Forum on Tracking Detector Mechanics 2022

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Book of Abstracts

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Strength Measurement of Tracker Detector Composite and Titanium Structures

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Tracker detector structures are designed to hold detector's sensors and its services on its place and to minimize the sensors'displacements during operation. As part of the ATLAS Hi-Luminosity LHC Upgrade, LBNL has recently developed the global support structures for the ITk detector. These structures are mostly made out of carbon fiber, chosen for lightness, strength, stiffness and radiation length. Two critical subassemblies were identified: the bracket & flange ring and mount pad assemblies. To validate and verify their design and strength two simplified experimental representations were designed and tested. Deformations and strains were measured with LVDTs and strain gauges respectively. Here we discuss the different designs of these structures and their computed and measured performances. We also identify potential approaches to integrate a Structural Health Monitoring system on the detector.

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Lattice strain mapping and tomography of thin-walled cooling pipe connections studied using synchrotron radiation

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In order to meet the increased thermal load associated with the enhanced detector chip designs, the CMS tracker upgrade will be cooled using two-phase CO_2. To minimise radiation shadowing, 2 mm diameter thin walled (100 μm) cooling pipes will be used within the detector. This system operates at low temperatures (-35℃) and high pressures (typical operating pressures of 8 bar to 70 bar, max test pressure 163 bar). Previous designs for these pipes have been based on CuNi alloys which do not possess the mechanical strength or reliability required for this new system. For this reason, investigations are currently ongoing into the suitability of new piping materials, and pipe joining mechanisms.

A number of characterisation techniques have been employed in the analysis of the pipes and their associated joining methods, however, this study has utilised synchrotron radiation to provide unique insight into the loading behaviour and failure modes of such connections. In this work, laser and orbitally welded connections of thin-walled stainless-steel pipes were subjected to in-situ tensile loading at the UK's synchrotron facility, Diamond Light Source in Oxfordshire.

X-ray diffraction (XRD) patterns were taken at various loading increments, alongside high-quality tomographic images around the central joint area, and above and below the joint, to determine the effect of heat affected zones (HAZ) on stress evolution. From preliminary testing at the University of Bath, it was determined that even without complete failure of the joint itself, there were significant changes to the pipes and joint, which would ultimately affect performance of the cooling system

Trends in axial and radial strain distribution within thin-walled cooling pipe connections under increasing load increments will be presented. Comparing between load states will then give information on how such samples carry load, the high strain regions, and the effects of any defect present from the manufacturing process. The insights gained will ultimately be used to refine finite element simulations of the joints and optimisation of joining parameters and methods.

Coffee and poster session / 15

Services Design for the CMS Phase II Outer Tracker Endcaps (TEDDs)

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To cope with the High Luminosty LHC (HL-LHC) data taking contidions the tracker detector of the CMS will be replaced by a completely new and enhanced version within the Phase-II Upgrade. The future outer tracker consists of two barrel parts and two end caps where one end cap is made of five double-disks, each hosting the p_T modules on all four surfaces. The building block of the mechanical structure of the end caps will be half-disks (Dees). The contribution will span the design of the services starting from the Dee level including the routing of the electrical, optical and cooling services, describe the current status of the design and the challenges encountered.

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Evaporation of CO2 in microchannels : CFD simulations with Fluent and microfabrication process

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Thanks to its good thermo-physical properties, in particular its high latent heat, CO2 is considered as a good choice for two-phase cooling devices [1]. The next generation of tracking detectors at LHC (CERN) will be cooled at temperatures between 10℃ and -40℃, by evaporating the liquid CO2 flow circulating in titanium mini-channels attached to the pixel silicon sensors of 4 cm². For the next eneration of pixel detectors installed on the Future Circular Collider (2045) , a new option, studied by the LEGI-LAPP team (Laboratoire d'Ecoulements Géophysiques et Industriels & Laboratoire d'Annecy de Physique des Particules) is to **circulate the CO2 within micro-channels integrated in the silicon covering the whole surface of the sensors**. Within the current decade, their thermal performances will have to be evaluated to validate this option. For this deadline, the **numerical simulation** of two-phase flows should help us to **predict the cooling performances** of CO2 in microchannels over a wide range of operating conditions (saturation temperature, cooling power,

hydraulic diameter and materials of the channels, mass flow rates, etc. . .). Until now, 2D simulations have been carried out on ANSYS Fluent 2020 for an isolated static bubble, with the Volume Of Fluid (VOF) method. This work has two main objectives which are discussed here: 1/ control and reduce the spurious currents induced by the low viscosity of CO_2 caused by the modeling of the surface tension force, 2/ set up a boiling model able to guess the correct bubble's growth rate for a given temperature field in the frame of VOF and VOF/Level Set approaches. With this work, we intend to simulate a CO_2 two-phase flow in a microchannel. In parallel, the fabrication in a clean room of silicon microchannels, sealed with pyrex, has begun. The primary objective is to measure the pressure resistance of prototypes of different dimensions, and to compare the results with the measurements done at CERN in 2020 [2]. Several challenges have to be overcome, in particular regarding the robustness of the connectors. The ultimate goal is to **manufacture prototypes of single and multi-microchannels**, in order to measure the dynamic and thermal behavior of CO_2 convective boiling on a test bench in the LAPP laboratory (Annecy, France), and to **compare experimental results with the numerical simulations**.

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Updates on an Advanced Radiation Dose Estimation Tool for the Decommissioning of High Energy Physics Experiments

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As CERN will move to the High Luminosity LHC (HL-LHC) during the Long Shutdown 3 (LS3, 2026), several detectors and components of the experiments need to be replaced with upgraded versions designed to take full advantage of the increased luminosity. The currently installed detectors will require significant person power over several months for their complete removal in a challenging radiation environment due to their exposure to intense high-energy beams for several years. Careful estimation and optimisation of the individual and collective dose for the personnel involved is therefore an essential part of the decommissioning planning.

