Diffraction and Low-x 2024 Workshop

Diffractive Physics Program at Electron-Ion Collider (EIC) 2nd Detector

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Palermo, Sicily, Italy

Brookhaven National Laboratory

Diffractive Physics Program at EIC

Talk by Alex Jentsch "Experimental prospects from exclusive/diffractive physics at ePIC (163)"

Not the full list…

- $e + p$ **Deeply Virtual Compton Scattering (DVCS)**
  → GPD – spin, total angular momentum
- $e + p$ **Exclusive Vector Meson Production (DVMP)**
  → Quark/gluon flavor GPD
- $e + d$ **with** p/n **spectator tagging**
  → Free neutron structure functions and nuclear modifications
- $e + {}^3H/{}^3He$ **light nuclei with spectator tagging**
  → Neutron structure
- $e + p$ **Sullivan process**
  → Meson form factor and structure functions
- $e + A$ **Coherent/incoherent Vector Meson J/ψ production**
  → Saturation

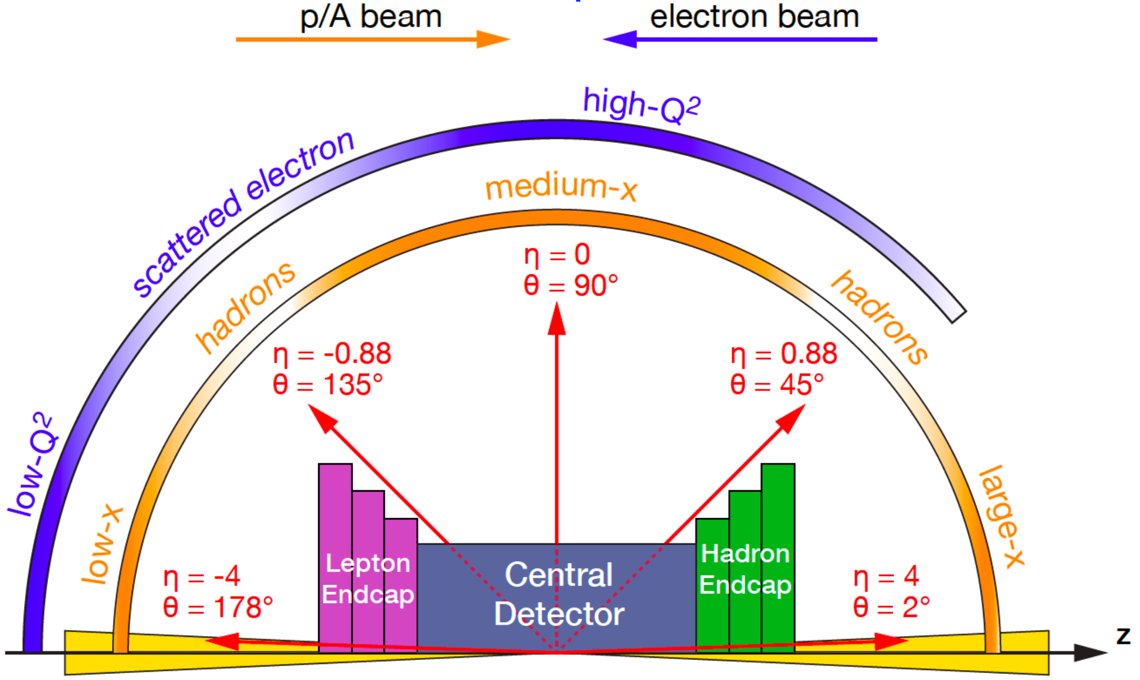
Same physics program at 1st Detector (ePIC) and 2nd Detector

Detector Requirements at EIC

Talk by Alex Jentsch "Experimental prospects from exclusive/diffractive physics at ePIC (163)"

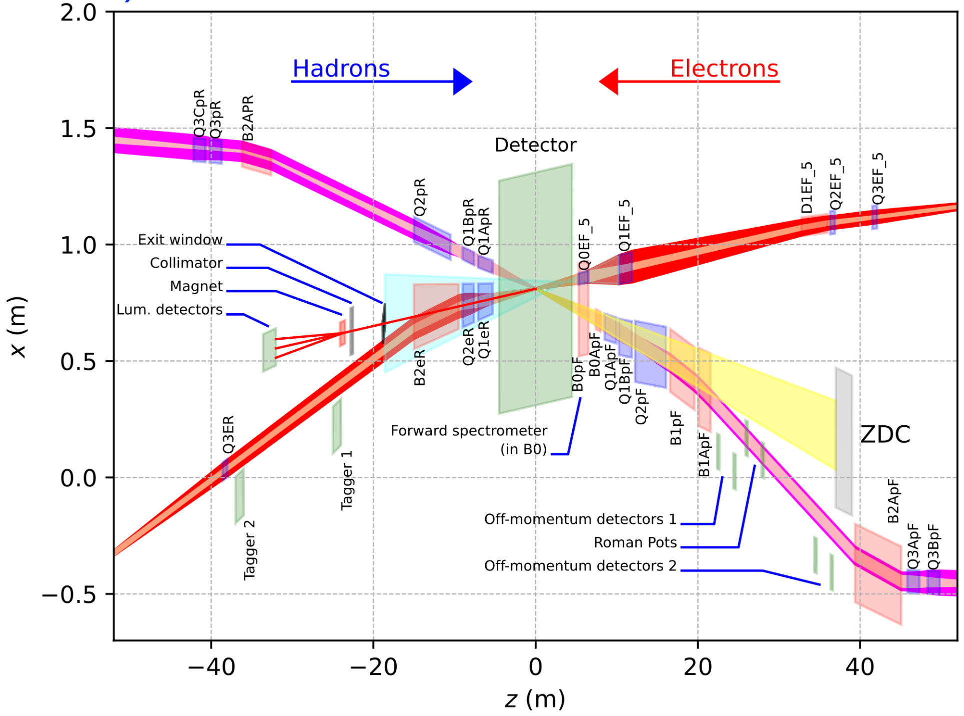
Central Detector

Requires large rapidity (-4 < η < 4) coverage:
Tracking, particle identification, electromagnetic and hadronic calorimetry
Aim to detect all final-state particles



