This report gives a summary of the mandate, structure and main activities of the EP-DT group during the year 2015.
http://ep-dep-dt.web.cern.ch
# Table of Contents

1. DT MANDATE AND ORGANIZATION ............................................. 7

2. COLLABORATIONS WITH LHC EXPERIMENTS ......................... 12
   2.1. ALICE ...................................................................... 12
      2.1.1. YEARLY TECHNICAL STOP (YETS) ACTIVITIES ........ 12
      2.1.2. ALICE DETECTOR UPGRADE ............................. 13
   2.2. ATLAS ...................................................................... 15
      2.2.1. COOLING COORDINATION .................................. 15
      2.2.4. ATLAS DETECTOR UPGRADE PROJECTS .............. 17
   2.3. CMS ......................................................................... 18
      2.3.1. COOLING COORDINATION .................................. 18
      2.3.2. CMS TRACKER LS1: LOWERING OF THE OPERATING TEMPERATURE ............................. 19
      2.3.3. CMS DETECTOR UPGRADE ................................. 19
   2.4. LHCb ......................................................................... 21
      2.4.1. LHCb DETECTOR OPERATION, MAINTENANCE AND PHYSICS ...................... 21
      2.4.2. DETECTOR UPGRADES FOR LS2 ............................ 21
   2.5. TOTEM, ATLAS-ALFA, ATLAS-AFP ............................... 24

3. COLLABORATIONS WITH NON-LHC EXPERIMENTS ............... 25
   3.1. AEGIS ...................................................................... 25
   3.2. CAST ........................................................................ 25
   3.3. CLOUD .................................................................... 26
   3.4. NA62 ........................................................................ 26

4. R&D PROJECTS .................................................................... 28
   4.1. RADIATION TOLERANT SILICON DETECTORS .................. 28
   4.2. MICRO-PATTERN GASEOUS DETECTORS ....................... 29
   4.3. ON-DETECTOR COOLING R&D .................................... 30
      4.3.1. MICRO-STRUCTURED PLATES FOR DETECTOR THERMAL MANAGEMENT ........ 30
      4.3.2. RELATIVE HUMIDITY OPTICAL FIBRE SENSORS ........................................ 31
   4.4. R&D ON GAS SYSTEMS .............................................. 31
   4.5. MICRO-SYSTEMS ENGINEERING .................................... 32
      4.5.1. NOVEL MICROFABRICATION APPROACHES FOR DETECTOR DEVELOPMENT ........ 32
      4.5.2. MICROCOOL: SILICON MICROCHANNEL COOLING .................................. 33
5. SERVICES PROVIDED BY DT

5.1. INFRASTRUCTURE FOR DETECTOR R&D

5.1.1. IRRADIATION FACILITIES

5.1.2. RADIATION MONITORING SENSORS (PH-RADMON)

5.1.3. SOLID STATE DETECTOR LAB, BOND LAB, QART LAB AND DSF

5.1.4. THIN FILM AND GLASS

5.1.5. MICRO-PATTERN TECHNOLOGIES (MPT) WORKSHOP

5.2. INFRASTRUCTURE FOR EXPERIMENTS

5.2.1. GAS SYSTEMS

5.2.2. DEVELOPMENT AND CONSTRUCTION OF CO₂ COOLING PLANTS

5.2.3. INSTRUMENTATION AND CONTROLS

5.2.4. B-FIELD MAPPING

5.3. ENGINEERING OFFICE

6. EU PROJECTS, REPRESENTATION IN COMMITTEES AND WORKING GROUPS

7. SAFETY IN EP-DT

8. SECRETARIAT

9. LIST OF SELECTED PUBLICATIONS
1. DT Mandate and Organization

*M.Capeans (EP-DT)*

The mandate of the EP-DT group covers development, construction, operation and maintenance of particle detectors for the experiments at CERN. The group is engaged in several detector projects for LHC and non-LHC experiments – ranging from detector construction, maintenance & operation to consolidation and upgrades –, operates services open to all CERN users for detector operation, research & development, and is involved in R&D projects on new detector technologies and related infrastructures.

Expertise in many different domains crucial for advanced detector-systems is available, among these are detector research development and system support, fine mechanics, engineering, micro-fabrication, thin film coatings, optics, silicon facility with wire-bonding lab, irradiation facilities, magnet support and B-field mapping, instrumentation and controls, gas and cooling systems for particle detectors. DT runs several mechanical workshops with conventional and CNC machines and equipment for specialized machining for scintillators, glass and ceramics.

The main EP-DT activities are listed below, organized in 3 main categories:

- **Services for developing and operating infrastructures for experiments and detector R&D.** They are available for all experiments at CERN. They offer a coherent, ready-to-use deliverable (e.g. gas system, cooling system, control system, B-field measurement, thin film coating), M&O support, advice and consultancy.
- **R&D Projects** on strategic fields related to new detector technologies and detector infrastructures that are of common interest for all the experiments. These projects also provide a host lab environment for external partners.
- **Joint Projects** with experimental teams in CERN experiments to develop, construct and operate particle detectors. Joint projects are set up for a defined amount of time and the scope of the collaboration is described in dedicated work package agreements.

### Services

**Infrastructure for experiments:**
- Gas systems
- Detector cooling systems
- Instrumentation and controls
- Magnet control and support
- B-field mapping

**Infrastructure for Detector R&D:**
- Thin film & glass Lab
- Silicon facility
- Wire-bonding & QART Lab
- Micro-Pattern Technologies
- Irradiation facilities
- Specialized labs (optics, gluing…)
- Scintillator production

**Engineering office**

### R&D Projects

**Radiation tolerant silicon detectors (RD-50)**
- Gaseous detectors (RD-51)
- Scintillating fibre detectors
- Novel on-detector cooling
- Micro-systems engineering

### Joint Projects

- M&O and Upgrades of the LHC experiments
- AEgIS, CAST, CLOUD, NA62
- R&D for Linear Collider Detectors

About 40% of the staff resources are allocated to projects; an indication of FTEs broken down by experiment is shown below. About 55% of the group works in services activities and related R&D. Finally, about 5% of the group’s resources are engaged in general service tasks that include workshop supervision, safety, participation to CERN-wide committees and leadership of R&D collaborations and EU co-funded projects, and the management of the group.
The DT group, thanks to the vast range of activities, infrastructure, expertise, and long-standing collaborations with CERN experiments, can provide centralized resources and expertise, in terms of personnel and facilities, for the development of future detector technologies, R&D and can contribute to detector construction projects. Moreover, specific partnerships for Phase 1 and 2 detector upgrades have been settled with CERN teams in the LHC experiments, in particular with ALICE and LHCb, where DT contributes to several challenging detector upgrade projects. Finally, agreements for engineering and detector prototyping support for the ATLAS and CMS detectors, and general support to the CERN Neutrino Platform activities at CERN, have started and will significantly ramp up in 2016.

Nowadays DT comprises about 85 active staff, 12 fellows, 15 students and about 10 trainees/year fully or partially funded by DT, and hosts two Field Support Units (FSU PH-02 and PH-40). The DT group structure was adjusted in September 2012 based on a competency-based organization, to reinforce the roles and capacity of the personnel and to avoid excessive and diverse fragmentation of resources. The number of changes was however limited due to LS1 commitments and no complete view of LHC detector upgrade projects at that time. With the completion of LS1 in early 2015, the group completed the organizational adjustment in the second half of 2015. The motivations of this adjustment were: i) to optimize the support to experiments in the next phase (2016-2020), where LHC operation overlaps with demanding detector R&D and detector prototyping and construction projects for LHC upgrades, and new experiments and studies; ii) better group competencies to exploit specialists experience at its maximum potential and to enhance flexibility by providing centralized expertise; iii) to drive a culture of innovation and support the generation of new ideas, preserve and promote current efforts on detector R&D and novel technologies and related infrastructures; and finally, to build-up knowhow and ensure successful careers of DT technical staff.

DT staff is currently grouped in 7 sections, with the following mandates:

- Technology and Physics: physicists and engineers in this section participate in experiments at CERN, both at the LHC and at smaller facilities. They take a leading role in the upgrade of the LHC detectors and various R&D related activities of future projects. They also ensure the direct contact between their experiments for all activities of the group.

- The section Detector Development contributes to detector projects in collaboration with experimental teams, and is deeply involved in the RD50 (Radiation Tolerant Silicon Detectors) and RD51 (Micro-Pattern Gas Detectors) collaborations by contributions to the R&D program as well as providing managerial and organizational support. The section operates state of the art services for...
detector R&D: departmental Silicon Facility, wire bonding and interconnect facility, quality and reliability assurance lab and the EP irradiation facilities.

- The Fluidic Systems section mandate is to design, prototype, construct, commission, operate and maintain fluidic systems (gas & cooling) for detectors in CERN experiments. It performs selective R&D in areas relevant to novel detector thermal management, gas systems, and for the upgrade of the existing systems in view of higher detector performances and sustainable operation.

- The Detector Interface section combines the EP-DT years-long expertise in control and safety systems for experiments’ infrastructure, with the introduction of the support for data acquisition and monitoring systems targeting small- and mid-scale experiments and projects. The long-term aim is to create a combined environment for controls and DAQ to be offered to the experiments requesting it.

- The Engineering Facilities section mandate is to provide to the CERN community specific solutions combining mechanical design, small-scale production and prototyping facilities and test benches for particle detectors’ CERN-core technologies.

- The Engineering Office provides design & engineering expertise for the group’s projects.

- Detector Construction & Operations provides to the CERN community specific solutions combining mechanical design, prototyping and small-scale production of particle detector systems, and to support the operation of CERN experiments.

Often, project work is carried out in project or service teams formed for a limited time, frequently with people from several sections and led by a DT project leader. Such teams include also fellows, students and scientists associated to DT. This strategy offers flexibility, efficiency and a fast reaction time for new requests and activity/load variations. The organigrams shown in pages 8 and 9 show the seven sections mandate and DT members as of April 1st 2016, respectively. The graph below shows the DT staff category composition.

Further information about the DT group is available at http://ep-dep-dt.web.cern.ch
### EP-DT Detector Technologies

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology &amp; Physics (DT-TP)</td>
<td>The TP section promotes and manages projects on detector construction, integration and operation. Pool of project leaders that plans and coordinates projects - established in collaboration with the experiments across different functional areas.</td>
</tr>
<tr>
<td>Detector Development (DT-DD)</td>
<td>The DD section leads R&amp;D projects in several detector technologies, and runs related detector R&amp;D facilities open to all users. Facilities: Gas Lab, Silicon Lab, QART, BondLab, DSF, Irradiation Facilities.</td>
</tr>
<tr>
<td>Fluidic Systems (DT-FS)</td>
<td>The FS section develops, maintains and operates gas and cooling systems for particle detectors. The service is available to all experiments at CERN. It offers a coherent, ready-to-use deliverable, M&amp;O support, advice and consultancy. Facilities: Gas Lab, Silicon Lab, QART, BondLab, DSF, Irradiation Facilities.</td>
</tr>
<tr>
<td>Detector Interface (DT-DI)</td>
<td>The DI section develops and supports large and medium scale control and DAQ systems for the infrastructure of CERN experiments and laboratory control systems.</td>
</tr>
<tr>
<td>Engineering Facilities (DT-EF)</td>
<td>The EF section develops and maintains technology expertise and facilities for particle detector prototyping and contributes to small scale parts productions for CERN experiments. Facilities/shops are used to develop parts, prototypes, and conduct validation experiments in support of the group and projects.</td>
</tr>
<tr>
<td>Engineering Office (DT-EO)</td>
<td>The EO section is in charge of mechanical design activities for CERN detector-related projects. Designers and engineers cover a wide range of disciplines in mechanical engineering, construction, and numerical simulation fields.</td>
</tr>
<tr>
<td>Detector Construction &amp; Operations (DT-CO)</td>
<td>The CO section expertise is mechanics for particle detectors, including know-how in detector design, prototyping, production, detector assembly, integration and testing. It represents the technical backbone of the group intervening and supporting through various detector projects the construction and operation of CERN experiments.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Projects</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Collaborations with LHC Experiments

2.1. ALICE

C.Gargiulo (EP-DT-EO)

2.1.1. Yearly Technical Stop (YETS) activities

After the first Long Shut down (LS1) ALICE has entered in a new intense run period. Detectors and services in this new phase have been closely monitored and maintained. The DT group has worked to guarantee high reliability of the ALICE services and extraordinary maintenance of the detectors, during the yearly short technical stops (TS1, TS2 and TS3) and the longer one at the end of the year (YETS).

