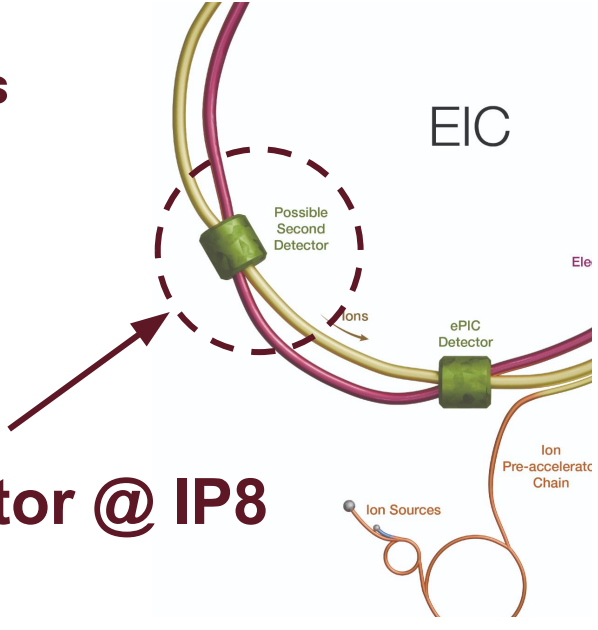
Perspectives on 2nd Detector

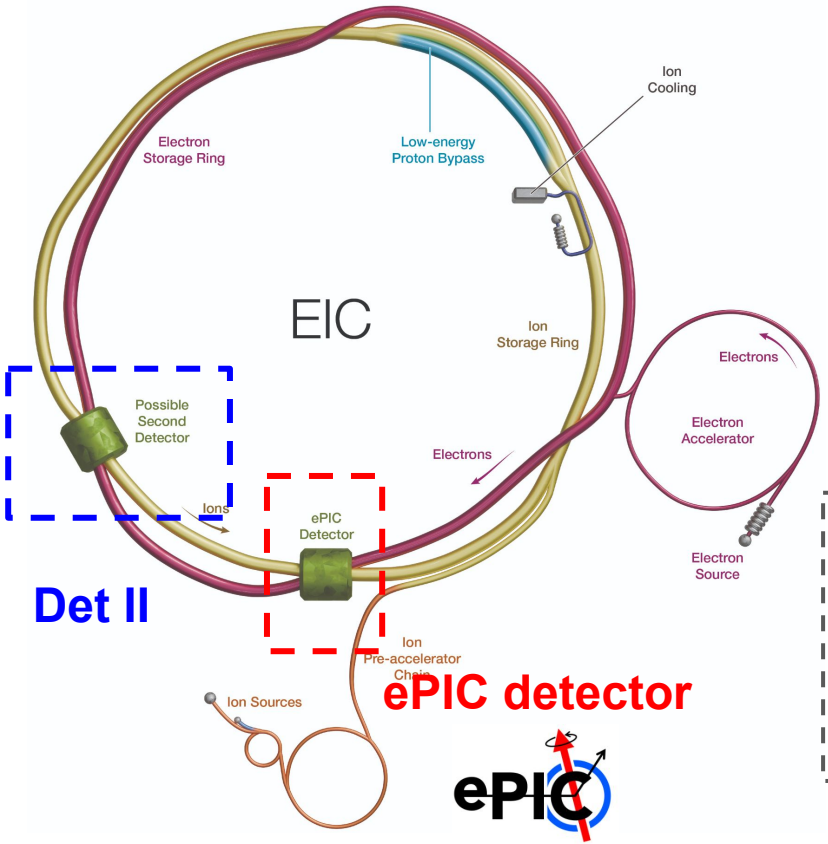
Wenliang 'Bill' Li
On behalf of Detector 2 Working Group Convenors
@ 2025 EICUG Annual Meeting

Convenor list: Anselm Vossen (Duke U), Charlotte van Hulse (U of Alcalà), Charles Hyde (ODU), Pawel Nadel-Turonski (U of SC), Björn Schenke (BNL), Simonetta Liuti (UVA), Vasiliy Morozov (ORNL), Wenliang "Bill" Li (MS State U)



2nd Detector @ IP8

2nd Detector at EIC? Do we need it?



- **Good cases and examples were made for both nuclear and particle physics experiments**
  - CMS & ATLAS
  - ZEUS & H1
  - CDF & D0
  - BELLE & BaBar
- **Opinion by P. Grannis and H. Montgomery**

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

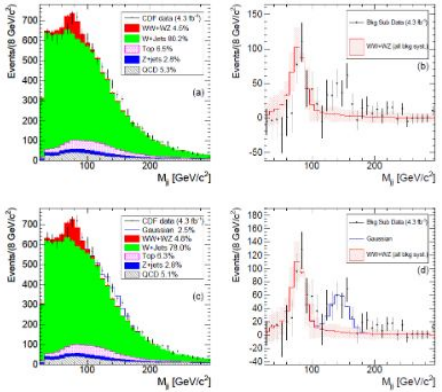
Paul D. Grannis* and Hugh E. Montgomery†

