



Challenges in the EIC Detector and Interaction Region Design

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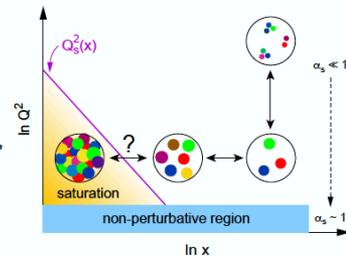
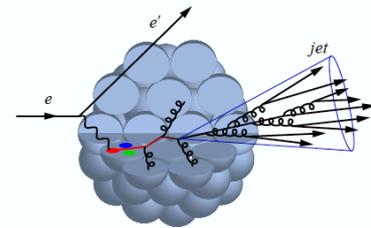
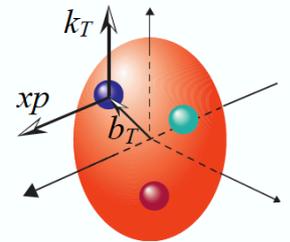
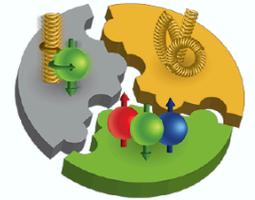
Torino DIS 2019 Workshop

EIC physics

Precision study of quark and gluon dynamics inside nucleon and nuclei

Key questions:

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Where does the saturation of gluon densities set in? Does this saturation produce matter with universal properties?

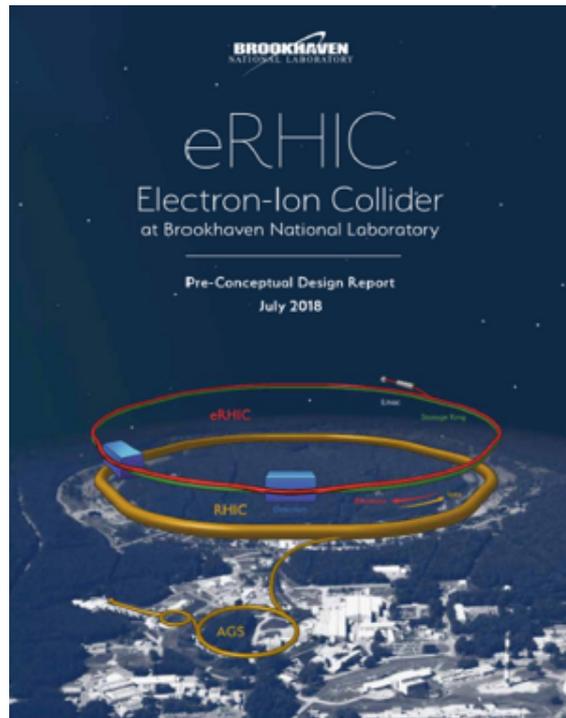
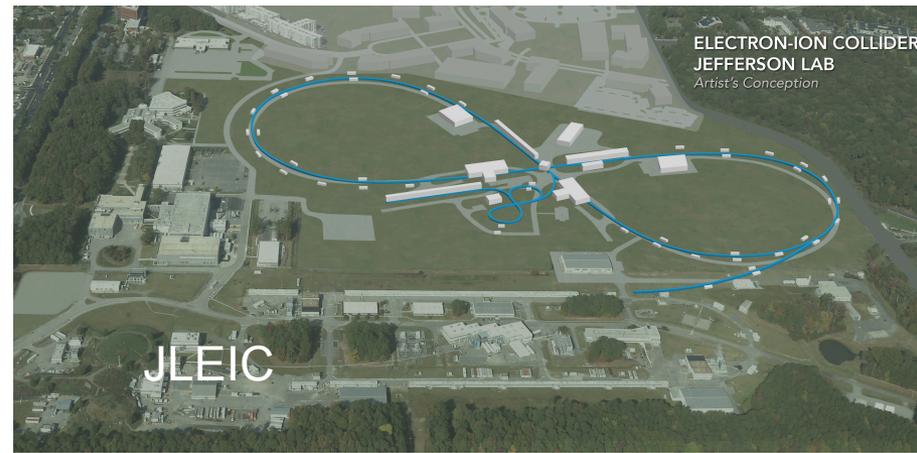
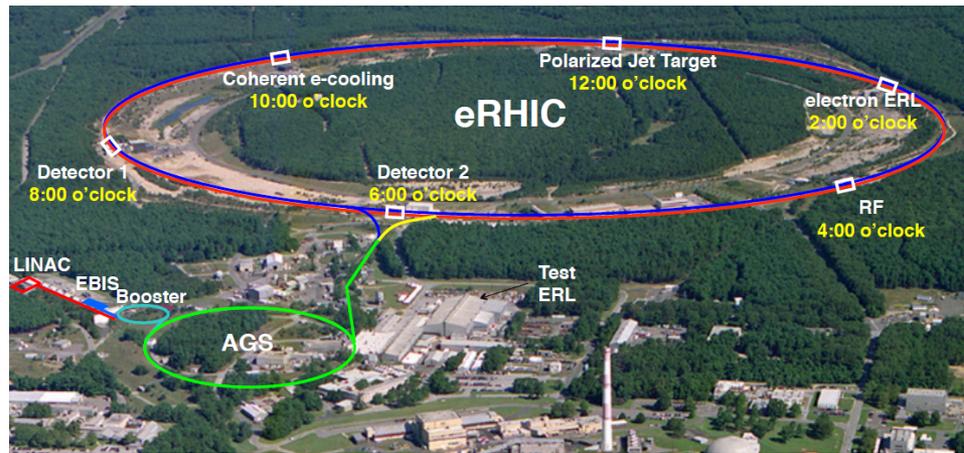


**Electron Ion Collider:
The Next QCD Frontier**

Understanding the glue
that binds us all

A.Acardi et al, EPJ A 52 9 (2016)

Machine requirements & EIC realization

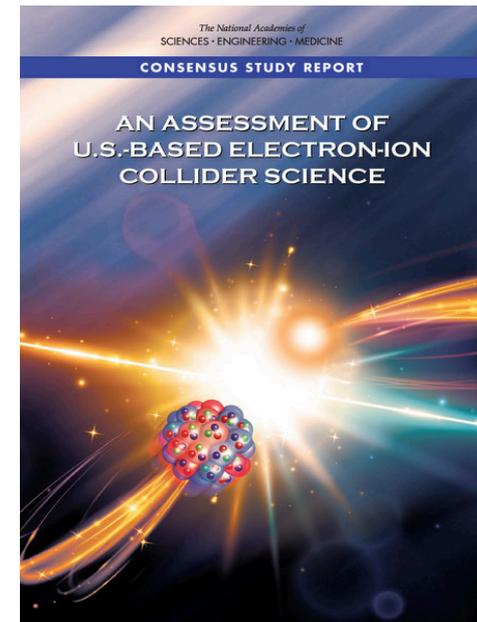
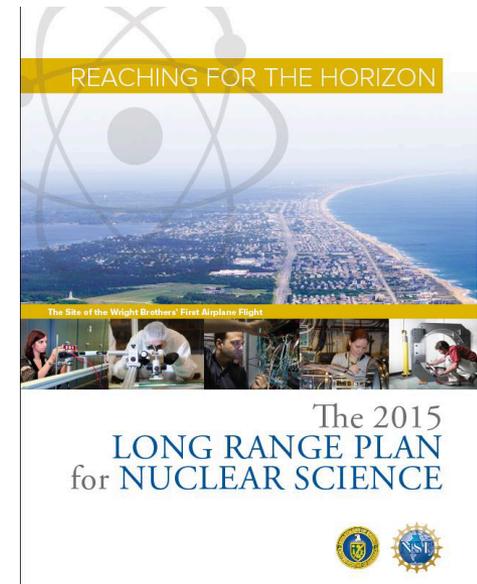


