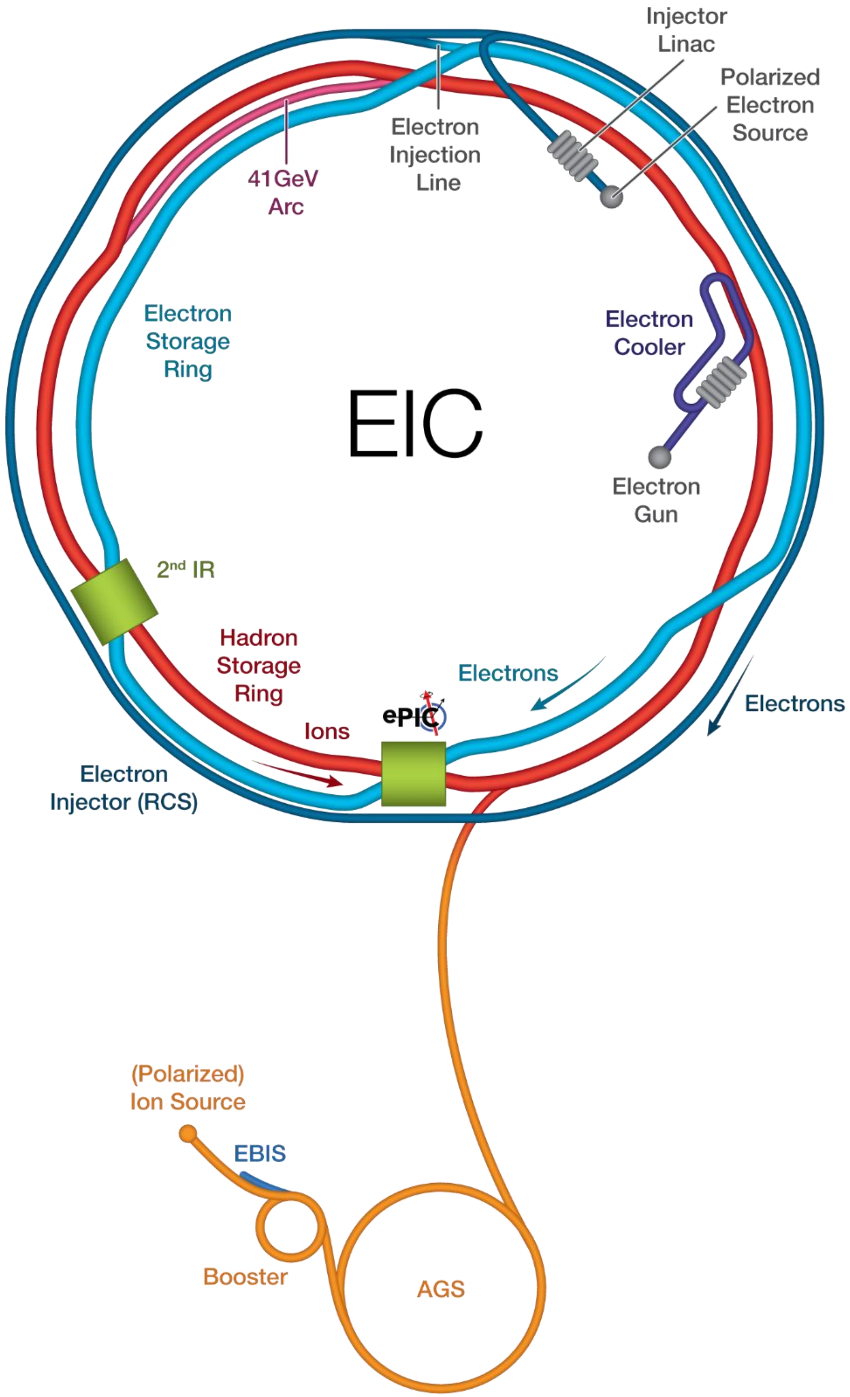


Physics program and detector technologies of ePIC at EIC

Carlos Muñoz Camacho
IJCLab, CNRS/IN2P3

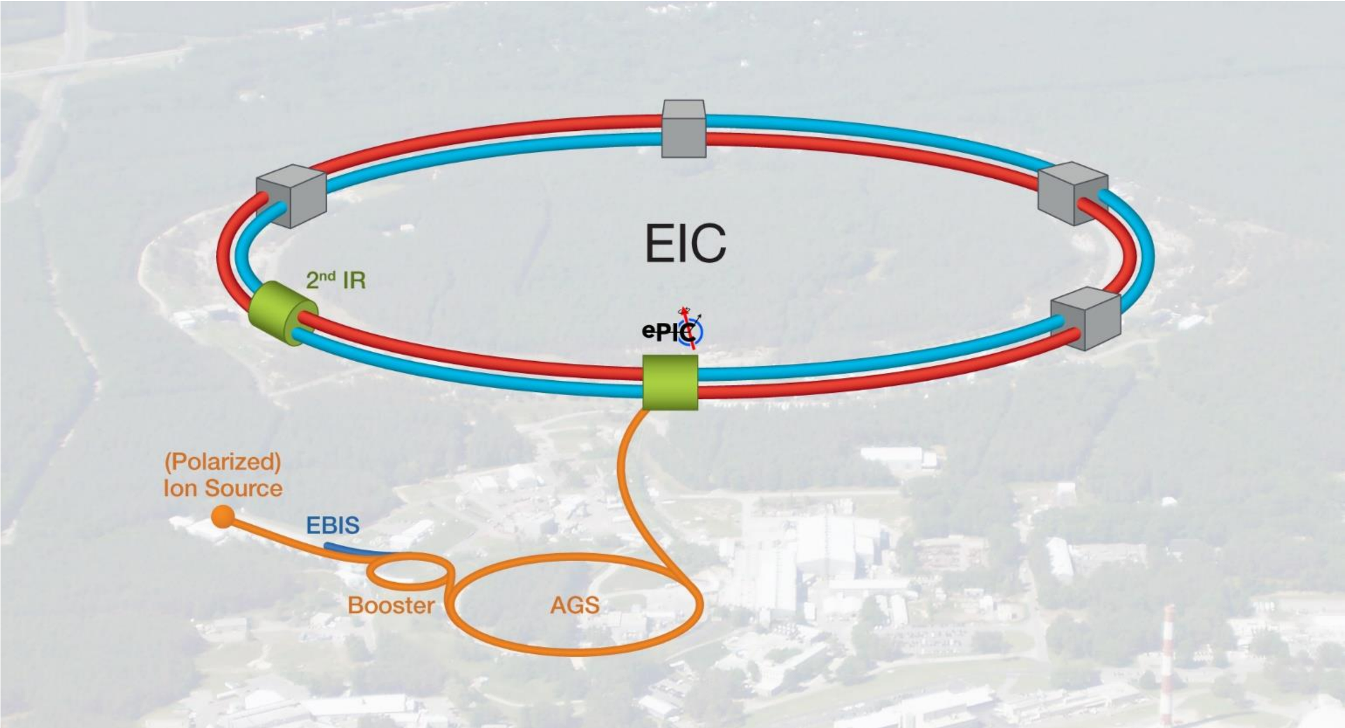
on behalf of the ePIC Collaboration

SQM 2024
The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

June 7, 2024

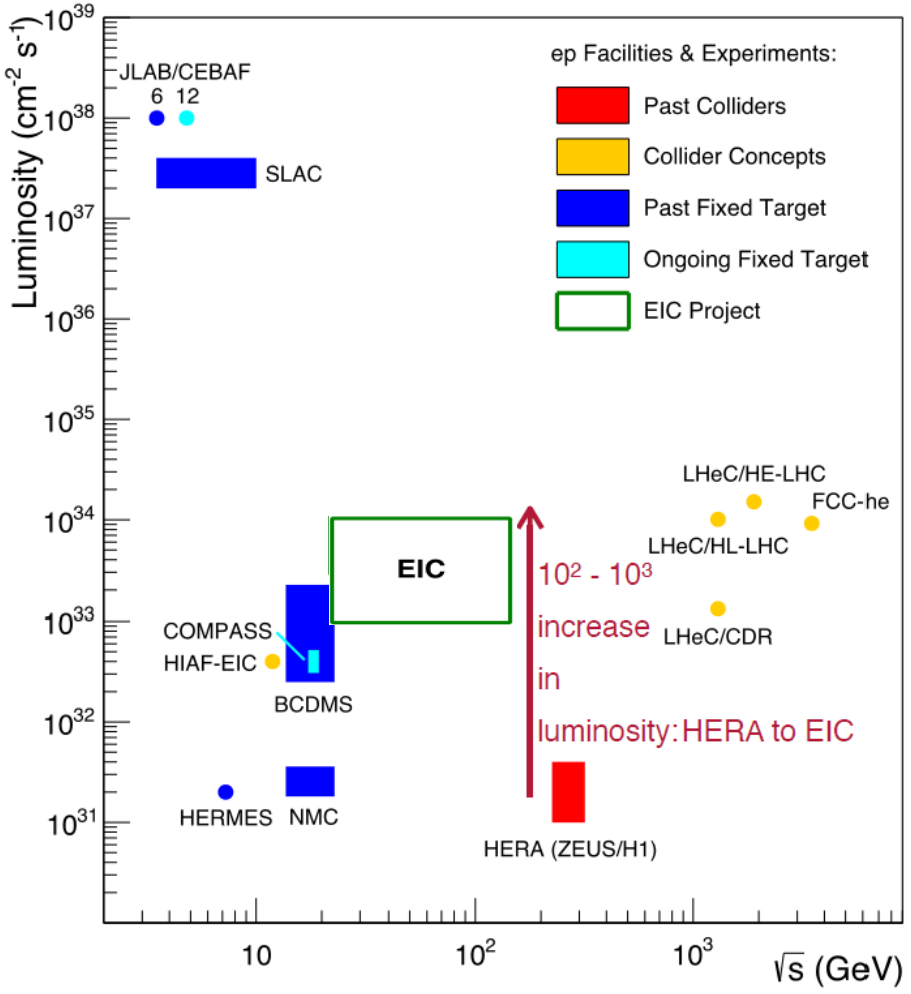
The EIC facility

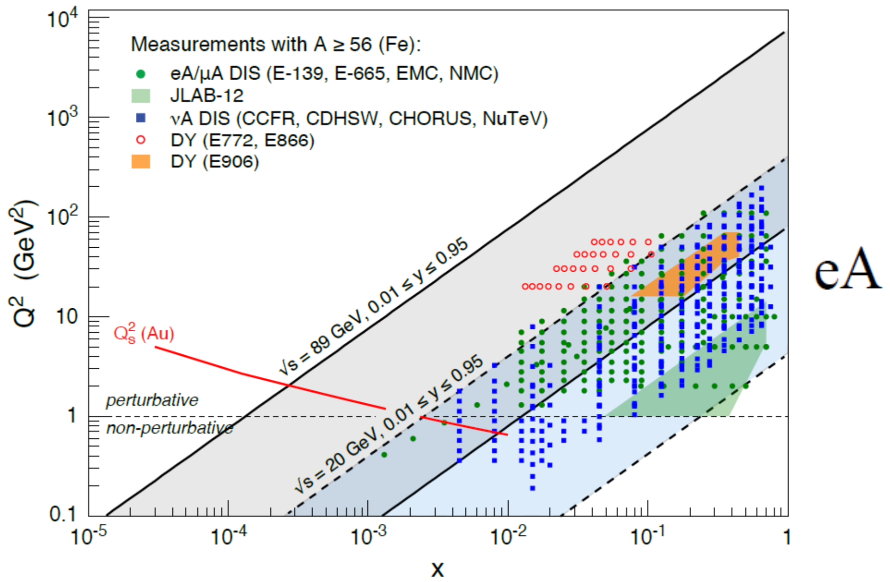
- Highly polarized electron / Highly polarized proton and light ions /Unpolarized heavy ions
- CME: ~ 20–140 GeV
- Luminosity: ~ $10^{33\text{-}34}$ $cm^{-2}s^{-1}$

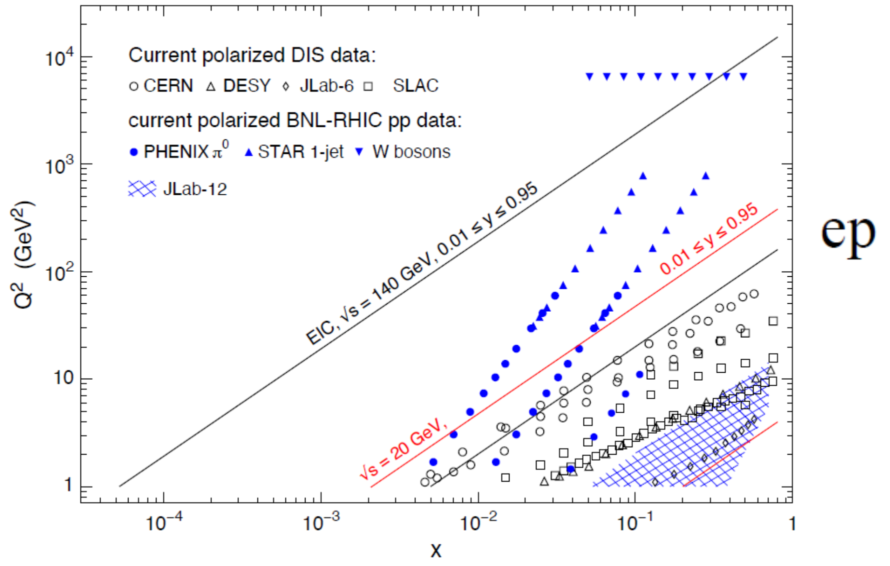


- Polarized electron source and 400 MeV injector linac to feed a rapid cycling synchrotron design to avoid depolarizing resonances up to the maximum e-beam energy of 18 GeV
- Polarized proton beams and ion beams based on existing RHIC facility
- 2 detector interaction points capability in the design

Luminosity and kinematic coverage



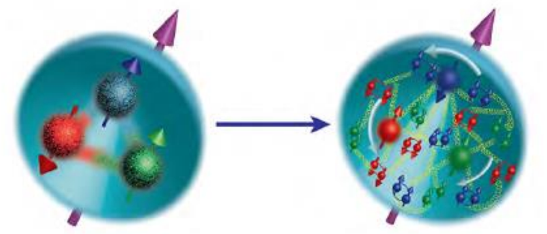




Motivation – the EIC science program

Origin of spin:

How does the spin-1/2 of the nucleon arise from the spin of quarks, gluons and their orbital angular momenta?

