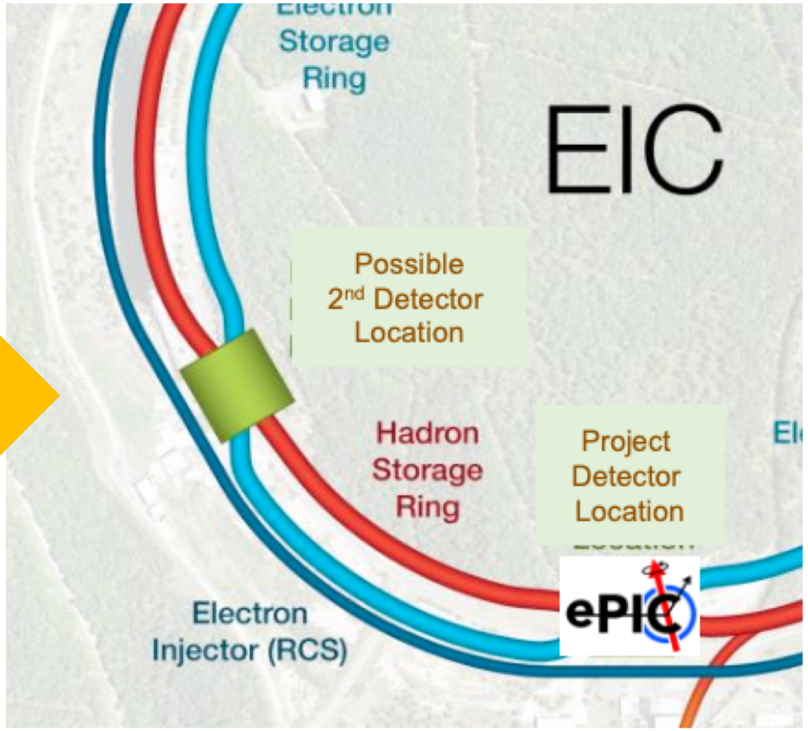
Opportunities with a 2nd EIC detector at IP8

Pawel Nadel-Turonski
CFNS Stony Brook University

The 2nd detector



JLUO meeting, June 28, 2023

Motivation for a 2nd detector

- Needed to unlock the full discovery potential of the EIC
  - Cross checks of key results are essential!
  - Implies 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 2nd focus,
  - Impacts, for instance, 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 and 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

Two documents: with overlapping arguments

Ent and Milner et al for the EICUG SC

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: 2303.08228v2 March 24, 2023

