R&D Day
16-17 April 2025

Barrel Imaging Calorimeter

eRD115

08/28/2024
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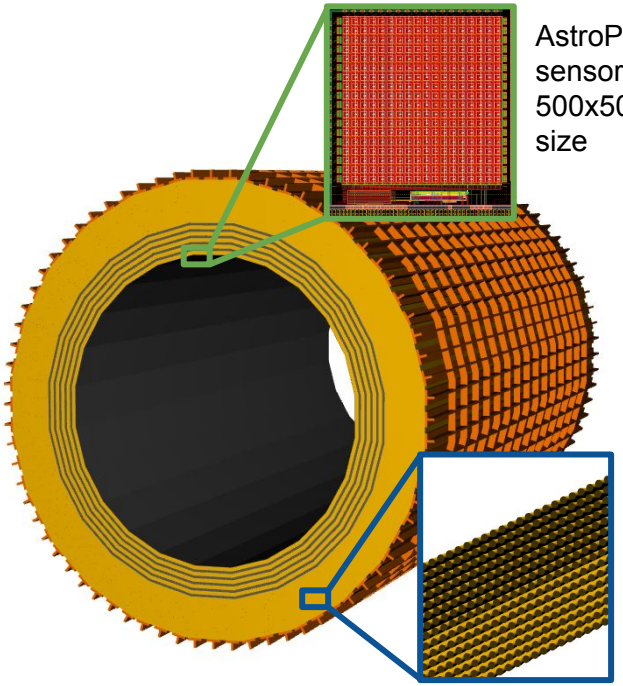
R&D Motivation

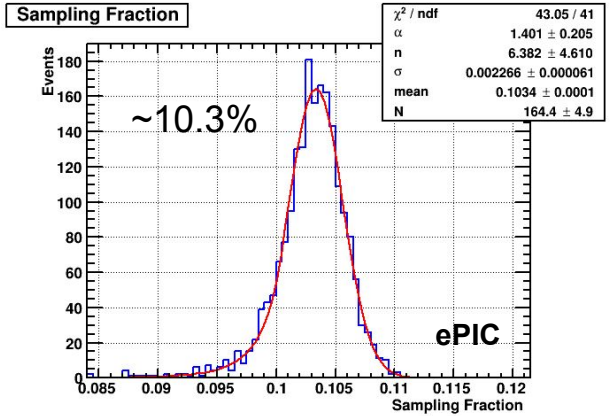
Barrel Imaging Calorimeter: General Overview



AstroPix: silicon sensor with 500x500μm^2 pixel size

ScFi Layers with two-sided SiPM readout

- **4(+2) layers of imaging Si sensors** interleaved with **5 Pb/ScFi layers**
- Followed by a **large section of Pb/ScFi section**
- Total radiation thickness ~17.1 X_0
- Sampling fraction ~10%



Simulations of **single photons** at η=0 (~17.1 X_0)

Sampling fraction = $\Sigma E_{fibers} / E_{thrown}$

Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-side Pb/ScFi readout)

R&D Directions

Pb/SciFi Barrel technology: Tested extensively for electromagnetic response in energies E_γ **< 2.5 GeV**

- **Energy resolution:** $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$[1)] 1) GlueX, Nucl. Instrum. Meth. A, vol. 896, pp. 24–42, 2018
  - 15.5 X_0, GlueX could not constrain the constant term (due to low energies)

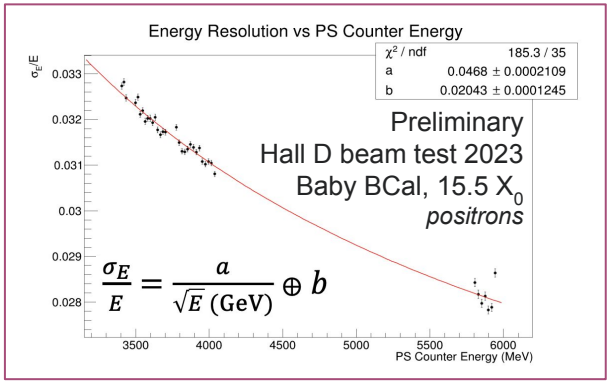
General BIC direction of R&D:
Demonstrate using Pb/SciFi and AstroPix in the environment of EIC:

- Benchmarking of high energy simulation performance (e.g., response to pions and electrons)
- Test of AstroPix in high rate/shower-like environment
- Pb/SciFi integrated with the AstroPix sensor layers

FY23 Snapshot:

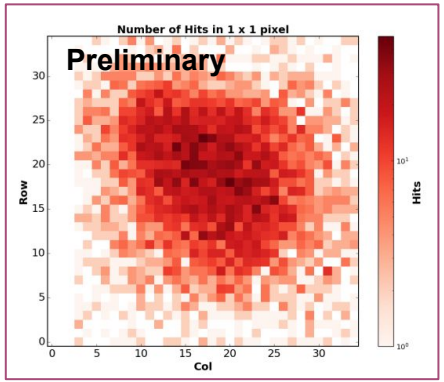
Response to positrons in **Pb/SciFi** measured in Hall D

