

New optics for IR12 developed by the EIC UG 2nd detector WG

Pawel Nadel-Turonski



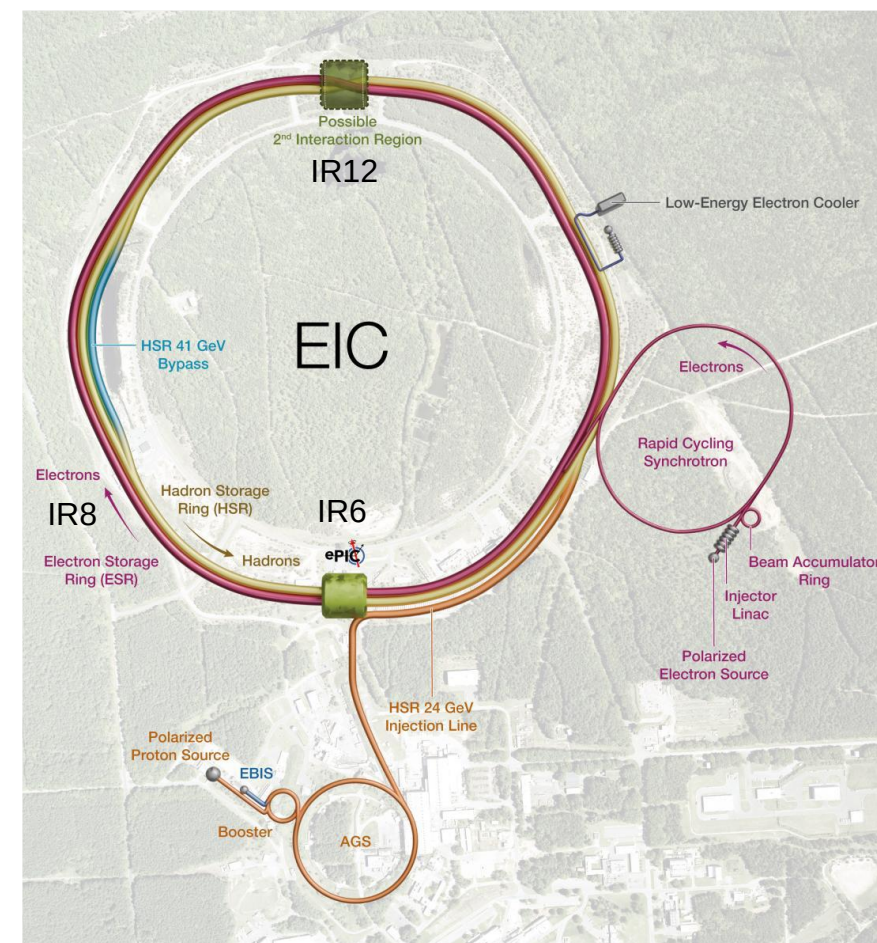
Vasily Morozov



Supported by NSF award PHY-2514907.



EIC IR12 meeting, September 2, 2026



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)
 - Björn Schenke (BNL) [bschenke at bnl.gov](mailto:bschenke@bnl.gov)
 - Charles Hyde (ODU) [chyde at odu.edu](mailto:chyde@odu.edu)
 - Pawel Nadel-Turonski (U of SC) [turonski at sc.edu](mailto:turonski@sc.edu)
 - Simonetta Liuti (UVA) [sl4y at virginia.edu](mailto:sl4y@virginia.edu)
 - Vasiliy Morozov (ORNL) [morozovvs at ornل.gov](mailto:morozovvs@ornl.gov)
 - Wenliang “Bill” Li (MS State U) [wenliang.li at msstate.edu](mailto:wenliang.li@msstate.edu)
- Liaison from the EIC UG SC: Charlotte van Hulse (Vrije Universiteit) [charlotte.barbara.van.hulse at cern.ch](mailto:charlotte.barbara.van.hulse@cern.ch)

Science impact of an IR with a second focus

- 3D imaging of the proton and gluon saturation in nuclei are key goals of the EIC program
- A detector with improved forward detection enabled by a second focus can help the EIC to deliver on both the goals above and create many new opportunities for eA.
- The impact of the improved forward detection on saturation studies can exceed that of an electron beam energy upgrade.

^{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

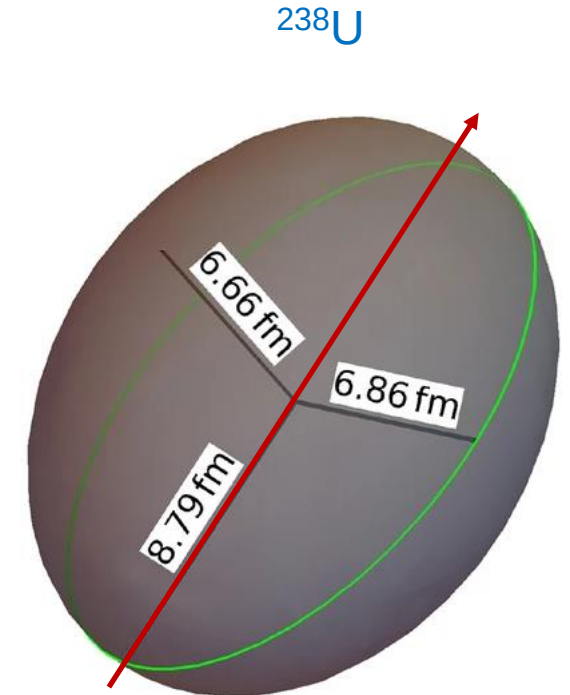
$$Q_s^2 \sim A^{1/3}/x^{0.3} \sim T(b) \cdot (E_e E_A)^{0.3}$$

- 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

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

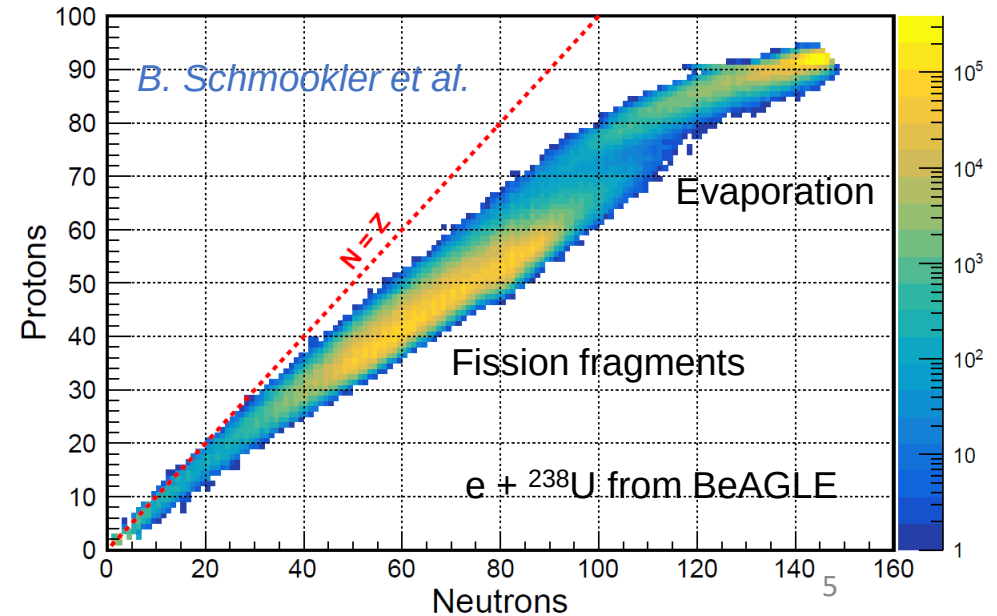
- This is equivalent to a very substantial increase in E_e .
 - A preliminary study showed that selecting a subsample of a few percent of the events using the final-state information from the second focus could be equivalent to a factor 4.5 increase in E_e .
 - A more comprehensive evaluation using ML-methods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



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

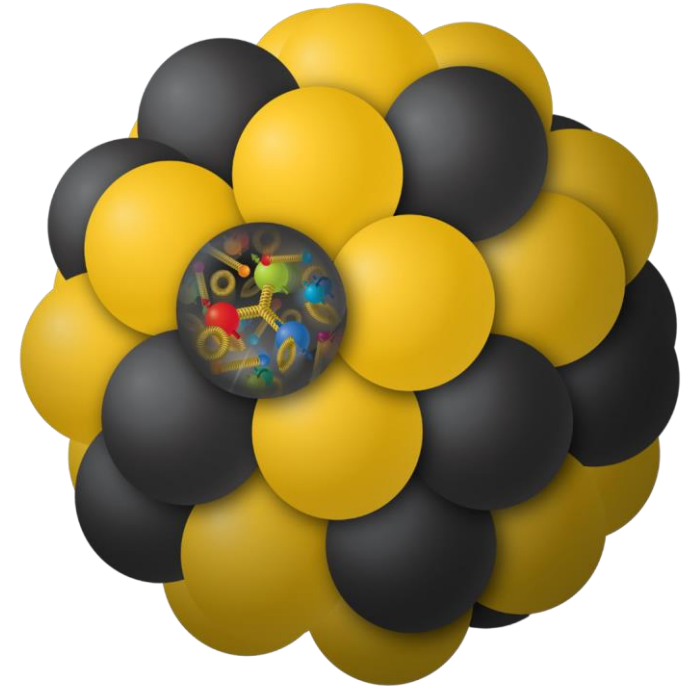
The nuclear final state

- 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.



