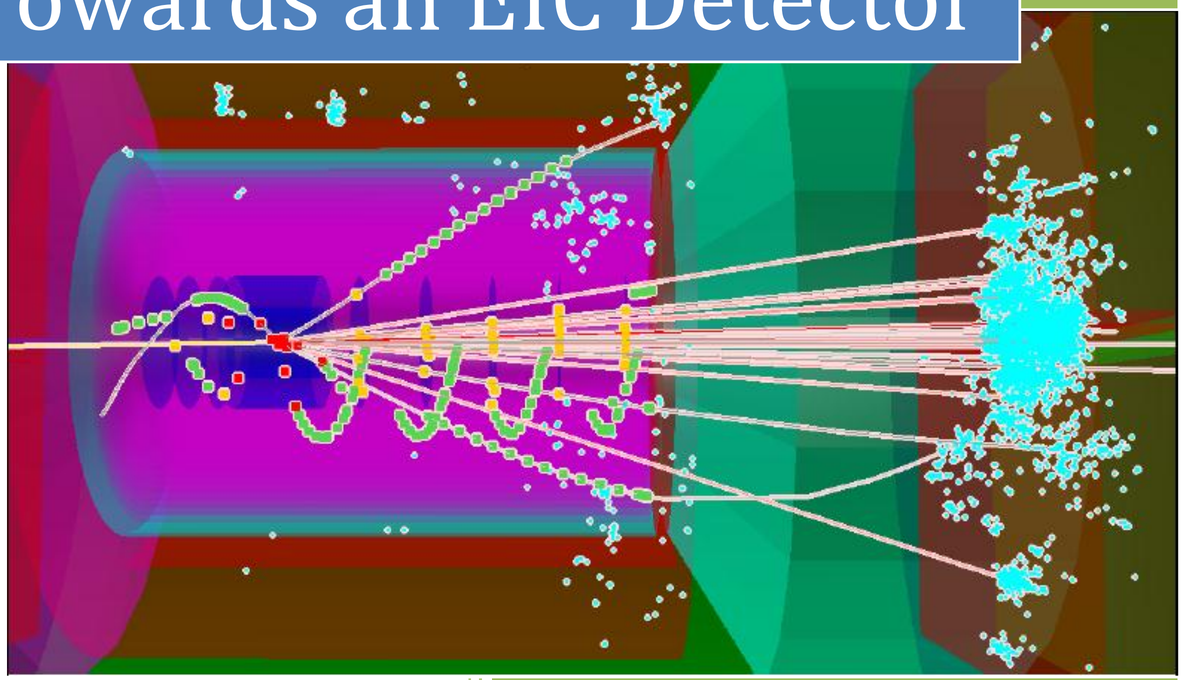
2011

Letter of Intent for Detector R&D Towards an EIC Detector



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11/14/2011

1 Introduction

This document is a follow-on to the Letter of Intent entitled “Letter of Intent for Detector R&D Toward an EIC Detector” sent to BNL in Spring 2011. At that time, we announced the formation of a new collaboration intending to work together on simulations to determine the required performance parameters of an EIC detector and also listed 5 immediate R&D tasks that we deemed to be of sufficient generic interest to warrant immediate investigation. The Letter of Intent promised a full and focused R&D proposal to be submitted to BNL in one year’s time. Our proposal was well received and generously funded. Highlights of the committee report are included here:

> *The formation of consortia of universities and national labs … are to be encouraged. In these six proposals we have already seen evidence of such consortia forming around tracking and PID…*
>
> *The collaboration emphasized their intention to carry out extensive physics simulations to shape the direction of future detector R&D proposals. … The committee appreciates and encourages this approach. Only after the demanding simulation effort progresses can detector R&D proceed with the desired focus.*
>
> *It was suggested that a funding request for post docs in support of simulations would be reasonable. It was also suggested that machine related backgrounds should be included in the simulations.*

This document will report on the collaboration status, progress made since the recent arrival of monies at our various institutions, and significant progress on the simulations. The principle focus of our current request for funding matches exactly the advice from last year’s review committee in that we seek salary funds for an individual to work on the simulation efforts.

1.1 Collaboration Status

In addition to simple collaboration membership issues, a more important aspect of our development is the trend toward a singular effort. Our first Letter of Intent was, not surprisingly, markedly divided in its various efforts along institutional lines. The five development efforts mapped cleanly onto five distinct institutions: Fast TPC development at BNL, zigzag readouts for large area GEM detectors at FIT, Electronics gap minimization for GEM detectors at UVa, CsI Photocathodes at SBU, and 3-coordinate readout geometries at Yale. Although such a division was a natural starting point for our collaboration, these lines should and have blurred over the past six months. Examples of cross-institution initiatives include:

- BNL and Yale working together on GEM TPC development.
- Stony Brook engineer Chuck Pancake designed layouts for zigzag TPC & GEM readout boards using input on the specifications from BNL and FIT to test a variety of zigzag pad geometries. The

system is designed to directly couple to the Scalable Readout System (SRS) used by BNL, FIT, and UVa.

- Kondo Gnanvo has moved from a post-doc position at FIT to a research position at UVa to implement SRS readout systems for system tests including those already performed at Mainz and those upcoming at JLab.
- Stony Brook, Temple, and UVa have combined forces to mount the Cherenkov test beam effort in Hall A of Jefferson Lab, using the UVa tracking coupled to the SBU Cherenkov detector.
- Stony Brook PhD student Huijin Ge has begun simulations of the three-coordinate readout system to determine the performance of this scheme as a function of particle multiplicity.
- Postdocs from SBU and ISU are contributing to the previously BNL-exclusive simulation effort.

We view this trend toward commonality of efforts not only as highly efficient, but also healthy for developing the spirit and mindset of a single collaboration.

We have grown overall in personnel. This growth includes not only the addition of new people (principally graduate students and postdocs), but a new institution as well (Temple University via Zein-Eddine Meziani's group). Furthermore we have undertaken the personally difficult, but collaboration-healthy effort to clarify the intentions of groups that have not regularly participated in our meetings. The Los Alamos National Laboratory group has withdrawn their single person from our efforts and the MIT group has scaled back involvement to include only B. Surrow, who will continue with our work and expand it as a Professor at Temple University. Finally, due to unforeseen administrative duties the participation from Lawrence Berkeley National Laboratory is expected to be minimal during the next 6 months, but to scale back to a full effort following the Spring 2012 proposal.

1.2 Document Overview

In the next sections we will briefly discuss progress on hardware efforts using the funds that have recently arrived at our various institutions. The bulk of the document will focus on initial results from our simulation efforts that have converged around a single flexible common toolset. These simulations illuminate the emerging path toward our final proposal/technology choices, highlight the closer cooperation that has emerged between detector and machine physicists, and demonstrate the need for funding to further advance the effort.

2 Hardware efforts

2.1 BNL Effort: Status Report on GEM Tracking Activities

Studies are continuing on the use of GEM detectors for tracking applications at EIC. The focus has been mainly to investigate a TPC type detector using a GEM readout that could be used in either the central region or forward direction of an EIC detector. This has begun by studying a short drift TPC with a drift gap of about 1-2 cm, rather than a full size, longer drift TPC that would be used as a complete central tracking detector. The reason for this is that it is not clear at the present time whether a full TPC is needed, when used in combination with the envisioned silicon vertex tracker, to achieve the overall spatial and momentum resolution that is required in an EIC detector. A short drift TPC could be used as a GEM tracker in both the central barrel as well as in the forward direction to provide a vector coordinate rather than just a single space point at each measuring station, thus reducing the number of physical detectors and readout planes, and therefore reducing the mass of the overall GEM tracking system.

