ECFA

European Committee for Future Accelerators

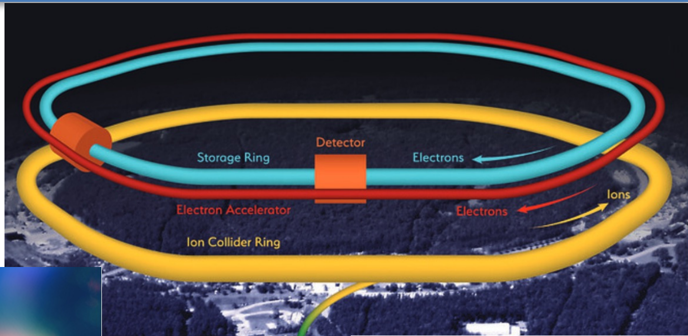
Discussion about European Strategy for INFN

November 6th 2024

The EIC project

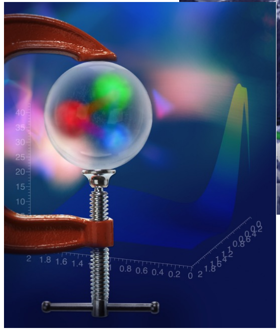
Annalisa D'Angelo, Lucilla Lanza

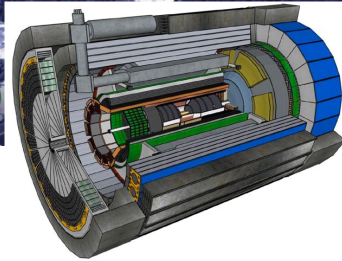
University of Rome Tor Vergata & INFN Rome Tor Vergata Rome – Italy



Outline:

- Physics case: color confinement and strong QCD
- TMD and DVCS – N spin structure and 3D image and the role of the glue
- The ePIC detector
- The Timeline
- The ePIC collaboration



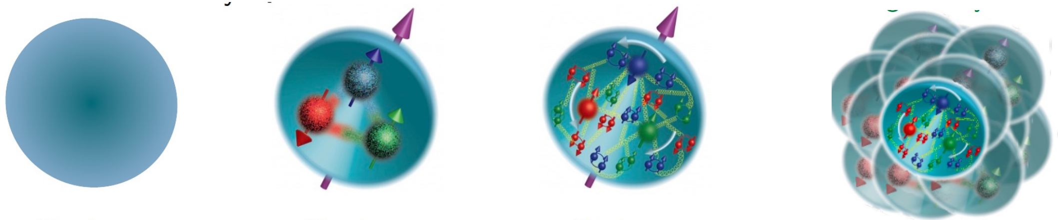


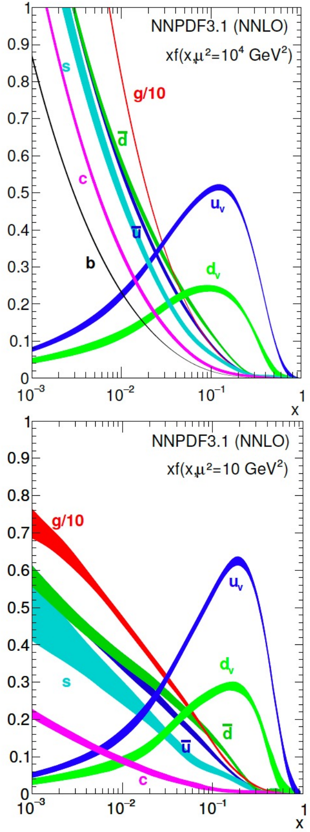
ePIC

Back to the basics of Hadron Physics

Where we are:

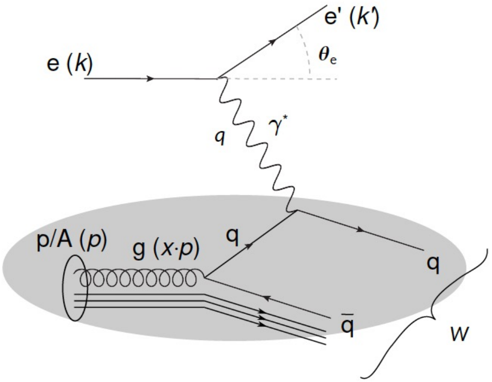
- Elastic lepton scattering determined the nucleon's charge & magnetism distributions in sphere with $\langle r_{ch} \rangle \approx 0.84$ fm
- Largest fraction of energy in proton (x) carried by 3 valence quarks (2u,d), but very small fraction of proton spin
- Nucleons show additional dynamically generated quark-antiquark pairs & gluons carrying low fraction of energy
- Quark & gluon longitudinal momentum fractions have been well mapped out - Nucleon spin & mass have large contributions from quark-gluon dynamics, described by QCD





How did we learn this?

Deep Inelastic Scattering (DIS)



$$Q^2 = s \cdot x \cdot y$$

s	center-of-mass energy squared
Q^2	resolution power
x	the fraction of the nucleon's momentum carried by the struck quark ($0 < x < 1$)
y	inelasticity

- As a probe, electron beams provide unmatched precision of the electromagnetic interaction
- Direct, model independent determination of parton kinematics and spin of physics processes at the leading order
- Additional information obtained indirectly from hadron-collider measurements

History of Nucleon Structure Studies

1950-1960: Does the proton have finite size and structure?

- Elastic electron-proton scattering
  - ✦ the proton is not a point-like particle but has finite size – seen through charge and current distribution in the proton G_E/G_M

Nobel prize 1961- R. Hofstadter

1960-1990: What are the internal constituents of the nucleon?

- Deeply inelastic scattering
  - ✦ discover quarks in 'scaling' of structure function - measure their momentum and spin distributions

Nobel prize 1990 - J. Friedman, H. Kendall, R. Taylor

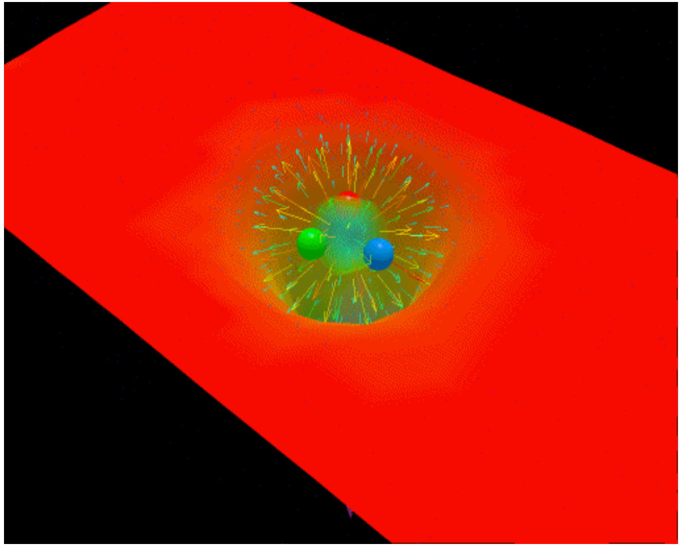
Today: Unraveling a 3-D image of the quark and gluon distributions, including mass, spin, and pressure distributions

Critical QCD Questions Addressed

- How do properties of colorless hadrons emerge from the confined dynamics of colored quarks and gluons?

$$\mathcal{L}_{\mathrm{QCD}} = \sum_q \bar{\psi}_q \left(i\not{\partial} - g\not{A} + m \right) \psi_q - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$

QCD is the most complex part of the Standard Model



Derek B. Leinweber – University of Adelaide

At Nucleon mass scale (1 GeV), dynamics is highly nonlinear and leads to **confinement** of partons.
How do N mass / size / spin emerge from these dynamics?

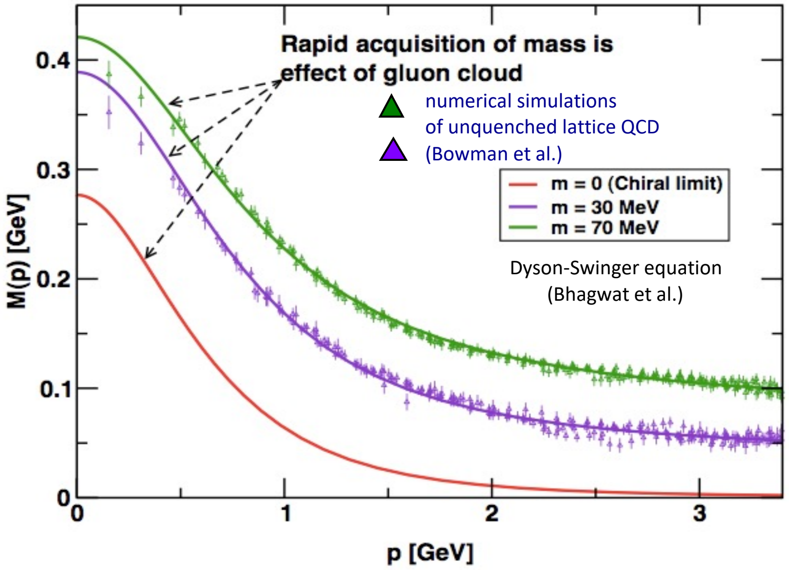
“Nucleons are the stuff of which our world is made.

*As such they must be **at the center of any discussion of why the world** we actually experience **has the character it does.**”*

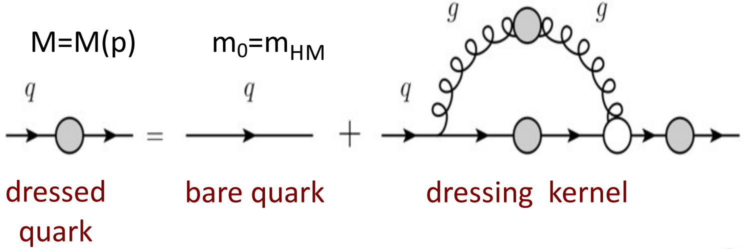
Nathan Isgur, 2000

Critical QCD Questions Addressed

- How do massless quarks acquire mass?

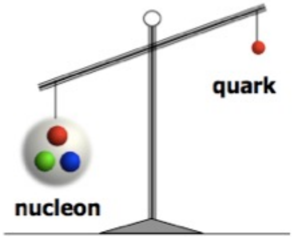


Effective quark mass depends on its momentum



<u>mass composition</u>

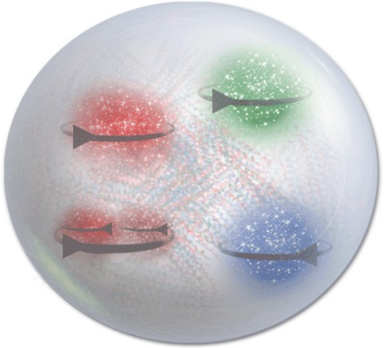
<2%	Higgs mechanism
>98%	non-perturbative strong interaction

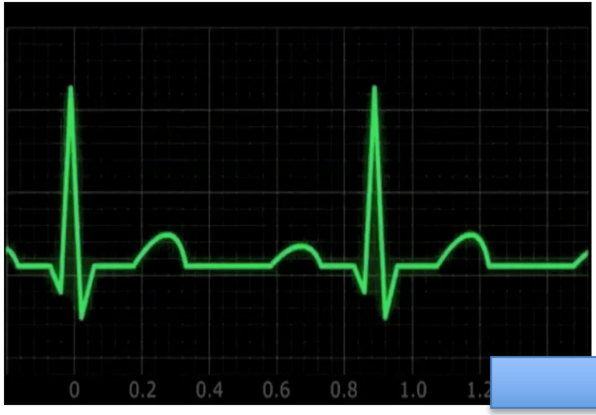


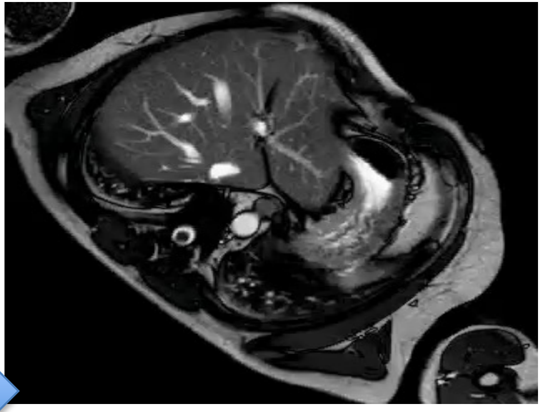
Almost all the nucleon mass comes from the energy spent to bind the quarks inside it!

Critical QCD Questions Addressed

- How are the quarks and gluons, and their intrinsic spins distributed in space & momentum inside the nucleon? What is the role of the angular momentum ?