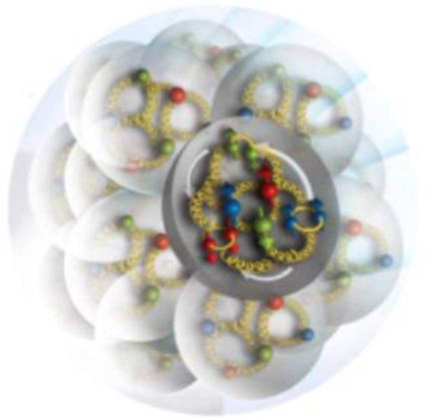


Origin of mass:

How do massless gluons make up for most of the nucleon mass?

Gluons in nuclei:

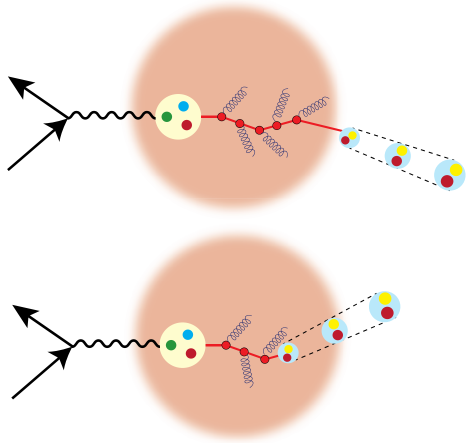
Does gluon density saturate at high energy giving rise to a new regime of matter?



Hadronization: emergence of hadrons from partons

Unprecedented ν, the virtual photon energy range @ EIC : *precision & control*

$$\nu = \frac{Q^2}{2mx}$$



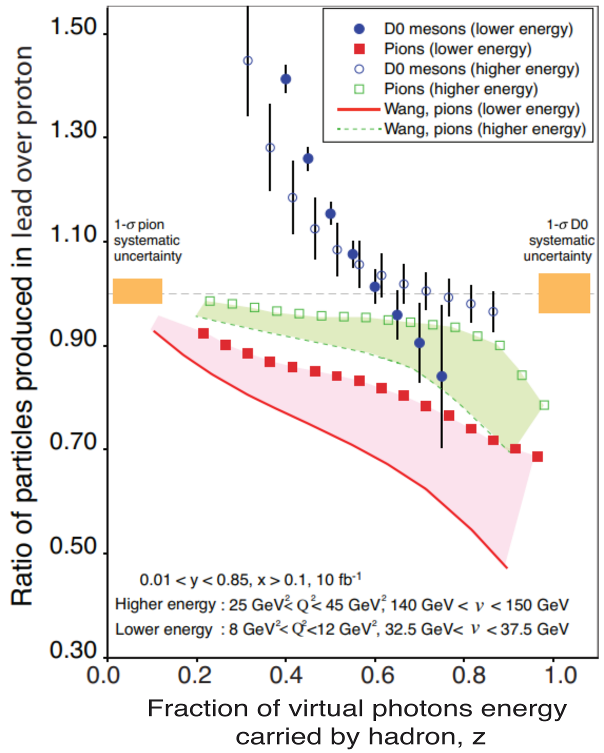
Control of n by selecting kinematics;

Also under control the nuclear size.

Colored quark emerges as color neutral hadron

What is the impact of colored media on confinement?

Energy loss by light vs. heavy quarks:



EIC White Paper
Eur. Phys. J. A (2016) 52

Identify light vs. charm hadrons in e-A:

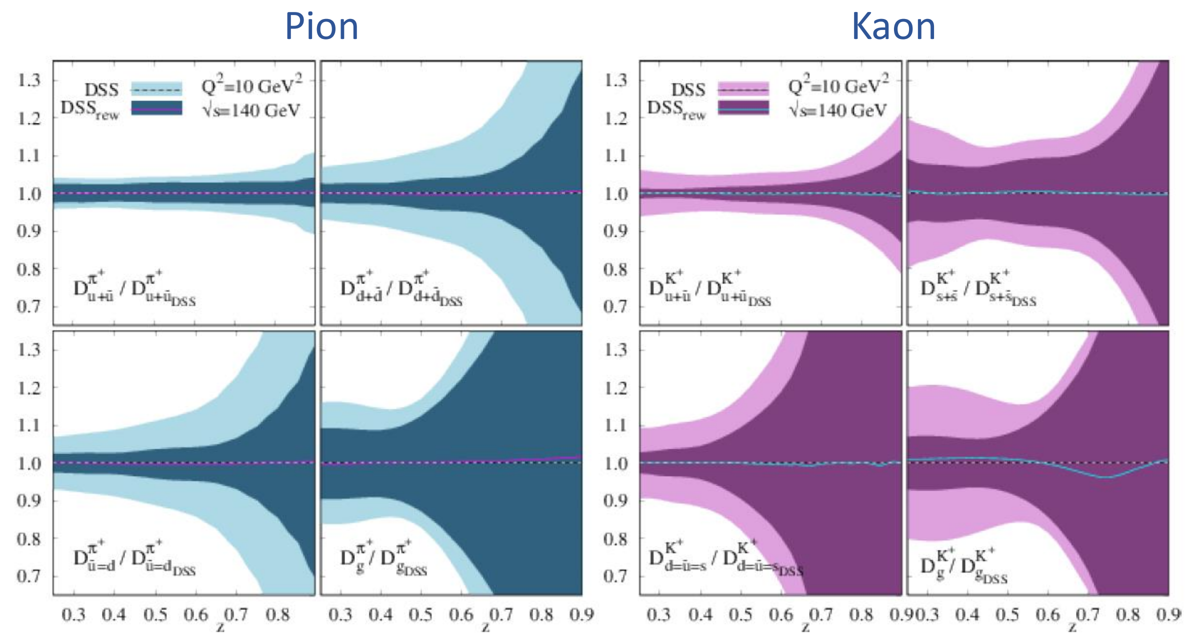
Understand energy loss of light vs. heavy quarks in cold nuclear matter.

Provides insight into energy loss in the Quark-Gluon Plasma

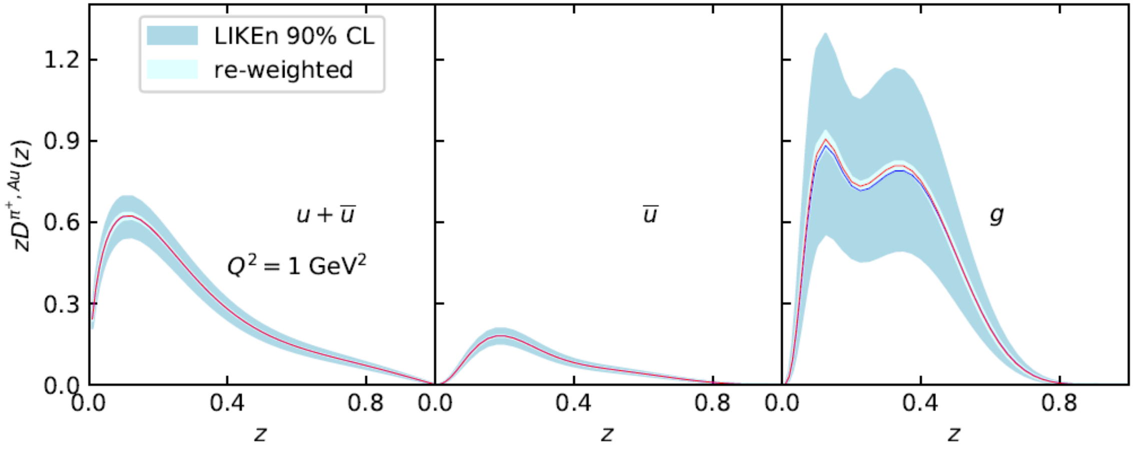
DIS at collider energies enables control of parton/event kinematics

Fragmentation functions

- Describe the formation of final-state hadrons off free partons
- Directly connect to the confinement of the strong interaction
- *pp* primarily constrain gluon FFs
- Light meson SIDIS constraints FFs from light quarks and anti-quarks (+ flavor separation)



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



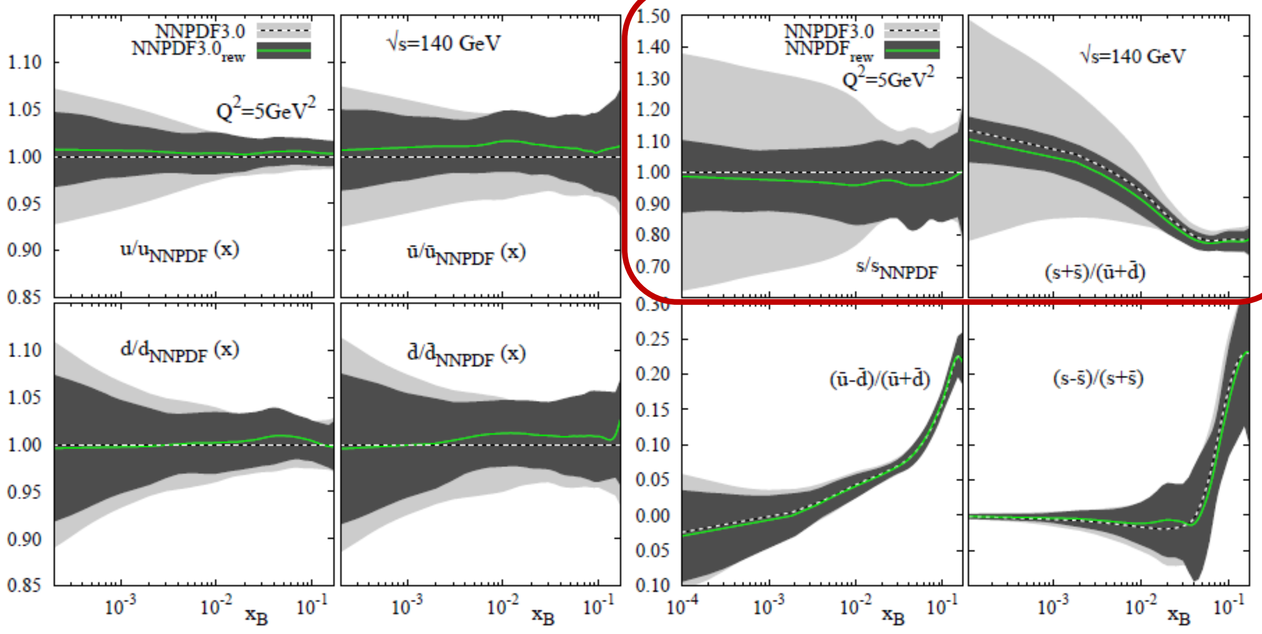
Impact of EIC data in nFFs

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

- In hadron-hadron collisions observables depend on both nPDF and nFF
- SIDIS is the cleanest way to study in-medium modifications of FF (multiplicity studies pioneered by HERMES)
- The much superior precision of EIC (with respect to HERMES) will allow us to fully characterize the nFFs

Quark PDFs from SIDIS

- Kaons sensitive to strange quarks
- Negative/positive pions sensitive to d/u quarks
- Combination of data on pions, kaons (and other hadrons) allow one to disentangle valence, sea and gluon (unpolarized) PDFs



Poorly known strange PDFs will be well constraint (in particular at low x)

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

Expected impact on the unpolarized (sea) quark PDFs when adding SIDIS information from pions and kaons in ep collisions.

