Forum on Tracking Detector Mechanics 2024

Wednesday, 29 May 2024 - Friday, 31 May 2024

Purdue CMSC

Report of Abstracts

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Opening & Welcome, Organisational

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Introduction & Session A / 3

Assembly and installation of the MVTX silicon vetex detector into the sPHENIX experiment

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The MVTX tracking detector in the sPHENIX experiment at the RHIC accelerator complex at BNL, is a Monolithic Active Pixel Sensor (MAPS) silicon detector that is based on the three inner most layers of the ALICE ITS2 tracking system. The design and installation of this detector into the sPHENIX experiment will be described in detail. The overall length and diameter of this detector assembly is 1,835.0 mm long, the diameter of the sensor region is 106.0 mm and the diameter of the service barrel is 215.0 mm. The entire detector is designed to be cantilevered off the end flange of the service barrel. The detectors mass is 24.0 kg. The integration of this detector was a key engineering issue with both the beampipe and outer tracking detectors already installed leaving minimal radial gaps to work with.

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Conceptual design for the ePIC SVT outer barrel staves

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The ePIC silicon vertex tracker (SVT) will consist of 5 barrel layers in addition to 5 disks at each end. The outer two barrel layers, at radii of 270 mm (L3) and 420 mm (L4), comprise the outer barrel (OB). All parts of the SVT will have to satisfy extremely low material targets, which are 0.25% X0 for L3 and 0.55% X0 for L4. One ingredient to achieve this goal are ultra-thin (40-50 µm) MAPS sensors.
The ePIC SVT will use a reduced size version of the MOSAIX MAPS sensor originally developed for the ALICE ITS3 detector. These large area sensors (LAS) will be thinned-down sensors (40 µm) which are ˜20 mm wide and either ˜110 or ˜130 mm long.
Mechanically, the outer layers will be segmented into staves. Currently, we are envisaging staves that are two sensors wide and support in total 8 sensors (L3) or 16 sensors (L4), with a total power per stave of about 35 W (L3) or 50 W (L4). To reduce structural material the silicon will be self-supporting, which is achieved by a curvature of the silicon.

To reduce service material, the aspiration is to use serial powering and cool the detector elements with air flow. The former requires a separate ancillary chip, which generates significant amounts of heat, and needs to be considered as part of the thermal management. For the latter we plan to rely primarily on forced air flow in the core of the stave.
We are currently in an early design phase, with prototyping planned for middle of 2024, and the submission of a TDR by the end of this year.
In this talk we will present the preliminary design for these staves, and results from mechanical and thermal FEA, including CFD of the airflow in the stave core.

Introduction & Session A / 24

Corrugated carbon composite disc design for the ePIC Silicon Vertex Tracker (SVT)

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Experiments at the future Electron-Ion Collider (EIC) pose stringent requirements on the tracking system for the measurement of the scattered electron and charged particles produced in the collision, as well as the position of the collision point and any decay vertices of hadrons containing heavy quarks. Monolithic Active Pixel Sensors (MAPS) offer the possibility of high granularity in combination with low power consumption and low mass, making them ideally suited for the inner tracker of the EIC detector(s). The forward discs are critical to the measurement of the scattered electron and thus minimizing the mass is crucial. To that end, we are developing a disc design for the ePIC Silicon Vertex Tracker (SVT) that makes use of a corrugated carbon fiber core to add strength and provide a channel for air cooling. In this talk, we will discuss the current disc design as well as the associated mechanical and thermal R&D.

Talks / 22

Large-Scale Comprehensive Thermal Simulation of the CBM Silicon Tracking System (STS) on the Virgo Cluster at GSI

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A thermal simulation of the STS detector in the CBM experiment using open-source computational fluid dynamics (CFD) software package OpenFOAM(R) is presented. The interactions of various detector components such as silicon sensors, heat sinks and electronics are simulated. The effects of radiation damage on power dissipation and the resultant electrical noise in silicon sensors are included in the model. This feature facilitates the analysis of how well the detector performs under

different irradiation scenarios and over time. The choice of open-source software for simulations, post and pre-processing allows to share results within the wider group of researches participating in model buildup and its parametrization.

The project uses the computational power of the Virgo cluster (Green IT Cube) at GSI/FAIR with up to 4096 processors and 18 Tb of RAM on a single user's disposal. This data center is one of the most powerful for high-energy physics experiments and CFD analysis of large-scale models.

The thermal model's accuracy is improved by comparing its results with experimental data from the Thermal Demonstrator, which is a prototype of the detector cooling system. It is used to minimize discrepancies between experimental and simulated results by refining the model for better predictive performance.