In 2019, we presented the proposal(1) for a novel dose estimation system for radiation intervention planning. The idea was to combine the existing CAD drawings with improved radiation simulations (FLUKA) and creating a 3D virtual environment which monitors the instantaneous dose rate with respect to position within the environment.

In this talk we will present the first results obtained with the prototype system. As first use case, we chose the removal of the ATLAS Inner Detector (ID), which will be replaced by the ATLAS Inner TracKer (ITk) during LS3. Using a commercially available motion tracking system, we were able to capture the real-time movements of a person while training the ID removal on a full-size mock-up. Working with realistic positions inside the radiation field allowed us to predict the collective dose of the intervention with a much improved accuracy compared to spreadsheet-based prior attempts.

After the prototype stage, the virtual reality radiation dose estimation system has now been re-implemented using the game engine Unity to be compatible with other CERN-based activities (e.g.

the robotics framework). We are currently in the process of extending the ways to record, analyse and display positioning data, opening new fields of possible applications. For example, a real time display of corresponding radiation values can be used to optimise procedures during the training of personnel on the mock-ups. Importantly, stored positional data of each person during the decommissioning training can be used to directly test the potential efficiency of various shielding concepts before production, by applying a corresponding, modified radiation dose map to the existing virtual model and recalculating the received radiation dose.
We will show the strengths and weaknesses of the system and discuss its usability and how the system can be applied for various other radiation critical interventions, where detailed CAD drawings and dose maps are readily available. In particular, for the HL-LHC, radiation levels will sharply increase with luminosity (LS4 and beyond), the radiation protection aspects during interventions will become significantly more challenging. Hence a future use case would be the exchange of the ITk Inner System in LS4 or LS5.

1) Forum on Tracking Detector Mechanics 2019, Cornell University

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Construction of the ultra-thin Mu3e tracker detector

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A low-mass detector is fundamental to experiments where multiple scattering limits the spatial and momentum resolution of the tracking system. This requirement applies to low-momentum experiments, such as the muon to 3-electron decay search, i.e., the Mu3e experiment, under commissioning at PSI. To fulfil the material budget specifications (0.1\% X_o per layer), Mu3e exploits High-Voltage Monolithic Active Pixel Sensors (HV-MAPS). These chips integrate sensor and readout electronics and can be thinned to 50 μm thickness (or 0.054\% X_o). The remaining material budget is used on the mechanical support structure, of which the high-density interconnect flex circuit forms an integral part. The minimal thickness of each layer introduces considerable challenges related to the mechanical stability and construction of the detector components.

We will present the design of the Mu3e tracker and the mechanical tooling used during its construction. The challenges set by the Mu3e requirements for a low material budget detector will be discussed, and first detector prototypes will be shown.

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Detector cooling R&D with multi-micro-channels: lessons learned & open issues

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Due to their superior thermal performance, multi-micro channel cooling devices in different layouts and geometries are being proposed for the thermal management of particularly demanding sectors of silicon trackers in HEP experiments. Especially for boiling flows, the design of those devices must anticipate known issues such as oscillating flows and flow maldistributions from a common manifold into the individual micro-channels, which otherwise can cause local hot spots and severe pressure fluctuations. The introduction of restrictions/capillaries at the channel inlet is a well-established

method to apprehend such flow instability phenomena. The hydraulic backward-facing step created by such restrictions at the inlet of the main micro-channels serves additionally as a trigger for boiling onset, due to the drop in the static pressure in the near-wall region, and thus enhances the efficiency of the cooling device. However, if the channel design and the target flow parameters are not chosen carefully in tandem, the above mentioned general micro-channel layout (i.e. a succession of manifold, inlet restriction and main micro-channel) may induce cavitation and other surface damaging phenomena.
The proposed presentation will introduce this issue, starting from examples of high-speed camera flow visualisations and "post-mortem" analyses of silicon-glass multi-micro-channels from the first generation of R&D prototype devices used with boiling flows of carbon dioxide. A short literature review on the issue of cavitation and its related damage at the micro-scale will be presented, some damaged micro-channels at hand will be shown and discussed and an analytical procedure resulting in a "parametrical map" to eliminate the critical working conditions will be proposed. This allows for the prevention of damaging flow regimes within existing device layouts, and provides guidelines that can then be applied to the design of any micro-channel cooling layout conceived in the future. Whilst far from being fully resolved, the issue deserves much more attention and a plan of action for the future will be proposed, also in view of the new era of micro-channel detector cooling, which is aimed away from costly Silicon devices and towards 3D-printed light-weight realisations in metals or ceramics. In particular, any potential pitting damage may prove much more disastrous for 3D-printed structures, compared to those produced by MEMS techniques in monocrystalline silicon or glass. This in conclusion underlines the necessity of a better understanding regarding the damaging potential of the flow/structure interactions, in order to safely design and operate future on-detector cooling devices.

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First successful demonstration of operating a helium gas cooled pixel detector

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The Mu3e experiment searches for the lepton flavour violating decay $\mu^+ \rightarrow e^+e^-e^+$ with an ultimate aimed sensitivity of 1 event in 10^{16} decays. This goal can only be achieved by reducing the material budget per tracking layer to $X/X_0 \approx 0.1$ % and by using gaseous helium as coolant, a novelty for particle detectors. The pixel detector itself is based on High-Voltage Monolithic Active Pixel Sensors (HV-MAPS) which are thinned down to 50 μm.

This talk presents the realization of the gaseous helium cooling system. Thermal studies of the two inner pixel layers, corresponding to the Mu3e vertex detector, will be shown including the first successful operation of a thin pixel detector cooled with gaseous helium. A miniature turbo compressor circulates the helium. Optimized channels with low pressure drop distribute the gas to the detectors. A mass flow of 2 g/s is sufficient to keep the detector temperatures well below 70℃ for a heat load of up to 350 mW/cm^2 and an inlet helium temperature of 0℃.
This study shows that gaseous helium cooling for future tracking detectors is definitely a viable option.

