

A general-purpose 2nd detector for the Electron-Ion Collider

Pawel Nadel-Turonski

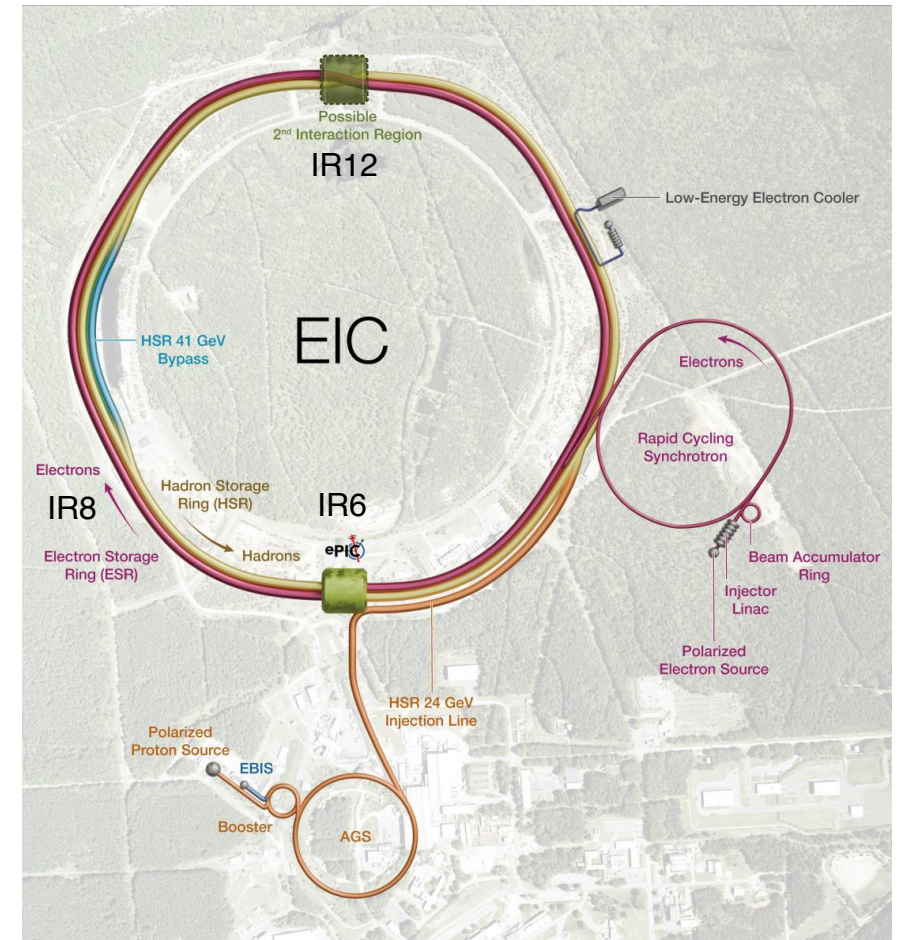


UNIVERSITY OF
South Carolina



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Precision QCD predictions for ep physics at the EIC (IV),
CFNS, Stony Brook University, September 21-15, 2026.



The Electron-Ion Collider at Brookhaven National Lab

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

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

- Longitudinal and transverse target

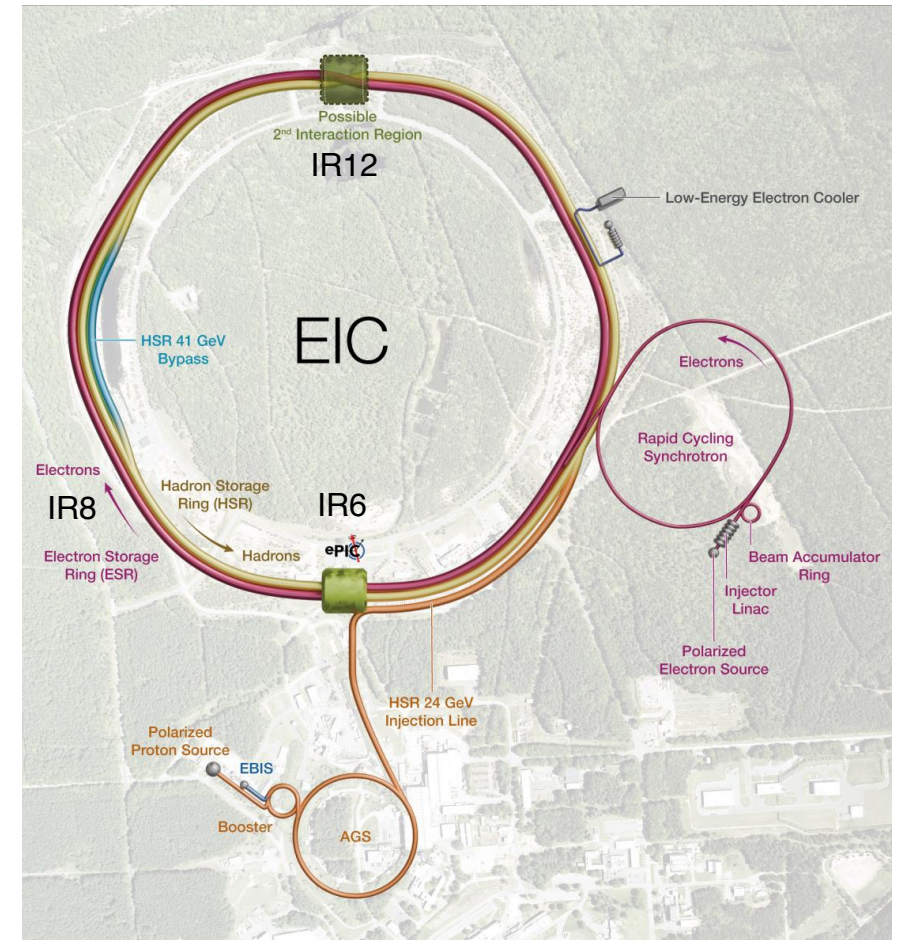
Beam energies:

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

Full range of ion species: protons – Uranium

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.



Electron-Ion Collider Detector II

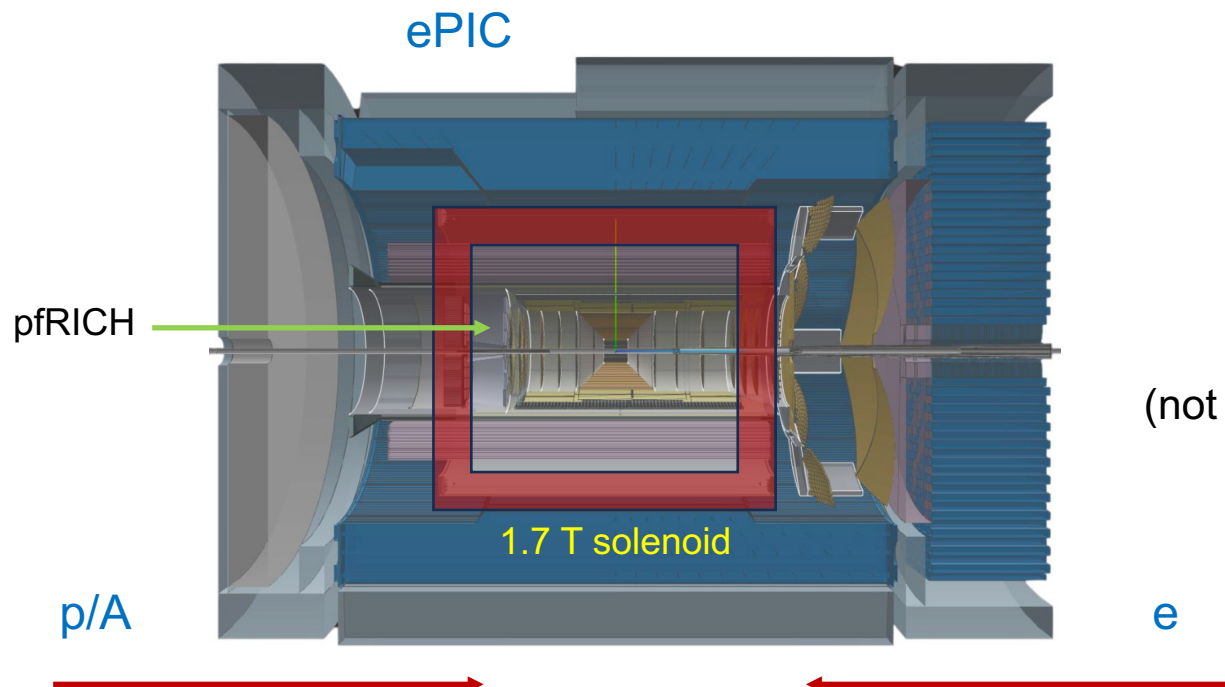
- Major facilities usually have at least two detectors to maximize the science.
 - Independent confirmation of results and discoveries, reduction of systematic uncertainties.
- A 2nd EIC detector will allow for enhanced capabilities in several sectors.
 - A novel far-forward detection system utilizing 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 (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 IR12.

Specialized vs General Purpose detectors

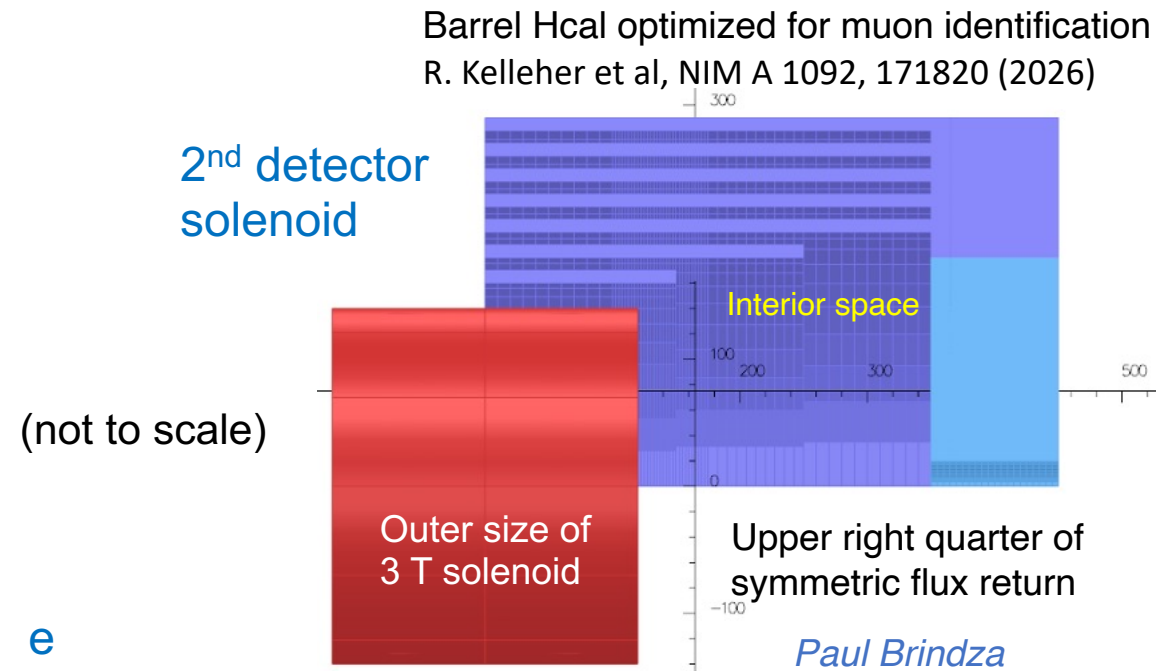
- Any detector in IR12 will require significant investments in a new interaction region, experimental hall, *etc*, and will require a large collaboration to operate.
- The savings of not fully instrumenting a 2nd detector are relatively modest, while even small cuts in capability greatly reduce the broader science impact and potential collaboration size.
- A more cost-effective strategy is to incorporate requirements from high-energy into the design of a general-purpose detector.
- The critical aspects of a detector are how it is integrated with the accelerator (forward detection), and how the solenoid and its flux return are designed (integration with muon detectors)
 - Other subsystems can to some extent be combined as required.