Case for two detectors being made from **Nuclear** and **Particle** Physics

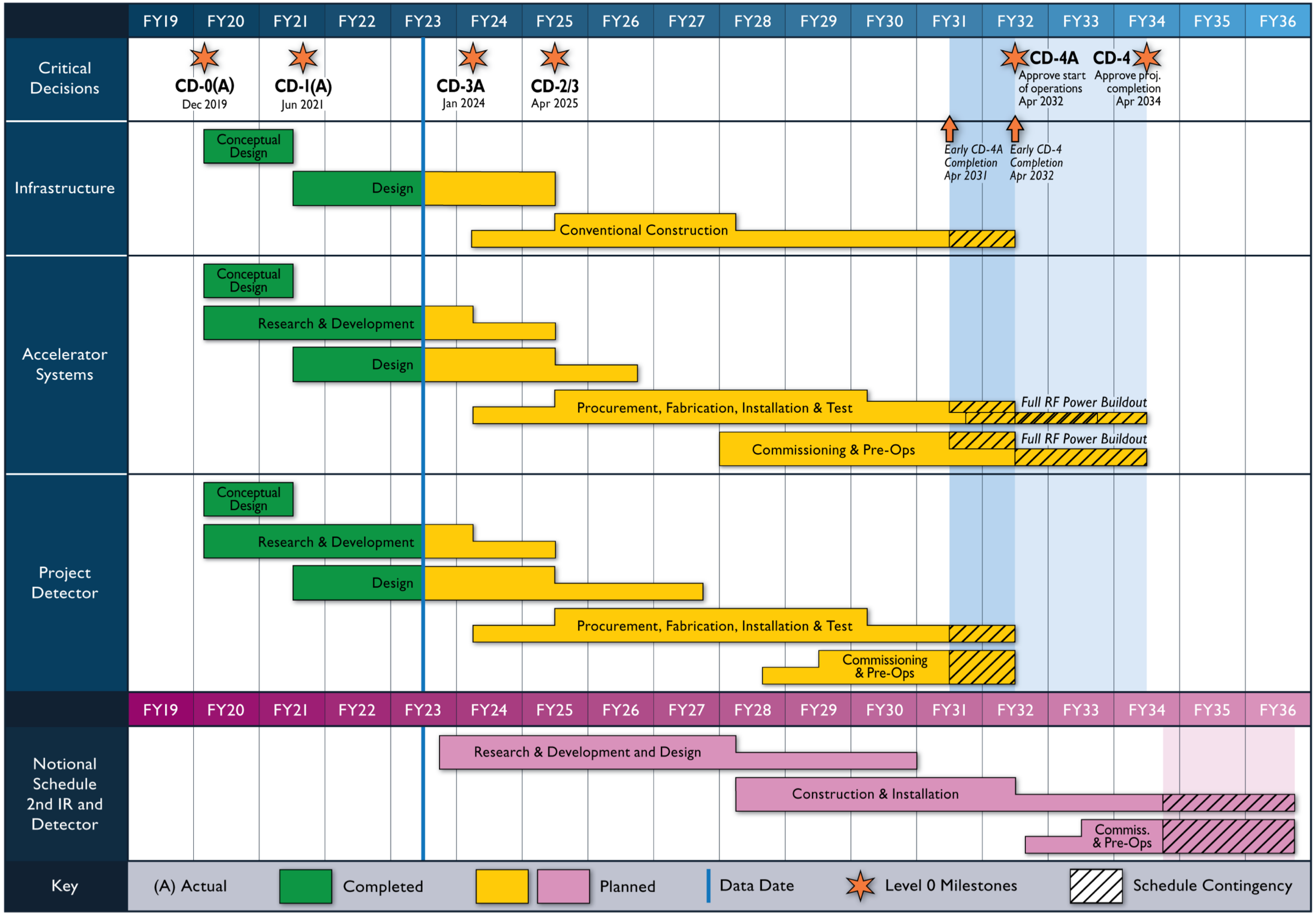
Project perspective on a 2nd Detector

- Project Design Goals
  - **Accommodate a Second Interaction Region (IR)**
- DOE, and BNL and JLab as the Host Labs, are establishing a governance structure intended to support the EIC. This includes the construction of a 2nd IR and detector.
  - EAB, RRB, DOE International Agreements
- Successful delivery of the EIC Project will be a major challenge, and the priority of the EIC project leadership team
- 2nd IR and Detector will be **installed after the EIC project** is complete
  - Science case must be compelling given resources required
  - IR and detector technologies should be state of the art
  - International engagement should be significant
- Organized effort needed now to prepare plans and build support for the 2nd IR and Detector