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Integration Test with 2S Module Prototypes on a CO2 Cooled Ladder

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To deal with the increased luminosity of the HL-LHC, the CMS experiment will be upgraded until 2028. During this Phase-2 Upgrade the CMS Outer Tracker will be equipped with modules each consisting of two silicon sensors, either two strip sensors (2S module) or one pixelated and one strip sensor (PS module), depending on the position in the tracker. In the barrel region of the CMS Outer Tracker, the 2S modules are placed on mechanical support structures called ladders. A fully equipped ladder contains twelve modules which are screwed down to so-called inserts. The inserts are connected to a cooling pipe which allows CO_2 cooling of the inserts and thus the modules.

During the prototyping phase integration tests with modules on the support structures are performed. This talk presents the results of the first integration test with three 2S modules mounted on a CO_2 cooled ladder. One of the modules was irradiated with a fluence slightly above the expectation for the end of the CMS runtime. This module is equipped with temperature sensors to measure the thermal performance of the module on the final ladder structure. The results of the thermal measurements are compared with the expectation derived from the thermal simulation of the modules on the ladder.

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Lessons learned LHCb VELO Upgrade module construction

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This spring, the LHCb collaboration installed a new vertex detector, the so-called upgraded VErtex LOcator (VELO). The Velo consists of 52 modules with hybrid silicon pixel detectors. The sensors are kept cold using bi-phase CO2 as a cooling medium. The CO2 flows through micro-channels embedded in a silicon substrate on which pixel sensors and the hybrids are glued. The first active detector elements are located within 5 mm from the interaction point inside a secondary vacuum. Cooling temperature, vacuum level, radiation hardness and radiation length define strict requirements for the design and materials used. The choice of the adhesives is therefore of utmost importance. They must be thermally conductive and retain tackiness after several thermal cycles.

In this presentation the module design and construction will be described. The glue selection and jig design with emphasis on geometrical precision and handling will be discussed in detail.

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Tilted TBPS Ring Mechanics for CMS Phase 2 Upgrade Tracker

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Tilted Tracker Barrel with Pixel-Strip modules (Tilted TBPS) will be one of the sub-detectors of the future CMS Tracker, due for installation in the LHC Long-shutdown 3. The detector modules of this device are tilted to point towards the LHC beam interaction point. This module arrangement reduces the number of modules needed, but complicates the detector's mechanical construction. The key elements for solving this challenge are the Tilted TBPS "Rings"that provide the required positioning and alignment of the modules. 72 Rings will be necessary to guarantee particle track hermeticity on the three layers of the TBPS.

The Ring production has started recently, with the first pre-production unit completed and measured. This presentation will focus on the Ring manufacture and quality control. Additionally, design choices and specific challenges related to the production of the needed carbon-fibre polymer and metal matrix composite parts, cooling pipes and assembly tooling will be presented.

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Dynamic Simulations of Phase 2 Detector Cooling Systems

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CO2-based 2PACL cooling systems have undergone significant design changes to meet the challenges of Phase-2 detector cooling. The introduction of the surface storage reservoir (with a 100m height difference from the cooling plants), a smaller accumulator size with respect to transfer line volumes, larger cooling loads, and the need for a back pressure regulator have all lead to non-trivial changes in the design and control of 2PACL systems. The impact of these changes in the performance and control of the new systems needs to be studied.

In this work, a simulation model of the Phase-2 2PACL CO2 cooling systems has been developed. The model is developed in the object-oriented physical modelling platform EcosimPro. It is component-based, and uses the staggered grid method to decouple the mass and energy balance equations from the momentum equation. It uses the upwind scheme to account for reverse flow and enable splitting/merging flows. It uses a slip-ratio based void fraction model to account for two-phase flow. It also incorporates the UNICOS PLC library to model the control system.

The model has been used to simulate the startup cycle for Phase 2 systems. The startup of these systems differs significantly from previous systems, in particular, due to the inability to pressurise the whole system just from the accumulator. This new startup procedure has been incorporated in the model. The model has also been used to simulate the performance of the plant in detector heat load cycling (power on / power off / power on again) in both cold and warm operating conditions. In particular, the role of the surface storage reservoir is described in handling the two scenarios. Finally, the model has been used to study the behaviour of the plant when a temperature set-point change is requested.

The simulations give insight into the performance of the forthcoming CO2 cooling systems and will enable the operation of the systems in a safe and controlled manner.

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Mechanical support structure of the CMS Phase-2 Outer Tracker Barrel (TB2S)

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The CMS experiment, installed at CERN, benefits from the LHC hadrons collisions for its research studies. In preparation of the upgrade of the accelerator toward high-luminosity conditions, called Phase-2 period, the CMS sub-detectors have to be renewed and their performances improved. In particular its silicium tracker will reach its end of life due to radiation damages at the end of the LHC Run 3. Beside the change of the damaged sensitive parts its concept is also being upgraded to cope with higher tracks multiplicity and larger data rate.

The upgrade of the CMS experiment requires a complete re-building of its tracker. The global architecture will be close to the one of the tracker currently in use: with barrel and end-cap parts. This contribution focuses on the preparation on the mechanical support structure of one of the largest part of the future tracker: the Tracker Barrel with 2S-sensors - sensors with 2 aligned strips sections. This part supports the most outer tracker layers in the barrel region.

The preparation of the construction of this mechanical structure will be discussed. Its design is inspired from the current tracker design but needed adaptations. The mechanical behaviour has been studied with finite elements analyses. The most delicate parts have been prototyped and undergone mechanical test for comparison with the expected performances. The construction process is defined for achieving optimal mechanical precision.

