BE Department Annual Report 2009

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Abstract

The Beams Department hosts the Groups responsible for the beam generation, acceleration, diagnostics, controls and performance optimization for the whole CERN accelerator complex. This Report describes the 2009 highlights for the BE Department.
LHC:

BE-ABP Group

Maintaining the official optics database has been a more than usually important task for the ABP-LCU section in 2009 because the LHC settings are directly generated from it. The structure contains not only the foreseen optical configurations (injection, top energy, squeeze sequences), but also the complete model of the aperture. This model contains both the description of the aperture of the magnetic elements, as developed during the magnet allocation phase and newer data concerning the vacuum chambers in the long straight sections and experimental beam pipes.

The decision to run the LHC at an intermediate energy of 3.5 TeV in 2009/2010 required the development of new squeeze sequences for ALICE and LHCb experimental insertions, in which the triplets’ gradients are reduced together with the value of $\beta^*$. This is meant to reduce the squeeze time by merging together the so-called pre-squeeze phase and the squeeze proper.

Numerous contributions were also made to the LHC beam commissioning effort, both during the data taking period and for the data analysis. It is important to highlight the first beat-beating measurement during the 2008 beam commissioning period, which made it possible detecting an aperture swap for the magnet MQTLI7.R3. In addition, a robust procedure was proposed, and successfully applied, for linear and higher-order polarity checks during the 2008 and 2009 injection tests. The checks in 2008 provided first evidence for a systematic polarity error in half of the trim quadrupoles. The measurements in 2009 indicated a systematic sign difference between the control system and the MAD-X optics model for all skew circuits (quadrupoles and sextupoles), whose origin is under investigation. Last but not least, systematic aperture measurements were performed in collaboration with the Operations team both in 2008 and during the 2009 injection tests.

The study and optimization of the beam conditions for the experiments were new tasks dealt with in 2009. A luminosity scan application was written and successfully tested. The new software allows varying automatically the beam separation at the IPs in steps to find the maximum luminosity and to determine the beam sizes at the interaction points. The application reads information from the LHC luminosity monitors (BRAN) as well as the luminosity information sent by the experiments. The synchronization and data exchange has recently been tested successfully with all four large LHC experiments.

Detailed simulations with tracking for beam-induced backgrounds were set up and include now also detailed tracking of beam-gas interactions.

Another important task for the section was the specification of the beam parameters for the forthcoming LHC run.
The main codes MAD-X, SixTrack, and PTC were significantly improved with a number of new releases to fit better the needs of the LHC beam commissioning. In particular, it is now possible to use the full power of PTC to describe the two-in-one structure of the LHC, which is an important feature for on-line model applications.

**Heavy Ions in the LHC**

The performance of the LHC when colliding lead nuclei is limited by a number of phenomena that do not occur with proton beams. The intense electromagnetic fields surrounding the colliding nuclei induce ultraperipheral interactions that can modify the beam particles and give rise to localized losses that may quench superconducting magnets (see Figure 12). Understanding of these quench phenomena has been brought to a new level using a three-step simulation approach, which consists of optical tracking, a Monte Carlo shower simulation, and a thermal network model of the heat flow inside a magnet. Similar interactions with collimator materials can lead other magnets to quench. Among the potential cures that have been studied, the installation of the so called cryo-collimators around active experiments and collimation insertions appears very promising.

Ultraperipheral interactions also contribute significantly to the luminosity decay. The LHC model of the beam evolution during a fill is a set of coupled differential equations embodying these and several other effects that modify the intensity and emittances. The model has been benchmarked against experimental data from the RHIC collider at Brookhaven National Laboratory, and against an alternative multi-particle simulation that also includes ion losses from the RF bucket. The model has been shown to be adequate for the LHC where the latter effect is expected to be less important.

Preparations for the first heavy ion physics run in 2010 are under way, with parameters adapted to the operating energy.

**Survey**

Repair of sector 3-4: 15 SSS and 39 dipoles were fiducialised in the hall SMA18 and SM12. The ABP SU section also participated actively in the Magnet Evaluation Board. In the tunnel, the replaced magnets were realigned with respect to the geodetic network and locally smoothed before interconnecting them and a final smoothing of all the magnets of the sector was realized, under cold conditions, in the vertical and horizontal plane. About 90 magnets were realigned in V and H. The dipole MB.A29L4 was left with a misalignment of ~2mm in the H direction. Regular maintenance of the alignment: During the shut-down 2008-2009, the smoothing of the magnets was done in the vertical plane for all the sectors. All the cryo-magnets were also measured and realigned if necessary, in the horizontal direction in the all LSSs between Q8L and Q8R using stretched wire of 160m. This operation ensures a good smoothing between the Arcs and the Interaction Regions. All the intermediate components (warm and cold) of the LSSs were realigned accordingly. In sector 7-8, the “hole”, located in the middle of the sector and already noticed at the time of the LEP reappeared and all the cryo-magnets on a length of 500 m were realigned. A sinking of -2mm of this area is foreseen year by year. For this reason a horizontal survey was done in this sector with no important movement detected since its installation. In LSS6, at the junction with the beam Dump TI68, some magnets were found higher than their
nominal position by almost +1mm and realigned. This is another potential unstable area where some maintenance has to be done every year. For the first time, ABP-SU measured the position of the vacuum chambers of all the LSSs and realigned them with the help of VSC people. An important work was done in the SU database to integrate theoretical and measurement data concerning these components. In the SU database, the circulating Beam 1 and Beam 2 have been inserted using MAD files produced by ABP-LCU section allowing the calculation of component deviation at the level of each beam and affecting a deviation to all the components located inside an assembly.

Collimator Survey Train (Figure 18): The camera system has been commissioned and the equipment for the underground installation has been produced and installed (targets, supports, pillars). The installations have been tested and are ready for the measurements during the next shut-down. The train itself will be upgraded to the TIM 2 Version end of this year. All subsystems are running but the global operation and calculation software have to be finished and tested before the train will be operational.

Low beta areas: concerning the low beta monitoring systems, the invar measuring system was upgraded around IP1 and IP5, and a very good correlation was seen concerning the position of fiducials determined either by standard means or either with these monitoring systems. All the alignment systems and motorized jacks have been validated. Consequently, the triplets around IP1 and IP5 were re-adjusted remotely.

Based on all the experience gained with these alignment systems, the technical specification concerning the alignment of the upgraded low beta is being written and space reservations have been made around the triplets.

**Metrology for Experiments:**

- Atlas: the complementary muon forward EEs, 40 % of the supporting structures and 15 % of the chambers were surveyed. The closure operations were controlled and new positions resurveyed. Stability measures of the floor cavern and of the Central Tile proved the whole experiment to be stable within the 0.3 mm with respect to the deep references in the tunnel over at least the last two years. The TASs were re-aligned with respect to the inner triplets geometry within an accuracy of 0.5mm (1σ) and they were equipped with permanent targets so that a remote survey control can be performed when necessary. The experimental detectors were surveyed and found within 0.6 mm radially and 0.2 mm vertically with respect to the inner triplets geometry. The Hydrostatic system (HLS) of the 8 sensors – 6 for the bed-plates - has been improved in such a way that results in verticality within an accuracy of better than 20 microns all the along the nearly 70 m water tube can be addressed regularly.
- CMS: except the central wheel, all the elements YBs and YE$s plus the HF$s were opened and then resurveyed during the closing operations. The BCAM$s (cameras angle monitors) were implemented in dedicated corridors so that the closure and the movements under the magnetic field were monitored at regular times within accuracy better than 0.2 mm, same for the 4 HLS sensors installed in the central wheel within accuracy better than 0.1 mm. A lot of the barrel and end-caps muon chambers plus the internal alignment systems were re-surveyed by photogrammetry after repairs and maintenance. Regular survey measures were carried out before, during and after the magnetic tests on critical points. Delicate measures were performed on the central tracker, the pixel and all along the experiment central beam pipe with metrology theodolites and laser tracker as well.

Fig. 19: Central pipe, pixel, central tracker and experiment pipe

The experimental detectors were surveyed (see Fig. 19) and found within 0.3 mm (1 mm) radially and vertically with respect to the inner triplets geometry. The TASs were re-aligned with respect to the inner triplets geometry within an of accuracy 0.5mm (1 mm) and were also equipped with permanent targets.

- Alice: most of the not completed operations in 2008 had been achieved and surveyed such as the TRD modules, the EMCAL and the PHOS inside the magnet, the total fiducialisation by photogrammetry and their installation of the di-muon and trackers chambers plus the beam pipe. Geometry measures were performed in the cavern to link the inner triplets both sides of the area and the experimental detectors were found within 0.5 mm radially and 0.2 mm vertically with respect to the inner triplets geometry.

- LHC-b: a newly BCAM network was installed in order to monitor the deformation of the RICH1 within an accuracy of better than 100 microns. Regular standard measures were performed on specific structures during the magnet tests plus complementary surveys on the muon plus the internal and outside tracking detectors. The beryllium beam pipe was aligned carefully and regularly checked during installation of surrounding detectors.
BE-BI Group

Beam Loss
The splice consolidation campaign of 2009 required the dismounting and remounting of over 500 of the ~3000 ionisation chambers used for LHC beam loss monitoring. Once re-installed, the complete system was tested by the generation of detector signals with a radioactive source. These tests ensured the correct cabling of the monitors and verified the chamber gain. The radioactive source tests required the availability of the full signal and logging chains, allowing the acquisition to be fully tested. This revealed several shortcomings in the reliability of the software protocols used at an early stage; issues that could then be addressed before injection of the first beams.

The beam loss monitoring system itself was also upgraded during 2009 with the addition of an FPGA reset functionality and a better separation of the high voltage supplies to reduce crosstalk between monitors. New software functionalities were also incorporated and tested for the comparison of settings in the reference database with those in the front-end computer. The thresholds themselves were refined with input from the short run in 2008. The whole system was available for the start-up with beam in November and has been heavily used and relied upon since.

Intensity
LHC DC BCTs
Additional diagnostic units were added to the system to give an overview of the current hardware state. The system was ready for the start-up in 2009, although the circulating beam current was too low to be accurately measured. The noise and resolution performance of the DC BCT meet expectations, but a larger than anticipated baseline drift was observed and will need to be addressed.

LHC Fast BCTs
The fast beam intensity measurement system profited from the long shutdown to review the measurement chain performance. In order to improve the precision of the measurement the RF front-end was re-designed, tested and installed in the machine. The new front-end significantly reduced the output DC offsets and hence assured maximal usage of the dynamic range of the integrators. The beam circulating flag detector was also re-designed to provide a detection capability of 2E9 charges. Several deficiencies have, however, been found in the calibration unit, which will require a redesign. This task is underway and a first functional prototype is expected in the first quarter of 2010.

The system was operational from the start-up and was the basis for all intensity and lifetime measurements with the low bunch charge injected in 2009.

Profiles
The standard LHC BTV system was already fully operational for the 2008 run so only minor modifications were implemented in 2009. Notably 4 of the standard CCD cameras in the injection regions were replaced by radiation tolerant CID cameras. The remaining 4 cameras of the injection region BTVs will be replaced during the next shutdown.

A modified version of the BTV devices (BTVM) is foreseen for multi-turn beam observation for correcting the injection matching between the transfer lines and the LHC ring. The BTVM is
based on a fast acquisition camera (up to 100'000 frames per second), which itself is very sensitive to radiation and can therefore only be installed in the tunnel during dedicated machine development periods. The infrastructure needed for the quick installation of these fast cameras was prepared during 2009 along with the associated software.

Due to problems with their first installation and commissioning in 2008, the synchrotron light monitors (BSR) were completely redesigned and reinstalled during 2009. The system was tested with beam during the 2009 run and gave very good results. This new system is much more flexible and will allow for extension of the BSR monitor functionality to include monitors such as the longitudinal density monitor (LDM) currently being developed by a Marie Curie fellow in the DITANET European network. In the present configuration the BSR allows the acquisition of beam images at all energies and for all beam intensities from pilot to ultimate (BSRT). The BSR also allows the observation of the particle population in the abort gap (BSRA) for machine protection purposes.

**Luminosity**

There are three different types of luminosity monitors installed in the LHC. The low luminosity regions (IR2 and IR8) use fast, polycrystalline, CdTe detectors in counting mode (BRAN-B) while the high luminosity regions (IR1 and IR5) use fast ionisation chambers developed by the Berkeley Laboratory within the LARP framework (BRAN-A). In order to cope with the sensitivity limitations of the fast ionisation chambers a third system, based on scintillators and photomultipliers (BRAN_Sci), has been developed and installed in parallel to the chambers to cope with the beam conditions during early LHC operation.

In 2009 the BRAN-A system was finalised and will be commissioned as soon as the beam energy and beam current is increased. Once commissioned, responsibility for this monitor will be transferred from Berkeley to CERN.

The BRAN-B and BRAN-Sci systems share many components and were ready for the 2008 run and are still ready to see collisions as soon as they occur.

**Position**

The LHC incident had consequences on the beam position monitoring (BPM) system requiring the in-situ cleaning and re-testing of all the pick-ups in the affected sector. The electronics cards and creates in the affected area were also removed to be cleaned and then re-installed. In addition, over-pressure valves where installed on the BPM flanges in all sectors that were warmed-up, requiring the dismounting and re-mounting of over one thousand connection cables. A complete check of the whole system was therefore required before restart of beam commissioning at the end of 2009.

Over 600 intensity cards were installed to allow the measurement of beam intensity via the BPM system, a recommendation of the LHC instrumentation review of 2001. The intensity readings are multiplexed at the analogue front-end level, allowing the measurement of either position or intensity for all equipped BPMs. The standard use for this system would see position measured on one beam, with the readout channels of the other beam used for its intensity measurement.
The complete BPM system was again ready and available from day 1 of re-commissioning and worked extremely reliably.

In addition to the standard LHC position system, R&D work was carried out on button pick-ups for use in the phase II LHC collimators. The variable distance of the buttons with respect to each other and with respect to the beam, along with the requested micron scale resolution and accuracy implied new challenges. A prototype of the system mechanics was completed and installed in a test collimator in 2009, and will be inserted into the SPS for machine development studies in 2010. A new electronics read-out system is also under development to meet the specified accuracy and resolution required for the system.

**Tune**
The Base Band Tune (BBQ) FFT acquisition system was again available from day one of LHC commissioning in 2009 and was essential for the optimisation of beam lifetime at injection. The effort in 2009 went on implementing and commissioning the tune feedback system, which played a major role in allowing the LHC to reach its record breaking energy of 1.2TeV per beam with minimal beam loss.

**Software**
The effort within the BI software team was firmly concentrated on preparing for the 2009 LHC restart. Many dry-runs were organised between OP and BI to ensure that the systems worked as foreseen and to allow for any necessary modifications to be made. The LSA concentrators for the distributed BLM and BPM systems were thoroughly tested during the year with several issues resolved in collaboration with OP and CO. All systems were therefore in good shape for the injection tests with both protons and ions, and later for the start with circulating beam.

An important addition with respect to 2008 was the introduction of Role Based Access Control (RBAC) which aims at ensuring that only users who know the risks are allowed to change settings and read acquisition results. The problem discovered in 2008 related to the number of clients accessing the popular BTV system was solved with the introduction of CMW proxies to limit access to the acquisition front-ends.

**BE-CO Group**

**LSA suite**
The data-driven LHC Software Architecture (LSA) software suite has been successfully used for the LHC hardware and beam commissioning, without forgetting the SPS ring, transfer lines and LEIR.

During this year it has been extended in functionality with many enhancements dedicated for the LHC settings management. At the same time, the collaboration with the Injector Control Architecture (InCA) project and the adaptation of the system for the PS machine is advancing well.
In parallel the functionality of the LSA data foundation has been steadily enriched to cater for the rapidly evolving requirements. The history of each parameter setting trim is kept to provide to possibility to restore past conditions. Currently some 10 million settings are stored, representing half a billion setting values.

**RBAC, Machine Critical Setting and Operational Mode**

The protection of the LHC was enhanced by the introduction of the Role Based Access Control (RBAC) system, which has been successfully commissioned and deployed in LHC equipment, controls middleware and applications software. RBAC provides infrastructure for controlling and tracing access to the equipment and offers the authentication and authorization services which the Management of the Critical Settings (MCS) facility requires.

RBAC was heavily used for the LHC operation and a major effort was invested in introduction of the strict access policy the majority of the LHC devices, which was conducted in collaboration with the operations and equipment groups.

The strict mode implies that the connecting clients have a valid RBAC token, hence a valid username, and also forces the equipment owners to protect at least their write properties. In addition, RBAC introduced the concept of Machine state, OPERATIONAL or NON-OPERATIONAL and the behaviour of the RBAC authorisation is different depending on the state of the LHC.

In the course of the year, several important extensions were provided including:

- support for piquet and critical roles which have been deployed to allow for limited intervention by equipment experts under the control of the operation crew
- configuration and authorization for virtual devices, and
- distribution of the Operational Mode and the RBAC policy.

RBAC is now fully operational and its potential introduction in the injector chain is investigated.
Common Middleware
Several MW releases were introduced in 2009, to correct or enhance the communication software suite. A new central directory service offering a much more stable service was deployed in operation in June. In addition our JMS brokers infrastructure has been reviewed and optimised to offer a better service to the user community.
A Proxy service has also been deployed in operation allowing application software to access devices via an intermediate process (the Proxy) thus reducing the load on the low level device, and offering a means to access these data from non-operational clients without putting additional load on the operational devices.

