PacificSPIN 2026 - The 13th Circum-Pan-Pacific Symposium on High Energy Spin Physics

Oct 27 – 30, 2026
Institute of Physics, Academia Sinica
Asia/Taipei timezone

Enter your search term

The ePIC Experiment at the Electron-Ion Collider From Detector Development to the Physics Program

TAKU GUNJI FOR THE EPIC COLLABORATION

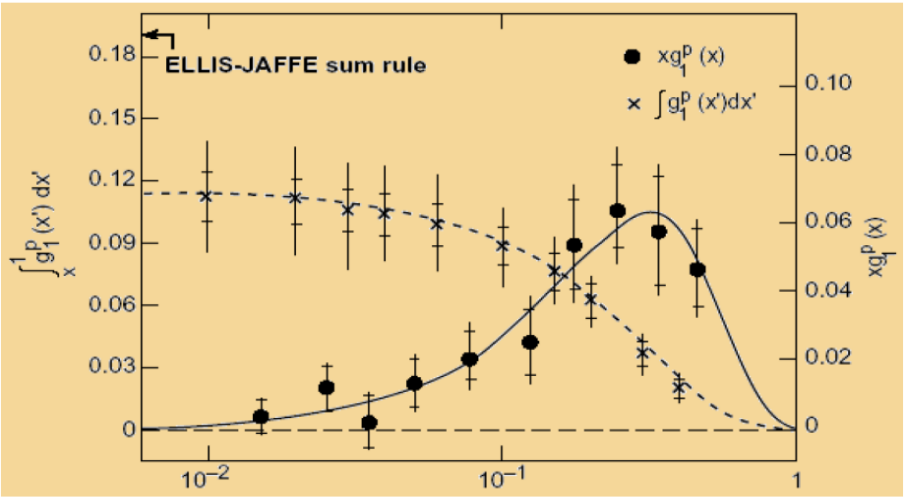
QUARK-NUCLEAR SCIENCE INSTITUTE, UNIVERSITY OF TOKYO

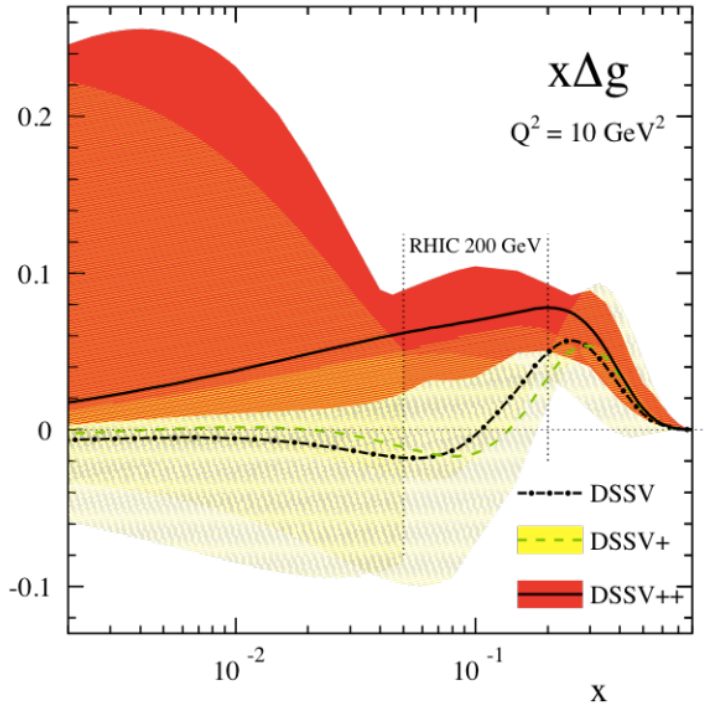
NISHINA CENTER, RIKEN

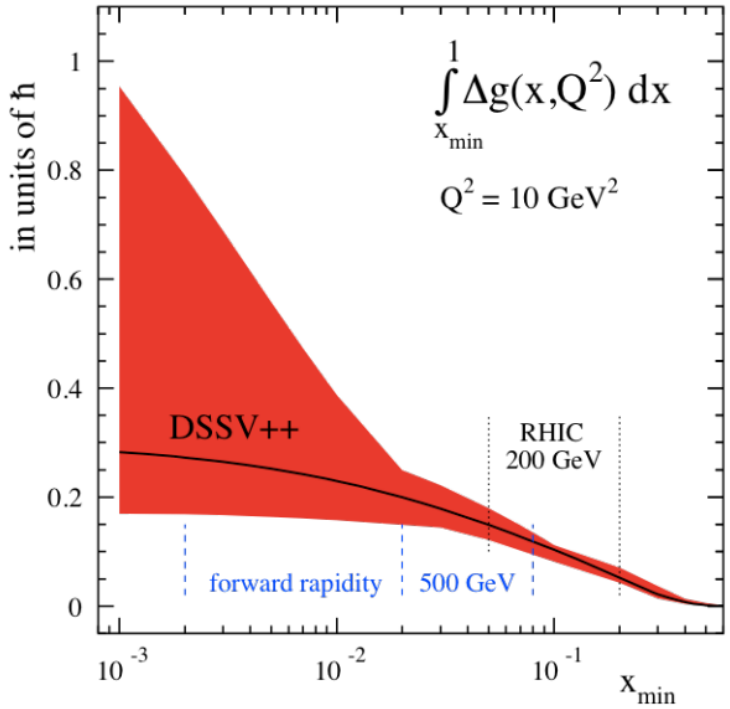
The Proton Spin Puzzle

- The proton has spin 1/2.
- Quark spins account for only part of the proton spin.
- What are the contributions from gluon spin and parton orbital angular momentum?
  - RHIC Spin program: non-zero gluon spin contribution ($x<10^{-2}$)

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + (L_q + L_g)$$

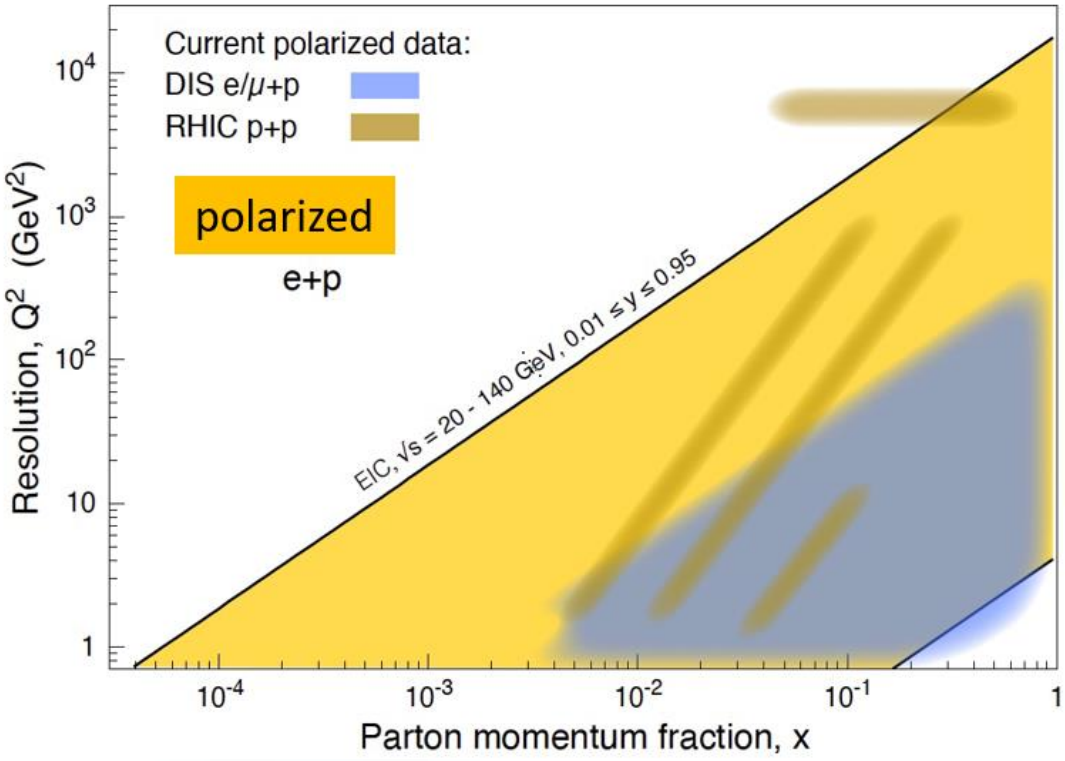


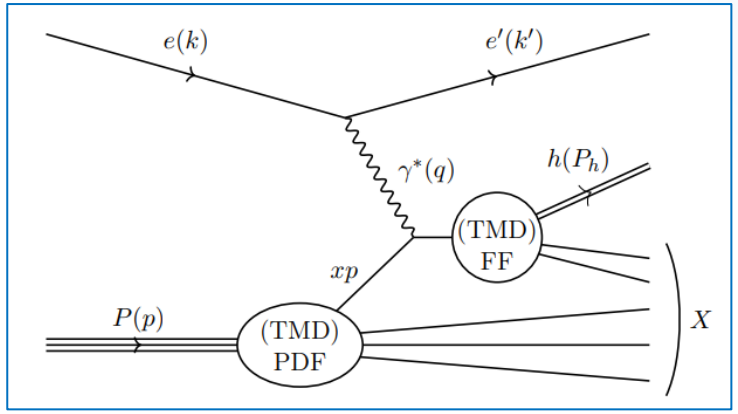


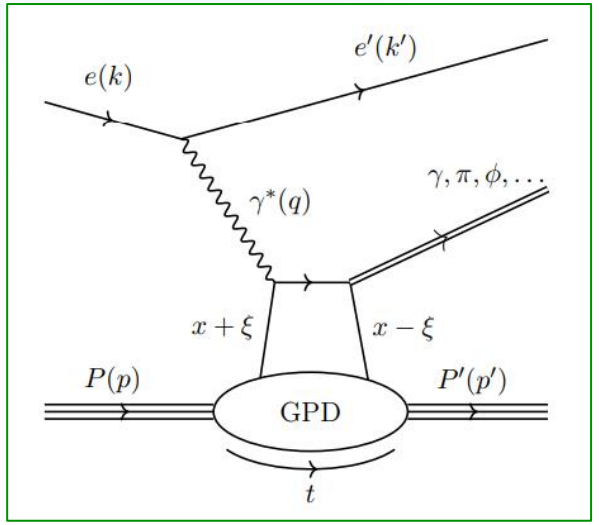


Why Do We Need the EIC?

- Polarized electron and polarized proton beams
- High luminosity and a broad kinematic reach covering gluon-dominated small-x region
- Precision measurements of inclusive, semi-inclusive, and exclusive processes that encodes quark and gluon spin contributions and their angular momenta.



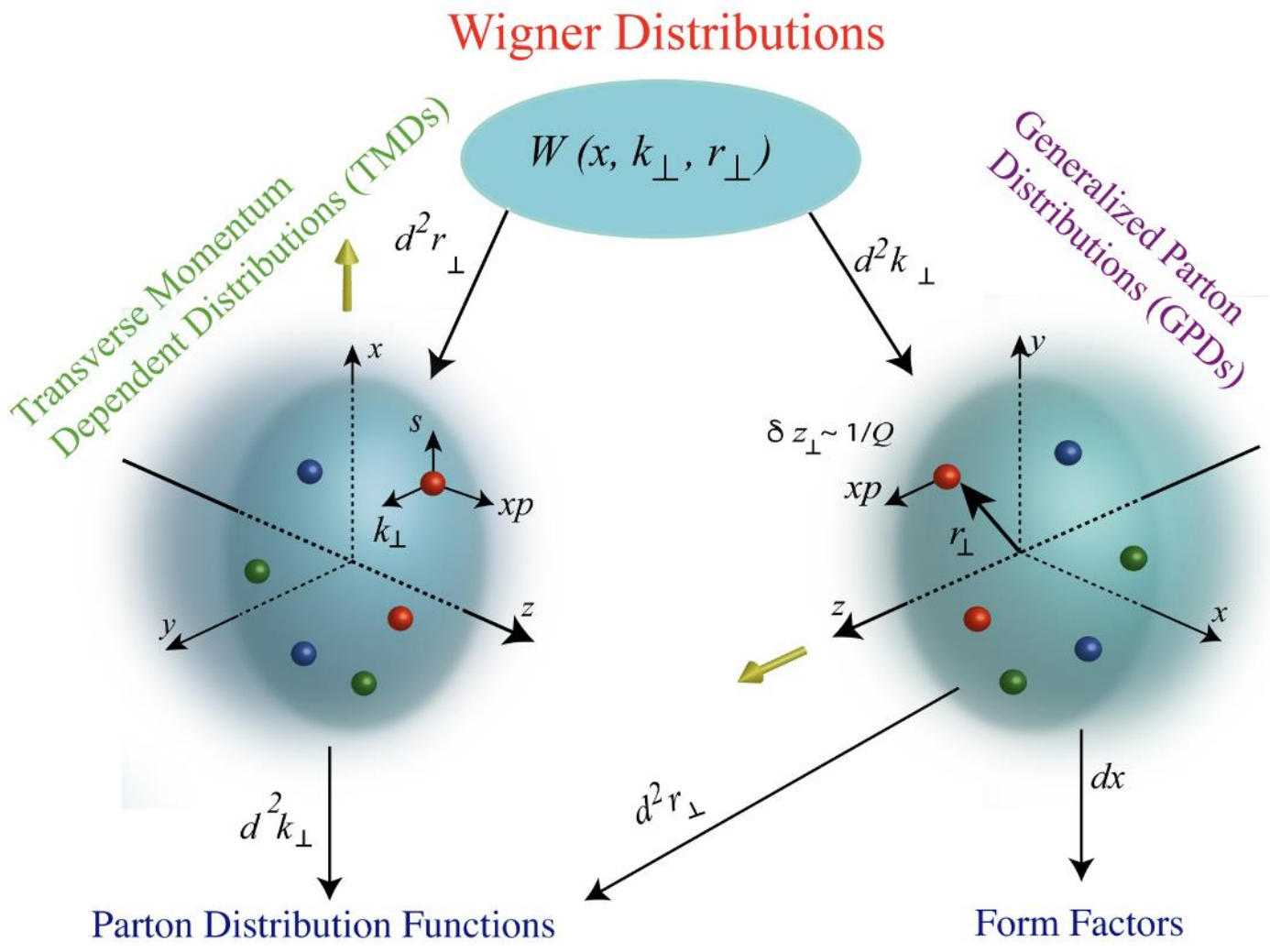




Three-Dimensional Imaging of the Nucleon

- What carries the proton's momentum and spin?
- TMDs: How are parton transverse momentum and spin correlated?
- GPDs: How are partons distributed in transverse space?
- Connecting partonic structure to orbital angular momentum

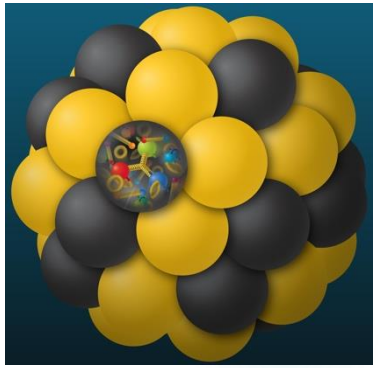
$$J_{q,g} = \frac{1}{2}\int_{-1}^{1} x\left[H_{q,g}(x,\xi,0) + E_{q,g}(x,\xi,0)\right]dx$$

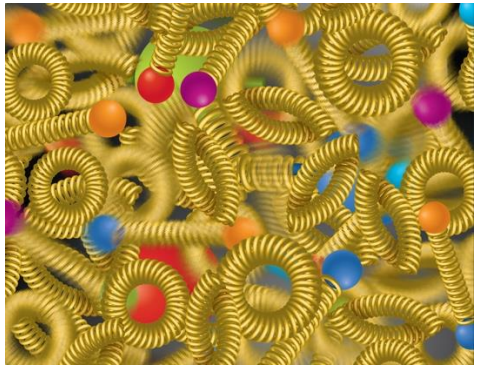


Examples of Other EIC Science Pillars

- **Origin of nucleon mass**
  - How do interactions among quarks and gluons generate the mass of the nucleon?
- **Color Confinement**
  - How do quark and gluon interactions confine quarks and generate the forces that stabilize the nucleon?
- **Meson structure**
  - How do quarks and gluons build mesons, and what can mesons reveal about the emergence of mass and the dynamics of confinement?
- **Nucleus at different scales**
  - How are nuclear binding, short-range nucleon correlations, and the EMC effect connected—and what do they reveal about quark and gluon structure and possible changes in hadron properties inside nuclei?
- **Gluon Saturation**
  - How does the rapid growth of gluon density at small x lead to nonlinear QCD dynamics, and how does that relate to nuclear properties?