Constant term integrated over probed impact z position and angle: ~2%



Beam hit map
FNAL, May 2023
AstroPix v3 Test
120 GeV protons

Performs well in much harsher conditions than EIC



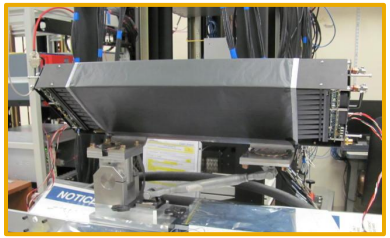
FY24/FY25 Goals

FY24 R&D Goals

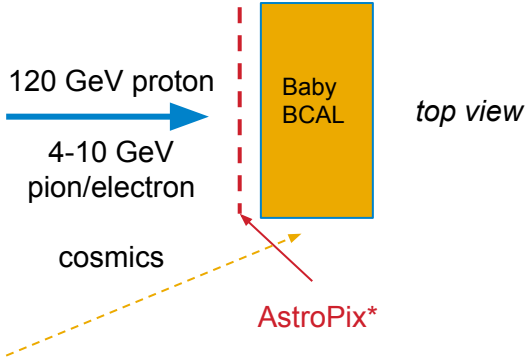
Goal: Characterize the integrated AstroPix and SciFi/Pb system with a mixed e/π beam and mips, benchmarking the response to charged pions, benchmarking the electron-pion separation capability, and testing the new generation SiPMs.

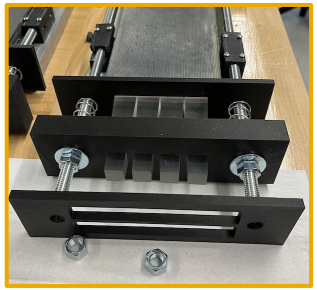
Possible options of system integration:

* System flexible for testing single AstroPix chip, quad chip, 9 chip PCB module

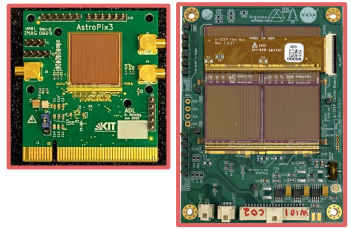


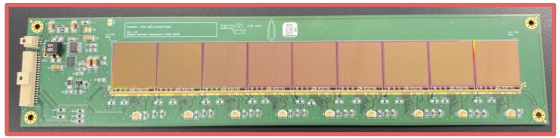
GlueX Baby BCal





SciFi interlayer (SFIL) with new SiPMs



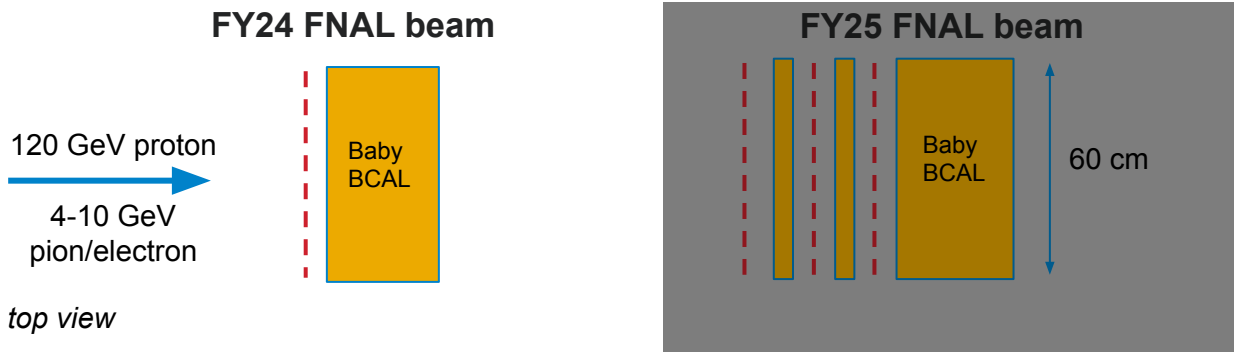


✅ FY24 FNAL beam (Astropix v3 single chip + BabyBCAL)
❗ FY25 FNAL Beam: Limited Beam

