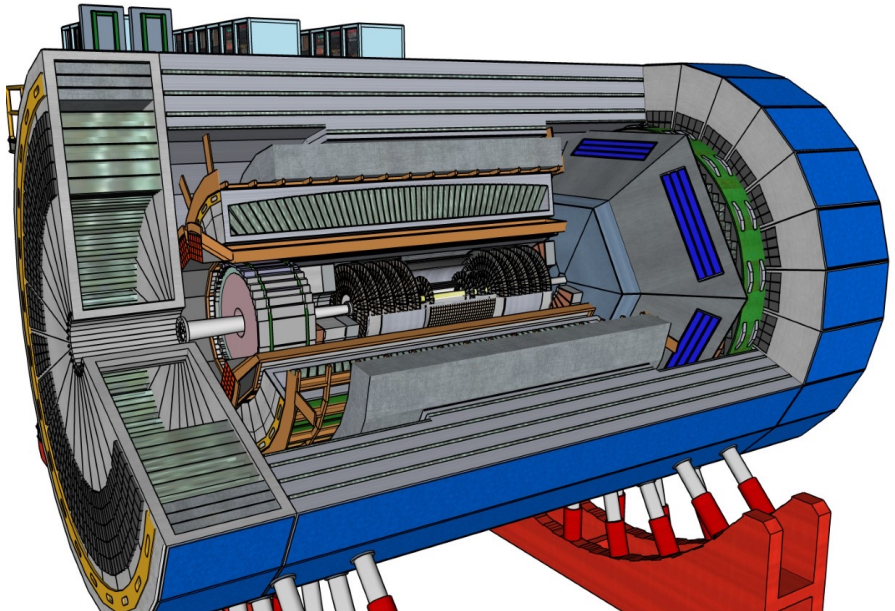
EIC Comprehensive Chromodynamics Experiment

Or Hen - MIT

for the ECCE Consortium

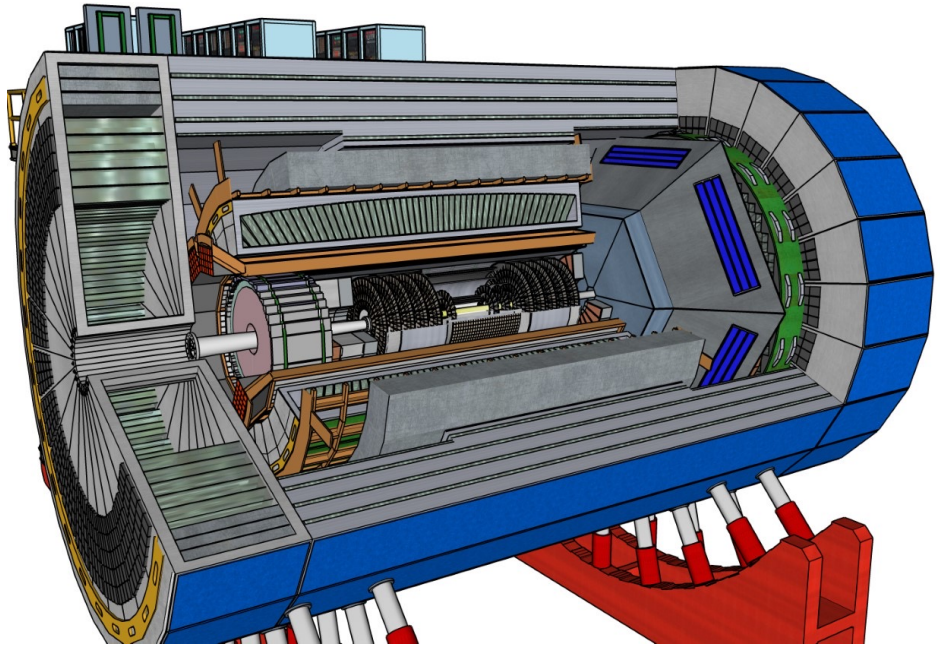


Precision Studies on QCD at EIC (PSQ@EIC), July 22nd, 2021.

What's ECCE?

Scientist from ~80 institutions

Designing (& building!) a detector



To deliver on EIC science mission

What's ECCE?

ECCE is after a low-risk, cost-effective, flexible and optimized EIC detector, capable of delivering on the full EIC physics program!

*EIC physics program? Defined by the U.S. National Academy of Science Study

What's ECCE?

ECCE is after a low-risk, cost-effective, flexible and optimized EIC detector, capable of delivering on the full EIC physics program!

Guiding principles:

- Reuse: 1.5T BaBar solenoid / detectors / infrastructure as possible
- Explore both EIC interaction regions (i.e. with\out secondary focusing)
- Respond to 'Detector 1' EIC call for proposals (i.e. ready for CD4a)
- Share & support community vision that the EIC science mission is best served by two detectors

ECCE Consortium

EIC Project POC
Rolf Ent (JLab)

Computing Team
Cristiano Fanelli (MIT)
David Lawrence (JLab)

ECCE Steering Committee
Or Hen (MIT)
Tanja Horn (CUA)
John Lajoie (ISU)

Institutional Board

Diversity, Equity and Inclusion
Narbe Kalantarians (VUU, co-chair)
Christine Nattrass (UTK, co-chair)
Simonetta Liuti (UVA)
Elena Long (UNH)

Editorial Team
Tom Cormier (ORNL)
Richard Milner (MIT)
Peter Steinberg (BNL)

Detector Team
Doug Higinbotham (JLab)
Ken Read (ORNL)

Physics Benchmarks Team
Carlos Munoz-Camacho (IJCLab-Orsay)
Rosi Reed (Lehigh U.)

Computing Working Groups:

- Artificial Intelligence
  William Phelps (CNU/JLab)
- Computing and Software
  Joe Osborn (ORNL)

Detector Working Groups:

- IP8/Equipment Re-use
  John Haggerty (BNL)
- Far Forward/Far Backward*
  Michael Murray (KU), Yuji Goto (RIKEN), Igor Korover (MIT)
- Tracking
  Xuan Li (LANL), Nilanga Liyanage (UVA)
- Calorimetry
  Friederike Bock (ORNL), Yongsun Kim (Sejong U.)
- Particle ID
  Greg Kalicy (CUA), Xiaochun He (GSU)
- Magnetic Field
  Paul Brindza (JLab), Renuka Rajput-Ghoshal (JLab)
- DAQ/Electronics/Readout
  Chris Cuevas (JLab), Martin Purschke (BNL)

***Alex Jentsch, Yulia Furletova**
(far-forward/backward POC)

Physics Working Groups:

- Simulations
  Cameron Dean (LANL), Jin Huang (BNL)
- Inclusive Processes
  Tyler Kutz (MIT), Claire Gwenlan (Oxford)
- Semi-Inclusive
  Ralf Seidl (RIKEN), Charlotte Van Hulse (Orsay)
- Exclusive
  Rachel Montgomery (Glasgow), Julie Roche (OU)
- Diffractive and Tagging
  Wenliang Li (W&M), Axel Schmidt (GWU)
- Jets and Heavy Flavor
  Cheuk-Ping Wong (LANL), Wangmei Zha (USTC)
- BSM and Precision Electroweak
  Sonny Mantry (UNG), Xiaochao Zheng (UVa)

Editorial Working Groups:

- Proposal Editing, Verification and Version Control
- Costing and Management

Website:

https://www.ecce-eic.org/

Mailing Lists:

https://lists.bnl.gov

- ecce-eic-public-l
- ecce-eic-ib-l
- ecce-eic-dei-l
- ecce-eic-det-l
- ecce-eic-phys-l
- ecce-eic-prop-l

Indico:

https://indico.bnl.gov/category/339/

EIC Science Mission

NAS Report highlights

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

EIC Science Mission

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EIC Yellow Report

- Global properties and parton structure of hadrons
- Multi-dimensional imaging of nucleons, nuclei and mesons
- The nucleus: a laboratory for QCD
- Understanding hadronization

EIC Science Mission

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EIC Yellow Report

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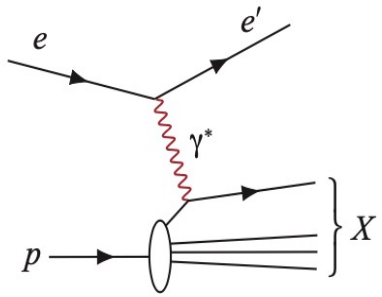
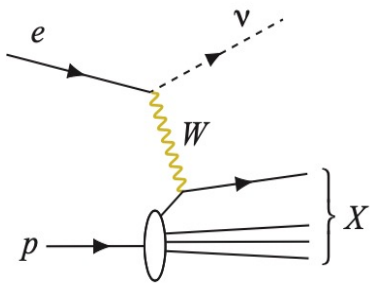
Tools for Realizing EIC's Science Mission

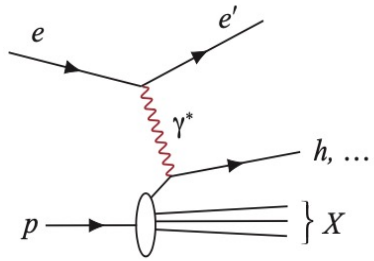
Neutral-current Inclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + X$; for this process, it is essential to detect the scattered electron, e', with high precision. All other final state particles (X) are ignored. The scattered electron is critical for all processes to determine the event kinematics.



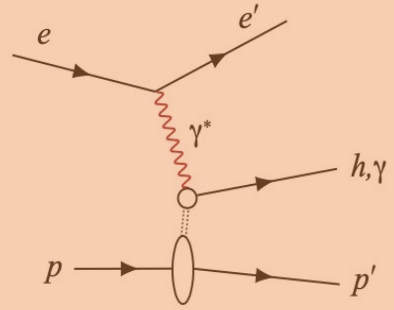
Charged-current Inclusive DIS: $e + p/\mathrm{A} \longrightarrow \nu + X$; at high enough momentum transfer Q^2, the electron-quark interaction is mediated by the exchange of a $W^{\pm}$ gauge boson instead of the virtual photon. In this case the event kinematic cannot be reconstructed from the scattered electron, but needs to be reconstructed from the final state particles.



Semi-inclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} + X$, which requires measurement of *at least one* identified hadron in coincidence with the scattered electron.

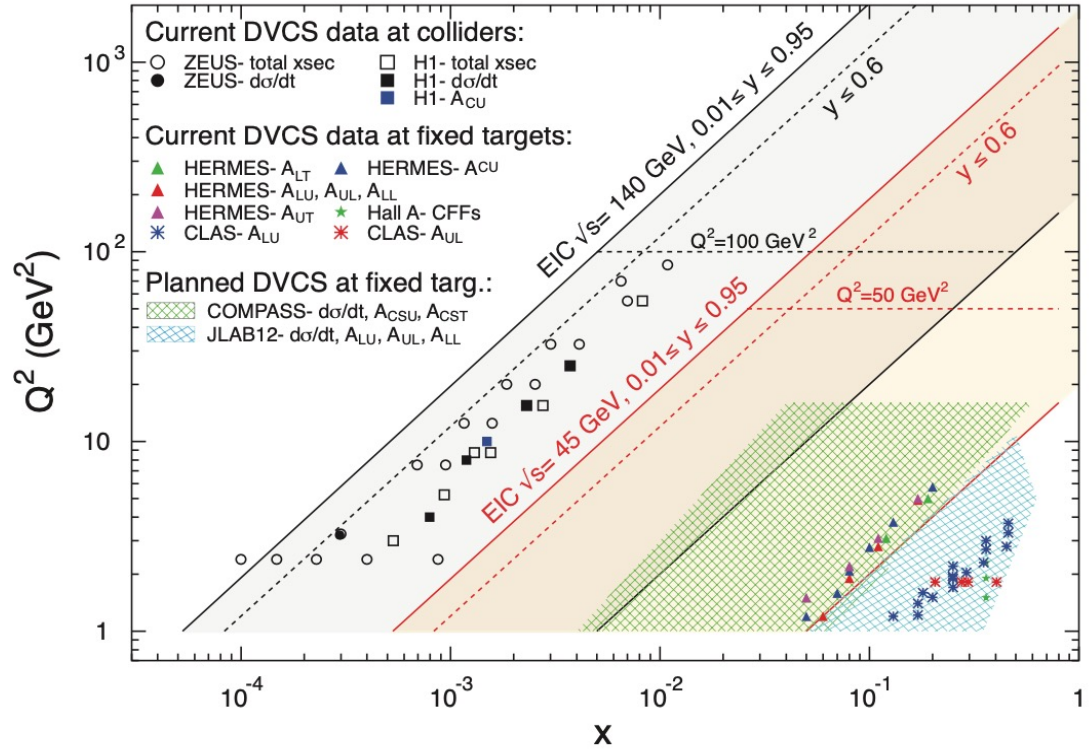


Exclusive DIS: $e + p/\mathrm{A} \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$, which require the measurement of *all* particles in the event with high precision.