Nuclear PDFs from inclusive DIS

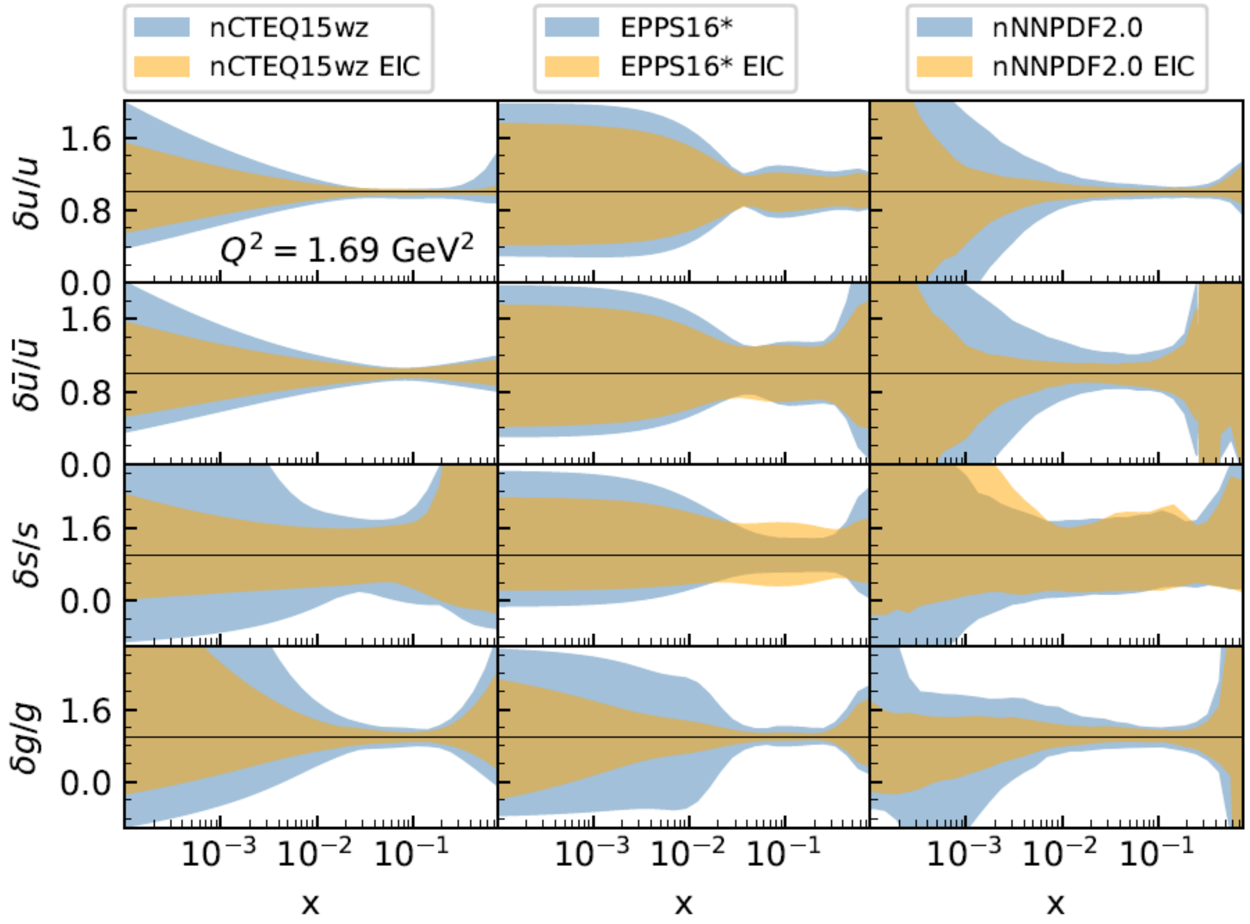
$$\sigma \propto F_2(x,Q^2) - \frac{y^2}{1+(1-y)^2} F_L(x,Q^2)$$

Sensitive to (anti-)quark content of nucleon
Dominant at high x

Direct contribution from the gluon density

- EIC will scrutinize the A-dependence of nPDFs (from p to Pb)
- Heavy flavor production at EIC will also constrain nuclear modifications of gluon PDFs
- EIC will allow a combined determination of proton, deuteron and nuclear PDFs within a global QCD analysis

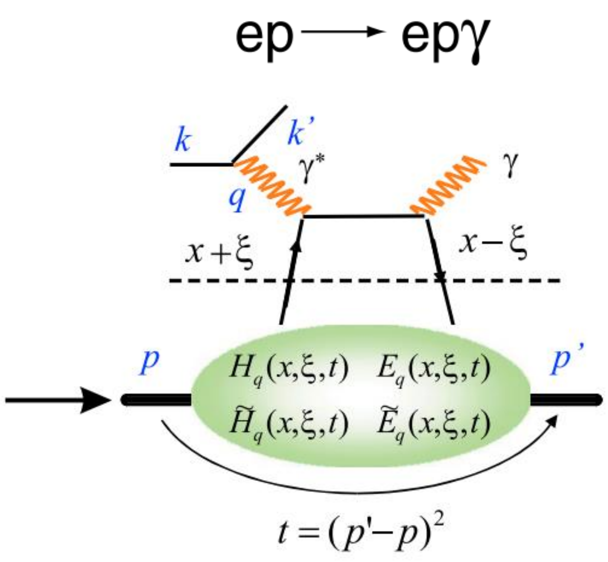
Expected impact of EIC on nPDFs
(significant reduction of uncertainties at low x)

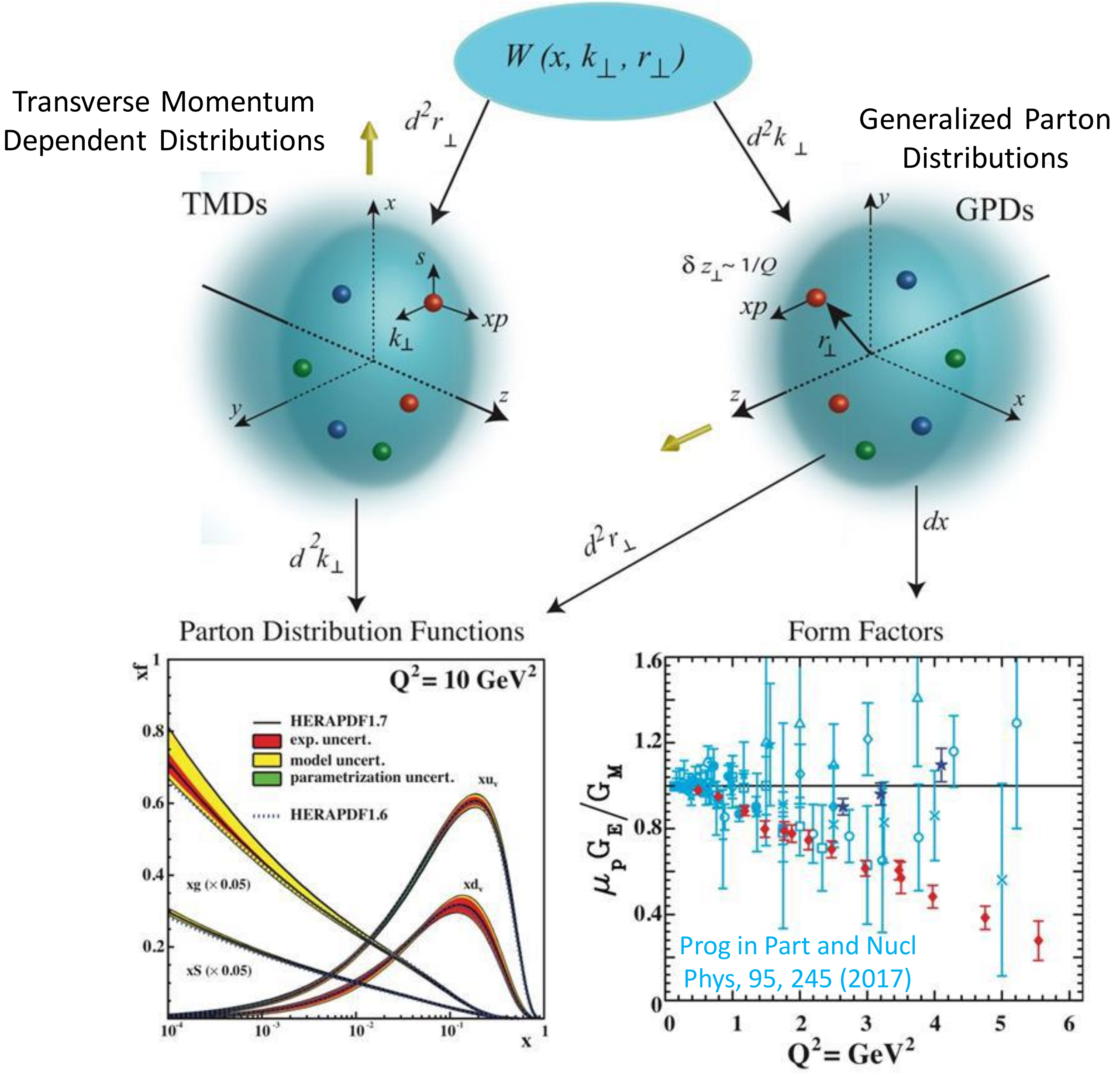


Relative uncertainty bands for Au at Q^2=1.69 GeV^2

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

3D imaging of the nucleon





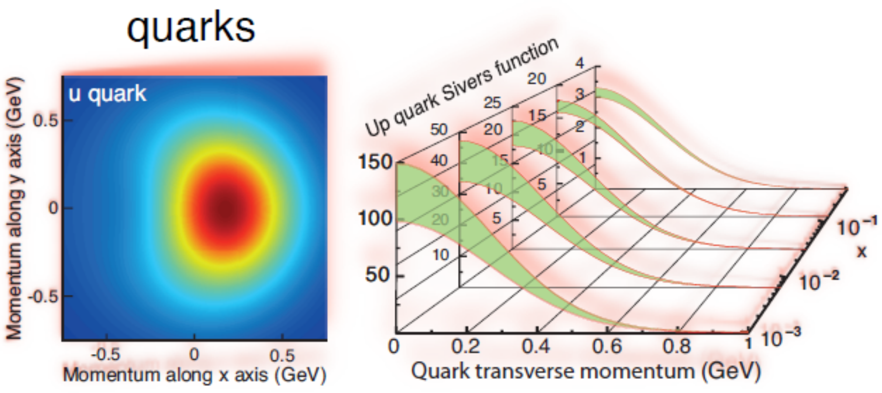
- Deeply Virtual Compton Scattering (DVCS)
- Deeply Virtual Meson Production (DVMP)
- Semi-inclusive pions, kaons… production

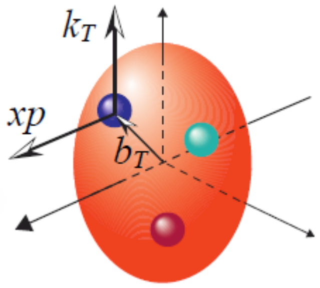
TMDs and GPDs at EIC

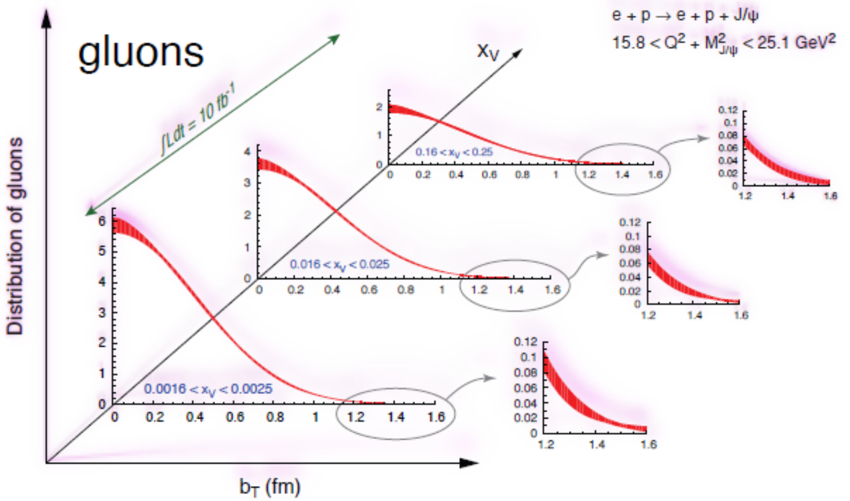
- Transverse Momentum Distribution and Spatial Imaging

$f(x, k_T)$ 1+2D $\int d^2 b_T$ $W(x, b_T, k_T)$ $\int d^2 k_T$ $f(x, b_T)$ 1+2D

Transverse Momentum Distribution (TMD) | Wigner Distribution | Impact Parameter Distribution