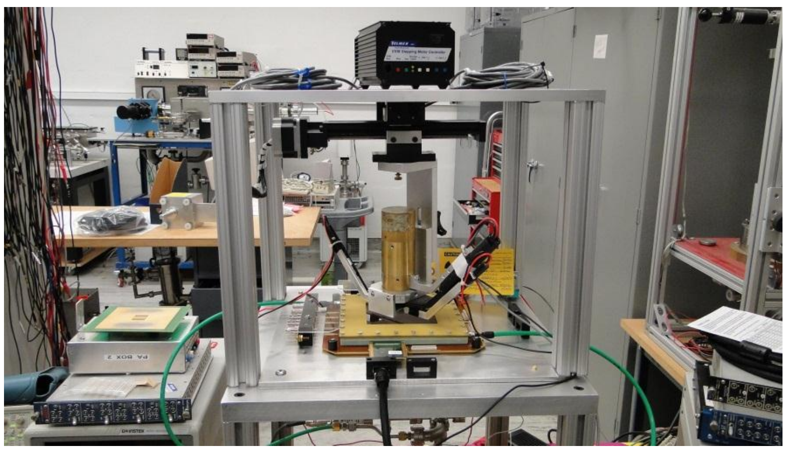

Figure 1: Beta source test stand used to study both TPC and planar type GEM readout configurations in the Gas Detector Lab at BNL.

We have constructed a test setup, shown in Figure 1 that is being used to provide a benchtop means to study various readout configurations utilizing either a TPC or planar type readout geometry. It uses a highly collimated Sr-90 source that produces betas up to an energy of 2.3 MeV, along with a thin (0.5 mm) scintillation counter that can be used as a trigger, and a second scintillator with a small hole that is used as a veto to reject scatter and background. The source can be rotated at various angles and scanned across the detector with high precision (about 10 μm) using a computer controlled scanning device. This will allow studies of the position and angular resolution of different GEM detector geometries and various types of readout planes.

We have also acquired a new GEM detector from CERN (also shown in Figure 1) with a COMPASS style readout plane that we will use to study the position and angular resolution of the short drift TPC detector. In addition, we have obtained a new readout system based on the CERN SRS electronics that will allow us to read out more than 2000 channels of strips or pads from this detector. The COMPASS style readout plane of the detector is removable and will allow us to study other types of readout planes, such as chevron pads or the strip-pad readout being developed at Yale University. We have already started to design a new chevron type readout plane in collaboration with Stony Brook University, shown in Figure 2, that will allow us to investigate some of the these different geometries, and we plan to make a similar design of the strip-pad readout in collaboration with Yale. In addition, we have begun developing a new Monte Carlo program that will allow us to study various detector properties such as charge collection, drift times, etc. and compare with actual data.

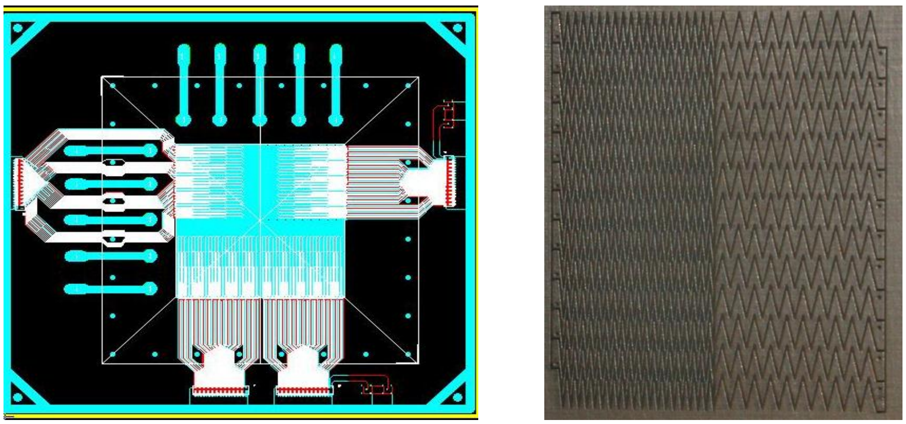

Figure 2: Left: Chevron pad readout board for the CERN GEM detector designed by Stony Brook University. Right: Detail of chevron readout showing fine (0.5 mm) zigzags on the left and coarse (1.0 mm) zigzags on the right. Overall pad dimension is 2 mm x 10 mm.

We have also begun to develop new readout electronics for a TPC type GEM tracking system that will be based on a new ASIC being developed by Brookhaven for the ATLAS Muon Trigger Upgrade detector. The new ATLAS Muon Trigger will use a Micromegas detector in a similar short drift TPC configuration to provide a vector at several positions that will be used to make a rapid determination of particle momenta that can be used at the trigger level. It will use a new 64 channel ASIC (VMM1) that includes a peak sensing ADC and a time to amplitude converter, along with FIFO multiplexer and trigger output. We have been working closely with BNL's Instrumentation Division on the design of this chip and have gotten them to incorporate a number of features that will allow us to use it for our own application (such as providing the ability to measure longer drift times up to 1 μsec). The first prototype of this chip will be submitted to MOSIS in mid November, and the first chips are expected back by mid February. These first prototypes will have only the front end components of the final chip and no digital output, but an adapter card is being developed by the University of Arizona that will allow them to be used and read out with the CERN SRS electronics. This should enable us to make a thorough study of the front end components of the chip and provide any feedback or changes that would be required for the design of the final chip.

For our future EIC tracking proposal, we expect to have preliminary measurements on several of the readout schemes that are currently being investigated, as well as some first results with the new chip. We anticipate that this will lead to more detailed studies on specific designs that will require additional effort and funding.

2.2 Florida Tech Effort: Development of large-area GEM detectors with high spatial resolution but low channel count

The research subcontract for this project between BNL and Florida Tech was officially put into place in September 2011 with a start date of Sep 15, 2011 and end date of Sep 30, 2012. Design of a first printed circuit board with zigzag readout strips to be used with a standard CERN 10 cm × 10 cm triple-GEM detector has started. For that purpose, the Gerber file for a PCB with 128 rectangular strips as used in the standard CERN 10 cm × 10 cm triple-GEM detectors was obtained from the CERN PCB workshop via Rui de Olivera. A conceptual design of this test PCB with 10 cm long zigzag strips was produced as shown in Figure 3. The board features 24 strips with 1 mm pitch ("coarse pitch") along the strip direction and 24 strips with 0.5 mm pitch ("fine pitch") along the strip direction. In the direction across the strips, the pitch is 2 mm in both cases. The active area of the PCB is 96 mm × 100 mm. The strips are routed to a 130-pin Panasonic high-density connector, which allows connection to an APV hybrid card for amplification and readout.

With help from the Stony Brook group, an engineer, Charles Pancake (SUNY), was recruited for the task of laying out this new PCB. He is currently combining the PCB information from CERN with detailed design information on zigzag strips from BNL into the final technical PCB design. We expect that the new PCB will be available for testing within a few weeks.

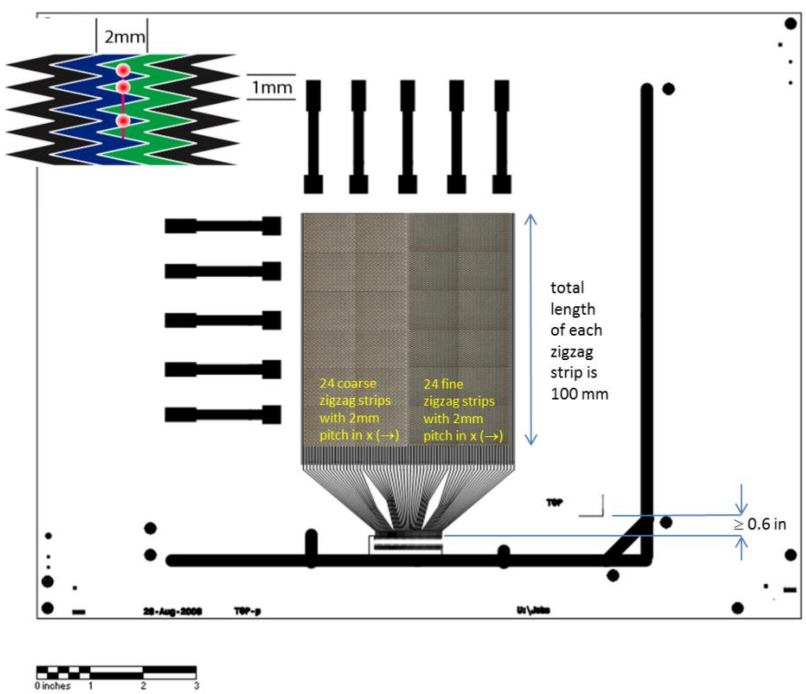

Figure 3: Conceptual layout of PCB for standard CERN 10 cm × 10 cm triple-GEM detector with 48 zigzag strips.