Initial study of a 3 T Detector-2 solenoid

- 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.



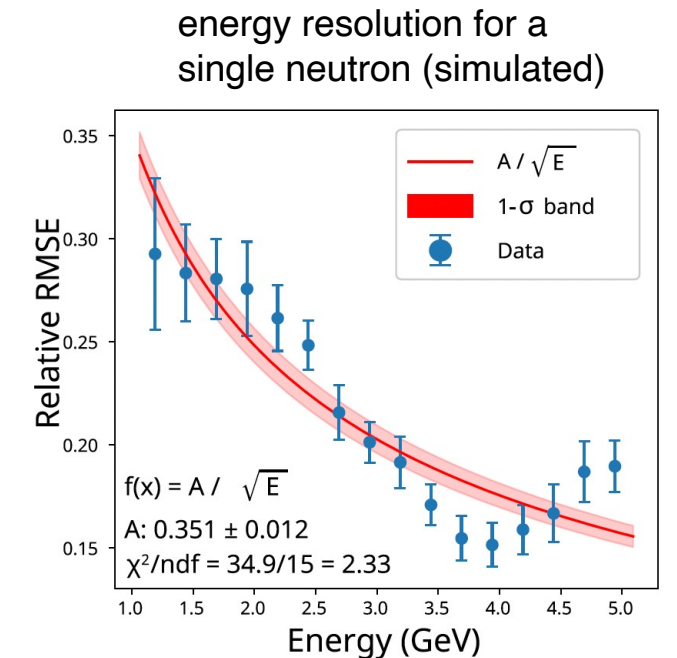
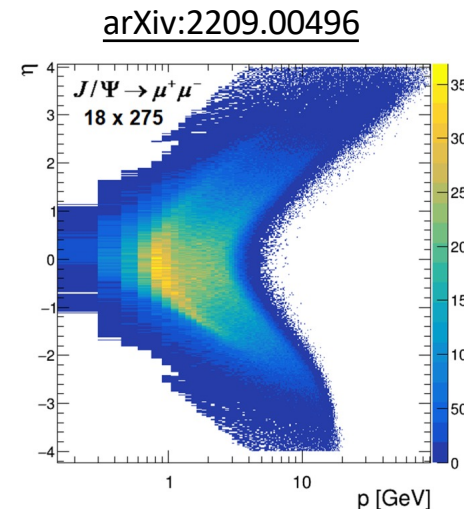
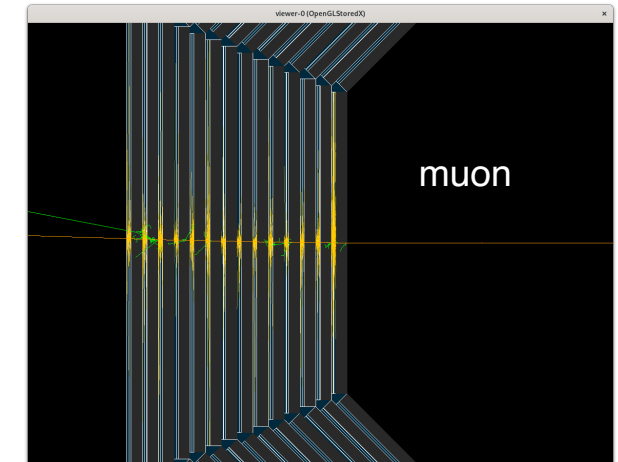
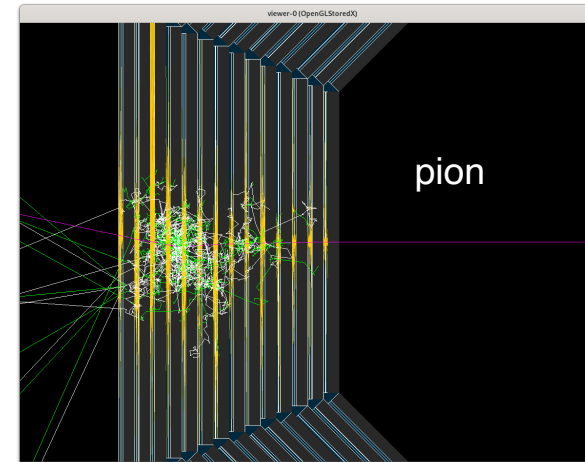
- A shorter 3 T solenoid creates more internal space
 - 30% (1 m) shorter
 - 15% smaller inner (bore) radius
 - The high-field region is matched to the tracker
 - Cables can be routed to the outer parts of the detector much earlier than in ePIC
 - Improves tracking on the (outgoing) electron side



Muon identification for a 2nd EIC detector

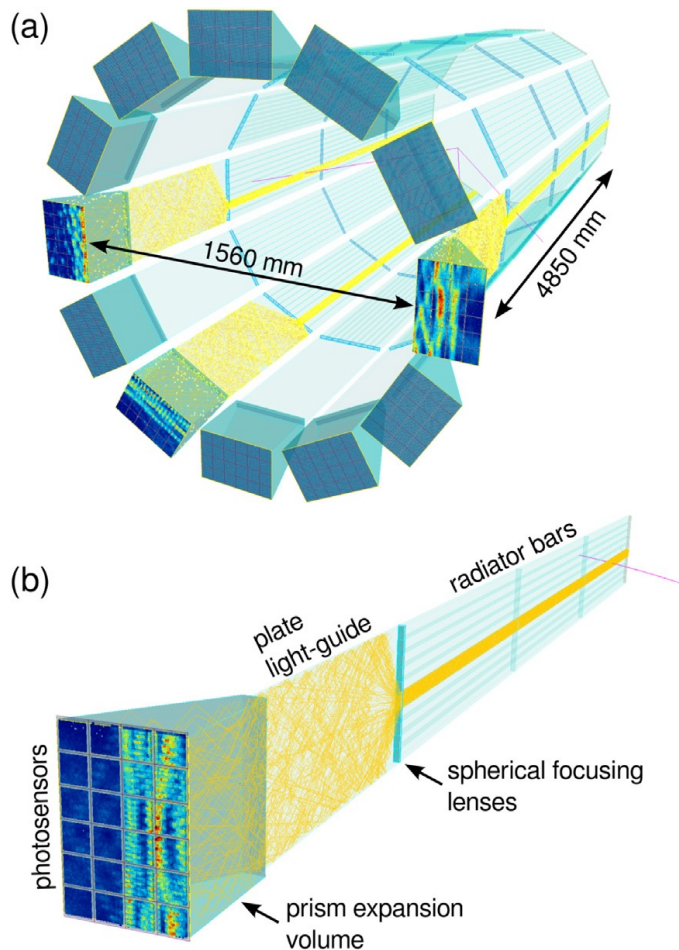
Barrel Hcal optimized for muon identification
R. Kelleher et al, NIM A 1092, 171820 (2026)

- 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.

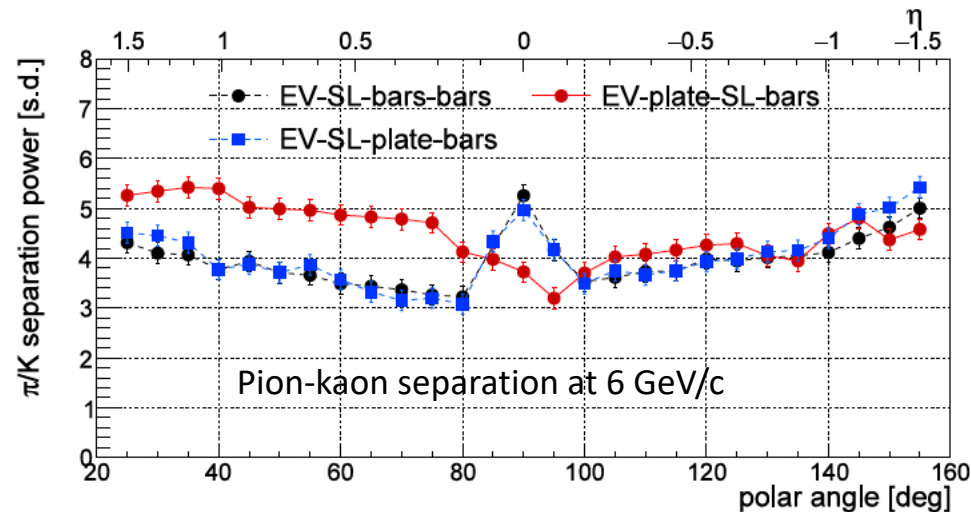
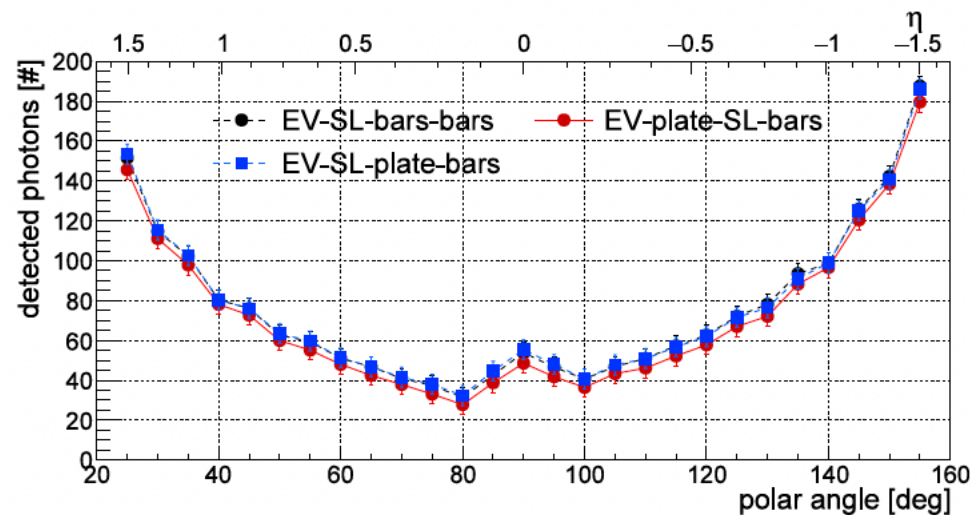


