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EIC Detector R&D Progress Report

Project ID: eRD16
Project Name: Forward/Backward Tracking at EIC using MAPS Detectors
Period Reported: from January 2019 to June 2019
Project Leader: Barbara V. Jacak
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Project members

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Abstract

We report on and 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 with respect to the EIC beams. The focus is on disks with thinned-silicon sensors with the overall goal to arrive at science-driven sensor specifications, optimized geometrical configuration of the forward/backward disks, disk layout, conceptual arrangement of services, and integration with tracking subsystems covering the central barrel region. Part of this work is being pursued in collaboration with eRD18, which focuses on mid-rapidity (vertex) tracking and sensor development.

1. Introduction

The overarching goal of eRD16 is to develop an optimized conceptual design for precision endcap trackers for use in a general-purpose experiment at the future Electron-Ion Collider (EIC). The envisioned silicon tracker endcaps will use thinned monolithic active pixel sensors (MAPS). The endcap trackers and the other detector subsystems will need to co-exist smoothly. The configuration and infrastructure for one must not interfere with the other, or with the physics objectives. This presents a number of challenges, for example in the integration of the disks nearest to the nominal collision point with the innermost barrel (vertex) layers while seeking to maintain physics performance. The eRD16 and eRD18 groups are collaborating to carry out the work to arrive at a well-integrated conceptual design for the innermost tracking systems with suitably optimized silicon sensors as part of a multi-year activity.

2. Progress Report

2.1 Past

What was planned for this period?

The goals for this funding cycle were to investigate trade-offs in the geometrical configuration of disk arrays and barrel layers, to devise and investigate an initial low-mass mechanical design concept and to evaluate its effects on physics performance by simulation, and to extend our very initial explorations towards an all-silicon tracker (based on past LDRD-funded effort) through a combination of fast and full simulations. Proposed exploration of low-mass cooling concepts was not funded.

What was achieved?

Past eRD16 simulation efforts have focused on the overall geometrical configuration of Si-disks in the envisioned 3.0T and 1.5T solenoidal fields of the BeAST concept [1] and the concept around the BaBar magnet [2]. In these concepts, the Si-barrel and Si-disks are inner trackers surrounded by a Time Projection Chamber. Our GEANT-based simulations using the EICroot framework have typically trailed after our fast simulations, which make use of a tracking framework originally developed for the Linear Collider [3].

As we reported during the January 2019 meeting, EICroot simulations for the 3.0T solenoidal magnetic field configuration were catching up. Since the January 2019 meeting, we have continued these and other EICroot simulations, now addressing also the 1.5T field configuration. This work was performed by Y.S. Lai funded by the remainder of our allocated EIC R&D funds from the 2017 proposal round and by E. Sichtermann.

Figure 1 contains results from one of these simulations, showing a scan of the anticipated relative momentum resolution for charged particles produced at a pseudo-rapidity of $\eta = 3$ for an equidistant set of five positioned orthogonal to the beamline at positions between z = 0.25m and z = 1.21m from the nominal interaction point for both magnetic field values. The results exhibit the expected scaling with the field integral also seen from our prior fast simulations.

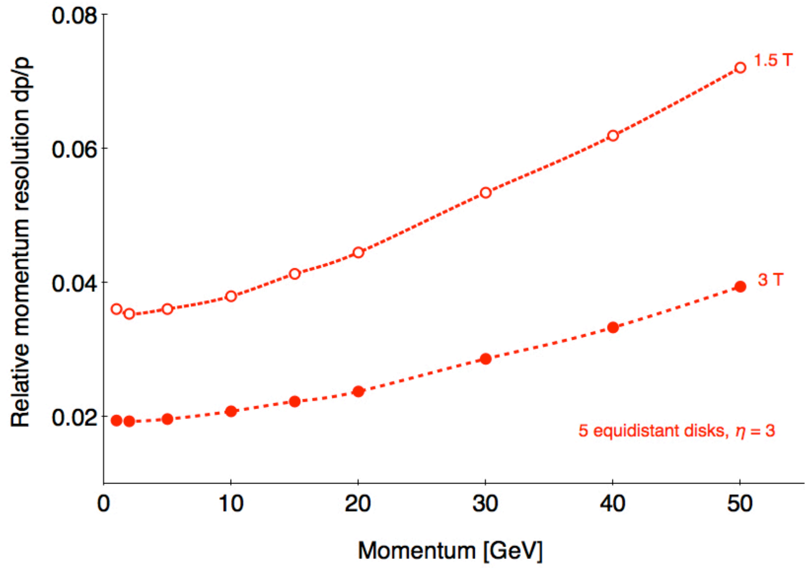

Figure 1: *The relative momentum resolution as a function of absolute momentum for standalone tracking with 5 equidistant disks spanning z = 0.25m to z=1.21m along z in a 1.5T and 3T solenoidal field as indicated. The sensor's pixel size is 20 ×20 µm in these simulations and the thickness of each disk corresponds to χ_0 = 0.3%. The statistical uncertainties are comparable in size to the size of the symbols.*

