This report gives a summary of the mandate, structure and activities of the EP-DT group during the year 2017.
In memory of Ferdinand Hahn, an enthusiastic and highly skilled colleague, and an openhearted friend, who passed away on March 4, 2018.

Ferdi joined the CERN Physics department in 1995 as member of the Gas Group in DELPHI. As section leader in TA1 and deputy group leader of the DELPHI detector unit, he perfected the operation of the many and complex DELPHI gas systems, while at the same time he structured the LHC gas working-group, an essential step towards a very professional and efficient development of common gas systems for all LHC experiment. After having led the Detector Technology group DT1 of the Physics department between 2007 and 2008, Ferdi was Deputy Group Leader of the DT group from 2008 to 2012. Already during this time he took over the technical coordination of the NA62 experiment. Without his considerable commitment and his great competence on the many experimental aspects, this experiment would probably never have reached its current excellent state. He was member of the DT group until 2015, when he became Deputy Department Head. Also in his new role he stayed in close contact with the DT group and supported our activities.

Ferdi was treasured as a close colleague by many; it was a pleasure to work with him. His open character and ready smile made it easy to discuss together, even when the discussion involved complicated issues. He was enthusiastic and full of energy, always ready to help. His friendly way of dealing with people was backed up by a deep competence in technical issues. He was one of a kind, and will be sadly missed.

http://ep-dep-dt.web.cern.ch
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1. DT Mandate and Organization

Burkhard Schmidt

The Detector Technologies (DT) group in the Experimental Physics department participates in the development, construction, operation and maintenance of particle detectors for experiments at CERN. The group is engaged in several detector projects for LHC and non-LHC experiments, 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 in the DT group. Among these are fine mechanics, engineering, micro-fabrication, thin film coatings, optics, a silicon facility with a wire-bonding and quality assurance 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 organized in three 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 deliverables (e.g. gas systems, CO₂ cooling systems, control and DAQ systems, B-field measurement, thin film coating), support for maintenance and operation, 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.

<table>
<thead>
<tr>
<th>Services</th>
<th>R&amp;D Projects</th>
<th>Joint Projects</th>
</tr>
</thead>
</table>
| 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 lab  

| Engineering office |  

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

- M&O and Upgrades of the LHC experiments  
- CLOUD, NA62, SHIP, Neutrino Platform  
- R&D for Linear Collider Detectors  

In 2017, about 45% of the staff resources were allocated to projects; about 50% of the group works in services activities and related R&D. Finally, about 4% 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.

**Generic R&D in DT**
- Clusters of expertise (R&D Projects), equipment, infrastructure and services for all experiments, providing important R&D for Upgrade projects.
- No WP are established.

**Services**
- Development and operation of infrastructures for experiments and detector R&D.
- Client-driven and available for all experiments at CERN.
- For M&O, WP describes the DT deliverables, cost of materials and PSU, and DT resources.
- DT resources are not accounted against a given experiment because they are considered common EP services.
  - Gas, Cooling, Magnets, DSF, TFG, MPT, Irrad, GIF++, Machining, Magnet support, Scintillator Lab, Composite Lab

**Projects**
- Collaborations with CERN teams in experiments to build detectors, usually covering the full project cycle (R&D, prototyping, construction, commissioning, M&O).
- WP documents the project, DT deliverables and resources.
- DT resources allocated to projects are assigned for a given period of time to the experiment's personnel budget code in APT.

**Management**
- GL and SL
- Safety roles

**Activities of DT Staff**

**FTE (Staff) in PROJECTS**

- FCC, 0.2
- SHIP, 0.7
- LCD, 1.8
- CLOUD, 0.8
- AEGIS, 0.2
- NA62, 3.1
- NEUTRINO Plat., 4.0
- ALICE, 8.95
- ATLAS, 6.3
- LHCb, 7.3
- CMS & TOTEM, 4.6
In 2017 the DT group had about 85 active Staff, 22 members who are Fellows, Project or Cooperation Associates, 15 members who are Doctoral or Technical Students and about 13 Trainees or participants to the Technical Training Experience (TTE) programme. Besides the staff, all other categories are partially funded through other groups. DT hosts also two Field Support Units (FSU PH-02 and PH-40) with in total 30 members.

The DT group structure was adjusted in the past years based on a competency-based organization, to reinforce the roles and capacity of the personnel and to avoid fragmentation of resources.

The present structure:

i) optimizes the support to the experiments in the phase 2017-2025, where LHC operation overlaps with demanding detector R&D and detector prototyping and construction projects for LHC upgrades and the preparation of new experiments and studies;

ii) enhances flexibility by providing centralized expertise to exploit specialist experience at its maximum potential in particular in the area of services;

iii) preserves and promotes current efforts on detector R&D and drives a culture of innovation of novel technologies and related infrastructures;

iv) build-up know-how and ensures successful careers of DT technical staff.

DT staff is currently grouped in seven 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. It 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: the departmental Silicon Facility with the wire bonding and interconnect facility, the 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 long lasting EP-DT expertise in control and safety systems for the infrastructure of experiments with the support for data acquisition and monitoring systems, targeting mainly 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 the core technologies of particle detectors at CERN.

The **Engineering Office** section is in charge of mechanical design activities for detector-related projects. Designers and engineers cover a wide range of disciplines in mechanical engineering, construction, and numerical simulation fields. The core competencies include 3D modeling and drafting, integration studies, structural and thermal analyses, fluid-dynamics and structural verifications according to relevant standards and codes.

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

Often, project work is carried out in 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 changes. The organigrams shown in pages 9 and 10 show the DT members as of October 1st 2017. The graph below shows the DT staff category composition.

![Professional Categories](http://ep-dep-dt.web.cern.ch)

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

Group leader: Burkhard SCHMIDT
Deputies: Andrea CATINACCI & Michael MOLL
Secretariat: Veronique WEDLAKE

Technology & Physics (DT-TP)
- Christian JORAM
- GYS Thierry
- MARTINENG Paolo
- PACIIFICO Nicola
- SICKING Eva
- WERTELERS Piet
- BRODSKI Michael (Fell)

Detector Development (DT-DD)
- Petra RIEDLER
- Silicon R&D
  - MAPELLI Alessandro
  - HONMA Akihiro
  - MCGILL Ian
  - MANOLESCU Florentina
  - MOLL Michael
  - BONNAUD Julien (Fell)
  - BRONZUZZI Tiziano (Doct)
  - CALVO Julio (Fell)
  - CARDELLA Roberto (Fell)
  - CENTI Matteo (Fell)
  - DIAS Pedro (TRNE)
  - BARG Timothee (CDAS)
  - GONZALEZ Joaquin (TRNE)
  - MATEU Jofre (TRNE)
  - OTERO Sofia (Doct)
  - SAMOTHRAMS Vasileios (Tech)
  - VENTURA Ana (TRNE)

Fluidic Systems (DT-FS)
- Paolo TROPEA
- PETAGNA (Cooling PL)
  - DAGUN Jerome
  - NOEL Jerome
  - VERLAAT Bart
  - ZWALINSKI Lukasz
  - BERRUTI Gaia (Fell)
  - BHANOT Viren (COAS)
  - BIERNACKI Anon (TRNE)
  - GIACOMONI Konstantina (Fell)
  - GORNIAK Patrycja (TRNE)
  - HELLENSCHMIDT Desiree (Doct)
  - INIGUEZ Noemie (TRNE)
  - LOPEZ MACIA Pedro (JIAS)
  - PAPAN Krystyna (TRNE)
  - RAPACZ Karol (COAS)
  - PIMENTEL Tiago (Doct)
  - SCHMIDT David (Doct)

Detector Interface (DT-DI)
- Giovanna LEHMANN
- PONS Xavier
  - BLANC Pascal
  - BOURGEOIS Nicolas
  - DERNER Laurent
  - OSTREGA Maciej
  - RAVAT Sylvain
  - BORETTI Marco (Doct)
  - GAMBERINI Enrico (Fell)
  - MALASSUTI Giulio (Fell)
  - RODRIGUEZ Manuel (TRNE)
  - SIPOS Roland (Fell)

Engineering Facilities (DT-EF)
- Hans DANIELSSON
- Thin Film & Glass
  - SCHNEIDER Thomas (PL)
  - DAVID Claude
  - VAN STENIS Miranda
  - FRANCHI Jonathan (Fell)

Micro-Patterning
- THOMAS DE OLIVEIRA Rui (PL)
- FERRY Serge
- GRS Alexandra
- MEHL Bertrand
- PIZZIBUSCO Olivier
- RANZIIN David
- RODRIGUEZ Alexis
- TEIXEIRA Antonio
- WILLIAMS Simon
- BONNAUD Rouch (Fell)

Machine Shops
- BODE Alain
- BREDINION Romain
- CANTIN Bernard
- KERUSEZ Zoltan

Magnets Support & Instrumentation
- BEGGSMA Felix (PL)
- GARNIER Francois
- GONCALVES Antonio

Composite Lab
- BONSBOURG Jean (Fell)
- GOMEZ Ruben (TRNE)
- NESS Korn (Tech)

Design room
- BÀUT Christophe (PL)
- DÉGRAIDE Jonathan
- JAMET Olivier
- LENORPHILIPPE
- PEREZ Alexandre

Engineering Office (DT-EO)
- Andrea CATINACCI
- UNIT1
  - BENDOTTI Jerome
  - DIXON Neil
  - DUMPS Raphael
  - KOTTELAT Luc
  - KRISTIC Robert
  - LOOS Robert
  - PIEDERGROSSI Didier
  - VERSAIN Marc
  - CICHLI Konrad (Fell)
  - FLENEUX Axel (Tech)
  - LEYPOD Eva (TRNE)
  - MANNEN Hana (Fell)

Detector Construction & Operations (DT-CO)
- ANSLEY Didier
- BOLIVIER Philippe
- IZERMANS Pieter
- LAHU Gregory
- LESENECHAL Yannick
- VAN BEELEN Jacob

FSU PH40: A Drozd, K Baran, F Bedendo, L Budun, T Budun, G Button, P Dubert, K Lauregul, B Martin, P Nguyen, E Pecaud, J Pereda, X Thery

Services
Projects
2. Collaborations with LHC Experiments

2.1. ALICE
Corrado Gargiulo

2.1.1. ALICE YETS activities

This end of the year technical stop (YETS) has been an opportunity for the ALICE Collaboration to perform preparatory works for the phase-1 Upgrade, which is targeted in LS2.

In particular, a delicate “cleaning” procedure was performed on the Time Projection Chamber (TPC). This operation will allow the TPC to be more efficient and afford higher collision rates in LHC Run 3. It is believed that this procedure will avoid the dark current, which have been observed in the TPC during high-luminosity tests performed in 2017.

Using endoscopic cameras, the TPC volume was explored from the inside and the presence of filaments of dust was detected, most likely cause of the parasitic currents. Because of the high voltage between the internal and external walls of the TPC containment vessel, flecks of dust that entered inadvertently get polarized and tend to form filaments standing on one wall – the cathode. When there are collisions, these filaments receive radiation and, as a result, emit electrons (in a continuous way), which cause additional (parasitic) currents that add to the normal currents through the resistor network of the central barrel.

By inserting small extractor tubes in the side holes of the TPC vessel, it was possible to remove some of the “dust”.

In order to test the effectiveness of the cleaning procedure in the absence of beam, during YETS, an X-ray tube was used. The correct amount of X-rays was calculated and applied in order to simulate the effect of the accelerator running at high luminosity. The test results after the cleaning shows encouraging improvements that suggest this is the direction to go, and a large cleaning procedure is being developed for the very first phases of LS2.

Various additional activities have been carried out in the ALICE experimental Cavern for LS2 preparation.
Examples are the preparation of LS2 cabling work in the cavern, cable trays, pilot cables, scaffolding and new air cooling duct installation, and ordinary maintenance of nearly all primary services (cooling, electricity).
2.1.2. ALICE Detector Upgrade

The ALICE upgrade programs entered in 2017 into the production phase. The ALICE upgrade strategy is based on the plans that, after LHC shutdown LS2 (2019 – 2020), the luminosity with lead beams will gradually increase to an interaction rate of about 50 kHz, about two orders of magnitude higher than the current readout rate capability.

In order to cope with the increased readout rate, the readout electronics of nearly all the ALICE detectors will have to be re-designed. The planned upgrades include a new beam pipe with a smaller diameter, a new Inner Tracking System (ITS), a vertex tracker for forward muons (MFT), the upgrade of the Time Projection Chamber (TPC) with GEM detectors, the upgrade of the forward trigger detectors and the upgrade of the online and offline system.

Beampipe

The new beampipe, is under production at Materion Electrofusion in Fremont, California. Production follow up is a close collaboration between the ALICE DT engineering team and the CERN Vacuum group VSC. Based on preproduction and tests VSC in 2017 decided to internalize at CERN the cleaning and etching process of the pipe in order to mitigate the risk related with NEG adhesion. This approach delays the delivery of the ALICE chambers on February 2019. With following VSC post-production inspections/coating and vacuum acceptance, it is expected to have the chambers ready for the installation by mid-2019. Contingency in this case is 6 months being the foreseen installation by beginning of 2020.

TPC

The production of large-size GEM foils at the EP-DT Micro-Pattern-Technologies workshop is advanced. The new TPC chambers equipped with the GEM foils will allow to cope with the high collision rate of the upgrade program. Their installation in the TPC, which will replace the existing wire chambers, will require to bring the TPC to the surface in the SXL2 clean room at P2. The EP-DT engineering team has worked in 2017 in close collaboration with the ALICE Technical Coordination to prepare jigs, infrastructure and the clean room as well procedures for the TPC de/installation from the cavern and installation in the clean room. Most critical steps of the entire process have been simulated on surface through full-scale tests. This has included simulation of TPC transport and handling on surface, simulation of TPC chamber replacement in the cleanroom. Detailed procedures have been prepared to guide the different delicate phases of the TPC rework.

ITS

The upgraded ITS will improve the track position resolution at the primary vertex by a factor of 3 in r-phi and even more in z with respect to the present detector. Monolithic pixel sensors and
special carbon fiber support structures realize the ITS upgrade as an ultra-light 7 layer/12GigaPixel detector that will allow a significant boost of the tracking performance.

**ITS Stave assembly at CERN and in five Stave Construction sites in EU and USA**

In 2017 the serial production of the staves has started. After a final optimization of the joining technique of the monolithic Silicon Chips to the Flex Printed Circuit, the stave assembly has started at CERN for the Inner Layers and at the five Construction sites in Europe and in the States for the Outer Layers. The ALICE DT technical team has a primary responsibility in the different assembly phases of the Chips with Flex Printed circuit. The DT Silicon Facility is providing a fundamental support in the wire bonding interconnection between the chip and the FPC, as well in the full characterization of the assembled staves.