Barrel PID – the xpDIRC

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

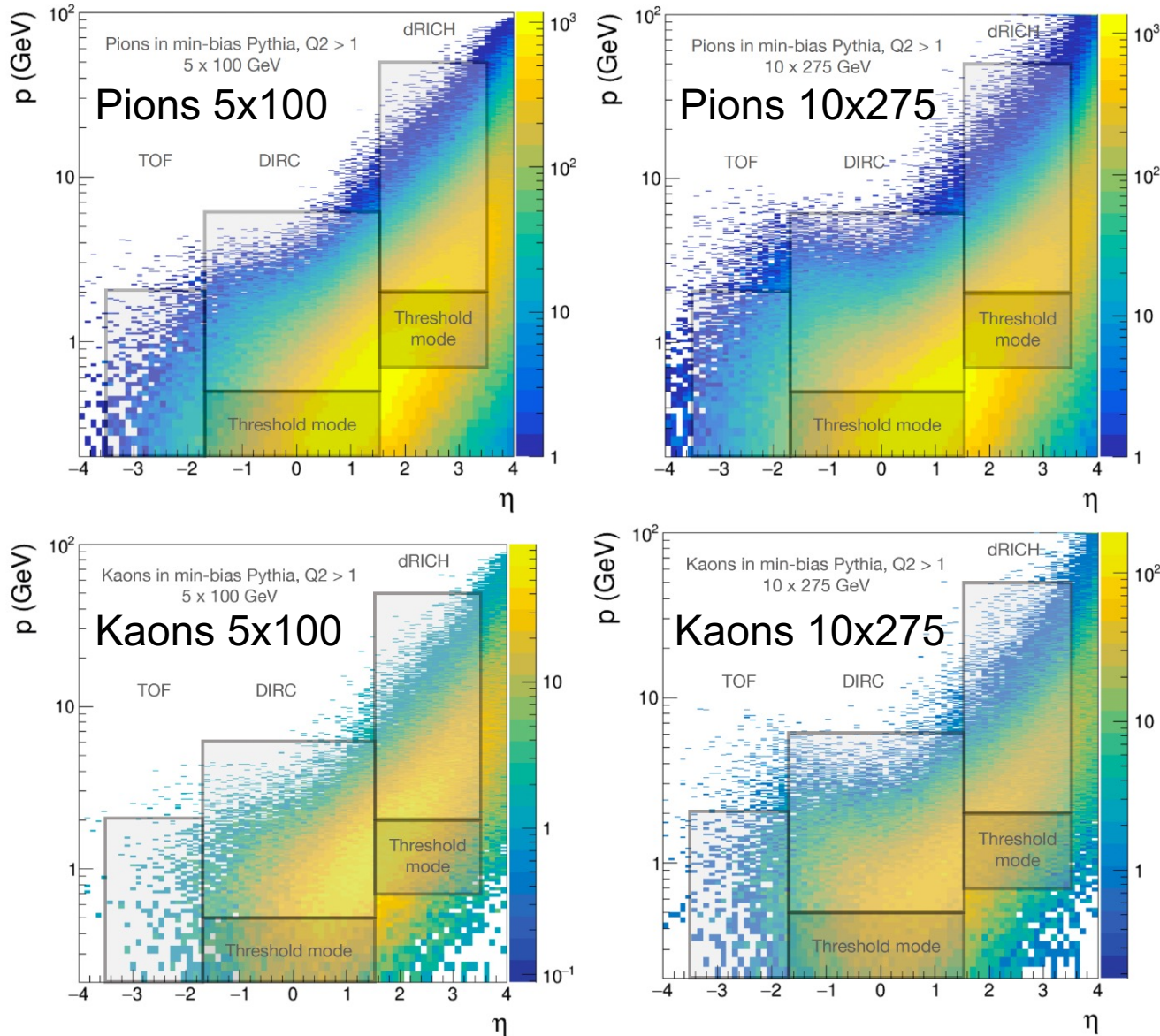


- Improved performance can be achieved through additional R&D.
- The xpDIRC can reach a higher separation at GeV/c or a higher momentum at 3 s.d. separation.
- The performance pseudorapidity (polar angle) can be optimized to better match the higher momenta of forward-going hadrons.
 - red curve in lower 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

Kaon ID in the outgoing electron endcap



- An aerogel RICH detector in the electron endcap is important for identifying kaons when using an 18 GeV electron beam
 - This would 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.
- Replacing the aerogel RICH with a longer tracker, a muon-optimized Hcal and additional space for improved electron acceptance would make the 2nd detector PID complementary to ePIC.

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

Complementarity and new opportunities

Central detector capabilities.

- Complementarity with ePIC 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)
 - Improved resolution for the scattered electron.
 - Add your ideas here!

Near-beam (outgoing) hadron-side detection capabilities.

- Taking advantage of 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
 - Higher gluon densities in collisions along the long axis of ^{238}U
 - Rare isotopes

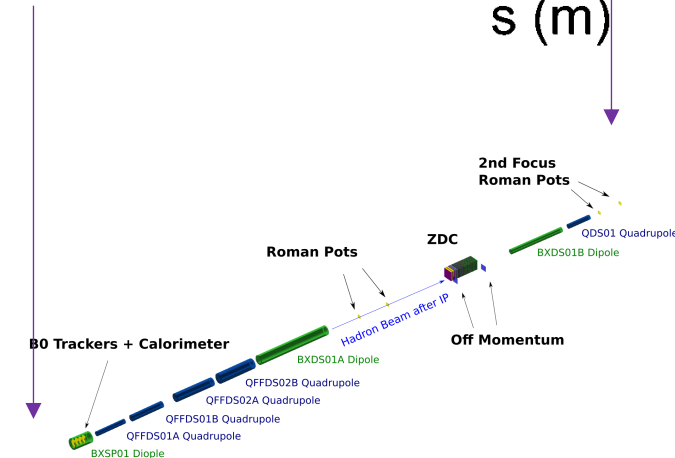
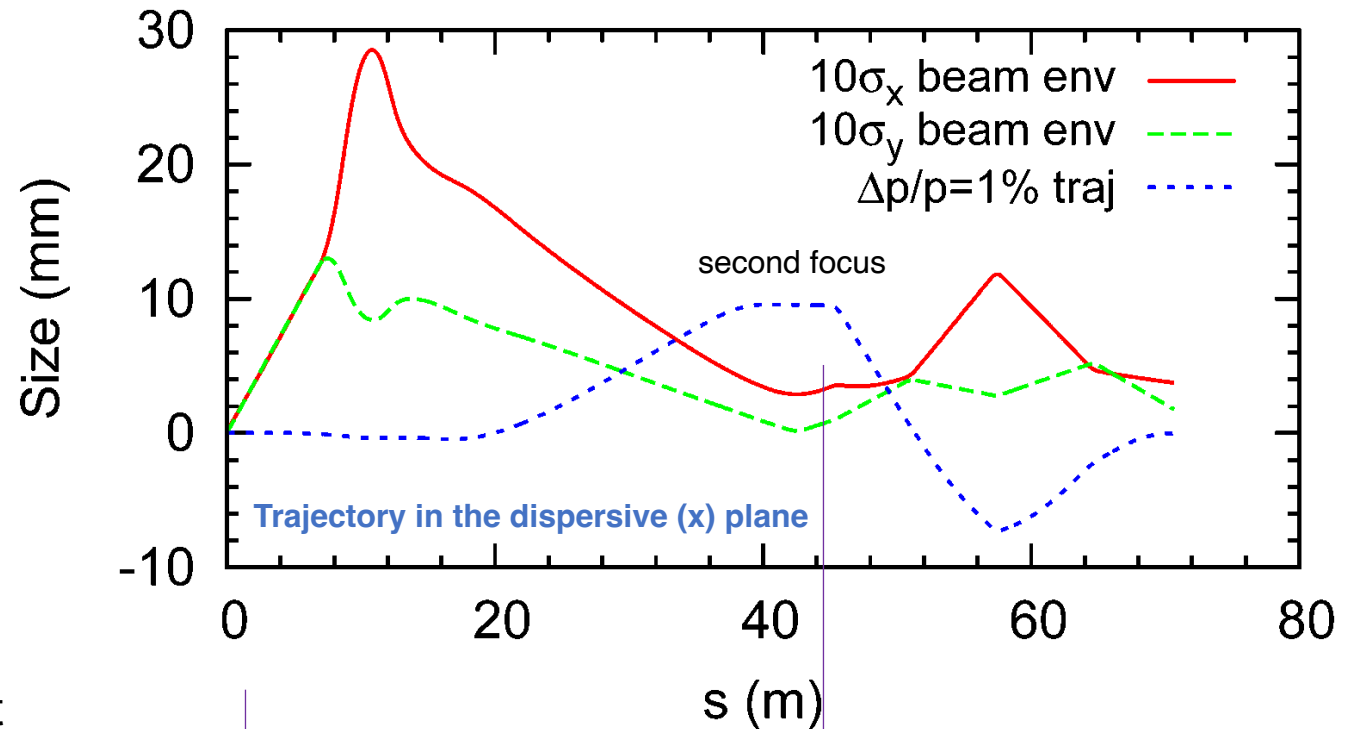
} eA

Near-beam (outgoing) electron-side detection capabilities.