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The DMAPS Upgrade of the Belle II Vertex Detector: mechanics and integration

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A major upgrade of the interaction region of Super-KEKB is needed to reach the design luminosity and it has been planned in the years 2026-27. This long shutdown gives the opportunity to install a new vertex detector (VTX) in the Belle II experiment, more robust with respect of the higher level of machine background and more performant, due to improved vertex detector standalone track finding efficiency.

A new DMAPS (TJ-180 nm) CMOS sensor will equip all the barrel-shaped ladders arranged in 5 layers with minimal material budget, ranging from 0.1 % X0 for the layer 1 and 2 to 0.8 % X0 of the 70-cm long staves of the layer 5.

A demonstrator has been designed for layer 1 and 2 (iVTX) with a monolithic self-supporting air-cooled structure to yield an all-silicon ladder. A 4-sensor wide module will be cut from the processed wafer and submitted two post-processing techniques: a large size signal redistribution layer (RDL) on top of the sensors and selective backside 50-um thinning.
For oVTX (layers 3, 4 and 5) an evolution of the ladder concept used in the ALICE ITS has been adopted, with a light mechanical structure, supporting a cold plate with liquid coolant hosting the sensors and on top traditional flex circuits to distribute power and for data output. The mechanical structure of the most challenging outer prototype ladder has been realized by a "subtractive method" : the truss structure is obtained by gluing, with a dedicated mask, the 3 planar carbon fiber layers,

obtained by a water-jet cut. The mechanical and thermal characterization of the prototypes will be presented.

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Space-flight readiness assessment of the PAN demonstrator mechanical design

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The Penetrating Particle Analyzer (PAN) instrument is intended to be installed on deep space and interplanetary missions and designed to measure the flux, the composition and the arrival direction of $100\frac{MeV}{n}$ to $20\frac{GeV}{n}$ highly penetrating cosmic particles.
While representing an additional cost for space missions, the PAN instrument could be a useful source of information on the space environment; information which can then be used to perform Space Weather forecast and to assess the radiation environment of other planets.

Being designed to be an additional payload to any purposes spacecrafts, the PAN instrument is compact, modular and has low-power needs. For the measurement of the particles properties, the instrument will relay on the magnetic spectrometer technique already employed on space experiments such as Pamela and AMS. Being more specific, the PAN instrument will be composed by two permanent magnets, three silicon-microstrip detective surfaces, two TOF - Time Of Flight - scintillators and two Pixel layers.

In this presentation, the current status of the PAN technology demonstrator will be presented. Specifically, a detailed introduction on the experiment scopes and mechanical design will be followed by the description of the peculiarity of the space environment in which the experiment will operate and on the mechanical loads which will be experienced by the instrument during the launch. Then the presentation will concern with the qualification tests performed on some components of the instrument and on the test which will be later performed on the whole assembly. To conclude, the FE mechanical simulations will be presented along with the correlation with the results obtained during the mechanical tests: deterministic and random vibrations and pyro-shock.

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Mass reduction by additive manufacturing

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Optimization of component geometry and minimization of metallic mass is crucial for building a well performing particle tracking detector. Although advances in composite technologies have allowed us to construct strong and lightweight assemblies from non-metallic, low atomic-number materials, metallic materials still have some key advantages over composites. Properties like non-permeability, isotropicity and compressive strength are some of the key factors why metals have not yet been replaced by composites in certain mechanical applications.

In the case of the CMS Tracker, the key areas where these constraints support the use of metallic components are fluid manifolds, tubing and fittings; wheel and wheel support assemblies, screws, nuts and bolts; detector coupling mechanisms and support pieces too complex, work-intensive and time-costly to justify replacement with composites. In these cases, it is crucial that the material usage is optimized to reduce excess metallic material.

A very promising technology for material optimization is the so called Selective-Laser-Melting -technology, SLM for short. In this process a mirror/lens guided laser is used to fuse together metal particles in a protective gas volume to create strong metallic components additively. With this technology it is possible to construct geometry that is impossible or impractical to create with traditional subtractive manufacturing methods alone. Moreover, when combined with traditional subtractive manufacturing the SLM technology can deliver parts that outperform traditional parts in accuracy, complexity, strength and mass, all at the same time.

The aim of this talk is to provide an in-depth look into the process of optimizing the mass and design of few key Inner Tracker components like manifolds, coupling pieces and supports to fully utilize the potential of the SLM manufacturing with by-hand, generatively or subtractively -optimized designs. Additionally, the talk aims to show the effectiveness of the SLM technology in the CMS Inner Tracker applications by comparing the resulting mass and performance of the components to those manufacturable by subtractive means with FEA studies.

Coffee and poster session / 35

Challenges on the experimental validation of Finite Volume Model thermal simulation of Modules for the CMS Phase II Outer Tracker

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The new Outer Tracker of CMS for the Phase-II upgrade will host about 13'000 Modules which will be cooled by two-phase Carbon Dioxide (CO_2) flowing at a temperature of around -35℃ at the evaporator. Given the mechanical and geometrical complexity of the Modules, simulations based on the Finite Volume Model have been extensively used in the R&D process for evaluating their thermal performance and comparing different design alternatives. Due to the huge number of Modules and the critical environment where they will be supposed to operate, simplifications were inevitably made in the definition of the boundary conditions, generally considering the worst-case scenario as a criterion choice between simulation alternatives. From this circumstance, it derives the need to compare numerical results with data coming from real tests on functional modules, to be executed on experimental apparatuses trying to recreate the environmental conditions of the new Tracker. A critical analysis between the boundary conditions modelled in the simulations and the real ones observed in experimental contexts is given, highlighting how these affect the comparison of results.