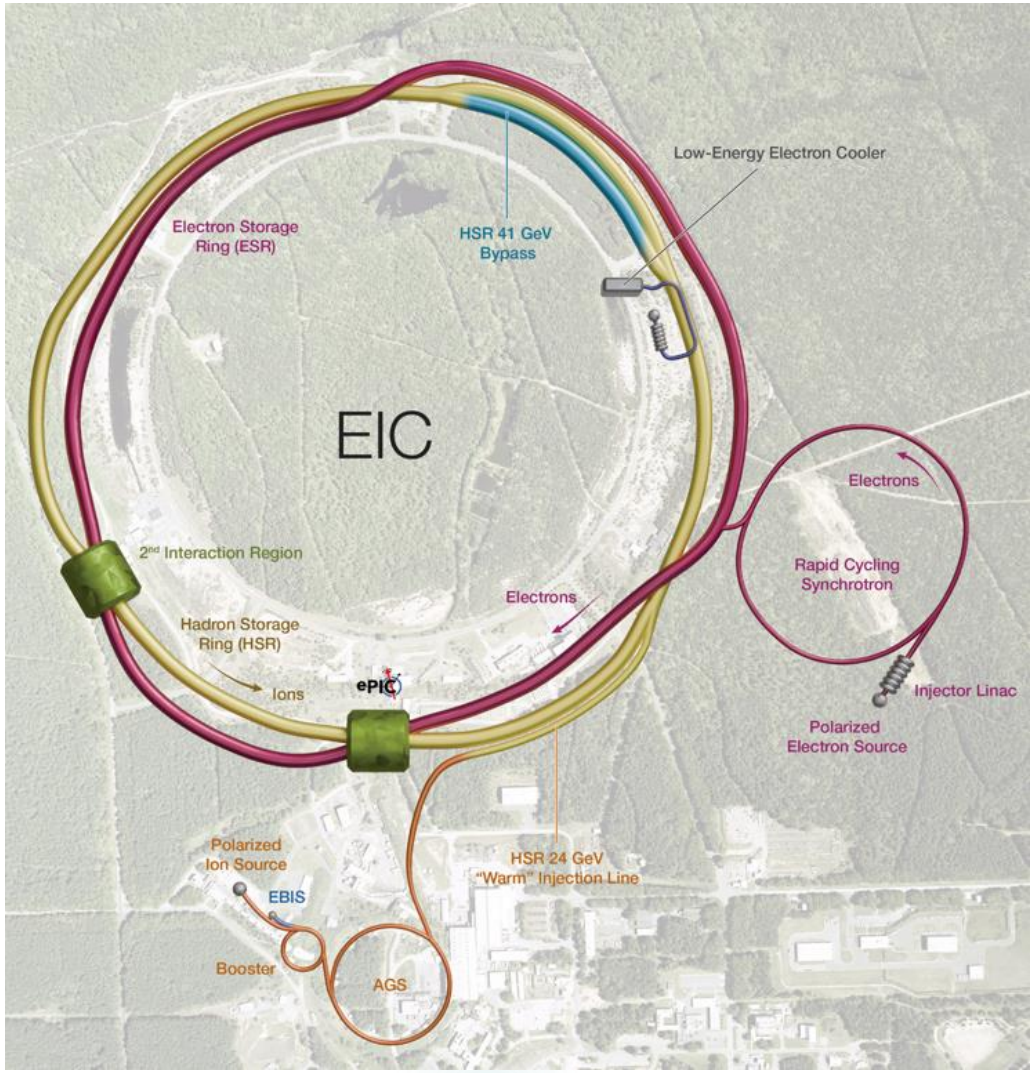






Electron-Ion Collider

- Polarized electron–proton and electron–ion collisions
- EIC Capabilities
  - Large center of mass energy range
    - ep: 20 – 141 GeV
    - eA: 20 – 63 GeV
  - High luminosity
    - $10^{33} – 10^{34}$ $cm^{-2}s^{-1}$
    - 10 – 100 fb^{-1} / year
  - Electron / proton (and light ion) beam polarization
  - Large range in ion species: proton – Uranium
- Start operation from middle of 2030s



The EIC starts construction

- **CD-3B approved — January 2026**
  Long-lead procurements authorized
- **EIC construction underway in 2026**
  New infrastructure and RHIC-to-EIC transformation
- **RHIC → EIC transition has begun**
  First cryostat move on May 2026

Blue Ring Removal – April 2026



Arrival of ANL APS & MIT Bates Magnets

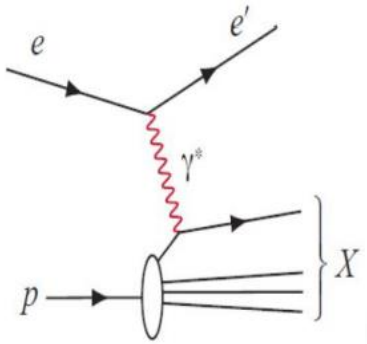






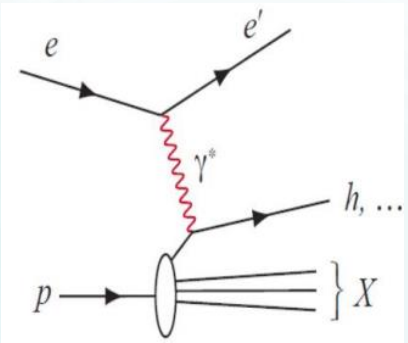


From Physics to Requirements



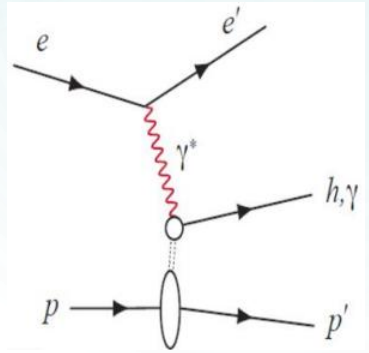
Inclusive DIS :
Fine binning in x and Q^2

- Large coverage to maximize phasespace reach
- High-resolution EM calorimetry and PID for e/π separation
- Low mass, high momentum resolution tracking



Semi-inclusive DIS :
5-D binning in x, Q^2 ,
z, p_T , and ϕ_h

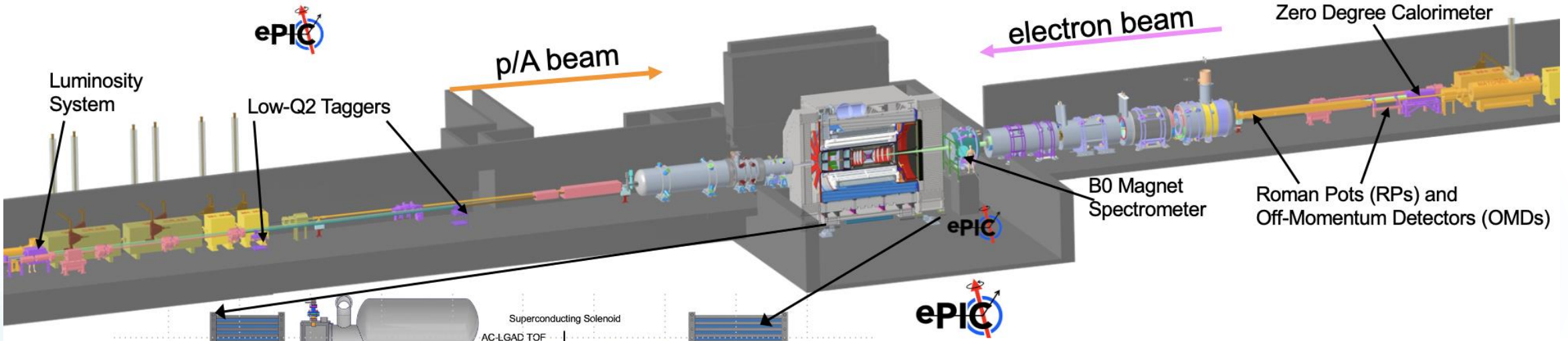
- Fine p_T (tracking) resolution
- Extensive PID coverage for hadron identification
- Hadron calorimetry for jet measurements (neutral hadron ID) and muon ID

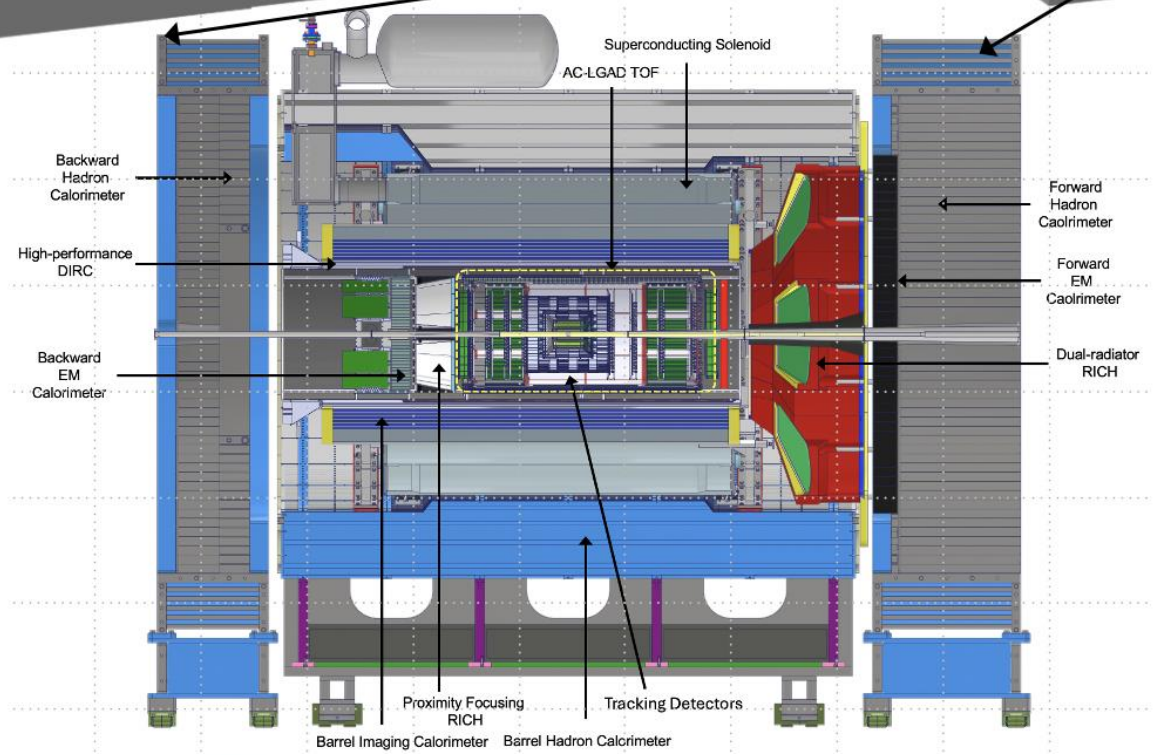


Exclusive processes:
4-D binning in x, Q^2 ,
t, and ϕ_h

- Extended acceptance at very small angles (IR integration and magnet design)
- Extensive beam-line instrumentation
- Good vertex resolution
- EM calorimetry and neutron measurements

The ePIC Detector: A General-Purpose Detector for EIC

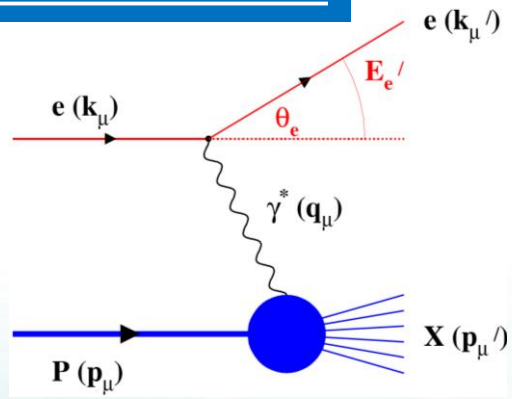




- Central detector follows familiar HEP detector layout: tracking, PID, EM and hadron calorimetry
- Asymmetric from forward to backward rapidity reflecting different beam species
- Extensive forward and backward instrumentation: lumi, polarimetry, roman pots, ZDC, etc

