Introducing the ePIC Experiment: Exploring Use Cases and Workflows

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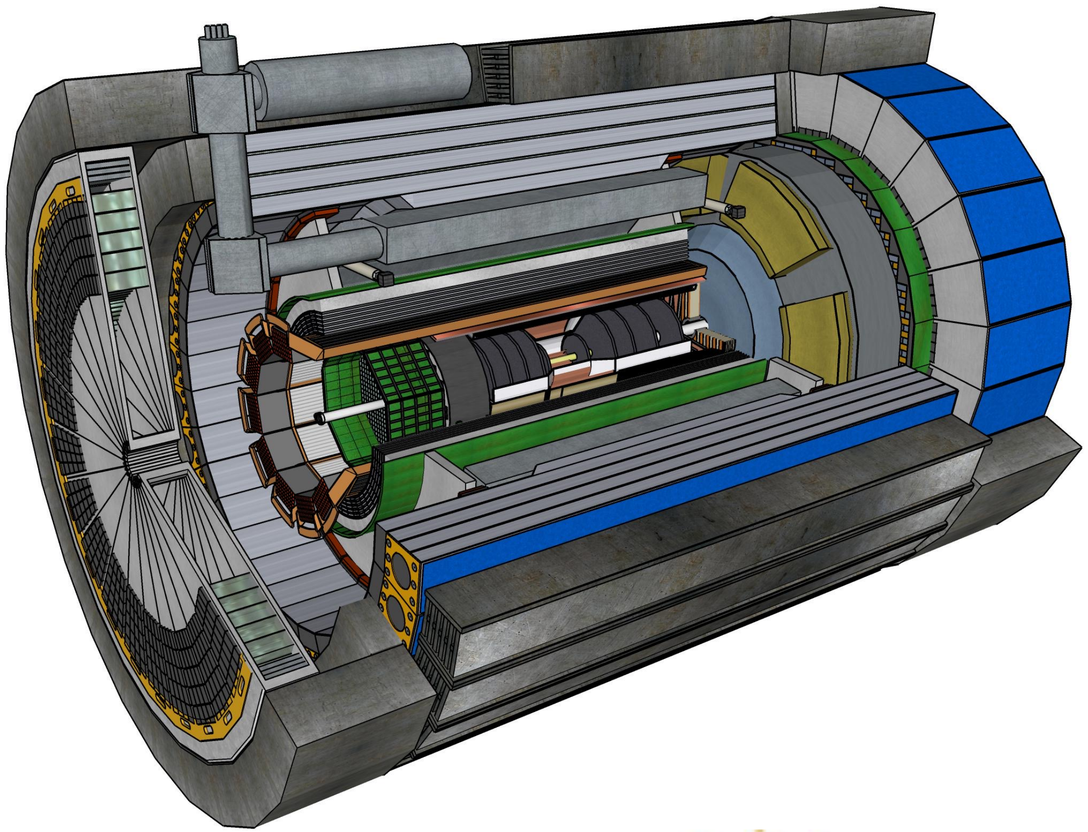


Review of ePIC Software & Computing

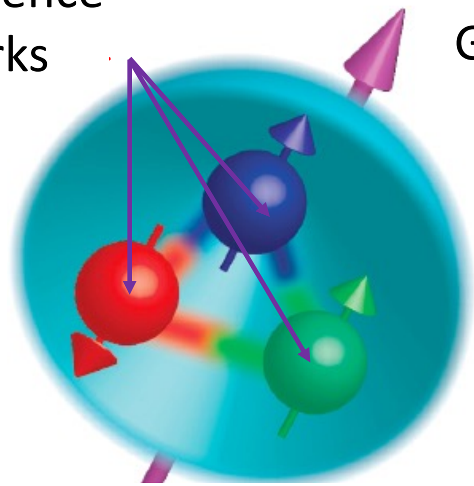
Quantum Chromodynamics and Nuclear Matter

The study of Nuclear Physics is the quest to understand the origin, evolution, and structure of the matter of the universe

- How do the **properties of the proton** such as **mass** and **spin** emerge from the sea of quarks, gluons, and their underlying interactions?
- What is the **configuration and motion** of quarks and gluons located within the nucleon?
- What happens to the **gluon density** in nucleons and nuclei at small x?
- How do **quarks and gluons interact** with a nuclear medium?
- How do the **confined hadronic states** emerge from quarks and gluons?

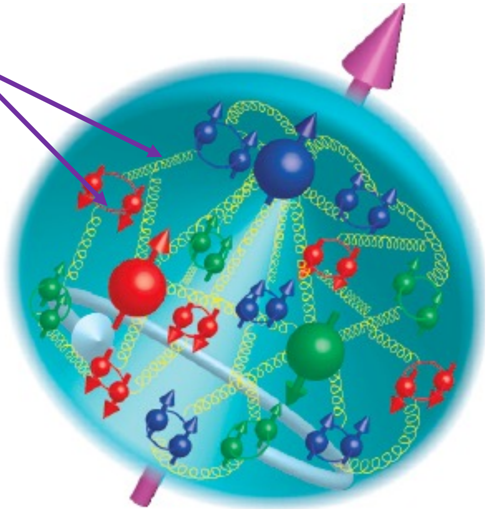
Properties of the Proton

3 Valence Quarks

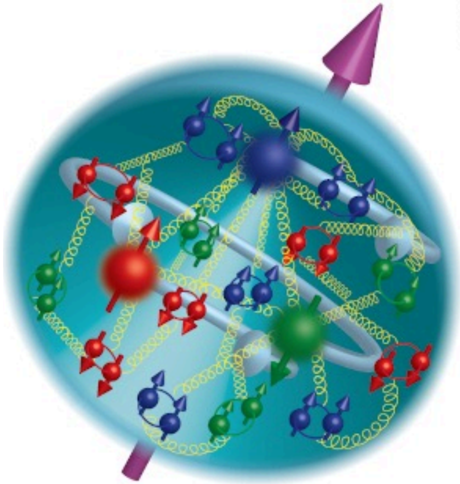


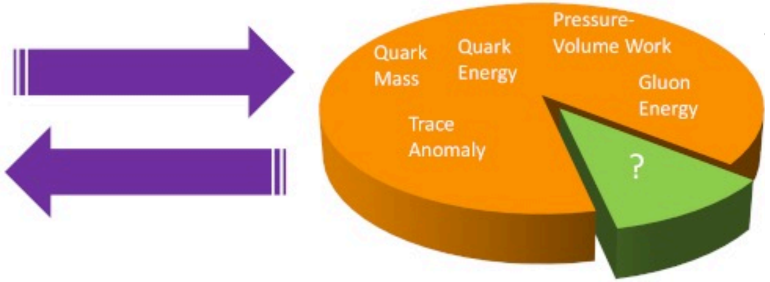
Sea Quarks and Gluons

Increase Energy



PROTON MASS BUDGET





Mass is driven by a complicated sum of various QCD interactions!

quarks gluons

Proton spin: $\frac{1}{2} = \frac{1}{2}\Sigma_q \Delta q + \Delta G + L_{g,q}$

Orbital angular momentum

Only 20-30% comes from the quarks!

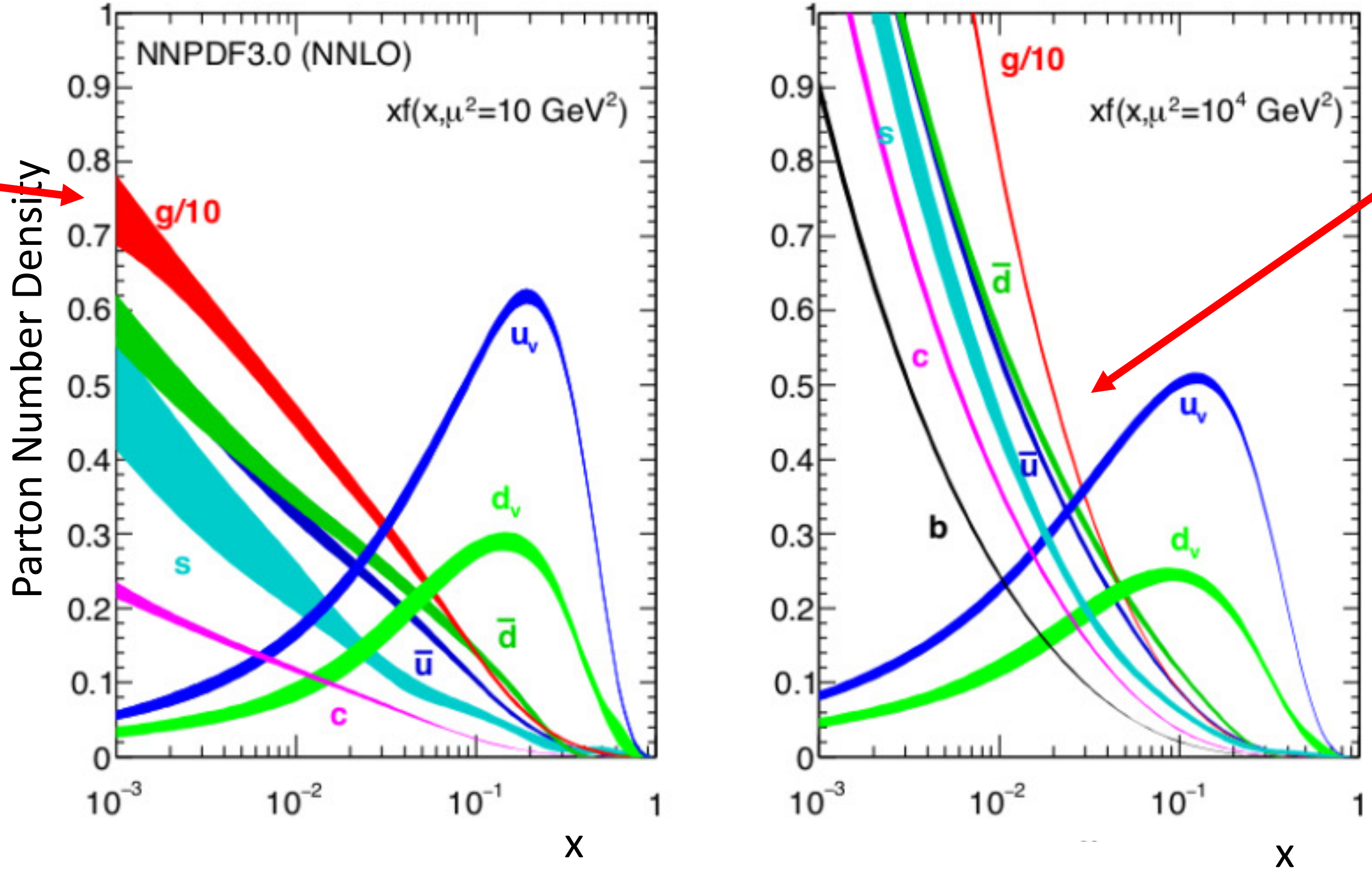
Quark and gluon internal motion

Gluon spin

Quark spin

Quarks and Gluons Structure and Motion

Where does this saturate?