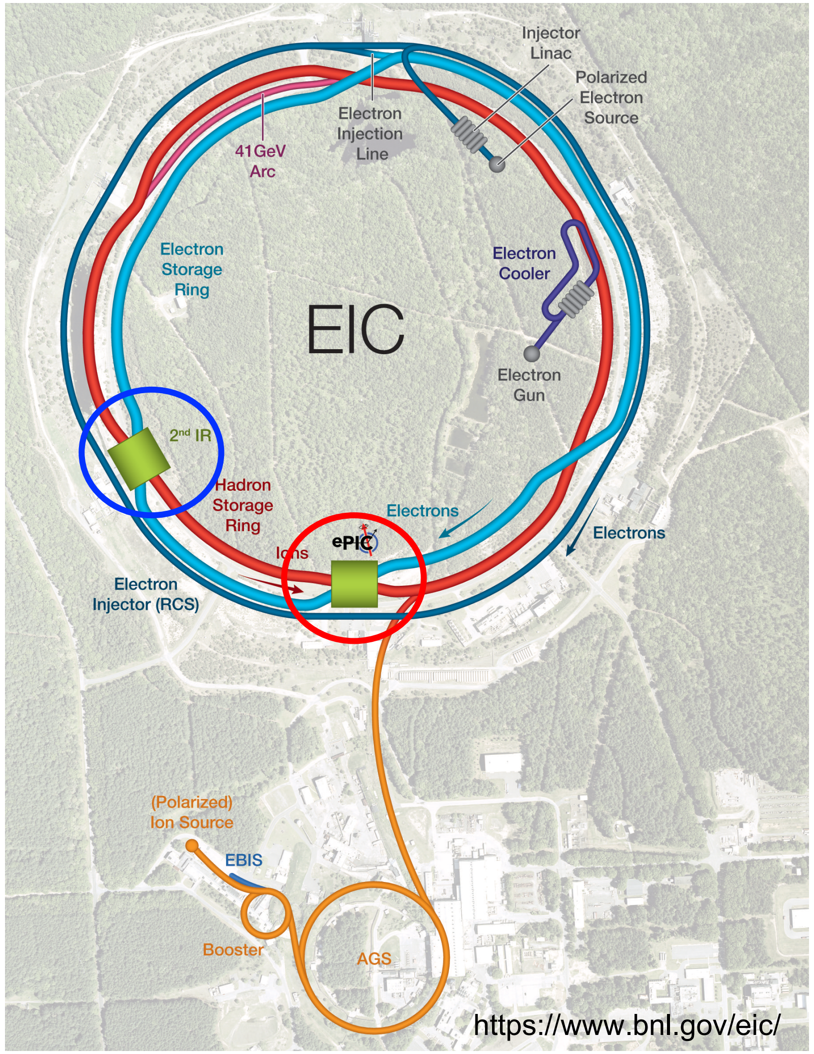
Interaction Region

Requires specialized detectors integrated in the interaction region over 100 m
Aim to detect/tag particles at very forward rapidity (η > 4.5)



EIC 2nd Detector Motivation

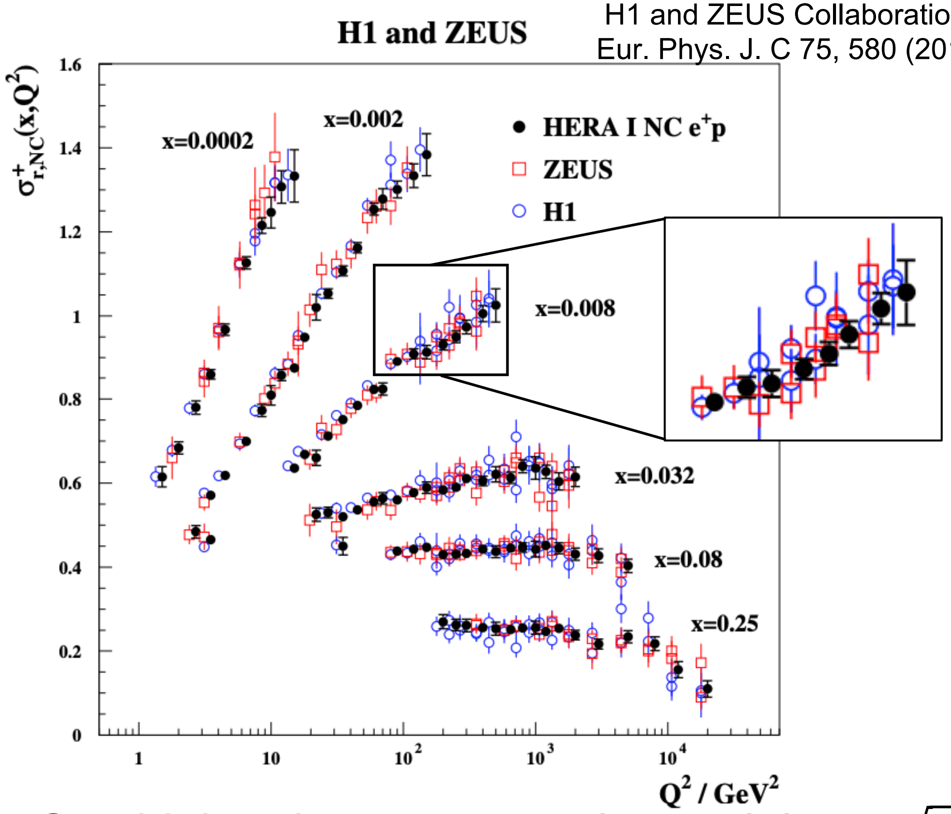
Talk by Pawel Nadel-Turonski "Spin physics at the EIC (116)"



- EIC Design
  - Two interaction points (IP-6 and IP-8) with two interaction regions (IR-6 and IR-8)
- **First Detector,** called **ePIC,** located at **IP-6**
- **Second detector at IP-8**
  - **A general-purpose collider detector** to support full EIC program (**complementarity**)
  - Cross-checks & control of systematics
  - Different subdetector technologies/acceptances
  - Different magnetic fields
  - Broaden physics program(different physics focuses)

EIC 2nd Detector Motivation

Complimentary Technologies of two H1 and ZEUS

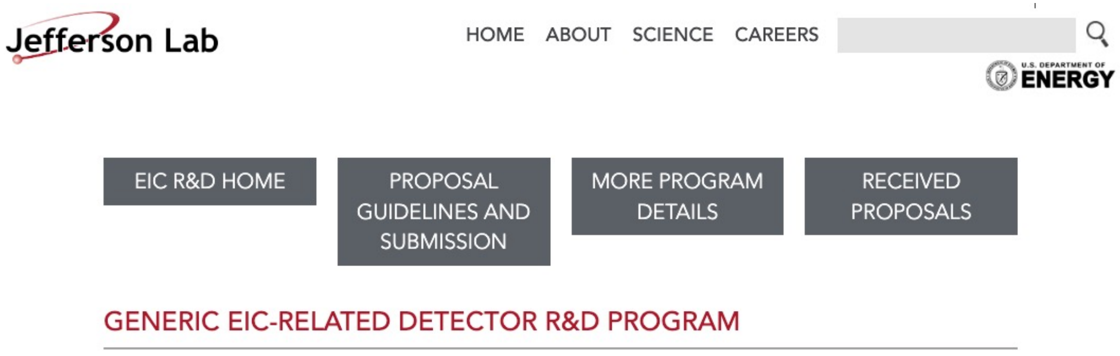


H1 and ZEUS Collaborations
Eur. Phys. J. C 75, 580 (2015)

Combining data gave well beyond the $1/\sqrt{2}$ statistical improvement by reducing uncertainties associated with a single detector configuration