Jim Yeck, EIC 2nd detector WS, May 2023

Reference schedule for a 2nd IR and Detector

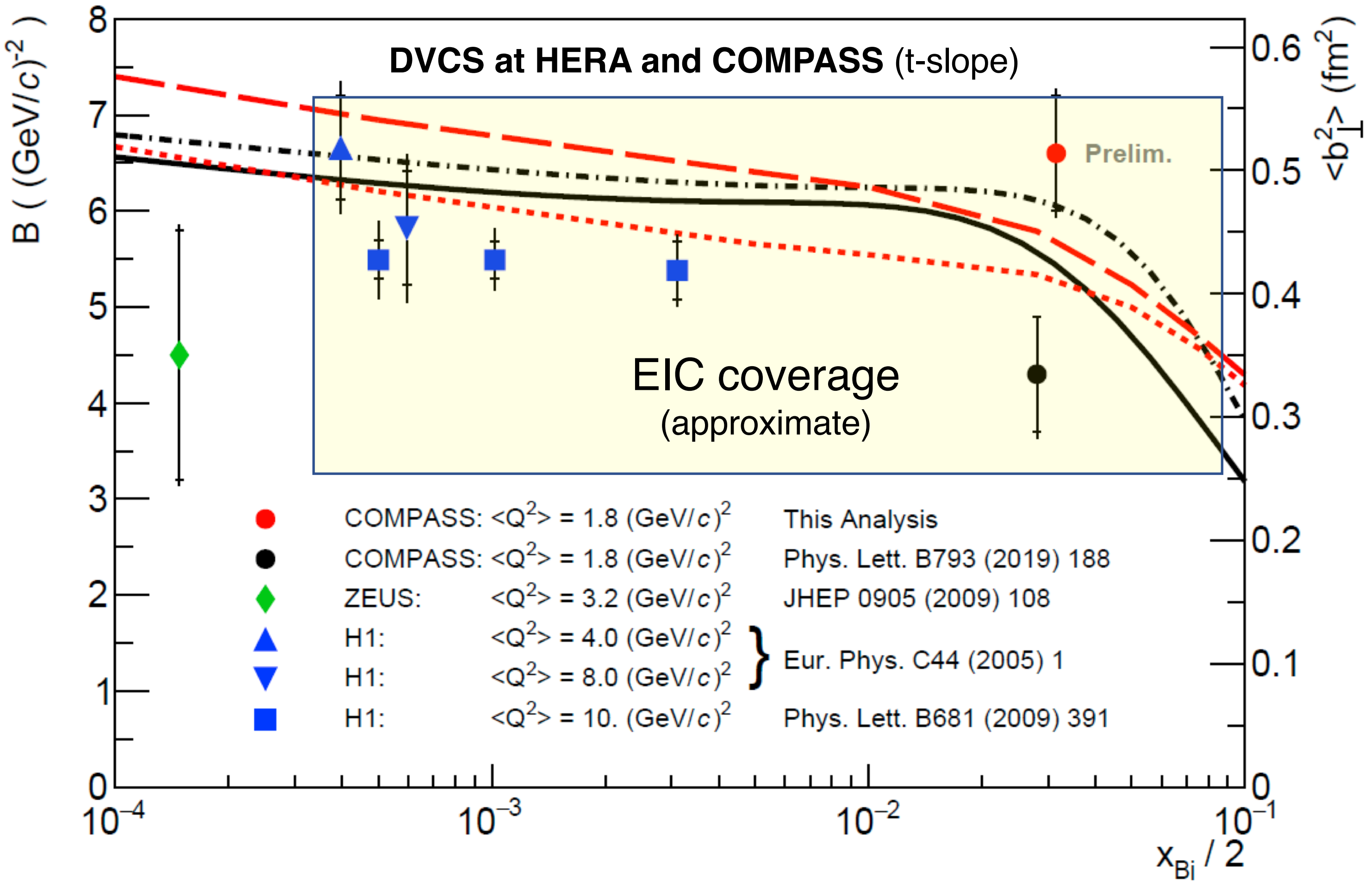
Jim Yeck, EIC 2nd detector WS, May 2023



Note that Detector 2 will be built a couple of years after the first one, which could be an advantage for groups that currently have a large involvement in the JLab 12 GeV program.

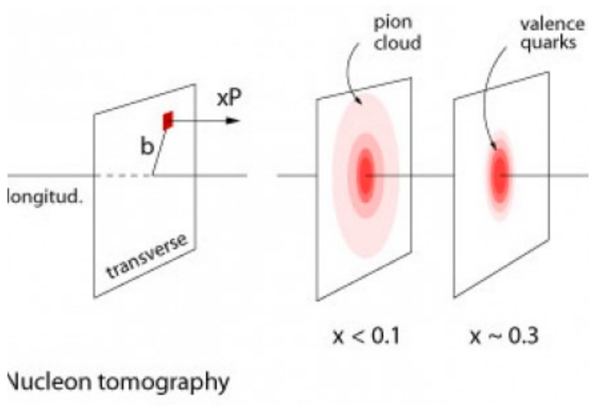
Second detector

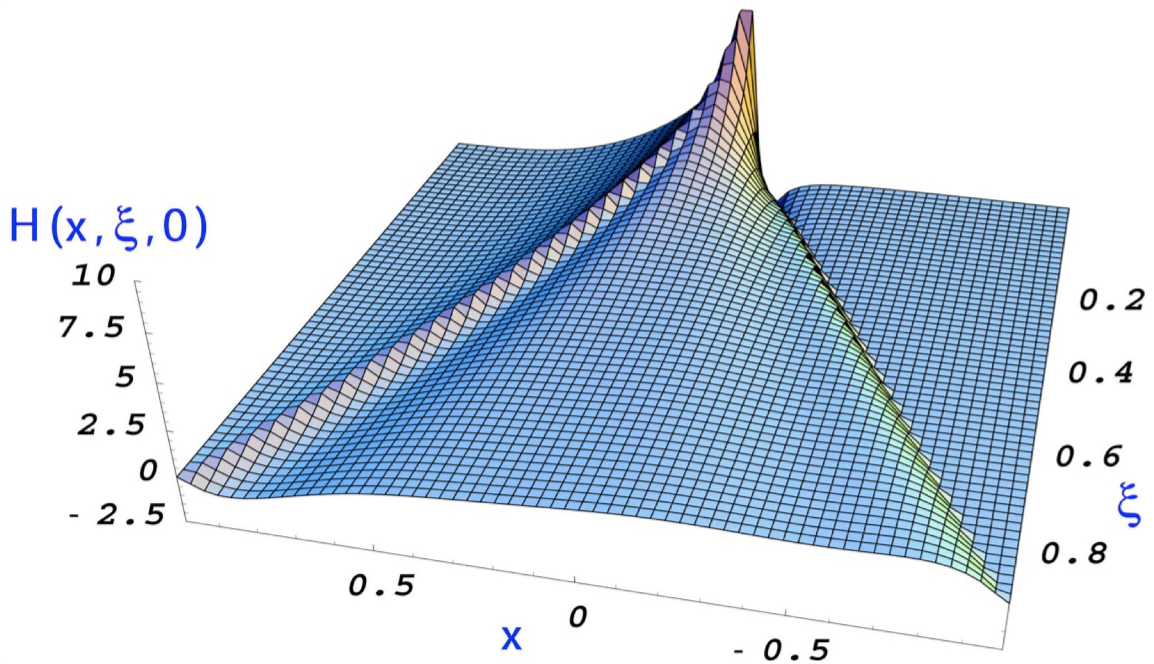
EIC and JLab have complementary kinematics



- The EIC covers a large range in x and Q^2.
  - High precision EIC measurements will greatly improve our knowledge of the sea region covered by HERA and COMPASS
- JLab 12 GeV and HERMES (27 GeV) zoom in on the valence region
  - (Outside the plot)