LHC central timing
The year was employed to carry out an extensive consolidation program for both hardware and software. On the hardware side, a new card to simulate LHC injection was developed and commissioned. In addition, hardware support for critical information, such as the Safe Machine Parameters, was incorporated in the MTT cards. On the software side, extensive tests for reflective memory were developed and uncovered a number of bugs. This testing effort was a general guideline throughout the year, resulting in a completely new test facility for the complete central timing system in building 864. This facility was instrumental in testing all modifications of the consolidation program before the startup at the end of the year. The central timing was fully commissioned through dedicated testing time in the real CCR installation and contributed to the successful startup without any hick-up.

Post Mortem Analysis
The first operational version of the Post Mortem Analysis (PMA) system was developed this year and deployed in time for the LHC start-up in November. The Post Mortem data is analyzed by so-called analysis modules, which are developed by domain experts. These analysis modules are executed in the PMA server, which was developed by members of the AP section. The PMA system receives data from the PM Data Collection system, a highly reliable and fully redundant system to which all relevant front-ends of the accelerators push post-mortem buffers. The PM Data Collection system, developed by members of TE/MPE (previously AB/CO), has been in operations for roughly three years now, during which it fulfilled an important role for LHC HW
commissioning. The PM project is an example of successful collaboration across groups and even departments (TE/MPE, BE/CO, BE/OP, BE/BI, TE/ABT, …).

The PMA application

Thanks to the flexible design, the PMA framework is also used to implement XPOC, the external post-operational check of the LHC Beam Dump System, and for the IQC, the LHC Injection Quality Check.

**LASER and DIAMON**

LASER has been used in everyday operation as in the previous years. Apart from normal maintenance, the focus was put on consolidation and improvement of the graphical user interface. The DIAMON diagnostic and monitoring suite was deployed and used in operation for all accelerators in 2009. Its new facilities to detect errors in the controls infrastructure and the tools to repair/reset or reboot the devices were very well received from the operation crew. The main features added to DIAMON in 2009 are the display of historical data, error notifications by e-mail and/or SMS and the possibility to monitor Java applications through the JMX protocol.

The picture below shows the graphical interface to DIAMON, which allows for visualisation, grouping, diagnosing the complete controls infrastructure:
Since the start of 2009, the data management for Alarms (LASER) and Diagnostics & Monitoring (DIAMON) has been taken under the responsibility of the DM section. The initial work consists of consolidation of the database structures, data flow procedures and interfaces, for the need for stability and reliability. In parallel, the occasion is seized to improve the ease of maintenance and to incorporate instrumentation for internal service diagnostics. In addition, the better integration with controls configuration also simplifies the procedures to exchange of data with the monitored front-end computers.

**Data management**

**nQPS**

The new extension of the quench protection system (nQPS) aims to acquire an enormous amount of additional data, captured by a new, vast controls infrastructure. Instead of managing merely the resulting logging data, we have persuaded TE/MPE and EN/ICE to include all aspects from electronics layout, automatic controls configuration up to the automatic generation of logging variables and alarm definitions. This involved the complete BE/CO/DM section, but consequently ensured the integrity and quality of the information. The impressive result in terms of numbers and complexity was deployed sector by sector in time for the LHC beam start-up.

<table>
<thead>
<tr>
<th>New QPS</th>
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</thead>
<tbody>
<tr>
<td>Controllers</td>
<td>436</td>
</tr>
<tr>
<td>Modules</td>
<td>4’886</td>
</tr>
<tr>
<td>Signals</td>
<td>+56’000</td>
</tr>
<tr>
<td>Alarms</td>
<td>3’708</td>
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</tbody>
</table>
Again, the complete controls data management section was implicated to cover all data domains of the beam loss monitors (BLM). Each monitor has its individual characteristics which are maintained in the central asset management system. This information needs to be combined with details on its positioned installation to determine its functional criticality. Hooked up to the beam interlock system, each monitor has a matrix of theoretical and operational beam loss thresholds, depending on energy and integration time. The operational software checks the layout image in the database with respect to the situation as seen by the front-end computers. During beam operation, the actual losses are compared with the threshold values, in order to trigger a beam interlock in time. The conditional disabling of monitors is checked by the database and a history of all actions is persisted in the database.

**Sector-wide**

Responding to an urgent request of the TE/CRG group, the database work necessary for the re-configuration of the cryogenics controls was taken up by BE/CO. The resources were found to accomplish the required tasks according to the timeline of the equipment commissioning. This type of request for resolving data management issues is recurrent, since the database expertise in the accelerator equipment groups is diminishing. Hence, the proposal to further centralize and provide sector-wide data management was welcomed and accepted by the management. An additional staff position will be opened in 2010 to sustain this service.

**Accelerator layouts**

The strategy to capture the layout of the complete accelerator complex has been pursued throughout 2009. Similar to what is already in place for the LHC, the three layout flavours are addressed: machine layout, electrical circuits and control system electronics. The emphasis returned to the LHC due to the important modifications to the controls infrastructure (cryogenics instrumentation, new QPS,...) with respect to last year.

On the injectors, the PS ring and Booster ring are fully described in the Layout database. Moreover, for all positioned magnets in these machines, the link to the physical magnet in the asset management system is established. This integration of information has been made possible due to the collaborative efforts with TE/MSC in terms of quality assurance.

**Controls Configuration**

A lot of work has been devoted to the most central database of the controls system, the Controls Configuration database. Most of this work has passed transparently for the majority of users. Nevertheless, the support for all device property models (including the new virtual devices), hardware configuration, drivers’ generation and also RBAC is part of the continuous consolidation work for the controls of all accelerators.
The Logging Service

The Logging Service comprises the complete chain of capturing time-series data from the industrial SCADA or custom data acquisition channels, processing, filtering and storing, up to the rendering of the data for analysis to a wide user community. The aim to keep all this information centralized with on-line availability is pursued, allowing cross-correlations of historic and heterogeneous data. After a relative calm data taking period, rates have boosted in the last quarter of 2009. Currently averaging on 75 GB/day, an impressive 20TB of data has been accumulated. The necessary infrastructure follows a continuous consolidation and expansion strategy.

The scope of the accelerator data logging, based on the Java controls infrastructure, has further grown with the LHC operation, covering almost all operational and equipment expert data, with more than 50000 signals in the logging database, well above design expectations. The enhanced monitoring infrastructure has outlined an extremely smooth operation of this service throughout the whole year for both LHC and its injectors.

The LHC BPM/BLM concentrators aim at combining, post process and log a large volume (counted in hundreds of megabytes) of data made available by the devices with various frequencies. Already operational for the LHC startup in 2008, in 2009 all the existing concentrators have been significantly improved with respect to the quality of data delivery, memory consumption and tuning capabilities and are now running 24/7, serving data to several OP applications. At the same time, a great deal of work has been invested to find out the reasons of occasional losses/delays of data sent from devices. This task was performed in a wider scope and involved members of several teams cooperating. Most of the shortcomings have been identified and addressed as far as it was possible. Changes have been implemented and deployed in operation.

TIMBER, the graphical tool of the Logging Service is used extensively. The first accelerated proton beam in LHC with its betatron tunes is nicely demonstrated with the logged data.
OASIS
OASIS, the signal observation system, was consolidated in 2009 by adding the latest features requested by OP and extending its capabilities (number of samples & number of triggers) to match the newest digitizers. To tackle the problem of noise in analogue signals, a signal quality improvement program was launched and has already produced results. The developments have also started to prepare for an easier integration of simple instruments with data source concept.

The OASIS analysis tool showing the last 1500 turns of the TOF beam with bunch rotation

AC Dipole
Hardware commissioning of the LHC AC Dipole system uncovered a series of problems for which the hardware design team worked out solutions in 2009. The remote control of the relays selecting operating mode was designed and implemented in collaboration with TE-ABT. In addition, we galvanically separated all high power parts (capacitor bank, magnet, audio amplifiers) from the low level control (gateway PC and analog I/O card), in order to avoid exposing the latter to unnecessary conducted electromagnetic interference. Finally, 100 Hz sidebands were visible around the 3 kHz carrier of the dipole current signal, and the problem was traced to micro-bouncing of the mains-powered relay which selects AC-Dipole operating mode. A fix was designed and tested, with installation and hardware commissioning scheduled before the LHC 2010 startup.

WorldFIP insourcing
WorldFIP is used in LHC for communication with very critical distributed systems, such as the control of power converters, QPS and Cryogenics. The announcement from Alstom of a gradual decline in WorldFIP support, coupled with worrying results in the radiation tests of the new generation of MicroFIP chips, triggered a sector-wide effort to insource WorldFIP technology at CERN. The first important deliverable of this project will be a radiation-tolerant FPGA-based alternative to the MicroFIP available as a core or as a radiation-tested chip for equipment groups. The involvement of some equipment groups had to be reduced with respect to the originally foreseen effort, due to LHC startup pressure, but the core team managed to go through a very detailed specification process followed by a complete design to be tested in the first half of 2010.

Front-ends
After several years of installation and commissioning of about 400 front-end computer systems and more than 400km of field bus networks, the low level LHC control system proved to work with a level of performance and reliability in accordance with the specifications. With more than 40,000 device instances, the Real-time Front-end Software Framework (FESA) developed by the
control group became in 2009 the standard solution for the development of a large majority of LHC systems (cryogenics, Quench protection, Radio Frequency, Beam Instrumentation, Beam Transfer systems, etc). Last but not least, extensive effort was put on the improvement of diagnostic and profiling tools.

**Hardware developments**

In 2009, two key designs were deployed in the injector complex, each of them replacing key hardware that had started to show maintenance and aging problems. The first one was the CBMIA, a MIL1553 bus master in PCI format, replacing VME units that had been running for some 20 years. The second one is the CVORB, a replacement of the GFAS, the workhorse of analog waveform generation for the control of power converters.

Another very important activity was the choice of key technologies on which to base the hardware kit which will satisfy the needs for the injector controls renovation project. The decision of basing all solutions on a combination of carrier and mezzanine boards was taken at a key moment, when both BE-BI and BE-RF were also studying upgrades of their own hardware. The VME carrier was quickly identified as a good candidate for sharing between BI and CO. The standard chosen for the mezzanines is VITA 57, FPGA Mezzanine Card (FMC). This strategic choice means not only will carrier design effort be shared but all subsequent mezzanines will be usable by both groups, irrespectively of where they were designed. Both the VME carrier (designed in BI) and the PCIe carrier (designed in CO) have gone through a functional specification phase and schematics are well underway. In addition, the first ADC FMC design (4 channels, 100 Ms/s, 14-bit) is ready for layout and will see the light in the coming weeks.

Another important part of the renovation project concerned hardware for the timing system, where lack of bi-directionality and bandwidth had been identified as serious shortcomings of the current system. The White Rabbit project was presented for departmental endorsement as a new Ethernet-based timing system capable of fulfilling all our requirements. The key deliverable this year was a proof-of-concept switch in MicroTCA format presented in the third White Rabbit workshop.

**Device drivers**

The biggest challenge for the driver development team was the adoption of a new operating system (Linux) and a new platform (Intel-based VME controllers). There is a major ongoing migration effort for existing LynxOS/PowerPC drivers along with new developments for new hardware being designed in the section. In addition, the DriverGen tool, provided by the section to facilitate quick development of device drivers in equipment groups, was migrated successfully to cover the new platform and OS.

**Control Room Infrastructure**

In 2009, the operator consoles in the CCR in the LHC area were upgraded to more recent model and were equipped with 4Gb of memory to allow for smooth and efficient operation for the LHC operators during the first weeks of LHC beam operation. In the PS and SPS bays, a new type of operational console with two 24” screens instead of three 19” screens was installed. A new window manager (ICE) has also been prepared and is currently tested by OP crew to be deployed
onto the CCC operational consoles. And finally all operational consoles have been upgraded to run SLC5 Linux.

On the backend side in the CCR a new server technology, the blade, has been introduced. This new blade technology that is now deployed in the CCR allows for reduced space, reduced power consumption and reduced heat dissipation while using edge technology. These blades were installed for the QPS, nQPS, DIAMON, OASIS and Virtualisation projects.

Four new 46” wall screens were installed in the TI bays in 2009.

**Operational Disk Space**

Accelerator operation software is producing a huge amount of datafiles that has to be stored locally in the fileservers located in the CCR. The LHC operation is very demanding and as a consequence additional disk space was prepared and deployed in operation during 2009. A specific disk server with 17 Tbytes of file space has been delivered for the LHC beam operation to store the datafiles acquired.

The figure shows the actual file server infrastructure in the CCR servers.

**Software Quality Assurance**

To continue the work on software quality improvement from previous years, this year the section has engaged in a consolidated effort to raise the quality awareness inside and outside the section. The section’s software (quality) improvement process (SIP) aims to answer questions like ‘How do we introduce quality improvement into our software development cycle?’ ‘What tools can we use to aid and automate quality improvement tasks?’ ‘What could we standardize and unify between projects wrt deliverables, deployment, release procedures?’ with the intention to improve on the quality and integrity of released products, and an ever-increasing code base, with obsolete and redundant code. Our integrated suite of project support tools for online issue tracking, documentation, source code inspection, testing plays an important role in this effort. These tools are now more closely integrated so one can trace an operational issue first opened via the operational elogbook to the code changes and tests that were done to fix it. The support and maintenance of these tools are done in collaboration with EN-ICE, and GS-AIS who also use these tools.

Also at the group level there is a related effort through the Controls Testbed project initiated at the end of 2008. This project will ensure reliability remains high while introducing modifications to the control system, by providing a testing facility for automated integration testing of its core components. An instance of each type of FEC is installed along with simulated accelerator timing and FESA Test devices. Using these, the Testbed currently runs regular automated tests (mainly from Inca) exercising the currently released control system components (eg. FESA, CMW, JAPC) to ensure they operate together correctly. Next year, this will be incorporated into the normal development workflow.
CNGS timing
The section is also in charge of the synchronization between CERN and LNGS in order to correlate neutrino events detected in LNGS with extractions from the SPS. In 2009, it was decided to log full BCT waveforms instead of just time-tagging extraction pulses. The resulting improvement in accuracy has opened the door to going beyond simple correlation (i.e. making sure the neutrinos came from CERN and nowhere else) into the realm of real time-of-flight measurements. The departure of neutrino speed from the speed of light is a hot subject in the neutrino community, and the improvements in the time transfer designed by HT enable the Opera experiment to deliver results of unprecedented accuracy.

BE-OP Group

Technical infrastructure
2009 was a very busy year for technical infrastructure operation with LHC repair works running in parallel to physics. Improvements to monitoring after the 2008 incident include development of comprehensive oxygen deficiency panels for the LHC, improvement of the ventilation system and continued integration of various technical infrastructure systems in a coherent operational environment now counting more than 65000 parameters. The technical infrastructure operation recorded 46 "Major Events" in 2009 (compared to 54 in 2008 and 41 in 2007). Although the number is high, the total downtime of physics is not exceptionally high. With the start-up of the LHC towards the end of the year, power consumption monitoring was put in place to ensure that CERN does not exceed the strict contractual limits.

LHC Operations
In the wake of the incident of September 19th 2008, the first half of 2009 was dominated with the repair of Sector 34 and the installation of new protection systems to prevent recurrence. One of these systems was the new Quench Protection System, which needed to be fully tested before machine-wide installation. Operations staff was redeployed to assist in this huge endeavor that is deemed critical for equipment safety at high current.

Sector 34 repair and deployment of protection systems resulted in a schedule which had to be adapted as the year progressed. This saw definitive cool down of the LHC sectors from July and subsequent power testing of the superconducting circuits from August. Under the coordination of the Hardware Commissioning team, LHC Operations played a major role in the power testing, with over 10000 tests performed in the 3 months leading up to beam commissioning in November. This work was carried out through shift work, with 24 hour per day coverage as required in the second half of the campaign. The Operations staff, as well as performing the tests, was throughout extremely proactive in finding ways and means to optimize testing procedures, thereby streamlining the activity as much as possible.
The 1600 superconducting circuits are a major part of the LHC, but there are many other systems that act on the beam that need to be made ready (injection, extraction, cleaning, acceleration, instrumentation, machine protection, to name the major ones). In collaboration with the respective equipment and control groups, LHC Operations drove an extensive campaign of testing of all accelerator systems from March onwards, thereby ensuring that all systems were ready for beam commissioning in November. This was pulled together in the last days into an overall machine checkout, orchestrated by LHC Operations.

As in 2008, equipment readiness was demonstrated as early as possible through a series of injection tests into sectors of the machine when they became available. Once again these proved invaluable for debugging of the implicated systems in the only way that is really definitive; with beam.

The final schedule for 2009 included a 4 week window for beam commissioning from late November. The status of new Quench Protection System dictated that operation would be possible up to beam energy of 1.18 TeV, resulting in an intense period of beam commissioning with clear goals.

Under the guidance now of Beam Commissioning, LHC Operations drove the machine through a stripped down version of the established beam commissioning procedures. Working throughout with safe beams, which allowed many aspects of the Machine Protection System to be relaxed, tremendous progress was made in the 27 days in which beam was available. All stated goals were achieved and more besides.
Commissioning a new machine, particularly one as complex as the LHC, is by definition a pioneering activity. Everyone involved was on a steep learning curve and working under considerable pressure as the world, or at least the physics world, looked on. The progress made is testimony to the abilities and dedication of the commissioning team, and bodes well for exciting LHC physics in 2010.

