A 2nd detector for the Electron-Ion Collider (EIC)

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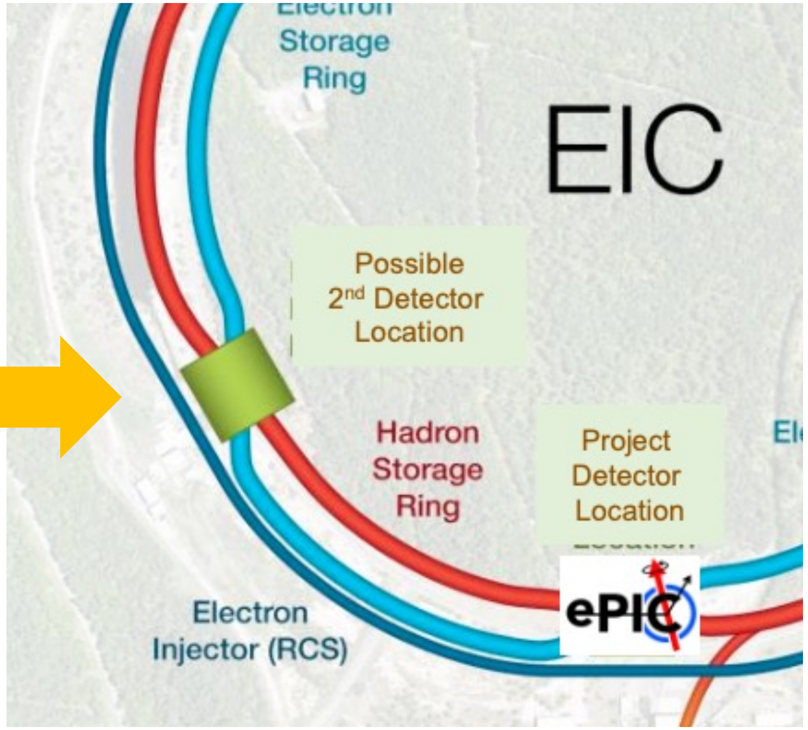
2nd Detector @ IP8



XXXI International Workshop on Deep Inelastic Scattering and Related Subjects, April 8-12, 2024

Motivation for two detectors – a HEP perspective

arXiv: 2303.08228

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

Paul D. Grannis[*] and Hugh E. Montgomery[†]

(Dated: March 27, 2023)

It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

- Inspired by their talk at the first EIC 2^{nd} detector workshop, Mont and Grannis wrote a paper on the benefits of two detectors in particle physics.
- Example from the Tevatron: Discovery of the top quark (CDF and D0)
- The authors also note that although D0 was built 5 years after CDF, both detectors had comparable contributions to the Tevatron physics.

A few other examples

- Discoveries
  - Discovery of Higgs boson: ATLAS and CMS
  - Quark-gluon plasma: RHIC experiments
- Mistakes or misinterpretations
  - Cold Fusion
  - Pentaquarks from the 2000's

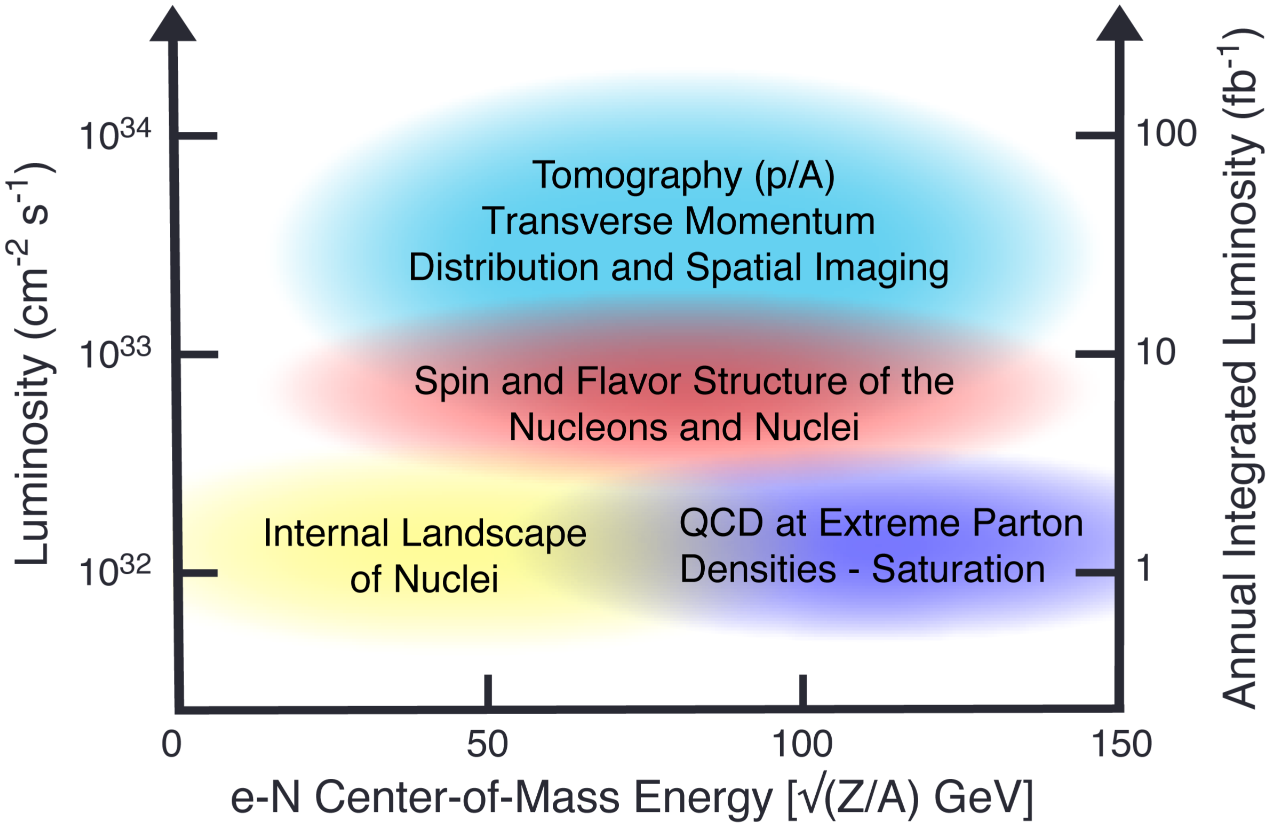
Motivation for a 2^{nd} EIC detector and IR with a 2^{nd} focus

- Needed to unlock the full discovery potential of the EIC
  - Cross checks of key results are essential!
  - Requires a general-purpose collider detector able to support the full EIC program

- New physics opportunities
  - Take advantage of much-improved near-beam hadron detection enabled by a **2^{nd} focus**,
    - *exclusive / diffractive, recoiling nuclei* and *fragments from nuclear breakup, etc*
  - Other capabilities for pursuing ideas beyond the White Paper / Yellow Report
    - *muons, spectroscopy, BSM, ... - Your input is essential!*

- Complementary with ePIC
  - Possible to reduce combined systematics (as for H1 and ZEUS)
  - Particularly important for the EIC where high statistics mean that uncertainties for a large fraction of the envisioned measurements will be **systematics limited**

Luminosity, acceptance, and systematics

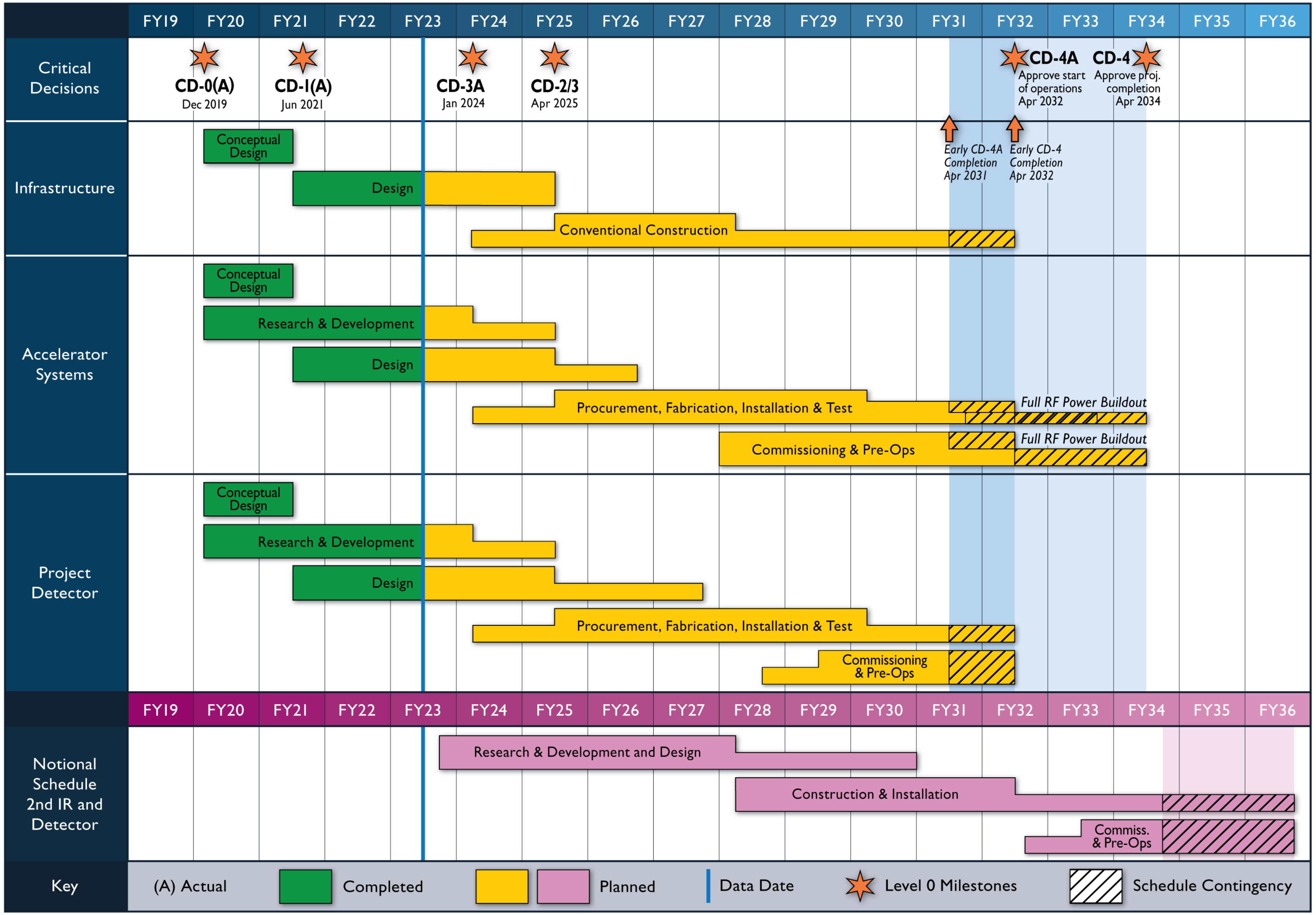


- Tomography / imaging requires a high **luminosity** – but also excellent far-forward **acceptance**
- When the EIC reaches its design luminosity, many measurements in these categories will become **systematics** limited, greatly benefitting from two detectors.

