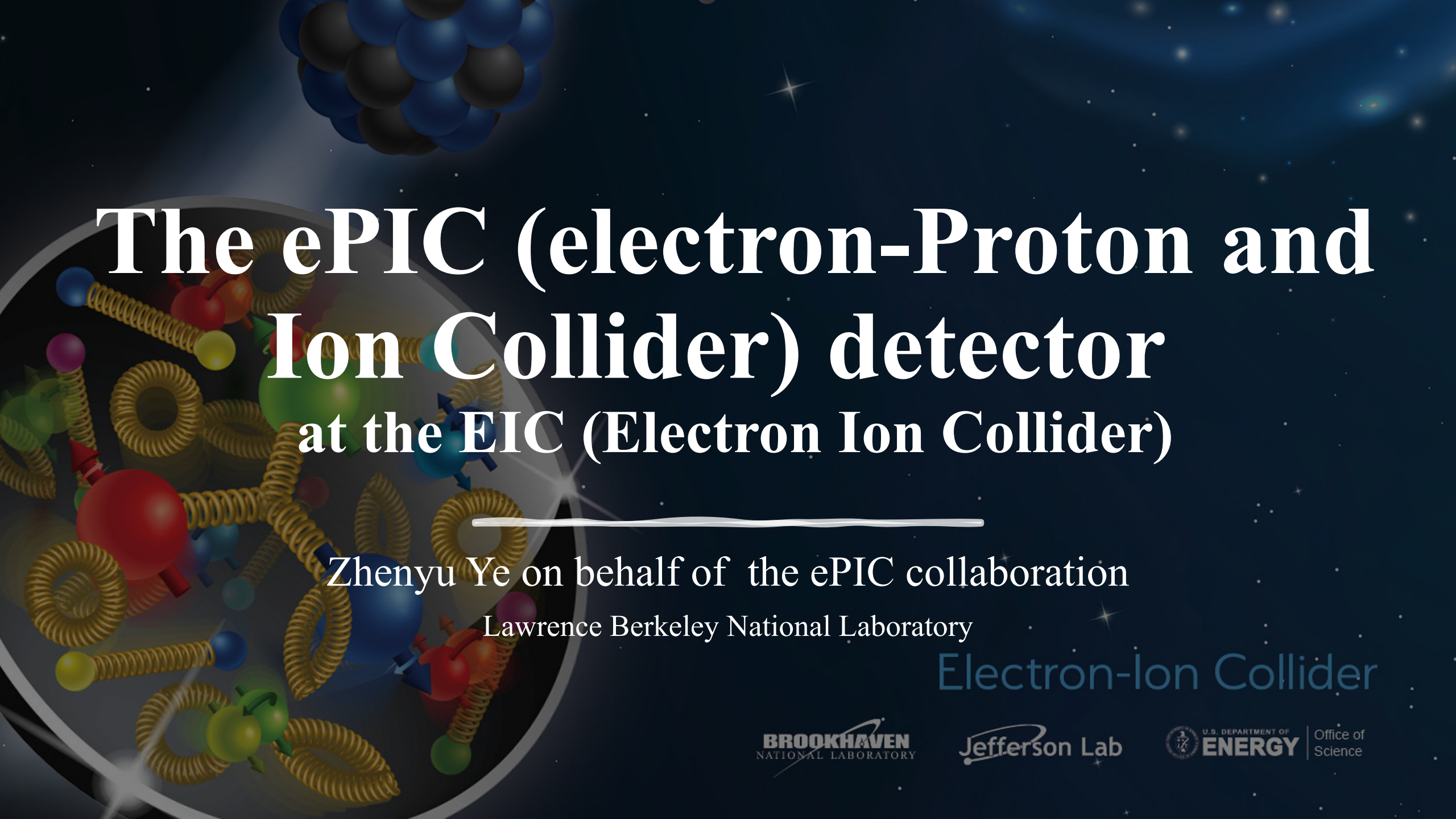


The ePIC (electron-Proton and Ion Collider) detector

at the EIC (Electron Ion Collider)

Zhenyu Ye on behalf of the ePIC collaboration

Lawrence Berkeley National Laboratory

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY

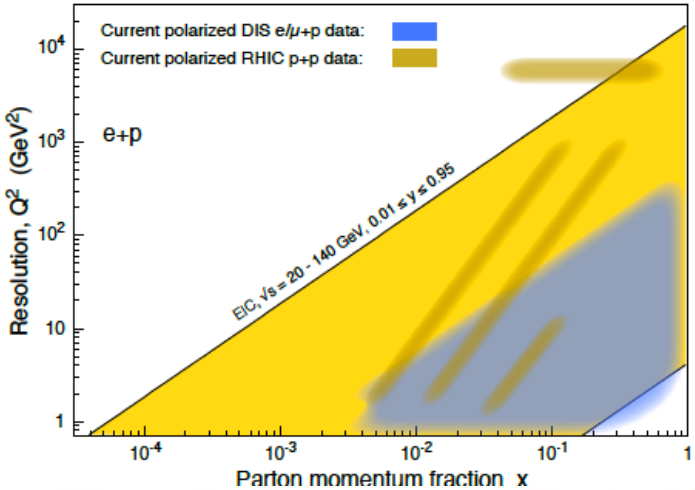
Jefferson Lab

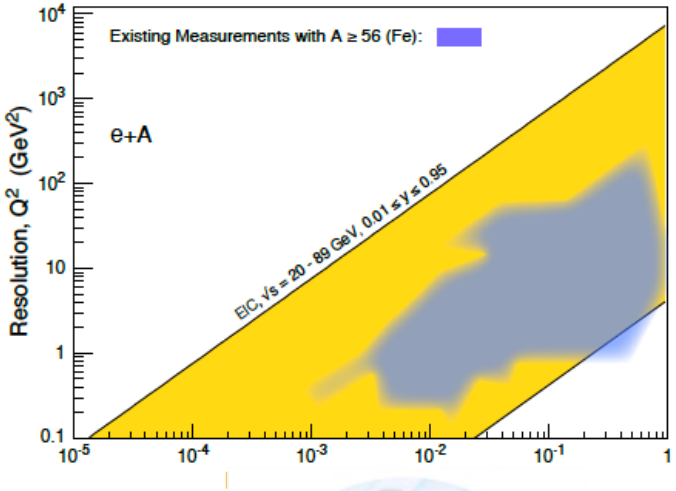
U.S. DEPARTMENT OF ENERGY | Office of Science

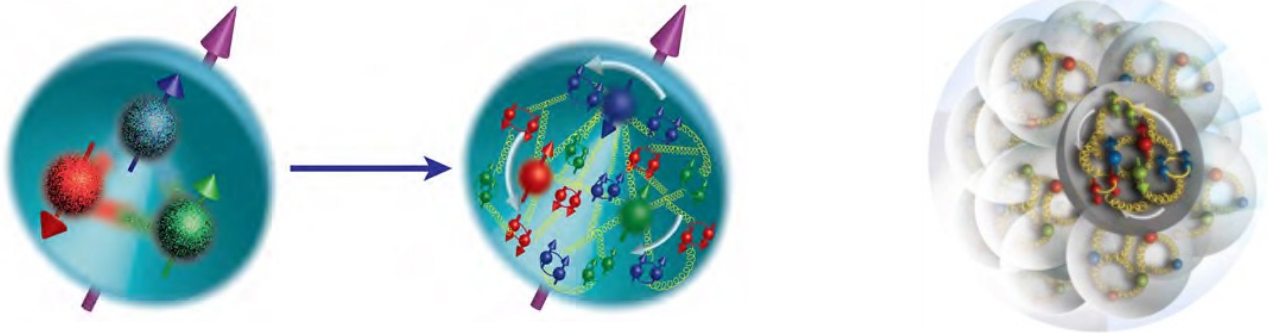
Electron Ion Collider (2031+)

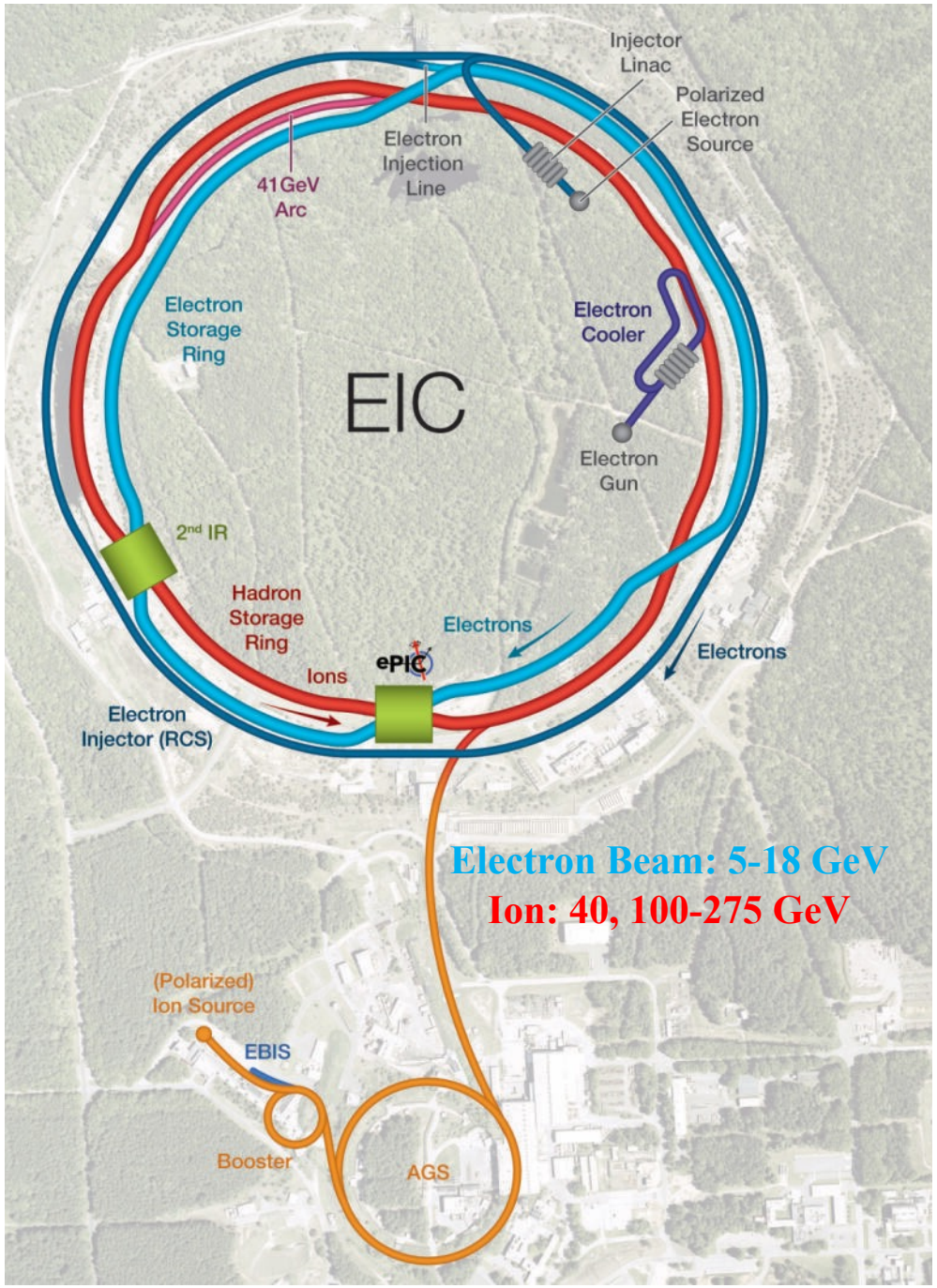
EIC among the highest priority of US Nuclear Physics

- **High luminosity**: L= 10^{33}–10^{34} $cm^{-2}s^{-1}$, 10–100 fb^{-1}/year
- **Highly polarized** electron and light ion beams: ~70%
- **Large center of mass energy range**: E_{cm} = 20–140 GeV
- **Large ion species range**: proton – Uranium
- **Particle production rate**: O(5) @ ~500 kHz



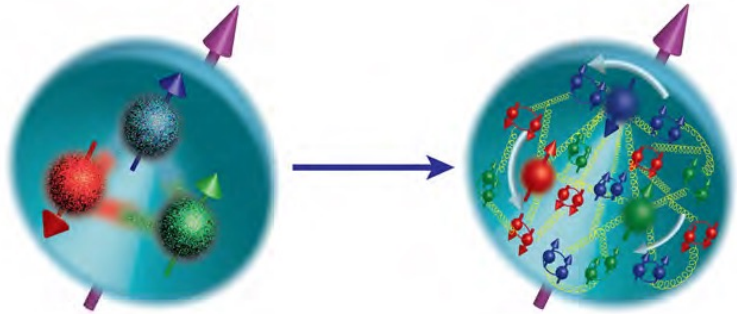


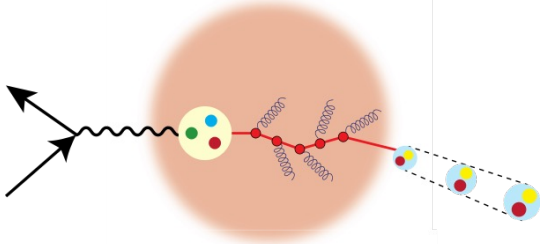


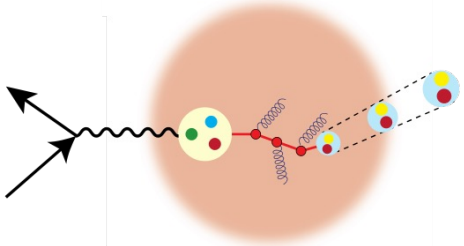


EIC Physics Programs

How are the gluons and sea quarks, and their spins, distributed in space and momentum inside the nucleon? What is the role of orbital motion in building the nucleon spin?