Talks / **26**

GridPix TPC as a tracking and PID device

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GridPix detectors are a relatively new detector technology with a high density pixelated readout ASIC and a Micromegas style gas amplification stage. Due to the aligned mesh holes and pixels, a high efficiency for detecting and separating single primary electrons can be achieved. This leads to excellent spatial and energy resolution which can be used as a readout for Time projection chambers (TPC). TPCs have high material budget at the end-plates because of cooling and support structures. This limits the performance of forward and backward detectors at collider experiments. In this talk, I will discuss ongoing R&D and future plans towards the reduction of material budget and cooling schemes with the GridPix TPC.

Talks / **9**

Outsource production and the design of Phase-2 CO2 cooling systems.

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During the planned long shut-down (LS3) period in the years 2026-2029, significant upgrades are scheduled for the LHC accelerator and its experiments." The main aspect of this upgrade involves installation of the next generation of silicon particle detectors in ATLAS and CMS experiments, which will require to dissipate several hundred kilowatts of heat. To manage the harsh conditions and thermal requirements of these detectors, a new CO2 cooling system based on the parallel operation of multiple modular units has been developed. Each one of these new modular CO2 units will consist of a cooling plant and an accumulator situated in the ATLAS and CMS service caverns, which deliver cold saturated liquid CO2 of -40℃ to the silicon detectors via distribution manifolds and a series of long transfer lines. The plants and accumulators produce together liquid CO2 at a minimum temperature of -53℃. The pressures in the systems can be as high as 100 bars, which is the design pressure of all the system components.
The new systems are one order of magnitude larger in cooling power and volume than the previous systems installed at LHC. Consequently, extensive modifications were necessary to adapt the well-established 2PACL concept to meet these demanding cooling requirements. This involved, among other things, enlarging the size of the 2PACL plant, increasing the diameters of the piping up to industrial standards size DN50, and enhancing the capacity of the LEWA pumps to deliver 1.58 kg/s of CO2. Additionally, the accumulator has been relocated from the 2PACL plant, with its primary function now focused on set-point control, while storage of the additional CO2 volume is managed by a separate surface storage vessel. Another big change in the CO2 cooling concept is the introduction of the so-called accumulator flow-through. This involves the condensation of the vapor in the accumulator rather than in the plant condensers. This has the benefit of saving large amount of control heat in the accumulator.

This talk will cover the design of the new 2PACL system made at CERN, the challenges that were encountered, including in outsourcing the production of in-house designed units, and the solutions that were implemented into the final mechanical design of both Plant and Accumulator by the companies who are producing the units. The presentation will cover the production status as well as the effort made to achieve CE marking for both sub-systems.

Talks / **23**

Overview of the CO2 cooling DEMO obtained results and a prediction of future system behavior.

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ATLAS and CMS are using CO2 cooling for their phase-2 upgrade inner detectors. The challenges for the new cooling with respect to past CO2 systems are the on-detector colder temperatures required (<-40'C) and the large increase of the heat load with 2 orders of magnitude. The final predicted heat loads for ATLAS is 300 kW and for CMS 550kW.The cooling will be segmented in sub-units with a maximum per-plant design capacity of 100kW.

A DEMO cooling system was built to demonstrate the feasibility of the larger plant design. Several new features were introduced compared to previous systems, which needed a feasibility demonstration: Accumulator flow-through to save electrical heating power, a common surface storage to minimize the CO2 volume used underground, and an R744 primary system to allow a surface-located chiller.

DEMO also acted as a test system for component qualification. The large scaling up required the introduction of new technologies to be tested under our special conditions. Special pumps, heat exchangers and valves have been developed together with manufacturers. DEMO also functioned as an overall system demonstrator. The full set-up had real-scale transfer lines and large dummy load power units to simulate the detector heat load.

DEMO has evolved over time to become similar to the final design. The plants and accumulators are now in production based on the lessons learned in DEMO. This talk will summarize the lessons learned in DEMO and will summarize the predicted behavior of the final systems.

Talks / **4**

Flow distribution capillary tube testing for the CMS silicon detector upgrades

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Flow distribution capillary tube testing for the CMS silicon detector upgrades

Abstract

At CERN, developments are ongoing around evaporative CO_2 cooling technologies used for thermal management of new silicon particle detectors for the high luminosity upgrade. These new detectors are set to be installed in the new CMS and ATLAS experiments during long shutdown 3. The 2 Phase Accumulator Controlled Loop (2PACL) principle will be scaled up to a size larger than ever before, 300 to 550 kW respectively compared to the 1 to 15kW in previous systems. The scaling up of the 2PACL principle brings numerous challenges compared to smaller scale 2PACL systems.