The stave assembly relays on advanced serial production of Chips, under DT responsibility, and of FPCs, based at CERN for the Innermost layers. The serial production of the stave ultra-light carbon structures, spaceframe and cold plate, have been also based at CERN in the ALICE Composite laboratory, under DT responsibility. Several hundred units have been produced and production has arrived to completion in 2017.
The Detector Barrels Mechanics that supports in position the staves and the detectors’ services, as well as the large composite structure named Cage, that provides support and positioning of the Detector Barrels and beam pipe, have been produced. The mechanics of the Barrel for the ITS innermost three layers, was produced in the DT Composite laboratory in a joint effort with ALICE team. The ITS new cooling plant has also been produced by EN-CV, based on DT definition of requirements and specification. The cooling plant has been temporary installed on surface in the large clean room prepared at CERN for the ITS assembly and pre-commissioning phase of the ITS.

2.1.3. New Central Detectors and LS2 overall de/installation

The ALICE DT engineering team has the responsibility of the definition of the installation procedure of the new Central Detectors (Inner Tracker System, Muon Forward Tracker, Fast Interaction Trigger) and is working with the ALICE Technical Coordination at the finalization of the detailed procedure that will allow to extract the detector within a YETS time frame.
2.2. ATLAS Upgrade

2.2.1. Phase I: Micromegas for the New Small Wheel

Hans Danielsson, Rui De Oliveira, Francisco Perez Gomez

EP-DT-EF has been involved in the detector development and several activities related to the start-up of the mass production for the New Small Wheels (NSW) for ATLAS. Colleagues have been involved in the site certifications for the LM2 modules (one out four module types). The assembly tooling and assembly procedures were developed in the DT-CO and DT-EF sections for the LM2 chambers. The technology was transferred to the two assembly sites in Dubna and Thessaloniki.

*Manipulation of the panel assembly tool in Thessaloniki, which was developed and produced in EP-DT-EF*

A crucial step in the Micromegas production is the cleaning and high voltage validation. The Micro-Pattern Technologies unit has been deeply involved in the development of the Micromegas technology for the New Small in ATLAS but also in the procedure for cleaning in high-voltage validation. The activities also include participation in ATLAS-wide reviews and task forces related to the implementation of procedures and quality control of the production of Micromegas detectors for the ATLAS NSW.

*Cleaning of a Micromegas panel for the New Small Wheel in ATLAS. The teams at the different assembly sites have come to EP-DT-EF for training in cleaning and high voltage testing techniques.*
The involvement of the EP-DT group in the ATLAS Phase II Pixel Upgrade increased in 2018. The efforts of the group, and in particular those of the members of the EO section, focused primarily on the Outer Barrel, covering design, prototyping, and coordination aspects of the project. Following the recommendation of the Layout Task Force (LTF), an inclined layout was adopted for both the inner layers and the outer barrel of the future Pixel detector. The DT group, in close collaboration with the University of Geneva, continued playing a leading role in the mechanical design for the Outer Barrel. The optimization of the global structures and the local supports, which combine a carbon truss longeron with module cells devised to ease the re-workability of defective modules, progressed throughout the year (see figure below left). An integration concept for the Outer System compatible with the tight space and schedule constraints was also proposed. In addition, the EO section developed a new engineering concept compatible with the use of inclined quad modules in the second pixel layer, where flat cells equivalent to those used in the Outer Barrel are arranged in a half-ring configuration in order to reduce the heat path to semi-annular cooling pipes (see figure below right). A system of carbon fiber semi-cylindrical shells linked at various intermediate positions is used to mount the local supports and route the detector services towards the patch panels. The solutions described above were adopted by the collaboration as the mechanical baseline for the Pixel Technical Design Report, which was submitted in December 2017.

In parallel to the design work, the prototyping activities for the Outer Barrel continued within the framework of the Demonstrator Program launched at the end of 2016. The aim of this program, which involves more than twenty collaborating institutes, is to validate the main thermal, mechanical, integration and system aspects of the proposed local supports. A new, optimized version of the truss longerons featuring a full filament winding construction was developed and prototyped. This effort, which involved the conception and production of the corresponding tooling in house, resulted in the manufacturing of a number of short prototypes and culminated with the assembly of three 1.6m long longerons matching the geometry of the demonstrator (see Figure). Several trusses were equipped with cooling lines and populated with module cells to validate the proposed integration scheme.
At the same time, a significant effort was devoted to study the thermal aspects of the Outer Barrel design. A short prototype of the longeron populated with a reduced number of cells was successfully used to qualify the thermal figure of merit (TFM) of a new fixation system for the cells combining micro-screws and a graphite-based gap filler (see figure below, left). In order to simulate the power dissipation of the pixel modules, these cells were loaded with new, thin-film silicon heaters featuring embedded RTD sensors to monitor the temperature of the module at various locations. These devices and the corresponding flexible printed circuits used to power and read them, were conceived, assembled and calibrated at EP-DT. In addition, a simplified prototype employing a 1.6m long stainless steel pipe and a series of brazed copper blocks equipped with polyimide heaters to simulate the flat and tilted cells was used to demonstrate that the thermo-fluidic performance can be maintained along the full length of the cooling line for different azimuthal orientations (see figure below, right).

This activity also entailed the development of the necessary infrastructure to test the different thermal prototypes. Two new setups to test stave-like structures with lengths up to two meters under vacuum, including a new purpose-built readout system, were installed and commissioned in building 154. In addition, a setup to characterize the performance of thermal interface materials before and after irradiation was built (see figure next page). The later and a new improved version
currently under construction, are part of an ATLAS ITk-wide material qualification campaign launched and coordinated by EP-DT.

![Thermal test setups installed in Building 154 to measure the performance of Outer Barrel prototypes (left) and the conductivity of thermal interface materials before and after irradiation (right).](image)

In order to perform system tests and gain a better understanding of the serial powering scheme to be used in the future ATLAS Pixel detector, a short longeron prototype loaded with pixel hybrid modules using FE-I4 front-end chips was also assembled. This prototype, which in the future will be replicated at various collaborating institutes, is currently under testing in SRL using an environmental box designed and constructed by DT. The group, and in particular the Detector Interface section, also plays a vital role in the development of the FELIX readout which is employed in these tests.

### 2.3. CMS Upgrade

#### 2.3.1. CMS Tracker Upgrade

**Antti Onnela**

The CMS Tracker's Phase 2 upgrade is scheduled for installation during LHC LS3 in 2025. The DT group collaborates with the CMS team in the development and construction of the Outer Tracker, as well as Tracker's common items and integration. Corresponding collaboration agreement between DT and CMS is available in EDMS 1735474.

DT has a central role in the development of the 2S (strip + strip sensors) and PS (pixel + strip sensors) modules. The focus of DT’s contribution is in the development of the assembly techniques for these novel module types, as well as preparing and maintaining 3D models and 2D drawings of the modules’ mechanical assemblies. Those reference models and drawings are used throughout the Tracker upgrade project. In 2017 new module prototypes were successfully built at CERN and in collaborating institutes, proving that the module assembly concept is valid.

![The modules of the future CMS Outer Tracker are ‘sandwiches’ of two sensors back-to-back. These photos some of the precision tools developed in EP-DT for module assembly and handling.](image)
The tilted detector concept, developed by the DT and CERN CMS groups, has become the base-line choice for the central part of the Outer Tracker. The design reached sufficient maturity in 2017 to enable start prototyping of the tilted “Rings”, key structures of this novel detector concept. First full Ring prototype is to be ready and tested within 2018. Another field of support of the DT group was the production of high-conductivity carbon-fibre plates, used as stiffeners and heat-bridges in the prototype modules and structures. Close involvement of the DT composites lab was essential in these tasks.

A “Ring” is the main sub-structure of the detector with tilted modules, currently under development in the DT group. 72 such Rings are stacked together to form the central part of the future CMS Tracker.

Engineers and designers of the DT group prepare and maintain Outer Tracker project’s reference 3D models used for integration and services studies (cooling pipework and cabling). In 2017 substantial progress was made in this field and now the models cover to a large extent the main detector elements from the individual detector module level up to the general mechanical assemblies and services.

A key achievement in the CMS Tracker Phase II upgrade 2017 was the completion of the Technical Design Report (TDR) [Ref. 1]. A DT physicist and a DT engineer acted as editors of the modules and mechanics paragraphs of the TDR.
2.3.2. CMS High Granularity Calorimeter  
Eva Sicking

Using a similar calorimeter approach as proposed by the CALICE collaboration for CLIC and ILC, the CMS experiment will upgrade its endcap calorimeters for the HL-LHC phase with a highly granular sandwich calorimeter, the CMS HGCal (High Granularity Calorimeter). Once installed, the HGCal will have an active area of 600 m$^2$ of silicon sensors with 6 million individual readout cells and 500 m$^2$ of scintillator tiles with 400,000 individual readout cells.

Since 2016, members of the DT and LCD groups have joined forces with the CMS HGCal effort. In 2017 they have focussed on HGCal silicon sensor testing as well as on beam tests with HGCal prototypes. With the results from both activities the team has actively contributed to the HGCal Technical Design report that was submitted to the LHCC in December 2017.

A silicon sensor characterisation station was set up in the DSF clean room (186/R-E10) for qualification of up to 8-inch HGCal silicon sensors. Electrical measurements with multiple prober needles were pursued as well as measurements with a novel probe-and-switching-card system. This system was designed for an automatic and fast full-sensor characterisation in terms of leakage current and capacitance measurements up to a bias voltage of 1000 V.

![A hexagonal HGCal silicon sensor from an 8-inch wafer is tested in a probe station using a probe-and-switch card system.](image)

The Figure shows the test system equipped for tests of 8-inch HGCal silicon sensors, imbedded in a probe station. The results of these tests are used to identify optimal sensor production parameters for the final HGCal detector. Silicon sensors qualified by these tests were also used for module production and in beam tests.

As the HGCal will be exposed to a harsh radiation environment at HL-LHC, irradiation tests are planned for all sub-components. For the irradiation tests with silicon sensors, an extension of the test system was started in order to test sensors in a cold environment. Also a system to characterise the sensor properties is terms of noise and charge collection efficiency using full readout ASICs was developed.

Several beam tests with HGCal prototypes were carried out in the H2 beam in the SPS North Area. The tested prototypes comprised up to twenty 6-inch silicon sensor modules and were arranged...
in various configurations with different absorber stacks. The HGCal prototype was complemented by a CALICE Analogue-HCAL prototype based on scintillator tiles that was acting as backing calorimeter. Test beam data from minimum ionising particles, electromagnetic showers and hadronic showers were used to investigate the energy, position and timing resolution of the HGCal prototypes.

2.3.3. Silicon Sensor Development for CMS HGCAL and Pixel

Michael Moll

The Silicon Sensor Development activities in the framework of the CMS HGCAL collaboration concluded in 2017 with a significant input to the TDR on the radiation hardness evaluation of planar pad sensors based on the data taken in the previous years. The activities for the CMS High Luminosity pixel upgrade continued with the measurement of 230 μm thick fine pitch 3D detectors (strips, diodes and pixels) before and after irradiation. Tests were performed in the SSD laboratory and in test beam campaigns at the CERN-SPS (June) and at DESY (November). Further test beam campaigns at DESY in the beginning of 2018 are under preparation.

2.4. LHCb Upgrade

2.4.1. VELO Upgrade

Raphael Dumps, Alessandro Mapelli

The VELO upgrade detector will be made of planar silicon sensors with pixels of 55x 55 μm$^2$, increasing the granularity and consequently the spatial resolution. It will be readout at 40 MHz by a new radiation hard ASIC chip capable to handle the large radiation dose, 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 elements have to be redesigned such as the vacuum feedthroughs which consist of complex parts assembled in a very confined space. The feedthroughs will allow the routing of all the services in and out of the secondary vacuum volume.

In 2017, DT continued working on the design, fabrication and assembly of all the related mechanical parts. It also provided engineering support for the cooling, mechanics and integration. Moreover, the group is now in charge of the upgrade of the motion control system and it provides technical consultancy for the development of the silicon microchannel cooling plates. The testing of the microchannel plates is being performed in a DT lab with logistical support from the group for the CO$_2$ cooling plant.

The upgraded VELO detector consists of two halves with 26 modules each housed in a secondary vacuum around the beam. They are separated from the primary vacuum of the LHC by a thin RF foil (not shown in the drawing).
The Velo Upgrade Mechanical Module EDR took place in Manchester in September 2017. All the options for the integration and the cooling of the upgrade were reviewed. At the end of the review, the silicon microchannel cooling plates and the associated module concept were selected for the LS2 upgrade. Members of the DT group were strongly involved in the preparation of the silicon microchannel modules for this review. In particular, DT participated to the acceptance process of the first batch of cooling plates delivered to the LHCb by CEA-Leti. Within the QA/QC procedure, DT performed all the tests necessary to validate the bonding strength of each cooling plates. It has been shown that 200 µm wide micro-channels of the cooling plates hold internal pressures greater than 300 bars without failure.

2.4.2. Upstream Tracker

Joao Batista

The UT detector comprises four detection planes perpendicular to the LHC beam pipe. The detection planes are materialized by placing vertically and on a stereo angle (±5°) staves. These staves, that serve as a support to the silicon sensors, are a carbon fibre reinforced polymer (CFRP) composite sandwich. The staves are cooled down with two-phase CO$_2$ fluid at -25°C. The staves are enclosed in a thermal insulated box that also serves as the support to the detector components. This box, as the detector, is intersected by the beam pipe and is physically divided in two halves in order to allow the detector movement with respect to the beam pipe.

During the last few years, several members of the DT group have been working on the design of the UT box and integration of the UT detector and services. The design of the UT box and supporting frames was re-evaluated and some modifications were performed on the UT box and the frames that support the staves to the box. These modifications were driven by the new alignment requirements and position of the UT staves. The manufacturability and alignment of the staves also played a critical role on the new design. Thermal tests have been performed on a prototype of the UT Box. These tests have been key to understand the heat flux through the box thermal insulation. These tests have been also used to assess the risk of condensation on the box and to validate the analytical heat transfer calculations used to design the UT box.

DT members have also been involved in the design of the water cooling system required to cool down the UT electronics; i.e. the peripheral electronics (PEPI) and service bays electronics (SBC). DT is also responsible for the mechanical design of the SBC.
A preliminary assembly scenario the UT detector on the surface and underground was performed in order to identify the timeline, manpower and equipment needs for such activities. DT group members have had an important and leading role on the design of several parts for the UT detector and the detector integration.

