Performance simulation studies for the tracking detector at the Electron-Ion Collider

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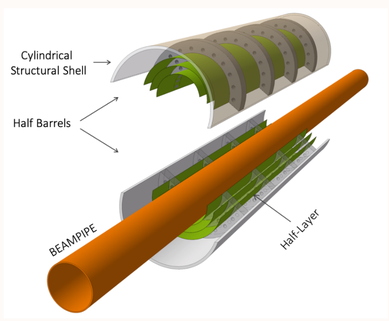
Introduction

- The US **Electron-Ion Collider (EIC)** project will allow to study the collisions of polarized electrons with polarized protons and ions. The project is devoted to build up an electron-ion collider at BNL, with the aim of systematically studying many open problems towards the complete understanding of the nuclear force.
- The **EIC_NET** experimental initiative brings together the Italian community of researchers participating to the EIC project in the US.
- **ATHENA** (A Totally Hermetic Electron-Nucleus Apparatus) is one of the proposed detectors for EIC based on the contribution of EIC_NET groups. It includes wide pseudorapidity (η) coverage, high granularity, low material budget to achieve a good momentum resolution, precise determination of primary and secondary vertices $\rightarrow$ **Precise tracking**.

ATHENA Tracker

- **Central Region:**

– 3 vertex (X/X_0=0.05%) and 2 barrel sagitta layers (X/X_0=0.55%) based on silicon MAPS in 65 nm CMOS technology currently being developed by ALICE ITS3, with expected spatial resolution $\sigma_{r\phi}=\sigma_z=$ 2.887μm.



Layout of ALICE ITS3 detector (https://cds.cern.ch/record/2703140/);

– 4 micromegas layers with a resolution of $\sigma_{r\phi}=\sigma_z=$ 150μm) and X/X_0=0.4% per layer.

- **Forward & Backward Region:**

– 6 forward and 5 backward silicon disks ($\sigma_r=\sigma_{r\phi}$=2.887 μm) with X/X_0=0.24% per layer.

– The two outer Si disks complemented by Gas Electron Multiplier (GEM) layers.

– One μRWELL layer in most forward region.

– Each GEM layer and μRWELL layer has X/X_0=0.4% and σ_r=250 μm, $\sigma_{r\phi}$=50 μm.

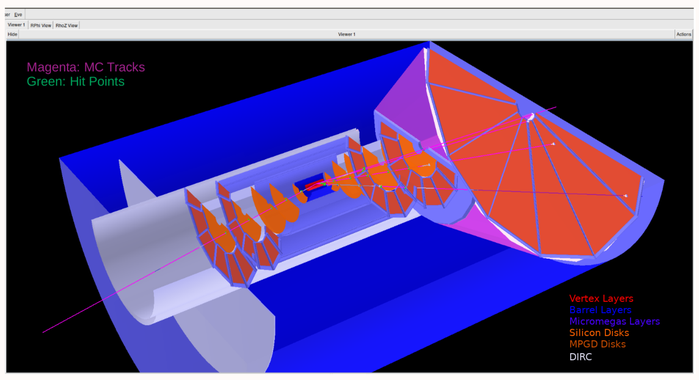


Figure 1: Event Display of ATHENA showing the detector volumes with embedded π^- MC tracks (magenta) and hits (green) using Fun4All simulation framework;

Simulation of ATHENA Tracker

- Negative pion are generated uniformly in pseudorapidity and momentum, propagated through the detector material using particle gun in GEANT4. This gives the true or Monte Carlo (MC) points on the detector planes. Digitization, hit reconstruction, tracking were performed at a later stage.
- Full simulation in Fun4All and Detector Description Toolkit for High Energy Physics (DD4HEP) framework are used to estimate the performance of tracking system.

