



EIC experimental opportunities and realization plans

Abhay Deshpande
Center for Frontiers in Nuclear Science (CFNS)
Brookhaven National Laboratory and Stony Brook University

June 25, 2026

Light Cone 2026 at Stony Brook University



If we hope to accomplish great things in the future, we must recognize that we are standing on the shoulders of giants

A modified quote from Isaac Newton:

“I have seen further by standing on the shoulders of giants”....

For the Electron Ion Collider this is particularly true

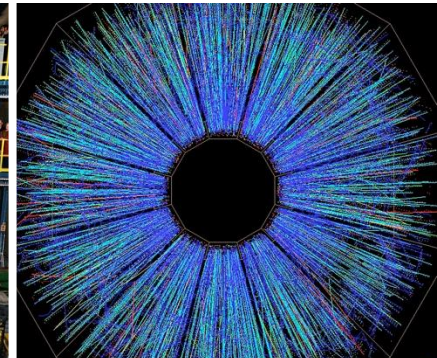
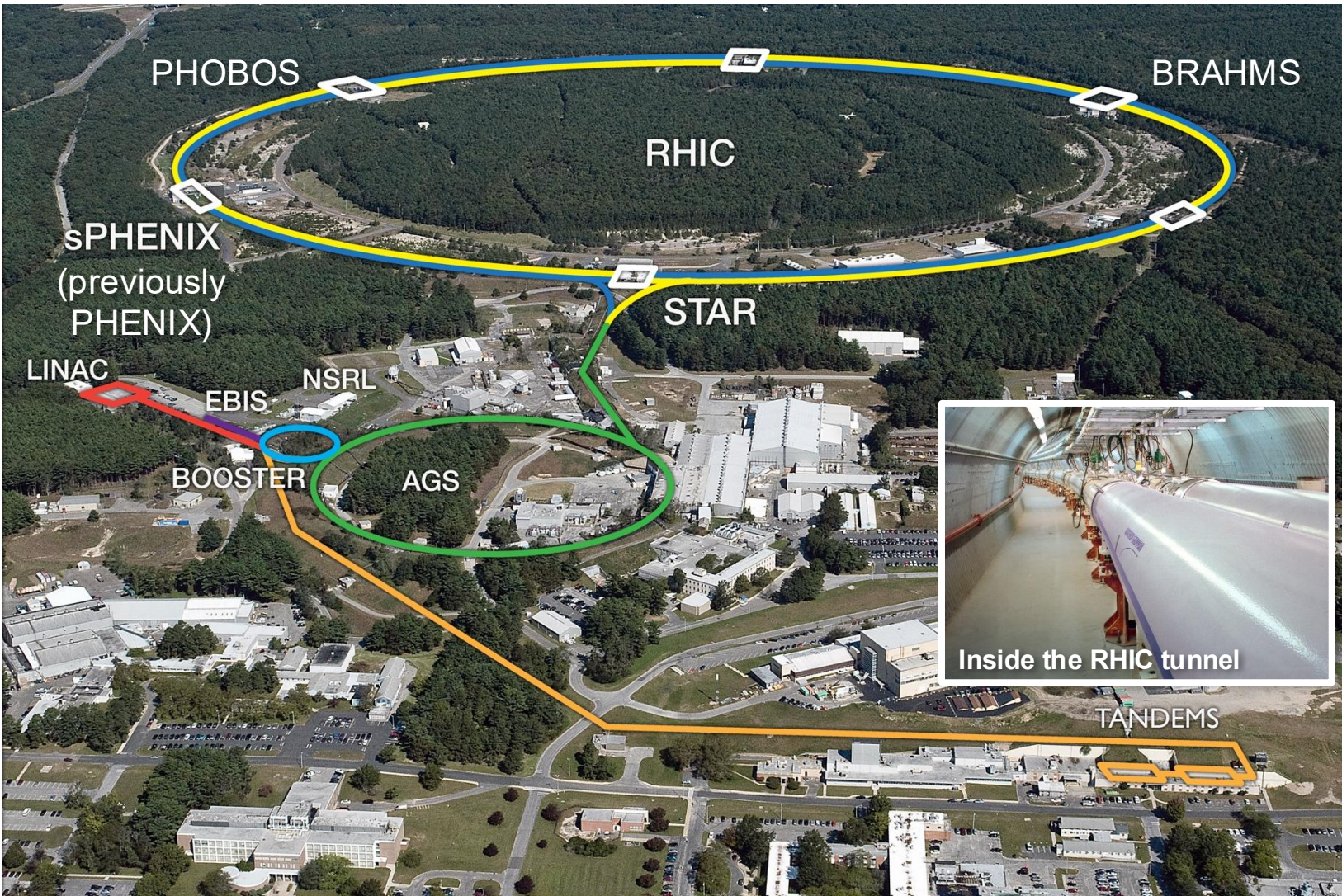
4th generation (polarized) DIS facility

Pioneering fixed target experiments at (SLAC, CERN), (DESY) from 1970's to-date
CEBAF@Jefferson Lab to the Electron Ion Collider (Zein-Eddine Meziani)

Including RHIC Spin, it will be a 5th generation spin physics facility

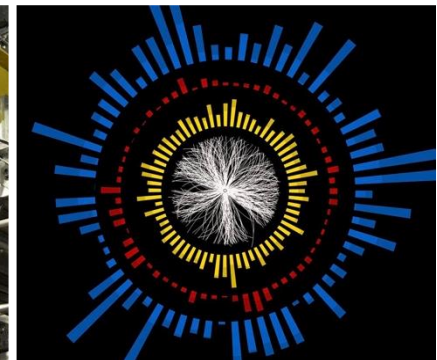
The Relativistic Heavy Ion Collider (2000-2026)

A machine built to explore fundamental matter at the dawn of time

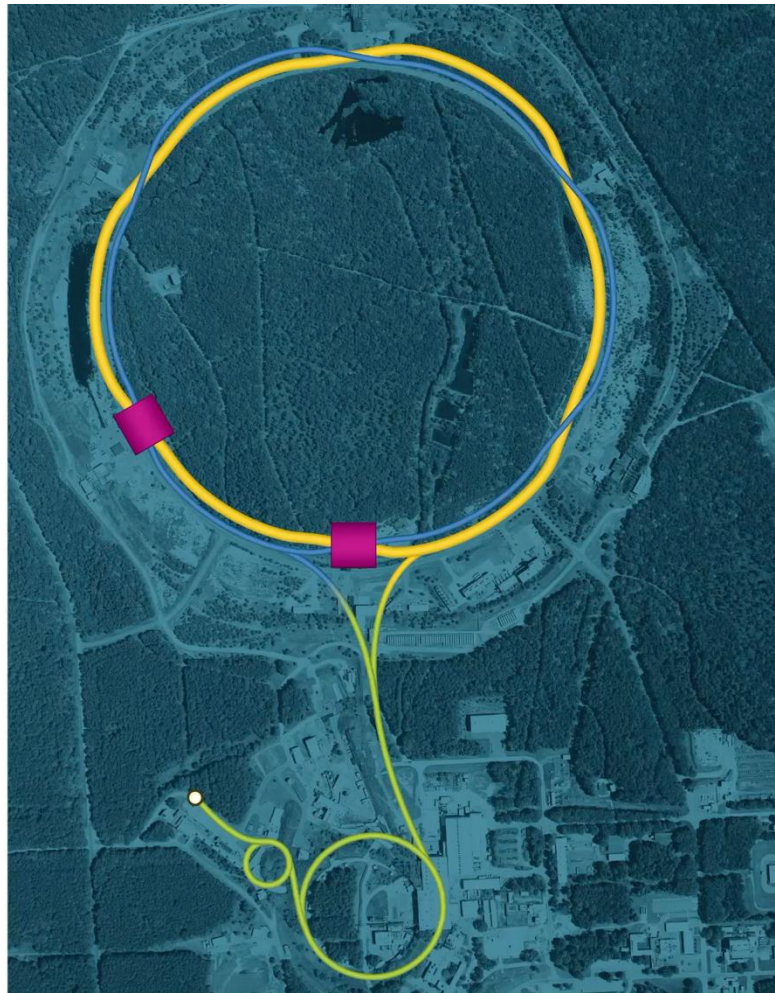


Collaborations, experiments

- PHOBOS: 2000 – 2005
- BRAHMS: 2000 – 2006
- PHENIX: 2000 – 2016
- STAR: 2000 – 2026
- sPHENIX: 2023 – 2026



RHIC: The World's Most Versatile Collider




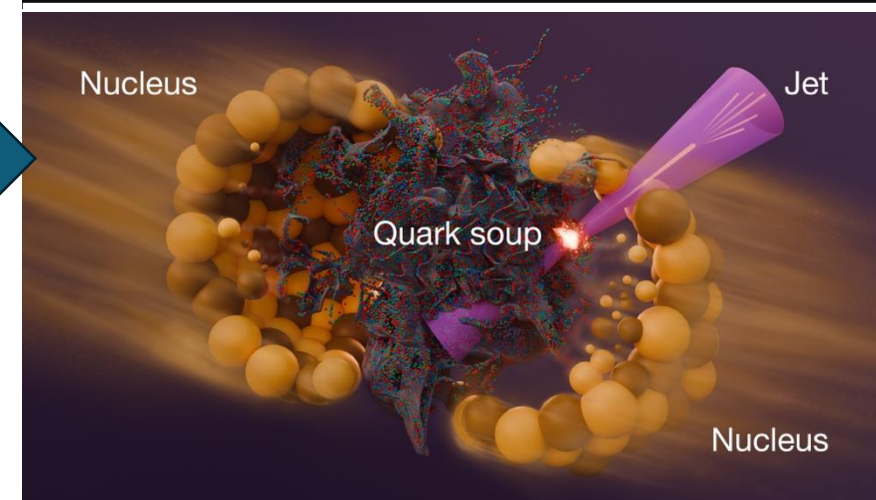
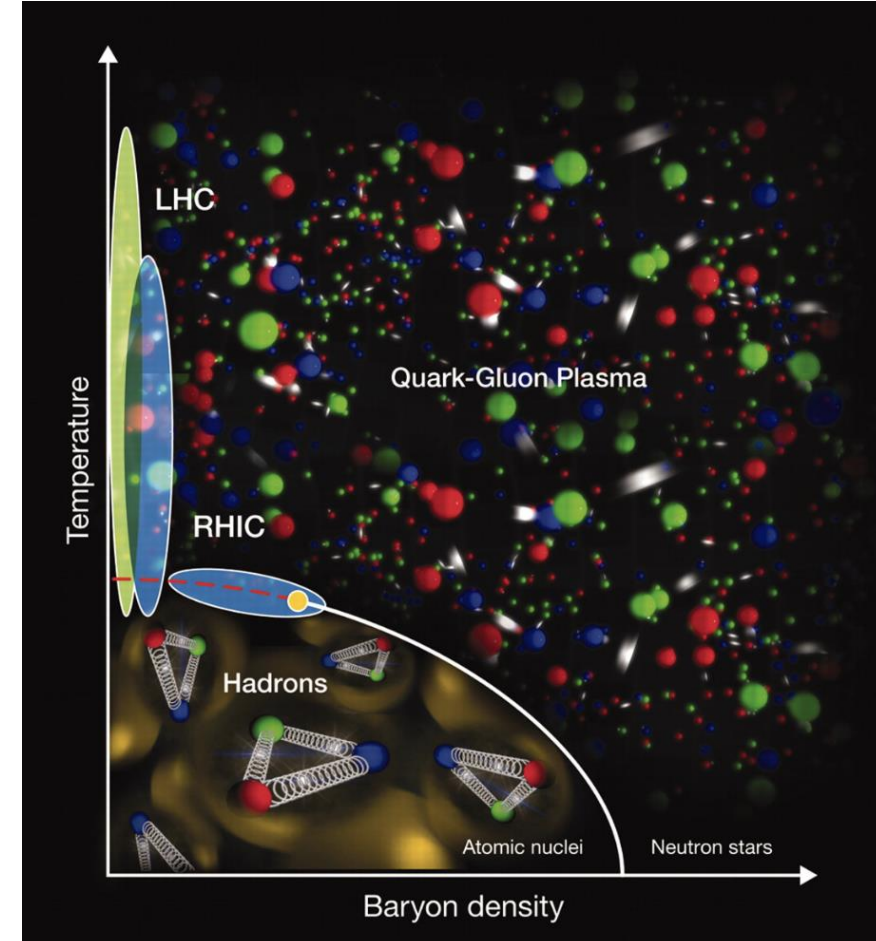
- High-intensity, high-brightness ion and proton sources
- 49 different combinations of energy, ions, and collision configurations
 - 10 different ion species
 - 18 center-of-mass energies
- Innovative accelerator technologies
- Gold-gold collision rates 44 times higher than design
- Only polarized proton collider in the world

Discoveries at RHIC

Quark-Gluon Plasma (QGP): A 'Perfect,' Ultra-Dense Fluid

RHIC re-created the quark-gluon plasma of the early universe.

- 4 trillion °C — **hottest matter** ever created at the time.
 - Expected to be a gas, but it **flows like a liquid**.
 - Extremely low viscosity — near the **quantum limit**.
 - Unique transition from **gas to liquid upon heating!**
-
- Extreme density “quenches” energetic “jets” of particles. 
 - Surprising: QGP “droplets” discovered in collisions of small nuclei as well!



Discoveries at RHIC

Gluons' Contribution to Proton Spin

- Unique ability to accelerate/collide spin-aligned protons.
- Enabled studies of how quarks and gluons contribute to proton spin.
- Experiments elsewhere showed quarks only contribute about 30%.
- RHIC found that gluons also contribute to spin, about as much as the quarks
- Establishes the groundwork for understanding this important quantum property.



Trillions of Collisions, Extraordinary Impacts

- ~300 trillion collisions, in total
- ~450 petabytes of data (raw and derived)
- 3,500+ scientific collaborators from 36 countries (2000-present)
- 650+ scientific publications; 640+ Ph.D.s awarded
- ~220 newsworthy announcements (1991 to present)
- Papers and their impact (1700+ papers, 120,000+ citations)
 - PHENIX (2000-2016, 635 papers, 41.6k Citations),
 - STAR (2000-2026, 869 papers, 61.3k citations)
 - BRAHMS (2000-2006, 90 papers, 6.6k citations)
 - PHOBOS (2000-2006, 121 papers, 10.5k citations)
 - sPHENIX (2023-2026, 8 papers, 80 citations)

RHIC science graduates now in leadership positions at LHC, Jlab, KEK, JPARC and facilities in Europe and Asia



February 6, 2026

EIC CD3 B approval announced



The button that shut RHIC down



Feb 3, 2026: Last weekly RHIC planning meeting started in 2000



PHYSICS
The only U.S. particle collider shuts down – so a new one may rise

The Relativistic Heavy Ion Collider stops work after more than 25 years of mind-bending discoveries
By Emily Conover

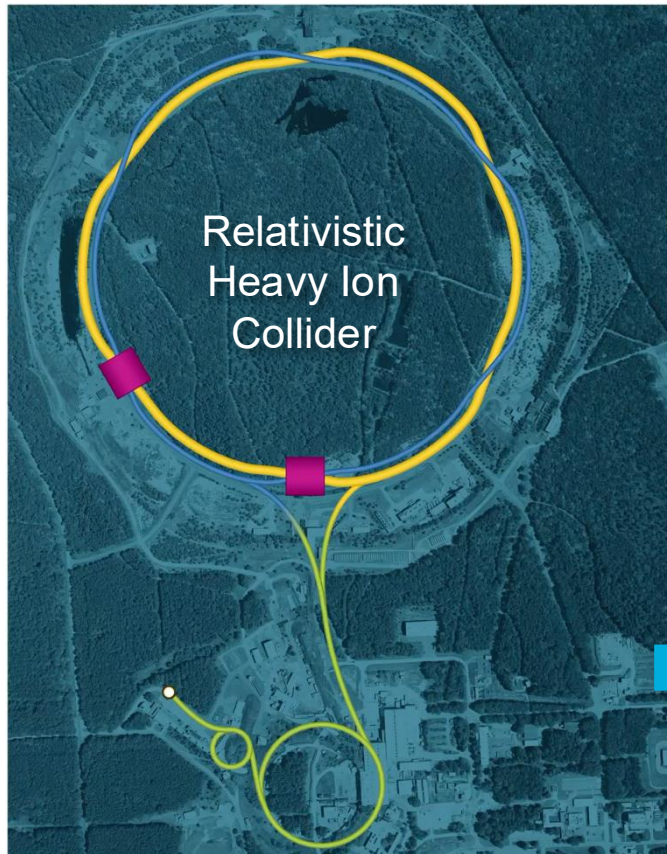


← SPHENIX

STAR →

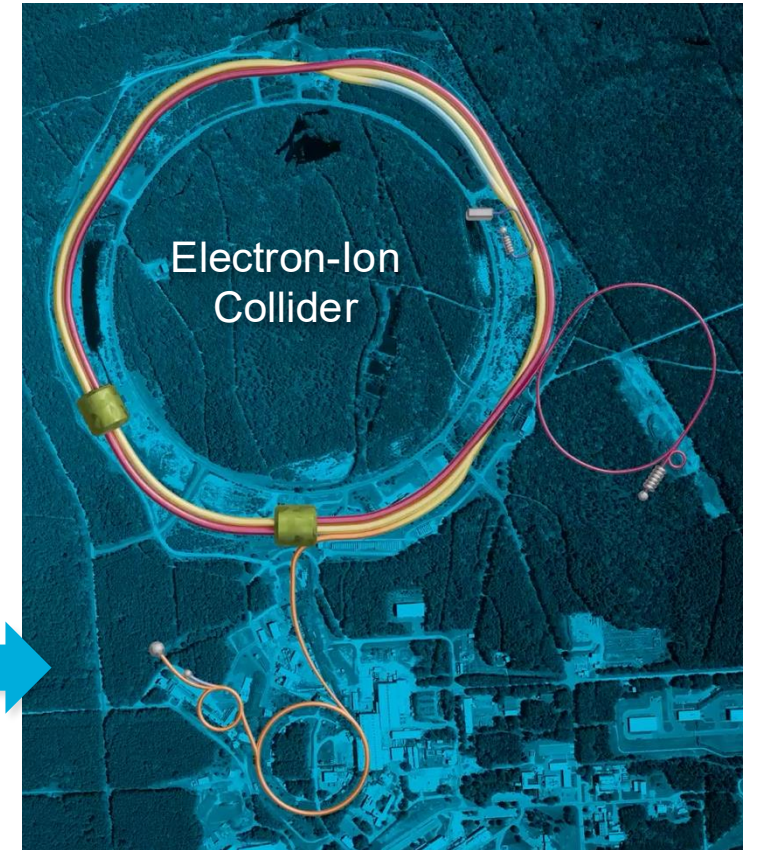


A New Era of Discovery: From RHIC to the Electron-Ion Collider (EIC)



Building on the ~\$2 billion+ investment in RHIC:

- Re-use existing tunnel
- Minimal modification to ion beam complex (yellow)
- New electron beam facility



Partnership between U.S. Department of Energy, Brookhaven Lab, Thomas Jefferson National Accelerator Facility, New York State, and collaborators around the world.

