Physics Potential with the Barrel Imaging Calorimeter

KHEP 2024 Spring Meeting

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Outline

- Key Physics Questions with Electro-Ion Collider

- Electron-Ion Collider

- ePIC Experiment

- DIS Processes

- Barrel Calorimeter Requirement

- Performance of the Barrel Imaging Calorimeter (BIC)

- Physics potential with the BIC

- Summary

Key science questions

SCIENCE REQUIREMENTS
AND DETECTOR
CONCEPTS FOR THE
ELECTRON-ION COLLIDER

EIC Yellow Report

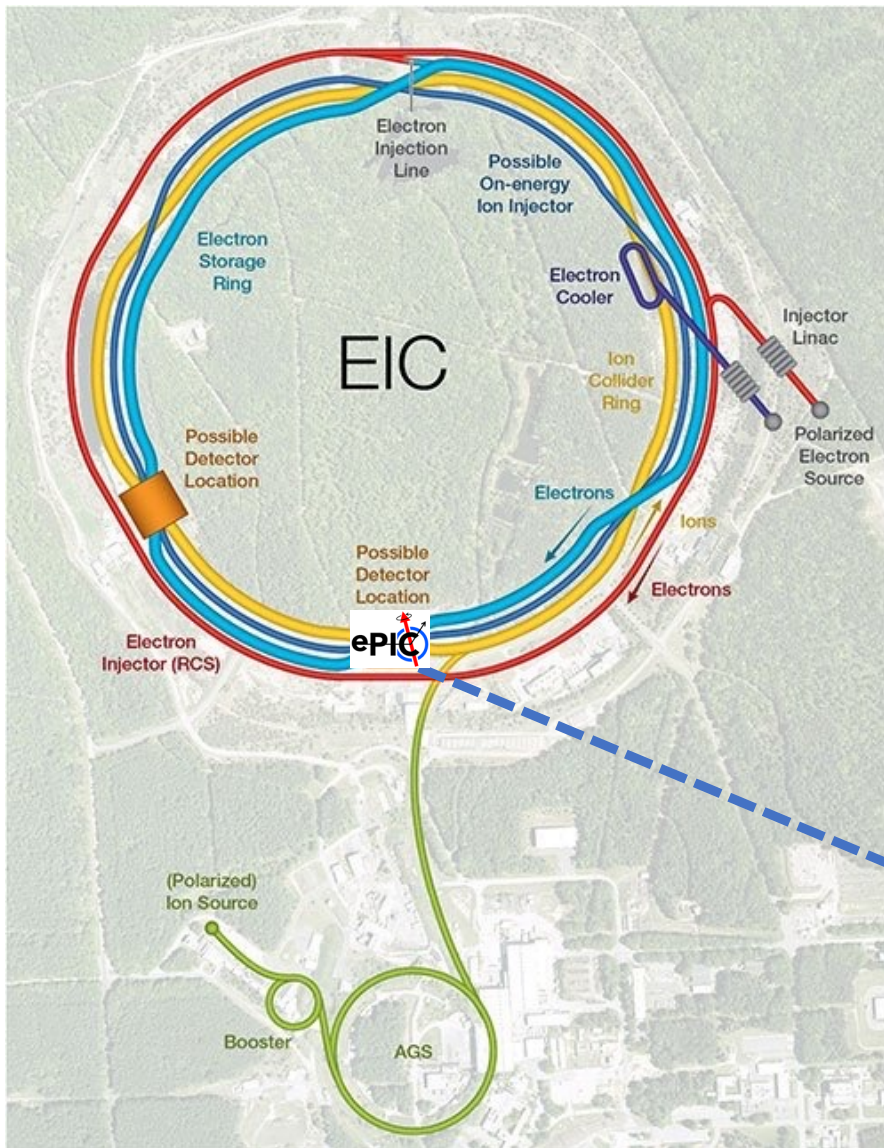- Emergence of the nucleonic mass/spin

- Parton distributions inside nucleon in
  - momentum and coordinate space
- Gluon saturation
- Nuclear modification of PDF
- Colour charge through Cold Nuclear Matter
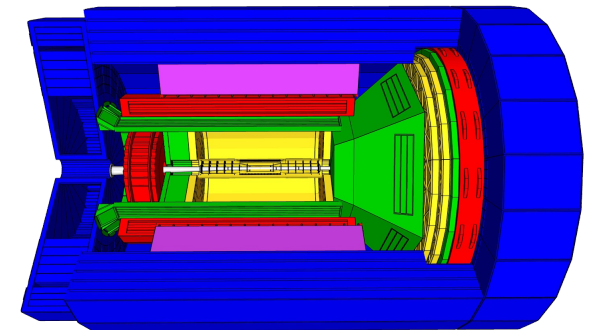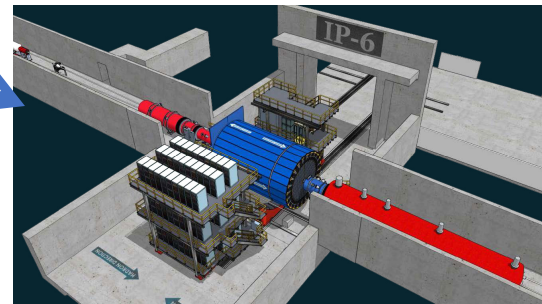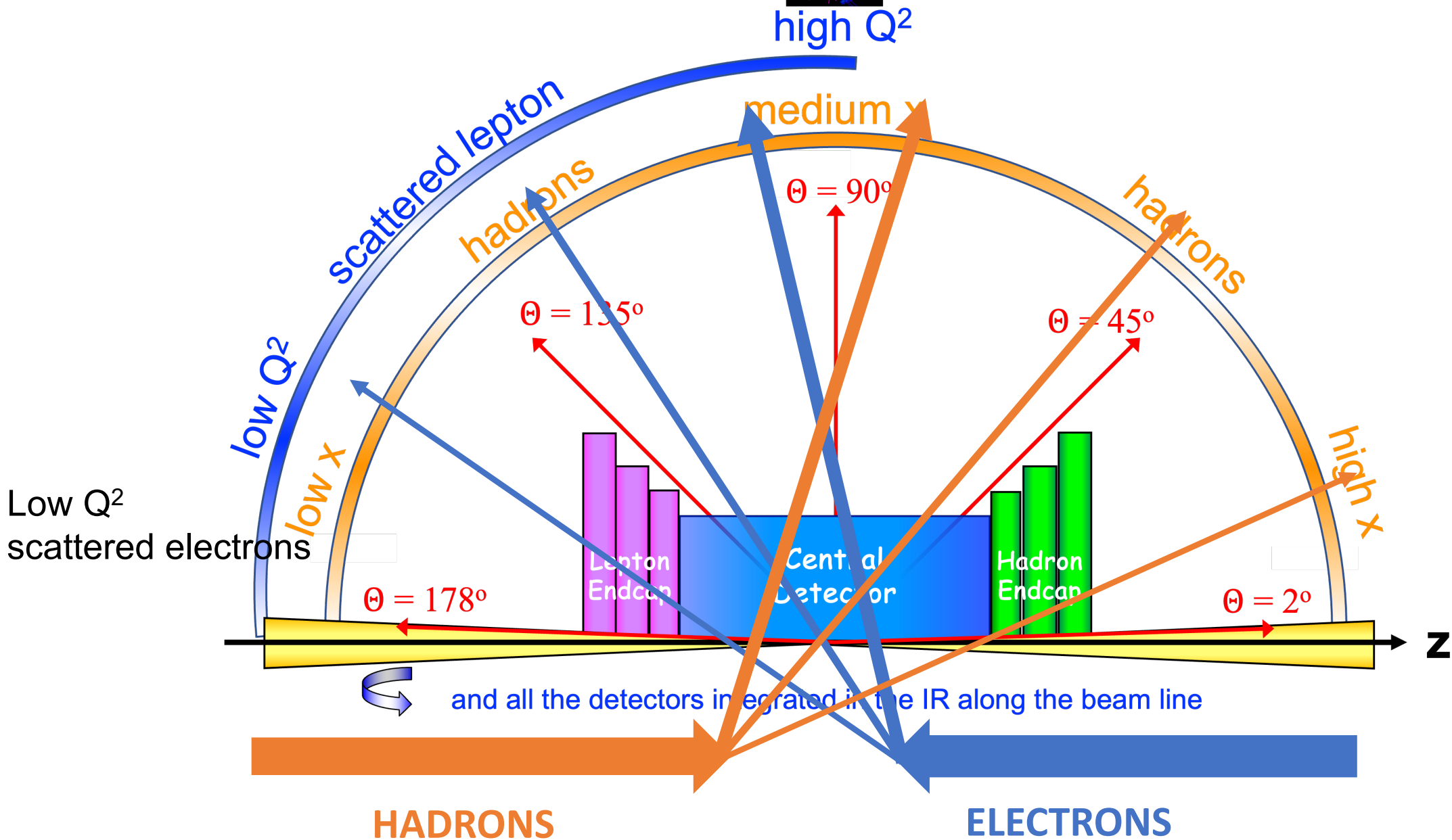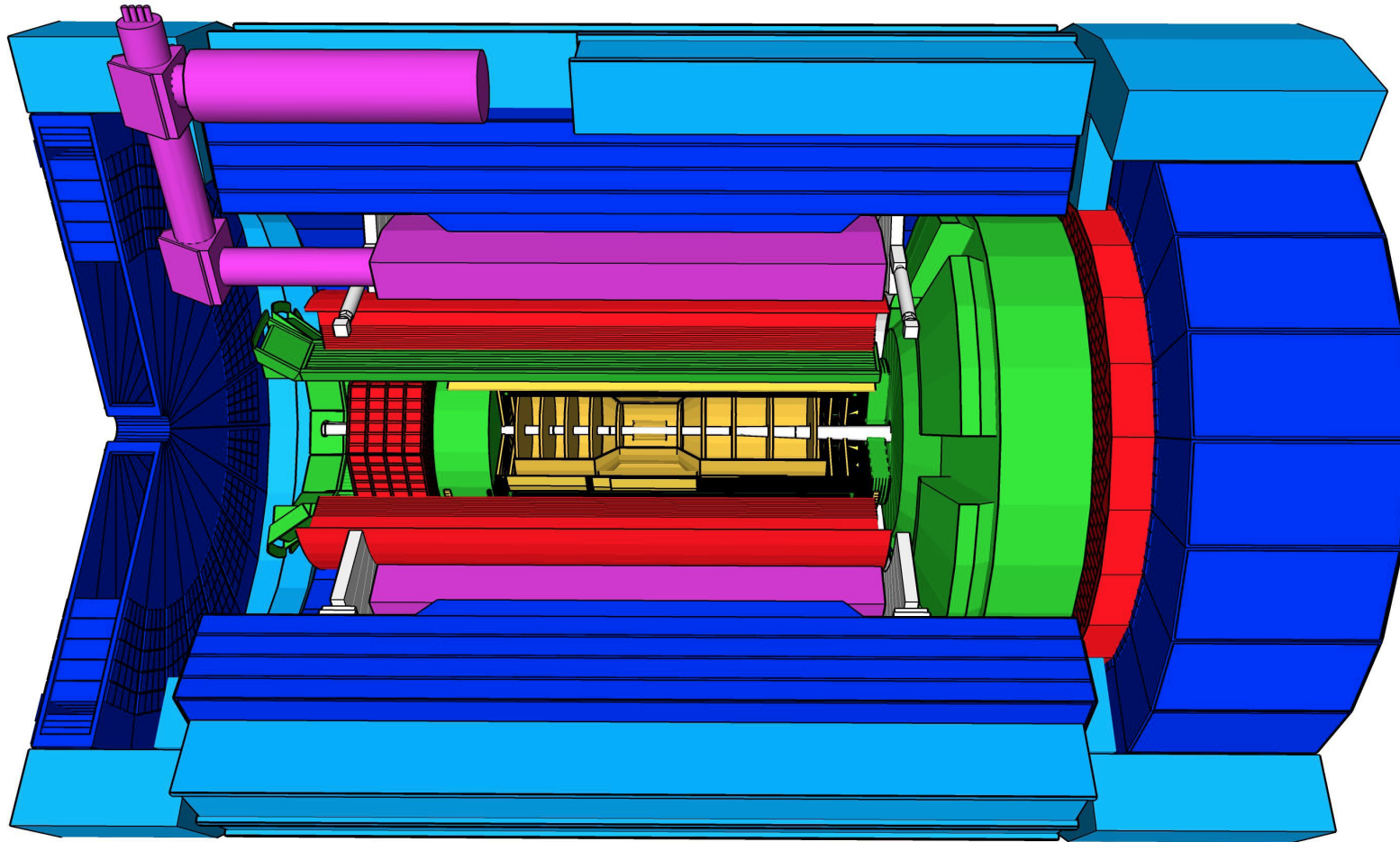
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The Electron-Ion Collider (EIC)