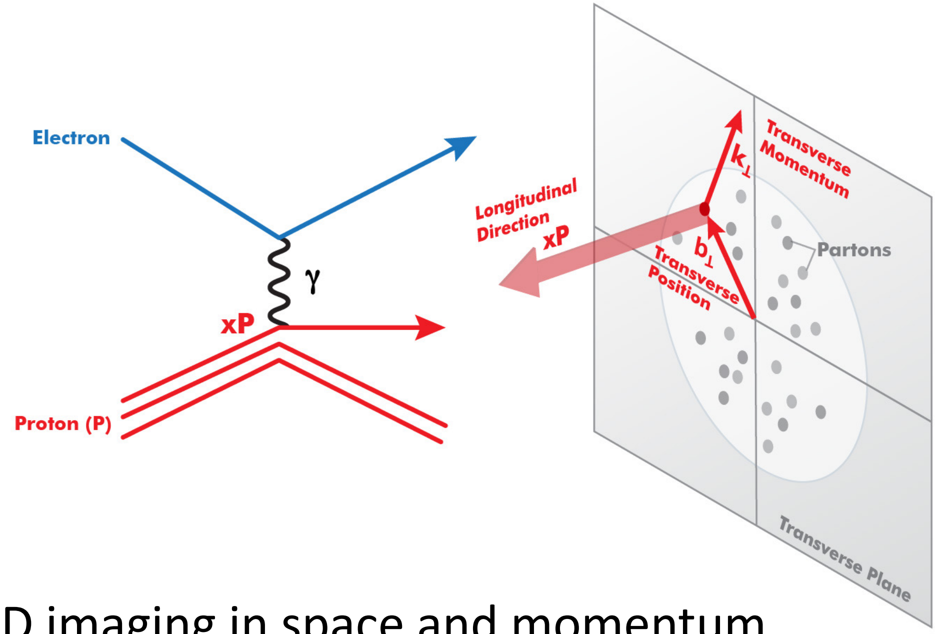


What do these distributions look like for protons in a nucleus?

Fraction of Proton Momentum Carried by Parton

3D Imaging in Space and Momentum

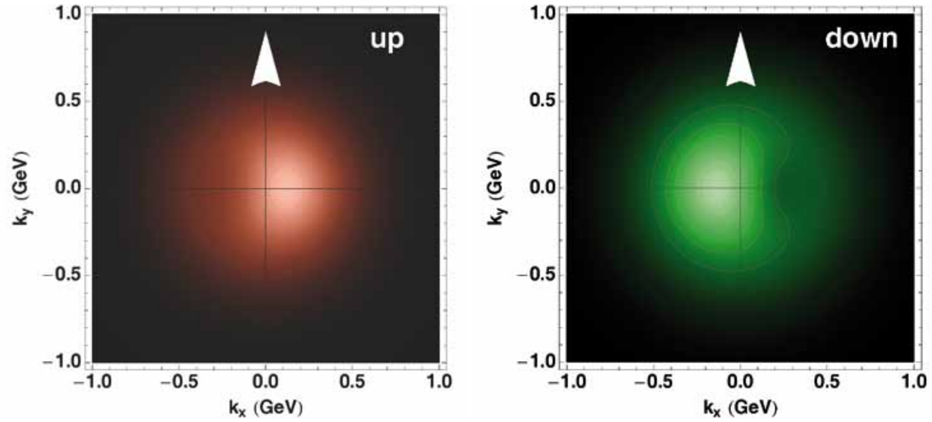
RHIC is the only polarized hadron collider in the world → EIC polarization capabilities



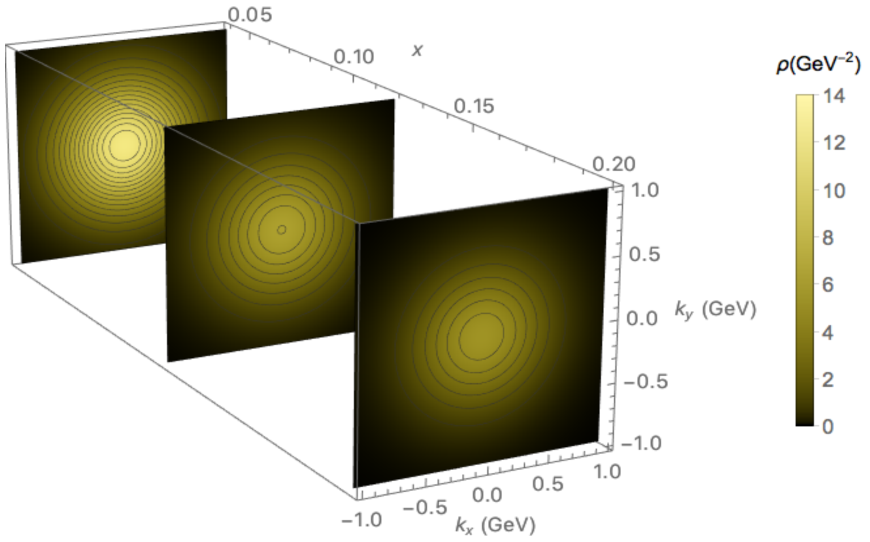
3D imaging in space and momentum

longitudinal structure (PDF)
+ transverse position Information (GPDs)
+ transverse momentum information (TMDs)

Transversely polarized nucleon



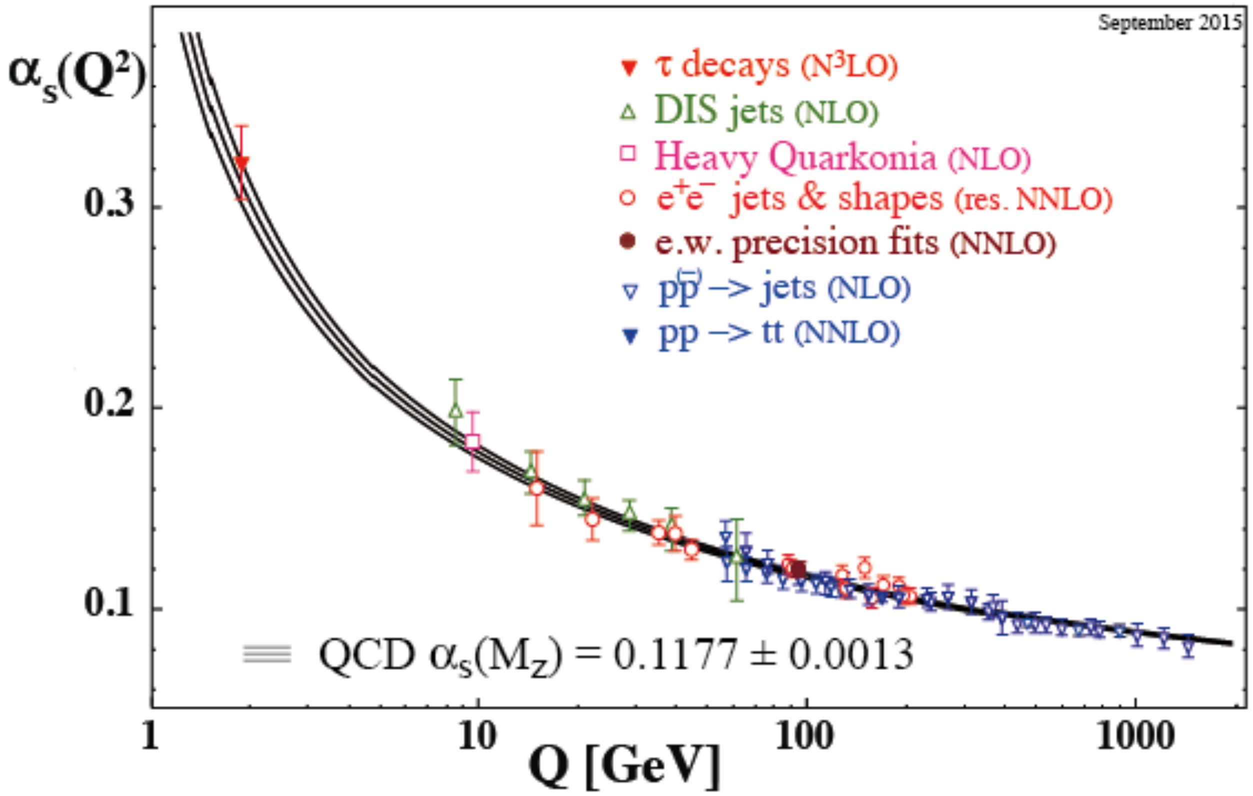
Unpolarized nucleon



Quantum Chromodynamics

Another interesting aspect of QCD:

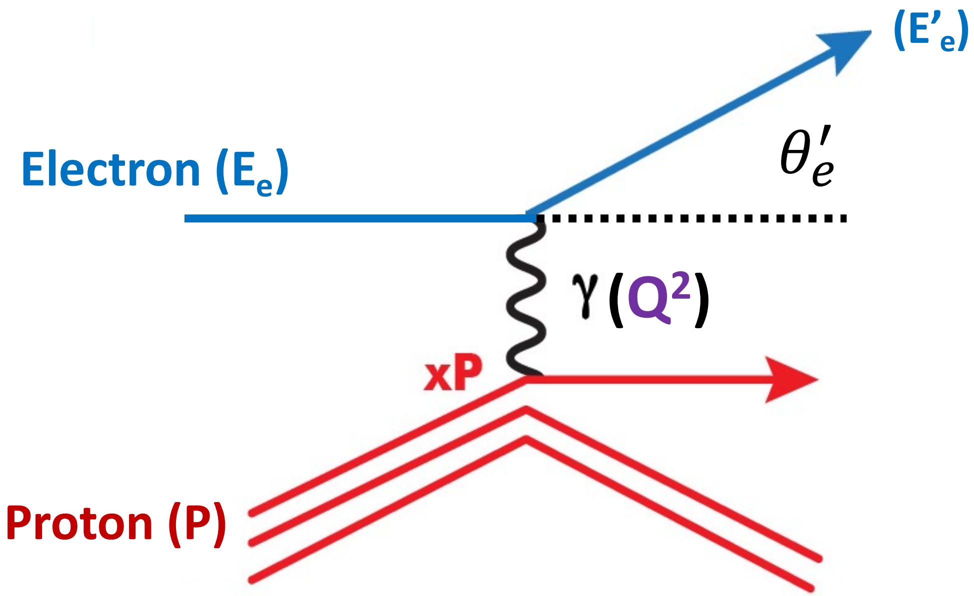
- Gluons can interact with themselves!
  - Leads to a coupling constant in QCD which varies with energy
  - At high energy (short distance), coupling is small and quarks are essentially free → perturbative
  - At low energy (long distance), coupling is large → non-perturbative
- QCD requires experimental data to make progress!



