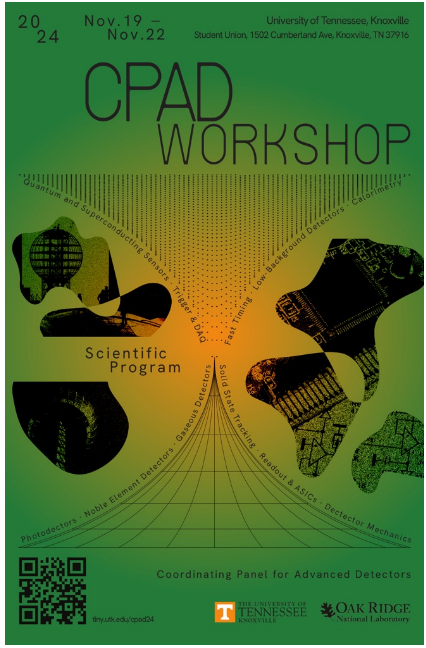
ePIC @CPAD2024

Nov 25, 2024 @TIC meeting

Bobae Kim (ANL)

Presentations about ePIC @CPAD2024



9 parallel talks and 3 posters related to ePIC Detector were presented at CPAD2024!

Barrel Imaging Calorimeter (2 parallel talks, 1 poster)

- Jared Richards: Electron and Pion Response Benchmarks for the ePIC Barrel Imaging Calorimeter (poster)
- Henry Klest: The Barrel Imaging Calorimeter of the ePIC Detector
- Bobae Kim: AstroPix for the Barrel Imaging Calorimeter in ePIC

Forward HCAL (4 parallel talks, 2 posters)

- Fernando Flor: First Test Beam Results from the LFHCal Prototypes for the ePIC Detector at the EIC
- Tristan Protzman: First Test Beam Results from the ePIC LFHCal Prototype utilizing the HGCROC Digitization
- Everett Hagen: ePIC LFHCAL Testbeam Module Production (poster)
- Cordney Nash: LFHCAL Test Modules (poster)
- Prakhar Garg: Automatization of LFHCal scintillating tile evaluation for the ePIC detector at the EIC
- Weibin Zhang: Testing a SiPM-on-tile calorimeter prototype with 200 GeV pp collisions at RHIC

pfRICH (1 parallel talk)

- Alexander Kiselev: EIC HRPPDs and their application in a proximity focusing RICH for the ePIC detector

Gaseous Trackers (1 parallel talk)

- Kondo Gnanvo: MPGD Trackers in the ePIC Detector at the EIC

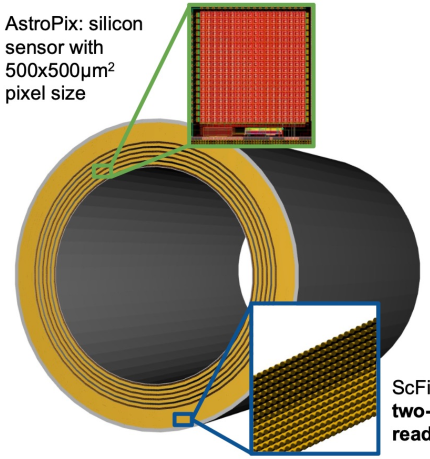
Si Trackers (1 parallel talk)

- Zhenyu Ye: MAPS Silicon Vertex Tracker and AC-LGAD Time-of-Flight Detectors for the Electron-Ion Collider

Barrel Imaging Calorimeter (1)

Barrel Imaging Calorimeter: The Concept

High-performance sampling calorimeter with Si sensors for shower profiling



ePIC Simulations: Barrel ECal Geometry Rendering

Start from mature layered Pb/ScFi technology with side-readout (same as the GlueX calorimeter) for **state-of-the-art sampling calorimeter** performance

Insert layers of monolithic AstroPix silicon sensors (ultra-low-power, developed for NASA at ANL) to capture a **3D image of the shower**

Pb/SciFi Technology

Mature technology

Pb/SciFi follows the **GlueX & KLOE Barrel Calorimeters**

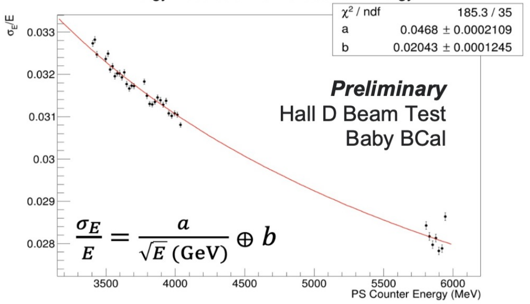
GlueX BCal Energy resolution: σ = 5.2% /√*E* ⊕ 3.6%[1)]

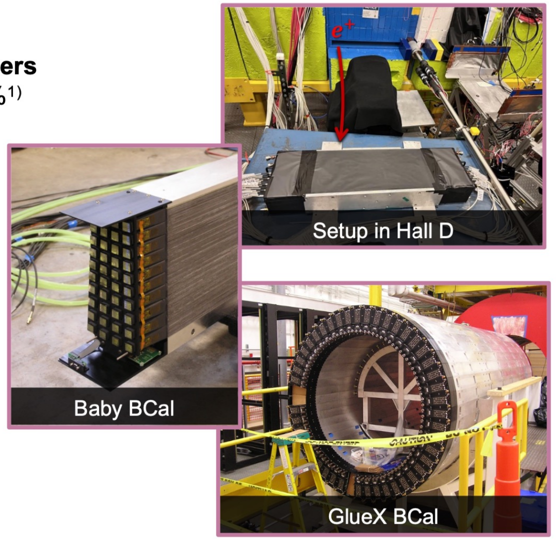
- 15.5 X_0, extracted for low energy γ < ~2.5 GeV

Position resolution in z: 1.1cm/√E [2)]

- 2-side SiPM readout, Δt measurement

Snapshot of R&D:

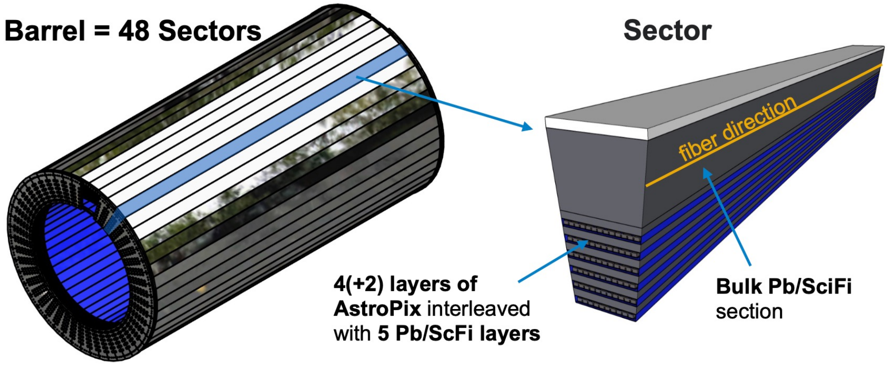




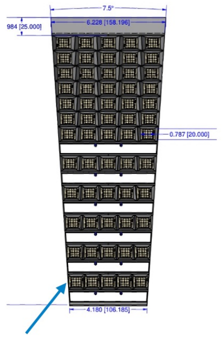
1) Nucl. Instrum. Meth. A, vol. 896, pp. 24–42, 2018
2) Nucl. Instrum. Meth. A, vol. 596, pp. 327–337, 2008

Detector Structure

Barrel = 48 Sectors



Sector End View



Length: ~435 cm

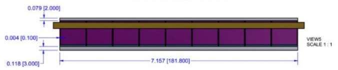
Radius: ~ 82 cm

η Coverage: -1.71 < η < 1.31

Depth: 17.1X0 at η = 0

Sampling fraction ~ 10%

AstroPix layers built from **Modules**



Module - 9 AstroPix chips daisy chained together

Pb/SciFi Layer (1.4X0)

- 5 readout cells per layers
- 1 light-guide per cell
- Instrumented with 1.2x1.2 cm HPK S14160-6050-04 SiPM

Barrel Imaging Calorimeter Technical Drawings T. O'Connor, K. Bailey

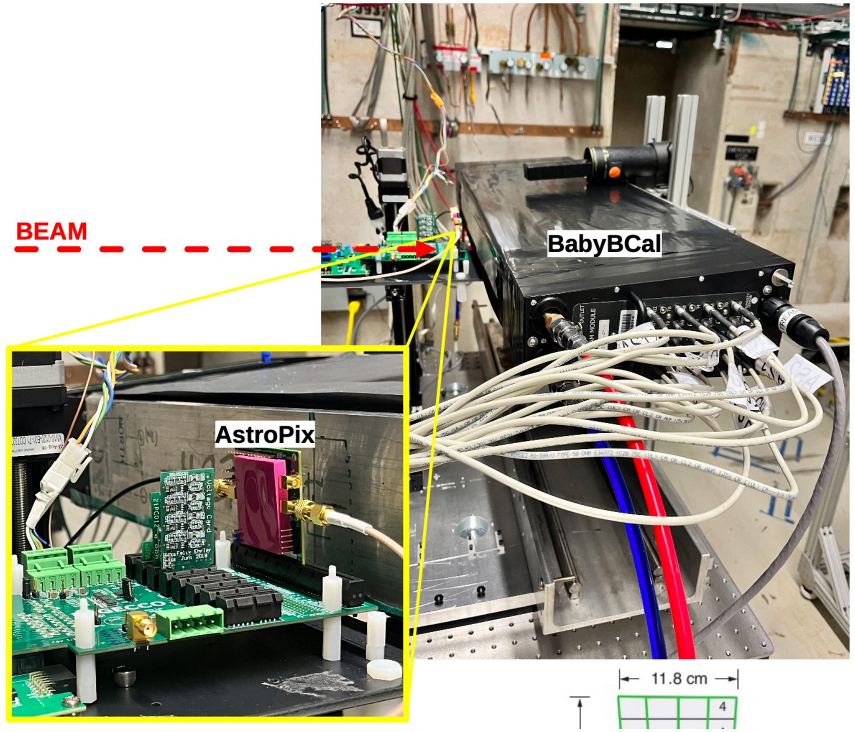
BIC (2): Beam test result

Beam test at FANL, June 2024

- e/π Beam at 4, 6, 8, and 10 GeV
- μ/π Beam at 10 GeV, inserted lead sheet absorbs electrons
- e/π PID: Two FTBF Cherenkov detectors
- Trigger: FTBF Beamline Scintillators

SETUP

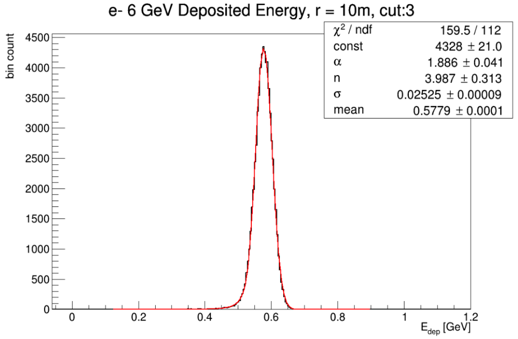
Fermilab Test Beam Facility (FTBF)
June 5-11, 2024

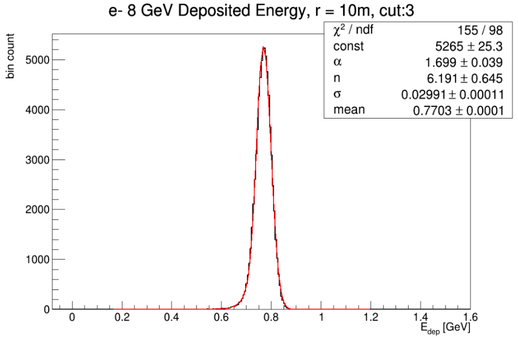


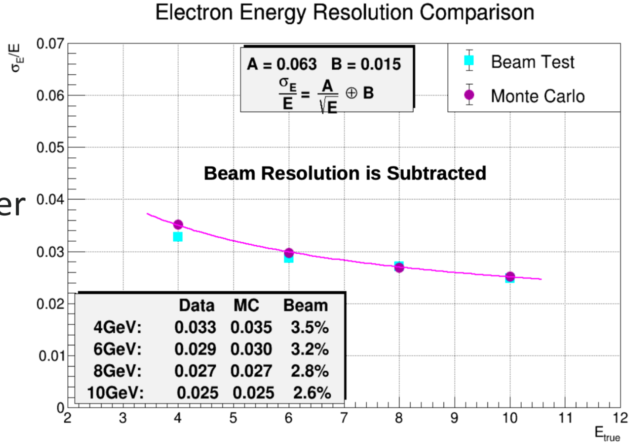
Key Challenges of barrel EM calorimeter
Energy resolution < **10%/√(E) + (2-3)%**