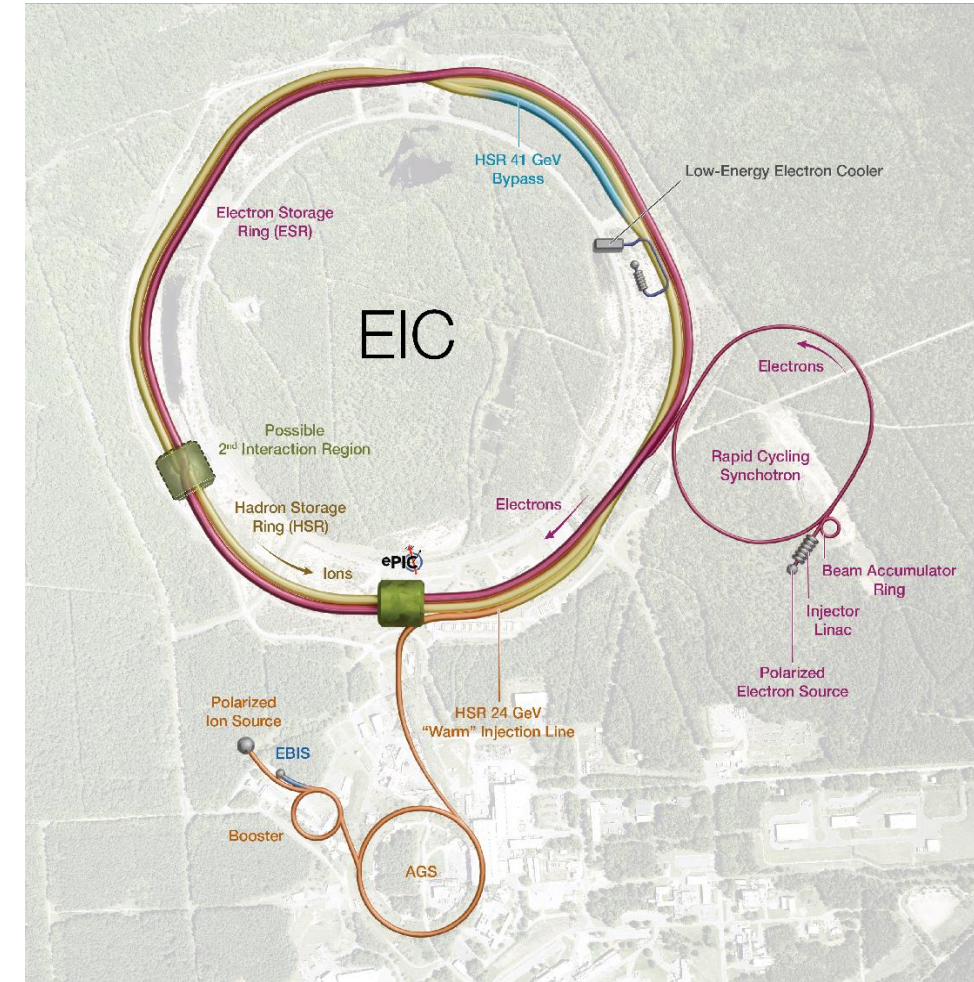
Present EIC Concept (2025)

Ultimate EIC Performance Parameters:

- High Luminosity: $L = 10^{33} - 10^{34} \text{cm}^{-2}\text{sec}^{-1}$
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: $E_{\text{cm}} = \sim 28 - 100 (140) \text{ GeV}$
- Large Ion Species Range: protons – Uranium
- Large Detector Forward Acceptance and Low-Background Conditions
- Possibility to Implement a **Second Interaction Region (IR)**

Accelerator Status at a glance:

- ✓ Polarized ion/proton source
- ✓ Ion injection and initial acceleration systems – Linac (200 MeV), Booster (1.5 GeV), AGS (25 GeV)
- UPGRADE** Hadron Storage Ring (40-275 GeV) – HSR
- NEW** Electron Pre-Injector (750 MeV linac)
- NEW** Beam Accumulation Ring (750 MeV) – BAR
- NEW** Electron Rapid Cycling Synchrotron (0.75 GeV – top energy) – RCS
- NEW** Electron Storage Ring (5 GeV – 18 GeV) – ESR
- NEW** Interaction Region(s) – IR
- NEW** Hadron Cooling System



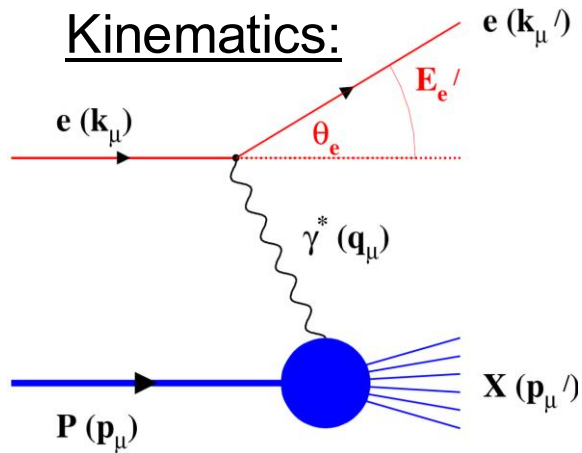
Protons: ~40 – 275 GeV
Electrons: 5 – 10 (18) GeV

Why Electron Ion Collider?

Deep inelastic scattering is one of the most successful technique to measure the internal structure of hadrons....

Versatility of RHIC – by the accelerator flexibility will be imparted to the Electron Ion Collider – both with polarized beams and with nuclei

Deep Inelastic Scattering: Precision and control



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

Measure of resolution power

$$Q^2 = 2E_e E'_e (1 - \cos \Theta_{e'})$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e} \cos^2 \left(\frac{\Theta'_e}{2} \right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

Hadron:

$$z = \frac{E_h}{\nu}; p_t$$

with respect to γ^*

$$s = 4 E_h E_e$$

High lumi & acceptance

Exclusive DIS
 detect & identify everything $e+p/A \rightarrow e'+h(\pi,K,p,jet)+\dots$

Semi-inclusive events:
 $e+p/A \rightarrow e'+h(\pi,K,p,jet)+X$
 detect the scattered lepton in coincidence with identified hadrons/jets

Inclusive events:
 $e+p/A \rightarrow e'+X$

detect only the scattered lepton in the detector

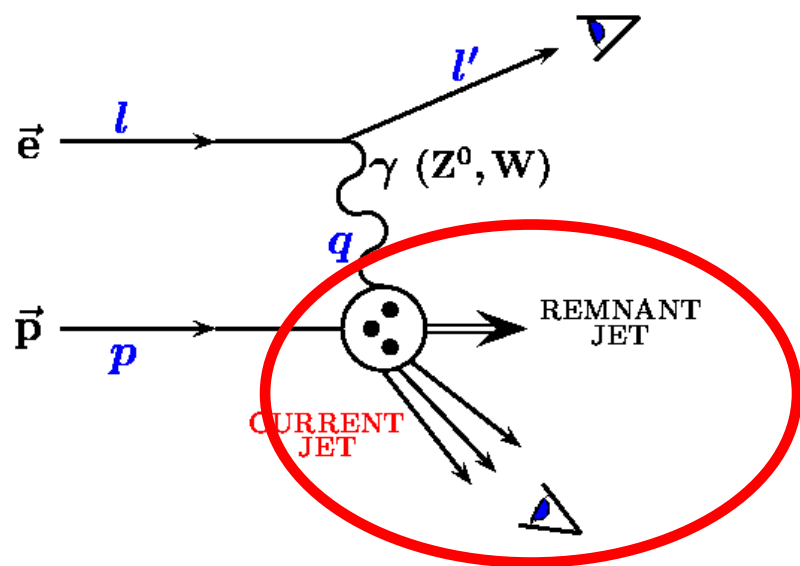
Low lumi & acceptance

Sometimes scattered electron can't be measured....

Reasons:

- 1) Scattering angle so small that it is too close to the beam pipe
- 2) Radiative correction too large, i.e. electron lost its energy due to Initial State Radiation or Brehmstrahlung through material -- So the kinematic reconstruction unreliable.

What to do? Then see if we can reconstruct the hadronic final state?



$$y = \frac{E_j}{2E_e}(1 - \cos\theta_j)$$

$$Q^2 = E_j^2 \sin^2\theta_j / (1 - y)$$

$$x = \frac{E_j}{2E_p}(1 + \cos\theta_j) / (1 - y)$$

$$E_j = yE_e + x(1 - y)E_p$$

$$\cos\theta_j = \frac{-yE_e + (1 - y)xE_p}{yE_e + (1 - y)xE_p}$$

$$E_j^2 \sin^2\theta_j = 4xy(1 - y)E_eE_p = Q^2(1 - y)$$

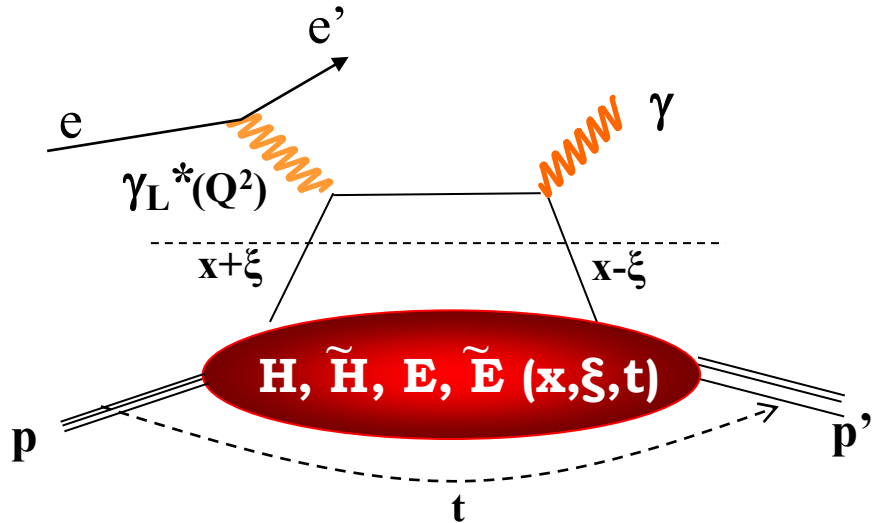
$$y_{JB} = \frac{1}{2E_e} \sum_h (E_h - p_{Zh})$$

$$Q_{JB}^2 = \frac{(\sum_h p_{Xh})^2 + (\sum_h p_{Yh})^2}{1 - y_{JB}}$$

$$x_{JB} = Q_{JB}^2 / (y_{JB}s)$$

Deep Inelastic Scattering: Deeply Virtual Compton Scattering

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

Measure of resolution power

$$Q^2 = 2E_e E'_e (1 - \cos \Theta_{e'})$$

Measure of inelasticity

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e} \cos^2 \left(\frac{\theta'_e}{2} \right)$$

Measure of momentum fraction of struck quark

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

$$t = (p - p')^2, \xi = \frac{x_B}{2 - x_B}$$

Exclusive measurement:

$e + (p/A) \rightarrow e' + (p'/A') + \gamma / J/\psi / \rho / \phi$
 detect all event products in the detector

Special sub-event category rapidity gap events

$e + (p/A) \rightarrow e' + \gamma / J/\psi / \rho / \phi / \mathbf{jet}$
 Don't detect (p'/A') in final state

Why a DIS collider for future?

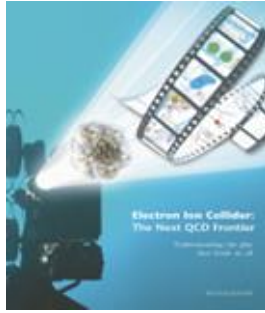
Simple answer: JLab6 and JLab12 – will cover most precise measurements of the quark-sector (valence region)

It's the Gluon that begs us to go with higher energy, and lower-x region explorations. Colliders do that most naturally

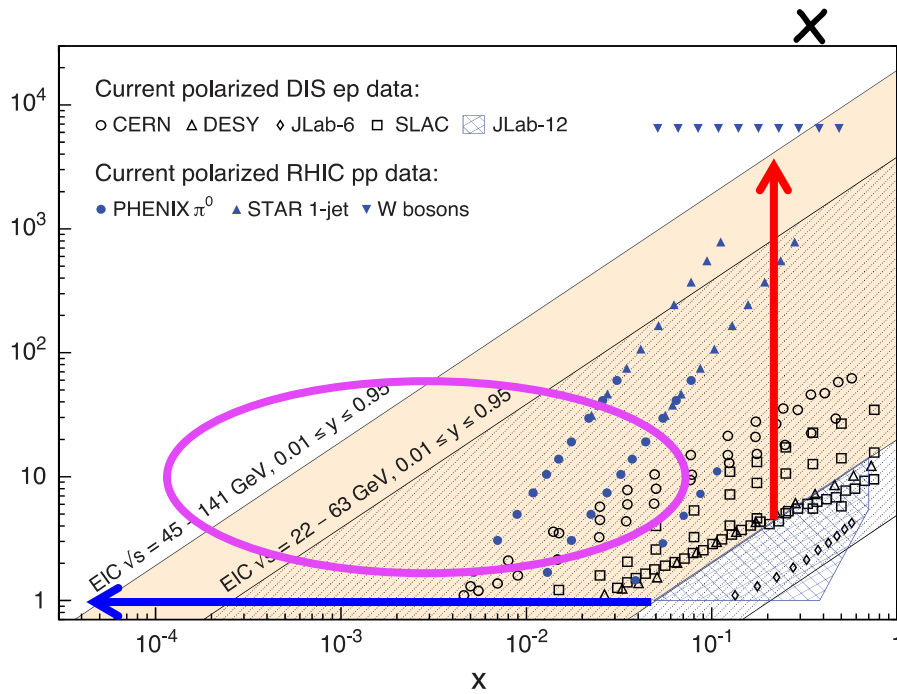
$S = 4 E_p E_e$ for 10 GeV electron, fixed tgt, $S = 40 \text{ GeV}^2$,

for 250 GeV proton, in a collider $S = 10,000 \text{ GeV}^2$

EIC: **NEW** Kinematic reach & properties



Q² (GeV²)

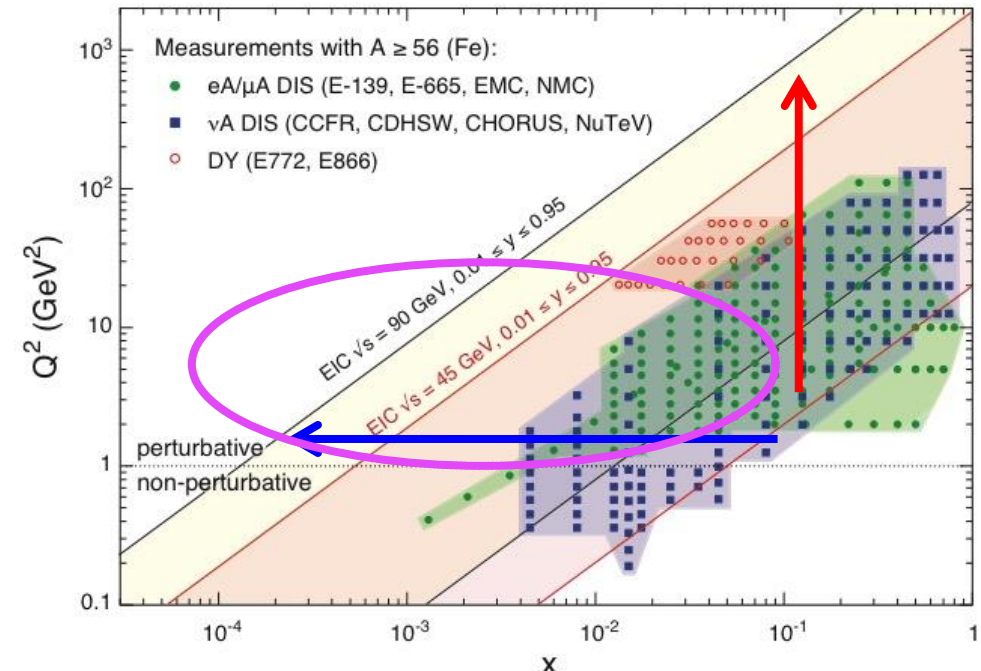


For e-N collisions at the EIC:

- ✓ Polarized beams: e, p, d/³He
- ✓ Variable center of mass energy
- ✓ **Wide Q² range → evolution**
- ✓ **Wide x range → spanning valence to low-x physics**

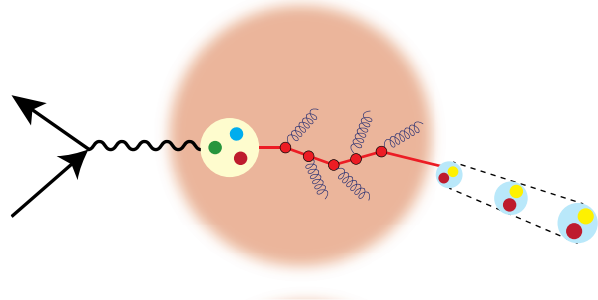
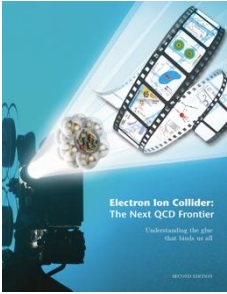
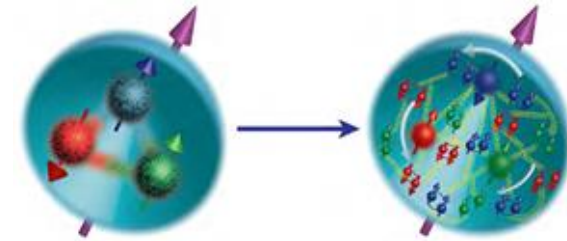
For e-A collisions at the EIC:

- ✓ Wide range in nuclei
- ✓ Luminosity per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ **Wide x range (evolution)**
- ✓ **Wide x region (reach high gluon densities)**



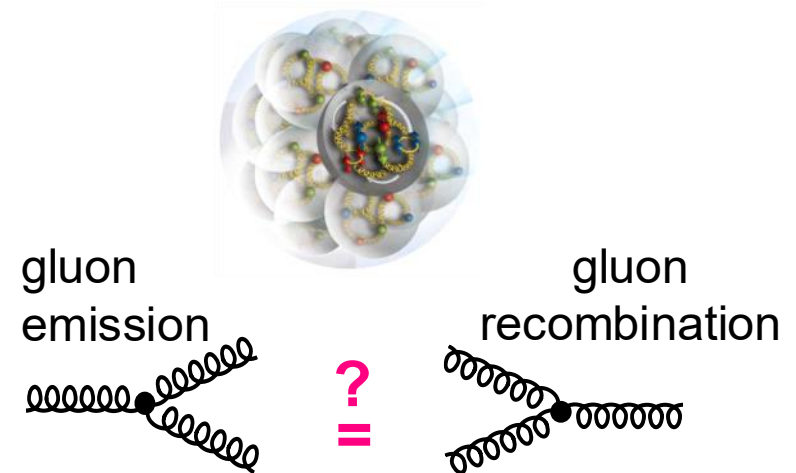
A new facility is needed to investigate, with precision, the dynamics of gluons & sea quarks and their role in the structure of visible matter

How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties emerge from them and their interactions?



