The EIC and synergies with FCC-ee

Ernst Sichtermann (LBNL)

Fourth US FCC Meeting

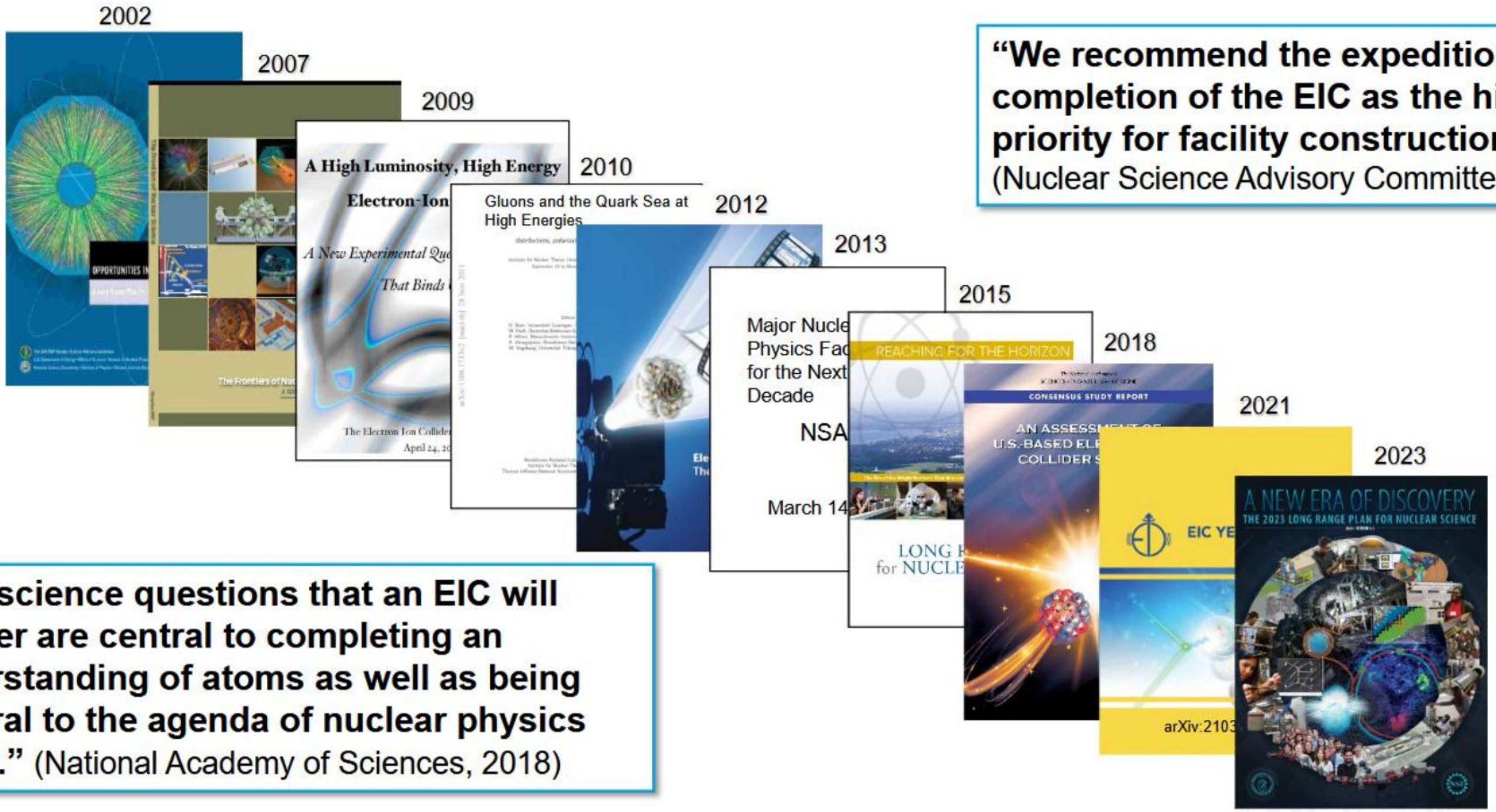
SLAC – September 8–11, 2026

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under Contract No. DE-AC02-05CH11231.

Outline

- EIC — why, what, and when
- Event topology and kinematics → detector
- ePIC — tracking, particle identification, calorimetry
- Interaction region and the far-forward detectors
- Silicon vertex tracker
- Common ground and closing comments

The EIC science case, built over two decades

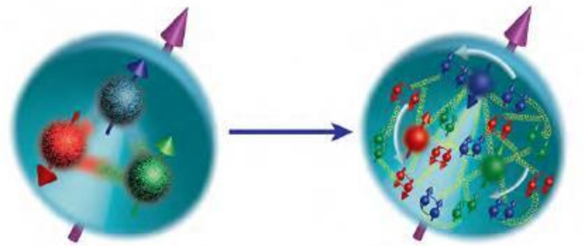


"We recommend the expeditious completion of the EIC as the highest priority for facility construction." (Nuclear Science Advisory Committee, 2023)

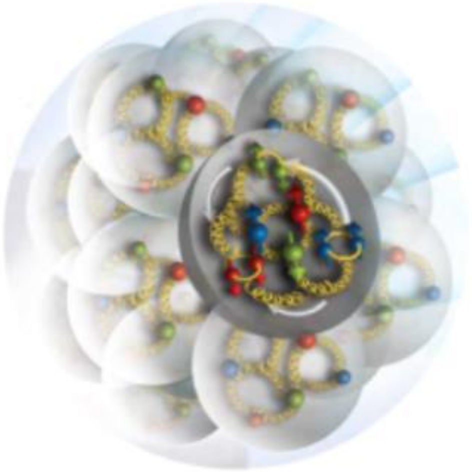
"The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today." (National Academy of Sciences, 2018)

Three questions

How does the mass of the nucleon arise?



How does the spin of the nucleon arise?

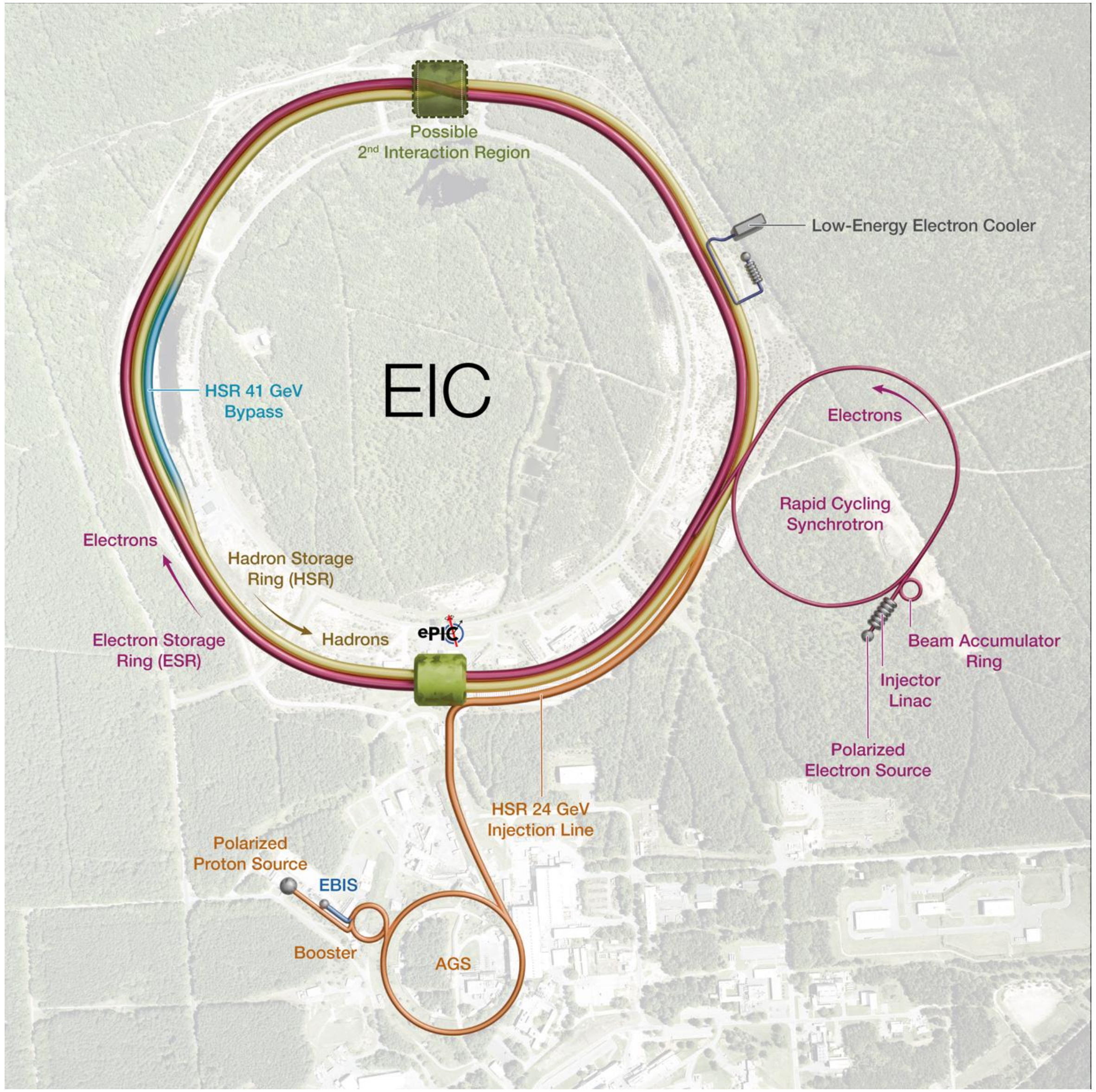


What are the emergent properties of dense systems of gluons?

"An EIC can uniquely address three profound questions about nucleons — neutrons and protons — and how they are assembled to form the nuclei of atoms." (National Academies, 2018, Finding 1)

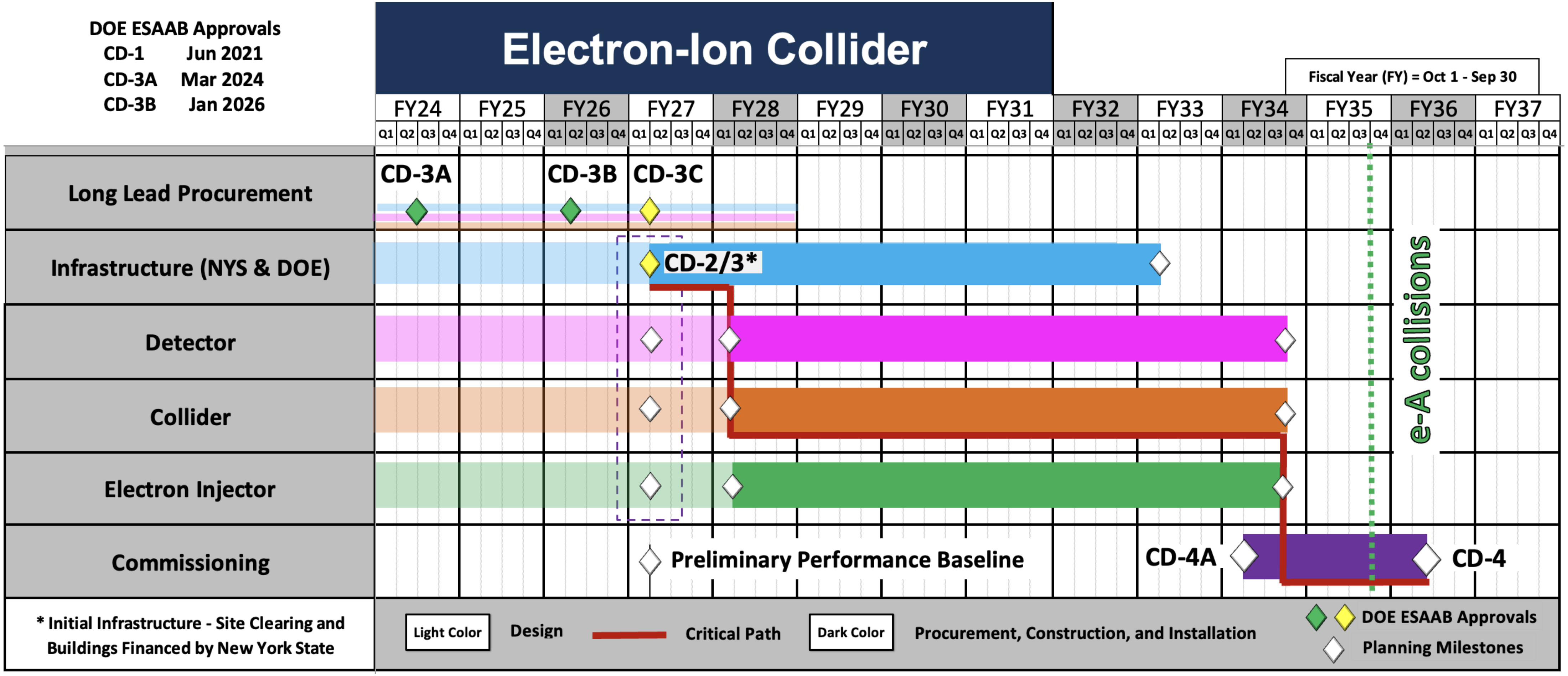
The same report's Finding 2: these questions can be answered with highly polarized electron and ion beams, sufficient luminosity, and sufficient and variable center-of-mass energy.

