# The 2nd EIC detector and exclusive/forward measurements

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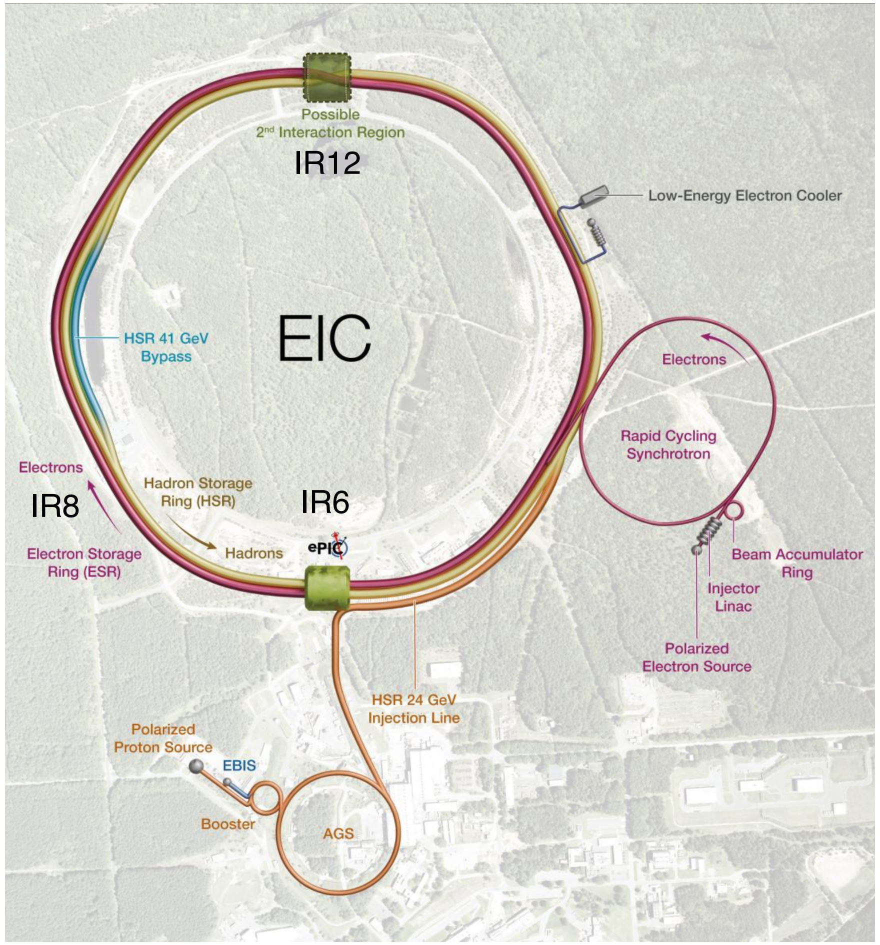



Supported by NSF grant PHY-2514907.

Towards improved hadron femtography with hard exclusive reactions, UVA, July 20-24, 2026

# The Electron-Ion Collider at Brookhaven National Lab

High luminosity: $\mathcal{L} = 10^{33} - 10^{34} \frac{1}{cm^2 s}$; $10 - 100\ fb^{-1}/year$

Polarized electron, proton, and light ion beams: 70%

- Longitudinal and transverse target

Center-of-mass energy: $E_{cm} = 30 - 140$ GeV

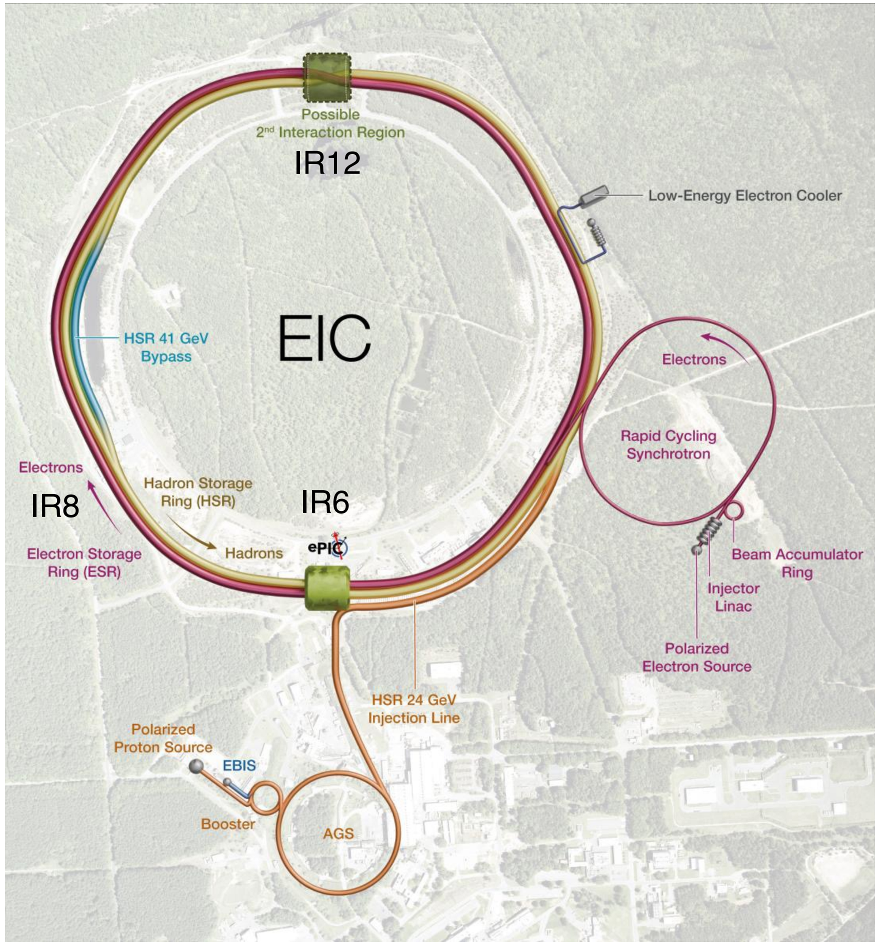
- Electrons: initially 5 – 9 GeV (upgradable to 18 GeV)
- Ions: $100 - \frac{Z}{A} \cdot 275$ GeV/A or 41 GeV/A using a bypass

Full range of ion species: protons – Uranium

Good detector acceptance and background conditions

- Many bunch crossings per collision (not other way around)

RHIC operations concluded after 25 years in February 2026.
The EIC will start construction in the RHIC tunnel.



# A second detector at the EIC

The EIC project includes one detector (ePIC) and will accommodate an interaction region for a 2nd detector.

- This staged approach is similar to that of the Tevatron at Fermilab where D0 started taking data 7 years after CDF.

Location:

It is now planned to be in IR12 (due north) instead of the PHENIX hall (IR8).

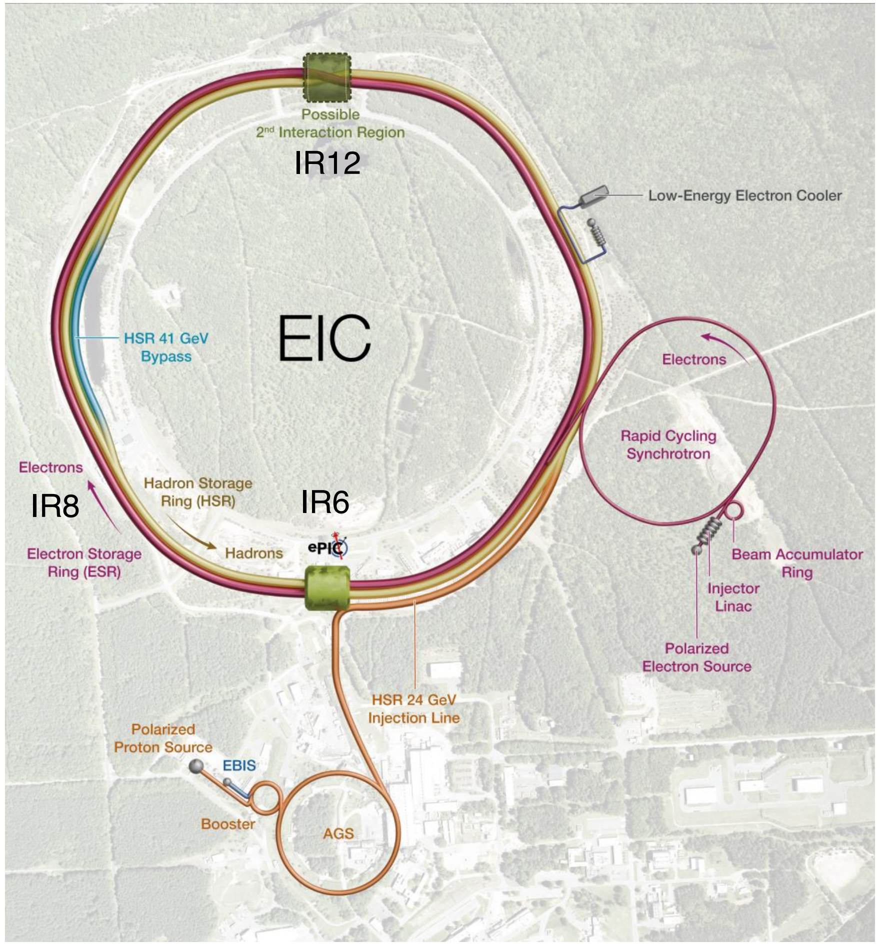
Beam energies and acceptance:

At any given time, the accelerator will deliver the *same beam energies* to both detectors.

The detectors cannot in a meaningful way be optimized for different beam energy combinations.

However, the *acceptance* of a second detector can be optimized to better suit certain processes, targets, and kinematics.

As an example, enhanced far-forward detection is particularly important for exclusive processes, nuclear targets, and low-*x*.



# Electron-Ion Collider Detector II

**Major facilities usually have at least two detectors to maximize the science.**

Independent confirmation of results and discoveries, reduction of systematic uncertainties.

**A 2nd EIC detector will allow for enhanced capabilities in several sectors.**

A novel far-forward detection system utilizing a second focus will significantly expand the opportunities for nuclear measurements and for the 3D structure of nucleons and nuclei. Improved muon identification is another example of complementarity with the 1st detector.

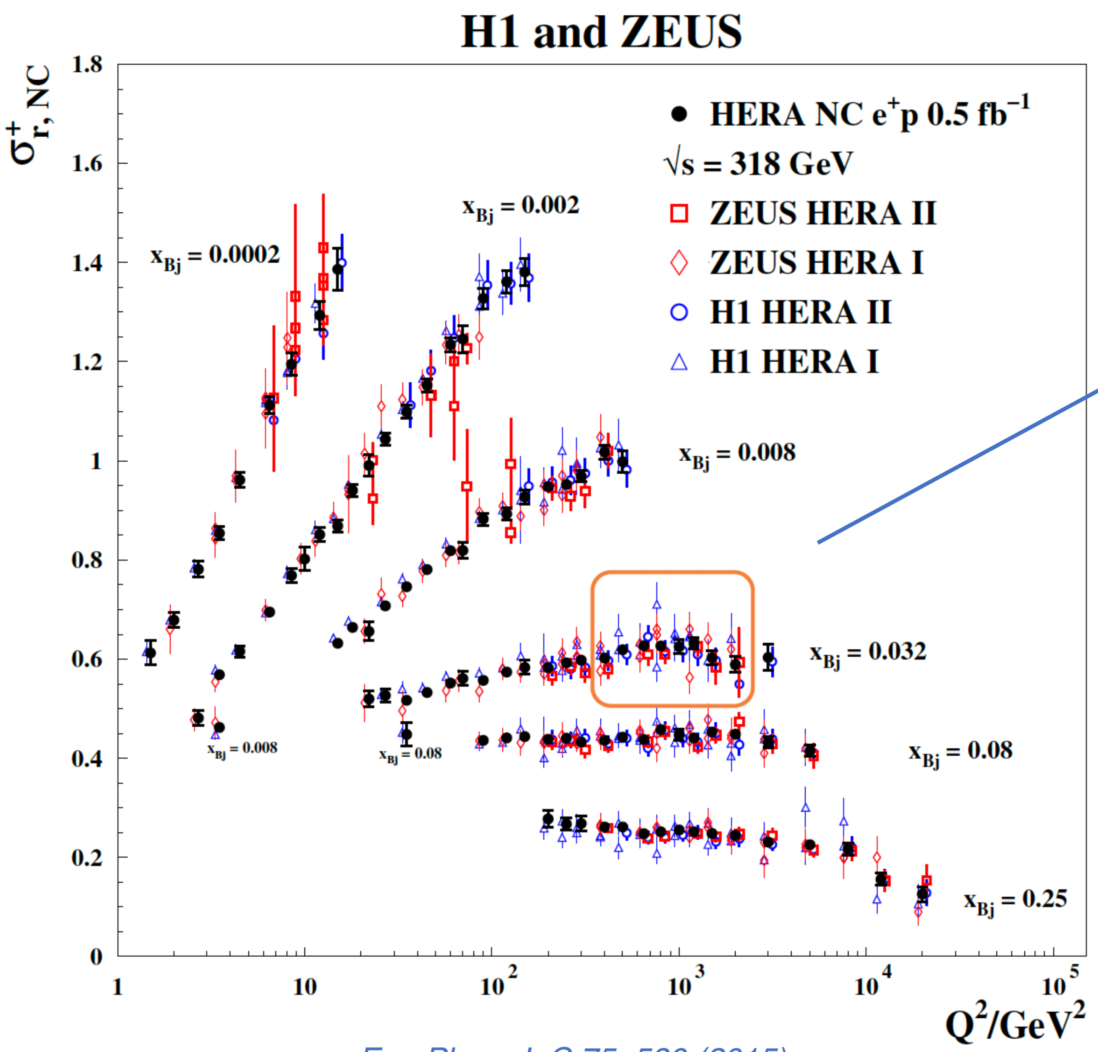
**A 2nd detector is essential to fully leverage the investment made in the EIC**