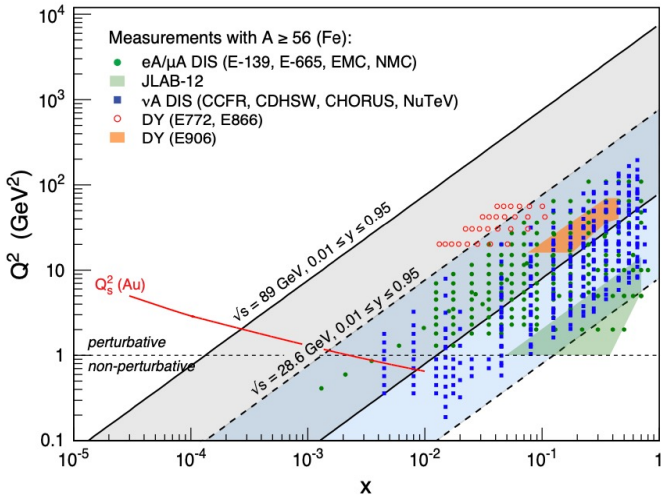


EIC Has Wide Kinematic Coverage

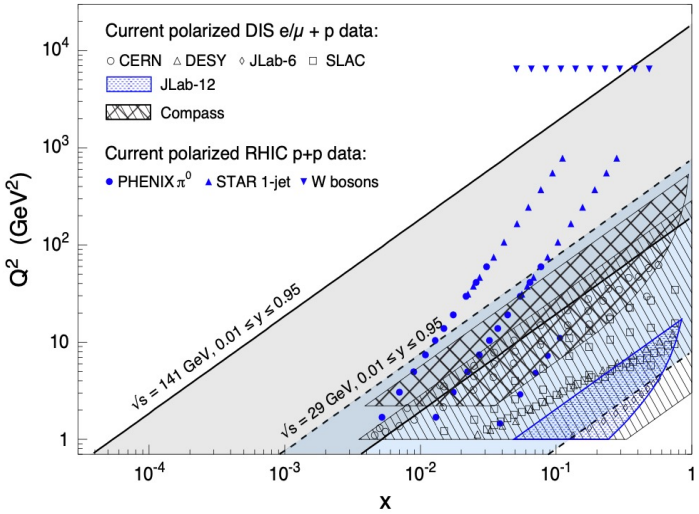
Exclusive: DVCS



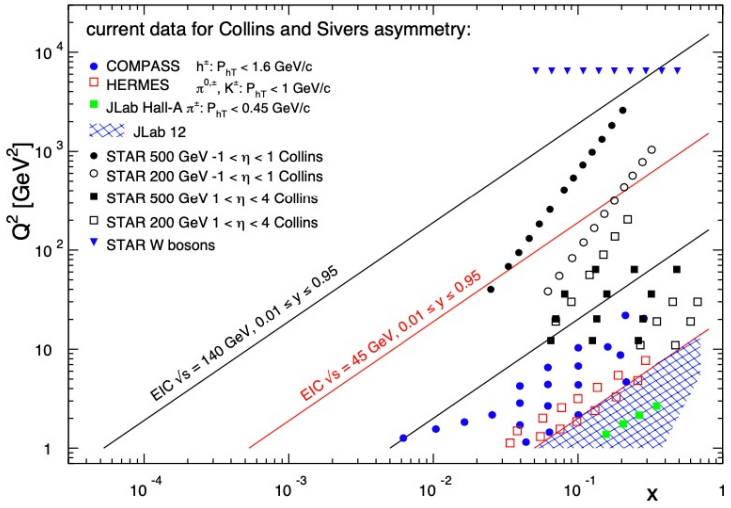
Inclusive



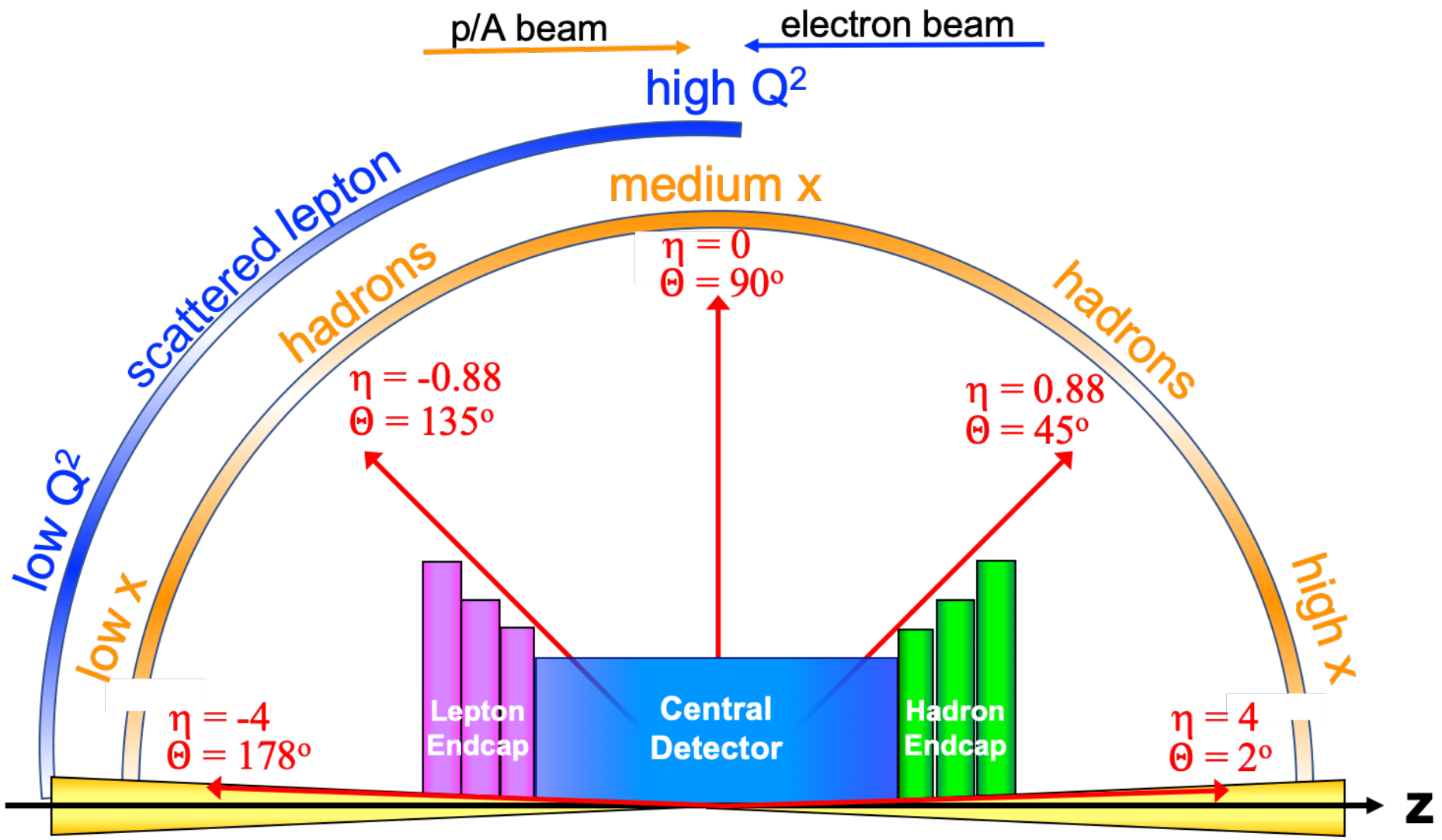
Polarized



SIDIS

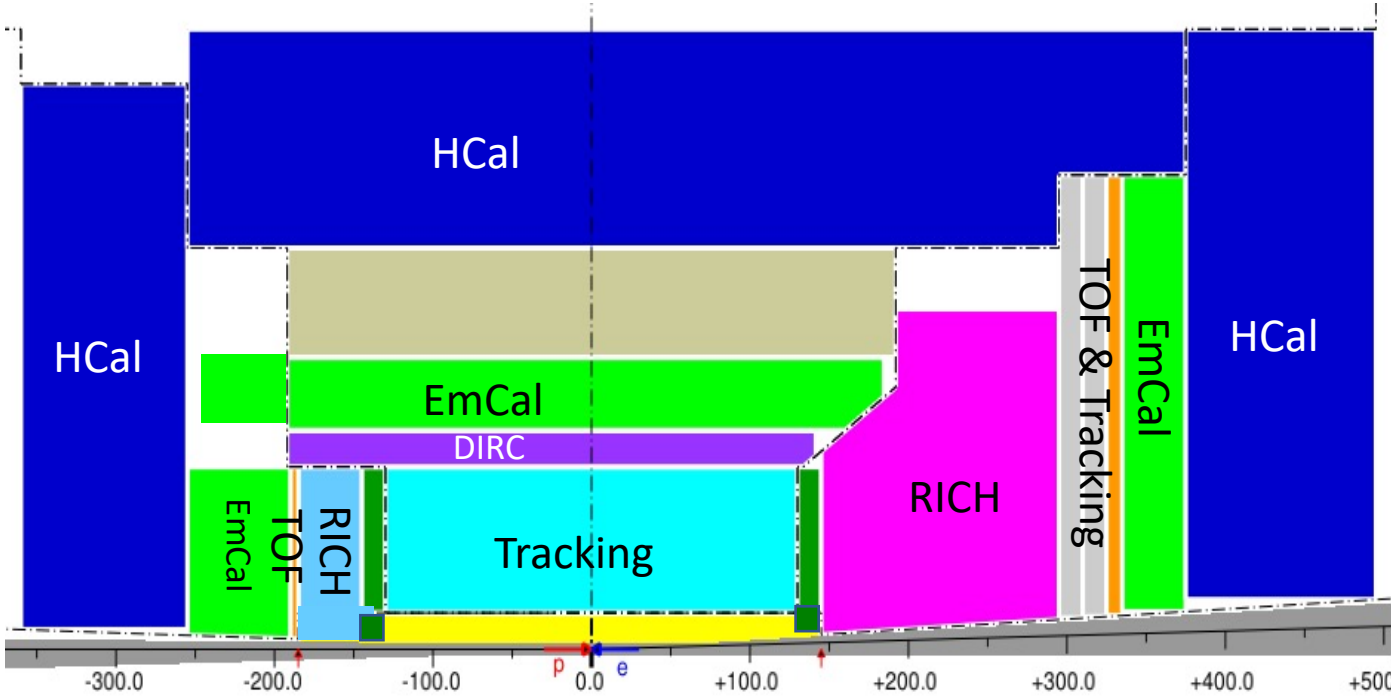


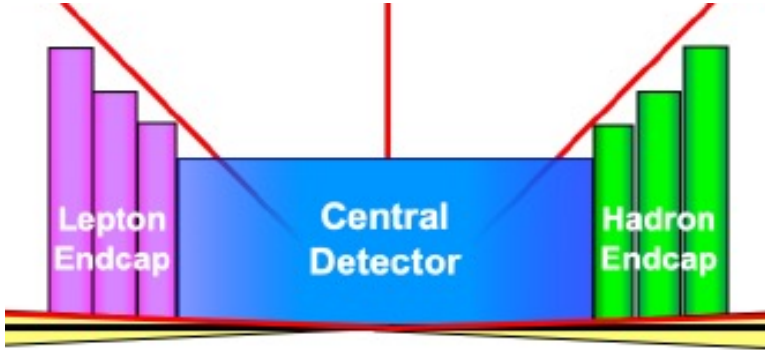
EIC Detector Layout



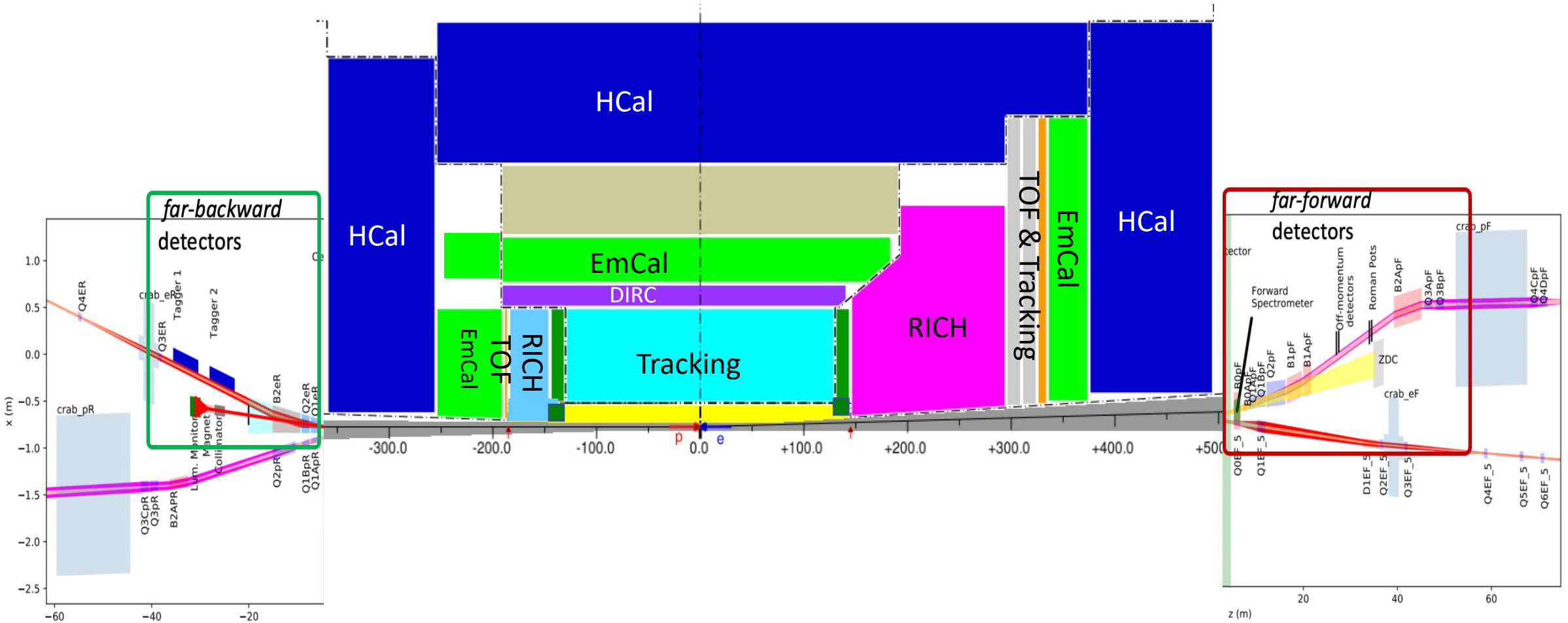
EIC Detector Layout

HCal
↑
EM-Cal
↑
Cherenkov & TOF PID
↑
Tracking

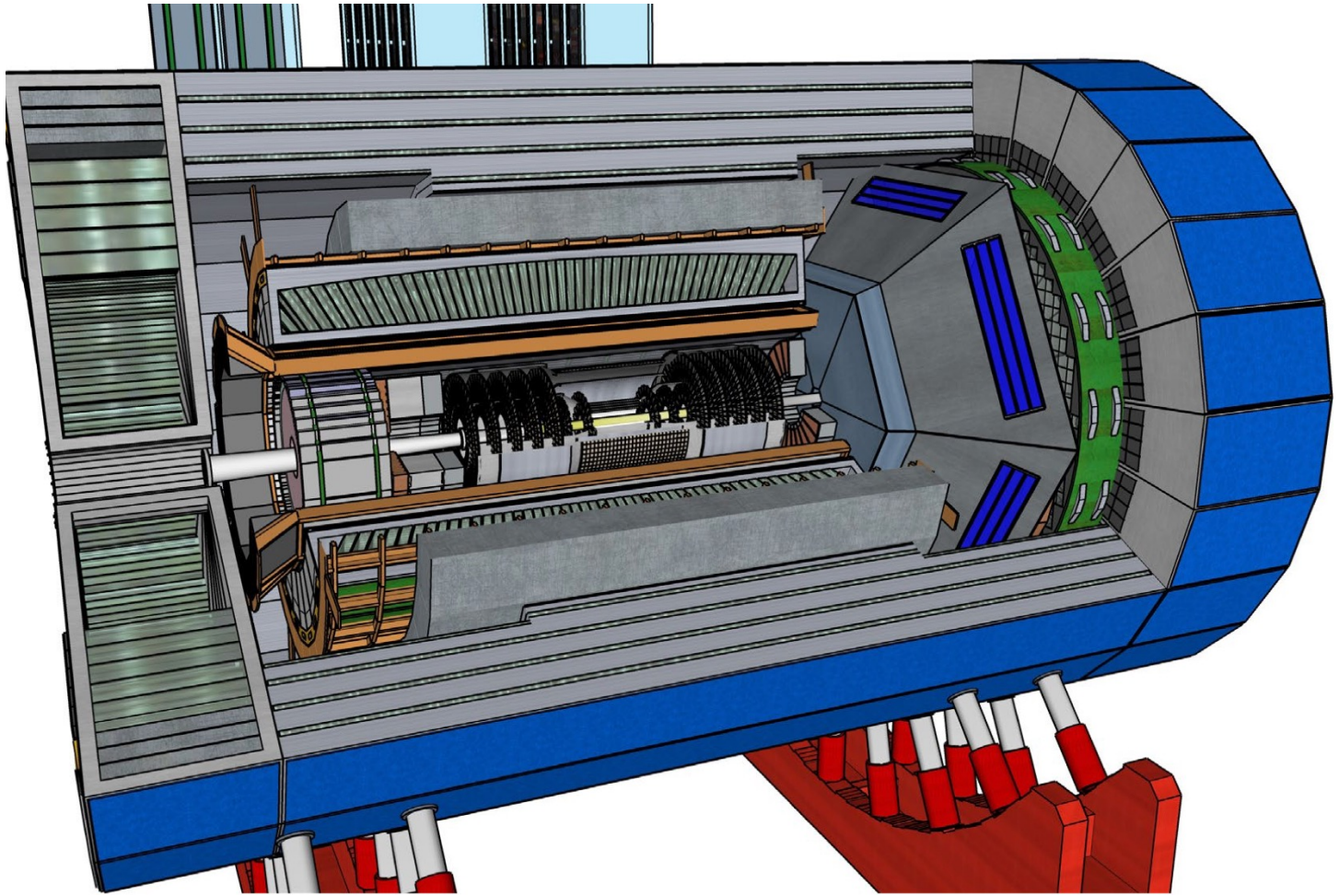




EIC Detector Layout



ECCE Detector Layout



ELECTRON ENDCAP

Tracking: Large area μRWELL