Generic EIC-related Detector R&D Program

https://www.jlab.org/research/eic_rd_prgm

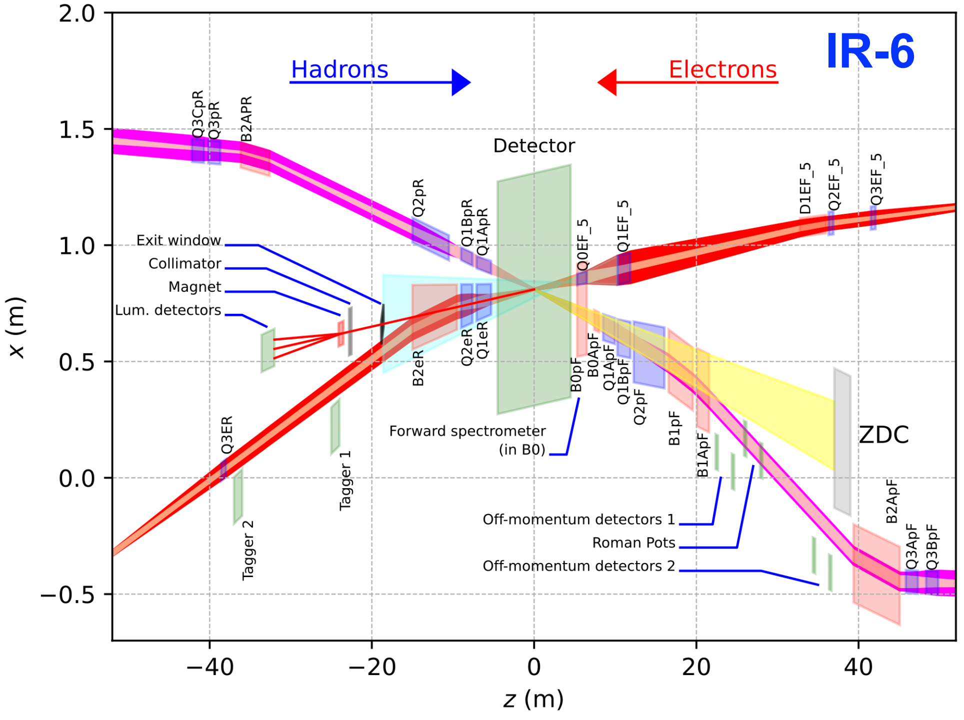


Annual proposal opportunity
Aim at 2nd Detector (or upgrades of 1st Detector)
Now used in ePIC and available for 2nd Detector

What other aspects
can EIC 2nd detector enhance?

EIC Interaction Regions

Requires specialized detectors integrated in the interaction region over 100 m



Crossing angle: **25 mrad**

IR-Design:

0.2 GeV < p_T < 1.3 GeV

Same

Accelerator highlights and challenges

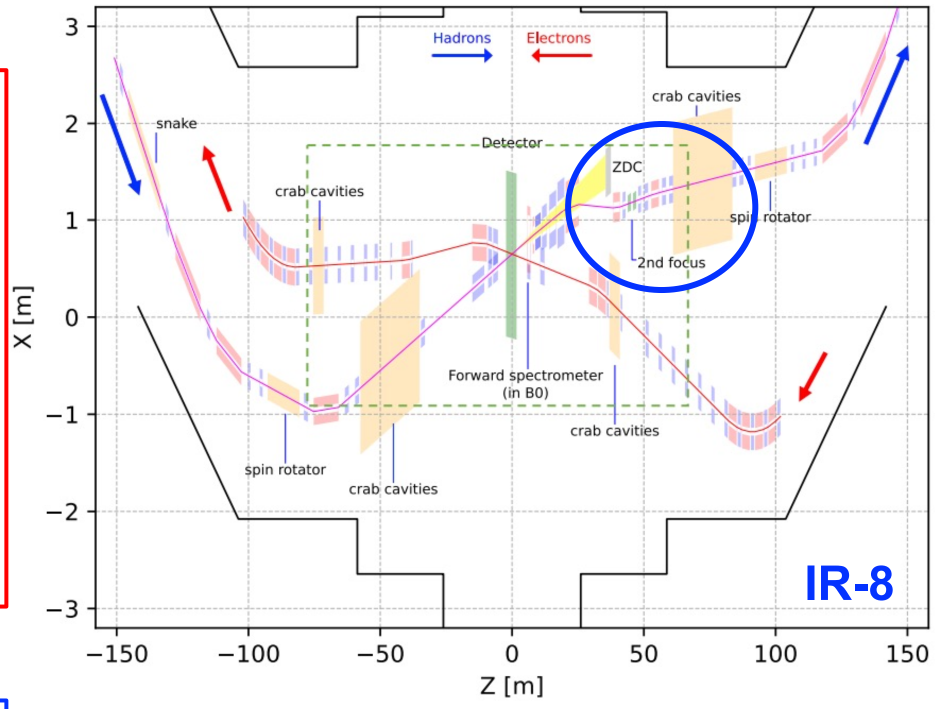
Shared luminosity between both IRs

Center-of-mass energy coverage

Different

blind spots

Far-forward detector acceptances



Crossing angle: **35 mrad**

IR pre-conceptual Design:

2nd “beam optics” focus

comes with challenges (ex. chromaticity budget & magnet design) in accelerator

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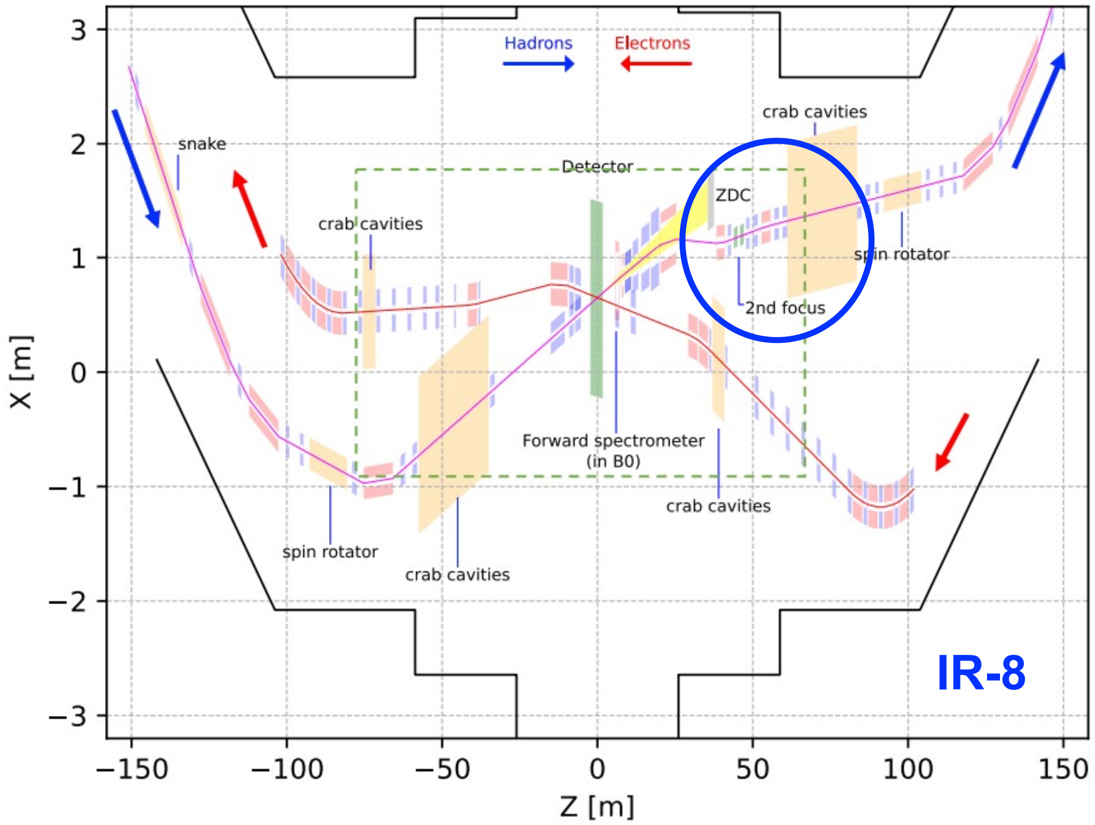
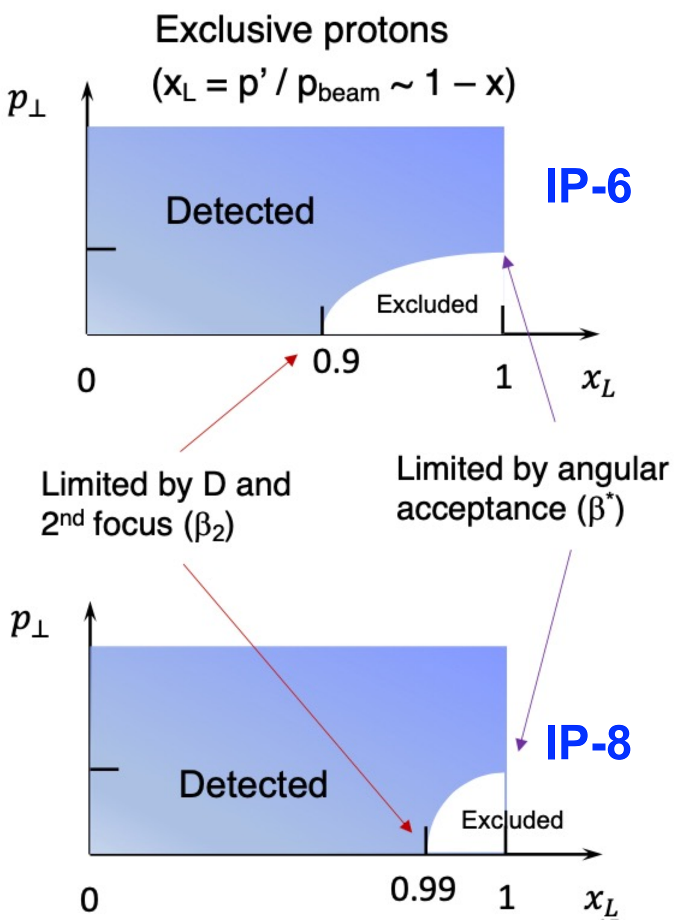
IR Concept – 2nd Focus in Far-Forward

