Forum on Tracking Detector Mechanics 2016

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Book of Abstracts

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PRESTO: Vacuum-compatible, ultra low material budget precursor of the Micro Vertex Detector for the CBM experiment at FAIR

Corresponding Author: klaus@physik.uni-frankfurt.de

The Compressed Baryonic Matter Experiment (CBM) is one of the core experiments of the future FAIR facility at Darmstadt/Germany. The fixed-target experiment will explore the phase diagram of strongly interacting matter in the regime of high net baryon densities with numerous probes, among them open charm. The Micro Vertex Detector (MVD) will contribute to the secondary vertex determination on a 10 µm scale, background rejection in dielectron spectroscopy and reconstruction of weak decays. The detector comprises four stations placed at 5, 10, 15 and 20 cm downstream the target and inside vacuum. The stations are populated with highly-granular Monolithic Active Pixel Sensors implemented in the 0.18 µm Jazz/Tower CMOS process. The sensors feature a spatial resolution of <5 µm, a non-ionizing radiation tolerance of >1013 neq/cm², an ionizing radiation tolerance of 3 Mrad and a readout speed of few 10 µs/frame.

In the upcoming Forum in Tracking Detector Mechanics, we would like to focus on presenting a next step w.r.t. mechanical integration, that is the precursor of the quadrant of the third CBM-MVD station, meeting the following requirements: material budget of x/Xo < 0.5 %, vacuum compatibility, double-sided sensor integration, heat evacuation of ˜350 mW/cmˆ2/sensor with temperature gradient of a few K/cm. The precursor (working name: "PRESTO") has been recently assembled and hosts 15 CMOS sensors: nine populated on the front side and six on a back side, respectively. The sensors are the MIMOSA-26 CPS and they were developed at IPHC Strasbourg. The sensors were probe tested prior to populating them on a 380 µm thin Thermal Pyrolytic Graphite (TPG) carrier with a precision better than 30 µm (edge-to-edg) proven during assembly of dummy modules The custom-made, low modulus, low viscosity and radiation-hard glue developed at Rutherford Appleton Laboratory allows a for vacuum-compatible sensor and cable assembly, keeping the material budget as low as possible. After integrating the PRESTO module, our research focused on a full characterization regarding vacuum compatibility and thermal management as well as aspects of metrology, e.g. survey of sensor positions and alignment. We aim at reporting on the PRESTO construction as well as on the first results regarding cooling efficiency, vacuum compatibility and R/O performance.

Summary:

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Controlling thermal deformations

Corresponding Author: f.sanders@nikhef.nl

For the LHCb silicon detector modules or VeloPix modules, thermal stability is an important issue. The sensors are being cooled down over a gradient of 50 degrees Celsius. Early prototype tests showed that the thermal deformation is in the sub millimeter range while the requirements only allow a few microns of movement. It is assumed that this issue is caused by different thermal expansions. To minimize this deformation a design is made that uses Borosilicate glass to match the coefficient of thermal expansion to that of Silicon and at the same time have a function as a thermal insulator. This prevents other materials from having a temperature gradient.

The presentation will go into detail in the following subjects; the material selection, the temperature depended properties, simulations and experiments.

Summary:

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Welcome

Corresponding Author: jochen.christian.dingfelder@cern.ch

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Micro-channel cooling for silicon detectors

Corresponding Authors: miguel-angel.villarejo.bermudez@cern.ch, nils.flaschel@cern.ch

Abstract 1:
In this contribution a novel cooling concept for light-weight position-sensitive detectors is proposed. Our solution is based on a micro-channel cooling circuit that is integrated in the silicon sensor. Results are presented of a characterization of the cooling performance of several mechanical samples fabricated at HLL in Munich. A moderate flow of order 1 l/h of mono-phase cooling liquid is found to be sufficient to evacuate a power dissipation of several tens of Watts with a minimal temperature gradient between coolant and the sensor surface. The liquid flow has no significant impact on the mechanical stability of the sensor. A finite-element simulation can provide an adequate description of the cooling performance and is used to extrapolate the results to a more realistic environment

Abstract 2:
In many high-energy experiments, the silicon sensors will need to be kept at very low temperatures. The main goals of cooling are to keep the leakage current low, to avoid thermal run-away as well as uncontrolled annealing of defects due to radiation damage in the sensors. This project aims at testing a method to reduce material and space needed for the cooling system. Micro-channels etched into silicon are a very promising alternative to the current cooling strategy based on the use of bigger cooling pipes. DESY, in collaboration with IMB-CNM Barcelona, is investigating this method in a generic R&D project.