**BE-RF Group**

**LHC ACS Main RF Accelerating System**

Following the sector 3-4 incident a complete clean up of the RUX 45 area was carried out. No damage obvious had occurred to any equipment but dust and light debris from the ventilation door sealing had to be removed from the equipment. Some concern was raised on the possibility of dust contamination having reached the ACS superconducting RF cavities on the sector 3-4 side of IR4, but it was considered that the likelihood was minimal and that any investigative measures would themselves carry high risk. During 2008 operation a partial failure had occurred on the tuning system of one cavity. In January 2009 the cryostat was opened up to reveal that a steel cable operating the cavity tuner frame had broken at the connection to its lever. The design of the connecting piece was modified and new cables fitted on the tuning systems of all cavities. This was successfully done in-situ. Prior to hardware commissioning power tests were carried out on the klystrons. Shortly after first cool down of the cavities in September a helium overpressure incident occurred: it was seen that the He safety outlet burst discs failed to operate at the pressure specified. It was discovered that the wrong discs had been fitted. All 16 discs (one per cavity) were replaced with ones operating at the correct pressure. A subsequent
(unintentional) He over-pressure verified correct release via the burst disk. Once He regulation and interlock systems were fully commissioned no further major overpressure incidents occurred. Conditioning of the cavities, making use of the remote controlled automatic conditioning hardware built into the cavity controllers, rapidly reached the 2 MV nominal per cavity. This was final confirmation that no contamination had resulted from the sector 3-4 incident of 2009. The cavity controller feedback and tuning loops were set up once conditioning had been completed. This was greatly facilitated by the use of remote Matlab based tools for measuring transfer functions developed in the context of US LARP collaboration. RF system controls, from the equipment layer, through front-end software to remote specialist LabView applications and LSA based operations were all thoroughly tested and exercised during hardware commissioning. The SR4 beam control and synchronization systems were tested in early November, in time for the first LHC beams of 2009. Successful capture of both beams was rapidly achieved on the night of 20th November. Commissioning of the phase loops ensued, bringing dramatic increase of beam lifetime from around two hours to 10 hours and above, for both beams. The fast synchronization and cogging systems, needed to ensure capture in the correct buckets and proper timing of collisions in the IRs had been carefully prepared, but could only be fully tested with beam. First tests with two single bunch beams took place on the 23rd November. With delay measurements from the experiments and from dedicated BI pick-ups around IR2 the injection timing delays were set up, firstly to a precision of one RF bucket, then more precisely by adjusting the phase between the two RF beam reference frequencies. First collisions were observed in ATLAS, and then the timings were set to allow the beams to collide in ALICE, LHCb and CMS. Ramping tests followed on the 24th November. Acceleration of beams in LHC requires the RF frequency to be precisely programmed to keep the beam in the centre of the vacuum chamber as the magnetic field is increased. During the hardware commissioning phase meticulous preparation and test of the hardware and software needed to drive the RF frequency ramp had been carried out, in close collaboration with PO, CO and OP groups. The first ramp and the ensuing ones which reached energy of nearly 1.2 TeV, all went very smoothly. Although radial loop control had been prepared, these initial ramps were done without this. Tests with multi-bunch beams and different filling sequences were successfully done towards the end of the 2009 run.

A number of potential weak points were nevertheless identified, for example in operational software and diagnostics of the synchro system. None of these seriously perturbed the operation of LHC in this important initial phase of its operation. However, running with low RF power and resulting high klystron collector dissipation over long periods became a concern. The klystron operating parameters will be modified for 2010 operation to reduce collector power.

LHC ADT Transverse Damper Systems

Again, following the sector 3-4 incident all 16 tetrode ADT power amplifiers were removed from the tunnel in point 4 (RB44 and RB46) for cleaning and to carry out required maintenance work. Reference measurements were carried out on the kicker electrodes from outside the tank using a network analyzer on the HOM ports. These measurements confirmed that there had been no internal damage to the ADT kickers. Amplifiers were subsequently re-installed and the power system re-commissioned. More than 2000 hours operating time are now accumulated. The system was ready for first beam in autumn and commissioning with beam continued in the shadow of the many systems commissioning activities in parallel.
During the use of the damper as beam exciter for the tune measurement it was noticed that a reduction of beam lifetime took place when the level 3 of the power system, an RF switch on the input side of the 200 W driver amplifiers was closed. The following investigation revealed a number of sources of noise and interference the most important arriving in the damper racks via the link from the tune measurement system. After correction lifetime issues were cured, but investigations of interference lines in the tune spectrum continued. With respect to the damper additional noise and interference sources have been identified, the second most important stemming from the UPS power supply in UX45 and SR4 where the switching frequency of 8 kHz sneaks into the RF circuits and perturbs the system. Common mode suppression filters have been installed and an improved grounding scheme in SR4 is being looked at.

An important new function of the ADT system, the abort gap cleaning, was tested with been during the last week of operation in 2009. To this end a number of nested DDS were implemented in the DSPU FPGA to generate an excitation signal which can be gated within the abort gap and remove any unwanted beam by driving it to large amplitudes in a transverse plane to be intercepted by the betatron collimation. The system was tested with beam 2 and vertical excitation. An application has been developed to provide remote control the parameters from the CCC. Optimization of the cleaning pulse shape will take place during the shutdown 2009-2010. It requires careful measurements of all power system transfer functions and the correct compensation of phase shift with frequency. During the abort gap cleaning the applied pulse had to be shortened in order not to affect with its tail the lifetime of trailing bunches just behind the abort gap. A cleaning efficiency of 90 % was demonstrated using an unbunched beam (originating from 16 bunches, de-bunching by RF off). The main improvements foreseen for 2010 are on the pulse shape, testing at full amplitude with a wider pulse and fully checking out the different possibilities of excitation implemented in the application.

Setting-up for operation as an injection damper with feedback loop closed continued after beam capture. This is done by adjusting the I,Q demodulation and sampling in the dedicated beam position front-ends. It was noticed that the pulse response from a single bunch did not correspond to that expected. This was traced back to pick-up cables which had been damaged during installation. It would have led to a bunch cross-talk of the position measurement if not corrected. Two 160 m long cable sections were therefore replaced. Measurements in 2010 will show if any other corrective actions need to be taken.

Closing the feedback loop would have required dedicated machine development time. This could not be scheduled during the short 2009 run. Preparation with beam was nevertheless done. An important result was that the passing bunched beam could be observed on the kicker plates. This provides a straightforward and accurate means for set-up of the loop delay. As LHC moves towards injection of batches of multiple bunches errors from injection kicker ripple will become significant. The ADT system will guarantee small emittances by damping these injection errors. Commissioning of this mode is planned for early 2010.

The 2009 run provided valuable experience with both the ACS and ADT RF and transverse damper systems and overall was an enormous success.
LHC IR Upgrade studies

BE-ABP Group

The optics and performance studies progressed on several fronts in 2009. Following the main guidelines consisting in maximizing the use of the present LHC infrastructure, in particular without any modification of the matching section (MS), the minimum possible is found to be 30 cm (see Fig. 13 – upper left). The main constraints leading to this result are: i) the 120 mm aperture chosen for the new inner triplet (IT); ii) the mechanical acceptance of the present matching section, in particular in the D2, Q4 and Q5 magnets; iii) the optical matching to the arcs (Q7 gradient close to 200 T/m, very low gradient in Q5 and Q6). In parallel, a new strategy was settled to solve the ten-year old long-standing problem related to the correction of the chromatic aberrations generated by the LHC IT in collision. These aberrations are even more severe for the new layout in terms of off-momentum beta-beating, non linear chromaticity Q‴ and Q‴‴, and also horizontal and vertical spurious dispersion generated by the beam crossing-scheme in the ATLAS and CMS insertions. The proposed strategy, however, requires a completely new overall LHC optics, with precise constraints for the betatron phase advances across the eight insertions of the ring, from mid-arc to mid-arc, as well as for the left and right sides of the two high luminosity experimental insertions. The resulting betatron tunes are 63.31/60.32 for sLHC in collision compared to 64.31/59.32 for the nominal LHC collision optics. As an illustration, the so-called Montague chromatic functions W(s) describing the amplitude of the horizontal and vertical off-momentum beta-beating around the ring, are shown in Fig. 13 (upper right) after correction (W=500 corresponding to a 50 % relative change of the beta function for a momentum deviation of 10⁻³). These functions are vanishing in the critical regions, namely the new inner triplets and the collimation insertions. In this configuration, half of the sixteen defocusing sextupole families per ring is pushed to the nominal current of 550 A.

Tracking studies with multipole field imperfections in the new IT and new cold separation dipoles D1 have then been performed, both at injection and in collision, with and without beam-beam effects. Despite the reduction of the tune split, three units for the sLHC layout instead of five for the nominal machine, the 10⁶ turns dynamic aperture (DA) of the sLHC at injection remains around 10⁻¹¹ without beam-beam, basically given by the field imperfections of the main dipoles, and does no decrease below the mechanical aperture of the ring (8.4 m) if beam-beam effects are included in the simulations (see Fig. 13 – lower part).

LHC injector chain (Linac 2, PSB, LEIR, PS, Experimental Areas and Associated Facilities)

BE-ABP Group

The ABP HSL section has continued the operation of the proton pre-injector (Linac2), the ion pre-injector (Linac3) as well as the low energy stage of the REX-ISOLDE radioactive beam
post-accelerator. Additionally it is heavily involved in the Linac4 and SPL projects, making the beam dynamics studies and preparation for commissioning of Linac4, as well as providing the sources.

LINAC2
Linac2 has run for more than 9 months in 2009, which is only half of the extended 2009-10 run. Operation has in general been trouble free, except for an extended 3 day stop when a vacuum leak on a power coupler proved to be very difficult to locate.

LINAC3
Linac 3 delivered Pb ions for the injector chain, for MDs in the SPS. After damage was found on the source plasma chamber during the start up, it was decided not to try to exploit the advantages of the new 18GHz until there are sufficient spare parts available to recover from a failure. Beam intensity was below values during the previous 14.5GHz ECR source operation, which was eventually tracked to an energy miss match from the source (partly due to an upgrade of the low energy power convertors during the previous shutdown). The beam was also delivered for ion beam desorption measurements using cryogenic targets.

PS-MTE
Losses are the major intensity limitation for the high intensity beams for fixed target physics in the PS-SPS Complex. In order to minimize the losses at extraction in the PS a new scheme (Multi-Turn Extraction – MTE) has been conceived and its commissioning has started in the second half of the 2008 run and has continued this year. At the end of the 2008 run the beam could be extracted in 5 turns with good intensity uniformity among the different turns but with poor reproducibility. The analysis of the data during the 2008-2009 shut-down revealed that the horizontal chromaticity was approaching zero, or even becoming negative, just before crossing the resonance, thus generating a large emittance blow up responsible for the above observations. New settings have been calculated for MTE in 2009 with improved control of the chromaticity allowing obtaining reproducible extraction conditions but with reduced capture efficiency. To-date the fraction of particles trapped in the islands is on average around 17 % (see Fig. 2 – upper left part) without any measurable losses during the splitting process. The best extraction efficiency measured was about 98% (to be compared with 94-95% for the Continuous Transfer Extraction used at present). Intensities up to $1.7 \times 10^{13}$ p/batch are routinely extracted from the PS with the new scheme and can be delivered to the SPS for extraction to the CNGS target (see Fig. 1 - upper right part). The time-profile of the beam injected in the SPS features a fifth turn with higher intensity than the previous ones. In Fig. 2 (lower left part) the beam intensity along the SPS circumference is shown right after the injection of the second batch. In the lower right picture the evolution of the beam intensity after the second injection is shown. The green curve refers to a situation without any proper setting up, while the blue curve reflects the improved performance after carefully setting the tunes and the longitudinal parameters. Injection losses in the SPS range between 3 and 6 % and the overall transmission in the SPS is about 94 % which is comparable to that obtained for the Fixed Target beam with the conventional Continuous Transfer Extraction. Presently the efforts are directed to improve the uniformity of the spill and to increase the intensity of the beam.
PS-Losses
Losses in the PS machine occur also at injection and at transition. The renovation and upgrade of the hardware for the gamma jump at transition in the PS has taken place during the shut-down 2007-2008 and 2008-2009 and the effort for understanding and improving the transition crossing process has continued in 2009 with experiments and simulations. A new configuration of beam position monitors used for the control of the beam radial position has been proposed in order to minimize the radial position excursions during transition crossing (see Fig. 3). After a series of machines studies the new configuration is used in operation for all the beams since week 45.

![Fig. 3: Evolution of the radial position at transition for different combinations of the beam position monitors. The combination including the beam position monitors in position 22-76-36 and 96 provides the minimum excursion as a result of the larger average dispersion at these monitors during transition.](image)

PS-Cycles
In case of a failure of the PS rotating machine the PS main power supplies can be powered via an 18 kV line connected to the SPS electrical network. In this configuration the nominal ramp rate cannot be achieved for the main magnets. Tests with beam have confirmed the estimates on the performance of the LHC and fixed target beams with the reduced ramp rate. A 6 second long magnetic cycle (Fig. 4) has been successfully set-up and an LHC beam with bunch population corresponding to 40% of the nominal one was extracted with nominal parameters. No limitation could be observed and the intensity was limited by the PSB during the machine study session.

PS-LHC Beam
The optimization of the production schemes for the LHC beam has also continued in 2009. The nominal scheme foresees a double batch injection from the PSB to the PS. Recent experiments have shown that 50 and 75 ns beams can be produced with a single batch injection form the PSB to the PS (Fig. 5). This allows reducing the cycle length in the PS from 3.6 to 2.4 s and correspondingly reducing the injection plateau in the SPS from 10.8 to 7.2 s or increasing the number of batches that can be injected in the SPS from 4 to 5. A 50 ns beam produced with such a scheme could be accelerated in the SPS up to top energy with emittances well below the nominal ones.
Figure 5. Tomogram pictures (bunch shapes and longitudinal phase space) of the LHC 50 ns beam produced in the PSB.

**PS-Ion Beam**

2009 saw the end of the commissioning of the ion injection chain for the LHC with the so-called early beam with the completion of the commissioning of the ion beam RF control for capture, acceleration, and rephrasing with the LHC. On October 23rd, for the first time, single-bunch beams of Pb$^{82+}$ were sent to the LHC through TI2 up to the long straight section in Point 3 and could be observed interacting with the residual gas by the ALICE experiment in Point 2 (see Fig. 6). The beam had the required characteristics for the ion run planned for the autumn 2010 i.e.: $7 \times 10^7$ ions/bunch, normalized r.m.s. transverse emittances below 1 m, bunch length below 1.8 ns, and a momentum spread smaller than $\pm 3 \times 10^{-4}$.

Before reaching that milestone, the machines had been operating during the whole spring and summer in order to prepare the “early” and “nominal” beams. Unfortunately a breakdown in the ECR source prevented using the newly commissioned 18GHz RF which should have supplied – with some extra margin – an intensity of $50 \times 10^5$ ions from the Linac 3. This was compensated by the good performance of the LEIR machine which was still able to deliver the nominal intensity of the “early beam” ($1.2 \times 10^8$ ions per pulse) to the PS and SPS with remarkable reliability.

The last weeks of the run saw, for the first time, a beam with nominal characteristics to generate four bunches in the LHC per LEIR cycle accelerated and ejected. Already during earlier runs in 2006 and 2007, it has been possible to accumulate nominal intensity. However, a loss during the early part of the ramp did not allow accelerating nominal LEIR intensity. In order to decouple investigations on this loss in the early part of the ramp from limitations of the accumulation rate, a special longer machine cycle with a longer accumulation plateau has been set-up. The beam intensity along the cycle is shown in Fig. 7. The final step towards the nominal LEIR beam is to shorten the machine cycle by improving the accumulation rate with an increased Linac3 beam current closer to the design value and/or by speeding up injection repetition rate and electron cooling. This result could be obtained after the completion of the commissioning of LEIR fully digital low level RF system. Some work remains to understand and suppress the losses observed after capture and during the first part of the acceleration.
Figure 7: Time evolution of the circulating beam intensity (vertical axis: number of charges). Significantly more than the required $5 \times 10^{10}$ charges are accumulated.

The ABP group also contributes to the study effort for the upgrade of the LHC injectors (e.g. PS2, SPS Upgrade) to the LINAC4 project and to R&D activities (e.g. Neutrino factory and Beta Beams Study) in the frame of the FP7 EU Programme.

Studies on the PS Booster aim at making sure that the increase in PSB performance, expected with the higher injection energy and the conversion to a H$^-$ charge exchange injection, can be met soon and efficiently after Linac4 becomes available.

A topic studied with high priority, in collaboration with the team from the TE department constructing the new Booster injection hardware, is the implication of the new H$^-$ injection on beam dynamics. The study aims at defining as soon as possible the general layout of the injection region and the required hardware to start construction. In particular, perturbations of the lattice due to the so-called injection chicane, a closed orbit bump in the injection section, required to merge the incoming H$^-$ beam with the circulating proton beam, and their impact on achievable performance have been investigated. Compensation schemes aiming at a reduction of the impact due to the chicane are studied. The choice of the scheme, either partial "passive compensation" by adding quadrupolar components to the chicane magnets or "active compensation" by additional quadrupolar components at appropriate location excited by dedicated power converters, have important impact on the required hardware and performance.