A slightly longer timeline will also make it possible to take full advantage of AI in all aspects of the project, which would be naturally synergistic with the Genesis mission. Completing the 2nd detector after early running would not significantly affect its overall contribution to EIC science (note that the D0 detector at the Tevatron came 7 years after CDF).

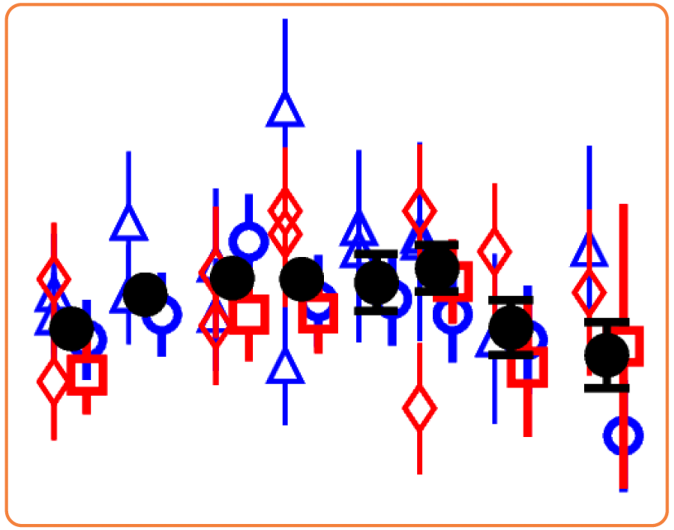
**Significant progress has been made on the implementation**

Includes an optimized beam optics that could be used in IR8 or IR12.

# Complementarity: reduction of systematics at HERA

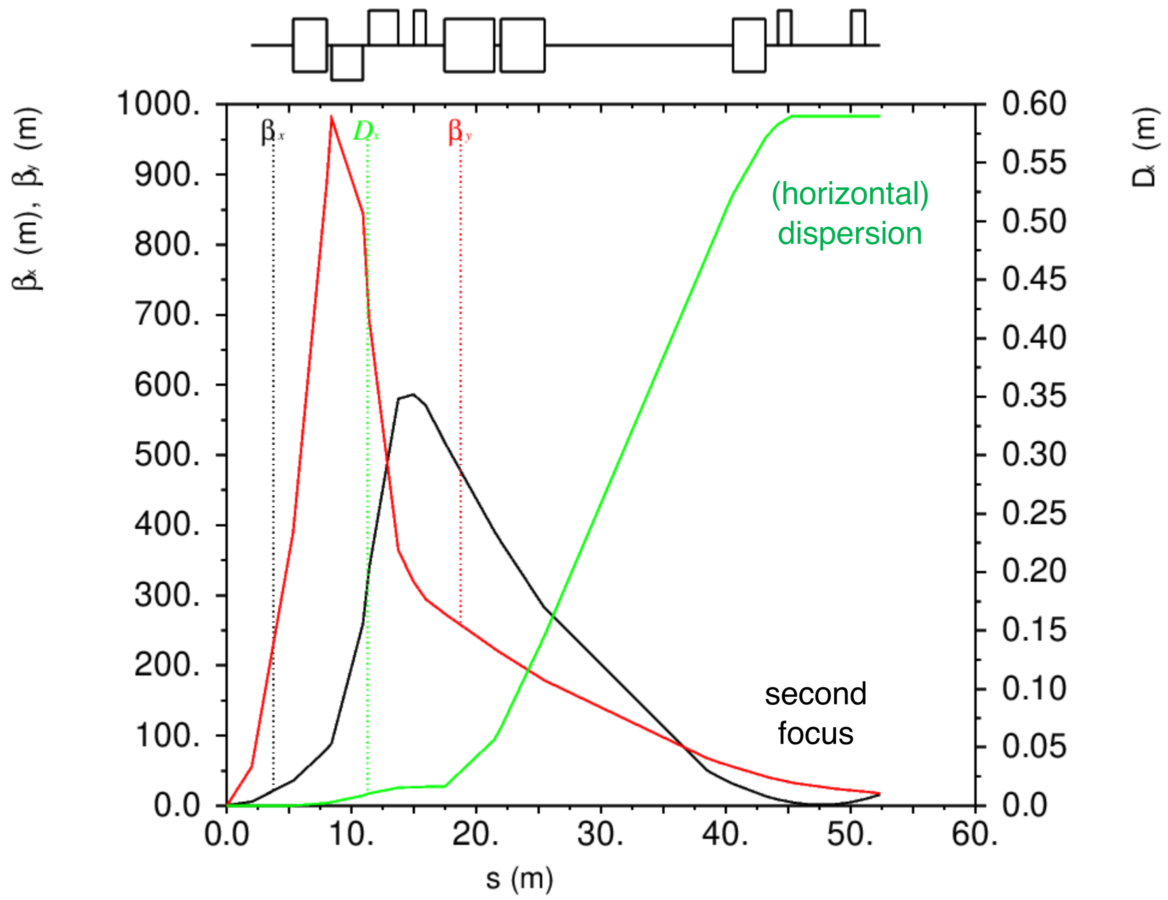



*Eur. Phys. J. C 75, 580 (2015)*



- If two complementary detector are not *too* different and use similar binning, it may be possible to combine the data.
- At HERA the combined data had significantly reduced systematic uncertainties.
- The EIC luminosity will be 100 times higher, making systematics even more important.

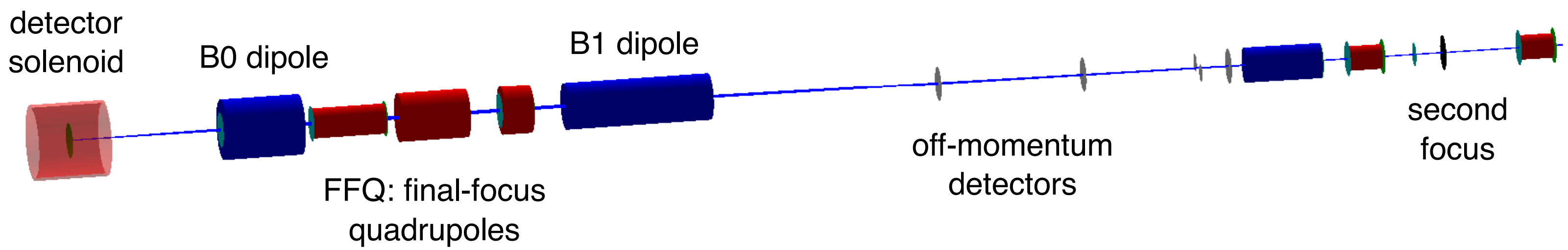
# Forward detection with a second focus



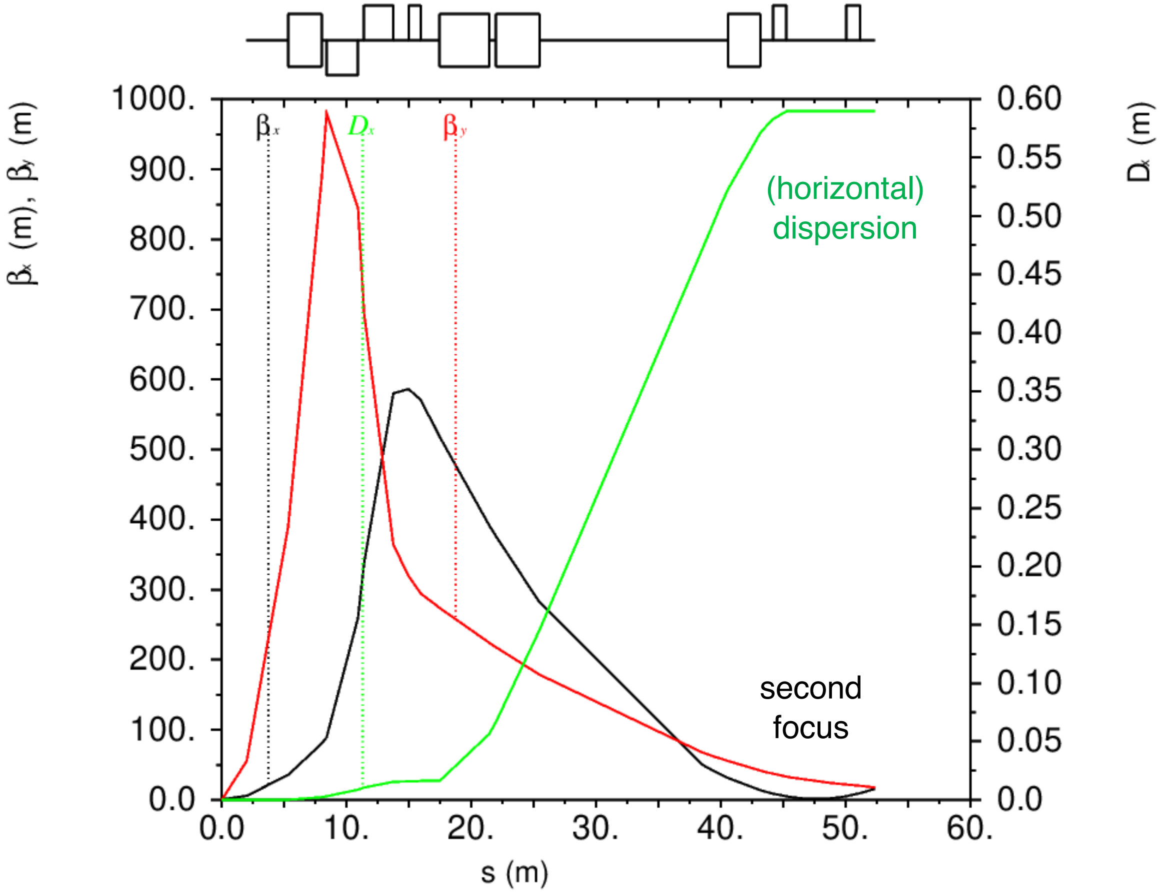

- An IR featuring the the novel idea of having a second focus to enhance the forward detection was originally developed for the JLab version of the EIC by V. Morozov and PNT.

- The idea was then adapted by V. Morozov for IR8 of the EIC @ BNL.
  - It featured a complicated split doublet configuration originally intended to be partially reversible.