One of the challenges is the flow distribution of the thousands of cooling loops. These loops will be fed with a fixed pressure drop of 10 bar. Flow restrictions at the inlet of the loops are needed to balance the resistance such that the designed flow is obtained.

In CMS and ATLAS these restrictions are made with capillaries, a total of ~1800 in CMS and ~1000 in ATLAS are needed. In order the define the proper capillary diameters and lengths two dedicated bottle-fed CO_2 blow-system were developed and built at CERN to allow rapid measurements of these capillaries, ensuring that the characteristics are within the desired specifications of the detector system's needs.

The proposed talk will go into more detail on the theoretical prediction, physical manufacturing, measurements, and quality control of these capillaries used for the CMS phase-II cooling systems planned for the 2026 LHC High Luminosity Upgrades.

Keywords: Refrigeration, Carbon Dioxide, CMS, ATLAS, 2PACL, CERN, Blow-system

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TB2S Ladder Assembly and Qualification for CMS Outer Tracker System

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The TB2S (Tracker Barrel 2S) is part of CMS tracker system. TB2S ladder is a specialized structure made with Carbon Fiber (CF) and Aluminum Carbon Fiber (Al-CF) materials designed to mount silicon modules on it, along with the necessary services inside the CMS tracker system. The TB2S ladder has two main features, firstly, it provides mechanical support to the silicon modules, and secondly, it cools down the silicon sensors and readout electronics installed on it. There are 48 contacts points (inserts) at the entire ladder, and each silicon module is supported by six points. One silicon module dissipates approximately 5 watts of power (totaling approximately 60 W for 12 modules on one ladder); the generated heat can be extracted through the ladder's cooling arrangements (inserts and cooling pipe). National Centre for Physics (NCP) will develop about 400 TB2S ladders and perform qualification tests. For this purpose, three prototypes were successfully developed at NCP. A dedicated thermal qualification setup has been developed at NCP to qualify the ladder's thermal contacts. Pre-production of the ladders has started, and three pre-production ladders have already been assembled. An overview of the pre-production ladders will be reported in the presentation. The ladder metrology and thermal qualification results will be presented in detail.

Talks / 8

Design and testing of a dynamic support frame structure for the CMS tracker installation process

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The installation process of the new Outer tracker (OT) and Barrel timing layer (BTL) -detectors in CMS will be a demanding operation, due to their combined weight is ~20% heavier than the old silicon strip tracker. This means that some of the existing installation tooling from the past cannot be re-used.

The dynamic support frame structure, often referred as the "eiffel tower", is used in the final installation motion when the tracker is brought into the middle of CMS inside the ECAL bore. The eiffel tower is fixed to the end of the tracker, and it is then used to pull the tracker in while rolling on top of bearing rollers. The structure is heavily loaded during the operation, as it's carrying a large portion of tracker's weight in an extended cantilevered configuration. In a structural study it was concluded, that the old eiffel tower would not be fit for the heavier boundary conditions of the phase-2 upgrade.

For the new eiffel tower several structural improvements were made. The horizontal section of the new structure was built from commercially available heavy-duty aluminum truss elements, and the vertical section was custom built around it. A lot of usability improvements were implemented to the system in parallel, mainly related to the longitudinal movement mechanism of the horizontal section.

A large-scale load test setup was built to mimic the real loading conditions. The whole motion path needed in the installation was successfully tested, and the behavior of different structural elements

was scrutinized. The FEM-analysis of the structure conducted earlier was benchmarked, and the measured value on the total deflection was satisfactorily close to the simulated one. Some improvements were done and tested on the longitudinal motion mechanism, and ideas to enhance the adjustability of the system were realized.

Talks / **6**

Design and manufacture of the supports for the ATLAS barrel strip staves

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In the ATLAS barrel strip system silicon strip modules are mounted on local supports (staves). The staves are supported on four large concentric carbon fibre support cylinders. During the integration the cylinders will first be installed within the Outer Cylinder that contains all of the Inner Tracker (ITk), and the staves will then be inserted into this structure from both ends. Insertion will be guided by a set of rails that are temporarily installed for this process.
The mechanical interface between the staves and the cylinders is provided by a system of ULTEM brackets, which also support the rails during the insertion. The position of the stave is defined by a cone-on-ball interface at the center of the support cylinders, and allows for differential thermal expansion of the staves and the support cylinders. Once the staves are in place they are secured in place by a locking cam for each bracket.
The mounting brackets are glued onto the support cylinders using precision jigs. Dressing of the support cylinders is currently under way. We have completed this for the largest cylinder (L3), and the gluing of brackets onto L2 is under way.
In this presentation we will present the design of this support system and the tooling for the dressing, the QA we performed in preparation of this assembly, and results and observations from this process.