2.3 Stony Brook University Effort: PID-RICH with CsI-GEM photocathode

SBU is investigating the possibility to use the RICH technology based on CsI-coated GEM detectors as photon detectors. GEMs are a solution for large area photon detection in a strong magnetic field and as cost effective devices. Candidates for radiators would be C_6F_{14} liquid along with C_4F_8O gas. These gases have indices of refraction 1.27 and 1.001389 in the deep UV and would produce Cerenkov angles as indicated in Figure 4.

The cleanroom and high vacuum evaporator facilities have been prepared and are ready for production.

A recirculating gas system capable of 5 lpm recycling flow with recurring purification of the gas and a gas chromatograph capable of measuring gas impurities at the ppb level have been finalized and is being prepared to be shipped for a test beam commitment. Finally, the custom-made glove box is fully operable and maintains water and oxygen contamination levels below 10 ppm during detector construction, a vital aspect for GEM handling after the CsI coatings are applied.

The SBU facility is fully capable for both uncoated and coated GEM measurements as well as construction of large scale detectors.

First prototype detector equipment from a previous PHENIX-RICH R&D project has been revived and adapted to accommodate a CsI-GEM photocathode in the focal plane. A mirror with high reflectivity for photons in the VUV range is being prepared. A facility for preparing such a mirror, i.e. evaporating MgF_2 on Aluminum, is available in the laboratory at SBU. A new effort at BNL will enable reflectivity measurements of these mirrors using their existing vacuum photo-spectrometer.

With the extension of the collaboration an opportunity developed such that the SBU group received parasitic beam test time at JLAB/Hall A. A prototype for a RICH for this beam test was identified as the vessel that has been used for prototyping a RICH detector in the mid 90's at SBU (Figure 5). It contains a radiator vessel that is variable in length due to an adjustable light baffle. The entrance and exit windows are made of 50 µm thick Kapton with a 500 nm thick layer of Aluminum in order to prevent diffusion of water from the environment into the gas volume. A front surface mirror with a radius to be determined will be used to focus the light which is produced in the radiator to the photo-sensitive detector. This detector will be based on three stacked GEMs of which the first is covered with a thin CsI layer towards the photons.

The mirror will be installed on a sliding seal which allows changing its angle without breaking the seal on the vessel. The gas contamination must be kept below a certain level for oxygen and water vapor for which the above mentioned recirculating gas system is best suited.

The prototype can be readily modified in order to use it as a proximity focus RICH detector which makes use of multiple refractive index radiators. The part of the vessel with the exit window will accommodate the GEM readout and will also get inserted a quartz window which acts as a phase separation between the liquid and gaseous radiator and serves also as a focusing type radiator itself.

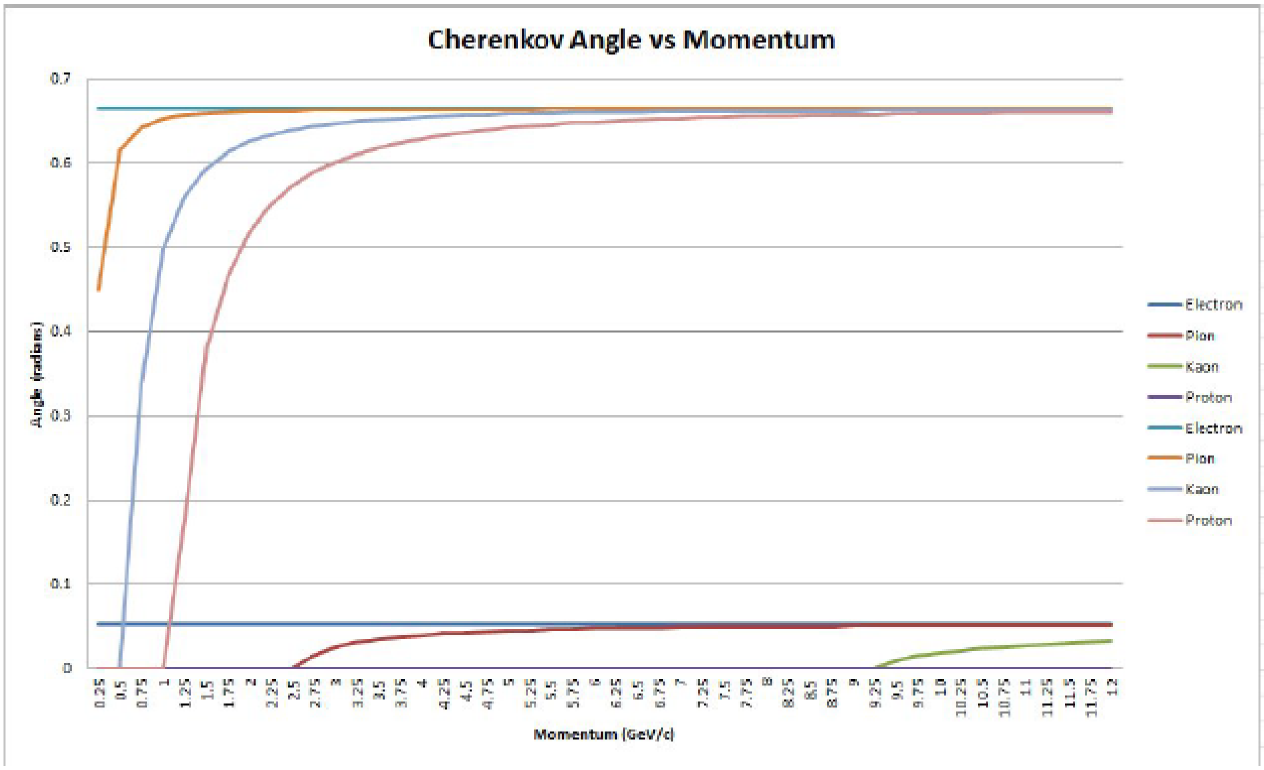

Figure 4: Cherenkov angle as a function of momentum, calculated for light hadrons. The upper curves indicate the liquid radiator and the lower curves the gaseous radiator.

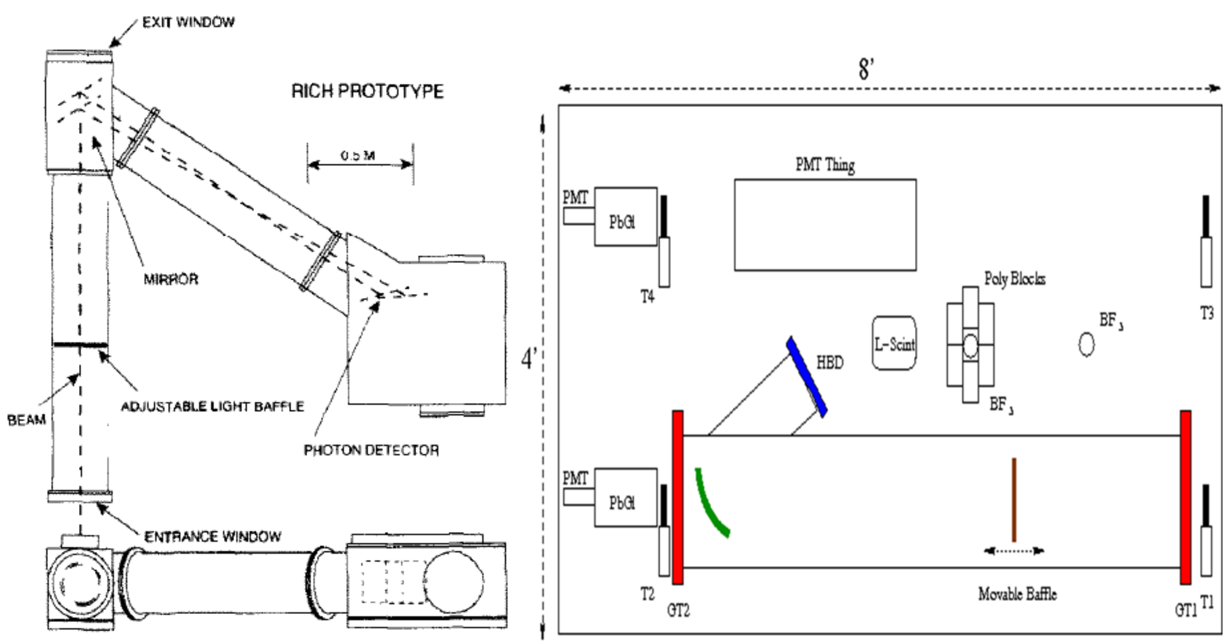

Figure 5: Left is existing RICH radiator vessel. Right is proposed setup for Test Beam.