The EIC at Brookhaven National Laboratory



- Polarized electrons 5–18 GeV on polarized protons 41–275 GeV, and ions up to uranium
- $\sqrt{s}$ ~20–100 GeV, upgradeable to 140 GeV
- ~70% polarization for both beams
- Luminosity 10^{33}–10^{34} cm^{-2} s^{-1}
- Hadron storage ring built from the existing RHIC arcs; new electron storage ring, rapid-cycling synchrotron and injector
- One interaction region, with provision for a second

Technically driven schedule



CD-3C and infrastructure CD-2/3 proposed in FY27

DOE comprehensive review 15–18 September 2026

Fiscal years — FY34 begins October 2033

Under construction — the machine and the collaboration

The machine

- RHIC operations concluded 6 February 2026; removal and repurposing began in April
- First cryostat relocated in the tunnel on 12 May 2026
- EIC long lead procurements under way

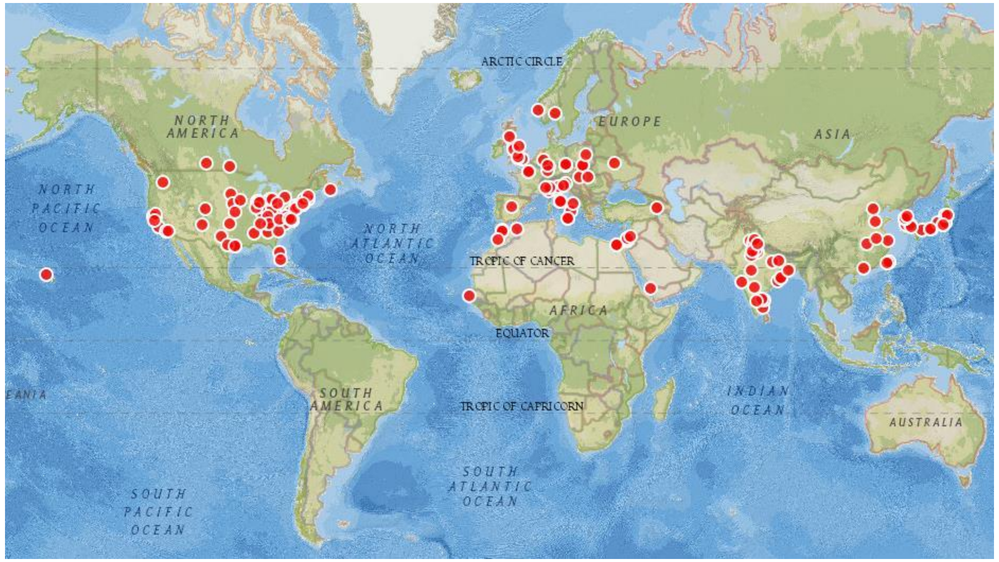
DOE Under Secretary D. Gil
End of RHIC and Start of EIC

Blue ring removal, April 2026

The collaboration

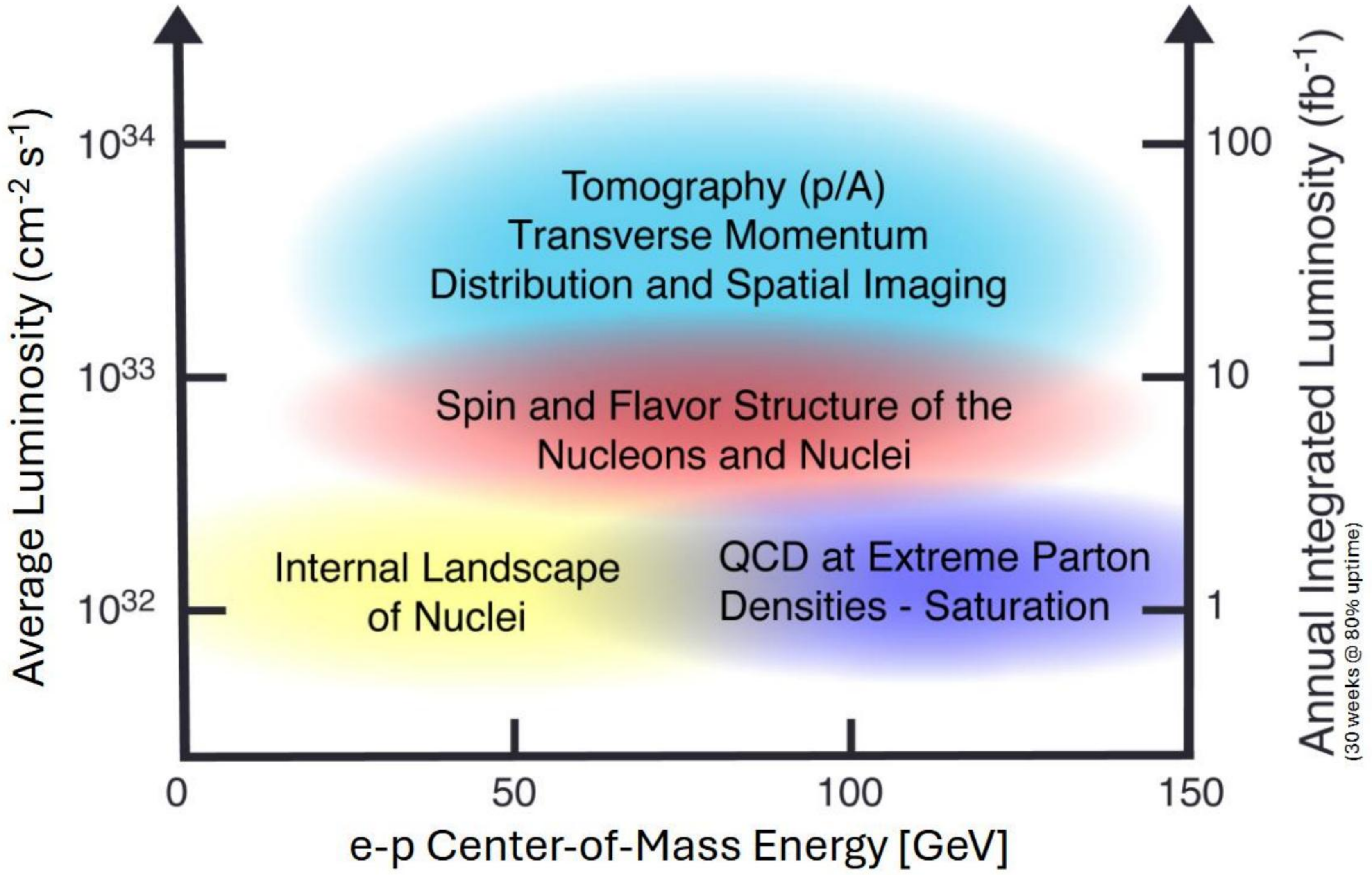
- >1150 collaborators, 183 institutions, 26 countries
- North America 46%, Europe 31%, Asia 22%, Africa 2%
- A CERN-recognized experiment, and still growing

ePIC collaboration meeting, Brookhaven, January 2026

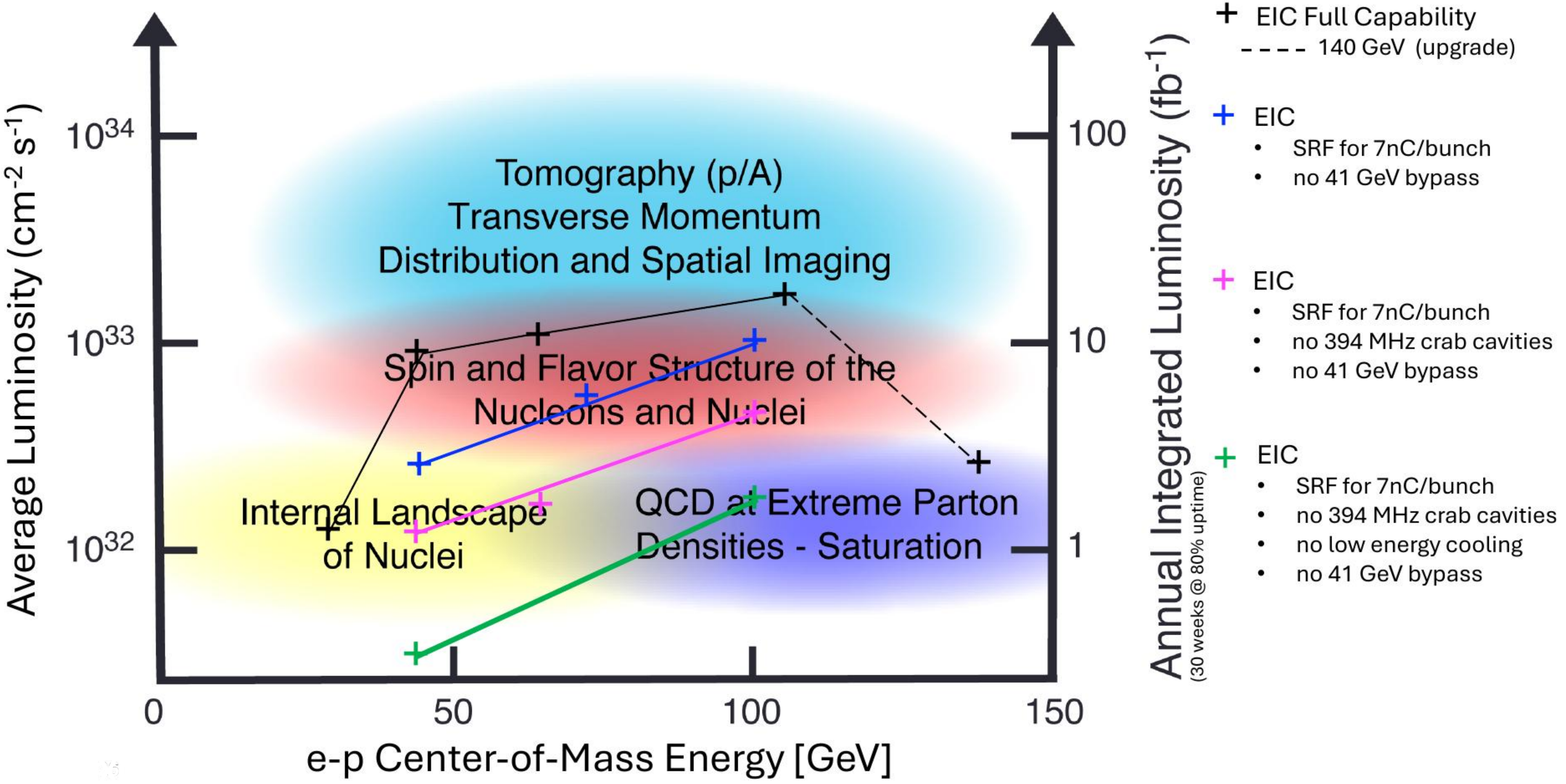


183 institutions in 26 countries

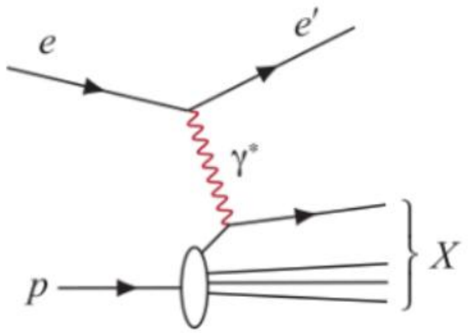
What the physics needs, in machine energy and luminosity

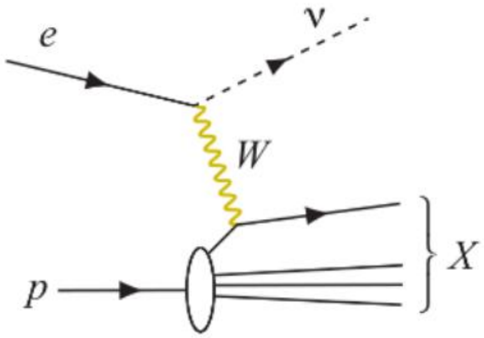


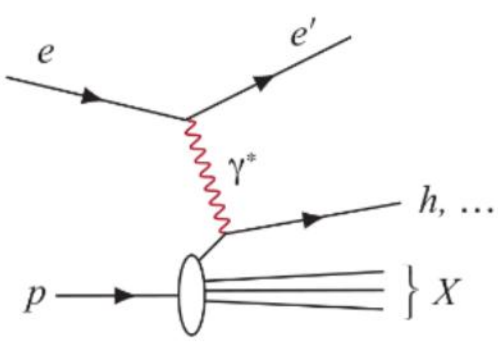
What the EIC will deliver, and when

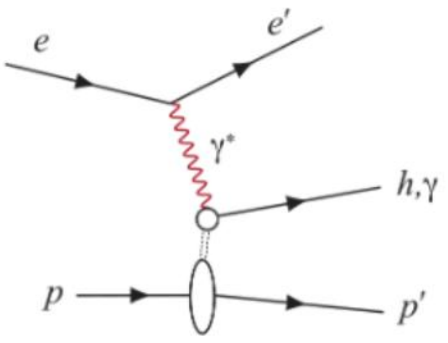


Access to the physics: what has to be detected









Neutral current DIS

Detect the scattered electron with high precision — event kinematics

Charged current DIS

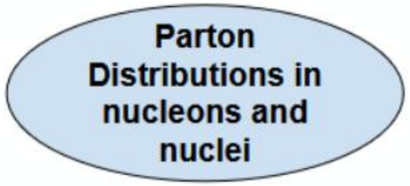
Kinematics from the final-state particles (Jacquet–Blondel)

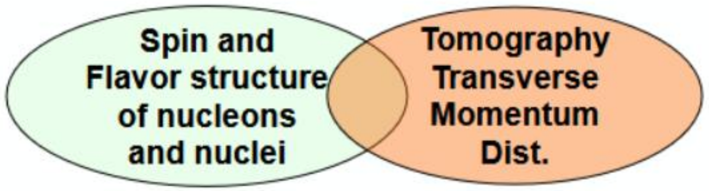
Semi-inclusive DIS

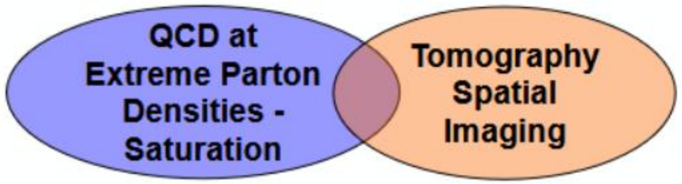
Scattered electron in coincidence with at least one identified hadron