Calibration

- Plot MIP peaks by channel in ADC units
- Convert ADC units to Energy by adjusting MIP peaks to simulated Energy deposits

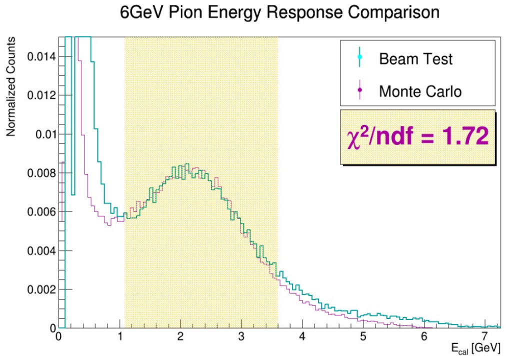


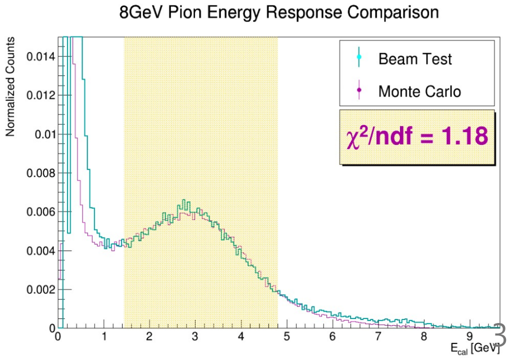




Analysis, e/π

- # of Photoelectrons was converted to Energy
- Energy was attenuated in the Scintillating Fibers
- Threshold of 1.0 MeV was applied at each SiPM
- Attenuated Energy was corrected back
- Containment Cuts applied to minimize leakage





BIC (3): Beam test result of Astropix

Testing and characterization of AstroPix_v3 is underway:

- First 120 GeV proton response: 39.41 keV for MIP which sits well within dynamic range (25 keV - 200 keV) in v3
- The proof-of-concept demonstration of the integration of two daisy-chained AstroPix layers in a beam-like environment

For the upcoming beam test at FNAL in 2025,

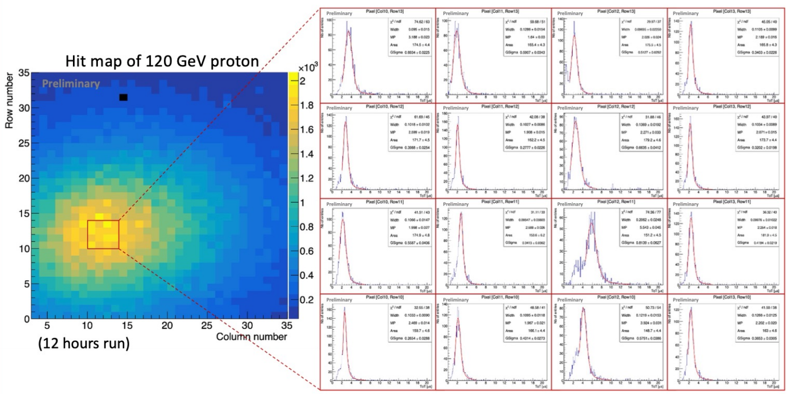
- Integration of AstroPix & Pb/SciFi DAQ using **HGCROC** (CALOROC)
- External clock in the current AstroPix readout system

Performance Test Results (3)

Beam Test of AstroPix_v3 (1)

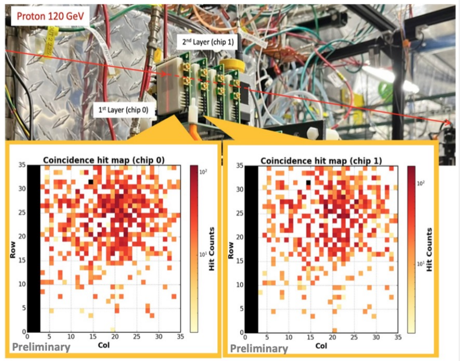
Single layer

- Data collected with a 120 GeV proton beam.
- The hit map reveals the proton beam profile: **$\sigma_x \times \sigma_y$ = 5.8 mm × 4.5 mm**
- Histograms of collected ToT values for the marked pixels with MIP response
  - Fit with Landau convoluted with gaussian function
- Behaves well in the particle rates of 13 kHz



Double layer

- 120 GeV proton beam events from the first two layers, **read in coincidence**, showing the position of the hit pixel.
- The **proof-of-concept demonstration of the integration of two daisy-chained AstroPix_v3 layers in a beam-like environment**



Performance Test Results (4)

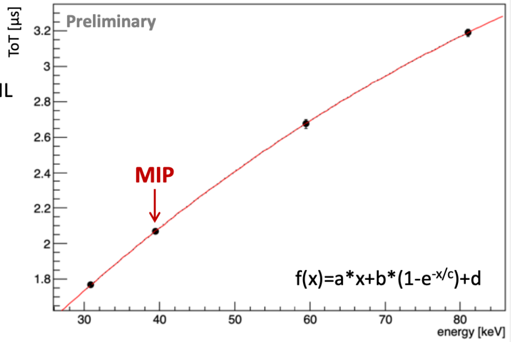
Beam Test of AstroPix_v3 (2)

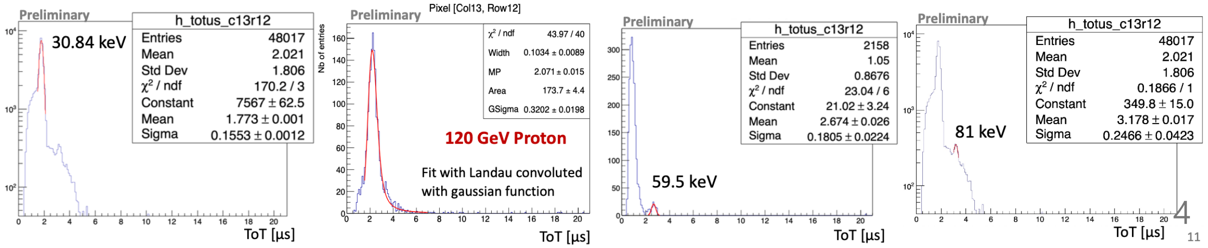
One example pixel [column 13, row 12] in single layer

- ToT Histograms of measuring gamma energies to obtain a calibration curve
  - Ba-133 (30.84 keV and 81 keV), Am-241 (59.5 keV) at bench test in ANL
- Calibration curve fitted using pol2 or linear+exp. decay functions
- MPV of 120 GeV Proton at pixel [c13,r12] ~ **39.41 keV**
- Paper in progress

	Ba133 (30.84 keV)	Proton (120 GeV)	Am241 (59.5 keV)	Ba133 (81 keV)
$\mu \pm \sigma$ [μs]	1.773 ± 0.1553	2.071 (MPV)	2.674 ± 0.1805	3.178 ± 0.2466
E_{res} (FWHM)	20.6 %	.	15.9 %	18.2 %

Calibration curve as a function of energies [keV] at [c13, r12]

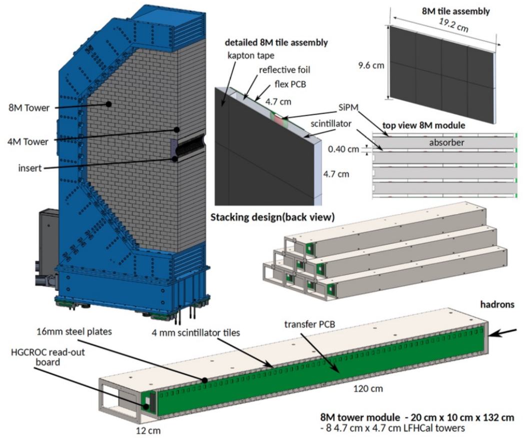




Forward HCAL: LFHCal

- Steel absorber, 4×2 plastic scintillator tiles + SiPM
  → Total 74 scintillation layers for beam test
- Module Production for beam test
- Beam test at CERN using HGCROC readout and CAEN readout
  - Muon @ 5 GeV
  - Electrons @ 1, 2, 3, 4 and 5 GeV
  - Pions @ 3, 5, 8, and 10 GeV
  - Additional hadrons @ 5, 8, 10 and 15 GeV
- QA for scintillator tiles

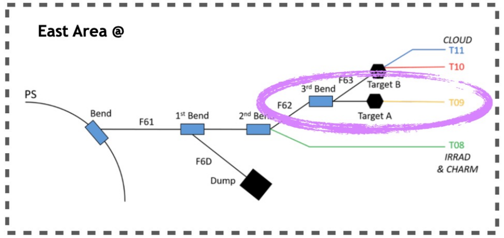
LFHCal at ePIC Purpose and Design



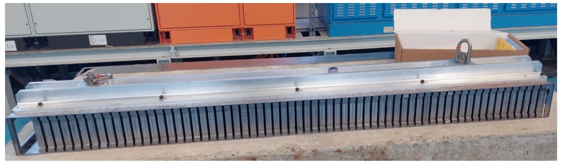
- When colliding electrons into a proton/ion, copious amounts of hadrons are generated in the scattering process
  - Majority of these particles will be produced in the same direction as the hadronic beam
  - Jets of particles of energies up to 150 GeV are thus expected to reach the forward region of the ePIC detector
  - Poses challenges at forward rapidities ($\eta > 3$)
    - Worsened tracking momentum and angular resolution
- The Longitudinally Segmented Forward Hadronic Calorimeter (LFHCal) will capture highly energetic particles up to ($\eta < 4$)
  - Providing excellent energy and spatial resolution
  - Located at z = 3.68 m from interaction point
  - 1.52 cm steel absorber layers alternating with ~600k 0.4 cm plastic scintillators coupled to SiPMs
  - Composed primarily of 8M and 4M modules
- Dedicated high granularity LFHCal insert closest to beam pipe
  - Talk by W. Zhang (Wednesday @ 4:15PM)

LFHCal Test Beam Overview and Objectives

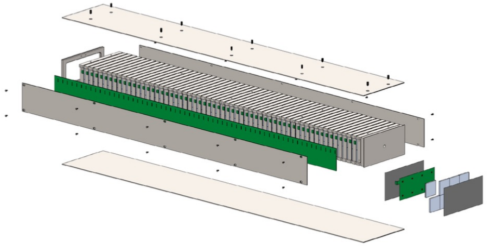
- Test Beam took place at the T09 beam line in the CERN East Area
  - A multi-target configuration in in place in order to produce different types of secondary beam types
    - T09 beam line received ~3 spills per every 40 second cycle
- Two continuous weeks of beam time (August 28 - September 11)
  - Week 1: HGCROC readout
    - Talk by T. Protzman (Wednesday @ 4:00PM)
  - Week 2: CAEN DT5202+DT5215 readout



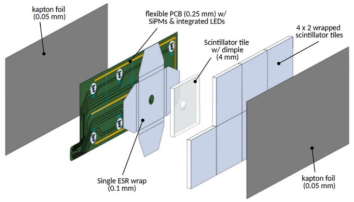
- Purpose was to fully expose the LFHCal module to multiple beam species in the 1 - 10 GeV energy range at different operating SiPM Voltages
  - Muons
    - Cell-by-cell MIP calibration
  - Electrons
    - Response and resolution
      - Single cell hit spectra and SiPM saturation effects
      - GEANT4 comparison
  - Pions
    - Longitudinal shower profiles
    - Lateral containment of shower outside of acceptance



LFHCal at ePIC Purpose and Design



- Each active scintillator layer is segmented into plastic tiles (5 x 5 x 0.4 cm), wrapped with highly reflective film
- Scintillation light from each tile is detected by the SiPM encased by a circular dimple in the center
- SiPM-tile couples are attached to a thin, flexible printed circuit board carrying the readout to the side of each module
  - 68,264 read-out channels in total
    - *This talk:* one channel = one "cell"



