ePIC detector at the Electron Ion Collider

Jaroslav Adam
Czech Technical University in Prague

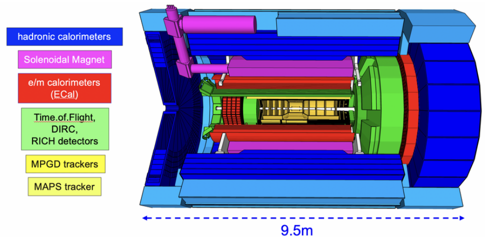
December 4, 2023

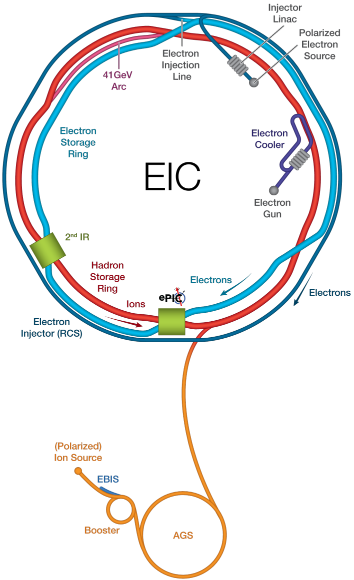
Zimányi School 2023

Electron Ion Collider (EIC)

- Polarized *ep* and *e*-ions up to 18$\times$275 GeV
- One of RHIC beams is re-used as hadron beam
- Physics of parton distributions, origin of proton spin and mass and jets in cold nuclear matter
- First data early 2030s

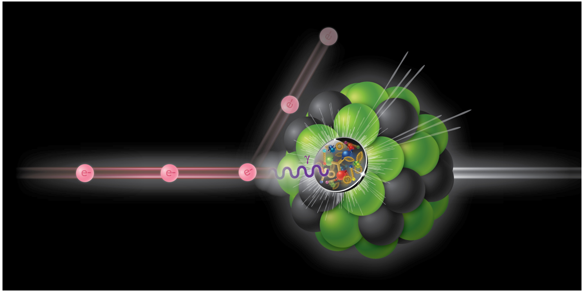
ePIC detector (Electron-Proton/Ion Collider Experiment)



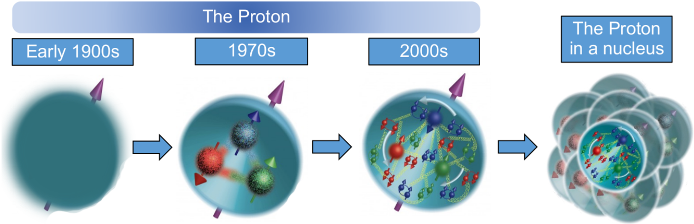


Physics case for the EIC

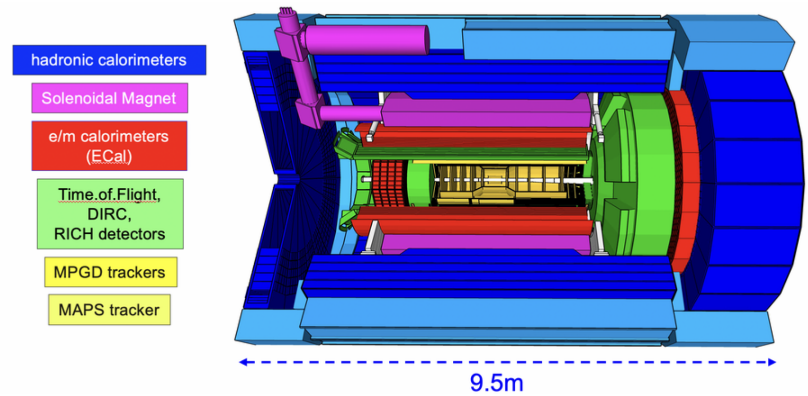
- Spin and mass composition of nucleons (*proton spin puzzle*)
- QCD dynamics in unexplored kinematic regions
- Jet interactions in cold nuclear matter
- Electroweak and beyond the standard model physics