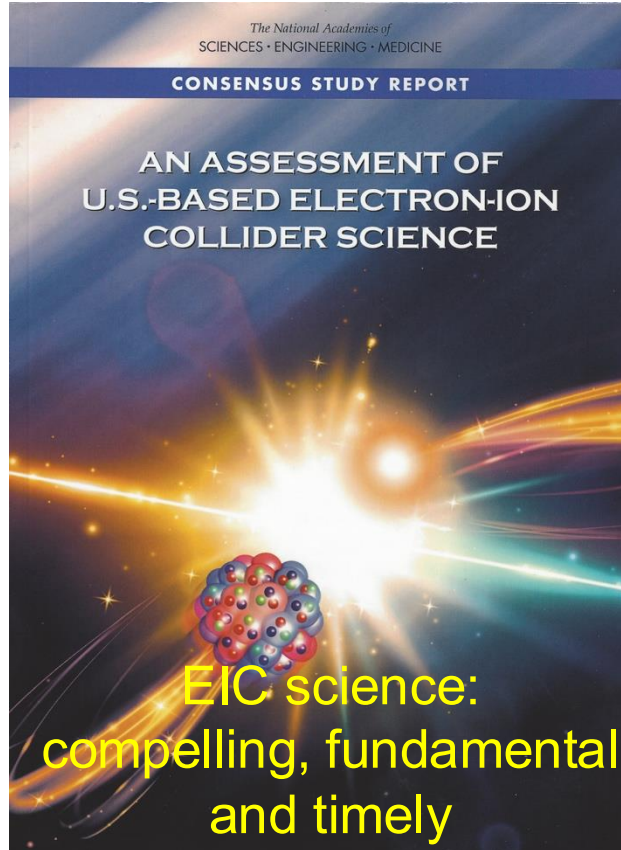
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?





US National Academy of Sciences, Engineering and Medicine: Assessment & Consensus Report



Physics of EIC

Emergence of Spin

Emergence of Mass

Physics of high-density gluon fields

Machine Design Parameters:

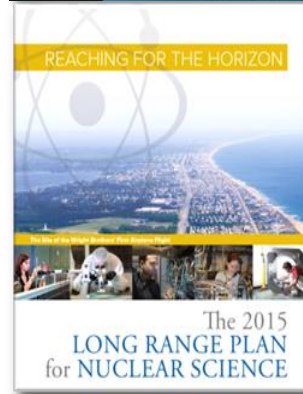
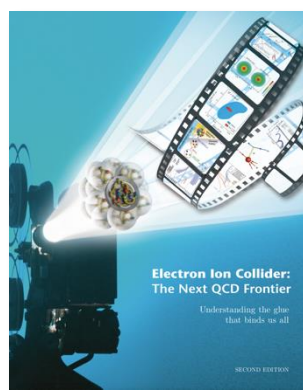
High luminosity: up to 10^{33} - 10^{34} cm⁻²sec⁻¹

Broad range in center-of-mass energy: ~20-100 (upgrade 140) GeV

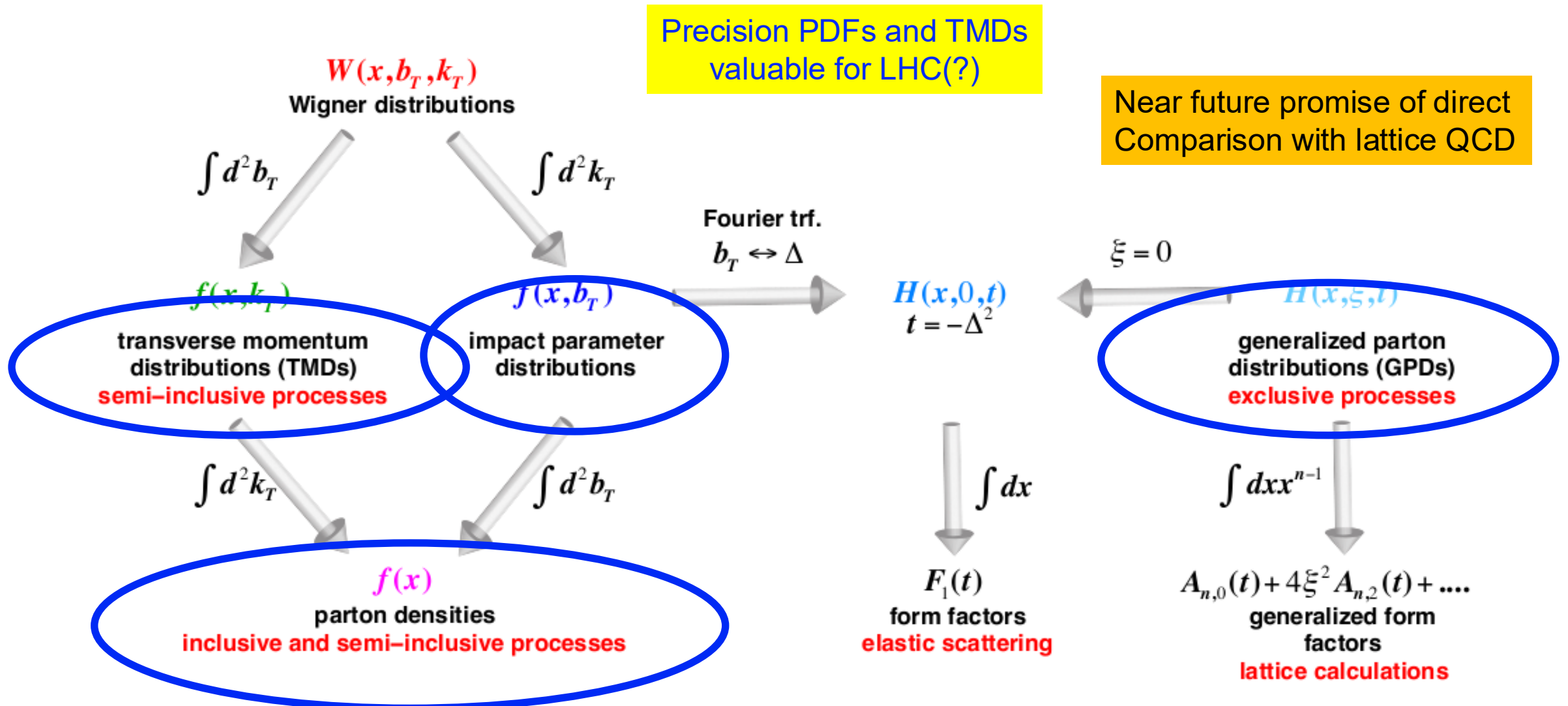
Polarized beams e⁻, p, and light ion beams

Broad range in hadron species: protons.... Uranium

Up to two detectors well-integrated detector(s) with machine lattice



2+1D Imaging of hadrons: **beyond precision PDFs**



From 1D to 6D: A Unified Picture of Hadron Structure

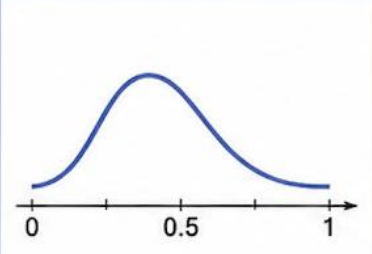
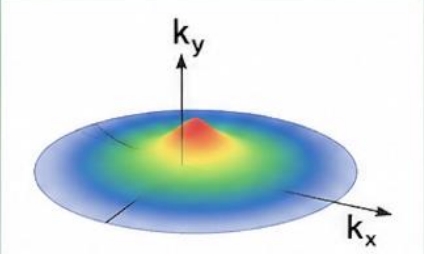
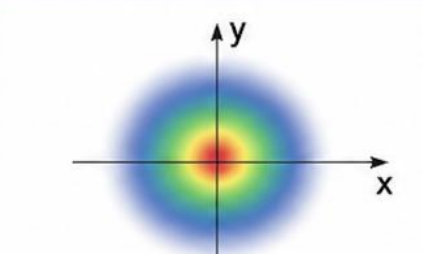
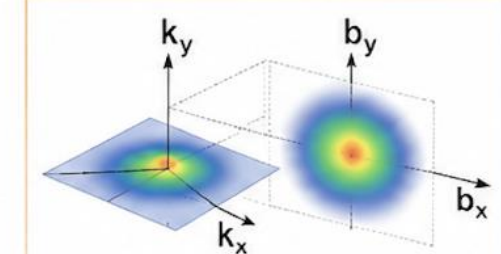
Increasing information = more dimensions = richer image

PDFs
1D

TMDs
3D

GPDs
3D

GTMDs
6D

Degrees of freedom	Only longitudinal momentum x	Longitudinal momentum + transverse momentum x, k_T	Longitudinal momentum + transverse position x, b_T	Longitudinal momentum + transverse momentum + transverse position x, k_T, b_T
Picture	 How much momentum?	 Momentum space (inside hadron)	 Transverse position (impact parameter)	 Quantum phase space (most complete picture)
Example observable	Inclusive DIS $e + p \rightarrow e' + X$	SIDIS, Drell-Yan, $e + p \rightarrow e' + h + X$	DVCS, Exclusive mesons $e + p \rightarrow e' + p' + \gamma^{(*)}$	Exclusive processes with measured hadrons, double distributions, etc.
What EIC measures	Structure functions $F_2(x), F_L(x), g_1(x)$	Transverse momentum distributions and spin asymmetries (Sivers, Collins...)	Spatial distributions, form factors, pressure, orbital angular momentum	Correlations between momentum and position – full 6D information

More dimensions → More correlations → Deeper understanding of QCD

PDFs \subset TMDs \subset GPDs \subset GTMDs (each framework contains the previous ones as special limits)

Many more opportunities at the EIC

Precision QCD Studies with proton & (light & heavy) nuclear targets:

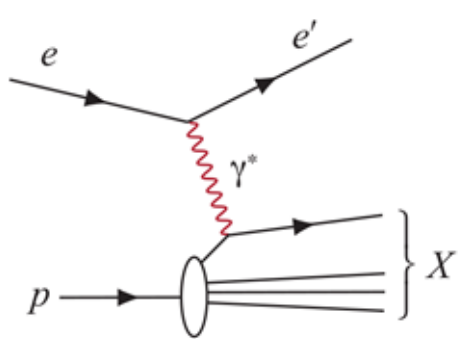
- Heavy quark and quarkonia (c, b quarks) studies with 100-1000 times lumi of HERA and with polarization
- Polarized light nuclei in the EIC
- Jets – probe of nuclear medium

Physic of jets, multiquark systems, confinement:

- Internal structure of jets in e-p/A collisions, momentum/energy correlators → novel observables with center of mass energy variability and polarized beams
- Entanglement-entropy, connections to fragmentation, hadronization and their relation to confinement
- Quark Exotica: 4,5,6 quark systems: Much interest based on BaBar/Belle, LHCb

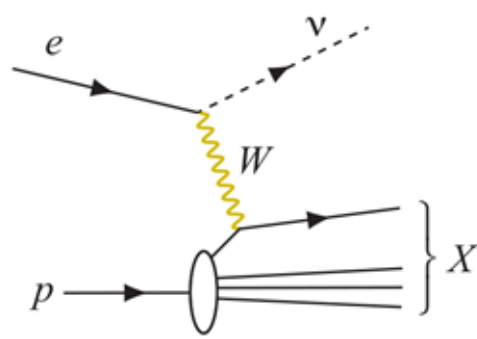
Experimental Processes to Access EIC Physics

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



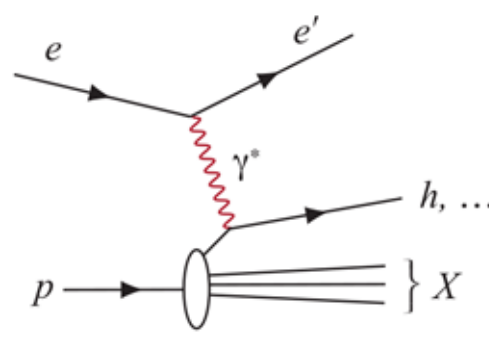
Neutral Current DIS

- Detection of **scattered electron** with high precision - event kinematics



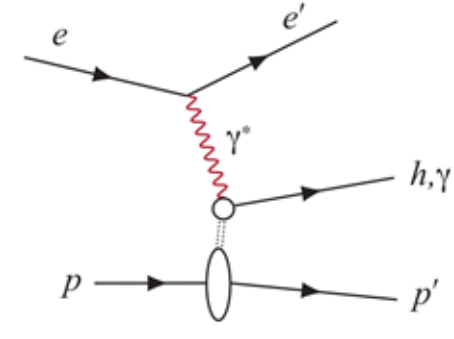
Charged Current DIS

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



Semi-Inclusive DIS

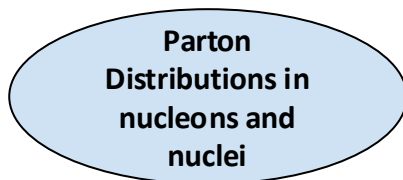
- Precise detection of **scattered electron** in coincidence with at least 1 hadron