- Polarization ~ 70%
  - $e^\uparrow + p^\uparrow$, $d^\uparrow$, $He^\uparrow$
  - $e^\uparrow$ + unpolarized ions up to U.
- $\mathcal{L} = 10^{33-34} \text{cm}^{-2}\text{s}^{-1}$

  $\leftrightarrow \mathcal{L}_{int} = 10-100 \text{ fb}^{-1}/\text{year}$
- h: 41-275 GeV, e: 5-18 GeV
- The first experiment "ePIC"

EIC General Purpose Detector: Concept

Detectors for ePIC

Magnet
Tracking
Particle Identification
Electromagnetic Calorimeter
Hadronic Calorimeter
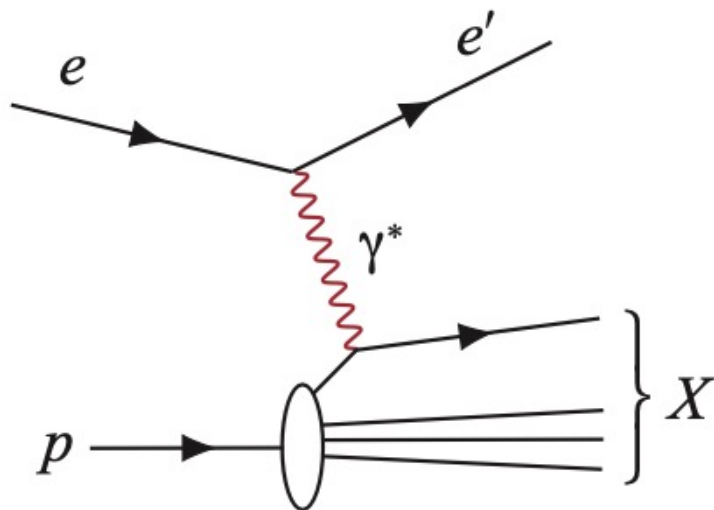
Coverage
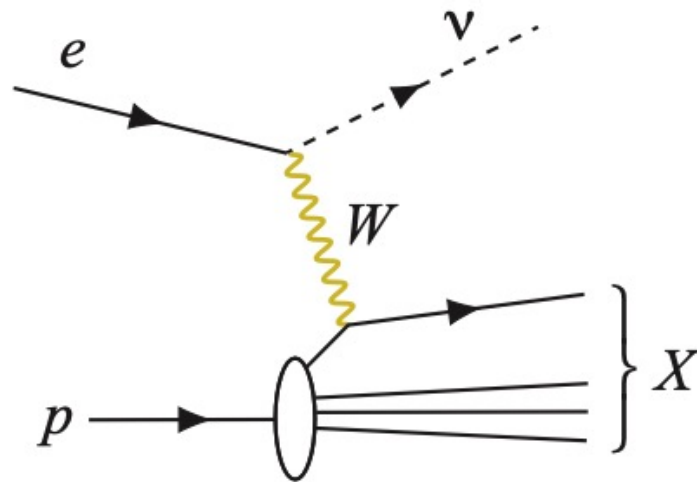ϕ:360°   2°<θ<178°   -4<η<4

HADRONS

ELECTRONS

DIS processes

Neutral-current Inclusive DIS
$$e + p/A \rightarrow e' + X$$

Charged-current Inclusive DIS
$$e + p/A \rightarrow \nu + X$$

Semi-Inclusive DIS
$$e + p/A \rightarrow e' + h^{\pm,0} + X$$

Exclusive DIS
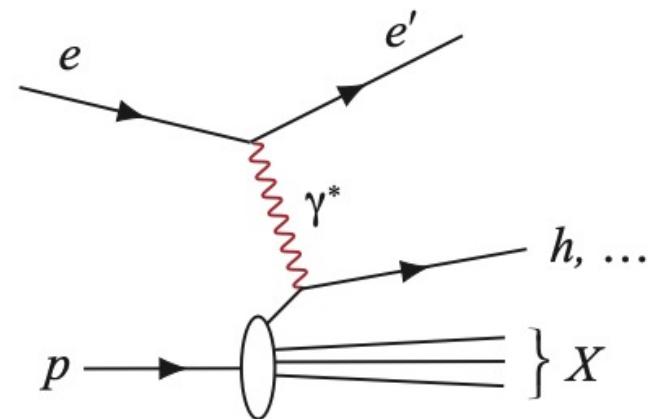$$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$$
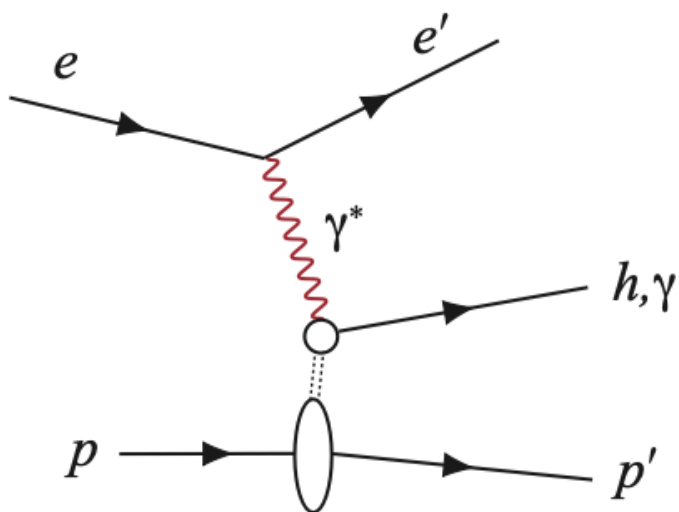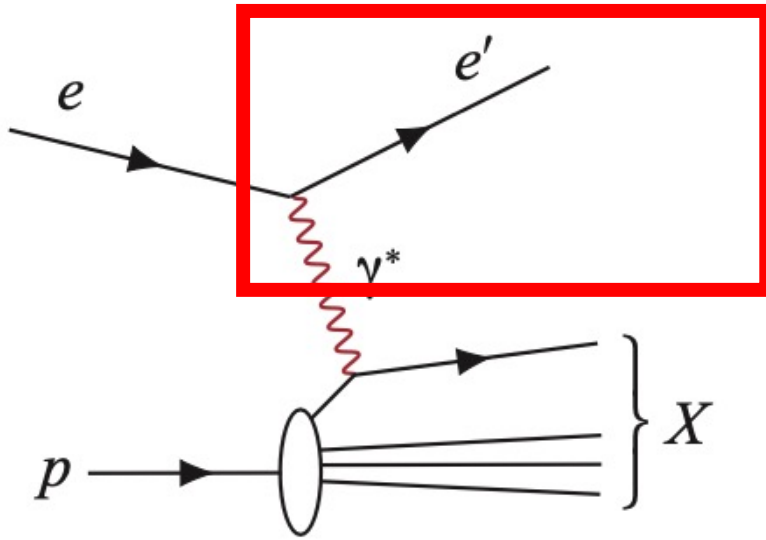
Barrel Calorimeter Requirement

