A second detector for the EIC

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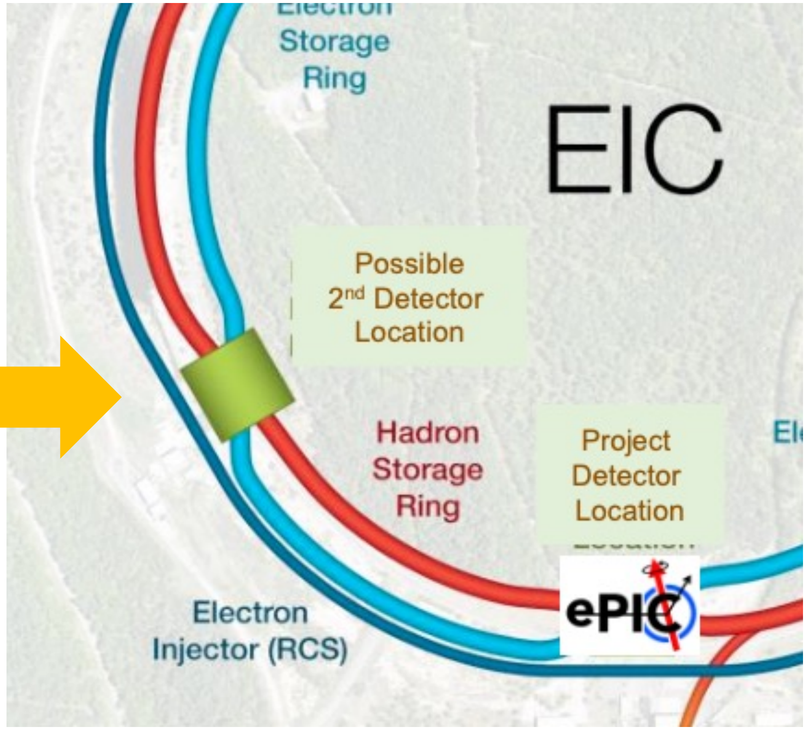
2nd Detector @ IP8



Physics Opportunities at an Electron-Ion Collider
(POETIC) XI, FIU, Miami, Florida, February 24-28, 2025

Motivation for two detectors

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.

arXiv: 2303.08228

Inspired by Mont's talk at the first EIC 2nd detector workshop in December 2022.

A second detector for the EIC

- Discovery potential and independent cross check of results
  - A second general-purpose detector would allow for mutual confirmation of results – a crucial component of discovery science at a facility that is unique worldwide.

- Additional physics opportunities

- Cost-effective
  - Adding a 2nd detector is does not significantly increase operations costs of the facility
  - Construction is a one-time cost – limited impact on annual nuclear physics budgets

- Timeline - lessons from Fermilab
  - The D0 detector came 7 years after CDF, but both made comparable contributions to the science program.
  - A 2nd EIC detector would come online when the machine operates nominal parameters (after early running)

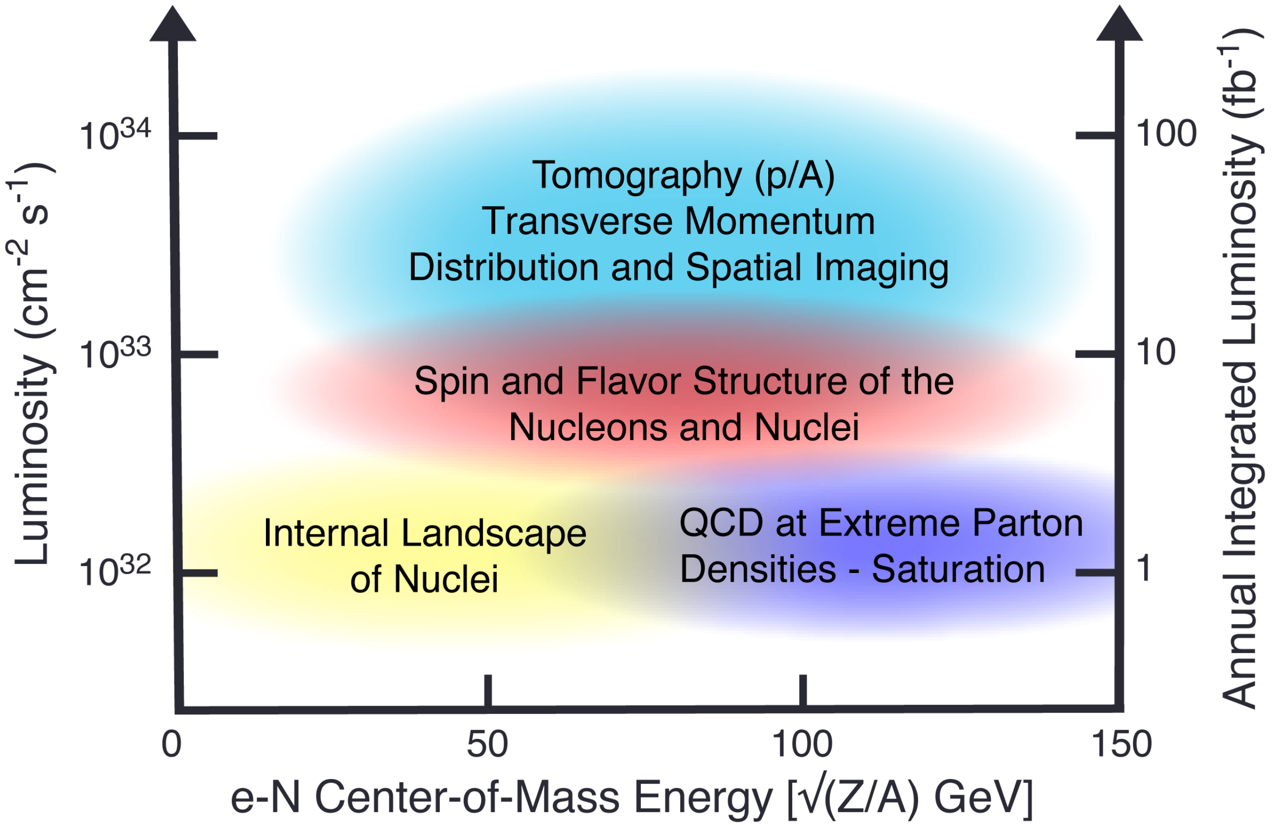
Expanding the EIC user community

- A slightly longer timeline may work better for some potential users
  - Other commitments, funding, etc

- Engaging with users interested in, for instance:
  - Expanded capabilities for eA
  - Beyond standard model physics
  - Hadron spectroscopy
  - Hypernuclei
  - Rare isotopes
  - Add your favorite topic here!