The ePIC Detector: A General-Purpose Detector for EIC

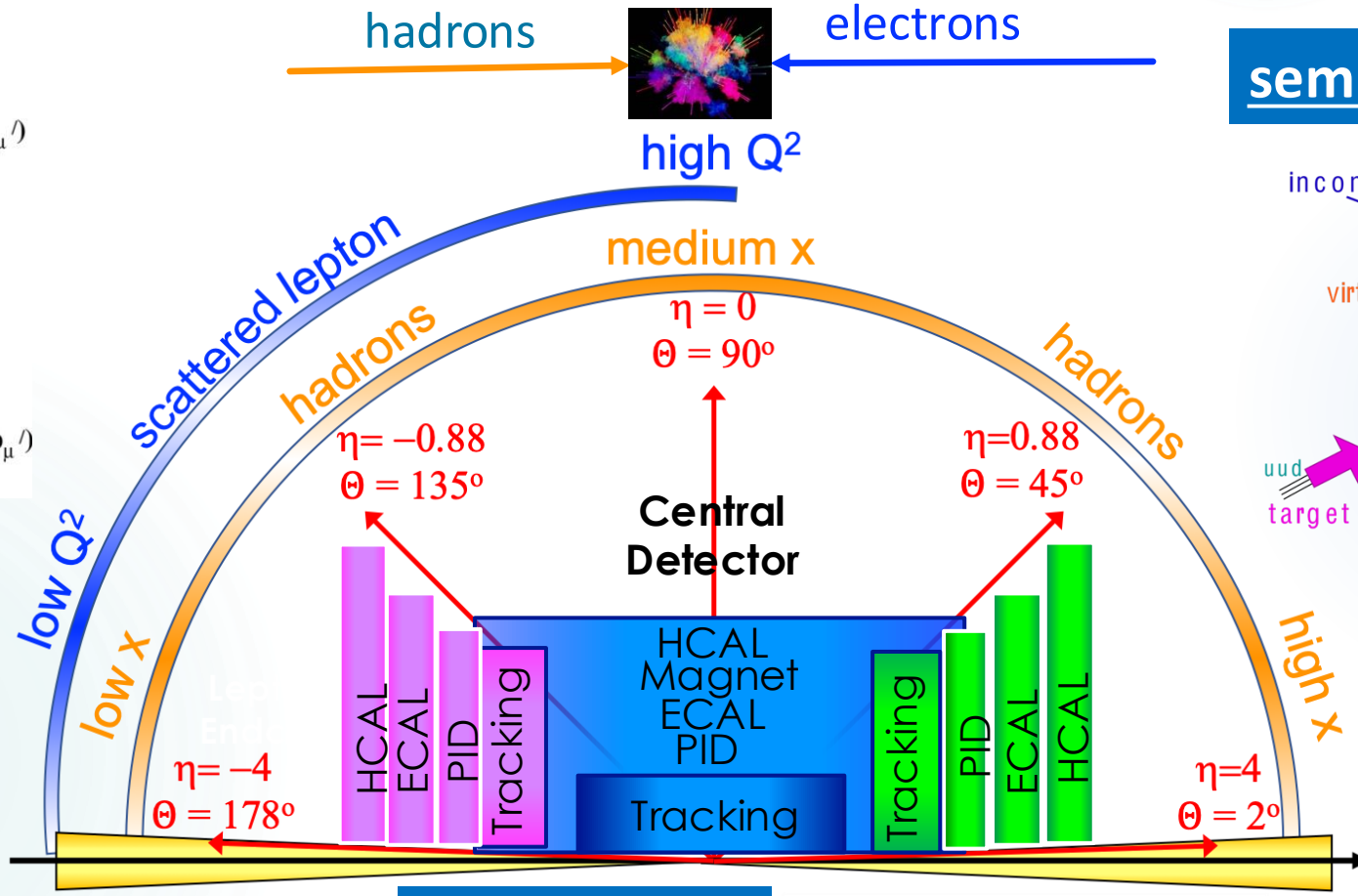
inclusive DIS:



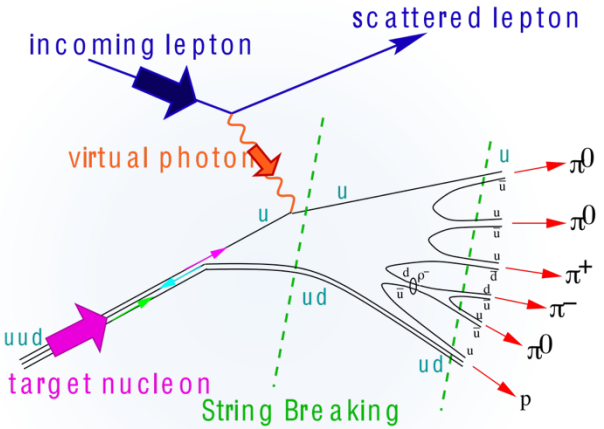
Detect only the scattered lepton in the detector

very low Q^2 scattered lepton Bethe-Heitler photons for luminosity

Luminosity Detector
Low Q^2-Tagger



semi-inclusive DIS



Detect the scattered lepton in coincidence with identified hadrons/jets

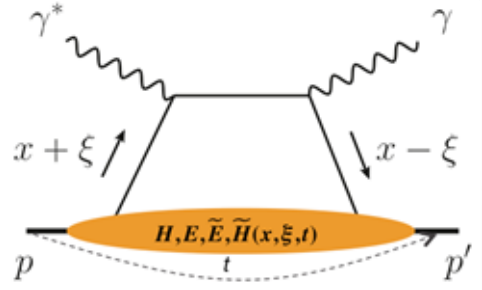
particles from nuclear breakup and from diffractive reactions

ZDC

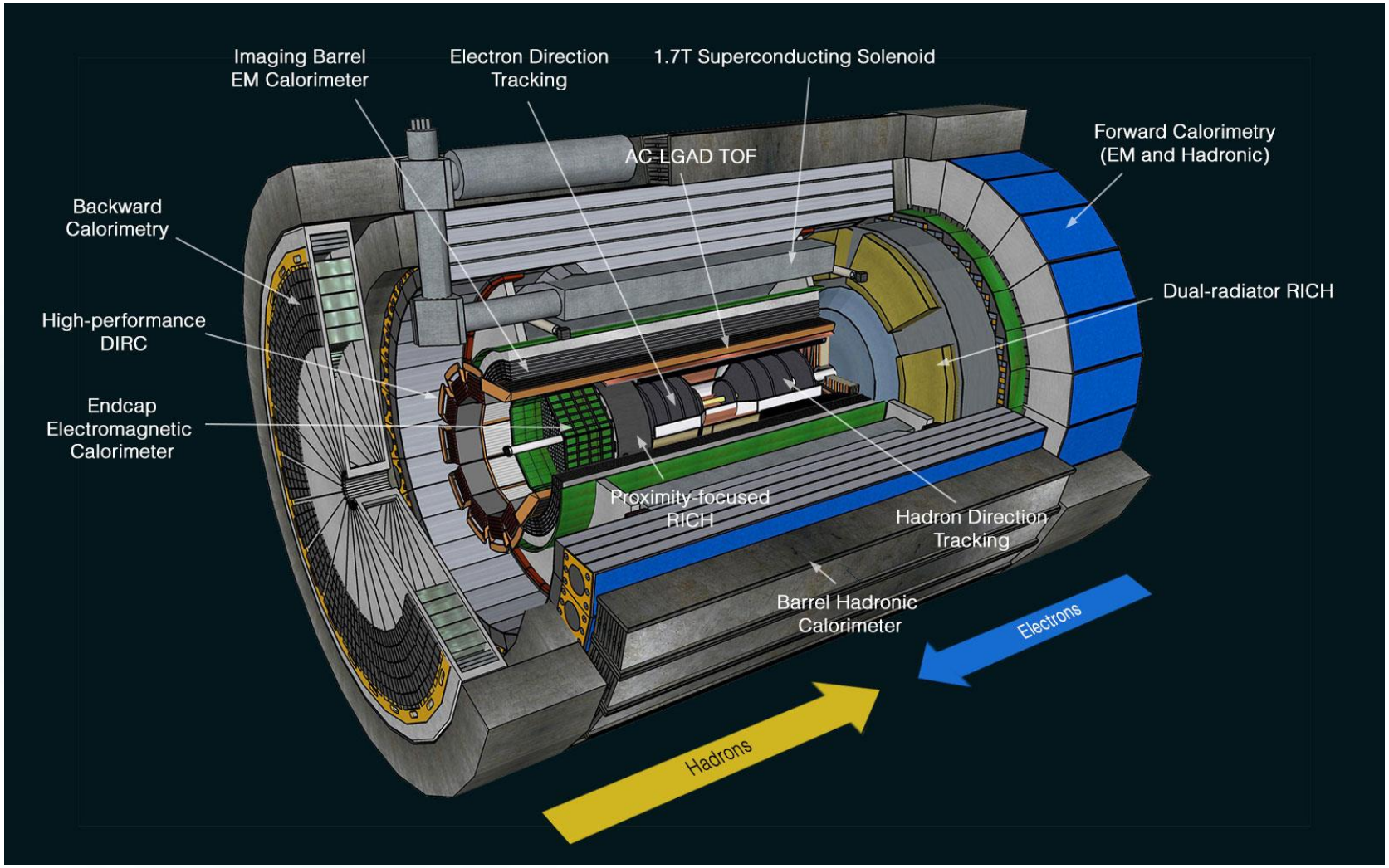
Forward Tracking

exclusive DIS

Detect scattered lepton, identify produced hadrons/jets and target remnants



The ePIC Central Barrel Detector



Tracking:

- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

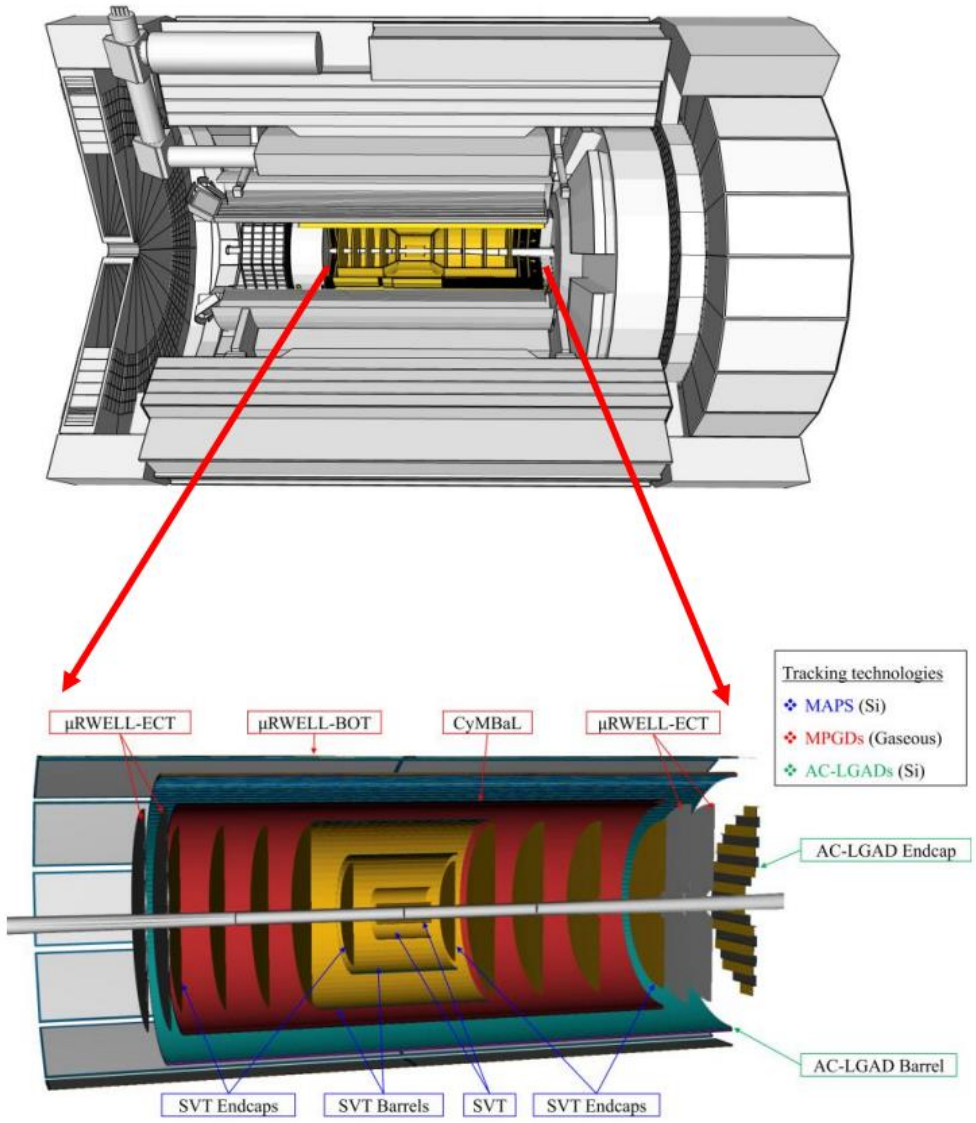
PID:

- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

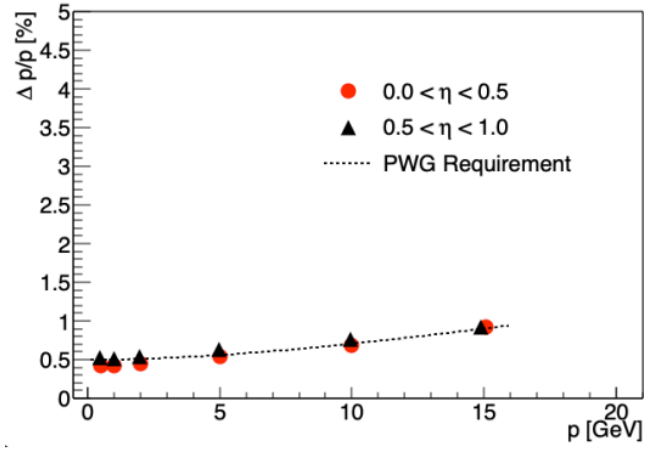
Calorimetry:

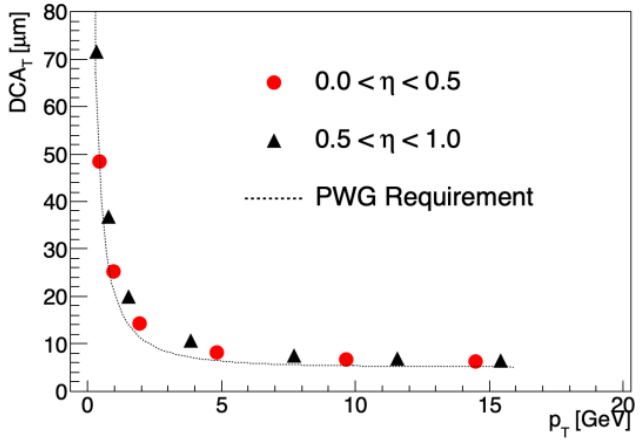
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