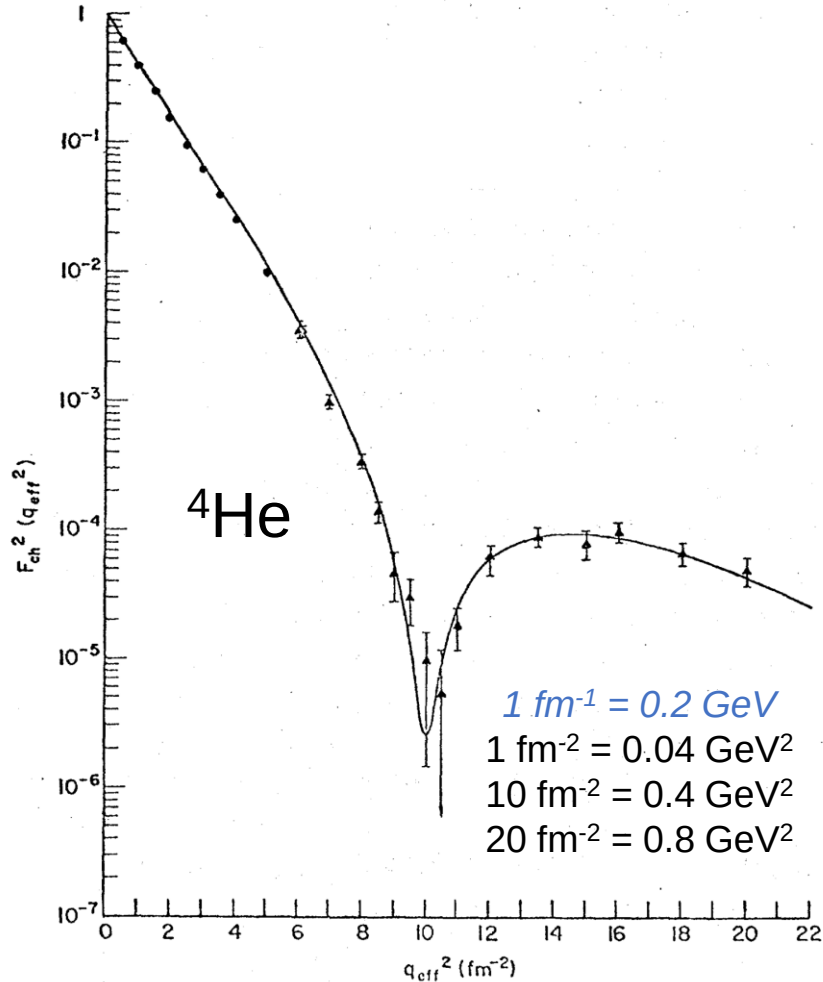
Coherent nuclear processes

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).

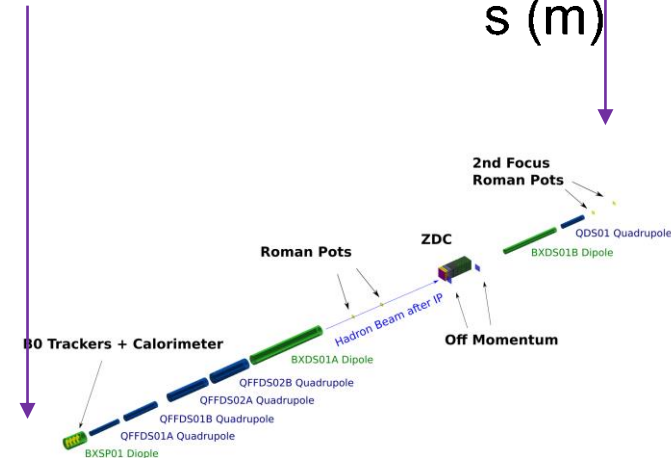
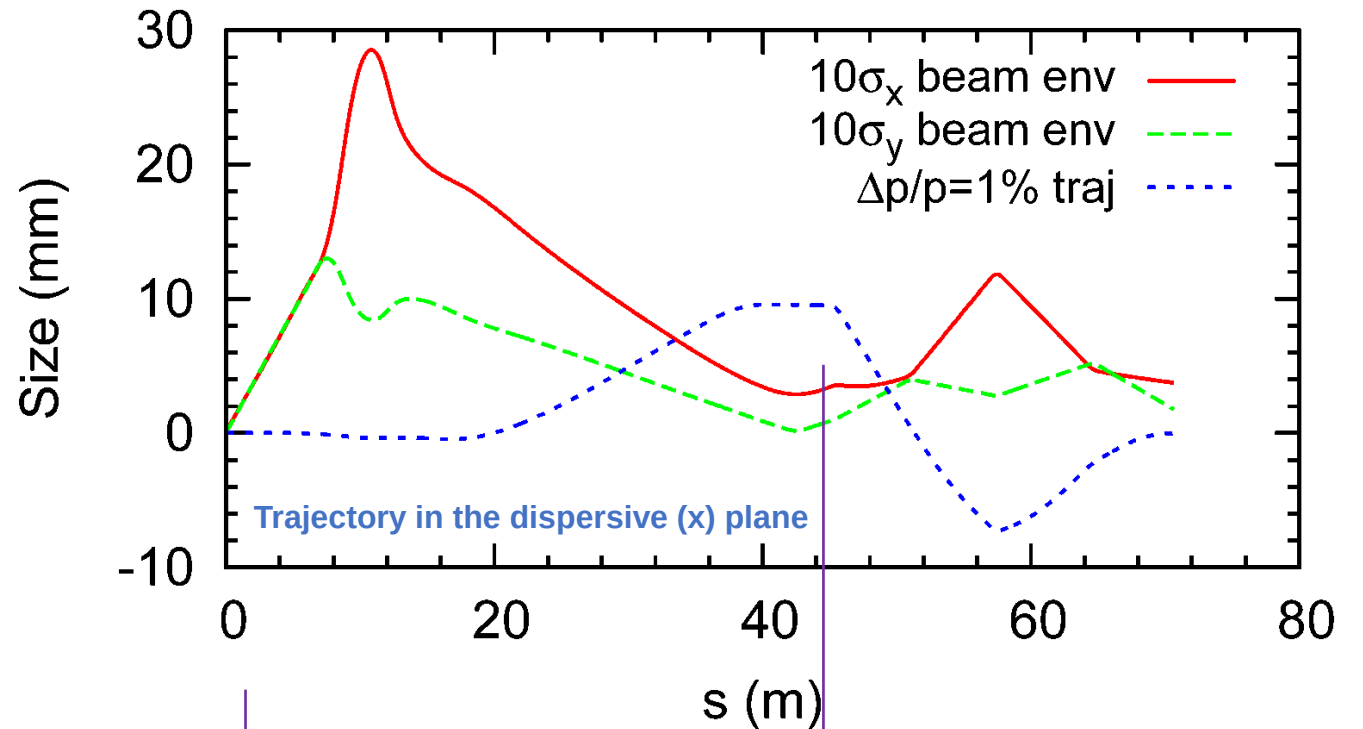
Medium- and heavy ions