(Dated: March 27, 2023)

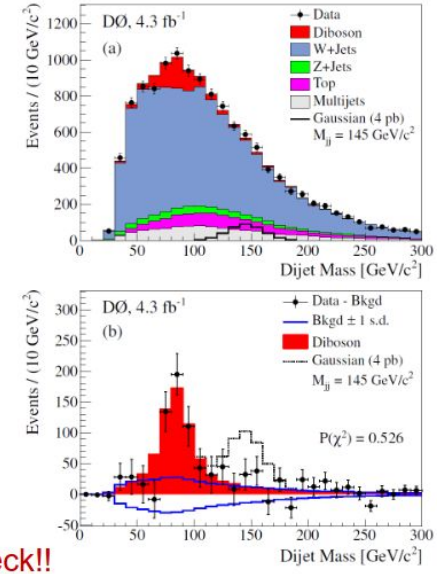
It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience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

Prime Example of Cross Checking Power

144 GeV Resonance? No!



- 2011 CDF study of dijet mass distributions in W + jets measurement.
- Statistically significant (p-value 7.6 10^{-4}, 3.2 σ) excess
- Fit to extra Gaussian with width scaled to dijet resolution→ mass 144+- 5 GeV, σ.BR = 4 pb.

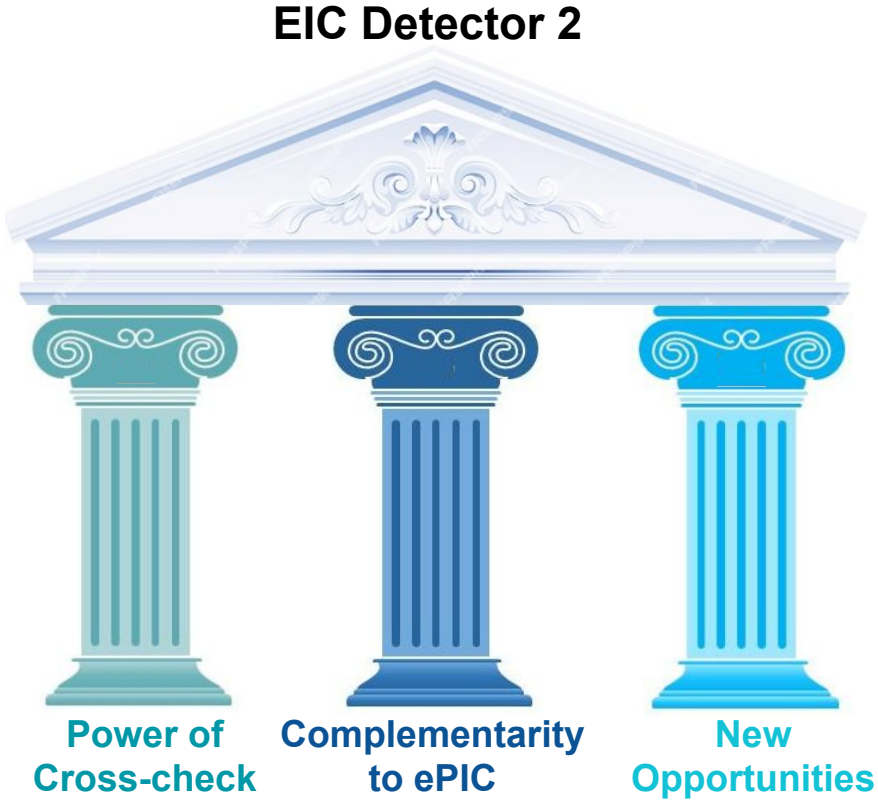


Crosscheck!!

- 2011 DØ study gives no excess, with likelihood of 145 GeV resonance of σ.BR= 4 pb of 8. 10^{-6} Rejection 4.3 σ, 95% CL UL 1.9 pb

- A slide stolen from Mont's talk at EICUG 2023 on vetoing false signal: https://indico.cern.ch/event/1238718/sessions/495759/
  - Result verification
  - Mass determination
  - Veto false signals
- My personal take: EIC carries the potential for discovery level physics: **would anyone believe our results without a cross-check?**

Pillars of Detector 2



Compiling reasons (beyond history)

- **Power of Cross-check**
  - Example from previous slide
- **Complementarity to ePIC**
  - Combining data from two general-purpose detectors can reduce the systematic uncertainties (cf. H1 and ZEUS)
- **New Physics Opportunities**
  - Capitalize on new design ideas and detector technologies