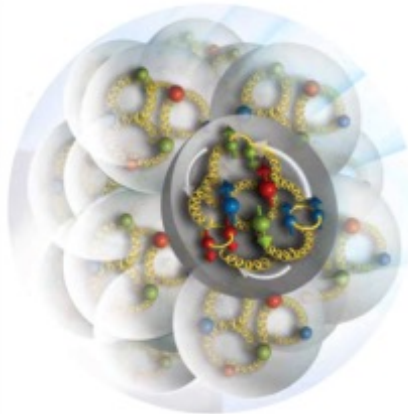






How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

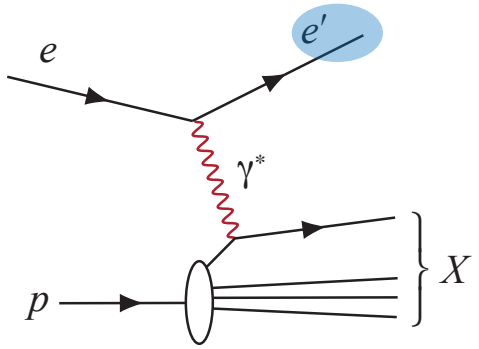
How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?



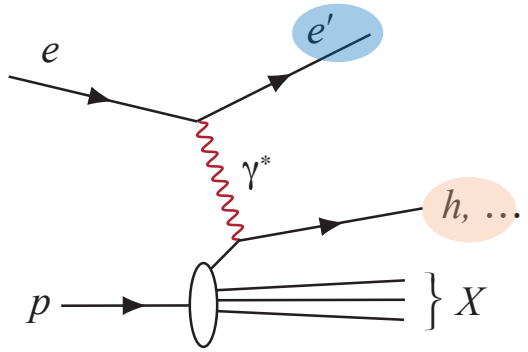
Precision EW, Beyond Standard Model, …

Particle Detection at EIC

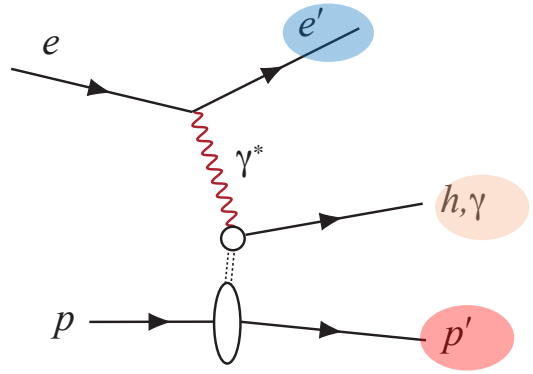
- Physics Processes in eN scatterings
  - Inclusive DIS : scattered electron only
  - Semi-inclusive DIS: scattered electron, one or more final state hadrons
  - Exclusive: all the final state particles including the recoiling nucleon



Inclusive DIS

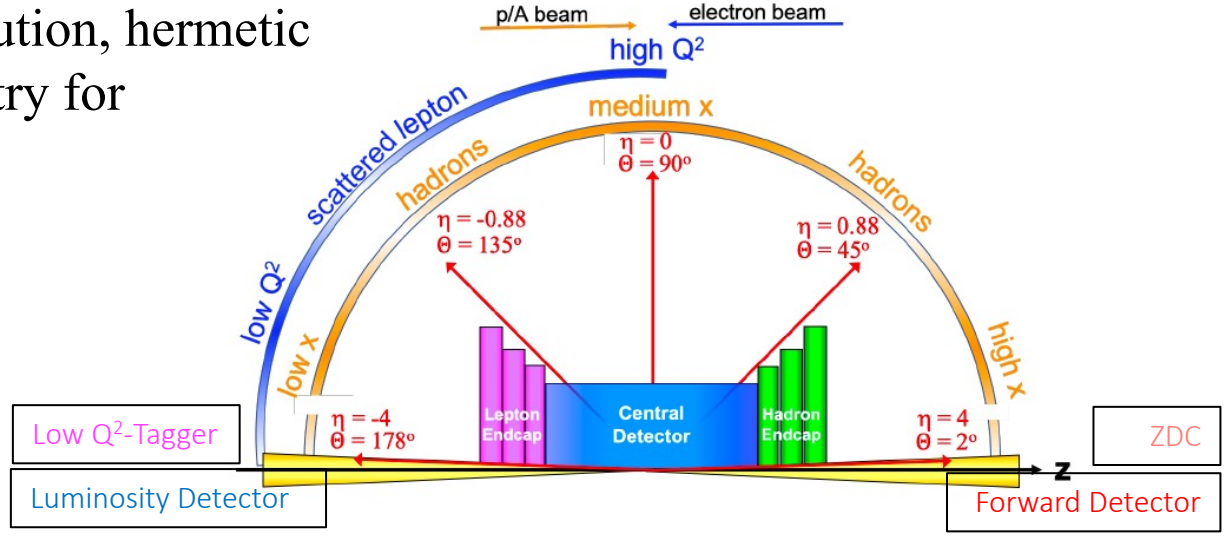


Semi-inclusive DIS



Exclusive

- It is critical to build a high efficiency, high resolution, hermetic detector with vertex/tracking, PID, and calorimetry for
  - electrons
  - hadrons
  - photons
  - jets
  - muons
  - …



Electron-Proton and -Ion Collider detector (ePIC)

Vertexing and Tracking:

- Silicon Vertex Tracker (MAPS)
- MPGD (μRWELL/μMegas)

Particle Identification:

- TOF (AC-LGAD also for tracking)
- pfRICH (Aerogel/HRPPD)
- hpDIRC (Quartz/MCP-PMT)
- dRICH (Aerogel+C_2F_6/MCP-PMT)

EM Calorimeters:

- EEMCal ($PbWO_4$/SiPM)
- Barrel EMCal (Pb+SciFi/SiPM) with imaging layers (Pb+SciFi/AstroPix)
- FEMC (W+SciFi)

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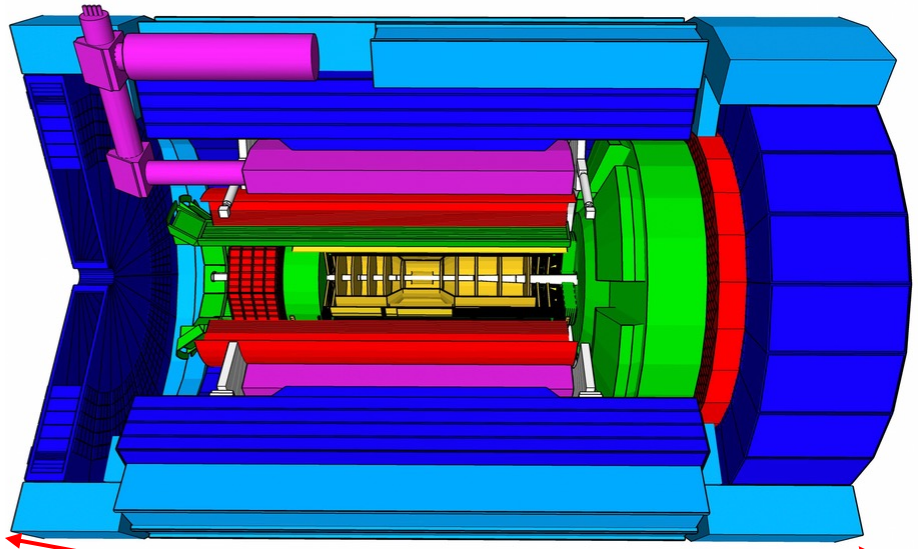

