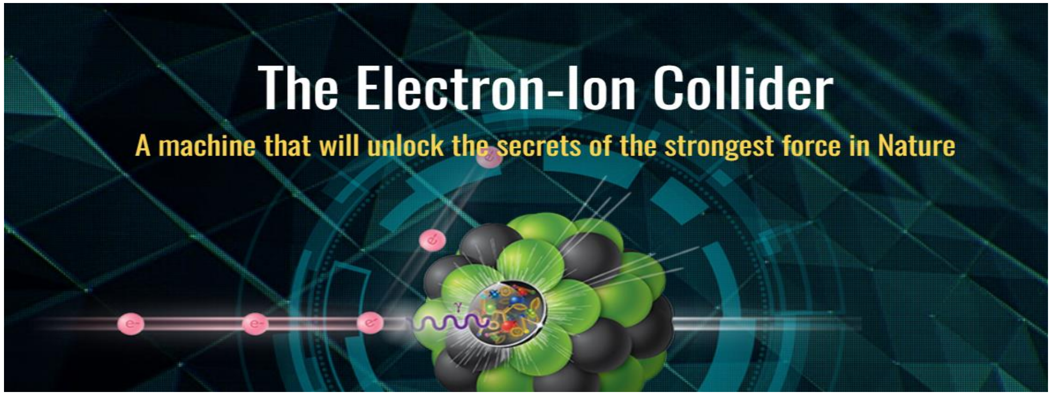
Overview of EIC and its ePIC detector

Liliana Teodorescu
on behalf of the ePIC Coll.

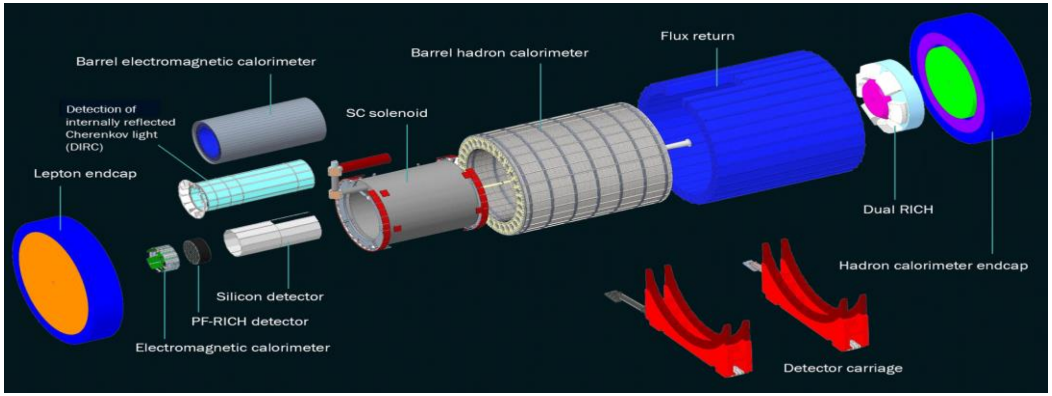
Outline

https://www.bnl.gov/eic/



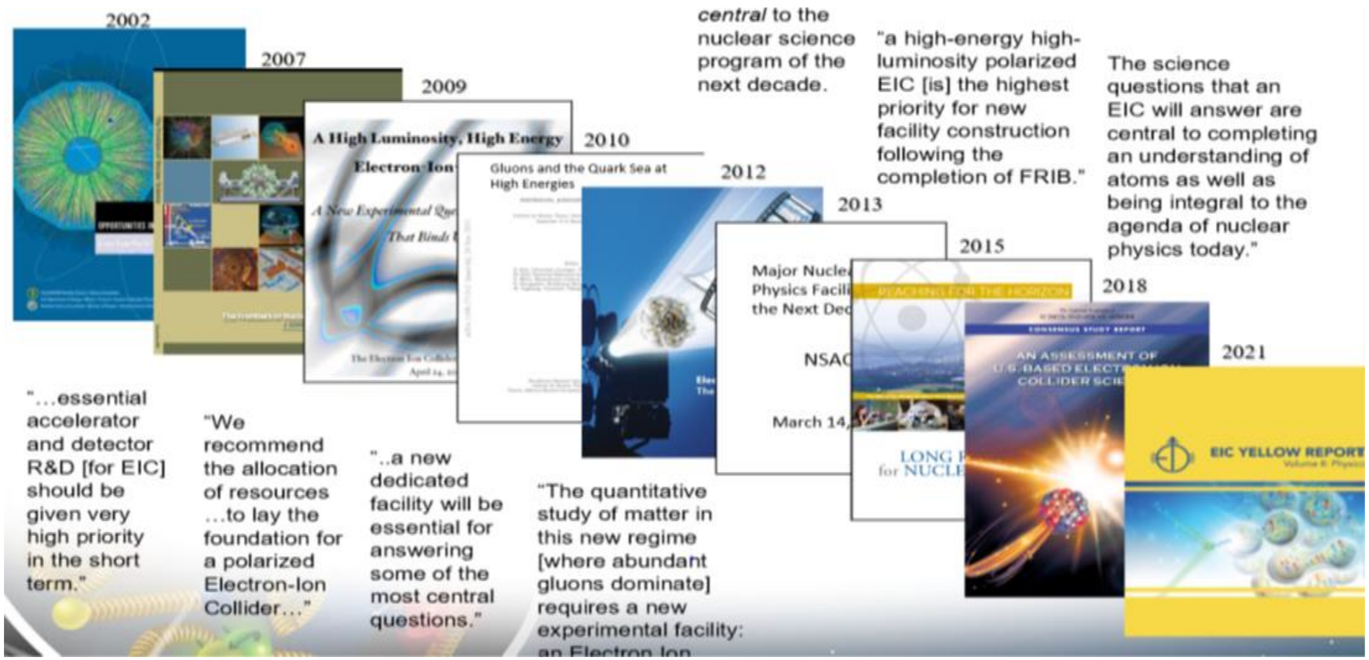
Overview of

- ➢ EIC scientific program
- ➢ EIC accelerator
- ➢ ePIC detector



Why EIC? - For the "ultimate" QCD exploration

Fundamentals of the EIC scientific program have been developed for more than 20 years



Nuclear Science Advisory Committee Long Range Plan for Nuclear Science 2023

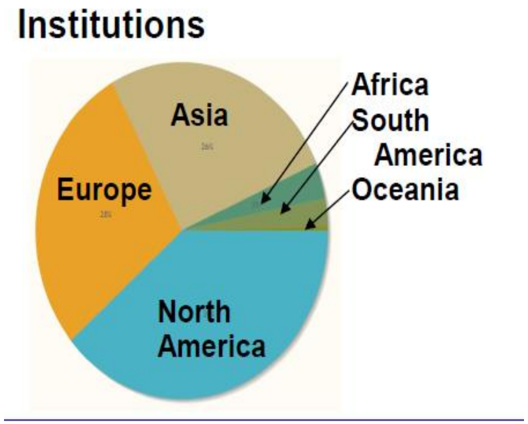
"We recommend the expeditious completion of the EIC as the highest priority for facility construction."

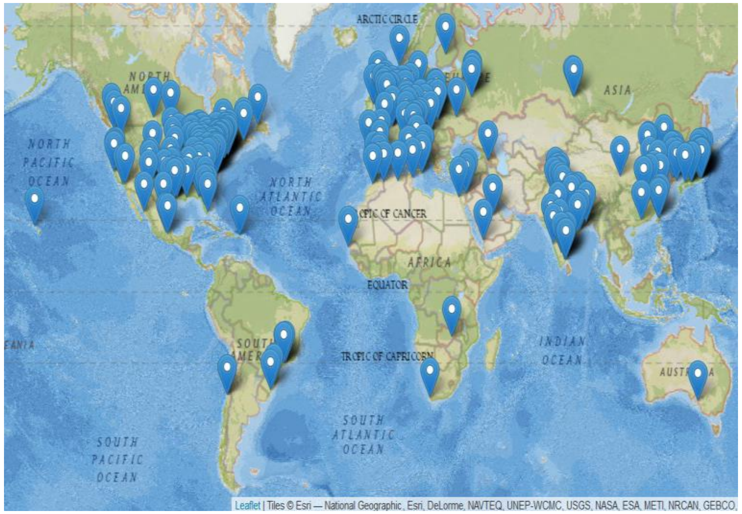
EICUG – EIC User group

EIC scientific program has been developed by a large international community → EIC User group (EICUG)

https://eicug.org/

Current membership
~ 1490 members
~ 40 countries
~ 290 institutions





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

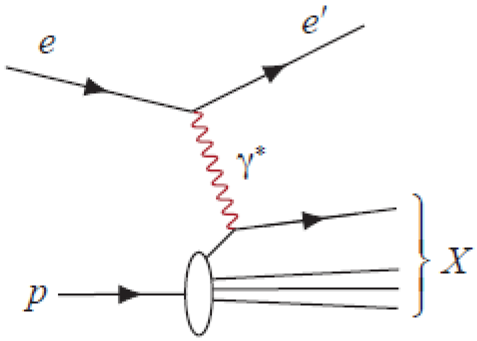
Defines
- scientific goals
- collider and detector requirements
- initial detector concepts

