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eRD16: Forward/Backward Tracking at EIC using MAPS Detectors

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Abstract:

We propose continued 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. The main focus is on disks with thinned-silicon sensors (MAPS) with the goal to arrive at physics-driven sensor specifications, the overall geometrical arrangement of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with central barrel tracking subsystems. Part of this work will be pursued in collaboration with eRD18, which focuses on mid-rapidity tracking and sensor development.

1. Introduction

The US Nuclear physics program plans to build an Electron Ion Collider facility to study the gluonic structure of nucleons and nuclei [1]. The facility will be built as an upgrade to the Relativistic Heavy Ion Collider accelerator at Brookhaven National Laboratory or as an upgrade to the CEBAF facility at the Thomas Jefferson National Accelerator Laboratory. The EIC is scheduled to come online in the 2030 timeframe.

The ultimate goal of eRD16 is to provide a conceptual design for precision endcap trackers for the EIC utilizing monolithic active pixel sensors. Achieving this goal requires work in several directions, and the eRD18 and eRD16 groups will collaborate to carry out this work over the next several years.

The need for and specifications of EIC endcap trackers are driven by science and include, in particular, the challenging measurement of the scattered electron. Successful endcap trackers must have excellent momentum and position resolution, very low mass, and fit together with the barrel tracker to provide full angular coverage. Both the barrel and the endcaps must be optimized for resolution and mass, while minimizing the cost of the combined system. Because of the asymmetry of the beams, the energies of the scattered electron and the produced hadrons vary between the two endcaps. This suggests an asymmetric silicon tracker design.

Excellent position resolution drives specifications for the pixel size, while momentum resolution drives both pixel size and the mass budget. Initial studies have been done, indicating that 20 to 30 micron square pixels are sufficient for momentum measurement at an EIC for the different magnetic fields and detector configurations being considered. Further simulations are needed to specify optimal sensor design.

Past work has already shown that mass must be minimized to avoid bremsstrahlung and degrading the momentum resolution by multiple scattering. This has a number of implications, in particular in the endcap regions. Once specified, the new sensors need to be laid out, and simulated to demonstrate feasibility of sensor design and production. Prototype sensors must subsequently be produced and tested. Furthermore, the readout speed, heat load and cooling, along with mechanical concept for barrel and endcaps must be worked out.

Accomplishing these goals is multi-year activity, which LBNL and Birmingham propose to undertake together. LBNL is well positioned to carry out physics simulation studies to specify the sensor size, shape, and pixellation. In addition, LBNL will optimize the barrel and endcap design. Birmingham will collaborate on the physics simulations and then simulate the resulting sensor design. Future steps will be for Birmingham to produce prototype sensors, which can be tested at CERN, Birmingham and LBNL. We note, in particular, that combining the proton beams available at the Birmingham cyclotron with proton and heavy ion beams at the LBNL 88" Cyclotron will allow characterization of the new sensor performance and its sensitivity to radiation damage.

In the sections below, we describe recent progress related to these areas for the proposed forward tracking stations. This is followed by proposed work for the upcoming period, personnel, and our funding request.

2. Progress on simulations

Initial simulations have been performed to develop a conceptual layout/design of pixel tracking stations in the forward and backward scattering regions at a future EIC. A postdoctoral researcher (Lai) is utilizing the tools developed at BNL specifically for EIC simulation. At the time of writing this report, he has performed a number of simulations for the 3T solenoid of 2m length and 1.2m radius and the symmetric detector geometry of the forward and backward silicon disk trackers envisioned in the BeAST detector concept [2]. These studies have focused so far on reproducing several of the baseline results and on detector variations with different pixel sizes and different numbers of disks. These studies are now transitioning to variations in the disk geometry and to support infrastructure.

Separately, a number of studies have been performed with UC Berkeley undergraduate students (DeGraw and Velkovsky) using a toolset that was developed originally for tracking studies for the ILC detector concepts [3]. This toolset performs a simplified simulation of the detector measurements, based on a helix track model and taking into account multiple scattering, followed by full single track reconstruction from digitized hits using a Kalman filter. Initial results for BeAST and the detector concept based around the 1.5T BaBar magnet [4] have been reported previously. Figure 1 illustrates momentum resolution for tracking with standalone arrays of disks in the BeAST forward-silicon-tracker envelope and its 3T field as a function of momentum and pseudo-rapidity.