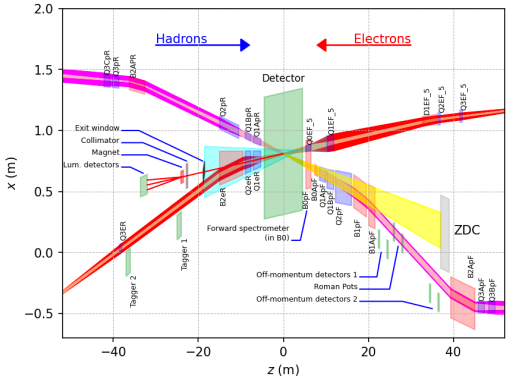

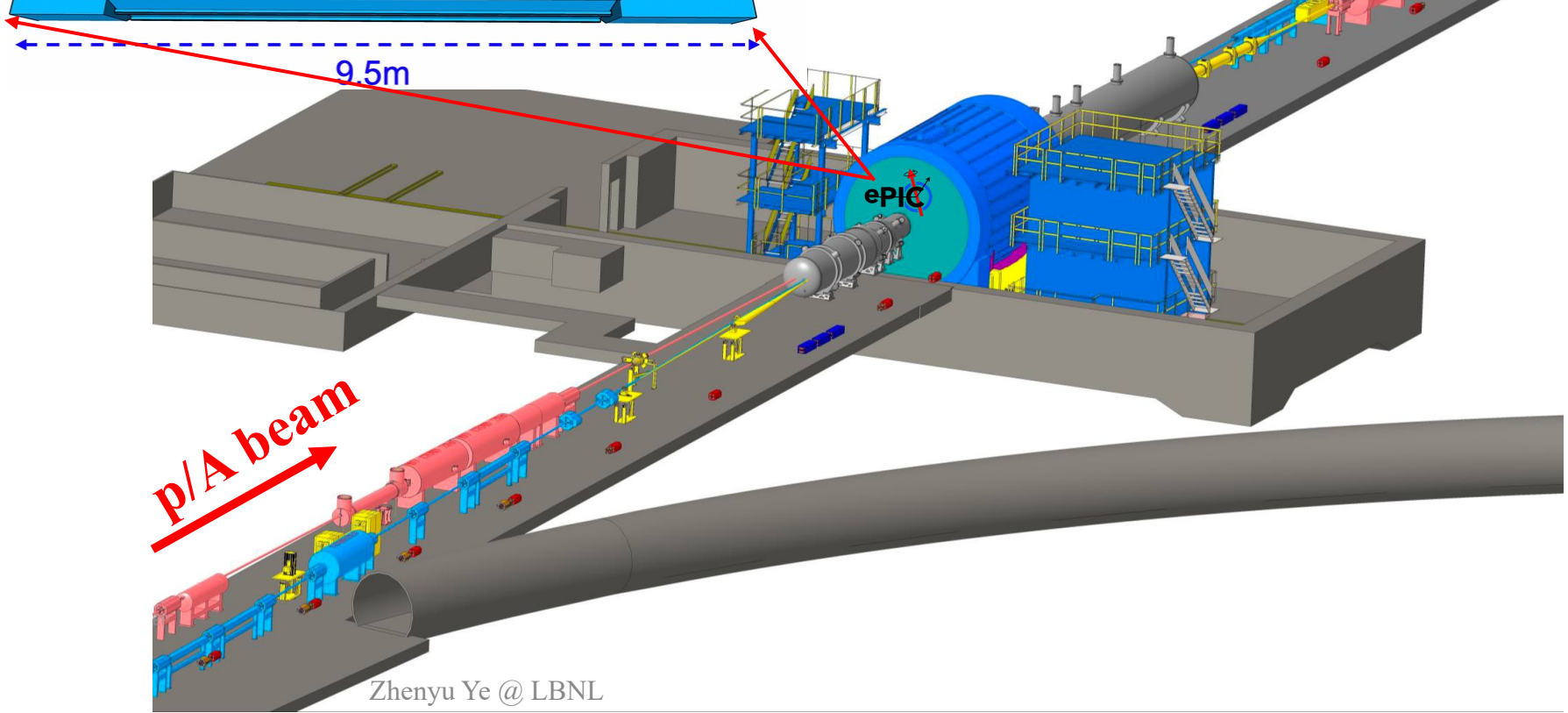

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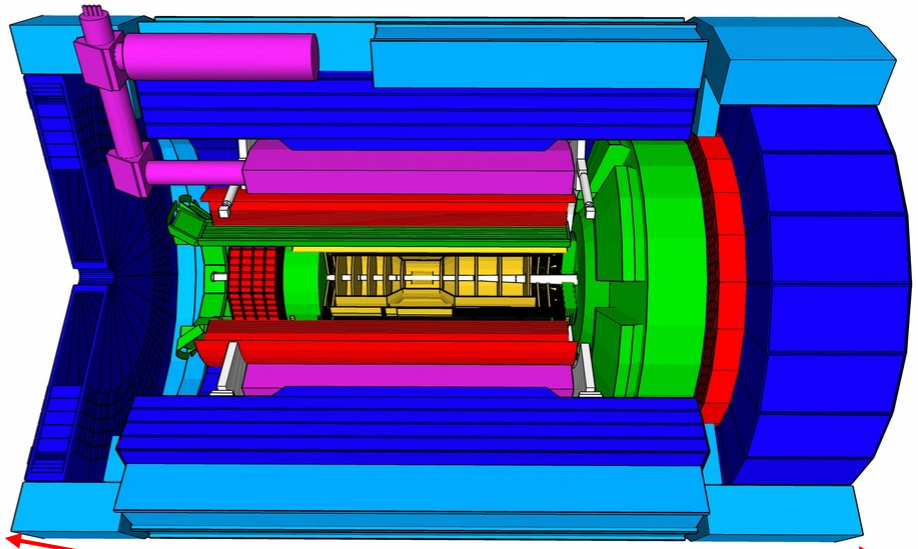
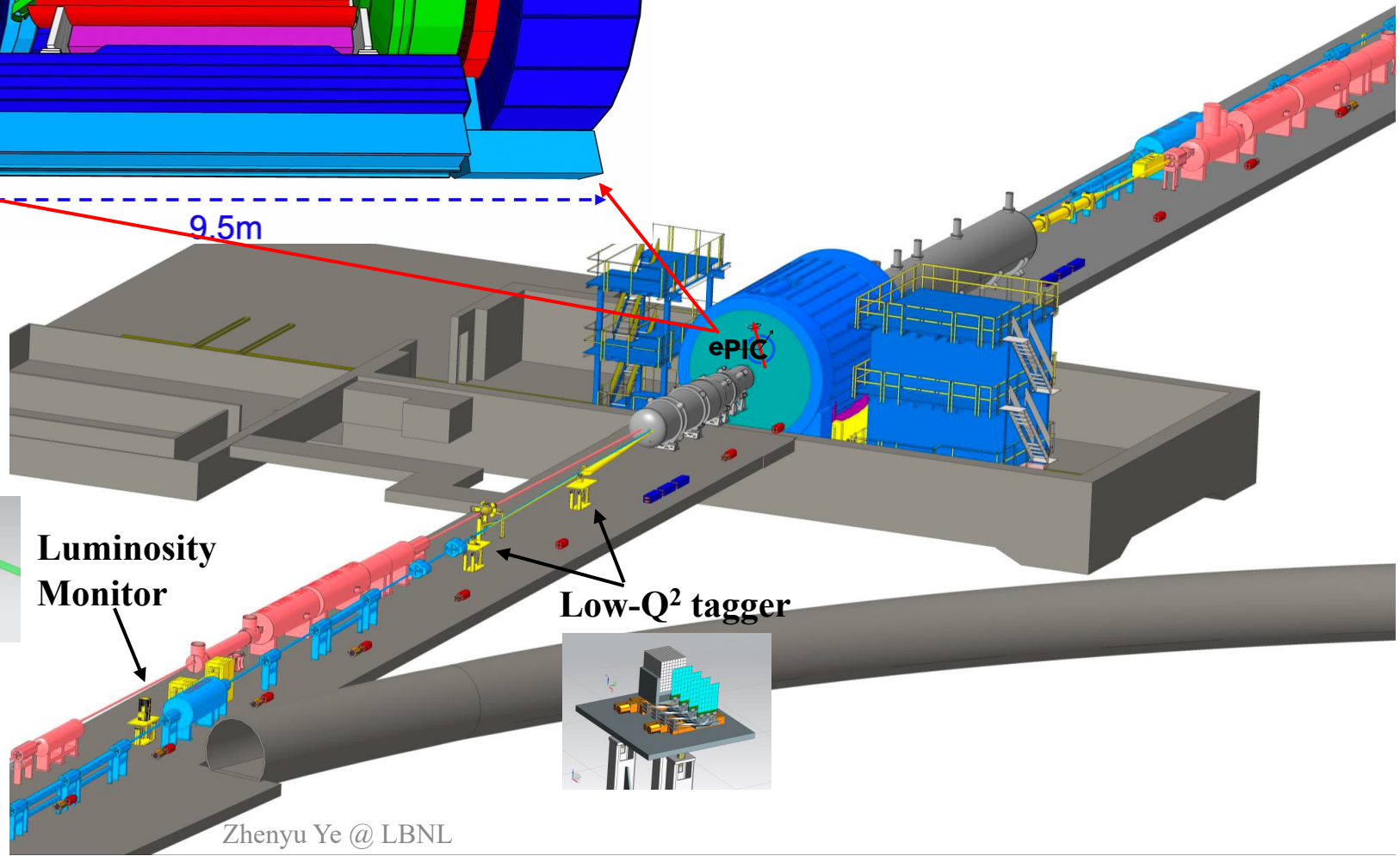
Far-Backward:

- Luminosity monitor (AC-LGAD, W+SciFi)
- Low-Q^2 tagger (Si/Timepix4)





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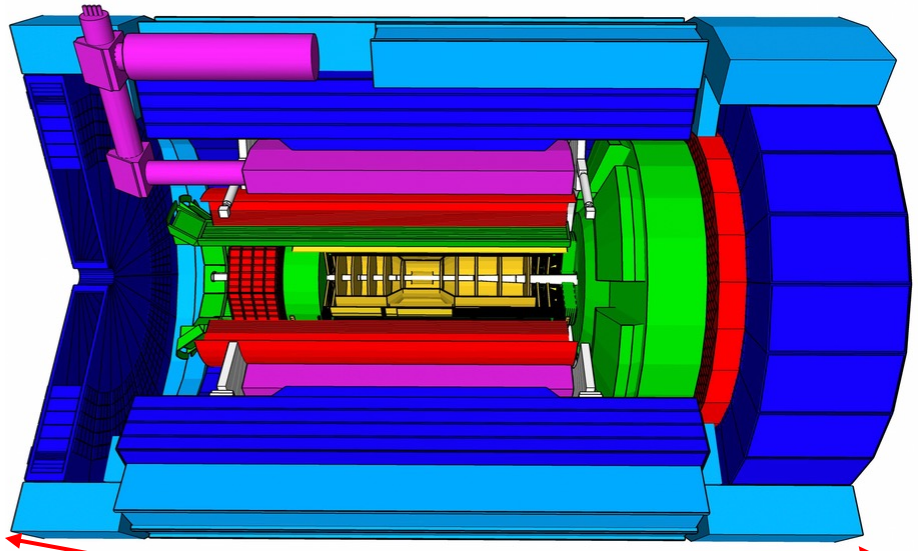
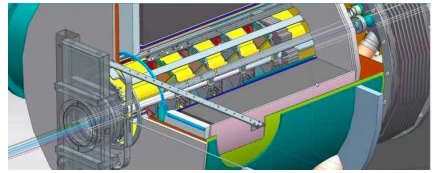


Far-Forward:
- Roman Pots (AC-LGAD)
- B0 Magnet Spectrometer (AC-LGAD, $PbWO_4$)
- Off-Momentum Detector (AC-LGAD)
- Zero Degree Calorimeter ($PbWO_4$, Fe/SiPM)



25 subdetectors incl. polarimeters

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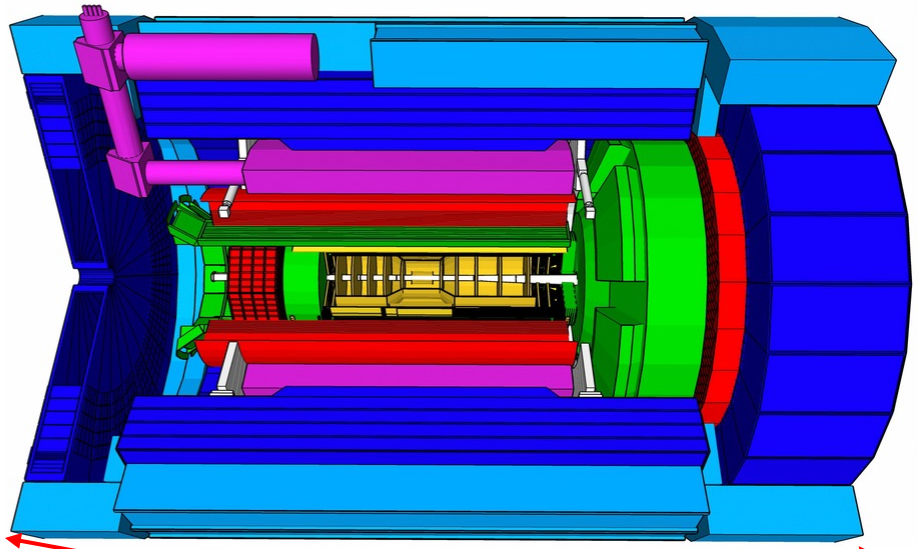

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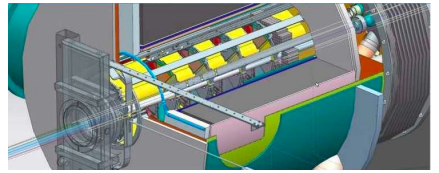
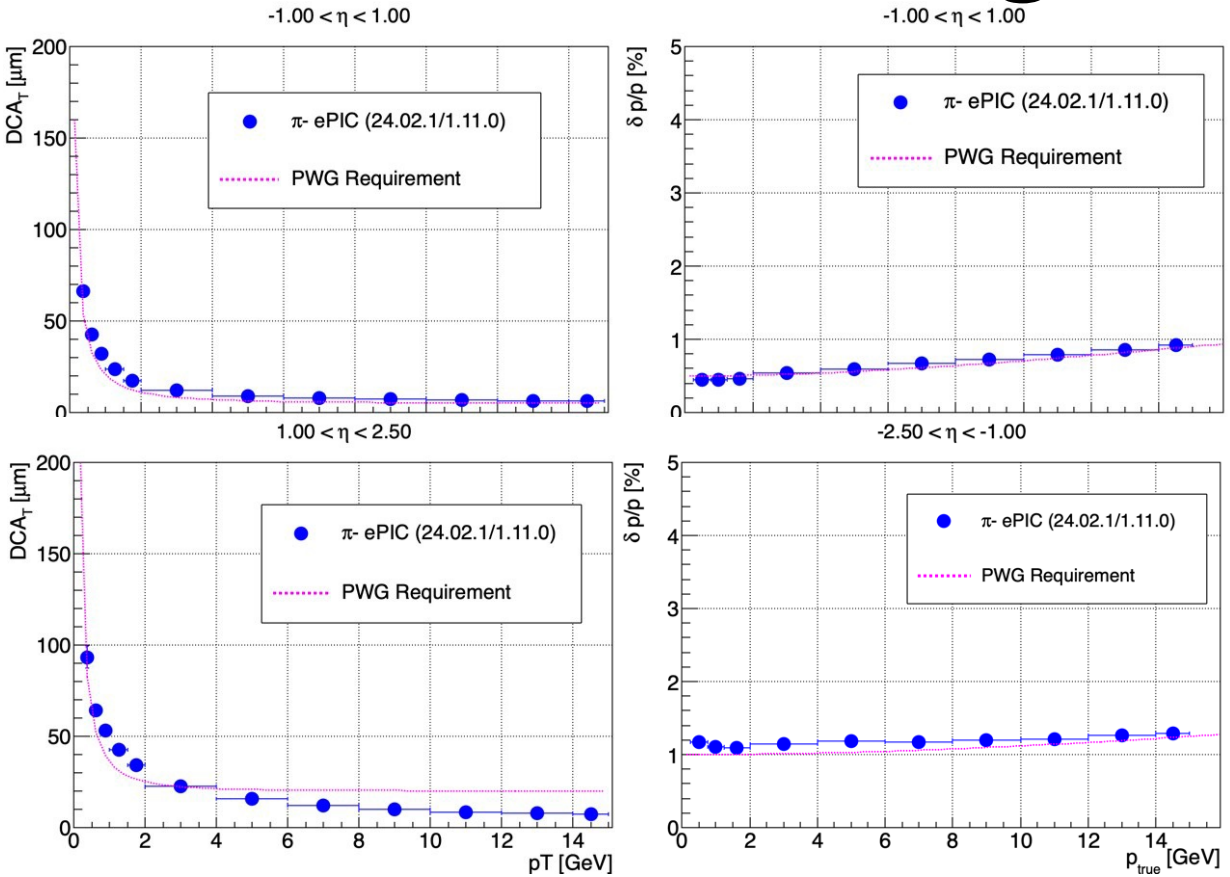
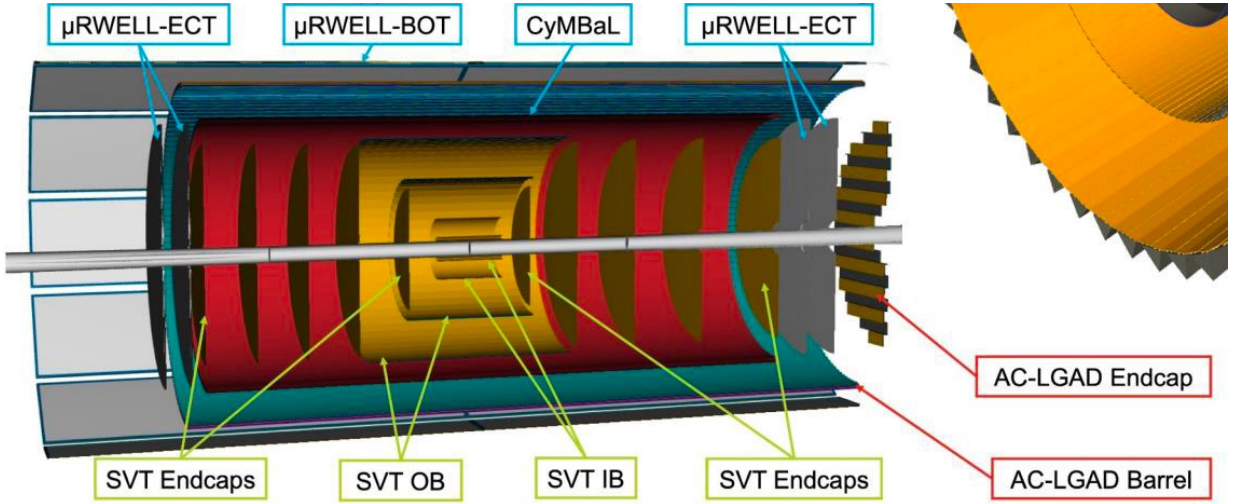