- Adding a second detector will benefit ePIC
  - Users who would want are interested in a 2nd detector may join the EIC early
  - This happened with spectroscopy in CLAS before GlueX was built

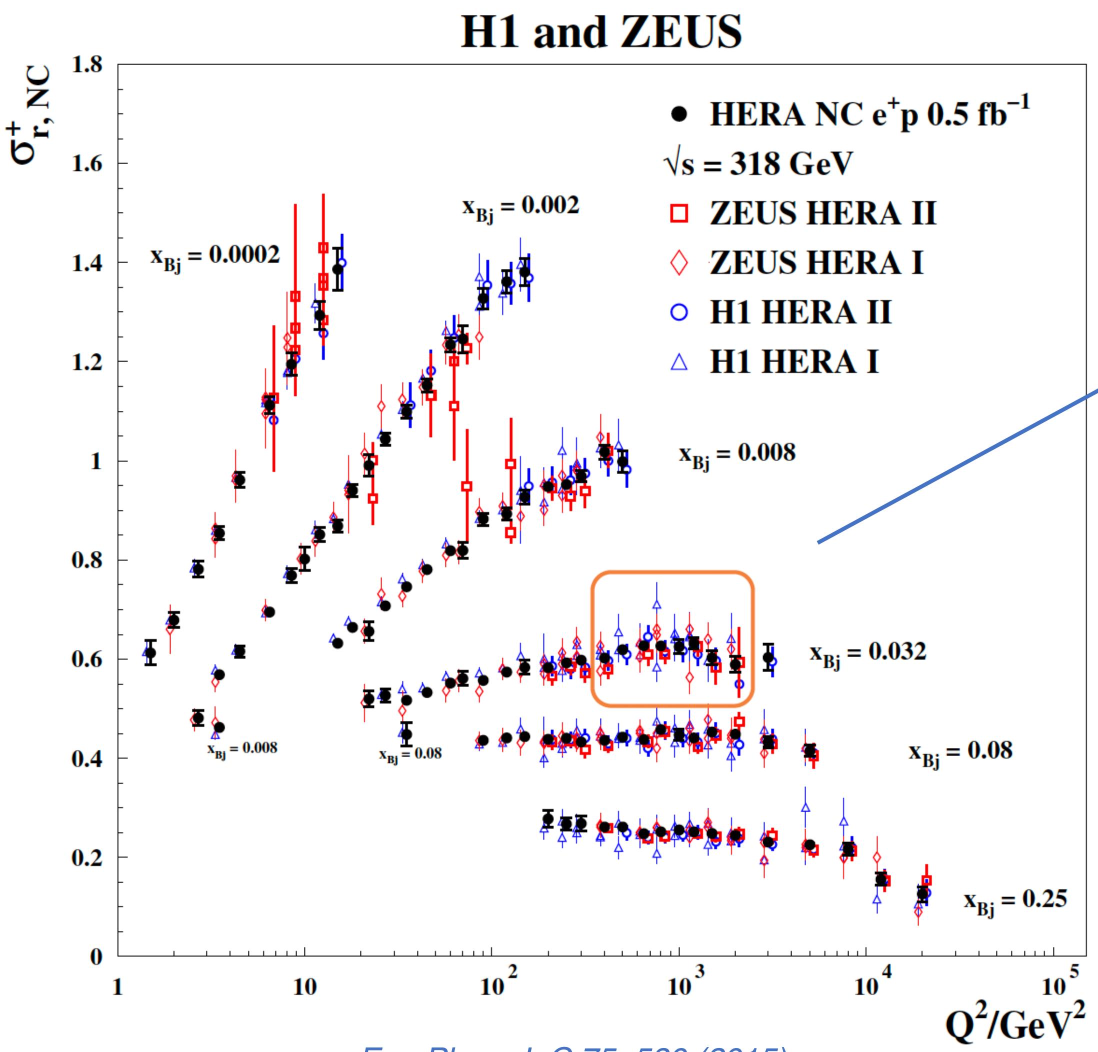
Luminosity, acceptance, and systematics



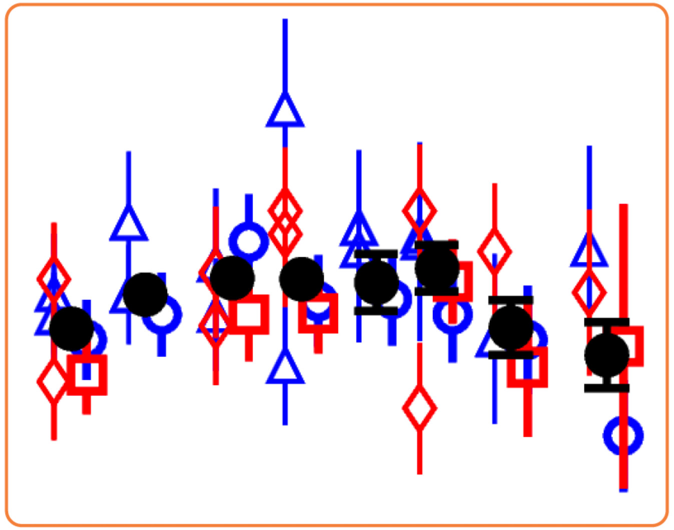
- Tomography / imaging requires a high **luminosity** – but also the best possible far-forward **acceptance**
- When the EIC reaches its design luminosity, many measurements will become **systematics** limited, and will greatly benefit from two detectors.

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

Reduction of systematics at HERA



Eur. Phys. J. C 75, 580 (2015)



- If two complementary detector are not *too* different and use similar binning, it is possible to combine data.
- In some kinematics the combined data have dramatically reduced systematic uncertainties.
- The EIC luminosity will be 1000 times higher.

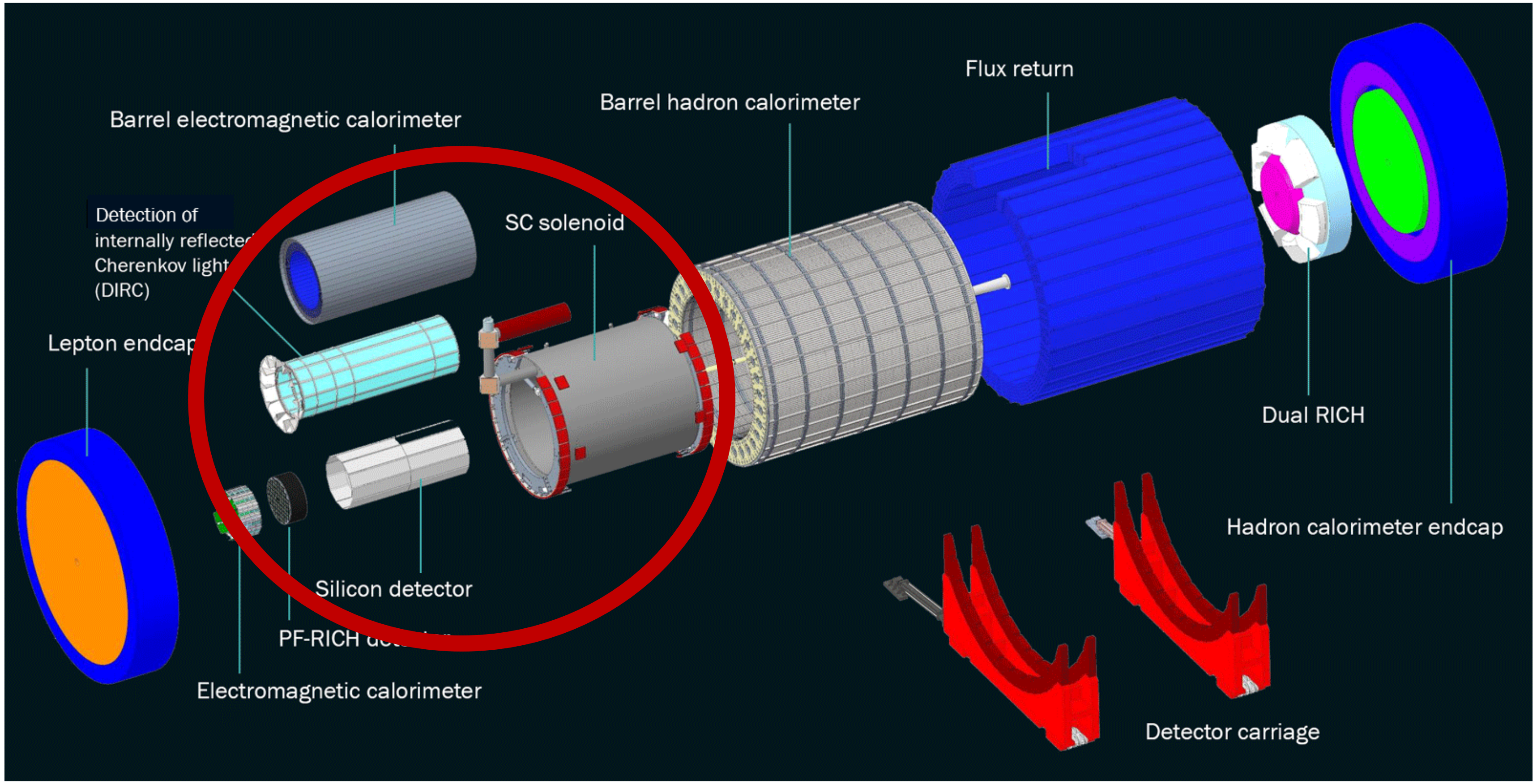
A second detector for the EIC – new opportunities