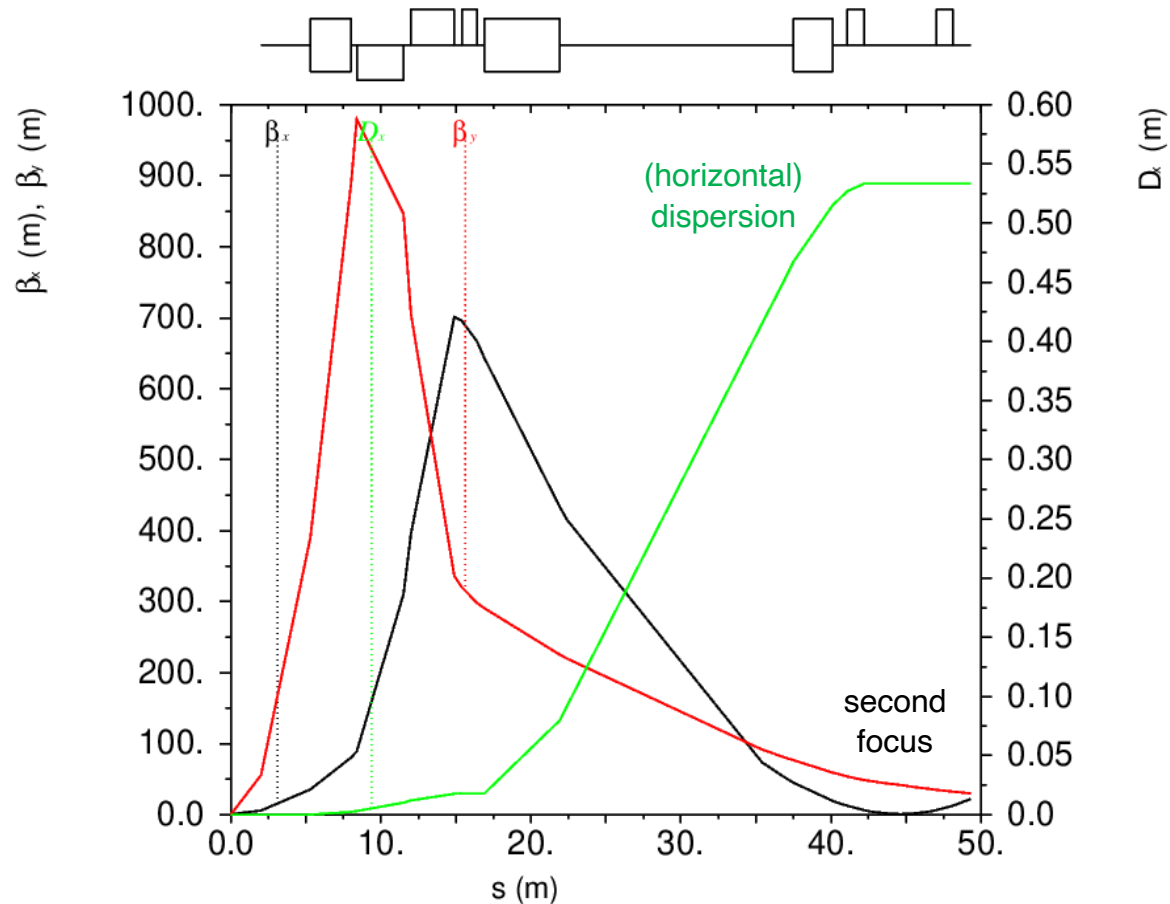
- Dark matter searches?

How the second focus works (old optics)

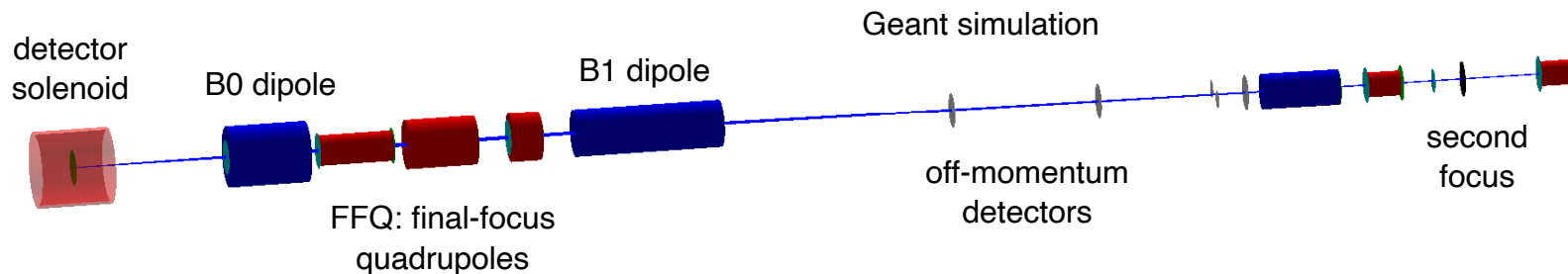
- Idea: make the beam small at the location where the transverse displacement Δr of scattered particles with $p_T = 0$ is the greatest
 - $\Delta r = \text{dispersion} \cdot \frac{\Delta p}{p}$
 - In DIS, $\frac{\Delta p}{p} \sim x$
- A particle (blue) initially scattered at 0 degrees ($p_T = 0$) briefly emerges from the beam (red) at the second focus where it can be detected.
 - Particles with $p_T > 0$ emerge earlier



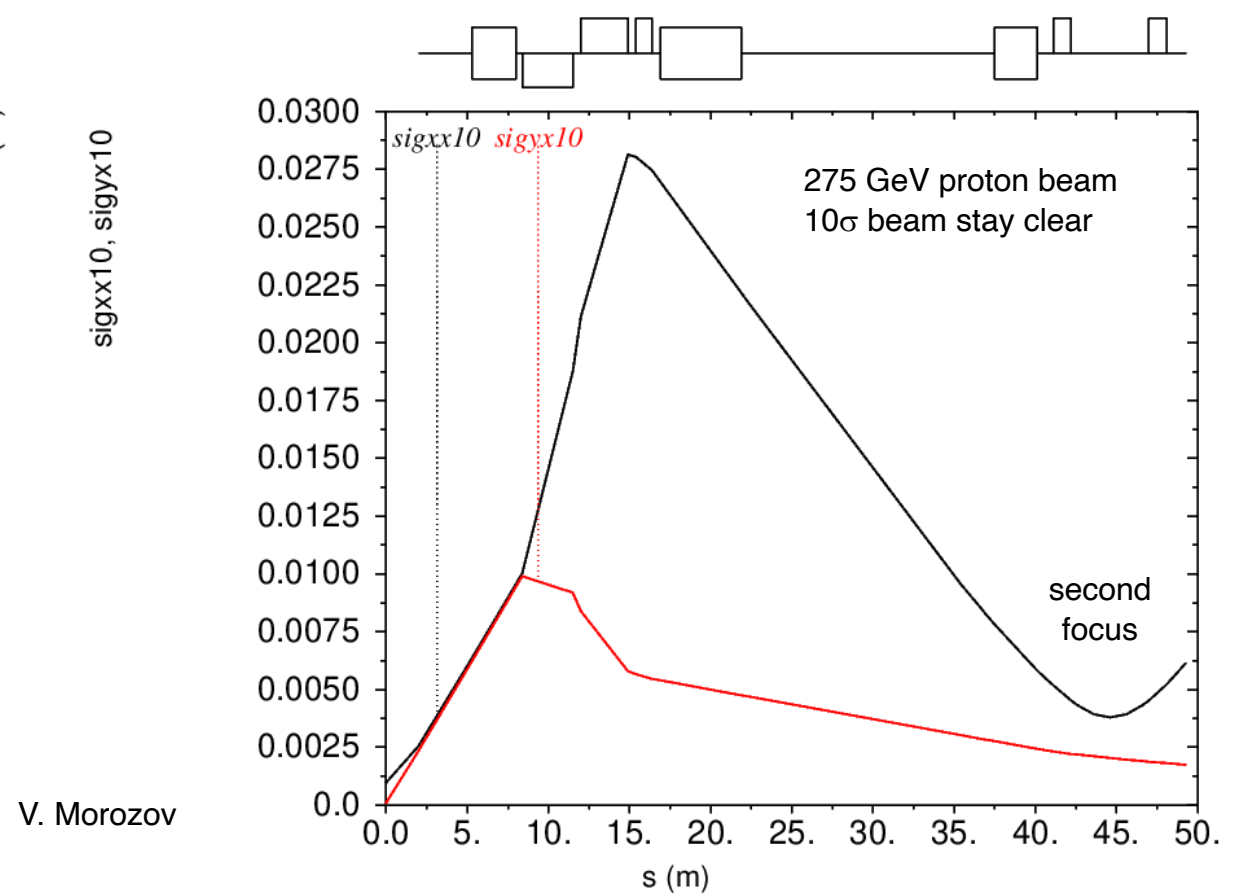
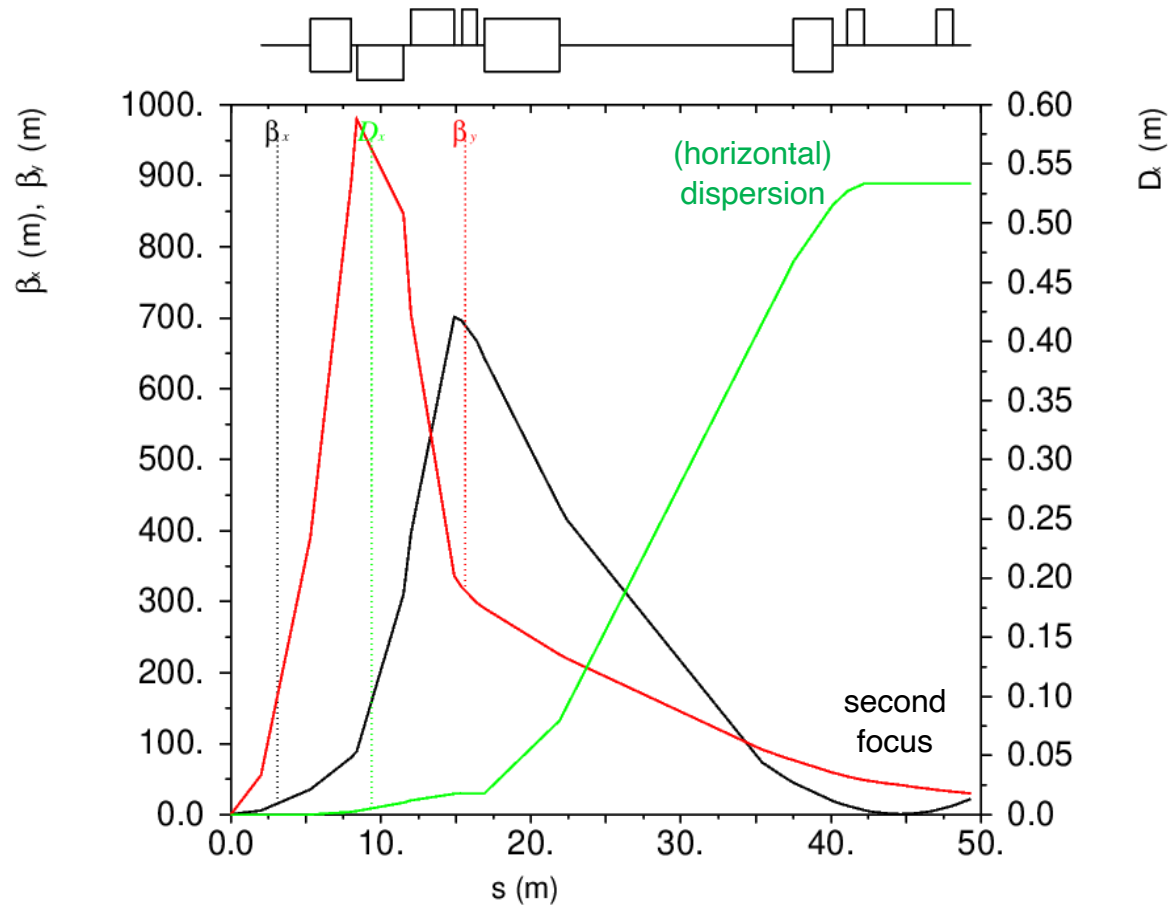
New ion optics for forward detection with a second focus in IR12



