Users highlight successful campaigns

On 5–7 December 2018, the annual ISOLDE Workshop and Users meeting took place at CERN, attracting 83 participate. The programme consisted of presentations, of which 22 were invited talks and 19 were oral contributions selected from 333 submitted abstracts.

ISOLDE, CERN’s long-running nuclear research facility, directs a high-intensity proton beam from the Proton Synchrotron Booster (PSB) at a target station to produce a range of isotopes. Different devices are used to extract, ionise and separate the isotopes according to their mass, forming low-energy beams that are delivered to various experiments. These radioactive ion beams (RIBs) can also be re-accelerated using the HIE-ISOLDE linear accelerators (linacs). An energy upgrade of the HIE-ISOLDE superconducting linacs was completed this year, enabling RIBs with an energy up to about 10 MeV per nucleon.

A focus of the 2018 ISOLDE workshop concerned the upgrades and consolidation works during the second long shutdown of CERN’s accelerator complex (LS2), including replacing the 15-year-old linac and adding more beam-monitoring systems. Five sessions were devoted to overviews from ISOLDE users on the outcomes of physics campaigns at the different experimental set-ups, two sessions discussed progress at other RIB facilities in the world, and one session focused on applications in life sciences with an emphasis on the CERN MEDICIS programme.

The meeting began with an overview of successful experimental campaigns at the HIE-ISOLDE RIB accelerator, with operational set-ups achieved at all three beam lines. A total of 17 different RIBs were accelerated during July–November 2018. Beams of isotopes with an atomic mass from 710 to 228, with the radium-228 beam being the heaviest ever accelerated beam at ISOLDE, were delivered.

The HIE-ISOLDE campaign began with seven experiments at the first beam line, with the MINIBALL-detector array and its ancillary detectors. In October, two experiments used the new ISOLDE solex-ESR spectrometer at the second beamline for the first time, with an inner detector from Anorganica Nuclear Laboratory. For these, the full accelerator capacity was used for the first time. At the third beam line, used for “traveling experiments”, those experiments used the scattering chamber – a large vacuum chamber that can hold several combinations of particle detectors brought by the users; one experiment used an optical time projection chamber to look for very rare proton decays from the halo nucleus beryllium-11.

The last experiment was performed in the scattering chamber, afterproton stopped circulating in CERN’s accelerator complex, by extracting long-lived beryllium-7 from an ISOLDE target that had been irradiated earlier. The first HIE-ISOLDE physics paper, accepted for publication in Physical Review Letters, was also highlighted. It provides the first direct proof that the very neutron-rich tin-132 nucleus, considered to be highly magic, does indeed merit this special status.

Other sessions were dedicated to the rich low-energy experimental physics programme at ISOLDE. Overview talks were presented on recent achievements in high-precision mass studies, with indium-116 as a highlight; on collinear laser spectroscopy studies, with a long series of exotic isotopes and isomers; on decay-spectroscopy experiments; and on the solid-state physics programmes.

Participants also heard about recent studies with antiprotons at the Antiproton Decelerator at CERN and about the extremely exotic isotopes produced at the Radioactive Isotope Beam Factory (RIBF) facility at RIKEN in Japan. The study of exotic isotopes using the NA455 spectrometer at the French GEMINI laboratory was discussed, as were new beam-production facilities at the Selective Production of Exotic Species (SPES) facility at Legnaro National Laboratory in Italy and the new neutron detector array NEULAND at the Facility for Antiproton and Ion Research (FAIR) at GSI in Germany. The meeting ended with the handing over of four prizes, sponsored by CAEN, for the best talks and posters presented by young researchers (see image). The 2018 ISOLDE users meeting was a great success, highlighting the important research being done at this unique facility.

Gerda Neyens (ISOLDE physics group leader), multi-cultural research environment such as CERN, participants learn how to collaborate in international networks, are exposed to leading-edge technologies and hone their language skills. The Austrian ambassador, Elisabeth Tichy-Fisslberger, who participated in the celebration, underlined that the programme has also helped strengthen broader links between CERN and Austria, allowing significant technology transfer and networking with Austrian universities and high-tech industries. The CERN-Austrian PhD programme serves as a model of efficient collaboration between CERN and its member states, and has inspired similar initiatives from other countries.

