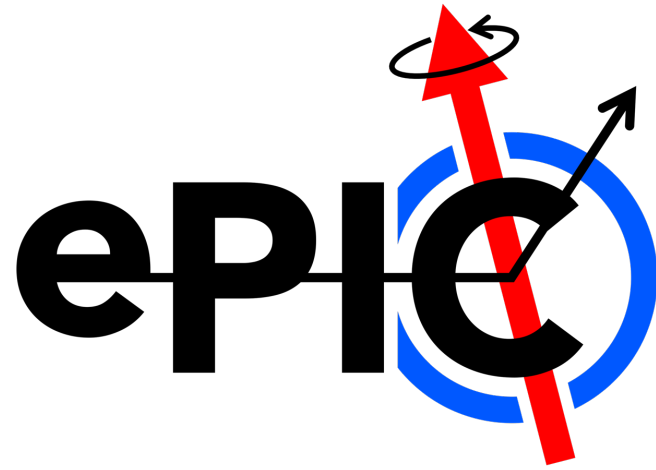




Addressing the Next Frontier in QCD

David Kapukchyan for the ePIC collaboration
Czech and Slovak High Energy Physics Workshop
Czech Academy of Sciences, Prague
September 10-11, 2026



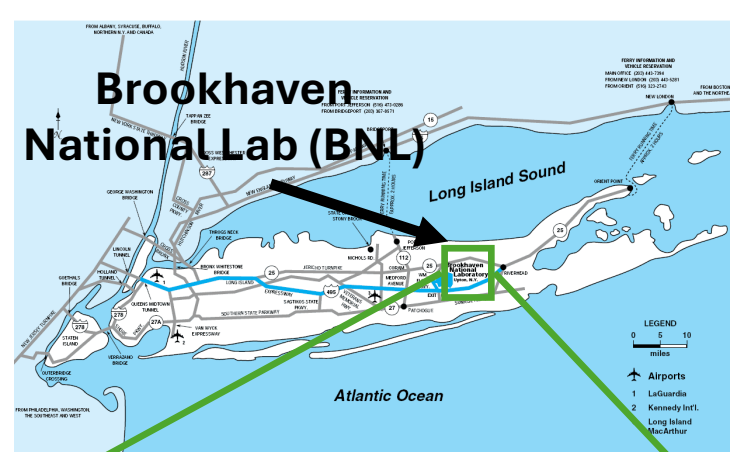
**FACULTY OF
NUCLEAR SCIENCES
AND PHYSICAL
ENGINEERING
CTU IN PRAGUE**



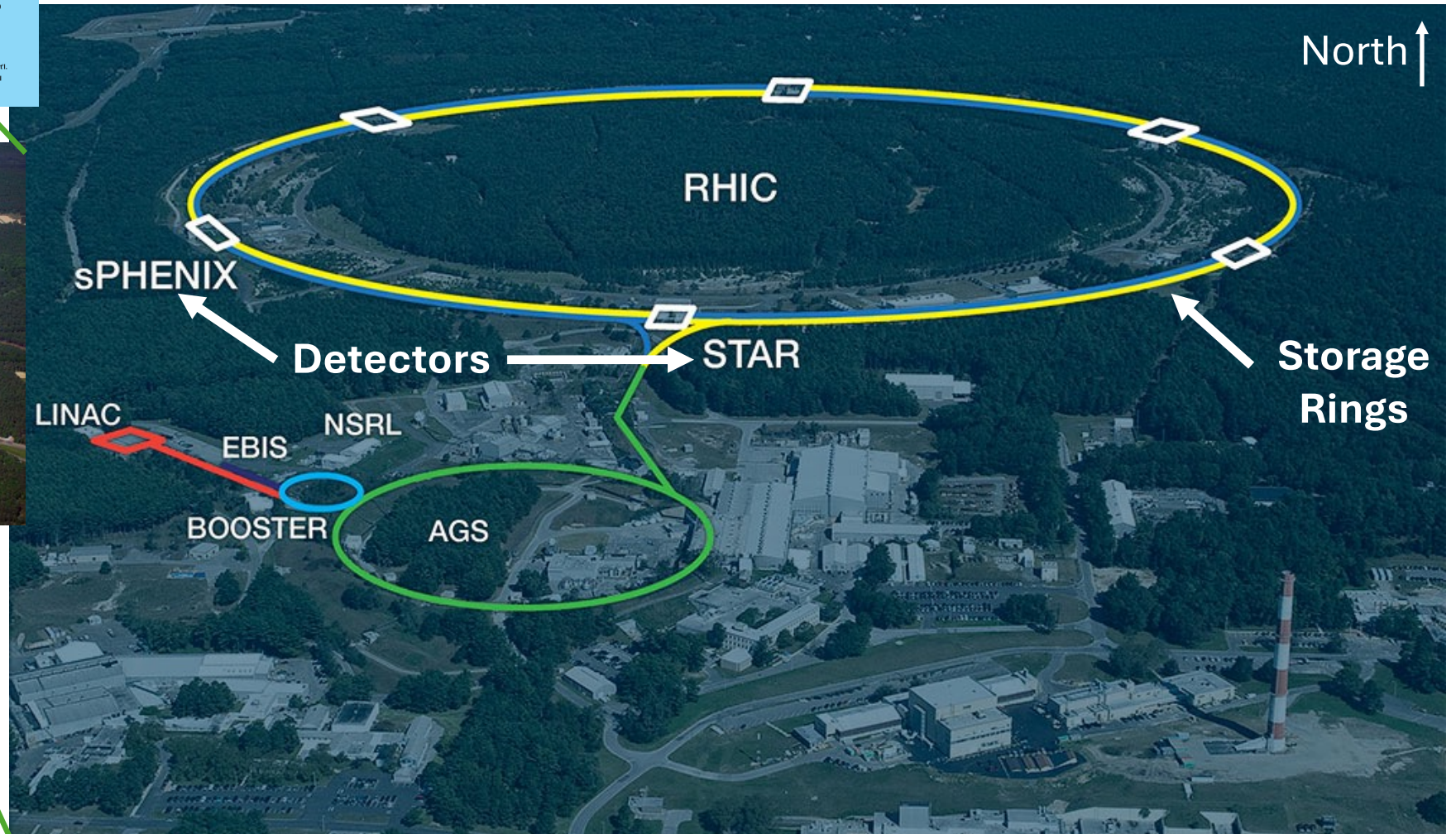
Supported in part by:

Co-funded by
the European Union





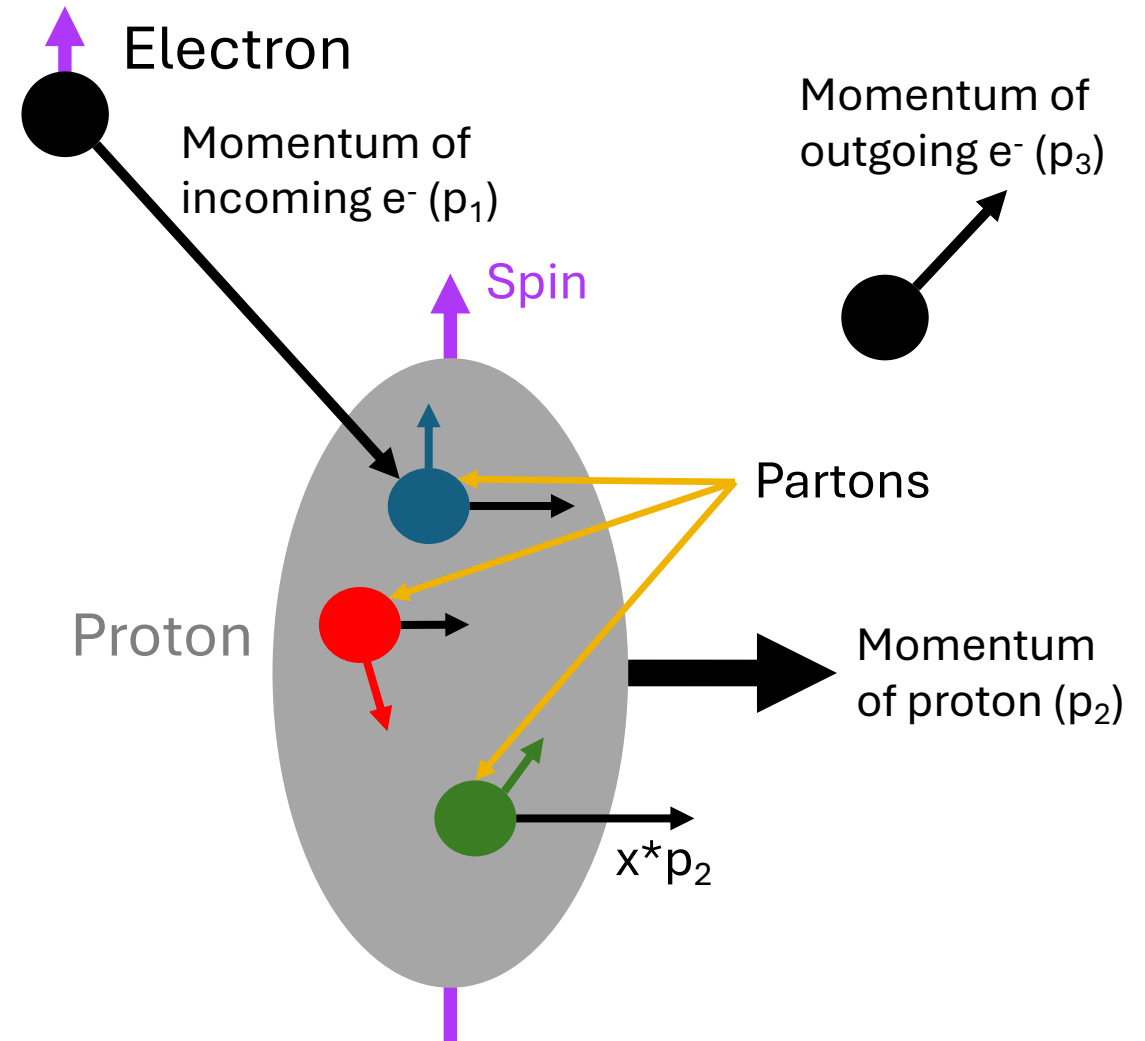
BNL and RHIC Facility



- BNL had the world's only **polarized proton proton collider** called the Relativistic Heavy Ion Collider (RHIC)
- It will be upgraded to the Electron Ion Collider (EIC)

