Far Forward Physics with EIC

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@ WWND 2022

WILLIAM & MARY
CHARTERED 1693

Center for Frontiers in Nuclear Science

EIC^2
EIC Center at Jefferson Lab

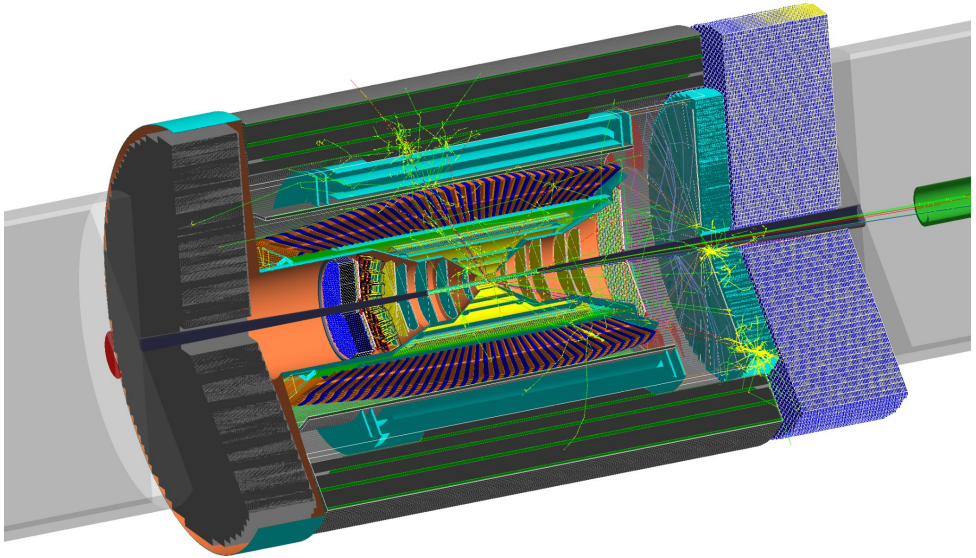
Stony Brook University

University of Glasgow

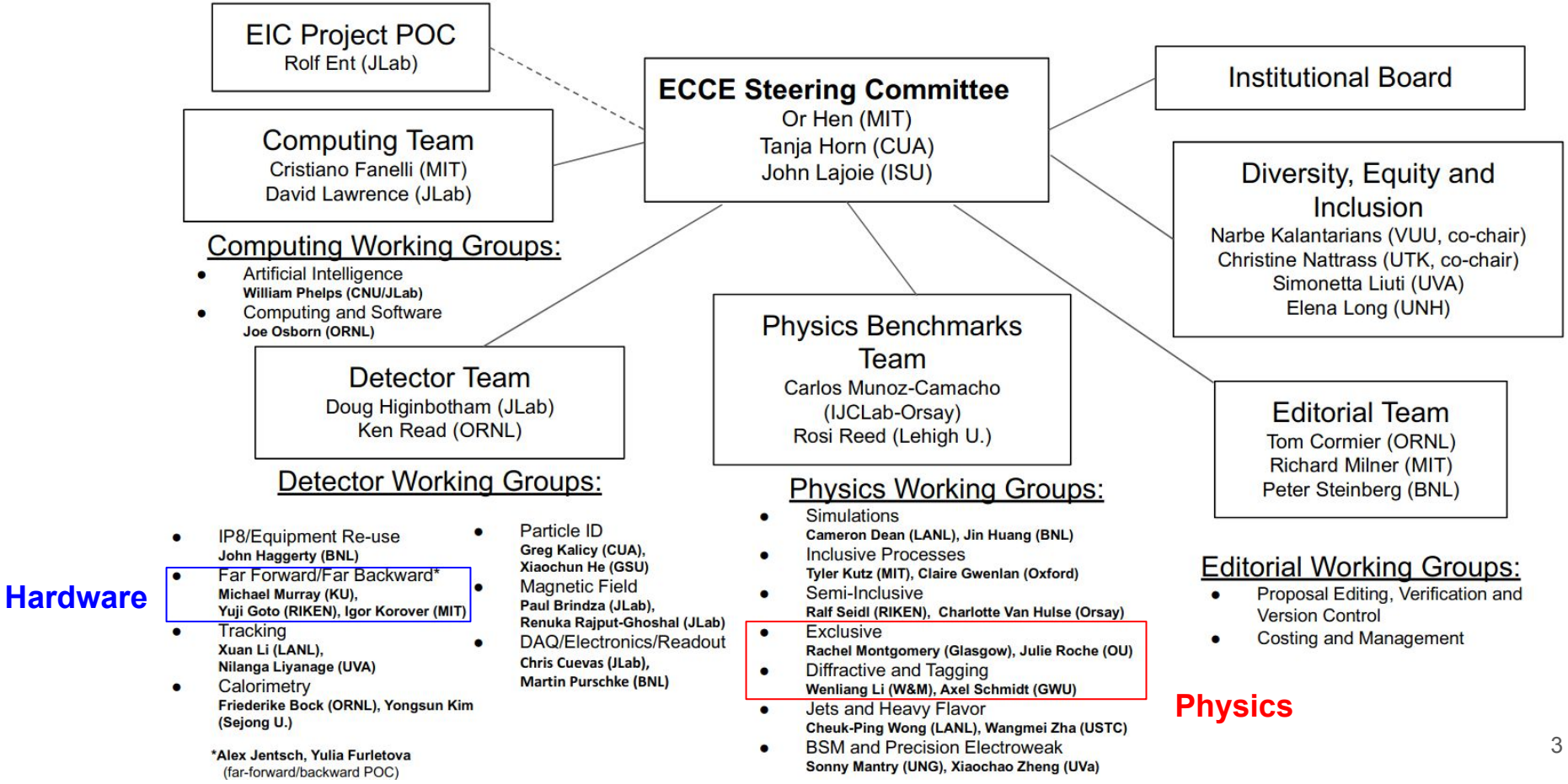
OHIO UNIVERSITY

Talk Outline

- EIC ECCE far forward and backward enthusiasts
- EIC ECCE far forward and backward hardwares
- Showcasing physics results and opportunities



EIC ECCE Consortium Structure



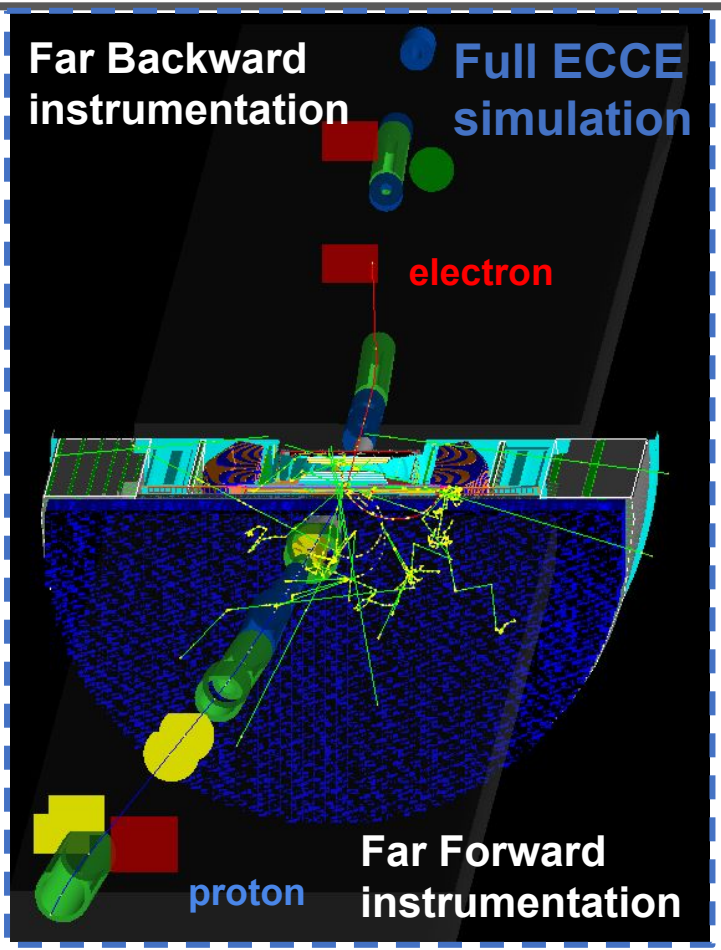
Exclusive and Diff & Tagg Working Group

- **Convenors:** R. Reed (Lehigh U.), C. Camacho (IJCLAB-Orsay)
- **Co-Convenors:** A. Schmidt (GW), W. Li (W&M),