A prototype micro-channel layout has been designed, produced and tested in collaboration with CNM in Barcelona. The micro-channels are etched into silicon using DRIE etching and are further fabricated using anodic and eutectic bonding. The sample has been implemented into a setup containing a Hydrofluoroether monophase coolant. Two different versions of the device were tested, one with the full wafer and one with the silicon cut to the structure of the channels. Measurements were done using temperature sensors and an infrared camera and the experiment was carried out in air and in vacuum. At the same time the micro-channels were simulated regarding the flow and the thermal properties.

Summary:

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Thermal test and monitoring of Belle II vertex detector

Corresponding Authors: hua.ye@desy.de, david.moya.martin@cern.ch

The Belle II, as an upgrade to the former Belle detector is undergoing at SuperKEKB which aims to increase the peak luminosity to 8×1035cm−2s−1. The two-layer DEPFET pixel vertex detector (PXD) and the surrounding four-layer silicon strip detector (SVD) consist the Belle II vertex detector (VXD). In order to guarantee acceptable operation conditions for the VXD and the surrounding Belle II drift-chamber (CDC) the cooling system must be capable of removing a total heat load from the very confined VXD volume of about 1 kW plus some heat intake arising from the SuperKEKB beam pipe. Evaporative two-phase CO2 cooling in combination with forced air flow has been chosen as technology for the VXD cooling system.

To verify and optimize the VXD cooling concept, we build a full VXD mock-up with the same mechanical and thermal properties as the finial detector, the humidity in the volume is monitored with fiber optical sensors. In this talk we mainly present the measurements to the PXD thermal mock-up.

Summary:

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Developments on the mechanics and cooling for the CLIC tracking detectors

Corresponding Author: szymon.sroka@cern.ch

The CLIC detector tracking system is currently composed of a vertex detector with three double-sided layers of silicon detectors in both the barrel and forward regions and of a silicon tracker consisting of six barrel layers and four/seven disks on the outer/inner tracker subsystems, respectively. The strict requirements in terms of material budget (2 x 0.2% X0 per vertex double layer and 1% X0 per tracker layer) require the development of novel low-mass support structures and non-conventional cooling solutions. This talk will present the support structures concepts that are currently being explored as well as first results from finite-element simulations and small-scale prototypes. Initial results from the studies on the feasibility of air cooling for the CLIC vertex detector will also be shown.

Summary:

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Using Foams for Ultra-Low Mass Vertex Detectors

Corresponding Author: joel.goldstein@cern.ch

Carbon and ceramic foams have the potential to be used as structural supports for thinned silicon pixel detectors to create ultra-low mass detector modules. They are easy to handle, have a high-specific stiffness, and good thermal and other properties. I will describe a programme of R&D using this concept carried out by the LCFI, LowMass and PLUME collaborations towards modules for

vertex detectors at future colliders. These designs have achieved material budgets of ˜0.1%X0 (single-sided modules) and ˜0.3%X0 (double-sided modules).

Summary:

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Laser Welding of the CMS FPIX Phase 1 Upgrade Cooling Pipes

Corresponding Authors: stimpone@fnal.gov, gregory.everett.derylo@cern.ch

The CO2 cooling system for the CMS Phase 1 FPIX Forward Pixel Upgrade uses thin walled stainless steel tubing fused by autogenous laser welding. The metallurgy, joint design, and welding process must all work in harmony to produce a reliable joint. We summarize the significance of alloy composition, impurities, and other problems specific to laser welding of austenitic stainless steels. Fully internal weld defects such as cracks or pores in the micron range necessitate precise inspection methods. We present our experience with several diagnostic methods such as micro-hardness measurements, metallographic inspection and 3D micro-CT scanning of welds.

Summary:

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CMS Phase 2 Outer Tracker Central Barrel Upgrade

Corresponding Author: kamil.cichy@cern.ch

A novel detector design with tilted silicon pixel/strip detector modules is being considered for the inner section of the CMS Tracker Upgrade Phase 2. The layout and a support structure concept for such tilted geometry are presented. The detailed design includes cooling interfaces, distribution of the services, cooling pipes and assembly sequence of the support structures.