The ePIC Tracking

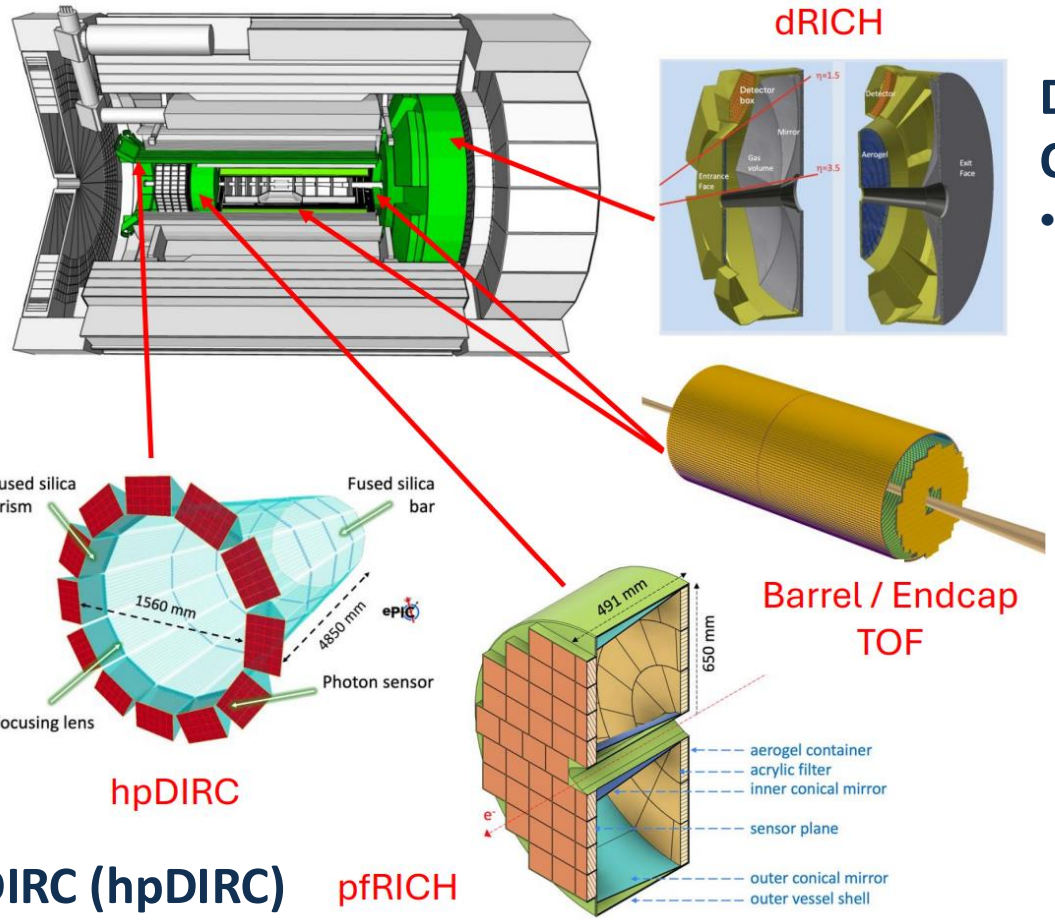


- **Silicon Vertex Tracker (Synergy with ALICE ITS3 development)**
  - MAPS technology using 65 nm CMOS process
  - 3 inner layers curved MAPS – 20 µm pixel pitch 0.05% X/X0
  - 2 outer layers and 5 forward/backward disks using ITS3-based EIC Large Area Sensor <= 0.55% X/X0
- **MPGD – based Trackers**
  - Additional hit points and fast (O~10 ns) timing capability
  - Cylindrical Micromegas Barrel Layer (CyMBaL) ~1% X/X0
  - µRWELL Barrel Outer Tracker ~1.5% X/X0 (central region)
  - GEM-µRWELL endcap disks
- **AC-LGAD**
  - Additional space point for pattern recognition/redundancy





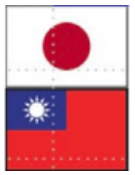
The ePIC Particle Identification



Dual Radiator Ring Imaging Cherenkov (dRICH)

- Aerogel + C2F6 gas for PID up and First-ever use of SiPMs

Time-of-Flight Barrel and Forward Endcap



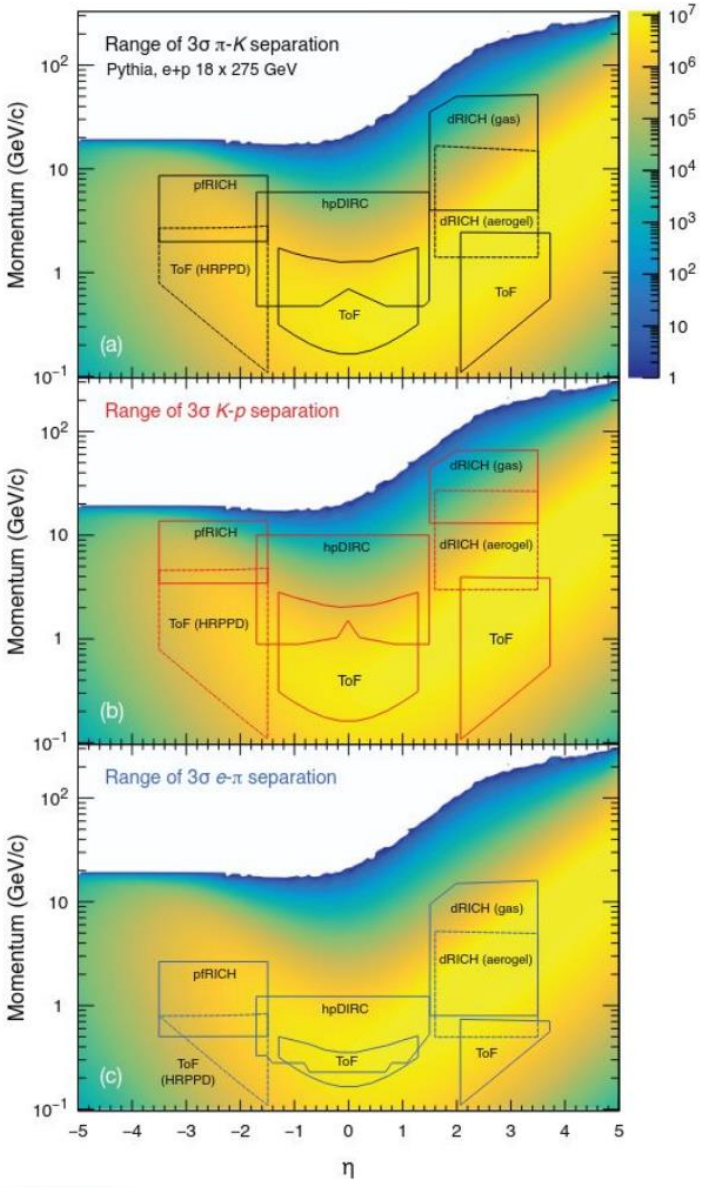
- AC-LGAD sensors provide 20-35 ps time resolution and 10um position resolution

DIRC (hpDIRC)

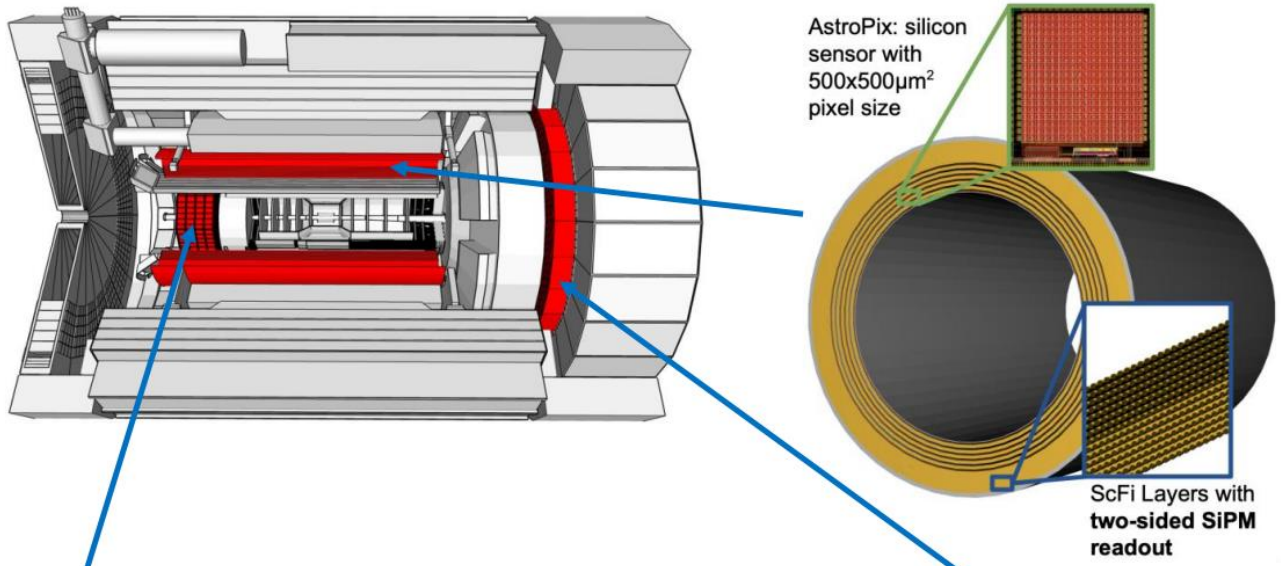
- Quartz bar radiators
- Pixelized MCP-PMTs as photosensors

Proximity Focusing RICH (pfRICH)

- Aerogel radiator for π/k separation
- HRPPDs and Excellent time resolution (< 30 ps)



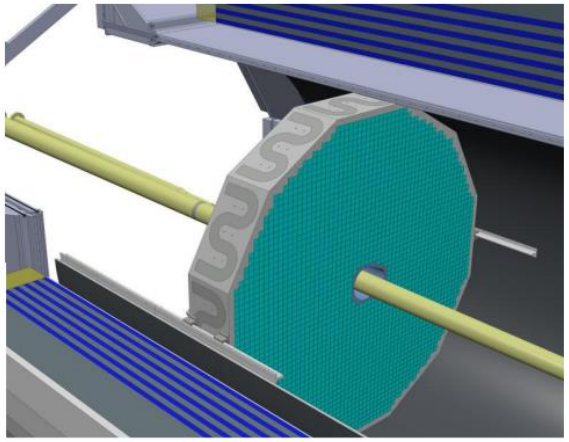
The ePIC EM Calorimetry



Barrel Imaging Calorimeter (BIC)

- Electron identification and hadron suppression for high Q2 events and electrons from vector meson decay
- Excellent spatial resolution to discriminate DVCS photons from π 0 decays
- 6 layers of AstroPix interleaved with 5 Pb/ScFi layers, followed by bulk Pb/ScFi
- AstroPix: MAPS sensors with 500 μm pixel pitch and ~3.2 ns time resolution

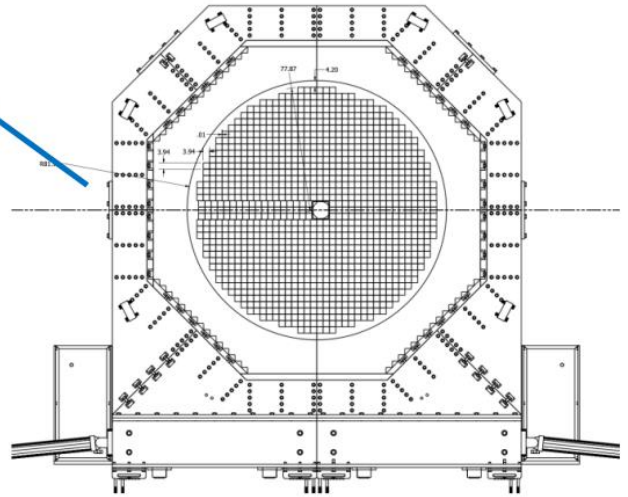
$10\%/\sqrt{E} + (2\text{-}3)\%$



$(2\text{-}3)\%/\sqrt{E} + (1\text{-}2)\%$

EEEMCAL

- Excellent energy resolution for precision determination of kinematics from scattered electron
- High-precision PbW04 crystal calorimeter
- First use of SiPMs

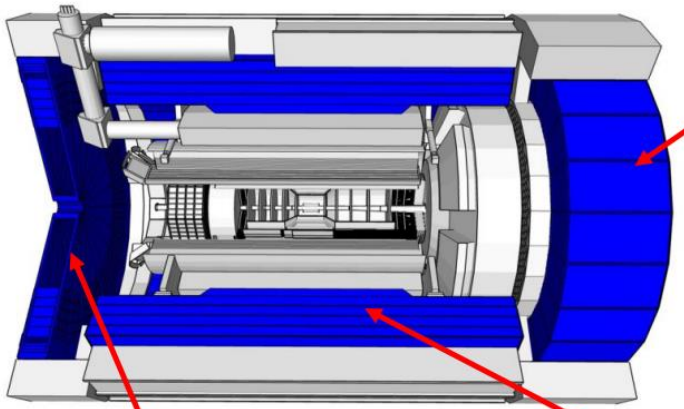


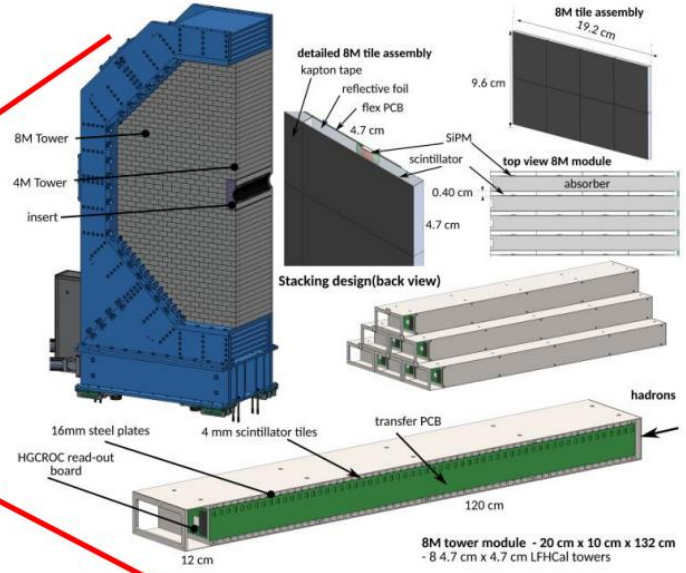
Hadron-Endcap Ecal

- Large area coverage for jet measurements
- Tungsten/SciFi SPACAL design with SiPMs
- Utilized in sPHENIX barrel EMCal

$12\%/\sqrt{E} + 2\%$

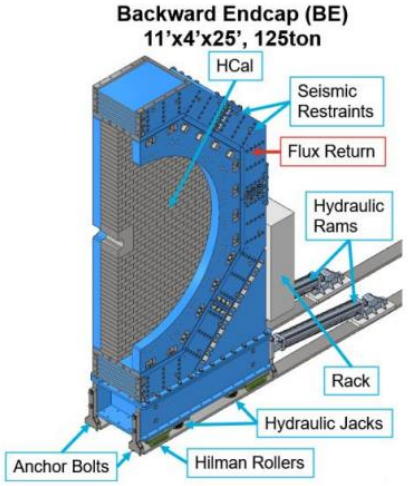
The ePIC Hadron Calorimetry





Forward HCal (LFHCal)

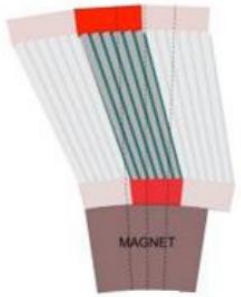
- Longitudinally segmented steel + scintillator SiPM-on-tile design
- 8752 towers x 7 individual longitudinal readout groupings ~6 interaction lengths
- High-granularity insert close to beam pipe
- CALICE-like design optimized for particle flow reconstruction



Negative HCal

- Similar layout to forward HCal
- Tail catcher for identifying neutral components of jets
- Muon ID

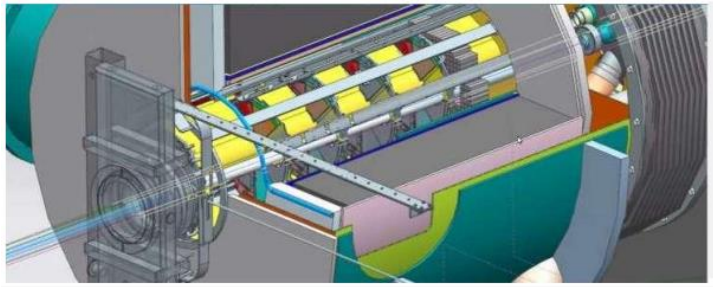




Barrel HCal

- Steel + scintillator design – tilted vertical plates
- Reuse of sPHENIX calorimeter
- Tail catcher and muon ID