25 subdetectors incl. polarimeters

ePIC Central Tracking Detectors



Rapidity Range	Momentum Resolution	Spatial Resolution
Backward (-3.5 to -2.5)	~0.10%×p ⊕ 2.0%	~30/pT μm ⊕ 40μm
Backward (-2.5 to -1.0)	~0.05%×p ⊕ 1.0%	~30/pT μm ⊕ 20μm
Barrel (-1.0 to 1.0)	~0.05%×p ⊕ 0.5%	~20/pT μm ⊕ 5μm
Forward (1.0 to 2.5)	~0.05%×p ⊕ 1.0%	~30/pT μm ⊕ 20μm
Forward (2.5 to 3.5)	~0.10%×p ⊕ 2.0%	~30/pT μm ⊕ 40μm



Silicon Vertex Tracker (SVT): ~6 μm point resolution

- **3 inner barrels**: ITS3-curved wafer-scale sensor, 0.05% X/X_0
- **2 outer barrels**: ITS3-based sensors (EIC-LAS), 0.25/0.55% X/X_0
- **5 disks** (forward/backward), EIC-LAS, 0.25% X/X_0

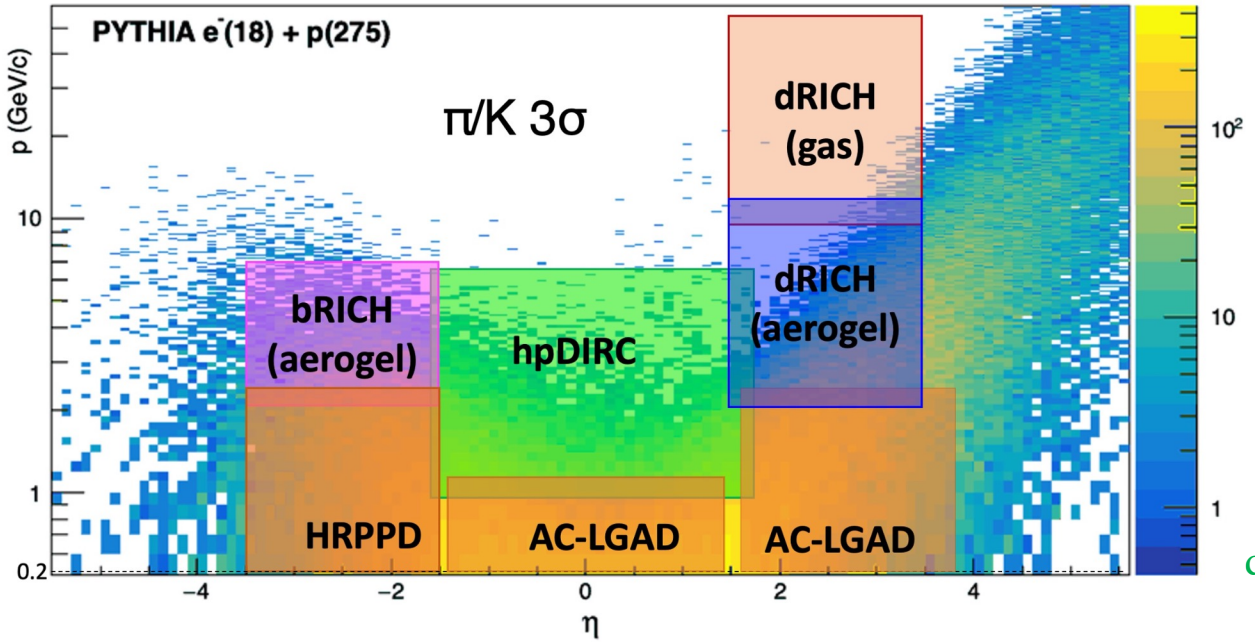
AC-coupled LGAD TOF: 30 μm + 30 ps resolutions

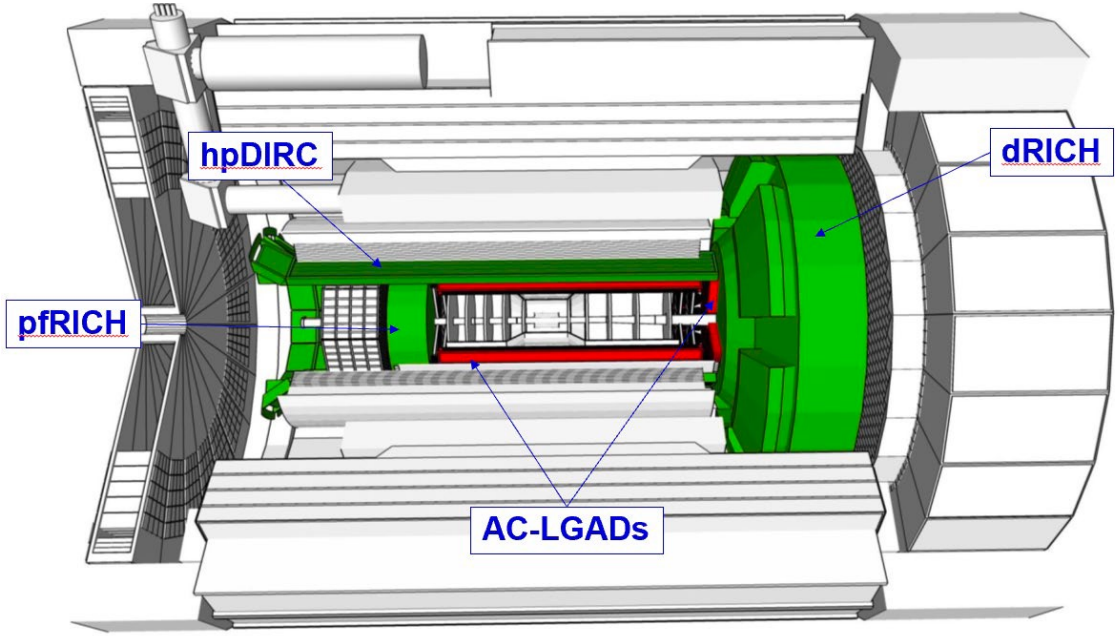
- Barrel TOF: 0.05 x 1 cm strip, 1% X/X_0
- Forward TOF: 0.05 x 0.05 cm pixel, 5% X/X_0

Multi Pattern Gas Detectors (MPGD):10 ns+150 μm resolutions

- **2 GEM-μRwell endcaps**: 1-2% X/X0
- **1 inner Micromegas barrel**: 0.5% X/X0
- **1 outer GEM-μRwell planar layer + Barrel ECAL AstroPix**: improve angular and space point resolution on hpDIRC

ePIC Central PID Detectors





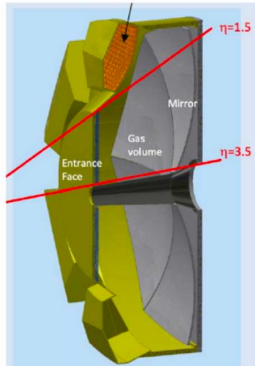
dRICH: dual radiator RICH
- Aerogel and C_2F_6 gas with SiPM for light detection

pfRICH: proximity focusing RICH
- Single volume with long proximity gap (~30 cm), using Aerogel as radiator and HRPPD as photon sensors

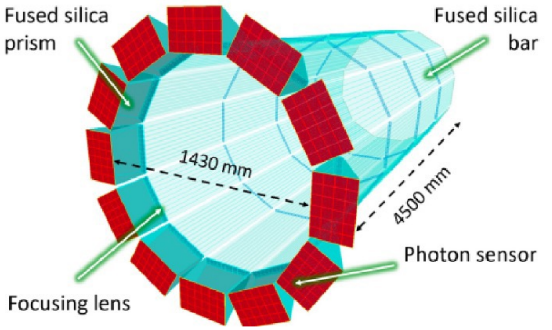
hPDIRC: high performance DIRC
- Quartz bar radiator (BABAR bars reuse) with MCP-PMT

Time-of-Flight: AC-LGAD
- Backward: HRPPD with 10-20 ps resolution
- Barrel: AC-LGAD strip sensors with 35 ps resolution
- Forward: AC-LGAD pixel sensors with 25 ps resolution

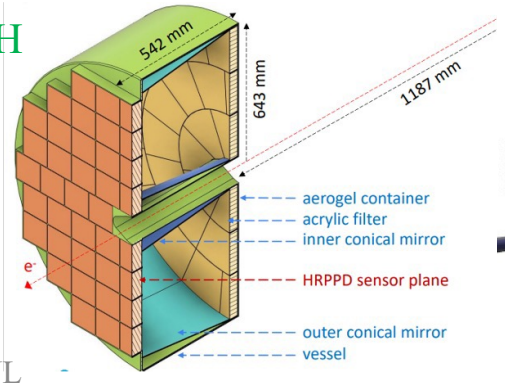
dRICH



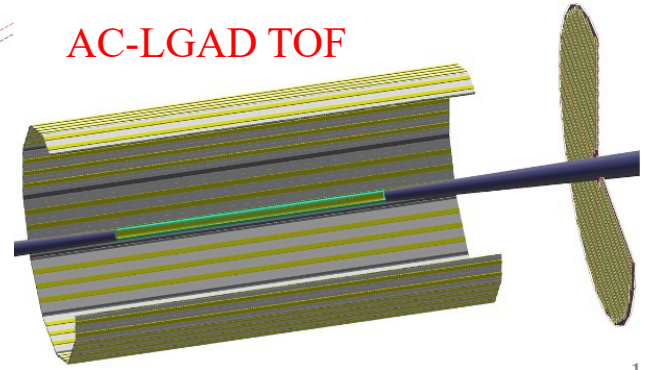
hpDIRC



pfRICH



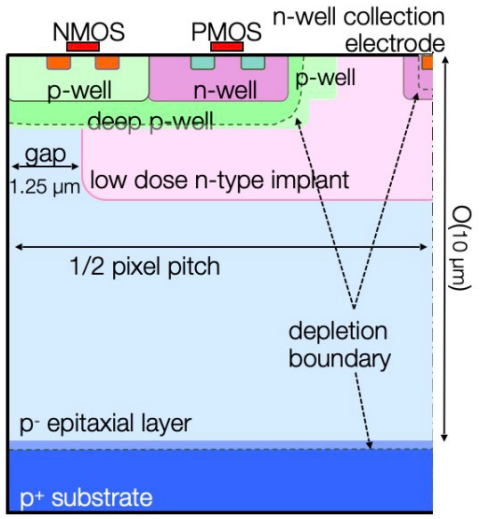
AC-LGAD TOF



ePIC Silicon Vertex Tracker – Inner Barrel Layers

ALICE ITS3

- Thinned, curved, self-supporting wafer-scale MAPS sensors based on 65nm CMOS Imaging Technology
- X/X_0~0.05% (air cooling, minimal support and no services in active area)
- Pixel pitch O(20×22.5) μm²
- Power consumption 40 mW/cm²
- Integration time 2 μs
- Radii of 19, 25.2, 31.5 mm
- Length of 27 cm