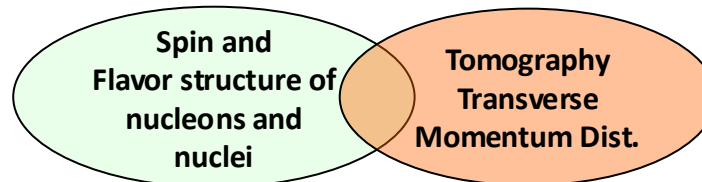
Deep Exclusive Processes

- Detection of **all particles** in event

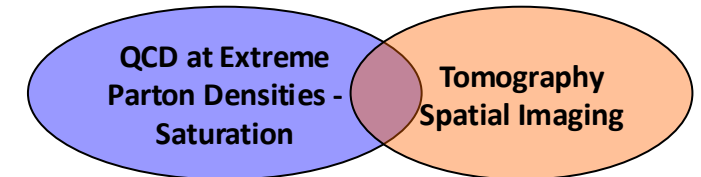
NUCLEI



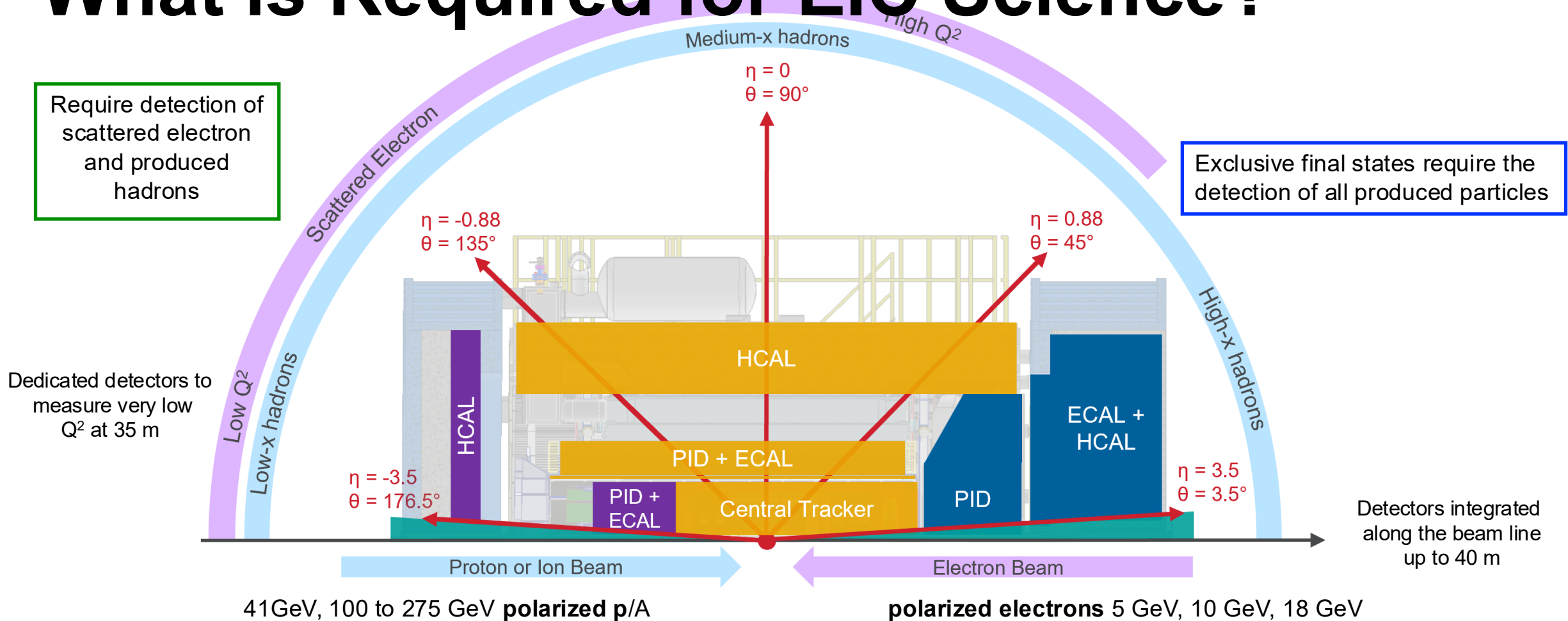
SPIN IMAGING



GLUONS MASS IMAGING

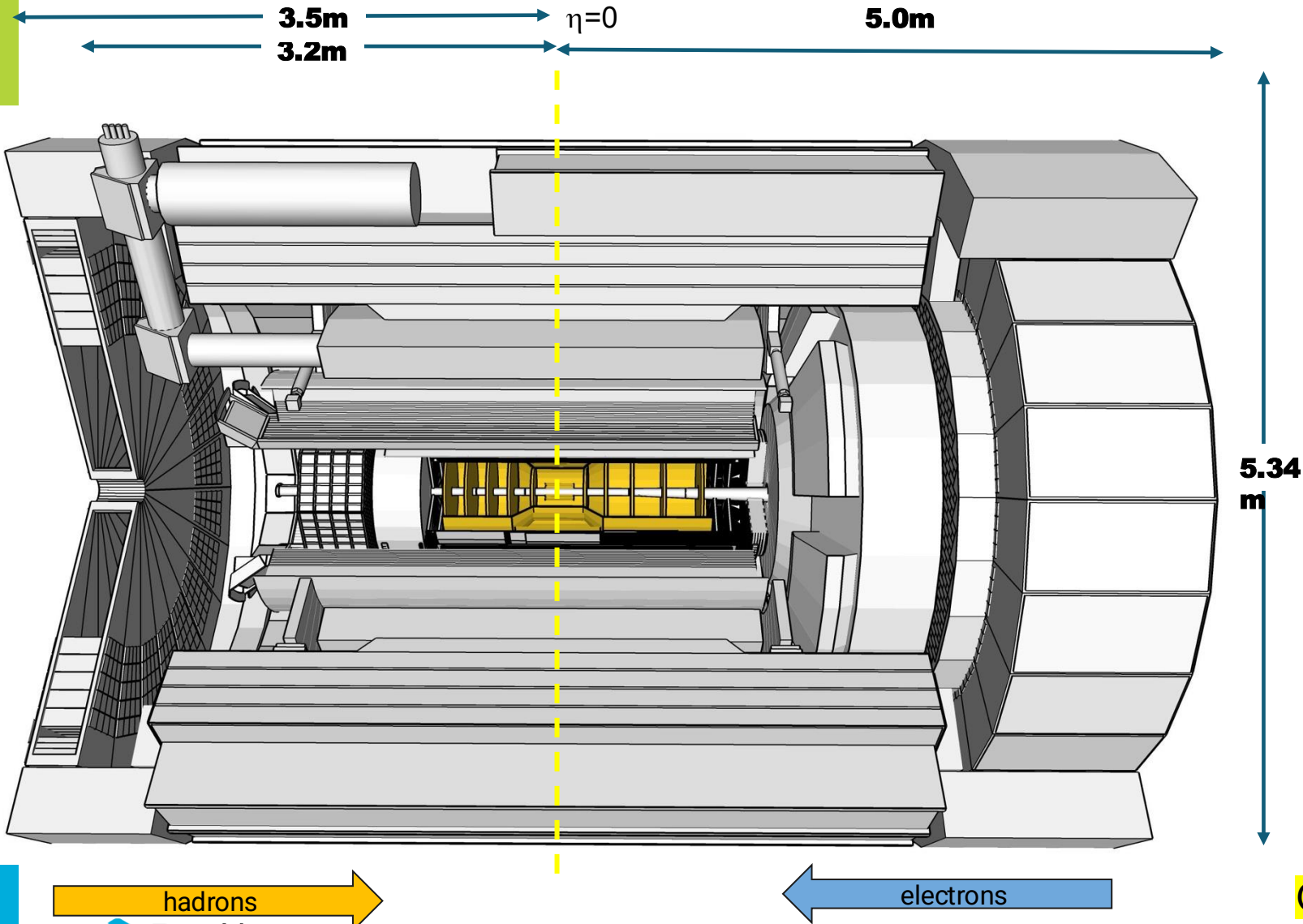


What is Required for EIC Science?



	MASS	IMAGING (Spatial)

ePIC Detector Design

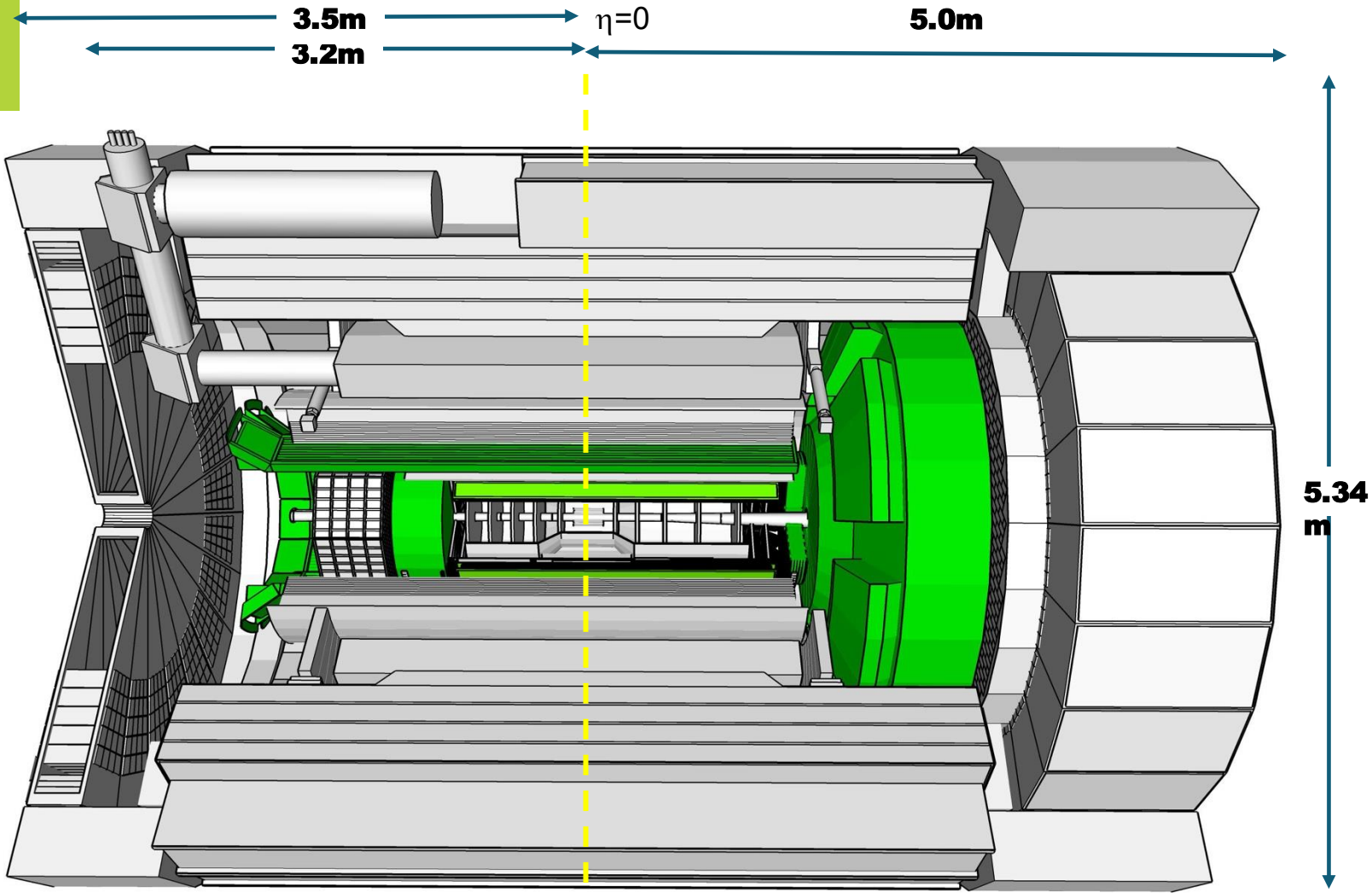
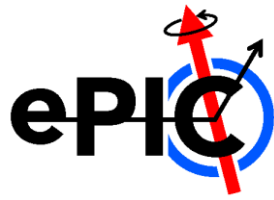


Tracking:

- New 1.7T solenoid
- Very thin Si MAPS Tracker
- MPGDs (μ RWELL/ μ Megas)

Overlap in technology R&D with LHC-future
(detectors)

ePIC Detector Design

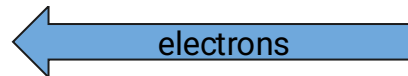


Tracking:

- New 1.7T solenoid
- Very thin Si MAPS Tracker
- MPGDs (μ RWELL/ μ Megas)

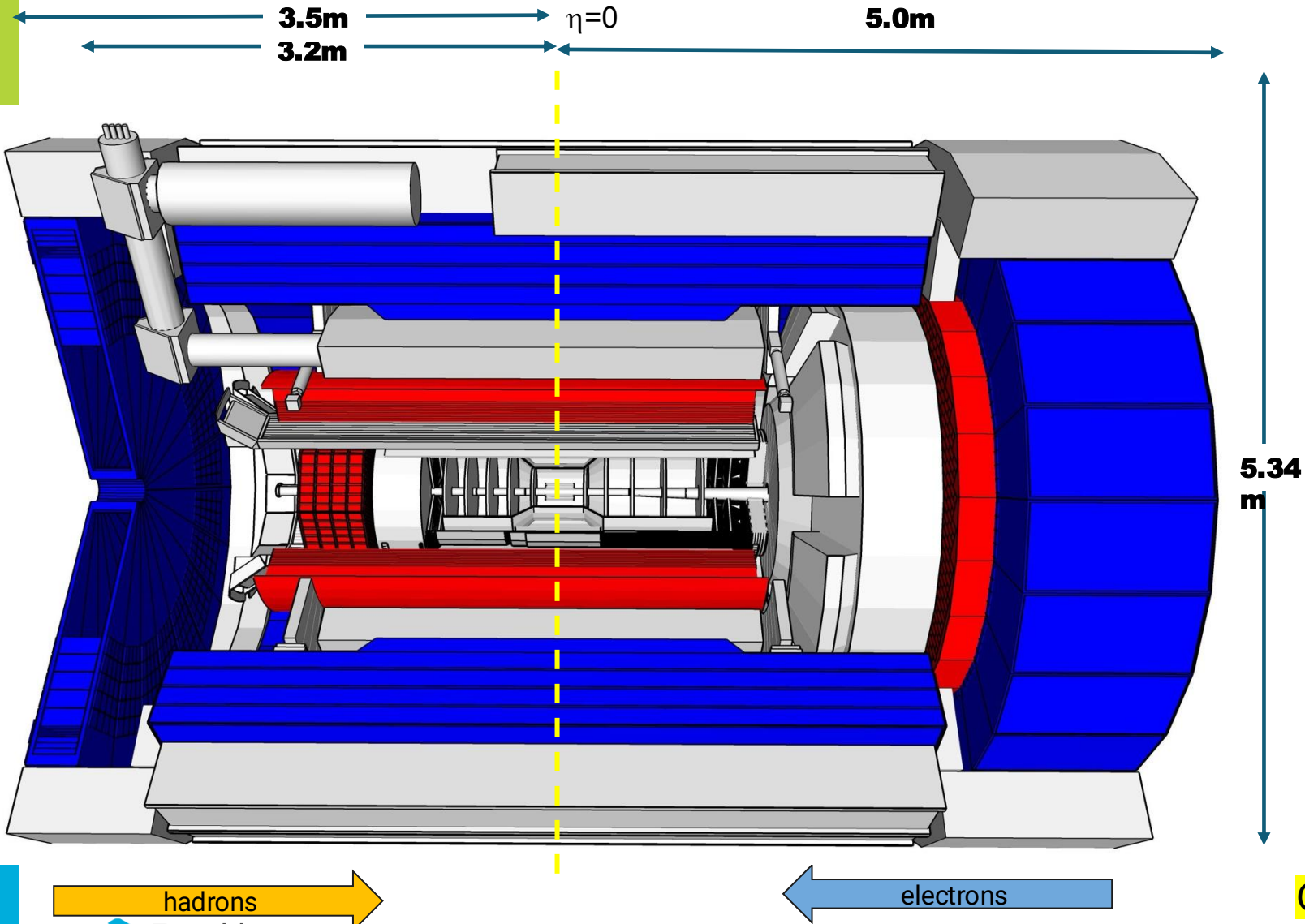
PID:

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



Overlap in technology R&D with LHC-future
(detectors)

ePIC Detector Design



Tracking:

- New 1.7T solenoid
- Very thin Si MAPS Tracker
- MPGDs (μ RWELL/ μ Megas)

PID:

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

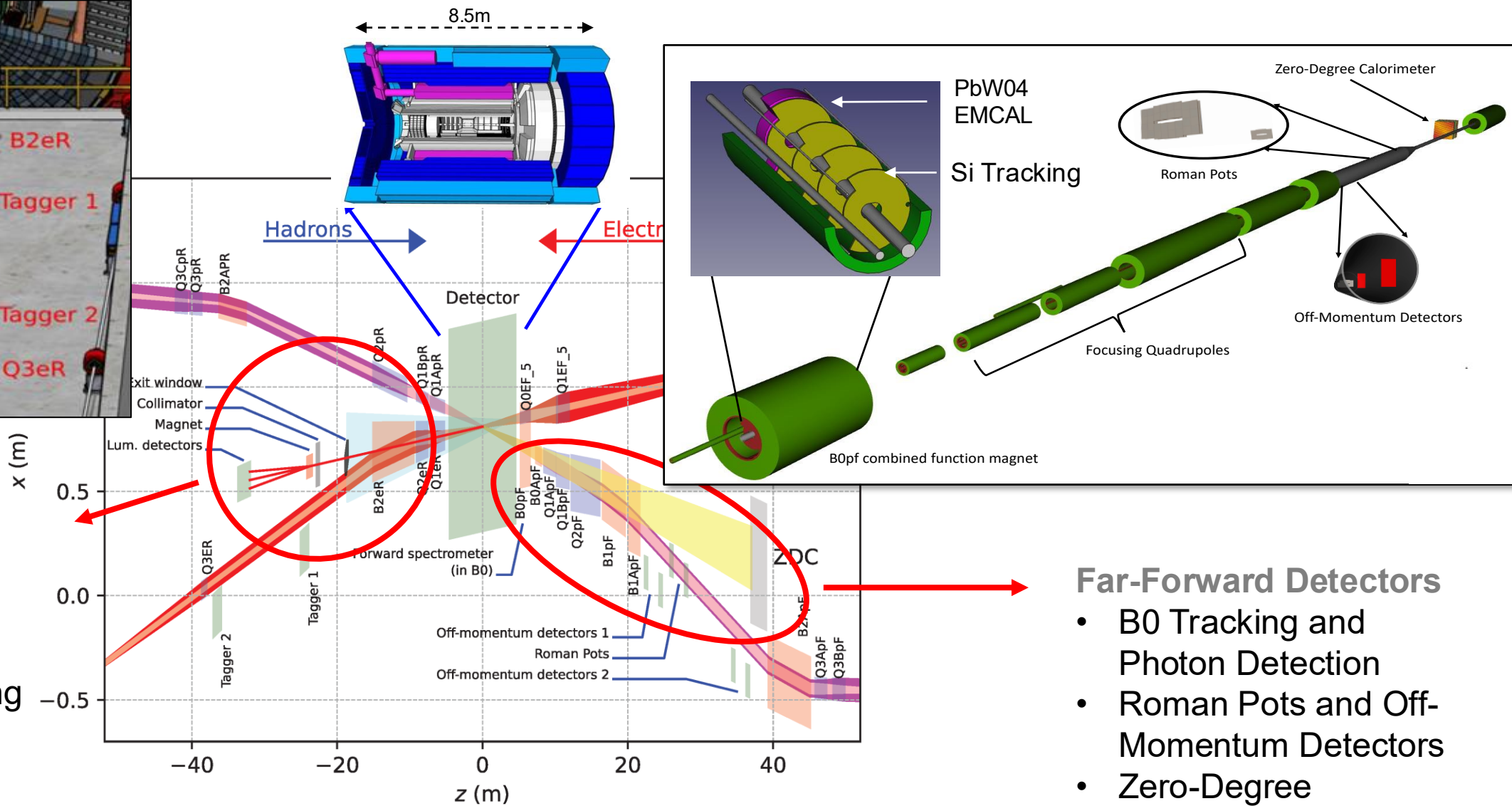
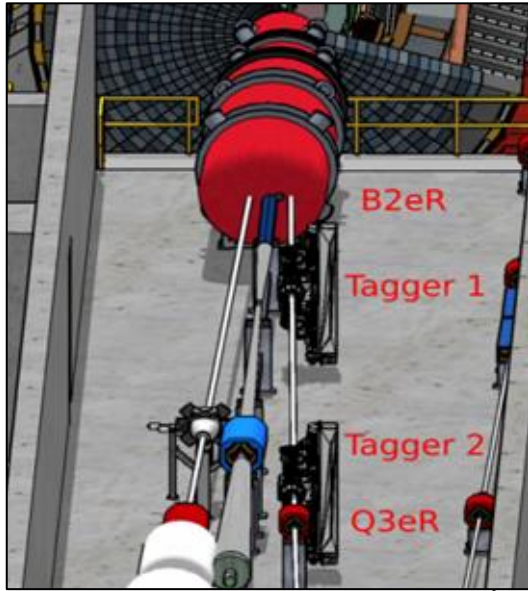
Calorimetry:

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

Overlap in technology R&D with LHC-future (detectors)



Far-Forward and Far-Backward Detectors



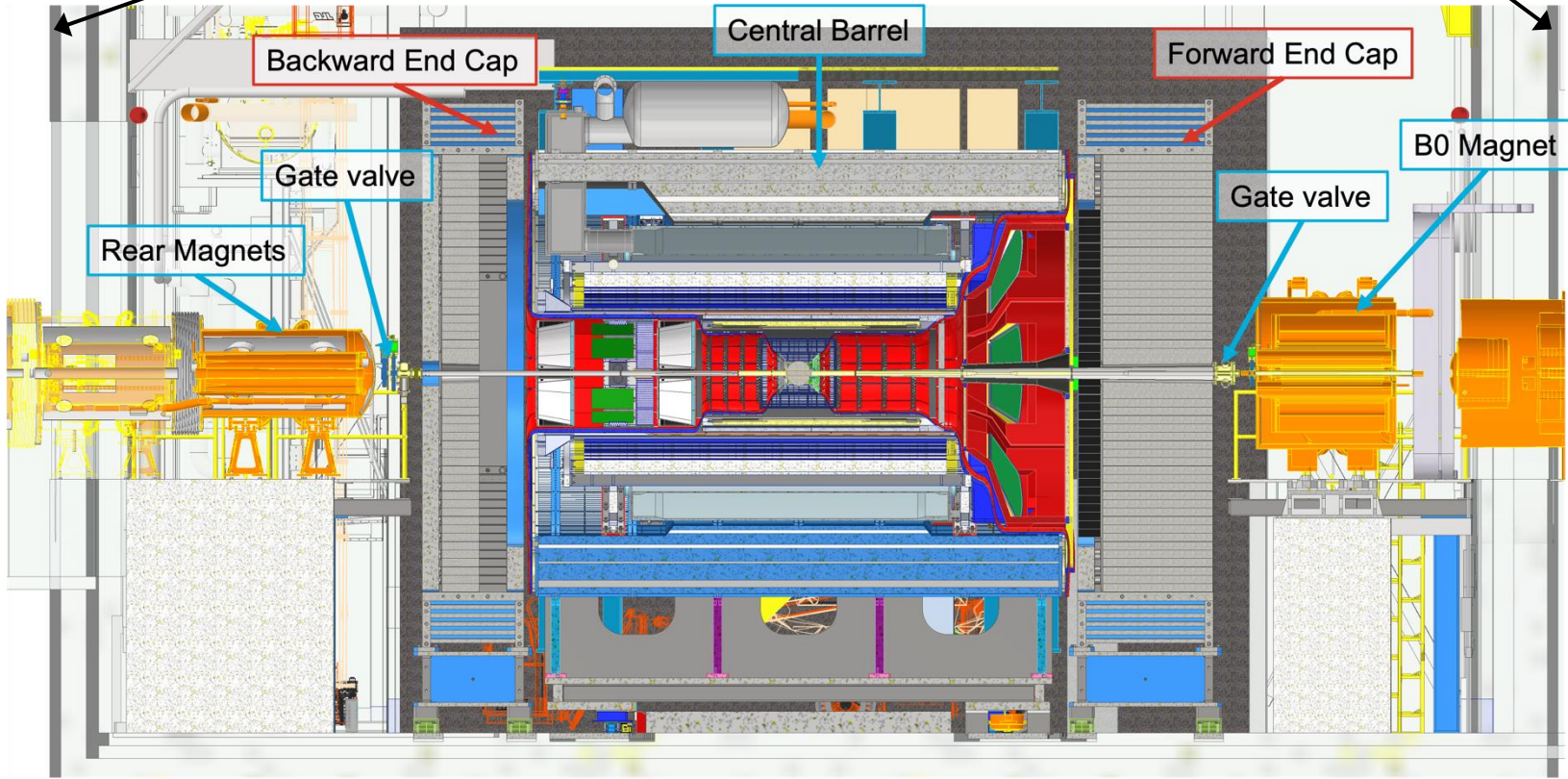
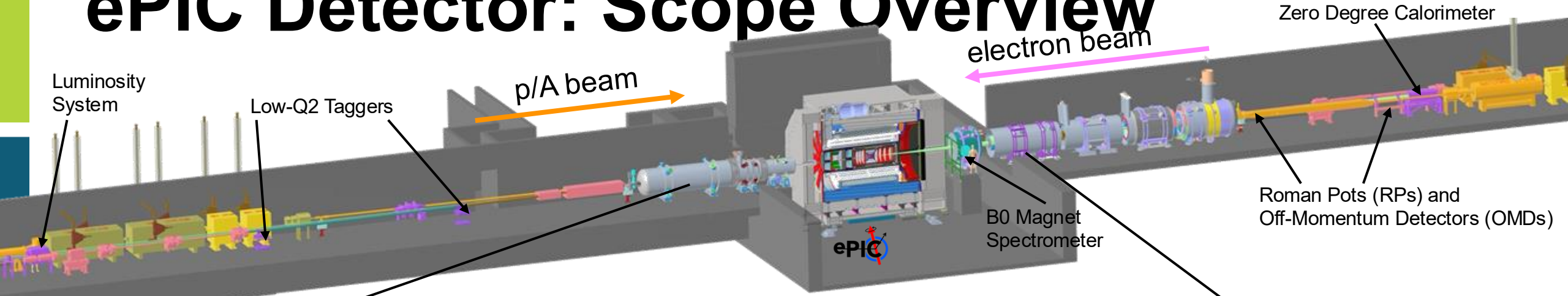
Far-Backward Detectors

- Luminosity monitor
- Low- Q^2 Tagging Detectors

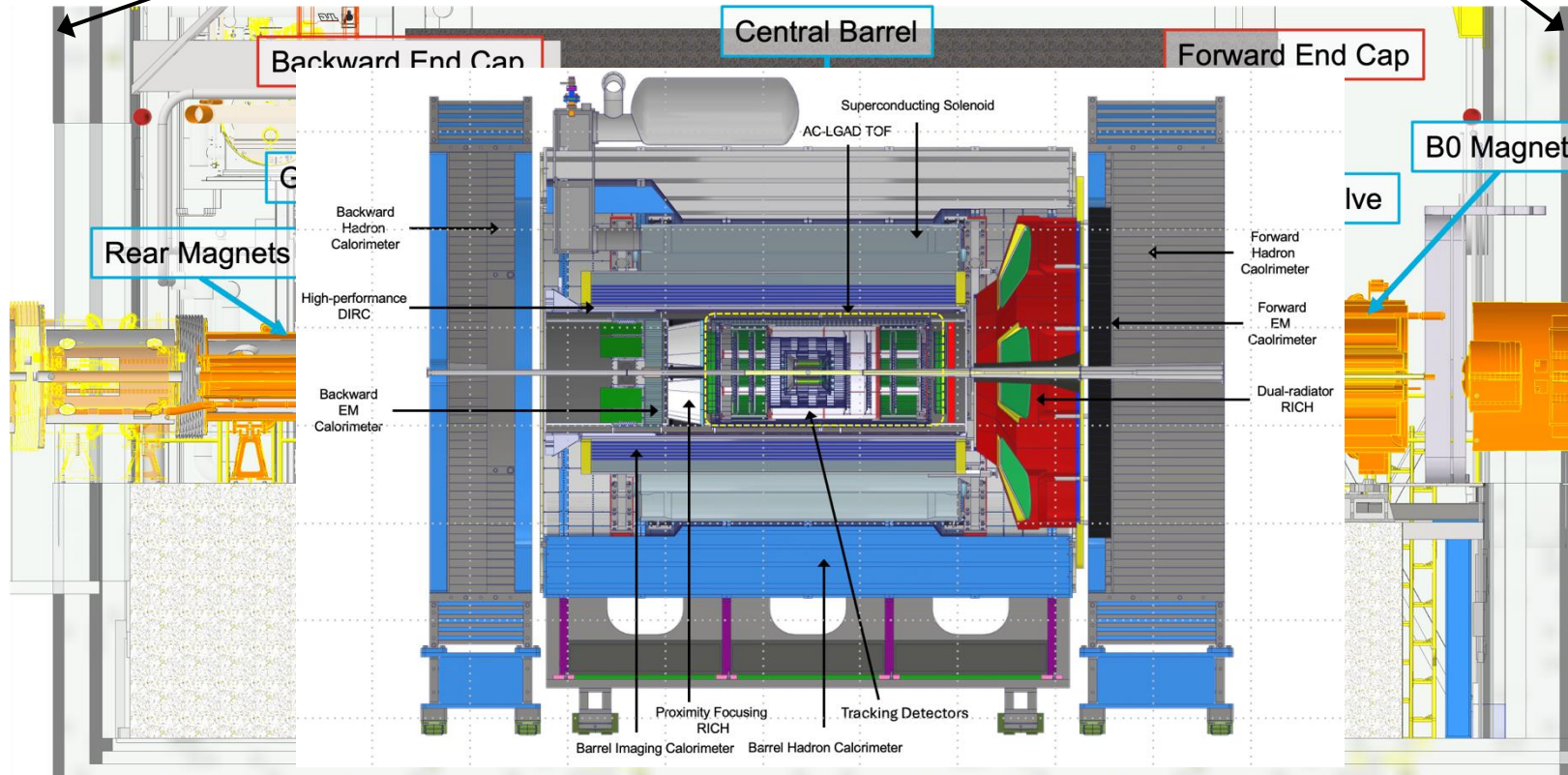
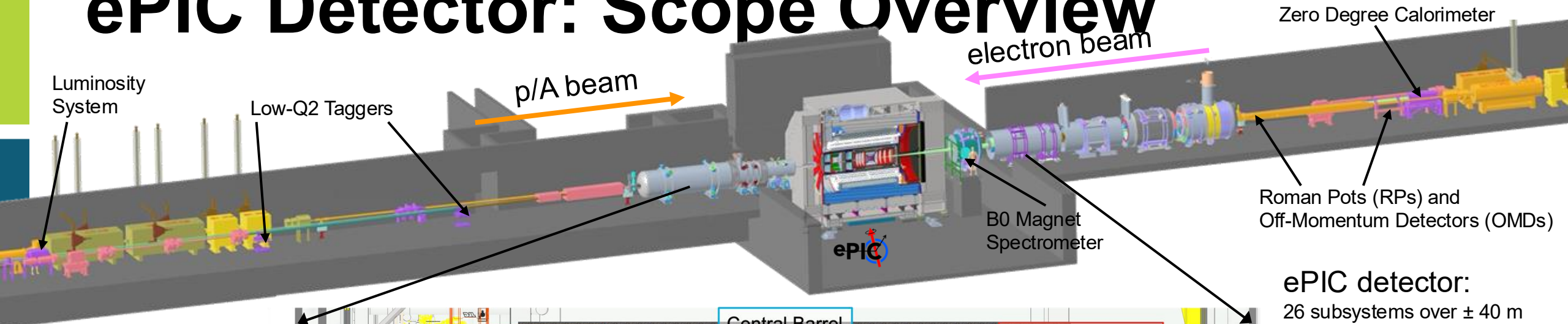
Far-Forward Detectors

- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors
- Zero-Degree Calorimeter

ePIC Detector: Scope Overview



ePIC Detector: Scope Overview



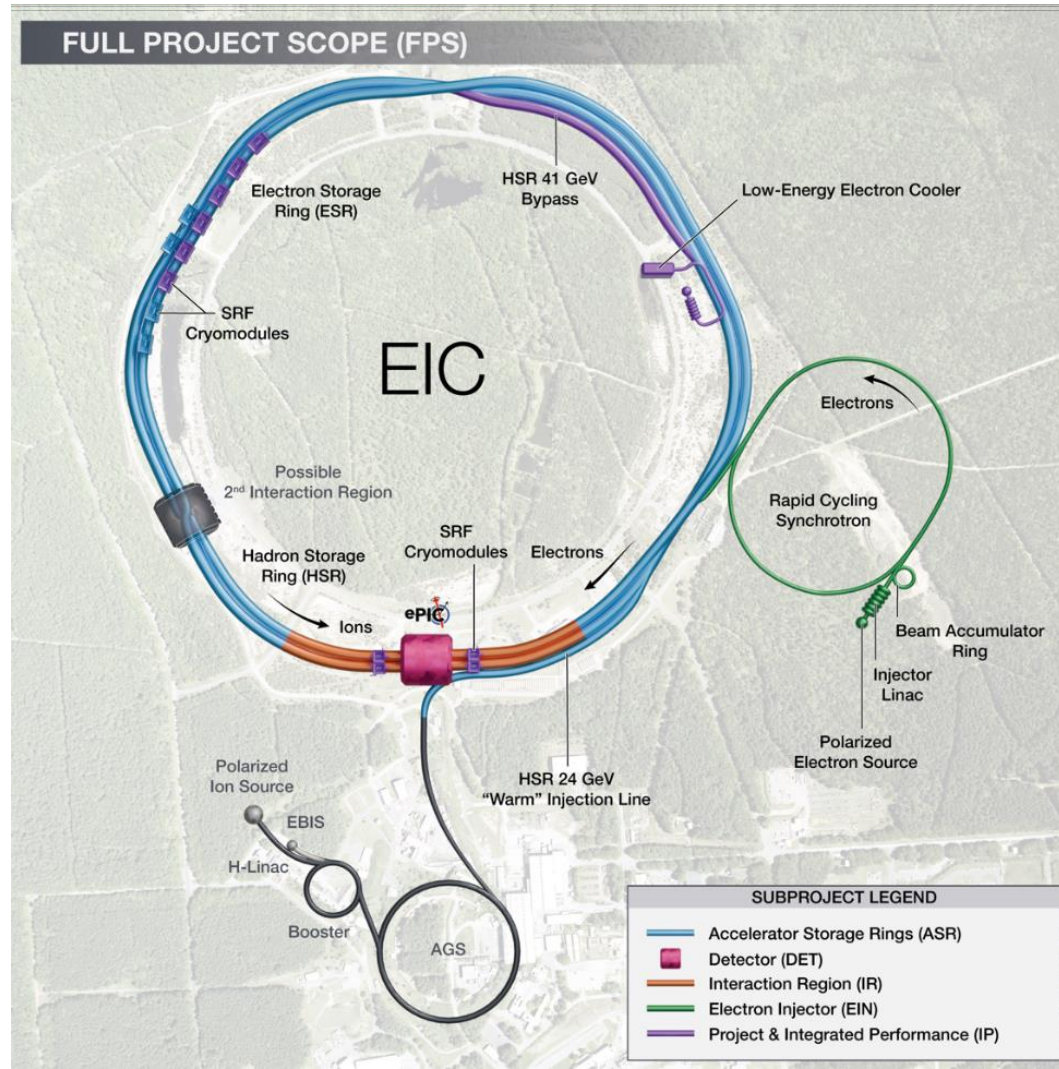
ePIC detector:

26 subsystems over ± 40 m to measure particle momenta, energy and particle type

- 3 electromagnetic calorimeters
- 3 hadronic calorimeters
- Silicon and Micro-pattern gas tracking detectors
- 3 RICH detectors + 2 time-of-flight detectors
- 7 Auxiliary detectors (Si + HCal + ECals)
- fully streaming readout electronics and DAQ
- electron and hadron polarimetry

Integration, Installation and Infrastructure
Non-Beam Commissioning

EIC Scope



EIC Scope

- A single integrated line-item construction project.
- Scope includes well-defined deliverables, interfaces, and draft Key Performance Parameters.