- 74 scintillation layers were assembled and tested at ORNL prior to the test beam at CERN
  - Posters by E. Hagen and C. Nash
- Various QA efforts in place in order to test the quality of the tiles (e.g. dimensional uniformity and light yield)
  - Talk by P. Garg (Wednesday @ 11:30AM)

Forward HCAL: LFHCal (1)

Module Production for beam test

SiPM calibration using LED and cosmic test

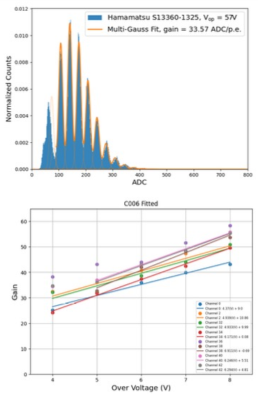
Construction

Each layer assembly consists of 8 tiles put together in a similar fashion to the tiles

The flexible PCB boards are then attached to the tile assemblies, so that the SiPMs fit into the dimples of the tiles

Completed a total of 76 layer modules, leaving 11 spares for the test beam

SiPM Characterization

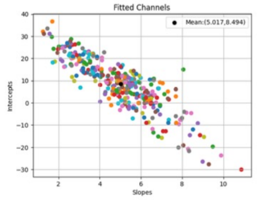


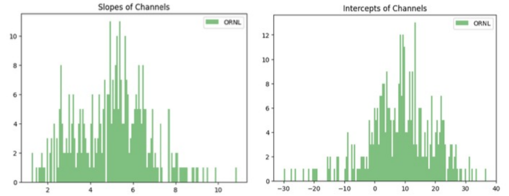
For the purpose of calibrating ADC to the number of photons in every SiPM

- Tested by exposing SiPMs to an LED with a 5ns pulse length for 3 ~ 5 minutes.
- performed with a different HV bias to obtain voltage scans for each board
- Fitting each channel with a multi-gaussian function that grouped the peaks together
- Data put into a linear regression function which excluded any data points where their Poisson distributions < 0.5, or standard deviations > 20

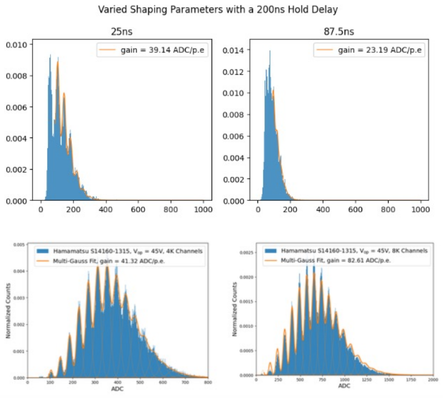
Most channels behaved as expected

- a mean increase of 5.017 for every volt
- an mean intercept of 8.494





Impact of Digitization Settings



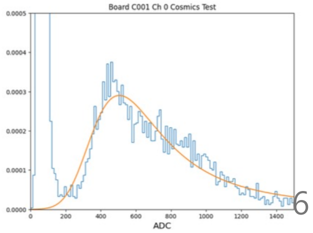
Inversely proportional relationship between the shaping parameter and the gain.

Directly proportional relationship between the number of channels and the gain

Cosmics Testing

For the purpose of finding the most probable amount of photo-electrons going through the channel during a hit.

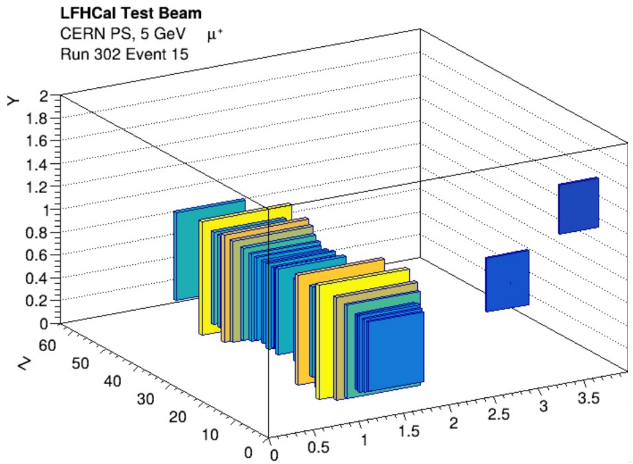
- Found by comparing the peak of the landau gaussian to the ADC to PE conversion found from the SiPM characterization
- For these tests, 8 layer assemblies were stacked and tested all together for roughly 16 - 24 hours



Forward HCAL: LFHCal (2)

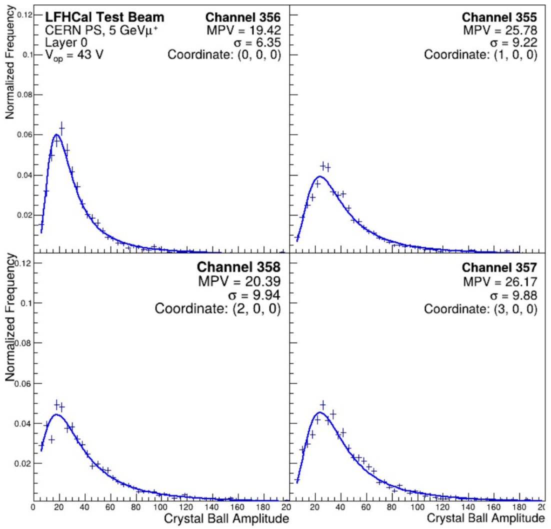
Beam test using HGCROC readout

- Full module at CERN PS
- First μ+ ADC results



MIP peak

- Fit for each channel the crystal ball amplitude distribution of muon hits
- Known good channels show preliminary MIP peak
  - Deliberately low to enable measurement of many-GeV showers
  - Still considerable work to do to refine



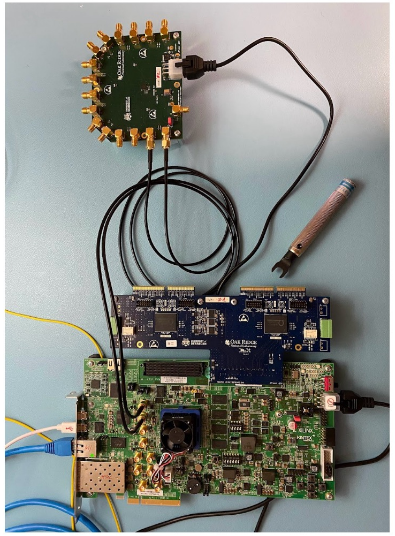
HGCROC readout

- Developed for CMS HGCAL Project
  - H2GROC features front end for SiPM readout
  - Measures ADC, Time of Arrival (ToA), and Time over Threshold (ToT) with large dynamic range
  - Adapted to sampled mode for ePIC streaming readout
  - EIC-specific CALOROC variant in development
- Two H2GCROC3A ASICs driven by Xilinx KCU 105 evaluation board
  - Each H2GCROC divided into two 36 channel halves
  - 4 KCUs, 8 H2GCROC needed to read 512 channel calorimeter prototype
- H2GCROC applied to ALICE FoCAL-H
  - Talk by S. Jia

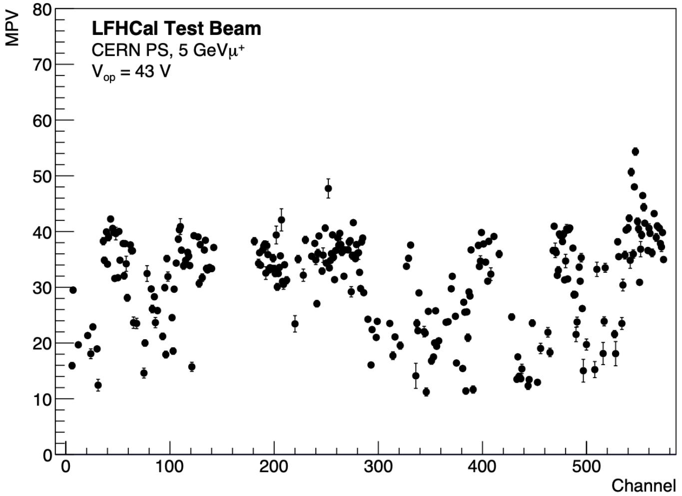
Common clock

Protoboard 2.0 with two H2GROC3A

Xilinx KCU



MPV per channel



- First steps towards understanding electron and hadron data
  - Create per channel calibration to give all channels an equal MIP response

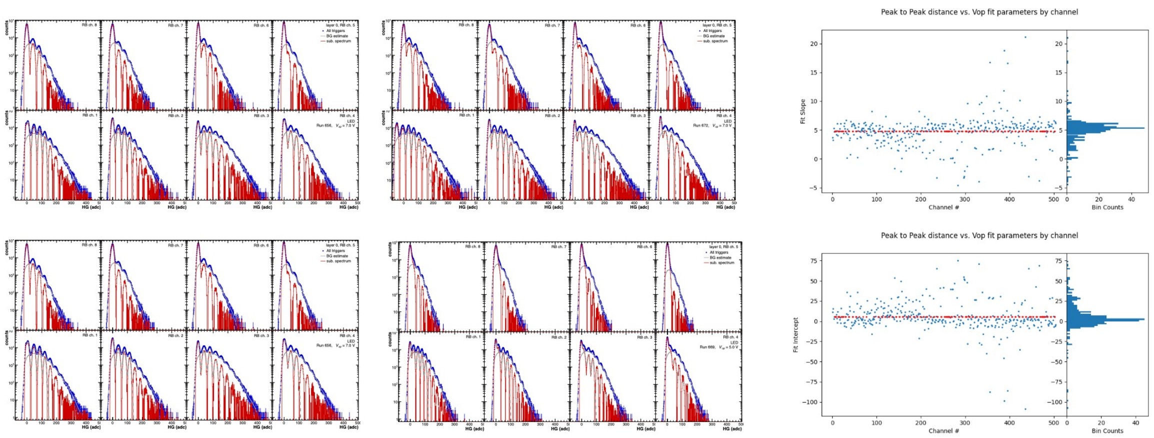
Forward HCAL: LFHCal (3)

Beam test using CAEN DT5202+DT5215 readout

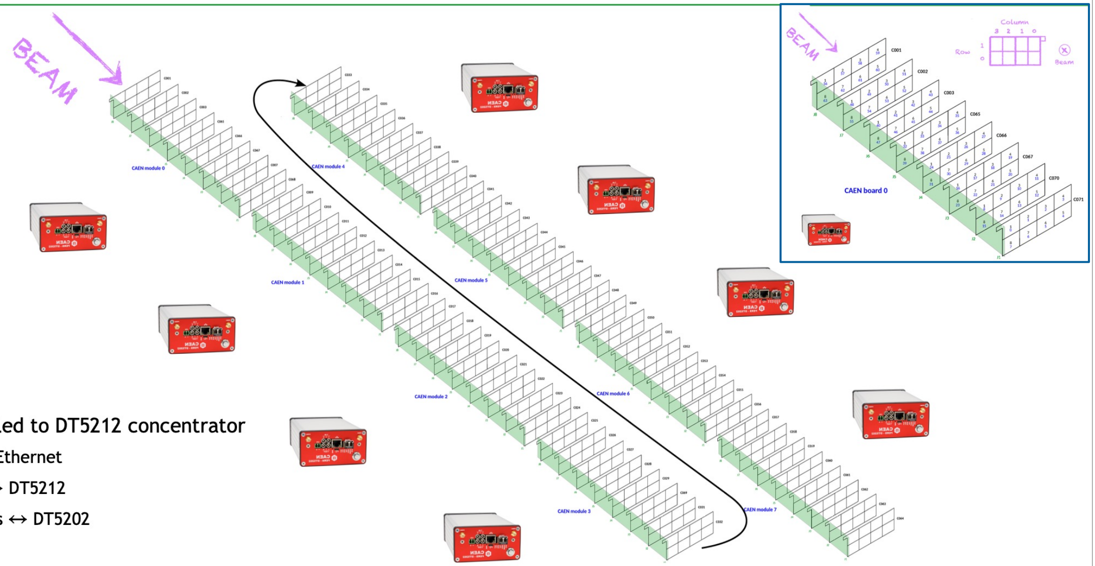
- DT5202 x 8 coupled to DT5212 concentrator
- First look at results from Fall 2024 Test beam at CERN PS using CAEN readout
- Cell-by-cell MIP calibration performed across entire 64-layer module (512 cells)