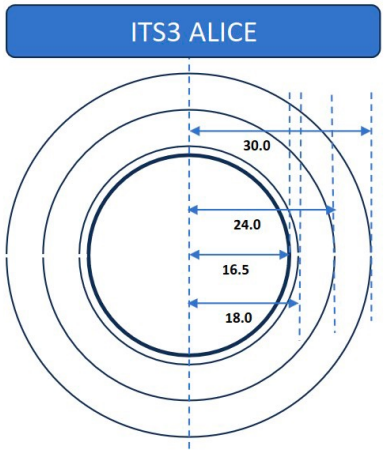


ePIC Silicon Vertex Tracker

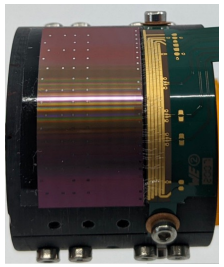
Inner barrels (L0-L2) inspired by ITS3

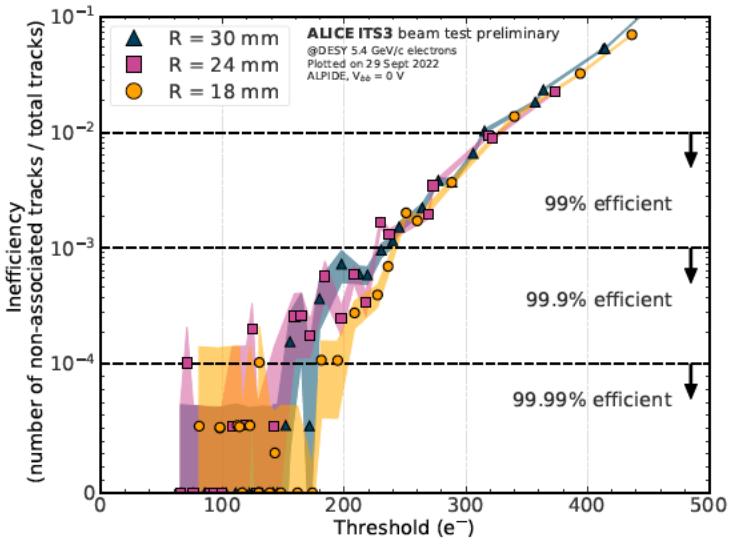
- Same sensor design and technology as ALICE ITS3 with X/X_0 ~0.05%
- Radii of 36, 48, and 120 mm
- Length of 27 cm

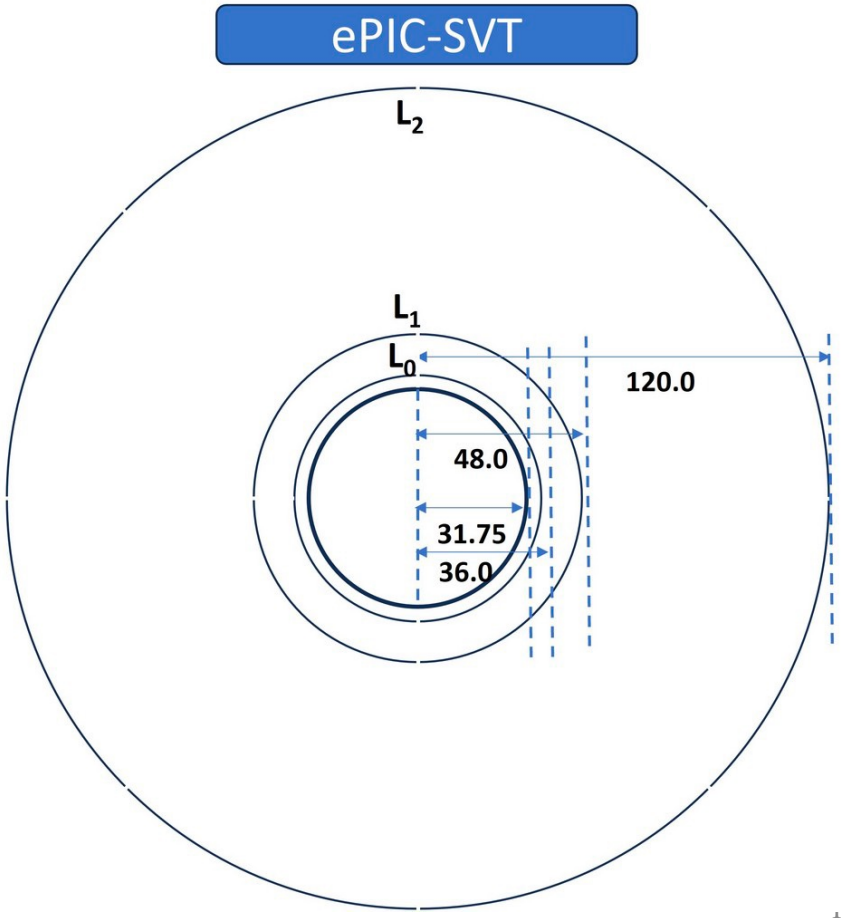
CERN-LHCC-2024-003 ; ALICE-TDR-021



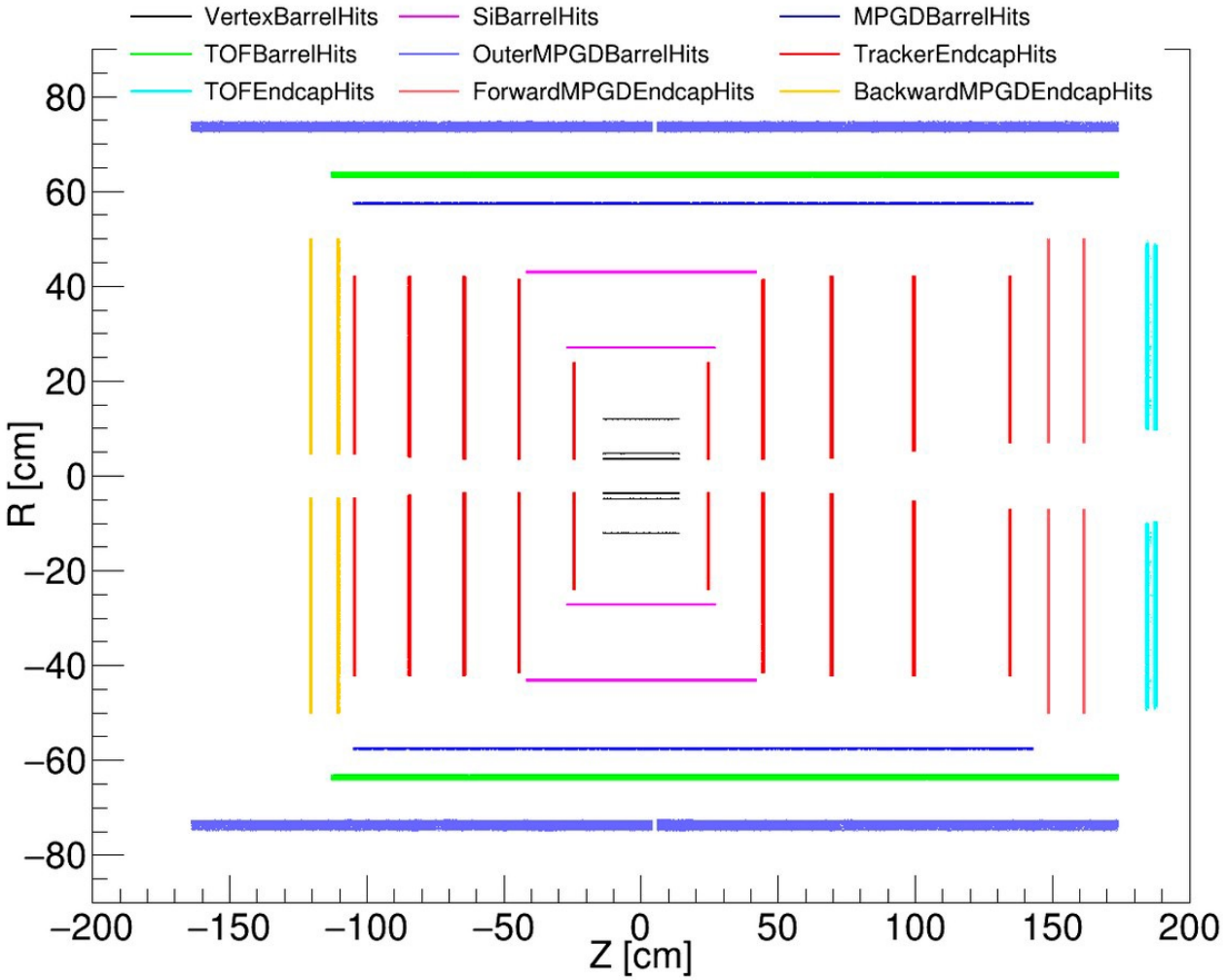
ALPIDE bent to 18mm radius







ePIC Silicon Vertex Tracker – Outer Barrel and Disks



More details in Nicole Apadula's talk tomorrow

ePIC Silicon Vertex Tracker: ~20B pixels

Inner barrels (L0, L1, L2):

- Same sensor design as ALICE ITS3 with X/X_0 ~0.05%
- Radii of 36, 41, and 120 mm
- Length of 27 cm

Outer barrels (L3, L4):

- Flat EIC large area sensors (EIC-LAS) with design modified based on ITS3 to have 5-6 repeated sensor units, mounted on more conventional staved structure with carbon fiber support and integrated liquid or air cooling
- Radii of 27 and 42 cm
- Lengths of 42 and 84 cm
- X/X_0 ~0.25% and 0.55%

Disks (5 forward, 5 backward):

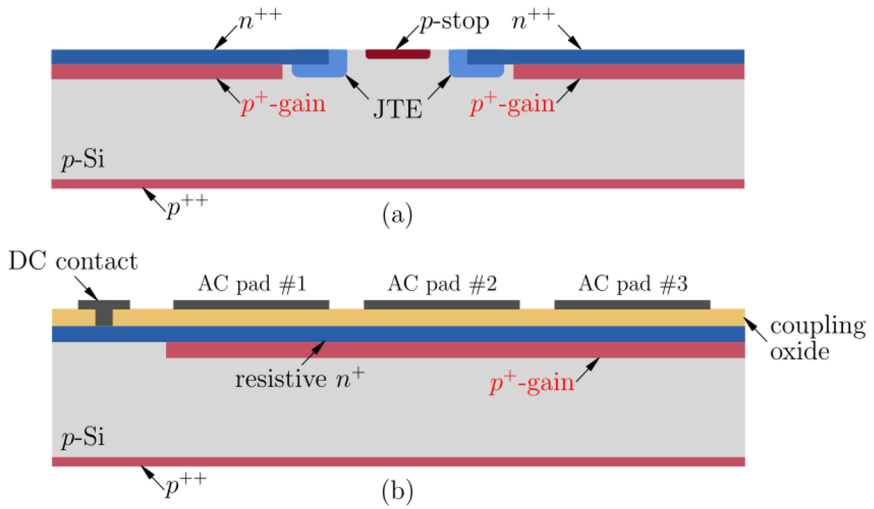
- EIC-LAS sensors mounted on more conventional structure with integrated air cooling
- Outer radii of 25 and 40 cm
- X/X_0 ~0.25%

AC-coupled Low Gain Avalanche Diode

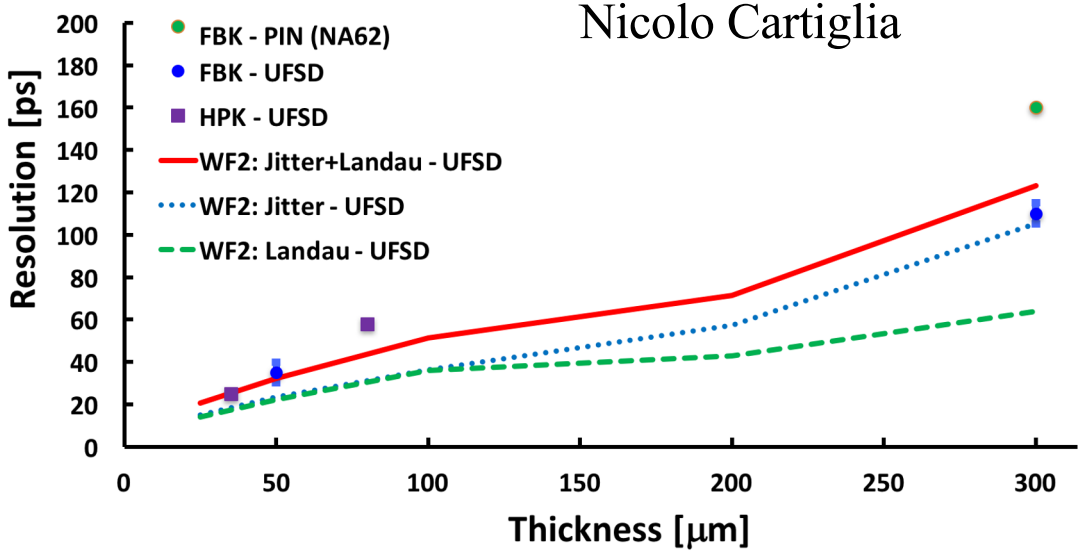
AC-LGAD provides both precise timing and spatial resolutions, with ~100% fill factor. Good candidate for **4D trackers** at future high energy experiments, e.g. EIC, HL-LHC, FCC.