Two effects limit the bunch intensity of the LHC beam in the SPS: a vertical Transverse Mode Coupling Instability (TMCI) and the electron cloud induced vertical instability. TMCI is observed for LHC type beams with small longitudinal emittance. This instability is a direct consequence of the overall impedance of the various elements of the machine and in particular of the kicker magnets. This instability could limit the LHC beam bunch intensity to approximately the ultimate bunch population. Detailed simulations of the longitudinal and transverse impedance of various components of the machine have been performed with CST-Particle Studio code and
have been benchmarked for simplified geometries against theoretical models (see Fig. 9). For the transverse impedance both the dipole and quadrupole terms have been calculated and can now be used to estimate observables like instability thresholds and detuning with intensity with the HEADTAIL code.

The present impedance data-base of the SPS includes the kicker magnets, Beam Position Monitors (detailed model) and the vacuum chamber. Work is ongoing to model the RF cavities and the Pumping port shielding with CST-Particle Studio.

Survey

**PS and Booster:** The survey of the BTP-line and the measurement of the roll angle of the Booster magnets were realized.

Others experimental areas: interventions were carried out for CAST (‘sun’ tracking grid and scanning telescopes), Compass, Isolde (Rex-line, Mini-ball) and AMS (full photogrammetry metrology during assembly). A significant increase of survey interventions was noted in the R&D beams (SPS North area and PS East hall). Active preparatory discussions for the future project HIE Isolde and proposal of an adapted BCAM electro-optics system to be applied to the internal monitoring of the cryo-modules.

Survey- Other Experimental Areas
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Geodesy:
The beginning of the year saw the delivery of a GNSS (Global Navigation Satellite System) system, able to operate with both the US GPS and the Russian GLONASS satellites. The system consists of two receivers - one for a fixed base station and the second to be used as a roving station. The base station receiver has been installed on building 864 in Prévessin. The setting-up and configuration of the system was difficult due initially to some firmware problems with the receiver, and also due to the security constraints of the CERN network environment. The system is now up and running, although a number of minor issues still need to be resolved, and is being used in several measurement campaigns (SU Surface Geodetic Reference Network, Astro-Geodetic measurements).

Geoid Studies
As part of the CLIC SURVEY Feasibility Study a Research Doctoral student is continuing with a project to examine the precision with which the vertical reference surface (geoid) for Survey measurements might be determined. The TZ32 tunnel area was selected for the project, since it will allow the necessary measurements to be made at both the surface and in the tunnel ~100 m underground. A campaign of gravimetry measurements was completed in the tunnel, and having obtained access to an area in the fields directly above the tunnel, a campaign of precise leveling has also been completed. The measurement campaign with the Astro-geodetic camera is nearing
completion and with some fine weather those measurements and a complementary campaign of gravimetry measurements on the surface should be finished by the end of the year.

A collaboration with METAS (Swiss Federal Office of Metrology) and ETHZ, also saw gravimetry reference points at Point 4, Préveslin, and underground at Point 8, measured with an absolute gravimeter.

**HLS modeling**

For the processing of the HLS (Hydrostatic Leveling System) measurements in the LHC, another Research Doctoral student is continuing to work on modeling and predicting the effects of Earth Tides on each of the installations. Whilst waiting for all the LHC systems to come online, the analysis is currently looking at data from a CLIC SU test facility in the TT1 using the Earth Tide modeling standard application ETERNA. Further analysis of this data is still required, before applying the acquired knowledge and techniques to the LHC HLS data.

**Laser scanning activity**

Integration scans were performed in four LHC LSS as well as around the TANs and DFBXs (see Figure 20). In the frame of studies, scans were requested for AD (DEM), the Hall SM18 (Cryogenics), the WANF (HiRadMat project) and the new PS access system.

An active collaboration project was launched with PH-DT in the Mechanical engineering R&D Project: ’3 D Digital Models for High Accuracy Reconstruction’. A demonstration and analysis of a full precise scan operation were performed to the entire 8 m diameter Atlas Tile barrel. Various laser instrumentations and modeling software for accurate reverse engineering operations were also tested on a dedicated mock-up.

![Laser scan image](image)

Fig. 20: Partial position with envelope reconstruction of services (cables, pipes) – spatial accuracy 2 mm and scan of DFBX

**Software:**

The arrival of a technical student at the end of the summer has allowed us to move towards the completion of the C++ version of LGC (Logiciel General de Compensation), the central application in the processing of all survey measurements, and the definitive replacement of the original FORTRAN version. Work will start on the implementation of the necessary functionality to process the measurements made by the CERN Laser Trackers before the end of the year. This will mean that these measurements can be combined with other types of measurements carried out by the Survey team.
BE-BI Group

PS complex:
Profiles
New Fast Wire Scanner Electronics
The PS and PSB wire scanner electronics was replaced by a new design to improve the system in terms of reliability and performance. The DC motor driven wire movement mechanism has been equipped with a potentiometer based angular position sensor and the acquisition electronics completely replaced with the reliability critical position feedback control now fully implemented in an FPGA. All cables have also been replaced and a new automated wire scanner calibration test stand designed, commissioned and used on all scanners. In addition the controls software has been renovated and is now common for all CERN accelerators. Following these changes the reliability of these systems has significantly improved, with no erratic movements observed. The reproducibility has also improved by a factor 10 with the new angular position measurement method.

New Fast Wire Scanner Tank for Multi-Turn-Extraction
For the new multi-turn extraction (MTE) for the PS machine, the BI Group has embarked on producing a new tank to house the wire scanners used to measure the circulating beam profile. New tanks are needed as the existing tanks create an aperture restriction with this extraction scheme where the beam is moved close to the vacuum chamber walls in order to be correctly extracted at the septum. Apart from the aperture restriction created by the current tanks, the wire scanner fork also limits the available beam aperture and has therefore been repositioned to maximise the available space. The same tank design will be used for the vertical and horizontal scanners with a 90° rotation between the two. In addition to the 4 existing scanners a 5th device is also foreseen to be installed in straight section 68.

Secondary Emission (SEM) Grids
The low-level software for the fixed SEM-grids in the PSB measurement line was successfully renovated to FESA, allowing them to be used in a much easier fashion for cross checks with the new wire scanner systems.

Orbits and Trajectories
PS Booster BPMs
The PS Booster orbit system was upgraded from a single plane, single ring measurement to a dual plane orbit measurement for a single ring. This required the development of a new 8 input to 2 output multiplexer card with in-built high and low gain stages, and the addition of new ADC acquisition cards.

Ten pick-ups in the PSB to PS extraction line suffer under the influence of stray particles created during the extraction process. These will therefore be exchanged with low impedance inductive pick-ups that should be much less sensitive to such beam loss. A first prototype was designed and manufactured this year and is now undergoing testing. Construction of the remaining monitors will start in 2010 with final installation foreseen during the 2010/2011 technical stop.
New PS Orbit
2009 was devoted to making the new PS Trajectory Measurement System (TMS) operational in order to allow the phasing-out of the old CODD system in 2010. All the pick-ups were connected to the new system (in parallel to the old system) and the front-end software completed in time for the 2009 start-up. Much time was then spent optimising the operation of the TMS, making sure the system worked correctly in all its acquisition modes and was correctly calibrated. Specialist software tools were developed to allow the editing of the state and phase tables necessary to tell the system how to behave for each type of beam. Different variants of the FPGA firmware algorithms were also developed and tested to cope with the details of beam injection and RF gymnastics. Several MDs took place with OP and CO to ensure that the necessary measurement quality and operational tools were available. Related to this, the software of the TT2 SEM-grids was renovated with the addition of PLC control for the movements to allow for an easier integration of the PS Automatic Beam Steering. This work, combined with the new TMS system, was necessary to allow full use of PS orbit steering and control under FESA.

Intensities
PS Complex Fast BCTs
An upgrade of the ageing analogue integrators in the PS complex fast BCTs was initiated in 2008 and continued throughout 2009. The new digital integrator cards (TRIC) have so far been installed on the PS Wall Current Monitor and 1000 turn transformer, as well as on one of the PS extraction transformers to monitor the multi-turn extraction. The new TRIC cards will now be deployed on all Fast BCTs in the PS Complex.

PS DC BCT
Perturbations related to high intensity and a low number of bunches (TOF 1 bunch or TSTPS 4 bunches) were observed and has led to the design of a filter to counteract this problem, which is to be installed in the machine during the next shut.

Other Beam Instrumentation in the PS Complex
Tune Measurement
The PS tune measurement has been equipped with a new system allowing variable excitation depending on the particle energy. This system has been used intensively and is one of the important instrumentation tools for optimising multi-turn extraction. There were, however, problems in measuring the low intensity ion beams throughout the acceleration cycle using the existing set-up. A more sensitive BPM is therefore being developed for this purpose.

PS Spill Monitor
The gas bottles for the slow spill monitor of the PS (LSD), previously installed inside the PS bunker, have been moved with the nitrogen gas now conveyed to the monitor by means of stainless steel piping.

PS East Area Beam Instrumentation
The consolidation of the Beam Instrumentation in the East Area (EAN) started in 2008 with operational Scintillation Counters and Delay Wire Chambers for beam profiles implemented using standards from the North Area. In 2009 two other families of devices, the Telescopes and the Secondary Emission Counters, which are still implemented in CAMAC were studied with a
view to being upgraded to VME during the 2009/2010 shut-down. It is also foreseen to provide a remote control of the Cerenkov Threshold Counters.

**BE-OP Group**

The year 2009 announced challenging with a full physics program and the final preparations and modifications of the different LHC beams for re-commissioning the LHC. The shutdown during which another set of main magnets were successfully exchanged for renovated magnets, was finished with thorough hardware testing that was followed by the cold check out and startup with beam. The beam based realignment of the main magnets resulted in the a reduction of the horizontal rms orbit from 3.7 mm to 1.8 mm whereas the vertical rms orbit was reduced from 0.8 mm to 0.6 mm.

Another important change that was made during the shutdown period concerned the first step towards replacing the old motor-generator based main power supply by a state of the art power converter connected directly to the mains. This first step concerned the renovation of the regulation and the control of the present main power converter. The old regulation was based on voltage while the new regulation is based on the measured magnetic field, which is a first at CERN. New low level and high level software were developed and the system was very successfully commissioned during the start up phase, which was roughly 2 months earlier than initially foreseen.

The nTOF facility, with its new target, water cooling station and ventilation system, was also successfully re-commissioned after a quick test in November 2008 and a realignment of the beam line elements during the shutdown period. Both dedicated $7 \times 10^{12}$ protons per bunch and parasitic $3.5 \times 10^{12}$ protons per bunch beams were send onto the new target. Initially the proton flux was reduced to $5 \times 10^{11}$ protons per second, but after improvement of the water cooling station shielding and improving the under pressure in the target sector the proton flux could be increased to approximately $2 \times 10^{12}$ protons per second, which allowed us to regain the planned integrated intensity curve. Three days before the end of the physics run the PS managed to deliver the committed $7.3 \times 10^{18}$ protons on target and when the nTOF facility was stopped for its annual shutdown, on the 23rd of November, they had received $7.45 \times 10^{18}$ protons.

The commissioning of the Multi Turn Extraction (MTE) scheme continued and during the last two months the MTE beam was sent regularly for several days to the SPS. Initially the intensity distribution requirement were not met, but the MTE commissioning finished on a high note when during the last days of the year 5 intensity-wise equal turns were sent to the SPS.

Unfortunately during the year a few problems did not go unnoticed and had a more or less major impact on the nevertheless good machine availability.

In the early morning of June 17th the vacuum pressure in the straight section 52 and 53 went up quickly as a consequence of a leaking ceramic seal between the two sections 52 and 53. The origin of the leaking was found to be a broken RF by-pass that caused sparking across the seal.
and was therefore damaged. A very efficient intervention by the vacuum team allowed us to put low intensity beam again in the machine in the evening of the same day.

On the 3rd of September the insulation of one of the bus bars interconnecting the magnets broke and caused an earth fault. At the same time one of the thyristors in the main power supply broke and required a repair. The main power supply was repaired and the bus bar was made operational again by applying a temporary fix. A few weeks later during a technical stop and machine development period the bus bar was finally replaced by a spare.

On the 10th of October the injection septum 42 broke with a vacuum leak between the hydraulic system and the vacuum, which meant exchanging the septum with its spare. The septum was replaced efficiently and a bake out followed. The beams could circulate again in the PS on Sunday 11 October.

During the entire run there was a very good support from all the equipment and service groups that have either consolidated existing systems like OASIS, tune measurement, etc, but also equipped the PS with new systems. Towards the end of the run together with BI we commissioned and validated a new orbit measurement system that will allow us to measure the orbit using all the bpm’s in both planes over large parts of the cycle.

Beside a good availability for all protons beams including the beams for the LHC the PS also successfully provided the ion beam to complete the early ion beam commissioning in the SPS. Finishing a challenging year with good results set a precedent for the next. Therefore we, as the PS operations team, will put all our efforts to try to meet these expectations, but this can only be achieved with the continuing support and good work of all our colleagues that contributed to the good results of 2009.

Some figure on the availability of the beam from the PS, including the LINAC2 and PS Booster are:
LHCPROBE: 94%
SFTPRO: 81%
CNGS: 83%
TOF: 86%
EASTA: 82%
EASTB: 84%
EASTC: 76%
AD: 84%

**BOOSTER**
The PS Booster had an exceptionally long operation period, starting by the end of March and going without any major interruption up to the X-mas closure. Technical problems were tackled and solved as they arose. The change of the injection septum early in the year was a major intervention which could be managed smoothly and rapidly, minimizing down time for our users. The usual spectrum of physics beams for ISOLDE, the PS and SPS fixed target physics, CNGS, nTOF and AD was delivered as scheduled and with high availability and beam quality. The year was marked by the presence of a large number of high-intensity beams in the Booster (for e.g.
A newly deployed end-user-fault statistics tool is now available to compute the beam availability for each user, based on the transformer readings and taking into account all relevant conditions.

Operational statistics for fixed-target beams from the Booster. Relative efficiency refers to periods when the beam request was ON; absolute efficiency includes periods when beam was not requested.

Besides the fixed target physics beams the Booster delivered its zoo of LHC-type beams for the LHC injection tests and commissioning. All LHC beams were delivered on request and within specifications, contributing to the successful LHC run during the last months of the year. The spectrum of LHC beams produced in the PSB ranges from very low intensity, low-emittance beams for commissioning to the full fledged high-brilliance physics beams. All these very different beams are delivered routinely, and without compromising on the rest of the physics program.

Besides physics beams the Booster delivered again MD beams for machine studies going on in the PS and SPS (e.g. beam for PS multi-turn extraction), and a number of machine studies were carried out in the Booster itself. On the side of new developments in the Booster, a highlight was the setting up of some LHC beams with single-batch transfer to the PS. In this operation mode the machine uses 3 rings with harmonic 2, rather than the traditional 6 rings (in 2 batches) at harmonic 1. The new operation mode, foreseen for the Linac4 era, has now already been made operational for the 50 and 75ns LHC beams. This is not only a proof of principle of this injection scheme, it is already in the short term beneficial by freeing slots in the supercycle and speeding up the LHC injection process.
Fig.: Six bunches of an LHC type beam produced with 3 Booster rings at $h=2$ and transferred to the PS in one batch.

The Booster team consists of 7 beam operators and a team of 5 machine supervisors from the OP, ABP, BI and RF groups. This composition of competences from different domains has once more proven to be very successful and has been one of the key ingredients for the successful 2009 run.

**BE-RF Group**

With the LHC taking centre stage, it must not be forgotten that LHC needs the reliable operation of the Meyrin accelerators which constitute its injector chain. Over the last decades the RF systems of these machines have gone through many generations of modernizations. While some of the basic concepts date from more than 50 years ago these accelerators have learned astounding new tricks over the years. The PS, whose versatile RF systems make it today probably the world’s most remarkable “RF gymnast” in longitudinal phase space, shaping and forming, splitting, merging, recompressing in order to accelerating a whole panoply of beams, e.g. production beams for antiprotons, beams for neutron time-of-flight experiments and for the Grand Sasso neutrino beam, plus of course the different intensity, high brightness beams to set up and operate LHC. The main 2009 achievement for the RF systems of the injector chain accelerators is certainly the fact that they have continued to provide this wide variety of beams in an extremely reliable manner.

Linac 2 continues to be a critical link. Its complicated vacuum seals running along the top side of its tanks carry a risk of single point failure. Its 200 MHz high power RF system runs with triodes that date from the 1960s, with the risk that manufacturers loose the capability to fabricate them. However Linac 2 will be superseded by Linac 4 in a few years, so these risks are only temporary.
The next link in the proton chain is the PS-Booster, upgraded in the 1990s with the new harmonic 1 (2 MHz) RF systems in preparation for the LHC era. In 2009 the PSB adopted a new scheme to fill the PS with LHC beam, in a single batch instead of the nominal double batch filling. This saves significant time in the LHC filling cycle. Since the circumference of the PS is exactly four times that of each PSB ring, the bunch spacing for a beam in harmonic 2 in the PSB corresponds to exactly one eighth of the PS. The PS however accelerates on harmonic 7 to be compatible with the subsequent beam manipulations. A scheme was proposed and successfully put into operation in 2009 that, by a correct superposition of harmonics 1 and 2, allows the PSB to cleanly fill the buckets of harmonic 7 in the PS. The booster also provided a remarkable 6.7 \times 10^{19} protons for Isolde in 2009.