Fundamental questions

The fundamental questions aimed to be answered by the core program of the EIC project:

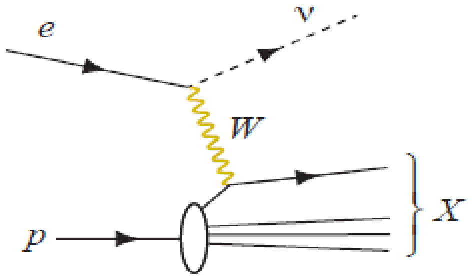
- How do the *mass and the spin of the nucleons* emerge?
- How are the *quarks and gluons distributed in space* and *momentum* inside the nucleon?
- How do the *colour charged quarks and gluons*, and *the colourless jets* interact with a nuclear medium?
  How do *hadrons* emerge? What is the nature of *confinement?*
  How do the quark-gluon interactions create *nuclear binding?*
- What happens to the *gluon density* in nuclei?
  Does it *saturate* at high energy?
  Does it give rise to a *new phase of matter* in nucleons/nuclei?

Processes (DIS) to explore the answers



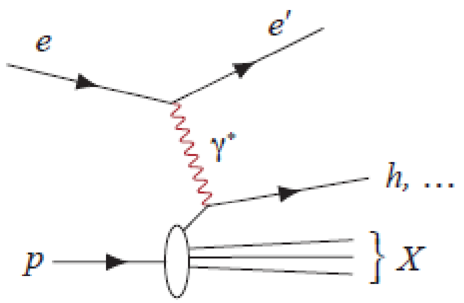
Neutral-current Inclusive DIS:

$e + p/A \longrightarrow e' + X;$



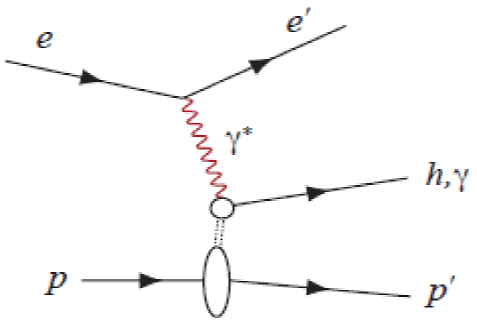
Charged-current Inclusive DIS:

$e + p/A \longrightarrow \nu + X;$



Semi-inclusive DIS:

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



Exclusive DIS:

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

Topics vs processes vs measurements (not exhaustive)

EIC Yellow Report, Nuclear Physics A 1026 (2022) 122447

Processes / Topics	Inclusive	Semi-Inclusive	Jets, Heavy Quarks	Exclusive	Diffractive, Forward Tagging
Global properties & parton structure	incl. SF	h, hh	jet, Q	excl. $Q\overline{Q}$	incl. diffraction, tagged DIS on D/He
Multidimensional Imaging		h	jet, di-jet, jet+h, Q, $Q\overline{Q}$	DVCS, DVMP, elast. scattering	
Nucleus	incl. SF	h, hh	jet, di-jet, Q, $Q\overline{Q}$	coh. VM, di-jet, h, hh, D/He FF	diffr. SF, incoh. VM, di-jet, h, hh, nucl. fragments
Hadronization		h, hh, jet+h	jet, Q, $Q\overline{Q}$		
Other fields	incl. SF with e^+, $\sigma_{\gamma A}^{tot}$	charged curr. DIS, $\sigma_{\gamma A \to hX}$		$\sigma_{\gamma A}^{elast}$	$\sigma_{\gamma A}^{diffr}$

SF – structure function
VM – vector meson
Q – heavy quark
$Q\overline{Q}$ - quarkonium
FF – form factor
H – identified hadron

Global properties and parton structure :

- nucleon spin, nucleon mass,
- PDF (Parton Distribution Function), structure of mesons

Multidimentional imaging:

- position space: form factors, generelised parton distributions (GPDs)
- 3D momentum space: transverse momentum dependent parton distributions (TMDs)

Topics \ Processes	Inclusive	Semi-Inclusive	Jets, Heavy Quarks	Exclusive	Diffractive, Forward Tagging
Global properties & parton structure	incl. SF	h, hh	jet, Q	excl. $Q\overline{Q}$	incl. diffraction, tagged DIS on D/He
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Hadronization		h, hh, jet+h	jet, Q, $Q\overline{Q}$		
Other fields	incl. SF with e^+, $\sigma_{\gamma A}^{tot}$	charged curr. DIS, $\sigma_{\gamma A \to hX}$		$\sigma_{\gamma A}^{elast}$	$\sigma_{\gamma A}^{diffr}$

Nucleus (as a QCD lab)

- the effect of the binding of nucleons on nuclear parton distributions,
- the space and momentum distribution of quarks and gluons in nuclei
- fluctuations of the density of quarks and gluons in nuclei

Hadronization studies

- hadronization in vacuum
- production for identified hadron species, production of quarkonia
- potential new particle production mechanisms

Other fields : neutrino, cosmic ray, HEP

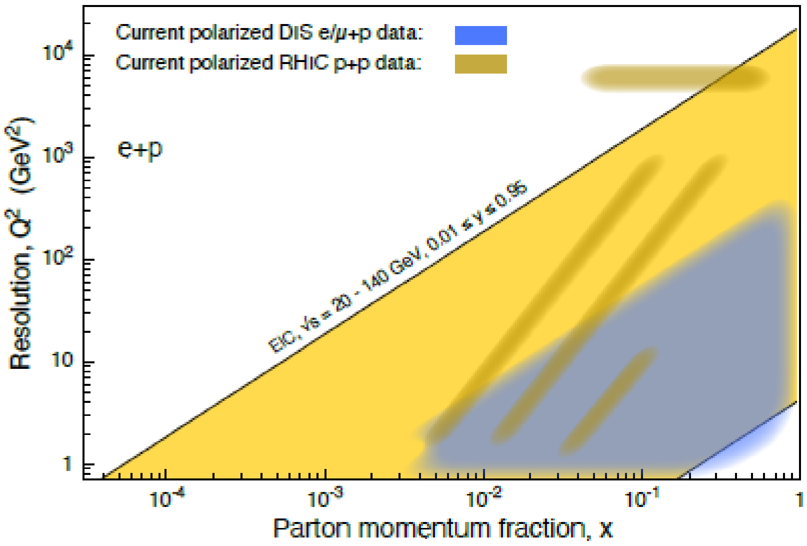
- opportunities for electroweak (EW) and beyond the standard model (BSM) physic

EIC performance requirements

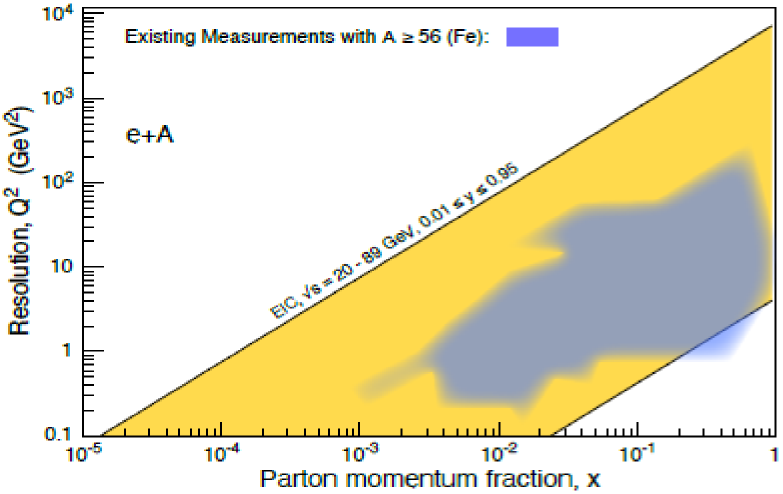
- large centre-of-mass energy $\sqrt{s}$: 29 – 140 GeV
  - ✓ map the nucleon and nuclei structure in a wide kinematic range in x and Q^2
- polarized electron, proton and light ion beams (time-averaged polarization ~ 70%)
  - ✓ access to spin structure of nucleons and nuclei
  - ✓ access to the 3D spatial and momentum structure of the nucleon
- wide range of nuclear beams: from d to U
  - ✓ accessing the highest gluon densities → saturation
  - ✓ study quark and gluon interaction with the nuclear medium
- high luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$ and integrated 10-100fb^{-1}/year
  - ✓ map the 3D spatial and momentum structure of nucleons and nuclei
  - ✓ access to rare probes
  - ✓
- large detector forward acceptance (0.2 – 1.3 GeV)
  - ✓ spatial imaging of nucleons and nuclei
- good background conditions
- possibility to implement a second interaction region

Kinematic range of EIC

EIC Yellow Report, Nuclear Physics A 1026 (2022) 122447



x-Q^2 range covered by the EIC (yellow) compared with existing data for polarized e/μ+p, and p-p



x-Q^2 range for e^+A collisions for ions heavier than iron (yellow) compared to existing world data.