Talks / **10**

Development of a robotic system for automatic prepreg layup and production of co-cured facesheets for the ATLAS ITk strip end-cap detector

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As part of the ATLAS detector upgrade at the LHC, the existing tracking detector end-caps are being replaced by more powerful silicon sensors. Newly developed sandwich support structures with modern silicon chips on their surface will be integrated. This new generation of sensors will maintain and increase the recording quality of the ATLAS detector for the high luminosity phase of LHC.
The sandwich support structures, known as petals, were developed and prototyped at DESY in Hamburg. For the series production, the core assembly was outsourced to industry while the involved institutes are providing pre-manufactured materials and performing the quality control. Each petal consists of two so-called facings, the top and bottom layers of the sandwich. These are currently produced using a hand-lamination process and then cured in an autoclave. A robot was developed and built for the series production of the facings, which takes over and considerably simplifies the lamination process.
In this contribution, the entire concept of such a robot will be considered. This concerns the development and construction of a suitable robot including a tool head for the automated laying of prepreg, which can take 6" or 12" wide UD tape on rolls as input. The manual laying of prepreg was imitated in prototypes and converted into various machine concepts. A complex task was realized with the help of simple mechanics and controllers in a prepreg robot, which now simplified the production of 800 facings. The entire manufacturing process from semi-finished product to finished facing will also be explained.

Talks / 11

First experience from the system test setup for the ATLAS ITk strips end-cap detector

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The new ATLAS Inner Tracker (ITk) will replace the current tracking detector of the ATLAS detector to cope with the challenging conditions for the Phase-II upgrade of the Large Hadron Collider experiment (LHC), the so-called High Luminosity LHC (HL-LHC). The new tracking detector is an all-silicon detector consisting of a pixel inner tracker and a silicon microstrips outer tracker, differentiated again in a central barrel section around the interaction point and two end-cap sections covering the forward regions for the collisions.
This contribution focuses on the full system test setup developed for the ITk strips detector system, being the testbed for testing and evaluating the performance of several close-to-final detector components before production. These will also serve in the future for training and testing purposes of the detector during operation. The system test for the strip end-cap sub-system is developed at DESY in Hamburg/Germany loaded with up to 12 petals - mechanical core structures loaded with trapezoidal shaped sensor modules of various strip lengths and pitches including the corresponding readout and power electronics. The local support structures are mechanically held in place within a global support structure, which mimics realistically the end-cap global structure. Similarly, the services in terms of electrical, optical and cooling are as realistic as possible as in the latter detector integration. Due to these design decisions for the system test development, it is possible to validate the detector design, verify the detector DAQ and perform tests with the services, e.g. concerning the dual-phase CO_2 cooling.
This contribution gives an overview of the developed end-cap system test for the ITk strip detector

and summarizes the first experience of insertion and operation of petals into the end-cap structure. From these, important lessons for the coming full detector integration at DESY and Nikhef for the end-cap sub-systems can be retrieved.

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Investigating Cracks in ATLAS ITk Strips

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The ATLAS ITk strip sensors employ silicon wafers, supported by carbon fiber staves with sandwich construction. The sensors are equipped with hybrid and powerboard flexes that are bonded with rigid adhesives. The sensor layout varies across different detector regions, including changes in wafer geometries, number and composition of the flexes, and adhesive layout. During preliminary cold testing of the first staves produced for the barrel section, high voltage testing failures were detected on several sensors. Upon visual inspection, these failures were found to be due to mechanical cracks propagating in the silicon wafer. In order to understand the origin of these cracks, analytical and numerical models were developed, reproducing the sensor assembly process, cooldown and operation. The results suggest that mechanical loads are introduced by the bonding procedure, and by the differential thermal contraction of the components. In particular, the silicon is captured in the middle of the larger shrinkage of the flexes, and the very stiff and stable carbon fiber stave constraint. This leads to bending motions and consequent large tensile strains in the unsupported silicon regions. In parallel, multiple measurement campaigns were performed to quantify the strength of the silicon wafers under different loading conditions, to check the crack morphology with CT scans, and to test the failure mechanism on simple but representative coupons. Finally, the models were used to evaluate different mitigation strategies aimed at reducing the mechanical loads experienced by silicon.