Neutral-current Inclusive DIS
$$e + p/A \rightarrow e' + X$$

Charged-current Inclusive DIS
$$e + p/A \rightarrow \nu + X$$

Semi-Inclusive DIS
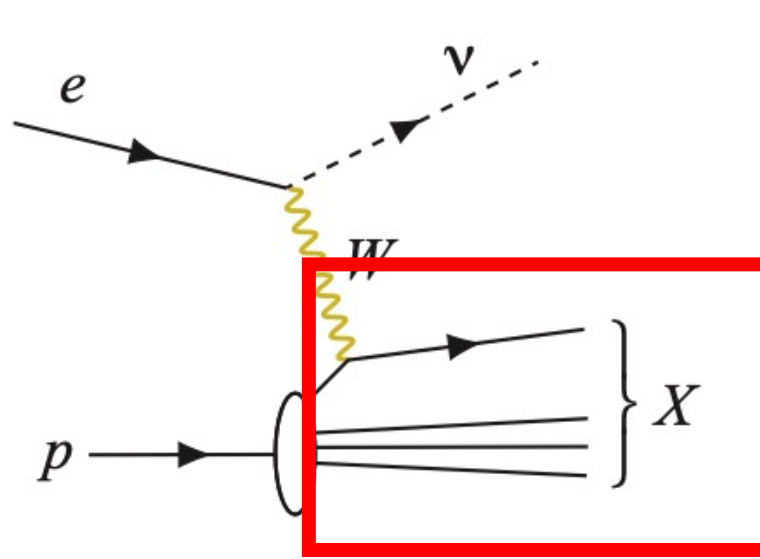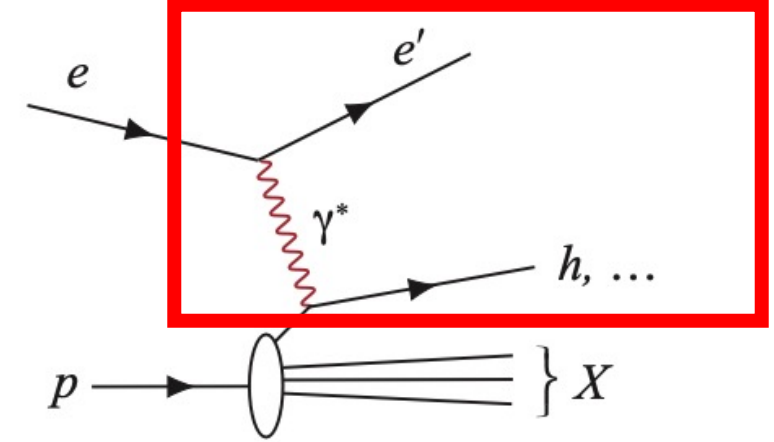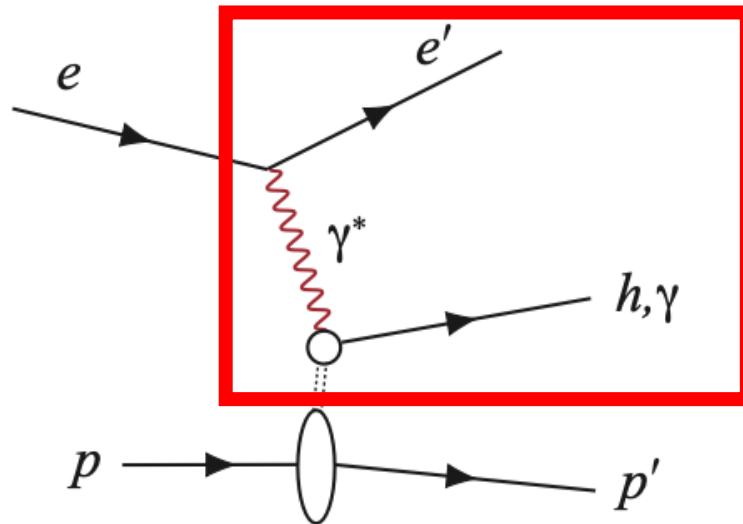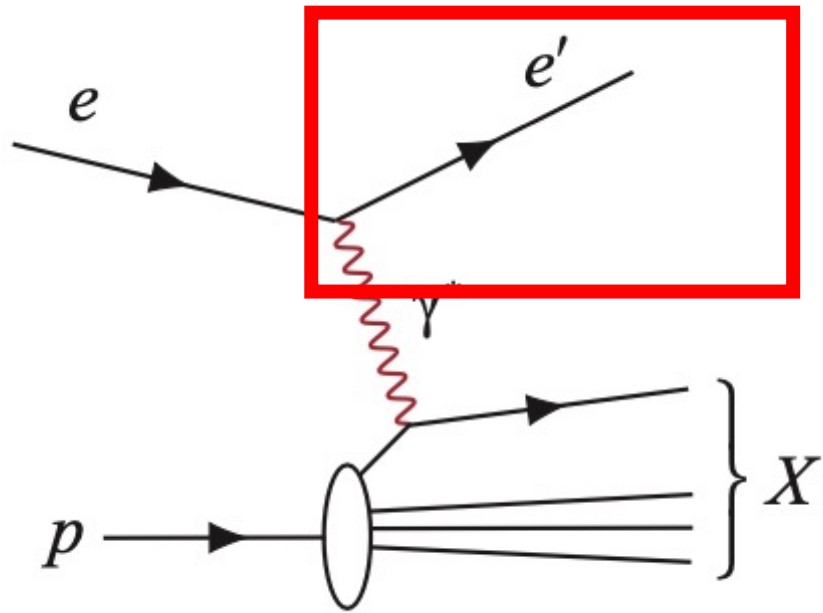$$e + p/A \rightarrow e' + h^{\pm,0} + X$$

Exclusive DIS
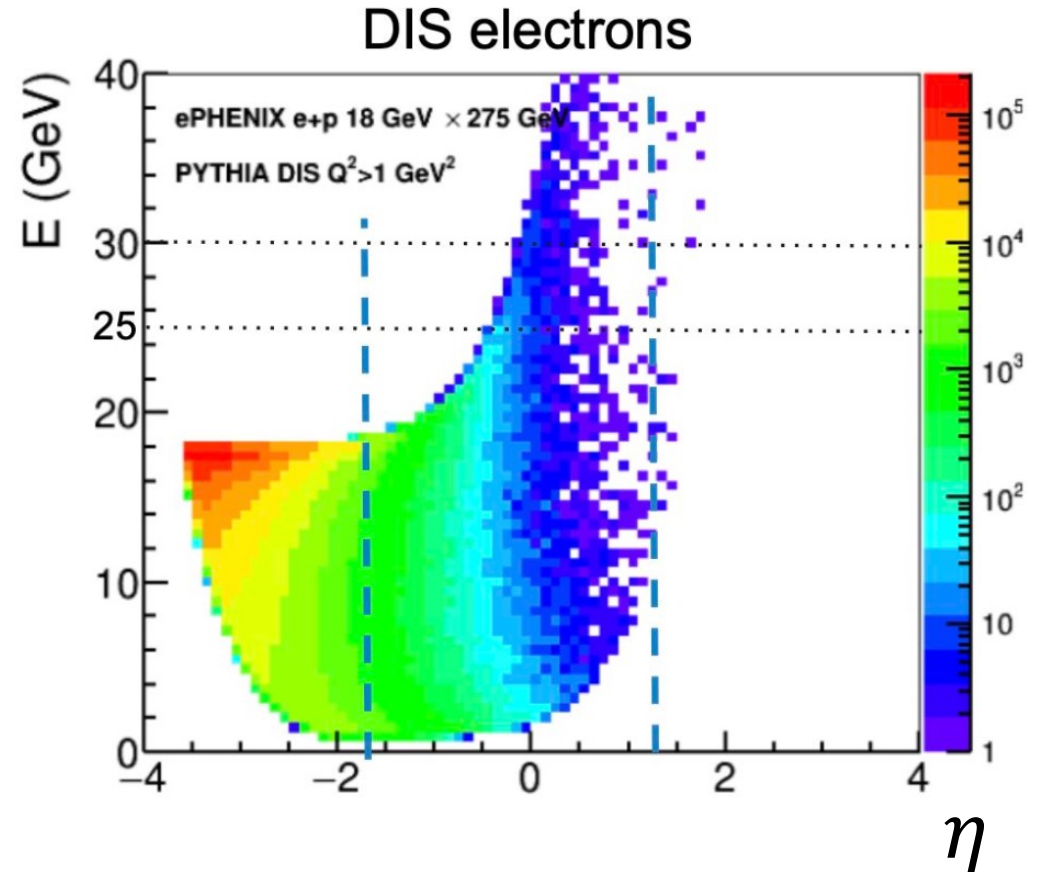$$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$$

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Barrel Calorimeter Requirement

- Inclusive DIS
  - Up to 10^4 π^- background suppression at low momenta in the barrel
- General: $100 \text{ MeV} < \gamma \text{ energy} < 10 \text{ GeV}$

Neutral-current Inclusive DIS
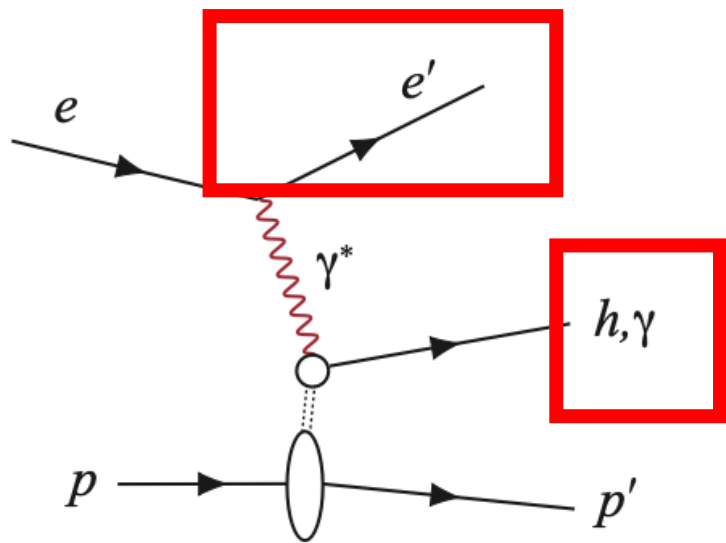
$e + p/A \rightarrow e' + X$
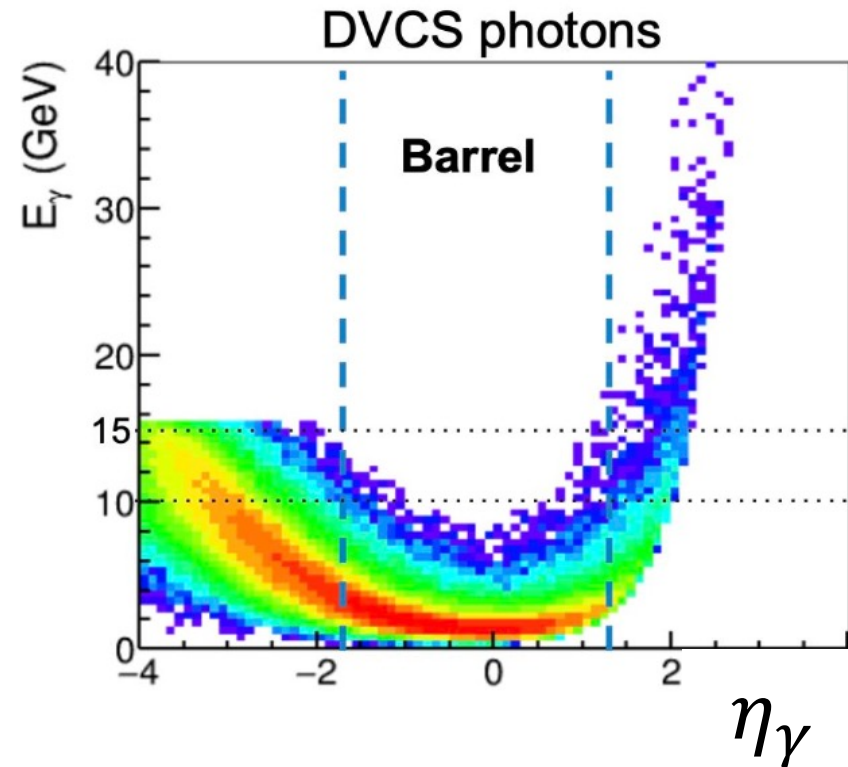
Barrel Calorimeter Requirement

