Generic R&D proposal: Simulations of the physics impact of a solenoid-based compensation scheme for the field of the main detector solenoid in IR8

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Abstract

Measurements relying on excellent forward detection are a cornerstone of the EIC physics program. A second detector in IR8, which encompasses an innovative design greatly improving the forward detection, thus has the potential to significantly enhance the EIC physics output. While the second detector itself is not part of the EIC project, an initial IR8 layout

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that later can evolve into the full configuration is. It is thus important to provide timely input for the accelerator experts at BNL. The findings will also be important for a discussion of opportunities enabled by a second detector in the context of the upcoming NSAC Long Range Plan.

One key aspect of this is the choice and implementation of a compensation scheme for the main detector solenoid. The choice between the use of anti-solenoids (solenoids with opposite polarity), or a scheme involving a number of skew quads in locations with appropriate betatron phase advance is consequential in terms of the complexity of the IR design and accelerator operations, the capability of the forward detection, and the longitudinal space available for the central detector.

This proposal focuses on developing a configuration for the instrumentation of an IR8 layout using an anti-solenoid compensation scheme, and to benchmark it using a set of high-impact EIC measurements.

1 Introduction

The EIC differs from most other colliders in that a large and important part of the physics program happens very close to the hadron beam and requires unprecedented detection of the scattered proton/ion ("target"), or any target fragments that may emerge from the reaction. Achieving these capabilities requires a high level of integration between the central detector and the accelerator, the optics of which also forms a forward spectrometer for target (fragment) detection.

The EIC project detector (Detector 1) will be located in interaction region 6 (IR6), currently used for the STAR detector. The location for a second detector is envisioned to be IR8, currently housing the sPHENIX experiment. The main difference between the two IR layouts is that IR8 will incorporate a second focus (making the beam size small) at the location of maximum dispersion, where off-momentum particles have the largest transverse separation from the beam. This combination creates an exceptional acceptance for scattered protons with a small p_T, in particular at low values of x, and for all nuclei and nuclear fragments. Details of the IR8 layout are, however, still evolving.

An important design choice is how to compensate the field of the detector solenoid, which impacts both the accelerator and forward detection. The most effective way to do this is to use a solenoid of opposite polarity. The alternative is to use skew quads. The former offers a number of significant advantages for both the accelerator and forward detection, and was repeatedly mentioned by the EIC Detector Proposal Advisory Panel (DPAP) during the review process. However, due to a lack of space, the baseline solution for IR6 and the initial IR8 layout is nevertheless to use only skew quads. With a shorter detector it is possible to incorporate an anti-solenoid in front of the final focusing quadrupole magnets (FFQs) of the ion beam.

Among the three EIC proposals reviewed by the DPAP, the COmpact detectoR for the EIC (CORE) had a half-length of 4 m (vs. 5 m for the other two), and could thus accommodate an anti-solenoid with minimal changes to the overall layout of the IR. The

DPAP assessment was that all three proposals, including CORE, "will be able to fully realize the baseline physics case and to make significant contributions in areas beyond," suggesting that a shorter length is a realistic and attractive option for a Detector 2 in IR8.

The focus of this proposal is to adapt the instrumentation and evaluate the physics performance of a forward detection system for an IR8 layout using an anti-solenoid compensation scheme (optimization of the accelerator / spectrometer optics and magnet design will be done in parallel but is not funded by this proposal). Our request thus focuses on support for simulations, although it is likely that hardware developments could follow in the future based on the simulation results (an example could be a LYSO EMcal for nuclear photons). Such spin-off projects could either become part of the Year 2 (or 3) activities, or evolve into separate proposals.

During the first year, the goal of the simulations will be to establish a baseline layout that can be be presented to the project and serve as input for the second detector working group of the EIC user group. For this, the proposal envisions an initial timeline of at least two years. In the first year the simulation software will be set up and a first set of studies carried out, while the second year will see more detailed studies and publication of key findings. We do, however, anticipate that as the design of IR8 progresses and new ideas are brought forward (both in terms of physics and instrumentation), it may be beneficial to extend the program to a third year.

The budget includes funding for an expert to who will develop the necessary tools (event generators) to study key processes, and (half) a postdoc who will take the lead on carrying out the simulations. An important aspect of work of the postdoc will be to interact with the accelerator and magnet experts to ensure that all findings are incorporated into the design. Thus, by bringing together accelerator, magnet, and detector experts, the proposal will provide an opportunity to train a postdoc in the concepts and simulation tools used by both nuclear- and accelerator physicists, making the postdoc uniquely qualified for future work related to the critically important topic of forward detection at the EIC.

2 Physics motivation and simulation needs

Forward detection at the EIC is essential for understanding the spatial structure of protons and nuclei - a key goal of the EIC physics program - but also for other topics such as the study of exotic nuclei. In general, the measurements involve detection of the target proton or nucleus, which survived intact, or the products from its breakup or decay. In most cases associated particles are produced at larger angles in the lab frame, but there is often a tail extending beyond the acceptance of the central detector, and sometimes this tail can be very significant (*e.g.*, for exclusive u-channel processes). The closer to the beam a particle emerges, and the smaller the difference is between its magnetic rigidity and that of the beam, the further away from the interaction point (IP) it is detected. The particles that are the most difficult to extract from the beam are detected at the Roman pots at the second focus, which is a unique feature of IR8. But the Roman pots downstream of the ion FFQs cover a range in transverse momentum p_T and remaining longitudinal momentum fraction x_L, and