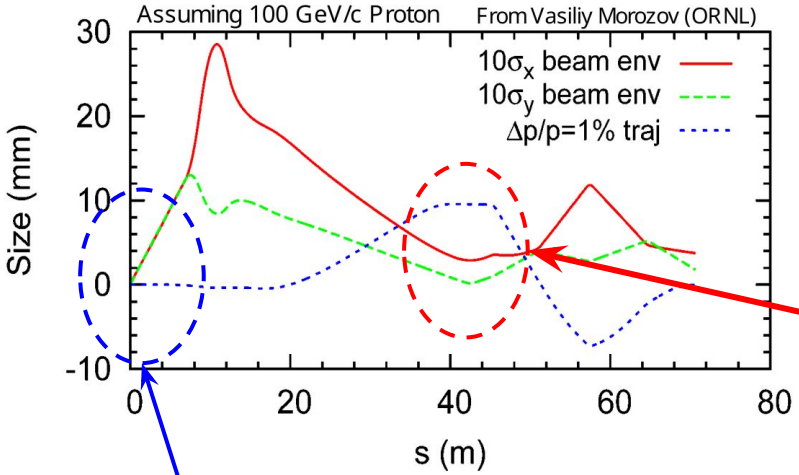
Detector II WG under EICUG Steering Committee and Charge

Path forward for Detector II/IP8 (from DPAP and the EICUG):

1. Broader community (Exp, theory, accelerator), develop measurements that are **complementary** to the ePIC, capitalize on the implementation of the second focus. Work with the EICUG Steering Committee and Project to recruit new institutions and establish a diverse and vibrant 2nd Detector working group.
2. 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.
3. 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 second focus at IR8.

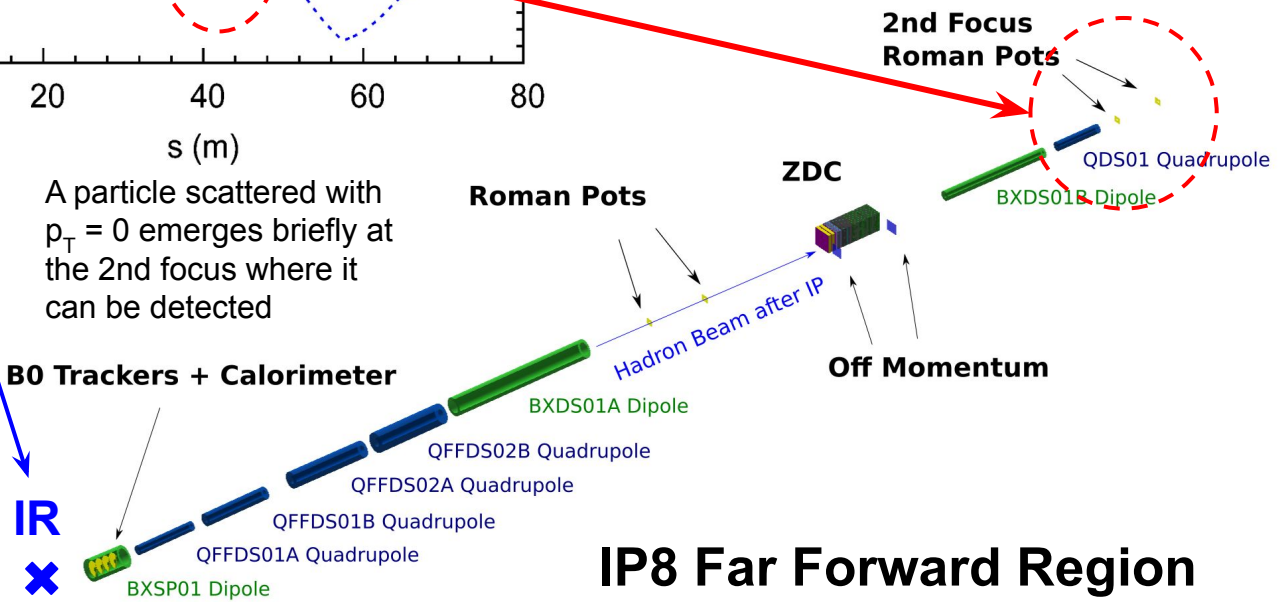
Full test of the charge here:
https://indico.bnl.gov/event/15342/contributions/64646/attachments/42444/71105/EICUG_AnnualMeeting2022_2ndDetector.pdf

Implementation of the Second Focus at Detector II



- **Beam squeezed twice**
  - First at the IP (flat beams for max luminosity)
  - Then at ~45 m downstream of the IP (weaker 2nd focus for optimal detection in the RPs)
  - 10σ beam envelope at 2nd focus in x is 4 mm (10σ beam envelope size at ePIC RP ~8 cm)

A particle scattered with $p_T = 0$ emerges briefly at the 2nd focus where it can be detected