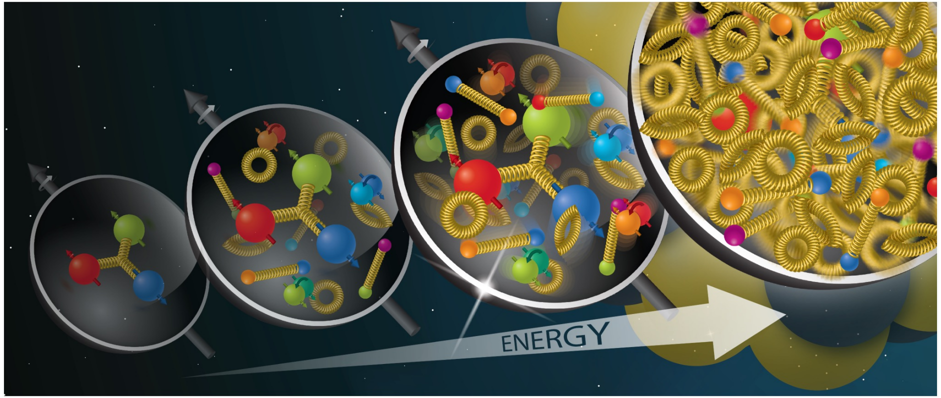
→ **SIDIS and TMDs measurements toward a 3D imaging of the proton**

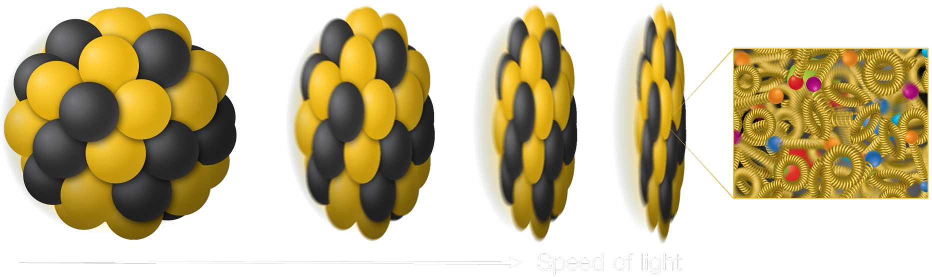
Transverse Momentum Distributions contain information about longitudinal and transverse motion of partons

Critical QCD Questions Addressed

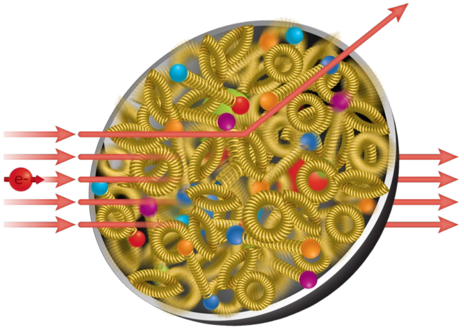
- **Where** does **gluon saturation** set in **? Universal gluonic matter** at high density **? quark-gluon** interactions in **nuclear matter ?**

There are hints and theory predictions that protons, neutrons, and nuclei accelerated close to the speed of light will appear (when observed with a high energy probe) as **dense “walls” of gluons**.





A high intensity electron beams to search for evidence of gluon saturation.



Critical QCD Questions Addressed

ePIC

- How do properties of colorless hadrons emerge from the confined dynamics of colored quarks and gluons?

  → **Measure the Q^2 dependence of hadrons electrocouplings and form factors**

- How do massless quarks acquire mass?

  → **Access the Energy - Momentum Tensor and the Gravitational Form Factors**

- How are the quarks and gluons, and their intrinsic spins distributed in space & momentum inside the nucleon? What is the role of the angular momentum ?

  → **SIDIS and TMDs measurements toward a 3D imaging of the proton**

- How is color confinement realized in the force and pressure distributions and stabilize nucleons?

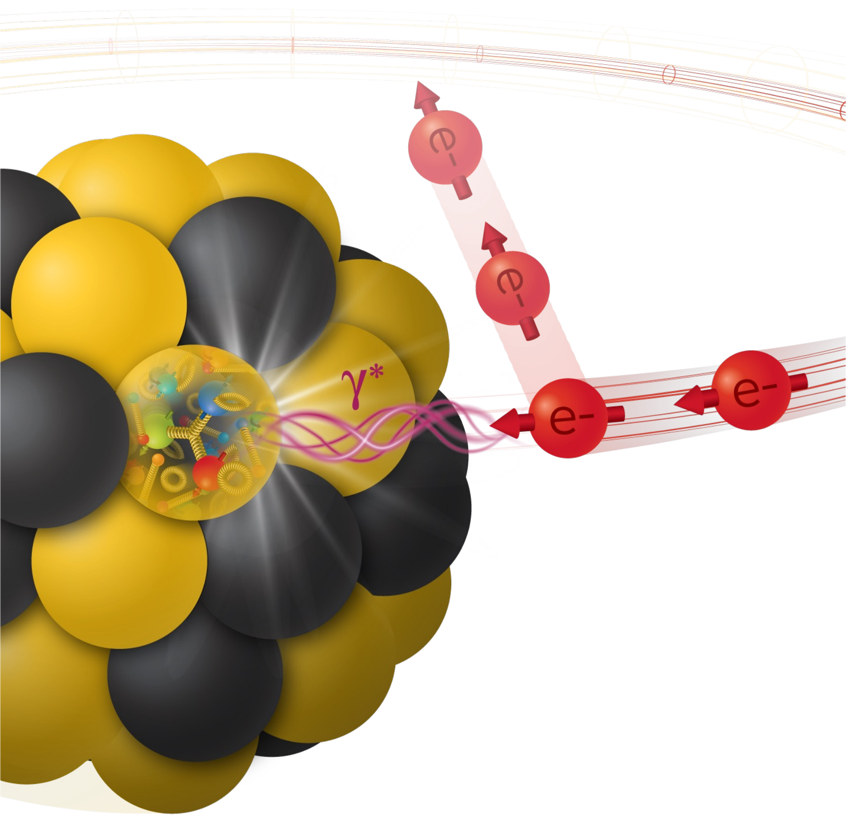
  → **Study GPDs and their moments from DVCS**

- Where does gluon saturation set in?

  → **Study deep processes on Nuclei**

The EIC scientific program addresses all these questions

QCD Exploration at EIC



At the Electron-Ion Collider (EIC), we'll study how the smallest building blocks of matter — the quarks and gluons that make up protons and neutrons — build up the structure and properties of all visible matter

QCD Exploration at EIC

REQUIREMENTS

- Access to gluon dominated region and wide kinematic range in x and Q^2
- Access to spin structure and 3D spatial and momentum structure
- Accessing the highest gluon densities
- Studying observables as a function of x, Q^2, hadronic flavour, …

THE EIC COLLIDER PROVIDES

- Large center-of-mass energy range:
  $\sqrt{s}$ = 21 -140 GeV
- Polarized electron, proton and light nuclear beams
  ≥ 70%
- Nuclear beams, the heavier the better (from H to U)
- High luminosity (100 x HERA): $10^{33\text{-}34}$ cm^{-2} s^{-1}

The Path to the EIC Project

2010 "Gluons and the quark sea at high energies: distributions, polarization, tomography", INT - Seattle, Sept 13 - Nov 19 2010, arXiv:1108.1713

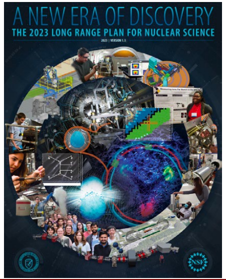
2012 - White Paper Electron Ion Collider: the Next QCD Frontier", E.P.J. A52 (16) 268, arXiv:1212.1701 - 1200 citations on Inspire

2015 Long Range Plan recommendations

2018 Assessment by the US National Academy of Science "The Committee finds that the science that can be addressed by an EIC is **compelling**, **fundamental** and **timely**"

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

arXiv:2103.05419



2023 NSAC - Long Range Plan

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

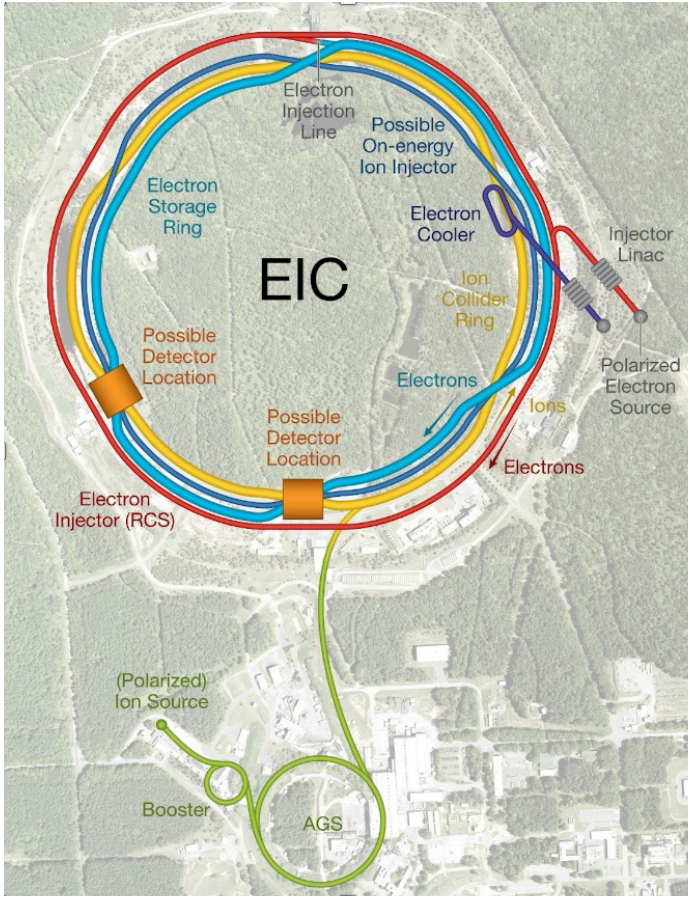
EIC @ BNL

The ~$1.7-2.8 billion Electron-Ion Collider (EIC) will be funded primarily by the U.S. Department of Energy's Office of Science, with contributions from New York State and other science agencies in the U.S. and around the world.

U.S. DEPARTMENT OF ENERGY | Office of Science

NEW YORK STATE

EIC @ BNL



The Electron-Ion Collider (EIC) will make use of existing components of Brookhaven's Relativistic Heavy Ion Collider (RHIC), including:

- Its ion sources
- Pre-accelerator chain
- Superconducting magnet ion storage ring.

In addition:

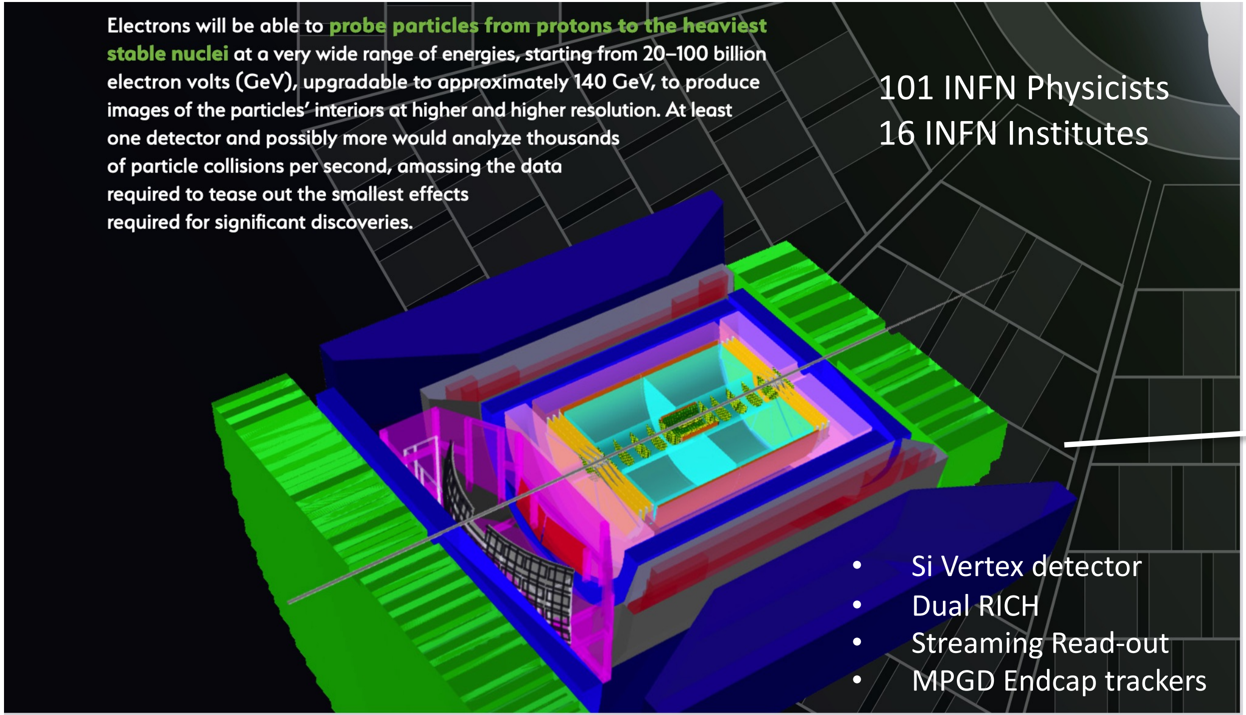
- New electron accelerator ring
- Electron storage ring inside the existing collider tunnel

Collisions can take place at points where the stored ion and electron beams cross.