A 2nd detector with improved forward acceptance will have a large impact on all aspects of the EIC physics program.

Reference schedule including a 2nd IR and Detector

Jim Yeck, EIC 2nd detector WS, May 2023



Second detector

DOE review by NSAC of new or upgraded facilities for 2024-2034

https://science.osti.gov/np/nsac/Reports

"… I am asking the SC advisory committees to look toward the scientific horizon and identify what new or upgraded facilities will best serve our needs in the next ten years (2024-2034)."

From DOE charge to NSAC

Facilities or upgrades included in the review

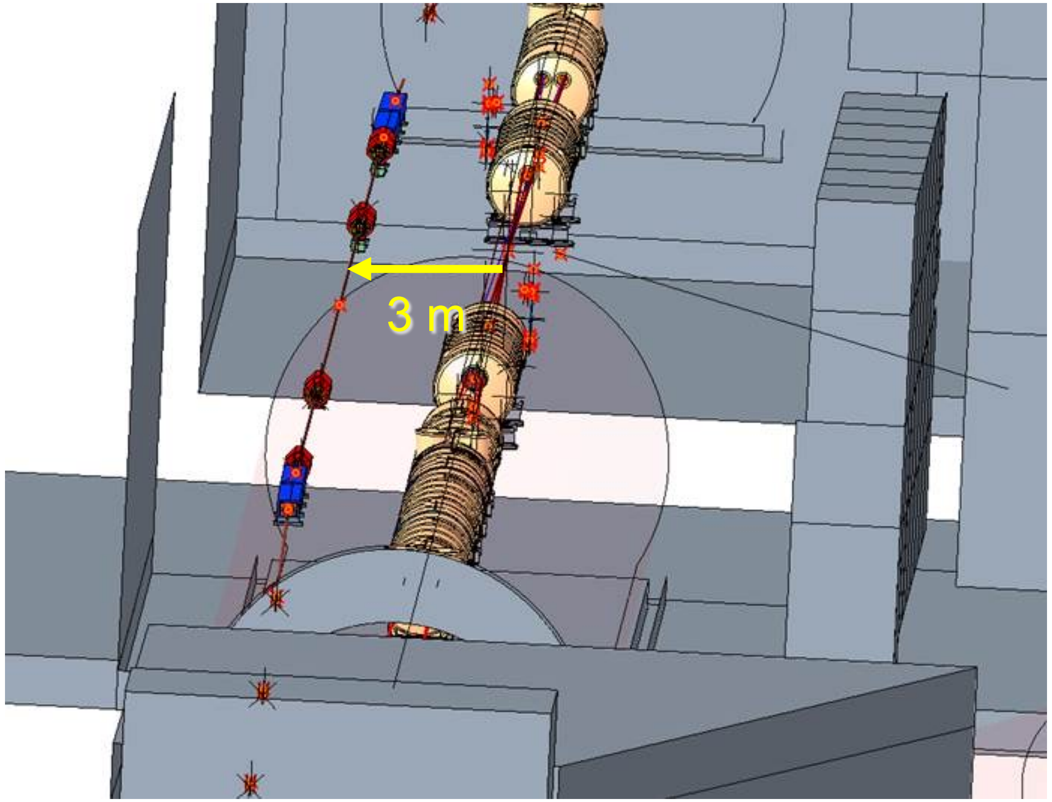
- **Electron-Ion Collider (EIC)**
- High-Rigidity Spectrometer (HRS) at FRIB
- Ton-Scale Neutrinoless Double-beta Decay (TS-NLDBD)
- Project 8
- Facility for Rare Isotope Beams Energy Upgrade (FRIB400)
- **Solenoid Large Intensity Device (SoLID) at JLab**
- **Electron-Ion Collider (EIC) Detector II**

Integration of the central detector with the interaction region (IR8)

- Detector space (outer size):
  - Longitudinal: +/- 4.5 m around the IP (original BNL spec)
  - Transverse: 3 m radius (limited by RCS line)

- Solenoid size:
  - Longitudinal: can be shorter than in ePIC, still providing more internal space (2.5-3.0 m coil)
  - Transverse: Inner radius will depend of B-field

- IR8 will have a far-forward spectrometer with a 2nd focus on the (outgoing) hadron side
  - Natural synergies with central detector



RCS line (left) in IR8

A 2nd detector for the EIC

- General-purpose detector able to carry out the full EIC physics program.
  - Cross checks of discoveries
  - Reduced systematic uncertainties from combined data with ePIC (*c.f.* H1 and ZEUS)

- Capabilities would / could include
  - Forward recoil / fragment detection with a **2nd focus**
    - Improves acceptance for low-p_T / low-x protons from exclusive reactions.
    - Allows tagging of nearly all ion fragments (or vetoing breakup of nuclei)
    - Enables detection of rare isotopes (*e.g.*, Z=89-94 not well covered by FRIB)
  - High **resolution**, *e.g.*:
    - B-field up to 3 T (vs 1.7 T in ePIC) for charged particles
    - Precision EM calorimetry could be extended into barrel (*e.g.*, DVCS on nuclei and spectrometry)
  - Much-improved **muon** detection
    - Unambiguous identification of scattered electron from decay leptons in dilepton production (*e.g.*, DDVCS)
  - Improved coverage for 0.1 < $\mathbf{Q^2}$ < 1 GeV^2 (gap between endcap and low-Q^2 tagger)

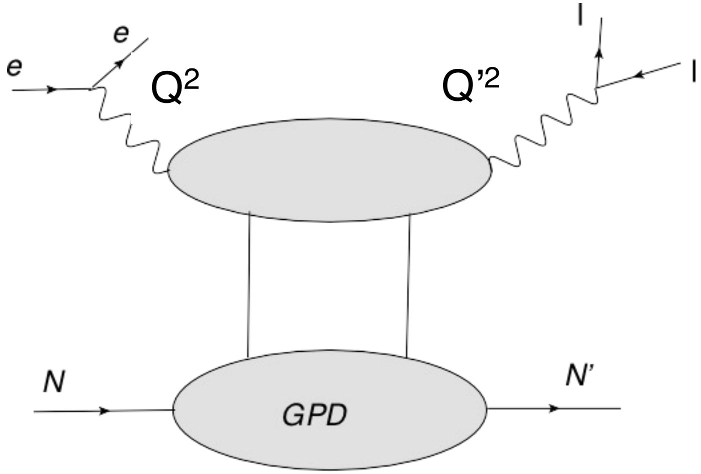
- Generic EIC detector R&D
  - Example: extended momentum coverage for PID in the barrel from further DIRC development

Example: double-DVCS

- Double DVCS makes it possible to probe GPDs outside of the $x = \xi$ line.
  - Measure ξ dependence at low t and moderate Q^2

- Experimentally, DDVCS is challenging because counting rates are lower than for DVCS or TCS
  - Cross section larger in EIC kinematics

- A 2nd EIC detector could provide a better DDVCS measurement than ePIC or JLab (fixed-target)
  - **muon ID** is *necessary* in order to distinguish the scattered electron from the DDVCS decay leptons
  - **low-t acceptance** for the recoil proton (2nd focus)
  - **$0.1 < Q^2 < 1$ GeV^2** coverage for the scattered electron



Q' has to be in a mass region without meson resonances decaying into l^+l^-

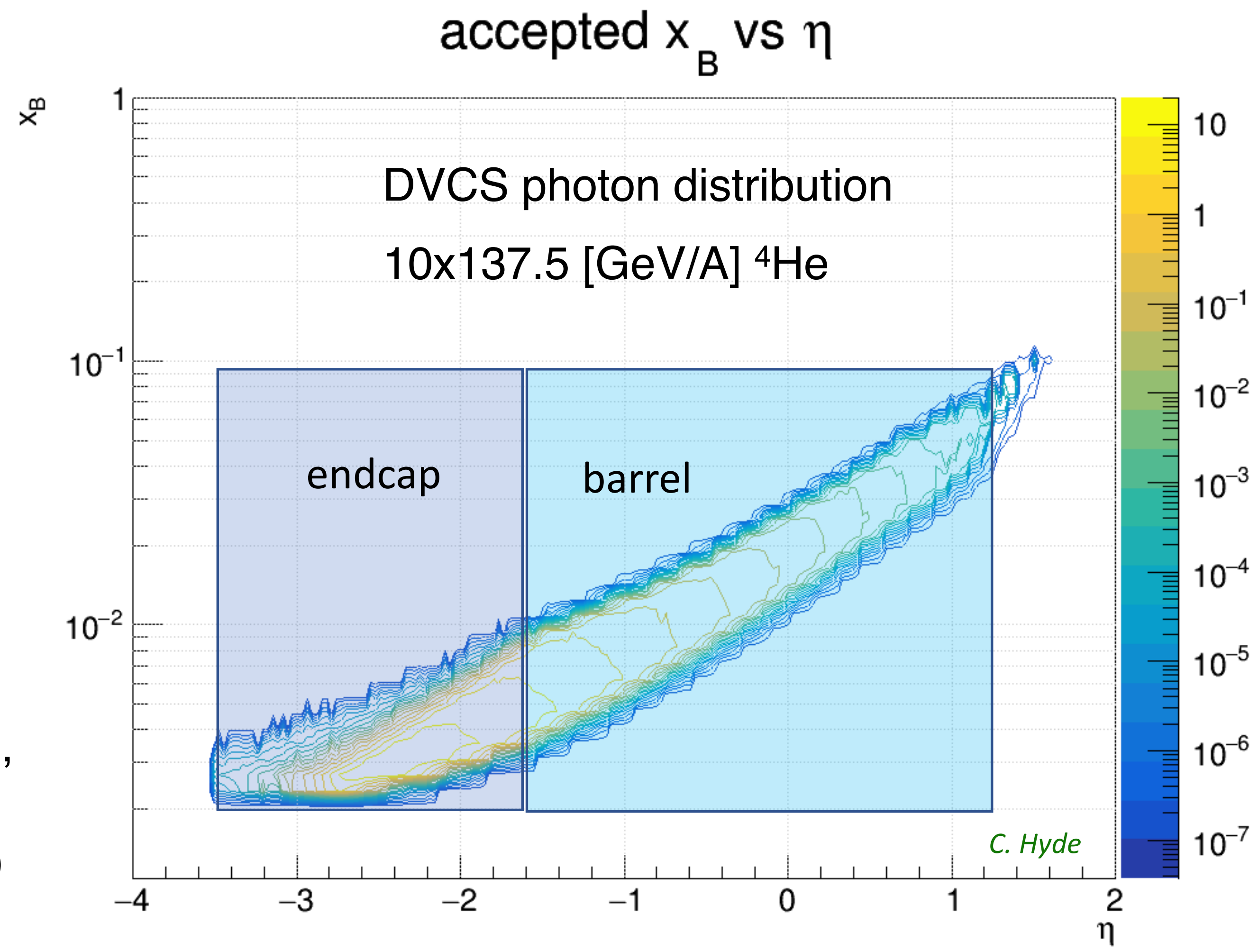
(*e.g.*, in-between the ϕ (or ρ') and the J/ψ)