Michael Benedikt, CERN
During the next two years of long-shutdown two (LS2), the LHC and its injectors will be tuned up for high-luminosity operations. Linac2 will leave the floor to Linac4, to enable more intense beams; the Proton Synchrotron Booster will be equipped with completely new injection and acceleration systems; and the Super Proton Synchrotron will have new radio–frequency power. The LHC is also being tested for operation at its design energy of 7 TeV, while, in the background, civil-engineering works for the high-luminosity upgrade (HL-LHC), due to enter service in 2026, are proceeding apace. The past three years of Run 2 at a proton–proton collision energy of 13 TeV have seen the LHC achieve record peak and integrated luminosities, forcing the detectors to operate at their limits. Now, the four main experiments ATLAS, CMS and LHCb, and the three smaller experiments LHCf, MoEDAL and TOTEM, are gearing up for the extreme high-luminosity operations LS2. TOTEM, which comprises two detectors located 220 m either side of CMS to measure elastic proton–proton collisions (see image on previous page), aims to perform total–cross-section measurements at maximal LHC energies. For this, the collaboration is building a new silicon-based detector to be integrated in CMS, in addition to service work on its silicon–strip and spectrometer detectors. Another “forward” experiment called LHCf, made up of two detectors on either side of ATLAS to perform total–cross-section measurements at maximal LHC energies, will also be ready in LS2. LHCf simulates cosmic-ray interactions.

ALICE REVITALISED

The ALICE experiment is being tuned up to make even more precise measurements of the quark–gluon plasma and other extreme nuclear systems. ALICE (A Large Ion Collider Experiment) will soon have enhanced physics capabilities thanks to a major upgrade of the detectors, data-taking and data-processing systems. These upgrades will improve the precision on measurements of the high-density, high-temperature phase of strongly interacting matter, the quark–gluon plasma (QGP), together with the exploration of new phenomena in quantum chromodynamics (QCD). Since the start of the LHC programme, ALICE has been participating in all data runs, with the main emphasis on heavy-ion collisions, such as lead–lead, proton–lead, and xenon–xenon collisions. The collaboration has been making major inroads into the understanding of the dynamics of the QGP – a state of matter that prevailed in the first instants of the universe and is recreated in droplets at the LHC.

At the limits

Since the beginning of the LHC programme, it was clear that the original detectors would last for approximately a decade due to radiation damage. That time has now come. Improvements, repairs and upgrades have been taking place in the LHC detectors throughout the past decade, but significant activities will take place during LS2 (and LS3, beginning 2024), capitalising on technology advances and the ingenuity of thousands of people over a period of several years. Combined, the technical design reports for the LHC experiment upgrades number some 20 volumes each containing hundreds of pages.

For LHCb, the term “upgrade” hardly does it justice, since large sections of the detector are to be completely replaced and a new trigger system is to be installed (p.31). LHCb is also undergoing major interventions to its inner detectors during LS2 (p.35), and both collaborations are installing new data centres to deal with the higher data rates from future LHC runs. ATLAS and CMS are upgrading numerous aspects of their detectors while at the same time preparing for major installations during LS3 for HL-LHC operations (p.32 and p.33). At the HL-LHC, one year of collisions is equivalent to 10 years of LHC operations in terms of radiation damage. Even more challenging, HL-LHC will deliver a mean event pileup of up to 200 interactions per beam crossing – 10 times greater than today – requiring totally new trigger and other capabilities.

Three smaller experiments at the LHC are also taking advantage of LS2. TOTEM, which comprises two detectors located 220 m either side of CMS to measure elastic proton–proton collisions (see image on previous page), aims to perform total–cross-section measurements at maximal LHC energies. For this, the collaboration is building a new silicon-based detector to be integrated in CMS, in addition to service work on its silicon–strip and spectrometer detectors. Another “forward” experiment called LHCf, made up of two detectors on either side of ATLAS to perform total–cross-section measurements at maximal LHC energies, will also be ready in LS2. LHCf simulates cosmic-ray interactions.

In terms of radiation damage, one year of HL–LHC collisions is equivalent to 10 years of LHC operations.
Detector upgrades

A new all-pixel silicon inner tracker based on CMOS monolithic active pixel sensor (MAPS) technology will be installed covering the mid-rapidity ($|\eta|<1.5$) region of the ITS as well as the forward rapidity ($1.5<|\eta|<3.5$) region of the APV. In MAPS technology, both the sensor for charge collection and the readout circuit for digitisation are hosted in the same piece of silicon instead of being bump-bonded together. The chip developed by ALICE is called ALPIDE, and uses a 180mM CMOS process provided by TSMC. With this chip, the silicon material budget per layer is reduced by a factor of seven compared to the present ITS. The ALPIDE chip is 8x10 mm$^2$ in area and contains more than half a million pixels organised in 302 columns and 532 rows. Its low power consumption ($\sim 100\mu $W/mm$^2$) and excellent spatial resolution ($\sim 5\mu$m) are perfect for the inner tracker of ALICE.

