



The ePIC Silicon Vertex Tracker IB-OB: Design and thermal-mechanical simulations

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ABSTRACT

The future Electron–Ion Collider (EIC) will offer a unique opportunity to explore the parton distributions inside nucleons and nuclei thanks to an unprecedented luminosity, a wide range of energies, a large choice of nuclei and polarization of both beams. The Electron–Proton/Ion Collider (ePIC) detector will be capable of precise determination of the position of primary and secondary vertexes, essential e.g. for the identification of charm hadrons, giving access to the gluon distribution inside hadrons. This measurement capability is achieved with a Silicon Vertex Tracker (SVT) placed as the innermost device in the ePIC experiment. The SVT Inner and Outer Barrel (IB, OB), developed by a collaboration of Italy-UK-USA institutes, provide five detecting layers made of silicon detectors, using the 65 nm Monolithic Active Pixel Sensor (MAPS) technology with stitching, pioneered by the ALICE collaboration for the Inner Tracking System 3 (ITS3) upgrade. The IB main focus is on vertexing performance. It is made of three layers of wafer-scale sensors bent to a cylindrical shape. The OB, composed of two layers, mainly contributes to the particle momentum measurement and it is equipped with a smaller version of the IB sensor mounted in a typical stave configuration.

This paper will present the design of SVT Inner and Outer Barrel and the first Finite Element Analysis (FEA) simulations for mechanical and thermal studies.

1. Introduction

The Silicon Vertex Tracker (SVT) is the innermost subsystem of the future ePIC detector [1,2]. It will be the first experiment at EIC (Electron–Ion Collider), the new accelerator facility that is under construction at the Brookhaven National Laboratory (Upton, NY, USA) [3]. The EIC physics program is broad and aims to continue the exploration of strongly interacting matter using Deep Inelastic Scattering (DIS), focusing in particular on four fundamental topics: nucleon spin, nucleon imaging, gluon saturation and hadronization. In order to explore them, a large range of center of mass energies (28–140 GeV) at luminosities up to $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ are foreseen. The EIC will offer the unique possibility of polarization of both beams (electrons and protons/deuterons) up to 70%. A wide range of nuclei will be available, up to uranium.

The role of the SVT in the ePIC detector is to perform the tracking of charged particles and the localization of the primary collision vertexes and of the displaced weak decay vertexes of hadrons containing heavy quarks. Constraints from the overall detector size and the outer subsystems limit the active volume of the SVT to $-105 < z < 135$ cm and a radius of approximately 50 cm. In combination with the 1.7 T solenoidal field, this leads to a requirement on the point resolution of

better than $10 \mu\text{m}$ exploiting high granularity of sensors (pixel pitch of $\sim 20 \mu\text{m}$). At the same time the traversed material must be minimized for the support and services.

The SVT is composed of the Inner Barrel (IB), the Outer Barrel (OB), covering the central pseudorapidity range, and the two groups of endcap disks (not discussed in this paper), for a total active area of approximately 8.5 m^2 .

2. Inner Barrel

The Inner Barrel (IB) is composed of three active layers L0–L1–L2. It is designed to provide precise vertex reconstruction with an asymptotic resolution better than $10 \mu\text{m}$, and contributing to momentum measurement. The current IB design foresees a cylindrical frame structure for each layer, whose radius will be 38, 50 and 125 mm respectively, made of two symmetric half-layers. Each half-layer will consist of the sensors, a local support structure mainly made in carbon foam, two sets of FPCs (Flexible Printed Circuits) wire-bonded to the sensor peripheries for powering and data/control transmission. The CAD exploded view of the IB design is shown in Fig. 1: the three layers are displayed in green, the

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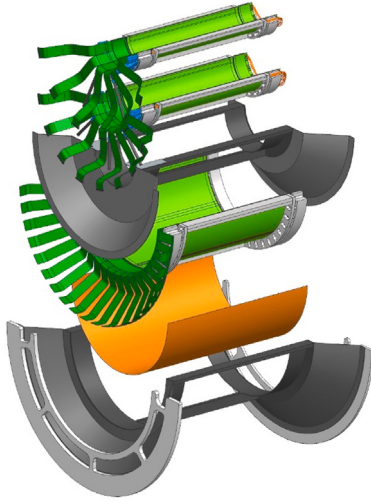


Fig. 1. CAD exploded view of IB support with cables and sensors.

mechanical supports for L1–L2 connection and for the entire IB are in gray and a kapton layer for air flow routing and mechanical protection is in orange.