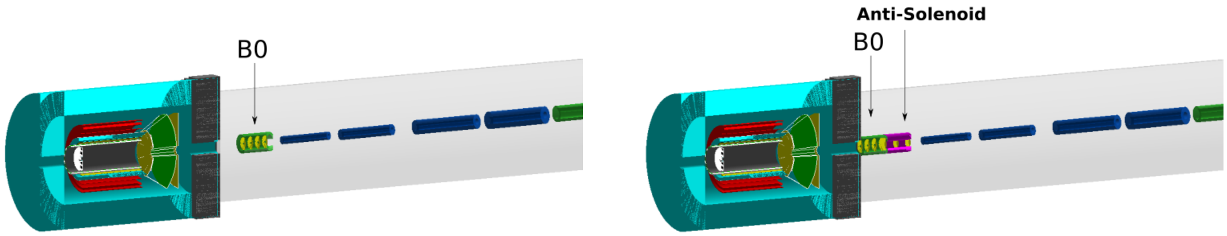

Figure 1: Left image: the baseline IR8 configuration for the (outgoing) hadron side. Right image: conceptual IR8 configuration showing the anti-solenoid (purple) in-between the B0 dipole (green) and the ion FFQs (blue). Note that the anti-solenoid can have a length and aperture that differs from the main solenoid.

their overall acceptance depends not only on the focus but the overall ion optics and the apertures of the ion FFQs and subsequent magnets. Thus, the impact of an improved solenoid compensation scheme and ion optics optimization will affect and potentially improve all aspects of the forward detection. To benchmark the physics performance it is thus essential to simulate a number of key processes that either are cornerstones of the general EIC physics program, or could be enabled by the unique capabilities of a second detector in located in IR8.

The tomography of the proton and nuclei is an essential physics goal for the EIC, for which the excellent forward detection enabled by the IR8 design can have a large impact - in particular for nuclei and low x (high x_L) protons. The 3D structure is revealed by deep exclusive measurements such as DVCS and deep exclusive meson production. In general, these processes differ in what is produced, but are similar in terms of the detection of the target proton. Since the spatial distribution creating the tomographic "image" is the Fourier transform of the t (p_T) distribution, it is necessary to cover a sufficient range in p_T for all relevant kinematics. The detector acceptance for the recoil proton can thus be benchmarked using a representative process such as DVCS (exclusive production of a photon). However, in order to evaluate the impact of the forward tails in the distribution of produced particles, or cases where the target does not remain a proton in the ground state, but becomes an excited nucleon or Δ that immediately decays, several processes would have to be studied. Simulations of DVCS on the proton can be carried out using existing generators such as EPIC or the older Milou. Generators are also available for several meson production channels. Thus, we think that initial studies of deep exclusive reactions can be carried out without further generator development - although additional efforts may be needed in the future to explore the best configuration of the instrumentation in the B0 and anti-solenoid.

For nuclear beams, only the lightest intact nuclei can emerge from within the beam envelope and be detected. In most cases the goal is thus to detect the breakup of the target, either to study the fragments themselves (*e.g.*, rare isotopes), or to tag/veto the breakup (*e.g.*, deep exclusive reactions and coherent diffraction on nuclei). Measuring breakup is complicated since the fragments that emerge have very different magnetic rigidities (A/Z) when compared with the beam. Thus, while for fragments with a small change in rigidity the main challenge is to separate them from the beam ions, for others it is to transport them through the magnets. In addition, there are also neutrons and photons emitted from the nucleus as it de-excites. For optimal performance one needs to be able to detect as many of these as possible.

Coherent diffractive vector meson production from nuclei, along with the rejection of the incoherent background, has been identified as a key physics driver of the forward detector and IR design, as it can be related to the gluon distribution in the nucleus and modifications due to saturation and/or leading twist shadowing. One of the most difficult challenges in vetoing the incoherent background is the case where the remnant nucleus emits very few, or even zero, nucleons.

Two strategies have emerged for improving the veto power in the IR8 detector compared to the project detector depending on whether the final state nuclear remnant from the incoherent event is the same as the incoming (emitting only photons) or different (emitting a small number of nucleons, but remaining close in rigidity to the beam).

In the case where the nuclear remnant is the same as the incoming, the strategy is have improved detection of the photons in the forward direction. Doubly magic nuclei such as ^{208}Pb and ^{90}Zr have the advantage that they must emit at least one detectable energetic photon which is at the MeV scale in the nuclear rest frame and 100 MeV scale if it is forward in the lab frame. Figure 2 shows that forward photons produced in ^{208}Pb collisions are more energetic than those from Au collisions as expected. Figure 3 shows that forward photons produced in ^{90}Zr collisions are also energetic. For ease of comparison, the energy setting for the ions was fixed at 110 GeV per nucleon, the maximum energy for Au. If Zr is run at the maximum energy of about 122 GeV the photons will be slightly easier to detect being more energetic and at a smaller angle.

In the case where the nuclear remnant is close to the incoming nucleus, but not identical (for instance A-1 and/or Z-1), the secondary focus and the detection of particles with rigidity very close to the beam in IR8 will be essential. Figure 4 shows the effect of the secondary focus. The bottom right hand plot shows the acceptance due to the secondary focus for nuclear remnants from full energy diffractive $e + {}^{90}Zr$ events at the EIC.

3 Overview of the optimized IR8 configuration

In addition to the anti-solenoid-based compensation scheme, the optimized IR8 layout also includes independent but synergetic updates to the ion optics, as well as an updated "B0" dipole.