The ITS consists of seven cylindrical layers of ALPIDE chips, summing up to 3.5 billion pixels and a total area of 16m$^2$. The pixel chips are installed on staves with radial distances 22–40mm away from the interaction point (IP). The beam pipe has also been redesigned with a smaller outer radius of 8.9mm, allowing the first detection layer to be placed closer to the IP at a radius of 22.3 mm compared to 39 mm at present. The brand-new ITS detector will improve the impact parameter resolution by a factor of three in the transverse plane and by a factor of five along the beam axis. It will extend the tracking capabilities to much lower $p_T$, allowing ALICE to perform measurements of heavy-flavour hadrons with unprecedented precision and down to zero $p_T$.

In the forward-rapidity region, ALICE detects muons using the muon spectrometer. The new MFT detector is designed to add vertexing capabilities to the muon spectrometer and will enable a number of new measurements that are currently beyond reach. As an example, it will allow us to distinguish [9] muons that are induced directly in the collision from those that come from decays of mesons that contain a beauty quark. The MFT consists of five disks, each composed of two MAPS detection planes, placed perpendicular to the beam axis between the IP and the hadron absorber of the muon spectrometer.

The TPC is the main device for tracking charged-particle identification in ALICE. The readout rate of the TPC in its present form is limited by its readout channels, which are based on multi-wire proportional chambers. In order to avoid drift-field distortions produced by ions from the amplification region, the present readout chambers feature a charge-gating scheme to collect back-drifting ions that lead to a limitation of the readout rate to 3 kHz. To overcome this limitation, new readout chambers employing a novel configuration of stacks of four GEMs have been developed, during an extensive R&D programme. This arrangement allows for continuous readout at 50 kHz with lead-lead collisions, at no cost to detector performance. The production of the 72 inner (one GEM stack each) and outer (three GEM stacks each) chambers is now practically completed and certified. The replacement of the chambers in the TPC will take place in summer 2019, once the TPC is extracted from the experimental cavern and transported to the surface.

The new forward interaction trigger, FIT, comprises two arrays of Chevrenkov radiators with MCP–PMT sensors and a single, large-size scintillator ring. The arrays will be placed on both sides of the IP. It will be the primary trigger, luminosity and collision time–measurement detector in ALICE. The detector will be capable of triggering at an interaction rate of 90 kHz, with a time resolution better than 30 ps, with 90% efficiency.

The newly designed ALICE readout system presents a change in approach, as all lead–lead collisions that are produced in the accelerator, at a rate of 50 kHz, will be read out in a continuous stream. However, triggered readout will be used by some detectors and for commissioning and calibration runs and the central trigger processor is being upgraded to accommodate the higher interaction rate. The readout of the TPC and muon chambers will be performed by SAMPA, a newly developed, 128-channel front-end/analog-to–digital converter with integrated digital signal processor.

Performance boost

The significantly improved ALICE detector will allow the collaboration to collect 100 times more events during LHC Run 3 compared to Run 1 and Run 2, which requires the development and implementation of a completely new readout and computing system. The 0° system is designed to combine all the computing functionalities needed in the experiment: detector readout, event building, data recording, detector calibration, data reconstruction, physics simulation and analysis. The total data volume produced by the front-end cards of the detectors will increase significantly, reaching a sustained data throughput of up to 75TB. To minimise the requirements of the computing system for data processing and storage, the ALICE computing model is designed for a maximal reduction in the data volume read out from the detectors as early as possible during the data processing. This is achieved by online processing of the data, including detector calibration and reconstruction of events in several steps synchronously with data taking. At its peak, the estimated data throughput to mass storage is 90GB/s.

A new computing facility for the 0° system is being installed on the surface, near the experiment. It will have a data-storage system with a storage capacity large enough to accommodate a large fraction of data of a full year’s data taking, and will provide the interface to permanent data storage at the tier-0 Grid computing centre at CERN, as well as other data centres.