- 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

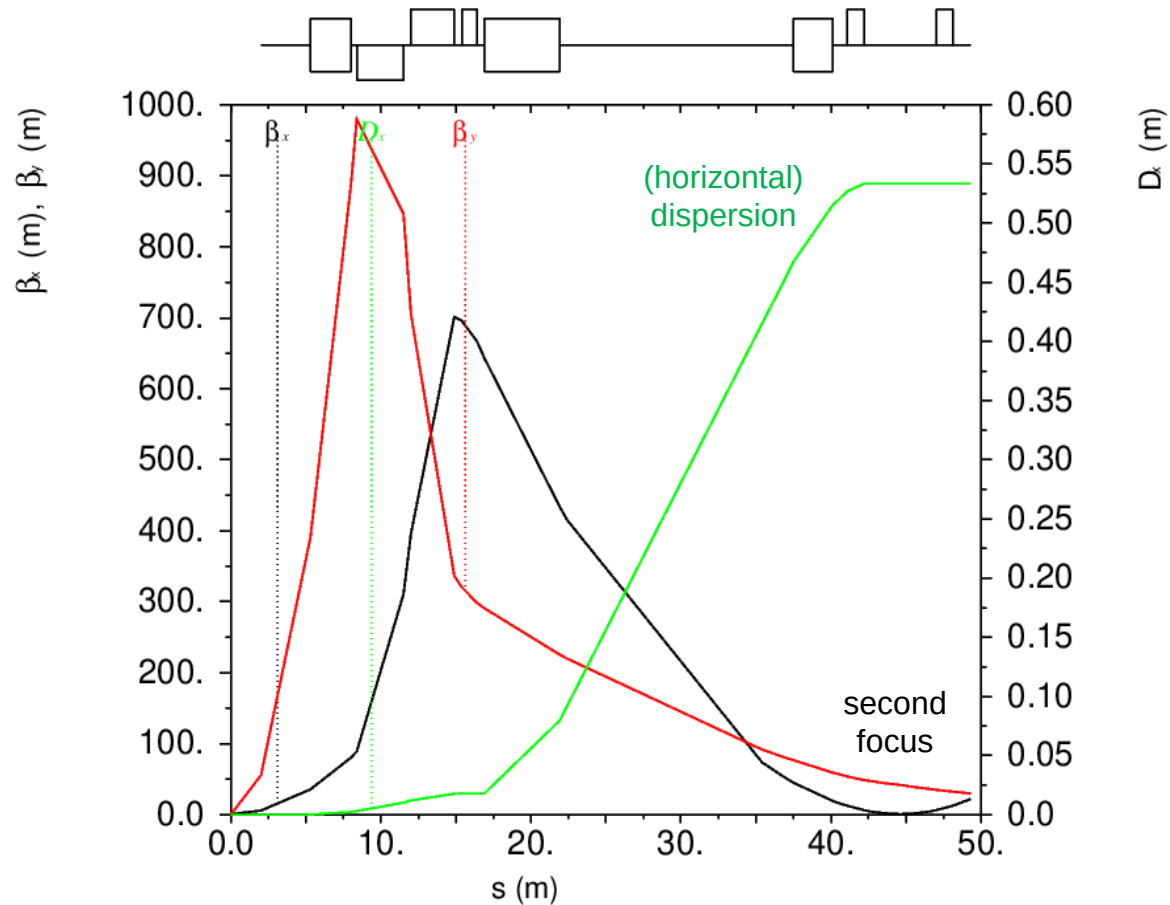


How the second focus works (older optics)

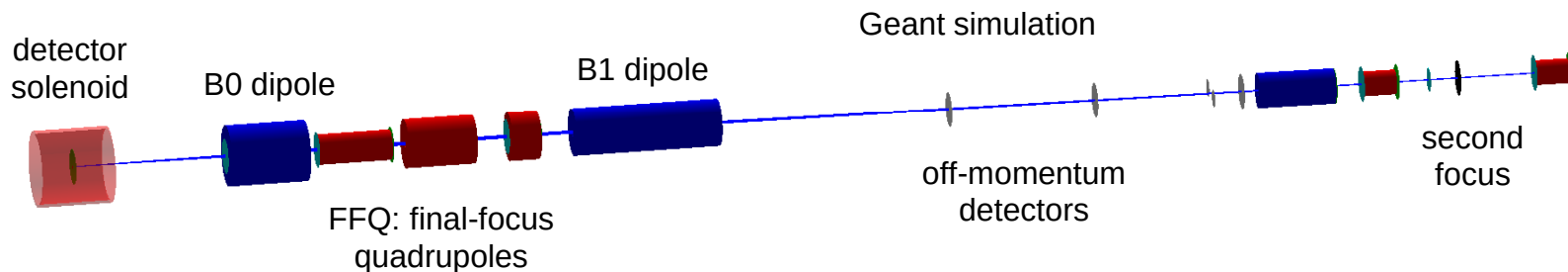
- Idea: make the beam small at the location where the transverse displacement of scattered particles is the greatest
 - Displacement: $dr = \text{dispersion} * dp/p$
 - In DIS, $dp/p \sim x_B$
- A particle (blue) initially scattered at 0 degrees ($p_T = 0$) briefly emerges from the beam at the second focus about 40 m downstream where it can be detected
 - Compare trajectory with horizontal (red) beam size
 - Particles with $p_T > 0$ emerge earlier



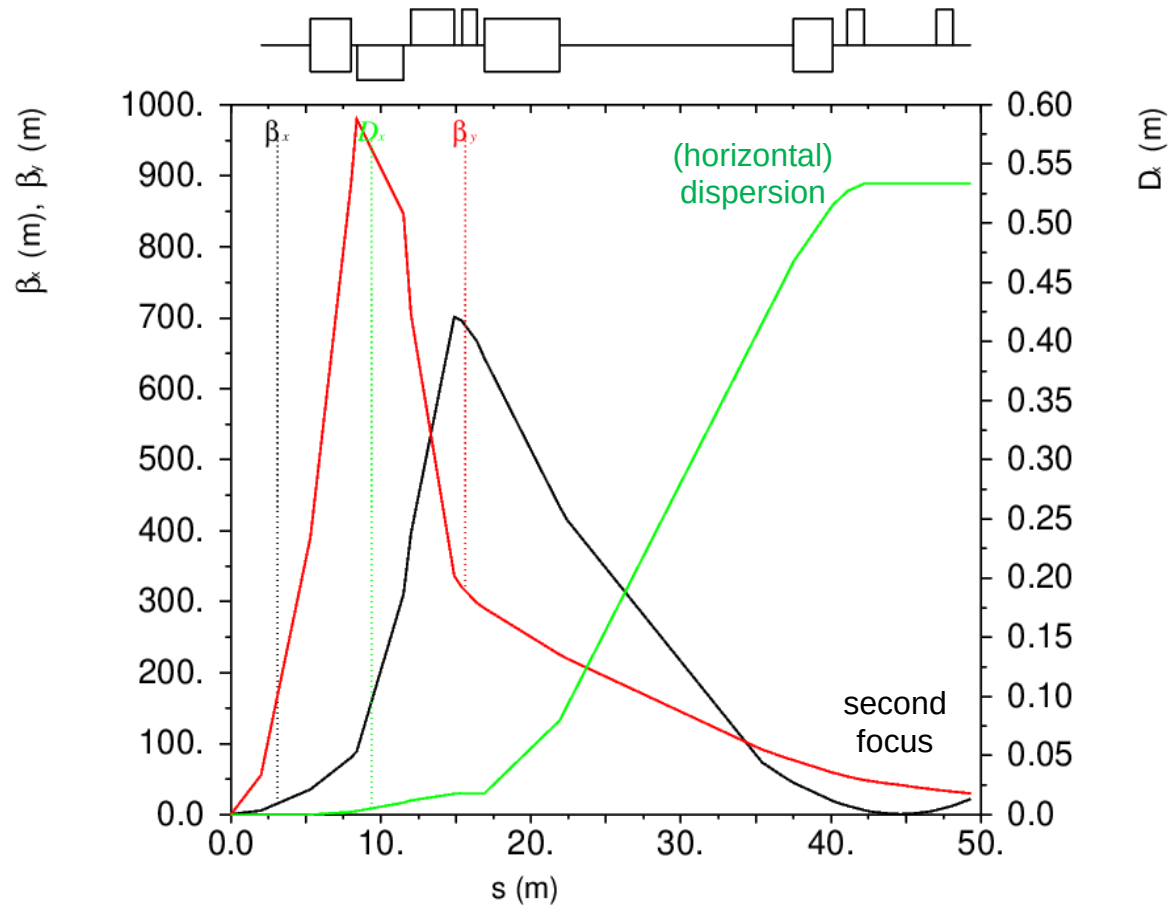
New ion optics for forward detection with a second focus in IR12