Far-Forward and backward Systems

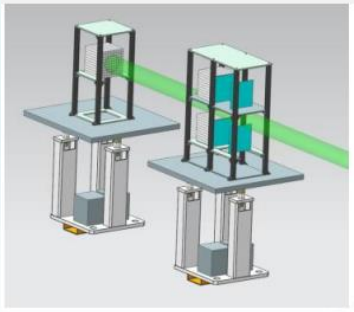


B0 Magnet Spectrometer

- detection of forward scattered protons and and γ
- 4 tracking layers each of AC-LGAD / EICROC (500x500 μm^2 pixel) – Synergy with forward ToF
- EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter – Synergy with backward ECal

Luminosity System

- Measure bunch-by-bunch luminosity through Bethe-Heitler process
- Pair-spectrometer: each with 2 tracking layers of AC-LGAD / FCFD – Synergy with Barrel-ToF
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal



Low-Q^2 Taggers

- detection of scattered electrons
- 2 stations with 4 tracking layers each (16x18cm^2) Si / Timepix4
- Calorimeter: Tungsten-powder + SciFi SPACAL – Synergy with forward ECal

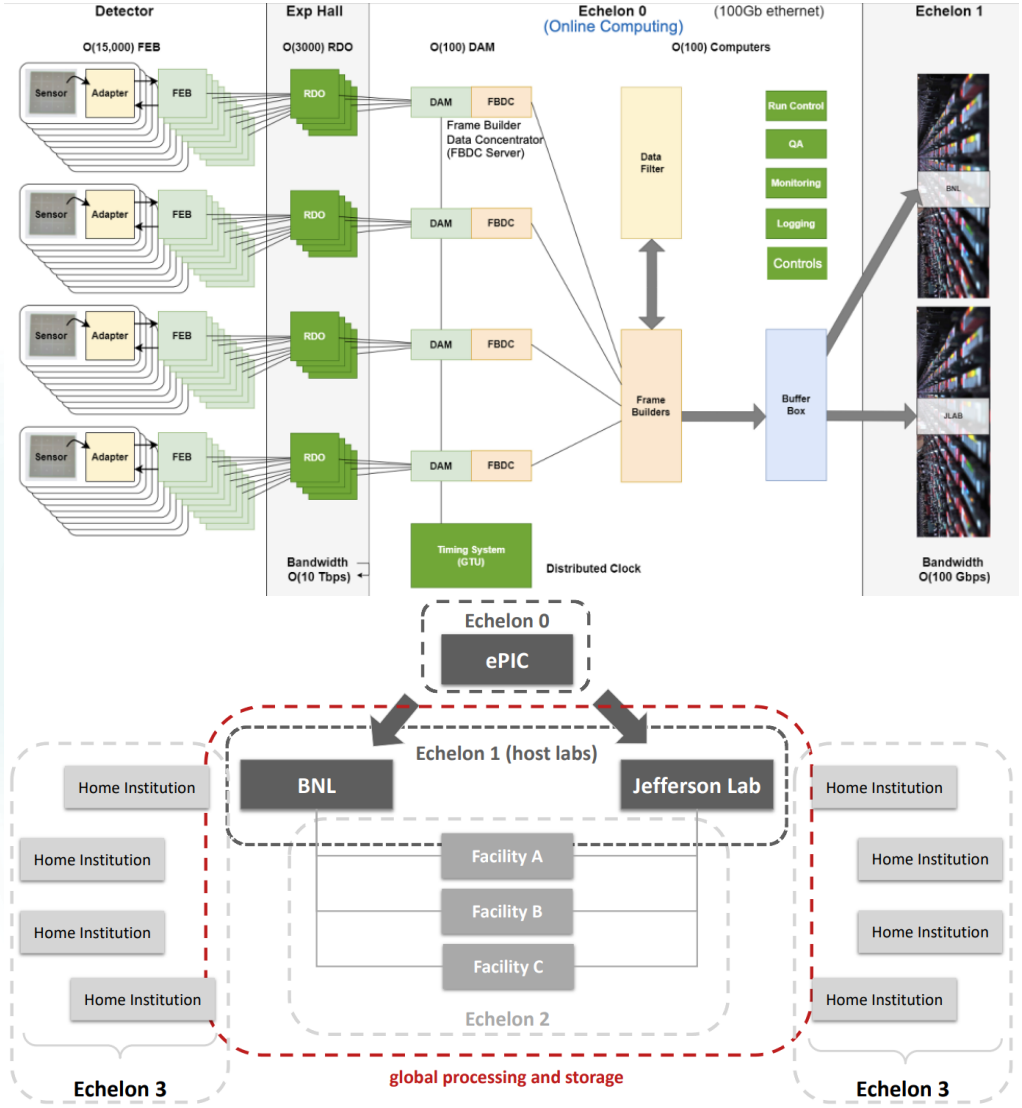
Roman Pots and Off-Momentum Detectors

- Detection of forward scattered protons and nuclei
- 2 stations with 2 tracking layers each
- AC-LGAD / EICROC (500x500 μm^2 pixel) – Synergy with forward ToF

Zero Degree Calorimeter

- Detection of forward scattered neutrons and γ
- EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter – Synergy with backward ECal
- HCAL: Steel-SiPM-on-Tile – Synergy with forward HCal

The ePIC Computing-Detector Integration



Streaming Readout and DAQ:

- By deploying streaming readout without a traditional hardware trigger, the system allows for unbiased data collection and maximizes scientific reach

AI and ML in the Data Pipeline:

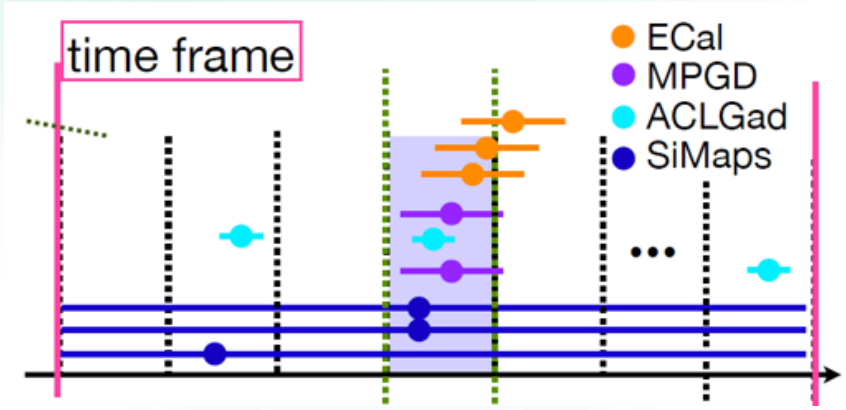
- Intelligent data filtering: AI/ML algorithms can select the most relevant collision events to study.
- Real-time feedback: AI can enable rapid detector diagnostics and optimization, with systems capable of automatically calibrating detectors and validating data.

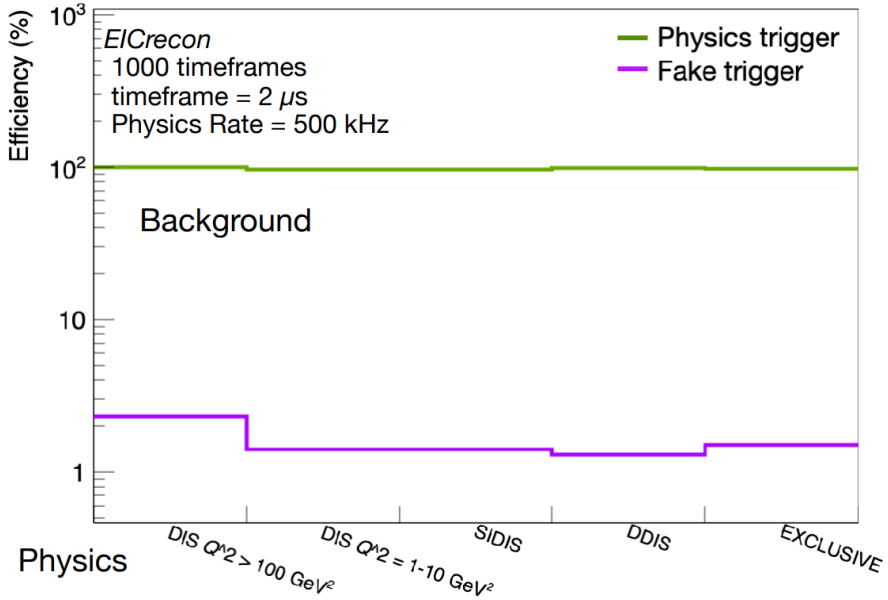
Streaming Computing Model:

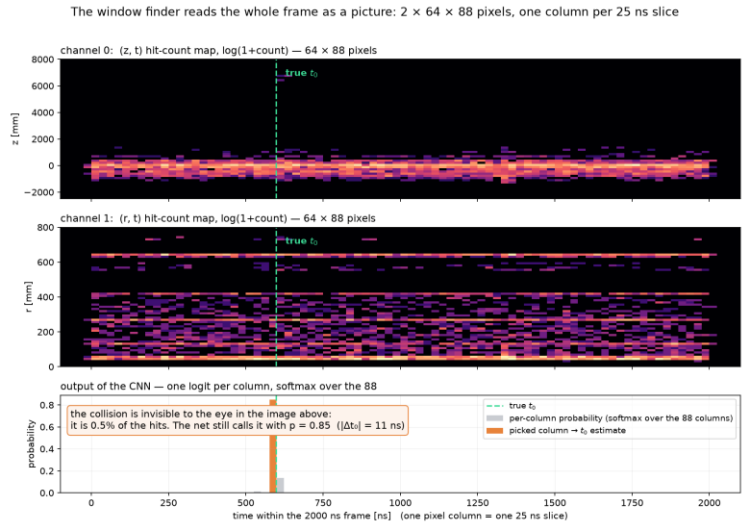
- Continuous data collection, processing, calibration and alignment: Enables rapid delivery of scientific results.
- Distributed computing : Organizes resources across the computing hierarchy and enables international contributions.

Streaming reconstruction

- **500 kHz:** Physics collision rate
- **~30 GHz:** Synchrotron-radiation background rate
- **Challenge:** Identify physics collisions within continuous timeframes
- **Two approaches:** Timing and geometrical coincidence; machine-learning-based identification
- **Goal:** Validate collision-finding algorithms and understand signal rates under realistic EIC background conditions





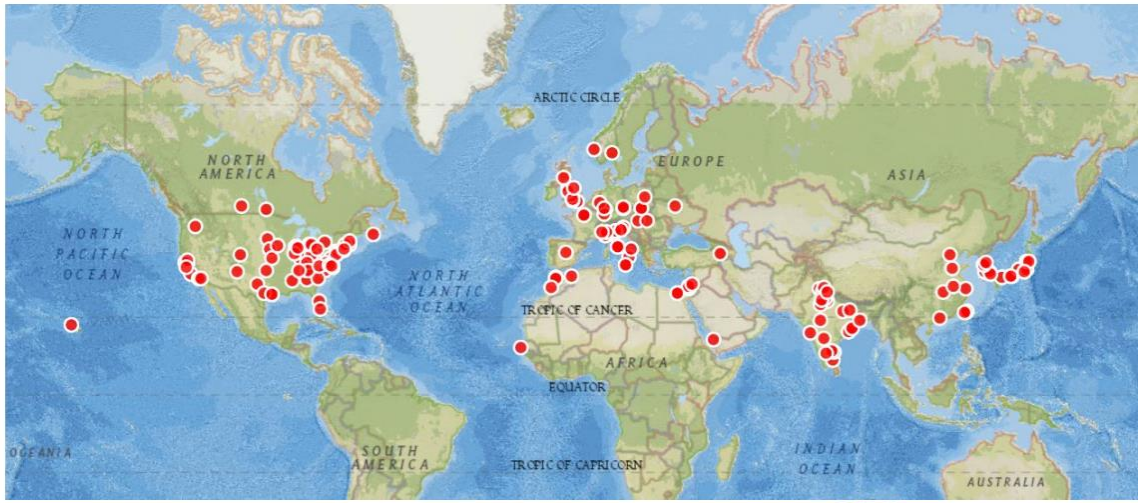


The Global Collaboration of ePIC

ePIC Institutions
183

ePIC countries
25

ePIC World Regions
4



ePIC initiated in July 2022

Currently:

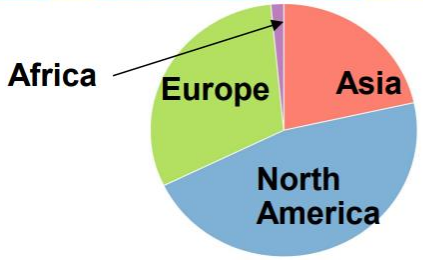
1158 collaborators

(as June 1st, 2026)



Members

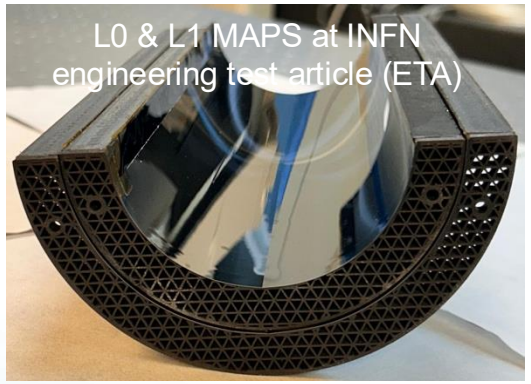


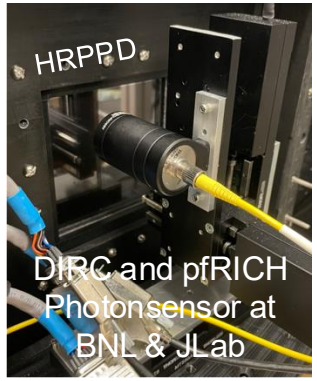


- International collaboration across detector technologies and physics
- Coordinated development of hardware, software, and computing
- Shared responsibility for detector integration and performance