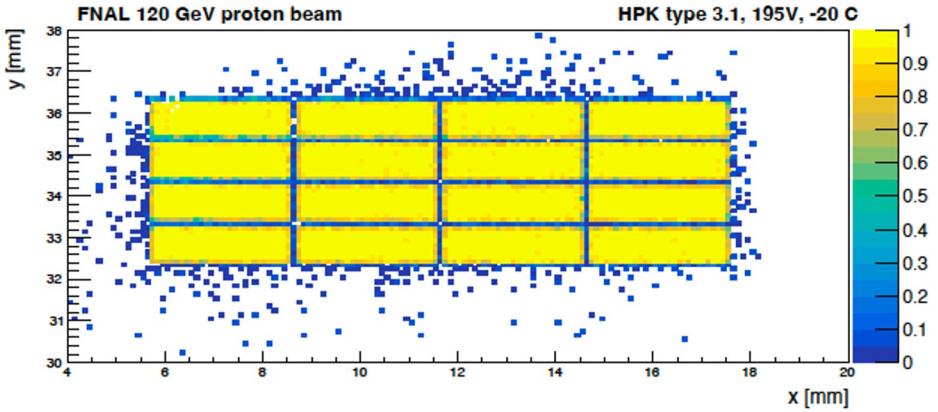
(DC-)LGAD

AC-LGAD

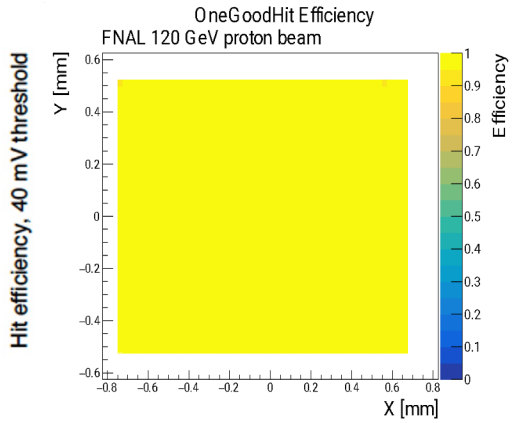


Nicolo Cartiglia

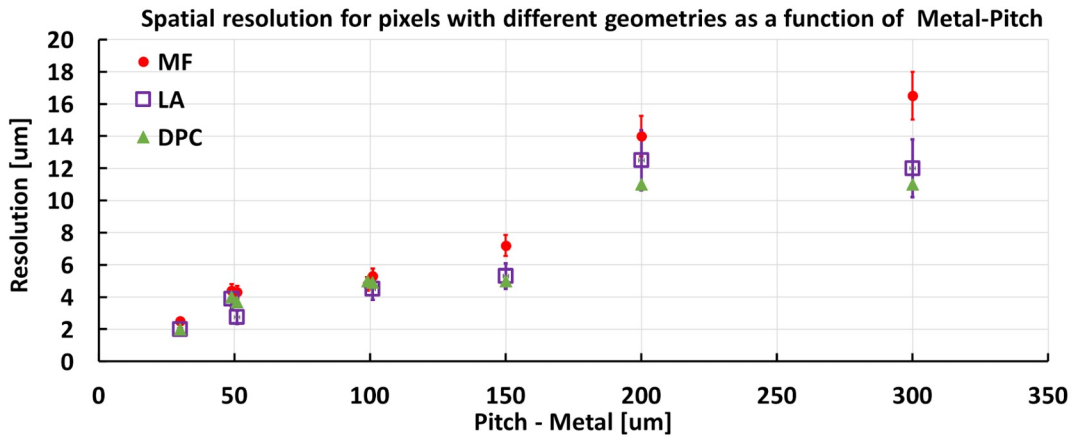




DC-LGAD

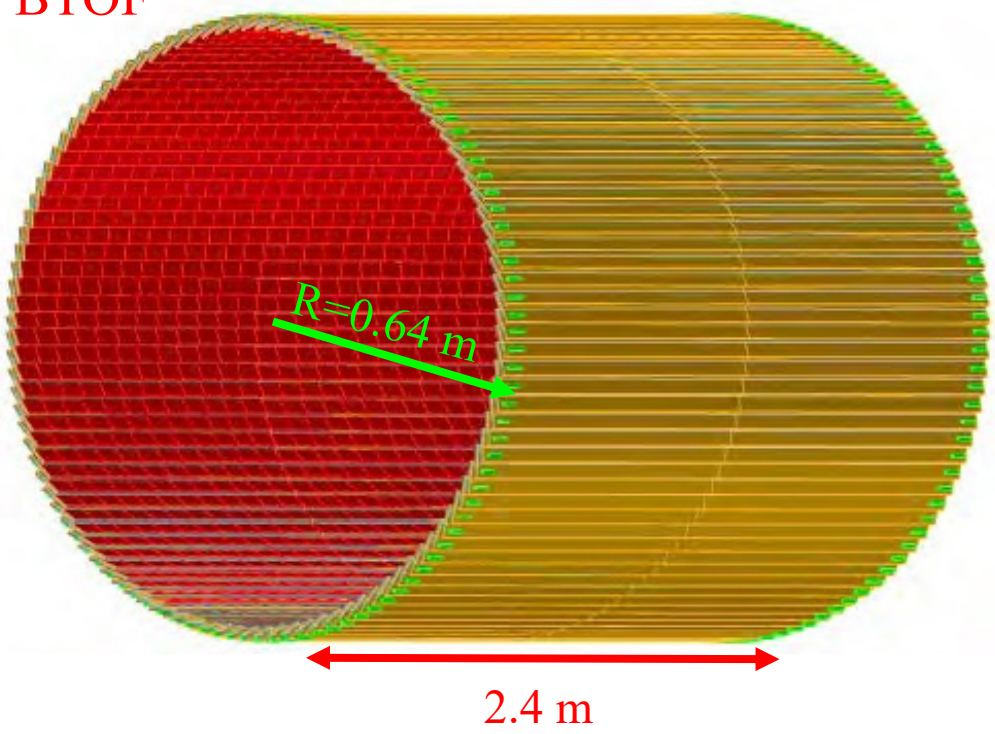


AC-LGAD

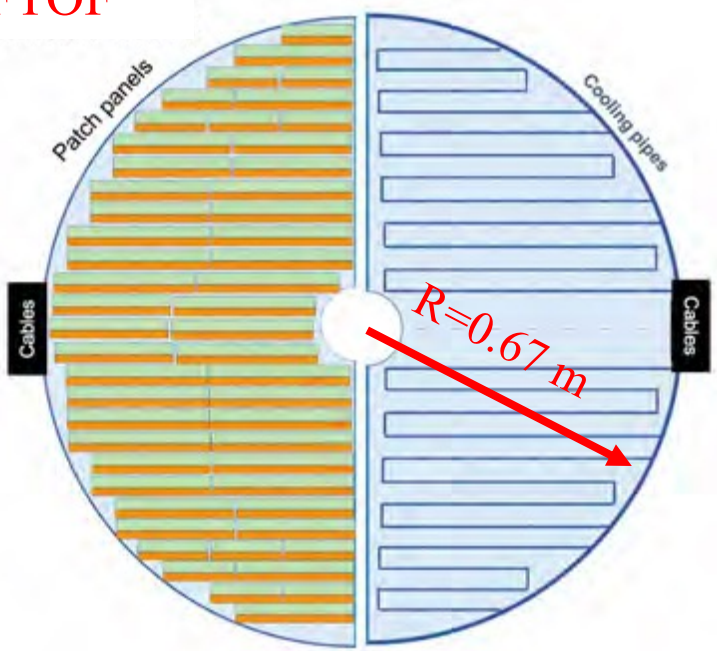


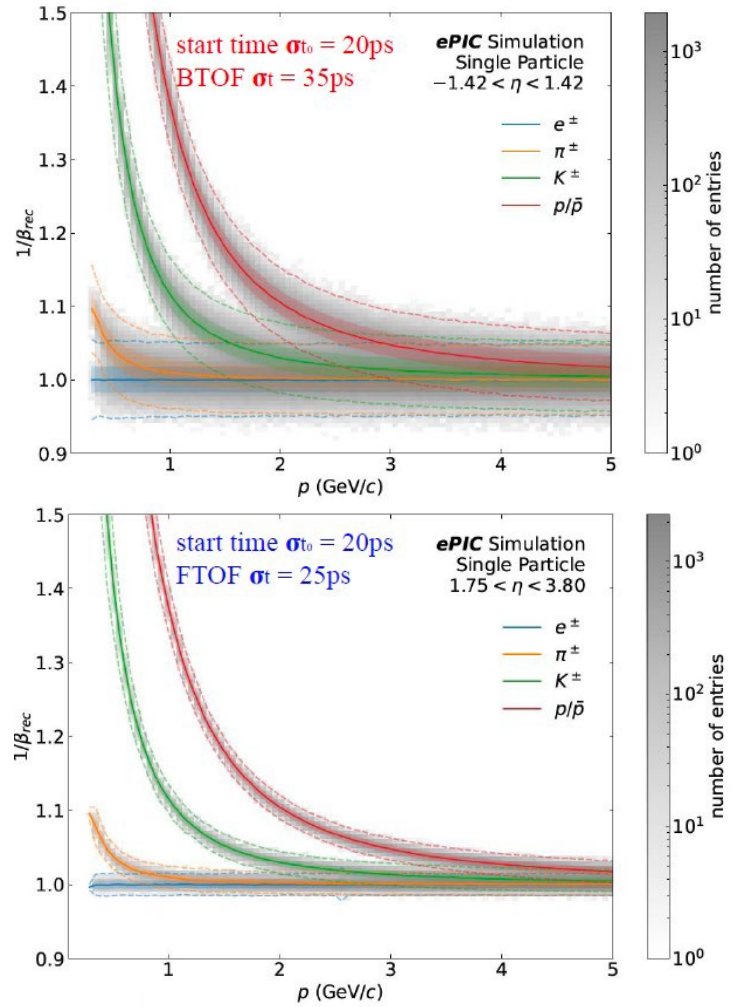
AC-LGAD Detectors for ePIC

BTOF



FTOF





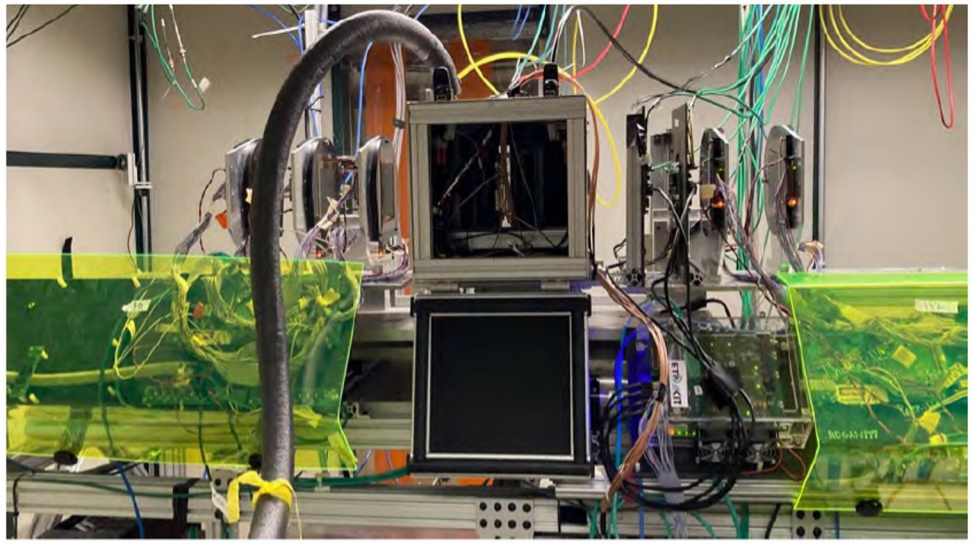
	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	10	0.5*10	2.4M	35 ps	30 μm in $r \cdot \varphi$	0.01 X_0
Forward TOF	1.4	0.5*0.5	5.6M	25 ps	30 μm in x and y	0.05 X_0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.05 X_0
RPs/OMD	0.14/0.08	0.5*0.5	0.56M/0.32M	30 ps	140 μm in x and y	no strict req.