For the SBU prototype the GEMs to be inserted into the stack have been ordered and the readout board is being designed. The corresponding electronics is also ordered and in the meantime electronics from other institutes within our collaboration is being shared.

The design of the readout board is a two-fold approach: the first is based on a standard 2-D perpendicular strip readout board and the second one is based on a 3-D board with hexagonal pads (Figure 6).

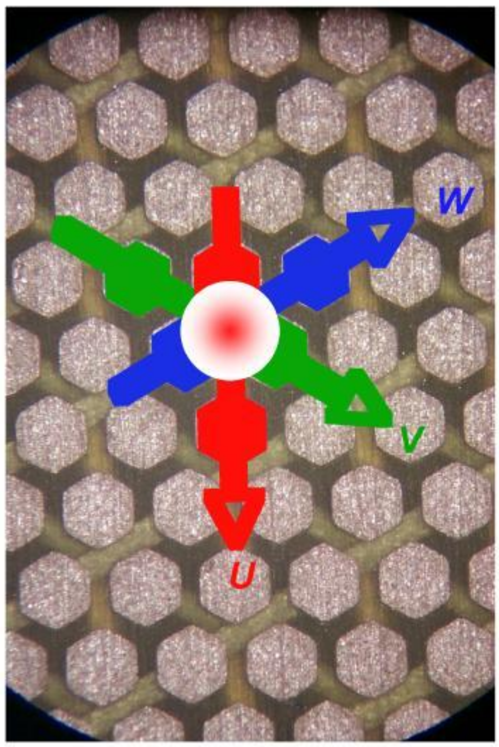

Figure 6: Readout board with hexagonal pads which are interconnected along three directions.

The new opportunity of using Hall A as a test beam facility has been made possible by the attraction of new collaborators to our project (Temple U.). However, the floor of Hall A is not ideally suited for test beam activities as there exists no detector support infrastructure (all support is directed to the spectrometer focal planes and none of the floor). We've adapted our plans accordingly, but the necessity of long runs for the gas flow, data lines, power, and other services will require additional funds that were previously not anticipated. As a result, we are requesting an additional $10k for test beam infrastructure items.

2.4 University of Virginia Effort: Construction and test of large prototype GEM chambers

The UVa portion of funding became available in mid-October. A new UVa research scientist, Dr. Kondo Gnanvo, also started his position in October. We have setup the APV25 based 2000 channel SRS at UVa. This system is now fully operational with the UVa prototype GEM tracker consisting of three 10 cm x 10 cm chambers. We have also placed the orders for the components of two 40 cm x 50 cm GEM chamber modules; we expect to assemble and test these modules by early next year.

Based on the lessons learnt from 40 cm x 50 cm GEM chambers we plan to design the large 90 cm x 40 cm prototype GEM chamber over the next few months. We will fabricate this chamber using funding from the EIC detector R&D program. We expect to place the orders for the components of this large prototype chamber by next May, and to assemble and test the chamber next summer.

We have also constructed and tested a 10 cm x 10 cm GEM chamber with pad readout. This chamber will be added to our prototype GEM tracker. This GEM tracker will be tested in beam at Jlab in the Spring, along with the beam tests described in the SBU section. The prototype tracker will also be taken to BNL in February to a beam test planned for the AnDY experiment.

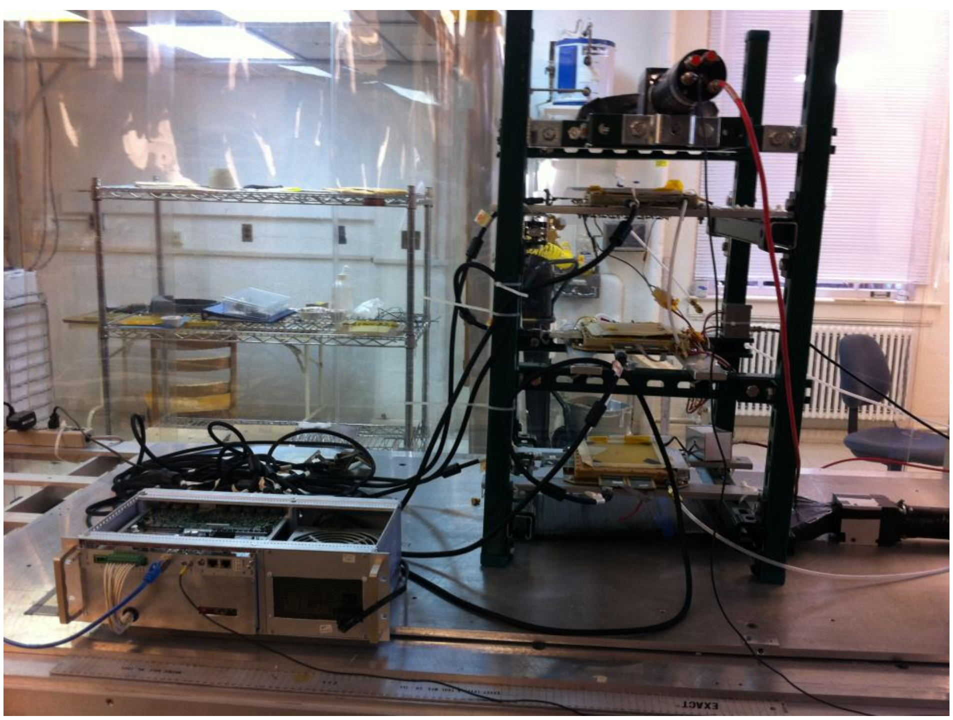

Figure 7: The UVa prototype GEM tracker being read by the SRS readout system.

2.5 Yale University Effort: Development of 3-coordinate single plane readout for GEM chambers.

Funding for this portion of the R&D proposals became available at Yale on October 7, 2011. In the intervening few weeks we have ordered the required GEM foils and many of the mechanical parts to construct the test chambers (frames for GEM foils, HV divider boards, etc.). Since the chambers will be similar to ones we have recently designed and constructed for STAR, much of the mechanical design can be copied or easily adapted from those chambers.

Design of the first 3-coordinate readout boards is nearly complete with only routing of signals to the readout connectors and placement of tooling holes for the chamber enclosure and gas and HV attachments remaining. Figure 8 shows a small section of the readout board pattern (top and bottom layer Gerber files overlayed - green is the top surface facing the GEM foils, red is the bottom signal routing surface). This version has 800 µm pitch and should not present any manufacturing challenges. Once this design is complete and submitted for manufacture we will design a 600 µm pitch 3-coordinate version. This is expected to be near the edge of the capability of Tech-Etch.

We expect to be receiving parts and constructing the test chambers through the winter and commissioning and doing the first characterization with radioactive sources and cosmic rays through spring and early summer. As a second part of this development we expect to run in a test beam near the end of 2012 although the precise schedule depends on the availability of a suitable beam and sufficient channels of readout.