Around the World Progress









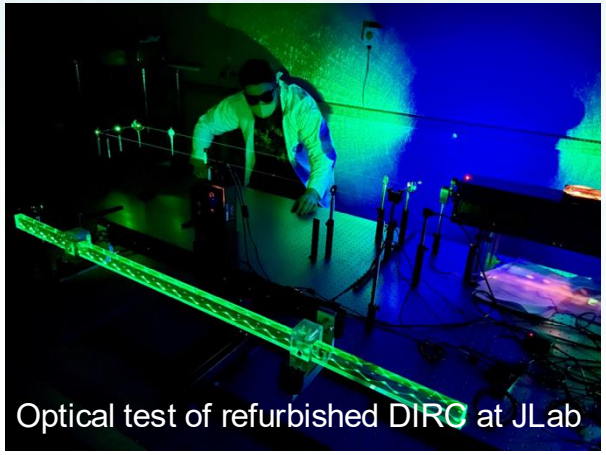


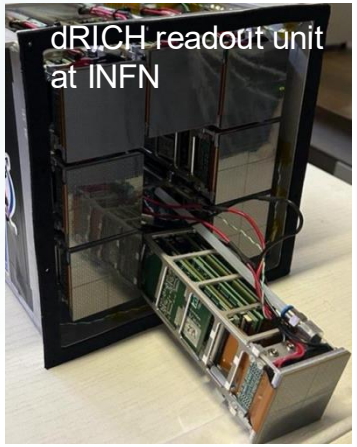


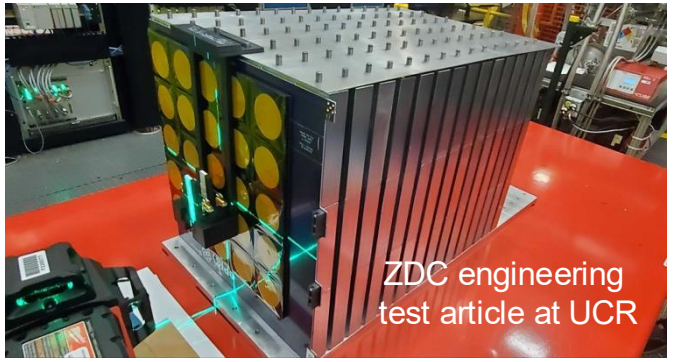








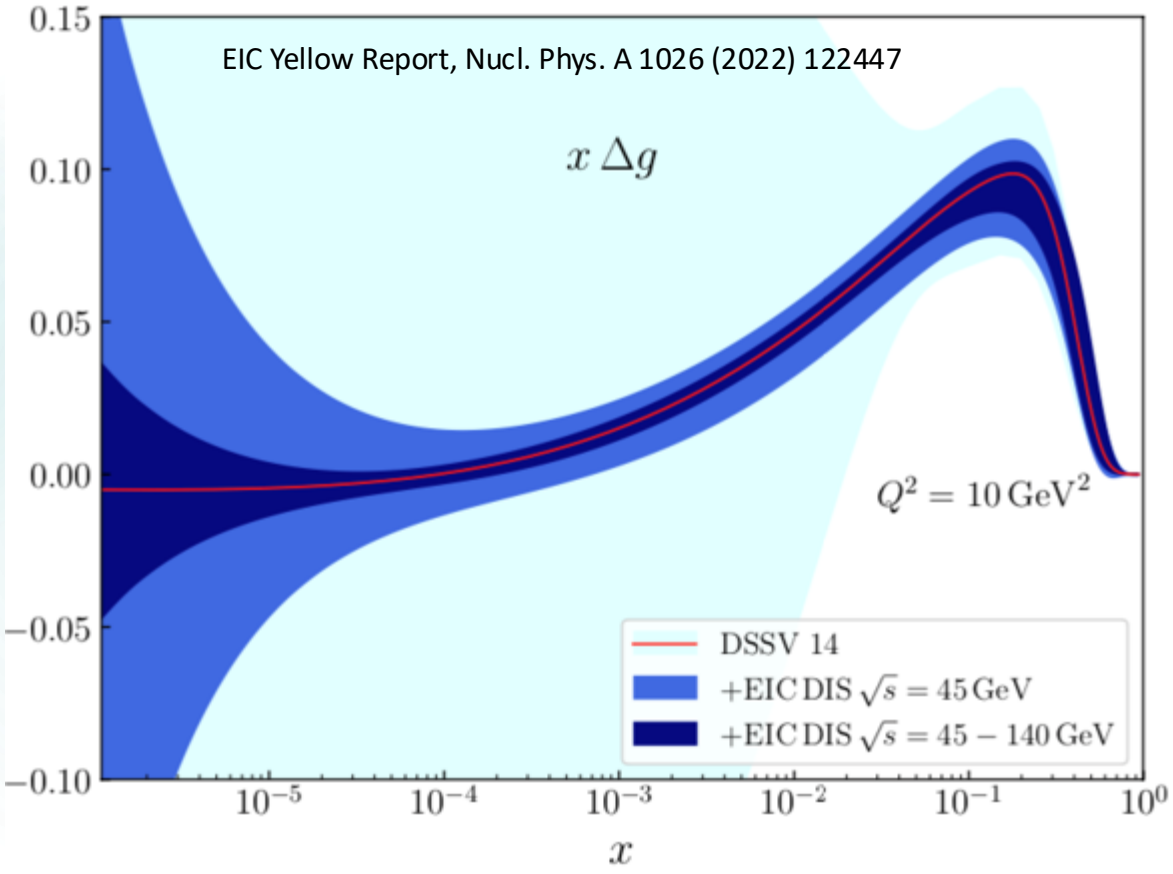


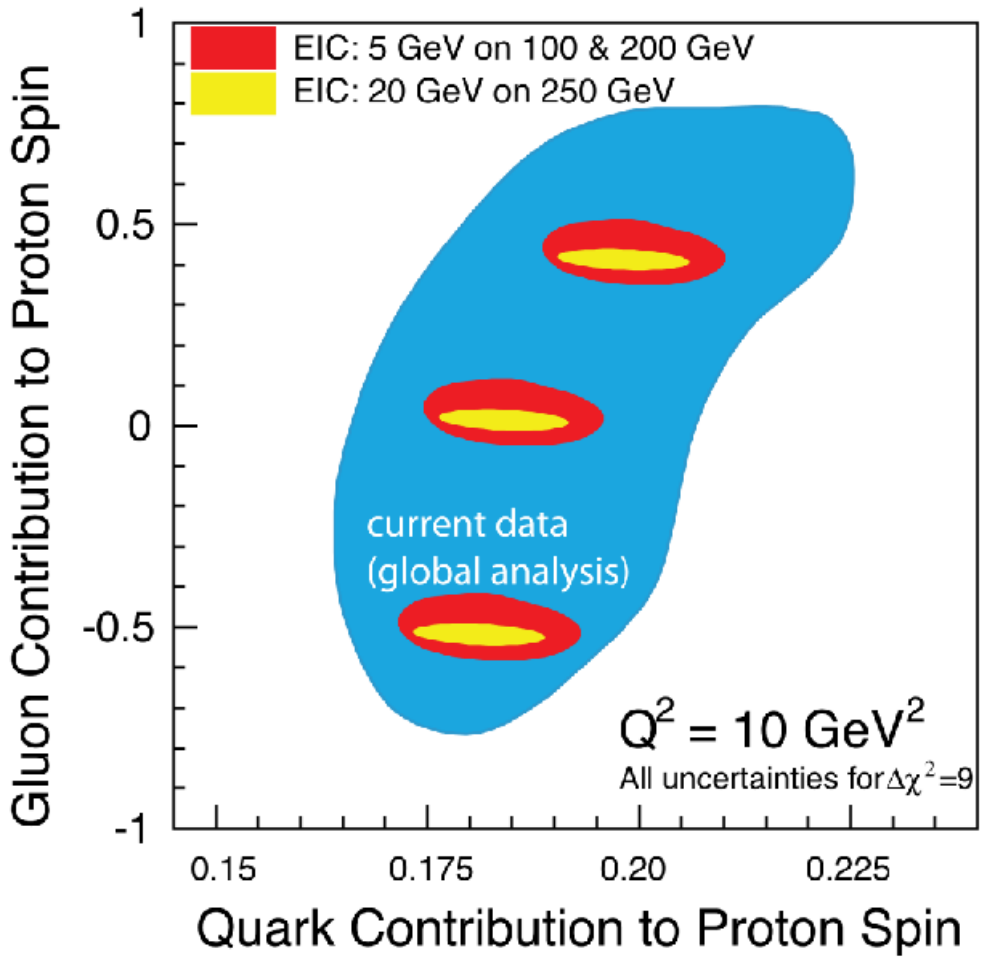




Spin: Unraveling the Gluon Contribution

- Combine inclusive and semi-inclusive observables
- Map the gluon helicity distribution, $\Delta g(x, Q^2)$ toward lower x
- Constrain the gluon contribution down to $x \sim 10^{-5}$

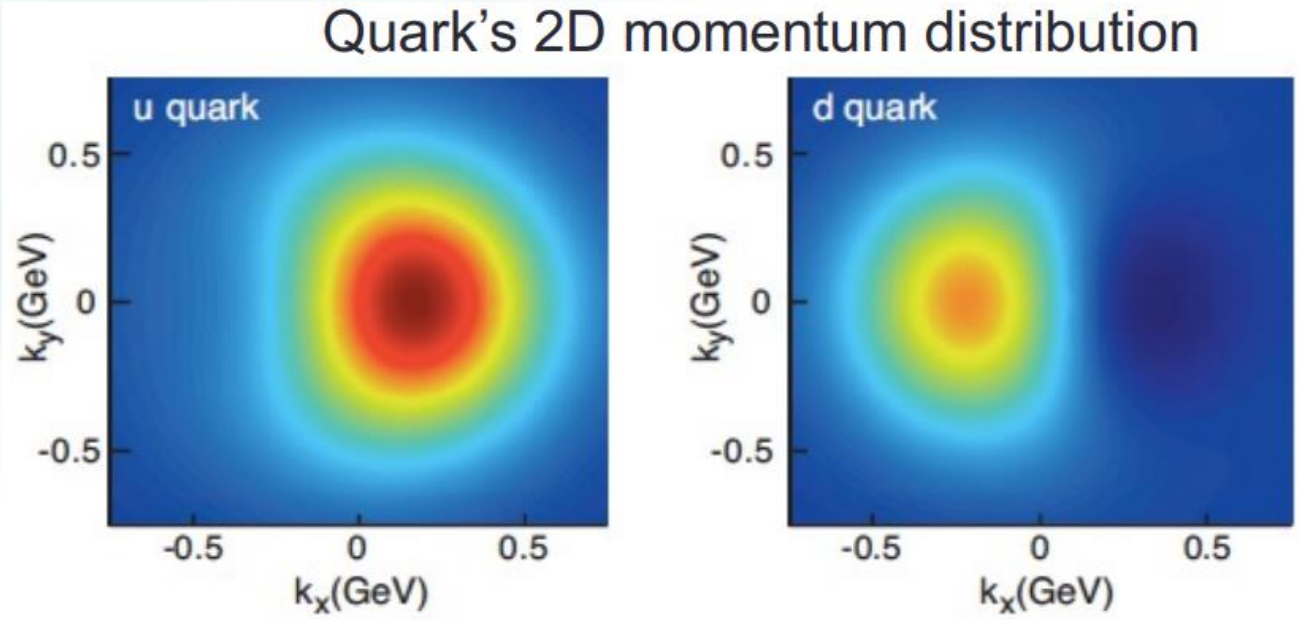


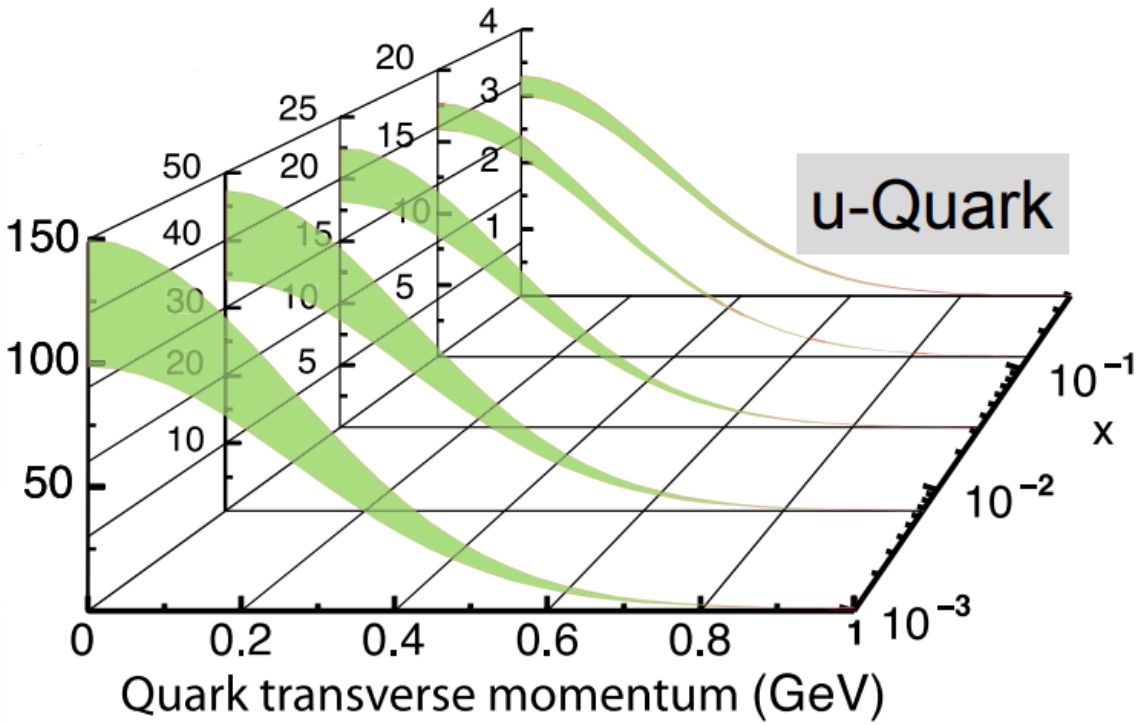


Transverse Spin: Mapping TMDs

- Measure **Single Spin Asymmtry in Semi-inclusive DIS**
- Use identified hadrons to separate flavor contributions
- Test TMD evolution over a broad Q^2 range

EIC Yellow Report, Nucl. Phys. A 1026 (2022) 122447

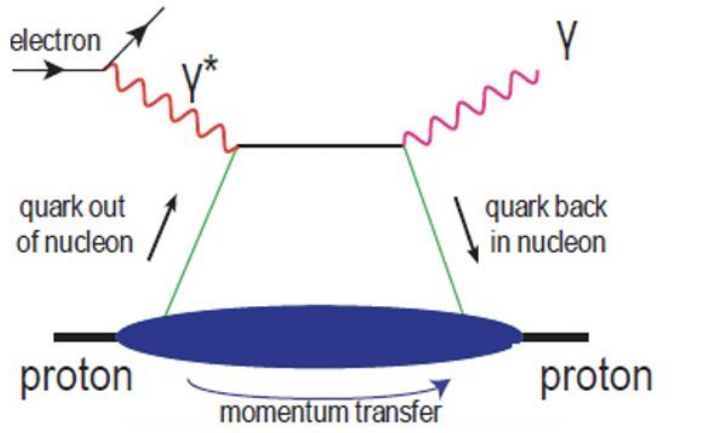


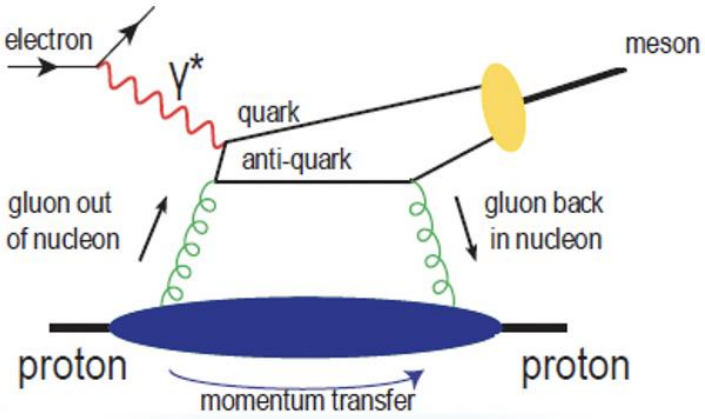


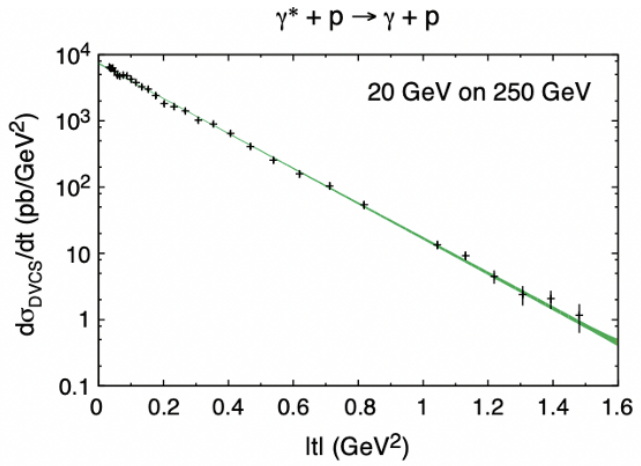
GPDs: Imaging the Nucleon in Transverse Space