2.4.3. Scintillating Fibre Tracker

Christian Joram

For the LHCb SciFi tracker project the year was marked by full-steam construction at all fronts. The SciFi tracker with 340 m$^2$ active surface will, from LHC Run 3 onwards, replace the currently installed Outer Tracker (based on gas straw tubes) and Inner Tracker (Silicon microstrips) by a single detector technology. The detector consists of 3 tracking stations with 4 independent planes each (X-U-V-X, stereo angle ±5°) and extends over 6 m in width and 5 m in height. Blue emitting scintillating plastic fibres of 250 μm diameter are arranged in a staggered close-packed geometry to 6-layer fibre mats. The mats are 2.5 m 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).

In addition to the responsibility for the procurement and quality assurance (QA) of the scintillating fibres, CERN started to play an increasing role in the preparation of the site and tools for the assembly and testing of the so-called C-frames, the mechanical structures which will carry the active elements and their services.

In 2017 the quality of more than 7000 km of fibres was validated and their geometry refined, a process also known as bump shrinking. The fibre supplier perfectly respected the delivery schedule (300 km every 2 weeks) and our 4-persons team managed to keep the pace thanks to a semi-shift mode. At the end of the year, it was decided to use an option in the purchase contract to order additional 1000 km of fibres, which will serve as spare material in case of unforeseen damage or losses during the production and assembly process.

The fibre scan team in autumn 2017

In phase with the fabrication of the detector components, the conception and design of several services were launched. The Detector Interface section of our group accepted the commitment for a vacuum system to guarantee the insulation vacuum of the coolant transfer lines and the so-called Novec manifolds. Furthermore, the DT gas systems team is involved in designing and building a dry
gas system, which prevents condensation and frosting on the SiPM photodetector arrays, which will be kept at a temperature of -40°C.

The R&D work on a novel type of scintillating fibre, called NOL (nanostructured organosilicon luminophores) was continued and the first results published in the Journal of Instrumentation. We seem to have developed the currently fastest fibre in the world. Unfortunately, the initial goal of higher light yield hasn’t been achieved yet.

From a management point of view, three items were in the main focus: (1) following up the production of a multitude of components and ensuring their timely delivery and testing, (2) the definition of the various services like SiPM cooling, electronics cooling, dry gas flushing, bias voltage, etc. and (3) the organisation and preparation of the assembly process at point 8. The CERN team is involved in the new work package dealing with the assembly and testing of the C-frames in a new assembly hall (B3852) at point 8. Since mid-2014, a DT group member acts as deputy project leader of the SciFi tracker.

2.4.4. RICH and TORCH

Thierry Gys

During the year 2017, the LHCb-RICH detectors have been running smoothly. Whenever required, the DT group has carried out the usual maintenance activities. A HPD re-processing campaign (25 units) started in February 2017 was completed at the end of the year. All re-processed HPDs, implementing getter strips, continue to show stable behaviour. Two HPD maintenance campaigns have been carried out in January and March 2017 in which 6 degraded HPDs from RICH1 and 10 degraded HPDs from RICH2 have been replaced.

Two SPS beam test campaigns in the H8 beam line have been successfully carried out in June and October 2017 with a test vessel designed, manufactured and upgraded by DT. The system included the latest versions of basic RICH upgrade units, including MaPMT photodetectors and dedicated front- and back-end electronics. Additional QE measurements of 1” and 2” MaPMTs used in the above beam tests have been performed in the laboratory. System tests of MaPMTs with LHCb upgrade readout electronics have been pursued.

*Photon Detector Module with 16 PMTs (left), together with a radiator lens and a readout electronics board in the H8 beam line (centre). The right figure shows a Cherenkov ring from 180 GeV/c pions.*
Within the framework of the ERC TORCH project, activities have been ongoing with extensive tests of final MCP prototypes and dedicated multi-channel readout electronics instrumenting a small-scale TORCH prototype. This prototype has been tested in one beam test campaign at the PS in November 2017 with an experimental setup complemented with an AIDA beam telescope. This campaign resulted in improved data taking rate and TORCH performance. MCP ageing tests are ongoing on MCP prototypes with extended lifetime.

2.4.5. Muon system
Burkhard Schmidt

Modifications to the beam plugs under the Hadron Calorimeter (HCAL) and Muon 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 are foreseen for upgraded detector. Simulations studies have shown that the particle flux in the innermost region of station M2 is reduced by 60% through a better absorption of shower particles in the proposed shielding. An EDR took place in January 2017, in which the design and installation of the new beam-plugs and the additional shielding has been reviewed. The Work Package Procedure (WPP) for the installation of the new beam plugs and shielding and have been prepared and reviewed in 2017 and the production drawings have been finalized. The order for the will be placed this year in view of a flexible installation of the new shielding in LS2. A DT group member follows the project and continues to act as deputy project leader for the Muon System.

Design of the new beam plugs for HCAL and Muon station M2 and the additional shielding behind HCAL. Parts to be produced in tungsten are shown in red, while parts in grey are made of lead. The green part (behind M2) will not be renewed.
3. Collaborations with non-LHC experiments

3.1. CLOUD

Antti Onnela

CLOUD main activity in 2017 was the CLOUD12 beam-run. This 3 months run was successfully completed and focused in three topics:

a. marine nucleation & growth involving iodine compounds
b. pure biogenic nucleation & growth under realistic environmental conditions
c. anthropogenic nucleation & growth under polluted urban conditions.

In addition, pure sulfuric acid growth measurements complemented data obtained in earlier CLOUD runs.

DT contributed to the experiment by an engineer acting as the CERN CLOUD team leader, CLOUD experiment’s resource coordinator and Safety officer, by a technician providing support to the experiment’s maintenance activities and to visiting scientific teams, and by the DT gas team adapting and maintaining CLOUD’s gas systems. CLOUD’s EU-funded Marie Curie program had ended in 2016, leading to a difficult manpower situation at CERN. The situation was substantially facilitated by a CERN research fellow joining CLOUD in autumn 2016 and the allocation of a CERN applied fellow position for CLOUD as of January 2017.

During CLOUD runs, typically 3-4 months per year, the population of the CLOUD contributors increases at CERN from few persons to several tens. Daily “3 o’clock” run coordination meetings gather the participants to discuss the results obtained through the past 24 hours and plan the next measurements.

Several enhancement projects were executed by the CERN CLOUD team in 2017 in order to enable the CLOUD Facility to meet the goals of the CLOUD12 (2017) and CLOUD13 (2018) runs. These projects concerned in particular the light sources and gas systems, as well as CLOUD’s central DAQ. In addition, since air ion measurements are critical for every CLOUD run, it was decided to procure and install a permanent NAIS (Neutral cluster and Air Ion Spectrometer) and a CIC (Cluster Ion Counter) into the CLOUD Facility. Detail design and planning work started in close collaboration with the EN-EA group to prepare CLOUD for the PS East Area renovation due in 2019-2020 and during which the T11 beam area and the CLOUD instrument platforms will be substantially modified.
3.2. NA62
Hans Danielsson, Giovanna Lehmann, Alessandro Mapelli

3.2.1. Operation and Maintenance

The NA62 experiment at CERN SPS is designed to measure the branching ratio of the $K^+ \rightarrow \pi^+ + \nu\bar{\nu}$ and another year run is scheduled in 2018. The analysis of the 2016 data shows that the decay-in-flight technique of NA62 to study \( K^+ \rightarrow \pi^+ + \nu\bar{\nu} \) works.

DT is heavily involved in the NA62 experiment e.g. in the Technical Coordination, the straw detector, the Giga Tracker and the DAQ/DSS systems. In 2016 major leaks were discovered on the LKr calorimeter. They were repaired in 2017 and a set-up was built to measure the life time of the newly acquired 400 l of liquid Krypton which will be added to the LKr calorimeter storage. The device was constructed in collaboration with TRIUMF and TE-CRG-CI. The device will be able to detect impurities down to the PPB level.

Set-up to measure the lifetime of the drift electrons and purity of the Krypton for the LKr calorimeter.
EP-DT-DI has continued supporting the NA62 DAQ and DSS systems in 2017. A new 10/40 Gb/s network has been installed and commissioned in collaboration with IT-CS during the winter shutdown and a configuration management tool has been introduced for the system administration of all the DAQ hosts. The consolidation of the DAQ software has continued, with particular emphasis on the data storage and transfer to CASTOR as well as the development of tools facilitating error diagnostic: services and tools supported by CERN IT have been introduced for better long-term maintainability and support.

The Detector Safety System has been updated on request, to include additional equipment (such as an additional CEDAR rack). In addition a roadmap has been prepared to improve and consolidate the DSS software during LS2.

An example of improvements carried out on the storage of data files in 2017. The plot shows the number of problematic data files (either duplicated files for a same run/burst or files without a correct timestamp) as a function of time.

3.2.2. GigaTracker module preparation

In 2017, six GigaTracker (GTK) detectors, namely GTK#10 to GTK#15, have been assembled and tested as foreseen by the work package between NA62 and DT (EDMS 1738693). Three of these detectors are foreseen to be installed early 2018 in the beam line and they will be operated during the physics run. The other three will remain available as spare.

The fabrication process of silicon microchannel cooling plates at CEA-Leti has been optimised in close collaboration with DT. The cooling plates are now fabricated with SOI wafers instead of bulk silicon wafers. The oxide layer embedded in SOI wafers allows to precisely control the thickness and uniformity of the cooling plates. 75% of the production of this new type of cooling plates has been delivered to DT in 2017. The first cooling plate of this batch was used to fabricate GTK#15 which will be installed in the third station for the 2018 physics run.

In December 2017, CEA-Leti circulated a press release to more than 30 journals about the GTK cooling plates entitled Leti Develops World’s First Micro-Coolers for CERN Particle Detectors¹. It

¹ [https://goo.gl/QKpmnQ](https://goo.gl/QKpmnQ), [https://goo.gl/f7v3kR](https://goo.gl/f7v3kR), [https://goo.gl/nXRpjR](https://goo.gl/nXRpjR)
highlights the innovation brought by such silicon microfluidic cooling plates to on-detector thermal management systems and integration.

The three GTK stations of the NA62 experiment

3.3. ISOLDE
Hans Danielsson

EP-DT-EF gives technical support to ISOLDE since 2017. The Figure below shows the new solenoid magnet in ISOLDE equipped with a dedicated measuring bench for B-field mapping. EP-DT-EF are working on a number of projects within ISOLDE and gives technical support to several of the experimental set-ups. In particular, work has been carried out on two ERC-funded experiments: beta-drop NMR and MIRACLS, with the ISOLDE decay station and solid state experiments. Numerous pieces have been produced for these experiments and technical assistance was given on the structure for the fourth cryo-module for HIE-ISOLDE. The activities at ISOLDE for 2018 involves mechanical support and consultations for projects such as the reconfiguration of the GLM/GHM area in cooperation with the EP safety team.

The B-field mapping of the solenoid in ISOLDE was carried out using a dedicated measuring bench developed in EP-DT-EF.
4. R&D Projects

4.1. The LINEAR COLLIDER DETECTOR Project

Eva Sicking

The Linear Collider Detector (LCD) project focuses on detector R&D for future e+e- collider projects at the energy frontier. In 2017, members of the DT and LCD groups worked together on ultra-low mass vertex and tracker detectors for the Compact Linear Collider (CLIC) as well as on highly granular calorimeters.

4.1.1. R&D for the VERTEX and TRACKER detectors

In 2017 the group continued to work on cooling systems for the vertex detector and on lightweight support structures for the vertex and tracking detectors of CLIC. In the context of the CLIC vertex detector R&D, the work focused on validating the concept of air cooling optimized for very low material budget. Double-sided dummy vertex detector staves as shown in Figure 2 were produced using thin silicon modules with resistive aluminum traces as heat loads, glued to low-mass CFRP supports and connected with conductive adhesive to Kapton flex cables with integrated temperature sensors. The staves were installed inside a CLIC vertex detector mock-up to test the cooling power of spiral air flow with realistic heat loads.

The work on the tracking detector consisted of the further development and optimization of its layout in preparation for physics simulations as well as prototyping of a large light weight tracker support structure.
4.1.2. **R&D for highly granular calorimeters**

Members of the DT and LCD groups work together with the CALICE (Calorimetry for Linear Collider Experiments) and FCAL (Forward Calorimetry) collaborations on highly granular calorimeters for future linear colliders.

In 2017, the work focused on preparations of FCAL beams tests scheduled for 2018. For this purpose a system to test FCAL silicon sensors prior to module assembly has been developed. The test system is based on the concept of the CMS HGCal probe-and-switch card test system for silicon sensor testing described in Section 2.3.2. Probe cards and mechanical infrastructure for the tests of FCAL sensors were designed and produced. First measurements are planned in 2018.

4.2. **NEUTRINO PLATFORM**

4.2.1. **Engineering studies for the Neutrino Experiments**

*Andrea Catinaccio*

During the 2017 period, the EO section has completed the design and calculation phase for warm structure of the Long Baseline Neutrino Facility (LBNF) liquid argon cryostats. The task has entailed a substantial contribution of four engineers and a senior designer in the section, covering all design iterations needed to fulfil the requirements evolving during the previous years and the course of 2017. The final design proposal, fully documented by CAD models, code verifications and FEA calculation reports, went successfully through the Final Design Review with Fermilab in August 2017 at SURF (Sanford Underground Research Facility) in South Dakota (US).

![Final Design of the LBNF cryostat warm structure (exploded view)](image)

On that occasion, the EO team had also the opportunity to visit the impressive SURF underground facilities, in what was the original gold mine at 1500 meters underground, and where excavation work has now started for the first access tunnel leading towards to the huge complex of underground cavers for the four LBNF cryostats.

Support to the LBNF project continued after the review on qualifications, testing and manufacturing engineering aspects. The first prototype of the rib-reinforced warm membranes went successfully trough the test done at CERN under the impressive load of above 150 tons.
The EO team (left) at SURF facility, 1500 m underground.

Load test of the rib-reinforced warm membrane prototype under 150 T

The manufacturing of the full-scale prototype connections has been launched for the planned ultimate load testing at the civil engineering laboratory of the University of Coimbra. Analysis was performed to validate the manufacturing solutions proposed by the company, weld procedures, qualifications and specification for pre-load bolts at low temperature.

4.2.2. DAQ, Control and Safety systems

Giovanna Lehmann Miotto, Xavier Pons

2017 has been a very busy year for the DT-DI section, for the construction of the computing infrastructure, the DAQ, the control and safety systems of the ProtoDUNE. In addition, support has been provided for the preparations and operations of the control system of WA105, which had been constructed previously.

