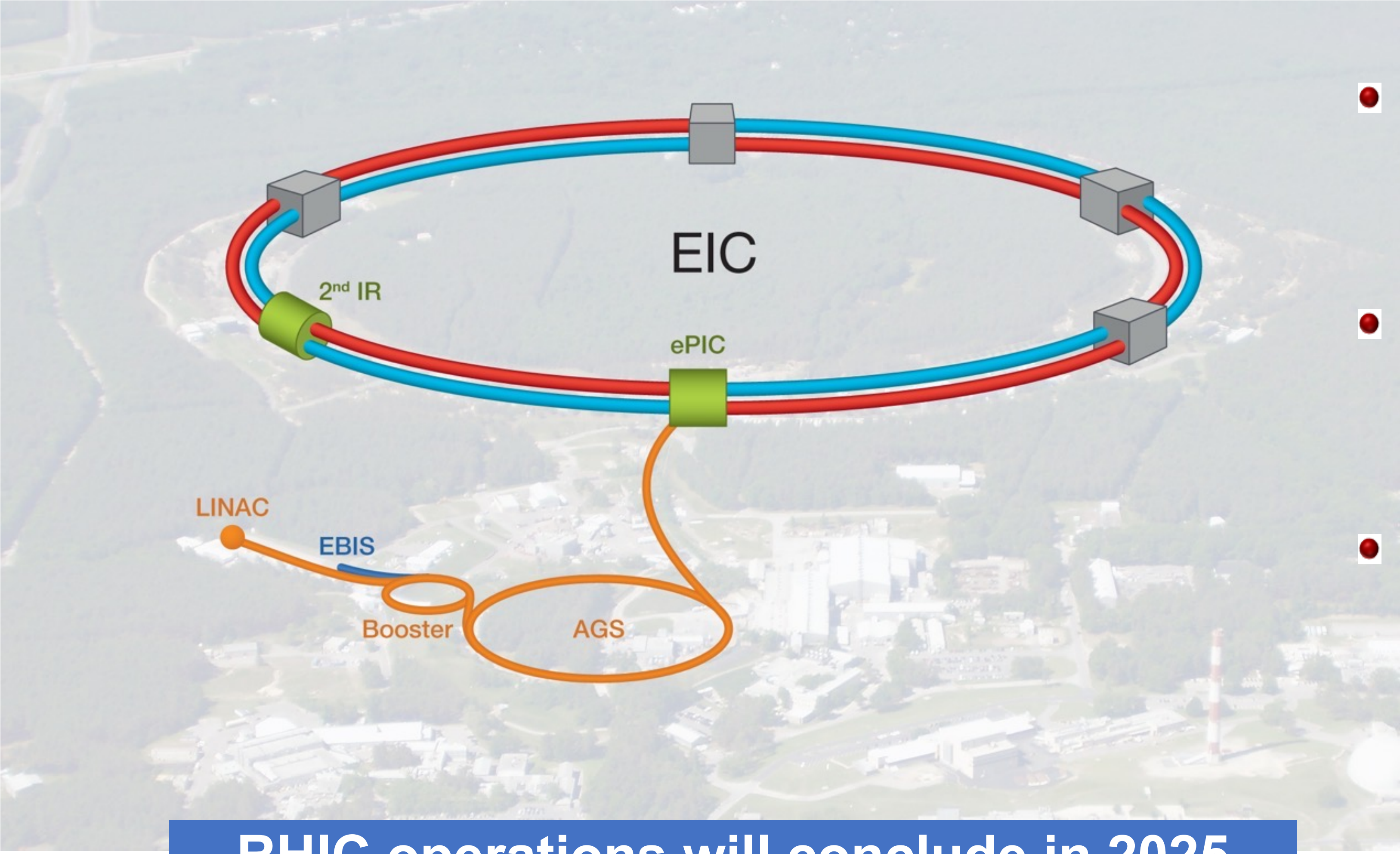
Spin physics at the EIC

Pawel Nadel-Turonski
University of South Carolina

Disclaimer: This talk is not given on behalf of the EIC project or the EPIC collaboration.

Diffraction and Low-x Meeting,
Palermo, Italy, September 8-14, 2024

The Electron-Ion Collider at Brookhaven National Laboratory



RHIC operations will conclude in 2025 and construction of the EIC will begin

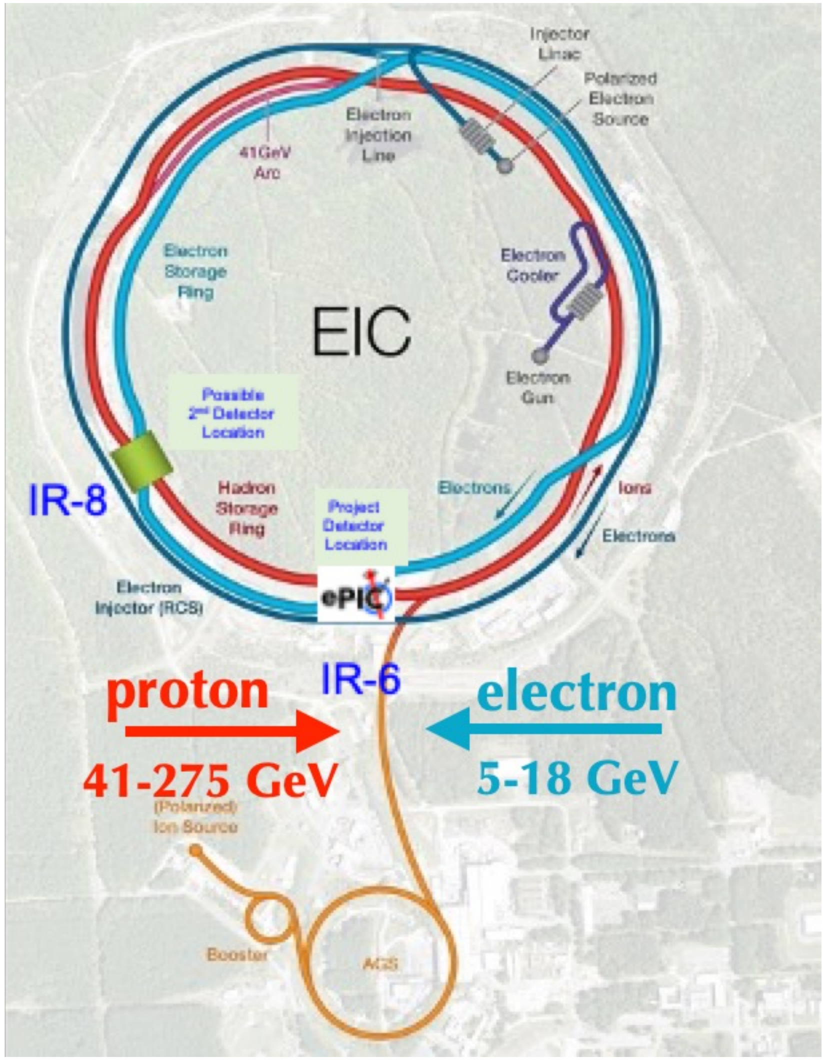
- Procurement of long-lead items has started (CD-3A).
- Accelerator and detector work is ongoing.
- The EIC user group (UG) now comprises:
  - 1391 collaborators from
  - 277 institution in
  - 37 countries

EIC project requirements

Project Design Goals

- High luminosity: L= 10^{33} – 10^{34}cm^{-2}sec^{-1}, 10 – 100 fb^{-1}/year
- Polarized electron and proton beams: 70%
- Center-of-mass energy: E_{cm} = 20 – 140 GeV
- Full range of ion species: protons – Uranium
- Good detector acceptance and background conditions
- Accommodate a second Interaction Region (IR-8)

The conceptual design scope and expected performance meets or exceed NSAC Long Range Plan (2015) and the EIC White Paper requirements endorsed by NAS (2018).



Note: the maximum ion energy is (Z/A)*275 GeV/A, *e.g.*, 108 GeV/A for ^{208}Pb and 183 GeV/A for ^{3}He.