QCD constant runs from ~1 to 0.1 which results in complex nuclear structures and dynamics

How do we study the complicated structure of QCD?

Deep Inelastic Scattering (DIS)

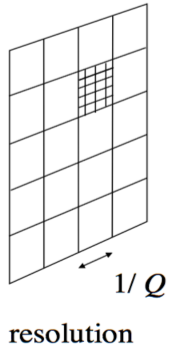


$$Q^2 = 2E_eE'_e(1 - \cos\theta'_e)$$

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

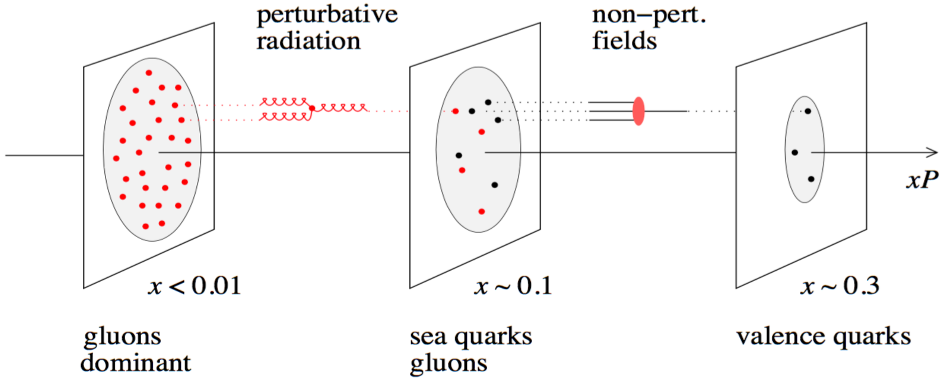
Measure of momentum fraction of struck parton

Changing **Q^2** changes the resolution scale

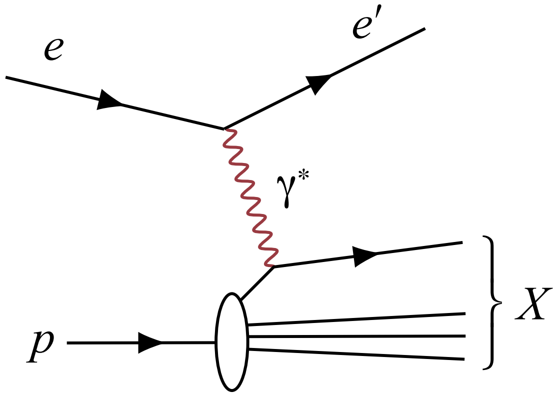


$Q^2 = 400\ GeV^2$
=> $1/Q = 0.01$ fm

Changing **x** projects out different configurations where different dynamics dominate

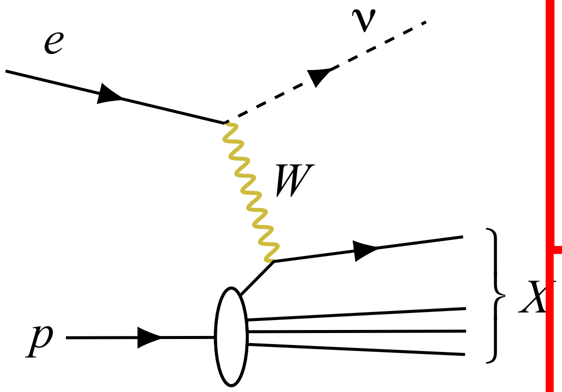


Deep Inelastic Scattering (DIS) Different Processes



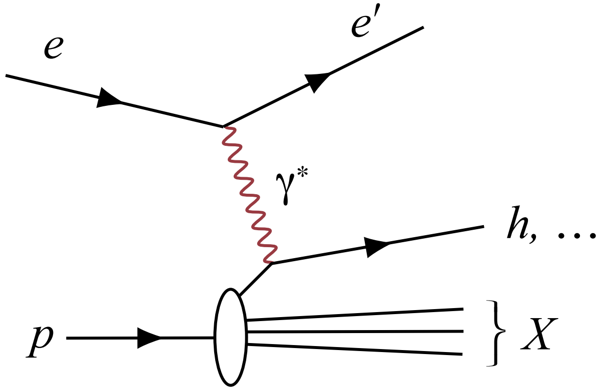
$$e + p/\mathrm{A} \longrightarrow e' + X$$

Neutral-current Inclusive DIS



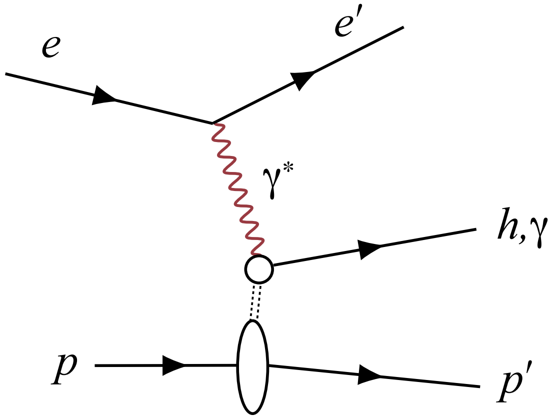
$$e + p/\mathrm{A} \longrightarrow \nu + X$$

Charged-current Inclusive DIS



$$e + p/\mathrm{A} \longrightarrow e' + h^{\pm,0} + X$$

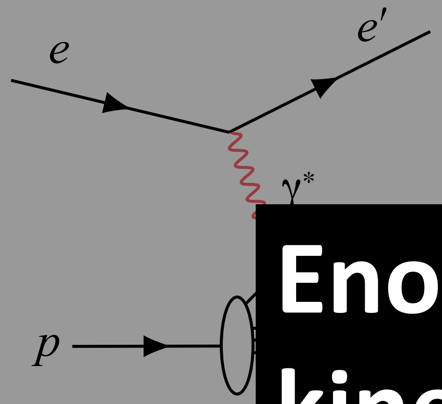
Semi-inclusive DIS



$$e + p/\mathrm{A} \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$$

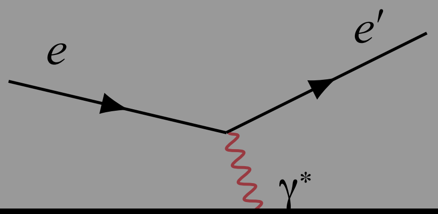
Exclusive DIS

Deep Inelastic Scattering (DIS) Different Processes

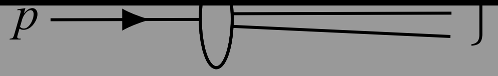


$e + p/\mathrm{A}$

Neutral
Inclus

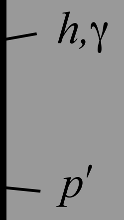


Enormous dynamic range in event kinematics and topology – requires streaming readout (SRO) to access the full EIC science program!



$e + p/\mathrm{A} \longrightarrow \nu + X$

Charged-current Inclusive DIS



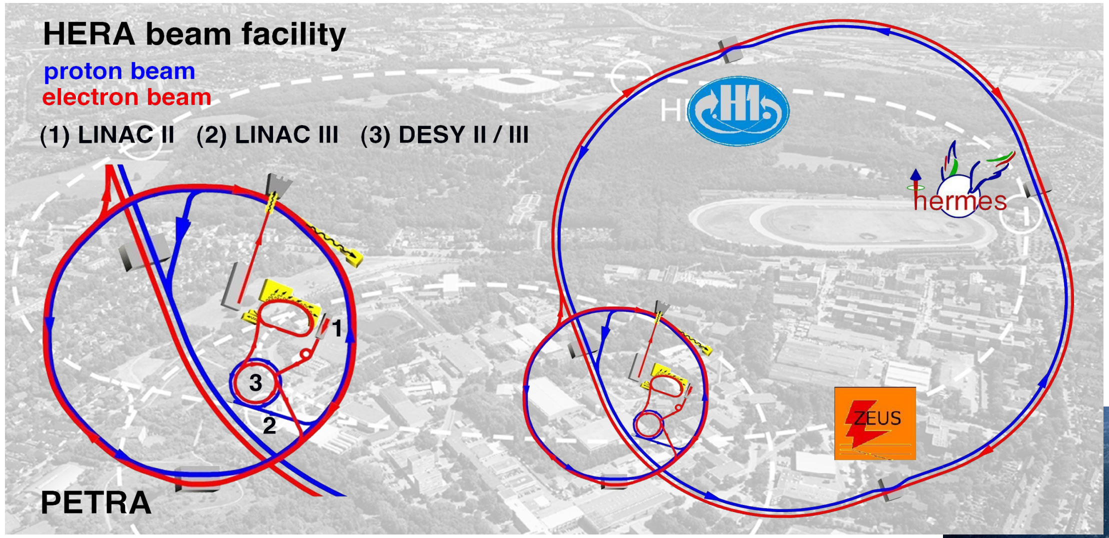
$e + p/\mathrm{A} \longrightarrow$
$e' + p'/A'$
$+ \gamma/h^{\pm,0}/VM$

Exclusive DIS

Streaming Readout (SRO)