A shorter central detector would also have a shorter solenoid. For instance, the CORE solenoid was 2.5 m long and had a maximum field on the z-axis of 3 T at the center, which

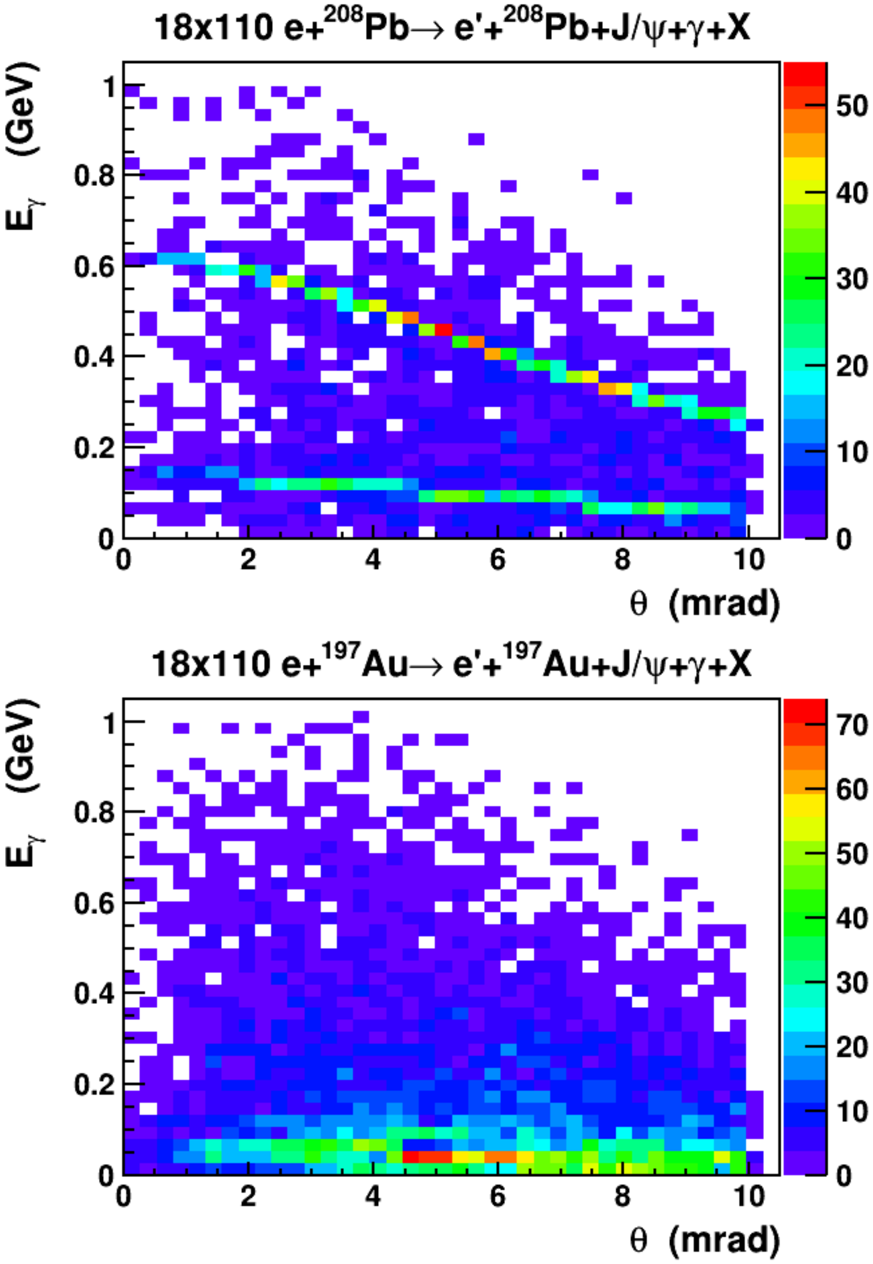

Figure 2: Energy vs. angle in the lab (collider) frame for forward photons emitted from incoherent diffractive events at 18 GeV x 110 A·GeV for events with a (upper) ^{208}Pb or (lower) ^{197}Au target as simulated in BeAGLE.

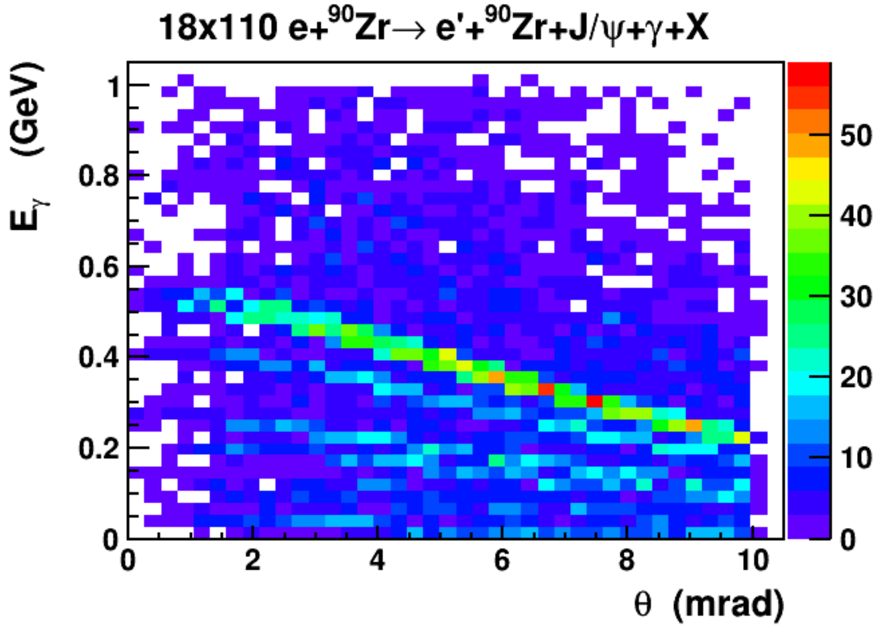

Figure 3: Energy vs. angle in the lab (collider) frame for forward photons emitted from incoherent diffractive events at 18 GeV x 110 A·GeV for events with a ^{90}Zr target as simulated in BeAGLE.

dropped by almost 30% at $z = \pm 1.2$ m (the edges of the all-Si tracker). The solenoid compensation would be implemented using two anti-solenoids (one upstream and one downstream), each with half the integrated strength of the main detector solenoid but with opposite polarity. The solenoid on the (outgoing) electron side could have a smaller aperture, and thus a higher field and shorter length. The solenoid on the ion side would be integrated with the forward detection system and thus a little larger, with a length of about 1 m, which is also the difference in half length between Detector 1 and a compact second detector for IR8. All three solenoids will be centered on the electron beam.