This work was supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, through the US Magnet Development Program.

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Mechanical Performance of Irradiated Adhesive Samples for ATLAS ITk

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One of the most mission-critical adhesive applications in ATLAS ITk, and indeed in any modern silicon tracker, is in the construction of the local supports and their interfaces to the detector modules. Adhesives in this application must bond to a variety of surfaces, including carbon and silicon, and embody a complex combination of traits in modulus, thermal conductivity, and reworkability. A favorite for this application is Dow Corning SE4445. However, this silicone-based thermal potting compound had never been rigorously strength tested under the irradiation levels expected to be encountered during high luminosity operation of the LHC. Its un-irradiated behaviour is visco-elastic, and does not suggest high radiation resistance. The authors therefore created standard 2cm square test coupons, of both silicon and carbon bonded together with both SE4445 and a range of other currently used adhesives. These coupons were irradiated, 300 in total, to levels of 5, 10, and 15 MGy. They were then bonded to thick-adherend single lap shear test coupons, which were pull tested to failure. The results conclusively prove that not only does SE4445 reliably exhibit shear strengths in excess of 6 MPa at 15 MGy, but it also transitions from a visco-elastic compound to an elastic solid with a well-defined shear modulus, with an improvement in overall structural performance. This study clears the way for SE4445 to be used in the LHC phase-2 upgrade without risk of radiation induced failure, even at the highest dose levels.

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A thermal interface material for the PS modules of the CMS Outer Tracker upgrade.

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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, one at each end. Two types of silicon detector modules are being utilized, the Strip-Strip (2S) modules for the outer radii and the Pixel-Strip (PS) modules for the inner radii. For the PS modules, the entire bottom of around 5 x 13 cmˆ2 must be thermally coupled to the mechanics to allow efficient cooling, for which a thermal interface material is needed. The current candidate materials for the use in the endcaps are room temperature curing two component thermal gap fillers.The contribution will outline the measurements and highlight the results to qualify gap filler materials to the radiation dose expected for the lifetime of the CMS Outer Tracker. Three different types have been tested thermally and mechanically in this campaign. A thermal test setup determines the thermal conductivity of a test sample by measuring the temperature gradient with a controlled amount of heat flow through a sample. Mechanical tests are needed to ensure structural integrity of the thermal interface even when under some extent of thermal stress. Resembling the style of an ISO 4587 lap shear test, and an ISO 25217 mode-1 fracture test, test samples were made with a large 5 x 5 cmˆ2 adhesion overlap using plasma cleaned carbon fibre plates to have a surface comparable to its intended use case. The testing method developed for this study will be presented and motivated. After testing of unirradiated samples, they have been irradiated to 600 kGy. The measured mechanical and thermal properties will be presented and the results before and after irradiation will be compared. We found that the gap filler material hardens significantly, however its thermal and adhesive properties are maintained. The hardening reduces the cohesion failure, leading to an increased mechanical strength of the bonds. A specific product has been chosen as suitable material. A follow-up campaign is being prepared to further quantify the properties before and after irradiation.Applying the thermal interface material in a thin layer reliably on the entire bottom of the module is a challenge. Particularly as many modules are mounted on a large structure in close proximity, the available space around the module being installed is very limited. The intended method of application will be explained. The reliability and quality of the interface are evaluated with thermal tests using a thermal dummy module and a cooling structure resembling the mechanics of the final detector.

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Thermal Metrology for Understanding Tracking Detector Materials

Authors: Aalok Gaitonde[1]; Amy Marconnet[1]; Justin Weibel[1]; Zixin Xiong[1]

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In the development of silicon detector with higher granularity for better tracking seeding and vertexing, the resulting higher heat dissipation needs to be efficiently extracted to maintain the readout chip (ROC) at its preferred operation temperature and avoid thermal runaway. The structural materials thermally connect the sensors and ROCs to the mixed phase CO2 cooling pipes. It is crucial to fully characterize the thermal properties in all directions of the structural materials to accurately estimate the heat extraction and thermal risks within the tracking detector. This presentation will introduce research in my group focused on techniques we developed to understand the thermal properties in the unique formfactors required for tracking detector. For materials with highly anisotropic thermal conductivities such as carbon fiber laminates, we are able to characterize both cross-plane and in-plane thermal conductivity using different methods with high precisions. The cross-plane properties are measured using modified reference bar method with high resolution infrared microscope to record the temperature variation across the entire material surface. This method can also be used to study the interface resistance between materials. To understand the in-plane thermal conductivity of materials, our team developed a new technique to quantify thermal transport leveraging concepts from the Angstrom method and updating the technique with modern tools including infrared thermal imaging and physics-informed neural networks for robust data analysis. Overall, new thermal challenges arise in the design of the next generation tracking detector drive the development of new thermally-engineered materials and new metrology techniques to understand performance.

