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

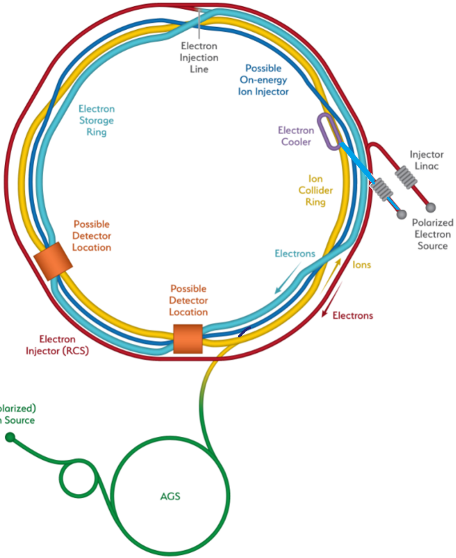
Jaroslav Adam

BNL

28 July - 6 August, 2020

Virtual ICHEP, Prague, 2020

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} cm^{-2} s^{-1}
- Very first polarized 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

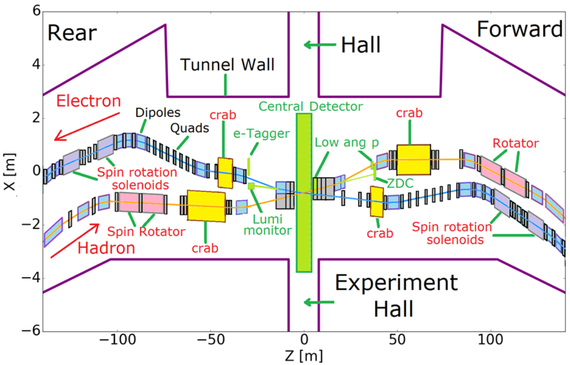


Figure: Schematic view on the IR

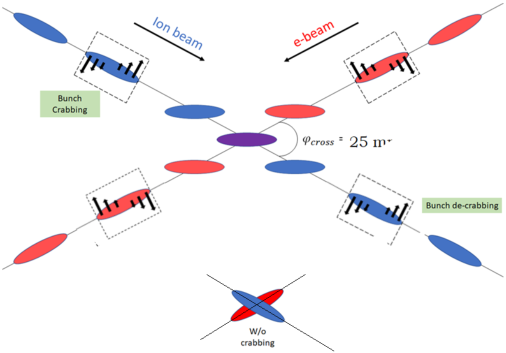
- The task of the IR is to focus beams to the collision point and then separate them to their beam lines
- Location of the current STAR detector
- Provides a 9 m of central free space for the detector
- Forward (proton-going) side instrumentation for neutrons (ZDC) and scattered protons
- Backward (electron-going) 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 4 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 with a 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 specialized magnets form the interaction region
- First dipoles on electron and hadron outgoing side act as spectrometers for scattered electrons and hadrons

