# ePIC's physics and detector overview

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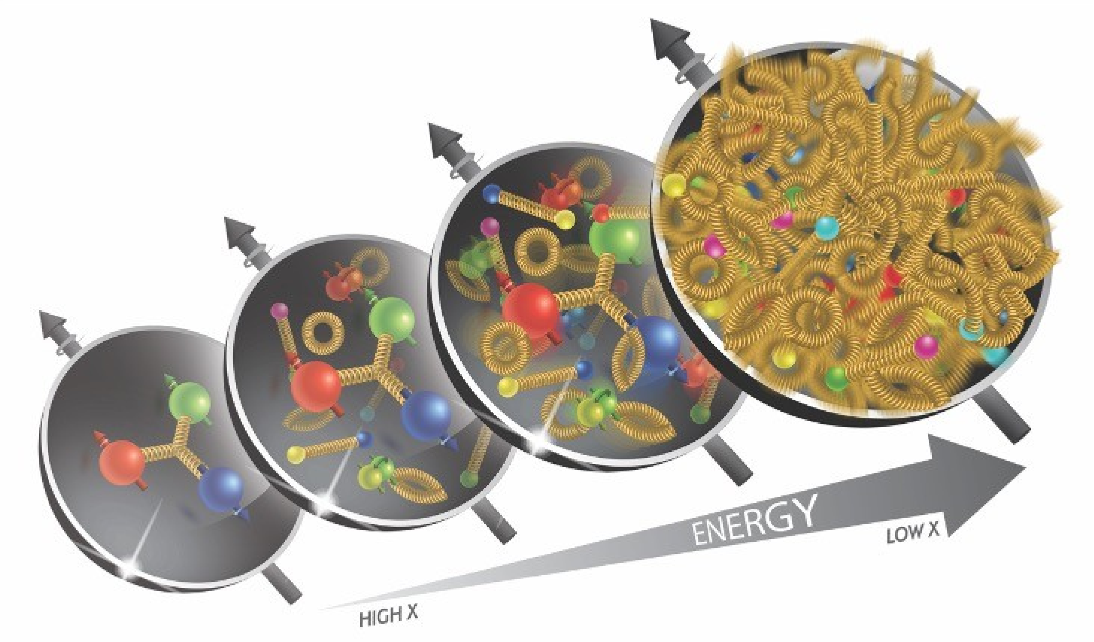
On behalf of the ePIC collaboration

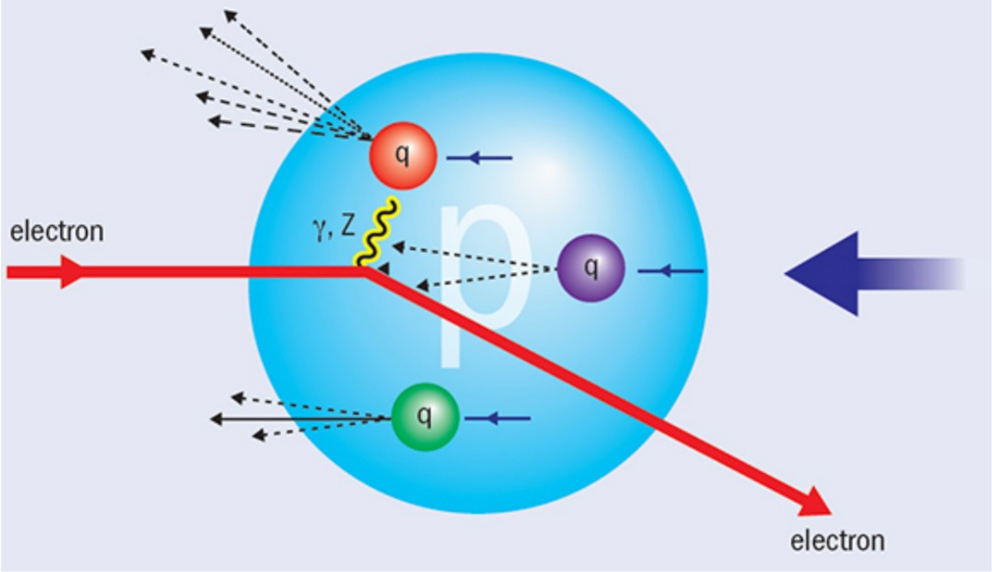
EuNPC
Caen, Nov 25th 2025

# Introduction




- Protons and neutrons make up most of the visible matter in the universe
- Nucleons and nuclei are composite objects in the non-perturbative regime of QCD
- Do we understand them?

- Deep Inelastic Scattering, the cleanest way to probe inside nucleons and nuclei
- An electron-ion collider would be a versatile and dedicated laboratory to study hadron matter properties



# The EIC physics case

A long history to strengthen the case for the electron-ion collider


DOI: 10.5281/zenodo.6423359

DOI: 10.17226/25171

DOI: 10.5281/zenodo.6423305

…

2010 : INT Workshop

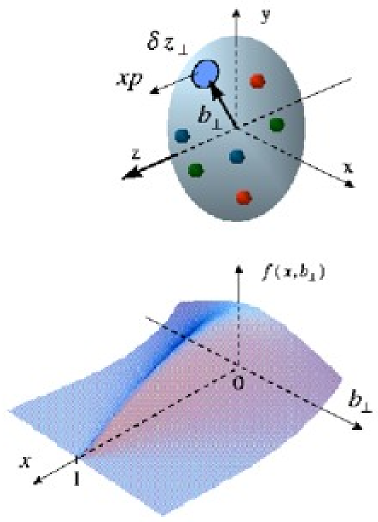
2012: EIC White Paper

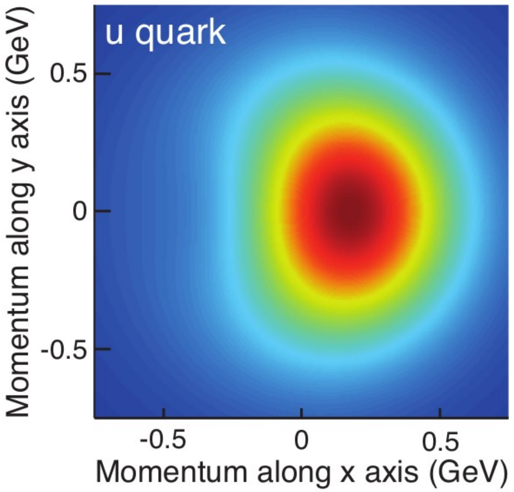
2015: Endorsement in the Long range plan of the Nuclear Science Advisory Committee

2018: National Academy of Sciences report on EIC

2020: EIC Yellow Report

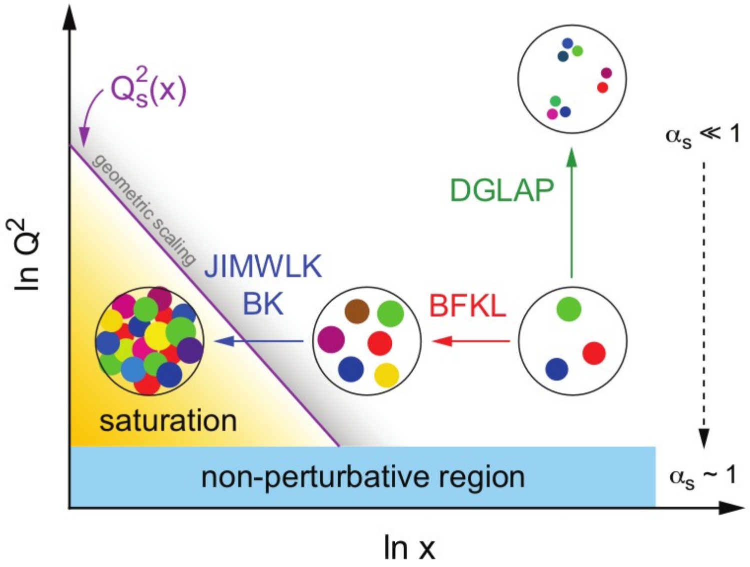
# The EIC physics case

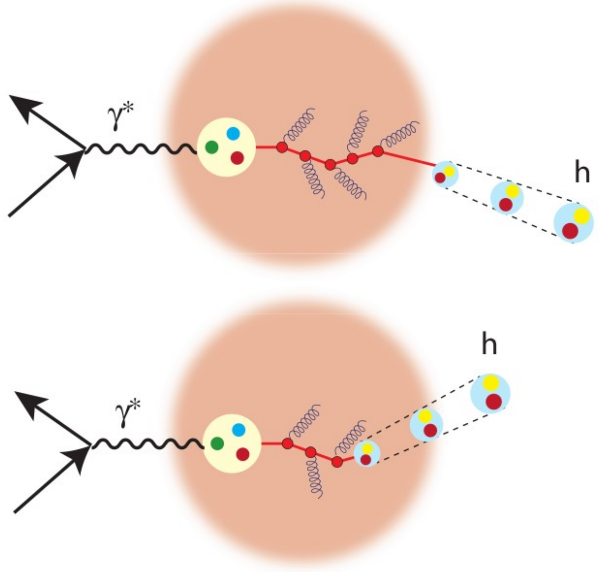



Three main general questions

- How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleons?
- Where does the saturation of gluon densities set in?
- How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?



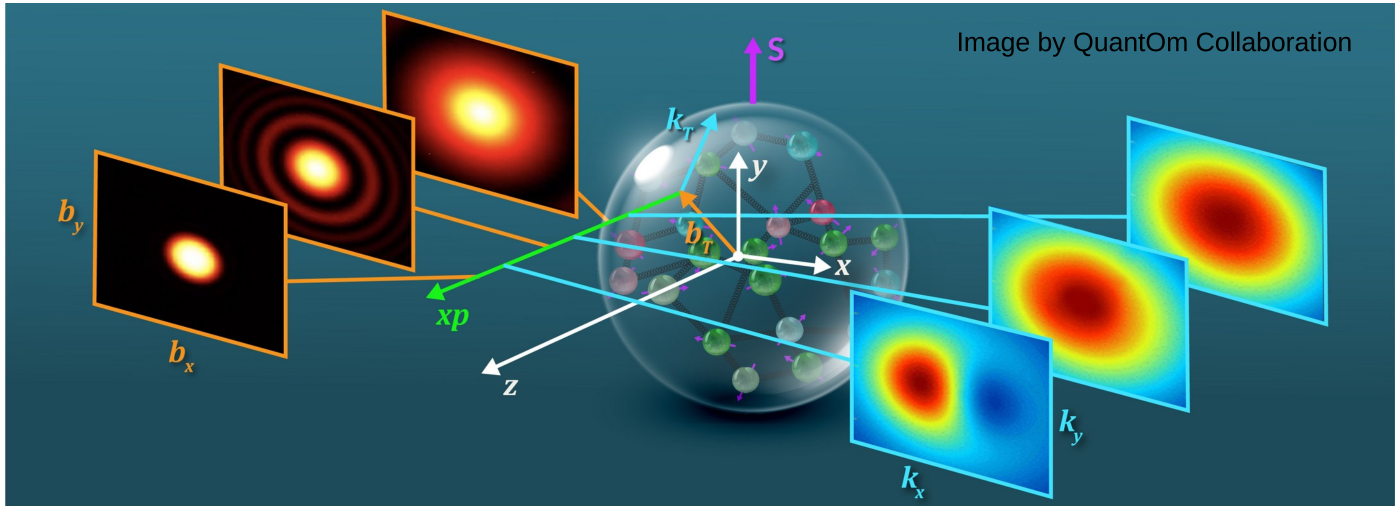



# Tomography of hadrons

**Coordinate space**
2D spatial images at different slices of momentum

Accessible via exclusive processes

Described by Generalized Parton Distributions (GDPs)