- The novel idea of using a second focus to enhance the forward detection was originally developed for the JLab version of the EIC by V. Morozov and PNT.
- A quick adaptation was made by V. Morozov for IR8 of the EIC @ BNL.
- As part of the EIC UG D2 WG activities, an updated design of the forward ion optics for IR12 is now ready.
 - Minor optimizations are still being made



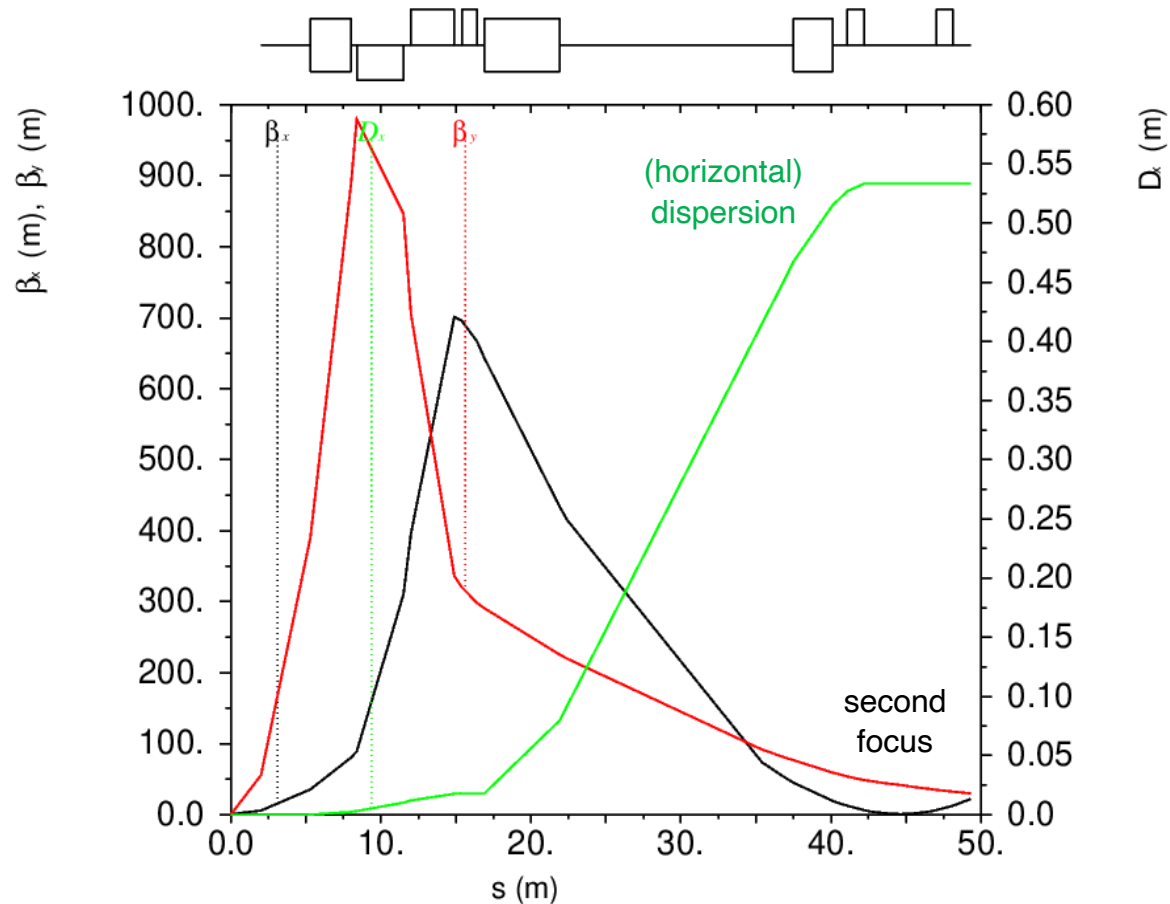
Beta functions and beam sizes



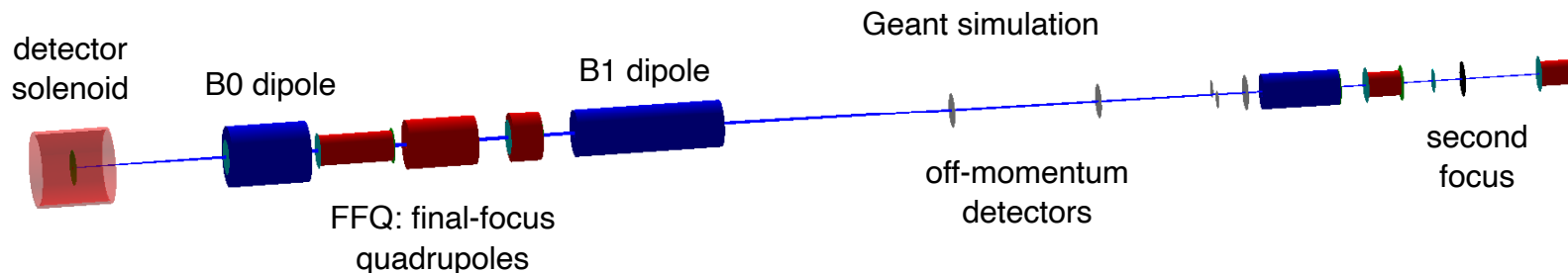
V. Morozov

- The new optics has a smaller (horizontal) β_x^{max} , improving both acceptance and accelerator integration.
- Due to different h/v emittances and no vertical dispersion, the vertical beam size is still smaller at the second focus.
- This allows shifting the vertical focus beyond the horizontal, dispersive one (the location of the Roman pots).

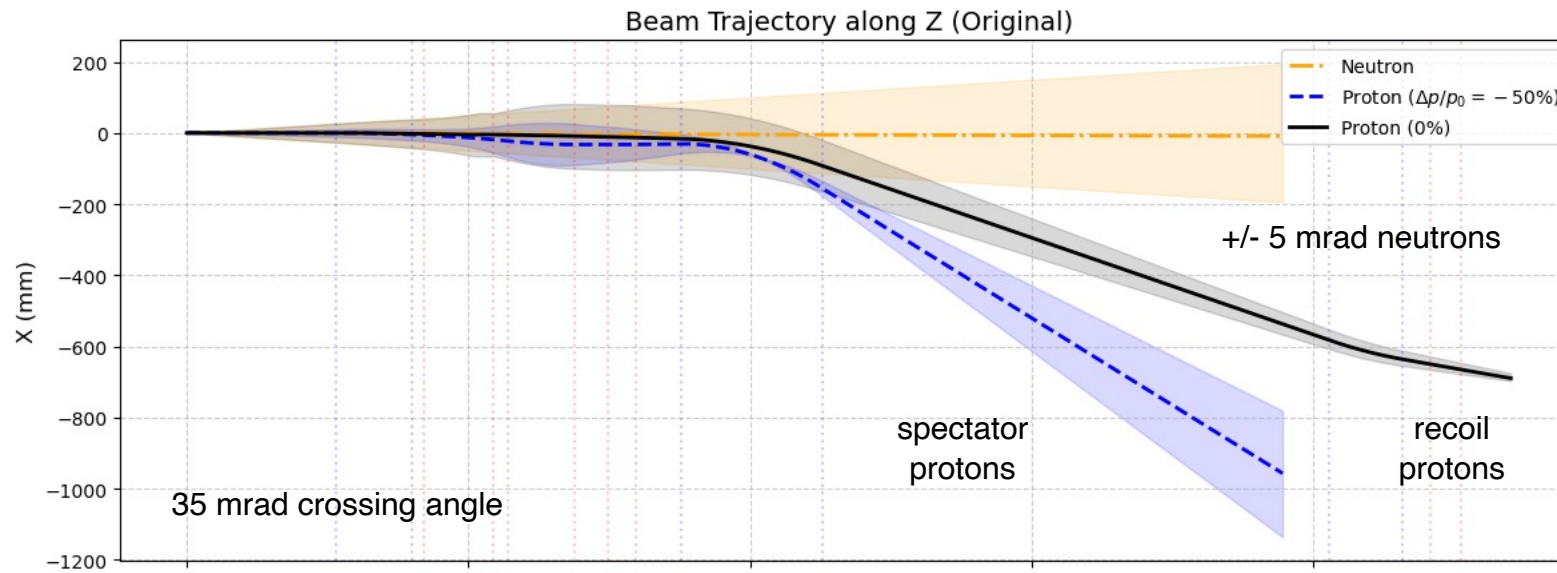
New ion optics for IR12 (or IR8)



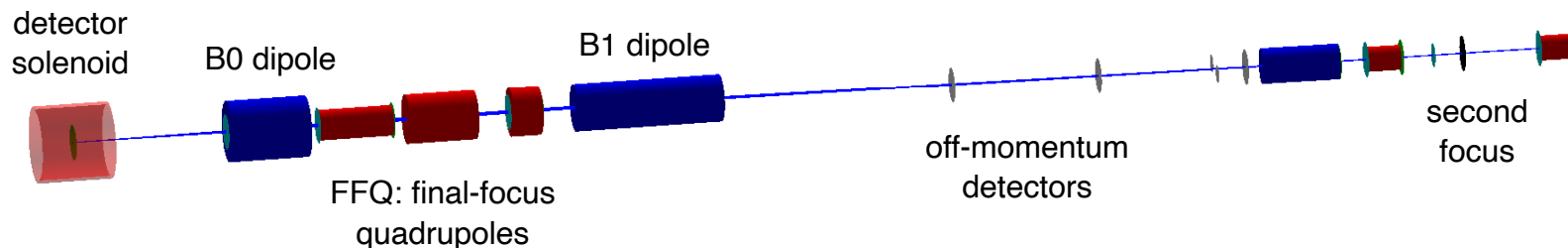
- A second focus with a large horizontal dispersion improves low- p_T acceptance.
 - Enables detection of particles with $dp/p > 0.7\%$ even at zero degrees ($p_T = 0$)
 - The dispersion shifts particles out of the beam and spreads them out along the trackers
 - The second focus makes the beam smaller at the Roman pot location.
 - The balance between dispersion and focusing is relatively straightforward to adjust.
- A more compact B0/FFQ/B1 “block” improves high- p_T acceptance and reduces magnet specs



Acceptance for large angles and rigidity changes



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



- Challenge: neutron cone and spectator protons from deuterium separate more quickly than linear with distance.
- Reducing the overall length of the B0/FFQ/B1 block improves acceptance while keeping magnet apertures and peak fields low.
- First-pass (no optimization of magnet shifts and tilts) for the new optics gives
 - Full transport for ± 5 mrad neutrons.
 - Full transport for spectator protons from deuterium.
 - Losses for high- p_T recoil protons only in first quad.