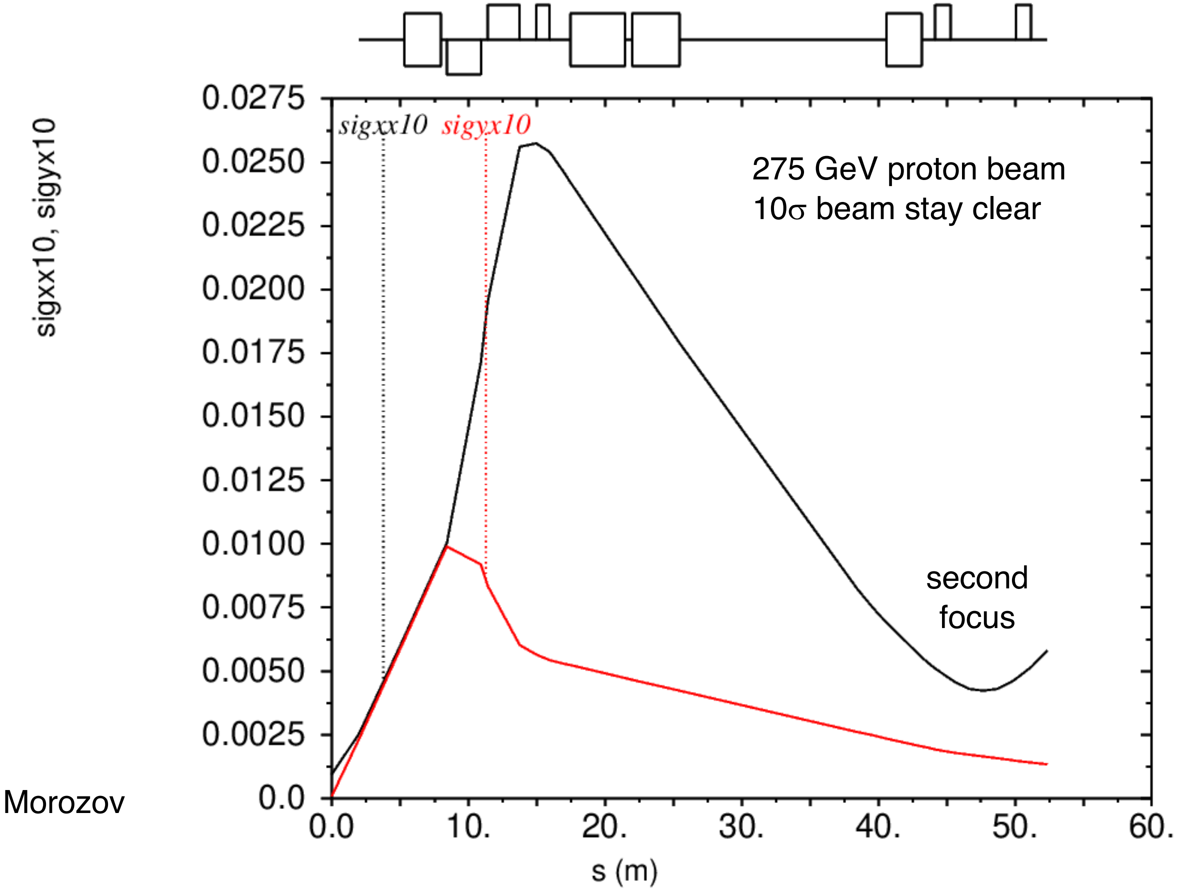
- As part of the EIC UG D2 WG activities, an updated design is now ready and will be implemented in the simulation tools for a 2nd detector that the WG is developing.

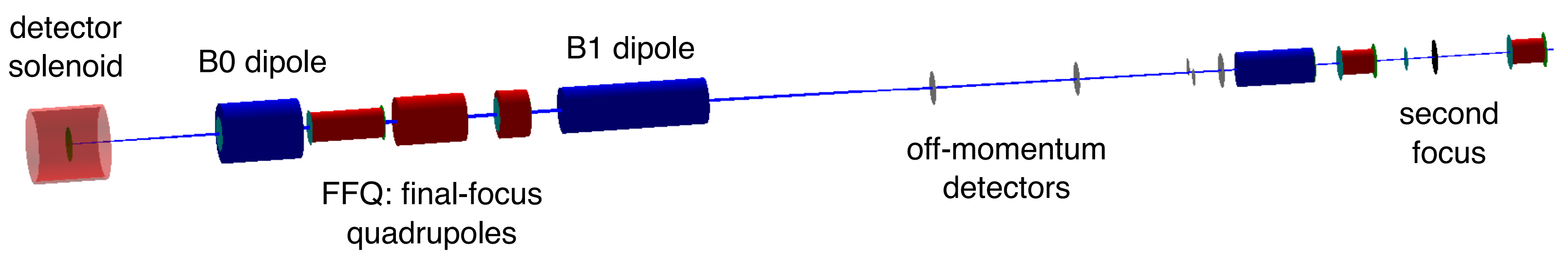


# Beta functions and beam sizes



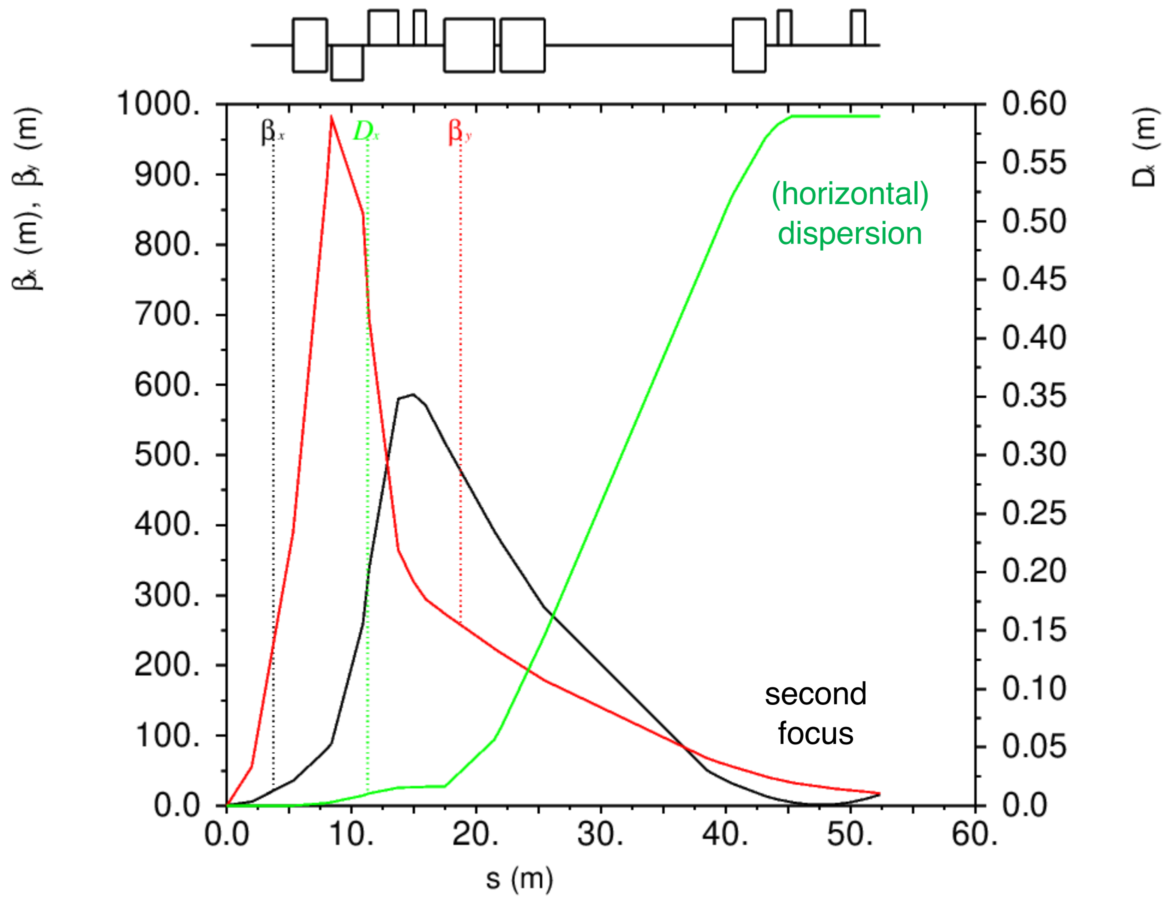

V. Morozov



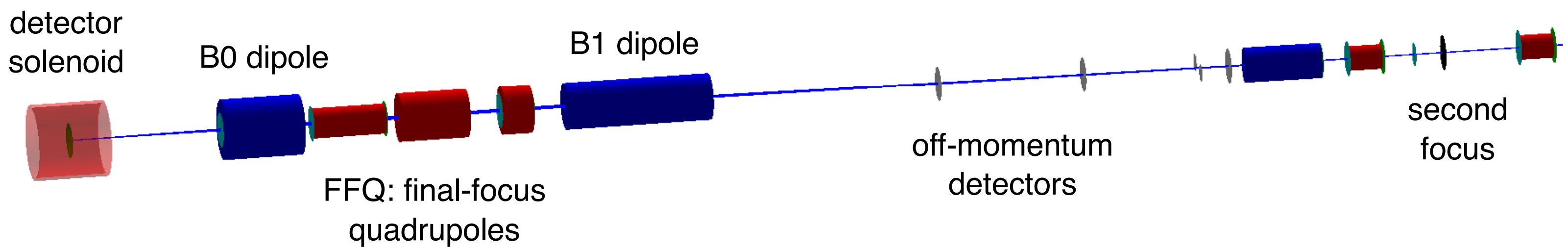

Geant simulation

# New ion optics for IR8 or IR12

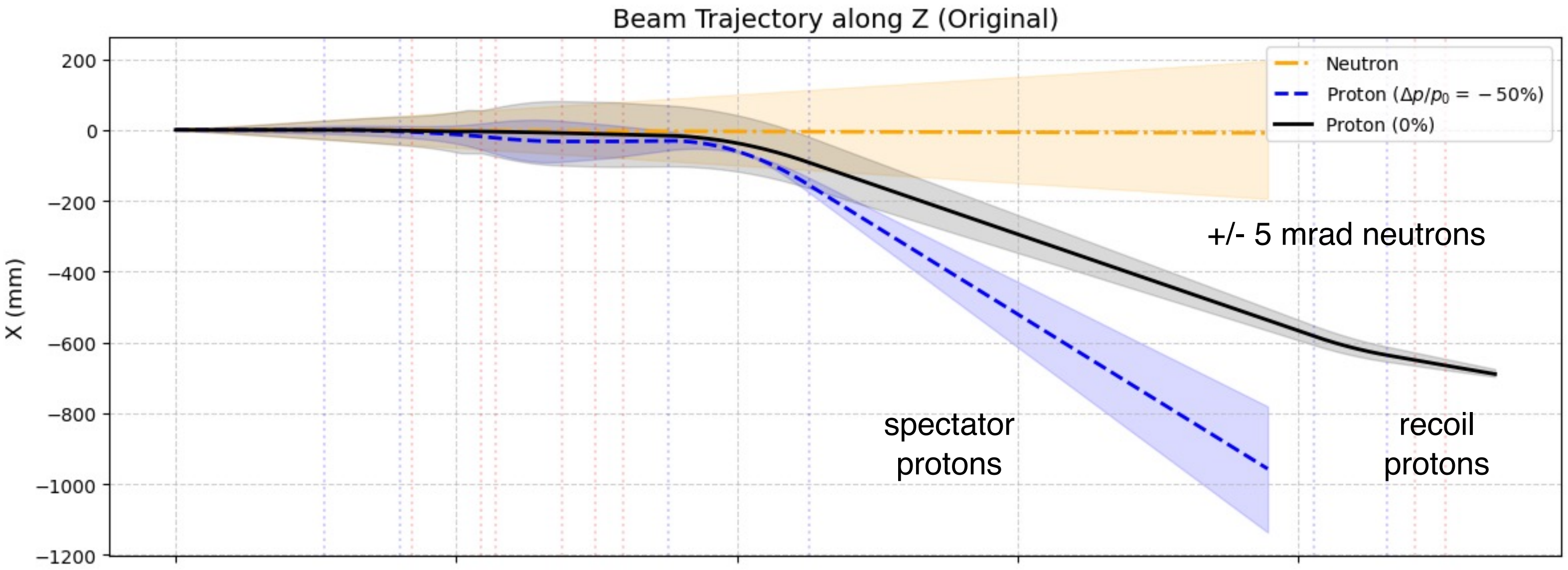



- A second focus at a location with a large horizontal dispersion
  - Enables detection of particles with dp/p > 0.7% even at zero degrees ($p_T$ = 0)
  - The dispersion shifts particles out of the beam and spreads them out along the trackers
  - The second focus makes the beam smaller at the Roman pot location there.
  - The balance between dispersion and focusing is relatively straightforward to adjust.