- By adding additional magnets to focus beam ~ 45 m downstream from interaction point challenges the chromaticity budget
- This is NOT the detector design, but it is the machine design that the detector can be benefit from
- 2nd focus enables
  - Higher probability to detect low p_T (< 250 MeV) particles
  - Detects near-beam particles that get out of the beam envelop
- Complementary to ePIC: exclusive, tagging, and diffractive physics analysis



Physics Opportunities with 2nd Focus

- 2nd focus at IR8 greatly improves forward acceptance
- Complementarity with Detector 1 (ePIC) @ IR-6
- Excellent low-p_T acceptance for protons and light nuclei from exclusive reactions at very low t
- Detection of target fragments makes it possible
  - to veto breakup to study coherent process
  - to study final state when breakup occurs
- Coherent diffraction on heavy nuclei by vetoing breakups
- PID detector: identification of ion fragments

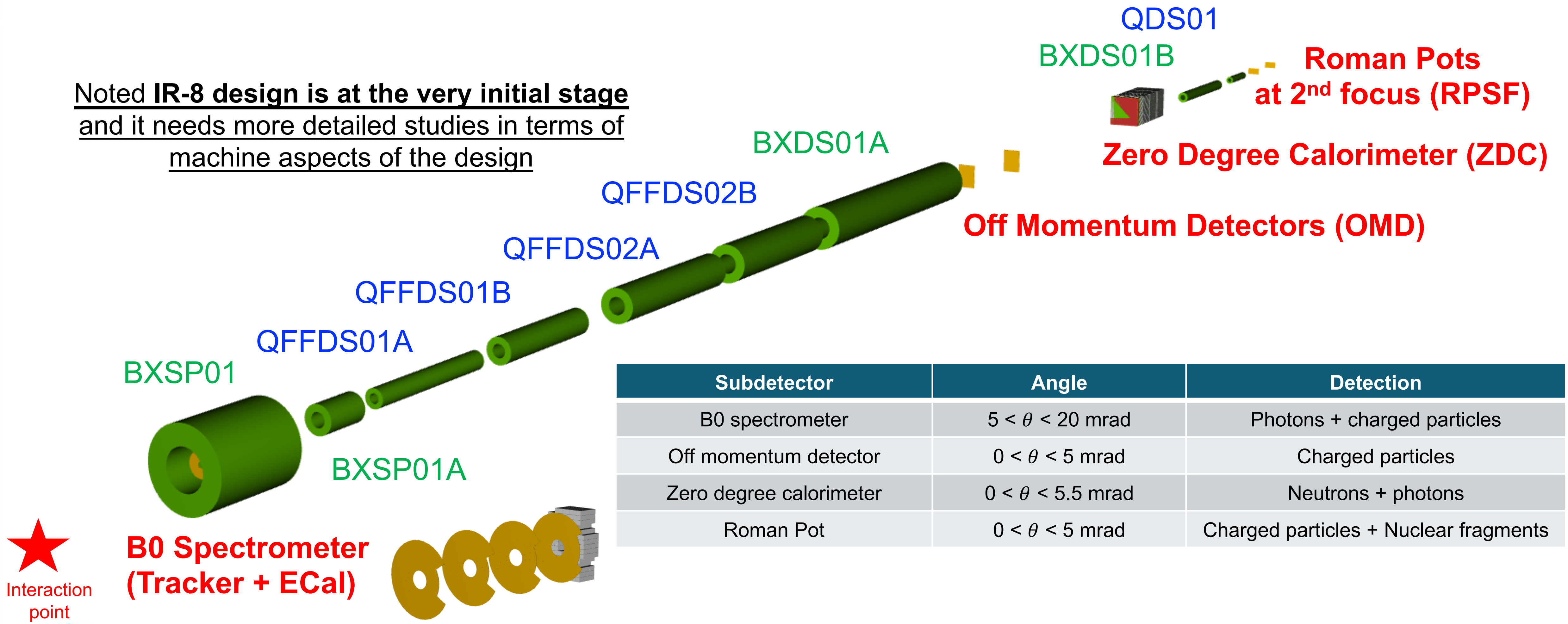


Order-of-magnitude improvement in forward acceptance

Far-Forward Detector – Layout

Implemented in **pre-conceptual IR-8 Forward Hadron Lattice** and required far-forward detectors

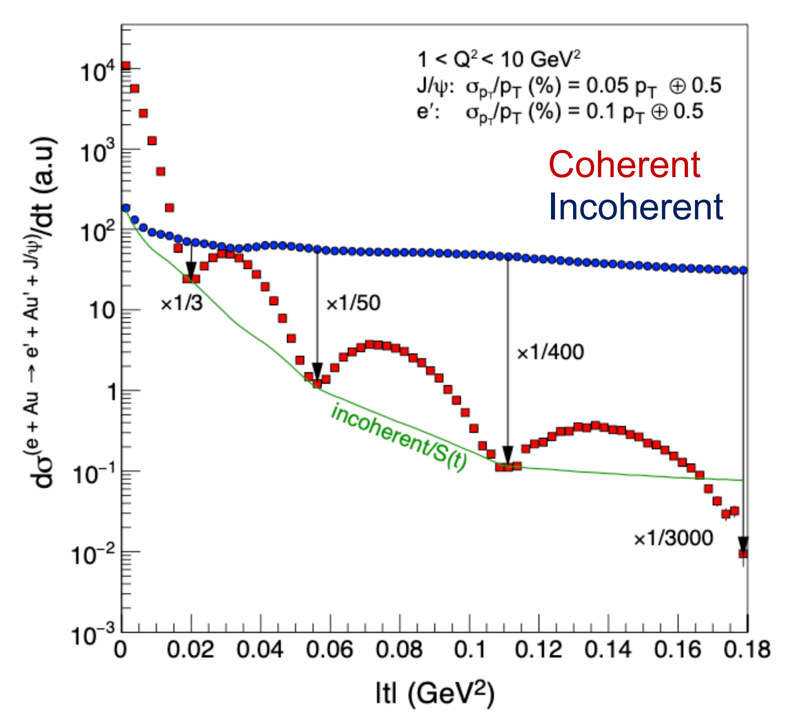
Noted **IR-8 design is at the very initial stage** and it needs more detailed studies in terms of machine aspects of the design