B0 dipole magnet

- The IR6 B0 design uses a short, strong dipole followed by a counterbending dipole used at lower energies.
 - A similar arrangement was also proposed for IR8, with the overall length was 2.7 m.
- The counterbending scheme creates an energy-dependent transverse shift of the beam position requiring a more stringent spec on field uniformity in the FFQs.
- A longer, weaker B0 improves tracking (more layers, longer path) for 275 GeV protons and all ions.
 - Small difference for low-energy proton beams
- Such a B0 can be scaled to any beam energy to provide the same bending angle. This would make it easier to shield the electron quad (B. Parker. The length of 2.7 was chosen to make both options interchangeable.

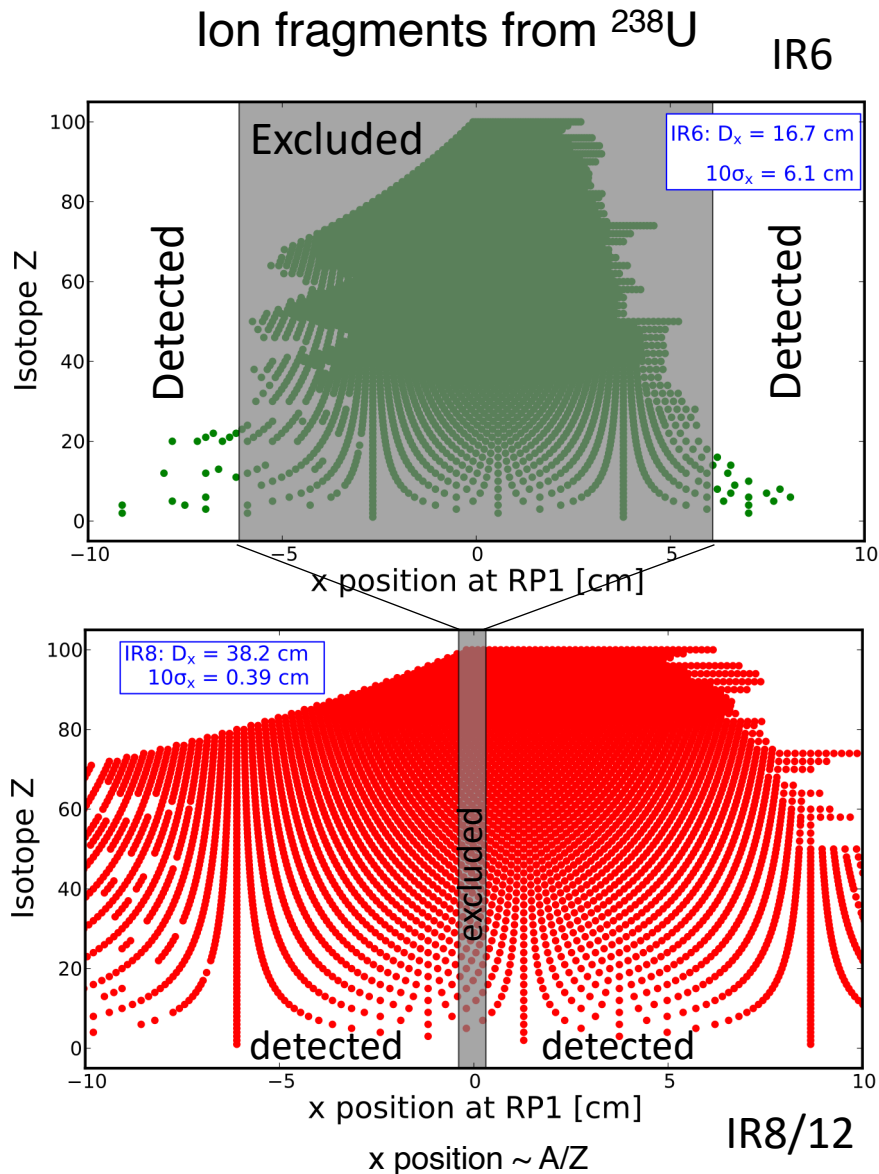
Parameter	IR6 Forward Hadron Magnets							IR12 Proposed Forward Hadron Magnets				
	BOPF	BOAPF	Q1APF	Q1BPF	Q2PF	B1PF	B1APF	BXSP0	QFFDS01	QFFDS02	QFFDS03	BXDS01
Length (m)	1.2	0.6	1.46	1.6	3.8	3.0	1.5	2.7	3.1	2.9	1	5
Inner radius (cm)	20	4.3	5.6	7.8	13.1	13.5	16.8	?	5.8	<7.5	<18.8	?
Peak field (T)	-1.3	-3.3	4.07	5.16	5.34	-3.4	-2.7	0.58	4.6	<4.6	<4.6	4.6
Field gradient (T/m)	0	0	-72.61	-66.18	40.74	0	0	0	-79.97	61.66	24.4	0

Final-focus quadrupoles (FFQs)

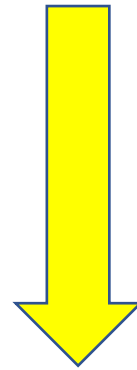
- Transport is optimized by keeping the initial quad which are defocusing in the dispersive plane strong and short. Splitting it in two, as was done in the preliminary IR8 layout creates inefficiencies.
 - The original motivation for this scheme was a request to reverse the polarity of some FFQs at low energy
- The new IR12 optics has 3-m-long first quad with a peak field chosen to be 4.6 T (this could be adjusted), allowing the following quads to be weaker.
 - The apertures of the other quad(s) could be reduced without a significant degradation in performance.
- Overall, the proposed IR12 magnets are less challenging than the CDR parameters for IR6.
 - As we optimize the IR12 layout further the magnet parameters can may become even more relaxed.

Parameter	IR6 Forward Hadron Magnets							IR12 Proposed Forward Hadron Magnets				
	B0PF	B0APF	Q1APF	Q1BPF	Q2PF	B1PF	B1APF	BXSP0	QFFDS01	QFFDS02	QFFDS03	BXDS01
Length (m)	1.2	0.6	1.46	1.6	3.8	3.0	1.5	2.7	3.1	2.9	1	5
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Field gradient (T/m)	0	0	-72.61	-66.18	40.74	0	0	0	-79.97	61.66	24.4	0

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

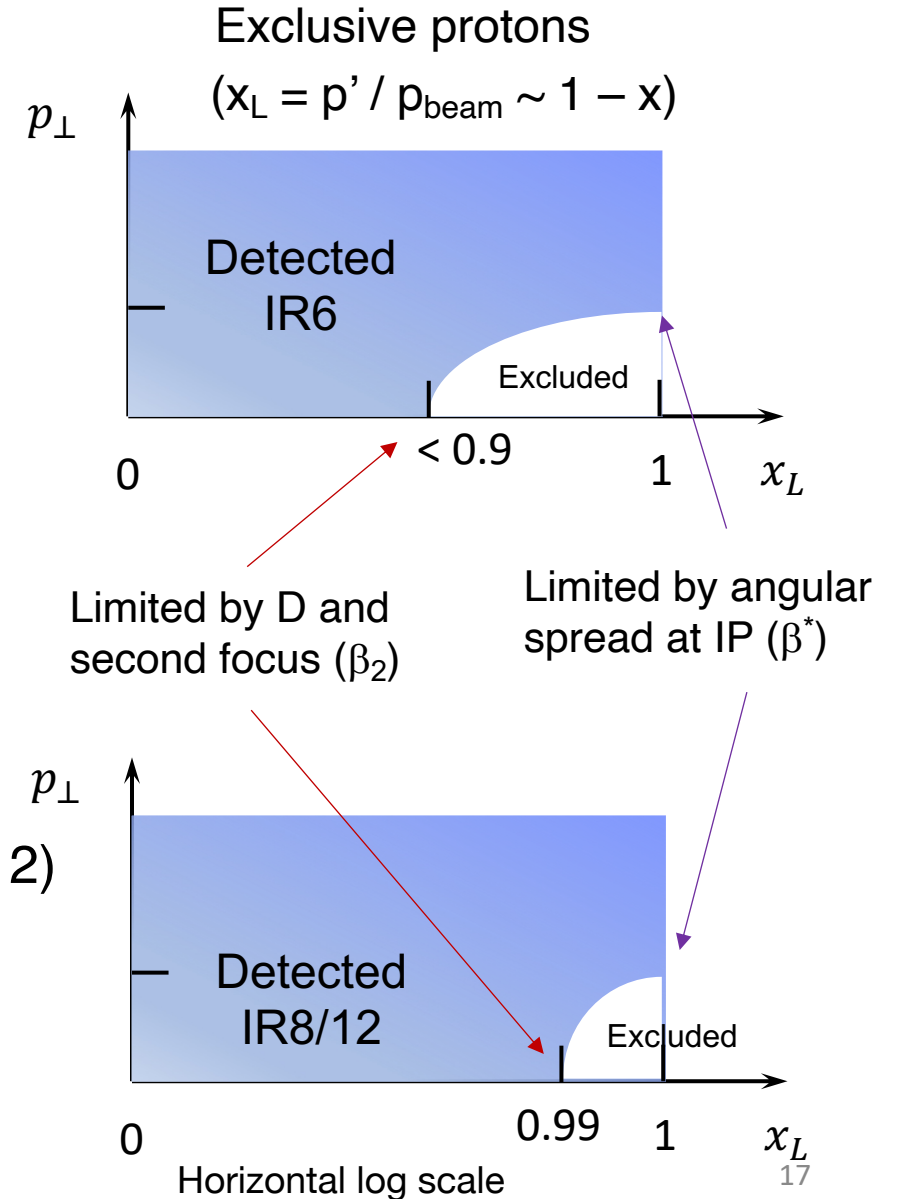


Without 2nd focus:
(ePIC @IR6)