- Wide kinematic range: \sqrt{s} from ~ 20 to 100 GeV, upgradable to 140 GeV
- Luminosity $\sim 10^{33-34} \text{ cm}^{-2}\text{s}^{-1}$
- Polarized protons, electrons and light ions
- Heavy ion beams up to U



Timelines

- 2015 NSAC (NP) Long-Range Plan:
 - “We recommend a high-energy high-luminosity polarized EIC as the highest priority for new facility construction.”
- 2018 NAS review:
 - “The committee finds that the science that can be addressed by an EIC is compelling, fundamental and timely.”
- President’s budget request for FY2020:
 - Critical Decision-0, Approve Mission Need, is planned for FY2019



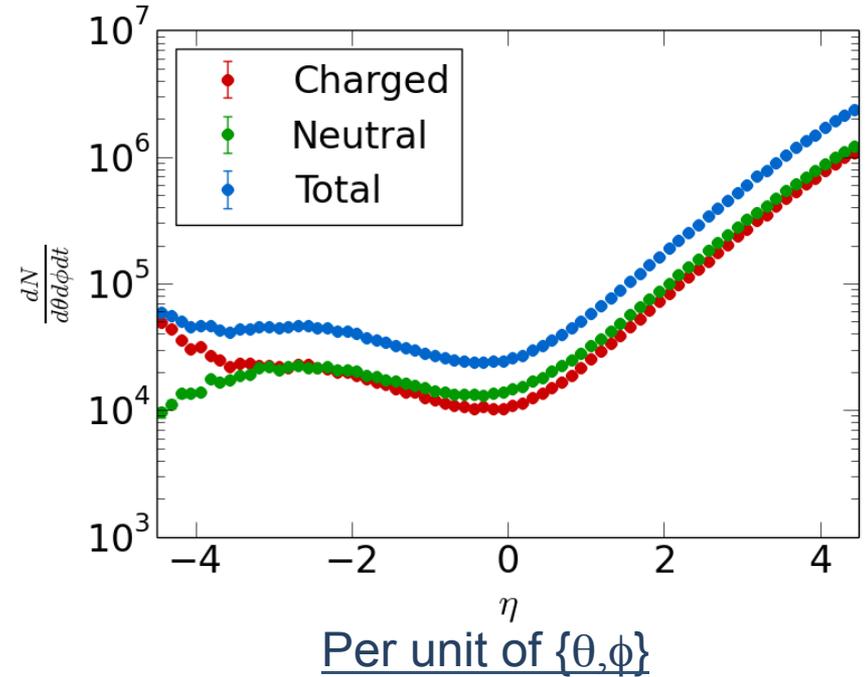
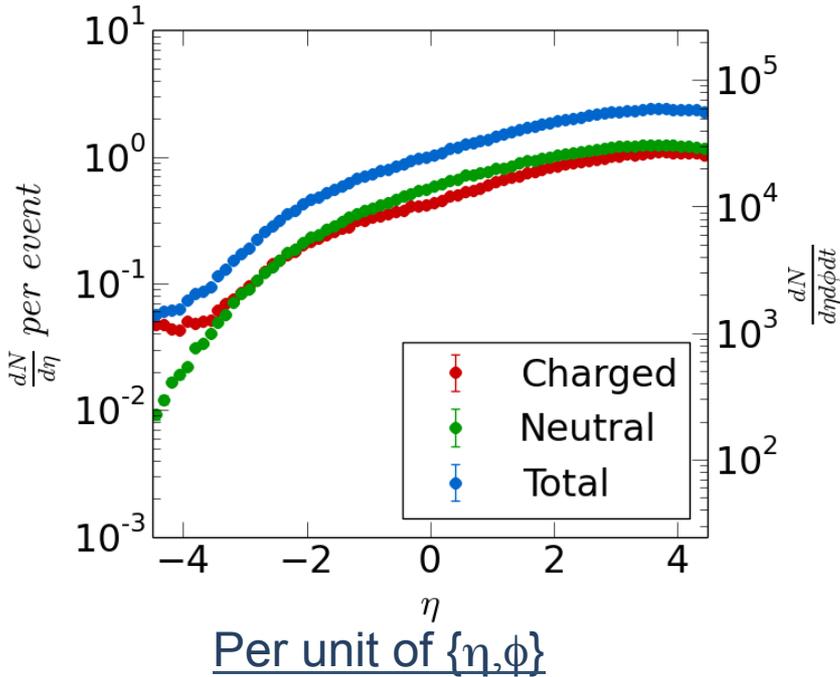
How does EIC compare to HERA?

- Luminosity at least ~ 100 higher
- Bunch crossing frequency 10..40 times higher
- eA collisions possible
- Proton (and light ion) beams are polarized
- Substantial crossing angle
- Wide anticipated \sqrt{s} range

- At most 7..9m “linear space” available for the main detector

Interaction rate & absolute yields

PYTHIA 20x250 GeV configuration; absolute particle yields for $L=10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

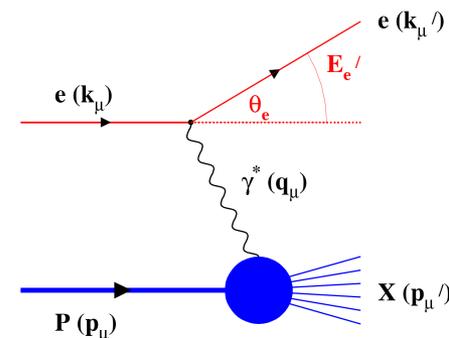


- Interaction rate $\sim 50 \text{ kHz}$
- At most few particles per unit of η per event
- Correspondingly low particle fluxes per unit of time

Experimental measurements

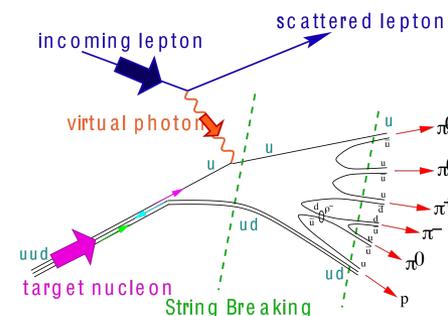
Inclusive Reactions in ep/eA:

- Physics: Structure Functions: g_1, F_2, F_L
- → Very good scattered electron ID
- → High energy and angular resolution of e' (defines kinematics $\{x, Q^2\}$)



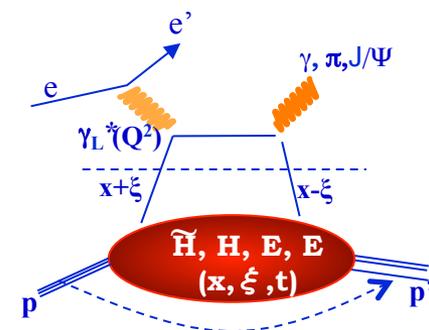
Semi-inclusive Reactions in ep/eA:

- Physics: TMDs, Helicity PDFs, FFs (with flavor separation); di-hadron correlations; Kaon asymmetries, cross sections; etc
- → Excellent hadron ID: p^\pm, K^\pm, p^\pm separation over a wide $\{p, \eta\}$ range
- → Full Φ -coverage around γ^* , wide p_t coverage (TMDs)
- → Excellent vertex resolution (Charm, Bottom separation)



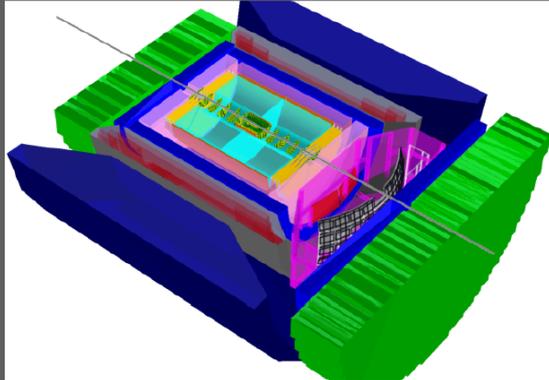
Exclusive Reactions in ep/eA:

- Physics: DVCS, exclusive VM production (GPDs; parton imaging in b_T)
- → Exclusivity (large rapidity coverage; reconstruction of all particles in a given event)
- → High resolution, wide coverage in $t \rightarrow$ Roman pots
- → (eA): veto nucleus breakup, determine impact parameter of collision
- → Sufficient acceptance for neutrons in ZDC

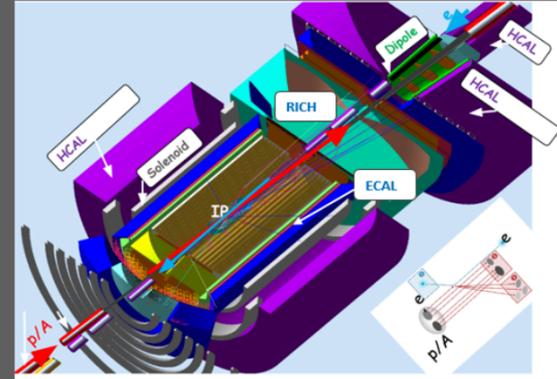


General purpose detector concepts

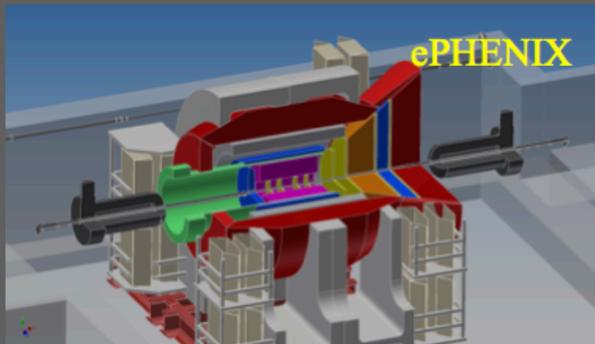
Brookhaven concept: BEAST



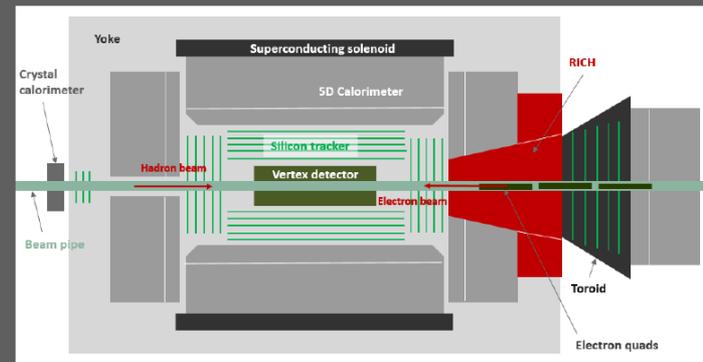
Jefferson lab concept: JLEIC



sPhenix → ePhenix



Argonne concept: TOPSiDE



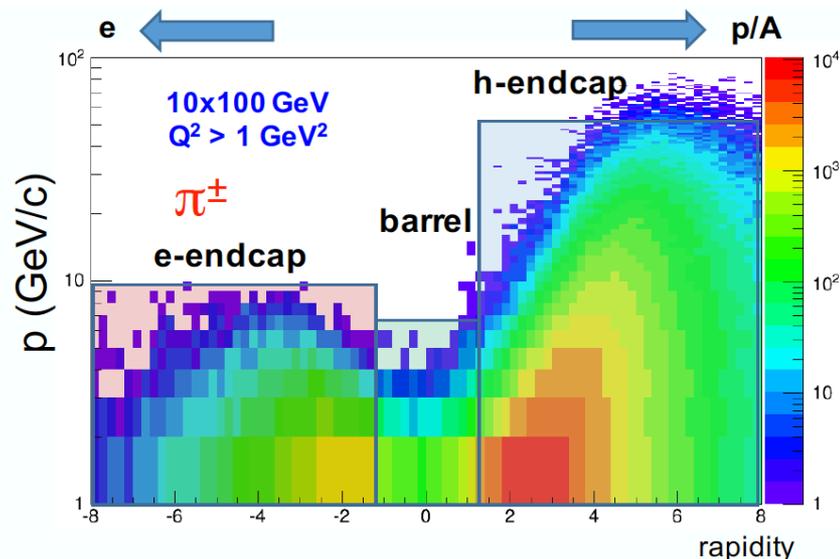
-> all very similar, except for the Argonne concept

Detector and IR requirements “short list”

- The more close to 4π acceptance the better
- Low material budget
- Reasonably high momentum resolution
- Reliable electron ID
- $\pi/K/p$ separation up to 5σ in the main detector acceptance
- High spatial resolution of primary vertex
- Ability to reconstruct jets

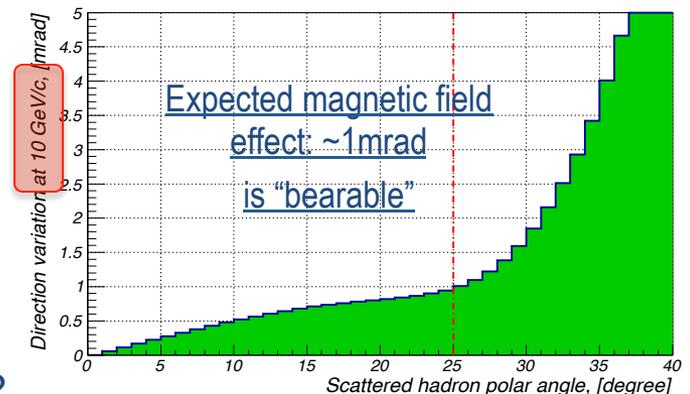
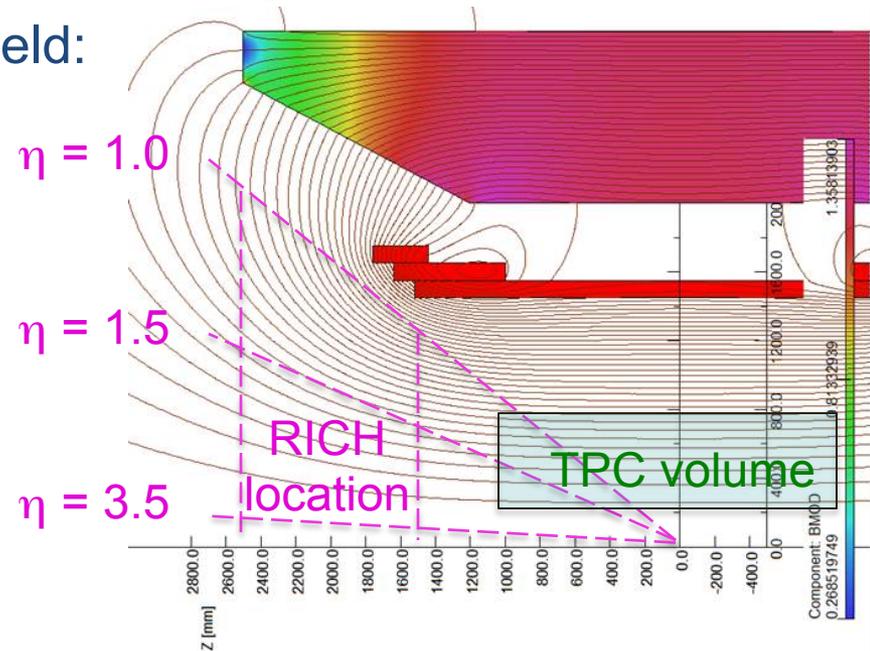
- e-endcap:
aerogel RICH
- barrel:
DIRC with ps timing
- h-endcap:
Dual-radiator RICH