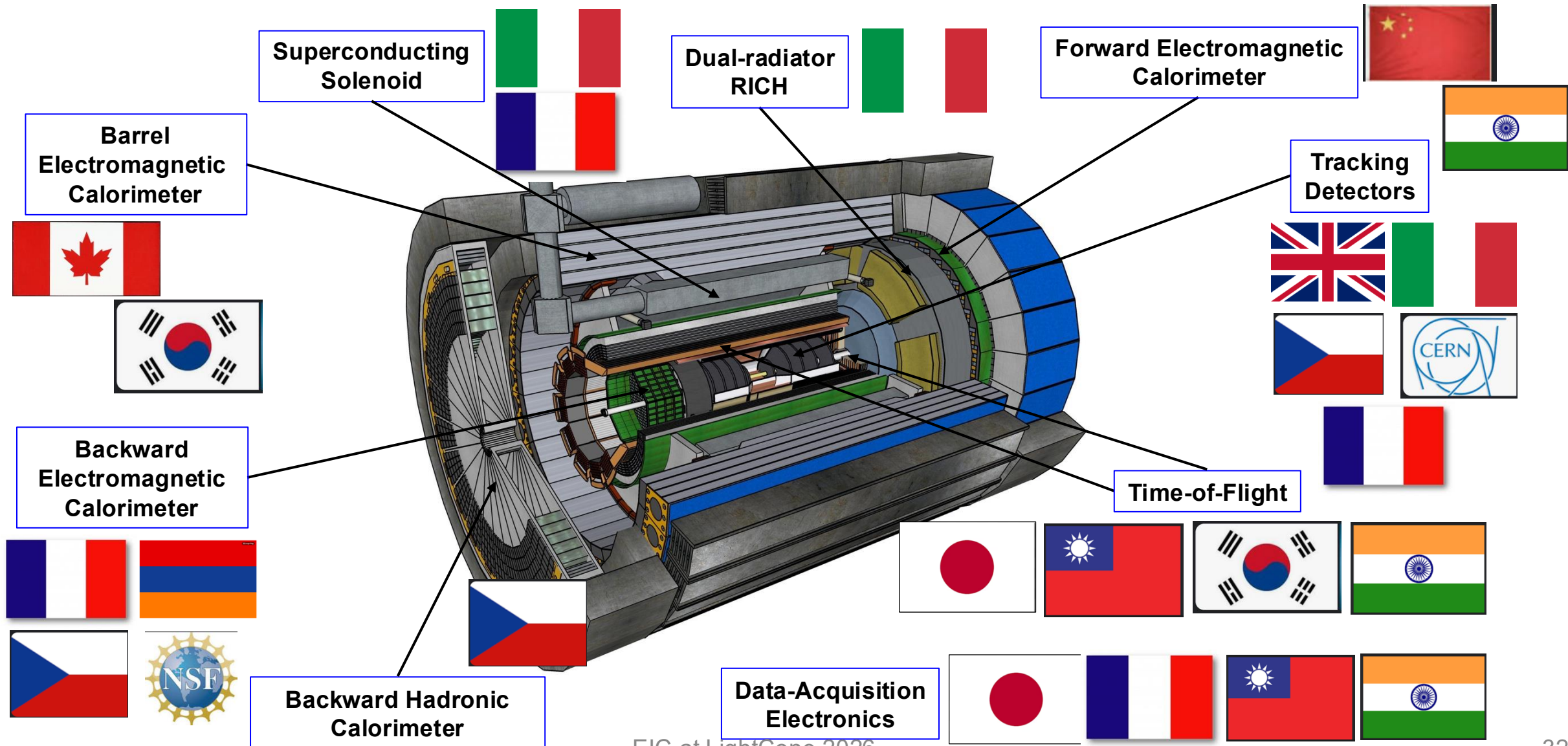
EIC Line-Item Project Scope:

- Infrastructure
- Accelerator Storage Rings (ASR)
- Interaction Region (IR)
- Electron Injector (EIN)
- Detector (DET)

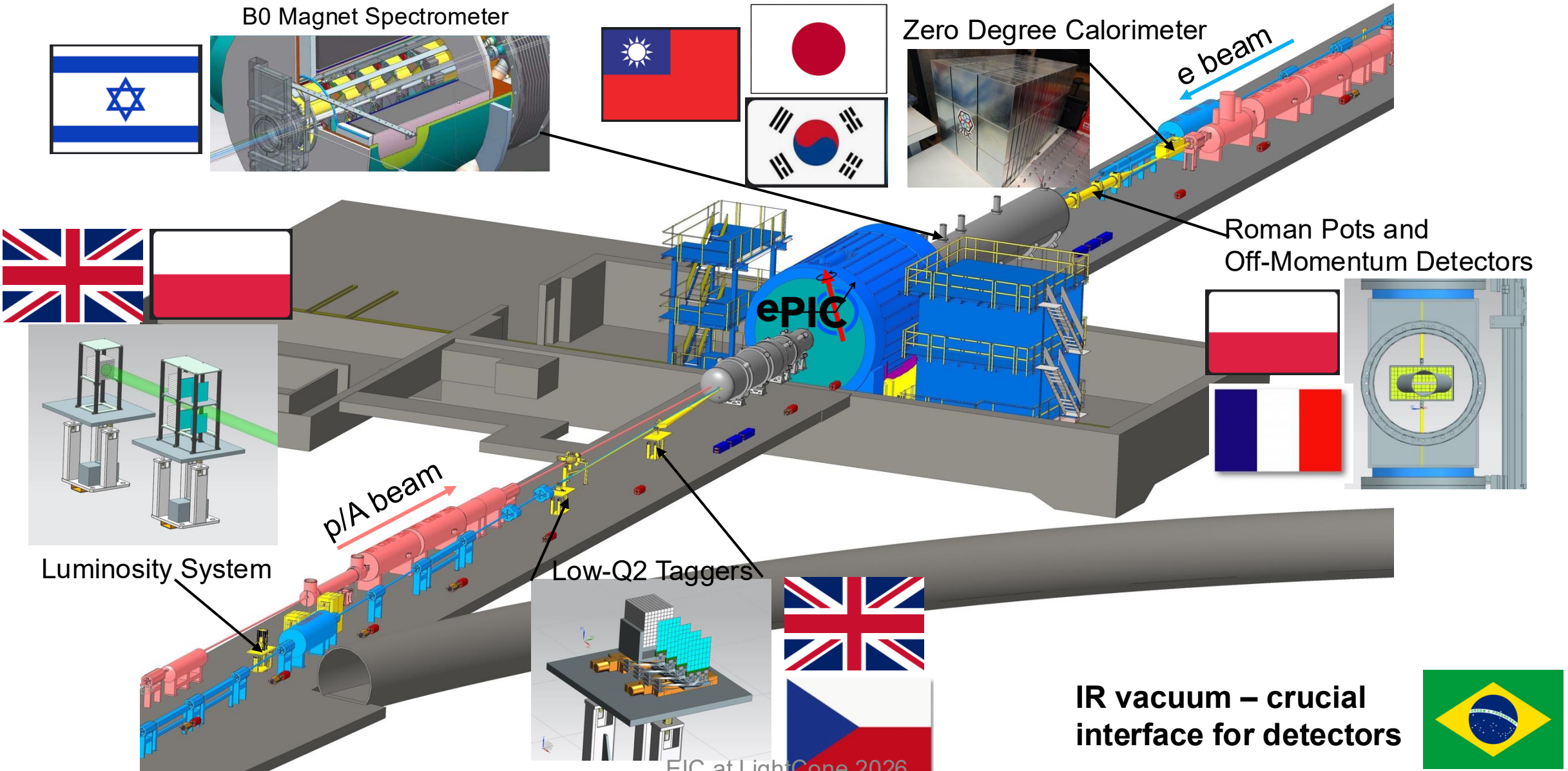
EIC Portfolio (Off-Project Scope)

- NP operations scope, including initial EIC ops
- Host Laboratory Infrastructure

Central Detector Non-DOE Interest & In-Kind



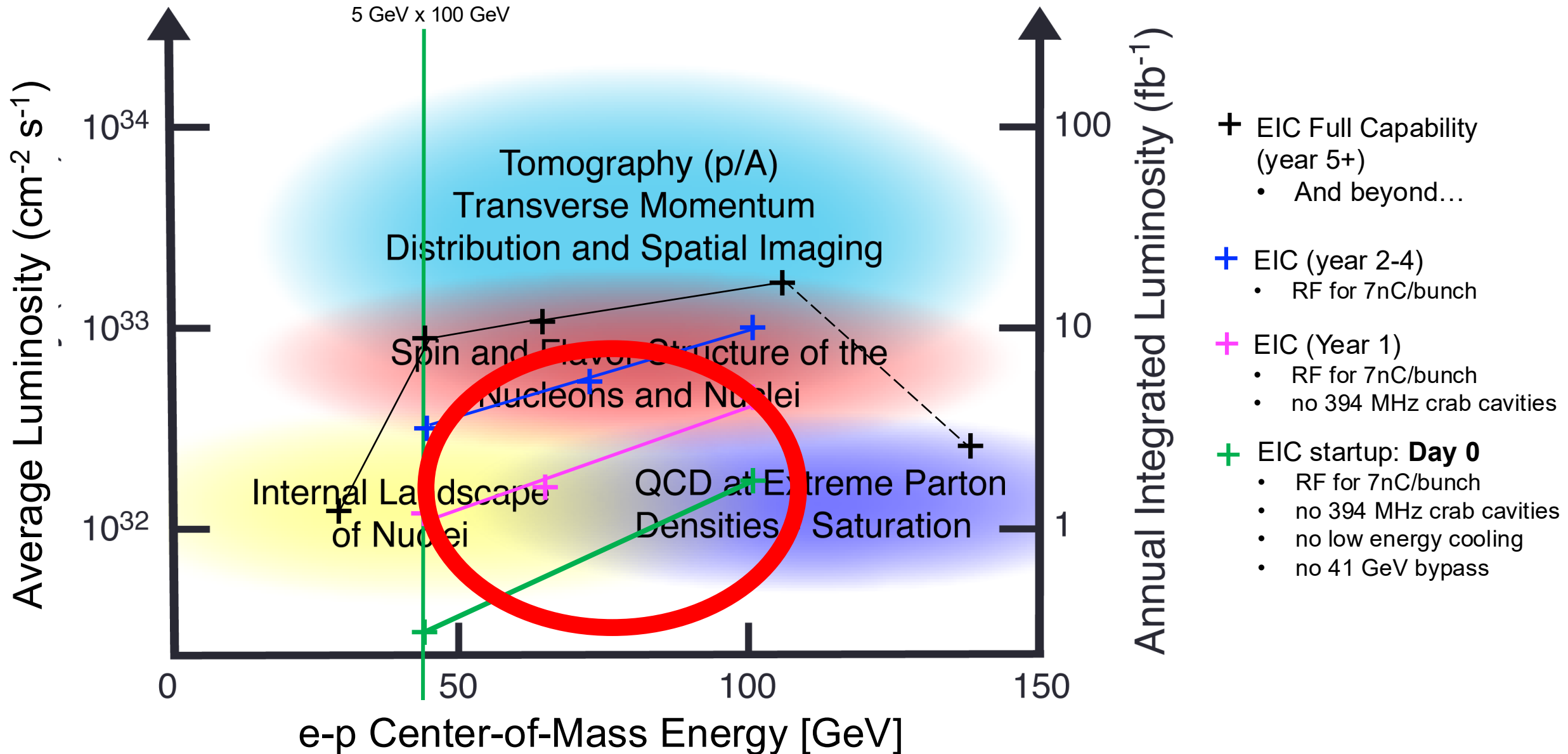
Far-Forward/Far-Backward Detectors Non-DOE Interest & In-kind



All Colliders Ramp Up

No collider turns on at the design beam parameters. The ramp up from safe set of parameters to the design parameters can take up to five years. RHIC, LHC, HERA, Tevatron, LEP – all are examples of this.

EIC Early Science [still unprecedented] → to full scope in ~5 years



- + EIC Full Capability (year 5+)
 - And beyond...
- + EIC (year 2-4)
 - RF for 7nC/bunch
- + EIC (Year 1)
 - RF for 7nC/bunch
 - no 394 MHz crab cavities
- + EIC startup: **Day 0**
 - RF for 7nC/bunch
 - no 394 MHz crab cavities
 - no low energy cooling
 - no 41 GeV bypass

EIC Science Program During Initial Operations

Year - 1	Year - 2	Year - 3	Year - 4	Year - 5
Start with Phase 1 EIC	Phase 1 EIC + long. electron polarization	Phase 1 EIC + long. electron polarization + proton polarization	Phase 1 EIC + long. electron polarization + proton polarization + spin rotators	Phase 1 EIC + long. electron polarization + proton polarization + operation of hadron spin rotators
New Capability: Commission electron polarization in parallel	New Capability: Commission proton polarization in parallel	New Capability: Commission running with hadron spin rotators	New Capability: Commission hadron accelerator to operate with not centered orbits	
Run: 9 GeV electrons on 115 GeV/u heavy ion beams (Ag, Nb, Cu, Ru)	Run: 9 GeV long. polarized electrons on 130 GeV/u Deuterium	Run: 9 GeV long. polarized electrons on 130 GeV transverse polarized protons	Run: 9 GeV long. polarized electrons on 110 GeV Au	Run: 9 GeV long. polarized electrons on 110 GeV Au
Physics: Dense Gluon Systems QCD in Nuclei	Physics: QCD in Nuclei Flavor structure of nucleons and nuclei	Physics: Flavor structure of nucleons and nuclei	Physics: Dense Gluon Systems QCD in Nuclei	Physics: Dense Gluon Systems QCD in Nuclei
	Run: Last weeks: 9 GeV long. polarized electrons and 130 GeV polarized protons	Run: Last weeks switch to longitudinal proton polarization	Run: 9 GeV long. polarized electrons on 275 GeV transverse and longitudinal polarized protons	Run: 9 GeV long. polarized electrons on 166 GeV transverse and longitudinal polarized He-3
	Physics: Flavor structure of nucleons and nuclei	Physics: Spin	Physics: Spin	Physics: Spin

Unique science questions addressed as performance ramps-up.

EIC Science Program During Initial Operations

Year - 1	Year - 2	Year - 3	Year - 4	Year - 5
Start with Phase 1 EIC	Phase 1 EIC + long. electron polarization	Phase 1 EIC + long. electron polarization + proton polarization	Phase 1 EIC + long. electron polarization + proton polarization + spin rotators	Phase 1 EIC + long. electron polarization + proton polarization + operation of hadron spin rotators
New Capability: Commission electron polarization in parallel	New Capability: Commission proton polarization in parallel	New Capability: Commission running with hadron spin rotators	New Capability: Commission hadron accelerator to operate with not centered orbits	
Run: 9 GeV elect GeV/u heav Nb, Cu, Ru)	Run:	Run:	Run:	Run:
Physics: Dense Gluo QCD in Nuc	Run: Last weeks: 9 GeV long. polarized electrons and 130 GeV polarized protons Physics: Flavor structure of nucleons and nuclei	Run: Last weeks switch to longitudinal proton polarization Physics: Spin	Run: 9 GeV long. polarized electrons on 275 GeV transverse and longitudinal polarized protons Physics: Spin	Run: 9 GeV long. polarized electrons on 166 GeV transverse and longitudinal polarized He-3 Physics: Spin

JLab Deputy Director and BNL Associate Lab Director Charged the ePIC to prepare an Early Science Planning Document. Due July 1, 2026

Unique science questions addressed as performance ramps-up.

EIC – BNL’s highest priority

Will be realized with a “Portfolio” strategy which has three parts:

- **EIC Project: EIC Construction: NP Cost objective ~\$3.0B**
 - ✓ working on preliminary performance baseline; point-estimate higher, working on further cost reduction
- **NP: Off-Project Items: “Nuclear Physics Operations”**
 - ✓ Includes RHIC data analysis, Maintaining hadron injector complex and buildings, many essential upgrades to existing infrastructure (one-time costs)
- **Other: BNL responsibility**
 - ✓ power, safety, fire protections, transportation onsite and such

Portfolio - NP Operations

NP Operations Supports

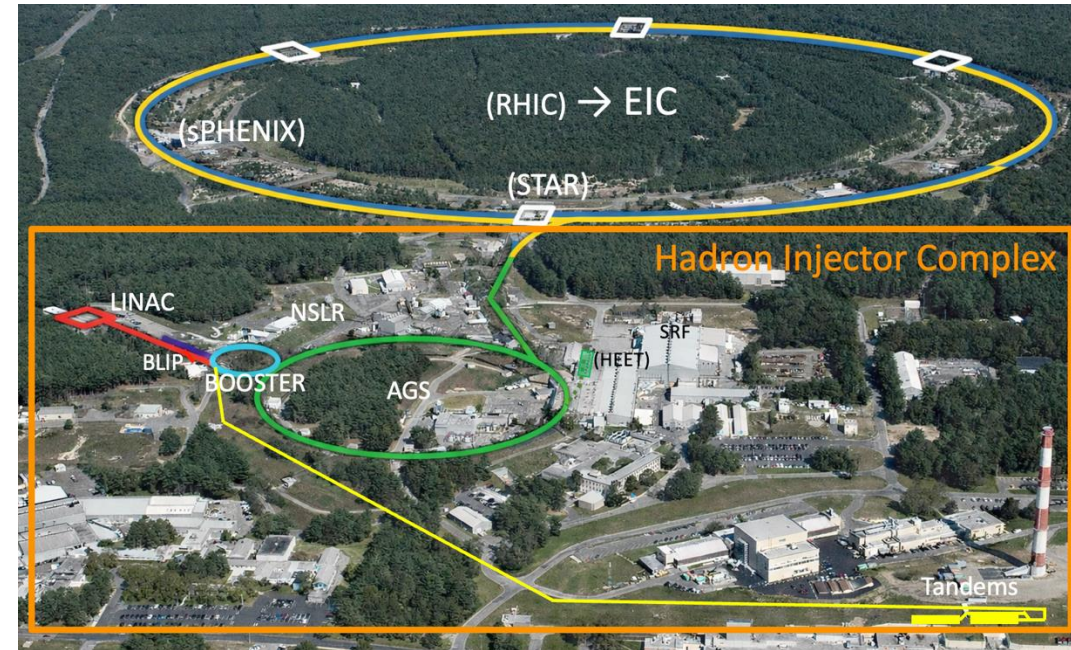
- RHIC data analysis
- Maintaining hadron injectors and infrastructure

Recurring Activities

- Provide Experimental Support => RHIC data analysis
- Maintain Hadron Injector Complex => in ready state
- Maintain Technical Infrastructure => space and shops (~100 buildings)

Time-Limited Activities

- RHIC Removals and Repurposing (R&R) : \$86M FY26-FY30+, ops with management plan
- Cryo-plant Reliability Improvements : \$30M AIP FY27+
- SRF Test Facility : \$9.6M, schedule TBD, ops with management plan
- AGS Cable and Cable Tray Replacement : >\$10M, FY26+, plan in preparation (ops and AIP)
- AGS Cooling Water System Replacement : \$9.8M, schedule TBD



Additional users of injectors pay incremental costs:

- BLIP (DOE isotope production)
- NSRL (space radiation studies)

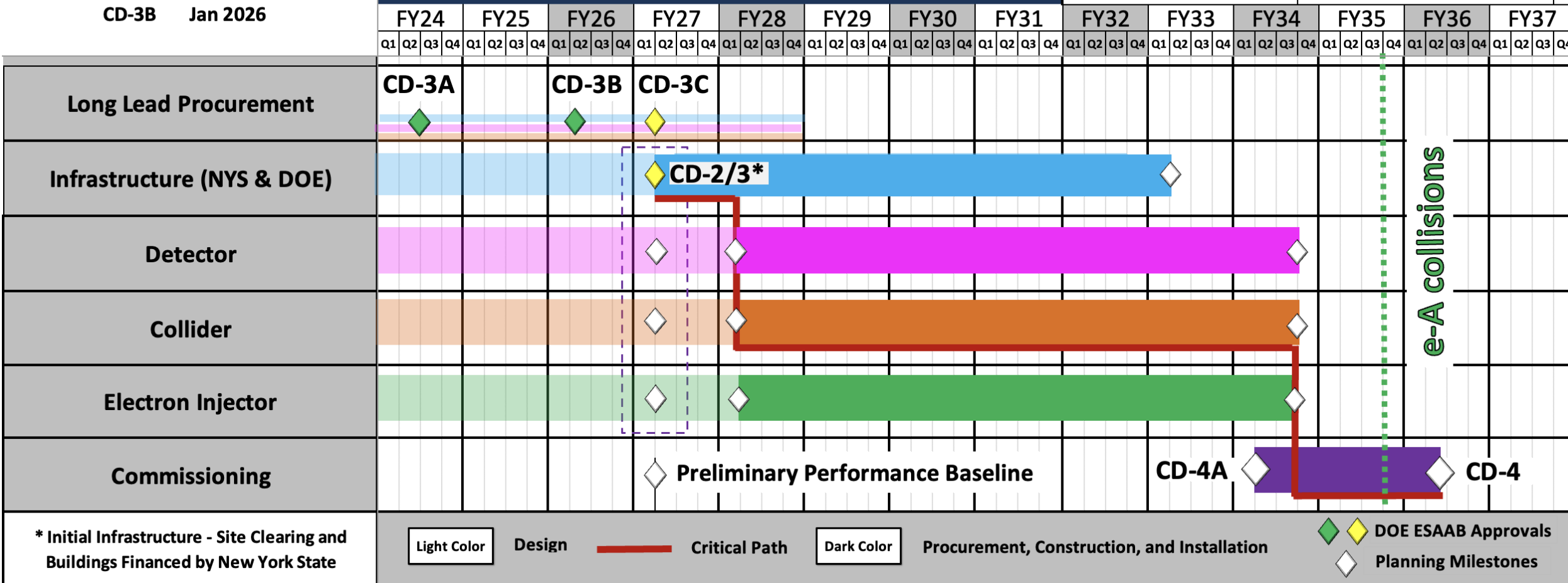
EIC Technically Driven Schedule

DOE ESAAB Approvals

- CD-1 Jun 2021
- CD-3A Mar 2024
- CD-3B Jan 2026

Electron-Ion Collider

Fiscal Year (FY) = Oct 1 - Sep 30



e-A collisions

EIC Project Status & FY27 Priorities

- The EIC project is already underway, with an estimated Total Project Cost of about **\$3.1 billion**, a **CD-3B, Long Lead Procurements, approved Jan 2026**, and roughly **\$402 million** spent so far.
- BNL using a “portfolio” strategy to plan all the activities required to ensure the EIC’s long-term success. Key activities planned for FY26–FY27 include:
 - Removal and repurpose RHIC equipment for EIC
 - New York State financed EIC buildings and infrastructure
 - Initiate EIC construction

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



Blue Ring Removal –
April 2026



Ultrasonic Tank –
Clean Room Assembly



Arrival of ANL APS &
MIT Bates Magnets



First EIC Cryostat Move on May 12

On May 12th, we reached a major milestone in starting to transform the Relativistic Heavy Ion Collider (RHIC) into the Electron-Ion Collider (EIC): moving the first cryostat.