✅ FY25 cosmics
❗ FY25 FNAL Beam: no Beam

FY24 Beam Availability Summary

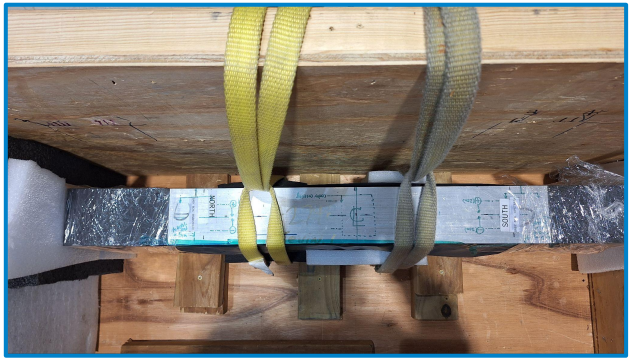
- Delays in the start of the beam at the Fermilab Test Beam Facility in FY24 caused by ESH paperwork: our team received only **one week** (6 half-days, 76 hours) of beam test **out of the planned 4-6 weeks**
  - Due to a heat wave in the Chicago area we were provided only **30.5 hours** of beam (**~ 30% of the nominal 1-week allocation**)
- Given these severe reductions we decided to **focus on setting up our DAQ system** for the Baby BCAL aiming **to collect initial analysis-quality data with the π/e** beam while **simultaneously working on the integration of AstroPix and Baby BCAL**
- Further integration with SFILs and AstroPix layers conducted ~~in FY25 at FBTF~~ on a bench because of lack of FNAL beam



Deliverables and Results

R&D Phase I - Preparations

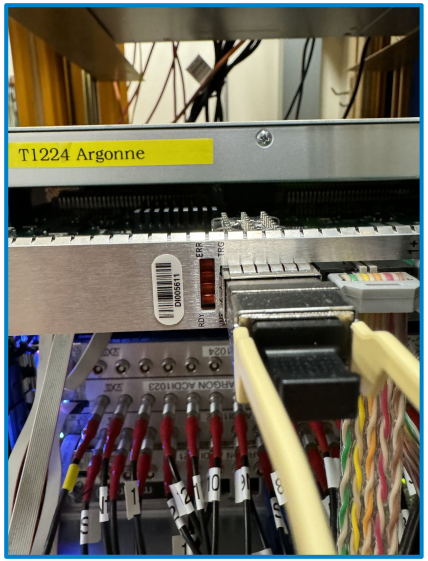
Baby BCal moved to Argonne



- Shipment of Baby BCAL, SiPM wedges, voltage distribution system, and cables ✅
- Final design of the system fixture ✅
- AstroPix telescope and Baby BCAL assembly and tests with cosmics ✅

AstroPix set up at Argonne

- Performance of chip v3 QA and noise threshold scans ✅
- Calibration with sources ✅

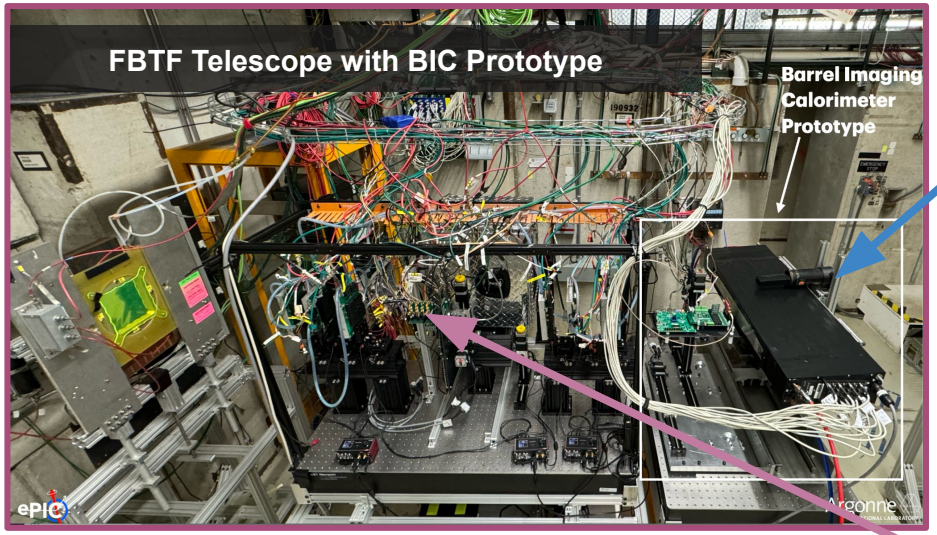


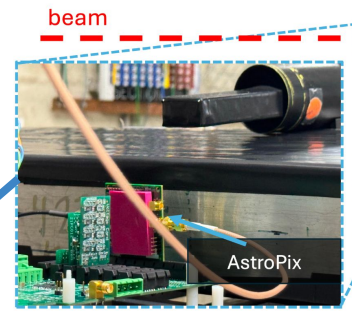
- Tests of the readout with the fADCs and the CODA-based DAQ system ✅
- Tests of the AstroPix readout system with and without an external trigger ✅
- Synchronization of both systems ✅

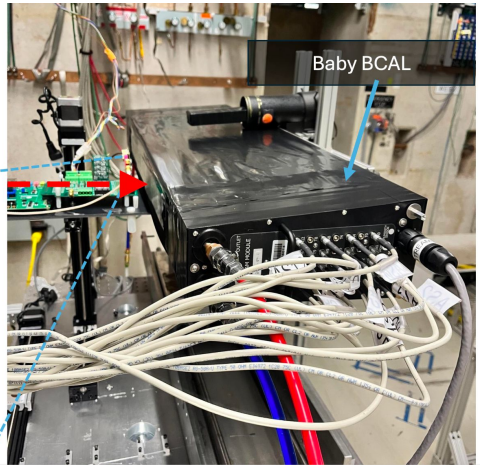
Deliverable (M1-M4): Integrated system with DAQ tested with cosmics/sources