Polarized light ions and positrons

polarized ions

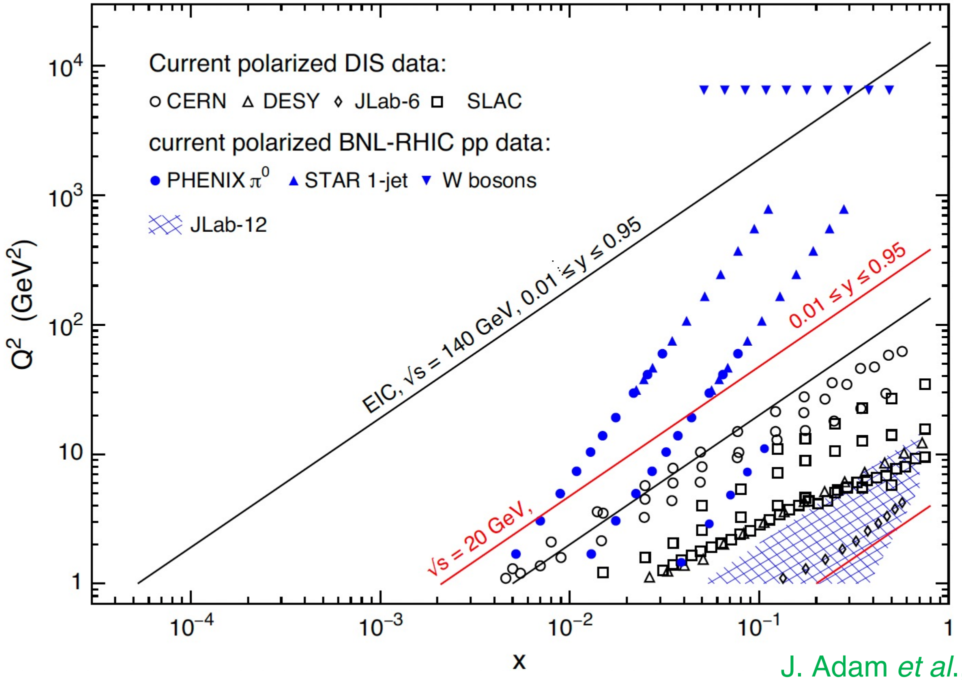
- ^{3}He – supported in the baseline design.
- ^{7}Li – is straightforward for the accelerator, but requires building a new polarized ion source.
- ^{2}H – polarized deuterium is difficult to accelerate and store with the available snakes.
  - There are a few discrete energies that offer simpler solutions
  - Tensor-polarized deuterium poses a universal polarimetry challenge

positrons

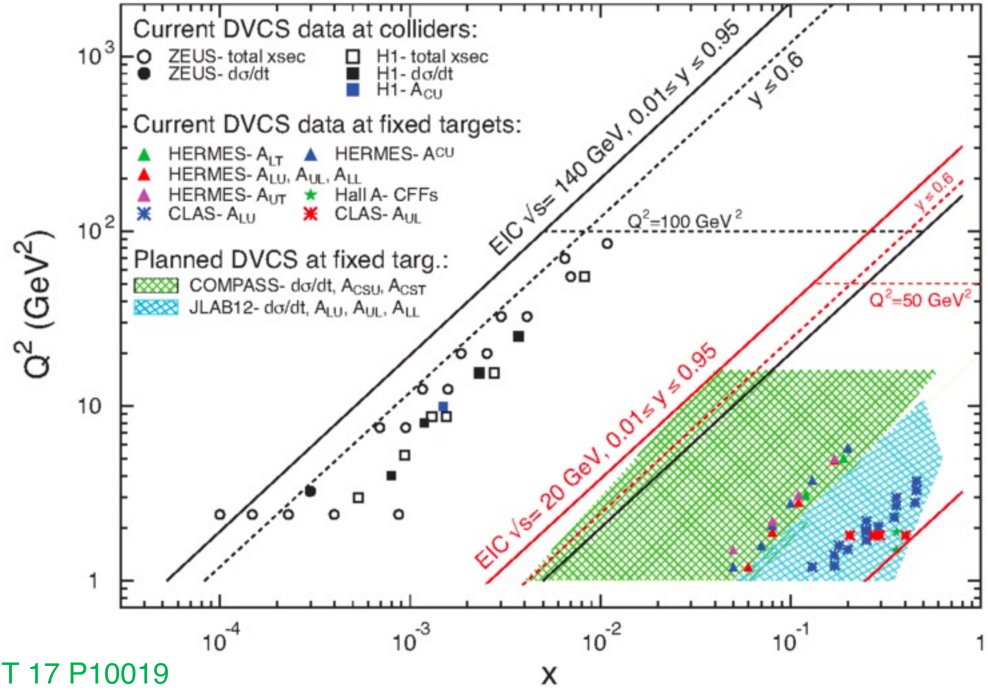
- A high intensity beam of *unpolarized* positrons can be accumulated as in HERA.
  - The polarity of all lepton-ring magnets would have to be reversed – not likely early on
- A *polarized* positron beam is possible but would require a strong polarized source (*cf.* JLab).
  - The EIC lepton ring is smaller than in HERA, and the self-polarization (Sokolov-Ternov) is weaker.

Kinematic coverage

Polarized



DVCS
(exclusive production of a photon)