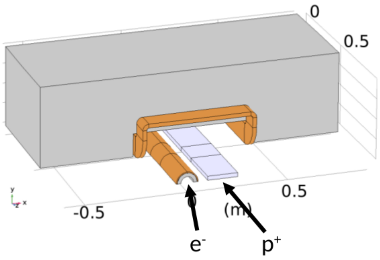


Figure: B0pF spectrometer magnet

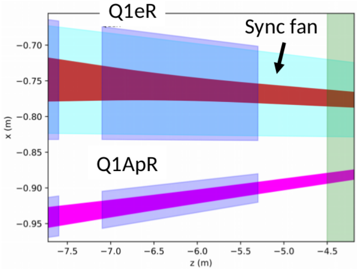


Figure: Rear-side quadrupoles

- 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

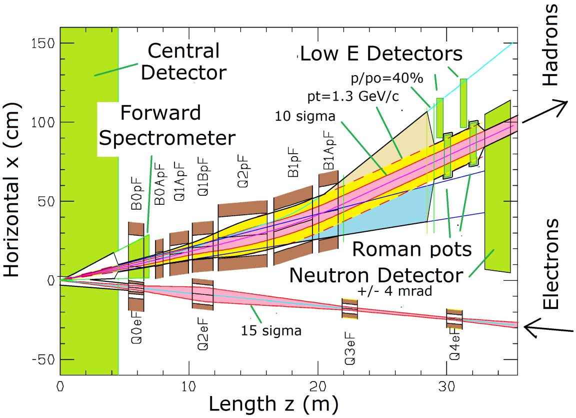


Figure: Schematics on forward region. Note different scale in x and z

- 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

Model of the forward region

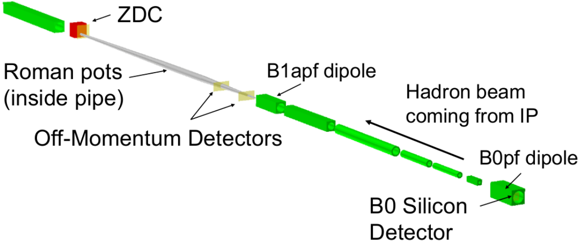


Figure: Geant4 for the forward IR

Detector	Detector Position (x,z)	Angular Acceptance
ZDC	(0.96m, 37.5m)	θ < 5.5 mrad
Roman Pots (2 stations)	(0.845m, 26m) & (0.936m, 28m)	0.0* < θ < 5.0 mrad
Off-Momentum Detectors	(0.8, 22.5m) & (0.85m, 24.5m)	0.0 < θ < 5.0 mrad
B0 Sensors (4 layers, evenly spaced)	x = 0.19m, 5.4m < z < 6.4m	5.5 < θ < 20.0 mrad

- B0 detector
  - Protons scattered within 6 to 20 mrad
  - A set of tracking layers inside B0 magnet volume
- Off-momentum detectors
  - For protons from nuclear breakup
- 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

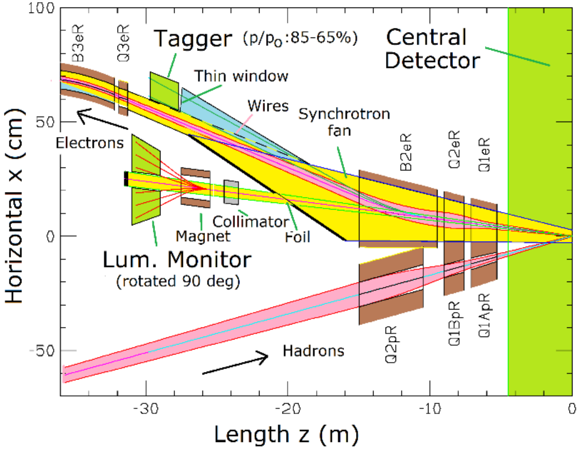


Figure: Rear region of the IR. Note different scale along x and z

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

Luminosity measurement

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

$$\frac{d\sigma}{dE_\gamma} = 4\alpha r_e^2 \frac{E'_e}{E_\gamma E_e}\left(\frac{E_e}{E'_e} + \frac{E'_e}{E_e} - \frac{2}{3}\right)\left(\ln\frac{4E_pE_eE'_e}{m_pm_eE_\gamma} - \frac{1}{2}\right); \qquad \frac{d\sigma}{d\theta_\gamma} \sim \frac{\theta_\gamma}{\left((m_e/E_e)^2 + \theta_\gamma^2\right)^2}$$

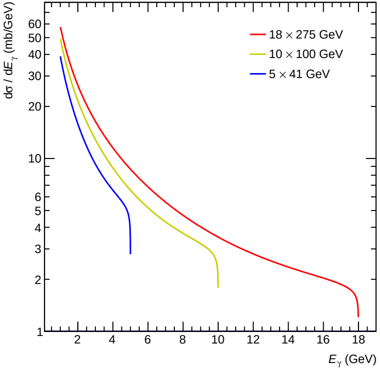


Figure: Bethe-Heitler cross section for several electron and proton beam energies