After a first run period, the ALICE dipole magnet triggered an alarm due to a minor leak in one of the magnet cooling lines in the cavern (UX25), for a faulty connection on the dipole side. The leak was repaired during TS1, and a detailed study for the assessment of all (50) the Dipole cooling lines started. A proposal was developed for the rework all the connections to increase the system reliability and avoid that a leak would occur again in any of the other lines. The proposal was extensively tested on surface and finally implemented in one of the Dipole connection in the cavern during TS2, as test solution. The positive result of the inspection, after few months of magnet run has provided the green light for the intervention on all the remaining Dipole cooling lines. EP-DT has leaded this activity from the identification of the cause of the leak, through the development of a technical solution, to the final implementation of the recovery actions on all the lines that was performed in the YETS.

Another major activity in which EP-DT has been involved during the end of the year technical stop, concerns the replacement of the TPC Readout Control Unit (RCU) boards, responsible for controlling the readout of the TPC and initializing and monitoring the Front-End cards. EP-DT supported the TPC team in the replacement of the 240 boards; this required an intervention in all the sectors of the TPC, with the de-installation of the old boards and the replacement of the new ones (RCU2). The difficult access, the delicate mechanical and electrical interfaces, the long duration of the intervention and the related safety implications are all aspects in which the EP DT support and experience was determinant for the success of the intervention.

Consolidation of the cooling connections in the Alice dipole.
2.1.2. ALICE Detector Upgrade

The ALICE team in EP-DT has a deep involvement in the ALICE upgrade program for the new Inner Tracker System foreseen to be installed during the 2019 long shutdown.

A large effort in 2015 has been devoted to prototyping of both the inner and outer staves. This includes the sensors connection to power and signal cables, their integration on an ultralight weight mechanical supports and their characterisation, both at components and system levels. EP-DT has followed closely this activity with responsibility on the assembly procedures development and on the production of the ultra light carbon composite structures as well on the characterisation activity. The design of the stave carbon structures has passed through detailed analysis and has been brought up to the level of production details. A large series of final quality prototypes have been produced and used to validate the next assembly steps.
Stave Mechanics: characterization and prototype.

The selection of the interconnection technology between the silicon pixel chip sensors and the Flex Printed Circuit has requested the design and production of a large series of high precision jigs and a long test phase to tune the interconnection process. The Hybrid integrated circuit, result of the wire-bonded connection between chips and FPC, has been finally glued on the composite support structure. This gluing process has to satisfy challenging requirements in terms of positioning accuracy and optimal thermal interface. The assembly of the first prototypes and their full electrical, thermal and structural characterisations have validated the choices made at the different assembly steps.

EP-DT has as well developed the mechanical design of the ITS barrels and the overall installation sequence for the new LS2 central detectors which includes Inner Tracker System, Muon Forward Tracker and Fast Interaction Trigger.
A requirement of a fast insertion/removal of the new ITS within a YETS (3 months) provides the challenge for the installation scheme. In order to validate the proposed scheme, the EP-DT team has developed a full-scale mock-up of the TPC bore and of the ITS barrels. The mockup will support the final design phase and will be used for a dry installation test to be performed with all the main final structures.

2.2. ATLAS

2.2.1. Cooling Coordination

L. Zwalinski (EP-DT-FS)

In 2015 the cooling team solved several issues with various cooling systems. The major problem appeared in March 2015. It was caused by clogging of the self-closing mechanism inside the flexible cooling pipes for TRT Maraton power supplies. A temporary solution applied to the electronics rack’s cooling infrastructure allowed to provide safe and successful TRT operation until end of the year. During the first days of YETS the complete reconnection of all TRT Maraton tracks and several Muon tracks from US15 water cooling system into Muon cooling system in UX15 was completed. Additionally a complete maintenance of the Maraton power supplies internal cooling elements was executed.

In 2015 the IBL CO₂ cooling system constructed in collaboration by EP-DT, Nikhef and MPI showed impressive performance on temperature stability control; no single major cooling failure required the detector to be switched off. The figure below shows the accumulator pressure profile over all 2015. The daily operation and M&O responsibility for IBL CO₂ cooling system has been transferred in May 2015 from EP-DT to EN-CV-DC followed by official hand-over process that included providing all technical documentation, operation procedures and operators training.
Liquid perfluorocarbons (PFC) have been used for many years as heat transfer fluids for the detector cooling applications in the CERN LHC experiments. Despite their very good performance as refrigerants, PFCs have a high Global Warming Potential which contributes to the environmental footprint of CERN. Consequently, alternatives to PFC must be considered.

In 2015, in collaboration with various CERN groups, a new study to check the use of alternative fluids has been launched. The activity is executed in two parallel branches. The first one consists of building an experimental test bench to verify the compatibility of Novec fluids with the current systems: is direct drop-in fluid replacement into existing systems possible, is the new fluid compatible with materials used in the detector cooling systems, what are the adequate filtering and purification methods? The second study focus on the fluid chemical analysis to verify its purity before and after radiation. The test bench will be ready for operation in mid-2016 in the ATLAS SR1 building. Design and thermal calculations progress well.

The AdvancedTCA (ATCA) telecom industry standard has been selected by ATLAS as platform for the “Phase II upgrade” of the back-end electronics systems. This hardware is going to replace part of the actual electronic equipment, mostly based on VME. As the ATCA boards will dissipate significant larger power with respect to the actual equipment, the cooling performance of the existing rack infrastructure has to be carefully studied. Different shelf layouts (vertical and horizontal cooling) and power loads must be verified and compared to simulations carried out by an ATCA shelf manufacturer before first installation. The project timeline is to provide an extensive report by mid-2016.

Left, sketch of the experimental test bench to verify the compatibility of Novec fluids with the current PFC cooling systems. Right, test track to verify the cooling needs of ATCA boards.
The present cooling system of the ATLAS silicon tracker is based on a conventional evaporative circuit. The compressors in the present circuit have proved less reliable than originally hoped, and will be replaced with a thermosiphon. The working principle of the thermosiphon uses gravity to circulate the coolant without any mechanical components (compressors or pumps) in the primary coolant circuit. In 2015 the thermosiphon system was able to demonstrate first fluid circulation via a dummy load located in USA15. The various operation and emergency procedures have been tested and confirmed. Unfortunately the primary chiller was unable to provide the designed cooling capacity, and mechanical improvements are needed; they should take place in early 2016. Currently the thermosiphon operation with the detector is planned for after YETS 2016.

2.2.4. ATLAS Detector Upgrade Projects
H. Danielsson (EP-DT-EF)

Micromegas (Micro-MEsh Gaseous Structure) is one of the detector technologies that have been chosen for precision tracking and trigger purposes for the upgrade of the forward muon detectors of the ATLAS experiment in view of the LHC luminosity increase. MicroMegas detectors are micro-pattern gaseous detectors with excellent high rate capability and good performance in terms of efficiency, spatial and time resolutions. Together with small-strips Thin Gap Chambers (sTGC), the MicroMegas will compose the New Small Wheel (NSW) that will replace the present Small Wheel of the ATLAS Muon Spectrometer in the LHC Long Shutdown in 2018/19 (LS2).

During 2015, the DT group has been involved in the design, development and construction of the module 0 of type LM2, one of the four types of MicroMegas modules. An important part of the work consists of developing tooling and procedures for the mass production of detector panels, which will take place in Dubna and Thessaloniki. The manufacturing of the panels is carried out in the DT clean room in building 154. A module contains two so-called readout panels, which contains the readout electrodes for signal collection. One of the two completed readout panels for module 0 is shown below.
2.3. CMS

2.3.1. Cooling Coordination

P. Tropea (EP-DT-FS)

The different cooling systems of CMS have been running smoothly up to the beginning of November, when a sudden leak developed on one water cooling system and kept busy the cooling coordination team with a complex leak finding procedure. The discovery of the leak led to a thorough investigation of the failure mechanism and a careful repair of the detector cooling circuit during the end of year technical stop. One expert technician, one FSUs and one engineer of EP-DT are part of the team coordinating the cooling activities at P5 and intervening, in collaboration with EN-CV, on the detector related operation and maintenance tasks.

In the framework of the cooling coordination support to the CMS upgrade activities, the team has been involved all year long in the understanding and curing of the vacuum insulation performances of the Pixel Phase I cooling system. A team of two engineers of EP-DT, one technician of EP-CMX and several experts from TE have assessed the issue, discussed with the contractor having installed the lines and implemented a permanent pumping system with getter pumps, compatible with the harsh environment of the CMS zone where the lines are installed (magnetic field and radiation). The EP-DT-DI section has given a substantial contribution to the project, designing, building, installing and commissioning the control and monitoring system for the four getter pumps installed.

The newly installed manifold with the getter pump used to maintain the vacuum on the Pixel Phase I CO₂ transfer lines.
2.3.2. CMS Tracker LS1: Lowering of the operating temperature
A.Onnela (EP-DT-CO)

Through the LS1 the DT group was closely involved in all of the work areas needed to allow the CMS Tracker to be operated at -10 °C temperature: condensation prevention in the Tracker bulkheads and service channels, increase of dry gas injection capacity, improvements to the cooling stations, and humidity measurement instrumentation. The distribution and monitoring system for the dry gas inside the Tracker volume has been designed, installed and commissioned by the DT Gas team. In the early 2015 the focus was in the final commissioning of these systems and handing them over to the CMS operators well before the end of the LS1.

2.3.3. CMS Detector Upgrade

CMS Tracker Phase 1 Upgrade

For the new CMS Pixel detector due to be installed in 2017, EP-DT has built the CO₂ cooling systems for the testing phase and the final operation at P5. The underground systems, installed at the end of 2014, have been thoroughly commissioned with dummy loads in 2015. The performance of the system, designed for delivering 15 kW of cooling power at -20 °C, has been verified along the year and has proven to go beyond specification. Newly designed and tested flowmeters have been installed in the P5 manifolds at the end of 2015, ready for flow balancing to the detector one it will be there.

The laboratory CO₂ plant full-scale prototype already in use for the Barrel Pixel mock-up in the laboratory of building 186 has been upgraded at the end of 2015 in order to operate following the same procedures as in P5. The Forward Pixel detector, which is going to be commissioned using this cooling plant in 2016, will profit as such of a system identical to the one in P5 from all operational points of view. A team of technicians, FSUs, designers, students, control experts and engineers of EP-DT has been responsible for the full activity.