EIC @ BNL

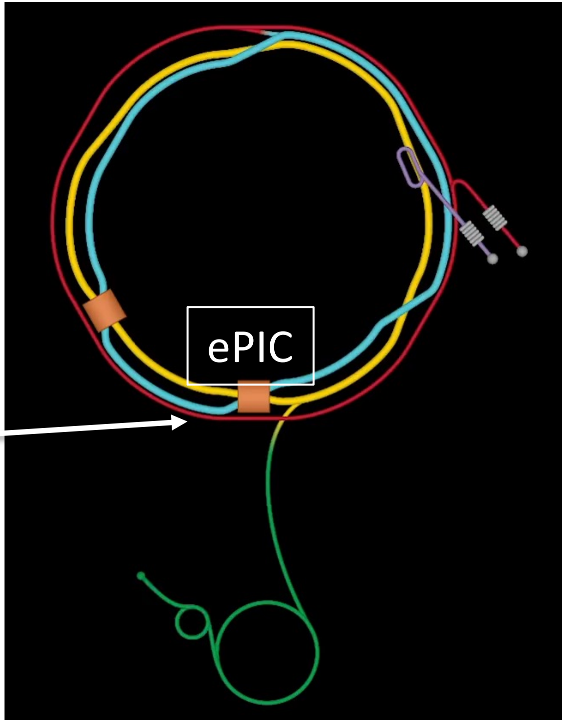
E_e =5-18 GeV

Electron-Ion Collider



101 INFN Physicists
16 INFN Institutes

- Si Vertex detector
- Dual RICH
- Streaming Read-out
- MPGD Endcap trackers

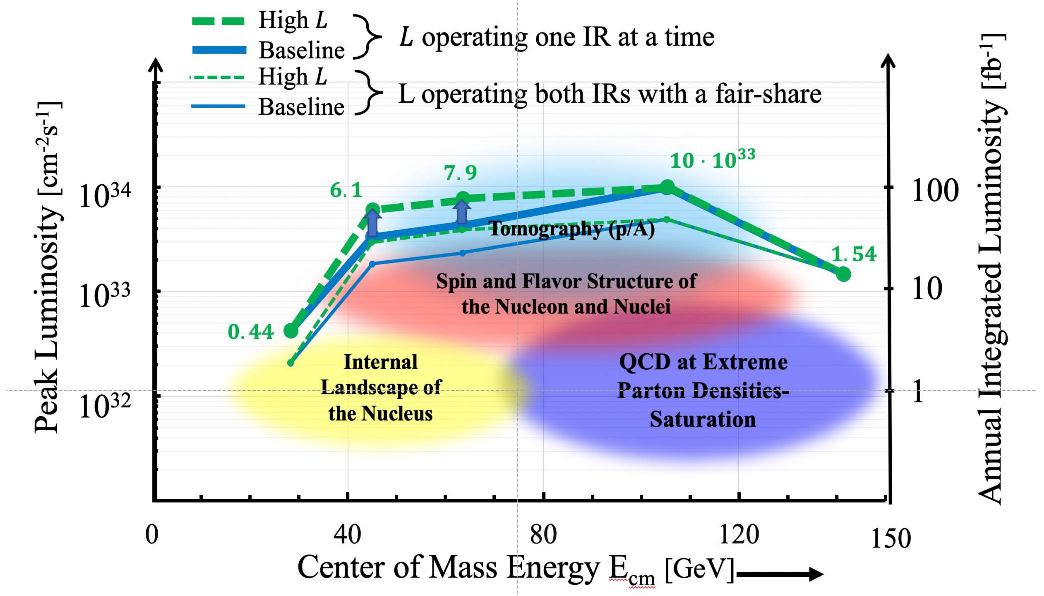


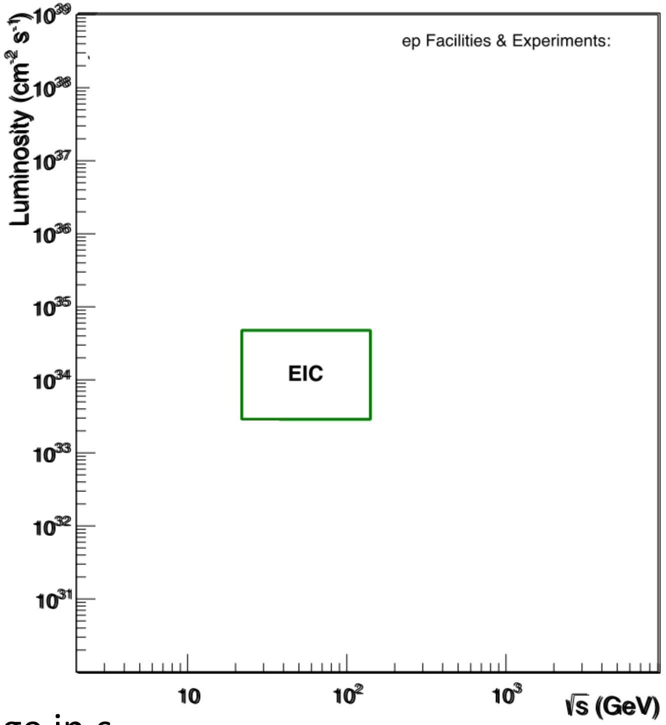
EIC @ BNL

E_e =5-18 GeV

$\sqrt{s}$= 28 - 140 GeV

Electron-Ion Collider



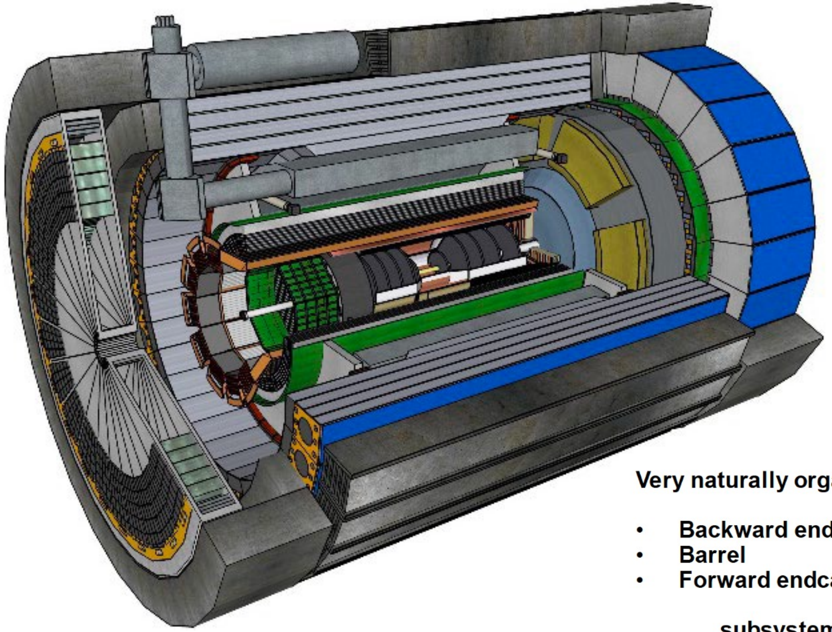


If we ask for:

- high luminosity (10^{33}-10^{34}cm^{-2}s^{-1}) and wide range in *s*
- polarized electron & light-ion beams
- large variety of ion beams

EIC stands out as unique facility

The ePIC detector



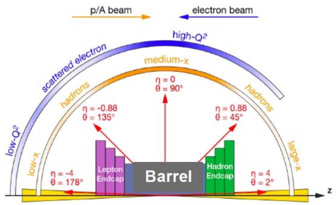
Very naturally organized in:

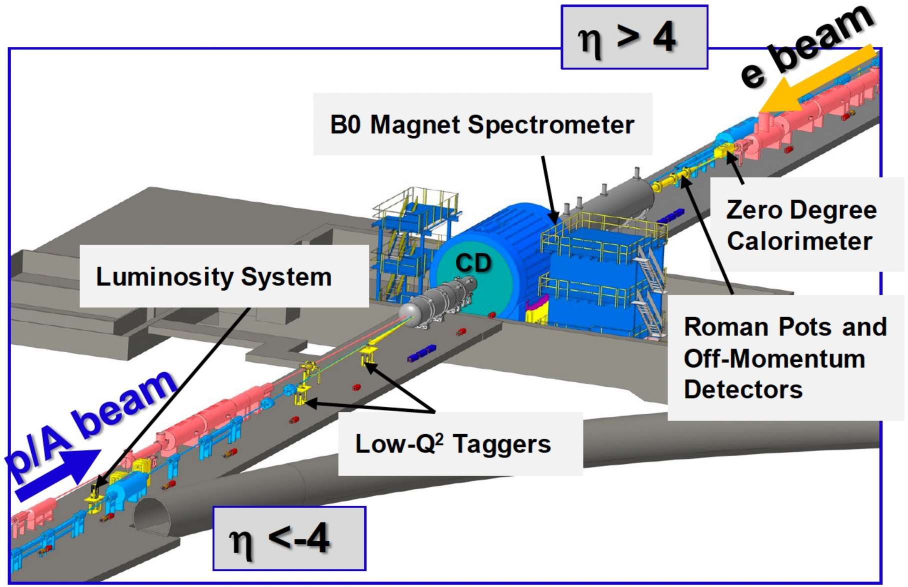
- Backward endcap
- Barrel
- Forward endcap

