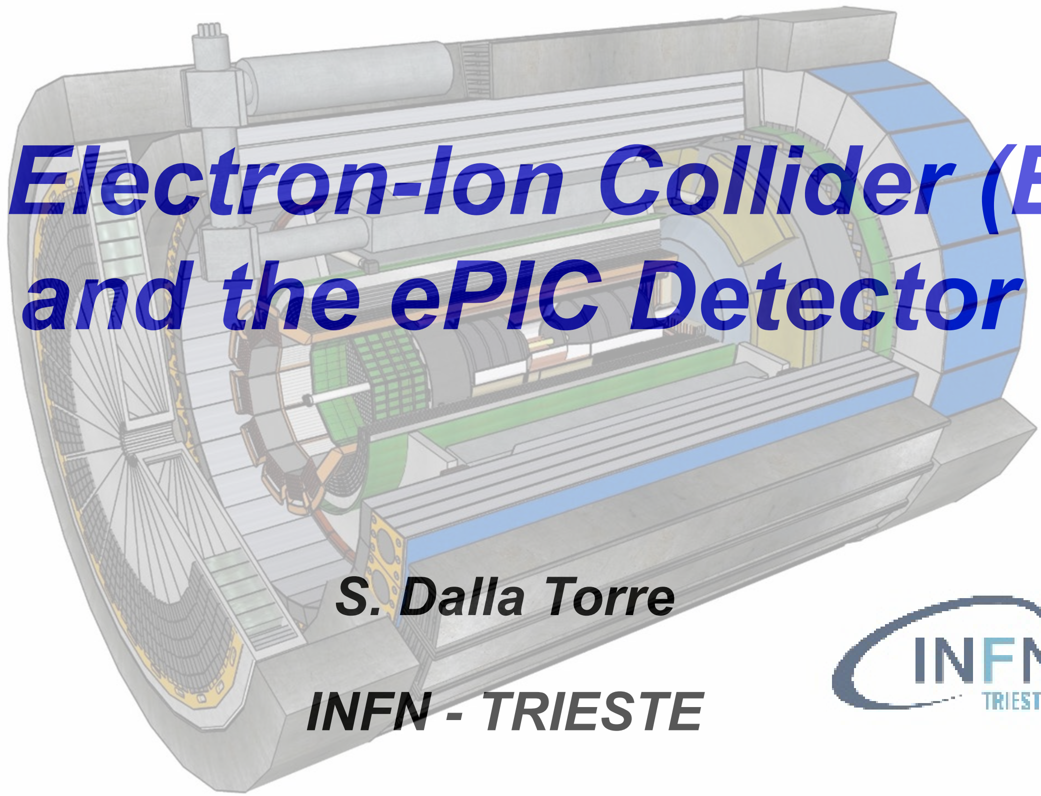


# The Electron-Ion Collider (EIC) and the ePIC Detector

*S. Dalla Torre*

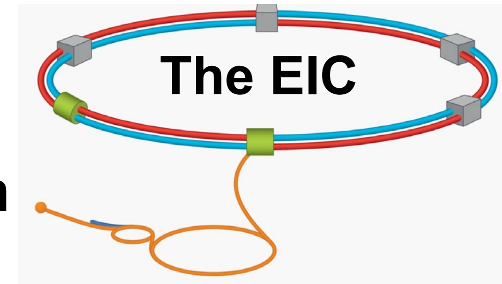
*INFN - TRIESTE*

# OUTLOOK

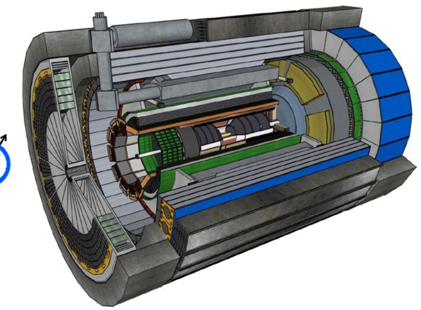
- **The EIC project and its physics scope**
- **The ePIC detector**

# The EIC Project in a nutshell

- **Enable the ultimate QCD exploration**
  - **By a high-luminosity polarized electron-ion collider: the EIC**




  - **By a detector highly integrated with the collider and capable to cope with the overall EIC physics scope, ePIC**



- **Status : approved project progressing towards its realization at BNL**
- **Key ingredients : the ample community supporting the EIC and the long dedicated effort path**

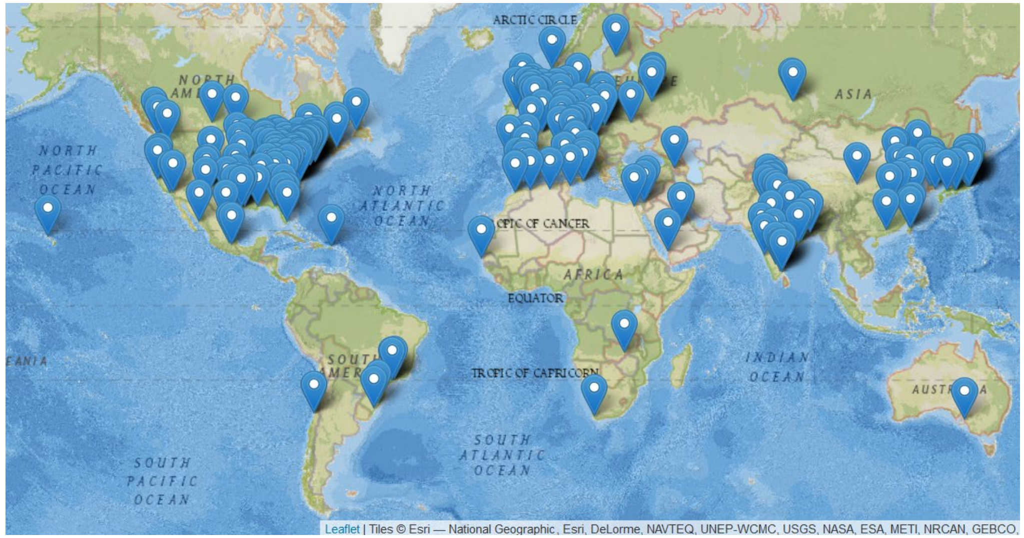
# THE INTERNATIONAL COMMUNITY: the EIC-User Group

**The EIC User Group:**
**https://eicug.github.io/**

**Formed in 2016 –**

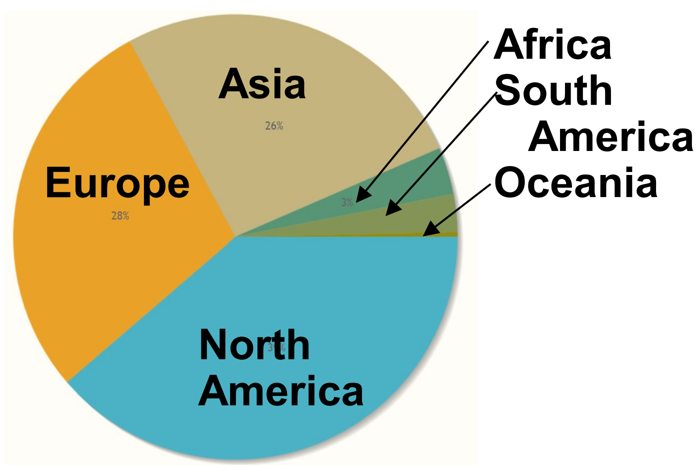
- **1548 members**
- **40 countries**
- **6 world regions**
- **298 institutions**

***As of October 10, 2024***




**Among the main Achievements: The Yellow Report (2020)**

## Institutions




**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 Lehigh U., PA


Nucl. Phys. A 1026 (2022) 122447

# The ePIC Collaboration

**The community dedicated to the EIC science mission by the realization of the ePIC detector**

Warsaw, July 2023

JLab, Jan. 2023

ANL, Jan. 2024

Lehigh, July 2024

# The ePIC Collaboration

**ePIC Institutions**
**179**

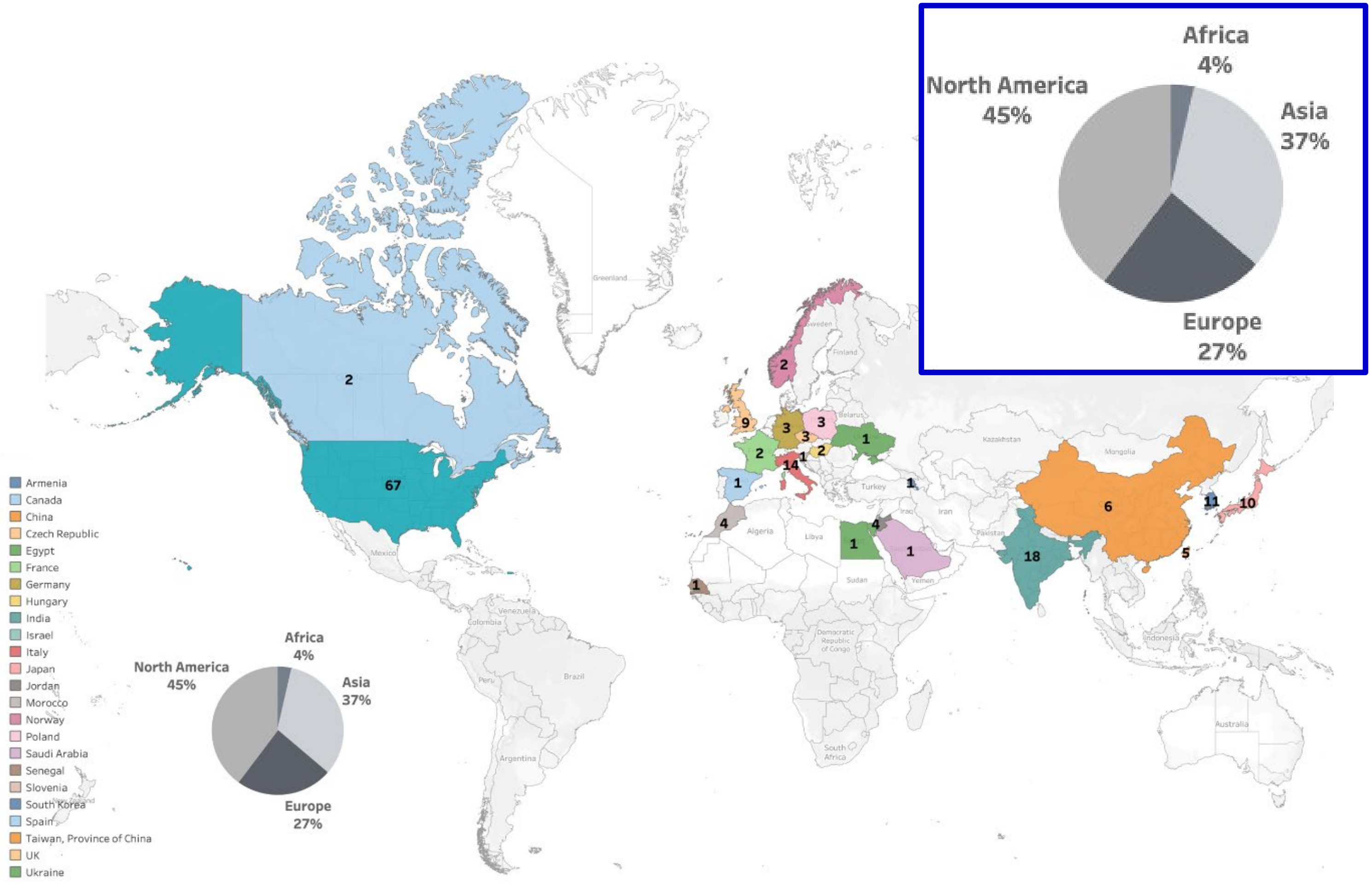
**ePIC countries**
**26**

**ePIC World Regions**
**4**

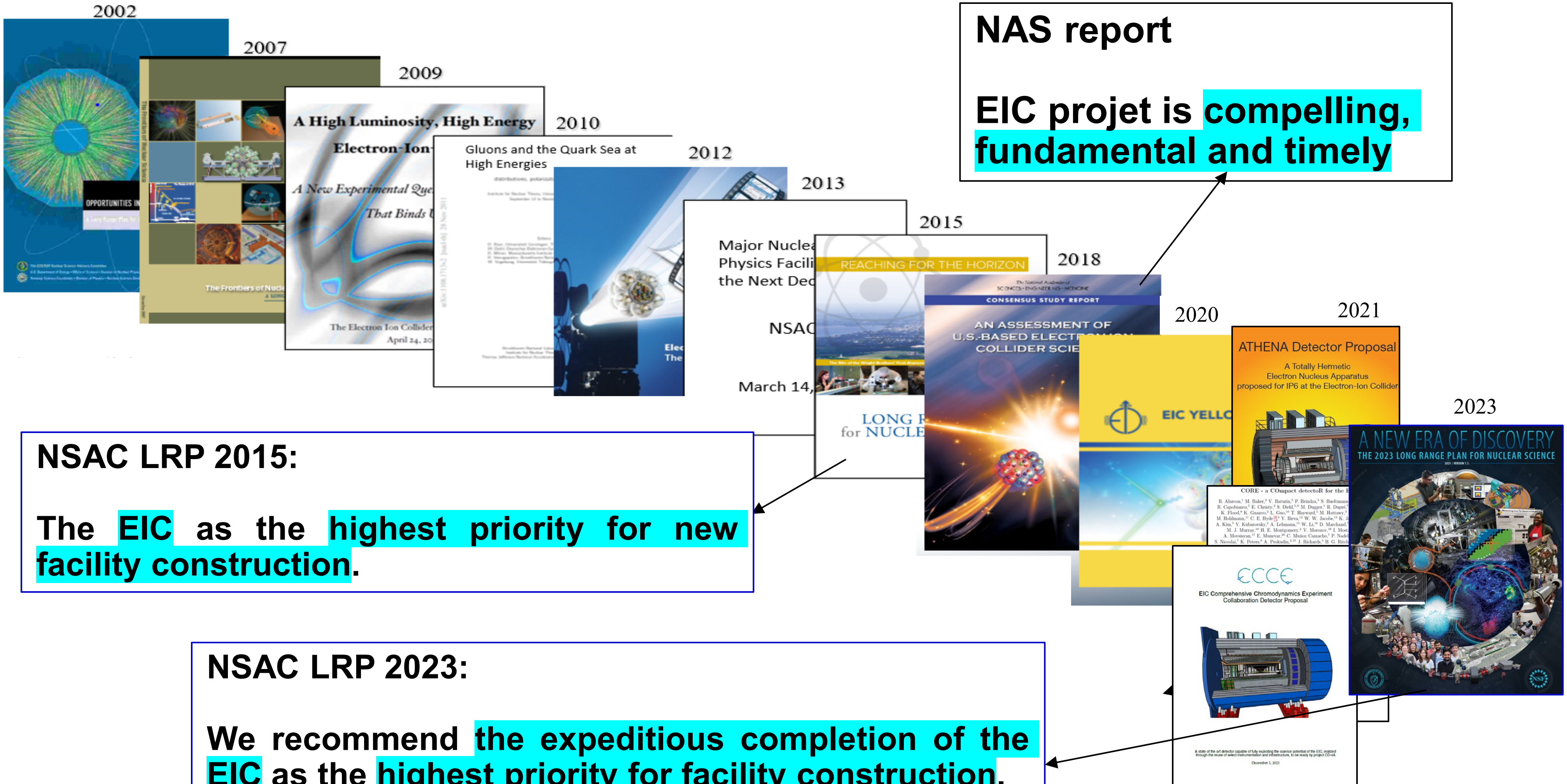
ePIC Initiated in July 2022

Currently:
>850 collaborators (from 2024 Institutional Survey)

>650 members active in ePIC activities



# THE PATH TO THE EIC PROJECT




**NAS report**

**EIC projet is compelling, fundamental and timely**

**NSAC LRP 2015:**

**The EIC as the highest priority for new facility construction.**

**NSAC LRP 2023:**

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

# EIC PHYSICS: ultimate QCD exploration

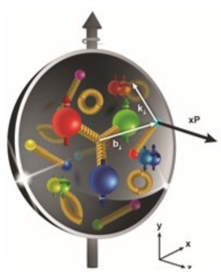
**In short words:**

***Investigate with precision the universal dynamics of gluons to understand the emergence of hadronic and nuclear matter and their properties***

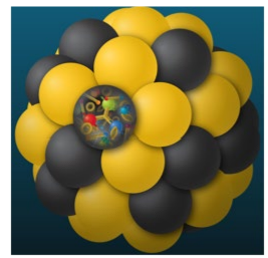
**In terms of major open questions:**

How does the **spin** of the nucleon arise?

How does the **mass** of the nucleon arise?



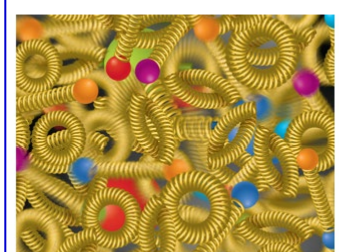
How are the **quarks and gluon distributed in space and momentum** inside the nucleon and nuclei?



How do quarks and gluons **interact with a nuclear medium**?

How do the **confined hadronic states** emerge?

How do the quark-gluon interactions create **nuclear binding**?



What are the emergent properties of **dense system of gluons**?

# Ultimate QCD exploration

## REQUIREMENTS

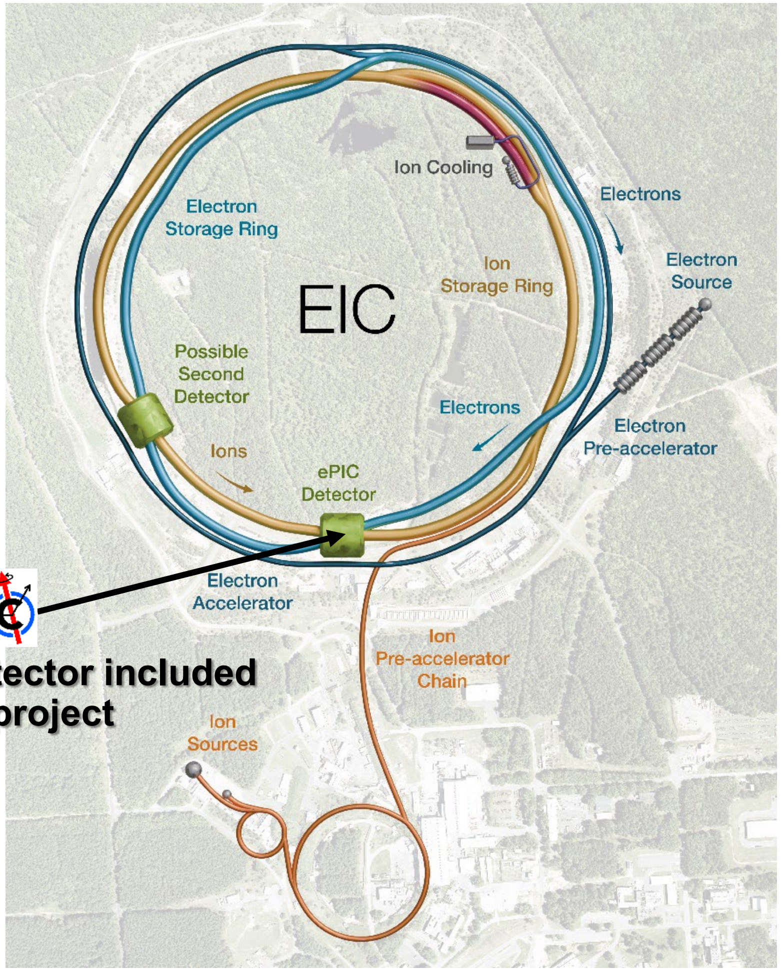
- Access to gluon dominated region and wide kinematic range in x and $Q^2$
- Access to spin structure and 3D spatial and momentum structure
- Accessing the highest gluon densities ($(Q_s^A)^2 \sim cQ_0^2 \left(\frac{A}{x}\right)^{1/3}$)
- Studying observables as a function of x, $Q^2$, A, hadronic flavour, …

## THE EIC COLLIDER PROVIDES

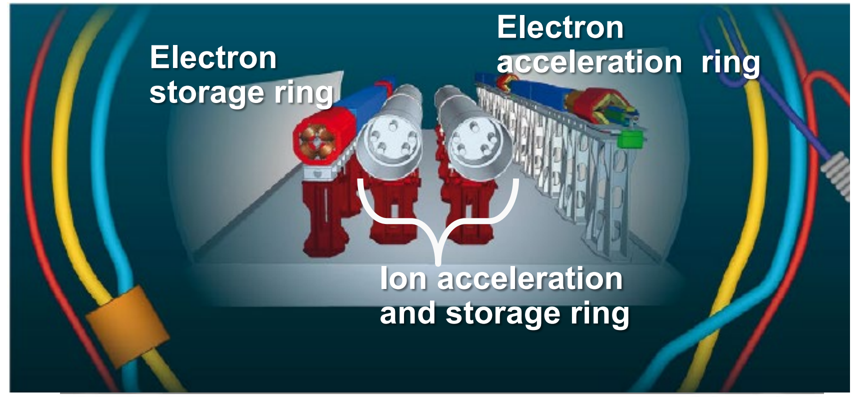
- *Large center-of-mass energy range:*
  $\sqrt{s}$ *= 21 -140 GeV*
- *Polarized electron, proton and light nuclear beams ≥ 70%*
- *Nuclear beams, the heavier the better (from H to U)*
- *High luminosity (100 x HERA):* $10^{33-34}$ $cm^{-2}$ $s^{-1}$

# The EIC Collider

## Usage of RHIC tunnel and RHIC p/ion complex




**IP6 detector included in the project**




- spanning a wide kinematical range
  - **ECM: 20 – 141 GeV**
- High luminosity
  - up to $10^{34}$ $cm^{-2}$ $s^{-1}$
- **highly polarized e (~ 70%) beams**
- **highly polarized light A (~70%) beams**
- wide variety of ions: **from H to U**
- **Number of interaction regions: up to 2**

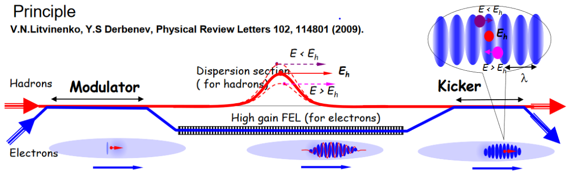
# The EIC Collider

## 4 critical ingredients for HIGH LUMINOSITY

### Coherent Cooling with FEL amplifier

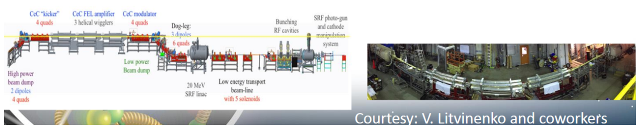
Principle

V.N.Litvinenko, Y.S Derbenev, Physical Review Letters 102, 114801 (2009).