The diagonal lines in each plot represent lines of constant inelasticity y

The EIC provides

- overlap with existing data
- access to new regions in both x and Q^2
- the low-x region, provides important information about the gluon-dominated regime.

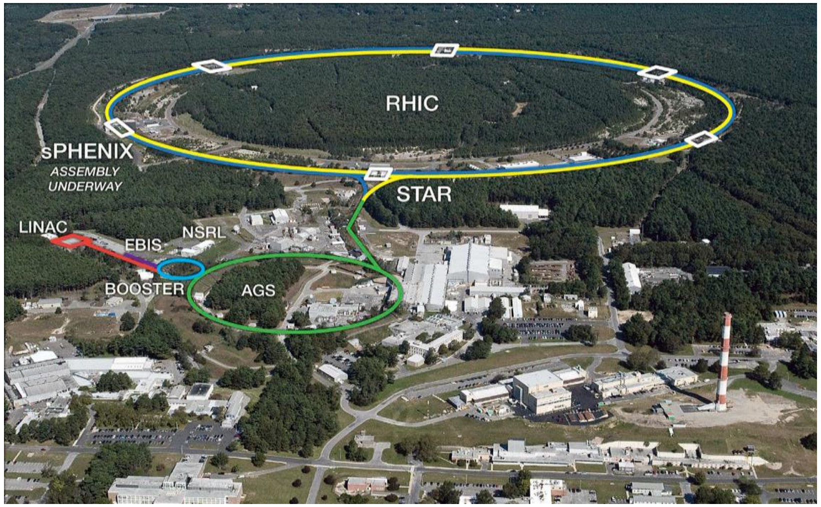
EIC implementation

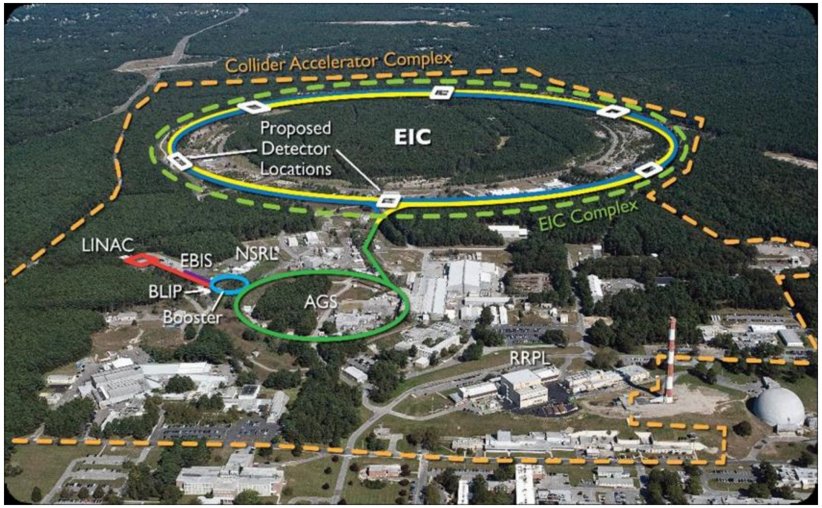
A joint endeavour by Thomas Jefferson National Accelerator Facility (Jlab) and Brookhaven National Lab (BNL).

Jlab

BNL

From RHIC → to EIC





Relativistic Heavy Ion Collider (RHIC)

- ✓ First accelerator capable of colliding heavy ions
- ✓ The only accelerator capable of colliding high energy (60%) polarised protons
- ✓ Can accelerate a wide range of ions from protons to uranium
- ✓ Has 2 detectors
- ✓ Operation ends in 2025

Electron Ion Collider (EIC)

(provides →) Tunnels and infrastructure
2 superconducting storage rings

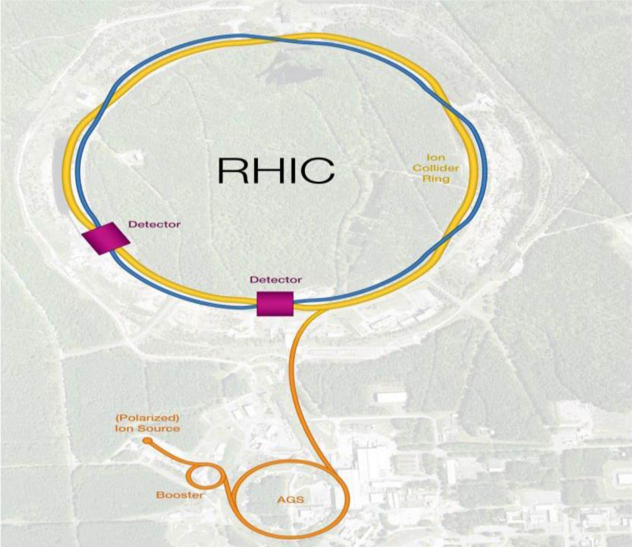
(develop for →) EIC polarization needs
(novel polarized beams)

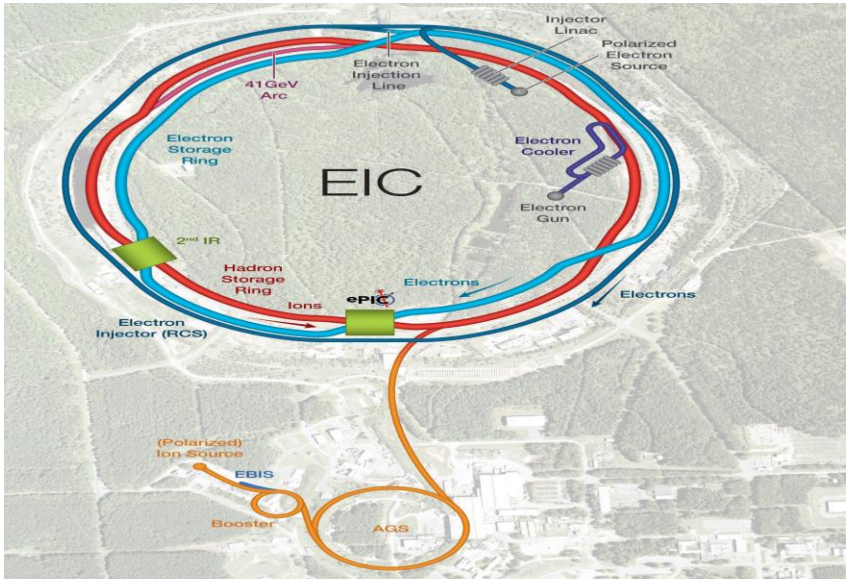
(provides →) Ion beams needed

(provides →) Up to 2 interaction regions

(→) Operation early 2030s

From RHIC to EIC





Use from RHIC

- ✓ Polarized ion/proton source
- ✓ Hadron injection and initial acceleration systems: Linac (200 MeV), Booster (1.5 GeV), AGS (25 GeV)
- ✓ The two storage rings – become the EIC Hadron Storage Ring (41, 100 to 275 GeV)

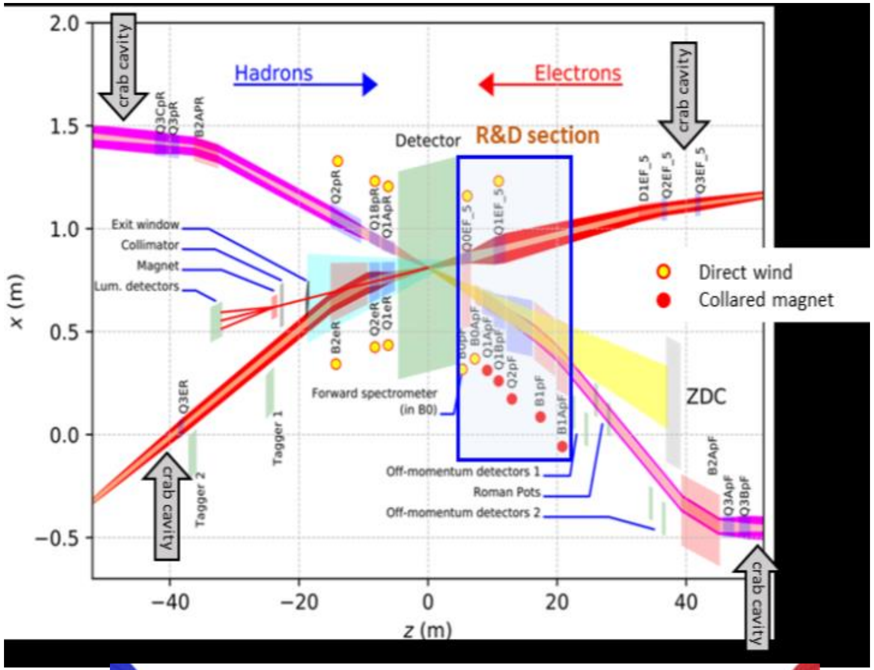
Add (new)