Following a suggestion from the Committee in 2018, we proposed for the current funding cycle to extend a prior exploration towards an all-silicon tracker (based on LDRD-funded effort) through a combination of fast and full simulations. We reported results from fast simulations, including considerations on the integration of the barrel and endcap regions, during the January 2019 meeting. Since then, we have implemented a similar all-silicon concept in EICroot and performed an initial set of simulations in this framework. Figure 2 shows this initial all-silicon configuration in the EICroot framework.

We have performed an initial set of EICroot simulations with this configuration. Figure 3 shows the anticipated momentum resolution from a scan of charged particle momenta at a fixed pseudo-rapidity of η = 0.5 from EICroot simulation (filled green symbols), fast simulations (open green symbols), and for BeAST as reported in Ref. [4] (grey squares). These results support that an all-silicon tracker with by comparison smaller volume (radius) can achieve a similar momentum resolution as the TPC-based BeAST model-detector of Ref. [4].

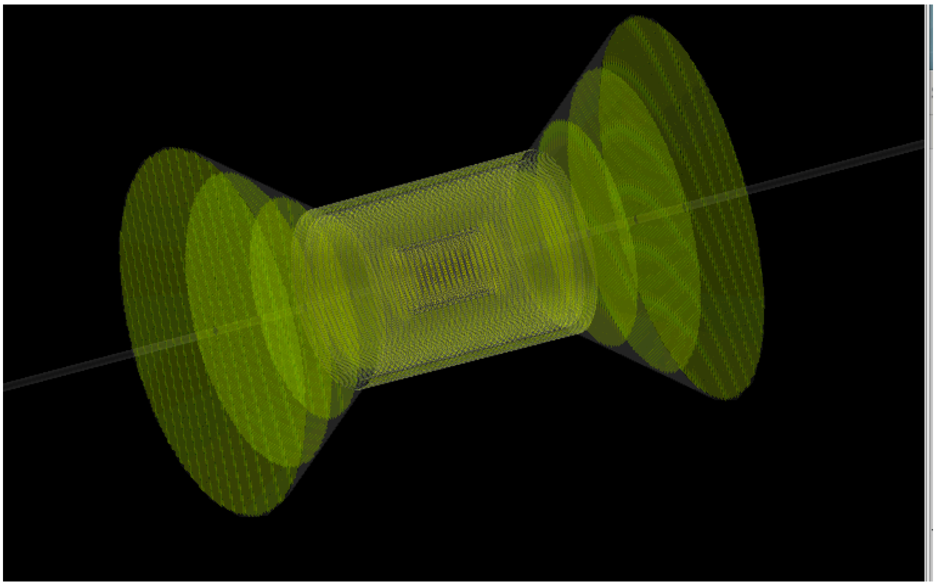

Figure 2: *Schematic view of an all-silicon barrel and endcap tracking configuration in the EICroot with a simplified cone-shaped support-structure surrounding the outer radii of the disks. The radiation thickness of the innermost barrel layers and the disks is χ_0 = 0.3%.*

We note that the BeAST concept of Ref. [1] has superseded Ref. [4] and that also the inner-silicon trackers, both ours and eRD18, introduce seemingly small further changes in the tracking configuration. Initial EICroot simulation results with these iterations incorporated indicate a slightly worse anticipated momentum resolution at the smallest momenta and slightly better resolutions at largest momenta compared to the results reported in Ref [4].

