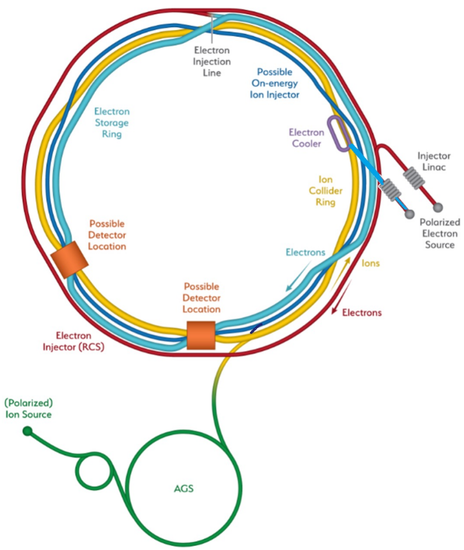
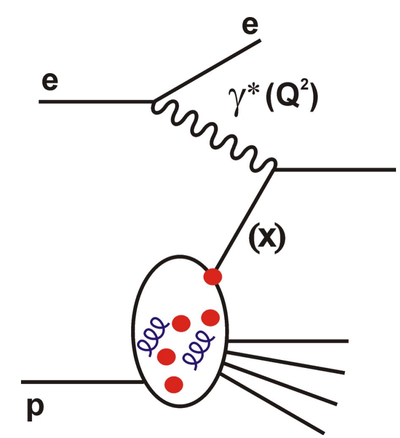
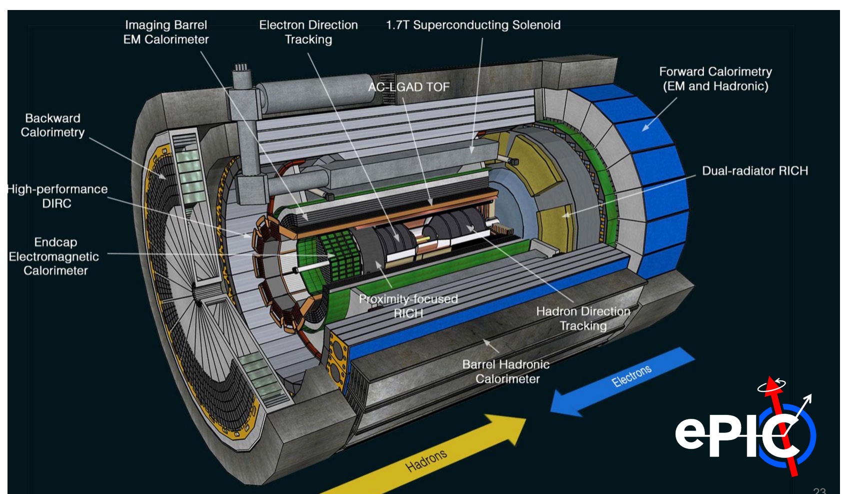
EIC Overview and UK Involvement

Paul Newman (Birmingham)





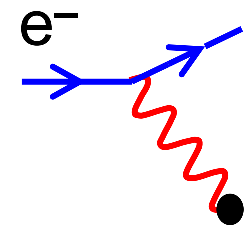
EIC-UK Gathering
York, 8 December 2025



Borrowing heavily from slides by many others

Probing the Proton with Electrons

Simple uncertainty principle arguments:



Resolved dimension: $\Delta x \sim \frac{200\text{MeV}}{E}$ fm

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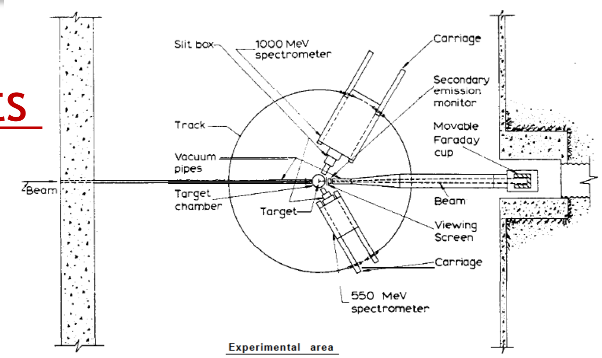


1950s, Hofstadter, 200 MeV electrons on fixed targets

First observation of finite proton size

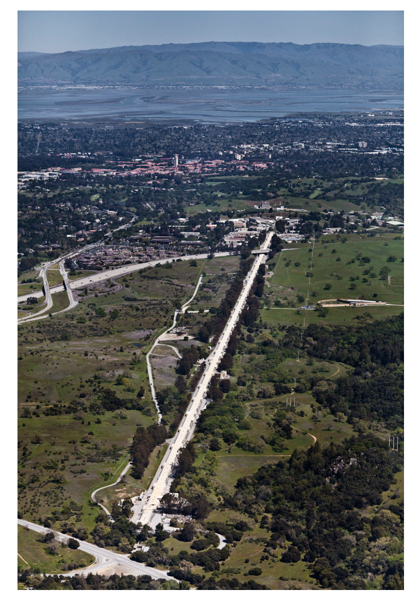
1969, SLAC, 20 GeV electrons on fixed targets

Direct evidence of scattering from point-like quarks

1990s-2000s, HERA, collider
equivalent to 50 TeV electrons
on fixed targets

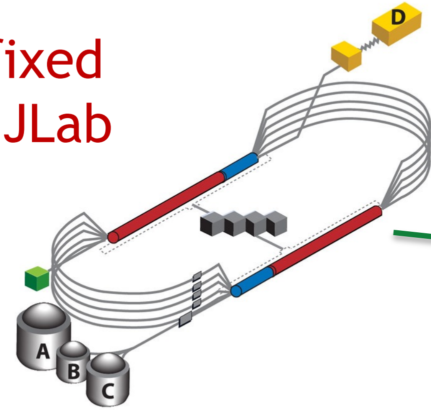
Partonic longitudinal structure
to momentum fractions $x<10^{-4}$

2030s, EIC …

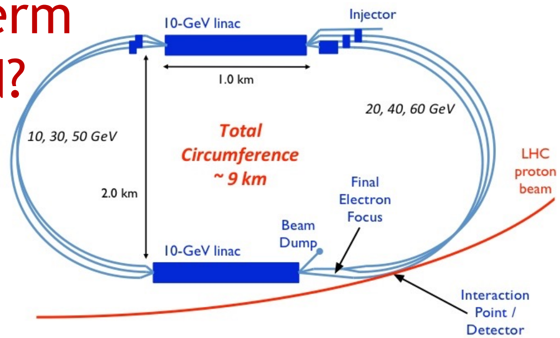


Current & Future ep Colliders

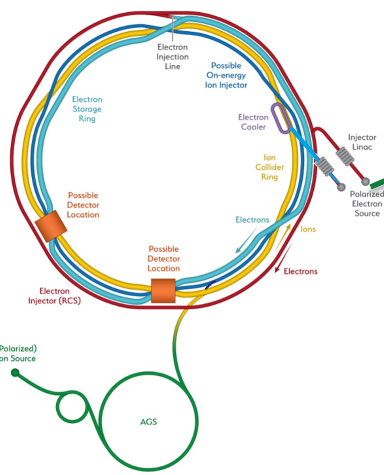
Ongoing fixed target @ JLab

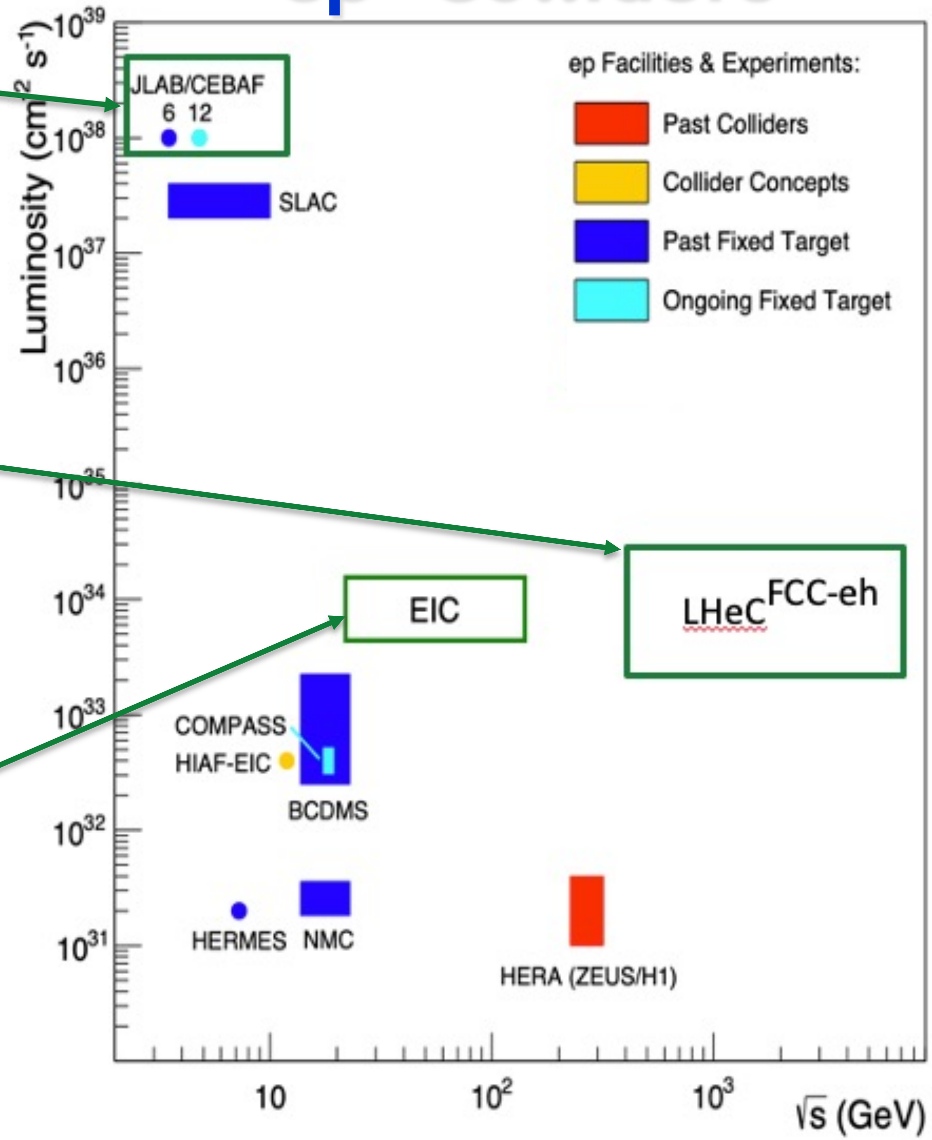


Longer-term @ CERN?



On-target for early 2030s @ BNL





See arXiv:2503.18208: 'Future Opportunities with Lepton-Hadron Colliders'

Crude Mapping Between Physics & Facilities

Partons with decreasing x →

[Kong Tu]

High x (Fixed Target/JLab)
Basic Structure

Intemediate x (EIC)
Emergent properties

Low x (HERA / LHeC)
Non-linear dynamics

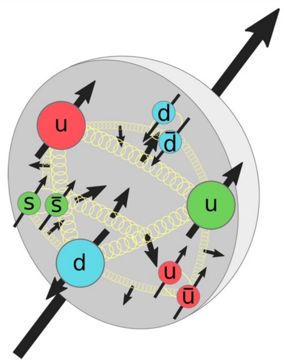
Very Low x
(LHeC,FCC-eh)
The unknown

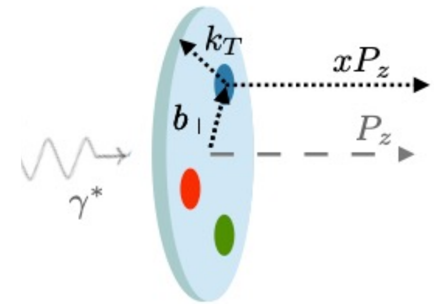
Fundamental Questions for the EIC

- How are the proton mass and spin generated from quark and gluon interactions?

… and what is the mechanism behind confinement?