Looking into a nucleus at the EIC



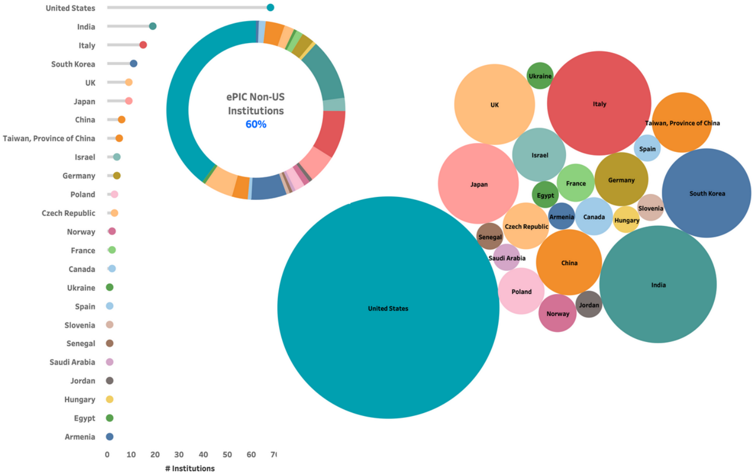
The ePIC experiment (Electron-Proton/Ion Collider Experiment)



Hermetic coverage for tracking, particle identification and calorimetry in asymmetric collisions

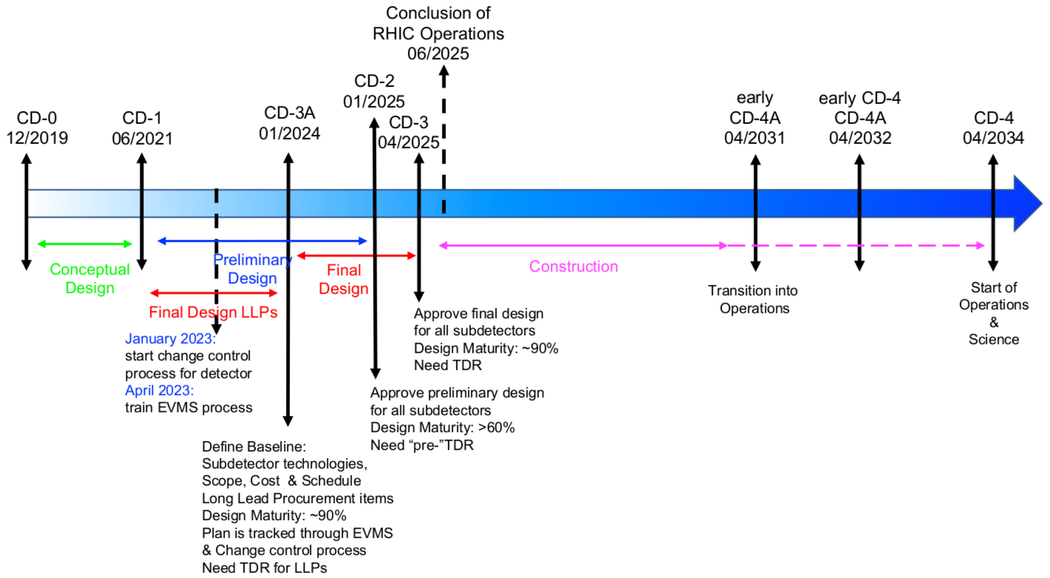
ePIC collaboration

- 500+ participants
- 160+ institutions
- 24 countries

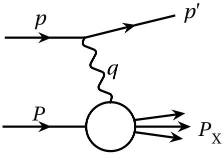


International community pursuing the new experiment

Timeline for EIC and ePIC construction



Detector tasks for ePIC experiment



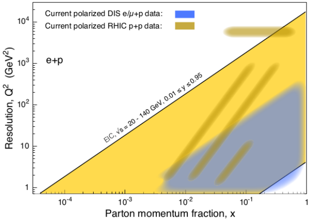
General DIS process

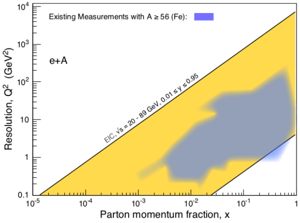
$$Q^2 = -(p - p')^2$$

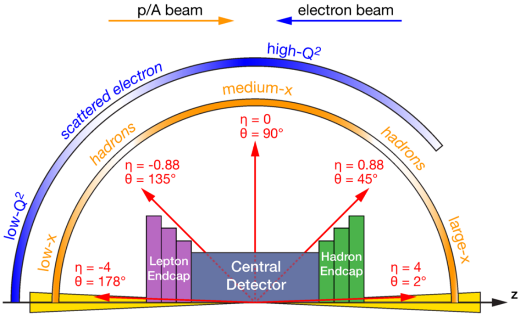
$$x = \frac{Q^2}{2Pq}$$

- Detection of scattered electrons (p') and final-state particles (P_X)
- Basic kinematics is given by virtuality Q^2 and Bjorken-x