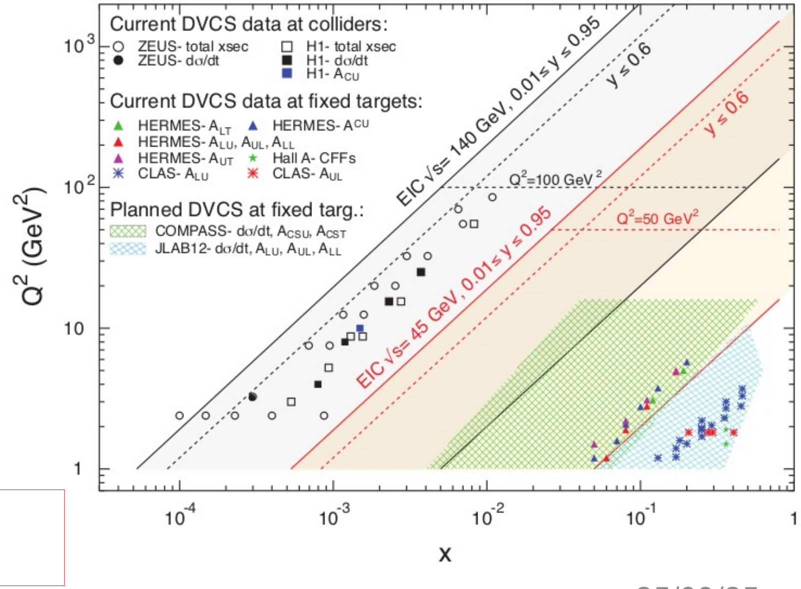

**Momentum space**
3D momentum images related to parton' motion inside hadrons

Accessible by measuring semi-inclusive processes

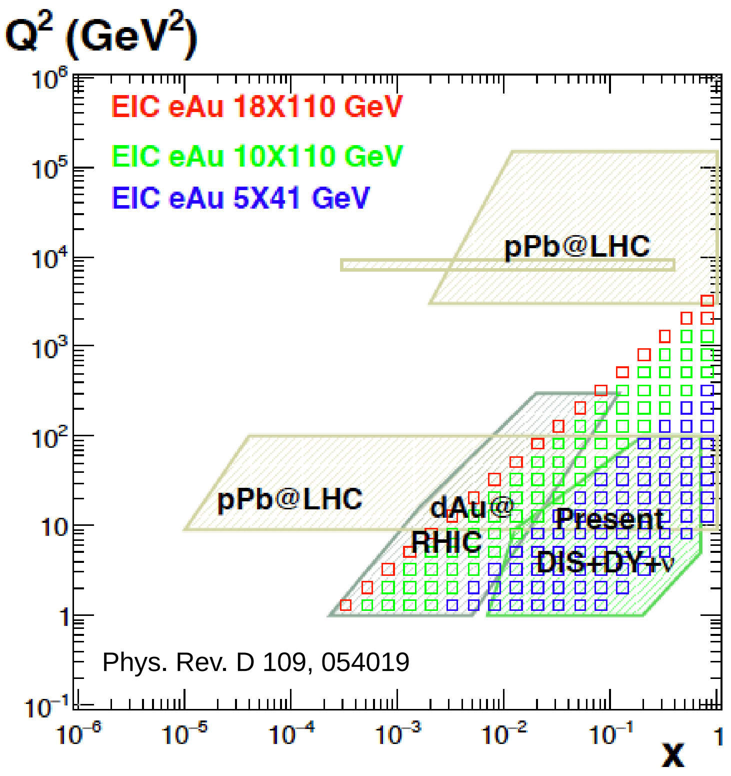
Described by Transverse Momentum Depended PDFs (TMD)

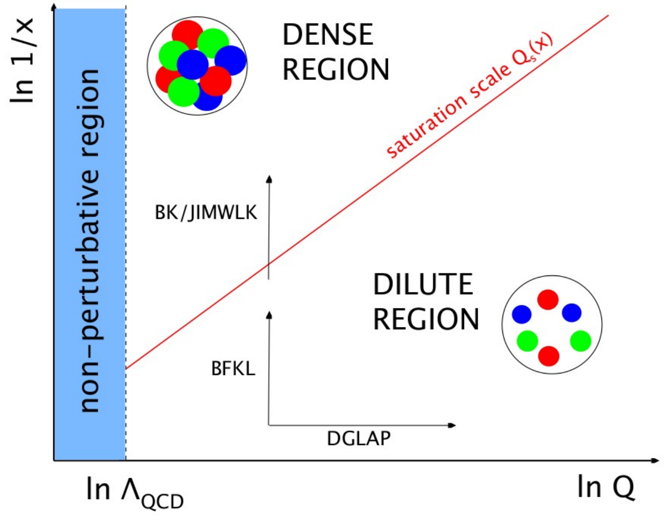
- Offers insights into properties like angular momentum, mass, and pressure inside hadrons
- EIC will provide unrivaled precision in tomography, extending beyond the valence quark regime into sea quarks and gluons

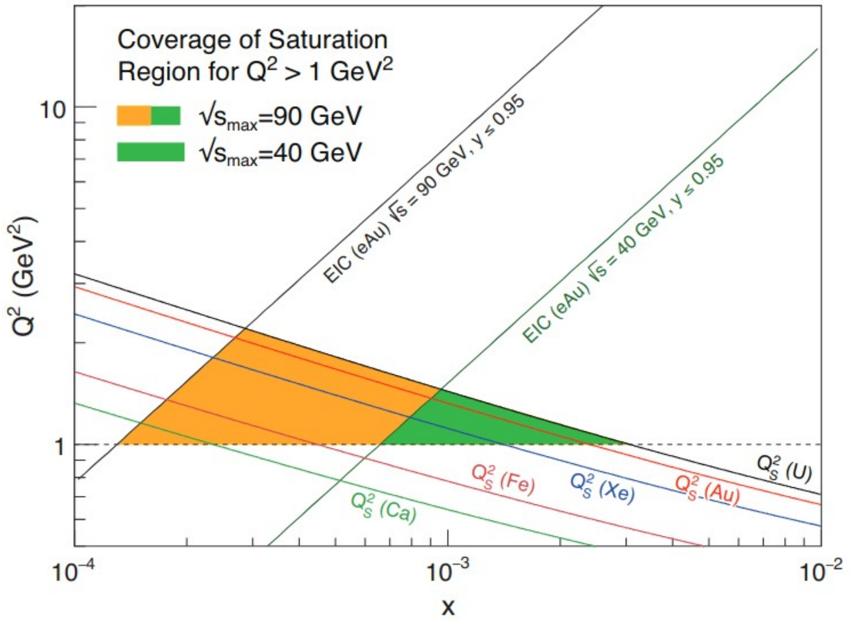
More in various talks:
C. Van Hulse, P. Chatagnon, parallel sessions



# Nuclei and saturation




EIC will provide large impact on nuclear PDFs:

- Extensive DIS data from **single nucleus species**
- Impact both at low and high x

At low-x EIC will allow us to study the gluon dense QCD regime.

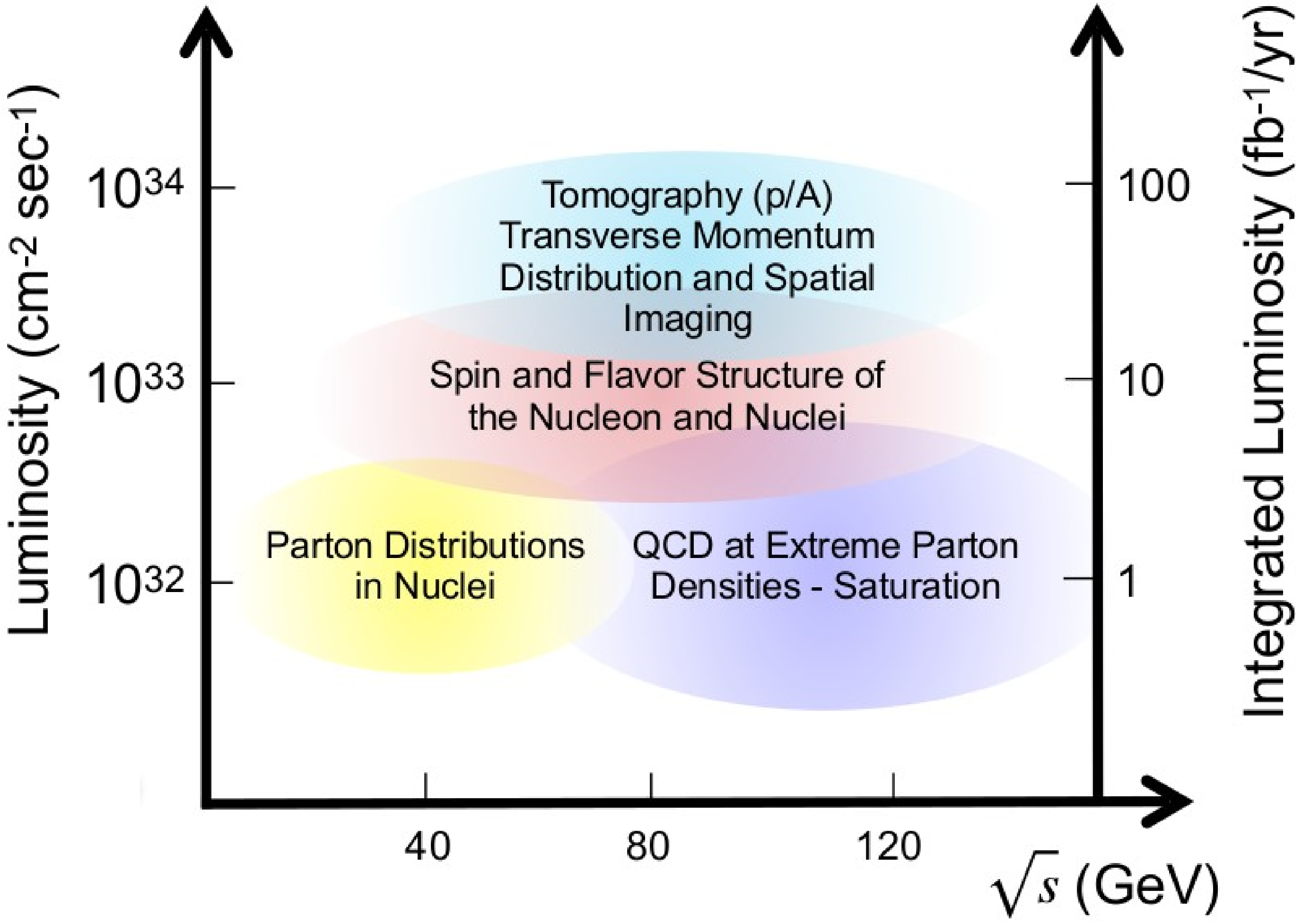
Possibility to study saturation in a clean environment at large $Q^2$

# The EIC requirements

The EIC must meet the following requirements for the full physics reach:

- high luminosities
- large center of mass energy range
- highly polarized beams: P > 70%
- wide variety of ion species: from p to U
- large detector acceptance

Requirements set by the Nuclear Science Advisory Committee (NSAC) Long Range Plan (2015) and the EIC White Paper endorsed by the National Academy of Sciences (NAS) (2018)

