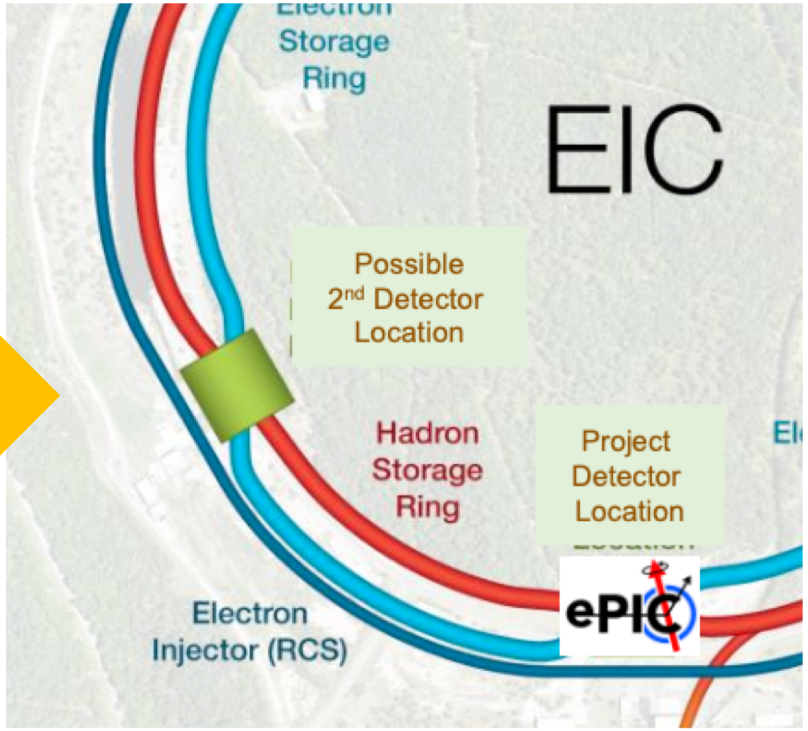
Designing the 2nd interaction region and detector

Pawel Nadel-Turonski
CFNS Stony Brook University

The 2nd detector



EINN, Paphos, Cyprus, 31 October - 4 November, 2023

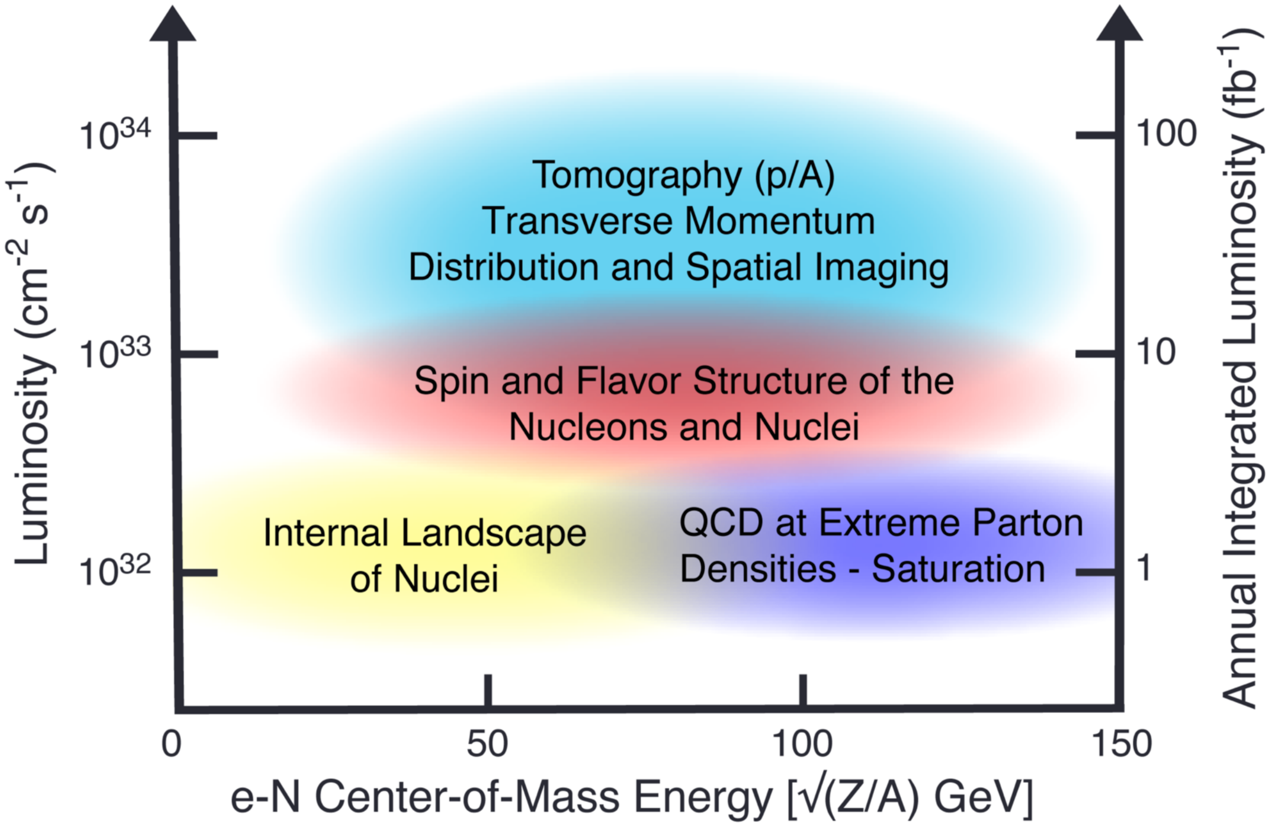
Motivation for a 2^{nd} detector and IR with a 2^{nd} focus

- 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**,
    - important for *exclusive / diffractive physics*
    - greatly expands the ability to measure *recoiling nuclei* and *fragments from nuclear breakup*
  - New ideas beyond the Yellow Report and CD0 (EW, BSM)? Your input is essential!

- Complementary design features
  - 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, measurements in these categories will mostly become **systematics** limited, greatly benefitting from two detectors.

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

Constraints, complementarity, and synergies

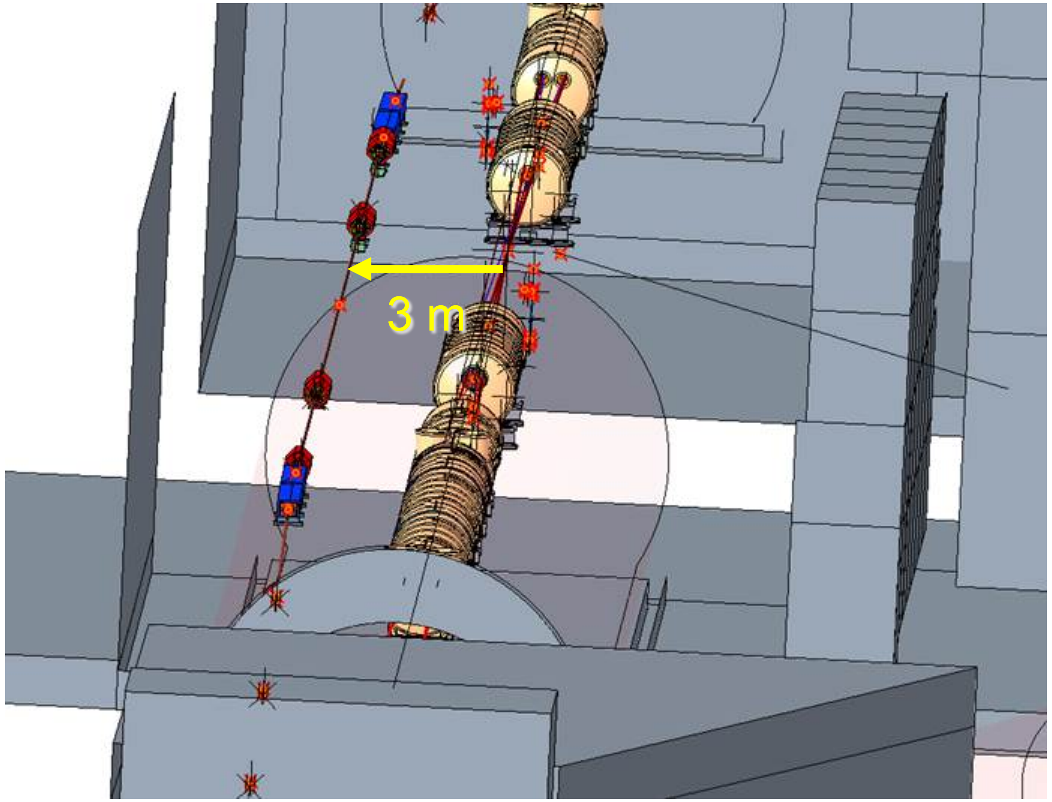
- The 2nd detector will be located in IR8, and has to fit some external **constraints**.

- For example, the RCS line will run 3 m to the side, and requires B to be essentially zero there.
  - This sets a constraint on the *outer size* of a detector - or requires the RCS line to go through it

- **Complementarity** with ePIC can go beyond subsystems to subsystem comparisons.

- Several measurements critically depend on a combination of capabilities.

- There are many natural **synergies** with a 2nd focus.