Subdetector	Angle	Detection
B0 spectrometer	$5 < \theta < 20$ mrad	Photons + charged particles
Off momentum detector	$0 < \theta < 5$ mrad	Charged particles
Zero degree calorimeter	$0 < \theta < 5.5$ mrad	Neutrons + photons
Roman Pot	$0 < \theta < 5$ mrad	Charged particles + Nuclear fragments

Ex: Incoherent Vetoing (Exclusivity)

Reference from EIC YR



At position of third diffractive minimum, **rejection factor for incoherent events better than 400:1 must be achievable (0.0025 % inefficiency)**

Diffractive Vector Meson Production: $e + Pb \rightarrow e' + J/\psi + X/Y$

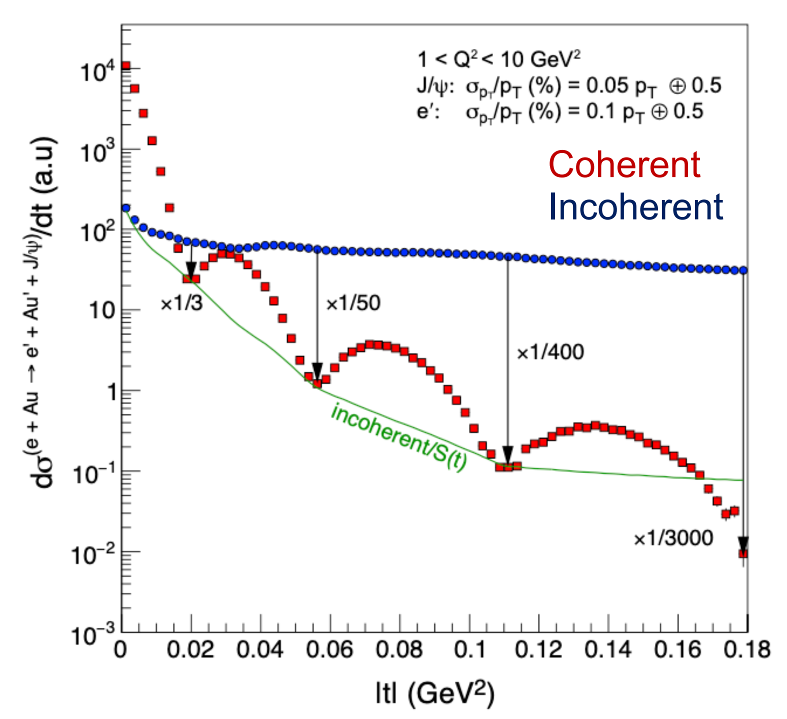
Experimentally diffractive cross section contains **sum of coherent (nucleus stays intact) and incoherent (nucleus breaks up) processes**

For $e + A$ program, **suppression of incoherent background up to necessary third minimum in t** should be achieved

Distinguish coherent from incoherent diffractive events by tagging nucleus breakups using far-forward detectors

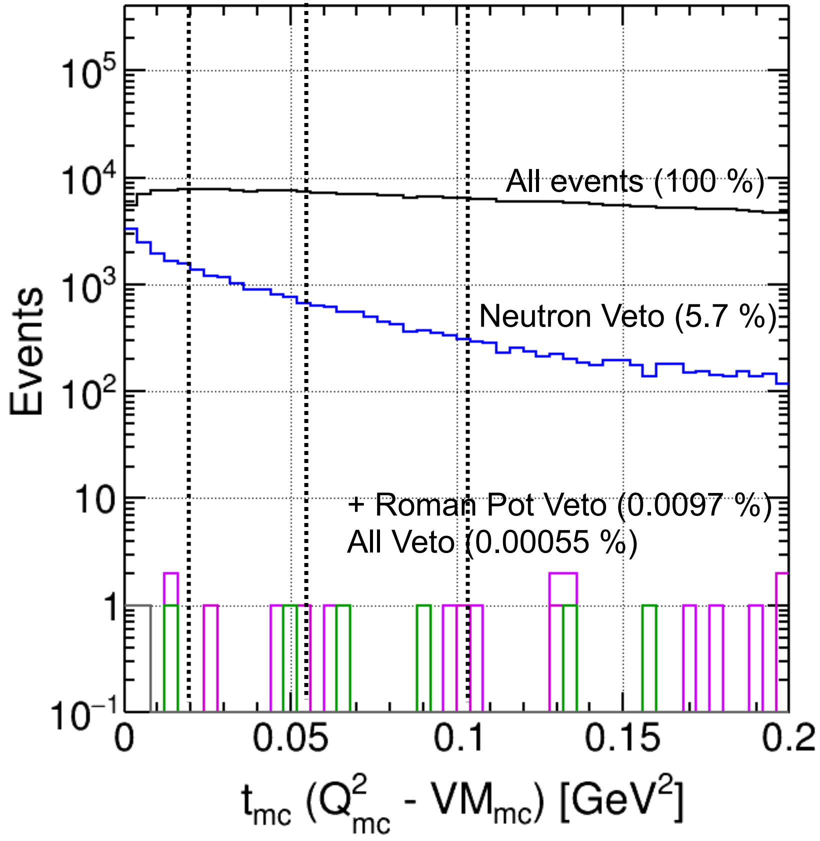
Ex: Incoherent Vetoing (Exclusivity)

Reference from EIC YR



At position of third diffractive minimum, **rejection factor for incoherent events better than 400:1 must be achievable (0.0025 % inefficiency)**

\# of non-vetoed incoherent events



ZDC hcal tagged (neutrons)
RPSF tagged (protons, nuclear fragments)
OMD tagged (charged particles)
B0 tracker tagged (charged particles)
B0 ecal tagged (photons)
ZDC ecal tagged (photons)

Fragment detection using Roman Pot at 2nd Focus at IR-8 provides a stronger veto at any *t* (complementarity + unique capability)