Atom:	Binding/Mass = 0.00000001
Nucleus:	Binding/Mass = 0.01
Proton:	Binding/Mass = 100

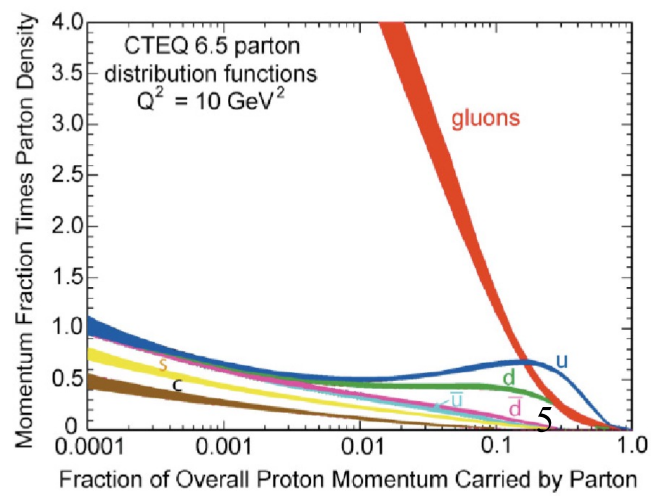




- What does the proton look like in 3D?

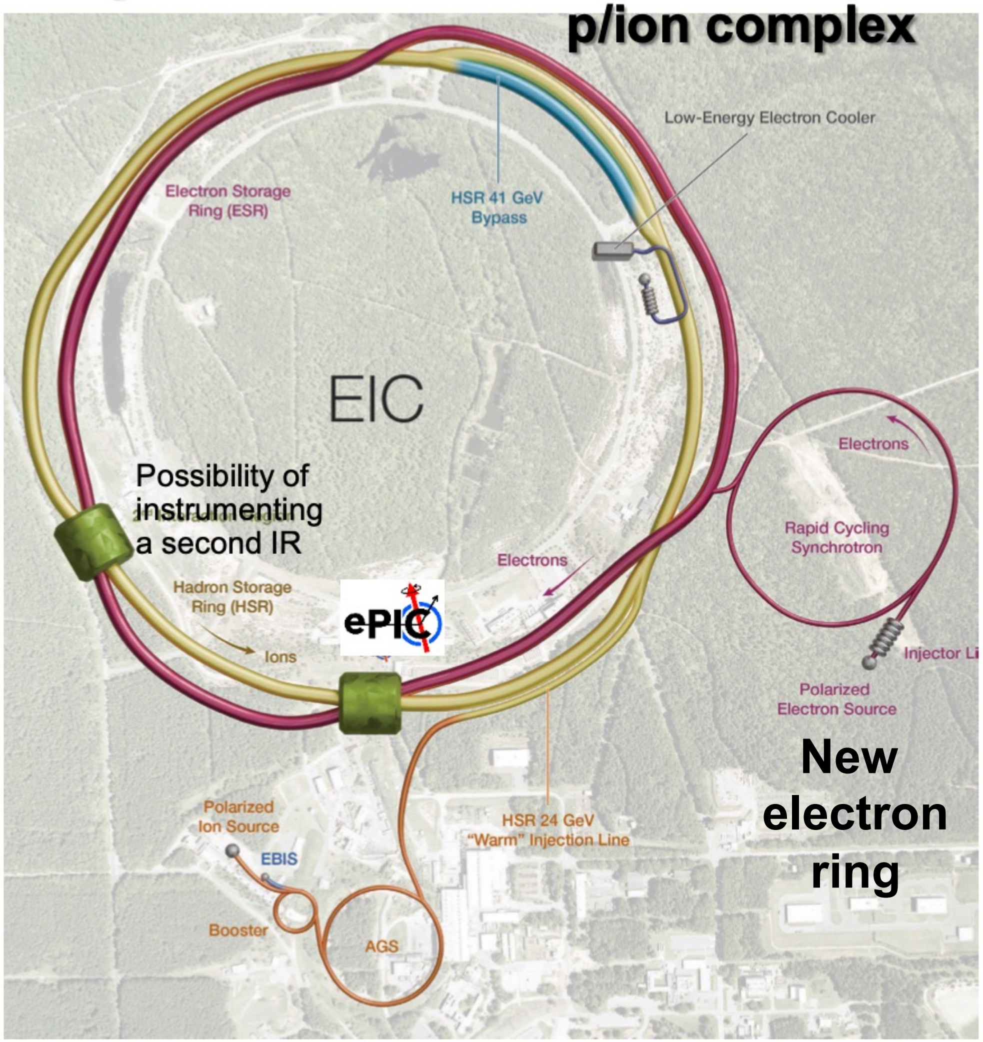
- What is the QCD science of high density systems of gluons?

… and how is the low x growth of the gluon density tamed?



The Electron-Ion Collider (BNL)

Usage of RHIC tunnel and RHIC p/ion complex



Specifications driven by science goals:

- Energy range **28 < $\sqrt{s}$ < 140 GeV**

World's first …

- High lumi ep Collider

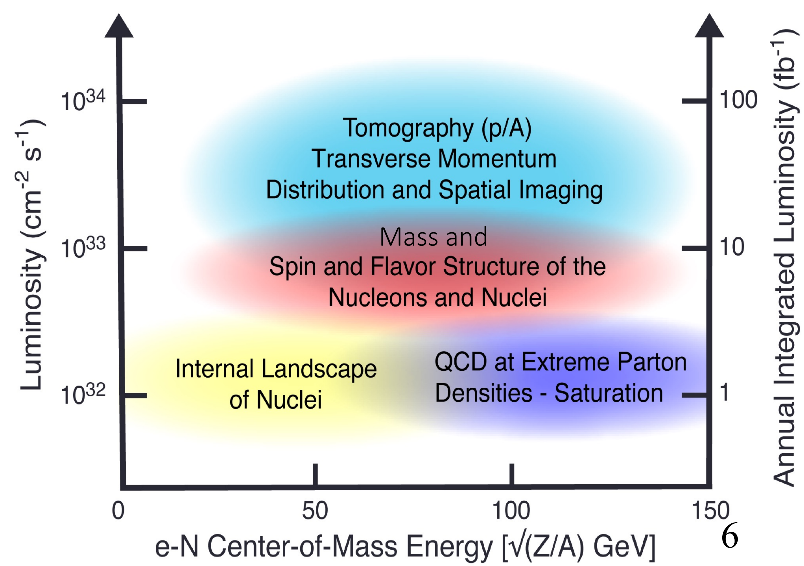
(~ 10^{33} -10^{34} cm^{-2} s^{-1})

- Double-polarised DIS collider

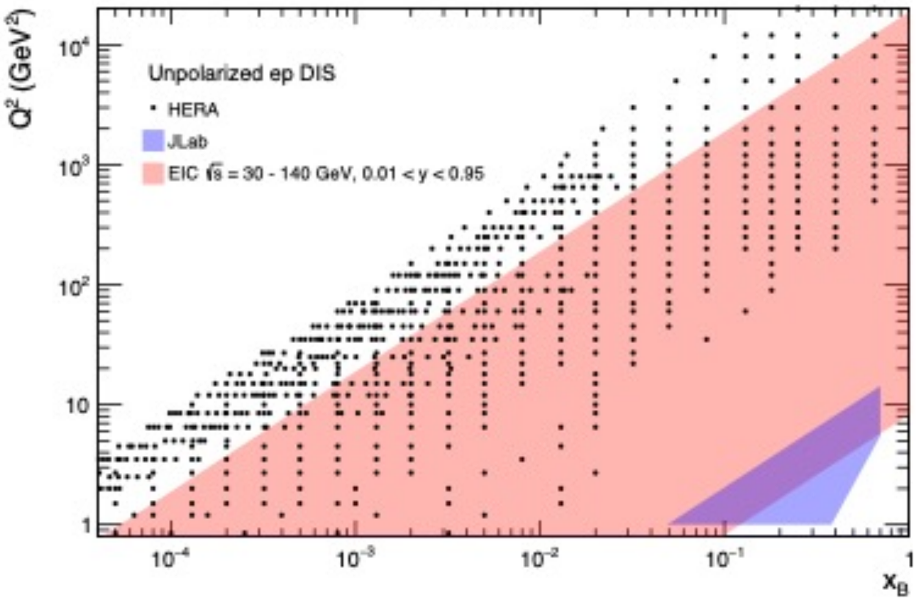
(~70% for leptons & light nuclei)

- eA collider

(Ions ranging from H to U)



EIC Kinematic Range v Previous Data



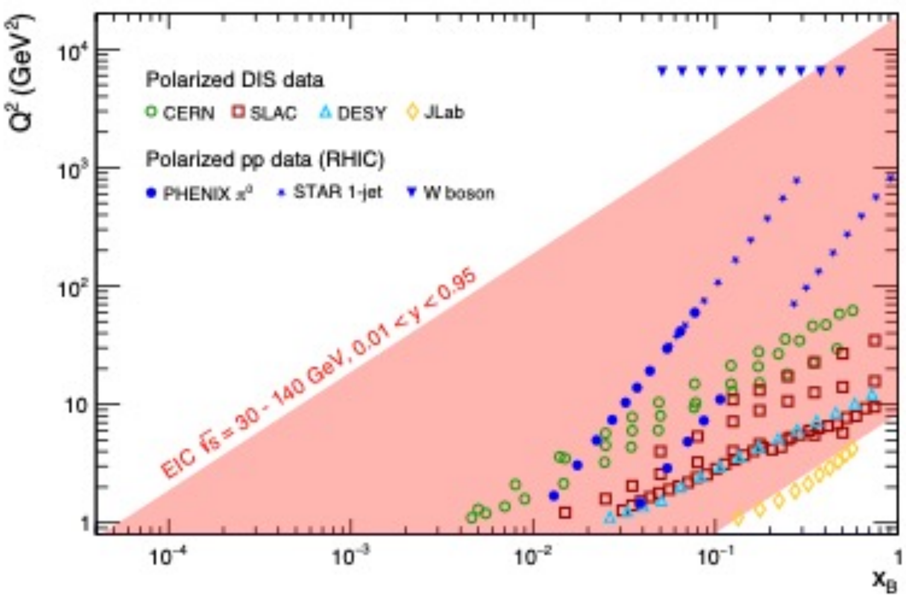
Inclusive ep DIS

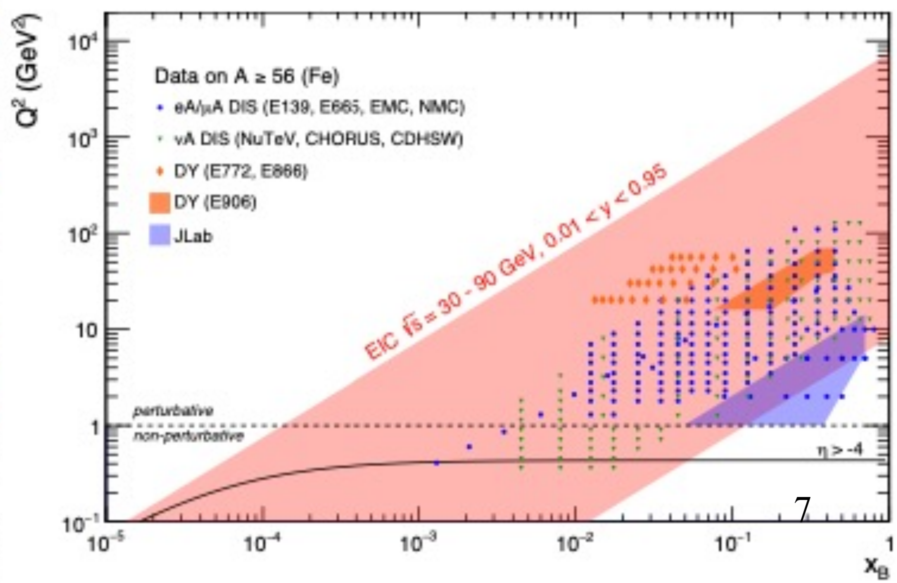
→ Closing gap and overlapping between fixed target & HERA