RCS line (left) in IR8

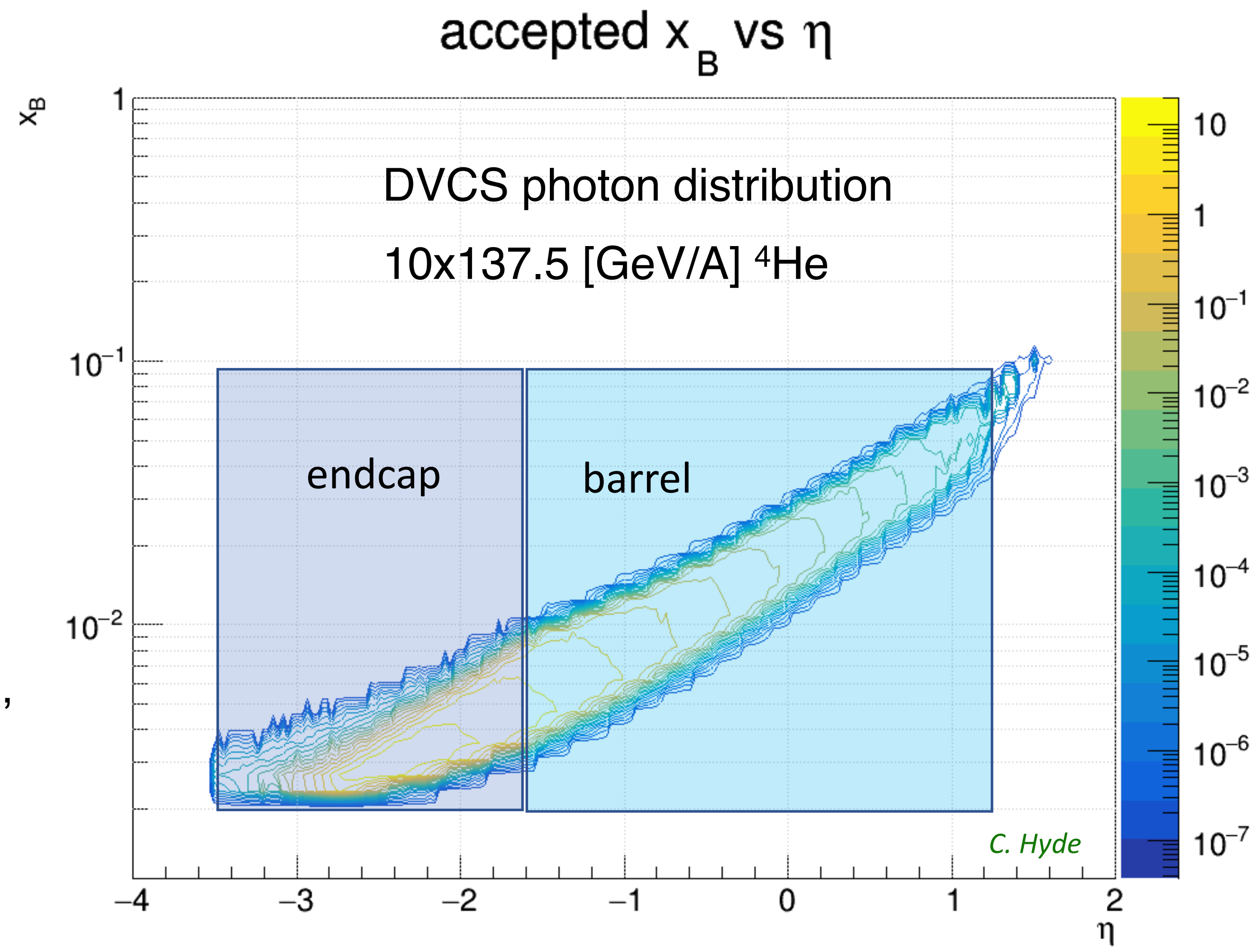
Example of synergies: DVCS on nuclei

- 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:
  - Excellent **low-t acceptance** (provided by the 2nd focus),
  - **High-resolution EMcal** coverage extending into the barrel region.

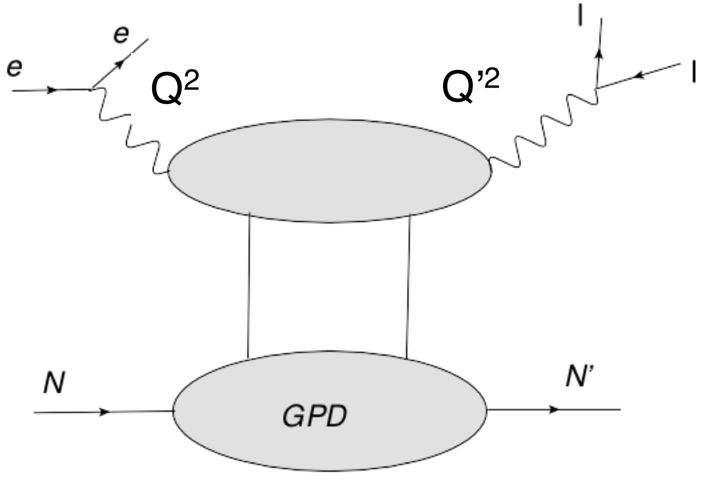


Example of synergies: double-DVCS

- Double DVCS makes it possible to probe GPDs outside of the $x = \xi$ line, making it important for a broader understanding of the measurements of the transverse spatial structure of nucleons.

- Experimentally, DDVCS is challenging because of smaller rates than in DVCS or TCS, so the ideal kinematics are lower x, low t, and moderate Q^2.

- For the best measurement of DDVCS, the 2nd EIC detector should have:
  - Excellent **low-t acceptance** (provided by the 2nd focus),
  - Good coverage for **$0 < Q^2 < 1$ GeV^2**,
  - Excellent **muon ID**, which is necessary in order to distinguish the scattered beam electron from the DDVCS decay leptons.



(c)

Q' has to be in a mass region without meson resonances decaying into l^+l^-, *i.e.*, in-between the ϕ (or ρ') and the J/ψ

Note: TCS ($Q^2 = 0$) is also an important measurement for the proton and possibly light nuclei at the EIC, but the experimental constraints are a subset of DDVCS

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

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

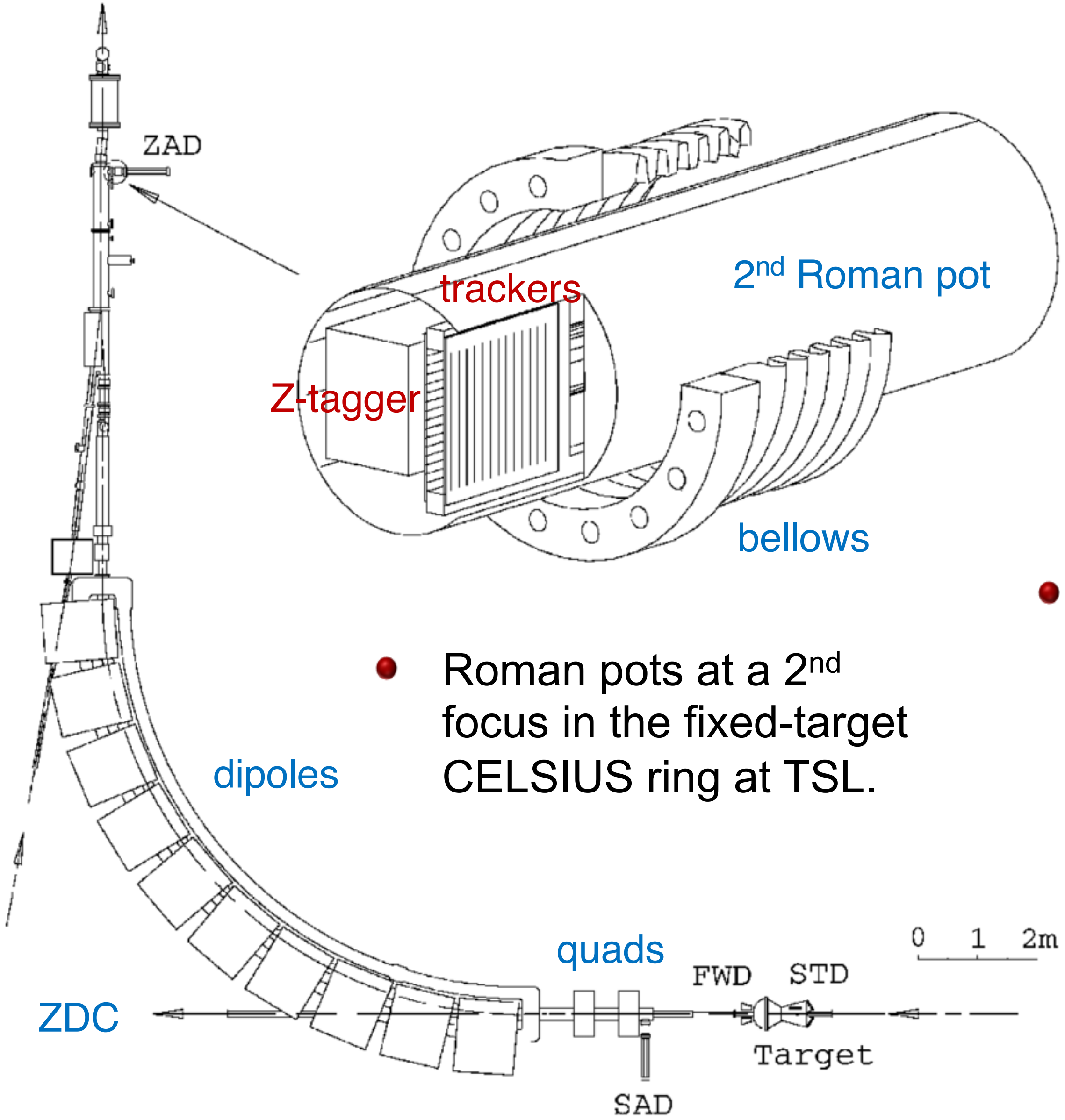
Three are mutually supportive strategies for detecting forward particles

- **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^*).

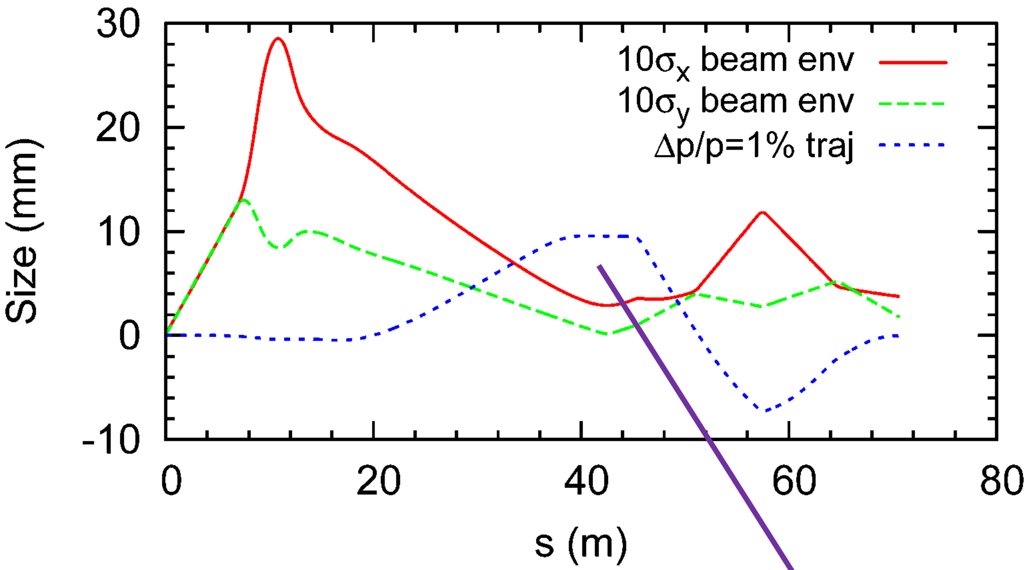
- **Dispersion** (D) translates a longitudinal momentum loss into a transverse displacement
  - dx = D dp/p , where dx is the transverse displacement at $p_T = 0$
  - With D = 0.4 m, dp/p = 0.01, and $p_T = 0$, the transverse displacement for would be **0.4 cm**

- **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)