Example: transverse imaging of the proton at low and high x





- The "landscape" of the proton changes with x, and all regions add pieces to the puzzle.
- The large lever arm in Q^2 at the EIC makes it easier to understand higher twist (t/Q^2) over the full t-range needed to image the proton
  - Larger t corresponds to smaller b
- The image interpretation requires the skewness xi to be small
  - But the DVCS beam spin asymmetry probes the x=xi line
  - At large x, an extrapolation to small xi is needed
  - Interpretation is easier at lower x

The figure of merit for EIC measurements is usually very high

Event rate: cross section x luminosity x acceptance (efficiency)

Polarized figure of merit: event rate x polarization^2

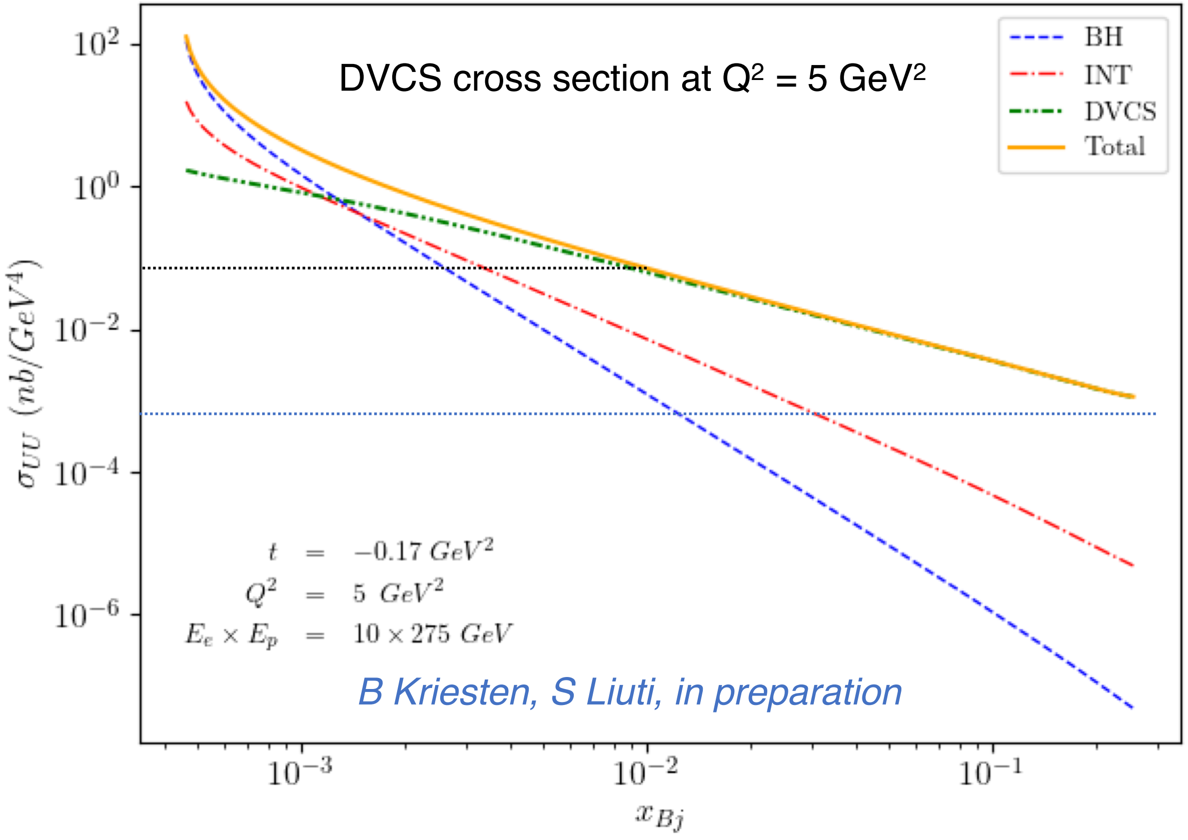
- Polarized protons (and He-3): > 70% longitudinal and *transverse* polarization
  - No dilution!
- No Moller electrons: low occupancies and high reconstruction efficiency
- Hermetic central detector: close to full acceptance also for multi-track events

In addition, a 2nd detector with a forward spectrometer with a 2nd focus can provide

- Hermetic forward detection for recoil protons, light ions, and ion fragments
  - For x > 0.01, this is true even at $p_T = 0$ (even though the proton initially is in the beam)
  - Ions and ion fragments are detectable since they move and don't get stuck inside the target, but good ion detection requires a 2nd focus