Electron Detection:
- Inner: PbWO4 crystals (reuse some)
- Outer: SciGlass (backup PbGl)

h-PID: mRICH & AC-LGAD
HCAL: Fe/Sc (STAR re-use)

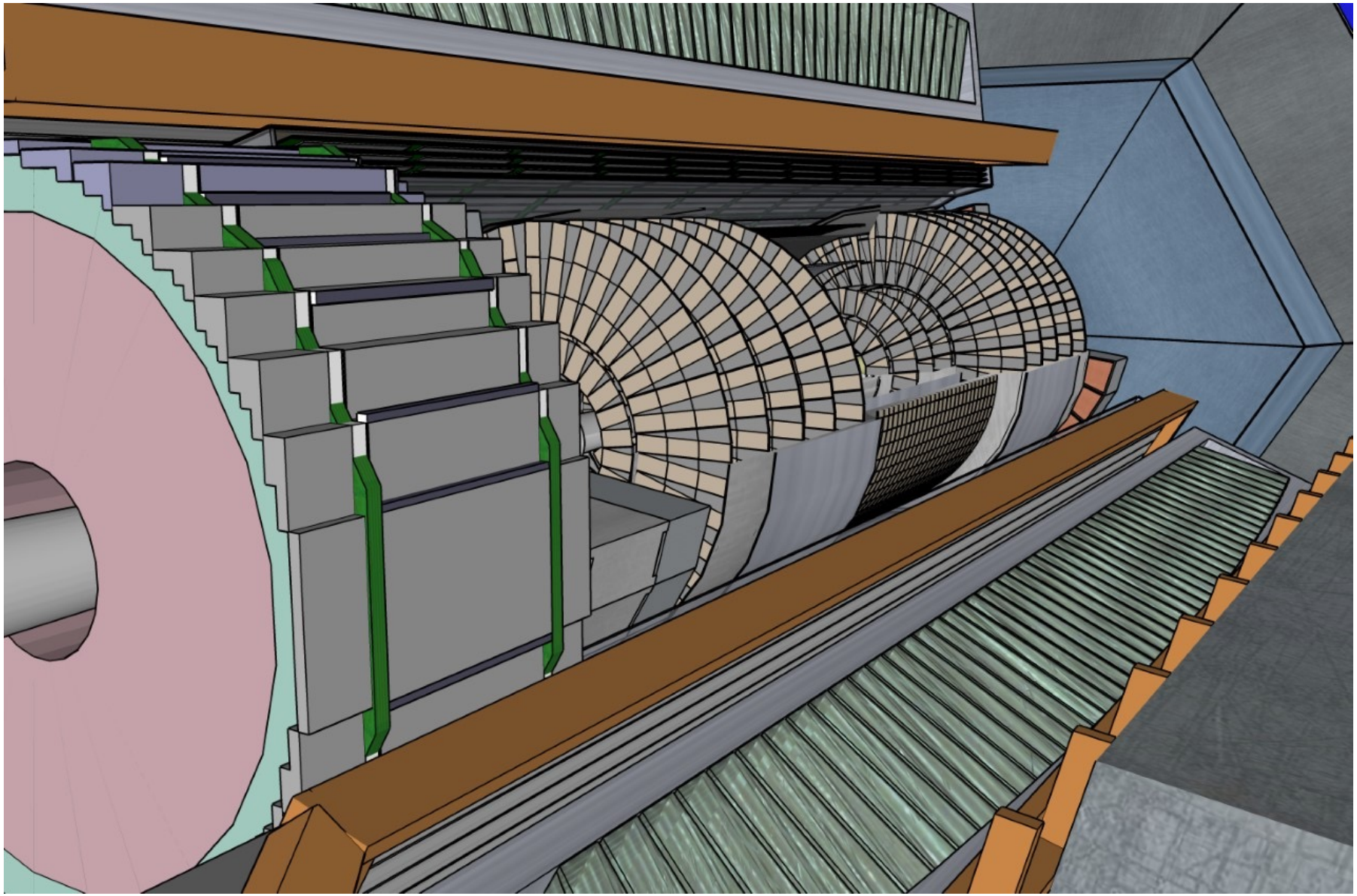
CENTRAL BARREL

Tracking: MAPS Si for vertexing and endcaps
(design to be optimized)
Electron PID: SciGlass (alt: PbGl or W(Pb)/Sc shashlik)
(plus instrumented frame)
h-PID: hpDIRC & AC-LGAD
HCAL: Fe/Sc (sPHENIX re-use)

HADRON ENDCAP

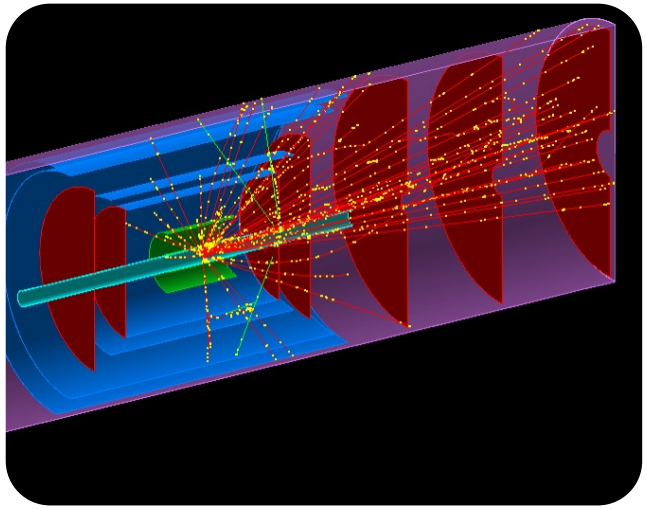
Tracking: Large area μRWELL
PID: dual-RICH & AC-LGAD
Calorimetry: (option A)
standard Pb/ScFi shashlik (PHENIX re-use)
long. sep. HCAL
(other options under study)