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Highly-integrated light-weight mechanical structures of Silicon Tracking System for the CBM Experiment

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The Silicon Tracking System (STS) of the future CBM experiment faces unique challenges regarding its mechanical structure. To cope with low-momentum reaction products originating from the heavy-ion beam-target interactions at rates up to 10 MHz we came up with the original design of the detector; it features double-sided double-metal (DSDM) silicon sensors, extended (up to 500 mm) analogue read-out aluminium polyimide micro- cables, and light-weight but stiff carbon-fibre support structures. The detector within its enclosure (made of carbon-fibre sandwich plates) is to be placed in the aperture of a 1 Tm dipole magnet.
The STS detector integration features very high level of the integration of various unique components. The building blocks of STS are 876 modules consisting of the 320μm sensor read out from both sides by a set of 64 micro cables of various lengths; there are 199 unique configurations of the modules. They are arranged on the light-weight carbon-fibre mechanical support structures forming ladders of 8 or 10 modules each. There are 106 ladders (38 ladder types) forming 8 tracking layers on 18 aluminium support frames. Latter also host powering and back-end read-out electronics, as well ass NOVEC-based cooling interfaces to cope with about 40 KW of heat produced by the STS electronics. Extensive test routines are performed on each level of the detector assembly to ensure proper performance of its components; due to the densely-integrated nature of our detector, only limited intervention is possible after system assembly. Our current approach to these challenging tasks is presented in this contribution.
The integration techniques, design choices and test procedures are being validated on the set of prototypes featuring different aspects of the system performance. Our experience with the ultimate up-to-date test bench of the future detector, the fully-functional down-scaled prototype mSTS with 11 functional modules on two tracking stations will be discussed.

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Evaporative CO2 pressure drops: comparison between measurements and calculations

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CO2 is becoming the main refrigerant for HEP detector thermal management. It has several advantages to achieve a compromise between material budget and cooling performance. The design of the cooling circuits for the Phase 2 CMS Tracker is being supported with a Matlab tool that implemetns correlations for liquid and 2-phase CO2 pressure drops. An analysis has been performed comparing the predictions of this MATLAB tool with measurements on real Phase-2 Outer Tracker cooling circuits to assess the accuracy of the correlations. Two Phase-2 CMS tracker subdetectors (TB2S and TBPS) with slightly different inner diameters of stainless steel pipe have been studied. The results of the measurements and the calculations are shown in the above-mentioned comparison, and the possible causes of the observed discrepancies are discussed, including a temporary solution for the design process.

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On the mechanical design of the SCD detector for the HERD experiment.

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The High Energy cosmic Radiation Detection (HERD) facility is an experiment part of the Chinese Cosmic Lighthouse Program currently under development and foreseen to be installed on the Chinese's Space Station (CSS). HERD's main science objectives are indirect measurement of dark matter, study of cosmic-rays composition and high energy gamma-rays observation. The experiment is foreseen to be installed on CSS in 2027 and is design to operate for at least ten years.

With a cubic shape and five active surfaces (the bottom being attached to the station), HERD will be made of five different detectors able to perform independent and redundant measurements. The core of the experiment will be a LYSO crystal calorimeter (CALO) surrounded by a fibre tracker detector (FIT), a plastic scintillator detector (PSD) and a silicon strip detector (SCD) as the outermost active component. A transition radiation detector (TRD) will be placed on one of the lateral sides to provide TeV proton calibration.

This presentation will mainly focus on the SCD design, integration and the space environment on which HERD will operate. After an initial description of the space environment on which HERD will operate and an overview of the experiment itself, the presentation will focus on the efforts done for the conceptual integration of the SCD and PSD as a sub-assembly to ease the AIV (Assembly, Integration, Verification) activities prior to the final integration into HERD. The mechanical design of the SCD planes will then be discussed together with the possibility to have two superimposed silicon detecting surfaces on the same plane. In conclusion the on-going investigation on possible alternatives to honeycomb for the sandwich core which could possibly increase the detector efficiency will be discussed.

Coffee and poster session / 39

Study of Thermal Interface Material for Front End Electronics Cooling of Silicon Tracking System

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The Silicon Tracking System (STS) is the main tracking detector of the future CBM experiment at the future FAIR facility. It is designed to reconstruct charged particles trajectories inside a 1 Tm magnetic field to achieve a momentum resolution better than 2%. The system comprises of 890 low-mass detector modules, based on double-sided silicon micro-strip sensors, distributed on 8 tracking stations.
Due to the expected non-ionising irradiation damage at the end-of-lifetime, the innermost sensors will dissipate upto 6 mW/cm2 at −10 ℃. So, it is crucial to always keep the silicon sensors and the front end electronics at temperatures close to -10℃ during the operation. In order to cool down the electronics, it becomes very important to choose the Thermal Interface Materials (TIMs) with good thermal conductivity.
This contribution will mainly focus on the testing of thermal interface materials between the Front End Electronics Board and the cooling shelves. This will include: [1] What are the basic requirements when it comes to TIMs from STS point of view [2] Thermal and mechanical tests performed with the TIM [3] Functionality tests using TIM with module.

Coffee and poster session / 40

Solutions for humidity and temperature monitoring in the Silicon Tracking System of the CBM experiment

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The Compressed Baryonic Matter (CBM) is one of the core experiments at the future Facility for Anti-proton and Ion Research (FAIR), Darmstadt, Germany. The Silicon Tracking System (STS) is a central detector system of CBM, placed inside a 1T magnet and with an operation temperature of about -10°C to keep low radiation-induced bulk current in the silicon sensors.

Due to the conditions inside the STS an efficient temperature and humidity monitoring and control are required to avoid icing or water condensation on the electronics or silicon sensors. Most important properties of a suitable sensor candidate are resilience to the magnetic field, ionizing radiation tolerance and fairly small size.

In this contribution, we introduce two different approaches to implement relative humidity (RH) and temperature Fiber Bragg Grating Fiber Optic Sensors (FBG FOS). The first approach is based on inscribing both RH and temperature FBG into one fiber and the second one features two separate FBGs arrays. In both cases, the RH-sensitive FBGs are coated with polyimide.