The details the 2nd detector are not yet defined.
Users will have a significant impact on design and construction.
There are some natural ways for a second detector to expand the capabilities of the EIC.

- Taking advantage of much-improved near-beam hadron detection enabled by a second focus in IR8
  - Low-x / low-p_T proton acceptance – (exclusive / diffractive reactions)
  - Detection of light nuclei from coherent processes – (down to $p_T = 0$ at mid-to-high x)
  - Tagging a wide range of spectator nuclei, including A-1 for reactions on a bound nucleon
  - Vetoing breakup of heavier nuclei by being able to detect the produced fragments
  - Properties of the nuclear final state – (hypernuclei, rare isotopes, etc, including gamma spectroscopy)

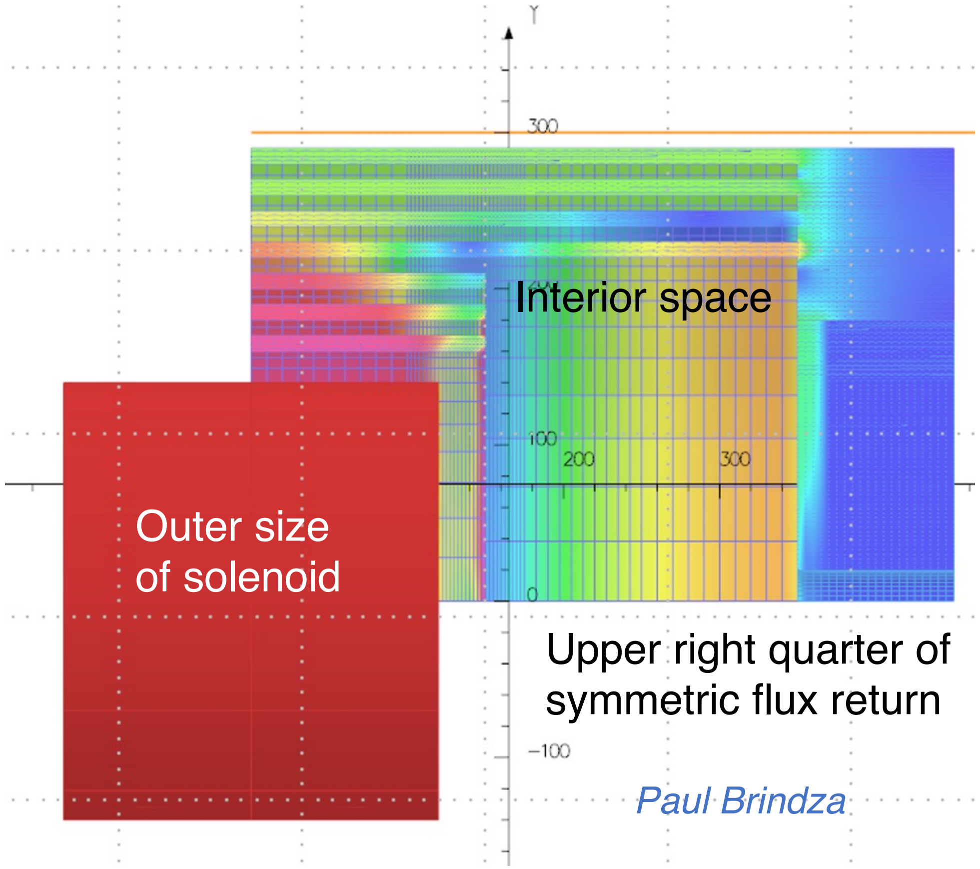
- Complementarity with ePIC
  - Much-improved muon identification – (quarkonia, TCS/DDVCS, jets, BSM, …)
  - Higher magnetic field for better tracking resolution – (diffraction on heavy nuclei, hadron spectroscopy)
  - High-resolution barrel EMcal – (DVCS on nuclei, hadron spectroscopy) ?
  - Improved hadron PID in the barrel from continued DIRC R&D – (SIDIS, jets, hadron spectroscopy) ?

ePIC detector – radial size



- Outer radius of the barrel EM calorimeter: 116 cm (from J. Lajoie)
- Inner (bore) radius of the SC solenoid: 142 cm (similar to BaBar)
- **ePIC would fit into a bore with a 120 cm radius**
  - Natural starting point for simulations – ePIC can be used as a benchmark

First study of a detector 2 solenoid



- Comparison with ePIC (MARCO) solenoid
  - 30% (1 m) shorter coil
  - 15% smaller inner (bore) radius
    - creates more radial space between solenoid and endcap
  - 3 T achievable within a 3 m outer radius
- Symmetric flux return
  - Reduced coil forces => thinner cryostat
  - Integrated with KLM-like Hcal in barrel
  - +/- 4.5 m overall detector length (original DPAP spec)
    - same solenoid-to-endcap desistance on hadron side, more space on the electron side than in ePIC