From an accelerator point of view it is preferable to do the correction for the solenoid field before the ion FFQs. Thus, while one could in principle place the anti-solenoid behind the FFQs, or even in the middle of the block, the natural baseline configuration is to place it in front of them. With a shorter central detector, this space will be available since the B0 dipole can be moved 1 m closer to the interaction point (IP). Moving the B0 closer has the advantages that a similar (larger) solid angle can be covered with a smaller (similar) aperture. The magnet can also be made simpler since the electron FFQ can be located behind the B0 rather than being integrated into the field-free region in its side (through which the electron beam passes).

The use of an anti-solenoid instead of skew quads also has improves the apertures of the ion FFQs, and thus acceptance of the ZDC and Roman pots located downstream of them. The reason is that the additional skew windings will also contribute to the peak field, and in order to keep the latter within the current 4.6 T limit (or a corresponding higher value if a

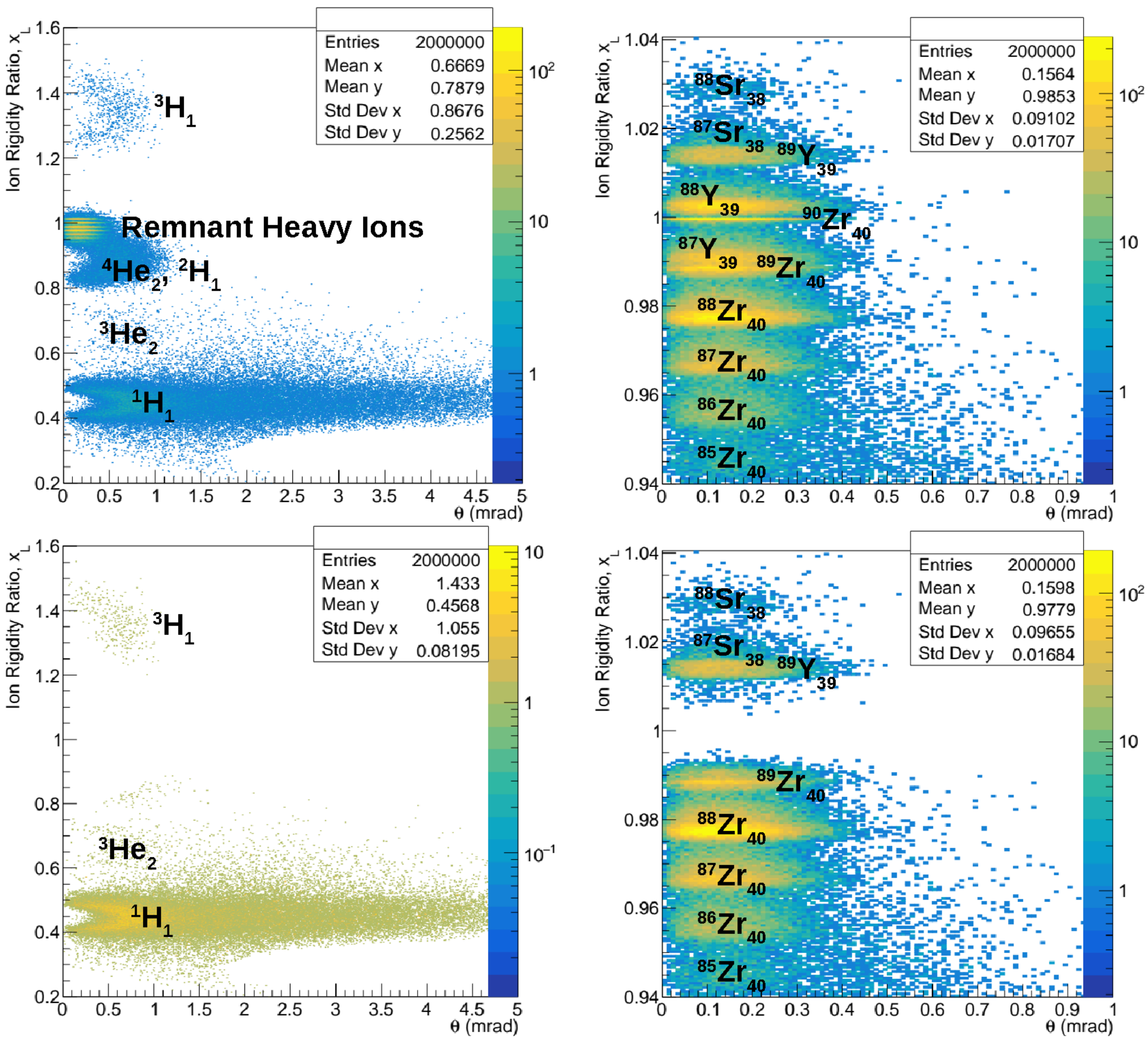

Figure 4: Roman Pot occupancies for diffractive $e +^{90} Zr$ events. Top left and right plots show RP occupancy x_L versus θ in BeAGLE for layer 1 and layer 3 (near the secondary focus) while the 10σ beam cut is not applied; bottom left and right show the same for the case when the 10σ beam cut is applied. x_L is defined as the rigidity fraction: $(p/Z)/(p/Z)_{\text{beam}}$. Note the different scales on the plots. Figure reproduced from ECCE [1].

different superconductor is used), the apertures would have to be reduced accordingly. This is synergetic with an overall optics optimization, where acceptance and magnet length can be improved by alternating the first two quads in both high- (DFFD / FDDF) and low-energy (DFD- / FDF-) configurations instead of using DDFF / FFDD at high energy. It is worth noting that the efficiency of the low-energy setting is enhanced by the second focus, which provides excellent low-p_T acceptance even with stronger focusing (smaller β^*). The neutron cone (ZDC acceptance) can be further optimized by using a split "B1" dipole after the FFQ block, where the strengths and apertures of the two dipoles can be chosen independently.