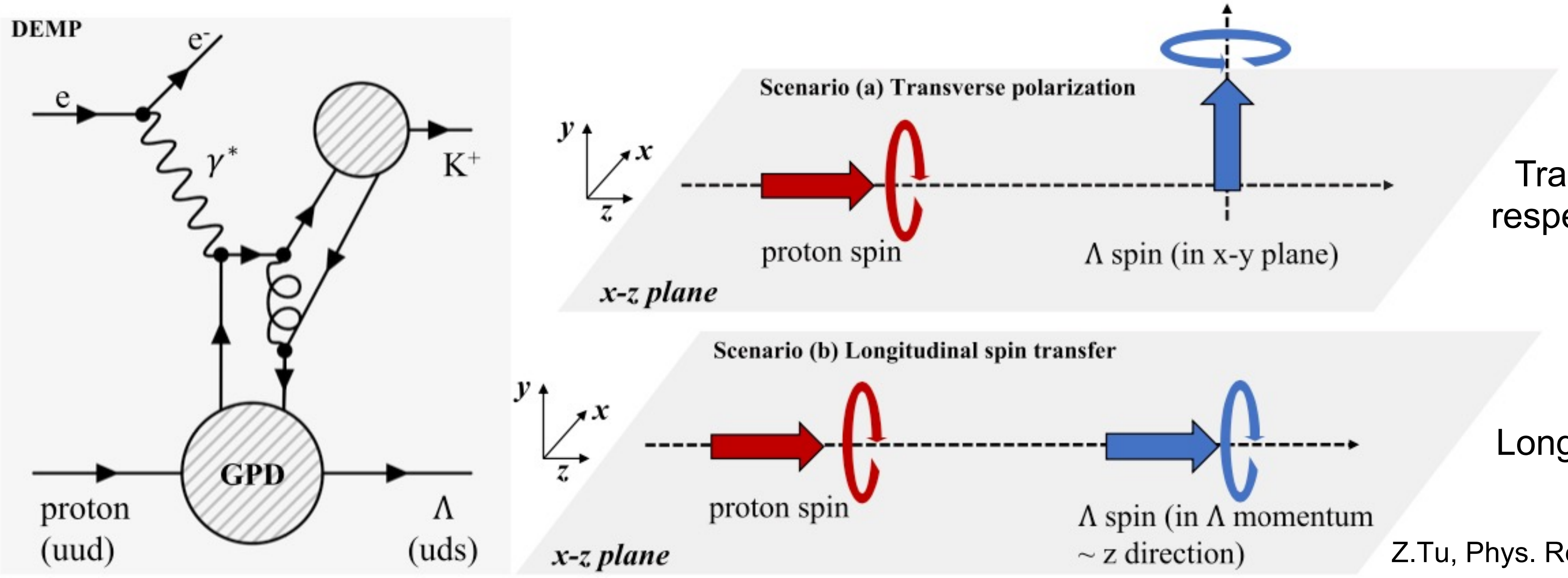
Found to be enough to suppress incoherent contribution at three minima
Vetoing efficiency is ≫ 99.99%

Studies still need to be done to understand how to operate the EIC with two IRs, get best luminosity, keep things stable, etc

Ex: Lambda Spin Measurement

Talk by Zhoudunming Tu "How does Lambda hyperon obtain polarization? (95)"

Λ hyperon polarization in DEMP with longitudinally-polarized protons



Transverse polarization with respect to the production plane

Longitudinal spin transfer from proton to Λ

Z.Tu, Phys. Rev. C 109, 055205 (2024)

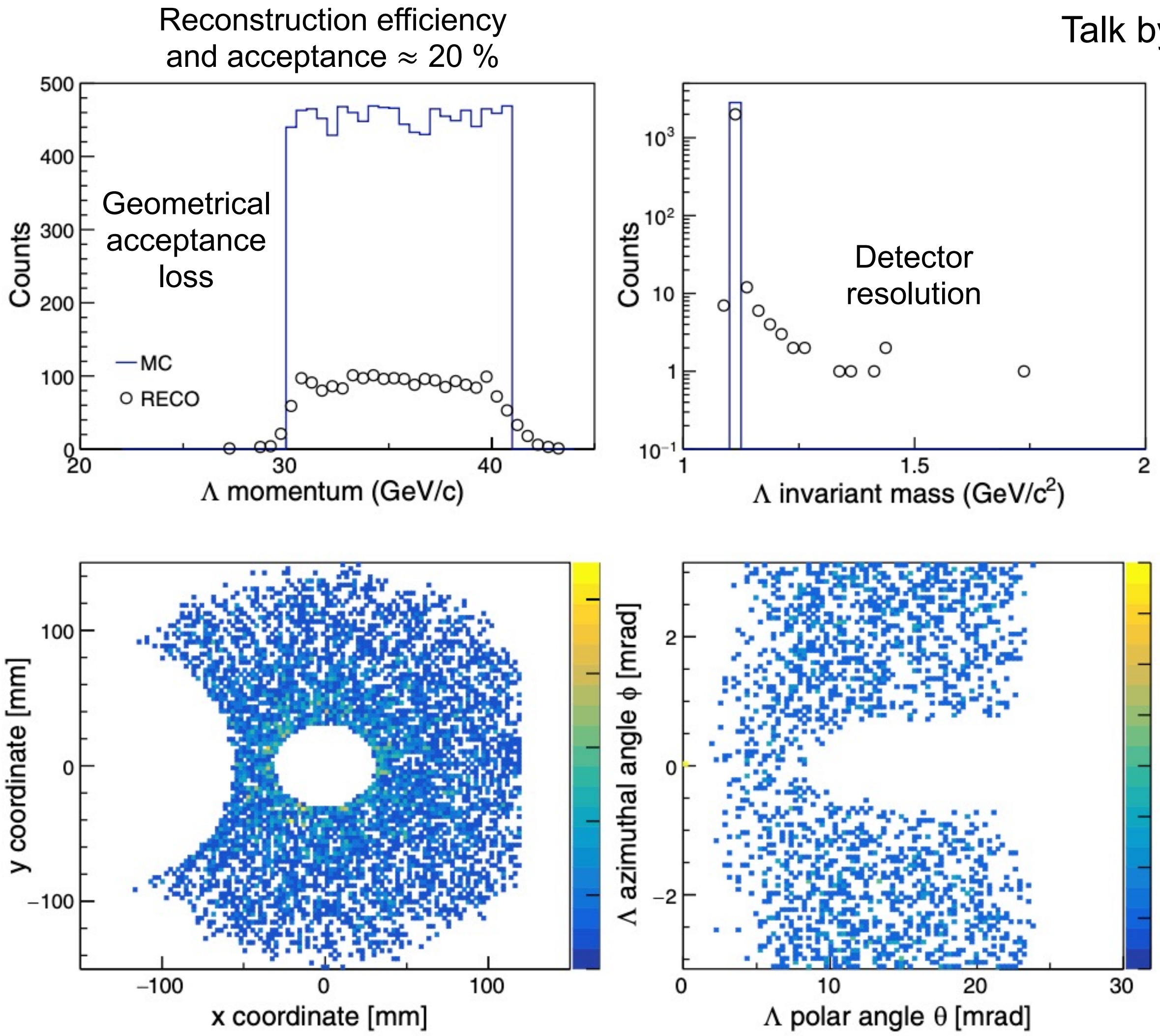
New $\boldsymbol{\Lambda}$ **polarization** measurement via deep exclusive meson production (DEMP): $e + p \rightarrow e' + K^+ + \Lambda$

$\boldsymbol{e', K^+}$ can be measured **within acceptance of central detector**

$\boldsymbol{\Lambda}$ (close to beam direction) decay particles can be **measured using far-forward detectors**

Ex: Lambda Spin Measurement

Talk by Zhoudunming Tu "How does Lambda hyperon obtain polarization? (95)"