→ High x, moderate Q^2 precision

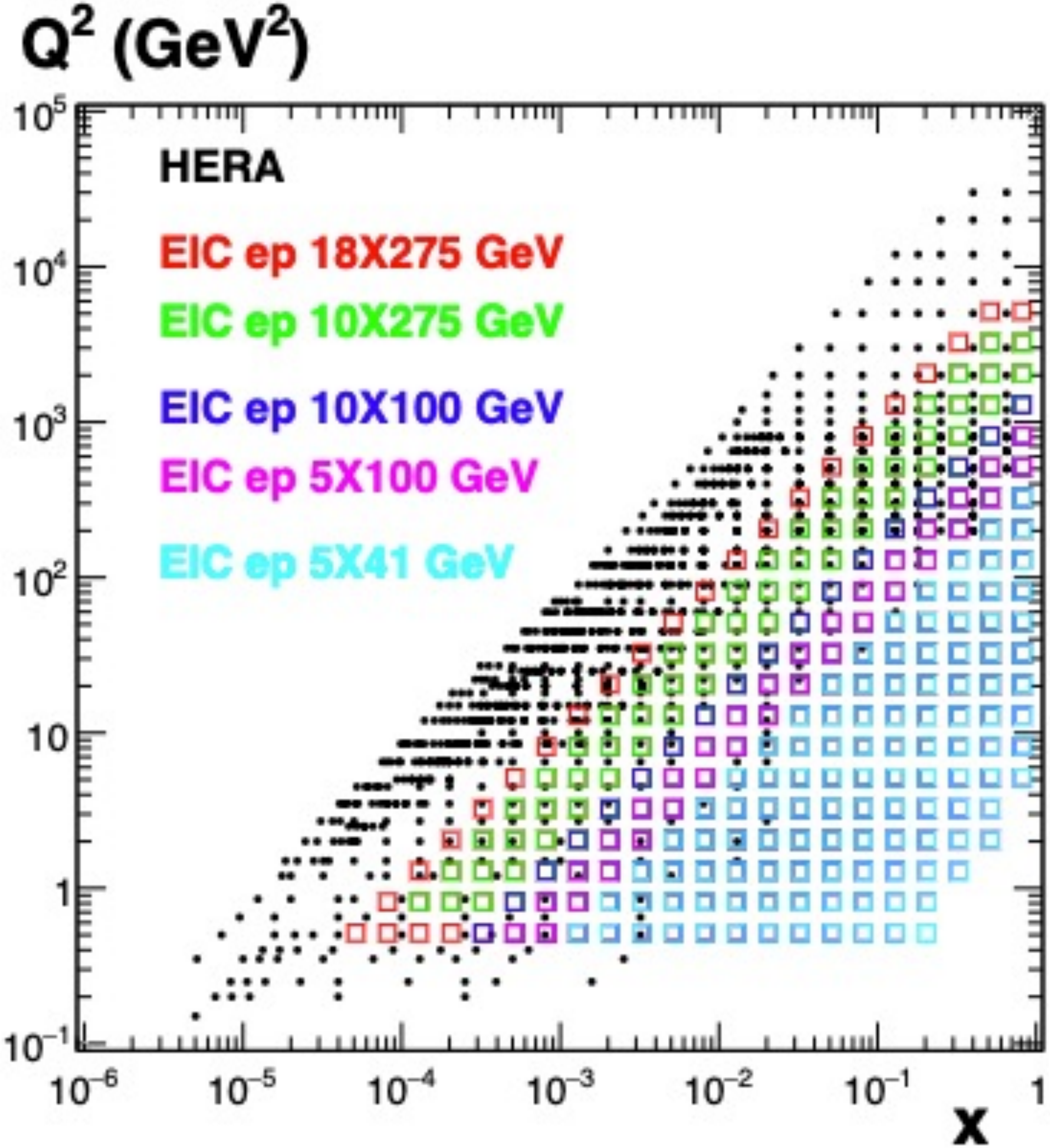
Polarised target ep & eA DIS

→ Completely unexplored regions, extending to low x





Importance of Multiple Beam Energies



Overlapping kinematic ranges at different √s fill broad region in x,Q^2 kinematic plane without needing measurements in extreme (low y) phase space regions

Estimated annual lumi

e-beam E	p-beam E	$\sqrt{s}$ (GeV)	inte. Lumi. (fb^{-1})
18	275	140	15.4
10	275	105	100.0
10	100	63	79.0
5	100	45	61.0
5	41	29	4.4

EIC Impact on Proton Parton Densities

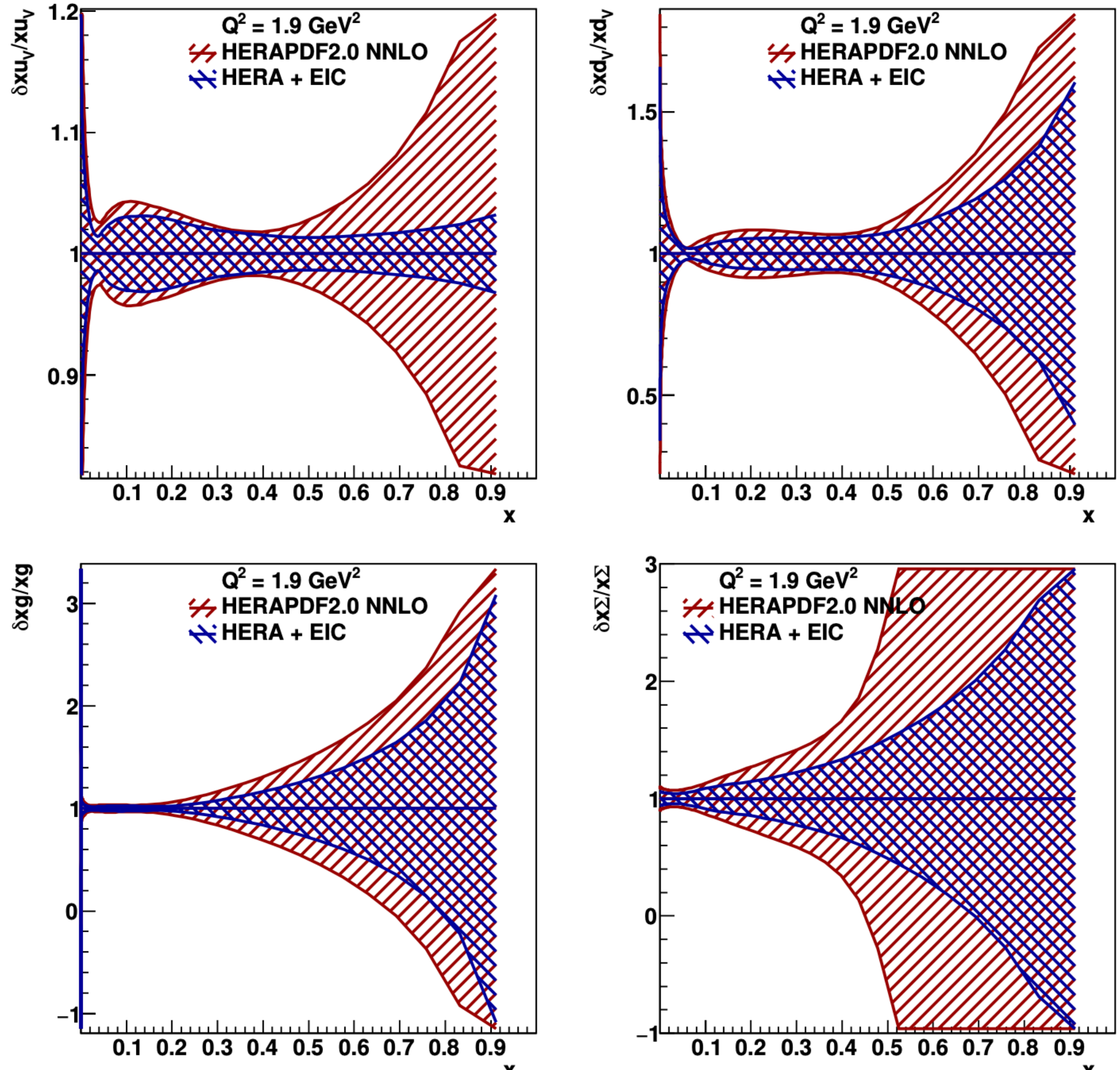
Fractional total uncertainties with / without simulated EIC data added to HERA (lin-x scale)

… EIC brings reduction in large x uncertainties relative to HERA for all parton species

Up quarks improve relative to global fits including LHC (not shown)

Precision high x data also yield world-leading strong coupling precision

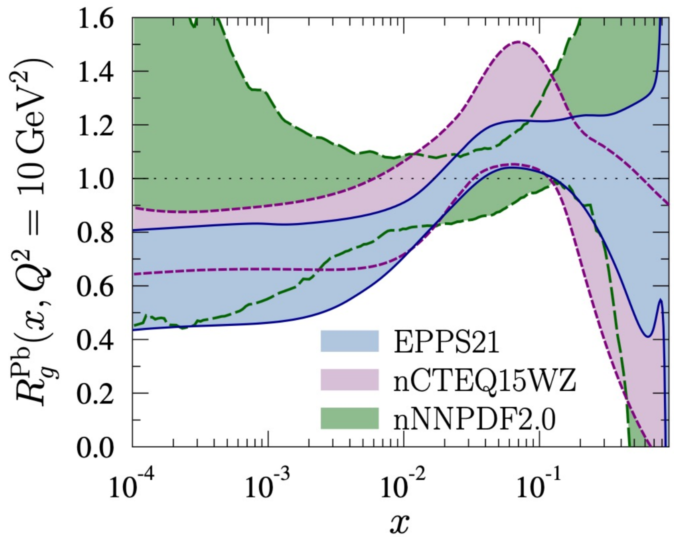
- $\alpha_s(M_Z^2)$ to 0.3%
  (cf world data → 0.6% now)



EIC Impact on Nuclear Parton Densities

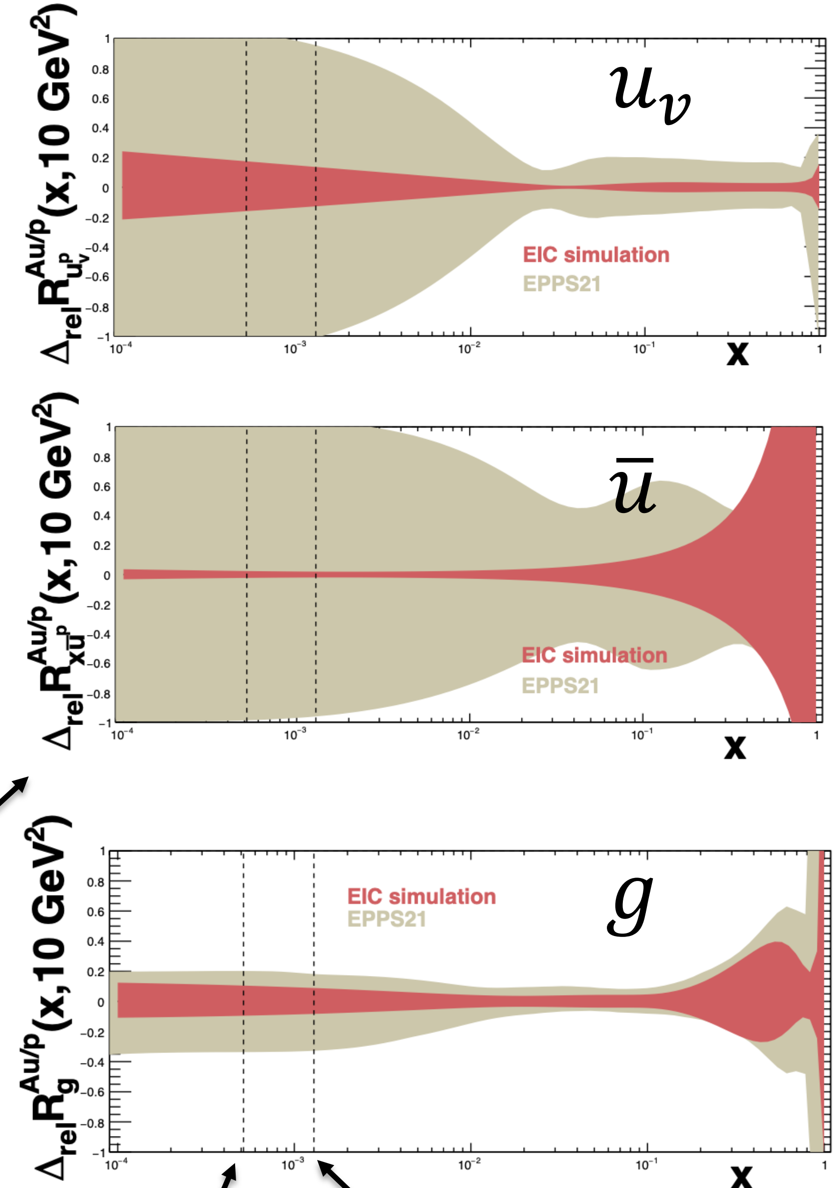
Parton nuclear modification ratio rel to scaled isospin-adjusted nucleons:

$$R = \frac{f_{i/A}}{A f_{i/p}} \approx \frac{\text{measured}}{\text{expected if no nuclear effects}}$$