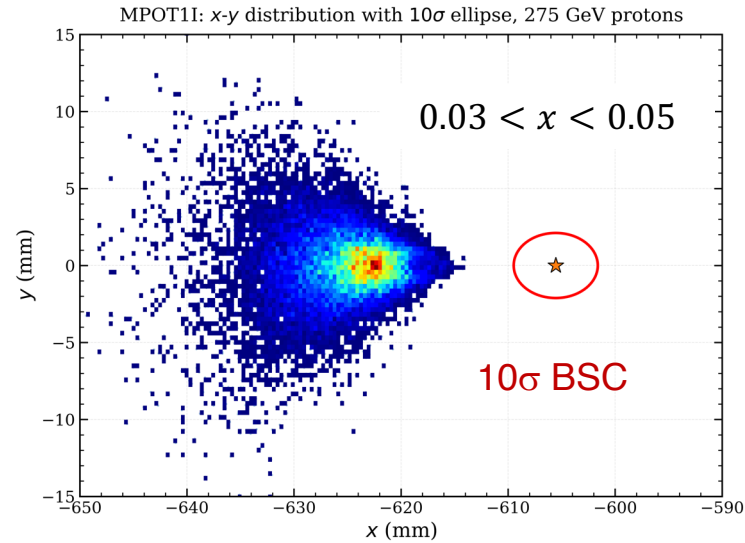
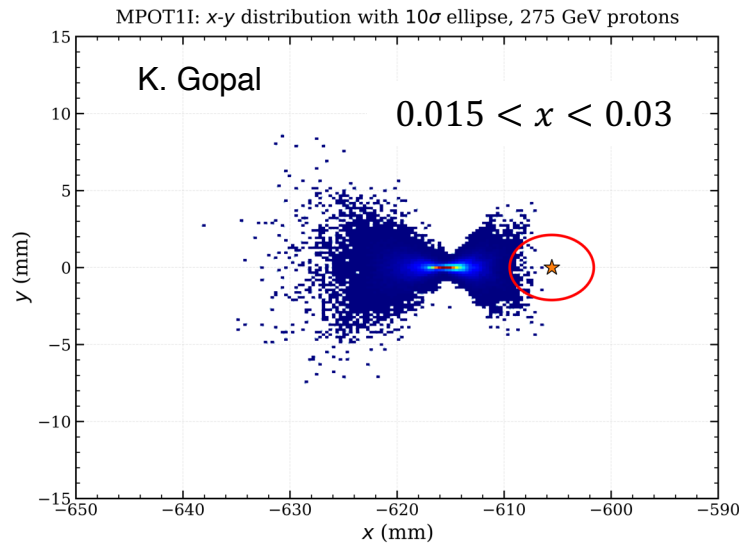


With 2nd focus:
(Detector 2 @ IR8/12)

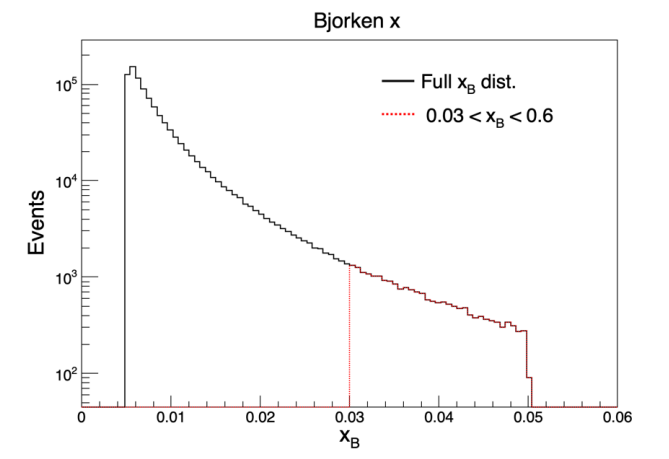
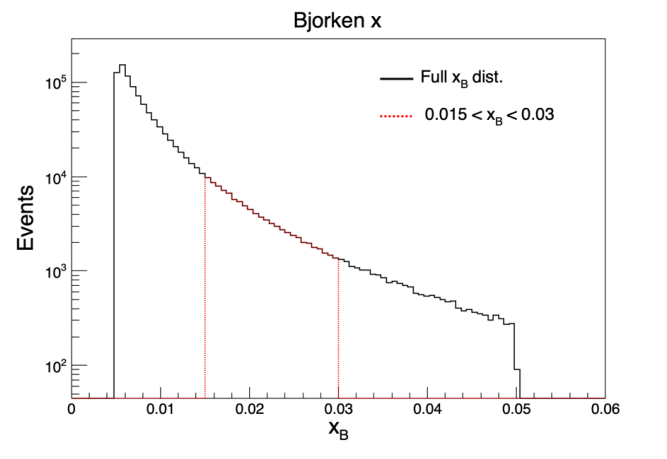
**Order-of-magnitude
improvement in
forward acceptance**



DVCS events for 275 GeV protons from the EPIC generator at RPs



- For $x > 0.01$ all DVCS recoil protons are outside of the 10σ beam envelope (BSC) at the second focus and can be detected.
- In IR6, which lacks a second focus, the BSC is much larger while the dispersion (shift to the left) is smaller.
- For very small x , $p_T = 0$ protons cannot be detected even with a second focus
 - improves acceptance for small-angle particles scattered away from the beam (“to the left”).



^{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

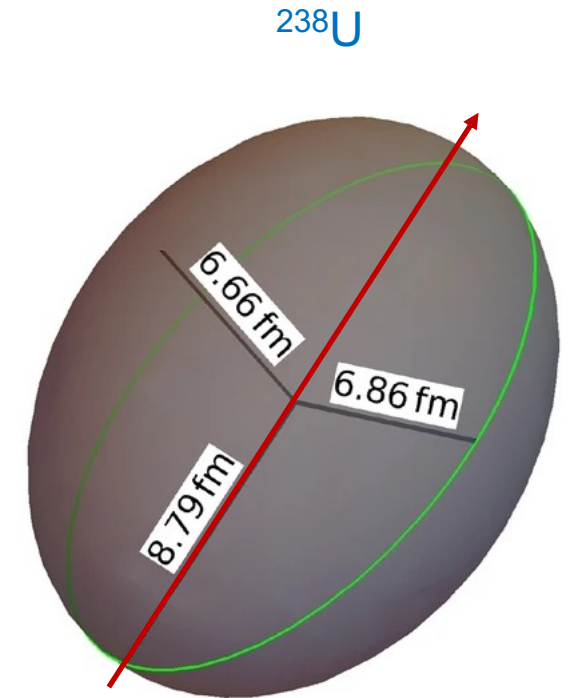
$$Q_s^2 \sim A^{1/3}/x^\lambda \sim T(b) \cdot (E_e E_A)^{0.3}$$

- 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

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

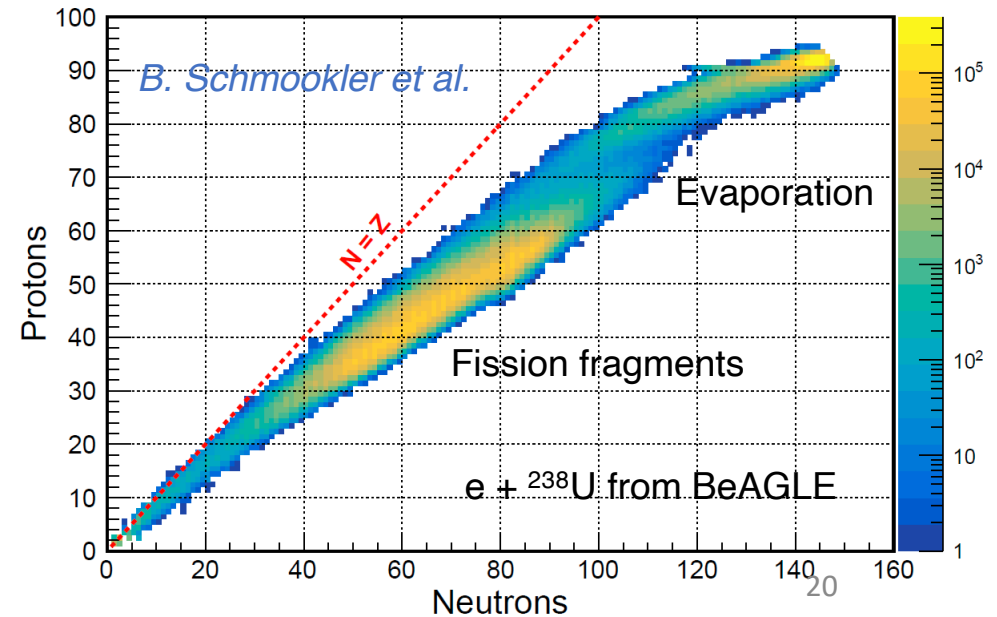
- This is equivalent to a very substantial increase in E_e .
 - A preliminary study showed that selecting a subsample of a few percent of the events using the final-state information from the second focus could be equivalent to a factor 4.5 increase in E_e .
 - A more comprehensive evaluation using ML-methods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



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

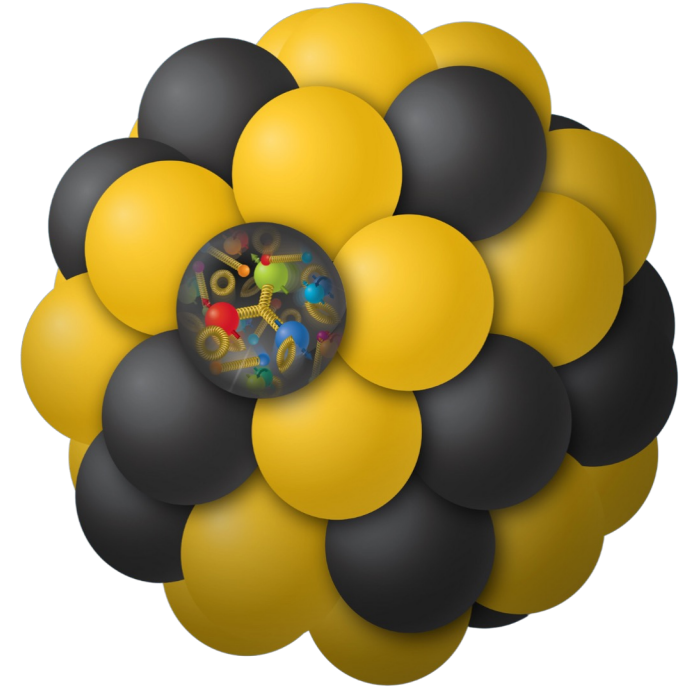
The nuclear final state

- 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 their de-excitation can reveal the internal structure
- Of interest to the FRIB community.



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.
- **Quasi-free neutron structure** can be accessed by measuring the spectator proton(s) in deuterium or polarized ^3He .
- **Bound nucleon structure** can be accessed by measuring the spectator nucleus (A-1 system).
- The ePIC forward detectors are good for spectator protons, but a 2nd EIC detector would be able measure A-1 nuclei over the full mass range.