The DT group provides space, infrastructure and engineering advisory support to the studies and mock-up work done for the Phase 1 Pixel detector installation. The focal point of this activity is the Tracker Bulkheads where the pixel detector’s services connections are located. A dedicated mock-up has been constructed and is used to study and test how the power cables, optical fibers and cooling pipes can be routed and connected in this congested area.

The newly tested and installed CO₂ flow meters for the CMS Phase I Pixel Upgrade cooling plant.
CMS Tracker Phase 2 Upgrade

DT has a central role in the development of the novel 2S (2 strip sensors) and PS (pixel and strip sensors) modules planned for the use in the CMS Tracker Phase 2 Upgrade, as well as in the design of the mechanics and cooling for the upgrade tracker. The work is done in collaboration with other CERN groups, notably ESE and CMX, and with several CMS collaborating institutes. A DT physicist and a DT engineer act as the conveners of the module and mechanics working groups of the Tracker Phase 2 Upgrade.

In autumn 2015 the first two functioning prototypes of the 2S modules were assembled ready, and successfully operated in a beam-test. Much effort has been put into developing assembly tools and methods that can be used for producing modules in the required quality also in the final ‘mass-production’ phase.

In the mechanics and cooling the DT focus is in the development of the ‘tilted’ detector geometry of the ‘TBPS’, Tracker Barrel with PS modules. First mock-up structures were constructed in 2015 and have proven the viability of this novel geometry concept, which now is the base-line choice in the CMS Tracker upgrade layout. Another key area of effort has been the preparation of 3D CAD models of the Tracker and its sub-structures down to the module level, all using common reference systems. These enable efficient updating and data exchange of the detector geometry models at CERN and with collaborating institutes.
2.4. LHCb

B. Schmidt, T. Gys, C. Joram (EP-DT-TP)

2.4.1. LHCb detector operation, maintenance and physics

Beyond its rich program in flavour physics based on proton-proton collisions, LHCb opened the door in 2015 to a new domain of physics exploration related to cosmic-ray and heavy-ion physics. Due to its forward coverage the detector has access to a unique kinematic range in colliding-beam physics. In addition, using a system developed for precise luminosity measurements based on the Beam-Gas Imaging method, neon, helium and argon gas has been injected during some periods into the interaction region in order to exploit the LHC proton and ion beams for fixed target physics at the highest available energies. During the last weeks of the LHC physics program of 2015 the LHCb collaboration participated as well in the heavy-ion run, taking data in both fixed-target mode by recording lead-argon collisions, and in colliding-beam mode, collecting lead-lead collisions at 5 TeV. The comparison of collisions in the various configurations allows disentangling Quark-Gluon-Plasma effects from Cold-Nuclear-Matter effects. A member of the DT group is involved in the physics exploration of this part of the LHCb program.

Members of the group are also involved in the operation and data-taking with the LHCb detector. They help as detector experts, in particular for the RICH and Muon systems. Also detector maintenance activities for various LHCb sub-systems are carried out by DT group members in the RICH and Muon systems. In addition, detector movements for the Calorimeter and Muon systems were required, which have been carried out by members of the DT group, who are also in charge of the maintenance of some of the detector infrastructure. Furthermore, the DT-FS gas team did maintenance work on the various gas systems of the experiment and installed and commissioned a closed-loop for the gas system of the GEM detectors. This closed loop will reduce the CF$_4$ consumption and thus the greenhouse gas emission of the LHCb experiment by 70%, which is an important achievement.

RICH detectors

During the start-up year of LHC Run II, the LHCb-RICH detectors have been running smoothly. Whenever required, the DT group has carried out the usual maintenance activities. The commercial framework for HPD re-processing has been re-negotiated with CERN Purchase and the HPD manufacturer and is now settled until the end of LHC Run II. A new HPD re-processing campaign (25 units) has been started in autumn 2015. All re-processed HPDs implementing getter strips show stable behavior. A major HPD maintenance campaign was carried out in January/February 2015 in which 43 degraded HPDs from RICH2 have been replaced.

Forward shower counters (HERSCHEL)

Forward Shower Counters (FSC) have been installed during LS1 to improve the performance for Central Exclusive Production (CEP) studies. Members of the DT group have been strongly involved in the design, construction and installation of the FSCs in the LHC tunnel. While the counters were installed already 2014, parts of the electrical installation was only completed during 2015.

2.4.2. Detector upgrades for LS2

The R&D work towards the Engineering Design Reviews (EDR) of the various sub-systems continued during 2015. It has been carried out rigorously with significant contributions of the DT group. A few key points are mentioned in this section.

Two sub-detectors, the Vertex Locator VELO and the Upstream Tracker UT plan to use evaporative CO$_2$ cooling as technology to keep the silicon sensors at a temperature of about -20°C and to remove the heat produced by the FE-electronics. In close collaboration with the DT-FS cooling team progress has been made with the specifications for the cooling systems and advice has been given to the design of the evaporators on the detector side. The EDR for the cooling systems, including cooling plants and transfer lines, was carried out in December 2015. Two group members work in very close collaboration with the Technical Coordination team of the experiment and provide support for engineering and integration studies for the upgrade of the experiment.
**VELO**

The VELO upgrade detector will be made of planar silicon sensors with pixels of 55x55μm², increasing the granularity and consequently the spatial resolution. It will be readout at 40 MHz by a new radiation hard ASIC chip (VELOpix) capable to handle the large radiation dose of up to $8 \times 10^{15}$ 1 MeV neutron equivalent fluence, and to cope with the expected data rates. The upgraded VELO will reuse parts of the current mechanical infrastructure, in particular the vacuum tank. Other mechanical parts have to be redesigned.

A member of the DT group provides engineering support and gives advice for the design of the mechanics and the evaporative microchannel CO₂ cooling used in this subdetector. In the past year the design of the support for the detector modules saw a significant advancement, allowing a short data path for the signals, a simplified electrical routing and easier installation. Figure 1 shows the design of the so-called hood, which integrates all key elements, including the safety valve mechanisms for the microchannel cooling system.

Technical support for the VELO was also related to several beam-tests, for which the beam telescope prepared in 2014 was further improved. Prototype sensors could be tested in several test-beam campaigns and the results are encouraging.

![Image of VELO module](image)

*The mechanical design of the so-called hood (in beige) is shown, which houses the VELO modules (in blue) positioned close to the beam-line (green line).*

**Upstream Tracker**

Several members of the DT group are involved in the integration studies for the Upstream Tracker, a Silicon micro-strip detector with four independent layers (X-U-V-X, stereo angle ±5°), positioned upstream of the spectrometer magnet and covering an area of about 2m² per layer.

Thermal and structural analyses have been carried out during the past year for the detector box. A prototype box with panels made of a core of AIREX (a material with a low heat transfer coefficient and good structural properties, which is also used by the aviation industry) and covered with CF plies fulfils the detector requirements. It is currently under construction.

A special challenge is the interface to the LHCb vacuum chamber. Extensive simulation studies have been done for a polymer interface, of which a prototype has been produced in collaboration with the...
TE-MSC group. It will be further evaluated on the prototype detector box, together with an alternative design based on AIREX and a foam interface.

The integration studies for the various detector components and services, in particular in relation to CO\(_2\) cooling will continue this year. A group member acts as work-package leader for the integration and infra-structure for the Upstream Tracker.

**Scintillating Fibre Tracker**

A large planar Scintillating Fibre (SciFi) tracker will replace the currently installed Outer Tracker (based on gas straw tubes) and Inner Tracker (Silicon micro-strips). The detector consists of three tracking stations with four independent planes each (X-U-V-X, stereo angle ±5°) and extends over 6m in width and 5m in height. Blue emitting scintillating plastic fibres of 250 mm diameter are arranged in a staggered close-packed geometry to 6-layer fibre mats. The mats are 2.5m long and mirror coated at one end. The scintillation light exiting at the other end is detected by linear arrays of SiPM detectors (128 channels of 0.25 x 1.6 mm\(^2\) size).

Within the SciFi collaboration of about 20 institutes, one of CERN’s responsibilities is the procurement and quality assurance of the scintillating fibres. The verification of the geometrical, optical and radiation parameters of about 11'000 km of fibres marks the start of the SciFi detector production sequence. The procurement of these fibres was launched with a market survey in spring and a call for tender in autumn 2015. As expected, the list of potential suppliers for such a highly specialised product with demanding technical specifications is very short (two). The negotiation phase with the cheapest bidder ended successfully with the contract signature in February 2016. Delivery at a weekly rate of 150 km will start in May 2016 and last until January 2018.

Two labs in B108 and B304 were refurbished and equipped with air conditioning. The test benches for attenuation length and light yield measurements are operational. The latter was recently upgraded from PMT to SiPM readout, which brings numerous advantages. The fibre diameter scanning machine built in the previous year is routinely operated.

Radiation qualification is one of our key tasks and, consequently, several irradiation tests were performed. Low dose test of a 3 m long fibre at the company AAA in Saint Genis, by immersing the fibre in an aqueous solution of F-18, to a dose of 340 Gy.

In autumn, together with the DT team which operates the PS IRRAD facility, we performed a complex irradiation of a 2.5 m long full size fibre mat to the dose profile expected at the end of the detector’s lifetime in LHCb. The profile extends over 3 orders of magnitude and reaches 35 kGy. The mat was characterised before and after irradiation in a beam test (SPS).

![Dose profile comparison](image)

*Measured ionizing dose (green points) compared to the targeted dose which is expected in the upgraded LHCb detector at the end of the detector lifetime (50 fb^-1). The profile extends over three orders of magnitude (please note the logarithmic scale).*
Irradiation of mirror/glue samples in the PS Irrad facility to 35 kGy. Encouraged by successful tests with an X-ray source, which was made temporarily available to us in the gas detector lab in B154, a dedicated X-ray set-up has been designed and components ordered from an industrial supplier. This set-up shall serve routinely for radiation qualification of fibre samples during series production.

Geometrical anomalies of the fibres, in particular the presence of small bumps, where the diameter increases locally from nominal 250 mm to more than 350 mm, remained a concern. The group has developed a method to shrink the bump diameter by pulling them through a heated conical drawing tool and integrated an automated set-up in the fibre diameter scanning machine. The first tests are promising, but the optimisation and full qualification of the method remains to be done in spring 2016. Since mid-2014, a DT group member acts as deputy project leader of the SciFi tracker.

RICH upgrade
SPS beam test data of an HPD with external readout have been analysed in further detail. Preliminary Cherenkov light yield has been estimated to be 7.9 detected photons and was found consistent with the predicted value of 7.1 from Monte-Carlo simulations.

Two SPS beam test campaigns have been successfully carried out with a test vessel designed and manufactured in DT. The system included basic RICH upgrade units, including MaPMT photodetectors and dedicated front- and back-end electronics. Specific QE measurements of MaPMTs used in the above beam tests have been performed in the laboratory. The related results have been used in the simulations.

TORCH R&D
Within the framework of the European Research Council TORCH project, laboratory activities have been on-going with extensive tests of customised MCPs and new dedicated multi-channel readout electronics. A small-scale TORCH prototype with dedicated quartz radiator, focussing optics and specific mechanics has been tested in the laboratory and in three beam test campaigns. Two campaigns have been performed at the SPS and one at the PS where a full TORCH infrastructure has been provided. Ageing tests are on-going on MCP prototypes with extended lifetime.