ECCE Detector Layout

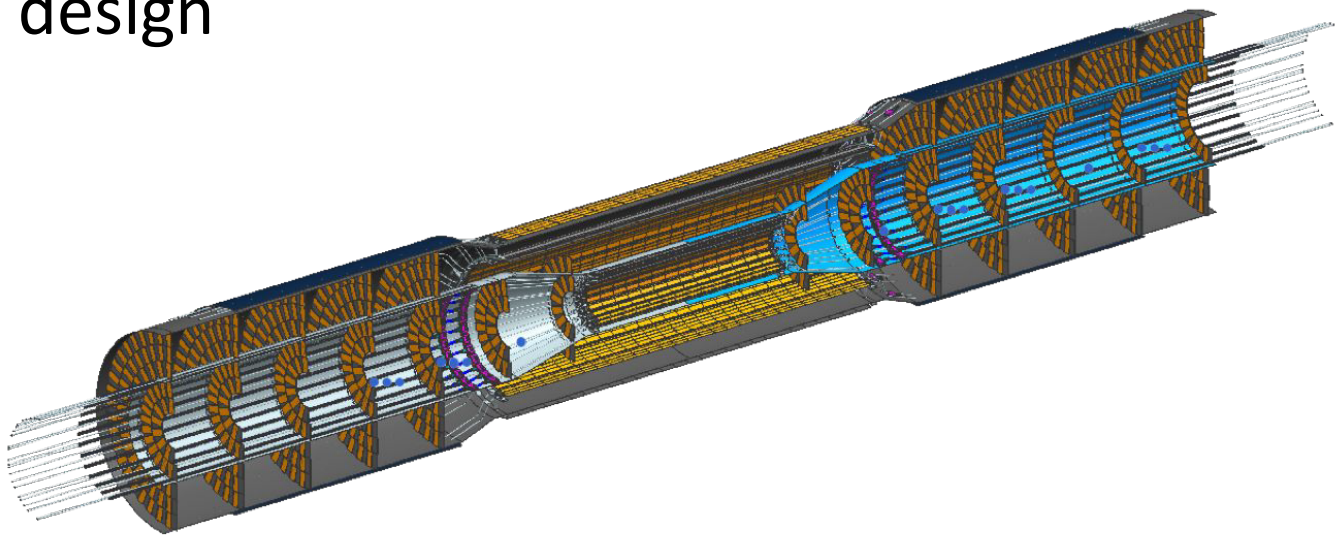


ECCE Tracking

- Baseline Layout:
  - Barrel: Silicon tracker + AC-LGADS & µRWELL around DIRC
  - Endcups: Silicon disks + AC-LGADS & µRWell around caloremeters



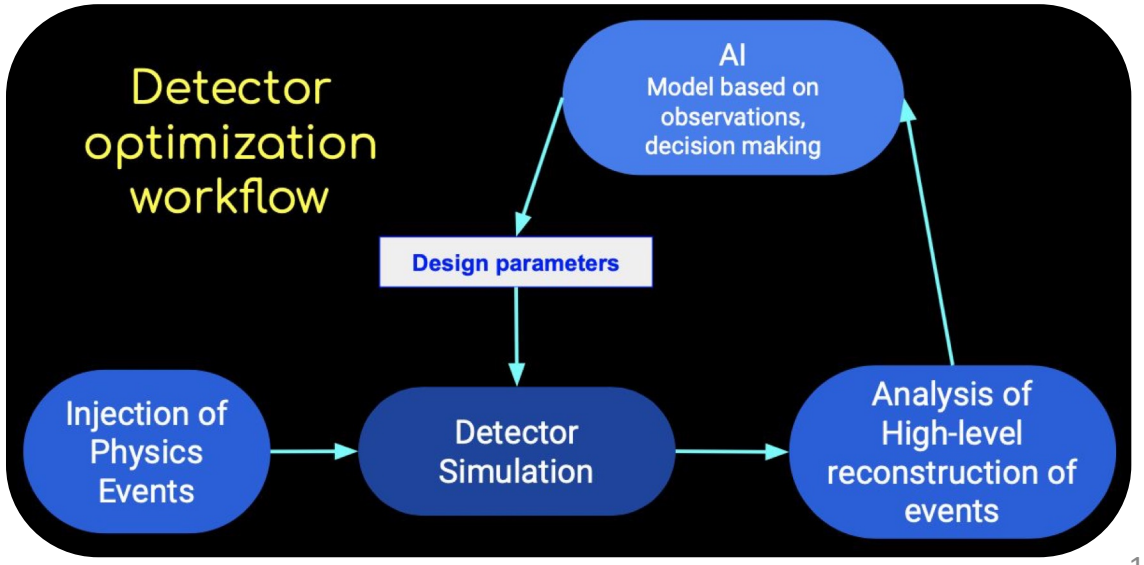
- AI pipeline for optimizing tracker design



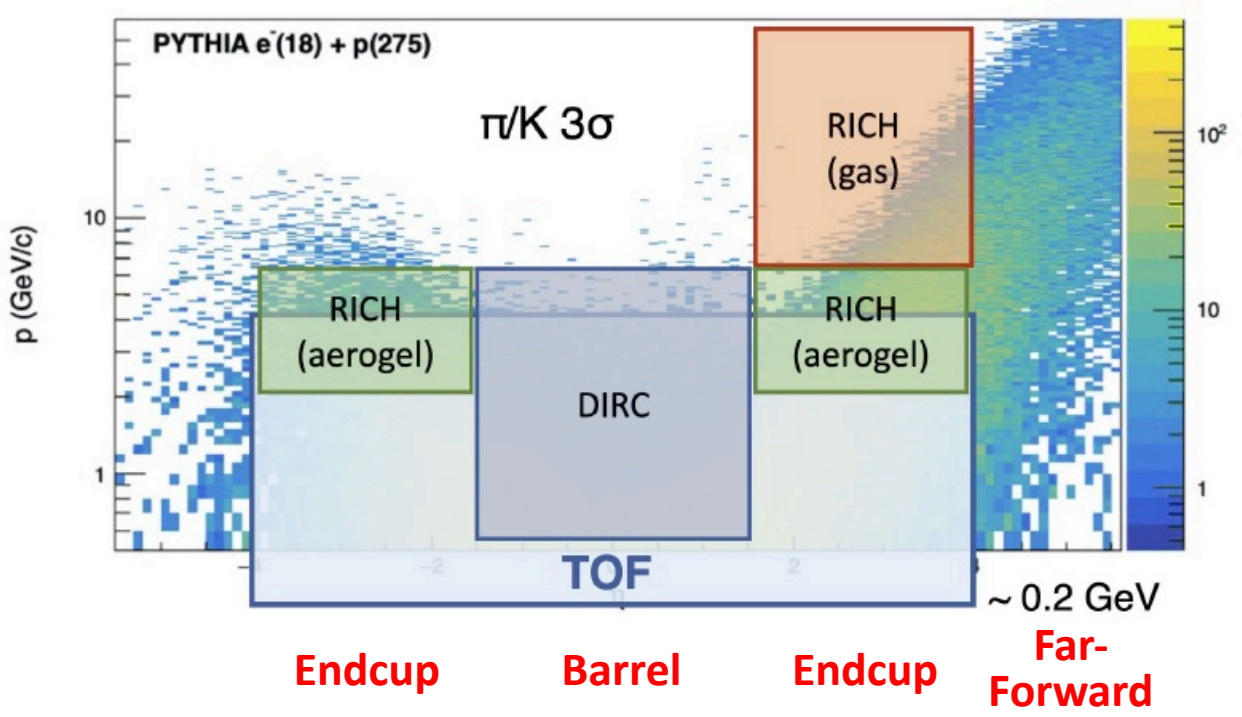
ECCE Tracking

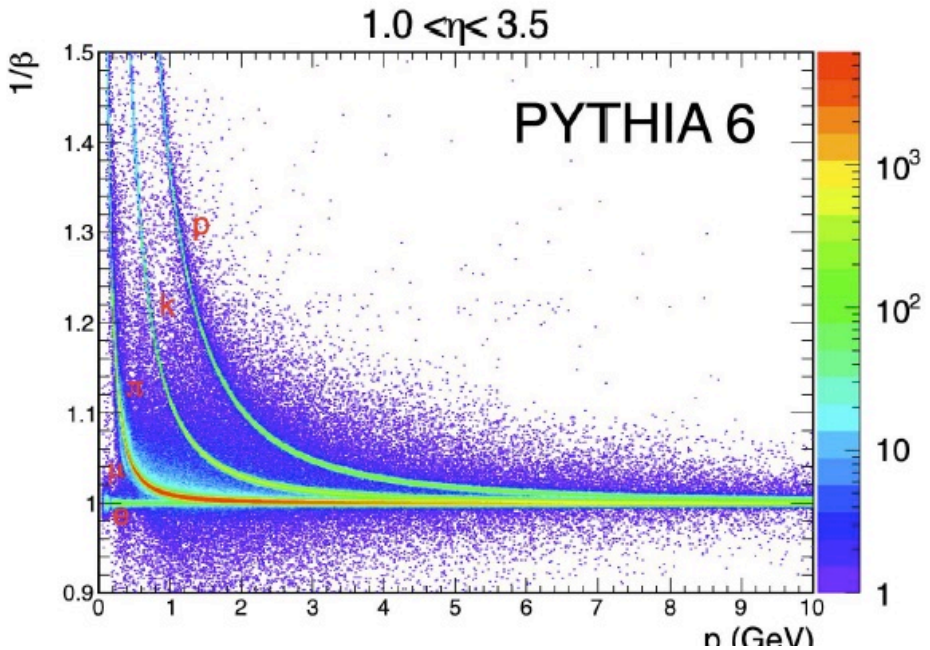
Multidimensional tradeoff optimization for a range of performance criteria including momentum, angle and pointing resolutions, reconstruction efficiency, etc.

- Baseline Layout:
  - Barrel: Silicon tracker + AC-LGADS & µRWELL around DIRC
  - Endcups: Silicon disks + µRWell around caloremeters
- AI pipeline for optimizing tracker design



ECCE PID


PYTHIA e⁻(18) + p(275)
π/K 3σ
RICH (gas)
RICH (aerogel)
DIRC
RICH (aerogel)
TOF
~ 0.2 GeV
p (GeV/c)
10
1
10²
10
1
Endcup
Barrel
Endcup
Far-Forward

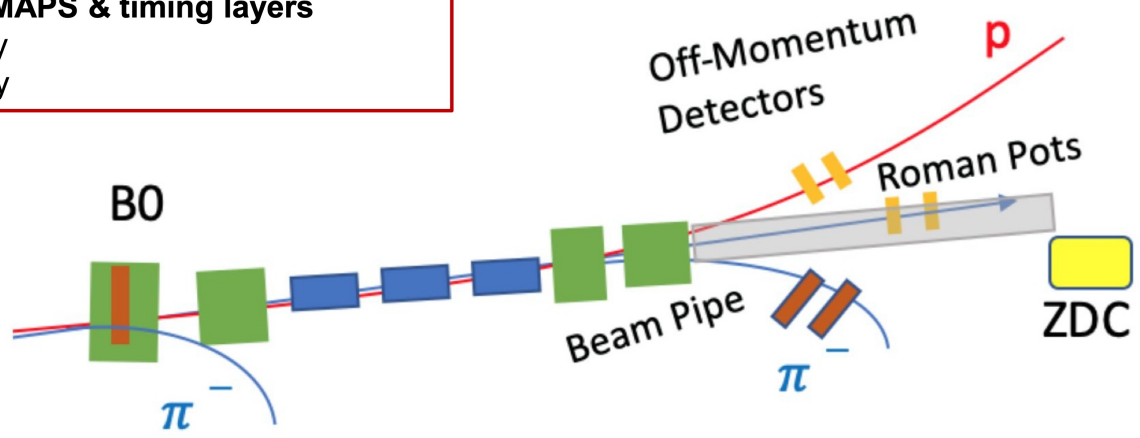

1.0 <η< 3.5
PYTHIA 6
1/β
p (GeV)
10³
10²
10
1

ECCE Far Forward / Back

FAR FORWARD DETECTORS

- ZDC – **Si/W & PWO (SciGlass)**
- Roman Pots – **Silicon sensors, AC-LGADs**
- Off-momentum det. – **Silicon sensors**
- B0-trackers – **MAPS & timing layers**