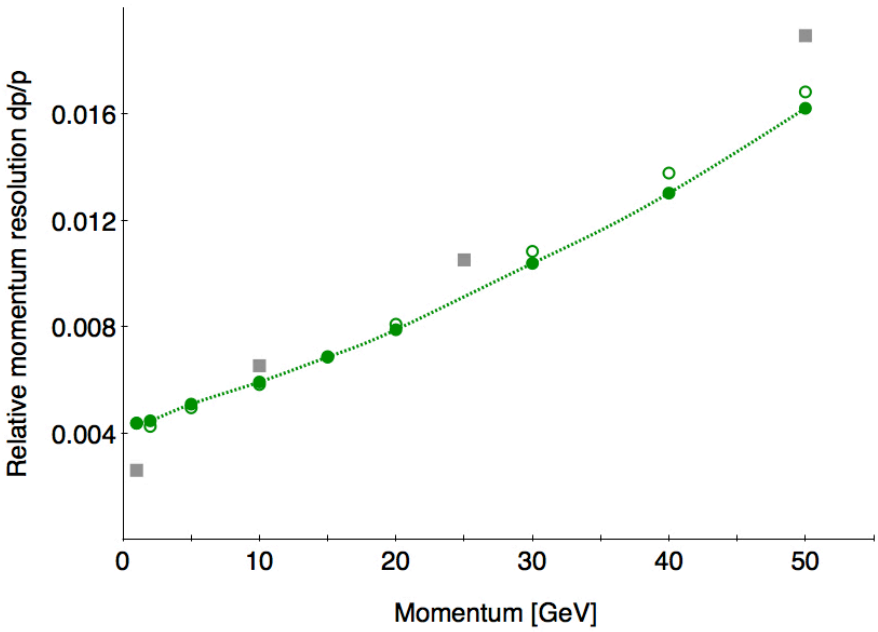

Figure 3: *Anticipated momentum resolution for a fixed pseudo-rapidity of η = 0.5 versus momentum from EICroot simulations (filled green symbols) and corresponding*

fast simulations (open green symbols), in comparison with the values reported in Ref. [4] for the TPC-based BeAST concept.

In conjunction with integrating an all-silicon tracker in EICroot, we have also incorporated a cone-shaped structure surrounding the outer radii of the disks in the EICroot simulations to be able to make a start on assessing the impact(s) that support infrastructure will have on tracking performance.

What was not achieved, why not, and what will be done to correct?

At the time of writing this report, we do not yet have in hand a sufficient set of results on the impacts of support infrastructure on tracking performance since we are still investigating several aspects of the BeAST-like EICroot simulations (discussed above) and also anticipate to first still incorporate several refinements in the all-silicon concept.

Since our initial assessment of the impact(s) of more realistic candidate support structures and infrastructure through simulations is still in a very early stage and several of the trade-offs remain to better understood, we have thus far held off on engaging LBNL engineering staff in investigating (im-)practicalities and identifying areas for potential future R&D in this area. We aim to do so as our simulations in this area are further along, in time for a tracking workshop we aim to hold in conjunction with the POETIC workshop at LBNL later this Summer. We will then iterate as necessary using the 2018 EIC R&D funds allocated for this purpose.

What is planned for the coming months and beyond?

In the near term, we plan a writeup together with eRD18 describing simulations and their conclusions. We aim to perform EICroot simulations with our initial, simplified implementations of candidate support structures to make a start on assessing potential impacts on tracking performance and their trade-offs. We will then aim to engage an experienced mechanical engineer at a small fraction of time in the integration-related efforts to insert realism and to identify areas for common or new R&D that can then potentially be pursued further through LDRD or other resources.

While we continue to view the development of aluminium conductor cables as key to developing low-mass tracking, we choose to defer this topic at this stage; ALICE-ITS is well into its production stage thus severely limiting possibilities to utilize R&D synergies and to make practical progress in this area at this time.

What are critical issues?

No show-stoppers are identified for the proposed activities at this time.

Additional information?

N.A.

2.2 Staffing

During this reporting period, forward disk conceptual design simulation efforts have been carried out part-time by Project Scientist Y.S. Lai, E.S., and Stony Brook University undergraduate E. Biermann. Lai's EIC effort is supported by eRD16 funds and concerns simulations within the BNL-developed EICroot framework. Lai is stationed at LBNL and supervised by B.V. Jacak.

2.3 External Funding

As noted in our January 2019 progress report, several of us and colleagues from other University of California (UC) campuses prepared a successful proposal in response to a 2019 UC Multi-campus Research Funding Opportunity. An initial meeting has taken place at LBNL to organize this effort. Although none of the work reported here was funded through this UC proposal and Laboratory staff cannot be supported through this opportunity, we anticipate that one or more UC graduate students will engage part-time in EIC-related Si-tracking effort in the future.

The work of undergraduate student E. Biermann on fast simulations was supported during 10 weeks of Summer 2018 with EIC R&D funds. She continued this work part-time during the 2018/2019 academic year for research credits through a collaboration with faculty at Stony Brook University. E. Biermann has just started her graduate studies at the University of Pittsburgh where she will focus on astrophysics.

As noted in earlier reports, several eRD16 co-authors were part of an LBNL strategic LDRD that ended past October 2018. This LDRD enabled several efforts distinct from, but with synergies with, the eRD16 effort.

2.4 Publications and presentations

E. Biermann has presented a poster on her fast simulation studies at the Spring 2019 URECA (Undergraduate Research and Creativity) Symposium.