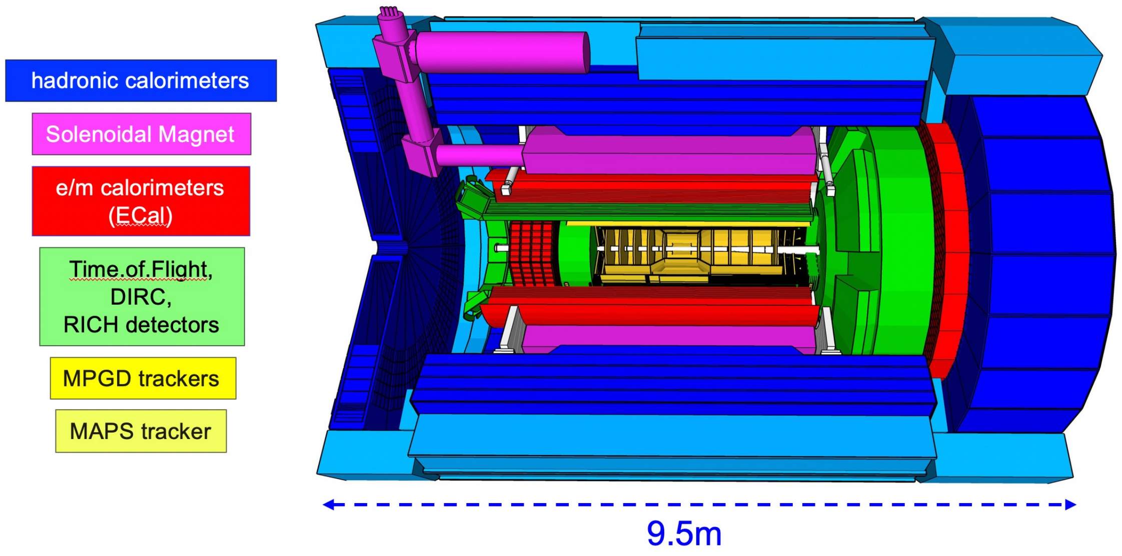
J. Adam *et al.*, 2022 JINST 17 P10019

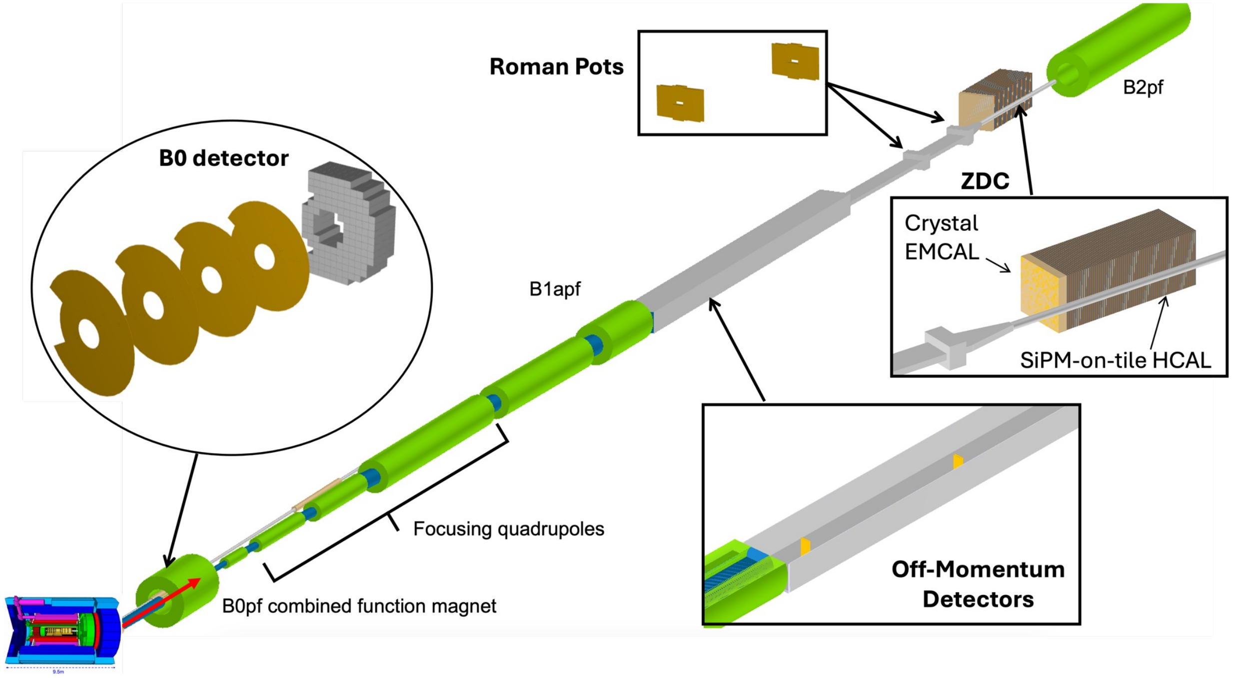
- The EIC will greatly expand the kinematic coverage for polarized measurements.

- Perhaps more surprising is that the EIC kinematic coverage will, for certain processes, also improve on HERA, which had a higher energy (27x920).

- One important reason for this is the EIC detector, including its extensive far-forward coverage.

The ePIC detector at IR6 of the EIC



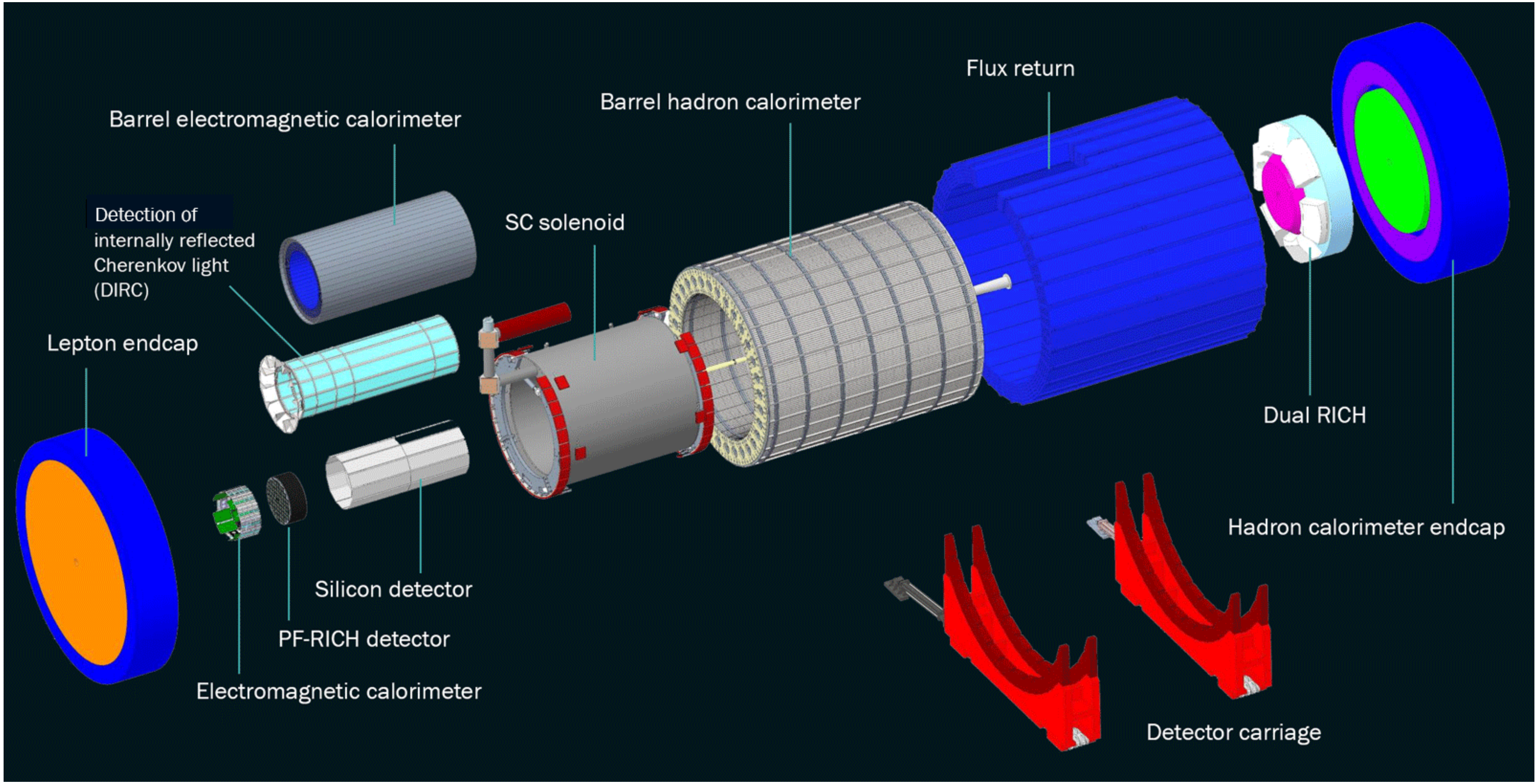


- The central detector provides hermetic acceptance for all subsystem categories.
  - Tracking, calorimetry, particle identification (PID)
- The 4π PID capabilities add flavor sensitivity lacking in many high-energy experiments.

- Comprehensive set of forward detectors at several locations.
  - Inside B0, off-momentum, Roman Pots, ZDC
- Fully integrated with the accelerator

→ talk by Alexander Jentsch on Friday

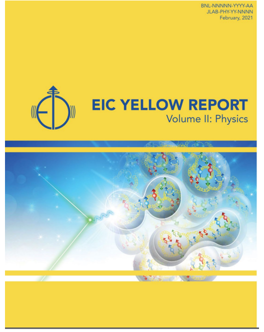
The ePIC detector – subsystems



Simulations and projections for the EIC

- The EIC supports a comprehensive spin program.

- Most of the measurements were outlined in the EIC Yellow Report.
  - arXiv:2103.05419 [physics.ins-det] (2021)
  - Nucl. Phys. A 1026 (2022) 122447



EIC YELLOW REPORT
Volume II: Physics

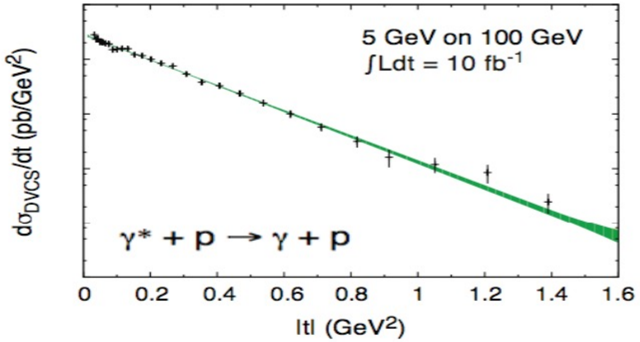
- Additional studies were made for the three proposals reviewed by the EIC detector proposal advisory panel (DPAP) in late 2021.