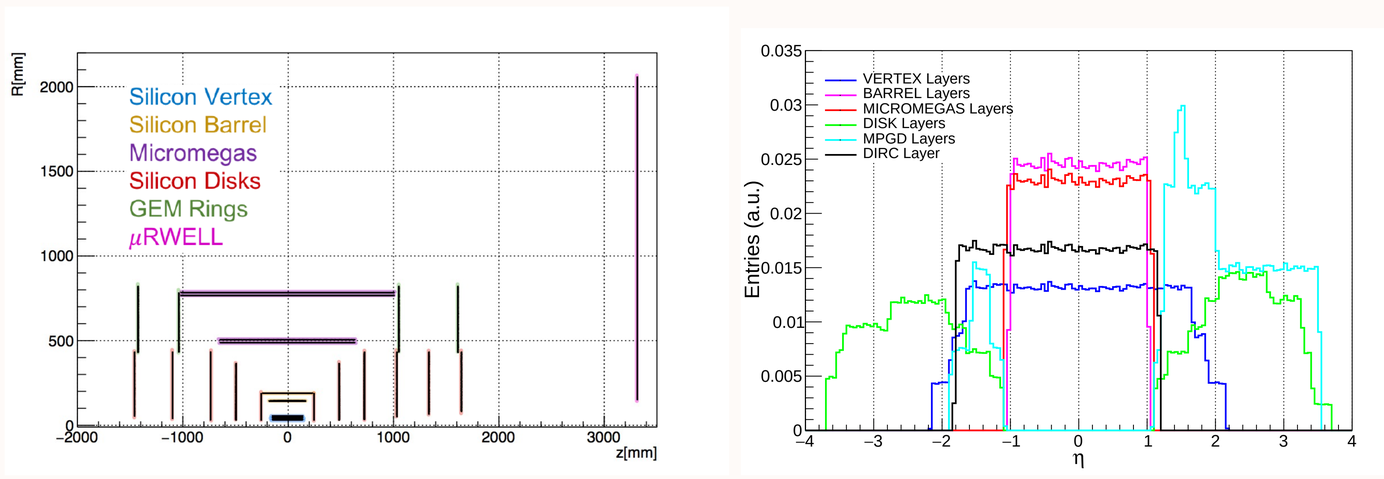


Figure 2: (Left) R-Z hit points map and (Right) pseudorapidity coverage of each detector from the hit positions;

ATHENA Tracking Performance

- Characterized by momentum and Distance of Close Approach (DCA) resolutions and fitted with $f(dp/p) = \sqrt{A^2p^2 + B^2}$ and $f(DCA_T) = \sqrt{(A^2/p_T^2) + B^2}$ respectively.
- Expected performances met the physics requirements as stated in the Yellow Report (YR), except for the most backward pseudorapidities (-3.5< η < -2.5) and momenta below 2 GeV, respectively.

– Further technology R&D to reduce material, combined with sophisticated analysis techniques and further overall detector layout optimizations needed to fully achieve physics goals.

Acceptance	Momentum resolution $\sigma(p)/p$		Transverse pointing resolution $\sigma(DCA_T)$	
	Performance	Requirements	Performance	Requirements
$-3.5 < \eta < -2.5$	$\sim 0.04\% \times p \oplus 1.5\%$	$\sim 0.1\% \times p \oplus 0.5\%$	$\sim 80/p_T \oplus 10\mu m$	$\sim 30/p_T \oplus 50\mu m$
$-2.5 < \eta < -1.0$	$\sim 0.01\% \times p \oplus 0.5\%$	$\sim 0.05\% \times p \oplus 0.5\%$	$\sim 50/p_T \oplus 5\mu m$	$\sim 30/p_T \oplus 20\mu m$
$-1.0 < \eta < 1.0$	$\sim 0.05\% \times p \oplus 0.4\%$	$\sim 0.05\% \times p \oplus 0.5\%$	$\sim 30/p_T \oplus 5\mu m$	$\sim 20/p_T \oplus 5\mu m$
$1.0 < \eta < 2.5$	$\sim 0.01\% \times p \oplus 0.5\%$	$\sim 0.05\% \times p \oplus 1.0\%$	$\sim 50/p_T \oplus 5\mu m$	$\sim 30/p_T \oplus 20\mu m$
$2.5 < \eta < 3.5$	$\sim 0.02\% \times p \oplus 1.5\%$	$\sim 0.1\% \times p \oplus 2.0\%$	$\sim 80/p_T \oplus 10\mu m$	$\sim 30/p_T \oplus 50\mu m$