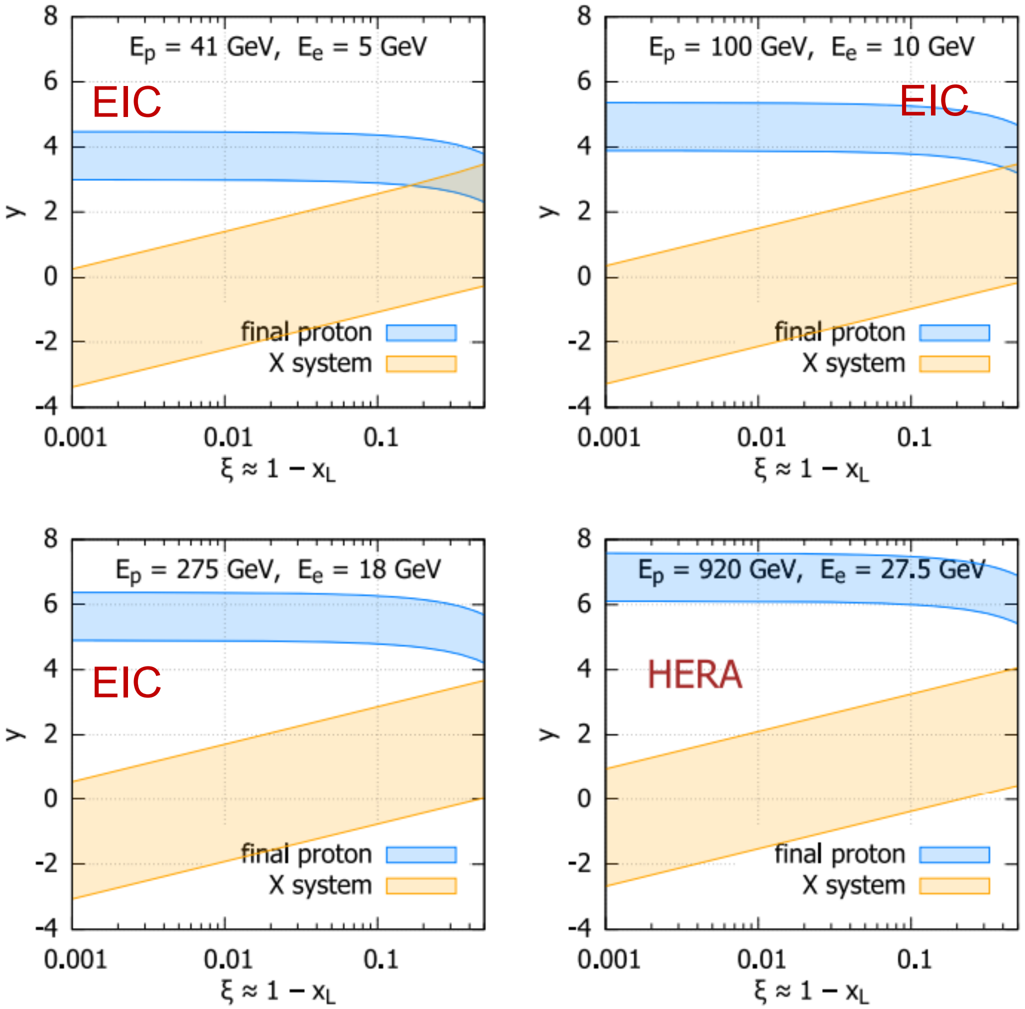
Z.Tu, Phys. Rev. C 109, 055205 (2024)

- **Low energy** configuration e.g. 5×41 GeV^2 **more feasible** (vertices of Λ decay **before B0**)
- **Higher energy** Λ decay occurs **beyond B0**

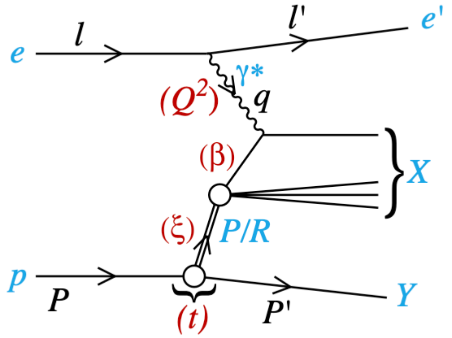
(**more feasible** for $\boldsymbol{\Lambda} \rightarrow n + \pi^0$ neutral final-state particles)

- **EIC 2nd Detector can be optimized baseline layout** of far-forward detector configuration (**complementarity**)
- comes with challenges (ex. beam pipe & magnet design) in accelerator to have larger aperture for on/off-momentum protons and neutrons

Ex: Diffractive Longitudinal Structure Function



N.Armesto et al, Phys. Rev. D 105, 074006 (2022)



Rapidity range of **scattered proton** and undecayed system X for **different beam energy configuration**

HERA: LRG method for gaps > 3 units of rapidity

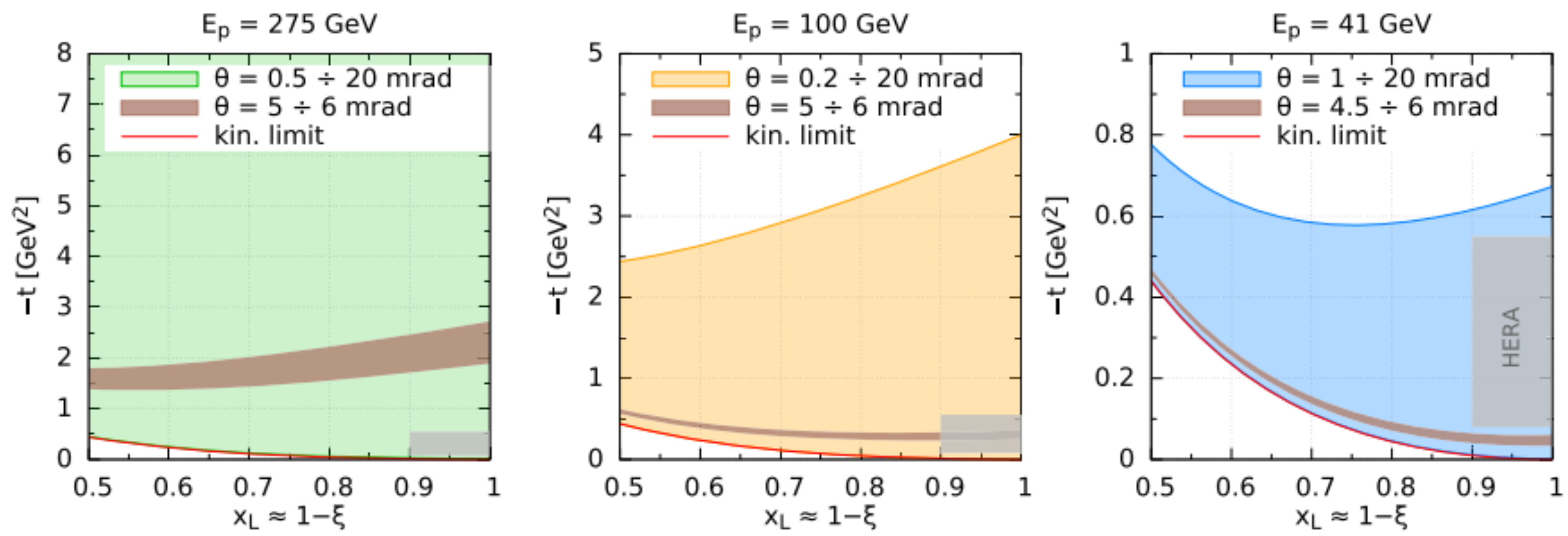
EIC: large gaps at smallest ξ and largest s