Lepton polarimetry
hadron polarimetry

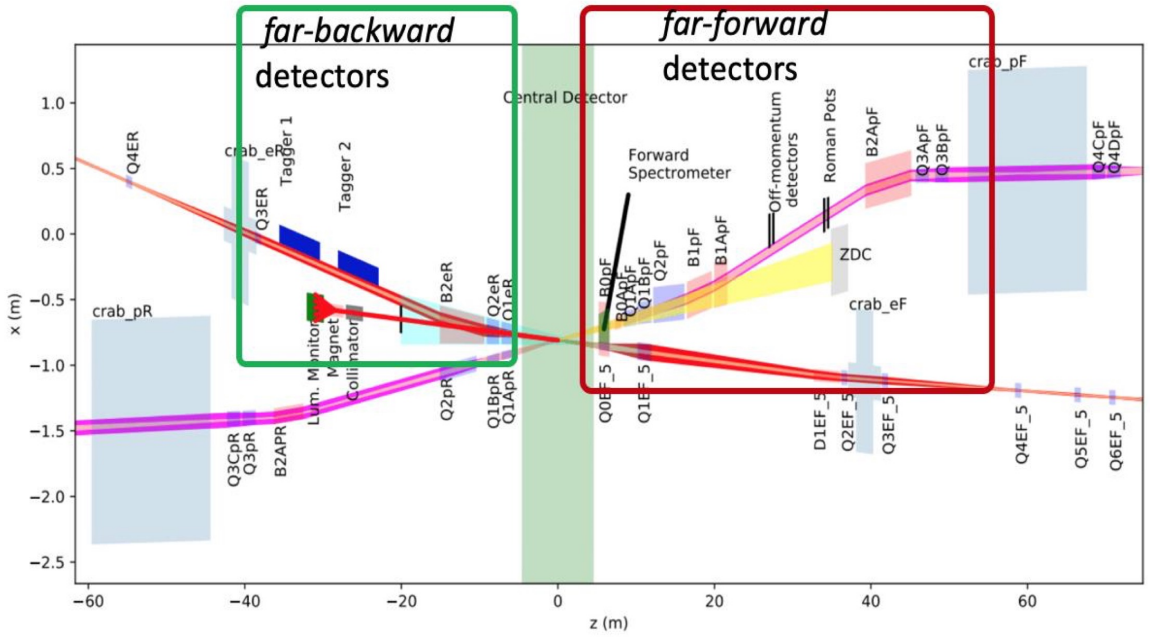


FAR BACKWARD DETECTORS

- low-Q2 tagger
- Lumi-detector

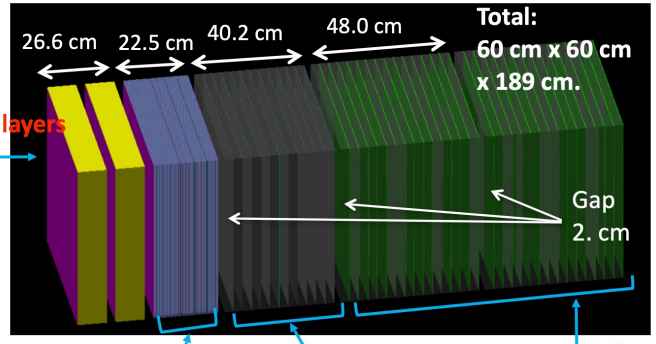
Lepton polarimetry
hadron polarimetry

Participating in coordinated meetings between all proto-collaborations, organized by EIC PM.



What I put in Fun4All
-- ongoing

Shima Shimizu



Silicon
3 mm x 3mm x 300 µm
PET (Glue) 0.11 mm
PET (FPC) 0.28 mm
Gap 1.2mm
Crystal (PbWO4)
3cm x 3cm x 10 cm
Gap 3 cm

2 layers

Si +

Tungsten 3.5 mm Thickness
PET (Glue) 0.11 mm
Silicon 1 cm x 1 cm x 320 µm
PET (Glue) 0.13 mm
PET (FPC) 0.28 mm
Gap 1. mm
5.34 mm

Tungsten 3.5 mm Thickness
PET (Glue) 0.11 mm
Silicon 3 mm x 3mm x 300 µm
PET (Glue) 0.11 mm
PET(FPC) 0.28 mm
Gap 1.2mm
5.5 mm

20 layers
x 2
+
1 layer

Total:
W: 42 layers,
Si: 3 layers,
Si: 40 layers

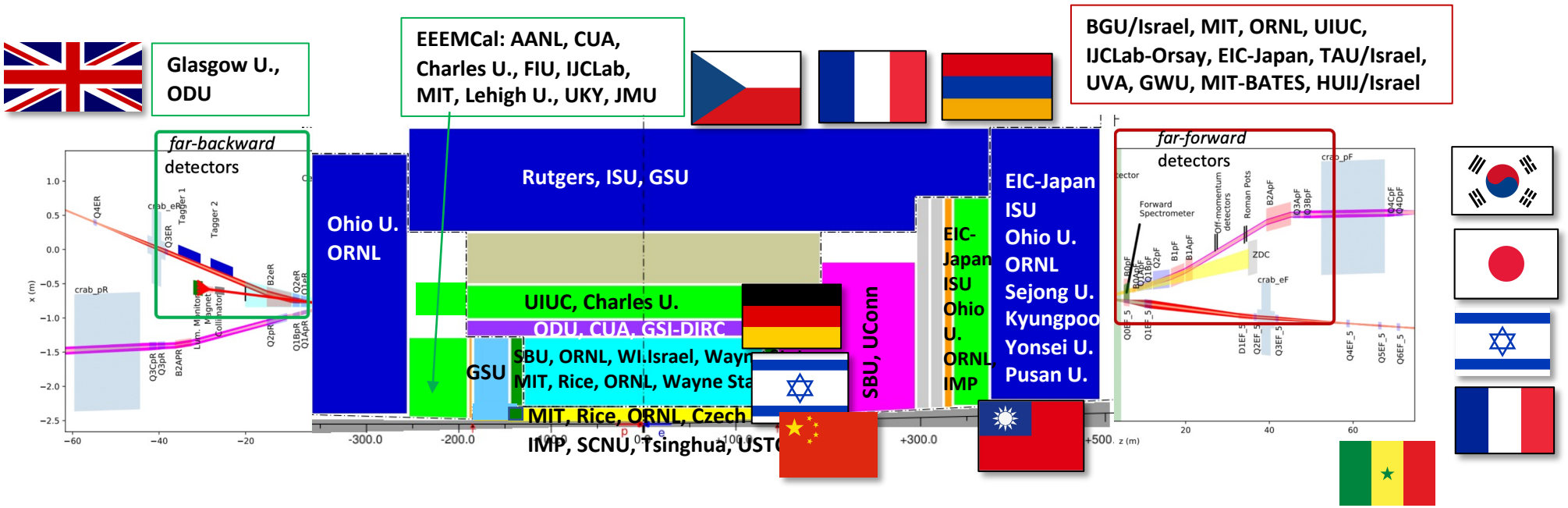
12 layers

Pb 3cm Thickness
PET (Glue) 0.11 mm
Silicon 1 cm x 1 cm x 320 µm
PET (Glue) 0.13 mm
PET(FPC) 0.28 mm
Gap 1. mm

30 layers
(15 layers x 2)

Pb 3cm Thickness
Scintilator 10 cm x 10 cm x 2 mm
Gap 0.0013 mm

ECCE International Interests



Polarized Beam and polarimetry: MIT, UNH, SBU

Electronics: Columbia, ORNL

DAQ/Trigger: ISU, CU Boulder, OU, ORNL, SBU, UConn, LLNL

Artificial Intelligence: MIT, CNU, Brunel U.

CENTRAL

Tracking:

- Silicon: China, Czech Republic, Japan

Calorimetry

- PWO and SciGlass: Czech Republic, Armenia, France
- Forward Calo/Dual Readout: China, Japan, South Korea