- Exclusive DIS (DVCS)
  - Up to 10^4 π^- background suppression at low momenta in the barrel
  - Good energy resolution ($<7\text{-}10\%/\sqrt{E} \oplus (1\text{-}3\%)$
  - Fine granularity for good π^0/γ separation up to 10 GeV
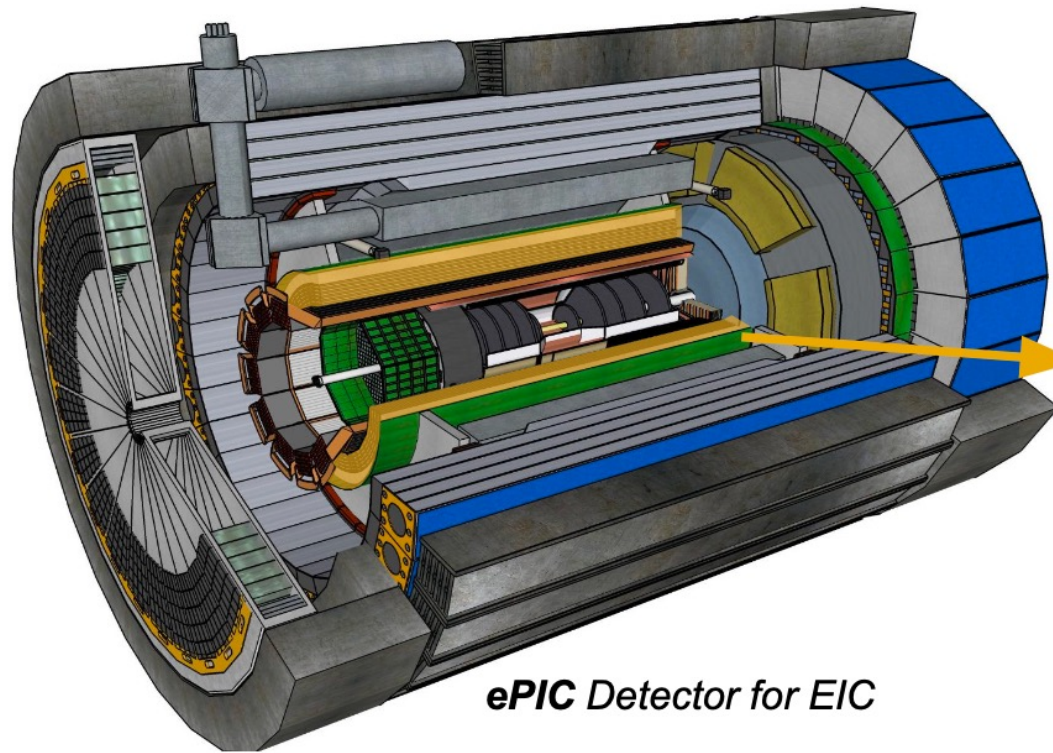

Exclusive DIS

$$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$$

DVCS photons

Barrel Imaging Calorimeter
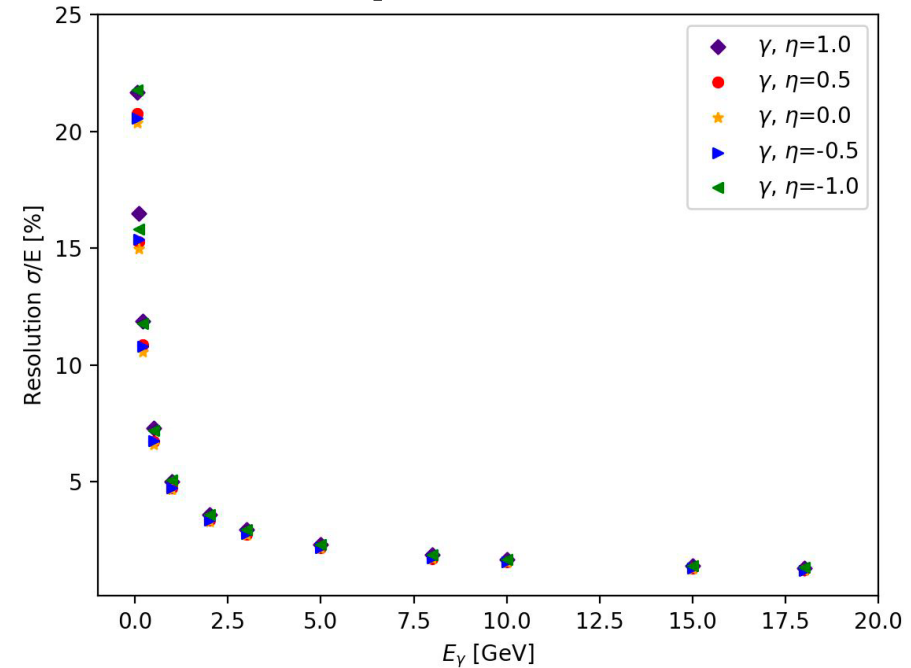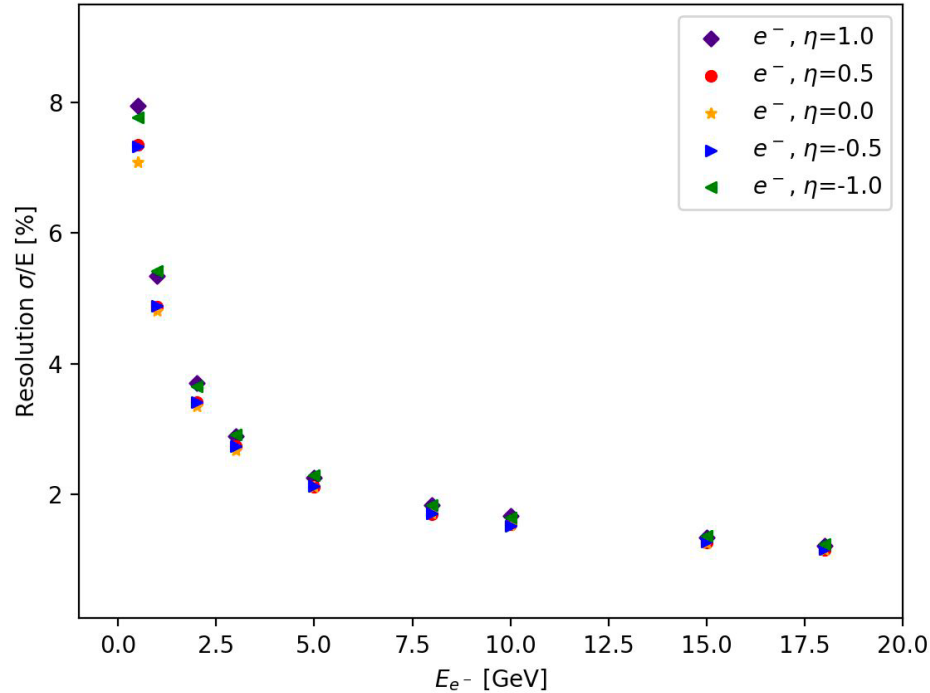

ePIC Detector for EIC
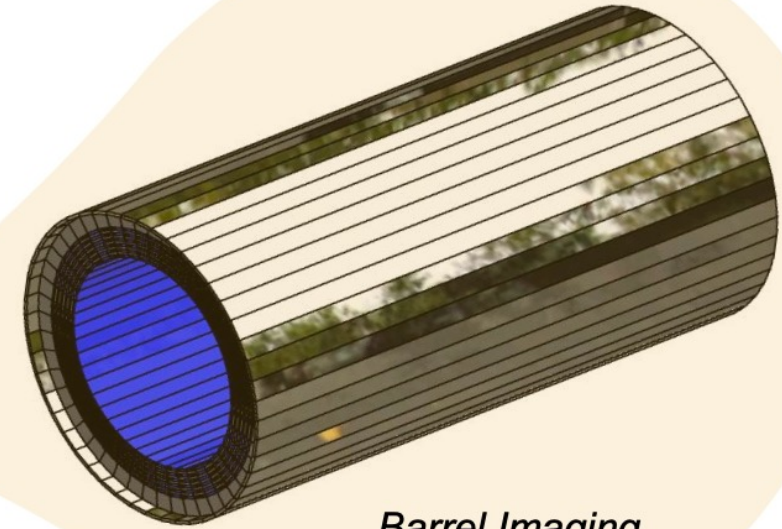
Barrel Imaging
Calorimeter

Solution: Hybrid SciFi/Pb calorimeter with a silicon tracker to precisely measure 3D image of electromagnetic shower