ALICE upgrade activities are proceeding at a frenetic pace. Soon after the machine stopped in December, experts entered the cavern to open the massive door of the market and started dismounting the detector in order to prepare for the upgrade. Detailed planning and organisation of the work are mandatory to stay on schedule, as Arturo Taura, the deputy technical coordinator of ALICE explains: “Apart from the new detectors, which require dedicated infrastructure and procedures, we have to install a huge number of services (for example, cables and optical fibres) and perform regular maintenance of the existing apparatus. We have an ambitious plan and a tight schedule ahead of us.”

When the ALICE detector emerges revitalised from the two busy and challenging years of work ahead, it will be ready to enter into a new era of high-precision measurements that will expand and deepen our understanding of the physics of hot and dense QCD matter.
CMS HAS HIGH LUMINOSITY IN SIGHT

One of the biggest challenges for the CMS collaboration during LS2 is to prepare its detector for the massive future installations necessary for the HL-LHC.

The CMS detector has performed better than what was thought possible when it was conceived. Combined with a drive to keep the cost of the project low, this has allowed the collaboration to make measurements – such as the coupling between the Higgs boson and bottom-quarks – that were once deemed impossible. Indeed, together with its sister experiment ATLAS, CMS has turned the traditional view of hadron colliders as "hammers" rather than "scalpels" on its head. In exploiting the LHC and its high-luminosity upgrade (HL-LHC) to maximum effect in the coming years, the CMS collaboration has to battle overall particle rates, higher "pileup" of superimposed proton–proton collision events per LHC bunch crossing, and higher instantaneous and integrated radiation doses to the detector elements. In the collaboration's annual to combat this assault, silicon sensors are able to withstand the levels of irradiation expected, a new high-rate trigger, and detectors with higher granularity or precision timing capabilities to help disentangle pile-up events.

The major CMS detector upgrades for the HL-LHC will be installed and commissioned during long-shutdown three (LS3). However, the planned 30-month duration of LS3 imposes logistical constraints that result in a large part of the muon-system upgrade and many ancillary systems (such as cooling, power and environmental control) needing to be installed substantially beforehand. This makes the CMS work plan for LS3 extremely complex, dividing into three classes of activity: the five-year maintenance of the existing detectors and services, the completion of so-called "phase 1" upgrades necessary for CMS to continue to operate until LS5, and the initial upgrades to detectors, infrastructure or ancillary systems necessary for HL-LHC. "The challenge of LS3 is to prepare CMS for Run 3 while not neglecting the work needed now to prepare for Run 4," says technical coordinator Austin Ball.

A dedicated CMS upgrade programme was planned since the LHC switched on in 2008. It is being carried out in two phases: the first, which started in 2014 during LS1, concerns improvements to deal with a factor of two increase over the design instantaneous luminosity delivered in Run 1, and the second relates to the upgrades necessary for the HL-LHC. The phase-1 upgrade is almost complete, thanks to works carried out during LS1 and regular end-of-year technical stops. This included the replacement of the three-layer barrel (two–disk forward) pixel detector with a four-layer barrel (three–disk forward) version, the replacement of photocathodes and front-end electronics for some of the hodosimeters, and the introduction of a more powerful, FPGA-based, level-1 hardware trigger. LS2 will conclude phase-1 by upgrading the silicon photodetectors (hybrid photodiodes) in the barrel hodosimeters with silicon photomultipliers and replacing the innermost pixel barrel layer.

Phase-2 activities start in 2023 and run until LS5. Part of the phase-2 preparation is the replacement of the pixel detector with the phase-2 pixel detector to cover closely the interaction point. Now, the plan is to extend the cylindrical section of the beamline further to provide space for the phase-2 pixel detector with enlarged pseudorapidity coverage, to be installed in LS5. In addition, CMS-PHO-GEN-2013-012-5