subsystems

$$-4 < \eta < 4$$

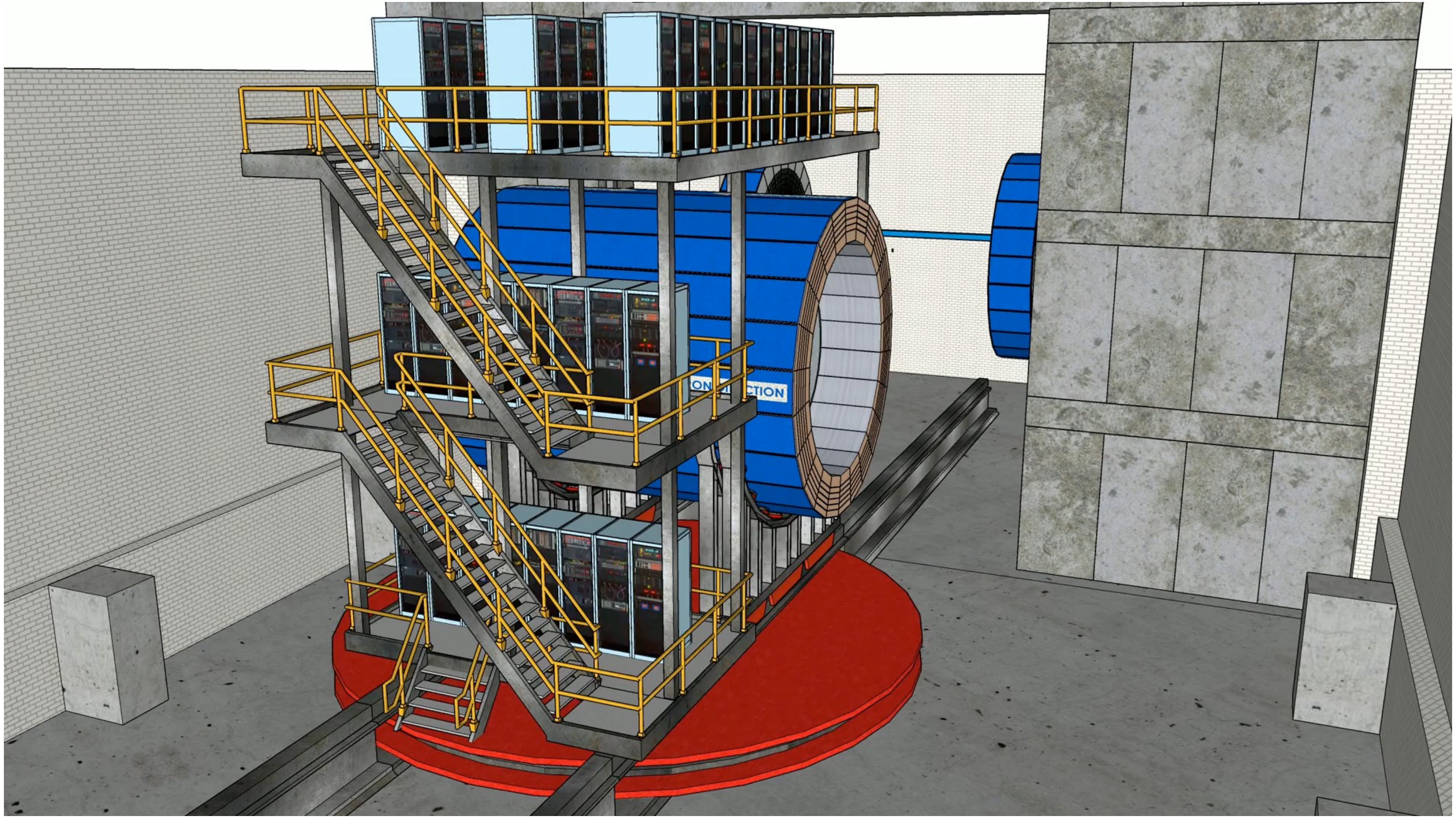
The Central Detector





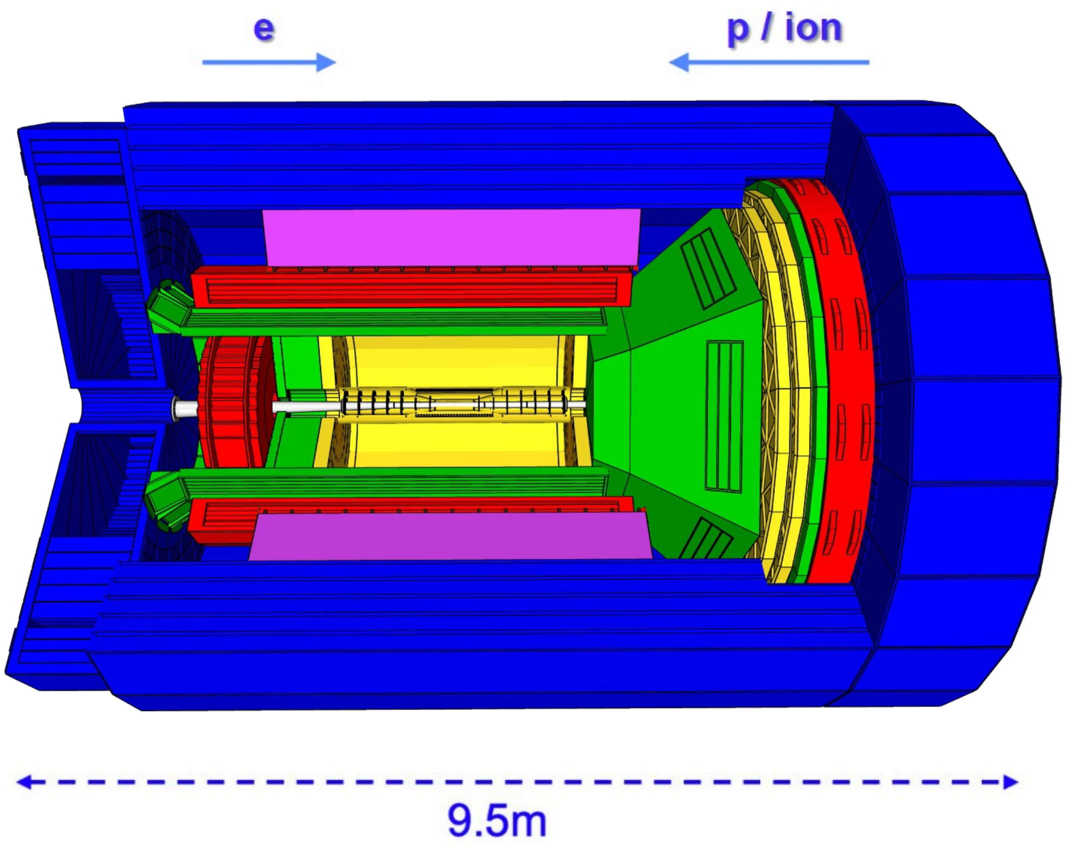
The Far Forward and Far Backward Detector

The ePIC detector



The ePIC detector

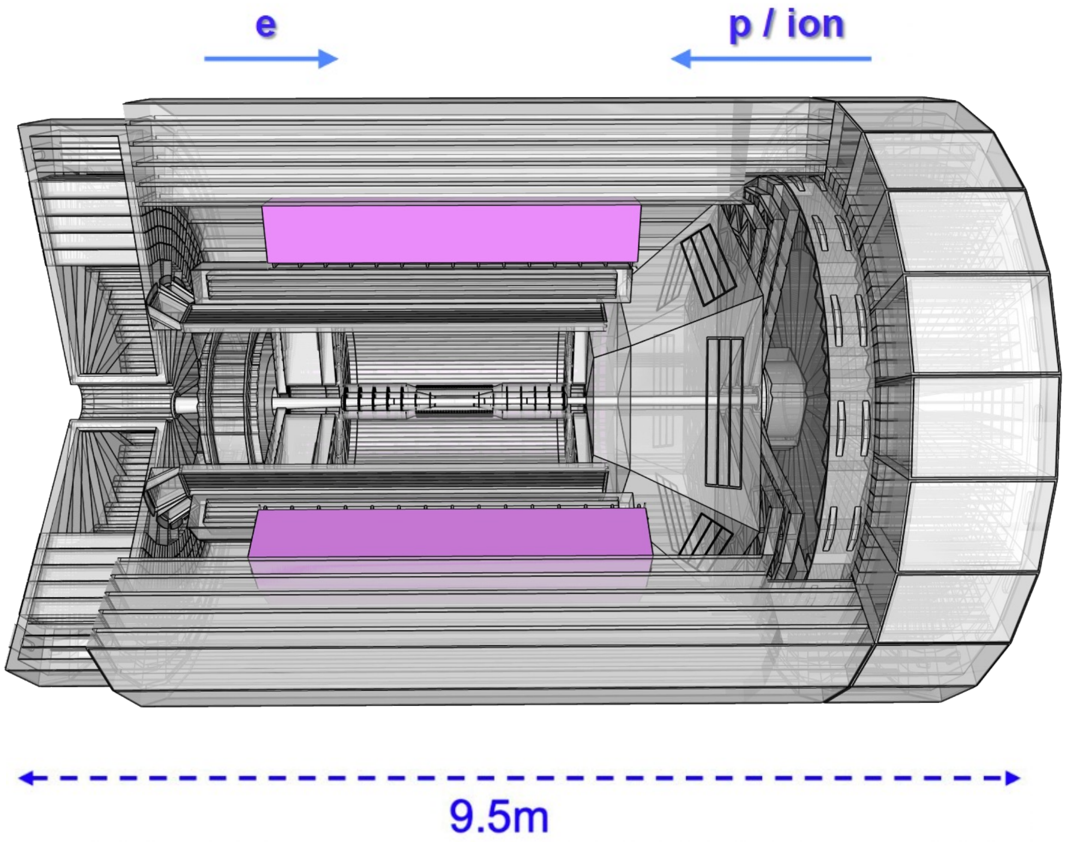
The Central Detector



The ePIC detector: Detector Magnet

Superconducting Solenoid Magnet

Parameter	Value
Coil length	3512 mm
Warm bore diameter	2840 mm
Cryostat length	< 3850 mm
Cryostat outer diameter	< 3540 mm

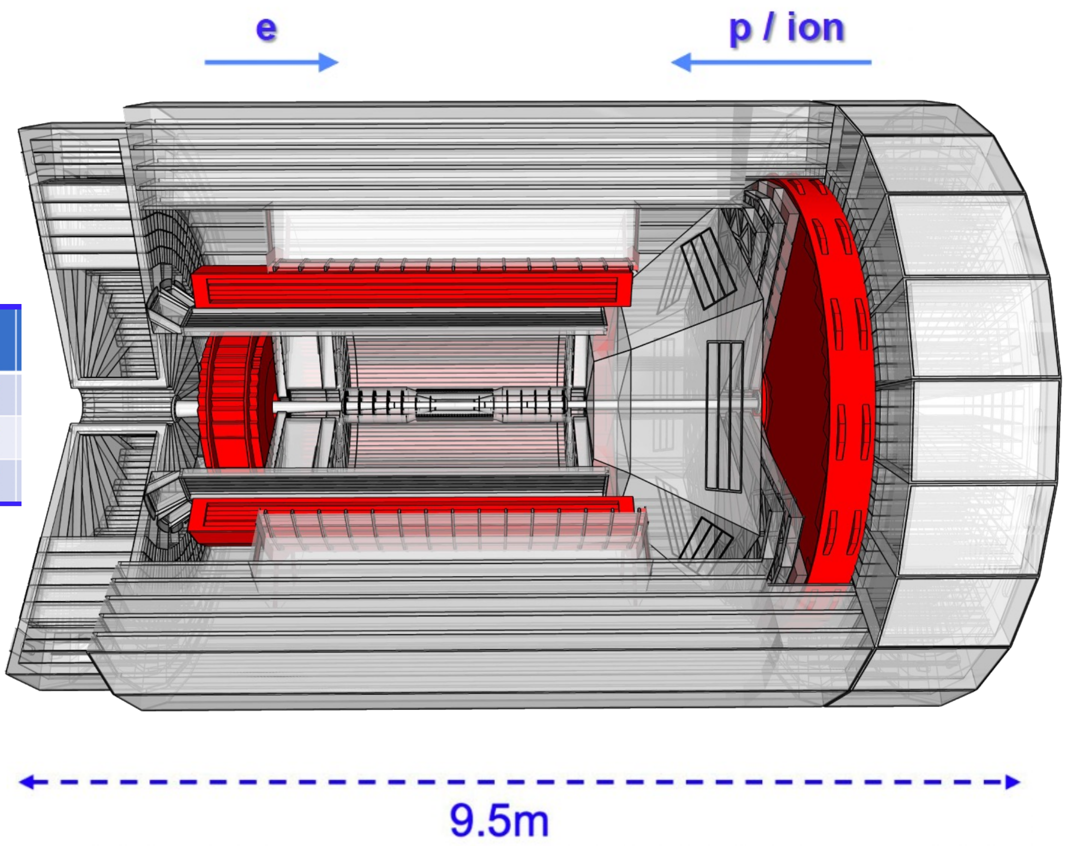


Parameter	Value	Comment
Central Field B_0	2.0 T	Magnetic Field Properties
Lowest operating field	0.5 T	
Field Uniformity in FFA	12.5 % ± 100 cm around center 80 cm radius	
Projectivity in RICH Area	< 0.1 (mrad@30GeV/c) < 10 T/A/mm² From Z = 180 cm to 280 cm	

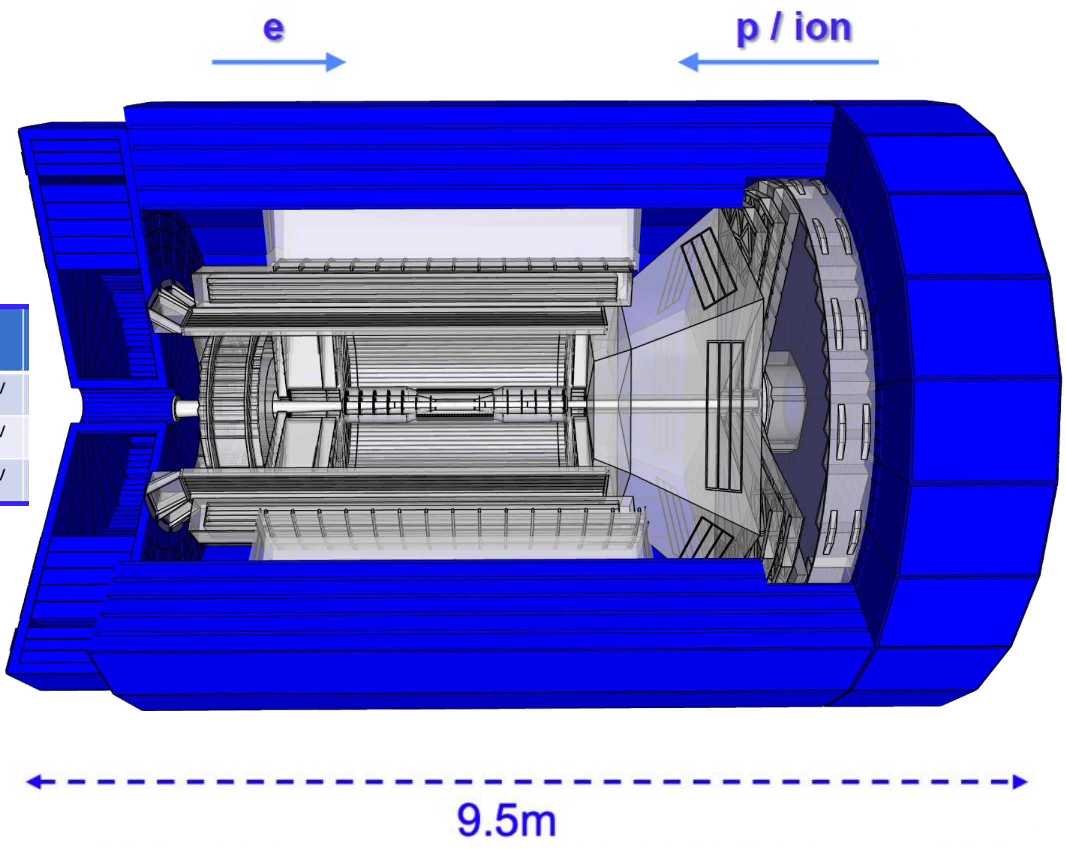
Reference field value: 1.7 T

The ePIC detector: EM Calorimeter

	σ_E/E	E range, GeV
e-endcap	$\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$	0.05–18 GeV
Barrel	$\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$	0.05–50 GeV
h-endcap	$\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$	0.1–100 GeV