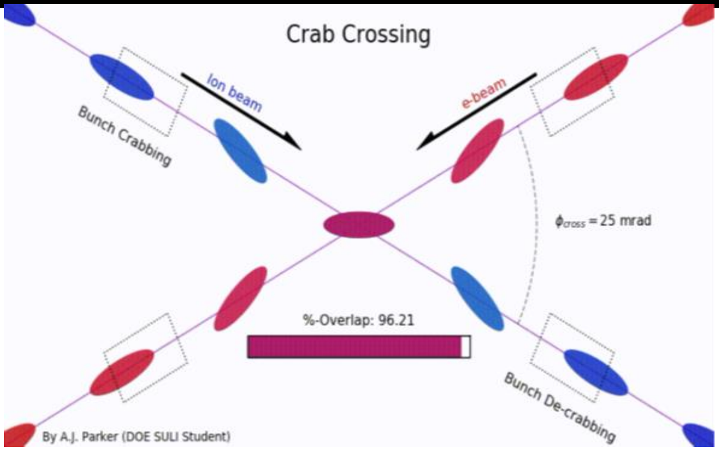
- ✓ Polarized electron source
- ✓ Electron Pre-Injector (3 GeV)
- ✓ Electron Rapid Cycling Synchrotron (3 GeV – top energy)
- ✓ Electron Storage Ring (5-18 GeV)

Interaction Region - IP6 for the first detector (ePIC)
- option for the second detector at IP8

Interaction Region (at IP6)

- ✓ 25 mrad crossing angle
- ✓ Crab cavity systems to create the bunch tilting and restore the head-on collision
- ✓ Small β* for high luminosity => quads close to IP
- ✓ Bunch crossing rate: ~ 10 ns/98.5 MHz
- ✓ No magnets within - 4.5 / +5 m from IP for detector
- ✓ Large detector acceptance
- ✓ Space for far-forward and far-backword detectors





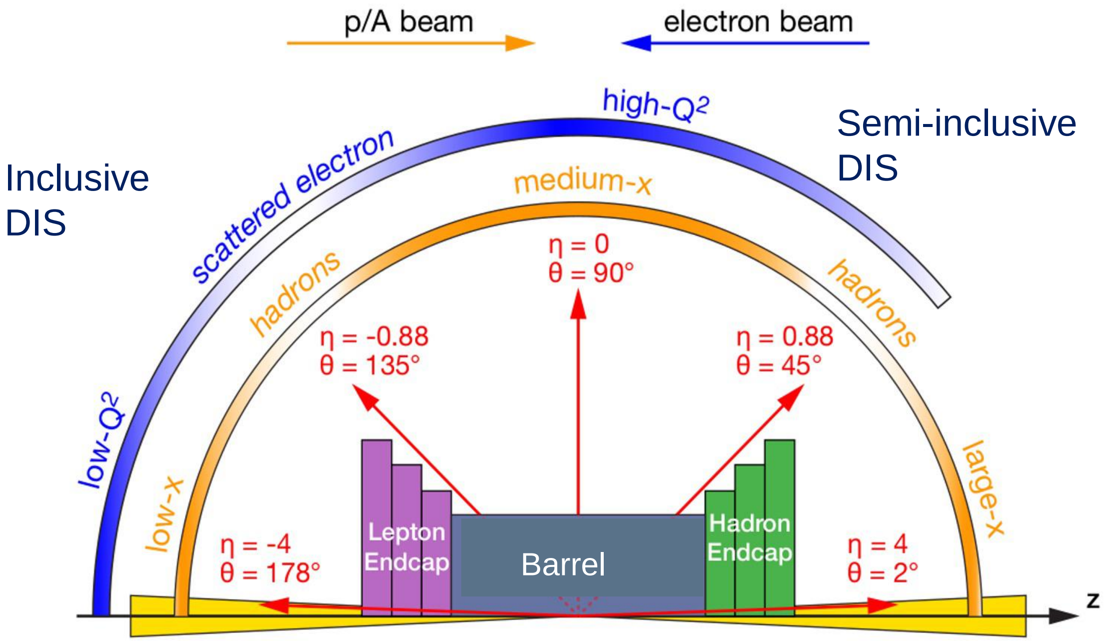
EIC Accelerator Collaboration

in formation (May 2024)

https://indico.jlab.org/event/834/

Detector requirements

Distribution of hadrons & scattered lepton in $x - Q^2$ plane & detector pseudorapidity μ



Far-Backword
- ✓ very low Q^2 scattered lepton
- ✓ Bethe-Heitler photons for luminosity

Far-Forward
- ✓ nuclear breakup particle
- ✓ exclusive DIS

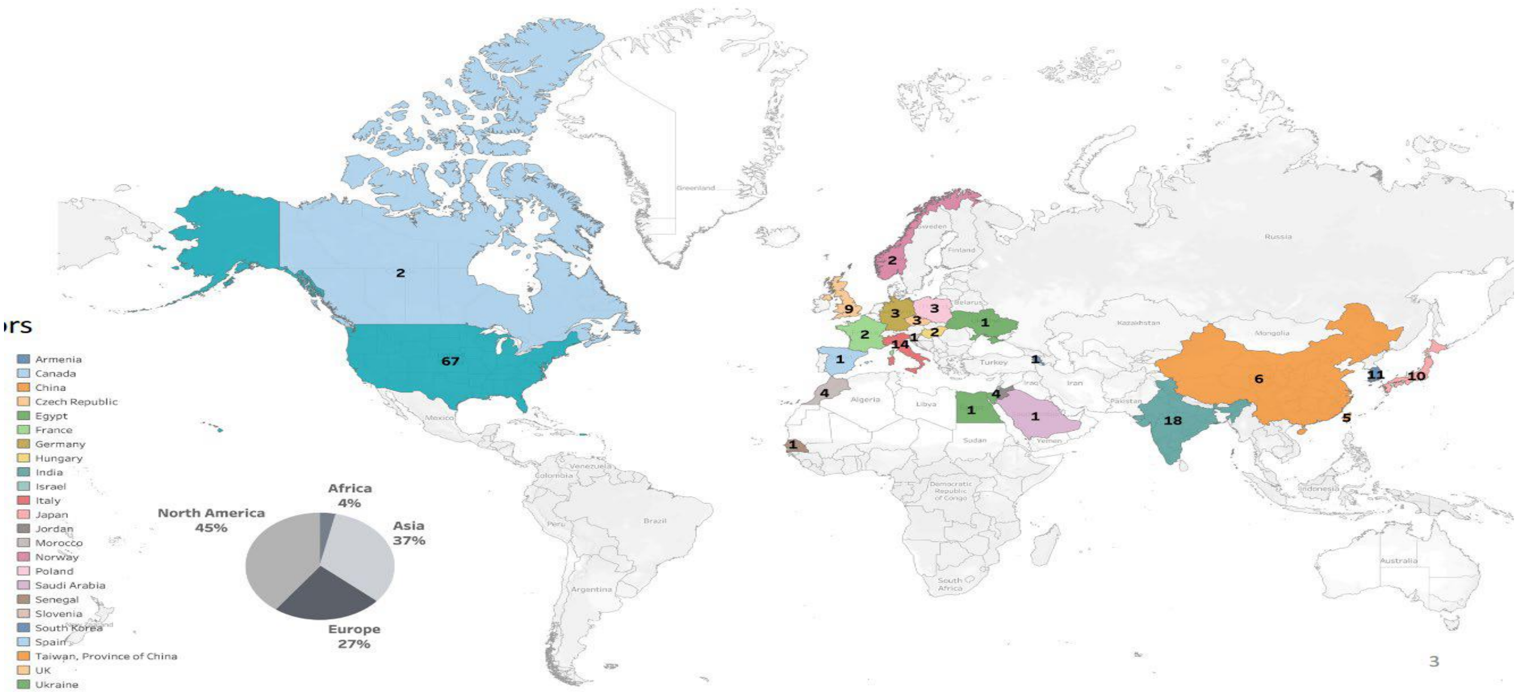
- ➢ Asymmetric beam energies => asymmetric detector
- ➢ Physics requires access to full $x - Q^2$ plane at different CM energy
  $\Rightarrow$ Reconstruct events over a large range η in the central region with
  - ✓ high precision low mass tracking
  - ✓ good e/h separation critical for scattered electron ID
  - ✓ High performance PID for good separation of e, p, K, π on track level
- ➢ Far forward and backward coverage => ancillary detectors integrated in the IR