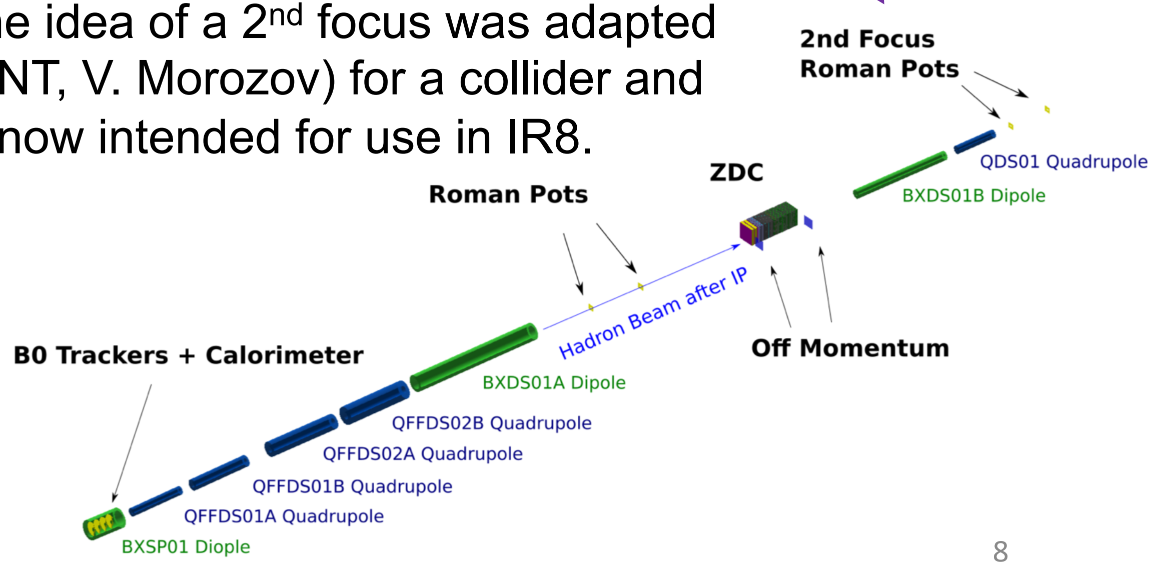
Optics for a 2nd EIC detector were inspired by the CELSIUS ring in Uppsala



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

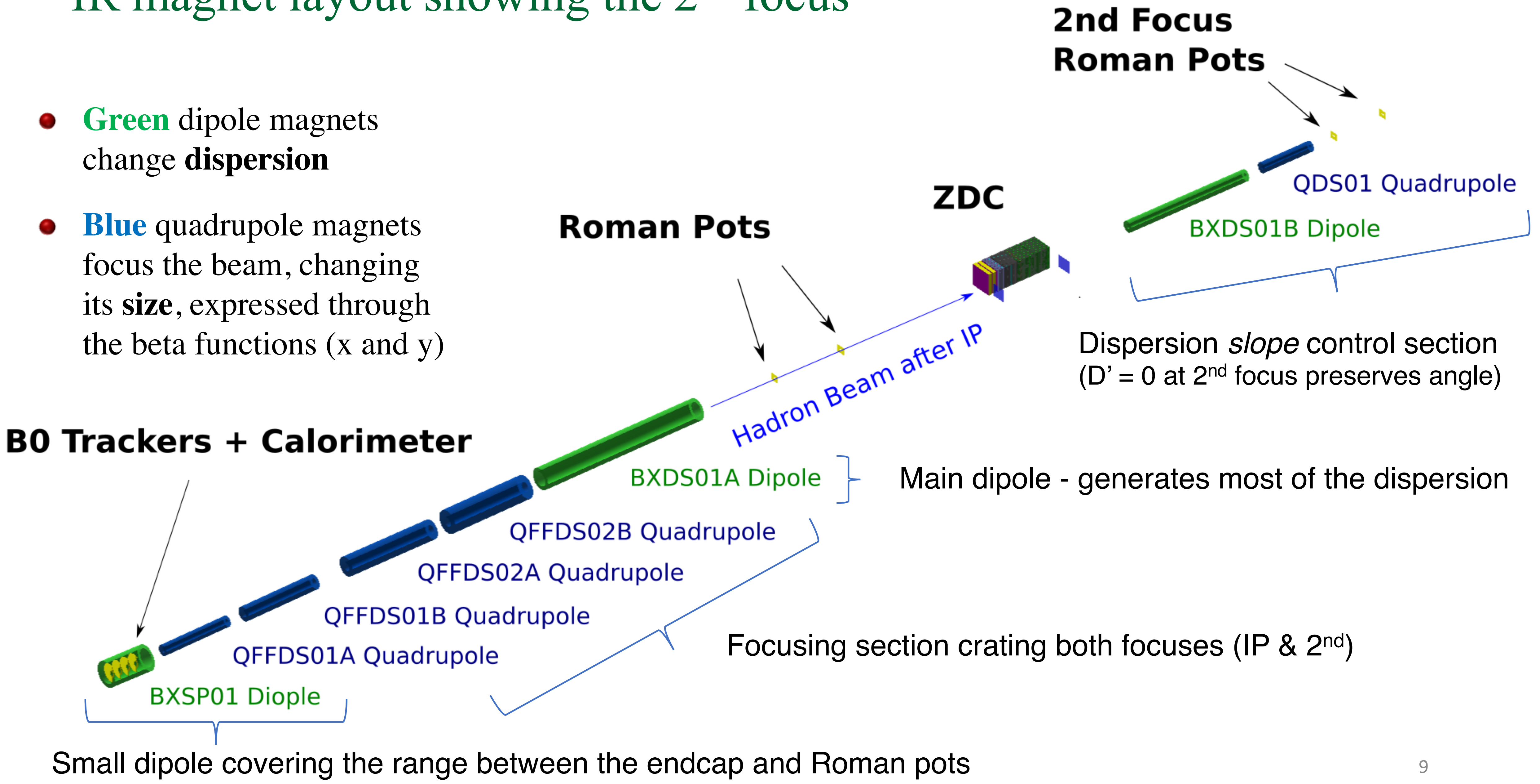


- The idea of a 2nd focus was adapted (PNT, V. Morozov) for a collider and is now intended for use in IR8.



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)

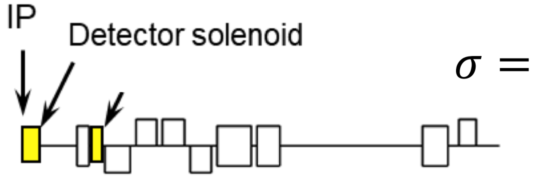


Beam optics and the actual trajectory of a $p_T = 0$ particle (blue)

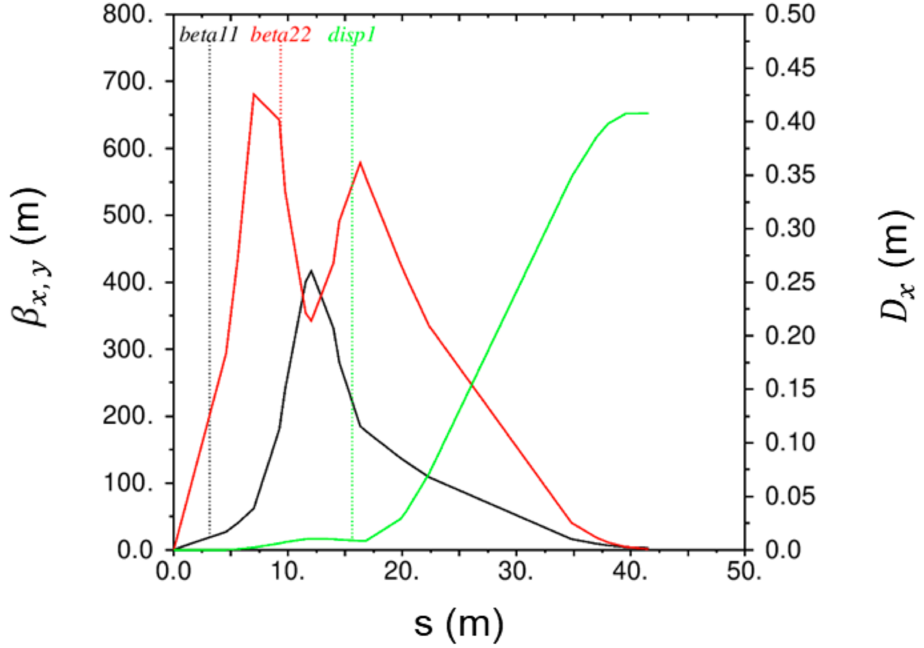
- For optimal detection, the (2nd) focus has to coincide in x and y at the point of maximum dispersion (green line below).
  - σ_x and σ_y should be comparable at the 2nd focus (and thus $\beta_x < \beta_y$ since $\varepsilon_x > \varepsilon_y$)

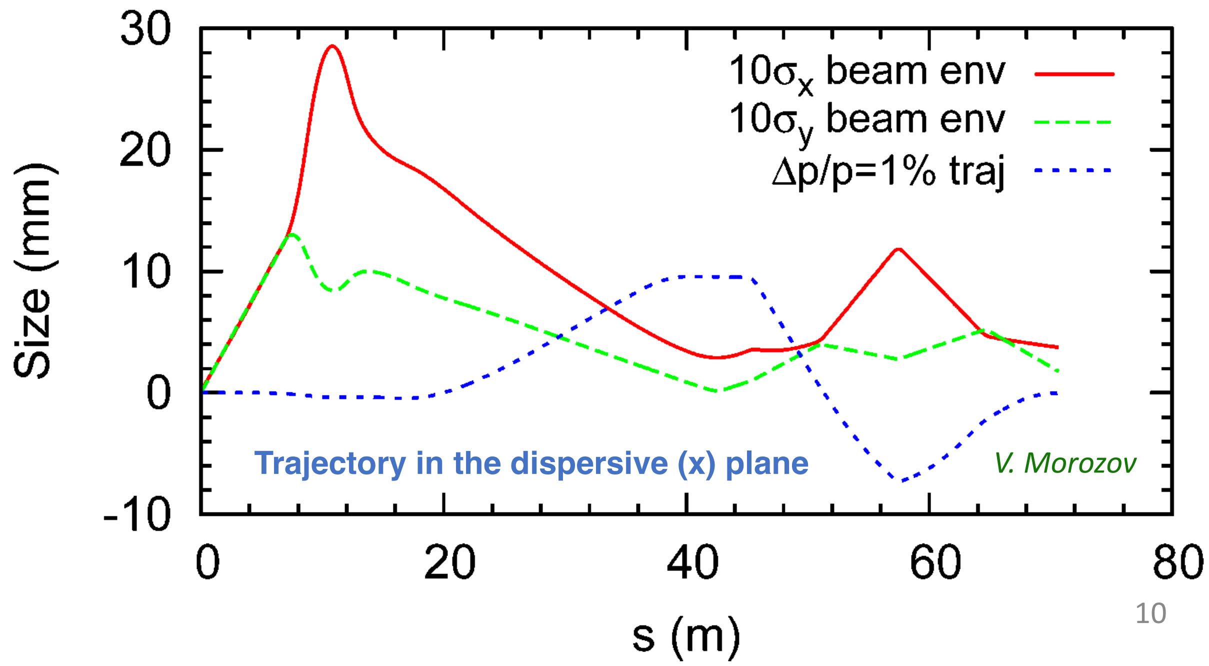
- A zero degree particle (blue) briefly emerges from the beam at the 2nd focus about 40 m downstream of the IP where it can be detected
  - Particles with a non-zero angle emerge earlier .

- The 2nd focus refers to the *beam*. Scattered particles have their *maximum* transverse displacement here.