Talks / **20**

A Finite Volume Analysis for evaluating the thermal performance of an air-cooling system for the IDEA Vertex Detector at FCC-ee.

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The IDEA detector is one of the concepts under research for the electron-positron Future Circular Collider (FCC-ee). The Vertex Detector, located in the innermost part, and occupying a cylindrical volume of 35 mm radius and 550 mm length, is expected to dissipate about 120 W. To remove this heat, a cooling system based on forced air convection is under development. Such a technical solution would minimize the quantity of material located in the tracking volume, concentrating all the services only in the two endcaps. The sensitive volume would therefore be occupied only by Silicon sensors and their carbon-fibre support structures, which would also act as cooling fins to maximize convective heat exchange. In this scenario, Computational Fluid Dynamics (CFD) and, more widely, Finite Volume Simulations, can offer a useful tool to evaluate the feasibility of this solution and to guide the designers in the optimization of the thermal performance. An example of a calculation model developed with the Ansys simulation suite will be given, showing how thermal performance varies by adopting different construction choices. Furthermore, starting from this model, an approach for exporting the results for a mechanical analysis will be given, to evaluate vibrational effects due to the interaction between the fluid and the lightweight structures.

Talks / 25

Energy Frontier Tracking Detector Mechanics R&D at Argonne National Laboratory

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As the energy frontier moves towards more extreme collision conditions –higher energies and luminosities –there is a strong need for the development of lightweight detector support structures. The Snowmass Instrumentation Frontier report mentioned the following as two of the critical near-term priorities for solid-state tracking:

• **IF03-2** Adapt new materials and fabrication/integration techniques for particle tracking in harsh environments, including sensors, support structures and cooling
• **IF03-3** Realize scalable, irreducible-mass trackers in extreme conditions [1]

One potential path toward this goal is to optimize mass by integrating services and cooling into support structures [2]. This could also help mitigate the problem that "complex stresses in composite structures consisting of multiple parts are a consequence of different manufacturing techniques utilized"[3]. This is a perfect fit for the expertise at Argonne National Lab –both cooling for ATLAS inner tracker local supports, materials science research, and additive manufacturing facilities. In this talk, we will discuss our plans to use novel materials and Argonne's manufacturing facilities to achieve the goal of scaleable, lightweight detectors for future colliders.

[1] "Report of the Instrumentation Frontier Working Group for Snowmass 2021", arXiv:2209.14111

[2] E. Anderssen, A. Jung, S. Karmarkar, A. Koshy, "Light-weight and highly thermally conductive support structures for future tracking detectors", arXiv:2203.14347v1

[3] A. Affolder, et. al. "Solid State Detectors and Tracking for Snowmass", arXiv:2209.03607

Posters / 19

Installation of CMS Phase-1 Pixel Detector

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The pixel detector of CMS was re-installed in June 2021 after being stored in a clean room at Point 5 for the duration of Long Shutdown 2. This talk will cover the operational experience of preparing and installing the CMS pixel detector. It will highlight the tools and support rails used for installation, the connections for detector cooling and power, and how the detector's temperature and humidity are currently monitored.

Posters / **21**

TBPS Flat Barrel End-Rings Fabrication

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An approach of how to fabricate all 3 layers of end-rings with a common tooling plate is presented.

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A 100µm/m contactless alignment system for the assembly of the outer layer of the Cylindrical GEM inner tracker for the BESIII experiment

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The new Inner Tacker of the Beijing Spectrometer III (BESIII), hosted at the Beijing Electron Positron Collider II (BEPCII) within the premises of the Institute of High Energy Physics (IHEP), is composed by three layers of cylindrical GEM detectors. Its installation is foreseen between August and December 2024. The large radius of the outermost layer (L3) makes it intrinsically prone to buckling effects. The deformation of its CGEM electrodes was contained by introducing PEEK spacer grids, at the cost of reducing the already limited clearance for the assembly.
Since the new design was validated only up to 7.5g, the BESIII Collaboration deemed an airborne shipment of the fully assembled detector dangerous and chose to split the construction procedure partially in Italy and partially in China. The electrodes were built in Italy and shipped wrapped on their production mandrels to be assembled in IHEP.
Due to the placement of the electrodes on the mandrels the traditional contact-based alignment approach evolved into a new contactless alignment system, adopted in order to align the Vertical Insertion Machine (VIM) used for the assembly. Specifications required for the new system were a 100µm/m accuracy on the mandrels inclination and a 100µm accuracy on their absolute positioning; while the specifications required are the same for the traditional alignment approach due to the limited clearance are now crucial for the success of the assembly.
This contribution will address the design of the contactless alignment system, composed by an array of laser triangulation sensors, its commissioning, the iterative procedure, and the outcome of the final
alignment before the Layer 3 assembly.