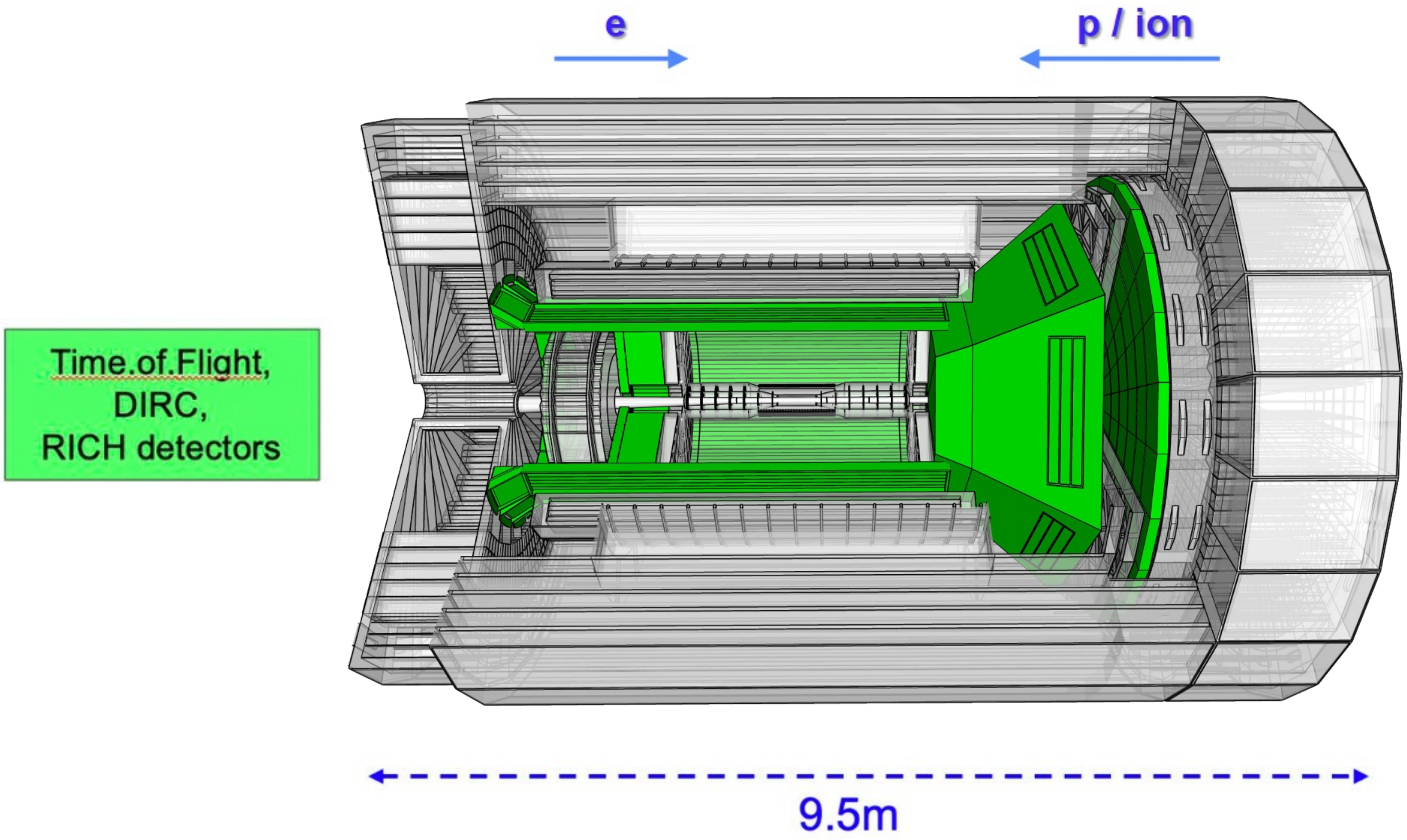


The ePIC detector: Hadronic Calorimeter



	σ_E/E	E range, GeV
e-endcap	$\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$	0.05–18 GeV
Barrel	$\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$	0.05–50 GeV
h-endcap	$\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$	0.1–100 GeV

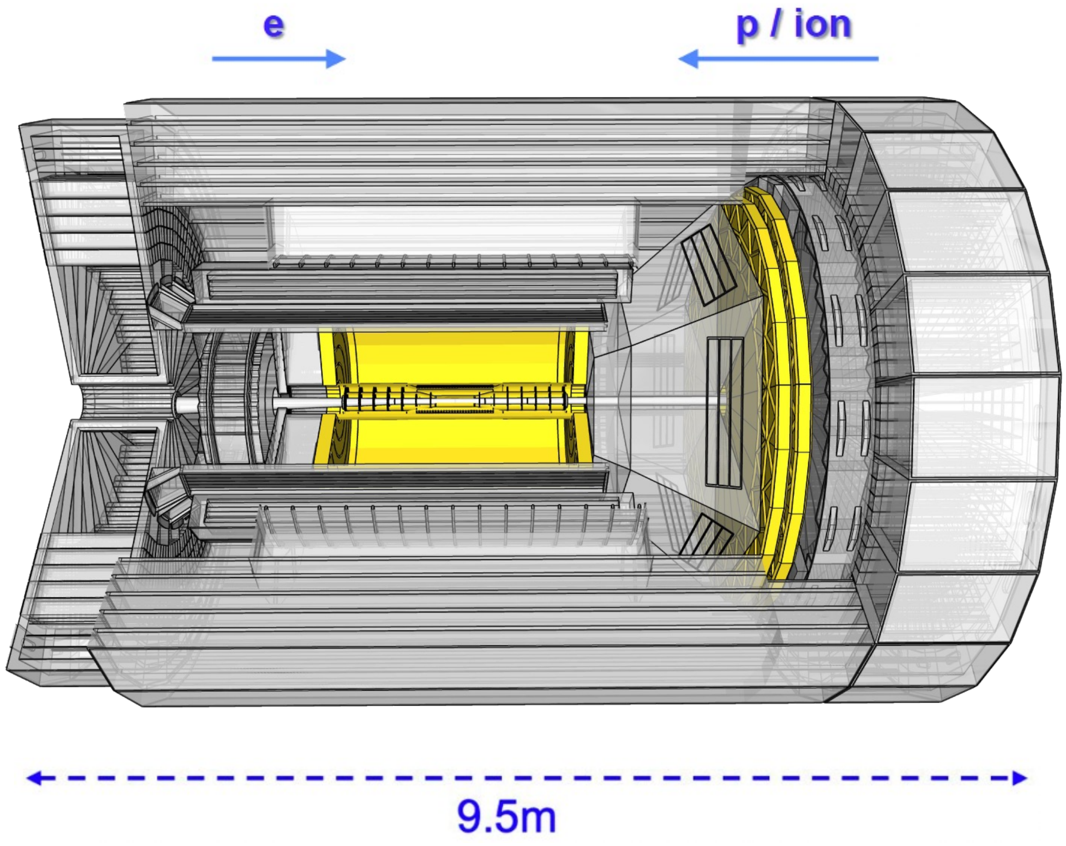
The ePIC detector: Particle ID Detector



The ePIC detector: Tracking Detectors

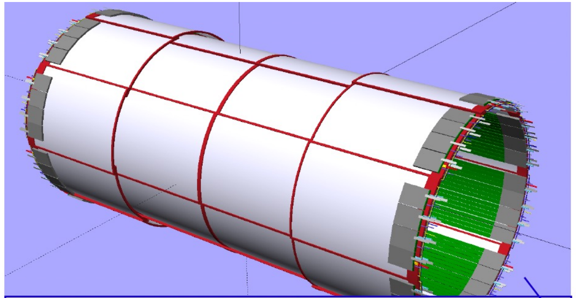
Components:
- SVT
- MPGD trackers

SVT:
- Fine space resolution < 20 μm
- Five cylindrical layers in the barrel and five disks in each endcap



MPGD trackers:
- Good time resolution (10 ns)
- Cylindrical **MICROMEGAS**
- Planar **μR-WELL with GEM pre-amplification**

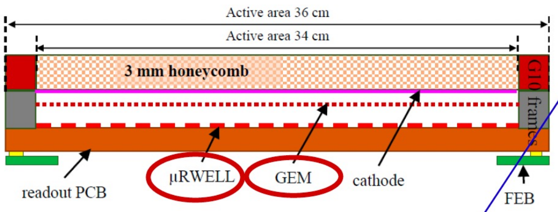
The ePIC MPGD Tracking

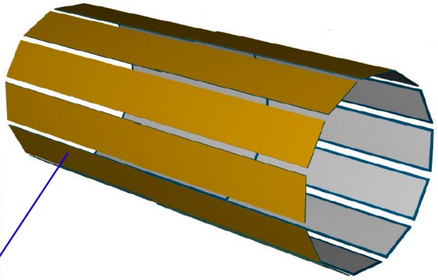


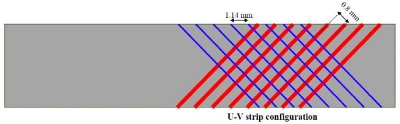
Cylindrical MICROMEGAS

- Successful implementation at CLAS12 (Jlab)
- A single module PCB readout design, with two curvature radii (55 cm and 57.5 cm)
- Overlaps in phi and z allow for hermeticity
- Front end boards (FEBs) on system edges to reduce material budget