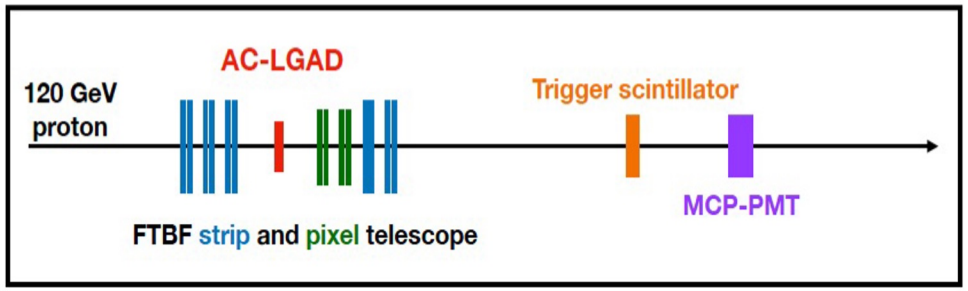
Sensor Prototyping for ePIC AC-LGAD (BNL, HPK)

- Sensors with different configurations produced by BNL-IO and HPK, and tested with 120GeV protons
- Prototype strip sensors with ~35 ps time resolution and <15 um spatial resolution (more in the next talk).
- Prototype pixel sensors with ~20 ps time resolution and ~20* um spatial resolution.

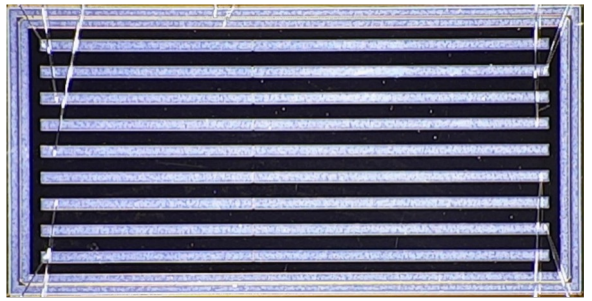
* ~50 um under metal electrodes. To be improved

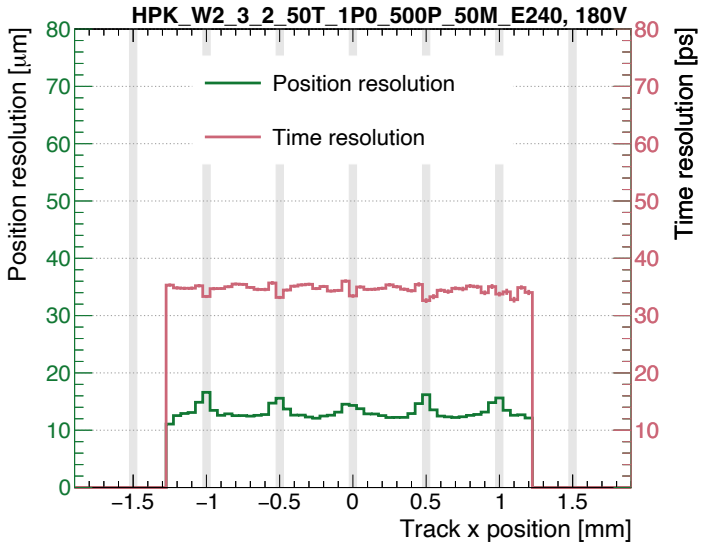
Fermilab Test Beam Setup



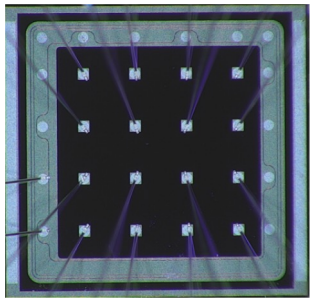


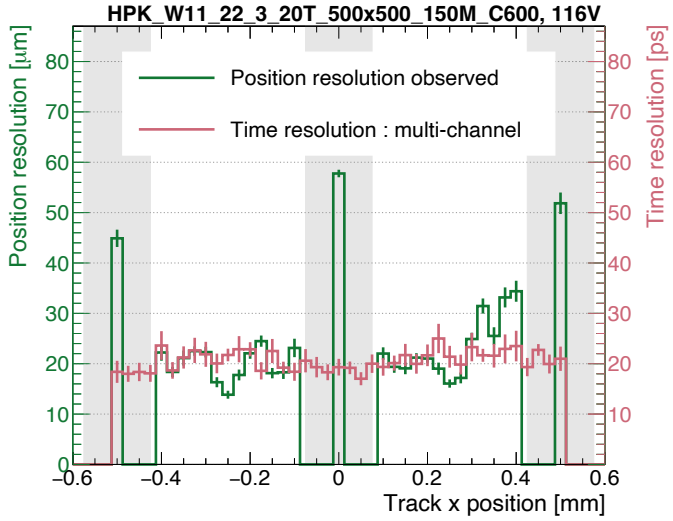
HPK Strip Sensor (4.5x10 mm²)



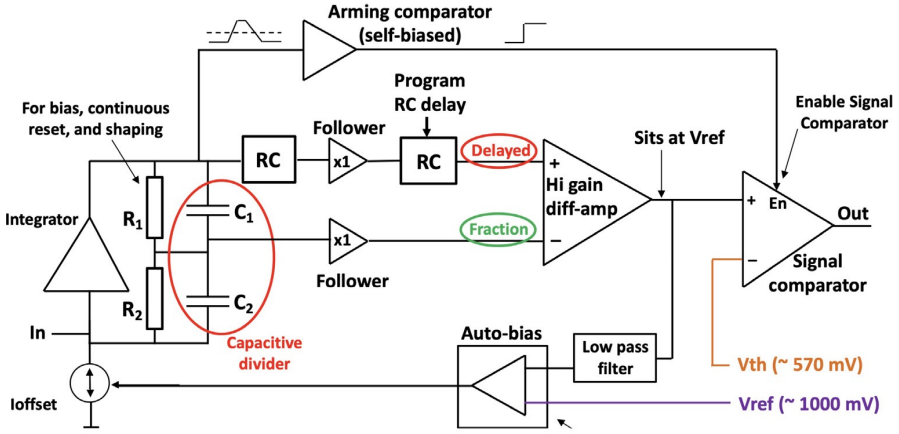


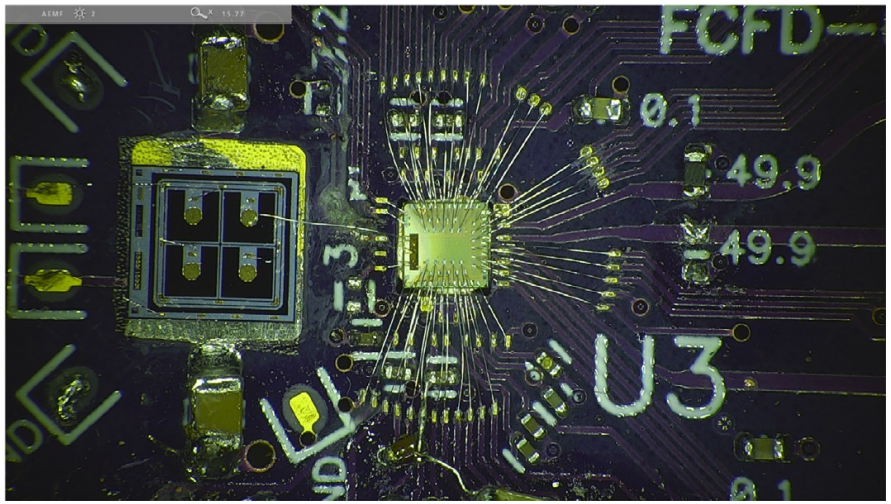
HPK Pixel Sensor (2x2 mm²)

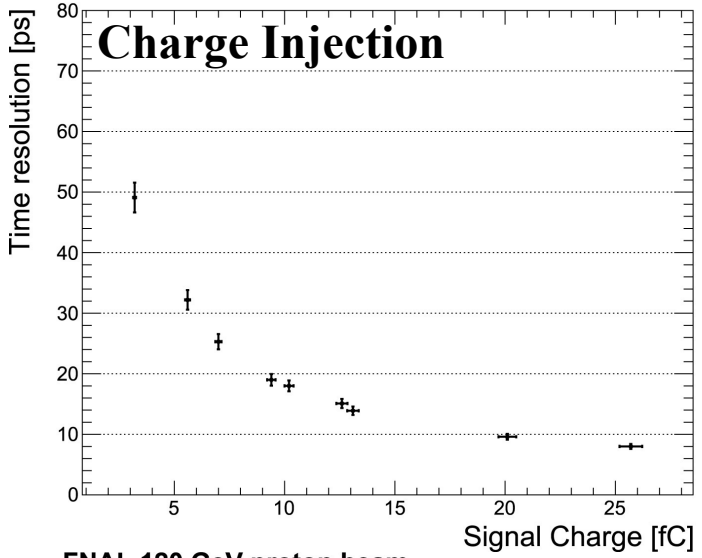


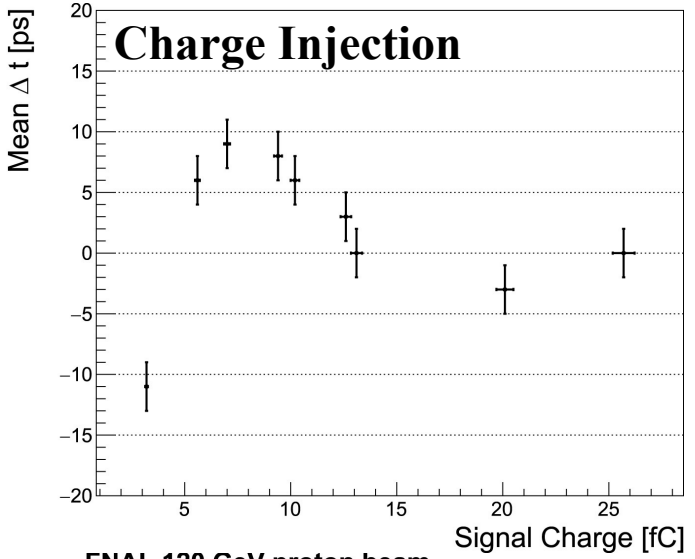


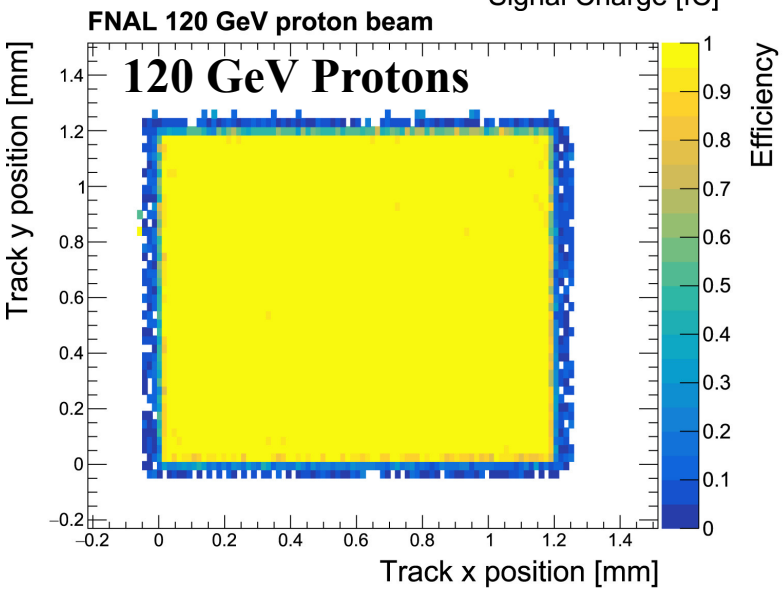
ASIC Prototyping for ePIC AC-LGAD (EICROC, FCFD)