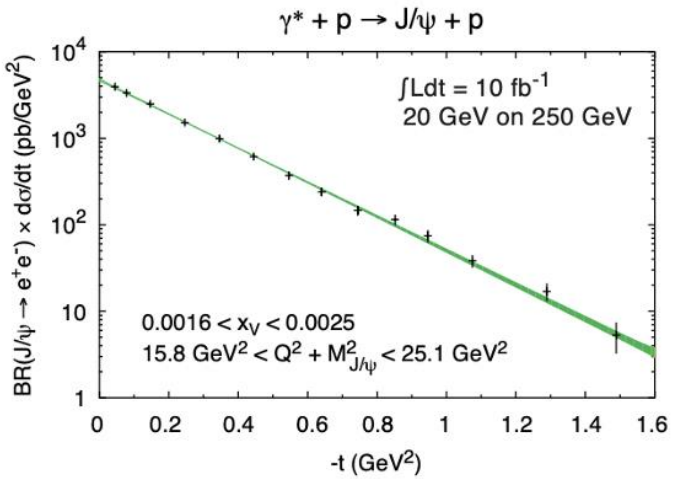
- Exclusive processes such as deeply virtual Compton scattering (DVCS)
- Reconstruct the momentum transfer t
- Connect spatial imaging and constrain generalized parton distributions

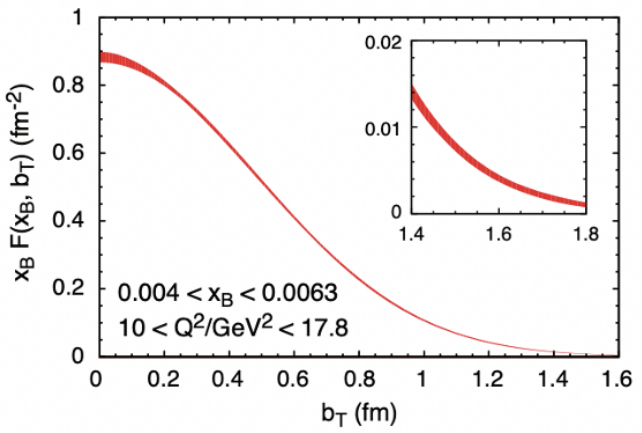
EIC Yellow Report, Nucl. Phys. A 1026 (2022) 122447

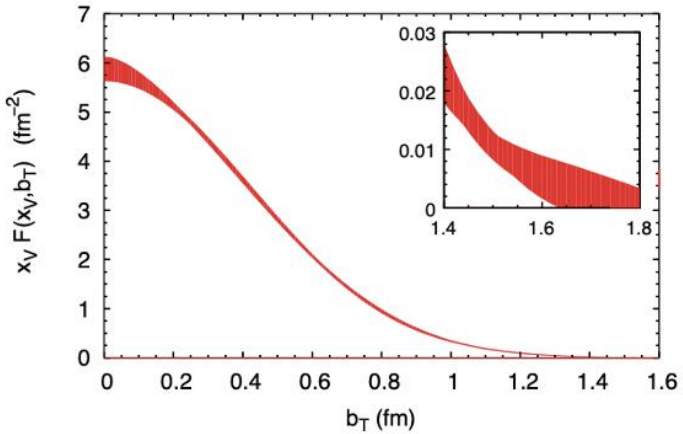










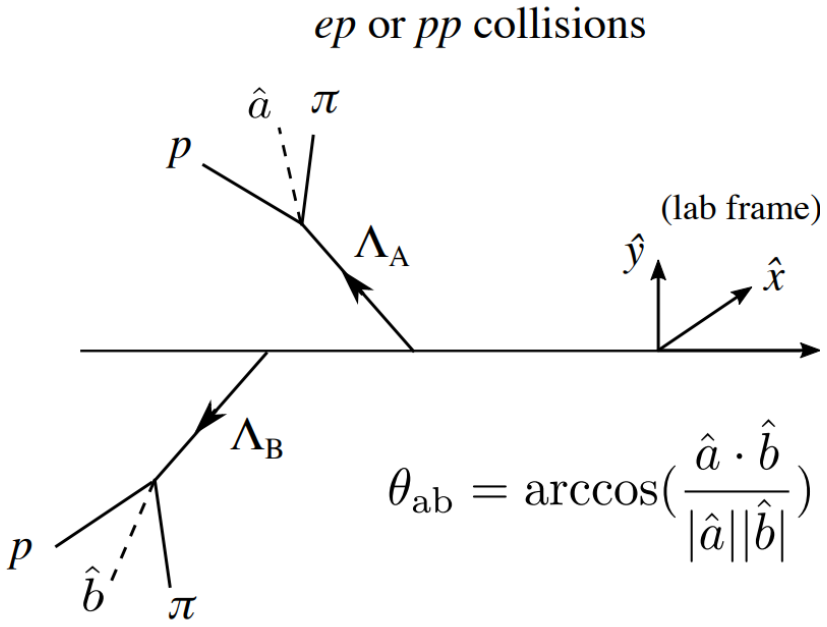


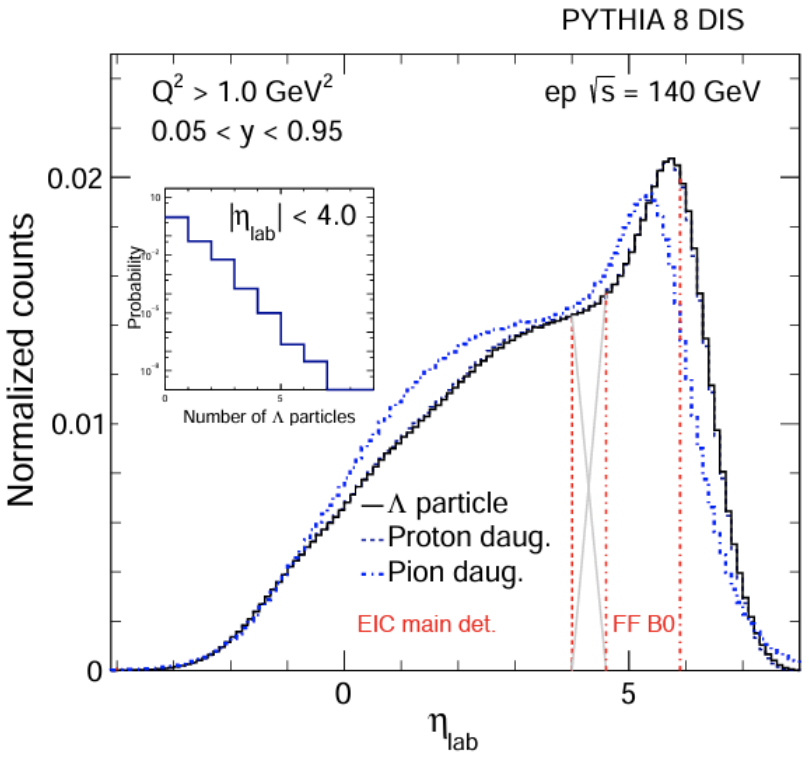
Spin-Spin correlation at the EIC

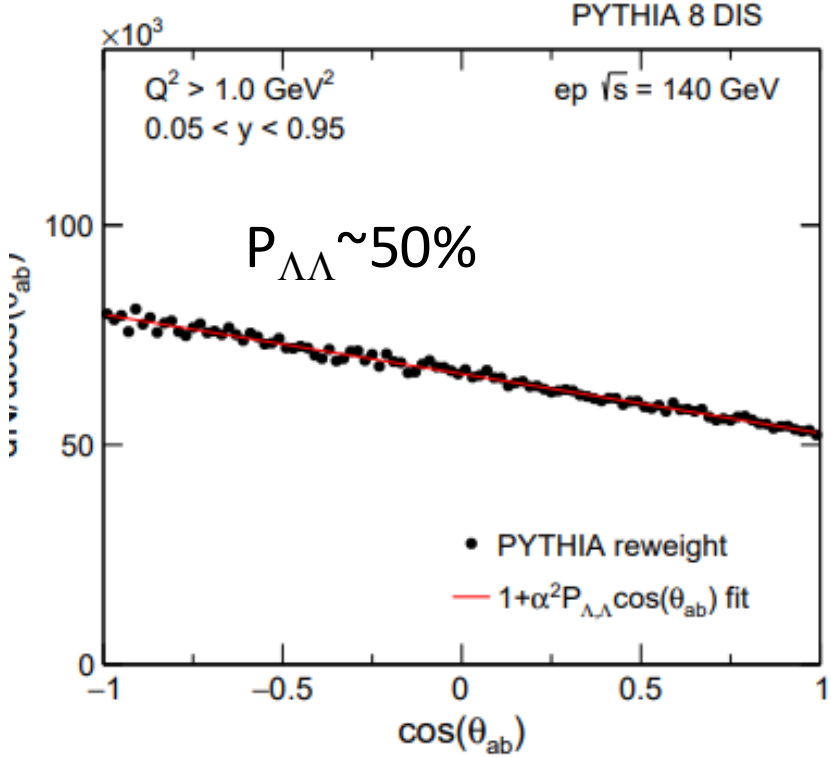
- **EIC provides a new experimental avenue to test quantum entanglement in QCD.**

W. Gong et al., Phys. Rev. D 106, L031501, 2022

$$\frac{dN}{d\cos(\theta^*_{ab})} = 1 + \alpha_1\alpha_2 P_{\Lambda\Lambda}\cos(\theta^*_{ab})$$



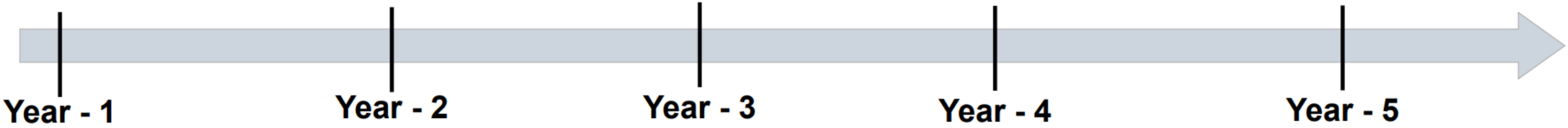




vs. multiplicity, rapidity gap, kinematics to see quantum/classical transition

EIC Program in First Years of Operation

→ *Carlos Munoz Camacho*



Year - 1

Potentially Run:
9 GeV electrons on 115 GeV/u heavy ion beams (Ag, Ru or Cu)

Commission:
electron polarization (in parallel)

Year - 2

Potentially Run:
9 GeV long. polarized electrons on 130 GeV/u Deuterium

Last weeks 9 GeV long. polarized electrons and 130 GeV polarized protons

Commission:
proton polarization (in parallel)

Year - 3

Potentially Run:
9 GeV long. polarized electrons on 130 GeV transverse polarized protons

Commission:
Commission running with hadron spin rotators.

(Last weeks switch to longitudinal proton polarization?)

Year - 4

Potentially Run:
9 GeV long. polarized electrons on 100 GeV Au

9 GeV long. polarized electrons on 275 GeV transverse and longitudinal polarized protons

Commission:
Commission hadron accelerator to operate with non-centered orbits

Year - 5

Potentially Run:
9 GeV long. polarized electrons on 100 GeV Au

9 GeV long. polarized electrons on 166 GeV transverse and longitudinal polarized He^3

Run plans notional but based on commissioning of the EIC collider capabilities

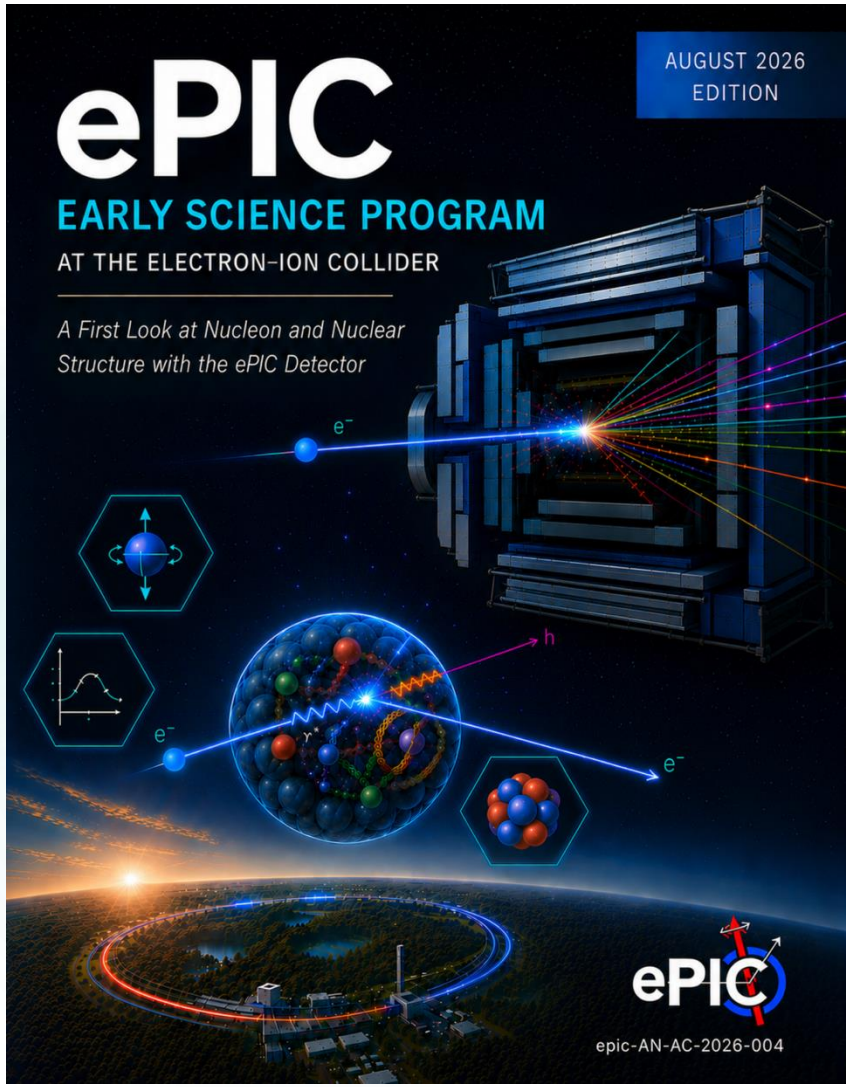
*9 GeV electrons allow 10nc/bunch (vs 7nc/bunch at 10 GeV) with limited SRF in ESR