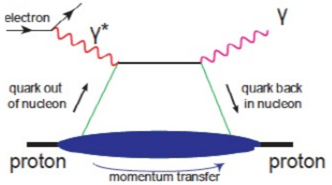
- A more comprehensive update is expected for the ePIC technical design report (TDR).
  - Expected in late 2024

3D structure - spatial imaging at the EIC

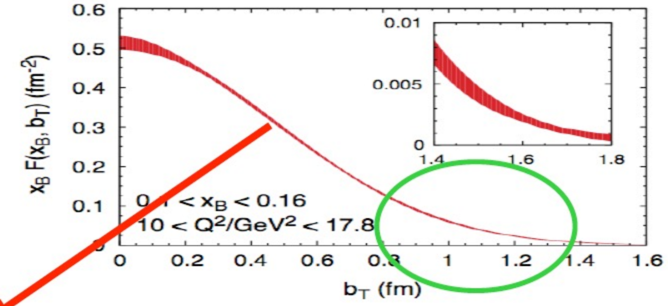
Slide borrowed from Jianwei Qiu, “Physics at the Electron-Ion Collider”, Phenomenology 2020 Symposium.

❑ DVCS at EIC:



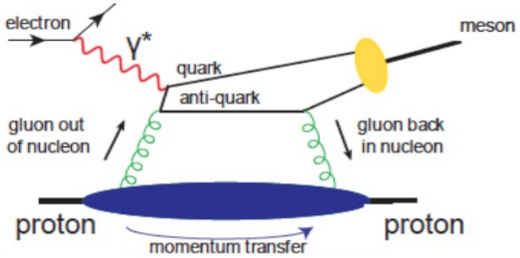


Factorization → **GPDs** **F.T.** →



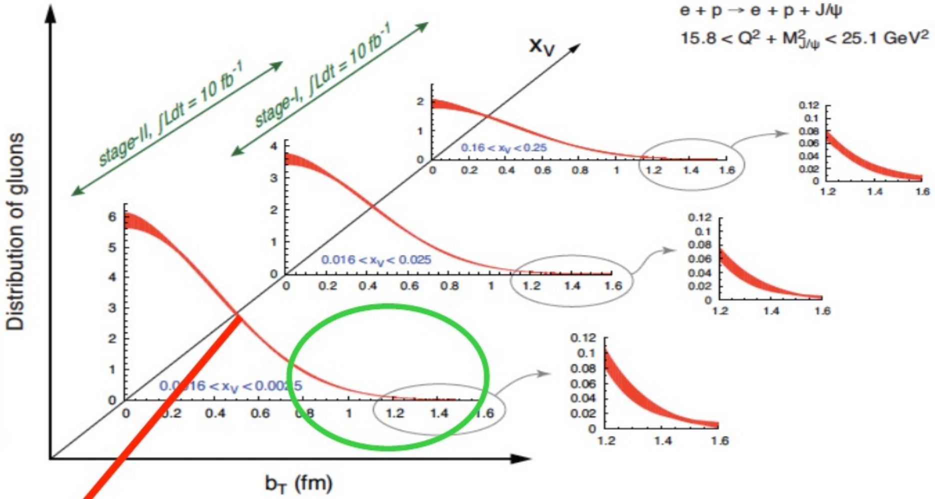
Proton radius of quark dist.(x)!

❑ “Seeing” the glue at EIC:



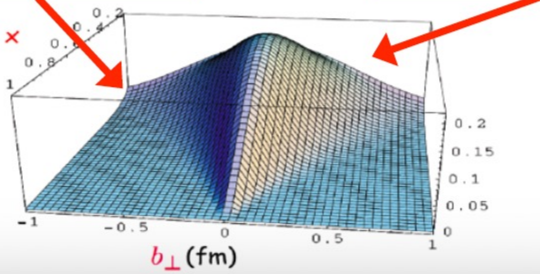
J/Ψ, Φ, …

F.T. **t-dep** →



How far does glue density spread?

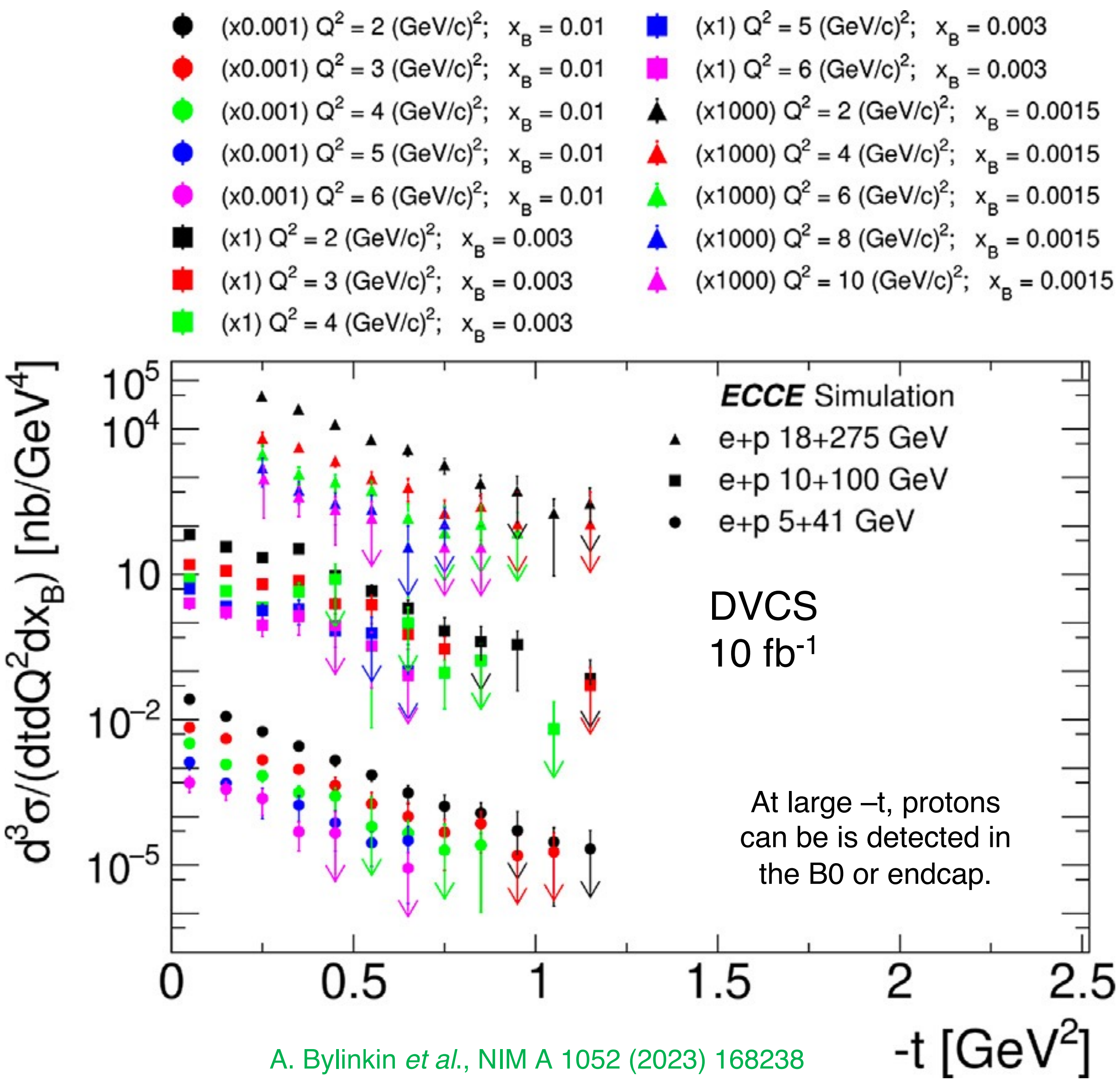
How fast does glue density fall?



Proton radius of gluons (x)!

Only possible at EIC!