Electron Proton Collisions

- Electron proton/ion collisions are called Deep Inelastic Scattering (DIS)
- Two relevant quantities in DIS
 - Q^2 : the momentum transfer
 - $Q^2 = -q^2$, $q^2 = (p_1 - p_3)^2$
 - Spatial Resolution parameter
 - Bjorken- x (x_{Bj} or just x) = $Q^2 / 2p_2 \cdot q$
 - x is momentum fraction of the struck parton
 - Higher x describes valence structure
- EIC will be the first polarized e^- and polarized p collider facility



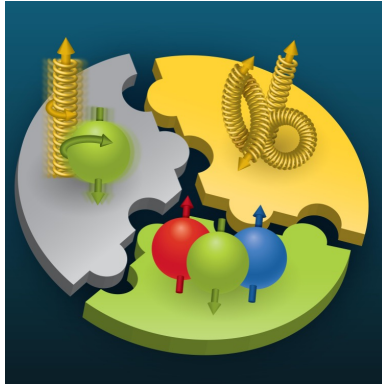
Questions in QCD that EIC will address

Nucleon Mass



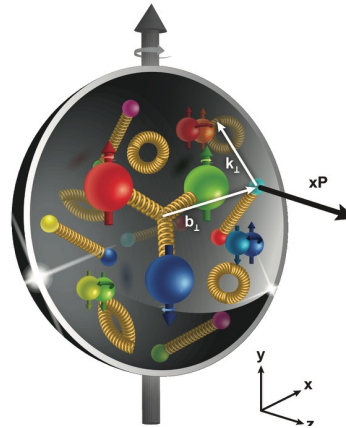
How does the visible mass of nucleons emerge from quark and gluon interactions or does it all?

Proton Spin



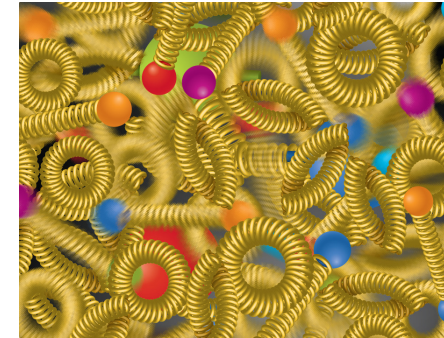
How does the quark and gluon motion generate the spin of the proton?

Imaging



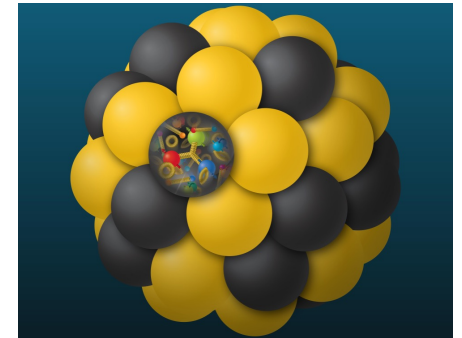
How are the quarks and gluon distributed in space and momentum inside the nucleon & nuclei?

Gluon Saturation



What happens to gluon density at higher energies?

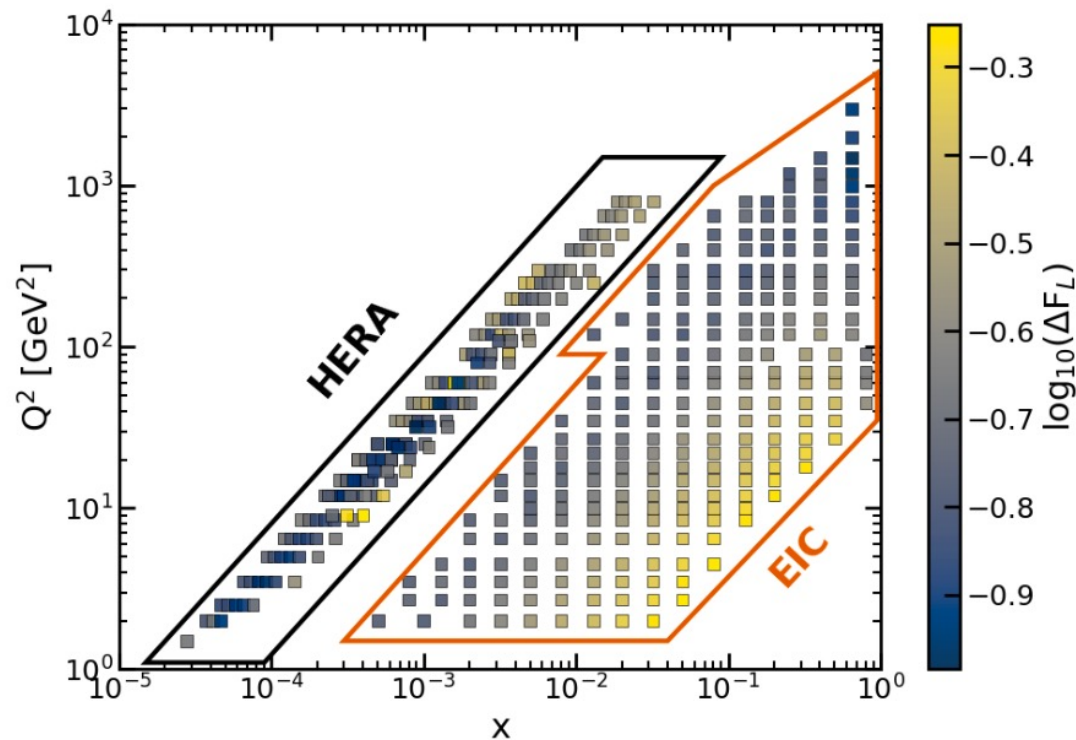
QCD in Nuclei



How does a confined nucleon differ from a free one? how do nucleon properties emerge from quarks and gluons?

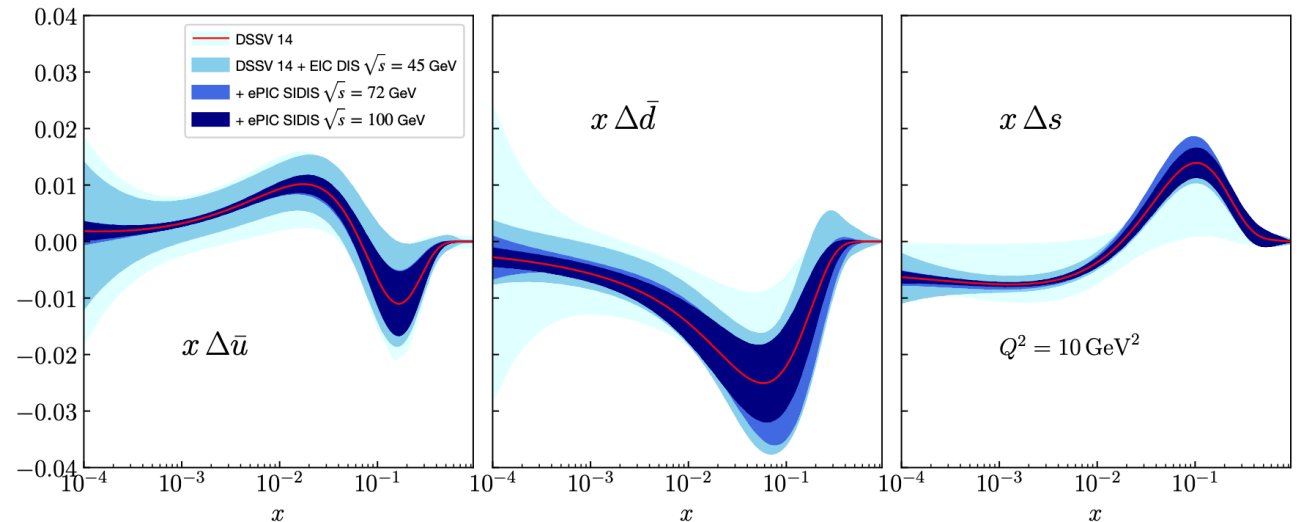
Selected EIC Science Highlights

- EIC x and Q^2 coverage at full design energy specification
- Colors represent the uncertainty in the measurement of proton structure function F_L



