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eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

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Abstract:

This report describes progress towards the conceptual development of tracking stations with silicon-sensors near the collision vertex to detect the scattered electron and produced secondary hadrons at forward and backward angles in the period between July and December 2016. eRD16 focuses on forward/backward disks of thinned-silicon sensors (MAPS) with the overall goal (extending beyond the current reporting period) of arriving at a layout including concept design for the arrangement of services (cooling, power, and readout) and their integration with central barrel tracking subsystems.

1. Introduction and Motivation

The US nuclear physics program plans to build an Electron Ion Collider to study the gluonic structure of nucleons and nuclei [1]. The facility will be built at Brookhaven National Laboratory as an upgrade to the Relativistic Heavy Ion Collider accelerator or at the Thomas Jefferson National Accelerator Laboratory as an upgrade to the CEBAF facility. The Electron Ion Collider is scheduled to come online in the 2025 to 2030 timeframe. eRD16 aims to develop forward tracking instrumentation, which is key for an EIC detector, building upon our experience in constructing silicon vertex trackers for heavy-ion experiments at RHIC and the LHC.

The scattering region along the direction of the *electron* beam is of particular scientific interest. Specifically, this region gives access to the gluon-dense ("small-x") nuclear environment through leptonic and hadronic observables with energies below the *electron* beam-energy. Tracking in this region serves both leptonic and hadronic momentum measurement and imposes considerable challenges in the solenoidal fields that are under consideration for the central detectors. The momentum measurement, together with the energy measurement with electromagnetic calorimetry, is key to the identification of the scattered electron through measurement of E/p. Unobserved losses of the scattered electron's energy, e.g. bremsstrahlung, introduce a bias in Bjorken-x, typically towards smaller values. The above combined point to a need to develop a well-integrated, low-mass tracker.

The scattering region along the direction of the *hadron* beam is of considerable scientific interest as well. Here, new insights are anticipated for example in the partonic energy-loss mechanism(s) in cold nuclear matter. The observation of identified charmed hadrons in semi-inclusive processes would be qualitatively new and is likely to require topological reconstruction with a precision tracker.

2. Progress on simulations

At the EIC Generic R&D meeting in July 2016 and as part of the proposal that was submitted at that time, eRD16 presented results from an initial set of simulations aimed at a conceptual layout/design of pixel tracking stations in the forward and backward scattering regions at a future EIC. This work made use of a toolset developed originally for ILC tracking studies [2], which performs simplified simulations of the detector measurements, based on a helix track model with multiple scattering, followed by full single track finding and reconstruction from digitized hits using a Kalman filter. The detector configurations that were considered for the initial simulations consisted of standalone forward and backward arrays of equidistant silicon disks in the 3T solenoid of 2m length and 1.2m of the BeAST detector concept [3] as well as such configurations for the detector concept based around the 1.5T BaBar magnet [4]. These simulations made it possible to draw initial conclusions and they provided guidance also for follow-on work.

The initial simulations led us to conclude, among other, that the ALICE ALPIDE sensor has sufficient granularity and thinness for application at an EIC. Optimization for single-track momentum resolution in the forward and backward regions resulted in arrays with a different number of disks on either side of the collision region, with fewer disks in the forward-electron (backward) direction where typical track-momenta are lower resulting in a different trade-off with multiple scattering than in the forward (hadron) direction. The arrays need to extend beyond ~0.8m along the beam axis (z) and/or be complemented with alternative large-z tracking to achieve 1 GeV track-momentum resolutions better than ~5% for track angles within 10 degrees from the beam-axes within a 1.5T field. Single-track pointing resolutions of better than 20μm can be achieved in $r.\phi$ for track momenta larger than ~5 GeV/c.

As planned, we have expanded the detector configurations to include the tracking sub-systems for the detector concept based around the 1.5T BaBar magnet [4]. This concept, in its original form, relies on tracking with GEM disks of different radii. It is reproduced schematically in figure 1. The corresponding tracking configuration for our current simulations, where the GEM disks that are closest to the collision point in the original concept have been replaced with a forward/backward symmetric variant of the silicon disk arrays from our initial simulations, is shown in figure 2. The combined tracking performance of both the original concept and variants with MAPS disks have been evaluated. Figure 3 shows a representative comparison of single-track momentum resolutions in the backward (forward electron) direction for a typical range of total (electron) momenta and track angles of 170 degrees with respect to the direction of the hadron beam. MAPS-based forward/backward tracking is seen to provide considerable

improvement in momentum resolution. The trade-off between the number of track hits and traversed material,