A NEW ERA IN CALORIMETRY

The high-granularity calorimeter (HGCAL) is a major upgrade of CMS, and is necessary to maintain excellent calorimetric performance in the endcaps during HL-LHC operations. HGCAL is one of the most ambitious detector projects undertaken, due to the combination of extremely high readout and trigger granularity, coupled with the harsh radiation environment of the CMS endcaps during HL-LHC operation. Two radiation-invariant materials – have been selected: silicon in the high-radiation region and plastic scintillator tiles in the less harsh regions. To mitigate the effects of radiation damage, the silicon sensors must be cooled to about -30 °C, which also allows the use of on-the-fly silicon photomultipliers for the scintillator readout. HGCAL has around 6.5 million detector channels, divided into 52 layers. The first 28 layers come from the electromagnetic section, which is based on hexagonal silicon sensors (maximizing the usable surface of 8° circular silicon wafers) divided into hexagonal cells. The sensors are sandwiched between high-density copper–tungsten alloy base plates on one side and printed circuit boards containing the front-end electronics on the other, and the resulting hexagonal modules are mounted on either side of CO2-cooled copper plates. The following eight layers are similar, forming the front part of the hadronic section of HGCAL, but are single-sided and use a lighter baseplate, while the final 16 layers incorporate both silicon modules and scintillator tiles. The use of both detector technologies optimizes the overall cost of the HGCAL, whilst maintaining excellent long-term performance.

Prototype development began in 2016, and hexagonal silicon sensors have been built into modules to evaluate the feasibility of the overall design and to study the performance in beams at Fermilab, DESY and CERN. Results from these beam tests compare very well with simulations. Thanks to HGCAL’s readout/triggering granularity and timing resolution for showers, the expected performance in terms of energy resolution, particle identification and triggering are all comparable to the present CMS endcap calorimeters – even in the presence of 20X pileup events and after the full radiation exposure expected at HL-LHC. The project has now moved to the final design and prototyping phase, with construction due to start in a couple of years.
for the muon detectors CMS will install a new gas electron multiplier (GEM) layer in the inner ring of the first endcap disk, upgrade the on-detector electronics of the cathode strip chambers, and lay services for a future GEM layer and improved resistive plate chambers. Several other preparations of the detector infrastructure and services will take place in LS2 to be ready for the major installations in LS3.

Work plan

Key elements of the LS2 work plan include: constructing major new surface facilities; modifying the internal structure of the underground cavern to accommodate new detector services; especially CO₂ cooling; replacing the beampipe for compatibility with the upgraded tracking system; and improving the powering system of the 3.8 T solenoid to increase its longevity through the HL-LHC era. In addition, the system for opening and closing the magnet yoke for detector access will be modified to accommodate future tolerance requirements and service volumes, and the shielding system protecting detectors from background radiation will be reinforced.

Significant upgrades of electrical power, gas distribution and the cooling plant also have to take place during LS2. The CMS LS2 schedule is now fully established, with a critical path starting with the pixel detector and beampipe removal and extending through the muon system upgrade and maintenance, installation of the phase-2 beampipe plus the revised phase-1 pixel innermost layer, and, after closing the magnet yoke, re-commissioning of the magnet with the upgraded powering system. The other LS2 activities, including the barrel hadron calorimeter work, will take place in the shadow of this critical path.

The future LS3 shutdown will see the CMS tracker completely replaced with a new outer tracker that can provide tracks at 40 MHz to the upgraded level-1 trigger, and with a new inner tracker with extended pseudo-rapidity coverage. The 36 modules of the barrel electromagnetic calorimeter will be removed and their on-detector electronics upgraded to enable the high readout rate, while both current hadron and electromagnetic-endcap calorimeters will be replaced with a brand-new system (see “A new era in calorimetry” box). The addition of timing detectors in the barrel and endcaps will allow a fast reconstruction of collision vertices and, together with the other new and upgraded detectors, reduce the effective event pile-up at the HL-LHC to a level comparable to that already seen.

“The upgraded CMS detector will be even more powerful and able to make even more precise measurements of the properties of the Higgs boson as well as extending the searches for new physics in the unprecedented conditions of the HL-LHC,” says CMS spokesperson Roberto Carlin.

Further reading

Extreme pile up
A simulated event at the HL-LHC with a future inner tracker.

During the current LS2 – including major interventions to the giant muon spectrometer at the outermost reaches of the detector.

The main ATLAS upgrade activities during LS2 are aimed at increasing the trigger efficiency for leptonic and hadronic signatures, especially for electrons and muons with a transverse momentum of at least 20 GeV. To improve the selectivity of the electron trigger, the amount of information used for the trigger decision will be drastically increased. Until now, the very fine-grained information provided by the electromagnetic calorimeter is grouped in “trigger towers” to limit the number and hence cost of trigger channels, but advances in electronics and the use of optical fibres allows the transmission of a much larger amount of information at a reasonable cost. By replacing some of the components of the front-end electronics of the electromagnetic calorimeter, the level of segmentation available at the trigger level will be increased, thereby improving the ability to reject jets and preserve electrons and photons. The ATLAS trigger and data-acquisition systems will also be upgraded during LS2 by introducing new electronics boards that can deal with the more granular trigger information coming from the detector.