3.1 Advantages for forward detection

The field of the main detector solenoid significantly affects both the spin and trajectories of beam electrons and ions, (as well as any scattered ones). A compensation scheme is thus necessary for accelerator operations. A solenoid-based scheme is more straightforward than one based on skew quads (*e.g.*, decoupling the solenoid field from the beam energies) and offers a number of number of specific advantages such as intrinsically larger ion FFQ apertures (mentioned in Section 3). It also provides compensation for both on- and off-momentum (scattered) particles, whereas skew quads can only fully compensate on-momentum (beam) particles.

Moving the B0 dipole closer to the IP and adding a solenoid in-between the B0 and the ion FFQs also has the potential of increasing the B0 acceptance, and provides more space for detectors behind it. This can translate into a longer level arm for tracking detectors, and thus improved momentum resolution or more relaxed requirements on position resolution. It could also make it possible to add an EMcal to cover larger angles for the detection of nuclear photons (important for, *e.g.*, rare isotopes and coherent diffraction), and forward π^0 production (from, *e.g.*, exclusive u-channel production). The best configuration for both the B0 dipole and anti-solenoid, as well as the detectors within, will require an extensive study with by multiple physics channels used as benchmarks. This is the main thrust of this proposal.

The improved far-forward acceptance made possible by the anti-solenoid and general optics improvements will also be evaluated. Here, the interplay between the far-forward detection and the detectors in and behind the B0 will be of particular importance (*e.g.*, simultaneous detection of photons going into an EMcal in the front layer of the ZDC and a possible EMcal behind the B0 covering larger angles).

3.2 Advantages to the accelerator

In addition to improvement of the forward detection, placement of an anti-solenoid in the detector region, before the forward ion FFQ offers significant advantages to the accelerator design. It greatly simplifies integration of the main detector solenoid into the accelerator lattice and compensation of the detrimental beam dynamics effects associated with it. Use of an anti-solenoid is the most straightforward and robust approach to compensation of a detector solenoid. Its main downside is that it requires a substantial amount of space in

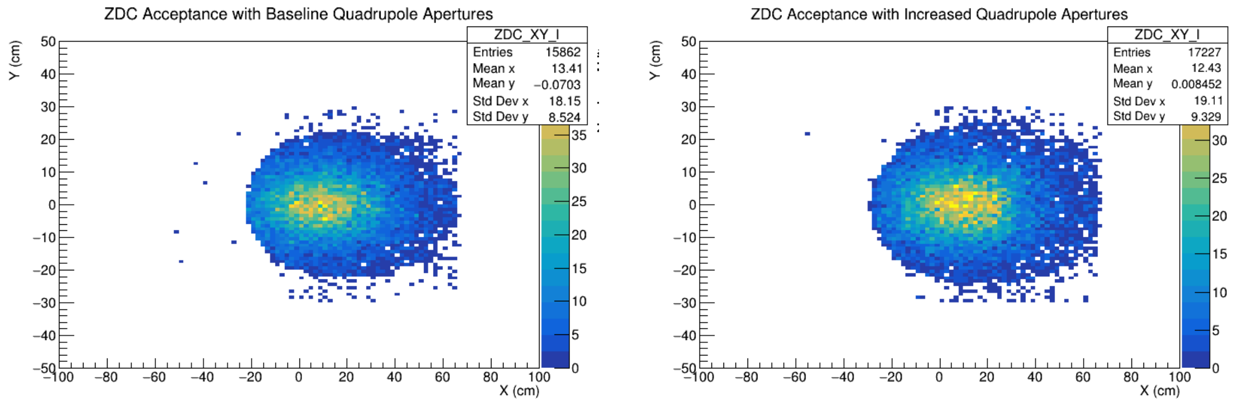

Figure 5: Example simulation study of ZDC acceptance using $\pi^0 \to \gamma\gamma$ events. Left: current conceptual IP design. Right: with anti-solenoid design with enlarged FFQ aperture. Potential increase in ZDC acceptance when quadrupole apertures are increased by 10%. (Work in progress)

the very-tightly packed forward detection region. Lack of adequate space is the main reason why it is not implemented in the IR6 design. The CORE concept with its relatively short detector solenoid not only allows one to allocate sufficient space for an anti-solenoid in the central detector region but, more importantly, to take advantage of it to benefit the forward detection as discussed above.

Even though the main goal of placing an anti-solenoid in the detector region is to advance the forward detection, it is worth pointing out in some detail its complementary benefits to the accelerator design. First, it provides the most natural way of compensating transverse betatron coupling by generating an effect exactly opposite to that of the main solenoid. Unlike skew quad compensation, this correction works precisely for particles of all momenta. Skew quad compensation, which has been successfully demonstrated in the past and which has been adopted by the IR design, relies on the betatron phase advance and provides exact correction only for the on-momentum particles. The betatron phase advance conditions necessary for perfect compensation are generally violated for off-momentum particles due to the chromatic effects. Moreover, skew quad coupling compensation requires at least 6 but in practice several more skew quad correctors on each side of the IP. Their setup may be more challenging from the operational point of view than adjustment of the current of a single anti-solenoid. It is rarely possible to place skew quads at locations with optimal betatron phase advance. This may lead to non-orthogonality of the 6 skew quads and the need for additional skew quads. This further complicates the decoupling procedure. In general, regular straight quads must also be adjusted to compensate for the focusing effect of the skew quads. Use of an anti-solenoid eliminates the need for this complicated setup.