We note that the Brookhaven group is developing a detailed simulation for the drift, diffusion and multiplication of electrons in GEM chambers. We expect to use this tool to compare with data we will take with the 3-coordinate GEM chambers and data already taken with 2-coordinate chambers. Conversely, we expect these data will prove useful in refining the model in the simulation so as to provide a powerful tool for predicting the behavior of various readout structures.

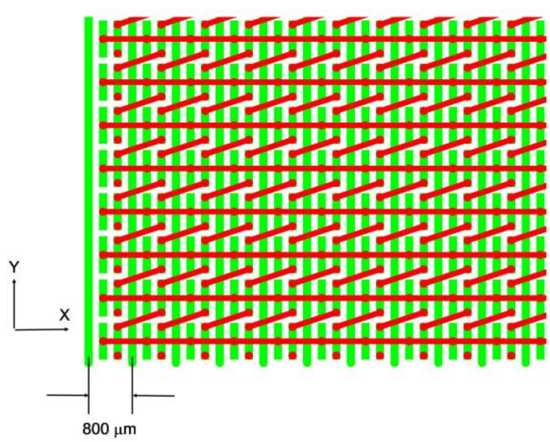

Figure 8: Small section of 800 µm pitch 3-coordinate readout board. Top (readout structure, green) and bottom (routing, red) Gerber files overlayed. Strips measure horizontal (X) coordinate, rectangular pads with single via measure vertical (Y), rectangular pads with two vias measure diagonal.

3 Simulation Efforts

3.1 Simulations for a dedicated EIC Detector

3.1.1 A short description of the dedicated EIC Detector

The layout of the eRHIC detector has been optimized to fulfill the requirements for the golden experiments at an EIC.

These requirements are described in detail in section 7 of the report from the INT-program on the physics case for an EIC [1] and shortly summarized here. Different to most of the accelerators, eRHIC will run with very different beam energies. The lepton energies vary from 5 GeV to 30 GeV and the hadron beam energies cover 50 GeV to 250 GeV.

The following requirements need to be fulfilled to make a dedicated EIC detector simultaneously highly efficient for inclusive, semi-inclusive and exclusive reactions at the same moment:

1. Wide acceptance $-5 < y < 5$ for both the scattered lepton and the produced hadron.
2. The same coverage in electromagnetic calorimetry and tracking.
3. High electron track finding / reconstruction efficiency, and good precision for momentum (energy) reconstruction.
4. Particle identification to separate electrons and hadrons as well as pions, kaons and protons over a momentum range of 0.5 GeV to 10 GeV for rapidities between -2 to 2 and 0.5 GeV to 80 GeV for $2 < |y| < 5$.
5. Good vertex resolution.
6. High acceptance for forward going protons and neutrons from exclusive reactions as well from the breakup of heavy ions.
7. Low material budget to reduce electron bremsstrahlung and to achieve good resolution in the all kinematic variables.

A schematic picture of the eRHIC detector is shown in Figure 9.

Currently, the technology under study for electromagnetic calorimetry in the forward (hadron beam) direction and backward (lepton beam) direction is a lead-tungstate crystal calorimeter. In the barrel region we are investigating a sampling calorimeter made of scintillating fibers and tungsten powder [2].

For the barrel electromagnetic calorimeter a crystal calorimeter of CsI might be another option, the advantages and disadvantages need to be investigated with Monte Carlo simulations. For hadron identification in the forward and backward directions a dual radiator RICH with Aerogel and a gaseous radiator, such as C_4F_{10} or C_4F_8O are under consideration.

In the barrel region for hadron identification two possibilities are available: a proximity focusing aerogel RICH or a DIRC.

Another possibility to be investigated in the barrel detector is the combination of dE/dx and high-resolution ToF detectors. The STAR experiment uses dE/dx in the TPC very successfully for electron identification and hadron identification (π, K, p separation) [3]. For this Letter of Intent the main emphasis is on the barrel and wide angle forward / backward tracking.

For the barrel tracking the technologies under study are a TPC and a barrel GEM tracker. The significant progress in the last decade in the development of Monolithic Active Pixel Sensors (MAPS) built in CMOS technology, in which the active detector, analog signal shaping, and digital conversion take place in a single silicon chip, provides a unique opportunity for a μ-vertex detector for an eRHIC detector. The design will build on the experience collected with the pixel part of the STAR HFT. In the forward and backward directions the tracking is a combination of disks made using the same MAPS technology as for the barrel vertex tracker, combined with GEM disks at bigger radii. The R&D of the Si-pixel disks is part of a BNL LDRD.

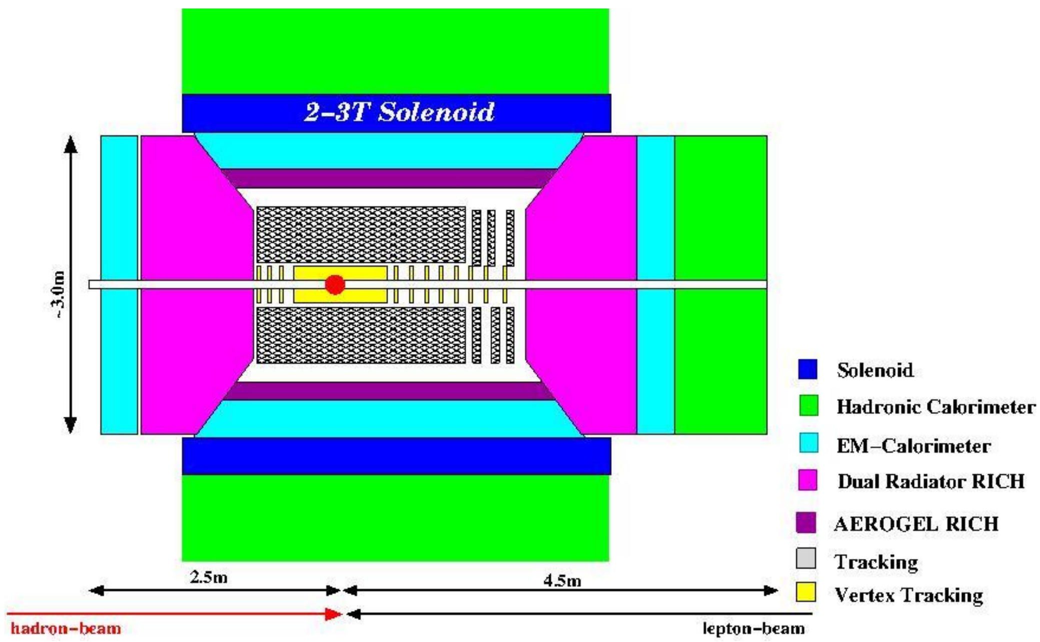

Figure 9: Schematic view of the dedicated detector at eRHIC.

3.2 Simulations Frameworks

3.2.1 GEANT Detector Simulations based on FairROOT

Over the summer two different frameworks have been developed to study the effects of detector acceptance and resolution on the golden EIC measurements. The first framework is based on FairROOT [4]. The key features of FairROOT are detector base classes that handle initialization, geometry construction, hit processing (stepping action), etc., Geant 3, Geant 4, and Fluka, can all be interfaced using a centralized geometry description. Geant 4 + Native G4 navigation and Geant 3 + Root navigation are pre-configured defaults. Features of the FairROOT framework include:

- IO Manager based on ROOT TFolder and TTree (TChain);
- Geometry Readers: ASCII, ROOT, CAD2ROOT;
- Radiation length manager;
- Generic track propagation based on Geane;
- Generic event display based on EVE and Geane;
- Fast simulation base services based on VMC and ROOT TTasks;
- a unified interface to integrate different Monte Carlo (MC) generators
- CUDA support

One additional extremely useful feature of FairROOT is the integration of a fast smearing generator based on the material and sub detector acceptances defined in the geometry file. This will allow a fast