Sensitivity of EIC-alone relative to EPPS21 global fits (include LHC pA)

→ Factor ~ 2 improvement at x~0.1
→ Very substantial improvement in newly accessed low x region

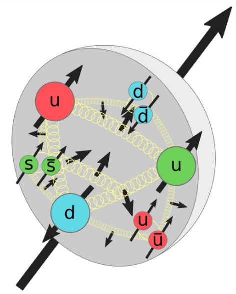


EIC eA data limit

EPPS21 data limit

Proton Spin

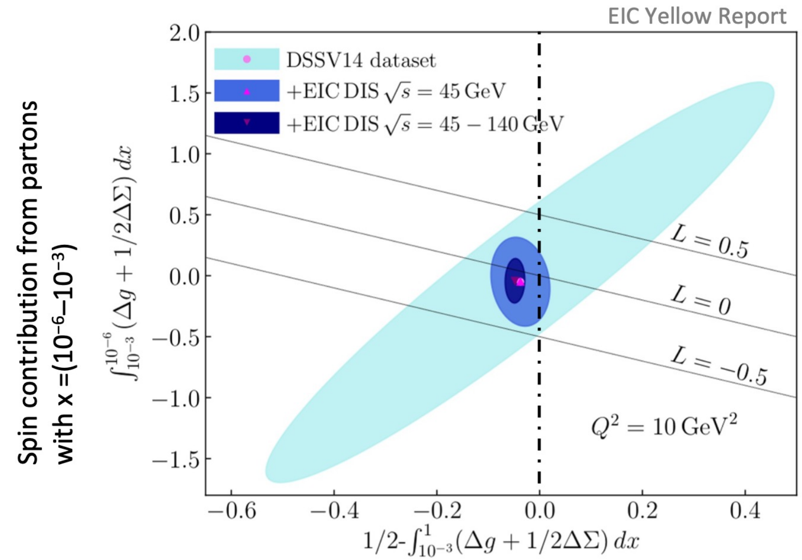
- Very little known about gluon helicity contribution and low x region



Jaffe-Manohar sum rule:

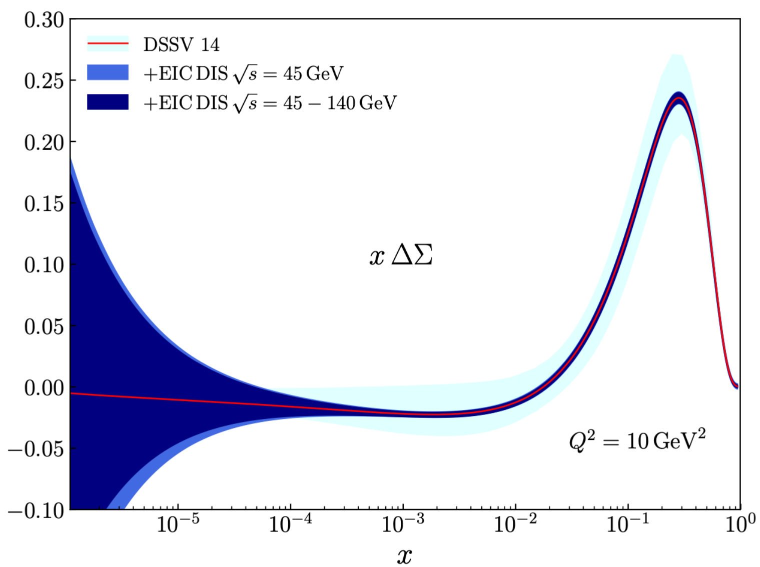
$$\Delta\Sigma/2 + \Delta G + \ell_q + \ell_g = \hbar/2$$

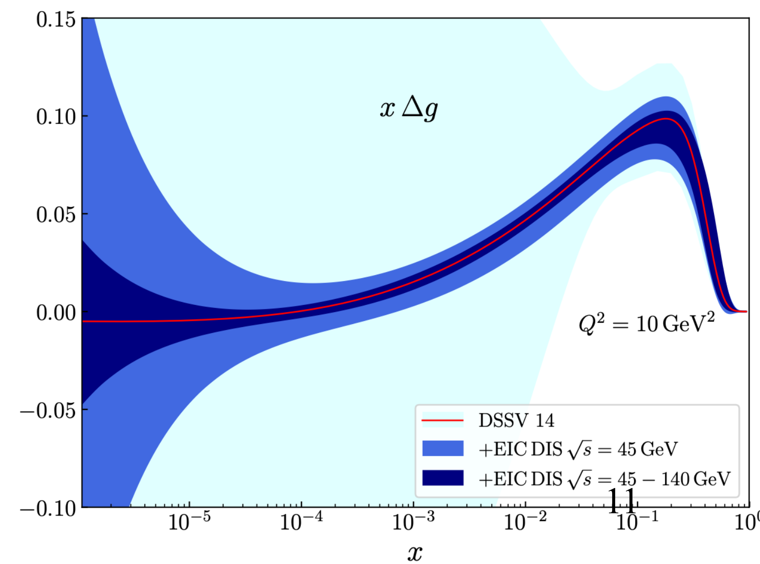
Quark helicity; Gluon helicity; Quark canonical orbital angular momentum; Gluon canonical orbital angular momentum



Room left for potential OAM contributions to the proton spin from partons with x > 0.001

- Simulated EIC inclusive data show very significant impact on polarised gluon and quark densities → orbital angular momentum constrained by implication … Full decomposition down to x~10^{-3}.





Proton Mass

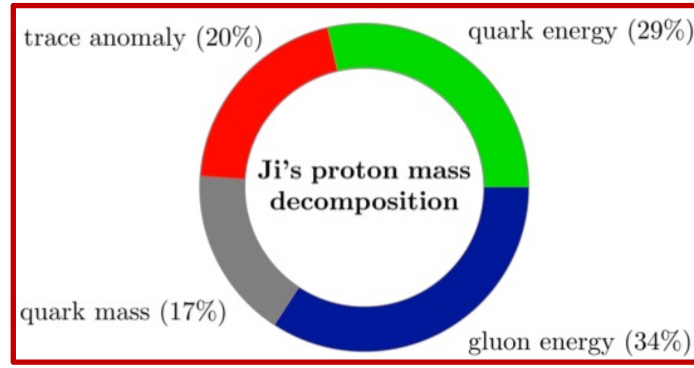
- Decomposition along similar lines to spin:

$$m_p = m_m + m_q + m_g + m_a$$

Valence and sea quark masses (including heavy quarks)

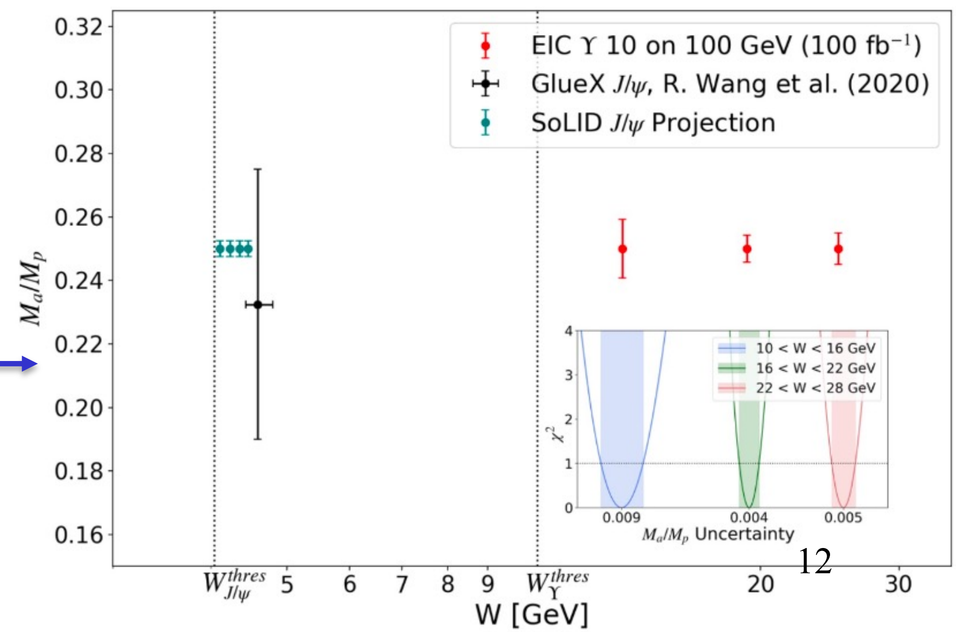
Quark & gluon ‘KE’ & ‘PE’: confinement and relative motion

QCD trace anomaly (purely quantum effect - chiral condensates)



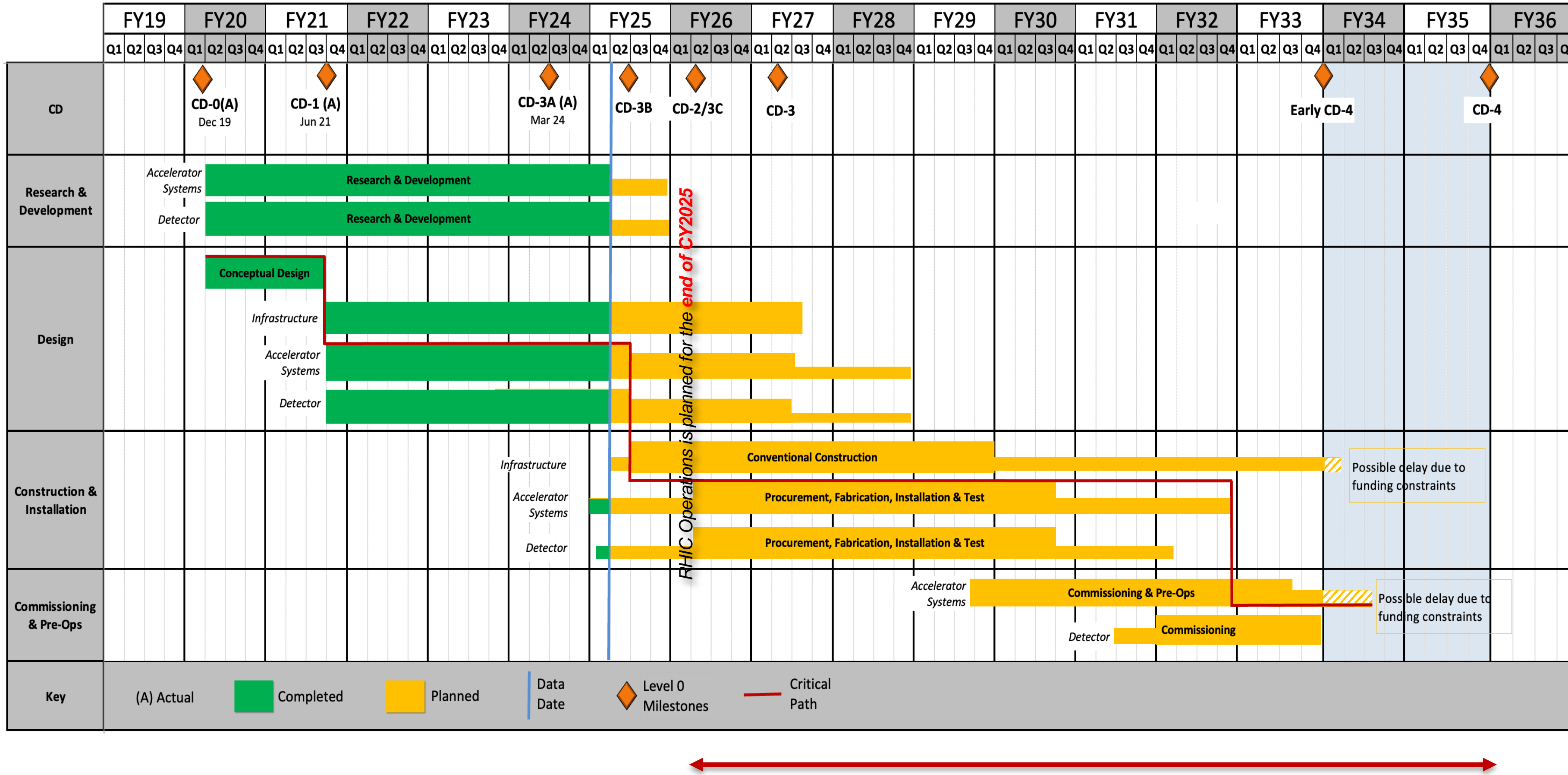
- Relations to experimental observables being understood