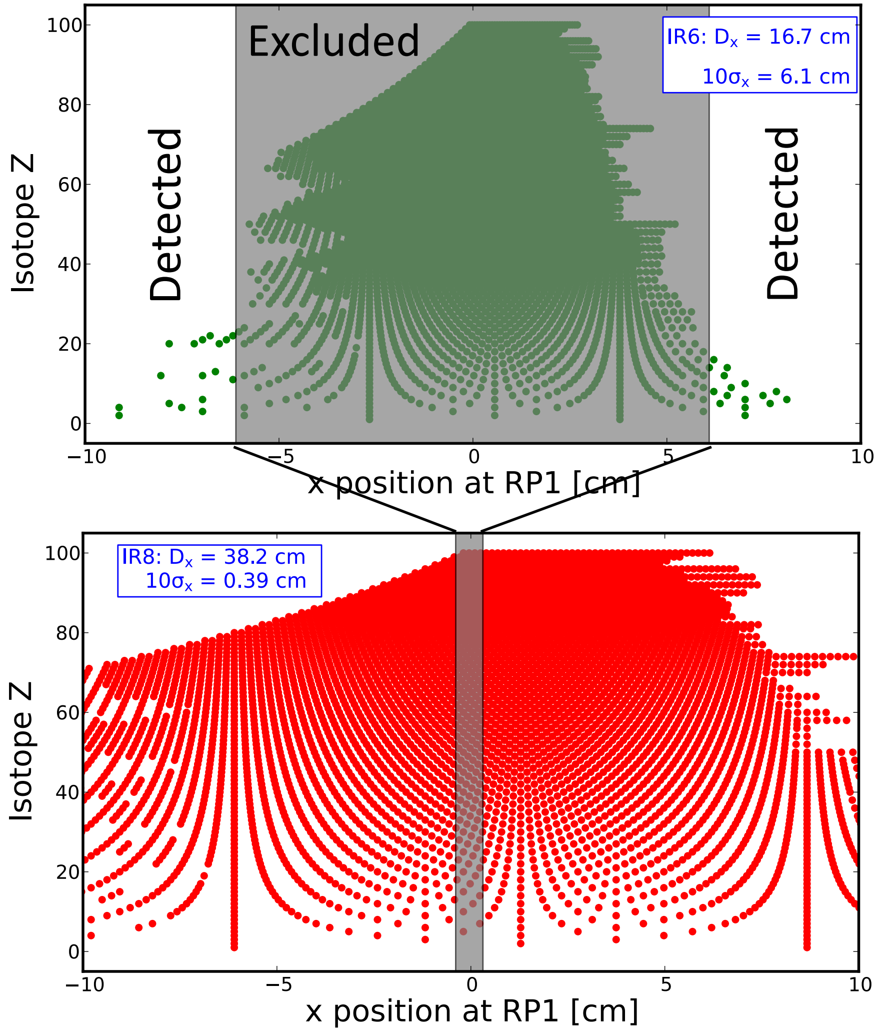
$$\sigma = \sqrt{\beta\epsilon + \left(D\,\frac{\Delta p}{p}\right)^2}$$





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}

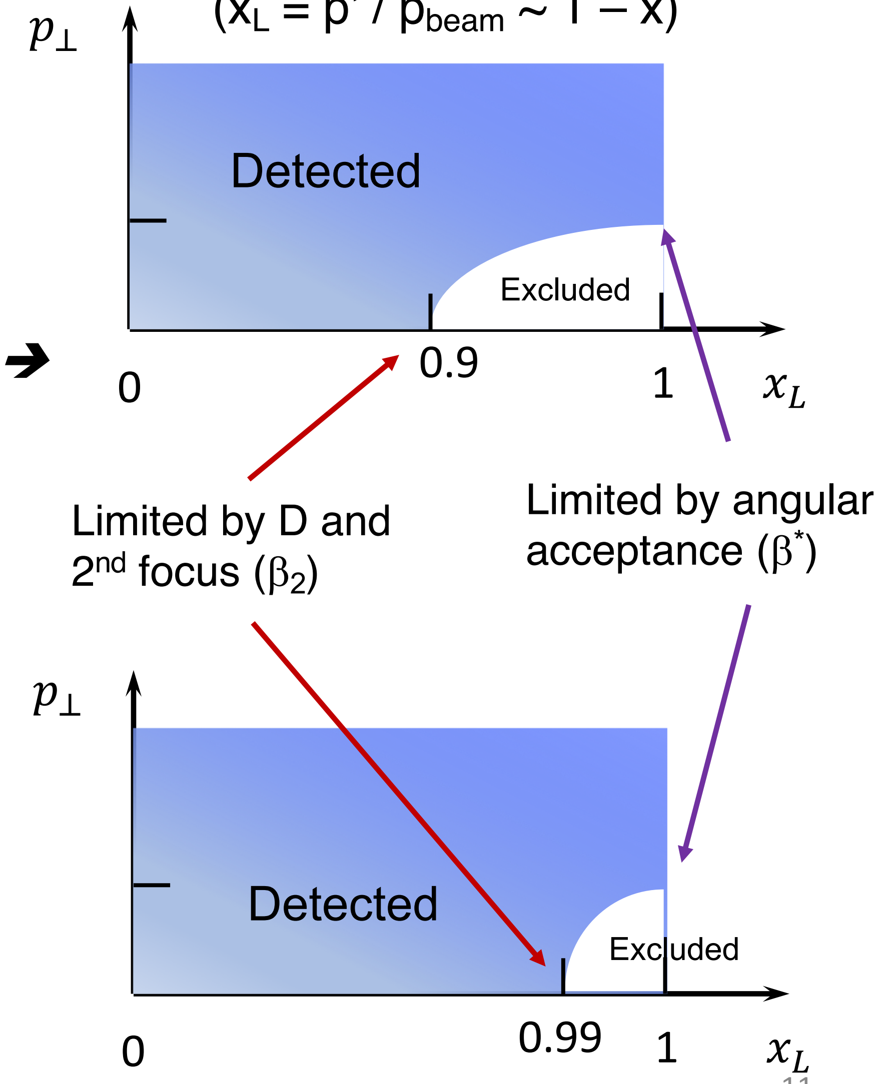
$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

Order-of-magnitude improvement in forward acceptance

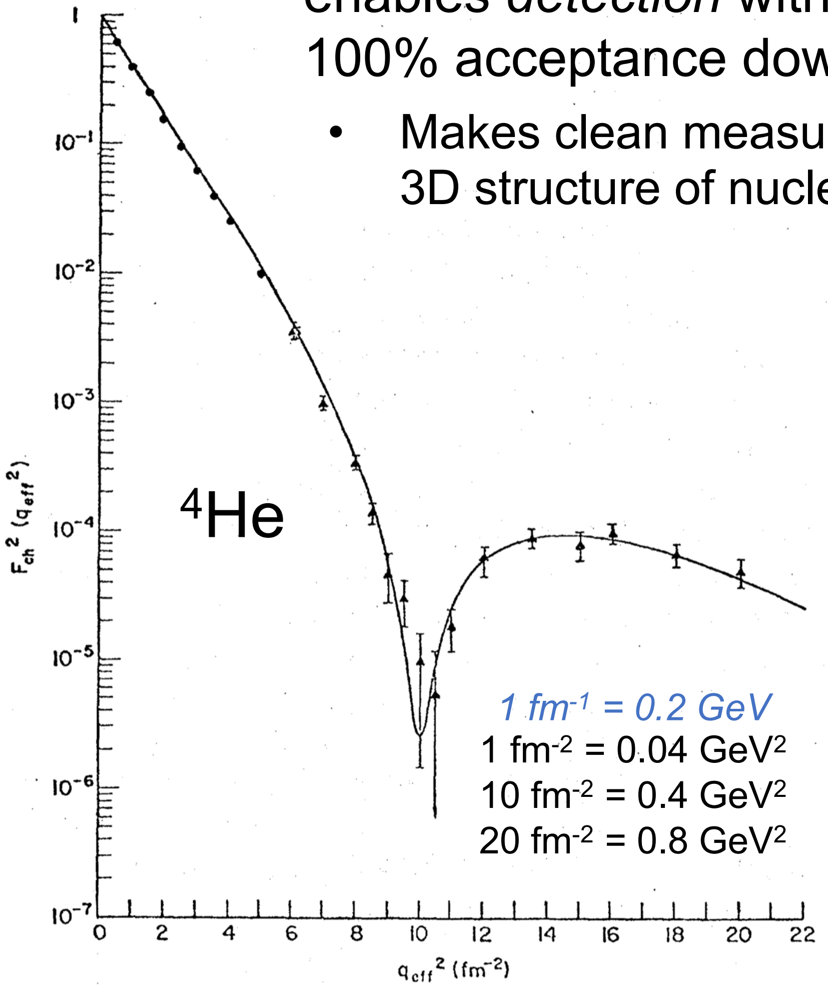
Exclusive protons

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

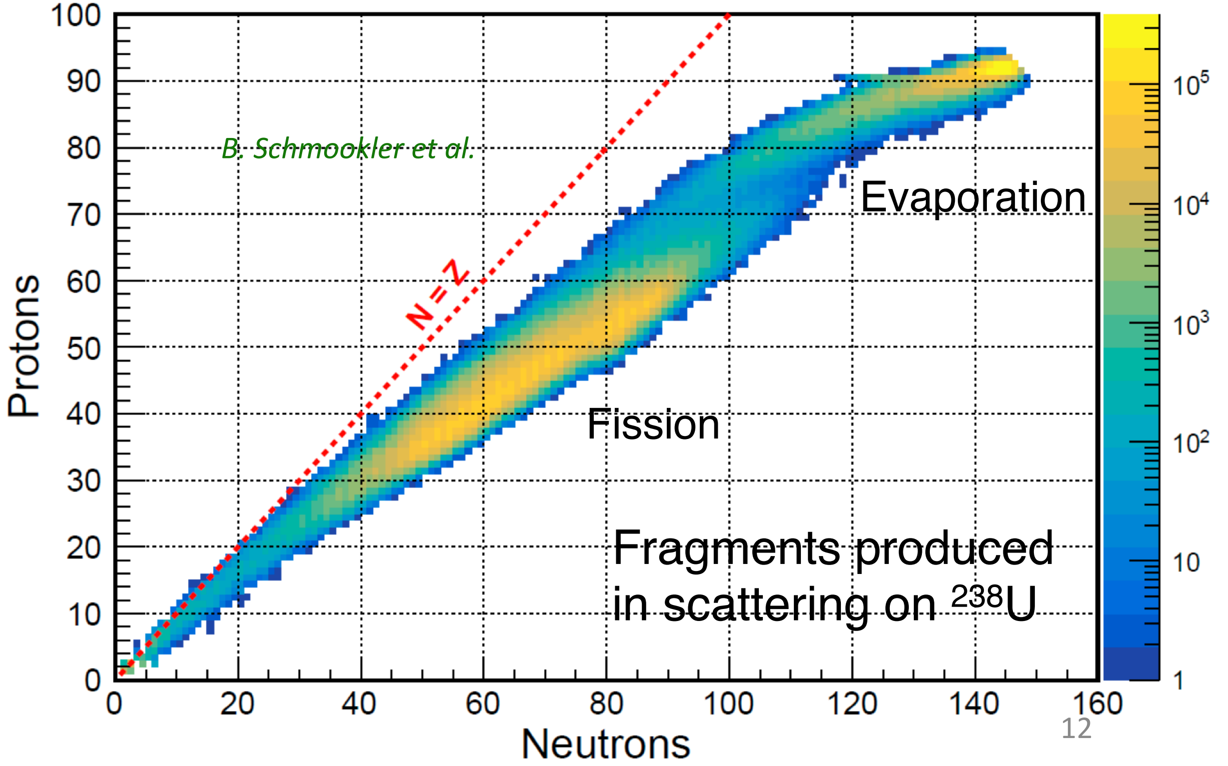


Example: exclusive coherent scattering on nuclei

- For light nuclei, the 2nd focus enables *detection* with essentially 100% acceptance down to $p_T = 0$.
  - Makes clean measurements of 3D structure of nuclei possible.