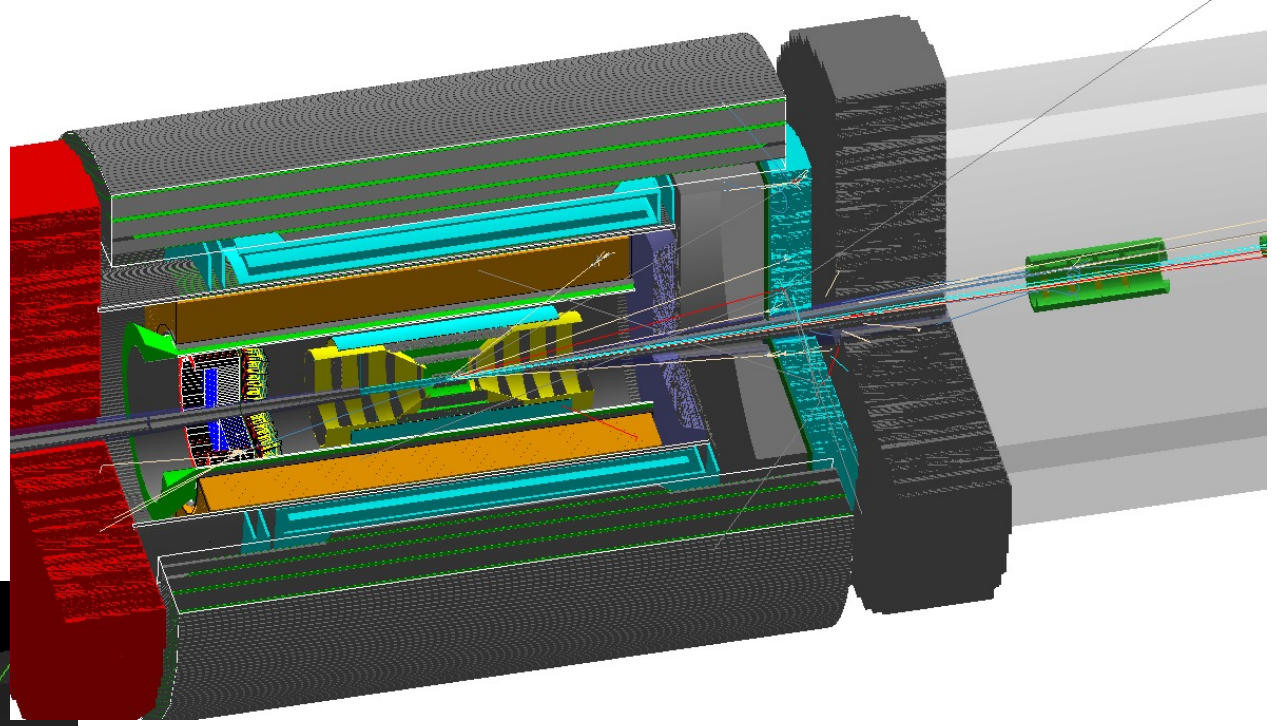
Particle ID

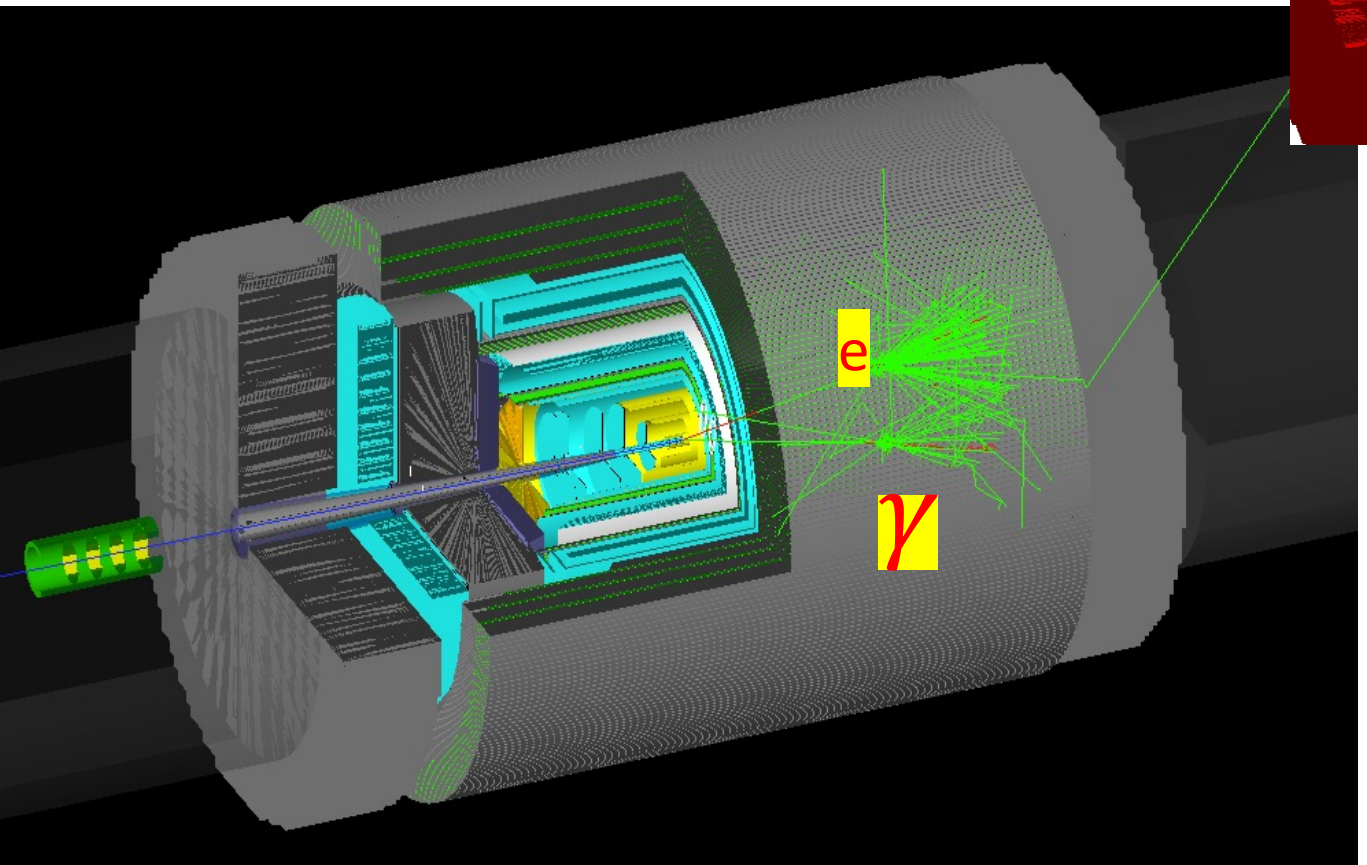
- DIRC: GSI/Germany

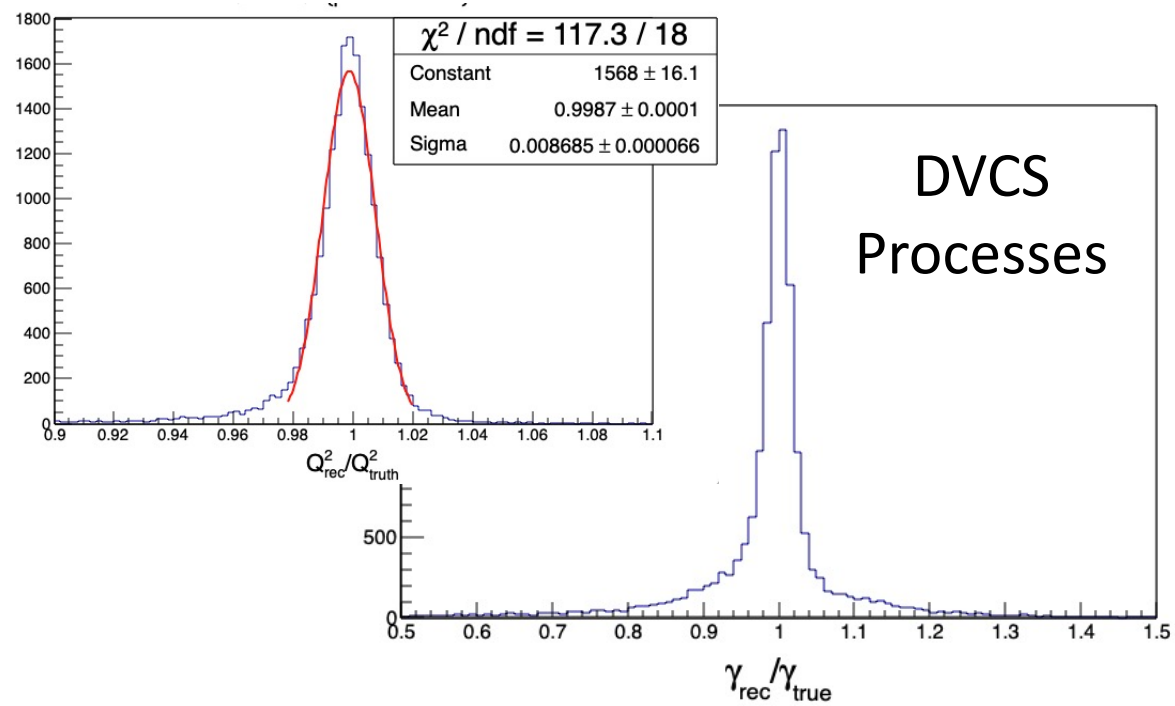
FAR FORWARD – FAR BACKWARD

- Roman pots: France
- Off momentum: Israel
- ZDC: Japan
- Luminosity monitors: Israel
- Low Q2 tagger: UK

G4 Simulations



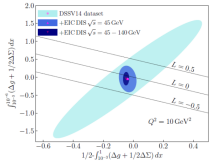




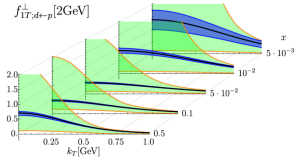
ECCE Physics Focus

Studies to demonstrate EIC NAS Study, Yellow Report physics

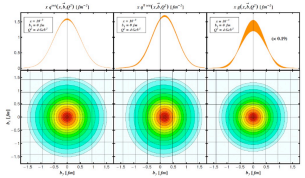
- Origin of Nucleon Spin



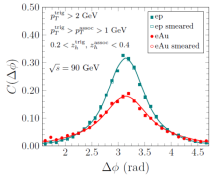
- Confined motion of partons



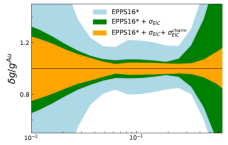
- 3D imaging of quarks and gluons



- Nucleon mass
- High gluon densities in nuclei

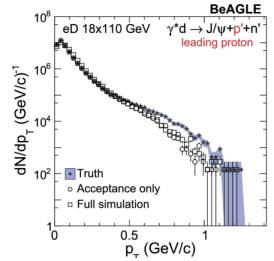


- Quarks and gluons in the nucleus

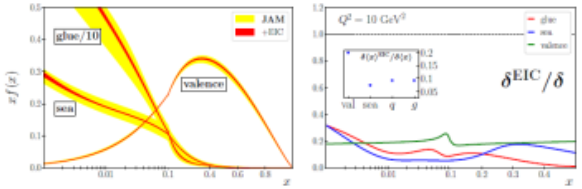


Studies to show unique ECCE strengths

- Light-ion tagging



- Pion/Kaon structure



- Diffractive jets?
- Nuclear modifications and in-medium evolution
  - D/D* reconstruction and heavy-flavor in jets.

ECCE Physics Focus

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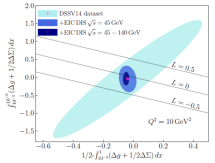
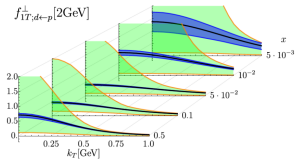
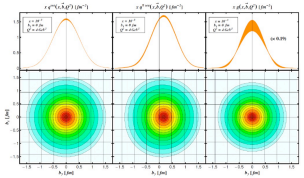
- Origin of Nucleon Spin



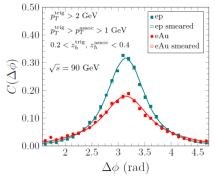
- Confined motion of partons



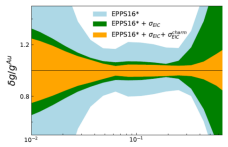
- **3D imaging of quarks and gluons**



- Nucleon mass
- High gluon densities in nuclei

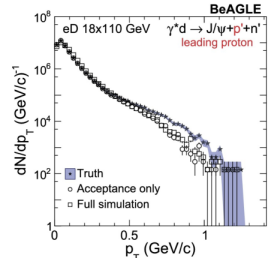


- Quarks and gluons in the nucleus

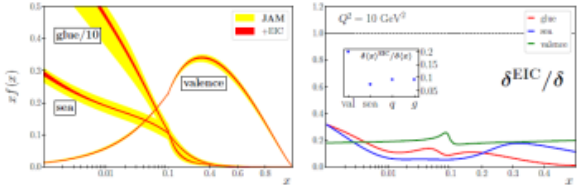


Studies to show unique ECCE strengths

- Light-ion tagging



- Pion/Kaon structure

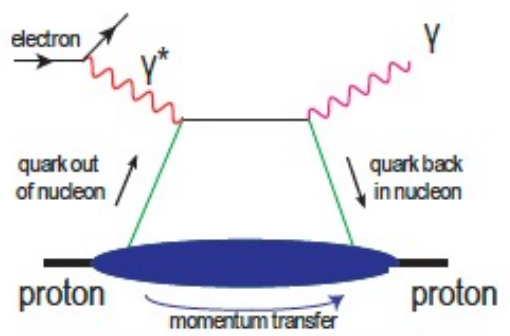


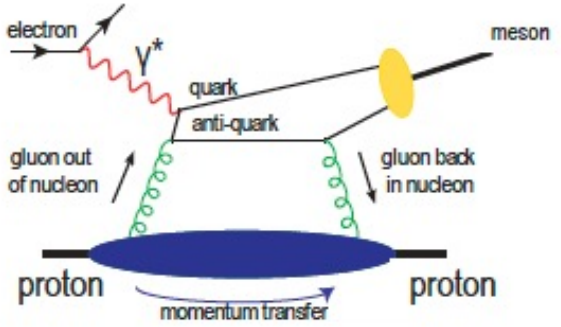
- Diffractive jets?
- Nuclear modifications and in-medium evolution
  - D/D* reconstruction and heavy-flavor in jets.

Exclusive Reactions Group

- priority studies:
  - DVCS ep (MIT, OU)
  - DVMP ep (VT, UoY, UConn)
- Key for GPD extraction.
- Crucial for multi-dimensional imaging of quarks and gluons inside nucleon
- Provide transverse position information

- Also studying:
  - DVCS eA (currently eHe) (UoG)
  - DVMP eA, currently phi production due to its sensitivity to gluon saturation (OU)
  - Coherent J/Psi production with eA (BNL) and related studies into incoherent backgrounds and p_t resolutions
  - High-Q^2 color transparency





real photon production from ep (left)

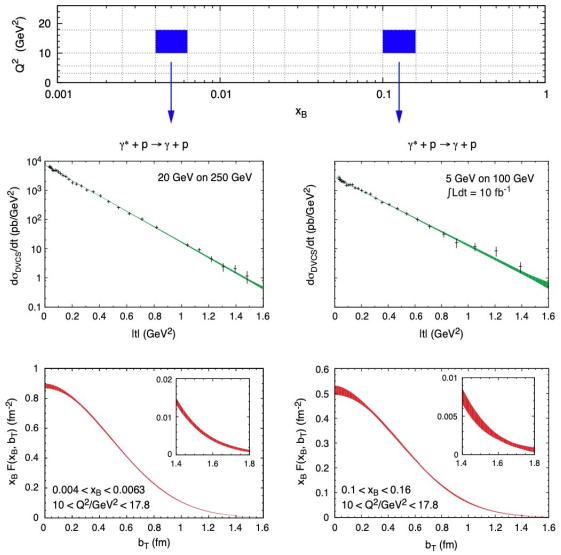


Figure 2.21: Top: The DVCS cross-section in two bins of x and Q^2. The error bars reflect statistical and assumed systematic uncertainties, but not the overall normalization uncertainty from the luminosity measurement. For the left panels the assumed luminosity is $10\,\mathrm{fb}^{-1}$ for $|t| < 1\,\mathrm{GeV}^2$ and $100\,\mathrm{fb}^{-1}$ for $|t| > 1\,\mathrm{GeV}^2$. Bottom: The distribution of partons in impact parameter b_T obtained from the DVCS cross-section. The bands represent the parametric errors in the fit of $d\sigma_{DVCS}/dt$ and the uncertainty from different extrapolations to the regions of unmeasured (very low and very high) t, as specified in Sec. 3.6 of [2].

J/Psi production from ep (right)

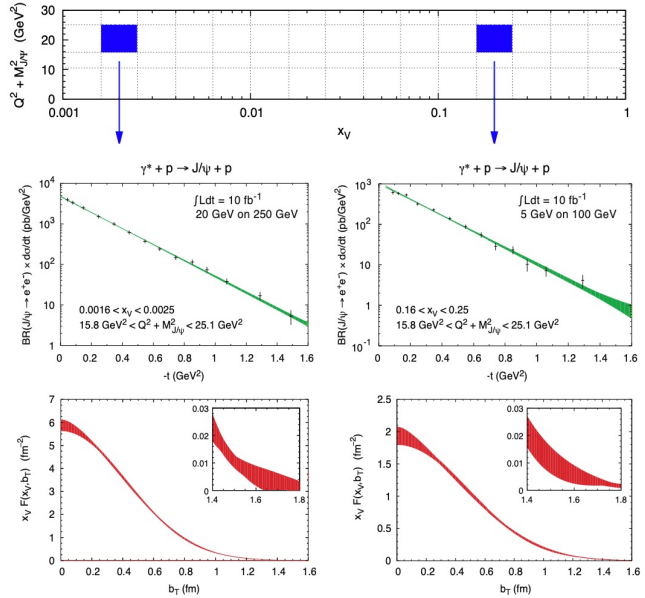


Figure 2.26: Top: cross-section for $\gamma^* p \to J/\Psi p$ in two bins of x_V and Q^2. Bottom: the distribution of gluons in impact parameter b_T obtained from the J/Ψ production cross section. The bands have the same meaning as in Figure 2.21.