Exclusive processes

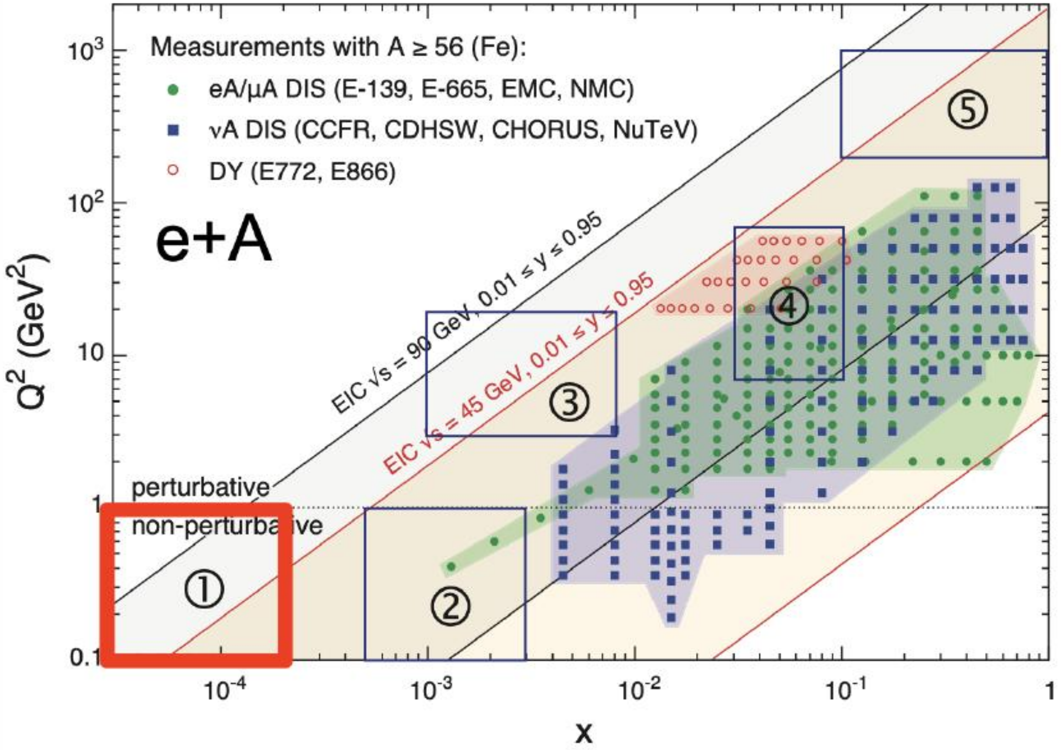
Every particle in the event

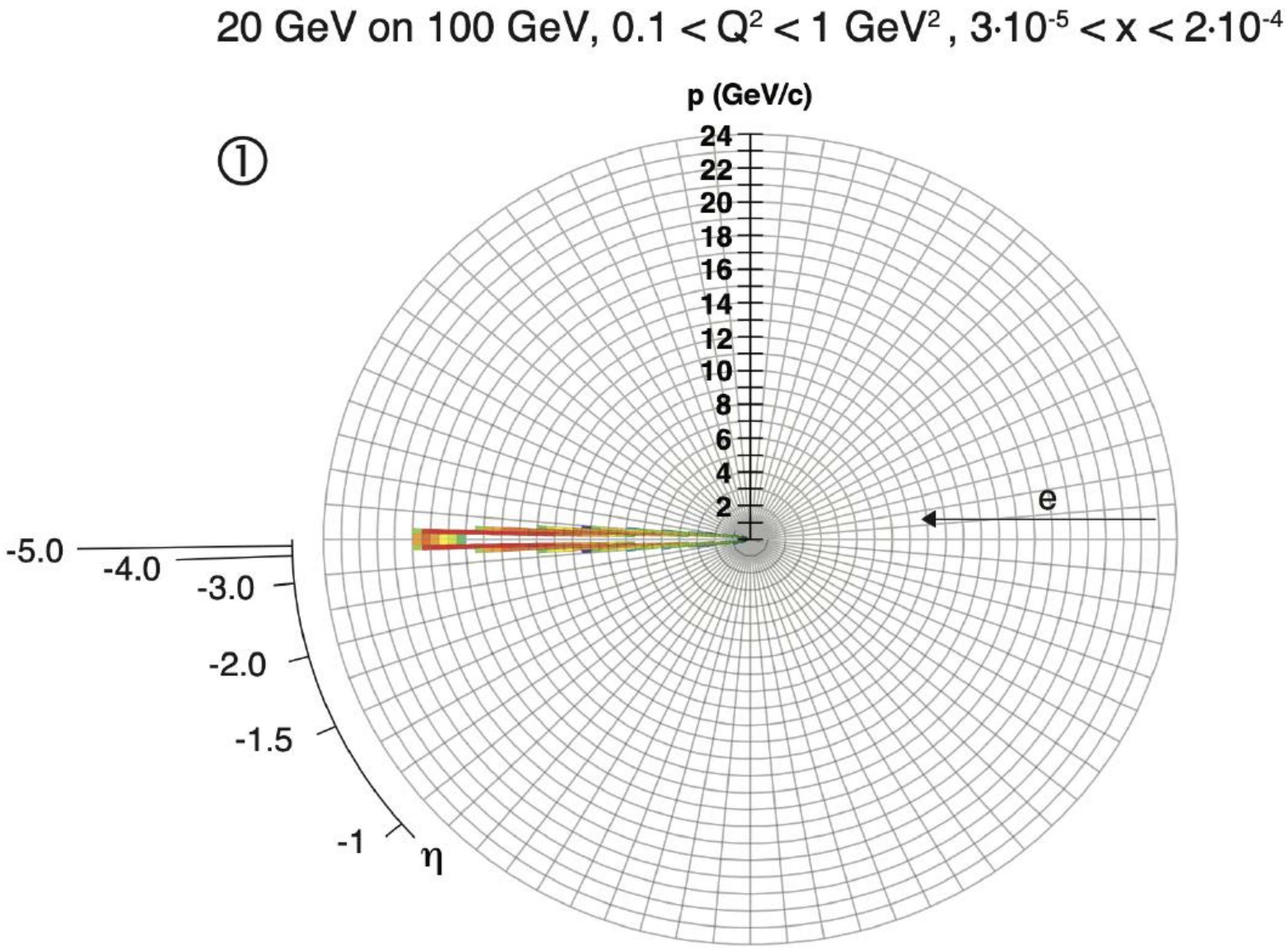




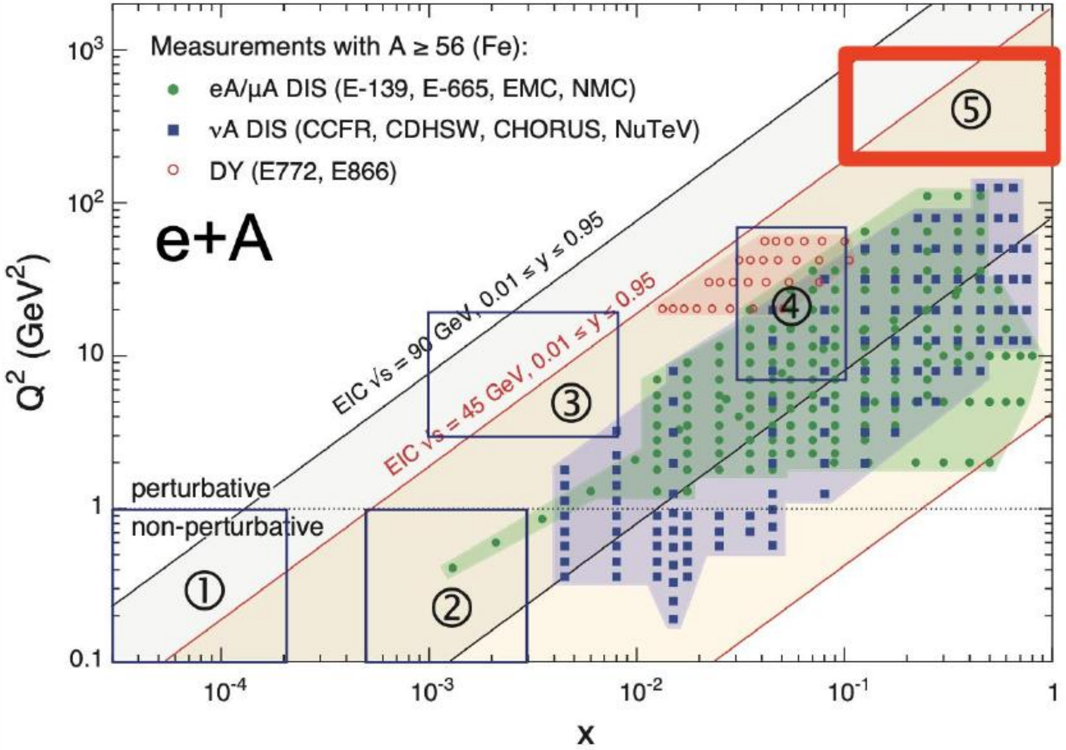


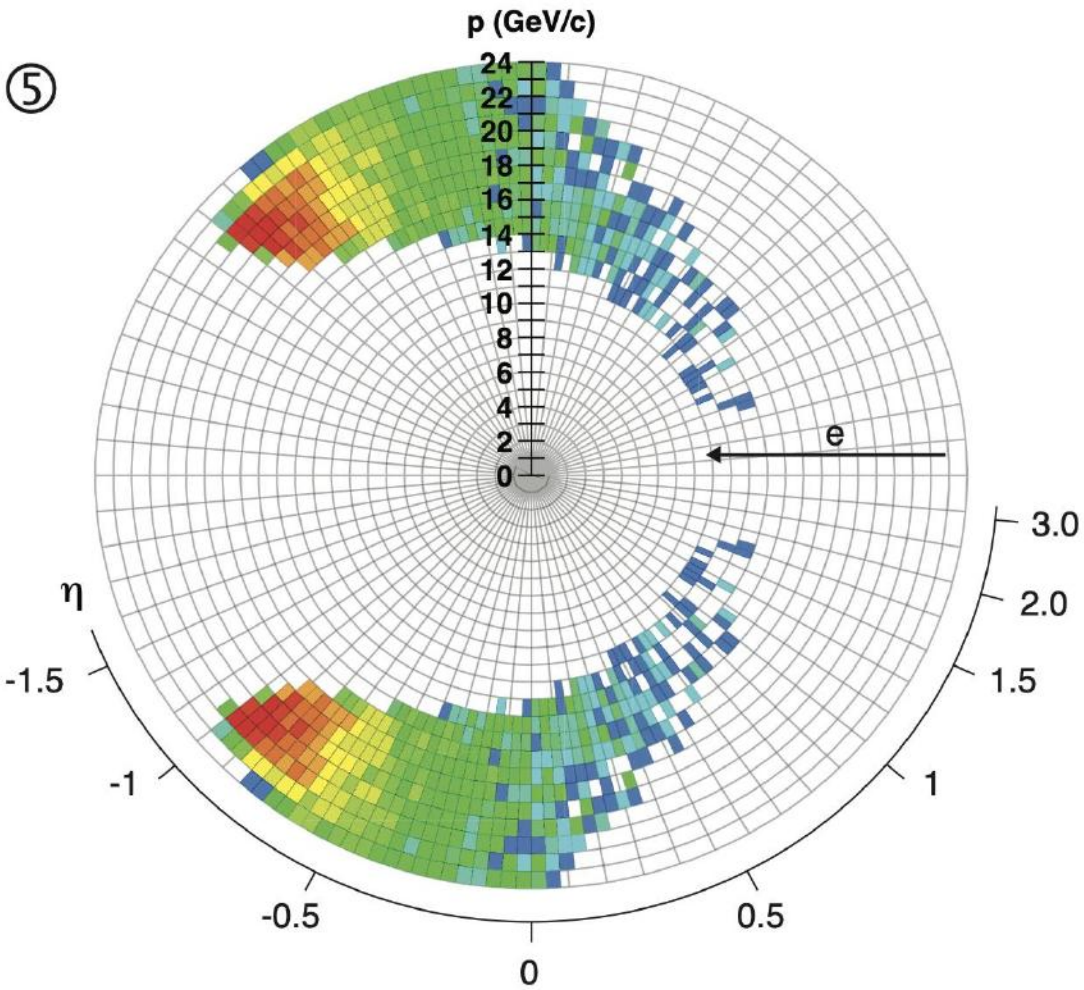
Deep-inelastic scattering coverage – scattered electron