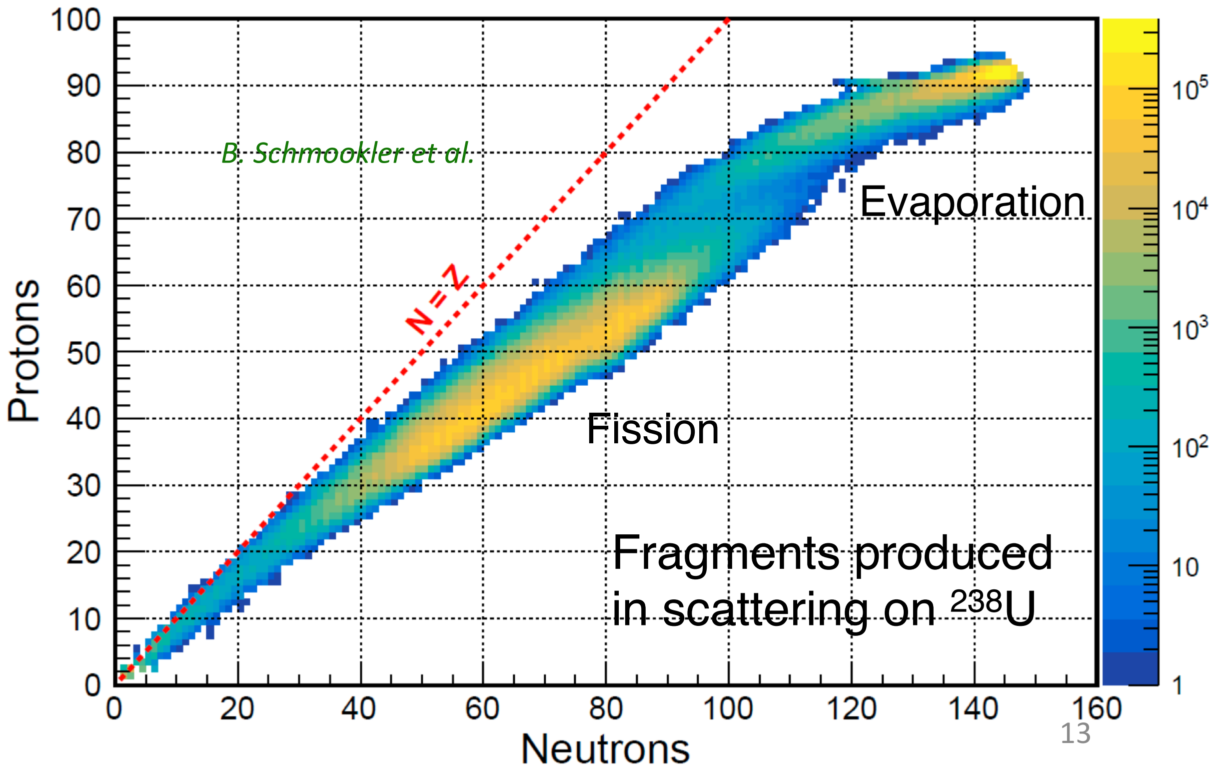
- For heavier nuclei, incoherent events can be suppressed with a high efficiency by detecting the fragments (including neutrons and photons) from the breakup.



Example: tagging of heavy spectators

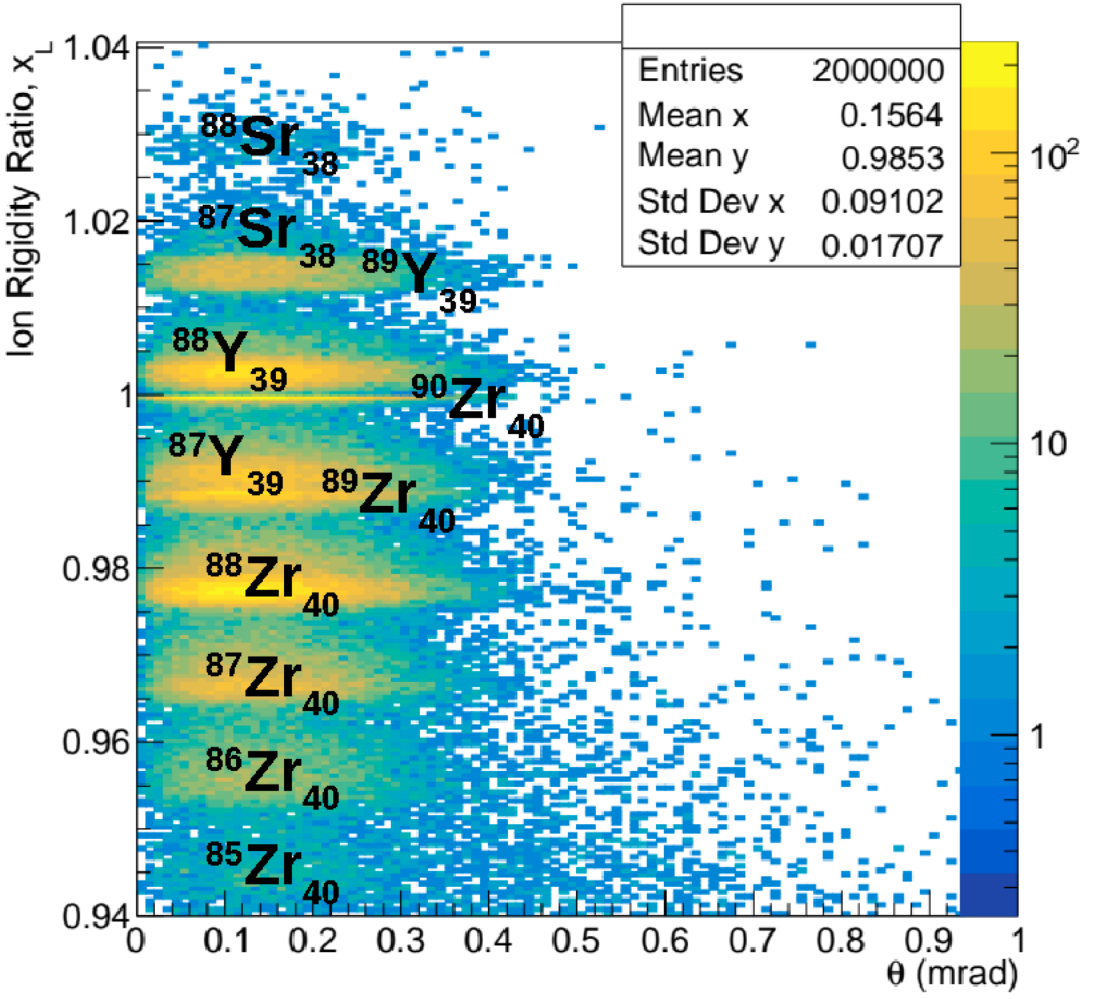
- Both IR6 and IR8 support tagging of spectator protons from light ions (d, He)
  - These spectators have magnetic rigidities that are very different from that of the beam ions
- A 2nd focus will allow tagging of heavy spectators
  - A-1 nuclei up to at least Zr-90
  - A-2, *etc*, for almost any nucleus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

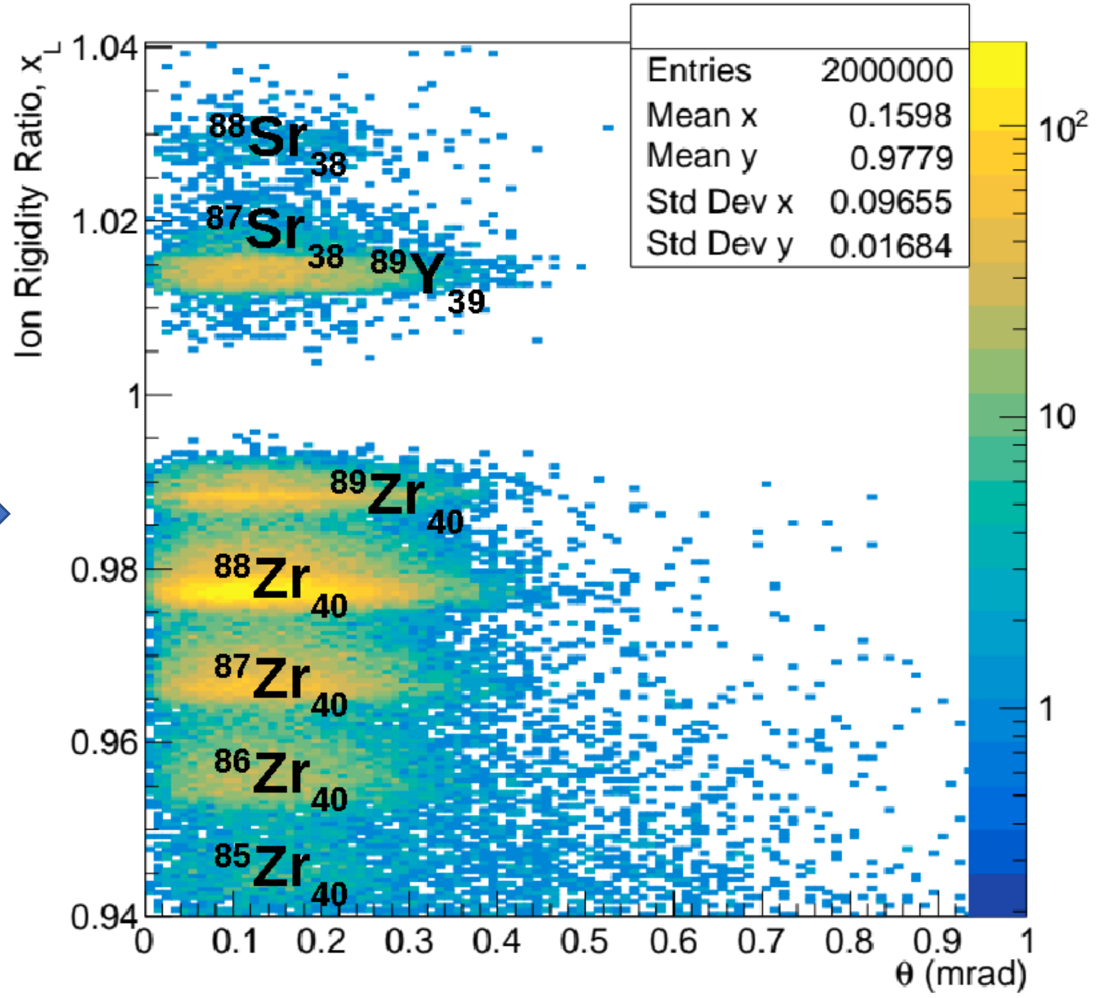


Example: A-1 tagging with 2nd focus using a ^{90}Zr beam

arxiv:2208.14575



generated (BeAGLE)