ePIC Detector and Collaboration

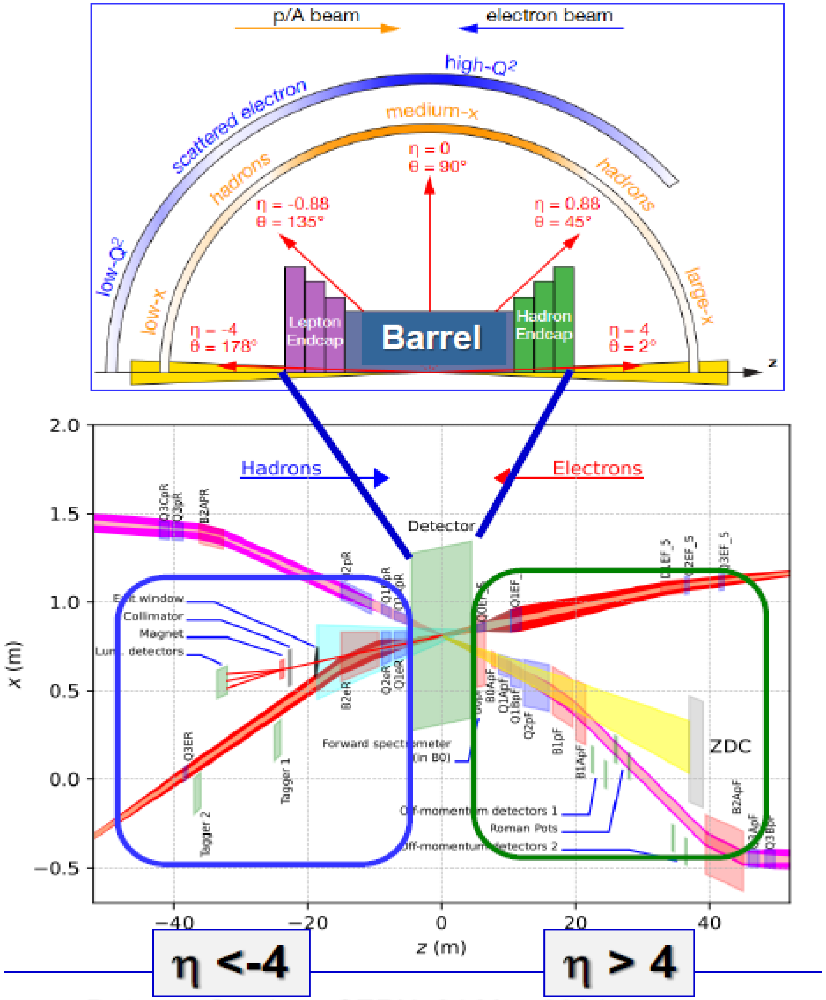
ePIC: electron Proton/Ion Collider

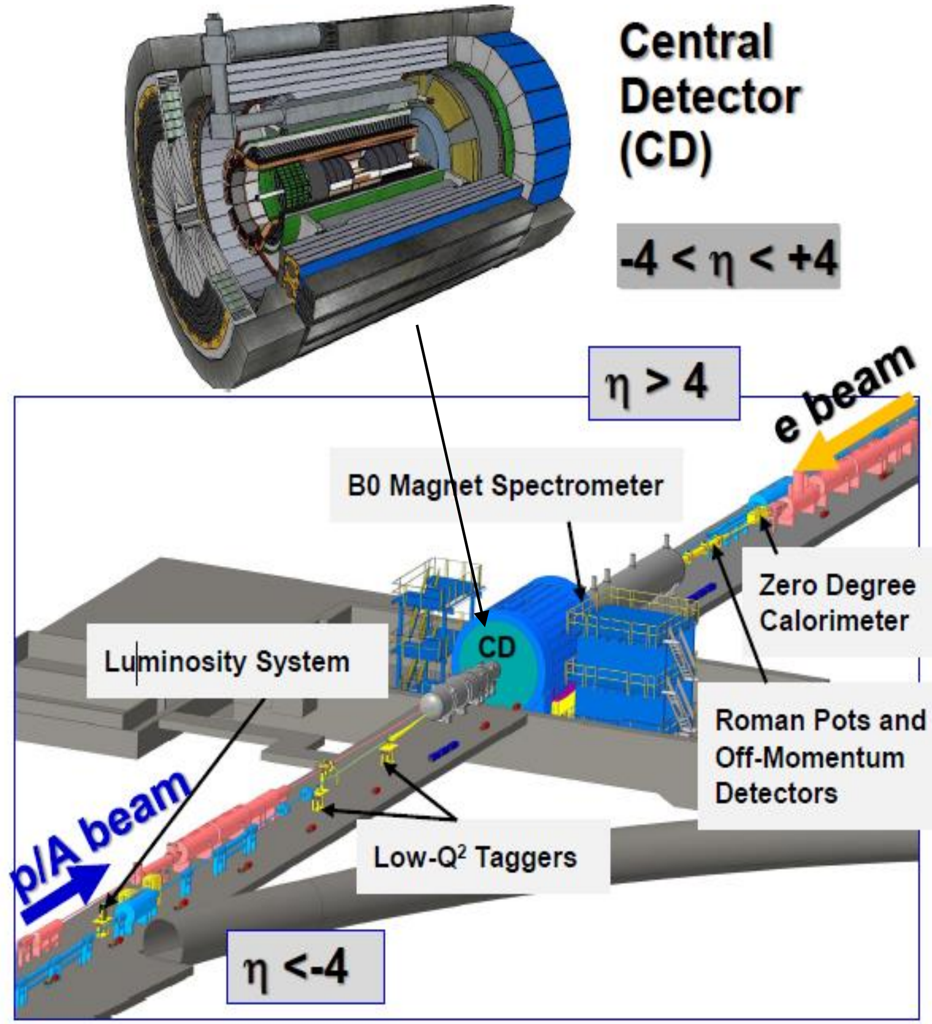
Collaboration created in July 2022 to implement the Yellow Report requirements