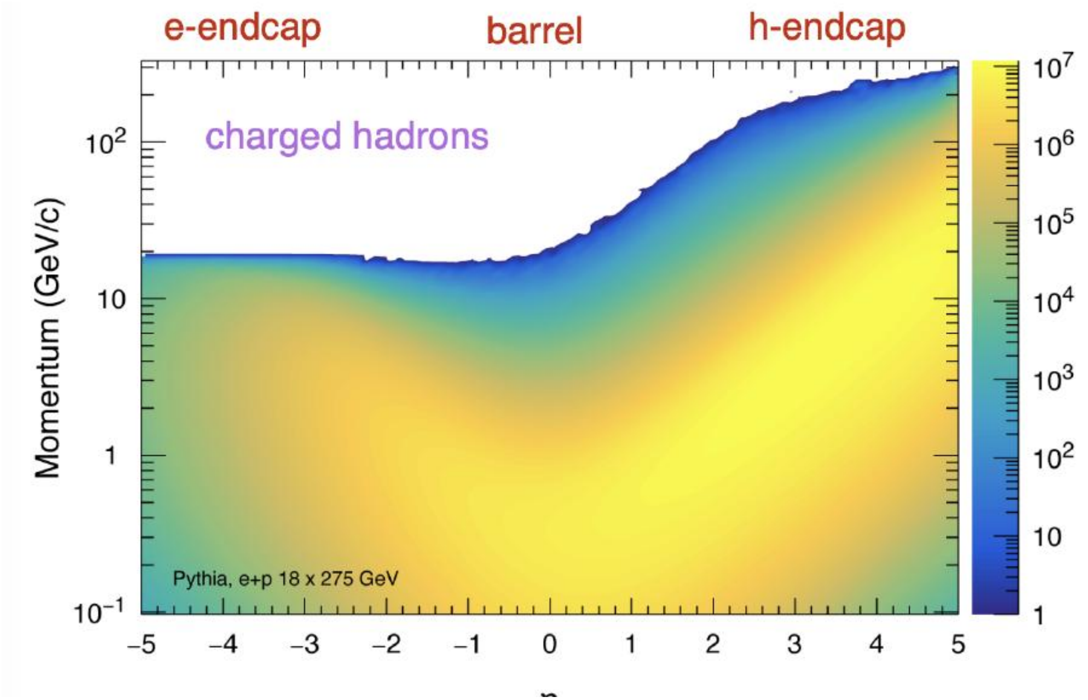
Deep-inelastic scattering coverage – scattered electron

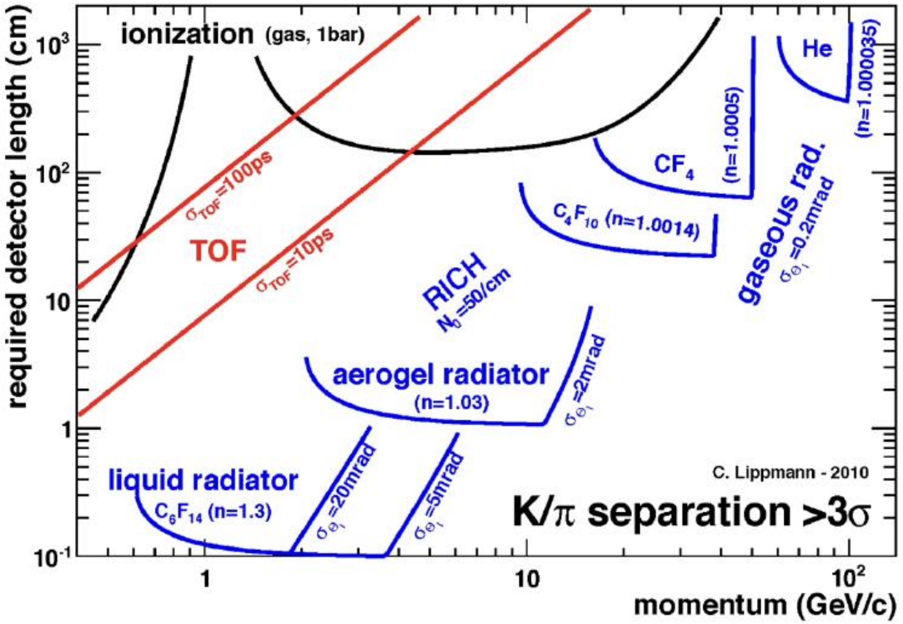




EIC energies and beam-energy asymmetries are very different from FCC-ee – considerable overlap in technologies nevertheless

Semi-inclusive DIS – hadrons and their identification





- π/K/p separation required over |η| ≤ 3.5
- Strong momentum–η correlation: $0.2 < p < 10$ GeV/c for $-5 < \eta < 2$; $0.2 < p < 50$ GeV/c for $2 < \eta < 5$

- Absolute particle identification at high purity and low contamination
- More than one technology is needed to cover the range
- EIC PID needs are more demanding than at most collider detectors

EIC detector requirements

- Hermetic detector, low-mass inner tracking
- Electrons and jets over $-3.5 < \eta < +3.5$
- $\sigma(p)/p = 0.05\%\ p \oplus 0.5\%$ (central)
- Impact parameter $\sigma = 5 \oplus 20/p_T$ μm
- EM resolution $< 2\%/\sqrt{E}$ backward, $10\%/\sqrt{E}$ central
- π/K/p separation to 50 GeV/c forward

What makes this detector hard:

- Integration and hermeticity,
- Low mass tracking, precision electron calorimetry, particle identification,
- Compactness

Streaming readout at ~500 kHz interaction rate at full luminosity; background rates are considerably higher.

Moderate radiation levels by collider standards.

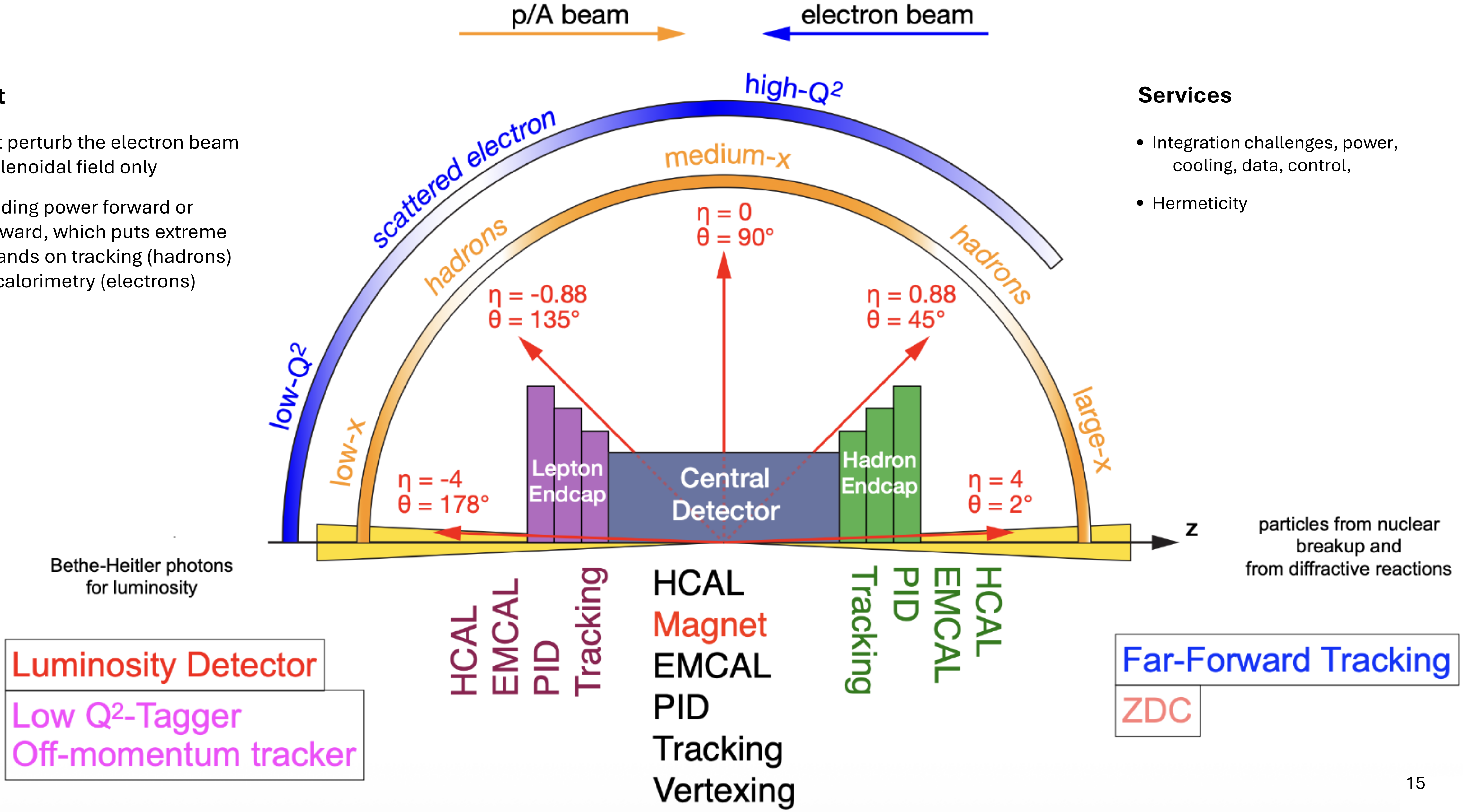
EIC detector layout – why it looks the way it does

Magnet

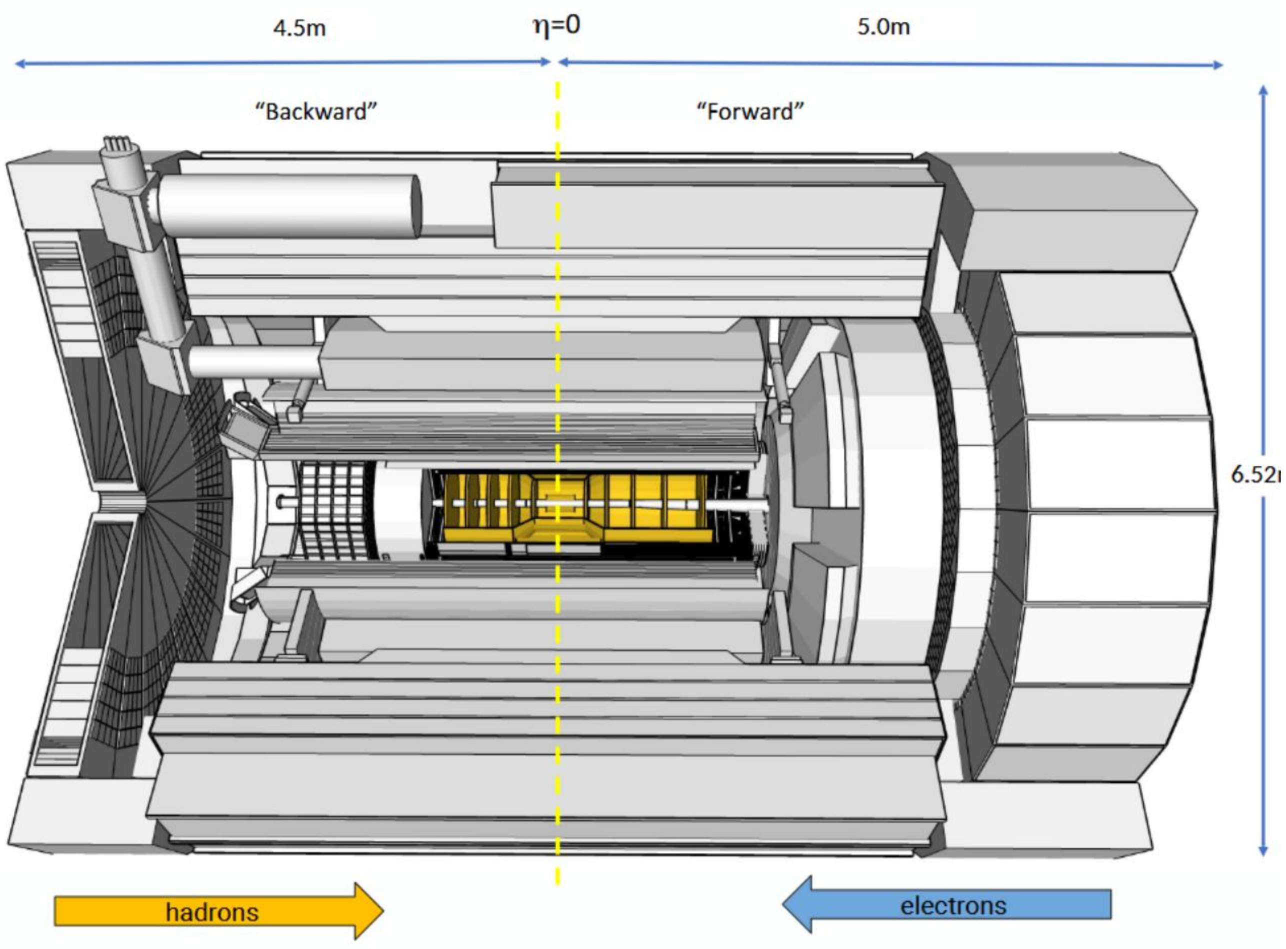
- Cannot perturb the electron beam — solenoidal field only
- No bending power forward or backward, which puts extreme demands on tracking (hadrons) and calorimetry (electrons)