➔ cooling of high energy Hadron beams with high band-width; BW: **1THz**
short cooling times to balance strong **IBS**

Proof of Principle Experiment at BNL, ongoing




## Strong Hadron Cooling

- Work continues on Strong Hadron Cooling, both the Coherent electron Cooling (CeC) approach and a backup solution based on a ring cooler
- Both approaches were reviewed in summer, no show stoppers found in either one

## Bunches and beam crossing rates

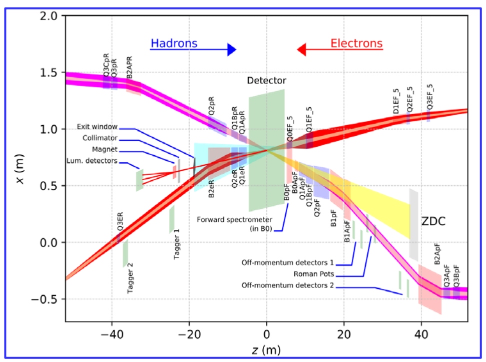
| Species | $p$ | $e$ | $p$ | $e$ | $p$ | $e$ | $p$ | $e$ | $p$ | $e$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Beam energy [GeV] | 275 | 18 | 275 | 10 | 100 | 10 | 100 | 5 | 41 | 5 |
| $\sqrt{s}$ [GeV] | 140.7 | | 104.9 | | 63.2 | | 44.7 | | 28.6 | |
| No. of bunches | 290 | | 1160 | | 1160 | | 1160 | | 1160 | |

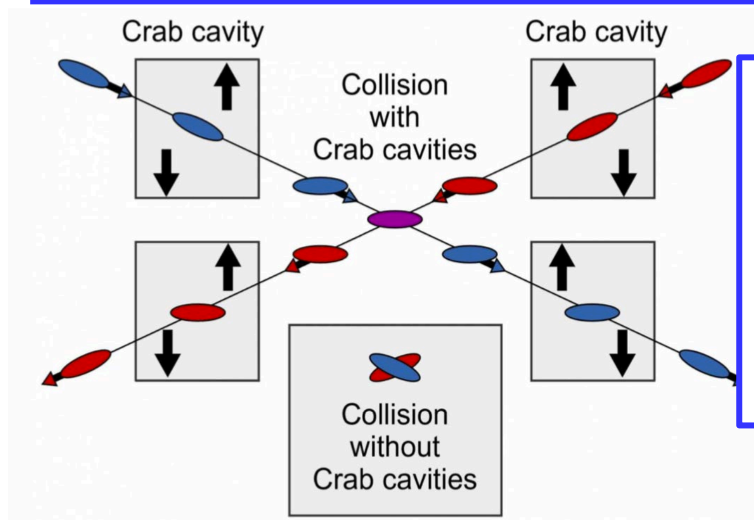
| Species | Au | $e$ | Au | $e$ | Au | $e$ | Au | $e$ |
|---|---|---|---|---|---|---|---|---|
| Beam energy [GeV] | 110 | 18 | 110 | 10 | 110 | 5 | 41 | 5 |
| $\sqrt{s}$ [GeV] | 89.0 | | 66.3 | | 46.9 | | 28.6 | |
| No. of bunches | 290 | | 1160 | | 1160 | | 1160 | |

**Up to a beam crossing rate at the IR every 10ns**

a challenge for the collider and the experiment !

**Small $\beta^*_y$ ➔ quads close to IP leaving ~10 m for the detector**




**CRAB CROSSING ANGLE (25 mrad)** to restore head-on collisions

# The EIC Collider

## MORE unique aspects

## ION SPECIES

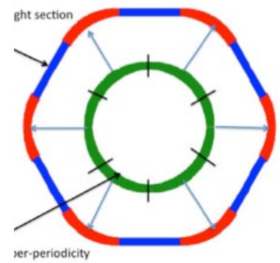
The existing RHIC <u>ion sources & ion acceleration chain</u> provides already **today** all ions needed at EIC

| Ion Pairs in the RHIC Complex | |
|---|---|
| Zr-Zr, Ru-Ru | (2018) |
| Au-Au | (2016) |
| d-Au | (2016) |
| p-Al | (2015) |
| h-Au | (2015) |
| p-Au | (2015) |
| Cu-Au | (2012) |
| U-U | (2012) |
| Cu-Cu | (2012) |
| D-Au | (2008) |
| Cu-Cu | (2005) |

Enormous versatility! is a unique capability!

## BEAM POLARIZATION

### ABOUT e POLARIZATION




→ resonance free acceleration up >18 GeV

on average, every bunch refilled in 2.2 min

### ABOUT p/ light ion POLARIZATION

presently

**Measured RHIC Results:**
- Proton Source Polarization 83 %
- Polarization at extraction from AGS 70%
- Polarization at RHIC collision energy 60%

empowerment

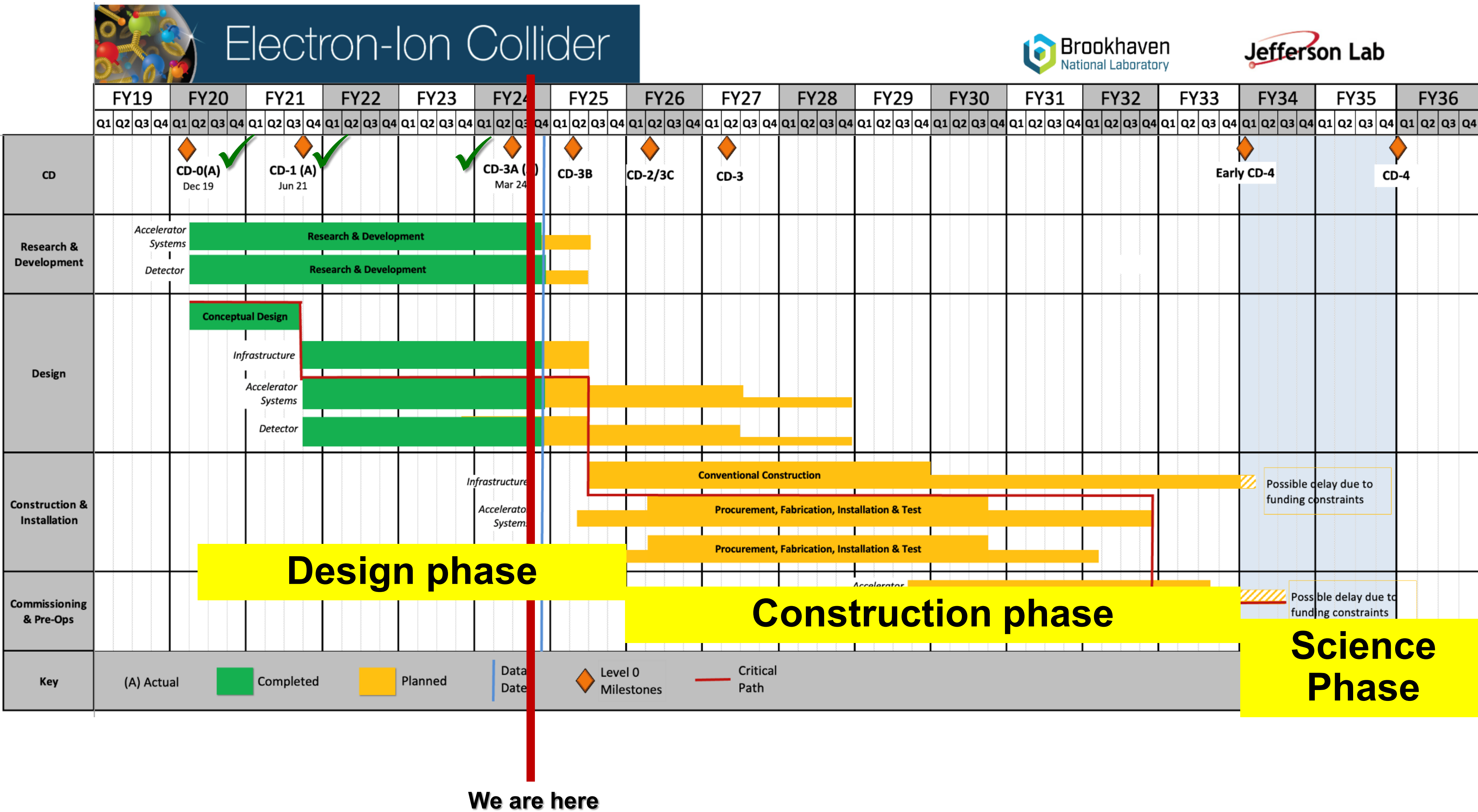
**Planned near term improvements:**

**AGS**: Stronger snake, skew quadrupoles, increased injection energy
→expect 80% at extraction of AGS

**RHIC:** Add 2 snakes to 4 existing no polarization loss
→ expect 80% in Polarization in RHIC and eRHIC

High polarization $^{3}He$ and D beams also possible

# The EIC schedule



# OUTLOOK

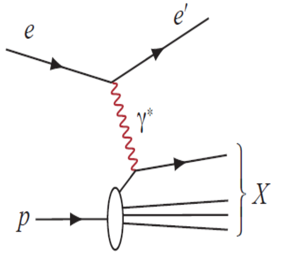
- **The ePIC context:**
  **the physics scope and the EIC project**

- **The ePIC detector**

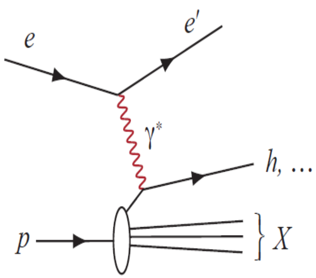
# Ultimate QCD exploration

## REQUIREMENTS → ePIC detector

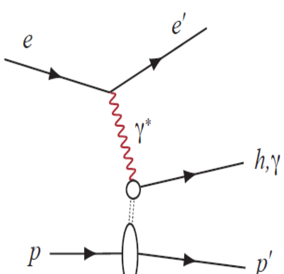
Measurement categories to address EIC physics:




- Inclusive DIS
  - fine multi-dimensional binning in x, $Q^2$




- Semi-inclusive DIS
  - 5-dimensional binning in x, $Q^2$, z, $p_T$, $\theta$




- Exclusive processes
  - 4-dimensional binning in x, $Q^2$, t, $\theta$ to reach |t| > 1 GeV2

**ePIC detector** (Inclusive DIS):

- ***Large coverage ($-3.5 < \eta < 3.5$) for wide phase-space reach***
- ***Excellent EM-calorimetry with PID support for e/$\pi$ separation***
- ***Fine resolution tracking by low mass detectors***

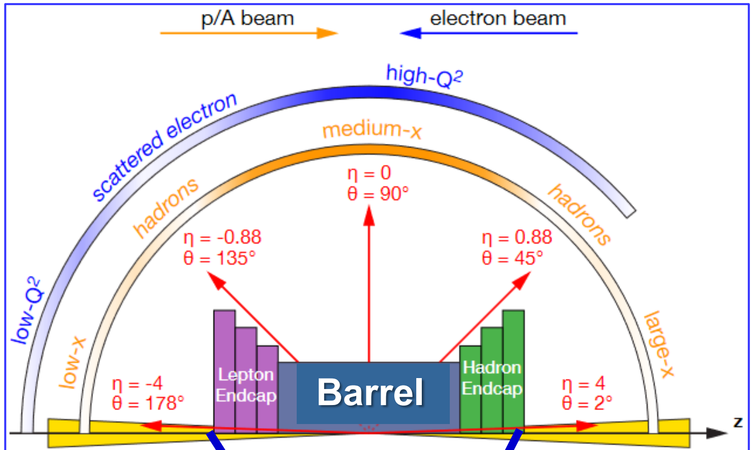
**ePIC detector** (Semi-inclusive DIS):

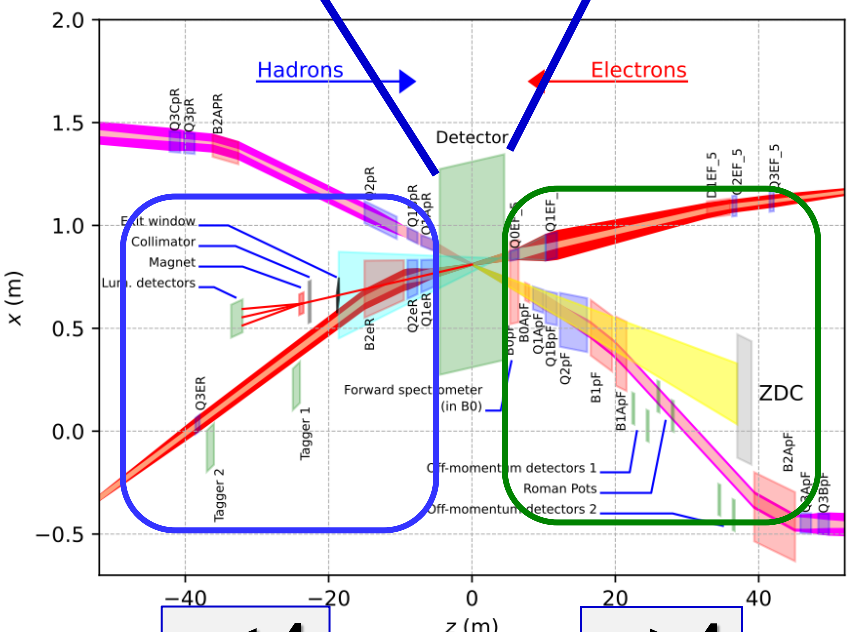
- ***Fine $p_T$ resolution***
- ***Extended PID systems for hadron identification***
- ***H-calorimetry to attempt TMD assessment with jets (new world-wide), as tail chatter, for $\mu$ identification***

**ePIC detector** (Exclusive processes):

- ***Extend acceptance at extremely small scattering angles***
- ***Fine vertex resolution by tracking***