- eg gluon contribution to trace anomaly from J/Ψ (Jlab, also J/Ψ-007) to Υ (EIC) near threshold



Timeline: slide from from May 2025

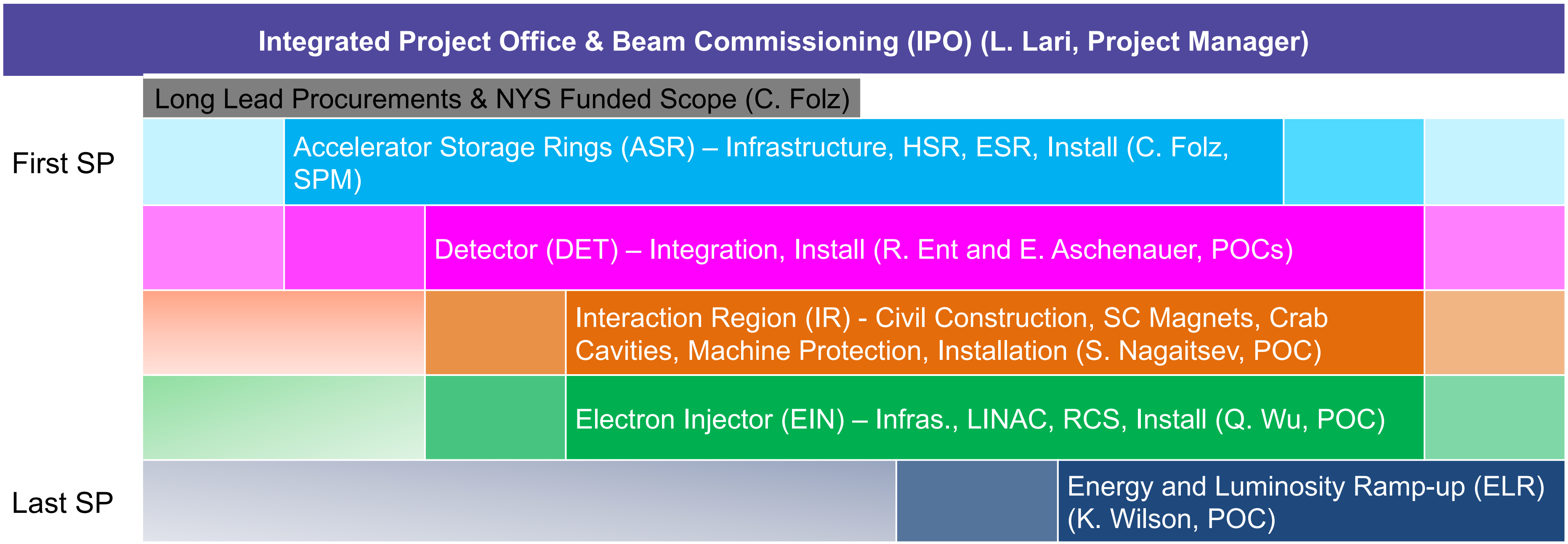
CD-0 (Mission need)	Dec 2019
CD-1 (Cost range)	June 2021
CD-3A (Start construction)	April 2024
CD-3B	Under review
CD-2 (Performance baseline)	Under review
CD-4 (Operations / completion)	2034-5



Project constrained to start physics operations within 10 years of RHIC end

Project Delivery Strategy

[EIC Project / Jim Yeck]



Now broken down into sub-projects overlapping in time, but with separate CD points.

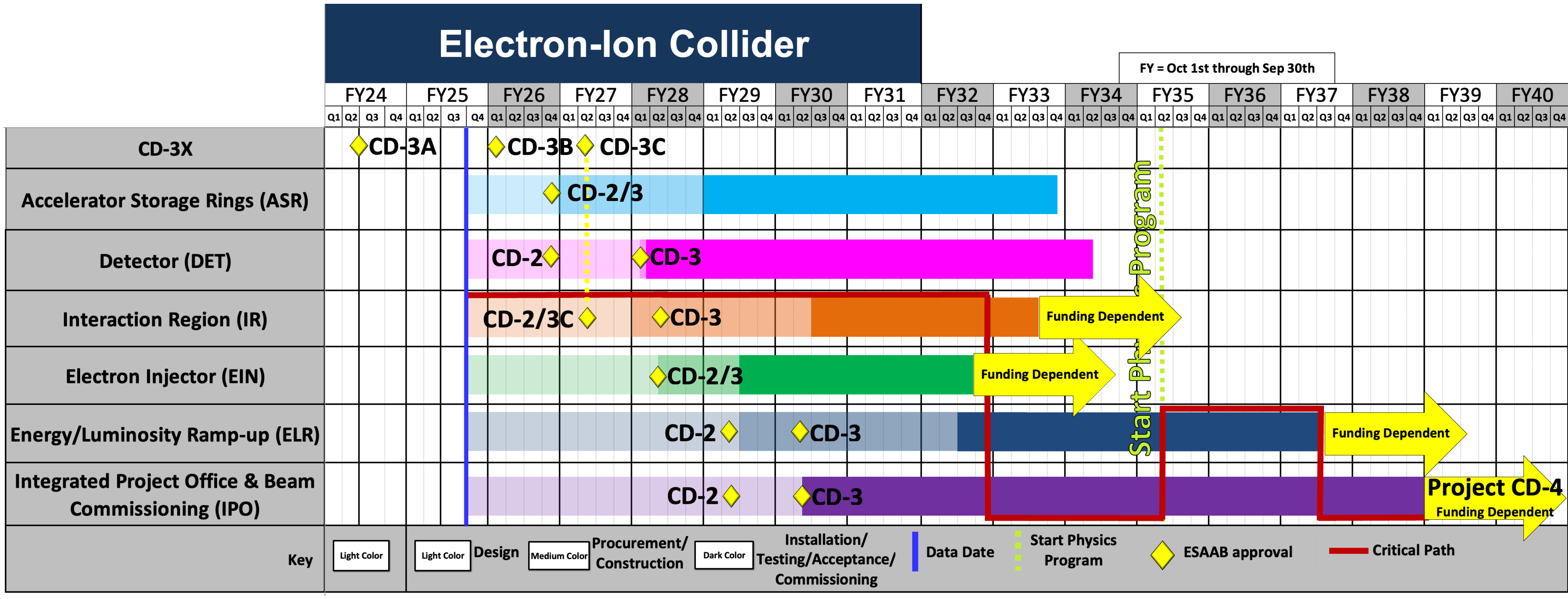
→ EIC construction can start when first sub-project ready

→ Science programme starts concurrently with commissioning and final stages of installation.

… implies a phased strart-up of physics operations.

→ Timeline Slide: December 2025

Plans for CD-2/CD-3 for ASR and CD-2 for DET remain aligned with conclusion of RHIC operations January 2026



- Separated CD points
  → eg detector has CD2 in Q4 of FY26 and CD3 in Q1 of FY28

- Period of several years between start of physics programme (Q1 of FY35) and completion / full operations (FY39/40)

Early Running

Strong current focus on evaluating scenarios for early running

	Species	Energy (GeV)	Luminosity/year (fb-1)	Electron polarization	p/A polarization
YEAR 1	e+Ru or e+Cu	10 x 115	0.9	NO (Commissioning)	N/A
YEAR 2	e+D e+p	10 x 130	11.4 4.95 - 5.33	LONG	NO TRANS
YEAR 3	e+p	10 x 130	4.95 - 5.33	LONG	TRANS and/or LONG
YEAR 4	e+Au e+p	10 x 100 10 x 250	0.84 6.19 - 9.18	LONG	N/A TRANS and/or LONG
YEAR 5	e+Au e+3He	10 x 100 10 x 166	0.84 8.65	LONG	N/A TRANS and/or LONG

Note: the eA luminosity is per nucleon

Center for Frontiers in Nuclear Science

ePIC/EIC Early Science Workshop

24–25 Apr 2025
America/New_York timezone

Inclusive electron-proton measurement prospects in the Electron-Ion Collider early science stage

Javier Jiménez-López *[1], Stephen Maple †[2], Paul R. Newman ‡[3], and Katarzyna Wichmann §[4]

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[2,3] *School of Physics and Astronomy, University of Birmingham, B15 2TT, UK*
[4] *Deutsches Elektronen-Synchrotron DESY, Germany*

DESY-25-164
November 2025

ePIC and EIC Physics Readiness Workshop

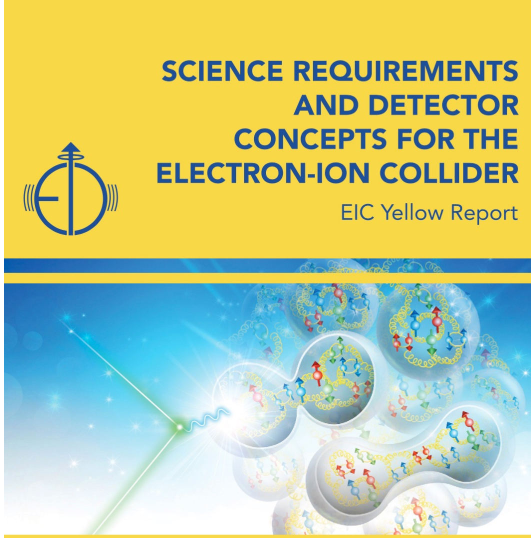
17–18 Sept 2025
Europe/London timezone

Enter your search term

Overview
Timetable
Virtual/Remote Connection

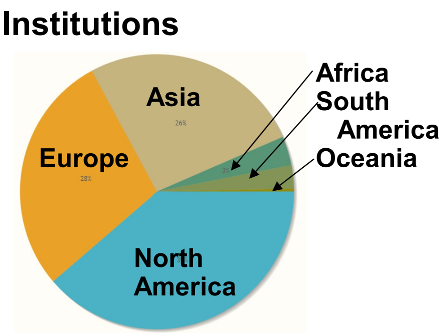
The scope of this workshop includes preparation and readiness of EIC focussed physics analyses and related activities for the upcoming ePIC preTDR and Early Science documents. We will also have the opportunity to discuss contributed topics outside of this scope. Everyone interested is welcome to attend!