SiPM LED Scans: ADC-to-PE Conversion

- Single photon to ADC conversion for all cells show consistent gain for test beam operating voltages

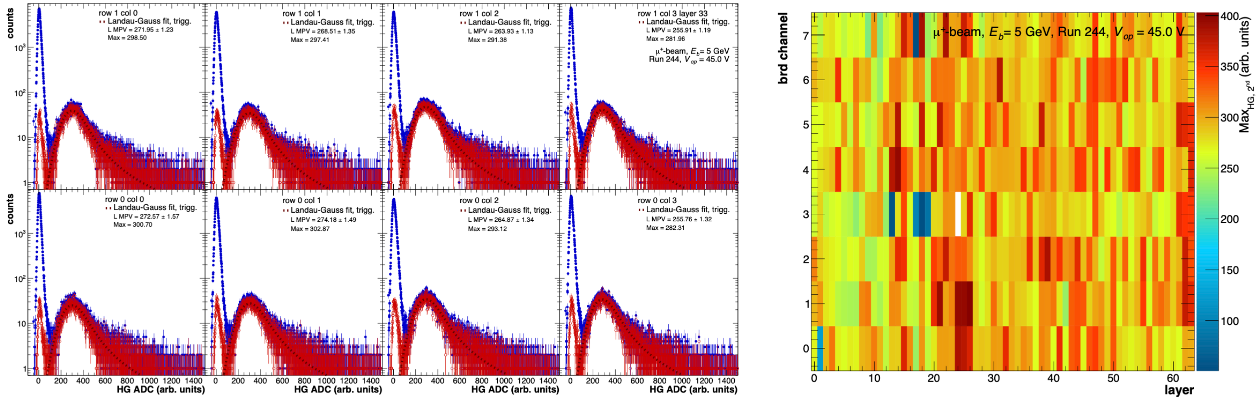


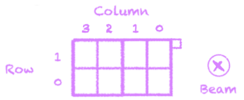
Test Beam Set Up (Week 2: CAEN DT5202s)



- DT5202 x 8 coupled to DT5212 concentrator
  - PC readout ↔ Ethernet
    - Ethernet ↔ DT5212
      - TDLinks ↔ DT5202

MIP Extraction: A First Look



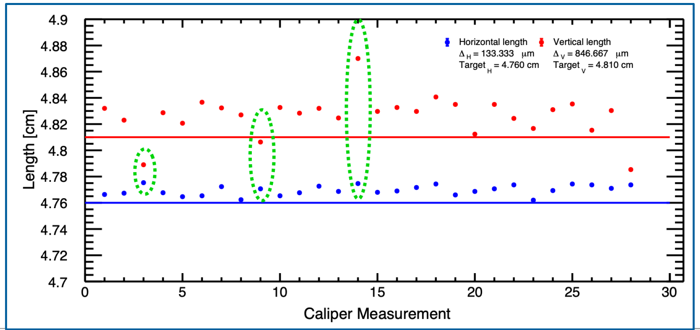


- Noise subtracted muon data with a Landau fit was used to extract MIP signal
- ADC distribution shifted by pedestal values to account for a large proportion of noise
- MIP signals can then be scaled from ADC to single photon spectra for comparison across operating voltages

Forward HCAL: LFHCal (4)

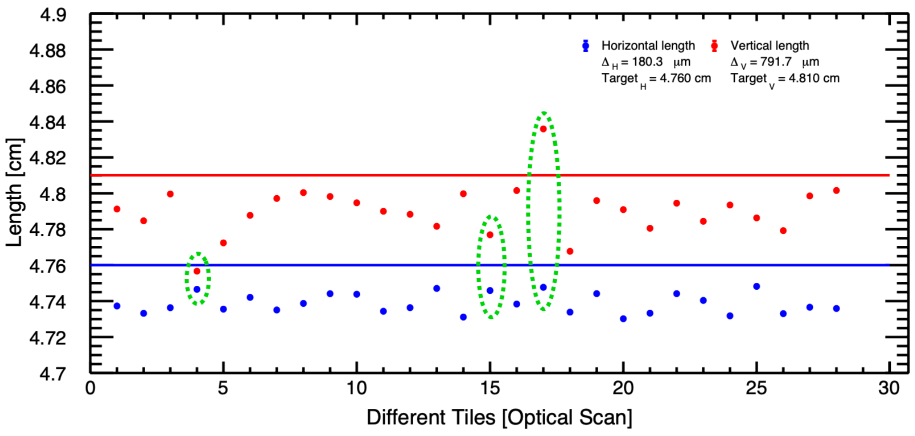
Automatization of LFHCal scintillating tile evaluation

- evaluate the quality of these tiles in terms of Dimensions (by optical scan) and Light yield (by Sr90 scan)
- Economic and easy to use setup for tiles characterization has been developed and initial results are very satisfactory
- Some fine-tuning is still in progress to be ready for prime time



Measurements with Optical Scan setup

- Indeed the image processing process can also identify them!
- Note that the numbers are lower then the calipers (in microns) but gross features are captured
- Can be of great use for sorting anomalous tiles because of machining tolerances



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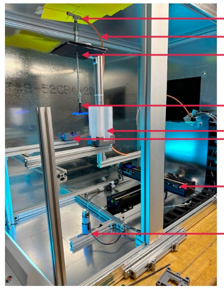
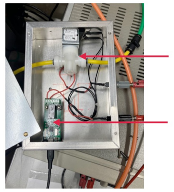
Optical Scan Setup



- Easy to use
- Minimum user interference required
- Fast and reliable



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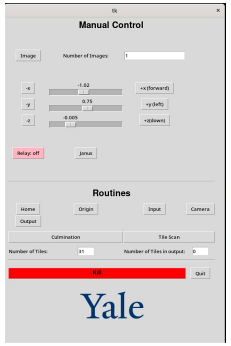
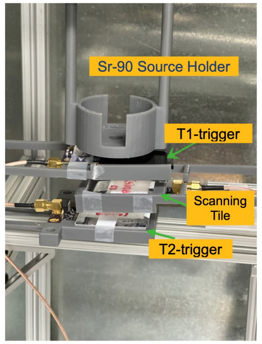
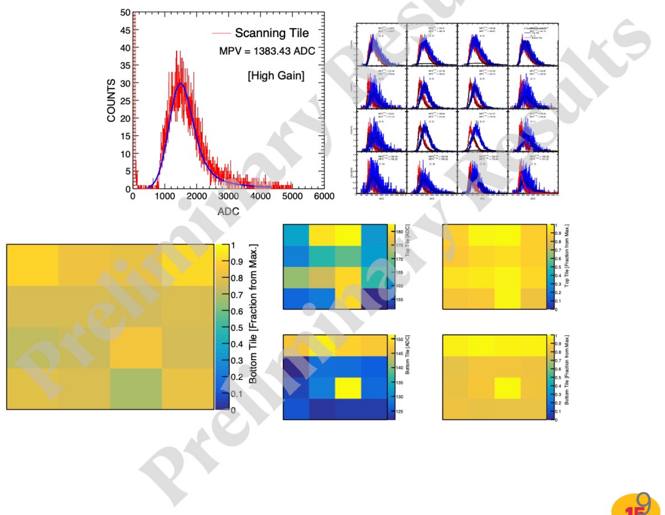
Sr-90 Scan Set-up





Some Preliminary Results From scanning

- Establish Proof of Principle
- Establish Communication from GUI to Electronics, DAQ and motion control
- Automatization worked successfully and reliably.
- Few minor modifications are in progress! after learning from the first scanning process



15

pfRICH: HRPPDs (1)

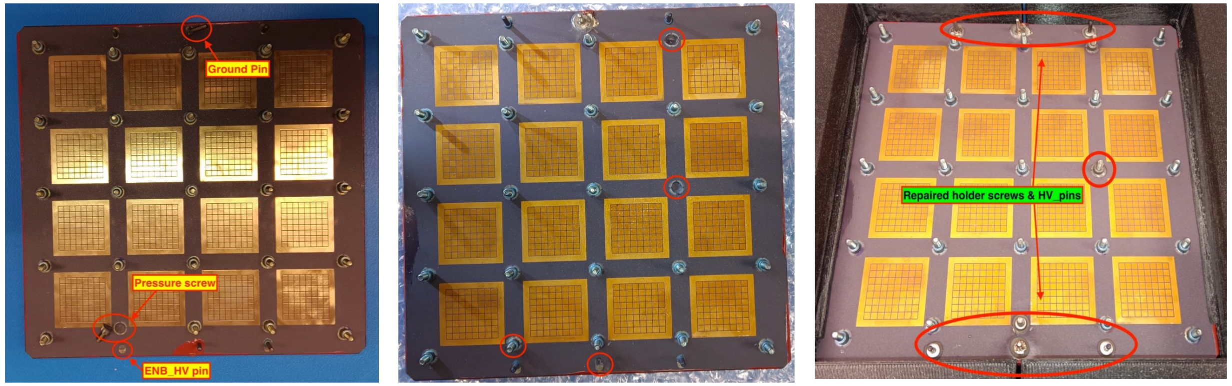
EIC HRPPD photosensors

- A 120mm x 120mm DC-coupled MCP-PMT produced by Incom Inc.
- 104 mm x 104 mm active area (~75% geometric efficiency)
- 5mm thick fused silica window with a bialkali photocathode
- A pair of 10 μm diameter pore MCPs in a chevron configuration

Demonstrate production capability and reproducibility of key performance parameters

- Gain, QE, Photon Detection Efficiency (PDE), Dark Count rates (DCR), timing resolution, ...

Highlights from initial QA process at JLab

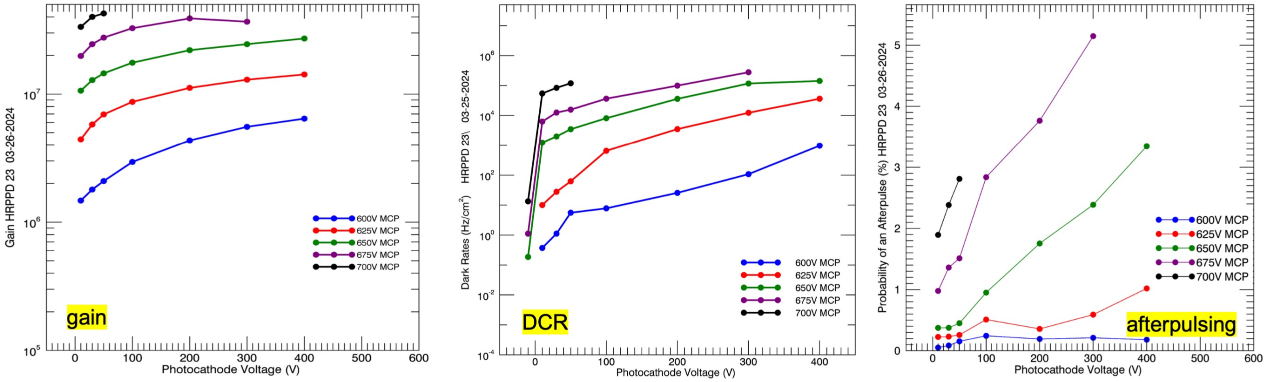


Examples of failed HV pins and screws

A present fix by Incom

- ➢ *Several HRPPDs showed issues with falling off HV pins and mechanical screws*
  - ➢ Those were promptly fixed by Incom
- ➢ Solutions for a “final EIC HRPPD design” are being developed
  - ➢ Get rid of HV pins; embed screws into the ceramic anode body

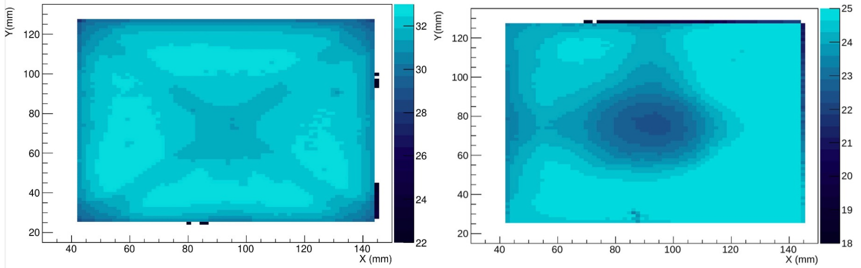
Incom’s internal testing: DCR, gain, afterpulsing