BIC Performance: Energy Resolution

electron

photon

- Resolution extracted from a Crystal Ball fit σ

- GlueX Pb/ScFi ECal: σ = 5.2% /√E ⊕ 3.6% *NIM, A 896 (2018) 24-42*

BIC Performance: electron/pion separation
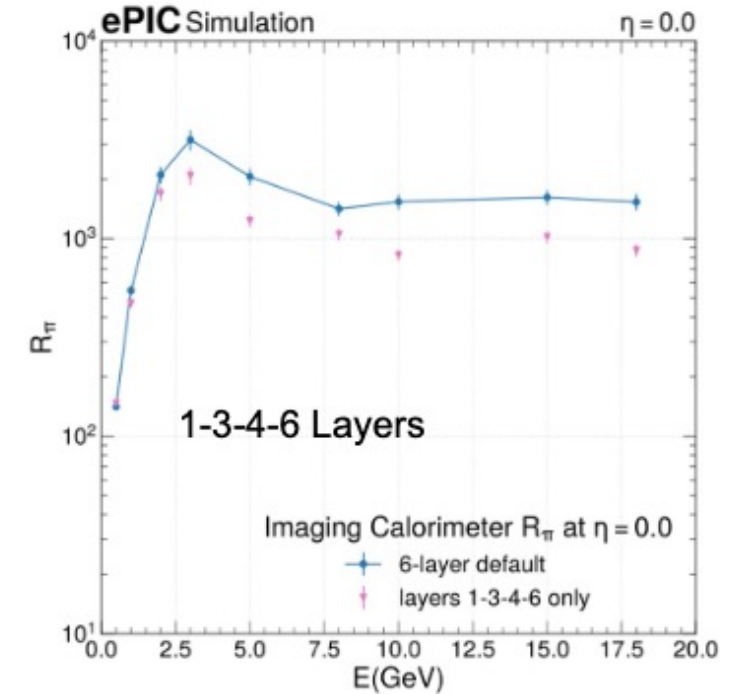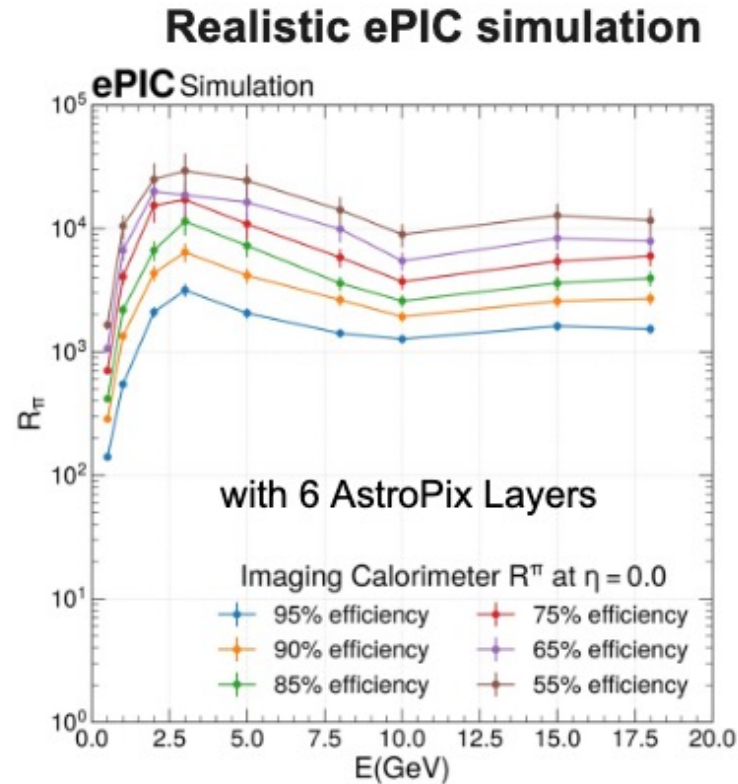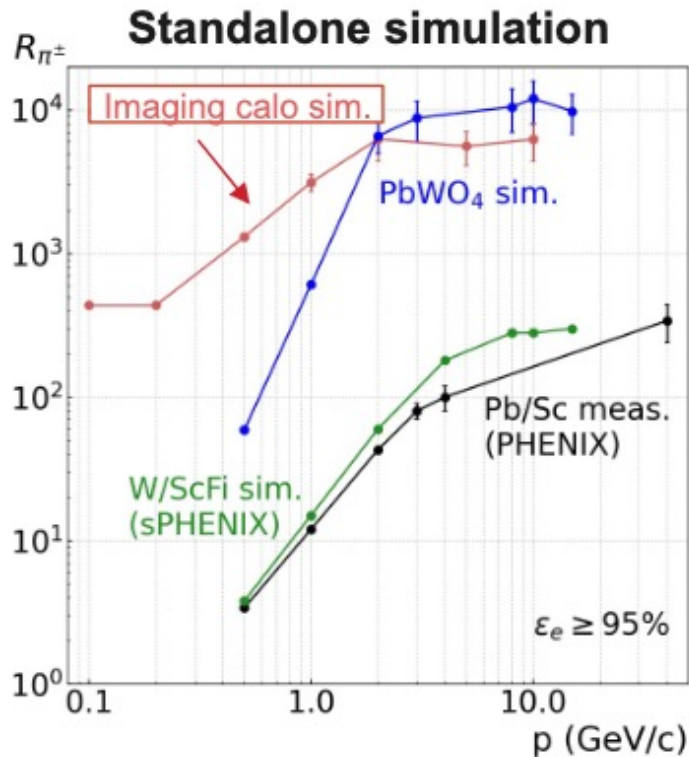
- Separation of electrons from background in Deep Inelastic Scattering (DIS) processes

- Method: E/p cut (Pb/ScFi) + NN using 3D position and energy info from imaging layers

- e-π separation exceeds 10^3 in pion suppression at 95% efficiency above 1 GeV

BIC Performance: Neutral Pion Identification

15 GeV $\pi^0 \to \gamma\gamma$

Separation of γ/π^0 (upper limit)

$\gamma\gamma$ Merging Probability of π^0 decay at R = 0.8 m

- Imaging Calo [6.0 × FWHM of Hits Distribution]
- $PbWO_4$ [20 mm]
- TF1 [38 mm]
- Shashlyk [55 mm]
- Shashlyk [110 mm]
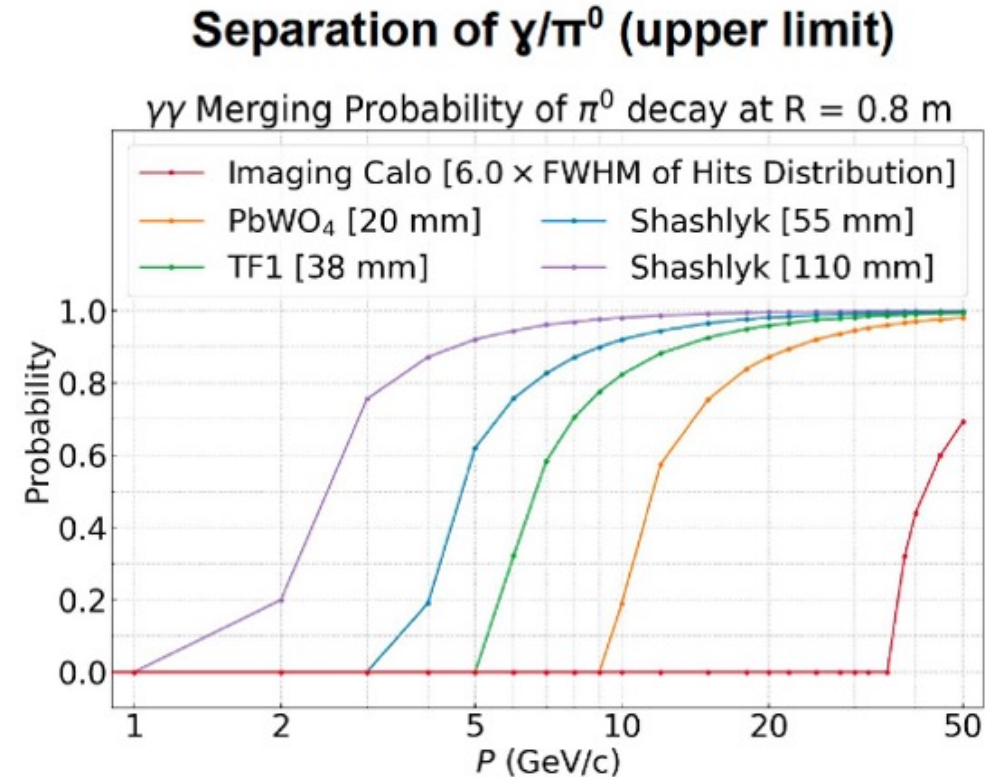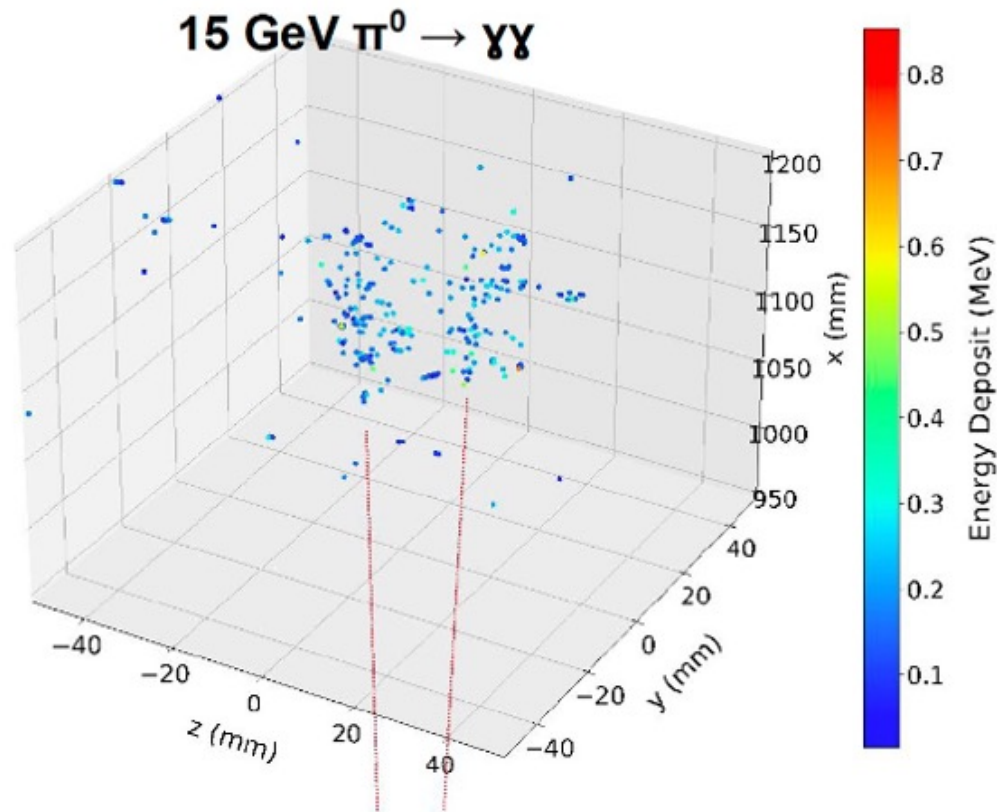
- Separation of two gammas from neutral pion well above required 10 GeV

- Discriminate between π^0 decays and single γ from DVCS, π^0 identification

- Precise position resolution allows for excellent separation of γ/π^0 based on 3D shower profile