Studies	Group Member	Institution
π and K Form Factor	M.Ali, G. Huber, S. Kay	UofR (Canada)
π and K Structure Function	R. Trotta	CUA
A1n through e+He3	D. Nguyen, J. Pybus	JLab, MIT
eA Diffractive Study	M. Baker, D. Gangadharan, A. Schmidt, P. Steinberg	BNL, UH
u-Channel π^0	W. Li	W&M, SBU, JLab
XYZ Meson	D. Glazier, J. Stevens	Glascow, W&M
DVCS	I. Korover	MIT
eA DVCS	G. Penman	Glascow
TCS	K. Gates	Glascow
J/ψ production	N. Santiesteban	NHU

Underlined names: students and postdocs (majority of our group members)

Simulation tool used for all ECCE studies

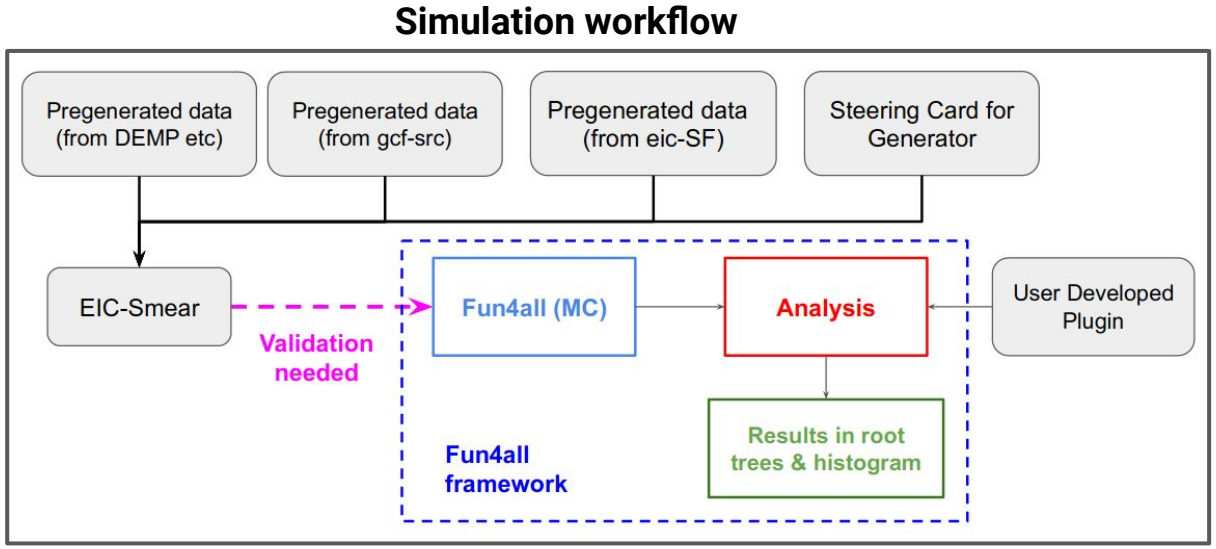


ECCE proposal based on a full simulation and analysis package: Fun4all

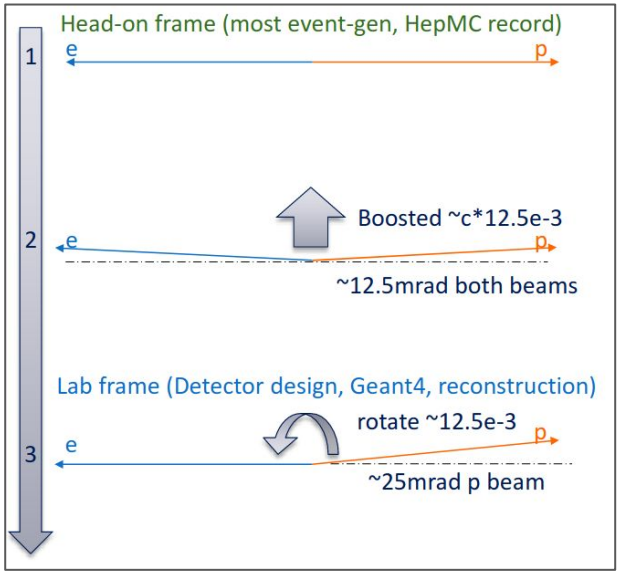
- Proven framework for Phenix experiment
- Will be used by Sphenix experiment
- Synergy between the Sphenix software team and User committee, such as myself (Jlab background previously)
- **Remarkable features:**
  - Project beam scattering parameterization
  - Realistic track reconstruction in the central detector (See Friederike and Xuan Li's talk)
  - Far forward and backward region fully implemented
- **Fun4all framework is and will be maintained**
  - could be used for CD2 approval for the project detector if needed.

Simulation workflow

- Fun4all Full simulation package
  - Standard simulation and reconstruction of sPHENIX experiment
    - https://github.com/ECCE-EIC/macros
  - Fun4all takes generated events in head-on collision in HEPMC or other formats

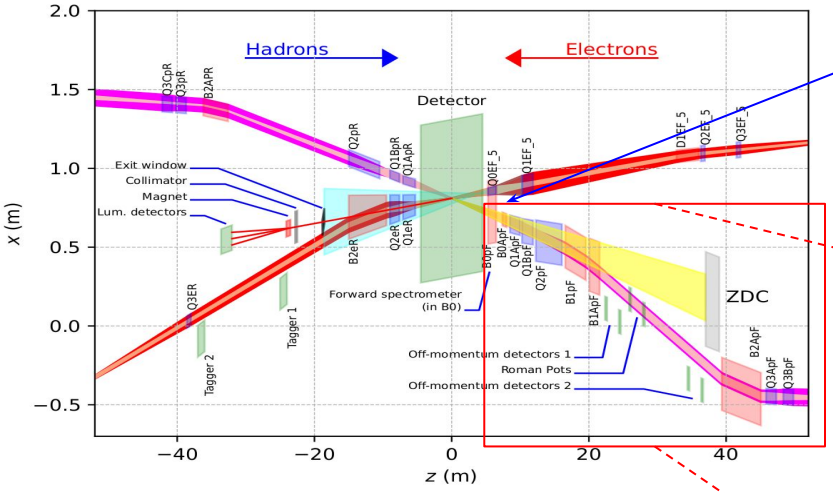


Fun4all handles beam effect such as cross angle, divergence, etc.