Unprecedented coverage in e+p and e+A

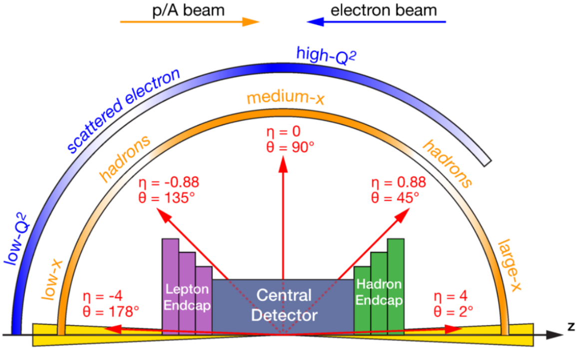






Detector requirements for ePIC experiment

- Vertex detector: precise spatial resolution, low material budget
- Central and endcap trackers: particle momenta (with help of solenoid magnet)
- Particle identification: $\pi/K/p$ separation for each track
- Calorimeters: eletromagnetic and hadron
- DAQ: streaming readout
- Far-forward and backward detectors: scattered particles at very small angles, luminosity measurement



Coordinate convention for ePIC:

- Forward – proton/ion beam direction, $z > 0$
- Backward – electron beam direction, $z < 0$

Central ePIC detectors in general

Vertex + tracking

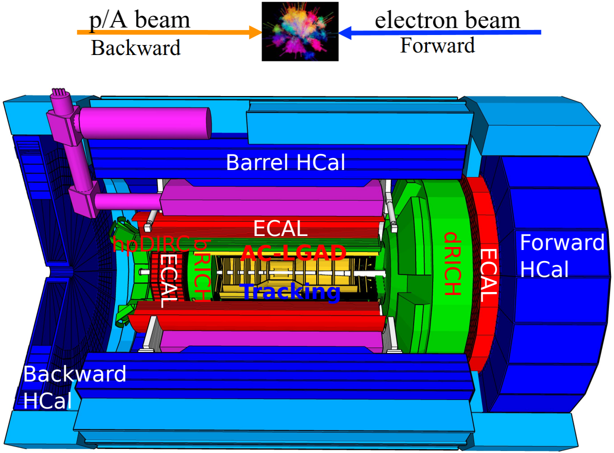
- Si and gaseous sensors
- 1.7 T solenoid field

Particle identification

- AC-LGAD for time-of-flight
- Cherenkov hpDIRC and RICH

Calorimeters

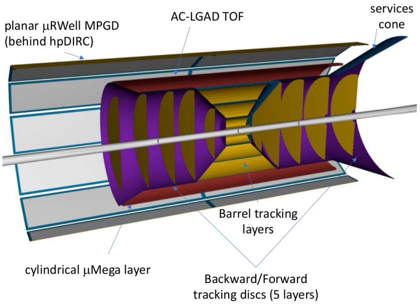
- Electromagnetic and hadron parts
- Full enclosure around tracking and identification detectors
- Homogeneous and sampling calorimeters

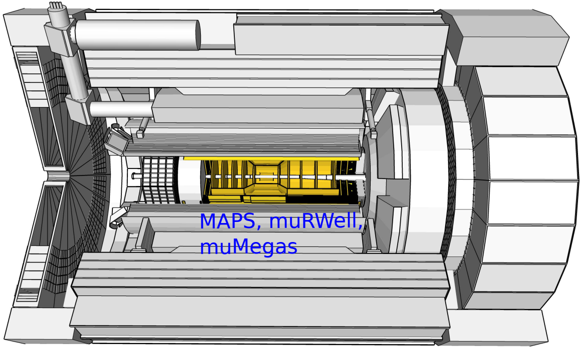


Meeting the requirements within space constraints

Central tracking detectors

- 6 Si layers + forward/backward disks
- Gaseous µRWell and µMegas
- TOF identification with AC-LGAD