International Community: EIC User Group



Nucl Phys A1026 (2022), 122447 [arXiv:2103.05419]

July 2025 snapshot: 41 Countries represented



1556 members from **307** institutions

- Experiment Scientists: **1031**
- Theory Scientists: **383**
- Accelerator Scientists: **125**
- Computer Scientists: **9**
- Support: **5**
- Other: **3**

- UK leadership includes MC event Generators (Frank Krauss)

Currently hosts five working groups:

→ Theory

→ Detector II

→ Software

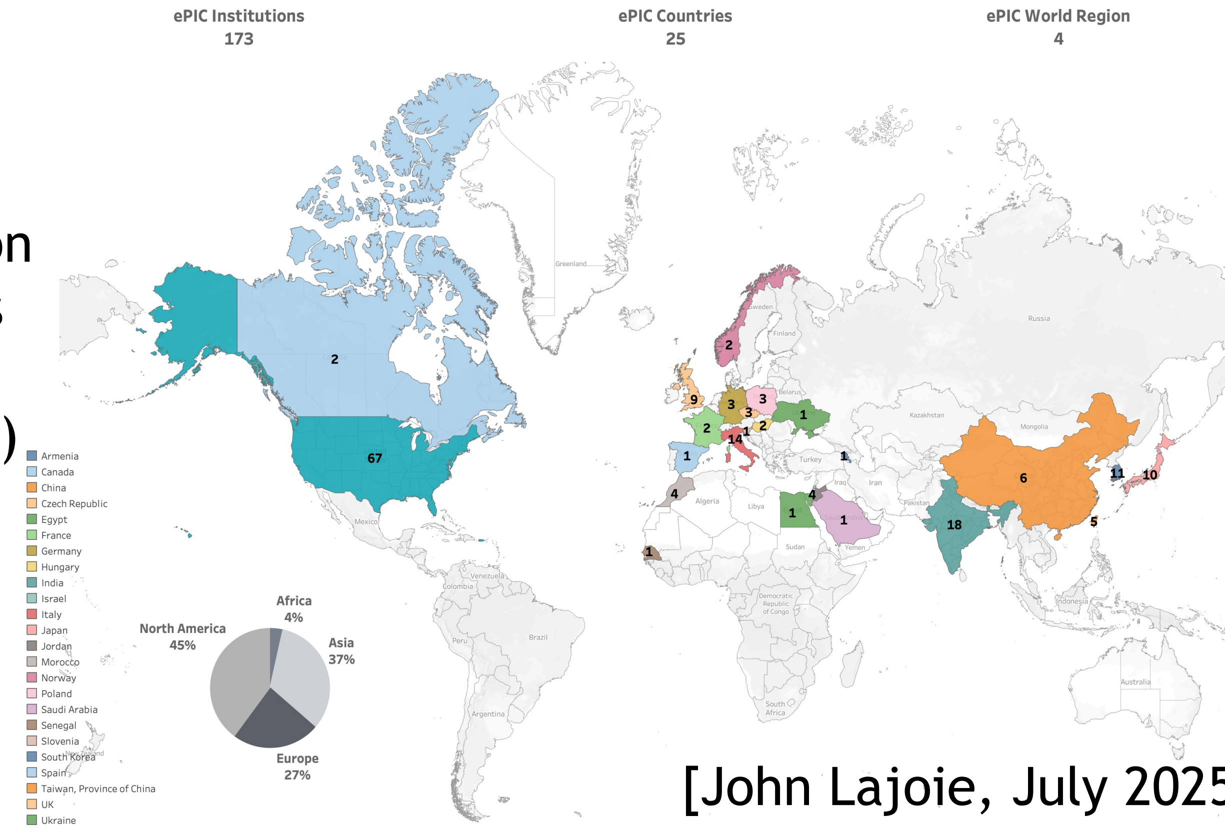
→ MC Event Generators

→ Artificial Intelligence

International Community: ePIC Collaboration

ePIC @Frascati, Italy, Jan '24

Experimental collaboration with >1050 collaborators from 177 institutions in 25 countries (48% USA)



[John Lajoie, July 2025]

A Detector for the EIC

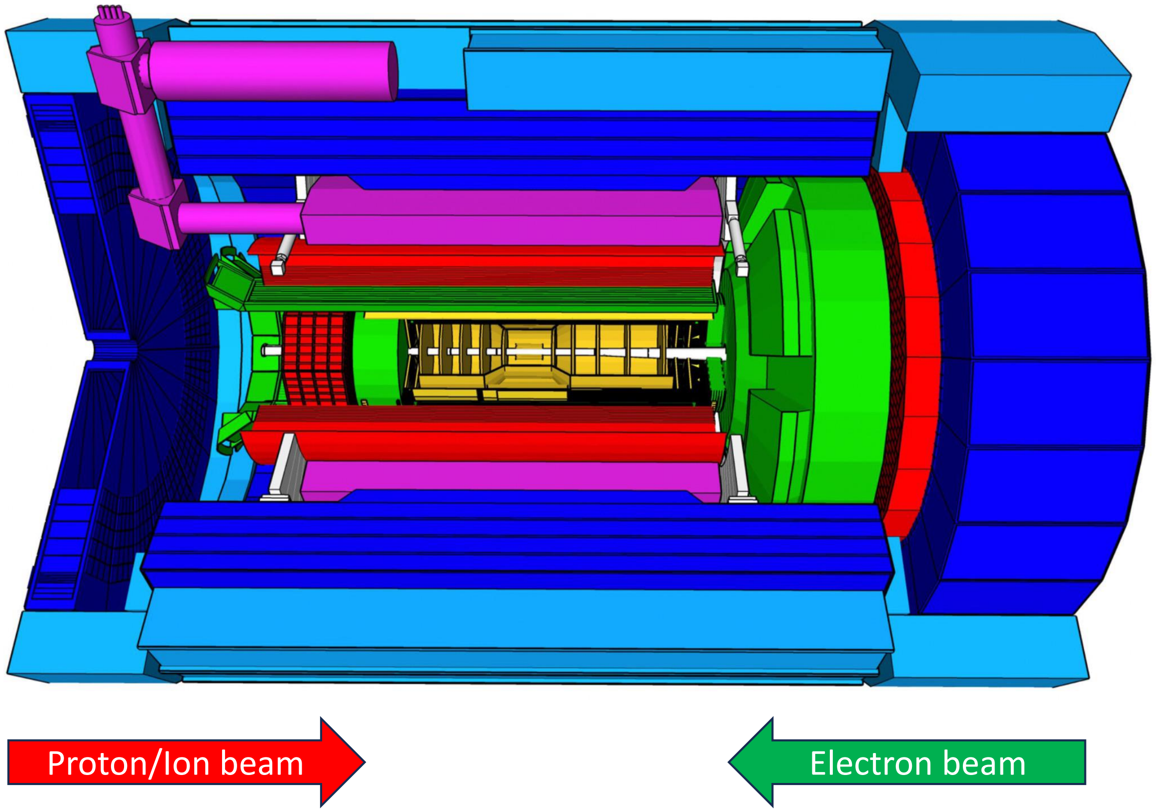
Magnet
- New 1.7 T SC solenoid, 2.8 m bore diameter

Tracking
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

PID
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

EM Calorimetry
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

Hadron calorimetry
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



- 9m long x 5m wide
- Hermetic (central detector $-4 < \eta < 4$)
- Extensive beamline instrumentation (see later)

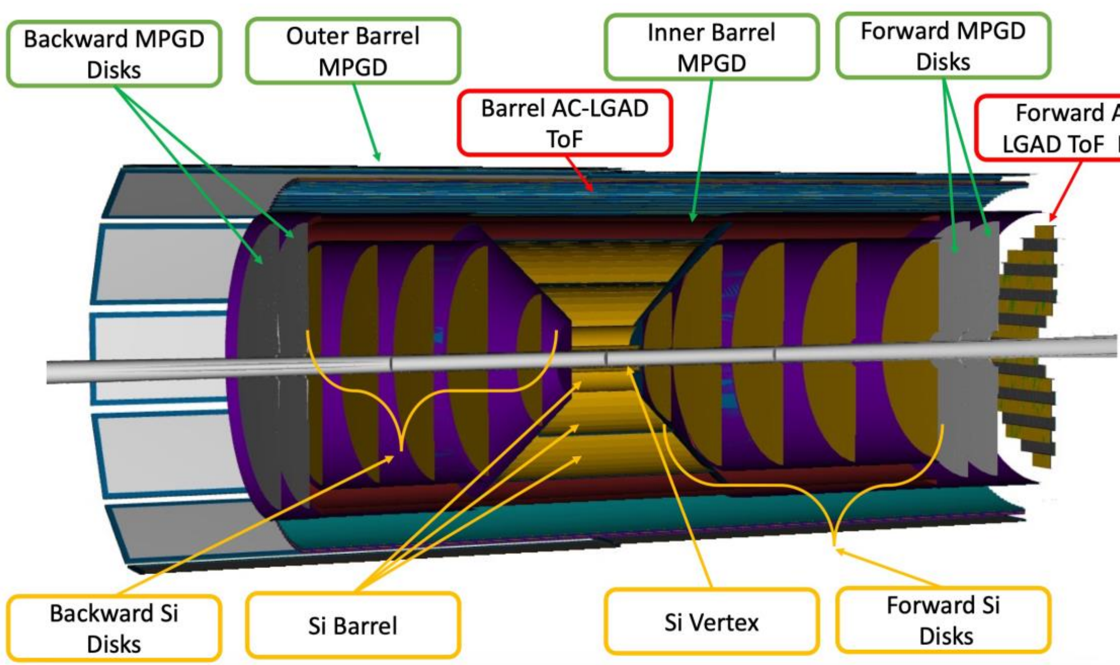
- Much lower radiation fluxes than LHC widens technology options

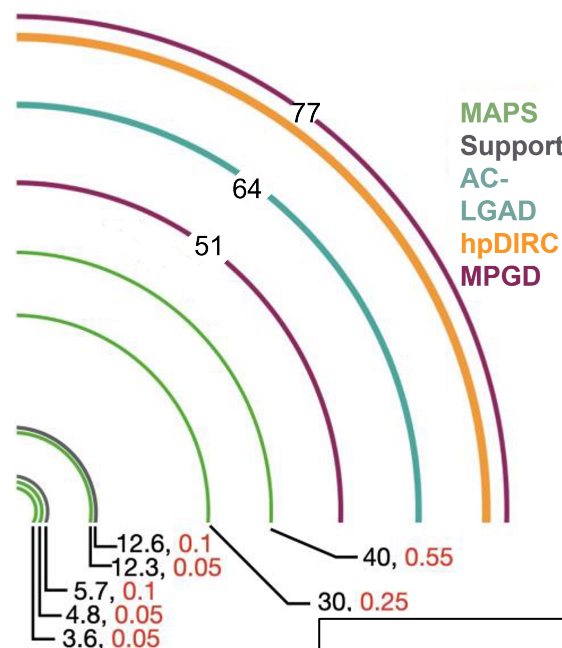
Tracking Detectors

Primarily based on MAPS silicon detectors (65nm technology)

- Leaning heavily on ALICE ITS3
- Stitched wafer-scale sensors, thinned and bent around beampipe

  → Very low material budget (0.05% X_0 per layer for inner layers)
- 20x20μm pixels
- 5 barrel layers + 5 disks (total 8.5m^2 silicon)





Black numbers are radii in cm

Red numbers are material in % X0

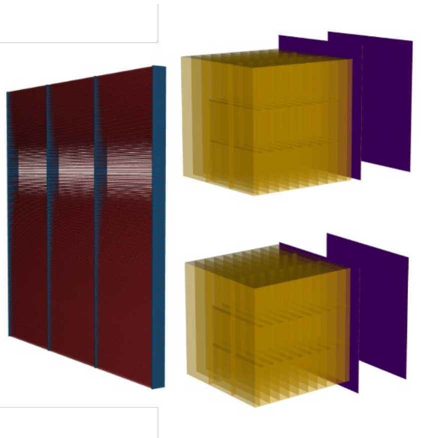
LGAD layers provide fast timing (~20ns)

Outer gaseous detectors add additional hit points for track reconstruction

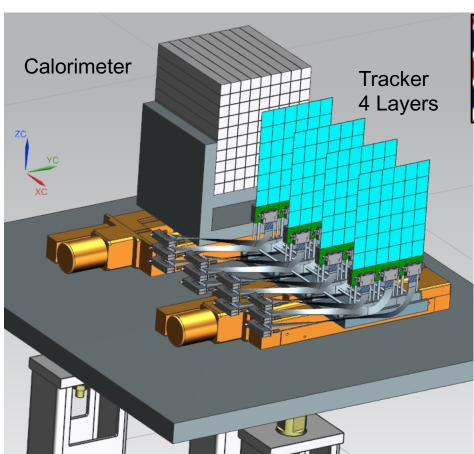
Interaction Region / Beamline Instrumentation