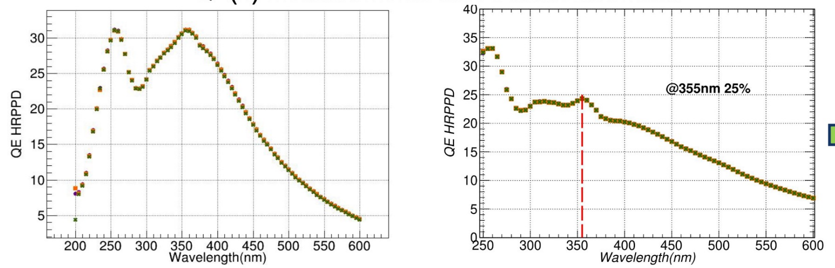
- ➢ Newly developed ALD process allows for a high gain at a remarkably low bias voltage
  - ➢ HRPPD #23: dark rates at mid-10^6 gain are below 1 kHz/cm^2 with afterpulsing on a ~1% level
- ➢ *Gain uniformity yet to be confirmed, especially towards the acceptance edges*

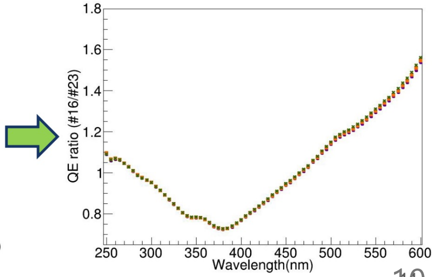
QE measurements at BNL

2D surface scans @ 365 nm



QE(λ) measurements with a monochromator





HRPPD 16 (sealing tank #1)

HRPPD 23 (sealing tank #2)

HRPPD 23 / HRPPD 16 QE ratio

- ➢ Pretty uniform across the active area
  - ➢ Watch the scale!
- ➢ Origin of non-uniformity is well understood
- ➢ All HRPPDs sealed in tank #1 have peak QE way above 30%

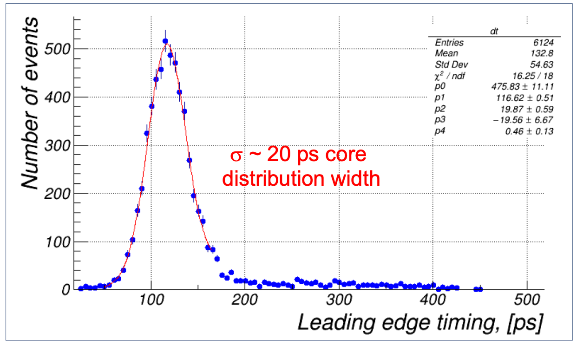
pfRICH: HRPPDs (2)

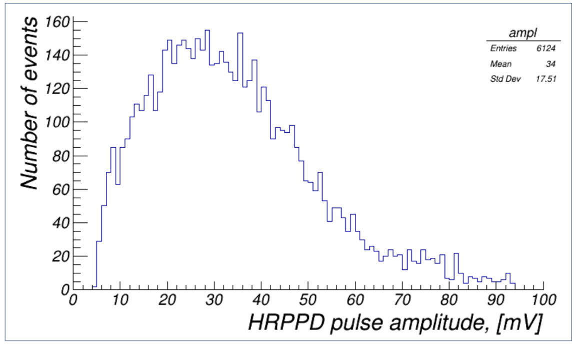
EIC HRPPD photosensors

- PDE and gain uniformity scans to be completed at BNL on a time scale of few months
- B-field resilience studies are planned at BNL, CERN (by INFN groups) and Argonne
- Aging studies are planned at JLab, INFN Trieste and BNL
- A final design and test production pass is anticipated (depends on the full evaluation outcome)

Single photon timing resolution using Elmo fs laser

- ➢ Laser beam focused on a single HRPPD pad center; intensity tuned down to >95% empty events
- ➢ HRPPD signal used for triggering (5 mV effective threshold)
  - ➢ To increase data taking efficiency
- ➢ Signal waveform data taken with a Tektronix MSO66B scope (50 GS/s, 8 GHz ABW)
  - ➢ Leading edge fits [10% .. 90%] performed offline; $\Delta t = t_{HRPPD} - t_{FastPD}$ is a plotted quantity



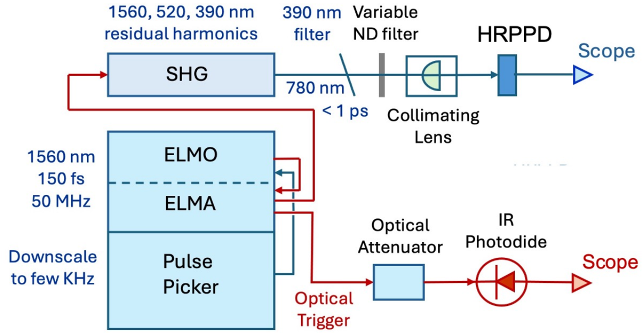


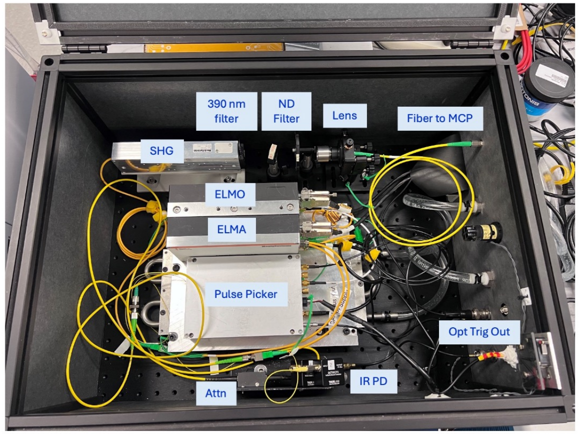
HRPPD 15: bias voltage 775 V, photocathode voltage 100 V (gain ~1.5*10⁶)

Elmo 780 femtosecond laser system at BNL

Menlo Systems Elmo 780 Erbium Fiber Femtosecond Laser

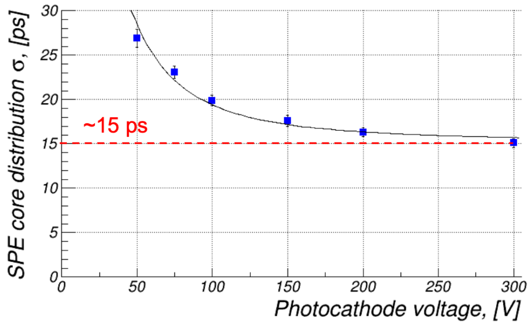
ELMO = Primary Laser Oscillator
ELMA = Optical Amplifier
SHG = 2nd Harmonic Generator



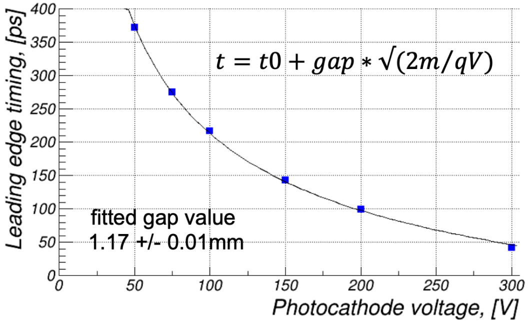


We make use of a very low intensity 4th harmonic @ 390 nm

Single photon timing resolution using Elmo fs laser



Single photon timing resolution



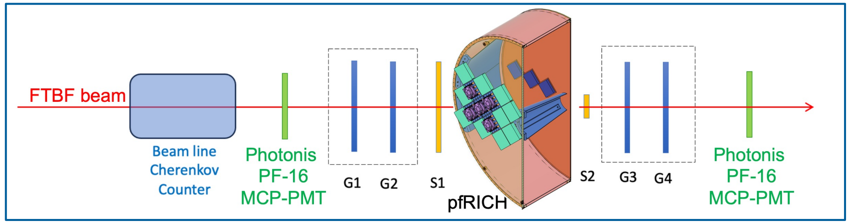
Primary electron drift time PC->MCP#1

- ➢ SPE timing resolution is below 20 ps for nominal HRPPD 15 HV settings (bias 775 V, PC 200 V)
- ➢ A scale cross-check: primary electron drift time decreases with PC voltage as expected
  - ➢ Nominal PC->MCP#1 gap is 1.1 mm per design [compare to a fit value of ~1.2 mm]

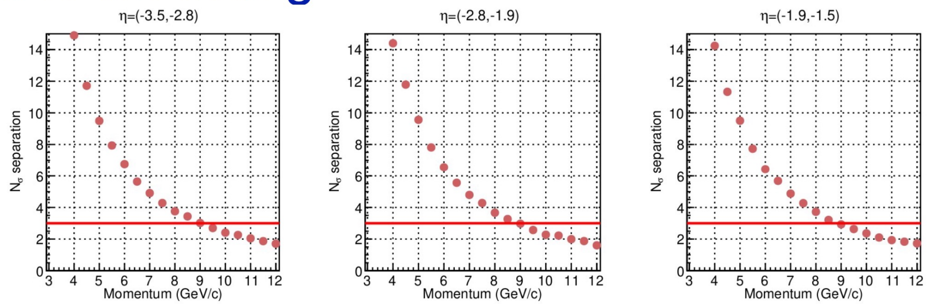
pfRICH (3)

pfRICH with HRPPD photosensors meets EIC Yellow Report requirements
- Track-level p/K/p identification up to 7 GeV/c (or higher, if efficiency can be somewhat sacrificed)

pfRICH prototype beam test at Fermilab is planned for spring 2025
- Confirm p/K separation reach (ring imaging) and high-resolution timing performance at once



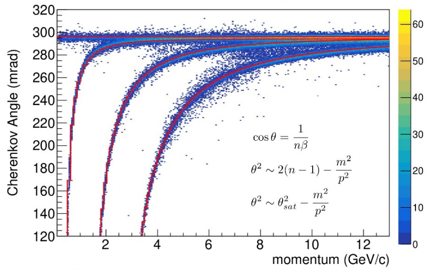
GEANT modeling



π/K separation in pseudo-rapidity bins

- ➢ Standalone GEANT4 code with (almost) all known optical effects included
- ➢ Event-level digitization / reconstruction chain
  - ➢ χ^2 based algorithm with a full combinatorial hit-to-track ambiguity resolution
- ➢ Comfortably reach 7 GeV/c momentum range with a higher than 3σ π/K separation level

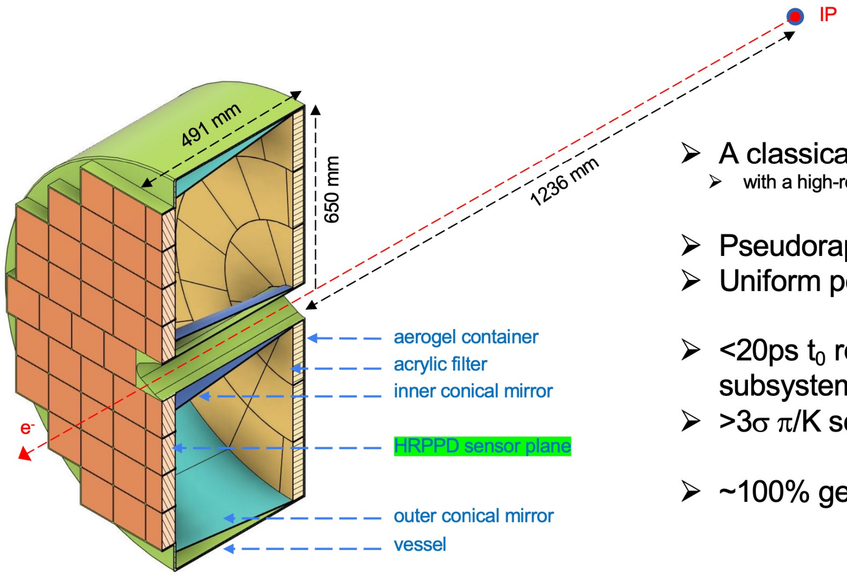
Momentum Vs Cherenkov angle (track)



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

21

pfRICH for ePIC detector electron-going endcap



- ➢ A classical proximity focusing RICH
  - ➢ with a high-resolution timing capability
- ➢ Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- ➢ Uniform performance in this $\{\eta,\phi\}$ range
- ➢ <20ps t_0 reference for the ToF subsystems
- ➢ >3σ π/K separation up to ~ 7.0 GeV/c
- ➢ ~100% geometric efficiency