- Close-to-beam-line acceptance detectors to measure:
 - recoil protons
 - low Q^2 electrons
 - neutrons in hadron going direction
- Luminosity measurement



Main detector magnet

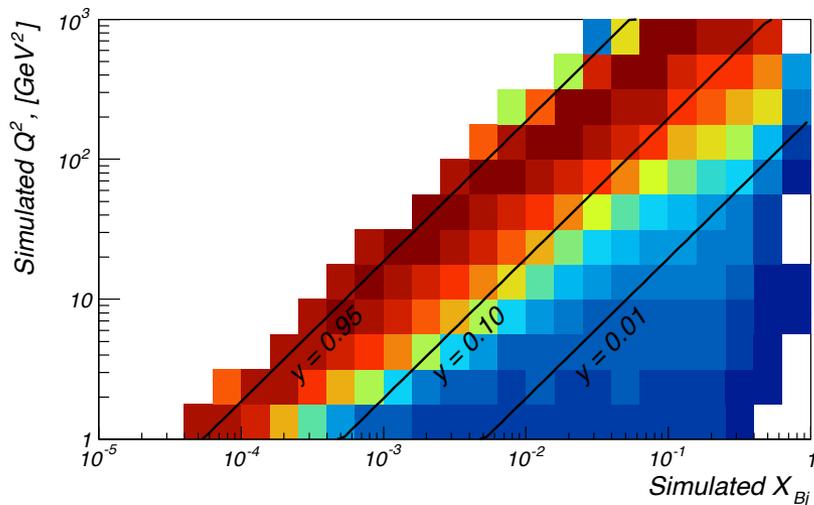
- Prefer open solenoid with a large (3T) field:
 - ideal for a TPC
 - sufficient $B \cdot dl$ integral at $|\eta| \sim 3.0..3.5$
 - almost azimuthally-symmetric acceptance
 - minimal adverse effect on the electron beam
 - no passive material in the acceptance
- However:
 - too high low-momentum particle cutoff
 - large inhomogeneous fringe field ...
 - ... causing severe problems for the gaseous RICH ...
 - ... which one can try to mitigate by shaping up the field
 - large stray fields, which may require clamping ...
 - ... therefore causing field degradation in the RICH ...
 - ... and large asymmetric forces on the support system
 - photo-sensors do not like magnetic field in general ...
 - ... and there is a huge difference between say LAPPD performance in 1.5T and 3.0T magnetic field ...
 - ... but modern MCPs with $<10\mu\text{m}$ pores may work well?



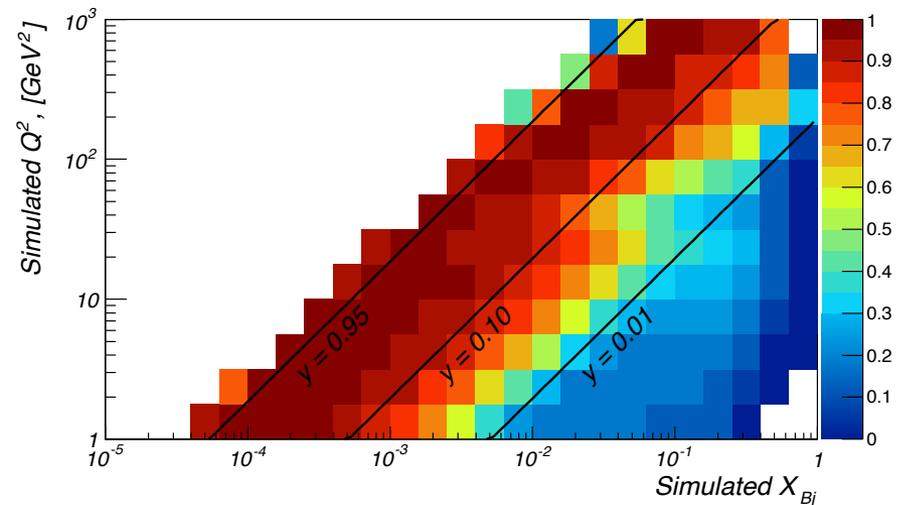
Scattered electron kinematics reconstruction

$$\text{Purity} = \frac{N_{gen} - N_{out}}{N_{gen} - N_{out} + N_{in}}$$

- Describes migration between kinematic bins
- Important to keep it close to 1.0 for successful unfolding
- A possible way to increase y range: use e/m calorimeter in addition to tracking
 - $\sim 2\%/\sqrt{E}$ energy resolution (and ~ 0 constant term) for $\eta < -2$ (PWO crystals)
 - $\sim 7\%/\sqrt{E}$ energy resolution for $-2 < \eta < 1$ (tungsten powder scint. fiber sampling towers)



Lepton tracking only

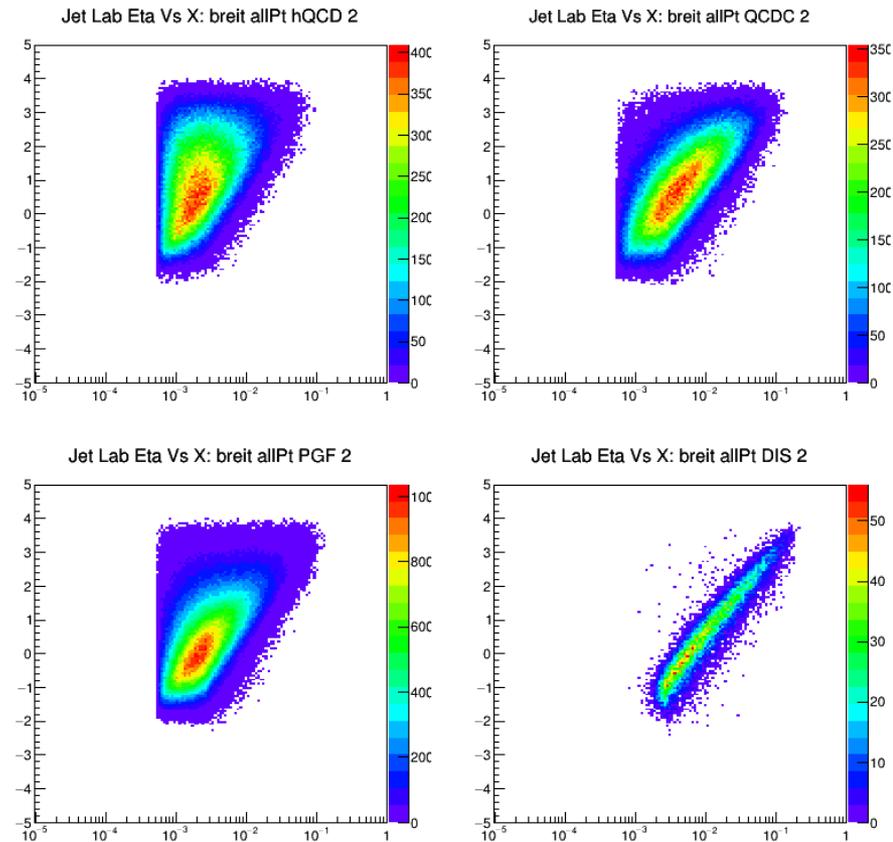


Lepton tracking + EmCal

- Apparently, the high-resolution crystal EmCal at very backward rapidities can help increasing the available y range ...
- ... but only if it has a very small constant term and is “radiation hard”