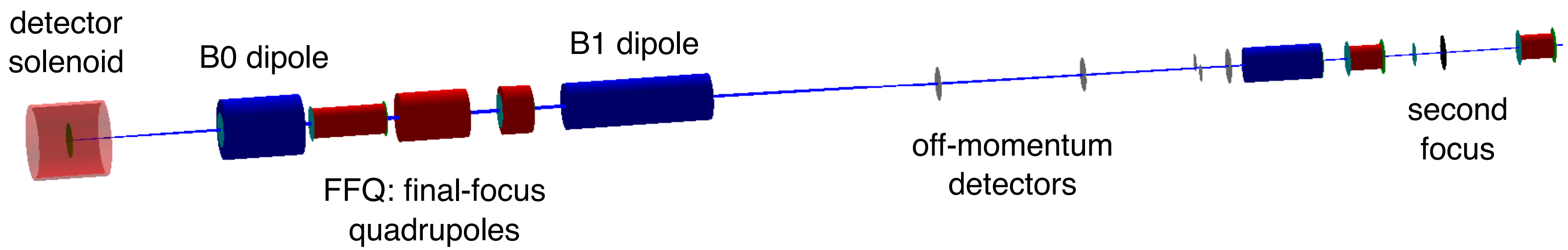
- The new version relaxes accelerator requirements
  - A small $\beta_x^{max}$ minimises chromaticity
  - A (2.7 m long) B0 dipole that can be scaled to any beam energy (B. Parker) allows simpler FFQs compared with ePIC@IR6 (field uniformity specs).



# Large-$p_T$ acceptance (first pass)



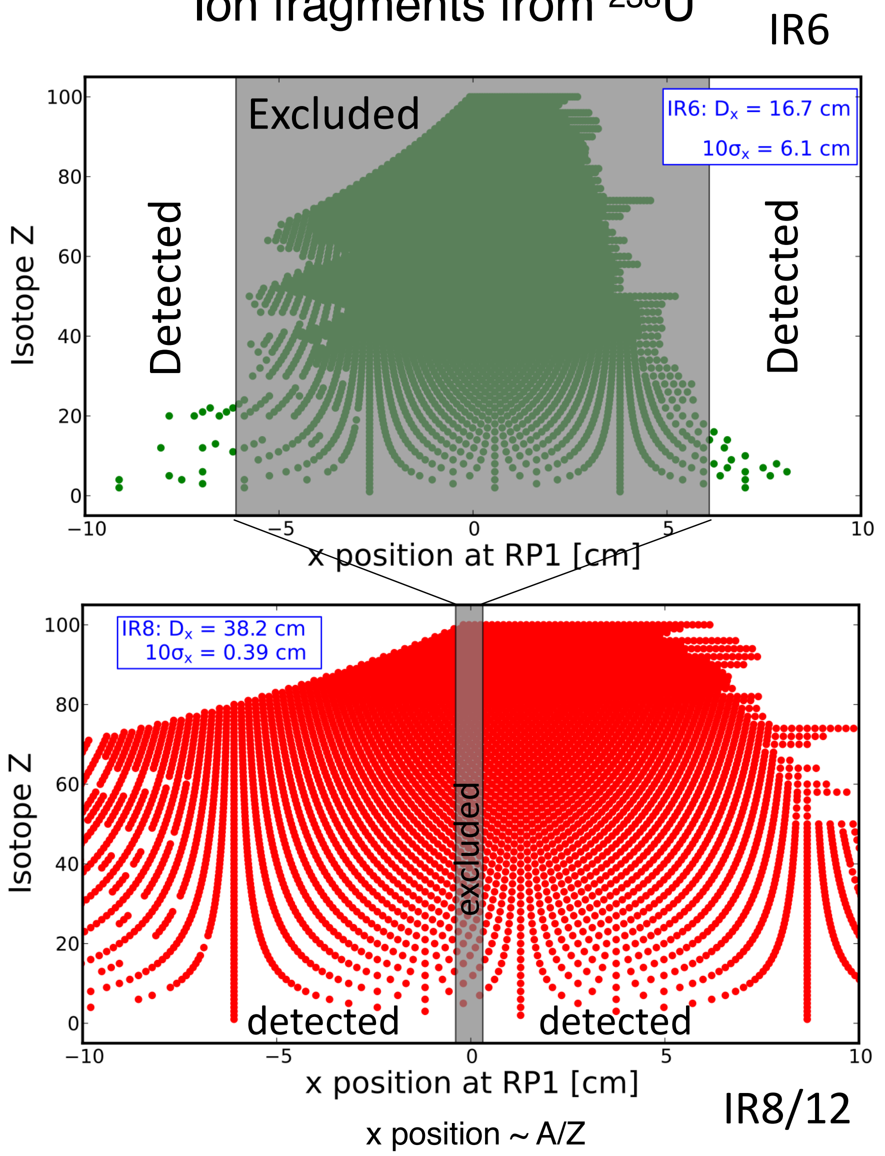

V. Morozov, T. Roth, K. Gopal, PNT




- First-pass apertures
  - Full transport for +/- 5 mrad neutrons.
  - Full transport for spectator protons from deuterium.
  - Losses for recoil protons only in first quadrupole.
- Quad peak fields equal to or smaller than for ePIC@IR6.

# EIC far-forward acceptance with and without a second focus (older optics)

Ion fragments from $^{238}U$

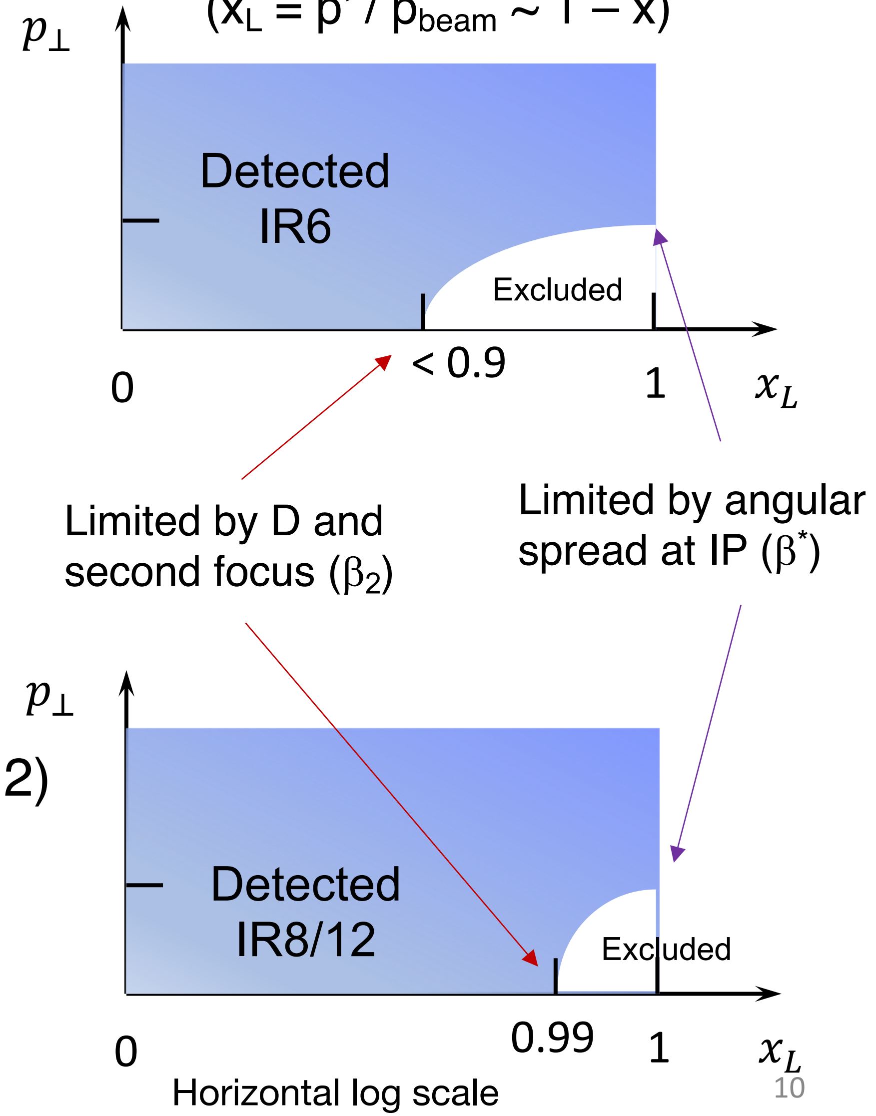



Without 2nd focus:
(ePIC @IR6)

With 2nd focus:
(Detector 2 @ IR8/12)

**Order-of-magnitude improvement in forward acceptance**

Exclusive protons
($x_L = p' / p_{beam} \sim 1 - x$)



# Complementarity and new opportunities

The details the 2nd detector are not yet defined.
Users will have a significant impact on both design and construction.
Still, there are some natural ways for a second detector to expand the capabilities of the EIC:

- Taking advantage of near-beam hadron detection in an IR with a *second focus.* Examples include
  - Low-$x$ / low-$p_T$ protons from exclusive / diffractive reactions
  - Coherent processes on nuclei – light ions *detected* down to $p_T$ = 0 at mid-to-high $x$
  - Bound nucleon structure – in a wide range of spectator nuclei
  - Processes benefiting from the measurement of the complete nuclear final state
    - Reaching higher gluon densities in collisions along the long axis of $^{238}$U
    - Rare isotopes

eA

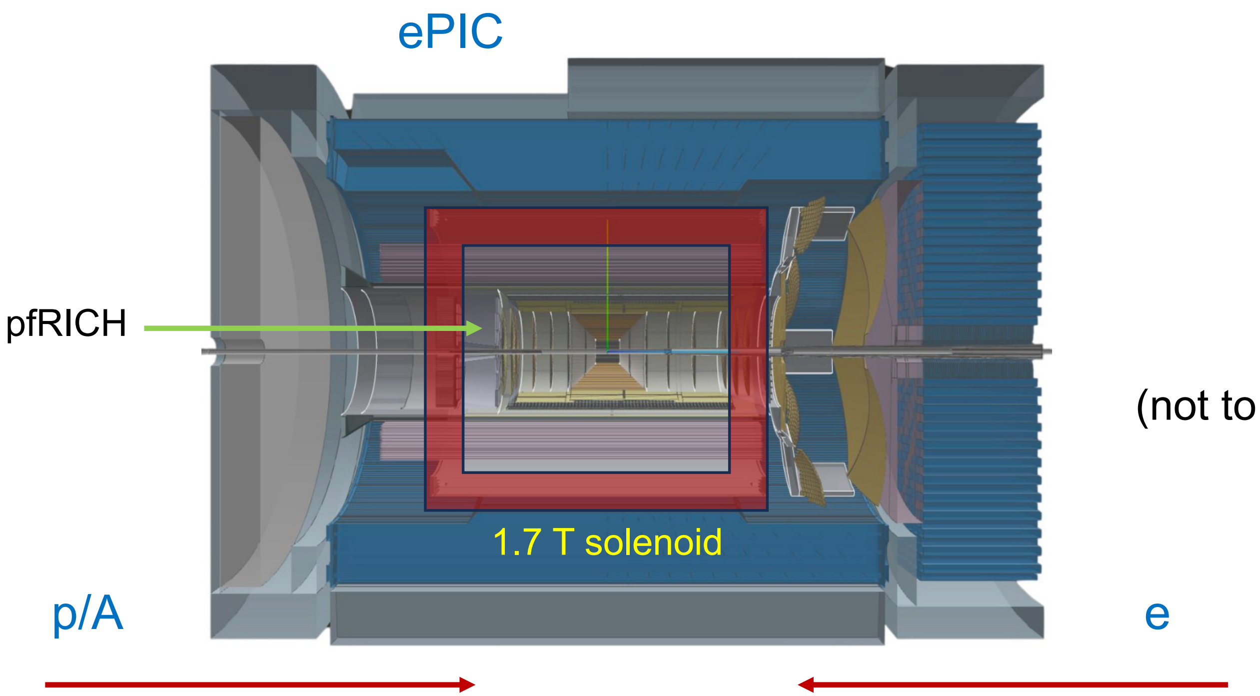
- Seeking complementarity with ePIC and synergies with the forward detection. These could include
  - Improved muon identification in the barrel and (outgoing) electron endcap
  - Improved hadron identification in the barrel from continued DIRC R&D (xpDIRC concept)
  - Add your suggestions here!