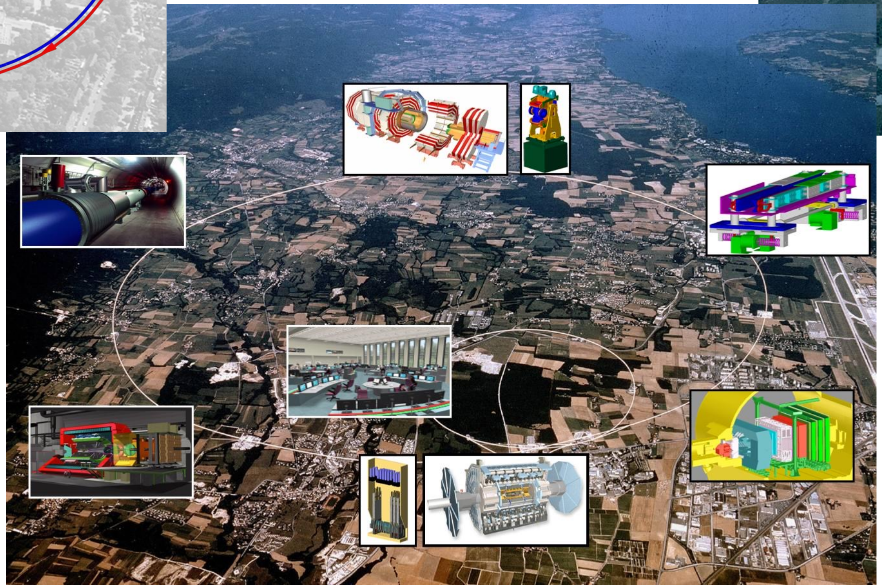
- Enormous dynamic range in event kinematics and topology – requires streaming readout (SRO) to access the full EIC science program!
    - Each detector element determines whether or not it has been “hit”
    - Passes timestamped data up the DAQ chain
    - At later stages the full event is available for decisions
- Allows for a truly minimum-bias sample
- Eliminates trigger bias and the associated systematics

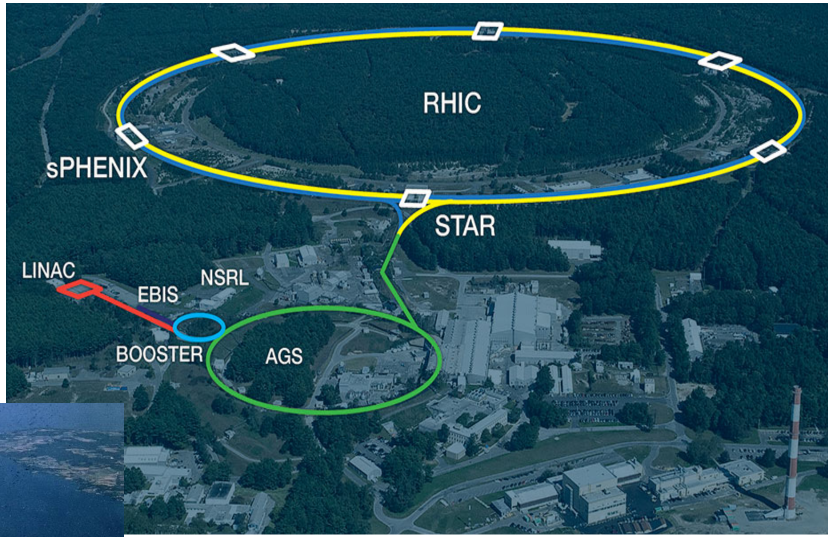
Previous Colliders



HERA: 1998-2007 (e + p)

LHC: 2009 – present (p+p, p+A, A+A)

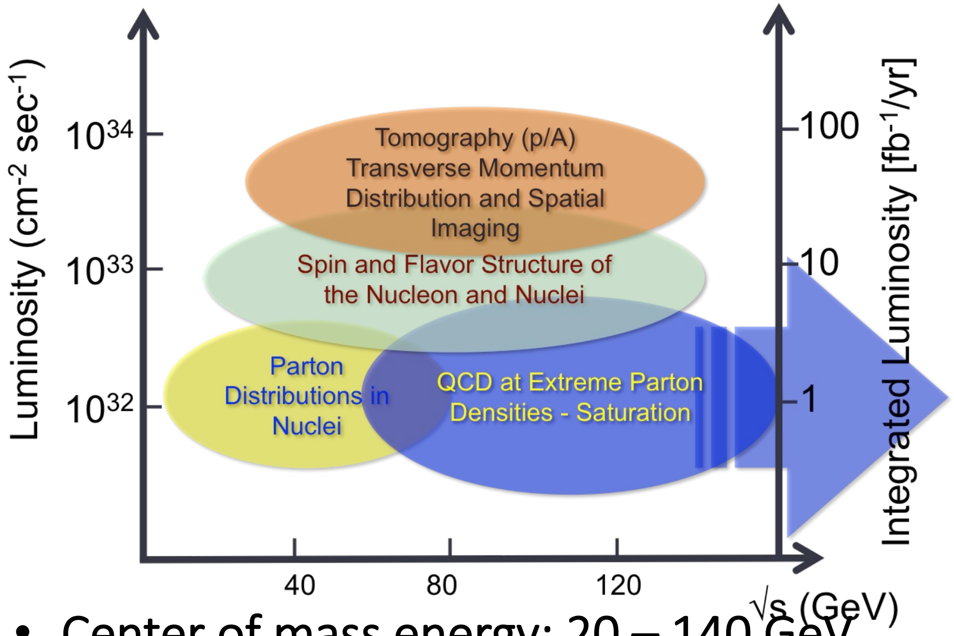


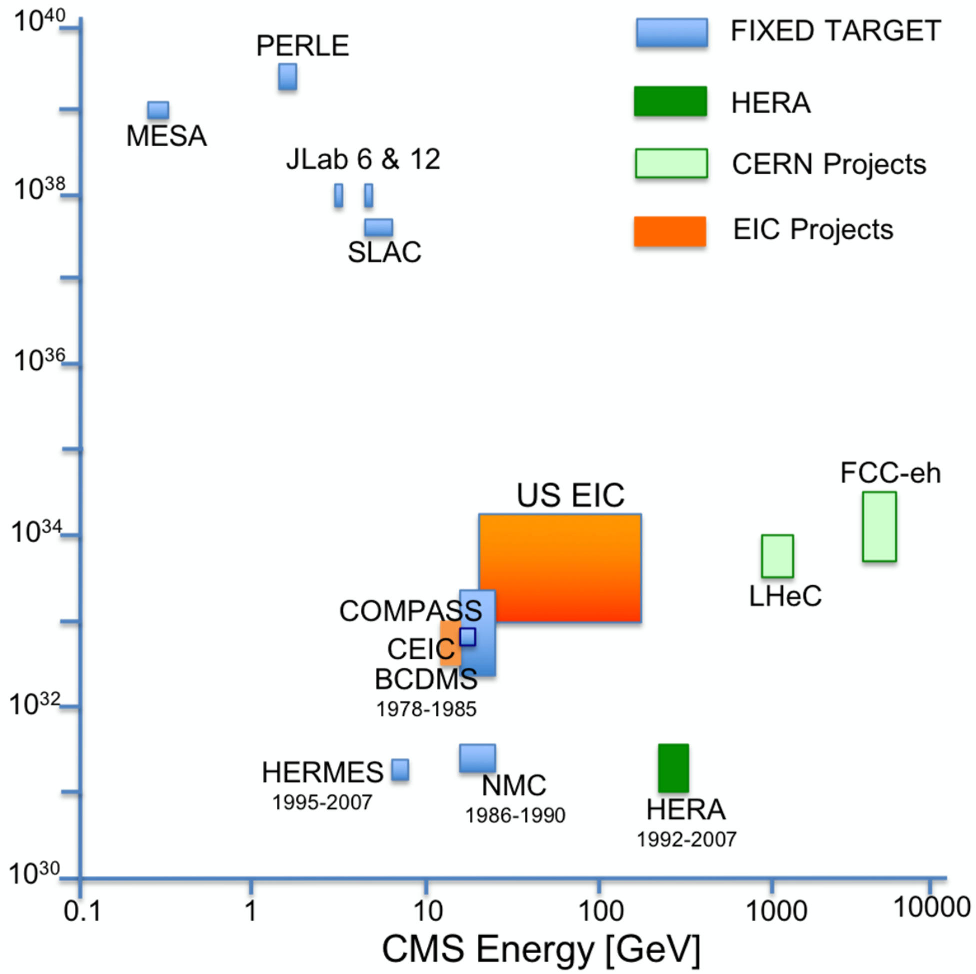


RHIC: 2000 – present (p+p, p+A, A+A, polarized protons)

In order to answer fundamental QCD questions, a new collider is required!