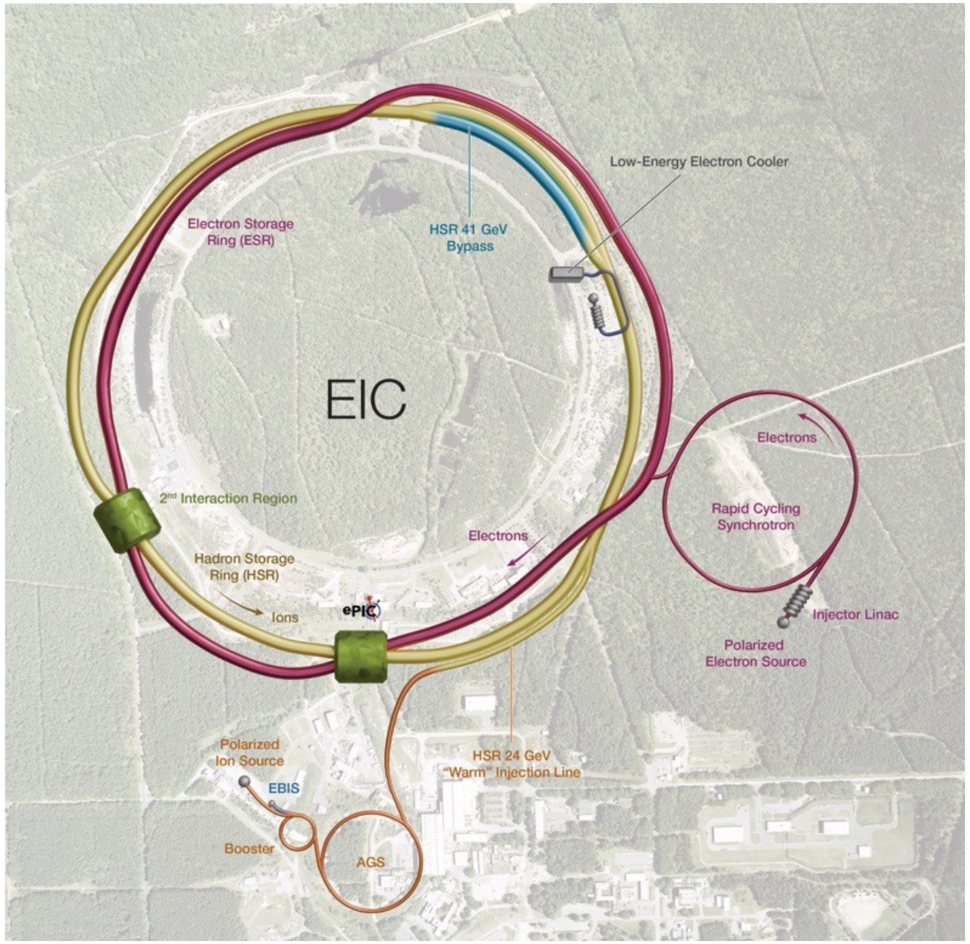


# EIC at a glance

Hosted at BNL, it is a partnership between BNL and Jefferson Lab
Two possible interactions regions, at the start just one detector

## Hadron beam

- Reuse most of RHIC complex:
  - Polarized ion/proton source
  - Injector, booster and AGS
- Upgrade hadron storage ring (41, 100-275 GeV)



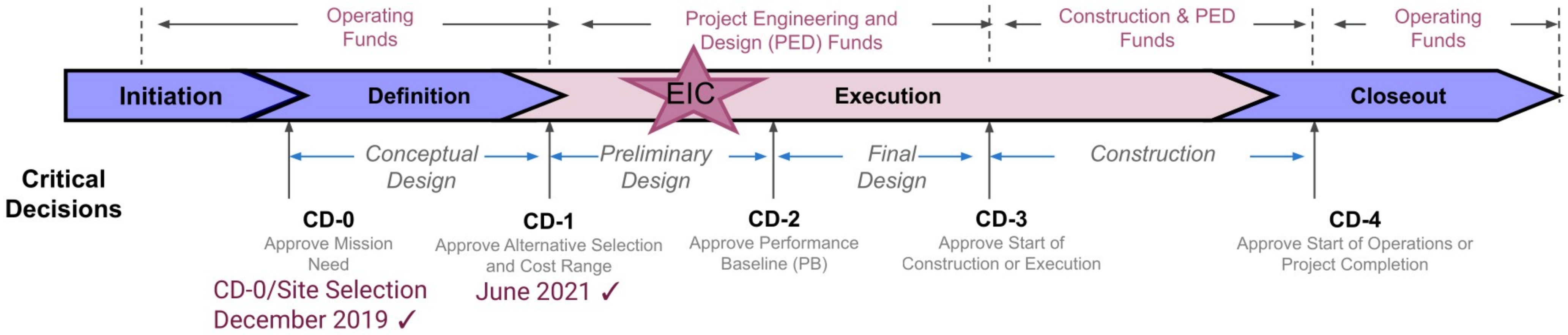

## Electron beam

- Polarized electron source
- Injector LINAC (750 MeV)
- Rapid Cycling Synchrotron
- Storage ring (5 – 18 GeV)

## Interaction region(s)

- High luminosity: $10^{33} - 10^{34}$ cm$^{-2}$s$^{-1}$
- Integrated luminosities up to 100 fb$^{-1}$/year
- High beam polarizations: 70%
- Crossing angle 25mrad and crab cavities
- Bunch crossing ~ 98.5MHz

# EIC Timeline




**2020**: CD-0, conceptual design

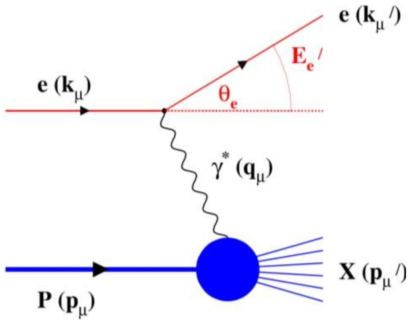
**2021**: CD-1, start of the design phase

CD-3: Aiming to start the detector construction around **2027**

**CD-4: First collisions in 2035**

# EIC requirements from physics observables

## Inclusive DIS

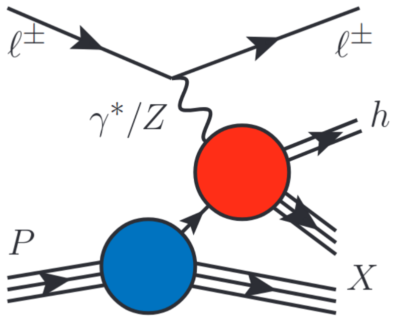



- Parton Distributions in nucleons and nuclei
- Saturation

*Requirements*:

- Scattered electron reconstruction and identification
  - **e-Calorimetry**

## Semi-inclusive DIS

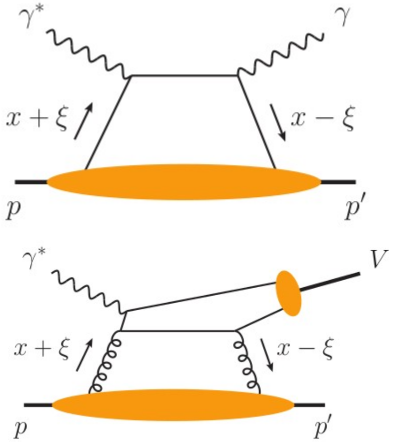



- Spin and flavor structure of hadrons
- Tomography with TMDs

*Requirements*:

- **Electrons and hadrons PID**

## Exclusive DIS




- Tomography with GPDs
- Saturation

*Requirements*:

- **Hermetic** acceptance also at small angles
- Measure all particles

# Requirements for an EIC Detector

Distance from IP

**Vertex detector** → Identify primary and secondary vertices

- Low material budget

**Trackers** → Find and measure charged track momenta

- dp/p ~ 0.5% at 1GeV/c at mid-rapidity

**Particle Identification** → pion, kaon, proton separation on track level

- Wide momentum ranges

**Electromagnetic calorimeter** → Measure photons (E, angle), identify electrons

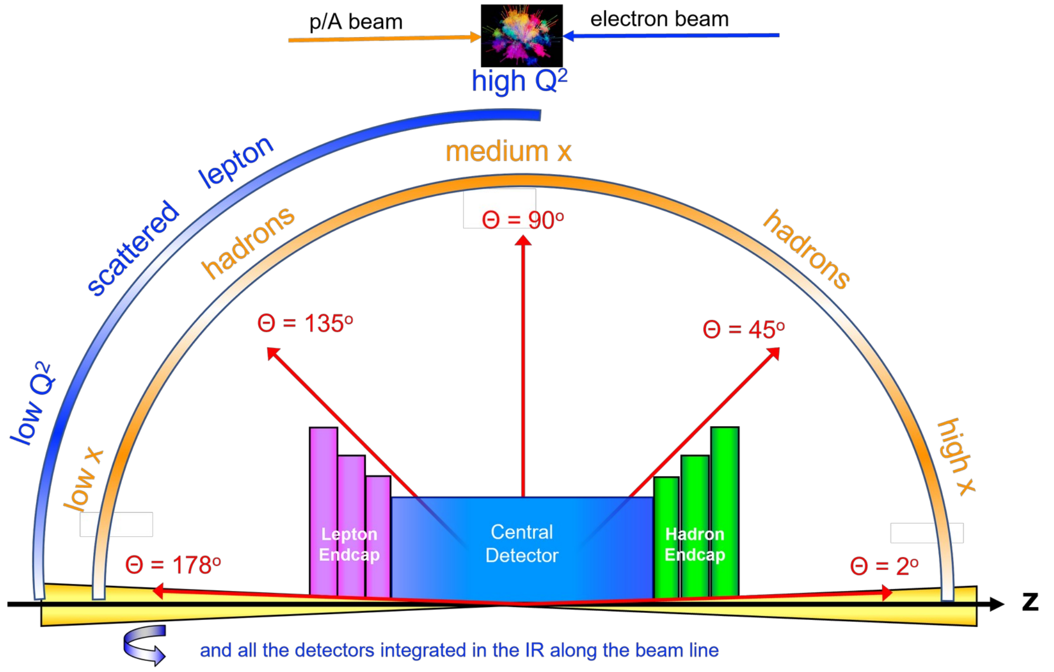
- gamma/Pi0 separation
- Hermetic coverage

**Hadron calorimeter** → Measure charged hadrons, neutrons and $K_L^0$

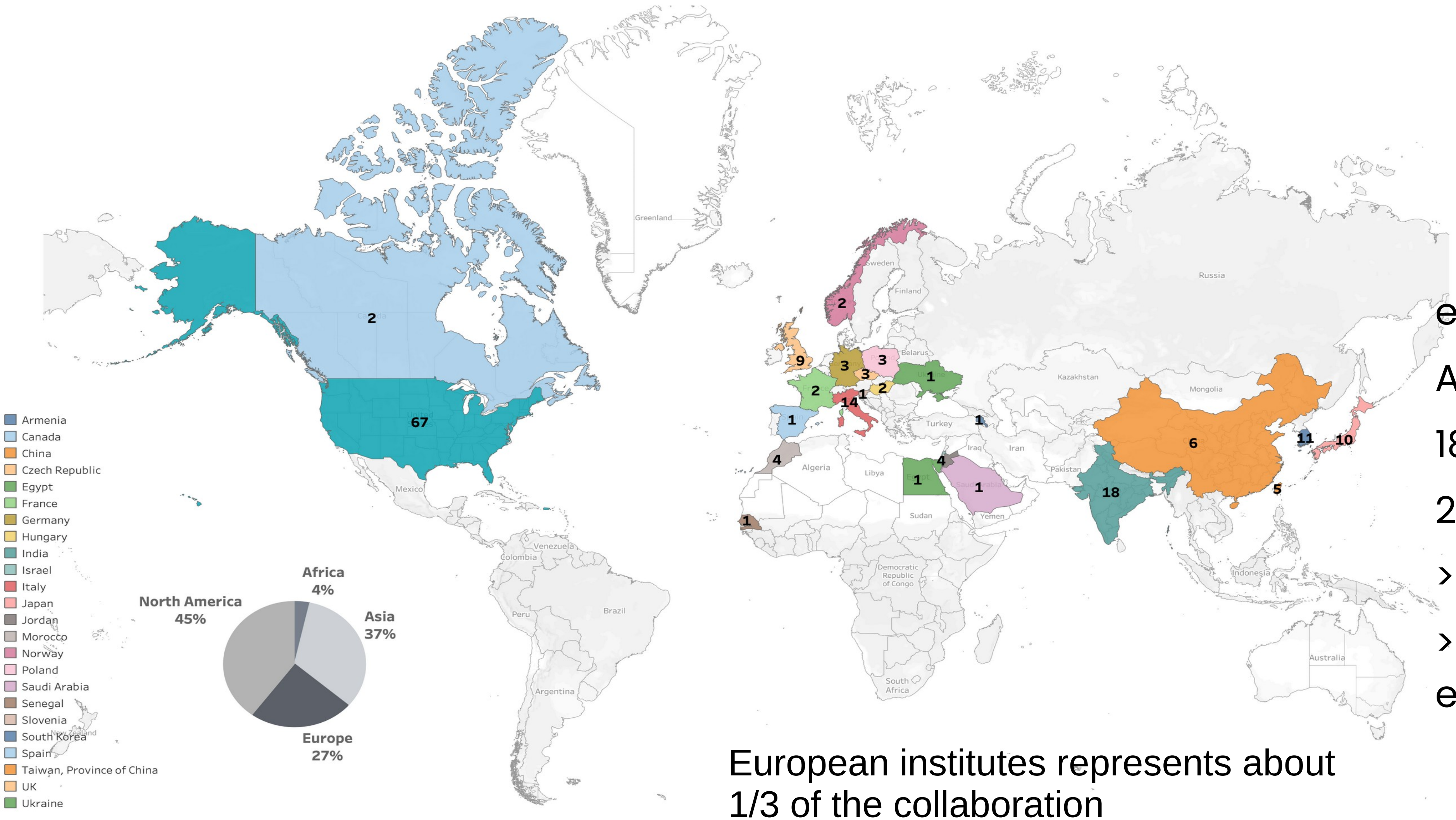
- challenge achieve ~50%/√E + 10% for low E hadrons (<E> ~ 20 GeV)