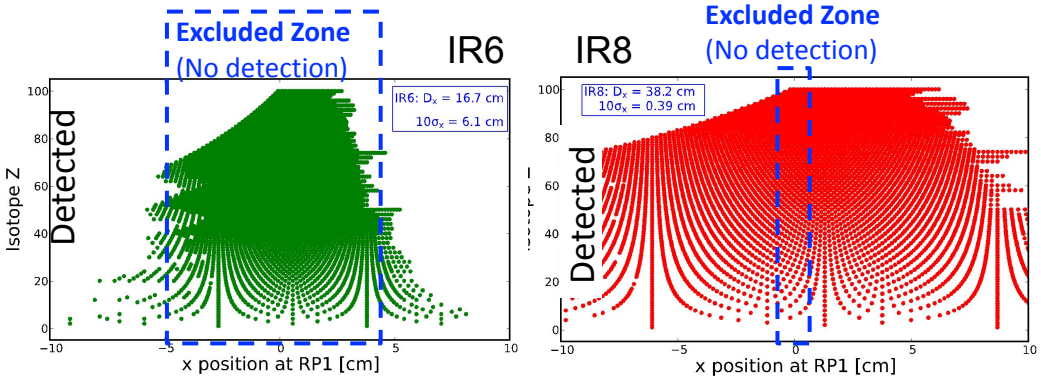
IP8 Far Forward Region

Opportunities from the Second Focus at Detector II

Much improved near-beam detection at Detector II:

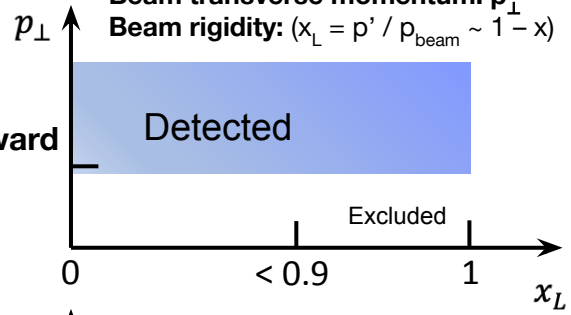
- Low-x / low-p_T proton acceptance
- Detection of light nuclei (coherent processes)
- Vetoing breakup of heavier nuclei (diffraction)
- Tagging a wide range of spectator nuclei
  - Including A-1 for studying the bound nucleon
- Properties of the nuclear final state
  - Hypernuclei, Rare isotopes, etc

Isotope fragments from ^{238}U, Brynna Moran, *et. al.*

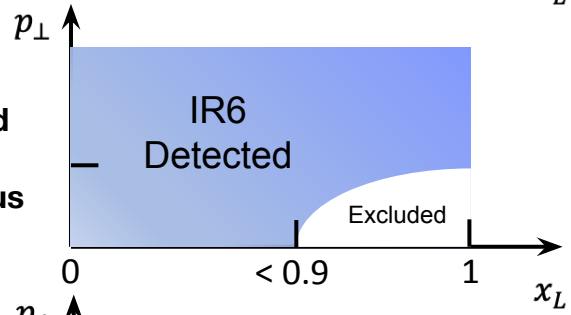


Beam transverse momentum: $p_\perp$
Beam rigidity: (x_L = p' / p_{beam} ~ 1 – x)

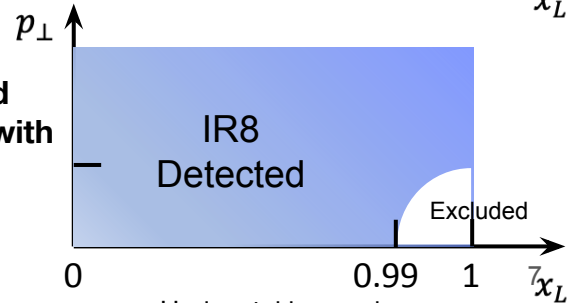
Without Far-forward Detection



With Far-forward Detection (RP), without 2nd focus

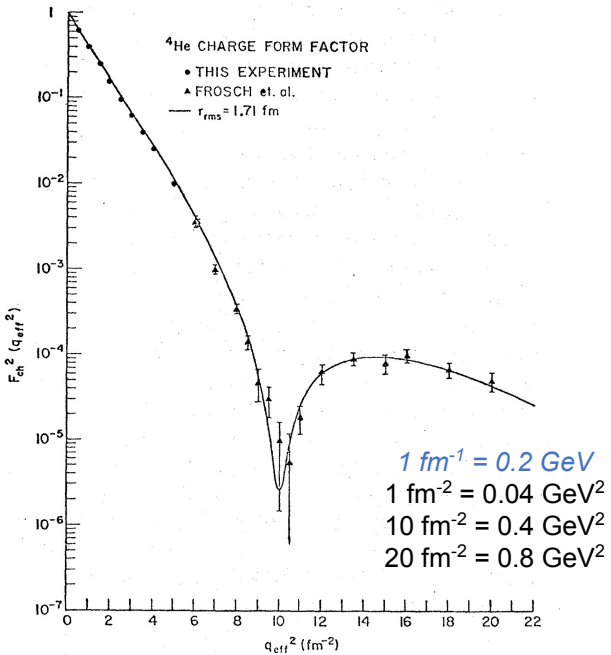


With Far-forward Detection (RP), with 2nd focus



Coherent Nuclear Processes

- **Light ions**
  - Detection of the recoil light ions
  - Acceptance over the full t-range for He and Li due to the 2nd focus
- **Medium and heavy ions**
  - Efficient vetoing of break up due to fragment detection at the 2nd focus