Luminosity and cross sections at the EIC

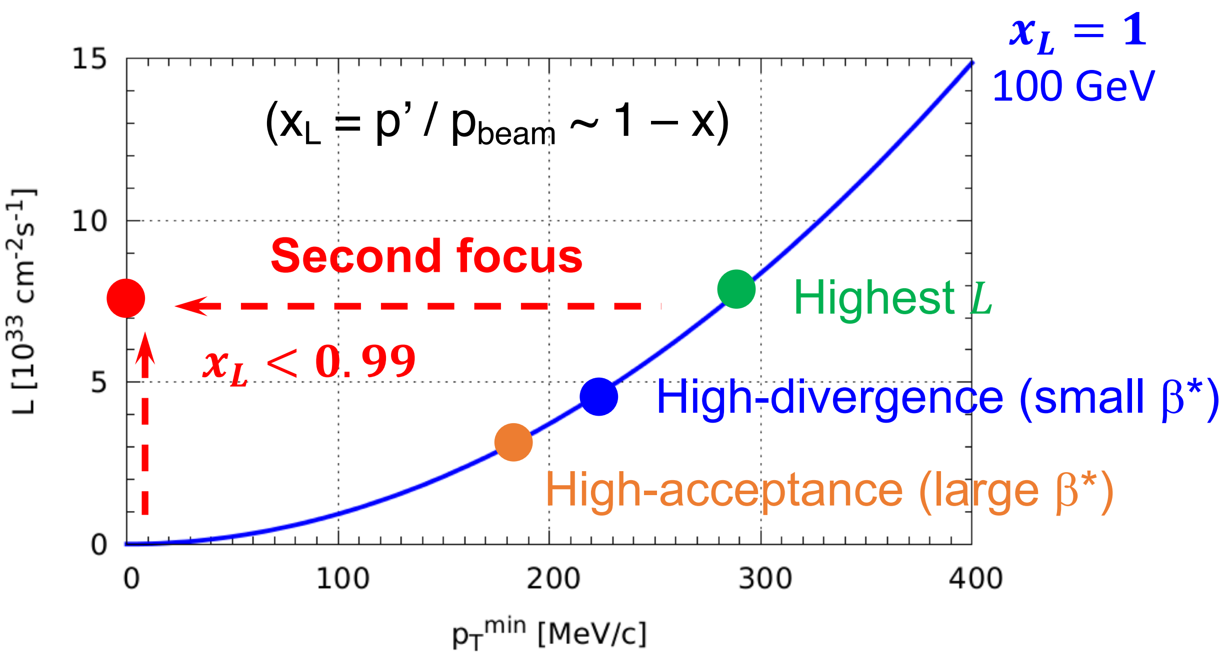
18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}



- The energies will be identical for both Detector 1 and 2.
- The EIC luminosity (10^{34}) is a little lower than in JLab 12 GeV experiments like CLAs12, but cross sections rise rapidly at low x
  - The **DVCS cross section** increases by a factor 100 between x = 0.3 and x = 0.01
  - Also, note that **BH** is much smaller than **DVCS**.

Luminosities in IR6 (ePIC) and IR8 (Detector 2)

18x275	10x275	5x275	10x100	5x100	5x41
1.65×10^{33}	10.05×10^{33}	5.29×10^{33}	4.35×10^{33}	3.16×10^{33}	0.44×10^{33}