Summary:

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Prototyping and R&D for the CMS Phase 2 Outer Tracker End Caps

Corresponding Author: andreas.mussgiller@cern.ch

For its future tracker, CMS will utilise two different module types throughout the tracker. Above radii of 60 cm the end caps will be equipped with modules composed of two closely spaced silicon strip sensors, whereas at smaller radii it will be equipped with modules made of a silicon strip and pixel sensor. The support structures foreseen in the CMS end caps are half-disks of diameter 2.4 m that will be equipped with modules on both sides. A combination of four half-disks with alternating module positions ensures hermetic coverage for particles originating from the interaction point. These so-called dees are highly integrated sandwich structures that provide the necessary mechanical support and at the same time integrate cooling and positioning inserts for the modules. To verify the concept a small-scale prototype has been developed and built at DESY. We will report on the design and assembly concept, lessons learned from the first prototype, results from thermal and mechanical measurements, and ongoing generic R&D efforts.

Summary:

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Mechanics and Construction of the LHCb Upstream Tracker Detector

Corresponding Author: raym@physics.syr.edu

The LHCb Detector will undergo an upgrade during the LHC shutdown in 2019. The UT (Upgrade Tracker) is a silicon strip tracking detector being designed and constructed as part of this upgrade. The UT will provide a fast momentum measurement for the trigger as well as function as part of the overall tracking system where it will severely reduce the presence of "ghost"tracks. The UT Tracker consists of ˜1000 ˜10x10 cm2 silicon strip sensors, with custom ASIC readout chips (SALT) arranged as modules containing flex circuits and ceramic substrates. These modules are to be mounted on staves, lightweight CFRP and foam sandwich structure supports with integrated CO2 cooling. The cooling tube follows a snake-shaped routing which allows the tube to run under all the ASICs and provide efficient cooling.

The first phase of construction is now underway. The design details of the UT Tracker staves and modules will be presented, as well as construction procedures and plans. These include the latest results on design finalization, component mechanical and radiation tests, simulations of dynamical behavior, construction techniques, handling of critical surfaces, outer frame and box design, and other relevant activities.

Summary:

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Module support structures and thermo-mechanical prototypes for the endcap of the ATLAS strips tracker

Corresponding Author: sergio.diez.cornell@cern.ch

The forward regions of the phase-II ATLAS strips tracker consist of 6 disks per side, constituted by low-mass wedge-shaped structures called petals. The active regions of the detector are constituted by the so-called silicon modules, constituted by silicon microstrip sensors and their associated readout and power electronics. The silicon modules are directly glued on top of carbon fiber-based structures,

called 'cores'which provide precise mechanical support, integrated cooling, power rails and high-speed data links from and to the outside world. The petal cores consist of carbon-fiber structures with integrated titanium cooling pipes. The titanium pipes are surrounded by thermal carbon-based foam in order to enhance the cooling power along the structure. The structure is enclosed by carbon-fiber skins co-cured together with thin, flexible, polyimide-copper PCBs called 'bus tapes'. Power, data and control lines run along the bus tapes and reach the silicon modules along the structures, which are electrically connected to it via wire-bonds and electrically conductive glue. The first batch of those high precision core prototypes was manufactured. This was achieved with custom-made mechanical tools, providing an accurate build and tight tolerances. A full mechanical and thermal evaluation program of these structures and the tools to build them is currently ongoing and initial results will be presented. As a first step to produce fully functional electrical petals, thermo-mechanical modules and petals were manufactured, in order to validate the layout. The first thermo-mechanical petal has already been assembled and is currently under test. Initial results will be shown in this presentation. In addition, detailed thermal simulations of the petals are also ongoing in combination with the thermo-mechanical prototypes and will also be presented. A strong effort was recently put in place in order to define the interface between the petals and the endcap integration structures. Locking mechanisms are in design and being introduced as an integral part of the core design. The different designs for the locking mechanism will be also introduced in this contribution.

Summary:

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Reinventing the Wheel

Corresponding Author: jesse.van.dongen@cern.ch

This talk shows a concept of a mechanical support structure for the ATLAS inner tracker (ITk) high-luminosity LHC upgrade.