NP04 DAQ

2017 has been the year of the bulk development of the DAQ system for NP04, after its successful design review in November 2016. The DAQ is designed to be able to sustain a readout throughput of ~450 Gb/s and to store triggered and compressed data at up to 3 GB/s.
Besides being charged with the overall DAQ project co-ordination, the DT-DI section took responsibility for:

- defining the DAQ network architecture,
- benchmarking and choosing the data storage hardware (0.5 PB, with up to 5 GB/s write performance with concurrent reading),
- designing and implementing the run control system (based on the JCOP framework),
- designing and implementing the FELIX based readout system and integrating it into the overall dataflow system,
- putting in place tools such as the electronic logbook (courtesy of ATLAS TDAQ) and the collection, archiving and visualization of log messages and operational metrics data.

At the end of summer, the core elements of the DAQ had been put in place and the system was connected to the NP04 cold-box setup, in which each detector component is readout and validated at low temperatures before installation into the cryostat. The DAQ chain was used since the first cool-down in October for the readout of the Photon Detectors in the cold-box, while the TPC wire readout remained largely in standalone mode for the initial tests, using only the DAQ hardware infrastructure. Stable readout of the TPC wires was achieved through the DAQ chain by the end of 2017.

The NP04 DAQ system is meant to be operated continuously for cosmic rays data taking and on a charged particles beamline from the second half of 2018.

**NP04 Control and Safety Systems**

In 2017 DT-DI installed the infrastructure and started populating the racks of the detector control (DCS) and safety system (DSS) for NP04. The first steps were the deployment of the transformer and the rack that decouples the detector and its control system from the building ground and the installation of the racks and electrical distribution for the experiment in EHN1, at the beginning of summer. This was followed by the preparation of the control system for the NP04 cold-box, together with the development of an ad-hoc control system for its cryogenic installation.

![Different stages of the infrastructure construction for the NP04 detector control system: installation of the racks (left); commissioning of the control system for the cold-box cryogenic plant (right).](image)

In parallel, work continued for the preparation of all the components of the NP04 DCS and DSS: external signals (cryogenics, fire, oxygen deficit) and interlocks for the DSS were defined, the layout of equipment in the racks established, the electronics for the control and monitoring of heaters on the detector flanges and fans in cold electronics racks was designed, a multiplexed readout system for hundreds of temperature sensors was developed, the supervisory layer for the control of power supplies was put in place and the overall control architecture was established. Last but not least, a basic web interface allowing to monitor the NP04 cryostat and detector status was prepared.

The bulk installation and connection of the DCS and DSS systems are scheduled for spring 2018, to be ready for commissioning of the experiment in spring-summer.
WA105 and NP02
The control system implemented by DT-DI in collaboration with ETH in the previous years was used during data taking in 2017. In parallel, work started in order to finalize the implantation of the NP02 DCS and the proximity DAQ racks in EHN1. The schema for the electrical distribution was prepared, similarly to the one of NP04. The development, installation and commissioning of the DCS and DSS for NP02 have been deferred to 2018. Both the NP02 and NP04 cryostats’ insulation spaces are being continuously monitored since autumn 2017 through a PLC based readout system of a network of PT100 sensors developed by DT-DI on request from the NP.

Installation and commissioning of the computing racks.
Computing infrastructure
DT-DI took the responsibility of defining the needs for the bulk computing infrastructure in the EHN1 extension, agreed with CERN/IT on the network architecture, and took care of the specification and selection of the water-cooled racks. It worked hand-in-hand with the NP technical coordination that manages the whole site and provides the civil engineering, mechanical and
logistics support, as well as guaranteeing the timely delivery of the required services (water and power). DT-DI participated to the connection and commissioning of the services for the racks with EN/EL and EN/CV, as well as taking care of the installation of the complete computing equipment in 18 racks, distributed over two barracks. Last but not least it developed a control and safety system to protect the material from cooling failures. The installation was completed in June 2017.

4.3. Search for Hidden Particles: SHiP

Piet Wertelaers, Burkhard Schmidt

The SHiP Experiment is a new general-purpose beam dump facility at the SPS to search for hidden particles as predicted by a large number of recently elaborated models of Hidden Sectors, which are capable of accommodating dark matter, neutrino oscillations, and the origin of the full baryon asymmetry in the Universe. Specifically, the experiment aims at searching weakly interacting long-lived particles, including Heavy Neutral Leptons – right-handed partners of the active neutrinos – and light supersymmetric particles. The high intensity of the SPS and in particular the large production of charm mesons and photons with the 400 GeV beam allow accessing a wide variety of light long-lived exotic particles of such models and of SUSY. Moreover, the facility is ideally suited to study the interactions of tau neutrinos.

The intended setup of the SHiP Experiment presents unprecedented engineering challenges, for which the EP-DT group provided support since 2017 in form of an engineer, who worked in particular on the SHiP Spectrometer Tracker (SST) region. The SST consists of a 4-station straw tracker embedded in a vacuum chamber and a dipole magnet, as shown in the figure, with an acceptance of about 5m (laterally) by 10m (vertically). The engineering design of the vacuum tank, spectrometer portion, and its interfacing to the straw stations, to the upstream decay tank, and to the magnet and the exit endcap, is a challenging task on which work will continue in 2018.

Overview of the SHiP experiment
5. R&D ON EXPERIMENTAL TECHNOLOGIES

5.1. Radiation Tolerant Silicon Detectors

Michael Moll

The Solid State Detector (SSD) lab of the EP-DT group participated in the framework of the RD50 collaboration and the CMS HGCAL and pixel upgrade projects in R&D activities related to silicon sensor developments. Within the RD50 collaboration (60 institutions, 350 members) EP-DT participated in the research on radiation tolerant silicon sensors for the vertex and tracking detectors for the luminosity upgrade of the LHC and beyond. EP-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 progressed in all four research lines: “Defect and Material Characterization”, “Detector Characterization”, “New Structures” and “Full Detector Systems”. While the overall RD50 research program kept its wide scope, the fields subject to most intensive studies remained 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 several $10^{17}$ particles/cm$^2$.

In close collaboration with the LHC experiments upgrade teams the implementation of RD50 developed technologies, like 3D sensors and in particular sensors based on p-type substrates, have been further consolidated and optimized. A workshop was organized together with the LHC experiments to review the radiation damage in the presently operating experiments and validate radiation damage models developed within the RD50 collaboration. The most intense research field became the development of precision timing detectors for pile-up mitigation. The promising RD50 results obtained with the Low Gain Avalanche Detectors (LGAD) technology have already pushed this new technology into the LHC experiments. CMS-TOTEM CTTPS has installed the first layers of LGAD sensors and ATLAS Forward Proton (AFP) is considering this option. For the HL-LHC upgrade, LGAD sensors are the baseline for the ATLAS High Granularity Timing Detector (HGTGD) and the CMS MIP Endcap timing layer. Silicon-based precision timing detectors are thus a very essential detector component for future experiments and at the same time a hot research and development field. RD50 has initialized this technology and pushed it within only 5 years from the first design to first operation in an LHC Experiment.

The CERN RD50 team in EP-DT (SSD team) was involved in several of these research activities, including the characterization of CMOS sensors, the development of new laser based device characterization techniques and the topics discussed in the following.

Left: Two test detectors of 2.5 x 2.5mm$^2$ size; front and backside are visible; a cavity is etched into the backside to remove the substrate layer and thin the device down to 50 µm. Right: acceptor removal parameter as function of acceptor concentration. The data on epitaxial silicon (EPI) are originating from this work.
**Acceptor Removal:** The in-depth study on the acceptor removal effect was continued. This effect is responsible for the loss of gain in LGAD sensors for timing and the radiation induced increase in charge collection efficiency in the bulk of CMOS sensors aiming for fully monolithic devices. Dedicated test structures with 50 μm thick epitaxial p-type silicon layers were produced, irradiated with protons and neutrons and characterized. A new improved parameterization of the acceptor removal effect was obtained (see Figure above), while the full understanding of the effect in terms of the underlying microscopic defect reactions is subject to further studies in 2018.

**Nitrostrip:** The influence of nitrogen on the radiation hardness of silicon sensor is under investigation within RD50. Microstrip sensors and pad diodes were realized using nitrogen rich float zone silicon. Identical structures were produced also on magnetic Czochralski, standard and oxygen rich float zone silicon to provide a comparison. In 2017 an extensive irradiation campaign was conducted on the produced sensors constituting to about 10% of the devices irradiated at the IRRAD facility in 2017. The irradiated devices will be characterized in 2018, including charge collection measurements using the ALiBaVa setup of the SSD lab.

**LGAD and APDs for precision timing:** Low Gain Avalanche Detectors (LGADs) and Avalanche photodetectors (APDs) are devices with internal gain that can be used in the measurement of time of arrival of minimum ionizing particles (MIPs). The APDs studied within the SSD team are produced by RMD and have a gain of about 500 at 1800 V. The uniformity of response of large area devices (8x8 mm²) was improved by applying a metal layer on their surface. The metallization was optimized in collaboration with a team member and carried out at CMi-EPFL (see Figure below). Devices with an active area of 2x2 mm² were irradiated with neutrons. The jitter before and after irradiation was measured using the TCT setup of the SSD group and is displayed in the right Figure, giving a timing precision of down to 9 ps. Furthermore, several LGAD devices, including the newly developed inverted LGAD, were characterized and measured. The Two-Photon-Absorption (TPA) TCT technique developed in collaboration with Spanish teams from Santander, Seville and Bilbao proofed to give much better data then the standard edge-TCT method.

**Device simulation:** For fast and efficient fitting of damage parameters a new software was developed in the SSD team to overcome shortcomings in computing speed of commercial TCAD software packages. The TRACS (TRAnsenst Current Simulator) software is C++11 based and has been made available to the public under a free software license (LGPL v.3) in 2017. In 2018 the software was extended with a data fitting module that allows to reproduce the space charge distribution in irradiated sensors by fitting edge-TCT data sets.
5.2. CMOS Pixel R&D

Petra Riedler

The activity on R&D for pixels in DT is focusing on developing generic large area pixel modules for future detectors, building on the experience of current projects. Main focus is to study the construction of pixel modules with large area coverage.

First large area, radiation hard CMOS prototype sensors have been designed and produced together with the CERN ATLAS Team, the STREAM Marie Curie Innovative Training Network and EP-ESE as option for the ATLAS ITK outermost pixel layer. The joint development aims at radiation hard (10^{15} \text{n}_{\text{eq}}/\text{cm}^2) and fast (25\text{ns}) CMOS sensors for pp-collisions at HL-LHC. The sensors were designed in a 0.18 \text{um} CMOS process provided by TowerJazz and were delivered from the foundry a few months ago. The wafers contain two pixel chips (MALTA, MONOPIX) as well as a number of small test chips and structures. MALTA and MONOPIX are 2 x 2 cm\(^2\) and 2 x 1 cm\(^2\) large, respectively. The chips are produced in a modified process in the foundry, originally explored for the ALICE ITS project to enhance the radiation hardness. The readout of both chips is compatible with the requirements of the outer pixel regions of ATLAS. First results from MALTA and MONOPIX are very encouraging based on tests carried out in the lab and at the ELSA testbeam facility in Bonn, Germany.

Together with the CMOS wafers, a set of pad wafers was produced by the foundry which is available for post processing and interconnection tests. The first wafers have been diced and thinned to 100 um and were mainly used for bonding tests. In a next step the special feature of the MALTA chip which allows to transfer data directly from chip to chip will be explored by directly bonding between two MALTA chips. Further interconnection and module assembly tests are underway.
5.3. Micro-Pattern Gaseous Detectors
Florian Brunbauer, Eraldo Oliveri, Leszek Ropelewski

The EP-DT Gas Detector Development (GDD) team is focused on research and development on gaseous detectors. Our research is exploring different technologies and applications. Current activities are normally based on Micro Pattern Gaseous Detectors (MPGD). The group plays a major role in the coordination and consolidation of RD51 collaboration, dedicated specifically to promotion and development of these technologies. A few examples of R&D lines and achievements in will be described: precise and fast timing with micromegas, optical readout for GEM detectors and neutron detection. The latter research line is done in collaboration with the European Spallation Source (ESS), BrightnESS EU project.

Precise and fast timing: The PICOSEC project, aiming precise and fast time response, achieved significant results in 2017. Sketch in the following figure shows the detector concept. Following several optimization steps, the 1cm² prototype built in 2016 with CsI photocathode and 3mm MgF2 radiator, has achieved in 2017 a time resolution of about 25psec with MIP as shown below.

Left: Detection concept: The passage of a charged particle through the Cherenkov radiator produces UV photons, which are then absorbed at the photocathode and partially converted into electrons. These electrons are subsequently pre-amplified and then amplified in the two high-field drift stages, and induce a signal that is measured between the anode and the mesh. Right: Signal arrival time distribution for 150 GeV muons for an anode and drift voltage of 275 V and 475 V, respectively.

Left: Readout PCB board with SMB connectors directly connected to the readout pads. The PCB is carrying the HV distribution of the individual pads. Right: Inner part of the detector with the readout pads visible and with the holder for the MgF2 radiator.

The Figure above shows micromegas and readout plane of the multi-pad PICOSEC prototype. Response to events fully contained in a single pad showed similar performances as for the single channel prototype. Preliminary results on events shared between two pads are showing that time resolution can be almost recovered properly combining the signals detected by the two electrodes.

In parallel with optimization studies, several crucial aspects have been investigated in view of the use in experiments. Scalability to multichannel readout for larger detectors and the use of resistive micromegas to increase detector robustness and stability are the most important examples.
Preliminary results are showing that the fast components of the signals are mostly preserved and that resistive micromegas can be considered in the development of fast and precise MPGD based detectors. All the positive previous results are justifying the current need of strong efforts in the most important aspect: the UV photocathode. Future activities will focus on R&D linked to this exploiting different type of photocathodes and possible protection. These activities are in synergy with the EP-DT MPT workshop (production of the micromegas detector) and with the EP-DT Thin Film and Glass Laboratory (evaporation of photocathodes).

**Optical readout:** The optical readout of gaseous detectors such as GEMs is an alternative readout modality, which relies on the recording of scintillation light emitted during electron avalanche multiplication by high granularity imaging sensors. Building upon previous studies of the capabilities of this readout approach, a beam-monitoring detector for applications in hadron therapy facilities was developed and tested in a clinical environment. The combination of optical readout with GEM-based detectors was shown to provide high spatial resolution and dose linearity in recording beam profiles, while maintaining a low material budget to minimise beam attenuation and scattering in beam monitoring applications both in high-energy physics as well as medical applications. A novel readout approach combining electronic and optical readout of a GEM-based TPC was developed to extend 3D track reconstruction capabilities to intricate track topologies. Electronic signals from a transparent ITO-based strip anode structured by direct laser lithography and etching were read out with an APV25 ASIC connected to the RD51 SRS and used to obtain arrival times of electrons. Subsequently, Z-depth information was extracted from the arrival times of electrons and combined with XY information from optically read out images. This combined readout approach permitted the reconstruction of curved and more complex particle tracks and extends the applicability of optically read out TPCs.