# Initial study of a 3 T Detector-2 solenoid (next iteration coming soon)

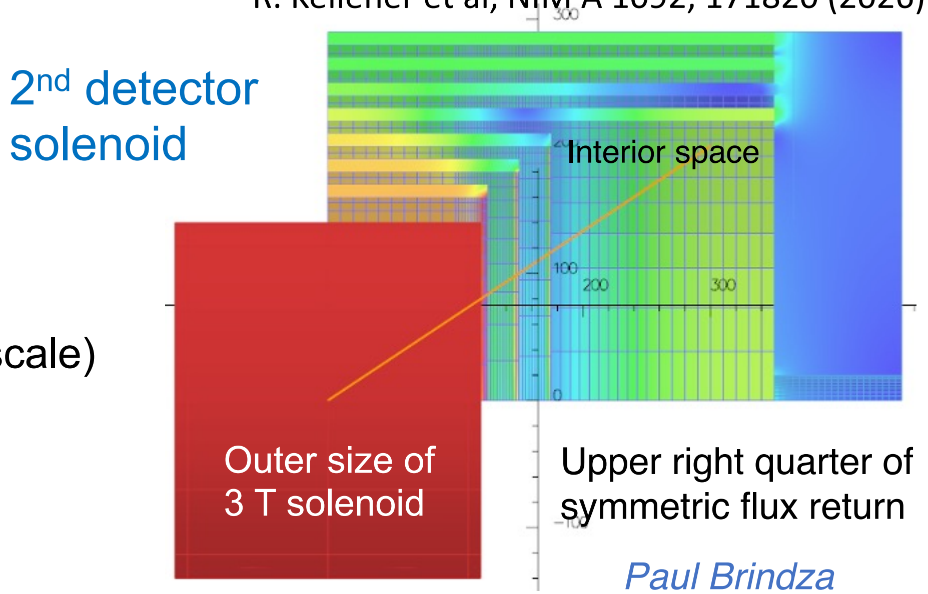
- The ePIC 1.7 T MARCO solenoid is similar to the BaBar solenoid.
- For structural reasons it covers both the tracker and the pfRICH PID detector.

- A shorter 3 T solenoid creates more internal space
  - 30% (1 m) shorter
  - 15% smaller inner (bore) radius
  - The high-field region is matched to the tracker
  - Cables can be routed to the outer parts of the detector much earlier than in ePIC
  - Improves tracking on the (outgoing) electron side

Barrel Hcal optimized for muon identification
R. Kelleher et al, NIM A 1092, 171820 (2026)



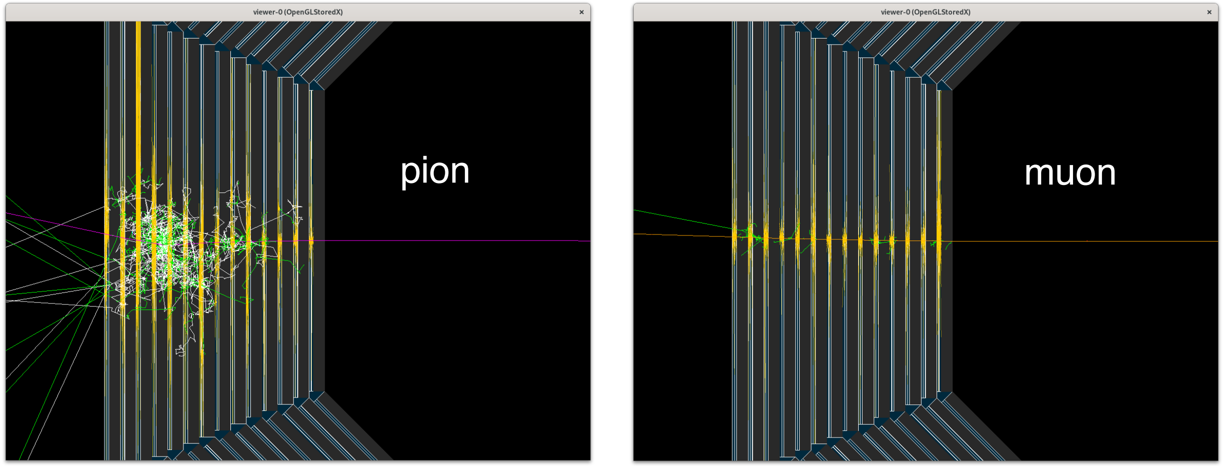

(not to scale)




*Paul Brindza*

# Muon identification for a 2nd EIC detector

Barrel Hcal optimized for muon identification
R. Kelleher et al, NIM A 1092, 171820 (2026)

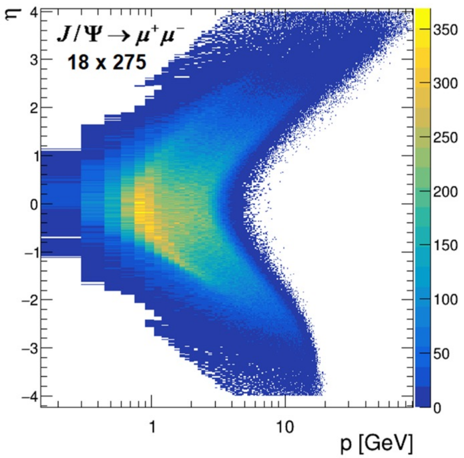



- At the EIC, most mid-rapidity muons have low momenta.
  - The traditional high-energy approach of placing muon detectors behind an Hcal does not work.
  - An integrated system is necessary.

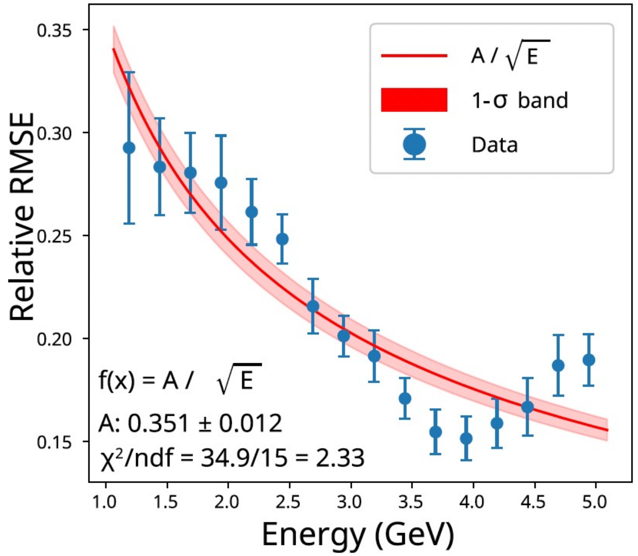
- **Muon ID:** most Hcals provide some level of muon ID, but an optimized system would improve both the efficiency and purity.
  - A high level of segmentation along the muon path is more advantageous than typical Hcal "towers"

- **Hcal**: ongoing R&D uses the Belle II KLM as a starting point but adds precision timing and energy measurements in each layer.
  - With AI methods for reconstruction, the resulting hKLM seems to be a surprisingly good Hcal.

arXiv:2209.00496

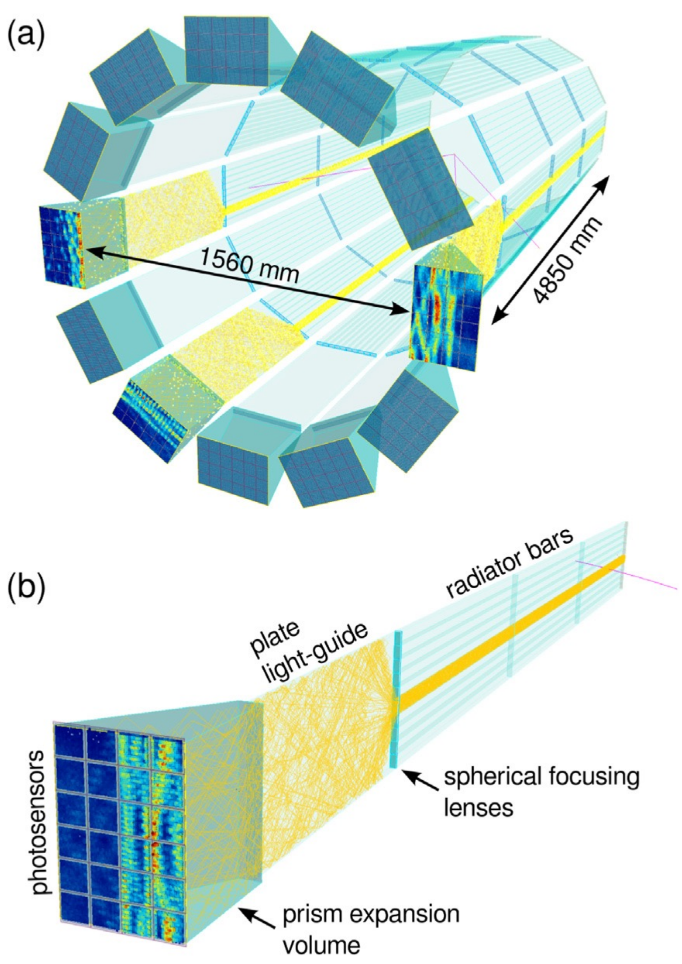



energy resolution for a single neutron (simulated)

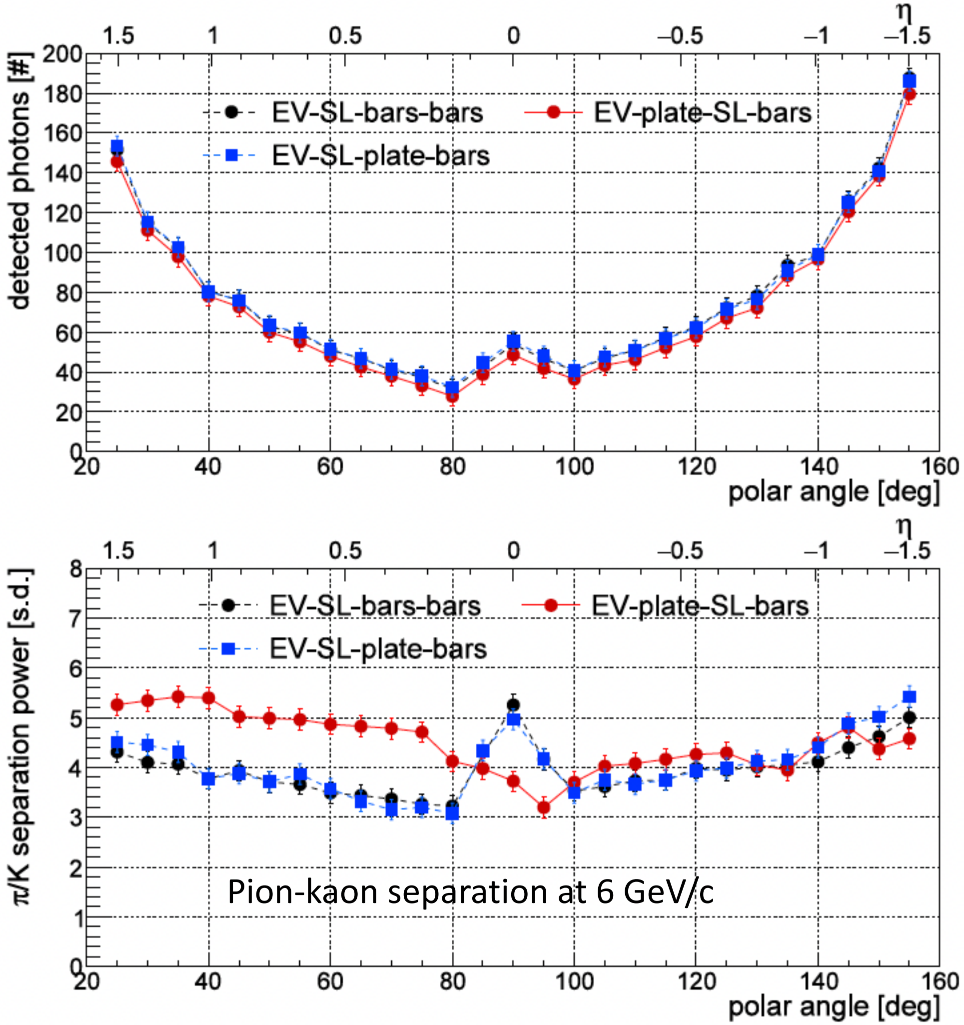


# Barrel PID – the xpDIRC

The xpDIRC concept for next-generation DIRC detectors
R. Dzhygadlo et al, NIM A A 1089, 171603 (2026)