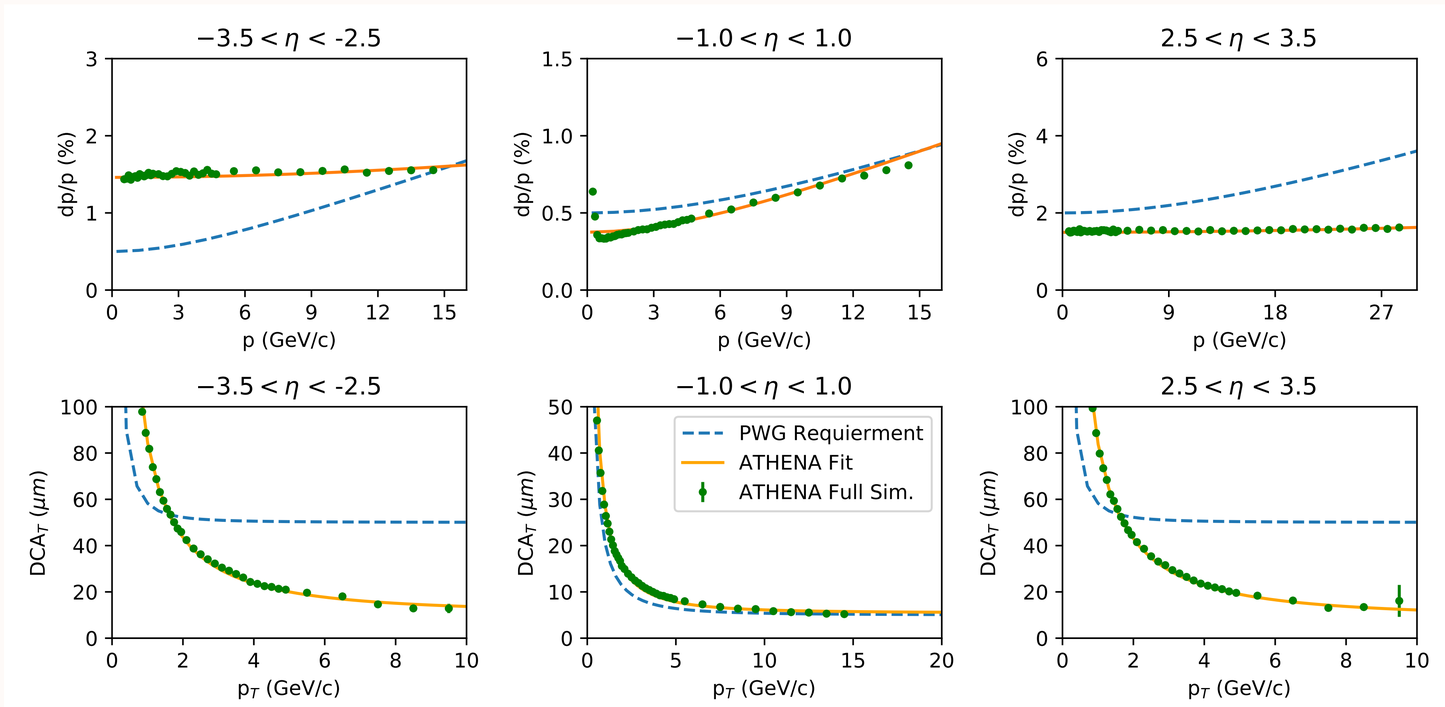


Figure 3: Tracking performances of ATHENA corresponding to simulated pions- uniform in η and momentum compared to the physics requirements in YR for selected η bins. (Top row) Momentum resolutions versus momentum and (Bottom row) Transverse DCA resolution versus transverse momentum;

References

- R. Abdul Khalek, *et al.* "Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report", [arXiv:2103.05419 [physics.ins-det]].
- EIC, A machine that will unlock the secrets of the strongest force in Nature https://www.bnl.gov/eic/.
- ATHENA, A new EIC experiment at IP6 at BNL https://sites.temple.edu/eicatip6/.