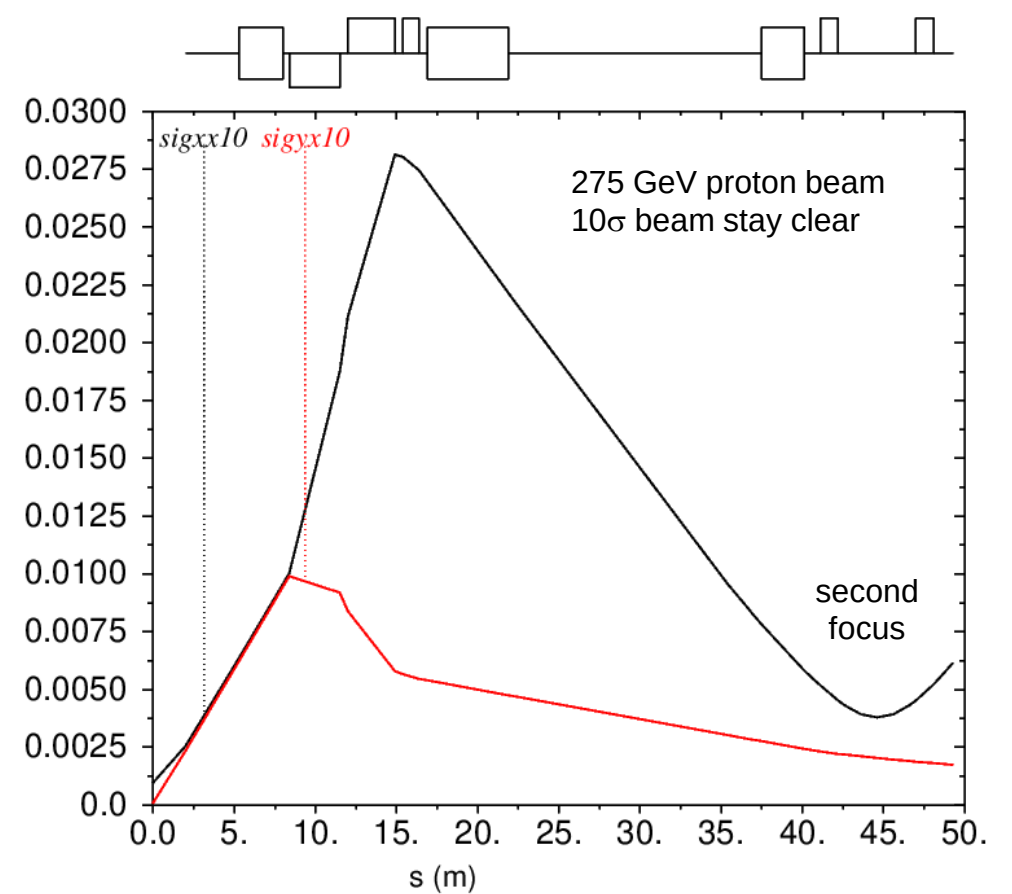
- An IR featuring the the novel idea of having a second focus to enhance the forward detection was originally developed for the JLab version of the EIC by V. Morozov and PNT.
- It was then quickly adapted by V. Morozov for IR8 of the EIC @ BNL before moving from JLab to ORNL. Then the design was prematurely frozen.
- As part of the EIC UG D2 WG activities, an updated design of the forward ion optics for IR12 is now ready to be implemented in the simulation tools for a 2nd detector that the WG is developing.



Beta functions and beam sizes

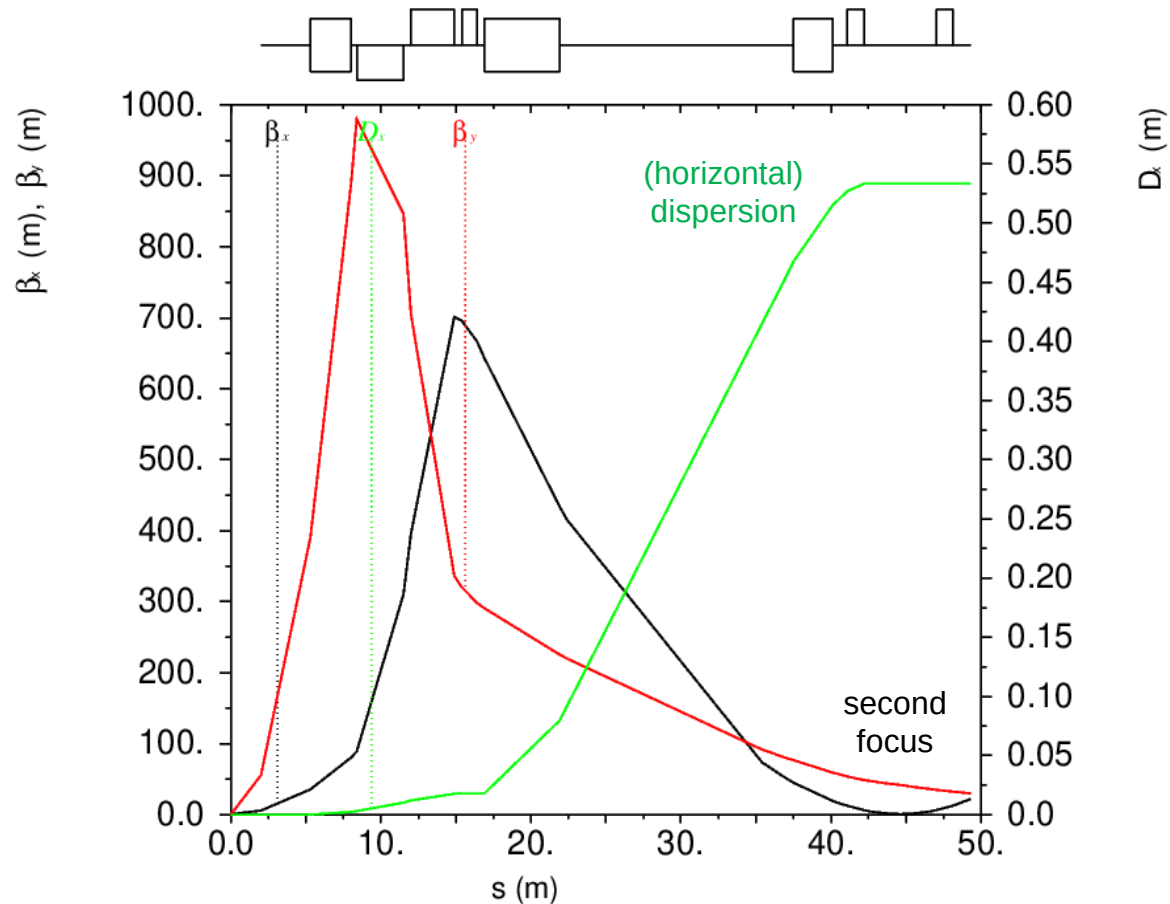


V. Morozov

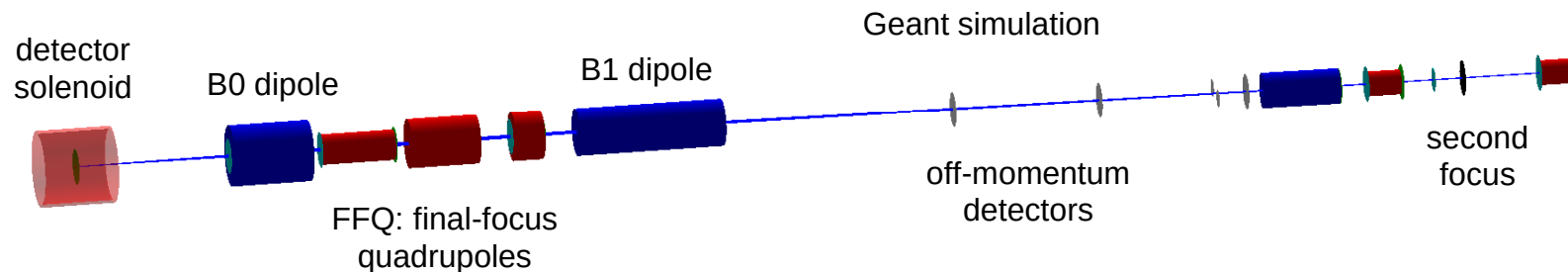


- The new optics reduces (horizontal) β_x^{max} by half, improving both acceptance and accelerator integration.
- Due to different h/v emittances and no vertical dispersion, the vertical beam size is still smaller at the second focus.
- This allows shifting the vertical focus beyond the horizontal, dispersive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