Example: Virginia Tech group (M. Boër, C. Mariani, M. Pitt, K. Sanford, T. Schroeder)

New dedicated event generator
DEEPSim = **D**eep **E**xclusive **E**lectro- and **P**hoto-production **Sim**ulations (of mesons, photons...)

status, plans: public soon, then simulations, analysis, fits of GPDs for motivations, (polarized?)

Hard Exclusive (vector) Meson Production

Light vector mesons:
GPDs H & E, flavor decomposition...
$\rho^0 \rightarrow \pi\pi$
$\omega \rightarrow \pi\pi\pi^0$, $\pi^0\gamma$

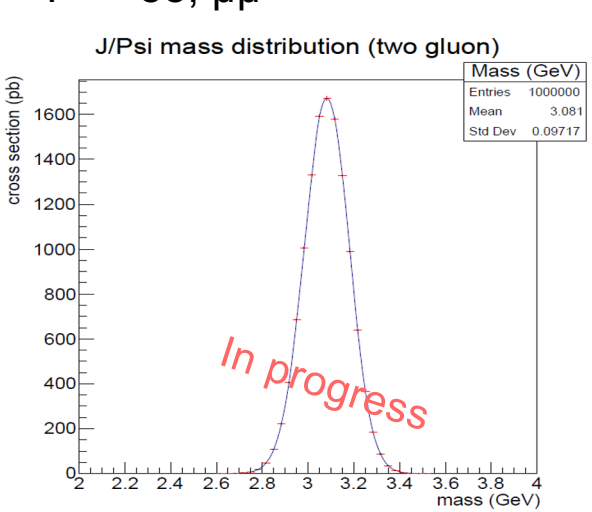
Quarkonia:
gluon GPDs, production mechanisms...
$J/\psi \rightarrow ee, \mu\mu, \pi\pi$
$\Upsilon \rightarrow ee, \mu\mu$

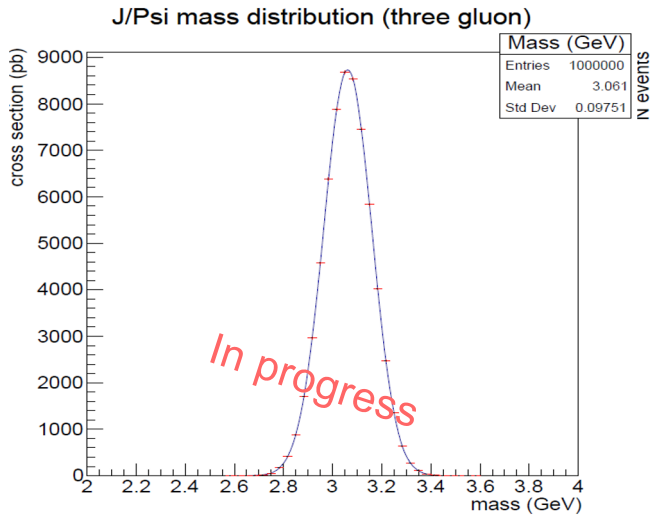
Deeply Virtual Compton-like Reactions

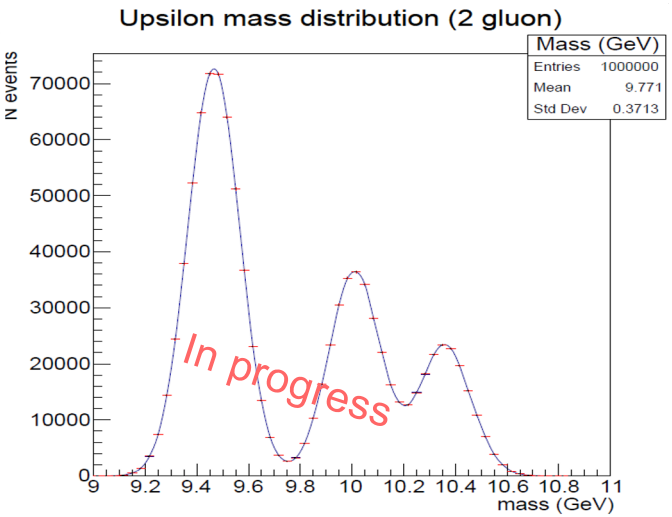
Timelike Compton Scattering (+BH)
GPDs universality, polarized observables...
$\gamma P \rightarrow ee$ (or $\mu\mu$) P' with quasi-real γ

Double Deeply Virtual Compton Scattering+BH
Nucleon tomography, angular effects...
$eP \rightarrow e' P' \mu\mu$

In progress !!





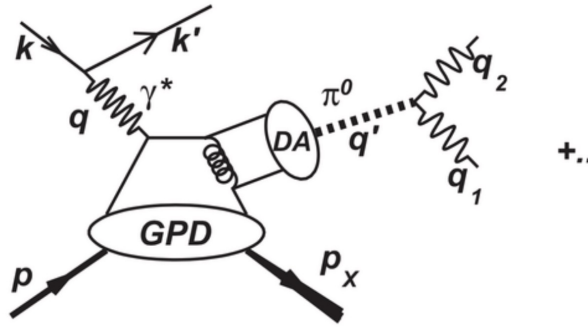


Figures: T. Schroeder (2021). based on generator "DEEPGen" from T. Schroeder, E. Wrightson, M. Boër

Deeply Virtual Exclusive Processes

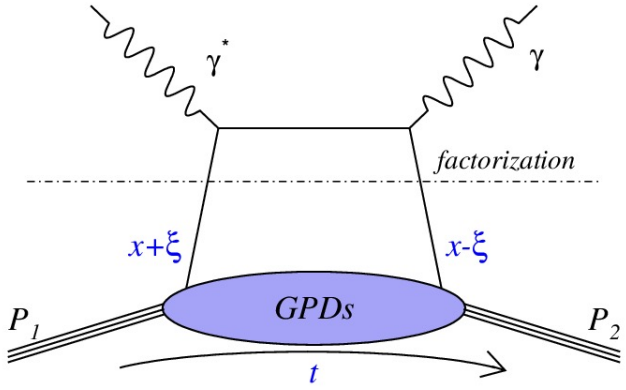
- Essential to establish experimentally in early EIC running the region of applicability of factorization.
- Need to separate $\sigma_L(t,Q^2)$ and $\sigma_T(t,Q^2)$ and verify Q^2 dependence follows factorization theorem predictions.

  How to do given limited ε reach? Complementarity with JLab!
- For DVCS, the goal is to isolate the QCD physics from QED.



Invariants

$$Q^2 = -(k-k')^2$$
$$x_B = Q^2/(2q\cdot P)$$
$$W^2 = (q+P)^2$$
$$t = (q-q')^2$$



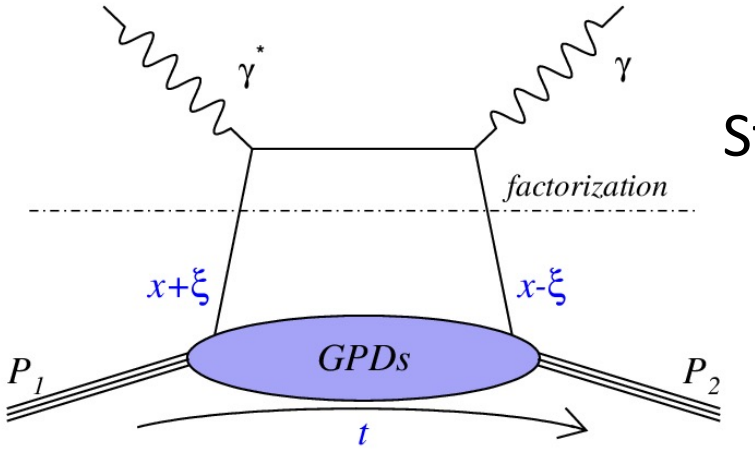
$\sigma_L \approx 1/Q^6$

$\sigma_T \approx 1/Q^8$

σ_T dominant

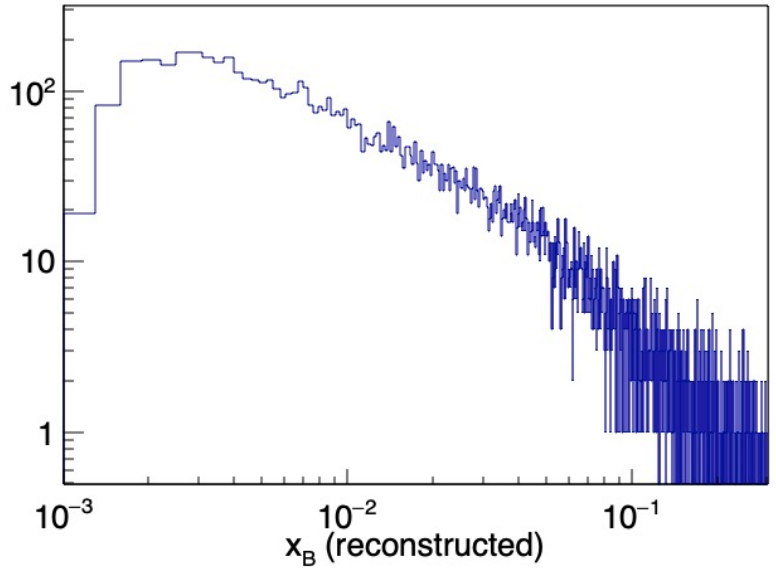
σ_{unpol}: BH, Int, DVCS contributions

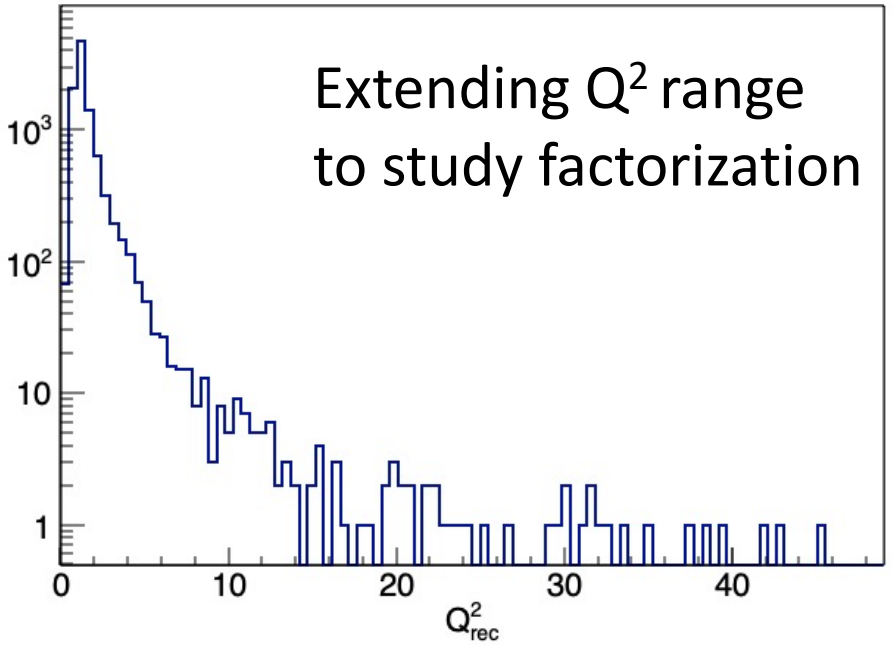
DVCS: ep → e'p'γ (5 x 41 GeV)