- Spin-dependent 1+2D momentum space (transverse) images from semi-inclusive scattering
- Spin-dependent 1+2D impact parameter (transverse) images from exclusive scattering

Fourier transf.
$b_T \longleftrightarrow \Delta$: $t = -\Delta^2$

$H(x, 0, t)$

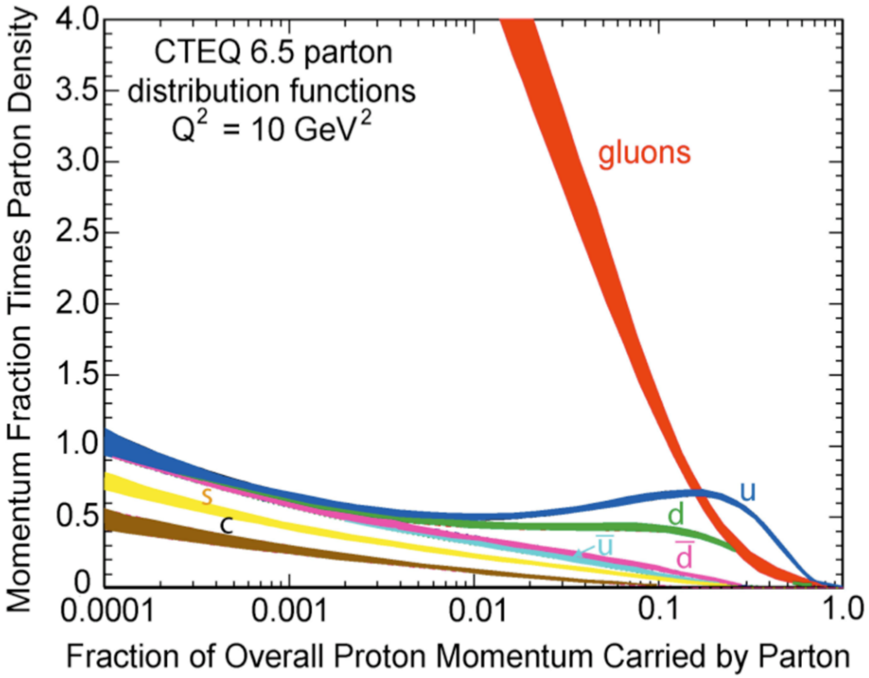
$\xi = 0$

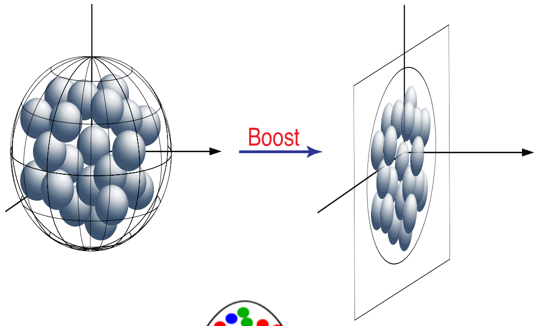
$H(x, \xi, t)$

Generalized Parton Distribution (GPD)

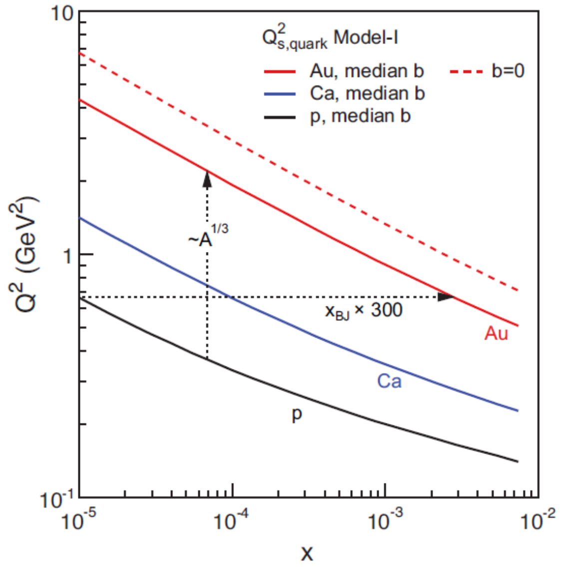
EIC White Paper
Eur. Phys. J. A (2016) 52

Gluon saturation

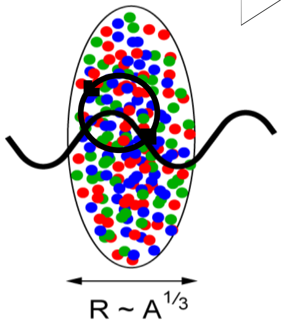




Advantage of nucleus



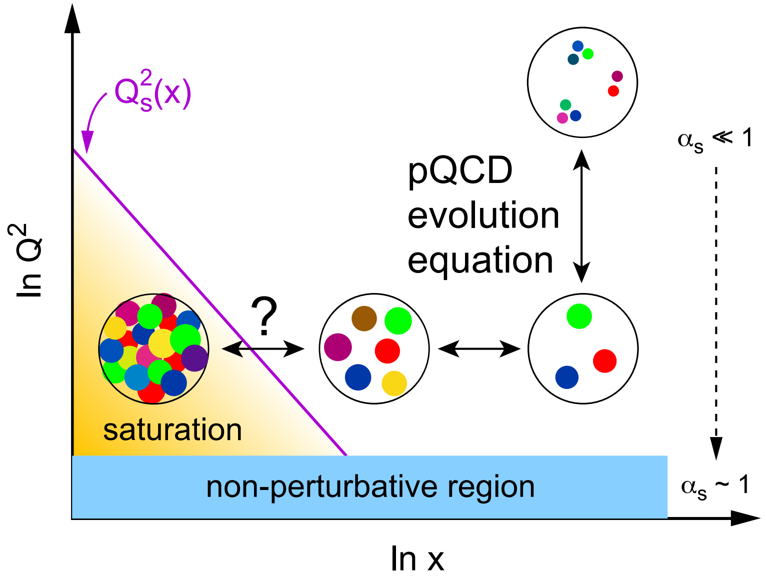
EIC White Paper
Eur. Phys. J. A (2016) 52



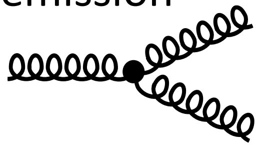
$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

L ~ $(2m_N x)^{-1} > 2\,R_A \sim A^{1/3}$

Enhancement of Q_S with A:
Saturation regime reached at significantly lower energy in nuclei



gluon emission



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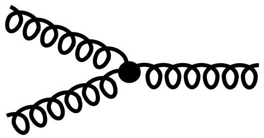
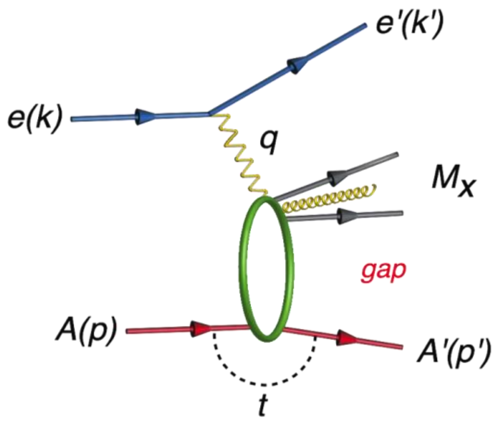
gluon recombination



At Q_S

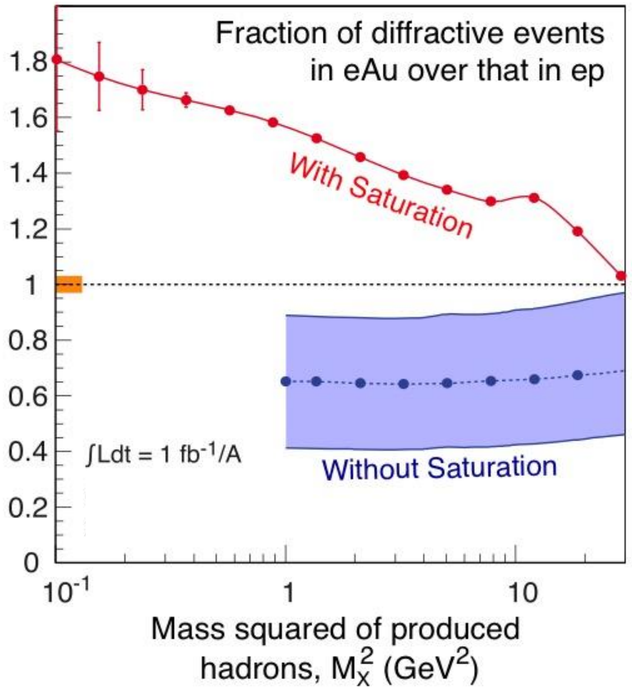
Diffractive events and gluon densities

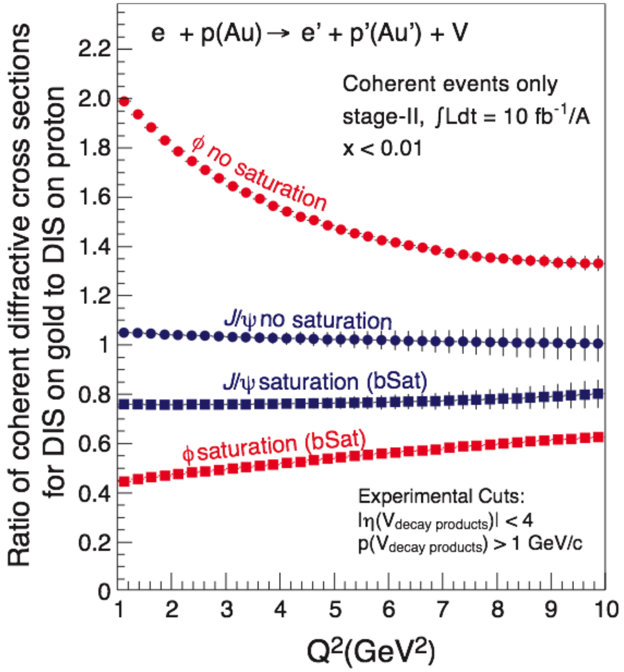


Diffraction cross-sections have strong discovery potential:

High sensitivity to gluon density in linear regime: $\sigma \sim [g(x,Q^2)]^2$

Dramatic changes in cross-sections with onset of non-linear strong color fields





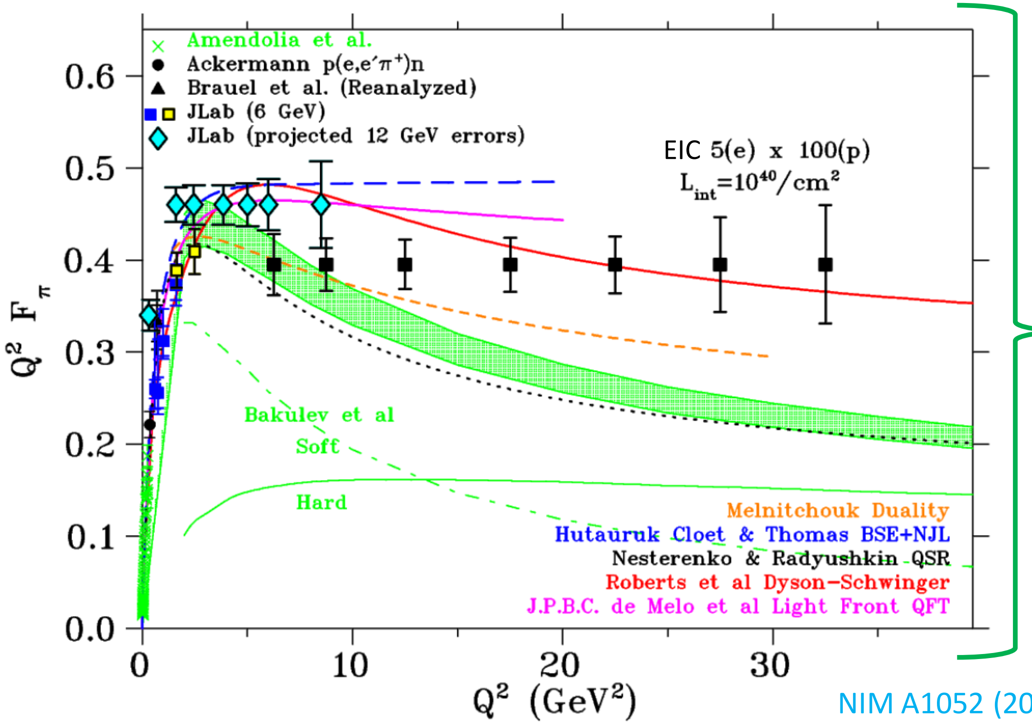
EIC White Paper
Eur. Phys. J. A (2016) 52