3D structure - EIC projections for DVCS and J/psi

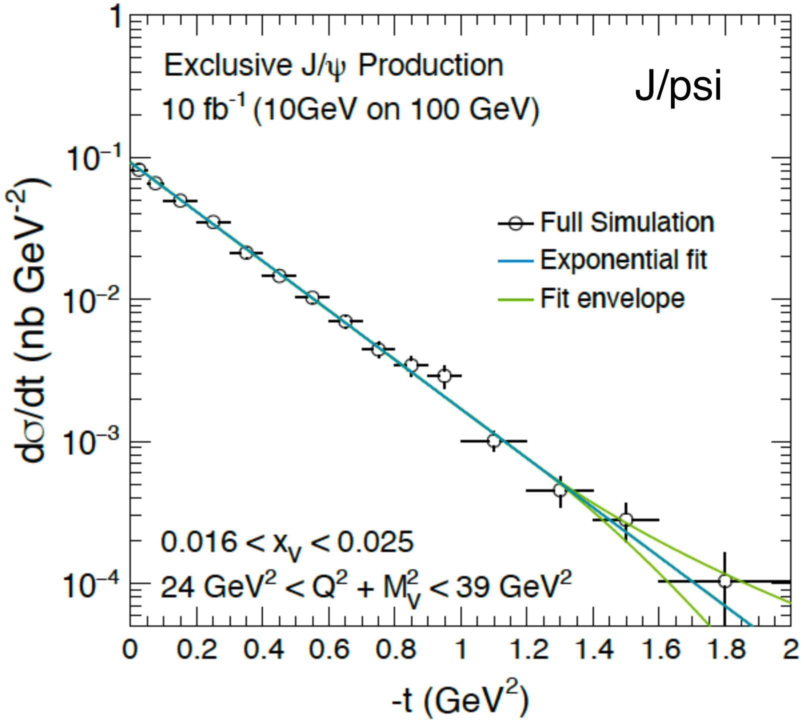


DVCS
10 fb^{-1}

At large –t, protons can be is detected in the B0 or endcap.

A. Bylinkin *et al.*, NIM A 1052 (2023) 168238

- At nominal luminosity, 10 fb^{-1} at 10+100 GeV will correspond to 1-2 months of beam time.
  - Max luminosity at 10x275 GeV
- Equal amounts of longitudinally and transversely polarized protons.
  - GPD E

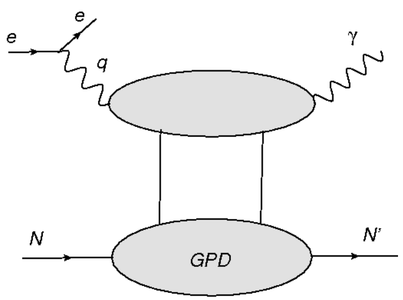


J/psi

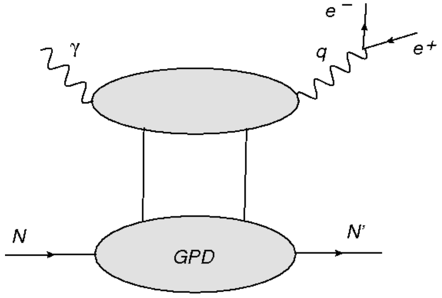
J. Adam *et al.*, 2022 JINST 17 P10019

3D structure – timelike Compton scattering (exclusive dilepton photoproduction)

(spacelike) DVCS



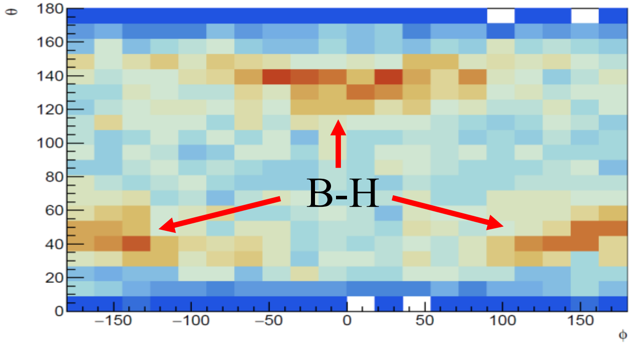
timelike Compton scattering (TCS)



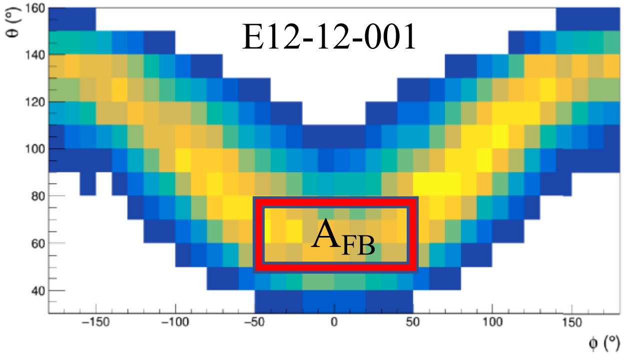
Initial photon spacelike, final photon real

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

EIC detector

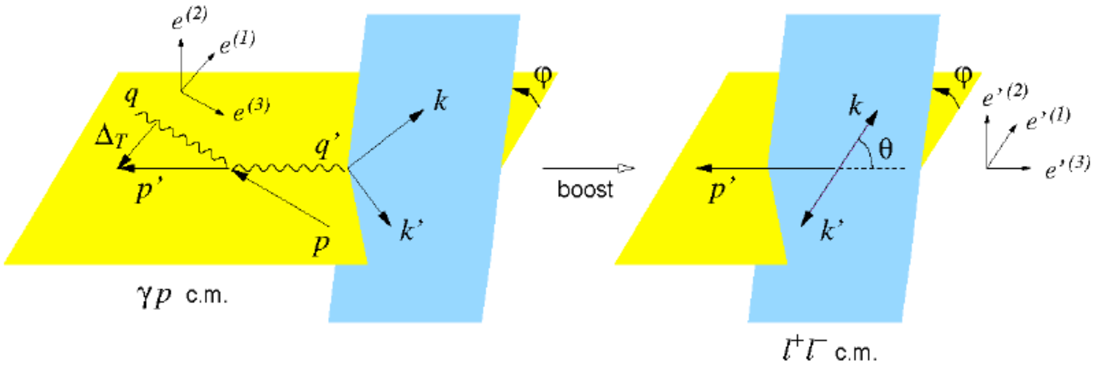


CLAS12



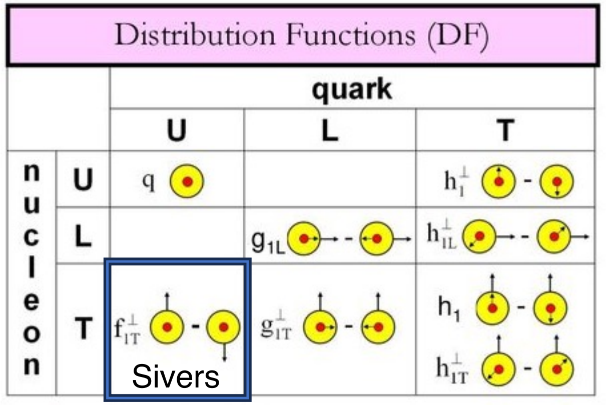
P. Chatagnon, EIC UG meeting, Warsaw, 2023

- Comparison of DVCS and TCS can test universality of GPDs.
  - *cf.* (spacelike) DIS and (timelike) Drell-Yan for PDFs
- TCS analysis uses the lepton c.m. angles θ and ϕ
- EIC benefits from excellent dilepton acceptance.
  - Straightforward interpretation (full θ - ϕ range).
  - Many fixed-target experiments have limited forward acceptance leading to loss of useful statistics and complicated systematics.