The bunches in the EIC are crabbed, or tilted, in the horizontal plane at the IP to restore their effective head-on collisions with a finite beam crossing angle. The detector solenoid essentially rotates the crabbing plane, perturbing the spatial orientation of the tilt. This has been shown to not only result in geometric luminosity loss but to also cause beam degradation. Correction of this effect of critical importance. Similarly to how it compensated betatron coupling, an anti-solenoid simultaneously corrects the crabbing plane distortion. The IR6 design uses 3 skew quads for correction of the unwanted vertical components of the crabbing tilt at the IP. Two out of the three quads in the adopted solution are implemented as additional windings on top of the main windings of the final focusing quads. This is particularly undesirable in case of the forward ion quads, since, besides further complicating their already challenging design, the extra windings take up additional space potentially resulting in shrinkage of the FFQ apertures and therefore of the forward acceptance. An anti-solenoid again eliminates the need for such extra quads.

The detector solenoid may also have a somewhat subtle effect on the electron polarization. Since the electron beam is longitudinally polarized and aligned with the solenoid axis, the solenoid does change the polarization orientation. It does change the spin precession rate, or the spin tune, in a momentum-dependent way, which is corrected by an anti-solenoid, but it is still not the main concern. The solenoid causes transverse spin mismatch. In other words, it causes the spin of the particles with non-zero betatron amplitudes to deviate from the vertical direction in the ESR arcs. This may, in turn, lead to degradation of the electron polarization lifetime. It is not possible to spin-match a single solenoid locally. The detector solenoid has to be spin-matched in conjunction with the spin rotators. An anti-solenoid, on the other hand, restores spin matching locally without the need to involve the spin rotators.

Finally, the detector solenoid causes distortion of the ion closed orbit. Since the ion beam goes through the solenoid at an angle to its axis, the solenoid field has a non-zero component transverse to the ion orbit. It results in a vertical kick of the ion beam. This kick must be corrected to bring the beam back to the magnet axes as quickly as possible. In IR6, it is done by a series of vertical kickers as illustrated in Fig. 6. One of the correctors is integrated into the B0 magnet. The physics requires that the interaction plane is oriented horizontally at the IP. Therefore, both the orbital angle and offset have to be corrected to zero at the IP. This, in turn, means that the orbit is distorted and has to be corrected on both sides of the IP. The main concern associated with this orbit distortion is that the beam is offset inside the FFQs and samples the fields that are less uniform than at the magnet centers. Non-linear field components experienced by the beam reduce the ring's dynamic aperture and therefore limit the beam and luminosity lifetimes. This is less of an issue on the forward side where the quad apertures are relatively large and contain large good-quality field regions. However, on the rear side the FFQ apertures have regular sizes where the relative orbit offset may become significant. This may result in tighter requirements on the multipole components of the FFQs making their design more challenging compared the centered beam scenario. An anti-solenoid is beneficial in this case in reducing the closed orbit distortion prior to the beam entering the FFQs. It may also relax the requirements on the orbit correctors.

3.3 IR8 optics design optimization

The acceptance and accelerator advantages of the CORE concept described above come from local optimization of the detector region. This approach simplifies detector integration as discussed in Section 3.2 but does not involve any changes in the basic IR8 lattice design.

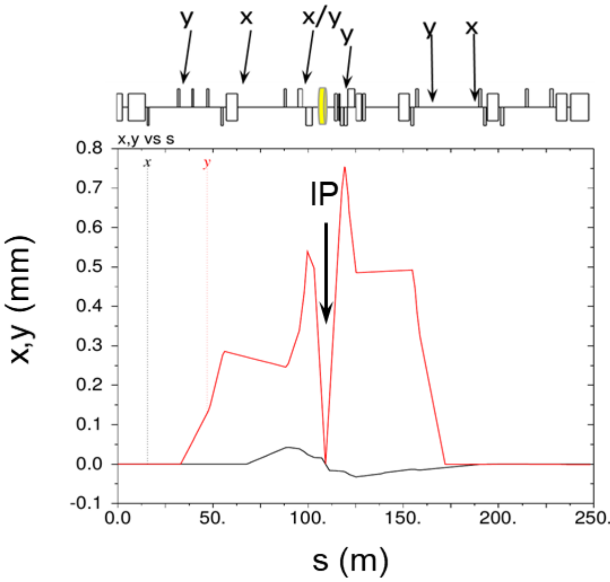

Figure 6: Correction of the ion closed orbit distortion caused by the detector solenoid using radial (x) and vertical (y) corrector dipoles.

To further optimize the detector acceptance, we would like to explore optimization of the lattice design as well. To minimize interference with the overall accelerator design, we only consider modifications localized to the region from the IP to the secondary focus. We keep the boundary conditions at those points fixed as much as possible.

The shorter detector space allowing for closer placement of the FFQs to the IP and elimination of the need for skew quads in the FFQs as discussed in Section 3.2 already help reduce the required FFQ apertures and/or make FFQs shorter for the same forward acceptance angle. Given the space constraints in the forward region of IR8, any reduction in the length of the FF block is extremely valuable.

To further optimize the forward acceptance, we propose to consider a triplet FFQ configuration in addition to the baseline doublet one. Figures 7 and 8 compare the baseline and proposed configurations, respectively. Admittedly, a doublet configuration provides the most efficient focusing of flat beams. That is why it was adopted for the baseline IR8 design. However, it may not be the most optimal design when folding in the forward acceptance requirements. By comparing Figs. 7 and 8, one can see that the horizontal β function in Fig. 8 is significantly smaller than in Fig. 7. This happens because horizontal focusing of the beam in the triplet configuration starts earlier than in the doublet one. A smaller horizontal β function indicates that the envelope of the near-beam-momentum fragments is also smaller. This suggests that the triplet design may provide better acceptance to those fragments than the doublet one. Note, however, that unlike the baseline design in Fig. 7, the design in Fig. 8 has not been optimized for acceptance and serves as illustration only.