Moreover, the applicability and efficiency of FOS in comparison to dew point transmitters and capacitive RH sensors will be discussed. The focus will also be put on the potential integration of the sensors in different levels of interlocks.

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Extrusion Deposition Additive Manufacturing of carbon fiber reinforced composite parts and tools for particle detector mechanics

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Detector mechanics play a significant role in in a detector's performance and improvements are often tied to reduction of total mass to save on material budget. Particle detectors at future colliders rely on ever more precise charged particle tracking devices, which are supported by structures manufactured from composite materials. This talk lays out engineering techniques able to solve challenges related to the design and manufacturing of future support structures. Novel manufacturing methods like Extrusion Deposition Additive Manufacturing (EDAM) along with associated simulation tools for prediction of part production and performance are highlighted with case studies from the High-Luminosity Phase Upgrade project for the CMS detector. The material selection method is reviewed along with radiation effects on material properties for in-performance part dimensional stability. The process simulations using Additive3D, a simulation tool developed at Composites Manufacturing and Simulation Center, Purdue University help identify the manufacturing challenges and shape changes in the EDAM parts like the inner tracker rails. Specific geometric and design considerations for the proposed CMS Inner Tracker Rails are discussed to illustrate advantages and constraints for additively manufactured structures. The applicability, benefits, and uses of this technique to replace conventional tooling methodologies for composite layup part manufacturing are also highlighted.

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IRIS vertex, how to get closer to the interaction point

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Positioning the first sensor layer as close as possible to the interaction point represents one of the major requirements for future generation vertex detectors. In view of the ALICE upgrade for LHC RUN5, a futuristic concept of a vertex detector inserted inside the beampipe has been proposed. The vertex is constituted by four different modules, called petals. Three layers of sensors are housed inside each petal in a secondary vacuum environment. The petals can open and close, like in an iris optics diaphragm such to leave a clear passage to the beam during injection. At stable beam in the close configuration, they leave a minimum passage for the beam and place the first layer at 5mm form the interaction point. The petal walls, which separate the detector from the primary LHC vacuum, are the dominant contribution to the material budget and their thickness must be minimized. The wall of the petals oriented towards the beam acts as a radio-frequency (RF) foil, that controls the electromagnetic fields induced by the beam. Since this is equally relevant for the open and close positions, the petal geometries are designed to achieve an almost closed round bore when opened or closed, respectively. Detailed studies to verify that the design fulfill the beam requirements in term of aperture, impedance and vacuum stability have started. A further critical challenge is to develop the mechanics and vacuum equipment to preserve the possibility of access for maintenance.

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ALICE ITS3: the first truly cylindrical inner tracker

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The ALICE experiment has planned to replace during the 3rd LHC long shutdown the three innermost layers of the ITS detector by a next generation vertex detector based on bent, wafer-scale CMOS sensors.
The new vertex detector, named ITS3, consists of three truly cylindrical layers, each made of two wafer-scale sensors, thinned down to below 40 µm and bent to 18, 24 and 30 mm curvature radius.
This talk highlights the R&D activity carried out to develop the assembly procedures and jigs for layer bending and positioning, as well as for wire bonding interconnection procedures.

Coffee and poster session / 44

CMS Phase-2 Tracker endcap module cooling

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For the high-luminosity LHC (HL-LHC), CMS will install a completely new silicon tracker. The future outer tracker will consist of two barrel parts and two endcaps (TEDD), one on each side. One endcap is made of five double-disks. One double disk is assembled from four half disks (Dees) on which the detector modules are mounted. The Dees are a highly embedded carbon fiber and foam sandwich with integrated cooling pipes and module positioning inserts.
Due to its large and homogeneous power density, the PS detector modules need to be cooled from their entire underside of about 5 x 13 cm2 area. The carbon fiber facings of the Dees act as cooling surface. Carbon foam blocks are glued to the embedded cooling pipes and to the facing to facilitate the cooling of the Dee surface. The integrity of the carbon foam blocks and the proper gluing to the facing is important to establish the necessary cooling contact and needs to be validated during the Dee reception testing. A test system using infrared imaging has been built to discover non-conformities that would lead to a deteriorated cooling performance. The capabilities of this system has been demonstrated by extensively studying the Dee prototype. The infrared measurement setup will be presented and results obtained from measurements of prototypes will be discussed.
One challenge is the identification of a thermal interface material (TIM) conforming to the requirements. The TIM must have a low thermal resistance even when used without pressure, re-workable in a potential module exchange, be radiation hard to the expected dose levels and an application technique has to be found, respecting the constrains of the handling of the fragile modules. Several candidate materials are being studied, with a focus on a two component self-curing thermal gap filler. The thermal performance and the mechanical properties of the TIM is being studied in preparation of an irradiation campaign to verify the material parameters at the end of life of the experiment. In this context a new thermal conductivity measurement setup has been built, commissioned and used to quantify the thermal performance of the candidate materials. The thermal conductivity measurement setup will be presented and the results will be discussed. The results of the mechanical testing will be presented as well as the plans and tests for the application of the material when integrating detector modules.

Coffee and poster session / 45

CO_2 evaporative cooling system for the LHCb UT Detector

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The LHCb Upgrade requires a new Silicon Strip Tracker detector with improved performance.
The Front-End read-out electronics will be in the active area, close to the sensors: this is a key feature driving the mechanical and cooling detector design, together with the requirement to mantain the maximum temperature of the Silicon Sensor below −5℃ during data-taking, to withstand radiation damage and thermal runaway effects.
The design of the detector implements an integrated cooling system exploiting CO2 evaporation and a cooling plant based on the 2-Phases Accumulator Control Loop cycle.
CO2 evaporation temperatures will be in a range from ambient temperature to −30℃, the working point being set after measuring and controlling the real detector components temperatures (i.e. read-out ASICs hybrid).
The support structure for the sensor modules is a lightweight carbon fiber mechanical structure embedding a cooling pipe, designed to pass underneath the read-out ASICs, which are the main thermal power sources to be cooled down.
The poster gives a technical description of the LHCb UT detector cooling system and CO2 flow control and distribution, with a focus on the “first time use of snake pipes” and “first time use of calibrated orifices (200 micron diameter)” inlet flow restrictors for the control of the flow ditribution into the 68 parallel detector local supports called “staves” (each one with a snake pipe cooling inside).