Example (by J. Huang) on crossing angle handling

The Far Forward Region @ IP6

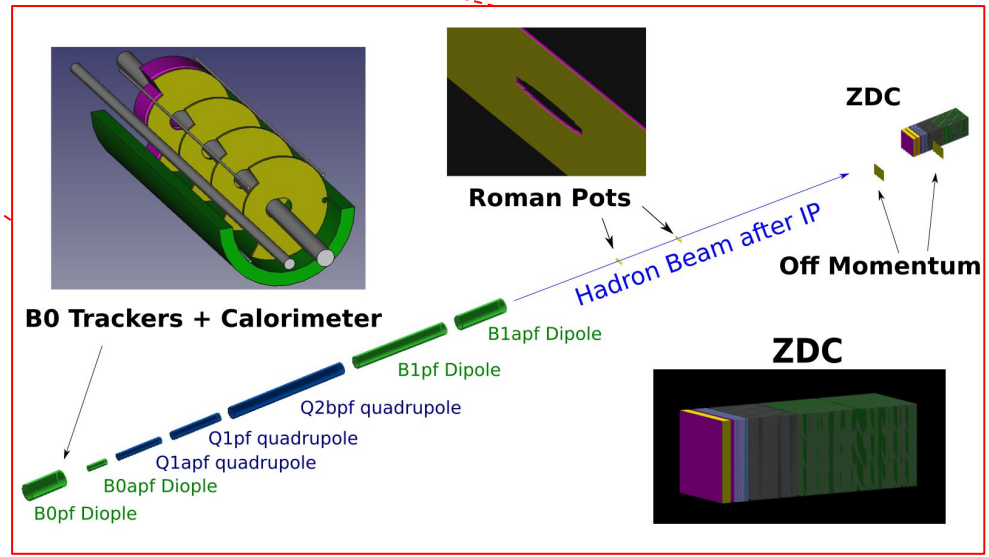


One distinct feature: 25 mRad crossing angle

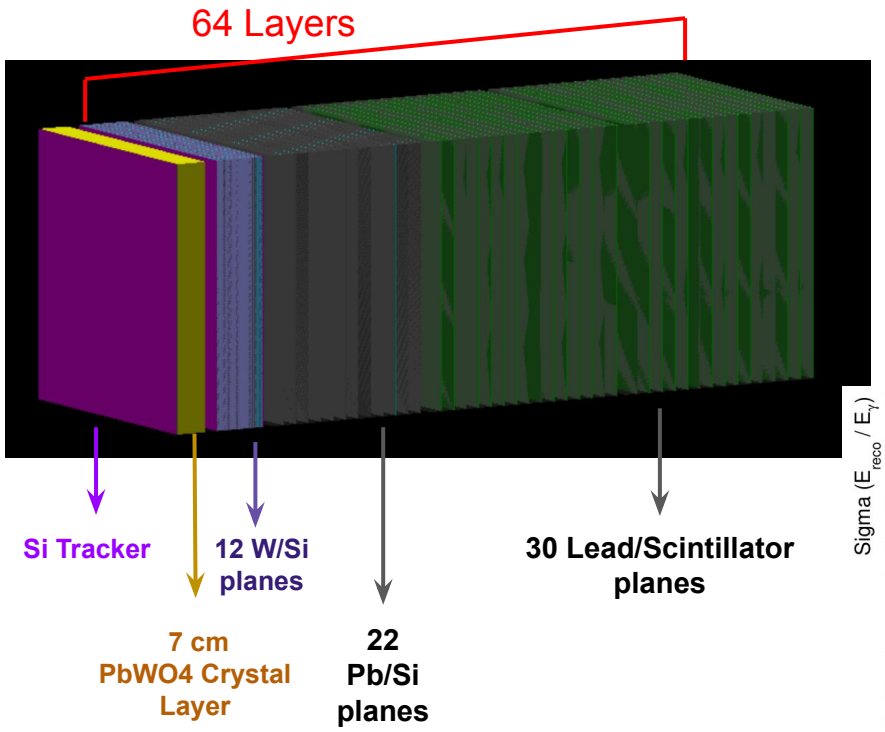
Benefit: Beamline tagging provides access to the kinematics closer to the fixed target (JLab) scenario

Far Forward Region (FFR)

- **B0**
  - Charged and neutral particles
- **Zero Degree Calorimeter**
  - Neutral particles detection
- **Roman Pots**
  - Beam proton tagging
- **Off Momentum detector**

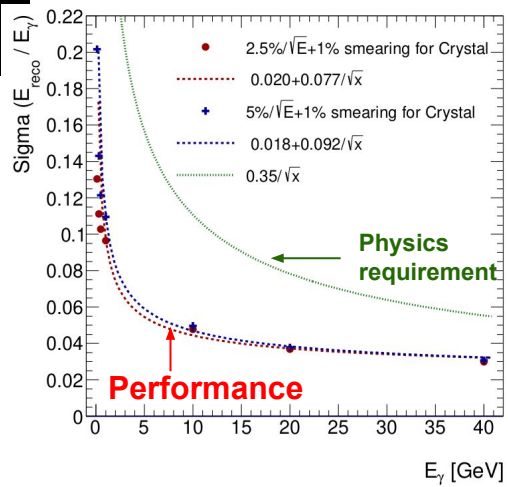


Far Forward Detector Systems: ZDC

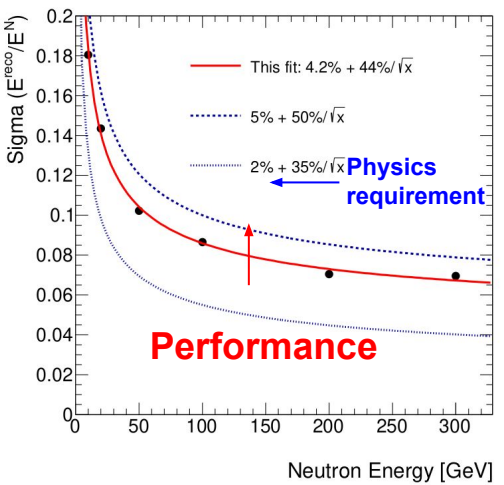


- **Zero Degree Calorimeter (improved ALICE design):**
  - **Dimension: 60 cm x 60 cm x 168 cm**
  - **30 m from IR**
  - **Detect spectating nucleon**
  - **Acceptance: +4.5 mrad, -5.5mrad**
  - **Position resolution ~1.3mm at 40 GeV**

