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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 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 sensor development and mid-rapidity (vertex) tracking.

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 Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Laboratory. The EIC is scheduled to come online in the 2030 timeframe.

The ultimate goal of eRD16 is to develop an optimized conceptual design for well-integrated, precision endcap trackers for the EIC utilizing monolithic active pixel sensors (MAPS). Achieving this goal requires research and development in a number of areas. The eRD16 and eRD18 groups are collaborating to carry out this work over the next several years.

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.

Unobserved losses of the scattered electron's energy, e.g. bremsstrahlung, introduce a bias in Bjorken-*x,* typically towards smaller values. Traversed material thus needs to be kept to a minimum. 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, tracking imposes considerable challenges in the 1.5 and 3T solenoidal fields that are 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.

Accomplishing this goal is multi-year activity, which LBNL and Birmingham have proposed to undertake together. LBNL has engaged in simulation studies to aid the specification of dedicated sensors and optimized barrel and endcap conceptual design. Birmingham collaborates in a number of these physics simulations and simulates the resulting sensor design. Once fully specified, the new sensors need to be laid out and simulated to demonstrate the feasibility of sensor design and their production. Prototype sensors will subsequently need to be produced and tested. Furthermore, the readout speed, heat load and cooling, along with mechanical concept for barrel and endcaps will need to be worked out. Birmingham will pursue prototype sensor production and produced sensors can be tested at both 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 future characterization of the new sensor performance and also its resistance to radiation damage.

In the sections below, we describe 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

eRD16 has performed initial simulations focusing in particular on developing a conceptual geometrical configuration of pixel tracking stations in the forward and backward scattering regions at a future EIC. In nearly all of these simulations so far, the endcap (and barrel) silicon trackers have been inner trackers that would be complemented by an outer tracker in the form of a Time Projection Chamber and one or more GEM planes.

Position resolution is the driver of specifications for the pixel size, while momentum resolution drives both pixel size and the mass budget. Initial studies indicate that 20 to 30 μm square pixels will suffice for momentum and position measurement at an EIC for the different magnetic fields and detector configurations being considered. These studies show also that the material budget will need to be kept at or below the challenging level of 0.3% of a radiation length per layer to limit degrading the momentum resolution by multiple scattering at typical momenta.

While EIC science goals call for high instantaneous luminosities of $10^{33\text{-}34}$cm^{-2}s^{-1}, the beam interaction cross sections at an EIC are sufficiently small that only a small fraction of the beam crossings will result in a beam collision. Multiple collisions from a single beam crossing are improbable, unlike in experiments at the LHC. Initial studies using pythia-eRHIC have evaluated the anticipated hit-densities/fluxes from beam collision events. These studies indicate furthermore that the effective μs integration times of even present-generation sensors in combination with one or more fast and segmented outer detection layers will suffice to disambiguate track pileup associated with beam collisions.

These and other simulations have been pursued with two independent toolsets. A project scientist (Lai) is utilizing the tools developed at BNL specifically for EIC detector simulation. 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 reproduced several of the baseline results and provided insights in detector response for different particle species and detector variations with different pixel sizes and different numbers of disks. At the time of writing this report, funds remain to complete the originally envisioned studies of variations in the disk geometries and overall layout. 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 the BeAST concept and the detector concept based around the 1.5T BaBar magnet [4] have been obtained. This toolset has been used also to perform tracking response studies for a variety of standalone arrays of disks within the BeAST forward-silicon-tracker envelope and its 3T field. Results from several of these studies and also corresponding studies for the detector concept based around the 1.5T BaBar magnet have been presented previously.

Separate from the above studies, LBNL-LDRD funds have made it possible to consider selected aspects of a low-mass inner silicon barrel tracker for mid-central rapidities at an EIC. These efforts, while distinct from our eRD16 efforts, are obviously related to the overall goal of developing a well-integrated tracker covering nearly the full angular range. This work (Klein, Lomnitz, Sichtermann) was performed using only the ILC-developed toolset [3]. An initial outcome from the combination of eRD16 and LDRD studies is that the desired angular range for tracks that are of displaced vertex detection will be a driving factor in determining the length the innermost barrel layers. This presents a trade-off with the demands of forward momentum measurement using the disk arrays upstream and downstream of the barrel layers.