Note: TCS ($Q^2 = 0$) is also an important EIC measurement, but the experimental constraints are a subset of DDVCS

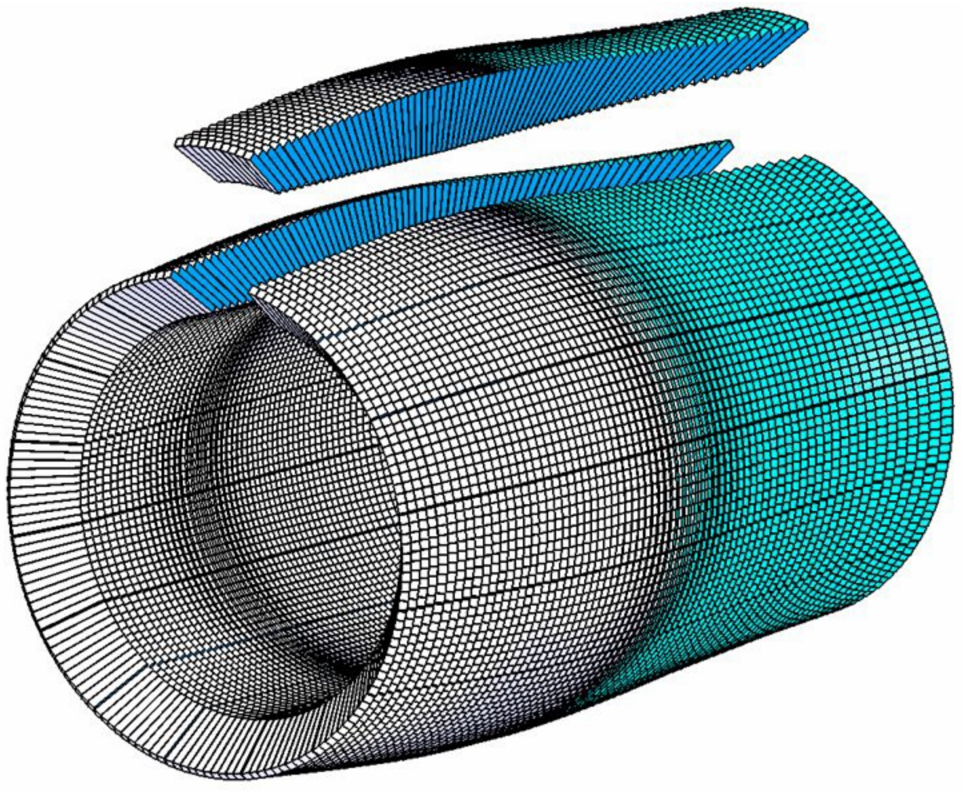
Example: DVCS on nuclei

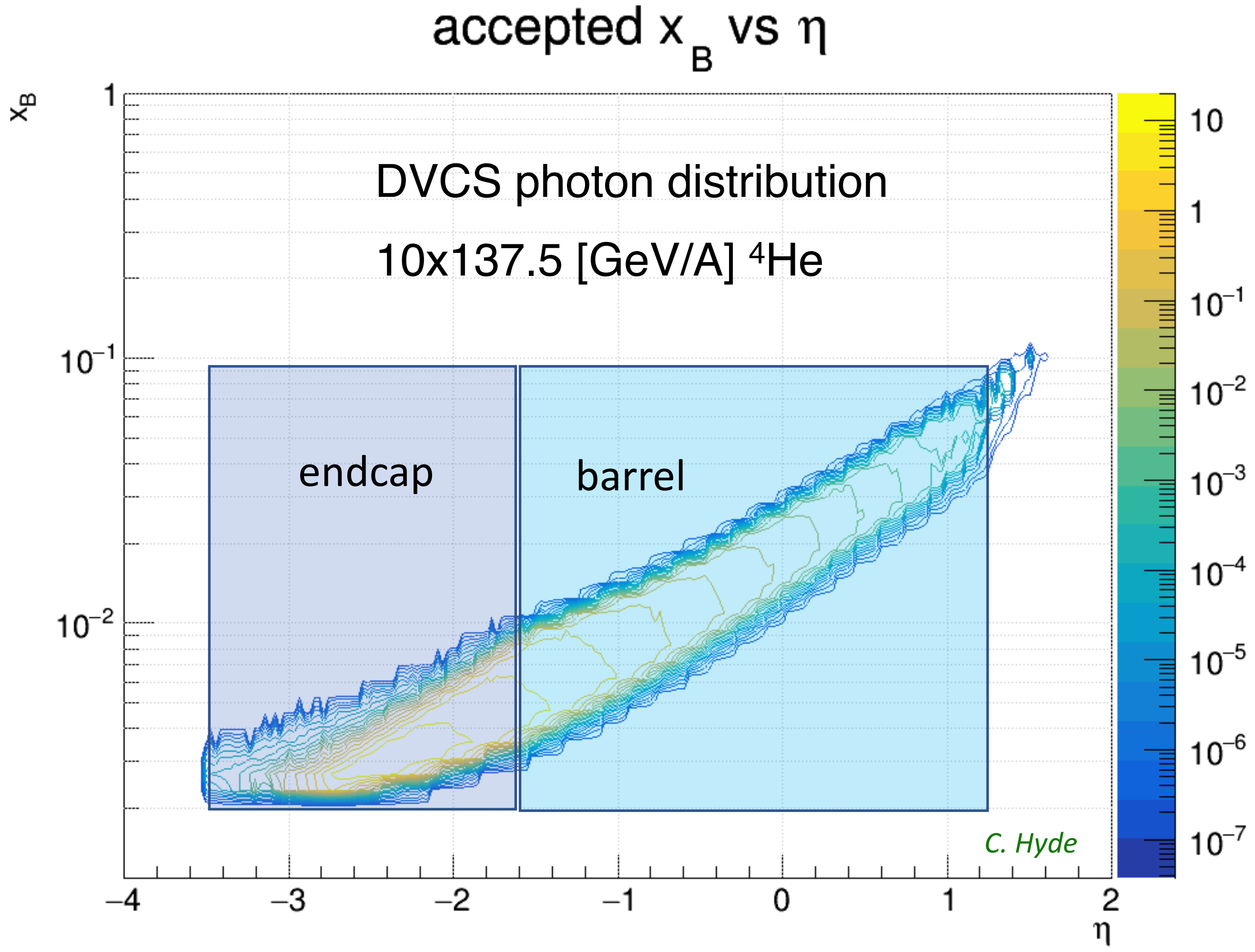
- In DVCS on the *proton*, both the photon and proton are detected for exclusivity
  - *t* can be determined from the ***proton***
- In DVCS on the *nuclei*, the nucleus has to be detected or the breakup vetoed to ensured coherence and exclusivity.
  - *t* is determined from the ***photon***

  (*cf.* coherent VM production on nuclei)
- For the best measurement of DVCS on nuclei, the 2nd EIC detector should have:
  - **low-t acceptance** (provided by the 2nd focus)
  - **high-resolution EMcal** coverage in the barrel



Example of a high-resolution EM calorimeter for the barrel

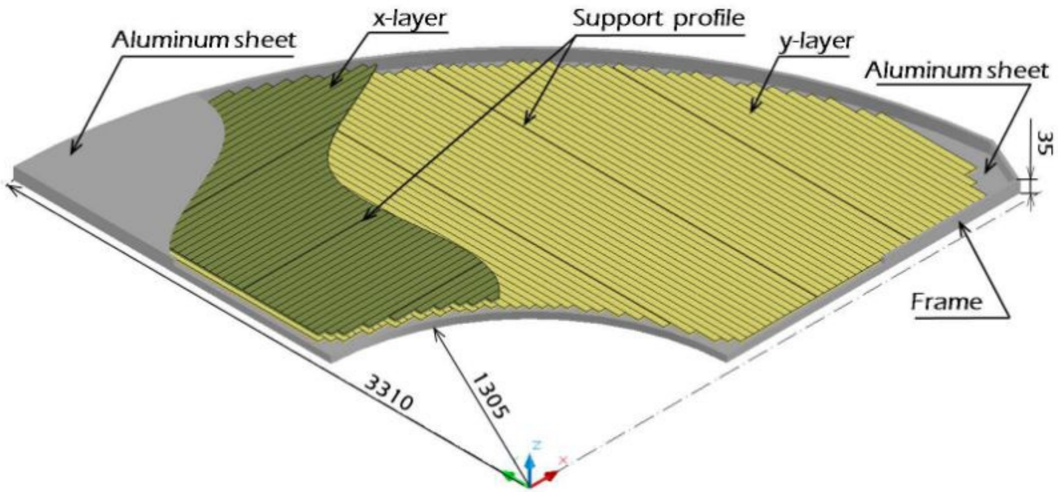




- A high-resolution EMcal like the one built for PANDA would be ideal for the 2nd detector.
  - DVCS on nuclei (extends coverage)
  - Spectroscopy (as in PANDA)