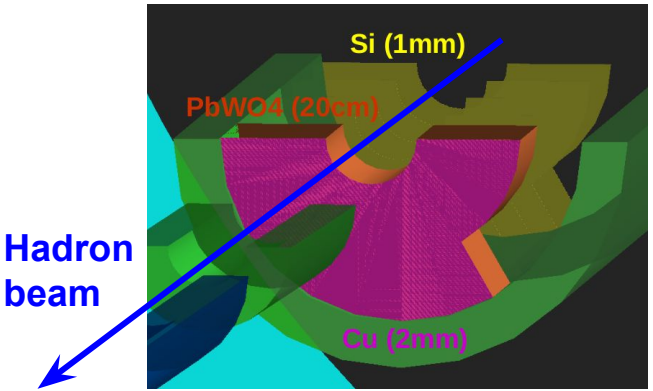
Photon energy resolution

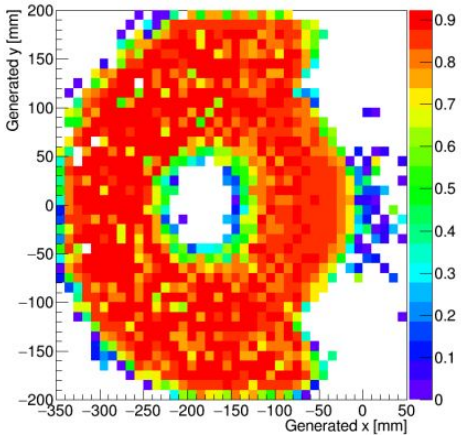


Neutron energy resolution

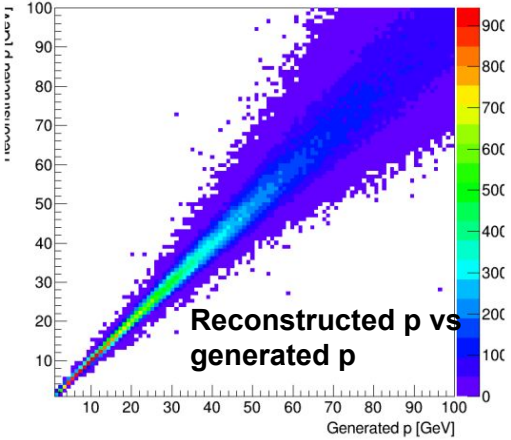


Far Forward Detector Systems: B0



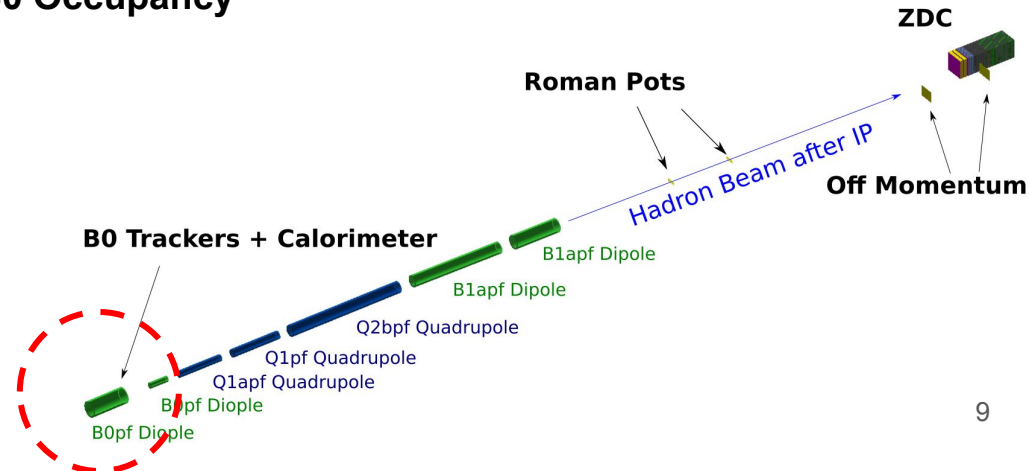


B0 Occupancy

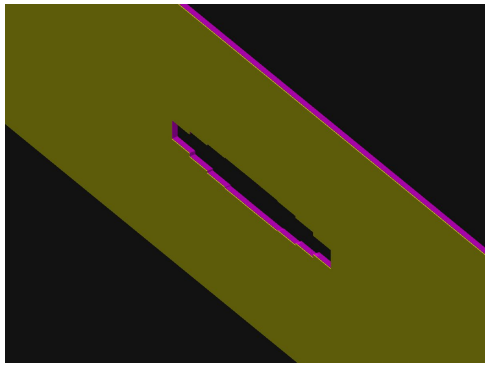


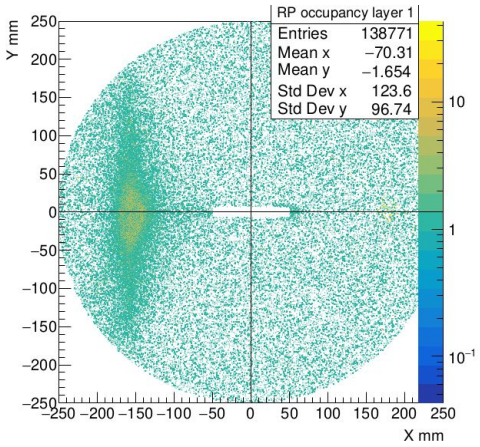
B0 detector stack

- B0 Dipole (2m in length)
- Include 4 layers of Si Tracker + 20 cm Calorimeter
- Detector both charged particle and neutral particles
- Optimization effort is ongoing

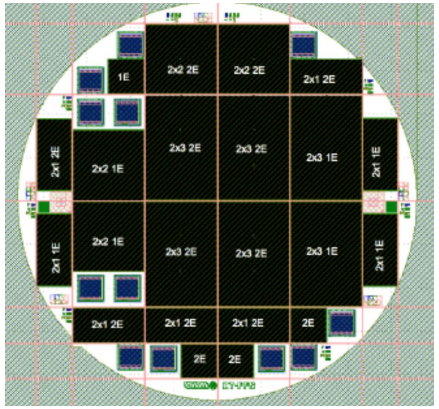


Far Forward Detector Systems: RP





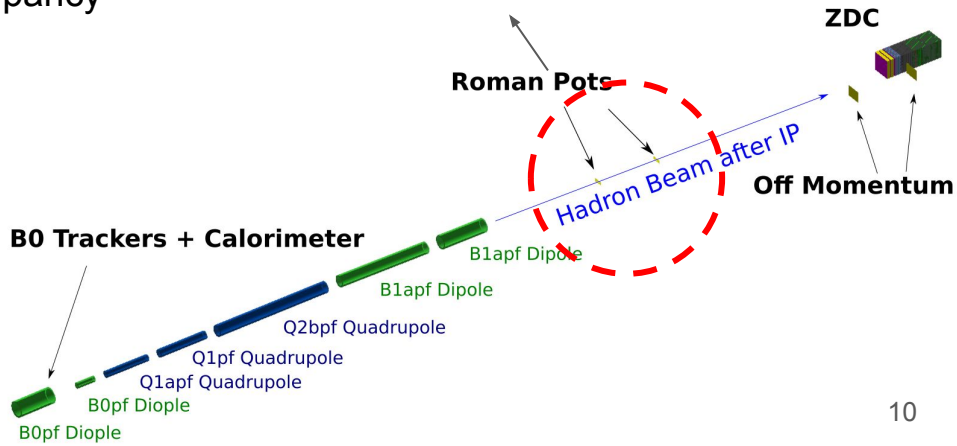
Roman pot occupancy



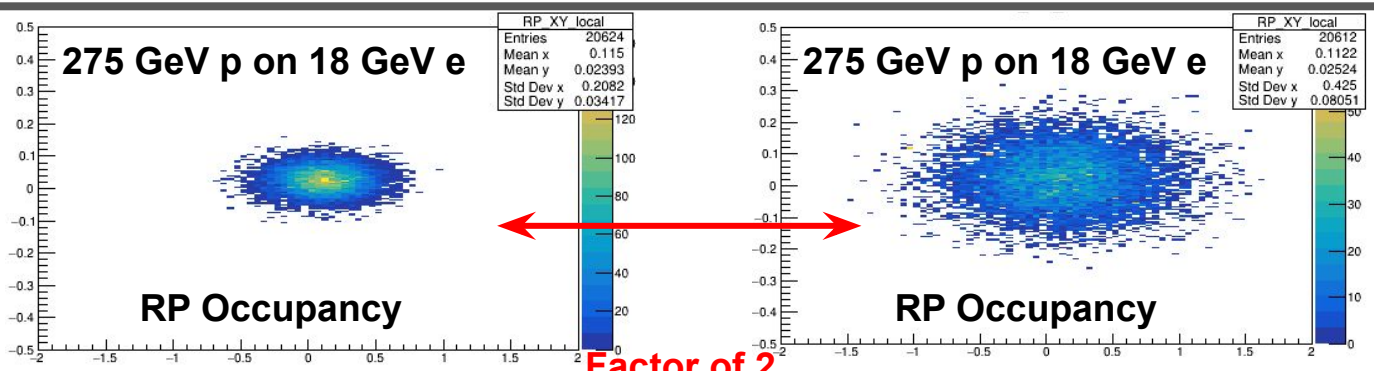
Si tracker layout of CMS RP

Roman pots:

- Used to detect slightly disturbed/recoiled nucleon
- Perfect to access low -t distribution of meson production processes
- Central hole represents the 10σ (beam width) boundary away from the beam



Far Forward Detector Systems: RP



Factor of 2 difference

High Acceptance Setting

Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	19.1	6.2
No. of bunches	290	
Beam current [A]	0.69	0.227
RMS norm. emit., h/v [μm]	5.2/0.47	845/71
RMS emittance, h/v [nm]	18/1.6	24/2.0
β^*, h/v [cm]]	80/7.1	59/5.7
IP RMS beam size, h/v [μm]	119/11	
K_x	11.1	
RMS $\Delta\theta$, h/v [μrad]	150/150	202/187
BB parameter, h/v [10^{-3}]	3/3	93/100
RMS long. emittance [10^{-3}, eV·s]	36	
RMS bunch length [cm]	6	0.9
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9