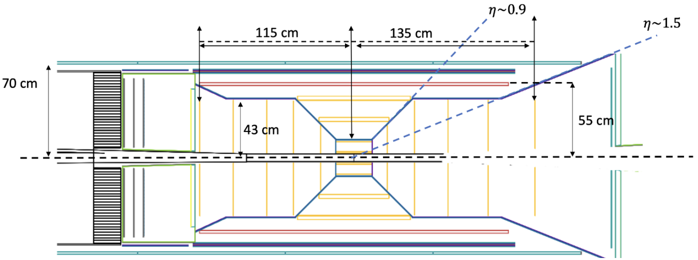


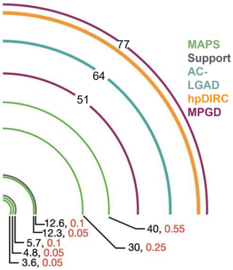


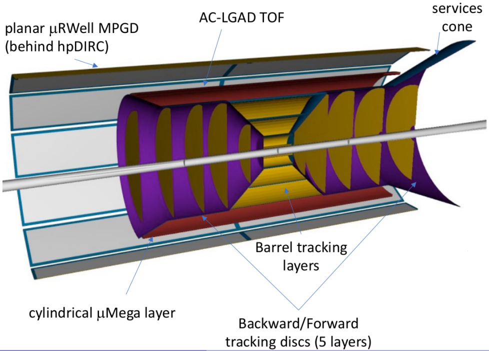
Collision vertex, charged particle momentum, time-of-flight identification

Layout for central tracking

- MAPS (Monolithic Active Pixel Sensor)
  - Based on 65 nm CMOS, developed with ALICE ITS3
- MPGD (Micro Pattern Gaseous Detector)
  - Connection between tracking and particle identification

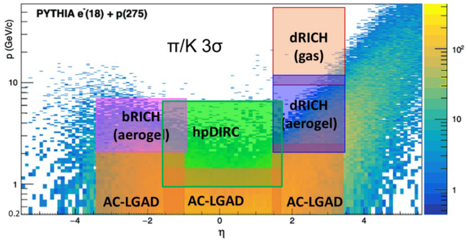




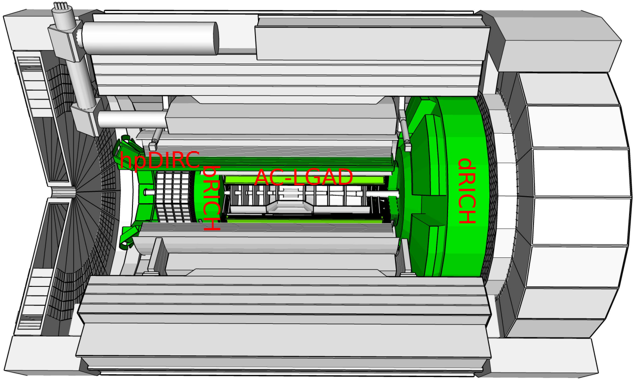


Particle identification

- Combination of time-of-flight and Cherenkov detectors



Expected momentum (p) and pseudorapidity (η) distribution

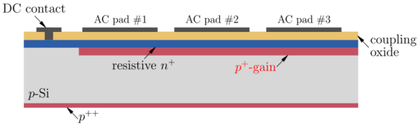


Complete coverage in particle momenta and pseudorapidity

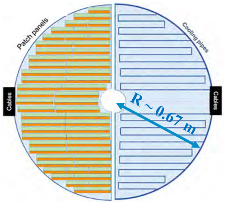
Particle identification by time-of-flight

- AC-LGAD - structure of Low Gain Avalanche Diodes with capacitive (AC) coupling
- 100% fill factor, timing resolution ∼30 ps

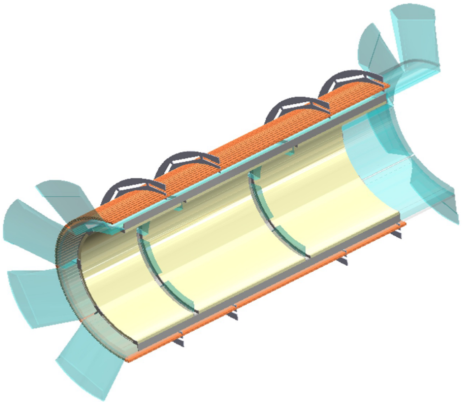
AC-LGAD structure



Forward disk



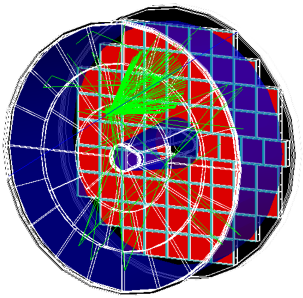
Barrel layer



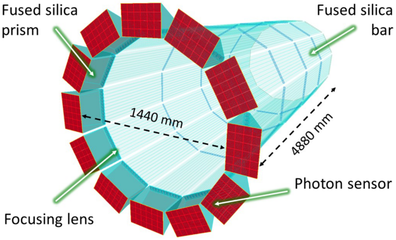
Particle identification by Cherenkov detectors