The IB will use the ALICE ITS3 [5] MAPS sensor MOSAIX fabricated in 65 nm commercial Complementary Metal–Oxide–Semiconductor (CMOS) technology and thinned to 50 μm . It is composed of twelve chips (Repeated Sensor Units, RSUs) stitched together on a single row to reach a total length of ~ 27 cm. The schematic of MOSAIX is shown in Fig. 2. IB sensors will have different sizes: three RSUs wide for L0, four RSUs wide for L1 and five RSUs wide for L2. The sensors, with a Left and Right Endcap (LEC, REC) for service connections and readout, will be placed one next to the other and bent on a cylindrical shape at the corresponding radius: there will be two wafer-scale sensors on L0 and L1, and four on L2. Stitching and bending expertise will be partially inherited from ITS3. MOSAIX will feature a pixel size of $21 \times 23 \mu\text{m}^2$ and a power consumption of 40 mW cm^{-2} .

2.1. Material budget

The extremely low power consumption of MOSAIX allows to use air flow as cooling mechanism for sensors, resulting in a dramatic reduction of services. In combination with the minimal mechanical support, this solution targets an extremely low material budget. As shown in the material budget estimation plot in Fig. 3, at the outgoing electron direction, i.e. in the pseudorapidity η range $[-1, 1]$, only sensors are present, reaching a value of $x/x_0 = 0.07\%$; elsewhere x/x_0 value is increased by cables and services. First design based on past experience considered copper cables as high material budget limit; better performance can be achieved with lower radiation length material, such

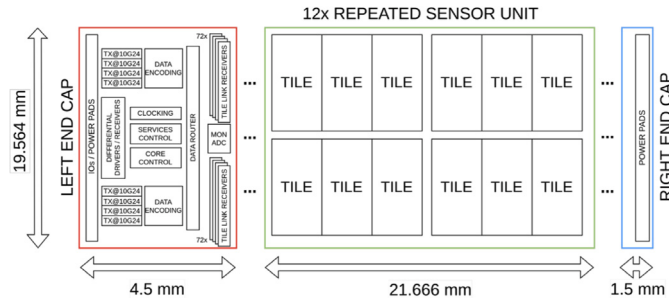


Fig. 2. Mosaix block diagram [4].

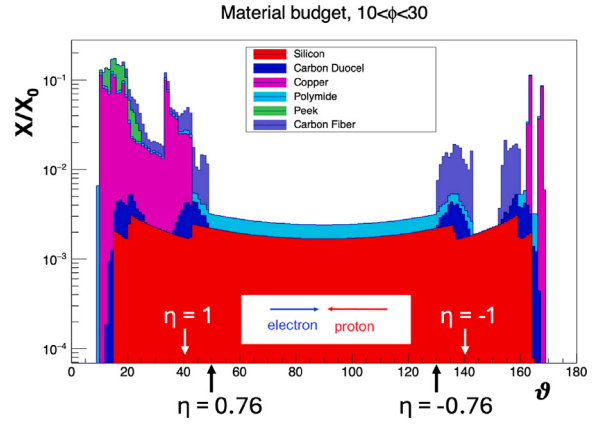


Fig. 3. Material budget estimation.

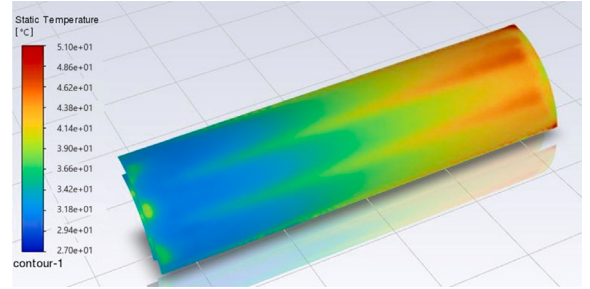


Fig. 4. Static temperature simulation.

as aluminum cables, which are under test. The simulation considers an upper safe estimate value for composite support thickness of 1 mm and a simplified L2 model whose the final design is not yet available.