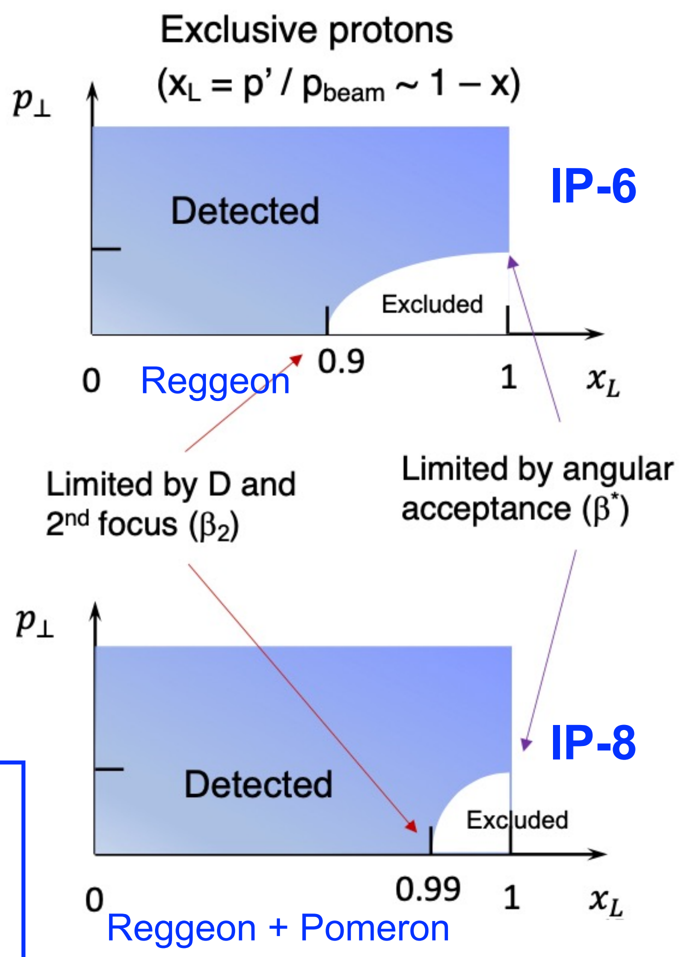
However, **most of regions LRG method can be challenging at EIC**

*LRG: Large Rapidity Gap

Ex: Diffractive Longitudinal Structure Function

N.Armesto et al, Phys. Rev. D 105, 074006 (2022)





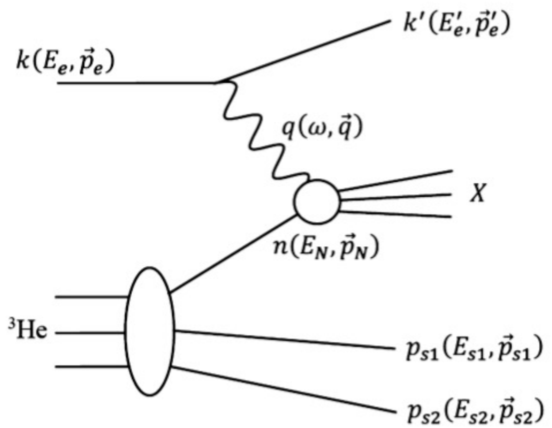
At **EIC**, select diffractive events using **proton tagging** thanks to Far-Forward detectors (ex. Roman Pots)

EIC 2nd detector can provide possibility for containing F_L^D;

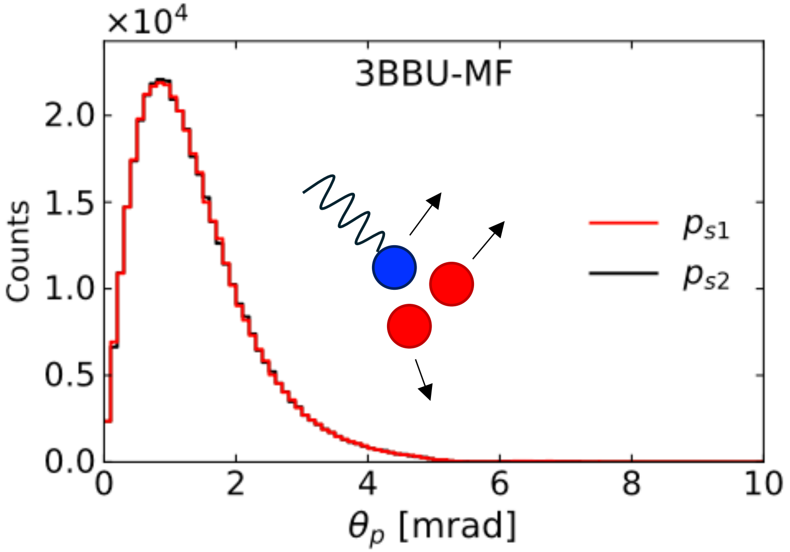
Reggeon and Pomeron exchanges at the same machine and may opens new opportunity to study separate from one contribution to another (**complementarity + unique capability**)

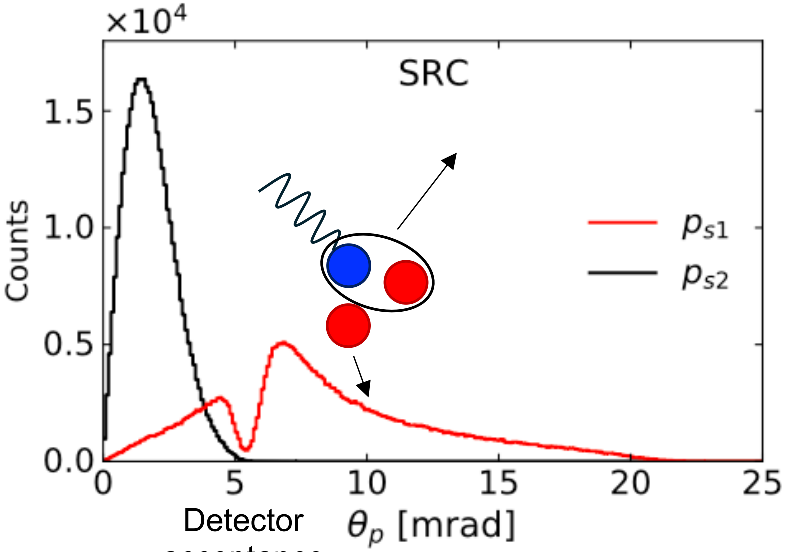
Ex: Light Nuclei Spectator Tagging

Double spectator tagging method



I. Friščić et al, Phys. Lett. B 823, 136726 (2021)





For ^3He nuclei
as **effective neutron target**,
tag spectator protons in far-forward

From different models of three breakup of ^3He,
two spectator protons land
within acceptance of different far-forward detectors (B0/OMD/RP)

EIC 2nd Detector can be optimized baseline layout of detector configuration and possibly larger low p_T acceptance may help in case of one of spectators in SRC model having high rigidity (**complementarity**)

Summary and Outlook

- **Complementarity of a Second Detector**
  - Cross-checking → Validate discoveries
  - Cross calibration → gives beyond the simple statistical improvement
  - Different physics focuses
  - Technology Redundancy → mitigate risks
  - Potential detector technologies
- **EIC 2nd detector and interaction region** could provide **complementarity** and **unique capabilities**
- Continue exploring detector technologies and establish **advantages in IR-8 and facility upgrade** toward physics program benefits
- **Welcome to bring new input, approach, perspective, participation**

EIC 2nd detector working group

- Group page: https://eicug.github.io/content/wg.html#detector-iiip8-group
- Conveners are: Charles Hyde (ODU), Sanbaek Lee (ANL), Simonetta Liuti (UVA), **Pawel Nadel-Turonski (USC)**, **Bjorn Schenke (BNL)**, Ernst Sichtermann (LBNL), Thomas Ullrich (BNL/Yale), Anselm Vossen (Duke/JLab)
- Software coordinators: Wenliang Li (MSU) and **Zhoudunming (Kong) Tu (BNL)**
- Convener mailing list: eic-det2-conveners-l@lists.bnl.gov

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