Origin of mass

- Threshold J/Ψ production as a function of Q^2 is sensitive to the trace anomaly contribution to the proton mass

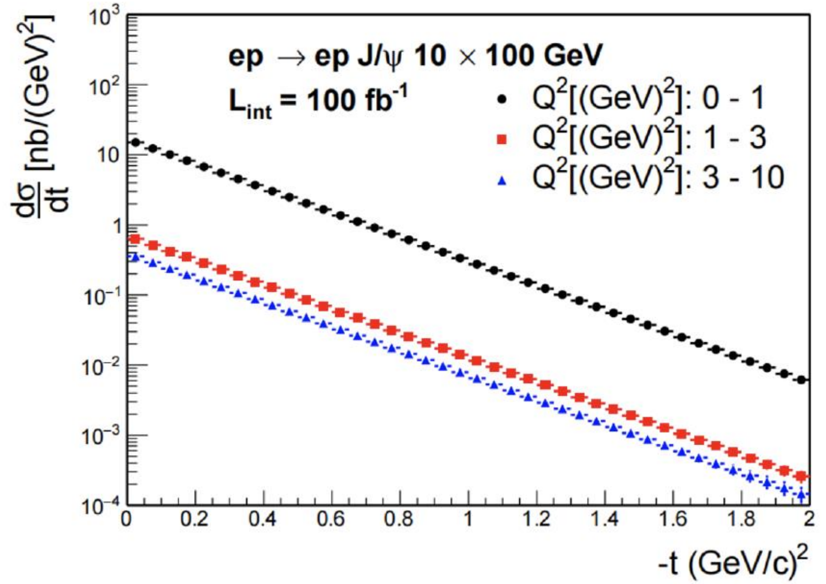
- Meson structure measurements (structure function & form factor) probe the hadron mass generation through chiral symmetry breaking

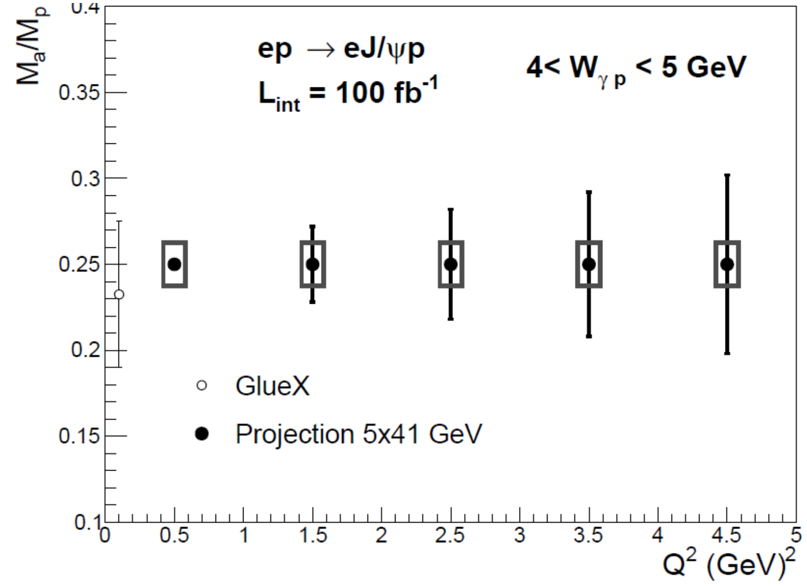
Pion form factor: measurements up 30 GeV^2



Far-forward detectors are key for reconstructing mesons at very forward η

NIM A1052 (2023) 168238



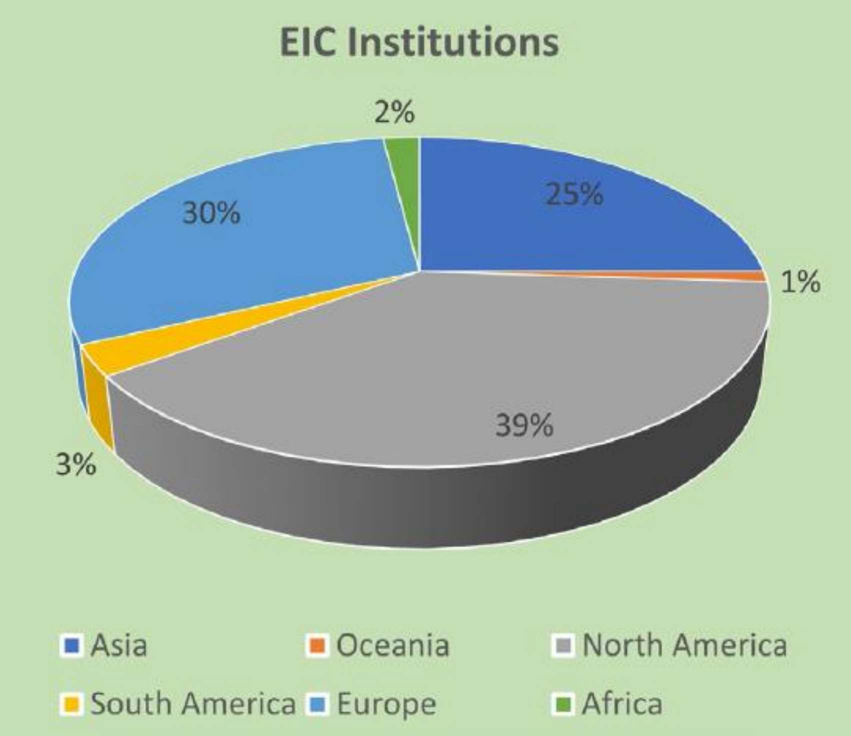


https://doi.org/10.5281/zenodo.6537588

The EIC Users Group

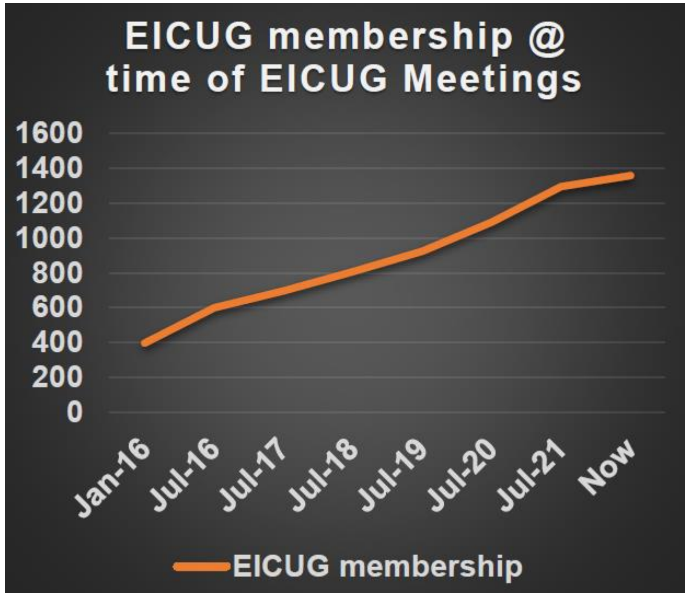
Formed in 2016, currently:

- 1487 collaborators,
- 40 countries,
- 292 institutions as of today



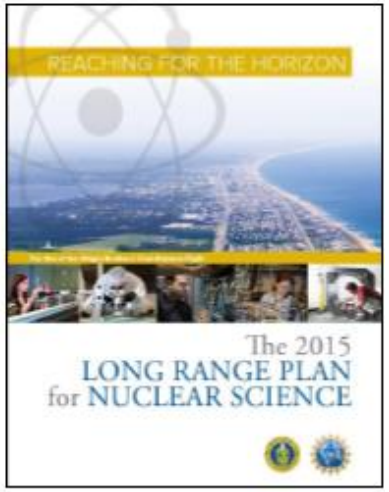
Annual EICUG meeting:

- 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 Bethlehem, PA



International participation growing

EIC development: some critical steps



- INT workshop series (2010) and white paper (2012, updated in 2014 for LRP)
- 2015: US Long-range plan (LRP)

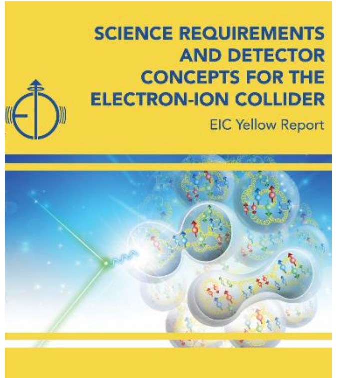
  Recommendation 3: construct a high-luminosity polarized electron-ion collider (EIC) as the **highest priority for new construction** following the completion of FRIB

- 2016: Formation of the EIC Users Group
- 2018: Review of the EIC science case by the National Academy of Sciences

  "The committee finds that the science that can be addressed by an EIC is **compelling, fundamental and timely**."

- 2020: DoE announcement of CD-0 ("mission need") and site selection (Brookhaven National Lab)
- 2020: Yellow report initiative

  Goal: advance the state and detail of the documented physics studies (White Paper, INT program proceedings) and detector concepts in preparation for the realization of the EIC.



2103.05419 (3/2021), Nucl. Phys. A 1026 (2022)

- 2021: EIC Conceptual Design Report (CDR)
- 2021: Call for detector proposals

  Choice of baseline detector concept

- 2022: Formation of the ePIC Collaboration in order to build the EIC project detector (ePIC)
- 2023: US Long-range plan (LRP) *Recommendation 3:* expeditious completion of the EIC

The ePIC Collaboration

JLab, Jan. 2023

Warsaw, July 2023

ANL, Jan. 2024

- More than 850 collaborators (650+ active members)
- 177 Institutions
- 26 Countries

The EIC project detector: ePIC

Tracking:
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:
- Backward pfRICH
- Barrel hpDIRC
- Forward dRICH
- Barrel & Forward TOF (AC-LGAD)

Calorimetry:
- Backward HCal (Steel+scint)
- $PbWO_4$ EMCal in backward direction
- Sampling & Imaging Barrel EMCal
- Outer HCal (sPHENIX re-use)
- Finely segmented EMCal +HCal in forward direction