Physics potential with BIC

Neutral-current Inclusive DIS

$$e + p/A \rightarrow e' + X$$

BIC Requirement: 7-10%/$\sqrt{E}$ $\oplus$ (1-3%
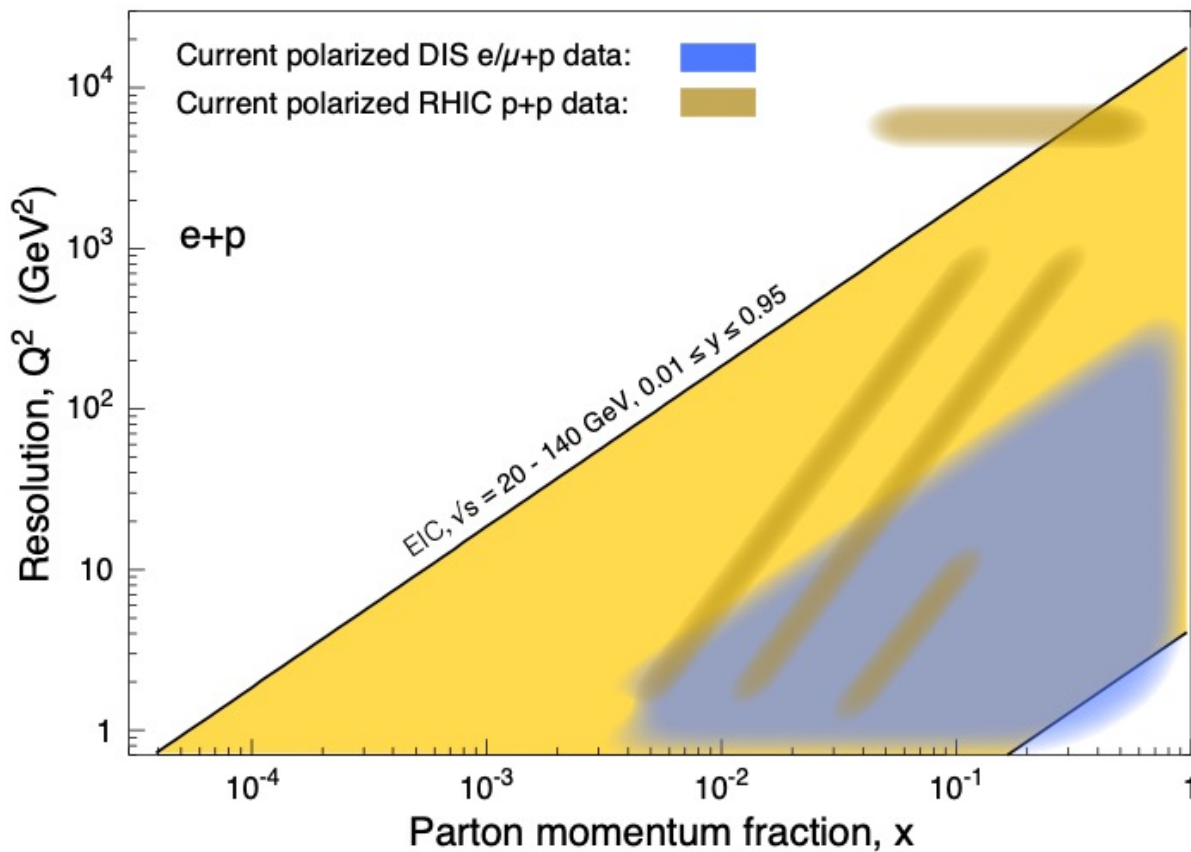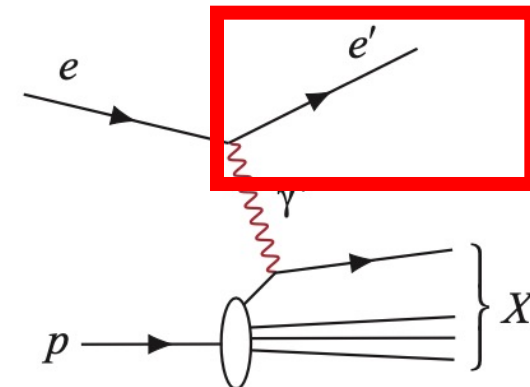
BLUE: CERN, DESY, Jlab, SLAC

BLUE: World data

Physics potential with BIC

Wigner function → QCD genetic map
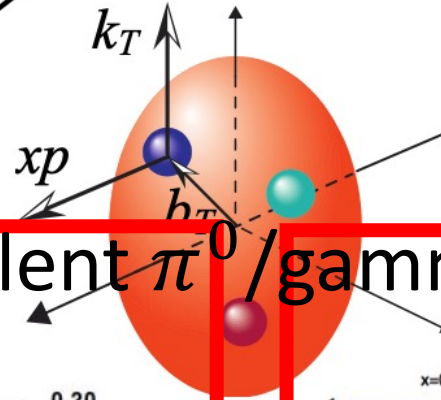
$$W(x, b_T, k_T)$$

