

Preliminary design of the Interaction Region of the future Electron-Ion Collider at BNL

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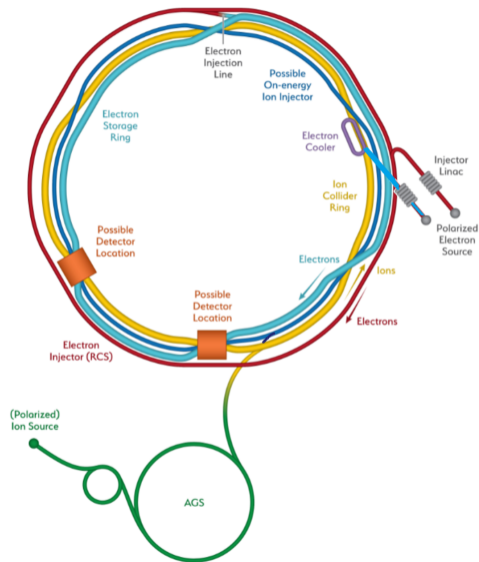
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From RHIC to the Electron-Ion Collider (EIC)



- Ion/proton beam from existing RHIC collider
- Ions up to uranium
- Polarized electron beam from 5 to 18 GeV
- CM energy from 29 to 141 GeV
- Luminosity up to $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Very first electron-ion collider
- Physics of spin structure, parton distributions and gluon saturation
- The Interaction Region (IR) is a critical component both for the accelerator and the detector

Interaction Region (IR) layout

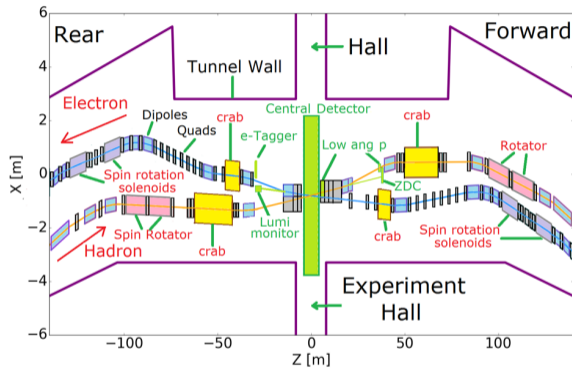


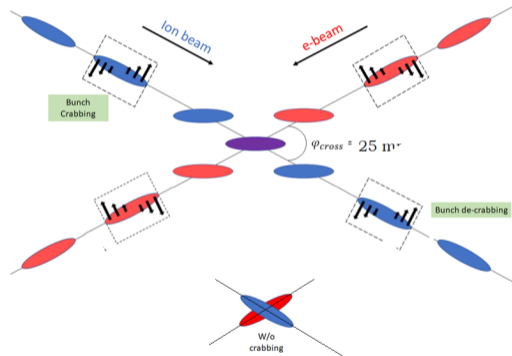
Figure: Schematic view on the IR

- The task of the IR is to focus beams to the collision point and then separate them to their beam lines
- Location of the current STAR detector
- Provides a 9 m of central free space for the detector
- Forward (proton-going) side instrumentation for neutrons (ZDC) and scattered protons
- Backward (electron-going) side is housing luminosity monitor and detector for scattered electrons (tagger)

Scientific requirements on the IR

- Besides the space for central detector, several phenomena need a dedicated instrumentation along outgoing electron and hadron beams
1. Scattered protons
 - Detection constrains exclusive processes
 - Acceptance in p_T within 0.2 to 1.3 GeV
 2. Forward neutrons
 - Neutrons from nuclear breakup, signature of electron-nucleus exclusive process
 - Cone of neutrons up to 6 mrad
 3. Scattered electrons
 - Necessary for Q^2 measurement
 - Electrons at low angles (low Q^2) are detected after passing through the first beam magnets
 4. Bremsstrahlung photons
 - Rate of the photons gives the luminosity

High luminosity at the EIC with beams crossing angle



- The beams collide at crossing angle of 25 mrad
- Allows for short bunch spacing by avoiding parasitic collisions — necessary for high luminosity
- RF resonators (crab cavity) rotate the bunches to achieve head-on collisions
- Central region is free of bending magnets, minimizes synchrotron radiation on central detector

Beam magnets related to the IR

- About 20 dipole and quadrupole magnets form the interaction region
- First dipoles on electron and hadron outgoing side act as spectrometers for scattered electrons and hadrons