hadronic calorimeters

Solenoidal Magnet

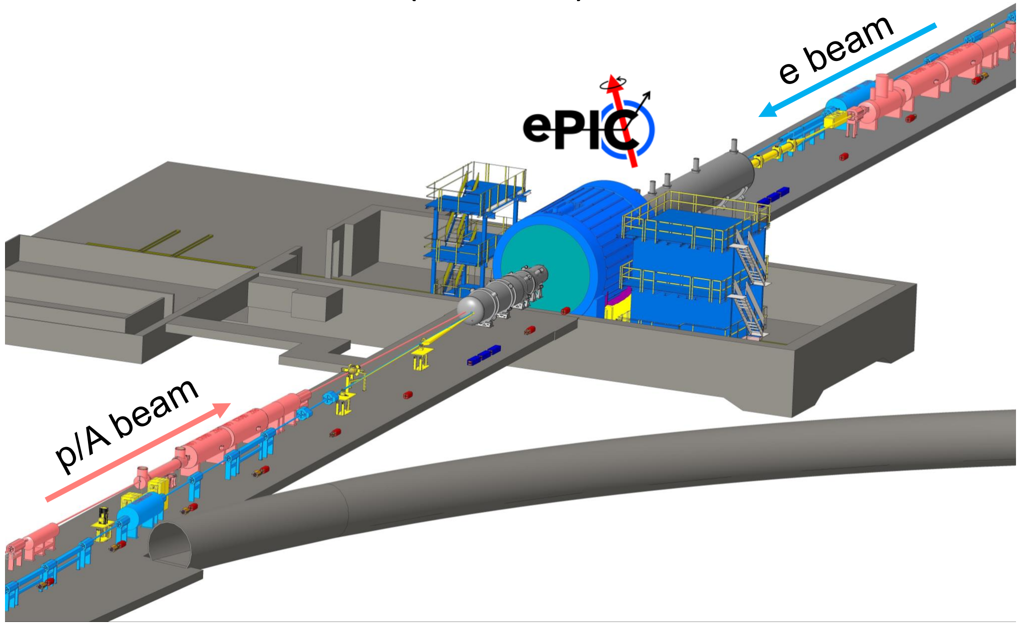
e/m calorimeters

ToF, DIRC, RICH detectors

MPG trackers

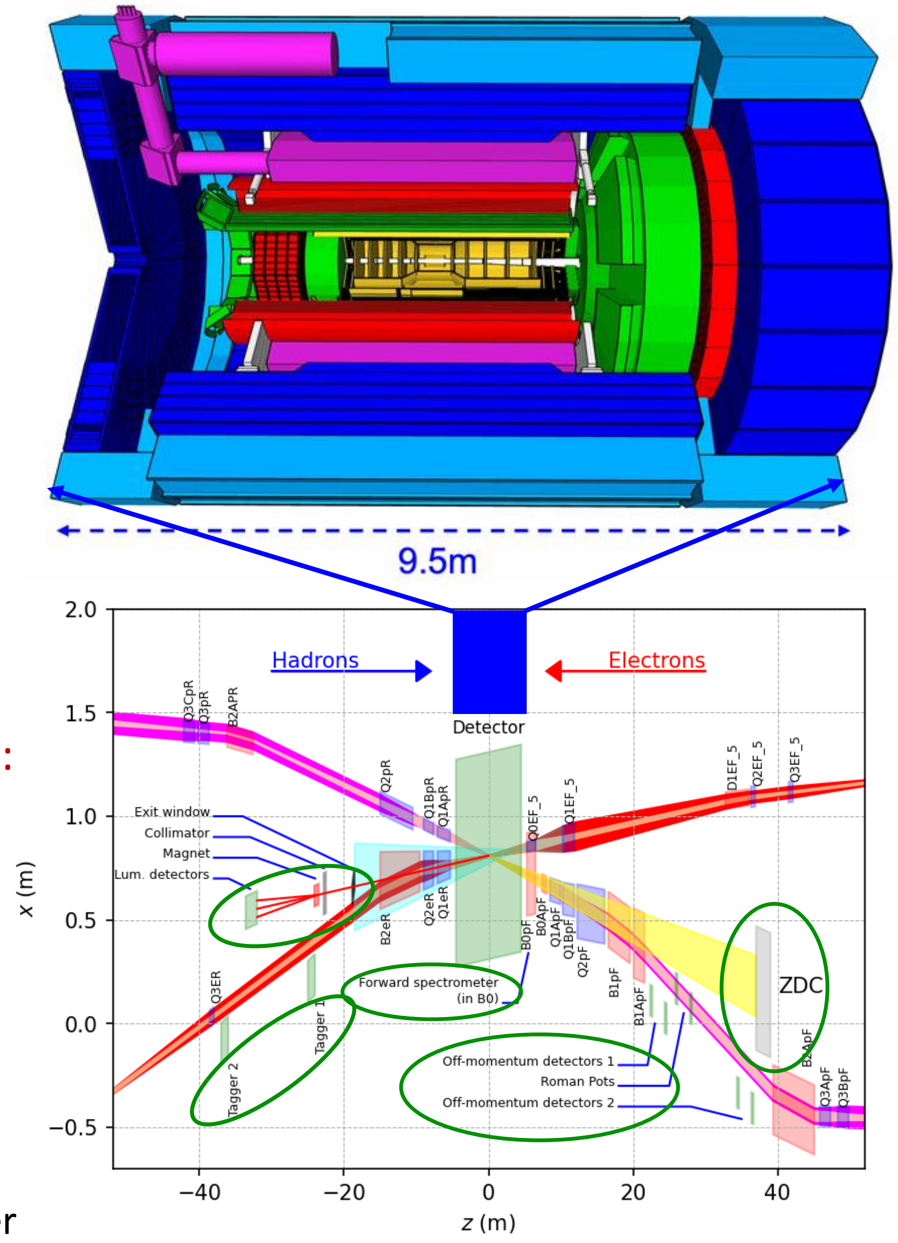
MAPS tracker

25 subdetectors incl. polarimeters

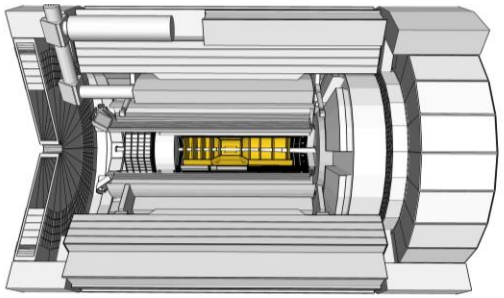


Far-Backward Detectors:
- Luminosity monitor.
- Low-Q^2 Tagger

Far-Forward Detectors:
- B0 Tracking and Photon Detection
- Roman Pots and Off-Momentum Detectors.
- Zero-Degree Calorimeter



ePIC Tracking Detectors



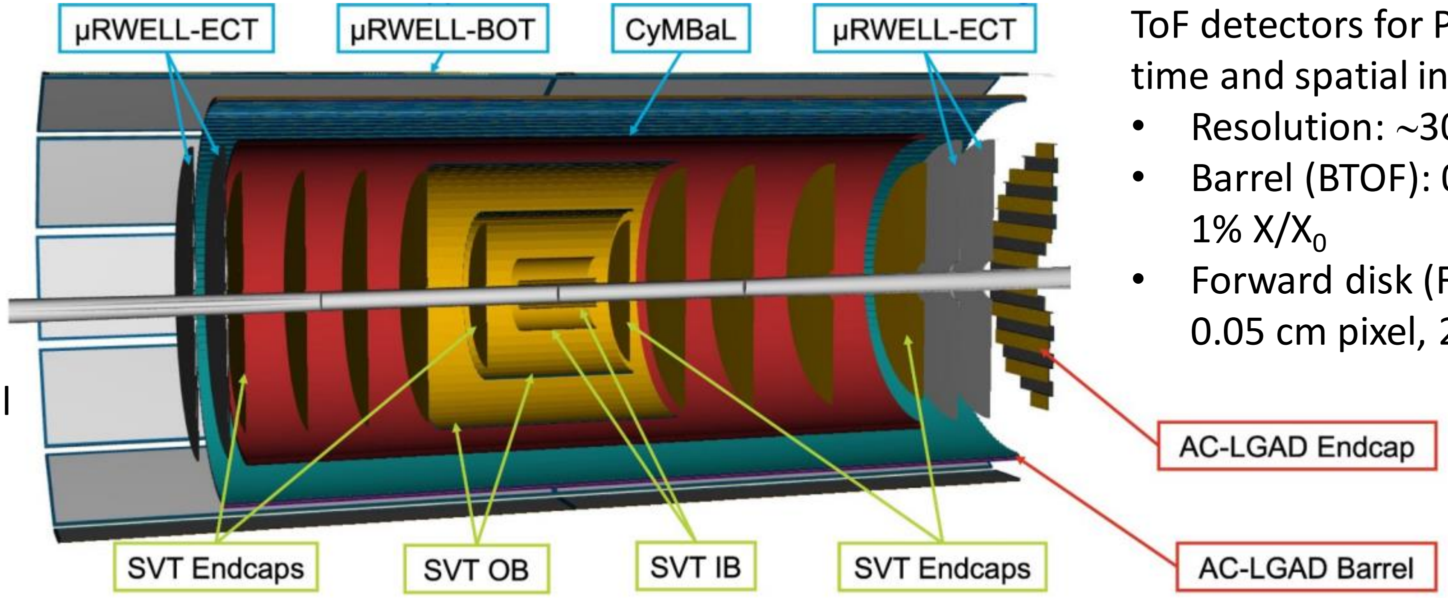
Requirements:
- ➢ High pattern recognition efficiency
- ➢ High spatial resolution
- ➢ Low material budget
- ➢ Good time resolution

Multi Pattern Gas Detectors (MPGD):
- 10 ns time resolution
- 150 μm spatial resolution

2 GEM-μRwell endcaps
- 1-2% X/X_0

Inner Micromegas barrel:
- 0.5% X/X_0

Outer GEM-μRwell planar layer + Barrel ECal AstroPix layer:
- improve angular and space point resolution on hpDIRC

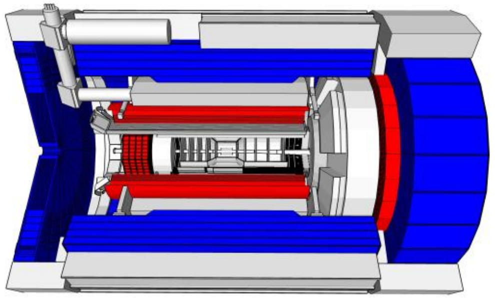


AC-coupled Low Gain Avalanche Diode (AC-LGAD)

ToF detectors for PID at low pT + time and spatial info for tracking
- Resolution: ~30 ps, 30 μm
- Barrel (BTOF): 0.05 x 1 cm strip, 1% X/X_0
- Forward disk (FTOF) : 0.05 x 0.05 cm pixel, 2.5% X/X_0

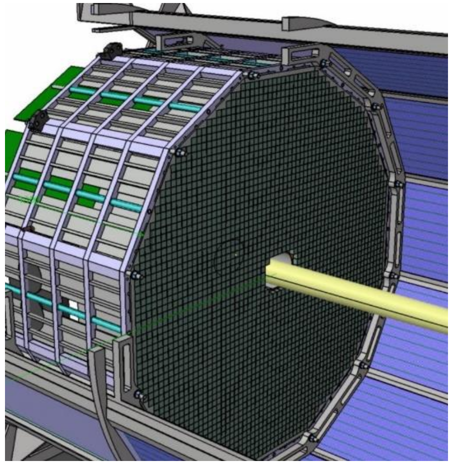
Silicon Vertex Tracker (SVT):
- Monolithic Active Pixel Sensor (MAPS): 20μm pitch, ~6 μm point resolution
- 3 vertex barrels: ITS3 curved wafer-scale sensor, 0.05% X/X_0
- 2 outer barrels: ITS3 based Large Area Sensors (EIC-LAS), 0.25 and 0.55% X/X_0
- 5 disks (forward/backward), EIC-LAS, 0.25% X/X_0

ePIC Calorimetry



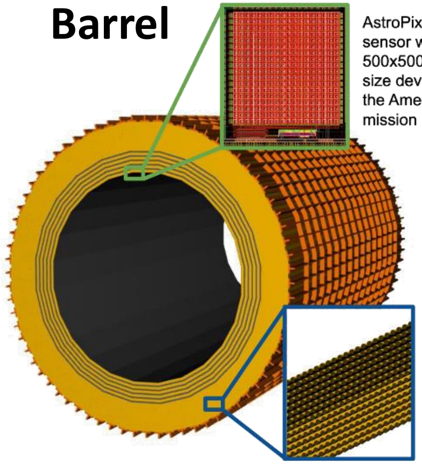
EMCals

Backward



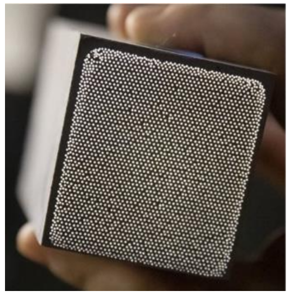
- $PbWO_4$ crystals + SiPM readout

Barrel



- Pb/SciFi sampling part (SiPMs)
- Imaging section (6 layers) interleaving Pb/SciFi with ASTROPIX

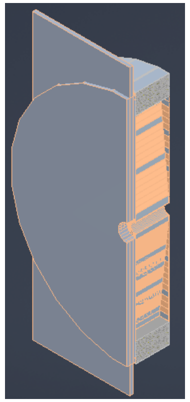
Forward



- Tungsten-powder SciFi SPACAL design

HCals

Backward

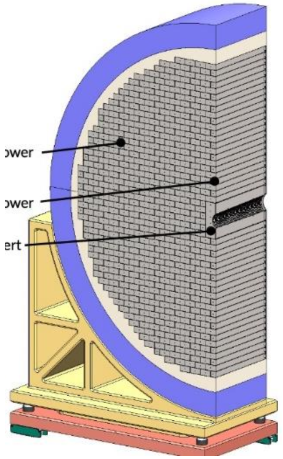


- Steel + Scintillator
- SiPM-on-tile

Barrel

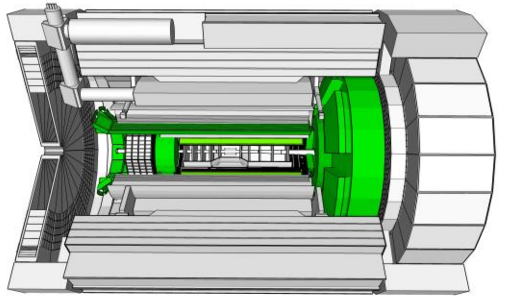
- Steel + Scintillator
- Re-used from sPHENIX