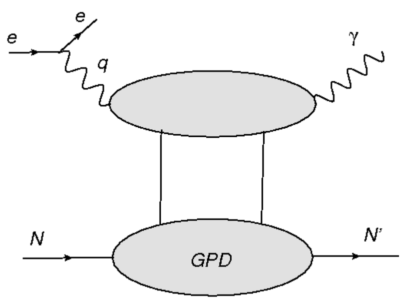

- Improved performance can be achieved through additional R&D.
- The xpDIRC can reach a higher separation at GeV/c or a higher momentum at 3 s.d. separation.
- The performance pseudorapidity (polar angle) can be optimized to better match the higher momenta of forward-going hadrons.
  - red curve in lower right panel
- The xpDIRC design may enable the use of SiPMs instead of HRPPDs.
  - Smaller EV prism area can reduce dark noise




Outgoing hadron direction

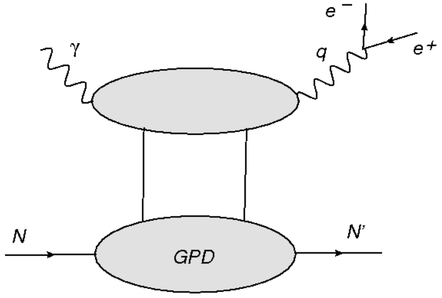
# Timelike Compton Scattering (exclusive dilepton photoproduction)

(spacelike) DVCS



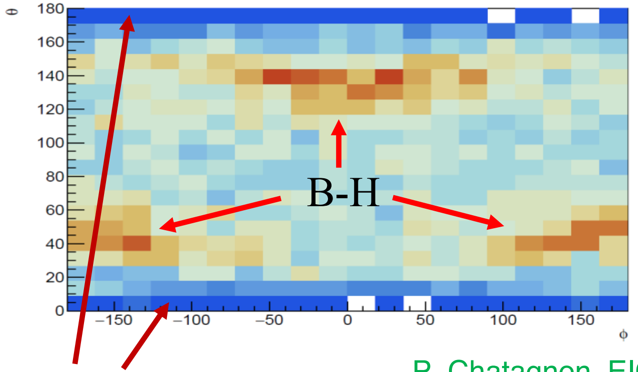

Initial photon spacelike, final photon real

timelike Compton scattering (TCS)



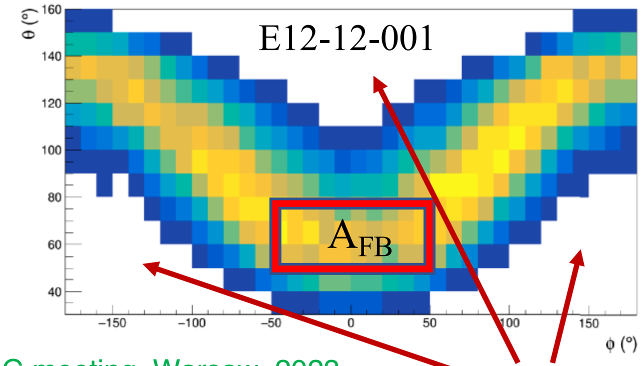

Initial photon real, final photon timelike → $l^+ l^-$

EIC detector




Losses due to lepton acceptance

CLAS12




P. Chatagnon, EIC UG meeting, Warsaw, 2023

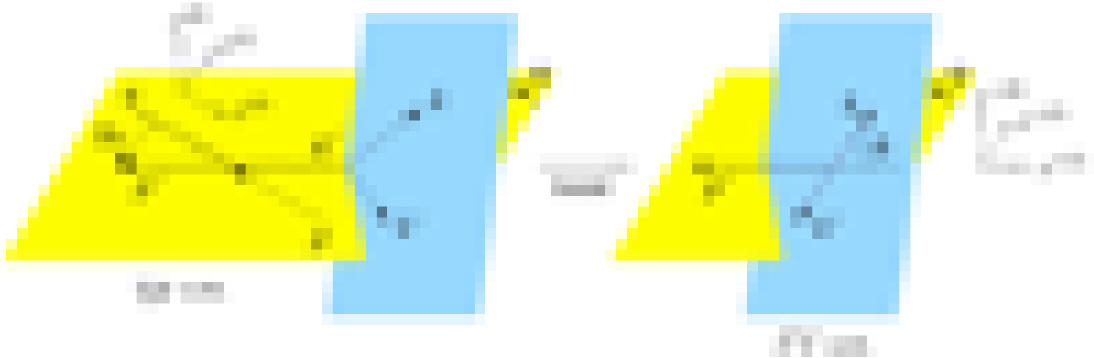
Losses due to lepton acceptance

- TCS analysis uses the lepton c.m. angles θ and ϕ
  - Integration over the angles projects out amplitude (CFFs)

*Eur. Phys. J. C 23, 675 (2002)*

- Fixed-target experiments have limited forward acceptance
  - Loss of useful statistics and complicated systematics
  - The forward-backward asymmetry $A_{FB}$ can be calculated locally

- The EIC benefits from excellent dilepton acceptance.
  - Straightforward to extract the ratio R



- k,k' = momentum of $e^-$, $e^+$ or $\mu^-$, $\mu^+$
- θ = angle between the scattered proton and the electron
- φ = angle between lepton scattering- and reaction planes

# Double DVCS ($Q^2 < Q'^2$ => TCS-like)

Challenging measurement Illustrative of many EIC / D2 features

# events = luminosity x cross section x acceptance x time

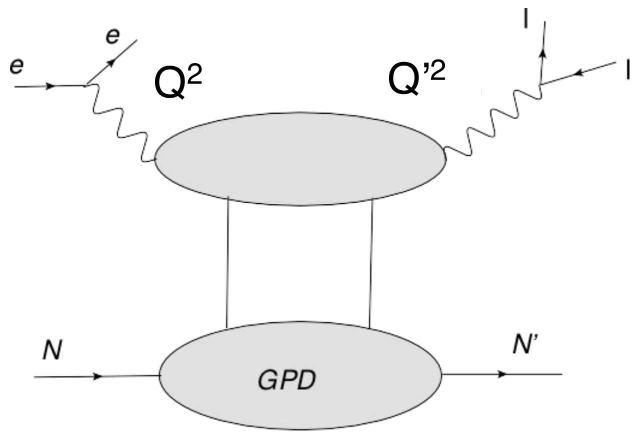
- Double DVCS can probe GPDs outside of the $x = \xi$ line.
  - Low rates challenging, but cross section increases at lower x
    - 0.14 pb - JLab @ 10.6 GeV
    - 4.7 pb - EIC @ 10 x 100 GeV

*PRD 107, 094035 (2023)*

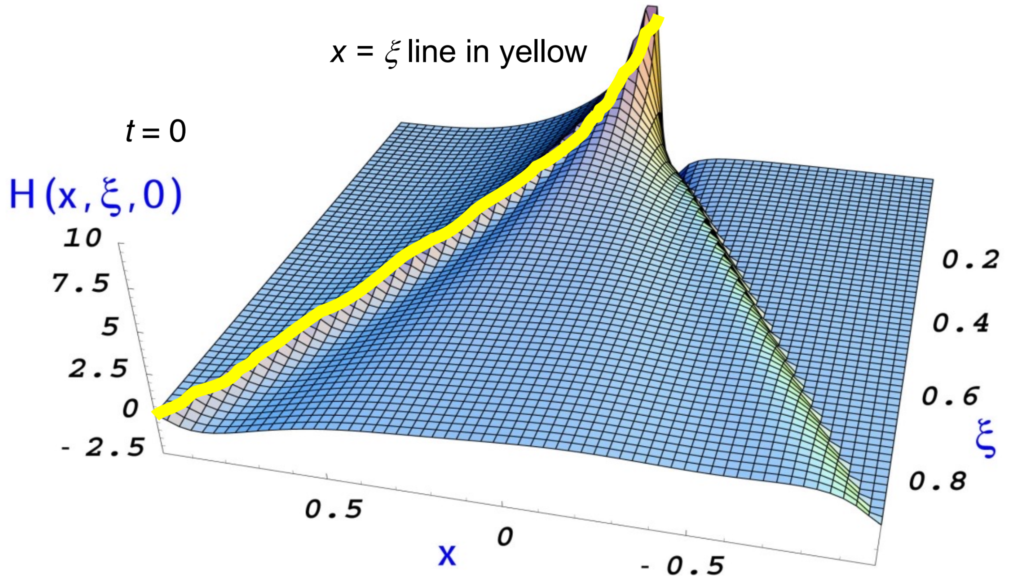
- Lepton acceptance and identification
  - Good muon ID is *necessary* to distinguish the scattered electron from the DDVCS decay leptons
  - The EIC has excellent di-lepton acceptance.
- Proton acceptance in an IR with a second focus
  - DDVCS measurements will provide data mostly at low $t$
  - A $2^{nd}$ focus gives a low-$t$ proton acceptance close to 100%

The $2^{nd}$ EIC detector could provide an opportunity for measuring TCS-like DDVCS at lower $x$.

DDVCS: initial *and* final photon virtual




$x = \xi$ line in yellow



# Bound and quasi-free nucleon structure through spectator tagging

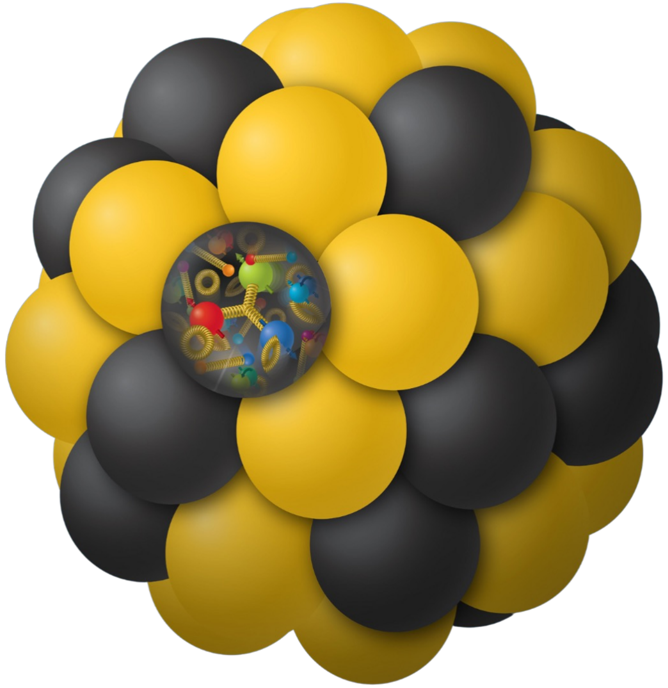
- The EIC forward detectors make it possible to measure processes on a single nucleon in coincidence with spectator nucleons and nuclei.
  - Due to final-state interactions this is essential for interpretation.