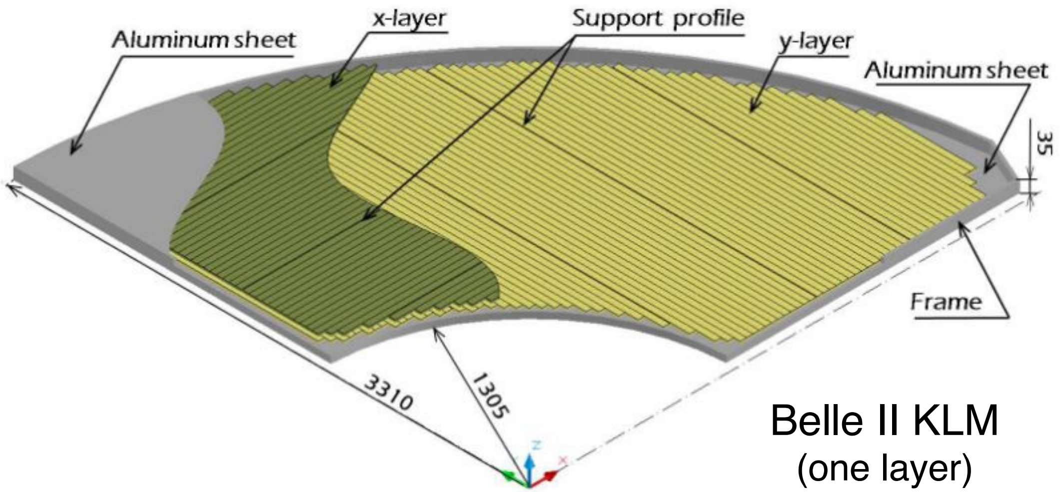
Note: the tracking resolution depends on the B-field and the tracker radius – not the solenoid radius

Muon identification for a 2nd EIC detector

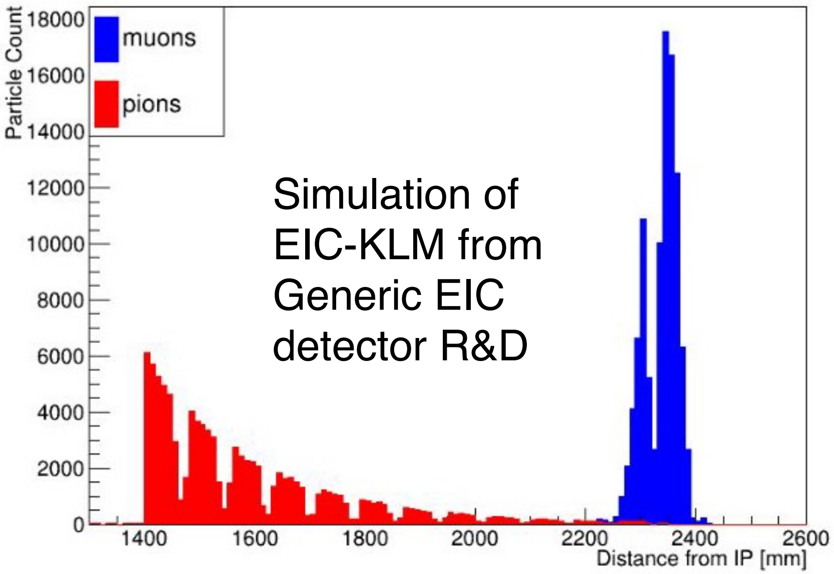
- Most Hcals can provide some level of muon ID, but an optimized system gives a much better efficiency and purity.
  - Requires a high level of segmentation along the muon path

- Ongoing R&D uses the Belle II KLM as a starting point, but adds precision timing and energy measurements in each layer.

- In combination with AI methods for reconstruction, simulations suggest that the EIC-KLM is also a surprisingly good Hcal.



Belle II KLM
(one layer)

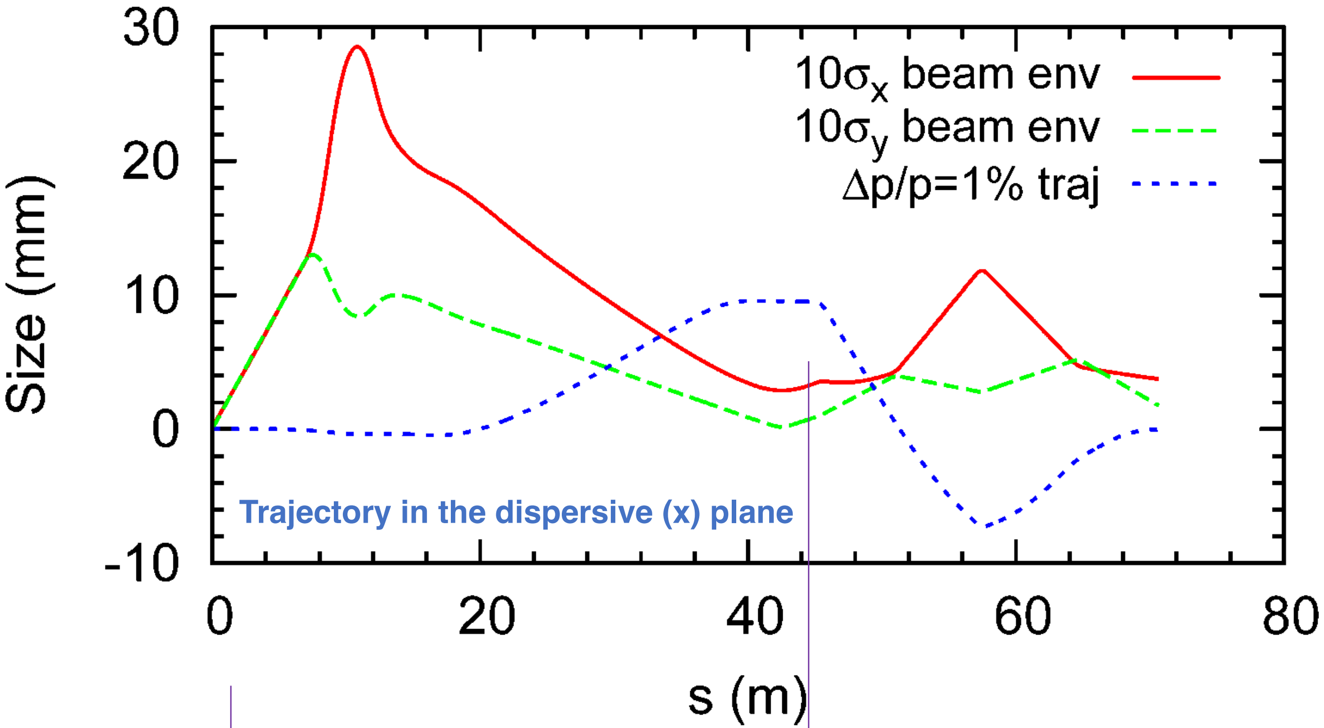


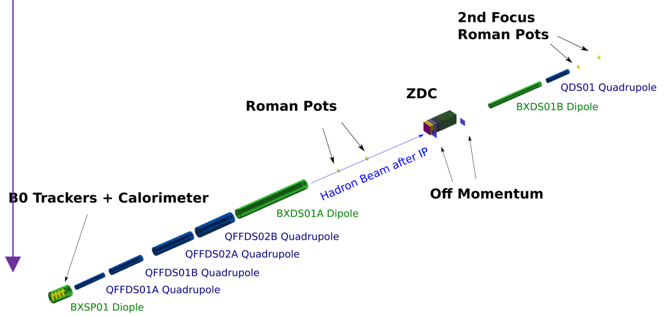
Simulation of EIC-KLM from Generic EIC detector R&D

How the second focus works

- Idea: make the beam small at the location where the transverse displacement of scattered particles is the greatest
  - Displacement: dr = dispersion * dp/p
  - In DIS, dp/p ~ x