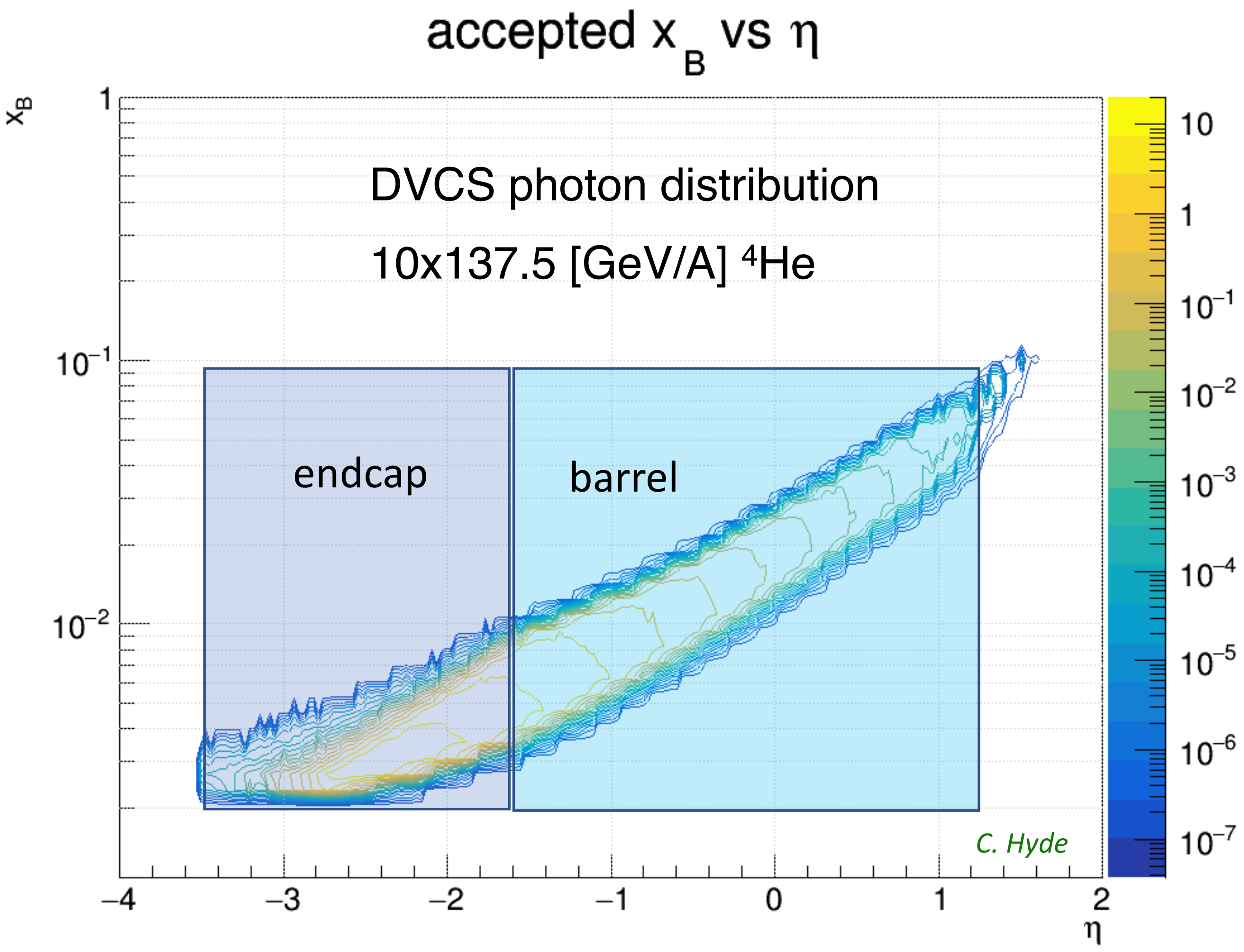


detected (Geant)

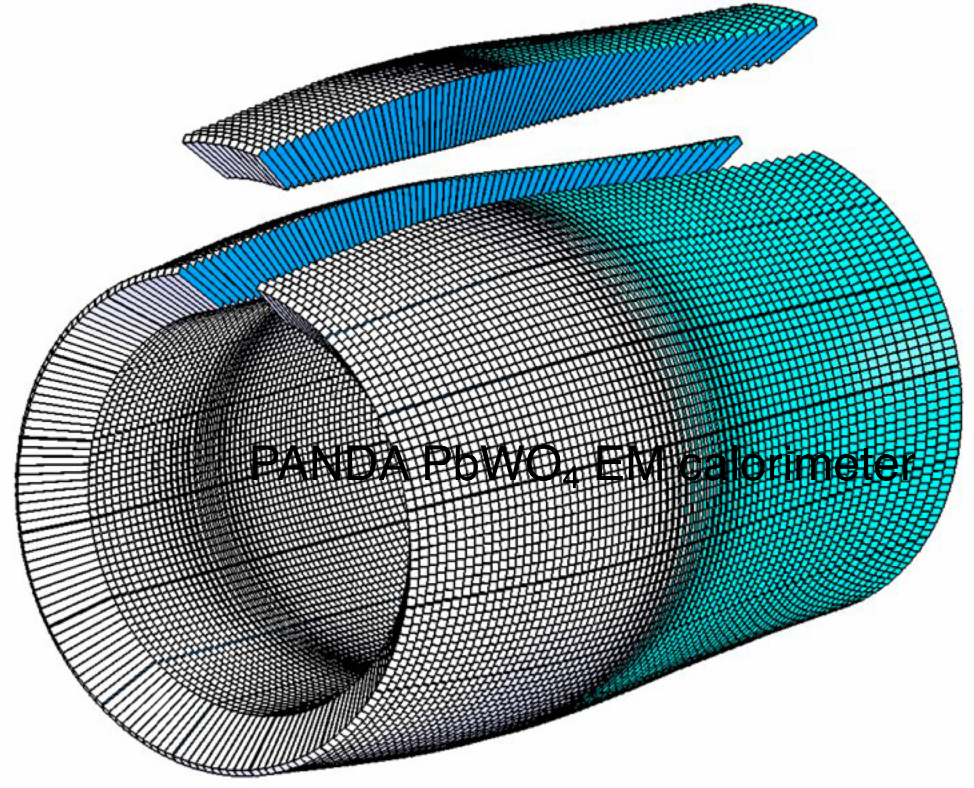
Aspirational goals for a 2nd EIC detector

- **SECOND FOCUS –** tagging for nearly all ion fragments and extending acceptance for low-p_T / low-x protons. Even enables detection of short-lived rare isotopes.
- **HIGHER MAGNETIC FIELD –** Solenoid field up to 3T (compared with 1.7 T in ePIC), allowing for high-resolution momentum reconstruction for charged particles.
- **PRECISION ELECTROMAGNETIC CALORIMETRY** – coverage extended into the barrel
- **ENHANCED MUON ID –** in the barrel and backward region.
- **IMPROVED INTERMEDIATE Q^2 COVERAGE –** low-Q^2 tagger covering $0 < Q^2 < 1$ GeV^2
- **IMPROVED PERORMANCE FROM ADDITIONAL R&D –** for example, extended momentum coverage for PID in the barrel from further DIRC development

High-resolution EM calorimeter



$PbWO_4$: 1-2%/sqrt(E), 1% constant term

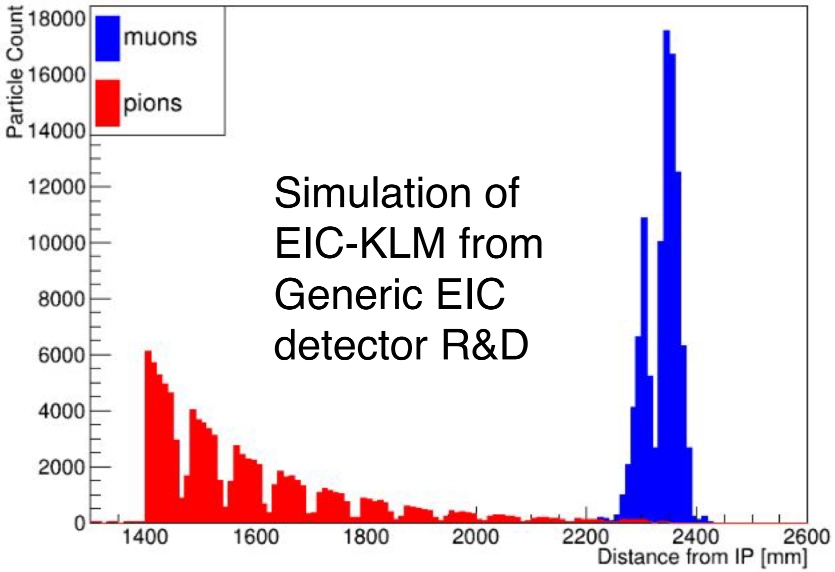


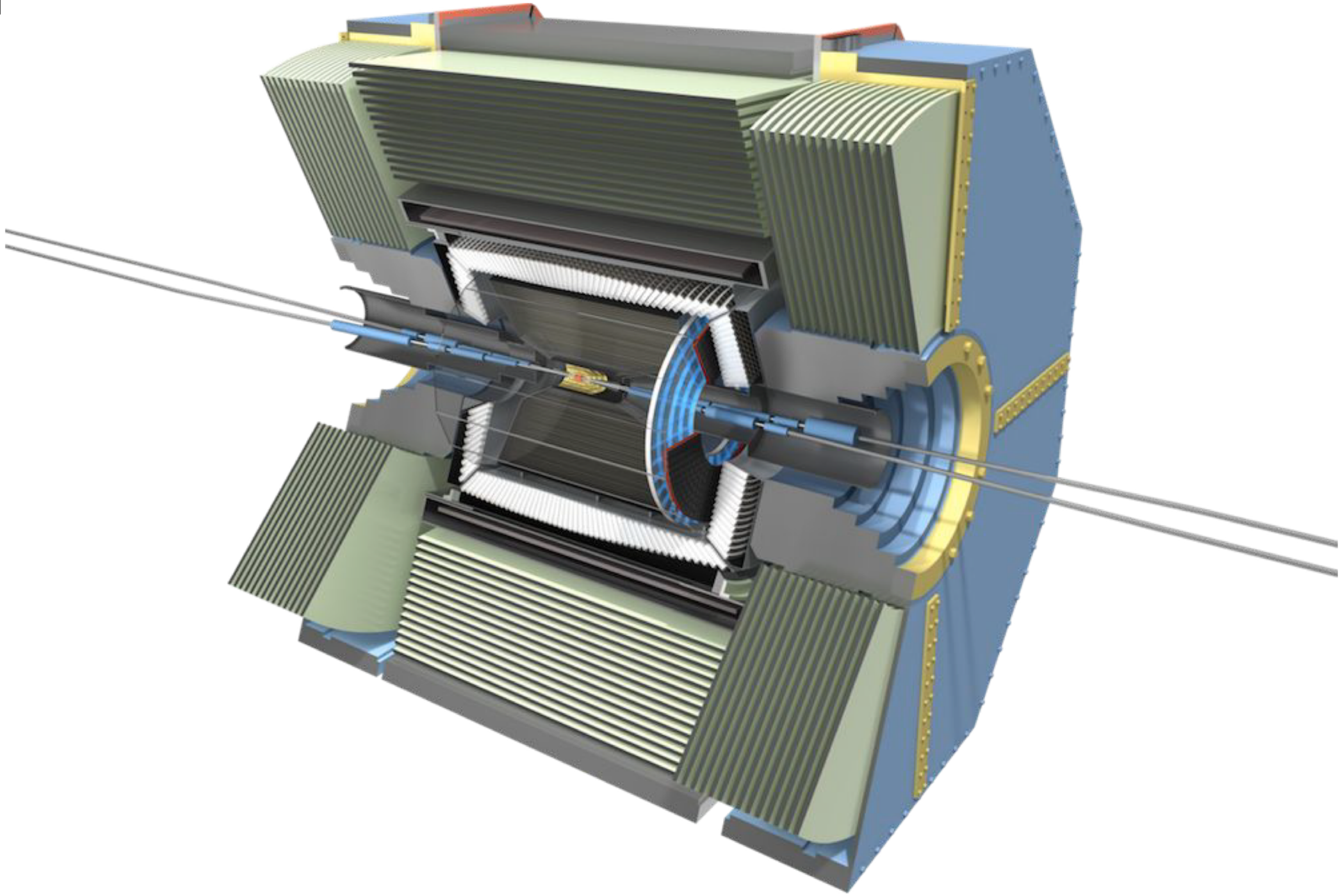
- A high-resolution EMcal like the one built for PANDA would be ideal for the 2nd detector.
  - DVCS on nuclei (extends coverage)
  - Spectroscopy (as in PANDA)
- Currently the main supplier of $PbWO_4$ is Crytur in the Czech Republic, but crystals for CMS were in the past also made at, *e.g.*, the Institute for Single Crystals in Kharkiv, Ukraine.