**DAQ & Readout Electronics** → trigger-less / streaming DAQ

**Very forward and backward detectors** → scattered particles under very small angles



# The ePIC Collaboration




ePIC Initiated in July 2022

As of today:

182 institutions

26 countries

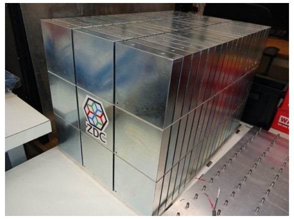
>1000 collaborators

>650 members active in ePIC activities

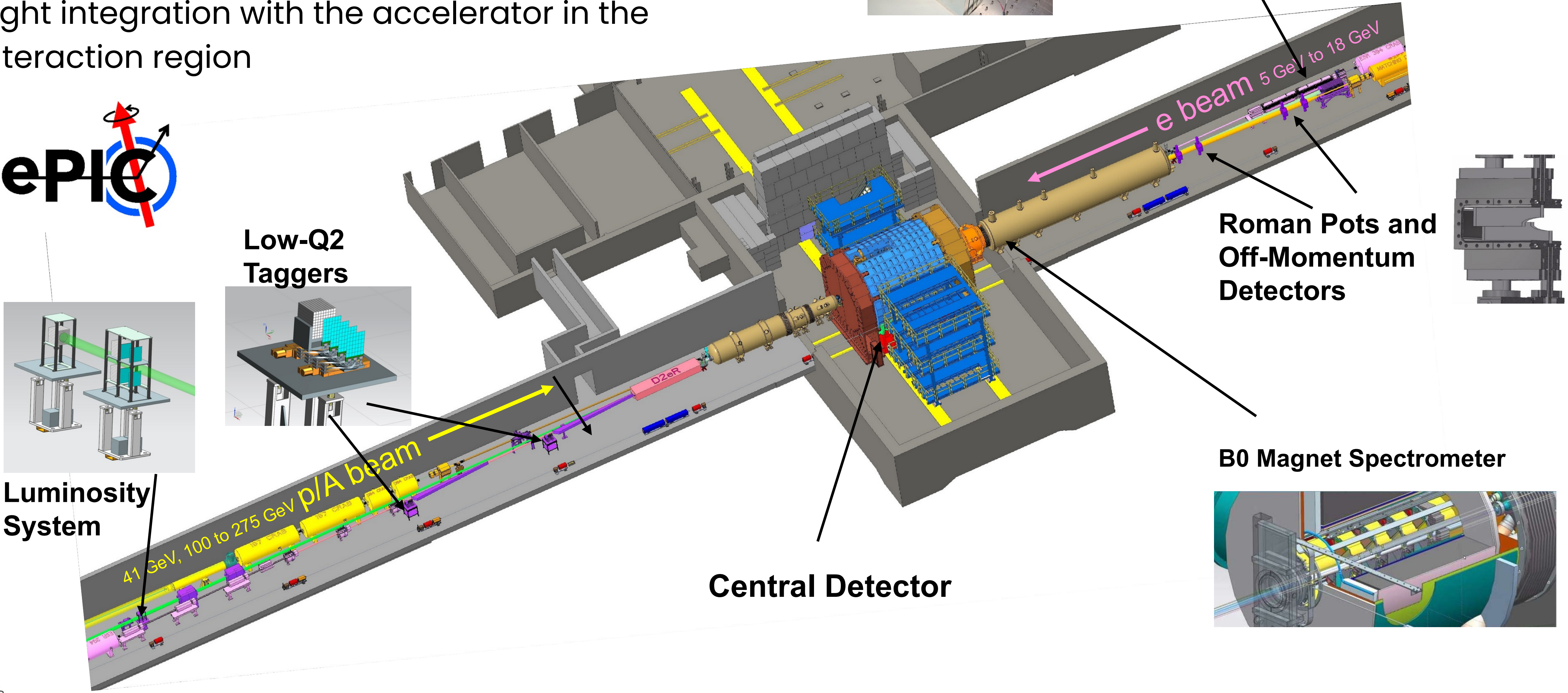
European institutes represents about 1/3 of the collaboration

# The ePIC detector

90m long set of detectors.
Tight integration with the accelerator in the interaction region



Zero Degree Calorimeter




Low-Q2 Taggers

Luminosity System

Roman Pots and Off-Momentum Detectors

B0 Magnet Spectrometer

Central Detector

# The ePIC central detector

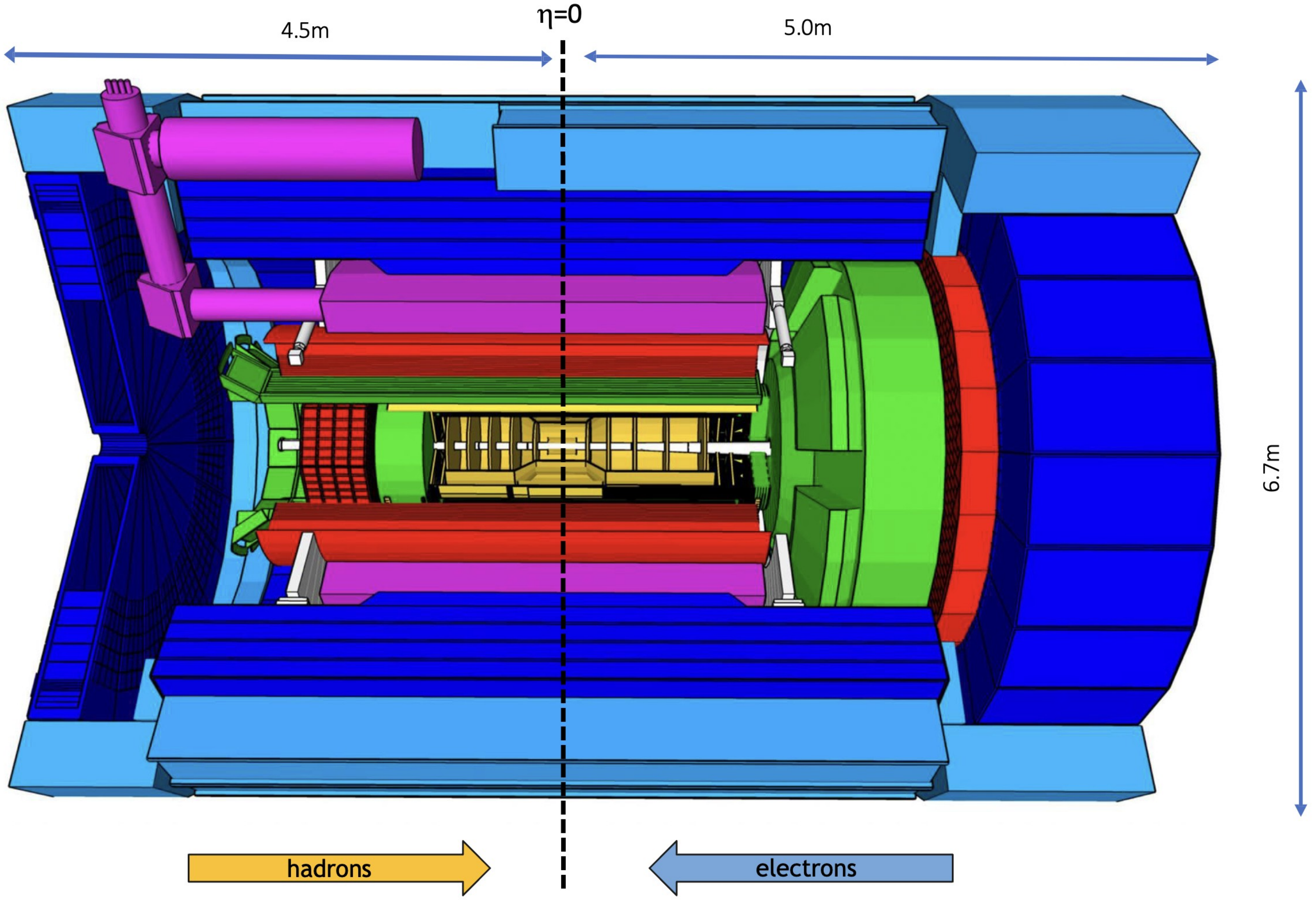
**Magnet**
- New 1.7 T SC solenoid, 2.8 m bore diameter

**Tracking**
- Si Vertex Tracker MAPS wafer-level stitched sensors (ALICE ITS3)
- Si Tracker MAPS barrel and disks
- Gaseous tracker: MPGDs (μRWELL, MMG) cylindrical and planar

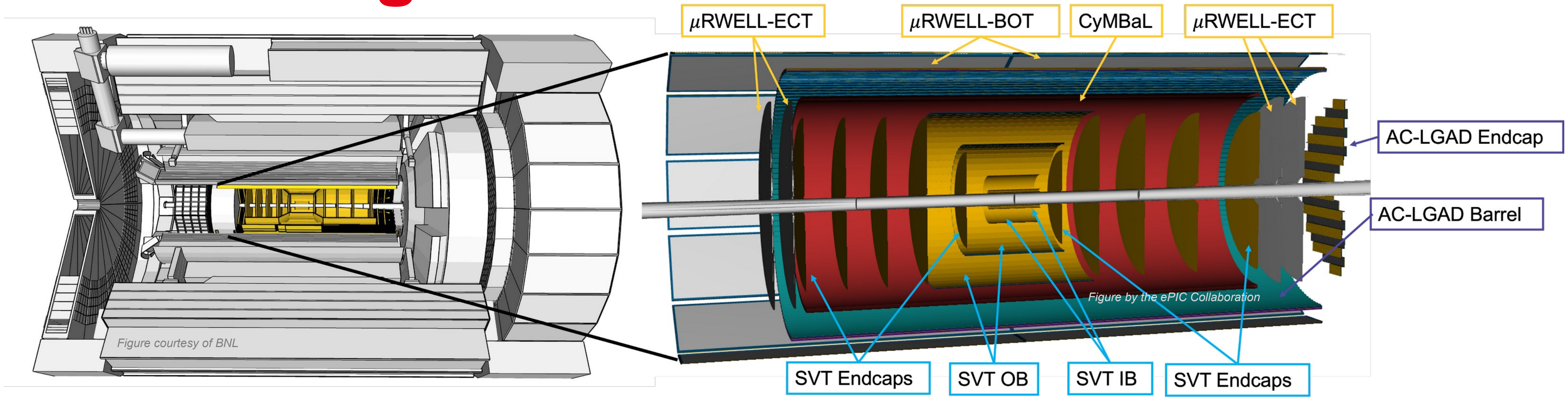
**PID**
- high performance DIRC (hpDIRC)
- dual RICH (aerogel + gas) (forward)
- proximity focussing RICH (backward)
- ToF using AC-LGAD (barrel+forward)