LEIR saw the successful completion of commissioning of the new, all digital low-level RF system – the first of a kind in the complex and a good model for future PSB and PS low level RF system upgrades. This was the successful culmination of a project started in 2003. 2009 saw the implementation of the second harmonic operation, control of all servo-loops and the integration with the control system, in particular with the Tomoscope and OASIS. On November 3rd, ion beams with nominal characteristics were accelerated (in spite of a longer cycle to compensate for lower Linac3 current) Following the injector chain downstream to the PS, major changes concerned the modernization and standardizing of its old 200 MHz system; now four of the six systems are completed in a new, modular fashion making them practically the same as the drivers for the SPS 200 MHz system, bring important advantages for operation and maintenance. For the beam control systems of the PS - the PS has five beam control systems to handle the different beam types - significant improvements were made for the LHC proton and lead ion beams, which certainly contributed to the smooth restart of the LHC in November. These systems are now fully remotely accessible from the CCC. In addition, a new system for phase control of the radio-frequency signals sent to the main accelerating cavities was commissioned, to facilitate the variety of RF manipulations needed to generate the final bunch spacings of 25 ns, 50 ns, 75 ns and 100 ns for both protons and lead ions. An issue successfully addressed during 2009 concerned the RF bypasses. These are high pass filters shunting the insulated vacuum flanges between different sections of beam pipe to give reduced beam impedance. Resistors in some of these filters were destroyed by the induced beam current. Certain resistors were identified as not being within specifications and were replaced by more reliable ones.

As for the ions, the delivery of the early, single-bunch lead ion beam to SPS and LHC became routine operation in the PS in 2009. In producing the nominal lead ion beam for the LHC for the first time, the PS demonstrated again its capability and flexibility. A cascade of sophisticated radio-frequency manipulations converts two bunches from LEIR with a length of more than 22 m (200 ns) each into four bunches shorter than 1.2 m (4 ns) delivered to the SPS, hence almost twenty times less than at injection. With so-called batch expansions, the distance between adjacent bunches is enlarged in a well controlled manner, finally separating them by about 30 m (100 ns) for the LHC. The splitting of each bunch in two equal parts allows to deliver four bunches to the SPS while receiving only two from LEIR. Additionally, as lead ions are injected at a velocity of only 37 % of the speed of light, the main cavities must be rapidly swept over a large frequency range to follow the increasing velocity during acceleration. On October 23rd, first Pb ions went into the LHC and first events were detected in Alice.
SPS:

BE-ABP Group –

Survey (transfer lines):
The smoothing of the quadrupoles of the SPS was done in the vertical plane. 14 quadrupoles magnets had to be realigned. The realignment of 1/3 of the dipoles was also done, which ends the dipole exchange campaign started two years ago. All the quadrupoles of TI2 were measured in the vertical direction and in roll angle, with very few magnets to realign. The same operation was done for the TI8 showing an important vertical step of ~4mm between the quadrupoles located in the SPS tunnel and the components located in TT40. The roll angles were also measured showing deviations up to 1.5mrad, all of them were put to the nominal values. The quadrupoles located in the downstream part close to the LHC were measured in the radial direction and aligned on the smoothed curve. A total of about 40 quadrupoles were realigned as well all the magnets located between the realigned quadrupoles. This survey proved that this line is very unstable and will require important alignment maintenance in the future.

BE-BI Group

Beam Loss
To test the feasibility of diamond detectors for beam loss measurements a detector consisting of a stack of 4 such detectors was installed in LSS5 of the SPS. The detector and its analogue front-end electronics are designed to detect single particles with nanosecond resolution. This specification has many interesting applications, such as particle halo characterisation. The measurements performed show that it is possible to clearly distinguish single particles from the noise floor with response times of less than 5 nanoseconds. These results are encouraging, and such a test system will now be installed in the LHC to principally look at un-captured beam halo.

Orbits & Trajectories
Two new interlock systems based on Logarithmic Amplifier BPM measurements have been installed and tested in LSS4 and LSS6 of the SPS. One of these systems ensures that during the whole acceleration cycle the beam excursion does not exceed 30 mm compared to the design orbit, with the beam dumped within a few machine turns if this condition is not met. This is foreseen to eventually replace the SPS 30mm analogue excursion interlock, which currently only works in the horizontal plane. The second interlock system is used during extraction to qualify the extraction bump, giving the OK to extract. Many tests were performed on these systems in collaboration with BE-OP to check their consistency with different beam types. A few issues have arisen which will be investigated during 2010, with the aim of making both systems fully operational by 2011.

Intensities
The SPS economy switch was re-instated in 2009 using the information given by the DC BCT acquired in Point 3 of the SPS. This switches the SPS to a dedicated lower-cost cycle if there is
no beam injected into the SPS and is estimated to have saved ~200 k€ in electricity costs for CERN in 2009.

After observing problems with the DC BCT in Point 1 of the SPS linked to degradation in its magnetic properties, the system was replaced by a spare. After the replacement the readings of the DC BCTs in Point 1 and Point 3 were still found to differ by ±30% for high intensity beams. An additional filter was therefore installed and reduced this difference to ±3%, a value which still needs to be improved.

**SPS Experimental Areas:**
The consolidation program for the SPS Experimental Areas came to an end in 2009 with the last detector still working on the in-house EquipmentBus being moved to VME. Seven new VME crates were installed in the North Area and newly developed equipment-oriented VME boards for Multi Wire Proportional Chambers replaced 50 XWCA interfaces on the EquipmentBus. On the software side yet another new FESA class replaced the old proxy/data-module and in the upper layer the CESAR application control programs were implemented in JAVA. 2009 also saw the responsibility for all absorbers, collimators and dumps successfully transferred to EN-STI.

**BE-CO Group**

**SPS PAGE1**
The old teletext based SPS page 1 was replaced by a new technology and it was developed using the Fixed Displays Framework. It is based entirely on Java with color charts and support for dynamic BCT signal changes depending on the user, obtaining the SPS magnetic cycle and BCT data from an OASIS crate (Vistar SPS).

During the startup of the SPS this year, the new SPS Page 1 was successfully commissioned. In addition the application automatically aligns the chart resolution to the length of the current supercycle reducing the need for human intervention to strict minimum. We have also managed to replace other teletext pages, the so-called LARGER pages, by their corresponding Java versions.

**SPS Economy Mode**
The introduction of the SPS Economy mode in the Software Interlock System (SIS) contributed to large savings to CERN of both energy and money. Due to strict timing requirements (close to soft real time) the sis-core library have been improved to provide required performance together with complicated fine-tuning of the virtual machine. The SIS as a system is proposed to be used not only for the SPS or the LHC but also to gradually replace existing legacy solutions in the injector chain.
**BE-RF Group**

In 2009, starting in Week 17 and until Week 52, the SPS delivered proton beams for fixed target physics, CNGS and the LHC. In addition, proton and lead ion beams were used for a variety of machine development sessions.

The main components of the SPS RF system, the 200 MHz and the 800 MHz RF power plants, the transverse damper system, the low level system and the controls software for these systems worked extremely well in 2009 and this certainly played its part in the overall performance of the SPS. The number of Protons on Target (PoT) for CNGS exceeded the requested value by about 10%: 3.5e9 PoT was delivered. The 200 MHz RF power plant initial transmitter trip rate was considerably improved in the course of the year in 2009. The RF power control application for the power plant (MMI) was integrated into LSA (LHC Software Architecture).

Following the routine replacement of radiation damaged cables between BA2 and LSS2 during the 2008/2009 shutdown the SPS transverse damper system had to be completely re-commissioned.

The main effort in 2009 for the SPS low level system was put into the commissioning of the lead beam for LHC (I-LHC beam). After re-commissioning the low level electronics, firmware and software which had been improved since 2007 the switching over from radial loop to synchronization loop and the whole re-phasing process at flat top energy were commissioned. During a machine development session it was even possible to extract the re-phased beam towards LHC. To reduce the longitudinal emittance spread within the I-LHC beam coloured noise was successfully applied for a controlled emittance blow-up.

There were no particular issues with the fixed target proton or with the standard CNGS beams. However, the MTE beam, intended to replace the beam extracted by CT from the PS, required some study in the SPS because of beam loss related to the more than a factor of two higher intensity of the fifth island with respect to the first to fourth island.

The proton LHC beam was operationally delivered to LHC at the end of 2009. While filling LHC the Beam Quality Monitor (BQM) was successfully used for the first time to assure that the extracted beam fulfilled specifications.
Principal SPS RF machine studies were related to beam stability in a double RF system using the 200 MHz and 800 MHz travelling wave cavities and to Transverse Mode Coupling Instabilities (TMCI). Studies on single bunch feedback against TMCI, using existing exponential stripline coupler pick-ups in the SPS have started in collaboration with LARP.

For the double RF system at injection the beam was seen to be much more unstable in the bunch-lengthening mode than in bunch-shortening mode. However, the bunch shortening mode also has limits and studies will continue. Electron cloud tests were carried out on three SPS dipole vacuum chambers coated with amorphous carbon. The results were highly encouraging: the electron cloud signal was observed to be 300 times lower than with uncoated the stainless steel vacuum chambers. Furthermore, no deterioration of the carbon coating could be observed. The measurements were done using the unique microwave transmission method specially developed for the purpose. All this work was done in the framework of the SPS Upgrade Working Group (SPSU WG) and in close collaboration with TE and EN Departments. Other important SPSU WG activities concerned a proposal for upgrade of the 200 MHz RF system in the SPS to handle ultimate LHC intensities and targeting impedance reduction.

**AD:**

**BE-BI Group**

**Electron Cooling**
The AD electron cooler was used to investigate the possibility of decelerating antiproton beams to lower energies than currently available. The energy of the electron beam is used to “drag” the circulating beam to a lower energy while synchronously ramping down the main magnets of the AD ring. In this manner the deceleration is lossless and the small emittances and momentum spread of the beam are conserved. An important aspect of this method is the control of the alignment of the electron beam with the antiprotons. During these investigations the control system did not allow us to properly correct the trajectory of the electrons and hence the “dragging” became less effective as the beam energy was lowered. Despite this setback, antiprotons were successfully decelerated from 100 MeV/c to 95.3 MeV/c, a 10% reduction in energy (5.3 MeV to 4.8 MeV), in 35 seconds. The deceleration time was in complete agreement with the expected value calculated from extensive drag rate measurements made at 100 MeV/c in 2009. These studies will continue in 2010.

**AD Experimental Areas**
The Beam Instrumentation in the Experimental areas of the Antiproton Decelerator (EAD) is composed of some twenty Multi Wire Proportional Chambers (MWPC) for tuning the beam and monitoring its correct delivery to the experiments. At low energies these detectors suffer from the fact that the profile of the second measured plane shows an emittance blow-up due to the material used for detecting the profile of the first plane. For this reason only one Multi Wire Proportional Chamber can be put into the beam at a time. During Machine Development studies in 2009, four new detectors based on Gas Electron Multiplication were tested in the EAD. Gas Electron Multipliers (GEM) have the advantage over Multi Wire Proportional Chambers that
both profiles are read out simultaneously, allowing undistorted dual plane measurements to be obtained. These initial test were very encouraging and will lead to further testing in 2010 with a view to a complete replacement of the MWPCs by GEMs in 2011.

**BE-OP Group**

Starting on the 12:th of May, a 4-week starting-up and machine study period took place. During this, it was confirmed that previous year’s problem with around 20% reduction in pbar yield was indeed due to the production target being in the wrong longitudinal position. The faulty positioning system which is placed in an area with high dose-rates could be repaired during a short intervention. This was followed by careful optimization of both target position and magnetic horn current in order to achieve best possible pbar yield.

Further machine studies that were carried out during the startup and also during the years 7 scheduled Monday md-sessions were:

- Improvements of the low-energy optics where smaller dispersion and smoother beta-functions at the electron cooler resulted in better deceleration efficiency and potentially better stability.
- Deceleration below 100 MeV/c using the electron cooler instead of the RF-system.
- Bunched beam cooling and longitudinal compression with barrier bucket at 100 MeV/c.
- Tests of GEM-detectors that will be replacing the MWPC:s in the ejection lines.

The physics program could start as foreseen on the 8:th of June with the AD-team supervising the machine on a weekly basis and their colleagues in the ccc looking after things during nights and weekends. Initial machine performance was good with the intensity of the 100 MeV/c beam delivered to the experiments gradually increasing during the run. A peak was reached in July where a one-week average of more than 4E7 delivered pbars per pulse was achieved. During the same period an all-time best deceleration efficiency of 93% was recorded.

The ALPHA collaboration are now well on their way to Hbar trapping where significant progress in the understanding of the new magnetic trap lead to some indication of possible events. In parallel, progress was made with the new silicon detector and in the development of evaporative cooling.

At ATTRAP, steady progress was made towards Hbar trapping including lowering of the electron and positron plasma temperatures which is required to produce Hbars cold enough for trapping.

A new mode of operation of the ASACUSA RFQ-Decelerator was successfully introduced where at ejection the beam is bunched at h=6 in AD and then ejected in 6 pulses 2.4 seconds apart. Physics activities include antiprotonic helium spectroscopy and progress towards Hbar formation using the MUSASHI trap for pbar accumulation and the CUSP trap for mixing of pbars and positrons.

Week 38 was entirely devoted to the ACE experiment with single pbar bunches ejected at 500 MeV/c.
Due to problems in the injector chain some physics time was lost, this was compensated by extending the run by 2 weeks. By the end of the run, on the 7th of December, a new record of 4460 hours of scheduled physics during 26 weeks had been achieved. Over the year, a global beam availability of 79% was recorded with an AD uptime of 92%.

**REX/ISOLDE:**

**BE-ABP Group**

**REX-ISOLDE**

REX-ISOLDE delivered 8 new isotopes this year (1 new element), stretching from 30Na to 200Po (30Na, 63Mn, 66Ni, 94,96Kr, 107,109Sn, 200Po). All in all 25 elements and over 70 radioactive isotopes accelerated so far. Versatility and broadness of the machine makes it unique and without competitors. It is important to state this as SPIRAL2 claims the future territory and reduction of investments at ISOLDE. The world unique, laser ionized, pure and intense 200Po beam at ISOLDE was post-accelerated this year at REX-ISOLDE and impressively high statistics was obtained in the Coulomb excitation spectrum.

For the first time, a 1 neutron transfer reaction has been performed on the proton closed shell nucleus 66Ni. With this experiment, ISOLDE joins GANIL and ORNL in the capability to obtain spectroscopic information on radioactive nuclei by means of direct reactions in inverse kinematics in the Ni region. The results so far show the superiority of (REX-)ISOLDE in terms of beam intensity, purity and quality of the spectra.

This year, unambiguous proof has been given for the production and post-acceleration of in-trap produced radioactive ion beams. At in-trap decay difficult elements are produced by decay from their abundantly produced mother isotope in the low-energy system before being accelerated. The method opens up the possibility for several new elements not ordinary accessible with the ISOL-method, such as B, Si, Fe etc.

Mass separation tests are finished. We conclude that a reasonable efficiency for the REX low-energy system can be maintained if bunched injection from the preceding RFQ cooler into REXTRAP is used. A mass-resolving power close up to 3E4 for 39K was achieved. The operation mode, however, is fairly complicated and has space-charge limitations so it’s not a solution for all isobarically contaminated beams but a complement to for example previously developed molecular sideband beams.

The development of polarized beams has gained momentum. In addition to a now operational mobile tilted-foil device for beam polarization a beta-NMR setup that can be used to characterize the polarization degree but also to perform a number of solid-state and nuclear physics experiment is under buildup. The first tests with the mobile device are scheduled for the end of 2009.

Otherwise 2009 was a problematic year at REX. 9-gap failure canceled one run, ISOLDE
vacuum problems prevented a second. The cathode failure almost completely stopped a 11Be run, but thanks to a swift repair most of the beam time could be saved.

**BE-BI Group**

**ISOLDE:**
Consolidation of the ISOLDE and REX-ISOLDE instrumentation has been ongoing for several years with the main aim of improving the reliability of the systems and reducing the manpower required for their maintenance. Until a few years ago all the instruments in the ISOLDE hall where controlled by PCs running Windows NT interfaced via serial ports, which, with the phase-out of NT, led to many maintenance problems. Today everything is controlled using CERN standard VME crates and PLCs. During 2009 a completely new VME based control and acquisition system for the REX instrumentation boxes was designed and produced. This new system is currently being deployed and will be operational for the 2010 run. The beam scanner system of ISOLDE is also being redesigned around the VME bus and will be deployed in the near future. Another major development undertaken in 2009 was that of the pico-ampere-meter used for the readout of the Faraday cups. This new device will replace the current unreliable readout system based on multiplexers and commercial electrometers. 2009 also saw the arrival of a new tape station for ISOLDE, with the BI Group involved in providing the control unit based on an adaptation of the existing, PLC based system.

**BE-OP Group**

**ISOLDE & REX**
The ISOLDE and REX facility ran successfully throughout the 2009 operational period. Despite a number of failures and problems, a large variety of radioactive beams were produced and delivered to experiments and an ambitious physics programme could be completed.

**ISOLDE**
The facility started on time with a first radioactive beam delivered on April 29th, and ran until November 22nd.