Workers relocated the cryostat from its original location in the RHIC tunnel to a new position along the ring, where it will become part of a “bypass” in the EIC.



National and International Support

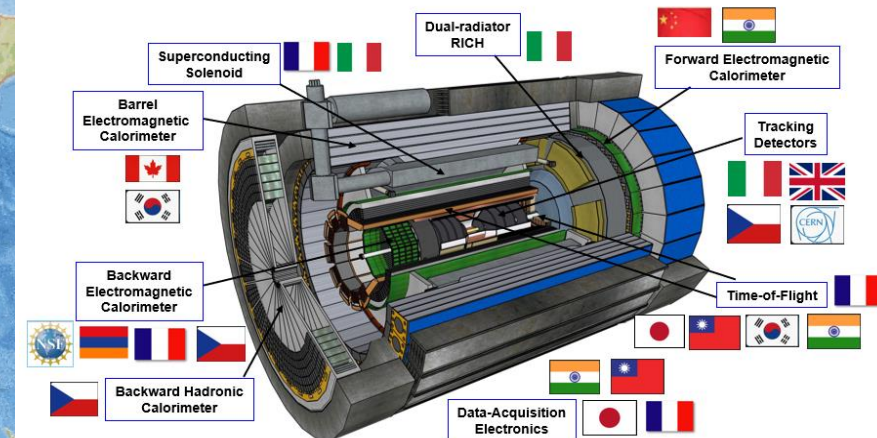
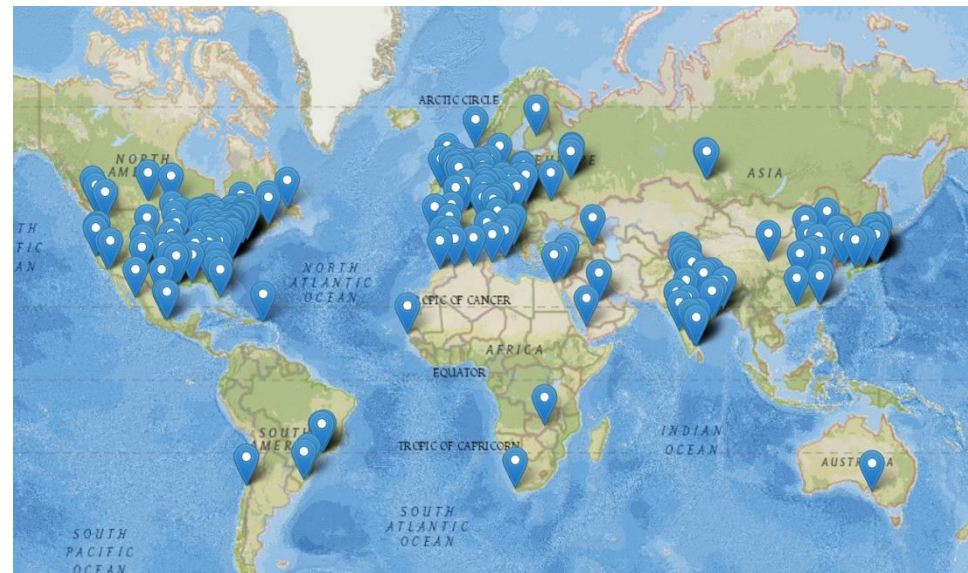
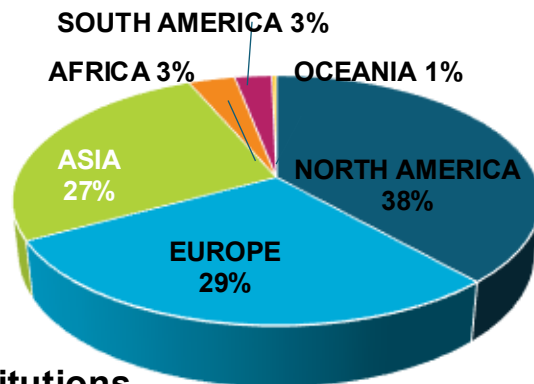
Current EIC US Partners (performing work and/or providing materials)

- Eight DOE Labs
- 22 universities

EIC Collaborators (developing experiments, contributing expertise)

- EIC User Group: 1,558 members -- and growing
- 907 institutions worldwide (41 countries)
- 80+ U.S. universities

Department of Energy Lab Partners



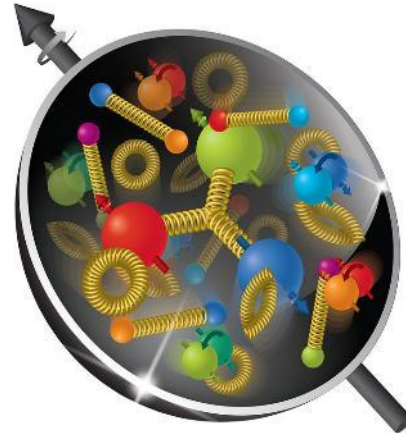
Institutions

The EIC design and construction has many scientific and technical challenges, creating opportunities for a worldwide collaboration to become part of this exciting endeavor.

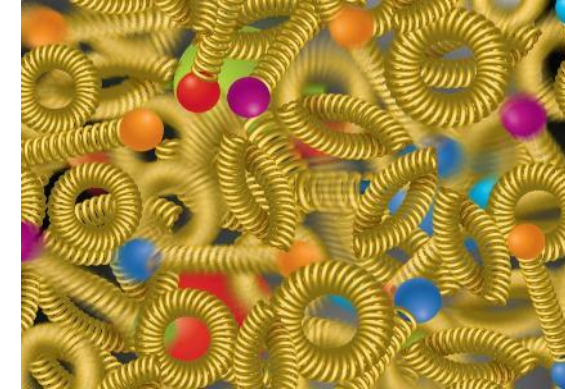
EIC Science Community



Origin of Mass



Origin of Spin



Discovery & investigation of dense gluonic matter in nuclei

Initial State of heavy ion collisions at RHIC and LHC: of primary interest to the Hot QCD Community at BNL/RHIC and CERN/LHC

Investigations carried out by Cold QCD community
Jefferson Lab/CEBAF and BNL/RHIC

EIC brings the two – Cold & Hot QCD communities together

Early career scientists trained at Jefferson Lab (cold QCD), BNL (cold and hot QCD) and at CERN (cold and hot QCD) are joining the EIC physics program and will be the future leaders at the EIC

EIC Partner Highlights

- **New York State** committed **\$100M** toward construction of buildings and infrastructure for the EIC.
- **In-kind contributions** developing with **Canada, France, Italy, and Japan**.
- **Statements of Interest** signed between DOE and **French** agencies.
- **EIC Accelerator Collaboration Kick-Off at IPAC'24**, Satellite Meeting held at IPAC'25 in Taiwan garnering growing interest.



- **5th EIC Resource Review Board Meeting** held in Prague in June 2025.
- **7th RRB @ MEXT Japan, June 9,10, 2026**; Strong support from **Canada, Czech Republic, France, Italy, Japan, South Korea, and Taiwan**.

In-kind contribution goals represent 30% of the Detector and 5% of the Accelerator

EIC Outlook

- Exciting time for EIC as we move into construction!
- Momentum is building with significant technical progress in the tunnel
- Good progress preparing the preliminary performance baseline, cost remains a major focus, and we will have the tool to manage cost
- Preparing for a DOE comprehensive Independent Project Review in September for CD2 approval soon after (~2027)
- Science is unmatched, and connections to other fields of science emergent.
- EIC is the only new collider being built in the world... with innovative accelerator and detector technologies and highly impactful physics, with synergies with future collider concepts ideas like FCCee and its detector(s).



Backups

EIC Science Pillars



How do quarks, gluons, and orbital angular momentum contribute to proton spin?

Spin is a fundamental property of matter. All elementary particles but Higgs carry spin.

Spin of composite particles such as the proton cannot be explained by a static picture but are caused by the **interplay of properties and interactions of quarks and gluons inside.**

SPIN

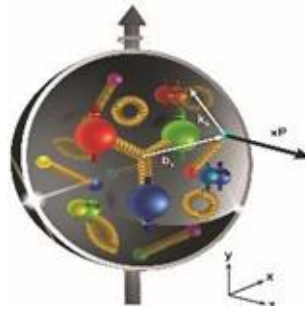


Does the mass of visible matter emerge from quark-gluon interactions?

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

The EIC will determine an important term contributing to the **proton mass**, the so-called QCD trace anomaly.

MASS



How are quarks and gluons distributed in space and momentum inside the nucleon & nuclei?

How do the nucleon properties **emerge from them and their interactions?**

How can we understand their **dynamical origin in QCD?**

What is the relation to **Confinement?**

3D-Imaging



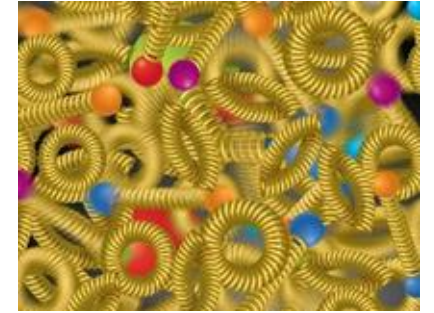
How do the confined hadronic states emerge from quarks and gluons?

Is the structure of a **free and bound** nucleon the same?

How do quarks and gluons **interact with a nuclear medium?**

How do the quark-gluon interactions **create nuclear binding?**

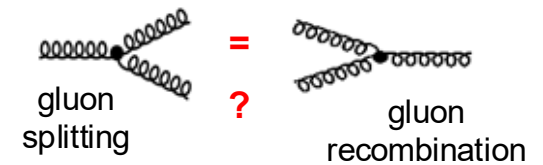
QCD in Nuclei



Does gluon density in nuclei saturate at high energy?

How many gluons can fit in a proton?

How does a **dense nuclear environment affect** the quarks and gluons, their correlations and interactions?



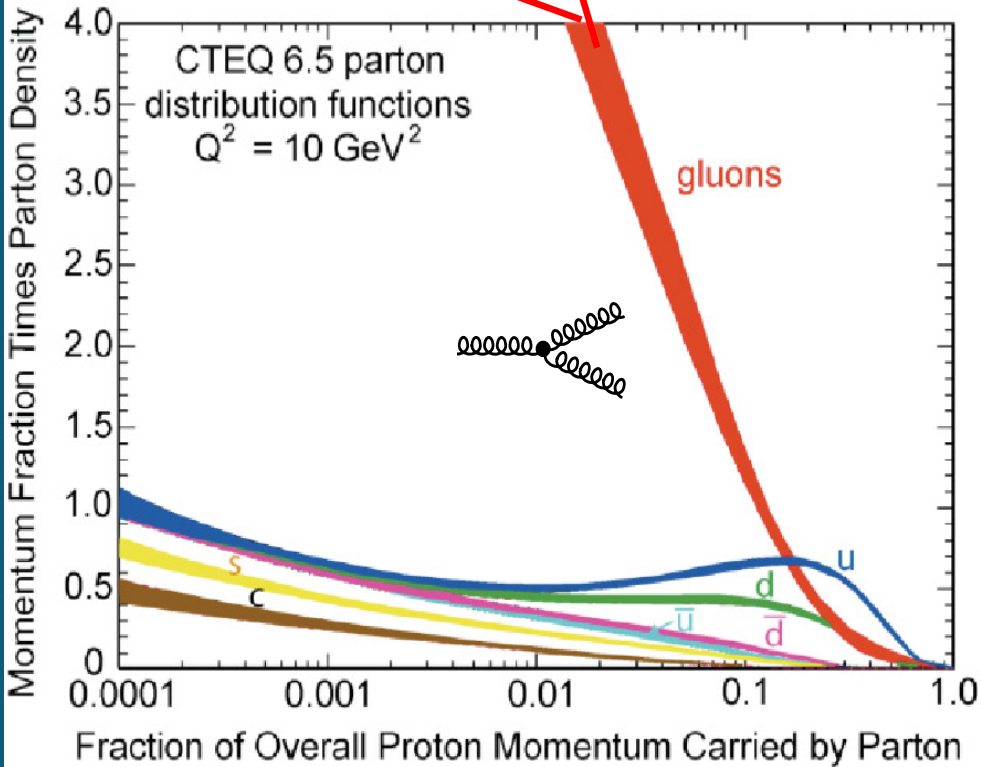
Dense Gluon Systems

(National Academies of Sciences, Medicine, and Engineering, 2018 Consensus Study Report)



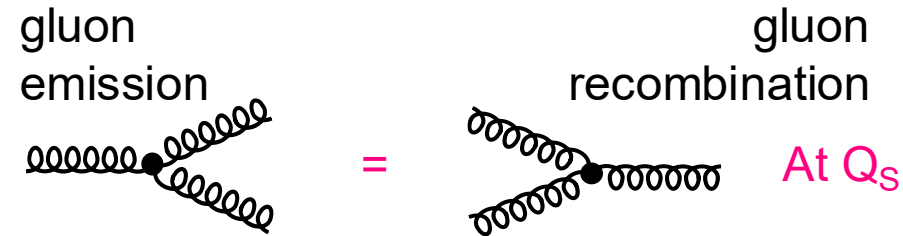
In search of a new state of matter!

?



What could tame the low-x rise?
Can EIC access this region?

QCD inherently has the needed mechanism for this taming but we don't know when it gets triggered.



Observation of gluon recombination effects

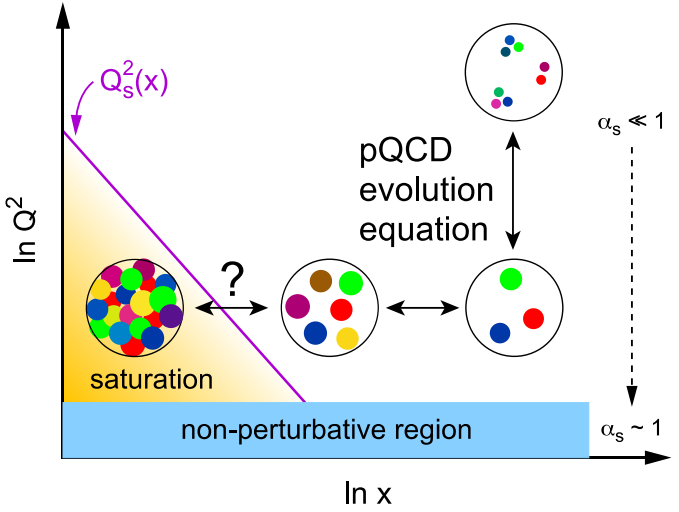
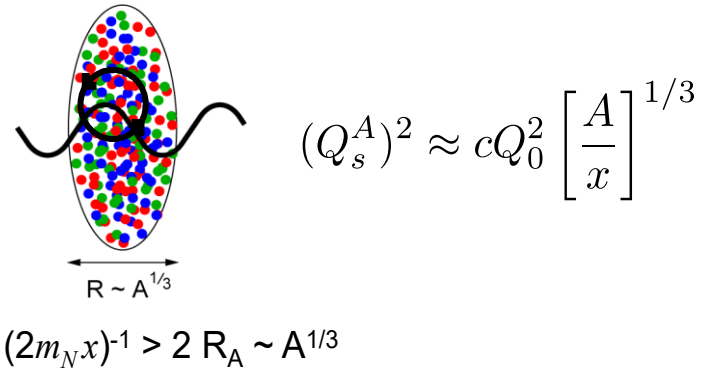
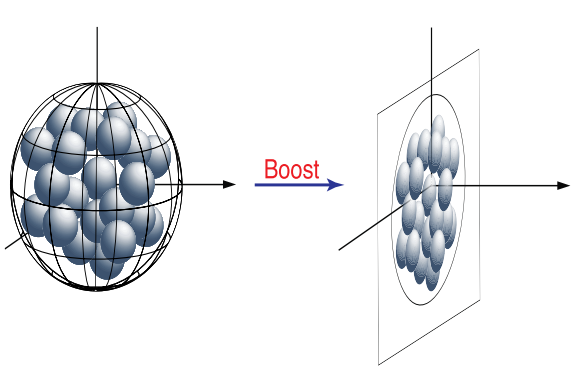
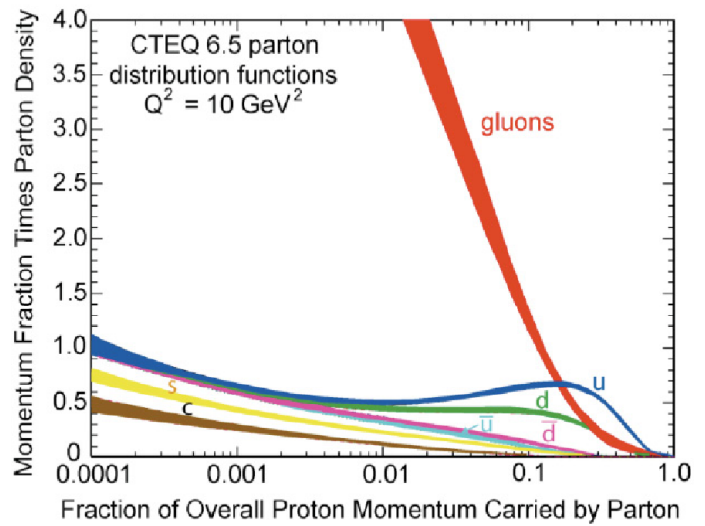
→ Is there such new state of matter?