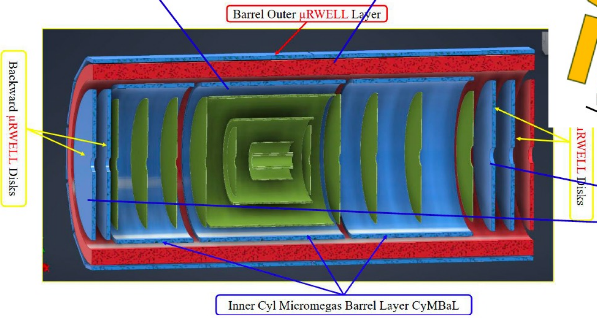
2-D readout for MPGDs in ePIC

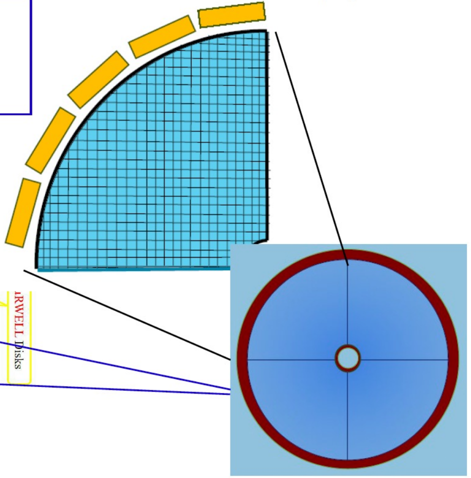




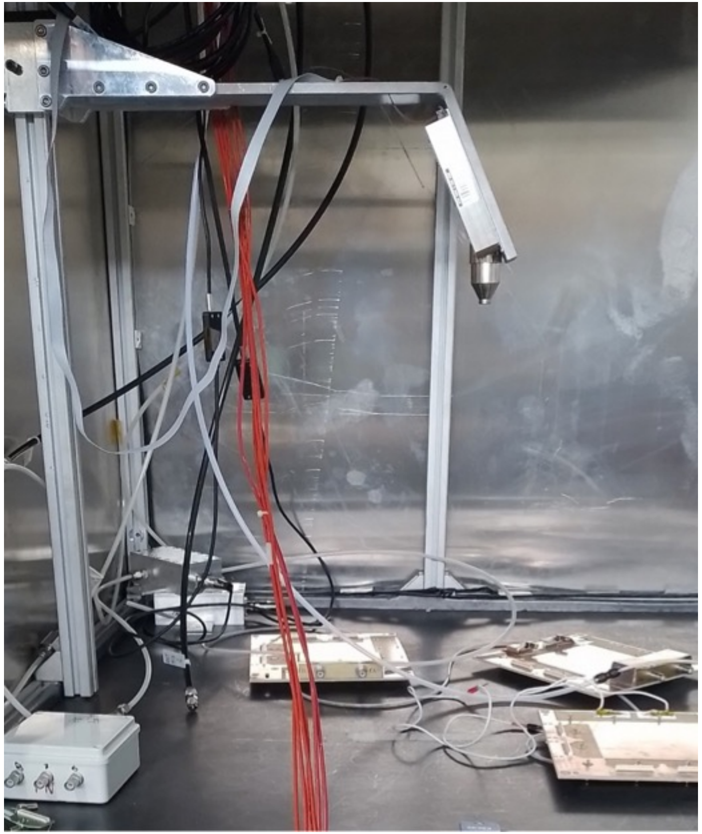


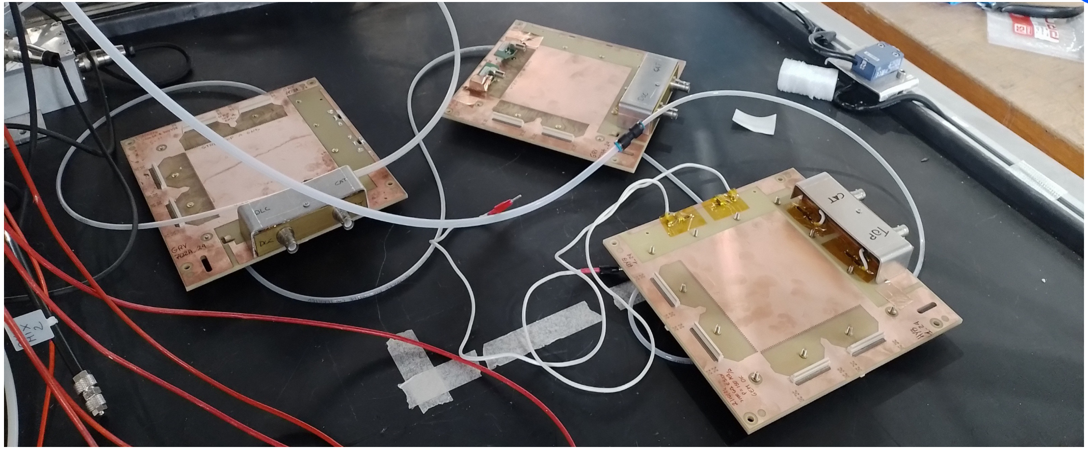
µR-WELL with GEM preamplification layer





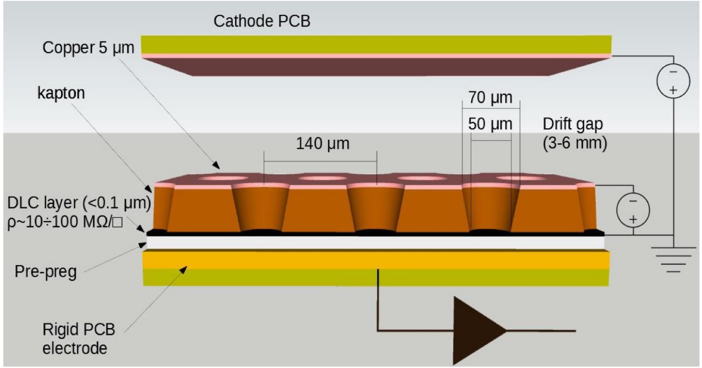
The ePIC MPGD Tracking



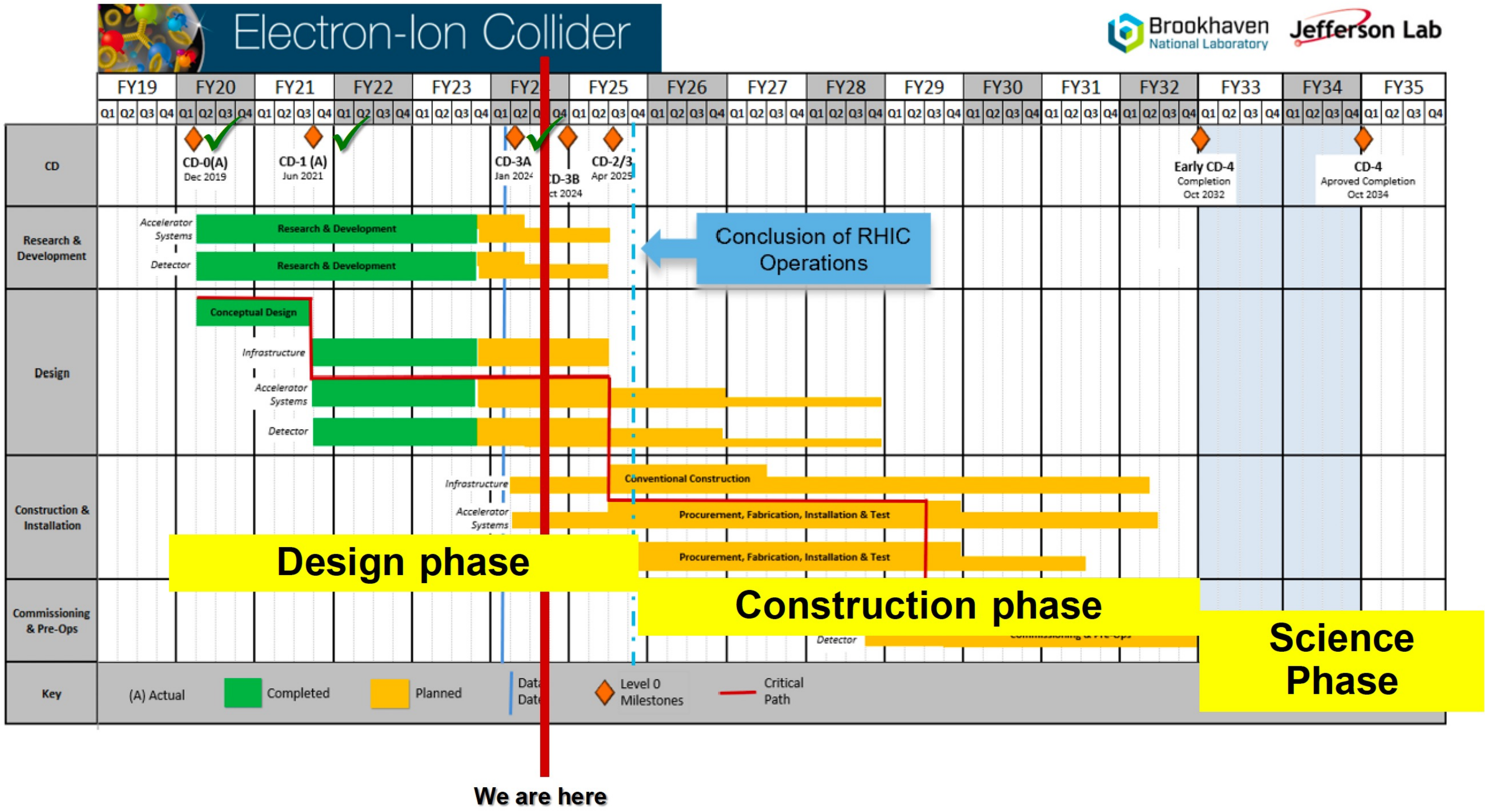


Test with Cosmic Rays made in November 2024 @ LNF

G. Bencivenni et al., The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD, 2015 JINST 10 P02008



The ePIC Schedule



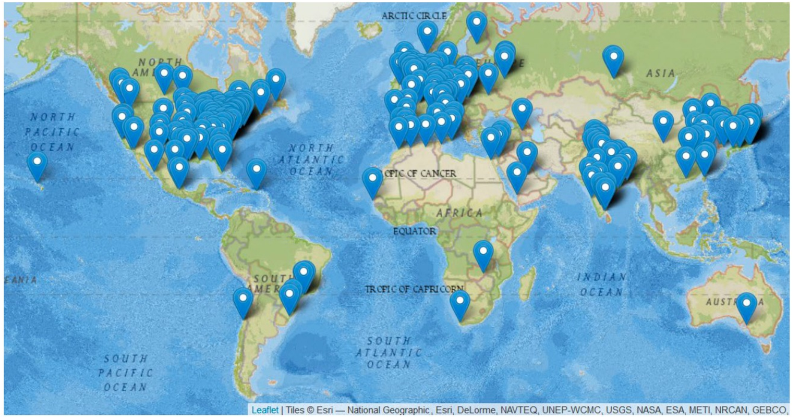
The EIC- ePIC International Collaboration

The EIC User Group:
https://eicug.github.io/

Formed in 2016 –

- **1487 members**
- **40 countries**
- **6 world regions**
- **292 institutions**

As of May 10, 2024

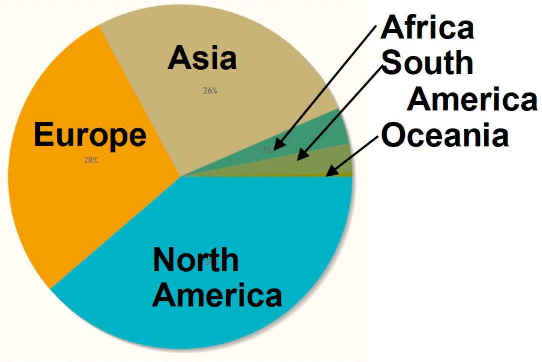


101 INFN Physicists
16 INFN Institutes

INFN In-Kind Responsibilities

- Si Vertex detector
- Dual RICH
- Streaming Read-out
- **MPGD Endcap trackers**

Institutions



Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland
2024 Lehigh U., PA

Final Considerations

The EIC is a unique project, the word only one approved for the ultimate understanding of QCD

Most likely, the only novel high energy collider in the next 15-20 years

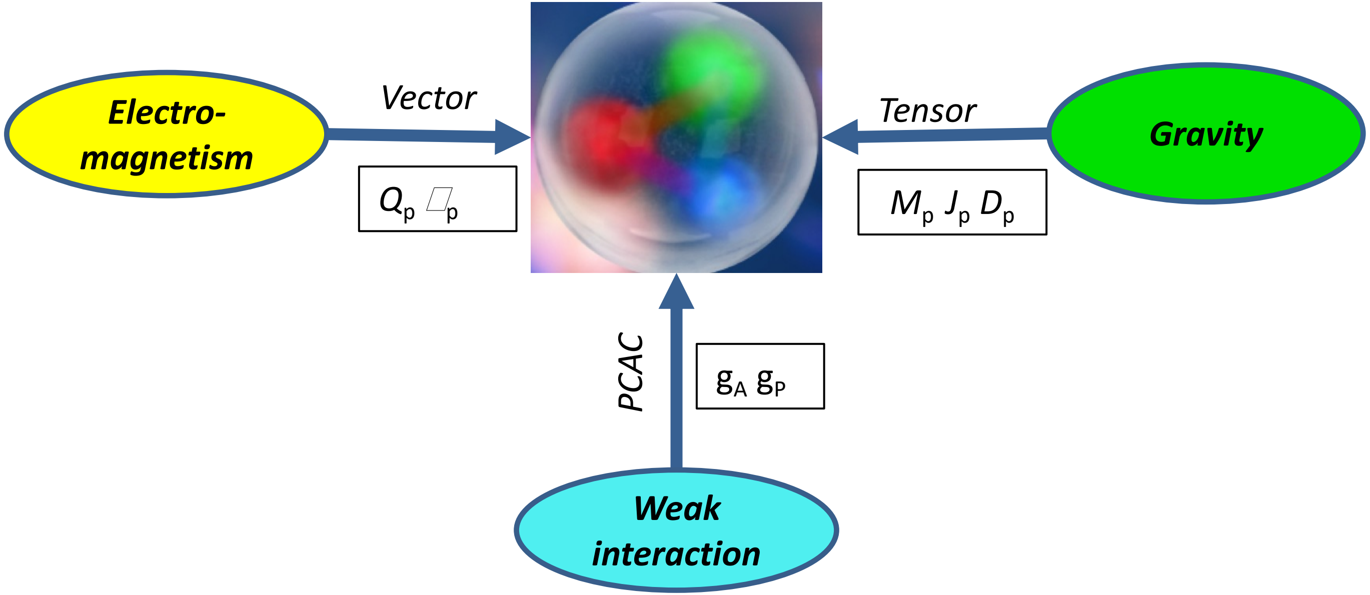
- **The EIC project is approved and progressing according to schedule**
- **The ePIC Collaboration for the project detector ePIC is working and highly committed**
  - **The ePIC detector design is dictated by the physics scope**
  - **A number of established and novel technologies needed to match this scope**
  - **Relevant synergies with CERN in physics (not discussed today) and in detector technologies**
- ***Exciting perspectives in front of us designing, building, operating ePIC and progressing in physics with our detector***

Thank you !

Back-up slides

Critical QCD Questions Addressed

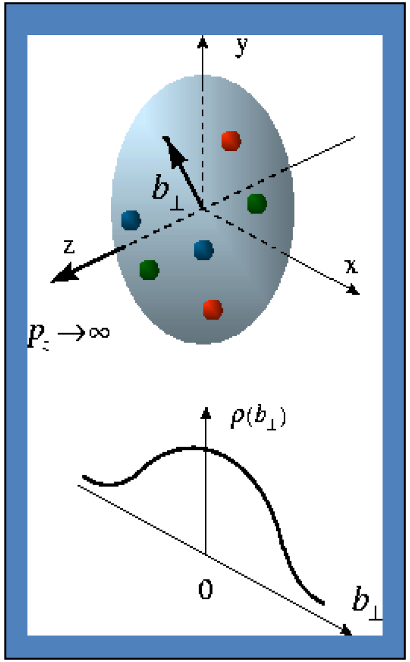
- How is color confinement realized in the force and pressure distributions and stabilize nucleons?