Muon ID

- 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.

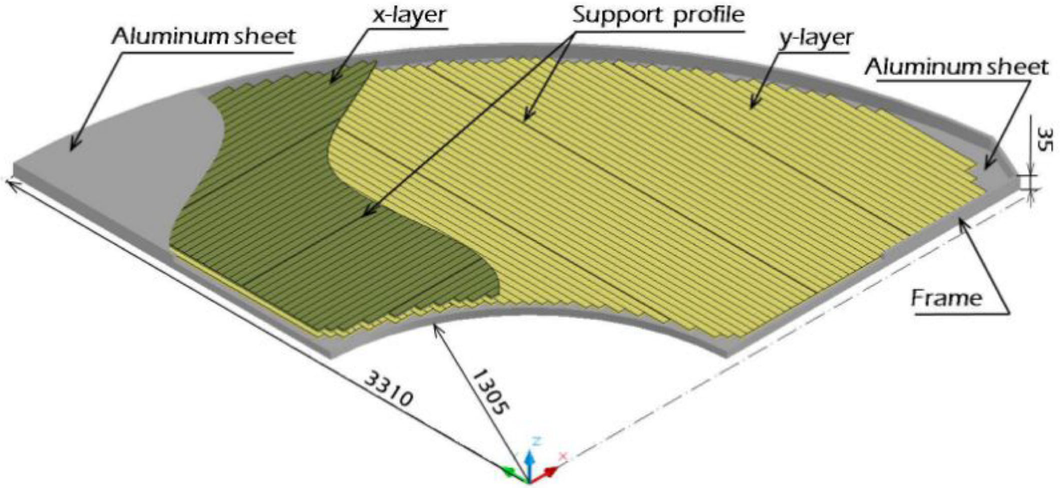
- Most muons traverse all layers, while most pions stop early: high purity, low mis-ID.
  - Each layer is read out individually
  - Works well also for low momenta

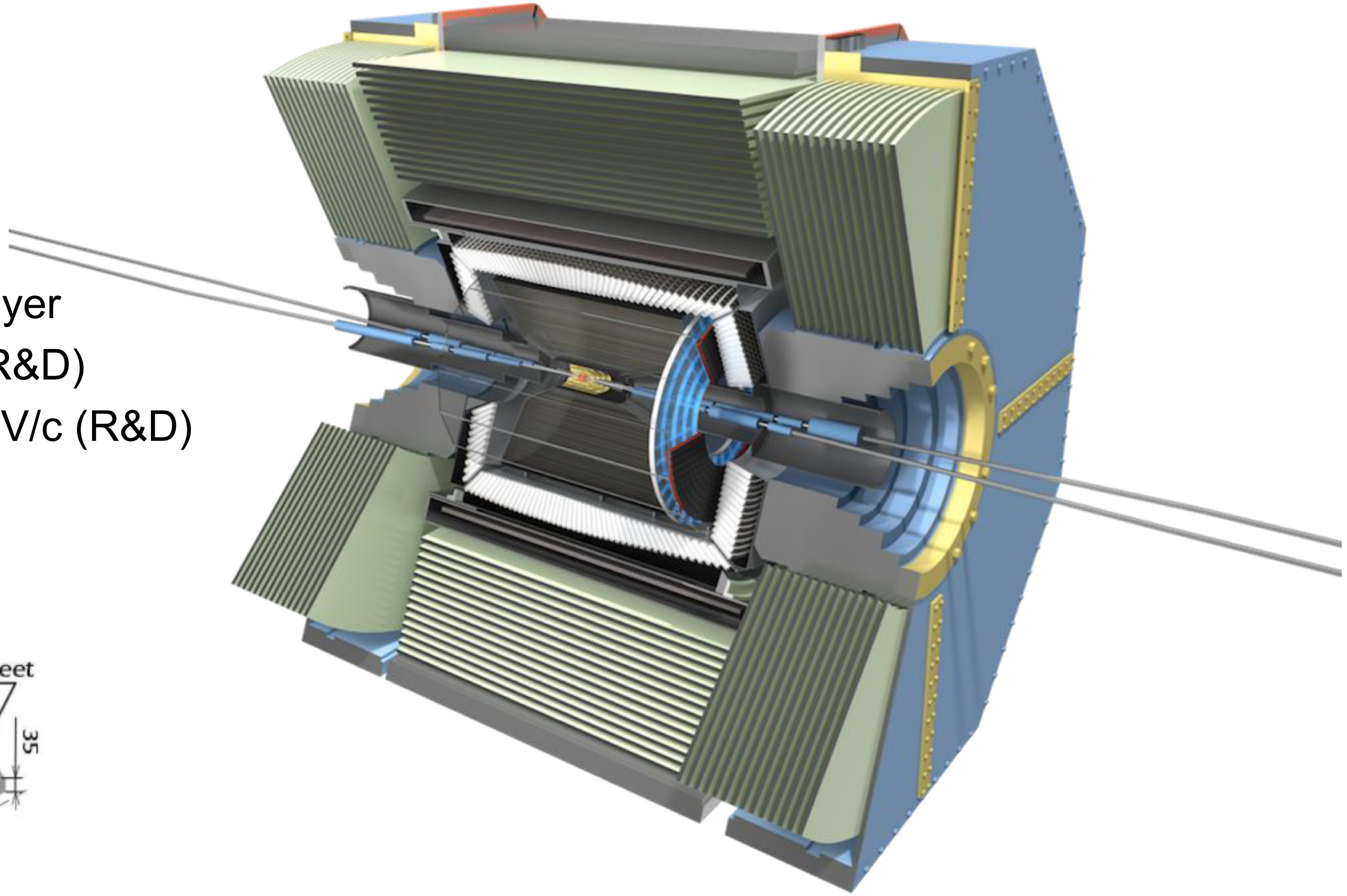




Neutral hadrons

- In the EIC, charged jets are best measured by tracking and PID
  - 1/3 of jets contains neutral hadrons
- The KLM measures neutral hadrons
  - Position from crossing scintillator strips in each layer
  - Total energy can be read as a sum of all layers (R&D)
  - Time-of-flight provides good resolution for 1-2 GeV/c (R&D)
  - Complementary to ePIC (sPHENIX) barrel Hcal





Generic EIC detector R&D – 2023 submissions

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

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

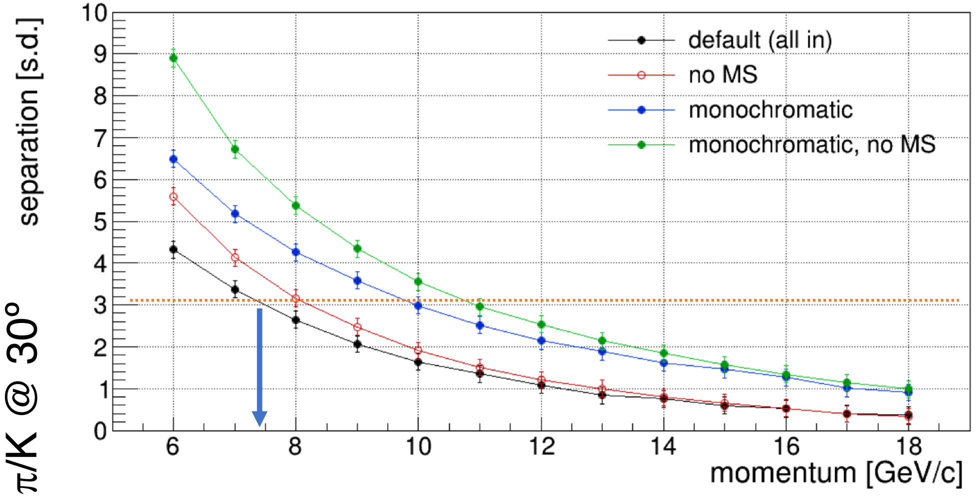
https://www.jlab.org/research/eic_rd_prgm

- **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

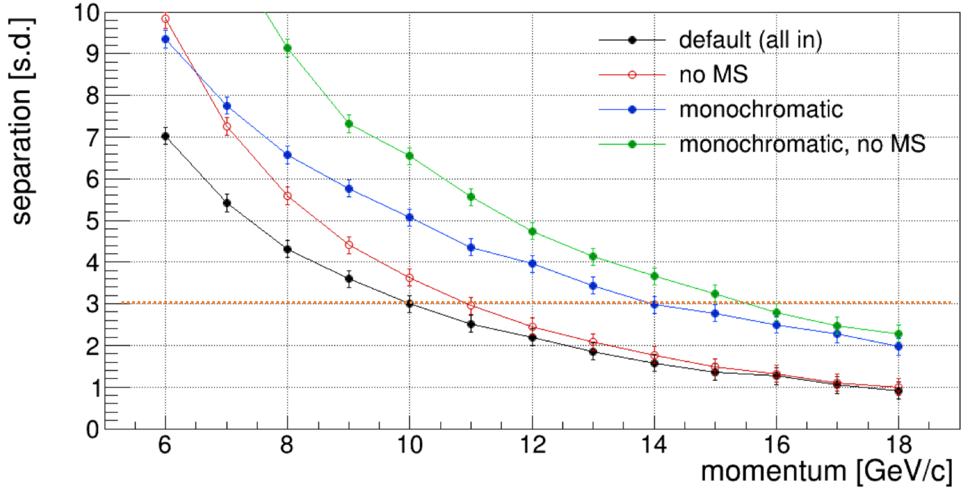
Example: DIRC R&D – theoretical limits for PID in the barrel