Expected impact of EIC data on sea quark helicities as a function of x

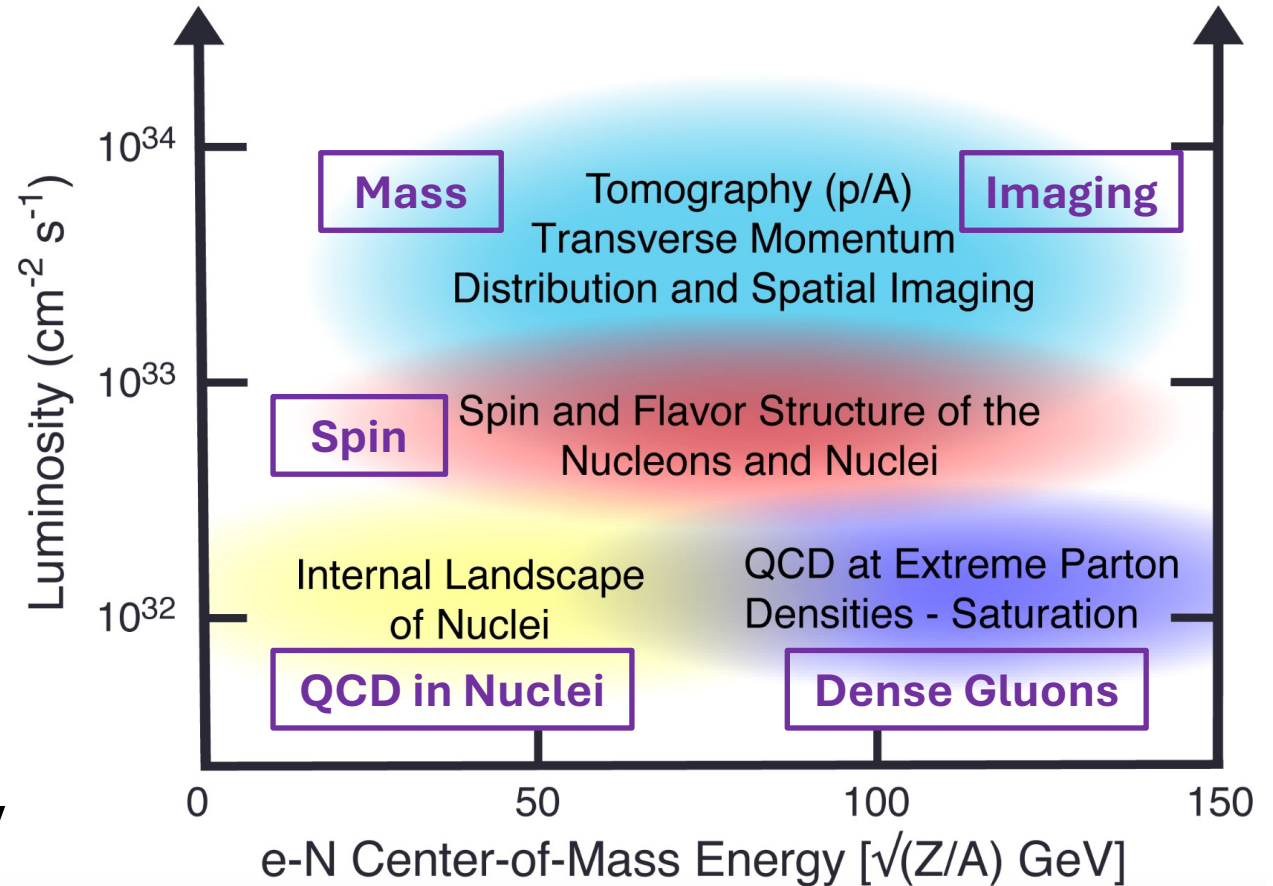
- Light blue is current knowledge
- Darker shaded regions are uncertainties from EIC data at different energies



Plots from EIC Early Science Report:
<https://arxiv.org/abs/2608.05377>

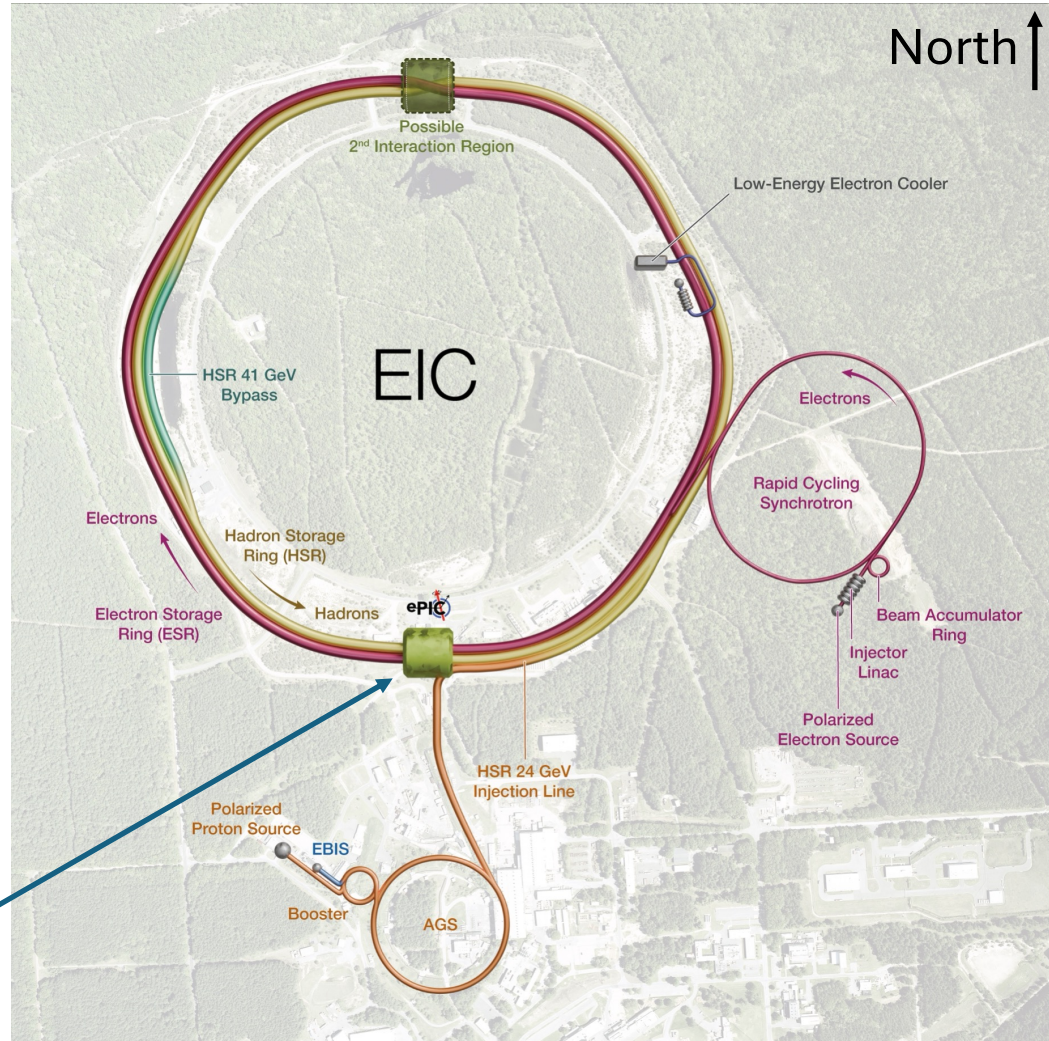
EIC Requirements For Exploring QCD Physics

- High collision luminosity
 - $L = 10^{33}-10^{34} \text{ cm}^{-2} \text{ s}^{-1}$
- Highly polarized electron and proton beams
 - Roughly 70%
- Ion beams from deuterons to uranium nuclei
- Large center-of-mass energy range
 - Electron beam: 5, 10, 18 GeV
 - Ion beam: 41 and 100 to 275 GeV



EIC Facility

- RHIC ended operations in February 2026 and site preparation for EIC has started
- Build a new electron accelerator facility
- Convert one of the RHIC hadron rings into an electron ring
- Ions can be protons as well as heavier nuclei
- Utilize RHIC's ability to maintain and measure polarization in both rings
- ePIC detector located at 6 o'clock



Detector Requirements for EIC program

Polarized ion beam
41 GeV, 100 to 275 GeV

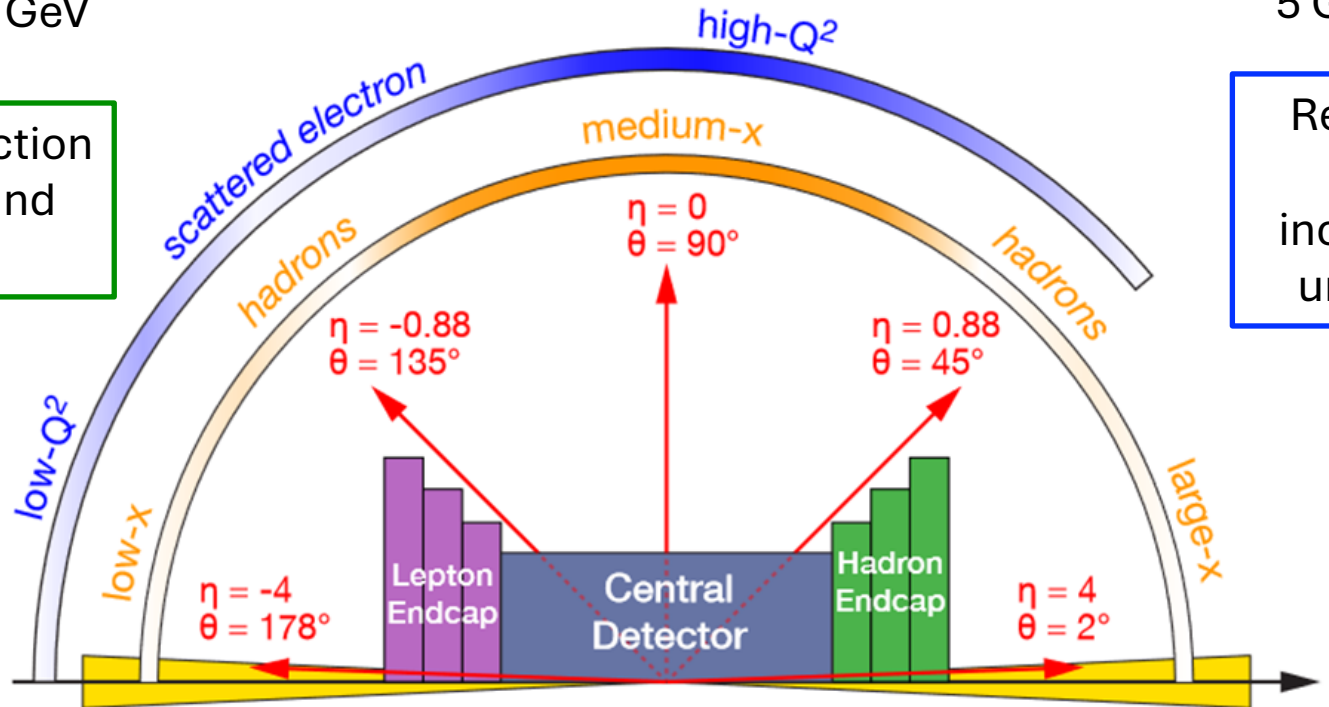
Polarized electron beam
5 GeV, 10 GeV, 18 GeV