Muon System
In view of the LHCb upgrade simulations studies have continued in order to improve the shielding in front of Muon station M2. Modifications to the beam plugs under HCAL and station M2, and additional tungsten shielding in the position of the PMs for the readout of the innermost HCAL cells not used in the LHCb upgrade, allow for a better absorption of shower particles and therefore a reduction of the particle flux in the innermost part of station M2 by about 60%. Studies on the implementation of the improved shielding have started with the goal to replace the beam plug under Muon station M2 in the technical stop during the winter 2016/2107 by a tungsten beam plug.

A DT group member continues to act as deputy project leader for the Muon System.

2.5. TOTEM, ATLAS-ALFA, ATLAS-AFP
S. Ravat, X. Pons (EP-DT-DI)

The DT group has completed all the commitments foreseen in the LS1 for Totem and ALFA experiments. The vacuum system and its control have been completely redesigned and reinforced; moreover the position control system has been also modified and enlarged with the new timing Roman Pots (RP) and adapted to new LHC safety standards. After the LS1, both experiments have been operated with good results.

Last year, DT and the ATLAS experiment signed a collaboration agreement for the design, assembly, installation, test and commissioning of the AFP (Atlas Forward Proton) Roman Pot’s position control and vacuum systems. The AFP Roman Pot Stations (RPS) will be installed in the LHC tunnel, in the two outgoing beam pipes at 205 and 217 meters from the ATLAS Interaction Point. In the first phase of the installation already executed, a single arm with two RPSs will be installed for the measurement of diffractive processes with AFP in special low-luminosity runs. The AFP Roman Pot houses the detectors and its vessel is placed under a primary vacuum separating them from the ultra-high vacuum in the
beam pipe. The RP can be moved horizontally into the beam aperture allowing the detectors to approach the LHC beam to a small but still safe distance.

Left, manual laser position calibration of the AFP Roman pots; right, AFP roman pot inserted in the LHC beam pipe.

3. Collaborations with non-LHC experiments

3.1. AEGIS  
S. Haider (EP-DT-TP)

The primary scientific goal of the Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy (AEGIS) is the direct measurement of the Earth's gravitational acceleration, g, on antihydrogen. The DT group gives support to the experiment in areas of technical coordination.

3.2. CAST  
M. Davenport (EP-DT-TP)

The CERN Axion Solar Telescope (CAST) aims to shed light on a 35 year old riddle of particle physics by detecting either axions originating from the 16 million degree plasma in the Sun's core, or relic axions /axion-like particles, transforming CAST to an antenna for relics. The DT group gives support to the CAST experiment in areas of technical coordination, CERN Contact-person, mechanical and electrical components of the magnet movement system, slow controls and vacuum interlocks. It operates the X-Ray test lab for detector calibration and also is involved in the development and analysis of sub-keV X-Ray detectors.

In 2015, CAST took data between mid-June and late-November with a full complement of X-ray detectors for a final data taking run at maximum sensitivity searching for solar axions with the CAST magnet cold bore under vacuum (sensitive to axion rest masses < 0.025 eV/c²). The system consisted of two low-background Micromegas detectors (coupled to the two cold bores on the sunset side of the magnet) which were surrounded by heavy shielding. On the sunrise side, the two cold bore exits were each coupled to an X-ray telescope with, in one case, a low-background Micromegas detector and in the other case an InGrid detector, capable of both sub-keV (chameleon) and multi-keV (axion) measurements simultaneously.

After the data run was completed, a thorough maintenance of magnet movement motors and lifting jacks was made since data taking with a KWISP detector to detect solar chameleons by radiation pressure technique is planned for early Spring 2016.

During the 2015 run, preparations were made together with a technical student to upgrade the old solar tracking PC to a new PC with a Windows 7 environment and to change the communications protocol between PC and motor frequency inverters from RS232 to Ethernet. This new system was successfully tested on the magnet at the end of data taking. The student also developed, installed and tested a
program to continuously monitor the horizontal movement laser alignment check system during data taking.

Towards the end of 2015, CAST-CERN coordinated a study for the integration of the new CAST-CAPP relic axion detector system inside the magnet cryostat. In May 2016, the detector cavities will be installed in the cold bore of the magnet and their cryo-amplifiers will be located in a copper vacuum vessel attached to the cold bore exit flange on the inside the cryostat. The aim is to operate the cavities and the cryo-amplifiers at or near to 2 Kelvin. This study involved expert physicists and engineers from EN-MME, TE-CRG and CAPP (Korea).

### 3.3. CLOUD

**A. Onnela (EP-DT-CO)**

In 2015 CLOUD had two runs. The first, CLOUD10-T in spring 2015, was a technical run to develop and test CLOUD instruments and infrastructure. The main run, CLOUD10 in autumn 2015, focused on measuring aerosol particle nucleation and growth in simulated boreal forest conditions. The CLOUD measurement results are then compared to observations done in field measurements.

DT contributed to the experiment by an engineer acting as the Technical coordinator, GLIMOS and Resources coordinator, by a technician providing support to the experiment’s construction and maintenance activities and by the DT gas team adapting and maintaining CLOUD’s gas systems.

![CLOUD diagram](image)

*An excimer Laser was added in 2015 to CLOUD’s UV system to increase the available light intensity injected to the aerosol chamber. Optical fibres connect the light sources to the chamber.*

### 3.4. NA62

**H. Danielsson (EP-DT-EF)**

The NA62 experiment is a fixed target experiment in the North Area. It has been designed and built to study ultra-rare kaon decays. The strong suppression to the Standard Model (SM) contributions and the remarkable theoretical precision of the SM rate makes these decays sensitive probes to possible new physics. The beam time in 2015 was from June 22 to November 15 and we collected \( \sim 2 \times 10^{10} \) triggers on tape. The experimented reached nominal beam intensity by the end of the run.
The data analysis shows that the detector performances of the main new systems (e.g., photon and muon vetos, the RICH and the Straw Tracker) meet fully the expectations. In particular the Straw Spectrometer, which has been fully designed in EP-DT, is running continuously with all of the 7168 straws operational, except one.

Important experience was obtained concerning the data acquisition system, which will undergo further optimizations to increase the acquisition rate so that the beam intensity can be increased to its nominal rate in 2016. Concerning the GigaTracker (GTK), the three stations were equipped and operated gradually. However, due to time constraints and technical difficulties, the detectors were read out only partially. The data taken are useful for performance studies and to correlate the GTK with the other detectors. The inlet pipes for the cooling of the three stations have been shortened in order to decrease the operation temperature of the detector.
4. R&D Projects

4.1. Radiation Tolerant Silicon Detectors

M. Moll (EP-DT-DD)

The Solid State Detector (SSD) lab of the EP-DT group participated in the framework of the RD50 collaboration and CMS High Granularity Calorimeter (HGC) project in R&D activities related to silicon sensor developments. In the framework of the RD50 collaboration (50 Institutions, 280 members) the EP-DT group participated in the research on radiation tolerant silicon sensors for the vertex and tracking detectors for the luminosity upgrade of the LHC and beyond. DT provided one of the two co-spokespersons, administrative support, the budget holder and the co-ordination of several RD50 common projects and participated actively in the ambitious R&D program.

RD50 made excellent progress in all four main research lines: “Defect and Material Characterization”, “Detector Characterization”, “New Structures” and “Full Detector Systems”. While the overall RD50 research program kept its very wide scope and took first steps to understand FCC requirements, the fields subject to most intensive studies in 2015 were sensors with intrinsic gain for radiation tolerance and fast timing, characterization of defects responsible for sensor degradation after irradiation, simulation of irradiated device performance, CMOS sensors and characterization of devices after extreme radiation fluences up to $10^{17}$ particles/cm$^2$. In close collaboration with the LHC experiments upgrade teams the implementation of 3D and edgeless sensors and in particular sensors based on p-type substrates was further consolidated and optimized.

The CERN RD50 team in EP-DT was involved in several of these research activities and in particular in the search for the defects responsible for charge trapping, the study of avalanche (AD) and low gain avalanche detectors (LGAD), the mapping of the electric field in various irradiated segmented sensors and CMOS devices, the TCAD simulation of irradiated detectors and finally the development of new laser based device characterization techniques. An example for new laser based characterization methods performed by EP-DT in close collaboration with the CSIC-University Cantabria, University of Sevilla and the SGIker Laser Facility is given below. The figure (left) shows the working principle of the two-photon absorption process (TPA) as observed in a fluorescent liquid. Photons with sufficient energy are absorbed in the organic material and produce a fluorescent light cone throughout the material. Photons with insufficient energy are not absorbed unless the light intensity is high enough such that two photons (or more) can be absorbed at the same time being then able again to produce fluorescent light. This will happen only in the focus of the beam leading to a spot like absorption. The same principle has been exploited for characterizing semiconductor sensors and detectors. The right Figure shows the experimental setup where a 1300 nm light pulse of 240 fs length and an energy of several tens of pJ is scanned over the device to produce a 3D map of the charge collection efficiency of the sensor. The nest Figure gives an example for a CMOS sensor that has been investigated. Unlike other methods used up to now, not only the depleted volume is visible with a very high resolution but also the deep implant can be precisely resolved by a time resolved measurement.

Left: A visual demonstration of the difference between Single Photon Absorption (SPA) and Two Photon Absorption (TPA). Right: CMOS sensor mounted on a PCB allowing to scan the laser beam over the edge of the device.
The SSD activities in the framework of the CMS collaboration were mainly focused on characterizing and understanding the impact of high neutron radiation levels on the performance of silicon pad sensors as foreseen for the High Granularity Calorimeter project. Several detectors of different type (n-type, p-type, FZ, EPI) and different thickness (50 to 320 microns) were irradiated to various neutron fluences and characterized and compared with respect to their performance. According results were presented to the HGC community and have been part of the decision of the CMS collaboration to build a silicon detector based forward calorimeter.

4.2. Micro-Pattern Gaseous Detectors

L. Ropelewski (EP-DT-DD)

The EP-DT Gas Detectors Development (GDD) team plays a major role in the coordination and support of the RDS1 Collaboration, which is focused on the promotion and development of Micro-pattern Gas Detectors (MPGD) technologies. The MPGD-based upgrades of CMS and ATLAS muon systems and of ALICE TPC adopted technologies such as single mask GEM and resistive anode MicroMegas that were developed in the RDS1 framework. As in previous years, emphasis was placed on the industrialization and quality assurance of the detector fabrication and on the simplification of the detector assembly allowing for low cost and large volume production. At the same time, the Collaboration maintains the efforts on the extension of the versatile Scalable Readout System (SRS), electronics for laboratory instrumentation, and the maintenance of the simulation tools for gaseous detectors. The GDD team serves as a center of expertise, links between collaborators and maintains extended laboratory and beam test facilities used by the RDS1 Community. For this purpose, since several years, the group supports lab instrumentation, tracker detectors, data acquisition and reconstruction software.

At the same time the GDD team is pursuing generic R&D of MPGDs in order to improve the state of the art of this technology and to push forward the actual limitations to meet increasing demand from the future HEP experiments and to explore possibilities of applications in other fields and in the industry.