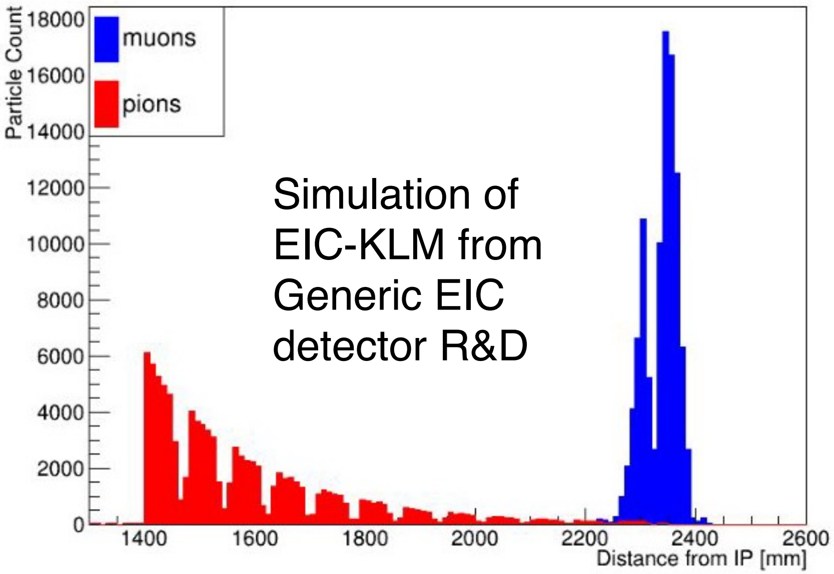
Muon and neutral hadron detection for a 2nd EIC detector

- A position-sensitive, radially segmented muon ID system like the KLM from Belle II would be ideal for the barrel and (outgoing) electron endcap
  - An Hcal is needed in the hadron endcap.



- Most muons will traverse most layers, while pions will stop early: high purity, low mis-ID.
  - Each layer with crossing strip is read out individually.
  - Works well for low muon momenta

- The KLM also measures neutral hadrons
  - In the EIC, jets are best reconstructed from tracking and PID
  - 1/3 of jets contains neutral hadrons
  - A KLM can provide the hit position
  - Energy and ToF capabilities are part of ongoing R&D
  - Complementary to ePIC (sPHENIX) barrel Hcal



Generic EIC detector R&D

- It is expected to be funded at an annual level of $2M, subject to availability of funds from DOE NP.

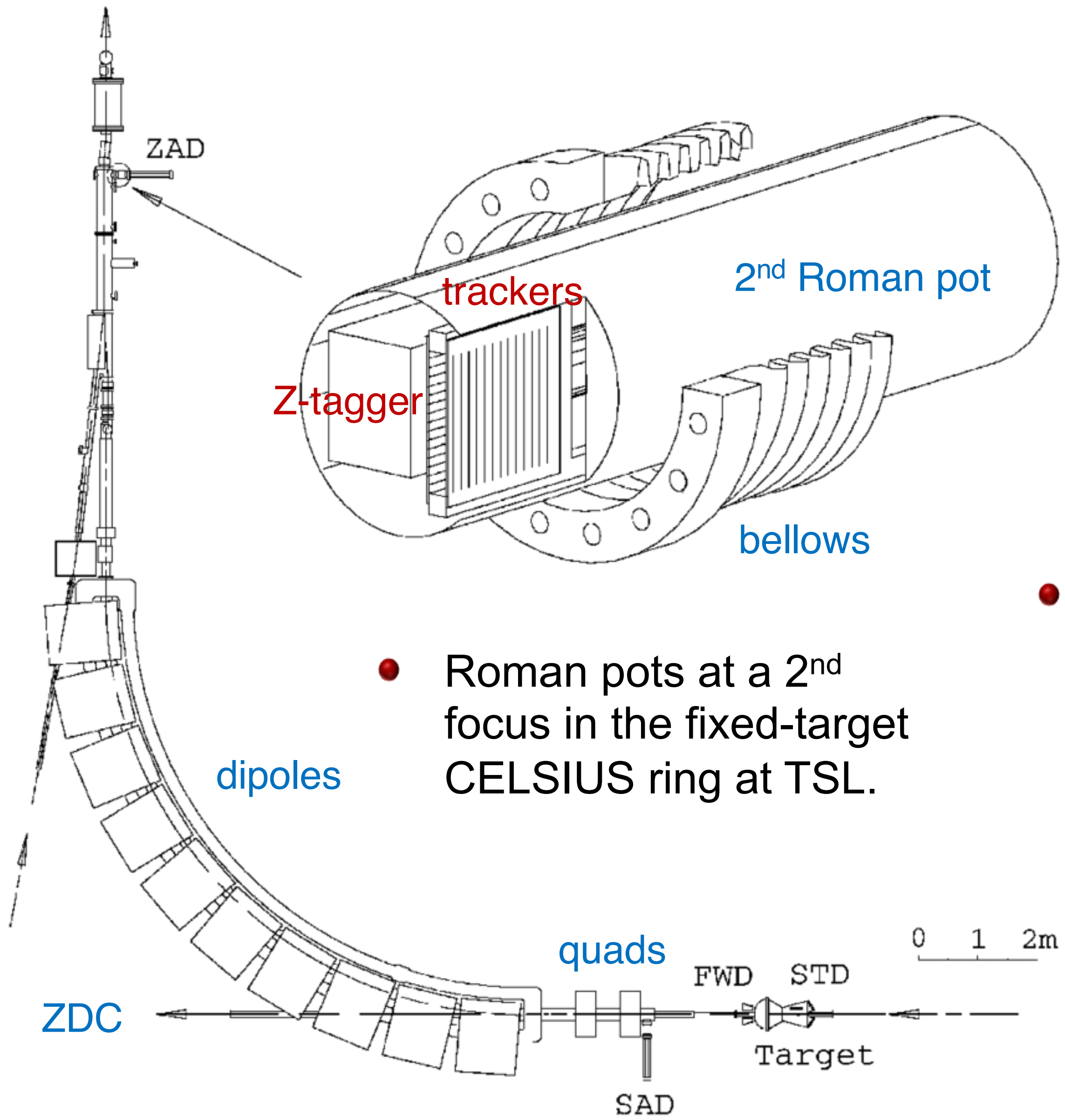
2023 submissions

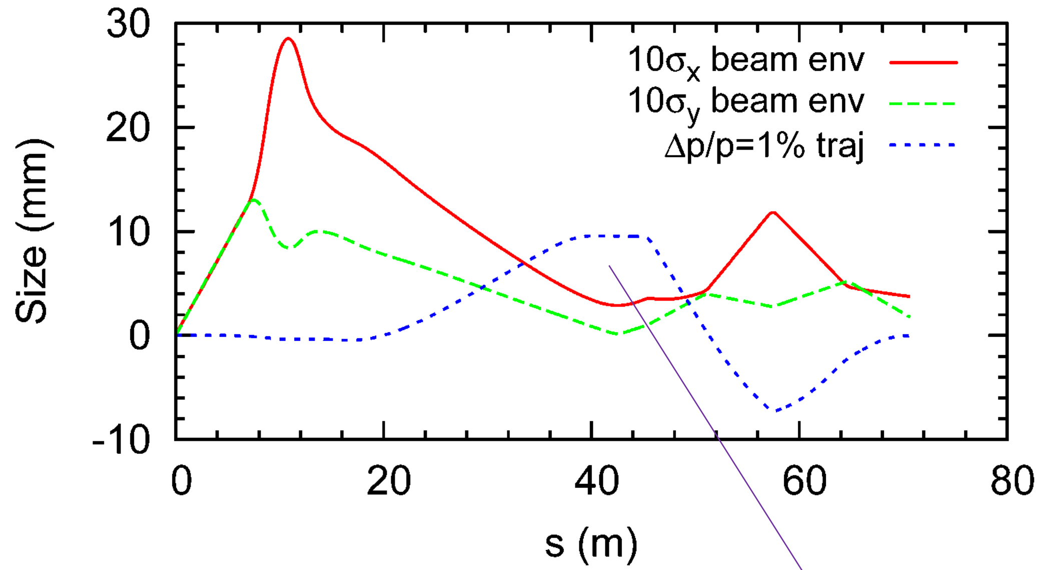
Topic	# of proposals submitted	Requested Funds	Preliminary Weight	Preliminary Funding Allocation
Calorimetry	4	$663K	2	$236K
PID (non-TOF)	4	$397K	2	$236K
Gaseous Precision Timing and/or Tracking	2	$359K	1	$118K
Front End Electronics	1	$222K	1	$118K
Silicon Detectors	6	$710K	3	$355K
Software Supporting Electronics/Detector Design or Physics Program	0	$0K	0	0
"Other New Detectors"	2	$100K	1	$118K
Studies to Support or Expand the Physics Program	1	$159K	1	$118K
				Total = $1.3M

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

- **Aimed at Detector 2**, or upgrades of Detector 1
- Proposals accepted from across the world from universities, laboratories, and companies
- Features of a proposal that add value: reduce risk, cost effective, increase physics scope, innovative, *etc*.