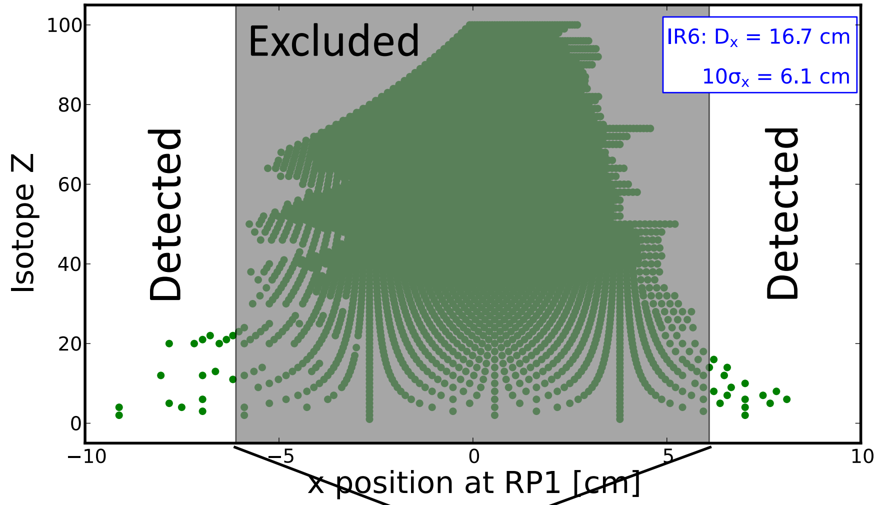


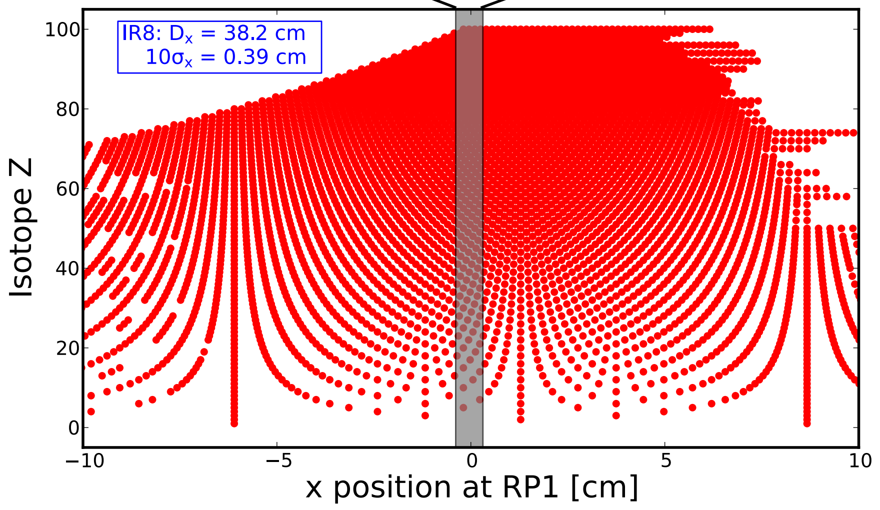
- The maximum luminosity will be similar for both Detector 1 and 2.
- When operated together, they will share the *beam current* (*luminosities* can be different).
- In IR6, a higher luminosity reduces the forward low-p_T acceptance.
- Due to the 2nd focus, IR8 can operate at max luminosity without any acceptance penalty for x > 0.01, and a smaller one at lower x

This complementarity will allow for a global optimization. Detector 2 will have a natural advantage for exclusive / diffractive physics, and in particular for detection of nuclei.

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

Ion fragments from ^{238}U





Without 2nd focus:
(EPIC @IR6)

← Z' vs x_{RP}

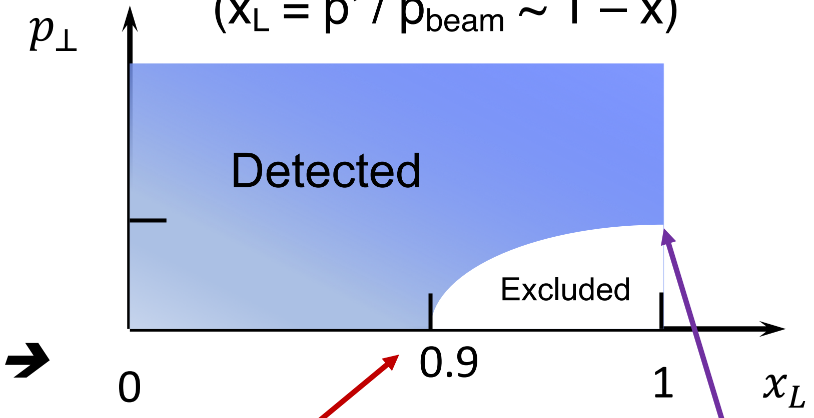
$p_\perp$ vs x_L →

With 2nd focus:
(Detector 2 @ IR8)