See backup slides for more preparation summary (slide 29)

R&D Phase II - Beam Test





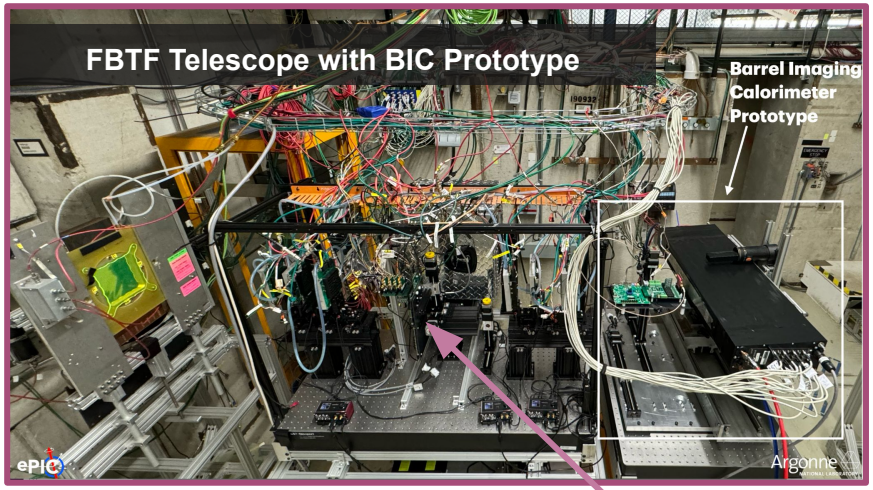


R&D Phase II - Beam Test

June beam test at Fermilab Test Beam Facility

Prototypes and test articles:

- **Setup 1:** Baby BCal (ScFi/Pb prototype) shipped from JLab to Argonne/FBTF integrated with single AstroPix v3 chip
- **Setup 2:** AstroPix multi-channel board and quad chip with successful daisy chain readout of v3



Beam Test goal:

- **Commission** both setups in the beam including the first test of the integration between AstroPix and Pb/SciFi
- Benchmark **response to electrons and pions**

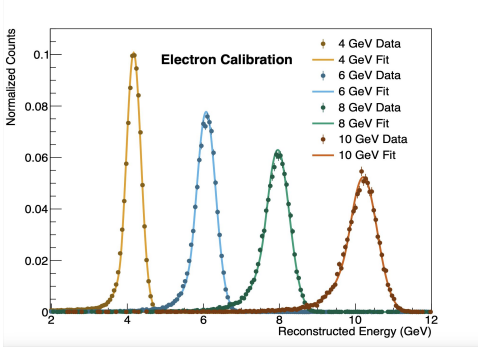
Deliverable (M6): Prototype commissioned in beam and data collected

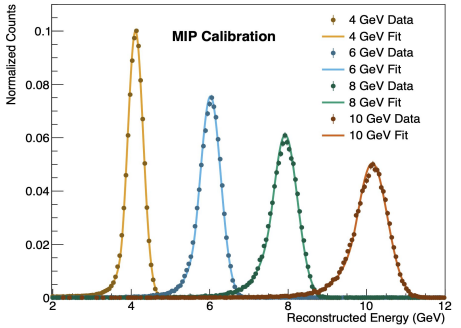
See backup slides for more details (slide 37)

R&D Phase II - Beam Test

Despite extremely challenging conditions:

- Successfully **commissioned the DAQ** system for the Baby BCAL
- Tuned and included **Cherenkov counter information** for electron/pion particle identification in our data stream
- Performed a **proof-of-concept integration between the AstroPix** layer and Baby BCAL using the AstroPix analog signal
- Collected sets of **electron/pion data at 4, 6, 8, and 10 GeV**, as well as sets of muon/pion and proton data for calibration purposes