Top Left: GDD laboratory facility. Top Center: Vacuum system for detector operation in high quality environment and out-gassing, desorption and contamination measurements. Top Right: LET prototype for studying scintillation in gases in controlled conditions targeted to TPC readout with emphasis also on the primary scintillation. Bottom: 2015 RDS1 test beam in H4-SPS North Area (ALICE TPC, ATLAS NSW, CMS muon system, BESSIII, Particle Flow calorimetry with MicroMegas and THGEM).
Last year generic R&D activities were focused on:

- Detector performance at extreme charge densities (high incident particle rates and/or gas amplification);
- Development of the high precision timing gaseous detector with the time resolution below 100 ps, based on the solid photocathode or solid secondary electron emitter;
- Applications of solid converters in the gaseous neutron detectors and gamma imaging devices;
- Application of glass for production of the GEM plates for sealed and radio pure imagers;
- Feasibility study of application of the graphene as a ion filter in the gaseous detectors;
- Study of the scintillation in gases for possible application in the optically readout TPC as a detector for directional dark matter searches.

Latest activity resulted in the development of the optically readout GEM detector demonstrating great potential of applications in X-ray, neutron, UV and gamma imaging, fluoroscopy, computer tomography, fluorescence and crystallography.

4.3. On-detector cooling R&D

P. Petagna (EP-DT-FS)

4.3.1. Micro-structured plates for detector thermal management

The year 2015 has seen the achievement of an important milestone for the general R&D work towards the application of silicon micro-structured cold plates for the thermal management of future HL-LHC detectors. In collaboration with the University of Manchester, a module composed by an ATLAS FE-I4 chip and a 3D pixel sensor has been integrated at CERN with a thin silicon cooling device. The integrated module has been tested under nominal pre-irradiation conditions, exhibiting an almost perfect temperature uniformity on the surface of the sensor and an unparalleled Thermal Figure of Merit of TFM ≤ 2. This is at least a factor 6 better than the best performance attained until now with the most advanced cooling solutions for pixel detector staves.

The FE-I4 + 3D sensor chip assembly (white square) mounted on the silicon cooling chip and integrated in the test board. Soldered hydraulic connectors are visible on the right.
4.4. A detailed analysis of the greenhouse gas (GHG) emissions from the LHC detectors was carried out and presented to the experiments. Two main research lines have been identified to limit and reduce the GHG emissions: optimization of the gas systems, and replacement of high global warming potential (GWP) gases.

The GHGs mainly used in the LHC experiments are C₂H₂F₄, SF₆ and CF₄. A recent European Union (EU) “F-gas regulation” will limit the total amount of the most important F-gases that can be sold in the EU from 2015 onwards and phase them down in steps to one-fifth of 2014 sales in 2030. Particular attention has been addressed to the replacement of the C₂H₂F₄ in the Resistive Plate Chamber (RPC) detectors, being the main contributors to the LHC GHG emissions. Recent research converge on fluorinated propene refrigerants as potential replacement (hydro-fluoro-olefins, HFOs). In particular, two structural isomers of HFO based on the propene structure have been selected: HFO-1234yf and HFO-1234ze, with a GWP of 4 and 6 respectively. Also several hydrofluorocarbons (HFC), as for example R32 (GWP 650) and R152a (GWP 140) have been identified as good candidates. Refrigerant properties of HFOs are well known while the effect of ionization processes in particle detectors using these new Freons is under investigation nowadays. These new gases, with the addition of other components, have been studied on 2 mm single-gap RPCs. The first results show that a complete replacement of C₂H₂F₄ with the HFOs does not give satisfactory results using the current LHC detector front-end electronics and high voltage systems. Promising results have been obtained with a five components gas mixture. The gas substitution is not easily feasible for the current and future LHC conditions and long R&D tests will be necessary to find a technically viable alternative.
RPC efficiency and streamer probability for different gas mixtures containing 20% of He, 4.5% iC4H10, a small fraction of SF6 (between 0 and 0.6%) and a partition of C2H2F4 and HFO-1234ze.

4.5. Micro-systems engineering
A. Mapelli (EP-DT-DD)

Microtechnologies and microfabrication techniques are investigated within EP-DT for the development of novel types of detectors and alternative approaches to on-detector services, such as cooling. Most of the microsystems under investigation are fabricated by EP-DT in the class 100 MEMS cleanroom of the EPFL-CMi Center for MicroNanoTechnology (cmi.epfl.ch) in close collaboration with the EPFL-LMIS4 Microsystems Laboratory (mis4.epfl.ch).

4.5.1. Novel microfabrication approaches for detector development

Beam monitors
In 2015, a new project was launched with the BE-BI Group at CERN to develop an Optical Diffraction Radiation (ODR) target for the ATF2 project at KEK in Japan. In this framework, the aim is to produce very small and precise slits (25 µm to 200 µm width), to pass a 4 GeV-1µm electron beam without beam/material interaction. The two mirrored sides of the slits are excited by the electric field of the particle bunch and give rise to optical diffraction radiation. Observation of the light emitted by this process gives access to the beam profile parameters.

Devices have been fabricated on 1.5 mm thick silicon substrates in the EPFL-CMi cleanroom and were successfully tested in the beam demonstrating the feasibility of such monitors in silicon. They devices fabricated exhibit very sharp and well-defined slits, and an optical quality flatness of the mirrored surfaces with a co-planarity better than 20 nm, corresponding to a tenth of the wavelength of observation.

Left, principle of the ODR; center, 1.5 mm thick Si wafer with 4 devices after dicing; right, surface measurement of the 80µm slit, the two mirrors have a co-planarity better than 20 nm co-planarity.
Monolithic pixel detectors
A collaboration has started in the fall of 2015 between CERN and EPFL on the development of monolithic pixel detectors fabricated by low-temperature direct bonding and on the study of the charge collection across their bonded interfaces. This project is being pursued in close collaboration between LHC experiments, EP support groups and the EPFL Group of Electron Device Modeling and Technology (EDLAB). A Finite Element Modelling environment as well as an analytic approach have been developed by a Doctoral Student shared between EPFL and CERN giving very encouraging results. The first prototype modules have been designed and are currently being fabricated at EPFL. Their characterisation is scheduled for the summer of 2016 at CERN. The expected outcome of this study is to define a novel approach for the fabrication of monolithic detectors with a great potential impact on the next generation of tracking systems for LHC experiments as well as for medical applications.

MicroScint: microfluidic scintillation detectors
The microScint project has been added to the Grey Book database for the CERN experimental programme as a project under study with two participating institutes; Ecole Polytechnique Fédérale de Lausanne (EPFL) and Università di Roma I La Sapienza e INFN Roma. This project aims at developing new types of liquid scintillation detectors based on microfluidics and microfabrication techniques. In 2015, the main developments were focused on the integration of photodetectors in the microfluidic channels and the development of a fabrication procedure for polymeric scintillating waveguides.

Integration of photodetectors in microfluidic channel: in close collaboration with three EPFL laboratories (Microsytems Laboratory LMIS4, Photovoltaics and Thin Films Laboratory PVLAB and the Group of Electron Device Modeling and Technology EDLAB), we have defined a fabrication process to integrate hydrogenated amorphous (aSi:H) silicon pn junction photodiodes to silicon microchannels. The first integrated devices are expected to be tested by mid-2016.

Manufacturing of polymeric microfluidic scintillating waveguides: PMMA has been selected as the best alternative to crystalline silicon to manufacture microfluidic waveguides. The main advantage of PMMA with respect to silicon is that scintillation light can be guided by Total Internal Reflection due to the lower refractive index of PMMA with respect to the refractive index of the liquid scintillator. In the case of silicon, the inner walls of the microchannels had to be coated with a metal to guide light by specular reflection leading to very short attenuation lengths. The first PMMA microchannels have been tested at CERN with a Sr-90 source demonstrating the principle of operation of polymeric microfluidic scintillation channels and their advantage in terms of light guiding efficiency with respect to silicon microchannels.

4.5.2. MicroCool: silicon microchannel cooling
In agreement with the NA62 collaboration, the second batch of cooling plates was ordered from CEA-Leti. New modules were assembled and installed in the beam line. The procurement of all the mechanics and fluidic circuitry (except the cooling plates) for 25 GTK modules has been launched and is expected to be ready by the end of 2016. This will allow for the production of all the GTK modules necessary for the 10 years of operation foreseen for the NA62 experiment.
In 2015, three main activities were carried out in the framework of the ITS Upgrade.

- Fabrication of silicon microchannel cooling frames at the Thai Microelectronics Center (TMEC) with the direct bonding of structured silicon wafers being performed by PHILIPS Innovation Services (PiNS) in the Netherlands. The wafers are then shipped to EP-DT for further processing at EPFL and stave assembly at CERN.

- Development of in-plane microfluidic interconnectors to daisy-chain silicon cooling frames in stave configurations.

- Fabrication of pALPIDE-3 dummy chips used for the calibration of the automatic tool for the assembly of Monolithic Active Pixel Sensors (MAPS) on the ITS staves.

5. Services Provided by DT

5.1. Infrastructure for Detector R&D

5.1.1. Irradiation Facilities


Gamma Irradiation Facility (GIF++) at SPS North Area

The new Gamma Irradiation Facility (GIF++) facility is located in the North Experimental area of the SPS accelerator and operated under the responsibility of EP-DT. On April 23rd 2015, the first irradiation experiments started marking the beginning of the GIF++ users operation. During the preceding period, the mandatory checks required to obtain the HSE Safety Clearance were completed, as well as the detailed characterization of the photon radiation field generated by the new 14TBq Cs-137 source. This measurement campaign, organized by the DT team, with the support of DGS-RP and some of the GIF++ facility users, focused on the understanding of the effects of the radiation attenuator system.

During 2015, the EP-DT team improved the functionalities of the control system developed for GIF++ by making available to the users the relevant environmental conditions data, as well as by commissioning the remote control of the radiation attenuator. At the same time, the commissioning of the GIF++ radiation monitoring system based on RADFET sensors provided by EP-DT (RADMONs) and developed within the AIDA project was also started. A standard LHC-like ELOG was developed for the facility in order to track operation, installation and data taking activities. Given the unavailability of the TGC beam trigger, a scintillators based beam trigger was also setup. The instability of environmental conditions was a big issue during 2015 data taking campaign. However, the design of the air conditioning and humidity control (HVAC) system was finalized in collaboration with EN colleagues. Its installation will be completed in the first months of 2016. The installation of water-cooling and compressed air has been completed in 2015.

The gas systems infrastructure (gas mixing units, gas recirculation, gas distributions and gas analysis) has been fully commissioned and made available to the users. All data from the gas systems (gas consumption, mixture composition, etc.) are distributed through DIP protocol and they are used by the specific detector DCS. The standard gas analysis module has been complemented with a gas chromatograph allowing performing detailed studies or the return gas from detectors.
2015 was a very successful year for GIF++. The efficiency of the facility in providing good conditions for detectors R&D was greater than 80%. The main problem being the absence of beamline elements (XTDV), which obliged to stop the irradiation during CMS-ECAL beam-time periods. This will be solved at the beginning of 2016 when the XTDV installation is foreseen. The facility has been fully exploited by a large collaboration (about 100 persons involved) from all LHC experiments. Many different real-size detectors (several m² of active surface each) and experiments are taking data. About ten setups with seven different gaseous detector technologies (CSC, DT, GEM, GRPC, MM, RPC and TGC) are under validation for the future HL-LHC upgrade programs.