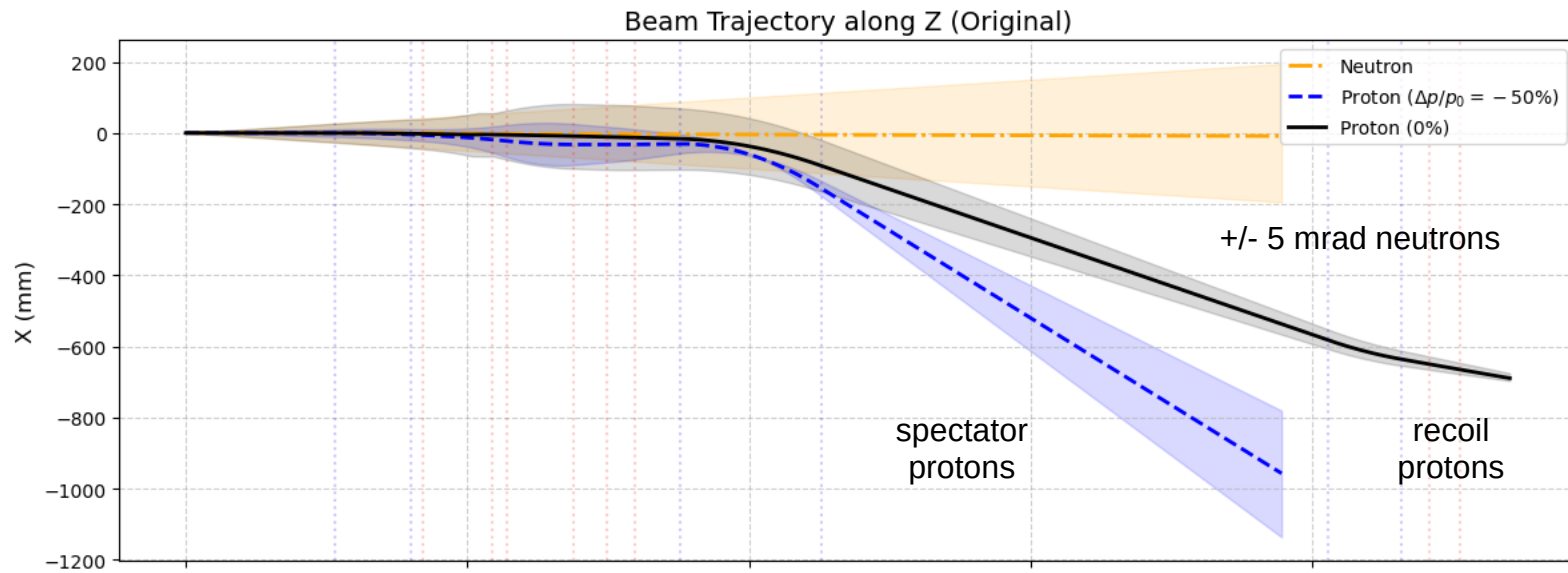
New ion optics for IR8 or IR12



- 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

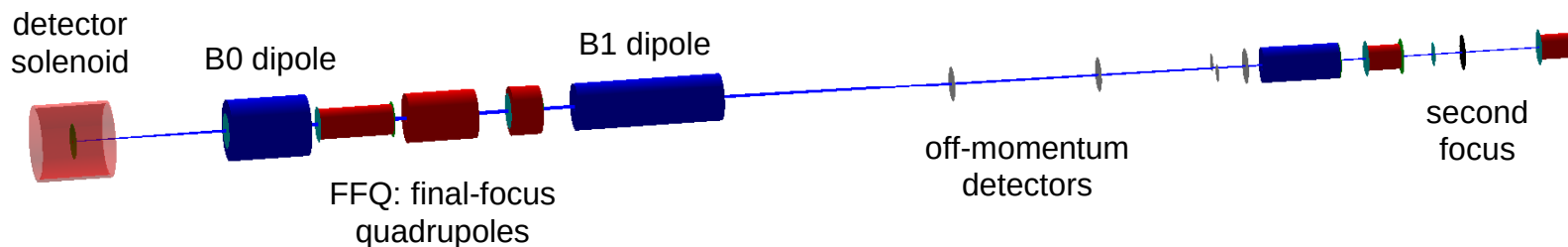


Large- p_T acceptance (first pass)

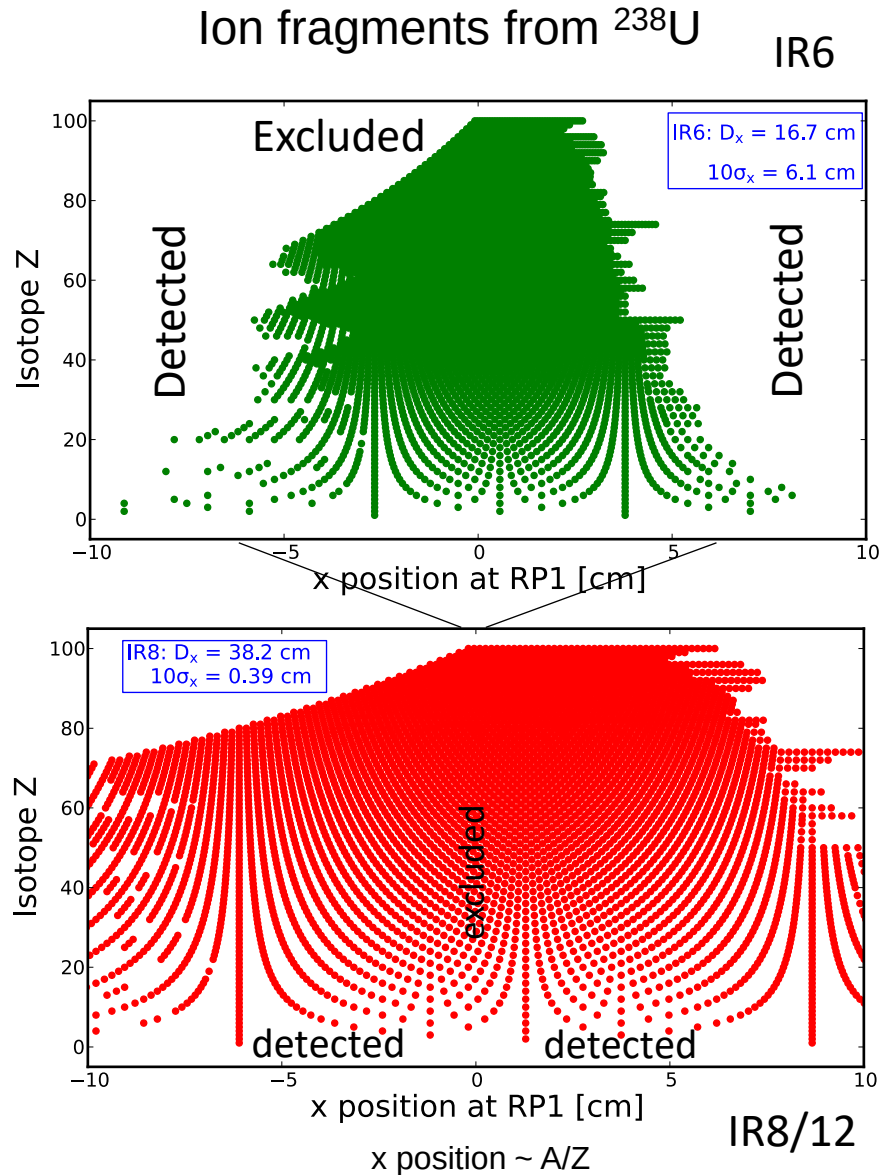


V. Morozov, T. Roth, K. Gopal, PNT

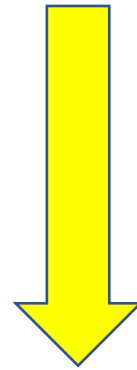
- First-pass apertures
 - Full transport for +/- 5 mrad neutrons.
 - Full transport for spectator protons from deuterium.
 - Losses for recoil protons only in first quadrupole.
- Quad peak fields equal to or smaller than for ePIC@IR6.