Another avenue for potential forward acceptance improvement is local optimization of the

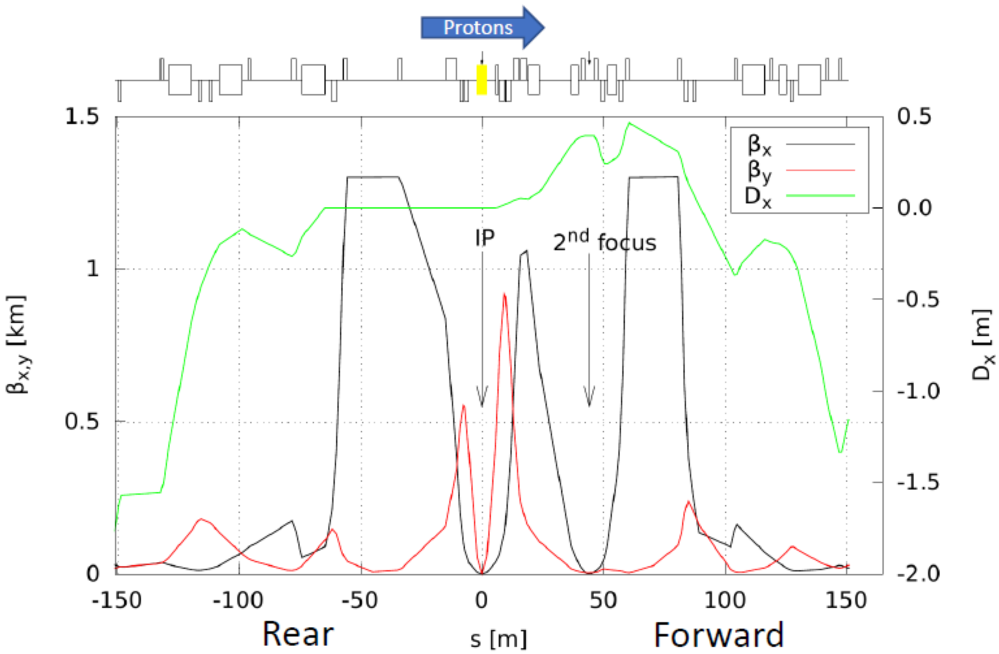

Figure 7: Baseline doublet optics of IR8.

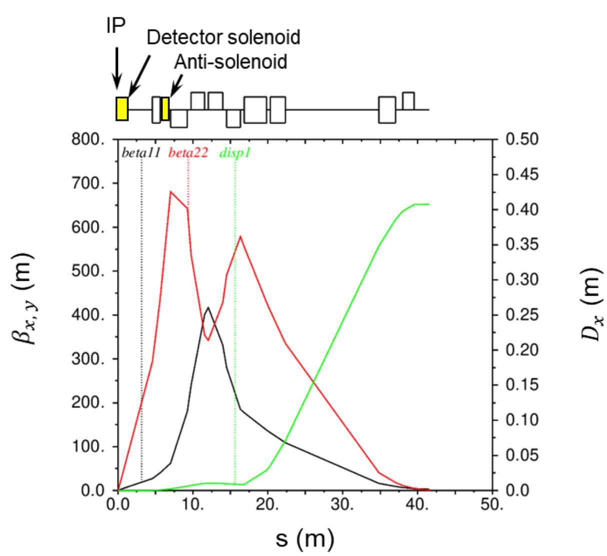

Figure 8: Possible triplet-based optics of the forward section of IR8.

ion dipole located after the FFQs. It currently creates a bottle neck for low-magnetic-rigidity fragments such as protons from deuteron breakup. Combined with optimization described above, it may be possible to improve its acceptance without increasing its aperture, which presents an engineering challenge. We propose to explore the possibility of splitting the dipole magnet in two segments and optimizing their apertures, positions and orientations for maximum acceptance. This may also help relax the parameters of the individual dipole segments compared to a single-dipole case.

As a final step, one must optimize the optics and forward acceptance of IR8 considering all of the relevant modification knobs described above simultaneously. They include:

- FFQ strengths. Note that the design dipole bending angles are fixed due to the geometric constraints.
- FFQ and dipole lengths.
- FFQ and dipole apertures.
- FFQ and dipole lateral offsets and yaw angles.
- Correcting components of the dipole fields for orbit control.

All of the above parameters will, at the same time, be kept withing engineering feasibility constraints.

4 Proposed work

The goal of this proposal is to evaluate the best way to instrument an IR based using an anti-solenoid compensation scheme and to benchmark its performance. The IR optics and magnets will be developed in a parallel unfunded effort.

In order to carry out the proposed work, we will need to have physics even generators for all the relevant physics processes and a simulation framework in place. Since the central detector has to be compact in order to provide space for the anti-solenoid, the COmpact detectoR for the EIC (CORE) proposal provides a good starting point.

Currently the full simulation for CORE and IR8 are implemented in Fun4All. However, since the EIC project management has expressed strong encouragement to have Detector 1 and 2 share the same simulation software at the current stage, and Detector 1 has decided to pursue the Geant4 based simulations using DD4HEP (CERN) for the geometry profile, and JANA2 (JLab) for analysis and reconstruction, it is important to translate the CORE and IR8 simulation and analysis/reconstruction to the framework that is used in Detector 1. Thus, an important aspect of this proposal will be to develop and maintain a simulation package for the forward detection of a Detector 2 in IR8, and make it available for the entire community. This effort would be synergetic with a similar effort presented in the "EIC KLM R&D proposal," which would focus on the central detector. The combined development of a simulation framework for Detector 2 would receive a significant in-kind contribution from Stony Brook University.

The simulation package will model the beam line and make it possible to place instrumentation in and behind the B0 dipole and in Roman pots downstream. Events will initially be generated using the EPIC and BeAGLE event generators to simulate deep exclusive reactions on the proton, coherent diffraction on nuclei, and production of rare isotopes, and the reaction products will be propagated through the simulation to benchmark the performance. Eventually other generators will be added to look at specific topics such as production of particles (from the current and not the target) at very forward angles, and the possibility to detect them with the instrumentation in and immediately behind the B0 dipole. The simulations will be carried out by the postdoc.