→ “Color Glass Condensate”

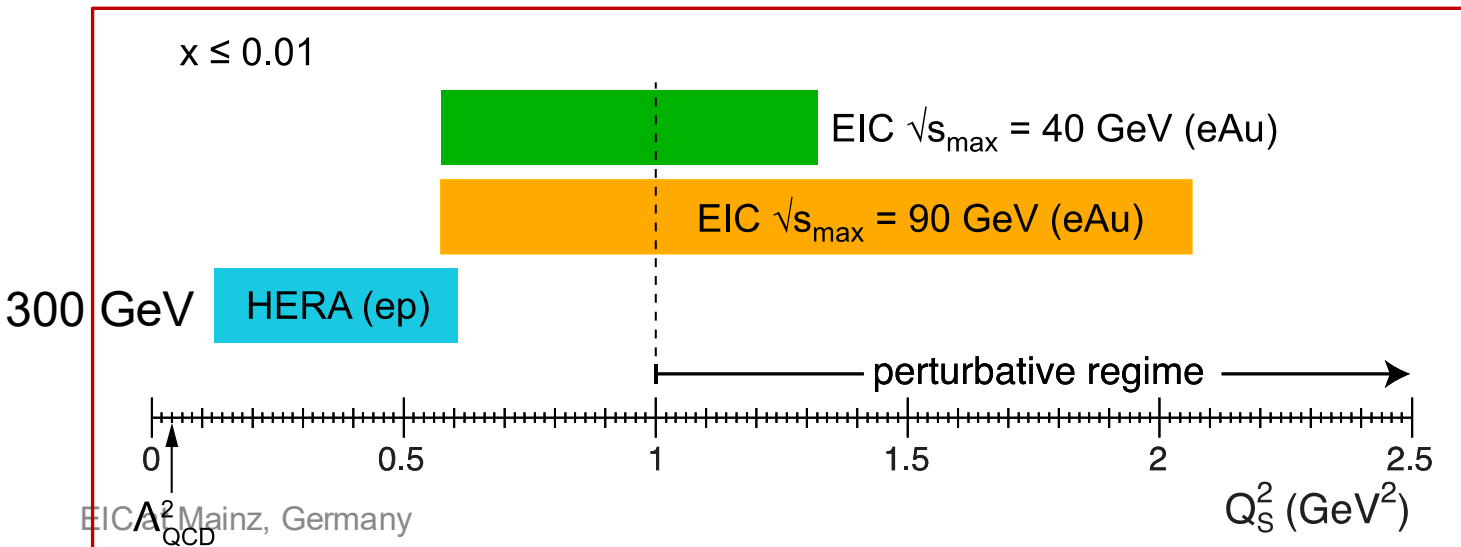
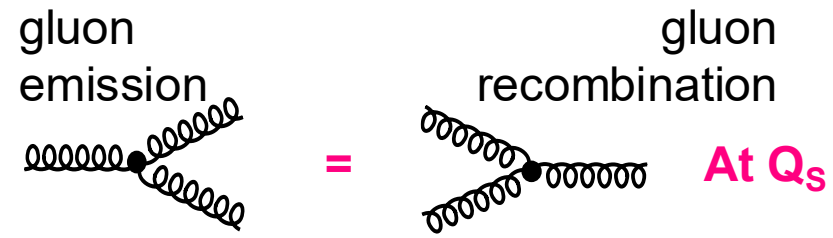
→ 50-100 times higher energy density than the core of the neutron star

Experimental evidence needed

Low x physics with nuclei



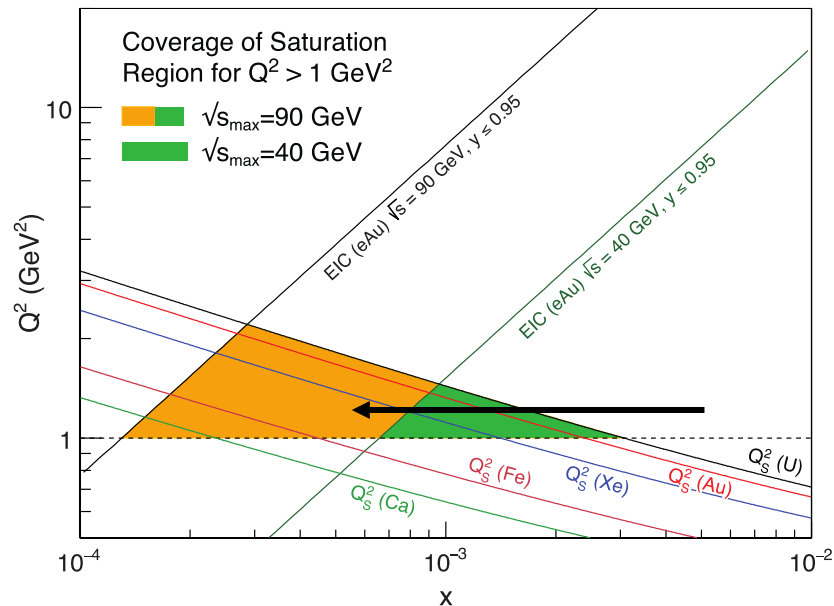
Accessible range of saturation scale Q_s^2 at the EIC with e+A collisions.
 arXiv:1708.01527



Can EIC discover a new state of matter?

EIC provides an absolutely unique opportunity to have very high gluon densities
 → electron – lead collisions
 combined with an unambiguous observable

EIC will allow to unambiguously map the transition from a non-saturated to saturated regime

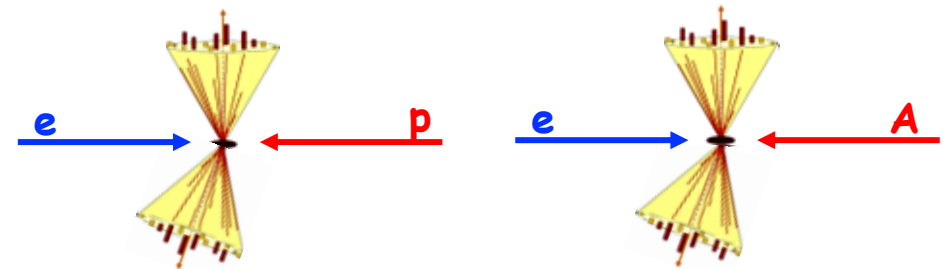


EIC at Mainz, Germany

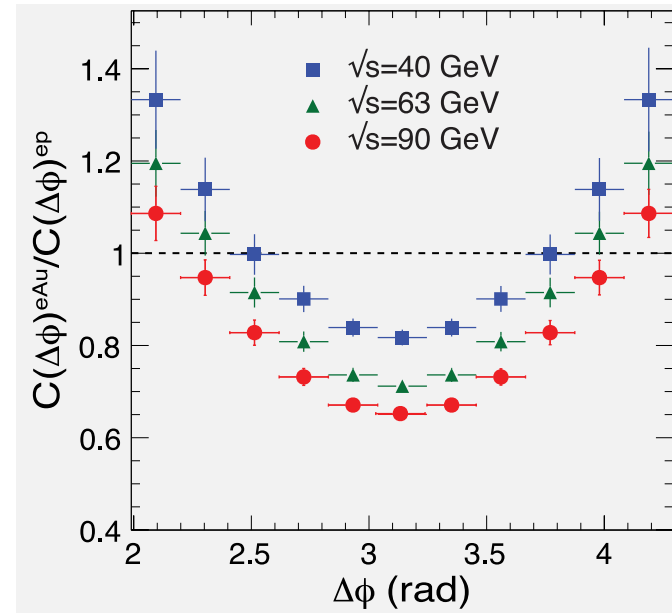
counting experiment of Di-jets in ep and eA

Saturation:

Disappearance of backward jet in eA



#backward jets in eA / ep



Nature does not distinguish between Nuclear Physics, High Energy Physics....

Humans do, for funding... but that too is changing. Offices of Nuclear and High Energy Physics have merged at the DOE. Opportunity?

Broader implications: connections to other fields

High Energy Physics, Condense Matter Physics and Gravity

Some connections established, some emergent

A special relation with HEP (ATLAS, CMS, ALICE and LHCb)

Detector & Accelerator Technology needs drive many R&D projects together

High mobility of early career scientists from HEP to NP (RHIC, [LHC](#) and now [EIC](#))

Connections and implications to High Energy Physics

Of HEP/LHC-HI interest to Snowmass 2021 (EF 05, 06, and 07 and possibly also EF 04)

LHC – EIC Synergies workshops in Europe

Ssee CFNS workshop: [QCD@LHC 2025 @ Stony Brook](#) – September 2025

See also [BNL Workshop on HEP-EIC connections](#) November 2024

Impact of precision SM measurements on search for BSM

- ❖ Precision calculation of α_S : higher order pQCD calculations, twist 3
- ❖ Precision measurements of unpolarized PDFs at high x/Q^2 , impact on LHC-Upgrade results

Precision electroweak and BSM physics: LHC – EIC Synergies –

- SM Effective Field Theory analyses: Connecting precision collider low-energy and electroweak data to probe Beyond Standard Model (BSM) physics.
- Searches for weak mixing angle variations, chiral structure in weak currents, charged lepton flavor violation (CLFV), sterile neutrinos, dark photons, and axion-like particles (ALPs).

Synergies between R&D for FCC/ee and EIC: accelerators & detector

New Physics Opportunities at the EIC – SMEFT, Precision Couplings, and BSM Searches

Key Themes of the Workshop at CFNS/Stony Brook

- SMEFT analyses: Connecting precision collider low-energy and electroweak data to probe Beyond Standard Model (BSM) physics.
- Searches for weak mixing angle variations, chiral structure in weak currents, charged lepton flavor violation (CLFV), sterile neutrinos, dark photons, and axion-like particles (ALPs).
- **SMEFT at the EIC and other discussions:**
 - LHC measurements are largely Standard Model (SM)-like; limits push new physics to above 1 TeV.
 - SMEFT provides a unifying framework to globally combine top, Higgs, diboson, EWPO, and flavor data. (S. Dawson)
 - Low-energy measurements (like Parity-Violating Electron Scattering, PVDIS) at the EIC can help disentangle dimension-6 from dimension-8 operators and break degeneracies missed by high-energy LHC data. (Vincenzo Cirigliano, Susan Gardner)
- **Precision Couplings:**
 - EIC can approach $\sim 0.1\%$ precision on the weak mixing angle. (Nycz, EIC White Paper)
 - Light quark electroweak couplings and α_s (the strong force constant) can be improved, contributing uniquely to global SM fits. (Kutz, Demiroglu)

Experimental Searches – CLFV, Sterile Neutrinos, Dark Photons & ALPs at the EIC

- **Charged Lepton Flavor Violation (CLFV):** (Fuyuto, Nycz, Furlatova)
 - EIC is competitive for certain CLFV operators, especially those involving third-generation.
 - Detector studies use advanced techniques (vertex tracking, tau/muon tagging) for signal-background separation in rare decays (e.g., $e \rightarrow \tau X$).
 - Preliminary simulations show EIC sensitivity could rival or complement low-energy and LHC bounds for certain scenarios.
- **Sterile Neutrinos:** (Sebastian U. Quiroga)
 - Studies consider lepton-number-violating (LNV) processes like $e^-p \rightarrow \nu jjj$, targeting sterile neutrino masses up to ~ 100 GeV.
 - Projected EIC exclusions at 95% C.L. can significantly improve for both $e\nu$ and $\mu\nu$ sectors—competitive with other collider and low-energy probes.
- **Dark Photon & Axion-like Particle (ALP) Searches:** (H. Davoudiasl, E. Niel, S. Gardner)
 - EIC enables unique searches in coherent heavy-ion scattering, leveraging large Z^2 enhancements.
 - Projected sensitivity contours competitive with and complementary to Belle II, LHC, and rare decay experiments.
 - Enhanced sensitivity for displaced decays and lepton-flavor-violating ALP final states.

Color Glass Condensate in QCD \leftrightarrow Condensed Matter Systems

The connection lies in their shared concepts of collective behavior, phase transitions, and emergent properties in many-body systems governed by quantum field theory

- ❖ **Collective Phenomena** Both CGC and condensed matter systems involve large ensembles of particles (gluons in CGC; electrons, atoms in condensed matter), leading to emergent macroscopic properties not evident at the single-particle level.
 - ❖ **Disorder and 'Glass' Analogy:** The term "glass" in CGC draws from disordered solids, as both CGC gluons and glassy matter exhibit slow relaxation and nontrivial temporal evolution.
 - ❖ **Phase Transitions:** The saturation of gluon density in CGC is conceptually similar to phase transitions (e.g., condensation, glass formation) seen in condensed matter, with universal scaling laws and critical phenomena.
- Theoretical Techniques:** used in condensed matter, such as effective field theories, renormalization group, and nonlinear dynamics, are directly applied to understand CGC.
- **Universal Principles:** Both fields reveal universal organizing principles—such as entropy limits, information packing, and thermalization—that connect subatomic (CGC) to macroscopic (condensed matter) systems.

This interplay enriches both fields, allowing powerful condensed matter concepts and tools to explain the rich dynamics and emergent phases in high-energy QCD, such as the CGC

CGC in QCD \leftrightarrow Black Holes in Gravity

Deep mathematical Analogies:

Both CGC in QCD and black holes (=gravitational shockwaves) in gravity emerge as macroscopic, highly entropic condensates of "weakly interacting" gauge bosons—gluons in QCD, gravitons in gravity

- ❖ **Both are Condensates:** A black hole can be described as a condensate of many soft gravitons, similar to the CGC as a condensate of gluons at small- x in QCD. Both reach a maximal entropy proportional to an area measured in units of the respective strong interaction scale: *Planck scale* [in gravity] and the *saturation scale* [in CGC/QCD].
- ❖ **Both saturate entropy and information:** Black holes and CGC systems both saturate universal entropy bounds and share features of maximal information packing—leading to analogies between Bekenstein-Hawking *black hole entropy* and *entropy in the CGC*
- ❖ **Thermalization and Quantum Information:** Transition from CGC to QGP in heavy-ion collisions is likened to black hole formation and evaporation. Both processes provide insight into scrambling of quantum information and thermalization in a highly occupied quantum state.
- ❖ **Holography and Duality:** AdS/CFT and gauge/gravity duality frameworks actively aim to use geometric models (gravity) to describe strongly coupled quantum gauge theories like QCD and CGC.

The CGC–gravity correspondence uncovers similarities in the QCD dynamics & gravity, and helps transfer computational & conceptual tools across these fields enriching the study of universal quantum phenomena

Early science and evolution

Project and ePIC Collaboration will work out the details, but dictated by accelerator needs and safety considerations

A guiding principle: Each of the early years should bring in some new machine component or capability that allows new physics to begin.

Year 1: 9 GeV electrons x 115 GeV/u heavy ion beams (Ru or Cu)

- Highest early energy of electron (with polarization setup requirements)
- Choice of Heavy dictated by the beam path centered in the magnet
- Unprecedented nuclear DIS at the highest energy could begin

Years 2 and beyond....

Year 2: Commission proton polarization, improve e-polarization

- 9 GeV polarized electrons x 130 GeV/u Deuterons
- 9 GeV polarized electrons x 130 GeV/u transverse polarized protons
- D-PDFs, transverse momentum distributions in protons

Year 3: Commission hadron spin rotators: longitudinal proton polarization

- Possibility to have polarized e on transverse and longitudinal polarized protons
- Longitudinal spin structure of proton, Delta-G, from scaling violations, jets, α_s

Year 4: Commission hadron ring for non-centered nuclei

- 9 GeV electrons on 110 GeV/u Au and any other nucleus if Au succeeds
- 9 GeV polarized e on 275 GeV polarized protons (transverse & longitudinal)

Years 5 and beyond....

Year 5: Commission polarized 166 GeV He-3

- First measurements of neutron spin structure function, first Bjorken
- Any e-A collision

Years 5+: Add additional RF power etc. to reach the 18 GeV for e to reach 140 GeV in e-p Center of Mass.

Year 6: Commission ESR and HSR for max energy and beam currents

- Possible 18 GeV polarized e on 275 GeV polarized protons

Year 7: introduce and commission 41 GeV by pass

- Possible 5 GeV e x 41 GeV transverse polarized protons

Comment on the selection of beam parameters:

Beam parameter dictated by the desire to have safe early operation, while accelerator operators learn to run a high current machine

Low luminosity earlier, beams easiest to center in beam pipe minimal energy variations etc. all stem from the safety considerations both for the machine elements and the detector elements (particularly those closest to the beam)

I still feel giving us a possibility of having one new experimental feature every year would enable exciting physics every year in the first few years (and later, when maximum parameters are realized)