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

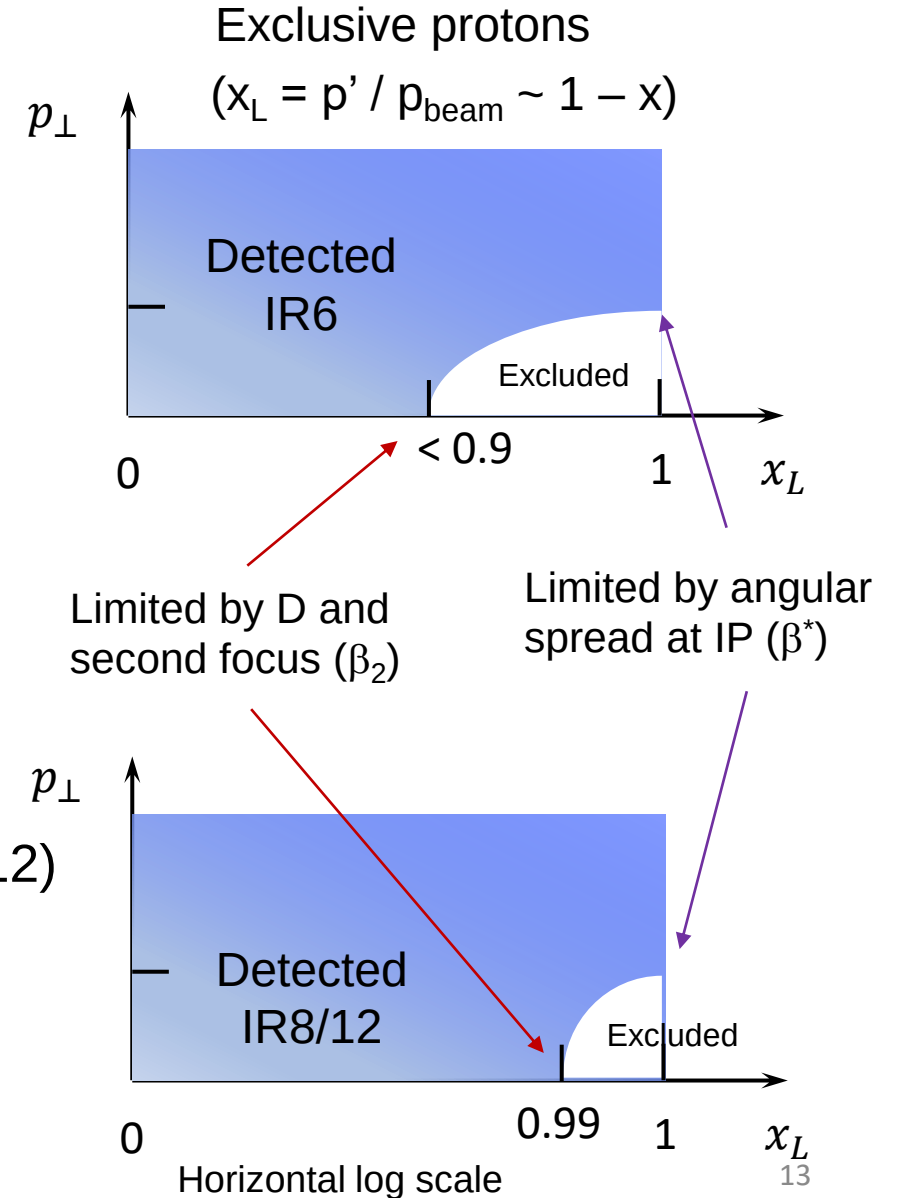


Without 2nd focus:
(ePIC @IR6)

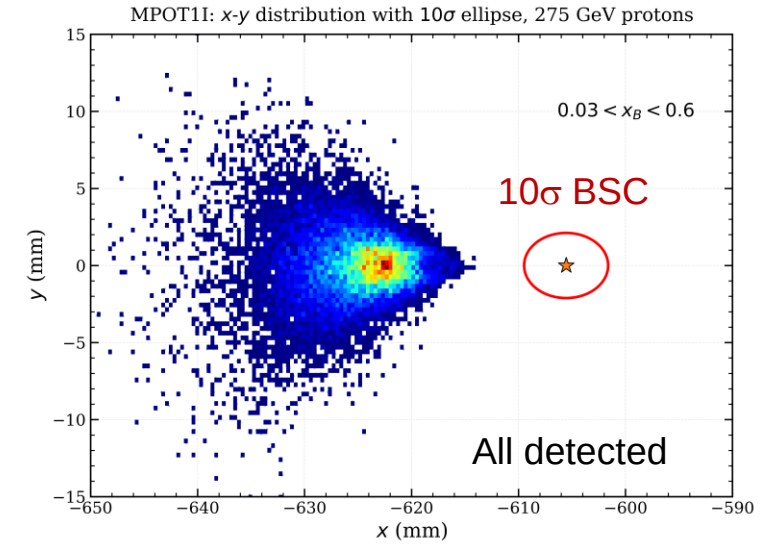
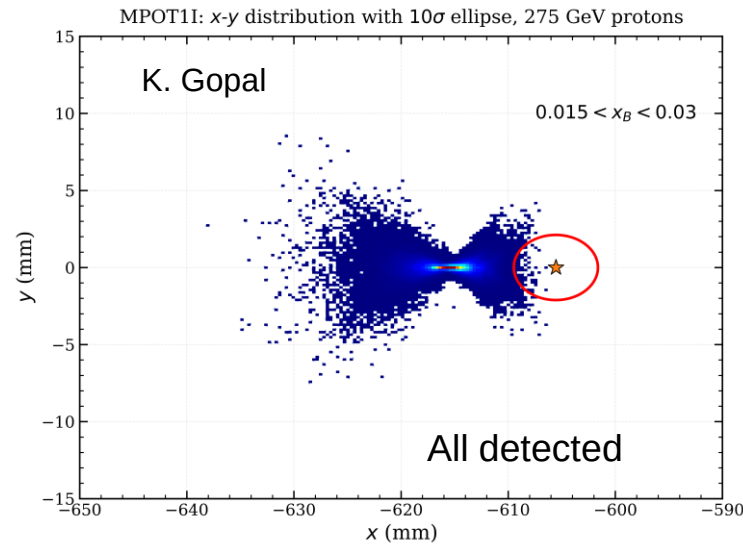
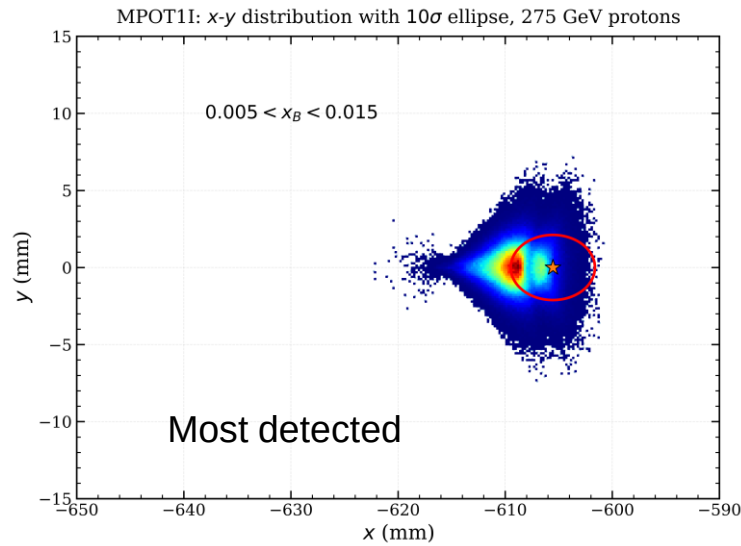


With 2nd focus:
(Detector 2 @ IR8/12)