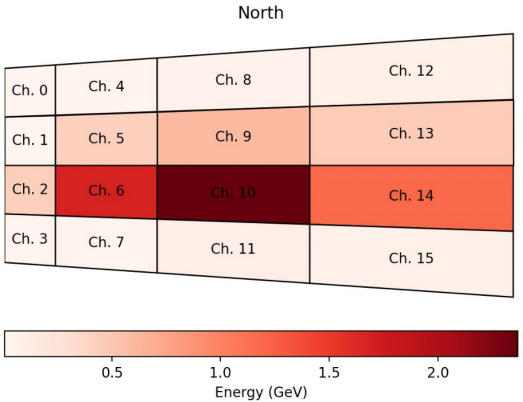




Calibrated **energy response** with two different calibration methods

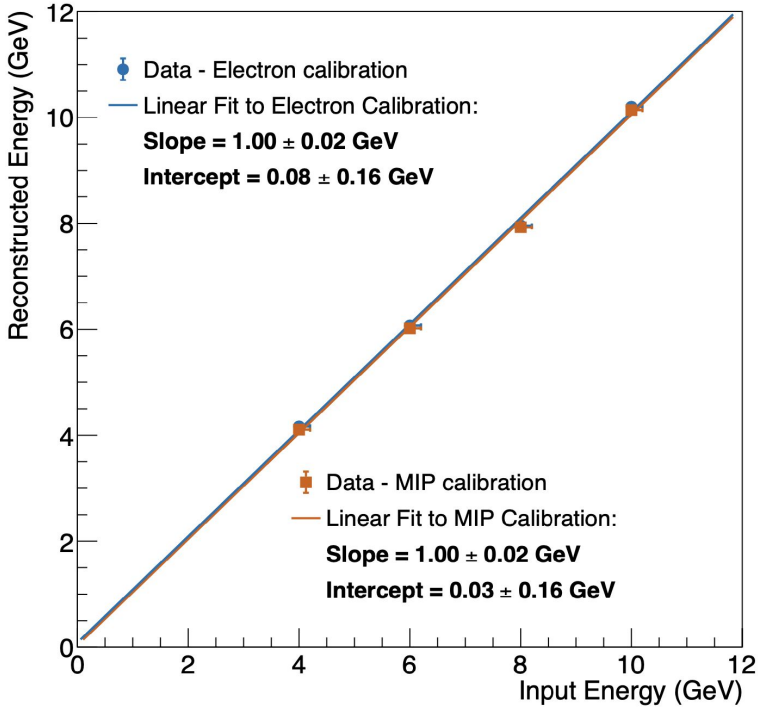
e/π beam

Example electron event energy deposit in Baby BCAL



R&D Phase III - Data Analysis in Abbreviation

- Baby BCal data **calibrated** with **muons** and **electron-based** calibration
  - Response to muons simulated for every Baby BCal cell for absolute calibration
- **Electrons selected** by events where upstream Cherenkov & downstream Cherenkov outer PMT fired
- **Refinement cuts** to remove spurious signals and to improve containment of showers
- Total energy from **geometric sum of North & South** (2 sides of Baby BCAL) reconstructed energies
- **Beam profile** from AstroPix (wide, especially for 4 GeV π/e)
- Non-negligible and not precisely known beam **Δp/p (~3%)** affecting constant term

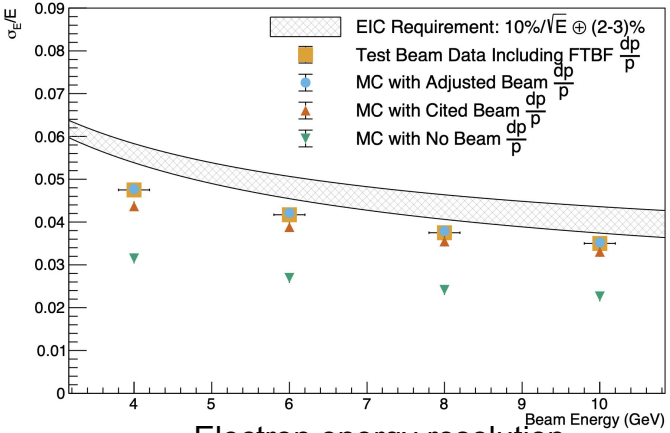


Linearity of the calorimeter response

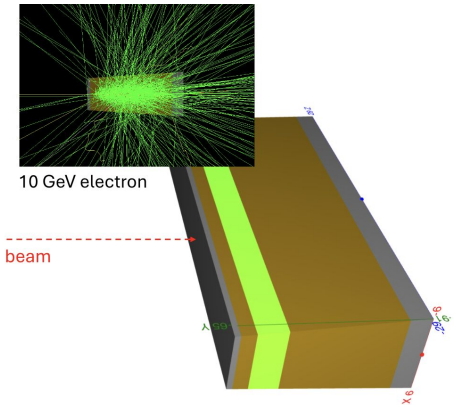
R&D Phase III - electron energy response

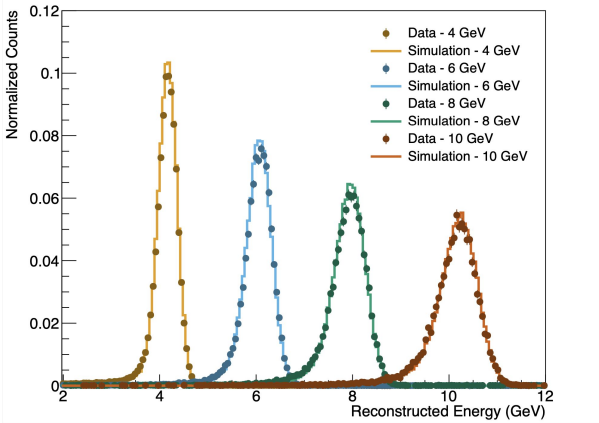
Benchmark simulations and beam energy spread using electron response