- Identification by combination of Cherenkov angle and momentum for each track
- Cherenkov radiators, readout by HRPPD (backward), MCP-PMT (barrel) and SiPM (forward)

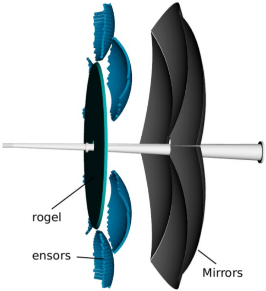
Backward modular RICH

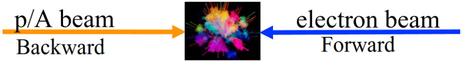


Barrel DIRC



Forward dual-radiator RICH

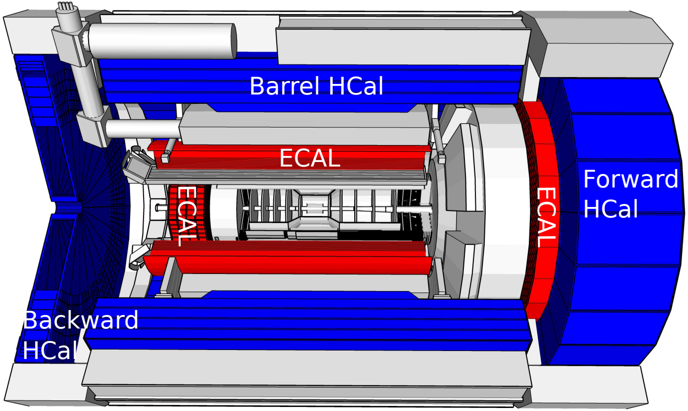




Calorimeters in ePIC detector

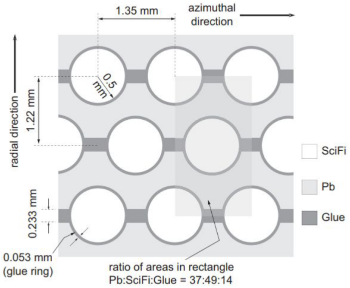
- Complete EM and hadron calorimeters in central region and forward (hadron) endcap
- Tail-catcher for hadron calorimeter in backward endcap

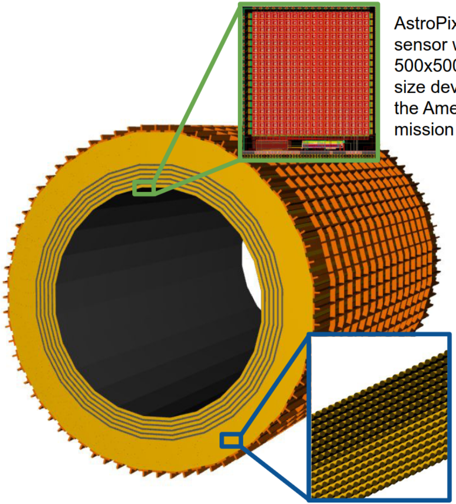
Electron / hadron separation, jet reconstruction



Barrel electromagnetic calorimeter

- Scintillating fibers (SciFi) in Pb absorber
- Imaging layers based on AstroPix sensors



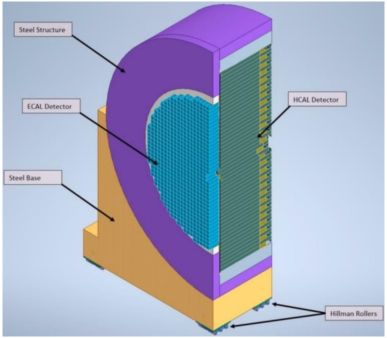


Forward and backward electromagnetic calorimeters

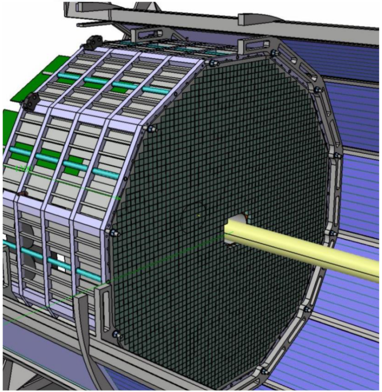
- Forward ECAL:
  - WScFi structure
  - Tungsten powder and scintillating fibers
  - SiPM readout
- Backward ECAL:
  - PWO crystals
  - SiPM readout