- 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

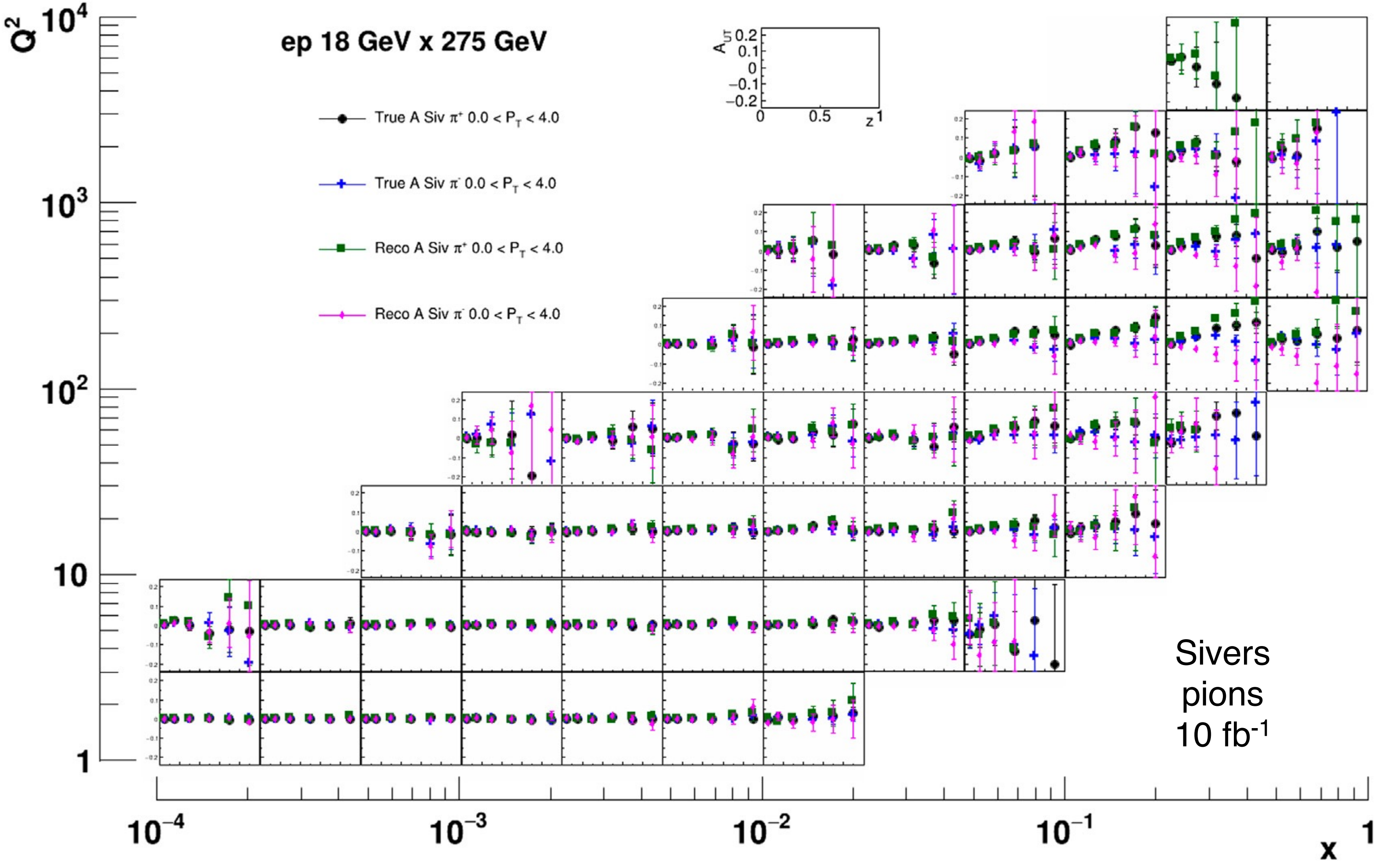
3D structure - transverse momentum distributions (TMD PDFs) in SIDIS



Distribution Functions (DF)				
		quark		
		U	**L**	**T**
nucleon	**U**	q		$h_1^{\perp}$
	L		g_{1L}	$h_{1L}^{\perp}$
	T	$f_{1T}^{\perp}$ Sivers	$g_{1T}^{\perp}$	h_1 $h_{1T}^{\perp}$

- A_{UT} as a function of z: small uncertainties already with 10 fb^{-1}.
  - Early results?
- Detailed mapping possible once luminosity ramps up to nominal values

R. Seidl *et al.*, NIM A 1049 (2023) 168017



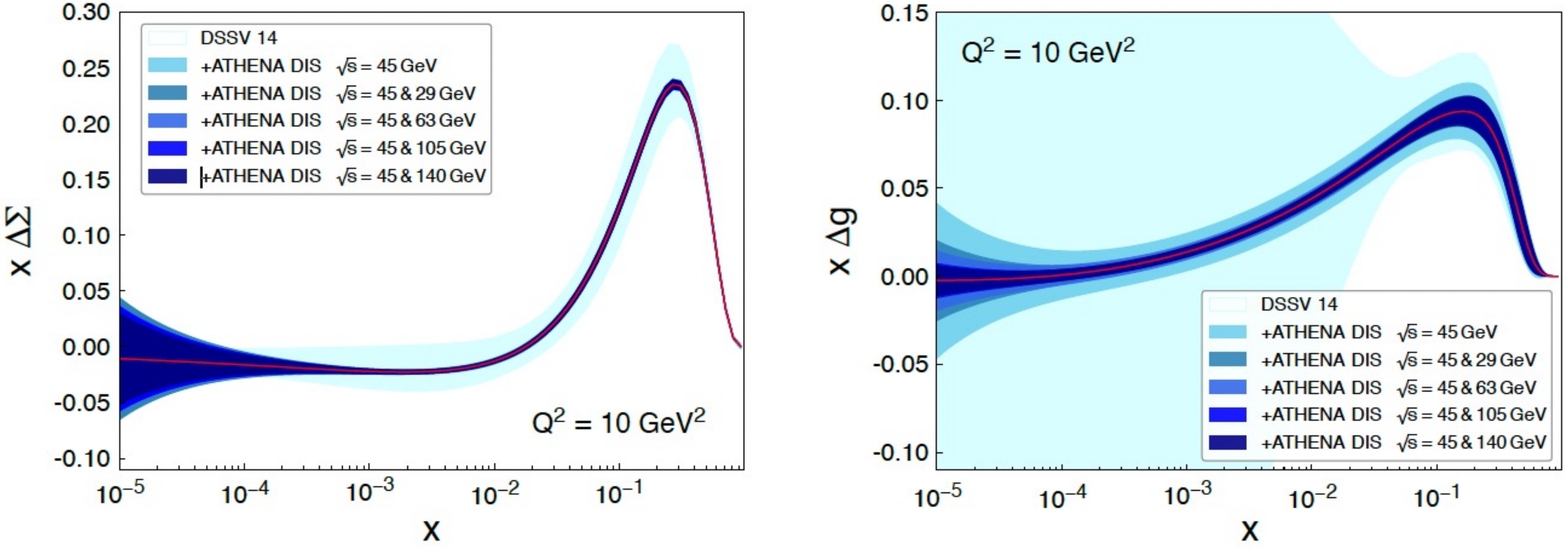
Sivers
pions
10 fb^{-1}

Spin of the nucleon in polarised inclusive DIS

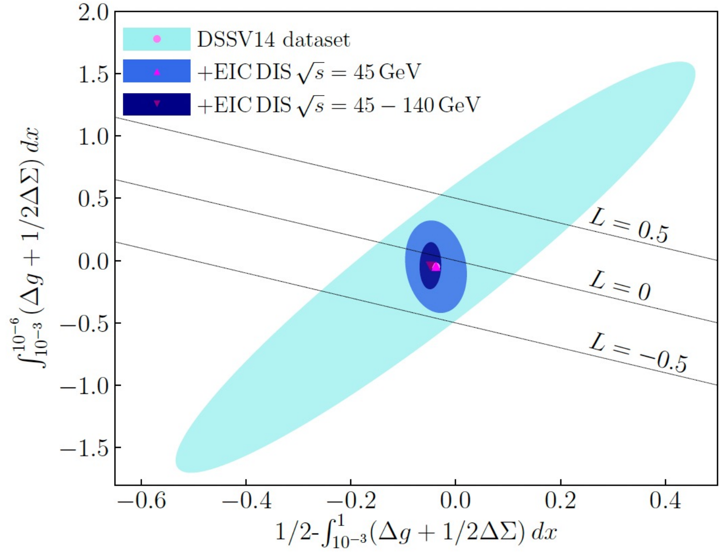
Nucleon spin:

$$\frac{1}{2}=\frac{1}{2}\Delta\Sigma+\Delta G+L_Q+L_G$$

J. Adam *et al.*, 2022 JINST 17 P10019



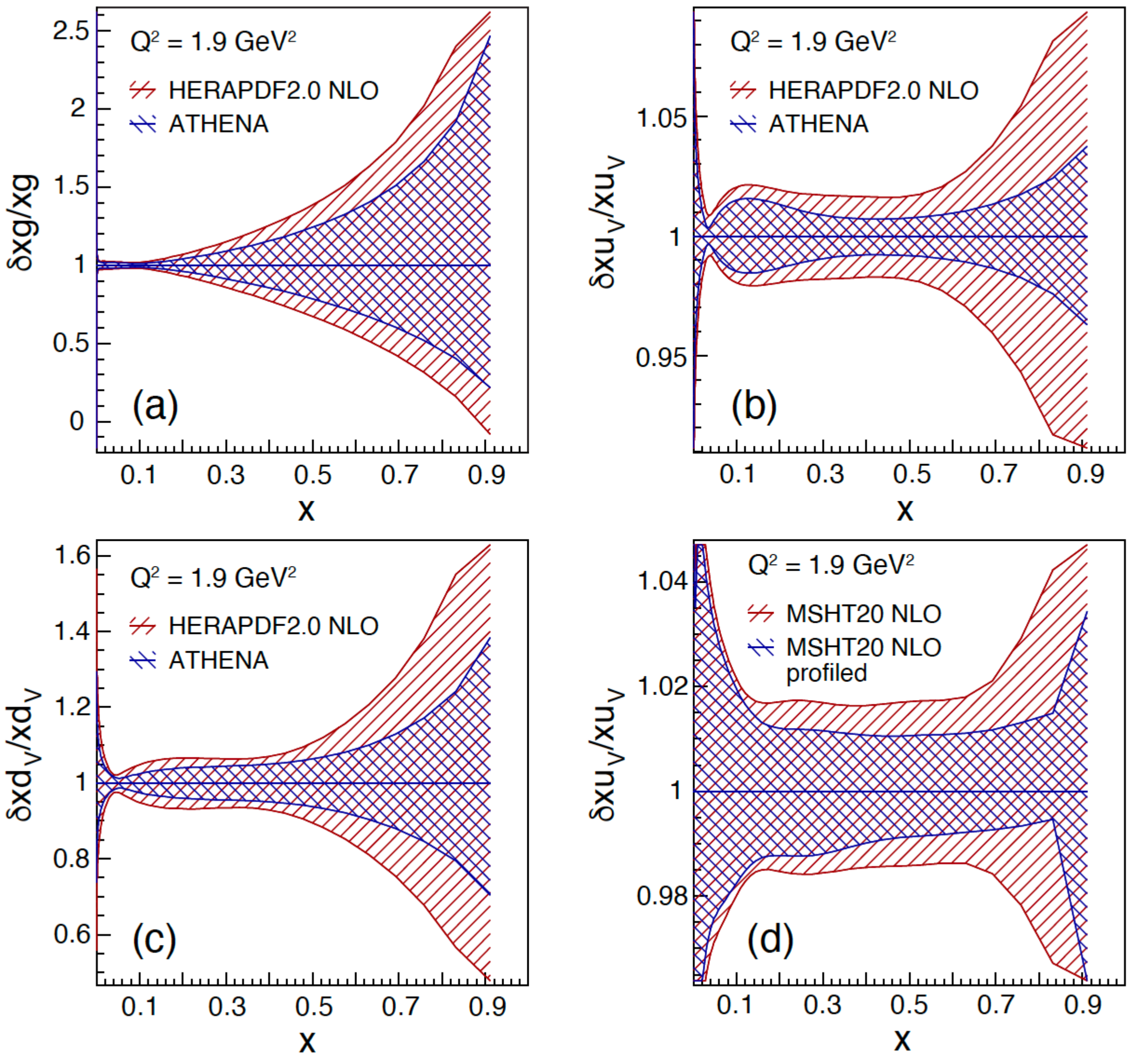
E. Aschenauer *et al.*, arXiv:2007.08300 [hep-ph] (2020)



- Constraints imposed on ΔΣ and ΔG by adding EIC pseudodata with different combination of cm energies to DSSV.
- The inclusive measurements also pose a constraint on L. But while this will be greatly improved by the EIC, measurements of OAM will still be important.

EIC impact on high-x PDFs

J. Adam *et al.*, 2022 JINST 17 P10019

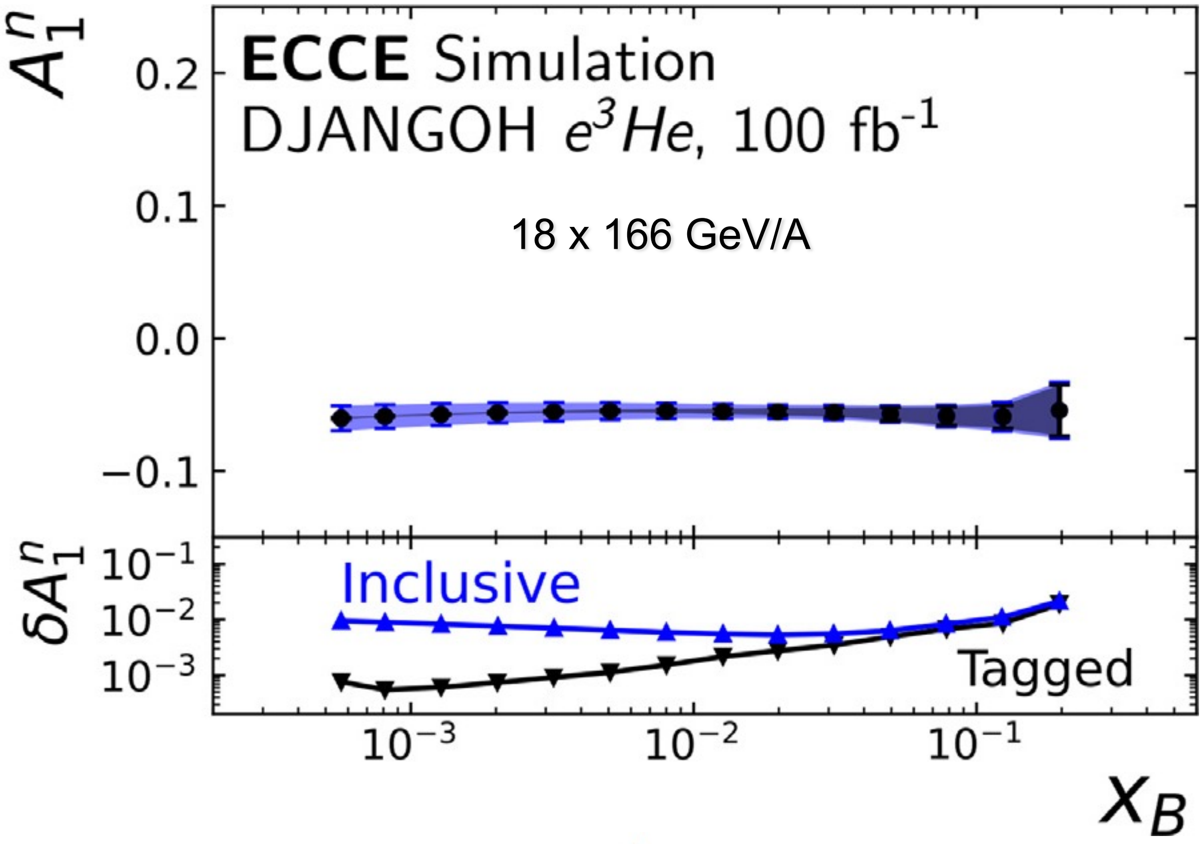


- Panels (a)-(c) show the constraints from HERA and the impact of adding EIC data (labelled ATHENA).
- Panel (d) shows the impact of adding the EIC to a fit that incudes data from the LHC.
  - Note the lightly different vertical scale than in panels (b) and (d)

Neutron structure – an example of nuclear spectator tagging

- The ePIC forward detectors can tag spectators protons from deuterium and ^{3}He.
- Measuring the doubly tagged neutron structure function A^n_1 could reduce the uncertainties at low x.
- Tagging can be applied to a wide range of processes and observables.

A. Bylinkin *et al.*, NIM A 1052 (2023) 168238



$$A_1 = \frac{A_{\|}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)},$$

(longitudinal and transverse target)

A second detector for the EIC

- Discovery
  - 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.