Order-of-magnitude improvement in forward acceptance

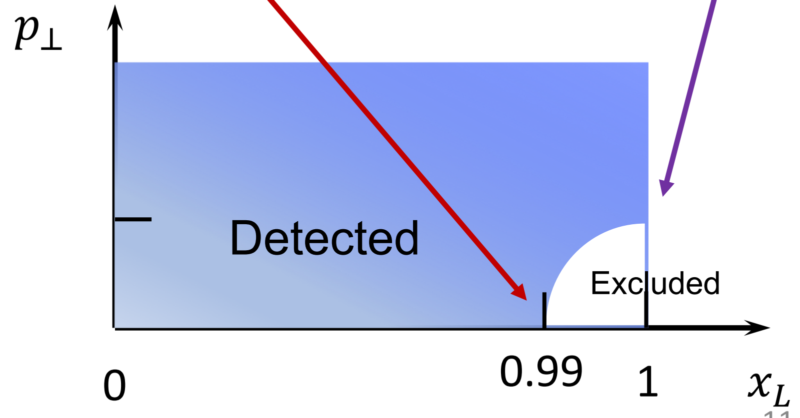
Exclusive protons

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



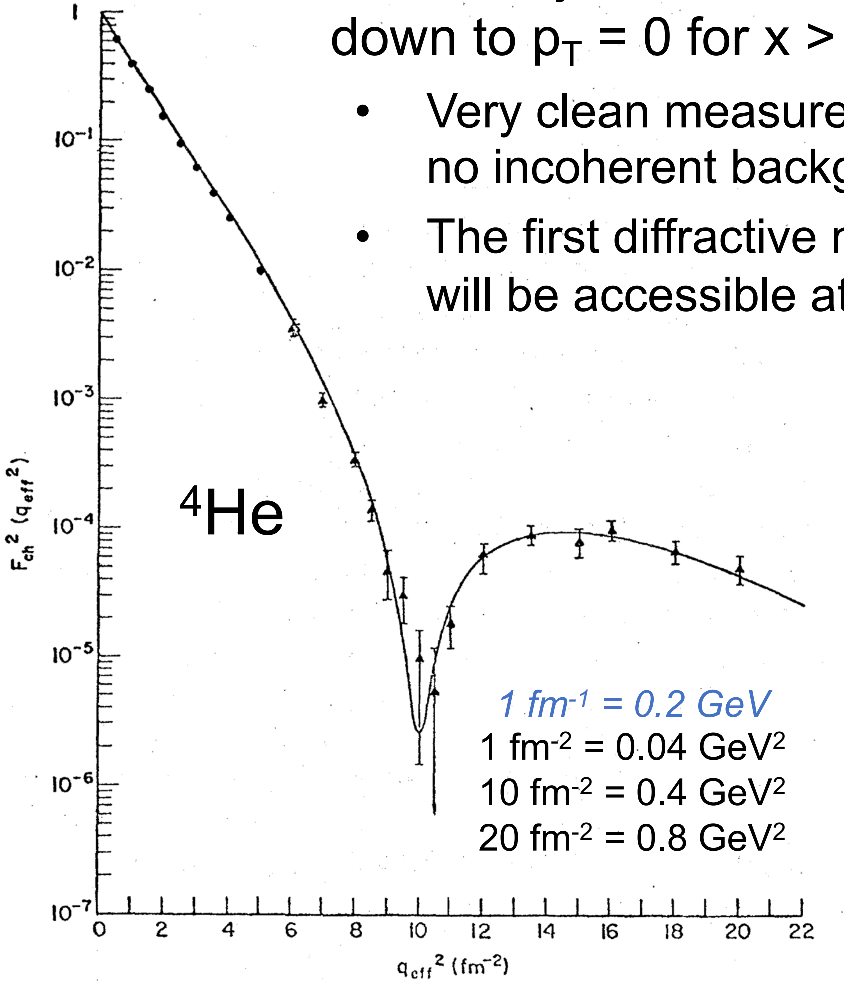
Limited by D and 2nd focus (β_2)

Limited by angular acceptance (β^*)

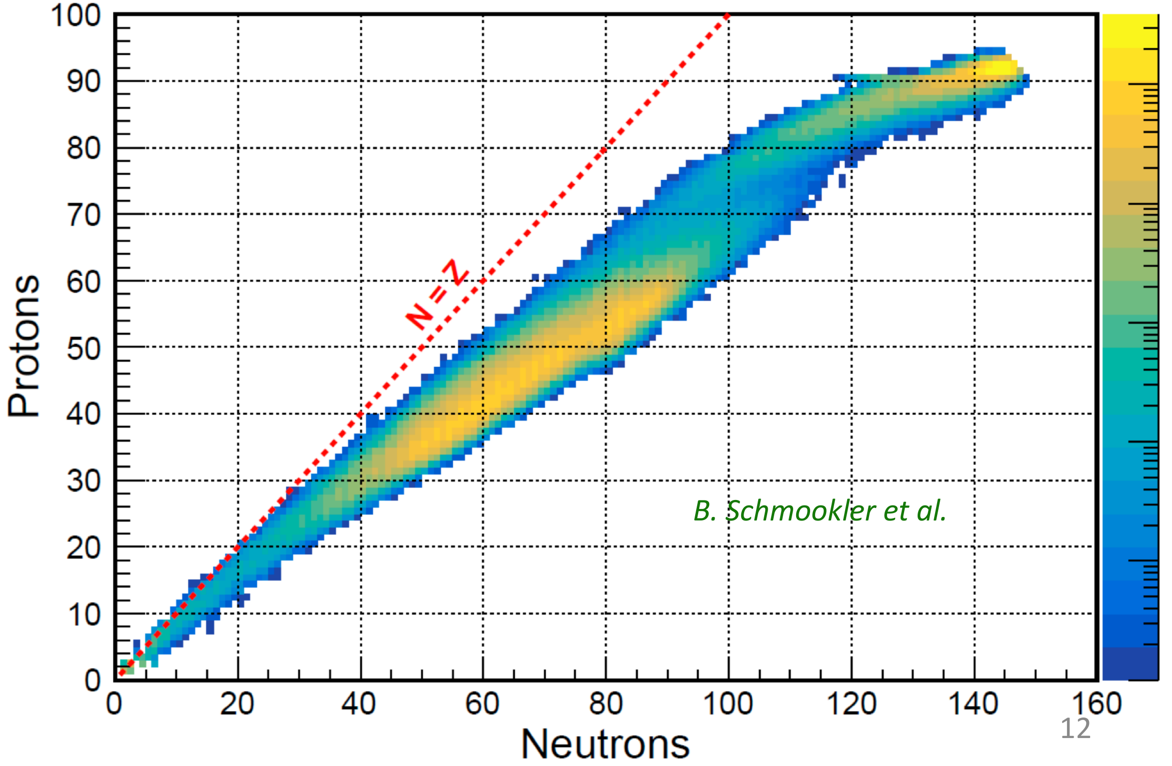


Example: exclusive coherent scattering on nuclei

- For light nuclei, the 2nd focus enables *detection* with essentially 100% acceptance down to $p_T = 0$ for $x > 0.01A$.
  - Very clean measurement with no incoherent background
  - The first diffractive minimum will be accessible at low x.