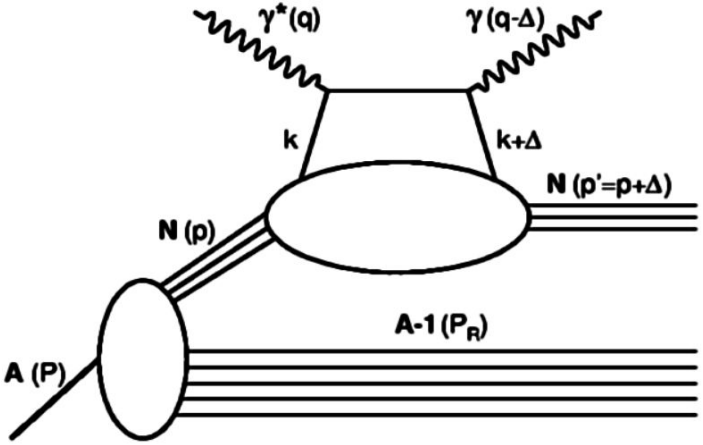


- **Example processes:**
  - DVCS, DVMP on He, Li, O, Ca, *etc*
  - Coherent diffraction (J/psi, phi) on ^{90}Zr, ^{120}Sn, ^{208}Pb, *etc*

Bound Nucleon

A-1 processes

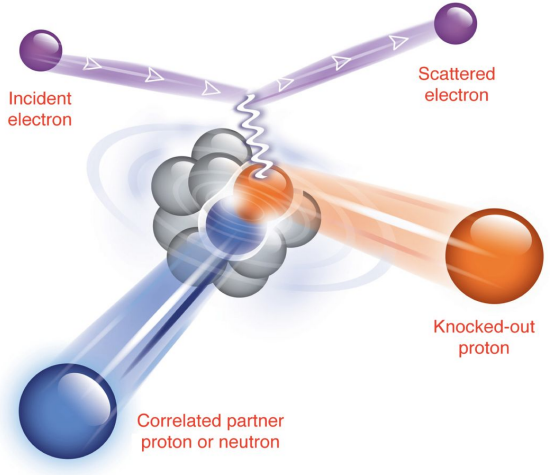
- A second focus enables measuring different processes on a bound proton in any nucleus while tagging the spectator A-1 system.
- Comparison with free protons and A-dependence of medium modifications.



R. Dupré and S. Scopetta. 3D Structure and Nuclear Targets. Eur. Phys. J., A52(6):159, 2016

A-2 processes

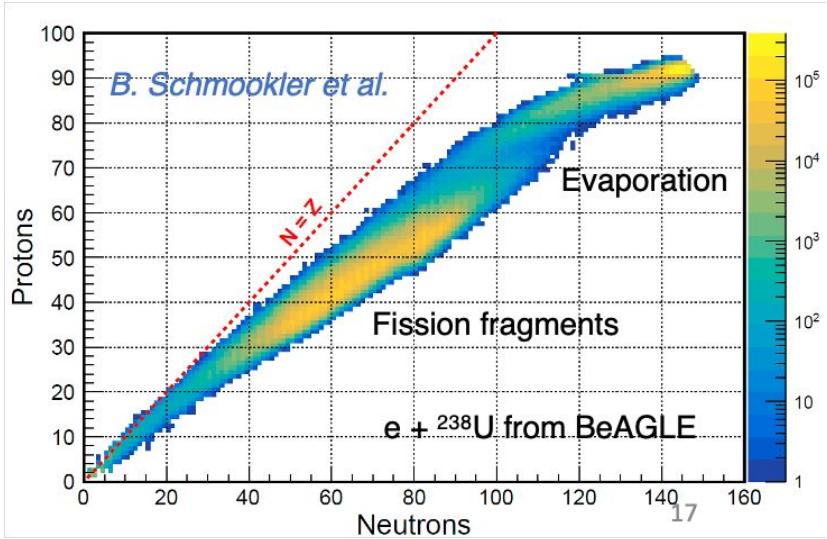
- Hitting a nucleon in a short-range correlation (SRC) with another nucleon also leads to the ejection of the latter.
- With a second focus we could tag (A-2)nn, (A-2)pp, (A-2)np SRCs with a combination of 2nd focus, ZDC and off-momentum detectors.



Fragmenting nuclei

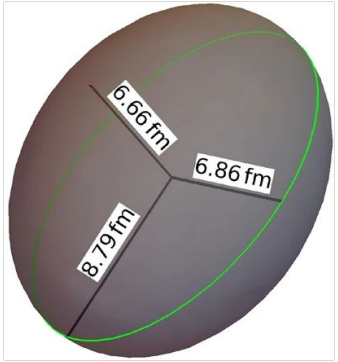
Rare isotopes

- In eA, all kinds of isotopes are produced through evaporation and fission.
- With a 2nd focus these can be detected and identified - and the gamma photons from their de-excitation can reveal their internal structure



Increasing the gluon density?