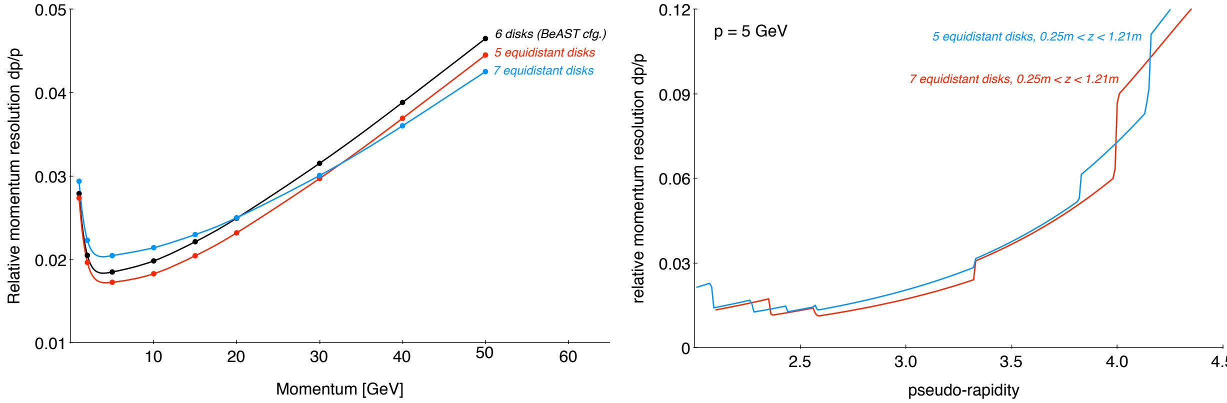

Figure 1: (left) Relative momentum resolution for standalone tracking with 5, 6, and 7 disks spanning 0.96m in a 3T solenoidal field versus momentum at fixed pseudorapidity η = 3, and (right) the pseudorapidity dependence at a fixed momentum p = 5 GeV. The pixel size is 28 microns in these simulations and the disk thickness is χ_0 = 0.3%.

Particle tracks at a fixed η = 3 traverse all disks for the inner and outer disk radii of 18mm and 185mm, respectively. The steps in the performance at larger and smaller pseudo-rapidities have their origin in acceptance edges. Their location depends on the inner and outer radii, as well as the positions of the disk along the beamline. At the highest and lowest pseudo-rapidity values on these curves, the tracking uses only three of the five or seven disks to measure momentum; for these extreme pseudo-rapidities, the disk configurations thus have no redundancy for momentum (curvature) measurement.

Figure 2 (left) shows the corresponding performance with the 7-disk configuration for different pixel sizes and (right) the variation of the 5-disk momentum resolution with a 20μm pixel with the (average) thickness for each disk at fixed η = 3. The effect of the 0.3% thick beampipe in these simulations results in slightly worse performance at momenta below ~5 GeV; this effect is smaller than that from the varying disk thicknesses as shown.

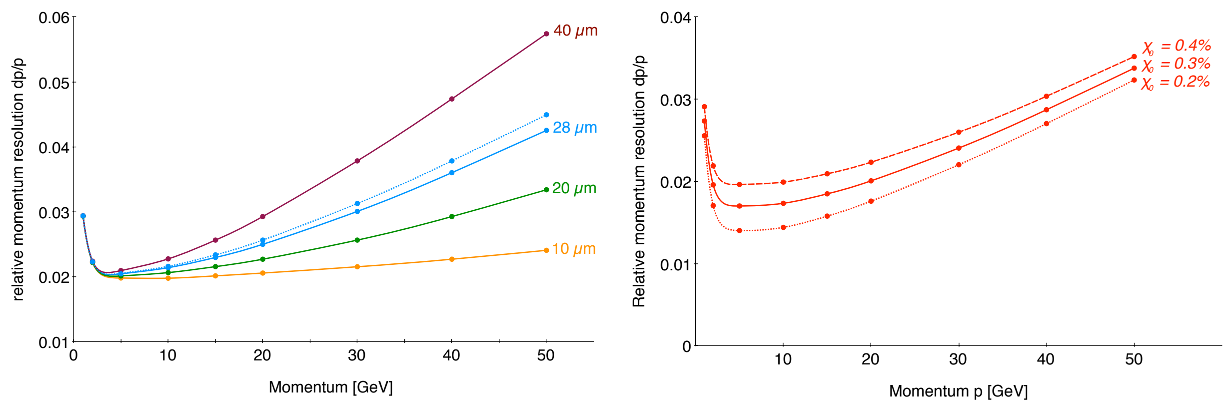

Figure 2: (left) Relative momentum resolution for standalone tracking with 7 equidistant disks spanning 0.96m in a 3T solenoidal field versus momentum at fixed pseudorapidity η = 3 for different pixel sizes, as indicated, and thickness χ_0 = 0.3% for each disk. (right) the corresponding 5-disk performance for different thicknesses of χ_0 = 0.2% to of χ_0 = 0.4% per disk.