**Neutron detection - BrightnESS:** Our team prepares a detector prototype for the NMX macromolecular diffractometer at the European Spallation Source ERIC (ESS), which is currently under construction in Lund. The Horizon2020 project BrightnESS funds those activities, in which a detector with 50 x 50 cm² active area and related electronics are developed. The detector is based on a three GEM amplification structure with a gadolinium neutron converter as cathode of the drift region. The VMM ASIC is implemented in the Scalable Readout System (SRS) of the RD51 collaboration for data acquisition. 2017 was a very fruitful period with three test beam campaigns at the SPS and one at a neutron facility in Norway. Two summer students, one internship student and a collaborator form Columbia were welcome at CERN supporting the project. The pioneering of a procedure for ultrasonic welding of gadolinium was completed and the SRS-VMM readout was improved allowing the instrumentation of complete 10 x 10 cm² mock-up detectors at the test beams. The design of the final large detector was fixed and production started.

![Cross section of the final detector design for the NMX prototype](image)

Cross section of the final detector design for the NMX prototype (left): The neutrons enter the detector through a thin readout foil and passes the triple GEM stack and drift volume, before it releases an electron in the gadolinium converter at the anode. The VMM readout is placed at the sides of the detector housing, as one of the design requirements is minimal size of the periphery.
**RD51:** The RD51 collaboration has 400 members from 80 institutes. The EP-DT group is involved in the management, including the spokesperson, the technical coordinator and several convenors of working groups. We are directly involved in the development and support for MPGD simulation and modelling and for MPGD electronics. The Scalable Readout System (SRS), distributed via the CERN store or KT, is one of the most important example in the context of common data acquisition and front-end electronics. We take responsibility of common facilities at CERN. The GDD laboratory is available for the groups of the collaborations that are using our facility with permanent or temporary installations. LHC upgrades (ATLAS, ALICE), beam line for schools, ESS are a few examples of current users. We do coordinate test beam activities of the collaboration at the SPS (three periods of two weeks per year, with an average presence of four groups per period) using a semi-permanent installation in the H4 experimental area.

5.4. On-detector Cooling R&D  
**Paolo Petagna**

5.4.1. On-detector Cooling R&D
The current predictive models available for CO₂ boiling flows show a wide range of accuracy, in particular when dealing with mini- and micro-channels. This situation poses severe problems to the designers of new CO₂ detector evaporators, forcing to retain large safety factors in the design and to condition final choices to complex and heavy experimental verifications. This is mainly due to the lack of reliable and accurate experimental data in literature. In order to fill this gap, a long-term study has been launched with the ambitious objective of developing a deeper understanding of the properties of boiling flows of CO₂ in view of their actual application in simple small diameter tubular evaporators as well as in complex silicon-substrate multi-microchannel cooling devices.

*The new EP-DT experimental set-up for a measurement of CO₂ boiling flows in mini- and micro-channels*

Combining the interests of the EP-DT Cooling Project and of the AIDA-2020 WP9, a new test stand dedicated to test mini- and micro-channel boiling flows of CO₂ with an unprecedented level of accuracy has been designed, built and commissioned. A test circuit is housed in a vacuum vessel to guarantee adiabatic test conditions. CO₂ flows in the circuit at saturation temperatures ranging from -25 °C to +20 °C. High precision sensors account for pressure drop, heat transfer and mass flow rate, with state of the art measurement accuracy level. RTD sensors in custom-made housings, calibrated to measure within an uncertainty of 0.015 °C, provide direct measurements of the fluid temperature before and after the test section, while point-like K-type thermocouples measure the outer wall temperature of the test section with an uncertainty better than 0.05 °C. A high-end differential pressure sensor in combination with a highly accurate read-out system can measure pressure drops along the tubes within an uncertainty of 1.5 mbar for a maximum of 3 bar.
The installed mass flow meter can measure flow rates from 0.16 down to 0.003 g/s with an accuracy of 0.2 % of reading. Tubing samples in stainless steel, titanium and glass, with accurately measured hydraulic diameter ranging from 2.15 mm to 0.13 mm are now ready to be tested under mass fluxes ranging from 200 to 1200 kg/m²s and heat fluxes from 10 to 40 kW/m². Single-phase pressure drop measurements on the test stand show a deviation well below 5 % from known accurate single-phase models, validating the outstanding level of flow measurement and control.

Important advantages on the design, commissioning and operation of the future CO₂ detector cooling plants are expected by the establishment of reliable tools to simulate the dynamical behaviour of a full CO₂ cooling system, including the detector cooling loops, the transfer lines and the plant itself. The second year of this activity, carried on by EP-DT in collaboration with the Department of Mechanical and Civil Engineering of the University of Manchester in the frame of a Collaboration Agreement, focused on the development of dedicated models for the simulation of all the cooling system components. The object-oriented modelling environment EcosimPro has been used to develop a simulation framework directly accounting for two-phase flow using state-of-the art methods used for dynamic simulations of industrial cycles.

![Comparison of dynamic simulations (continuous line) vs. experimental data (dotted lines) for transitory trends of a benchmark heat pump system.](image)

For validation purposes, the framework has been used to simulate a relatively complex heat pump system, for which the accurate experimental results from cyclic tests, based on the ASHRAE Standard 116 were available. The simulations matched the measured values of the heat pump system well and compared favourably with dynamic simulations studies previously performed on a different platform by another team. There is a significant overlap between the thermos-fluid characteristics of 2PACL systems and those of the test bench selected, which is therefore a good candidate to use for the purposes of validating the developed models in order to gain confidence in them. The simulation framework has been used for a preliminary simulation of a CO₂ 2PACL cycle under step change transients: the simulations evolve as expected, confirming that the developed models can now be used for further studies on the dedicated EP-DT CO₂ 2PACL test system.

5.4.2. Optical Fibre Thermo-hygrometry

**Distributed sensing by LPG sensors:** This year the activity has been focused along two main directions: a further optimization of the TiO$_2$ deposition method over the grating for relative humidity sensing, and the continuation of thorough irradiation campaigns on sensor samples. For the first activity, thanks to a slight modification of the latest TiO$_2$ deposition sequence developed, it has been possible to reduce the wavelength of the interrogation window required to provide a complete read-out of the sensor over the full range of humidity. Thanks to this, the extremely high sensitivity to very low-dew points humidity variations is maintained and the number of distributed sensors on a single fibre is increased. For the second activity, the long-term irradiation in the ATOMKI facility in Debrecen has been prosecuted on uncoated LPG sensors and launched on TiO$_2$-coated sensors. The results of these campaigns, combining on-line reading of the sensors during irradiation and continuous observation of the post-irradiation behaviour, are of fundamental relevance for the development of new models for the accurate simulation of the radiation-induced effects on the sensors.

**Continuous sensing fibres:** In order to cover at best the different needs of several HEP applications, the study of a third generation of sensors has been launched in 2017, in the frame of a new collaboration with the Group for Fibre Optics (GFO) of the EPFL School of Engineering. Based on an evolution of existing techniques, this study aims at the definition of functionalization and interrogation techniques capable of making a fibre sensitive to relative humidity changes along its whole length. The theoretical studies conducted until now permitted to individuate at least two very promising technologies, for one of which a preliminary rough test already provided promising results. A thorough experimental activity, to be conducted in strict collaboration between the laboratories of CERN EP-DT and EPFL-GFO is now in preparation. A dedicated EP-DT climatic chamber has been sent to EPFL, and different samples of fibres have been procured and pre-processed. The tests are planned to start in Q2 2018 and will lead to the definition of the investigation lines towards the production of optical humidity sensors of new generation. This new generation, in combination with the two previously developed by EP-DT (distributed sensing based on FBG and LPG) is expected to have the potential of providing full coverage to all the different environmental monitoring needs of HEP experiments.

### 5.6. R&D on gas systems

*Roberto Guida, Beatrice Mandelli*

During 2017 an agreement between the LHC experiments and the gas team was formalized to define new objectives (beyond the maintenance and operation of existing plants) and ensure additional resources. Indeed, present and new detectors for the LHC experiments are expected to run for the coming decades and to maintain excellent performance, despite the new LHC luminosity increase planned for the years to come. Three research lines have been identified: R&D for gas systems upgrades, new gas analysis techniques for the optimization of current technologies and R&D for the reduction of greenhouse gas (GHG) emissions.

In the framework of exploiting/optimizing current technologies and reducing the GHG emission, the R&D on gas recirculation systems for GEM and RPC detectors continued. The test setup for triple-GEM detectors operation under gas recirculation that paved the way for the upgrade of the LHCb-GEM detector gas system in 2017 has been moved to the Gamma Irradiation Facility (GIF++). Two triple GEM detectors are operated with gas recirculation and in presence of a radiation background similar to the one expected during the HL-LHC phase. The effects of different recirculation fractions, presence and accumulation of impurities, gas composition, detector operational conditions, gas flows are studied. The search for new environmentally gases to replace the R134a and SF6 replacement in the RPC mixture continued. Several candidates have been tested.
A gas recirculation unit has been developed and built for RPC detectors. For the first time, RPCs were operated with gas recirculation by using new environmentally friendly gas (see figure below).

**RPC detectors operated with mixture recirculation system by using new environmentally friendly gas: gas mixture composition (left) and stability of the high voltage working at detector efficiency (right)**

A big effort continued to be addressed to the improvement and research of advanced gas analysis techniques for LHC experiments and laboratory applications. The systematic campaign started in 2016 on ALICE-MTR with mass spectrometer continued. A sampling method was developed for the measurement of Fluoride in the gas stream. The results obtained show a clear correlation with the luminosity as seen by the ALICE experiment. The study will continue in order to accumulate enough statistic both on gas mixture and detector performance to assess potential effects for long-term detector operation.

**Accumulation of Fluoride in the ALICE-MTR mixture. Two different slopes are visible due to the increase of luminosity before and after the September technical stop.**

### 5.7. Microfabrication technologies

**Alessandro Mapelli**

The DT group continued providing support to LHC and non-LHC experiments for microfabrication technologies and microsystems engineering. The group also assisted many CERN users for microtechnologies activities in external silicon-processing facilities. In 2017, this involved people from different groups and departments (BE-BI, BE-RF, EP-DT, TE-CRG) covering activities for LHC upgrades (ATLAS and LHCb) and non-LHC experiments (NA62, FCC and STREAM) as well as devices for beam instrumentation and monitoring.

A process-flow has been defined by DT to fabricate TiN-based silicon micro-heating devices integrating precision Resistance Temperature Detectors (RTD). This allows the “in-house”
fabrication of thermal mock-ups, in the EPFL cleanrooms, with a turnaround time of two to three weeks. Thermo-mechanical mock-ups have been already fabricated for ATLAS ITk studies at CERN.

5.7.1. Microfabrication processing in the EPFL cleanrooms

The DT group assists users across CERN for microfabrication activities. The support includes the design of devices and the definition of the whole fabrication process-flow as well as the follow-up and assistance during the fabrication. DT collaborates with many cleanrooms in Switzerland and elsewhere among which EPFL in Lausanne, CSEM in Neuchatel, FBK in Italy, CEA-Leti in France and TMEC in Thailand. Many collaborations are ongoing with cleanrooms and laboratories at EPFL² among which four PhDs. DT also provides administrative support and training to CERN personnel for their work in these cleanrooms. A centralized billing system for CERN has been established between DT and the cleanrooms of the EPFL Physics Institute (IPHYS) and the class 100 (ISO 5) MEMS cleanrooms of the Center of Micro-Nanotechnology (CMi). In 2017, eight projects from CERN were presented during the poster session of the CMi Annual Review Meeting, which was attended by more than 600 academic and industrial participants. Since the fall of 2017, a one-day training program is available within DT for CERN students and trainees to manufacture and characterize thin film resistances in the EPFL-CMi cleanrooms.

Interface characterization of monolithic silicon detectors

The Transient Current Technique (TCT) is widely used to study silicon detectors. This technique allows for the characterization of the electric field and the charge trapping profile inside the detectors, where particles or photons create electron-hole pairs in the bulk of a semiconductor device. In the standard approach, the TCT signal originates from the free carriers generated close to the surface of a silicon detector, by short pulses of light or by alpha particles. A novel approach developed within DT in collaboration with ESE, ALICE, EPFL and CEA-Leti proposes a different principle of charge injection by means of lateral PN junctions implemented in one of the detector electrodes, called the electrical TCT (el-TCT). This technique is fully compatible with CMOS technologies and therefore opens new perspectives for the assessment of radiation detectors performances. In particular, we have successfully used it to study the electrical properties of the interfaces obtained by low temperature CMOS-compatible direct bonding of silicon wafers.

Microchannels embedded in silicon pixel detectors

²LMIS4 - Microsystems Laboratory (lmis4.epfl.ch)
EDLAB - Group of Electron Device Modeling and Technology (edlab.epfl.ch)
IPHYS - Institute of Physics (iphys.epfl.ch)
CMi - Center for MicroNanotechnology (cmi.epfl.ch)
Two approaches are being investigated to embed the micro-channels directly inside pixel sensors or read-out chips. The first one aims at closing the micro-channels with the CMOS device itself while the second one consists in etching lollipop-shaped micro-channels (see figure) on the backside of the sensor or chip and closing the narrow trenches by a conformal deposition, or growth, of a thin film. Both approaches are being studied and developed by DT in collaboration with EPFL, CEA-Leti and FBK. In 2017, a process-flow to embed micro-channels on the backside of MALTA monolithic pixel sensors was validated. It will be implemented in 2018 when the first batch of sensors will be available. This work is performed in the EPFL-CMi cleanrooms with the STREAM ITS network3.

5.7.2. Further R&D on microfabrication processes

Thermal management solutions for HEP and space missions
Following the signature of a collaboration agreement between CERN and the Swiss Space Center (SSC), a new project has been launched in 2017 for the common development of micro-engineering solutions for thermal management in HEP and space applications.

Radiation monitoring technologies for the Future Circular Collider at CERN: To overcome the current radiation measurement limitations, a solution for Ultra High Fluence monitoring based on metal nanolayers is under development. The prototypes of these Radiation Dependent Resistors (RDR) have been fabricated at EPFL-CMi and specific high-fluence irradiation tests (with gamma, protons, neutrons) have been carried out in CERN facilities and outside CERN.