3. Proposal for FY20

Motivation

The EIC science program requires one or more collider detectors with tracking subsystems in the endcap regions to measure the scattered electron and charged hadrons produced in the collisions. The scattering region along the direction of the EIC electron beam gives access to the gluon-dense ("small-x") nuclear environment through leptonic and hadronic observables with energies below the EIC electron beam-energy. Tracking in this region serves both leptonic and hadronic momentum measurement. The momentum measurement, together with the energy measurement using electromagnetic calorimetry, serves electron identification through measurement of *E*/*p*. Traversed material must be minimized to reduce kinematic bias from bremsstrahlung. The hemisphere along the direction of the EIC ion beam is of considerable scientific interest as well. Here, new insights are anticipated for example from the production of heavy quarks and jets, and their propagation through cold nuclear matter. Particle energies along the direction of the forward-going hadron beam are typically considerably higher than those along the forward-going electron beam at an EIC. In general, forward/backward particle tracking imposes considerable challenges in the 1.5 and 3T solenoidal fields that are currently under consideration for the general purpose EIC detector concepts. Successful EIC endcap trackers must provide excellent momentum resolution over wide ranges that are different for the electron and ion beam regions. They must have very low mass. Together with the barrel tracker, they must provide full azimuthal and (near) full polar coverage. These and other aspects point to a need to develop low-mass, well-integrated, barrel and endcap silicon trackers.

Simulation studies thus far have derived their (geometric) specifications mostly from single particle momentum resolution and pointing resolution to the interaction vertex or beamline. These studies address the important class of inclusive measurements at a future EIC, as well as measurements involving heavy quarks. Notably missing thus far are investigations that quantify the relevant resolutions from correlated observables in semi-inclusive measurements or derive associated specifications [5]. Figure 4 shows an example of the well-known additional angles and momenta that are part of core EIC science with (transverse) polarization.

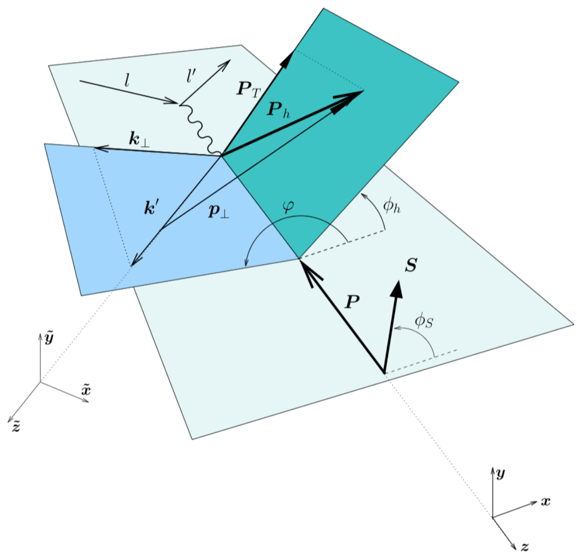

Figure 4: *Kinematics of the semi-inclusive deep-inelastic scattering process in the photon-nucleon center-of-mass frame. Reproduced from Ref. [6].*

Newly Proposed Research

For the upcoming funding cycle, we propose to perform a new simulation effort to assess correlated resolutions in charged-particle semi-inclusive deep-inelastic scattering measurements for both an all-silicon general tracking concept and one of the TPC-based general purpose tracking-detectors. Our default approach will be to (continue to) work in the EICroot detector framework, although we will consider alternatives in consultation with eRD20 (Software Consortium). We see this effort as not by nature specific to either eRHIC or JLEIC. This new effort is intentionally proposed to be of a smaller scale than our proposals in previous cycles for reasons that are pragmatic; the considerations are pragmatic and entail the still ongoing R&D effort from the earlier proposal round, anticipated availability of staff, as well as other factors.

4. Funding request for FY20

Cost, including LBNL overhead:

8% project scientist	$17,954
15% postdoc	$23,642
Total	$41,596

Funded staff will be situated at LBNL and will be supervised by either the Project Leader or Contact Person in this effort.

The proposal guidelines ask us to consider also funding scenarios that are 20% and 40% below the above-requested funds. In a -20% scenario, we will reduce the scope of the proposed physics performance simulations. In a -40% scenario, we will descope either the TPC or the all-silicon detector assessment.

References

[1] A. Kiselev et al., presentation at the 2016 Deep-Inelastic Scattering conference.
[2] A. Adare et al. [PHENIX Collaboration], arXiv:1402.1209 and references therein
[3] M. Regler et al., J.Phys.Conf.Ser. **119** (2008) 032034 and references therein.
[4] E.C. Aschenauer et al., arXiv:1409.1633.
[5] Electron-Ion Collider Detector Requirements and R&D Handbook, Eds. A. Kiselev and T. Ullrich, v1.0 (2018).
[6] M. Anselmino et al., Eur. Phys. J. **A39** (2009) 89.