- Baby Bcal implemented in dd4hep
- Response simulated including **realistic beam momentum and position spread**, realistic model for **attenuation and photoelectron response** based on measured phe/GeV and fiber attenuation and **digitization**
- Beam **momentum spread quoted by FBTF: 2.7%, very likely higher for lower energies** (backup)



Electron energy resolution



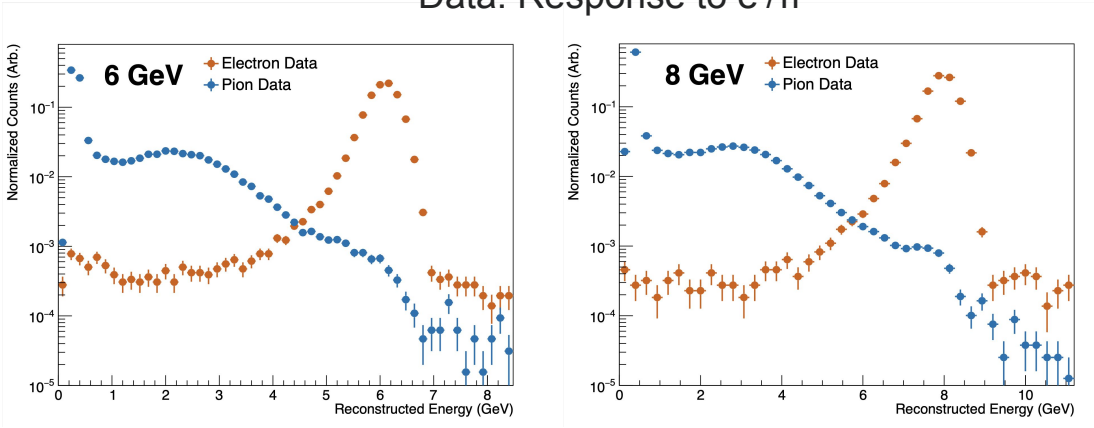


Comparison between e^- data and simulation

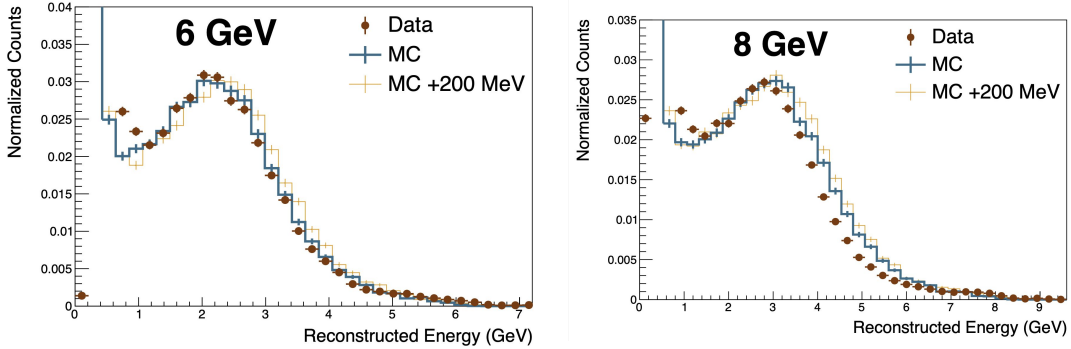
R&D Phase III - pion response

- Pions selected with **no hits in the Cherenkovs** exhibit a **MIP peak** and a **shower peak**
- **Electrons and pions well separated**, but both have tails: Electron tail – showers upstream, horizontal leakage, Pion tail – electron misID, pileup.
- **Data/simulation agreement reasonable**, agrees well in 6GeV, slightly overshoots at 4GeV, and undershoots at 8GeV
  - A possible contributor: mean beam momentum and its spread.
  - Given the constraints of the FTBF dataset, this level of agreement represents the best achievable precision to test.