A note summarizing the fast simulations is in preparation as of the writing of this proposal.

3. Proposed work

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 and the concept around the BaBar magnet. In these concepts, the Si-barrel and Si-disks are inner trackers surrounded by a TPC. EICroot-based studies will be completed with remaining funds. Collaboration with eRD18 has made it practical to consider sensor designs driven directly by EIC science demands.

The development of the envisioned low-mass MAPS-based endcap trackers will require advances on multiple fronts, including mechanical support and integration, cooling, and low-mass conductor cables. The silicon tracker endcaps will need to coexist smoothly with tracking in the central rapidity (barrel) region. Coordination of designs is crucial to ensure hermeticity of tracking and appropriate overlap to optimize performance in the region of overlap. The infrastructure for one must not interfere with the other, or with the physics objectives. This presents particular challenges in a number of areas, for example for the integration of the innermost barrel layers and the discs nearest to the nominal collision point while seeking to maintain physics performance.

For the upcoming R&D period, we aim to make a start on such investigations. Specifically, we aim to devise an initial low-mass mechanical design concept to support the barrel and disk arrays and evaluate its effects on physics performance in simulations. We aim also to investigate low-mass cooling. 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 prior R&D, tests have been performed for stave configurations. We propose to explore the viability for our intended disk configurations, building on prior work within the physics and engineering divisions for staves. While we continue to view development of aluminum conductor cables as key to developing truly low-mass staves, we choose to further defer the pursuit of this topic at this stage; ALICE-ITS is well into its production stage thus severely limiting possibilities to utilize R&D synergies and make practical progress in this area at this time.

Following the suggestion from the committee past January, we propose 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. A further set of fast simulations will be performed to arrive at an initial geometrical configuration. This geometry will then be implemented in EICroot and its performance will be evaluated and compared with the default BeAST (TPC) tracking configuration.

4. Personnel

Forward disk conceptual design simulation efforts have been carried out by Project Scientist Yue Shi Lai, ES, and several younger scientists. 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, and will complete already started EICroot studies. A new postdoctoral researcher will pursue the newly proposed simulation studies as a part-time effort while analyzing existing data from ongoing experimental efforts (STAR, ALICE) within the RNC program.

UC Berkeley undergraduate students Winston DeGraw and Ivan Velkovsky have participated in the past in fast-simulations towards viable conceptual design improvements for BeAST and the concept based around the 1.5T BaBar magnet. Their effort was supported in parts through eRD16 funds and in parts through other programs. We aim to continue incorporating undergraduate students in fast simulation efforts and in aspects of the proposed infrastructure (mechanics, cooling) development.

We request support to engage an experienced mechanical engineer at a small fraction of time early on in the integration related efforts; we believe this type of engagement will benefit the conceptual development and possibilities to identify areas for common or new R&D that can then potentially be pursued further through LDRD or other resources.

5. Funding request

Cost, including LBNL overheads:

33% postdoc	\$53,417
5% engineer	\$27,311
student support	\$11,035
Total	\$91,763

The deliverables are EICroot simulation development and physics performance evaluations towards an all-silicon tracking concept, as well as a preliminary investigation of realistic mechanical infrastructure and of a possible option towards sensor cooling. No prototype(s) will be constructed as part of the latter efforts.

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 forego the initial assessment of cooling this upcoming period and reduce the scope of the physics performance simulations. In a -40% scenario, we will forego (also) any and all engineering involvement.

6. Closing comments

As noted in earlier reports, LBNL identified the EIC as a focus for near term strategic institutional support. This has led to LDRD funding 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 the original proposal (and, consequently, deemphasizing some of the instrumentation development). The allocation of FY19 LDRD funds is anticipated to become known by late Summer or early Fall.

Besides this LDRD, several of us have submitted a Letter of Intent in response to a 2019 University of California Multi-campus Research Funding Opportunity and have been encouraged to develop and submit a full proposal to this highly competitive funding opportunity. This proposal is in the early stages of development at this time.

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