Traditionally the silicon modules for the ITk strip-endcap detector were mounted on sandwiched carbon fiber discs. In order to minimize the amount of used material we looked into changing these discs with pretensioned spoked carbon fiber wheels, combining low-mass with intrinsic stiffness.

This talk will show the process, challenges faced and lessons learned, when coping with environmental factors and mechanical requirements and ability to manufacture such a wheel. Showing the progress from the initiation of a concept, towards the current status in realization and validation of prototypes.

Summary:

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Industry talk: Pretreatment of CFRP for improved adhesive bonding performance

Corresponding Author: joerg.ihde@ifam.fraunhofer.de

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Industry talk: Carbon Fibre Reinforced Polymers in High-End Applications –Potentials and Limitations

Corresponding Author: fabian.preller@invent-gmbh.de

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ATLAS pixel endcap upgrade

Corresponding Authors: peter.sutcliffe@cern.ch, joleen.pater@cern.ch

The tracking detector of the ATLAS experiment will be entirely replaced during the Phase-II LHC shutdown in 2024-25, in preparation for high-luminosity LHC running during the following years. Such particle tracking systems must have high stability and low mass, and therefore they make extensive use of carbon-fibre composites with their high stiffness-to-mass ratios and low coefficients of thermal expansion, but accurate FEA simulation of these systems, vital to successful design of a performant system, is highly complex and requires detailed materials properties and appropriate FEA modelling strategies.

An overview of the design of the mechanical support structures and services for the proposed endcap pixel detector will be presented. Measurements of static deformation and vibrational response on prototypes manufactured from M55J/LTM110 pre-preg will be compared to simple models using classical laminate theory. Experimental data on the engineering properties of M55J/LTM110 laminate will be presented along with calculations of the expected structural properties of these prototypes using ANSYS/ACP.

Summary:

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A Verified Thermo-Mechanical Prototype and Model for Integrated Local Supports in the ATLAS ITk Pixel Detector Upgrade

Corresponding Author: neal.hartman@cern.ch

The first integrated coupled-layer local/global support structure for ATLAS ITK Pixels is the I-beam design, originally conceived in 2010. It has proven mechanical stability and low mass. This I-beam prototype has now been modelled within Ansys and compared to measurements in a dry box under CO2 cooling at CERN. It shows that in many cases the Thermal Figure of Merit specification can be met already with the existing design, but that for the most stringent cases, special attention must be paid to the interfaces between facesheets and carbon foam, and between carbon foam and titanium pipe. Using graphite loaded adhesives developed under an LBNL research program last year, it should be possible to meet all Thermal Requirements of the ITK Pixel Detector with this simple, single-assembly design.

Summary:

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Lightweight support structures and thermal management materials for silicon tracker detectors featuring tilted modules

Corresponding Author: d.alvarez.feito@cern.ch

In parallel with the major upgrade planned for CERN's Large Hadron Collider (LHC), the trackers of the current experiments will be replaced by lighter and more efficient detectors capable of coping with the demands of the future High Luminosity LHC (HL-LHC). In this respect, layouts featuring tilted modules are currently under consideration for both ATLAS and CMS future trackers, as they would open the door to important savings in the overall silicon area and the corresponding services. However, such configurations would give rise to a series of new engineering challenges, the answer to which calls for innovative approaches in the design of the support structures, the cooling strategy and the overall integration. This talk will describe the work carried out at CERN's Detector Technologies group in these areas of research, focusing on two different subjects: Firstly, the development of an ultra-light carbon fibre truss structure manufactured using filament winding; Secondly, the thermal characterisation of advanced materials which could help circumventing the heat management difficulties imposed by the tilted arrangement of the modules.