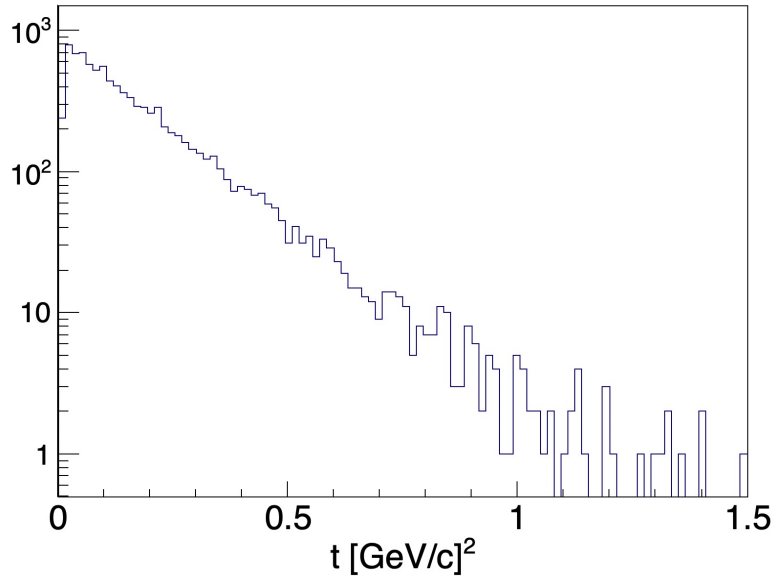
Study cross-section
Q^2 dependence

Low x_B to access gluonic GPDs





Extending Q^2 range
to study factorization

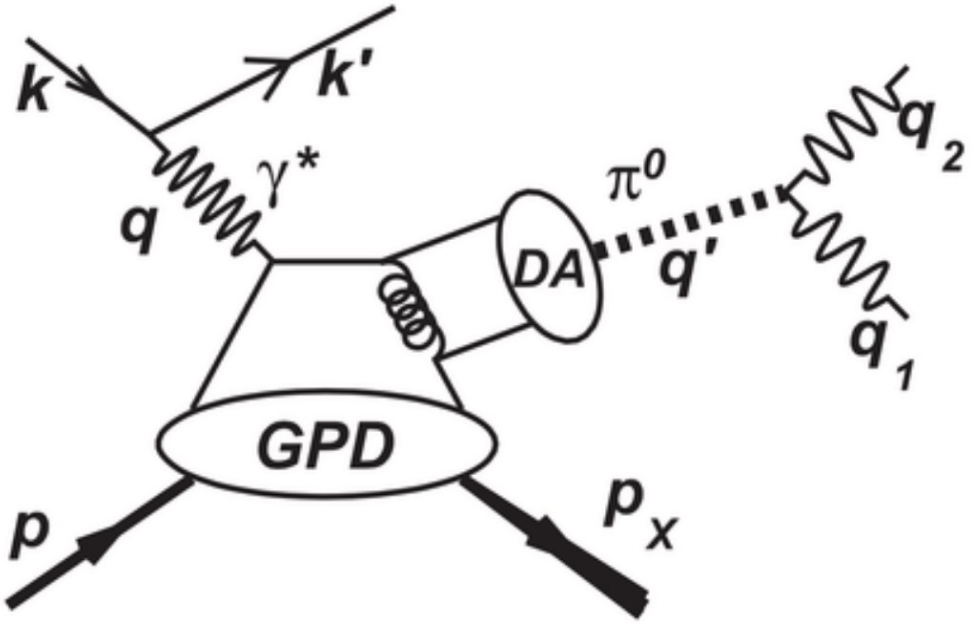


$$t = (p - p')^2 = (\gamma + e' - e)^2$$

DVMP: ep → e'p'π^0

- Background to DVCS process.
- Performing Rosenbluth separation

$$\frac{d^2\sigma}{dt\,d\phi_\pi} = \frac{1}{2\pi}\left[\left(\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt}\right) + \epsilon\cos 2\phi_\pi \frac{d\sigma_{TT}}{dt} + \sqrt{2\epsilon(1+\epsilon)}\cos\phi_\pi \frac{d\sigma_{LT}}{dt}\right].$$



Test for factorization

ECCE Future Highlights

- ❑ July 1st - Aug. 1st [1 month]:
  - Large scale simulations production
  - Drafting ‘collaboration structure’ part of the proposal by writing team.
- ❑ Aug. 1st - Sep. 15th [1.5 months]:
  - Analysis of simulation data to demonstrate physics extraction.
  - Presentation at August 2-6 EIC UG meeting
- ❑ Sep. 15th - Nov. 1st [1.5 months]:
  - All physics ‘plots’ are done.
  - Final evaluation of technology selection based on physics studies results.
  - Compose narrative around simulation results and selected technologies.
- ❑ Nov. 1st - Nov. 30th [1 month]:
  - Proposal review by external colleagues.
  - Final edits

Conclusions

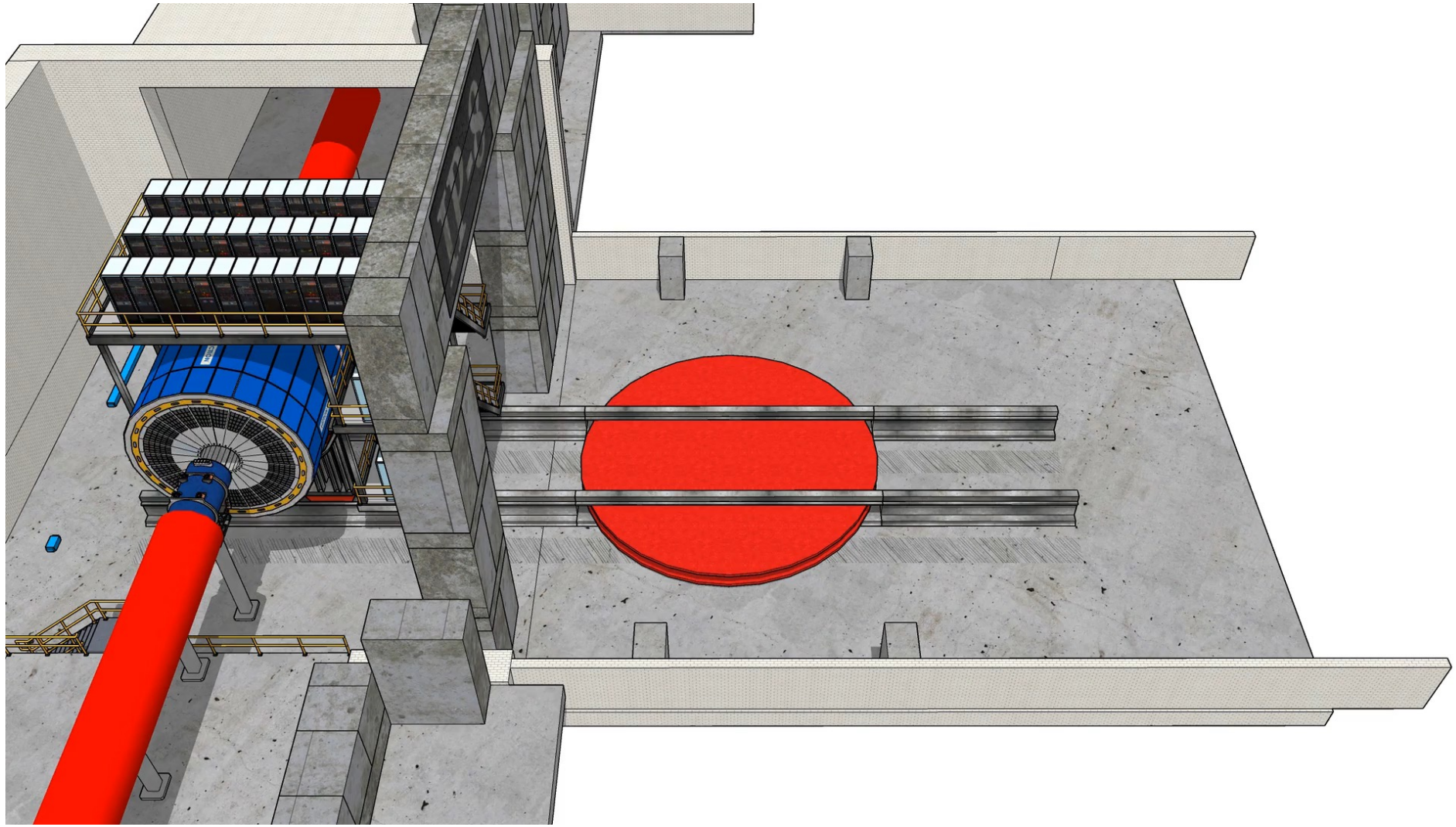
- The ECCE consortium consists of 80 institutions working to design the EIC project detector based around the BaBar solenoid
- ECCE plans to be ready for physics by EIC CD4a for start of machine operations.
- The physics program spans the entirety of that outlined in the NAS study and the Yellow Report
- The detector design process is fully underway, in tandem with a wide range of full physics simulations
- MANY ways to get involved!

www.ecce-eic.org

Why ECCE ?

ECCE is a low-risk, cost-effective, flexible and optimized EIC detector!

- **Low risk** due to re-use of existing magnet and various detectors.
- **Cost-effective** due to magnet and detectors reuse.
- **Flexible and optimized** by studying both IRs.
- **Most realistic detector to be ready by CD4a.**

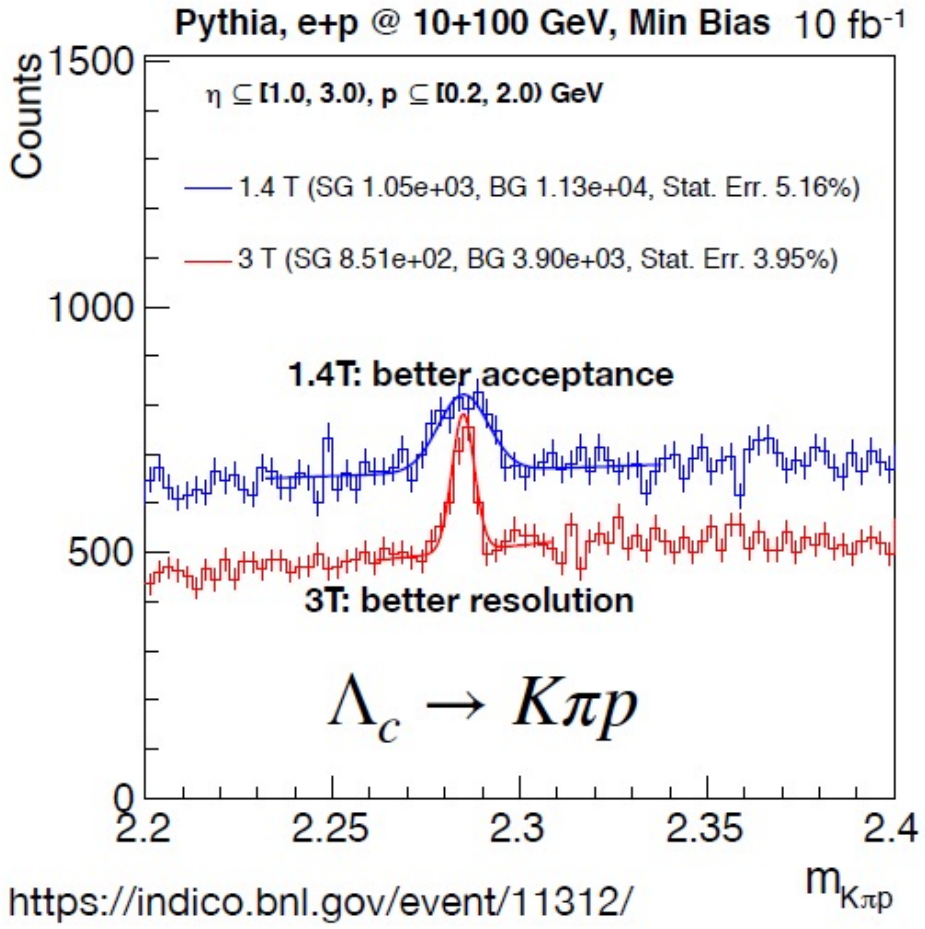


CCCE Consortium

1. AANL/Armenia
2. AUGIE
3. BGU/Israel
4. BNL
5. Brunel University
6. Canisius College
7. CCNU/China
8. Charles U./Prague
9. CIAE
10. CNU
11. Columbia
12. CUA
13. Czech. Tech. Univ.
14. Duquesne U.
15. Duke
16. FIU
17. Georgia State
18. Glasgow/Scotland
19. GSI/Germany
20. GWU
21. Hampton
22. HUJI
23. IJCLab-Orsay
24. IMP/China
25. Iowa State
26. IPAS/Taiwan
27. JLab
28. Kyungpook Natl. Univ.
29. LANL
30. LBNL/Berkeley
31. Lehigh University
32. LLNL
33. Morehead State
34. MIT
35. MSU
36. NCKU/Taiwan
37. NCU/Taiwan
38. NMSU
39. NRNU MEPhI/Russia
40. NTHU/Taiwan
41. NTU/Taiwan
42. ODU
43. Ohio U
44. ORNL
45. PNNL
46. Pusan Natl. Univ.
47. Rice
48. RIKEN/Japan
49. Rutgers
50. Saha / India
51. SBU
52. SCNU/China
53. Sejong U.
54. TAU/Israel
55. Tsinghua U./China
56. Tsukuba U./Japan
57. CU Boulder
58. UCAD
59. UConn
60. UH
61. UIUC
62. U. Kansas
63. UKY
64. U. Ljubljana/Slovenia
65. UNH
66. University of Regina
67. USTC/China
68. UT Austin
69. UTK
70. UTSM/Chile
71. UVA
72. Vanderbilt
73. Virginia Tech
74. Virginia Union
75. Wayne State
76. WI/Israel
77. WM
78. Yonsei Univ.
79. York
80. Zagreb U./Croatia

*Non-US institutions (36%)

Heavy Flavor in ECCE



Recent Study by Wenqing Fan (LBNL)

- *Fast simulation of PID, based on YR specifications*
- *Parallel effort ongoing with full detector G4 simulations*