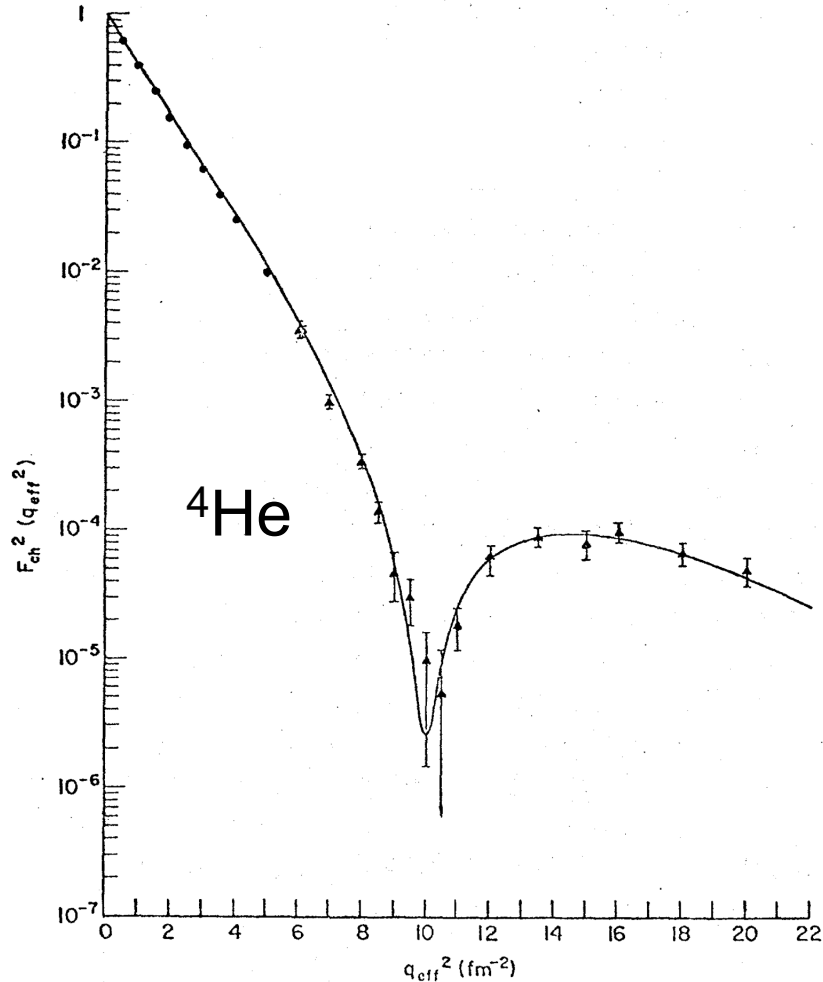
Coherent nuclear processes

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 ^3He over a range in t , but a second focus would be essential for heavier light ions such as ^4He and Li. (^6Li and ^7Li could be polarized in the future).

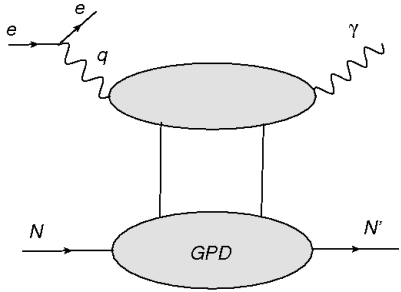
Medium- and heavy ions

- Coherent diffraction
 - Spacing of minima is reduced at larger A
- Incoherent events are separated by vetoing of breakup
 - Detection of neutrons, protons, and photons
 - With a 2nd detector also light ions and nuclear fragments



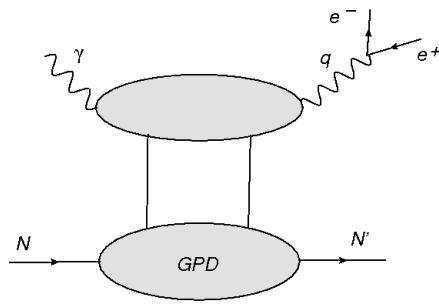
Timelike Compton Scattering (exclusive dilepton photoproduction)

(spacelike) DVCS

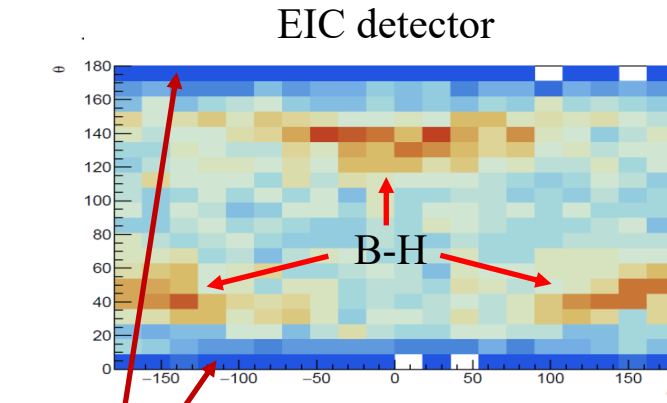


Initial photon spacelike,
final photon real

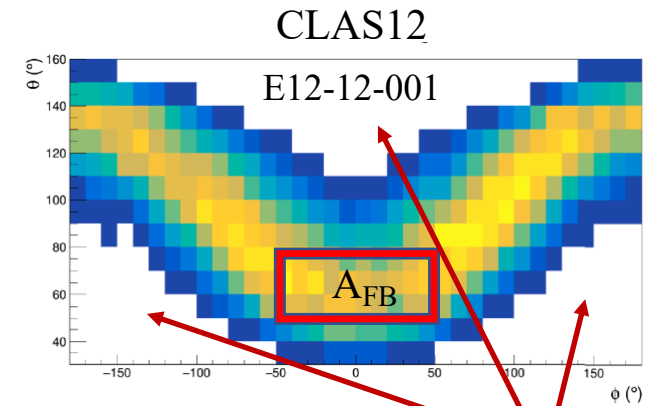
timelike Compton
scattering (TCS)



Initial photon real, final
photon timelike $\rightarrow l^+ l^-$



Losses due to
lepton acceptance

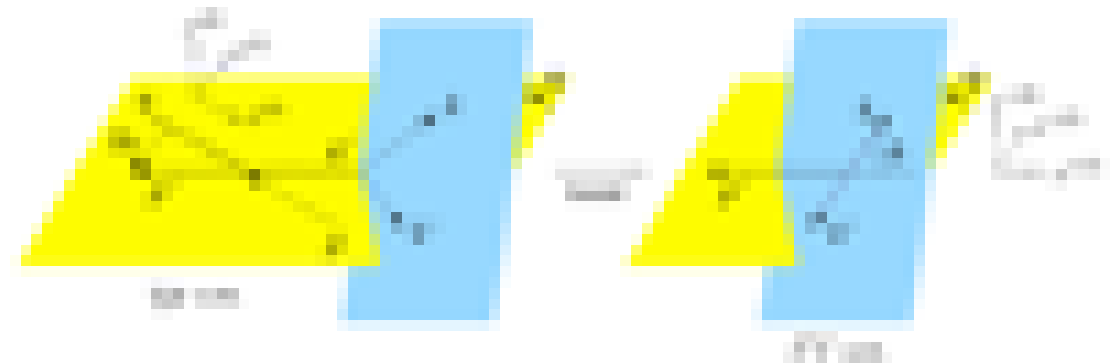


Losses due to
lepton acceptance

P. Chatagnon, EIC UG meeting, Warsaw, 2023

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

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



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

Double DVCS ($Q^2 < Q'^2 \Rightarrow$ TCS-like)

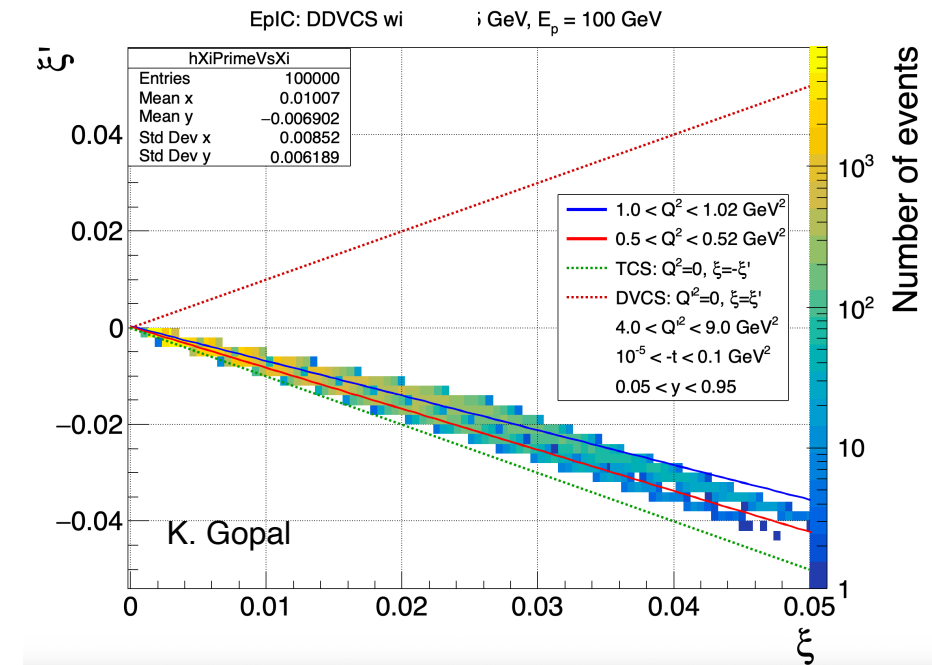
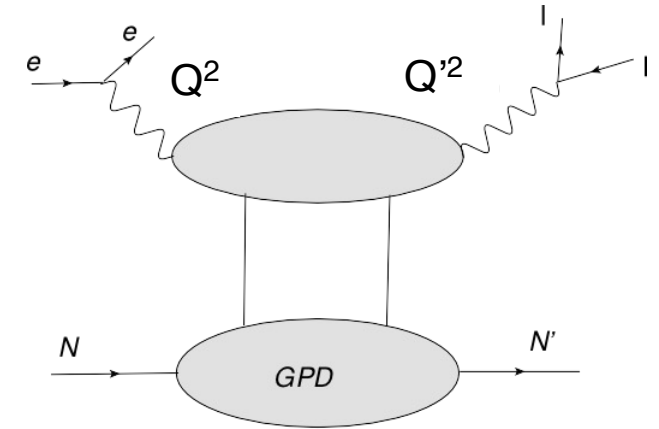
Challenging measurement Illustrative of many EIC / D2 features

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
- 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 2nd focus gives a low- t proton acceptance close to 100%

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

DDVCS: initial *and* final photon virtual



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 the far-forward detection and a strawman design of the central detector to be used in simulation tools reflecting the envisioned capabilities of a 2nd detector
 - We aim for a short publication early next year and then starting the work on a longer white paper
 - Conveners
 - Anselm Vossen (Duke U) [anselm.vossen at duke.edu](mailto:anselm.vossen@duke.edu) (chair of the EIC UG steering committee)
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Summary

- Having two detectors is important to maximize EIC science and take full advantage of the investment made into the EIC.
- A novel far-forward detection with a second focus could make it easier to probe the transition to gluon saturation.
- A second focus can also improve 3D structure measurement on both the proton and nuclei and create many new opportunities for eA.
- The central detector could add enhancements to several key areas such as muon identification, hadron identification, and electron tracking, creating a complementarity with the ePIC detector.
- Input on HEP requirements to the EIC UG 2nd detector WG would be very helpful!

Thank you!