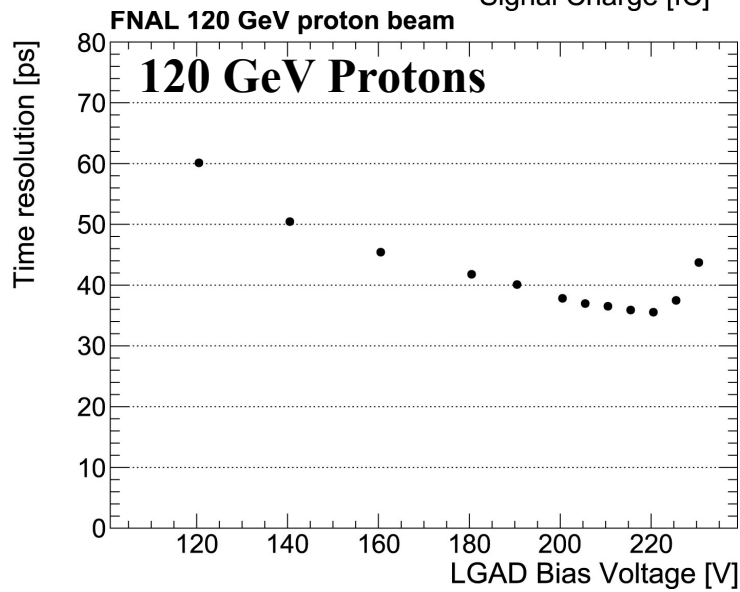








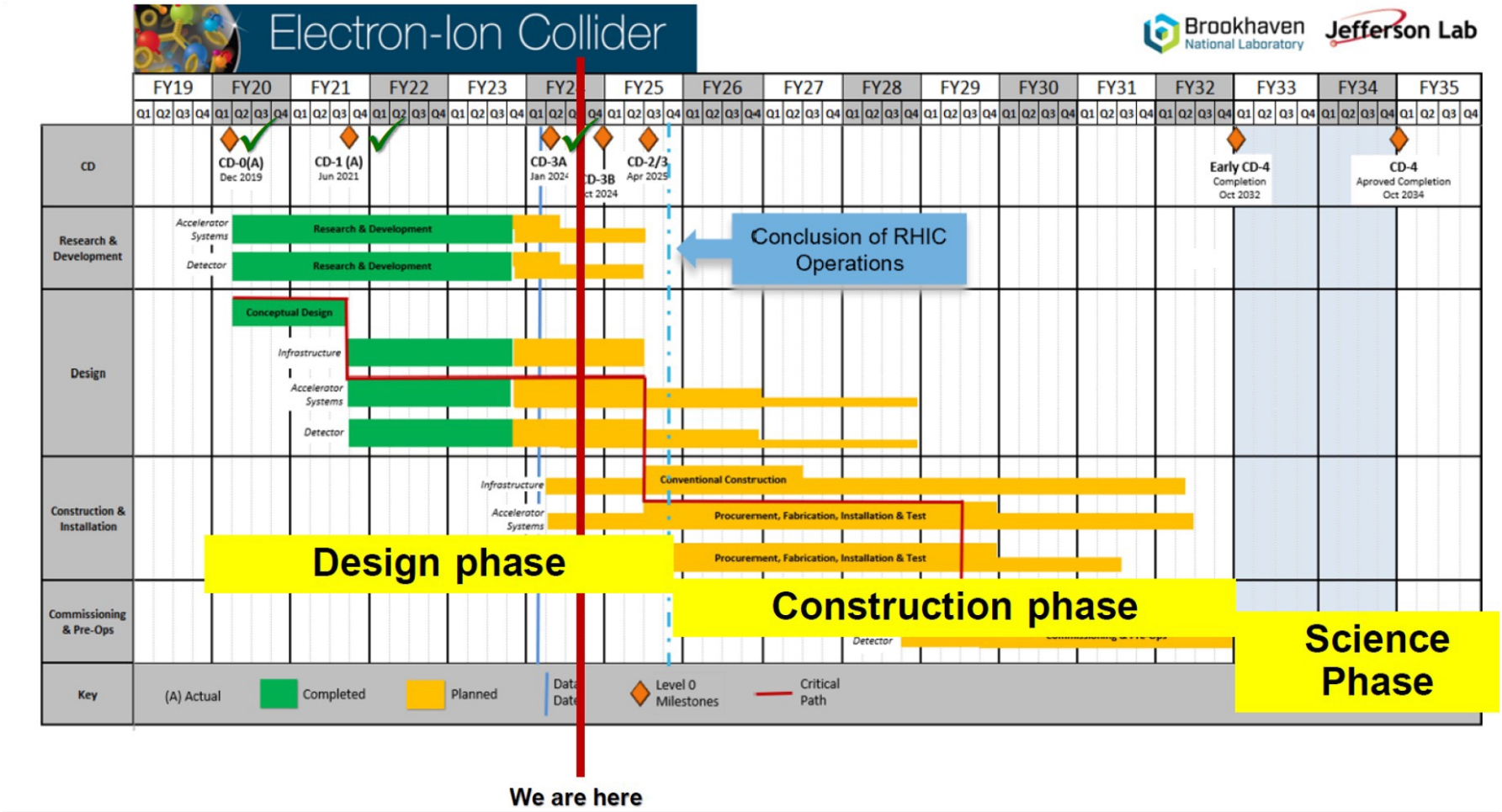




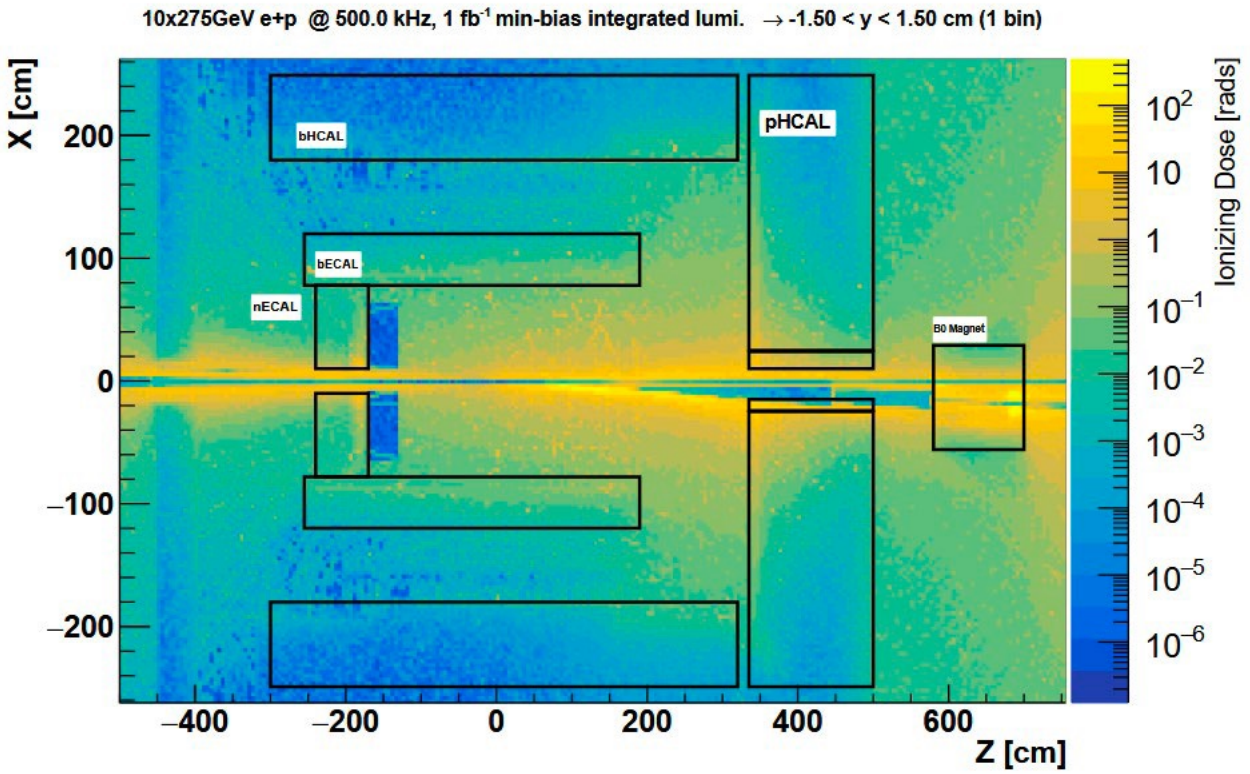
- Charge injection: TOA varies less than +/-10 ps for 3-26 fC. Jitter smaller than 20 (10) ps for charge > 10 (20) fC.
- Timing resolution with 120 GeV protons is around 35 ps, close to the limit of the LGAD sensor.

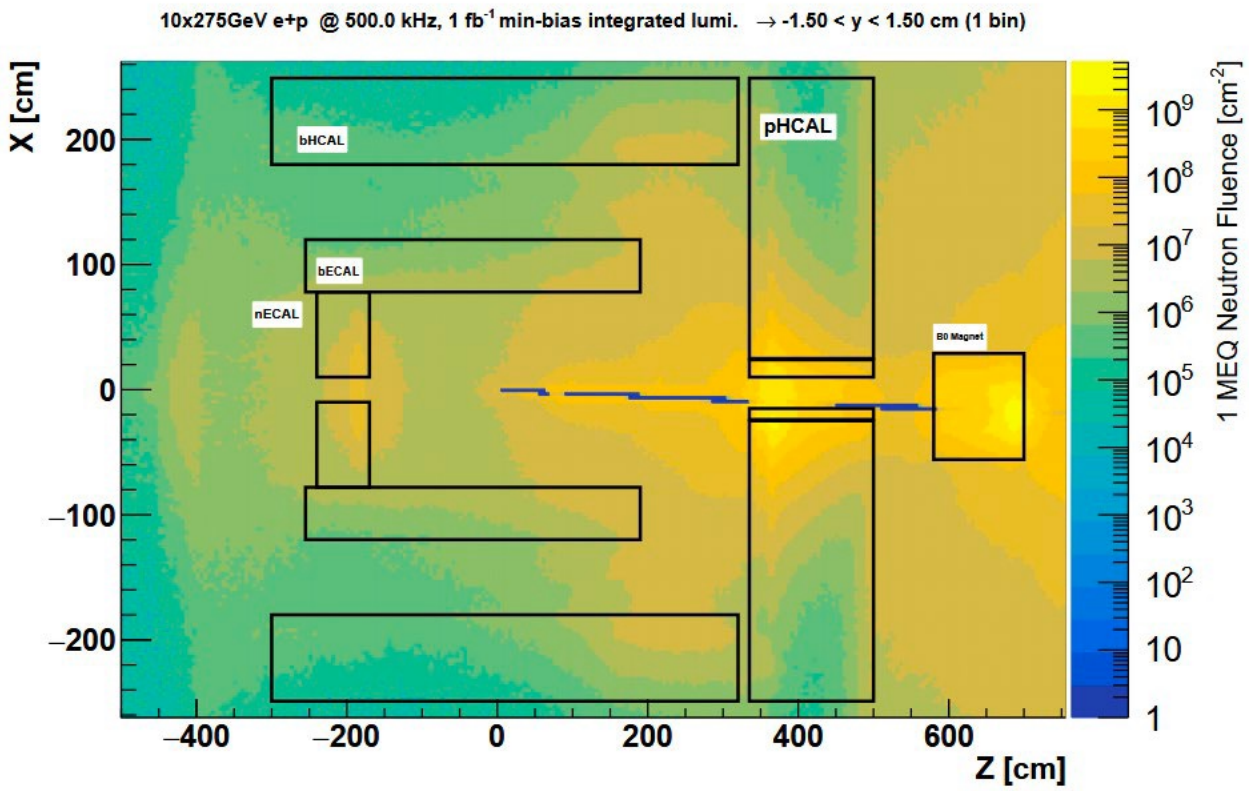
Summary

- Exciting perspectives in **detector designing, building, operating** for **Electron-Ion Collider**, which will start operations 10 years before FCC-ee, providing detector R&D opportunities for FCC-ee: **AC-LGAD, MAPS, HRPPD, streaming readout …**



ePIC Radiation Environments





Doses and fluxes ~10^{-3} compared to HL-LHC

Electron-Proton and -Ion Collider detector (ePIC)

Tracking and Vertexing:
- MAPS Silicon Vertex Tracker
- MPGD (μRWELL/mMegas)

Particle Identification:
- AC-LGAD TOF (also for tracking)
- hpDIRC
- pfRICH
- dRICH

Far-Forward/Backward:
- AC-LGAD Roman Pots
- AC-LGAD B0 Tracker/OMD
- Zero Degree Calorimeter
- Luminosity monitor
- Low-Q^2 tagger

EM Calorimeters:
- $PbWO_4$ EEMCal
- Pb/SciFi Barrel EMCal with Imaging
- W/SciFi FEMC

Hadronic Calorimeters:
- Fe/Sc Backward HCAL
- Barrel HCal (sPHENIX re-use)
- Fe/Sc&W/Sc LFHCAL