Post-processing of silicon dies
Deep diffused avalanche photodiodes (APDs) produced by RMD Inc. are being studied for charged particle timing applications by the DT SSD team. In order to reduce the resistance of the detector surfaces, metal layers were applied to the detectors using photolithography and sputtering on single dies at EPFL-CMi.

Thermal mapping of superconducting cavities
DT is providing support to the BE and TE departments for the development of Transition Edge Sensors on glass substrates in the EPFL-CMi cleanrooms. They are foreseen to operate in superfluid He-II for non-contact thermal measurements.

3 https://stream.web.cern.ch/
6. Services Provided by DT

6.1. Gas Systems

Roberto Guida

The activities on the 40 LHC and non-LHC gas systems continued to be driven by preventive maintenance, consolidations and upgrades. The past few years of operation have been characterized by an increased level of attention, new stringent requirements for operation and the necessity to develop additional modules to satisfy new detector requirements coming from the LHC luminosity increase. Indeed, during 2017 new upgrades/modifications have been implemented on about half of the gas systems. For example, additional gas mixing modules with higher flow capacity for detector filling have been installed for the new ALICE-MTR and LHCb-GEM gas recirculation systems. New humidifier modules or upgrades of existing have been installed on CMS-DT, ATLAS-CSC and MDT. An additional gas mixture component has been added to CMS-DT allowing to maintain the same mixture composition in open mode and gas recirculation and therefore minimizing the risk of detector ageing for long-term operation at high luminosity LHC (see figure). A new CO2 analyser has been installed on the LHCb-RICH2 system. It will allow monitoring the gas mixture concentration during run.

As usual the end of the 2017 was a very intense period due to the start of the winter technical stop (EYTS). During the EYTS a special maintenance program was performed in all sites. As an example, several hundreds of flowmeters used to monitor supply and return flows from detectors have been recalibrated (especially for CMS-RPC, CMS-DT and ATLAS-TGC). A similar calibration campaign has been performed on more than hundred mass-flow controllers which provide the gas mixture to all the gaseous detectors at the LHC experiments. The activity for the replacement of all the power supplies (more than hundred in total) started and about one-fourth have been replaced successfully.

The gas team continued to be involved in the effort for reducing gas consumption and, consequently, the greenhouse gas (GHG) emission from particle detection at CERN. In this context, after one year of stable operation of the new LHCb-GEM gas recirculation system the recirculation
fraction has been increased from 70% to 90%. A similar increase of the recirculation fraction has
been applied to the ALICE-Muon Trigger RPC system. R&D studies on gas systems and gas analysis
were performed to monitor the gas mixture quality and to evaluate the possibility to further
increase the recirculation. The efficiency of the CMS-CSC-CF4 recuperation plant has been studied
at the level of each module. Several consolidation activities have been performed and their effect
will be evaluated during 2018.
About 1000 interventions (monitoring, follow-up of detector performance or specific requests)
have been recorded during 2017. The gas systems availability continued to be higher than 99.98%
equivalent to less than 1 hour downtime per year (external sources excluded, i.e. like power-cuts).
Indeed, only about 70 interventions were due to issues during operation.
Concerning the non-LHC part, the gas team continued to be involved in the maintenance, operation
and development of the CLOUD, LINAC4 and NA62 systems. Five additional modules have been
installed on the CLOUD experiment allowing the injection of new chemical species and to study
their effect on the atmosphere. Dedicated O2/H2O analysers have been installed on the NA62-
RICH to monitor the mixture quality all year long.
The gas team has offered occasional support to many CERN users and other CERN experiments like
Aegis, CAST, COMPASS, etc.
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.

6.2. **CO₂ Cooling Systems**

6.2.1. Cooling coordination with LHC experiments

*Paola Tropea, Lukasz Zwaliński*

The cooling activities of both ATLAS and CMS during 2017 have been supervised all along the year
by the two cooling coordinators from EP-DT-FS.
On the ATLAS side, the main operational issue encountered has been a leak on the C6F14 cooling
system of the TRT, where the cooling coordinator has been active as main engineering support to
the teams involved. The performances of Thermosiphon cooling system for the ATLAS ID have been
validated, but the system has not been put in continuous operation due to a leak on the surface
condenser, which has then been replaced during YETS 17-18.
In view of the foreseen detector upgrades, the cooling coordination team has been strongly
involved in the thermal performance tests of new ATCA crates, the installation and commissioning
of the surface cooling plant for the New Small Wheels and several projects on the procedural and
control improvements for the cooling system operation.

On the CMS side, the operation has been extremely smooth and no major interventions were
needed during data taking on the cooling systems. The activities of the cooling coordination team
focused on the update of the cooling upgrade requirements after the TDR approvals and the
engineering support to the definition on the major infrastructure changes to be anticipated to LS2
(ECAL barrel cooling requirements reduced to 8°C instead of 18°C, the design and construction of
a new cooling system for the new magnet freewheel thyristor, which will reduce the risk of CMS
magnet slow dump in case of power cut, both handed over to EN-CV).
Both on ATLAS and CMS, the cooling coordinators and the EP-DT CO₂ team have contributed to the
TDR phase for the trackers, taking care of the cooling chapters writing and the detailed cost
estimate for the overall CO₂ cooling systems, both approved at this stage.

The EP-DT-FS section has been responsible for the first year of maintenance and operation of a CO₂
cooling plant serving an operational detector, i.e. the CMS Pixel. The performances of the system
have been excellent, with one unique non-foreseen interruption due to the failure of an upstream service (dry air for valve piloting). The database of spare parts had been migrated to the CERN standardized spare management platform INFOR EAM, and the storage areas are organized for a fast retrieval of parts. Following the success of the M&O service of EP-DT and a re-organization of the CERN wide experiment support services, the DT-FS team has been requested to take over form EN-CV the responsibility for the maintenance and operation of the ATLAS IBL CO$_2$ cooling system. The stand-by duty team has been trained on the new installation by the ATLAS cooling coordination team and the EN-CV team, and the handover has been signed at the beginning of 2018.

6.2.2. Construction of new cooling plants

Paolo Petagna and Paola Tropea for the CO$_2$ cooling team

MAUVE: The MAUVE (Multiple Apparatus for cooling of UT and Velo Experiments) project includes two identical CO$_2$ cooling systems, each featuring 7 kW of cooling power at -35°C, for the upgrade of LHCb Velo and UT. In 2017, the system has seen the design phase for the plants completed and the construction of the junction box to distribute coolant in the experimental cavern achieved. The plant production readiness review has been positively passed in autumn, and all parts ordered such that construction can be completed, as foreseen, by mid 2018. End of the year updates on the detector operation requirements ask now for few modifications on the local distribution systems at the entrance of the detectors, which remain to be finalized in close collaboration between the EP-DT-FS team and the on-detector experts. A major effort has gone already in 2017 in the detailed study of integration for both the hydraulic and the electrical and control components, including the preparation of services in the cavern and agreement with the LHCb technical coordination about the installation procedures and schedule. A trial installation of the distribution junction box has proven that the integration studies and the anticipated installation of the transfer lines are fully in line with the overall integration scheme.

BABY DEMO: The Baby Demo CO$_2$ cooling system, whose commissioning was achieved at the end of 2017, is an ATLAS project with a CMS financial contribution under the scientific supervision of the EP-DT-FS cooling team. The of the project, whose time scale was extremely tight, was to prove the possibility to deliver stable CO$_2$ cooling to a detector stave with an evaporation temperature down to -40°C. The preliminary results obtained in 2017 allowed reaching such an unprecedented record for carbon dioxide refrigeration in pumped mode. Further studies will continue in 2018 in order to optimize the full detector/transfer line/cooling plant design.

LUCASZ: Following the first unit of the class LUCASZ (Light Use Cooling Appliance for Surface Zones), delivered to CMS at the end of 2016, three more CO2 cooling units of the same class got out this year from the EP-DT-FS workshop. The first one was again earmarked for CMS and was used at P5 in the frame of the exceptional maintenance intervention on the Pixel detector during the 2017 YETS. The following two are presently under commissioning and will be soon delivered to LHCb for the assembly work of the Velo and the UT detector. The new units incorporate all the hardware and software upgrades derived from the operational experience on the 2016 specimen and their design can be now considered stable. This marks the end of the prototyping phase of this new class of cooling units, and different options for outsourced production are now being considered, based on the possible future needs of the experiments.
MARTA: The launch of the industrial production of the CO2 cooling units for small laboratory applications, and their commercial availability under the name “MARTA” (Mono-block Approach for a Refrigeration Technical Application) has been officially announced in July. The announcement marked the completion of a long and complex transfer process of a technology developed and prototyped by EP-DT cooling team. These units fill a gap in the market making available to non-expert users a user-friendly technology providing stable boiling flows of CO2 at very precisely controlled temperatures. A licence agreement has been signed with the CERN IPT-KT group by the industrial consortium producing the units. The first orders are being presently issued by external institutes engaged on the phase-II upgrades of the ATLAS and CMS trackers, which were in urgent need of such units for their testing programmes. However, an opening to a wider market is also envisaged in the future.

DEMO: The DEMO project needs to prove the conceptual design of the basic CO2 cooling module which will serve both ATLAS and CMS phase II detectors which have chosen carbon dioxide as a refrigerant for their future. In 2017, both conceptual design and experimental activities have been advancing. Exploiting the CO2 system of the CMS Tracker integration facility, a setup has been put in place to prove a new concept for temperature regulation: the use of two control valves and a by-pass allow to reduce significantly the volume for CO2 storage in proximity of the cooling system, thus opening easier integration scenarios for the use of CO2 in underground for large systems. An additional challenge for the construction of large cooling power systems is the procurement of qualified components, whose availability on the market is limited. A market survey has been launched and completed in 2017 for the selection of the CO2 liquid pumps.
6.3. Instrumentation and Controls

Giovanna Lehmann Miotto

6.3.1. Magnet Control and Safety System

The Magnets Control Project (MCP) delivers control and safety systems to the LHC experimental magnets and ensures their operation and maintenance throughout the lifetime of the experiments. Additionally, adapted variants of the systems developed within this framework have been deployed on several other magnets at CERN. The main components of the MCP are the Magnet Control System (MCS), the Magnet Safety System (MSS) and the Magnet Diagnostic System (MDS).

The MSS is a critical system that ensures the safety of experimental magnets, both warm and superconducting. It was developed within EP-DT for the LHC experiments, starting at the end of the 90’s. In 2012 a new project was launched within EP-DT in order to develop a modern and improved safety system, the MSS2, applicable to very different types of magnets, from test beam magnets and experimental magnets at the SPS North Area (COMPASS, NA61, CMS & ATLAS test beams) to the large LHC experimental magnets (ALICE, ATLAS, CMS, LHCb). The system is based on the CompactRIO platform of National Instruments: the user programmable FPGA takes care of the safety logics, while a real time processor allows for monitoring and logging. The visualization of the status and actions of the MSS2 system is integrated into the MCP supervisory layer.

Bridge signal after electronics modification read by the MSS during the SLOW_DUMP to FAST_DUMP at 3.4 kA on 27/03/2018
After an initial period of design and prototyping, the new system was deployed initially for the COMPASS and CMS test beam (M1) superconducting magnets, then for the warm magnets of ALICE and LHCb (2013 - 2014), for the ATLAS solenoid (2016) and finally for the CMS solenoid and ATLAS toroids (2017). The systems deployed in 2017 are by far the most complex. As an example, the ATLAS toroidal magnet alone requires four independent MSS systems: one for the Barrel Toroid BT-MSSa another one for the End Caps ECT-MSSa and their redundancy BT-MSSb and ECT-MSSb.

Since the final commissioning of the MSS2 in ATLAS and CMS could only be done once the experiments were closed, and cryogenic conditions stable, the time for testing and tuning of the systems was squeezed in a very short time-window at the end of the 2017 EYETS. Sufficient tests were carried out in order to guarantee full safety of the magnets, but fine tuning could not be completed, nor could a slow dump sequence be tested from nominal current. Therefore, it was not noticed that some signals of the magnet instrumentation (the so-called bridges) could become too large and saturate the input electronic interface of the MSS2 during a slow dump transition from nominal current. As a consequence, when the first slow dump transition to protect the magnets occurred, it triggered an unwanted fast dump transition implying longer recovery times. As soon as this incident happened, a modification was designed and applied in order to enlarge the input voltage range of the MSS2 instrumentation (see figure above).

The MSS2 has also been deployed on magnets that were showing an abnormal behavior (VTX1&2 magnets for NA61 and the Morpurgo magnet for the ATLAS test beam), and for which the existing diagnostics systems could not establish the root cause of failures. In both cases the improved diagnostic capabilities within MSS2 allowed to verify that the magnets were healthy and that nominal working conditions could be re-established.

The ATLAS_H8 magnet (Morpurgo) is an old superconductor magnet built 1977 that after many years of stable operations started quenching at relatively low current. After the installation of the MSS2 in 2017 and during the preliminary diagnostic tests it was established that the reason of the magnet malfunction were cryogenic pumping instabilities in certain operational conditions. The pump instabilities produced over-temperature peaks in the magnet current leads, triggering a Fault condition, i.e. a “quench”. After the cryogenics team fixed the issue in its equipment, the MORPURGO magnet could restart operating without any major problems.

Last, but not least, work started in 2017 to re-insert the target magnet system for COMPASS, on the experiment’s request. The magnet has been reconnected, the PLCs for the magnet and vacuum control systems have been displaced into a bunker, to protect them from radiation, and the MSS2 has been upgraded to its latest version. Recommissioning and tuning are planned for 2018, in order to be ready for the 2018 data taking. The MSS2 project is now in its operations and maintenance phase, ready to be deployed on any additional experimental magnets that may need it. The next major development project within the MCP is the equivalent upgrade of the Magnet Control System (MCS): in this respect, a software upgrade was already carried out and deployed for the ALICE and LHCb magnets in 2017.
6.3.2. Magnetic Field Measurement Service

Felix Bergsma

The process of mounting the Hall probes on the PCB has been further improved. The reduction of the size of the Hall probes is now done on a CNC machine, increasing precision, decreasing stress on the dye and gaining time. A second wire-wrap station was produced and a 2nd camera installed for Hall probe and glass cube mounting. The mounting precision is now 0.05 mm.

All modifications tested and approved on the B-sensor PCB-layout have been put in a new design, a test production of 100 cards is planned for 2019. 200 B-sensors have been produced for ATLAS-NSW, 20 for Mu2e at BNL. The loan of 110 B-sensors with their DAQ to BELLE2 at KEK was completed. The system was mounted in a mapping device built by the BELLE2 collaboration and successfully operated.