About 350 shifts of radioactive beam were delivered this year (210 for GPS and 140 for HRS) in 30 weeks of physics. In total 62 different beams were scheduled with 28 target units. Beams were delivered for experiments covering a broad spectrum, including weak interaction and nuclear physics but also atomic physics, solid-state physics and biophysics. Mass measurements of silver, krypton and manganese isotopes were performed at ISOLTRAP. Some very good data was obtained for $^{64-66}$Mn ($T_{1/2}(^{66}$Mn) $= 64.4$ms new ISOLTRAP record). For the first time nuclear charge radii of magnesium isotopes were obtained from isotope shift measurements at COLLAPS. Decay of $^{81}$Zn to $^{81}$Ga was studied by Ultra Fast Timing measurements. Several new gamma transitions were identified in this N=50 nucleus and level lifetimes of the lowest-lying states were measured.
REX-ISOLDE
Despite several technical issues, 8 new isotopes (and one new element) were post-accelerated this year stretching from $^{30}$Na to $^{200}$Po ($^{30}$Na, $^{63}$Mn, $^{66}$Ni, $^{94,96}$Kr, $^{107,109}$Sn, $^{200}$Po). All in all 25 elements and over 70 radioactive isotopes have been post-accelerated so far.
The pure and intense, laser ionized, $^{200}$Po beam available at ISOLDE, was post-accelerated this year at REX-ISOLDE and impressively high statistics was obtained in the Coulomb excitation spectrum.
For the first time a neutron transfer reaction has been performed on the proton closed shell nucleus $^{66}$Ni at ISOLDE.
This year unambiguous proof has been given for the production and post-acceleration of in-trap produced radioactive ion beams. The method opens up the possibility for several new elements not ordinarily accessible with the ISOL-method, such as B, Si, Fe.
This clearly shows all the potential and versatility of the technique. With the capability of charge breeding heavy ion beams and the future linac energy upgrade, REX-ISOLDE offers a unique tool for future physics at ISOLDE.

LINAC 4:

BE-ABP Group
The Linac4 ion source ignited its first plasma in the summer of 2009, and then delivered its first beam soon after. A beam current of 20mA of H- was quickly achieved while the reliability of the sub systems was improved. Precise measurements of the RF coupling (for the first time with low frequency RF ion sources) showed that less than half of the RF power is coupled to the source at the CERN installation, and improvements to the matching scheme are to be considered. Towards the end of the year the first phase space measurements were made with a slit and grid emittance meter developed for the Linac4 source.

With Linac4, the injection energy into the PS Booster will be increased to mitigate direct space charge effects in order to improve the performance in terms of maximum achievable beam brightness and intensity. At the same time, the conventional multi-turn injection of protons with stacking in horizontal phase space will be replaced by a H- charge exchange injection to minimize losses and maximize the beam brightness. Furthermore, Linac4 will be equipped with a low energy chopper and an energy modulation system, allowing programming (small) variations of the output energy along the beam pulse, in order to tailor the beam distribution in the longitudinal plane to the receiving bucket and to minimize losses during acceleration and space charge detuning. A functional description of an interface between the two machines is now complete.

First studies on the impact of Linac4 on machine activation and whether a collimation system may be possible to optimize performance have started. It should be noted that the single batch injection scheme, successfully tested for the 50 and 75 ns beams, was conceived in view of the operation of the PS-Booster with LINAC4 when the production of the 25 ns beam in a single batch will also be possible.
**Beam Instrumentation for the Source**
At the end of 2009 the ion source at the 3 MeV test stand came into operation. The first measurements were performed using a Faraday cup installed directly after the source to give the total current coming from the source. The next instrument to be installed was the emittance meter, comprised of slits and secondary emission (SEM) grids, to measure the distribution and angular spread of the beam emitted from the source. Construction of the emittance meter was not without its problems, with a re-design of the actuator required to reach the specified precision once the tank was under vacuum. A big effort from the BI Group mechanical, profile and software sections, however, ensured that system was installed and operational by the time it was required for source measurements. The initial results showed that the divergence of the source beam was much larger than expected, which required the emittance meter to be moved closer to the source exit, necessitating the removal of the Faraday cup. In this configuration data taking started in earnest, allowing the first measurement the beam profiles and emittances.

**Beam Instrumentation for the 3 MeV measurement line**
Good progress was made towards the construction of instruments needed for the 3 MeV measurement line. Installation of these devices is foreseen for the beginning of 2011 once the RFQ is installed. The line will contain a second emittance meter similar to the one used for source measurements. This emittance meter is also foreseen to be used after the first DTL tank, at 12MeV, and therefore the slit must be designed in such a way as to withstand the large heat load deposited when using H- ions at this energy. A DITANET Marie Curie fellow is working on this issue and already has a preliminary design for such a system.

The beam intensity in the line will be measured with current transformers. One transformer will be used in the Low Energy Beam Transport line (LEBT), at the entrance of the RFQ, while two additional transformers will be installed in the measurement line itself. The LEBT transformer is already built and the other transformers are currently under construction in the CERN workshop. Beam position and beam energy will be measured using stripline BPMs. Extensive simulations have been performed to try and understand the fields within these BPMs with such low energy beams to optimise the design parameters. This has resulted in a 3D design that is close to being finalised. On the electronics side the design of the acquisition system has been intensively studied for the wide range of possible beam types. The analogue electronics will be housed in a two unit VME module with the digital part foreseen to use the new FMC VME board being designed as a collaboration between BE/BI and BE/CO.

In addition to the instruments constructed at CERN a contract has been signed with INR Troitsk, Russia to provide a bunch shape monitor (BSM) similar to those provided for SNS in the USA. A complete set of design documents for this system were delivered at the end of 2009 and are currently under study. This detector is foreseen to be available for the start of commissioning with the 3 MeV test bench.
BE-RF Group

The year was marked by the preparations for the construction of the Linac4 accelerating structures. Linac4, which is planned to be connected to the PSB in the 2014/2015 shut-down, consists of 4 main accelerating structures: firstly the Radio Frequency Quadrupole (RFQ), which accelerates the beam from the source extraction energy of 45 keV to 3 MeV, secondly the Drift Tube Linac (DTL), consisting of three tanks, taking the energy to 50 MeV, thirdly the Cell-Coupled DTL, which brings the beam to 102 MeV, using 7 modules of 3 short DTL-type tanks, and finally the PI-Mode Structure (PIMS), based on the design of the LEP normal conducting cavities to finally accelerate the beam to the 160 MeV design output value. In Linac4 all structures will work at a modest duty cycle of 0.1 %, but they are all designed for operation at high duty cycles of over 5%. The mechanical design of all structures was done at CERN, together with the design office and the mechanical experts from the central workshops. The installation of the structures in the Linac4 tunnel is planned for 2012. All structures have to be delivered at CERN during the period from the end of 2011 to early 2012, in order to meet the schedule for going through vacuum tests, cooling circuit tests and high-power RF testing prior to installation.

The Linac4 RFQ has been designed and is being built at CERN, with contributions to the RF design coming from CEA in France. It is made of three 1 m long modules, the tuning and conditioning done after final assembly. In 2009 the design phase was completed and the machining of the copper pieces started at the CERN mechanical workshop. All main parts have been pre-machined and the four vanes that constitute the first module were pre-machined. The completion of the first module is now in progress and the first step of the overall assembly is planned for the end of March 2010.

2009 also saw the high-power testing of a DTL prototype in SM18. The prototype parts have been machined at CINEL in Italy under a collaboration agreement with INFN Legnaro and were delivered to CERN in the beginning of 2008. After the copper plating and drift tube welding at CERN the cavity was assembled and RF tested at low power. In spite of initial problems with vacuum tightness, the prototype was ready for high-power testing in the autumn. The required Linac4 duty cycle and field level was achieved after a few days, and after further conditioning the structure even comfortably surpassed the nominal SPL duty cycle.

Two high-power prototypes of the CCDTL had been constructed and tested successfully in previous years. In 2009 an ISTC contract was signed for the construction of the complete CCDTL in Russia, in collaboration with BINP Novosibirsk and VNIITF Snezhinsk. The project collaboration started in July 2009 with a technical kick-off meeting at CERN, followed by an official kick-off meeting in October with the participation of all institute heads, including the ISTC and CERN management. The ISTC contributes around 900 k$ to the total construction cost of approximately 2.4 M$. In addition CERN supplies all raw materials, ordered in 2008 and 2009. By the end of 2009, 38 tons of material (680 items) with a value of 770 k$ had left CERN for the participating institutes. The first module is scheduled to arrive at CERN by end of 2010/beginning of 2011.
Early in 2009 the construction of the PIMS “hot” prototype started in the CERN workshops. First low-power tests are planned for the beginning of 2010, with high-power tests starting in early summer of 2010. Construction of the full series of 12 cavities will start in 2010 and a collaboration agreement for construction is under negotiation with the Soltan Institute in Poland. FZ Jülich in Germany has expressed interest as a third partner.

Other important Linac 4 milestones were the preparation of the contract for the 2.8 MW klystrons to drive the acceleration structures, and also the loads and circulators of the RF power chain. The integration studies for the equipment in the tunnel were more or less completed.

CTF3/CLIC:

BE-ABP Group

The aim of CTF3, built at CERN by an international collaboration, is to prove the feasibility issues of the CLIC two-beam acceleration technology. The two main points which CTF3 should demonstrate by 2010 are the generation of a high current drive beam and its use to efficiently produce and transfer RF power to high-gradient accelerating structures, used to bring the main beam to high energies.

CTF3 consists of a 150 MeV electron linac followed by a 42 m long delay loop and a 84 m combiner ring. To prove the first point, the beam current is first doubled in the delay loop and then multiplied again by a factor four in the ring by interleaving bunches using transverse deflecting RF cavities. The power generation and the high-gradient acceleration are instead demonstrated in the CLIC experimental area (CLEX), where the drive beam can be transported to be decelerated and produce RF power in resonant structures called PETS (Power Extraction and Transfer Structures). In the same area a 150 MeV injector (CALIFES) generates a probe beam for two-beam experiments. CTF3 is being installed and commissioned in stages from 2003. Delay loop running-in was basically completed in 2006. The combiner ring was installed and put in operation in 2007, while the transfer line to CLEX was installed in 2008.

The year 2009 was a busy one, since the transfer line and the drive beam lines in CLEX had to be commissioned, and delay loop and combiner ring operation had to be put together, to obtain the final multiplication factor of eight. On top of that, support for the commissioning of the CALIFES drive beam injector (collaboration with CEA/Saclay) had to be provided. In the first part of 2009, we made significant progress in improving the optics in several parts of the machine. A series of measurement helped to refine the modeling, finally obtaining a satisfying correspondence up to the newly installed CLEX beam lines. The setting up procedures were improved as well. Such work eventually paid off in September, when we could finally put back into operation the delay loop, and obtain a very stable combination factor 4 operation in the ring, with a current stability of the combined pulse of about $3 \times 10^{-3}$, not very far from the CLIC requirements. Shortly after that, it was finally possible to get a combination factor $2 \times 8$ obtaining for the first time a 25 A, 140 ns pulse (see figure 16).
During 2009, we also helped to provide beams to produce RF power pulses for structure testing, both in the “old” 30 GHz test stand and in the newly installed Two-Beam Test Stand (collaboration with Uppsala University), operating at 12 GHz. In the latter, a PETS prototype was conditioned to produce up to 140 MW with a total pulse length of about 200 ns.

Coming to beam dynamics, we are actively participating in a wide range of collaborative efforts on the main beam sources, an important part of CLIC. In this area, the more challenging task is the generation of polarized positrons, for which a number of options are being studied.

At production the CLIC main beam emittances are large; the CLIC design includes damping rings in order to provide the small beam emittances needed for efficient luminosity production. A pre-damping ring is required in order to reduce them to a level that allows injecting the beams into the damping ring. Systematic studies have been performed of the different design options. Based on the results a pre-damping ring baseline design has been developed. For the damping ring itself a design existed, but with very challenging if not impossible technical systems. The impact of the damping ring energy on different beam parameters has been reviewed, and higher beam energy has been chosen. A new baseline lattice has then been developed, that eases most of the technical challenges considerably. One of the damping ring challenges is the large impact of intra-beam scattering (IBS). This effect can be estimated analytically making some simplifying assumptions. A code (MOCAC) that can simulate the effect exists, but does not include radiation damping, vital for a damping ring. A new Monte Carlo code (SIRE) has then been developed to study IBS. It is in part based on algorithms of MOCAC adding the other effects relevant for the CLIC damping ring. The predictions of this code support our design choice.

The design of the beam transport and manipulation system (RTML) from the damping ring to the main linac has been improved and tolerance studies are continuing. The RTML contains a 25 km long transport line for each main beam. The impact of dynamic magnet fields has been studied in this line, showing that the tolerances are very tight. An R&D programme needs to be launched to address the issue.

Very good vacuum of about 0.1 nTorr is required in almost the whole main beam complex of CLIC, otherwise the beam emittance will increase significantly due to the fast beam-ion instability. Achieving such a good vacuum level in the main linac appears challenging since heating of the components for bake-out or activation of coatings would most likely interfere with the very tight mechanical accuracy requirements. In addition, the beam size at the end of the main linac is so small that it will generate ions not only by collision ionization but also due to field ionization. A program (FASTION) has been developed to simulate the instability. It has
been extended to include a preliminary model of the field ionization. The simulations showed that the vacuum level specifications tighten but remain consistent with the achievable vacuum. Further improvement of the ionization model and of the studies is ongoing.

The performance of the beam-based alignment has been evaluated for the new main linac design. The procedure uses first a flat steering of the machine, then a dispersion-free steering algorithm applied and finally built-in wake-field monitors for aligning the accelerating structures to the beam. In addition emittance tuning knobs can be used to further improve the performance. The studies showed that even without the knobs the emittance preservation target is achieved with a probability of 90%.

The baseline design if the CLIC final focus system has a distance of $L^* = 3.5$ m between the end of the last quadrupole and the interaction point; the quadrupole is thus positioned inside of the detector. An alternative system has been suggested by A. Seryi with a distance of $L^* = 8$ m. This would allow to position the quadrupoles outside the detector, but the system shows a reduced luminosity. We performed optimizations of the system reducing such a loss. The tolerances for the initial misalignments were also studied, revealing that they are about five times tighter than the already challenging ones for the baseline design. Efforts have started on a design with $L^* = 6$ m. An important test facility for the beam delivery system is ATF2. We contributed to the commissioning of this facility and to the studies of beam-based alignment.

Dynamic imperfections can be challenging for CLIC. In particular ground motion and technical noise can induce vibrations of beam line components, which can lead to orbit oscillations. A baseline for the feedback system in the main linac has been defined and its expected performance has been studied. One of the challenges is to ensure good consistency between the model and the machine, since the beam performs about 200 betatron oscillations. The model is further complicated by the fact that the beam has a large, varying energy spread leading to damping of the oscillation. A method has been developed to describe the machine in a form that takes this into account and which can be fit from the BPM data. Further studies are ongoing to include more dynamic imperfections and secondary effects.

Dynamic variations of the relative phase of main and drive beam in the CLIC main linac are potentially a serious source of luminosity loss. The phase tolerance has been evaluated in detail and the results published. A baseline for the longitudinal feedback system is being developed. The drive beam complex of CLIC consists of a chain of components, the injector to produce the beam, the drive beam accelerator to store the energy in the beam, the delay loop and the combiner rings to manipulate the beam pulses, the transfer lines to the main linac complex and the decelarators in which the RF power is produced. Tools for the design of the drive beam accelerator have been prepared in collaboration with Ankara University. The work will proceed in close collaboration with experts from the RF group. Work on the design of the delay loop and the combiner rings is progressing.

In the CLIC decelerator the RF power is produced to accelerate the main beam by decelerating a high current (100A) drive beam. In this process most drive beam particles are decelerated down to 10% of their original energy. This leads to spread in the beam of a factor ten between highest and lowest energy. The stability of this beam has been studied in detailed simulations in the framework of a thesis in close collaboration with the RF group. A structure was chosen that
allows the beam to remain stable. Further studies addressed the level of static and dynamic
imperfections that can be accepted in the decelerator. This included the simulation of beam-
based alignment.

We performed studies of the beam induced background in the CLIC detector, in particular the
beam-beam background. The linear collider detector project used these studies to make basic
choices for the detector design. The predicted level of coherent pair production led to the
adoption of a 20 mrad crossing angle in the CLIC interaction point. The predicted level of
incoherent pairs to the choice of an inner radius $r = 30$ mm of the beam pipe in the vertex
detector. The data base with hadronic background events that we have provided is being used to
understand the implications for the experiments a preliminary conclusion is the adoption of a
time stamping goal of 10 ns. Further we developed a code to simulate the emission of
synchrotron radiation in combined fields of beam line elements and the detector solenoid field.
The studies showed that the preferred field configurations would lead to large luminosity loss
while other configurations are acceptable.

The section is active in providing information and specifications to other working groups on the
different technical issues of CLIC.

A large part of the beam simulations are performed with PLACET, which had been developed at
CERN and is now used in a number of institutes. The code has been further improved, in
particular regarding the interface. Beam loss can have an important impact on the performance of
the CLIC detector and of the operation of the machine. A package (HTGEN) had been developed
to simulate halo and tail formation, this package is available in PLACET. Further improvements
of this code were made and it has been used to predict losses in the CLIC drive beam decelerator
and at the main beam collimation section.

Further activities of the section included the organization of an ILC-CLIC beam dynamics
workshop, the organisation of the CLIC annual workshop and the participation to the ILC effort
in beam dynamics. We are also helping in the review of the ILC project.
The section contributed as well to the Joint University Accelerator School courses and prepared a
new twelve hour course on the beam physics of future linear collider main linacs.