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Multifunctional Composite Structures for Future Particle Accelerator Detectors

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Future particle accelerators present unique challenges for detector support structures, particularly in their innermost regions. These challenges require the development of novel structures with minimal mass, effective active cooling, high thermal conductivity, robust structural integrity, and shape stability under operational temperatures. Our research explores a novel design approach integrating printed preforms of continuous and discontinuous fiber composites using compression molding. We employed Polyphenylene Sulfide (PPS), reinforced with both pitch and pan based carbon fiber, due to its radiation tolerance. The design features a support structure incorporating a molded cooling channel, highly thermally conductive pitch-based carbon fibers to facilitate heat transfer from the detector to the cooling channel, and connections capable of withstanding high-pressure cooling fluids. This configuration leverages the advantages of 3D-printed discontinuous fiber (DF) preforms and continuous fiber (CF) layups consolidated through compression molding with highly tailored orientations. We conducted Finite Element Analysis (FEA) to investigate the thermal performance of the structure under typical operational loading conditions, as well as to assess thermal gradients across the prototype. Prototypes were manufactured and tested under similar thermal loading conditions used in the analysis. The test setup consisted of a surface heat source that provided a controlled heat flux on a region of the structure, internal forced convection through the cooling channel was provided with chilled water, and a thermal camera was used to monitor the temperature field on the surface of the structure. This testing regime provided a basis for comparative evaluation against state-of-the-art commercial carbon fiber (CF) prepregs and those specifically manufactured for this study. Preliminary results from pressure and thermal performance tests demonstrate the potential of this integrated approach for meeting the demanding requirements of high energy physics detectors.

Posters / **34**

Prototyping efforts for EIC ePIC pfRICH detector

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The upcoming Electron-Ion Collider (EIC) at Brookhaven National Laboratory features a proximity focusing RICH detector (pfRICH) in the electron-going endcap for particle identification (π/K/p as well as electron vs pion separation), comprising of enclosed gas volume held with solid carbon fiber end rings and a composite sandwich vessel. This talk highlights the prototyping efforts for the solid carbon fiber end rings as well as the sensor plate support structure for pfRICH HRPPD photosensors. The tool shape compensation analysis is presented for the segmented end rings with studies on different types of composite bonds for solid rings. A finite element analysis is presented for the structural performance simulations for the pfRICH detector. This analysis informs the design of the sensor plate composite structure to minimize deflection under loading while maintaining the position of the HRPPDs and minimizing mechanical stress on the sensors. Results from the first prototype for the sensor plane structure are also presented.

Posters / **33**

Design, prototyping and heat transfer simulation for EIC-EPIC AC-LGAD time of flight barrel detector

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The upcoming Electron-Ion Collider (EIC) at Brookhaven National Laboratory features a state-of-the-art time-of-flight barrel detector, comprising 144 staves that extend over a 2.7-meter length and support strip silicon sensors. Managing the thermal gradient along these staves is critical for optimizing sensor performance and is a primary focus of the design challenge. This research investigates various stave configurations to achieve minimal mass and deflection under self-weight across the entire length, enhancing the structural integrity and operational stability of the detector. We conducted a series of heat transfer analyses to evaluate temperature gradients on the stave surfaces, guiding multiple design iterations. These analyses involved comparing different cooling methodologies, including water, glycol, and nitrogen-based systems, to determine their effectiveness in maintaining optimal sensor temperatures. Each cooling option was modeled to assess its impact on the thermal performance and mechanical properties of the staves. Prototyping and manufacturing of the staves were carried out at Purdue University. Validation of the heat transfer models was performed through experimental testing using a dedicated water-cooling circuit at National Cheng Kung University (NCKU) in Taiwan. This poster presents a comprehensive overview of the design process, prototyping, manufacturing techniques, and the results from both simulation and experimental validation of the thermal management system. Our findings provide crucial insights into the thermal and mechanical considerations necessary for the successful deployment of the EIC's time-of-flight detector.