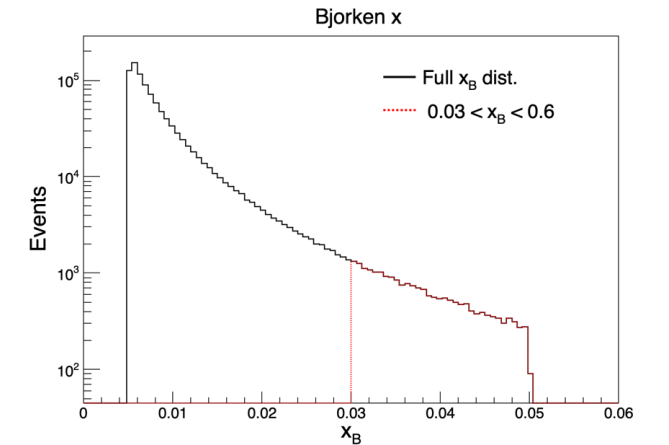
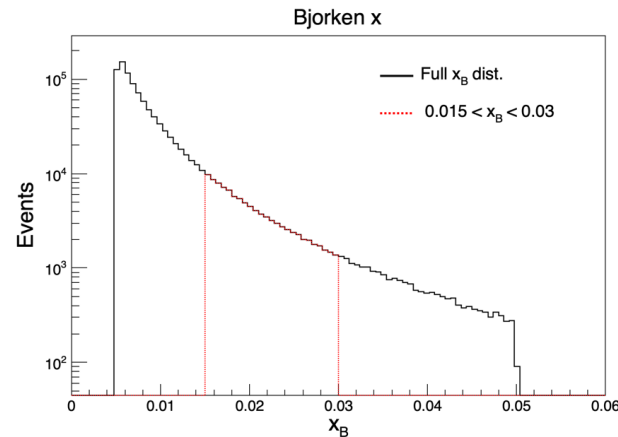
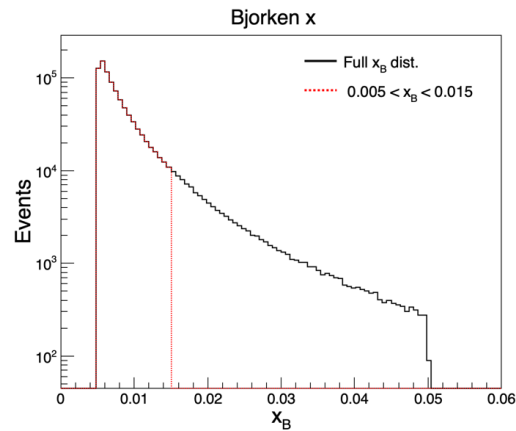
**Order-of-magnitude
improvement in
forward acceptance**



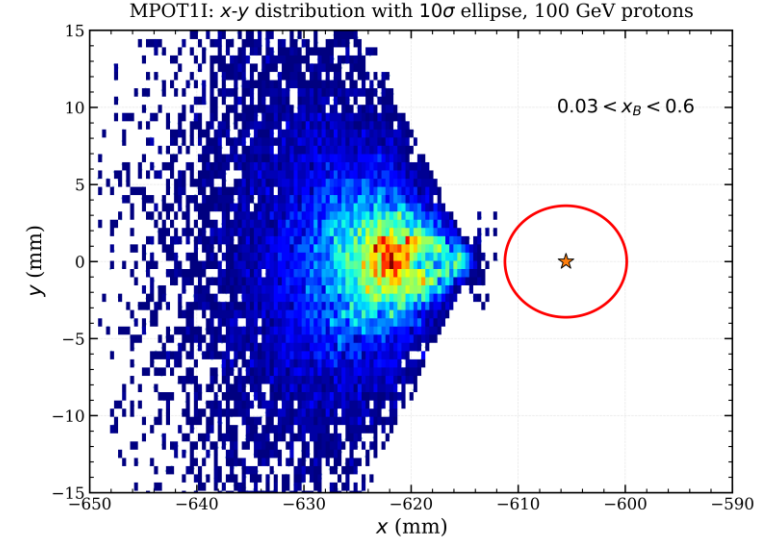
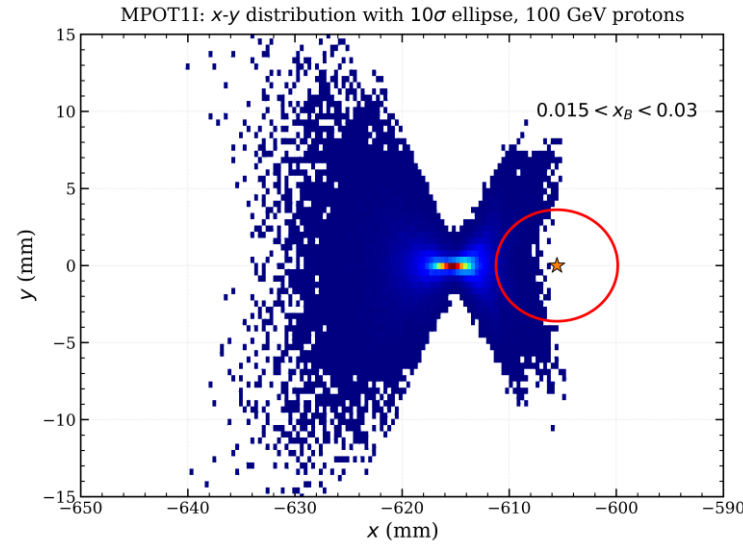
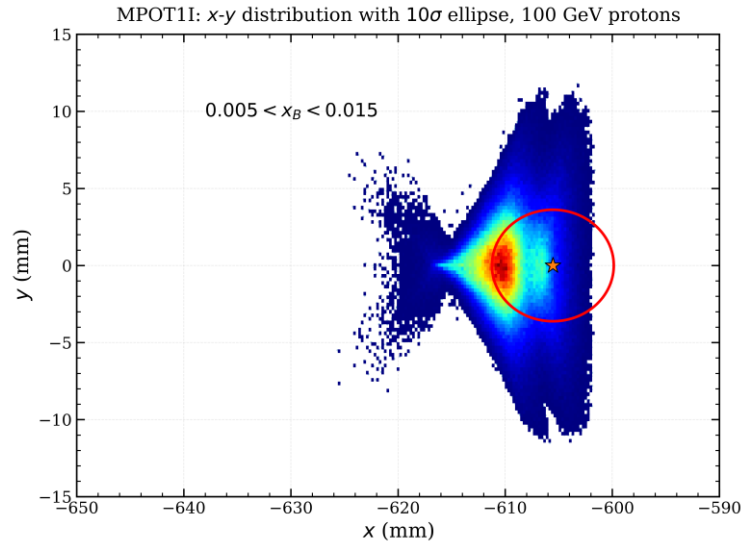
DVCS events for 275 GeV protons from the EPIC generator at RPs



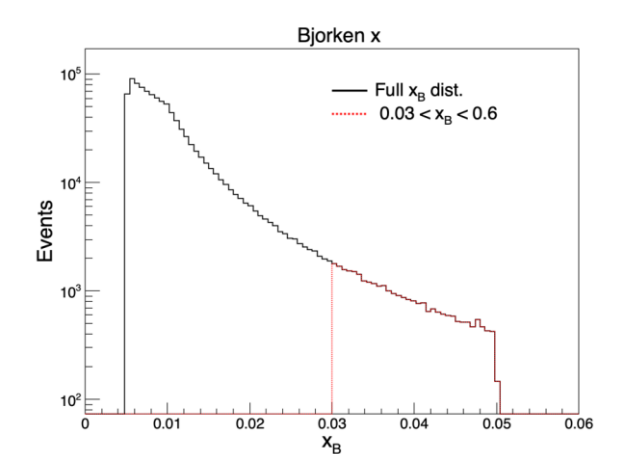
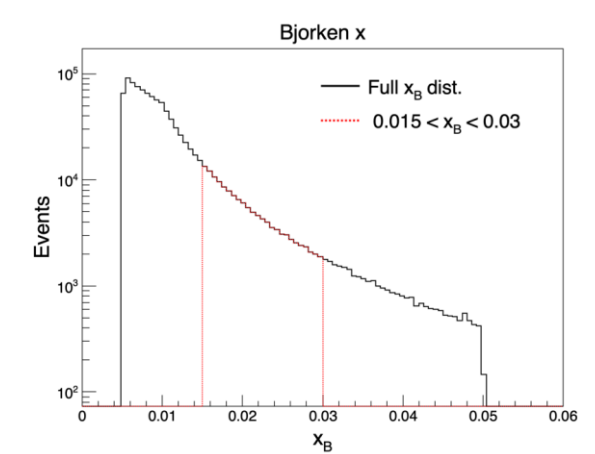
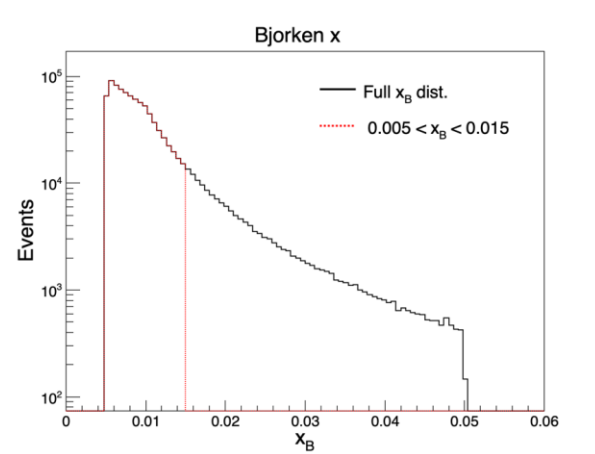
- Recoil protons on the focal plane. Full acceptance at higher x (lower x_L , the main region of interest) even for $p_T = 0$.
- In IR6 the 10s beam-stay-clear (BSC) is much larger and the dispersion smaller.