Data: Response to e^-/π^-



Data and Simulation: Response to e^-/π^-

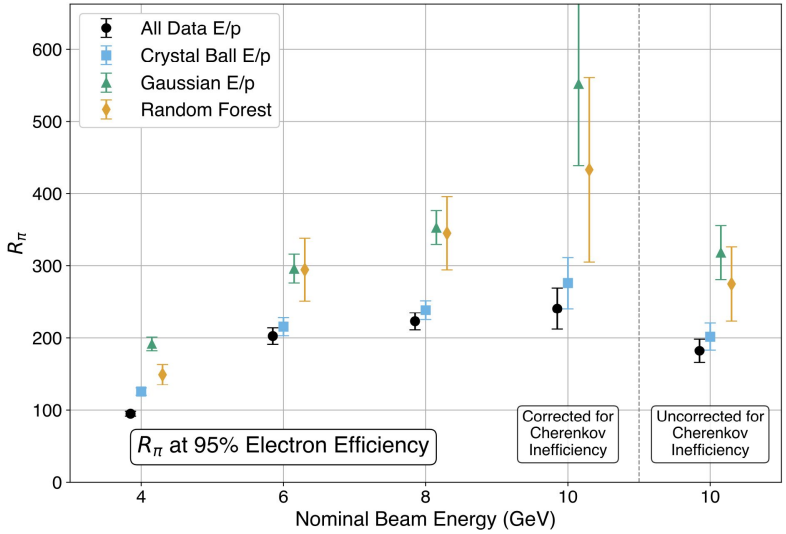


R&D Phase III - Beam Test Summary

SciFi/Pb results from June 2024 summarized in

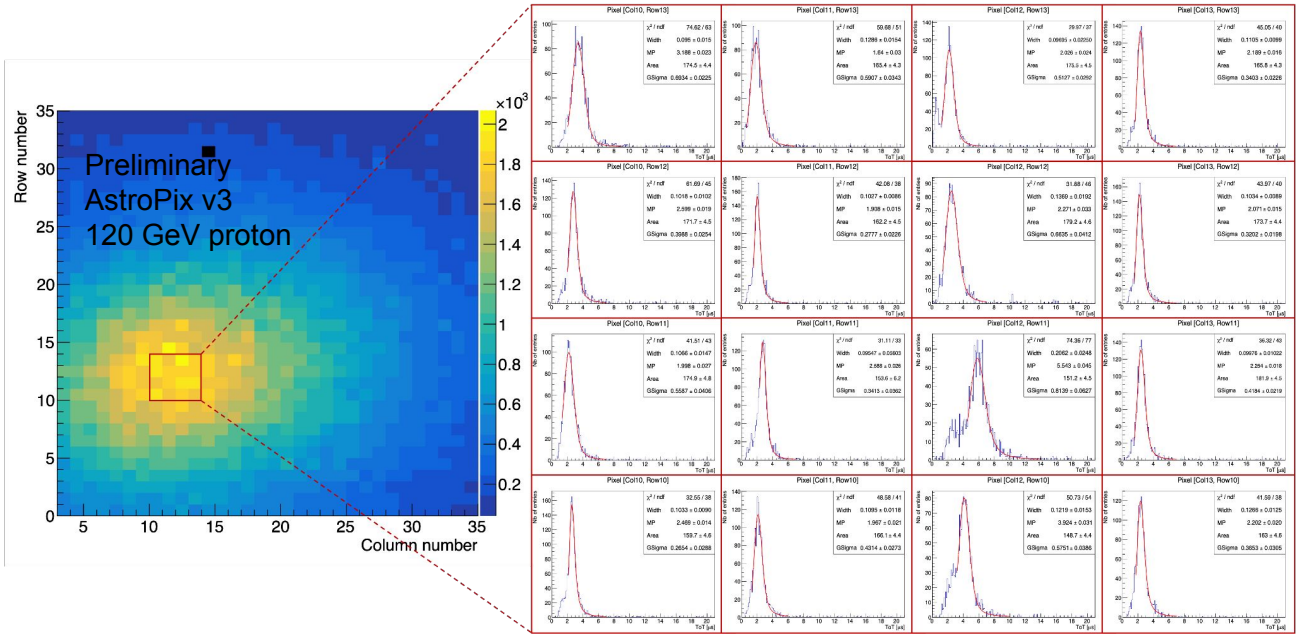
https://arxiv.org/abs/2504.03079

- Electron and pion response measured
- Energy resolution extracted (measurement limitation: 2-3% dp/p at FTBF)
- Good constrain power over the constant term ~1.5 ± 0.4%
- Simulations describe the electron and pion data well
- e/pion separation extracted within the full system in the test beam environment
  - affected by FTBF beam conditions including Δp spread

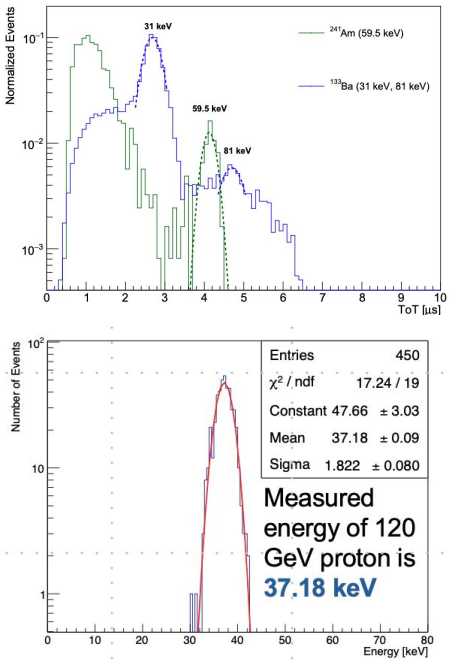


Presented methods in various degree incorporate artifacts of the test beam setup: beam momentum smearing, effects of upstream material, possible pileup, and beam profile variations