Services

- Integration challenges, power, cooling, data, control,
- Hermeticity



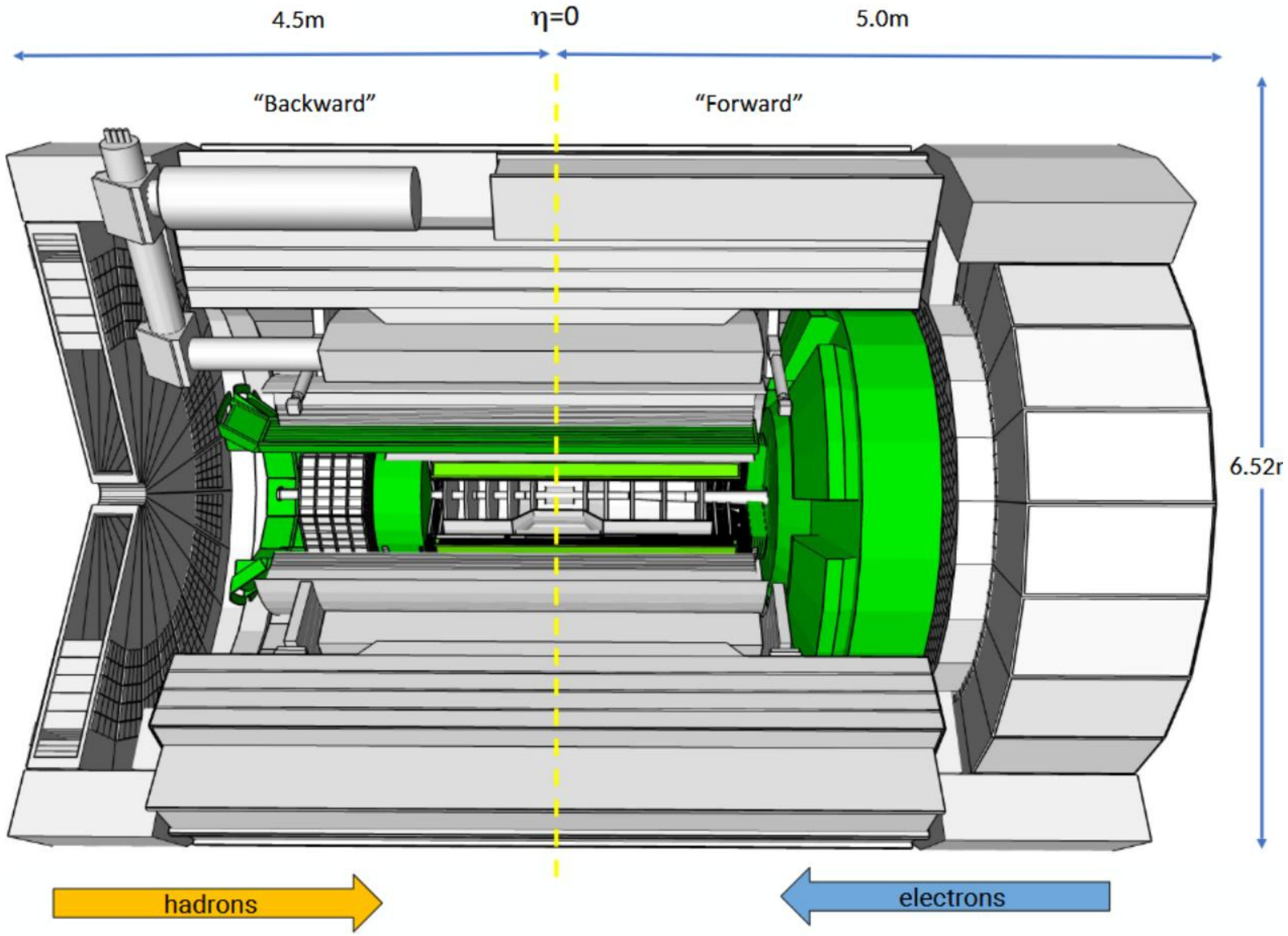
ePIC – Tracking



Tracking

- 1.7 T solenoid (2.0 T capable)
- Silicon Vertex Tracker — stitched MAPS, TPSCo 65 nm, ITS3 lineage
- MOSAIX inner barrels at 38 / 50 / 126 mm, 0.07% X/X_0 per layer
- EIC-LAS outer barrels (0.25%, 0.55%) and 2 × 5 disks (0.25%)
- MPGDs — μRWELL endcaps, Micromegas inner barrel
- AC-LGAD time-of-flight, 30 ps (dual function)

ePIC – Particle Identification

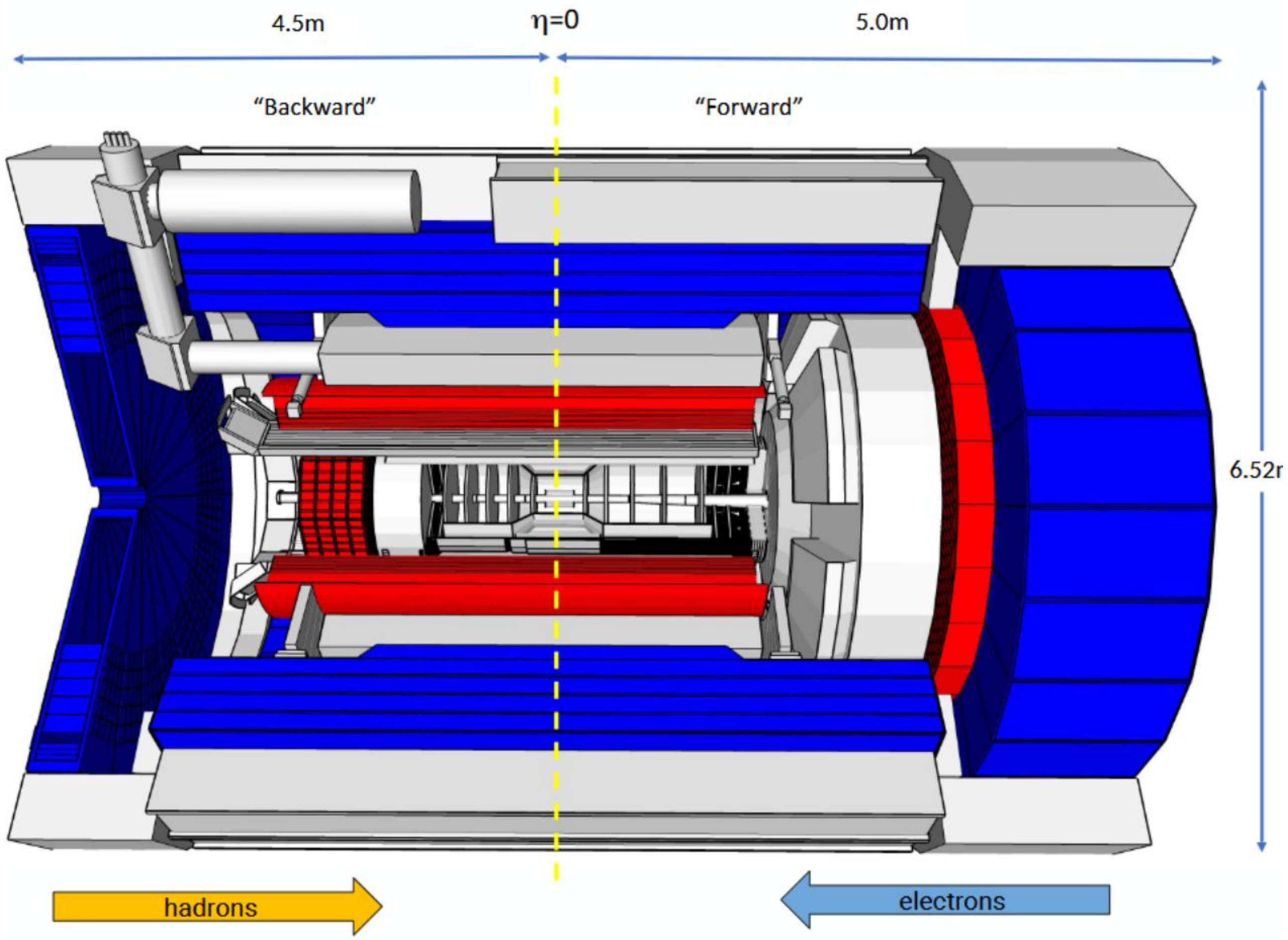


Particle identification

- Backward pfRICH — aerogel, ~30 cm proximity gap, 3σ π/K to 7+ GeV/c
- Barrel hpDIRC — refurbished BaBar quartz bars, MCP-PMTs, π/K to ~6 GeV/c
- Forward dRICH — aerogel and C_2F_6, e/π to 15 GeV/c
- Barrel and forward ToF — AC-LGAD strips and pixels, π/K to ~3 GeV/c
- AC-LGAD time-of-flight, 30 ps (dual function)

- Note: no muon capability

ePIC – Calorimetry

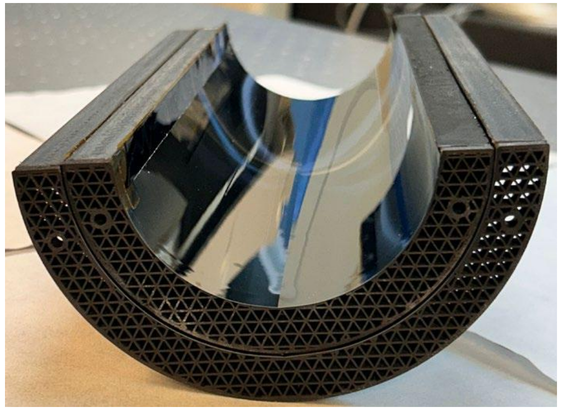


Calorimetry

- Backward EMCal — $PbWO_4$ crystals with SiPM readout, < 2%/√E
- Barrel EMCal — Pb/SciFi sampling with a six-layer AstroPix imaging section
- Forward EMCal — tungsten-powder SciFi SPACAL
- HCals — steel and scintillator, SiPM-on-tile; barrel reused from sPHENIX
- High-resolution forward insert close to the beampipe

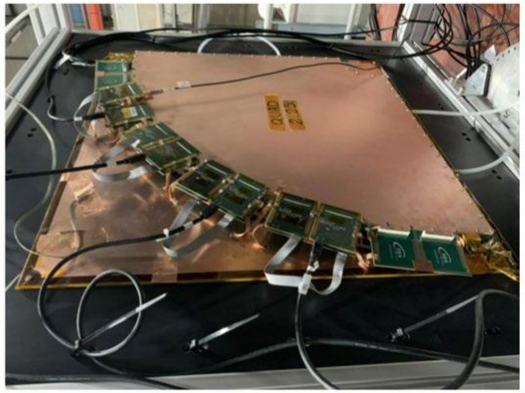
26 subsystems over ±40 m — 3 EMCals, 3 HCals, 3 RICH detectors plus time-of-flight, 7 auxiliary detectors, fully streaming readout, electron and hadron polarimetry.

Examples of what is being built

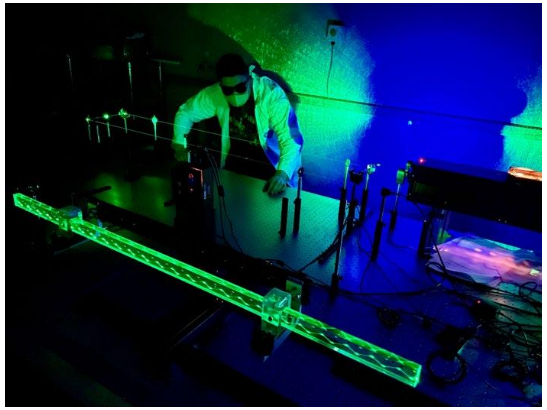


Silicon Vertex Tracker — carbon-fiber inner-barrel support and cooling vessel

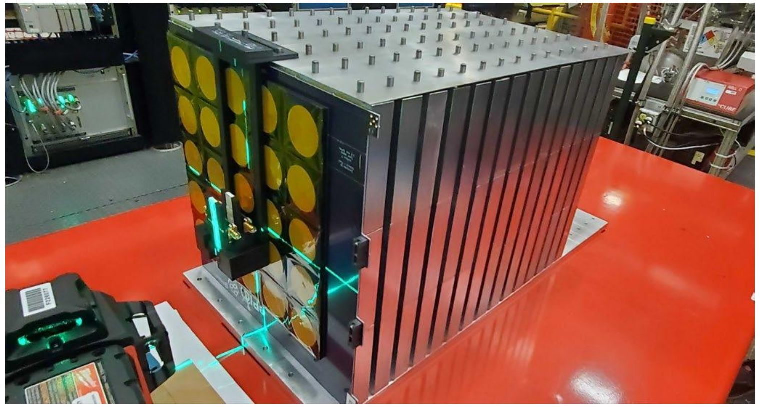
Forward EMCal — tungsten-powder SciFi SPACAL block