Summary:

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Material studies for the ATLAS Phase-II Upgrade for the High Luminosity LHC: carbon fibre laminae measurements and investigation of moisture expansion of an adhesive used in support structures

Corresponding Author: anne-luise.poley@cern.ch

For the High-Luminosity Phase of the Large Hadron Collider, the current ATLAS tracking detector will be replaced by an all-silicon tracker composed of a pixel and a strip part. The strip tracker consists of silicon strip detector modules, composed of circuit boards with readout chips glued onto silicon sensors, which again are glued onto carbon fibre support structures. The support structures are composed of carbon fibre face sheets and honeycomb for mechanical stability, containing a titanium cooling pipe (for evaporative CO_2 cooling) enclosed in thermally conductive carbon foam. All support components are connected using a two-component glue (Hysol 9396), loaded with boron nitride for good thermal conductivity. In order to obtain reliable simulations of the mechanical properties of the complete support structures, the mechanical characteristics of the individual components need to be well understood. This contribution presents investigations of the mechanical characteristics of carbon fibre laminae as well of measurements of the expansion of adhesives due to moisture absorption. Discrepancies with traditionally used material property values are found and methods for their estimates in simulations are presented.

Summary:

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Vibration issues on particle detector components during transport and in operation –Experimental approach

Corresponding Author: michael.guinchard@cern.ch

CERN's specialised structures such as particle detectors are built to have high rigidity, low weight and are very fragile. Shock and vibration issues are a key element for successful transport, handling operations around the CERN infrastructure, as well for operation underground. This talk will present results obtained over the last ten years of experimental modal analysis of tracking detector structures or sub-structures. This measurement technique is performed with the purpose of determining the fundamental frequencies, damping and mode shapes of light and fragile detector components. This process permits to confirm or replace Finite Element Analysis in the case of complex structures (with cables and substructure coupling). It helps solving structural mechanical problems to improve the operational stability and determine the acceleration specifications for transport operations. In the second part of the talk, the last vibration measurements performed around the ATLAS SCT-TRT barrel, and the last ground motion measurements around CMS experiment will be presented and discussed. Finally, an overview of advanced measurement techniques in the field of vibration and thermo-mechanical properties characterisation will be exposed.

Summary:

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The CMS PIXEL Phase 1 CO2 cooling system: Commissioning and operation of a large scale CO2 system

Corresponding Author: jerome.daguin@cern.ch

CO_2 evaporative cooling has been selected as cooling method for the CMS PIXEL Phase 1 detector upgrade. With the needs of 2 x 15 kW at -20 ℃, it makes the CMS PIXEL Phase 1 CO_2 cooling unit the largest system of its kind. After presenting the system and its prototype, we will focus on the commissioning and operation experience of such a large system. In particular, we will develop the performances achieved, the back-up procedures and the 24/7 operation.

Summary:

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The vacuum insulated transfer lines for CMS CO2 cooling: performances and lessons learnt

Corresponding Author: paola.tropea@cern.ch

In 2014, vacuum insulated transfer lines have been installed on CMS in order to feed with CO_2 coolant the Phase I Pixel detector. Three different designs have been used in order to cope with the severe space constraints. The performances of the lines have been assessed during the CO2 plant commissioning in 2015. We present the results of the performance tests, the studies performed in order to understand the non-conformities and the remedy applied in order to match the system requirements.

Summary:

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Commissioning and operational experience of the ATLAS IBL CO2 cooling system

Corresponding Author: bart.verlaat@cern.ch

In 2014 the ATLAS IBL CO2 cooling system became operational. The IBL detector has run successfully since then with a CO2 cooling system being successful in operation. This talk will present the results and lessons learned from the commissioning period and will report on the operational performance and experience with the cooled detector during the physics run in 2015.

Summary:

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LHCb UT Upgrade: Studies and test for the detector cooling system design

Corresponding Author: simone.coelli@mi.infn.it

The upgrade of the LHCb UT silicon tracker implements a sensors read-out with thermal dissipation in the range of 4 kW, operational temperatures lower than -5 ℃, low material budget cooling/support structures. The detector supports, a total of 68 vertical staves, have an integrated cooling pipe embedded in conductive foam into the sandwich structure, exploiting CO2 evaporation in the temperature range of -30 ℃. Current design implements a 3 m long Titanium 2 mm I.D. pipe with a vertical snake geometry. The pipe routing is underneath the stave concentrated power sources, the read-ot chips, so that dissipated power is efficiently removed. R&D activities and real scale test on prototypes have been done and are in progress to prove and finalize the design concept.