Hadronic calorimetry

- Hadronic energy resolution, especially in the forward endcap, is important for several EIC physics measurements
- Jets at an EIC are typically low-multiplicity and soft
- Pending questions:
 - Should one stick to the compensated calorimeter design (which by the way never showed high energy resolution for jets) or consider other options (dual-readout or dual-gate concepts, in particular)?
 - How at all one can get a decent performance out of a $5-7\lambda$ deep HCal?
 - If iron can be used as an absorber, should one use HCal as a flux return?
 - Is high-granularity calorimetry an option for EIC, at least in the forward endcap?



Plots provided by Brian Page

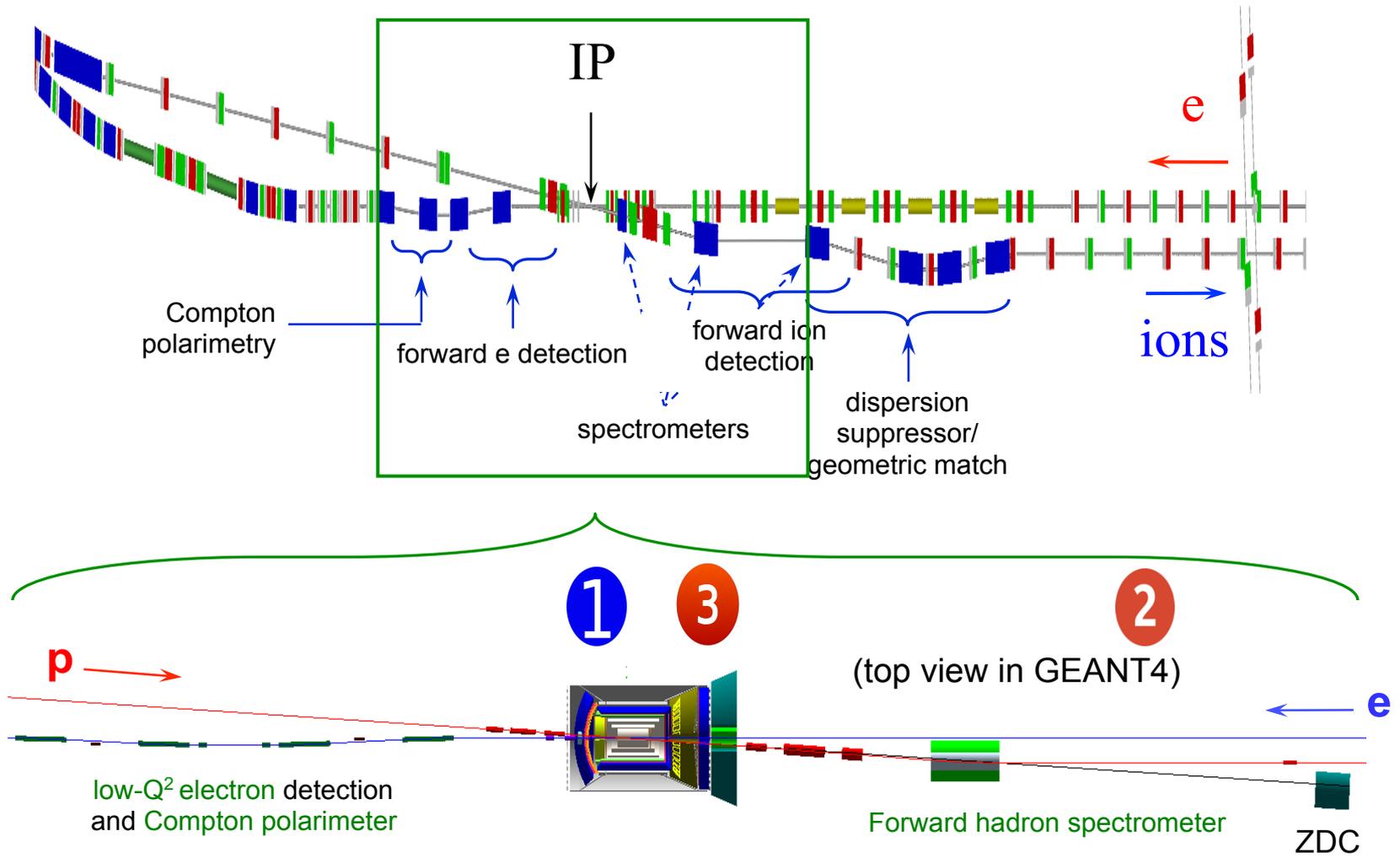
Time of flight hadron PID

- Hard to realize in a compact detector in general; very hard to get to $p \sim 6..8 \text{ GeV}/c$
- Not only “STOP”, but also somehow a “START” signal is required ...
- ... while NO precise accelerator timing signal available (finite bunch lengths!) ...
- ... so high-resolution timing in the silicon μ Vertex detector is required ...
- ... with a usual problem of having small pixels, low material budget, high resolution timing and low power consumption, all at the same time