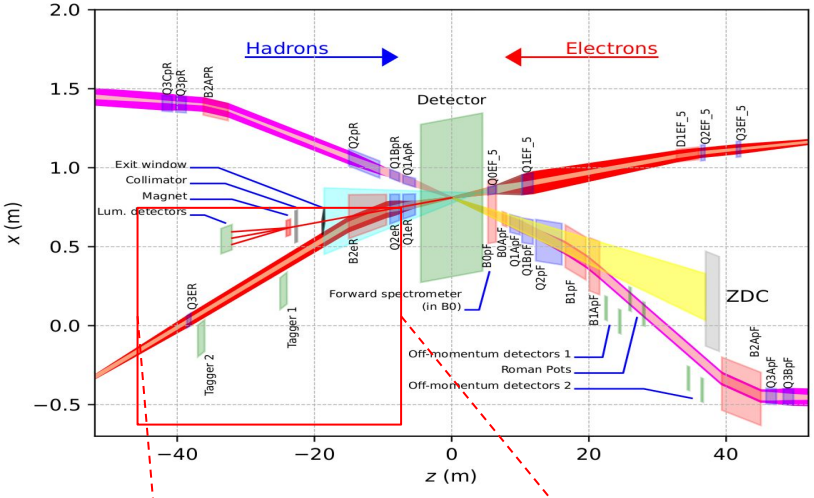
High Divergence Setting

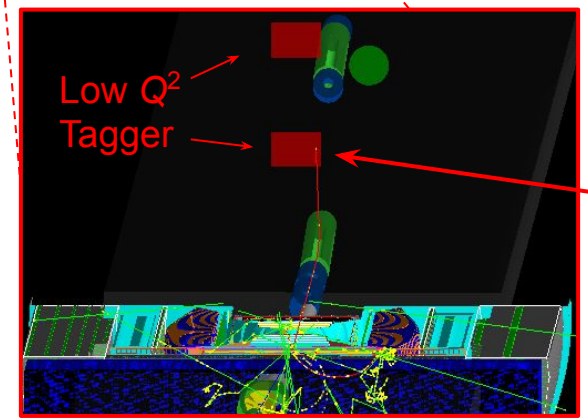
Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	18.9	6.2
No. of bunches	290	
Beam current [A]	0.69	0.227
RMS norm. emit., h/v [μm]	5.2/0.46	845/70
RMS emittance, h/v [nm]	17.6/1.6	24.0/2.0
β^*, h/v [cm]]	417/38	306/30
IP RMS beam size, h/v [μm]	271/24	
K_x	11.1	
RMS $\Delta\theta$, h/v [μrad]	65/65	89/82
BB parameter, h/v [10^{-3}]	3/3	92/100
RMS long. emittance [10^{-3}, eV·s]	36	
RMS bunch length [cm]	6	0.9
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9

Beam scattering parameterization available here: https://www.osti.gov/servlets/purl/1765663

Effect P_T or -t limit significantly!

The Far Backward Region @ IP6

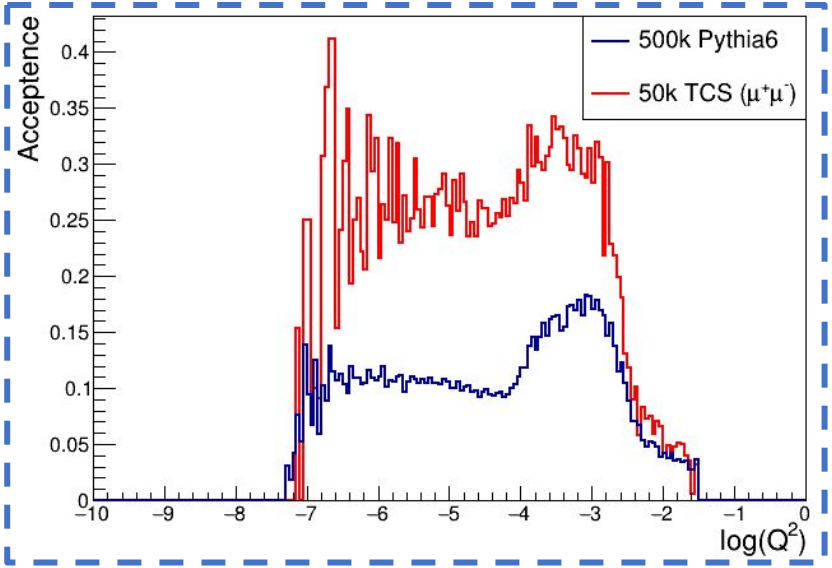




Far Forward Region (FBR)

- **Luminosity monitor**
  - Monitoring the e beam intensity
- **Low Q^2 Tagger**
  - Q^2 coverage from $10^{-6} < Q^2 < 10^{-1}$ GeV^2
  - **Two taggers @ z=24m and z=37m**
  - **@ z=27 m: 40.5 cm × 40.5 cm**
  - **@ z=34 m: 30 cm × 21 cm**
  - **Tagger design: double layered AC-LGAD tracker, followed by a PbWO4 (20 cm)**

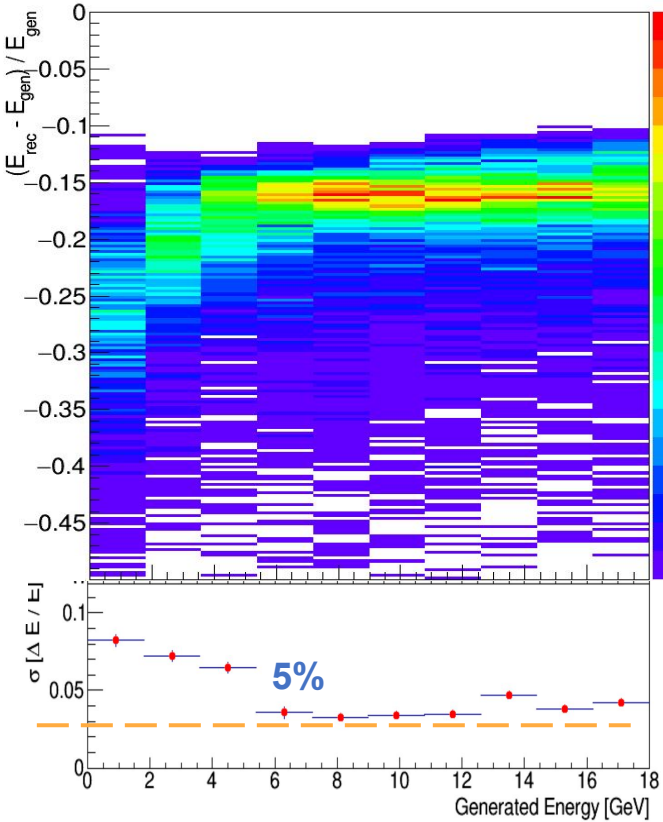
ECCE low Q^2 tagger acceptance and performance



$$\text{Acceptance} = \frac{\text{Tagged Events}}{\text{Total Events}}$$

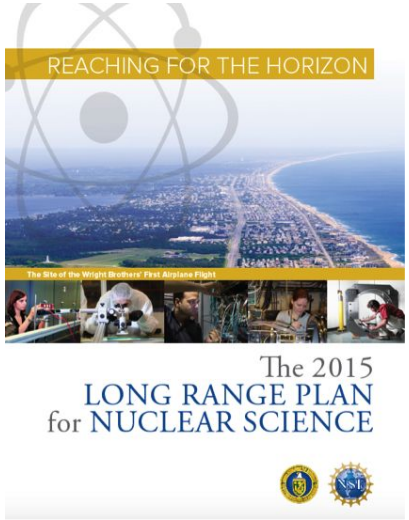
Expected performances:

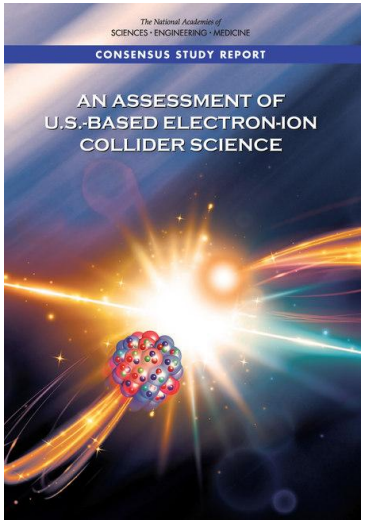
- **20-50% Acceptance**
- **Resolution: <10%, ~5GeV for most energy range.**



3-7% for e Energy 0.5-20 GeV

Physics: Objectives (Big Picture)





Scientific objectives and question posed by the Long Range Plane and National Academy of Science (NAS) Report. EIC will explore:

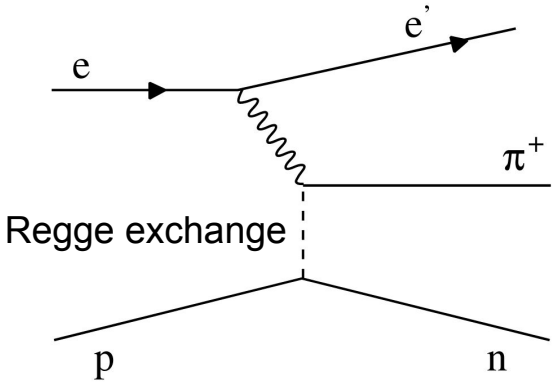
1. **Origin of nucleon spin**
2. **Three-Dimensional structure of nucleons and nuclei**
3. **Gluon structure of nuclei**
4. **Origin of hadron mass**
5. **Science beyond NAS report**

Scientific impact of the Forward Studies

Studies	Detector used	NAS Objectives
π and K Form Factor	**ZDC, Off Mom,** ECap, HCap	2. Three-Dimensional structure of nucleons and nuclei
π and K Structure Function	**ZDC, Off Mom**, ECap, HCap	2. Three-Dimensional structure of nucleons and nuclei
A1n via e+He3	**ZDC, Off Mom, B0, RP,** ECap, HCap	1. Origin of nucleon spin
eA Diffractive Study	**ZDC, Off Mom, B0, RP, 2nd RP,** ECap, HCap	3. Gluon structure of nuclei
u-Channel π^0	**ZDC, Off Mom, B0, RP,** ECap, HCap	5. Science beyond NAS report
XYZ Meson	**HCap, RP, ECap, Far Back**, Barrel	4. Origin of hadron mass
eA DVCS	**Off Mom, B0, RP**, 2nd RP, ECap, HCap	2. Three-Dimensional structure of nucleons and nuclei
TCS	**Off Mom, B0, RP,** ECap, HCap	2. Three-Dimensional structure of nucleons and nuclei
J/ψ production	**Off Mom, B0, RP,** ECap, HCap	4. Origin of hadron mass

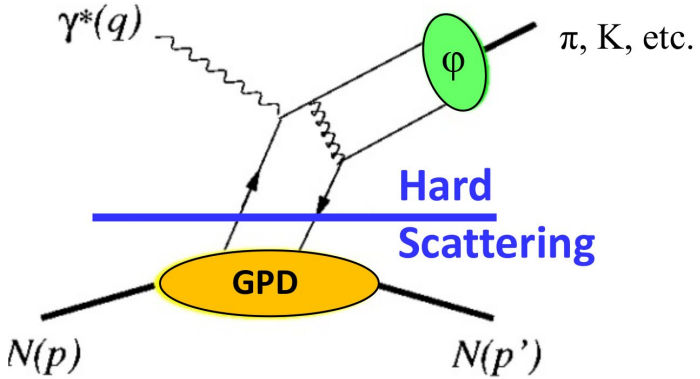
Bold: Far forward and backward detector stack

Charged Pion Form Factor



Scale as raising Q^2

@ low -t (or p_t), p should remain intact



"Softer" Regge Exchange @ JLab 12 GeV
(Probing meson-cloud like proton structure)

Hard Exchange @ EIC
(Probing parton within nucleon)

Deep Virtual Meson Production (DVMP) and Deep Virtual Compton Scattering (DVCS) offers the cleanest access to the GPD

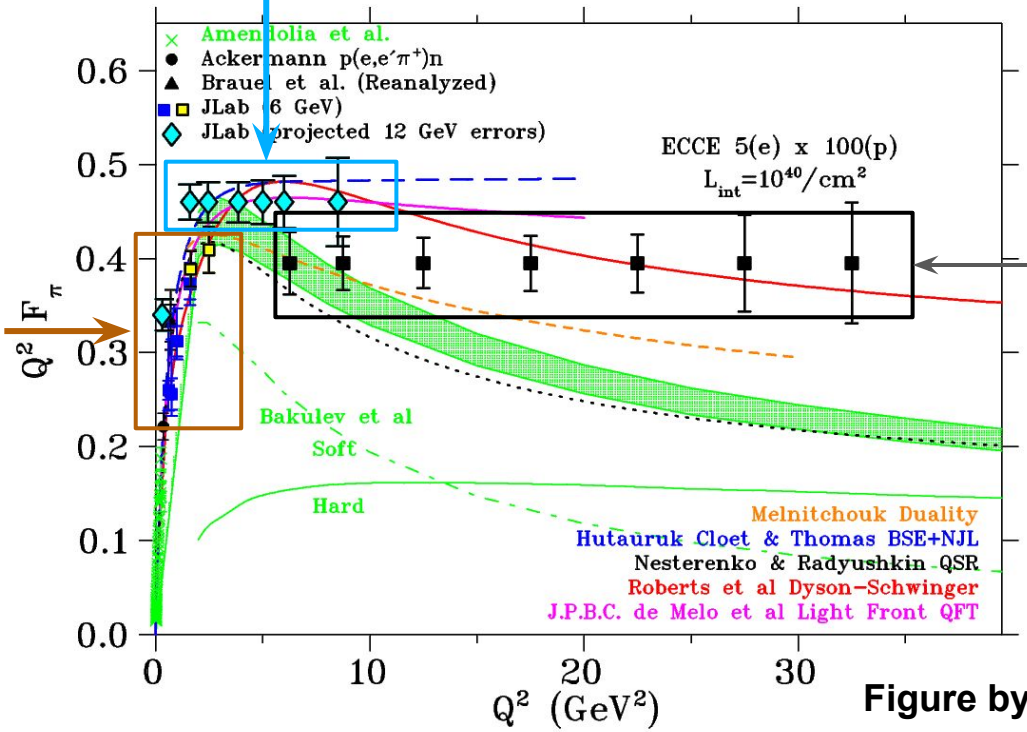
Mission: studying the transition from the "softer" interaction (JLab) to "hard" interaction (EIC) is equivalent to studying QCD collinear factorization.

Charged π Form Factor from JLab 6 to EIC

Fpi-12 E12-19-006 (2020)
88 days
(T. Horn*, G. Huber*, D. Gaskell)
(running at Hall C right now!)

Fpi-2 E-01-004 (2001)
14 days
(H. Blok*, G. Huber, D. Mack)

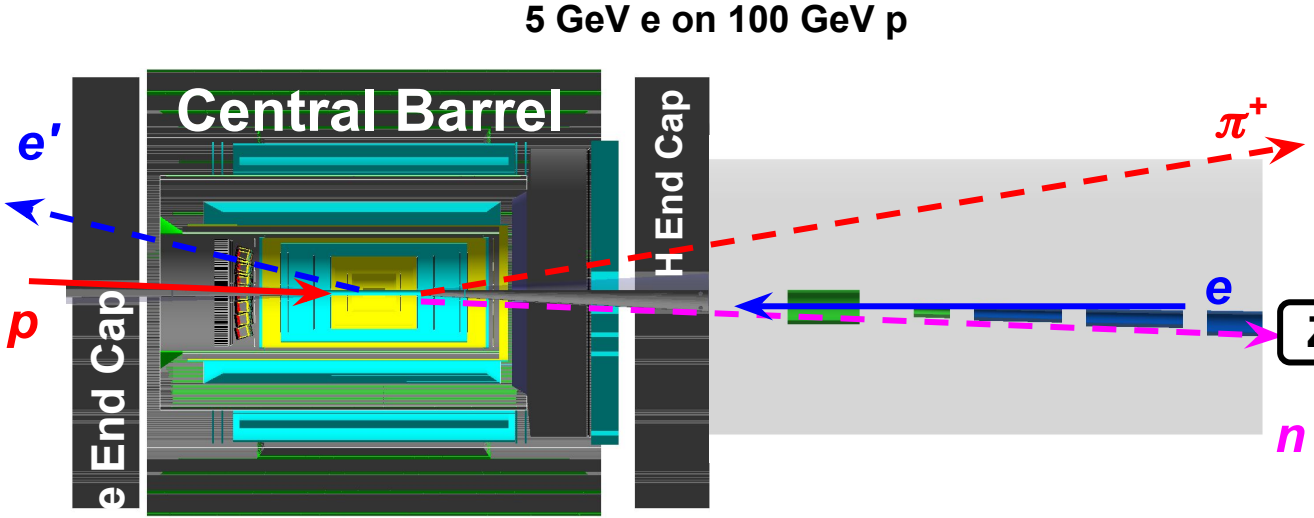
Fpi-1 E-93-021 (1993)
9 days
(D. Mack*, R. Whitney)