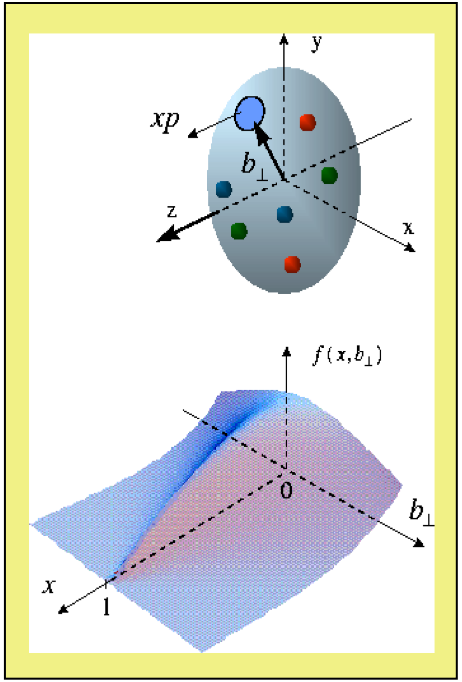
→ **Study GPDs and their moments from DVCS**

Nucleon Structure Evolution

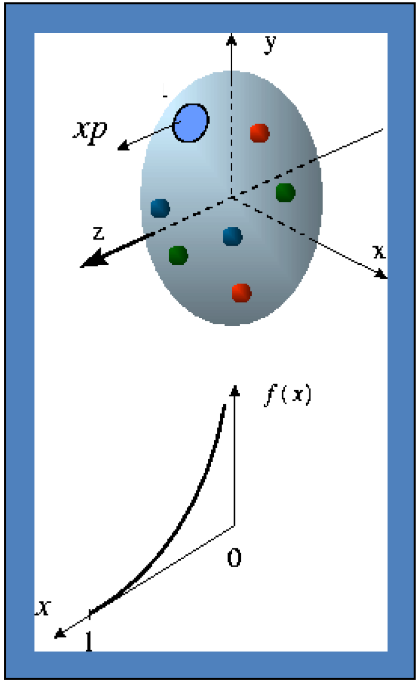
elastic scattering



deep-exclusive scattering



deep-inelastic scattering

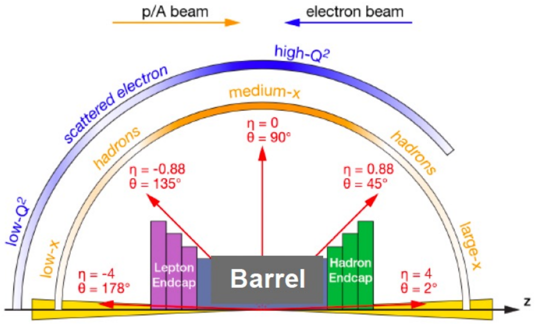


Transverse quark distribution in coordinate space

Correlated quark space and momentum distributions – GPD

Longitudinal quark distribution in momentum space

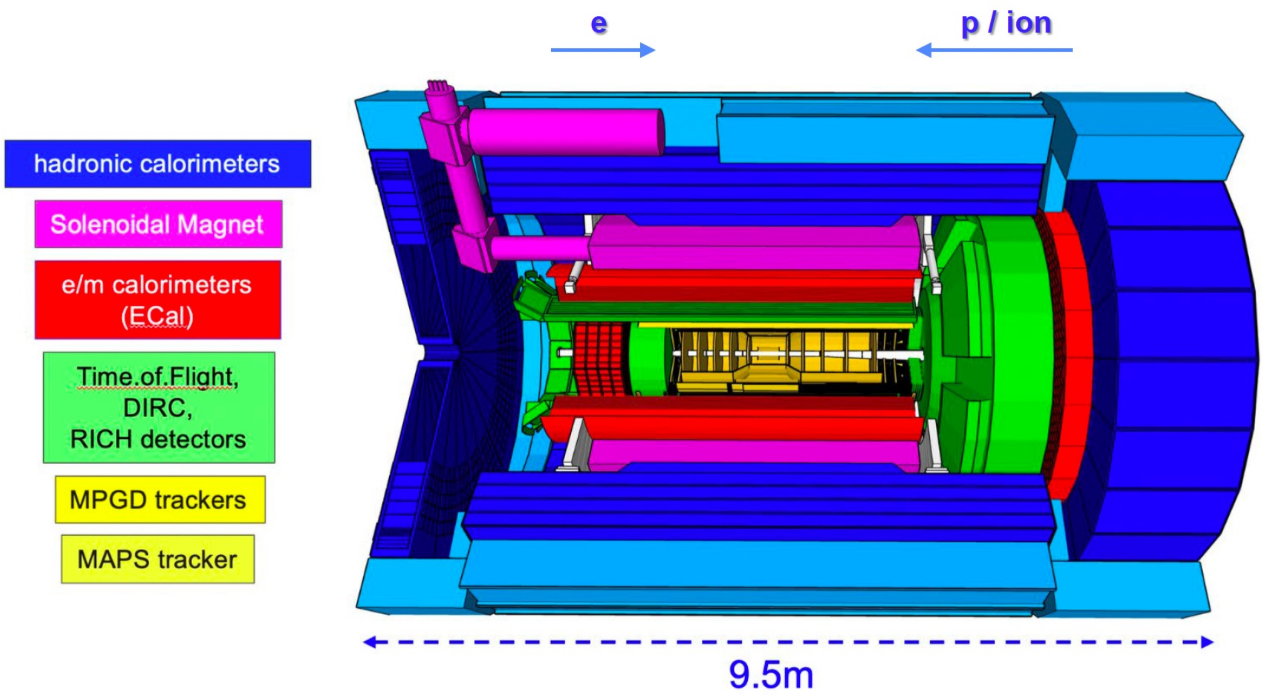
The ePIC Central Detector



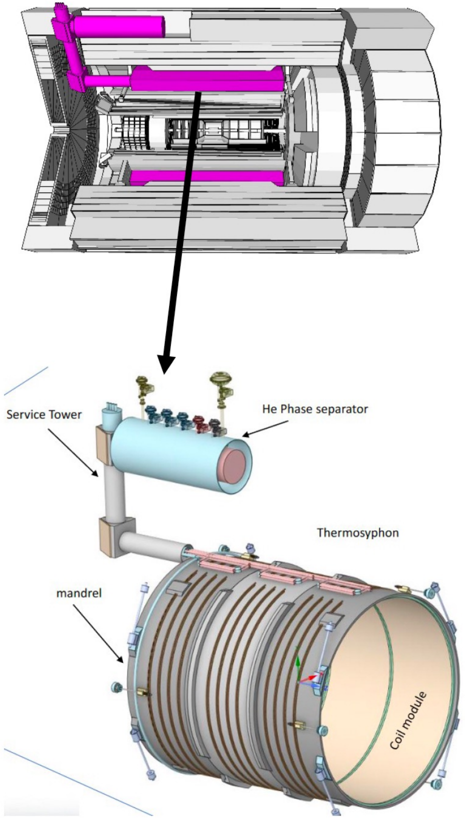
Very naturally organized in:

- **Backward endcap**
- **Barrel**
- **Forward endcap**

subsystems



The ePIC Solenoid

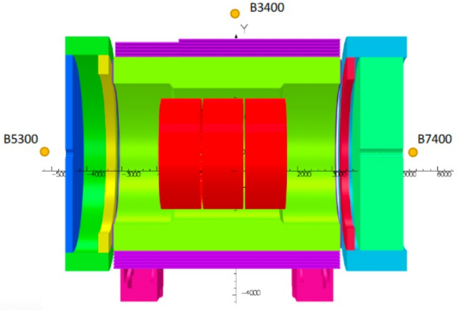


Parameter	Value
Coil length	3512 mm
Warm bore diameter	2840 mm
Cryostat length	< 3850 mm
Cryostat outer diameter	< 3540 mm

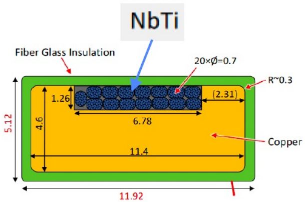
Parameter	Value	Comment
B5300 (B @ Z= -5300 mm)	< 10 G	Stray field requirement is based on IR magnet location
B7400 (B @ Z= 7400 mm)	< 10 G	
B3400 (B @ R= 3400 mm)	< 10 G	

Parameter	Value	Comment
Central Field B_0	2.0 T	Magnetic Field Properties
Lowest operating field	0.5 T	
Field Uniformity in FFA	12.5 % ± 100 cm around center 80 cm radius	
Projectivity in RICH Area	< 0.1 (mrad@30GeV/c) < 10 T/A/mm² From Z = 180 cm to 280 cm	

Reference field value: 1.7 T

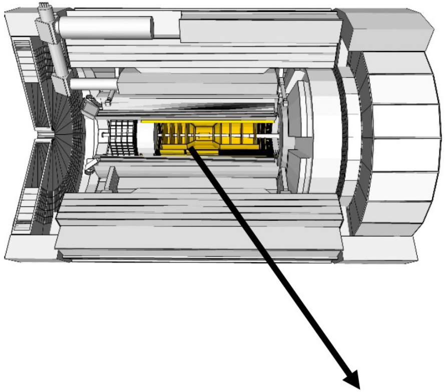


Conductor Design



90% readiness review successfully passed in Fall 2023; finalization review at the end of May 2024

The ePIC Tracking

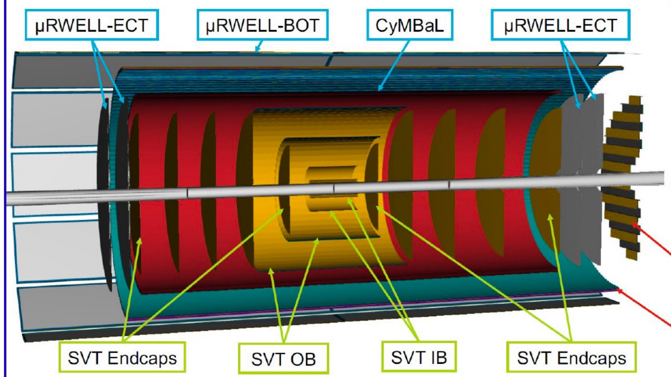


Complementary tracking technologies characterized by light materials

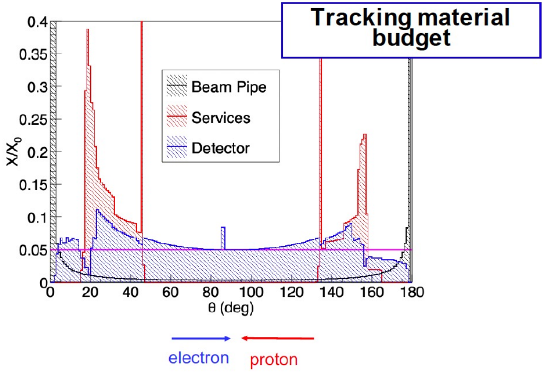
SVT: Si trackers based on ALICE ITS3 65 nm MAPS sensors
- **Fine space resolution < 20 μm**
- **Five cylindrical layers in the barrel and five disks in each endcap**

MPGD trackers
- **Good time resolution $\mathcal{O}$ (10 ns)**
- **Cylindrical MICROMEGAS**
- **Planar μR-WELL with GEM pre-amplification**

Additional information
- AC-LGADs for ToF (PID) - very fine time resolution: 20/30 ps
- First layer of the barrel imaging EM calorimeter – fine space resolution (150 μm), good time resolution (~ 2 ns)