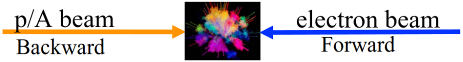
Electron/pion and $2\gamma/\pi^0$ separation

Forward endcap



Backward ECAL

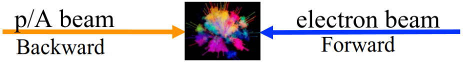




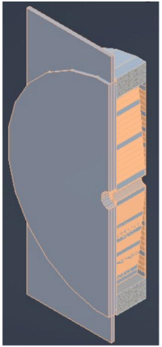
Hadron calorimeters

- Absorber layers and scintillator tiles + SiPM

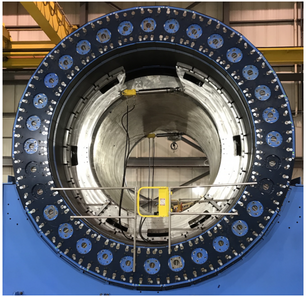
Jet kinematics reconstruction

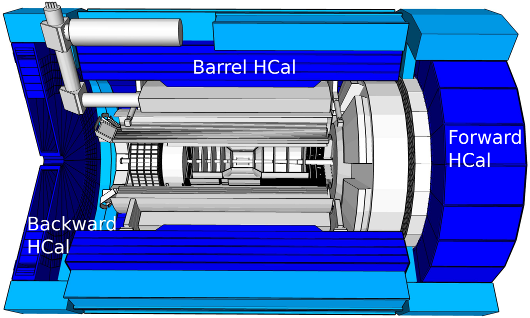


Backward tail-catcher



Barrel HCal





Far-forward / backward detectors

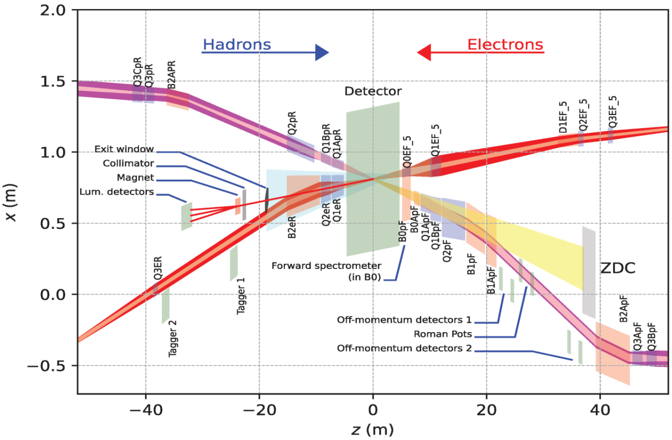
- Particles scattered at small angles, outside central detector
- Detectors are placed along beam magnets

Far-forward ($z \gg 0$)

- Hadron beam direction
- Tracking and calorimeters

Far-backward ($z \ll 0$)

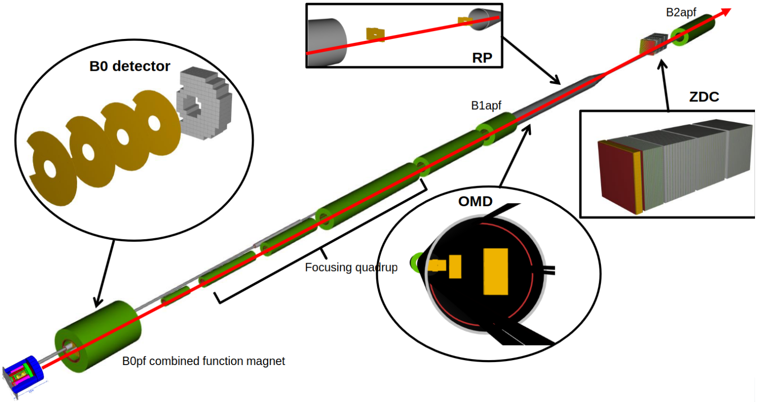
- Electron beam direction
- Luminosity measurement, electrons at low-Q^2