Posters / **7**

Design of complex services routing of the CMS Upgrade Tracker TBPS

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The Tracker Barrel with PS-modules (TBPS) is one of the subdetectors of the new CMS Phase-2 Tracker. It will have 2872 Pixel-Strip (PS) modules on three concentric layers. Each layer has three sections, one Flat section in the middle surrounded by two Tilted sections. In the Flat section the modules are on straight Planks while in the Tilted section they are on conical Rings. A particular difficulty is the routing of the cooling, electrical and optical services of the TBPS. The services need to fit in small spaces, be compatible with the detector assembly sequence and be constrained reliably. Services routing and supporting have been designed to fulfil these requirements, still keeping the mass as low as possible.

R&D session / 30

Mechanics and Cooling for ALICE future vertex detectors

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In the research and development for ALICE's future upgrades, there's a strong focus on creating new mechanical and cooling solutions for upcoming low-mass vertex detectors.
With the assumption of utilizing next-generation monolithic pixel sensors based on stitched technology, capable of covering large bent-to-shape surfaces, the focus lies on offering the lightest substrate with integrated cooling.
Within this developmental journey, shared with the CERN EP R&D program, the ITS3 of LS3 places its reliance primarily on gas cooling methods trying to achieve a record minimum material budget, while the IRIS vertex for LS4 opts for a two-phase cooling approach to fulfill more demanding cooling requirements.
Within these ambitious plans, a significant effort has resulted in the design and optimization of a thermal conductive carbon foam radiator capable of efficiently dissipating heat generated at power densities of up to 2 W/cm2 to be used in the ITS3.
When it comes to higher radiation environment, like in the IRIS vertex detector for LS4, and the necessity to go colder with evaporative system, different cooling substrate ideas have been experimented. Promising concept involves thin ceramic cold plate modules with tiny channels, created using advanced 3D printing techniques or other designs like microvascular carbon substrates either with Kapton pipes or pipeless.
Design choices and test results will be presented to elucidate the efficacy of these substrate concepts, offering insights into their potential applications and contributions to the advancement of tracker's detector systems

R&D session / 32

Advancing Lightweight Mechanics and Automated Detectors for future HEP Experiments

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In 2020, CERN's Experimental Physics Department embarked on an ambitious project known as the EP R&D, aimed at advancing detector technologies for future experiments. This comprehensive initiative addresses various aspects of mechanics, including the development of lighter detectors and the implementation of more automated processes for installation, inspection, and maintenance.
The focus on reducing material budget within the detection area goes beyond just tracker mechanics. It extends to larger structures, encompassing detector superconductive magnets and calorimeters. This overall plan aims to investigate mechanics limits and identify ultralight solutions that can be tailored for specific detectors application.
Concurrently, a Global Mechanics Robotic Installation concept is being developed as part of the program. This concept aims to automate installation procedures across all detector modules, improving safety and minimizing the time required for installation, extraction and maintenance. This idea is based on having common interfaces across detectors and using a unique robotic handling system.
In terms of cavern inspection, mapping, and initial interventions, the strategy involves identifying various movable platforms and equipping them with specialized payloads. Both ground and aerial solutions are currently under development, with specific adaptations being made to address challenges posed by the cavern environment.
Main highlight of these development will be presented to trigger discussion on common requirements and future directions.

R&D session / 15

Microchannels cooling plates

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Microchannel cooling technology offers an excellent thermal figure of merit solution to remove the heat from the front-end electronics and/or sensors. This presentation will cover different techniques and substrate materials to deliver the next generation of cooling plates based on power dissipation up to 2W/cm2 (LHCb VELO Upgrade 2 as benchmark), material budget equal or below 0.5%X0, better electronics integration and/or cost. Along those lines four different topics will be presented: Silicon microchannels via buried channels exploring better electronics integration via re-distribution metal layer; Silicon microchannels production via thermo-compression and hyperbaric process aiming for cost-reduction, integration and scalability; 3D metal printing for design flexibility and cost-reduction; ceramics manufacturing processes such as LTCC and HTCC to include electronic features in the cooling substrate by inclusion of lines in between layers or components on its surface.

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DRD8 Plans and next steps

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DRD8 WP 1 Overview

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DRD8 WP 2 Overview

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DRD8 WP 3 Overview

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DRD8 WP 4 Overview

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RDC10 Plans, next steps and funding

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R&D Collaborations (RDC 10 & DRD8 synergies & next steps)