New small wheels
Since 2013, ATLAS has been working on a replacement for its “small wheel” forward-muon endcap systems so that they can operate under the much harsher background conditions of the future LHC. The new small wheel (NSW) detectors employ two detector technologies: small-strip thin silicon strip chambers (sTSC) and Micromegas (MM). Both technologies are able to withstand the higher flux of neutrons and photons expected in future LHC interactions.

Upgrade path: Assembling cathode strip chambers during the end-of-year shutdown in 2019/2020.

which will produce counting rates as high as 20 kHz cm⁻² in the inner part of the NSW, while delivering information for the first-level trigger and muon measurement. The main aim of the NSW is to reduce the fake-muon triggers in the forward region and improve the sharpness of the trigger thresholds drastically, allowing the same selection power as the present high-level trigger.

The first NSW started to take shape at CERN last year. The inner shielding disks (see image on previous page), which serve as the support for the NSW detectors in addition to shielding the endcap muon chambers from hadrons, have been assembled, while the service team is installing numerous cables and pipes on the disks. Only a few millimetres of space is available between the disk and the chambers for the cables on one side, and between the disk and the calorimeter on the other side, and the task is made even more difficult by having to work from an elevated platform. In a nearby building, the sTSC chambers coming from the different construction sites are being integrated in full wedges and, soon this year, the Micromegas wedges will be integrated and tested at the test-beam facility. The construction of the sTSC chambers is taking place in Canada, Chile, China, Israel and Russia, while the Micromegas are being constructed in France, Germany, Greece, Italy and Russia. On a daily basis, cables are arriving at the facility with connectors and tested, piped to length, chased and protected until installation; and gas, vacuum and high-voltage test stations are employed for quality control. In the meantime, several smaller upgrades will be deployed during LS3, including the installation of 16 new muon chambers in the inner layer of the barrel spectrometer.

The organisation of LS activities is a complex exercise in which the maintenance needs of the detectors have to be addressed in parallel with installation schedules. After a first period devoted to the opening of the detector and the maintenance of the forward muon spectrometer, the first major non-standard operation scheduled for January will be to bring to the surface the first small wheel. Having the detector fully open on one side will also allow very important tests for the installation of the new all-silicon inner tracker, which is scheduled to be installed during LS3. The upgrade of the electromagnetic calorimeter electronics will start in February and continue for about one year, requiring all front-end boards to be disconnected from their crates, modifications to both the boards and the crates, and reallocation of the modified boards in their original position. Maintenance of the ATLAS Tile calorimeter and inner detector will take place in parallel, a very important aspect of which will be the search for leaks in the front-end cooling system.

Delicate operation
In August, the first small wheel will be lowered again, allowing the second small wheel to be brought to the surface to make space for the NSW installation foreseen in April 2020. In the same period, all the optical transmission boards of the pixel detector will have to be changed. Following these interventions, there will be a long period of commissioning of all the upgraded detectors and the preparation for the installation of the second NSW in the autumn of 2020. At that moment the closing process will start and will last for about three months, including the bake-out of the beam pipe, which is a very delicate and dangerous operation for the pixel detectors of the inner tracker.

A coherent upgrade programme for ATLAS is now fully underway to enable the experiment to fully exploit the physics potential of the LHC in the coming years of high-luminosity operations. Thousands of people around the world in more than 200 institutes are involved, and the technical design reports alone for the upgrade so far number six volumes, each containing several hundred pages. At the end of LS3, ATLAS will be ready to take data in Run 3 with a renewed and better-performing detector.

Further reading

The True State-of-the-Art
- New in-house manufacturing
- Lower noise
- Lower leakage current
- Better charge collection
Compatible with EPICS tools & libraries

The True State-of-the-Art
- New in-house manufacturing
- Lower noise
- Lower leakage current
- Better charge collection
Compatible with EPICS tools & libraries
In November 2018 the LHCb brilliantly fulfilled its promise to the LHCb experiment, delivering a total integrated proton-proton luminosity of 10 fb⁻¹ from Run 1 and Run 2 combined. This is what LHCb was designed for, and more than 400 physics papers have come from the adventure so far. Having recently finished swallowing these exquisite data, however, the LHCb detector is due some tender loving care.