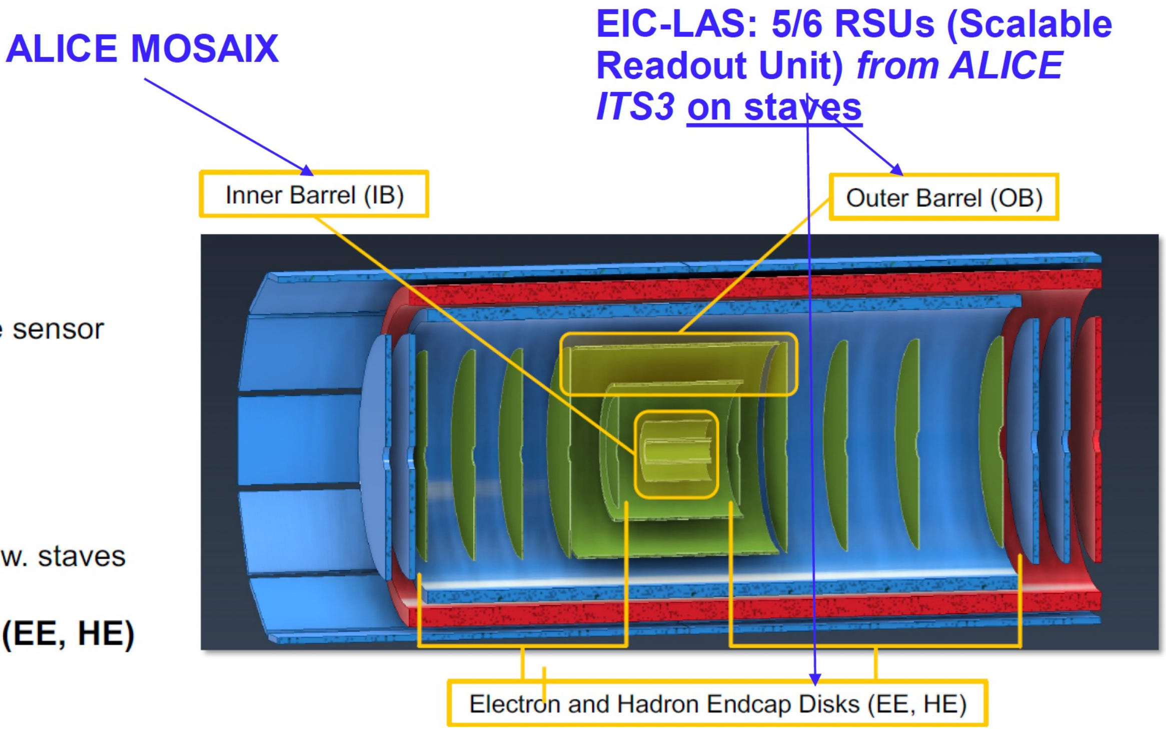


- MPGD
  - BOT Length: 340 cm
  - BOT Radius: 72.5 cm
- Silicon
  - Outer Length: 84 cm
  - Outer Radius: 42 cm
- AC-LGAD
  - ToF: Part of PID



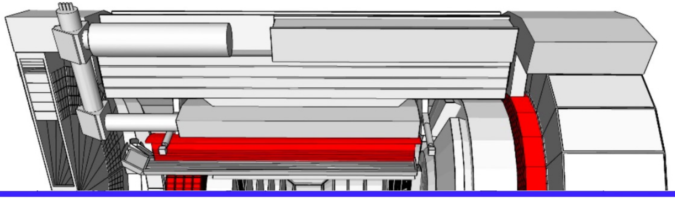
The ePIC Silicon Tracking

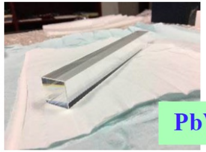
- **Inner Barrel (IB)**
  - Three layers, L0, L1, L2,
  - Radii of 36, 41, 120 mm
  - Length of 27 cm
  - X/X_0 ~ 0.05% per layer
  - Curved, thinned, wafer-scale sensor
- **Outer Barrel (OB)**
  - Two layers, L3, L4
  - Radii of 27 and 42 cm
  - X/X_0 ~0.25% and ~0.55%
  - More conventional structure w. staves
- **Electron/Hadron Endcaps (EE, HE)**
  - Two arrays with five disks
  - X/X_0 ~0.25% per disk
  - More conventional structure

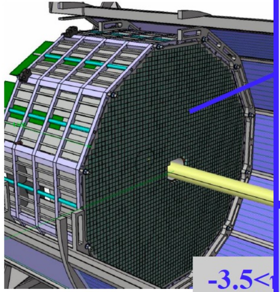


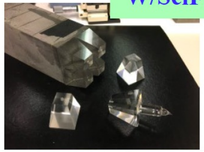
- **Lengths for L2—L4 increase so as to project back to z = 0; disk radii adjust accordingly**

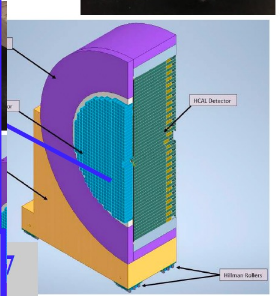
The ePIC Calorimeters

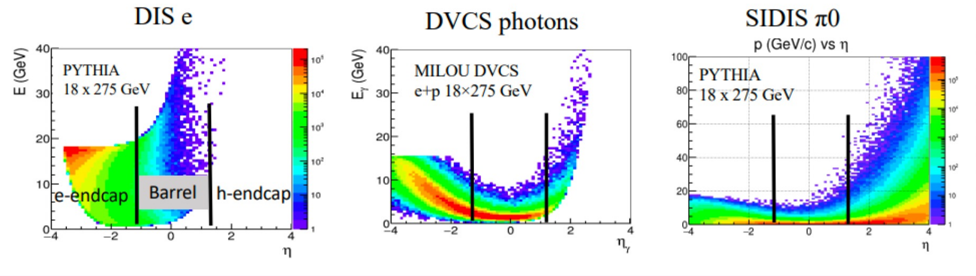






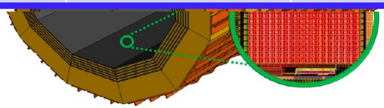






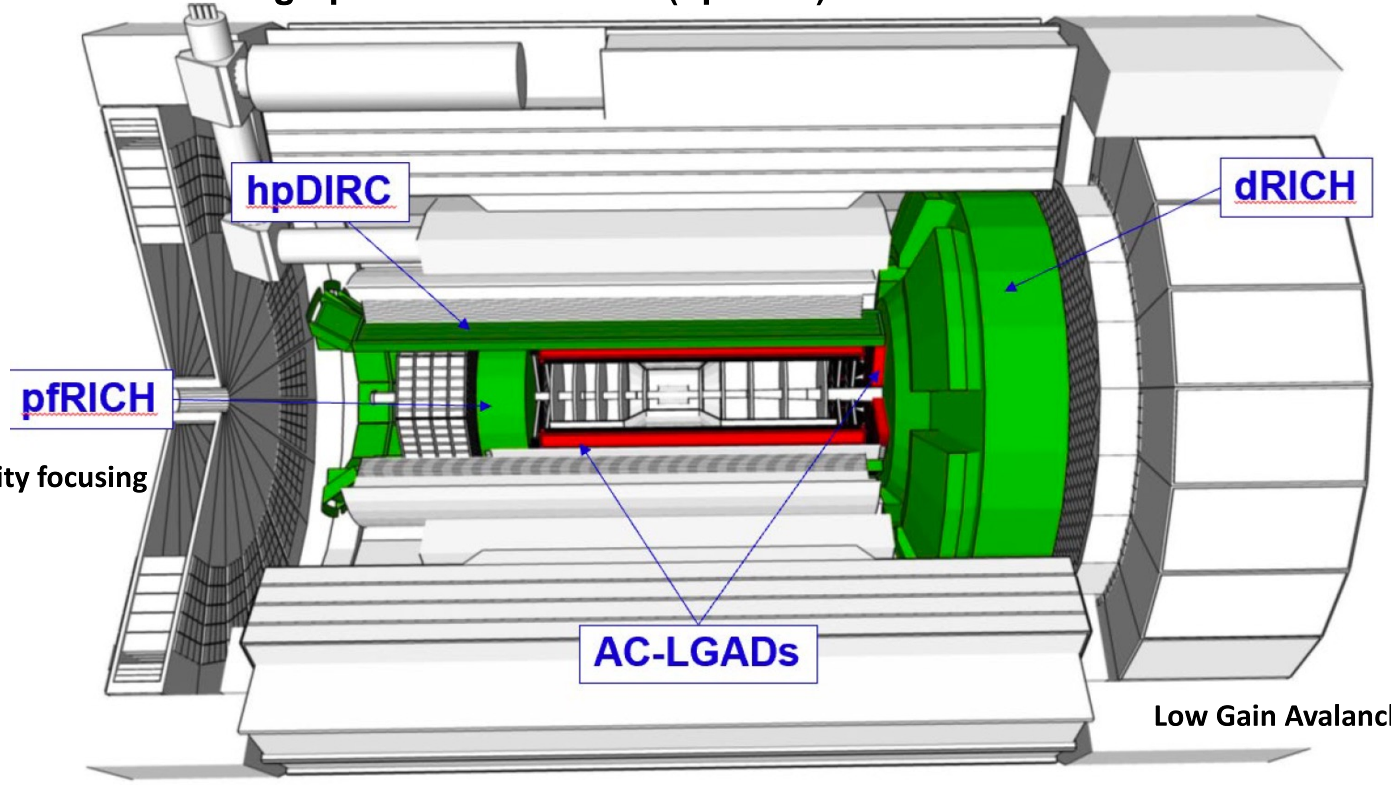
	σ_E/E	E range, GeV	$\pi^{\pm}$ suppression (In combination with other subsystems)	$\pi0/\gamma$ discr.
e-endcap	$\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$	0.05–18 GeV	Up to 10^4	Up to 7 GeV/c
Barrel	$\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$	0.05–50 GeV	Up to 10^4	Up to 10 GeV/c
h-endcap	$\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$	0.1–100 GeV	Up to 10^4	Up to 50 GeV/c

-3.5<
$22X_0$
~3k cry
R_{outer}=



The ePIC PID

high performance DIRC (hpDIRC)



Dual radiator RICH (dRICH)
Aerogel and C_2F_6

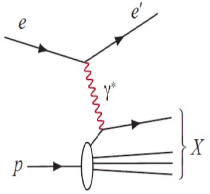
proximity focusing RICH

Low Gain Avalanche Detector

The ePIC detector

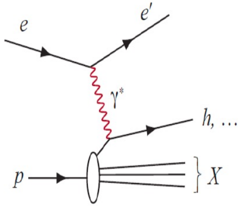
REQUIREMENTS → ePIC detector

Measurement categories to address EIC physics:



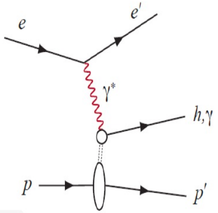
- Inclusive DIS
  - fine multi-dimensional binning in x, Q^2

- ***Large coverage ($-3.5 < \eta < 3.5$) for wide phase-space reach***
- ***Excellent EM-calorimetry with PID support for e/π separation***
- ***Fine resolution tracking by low mass detectors***



- Semi-inclusive DIS
  - 5-dimensional binning in x, Q^2, z, p_T, θ

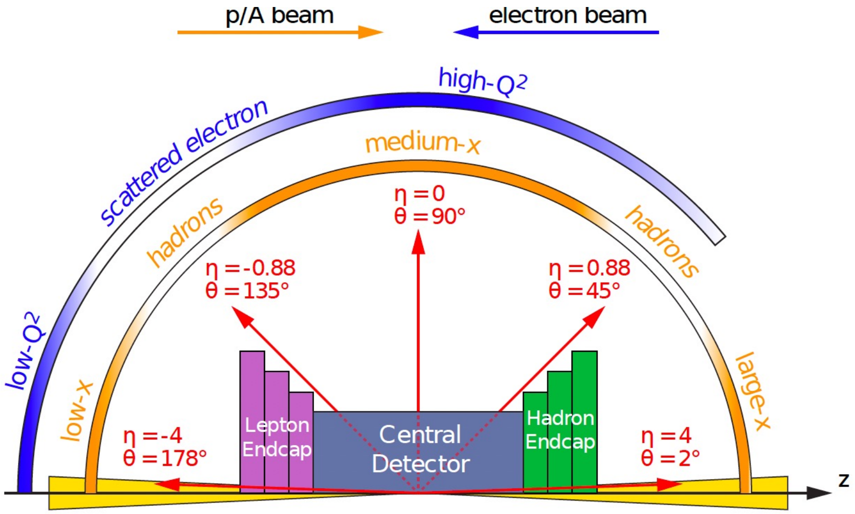
- ***Fine p_T resolution***
- ***Extended PID systems for hadron identification***
- ***H-calorimetry to attempt TMD assessment with jets (new world-wide), as tail chatter, for μ identification***



- Exclusive processes
  - 4-dimensional binning in x, Q^2, t, θ to reach $|t| > 1$ GeV2

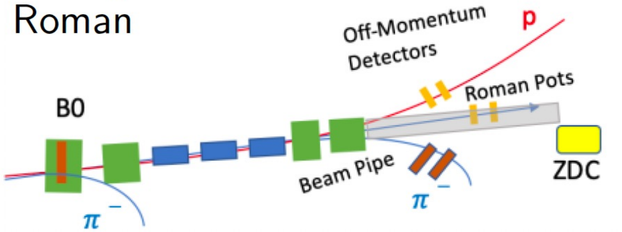
- ***Extend acceptance at extremely small scattering angles***
- ***Fine vertex resolution by tracking***

Generalized detector design considerations



- Large rapidity coverage for central detector
- Specialized far-forward detectors for *p* kinematics measurements
- High precision low mass tracking
- Hermetic coverage of tracking, electromagnetic & hadronic calorimetry
- High performance single track PID for π, K, p seperation

- Large acceptance for diffraction, tagging, neutrons from nuclear breakup
  many auxillary detectors integrated in beam line: low-Q^2 tagger, Roman pots, ZDCs . . .
- High control of systematics
  luminosity monitors, electron & hadron polarimetry



Highly integrated design between detector and accelerator