20

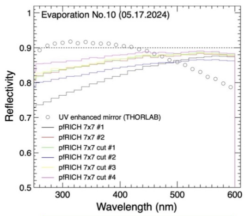
pfRICH prototyping

Mandrel (Stony Brook)

End rings (Purdue)

Vessel construction is in progress

Mirror sample (Stony Brook)

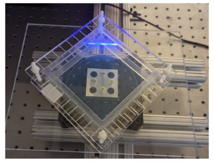


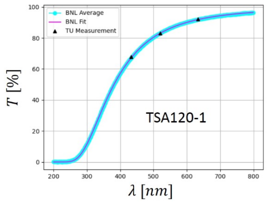
Reflectivity data (BNL)

Mirror reflectivity approaches a target goal of 90%

Tile	TU (λ = 403 nm)	AF (λ = 405 nm)
TSA88-1	1.0398 +/- 0.0007	1.0390

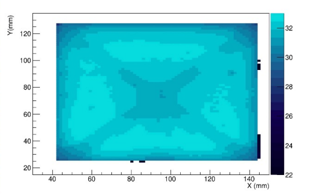
Refractive index study (Temple)



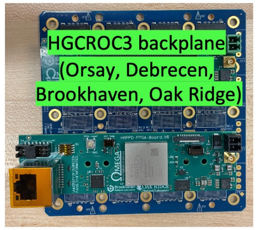


Transmission data (Temple, BNL)

First **aerogel** samples look very promising



QE uniformity scan (BNL)



HGCROC3 backplane (Orsay, Debrecen, Brookhaven, Oak Ridge)

HRPPD evaluation and **interface work** ongoing

22

Gaseous Trackers: MPGD (1)

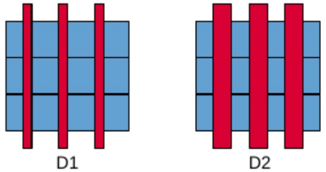
MPGD subsystems in ePIC Central tracking detectors:

- **CyMBAL: Barrel Inner Cylindrical Micromegas Layer**
  - 12 cm X 12 cm micromega prototypes tested.
  - Module prototype is in progress.

CyMBAL - Ongoing R&D

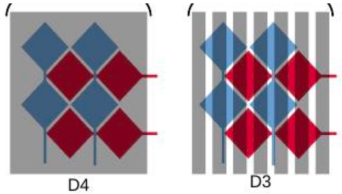
Several 12 cm × 12 cm low material budget (0.2% X0) micromegas prototypes tested with various R/O pattern and resistive motifs

Straight strips

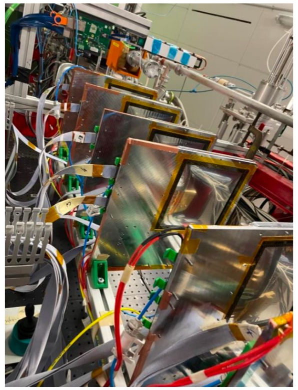


- D1: pitch from 0.5 to 1.5 mm, interstrip 25%
- D2: pitch 1 mm, interstrip 50%
- Resistive layer: full, resistivity ~10MΩ/□

ASACUSA strips

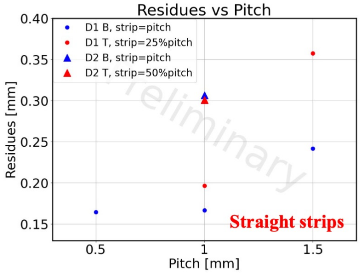


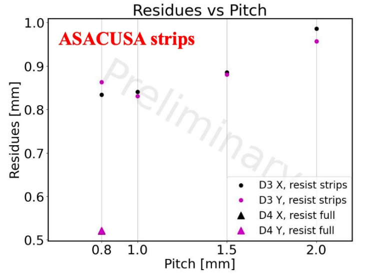
- D3: resistive strips of 500µm pitch
- D4: full layer with resistivity ~500kΩ/□



MAMI beam test (June 2023)

- 880 MeV electron beam
- ALPIDE-based reference telescope
- Important multiple scattering effect
- Geant4 simulations to cross check

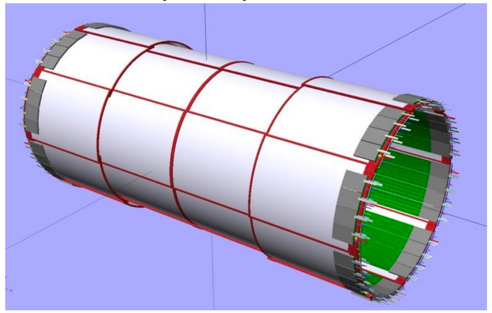




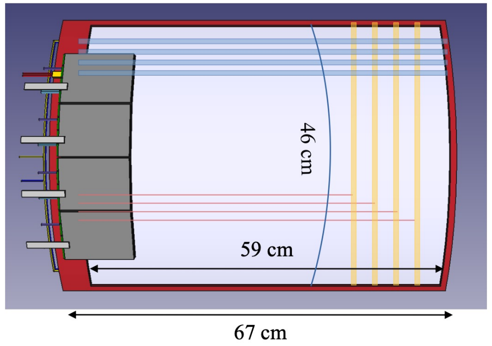
ePIC Barrel Inner MPGD Layer - CyMBAL

Cylindrical Micromegas Barrel Layer (CyMBAL)

CyMBaL layout in ePIC



CyMBAL module design



Requirements:

- Spatial resolution ~150µm
- Time resolution ~10ns
- Light, less than 1% X0
- Hermetic
- Tight space: ~5cm in R
- Magnetic field: ~2T

Detector layout:

- 32 modules: 8 modules in ϕ × 4 modules in z
- Full overlaps in ϕ and in z for hermeticity
- 1024 readout channels/module
- 32K readout channels

Module dimensions

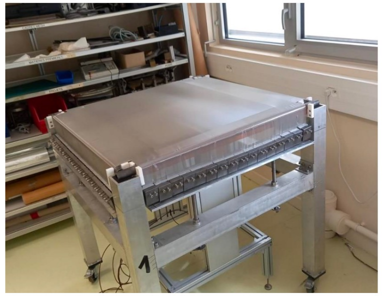
- Z = 67 cm
- R*phi = 48 cm

Active zone dimensions

- Z = 59 cm
- R*phi = 46 cm

CyMBAL module: Toward a scale 1:1 prototype

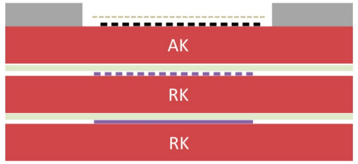
Mesh tensioning system: it allows us to reach low tension values



- Bulk of a resistive CLAS12 PCB
- Bent in shape

Low material budget: Achieved by stretching flexible PCB on a carbon frame

Mesh – resistive layer



R/O flexible PCB (Kapton)

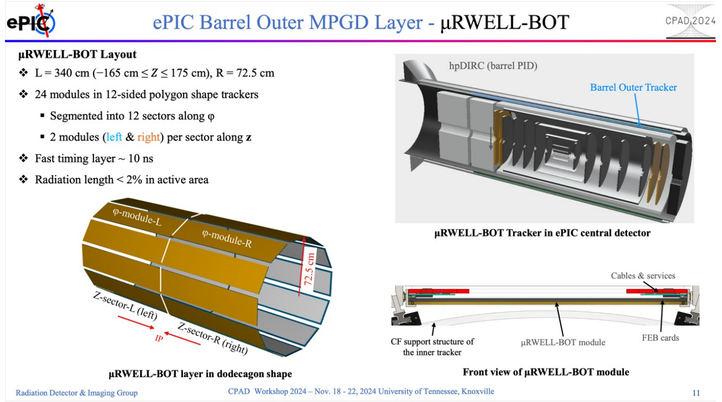
Photo-resistive material:

- Pyralux out of production
- Switched to Vacrel (was used in the past)
- Difference film thickness (from 64 µm to 50 µm)
- Difference in composition:
  - Check adherence
  - Adjustments of the development stage
- Tests with 40x40cm2 detectors ongoing

Gaseous Trackers: MPGD (2)

MPGD subsystems in ePIC Central tracking detectors:

- **µRWELL-BOT**: Barrel Outer MPGD tracker
  - Thin-gap double-amplification GEM-µRWELL hybrid detector

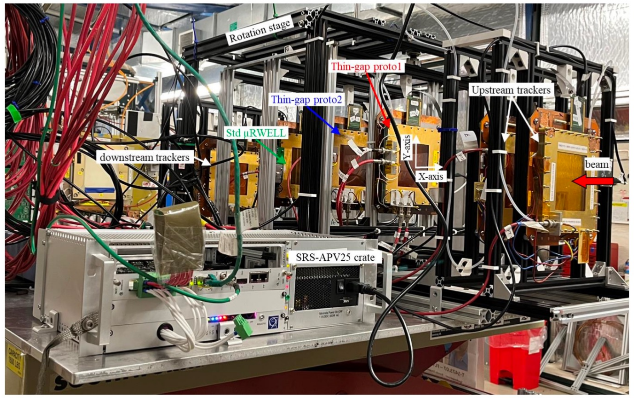


Thin-gap GEM-µRWELL hybrid detector: Proof of concept

CPAD 2024

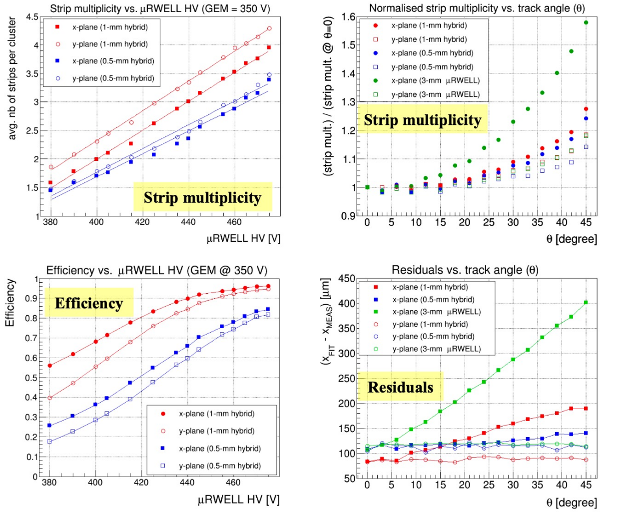
Performance in beam of thin-gap GEM-µRWELL hybrid (FNAL 2023)

- ~10 small thin-gap MPGD prototypes tested
  - All 3 MPGD technologies: GEM, µRWELL, Micromegas tested
- 2 thin-gap GEM-µRWELL hybrid & 1 standard gap prototypes
  - 0.5-mm tin-gap, 1-mm thin-gap & 3-mm std-gap



Beam test setup

Space resolution < 150 µm & efficiency > 92% on for 1-mm prototype (red) - track angle range of between 0 – 45 degrees

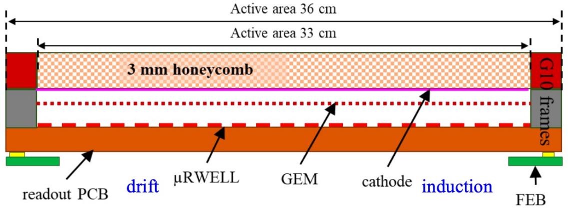


Thin-gap GEM-µRWELL hybrid - R&D and prototyping

CPAD 2024

3 critical components of thin-gap MPGDs:

- **Thin gap drift:** 1 mm gas gap in the ionization region
  - Improve both spatial and time resolution
  - Reduce E × B effect
- **Double amplification:** High gain & stable detector operation
  - Hybrid amplification ➔ GEM pre-ampl. + µRWELL for 2nd ampl.
  - Compensate for ionization charges loss in the thin gap
- **Capacitive-sharing structures:** Coarse pitch / Excellent spatial resolution
  - Versatile readout pattern (U / V, X / Y, zigzag strips …)
  - K. Gnanvo, NIM A1047, 167782 (2023)