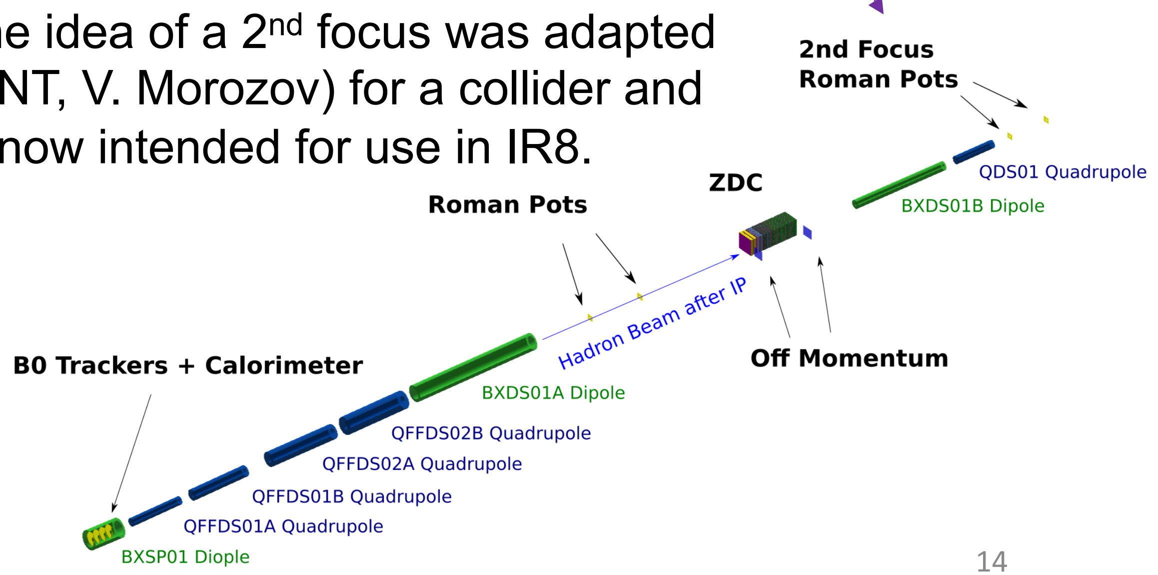
Optics for a 2nd EIC detector were inspired by the CELSIUS ring in Uppsala





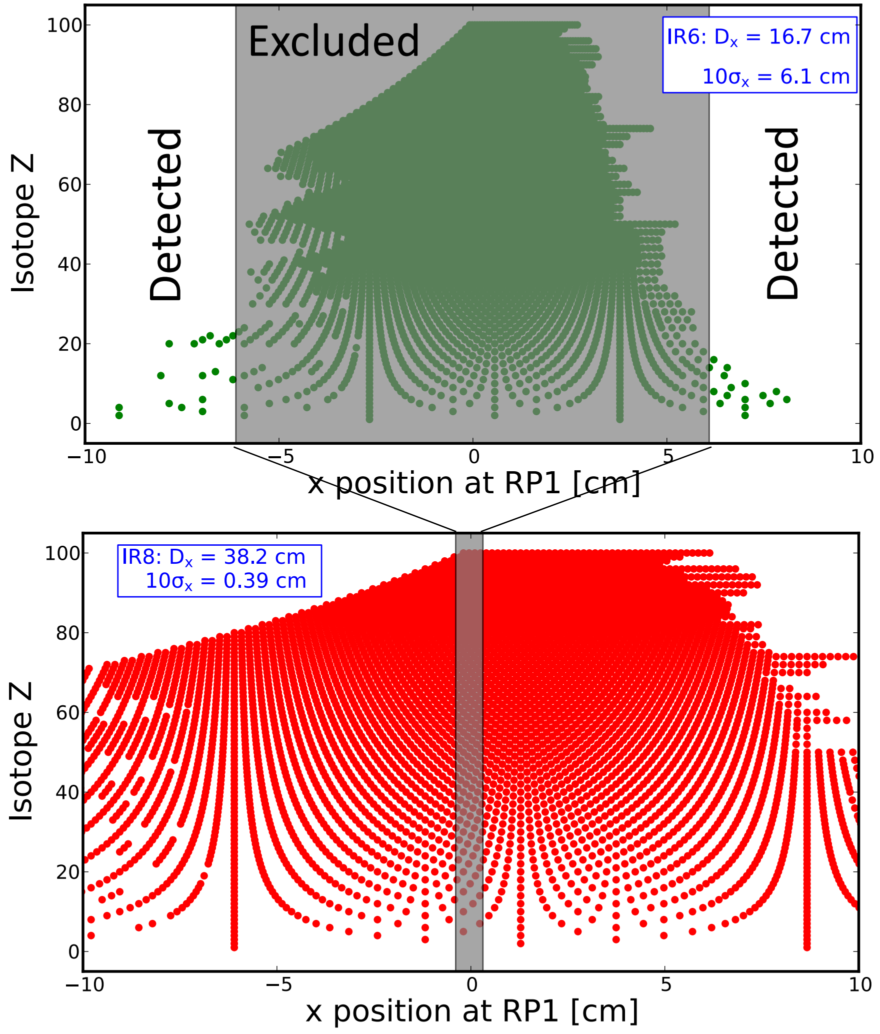
- Roman pots at a 2nd focus in the fixed-target CELSIUS ring at TSL.

- The idea of a 2nd focus was adapted (PNT, V. Morozov) for a collider and is now intended for use in IR8.



EIC far-forward acceptance with and without a 2nd focus

Ion fragments from ^{238}U



x position ~ A/Z

Without 2nd focus:
(EPIC @IR6)

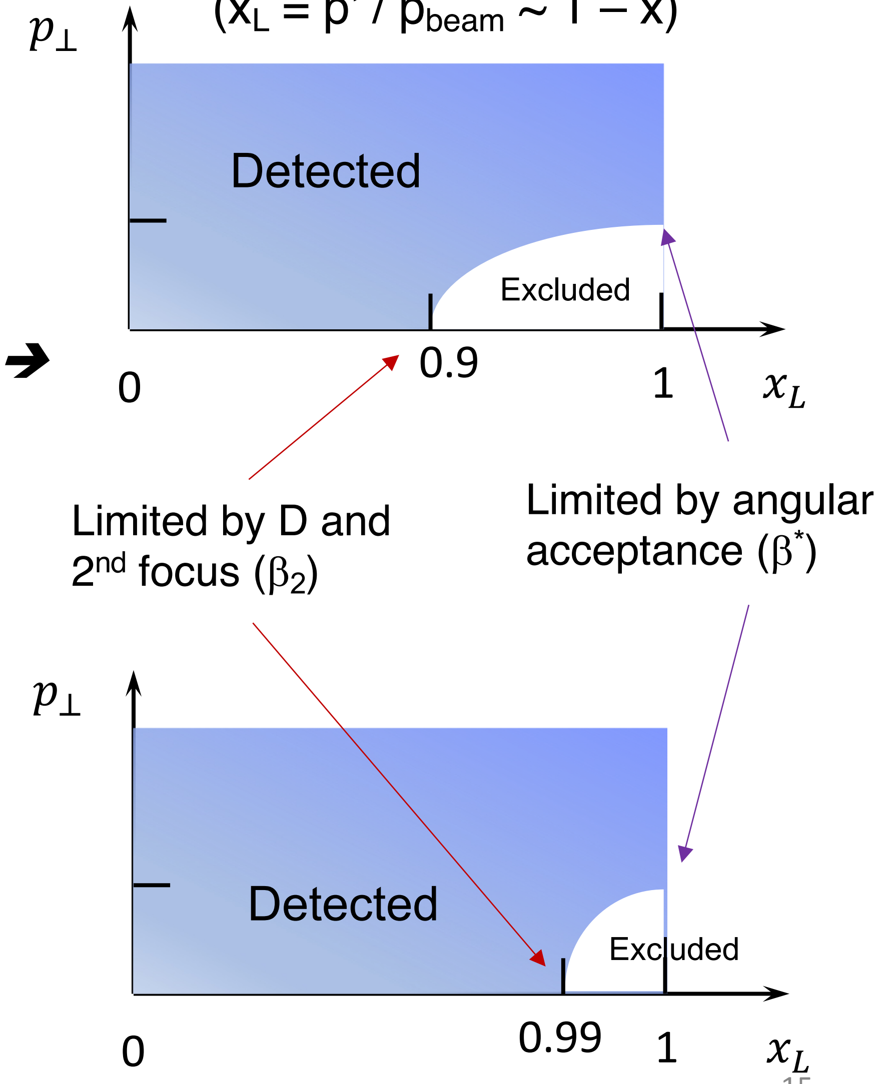
← Z' vs x_{RP}

$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

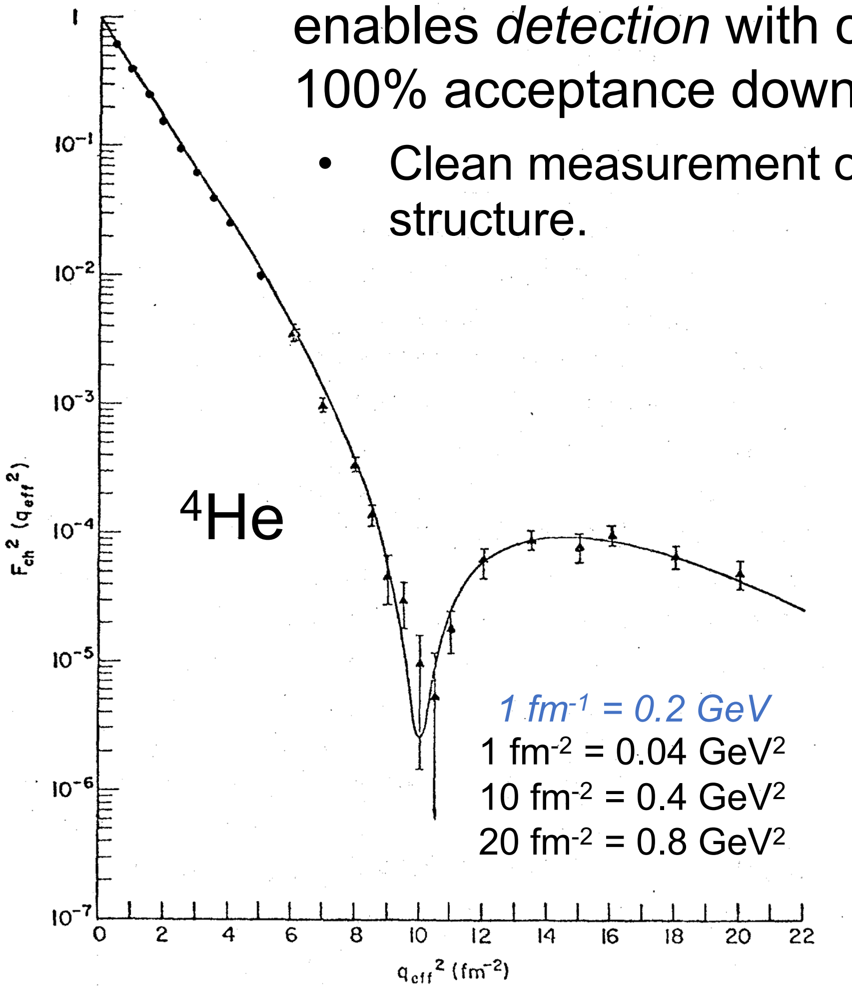
Order-of-magnitude improvement in forward acceptance