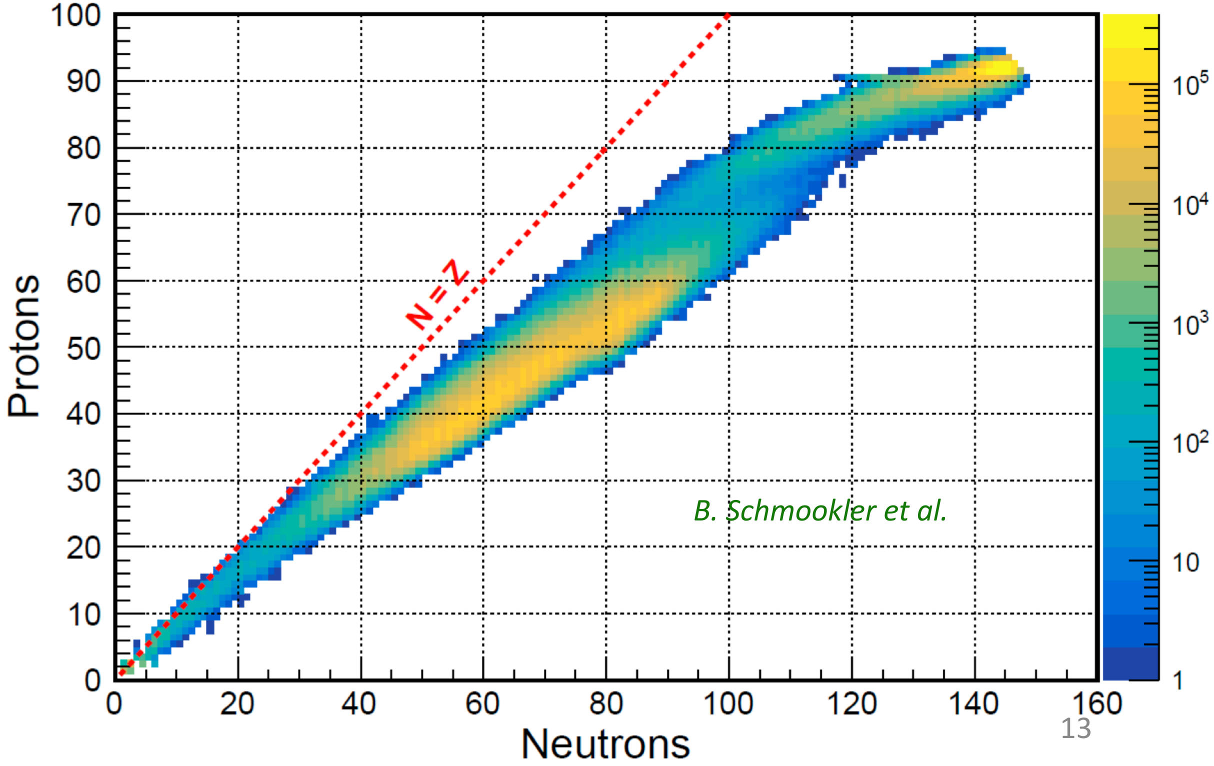


- For heavier nuclei, incoherent events can be suppressed by detecting fragments (including neutrons and photons) from the breakup.
  - Note that spin zero nuclei have only one GPD



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 Zr-90
  - A-2, *etc*, for almost any nucleus
- Tagging of heavy spectators enables, for instance, measurements of reactions on a bound nucleon
- The produced fragments will also contain rare isotopes.
  - Gamma spectroscopy possible by measuring boosted forward-going photons in coincidence
  - Interest from FRIB community



Aspirational goals for a 2nd EIC detector

- **MAGNETIC FIELD –** Solenoid field up to 3T, allowing for high resolution momentum reconstruction for charged particles.
- **EXTENDED COVERAGE** for precision electromagnetic calorimetry – important for DVCS on nuclei.
- **MUONS –** enhanced muon ID in the barrel and (possibly) backward region.
- **BACKWARD HADRONIC CALORIMETER –** Low-x physics, reconstruction of current jets in the approach to saturation.
- **SECONDARY FOCUS –** tagging for nearly all ion fragments and extended acceptance for low-p_T/ low-x protons. Enables detection of short-lived rare isotopes.

Renee Fatemi, EIC 2nd detector WS, May 2023

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

- Please note that these were selected to illustrate particular opportunities
- You are most welcome to add your favorite process!

EIC UG 2nd detector / IP8 working group – a timeline

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

- Spring 2022 – EICUG-SC produced a brochure on a 2nd EIC detector
  - Distributed to same international funding agencies that received copies of the yellow report

- July 2022 – the Det II / IP8 WG was formed. **Everyone is welcome to join!**
  - Conveners: Klaus Dehmelt (CFNS/SBU), 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 were / are already 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

Thank you!