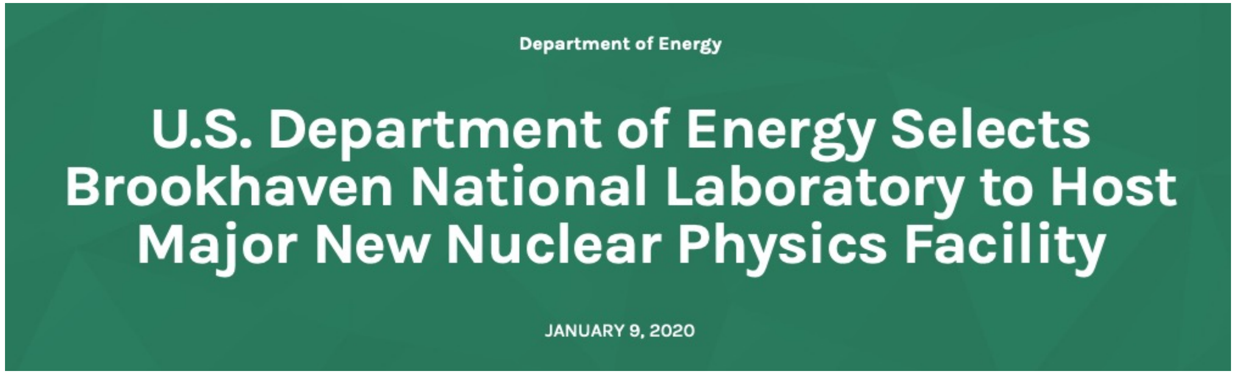
Electron Ion Collider (EIC) Requirements





- Center of mass energy: 20 – 140 GeV
  - Electrons: 5 – 18 GeV
  - Protons: 41 GeV, 100 - 275 GeV
  - Luminosity: 10^{33} - 10^{34} /cm^2/sec
- Polarization: <70% (both electron and light ion)
- Ion Species: proton - Uranium

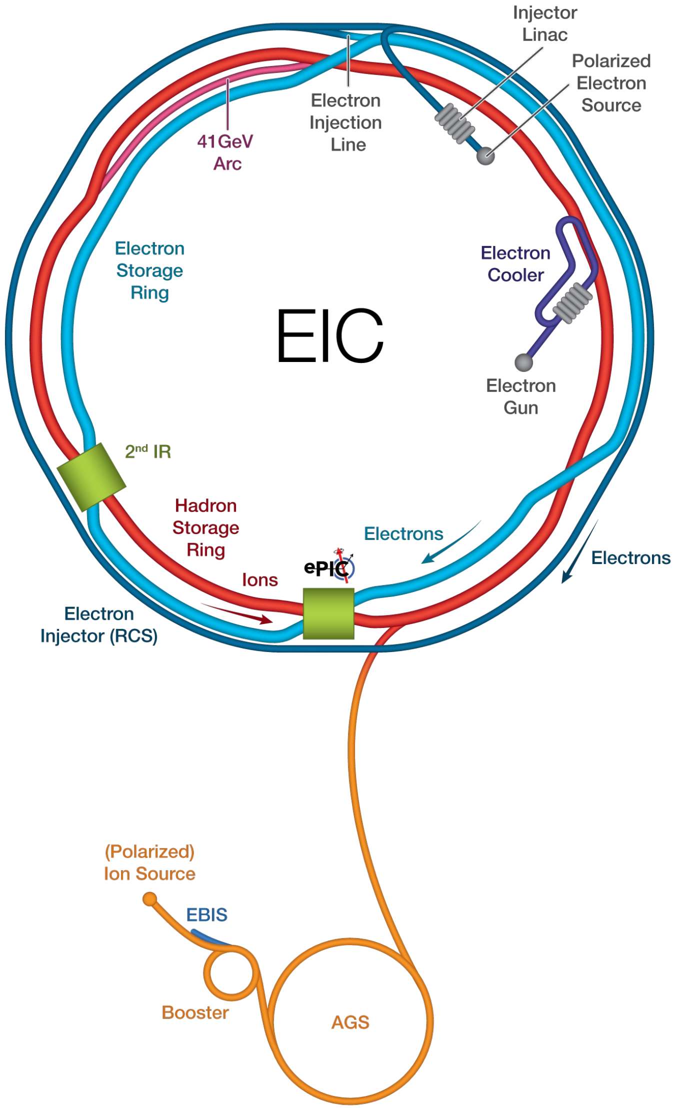
EIC Site Selection in 2020


Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

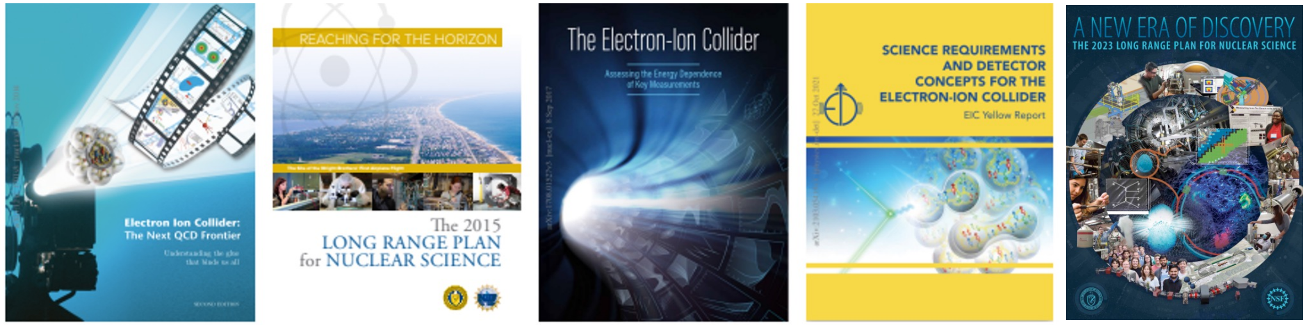
Brookhaven National Laboratory and Jefferson Lab will be host laboratories for the EIC Experimental Program. Leadership roles in the EIC project are shared.



2023 NSAC Long Rang Plan Recommendation

We recommend the expeditious completion of the EIC as the highest priority for facility construction

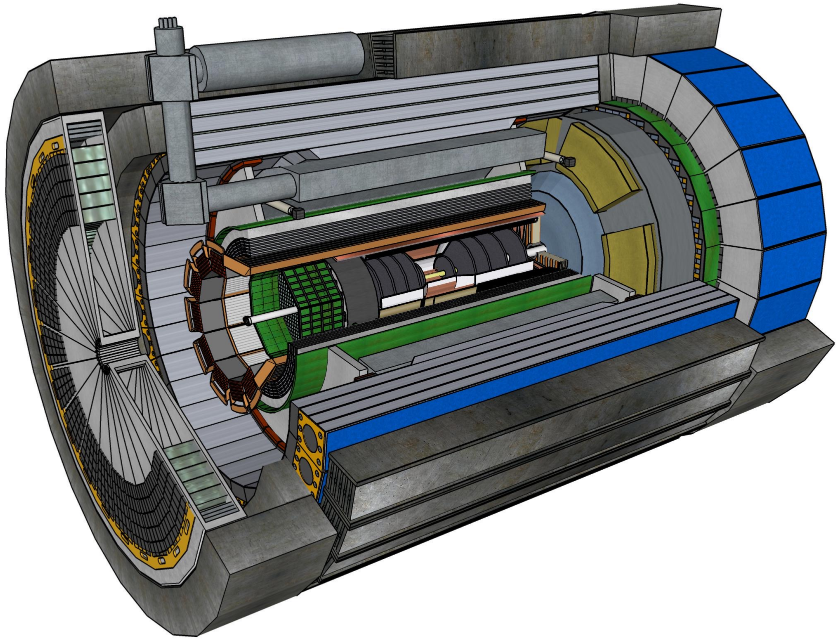
Detector Design Process Timeline



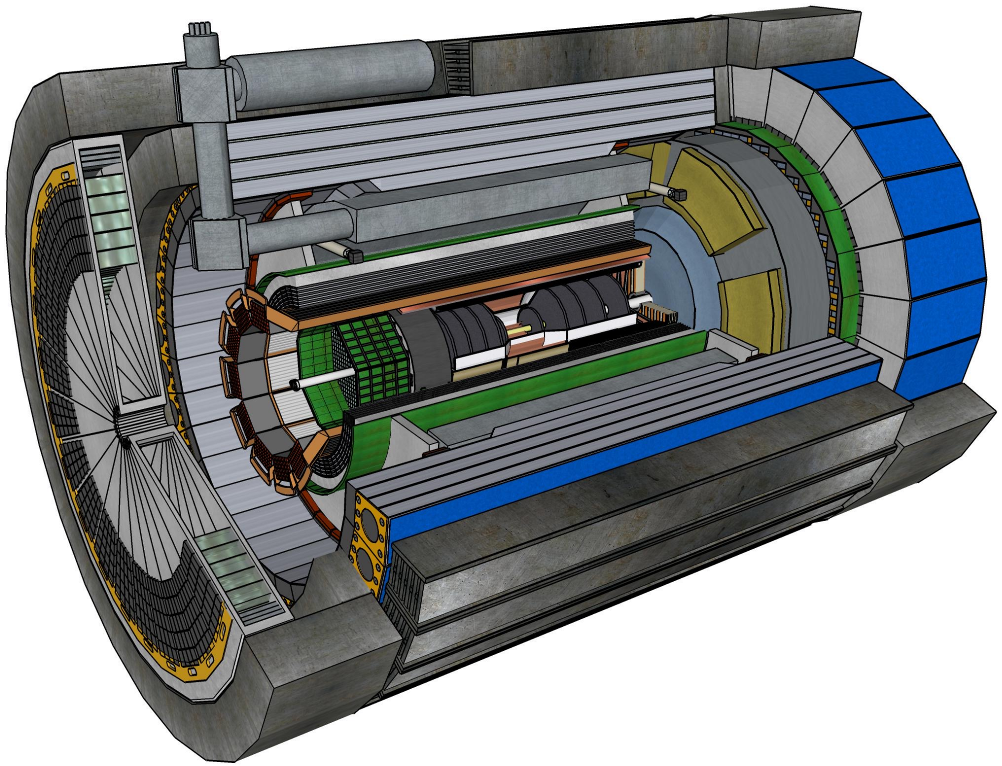
2012 2015 2017 2020 2023

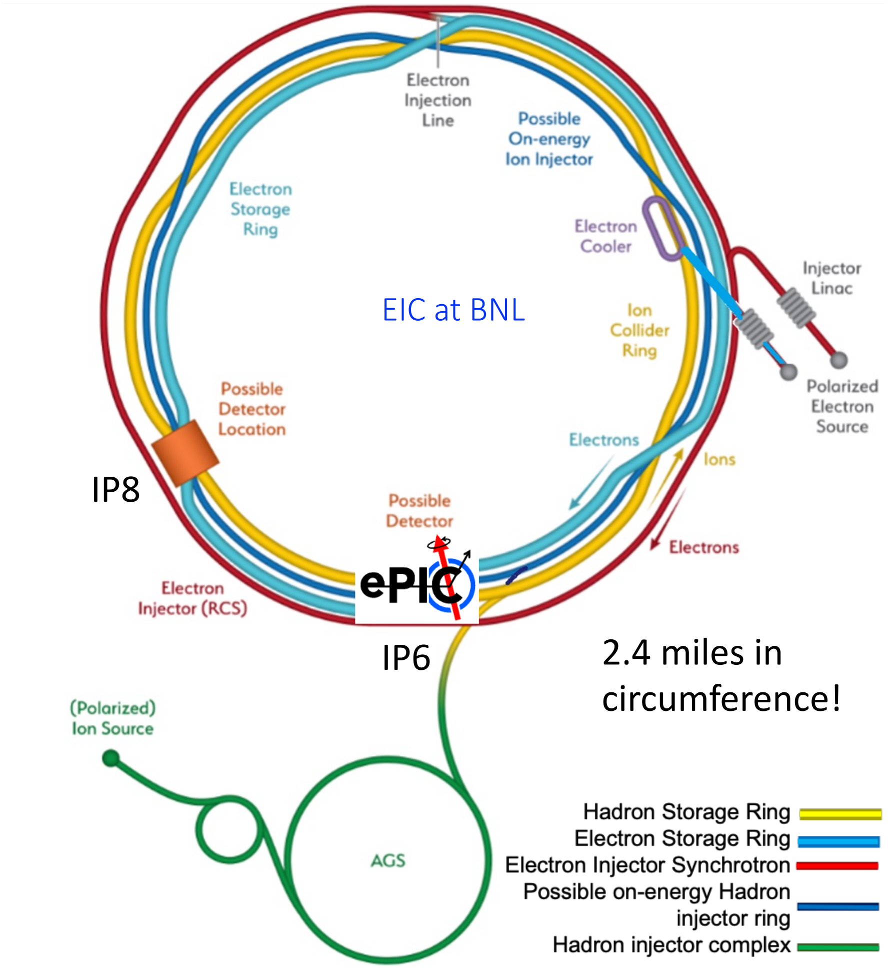
Detector and machine design parameters driven by physics objectives