1.7 mm pixels, 100 ps timing, 0.5 mrad tracking

π/K @ 30°



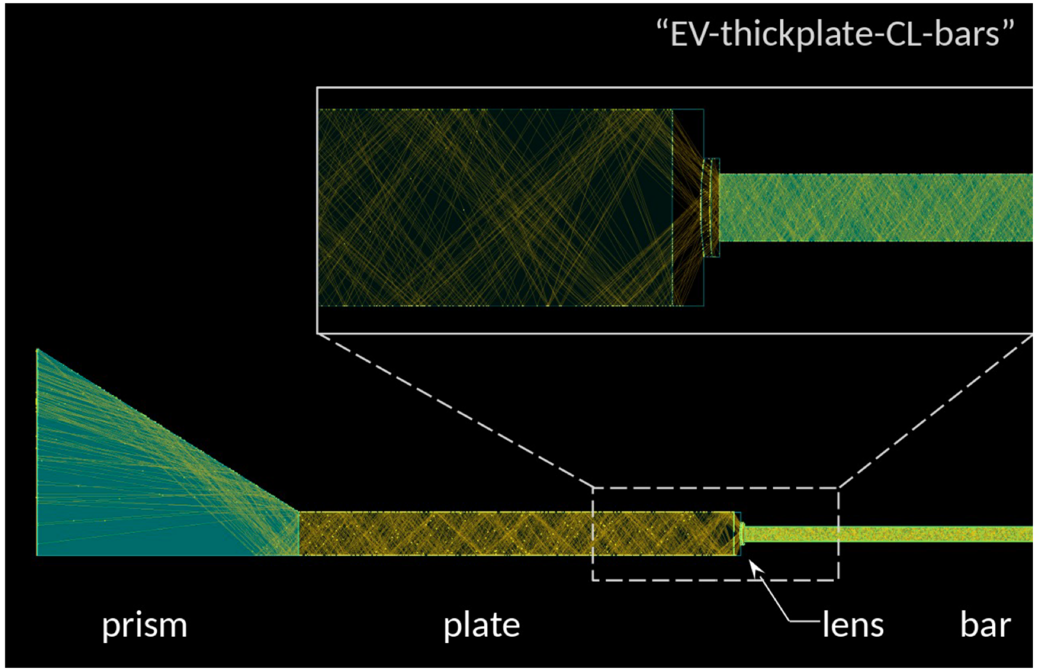
also ideal focusing

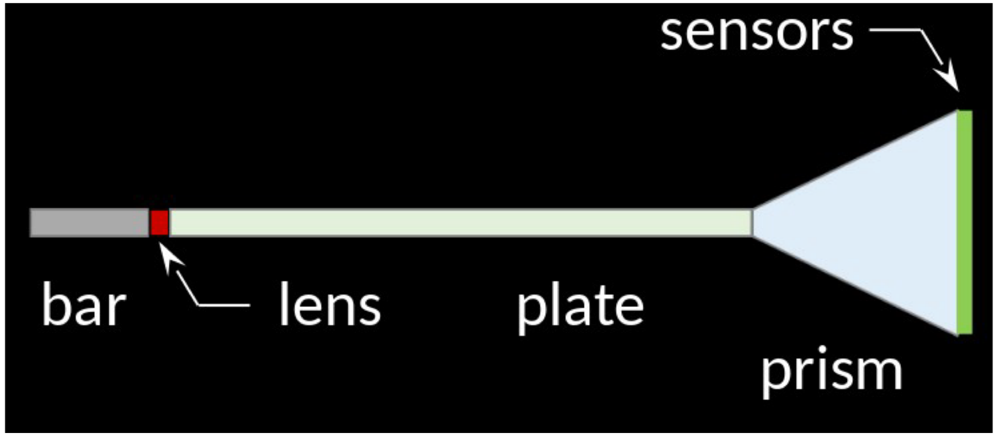


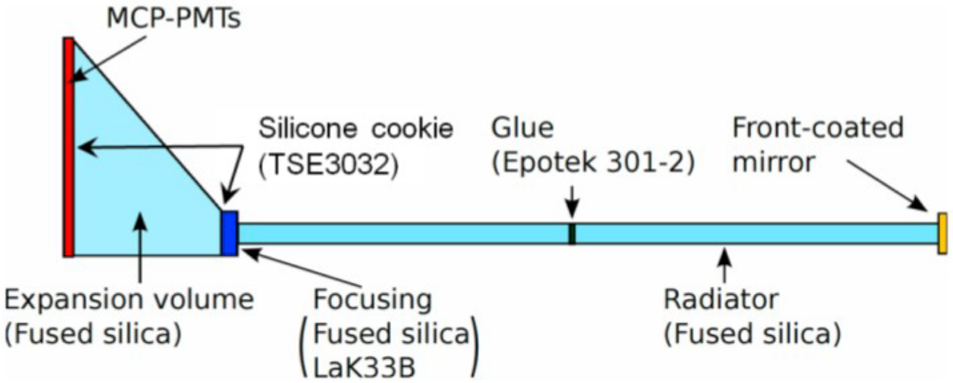
R. Dzhygadlo, EIC UG meeting, Warsaw, July 30, 2023

- Factors constraining performance
  - multiple scattering (MS) inside the bar (dominates at lower momentum)
  - chromatic dispersion of angle and time
  - aberrations of focusing system
  - timing precision
  - photo-sensor's pixel dimensions
  - angular resolution of tracker
- Possible improvements
  - 100 ps and 0.5 mrad are state-of-art
  - 1.7 mm pixels are straightforward to implement
  - Multiple scattering can be reduced, for instance by using thinner bars
  - Chromatic effects can be mitigated
- Realistically, for a 2nd detector it may be possible to increase the momentum reach **from 6 to 8-10 GeV/c** (|p| not p_T)

Example: DIRC R&D – alternative designs of the imaging system



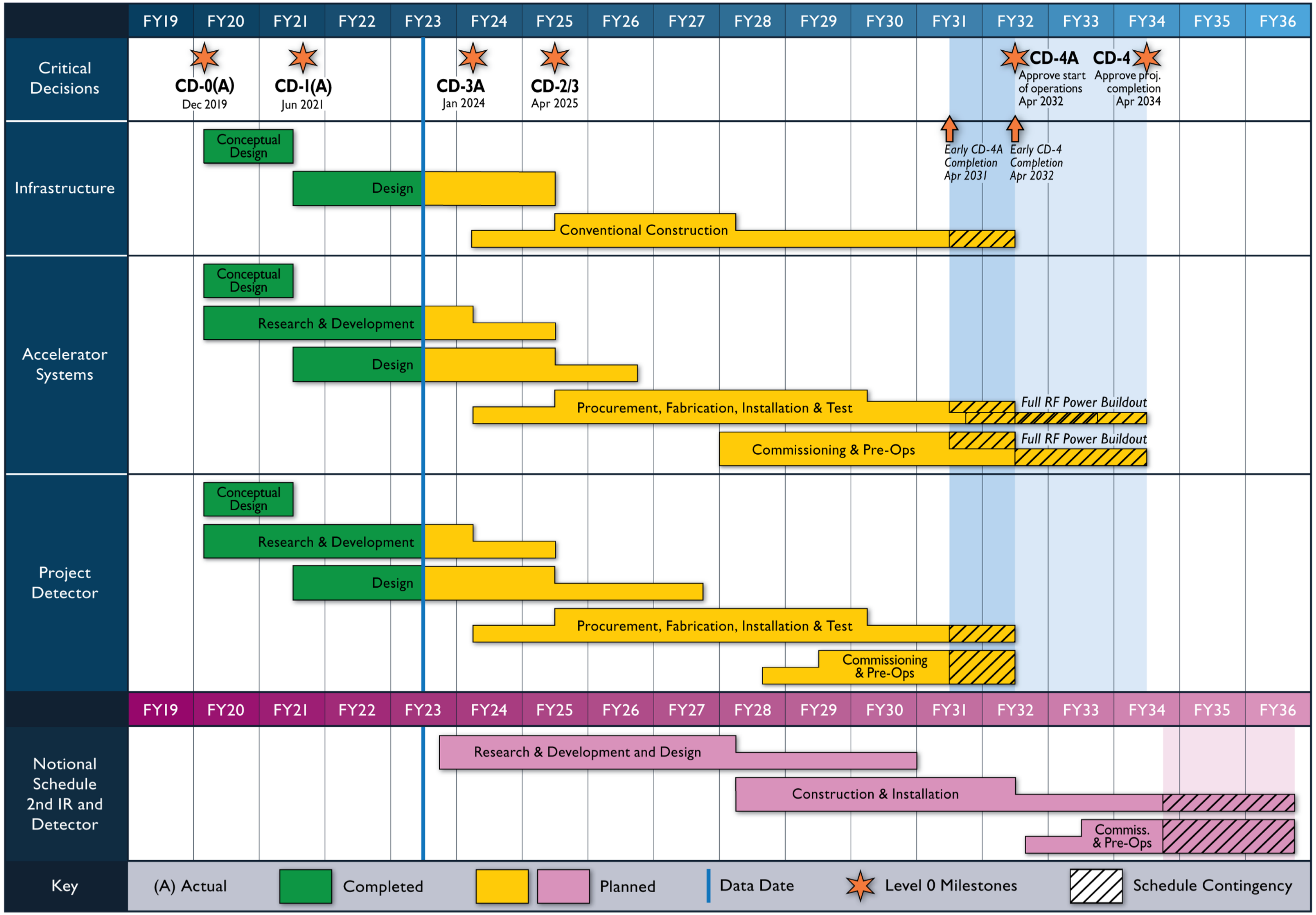




- Top left: Inserting a plate in-between the focusing lens and expansion volume prism can improve performance and reduce cost
  - Plates are less expensive than bars
- Top right: in addition, a more compact prism can reduce the mass and photosensor area
  - In this configuration it may be possible to use SiPMs

Reference schedule for a 2nd IR and Detector

Jim Yeck, EIC 2nd detector WS, May 2023



Second detector

Thank you!

Five initial benchmark channels for Detector 2 simulations

CHANNEL	PHYSICS	DETECTOR II OPPORTUNITY
Diffractive dijet	Wigner Distribution	detection of forward scattered proton/nucleus + detection of low p_T particles
DVCS on nuclei	Nuclear GPDs	High resolution photon + detection of forward scattered proton/nucleus
Baryon/Charge Stopping	Origin of Baryon # in QCD	PID and detection for low p_T pi/K/p
F_2 at low x and Q^2	Probes transition from partonic to color dipole regime	Maximize Q^2 tagger down to 0.1 GeV and integrate into IR.
Coherent VM Production	Nuclear shadowing and saturation	High resolution tracking for precision t reconstruction

- These were selected to illustrate particular opportunities
- Please add your favorite process!

Detector II/IP8 and WG charge

Renee Fatemi, EIC UG meeting, Stony Brook, July 2022

"With a clear mandate from DPAP and the EICUG to support and organize a Detector II/IP8 effort, the SC held discussions with Project, Detector I and CORE leadership. We agreed to form a dedicated working group that would address the following charge:"

1. Engage the broader community, ***including theorists, accelerator physicists and Detector I experimentalists***, to fully develop projections for the portfolio of measurements that are complementary to the Detector I physics program, including those that capitalize on the implementation of the secondary focus.

2. Work with the EICUG Steering Committee and Project to ***recruit new institutions*** and establish a diverse and vibrant 2nd Detector working group.

3. Utilize the extended design period for Detector 2 to identify groups that will focus on ***R&D for emerging technologies*** that could provide another aspect of complementarity to Detector 1.

4. Facilitate the development of a ***unified concept*** for a general-purpose detector at IR8. In particular, the 2nd detector should be complementary to the project detector at IR6 and may capitalize on the possibility of a secondary focus at IR8.