Proton (IRRAD) & mixed-field (CHARM) Irradiation Facilities at PS East Area
The year 2015 has been also the first full year of operation for the new East Area Irradiation Facilities. The upstream part of the new infrastructure hosts the proton irradiation facility IRRAD (operated and maintained by DT) while, in the downstream area, the mixed-field CHARM facility (operated by EN-STI) is installed. These facilities exploit the intense 24GeV/c proton beam of the PS accelerator extracted on the T8 beamline.

[Image: Several experimental setup installed in the upstream (left-hand side picture) and downstream (right-hand side picture) irradiation area at GIF++. The structure of the 14TBq Cs-137 irradiator is also visible on the left-hand side picture.]

[Image: View of the three zones inside the new IRRAD facility. Nine irradiation tables have been fully commissioned during 2015 allowing the users to precisely position and expose their samples to the direct high-energy proton beam in IRRAD. Tables are labelled from IRRAD3 to IRRAD19 using odd numbers only.]

In particular, for the IRRAD proton facility, the three-irradiation zones have been fully completed and equipped with all services necessary for the user experiments. Every irradiation zone hosts now three irradiation tables where room temperature, cold (down to -25 °C) and cryogenic irradiation experiments (down to 1.8K) can be performed. The figure above (from the right to the left, following the proton beam path indicated by the red dashed arrow) shows some views inside the three irradiation zones of IRRAD. The tables IRRAD5 and IRRAD11 are equipped with cold boxes, while the table IRRAD15 allows the positioning in the beam of the cryogenic system. The new IRRAD facility houses also bigger service
area including dedicated radiation storage and workspace areas. The refurbishment and upgrade of the equipment in these areas started in 2015 within the EU-funded AIDA-2020 project.

The first weeks of operation in 2015 have been spent working together with the secondary beam-line physicist and the BE-OP operator crew for the steering of the proton beam and the commissioning of several T8 optics configurations required for special irradiation runs in IRRAD and CHARM. IRRAD can now exploit, during the standard runs, a beam spot variable from about 12x12mm$^2$ to 20x20mm$^2$ as well as beams of much bigger cross-section for dedicated special experiments. The beam can be focused down to 5x5mm$^2$ to increase the total integrated particle fluence. The tables, equipped with an individual control system each, give the possibility to displace the samples across the beam in order to irradiate bigger surfaces. The run 2015 for the users in IRRAD and CHARM was very successful. This started on May and lasted until the beginning of November 2015. In total, 341 samples organized in 127 SETs (groups of similar samples irradiated to same conditions) were irradiated at RT, low and cryogenic temperatures in IRRAD to different fluence levels as requested by the users. The pictures below show examples of material samples and experiments irradiated in IRRAD during 2015.

Examples of irradiation experiments in IRRAD during 2015. Irradiation of an LHCb SciFi detector prototype (left-hand side) on IRRAD17. Small material samples mounted on a three-arms samples holder and ATLAS electronics boards on IRRAD19 (right-hand side).

5.1.2. Radiation Monitoring Sensors (PH-RADMON)

In the framework of the RADMON project, the DT group manufactured during 2015 new integrated sensors (62 units) and distributed several tens of dosimeter samples (RadFETs, p-i-n diodes, radiochromic films and passive dosimeters). Customers were experiments and groups within CERN (TOTEM, CMS) but also external experiments and irradiation facilities (PHENIX experiment at BNL, US and the TRIGA reactor of the Jožef Stefan Institute in Ljubljana, Slovenia). The new delivered integrated sensors were configured to cope with the increasing intensity of the radiation fields and went to replace, during LS1, devices previously operational at the LHC Experiments that reached saturation.

Towards the end of the year, a new PhD project has been kicked-off in DT. It targets the development of a new generation of RADMON sensors tailored for the needs of the Future Circular Collider (FCC) at CERN. The current FCC studies forecast doses exceeding tens of MGy representing a new and unprecedented challenge for the radiation monitoring technologies at HEP experiments.

The continuous demands to supply RADMON devices, as well as the new R&D activities in this area confirm the success and the interest of the present and future experimental community in the radiation sensors developed in DT.
Solid State Detector Lab

The hardware infrastructure of the Solid-State Detector laboratory (SSD) in buildings 28 and 186 was maintained and extended with a detector storage cabinet, a cryo-cooler for Thermally Stimulated Current (TSC) measurements and a beta source (Sr-90) based single-channel charge collection efficiency (CCE) measurement system based on discrete electronics and imbedded in a climate chamber that can reach -70 °C. LabView based control and data taking software has been developed for both systems. While the CCE system is readily taking data, the TSC system in the cryocooler will need some development in 2016. Further available systems in the lab are set-ups for Transient Current Technique (TCT), edge-TCT, Current DLTS (down to -30 °C), Capacitance-Voltage (CV), Current-Voltage (IV) and a multichannel (Sr-90 beta source based) Charge Collection Efficiency measurement system employing the Alibava readout (LHcb Beetle chip). The CV/IV system can be cooled down to about -30 °C for the measurement of highly irradiated samples, which is also the temperature at which most of the CCE measurements in the lab are performed. Part of the equipment was made available to external groups: colleagues from ATLAS, CMS, LHcb, RD39, RD50 and BE-BI performed measurements for their individual solid-state sensor projects in the laboratory.

New systems: (Left) Climate Chamber cooling down to -70°C and containing a beta source based Charge Collection Efficiency (CCE) measurement system. (Right) Closed-cycle He cryostat capable of cooling small samples to 10K. Main purpose is to perform defect characterization in irradiated silicon samples using the Thermally Stimulated Current Technique (TSC) method.

Bond Lab

The primary projects for the Bond lab in 2015 concerned CMS phase 1 pixel module production, ALICE upgrade R&D, Medipix/Timepix (used in many different projects), LHcb upgrade modules, NA62 GigaTracker, CMS GEM upgrade R&D, EP-ESE (DC-DC converters, opto components), and ATLAS tracker upgrade R&D. As usual there were a very large number of smaller jobs from a large variety of clients: LHcb, RADMON, CALICE, CMS tracker phase 2 upgrade, ATLAS, CristalClear, etc. A significant amount of time was spent giving advice and aid for detector construction and connectivity issues to a variety of projects. The Bond lab throughput is saturated so some jobs can no longer be processed on schedule.

Quality Assurance and Reliability Testing (QART) Lab

The QART lab was fortunate to have an injection of new manpower in the form of 50% of an applied fellow starting in November 2015. The QART lab, containing high-end environmental chambers, a powerful vibration test system, a small aperture high field (2T) electromagnet, and numerous smaller specialized test equipment, was used by a variety of users. Some of the larger jobs included continued ESE group DC-DC converter testing, CMS pixel upgrade module aging tests and ALICE pixel upgrade thermal cycling tests. All the 4 main LHC experiments had upgrade projects, which used the QART lab facilities and advice. Both of our fast temperature cycling environmental chambers saw moderate use.
(although often for very long duration tests) and 2015 saw significant user interest in the high field electromagnet.

**DSF (Departmental Silicon Facility)**

ALICE pixel R&D, CMS pixel upgrade production, and NA62 were active users of DSF clean room in 2015. The request for significant new space from ALICE resulted in the start of a clean-up and re-allocation of space for their coming upgrade pixel production. This should be followed in 2016 with a partition defining the ALICE zone and an extension of the personnel airlock to be able to accommodate the increase in the number of people working in the DSF. New requests for space in the DSF clean room have made it such that all available space will be allocated in 2016.

*Thermal measurements of the CMS Electromagnetic Calorimeter front-end electronics for longevity studies.*

5.1.4. Thin Film and Glass

*T.Schneider (EP-DT-DD)*

The mandate of the TFG service is to give support to the different detector groups in terms of thin film coating and glass and ceramic machining. The TFG glass and ceramics workshop is equipped with dedicated diamond tools to machine with high precision hard and porous material (glass, Pyrex, quartz, sapphire, ferrites and other ceramics). In 2015 several prototypes and small series have been produced for LHCb SciFi, ALICE, ISOLDE, CMS ECAL, AEGIS, HiRadMat and the micro-channel cooling activities in EP-DT.

The TFG sservice is equipped with several multipurpose and dedicated coating devices. Common for these installations is the "Physical Vapour Deposition (PVD)" thermal evaporation process. With this technology nearly all kinds of materials can be deposited on a multitude of substrate. These coatings, used either for optical or functional applications, are produced in a clean room environment. Pure metals and dielectrics handled in the multipurpose coaters are completed by the organic materials for wavelength shifting (WLS) and photocathode purpose applied in the dedicated devices. In more than 30 years of activity, highly specialized technical solutions have been developed in the TFG lab for the different detector applications (UV enhanced spectral reflectors, plastic fibre coatings, photomultiplier WLS coatings, photocathode coatings etc.). Due to the comprehensive contribution of TFG to several optical fibre detectors projects (ATLAS ALFA, LHCb SciFi) the accumulated fibre-expertise and built-up infrastructure (fibre coating, machining, handling, gluing etc.) is now highly appreciated by the detector community.

Important productions of optical coatings in 2015 were UV enhanced reflector coatings (NA62/Jefferson lab), optical fibre coatings (CMS ECAL/ LHCb SciFi/ Prototypes for Beam Instrumentation) and WLS coatings for WA 105. Functional layers have been produced for example for the micro channel activities in DT and the Microbuses R&D project together with EN-MME.
In 2015 special effort has been given to the request of COMPASS to produce photocathode CsI coatings on their THICK-GEM substrates of the inner RICH detector. At the beginning of the year the existing coater was completely upgraded and devoted to this new task. Following an intense and crucial R&D phase, end of the year the goal was reached to achieve good and stable-in-time Quantum Efficiency results. In the first 2 months of 2016 the COMPASS CsI photocathode coating campaign has been successfully accomplished.

5.1.5. Micro-Pattern Technologies (MPT) workshop
R. de Oliveira (EP-DT-EF)

The Micro-Pattern Technologies (MPT) workshop focuses on the production of interconnection devices and radiation detector parts having features in between nanometric (wafer fab) and millimetric (traditional mechanics) production technologies. The workshop is involved in the development and production of parts, components and detectors for many projects for High Energy Physics and other fields of applications.

The list below is just a small selection of key projects in 2015. Many more MPGD requests from CERN and other institutes around the world have been handled in the workshop.
• ALICE TPC upgrade: The mass production of GEMs is ongoing. More than 500 GEMs will be needed to equip the full TPC. It is expected that at least half of the production will be done during 2016.
• CMS muon upgrade: The mass production of GEMs is also going on. We expect more than 200 GEMs produced in 2016.
• ALICE inner tracker: Special low mass circuits made only with aluminium and kapton are needed in ALICE tracker to avoid multiple scattering induced by copper. The mass production is supposed to start in 2016.
• DUBNA-BM@N: The world largest triple GEM detector have been produced and assembled early 2016 (see picture above). The active area 1.7m x 0.55m is now closely reaching the single GEM maximum size allowed by the production equipment estimated at 2m x 0.55m.
• GEM detectors for CBM at Fair: Test and design modification of the triple GEM detectors are now accomplished. The mass production is starting in 2016 (30 to 40 detectors 1m long x 0.45m wide)

5.2. Infrastructure for experiments

5.2.1. Gas Systems
R.Guida (EP-DT-FS)

The activity on the 40 LHC and non-LHC gas systems during 2015 continued to be focused on preventive maintenance and upgrades needed to improve gas systems performance or to cope with an increase of the LHC luminosity. About 20 modules have been upgraded/modified last year. For example, two new Xenon recuperation modules have been prepared for the ATLAS-TRT and the ALICE-TRD detectors. Additional units have been built for the CMS-Inner detector flushing systems.

