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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 July 2019 to December 2019
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Abstract

This report describes progress in the period between July 2019 and December 2019 on 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 overall goal is to arrive at an optimized geometrical configuration of disks with thinned-silicon sensors using science-driven specifications as a tracking subsystem that includes conceptual arrangement of services and is well-integrated 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 Past

What was planned for this period?

In June 2019, we proposed 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.

Many of the prior eRD16 simulation studies had yielded results from single track response. While these studies are directly relevant to the class of inclusive measurements at a future EIC, as well as aspects of other key measurements, they do not quantify the relevant resolutions from track-correlations. Semi-inclusive measurements at a future EIC are part of the core science program and rely intrinsically on measurements of track correlations (see e.g. Ref. [1]). Heavy-quark studies using displaced vertex techniques rely on correlated tracks if both the decay and collision points need to be determined. Both of these and other considerations formed the motivation for the newly proposed work in June 2019.

What was achieved?

During the June 2019 meeting, we presented initial studies towards an all-silicon tracking detector concept and comparisons with the performance of the TPC-based BeAST detector concept as reported in Ref. [2]. These studies were performed in the EICroot simulation framework and were a follow-up to fast-simulation studies towards an all-silicon design concept reported previously.

Since the June 2019 meeting, we have extended these initial single-track studies towards an all-silicon tracking detector concept and considered several variants on the concepts presented at the June 2019 meeting. To make progress towards the goal of quantifying resolutions from track-correlations we started EICroot response-simulations of semi-inclusive deep-inelastic scattering events generated with PYTHIA-eRHIC. Figure 1 visualizes examples of single events from 10 GeV electrons colliding with 100 GeV protons propagated through the BeAST(-like) and all-silicon detector concepts.

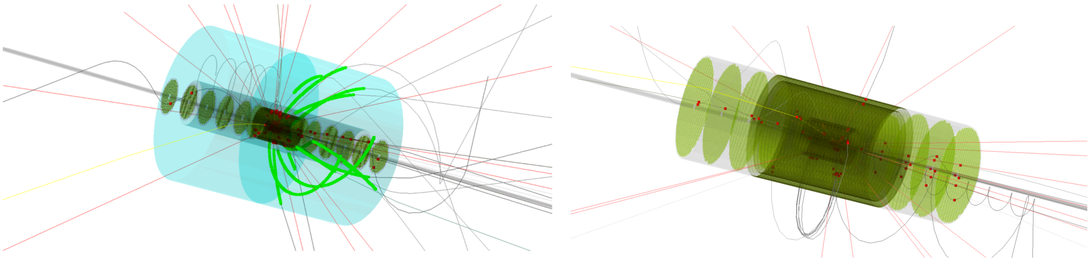

Figure 1: *Schematic view of PYTHIA-eRHIC generated events propagating through EICroot implementations of (left) the BeAST detector concept and (right) an all-silicon tracking detector concept. Only the charged-particle tracking subsystems are shown. The innermost barrel-silicon layers are identical in both concepts (the scales for the left and right figure are different).*

Both concepts have inner silicon barrel layers with radii of 2.3, 4.7, 14, and 16 cm. The all-silicon tracking detector concept has additional outer barrel layers with radii of 39 and 43 cm. The solenoidal field has a strength of 3T. Hits are digitized in EICroot by Gaussian smearing corresponding to a pixel size of 20×20 μm.

For the results below, the digitized hits were then exported for event reconstruction and vertexing with GENFIT/RAVE. There is no pattern recognition in this reconstruction; instead, tracks are seeded by association with MC-truth. The reconstructed tracks for each event were analyzed following the approach of the heavy-quark analysis by the H1 collaboration at HERA using their vertex detector [3]. A central observable in this analysis is the track significance, S. It is determined for each track in an event as the ratio of the distance of closest approach of the track from the primary vertex, δ, and the uncertainty in this displacement, $\sigma(\delta)$. The direction of the struck or heavy quark, determined through jet reconstruction or from the scattered electron, is used to assign a sign to each S in the event and the signed significances observed in an event are then ordered by their size. For selected track multiplicities, the leading significances and other observables are combined using an artificial neural network to select (enhance) the heavy-quark event samples. The third-highest significance distribution is found to be an important input in this analysis [3].

The immediate goal of the initial work shown here is not to repeat the H1 analysis or develop an optimized analysis to extract physical charm or beauty signal and assess backgrounds, but rather to construct a key observable in such an analysis from correlated tracks in a QCD sample and evaluate the distributions for the tracking detector concepts in Figure 1. To this end, we have taken the simplified approach of reconstructing the struck quark direction from the scattered electron observables, thus forgoing jet reconstruction[1]. The primary vertex, on the other hand, was reconstructed directly from the tracks associated with each event without assumptions for the collision point or external beamline constraints. Figure 2 shows the resulting third-highest significance distributions for both tracking detector concepts.