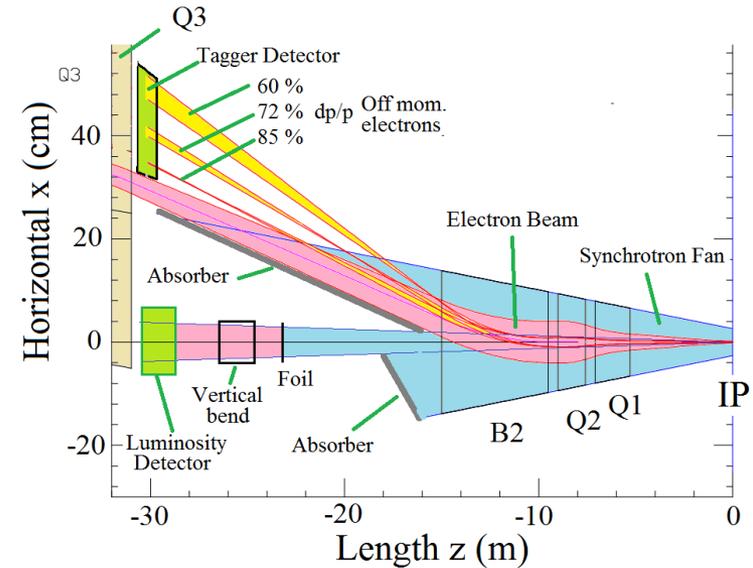
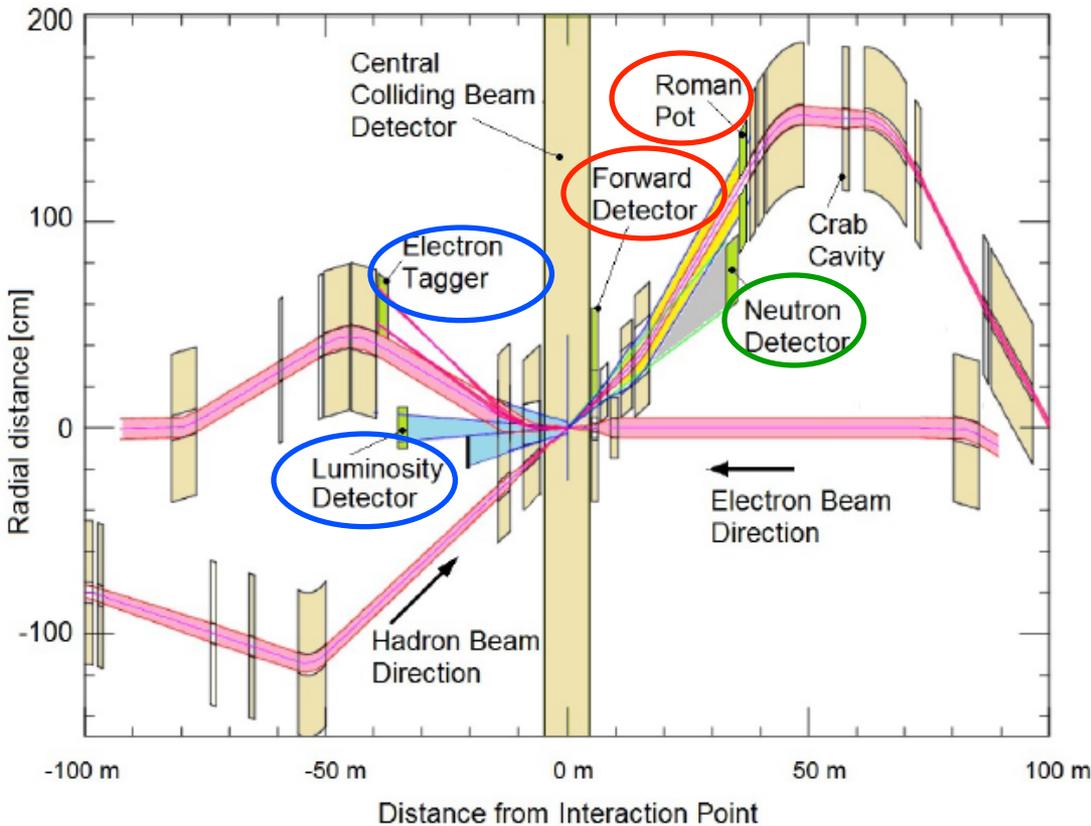
- Alternatively, for multi-particle track events one can **extract** “START” time on event-per-event basis ...
- ... which seemingly requires covering the whole acceptance by $<10\text{ps}$ timing equipment and introduces unwanted dependencies between different parts of the detector

-> next talk by Jose

JLEIC Interaction Region Design



eRHIC Interaction Region Design



- main emphasis on integrating requirements for hadron beam direction
 - Forward Spectrometer (6 - 20 mrad)
 - Roman pots (Sensitive 1 to 5 mrad)
 - Neutron Detector (0 to 4 mrad)
- e-side dipoles: separate BH photons from beam, separate low Q^2 electrons from beam and lepton beam from SR-fan

Obtaining high luminosity

- Luminosity is in general inversely proportional to L^* ...
- ... and stronger focusing at the IP provides higher lumi for the same beam emittance
 - > prefer to move FFQs into the main detector and use “high-divergence” regime
- However:
 - these quads would obscure forward and backward acceptance
 - too strong beam divergence (hundreds of μrad) would contribute to the Pt resolution ...
 - ... which – for exclusive reactions - one can possibly deal with on event-per-event basis (?)
- NB: large acceptance spectrometer dipole in the forward direction pushes FFQs even further away from the IP

Measuring the luminosity

- EIC is a high luminosity machine $10^{33-34} \text{ cm}^{-2} \text{ s}^{-1}$

most of the measurements we will be systematically limited

→ Dominant systematics for double spin asymmetries

→ Luminosity Measurement → Relative Luminosity

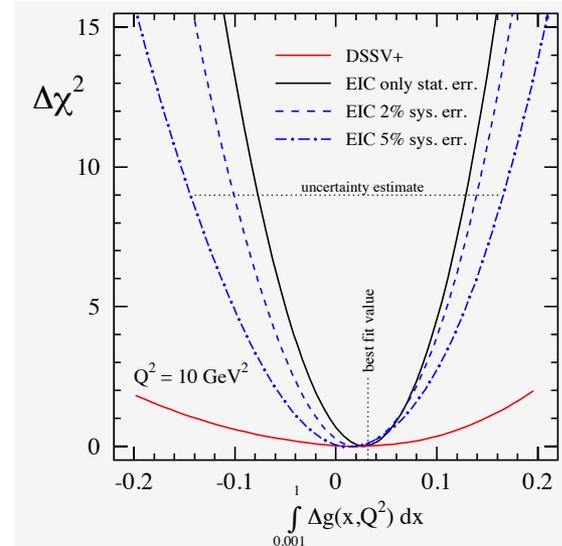
$$A_{LL} = \frac{1}{P_e P_p} \left(\frac{N^{++/--} - R N^{+-/--}}{N^{++/--} + R N^{+-/--}} \right); \text{ with } R = \frac{L^{++/--}}{L^{+-/--}} \quad \delta A_{LL} \sim \frac{1}{P_e P_p \sqrt{L_{\text{int}}}}$$

- EIC is the first collider with polarized lepton and hadron beams
luminosity measurement depends on beam polarization

$$\sigma_{\text{Brems.}} = \sigma_o (1 + a P_e P_p)$$

How big is “a”? Need a theorist to calculate

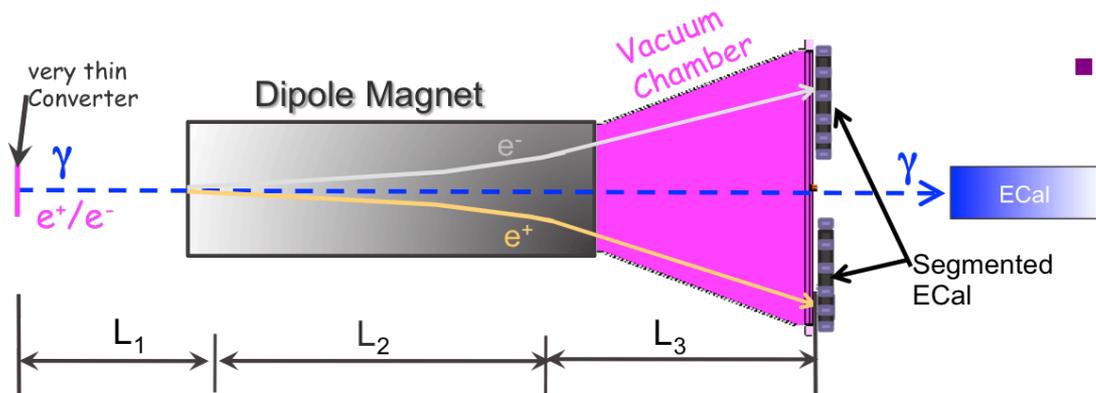
- Need overall systematics $\leq 2\%$ (arXiv:1206.6014)