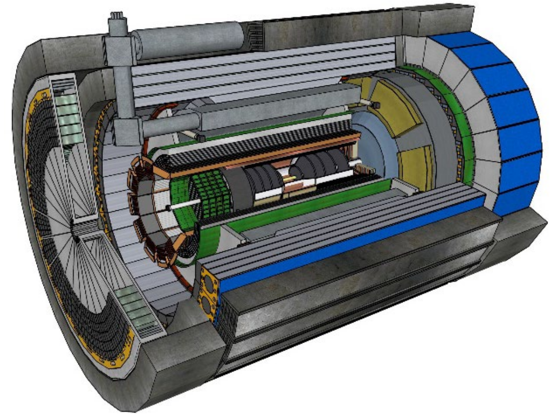
# THE COMPLETE ePIC DETECTOR




η <-4

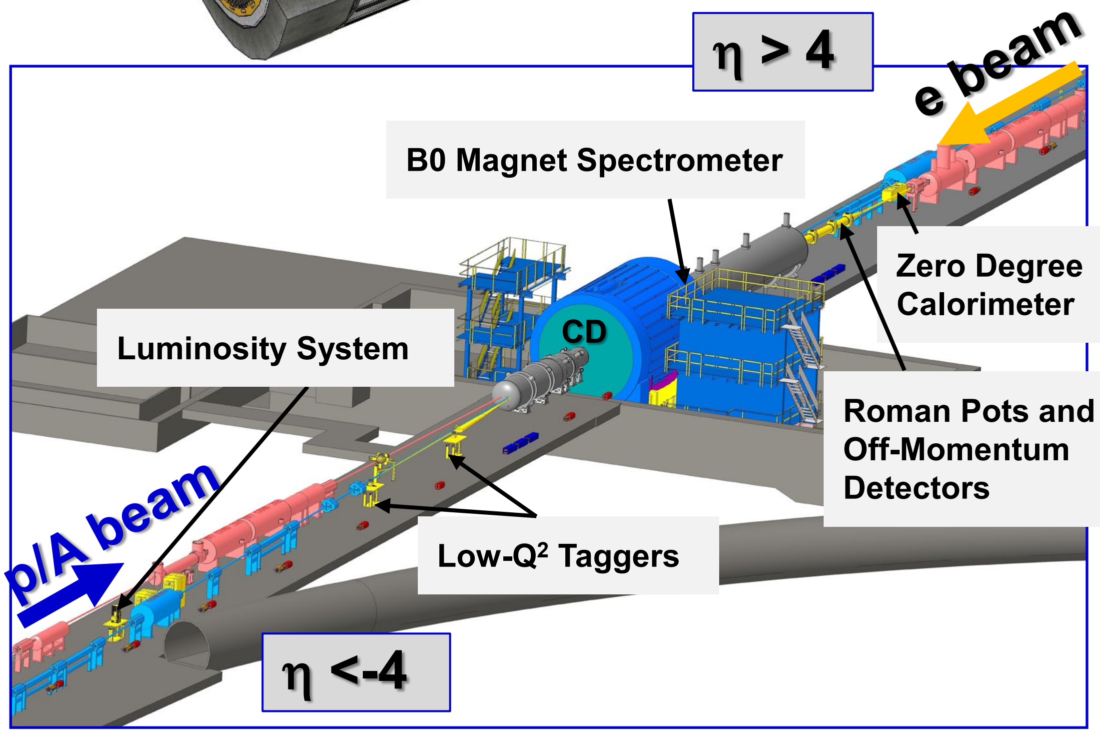
η > 4



**Central Detector (CD)**

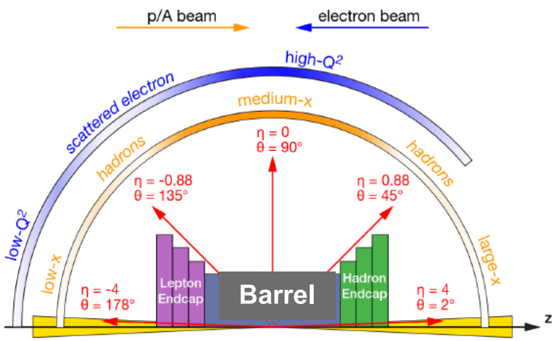
**-4 < η < +4**

η > 4




η <-4

# ePIC Central Detector (CD)




**Very naturally organized in:**

- **Backward endcap**
- **Barrel**
- **Forward endcap**

**subsystems**

hadronic calorimeters

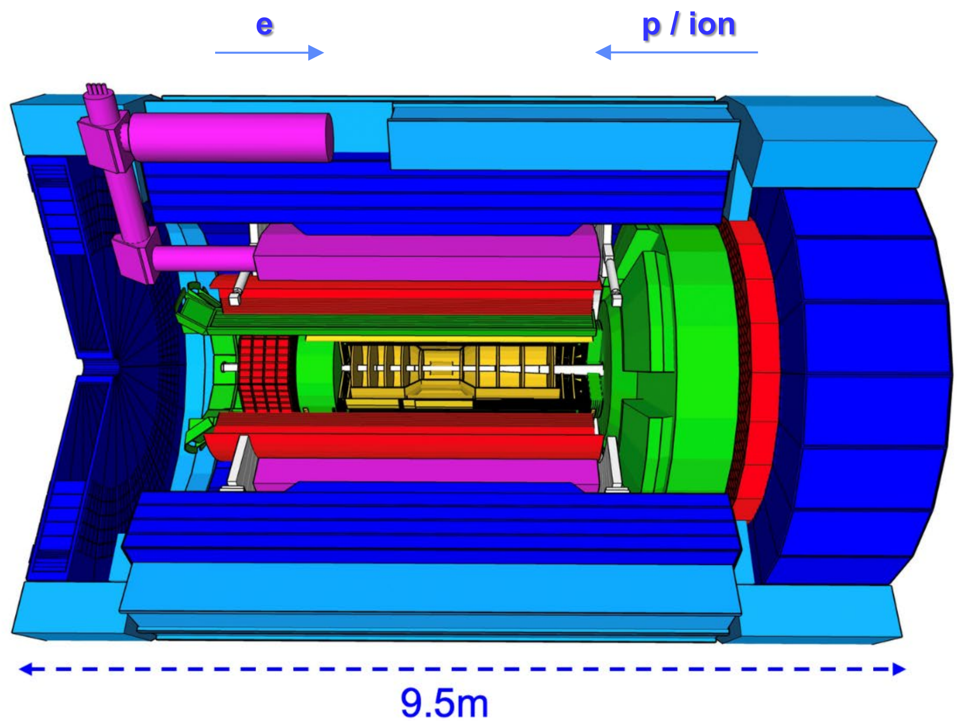
Solenoidal Magnet

e/m calorimeters (ECal)

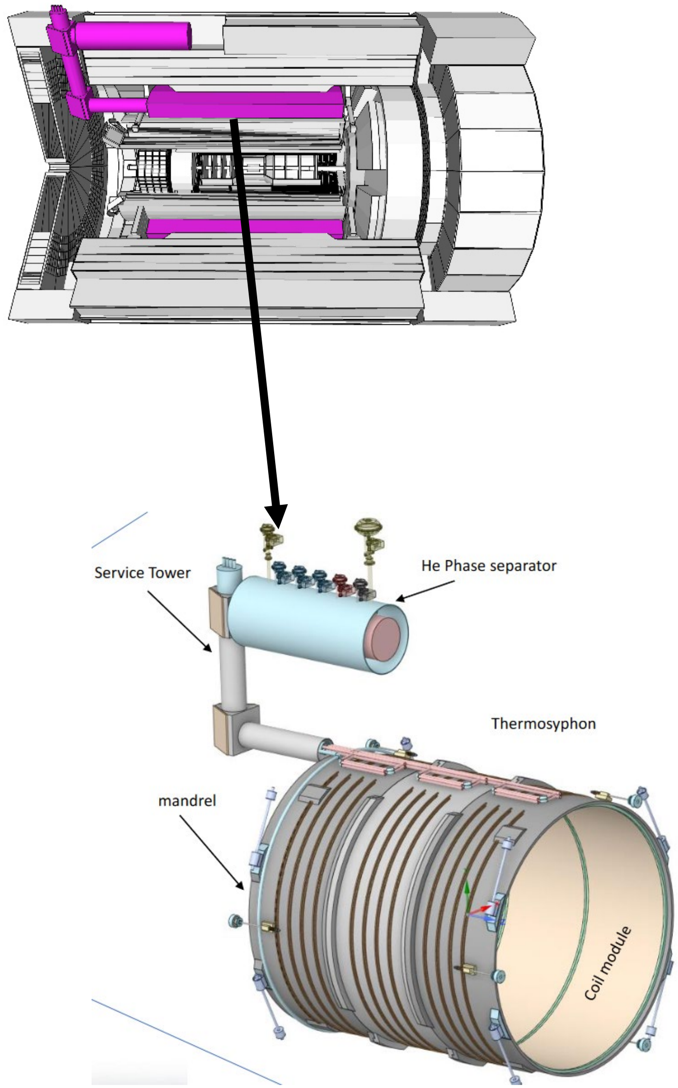
Time.of.Flight, DIRC, RICH detectors

MPGD trackers

MAPS tracker



# The ePIC solenoid

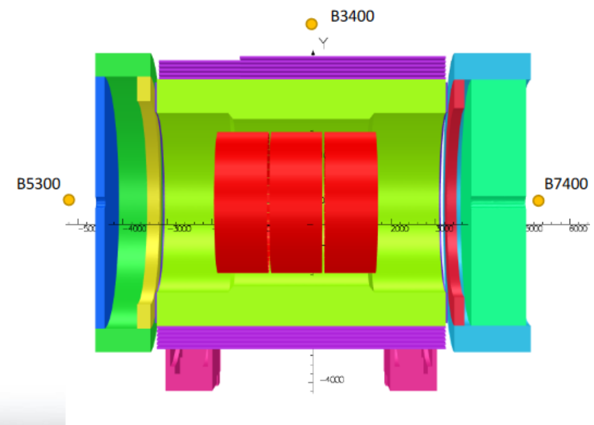



| Parameter | Value |
|---|---|
| Coil length | 3512 mm |
| Warm bore diameter | 2840 mm |
| Cryostat length | < 3850 mm |
| Cryostat outer diameter | < 3540 mm |

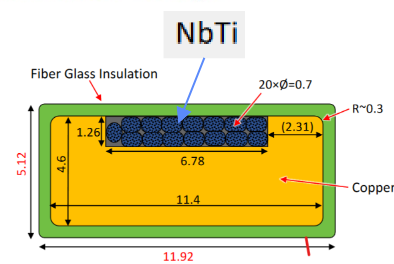
| Parameter | Value | Comment |
|---|---|---|
| B5300 (B @ Z= -5300 mm) | < 10 G | Stray field requirement is based on IR magnet location |
| B7400 (B @ Z= 7400 mm) | < 10 G | |
| B3400 (B @ R= 3400 mm) | < 10 G | |

| Parameter | Value | Comment |
|---|---|---|
| Central Field $B_0$ | 2.0 T | |
| Lowest operating field | 0.5 T | |
| Field Uniformity in FFA | 12.5 % ± 100 cm around center 80 cm radius | Magnetic Field Properties |
| Projectivity in RICH Area | < 0.1 (mrad@30GeV/c) < 10 T/A/mm² From Z = 180 cm to 280 cm | |

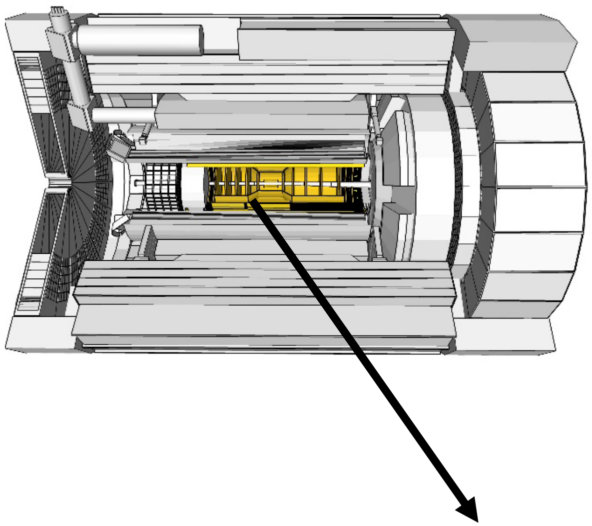
**Reference field value: 1.7 T**




## Conductor Design



# TRACKING IN ePIC CD

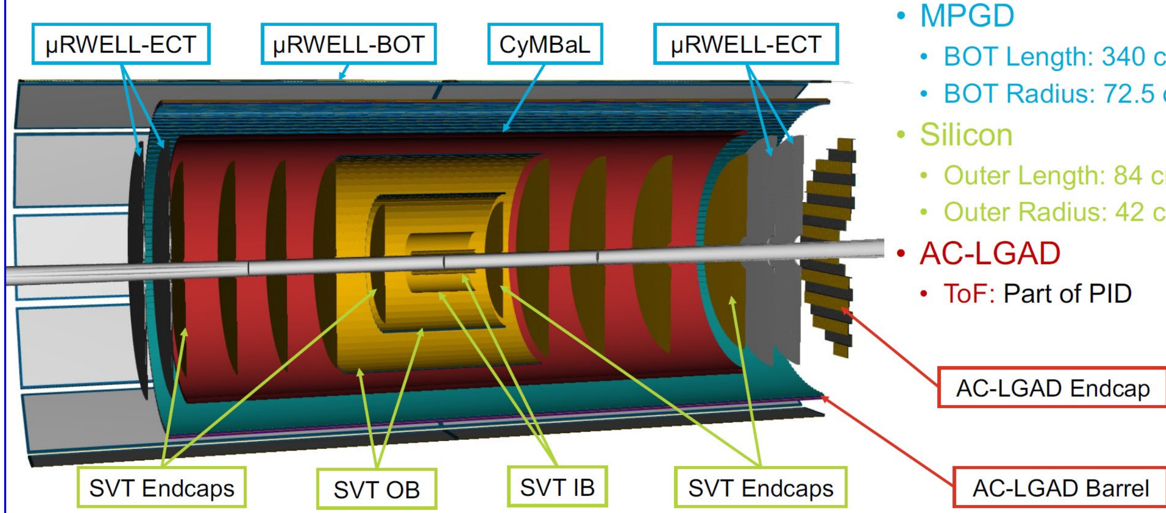


**Complementary tracking technologies characterized by <u>light materials</u>**

**SVT: Si trackers based on ALICE ITS3 65 nm MAPS sensors**
- **<u>Fine space resolution</u> < 20 μm**
- **Five cylindrical layers in the barrel and five disks in each endcap**

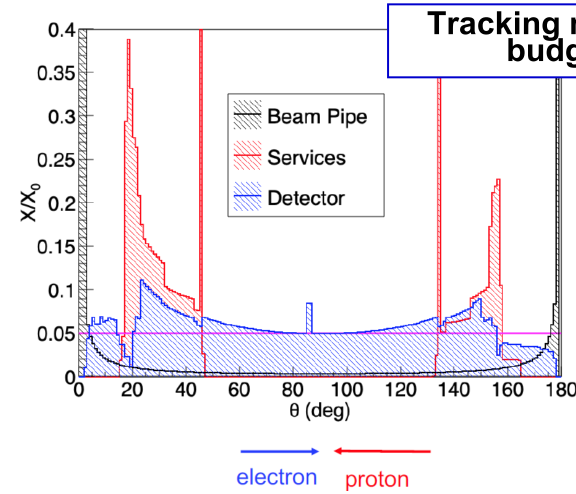
**MPGD trackers**
- **<u>Good time resolution</u> $\mathcal{O}$ (10 ns)**
- **Cylindrical MICROMEGAS**
- **Planar μR-WELL with GEM pre-amplification**

Additional information
- AC-LGADs for ToF (PID) - very fine time resolution: 20/30 ps
- First layer of the barrel imaging EM calorimeter – fine space resolution (150 μm), good time resolution (~ 2 ns)

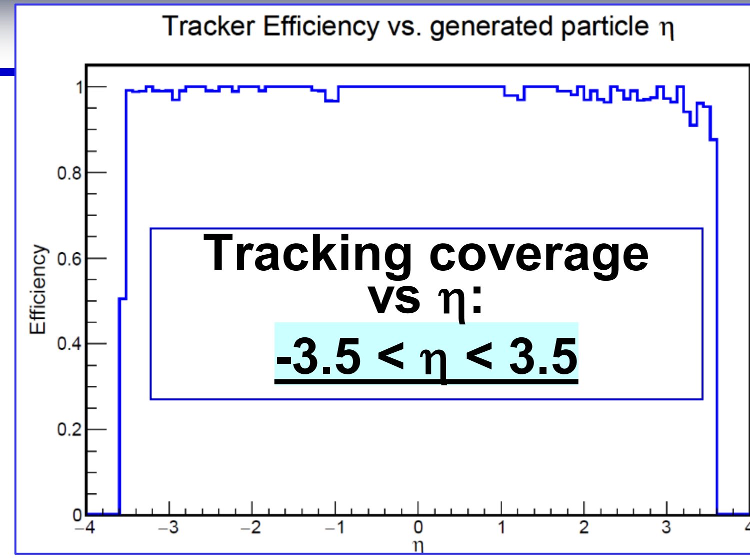



- MPGD
  - BOT Length: 340 cm
  - BOT Radius: 72.5 cm
- Silicon
  - Outer Length: 84 cm
  - Outer Radius: 42 cm
- AC-LGAD
  - ToF: Part of PID

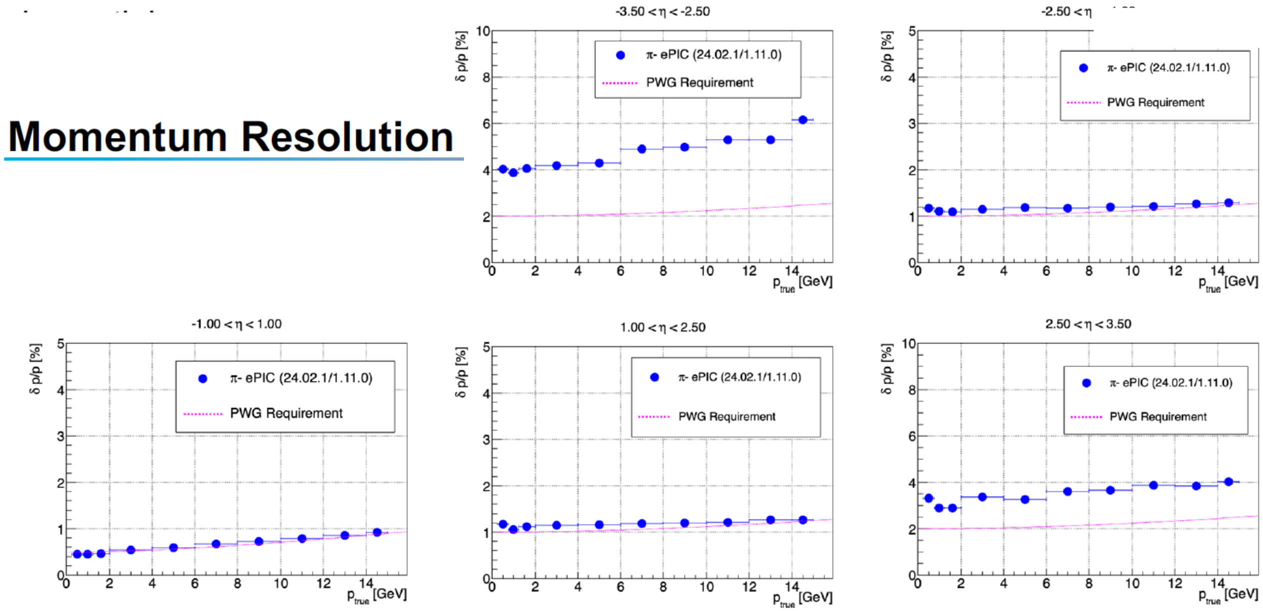
**Tracking material budget**



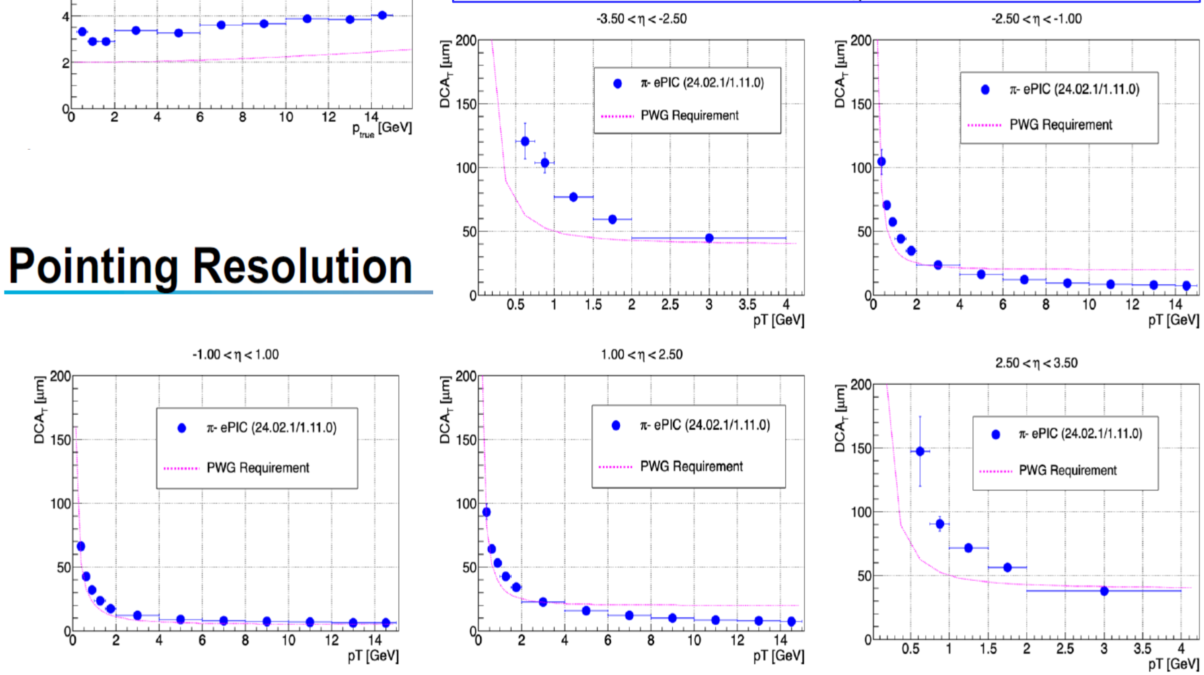
# TRACKING IN ePIC CD




## Momentum Resolution




## Pointing Resolution




- Single particle
  - Includes AC-LGAD layers
  - Extreme $\eta$ regions will require use of other ePIC sub detector information
  - Follows requirements elsewhere

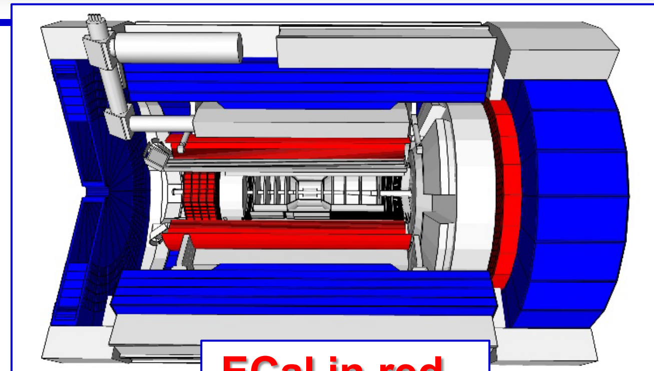
# SENSORS FOR CALORIMETRY IN ePIC

## SiPM sensors for all Calorimeters in ePIC

- **SiPMs recently introduced in calorimetry**
- direct experience is coming from the applications in GlueX, STAR and sPHENIX
- these colleagues now at work for ePIC calorimetry