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Hybrid cycle with Krypton for cooling of future silicon detectors in HEP

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The Large Hadron Collider (LHC) will soon deliver much more radiation after LS4. The level of radiation has already pushed the current CO2 cooling unit to its limit, represented by the triple point (≈ -56℃). To sustain the harsh requirements imposed in terms of radiation, temperature levels and mass minimization the sensors should be maintained at a temperature sufficiently low to prevent the thermal runaway while at the same time the heat load generated inside in the readout electronics and sensor must be removed. The refrigerant Krypton stands out as the most promising coolant thanks to the best thermal performance with the smaller cooling pipes inside the detector and to the highest resistance to radiation, being a noble gas. As side-effect to reach temperature levels unattainable by CO2, higher radiation length is expected due to the larger atomic number and lower liquid-vapor density ratio. Besides investigating the work done so far on thermal management design aimed to reduce the temperature difference sensor –coolant it is crucial to ensure a stable and controlled cooling rate without shocking the detector.
Krypton being a high-working pressure fluid is able to remove efficiently the heat generated inside the detector via the use of small tubes, with less impact in terms of space compared to others low-temperature working fluids. The same silicon sensor technology currently used with two-phase CO2 flowing in titanium tubes located close to the heat source (electronics & sensors) will be adopted. A much lower critical and NBP temperatures compared to CO2 require a completely new cooling cycle. In fact, the vapor phase at room temperature imposes a gentle supercritical cool-down process to avoid the shock of the detector. A special cycle technology is also needed to work either in sub or supercritical state, covering a very large temperature range. A specific control logic must be implemented to cool down gently the detector while maintaining an acceptable temperature gradient along the detector. Different components are activated according to the operating conditions in terms of working envelope (either sub or supercritical), as well as according to the temperature levels.

Coffee and poster session / 49

LPG sensor technology for environmental monitoring: from the laboratory to the detector

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For the Inner Tracker (ITk) detector of the ATLAS experiment at CERN the environmental monitoring is essential for optimal operative conditions. A constant relative humidity monitoring is required in fifty different points inside the ITk detector, where the dew point is lower than -60℃.
In this context, Fiber Optic Sensor (FOS) technology based on Long Period Grating (LPG) and Fiber Bragg Grating (FBG) have been combined to provide a unique sensing device. The FBG sensors are a consolidated technology that can provide relative humidity and temperature monitoring over a wide range. However, with intrinsic sensitivity of 1% RH and accuracy of 2% RH, they fail to detect relative humidity with satisfactory precision when it goes below 10%. In this range, the very high sensitivity of LPG sensors to relative humidity enables its accurate measurement. This device must be installed in an ad-hoc package that guarantees its protection against damages while leaving unchanged its response and performance. Moreover, a customized multiplexing system has been developed to continuously and simultaneously monitor the fifty measurement points inside the ITk detector with a single optical fiber interrogator.
The talk will focus on the engineering aspects that led to the development of the final device for environmental monitoring in the ATLAS ITk detector.

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Welcome

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Introduction to posters

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Introduction to posters

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Introduction to R&D

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Closeout

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Tour of LNF

Coffee and poster session / 57

Overview of the production preparations for the ATLAS ITk strip end-cap detector at DESY

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The ATLAS Inner Tracker (ITk) of the phase-II upgrade of the current ATLAS tracking detector and is designed to meet the challenges at the high-luminosity LHC. The ITk silicon strip end-caps will cover the forward directions of the detector and consist of six disks populated with wedge-shaped silicon micro-strip sensors, divided in modules containing the readout, power and control electronics. The modules are directly glued on likewise wedge-shaped local support structures called petal cores, consisting of carbon fiber-based sandwich structures with embedded titanium cooling pipes as well as data and power buses. The petals are the fully loaded structures with in total 18 sensor modules in six different shapes and each end-cap disk will be constituted of 32 instances, requiring overall 384 petals.
After finalizing in most areas the R&D phase of the ITk strip detector, the project is in the transition phase towards production. In the currently ongoing pre-production, the multi-stage assembly process of the various components is trained, the worldwide distributed construction sites are qualied for production and the complex logistics chain is validated.
In this contribution, an overview of the production preparations of the petal cores up to the loaded petal at DESY will be given. The production chain starts with the machining of components for the petal core, goes on with the actual core assembly by an industry partner and the following quality control tests performed on the local support structures before being ready for module-on-core loading to have the final petal object.

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Pressure resistance characterisation of micro-vascular networks embedded in carbon composites for High Energy Physics applications

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Carbon composite materials are ideal candidates for High Energy Physics (HEP) applications due to their low density, high stiffness-to-weight ratio and excellent thermal properties. They are widely used in the support structures of tracking detectors, where they play a key role in the thermal management of the silicon sensors and readout electronics. In state-of-the-art trackers such as those installed in the experiments at CERN's Large Hadron Collider, lightweight composite structures provide the main heat path between the silicon modules and a network of metallic or plastic pipes containing a cooling fluid. However, despite the good results obtained with this approach, the performance targets of future HEP experiments call for even lighter and more efficient technologies. In this respect, the use of sacrificial materials to create micro-vascular networks in the composite laminates represents a very appealing solution to integrate the cooling circuit in the support structure.