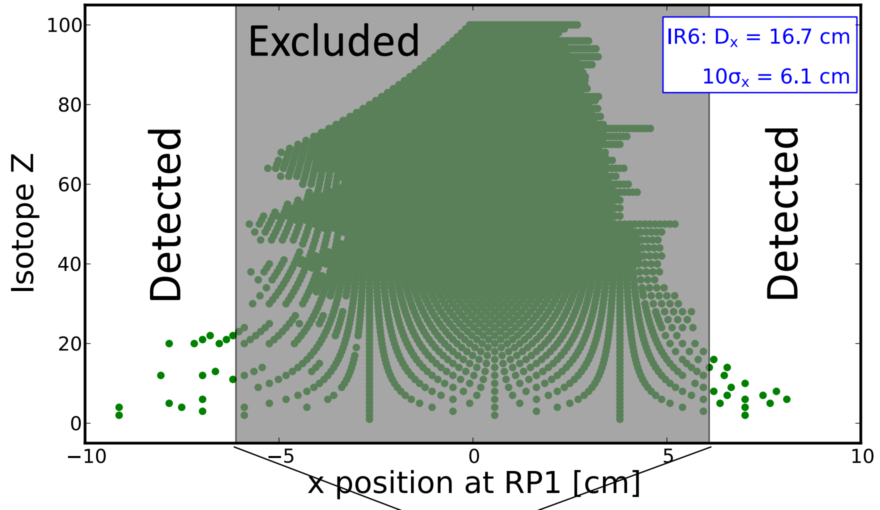
- A particle (blue) initially scattered at 0 degrees (p_T = 0) briefly emerges from the beam at the second focus about 40 m downstream where it can be detected
  - Compare trajectory with horizontal (red) beam size
  - Particles with p_T > 0 emerge earlier

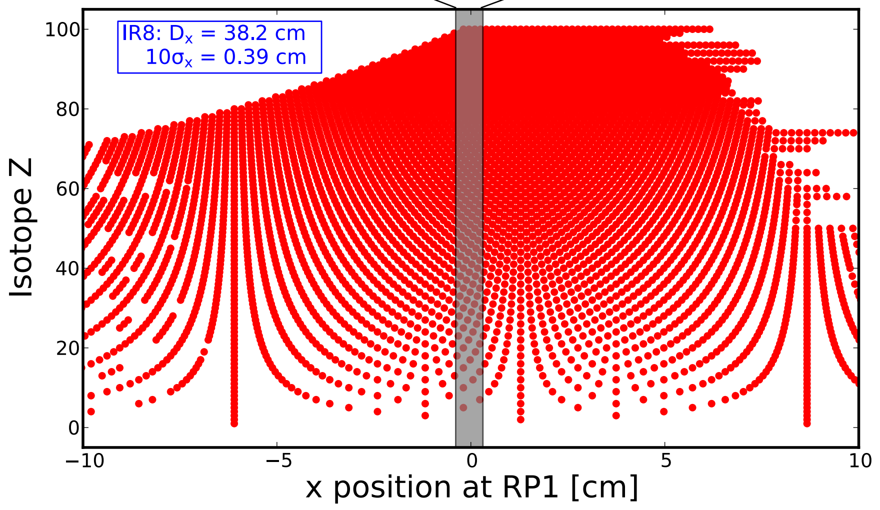




EIC far-forward acceptance with and without a 2nd focus

Ion fragments from ^{238}U





x position ~ A/Z

Without 2nd focus:
(EPIC @IR6)

← Z' vs x_{RP}

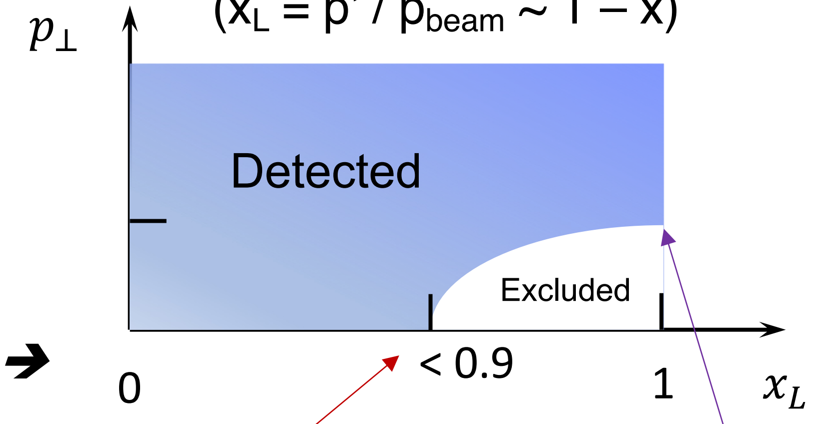
$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

Order-of-magnitude improvement in forward acceptance

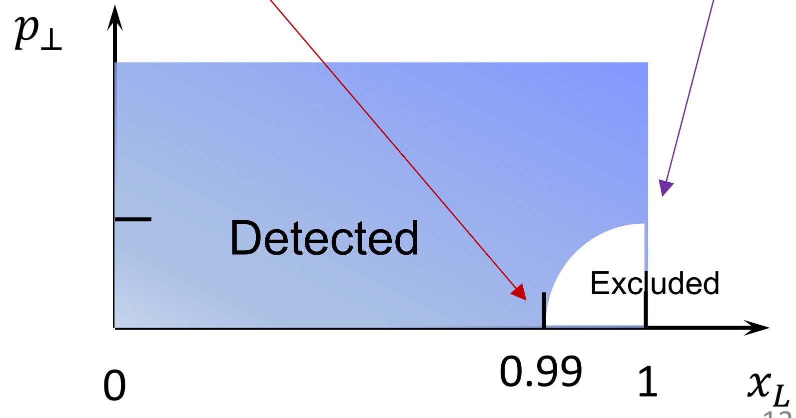
Exclusive protons

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

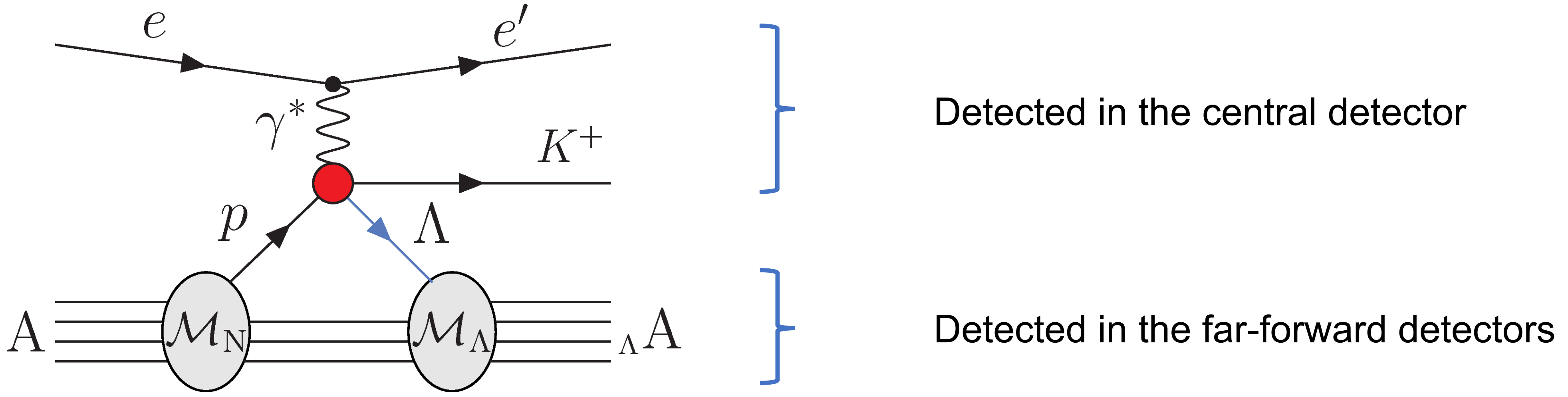


Limited by D and 2nd focus (β_2)