Survey - CLIC/CTF3:
Some important results were obtained concerning the CLIC pre-alignment studies towards the
CDR. After an inventory of the existing solutions, a cam based repositioning system was chosen
for the pre-alignment of the Main Beam quadrupoles. It should be compatible with the
stabilization requirements, and its resolution and modal behavior will be checked on a 1 Degree
Of Freedom (DOF) mock-up, before implementation on a 5 DOF mock-up. A low cost Wire
Positioning System (WPS), based on two cameras looking at the wire, has been developed and
received; the first validation tests have started. In the same time, the capacitive based WPS have
been upgraded. A dedicated absolute calibration bench was developed to improve their accuracy.
The TT1 facility has been upgraded in order to have a better understanding of the precision and
accuracy of measurements with stretched wire. A precision of 1 micron over 30 days along wires
of different length (50m, 90m and 140m) was demonstrated.
BE-BI Group

The BI Group has a large range of activities on CTF3 and CLIC covering both R&D and exploitation. There are a number of monitors for the observation of the transverse beam profiles: optical transition radiation stations (OTR), scintillating screens, synchrotron light stations, segmented dumps, as well as beam position, beam current and wall current measurement systems.

The transverse profiles are used to measure and tune the transverse optics of the machine, measure the energy spread and adjust the RF in the cavities. OTR and synchrotron light is also sent to streak cameras for monitoring bunch structure and longitudinal bunch size. As many of the above mentioned devices are novel or are used beyond previous limits, the R&D activity is considerable even for devices used for day to day exploitation. Much time is spent analysing data and comparing the results of different systems. In particular, over the past year, effort and attention has been given to the instruments capable of giving time resolved energy measurements, required for the compensation of effects caused by large beam loading, and bunch separation measurements for the optimisation of the recombination process.

On the beam position side, a collaboration between IFIC (Valencia, Spain), UPC (Barcelona, Spain), LAPP (Annecy France) and CERN permitted the construction and installation of 16 new BPMs together with their associated front end electronics and acquisition systems in the CTF3 CLEX TBL line. Much higher than expected radiation doses in CTF3, however, led to the damage of several of the electronic systems. It was therefore decided to replace the digital front-end systems located in the tunnel with a standard VME based ADC system located outside the tunnel and connected to the BPMs using coaxial cables. The design and construction of this new system, entirely under CERN responsibility, is well underway with everything expected to be ready for the CTF3 start-up in 2010.

With a view towards its contribution to the CLIC CDR, the BE/BI Group organised a 2 day workshop in June 2009 with over 50 participants to cover all aspects of instrumentation for the entire CLIC complex. The outcome of this meeting was a list of measurements requiring further investigation in order to demonstrate proof of principle for achieving the CLIC specifications. In the same vein, new collaborations were initiated with both FNAL and SLAC within the CLIC collaboration with the aim of demonstrating a design for the CLIC main beam and drive beam BPMs. This will result in one SLAC instrumentation expert joining the BE/BI Group in 2010 as a project associate for development of a drive beam BPM, and the delivery in 2010 of a design for a main beam BPM from FNAL.

BE-RF Group

Significant progress was made during 2009 towards demonstrating the feasibility of two of the most crucial RF performance specifications for CLIC - 100 MV/m accelerating gradient in accelerating structures and 135 MW power generation by PETS (decelerating) structures. The latest experimental results, which are described below, are the culmination of an effort that underwent a major redirection approximately three years ago following the decision of CLIC to
change frequency from 30 GHz to X-band. Since then an intense development program has been pursued which has included: Fundamental studies of breakdown and other high-gradient phenomenon, detailed RF design studies using newly developed high-power scaling laws, working with industry to develop the machining capability for fully three-dimensional few-micro-precision parts, adapting assembly and high-gradient preparation techniques developed by the NLC/JLC linear collider study to the CLIC design and designing, ordering, assembling and finally high-power testing prototype structures. The development program is being carried out in a collaboration, led by CERN, with over twenty five participating institutes.

The first demonstration that accelerating structures can be operated at an accelerating gradient in the range of 100 MV/m at the full CLIC pulse length, 240 ns, and required low, $3 \times 10^{-7}$/pulse/m, breakdown rate already occurred in 2008 with the test at the NLCTA facility at SLAC of a so-called T-18 structure. 2009 saw the confirmation of this result with the test of an identical structure at the NEXTEF facility at KEK and the successful start of the test of a third T-18 at SLAC. These three results taken together are very significant in the process of demonstrating that 100 MV/m can be reproducibly and reliably achieved. The next crucial step in the feasibility demonstration process was to show that the gradient can also be achieved in an accelerating structure with the higher-order-mode damping features that are necessary for beam stability. This step in the demonstration made an excellent start at the end of 2009 with the beginning of testing of a so-called TD-18 structure at SLAC. At the time of this writing the structure had already passed 90 MV/m at the CLIC breakdown rate and conditioning was proceeding well. Even though the test was not complete, the results already showed that the rather large damping waveguides in the cells do not significantly influence gradient. This was a major result in the CLIC study.

The PETS are rather unique RF structures which generate the 135 MW necessary to feed two accelerating structures by decelerating the 100 A drive beam. They are travelling wave structures with very low impedance and strong high-order-mode damping. They are built from eight longitudinal bars. Because CTF3 is limited to 30 A, special versions of the PETS were made in order to show different aspects of feasibility in different tests. The first of these tests is a PETS operated in a klystron driven transmission “waveguide-mode” at the ASTA facility at SLAC. Initial testing uncovered a number of issues relating to the fabrication of the PETS and of the high-power performance of the facility itself, however the problems were resolved and the PETS operated for approximately 30 hours at a power level of 140 MW at a breakdown rate of $10^{-6}$/pulse by the end of the year. This tests will continue this year with a newly fabricated PETS prototype. The klystron based test was complemented with a beam driven test in the Two-Beam Test Stand (TBTS) in CTF3. In order to obtain the full power with only 30 A, a special 1 m long PETS was built and equipped with an adjustable RF recirculation ring. The tests were limited by breakdown in components the recirculation loop but the PETS gave clear indication of running stably at least up to 120 MW. Here too the tests will be continued this year with improved hardware. Finally the first of sixteen PETS was installed in the Test Beam Line (TBL) in 2009. The TBL is primarily a test of drive-beam stability under significant deceleration; however it provides another opportunity to test the performance of PETS structures. The first TBL PETS saw its first beam and generated 30 MW without any difficulty. More structures and more current, and hence more power, are expected this year in the TBL.
CTF3 status
The CLIC test facility CTF3 made important progress in 2009. The facility neared its completion, and commissioning with beam made good progress. All beam lines have had beam. An important focus in CTF3 is the commissioning of the CLIC RF power production scheme. A major highlight in 2009 was the successful combination of bunch trains from the Linac into the required short high-intensity trains using the Delay Loop and the Combiner Ring simultaneously. The final sub-system to be completed is the Test Beam Line TBL. This line will be equipped with 16 PETS (Power Extraction and Transfer) structures. The beam line was completed, with all quadrupoles and vacuum chambers in place. One PETS has been installed so far. Seven more are on order and are to be installed in 2010. The installed PETS was operated with the available beam and produced 20 MW of RF power at 12 GHz.

The high power RF installation saw the addition and successful commissioning of a further S-band klystron system with modulator and RF distribution network in order to feed the Probe Beam Linac (CALIFES) in CLEX with up to 86 MW of RF power. This brought the High Power RF system for CTF3 to 11 S-band and one L-band klystrons and modulators as well as three Travelling Wave Tube amplifiers. The system ran reliably throughout the year, the temporary failure of one TWT having been compensated by the two remaining ones.

The low level RF system for CTF3 also worked well without major failures. New 12 GHz systems for RF power measurements and diagnostics for the Two Beam Test Stand and the first PETS in TBL were put into operation operational and gave good results.

Photo Injector PHIN
A photo injector has been built in the ex-CTF2 area with support from the EU FP6 program in collaboration with RAL, LAL and CERN. This is to test the feasibility of a photo injector instead of the thermionic gun already in CTF3, and in CLIC. The advantage is that the bunch phase-coding can be done without a sophisticated bunching system and sub-harmonic bunchers. Definition the time structure of the bunch train would be done by modulating the laser timing, avoiding the parasitic bunches inside the 1.5 GHz train structure, which contain about 7% of the beam current in CTF3. The system is now installed, commissioning has started. The phase-coding is not yet available, it will be provided by EN/STI in 2010.

The PHIN test stand was equipped with diagnostics equipment to measure beam properties. Very good results have been achieved, the bunch charge of 2.5 nC is above the design value, a beam energy of between 5 and 6 MeV has been obtained and the beam emittance could be measured to be 7 µm mrad, which was in good agreement with simulations.

Stand-alone 12 GHz RF power source
For the CLIC accelerating structure development program build-up of a stand-alone RF power test stand has started in collaboration with IRFU/CEA, Saclay. It consists of a 50 MW klystron with modulator and RF pulse compression system. All components have been ordered, the design work for the layout has reached an advanced state. Installation is planned from February 2010 onwards, to be ready for tests mid 2010. A new 12 GHz low-level RF system with RF generation, diagnostic and control equipment is under construction.
HIE-ISOLDE:

BE-RF Group

The High Intensity and Energy ISOLDE (HIE-ISOLDE) project is a major upgrade of the existing ISOLDE and REX-ISOLDE facilities with the objective of increasing the energy and the intensity of the delivered radioactive ion beam (RIB). This project aims to fill the request for a more energetic post accelerated beam by means of a new superconducting (SC) Linac based on Quarter Wave Resonators (QWRs). A research and development program looking at all different aspects of the SC Linac has started in 2008 and continued throughout 2009. In particular the R&D effort has focused on the development of the high β cavity (β = 10.3%), for which it has been decided to adopt the Nb sputtered on Cu substrate technology. Other R&D activities are related to the beam dynamics studies which seek to define a very compact accelerating lattice and consequently the shortest possible machine, a design of compact SC solenoids with limited fringe fields, and the study of the cryomodule concept. The superconducting Linac is designed to deliver an effective accelerating voltage of at least 39.6 MV with an average synchronous phase φs of -20 deg. This is the minimum voltage required in order to achieve a final energy of at least 10 MeV/u with A/q = 4.5. Because of the steep variation of the ions velocity, at least two cavity geometries are required in order to have an efficient acceleration throughout the whole energy range. A total number of 32 cavities are needed to provide the full acceleration voltage. The geometries chosen corresponding to low (β0 = 6.3%) and high (β0 = 10.3%) “β” cavities maintain the fundamental beam frequency of 101.28 MHz and their design parameters are given in the table here below. The design accelerating gradient aims at reaching 6 MV/m with a power consumption of 7 W per low β cavity and 10 W per high β cav. Fig. 1 and Fig. 2 show respectively the copper substrate of the prototype cavity after the chemical etching and the new sputtering chamber.

A study covering all the issues of the infrastructure and the integration of the machine inside the experimental hall has also being carried out. This has permitted to identify the suitable area for the construction of the building for the compressor for the liquid He system, the location of the He liquefier with the associated control room and also the other subsystem like the new ventilation unit, the new electricity distribution panels and the position of the different racks. Fig. 3 shows the result of the study. Around the Linac a semi-permanent tunnel- like shielding made of concrete blocks will be installed all along the machine length. This is strictly required from the radioprotection point of view as the whole area will remain accessible during the physics runs. The LHe liquefier will be installed at the end of the machine in a separate light construction building. In this way it is possible to minimize the length of the LHe distribution system and to maintain the geometry of the line as simple as possible which is a condition for a easier and stable operation of the cryogenic system.
SPL:

BE-ABP Group

The ion source development for a future high power SPL is partly funded by the European Union under the umbrella of the SLHC-PP project. During 2009 extensive thermal and fluid dynamics simulation allowed the redesign of the RF type source, in order to allow the plasma chamber to be correctly cooled. The design uses new materials (for example aluminium nitride, well suited to the task with its high thermal conductivity), and highly optimised cooling channels. The source will be constructed in the next year, while in 2009 construction began on the sub-systems (for example the RF generator) and the renovation of an experimental hall in the PS central ring area.

BE-RF Group

The SPL is a 4-5 GeV superconducting linear accelerator, which, as low-power machine (LP-SPL) can become a part of the LHC proton injector chain. With its potential for high average beam power (HP-SPL) it can also be used for the generation of high-power radioactive ion beams, or as a proton driver for various neutrino facilities on the CERN site.

The RF systems in the SPL are the major cost driver of this machine, which means that R&D in the areas of SC cavities, RF distribution, and RF generation has a significant impact on the Linac performance and cost. In 2009 two meetings of the SPL collaboration took place, gathering participants from 18 institutes first at Vancouver (May 2009) and then at CERN (November 2009). Furthermore a number of workshops with dedicated technical issues took place.

In 2009 a choice was taken on the RF distribution scheme for the SPL, foreseeing 1 cavity per RF power source for the HP-SPL and 2 cavities per RF power source for the LP-SPL, which operates at half the pulse current. This principle avoids complicated RF splitting schemes, whose reliability has never been tested and which are not expected to be significantly cheaper than a 1 source per cavity set up. While klystrons are the obvious choice for the high-energy part of the Linac, the low-energy part needs significantly less power per cavity, and it was concluded to study IOT based systems, or even phase-locked magnetrons, which are studied at Lancaster University in the UK. Since the installation of the RF system needs a significant amount of underground volume, the option was studied to have klystrons and their modulators on the surface. No show-stopper was found regarding LLRF feedback control, or due to the increased losses in the waveguide system and as a consequence it is now foreseen to locate the RF system for the high-energy part of the SPL over ground and to use waveguide shafts for the connections to the cavities. Within the collaboration with ESS, Scandinova will build a prototype klystron modulator to be tested and installed at CERN in SM18. At the same time the CERN power group has started to look at design options for an SPL type klystron modulator to be developed at CERN. Further upgrades of the SM18 test stand infrastructure have been determined and work is scheduled to start in 2010, together with the order of a 704 MHz klystron in industry.
After an HOM workshop in June 2009 it was concluded that only weak damping of HOMs will be required in the SC cavities, which can probably be provided by the inter-cavity bellows. While the exact properties of an inter-cavity damping system is still under study 3 HOM ports per cavity are foreseen to be able to provide additional damping should it become necessary. A first cavity design will soon be frozen to start construction of a copper model. In parallel the construction of the 704 MHz Niobium cavities will be launched, with the aim to test a fully equipped cryo-module towards the end of 2012. The development of the high-power coupler started on the basis Saclay coupler, which is being used for high-power tests at CEA. The final options for an SPL type coupler will be decided during a workshop in March 2010 at CERN, after which the construction of prototypes will be launched. In 2009 CERN received a 704 MHz mono-cell cavity from CEA, which is presently used to test surface treatment recipes developed for the XFEL project. For the characterization of Nb samples a quadrupole resonator has been resurrected and is now being prepared for operation.

COLLIMATION PROJECT

ABP Group

Since 2002, the design, prototyping, construction, installation and commissioning of the LHC collimation system has been driven through the LHC collimation project, led from the ABP group. The installation for phase I of LHC collimation was fully completed in 2009.

The LHC ring and the transfer lines are now equipped with 100 fully movable collimators (each with 5 degrees of freedom) which define the typical 2-3 mm gaps for the circulating beams. A four stage cleaning system is implemented which should allow cleaning any stray protons and ions with efficiencies of up to 99.98%. The phase I of the LHC collimation system is already the by far largest, most precise and most efficient collimation system ever deployed for an accelerator. It was used with first beam in the LHC for guiding the beam in steps around the ring and producing test events for the experiments (splash events). Performance without beam was as specified and a 10 day reproducibility and stability of better than 30 μm was demonstrated. Detailed plans and settings for beam commissioning of the phase I system were defined.

In parallel to the phase I collimation work, preparations and studies for “phase II” of LHC collimation picked up speed, supported by the “New Initiatives” program at CERN and EU FP7 support (EuCARD work package “ColMat” for collimators and materials in high intensity accelerators).

The direction for the Phase II work was presented and discussed at a conceptual design review on 2-3 April 2009. A solution for gaining a factor 15 in cleaning efficiency beyond phase I was presented to the review committee and well supported. This solution would involve second-generation collimators in the phase II tunnel slots, hollow e-beam lens scrapers and collimators in the dispersion suppressors downstream of the cleaning insertions. Both nominal and possibly ultimate intensity would be possible for proton and ion beams. Work at CERN and SLAC is ongoing to prototype the necessary hardware. The use of bent crystals was studied for further
future improvements. Work on a test facility for beam-induced shock waves was spawned off into a separate “HiRadMat CERN project” after approval by CERN management. The EuCARD ColMat work with European collaborators was started by a kick-off meeting on 17 June 2009.

LHC Luminosity Upgrade within EUCard

ABP Group

Besides the co-ordination of key CARE activities in the framework of FP6, since 2009 non-negligible resources were devoted to leading roles for several of the FP7 EuCARD work packages. The CARE-HHH network activities were successfully finalized at the start of 2009, and the results compiled in a Yellow Report. The EuCARD-AccNet networking activity was launched in the spring. Three topical AccNet workshops were organized in the fall of 2009: on LHC crab cavities “LHC-CC09” in September, on anti-electron cloud coatings “AEC’09” in October, and on crystal collimation “CC’09” in November.

At the occasion of the LHC-CC09 workshop an LHC Crab Cavity Advisory Board was created. The workshop and subsequent board meeting resulted in a set of official CERN statements on LHC crab cavities issued by the CERN Director of Accelerators and Technology, which strongly support and guide the future R&D effort. The workshop also gave rise to the idea of a demonstration experiment for proton beams with a KEKB crab cavity in the SPS, and led to the establishment of a new working group to explore the feasibility of such experiment.

The AEC’09 workshop was motivated by the requirements for the SPS upgrade. Beam experience from SNS and PEP-II was welcomed, and so were news on in-situ coating plans at BNL and FNAL. In particular, at AEC’09 ICMM-CSIC and KEK presented new potential cures such as diamond like carbon and micro-particles coated with an insulating layer.