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[1] In the H1 analysis, jet reconstruction was used for the dominant fraction of the heavy-quark events. There is a marked difference between these approaches for events produced by photon-gluon fusion.

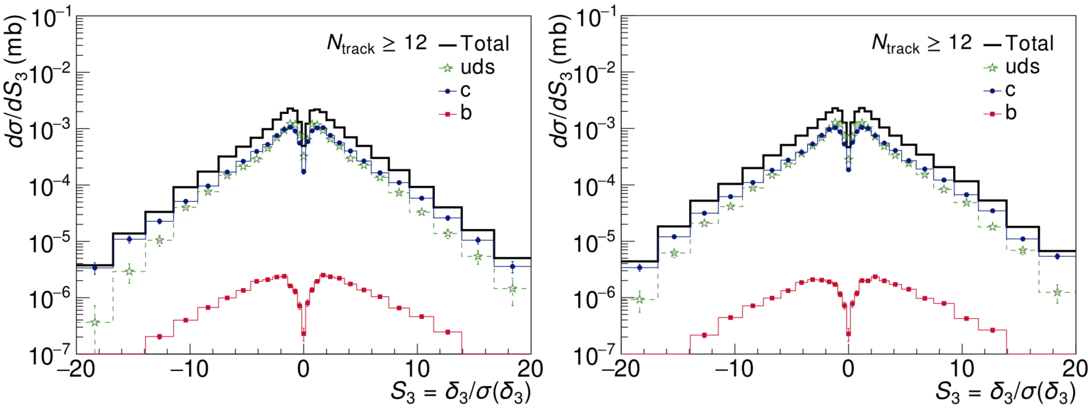

Figure 2: *The significance distribution for the tracks with the third-highest significance for (left) the BeAST and (right) the all-silicon tracking detector concepts shown in Figure 1 for selected total track multiplicities as indicated. The events were generated with PYTHIA-eRHIC, passed through EICroot detector response, and reconstructed using GENFIT/RAVE as described in the text.*

The distributions are very similar for the two detector concepts. This is consistent with the earlier conclusion from our single-track studies that vertexing performance is determined primarily by the innermost barrel layers, provided that these layers have sufficient acceptance. Y.S. Lai has presented this work, extended with a neural-network combination of this and other event parameters to demonstrate charm-tagging, at the 2019 APS-DNP Fall meeting.

At the time of writing this report, studies to quantify angular and other resolutions in 1-particle semi-inclusive deep-inelastic scattering processes are in progress.

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

In its report from the June 2019 proposal round, the committee encouraged us to compare aspects of pattern recognition for the TPC-based and an all-silicon concept. We have chosen not to pursue this for this reporting period. The EIC User Group is in the start-up phase of a 12—18 month intensive study of the EIC physics and detector concepts (yellow-report). This effort seeks to build on the EIC whitepaper [4] and the R&D handbook [5] and will rely on a commonly adopted software framework, which is in development [6]. Rather than pursuing a one-off study now, such a study appears better performed once in particular the common event reconstruction toolkit is somewhat further along.

We aimed to hold a small-scale tracking workshop as a satellite to the POETIC workshop [7] at LBNL past Summer. This proved impractical to schedule. The main goals are closely aligned with the now started EIC yellow-report effort and its four associated workshops that are now scheduled [8].

3 Future

In the near term, we aim to complete all our proposed simulation studies within the EICroot framework. Going forward, EICroot is currently not anticipated to be part of the software framework for the EIC yellow-report. Since we will integrate ourselves with the EIC yellow-report, we will thus transition away from EICroot towards Fun4All or G4E, which are currently part of the software framework for the EIC yellow-report.

Members of eRD16 have recently joined the R&D effort associated with the proposed ALICE ITS upgrade in LS3 [9]. We consider this effort well aligned with the overall goals of silicon tracking development for EIC currently pursued by eRD16 and eRD18. Discussions to transition to a consortium have started.

4 Staffing

The simulation efforts during this reporting period were carried out part-time by Project Scientist Y.S. Lai and by E.S. 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.

5 External Funding

As noted in recent eRD16 reports, 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. 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 foreseeable future.

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

6 Publications and presentations

Y.S. Lai included the vertexing study as part of a presentation on EIC heavy-quark energy-loss measurements at the 2019 APS-DNP Fall Meeting.

References

[1] M. Anselmino et al., Eur. Phys. J. **A39** (2009) 89.
[2] A. Kiselev et al., presentation at the 2016 Deep-Inelastic Scattering conference.
[3] F.D. Aaron et al. [H1 collaboration], Eur. Phys. J. C65 (2010) 89.
[4] A. Accardi et al., Eur. Phys. J. A52 (2016) 268.

[5] Electron-Ion Collider Detector Requirements and R&D Handbook, Eds. A. Kiselev and T. Ullrich, v1.1 (2019).
[6] M. Diefenthaler at the December 2019 EIC Yellow-Report kick-off meeting, https://www.jlab.org/indico/event/348/
[7] https://poetic9.lbl.gov
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