Requires precision detection of scattered electron and produced hadrons

Requires detection of all produced particles, including those scattered under very small angles

Dedicated detector to measure very low Q^2 at 35 m

Detectors integrated along the beam line up to 40 m



Spin

QCD in
Nuclei

Gluon
Saturation

Mass

3D-Imaging

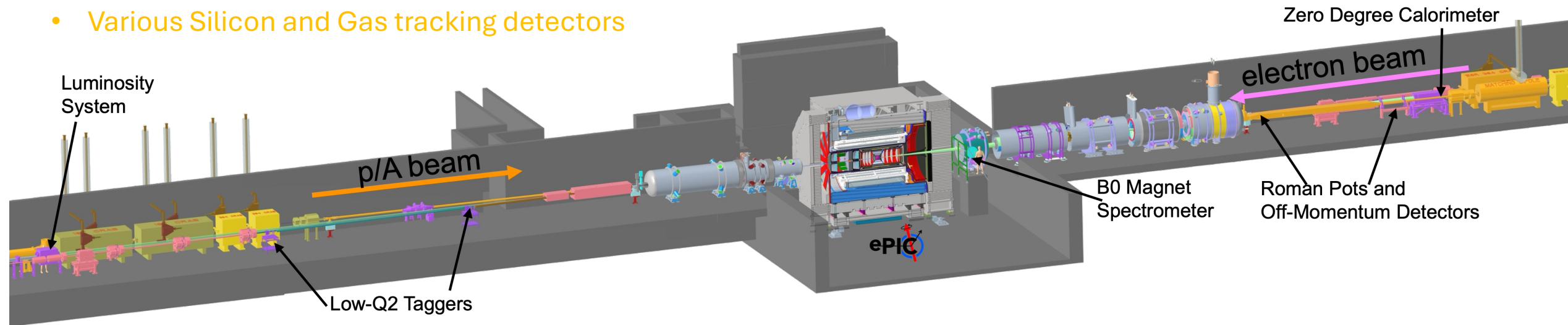
Need tracking, particle ID, and electromagnetic and hadronic calorimetry in all directions covering $-4 < \eta < 4$

ePIC detector

26 subsystems over $\pm 40\text{m}$ to measure particle momenta, energy, and type

- 1.7 T solenoid ($\varnothing 2.84\text{ m}$)
- 3 Hadronic Calorimeters (Hcal)
- 3 Electromagnetic (EM) Calorimeters
- 5 Particle identification detectors
- Various Silicon and Gas tracking detectors

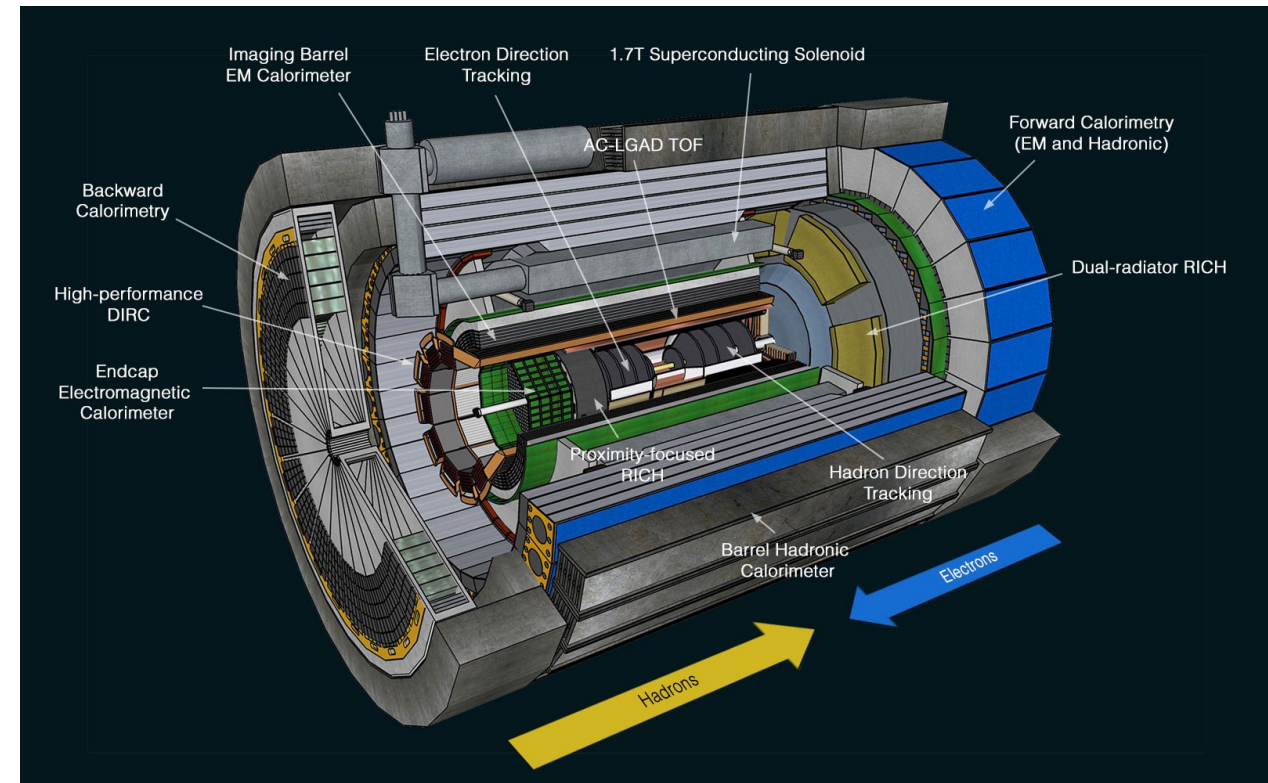
- Fully streaming readout electronics
- Electron and hadron polarimetry to measure the spin of the beams



ePIC Closeups and Plans

- ePIC construction expected to start in 2029
- Central Region detectors expected to be constructed by 2033
 - Start of cosmic commissioning
- Finish installing forward detectors
- First beams expected 2034!

Central Region: $-4 < \eta < 4$



Czech Contributions to EIC and ePIC



Czech Institutions:

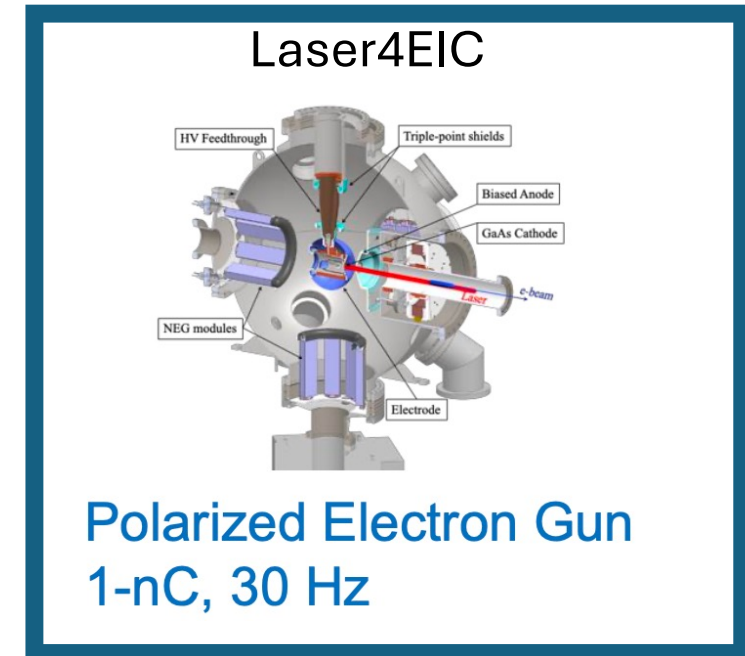
- Czech Technical University in Prague
- Charles University
- Nuclear Physics Institute of Czech Academy of Sciences