Momentum space

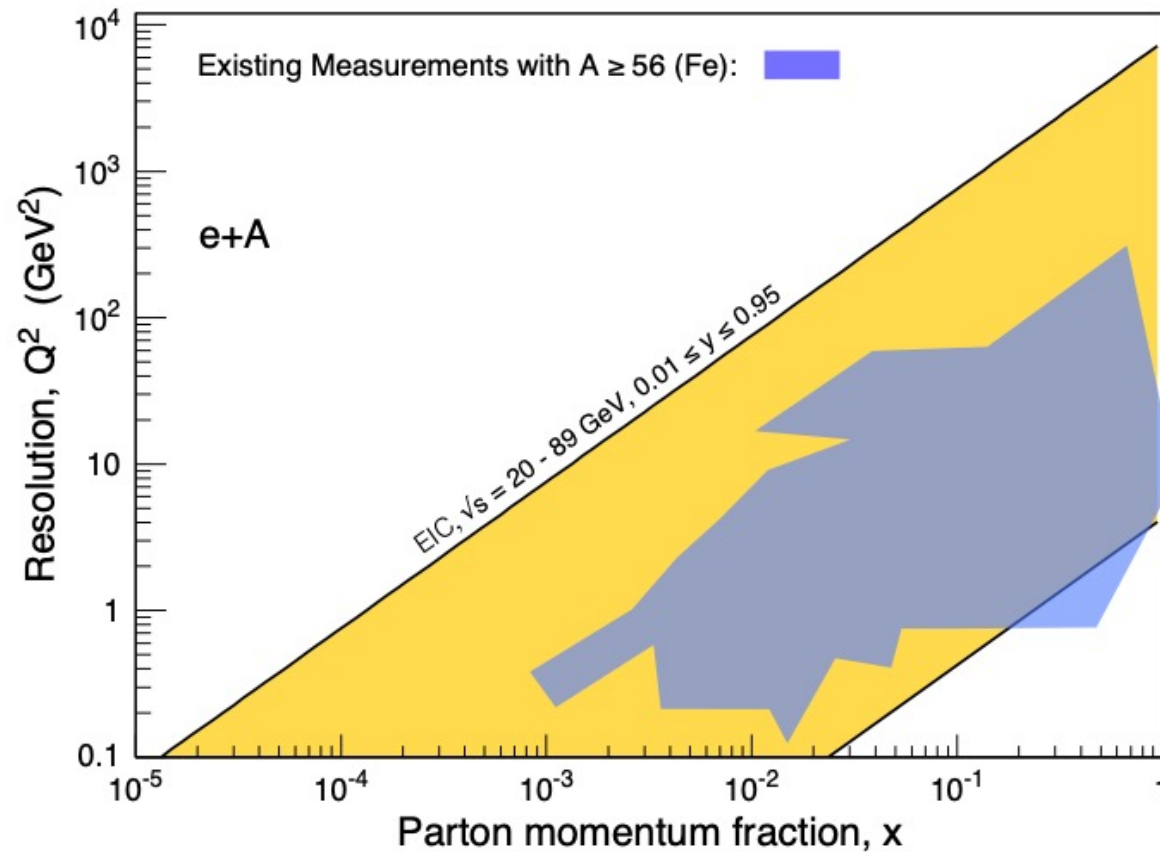$\int d^2 b_T$

Coordinate space

$\int d^2 k_T$

k_T

xp

b_T

Quarks

$f(x, k_T)$

$f(x, b_T)$

BIC: Excellent π^0/gamma seperation

Quarks

up

down quark

Semi-Inclusive DIS

$e + p/A \rightarrow e' + h^{\pm,0} + X$

Exclusive DIS

$e + p/A \rightarrow e' + p'/A' + \gamma/h^{\pm,0}$

Physics potential with BIC

$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + [\Delta g + L_G]$$

~ 0.12 +/-0.02   ~ 0.20 +/- 0.10

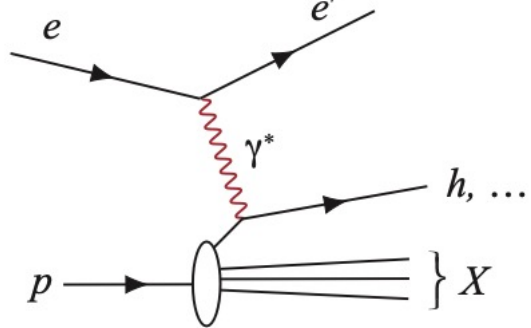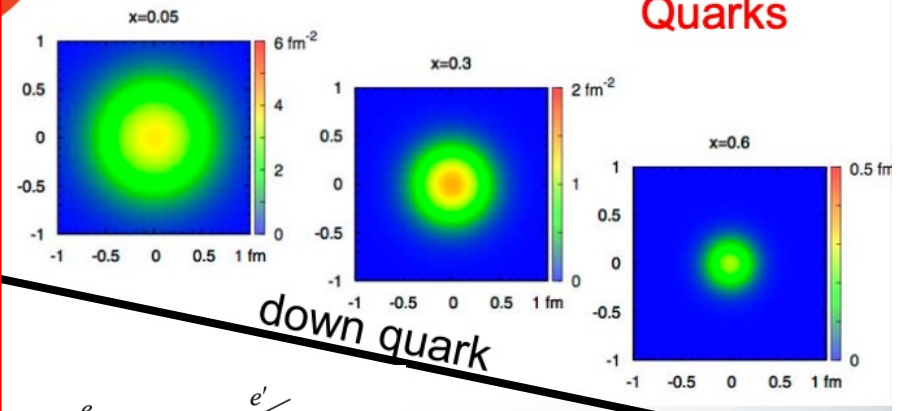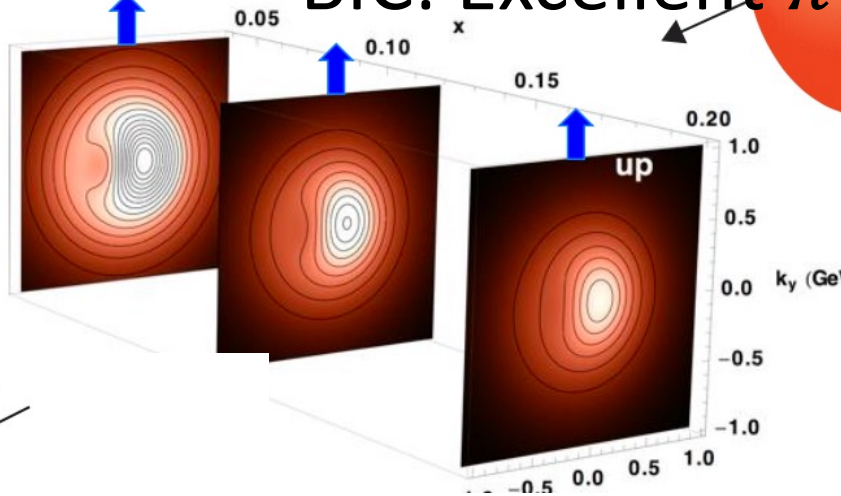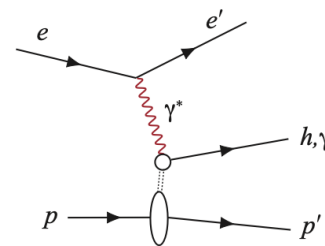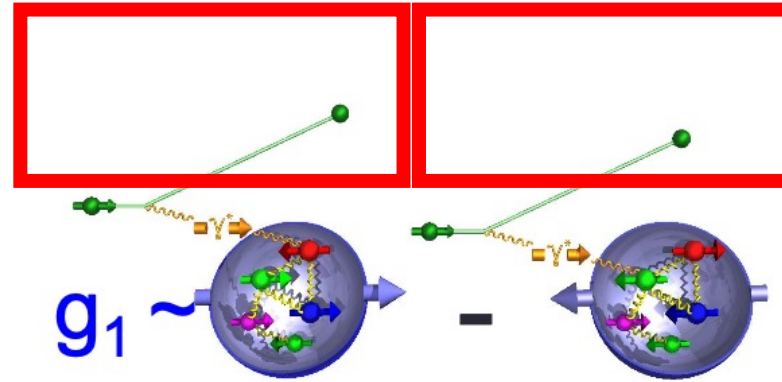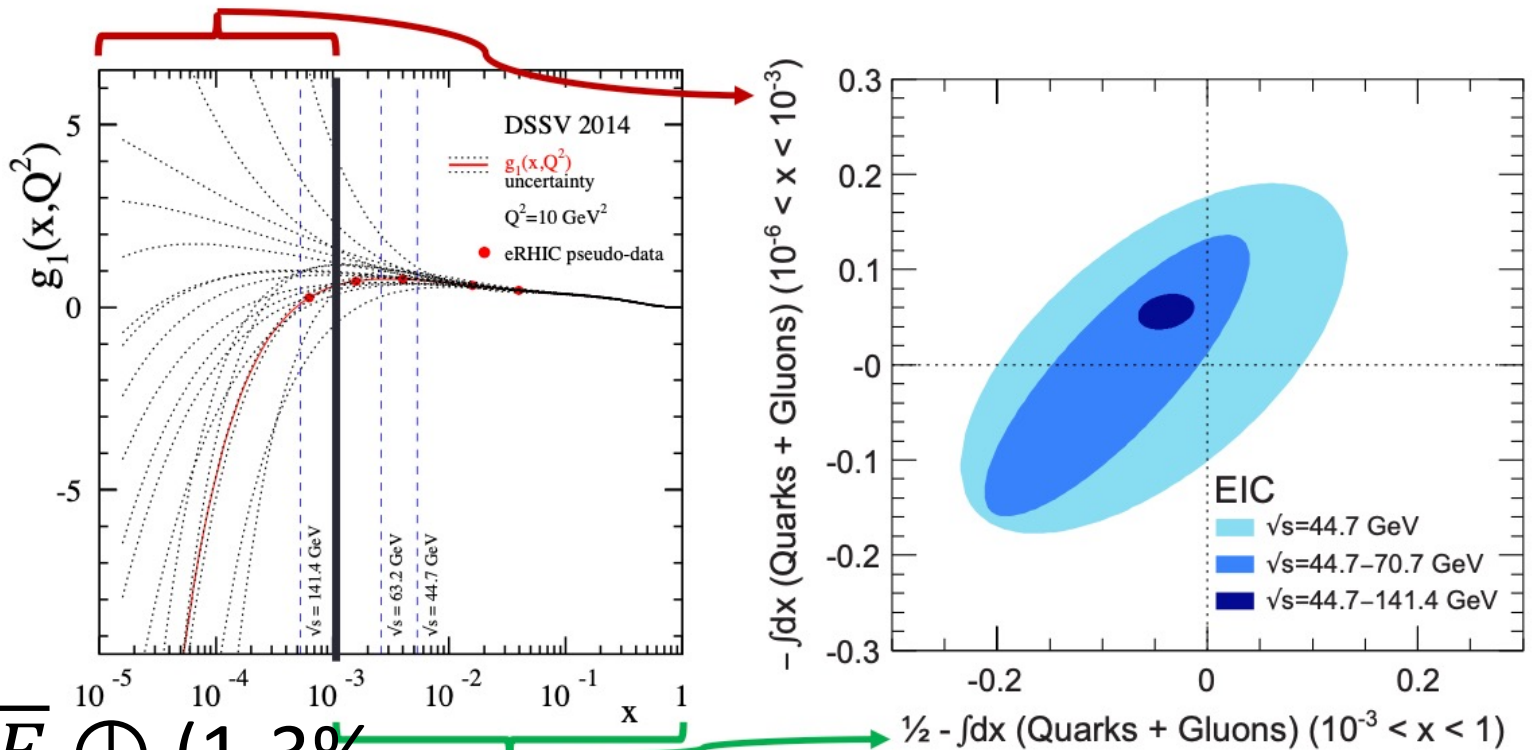$\Delta\Sigma/2$ = Quark contribution to Proton Spin
Δg = Gluon contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom ??
L_G = Gluon Orbital Ang. Mom ??

$g_1 \sim$

Spin structure function g_1 needs to be measured over a wide range in x-Q^2
Especially low-x

Precision in $\Delta\Sigma$ and Δg ➜ A clear idea Of the magnitude of $L_Q + L_G = L$ Lattice Calculations : comparison

DSSV 2014
$g_1(x,Q^2)$ uncertainty
$Q^2 = 10$ GeV^2
eRHIC pseudo-data

$g_1(x,Q^2)$

$\sqrt{s}=141.4$ GeV
$\sqrt{s}=63.2$ GeV
$\sqrt{s}=44.7$ GeV

EIC
$\sqrt{s}=44.7$ GeV
$\sqrt{s}=44.7-70.7$ GeV
$\sqrt{s}=44.7-141.4$ GeV

$-\int dx$ (Quarks + Gluons) ($10^{-6} < x < 10^{-3}$)

½ - $\int dx$ (Quarks + Gluons) ($10^{-3} < x < 1$)

BIC Requirement: 7-10%/$\sqrt{E}$ ⊕ (1-3%

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Physics potential with BIC

- Emergence of the nucleonic mass and spin
  - Mass: Quarkonium production cross-section at threshold at low Q^2
  - Spin: BIC Requirement: 7-10%/$\sqrt{E}$ $\oplus$ (1-3)%, Up to 10^4 π^- background suppression

- Parton distributions inside nucleon
  - momentum and coordinate space using SIDIZ and DVCS
  - BIC Requirement: 7-10%/$\sqrt{E}$ $\oplus$ (1-3)%, π^0/γ separation up to 10 GeV, Up to 10^4 π^- background suppression

- Gluon saturation: Forward rapidity

- Nuclear modification of PDF: The same BIC requirement

- Colour charge through Cold Nuclear Matter: Jet Physics

Summary

- Origin of Nucleon Spin
  - DIS with polarized electrons and protons for a large range in x and Q^2
  - Good electromagnetic calorimetry at the level of 7-10%/$\sqrt{E}$ $\oplus$ (1-3)%