- Lessons from HERA
  - Combining data from H1 and ZEUS reduced systematic uncertainties.
  - This would be even more important for the EIC where many measurements will be systematics limited due to the much higher luminosity.

- Lessons from Fermilab
  - The D0 detector came 7 years after CDF, but both made comparable contributions to the science program.
  - Adding a 2nd detector improves physics output without significantly adding to the operations costs

A second detector for the EIC – new opportunities

The details the 2nd detector are not yet fully defined. Users will be able to make a significant impact. But 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
  - A 2nd focus at a location with high dispersion improves acceptance even with a small beta*
  - 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 any 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) ?

Double DVCS

Challenging measurement, but Illustrative of many EIC / D2 features.

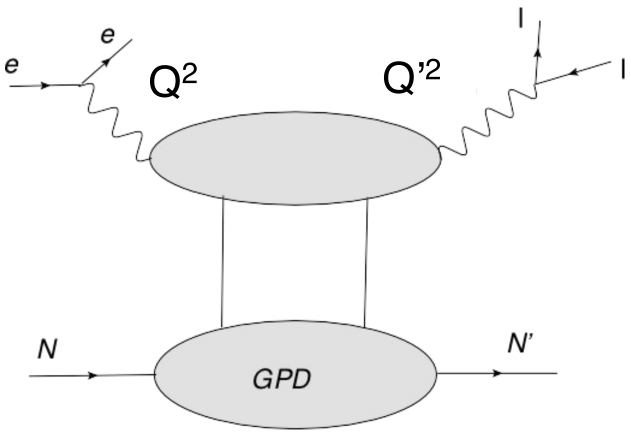
- DVCS probes the GPD along the $x = \xi$ line;
- Double DVCS can access GPDs outside of this line.
  - Important experimental cross check
  - Low rates challenging, but cross section increases at lower x

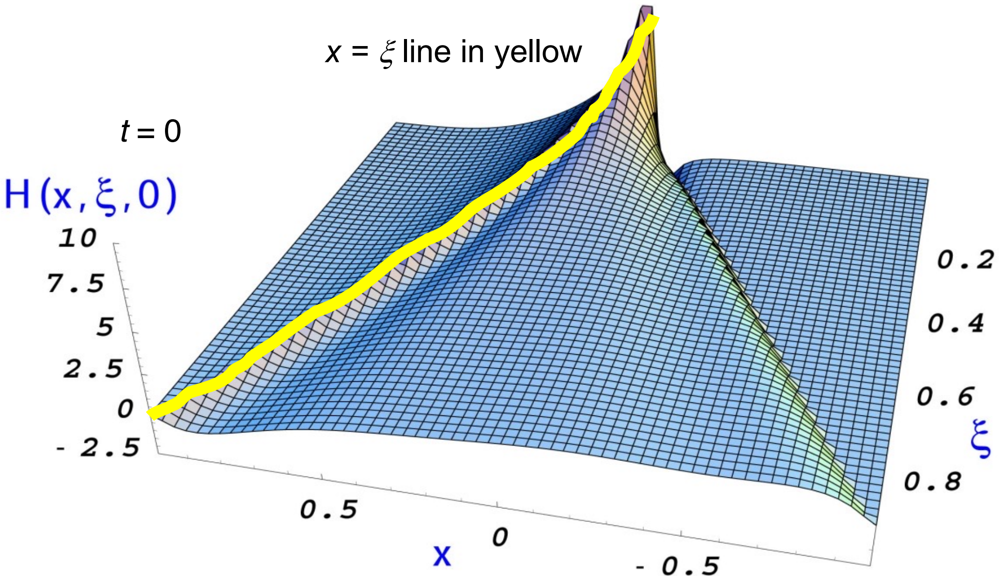
- Lepton acceptance and identification
  - Muon ID is *necessary* in order to distinguish the scattered electron from the DDVCS decay leptons
  - EIC di-muon acceptance helpful (as in TCS)

- Proton acceptance in IR with second focus
  - DDVCS measurements will focus on low *t*
  - A 2nd focus enables 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

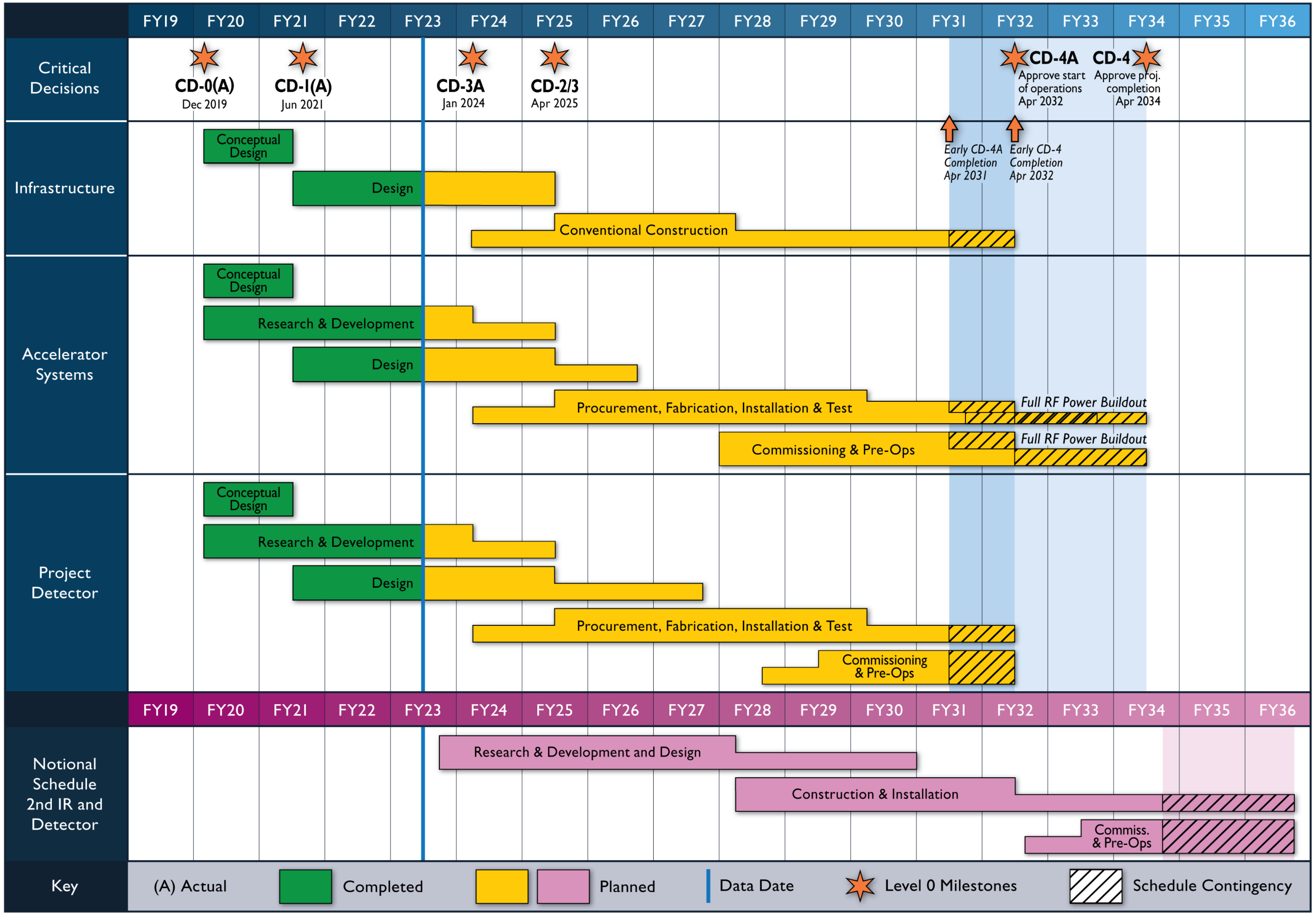



$x = \xi$ line in yellow

$t = 0$

Reference schedule

Jim Yeck, 2nd EIC detector workshop, May 2023



Tentative schedule for a 2nd detector

Thank you!