Czech Contributions to EIC and ePIC

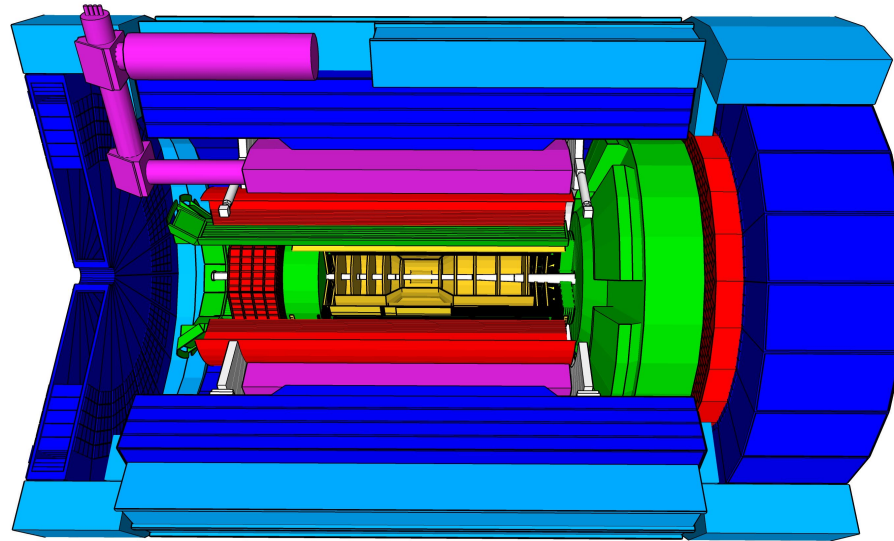


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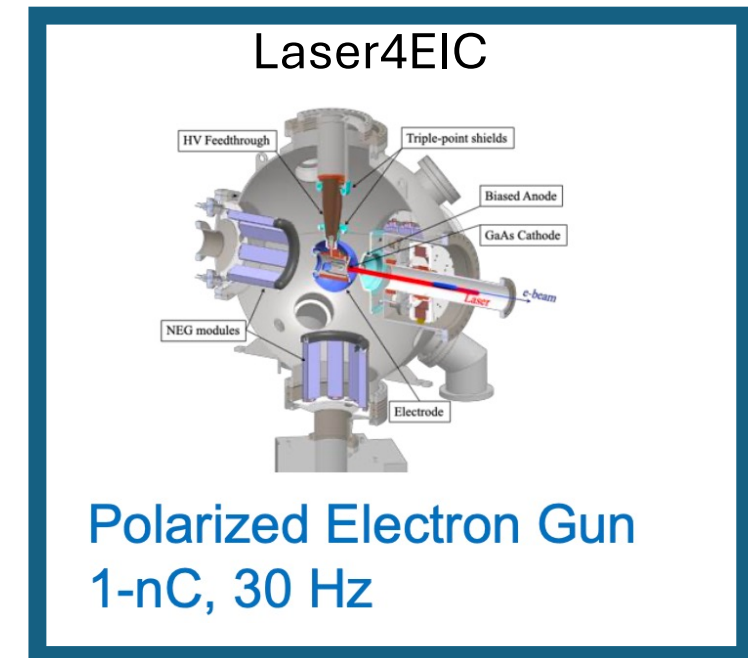


Czech Contributions to EIC and ePIC



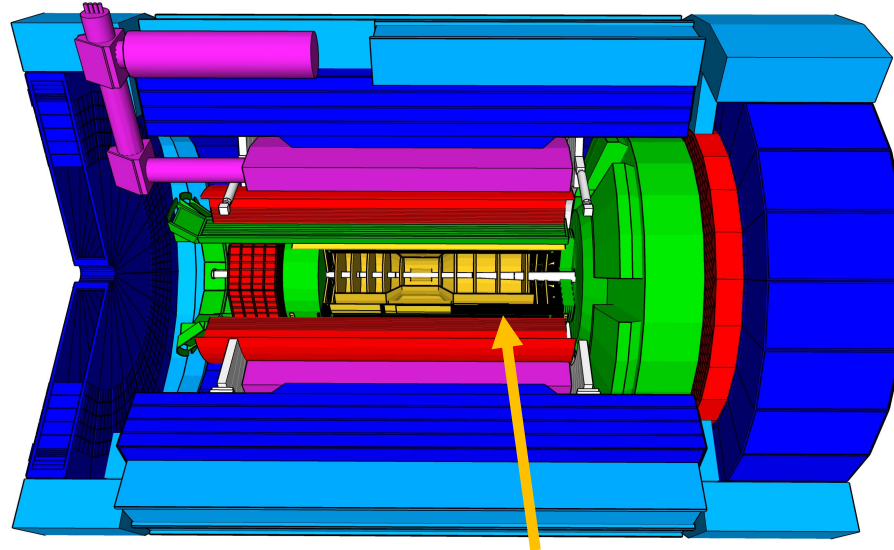
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Czech Contributions to EIC and ePIC

Tracking



Silicon Vertex Tracker

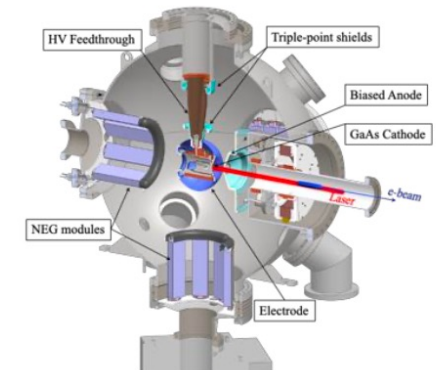
- Uses MAPS technology
- Testing



Czech Institutions:

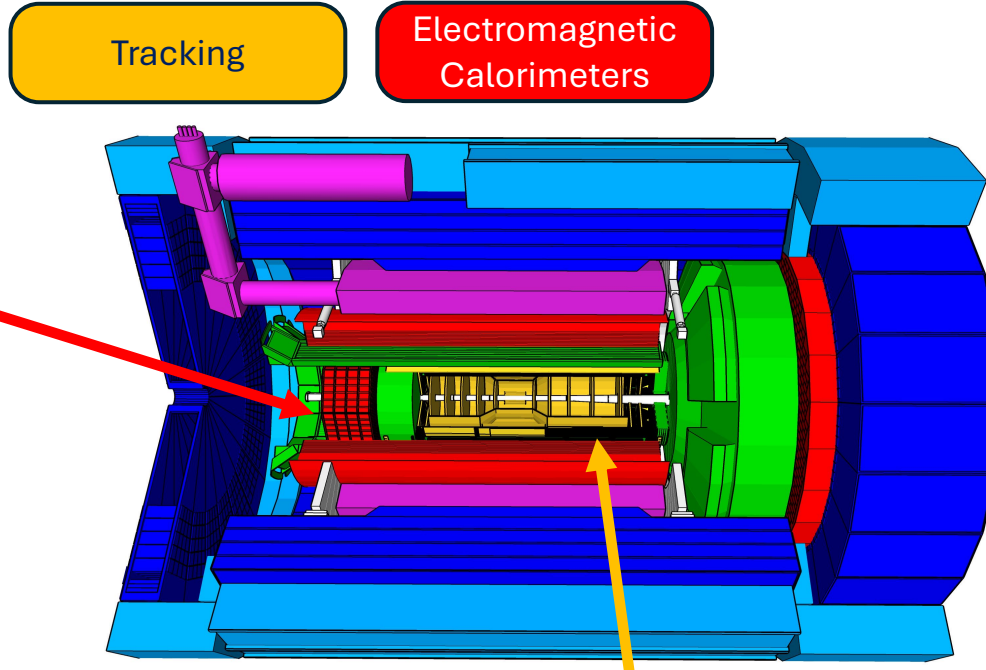
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Laser4EIC



Polarized Electron Gun
1-nC, 30 Hz

Czech Contributions to EIC and ePIC



Endcap EM Calorimeter

- $-3.5 < \eta < -1.7$
- Testing and delivery of PbWO_4 crystals

Electromagnetic Calorimeters

Silicon Vertex Tracker

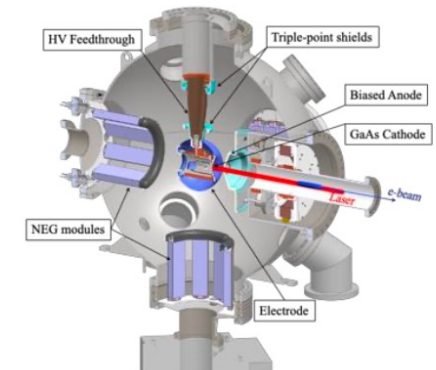
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Laser4EIC



Polarized Electron Gun
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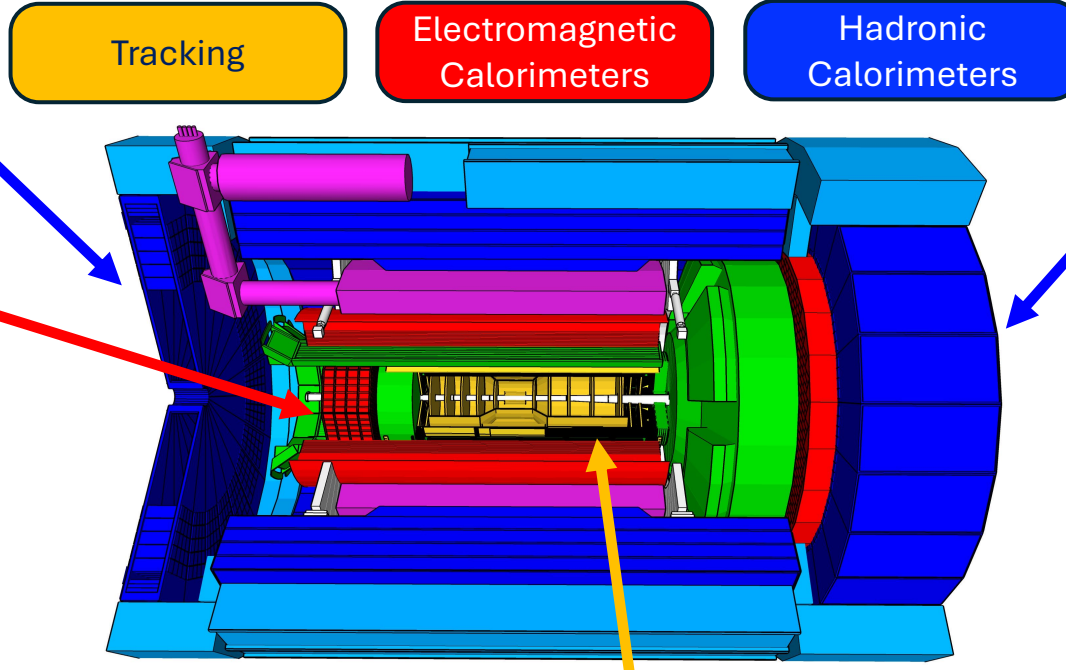
Czech Contributions to EIC and ePIC

Negative HCal (nHCAL)