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

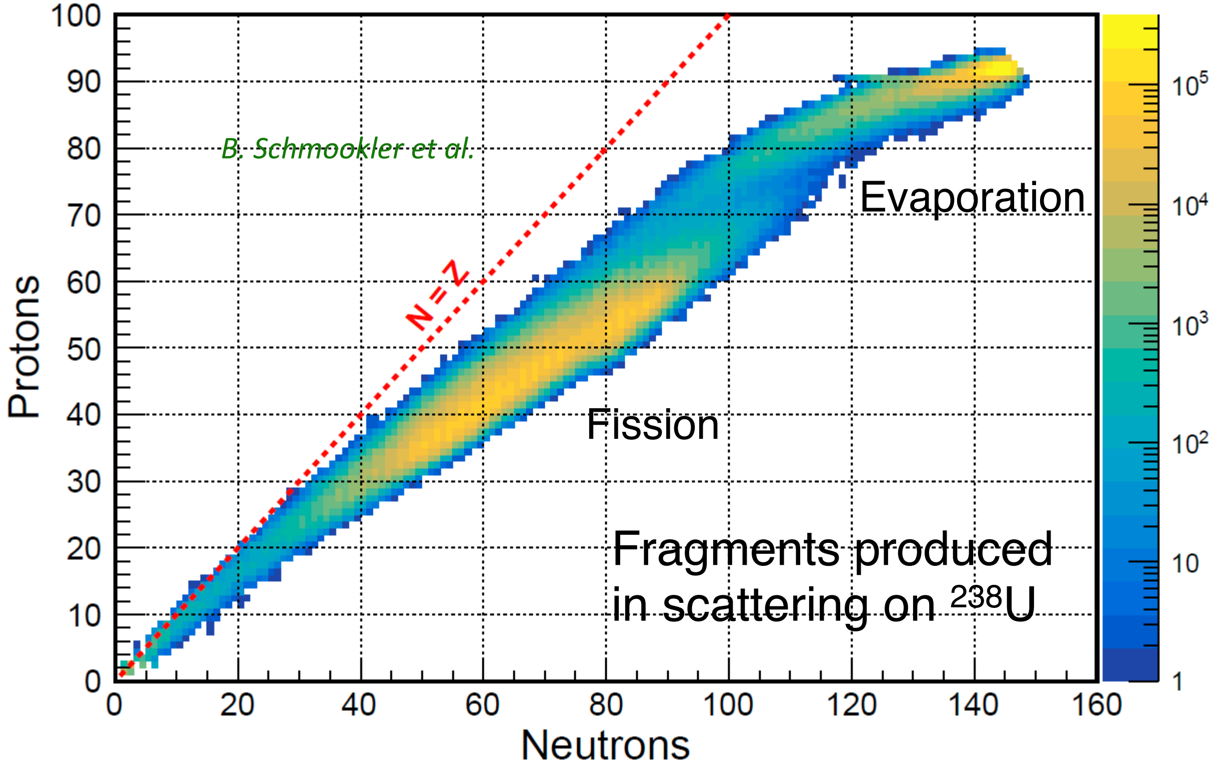


Example: exclusive coherent scattering on nuclei

- For light nuclei, the 2nd focus enables *detection* with close to 100% acceptance down to $p_T = 0$.
  - Clean measurement of 3D structure.

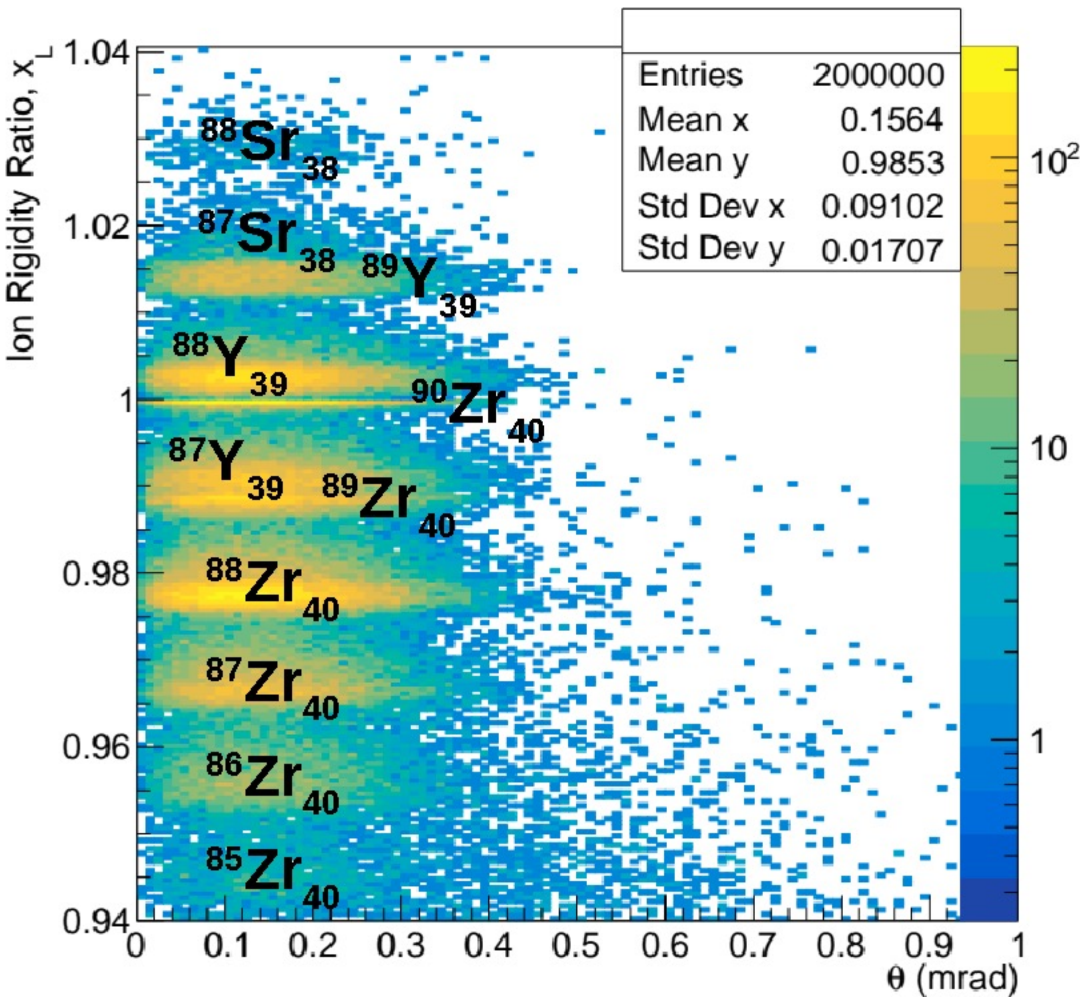


- For heavier nuclei, incoherent events can be suppressed with a high efficiency by detecting the fragments (including neutrons and photons) from the breakup.

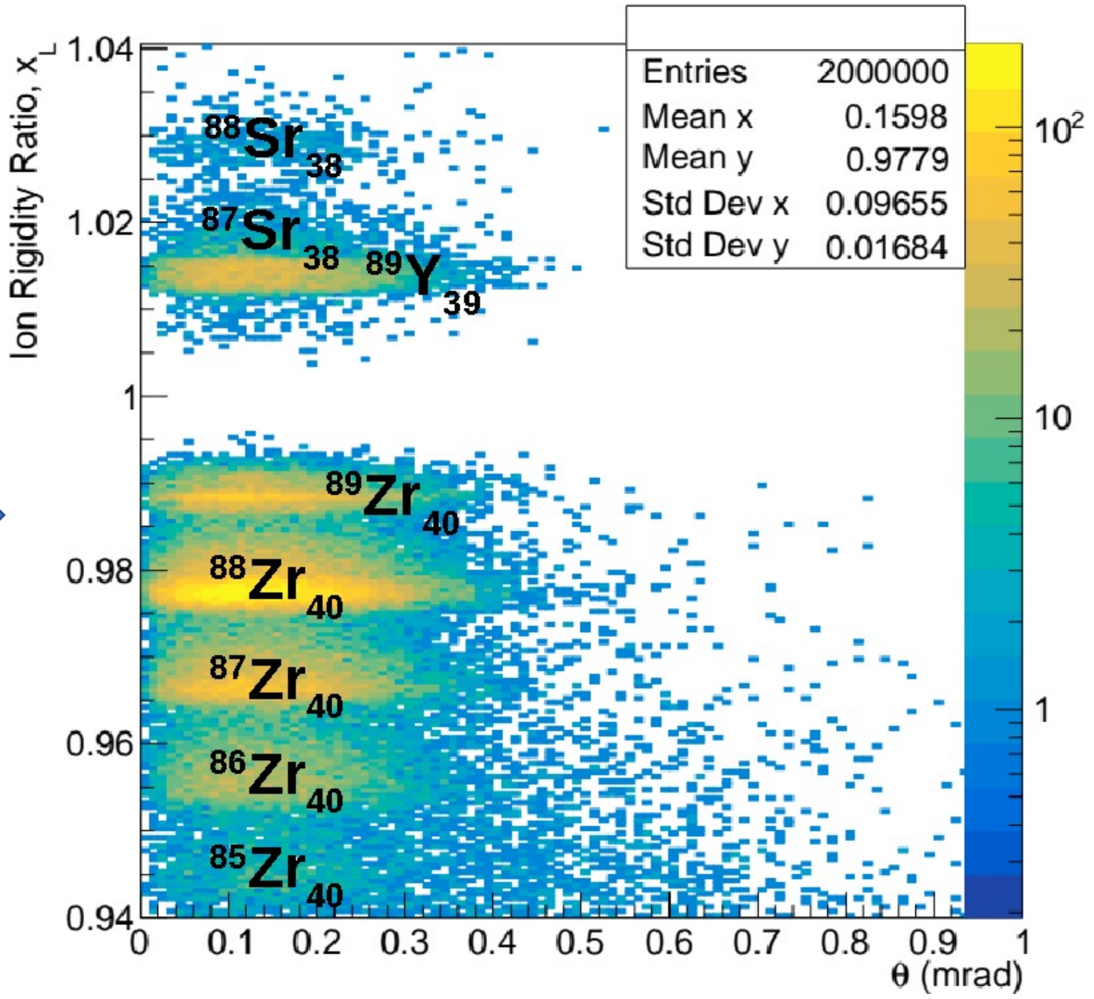


Example: A-1 tagging with a 2nd focus using a ^{90}Zr beam

arxiv:2208.14575



generated (BeAGLE)