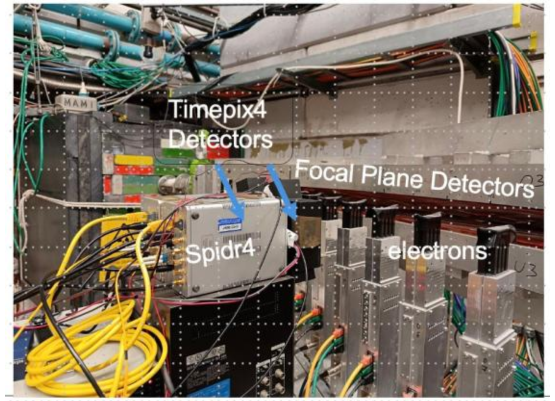
MPGD engineering test article



hpDIRC — optical test of a refurbished quartz bar



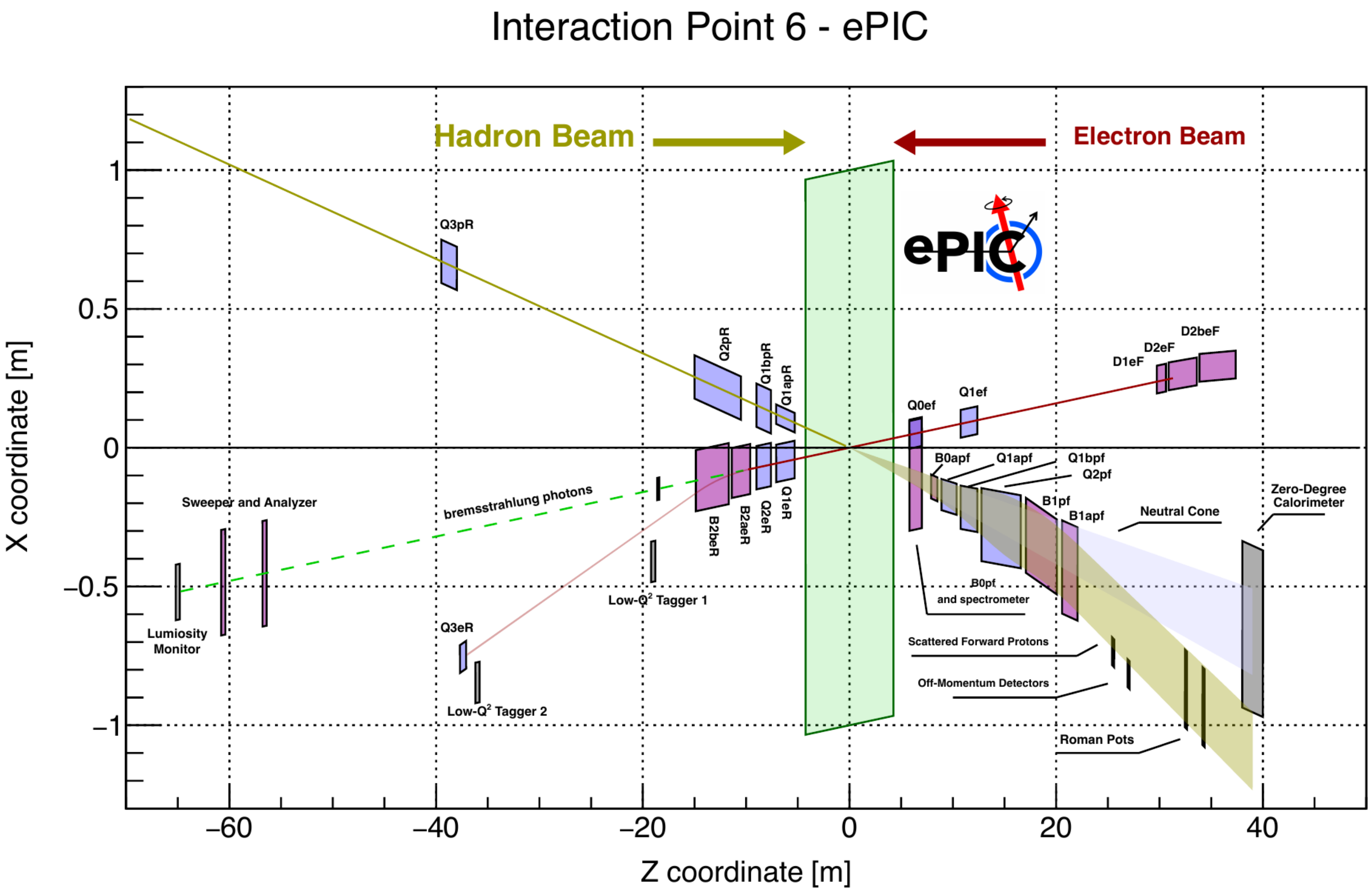
Hadronic calorimeter engineering test article, SiPM-on-tile



Low-Q^2 tagger engineering test article in a test beam

Engineering test articles under evaluation; several subsystems in recent test beams. Subsystem design reviews continuing, preliminary TDR in preparation.

The EIC interaction region

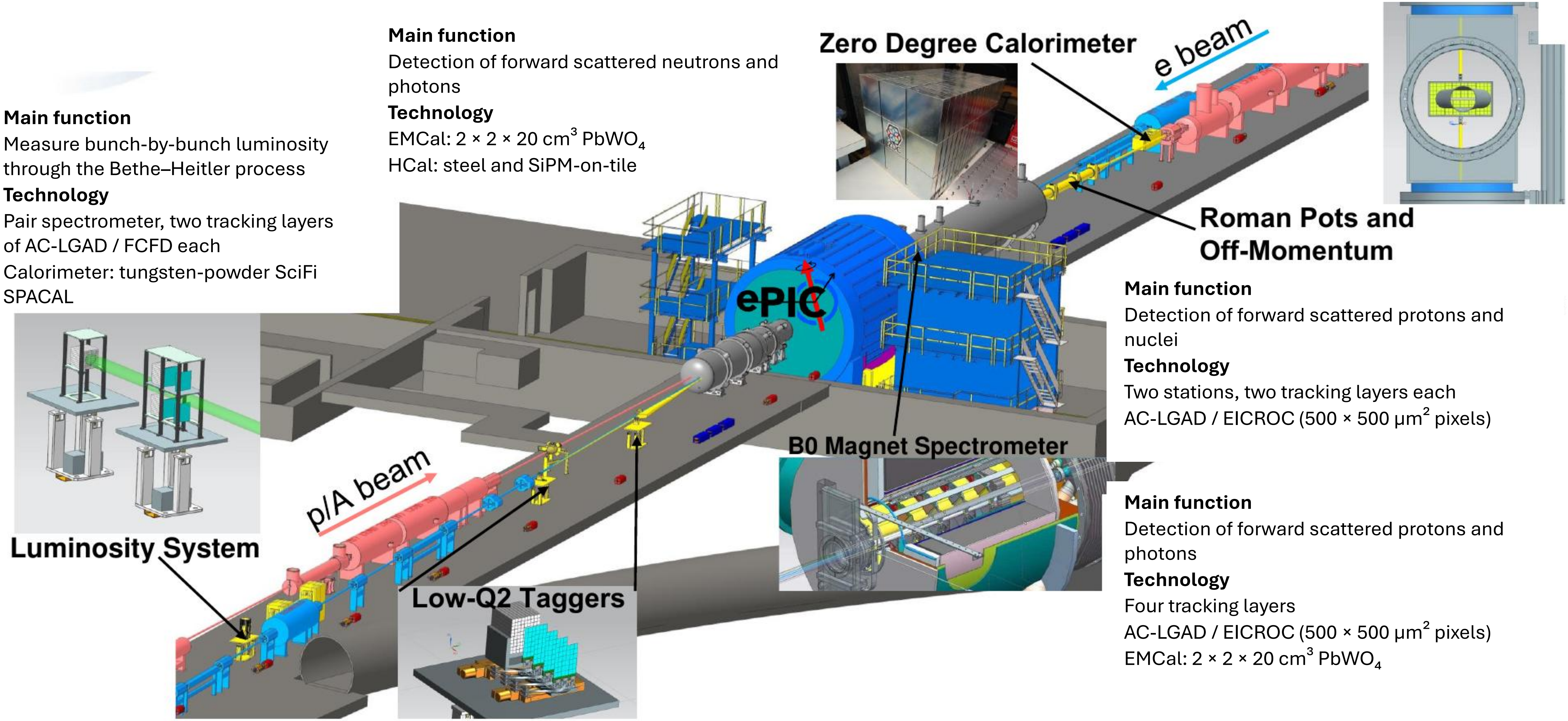


Interaction Point 6, to scale over ±70 m in z. 25 mrad crossing angle; the far-forward and far-backward detectors sit inside the machine lattice.

Far-forward and far-backward detectors

Main function
Measure bunch-by-bunch luminosity through the Bethe–Heitler process
Technology
Pair spectrometer, two tracking layers of AC-LGAD / FCFD each
Calorimeter: tungsten-powder SciFi SPACAL

Main function
Detection of forward scattered neutrons and photons
Technology
EMCal: 2 × 2 × 20 cm^3 $PbWO_4$
HCal: steel and SiPM-on-tile

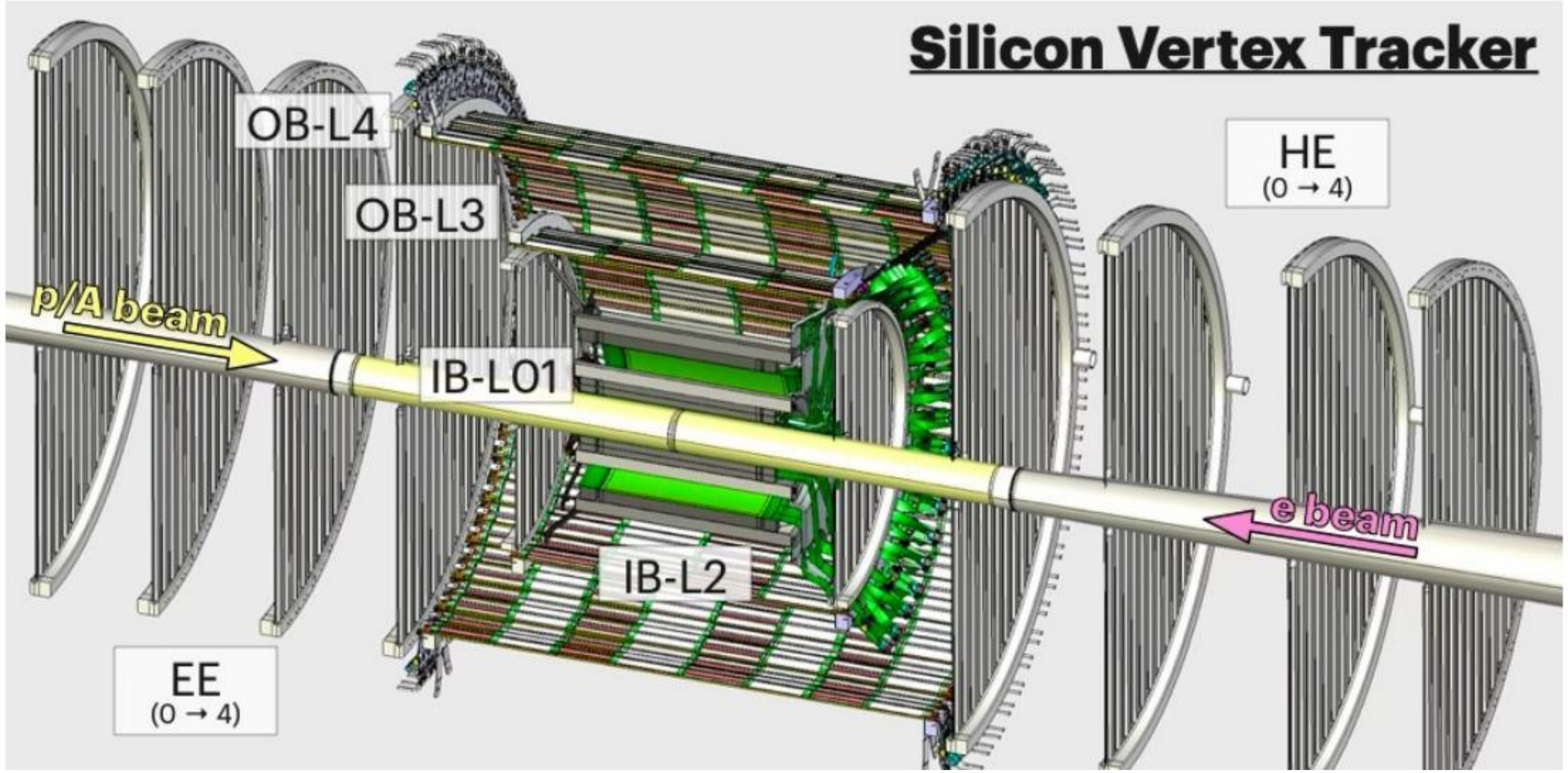


Main function
Detection of forward scattered protons and nuclei
Technology
Two stations, two tracking layers each
AC-LGAD / EICROC (500 × 500 μm^2 pixels)

Main function
Detection of forward scattered protons and photons
Technology
Four tracking layers
AC-LGAD / EICROC (500 × 500 μm^2 pixels)
EMCal: 2 × 2 × 20 cm^3 $PbWO_4$

Complexities of far-forward integration are EIC-specific – technologies are not

Silicon Vertex Tracker — design overview



Inner Barrel (IB)

- Three layers: L0, L1, L2
- Radii: 38, 50, 126 mm; length 27 cm
- $X/X_0 \approx 0.07\%$ per layer
- Bent, thin, wafer-scale ITS3 sensor

Outer Barrel (OB)

- Two layers: L3, L4
- Radii: 270 and 420 mm
- $X/X_0 \approx 0.25\%$ (L3) and 0.55% (L4)
- Hollow stave structure; EIC-LAS sensor

Endcaps (EE, HE)

- Two arrays of five disks: EE0–4, HE0–4
- Radii: 240 and 420 mm
- $X/X_0 \approx 0.25\%$ per disk
- Corrugated disk structure; EIC-LAS sensor

Overall dimensions

- $-1.0\text{ m} < z < 1.2\text{ m}$,
- $r < 0.5\text{ m}$

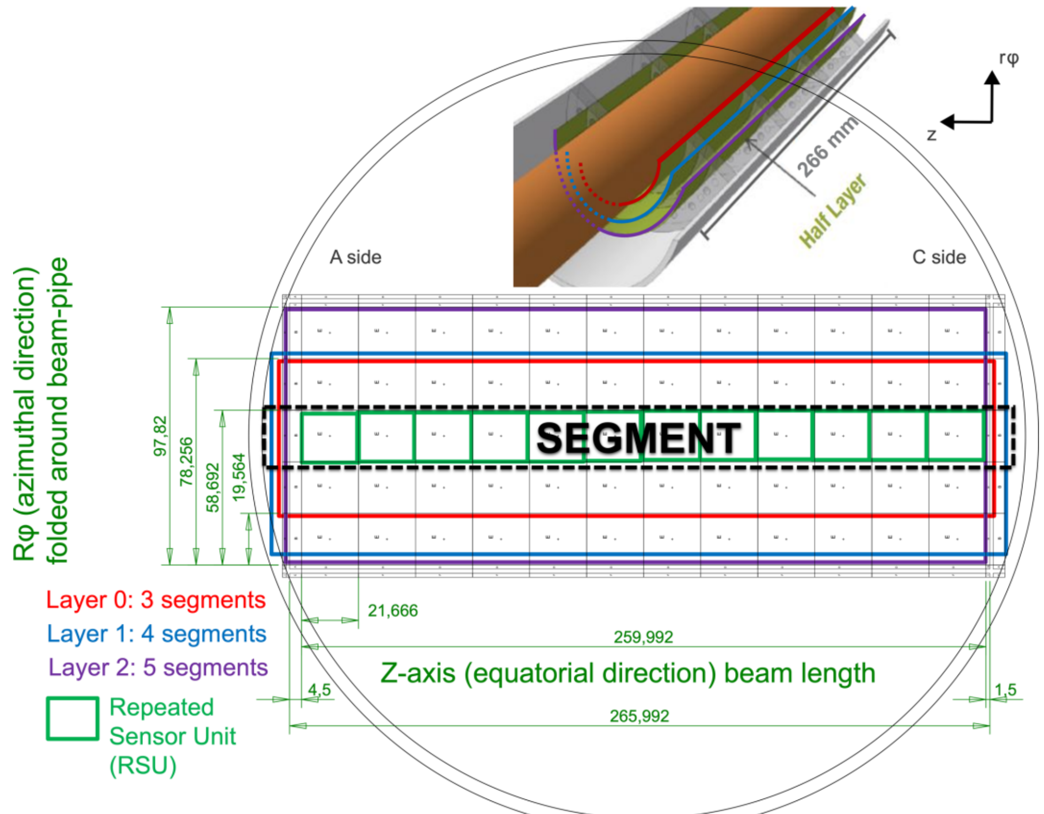
Sensors

- Monolithic active pixel sensors, TPSCo 65 nm
- Pixel pitch $O(20 \times 22.5)\ \mu m^2$
- Integration time ≤ 2 μs
- Power density ~40 mW/cm^2