Forward

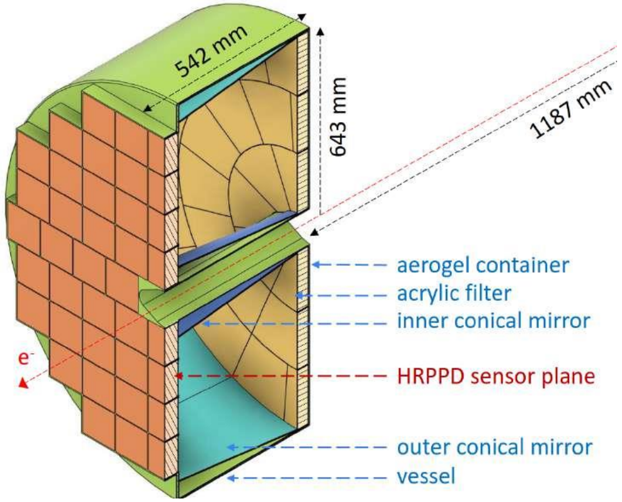


- CALICE-like longitudinally segmented Steel + Scintillator
- SiPM-on-tile
- High resolution insert close to beampipe

ePIC Particle Identification

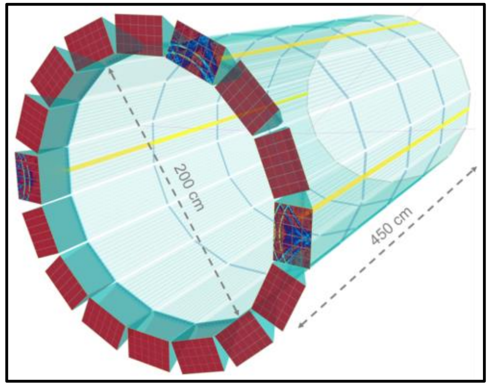


Backward pf-RICH



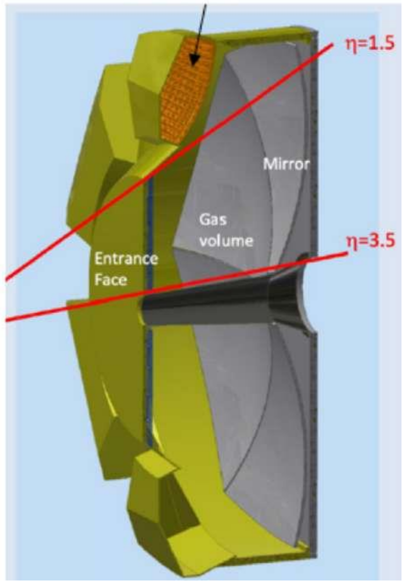
- Single volume proximity focusing aerogel RICH with long proximity gap (~30 cm)

Barrel DIRC



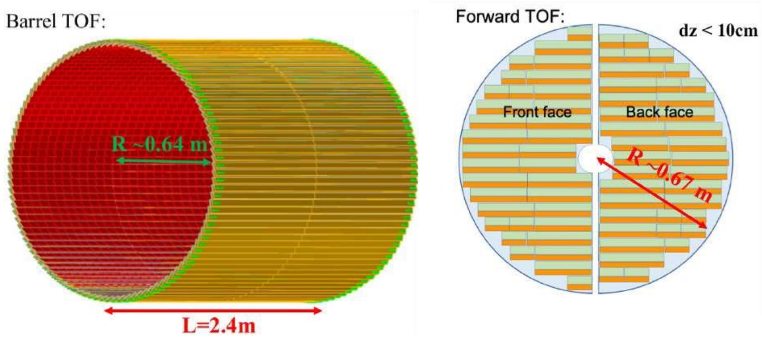
- High Performance DIRC
- Quartz bar radiator (BABAR bars reuse)
- Light detection with MCP-PMTs

Forward mRICH



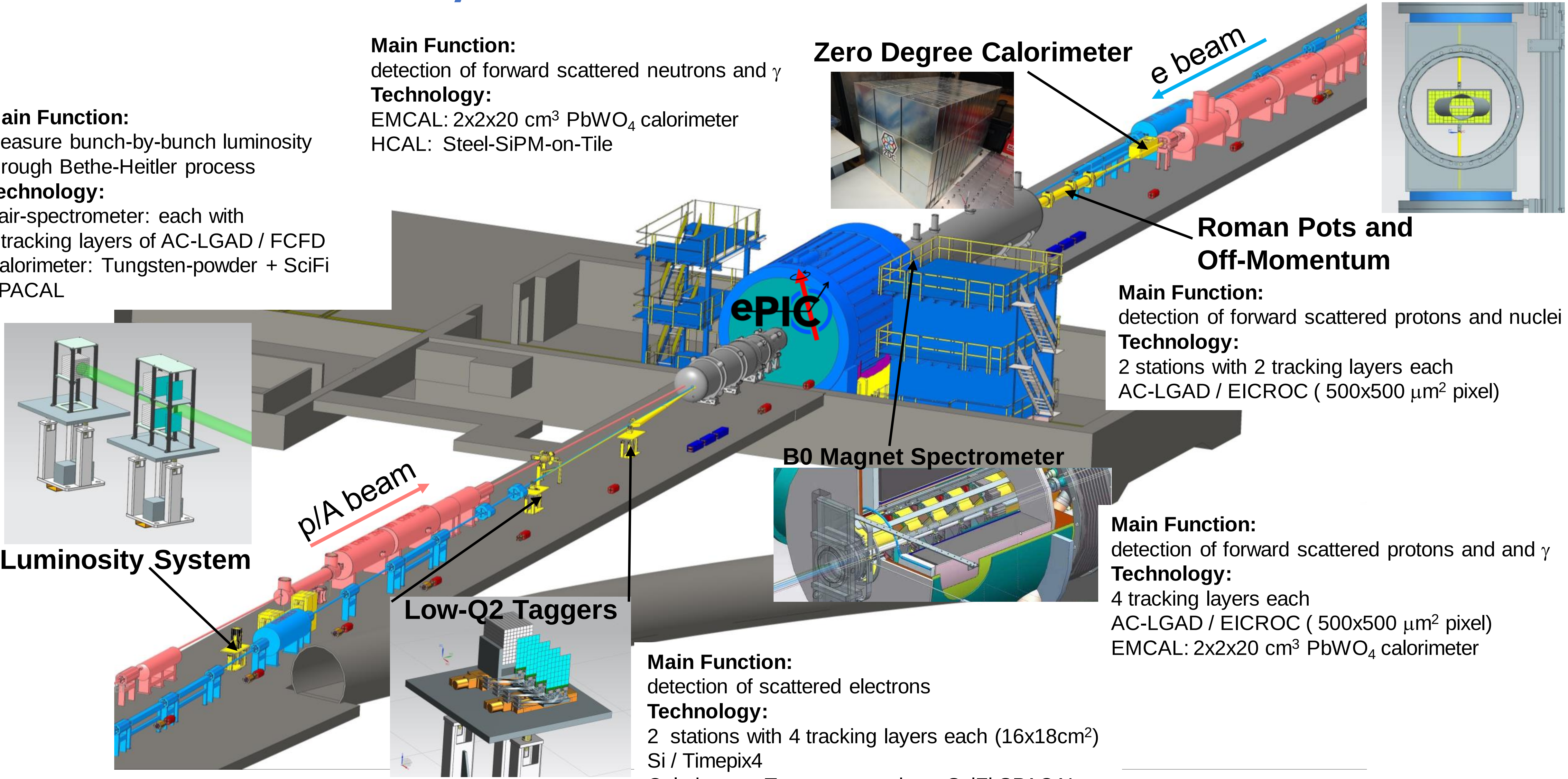
- Dual Radiator RICH
- Aerogel and C_2F_6 gas
- Light detection with MCP-PMTs

Time-of-Flight (Barrel, Forward)



- AC-LGAD technology
- Pixels (forward) and strips (barrel)

ePIC Far-Forward/Far-Backward detectors



Main Function:
detection of forward scattered neutrons and γ
Technology:
EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter
HCAL: Steel-SiPM-on-Tile

Zero Degree Calorimeter

Roman Pots and Off-Momentum

Main Function:
detection of forward scattered protons and nuclei
Technology:
2 stations with 2 tracking layers each
AC-LGAD / EICROC (500x500 μm^2 pixel)

Main Function:
measure bunch-by-bunch luminosity through Bethe-Heitler process
Technology:
Pair-spectrometer: each with
2 tracking layers of AC-LGAD / FCFD
Calorimeter: Tungsten-powder + SciFi SPACAL

Luminosity System

B0 Magnet Spectrometer

Main Function:
detection of forward scattered protons and and γ
Technology:
4 tracking layers each
AC-LGAD / EICROC (500x500 μm^2 pixel)
EMCAL: 2x2x20 cm^3 $PbWO_4$ calorimeter

Low-Q2 Taggers

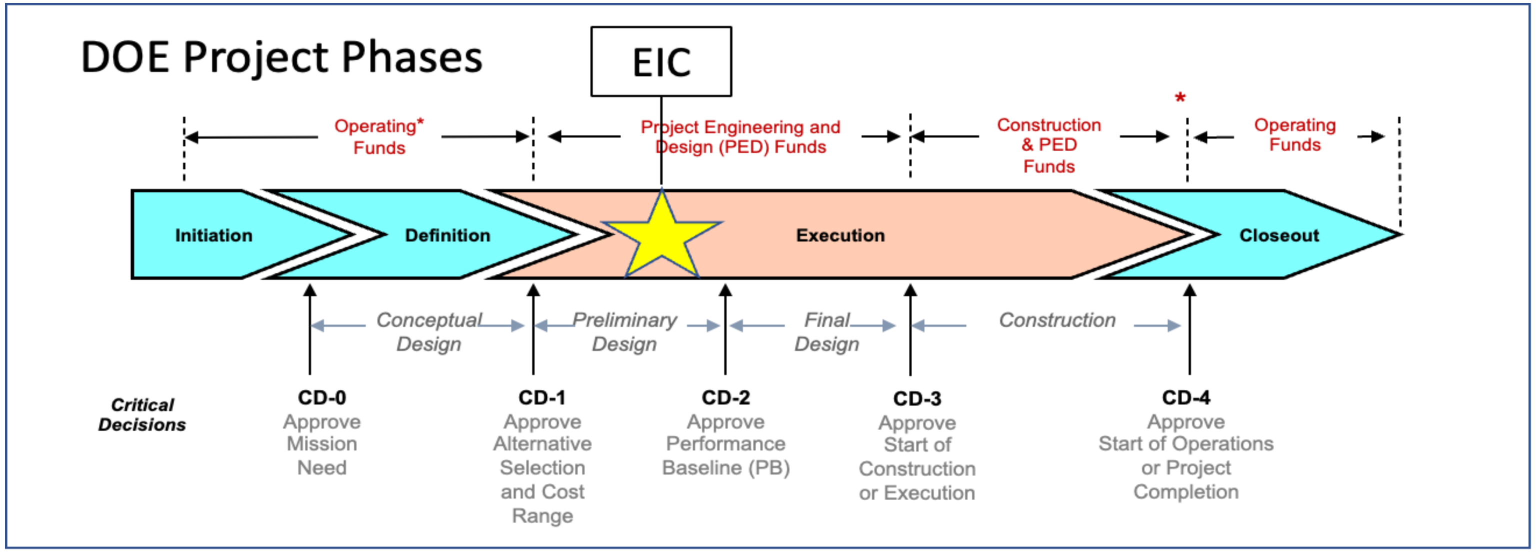
Main Function:
detection of scattered electrons
Technology:
2 stations with 4 tracking layers each (16x18cm^2)
Si / Timepix4
Calorimeter: Tungsten-powder + SciFi SPACAL

EIC project timeline

CD-0, Mission Need Approved	December 2019
DOE Site Selection Announced	January 2020
CD-1, Alternative Selection and Cost Range Approved	June 2021
CD-3A, Long-Lead Procurement Approved	**March 2024**
CD-3B, Long-Lead Procurement Planned Approval	**March 2025**
CD-2/3, Performance Baseline/Construction Start Plan	**End 2025**

Project cost

- EIC detector: $300M ($200M DoE; $100M in-kind)
- EIC accelerator: $1.3B ($1.25B DoE; $50M in-kind)
- Other: management ($200M), infrastructure ($250M), pre-ops ($50M), contingency…