**EM Calorimetry**
- imaging EMCal (barrel)
- W-powder/SciFi (forward)
- $PbWO_4$ crystals (backward)

**Hadron calorimetry**
- FeSc (barrel, re-used from sPHENIX)
- Steel/Scint – W/Scint (backward/forward)



# ePIC tracking




**Requirements: high precision low mass tracking**

- High spatial resolution 20μm/pT⊕ 5μm
- Excellent momentum resolution 0.05%pT⊕0.5%
- Low material budget
- Good pattern recognition efficiency
- Sufficient time resolution to resolve 10ns bunch crossing
- Good angular resolution for the DIRC

## Detector Solutions

Poster by D.Colella

### Silicon Vertex Tracker (SVT)

- Ultra-low-mass **barrel vertex tracker** using ALICE ITS3 curved MAPS technology, with 20μm pixel pitch and 0.05% $X/X_0$
- **Outer barrel and endcap silicon tracker** using new ITS3-based EIC Large Area Sensors (LAS), with 20μm pixel pitch and 0.55% $X/X_0$

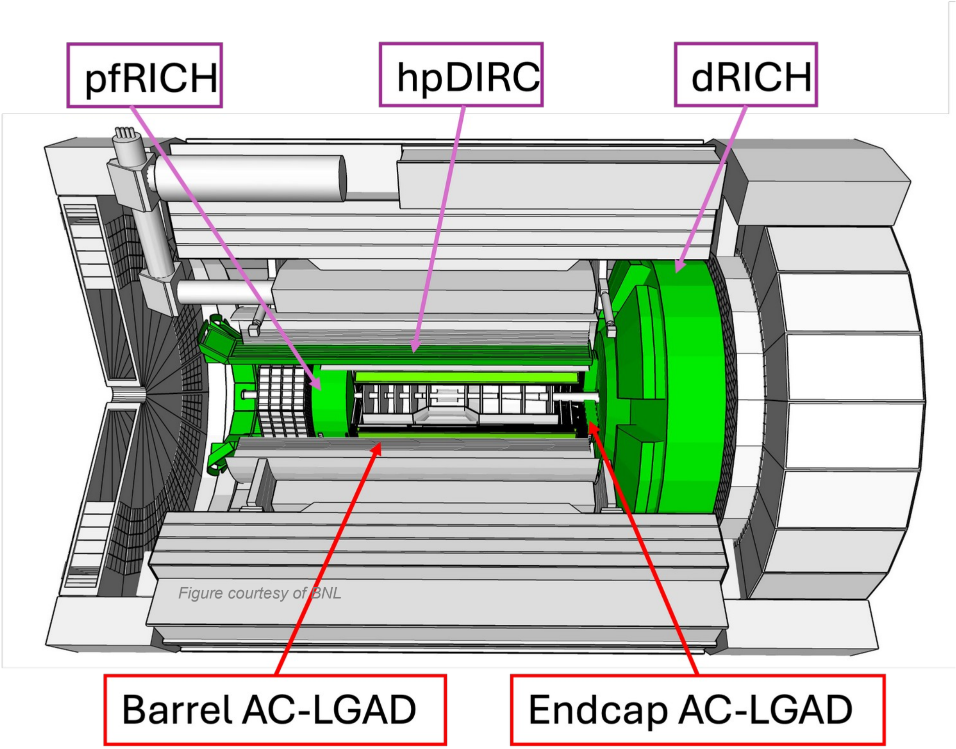
### Micro Pattern Gaseous Detectors (MPGDs)

- **MicroMegas barrel tracker** (CyMBaL) with 0.5 $X/X_0$
- **GEM-μRWell barrel and endcap tracker** with 10ns time resolution, 150μm spatial resolution and 1-2% $X/X_0$

### AC-Low gain avalanche diode (AC-LGAD)

- combines time and spatial information, with ~30ps time resolution and ~30μm spatial resolution

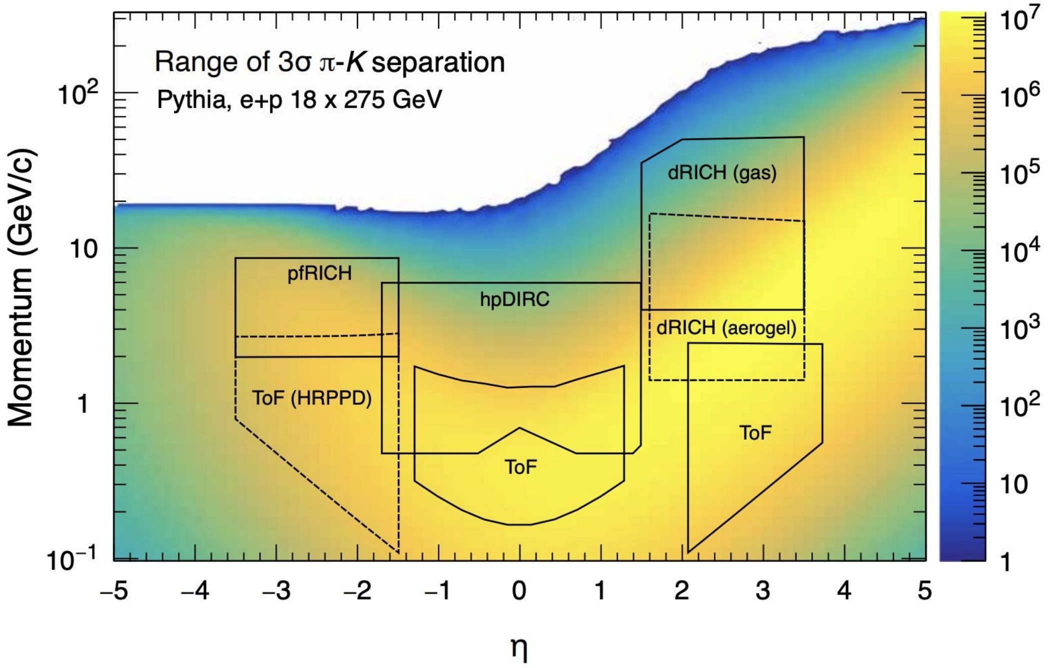
# ePIC particle identification



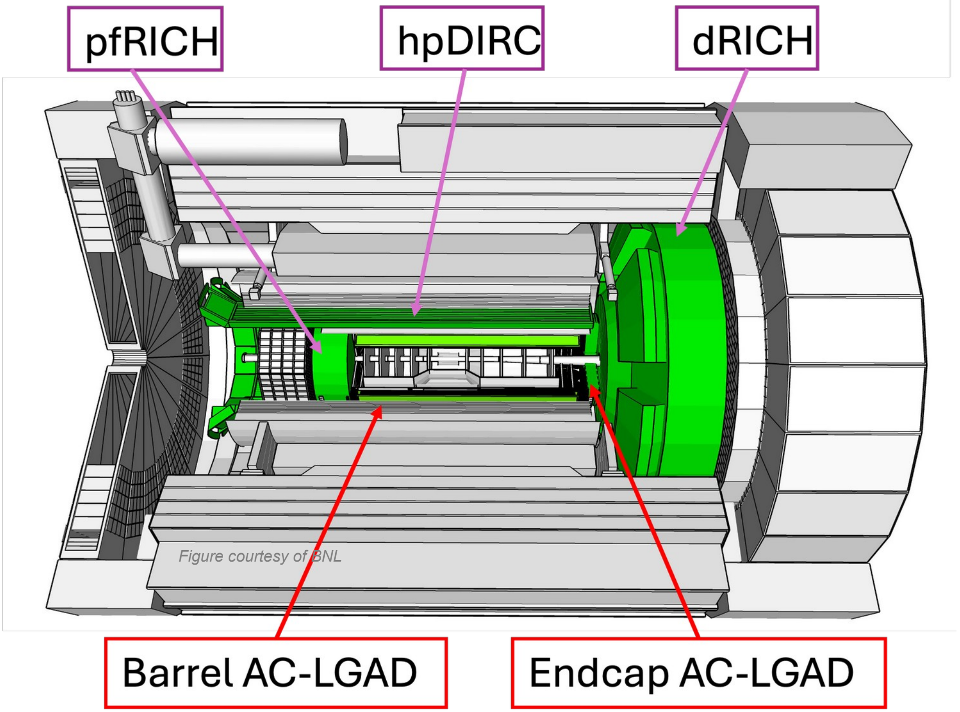

**Requirements:**

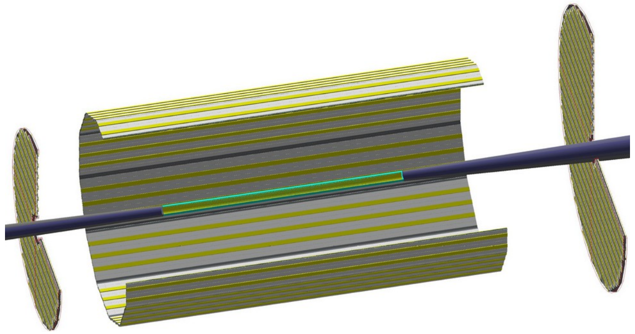
Particle ID in full momentum coverage across rapidity and for different collision energies.

- Electron-photon separation → hermetic tracking
- Electron-hadron separation → calorimetry
- Hadron species separation → Cherenkov and time of flight



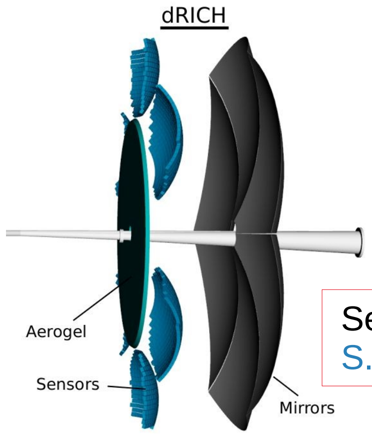
# ePIC particle identification



## Dual Radiator Ring Imaging Cherenkov (dRICH)

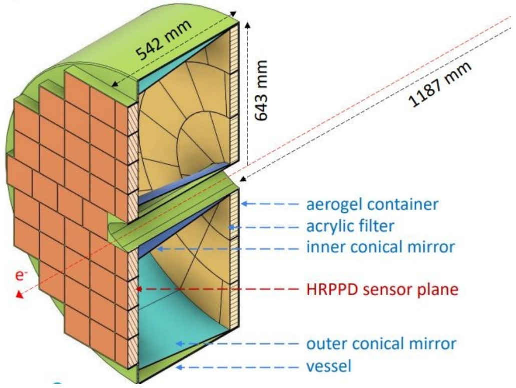
- Aerogel + $C_2F_6$ gas for high-momentum PID up to 50 GeV/c
- First-ever use of SiPMs in a RICH