## Relevant SiPM features for ePIC calorimetry

- **Cost-effective** technology
- Operation in **magnetic field**
- Wide **dynamic range** with tuned parameters for the different calorimeters
- Low **noise** with appropriate thresholding
- Effect of the radiation
  - Not new, already addressed for STAR and sPHENIX
  - Further irradiation campaigns on-going

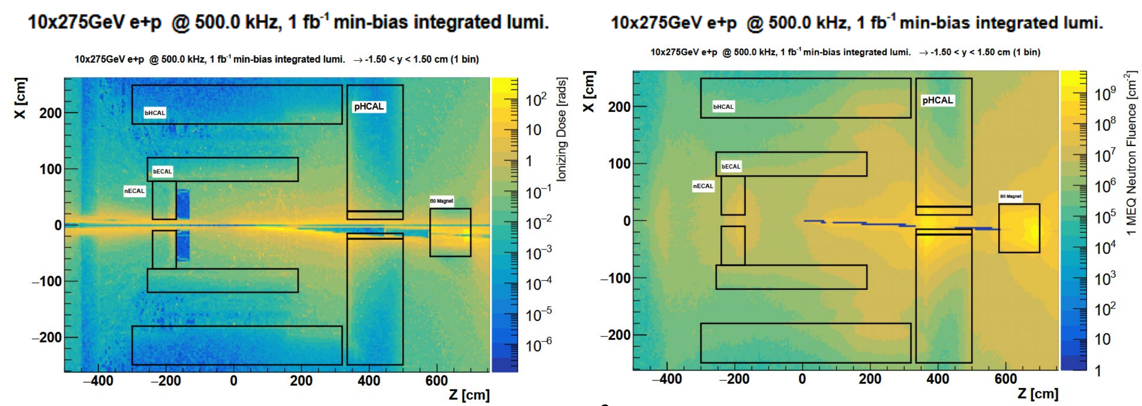


ECal in red
HCal in blue

**SiPM requirements for HCals**

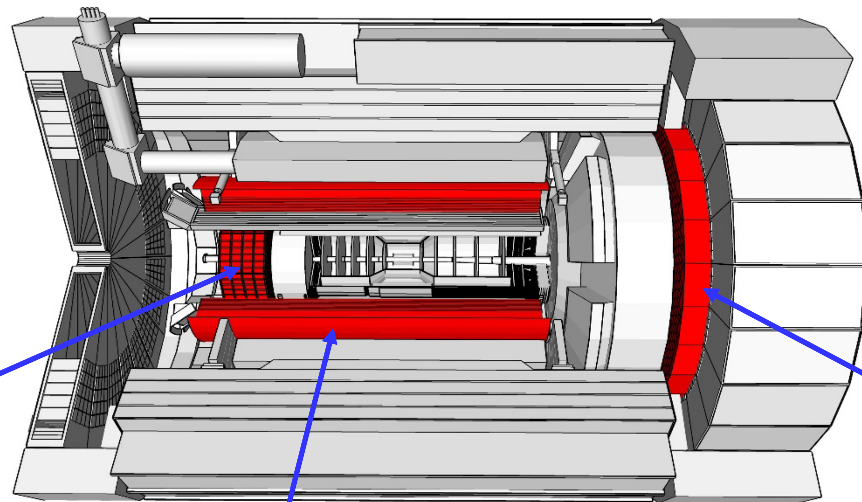
| Parameter | Value |
|---|---|
| Size | 1.3mm x 1.3mm |
| Pixel size | 15 µm |
| Photon Detection Efficiency (PDE) | >25% |
| Dark Count Rate (DCR) | <400 kHz |
| Gain | > 5*10$^5$ |
| Fill factor | >40% |
| Peak sensitivity | ~450 nm |

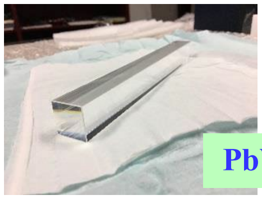
## Rad Dose and Neutron Flux



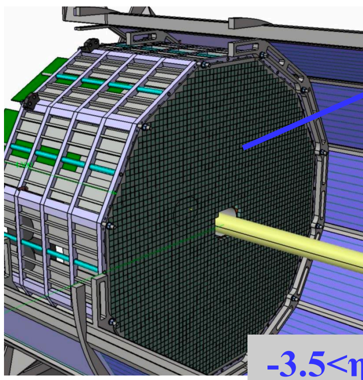

Doses and fluxes ~ 10$^{-3}$ compared to HL-LHC

# ELECTROMAGNETIC CALORIMETRY IN ePIC CD

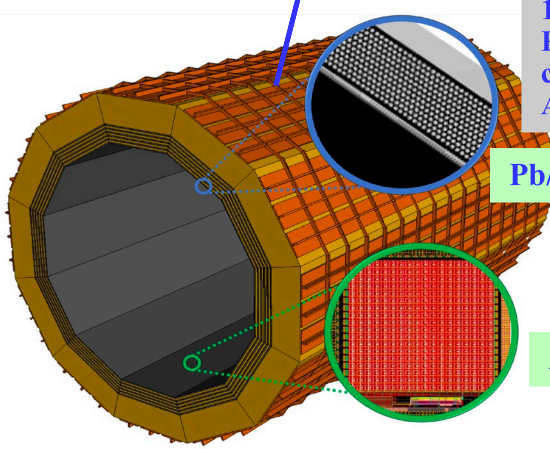




PbWO4



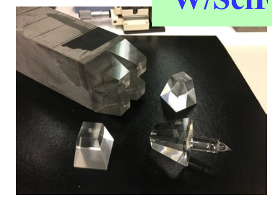
$-3.5<\eta<-1.7$
$22X_0$
~3k crystals
$R_{outer}$=64cm



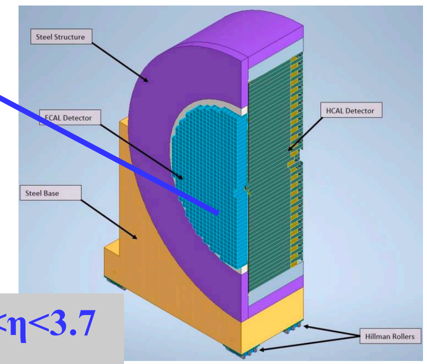
$-1.7<\eta<1.4$
$17X_0$
Pb/SciFi: 5760 readout ch.s
AstroPix: ~0.5B pixels

Pb/SciFi

AstroPix

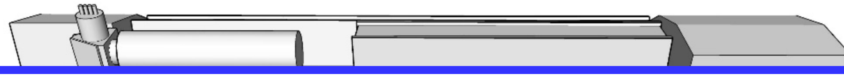


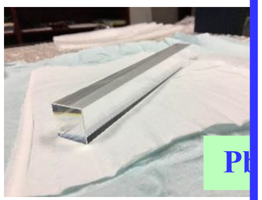
W/SciFi

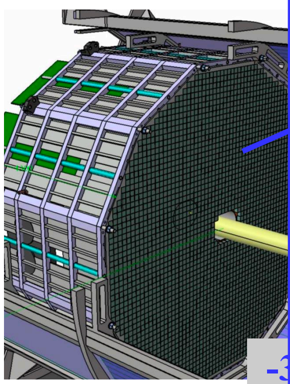


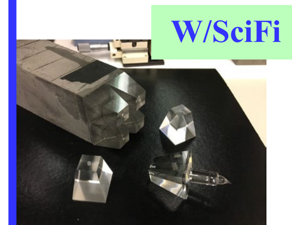

$1.4<\eta<3.7$
$23X_0$
~16k towers
$R_{outer}$=160cm

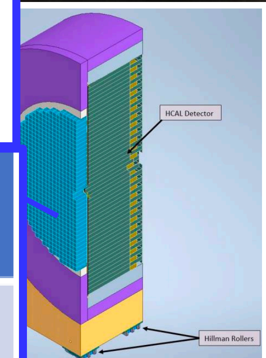
# ELECTROMAGNETIC CALORIMETRY IN ePIC CD

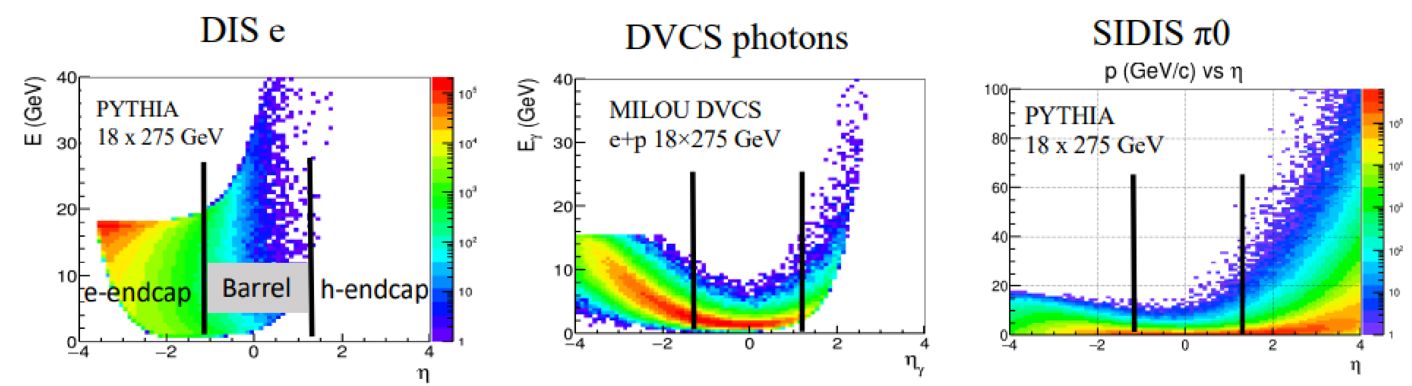




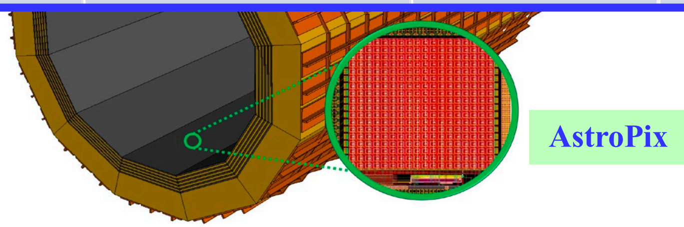




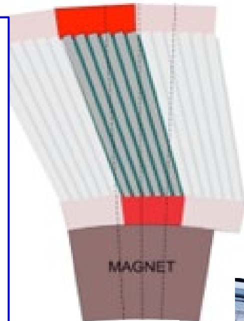

| | $\sigma_E/E$ | E range, GeV | $\pi^\pm$ suppression (In combination with other subsystems) | $\pi0/\gamma$ discr. |
|---|---|---|---|---|
| e-endcap | $\frac{(2-3)\%}{\sqrt{E}} \oplus (1-2)\%$ | 0.05–18 GeV | Up to $10^4$ | Up to 7 GeV/c |
| Barrel | $\frac{(7-10)\%}{\sqrt{E}} \oplus (1-3)\%$ | 0.05–50 GeV | Up to $10^4$ | Up to 10 GeV/c |
| h-endcap | $\frac{(10-12)\%}{\sqrt{E}} \oplus (1-3)\%$ | 0.1–100 GeV | Up to $10^4$ | Up to 50 GeV/c |



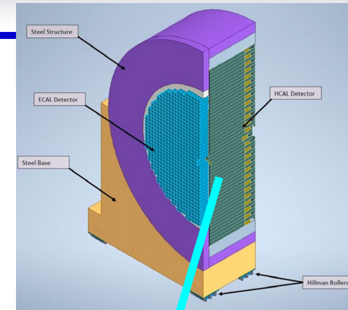
## Backward and barrel:

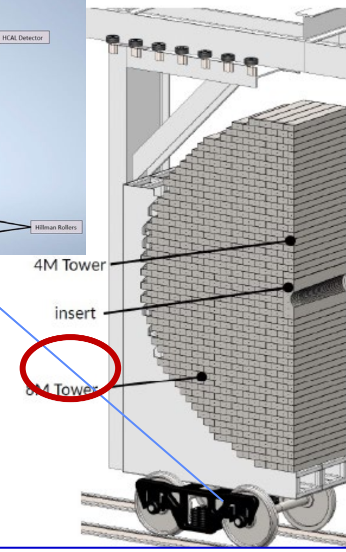
Steel/scintillator sampling calorimetry - CONSOLIDATED TECHNOLOGY

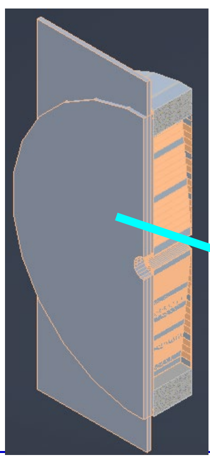
- Identification of neutral hadron jets, especially at low x
- Tail catcher for e/m calorimeter
- μ identification

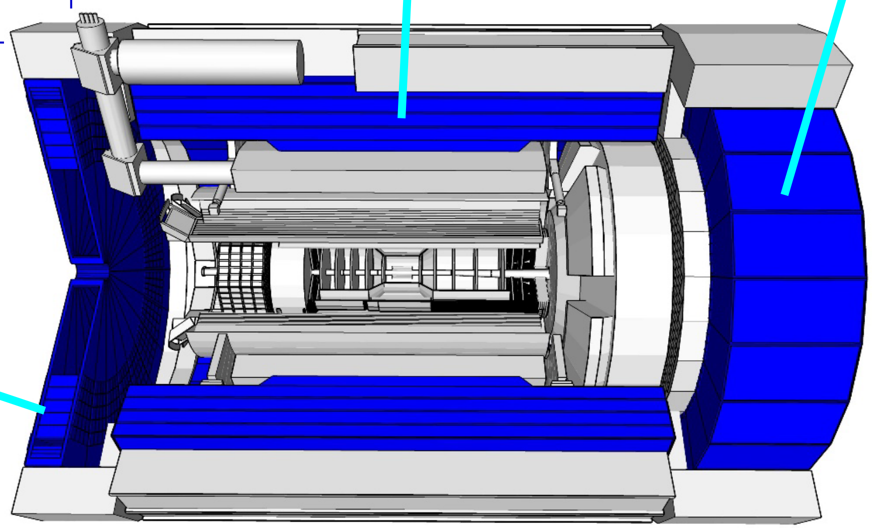



**Barrel Hcal**
**(re-use from sPHENIX)**



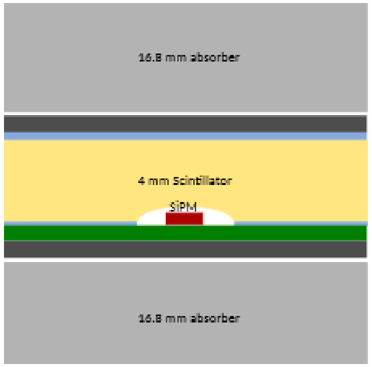





## Forward endcap

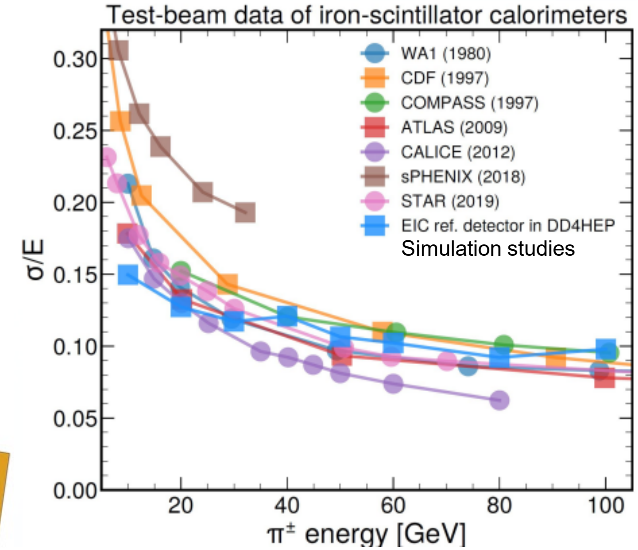
- Original design inspired by CALICE development:
- "SiPM on TILE"
- High granularity insert at high η
- Jet energy measurement
- DIS kinematics reconstruction "Hadronic method"
- muon ID

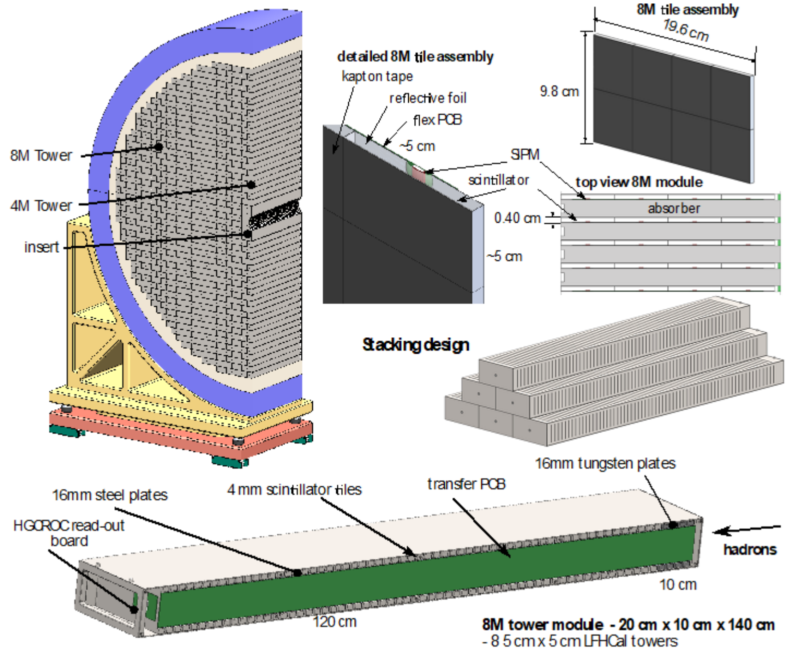
# HADRON CALORIMETRY IN ePIC CD



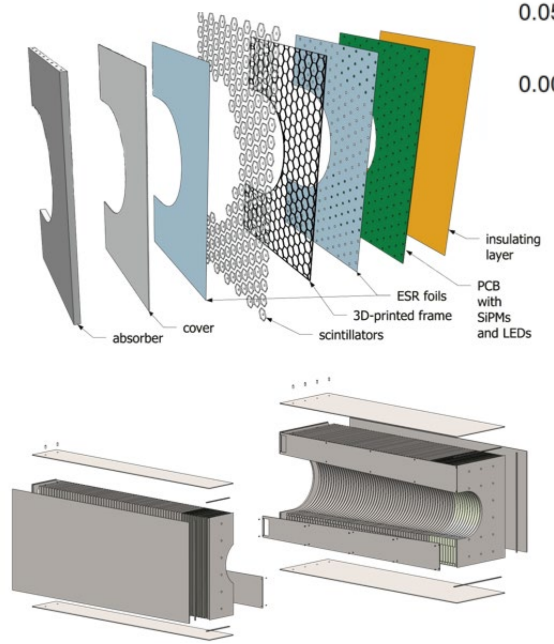

## EHal in forward endcap: "SiPM on tile"

- **Sampling calorimetry with Fe absorber**
- **Derived by a development for CALICE**
- Tower structure with read-out at the rear face