Measuring the luminosity

- Concept: use bremsstrahlung $ep \rightarrow ep\gamma$ as a reference cross-section
- HERA: reached 1-2% systematic uncertainty
- EIC challenges:
 - With $10^{33}\text{cm}^{-2}\text{s}^{-1}$ luminosity (and 10MHz bunch crossing frequency) one gets on average 23 bremsstrahlung photons per bunch
 - Z^2 -dependence with the nuclei beams

-> this clearly challenges single photon measurement at 0°

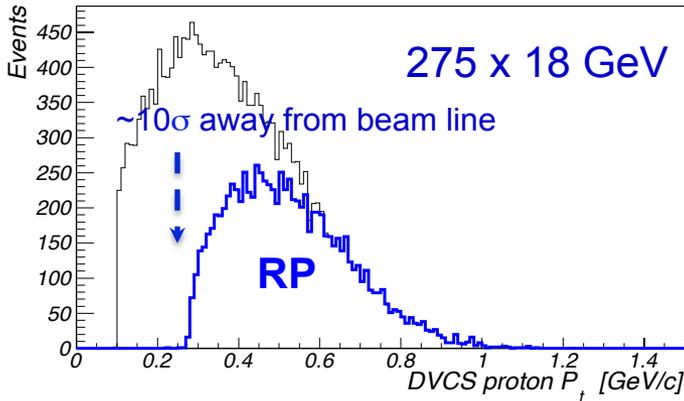


- Zero degree photon calorimeter
- Excellent fast luminosity monitor
- Subject to synchrotron damage

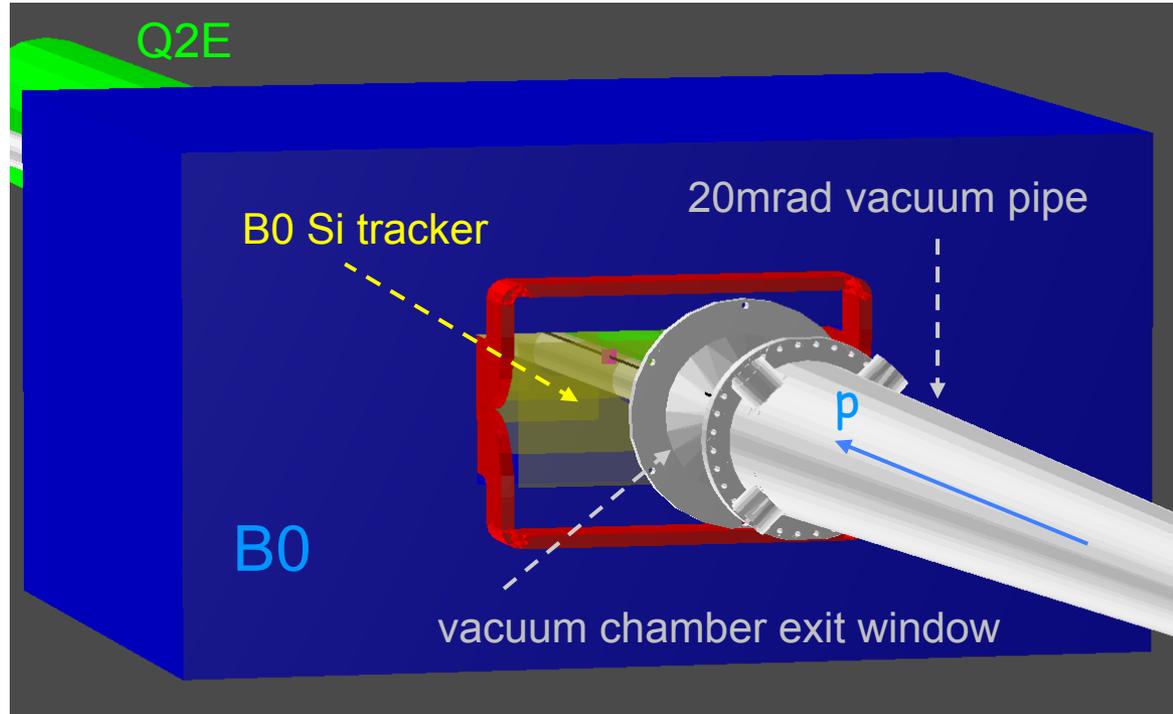
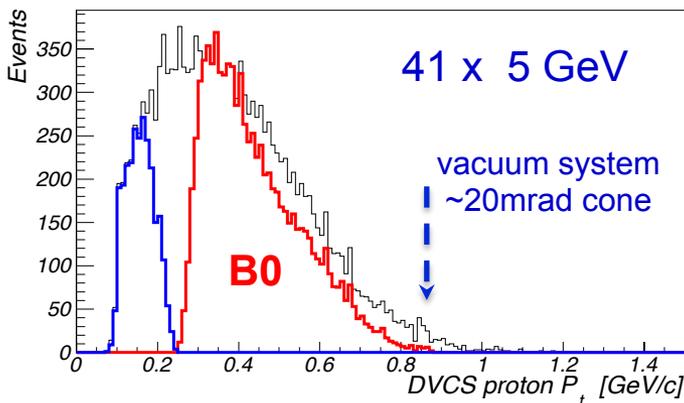
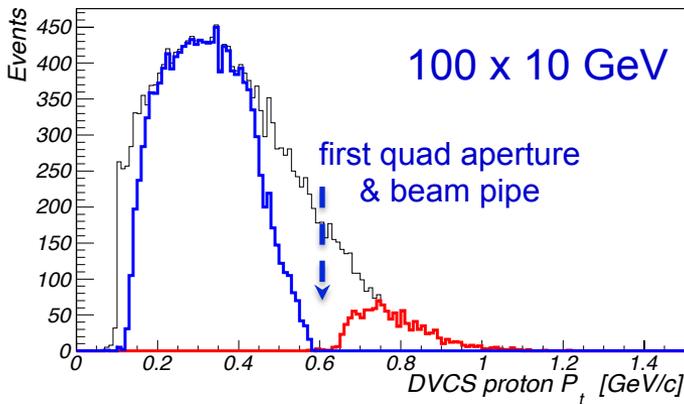
- Pair spectrometer
 - Low rate (tunable by the exit window thickness)
 - Calorimeters are outside of the primary synchrotron fan

-> modeling and adaptation to a particular IR design required; but no showstoppers identified so far

Far forward acceptance (Roman Pots & B0)