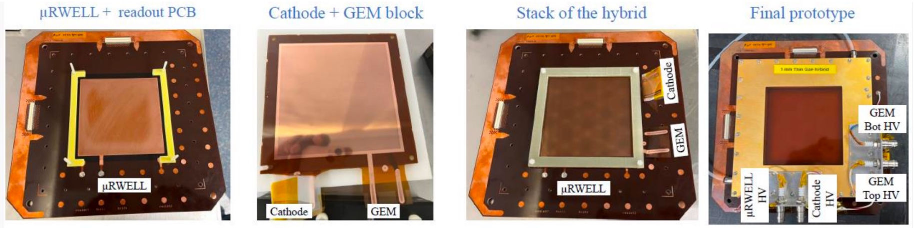


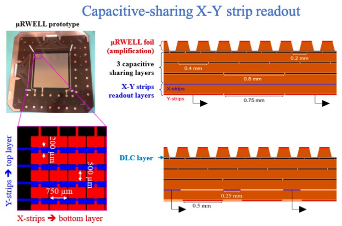
cross-section view of thin-gap GEM-µRWELL detector

https://indico.jlab.org/event/751/contributions/13585/attachments/10462/15726/20231031_EICGENRD16_ThinGapMPGD_KG.pdf

https://www.jlab.org/sites/default/files/eic_rd_prgm/files/2023_Proposals/20230714_eRD_tgMPGD_Proposal_FY23_Final_EICGENRandD2023_16.pdf

Assembly of small (10 cm × 10 cm) thin-gap GEM-µRWELL hybrid detector

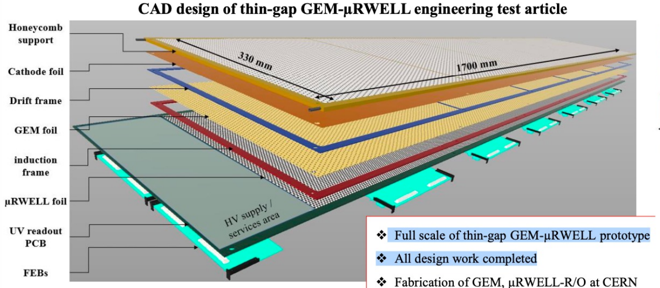




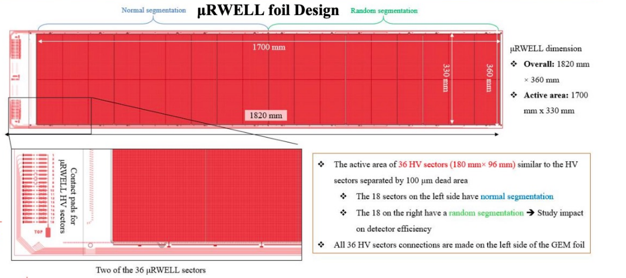
µRWELL-BOT module: Design of full scale engineering test article

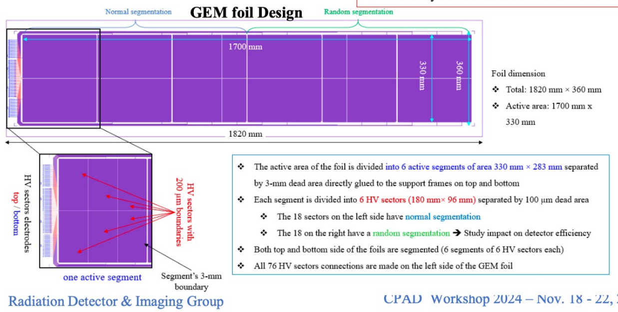
CPAD 2024

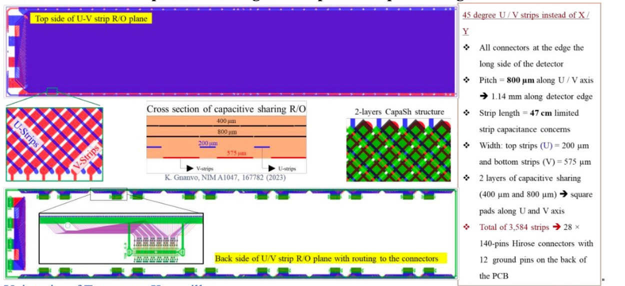
CAD design of thin-gap GEM-µRWELL engineering test article



- Full scale of thin-gap GEM-µRWELL prototype
- All design work completed
- Fabrication of GEM, µRWELL-R/O at CERN
- Assembly and test at JLab ➔ second half off 2025







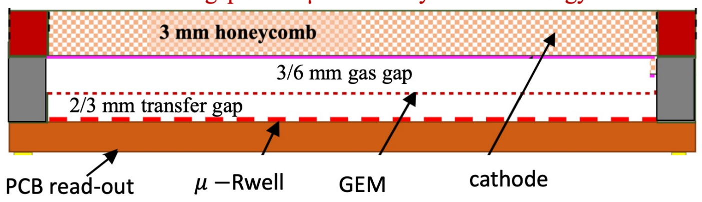
Gaseous Trackers: MPGD (3)

MPGD subsystems in ePIC Central tracking detectors:

- **µRWELL-ECT**: End cap MPGD disks

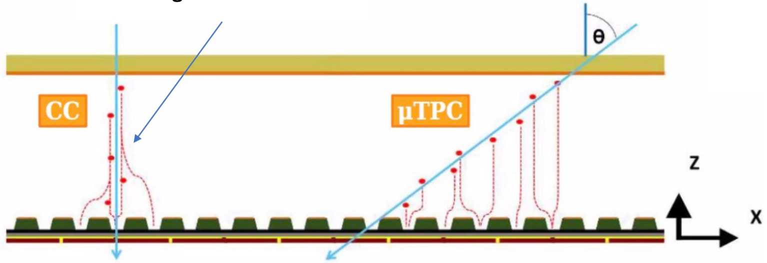
µRWELL-ECT Ongoing R&D: GEM-µRWELL + µTPC

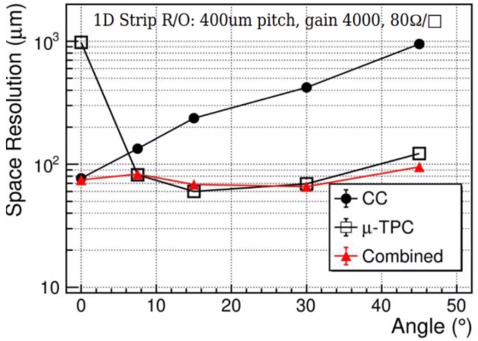
Standard gap GEM-µRWELL hybrid Technology



Combinig the CC and µTPC reconstruction (through a wheighted average) a **resolution well below 100 µm** could be reached over a wide incidence angle range.

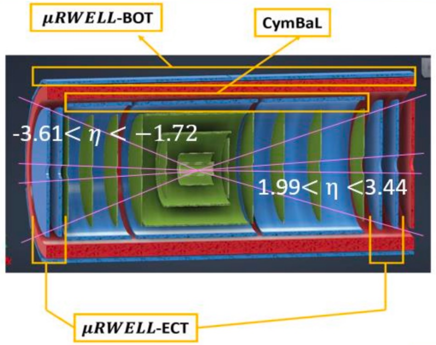
CC= Charge Centroid



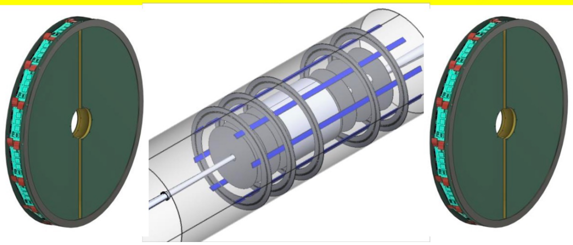


Ongoing test beam effort (Oct / Nov 2024)

ePIC End Cap Tracker - µRWELL-ECT Disks



Adding **two MPGD Endcap Tracking (ECT) disks** both in the **hadronic** and in the **leptonic regions** increased the number of hits in the |η| > 2 region to improve pattern recognition.



Lepton Disk (LD) µRWELL-ECT **Hadron Disk (HD) µRWELL-ECT**

GEM-µRWELL hybrid disks

- Double amplification with hybrid configuration ➔ high gain > 10^4
- 2D strip read-out a la "COMPASS"
- 500 - 600 µm pitch guarantees a spatial resolution better than 150 µm
- time resolution ~10 ns

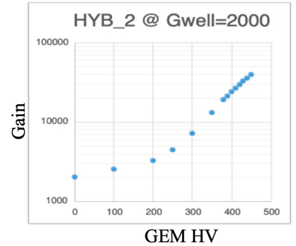
On-detector Front End Boards (FEBs)

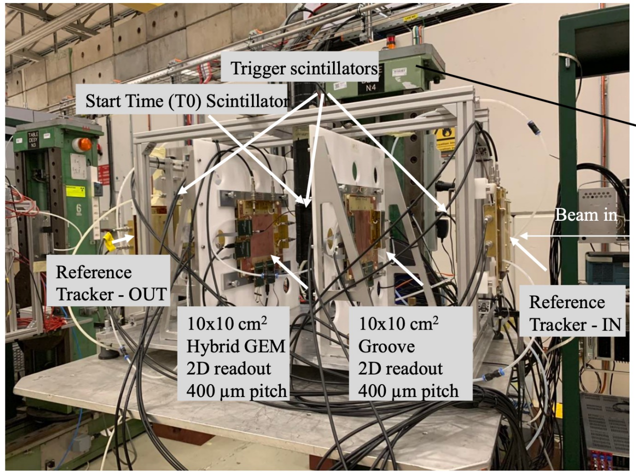
- based on SALSA chips

MPGD Disk	Z Pos (cm)	Outer Radius (cm)	Outer Active Reg. radius (cm)	Calculated Beam pipes radii (cm)	Offset (mm)	Inner Radius (cm)	Inner Active Reg. radius (cm)
HD MPGD 2	163.5	50	45	5.58	22.5	9	10.5
HD MPGD 1	150.5	50	45	5.31	19.9	9	10.5
LD MPGD 1	-112.5	50	45	3.77	-3.1	4.5	6.0
LD MPGD 2	-122.5	50	45	3.92	-3.4	4.5	6.0

Ongoing R&D: Test at CERN PS T10 beam line (Nov 2024)

- Reference Trackers: 2 Hybrid GEM-µRWELL with 2D readout
- Detectors Under Test:
  - 2 Hybrid GEM-µRWELL with 2D readout
  - 2 Groove with 2D readout



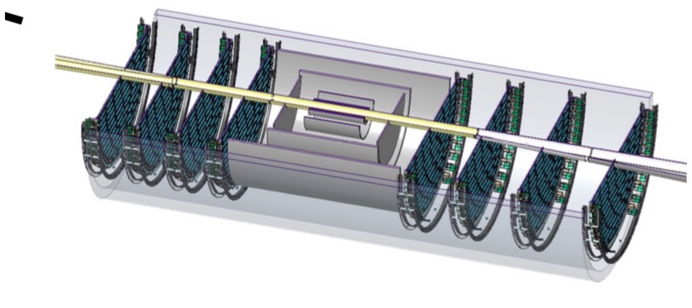


Detectors Under Test may be rotated to study resolution dependence for inclined tracks

Si Trackers (1)

MAPS Silicon Vertex Tracker

MAPS-based Silicon Vertex Tracker

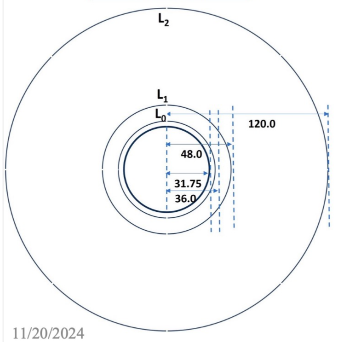


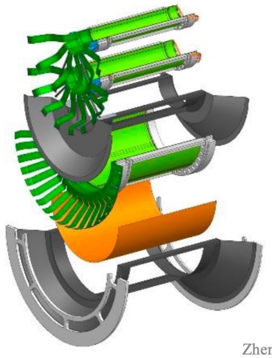
ePIC Silicon Vertex Tracker – Inner Barrel Layers