The gas service team is also heavily involved in the effort of reducing gas consumption and, consequently, the greenhouse gas (GHG) emission from particle detection at CERN. In this context, the ALICE RPC muon trigger (MTR) has been operated for the first time with the new gas recirculation system built at the end of 2014 and commissioned at the beginning of 2015. The new system allowed to reach a 50% reduction of the R134a (C2H2F4) emission from ALICE-MTR. Further tests are ongoing to achieve a complete exploitation of the system with a target reduction up to 90%.

The team has been involved in the challenging gas leak search campaign of the experiments by participating to the tests and developing new systems allowing to reduce the gas consumption in the future. As an example, the ATLAS-RPC gas distribution modules have been equipped with a double level...
flow regulation. The system is designed to permit an automatic change of the gas flow in the detector distribution depending on the LHC beam intensity allowing a remarkable reduction of GHG consumption.

A long R&D study in laboratory has been completed and it confirmed the possibility to run prototype GEM detectors with gas recirculation (Ar-CO$_2$-CF$_4$ mixture). Following the positive result, the LHCb-GEM gas system has been almost completely dismounted and replaced with a new gas recirculation. Installation and commissioning of the new system has been completed early 2016. The improved gas system allows a 90% reduction of the CF$_4$ consumption. The initial important investment will be recuperated in the coming three years. Concerning another expensive and greenhouse gas, the CF$_4$ recuperation plant for the CMS-CSC detector has been operational all year long. A 30-40% reduction of the consumption was achieved during 2015.

The gas system infrastructure for the new Gamma Irradiation Facility (GIF++) was an important activity during 2015. The installation and commissioning of several gas system modules (gas mixing units, gas recirculation units, standard gas analysis and gas chromatographic analyser) have been fundamental for starting detector R&D activities in view of the future upgrades projects of the LHC experiments.

The gas team contributed to the CLOUD and NA62 experiments ensuring the maintenance, support to operation and new developments. In particular the NA62-CEDAR gas system has been completely re-designed (hardware and software controls) to allow operation with pure Hydrogen during 2016 run.

The EP-DT gas laboratory hosted a detector hands-on session of the ESIPAP School for master and PhD students: a setup based on RPC detector was used to show how the gas mixture composition can affect detector performance.

5.2.2. Development and construction of CO$_2$ cooling plants

P.Petagna (EP-DT-FS)

The commissioning of the two plants completed and installed in the experiments in 2014 has marked the year. The one for the ATLAS IBL has been commissioned with the detector in place and handed over to the EN/CV team, who will take care of its maintenance and operation. The one for the CMS PIX has been commissioned by shortcutting the connections at the detector level and adding suited dummy thermal loads in the circuit, and it is now ready to operate upon the detector arrival. For this cooling plant, the EP-DT-FS team will bear the direct responsibility for maintenance and operation, marking an important step in the transformation of the CO$_2$ cooling activity into an infrastructural service to the experiments. The commissioning activity has been rich in experience for the team: long distributed vacuum insulated tri-axial concentric transfer lines have been indeed used for the first time in both experiments, bringing in important new knowledge for future, more complex installations. Furthermore, the IBL case saw the first application of cold CO$_2$ evaporation in relatively long staves organized in “barrel” geometry with very small pipes, providing useful indications on the onset of boiling and its effect on the optimal performance of the detector.

The team also tackled a new request received from another experiment: the design and construction of the new CO$_2$ cooling systems for the upgrade of LHCb. During LS2, the experiment will see a major upgrade: this includes the complete reshuffling of the present Velo detector, passing from silicon strip modules to silicon pixel modules; and the installation of a brand new silicon subdetector, the Upstream Tracker (or UT). Both subdetectors require to be cooled at similar sub-zero target temperature, and for both CO$_2$ evaporative technology provides adequate performances in terms of mass and space minimization, thermal uniformity and low temperature set-point. Following the experience gained with ATLAS and CMS, it has been decided to design two coupled plants, each one dedicated by default to one subdetector, but still capable of cooling down efficiently both subdetector at the same time in case of need (e.g for planned maintenance interventions, or for unexpected faults of the other plant). This requires the design of two identical units, capable of 7 kW refrigerating power at a saturation temperature of -30 °C on the detector, interconnected and rapidly switchable. LHCb endorsed the
concept presented in the frame of an Engineering Design Review at the end of the year. The system is presently in the process of detailed design.

In the course of the year, at the request of both CMS and LHCb, the team has also launched the design of a new class of cooling units, conceived for testing and/or commissioning significant portions of detectors prior to their final installation, typically on a surface lab. Named “LUCASZ” for Light Use Cooling Appliance for Surface Zones, this new class of unit is based on the simplified 2-PACL loop already implemented with success in the units of the class “TRACI”. This allows for a fully automated operation with an extremely user-friendly interface, well adapted for non-expert users. The engineering design is presently being finalized, and the production of the first prototype of this new class is planned for 2016.

![Image of 2PACL CO₂ cooling plants for the ATLAS IBL (left) and the CMS PIX Phase-I upgrade (right) installed in the experiments' service caverns.]

5.2.3. Instrumentation and Controls


The Detector Interface section combines the EP-DT years-long expertise in control and safety systems for experiments’ infrastructure, with the introduction of the support for data acquisition and monitoring systems targeting small- and mid-scale experiments and projects. The long-term aim is to create a combined environment for controls and DAQ to be offered to the experiments requesting it. The 2015 activities all focus on control systems, but watch this space for 2016, to read about new projects and activities!

LHC Experimental Magnets

The DT group has carried out an intense maintenance, consolidation and upgrade program of the Magnet Control and Safety Systems (MCP) during the LS1. All these tasks were fully completed allowing a successful run for all experimental magnets after the technical stop. Despite the good behaviour of the equipment under DT responsibility two major problems were discovered during the last run in the superconductor magnets of CMS and ATLAS. In the CMS magnet a pollution inside the cryogenic circuit appeared, clogging the internal filters preventing to reach the nominal current for long time. In ATLAS C-Side End Cap Toroid a serious mechanical damaged was discovered in the current lead bellows of the magnet. Immediately, a precise repair campaign was put in place and executed during the 2015-2016 winter technical stop. The DT group has actively participated in this repair, monitoring and surveying the magnet instrumentation and vacuum health.

ALICE and LHCb magnets have been operated without any special event and equipped with the new Magnet Safety System (MSS2) version, proving its reliability for later deployment in ATLAS and CMS. To notice that this reliability and performance of the magnet is statistically measured according to the missed operation hours while STABLE BEAMS is present in the LHC. As example the following tables show the ATLAS Toroids and Solenoid magnet performance from beginning of the LHC operation.

42
<table>
<thead>
<tr>
<th>ATLAS Toroid Statistics</th>
<th>Run Time</th>
<th>Run Time</th>
<th>Missed Stable Beam</th>
<th>Counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total run time in total</td>
<td>Days</td>
<td>Hours</td>
<td>Hours</td>
<td>Ramp</td>
</tr>
<tr>
<td></td>
<td>973</td>
<td>23352</td>
<td>36</td>
<td>88</td>
</tr>
<tr>
<td>Average run time</td>
<td>11</td>
<td>265</td>
<td></td>
<td>82</td>
</tr>
<tr>
<td>Maximum run time</td>
<td>71</td>
<td>1707</td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ATLAS Solenoid Statistics</th>
<th>Run Time</th>
<th>Run Time</th>
<th>Missed Stable Beam</th>
<th>Counter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total run time in total</td>
<td>Days</td>
<td>Hours</td>
<td>Hours</td>
<td>Ramp</td>
</tr>
<tr>
<td></td>
<td>1074</td>
<td>25767</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td>Average run time</td>
<td>14</td>
<td>335</td>
<td></td>
<td>44</td>
</tr>
<tr>
<td>Maximum run time</td>
<td>72</td>
<td>1719</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

Atlas Toroids magnet operation statistics from beginning of the LHC operation.

Atlas Solenoid magnet operation statistics from beginning of the LHC operation.

Left, picture of a damaged ATLAS ECT-C current lead below; right, picture of the repair, where an outer below covers the damaged part.

Control and Safety for non LHC Magnets
In addition to the LHC experimental magnets, the DT group has successfully installed and commissioned the Magnet Control and Safety System for the COMPASS experiment and for the M1 magnet used for CMS test-beams with the new MSS2. The COMPASS collaboration took physics data from May to December 2015, while the final commissioning of M1 will occur in 2016.

Left, user interface of the COMPASS magnet control system; right, picture of the safety and control system of the M1 magnet in the SPS experimental area.
Control and Safety systems for WA105

N. Bourgeois (EP-DT-DI)

The WA105 collaboration, included in the CERN Neutrino Platform project, requested DT support for the production of the Slow Control system, which includes the DCS and safety system hardware and software of the experiment. A prototype system is being implemented to support the detector development as well as to assess the needs and prepare for the final system.

NA62 Detector Safety System

G. Maire (EP-DT-DI)

The Detector Safety System (DSS) is responsible for assuring the equipment protection for the NA62 experiment. The DSS requires a high degree of availability and reliability. It is composed of a front-end and a back-end parts. The front-end is based on a cRIO material of National Instrument, to which the safety critical part is delegated. The cRIO front-end is capable of running autonomously and of automatically taking predefined protective actions whenever required. It is supervised and configured by the standard CERN PVSS SCADA system. In NA62, the DSS system is required to check the temperatures of 40 electronic racks installed along the experiment in TCC8 and ECN3, the vacuum conditions to generate an interlock to the LAV HV controllers, the status of the radiation monitor, the level 3 alarms, the gas status to generate an interlock to the STRAW sub-detectors. Recently the DSS system has been updated to check the gas conditions in hydrogen mode for the CEDAR sub-detector, in case of bad conditions DSS generates an interlock to the KTAG HV&LV controllers.

The user interface to the NA62 Detector Safety System.
Support for other facilities
In addition the DT group has been involved in other projects and collaborations related to the instrumentation and control domain in the EP department: as an example, the DT group has been in charge of the design and construction of control and safety system of GIF++ irradiation facility at the SPS. Also, in the framework of DT Thin Film Lab agreement with the COMPASS experiment for the Thick Gem production of the RICH detector, a complete refurbishment of the Cesium iodate Evaporator for DT Thin Film Lab has been performed. This task consisted on upgrading the control system, instrumentation and the associated hardware to the new technologies.

5.2.4. B-Field mapping
F.Bergsma (EP-DT-DI)

This service provides magnetic field measurements and develops custom mechanical setups for precise B-field measurements of large magnets in experiments. The service maintains a considerable magnet park for precise calibrations and measurements in magnetic fields and specialized equipment.

In 2015, the production of 320 B-sensors, 220 for ATLAS, 100 for mappers and monitor systems (BELLE 2, MPD, sPHENIX) have been launched. In terms of equipment, a number of developments have been carried out to improve the accuracy and usability of the B-field mappers. For instance, a microprocessor board to control pneumatic motors has been designed and built. A prototype of a pneumatic piston engine was built, that consumes less air, is easier to build and is more robust. Improvements to the 3D-bench consist if adding a new ceramic head that can measure at 0.5 mm from the magnet surface + lightweight carbon fiber pole with TMD. A cylindrical bench for upcoming mappings of BELLE 2, MPD and sPHENIX has been built.