- $-4 < \eta < -1.2$
- Similar design to LFHCal
- Testing and R&D

Endcap EM Calorimeter

- $-3.5 < \eta < -1.7$
- Testing and delivery of PbWO_4 crystals



Silicon Vertex Tracker

- Uses MAPS technology
- Testing



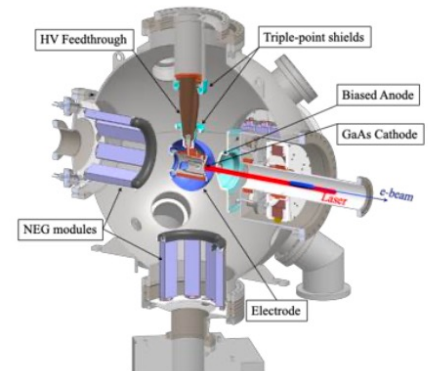
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Forward HCal (LFHCal)

- $1.2 < \eta < 4.4$
- Steel Scintillator Sampling
- Segmented Longitudinally
- Testing and R&D

Laser4EIC



Polarized Electron Gun
1-nC, 30 Hz

Czech Contributions to EIC and ePIC

Negative HCal (nHCAL)

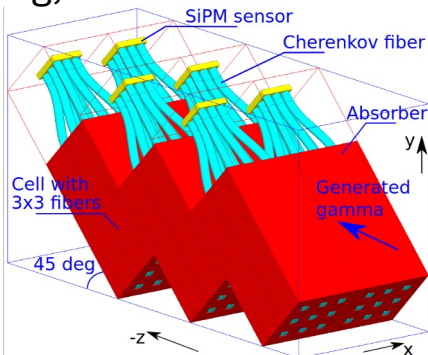
- $-4 < \eta < -1.2$
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Endcap EM Calorimeter

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- Testing and delivery of PbWO_4 crystals

Luminosity monitor

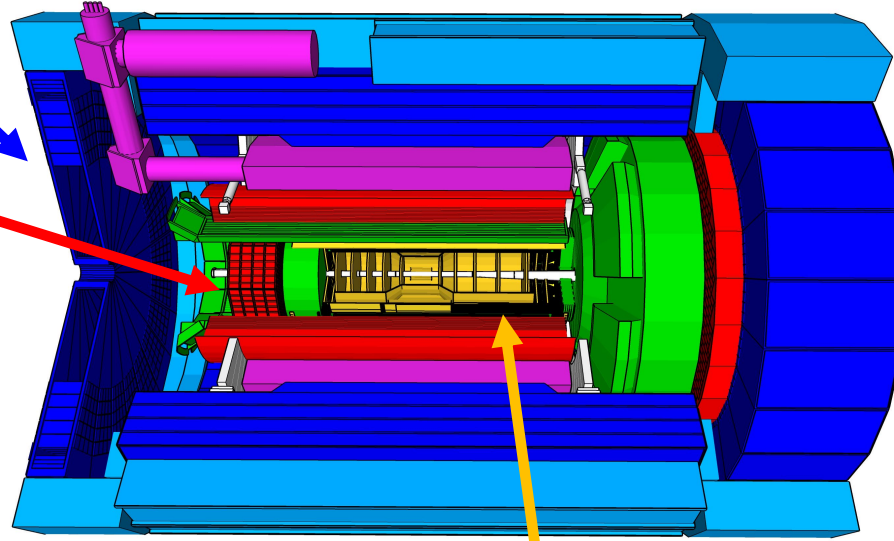
- Far backward
- Tag Bremsstrahlung photons
- Lead absorber embedded with quartz fibers
- Testing, R&D



Tracking

Electromagnetic Calorimeters

Hadronic Calorimeters



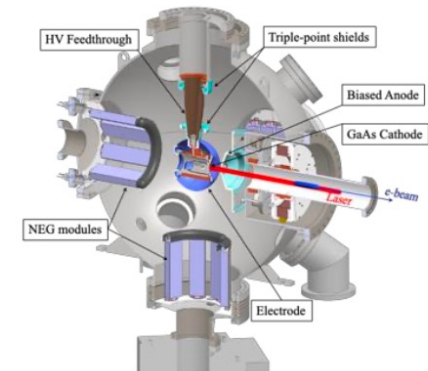
Silicon Vertex Tracker

- Uses MAPS technology
- Testing

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Laser4EIC



Polarized Electron Gun
1-nC, 30 Hz



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Czech Contributions to EIC and ePIC

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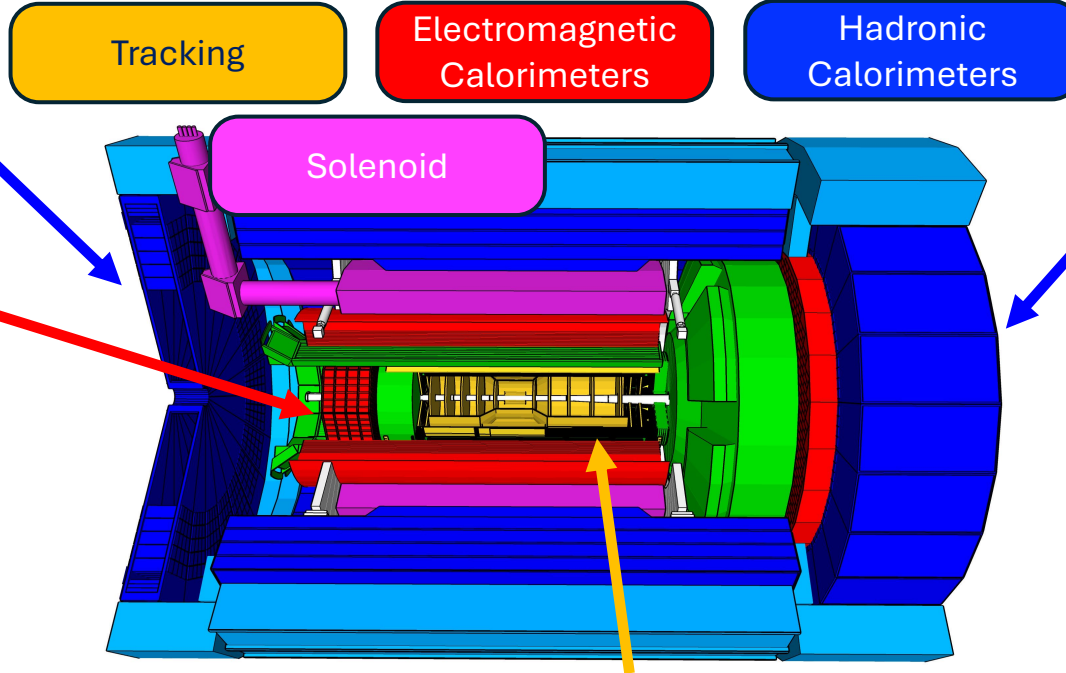
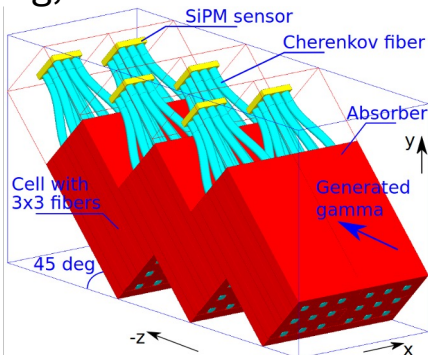
- $-4 < \eta < -1.2$
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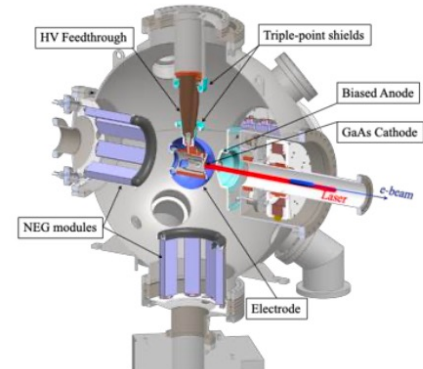
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Laser4EIC