Inner barrels (L0-L2) inspired by ITS3

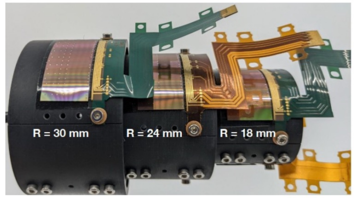
CERN-LHCC-2024-003 ; ALICE-TDR-021

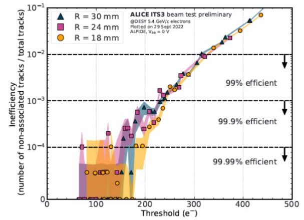
- Same sensor as ALICE ITS3 with thinned, curved, self-supporting wafer-scale MAPS sensors based on 65nm CMOS technology
- Pixel pitch O(20×22.5) μm^2; power consumption 40 mW/cm^2; integration time 2 μs;
- Radii of 36, 48, and 120 mm; length of 27 cm
- X/X_0 ~0.05%



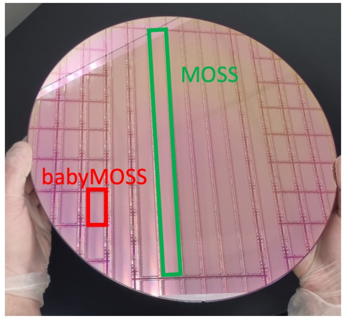


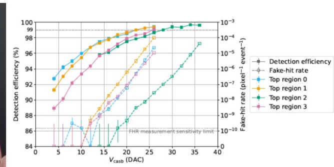
ITS2 ALPIDE chips bent to different radii

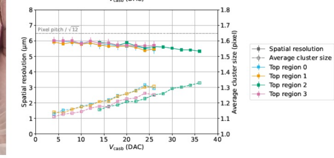




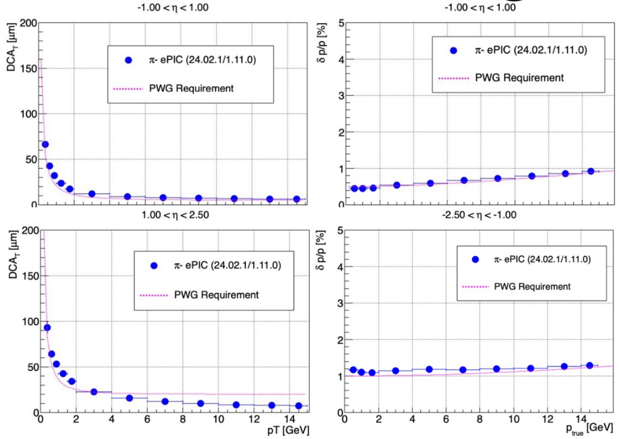
ITS3 300mm ER1 wafer

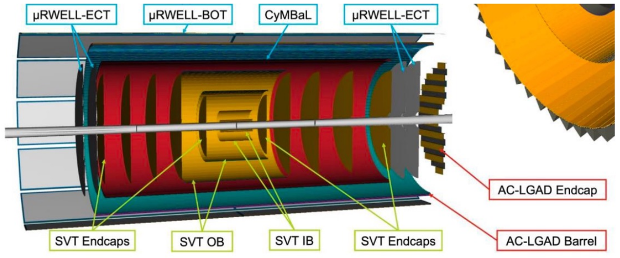






ePIC Central Tracking Detectors





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

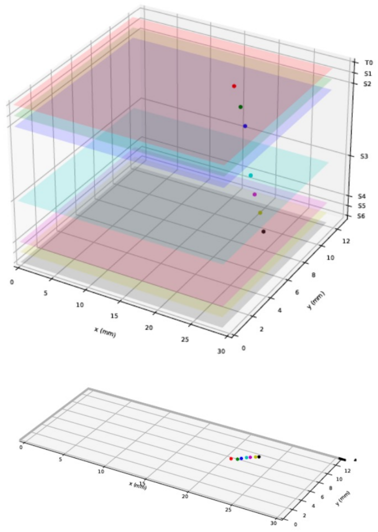
Multi Pattern Gas Detectors (MPGD): 10 ns+150 μm resolutions

- **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

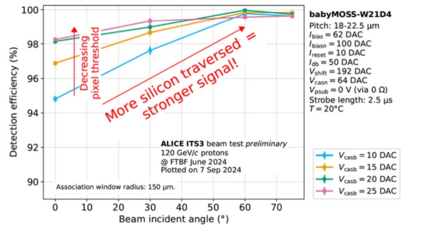
BabyMOSS Beam Tests at FTBF in 2024

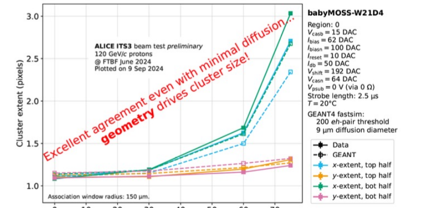
babyMOSS Telescope at FTBF

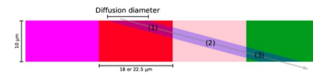
A 120 GeV proton event



Performance vs Incident Angle







~5 um resolution consistent with ITS3 TDR

Si Trackers (2)

AC-LGAD Time-of-Flight Detectors

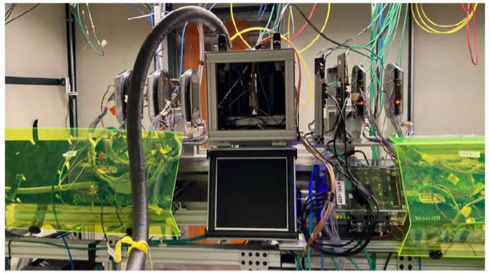
- Backward: HRPPD with 10-20 ps resolution
- Barrel: AC-LGAD strip sensors with 35 ps resolution
- Forward: AC-LGAD pixel sensors with 25 ps resolution

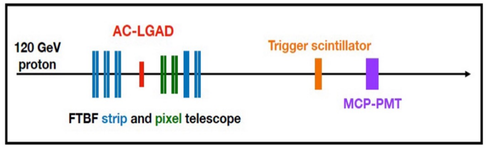
Sensor Prototyping for ePIC AC-LGAD (BNL, HPK)

- 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.
  - Prototype pixel sensors with ~20 ps time resolution and ~20* um spatial resolution.
- New HPK strip sensors as large as 3.2x4 cm^2 (and 1.6x1.6 cm^2 for pixel sensors) under evaluation

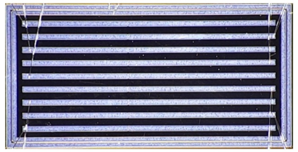
* ~50 um under metal. To be improved

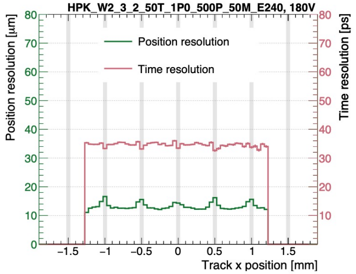
Fermilab Test Beam Setup



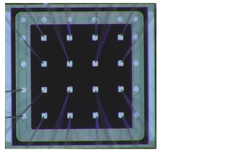


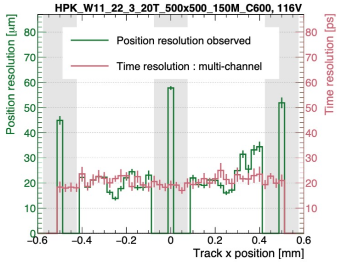
HPK Strip Sensor (4.5x10 mm²)





HPK Pixel Sensor (2x2 mm²)

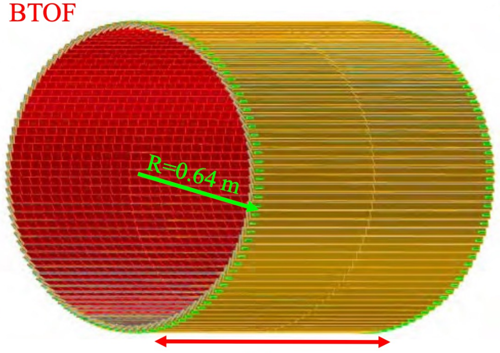




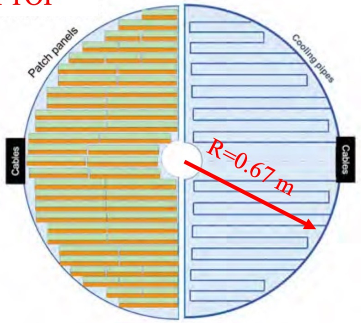
arXiv:2407.09928

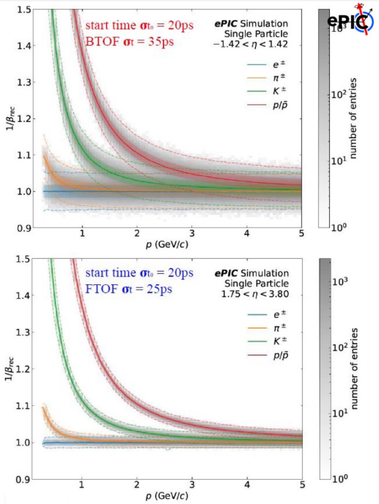
AC-LGAD Detectors for ePIC

BTOF



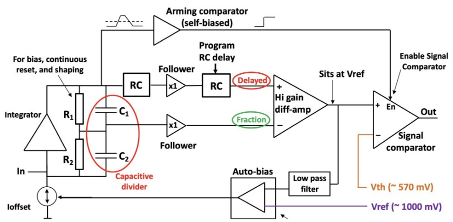
FTOF

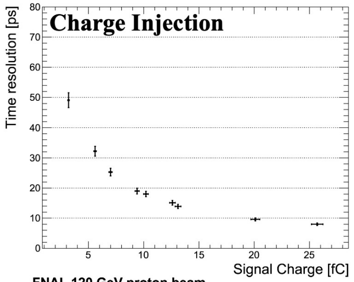


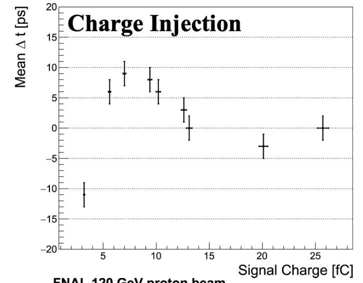


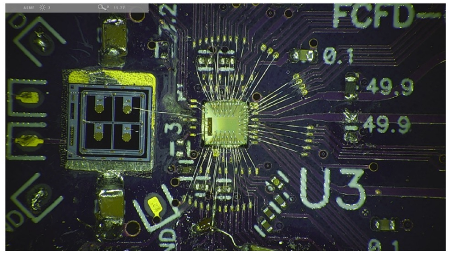
	Area (m^2)	Channel size (mm^2)	# of Channels	Timing Resolution	Spatial resolution	Material budget
Barrel TOF	10	0.5*10	2.4M	35 ps	30 μm in $r \cdot \varphi$	0.01 X_0
Forward TOF	1.4	0.5*0.5	5.6M	25 ps	30 μm in x and y	0.05 X_0
B0 tracker	0.07	0.5*0.5	0.28M	30 ps	20 μm in x and y	0.05 X_0
RPs/OMD	0.14/0.08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

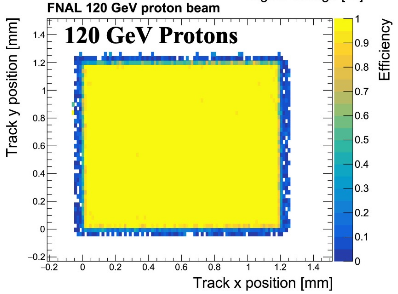
ASIC Prototyping for ePIC AC-LGAD (EICROC, FCFD)

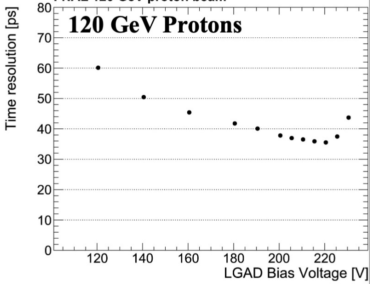












- Charge injection: TOA varies less than +/-10 ps for 3-26 fC. Jitter smaller than 20 (10) ps for charge > 10 (20) fC.
- Timing resolution with 120 GeV protons is around 35 ps, close to the limit of the LGAD sensor.

Summary

- Total 9 parallel talks and 3 posters related to ePIC Detector were presented at CPAD2024.
  - Barrel Imaging Calorimeter (2 parallel talks, 1 poster)
  - Forward HCAL (4 parallel talks, 2 posters)
  - pfRICH (1 parallel talk)
  - Gaseous Trackers (1 parallel talk)
  - Si Trackers (1 parallel talk)

→Presented significant R&D progress, highlighting key advancements and promising results.