- Extensive beamline instrumentation integrated into IR design

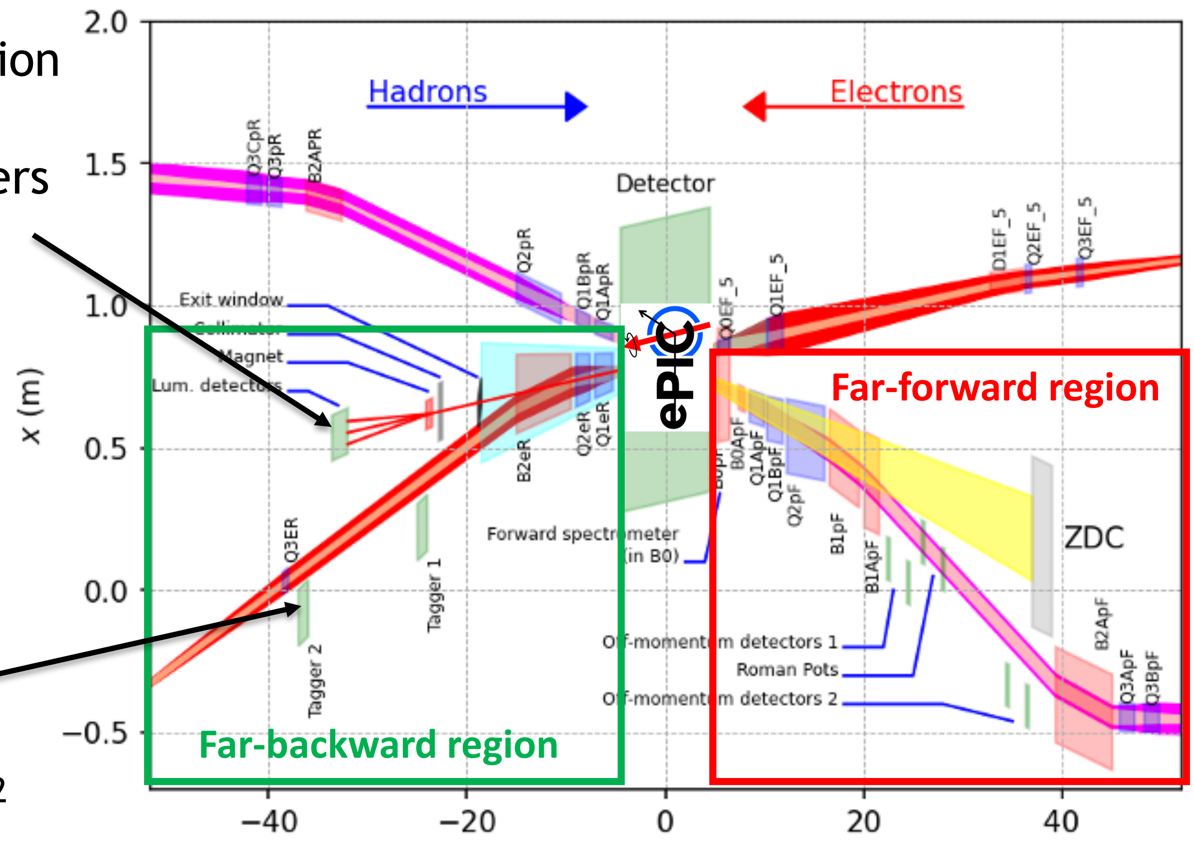
- Tagging electrons and photons in backward direction for lowest Q^2 physics studies and lumi monitoring via photon counting in ep→epγ



Pair-production lumi spectrometers

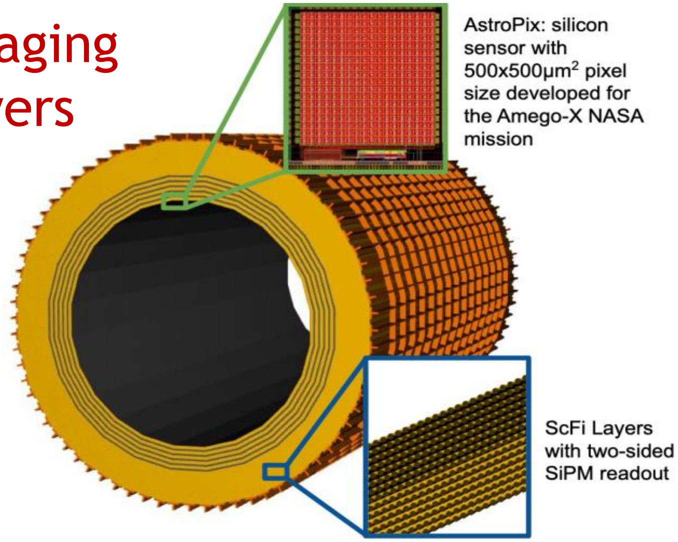


2 low Q^2 electron taggers

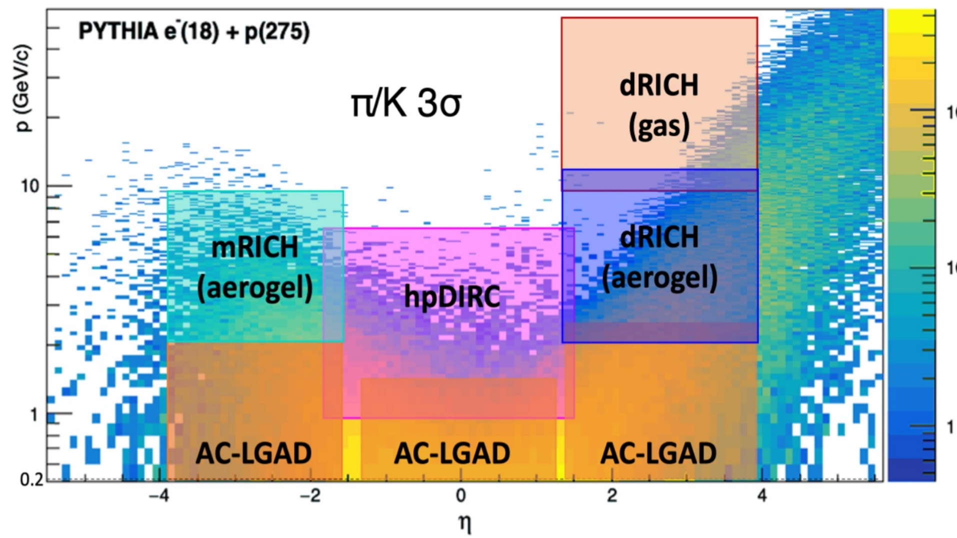


More Novel Detector Components

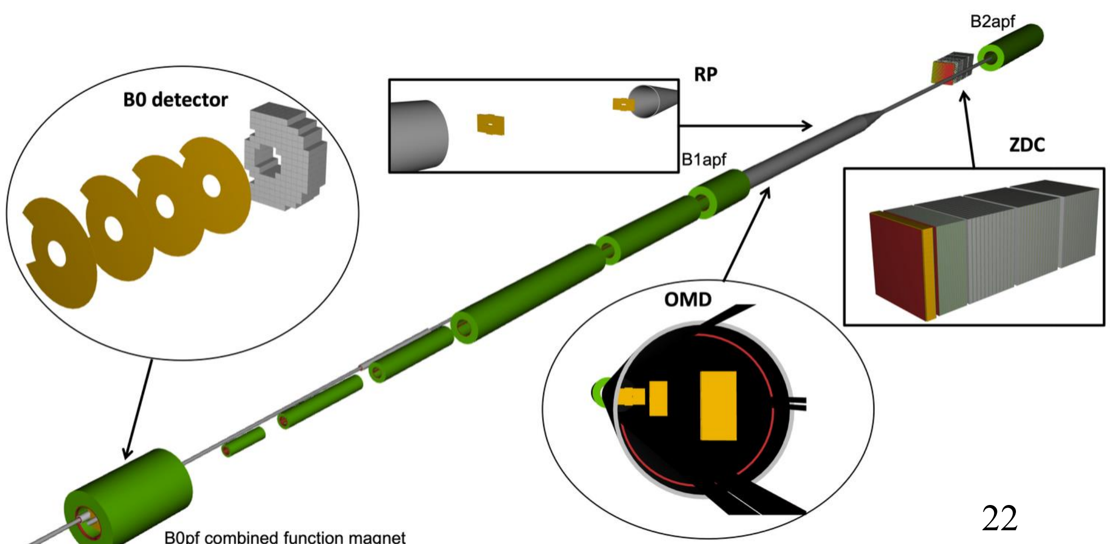
Imaging eCAL
Pb/SciFi sampling + AstroPix imaging layers



Comprehensive Particle ID

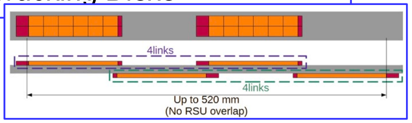


- Forward protons inside and outside beampipe (0.45 < E_p'/E_p < 1)
- Forward neutrons with ALICE FOCAL-like ZDC

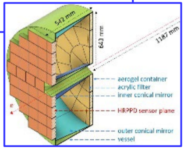


TECHNOLOGIES: WORLD FIRST AT ePIC

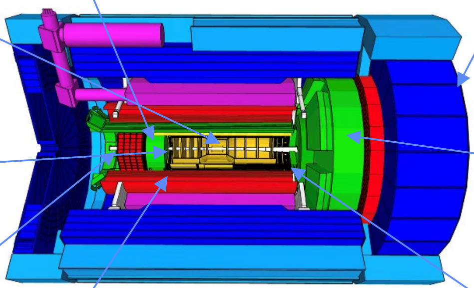
EIC Large Area Sensor (**LAS**), modification of ITS3 sensor with 5 or 6 RSU forming staves as the basic building elements *for the Outer Barrel and the Tracking Disks*

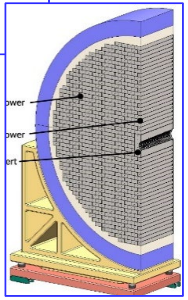


HRPPDs for Cherenkov imaging and Time-of-Flight *for pfRICH*

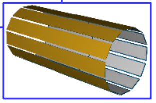


first-time **full-size CALICE-like calorimeter** in collider experiment *in the forward HCal*

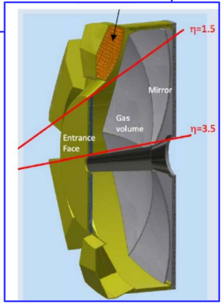




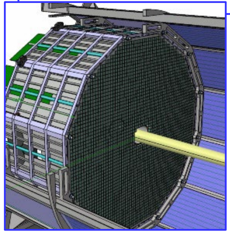
planar **double amplification (GEM & μRWELL)** modules & 2D-strip readout *for the MPGD outer trackers and disks*



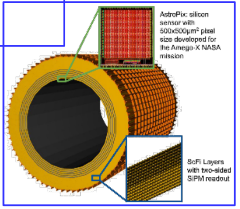
First use **of SiPMs as Photonsensors in a RICH** for the dRICH



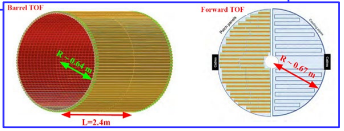
SiPM as Photonsensors in crystal calorimetry *for backward endcap ECal*



Use of **ASTROPIX in Calorimetry** *for the imaging barrel ECal*



First time use of **AC-LGAD** in a collider detector *for barrel and forward endcap ToF*