See talk by S. Vallarino

## Proximity Focusing RICH (pfRICH)

- Aerogel for PID up to 9 GeV/c
- First-ever use HRPPDs as photosensor

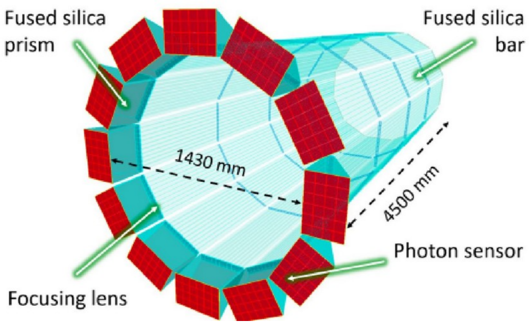



## High-Performance DIRC Detector (hpDIRC)

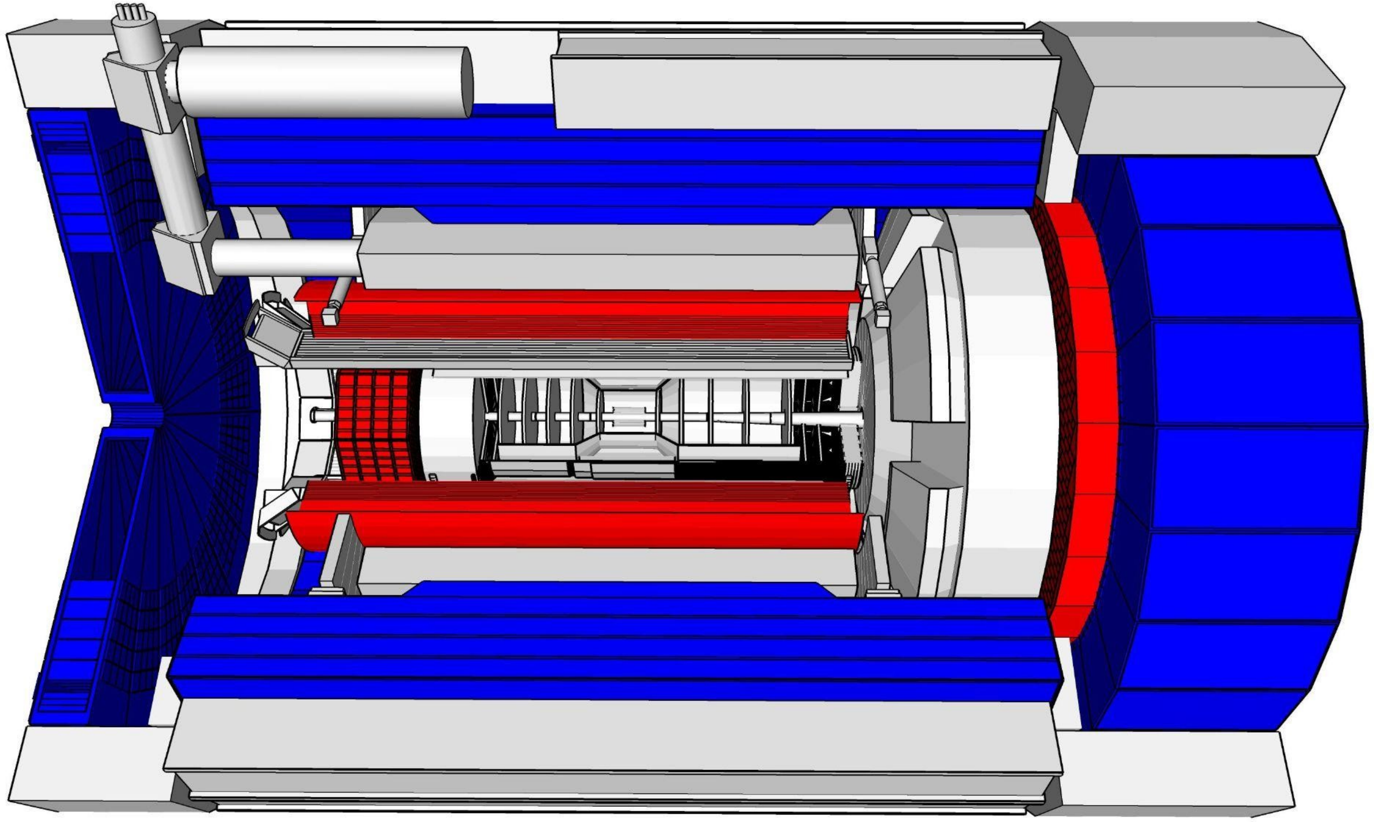
- Quartz bar radiator for PID up to 6 GeV/c
- Fully focused design with lens and large expansion volume

## Time-of-Flight Barrel and Forward Endcap (BTOF and FTOF)

- AC-LGAD sensors give 20-35ps time resolution for ToF, for PID up to $p_T$ < 1.5-2.5 GeV/c
- First-time use of AC-LGAD technology in a collider detector



# ePIC calorimetry

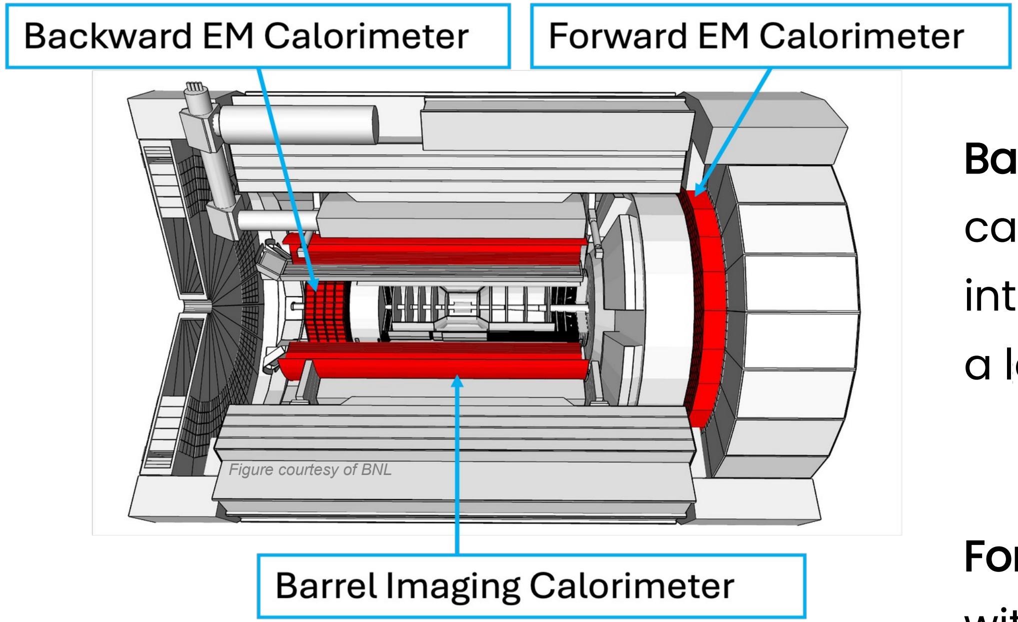


Electromagnetic Calorimetry Hadronic Calorimetry

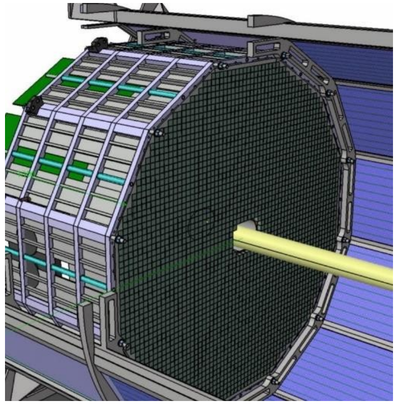
**Requirements:**

- Electron detection over the whole rapidity range
- High granularity to identify $\pi^0 \rightarrow \gamma\gamma$
- Improve electron momentum reconstruction at backward rapidity
- Contain the forward rapidity hadronic shower and separate their clusters

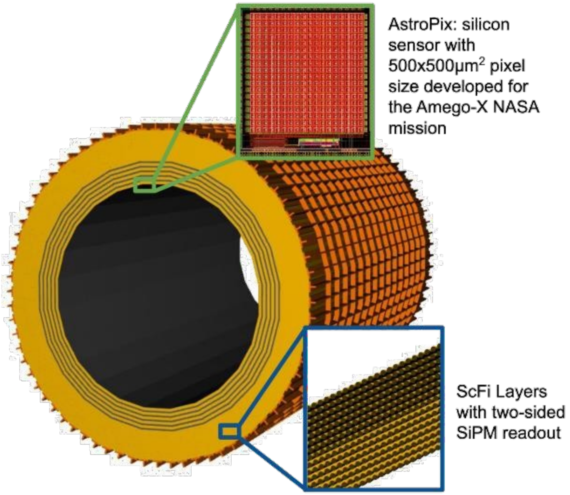
# ePIC electromagnetic calorimetry



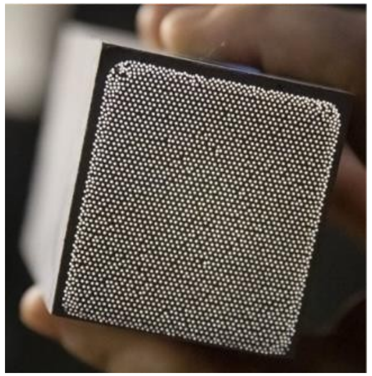

**Backward Ecal**: High-precision PbWO4 crystal calorimeter with SiPM readout



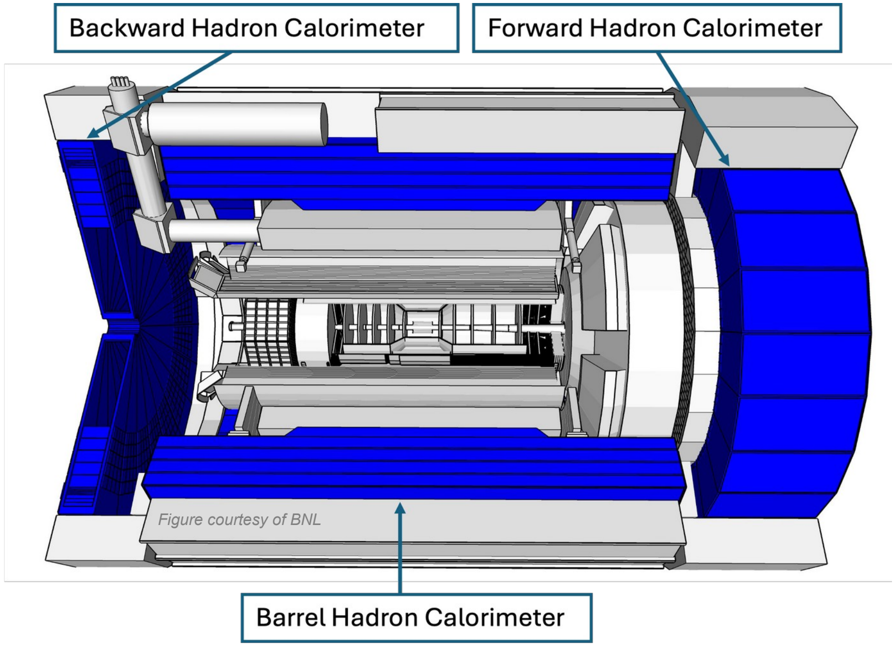
**Barrel Imaging Calorimeter:** Hybrid imaging calorimeter: 6 layers of AstroPix sensors interleaved with 5 Pb/ScFi layers, followed by a large section of Pb/ScFi