Limited by angular acceptance (β^*)

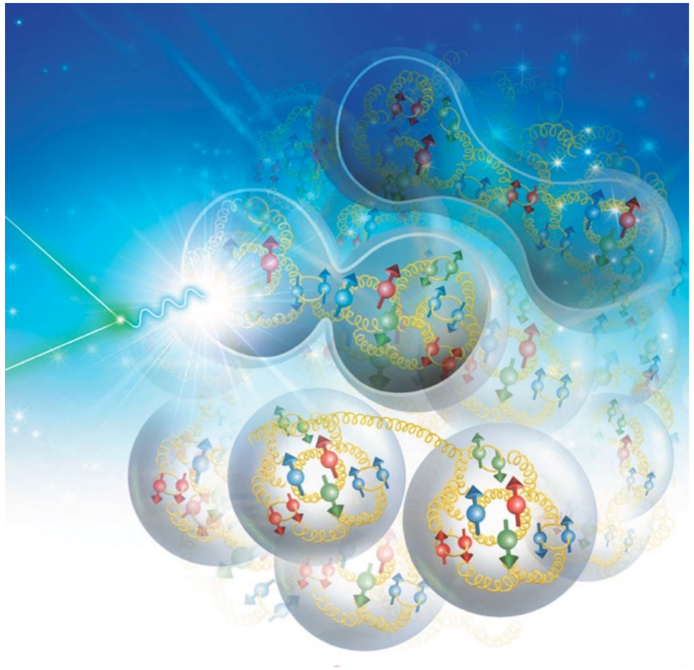


Production and detection of hypernuclei



- Coherent exclusive K^+ production creates a hypernucleus differing by one unit of charge.
  - Sufficient for any hypernucleus to be detected by the 2nd detector using the second focus of IR8
  - Coincidence with K^+ will provide a clean signature
- A broad range of hypernuclei can be discovered and characterized
  - Boosted gamma photons can be detected at the ZDC and B0
  - Synergetic with studies of rare isotopes

Scattering on nuclei

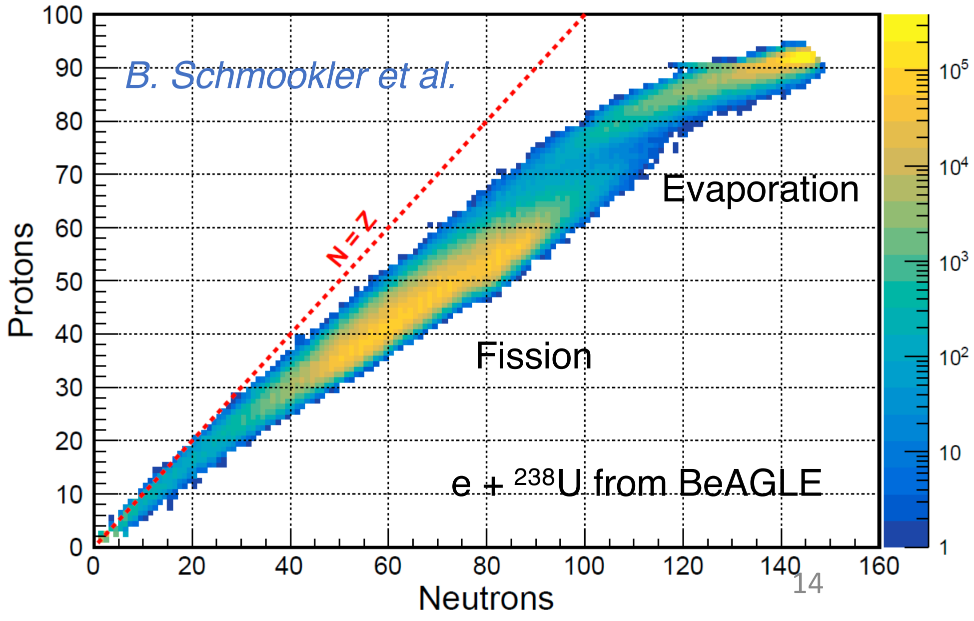


Scattering on a bound nucleon, measuring the spectator nucleus

- Neutron (and bound proton) structure can be studied using deuterium beams by tagging the spectator A-1 nucleus
- With a second focus, we can measure scattering a nucleon while detecting the A-1 spectator nucleus for almost any beam

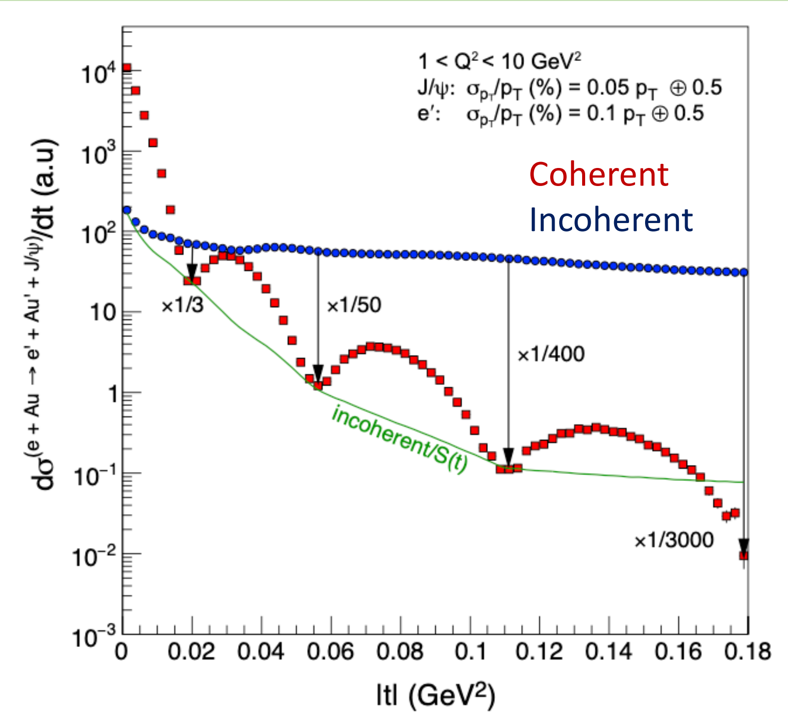
Coherent exclusive scattering

- For light nuclei, the 2nd focus enables *detection* of the nucleus with close to 100% acceptance down to $p_T = 0$.
  - Clean measurement of 3D structure.
- For heavier nuclei, fragment detection helps to create a very efficient breakup veto.