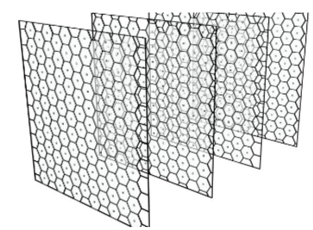



**The Insert**



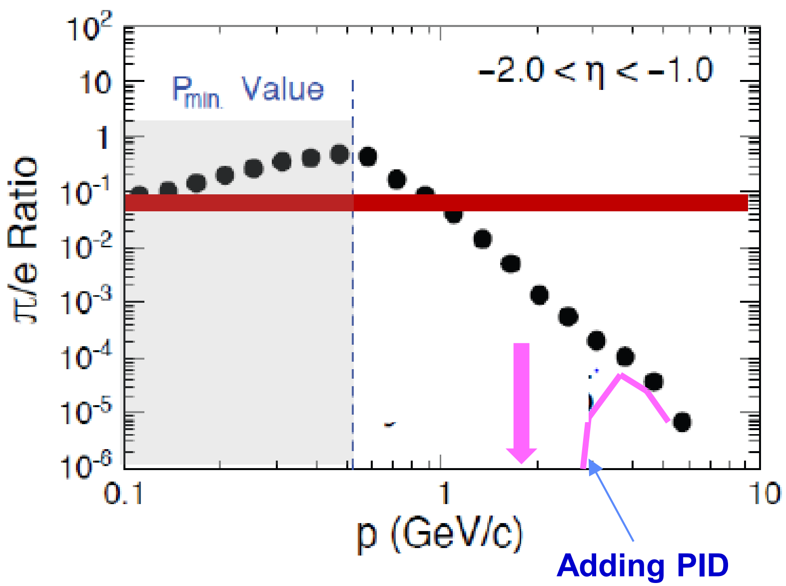

**with staggered tiles for improved space resolution**



# The double role of PID in ePIC CD

## **Support electron identification**, which cannot be provided by ECals only in DIS experiments with electron beams (see HERMES, JLab)

**275 GeV p → ← 18 GeV**

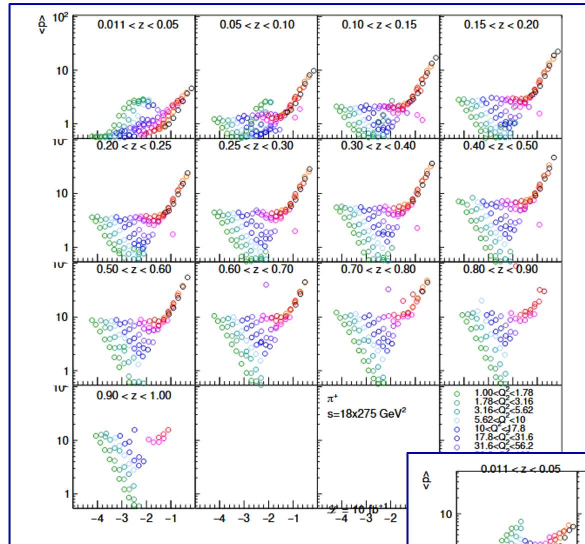



**The different physics channels require $\pi$ contamination in the electron sample down to $10^{-4}$**

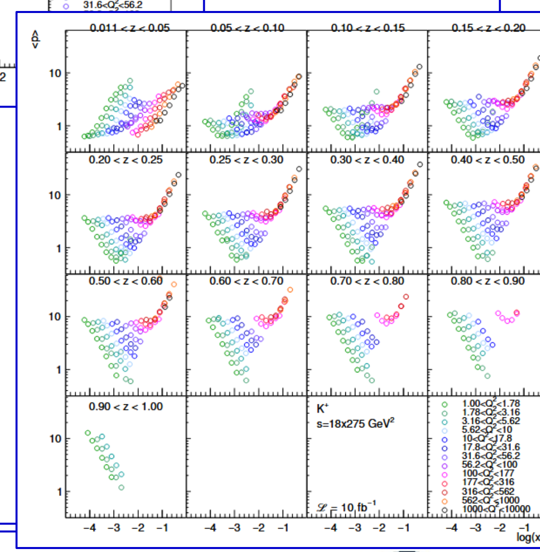
## **Hadron identification**, a key ingredient for TMDs address by SIDIS and with the novel approach of jet reconstruction

**275 GeV p → ← 18 GeV**

Momentum coverage of hadrons




**π**

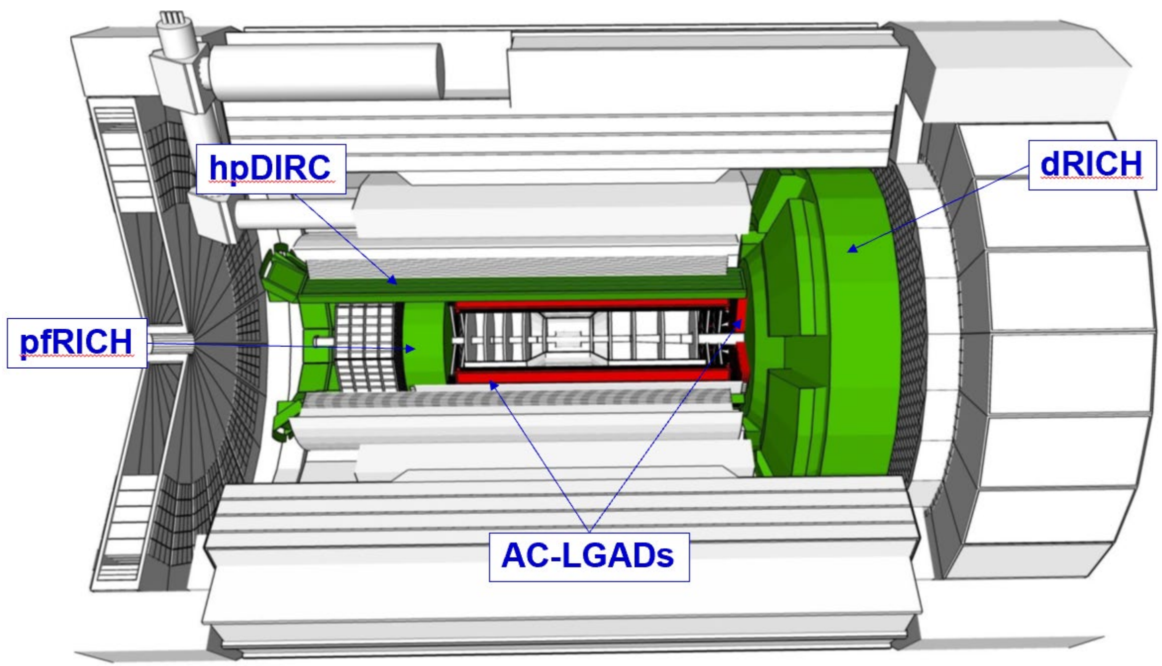


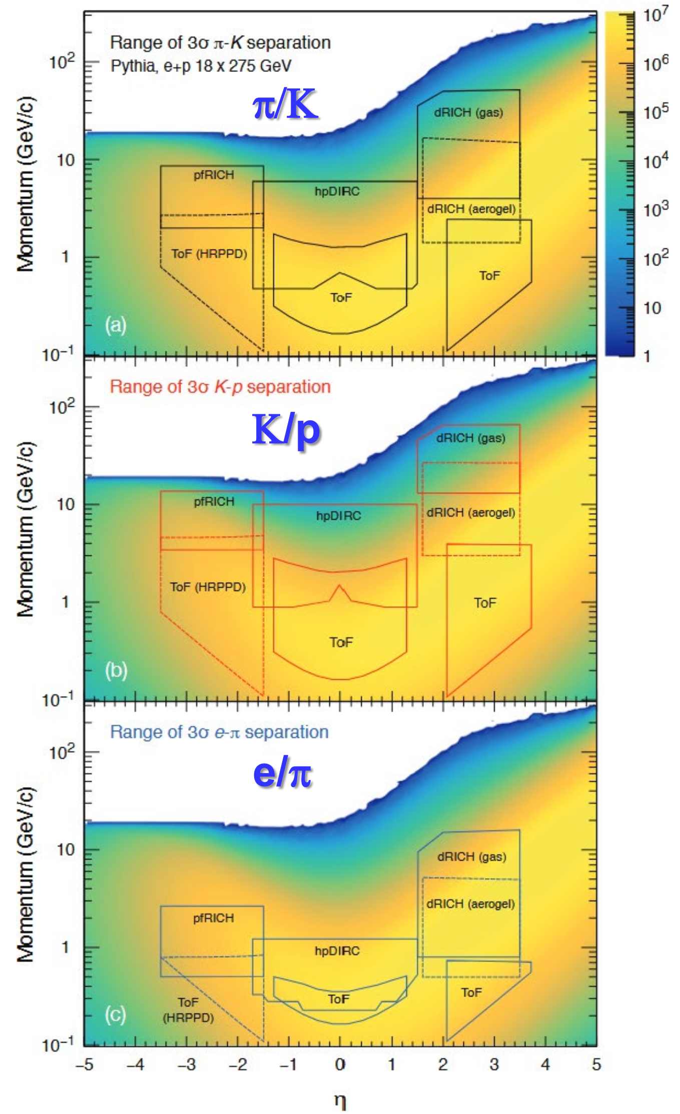

**K**

# PID IN ePIC CD

**DIS** Pythia, e+p 18 x 275 GeV

3 σ separation areas



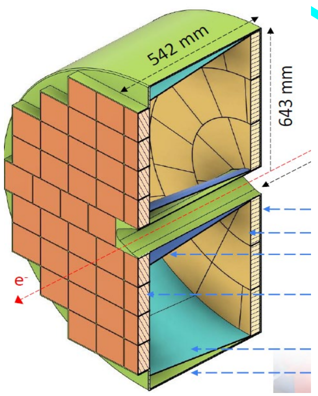



# PID IN ePIC CD

Cherenkov imaging PID in backward endcap:

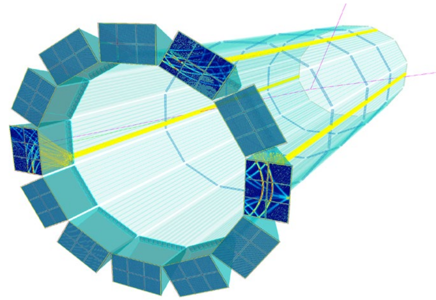
**proximity focusing RICH (pfRICH)**

The long proximity gap (~ 35 cm) enhances the resolution

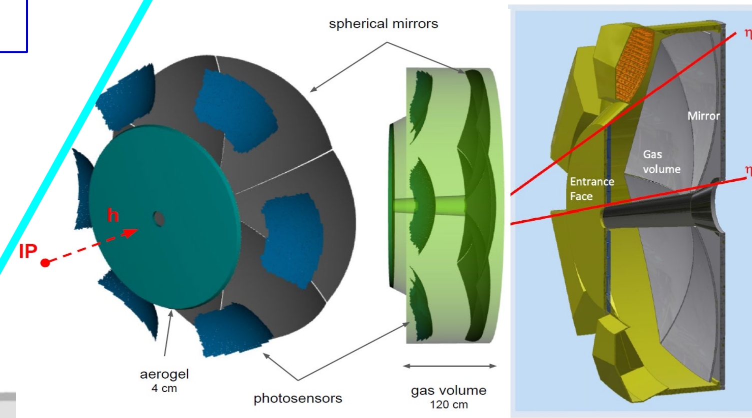


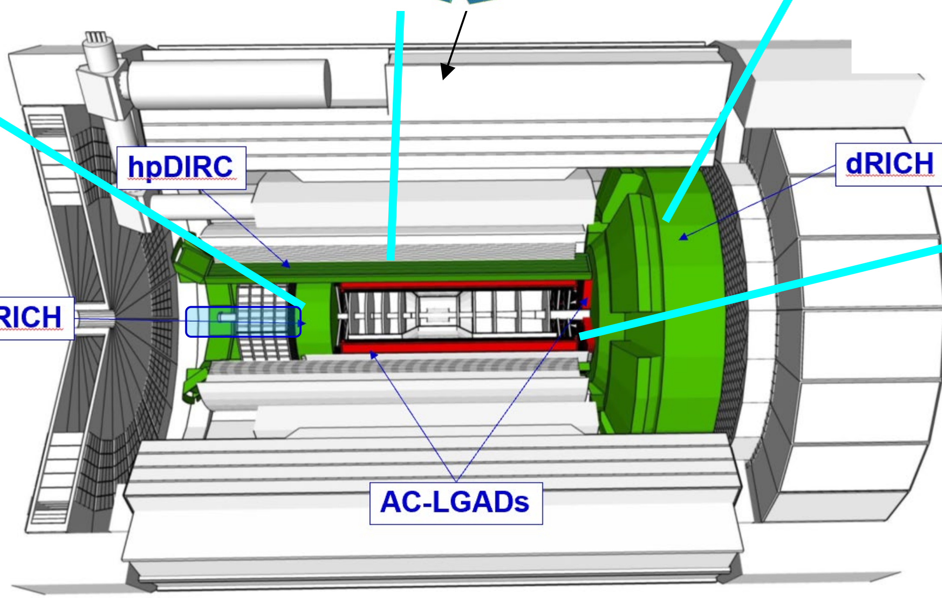

**High performance DIRC (hpDIRC)**

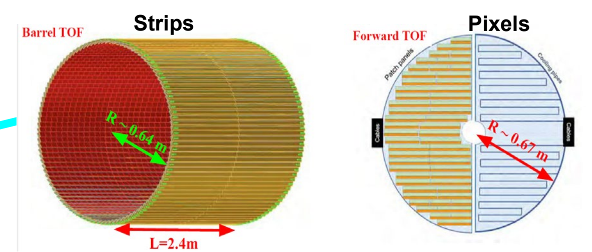
High performance thanks to **focalization** and **fine photosensor pizelization**



**Dual radiator RICH (dRICH); Areogel  and gas**



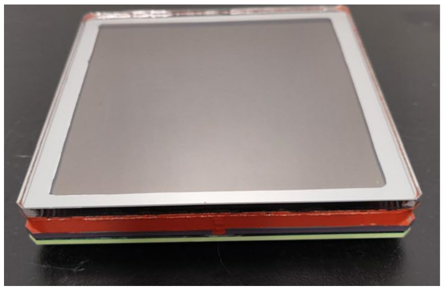

**ToF by AC-LGADs**

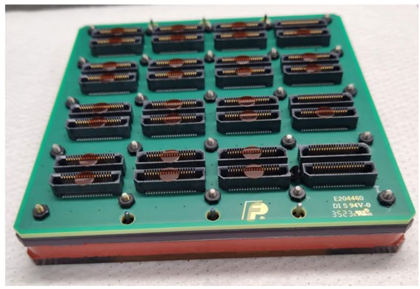
**Goals for the application in ePIC:**

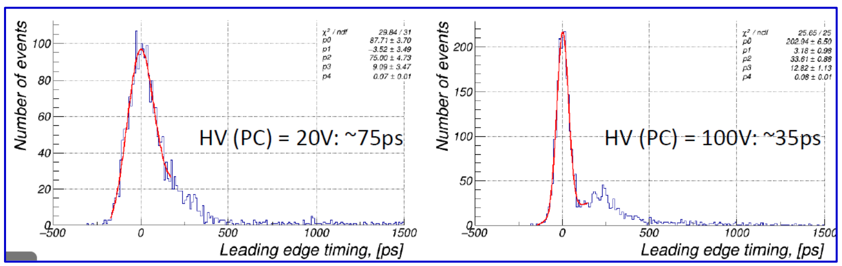
- **30 μm space resolution**
- **25-35 ps time resolution**

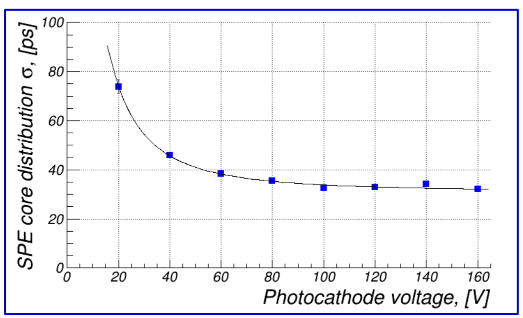
# PHOTOSENSORS for CHERENKOV PID IN ePIC

For pfRICH (option for hpDIRC) :
**HRPPDs by INCOM**
→ large-size (12 x 12 cm$^2$) MCP-PMTs, pixelized





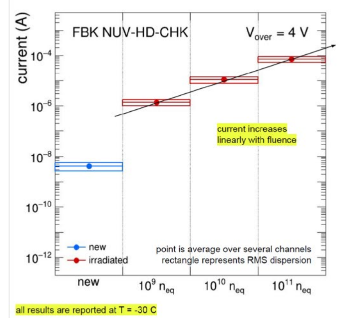


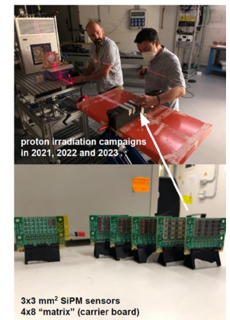




For dRICH : **SiPMs at -30°C**

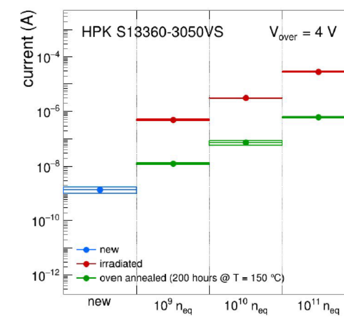
→ Robust R&D for the validation

Studies of radiation damage on SiPM

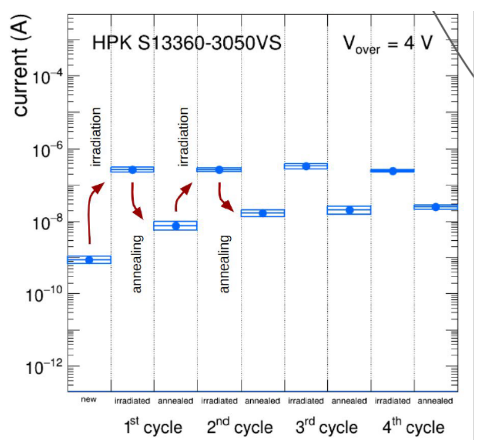


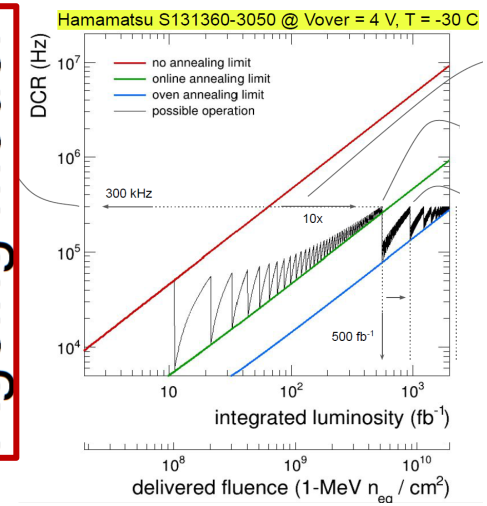

High-temperature annealing recovery
"Online" self-induced annealing



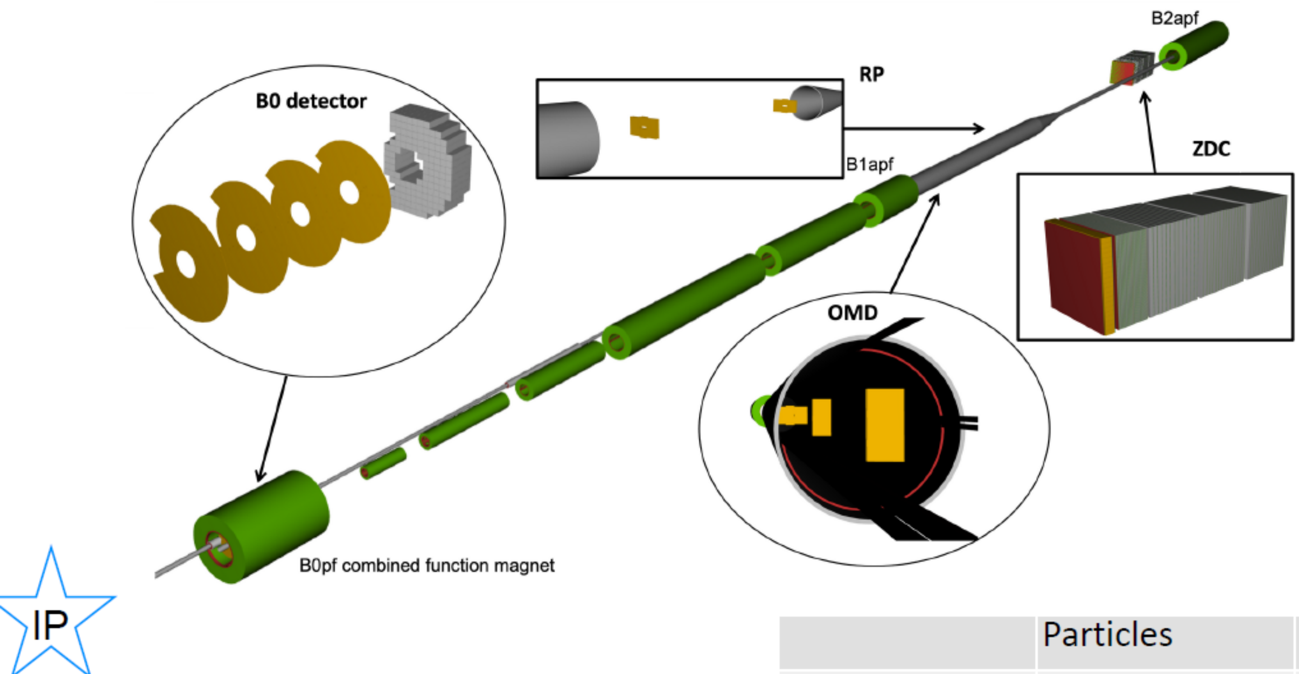

Repeated irradiation/ annealing cycles



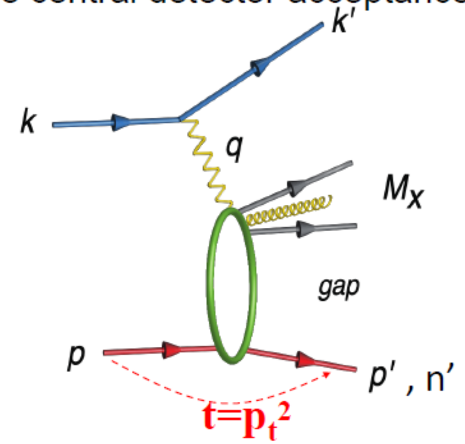

**Ageing model**



# FAR FORWARD DETECTORS




Exclusive /diffractive reactions driving the design of FF area -> reconstruction of particles outside of the central detector acceptance