2.2. Thermal and mechanical FEA

The thermal load must be properly simulated to investigate the feasibility of air cooling for the L0–L1. For L2, while convection could be in principle sufficient to dissipate the heat generated by the electronics, the addition of cooling elements is still under investigation. Fig. 4 shows the results for the static temperature simulation for the quarter-barrel L0–L1. The simulation is carried on considering a uniform air flow at speed of 15 m/s entering the space between layers. The layers are parametrized as two surfaces with a maximum thickness of 0.2 mm and a power consumption of 400 W m^{-2} , not including the contribution from the LEC. The heat exchange between the air flow and the surface is evaluated and, across the quarter-barrel, 15°C temperature difference between air and surfaces (both temperatures are assumed uniform) is reached. The heat transfer coefficient simulations give a variation of approximately one unit along for the L1 quarter-barrel length. The results are obtained without the implementation of turbulence (critical for proper cooling) because it cannot be easily achieved. Thermal FEA analysis are useful in understanding the distribution of heat on the structure but tests on a thermal prototype will be needed to fix simulations parameters in order to obtain realistic values of temperature and flux.

FEA for the mechanical load are carried out with a load safety factor of 1.5 and L2 deformation results are extrapolated by L0–L1. The last design, which considers a one-piece support, presents an enhanced deformation on electron-side (e-side) arms highlighted in orange and red, which could generate a displacement of the support dangerous for the sensors (Fig. 5). An alternative is constituted by a 200 μm thick support made of separated parts glued together: in this case the

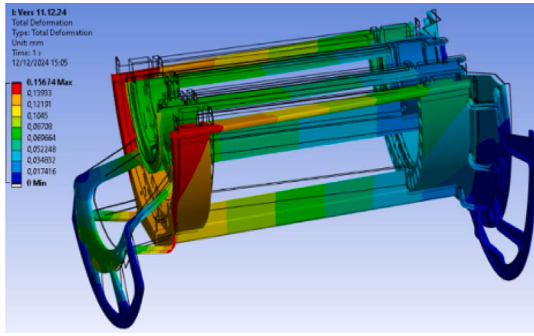


Fig. 5. Mechanical load simulation.

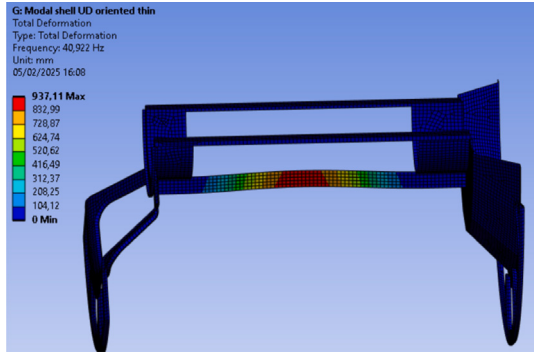


Fig. 6. First mode modal simulation for Inner Barrel support.

deformation is 600 μm on edges, due to copper cables, not affecting the sensor region. Benchmark of these results by experimental tests on prototypes are necessary and foreseen by the end of the year.

The support first mode modal simulation is shown in Fig. 6. It highlights a deflection of the bottom beam setting the half cylinder element thickness at 0.4 mm and the support cones one at 0.6 mm. The first mode is predicted at 40.9 Hz. It is encouraging that proper frequencies are far from the typical ones induced by air flow, which are expected to be much higher (order of hundreds of Hz), but studies are still ongoing and a test campaign will follow the availability of a support prototype

3. Outer Barrel

The Outer Barrel (OB) will provide high precision position measurements with large lever arm delivering the required momentum resolution and acceptance at intermediate pseudorapidity. OB is composed of two active layers L3–L4 assembled into a tiled like barrel

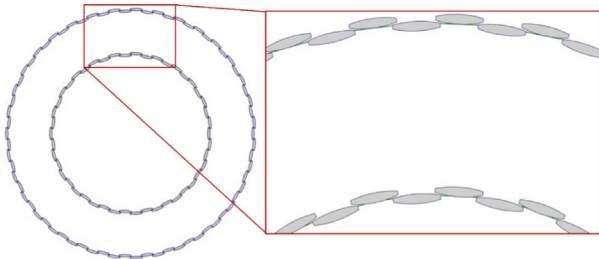


Fig. 7. Outer Barrel design with pictorial view of staves placement in the layers.