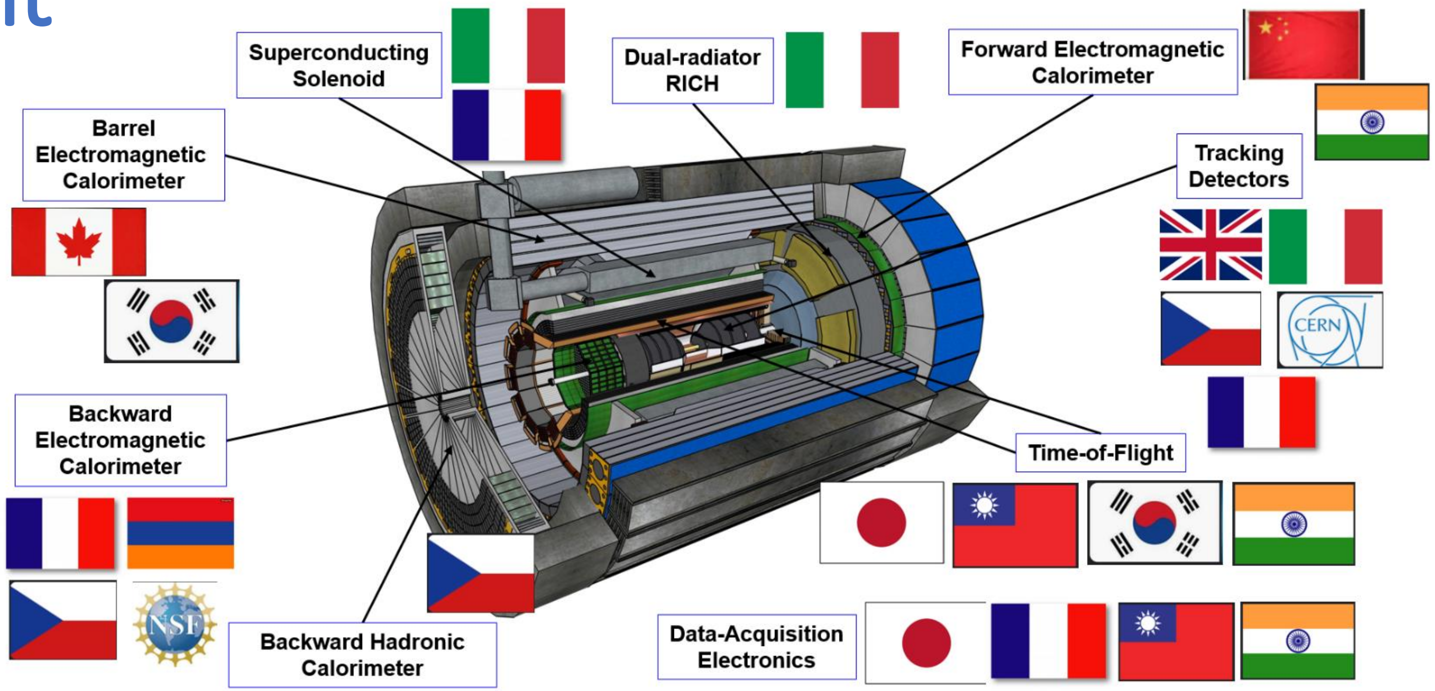
EIC detector milestones

- **Dec 2021:** Detector design
- *Currently: Detector R&D*
- End 2025: TDR completed (CD-3), start of construction
- 2030: Detector commissioning
- 2031: Pre-ops
- 2034: Start of physics program (CD-4)

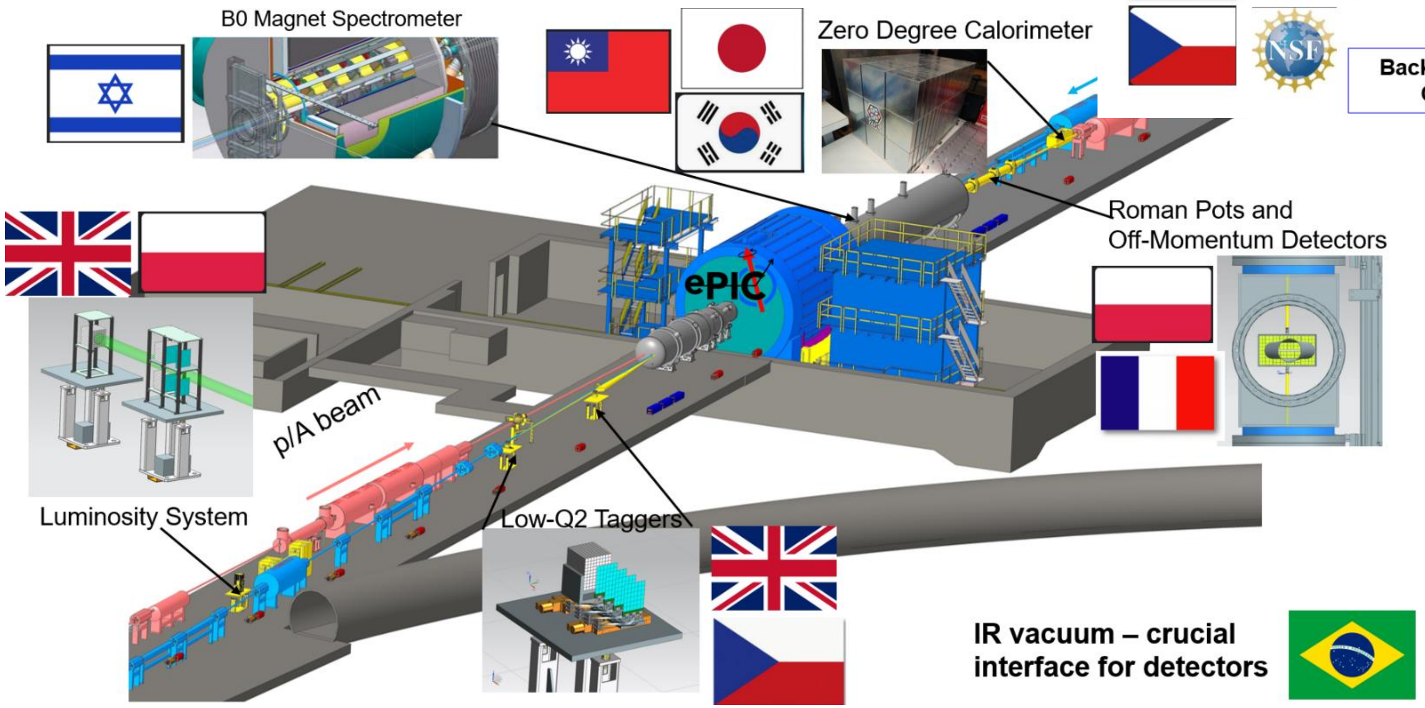
International engagement

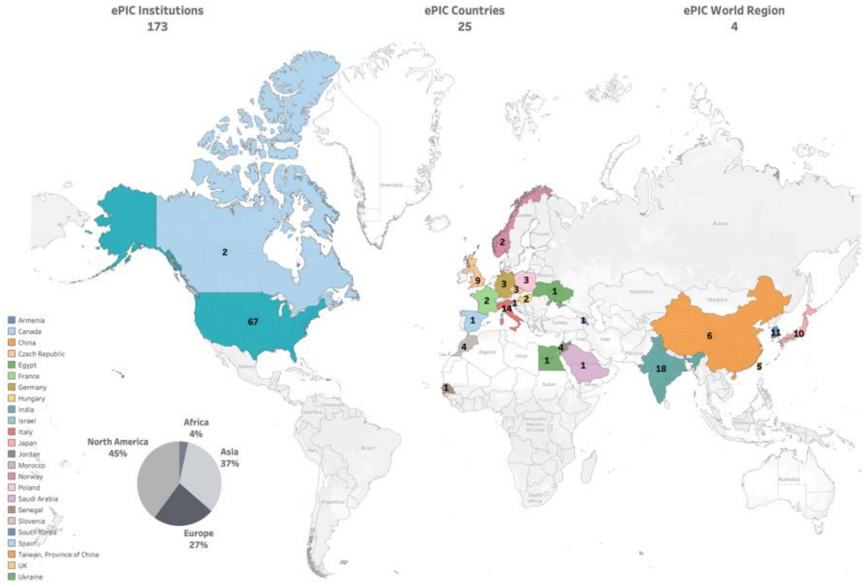
- Large involvement from non-US institutions in ePIC central & far-forward/far-backward detectors
- Also contributions to EIC accelerator (magnets, cryomodules…)

Central detector



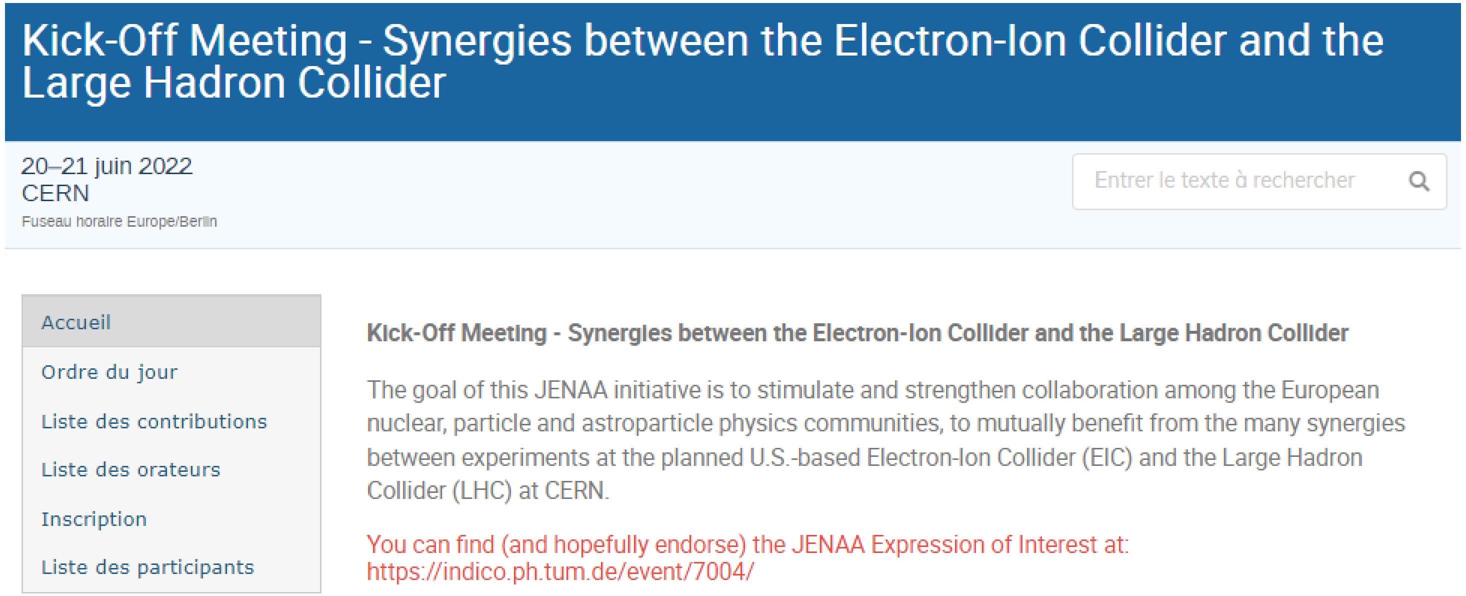
Far-forward/far-backward detectors





Strong synergy with LHC physics

- Initial state of QGP
- Small x physics
- Hadronization
- Saturation physics
- PDFs, and nuclear PDFs
- Quarkonia



Kick-Off Meeting - Synergies between the Electron-Ion Collider and the Large Hadron Collider

20–21 juin 2022
CERN
Fuseau horaire Europe/Berlin

Entrer le texte à rechercher

Accueil
Ordre du jour
Liste des contributions
Liste des orateurs
Inscription
Liste des participants

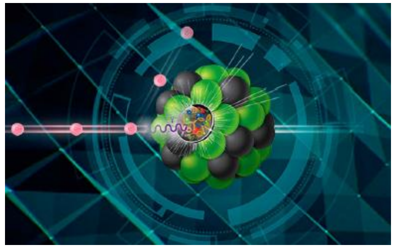
Kick-Off Meeting - Synergies between the Electron-Ion Collider and the Large Hadron Collider

The goal of this JENAA initiative is to stimulate and strengthen collaboration among the European nuclear, particle and astroparticle physics communities, to mutually benefit from the many synergies between experiments at the planned U.S.-based Electron-Ion Collider (EIC) and the Large Hadron Collider (LHC) at CERN.

You can find (and hopefully endorse) the JENAA Expression of Interest at:
https://indico.ph.tum.de/event/7004/

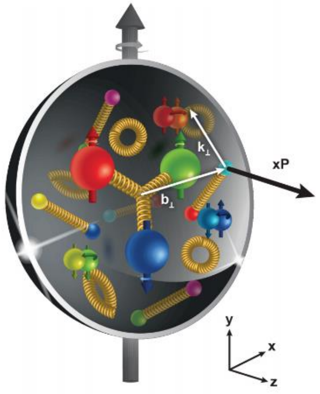
- EIC-LHC synergy Workshop, CERN, 21-22 June 2022
- EIC-LHC synergy Workshop, DESY, 14-15 Dec. 2023
- CERN EP R&D Day 2021, CERN, 11-12 Nov. 2021
  - Session 3 : EIC R&D
- CERN/EIC PID R&D meeting, CERN, 25 April 2023
- ITS3 MAPS adopted in the ePIC detector
  - with contributions to the development

Summary



- The EIC facility will address fundamental questions on the structure and dynamics of nucleons and nuclei in terms of quarks and gluons, using precision measurements including:
  - Parton distributions in nuclei/QCD at extreme parton densities – saturation
  - Spin and flavor structure of the nucleon and nuclei
  - Tomography (p/A) Transverse Momentum Distributions and Spatial Imaging
  - Synergies with pA and AA (PDFs, nPDF, FFs…)
  - Many important measurements to understand initial conditions in HIC

- The EIC will be built at BNL by adding an electron storage ring to the existing RHIC facility
  - Luminosity: ~10^{33-34} $cm^{-2}s^{-1}$
  - Polarized e/p and unpolarized heavy ion beams/ CME ~20-140 GeV



- Exciting opportunities for international involvement and contributions towards the realization of the EIC detector ePIC.