Interaction region layout, note different range in horizontal (x) and longitudinal (z) directions

Far-forward layout

- Roman Pots (RP) for very forward hadrons
- Off-Momentum Detectors (OMD) for nuclear breakup and Λ decays
- ZDC for neutrons and low-energy photons
- B0: tracker and calorimeter inside beam magnet



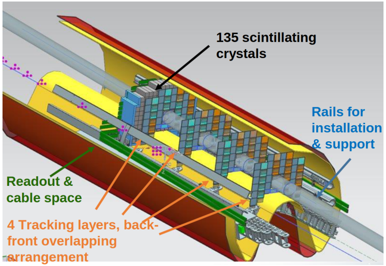
Diffractive processes, spectators in e+A collisions, nuclear excitation and breakup

The drawing is illustrative, not to scale

Far-forward detectors

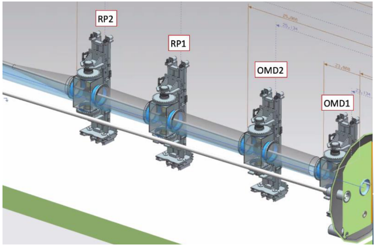
B0 detector

- 4 Layers of AC-LGAD
- LYSO crystals for calorimeter



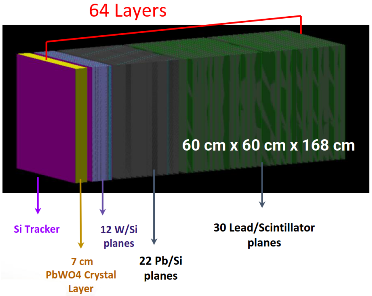
Roman Pots + OMD

- AC-LGAD sensor
- Part of outgoing hadron beampipe



ZDC

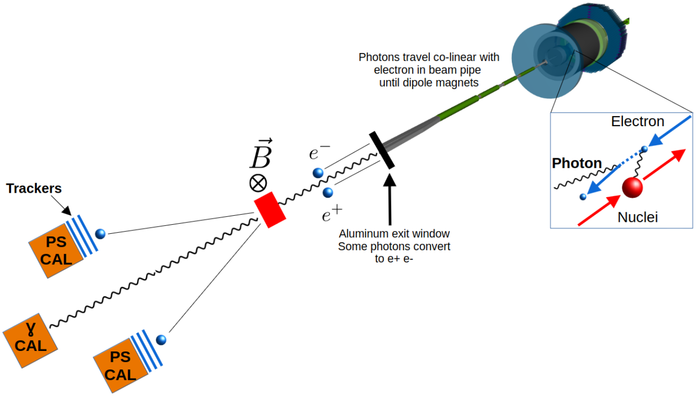
- Electromagnetic and hadron parts



Far-backward region, luminosity measurement

- γ photons from Bethe-Heitler bremsstrahlung, $ep(A) \to e\gamma p(A)$
- Cross section is well known from QED
- Two methods to count the γ photons:

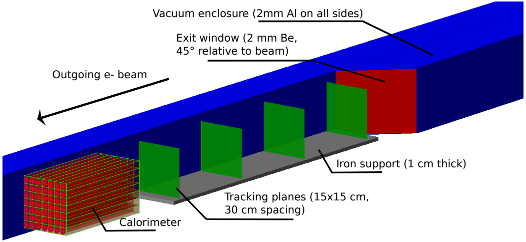
1. Direct γ calorimeter (γ cal)
   - Approximate γ counts
   - Online collider performance
2. Conversion pair spectrometer (PS)
   - Precise counts for physics
   - γ conversions to e^+e^- pairs
   - Dipole magnet, trackers and calorimeters



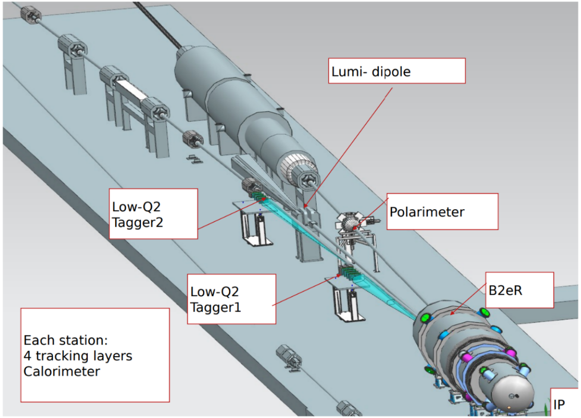
Key part to all cross section measurements (most of EIC physics program), target precision of 1%