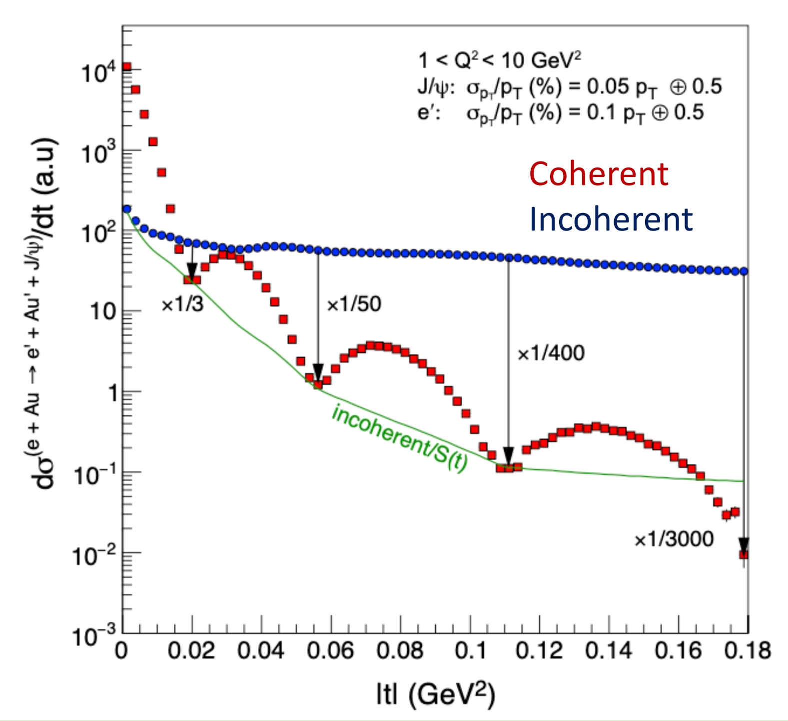


detected (Geant)

Example: vetoing breakup in coherent using a 2^{nd} focus

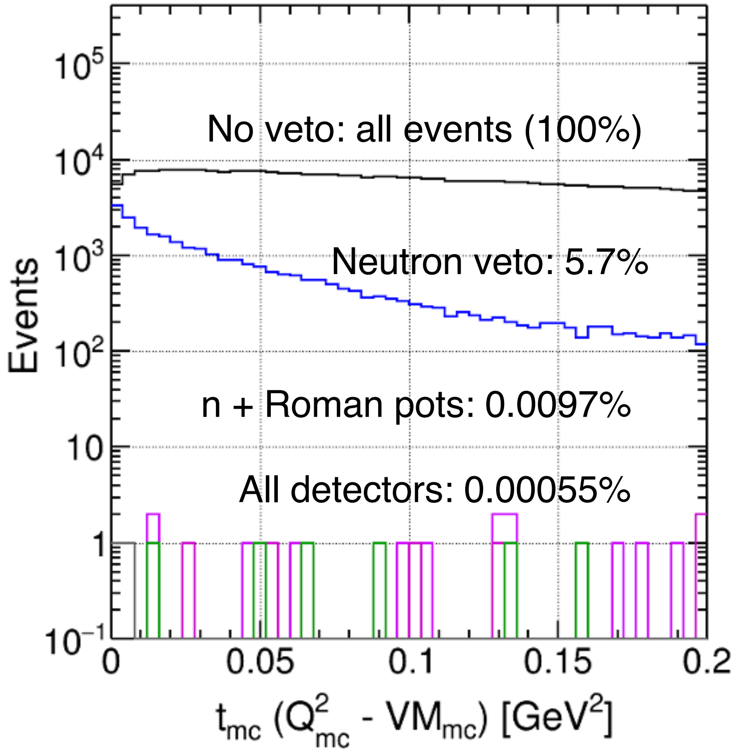
Jihee Kim

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



Fragment detection using the Roman pots at the 2^{nd} focus provides a stronger veto at larger values of t.

EIC UG 2nd detector working group

- December 2021 – DPAP review of EIC detector proposals
  - The call included a 2nd detector
  - While the DPAP did not make a selection of a 2nd detector, it endorsed the idea

- July 2022 – the Det II / IP8 WG was formed. **Everyone is welcome to join!**
  - Regular public meetings
  - Conveners:

  Charles Hyde (ODU), Sangbaek Lee (ANL), Simonetta Liuti (UVA), Pawel Nadel-Turonski (CFNS/SBU), Bjoern Schenke (BNL), Ernst Sichtermann (LBL), Thomas Ullrich (BNL), Anselm Vossen (Duke/JLab)

- Several workshops have also already been organized by the WG
  - December 2022: first in a series of CFNS workshops at Stony Brook U. (98 participants)
  - May 2023: 1st International workshop on Detector II at Temple U. (115 participants)
  - July 2023: Detector II workshop as part of the EIC UG meeting in Warsaw, Poland

Summary

- Having two detectors at the EIC would provide the necessary cross checks of discoveries and potentially reduce the systematic uncertainties (*cf.* H1 and ZEUS)

- A 2nd detector could also provide expanded and unique capabilities

- A generic detector R&D program is already in place.

- The EIC UG 2nd detector WG is pursuing and coordinating ongoing activities.

Thank you!

So what is a 2nd focus and what does it do?

$$\sigma = \sqrt{\beta\epsilon + \left(D\frac{\Delta p}{p}\right)^2}$$

Three are mutually supportive strategies for detecting forward particles

- **Drift**
  - A particle scattered at a small angle will eventually leave the beam (which could be far away).
  - When using *only* this method, the scattering angle has to be larger than the angular spread (divergence) of the beam, which is determined by the strength of the focus at the collision point (β^*).

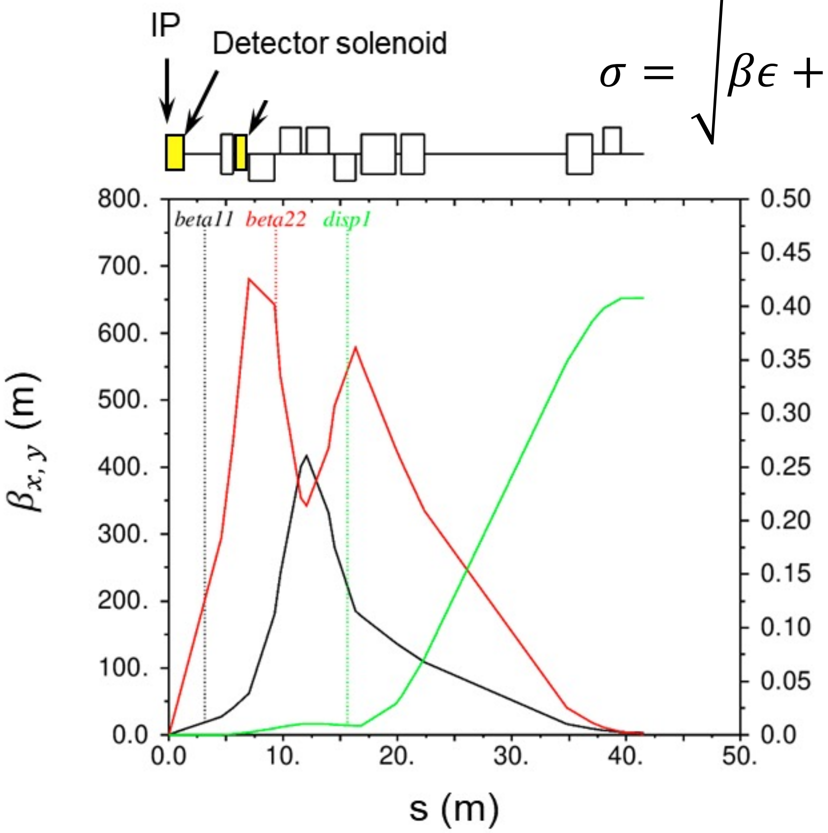
- **Dispersion** (D) translates a longitudinal momentum loss into a transverse displacement
  - dx = D dp/p , where dx is the transverse displacement at $p_T = 0$
  - With D = 0.4 m, dp/p = 0.01, and $p_T = 0$, the transverse displacement for would be **0.4 cm**

- **A 2nd focus** can reduce the (10σ) beam size at the detection point
  - Enables detectors to be placed closer to the beam – very effective in combination with dispersion
  - Without a 2nd focus (IR6): **4 cm** (high luminosity / divergence), **2 cm** (low luminosity / divergence)
  - With a 2nd focus (IR8): **0.2 cm** (high luminosity / divergence)