In fact, during the next 24 months of long-shutdown two (LS2), the 450-tonne detector will be almost entirely rebuilt. When it emerges from this metamorphosis, LHCb will be able to collect physics events at a rate 10 times higher than today. This will be achieved by installing new detectors capable of sustaining up to five times the instantaneous luminosity seen at Run 2, and by implementing a revolutionary software-only trigger that will enable LHCb to process signal data in an upgraded DAQ farm at the frenetic rate of 40MHz – a pioneering step among the LHC experiments.

LHCb is unique among the LHC experiments in that it is asymmetric, covering only one forward region. That reflects its physics focus: B mesons, which, rather than flying out uni-directionally in all directions, are preferentially produced at small angles (i.e. close to the beam direction) in the LHC’s proton collisions. The detector stretches for 23m along the beam pipe, with its sub-detectors stacked behind each other like books on a shelf, from the vertex locator (VEL) to a ring-imaging Cherenkov detector (RICH), the silicon upstream tracker (UT), the scintillating fibre tracker (Scif), a second RICH (RICH2), the calorimeters and, finally, the muon detector.

The LHCb upgrade was first outlined in 2008, proposed in 2011 and approved the following year at a cost of about 1.7 million Swiss francs. The collaboration started dismantling the current detector just before the end of 2018 and the first elements of the upgrade are about to be moved underground.

Physicists boost

The LHCb collaboration has so far made numerous important measurements in the heavy-flavour sector, such as the first observation of the rare decay $\Lambda_c \rightarrow \mu^+ \mu^-$, precise measurement of quark-mixing parameters and the observation of new hGlyphic and pentagonal states. However, many crucial measurements are currently statistically limited. The LHCb upgrade will boost the experiment’s physics reach by allowing the software trigger to handle
Subdetector activities

The VELO, at the heart of LHCb, which allows precise measurements of primary and displaced vertices of short-lived particles, is one of the key detectors to be upgraded during LS2. Replacing the current system based on silicon microstrip sensors used by the current three tracking systems: RICH1, which discriminates kaons from pions in the low-momentum range, and RICH2, which performs this task in the high-momentum range. The RICH mirror system, which is required to defect and focus Cherenkov photons onto photodetector planes, will be replaced with a new one that has been optimised for the much increased rate of high-energy particles at the Super Proton Synchrotron.

Further downstream, nestled between the RICH and the magnet, will sit the SciFi – a new tracker based on scintillating fibres and silicon photomultiplier (SiPM) arrays, which replaces the drift straw detectors and silicon microstrip sensors used by the current three tracking stations. The SciFi represents a major challenge for the collaboration, not only due to its complexity, but also because the technology has never been used for such a large area in such a harsh radiation environment. More than 11,000 km of fibres was ordered, meticulously verified and even cured from a few rare and local imperfections. From this, about 1490 mats of fibre layers were recently fabricated in four institutes and assembled into 140 rigid 5 m × 5 m modules. In parallel, SiPMs were assembled on flex cables and joined in groups of 16 with a 3D-printed titanium cooling tube to form sophisticated photodetection units for the SciFi modules, which will be operated at about -40°C.

As this brief overview demonstrates, the LHCb detector is undergoing a complete overhaul during LS2 – with large parts being totally replaced – to allow this unique LHC experiment to deepen and broaden its exploration programme. CERN support teams and the LHCb technical

Under construction Modules being lowered into place for LHCb’s new data centre.

Development The SciFi tracker modules being assembled.

an input rate around 30 times higher than before, bringing greater precision to theoretically clean observables. Placing at an immense rate of 4 TW, data will travel from the cavern, straight from the detector electronics via some 8000 300 μm-long optical fibres, into front-end computers located in a brand-new data centre that is currently nearing completion. Once there, around 500 powerful custom-made boards will receive the data and transfer it to thousands of processing cores. Current trigger hardware will be removed and new front-end electronics have been designed for all the experiment’s sub-detectors to cope with the substantially higher readout rates.

For the largest and heaviest LHCb devices, namely the calorimeters and muon stations, the detector elements will remain mostly in place. All the other LHCb detectors are to be entirely replaced, apart from a few structural frames, the dipole magnet, shielding elements and gas or vacuum enclosures. Lightweight staves, with a carbon foam back-end and instrumented with 14 modules, each composed of a polyimide hybrid circuit, a boron nitride stiffener and a silicon microstrip sensor.

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Further reading


VELO upgrade Testing the new VELO modules at CERN.

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