In parallel, work on the “large-Piwinski angle” scheme has moved forward. In collaboration with US-LARP several options for generating intense, longitudinally flat bunches, and their stability, were explored in simulations as well as in experiments at the PS and SPS.

Electron cloud studies for various high luminosity upgrade scenarios have been performed with the help of CINVESTAV Mexico. The proposed high-luminosity scenarios appear feasible both with 25 ns and 50 ns spacing, assuming a dedicated new cryo-plant for the interaction regions in LHC Points 1 and 5. Super-LHCb requests could be accommodated with a 50 ns spacing and intermediated lower-intensity satellite bunches, with only a marginal increase in the arc heat load.
ABP Group

The LHC could form the basis of a new high-energy lepton hadron collider. A variety of schemes for bringing electrons into collision with the proton and heavy-ion beams of the LHC ring have been proposed.

The electron ring for the so-called “ring-ring” option would not be a straightforward copy of the former LEP ring as the magnets would have to be lighter and more compact for installation on top of the LHC magnets and the ring would have to bypass the LHC detectors. Moreover the coupling to the hadron ring also intimately constrains the electron optics. An arc optics providing the correct emittance and flexibility to run up to 70 GeV has been found and studies of bypass layouts and the lepton-hadron interaction region have advanced.

In parallel a number of alternative scenarios for a linac-ring collider have been developed, covering a lepton energy range from 5 to 140 GeV. The linac of the linac-ring collider is considered to be superconducting and of the re-circulating (RLA) type. A possible implementation of deceleration loops with energy recovery (ERL) up to 70 GeV could achieve extremely high luminosities. Optics for two RLAs and one ERL version of the linac-ring collider were designed, and, for all of them, the emittance growth due to chromatic effects and synchrotron radiation was shown to be small. Also conceptual layouts for various LHeC interaction regions have been drafted, and a first look was given to the electron and positron sources required for such a collider.

Accelerator Controls Renovation Project (ACCOR)

BE-CO Group

Officially approved in 2009, this project has the objective to renovate the control system of all CERN machines, hardware and software wise, LHC excluded. Major technical decisions have been taken this year concerning the future front-end processor platforms and large-scale commercial contracts have been put in place with the help of the FI department. After an initial integration phase, a first set of prototypes has already been installed in operation for validation. With more than 500 front-ends to be renovated, this project is a big challenge in terms of strategy and priorities for the different departments of the A&T sector. A development roadmap for the core controls components (hardware modules, generic software classes) is currently under validation with all parties involved. Development systems have now been given to the equipment groups of the A&T sector in order for them to start their own validation tests in view of first operational deployments in 2010.
InCA Project

BE-CO Group

April 9th was an important date for the Injector Controls Architecture (InCA) project. After several months of development, a first version of the middle tier acquisition and control server was deployed in operation for a 2-day long MD. These days were extremely fruitful and gave a lot of information on the reliability and scalability of the acquisition core. The following months were focused on the preparation and deployment of a simplified version of InCA for the run of LEIR. The main incentives for this exercise were a homogenous archiving system for the operation crew and an extensive validation period for the InCA team. This exercise was successful and has given us confidence in the deployment plans we have for the PS next year. In parallel, we started development of crucial tools such as the FunctionEditor and a brand new archive environment with performance improved by more than an order of magnitude compared to the system currently in operation. Besides, a version of the LHC-SPS-LEIR beam steering application, “YASP”, has been successfully commissioned with beam on the PS closed orbit and on the PS-SPS transfer line steering. This has allowed us to validate the optics and the layout model defined in the LSA database as well as the adaptations made in YASP to cover PS specific features.

The FunctionEditor during one of the InCA MD's during the year
Cross Departmental Activities

BE-CO Group

Site video and Intercom infrastructure
In 2009, the IN section took the full responsibility of the CERN wide video distribution system (CATV). New installations were made in the main building for the DG floor, in the bat 102 (machine Interlock lab) to distribute the video information pages (e.g. SPS page1, LHC page1, …).
General maintenance has been done with about twenty TV sets replaced, two video amplifiers changed, and several interventions in Isolde, AD, zone PS, ISR and booster, and all zones in SPS.
Eight 32” LCD TVs were also installed in the Roy Billinge room following a demand from the “CMS visit” office.
In 2009, the old SPS intercom system demanded many interventions for maintenance. Fortunately, all problems could be fixed with our spare parts in stock.

Computer and Network Security
In 2009 effort was put into reducing the EXPOSED and TRUSTED security hosts lists, in order to reduce as much as we can the connections between the Technical network and the General Purpose network. In addition, a few kernel and Operating System security upgrades have occurred during 2009 to address security issues.

Virtualisation
As shown in the figure, one hundred Virtual PCs have been configured and deployed to offer to the BE developers stable and coherent development and testing environments. These Virtual PCs are running WindowsXP on 2 CPU cores, with 2Gb of memory and 16Gb of local disk. The underlying hardware infrastructure is based on 4 ProLiant Blades hosting the actual virtual PCs, a ProLiant with 2 Terabytes of disk space to host the local virtual diskspace and a connection broker that offer the interface to the actual users.

BE-ASR Group

All too often, the work of the Administration, Safety and Resources (ASR) Group is not visible. Even if this might appear counter-intuitive, in the case of ASR this is a success criteria. Indeed, carrying out administrative procedures or planning and following-up resource usage should be as smooth and uneventful as possible. Also, such activities shouldn’t represent too visible a
workload or, worse yet, hinder the daily work performed by staff in the Department. Above all, the safety of people and equipment, and as low a number of accidents and operation interruptions as feasible has to be ensured, even if, clearly, the prevention of the former sometimes necessarily implies the latter and that, therefore, one cannot completely exclude them. A perilous exercise. A restructuring like the one implemented at the beginning of 2009 implies a large number of administrative changes which have to be implemented in a small amount of time. To take on and assimilate new activities and responsibilities (e.g. safety, training, and space management) into an existing team, together with the corresponding personnel also brings its share of challenges, both human and technical. Finally, (re)starting an accelerator like the LHC requires the mobilisation of everyone in charge of safety. ASR Group has had to face up to these challenges and events in the course of 2009. This year was thus a particularly busy one, and everyone in the Group had to call upon all their available energy and competencies to meet these challenges. I take this opportunity to thank everyone in the Group for having done this.

Administration & Secretariats – BE-ASR-AS
The AS Section is a team which is made up of the Central Secretariat and 6 Group Secretariats split between Meyrin and Prevessin sites. The main role of the Section is to ensure an effective and high-quality administrative assistance for Group Leaders, Section Leaders as well as an administrative support for all categories of personnel for a wide range of activities:

- Welcoming new arrivals, transfer/detachment/departure formalities
- Coordination of Selection committees for Doctoral and Technical students, Fellows, Summer students
- Arranging official travel and calculation of reimbursements, management of subsistence fees, control of special leaves and sick leaves, third party claims…
- Administrative organization of workshops and conferences
- Coordination of visits within the CCC (195 this year)
- Management and follow up of the expenditures of the Group and their update in APT
- Creation and update of Group web pages
- Treatment and monthly control of overtime, shift and stand-by duty
- Coordination of MARS exercise as well as all actions related to advancement, promotion of staff members within the Department.

The setting up of the new Departmental structure in close collaboration with DPOs and DAOs from TE and EN Departments has reduced the Department from 554 to 371 staff members from 10 Groups to 6 Groups. Several Groups and Sections have been transferred and/or restructured and corresponding administrative roles have been removed or attributed. This reorganization has been carried out with the help of a common tool “ReorganisationTool” conceived by the IT Department. In some cases, tactful negotiations on the subject of office redistribution have been necessary. The MARS exercise has been made more complex with the turnover of a large number of supervisors.

Two activities particularly marked 2009: the equipment inventory and the introduction of the new contract policy.

The Inventory exercise concerning informatics, instrumentation and moveable material from BE Department was particularly heavy. To complete it successfully, all Group secretaries were
requested to update completely the material inventory from their own Group. This generated multiple searches on different databases which were not always matching. Thanks to the collaboration of all members of the BE Department, this exercise has been completed at very short notice. Since January 2009, a new procedure has been set up for the Department which is continuously updated thus making the exercise much lighter.

The application of the new contract policy (Administrative Circular No. 2, revised) introduced this autumn has also created a certain number of new administrative actions: At the level of each Group: determination of the needs; drafting of vacancy notices, drawing up of long and short candidates lists, etc. all activities requiring considerable administrative support; at the level of the Department: editing of reference documents, extension of LD contracts from 4 years to 5 years (24 Staff concerned) and the publication and follow-up of 25 vacancy notices.

Ressources & Logistics – BE-ASR-RL
Following the Departmental restructuring, the RL section integrated three new areas of activities within its functions, which are: space management, training, and the follow-up of the Department European projects. Throughout 2009, considerable efforts were invested in the integration and assimilation of these additional activities within the section while continuing to ensure the existing activities. During this year, the RL section consisted of four persons, one of whom in part-time (20%). Another member joined the section in August, replacing a colleague leaving for retirement.

Follow-up of the European Projects
As DG-RPC transferred this activity to each Department, the RL section had the responsibility of assimilating and integrating it within its responsibilities. It consists of: creating new budget codes; providing support to the task and group leaders to establish and implement the staff plan in the appropriate tools; control and monitoring of the personnel and material expenditure to ensure consistency towards the Eucard overall resources forecast, through the monitoring tools (APT/HRT/PPT/CET).

Financial and budget planning
Assisting the DPO: during 2009 this consisted mainly of putting in place the new structure in APT as well as the control and monitoring of data entry in APT; and monitoring of the GSM invoices. The monitoring and follow-up of the invoices received by the Department has been centralized in the RL section. Whenever necessary, the section will provide support to the technical persons in the DAI process.
Moreover, an on-line filing procedure regarding invoices and changes and/or creation of new budget codes has been created and implemented, allowing for a prompt and secure access to information whenever needed.

The RL section also has the function of managing the Departmental keys, cylinders and budget codes. The restructuring had a significant impact on the workload as it implied a large number of changes and creation of budget codes and signature rights, and the update of all keys and cylinders (e.g. emergency and furniture keys). Management, control and validation of two “plans de fermeture” are also included in the section functions.
During 2009, the Department material and equipment has been subject to a thorough inventory made by the ASR Group. The RL section has contributed to listing all material and equipment;
transferring all information to FP Department; and made the necessary transfers of material and equipment to other Departments; inserted on the inventory database the new material and equipment arriving in the Department. During September and October, all open commitments are systematically controlled and modified if necessary.

**Space Management**
Assimilating and integrating this activity within the section activities allowed RL to begin the implementation of an integrated method that will contribute to a more efficient coordination of small works for the Department, and to optimize the planning and procedure of removals. However, this integration together with the Department restructuring required an enormous effort from all members of the section. During 2009, the section mainly worked on: updating the GESLOC database; optimizing the use of space through the regrouping and centralization of activities, as well as the exchange of space between units within and without the Department; planning, oversight and acceptance of numerous small works and removals; and the centralization of furniture management (including the creation of a Departmental reserve).

The centralized management of the works includes the contact and discussion with: the members of the Department; the concerned services in other departments and the follow-up, supervision and acceptance of the works.
Active collaboration in the GTPE working group for space management, on which all space managers of the Organisation have their seat, as well as on the working group to study and make proposals for the radioactive workshops for the Organisation. The mandate of the latter includes identification of needs, proposals aiming to minimize the number of radioactive workshops throughout the Organisation, modification of existing and/or new infrastructure together with the appropriate equipment, analysis and estimate of the financial resources required.

**Logistics**
This activity includes the supervision of the invoices and payment regarding the Department cars and administration of the long distance cars; update of the number of existing Departmental cars and transfer to other Departments due to the restructuring; management of the departmental economat.
During 2009, the section has: 1) concentrated efforts in centralizing the orders; analysis of the expenses concerning the central economat of Prevessin, because of its use by three different Departments; the same analysis was foreseen for the central economat of Meyrin; access card implementation for a more efficient control of the expenses; and 2) management of the departmental photocopiers (which includes analysis of the Department needs, suppression of unnecessary machines and/or replacement of the machines for new ones; follow-up of the contractual conditions and ensuring their correct implementation; transfers of machines into other departments following the restructuring).

**Training**
- On-site organisation of the course « Synchronization and Interconnect in Multi-Clock Domain Systems-on-Chips », for 20 members of three different groups of the Department;
- Member of the Training Executive Committee (TEC); chairperson of the TEC working group on training statistics;
- Report to the BEMB concerning training in 2009.
Safety Unit – BE-ASR-SU
At the beginning of 2009, the Safety Unit of the Accelerators and Beams Department (AB-SU) was transformed into a section in the Administration, Safety and Resources group of the new Beams Department (BE-ASR-SU). The mandate of the Safety Unit has however not changed. In January 2009, the Safety Unit was staffed with four persons: a Departmental Safety Officer (DSO), a Deputy DSO and Laser Safety Officer, a Radiation Safety Officer and a Safety Coordinator. In 2009 one person joined the Safety Unit by internal mobility and is in charge of implementing Quality Assurance for all aspects of the safe operation of the beam facilities. Another person was selected to join and reinforce the Safety Unit for General Safety issues and to take over the role of DSO.

Safety of Personnel
The Safety Unit is in charge of General Safety around the beam facilities when they are operated with beams, as well as the General Safety of the personnel of the Beams Department and in all premises under the responsibility of the department (offices, workshops, laboratories and halls). In 2009 we had in particular to face the consequences of the accident that affected the LHC in September 2008. An important effort has been produced within the « Task Force on Safety of Personnel in LHC underground areas following the accident of 19th September 2008 » and in the follow-up of recommended actions. Technical measures taken to protect the accelerator against a similar accident, such as the installation of additional safety relief valves on the magnet cryostats, have also required that additional protection measures be taken for the personnel, in this case painted marks on the floor and on the valves themselves, as well as an update of the Safety training.

In other accelerators, as well as in workshops, laboratories and halls where personnel from the Beams department is present, General Safety aspects were monitored according to the findings of the Safety inspections on the one hand, and direct and indirect requests on the other hand. The DSO of the Beams department has also lead the Fact Finding group mandated by the Director General following a fatal accident on the Prévessin site early May. Concrete measures have been proposed to improve the safety of access into confined spaces on the CERN site. The Laser Safety Officer has drawn-up the inventory of the most dangerous lasers in use in the department. Most lasers are now identified and inspected, and the persons responsible and the users have been informed of the dangers and the procedures specific to each case. Moreover the LSO of the Beams department has taken charge of the safety of the lasers in the Engineering (EN) and General Infrastructure Services (GS) departments and in the DG unit, on their request. Training and information actions have been triggered in collaboration with the LSO of the Physics department (PH), where high power lasers are also in use. The database containing the technical data of all lasers declared on site has also been entrusted to the LSO of the Beams department. For radiation protection, the procedures for intervention in radioactive environment in the facilities of the Meyrin site have been strengthened: the write-up and review of the « Dossier d’Intervention en Milieu Radioactif » is now mandatory before any major intervention on the beam facilities of the Laboratory can take place. Corresponding procedures have been published. Finally the CERN Safety Coordination, with three qualified safety coordinators, has ensured its mission with the following priorities: repair works in Sector 3-4 of the LHC and conformity
works in other sectors, maintenance works and upgrades in the CNGS, works on large projects such as Linac4, and, time permitting, maintenance and works in other facilities, including the injectors and the part of the accelerator complex located on the Meyrin site. A fourth safety coordinator was recruited at the end of 2009 on a post in the GS department. This additional workforce will allow the extension of the mission of the team of safety coordinators and a better planning of their activities.

**Safety of Installations**

The safety aspects of CERN’s beam facilities are discussed in the « Beam Facilities Safety Panel » which is co-chaired by the Director for Accelerators and Technologies and the Head of the Beams department, and for which the Safety Unit assures the scientific secretariat. In 2009 a reorientation of the panel’s activities was started to best cover the activities in facilities other than the LHC. This reorientation fits with the spirit of the new Tripartite Convention, between the French Republic, the Swiss Confederation and CERN, which foresees that all beam facilities at CERN shall be treated in a uniform way in matters of Safety.

In particular the French and Swiss Safety authorities insist that the Safety aspects of the operation of the beam facilities must be covered by a Quality Management plan. The activities to be covered have been identified in the Safety report for LHC, SPS and CNGS, finalized in 2007, and the write-up of the plan has started this year with a complete list of all important safety elements covering the risks linked to the injection or circulation of beams, including their dependencies and links to other systems.

The promotion of the concept of Safety Folder has continued in 2009 and several risk analyses have been added in the Safety Folders of CERN’s beam facilities. In particular for the recasting of the access system in the PS complex, we have participated to the writing of the functional specification for the new system, as well as to the work on the preliminary risk analysis which will allow the specification of the safety objectives of the major functions of the system.

The need for workshops and laboratories designed and equipped for the work on radioactive parts and equipment has long been identified. In 2009 an interdepartmental working group under the leadership of the RSO of the Beams department has identified the needs of different units across the Organization and has drafted a master plan covering the Prévessin site. This plan takes into account the needs for storage of equipment as well as all necessary workshops and laboratories across the Prévessin site. The hall 867 will therefore be entirely rearranged to house most of these workshops and laboratories. All activities on radioactive parts and equipment will be grouped in an area with proper access control and equipped according to applicable norms and regulations. The Site Committee has recently approved this project and the implementation has started. A similar project is now running for the Meyrin site.

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