Summary:

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Industry talk: Development, optimization and industrial production of Transportable Refrigeration Apparatus for CO2 Investiga-

tion (TRACI)

Corresponding Author: ryszard.kantor@cern.ch

In the context of its High Energy Physics related activities, CERN in collaboration with NIKHEF has developed the Transportable Refrigeration Apparatus for CO2 Investigation (TRACI). TRACI is an evaporative CO2 cooling system for scientific and industrial R&D equipment based on I-2PACL (Integrated 2 Phase Accumulator Controlled Loop) technology. The I-2PACL is the method that can instantly control the evaporative conditions in an experimental set-up vary from room temperature down to -35 °C. This technology is therefore an ideal way of controlling set-ups with a high demand on thermal stability and flexibility with a minimum of added hardware. It is considered a disruptive technology compared to the traditional methods used in commercial refrigeration. Cracow University of Technology (CUT) in collaboration with industrial partners: PONAR Silesia S.A. and CEBEA Bochnia have undertaken mission of production and development of a new optimized version of TRACI. The current prototype of TRACI is currently in redesign phase with the aim of reduction of the production costs to offer this technology for a broader field of use. The CO2 laboratory coolers will be characterized by more efficient and environmental friendly technology than the traditional systems. Optimization will be found in power consumption, applicable range of temperature and cooling power. Cracow University of Technology (CUT) is a multi-profile school of higher education and research in the fields of basic sciences, engineering technologies, and architecture, has expertise in the domains of Mechanical Engineering, Computer Science and Information Technology, Materials Science, Technical Physics, Mathematics, Electrical as well as Chemical, Civil, and Environmental Engineering technologies. CEBEA Bochnia is a manufacturing company specialized in cooling technology for food industry, particularly in production of refrigerating equipment used for storage and direct selling of food. PONAR Silesia S.A. is the largest Polish producer of oil hydraulics elements and systems, offering a full range of services from design, production, maintenance and repairs – up to complete, final products. Many applications of hydraulic systems contain advanced cooling systems and complex high pressure liquid distribution systems. CUT, CEBEA and PONAR have created a consortium in order to facilitate their relationship with CERN, particularly in the TRACI development and production project. In the presentation the new optimized system based on TRACI concept as well as production schedule and plans of development will be shown.

Summary:

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The STAR PXL detector cooling system

Corresponding Author: eric.anderssen@cern.ch

The PiXeL detector (PXL) of the STAR experiment at RHIC is the first application of the state-of-the-art thin Monolithic Active Pixel Sensors (MAPS) technology in a collider environment. The PXL detector is part of the Heavy Flavor Tracker (HFT), which has been designed to improve the vertex resolution and extend the STAR measurement capabilities in the heavy flavor domain, providing a clean probe for studying the Quark-Gluon Plasma. The two PXL layers are placed at a radius of 2.8 and 8 cm from the beam line, respectively, and accommodate 400 ultra-thin (50 µm) high resolution MAPS sensors arranged in 20 cm long 10-sensor ladders to cover a total silicon area of 0.16 m2. After a description of the detector design and characteristics, we will focus on the PXL air cooling system. We will report on design details and testing addressing the successful control of thermal deformations, air induced vibrations and other stability issues. We will show the detector

and cooling system performance during the 2014-2016 STAR Runs.

Summary:

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Radiation length imaging with high resolution telescopes

Corresponding Author: ulf.stolzenberg@phys.uni-goettingen.de

The construction of low mass vertex detectors with a high level of system integration is of great interest for next generation collider experiments. Radiation length images with a sufficient spatial resolution can be used to measure and disentangle complex radiation length X/X0 profiles and contribute to the understanding of vertex detector systems. Test beam experiments with multi GeV particle beams and high resolution tracking telescopes provide an opportunity to obtain precise 2D images of the radiation length of thin planar objects. At the heart of the X/X0 imaging is a spatially resolved measurement of the scattering angles of particles traversing the object under study. The main challenges are the alignment of the reference telescope and the calibration of its angular resolution. Systematical uncertainties can be minimized by conducting a calibration measurement, where the module under study is replaced by an aluminum target with a well known thickness profile. In order to demonstrate the capabilities of X/X0 imaging, a test beam experiment has been conducted. The devices under test were two mechanical prototype modules of the Belle II vertex detector. A data sample of 100 million tracks at 4 GeV has been collected, which is sufficient to resolve complex material profiles on the 30µm scale.

Summary:

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Closeout