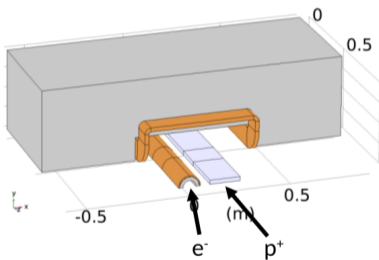


Figure: B0pF spectrometer magnet

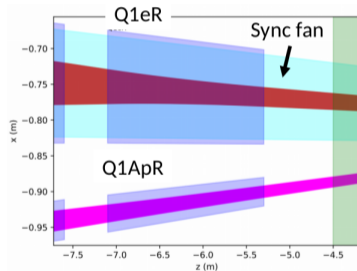
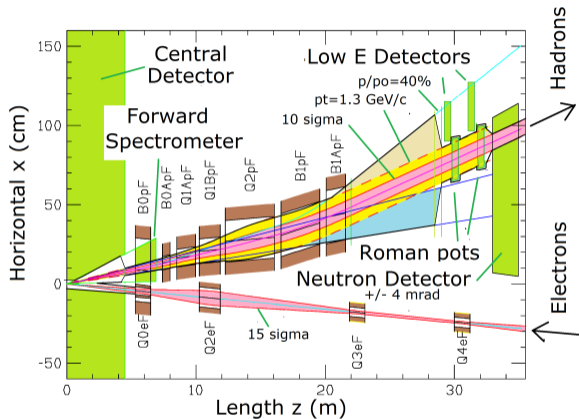


Figure: Rear-side quadrupoles

- B0pF is the first forward magnet
- Q1 quadrupoles enclose the detector on rear side
- Aperture for Q1eR is driven by synchrotron radiation

IR in the forward (proton/nucleon - outgoing) direction



- Electron beam is moving towards the detector, hadron beam is extracted away
- Instrumentation to detect scattered protons, light ions and neutrons
- Beam envelope puts constraints on placement of individual detectors

Figure: Schematics on forward region. Note different scale in x and z

Model of the forward region

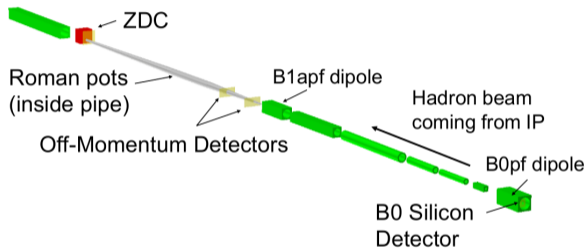
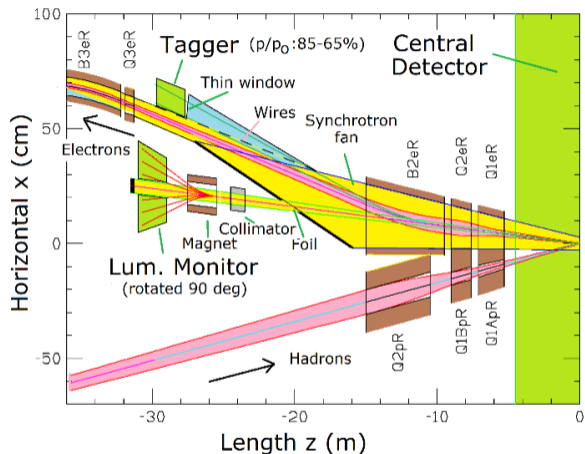


Figure: Geant4 for the forward IR

- B0 detector
 - ▶ Protons scattered within 7 to 20 mrad
 - ▶ A set of tracking layers inside B0 magnet volume
- Roman Pots
 - ▶ Two silicon tracking layers
 - ▶ Scattered protons up to 5 mrad
- Zero-degree calorimeter (ZDC)
 - ▶ Neutrons emitted at small angles, up to 4 mrad
 - ▶ Placed at 30 m from nominal interaction point

IR in the rear direction

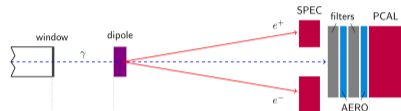
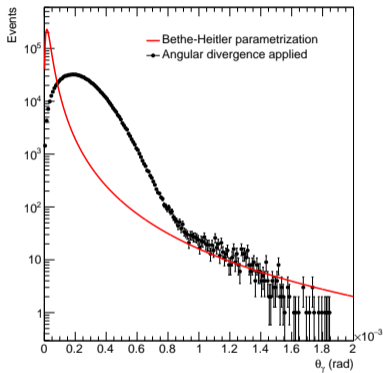
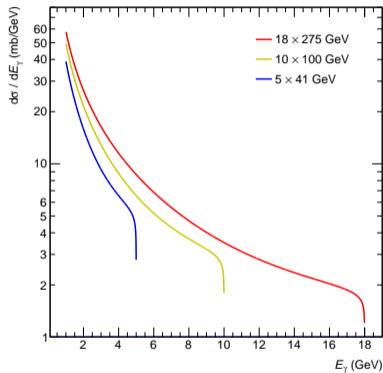


- Side of outgoing electron beam
- High load of synchrotron radiation along electron beam
- Instrumentation for luminosity measurement and detection of scattered electrons