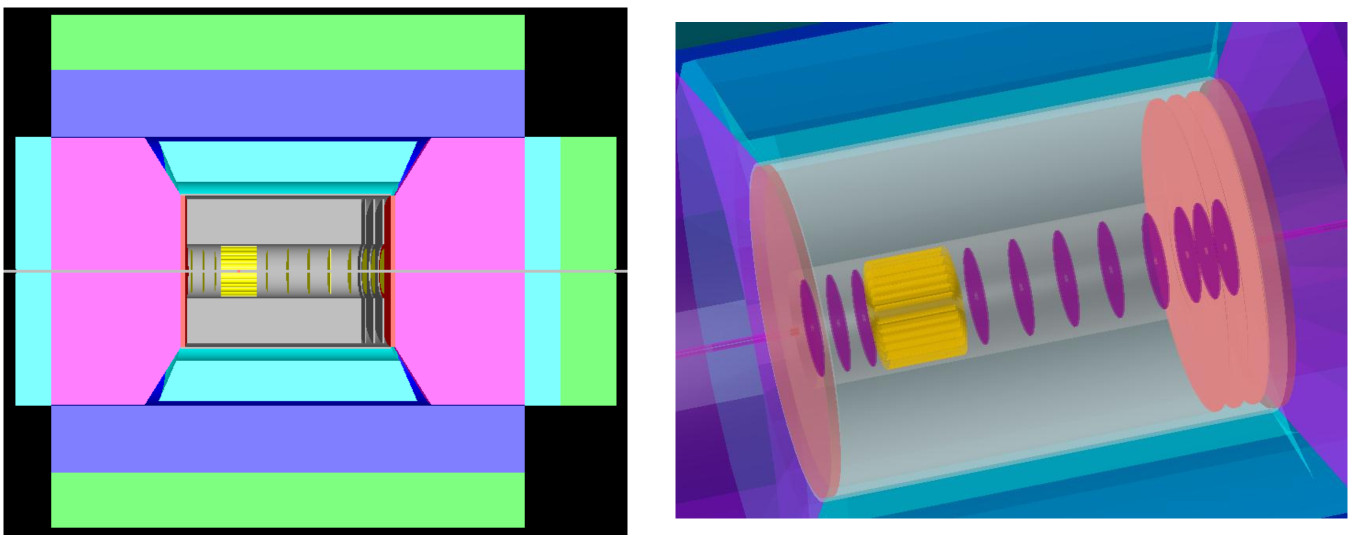

Figure 10: 2- and 3- dimensional views of the sub-detectors implemented.

turnaround to study the impact of changes in the detector layout on physics observables.

Yulia Zulkarneeva has started to implement the eRHIC detector design in the FairROOT package. Figure 10 shows 2- and 3-dimensional views of the current status of the implemented detectors, Figure 11 shows a PYTHIA event interacting in the detector; Figure 12 shows a radiation length scan as a function of rapidity as well as the momentum resolution for leptons integrated over all rapidity. The basic detector features of the detector are implemented and the first simulations based on GEANT can be performed. A list of studies to be done is provided at the end of this chapter.

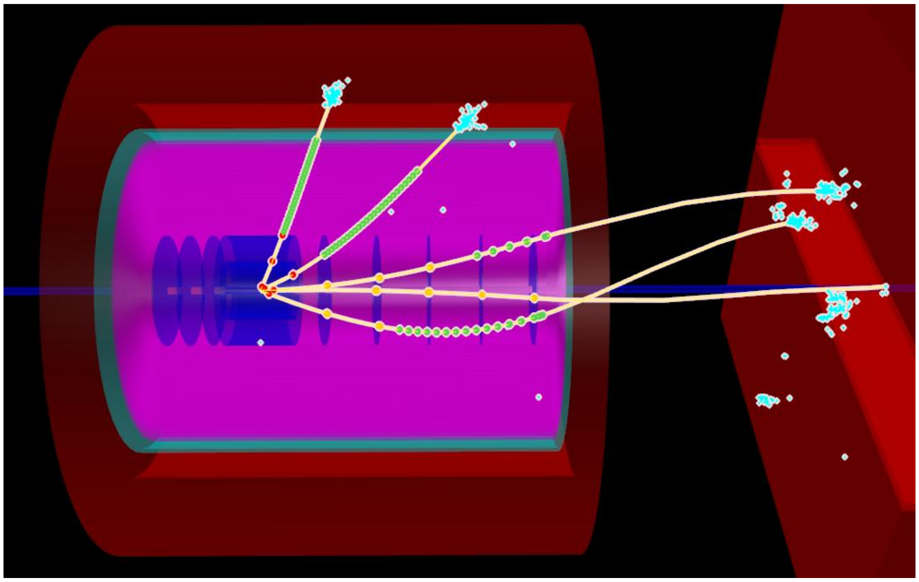

Figure 11: PYTHIA ep event in the detector.

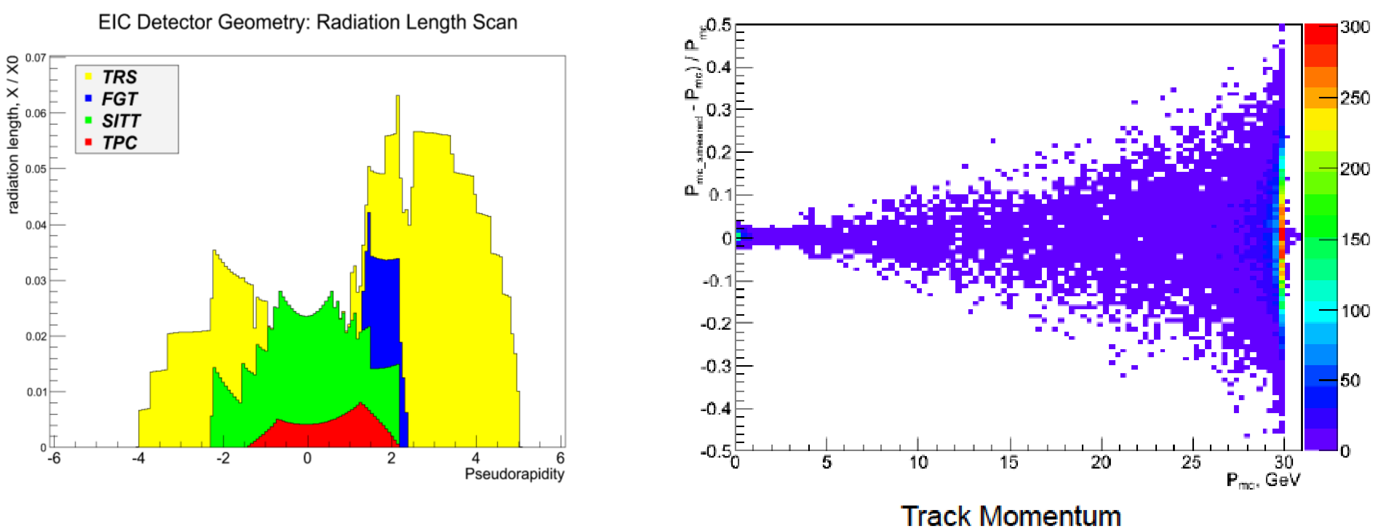

Figure 12: Radiation length scan and lepton momentum resolution integrated over all rapidities.

3.2.2 Simulations based on a fast smearing generator

To have a fast method to test the influence of momentum and energy smearing on physics observables a smearing generator based on ROOT was developed [5]. Several momentum and energy resolution functions together with acceptance functions have been implemented. Here are two examples of energy and momentum smearing functions implemented

- $0.18\sqrt{E}$ $0.0085p + 0.0025\,p^2$ (motivated by Zeus)
- $0.015E + 0.14\sqrt{E}$ $0.005p + 0.004\,p^2$ (motivated by STAR)

Further identification as well as misidentification "efficiencies" for a dual radiator RICH (Aerogel + C_4F_{10}) for π, K, p separation have been implemented based on the HERMES detector. Bremsstrahlung of leptons is simulated following a parameterization using the crystal ball function [6]. Figure 13 shows as an example the momentum resolution for leptons inspired by ZEUS without taking bremsstrahlung into account, for two beam energy combinations (20 GeV x 100 GeV and 5 GeV x 100 GeV).