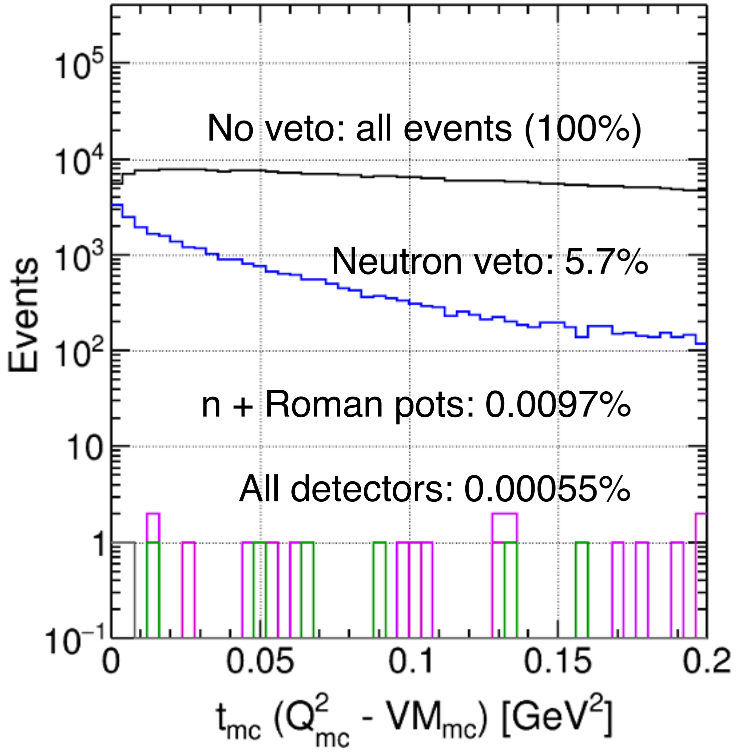
Vetoing breakup in coherent scattering using a second focus

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



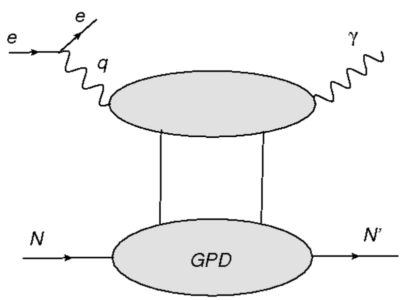
J. Kim

Fragment detection in Roman pots at the second focus suppresses incoherent backgrounds even at large *t*.

Also applicable to, *e.g.*, DVCS on medium nuclei

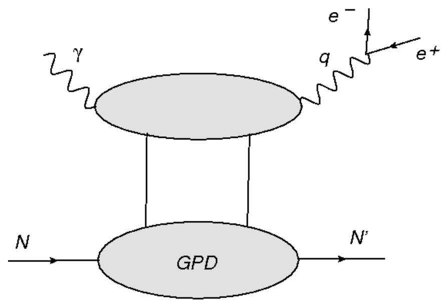
Timelike Compton Scattering (exclusive dilepton photoproduction)

(spacelike) DVCS

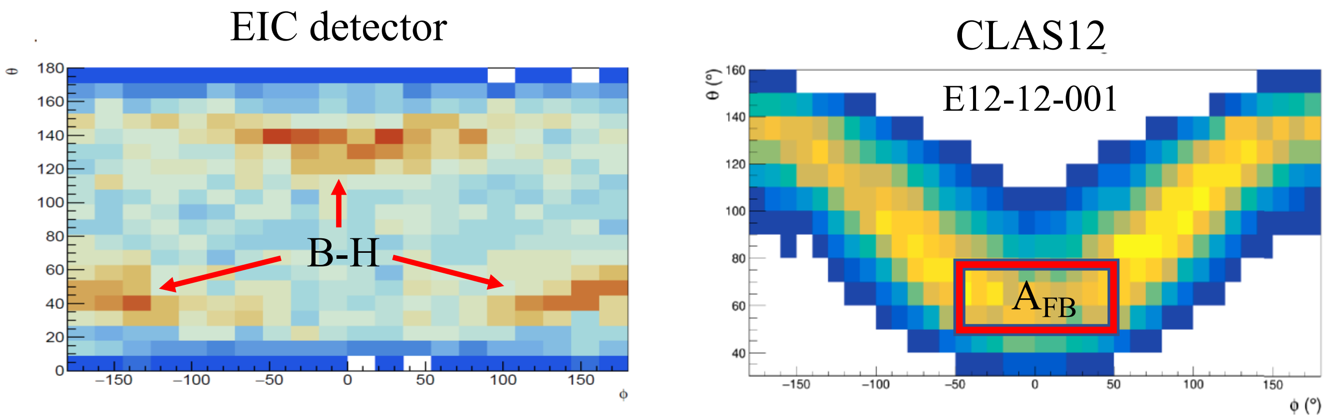


Initial photon spacelike, final photon real

timelike Compton scattering (TCS)



Initial photon real, final photon timelike → $l^+ l^-$



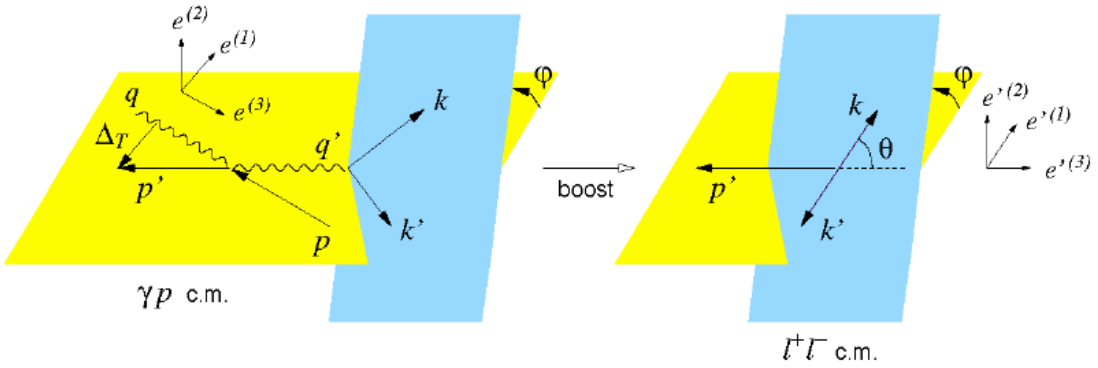
P. Chatagnon, EIC UG meeting, Warsaw, 2023

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

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

- Fixed-target experiments have limited forward acceptance
  - Loss of useful statistics and complicated systematics

- EIC benefits from excellent dilepton acceptance.