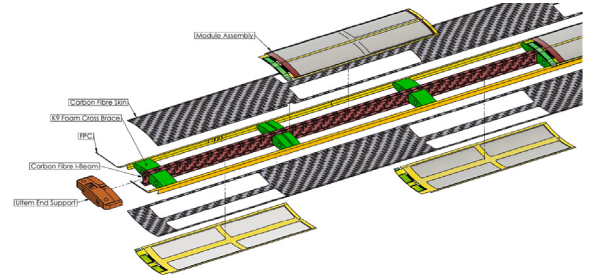


Fig. 8. Outer Barrel stave structure.

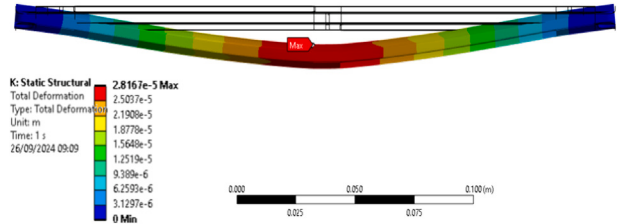


Fig. 9. Three point bend simulation of a quarter stave.

structure with radius of 270 and 420 mm respectively. The layers will be segmented in staves and each stave is currently planned to be placed in alternating top-bottom arrangement so that the active areas overlap. The OB design and a pictorial view of stave placement is presented in Fig. 7. The OB will be equipped with a modified version of the ALICE ITS3 sensor called the EIC Large Area Sensor (LAS), thinned down to 50 μm and optimized for high yield, low cost, and large area coverage. One LAS, composed of five or six RSUs, will be coupled with an auxiliary chip called Ancillary ASIC (AncASIC), which will provide serial powering, bias and slow control of signals. Two units of this kind will form a module. The staves will present modules on both facings, as can be seen in Fig. 8, two for L3 and four for L4, aiming for material budgets of 0.25% x/X_0 and 0.55% x/X_0 respectively.

3.1. Mechanical and vibrational FEA

FEA and mechanical simulations are very important to predict the frequency response and the deformation of the structures considering the very low mass of LAS sensors (3.3 g) and the air cooling speed of few m/s.

In parallel, two L4 quarter staves prototypes have been produced, comprehensive of the carbon fiber top/bottom skins, pure Kapton FPC mock-ups and SLA 3D-printed stave-end supports. They show no noticeable twists caused by the manufacturing process, but reinforcements are needed because of end support deformation. The prototypes are tested with a three-point bending test, measuring the deformation of the center as a function of the load placed upon it. The measurements results are compared with the mechanical FEA simulation (Fig. 9) in the plot shown in Fig. 10: the results represented as blue dot and the orange line of the FEA are in good agreement.

The behavior under vibration is also studied with ANSYS Modal model on a cantilevered, i.e. a diving board, quarter-stave without sensors: the FEA gives a frequency of 97 Hz for the first mode. This configuration gives similar magnitude frequencies of a fully supported L4 stave.

4. Outlook

The SVT design is well advanced.

Inner Barrel thermal and mechanical FEA are promising. Implementation of design details in simulations are needed as well as a complete

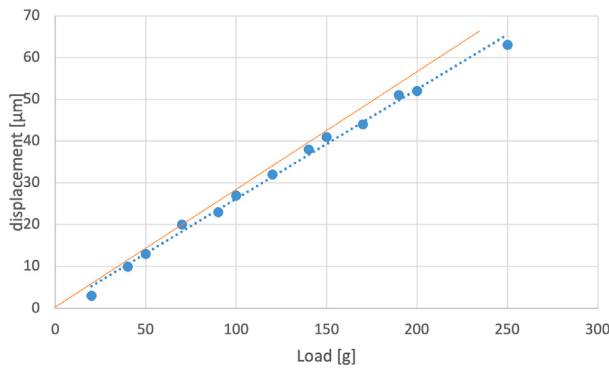


Fig. 10. Three point bend simulation (orange line) and test results (blue dots) comparison plot.

FEA crosscheck on mock-up to confirm the preliminary evaluations. The production of prototypes is planned by the end of 2025, to optimize the choice of materials and of design parameters to match required performances of mechanical stability and material budget. In parallel, more ePIC-oriented tests, such as timing and fake hit rate, will be performed on MOSAIX sensors.

Outer Barrel quarter-staves production will continue including carbon I-shaped support and K9 foam blocks. A full stave assembly is

targeted following the drawings update for remaining mold parts. Several tests on the full stave are planned: vibrational test to compare with FEA, measurement of stave deformation with heat generation and internal pressure, study of temperature with air flow adding dummy AncASIC.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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