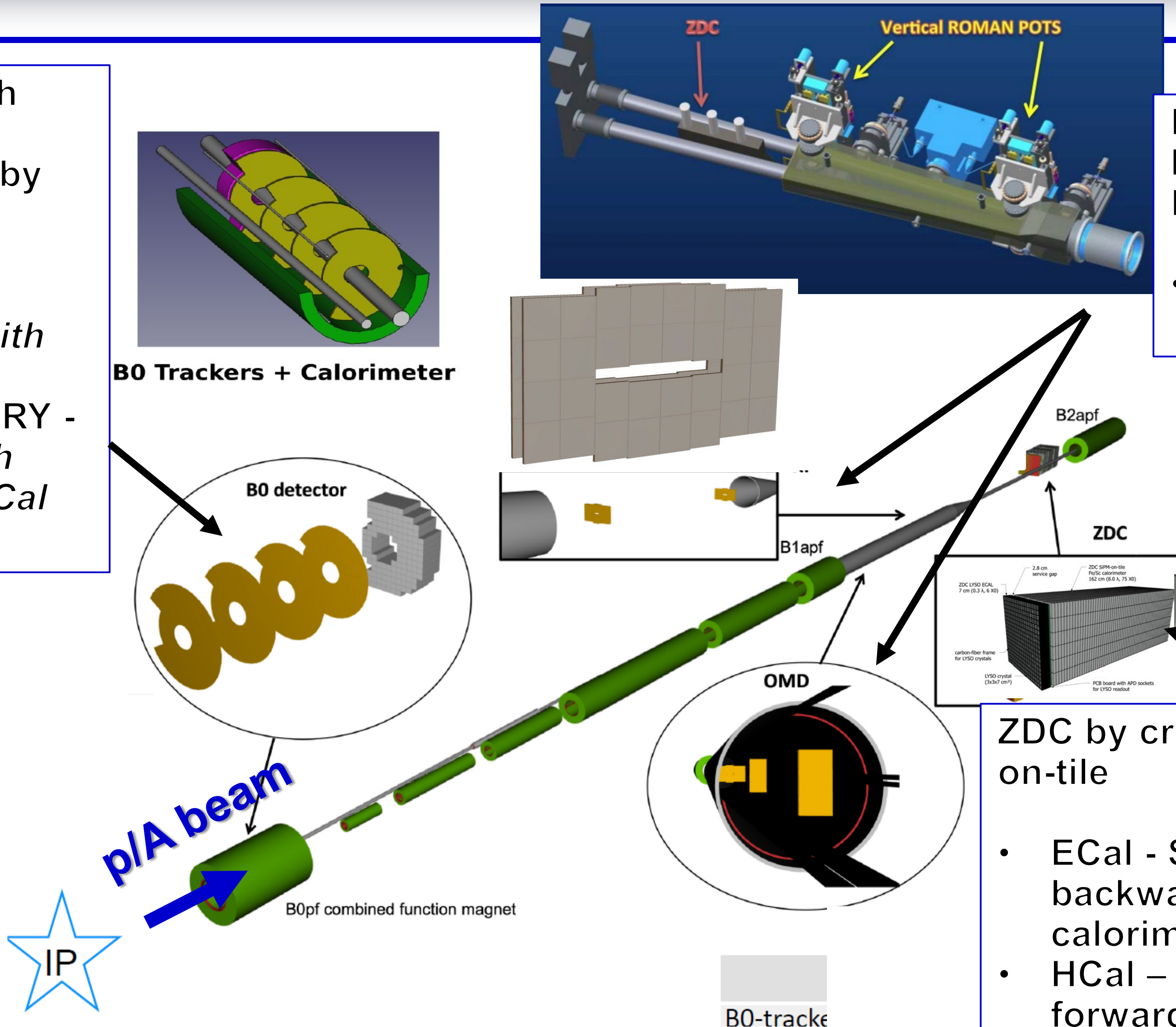

- ✓protons at wide range of $p_T^2$
- ✓protons with **different rigidity**
- ✓**neutrons and photons**

| | Particles | Angle [mrad] | | Distance from IP |
|---|---|---|---|---|
| B0-tracker | Charged particles<br>Photons ( tagged) | 5.5 - 20 | | ca 6-7 m |
| Off-momentum | Charged particles | 0-5.0 | 0.4< xL< 0.65 | ca 23-25 m |
| Roman Pots | Protons<br>Light nuclei | 0*-5.0 | 0.6 < xL< 0.95 | ca 27-30 m |
| ZDC | Neutrons<br>Photons | 0-4.0 (5.5) | | ca 35 m |

# THE ePIC FAR FORFWARD DETECTORS

B0 trackers with AC-LGADS
B0 calorimetry by crystals

- TRACKING - *Synergies with forward ToF*
- CALORIMETRY - *Synergy with backward ECal and ZDC*




RPs and OMDs by pixelized AC-LGADs

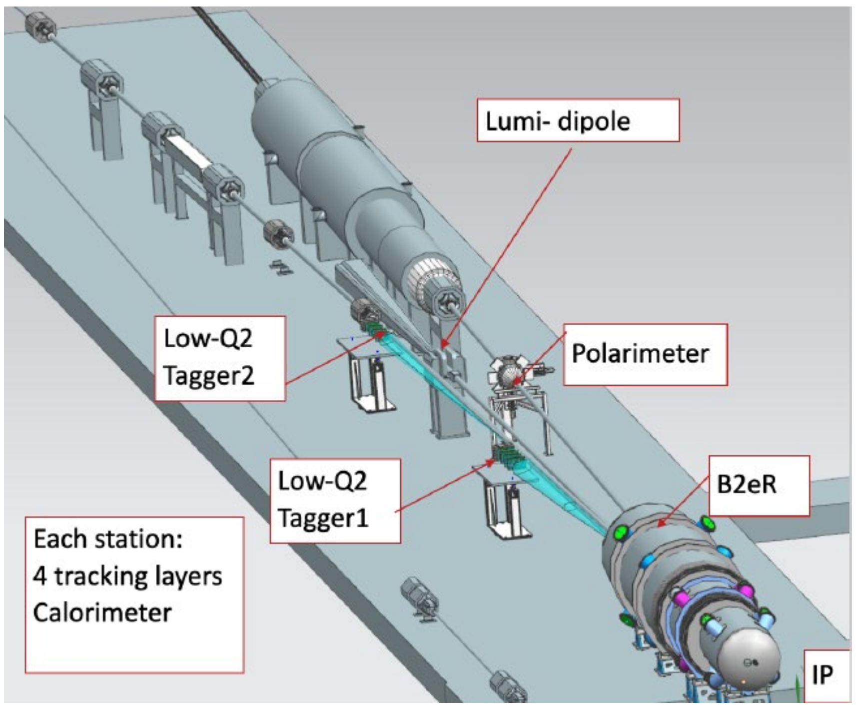
- *Synergies with forward ToF*

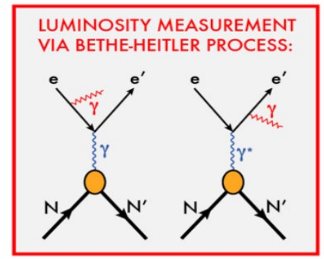
ZDC by crystals and SiPM-on-tile

- ECal - Synergy with backward ECal and B0 calorimetry
- HCal – Synergies with forward ECal insert

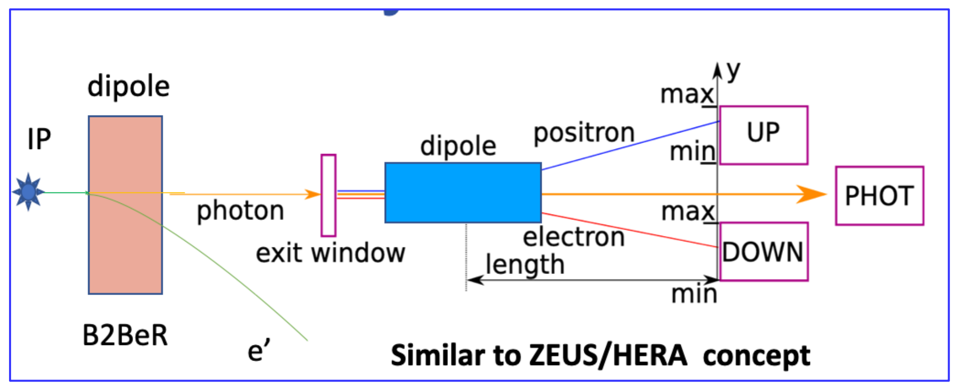
# THE ePIC FAR BACKWARD DETECTORS

- This area is designed to provide coverage for the low-$Q^2$ events (photoproduction, $Q^2 < \sim 1 GeV^2$) . Need to measure a scattered electron position/angle and energy
- And luminosity detector (ep -> e'p$\gamma$ bremsstrahlung photons)

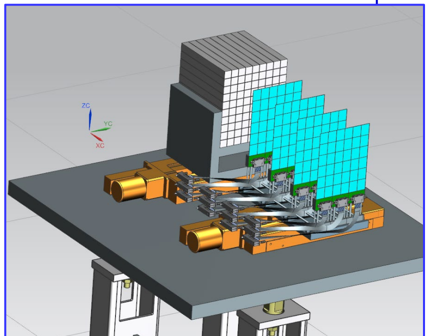



Luminosity monitor

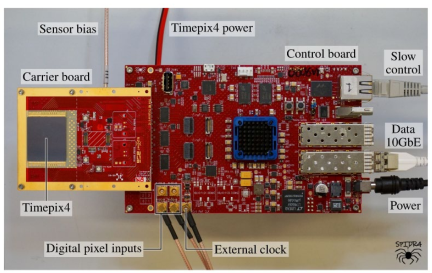


Low Q2 taggers
- High rate capability
- Fine tracking pixelization

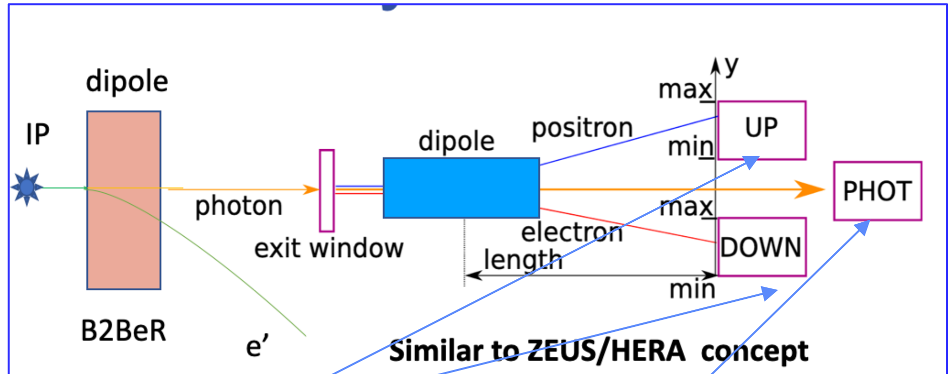


- Tracking – Timepix4 Hybrid (ASIC+Si tracker) – FRONTIER APPLICATION
- Calorimetry – SciFi's

- Timepix4 – wide experience accumulated with the different timepix versions




- CALORIMETRY - Synergy with forward ECal




LUMINOSITY – pair spectrometers

- TRACKING – AC-LGAD strips *Synergies with barrel ToF*
- CALORIMETRY – W-SciFi - *Synergy with farward ECal*

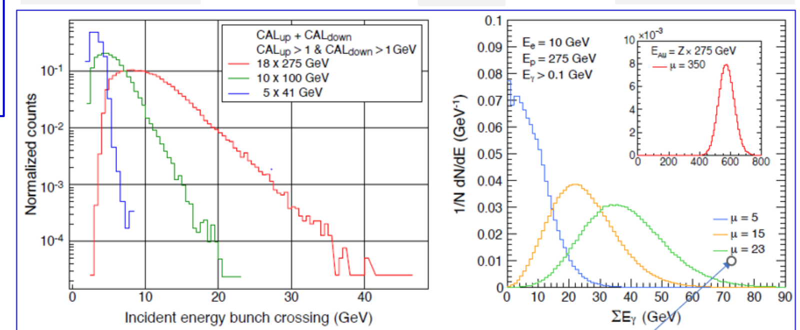
Luminosity – high rate calorimeter – CONSOLIDATED TECHNOLOGIES

- W-SCiFi – *synergies with forward ECal*
- Cu-QFi

different CM energy

PHOT

different Luminosity

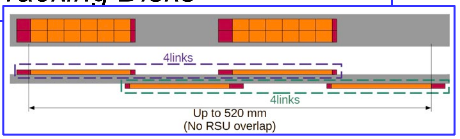



L = 2.2, 6.5 and 10 × $10^{33}$ $cm^{-2}s^{-1}$, corresponding to the average photon multiplicity μ

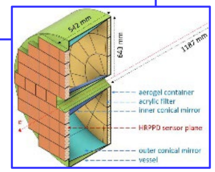
27

# TECHNOLOGIES: WORLD FIRST AT ePIC

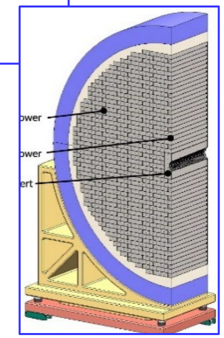
EIC Large Area Sensor (**LAS**), modification of ITS3 sensor with 5 or 6 RSU forming staves as the basic building elements *for the Outer Barrel and the Tracking Disks*

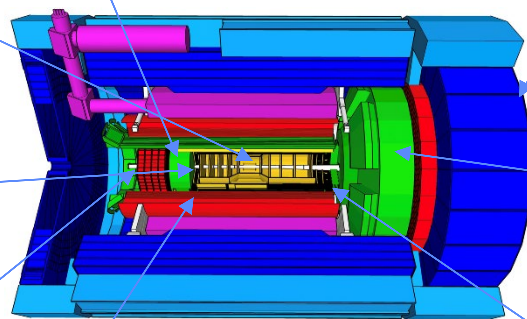



**HRPPDs** for Cherenkov imaging and Time-of-Flight *for pfRICH*

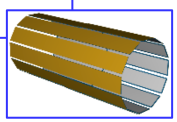



first-time **full-size CALICE-like calorimeter** in collider experiment *in the forward HCal*

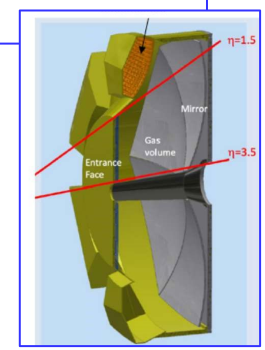




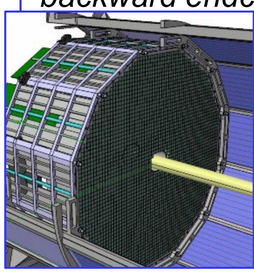
planar **double amplification (GEM & µRWELL)** modules & 2D-strip readout *for the MPGD outer trackers and disks*



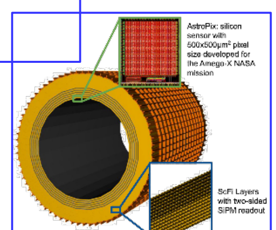
First use **of SiPMs as Photonsensors in a RICH** for the dRICH



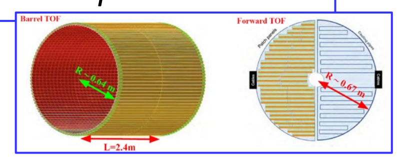

**SiPM as Photonsensors in crystal calorimetry** *for backward endcap ECal*



Use of **ASTROPIX in Calorimetry** *for the imaging barrel ECal*




First time use of **AC-LGAD** in a collider detector *for barrel and forward endcap ToF*



# TAKEAWAY MESSAGES

**The EIC is a unique project, the word only one approved for the ultimate understanding of QCD**

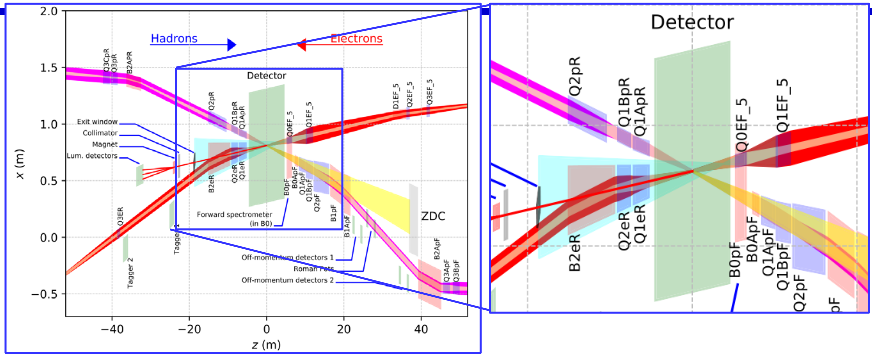
**Most likely, the only novel high energy collider in the next 15-20 years**

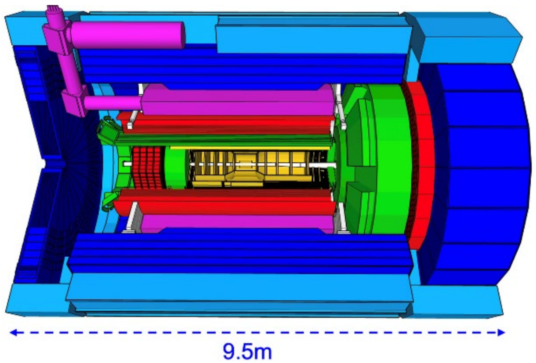
- **The EIC project is approved and progressing according to schedule**
- **The ePIC Collaboration for the project detector ePIC is working and highly committed**
  - **The ePIC detector design is dictated by the physics scope**
  - **A number of established and novel technologies needed to match this scope**
- ***Exciting perspectives in front of us designing, building, operating ePIC and progressing in physics with our detector***