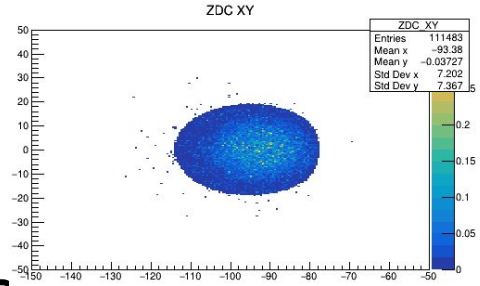


Fpi @ EIC (data by 2032)
10fb^{-1} a year of running
(G. Huber and others)

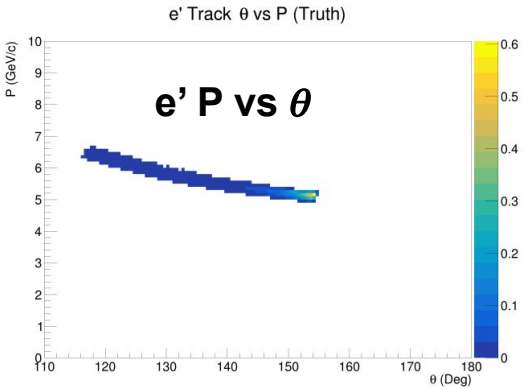
Figure by G. Huber and S. Kay

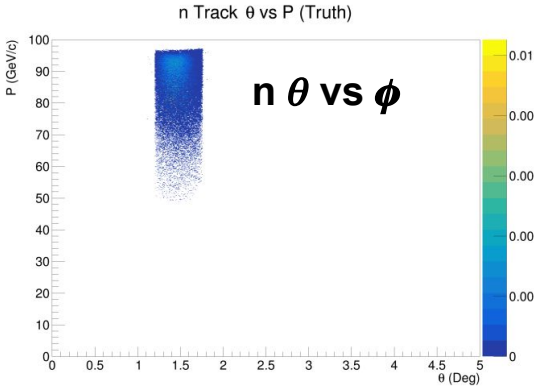
Physics Results Highlights: Pion Form Factor

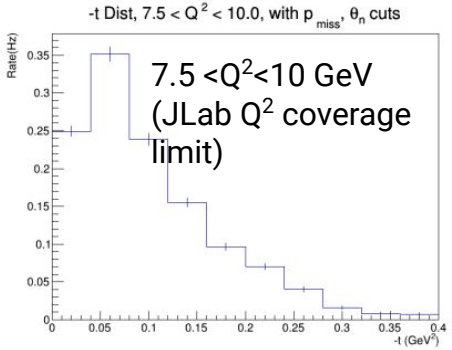




ZDC Occupancy

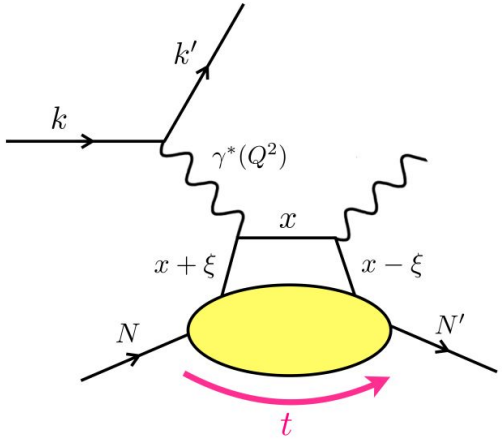




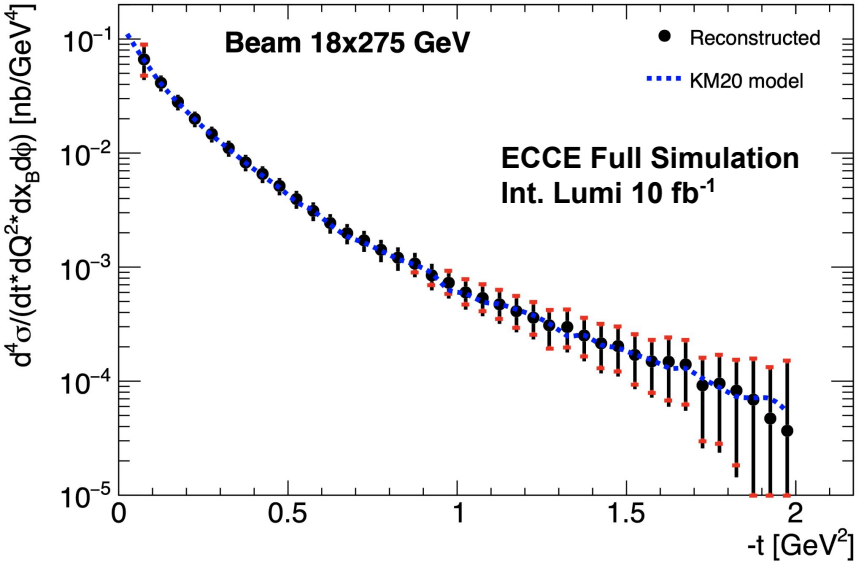


Normalized yield vs *-t*

Deep Virtual Compton Scattering



- **Full simulation include: DVCS + BH + Interference term**
- 9 GeV^2 < Q^2 < 16 GeV^2
- 0.003 < x_B < 0.007
- 0< -t < 2.0 GeV^2
- On-going work: studying the exclusive π^0 contamination



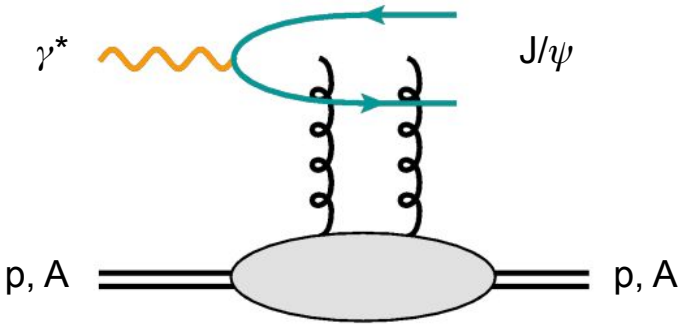
Study credit to I. Korover and C. Camacho.

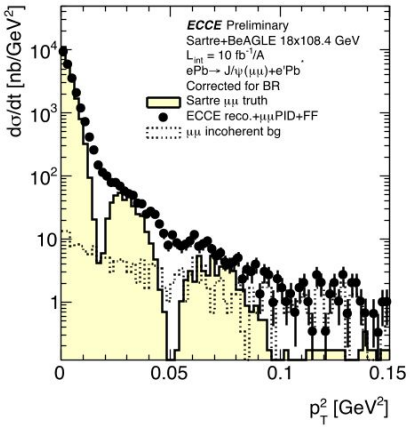
eA Diffractive Studies

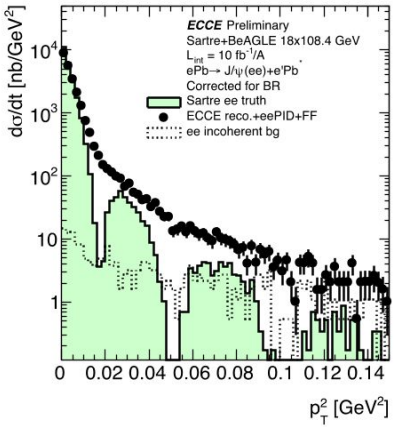
- **Most challenging measurement**
  - e+A→e'+(A-1)+J/ψ through diffractive process
  - e+Zr, e+Pb and e+Au were studied
    - e + ^{208}Pb → e' + ^{208}Pb + J/ψ + γ + X
    - e + ^{90}Zr → e' + ^{90}Pb + J/ψ + γ + X
    - e + ^{197}Au → e' + ^{197}Au + J/ψ + γ + X
  - Objective: observe/resolve the coherent diffractive background with the incoherent background, link to the nucleon PDF.

- Strict Measurements are required to ensure no nuclear break-up or fragment of events (rejection of incoherent background).