→ Reasonably complete GEANT simulation of DVCS events



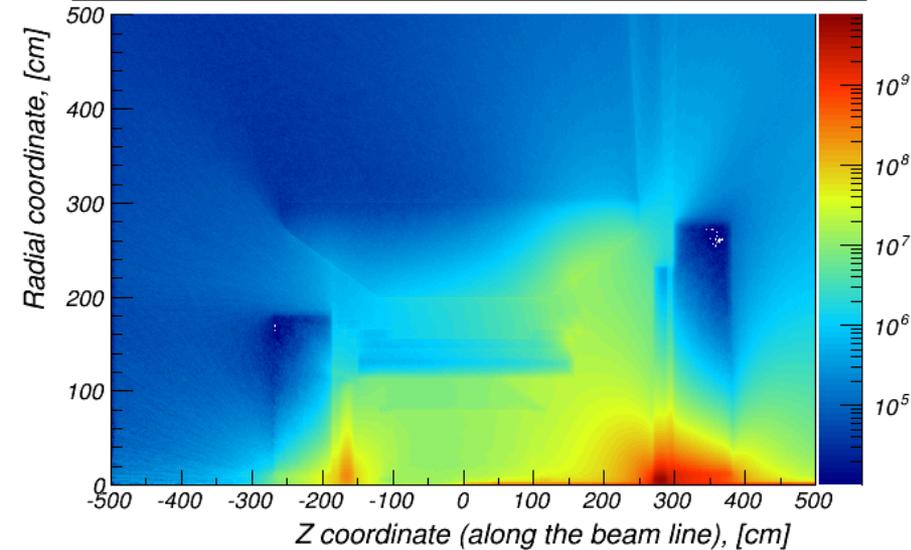
- One can more or less achieve the required P_t range of 0.2 .. 1.3 GeV/c, ...
- ... but acceptance is strongly affected by the “stay clear to the beam line” requirement, as well as the “transition” regions from RP to B0 and from B0 to the main spectrometer domains, respectively

Neutron fluence & radiation dose

Neutron Fluence = "a sum of neutron path lengths"/"cell volume" for N events

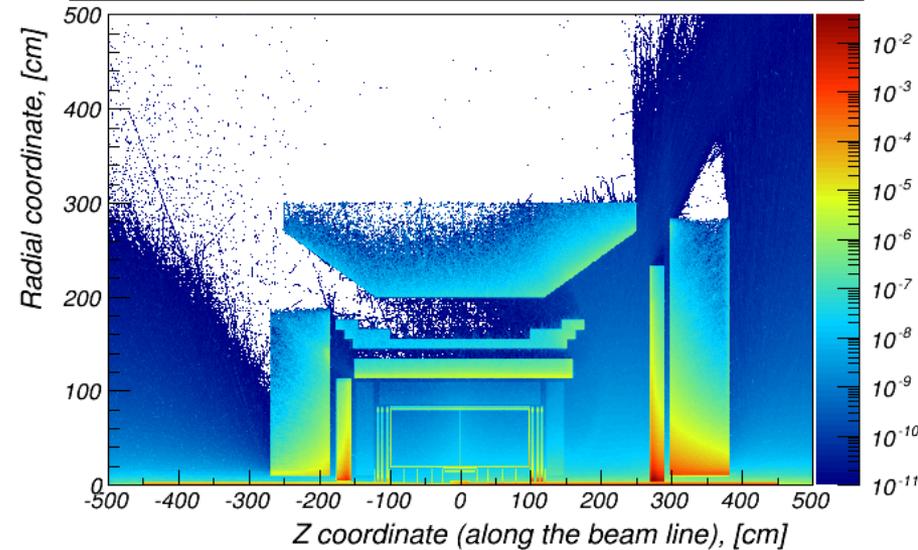
Radiation dose: "a sum of dE/dx"/"cell volume" for N events

neutron flux above 100.0 keV in [n/cm^2] for 1.0 fb^{-1} integrated luminosity



-> forward EmCal: up to $\sim 5 \cdot 10^9 \text{ n}/\text{cm}^2$ per fb^{-1} (inside the towers); perhaps ~ 5 less at the SiPM location;

Radiation dose in [J/cm^3] for 1.0 fb^{-1} integrated luminosity



-> backward EmCal: $\sim 250 \text{ rad}/\text{year}$ (at a "nominal" luminosity $\sim 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$)

-> EicRoot Monte-Carlo pass using Pythia events and BeAST geometry

Neutron fluence & radiation dose

So far the only modeling source of information used to question SiPM readout (integrated flux is too high) and to help justify PWO as inner crystal EmCal (integrated dose is pretty low)

Numbers look reasonable (and neutron flux cross-checked with STAR), but:

- These are the rates **from primary interaction only**:
 - No synchrotron radiation
 - No beam-gas scattering
- Neither machine elements were incorporated in that simulation nor the experimental hall material
- It is a particular detector geometry (BeAST)
- GEANT3 used; comparison against GEANT4 has never been done
- Thermal neutrons are not accounted
- Strictly speaking, integrated neutron flux is high only close to the beam pipe ...
- ... and the new generation Hamamatsu SiPMs show much higher neutron fluence resistance

Other backgrounds

- Synchrotron radiation:
 - Avoid incoming electron beam bending -> introduce a crossing angle ...
 - ... which requires crabbing to avoid luminosity losses ...
 - ... which in turn causes several non-trivial consequences, seemingly including picosecond timing resolution requirement for the Roman Pot stations

 - Do not let synchrotron fan to “touch” the vacuum chamber walls at the IP ...
 - ... which requires using noticeably bigger diameter beam pipe ...
 - ... with all the associated consequences for vertex resolution and forward acceptance

- Beam-gas interaction:
 - want highest possible vacuum in the main detector region and upstream of it ...
 - ... but no pumps close to the IP (dead material & acceptance loss) ...
 - ... therefore use NEG coating on the IR vacuum system elements ...
 - ... which requires regeneration (heating) once every several weeks ...
 - ... with the heating elements most likely mounted directly on the beam pipe -> extra material, potential issues with the silicon vertex detector

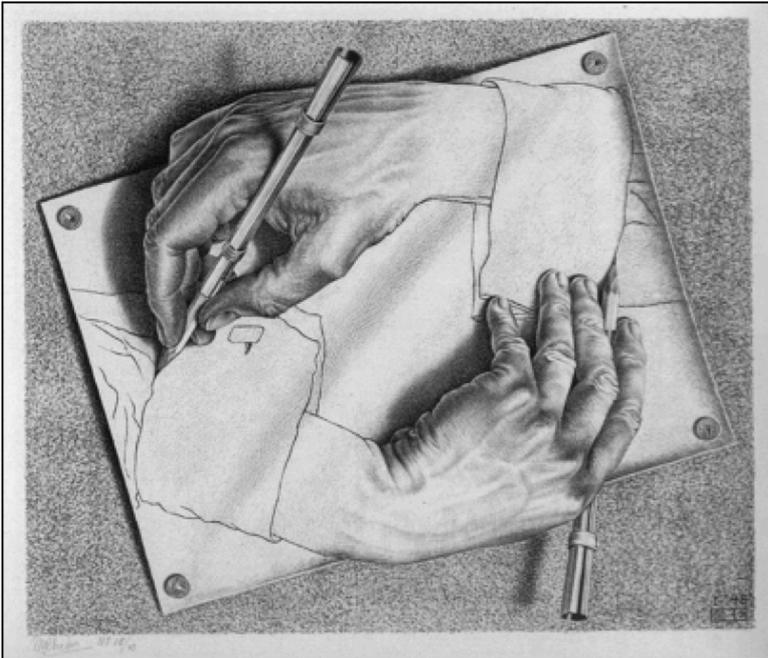
- Dynamic vacuum as a combination of the two

Background studies is one of the main tasks for the IR Working Group and eRD21

References

Electron-Ion Collider Detector Requirements and R&D Handbook

<http://www.eicug.org/web/content/detector-rd>



- EIC Detector R&D program:
https://wiki.bnl.gov/conferences/index.php/EIC_R%25D
- EICUG IR Working Group meeting 02/15/19:
<https://indico.bnl.gov/event/5743/>