**Forward Ecal:** W-powder/SciFi SPACAL design with SiPM readout



# ePIC hadronic calorimetry

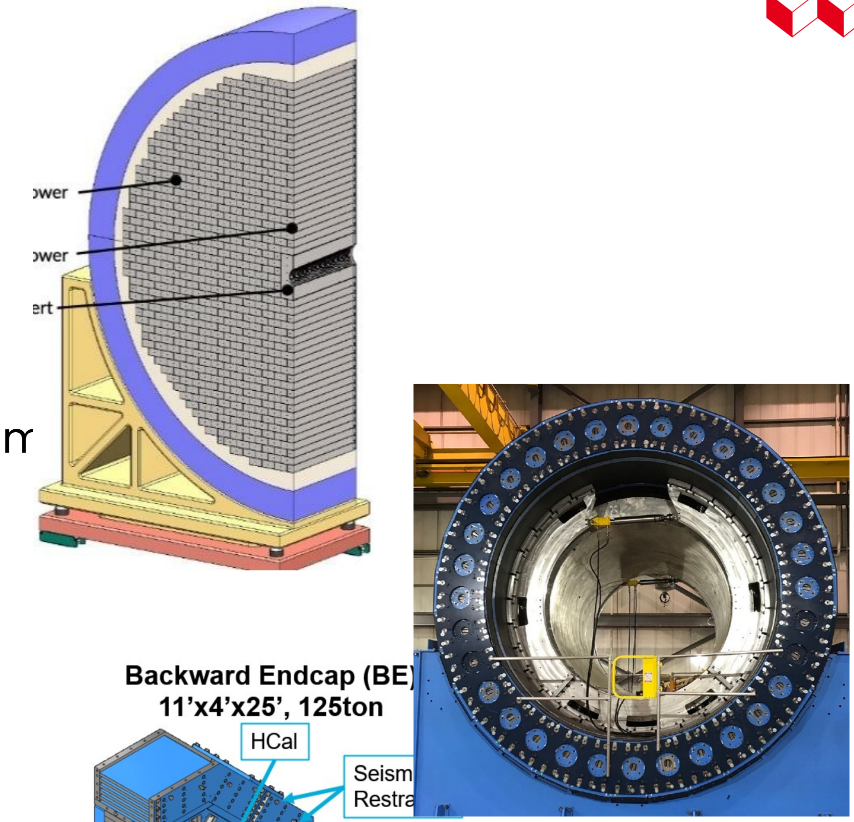



**Foward HCal:**

CALICE-like design

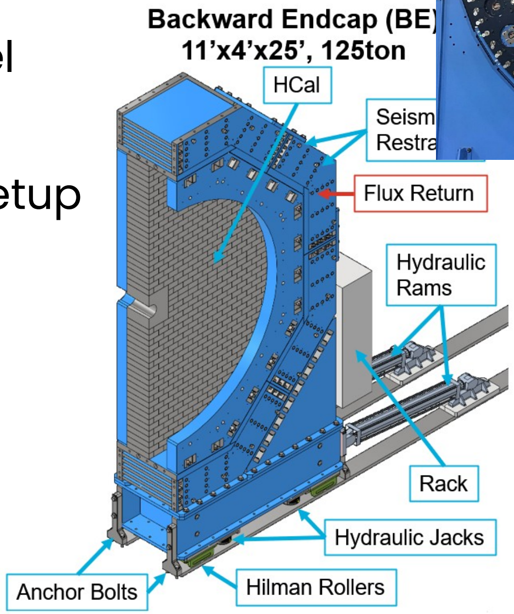
Longitudinally segmented steel-scintillator modules

High resolution insert close to beam pipe



**Barrel HCal:**

- Longitudinally segmented steel
- scintillator SiPM-on-tile
- Reuse and refurbish sPHENIX setup

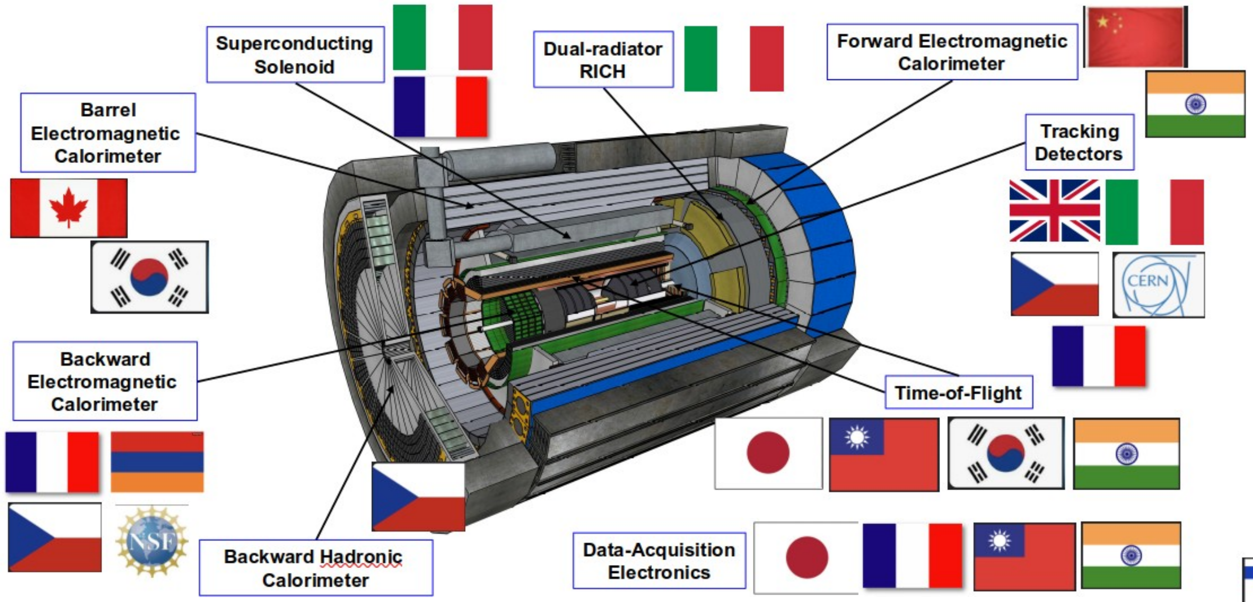



**Backward HCal:**

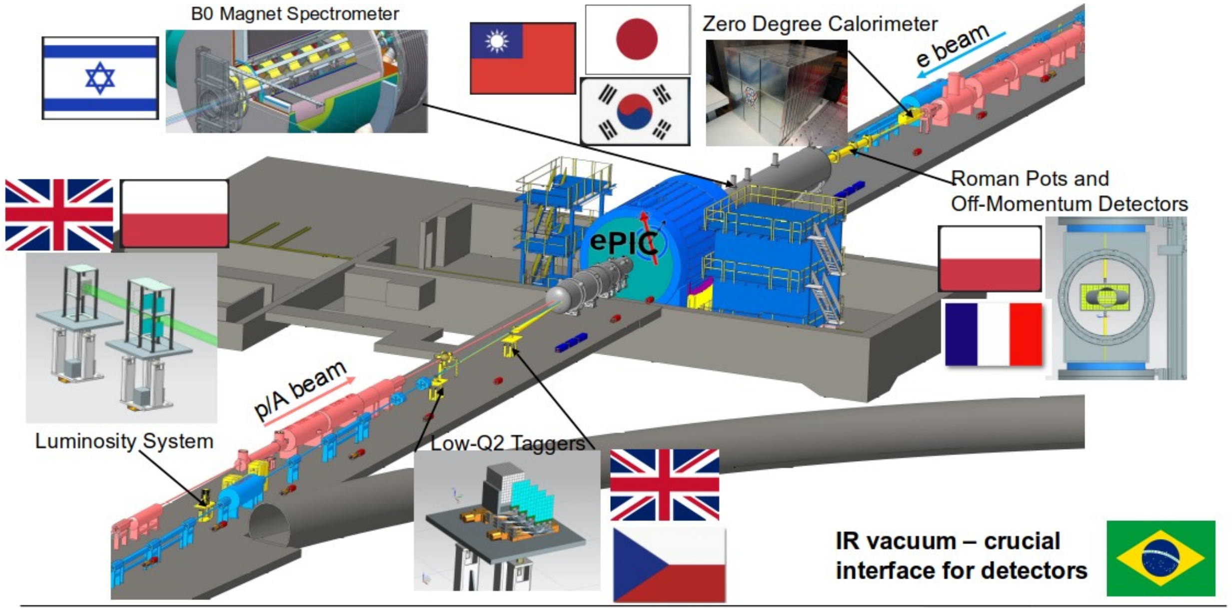
- Steel and scintillator sandwich tiles
- SiPM-on-tile readout
- Similar design as FHCal

# International engagement in ePIC

Central detector




Forward/backward detectors




Large non-US participation and contributions.

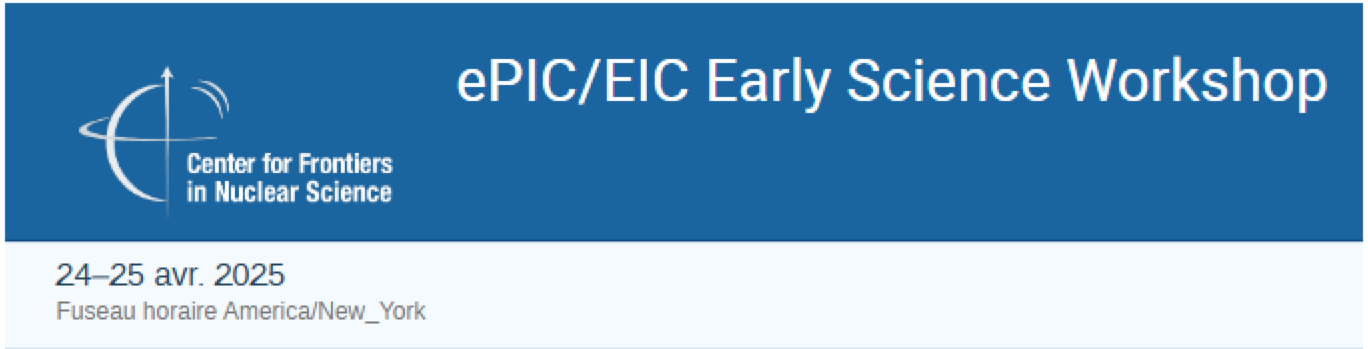
# EIC Early Science

| | Species | Energy (GeV) | Luminosity/year (fb-1) | Electron polarization | p/A polarization |
|---|---|---|---|---|---|
| **YEAR 1** | e+Ru or e+Cu | 10 x 115 | 0.9 | NO (Commissioning) | N/A |
| **YEAR 2** | e+D<br>e+p | 10 x 130 | 11.4<br>4.95 - 5.33 | LONG | NO<br>TRANS |
| **YEAR 3** | e+p | 10 x 130 | 4.95 - 5.33 | LONG | TRANS and/or LONG |
| **YEAR 4** | e+Au<br>e+p | 10 x 100<br>10 x 250 | 0.84<br>6.19 - 9.18 | LONG | N/A<br>TRANS and/or LONG |
| **YEAR 5** | e+Au<br>e+3He | 10 x 100<br>10 x 166 | 0.84<br>8.65 | LONG | N/A<br>TRANS and/or LONG |

**Note: the eA luminosity is per nucleon**

Based on machine capabilities and evolution over the first years
EPIC started a series of workshop with the goal of identifying impacting science while commissioning different machine and detector systems