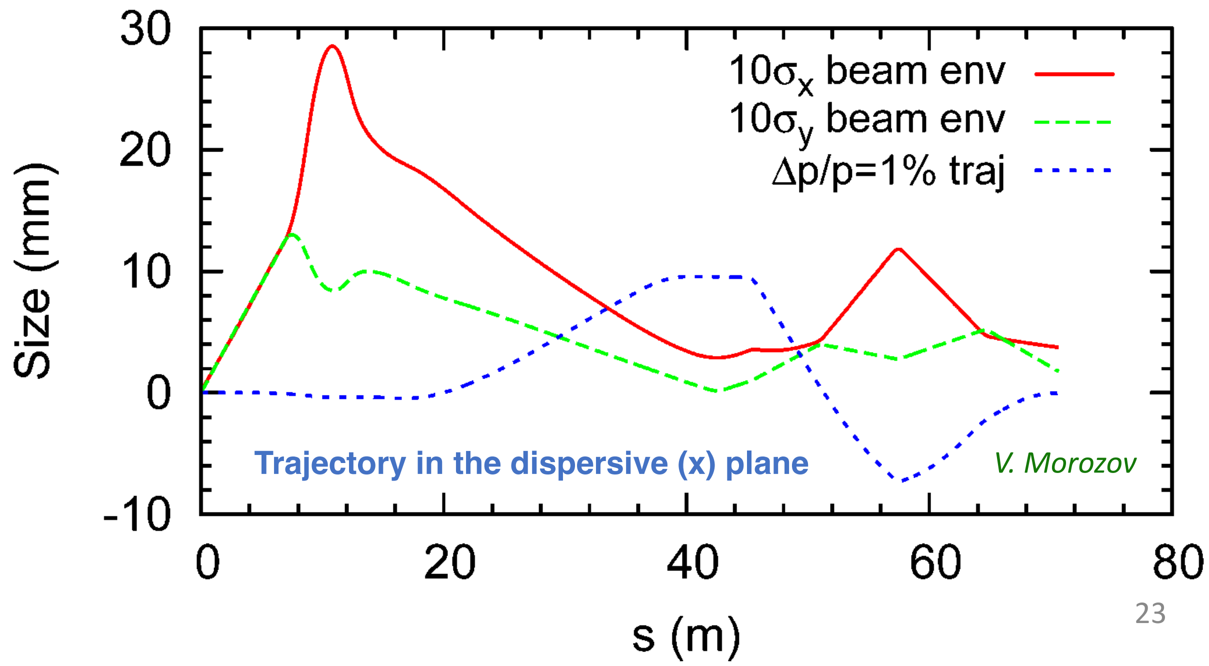
Beam optics and the actual trajectory of a $p_T = 0$ particle (blue)

- For optimal detection, the (2nd) focus has to coincide in x and y at the point of maximum dispersion (green line below).
  - σ_x and σ_y should be comparable at the 2nd focus (and thus $\beta_x < \beta_y$ since $\varepsilon_x > \varepsilon_y$)

$$\sigma = \sqrt{\beta\epsilon + \left(D\frac{\Delta p}{p}\right)^2}$$



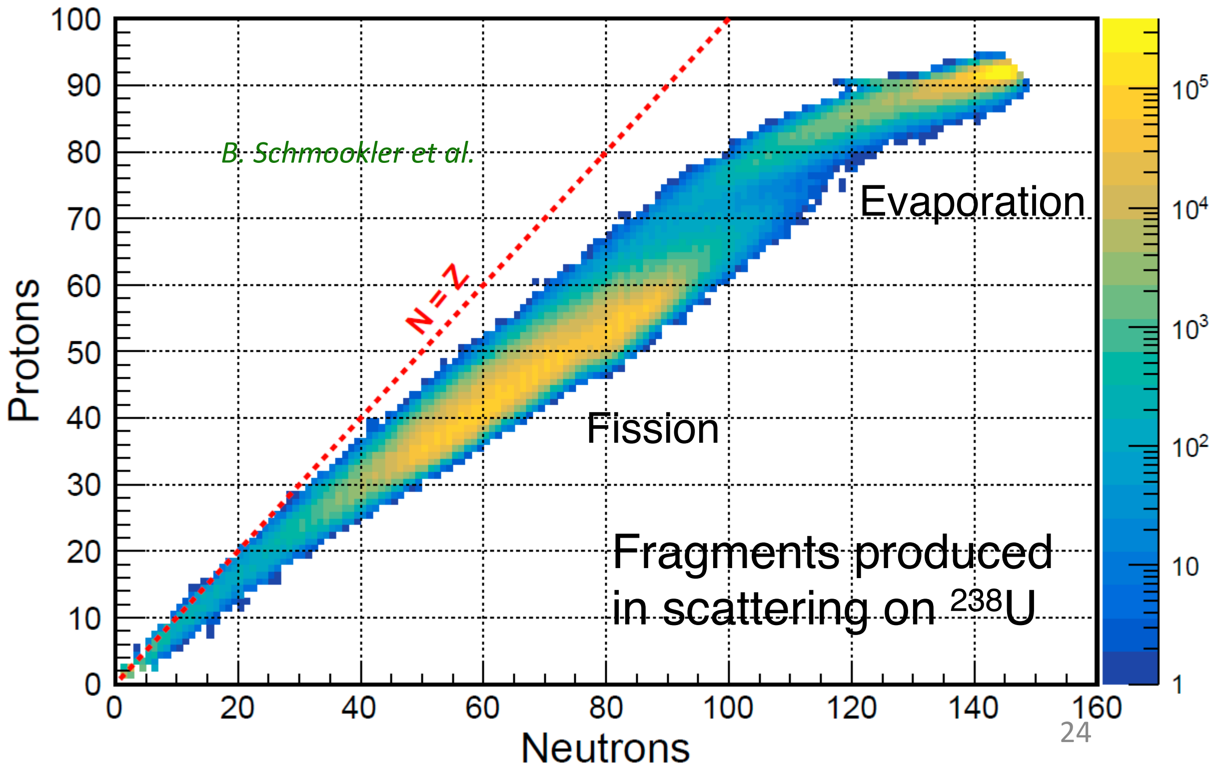
- A zero degree particle (blue) briefly emerges from the beam at the 2nd focus about 40 m downstream of the IP where it can be detected
  - Particles with a non-zero angle emerge earlier .
- The 2nd focus refers to the *beam*. Scattered particles have their *maximum* transverse displacement here.



Example: tagging of heavy spectators

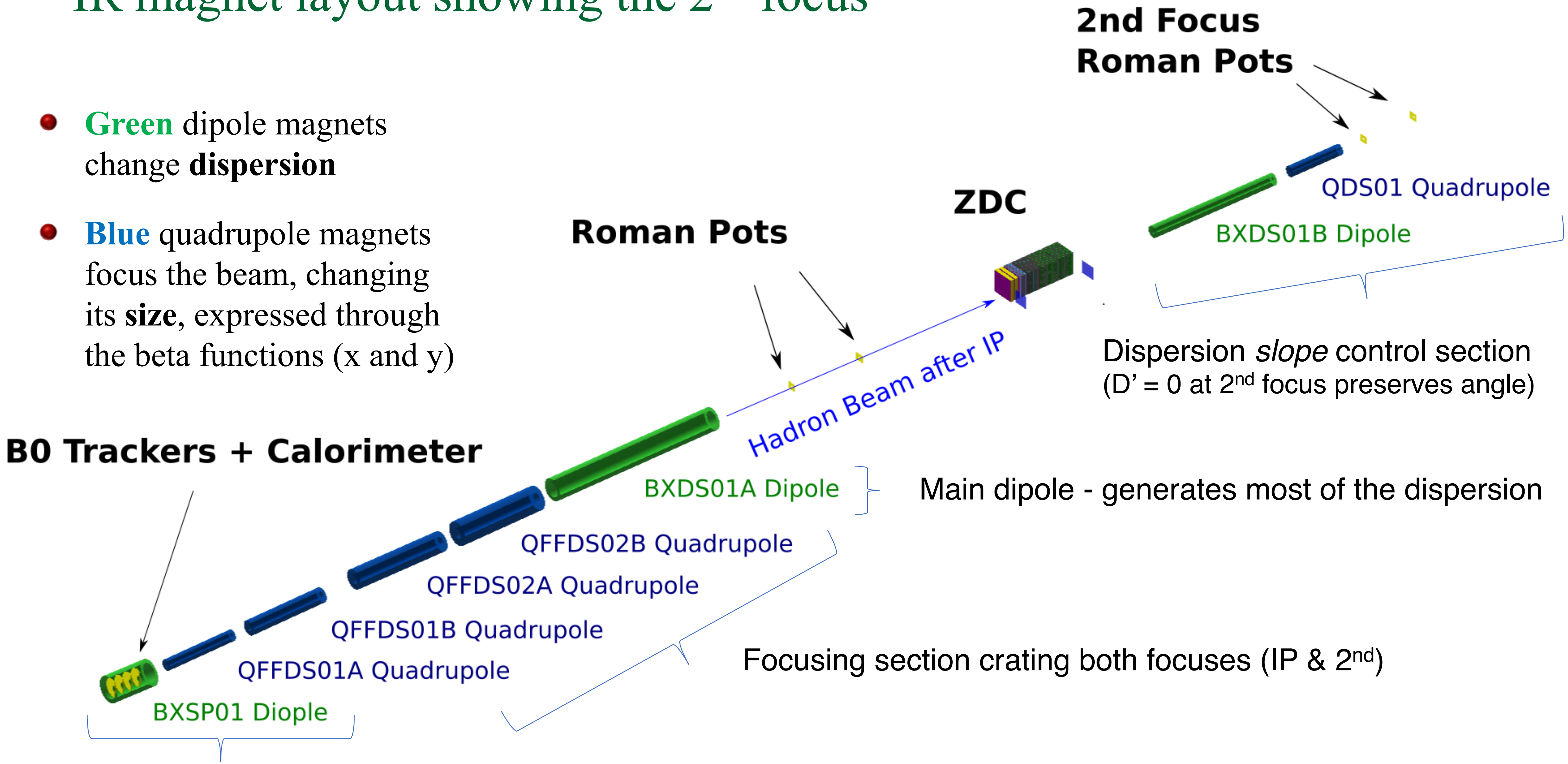
- Both IR6 and IR8 support tagging of spectator protons from light ions (d, He)
  - These spectators have magnetic rigidities that are very different from that of the beam ions
- A 2nd focus will allow tagging of heavy spectators
  - A-1 nuclei up to at least Zr-90
  - A-2, *etc*, for almost any nucleus
- Tagging of heavy A-1 spectators enables measurements of reactions on a bound nucleon

- The fragments will also contain rare isotopes
  - Gamma spectroscopy possible by measuring boosted forward-going photons in coincidence
  - Interest from the FRIB community
    - Proton rich Z=89-94 nuclei, etc



IR magnet layout showing the 2nd focus

- **Green** dipole magnets change **dispersion**
- **Blue** quadrupole magnets focus the beam, changing its **size**, expressed through the beta functions (x and y)



Small dipole covering the range between the endcap and Roman pots