For coherent diffraction and rare isotopes, both heavy (^{208}Pb) and medium ^{90}Zr nuclei will be used. For the latter, detailed studies will require generation of Sar*t*re tables for ^{90}Zr. Since e+Zr diffractive scattering is one of the 'golden' physics channels for IR8, where the capability of the second focus to tag A-1 fragments will allow for a cleaner measurement, unveiling an important complementarity. The fragments generated in the incoherent scattering on medium nuclei also provide an interesting way of accessing rare isotopes in this mass region through evaporation rather than fission. Both examples also benefit from improved detection of nuclear photons, for which the B0 and anti-solenoid combination may offer an improved acceptance. This work will also include further development of the BeAGLE event generator (*e.g.*, updating its output format), and will be carried out by M.D. Baker, who is the main developer of BeAGLE and a collaborator on this proposal.

The initial simulations of deep exclusive reactions, coherent diffraction, and production of rare isotopes will be carried out in year 1, and the results folded into the design. Year 2 will see further refinement of the simulations, and publication of key findings. All results will also be presented in a report to the R&D committee.

In year 2, we will also look into an IR configuration incorporating magnets with superconductors that will allow higher peak fields, which would translate into larger apertures and shorter lengths. It is possible that even a limited use of such magnets (*e.g.*, for the first two ion quads only), could have a significant impact on the capabilities of the IR.

4.1 Deliverables

If the proposal receives full support, the deliverables for Year 1 and 2 would be as follows:

- Year 1

  Complete a version of IR8 conceptual design using an anti-solenoid compensation scheme.

  Iterate on the design using the Geant4 simulation and engineering feedback.

  Incorporate the IR design and relevant beam line instrumentation - in particular within and behind the B0 dipole - into the simulation framework.

  Complete physics study for DVCS on the proton.

Complete physics studies for coherent diffraction on medium- and heavy nuclei to benchmark the physics performance of the new IR8 design. (Note that the photon and fragment acceptance will also be important for rare isotopes.)

- Year 2

  Publish key findings from Year 1 (arXiv or journal).

  Carry out additional simulations focusing on the B0 instrumentation and acceptance such as u-channel π^0 production.

  Investigate the impact on physics performance of a limited use of IR magnets with superconductors that would allow higher peak fields.

The findings will also be reported to the EIC user community though the 2nd detector WG of the EIC UG.

5 In-kind Contributions

The proposed project will benefit from three major in-kind contributions from its participants.

- IR optics design (V. Morozov).
- Design of key IR magnets (P. Brindza).
- Development of the simulation framework (W. Li and students at SBU). Synergetic with a similar effort for the central detector for the "EIC KLM R&D proposal."

6 Funding Request

The in-kind contributions make this proposal very cost effective. We only request funding for further development of event generators, modeling the instrumentation of the IR, and benchmark the physics performance by simulating key processes.

Generator development and expert guidance on nuclear simulations will be provided by M.D. Baker whose work will be contracted from MDBPADS LLC (a small business).

The modeling of the instrumentation and physics simulations will be done by a postdoc (50% FTE with matching funds) at Stony Brook. We believe that with the proposed timeline a postdoc is essential. In the 100% funding scenario we also ask for a graduate student (50% FTE with matching funds) who would support the simulations. We also ask for funding for 10 weeks of an undergraduate student and some funds for travel.

The detailed request for each budget scenario is shown in Table 1 in the following section. The totals do not exactly match the nominal 80% and 60% since the requested items are few and not easily scalable, but they follows the spirit of the guidance.

6.1 Budget Table

Item	100%	80%	60%
MDBPADS LLC	$42.2k	$42.2k	$35.2k
SBU PostDoc (50% FTE)	$52.5k	$52.5k	$52.5k
SBU Graduate student (50% FTE)	$28.0k		
SBU Undergraduate student (8 weeks)		$6k	
Travel	$5.3k	$1k	
Total	$128k	$101.7k	$87.7k

Table 1: Budget for Year 1. All items include institutional overheads.

6.2 Impact of Reduced Funding Scenarios

The level of funding will impact the timelines and deliverables for the proposed work.

- At 100%, the goals and deliverables will be achieved.
- Under the 80% funding scenario, some of the Sar*t*re tables may not be ready until the end of the year and the diffractive physics studies may be incomplete and need to be finished in year 2. The DVCS result will only be preliminary without background studies by the end of year 1. u-Channel studies will be preliminary by year 2.
- The 60% funding scenario will lead to the bulk of the diffractive physics studies being moved to year 2 as we will need all of year 1 just to prepare the tables, but will not have time to make the studies. Replacing the postdoc with a graduate student would also affect other aspects of the simulations. Some results may be delayed to year 2. u-Channel studies won't be completed.

7 Diversity, Equity, and Inclusion

The proposed activities provide an excellent opportunity for training and career development through engagement in research for students from underrepresented groups as well as from economically disadvantaged communities and first-generation college students. During their research on the project, students will work with the senior personnel committed to the project, and receive training in nuclear instrumentation, simulations, and data reduction techniques. Students will be also be encouraged to present at collaborative meetings and workshops where they will get an opportunity learn how to communicate their research to an audience of peers and be able to network with other researchers. The interdisciplinary nature of the work that will be carried out by the postdoc, combining aspects of nuclear- and accelerator physics, will also create unique career opportunities supporting retention of highly-skilled individuals in nuclear physics. Overall, the proposed program supports the commitment of the participants to educate and mentor a diverse work force through research.

References

[1] A. Bylinkin, et al. *Exclusive and Diffractive Processes and Tagging with the ECCE Detector at the Electron Ion Collider*. to be published in Nucl. Instrum. Methods A. 2022.