*Wim Cosyn*

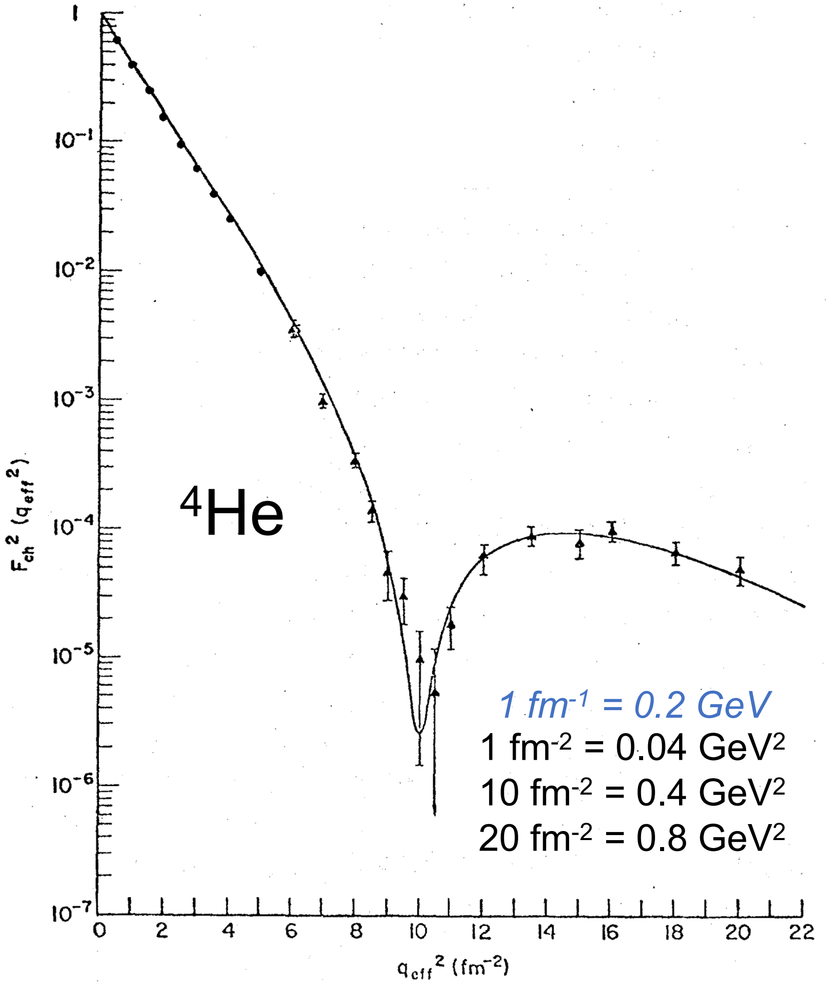
- **Quasi-free neutron structure** can be accessed by measuring the spectator proton(s) in deuterium or polarized $^3$He.

- **Bound nucleon structure** can be accessed by measuring the spectator nucleus (A-1 system).
  - A-2 for SRCs

- The ePIC forward detectors are good for spectator protons, but a 2nd detector would be able measure A-1 nuclei over the full mass range.



# Coherent nuclear processes




## Light ions

- Access to 3D structure (GPDs)
  - Exclusive reactions like DVCS, DVMP
  - Combines spin and nuclei
- Recoiling ion is *detected* in Roman pots
  - ePIC can detect $^3$He over a range in $t$, but a second focus would be essential for heavier light ions such as $^4$He and Li. ($^6$Li and $^7$Li could be polarized in the future).

## Medium- and heavy ions

- Coherent diffraction *→ Talk by Maci Kesler*
  - Spacing of minima is reduced at larger A
- Incoherent events are separated by vetoing of breakup
  - Detection of neutrons, protons, and photons
  - With a 2$^{nd}$ detector also light ions and nuclear fragments

# $^{238}$U – using deformed nuclei to increase the effective nuclear thickness

- At the EIC, nuclei will be used to probe the transition to gluon saturation

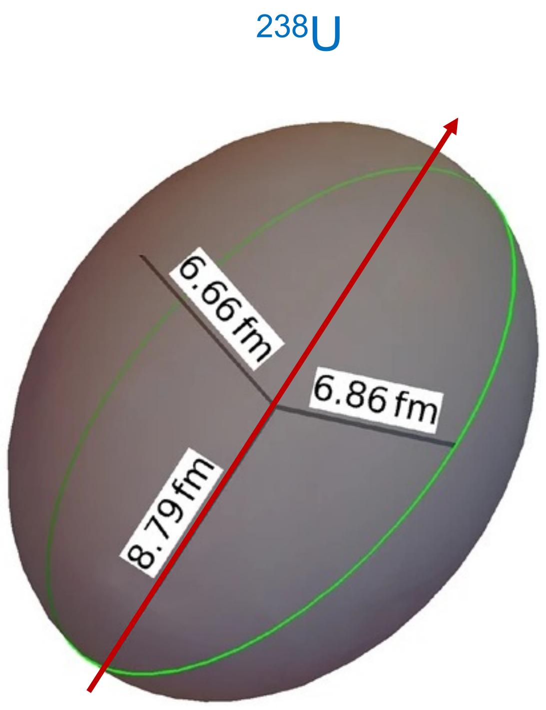
$$Q_s^2 \sim A^{1/3}/x^{0.3} \sim T(b) \cdot (E_e E_A)^{0.3}$$

  - where *T(b)* is the nuclear thickness as a function of the impact parameter
  - and $E_e$ and $E_A$ are the electron and ion beam energies, respectively.

- Striking the nucleus *centrally* along the *long* axis creates an enhancement

$$\frac{T(b=0)_{long\ axis}}{\langle T(b)\rangle_{\min\ bias}}$$

- This is equivalent to a very substantial increase in $E_e$.
  - A preliminary study showed that selecting a subsample of a few percent of the events using the final-state information from the second focus could be equivalent to a factor 4.5 increase in $E_e$.
  - A more comprehensive evaluation using ML-methods is underway *(Fanelli, Schmookler, Li, Vossen, PNT)*

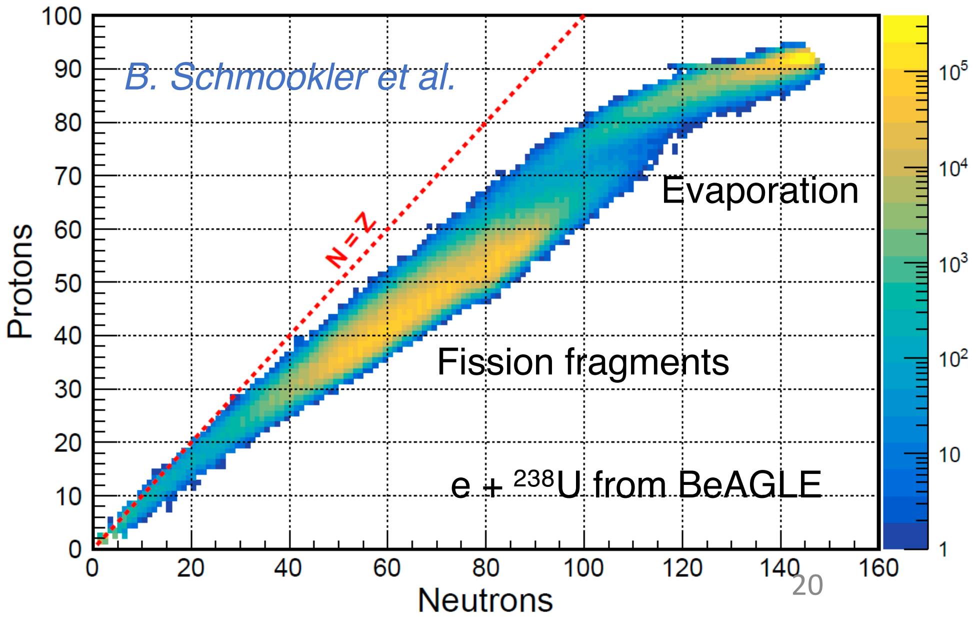



*PNT et al, POETIC8, Regensburg, Germany (2018)*

# The nuclear final state

- In high-energy eA scattering most nuclei can fission, but $^{238}U$ fissions most of the time.

- An event with a large thickness is likely to produce more breakup, but the forward activity is more than "evaporation" neutrons.
  - Fission fragment produce neutrons. The number depends on which fragments are produced.
  - Protons and light ions are also emitted.




- With a second focus we can detect the complete final state including the fission fragments.

- This will also make it possible to study the fragments themselves in search of rare isotopes.

- Gamma photons from the de-excitation can reveal the internal structure.

- Of interest to the FRIB community.

# The EIC user group 2nd detector working group

- Formed in 2022 following DPAP and the establishment of the ePIC collaboration
- The current focus is on developing simulation tools reflecting the envisioned capabilities
- We aim for a short publication early next year and then starting the work on a longer white paper
  - Your input will be essential!
- We organize regular WG meetings. Please let us know if you have something you would like to share!
- Conveners
  - Anselm Vossen (Duke U) anselm.vossen at duke.edu (chair-elect of the EIC UG steering committee)
  - Björn Schenke (BNL) bschenke at bnl.gov
  - Charles Hyde (ODU) chyde at odu.edu
  - Pawel Nadel-Turonski (U of SC) turonski at sc.edu
  - Simonetta Liuti (UVA) sl4y at virginia.edu
  - Vasiliy Morozov (ORNL) morozovvs at ornl.gov
  - Wenliang “Bill” Li (MS State U) wenliang.li at msstate.edu

  Liaison from the EIC UG SC: Charlotte van Hulse (Vrije Universiteit) charlotte.barbara.van.hulse at cern.ch

# Summary

- Having two detectors is important to maximize EIC science and take full advantage of the investment made into the EIC.

- The novel far-forward detection with a second focus could allow probing deeper into the gluon saturation region well before any electron beam energy upgrade.

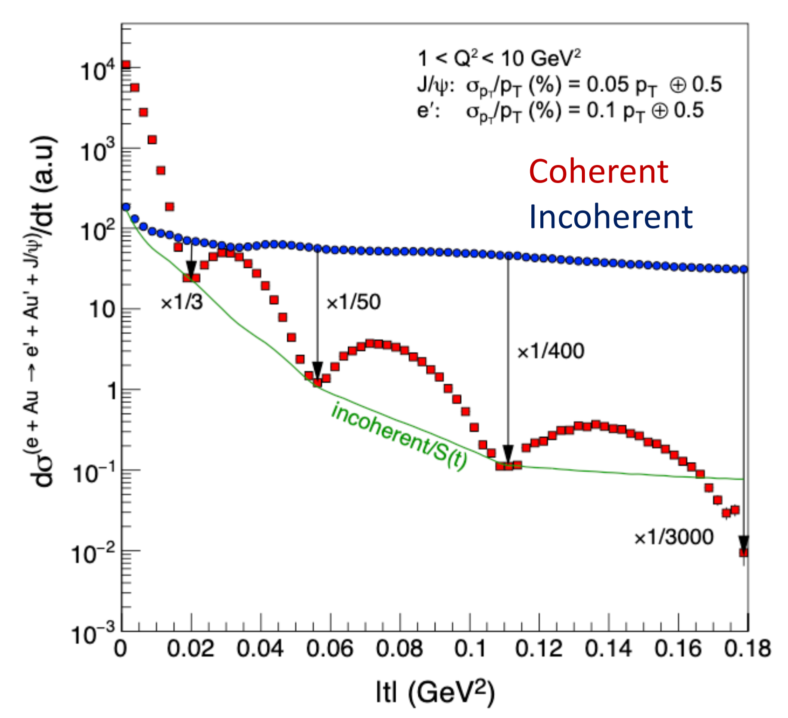
- A 2nd detector could have capabilities more aligned with the requirements for exclusive reactions and other ”JLab-centric” measurements.

- If you are interested or have good ideas, please join the EIC UG 2nd detector WG activities!

Thank you!