Far-backward region, low-Q^2 electron tagging

- Two tagger stations (-20 m) and (-35 m) from interaction point (IP)
- Timepix4 tracker and EM calorimeter



Detail at one of tagger stations

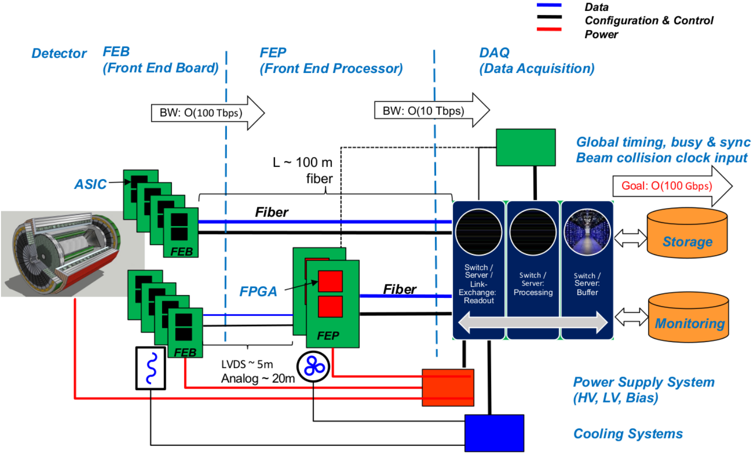


Photoproduction physics at low-Q^2 and luminosity precision (coincident e^- and γ detection)

Streaming DAQ

No need for external trigger

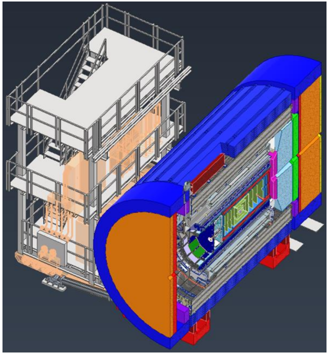
- Digitization for all detector data
- Event selection with data from all detectors
- Data volume is reduced at each stage
- Expectation for $\mathcal{O}(100)$ PB per run, feasible to store for analysis

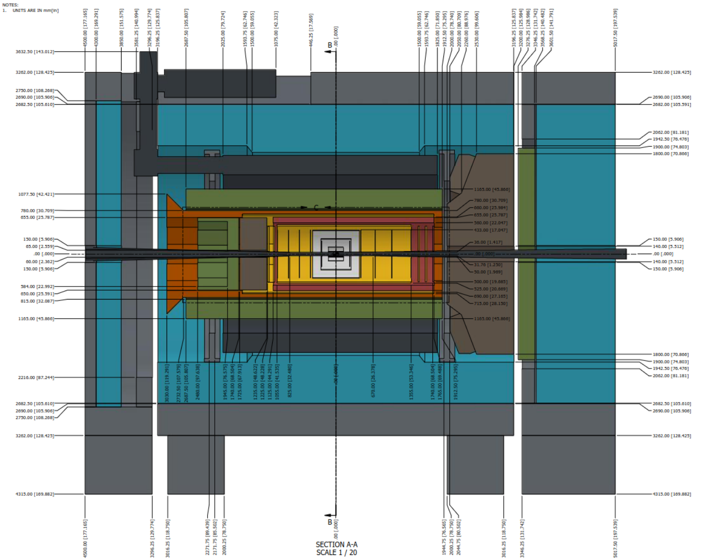


Engineering design for ePIC

- Full CAD design ongoing with real dimensions

Integration of services like cabling and cooling





Summary and outlook

- The ePIC collaboration was established, enthusiastic international community
  - Latest meeting in Warszaw, July 2023: https://indico.cern.ch/event/1238718/
  - Next meeting will take place at Argonne National Lab in January 2024: https://indico.bnl.gov/event/20473/
  - Effort on preparing technical design for CD-2/3A

- The ePIC detector is closing to its detailed technical design
  - Requirements specified in Yellow Report are met by ePIC detector
  - Built on strong commitment from all RHIC, JLab and international communities