Yet, despite the potential advantages in material budget, thermal performance and mechanical stability, the difficulties to predict the pressure resistance and long-term leak tightness of the embedded networks hinder their application in detector areas where reliability is paramount.
In this work, both experimental and numerical methods have been used to investigate the pressure resistance of channels embedded in carbon composite laminates. Modified poly(lactic) acid (PLA) preforms have been combined with a post-cure vaporization technique [1] to manufacture plates with longitudinal channels. Destructive tests have been carried out to determine the burst pressure of the plates as a function of the layup and the cross-section geometry of the channels. The deformation of the composite plates during the tests has been monitored using Digital Image Correlation (DIC).
In parallel, a finite element model has been developed to predict the resistance of the plates, relying on cohesive elements to simulate the failure of the channels subject to internal pressure. Experimental delamination results obtained with mode I double cantilever beam (DCB) test specimens have been used to determine the input parameters for the numerical model.

[1] Stephen J. Pety, Marcus Hwai Yik Tan, Ahmad R. Najafi, Philip R. Barnett, Philippe H. Geubelle, Scott R. White. Carbon fiber composites with 2D microvascular networks for battery cooling. International Journal of Heat and Mass Transfer, Volume 115, Part A, December 2017, Pages 513-522

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Heat Extraction through Structural Components of the CMS Phase II Inner Tracker Forward and Endcap Pixel Detector

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The CMS Inner Tracker pixel detector will be rebuilt for the instantaneous luminosity of 7 x 10ˆ34 cmˆ-2 sˆ-1 and up to 200 pp collisions at the High Luminosity LHC. The detector will consist of a barrel section, the TBPX, and small and large forward discs, the TFPX and TEPX, respectively. To achieve per mille hit occupancy, the new sub-detectors will feature higher granularities that will result in higher heat dissipation. Cooling the detector will be of paramount importance to avoid thermal runaway and some structural components must serve to extract heat.

This talk focuses on the TEPX and TFPX sub-detectors and first outlines their cooling requirements through finite element analyses. For the TEPX, we showcase the cooling performance of the prototype Dee structure and simulate the effects of the parylene module coating, necessary for the modules' operation at high voltages after large accumulated radiation. We also present results using titanium cooling loops that reduce the effective cooling loop mass to half. We then present detailed thermal conductivity measurements of structural materials proposed for the TFPX using novel, custom-made apparatuses. Through a comprehensive campaign of measurements, we motivate our choices for high thermal conductivity materials that survive high radiation: graphite-doped carbon fiber cured at high pressures, diamond-doped adhesives, and diamond-doped greases. Finally, we present procedures to apply the adhesives and greases using a gantry to construct TFPX Dee structures and mount detector modules on the Dees.

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The ATLAS patch panel 01 (PP1): engineering aspects and cooling system

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PP1 is one of the most critical components in the ATLAS pixel detector that has to guarantee a dew point temperature in the detector volume less than -60℃, close the Faraday cage, allow the passage of more than 14k links and 14 cooling lines. New rubber like sealing materials have been qualified up to 6 MGy and data cable feedthtroughs have been developed to seal the data links. The PP1 mechanical design and manufacturing as well as the gasket qualification and data feedthrough design and prototyping are discussed. The sub-detectors have to be cooled down to -35 ° C using biphasic CO2 refrigerant. The PP1 cooling system is designed to connect the main cooling system to the pipes of the individual sub-detectors. The design of the cooling distribution for the 3 sub-detectors and also the description of individual components will be discussed.

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ATLAS upgrade module production activities at Oxford

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The HL-LHC project will improve luminosity at the LHC by an order of magnitude, increasing the potential for the discovery of new physics. As such, detectors operating at the LHC must simultaneously be upgraded in order to sustain higher luminosities, tolerate an increased radiation environment and improve spatial and temporal resolution. The OPMD group at the University of Oxford are involved in the ATLAS detector upgrade project, and specifically will produce hundreds of RD53 modules for the ATLAS upgrade inner tracker outer-endcaps. The approach to module production at OPMD incorporates the use of a precision robotic gantry positioning system, providing a semi-automated process. The robotic gantry system is integrated with vision and a micron-precise laser rangefinder for in-situ measurement capability. Custom vacuum and air-pressure tooling has been designed to enable the production process. High precision post-production metrology is carried out through the use of an OGP SmartScope. This paper summarises the RD53 production experience at Oxford to date, detailing the process and its evolution, and providing measurements relating to reliability, accuracy, and repeatability.

Coffee and poster session / 63

Thermal pretest @ the front-end electronic area of the STT detector

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Within the Panda experiment, the STrawTube - detector (STT) is one of the innermost detectors at the interaction point for recording information of the generated events. In order to record as much data as possible in high quality, a high detector recording density is provided. This leads to the minimum packing space for the required electronic hardware in the STT setup. One aspect in the overall design is the thermal load due to the power consumption, internally as well as of the adjoining detectors. For this purpose, an experimental setup with similar geometric dimensions was produced at the IKP.
The basic framestructure of the setup consists of sectional exchangeable aluminum elements. The frame is used like the final design for support forces, cable routing and card positioning. To represent the internal thermal power dissipation, 29 layers in total have been installed within three sectors.

Each layer was equipped with the appropriate number of resistors to represent the front-end card number. In order to determine the influence of the respective factors, the experimental setup was set up sequentially in different variations. Our experience and results will be discussed.

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Titanium orbital welding: 3D printed parts to bulk

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Additive Manufacturing (AM) is an incredibly interesting solution for high energy physics due to its design flexibility and to its lightweighting opportunities. As this technology is spreading in physics experiments, several new issues have to be solved. The integration of parts produced by AM is one of the open questions. This study described the tests done on orbital welding of Ti6Al4V Grade 5 pipes produced with AM and standard bulk Ti6AL4V Grade 2 pipes. Welding procedure was optimized, and the finished parts were then verified according to ISO 15614-5 regulation. Computed micro-tomography (CT), leak test, pressure test up to MDP (Maximum Design Pressure), leak test after pressurization and destructive tests such as metallographic examination and tensile test are presented in this work.