- ✓ has over 850 collaborators
- ✓ from over 175 institutes
- ✓ in 26 countries

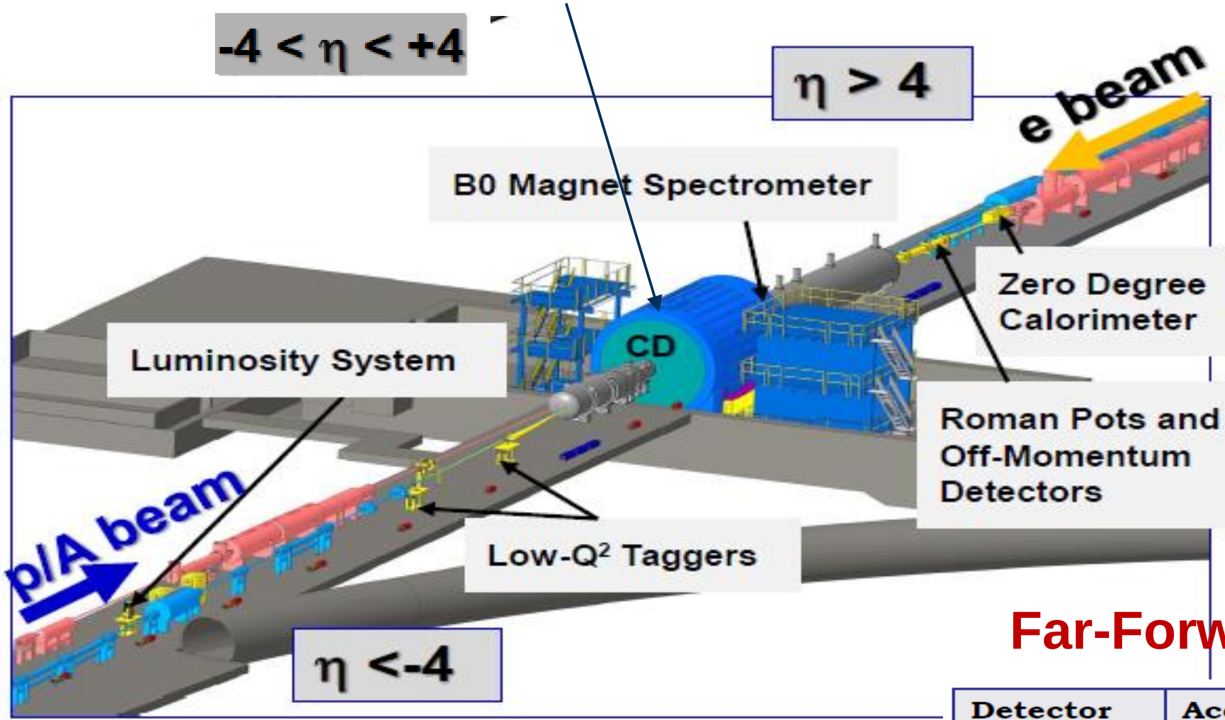


Full ePIC detector





ePIC detector



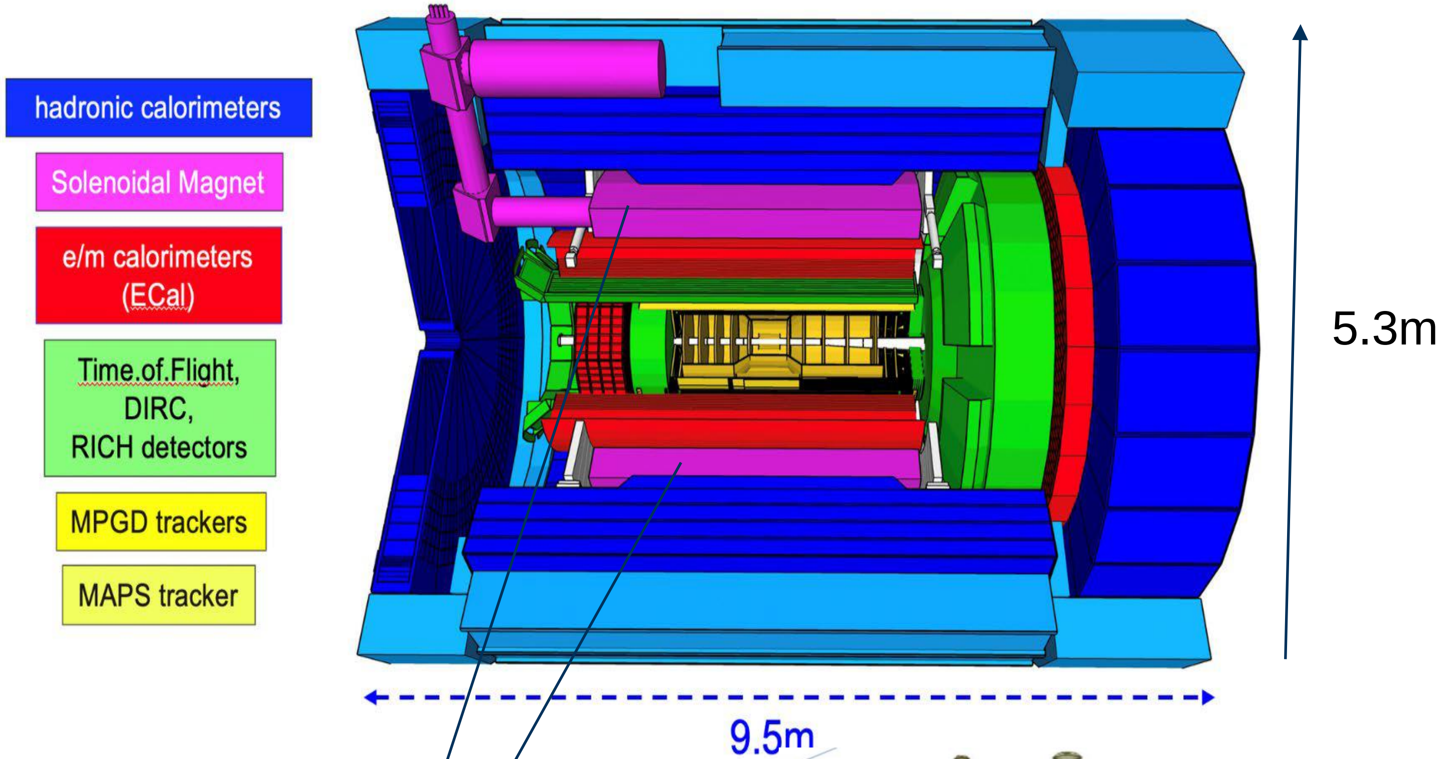
Far-Forward detectors

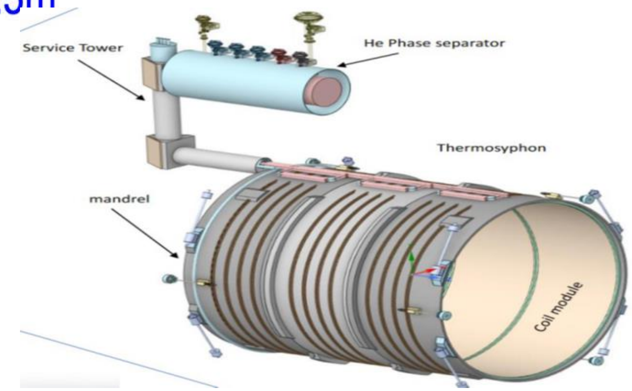
Detector	Acceptance	Particles
ZDC	$\theta < 5.5\ mrad$ ($\eta > 6$)	Neutrons, photons
Roman pots (2 stations)	$0.0 < \theta < 5.0\ mrad$ ($\eta > 6$)	Scattered protons, light nuclei
Off-Momentum Detectors (2 stations)	$\theta < 5.0\ mrad$ ($\eta > 6$)	Charged particles from decays
B0 Detector	$5.5 < \theta < 20.0\ mrad$ ($4.6 < \eta < 6$)	Charged particles, tagged photons

Far-Backward detectors

- Luminosity monitor
  luminosity precision less 1%
- 2 Low-Q^2 electron taggers
  clean signal for $10^{-3} < Q^2 < 10^{-1}$ (GeV^2)

Central Detector

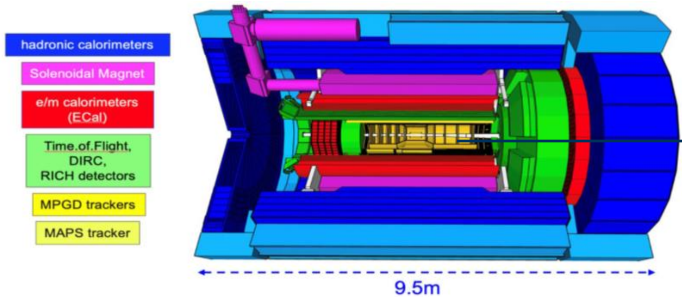


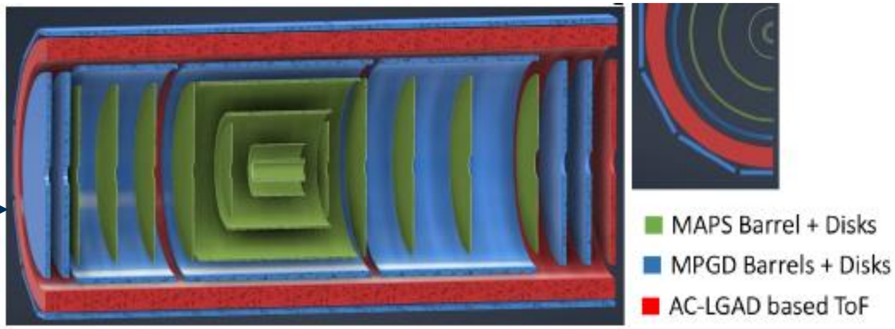


new 1.7 T solenoid magnet

hermetic coverage:
$0^o \leq \phi \leq 360^o$
$2^o \leq \theta \leq 178^o \Leftrightarrow -4 < \eta < 4$

Tracking

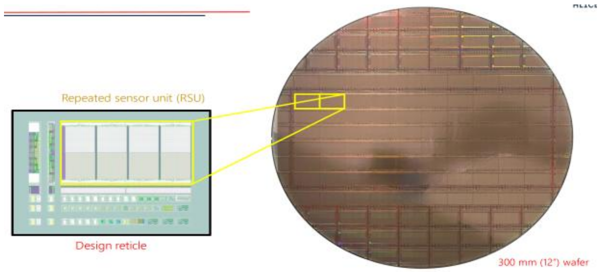




Silicon Vertex Tracker (SVT) - Monolithic Active Pixel Sensor (MAPS)

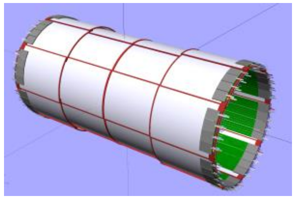
- ✓ based on ALICE ITS3 sensors
- ✓ ultra thin, 20 μm pixels
- ✓ low power consumption (<20 mW/cm^2)
- ✓ low material budget (0.05-0.55% X/X0) per layer

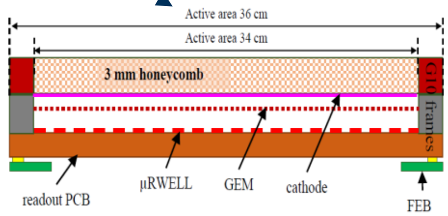
- ✓ 3 inner barrels: ITS3 curved wafer-scale sensor, 2 outer barrels: ITS3 based Large Area Sensors (EIC-LAS), stave based support structure
- ✓ 5 endcap disks (forward/backward), EIC-LAS,