# THANK YOU

# ePIC DETECTOR CHALLENGES

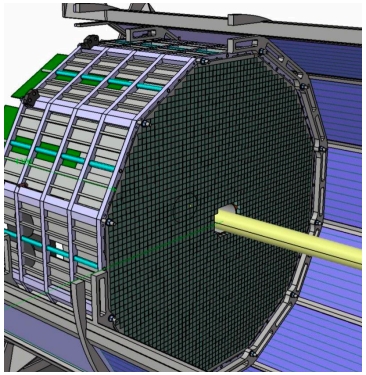
- ***Small β****
  - → ***quads near to IP***
  - → ***9.5 m to host the central detector***
- ***Asymmetry beam energies***
  - → ***Asymmetric detector design***
- ***Far detectors highly integrated with the storage rings***
- ***Synchrotron radiation background***
  - → ***solenoid axis aligned with e beam***
  - → ***p/ion beams follow a helical path in the CD solenoid***
- ***Other physical backgrounds***
  - → ***beam-gas scattering***
- ***Crab crossing***
  - → ***Vertex smearing to be removed with timing information fast timing in the range ~30 – 40 ps***
- ***Bunch crossing rate and crossing time***
  - → ***Up to a bunch crossing every 10 ns***
  - → ***The whole bunch crossing takes ~ 3 ns***

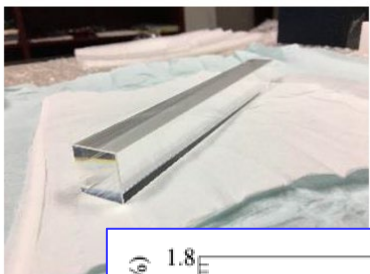



| rates in kHz | 5x41 GeV | 5x100 GeV | 10x100 GeV | 10x275 GeV | 18x275 GeV | Vacuum |
|---|---|---|---|---|---|---|
| Total ep | 12.5 kHz | 129 kHz | 184 kHz | 500 kHz | 83 kHz | |
| hadron beam gas | 12.2kHz | 22.0kHz | 31.9kHz | 32.6kHz | 22.5kHz | 10000Ahr |
| | 131.1kHz | 236.4kHz | 342.8kHz | 350.3kHz | 241.8kHz | 100Ahr |
| electron beam gas | 2181.97 kHz | 2826.38 kHz | 3177.25 kHz | 3177.25 kHz | 316.94 kHz | 10000Ahr |
| DIS eA | kHz | kHz | kHz | / | / | |
| hadron beam (Au) gas | 7.36kHz | 10.3kHz | 10.3kHz | / | / | 10000Ahr |
| | 79.1kHz | 110.7kHz | 110.7kHz | / | / | 100Ahr |

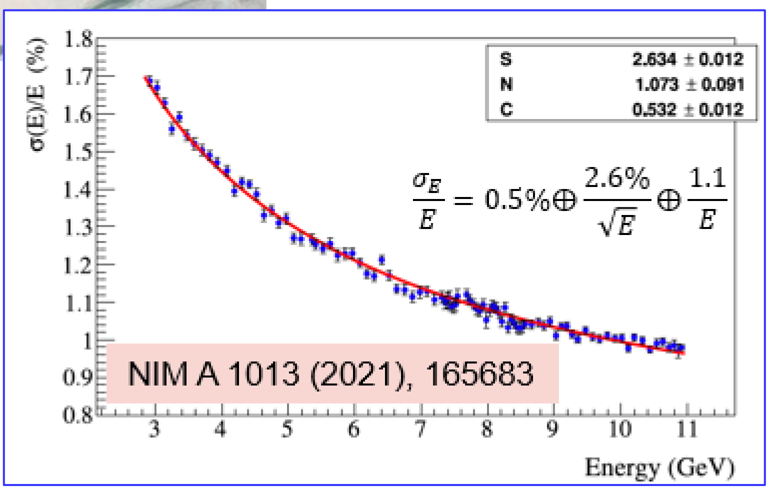
# ELECTROMAGNETIC CALORIMETRY IN ePIC CD



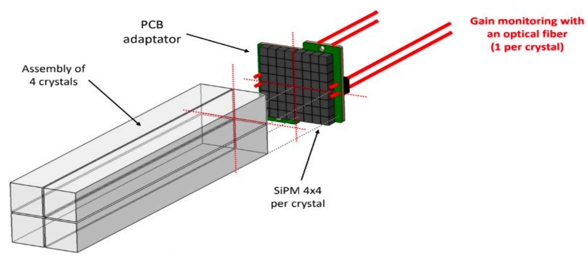


**ECal in backward endcap: $PbWO_4$**

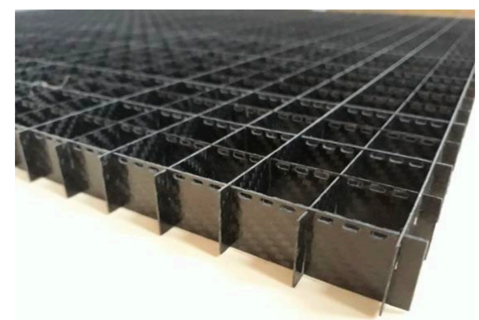
- **Consolidated** technology
- **Finest energy resolution**
    - New challenge: preserving the resolution with SiPMs
- Fine granularity

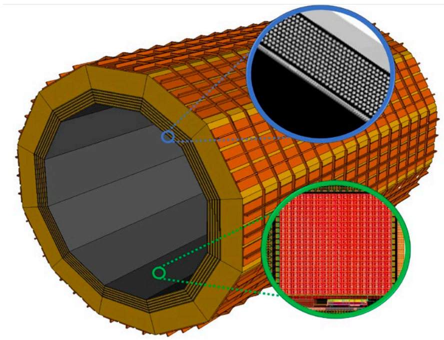



**Readout coupling**




**C-fiber structure to hold crystals**

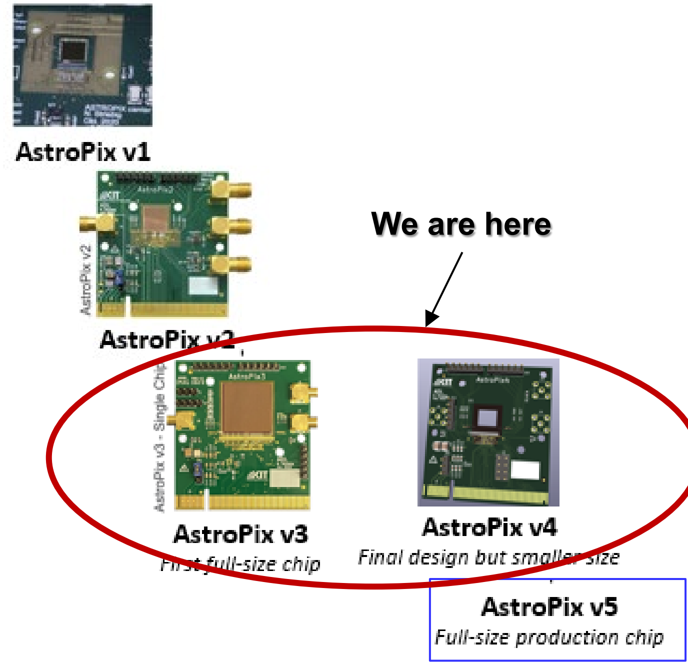




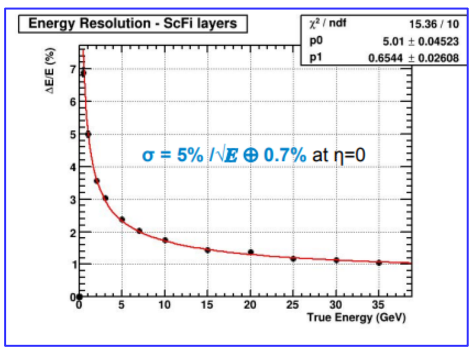
## ECal in the barrel: hybrid architecture

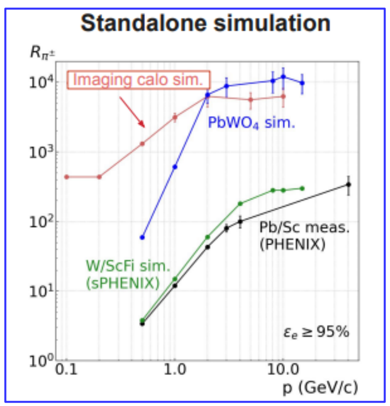
- **Internal layers: imaging**
  - SENSOR : **Astropix** (derived from ATLASpix3, design for NASA AMEGO-X mission)
  - New: **active interposing layers**

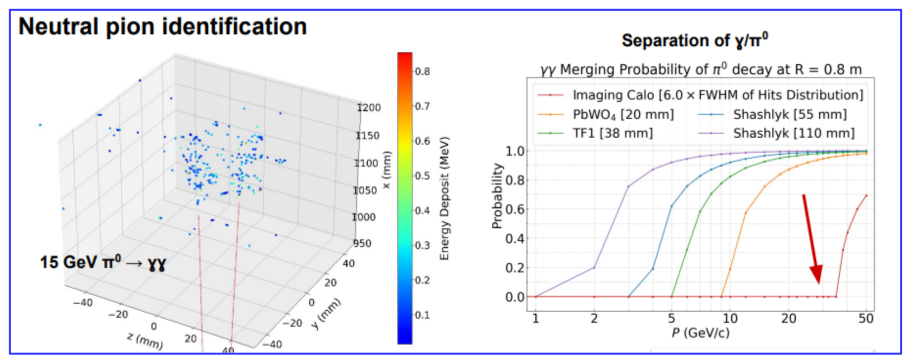
- **External and interposing layers:**
  - **Pb/Sci** (validated: KLOE, GlueX, …)

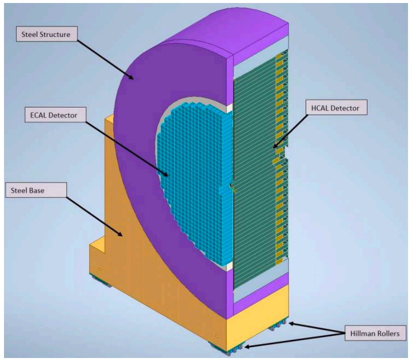


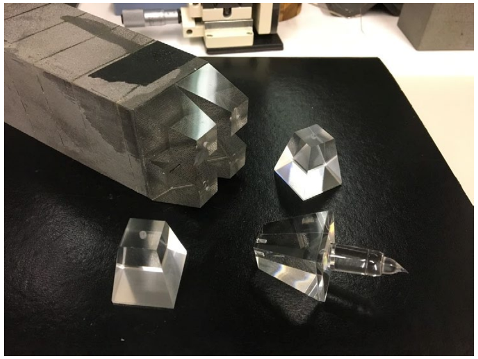

# Performance based on simulations



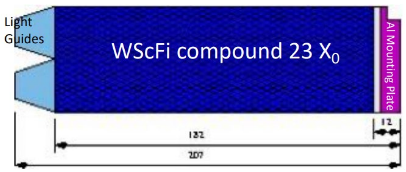



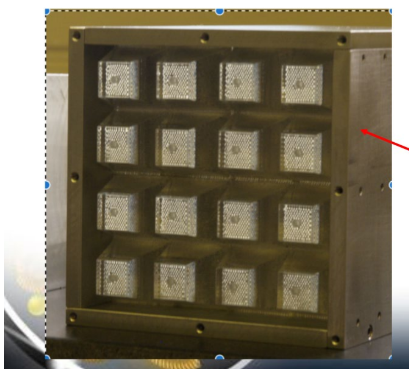


## ECal in forward endcap: W/SciFi

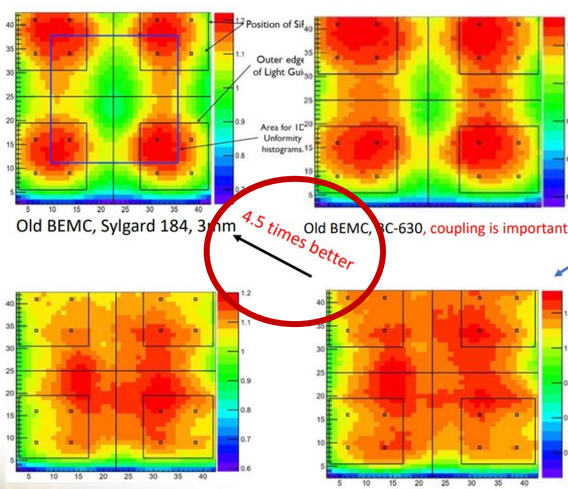
- **Pioneered by UCLA**
  - sPHENIX EMCal: 25k towers
- Good resolution
- High granularity for $\pi^0$
- e/h~1 for jets
  → ideal to operate in duet with the forward endcap HCal



Optimization of light collection:

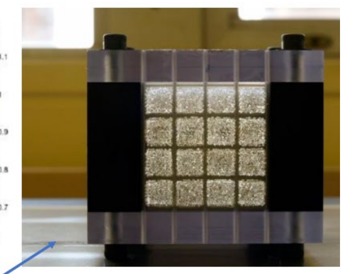
BEMC Superblocks, UV LED Map



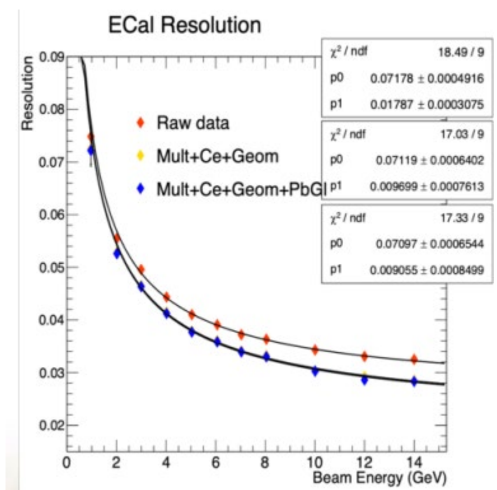

Old BEMC, Sylgard 184, 3 mm

Old BEMC, BC-630, coupling is important

New BEMC, Lumisil 591
Better fiber arrangement and better coupling.

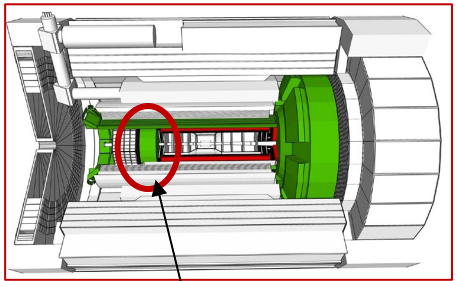


One Ecal block was build with pre-bunched fibers to perform scans with UV LED. But there were no beam test.



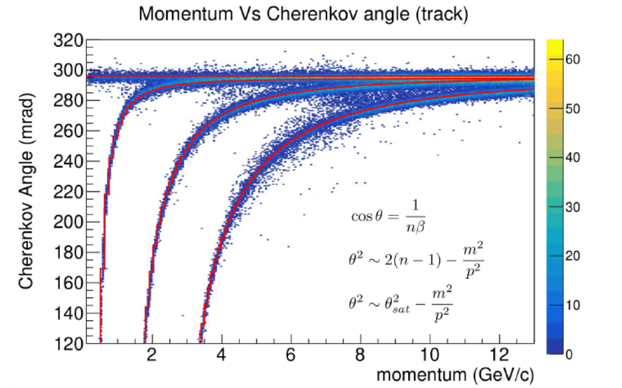

EIC Backward, FNAL 2016

# CHERENKOV PID IN ePIC CD



Cherenkov imaging PID in backward endcap:

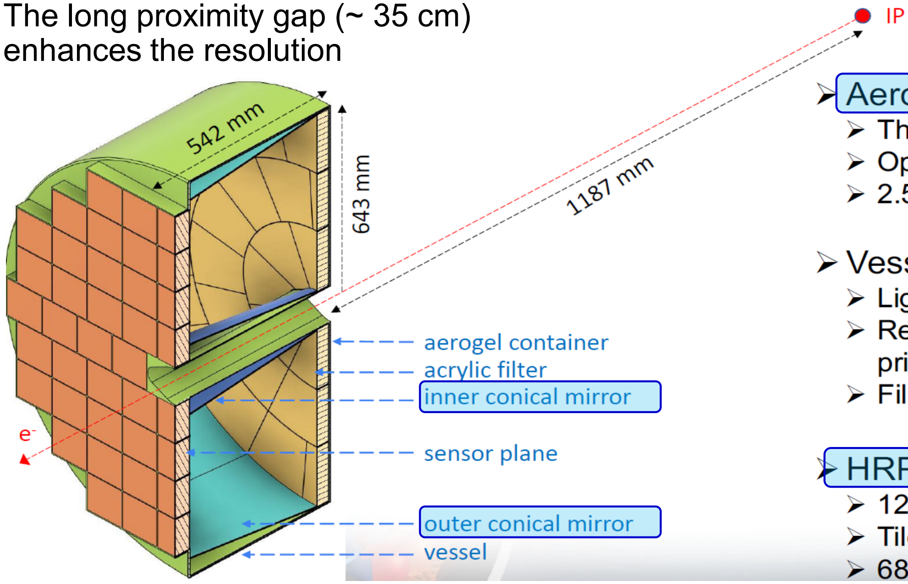
**proximity focusing RICH (pfRICH)**



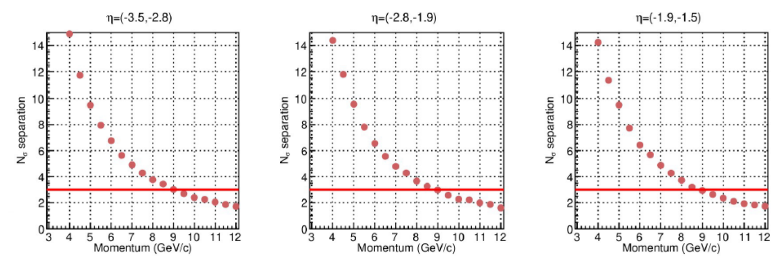

e/π/K/p response integrated over the whole η acceptance

n = 1.040 → 10-11 detected photons/ring at saturation

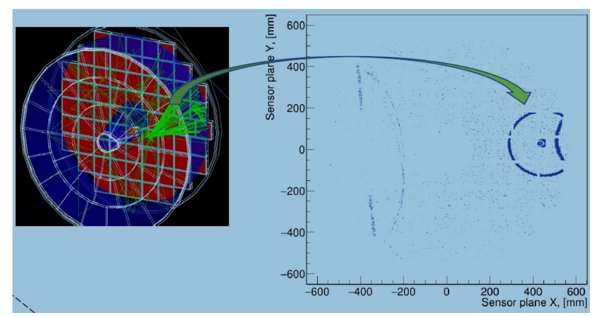
The long proximity gap (~ 35 cm) enhances the resolution

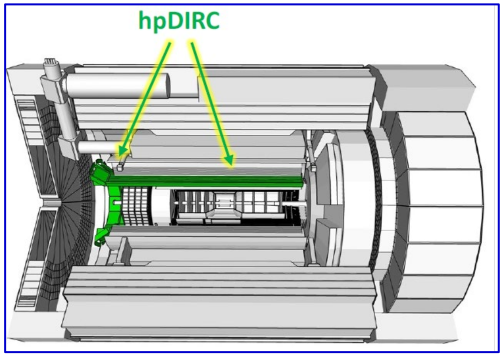



- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Lightweight structure
  - Reinforced carbon fiber and 3D printed materials
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total