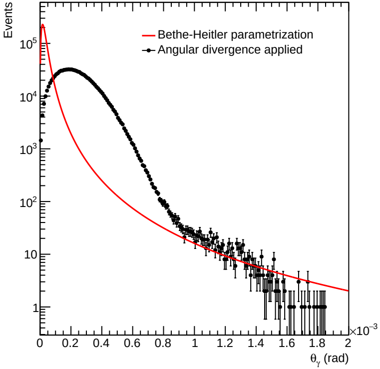
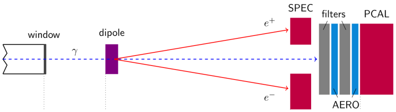
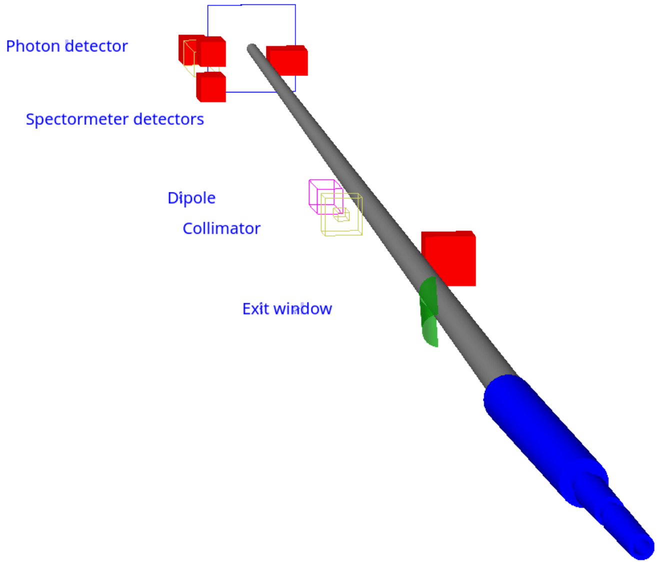


Figure: Photons angular distribution, effect of beam angular divergence is illustrated



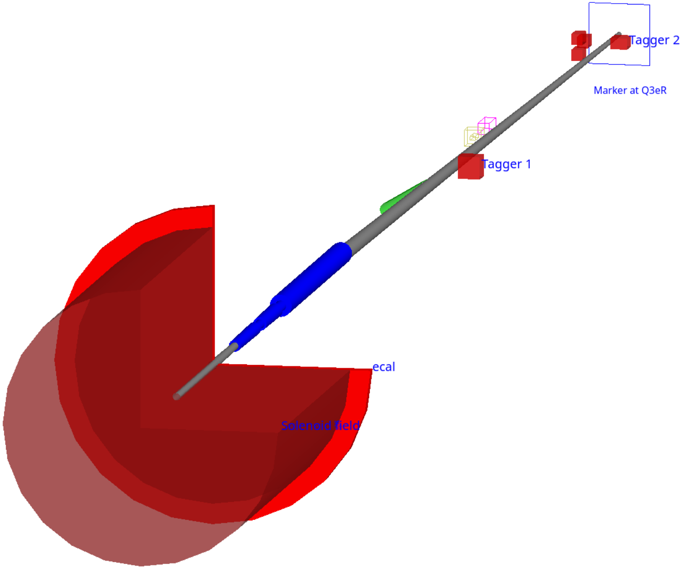
- Conversions on exit window are detected in spectrometer SPEC (precision luminosity)
- Non-converted photons reach photon calorimeter PHOT (instantaneous performance)

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 $Q^2 < 0.1$ 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

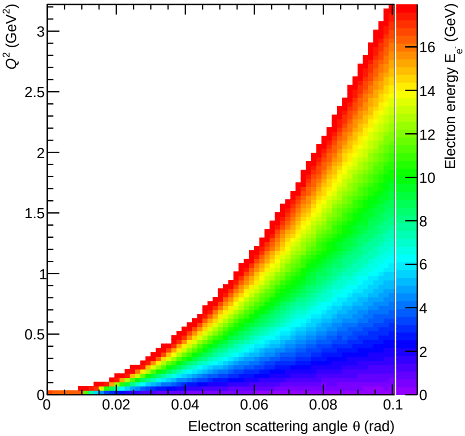


Figure: Relation between scattered electron energy E_{e-}, polar angle θ and virtuality Q^2

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

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

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

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

Acknowledgements

Mike Anerella, Elke Aschenauer, J Scott Berg, Alexei Blednykh, John Cozzolino, Dave Gassner, Karim Hamdi, Charly Hetzel, Doug Holmes, Henry Hocker, Alex Jentsch, Alexander Kiselev, Henry Lovelace III, Gary McIntyre, Christoph Montag, Guillaume Robert-Demolaize, Brett Parker, Bob Palmer, Stephen Plate, Mike Sullivan (SLAC), Steve Tepikian, Roberto Than, Peter Thieberger, Qiong Wu