- EIC measurement will attempt to provide insights on coherent vs incoherent contributions

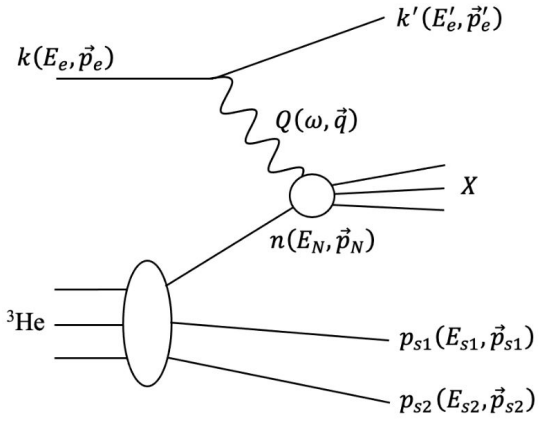






Study credit to P. Steinberg, M. Baker, D. Gangadharan.

A1n through e-^{3}He Observable



$$A_1^{^3\mathrm{He}} = P_n \frac{F_2^n}{F_2^{^3\mathrm{He}}} A_1^n + 2P_p \frac{F_2^p}{F_2^{^3\mathrm{He}}} A_1^p$$

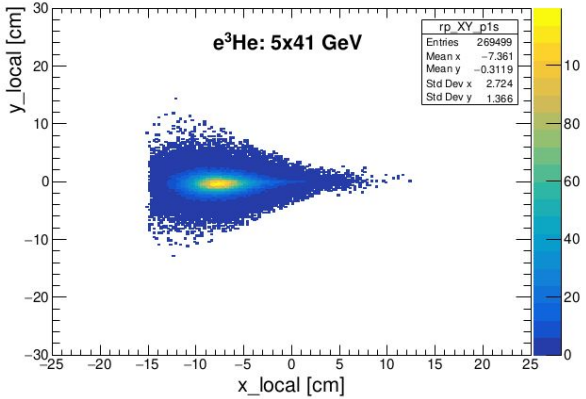
Extract A_1^n — Parameterized A_1^p

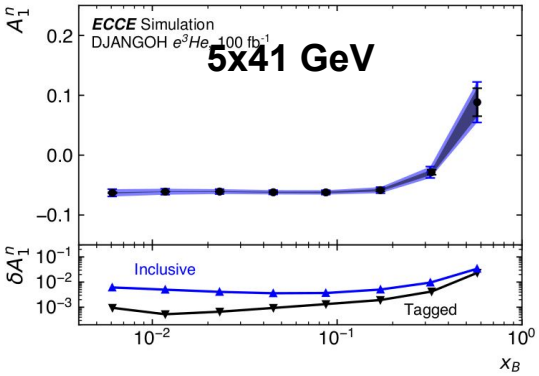
Measured through

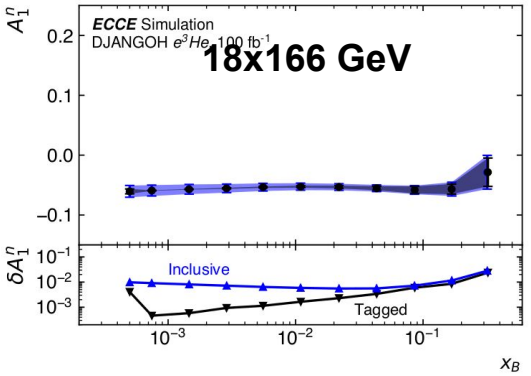
1) Inclusive: e+^{3}He→ e'+X
2) Double tagged: e+^{3}He→ e'+p_1+p_2+X

Goal: g_1 and g_2 spin structure function

Spectating p distribution at Roman Pots

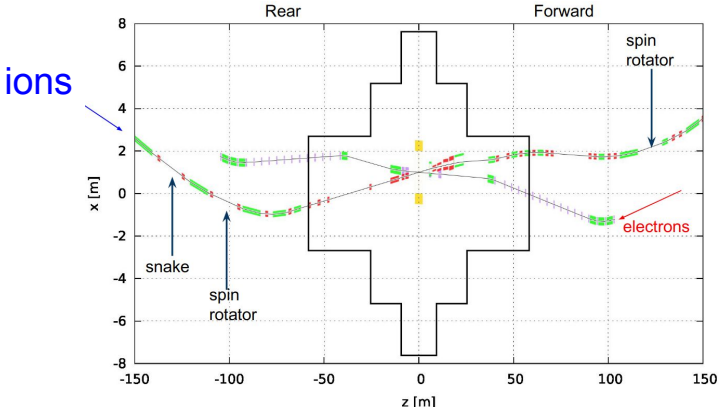






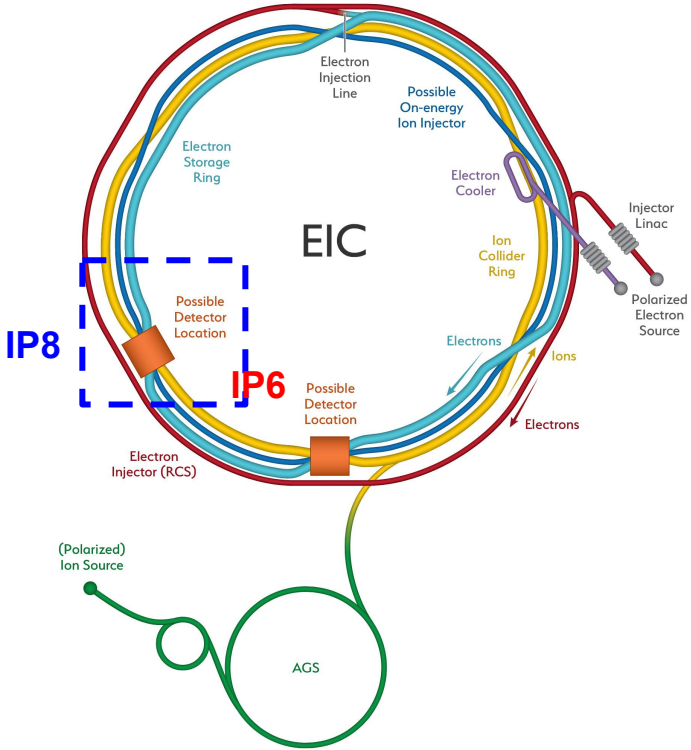
Asymmetry vs x_B , credit to D. Nguyen, J. Pybus

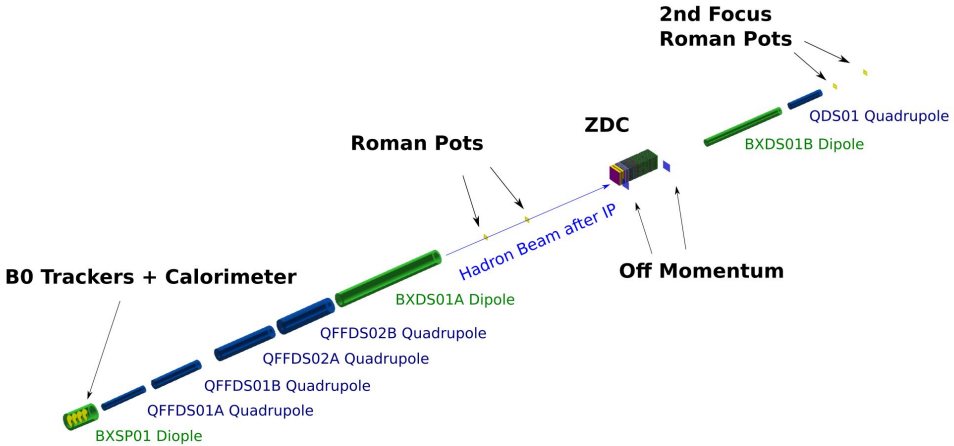
Fun4all is also IP8 Ready!



Main difference

- 35 mRad crossing
- 2nd focus
- ECCE software is IP8 ready!





Summary and invitation to join us!

- Introduction to the ECCE Forward/Backward enthusiasts
- Show cased the Physics results from the ECCE Diffractive and Tagging
- EIC project is developing fast. Now is the best time to get involved! Join us!
  - My contact info: wenliang.billlee@gmail.com