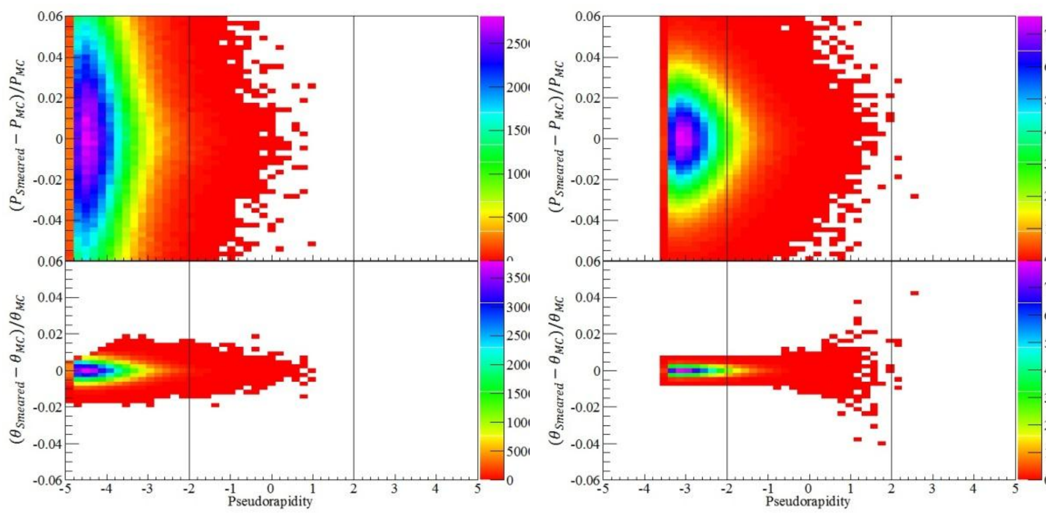

Figure 13: Momentum and theta resolution using parameterization inspired by ZEUS for 20 GeV x 100 GeV (left) and 5 GeV x 100 GeV (right).

In addition to the resolution parameterizations based on existing detectors outlined above, a generic resolution function was implemented, which simulates the intrinsic resolution due to the position resolution of the tracker and the contribution due to multiple scattering.

$$\frac{\delta p}{p} = \frac{1}{0.3\,B}\frac{0.0136z}{L\beta cos^2\gamma}\sqrt{n_{r.l.}} + \frac{p}{0.3B}\,\frac{\sigma_{r\varphi}}{L^{`2}}\,\sqrt{\frac{720}{n+4}}$$

This will allow a first order optimization of the magnetic field value, the position resolution of a tracker in different configurations and the total radiation length of a tracker.

It is of course clear to us that none of these fast simulations will replace the full GEANT simulations as described earlier. However, they can give a first impression on the impact of the detector resolution on physics observables.

3.3 Sensitivity of the Structure Functions F_2 and F_L to Detector Smearing

As described in our LoI we want to use key EIC physics observables to benchmark the detector

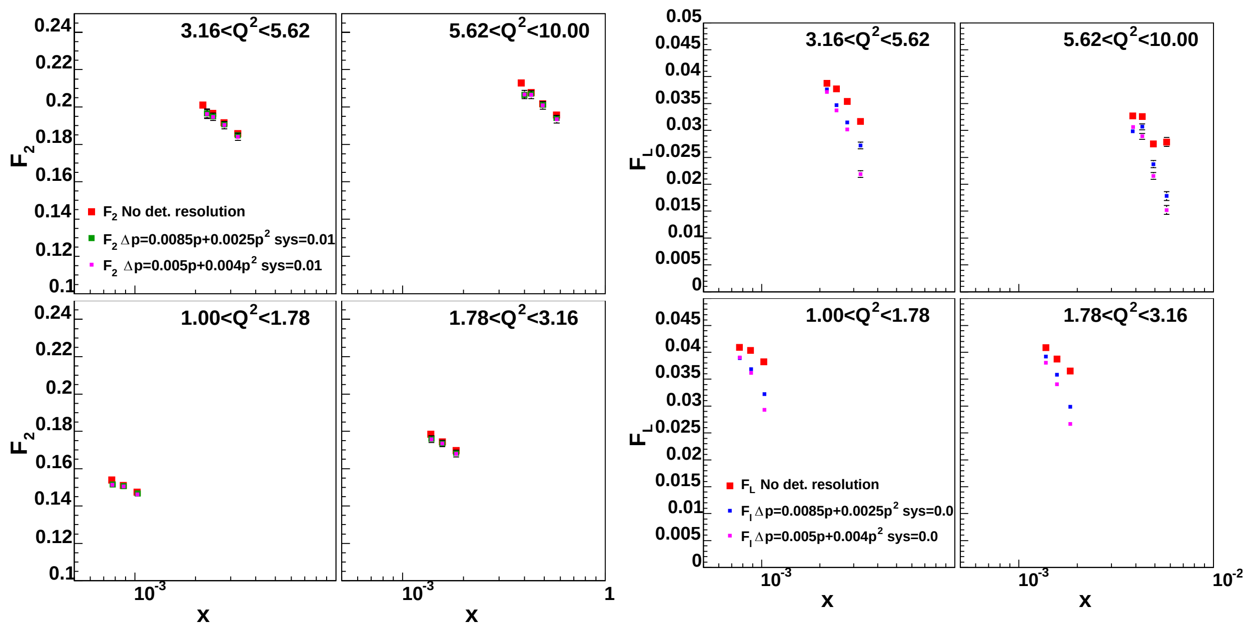

Figure 14: The structure functions F_2 and F_L extracted using different detector momentum resolutions.

performance.

The first such impact study, which has been performed, is for the structure functions F_2 and F_L. We simulated the reduced cross section using the MC generator LEPTO [7]. If the reduced cross section is plotted vs. y^2/Y_+ and fitted with a line, the slope of the line represents F_L and F_2 is the intercept with the y-axis.

$$\sigma_r(x, Q^2) = \frac{xQ^4}{2\pi\alpha_{em}^2 Y_+}\frac{d^2\sigma}{dx dQ^2} = F_2(x, Q^2) - \frac{y^2}{Y_+}F_L(x, Q^2),$$

with $Y_+=1+(1-y)^2$. Figure 14 shows the result extracting F_2 and F_L in four Q^2-bins as function of the Bjorken scaling variable *x*.

The detector smearing was implemented via the fast smearing generator using two different momentum-smearing functions. The effect on F_2 is minimal compared to the effect on F_L. No attempt has yet been made to do an unfolding on the detector smearing to decrease the effect on F_L. To implement an algorithm to unfold the effect of radiative corrections and detector smearing as for example used by the HERMES collaboration [7] is the next step in the feasibility study of how well F_L^p and F_L^A can be measured at an EIC.

Nevertheless these plots make clear that F_L as an observable is extremely sensitive to the momentum resolution of the detector and therefore perfect to optimize the design of the tracking system.

3.4 The effect of synchrotron radiation on the detector performance

During the last advisory committee meeting the committee urged the group to study the impact of synchrotron radiation on the detector and especially the tracking detector performance. The eRHIC group at CAD has completed first simulations for the energy spectrum and the intensity of the synchrotron radiation.

The CAD group has simulated the synchrotron radiation reaching into the IR from the electron beam bending (soft, medium and hard) before the IR and from the crab cavities. Currently the synchrotron radiation from the focusing triplet before the IR and synchrotron radiation backscattered into the IR from the bending of the outgoing lepton beam is not yet simulated.

Figure 15 shows how the lepton beam is bent in vertical direction into the IR and the layout of the magnets in the IR, with the leptons coming from the right and the protons from the left.