Figure: Rear region of the IR. Note different scale along x and z

Luminosity measurement

- Based on Bethe-Heitler bremsstrahlung photons, large cross section in a narrow angular cone

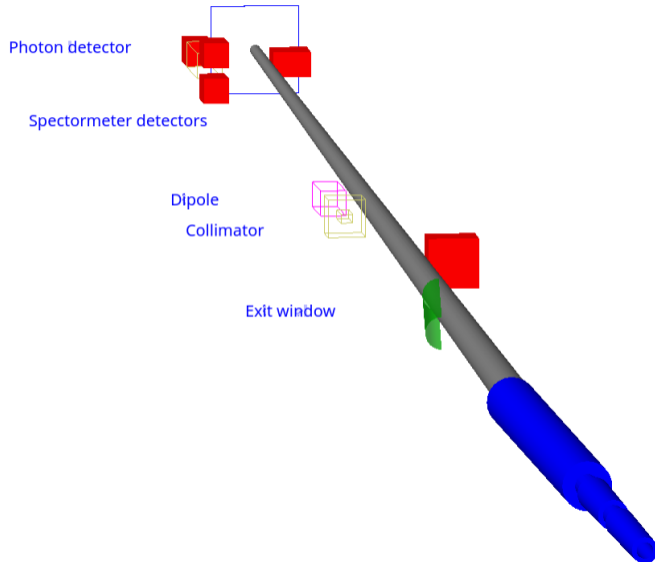


- Conversions on exit window are detected in spectrometer SPEC (precision luminosity)
- Non-converted photons reach photon calorimeter PHOT (instantaneous performance)

Figure: Bethe-Heitler cross section for several electron and proton beam energies

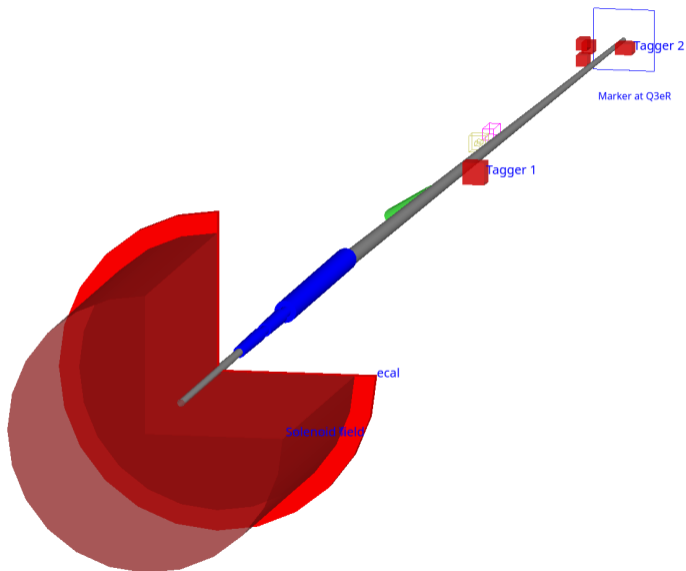
Figure: Photons angular distribution, effect of beam angular divergence is illustrated

Model of luminosity detector



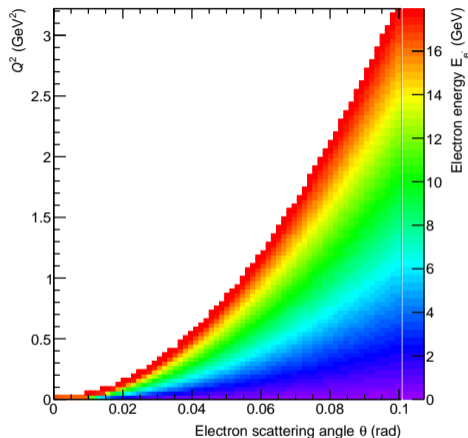
- Geant4 model of all essential components
- Bremsstrahlung photons are incident on aluminum exit window
- Non-converted photons are detected by the photon detector with graphite filter in front
- Conversion pairs are split in dipole magnet
- Electrons and positrons are detected in spectrometer detectors
- Beam magnets are shown in blue

Detection of scattered electrons



- Opposite side to luminosity detector
- Taggers 1 and 2 detect scattered electrons after the magnets
- Acceptance for $Q^2 < 0.1 \text{ GeV}^2$
- Electromagnetic calorimeter ECAL is a part of central detector
- Drift spaces in grey are transparent in the model

Q^2 measurement with electron tagging



- Virtuality Q^2 as measured with scattered electron is given by its energy E' and polar angle θ :

$$Q_e^2 = 2EE'(1 - \cos(\theta_e))$$

- E is energy of electron beam
- The tagger measures energy (calorimeter), angle is reconstructed from electron position

Figure: Relation between scattered electron energy E_{e-} , polar angle θ and virtuality Q^2

Summary

- Ongoing study to design the interaction while accommodating all technical and physics requirements
- With the EIC we will go where no one has gone before



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