Micro Pattern Gas Detectors (MPGD):

- ✓ Resolution: 10 ns, 150 um,
- ✓ 2 μRwell endcaps
- ✓ Outer μRwell planar layer + Barrel ECal layer
- ✓ :Inner Micromegas barrel





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

Resolution: ~30 ps, 30 um

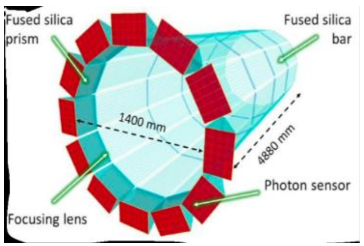
ToF detectors for PID at low p_T + time and spatial info for tracking

- ✓ Barrel: 0.05 x 1 cm strip,
- ✓ Endcap: 0.05 x 0.05 cm pixel

Particle Identification

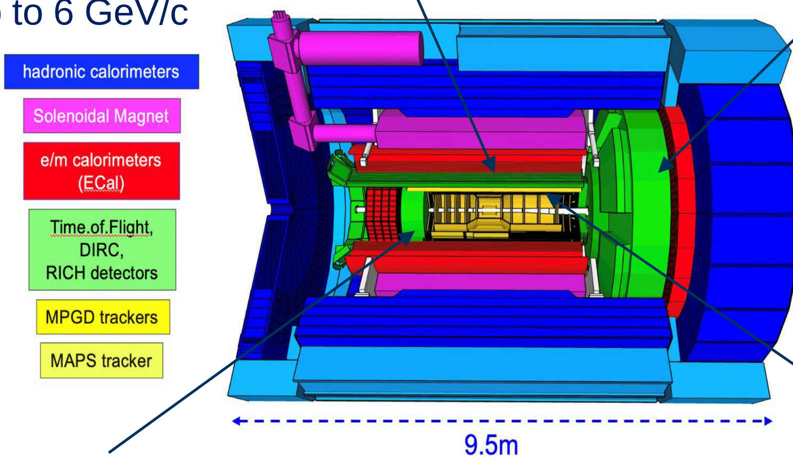
High-Performance DIRC (hpDIRC)

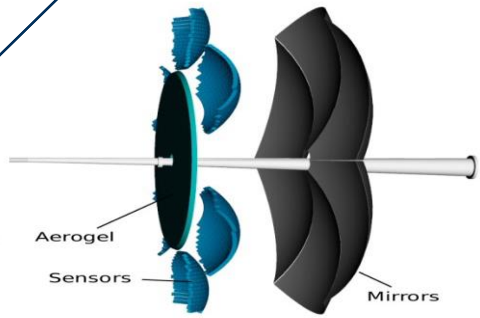
- ✓ Quartz bar radiator (reuse BaBAR bars)
- ✓ Sensors: High Rate Picosecond Photon Detectors (HRPPDs)
- ✓ π/K separation at 3σ up to 6 GeV/c



Dual-Radiator RICH (dRICH)

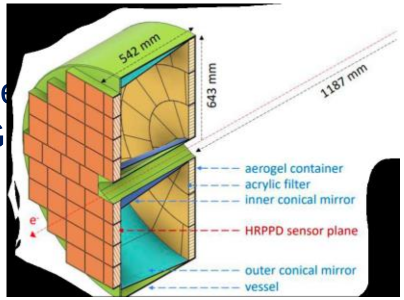
- ✓ C2F6 gas volume and Aerogel
- ✓ Sensors: SiPMs tiled on spheres
- ✓ π/K separation at 3σ up to 50 GeV/c





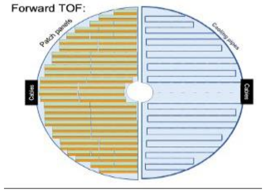
Proximity Focused RICH (pfRICH)

- ✓ Proximity gap (~40 cm)
- ✓ Sensors: High Rate Picosecond Photon Detectors (HRPPD) (provides also reference time for TOF)
- ✓ π/K separation at 3σ up to 10 Ge
- ✓ e/π separation at 3σ up to 2.5 G



AC-LGAD based TOF:

- ✓ t ~30 ps
- ✓ Accurate space point for tracking ~30 cm
- ✓ Forward disk and central barrel

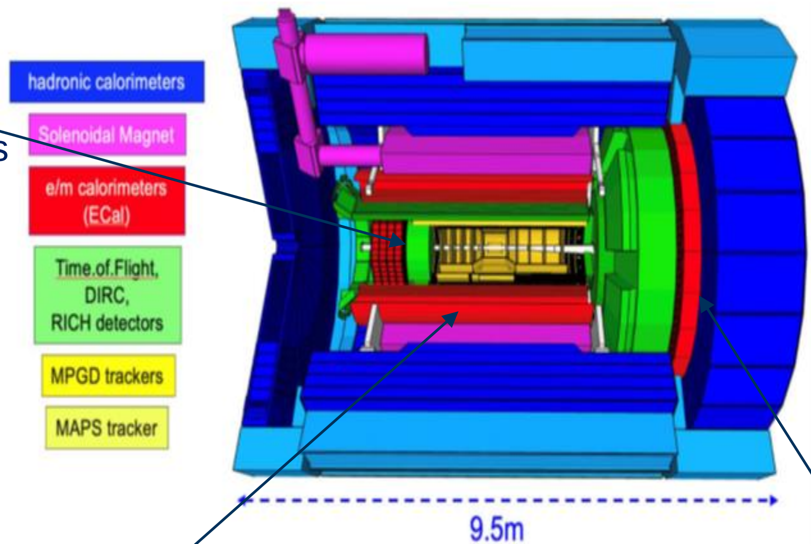


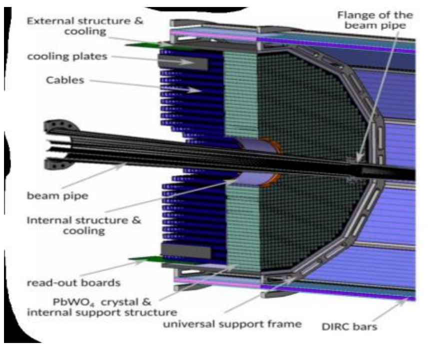
Electromagnetic Calorimeter

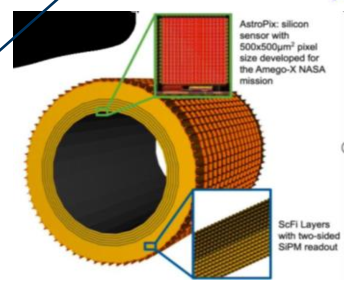
Backward Endcap EMCal

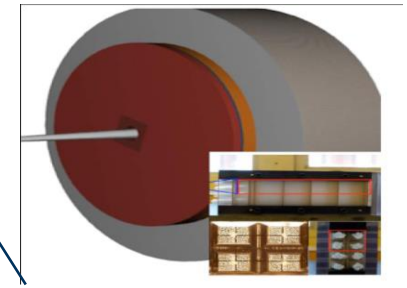
Lead tungstate (PbWO4) crystals

- ✓ 2 × 2 × 20 cm3 crystals
- ✓ Readout: SiPMs 10μm pixel
- ✓ Depth: ~20 X0









Forward Endcap EMCal

- ✓ High granularity W/SciFi

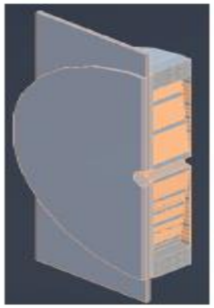
(Tungsten powder mixed with epoxy + scintillating fibers)

- ✓ 5 cm x 5 cm x 17 cm blocks
- ✓ 4 independent towers per block
- ✓ Readout: 4 SiPM per tower, 50 μm pixel
- ✓ Depth: ~23 X0

Barrel Imaging Calorimeter

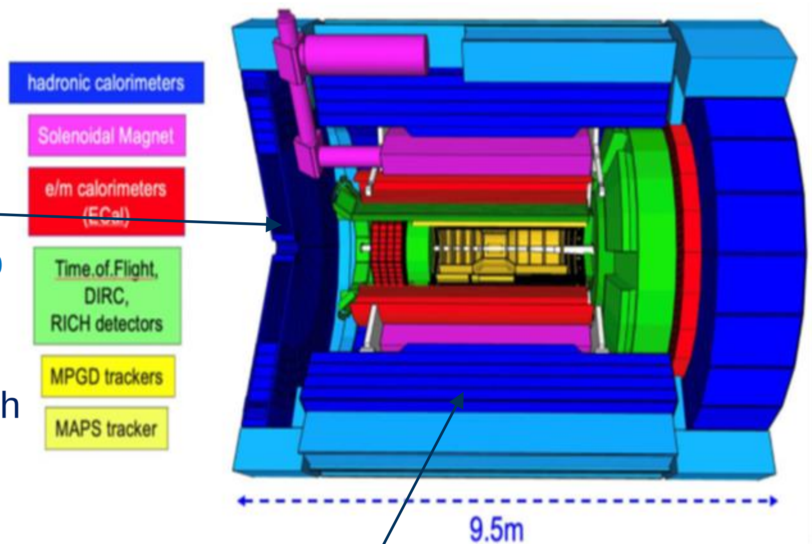
- ✓ 4(+2) layers of AstroPix MAPS sensor, 500x500 μm
- ✓ Interleaved with scintillating fiber/Pb layers
- ✓ 2-side SiPM readout, 50 μm pixel
- ✓ Depth: ~17.1 X0 at eta=0