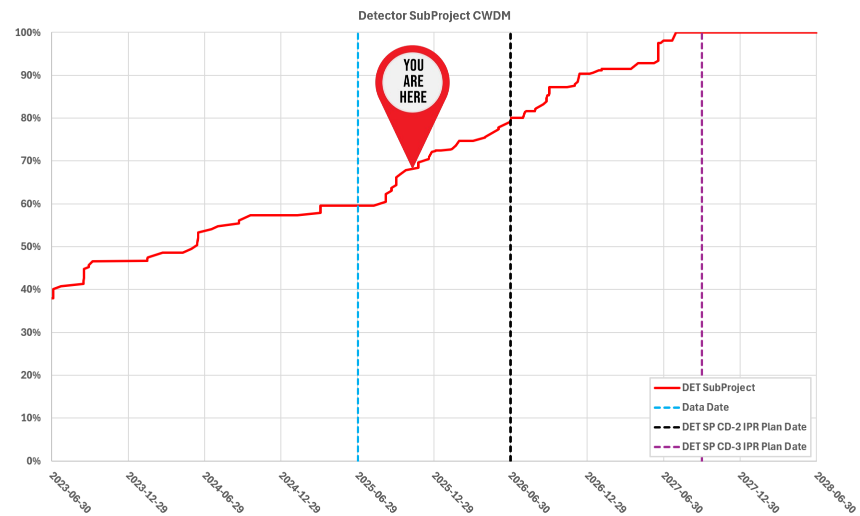


ePIC Design Maturity

Path to Baseline – Design Maturity

Cost-weighted design maturity:

- Present design maturity >60%
- Jun. 11-13: Comprehensive Design Review by DAC
- Projected ~80% in June 2026
- Nov. 12-14: Baseline Readiness Assessment review planned. *(postponed to Feb. due to impacts of government shutdown)*
- All 26 subsystems have already received at least one PDR
- Until Late 2025/Early 2026: 6 subsystems need a final PDR
- Until CD-3 (Q1FY28): 17 FDR



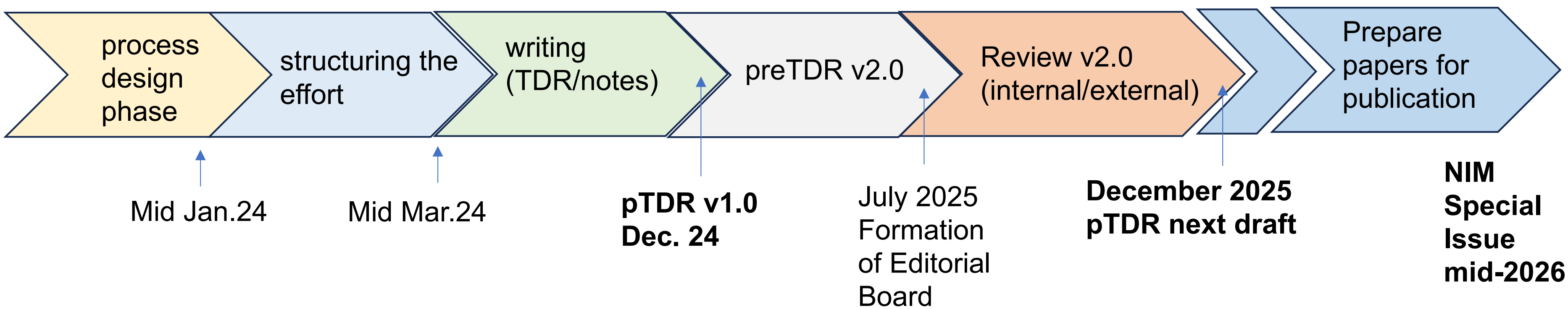
Electron-Ion Collider
Peer Review of the EIC Particle Identification Detectors based on AC-LGAD, December 3rd, 2025
R. Ent, E.C. Aschenauer 8

"Construction has started" (Elke, July 2025)

1. Lead Tungstate Crystals for Detector Backward Electro-Magnetic (EM) Calorimeter
2. Scintillating Fibers for the Detector Barrel and Forward EM Calorimeters
3. Silicon Photomultipliers for the Detector Forward Hadronic Calorimeter
4. Steel and Tungsten for the Detector Forward Hadronic Calorimeter
5. Detector Solenoid Magnet Design and Fabrication and Conductor

ePIC now: Pre-TDR and Physics Publication

- Preparing detector input to EIC Technical Design Report
- Pre-TDR and associated physics documentation under review, for publication in Nuclear Instruments & Methods



- Will open a NIM Special Issue in early 2026, open for ~6 mos
  - Goal of the issue is a comprehensive overview of ePIC
  - Paperwork in preparation
    - Potential solution to open access costs identified but not yet secured
  - Plan to publish a super-set of the material prepared for the pre-TDR
    - Subsystem technical papers derived from pTDR
    - Physics performance paper spin-off from pTDR (full collab author list)
    - Early Science whitepaper (full collab. author list)
    - Exclusive, Diffraction and Tagging paper
- Streaming Computing Model publication also in preparation
  - Full collab. author list
  - Confirmed with NIM editors that S&C papers are welcome

ePIC structure and current UK Leadership

SPOKESPERSON'S OFFICE
J. Lajoie (ORNL), Spokesperson
S. Dalla Torre (INFN), Deputy Spokesperson

TECHNICAL COORDINATION OFFICE
Silvia Dalla Torre (INFN, acting)
John Haggerty (BNL)
Prakhar Garg (Yale), Deputy
Oskar Hartbrich (ORNL), Deputy

ELECTRONICS, READOUT AND DAQ
Fernando Barbosa (JLab)
Jeff Landgraf (BNL)

TRACKING
Barbara Jacak (Berkeley)
Barak Schmookler (Houston)

PID
Sourav Tarafdar (JLab)
Brian Page (BNL)

CALORIMETRY
Oleg Tsai (UCLA)
Julie Roche (Ohio)

AC-LGAD
Alex Jentsch (BNL)

SOFTWARE AND COMPUTING COORDINATOR
Markus Diefenthaler (JLab), Coordinator
Wouter Deconinck (Manitoba), Deputy
Dmitry Kalinkin (Kentucky), Deputy
Torre Wenaus (BNL), Deputy

PRODUCTION
Sakib Rahman (BNL)
Thomas Britton (JLab)

USER LEARNING
Holly Szumila-Vance (JLab)
Stephen Kay (York)

PHYSICS AND DETECTOR SIMULATION
Sakib Rahman (BNL)
Chao Peng (ANL)

RECONSTRUCTION
Shujie Li (LBNL)
Derek Anderson (ISU)
Chandradoy Chatterjee (INFN)

STREAMING COMPUTING MODEL
Marco Battaglieri (INFN Genova)
Taku Gunji (Tokyo)
Jeff Landgraf (BNL)

ANALYSIS COORDINATORS
Salvatore Fazio (Unical)
Rachel Montgomery (Glasgow)
Rosi Reed (Lehigh), Deputy

INCLUSIVE PHYSICS
Tyler Kutz (MIT)
Stephen Maple (Birmingham)

EXCLUSIVE, DIFFRACTION AND TAGGING
Raphael Dupre (Orsay)
Zhoudunming Tu (BNL)

SEMI-INCLUSIVE PHYSICS
Stefan Diehl (UConn)
Ralf Seidl (RIKEN)

JETS AND HEAVY FLAVOR
Olga Evdokimov (UIC)
Rongrong Ma (BNL)

BSM AND PRECISION EW
Ciprian Gal (JLab)
Juliette Mammei (Manitoba)

Working Groups
revised: 11/17/2025

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John Haggerty (BNL), Deputy
Oskar Hartbrich (ORNL), Deputy
Matt Posik (Temple), Deputy

Detector Subsystem Collaborations
revised: 11/13/2025

Particle Identification

dRICH
DSL/DSTC: Marco Contalbrigo (INFN)

hpDIRC
DSL/DSTC: Greg Kalicy (CUA)

BACKWARD RICH
DSL/DSTC: Alexander Kiselev (BNL)
Deputy DSL: Brian Page (BNL)

AC-LGAD TOF
DSL: Zhangbu Xu (Kent State)
Deputy DSL: Satoshi Yano (Hiroshima)
DSTC (barrel): Simone Mazza (UCSC)
DSTC (forward): Mathieu Benoit (ORNL)

Calorimetry

BARREL ECAL
Co-DSL: Sylvester Joosten (ANL)
Co-DSL: Hwidong Yoo (Yonsei)
Deputy DSL: Maria Zurek (ANL)
DSTC: Jessica Metcalfe (ANL)

BACKWARDS HCAL
DSL: Daniel Brandenburg (OSU)
DSTC: Caroline Riedl (UIUC)

FORWARD HCAL
DSL/DSTC: Friederike Bock (ORNL)
Deputy DSL/DSTC: Miguel Arratia (UCR)

BARREL HCAL
Co-DSL: Stefan Bathe (Baruch)
Co-DSL: Murad Sarsour (GSU)

FORWARD ECAL
Co-DSL/DSTC: Oleg Tsai (UCLA)
Co-DSL: Huan Huang (UCLA)

BACKWARDS ECAL
DSL: Tanja Horn (CUA)
DSTC: Carlos Munhoz Camacho (IJCLab)

Far-Forward Far-Backward

FAR FORWARD
DSL: Alex Jentsch (BNL)
Co-DSL: Yulia Furletova (Jlab)
DSTC (B0): Zvi Citron (Ben-Gurion)
DSTC (Roman Pots/OMD): Alex Jentsch (BNL)
Co-DSTC (ZDC): Yuji Goto (RIKEN)
Co-DSTC (ZDC): Miguel Arratia (UCR)

FAR BACKWARD HIGH RATE TRACKER
DSL: Jaroslav Adam (CTU)
DSTC: Simon Gardner (Glasgow)

LUMINOSITY
Co-DSL: Nick Zachariou (York)
Co-DSL: Krzysztof Piotrzkowski (AGH Krakow)
DSTC (Pair Spectr.): Stephen Kay (York)

Tracking

Si TRACKERS
DSL: Ernst Sichtermann (LBL)
Co-DSTC: Laura Gonella (Trieste)
Co-DSTC: Georg Viehhauser (Oxford)

GASEOUS TRACKERS
DSL: Kondo Gnanvo (JLab)
DSTC: Maxence Vandenbroucke (Saclay)
DSTC: Annalisa D'Angelo (INFN Roma II)

+ Executive Board: Paul Newman (Birmingham)
+ Conference and Talks Committee: Nick Zachariou (York)

Summary

The Electron Ion Collider will transform our understanding of nucleons, nuclei and the parton dynamics that underlie them

The UK is deeply involved in the development of the Science Case and the ePIC General Purpose Detector

On target for data taking in the mid 2030s

Summary of UKRI Infrastructure Project

WP1: MAPS → 65nm CMOS (wafer scale) stitched sensors, developed from ALICE-ITS3, to be deployed in central tracker
→ Construction of 2 barrel layers, corresponding to around 1/3 of silicon tracker

WP2: Timepix → Application of pixel sensors for beamline electron tagger for luminosity and physics at $Q^2 \to 0$

WP3: Lumi Monitoring → Novel pair-spectrometer, beamline $\gamma \to ee$ counting

WP4: Accelerator → Primarily SRF systems for Energy Recovery cooler.
→ Also crab-cavity LLRF synchronisation, beam position monitoring, Energy Recovery modelling and design

Daresbury Laboratory
Rutherford Appleton Laboratory
ASTeC

EIC Machine Design Parameters

Double Ring Design Based on Existing RHIC Facilities	
Hadron Storage Ring: 40, 100 - 275 GeV	**Electron Storage Ring: 5 - 18 GeV**
RHIC Ring and Injector Complex: p to Pb	9 MW Synchrotron Radiation
1A Beam Current	Large Beam Current - 2.5 A
10 ns bunch spacing and 1160 bunches	
Light ion beams (p, d, ^{3}He) polarized (L,T) > 70%	Polarized electron beam > 70%
Nuclear beams: d to U	**Electron Rapid Cycling Synchrotron**
Requires Strong Cooling: new concept →CEC	Spin Transparent Due to High Periodicity
One High Luminosity Interaction Region(s)	
25 mrad Crossing Angle with Crab Cavities	

Challenges from high lumi requirement include high beam currents and correspondingly short bunch spacings:

→ Synchrotron load management

→ Significant crossing angle