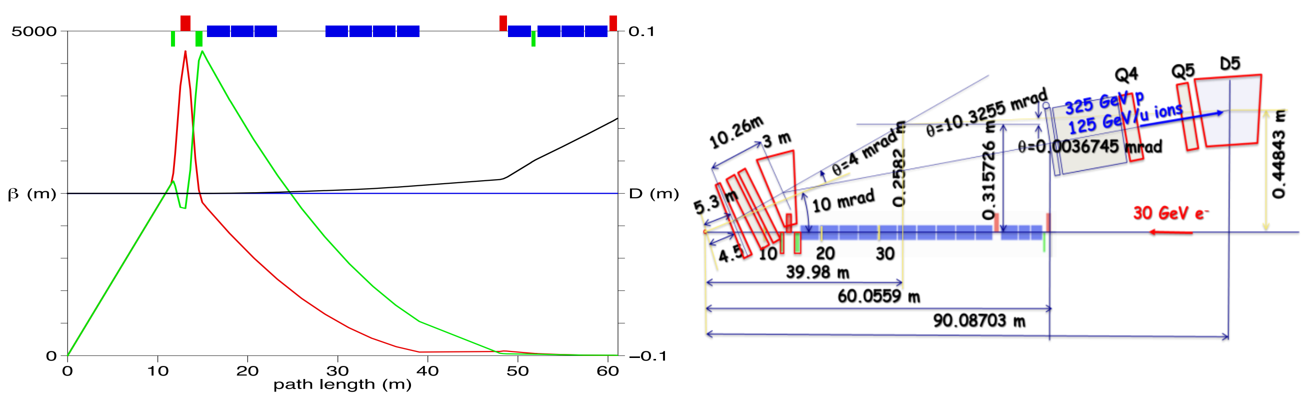

Figure 15: Layout of the lepton beam line and the IR for eRHIC.

Figure 16 shows the resulting energy spectrum and intensity profile for the primary and secondary synchrotron radiation entering the IR for a 30 GeV lepton beam. This spectrum was the basis for a currently still analytical calculation of the interaction of the synchrotron radiation photons with the beryllium beam pipe. This calculation did not yet use the final dimensions of the Be-beam pipe.

We are aware that there is a still significant amount of work to be done before all sources of synchrotron radiation are simulated and the final intensity and energy distribution spectrum of synchrotron radiation photons entering the detector is simulated.

To achieve this goal Oleg Tchoubar, an expert from the NSLS-II will simulate the synchrotron radiation coming from different sources with his highly developed codes for the NSLS and provide intensity energy spectra of primary and secondary synchrotron radiation photons, which can be used as input to our full GEANT simulation (see 3.2.1). Then, the interaction with the beam pipe and the detector material can be fully simulated.

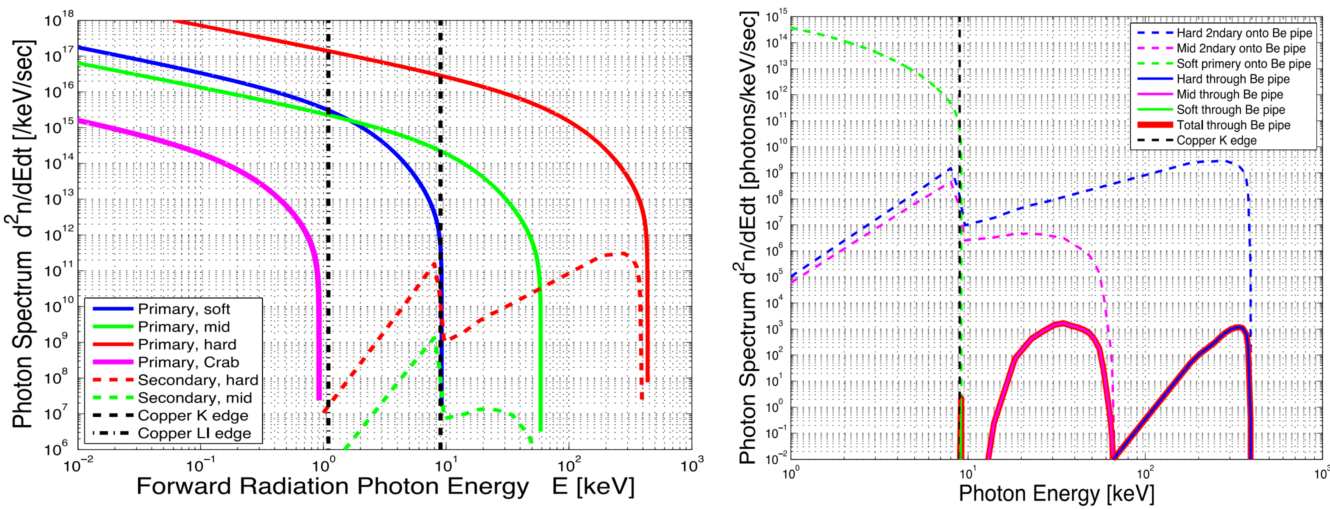

Figure 16: Left: Intensity profile vs. energy for initial and secondary synchrotron radiation entering the IR. Right: Intensity profile vs. energy for initial and secondary synchrotron radiation entering the detector after scattering on the Beryllium beam pipe

3.5 Future Work

Significant progress has been made in developing software packages, which will allow us to answer important questions, such as what momentum resolution is needed to allow a measurement of the golden observables of an EIC. Answering these questions is crucial to guide the R&D on tracking detectors and particle identification detectors described in the original LoI.

The next important steps are

- Complete the geometry implementation of the detector for the GEANT simulations.
- Implement all IR magnets to allow for tracking of, e.g. the forward going protons from exclusive reactions in Roman pots.
- Simulate the impact of synchrotron radiation on the detector.
- Provide results on the following questions:
  - Is the occupancy in the CMOS-pixel µ-vertex tracker small enough that we can track from inside out?
  - Is any intermediate tracking detector needed between the CMOS-pixel µ-vertex tracker and the TPC / Barrel GEM tracker?

- What is the occupancy for the different CMOS-pixel μ-vertex layers in the barrel and in the forward direction?
- Is the material budget of a barrel GEM tracker tolerable?
- What magnetic field is needed given the intrinsic resolutions of a TPC or Barrel GEM tracker and the CMOS-pixel μ -vertex disks and a GEM tracker in the forward direction?
- Do we have heavy fragments in the direction of the forward CMOS-pixel μ-vertex disks?
- What is the achievable Q^2, x and y resolution for the different tracking solutions?
- What efficiency and misidentification can be tolerated in hadron (π, K, p) identification?

An EIC will be a machine running at various different beam energy combinations from almost symmetric, e.g. 30 GeV x 50 GeV to very asymmetric beam energies, e.g. 5 GeV x 250 GeV. This might make some standard techniques like a projective design for the electromagnetic calorimeter difficult to implement.

Another question to be answered by simulations is - should the IR be in the middle of the detector or moved in the direction of the outgoing electron beam?

This is only a small selective list of studies to be performed before a choice on the technology for tracking and particle identification detectors can be done. To be able to perform all these studies we request funding to hire an expert in MC detector simulations for the next 3 years. This person should perform a significant fraction of these studies, be the code keeper for the detector simulations based on FairROOT and also be the contact to people who want to start / perform their own simulations on a special question.

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4 Budget request

4.1 Software specialist

In order to fully exploit the studies as described in Chapter 3 we are requesting to hire a Monte-Carlo simulation software specialist for the next three years. The yearly salary requested for this specialist can be seen in Table 1.

Table 1: Request for a professional Monte-Carlo software specialist per year. The third column shows the overall costs which is residing in the middle of the salary band (second column).

Item		**Costs in $k**
Labor Band Salary per year	**$60,501 to $89,700**	
Salary per year		**75.1**
Fringe + Overhead		**97.6**
Total yearly request		**172.7**

4.2 SBU request

As discussed in Section 2.3 the SBU group requests additional funding for test beam infrastructure items. The request can be seen in Table 2 and is based on the installation of hardware and equipment due to the remote nature of the test beam accomplishments.

Table 2: Additional funding requested for test beam equipment at JLab.

Item	**Costs in $k**
Equipment (gas lines, cabling, support structures, remote control devices)	**10**