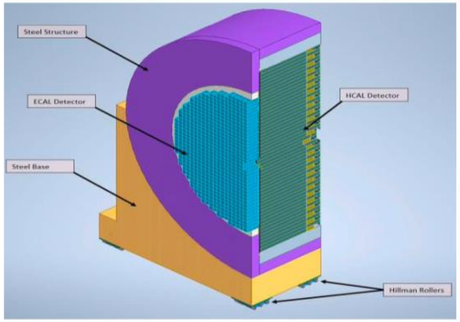
Hadronic Calorimeter



Backwards Endcap HCal

- ✓ Steel + large scintillator tiles sandwich
- ✓ SiPM readout
- ✓ Design in progress





Forward Endcap Hcal

- ✓ Longitudinally separated HCAL with high-η insert
- ✓ Steel + Scintillator SiPM-ontile
- ✓ Highly segmented longitudinally
- ✓ 65 layers per tower 565,760 SiPMs

Barrel HCAL (sPHENIX re-use)

- ✓ Tilted Steel/Scintillator plates with SiPM readout

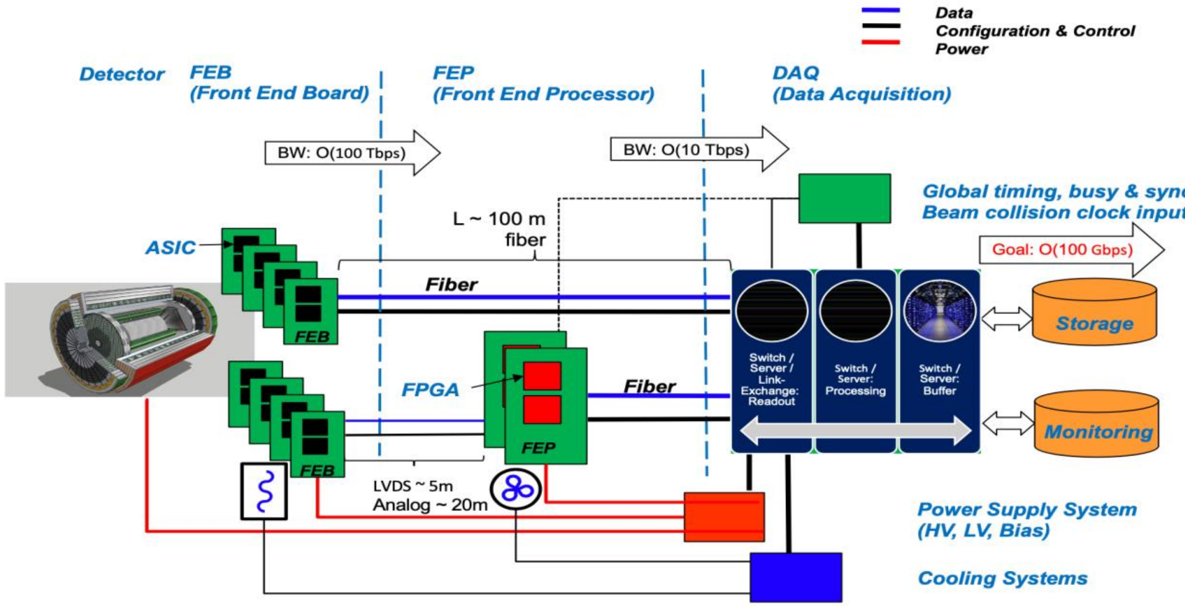
Refurbished for EIC

- ✓ Minor radiation damage replace SiPMs
- ✓ Upgrade electronics to HGCROC
- ✓ Reading out each tile individually

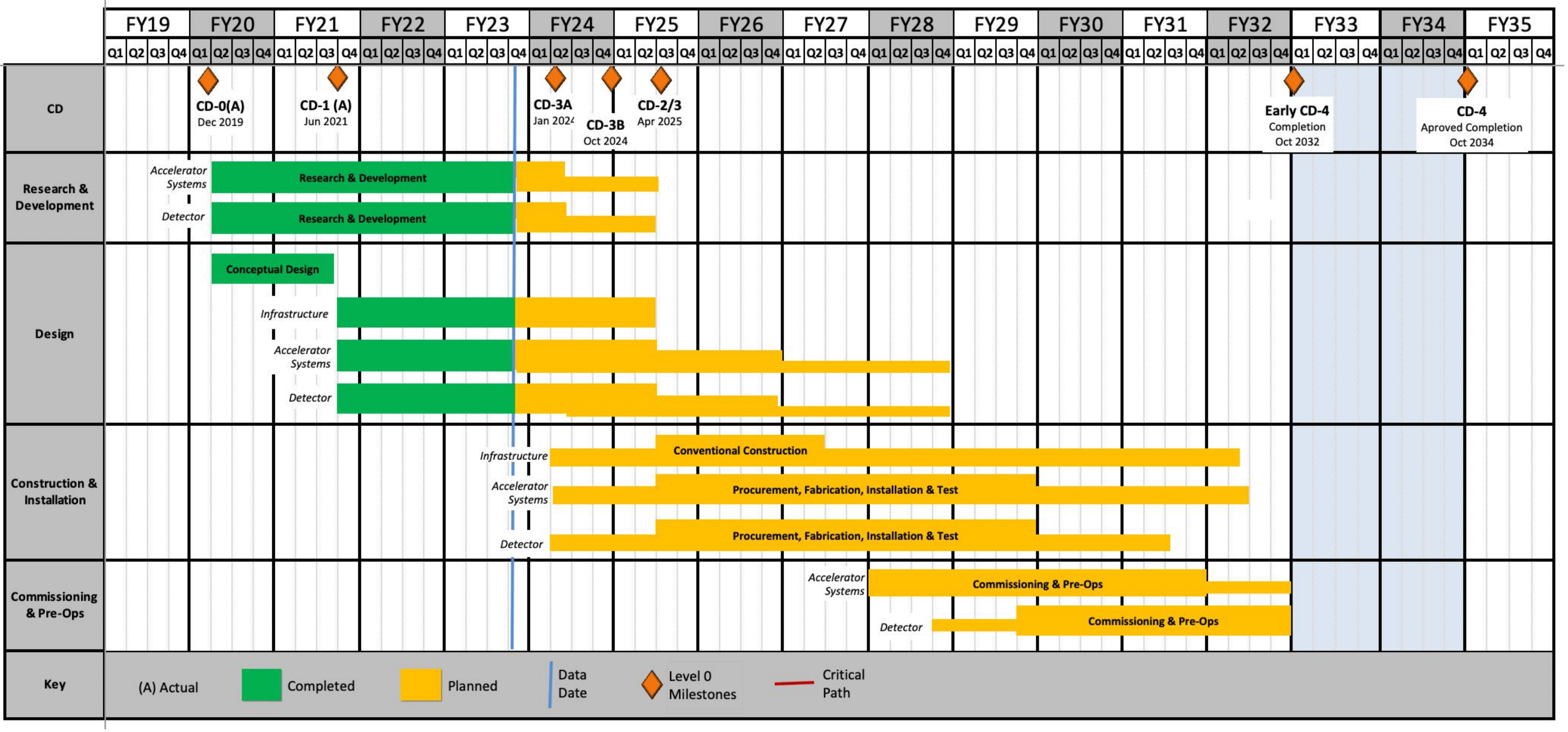
Streaming DAQ

Triggerless streaming architecture => more flexibility for physics

- ✓ All collision data digitized but aggressively zero suppressed at FEB
- ✓ Low / zero deadtime
- ✓ Collision data flow is independent -> no global latency requirements
- ✓ Event selection can be based upon full data from all detectors (in real time, or later)
- ✓ Data volume is reduced as much as possible at each stage



Current schedule



https://www.bnl.gov/eic/rhic-eic-comparison.php

Summary

EIC & ePIC

- ➢ powerful and flexible facility under development
- ➢ challenges and excitement ahead for both
  - ✓ instrumentation development
  - ✓ wide frontier physics scope