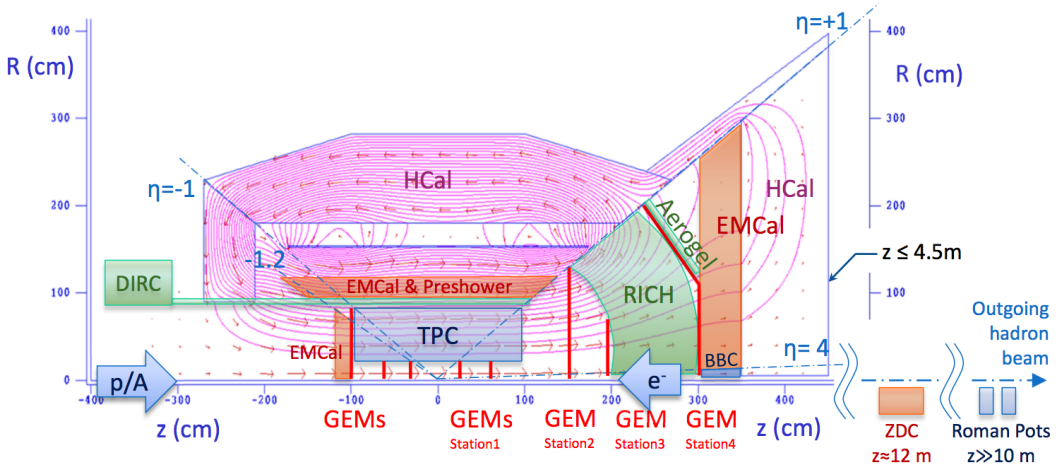


Figure 1: A cross section through the top-half of the ePHENIX detector concept, showing the location of the superconducting solenoid, the barrel calorimeter system, the EMCal in the electron-going direction and the system of tracking, particle identification detectors and calorimeters in the hadron-going direction. Forward detectors are also shown along the outgoing hadron beamline. The magenta curves are contour lines of magnetic field potential as determined using the 2D magnetic field solver, POISSON. This figure is reproduced from ref [4].

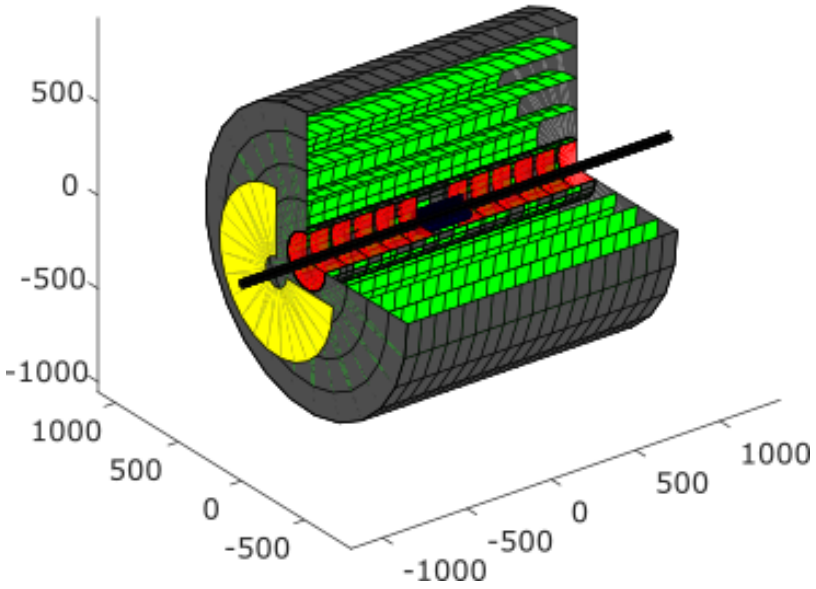


Figure 2: The corresponding tracking model for our (fast-)simulations. Shown are the beam-pipe (in black), the TPC with its field cage (green and gray, respectively), the large-radius GEMs in the forward-electron direction (yellow) and two arrays of six equidistant MAPS disks (red) that replace the small-radius GEM disks of the original concept as discussed in the text. Not shown

are the large-radii GEM trackers in the forward-hadron direction. The field in this tracking model is a uniform solenoidal field with a magnitude of 1.5T. The distance scales are in mm.