Calibration
Measurement and analyses were integrated and automated. The analysis is performed on-line, the produced calibration files can be directly used in the DAQ programs. Next step is implementation of automatic quality control with on-line diagnostics, to get a set-up operable by non-experts. A pre-test station has been installed to remove faulty cards in an early stage. The NMR absolute control has been made semi-automatic. It still needs some intervention by hand, but is only necessary at begin and end of a calibration session. Electronic temperature and pressure measurement was installed on Pt7.

Test benches
The pneumatic, cylindrical bench used in 2016 for the mapping of the BELLE2 magnet was scaled up to the dimensions of the MPD magnet. It will be used in 2019 to map this magnet at NICA. The cost of this project is defined in a work-package. The bench is installed in hall 164 and used to test new features to make it easier to operate (see photo). The production of 60 B-sensors for the central bar is on its way.
A new semi-automatic bench was designed to map the ISS magnet of ISOLDE. It consists of a trolley, which can be moved over two parallel bars. This concept was chosen to be able to measure close to the magnet axis.

**Mapping**
The field of the GOLIATH magnet in the north area was mapped at several current settings in two sessions in July and August 2017. Our manual bench with 18 B-sensors was used. The maximum field was 1.5 Tesla and some interesting features were discovered.

In November 2017 the superconducting ISS magnet of ISOLDE was mapped with a new device, which carried 20 B-sensors. The ISS magnet is a magnet used before in hospital for NMRI imaging. The maximum field was 2.5 Tesla and is very stable due to superconductive shunting.

**Calculation**
A magnetic model of the SM2 magnet, used by COMPASS, was made and the results shared with the collaboration. The power supply of the SM2 magnet is replaced and the maximum current goes from 5000 Amp to 4800 Amp. The calculation is necessary to scale the measured field map. Scaling is non-linear due to the non-linear dependence of the iron magnetisation with magnetic field intensity.

**Future prospects**
The goal for the future is to have all equipment for 2020 operable by non-experts, i.e. people with technical skills who have read the manuals. This is kept in mind with all developments described below. For field mapping requests, new designs are tested on reusability and ease of operation. Existing devices are adapted to the new standards. In 2018 some modifications to the existing B-sensor PCB will be made, in order to facilitate production. The assembly line for the mounting of Hall probes on the B-sensors has been optimized. The calibration station has been automated.

### 6.4. DAQ, Control and Safety Systems

*Giovanna Lehmann Miotto*

#### 6.4.1. DAQ Systems

The support for developing DAQ systems for experiments and detectors is a recent activity in DT. It started after the EP management established the need for offering this kind of service to the community, in 2015. Two use cases were selected in 2016 as initial “customers”, in order to find the best working model for supporting experiments in an aspect that is at the core of the experiments themselves, i.e. the acquisition of physics data: NA62 and NP04 (see other chapters in this report). After the successful launch of these pilot projects, several other contacts have been established with experiments and R&D communities in 2017: SHIP, RD51, CLOUD, NA61. In order to remain up-to-date with the latest technologies and trends of DAQ systems, DT-DI is working in close collaboration with industry and the LHC experiments. As an example, a joint R&D project with Intel and the LHC experiments has been launched on large distributed key-value stores for DAQ, in the framework of CERN OpenLab project.
DAQ support is provided in terms of a collaborative effort with the experiments. For systems that need to be developed, DT-DI advises on viable design choices, suggests suited toolkits for the implementation of functionality and carries out joint development of the aspects that need to be tuned specifically to the needs. The aim is to allow the experiment communities to remain the owners of the DAQ system and to actively participate to its shaping, avoiding the inevitable mistakes that occur when “starting from scratch” and offering the experience gained on the development of many other DAQ systems. For existing systems, DT-DI can provide assistance in identifying issues, reviewing designs and implementations and can help in the development effort needed to achieve the desired performance and/or functionality.

6.4.2. Other Control Systems

DT-DI develops control and safety systems for experiments and facilities, such as the LHC roman pots (ATLAS ALFA/AFP and TOTEM), CAST, AEGIS, the GIF++ facility and the thin-films lab. It also supports detector design assemblies, e.g the ATLAS ITK pixel demonstrator, and provides test bench systems for detector QA. It represents the EP department in inter-departmental working groups such as CNIC, GUAPI, Fieldbus, PXI, FESA. The DT-DI section leader is a member of JCOP Collaboration Board and Steering Group, representing non LHC experiments and the DT group.

In 2017 preparatory work continued in view of the LS2, to establish commitments and start designing systems to support the upgrades of the LHC experiments, such as the LHCb VELO motion control and safety systems, and the LHCb SciFi vacuum control system for the cooling plant.

The main modification for all Roman Pots Position Control systems in 2017 was related to the control software. Currently a new version with the EXECUTABLE mode feature has been deployed allowing to automatically restarting of the Position Control System without manual intervention after a power cycling or Reset. In addition, DT-DI contributed to the TOTEM detector upgrade consisting in the installation of the Ultra-Fast Silicon Detector (UFSD) in several stations, preparing the services for those detectors and adapting the vacuum circuit to the new detector conditions.
7. Infrastructure for Detector R&D

7.1. Irradiation Facilities

7.1.1. Gamma Irradiation Facility (GIF++) at the SPS North Area

*Martin Jäkel*

The CERN Gamma Irradiation Facility (GIF++) is a joint EN- & EP- Department facility located on the H4 beamline (Zone PPE-154) in EHN1. It is a unique place for detector R&D tests where a strong gamma source and a muon particle beam are simultaneously available. The facility provides two independent radiation fields, each one equipped with an attenuation system of iron/lead filters, with the purpose of optimizing the gamma field for the required tests. The facility is equipped with an excellent gas and electronic infrastructures, a unified control/monitoring system, setups for beam- and cosmic- trigger as well as radiation- and environmental conditions- monitoring.

*GIF irradiation bunker during muon beam time 2017. Top: on the left side is the downstream irradiation field, on the right side the upstream irradiation field. Bottom: Example layout of one muon beam time with up to 9 setups placed in the beam simultaneously.*

The facility is intensively exploited by a large collaboration from the LHC experiments. The main detector R&D programs remains the upcoming upgrades of the Muon systems for the LHC experiments in view of the High Luminosity LHC phase. This includes seven different gaseous detector technologies: Drift Tubes (DT), Gas Electron Multiplier (GEM), Cathode Strip Chambers (CSC), MicroMegas (MM), Resistive Plate Chambers (RPC), glass based Resistive Plate Chambers and Thin Gap Chambers (TGC).

During 2017, more than 25 full size setups requested long-term irradiation, with 15 setups requesting muon beam. Up to 9 setups could be fitted simultaneously along the beam path (see figure). We could provide 9 weeks of muon beam (split over 4 periods) which were successfully shared with RD51. Results obtained by each group have been presented at international conferences. Several smaller setups, ranging from electronic to optical components, have been
irradiated throughout the year. In addition, two research groups started to plan at GIF++ quality acceptance tests of the final production chambers just before their installation on the LHC experiments.

During 2017, several infrastructure improvements could be realized. The GIF control systems now stores all parameters in the CERN oracle database (TIMBER) instead of locally, and values can easily be retrieved via a dedicated web interface. The temperature & humidity control inside the bunker could be improved, and the temperature in the gas rack area stabilized. The second ground chamber of the cosmic tracker system was installed (see Fig. left-hand side), and a new gas detection system commissioned. A new material access door was installed in December, removing the need of frequent crane operations to open/close the irradiation bunker (see Fig. right-hand side). The installation of an upstream beam dump (XTDV) finally allows us to use the Irradiator independently of the access mode in other H4 beam areas. A new web site gives easy access to all relevant plans and information needed for irradiation at the GIF++ as well as a complete user overview.

In September, we held the first Annual GIF User Meeting, with talks covering the various aspects of the infrastructure as well as presentations form all user groups active during 2017. Also at GIF++ several users profited from financial support provided through the AIDA-2020 Transnational Access program.

7.1.2. Proton (IRRAD) & mixed-field (CHARM) Irradiation Facilities at PS East Area

Federico Ravotti

The proton irradiation facility (IRRAD) at the PS East Area was built during LS1 to cope with the increasing need for irradiation tests of the community working for the HL upgrade of the LHC and beyond. This new facility is the natural upgrade of a historical service in the EP department that, since the 90’s, exploit the 24 GeV/c proton beam of the CERN PS for studying the radiation hardness of semiconductor devices (RD50) and materials. The IRRAD facility, operated by EP-DT, is
part of a more complex infrastructure in the PS East Area that includes, on the T8 beam-line, also the mixed-field facility (CHARM) operated by the EN department.

As shown in Figure 1, the number of samples irradiated in IRRAD constantly increased year after year since the new facility begun its operation after LS1 (2012-2014). More in detail, the proton run 2017 started in April and ended on December 3rd. During 32-weeks of operation, more than 800 objects, belonging to 33 users of 19 different institutes from 12 countries, were exposed to the proton beam. This large number of samples (about 50% more than in 2016) represents a record for the new facility. This exceptional performance was possible also thanks to the excellent availability of the PS and the high beam quality provided by the BE-OP team which nowadays steadily approach the design limit of 5x10^{11} p/spill delivered to IRRAD.

![Statistics for the IRRAD facility before and after LS1 (2012-2014)](image)

About 40% of the samples in IRRAD were solid-state detector test-structures belonging to R&D collaborations (RD50, RD53). Another 40% of the samples came from the LHC and other CERN experiments (NA62, etc.). This includes also all the LHC experiments that are now evaluating new detector technologies for the Phase II and future upgrades of their tracking and calorimeter detectors, as well as samples from common development projects within CERN (EP-ESE, etc.) and R&D projects for future accelerators (FCC). The final 20% are material samples for radiation hardness studies belonging to LHC equipment groups (within EN and TE) as well as to the CERN safety unit (HSE). Finally, the first two weeks of December 2017 were dedicated to the development and commissioning of a Xe-ion beam on the T8 beamline. This had as main goal to provide a beam for Single Event Effect (SEE) studies in electronic components for space applications, but also to propose a HI beam (with Pb-ions) to the users of IRRAD for the end of the run 2018, the last one before the LS2 (2019-2020).

The IRRAD facility is also part of the AIDA-2020 Transnational Access to irradiation facilities program that provides funding for external users to perform their irradiation tests at CERN. Since detector and accelerator developers need irradiation facilities to test their components under conditions that are as close as possible to real applications, as well as to predict and prevent failures in materials, a new database of worldwide irradiation facilities was developed and published online during 2017 by the IRRAD team. With more than 200 entries at the end of 2017, this is a unique database of this kind in the world. More details about this development within the AIDA-2020 project are available on the “On Track” newsletter. Always within the AIDA-2020, and in collaboration with the MINES ParisTech, PSL Research University in Paris, the new IRRAD data manager software application has been developed. The deployment of its first version begun during 2017 with the aim to be tested and validated during the irradiation run 2018.
7.1.3. Radiation Monitoring Sensors (RADMON)
Federico Ravotti

The PH-RADMON integrated sensors monitor radiation levels at the LHC experiments that may cause damage to sensitive electronics equipment and particle detectors. During 2017, the IRRAD team within EP-DT manufactured 10 new PH-RADMON’s for CERN experiments (CMS, ATLAS-AFP and CT-PPS) configured with RadFET and pin-diode devices to cope with the increasing radiation levels of the CERN accelerator complex. The first complete prototype of a new, general-purpose and portable readout system for these sensors (named “ReadMON”) was also assembled and validated in 2017 with measurements in mixed-field, Xe-ion beam (IRRAD) and using\(^{60}\)Co-rays (GIF++). The left-hand side of the figure below shows the ReadMON electronics board. The team provided support also to several CERN users for measurements with passive dosimeters (mainly Ga\(\text{F}\) films) during irradiation campaigns inside and outside CERN.

The silicon-based devices employed in the PH-RADMON sensor proved to be the right choice for the LHC. However, the HL-LHC upgrade and other anticipated future colliders such as the FCC are expected to generate unprecedented amounts of radiation, posing new challenges for radiation monitoring. As a possible new technology for ultra-high level particle fluence monitoring, the team (in the framework of the FCC Radiation Hardness Assurance – Special technologies WP 11, together with the Centre of Micronanotechnology (CMi) of EPFL in Lausanne) has proposed the novel idea to use metal thin films. These nanometre-size films exhibit resistivity changes at high particle fluence, and can possibly be used as Radiation Dependent Resistors (RDRs). More details about this technology were published in the EP newsletter of September 2017.

![Prototype of the ReadMON device for the readout of 8 PH-RADMON. All hardware is integrated on the same PCB. Final dimensions are ~20x15x10 cm\(^3\) (left-hand side). FCC-RADMON with a temperature sensor and 5 RDR of different metals ready for irradiation (right-hand side).](image)

During 2017, several prototypes of RDRs with different materials and film thickness (down to 100’s nm) were built, mounted on newly designed carriers (FCC-RADMON) and exposed to high-levels of protons (IRRAD), neutrons (JSI, Ljubljana), photons (GBAR LINAC at AD) and in a mixed-field radiation (TAN absorber at the LHC) exceeding 1x10\(^{17}\) p/cm\(^2\). Although the in-depth analysis of these data sets is still ongoing, some preliminary results illustrating the clear potential of this new technique have been presented to the RADECS 2017 conference at CERN. Based on these results, new irradiation experiments have been scheduled during 2018. This will include the study of metal monolayers produced by Atomic Layer Deposition (ALD) down to few nm thicknesses.
7.2. **Solid State Detector Lab, Bond Lab, QART Lab and DSF**

*Alan Honma, Michael Moll*

7.2.1. **Solid State Detector Lab**

The hardware infrastructure of the solid-state detector laboratory (SSD) in bldgs.28 and 186 was maintained and extended. The lab is equipped with a Transient Current Technique (TCT) system with red and infrared lasers delivering light pulses of about 250 ps length on temperature controlled devices under test (DUT) down to -20°C (see figure below, left). It is used to characterize the electric field inside silicon sensors in standard- or edge- TCT mode. In 2017 the system was extended to allow for precision timing jitter measurements. This required a modification of the optical system to shine on the DUT two infrared light pulses with a well-defined separation in time and was achieved by using a beam splitter and a delay system realized in optical fibers that result in two light pulses reaching the DUT for each pulse generated by the laser. The jitter of the DUT is then determined by measuring the distribution of the difference in time of arrival of the light pulses. The intensity of the light shone on the DUT was calibrated using a detector of known characteristics, allowing to mimic the amount of charge released by a minimum ionizing particle. An example measurement is given in section 5.1. Improvements were also implemented on the Thermally Stimulated Current (TSC) system, which allows to perform defect characterization in the temperature range from 20 K to room temperature by measuring emission currents down to tens of femto amperes. The main modification was the re-design of the cryostat cold head (in collaboration with R.Loos (DT-CO)) and the production of ceramics carrier boards specifically designed for this test bench. While the cold head is still a prototype (see right figure below) the modifications already allow a better heating rate control and a more accurate temperature measurement on the DUT. In addition, the TSC cryostat has been equipped with an LED based light injection system. Finally, the LabView software across all setups was revised using now common driver libraries and automatic backup tools copy all measured data to CERN centrally managed repositories on the EOS system.