https://indico.cfnssbu.physics.sunysb.edu/event/410/



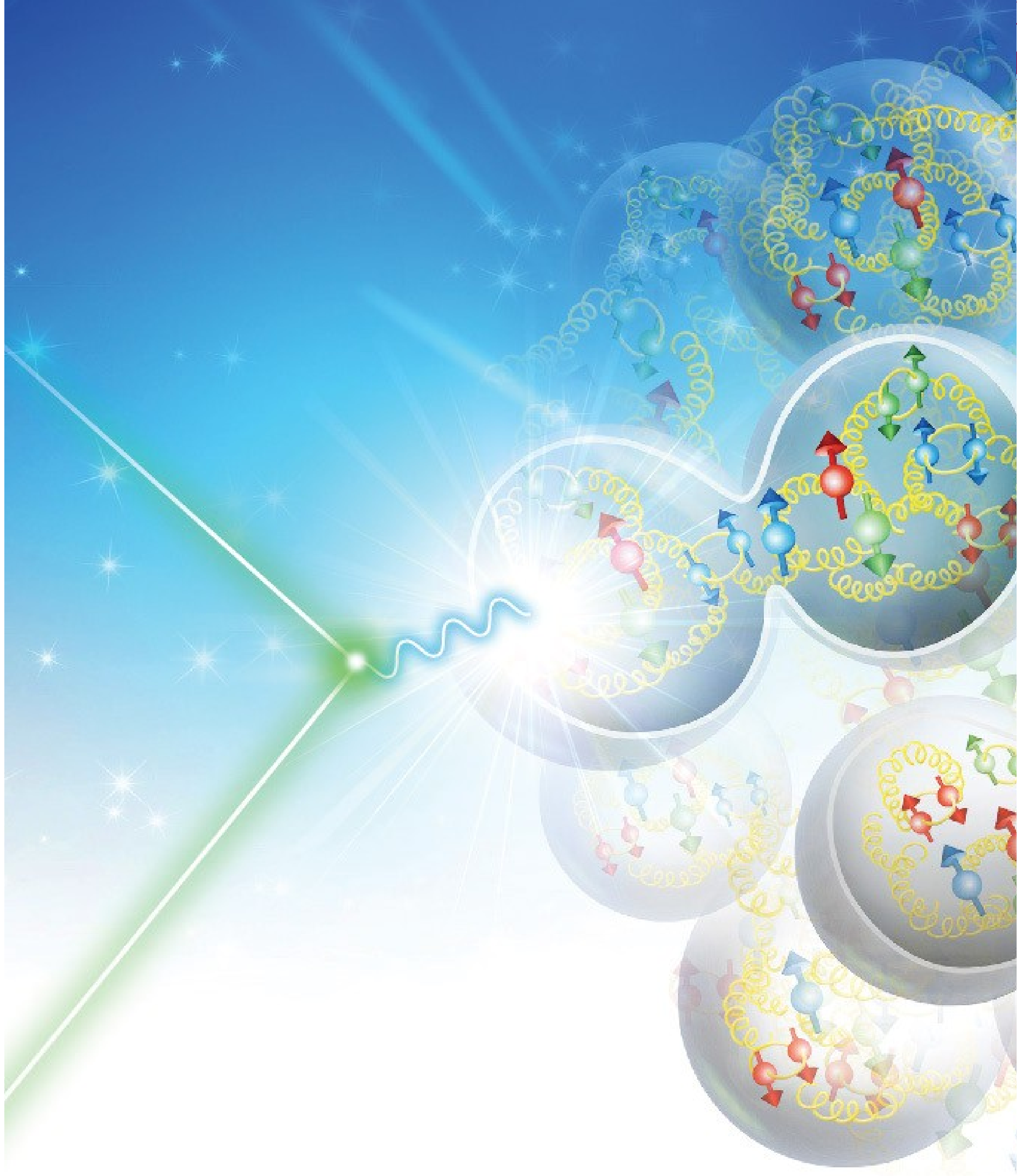

https://indico.global/event/15249/

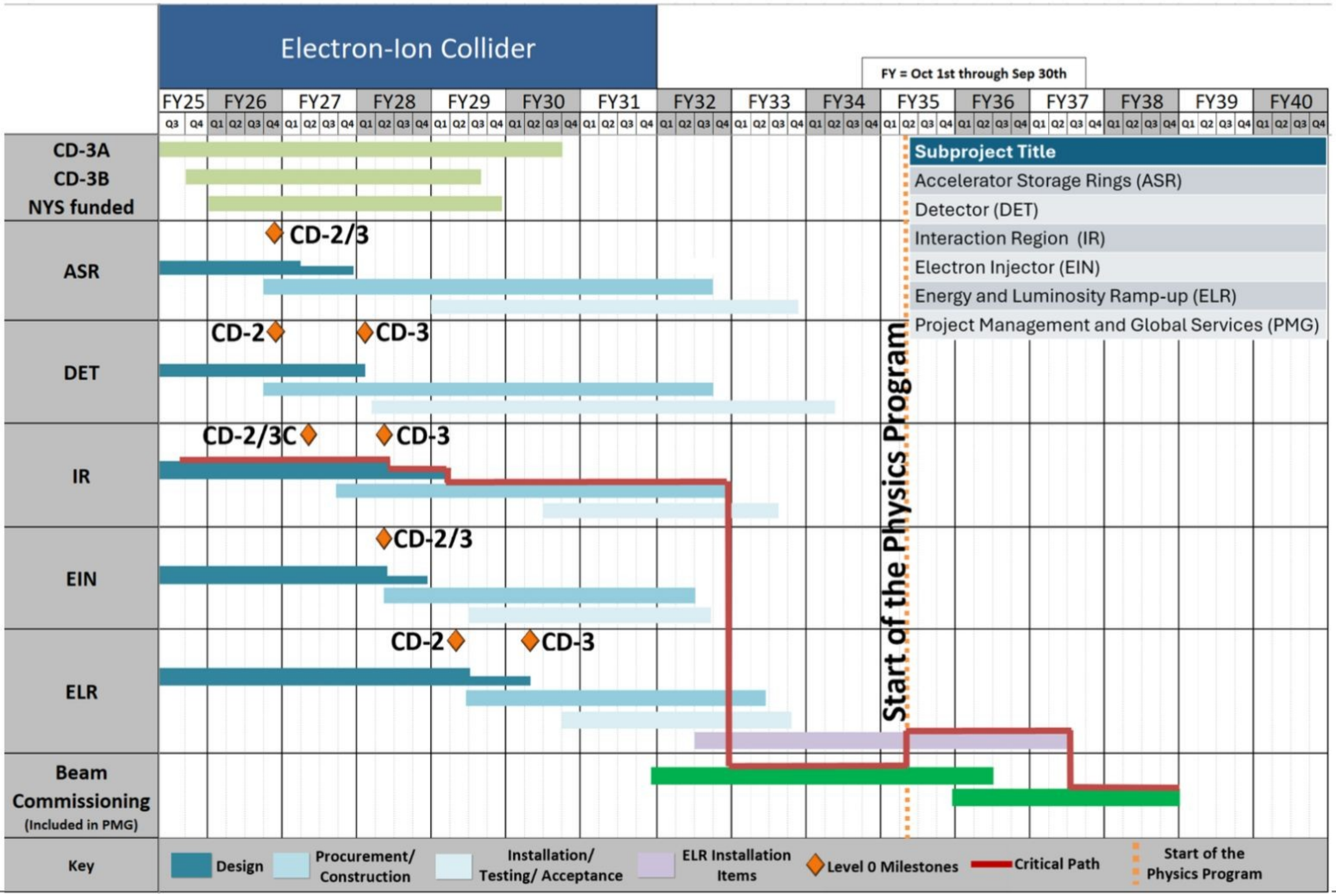
# Summary

EIC is a unique, high-energy, high-luminosity, polarized beam collider for the ultimate understanding of QCD: the only new collider in the next 15-20 years

Based in the US, large international participation

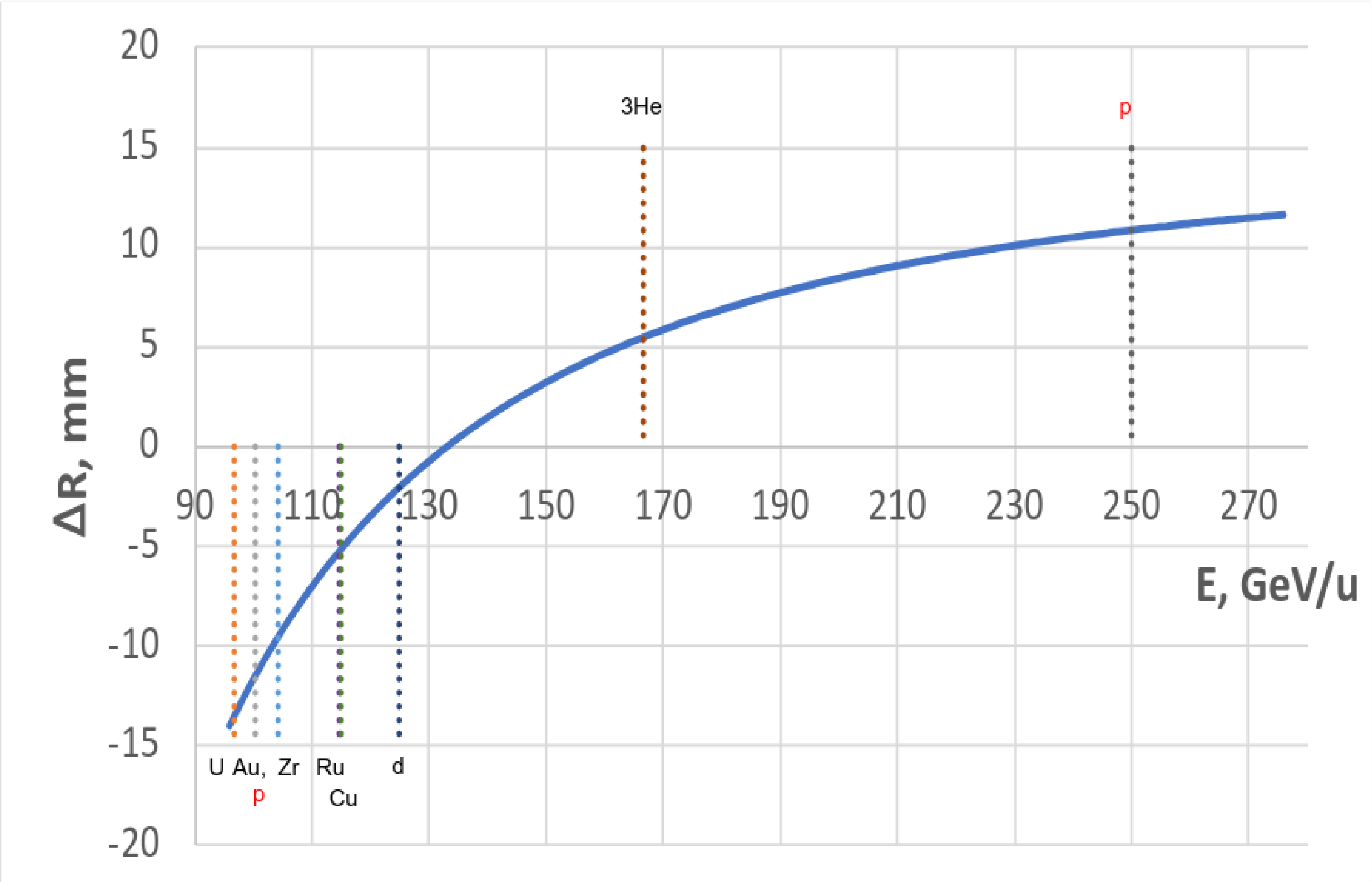
ePIC is designed as a multipurpose detector to be able to cover all the physics highlighted in the EIC Yellow Report

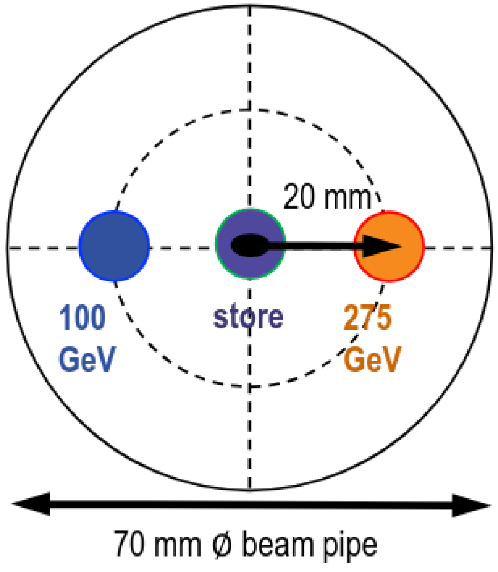




Electron-Ion Collider
FY = Oct 1st through Sep 30th
FY25
FY26
FY27
FY28
FY29
FY30
FY31
FY32
FY33
FY34
FY35
FY36
FY37
FY38
FY39
FY40
CD-3A
CD-3B
NYS funded
ASR
CD-2/3
DET
CD-2
CD-3
IR
CD-2/3C
CD-3
EIN
CD-2/3
ELR
CD-2
CD-3
Beam Commissioning
(Included in PMG)
Start of the Physics Program
Subproject Title
Accelerator Storage Rings (ASR)
Detector (DET)
Interaction Region (IR)
Electron Injector (EIN)
Energy and Luminosity Ramp-up (ELR)
Project Management and Global Services (PMG)
Key
Design
Procurement/ Construction
Installation/ Testing/ Acceptance
ELR Installation Items
Level 0 Milestones
Critical Path
Start of the Physics Program

# Beam Energy and Average Orbit Radius in the HSR




Since the electron revolution frequency is fixed, the hadron orbit must be adjusted with energy to keep the collisions in sync.

1. Prefer ~130 GeV/u, which corresponds to a 'centered' hadron beam (path length difference ΔR ~ 0, this is achieved for a beam where Z ~ 0.5A) → Ru, Cu, Ag, …..
2. Do not want to exceed the present RHIC maximum dipole fields (corresponds to 250 GeV protons or 833 T-m)

Slide by E. Aschenauer and R. Ent