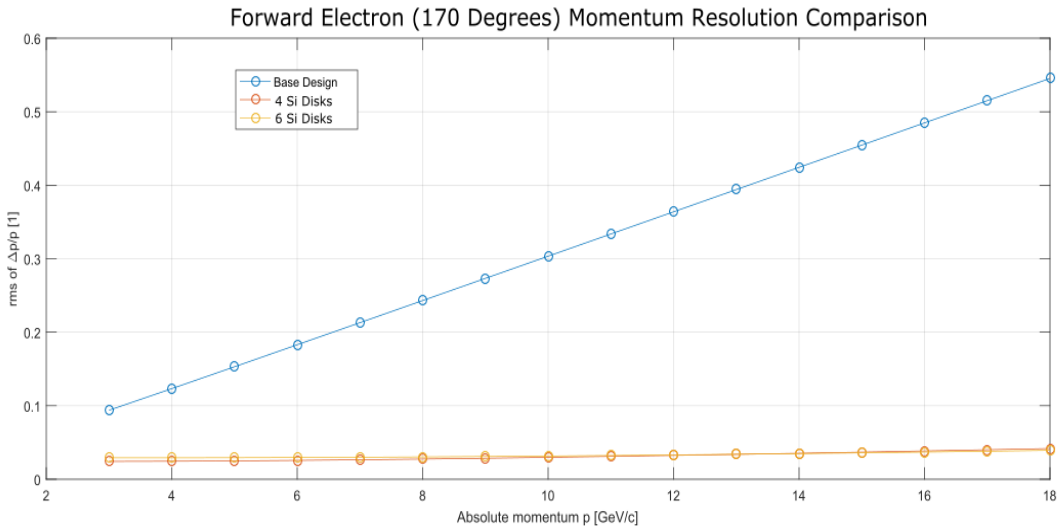


Figure 3: A representative performance comparison of single-track momentum resolution with the base design (c.f. Fig 1) and two variants with inner MAPS-based Si-disks (c.f. Fig 2).

observed in our initial simulations with standalone silicon disks, is seen to be preserved in these simulations. The size of this effect, in essence a refinement, is – as expected – considerably smaller than that of the technology change from a sparse array of GEM-disks to an array with 4-6 disks based on the ALICE-ALPIDE sensors. This work, as well as evaluations of single-track pointing resolutions, was performed with UCB undergraduate student Ivan Velkovsky.

We have performed similar exercises with the/a BeAST detector concept, albeit in an older incarnation that predates the incorporation of the micromegas outer-barrel-tracker of the current BeAST concept and other changes. As this report is being prepared, UCB undergraduate student Winston DeGraw is about to join the eRD16 fast-simulation effort. We intend to update our (currently outdated) BeAST tracking model and evaluate its performance with various forward/backward silicon-disk configurations this Spring. This will now mark also the start of GEANT-based simulations within the BNL-developed framework with postdoctoral researcher Yue-Shi Lai, as originally envisioned.

As described also in section 3 below, postdoctoral researcher Michael Lomnitz has joined LBNL in December 2016 on LBNL-LDRD funds to pursue EIC R&D related to event-generator development and simulations to optimize the dimensions and number of barrel layers of a low-mass inner silicon barrel tracker for the EIC, with a goal of developing one or more plausible designs for such a subsystem. The latter part of this (distinct) effort has direct synergies with eRD16. At this time, it has already aided in the aim to extend the fast-simulation studies of single-track pointing-resolutions to multi-track vertex-reconstruction by interfacing with and

initial tests of the RAVE package [5]. We are now about to start our planned investigations of the performance of arrays of non-equidistant disks and, related, implications for sensor and infrastructure layout. It is helping also in our planned and now starting studies of hit pile-up within the 4us effective integration time of the ALPIDE sensors.

3. Closing coments

As noted in an earlier report, LBNL identified the EIC as a focus for near term strategic institutional support. This has led to LDRD funding in FY17. Several of the eRD16 co-authors are part of this LDRD, in collaboration with other colleagues at the Laboratory. The LDRD support has made it possible to hire a postdoc for EIC-related studies; Michael Lomnitz joined in December 2016. He is carrying out tracking R&D for the barrel region with approximately 50% of his time. Of course, conceptual design of a barrel silicon tracker has great synergy with eRD16, as the two will need to coexist mechanically, and share services as much as possible. The importance of developing an integrating conceptual design of barrel and forward tracking precluded us from pursuing comparative evaluation of HV/HR-CMOS and MAPS in 2016. The same holds for studies of tracking in the very forward region. Investigation of possible closer synergies with tracking for polarimetry will have to follow the current work toward an integrated central and forward silicon tracker.

R&D on low-mass conductors is a key aspect of developing truly low-mass trackers. Synergies between EIC and ALICE developments are indeed evolving, now that the ALICE-ITS project is entering its production stage. During this reporting period, we acquired longer conductor cables from CERN than had been previously produced, and have improved their designs in order to reduce the need for vias. We will return to this topic in more detail in a future update when our concepts for the practical sensor layout on forward disks are further advanced.

References

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