*Left: Faraday Cage with Transient Current Technique (TCT) system. In 2017 the system was modified to allow for timing jitter measurements. Right: Prototype cold-head of the cryostat for Thermally Stimulated Current (TSC) measurements in the temperature range of 20 K to room temperature.*

Other available systems are a CV/IV system imbedded in a climate chamber allow measuring sensor characteristics down to -70°C and up to 2000V. The same climate chamber holds a beta source (Sr-90) based single-channel charge collection efficiency (CCE) measurement system based on discrete electronics. Multichannel CCE measurements on segmented (strip) detectors can be performed with an Alibava (LHCb Beetle chip based) system and for less demanding CV/IV measurements a cold chuck system with probe needles reaching a maximum voltage of 1000V and sensor cooling down to -30°C is available. Finally, for defect characterization, a Current DLTS system (down to -30°C) and the above described TSC system allow for measuring radiation induced defects. Further available systems in the lab are dry air storage cabinets and freezers for storage of irradiated sensors. The equipment is heavily used by the SSD team for detector research, serves visiting
scientists from the RD50 collaboration and has been made available as a service to several external
groups: colleagues from ATLAS, CMS, LHCb, DT and EN-EL performed measurements for their
individual solid-state sensor projects in the laboratory.

7.2.1. Bond Lab
The wire bonding lab had a large number of jobs in 2017, owing to the many activities for the LS2
and LS3 upgrades in the LHC experiments. The lab has 3 identical Delvotec G5 bonding machines,
all in good working order. The principal activities concerned the ALICE pixel upgrade (ITS and MFT)
production, VFAT3 chip bonding for the CMS GEM R&D and slice production, NA62 GigaTracker
modules, CMS HGC/LCD R&D, MALTA chip, Medipix/Timepix (used in many different projects),
PH/ESE chip testing PCBs, 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, CMS phase 2 upgrades,
ATLAS, TOTEM, CALICE, RD50, RD51, RD53, etc. There was a significant amount of advice and aid
given for detector design and connectivity issues to a variety of projects. There was also guidance
in the use the G5 bonding machine given to several outside institute bonding sites.

7.2.2. Quality Assurance and Reliability Testing (QART) Lab
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,
also saw significant activity in 2017. Some of the larger jobs included testing of more than 2000
DC-DC converters (ESE group), ATLAS ITk demo heaters calibration, NSW ATLAS upgrade study of
Micromegas PCBs, ALICE ITS HiC and staves cycling and ageing within a humid environment. All
the 4 main LHC experiments had upgrade projects (LHCb RICH upgrade schedule to use the facilities
in 2018, simulations done in 2017) that used the QART lab facilities and advice. Both of our fast
temperature cycling environmental chambers were quite active and our high field electromagnet
was in frequent use by several different projects. Moreover, many experiments asked the QART
lab for support, technical and technology advice.

7.2.3. Departmental Silicon Facility (DSF)
Alice pixel R&D and production, ATLAS pixel R&D, and CMS silicon R&D were active users of DSF
clean room in 2017. The new cleaner zone for ALICE in the back of the DSF is working well for the
ALICE production activities. A reconfigured airlock and more strict procedures has aided in
increasing the cleanliness of the whole DSF. The CMS zone has been rearranged for the CMS silicon
HGC (end-cap calorimeter) and for the CMS phase 2 silicon tracker. The new electronic access
system for the DSF clean room works well and allows better control of access to the clean room.
With the continuing LS2 and LS3 upgrade activities, the two labs and the DSF clean room are
expected to be heavily used in 2018.

7.3. Thin Film and Glass
Thomas Schneider

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 2017, several prototypes and small series
have been produced for Isolde, EN-VSC, HiRadMat and the μ-channel cooling activities in EP-DT.
The TFG thin film service is equipped with two multipurpose and several more dedicated coating
devices. Common for these installations is the Physical Vapour Deposition (PVD) thermal
evaporation process. With this technology, all kinds of materials (metals, dielectrics and even
organic material) can be deposited on a multitude of substrate. These coatings, either for optical
or functional applications, are produced in a clean room environment. In more than 30 years
highly specialized technical solutions have been developed in the TFG lab for the different HEP detector applications (UV enhanced spectral reflectors, photomultiplier WLS coatings, photocathode coatings, plastic fibre coatings etc.). Important productions of optical mirror systems in 2017 have been done for HiRadMat, AWARE and LHCb RICH1 upgrade R&D. Functional layers have been produced for example for μ-channel activities (EP-DT), bond lab (EP-DT) and the Microbuses R&D project together with EN-MME. The attached optical quality control infrastructure (several optical spectrometers, microscopes and 3D measurement devices) is getting more and more adopted by other groups and CERN users. Due to comprehensive contributions to several scintillating fibre detectors projects (ATLAS ALFA, LHCb SciFi) the accumulated fibre-expertise and built-up infrastructure in the TFG lab (fibre coating, machining, handling, gluing etc.) is now highly appreciated by the detector community. A common project in collaboration with BE-BI has been launched in 2017 to develop fibre based beam monitors for the different test beam areas. Several prototypes have been built in the TFG lab. Promising results from T11 November 2017 test-beam and cosmic telescope data have triggered now a follow-up pre-series production in the TFG lab for the Neutrino platform in 2018.

Fiber based beam monitor XBPF proto-type
Test-beam and design of X/Y beam monitor unit

7.4. Micro Pattern Technologies (MPT) workshop
Rui de Oliveira

The Micro Pattern Technologies (MPT) workshop focuses on the production of interconnection devices and radiation detector parts having features in between nano-metric (wafer fab) and milli-metric (traditional mechanics) production technologies. The workshop is involved in the development and production of parts, components for many projects for High energy, neutrino, nuclear and many other fields of applications.

7.4.1. Large GEM mass productions

Large GEM mass production started in 2016 at the MPT workshop. To reach the expected production quantities requested by the two main projects (780 GEM for ALICE TPC and 490 for CMS muon detectors) two persons have been hired in 2016 to increase the throughput of the historical team of three persons. The production during 2017 went smoothly without any big technical problems. Despite this good result, the Alice collaboration

GEM mass production situation for CMS GE11 and ALICE TPC
asked MPT to increase the production rate. We have hired and trained a new technician to reinforce our production capability in 2017. We are now in 2018 at full production rate (80 ALICE TPC GEM every 5 weeks and 20 CMS GE1/1 GEMs every 4 weeks). The excellent yield of production is regularly above 90%. These two productions are supposed to be complete by mid-2018 and we are now investigating seriously the mass production of the GEM for the next CMS GE2/1 project. With these two productions, MPT workshop can now claim that the GEM technology is well adapted to mass productions and that these productions exhibits excellent yields.

7.4.2. Machine installation program in Building 107

Last December the construction of the new building 107 was officially handed over to us for installation of our equipment. This implies the move of most of the machines from the present building 102. It is mandatory that the workshop activity should not be interrupted through long technical stops. This big constraint is defined by sharp deadlines on crucial activities, to keep on track LS2 planning, taking place in the workshop. To overcome this problem, it has been decided to split the move into many smaller resettling activities. This affects clearly the final date of the move. A detailed planning have been set up in 2017, bringing the last machine transfer to the end of August 2018. Up to now, no extra delays occurred.

Nearly all the wet machines are now already installed and waiting for pipe connections. The commissioning of these machines will be performed before stopping the wet activities in building 102. Doing this way the resettling of wet machines will not create any technical stop. The next steps are the CNC and press machine move.

7.4.3. Aluminum bus production for ALICE inner tracker

After many years of R&D, the Alice inner tracker aluminum bus project moved in 2017 to mass production mode at the MPT workshop. This special bus is doing the electrical interconnection of many ALPIDE solid-state silicon chips in order to create Long ladders. The only metal present on this flex is Aluminum. The multiple scattering induced by all the power connections is considerably reduce by the choice of this metal. This technology is unfortunately not available in industry, mainly because of the fact that the technologies used to process Aluminum are not competitive in term of price with the equivalent ones used for copper treatment. In addition, volumes requested by ALICE are not large enough to justify dedicated production lines that could reduce these costs.

One of the biggest challenges was to vacuum deposit thick Aluminum layer up to 30um on laser drilled polyimide foils to make proper plated through holes, then pattern these layers to finally get adapted signal transmissions lines with widths lower than 80um in some places. The production is following the expected planning, and we are confident to finish all the parts in 2018.
7.5. Composite laboratory
François Boyer

The composite lab continued to increase its infrastructures. In fact, a new area of 70 m² was added by including the lab 153/R-038. Some infrastructures works are still ongoing to optimize the use of this space. One room is now dedicated to the filament winding and ATLAS Truss production. To improve the capabilities and the quality of carbon production, a new automatic cutting table machine has been also procured and commissioned. This Cutting table has an exploitable area of 1400 x 1000 mm² and is able to cut carbon prepreg, foam, polymer films with a thickness below 10 mm. A new 4-axis filament winding machine was also procured in order to begin some R&D on carbon tubes.

![New cutting table with a dimension of 1400 x 1000 mm²](image)

The composite lab plans to improve continuously its capabilities with some additional future investments, like a new Freezer room, and boost even further its strong involvement in Alice, LHCb, LCD and Phase II projects as the ATLAS Pixel upgrade and CMS Outer Tracker. As mentioned previously, the composite lab was involved in several projects for the different experiments. Some examples of activities of this year are detailed below:

**ALICE**

The entire Detector Barrels Mechanics, that supports in position the staves and the detectors’ services, has also been produced at CERN, at INFN Padova and at LBNL Berkeley. The large carbon sandwich mechanics of the Barrel for the ITS innermost three layers, has been produced in the DT Composite laboratory as a shared effort between ALICE and DT.

![Production of ITS Inner Barrel Mechanical structure](image)
ATLAS
Development and production of Truss longeron prototypes in the frame of ITK program for ATLAS Phase 2 Pixel upgrade. All the cooling support and end parts have been also produced in-house. Two long prototypes (≈1.6 m) and three short prototypes (≈300 mm) have already been made in the lab.

CMS
In the frame of the upgrade of CMS Outer Tracker, the composite lab realized some carbon sandwich plates for the prototyping of TBPS ring (Error! Reference source not found.). A good control of the thickness (4.8 mm) is necessary in order to allow a good assembly of the different parts. This sandwich is composed of two skins of carbon prepreg M55J with the lay-up [0; +60; -60]s and a core composed of Airex foam (AIREX R82.80). In the meantime, composite lab keeps producing and improving the surface’s quality of carbon plates used for 2S and PS modules.

Collaboration with Micro Pattern laboratory
The composite lab is now involved in the construction of triple GEM detector for the BM experiment at NICA. Some readout PCB are cured in the composite lab’s autoclave due to their large size. These PCBs are cured at 200°C with 7.5 bars of pressure.

PCB stack before and after curing in the autoclave
8. Safety in EP-DT

Andrea Catinaccio, Isabelle Mardirossian, Burkhard Schmidt

During 2017 the group has further consolidated the conformity of the park of machine-tools attaining a steady state 96% conformity of the total WS machines (~170 machines in total) and 82% for the Micro Pattern Technologies (MPT) workshop (~60 machines in total). Several hundreds of safety documents and procedures have been stored in the new EDMS safety structure for DT group.

Meetings were organized with each DT-TSO in order to support them in the follow-up of actions reported during the safety inspections but also in the update of the SAILOR application. New additional safety measures were taken to follow-up safety issues in the MPT workshop.

The installation and commissioning of a new CNC in the workshop in building 166 was completed, together with the setting up of new equipment for the composite lab. Support was provided to the technical responsible in the framework of the supply and for all purchasing and logistics aspects.

A review process for DT safety is starting with special emphasis on lab conformity. This will be done in collaboration with the DSO and is planned to progress in the course of 2018, together with the logistics of all safety aspects related to the move of the MPT workshop to the new facilities in building 107.

9. Secretariat

V. Wedlake

In 2017 the DT secretariat continued to provide administrative and secretarial support to the group and to the following experimental collaborations: NA62, RD50, RD51, CLOUD
10. Selected Publications and Contributions to Conferences


7. E. Currás, M. Mannelli, M. S. Nourbakhsh, G. Steinbrück, I. Vila, Radiation hardness study of Silicon Detectors for the CMS High Granularity Calorimeter 2017 JINST 12 C02056


12. W.Adam et al. (The Tracker Group of the CMS Collaboration); *P-Type Silicon Strip Sensors for the new CMS Tracker at HL-LHC*; [JINST 2017 12 P06018](https://doi.org/10.1088/1748-0221/12/06/P06018)


17. C. Bortolin, D. Dyngosz, M. Kalinowski, P. Koziol, J. Mendez, J. Waleryczek, L. Zwalinski; *ATCA thermal management study for the ATLAS phase II upgrades*, PoS (TWEPP-17) 112

18. R. Cardella, I. Berdalovic, N. Egidios Plaja, T. Kugathasan, C.A, Marin Tolon, H. Pernegger, P. Riedler, W. Snoeys; *LAPA, a 5 Gb/s modular pseudo-LVDS driver in 180 nm CMOS with capacitively coupled pre-emphasis*, PoS (TWEPP-17) 038

19. R. Guida, B. Mandelli; *A portable gas recirculation unit for gaseous detectors*; [2017 JINST 12 T10002](https://doi.org/10.1088/1748-0221/12/10/T10002)


33. Eva Sicking; *Detector challenges for high-energy e+e- colliders*; Plenary talk at TIPP 2017, Beijing

34. R. Guida, M. Capeans, B. Mandelli; *Gas Systems for Particle Detectors at the LHC experiments: overview and perspective*; Contribution to TIPP 2017, Beijing

35. B. Mandelli, R. Guida, M. Capeans; *Performance of Resistive Plate Chamber operated with new environmental friendly gas mixtures*; Contribution to TIPP 2017, Beijing

36. R. Guida, M. Capeans, B. Mandelli; *Gas mixture monitoring techniques for the LHC Detector Muon System*; Poster Contribution to TIPP 2017, Beijing
Reflective Mylar foil glued to the NA62 Cone disc

PH-DT TFG Lab