- Nuclear targets make it possible to map out the onset of gluon saturation at the EIC.
- However, if one could select a subset of events where a deformed nucleus (e.g., ^{238}U) was preferentially struck along the long axis, this would correspond to nuclear thickness of a A ~ 500 nucleus.
- With a 2nd focus, we can use the complete final state to select a subset of events where the average thickness is significantly larger.

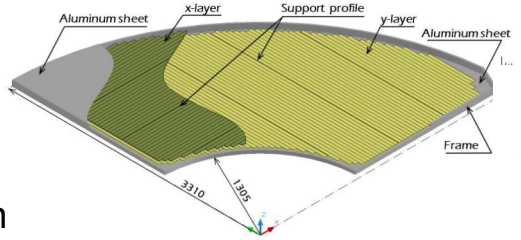


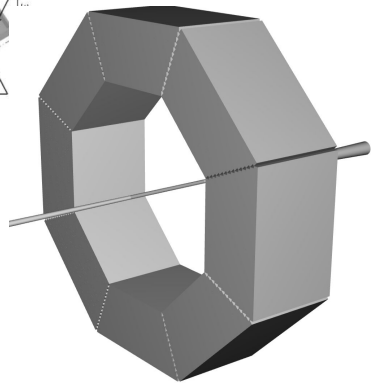
Nucl. Sci. Tech. 35, 218 (2024)

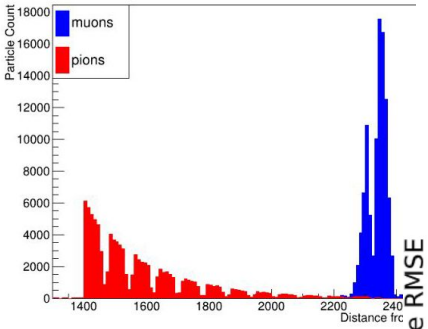
A KLM based detector

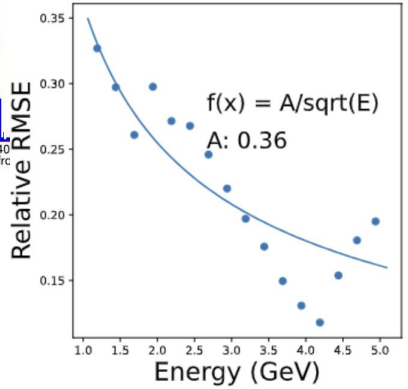
- **Ongoing Generic R&D (led by Anselm Vossen, Duke) building a the Belle II KLM (K_L&M) stype detector**
  - Hcal is part of the solenoid flux return, with x-y segmented layers.
  - Adds precision timing and energy measurements in each layer.
  - Provide some level of muon ID and optimized system would improve both the efficiency and purity, specially low energy muons.
  - A high level of segmentation along the muon path is more advantageous
  - Latest study suggest energy resolutions of the order of ~36%/√E are achievable for both K_L and neutrons.

- **Physics examples:**
  - Time-like Compton scattering and Double-DVCS
  - Quarkonium production
  - BSM









Anselm Vossen, Rowan Kelleher, work to be published

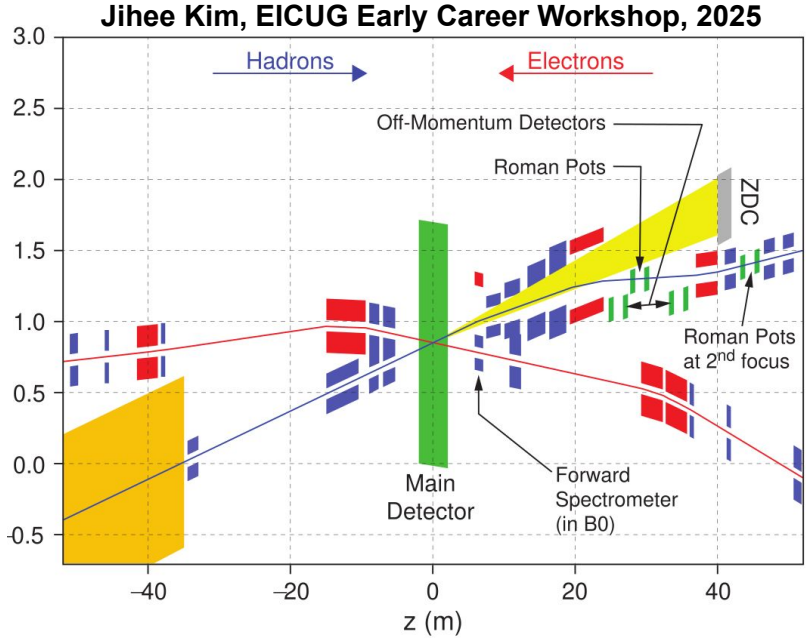
EIC UG 2nd detector working group

- **Please contact us if you would like to participate in the 2nd detector effort!**
  - **Current conveners (volunteer based)**