Polarized Electron Gun
1-nC, 30 Hz

Czech Contributions to EIC and ePIC

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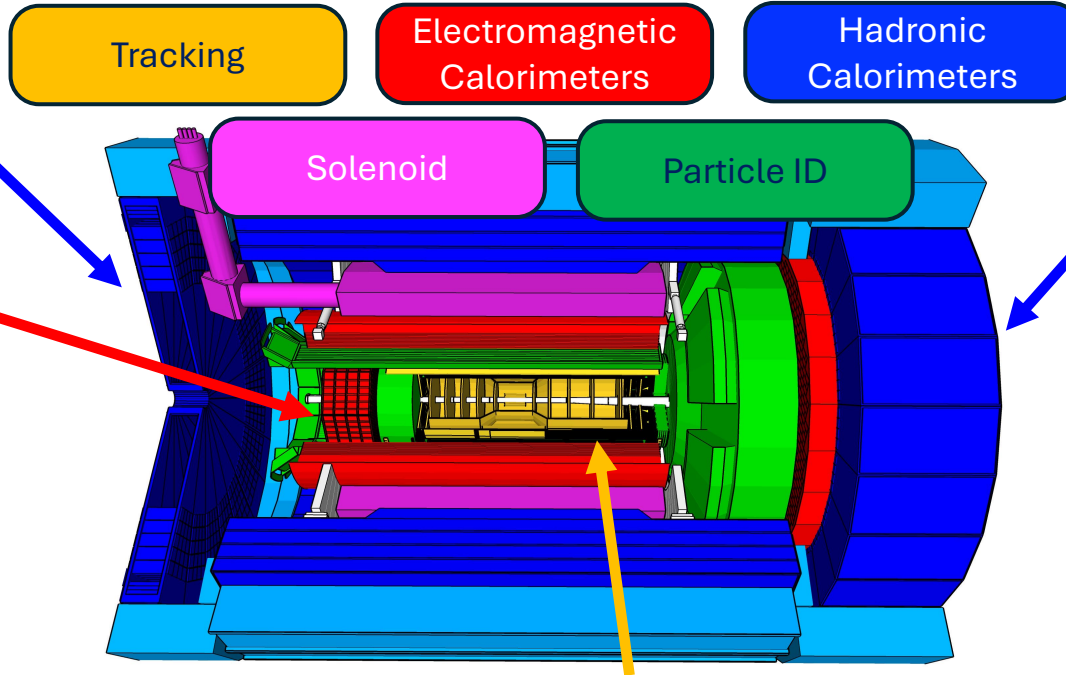
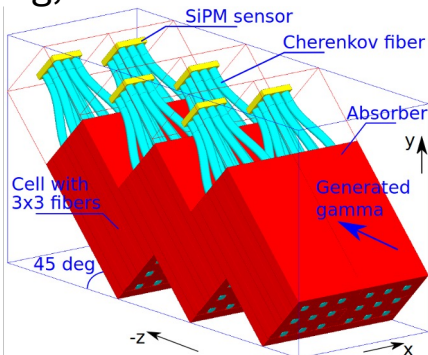
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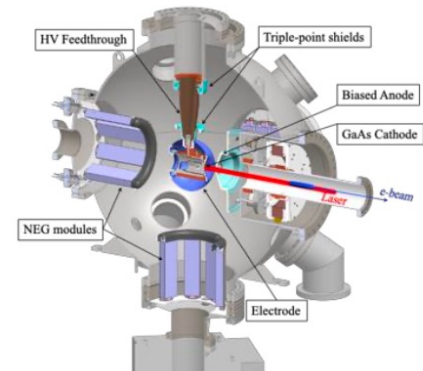
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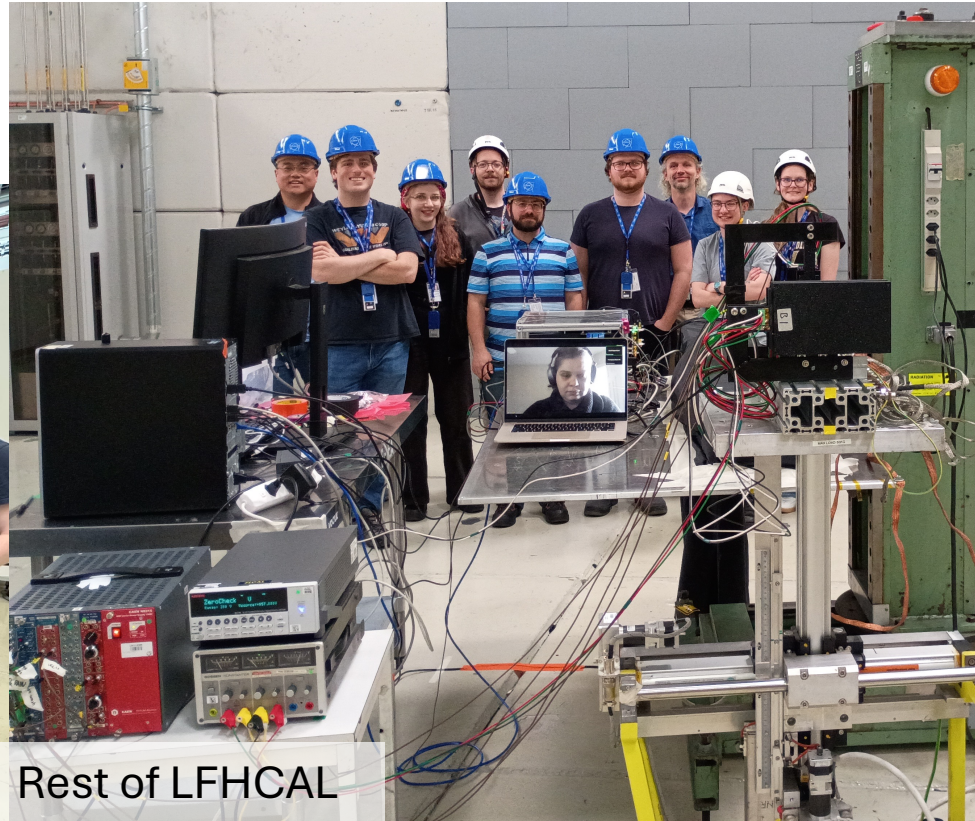
Laser4EIC



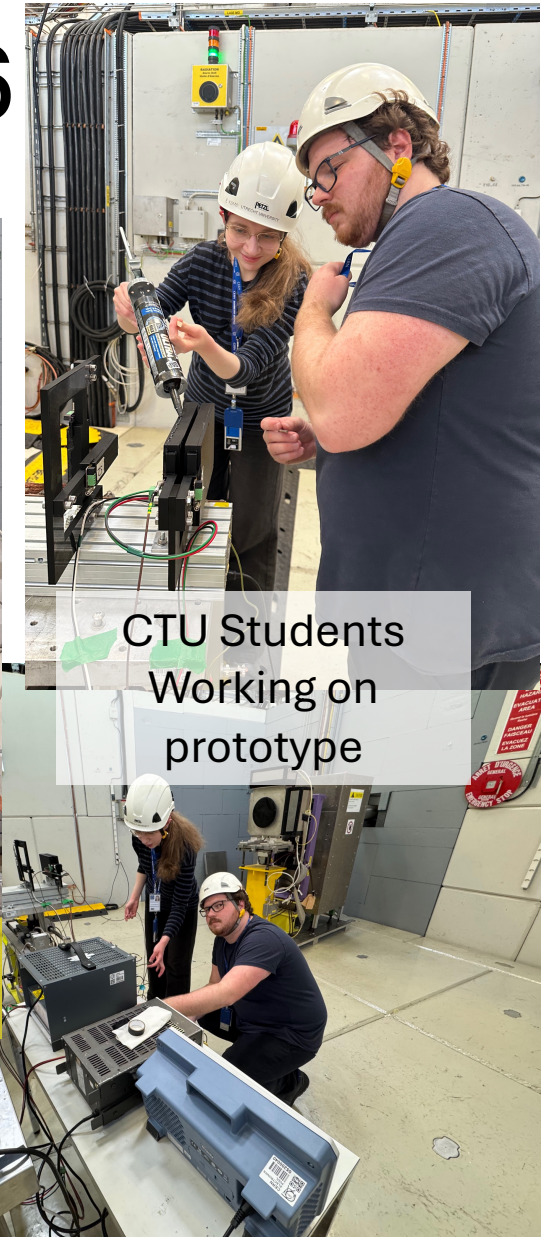
Polarized Electron Gun
1-nC, 30 Hz

LFHCAL Test Beam April 2026

CERN PS facility with first
working prototype of 2 LFHCAL
modules (16 towers)



Rest of LFHCAL
Test Beam Crew



CTU Students
Working on
prototype

LFHCAL Test Beam May 2026

CERN SPS facility with 6 working modules to test shower reconstruction



CTU Students and rest of LFHCAL Test Beam Crew



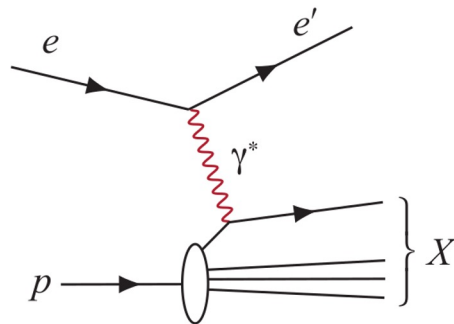
Conclusions

- There are still many open questions about QCD 50 years after it was formulated
- The EIC facility will be the next generation ep collider to answer those questions
 1. Upgrades and builds on the experience from RHIC, HERA and other DIS experiments
 2. High luminosity and ability to collide electrons and ions at various energies
 3. First facility to collide polarized electron beams with polarized proton beams
- The ePIC detector is the tool needed to study QCD and utilize EIC capabilities
 - Covers all angles in azimuth and as much in polar as space allows
 - Full tracking, PID, and calorimetry capabilities to measure scattered electron and hadrons
- Czech Universities and institutes are working on several subsystems
- Lots of tasks ahead and many ways to get involved
 - Getting started: <https://www.epic-eic.org/>
- EIC on track for first run in 2034!

Backup

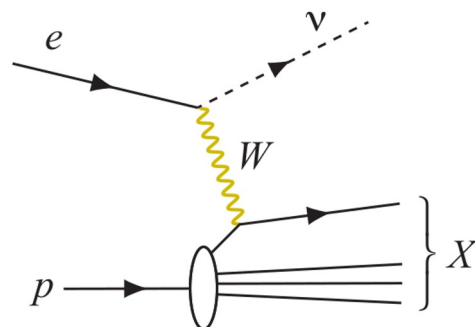
eP processes for the QCD program

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



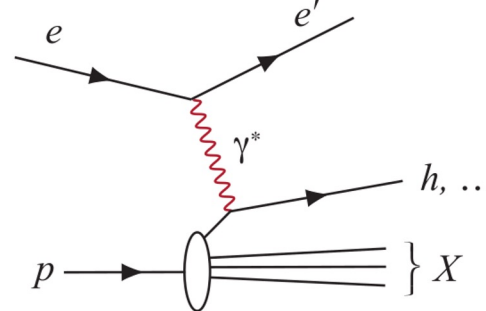
Neutral Current DIS

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



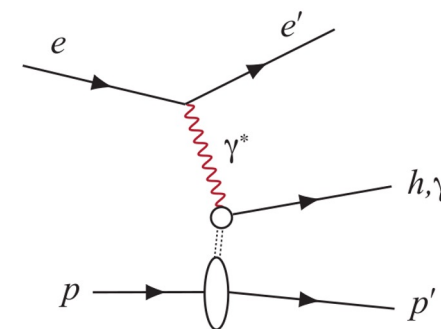
Charged Current DIS

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



Semi-Inclusive DIS

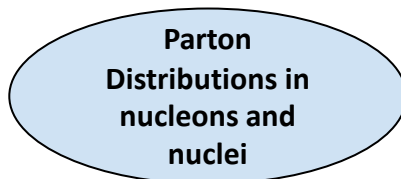
- Precise detection of **scattered electron** in coincidence with at **least 1 hadron**