The magnet service area had visitors from ATLAS, CMS, EP-ESE and the Beams Department for a total of 69 days magnet time. Equipment was on loan for 222 days.
5.3. Engineering office
A.Catinaccio, P. Wertelaers (EP-DT-EO)

In the year 2015 the Engineering Section has covered over thirty activities and projects, a selection of which is briefly treated hereunder.

ALICE
A large effort in 2015 has been devoted to the prototyping of the stave for the ALICE Inner Tracker System (ITS), which includes the sensors’ connection to power and signal cable, their integration on the ultra-lightweight mechanical supports, and their final characterization. The Section has followed this activity with responsibilities on the mechanics of the different assembly phases and on the production of the carbon composite structures with an embedded cooling. We also developed the mechanical design of the ITS barrels and the overall installation sequence for the new LS2 central detectors: Inner Tracker System (ITS), Muon Forward Tracker (MFT), Fast Interaction Trigger (FIT), see figure below. The design of the insertion jigs and infrastructures, the verification of the new Central Detectors interfaces, and the new beam pipe layout, are but some of the tasks that have challenged the EO team.

ATLAS
The New Small Wheel is an array of Micromegas detectors of four types, and the CERN team is in charge of one. Detector assembly has been studied and tooling has been fabricated, allowing Module 0 to start at the end of 2015.
The Section is heavily involved in the development of the SLIM (A Stiff Longeron for ITk Modules) concept for the outer layers of the future ATLAS pixel detector. During 2015, the focus has been the development of a carbon-fibre composite truss structure capable of supporting up to four rows of pixel sensors, while meeting the stringent stability and mass requirements. A hybrid filament winding process was developed and initial prototypes built. They were then tested so as to validate the finite element models to be employed in the subsequent optimisation phase.

Top Left: Schematic representation of the SLIM concept for the future ATLAS Pixel detector; Bottom Left: Detail of a prototype of the carbon fibre reinforced plastic (CFRP) truss to be used as a support structure; Right: Deformation of the support structures due to own weight, obtained with a preliminary finite element model of layers 2 and 3.

CMS

The Section continues its contribution in the Group’s effort to the new Tracker, Phase-2 upgrade: development of the "2S" and "PS" modules for Inner Barrel, Outer Barrel, and Endcap Double-Disks; structure and services for Inner Barrel; general integration.

The Group has been involved in a penetrating rework of the power connectivity of the Pre-shower detector at its feedthroughs, ending a series of reliability problems. The Section has produced an alternative engineering concept for the "High Granularity Calorimeter", a huge silicon-pad-based array to be fitted onto the Endcaps of the Phase-2-upgraded CMS. We have also started to contribute in the Phase-2 upgrade of the Barrel ECAL.

General integration; CMS Phase-2 upgrade of Tracker.
**LHCb**

Mechanical and thermal design and prototyping has been done on the Upstream Tracker (UT) which will replace the current Trigger Tracker. The surrounding box has to provide easy accessibility to the detector internals, has to possess adequate stiffness, light tightness, electromagnetic shielding, and provide an acceptable cold-warm barrier. To this end, sandwich panels have been prototyped. They have carbon fibre composite skins with embedded copper netting, around a polymer foam core. Together with CERN’s Polymer Lab, the “UT plug”, a skirt of EPDM elastomer, has been developed, to provide interfacing to the beam pipe.

![Sandwich plates with skins of carbon fibre composite with a copper net.](image)

**NA62**

The Gigatracker (GTK), in operation since 2014, saw improved securing of services (cooling lines and electronics), and new tools for all fabrication steps. The Group has participated in the activities around the winter shutdown, among which interventions to the RICH, and various complicated leak tests.

![Sandwich plates with skins of carbon fibre composite with a copper net. Right: Compression test of plug. UT project for the LHCb upgrade.](image)
Studies for the CLIC vertex detector

W. Klempt (EP-DT-TP)

The group has been involved in CLIC (Compact Linear Collider) tracker detectors studies. The tracker is based on silicon strip detectors. Background from $\gamma\gamma$ to h and incoherent electron positron pairs require the strip lengths to be between 1mm and 10mm to achieve occupancies of $< 10^{-3}$. The activity in the group consisted to develop a first coherent conceptual design for the tracker, including supports, services and a convincing installation scenario. Also a support structure for the beam pipe and the vertex detector had to be included.
In the proposed design the tracker is actually divided into an inner and an outer part, separated by a rigid tube supporting the beam pipe. As can be seen in the figure below, the tracker includes in total 6 barrel layers 2*7 inner forward disks and 2*4 outer forward disks. The required spatial resolution is 7 µm and the overall thickness of one layer should stay below 1-2% X₀. First studies have shown that with cylindrical barrels made from a carbon fiber honeycomb sandwich structure one would achieve radiation length in the order of 2% X₀. This could be even reduced by the use of structural space frames made from thin carbon fiber rods. The design is based on monolithic silicon detectors with a size of 30mm*30mm. As shown in the bottom figure, these chips will be mounted to thin carbon fiber staves, with 4 rows of detectors, which in turn will then be fixed inside to the rigid barrels. One stave has the length of 1.5 m covering half of one barrel.

Fracture behavior of single-crystal silicon
An R&D program was launched into fracture behavior of single crystal silicon. Single-edge V-notched beam specimens were manufactured at EPFL -- using etching techniques -- and tested in bending. The measured fracture toughness was then used in advanced computational models -- J-integral -- in an effort to predict failure in single-channel silicon micro-devices subjected to internal pressure.

Top Left: Schematic representation of the four point bending test configurations used to characterize the fracture behavior of ScSi; Top Right: Variation of the fracture toughness with the mixed mode ratio measured experimentally with the SEVNB test specimens; Bottom: SEM images of the fracture planes obtained in a pure mode I test (left) and in a mixed mode I/II case (right).
Composite laboratory
The lab continued to provide training, and worked on its stock management. It received an autoclave, and a chemical dissolution bench under commissioning. Research is being done on alternative processes, such as liquid resin injection under vacuum (a variant of Resin Transfer Moulding). Furthermore, prototypes have been produced for CLIC, CMS, LHCb and ATLAS.

![Carbon staves for I-Beam project (ATLAS) produced in the DT Carbon Composite Lab.](image)

Neutrino LBNF Cryostats
The Section played a major role in the design of the 20-kiloton liquid argon cryostats for the future Long Baseline Neutrino Facility (LBNF). Analytical and numerical tools were employed to study the static and buckling response of the steel support structure around the cryostat vessel, and to ensure the compliance of the main connections with the relevant construction codes (i.e. ASME Div 2 and EuroCode3). These efforts lead to the successful completion of the Independent Conceptual Design Review, May 2015.

![Left, the new autoclave; right, resin injection under vacuum.](image)
Top: Schematic representation of the liquid argon cryostats designed for the future Long Baseline Neutrino Facility (LBNF); Bottom: Deformation of the steel support structure and detailed stresses in some of the main connections, obtained with finite element models.

Other
In support to Gaseous Detectors R&D, we have defined the mechanics and followed the manufacturing of the X-ray generator and of the optical time projection chamber, both with internal equipment. Various challenges had to be overcome: vacuum ports and optical windows, short circuit risks, high voltage, mechanical loads from vacuum and overpressure.

In support to the Fluidic Systems Section, DT-EO collaborated in the creation of the carbon dioxide cooling plant.
6. EU projects, representation in committees and working groups

EP-DT has been involved in the submission of proposals to Horizon 2020 (the EU Framework Programme for Research and Innovation). Currently, DT staff lead several workpackages and tasks in the large project AIDA2020\(^1\), continuation of the AIDA project (Advanced European Infrastructures for Detector and Accelerators): P.Petagna co-leads WP9: New support structure and micro-channel cooling; A.Mapelli leads Task 9.2: micro-channel cooling building blocks; M.Moll leads Task 11.1: Transnational access to the GIF++ and IRRAD facilities at CERN. E.Oliveri leads Task 13.3: Tools to facilitate the detector development. F.Ravotti leads WP15 Upgrade of beam and irradiation test infrastructure.

DT staff is also involved in BrightnESS\(^2\) Building a research infrastructure and synergies for highest scientific impact on ESS, and the Marie Curie network STREAM\(^3\) Smart Sensor Technologies and Training for Radiation Enhanced Applications and Measurements.

Staff from the DT Engineering Office hold key roles in the following EP- and CERN-wide engineering committees and working groups: Computer-Aided Engineering Committee (CAEC), Groupe d’Utilisateurs Catia-SmarTeam (GUCS), CAD Use in Experiments (CADEX), and Computational Structural Analysis Committee (CoSAC). DT-DI control engineers represent EP in inter-departmental working groups such as CNIC, GUAPI, Fieldbus, PXI, FESA.

7. Safety in EP-DT


During 2015 the group continued to increase the conformity of the machines tools reaching 94% of the EP-DT machine park (\~170 machines in total). In addition, following the conformity check of all the machines of the Micro-Pattern Technologies workshop in B102, a conformity action plan was started enabling to make conform the two-thirds of the park (\~60 machines in total).

A new machine has been procured for the lab in B153 (composite autoclave) increasing the level of service in full compliance with safety regulations.

In collaboration with the HSE Unit and EP safety office the documents GSI-SO-12 Workshop Supervisors defining the mission and scope of work of the Workshop Supervisors was finalised and published in November 2015.

A DT- TSOs’ support has been put in place in order to review with them all the safety recommendations for DT buildings and check their follow up and completion. This review included the infrastructure issues raised both by the HSE Unit and the TSOs leading to an EP consolidation request included in the SMB consolidation programme of work.

The new DT safety EDMS structure leading to building up the safety files has been put in place and is now under the feeding process collecting all related safety documentation.

---

\(^1\) http://aida2020.web.cern.ch
\(^2\) https://brightness.esss.se
\(^3\) https://stream.web.cern.ch
8. **Secretariat**

*V.Wedlake (EP-AGS-SE)*

The DT secretariat continued to provide administrative and secretarial support to the group and to the following experimental collaborations: NA62, RD50, RD51, CLOUD.

*Veronique Wedlake in the EP-DT secretariat in 166-R-010.*
9. List of selected Publications

C. Joram, G. Haefeli, B. Leverington, Scintillating Fibre Tracking at High Luminosity Colliders, 2015 JINST 10 C08005.

C. Joram et al., Irradiation of a 2.5 m long SciFi module with 24 GeV/c protons to the dose profile expected in LHCb, Public note LHCb-PUB-2016-001.


CAST Collaboration, New solar axion search using the CERN Axion Solar Telescope with He4 filling, PHYSICAL REVIEW D 92, 021101(R)

A. Dias et al., Analysis of temperature homogeneity of the CLOUD chamber at CERN, Symposium on Engineering Physics, Porto, Portugal, 11-13 June 2015.


R. Guida, M. Capeans, B. Mandelli, Strategies for reducing the environmental impact of gaseous detector operation at the CERN-LHC experiments, IEEE N2AP-36.


R. Guida et al., The ultra-pure water production system for the CLOUD experiment at CERN, IEEE2015 Conference Proceeding.