- Multi-dimensional imaging of the Nucleon
  - Transverse Momentum Distribution measurement by Semi-Inclusive DIS
  - Generalized Parton Distribution measurement by Exclusive DIS
- Nuclear modification of PDF: The same BIC requirement
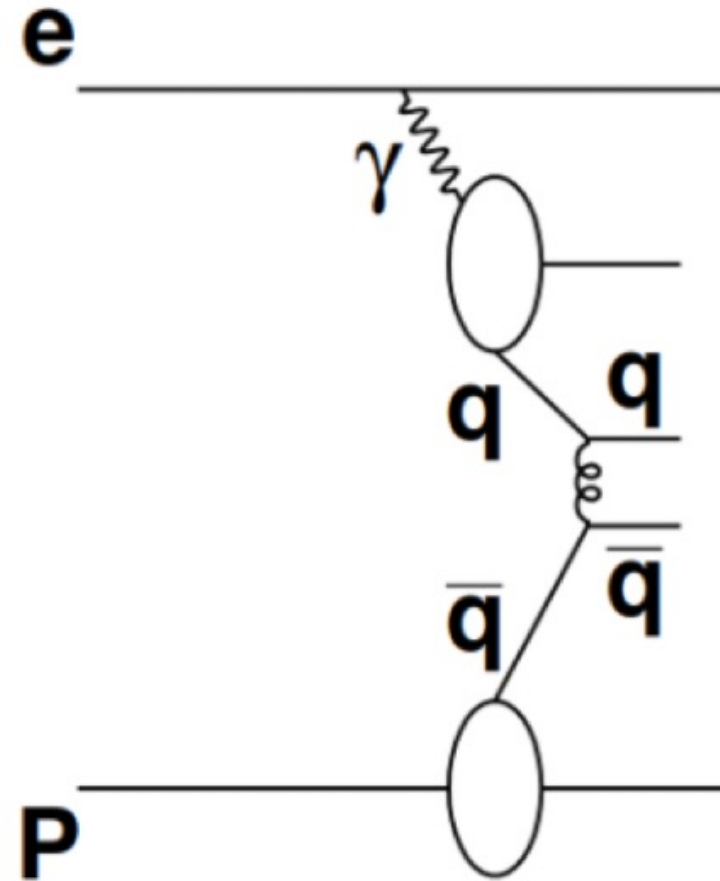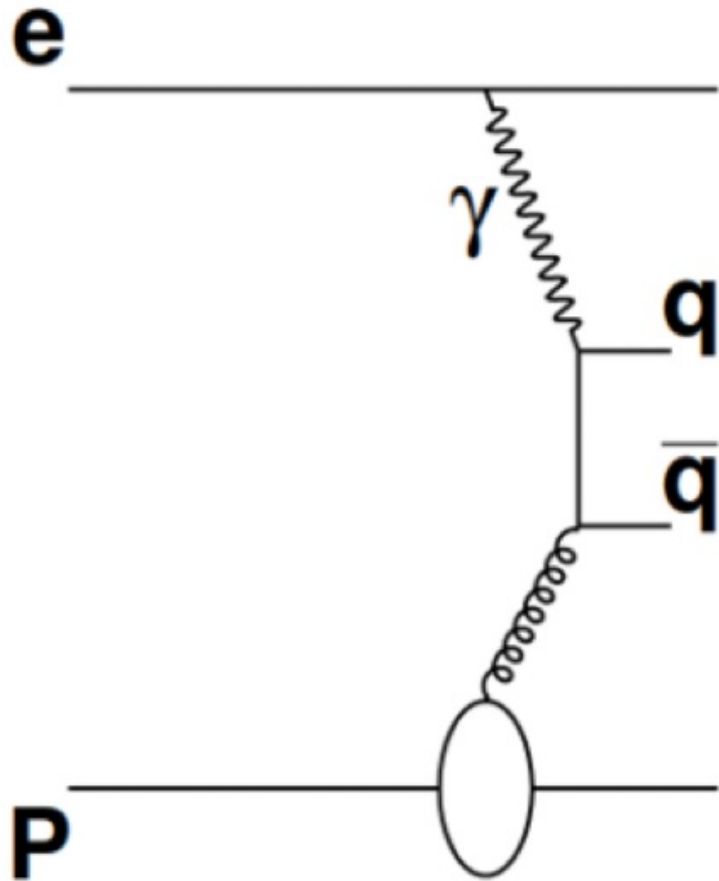- Colour charge through Cold Nuclear Matter: Jet Physics
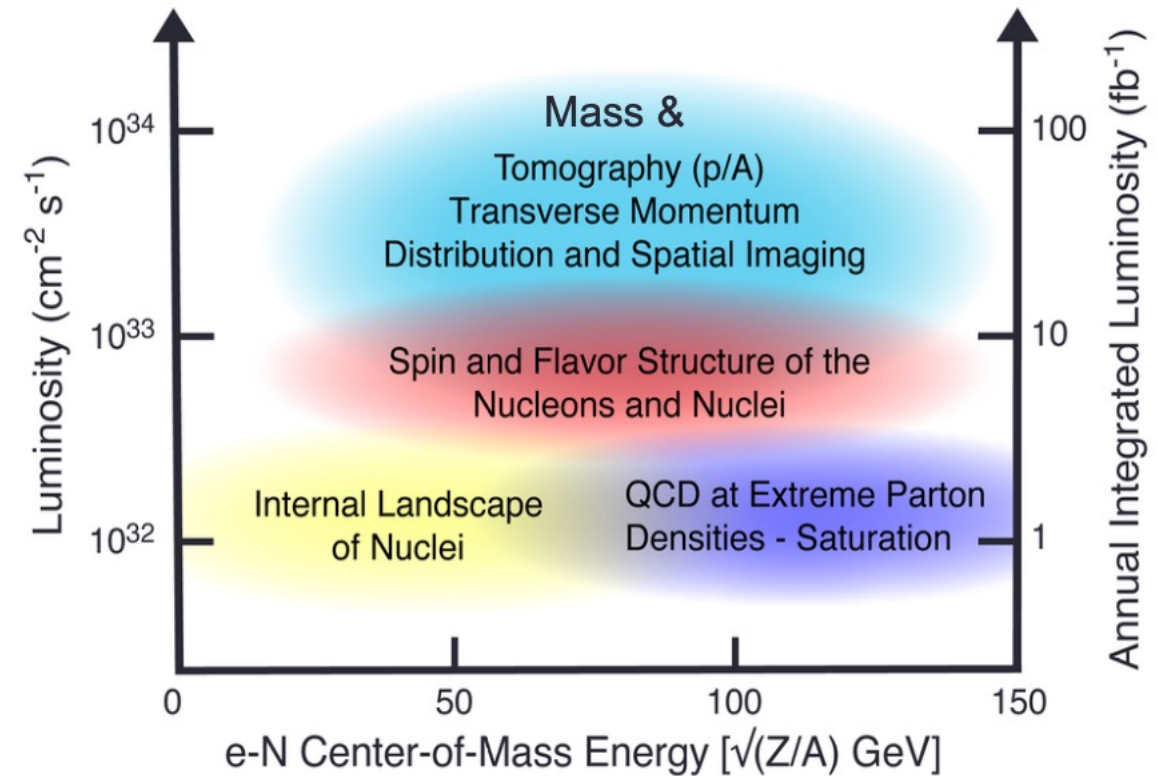
Backup

Physics potential with BIC
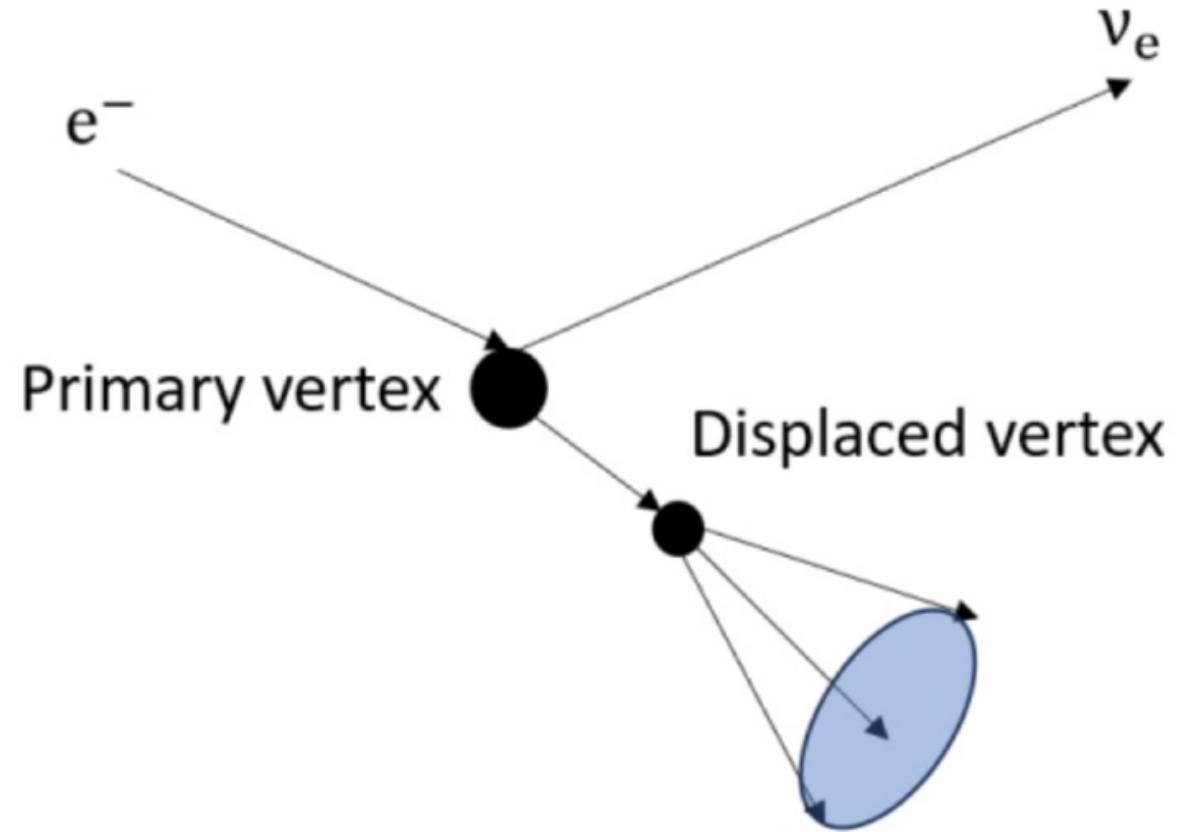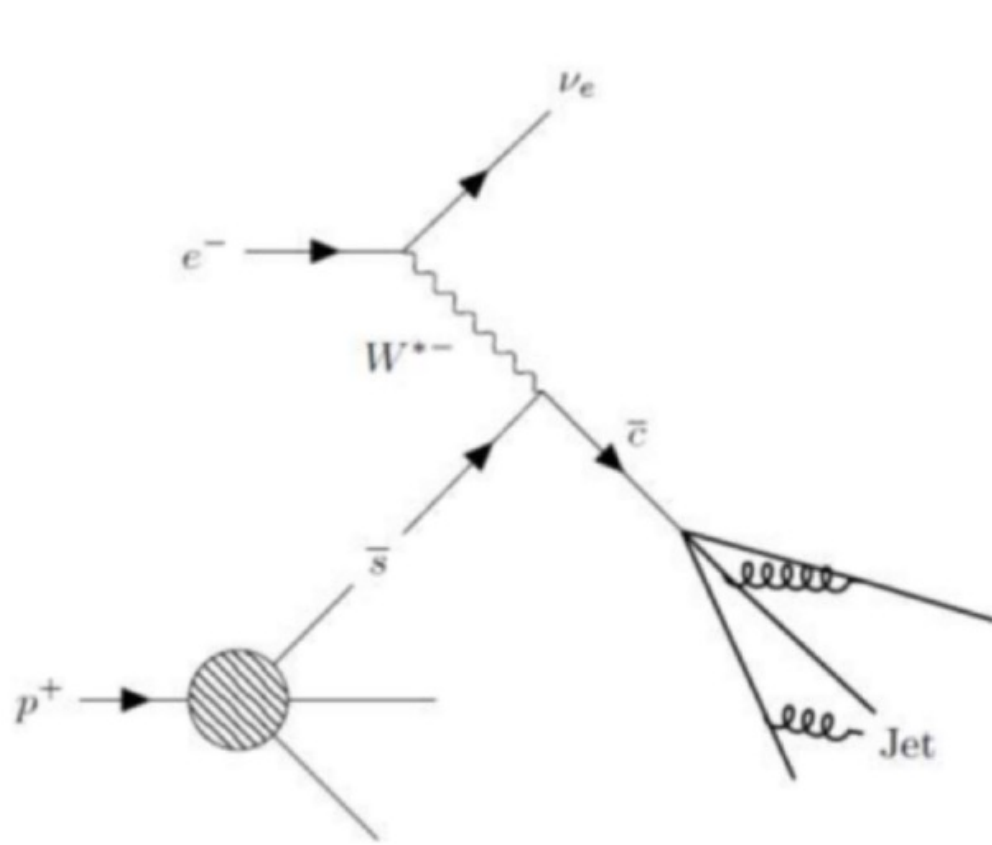
Strange quark parton distribution fuction

Physics potential with BIC

Polarized photon structure using dijets