An important further characteristic of the proposed MAPS sensors is the duration of their signal integration in relation to the anticipated collision rates and particle densities at an EIC. Their effective integration time is typically several μs. Since the EIC beam crossing frequency will be 10MHz or higher, the sensors integrate over multiple crossings. For the anticipated EIC luminosities of $10^{33\text{-}34}cm^{-1}s^{-2}$, the total anticipated collision rates are well below the beam crossing rate and multiple collisions per crossing are thus unlikely to occur at the EIC, unlike at the LHC. Nevertheless, multiple collisions can occur within the sensor effective integration time. The resulting hits/tracks need to be disambiguated with external fast(er) detectors. We have done initial standalone simulations in which tracks traversing the forward disks, generated independently according to the anticipated rate profile [4], are 'anchored' in time to hits in the (fast) large-area forward GEM disks that are part of the BeAST baseline design in both the forward electron and the hadron going directions. These studies are now being extended to the (in this respect more involved) central detector region; their incorporation in the EICroot simulation framework is part of the proposed simulation work for the upcoming period.

3. Proposed work

Past eRD16 simulation efforts have been focused on the overall geometrical configuration of disks in the envisioned 3.0T and 1.5T solenoidal fields of the BeAST concept and the concept around the BaBar magnet, and on (im-)possibilities with the existing ALICE ALPIDE sensor. Detailed simulations how these sensors, or sensors of similar shape, can be best laid out to construct a disk will be pursued with the still remaining funds.

Collaboration with eRD18 opens the exciting possibility to meaningfully pursue a sensor design that is better suited to EIC science demands. We propose to expand the scope of our studies of sensor characteristics. Contingent on funding, we will integrate our studies of readout speed and other characteristics in the EICroot framework and will do studies to aid sensor specifications.

The development of low-mass trackers requires advances on multiple fronts, including low-mass conductor cables and cooling. For the upcoming R&D period, we aim to make a start on cooling investigations. Traditionally, silicon trackers have been cooled with liquid circulating through part of the support structure or by air-flow across the sensors. Cooling through micro-channels incorporated in the sensor is being researched for application at the ILC, currently still with high material impact but also with ambitious goals. Prior R&D performed by the LBNL physics and engineering divisions, and successful SBIR rounds with an industrial partner have led to the development of porous foams with high thermal conductivity opening the possibility in specific cases to cool by air through the silicon support structure. As part of this R&D, tests have been performed for stave configurations. We will explore the viability for disk configurations, building on prior work within the physics and engineering divisions for staves.

4. Personnel

Forward disk conceptual design simulation efforts have been carried out by Project Scientist Yue Shi Lai, ES, and several younger scientists. UC Berkeley undergraduate students Winston DeGraw and Ivan Velkovsky have been supported by eRD16 funds to participate in fast-simulations towards viable conceptual designs for BeAST and the concept based around the 1.5T BaBar magnet. Lai's EIC effort focuses on simulations within the BNL-developed EICroot framework. He is anticipated to remain at LBL in the near-term, with the usual caveats of temporary positions. Looking ahead, the emphasis of our simulation efforts is naturally shifting from fast simulations towards full simulations. We intend to engage an undergraduate student in our proposed effort to investigate cooling.

The development of aluminum conductor cables is a key aspect of developing truly low-mass trackers. The characterization of long conductor cables, reported on before, was carried out by Contin and Greiner in the context of R&D for the ALICE-ITS project. Now that the ITS is entering its production stage, we do not anticipate renewed ALICE R&D on conductor cables. We intend to return to the topic of low mass conductor cables focusing on design for forward and backward disks when our concepts for the practical sensor layout on these disks are further advanced, towards the end of the upcoming period.

5. Funding request

1.0 student (Summer support); to work on simulations
0.5 postdoc FTE; to work on simulations
$2k M&S; for continued cable prototyping

Cost, including LBNL overheads:

50% postdoc	$83,616
student support	$ 8,276
M&S	$ 2,584
Total	$94,814

6. Closing comments

Silicon tracker endcaps will need to coexist smoothly with tracking in the central rapidity (i.e. barrel) region. Coordination of designs is crucial to ensure hermeticity of tracking and appropriate overlap to optimize performance in the region of overlap, around $\eta=2$. The infrastructure for one must not interfere with the other, or with the physics objectives. It is natural to seek collaboration in the inner tracking region and, as described in the introduction, we have followed the committee's recommendation to establish collaboration with eRD18.

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 for effort distinct from, but with synergies with, the effort discussed here. Several of the eRD16 co-authors are part of this LDRD, in collaboration with other colleagues at the Laboratory. Several of us have applied for a continuation, in this round emphasizing more of the physics studies of our original proposal (and, consequently, deemphasizing some of the instrumentation development). The allocation of FY18 LDRD funds is anticipated to become known by late Summer.

References

[1] D. Geesaman et al., The 2015 Long Range Plan for Nuclear Science.
[2] E.C. Aschenauer et al., arXiv:1409.1633 and references therein.
[3] M. Regler et al., J.Phys.Conf.Ser. 119 (2008) 032034 and references therein.
[4] A. Adare et al. [PHENIX Collaboration], arXiv:1402.1209 and references therein