Time to install additional equipment to reach design current, luminosity and maximum energies

Early Science Report

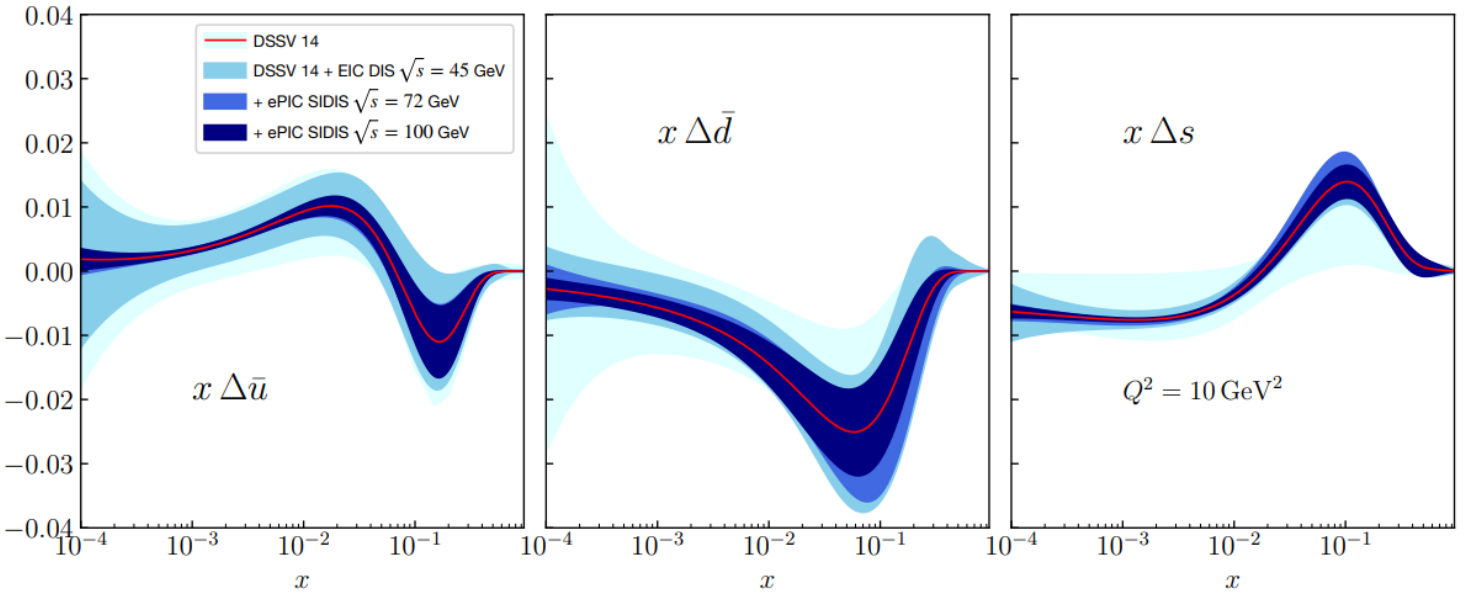
→ *Carlos Munoz Camacho*

https://arxiv.org/pdf/2608.05377



Note: e + A luminosity is per nucleon

Species	Beam energy (GeV)	Integrated luminosity (fb^{-1})	Electron-beam polarization	Hadron-beam polarization
e+Ag	9×115	1.0	NO	N/A
e+D	9×130	1.5	LONG	NO
$e + p$	9×130	1.0	LONG	TRANS and/or LONG
$e + p$	9×275	2.5	LONG	TRANS and/or LONG
e+Au	9×100	1.0	LONG	N/A
$e + {}^3$He	9×166	1.5	LONG	TRANS and/or LONG



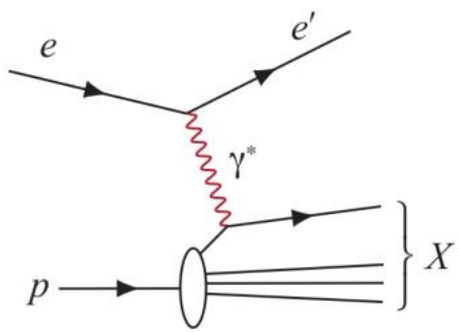
Summary: Enabling Precision QCD with ePIC

- **Physics:** Unravel the proton spin and image the three-dimensional structure of nucleons.
- **Beyond Spin:** Explore the origin of nucleon mass, color confinement, nuclear structure, and gluon saturation.
- **Detector:** Integrate precision tracking, particle identification, calorimetry, and forward detection to enable precision measurements.
- **Streaming Computing:** Develop continuous readout, real-time collision identification, and AI/ML-assisted reconstruction to cope with challenging EIC backgrounds.
- **Looking Ahead:** With the EIC physics program still years ahead, we have an opportunity to develop new scientific questions, innovative analysis methods, and new approaches to QCD together with the global community.

Backup slides

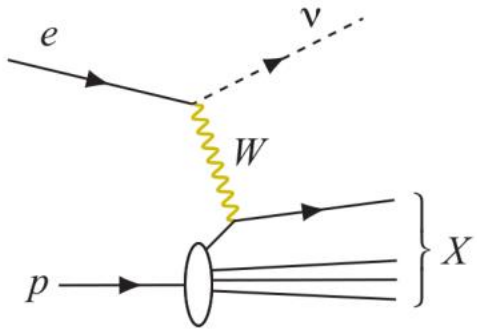
Experimental Processes to Access EIC Physics

DIS event kinematics - scattered electron or final state particles (CC DIS, low y)



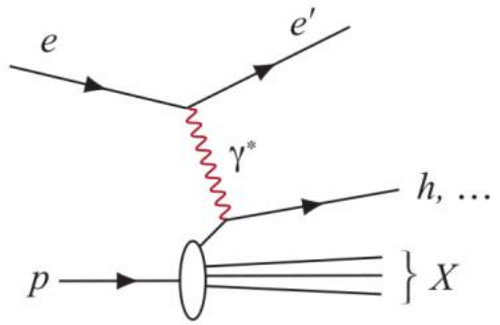
Neutral Current DIS

- Detection of scattered electron with high precision - event kinematics



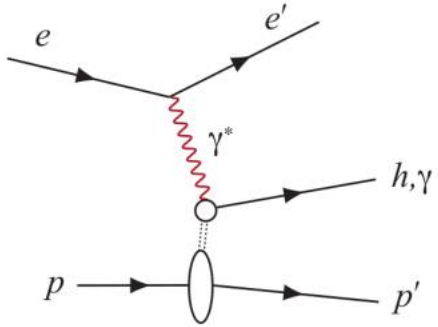
Charged Current DIS

- Event kinematics from the final state particles (Jacquet-Blondel method)



Semi-Inclusive DIS

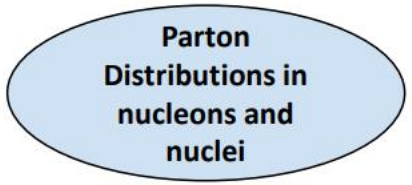
- Precise detection of scattered electron in coincidence with at least 1 hadron



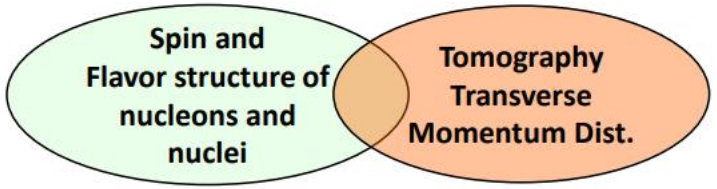
Deep Exclusive Processes

- Detection of all particles in event

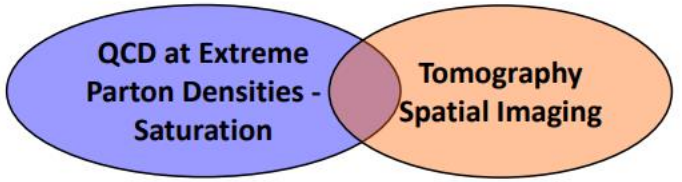
NUCLEI



SPIN IMAGING



GLUONS MASS IMAGING

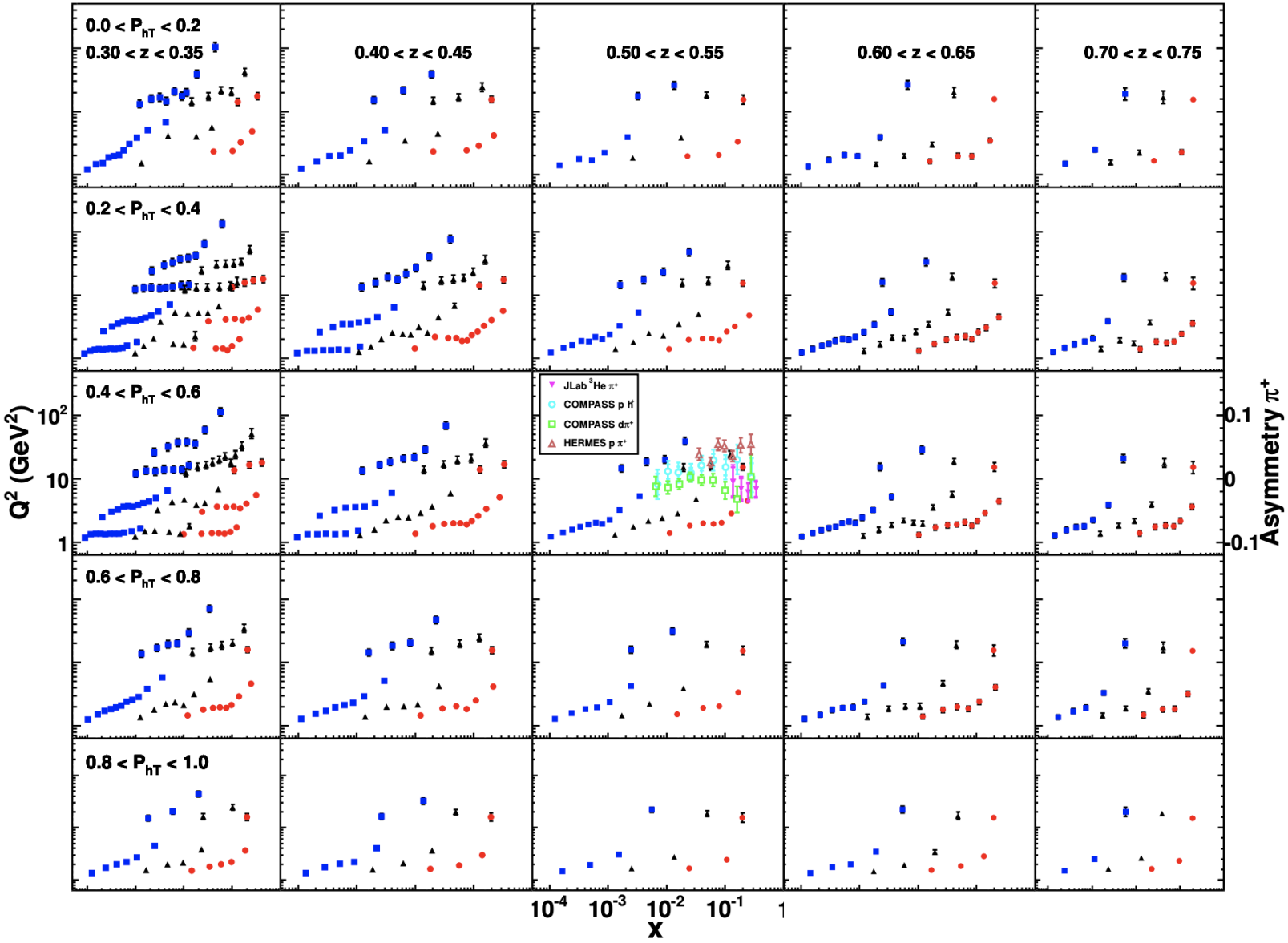


TMD at EIC through SI-DIS

√s = 140 GeV

√s = 45 GeV

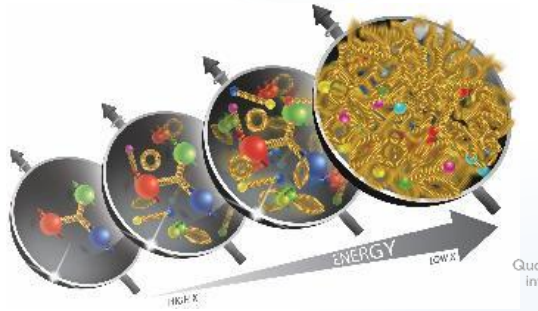
√s = 15 GeV



The EIC Accelerator Performance Drivers

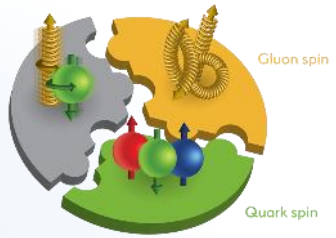
wide center-of-mass energy √s: 20 – 140 GeV :

- map out the nucleon and nuclei structure from high to low x



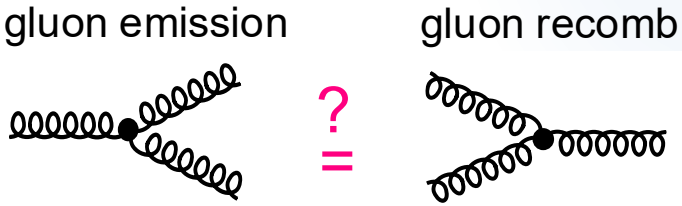
polarized electron and polarized hadron (p, d, He^3) beams:

- access to spin structure of nucleons and nuclei
- access to the q-g structure of NN and NNN interaction in light nuclei



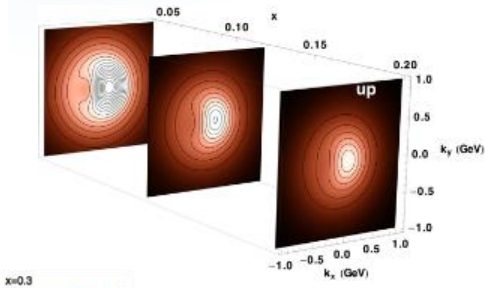
nuclear beams: d to Pb

- accessing the highest gluon densities → saturation
- quark and gluon interact with a nuclear medium



high luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$:

- mapping the spatial and momentum structure of nucleons and nuclei in 3d
- access to rare probes



large acceptance (0.2 – 1.3 GeV) through forward focusing IR magnets

- spatial imaging of nucleons and nuclei