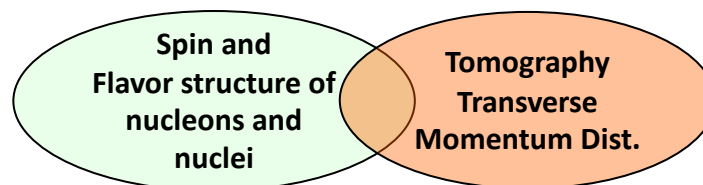
Deep Exclusive Processes

- Detection of **all particles** in event

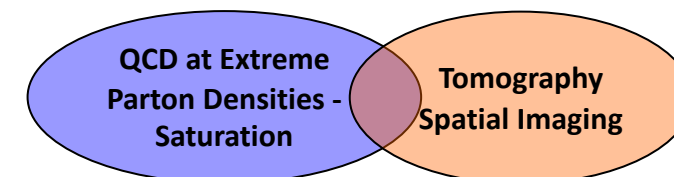
NUCLEI



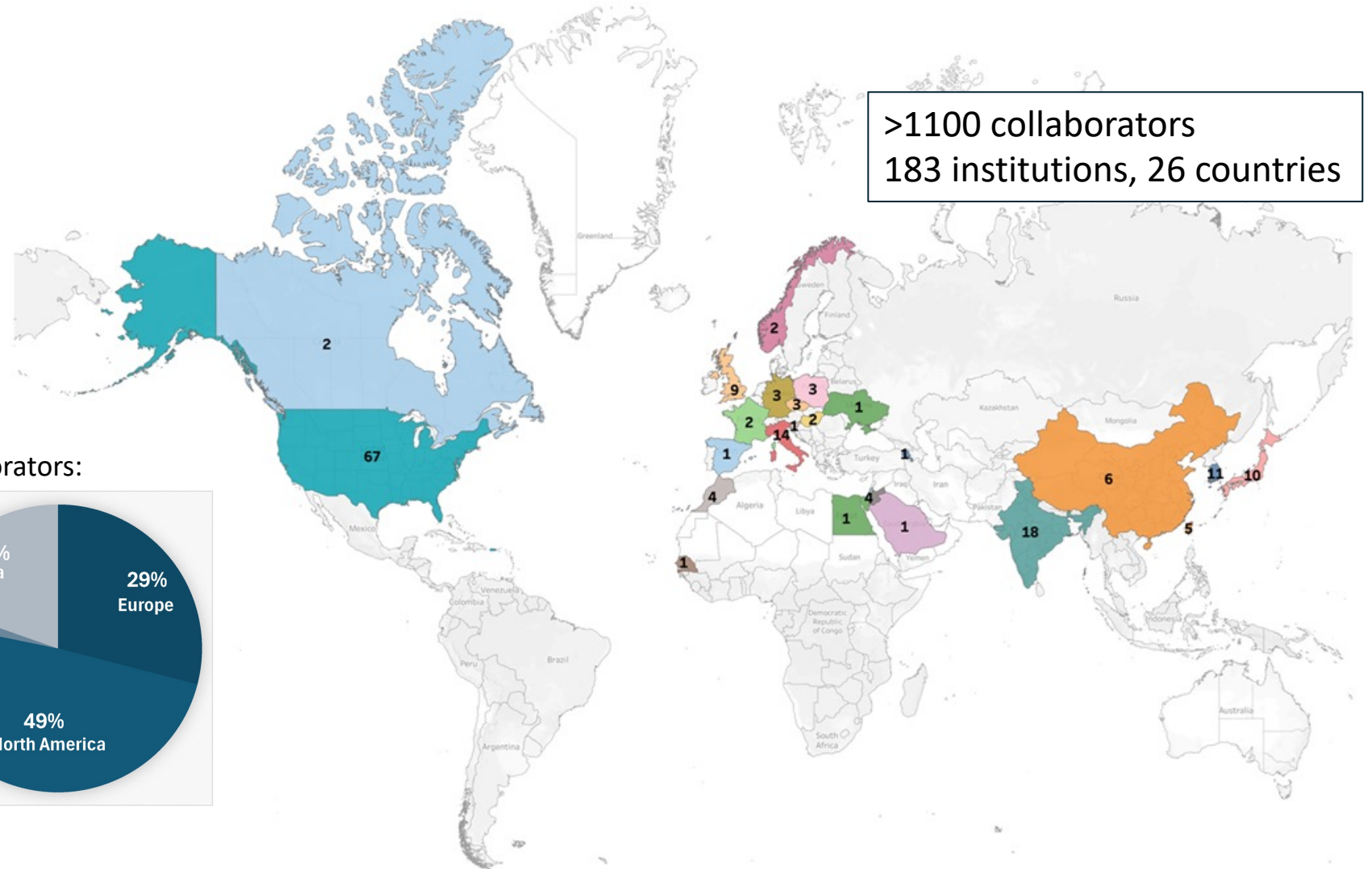
SPIN IMAGING



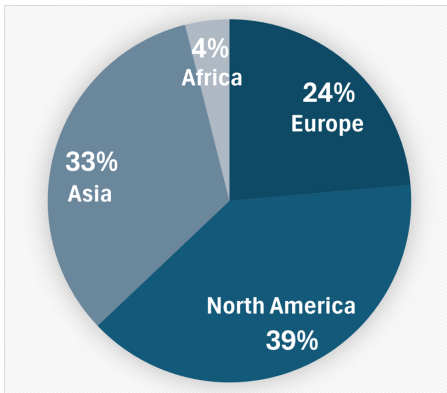
GLUONS MASS IMAGING



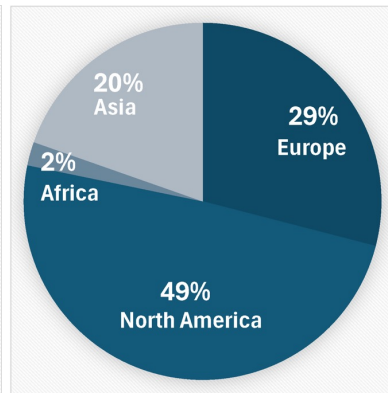
ePIC Collaborators



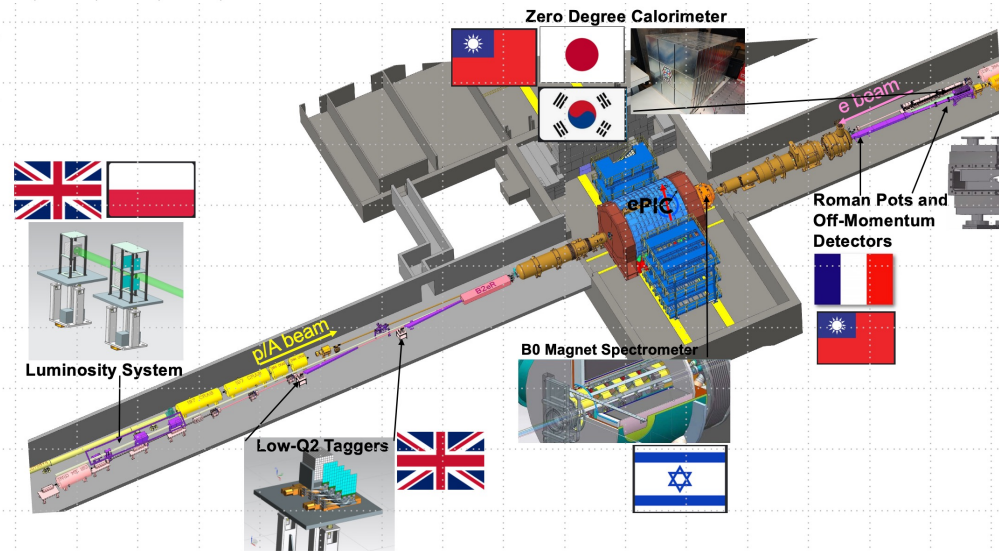
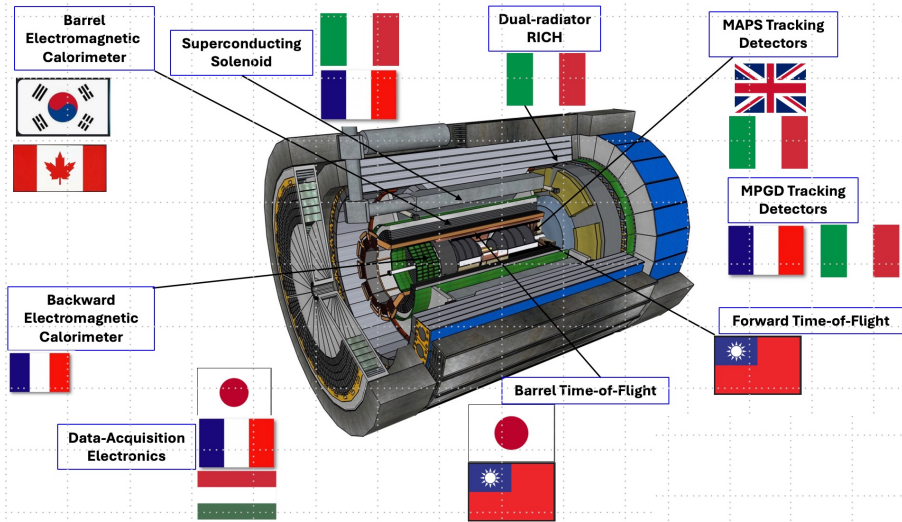
Institutions:



Collaborators:



Contributions by Country



Labor In-Kind contributions



India:
contribution to construction of forward ECal



Czech Republic:
contribution to construction of backward ECal, Low-Q2 tagger, MAPS sensor testing



Germany
contribution to construction of DIRC and design of Barrel ECal AstroPix - Sensors



Poland
Far-forward detector systems and luminosity detector