DVCS events for 100 GeV protons from the EPIC generator at RPs



- At 100 GeV the beam emittance is larger but one still has full acceptance at mid- to large x .



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 the IR8 layout, where the combined length was 2.7 m.
- Since tracking resolution depends on Bdl, resolution per layer, # of tracking layers, and distance traveled, the IR6 design works well for 100 GeV protons, but is not ideal for 275 GeV protons and all ions.
- The counterbending scheme also created an energy-dependent transverse shift of the beam position requiring a more stringent spec on field uniformity in the FFQs.
- A longer, weaker B0 providing the same bending angle that can be used for all energies addresses both the detection and accelerator issues. As pointed out by Brett Parker, it would also make it easier to shield the electron quad. The length of 2.7 is, however, 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

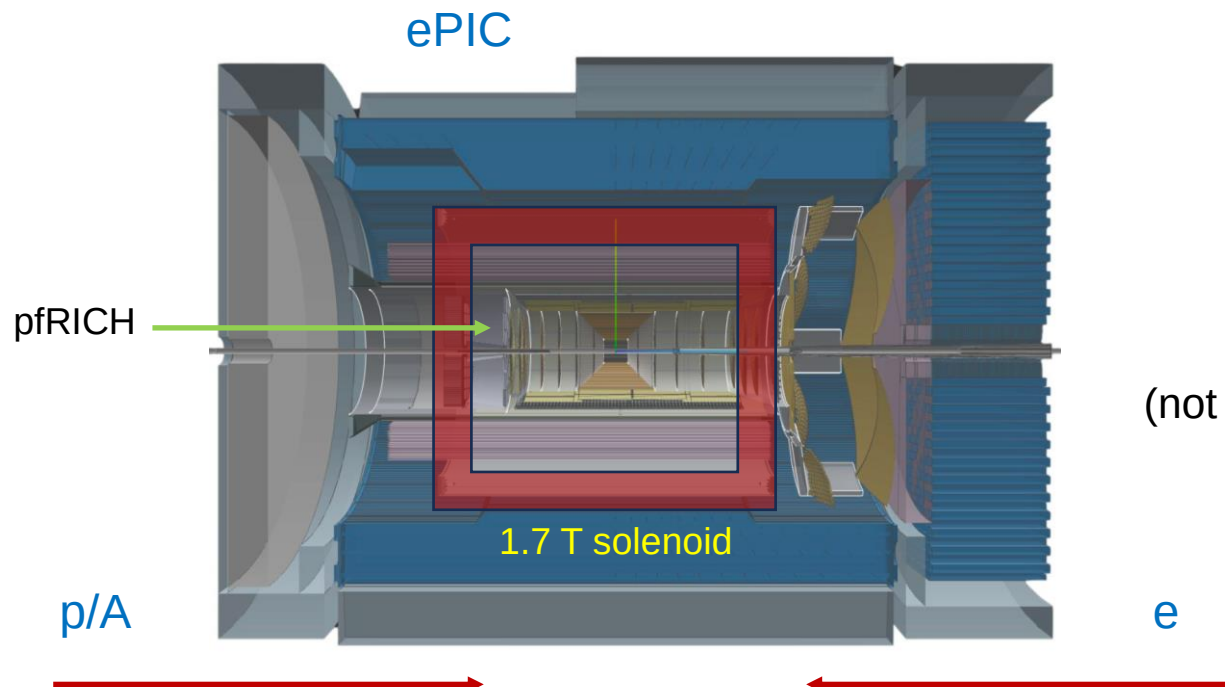
Other magnet specs

- Transport for high- p_T particles is optimized by keeping the initial quad(s) which are defocusing in the dispersive plane as strong and short as possible. Splitting it in two, as was done in the preliminary IR8 layout (so that the polarity of some FFQs could be reversed at low energy) creates potential inefficiencies.
- The new IR12 optics has 3 m long first quad with a peak field of 4.6 T, allowing the following quads to be weaker. Their apertures could be reduced further without a significant degradation in performance.
- Overall, the proposed IR12 magnets are less challenging than the CDR parameters for IR6 and could be relaxed further. The main performance driver lies in the parameters of the first quad.
- As we optimize the IR12 layout further and match it specifically to the geometry of IR12 the magnet parameters can change, but the changes would likely be towards less demanding specs.

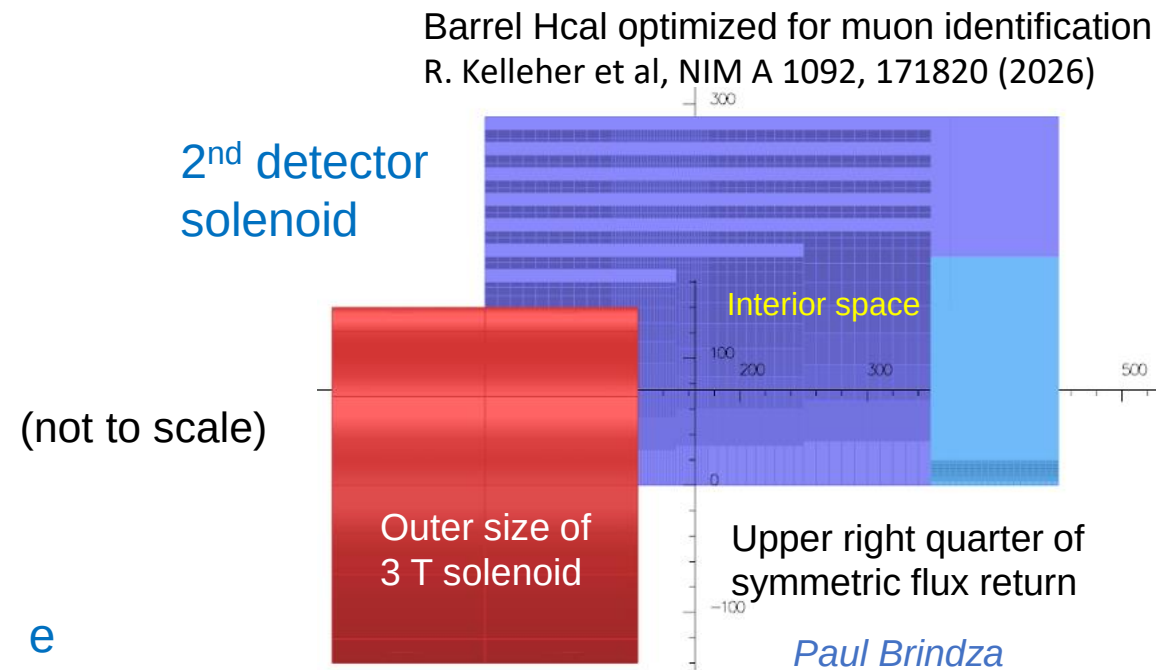
Parameter	IR6 Forward Hadron Magnets							IR12 Proposed Forward Hadron Magnets				
	BOPF	BOAPF	Q1APF	Q1BPF	Q2PF	B1PF	B1APF	BXSP0	QFFDS01	QFFDS02	QFFDS03	BXDS01
Length (m)	1.2	0.6	1.46	1.6	3.8	3.0	1.5	2.7	3.1	2.9	1	5
Inner radius (cm)	20	4.3	5.6	7.8	13.1	13.5	16.8	?	5.8	<7.5	<18.8	?
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Field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

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



Thank you!

Electron-Ion Collider Detector II

Slide by the EIC UG 2nd detector WG
presented to the SCAC in May 2026.

Major facilities need 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.