Mechanics, services and cooling

- Aluminum-based flexible printed circuits
- Room-temperature operation, air cooling
- Carbon foam and carbon-fiber composite supports
- DAQ boards based on lpGBT, VTRX+, FELIX
- Serial powering for OB, EE and HE

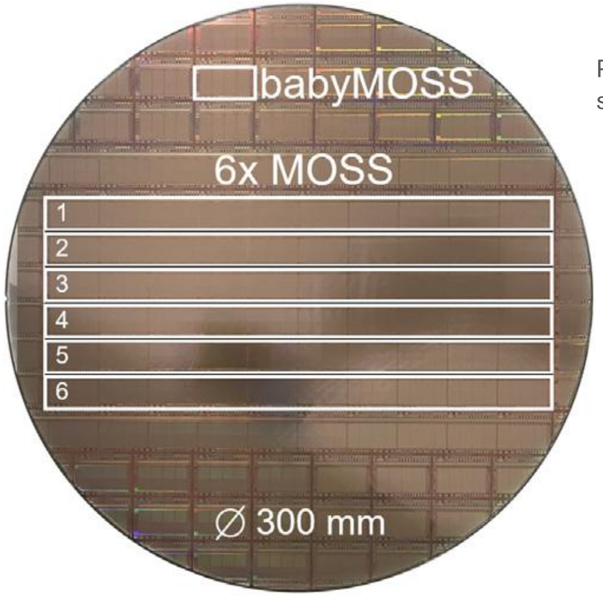
Silicon Vertex Tracker — MOSAIX



ALICE ITS3 Technical Design Report, CERN-LHCC-2024-003 / ALICE-TDR-021

- SVT Inner barrel uses MOSAIX, the ALICE ITS3 wafer-scale stitched sensor, in TPSCo 65 nm
- SVT Outer barrel and disks use EIC-LAS, modified from MOSAIX by reducing the repeated sensor units from 12 to 5–6, the high-speed data links from 8 to 1, the voltage of one power-domain, and the clock frequency

- ER1 is fully characterized:



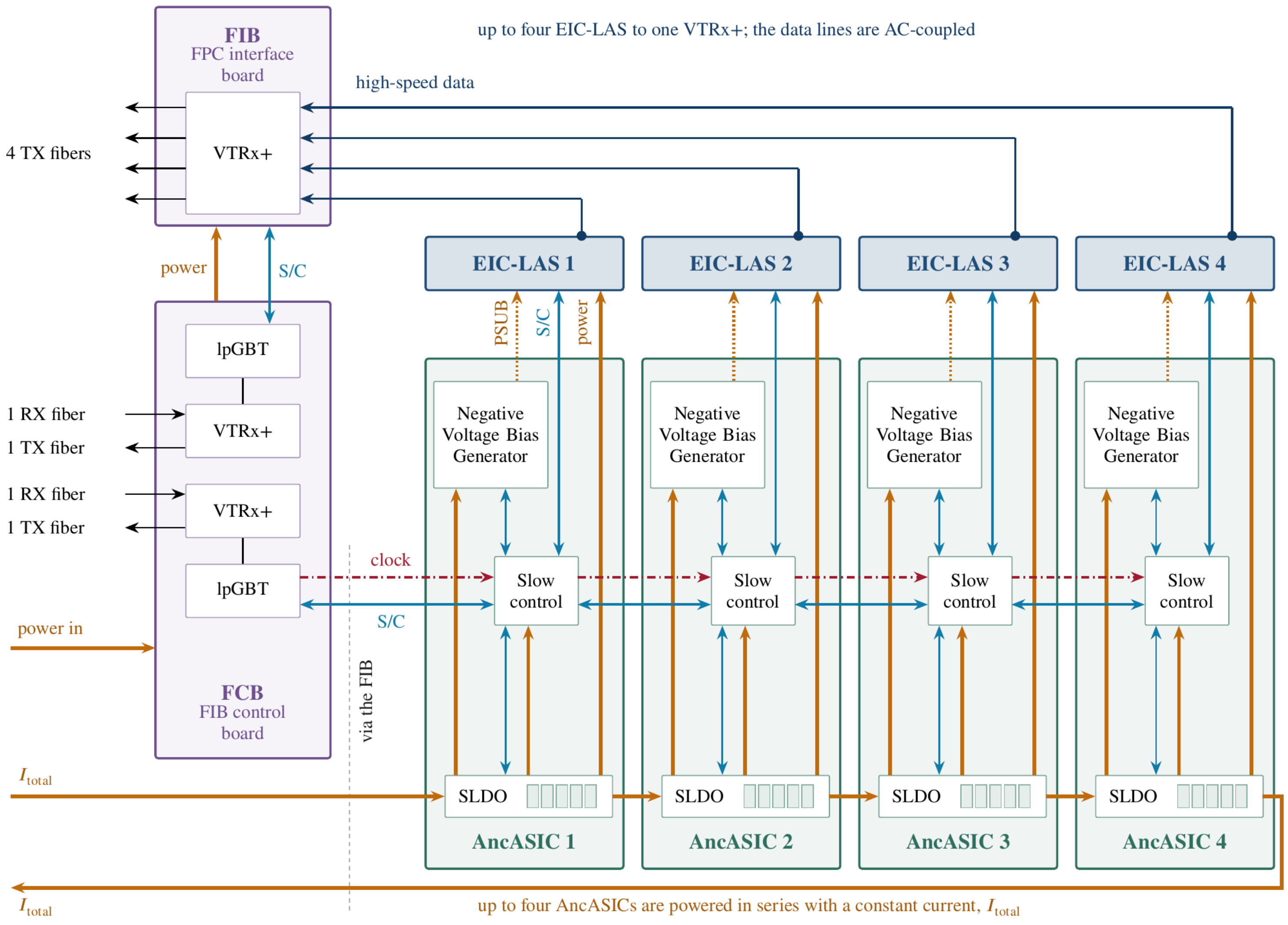
Processed 300 mm wafer with six MOSS (ER1) sensors

O. Abdelrahman et al., Nucl. Instrum. Meth. A 1086 (2026) 171297

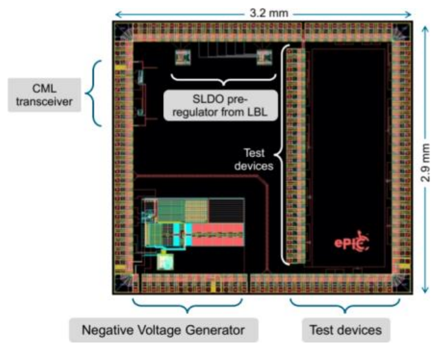
- ER2 MOSAIX sensors are being wafer-probed at CERN

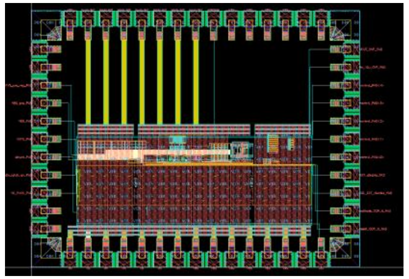
- ER3 submission is targeted for later this year or early next.

Silicon Vertex Tracker — reducing the services



- An ancillary ASIC minimizes the modifications that would otherwise need to be made to MOSAIX → EIC-LAS
- Reduces the services that would otherwise dominate the material budget
- Shunt-LDOs power the four sensor voltage domains — up to four AncASICs run in series on one current
- A programmable charge pump generates the negative sensor bias
- Slow control (AncBrain) is daisy-chained across AncASICs to cut traces and cables
- Up to four EIC-LAS to one VTRx+; data lines AC-coupled
- XFAB 110 nm BCD-on-SOI; MPW1 and MPW2 characterized, MPW3 with full functionality just taped out

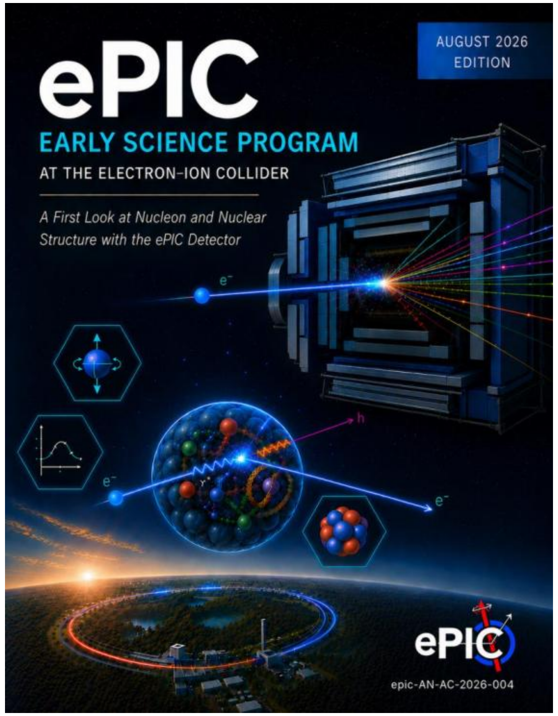




Closing comments

- EIC:
  - Under construction — RHIC operations ended February 2026; ePIC has a mature design, engineering test articles under evaluation, and is preparing for baseline and start of construction in FY28.
  - First beams FY34, start of the science program ~2035, full capability roughly five years later. A just-released Early Science Report sets out what is measurable before then, from GEANT simulation with full reconstruction and increasingly realistic beam backgrounds.

- Common ground:
  - polarized electron storage ring with swap-out injection, machine–detector integration, and one-of-a-kind IR magnets; simulations coupling machine lattice to detector backgrounds.
  - low-mass precision tracking (MAPS), fast-timing (AC-LGADs), precision calorimetry (SiPM on $PbWO_4$ crystals), …



ePIC Early Science Program, August 2026 (arXiv:2608.05377)

Much of the R&D began in the HEP community. A good part of it will get built, integrated, and operated at experiment scale at the EIC.

Acceptance and systematics are specific to each machine; the methods and technologies to address them are not.

Backup

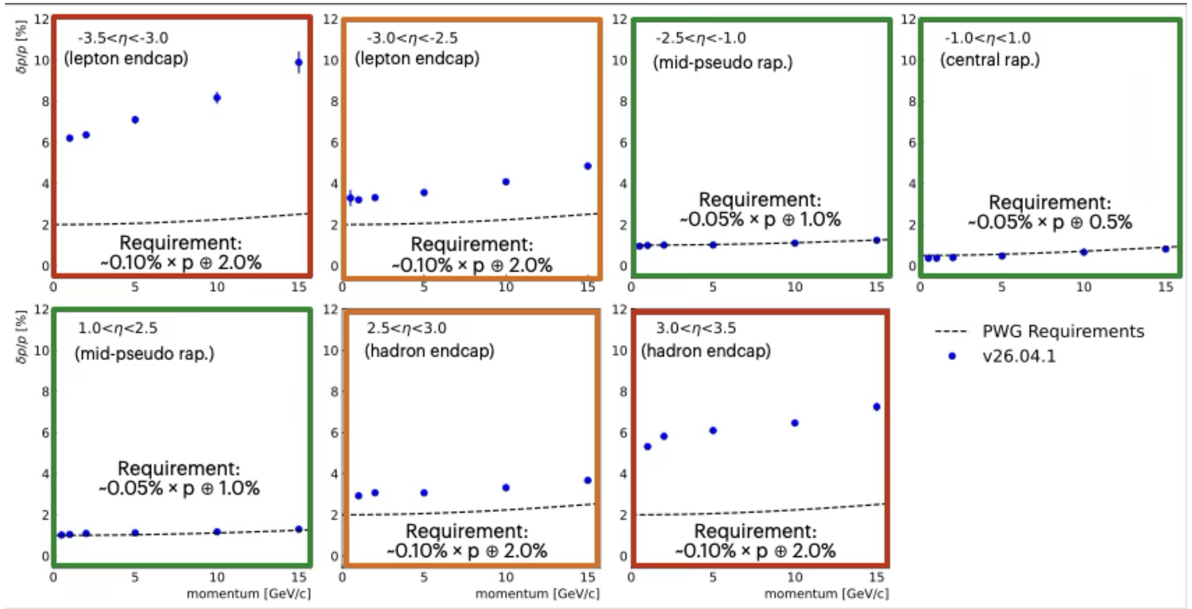
Backup — tracking resolutions

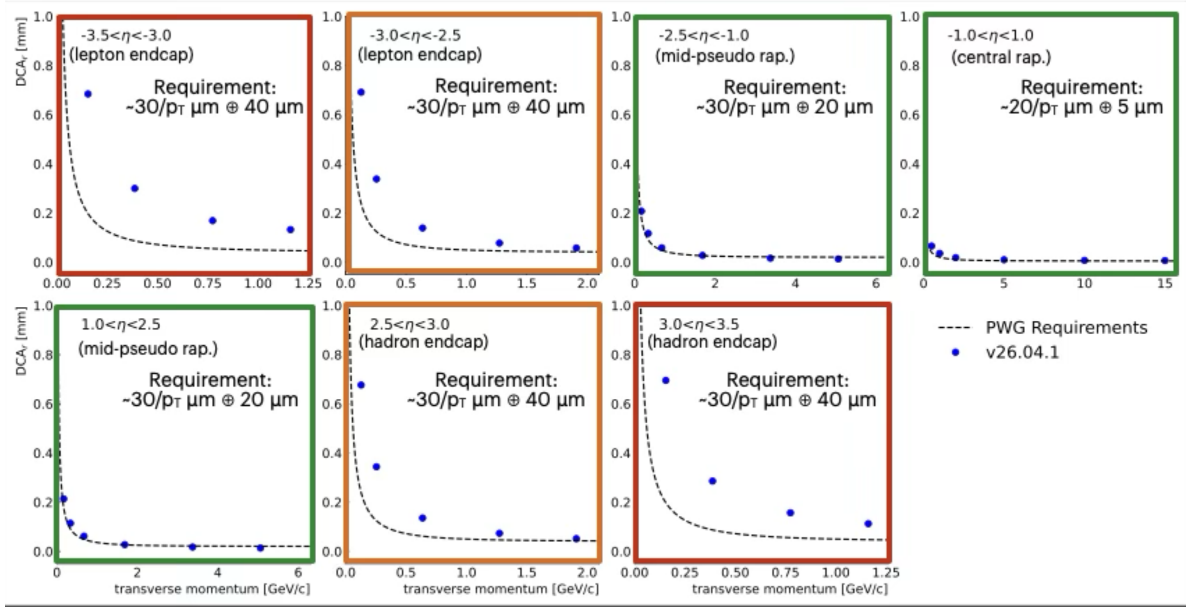
Relative momentum resolution

- Requirements met in the central region and at mid-pseudorapidity
- Fair agreement at large η
- Challenging at very large η, especially the lepton endcap

Pointing resolution

- Requirements met in the central region and at mid-pseudorapidity
- Good agreement at large η
- Fair agreement at very large η





Single pions, 0.5–15 GeV, generated at the nominal collision vertex and propagated through a preliminary detector design (geometry, material and point resolutions); recorded hits processed with the ACTS combinatorial Kalman filter.