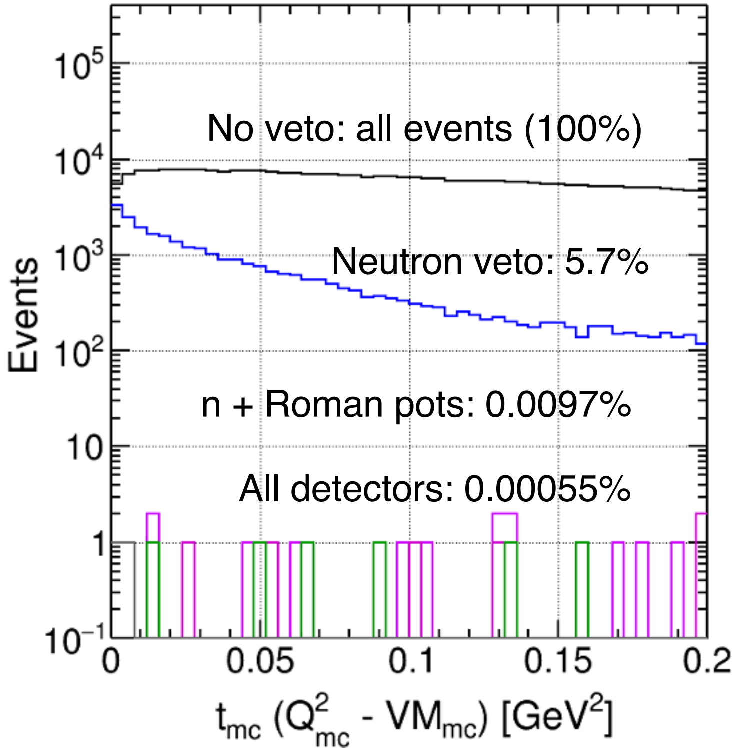
# Coherent diffraction on heavy nuclei vetoing breakup with a second focus

Reference from EIC YR p.352




At the third diffractive minimum, a rejection factor for incoherent event better than 400:1 (0.0025% inefficiency) must be achieved

Veto inefficiency for incoherent events

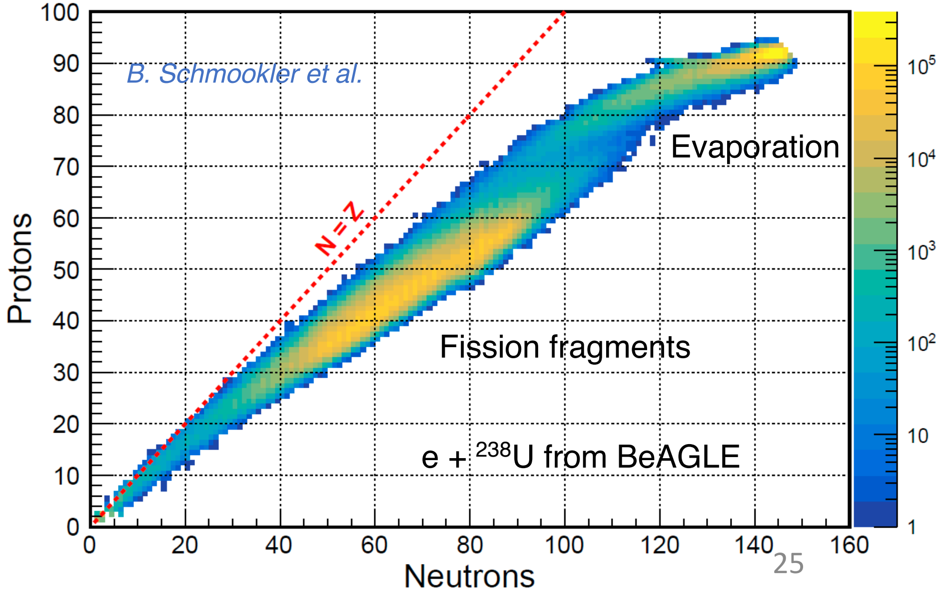


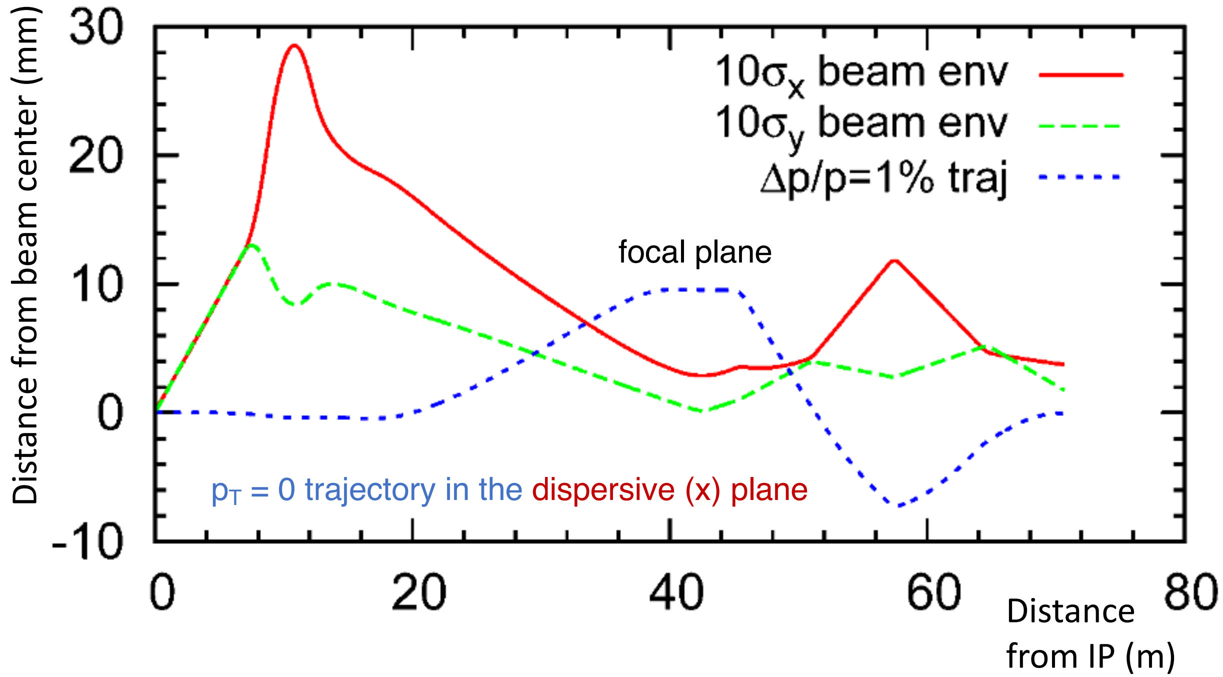

*J. Kim et al*

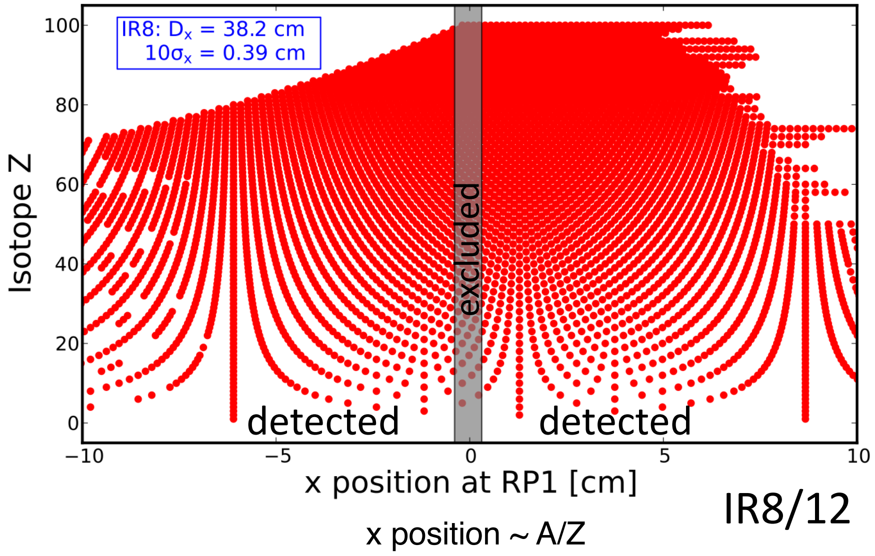
Fragment detection in Roman pots at the second focus suppresses incoherent backgrounds even at large *t*.

Also applicable to, *e.g.*, DVCS on medium nuclei

# Example: nuclear fragment detection in a 2nd EIC detector (older optics)

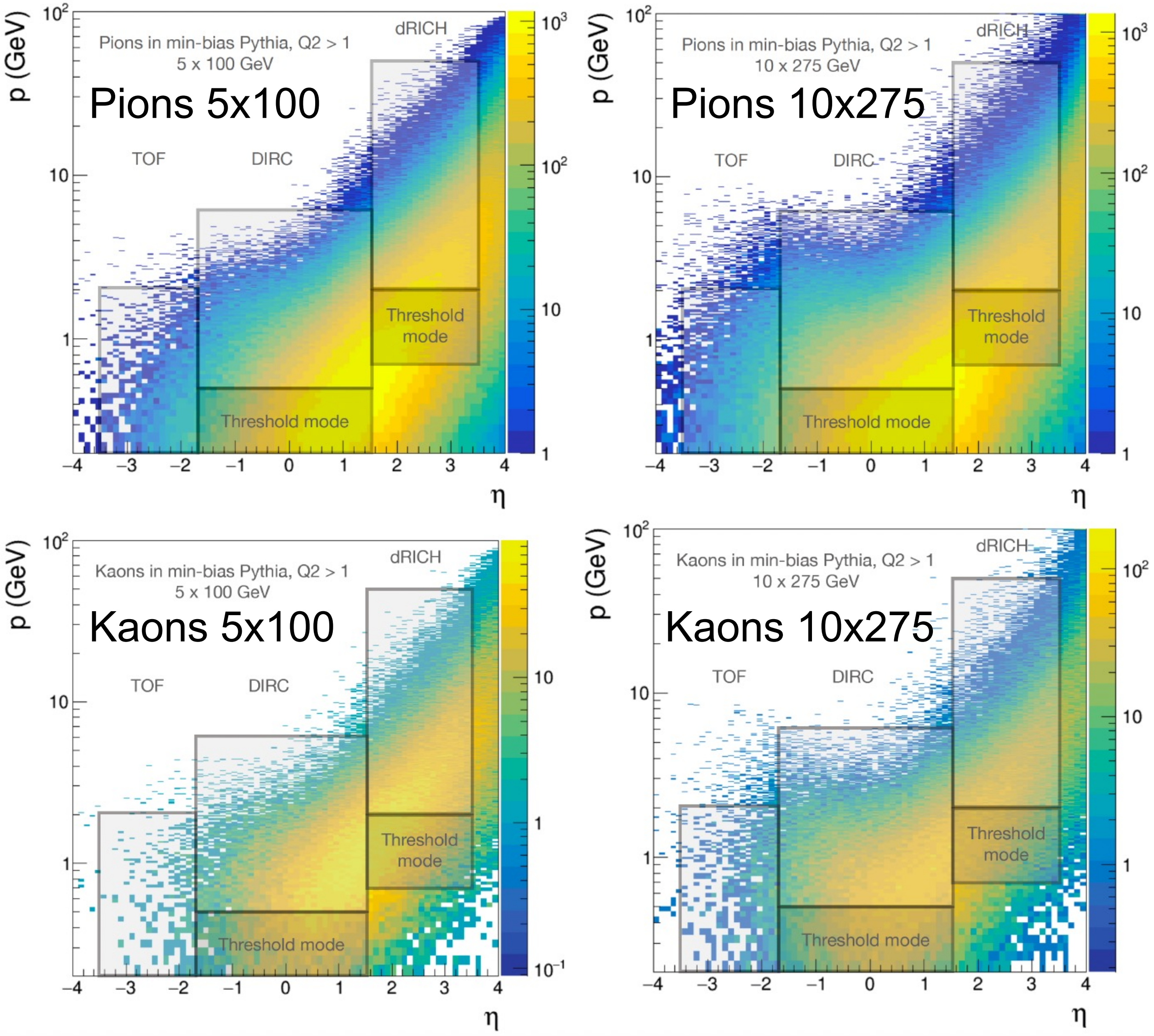



- ePIC forward detection is optimized for protons
  - Nuclear fragments stay within the 10σ beam envelope.
- A 2nd detector would provide point-to-point focusing (second focus) enabling
  - Detection of most fragments from any nucleus
  - Detection of light reoiling nuclei down to $p_T = 0$
  - Better acceptance for low-$x$ exclusive protons (*e.g.*, DVCS)

# Example: kaon ID in the outgoing electron endcap




- A TOF detector in the electron endcap is not be sufficient for identifying all kaons when using an 18 GeV electron beam
  - This would have to be provided by ePIC.

- Plotting pions and kaons separately shows that at lower electron beam energies there are few kaons in the electron endcap, and those have momenta well suited to a TOF detector.

- When combined with a muon-optimized Hcal in the same endcap, the 2$^{nd}$ detector PID could be quite complementary to ePIC.

*Threshold mode: positive ID ("ring") for pions but kaons are below Cherenkov threshold.*