- k,k' = momentum of e^-, e^+ or μ^-, μ^+
- θ = angle between the scattered proton and the electron
- φ = angle between lepton scattering- and reaction planes

Double DVCS ($Q^2 < Q'^2$ => 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

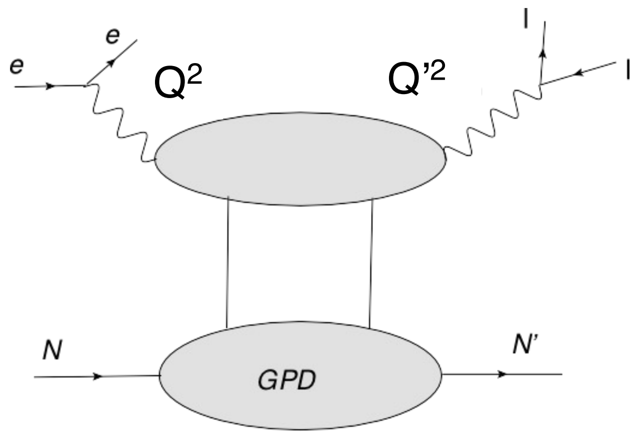
PRD 107, 094035 (2023)

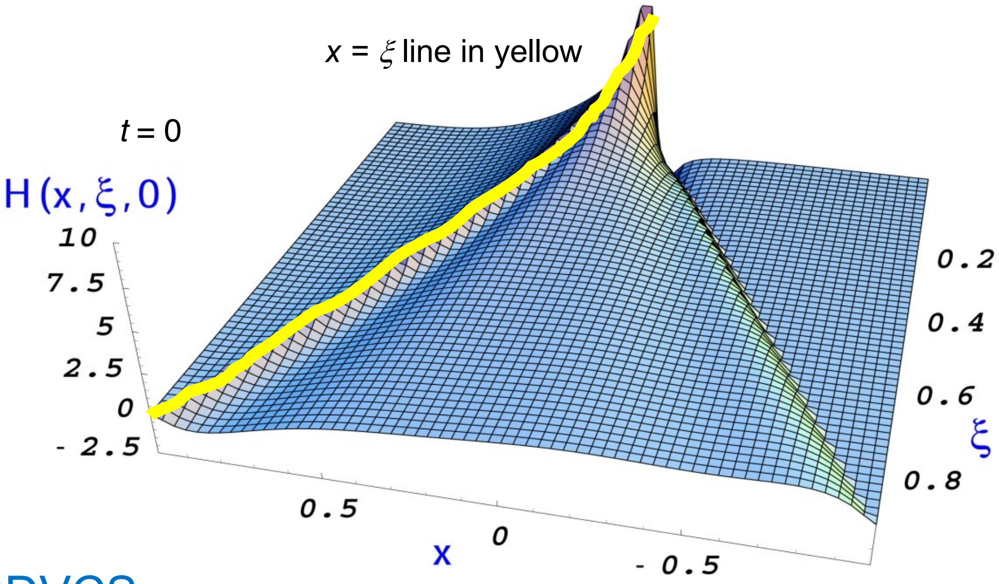
- Lepton acceptance and identification
  - Muon ID is *necessary* in order to distinguish the scattered electron from the DDVCS decay leptons
  - EIC di-muon acceptance helpful (as in TCS)

- Proton acceptance in an IR with a second focus
  - DDVCS measurements will focus on low *t*
  - 2nd focus gives a low-*t* proton acceptance close to 100%

A 2nd EIC detector may give us the best chance for measuring DDVCS

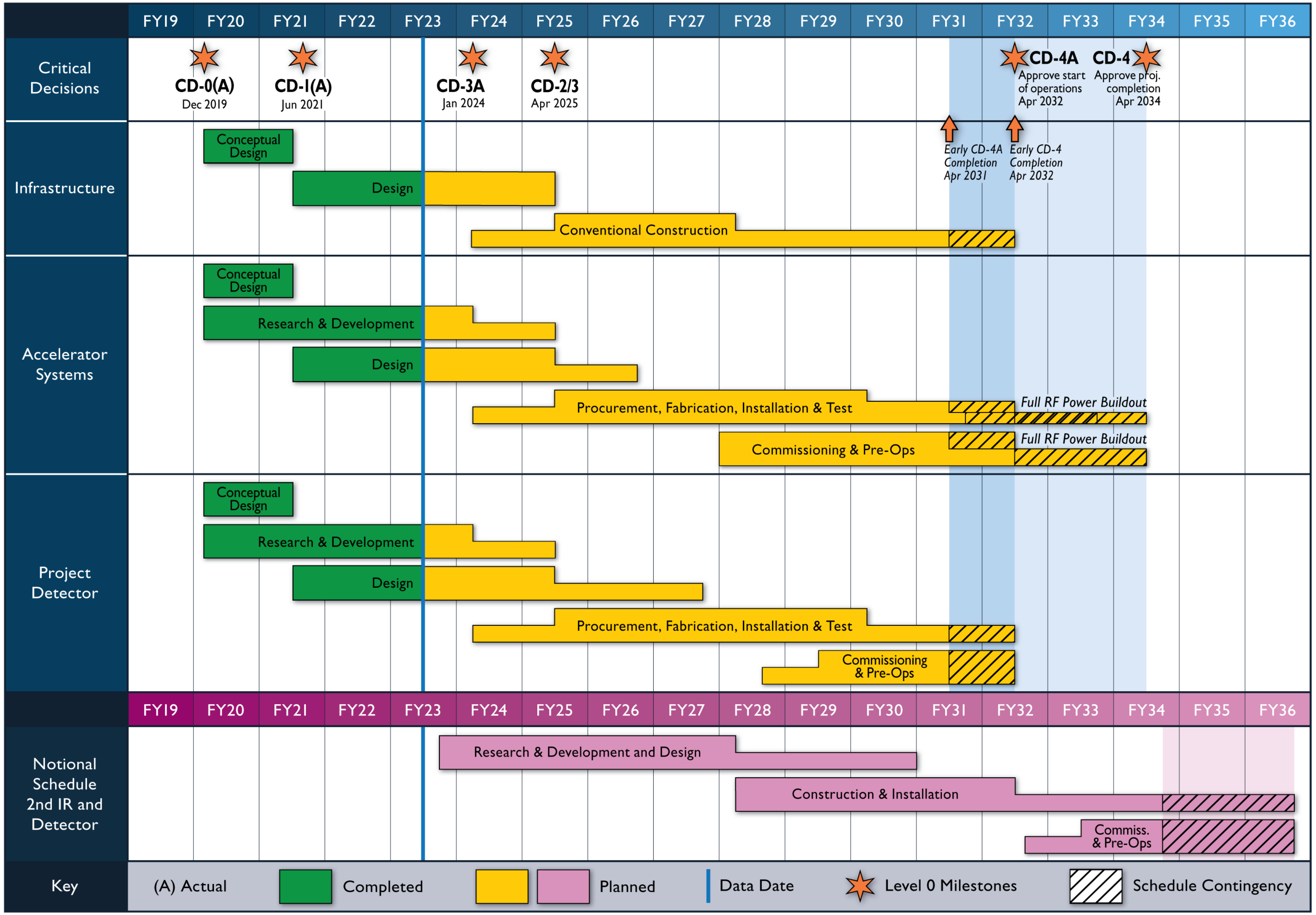
DDVCS: initial *and* final photon virtual





Tentative schedule including a 2nd detector

Jim Yeck, EIC 2nd detector workshop, May 2023



A little out of date but nevertheless illustrative

2nd detector

Summary and outlook

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

- A 2nd detector will also introduce new capabilities and opportunities

- The EIC UG has set up a 2nd detector WG to coordinate ongoing activities.
  - If you have questions or would like to contribute, please don't hesitate to contact us!

  Anselm Vossen (Duke/JLab), Bjoern Schenke (BNL), Charles Hyde (ODU), Charlotte van Hulse (U. Alcalà, Madrid), Pawel Nadel-Turonski (UofSC), Simonetta Liuti (UVA), Wenliang Li (MS State)

Thank you!

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