Backup — ePIC technologies as precursors

Technology	In ePIC	Stated onward relevance
Silicon vertex tracker	Wafer-scale stitched MAPS from ALICE ITS3; EIC-LAS; air cooling on a scale unprecedented in particle physics; services co-cured into the structures	Central to tracking systems in future lepton colliders
Superconducting solenoid	2 T, 3.5 m coil, 2.84 m warm bore, Cu-stabilised NbTi Rutherford cable	First large-bore collider detector magnet since 2010; rebuilds skills lost since CMS and ATLAS
SiPMs on $PbWO_4$ crystals	~3000 crystals, 4–16 high-pixel-density SiPMs each, linear to 3500 photoelectrons	High-resolution electromagnetic calorimetry at future e^+e^- colliders
Barrel imaging calorimeter	Pb/SciFi sampling interleaved with AstroPix HV-MAPS layers; >100 m^2 of silicon; $5.2\%/\sqrt{E} \oplus 1.0\%$	First large-scale application of HV-CMOS for particle detection
SiPM-on-tile hadronic calorimetry	CALICE lineage; 18 320 forward towers; high-granularity insert; ZDC prototype run in STAR	Particle-flow calorimetry for Higgs-factory detectors
AC-LGADs	Below 35 ps and 30 μm in a single layer; strips in the barrel, pixels forward	Tracking and timing layers in future large collider experiments
Cherenkov photosensors	HRPPDs of 10.4 × 10.4 cm^2 at <15 ps single-photon timing; annealed SiPMs in the dRICH	Considered as an option for FCC-ee; also ALICE3, LHCb, Belle II
Triggerless front-end and streaming readout	Five new ASICs (EICROC, CALOROC, FCFD, SALSA, ALCOR); $16\cdot10^9$ pixels, 500 kHz, no global dead time	Broad relevance for other experiments, such as those planned for the FCC
Synchrotron-radiation simulation	SynradG4, a Geant4 framework coupling machine lattice to detector backgrounds	Next generation of colliders, with particular reference to e^+e^- machines

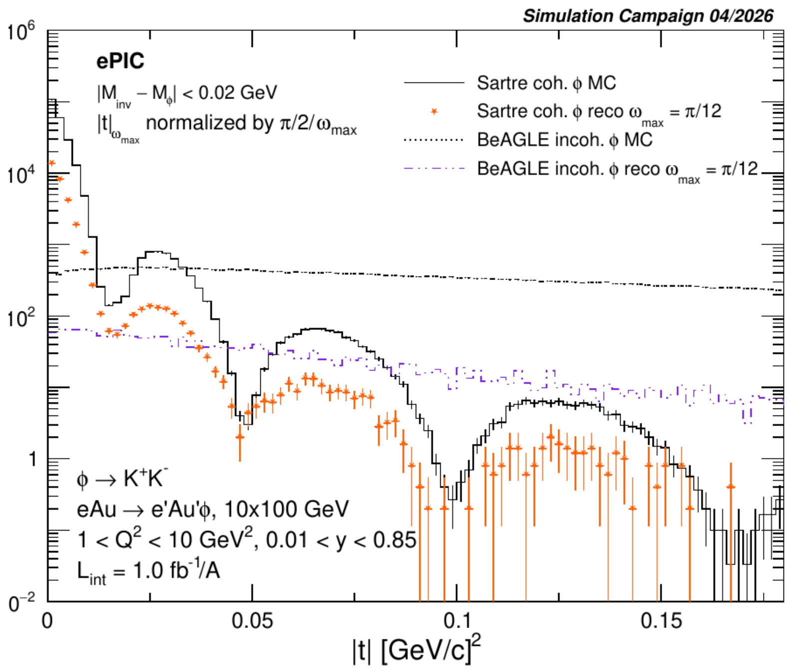
“The detector technologies that will be realized and operated on a large scale in ePIC can be regarded as precursors for the needs of the detectors at the large electron-positron collider. These precursors will be in operation ten or more years in advance.”
ePIC input to the European Strategy for Particle Physics — 2026 update, March 2025

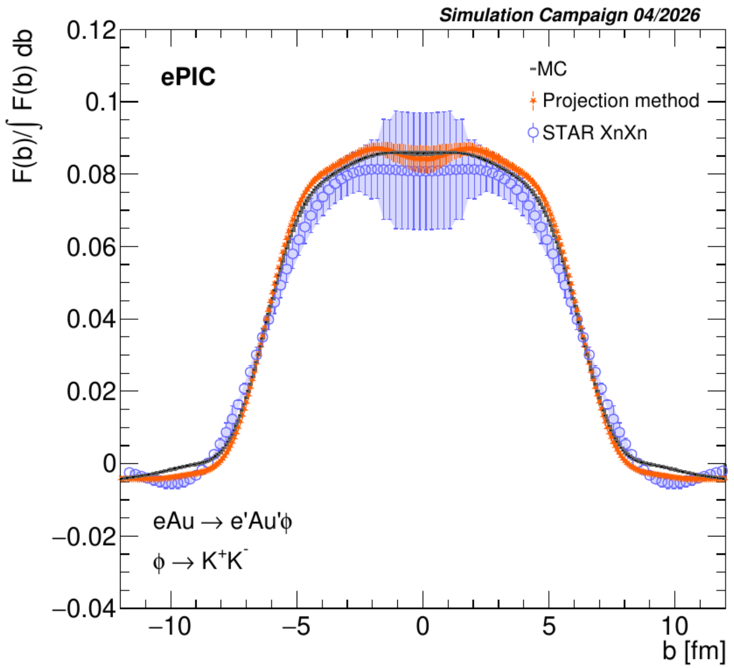
Backup — how the EIC comes online

	Year 1	Year 2	Year 3	Year 4	Year 5
New capability	Electron polarization, commissioned in parallel	Proton polarization, commissioned in parallel	Running with hadron spin rotators	Hadron accelerator operating with non-centered orbits	—
Run	9 GeV electrons on 115 GeV/u heavy ions (Ag, Nb, Cu, Ru)	9 GeV longitudinally polarized electrons on 130 GeV/u deuterium; last weeks 10 GeV on 130 GeV polarized protons	9 GeV longitudinally polarized electrons on 130 GeV transversely polarized protons; last weeks switch to longitudinal	9 GeV polarized electrons on 110 GeV Au; 10 GeV on 275 GeV transversely and longitudinally polarized protons	9 GeV polarized electrons on 110 GeV Au; 10 GeV on 166 GeV transversely and longitudinally polarized He-3
Physics	Dense gluon systems; QCD in nuclei	QCD in nuclei; flavor structure of nucleons and nuclei	Flavor structure; spin	Dense gluon systems; QCD in nuclei; spin	Dense gluon systems; spin

Run plans are notional and follow the commissioning of collider capabilities; luminosity ramps as equipment is installed. Phase-1 EIC accumulates capability year by year.

Backup — imaging gluons in a nucleus

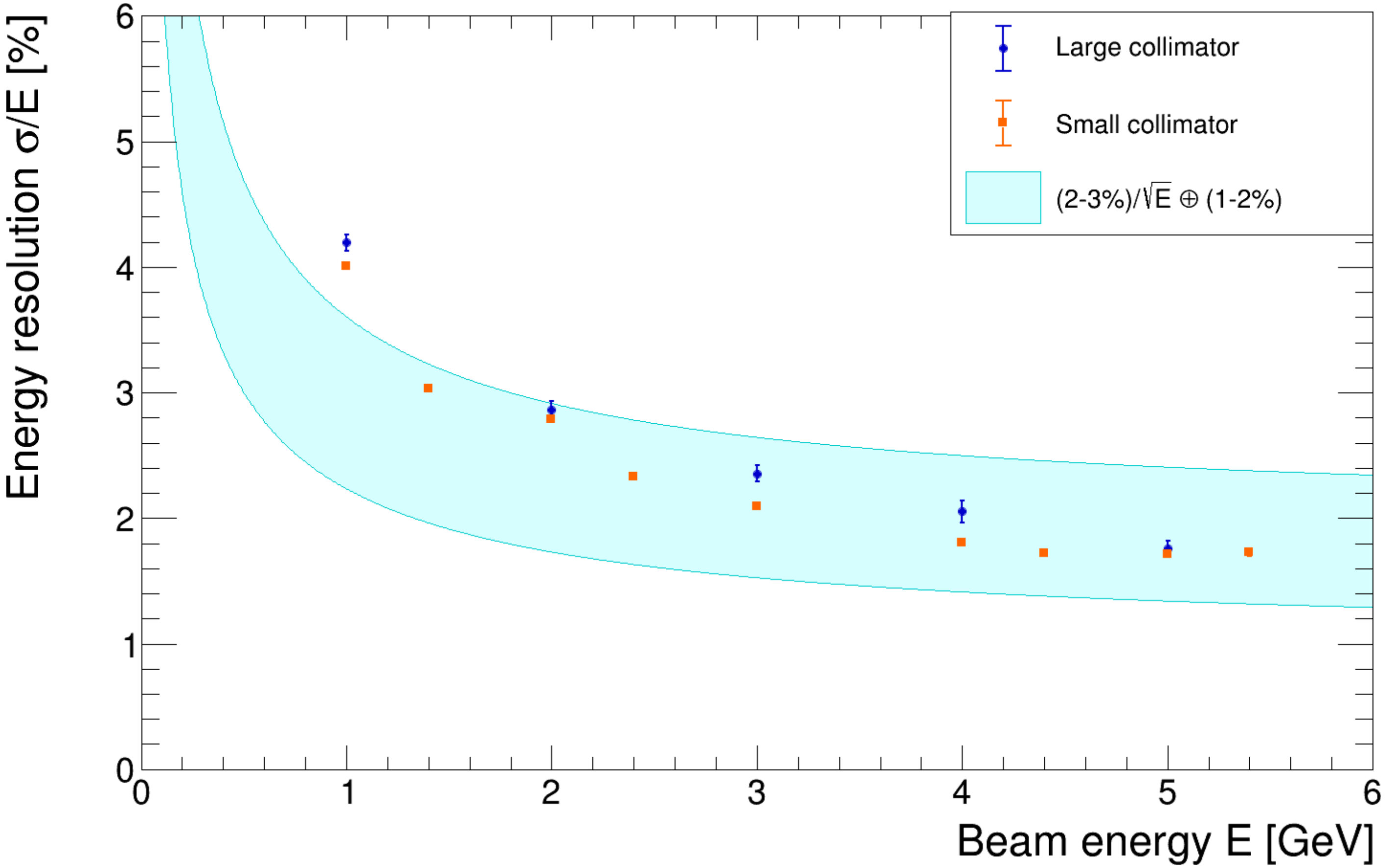




- Coherent $\phi \to K^+K^-$ in e+Au at 10 × 100 GeV, 1 fb^{-1}/A, $1 < Q^2 < 10$ GeV^2, $0.01 < y < 0.85$
- Projection-method |t| reconstruction resolves the diffractive minima and follows the generated distribution more closely than the standard method
- The Fourier–Bessel transform of the |t| distribution gives the transverse spatial distribution of gluons in the nucleus
- Off-momentum detectors, Roman pots and the zero-degree calorimeter separate coherent from incoherent breakup; electron and kaon reconstruction control exclusivity

ePIC simulation campaign 04/2026; ePIC Early Science Program report, arXiv:2608.05377

Backup — backward ECal beam test



- 5 × 5 $PbWO_4$ prototype of the ePIC backward electromagnetic calorimeter, DESY T24 electron beam
- SiPM readout; H2GCROC front end compared against a discrete electronics chain
- Energy resolution inside the (2–3)%/√E ⊕ (1–2)% requirement band from 2 GeV upwards
- High-energy behavior approaches a constant term of about 1.7%
- The 1 GeV point sits above the band; likely dominated by the beam energy spread, to be checked at a low-energy facility
- H2GCROC performance comparable to the discrete chain across the measured range

Energy resolution versus beam energy, two collimator settings, against the requirement band