π/K $N_\sigma$ separation in η bins

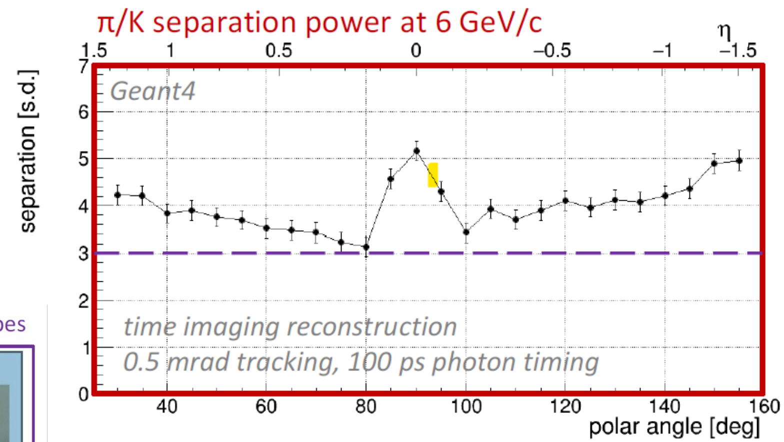


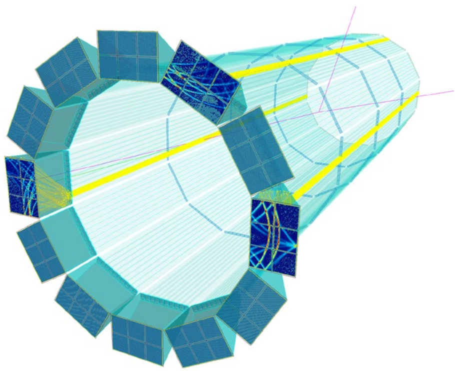


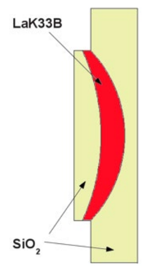

Cherenkov imaging PID in the barrel:

**High performance DIRC (hpDIRC)**

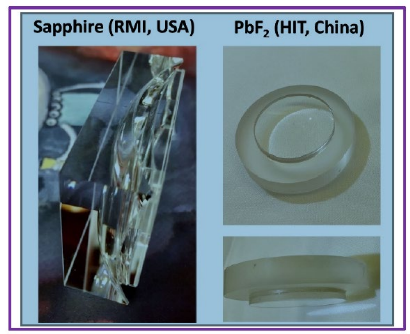
High performance thanks to **focalization** and **fine photosensor pizelization**

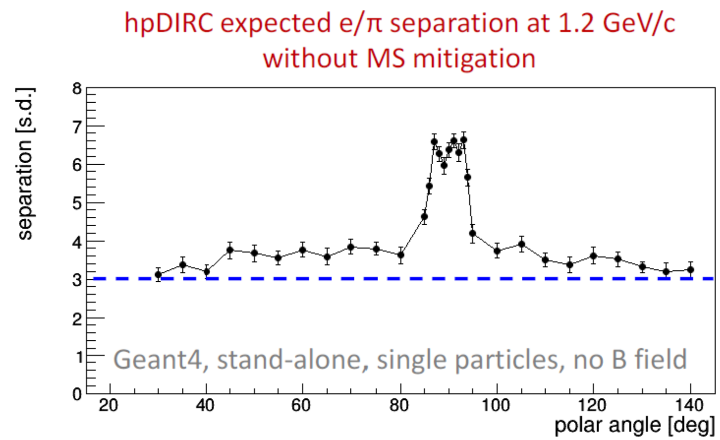


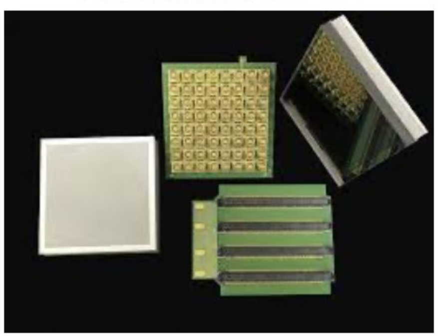



Radiation-hard 3-layer lens prototypes



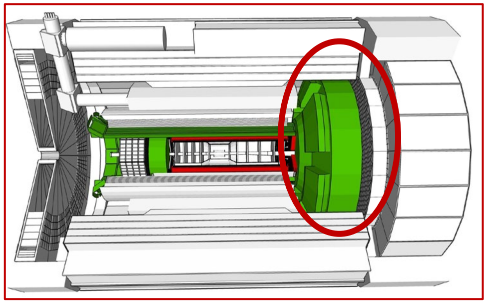




*Photek MAPMT 253*



*A further option: HRPPDs*

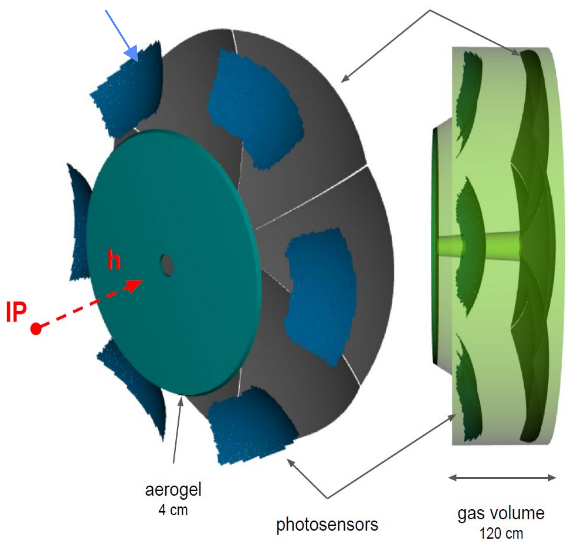
# CHERENKOV PID IN ePIC CD

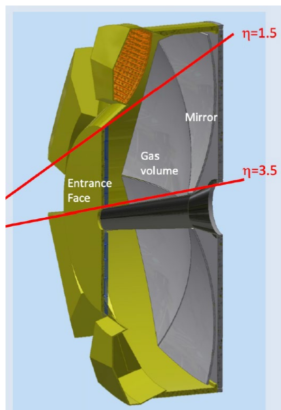


**Cherenkov imaging PID in the forward endcap:**

**Dual radiator RICH (dRICH)**

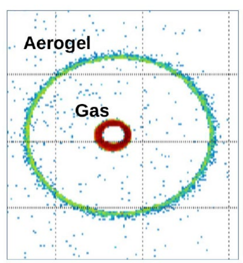
**SiPMs**



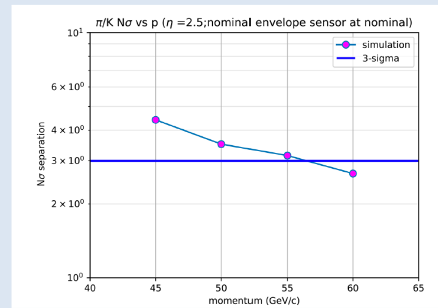

**Aerogel: n = 1. 020 – 1.026**

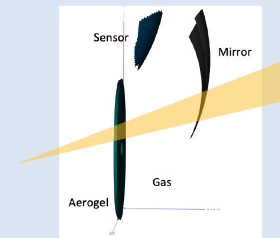
**Gas: $C_2F_6$**



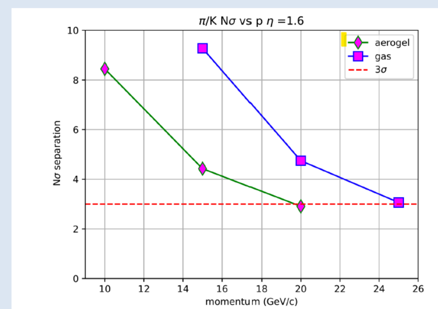

## dRICH Simulation: Momentum reach

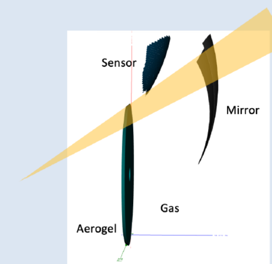
Momentum reach



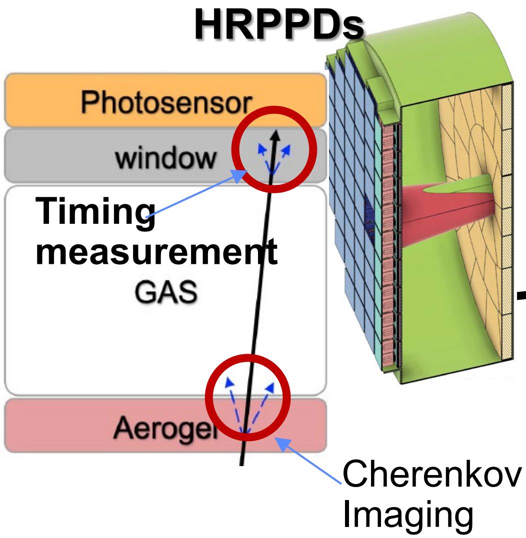



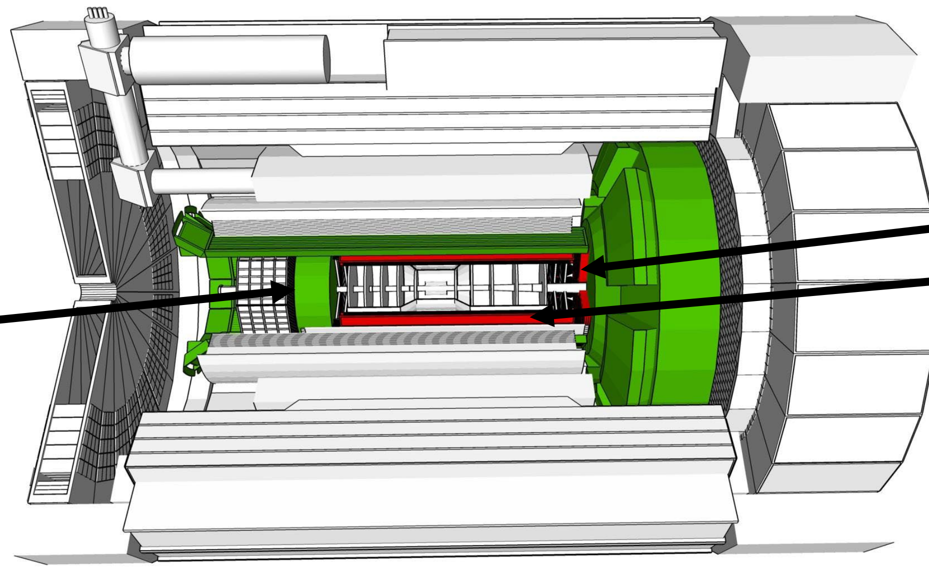

Interplay between radiators

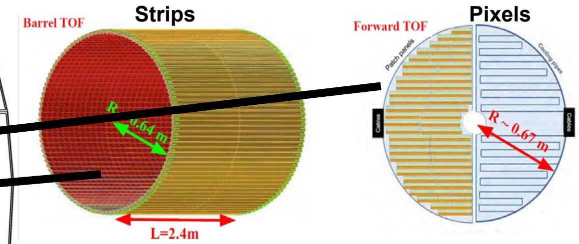


# ToF PID IN ePIC CD





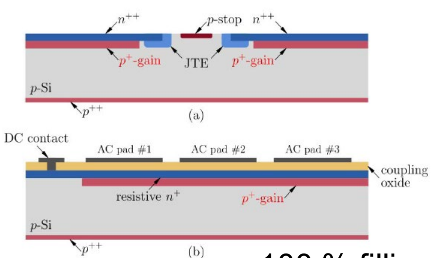

AC-LGADs

**Goals for the application in ePIC:**

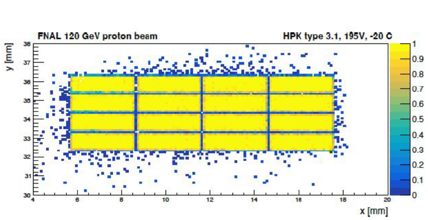
- **30 μm space resolution**
- **25-35 ps time resolution**

(DC-)LGAD

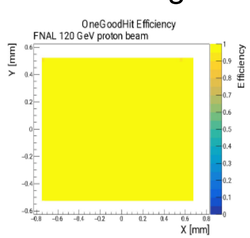
AC-LGAD




~ 100 % filling factor

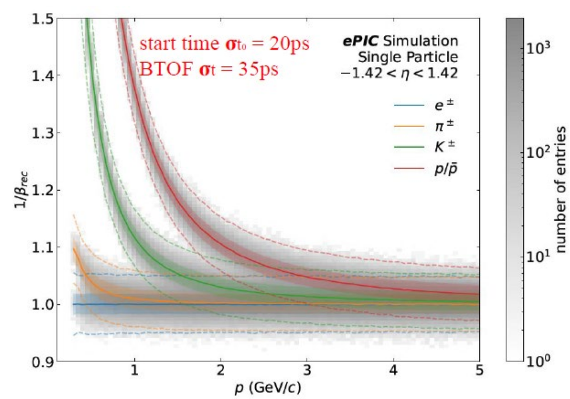



DC-LGAD

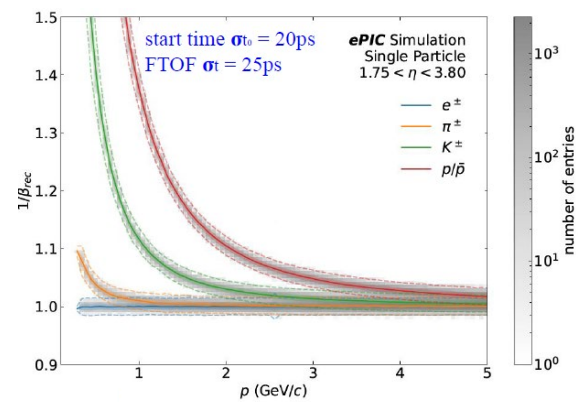



AC-LGAD

- BTOF with timing resolution of 35 ps can provide 3$\sigma$ $\pi$/K separation upto ~1.3 GeV/c




- FTOF with timing resolution of 25 ps can provide 3$\sigma$ $\pi$/K separation upto ~2.4 GeV/c

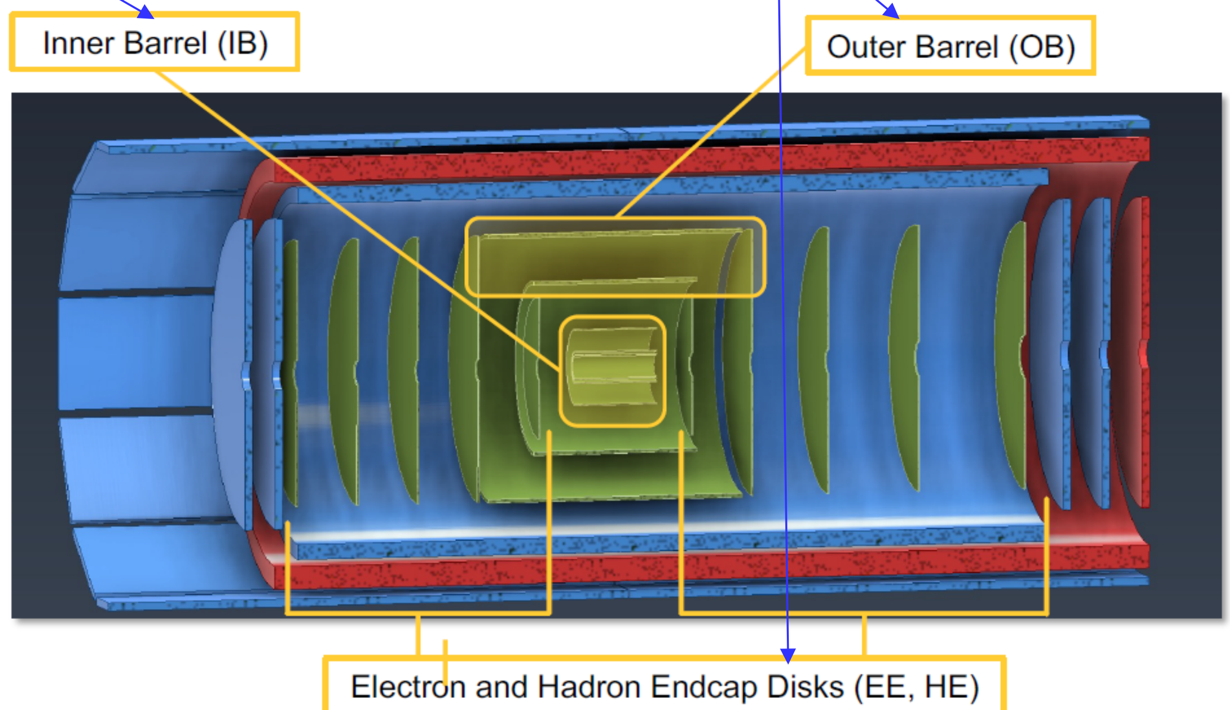


# Si TRACKING IN ePIC CD

ALICE MOSAIX

EIC-LAS: 5/6 RSUs (Scalable Readout Unit) *from ALICE ITS3* on staves

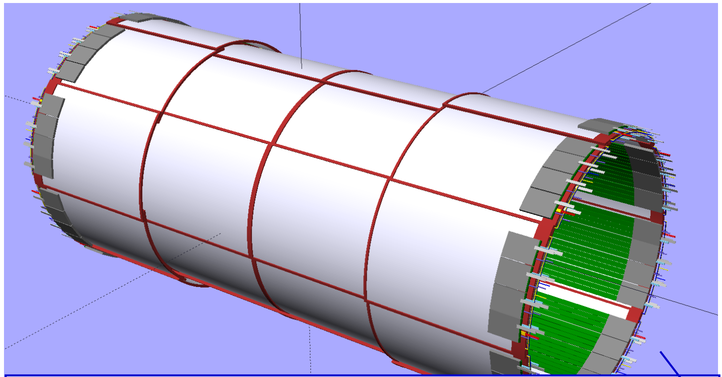
- **Inner Barrel (IB)**
  - Three layers, L0, L1, L2,
  - Radii of 36, 41, 120 mm
  - Length of 27 cm
  - $X/X_0$ ~ 0.05% per layer
  - Curved, thinned, wafer-scale sensor
- **Outer Barrel (OB)**
  - Two layers, L3, L4
  - Radii of 27 and 42 cm
  - $X/X_0$ ~0.25% and ~0.55%
  - More conventional structure w. staves
- **Electron/Hadron Endcaps (EE, HE)**
  - Two arrays with five disks
  - $X/X_0$ ~0.25% per disk
  - More conventional structure




- **Lengths for L2—L4 increase so as to project back to z = 0; disk radii adjust accordingly**

# MPGD TRACKING IN ePIC CD

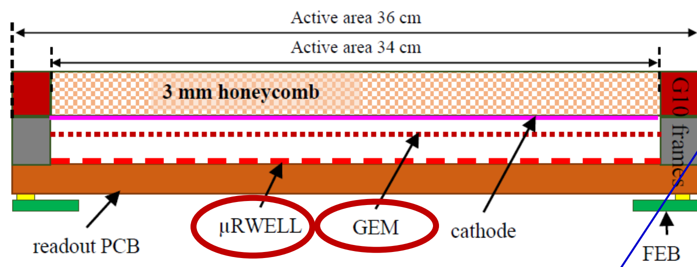
Precious synergies with RD51

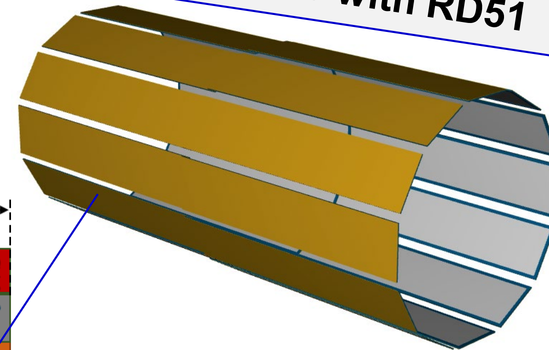


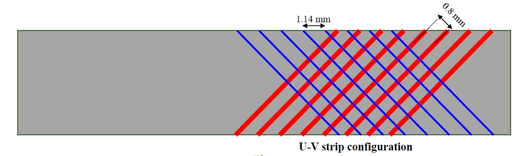
## Cylindrical MICROMEGAS

- Successful implementation at CLAS12 (Jlab)
- A single module PCB readout design, with two curvature radii (55 cm and 57.5 cm)
- Overlaps in phi and z allow for hermeticity
- Front end boards (FEBs) on system edges to reduce material budget

## 2-D readout for MPGDs in ePIC






## µR-WELL with GEM preamplification layer