Anselm Vossen (Duke U) anselm.vossen@duke.edu (EICUG steering committee, chair elect)	Experiment
Charlotte van Hulse (U of Alcalà) charlotte.barbara.van.hulse@cern.ch (EICUG steering committee)	Experiment
Charles Hyde (ODU) chyde@odu.edu	Experiment
Pawel Nadel-Turonski (U of SC) turonski@sc.edu	Experiment
Björn Schenke (BNL) bschenke@bnl.gov	Theory
Simonetta Liuti (UVA) sl4y@virginia.edu	Theory
Vasiliy Morozov (ORNL) morozovvs@ornl.gov	Accelerator
Wenliang “Bill” Li (MS State U) wenliang.li@msstate.edu	Software

- **Past 2nd detector meetings and workshops:**
  - **Preparation meeting (SBU CFNS):**
    - **https://indico.bnl.gov/event/17693/**
  - **1st International Workshop on A 2nd Detector for the EIC (Temple U.)**
    - **https://indico.bnl.gov/event/18414/**
  - **EICUG 2023 (Warsaw, Poland)**
    - **https://indico.cern.ch/event/1238718/**
  - **"Precision QCD predictions for ep physics at the EIC (III): opportunities with a second IR**
    - **https://indico.cfnssbu.physics.sunysb.edu/event/322/**

Information and Software Page



- **Crossing angle of 35 mrad**
  - Better fit for the IR8 hall geometry
- **Slightly shorter and wider central detector**
  - Made possible by a compact 3T solenoid
- **A symmetric detector (+/- 4.5m) gives more flexibility in the IR design, especially the B0**

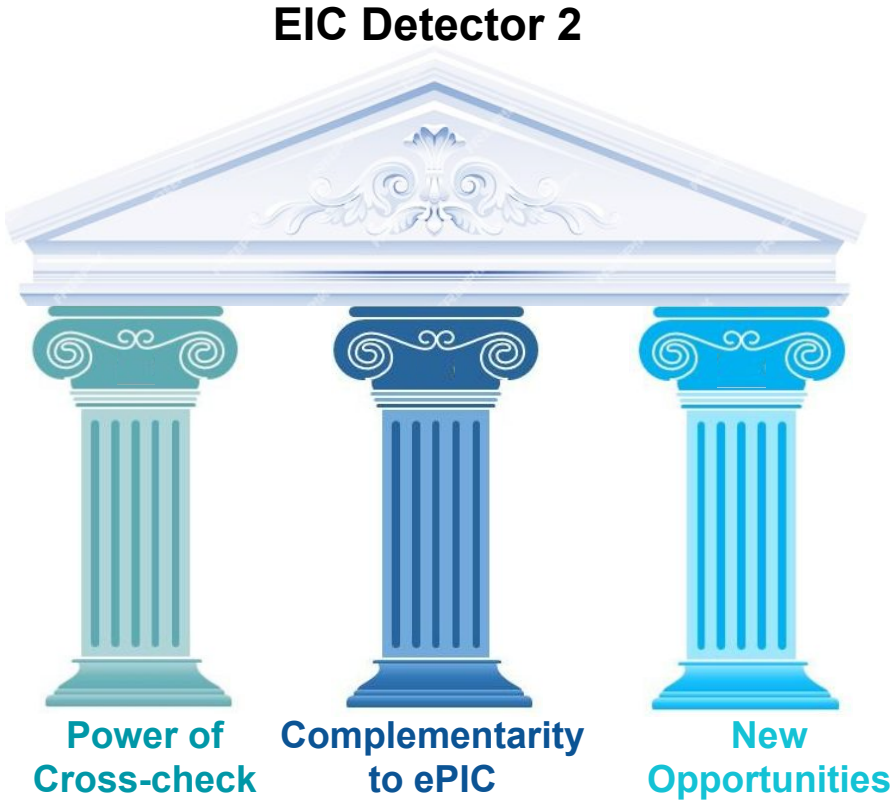
- **Beamline Information:** https://wiki.bnl.gov/eic-detector-2/index.php?title=Project_Information
- **Simulation tools**
  - Based on the ePIC simulation and reconstruction stack
  - Github page: https://github.com/eic/D2EIC

New charge from the EICUG and Path Forward

- Monthly meetings will resume in August
  - Contact us if you would like to present something!
  - Talks for August 14 include Wim Cosyn on A-1 tagging and Paul Brindza on an updated design of the detector 2 solenoid

- An important update to the charge is to start preparing for a 2nd detector white paper – your input will be essential!