- Call for proposals issued jointly by BNL/JLab **March 2021** (Due Dec 2021
  - ATHENA, CORE and ECCE proposals submitted
- DPAP closeout **March 2022**
  - ECCE proposal chosen as basis for 1st EIC detector reference design
- **Spring/Summer 2022** – ATHENA and ECCE form joint leadership team
  - Joint WG's formed and consolidation process undertaken
  - Coordination with EIC project on development of technical design
- Collaboration formation process started **July 2022**
- Charter ratified & elected ePIC Leadership Team **February 2023**
- **Working towards TDR and CD-3A and CD-2/3**



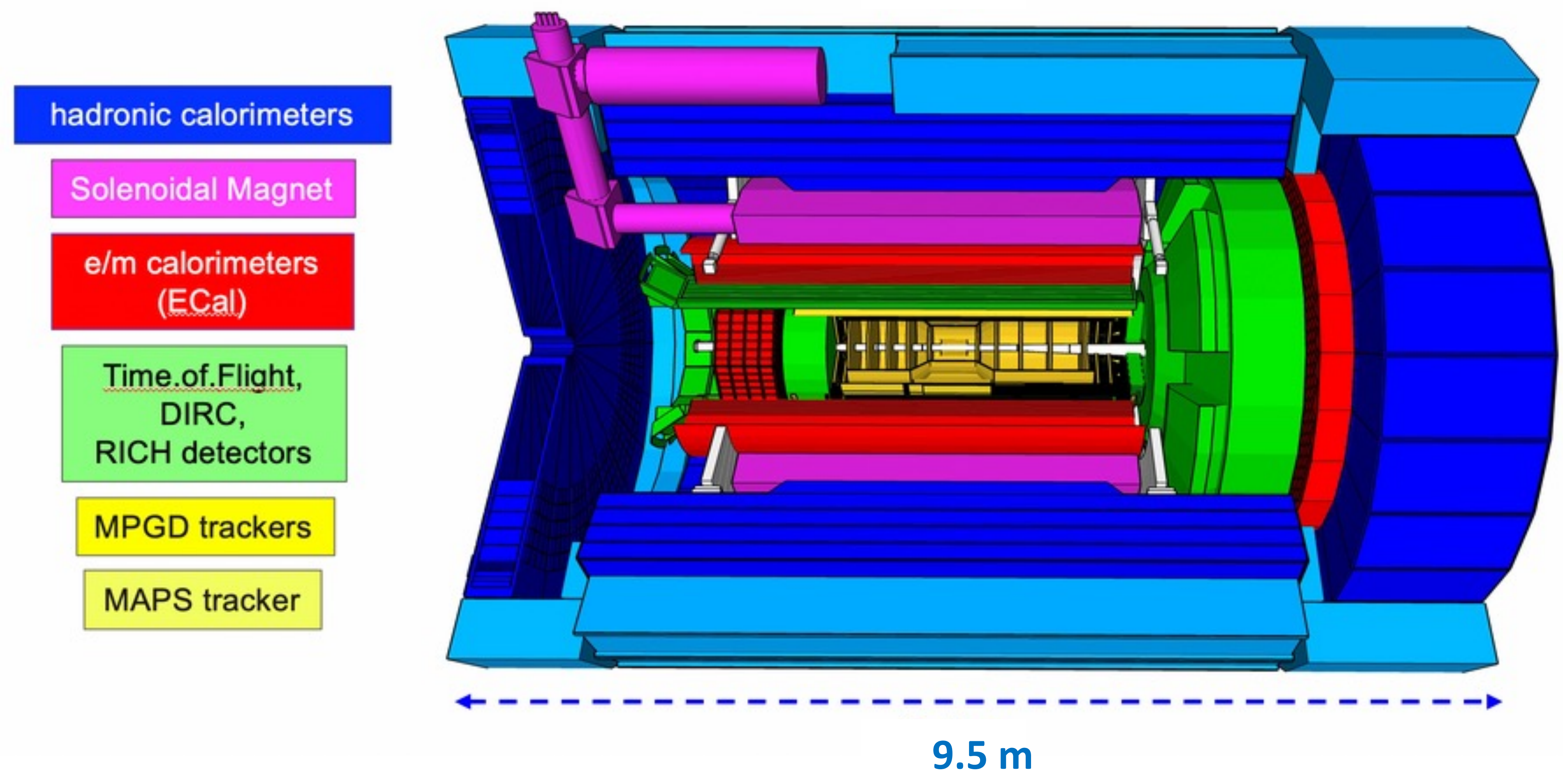
ePIC at EIC



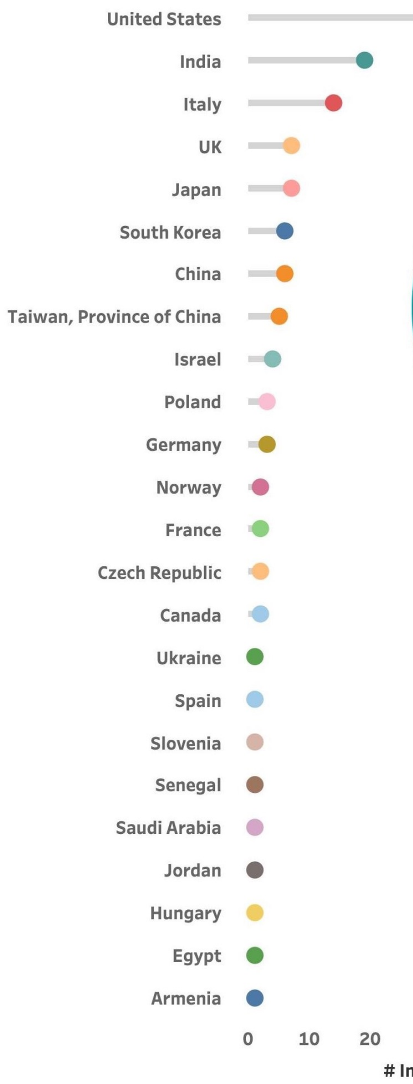


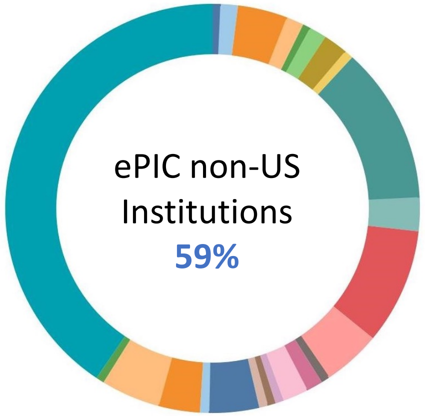
2.4 miles in circumference!