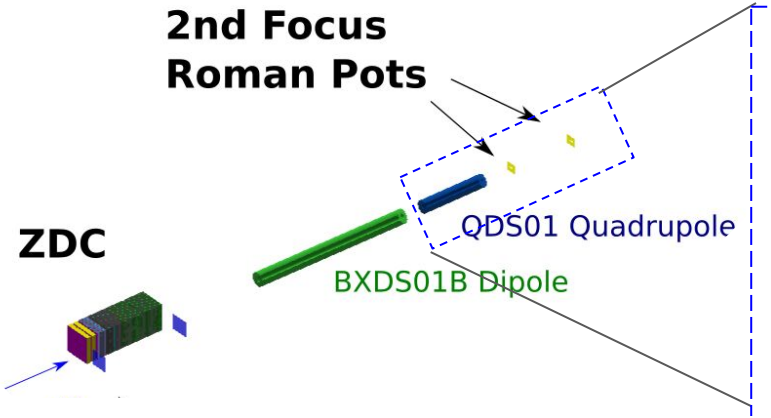
Thank you!

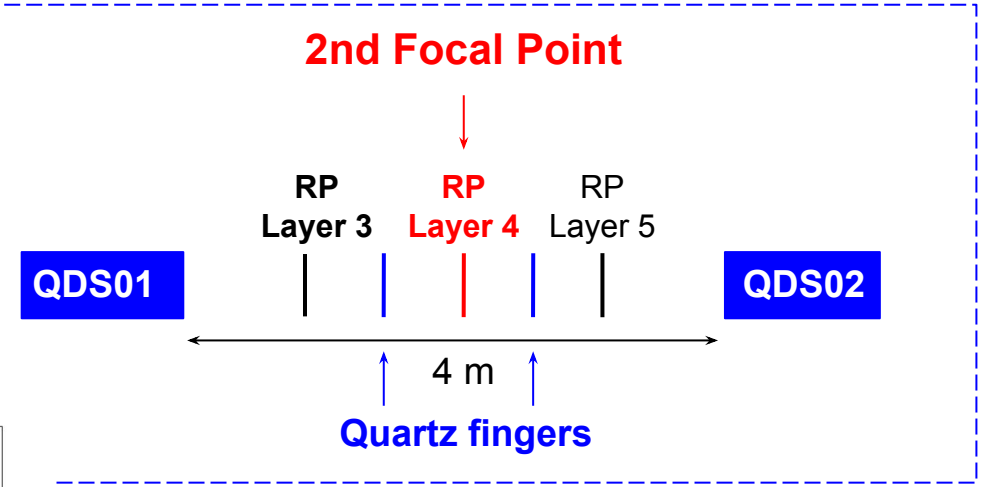


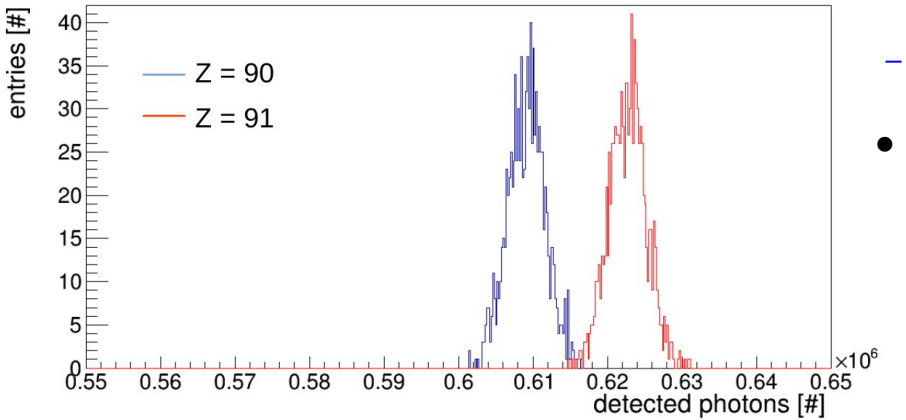
Acknowledgement for the former WG members

- Renee Fatami (Kentucky U.)
- Sangbaek Lee (ANL)
- Thomas Ullrich (BNL)
- Klaus Dehmelt (JLab)
- Walter Wittmer (JLab)
- Kong Tu (BNL)

A Quartz Based PID Detector







- **Z-Tagging Mini DIRC** (Generic R&D detector led by C. Hyde, Old Dominion)
  - Photon counter

$$\frac{dN}{dX} \approx z^2\,(0.013/\mathrm{cm}) = \frac{106}{\mathrm{cm}} \text{ for } z = 90$$

Opportunities at 2nd EIC detector so far

- **Second FOCUS** – tagging for nearly all ion fragments and extended acceptance for low-pT/ low-x protons. Enables detection of short-lived rare isotopes.

- **MAGNETIC FIELD** – Solenoid field up to 3 T, allowing for high resolution momentum reconstruction for charged particles. (ePIC magnets 1.7 T)

- **EXTENDED COVERAGE** for precision electromagnetic calorimetry – important for DVCS on nuclei.

- **MUONS** – enhanced muon ID (not only MIPs).

- More in the future…