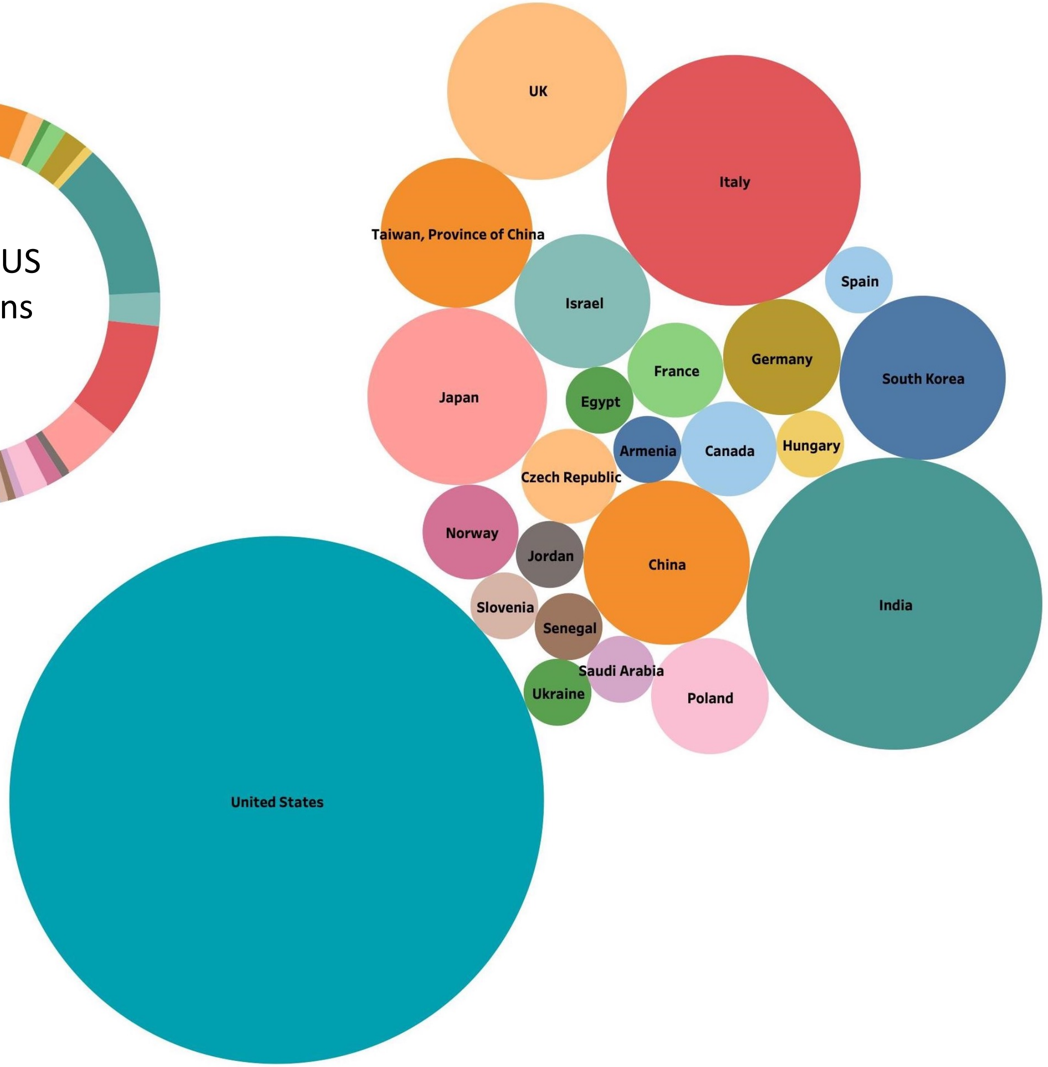
ePIC Subsystems



The ePIC Collaboration



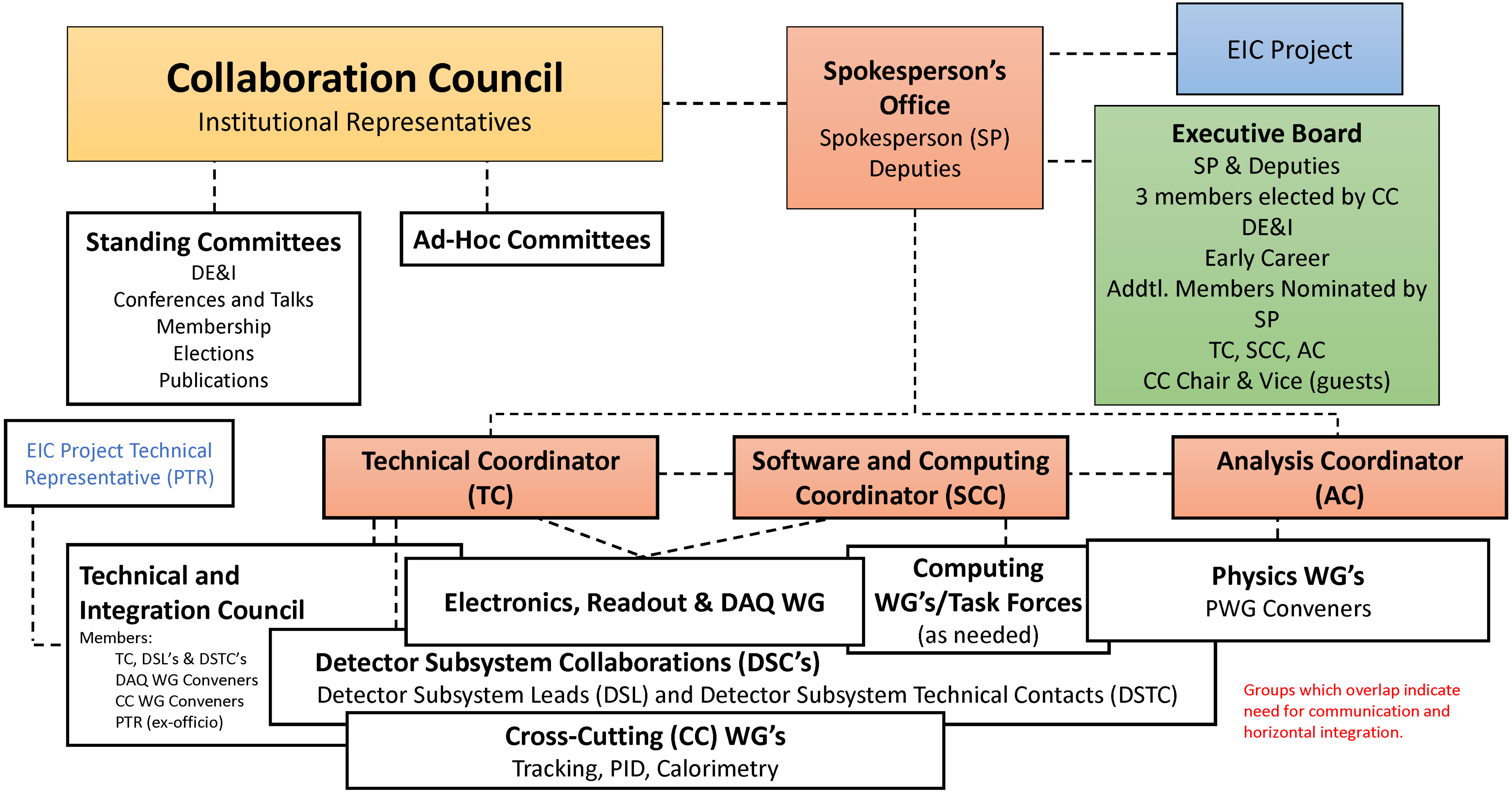




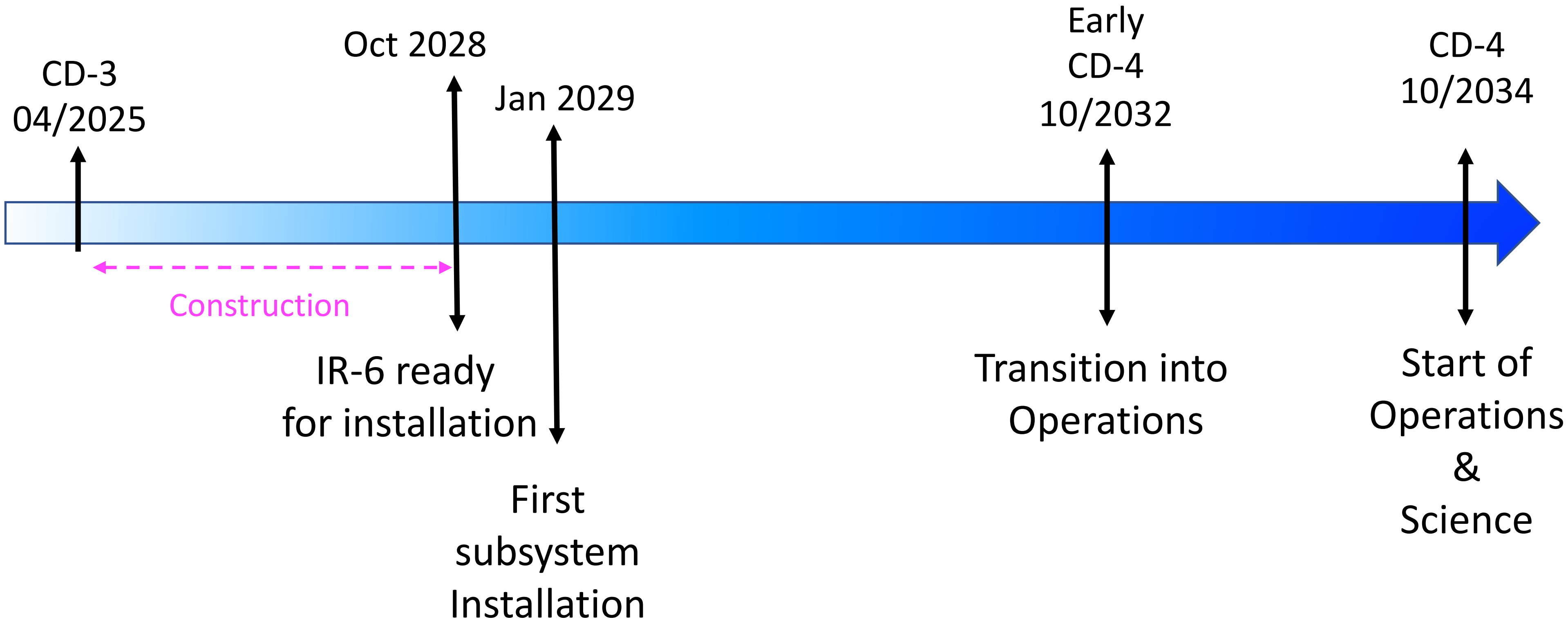
171 institutions and increasing
24 countries

500+ participants
A truly global pursuit for a new experiment at the EIC!

ePIC Collaboration Structure



High Level Timeline



Beam Backgrounds

Electron beam:

- Synchrotron radiation
  - Backscattering
  - Photo desorption
  - → degradation of vacuum
- Beam gas interactions
  - Off momentum electrons
- Higher order mode losses
  - Local heating at injection and ramp (short bunches)
  - Degradation of vacuum
- Background due to de-excitation of beam if bunches are replaced

Proton beam:

- Low beam lifetime during injection and ramping
- Beam gas interactions, large hadronic cross section
  - Secondary interactions with aperture limitations, i.e. with magnets, beam pipe, masks

Requirements:

Keep beam backgrounds as low as possible

→ Careful design of interaction region, beam-pipe masks and photon beam dump

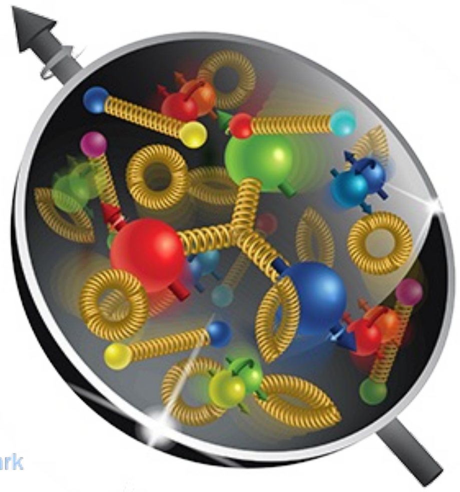
→ Excellent vacuum system

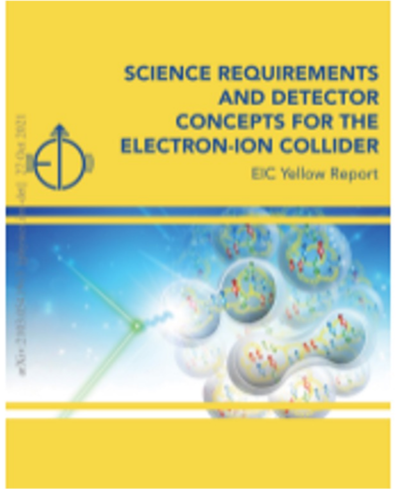
Important to note:

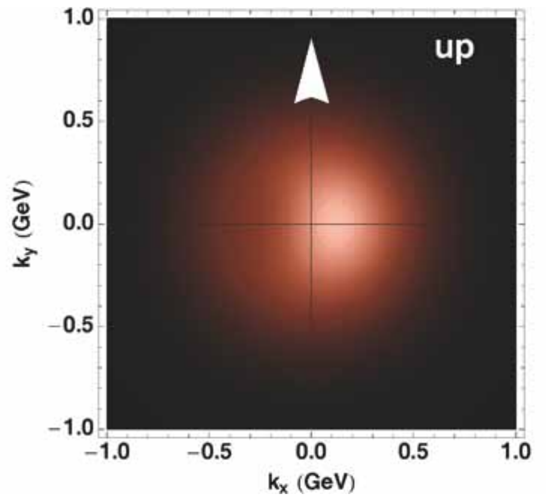
- Low multiplicity per event: < 10 tracks
- No pileup from collisions 500 kHz @10^{34} $cm^{-2}s^{-1}$ → DIS event every 200 bunches
- Radiation environment much less harsh than LHC → factor 100 less

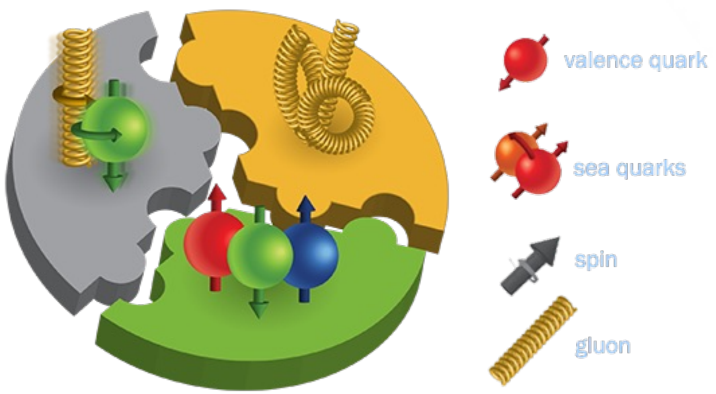
Translation to Physics

- Detector requirements stated in the Yellow Report are what is required to measure the key observables needed to answer the fundamental questions
  - 3D structure of protons and nuclei (space and momentum)
  - Gluon saturation and the color glass condensate
  - Solving the mystery of proton spin
  - Quark and gluon confinement





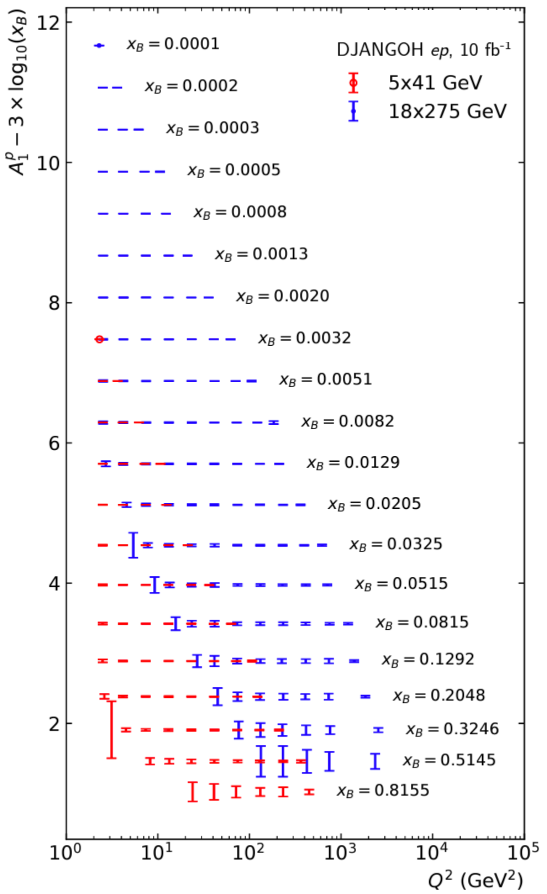


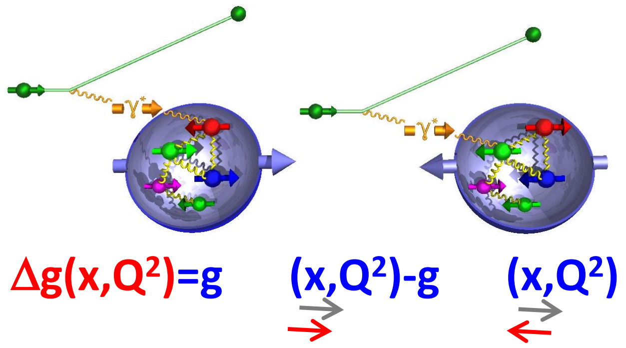


Helicity Structure and Momentum Tomography

Physics Observables Example

- Proton's helicity structure
- Observable: Longitudinal double spin asymmetries (A_{LL})
- DIS scaling violations determine gluons at small *x*



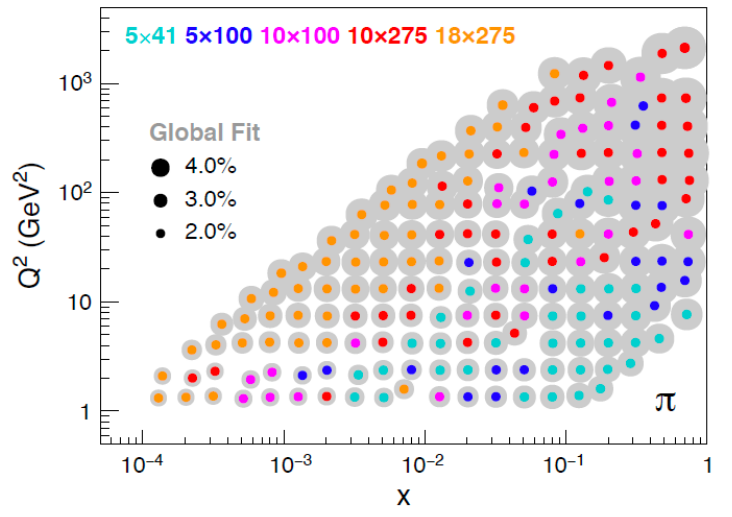


Key Components

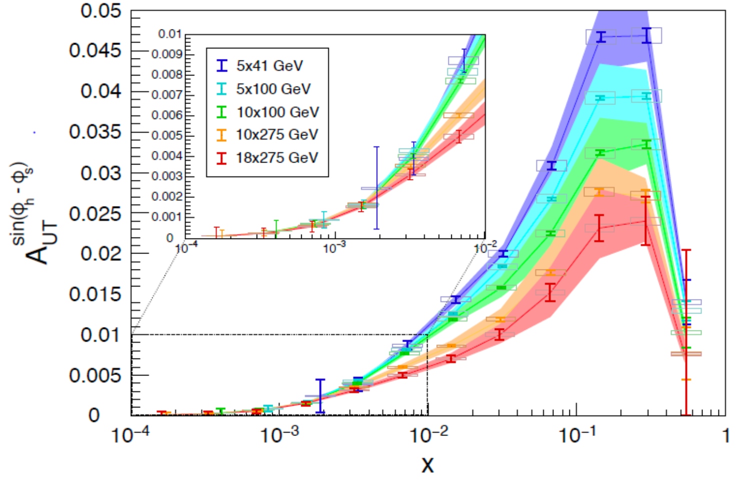
- Azimuthal acceptance
- PID (electron + hadron)
- Acceptance
- Vertexing (heavy flavor)
- Quality of tracking
- HCal (for jets)

Sivers function → measure for the anisotropy of the parton distributions in momentum space inside a transversely polarized nucleon

Unpolarized cross section uncertainties

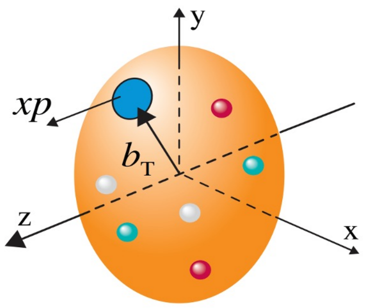


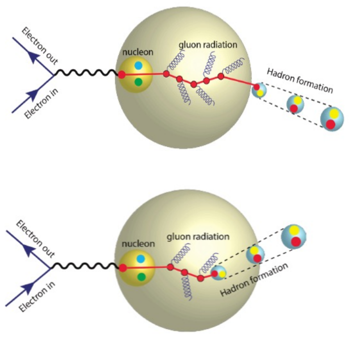
Projected Sievers asymmetries

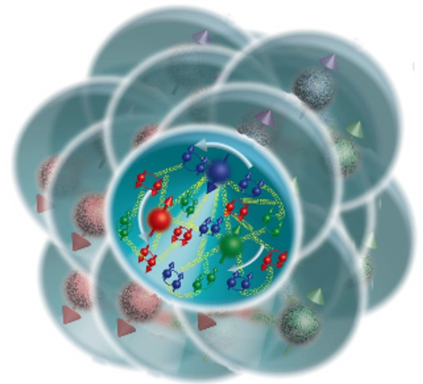


Conclusions

- The EIC is a new QCD laboratory designed to elucidate:
  - Origin of Nucleon Mass & Spin
  - Confinement
  - Nucleon / Nuclear Femtography
  - Dense Gluon States
  - BSM physics







- The EIC science goals are a natural extension of QCD studies at JLab and RHIC, and there is complementarity between the future programs at the EIC and JLab
- The ePIC Detector is maturing into a detailed technical design to pursue the EIC science program
  - EIC detectors are an enormous undertaking that will require participation and expertise from both the RHIC and JLab communities, as well as key international contributions!
- Large range in kinematics and event topology requires Streaming Readout