R&D Phase III - AstroPix Beam Data Analysis



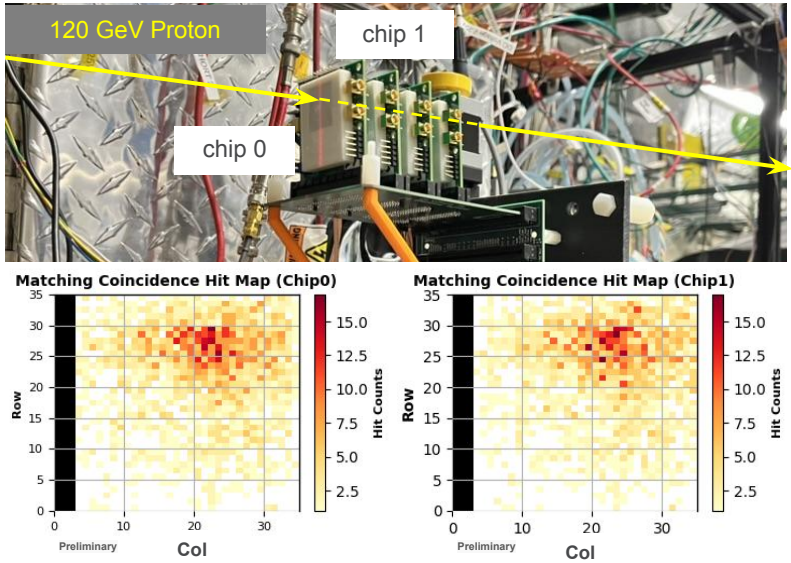
Example AstroPix data collected with a 120 GeV proton beam. The hit map reveals the proton beam profile. The collected ToT values for the marked pixels are presented in the matrix of plots on the right

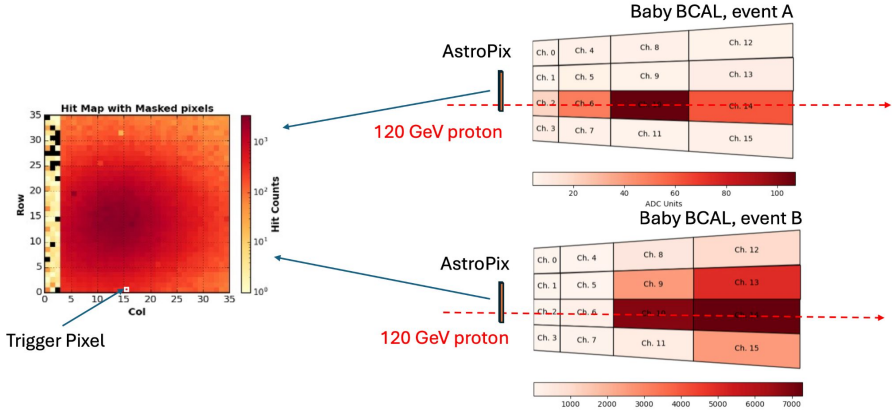


Calibrated response to 120 GeV protons and Am-241 and Ba-133 calibration response

R&D Phase II & III - AstroPix Integrations

AstroPix v3 integration tests: first proof-of-concept demonstration of the integration of two daisy-chained AstroPix layers and Baby BCal and AstroPix in a beam-like environment.

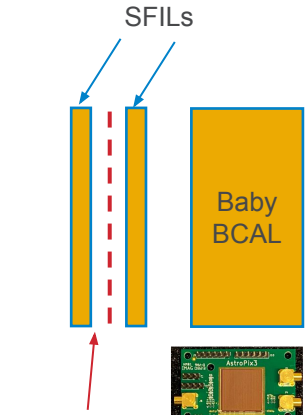




The multilayer AstroPix v3 setup which we tested at FTBF, and an example of the recorded **120 GeV proton beam events from the first two layers, read in coincidence**

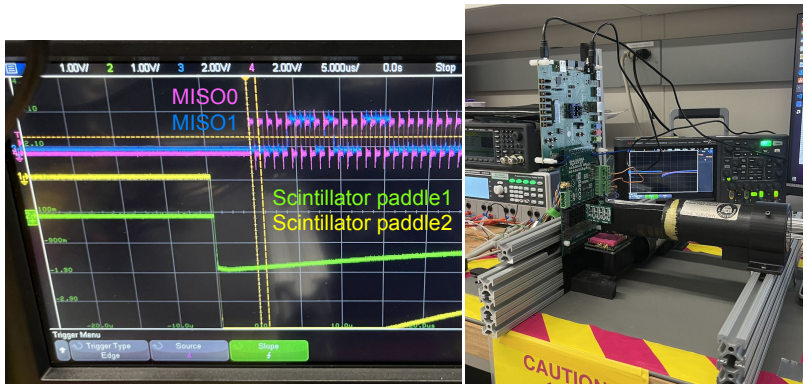
Baby BCal event triggered on AstroPix signal from 120 GeV proton. Event A shows MIP-like behavior, event B shows hadronic shower behavior.

R&D Phase II & III - AstroPix/SFILs Integrations

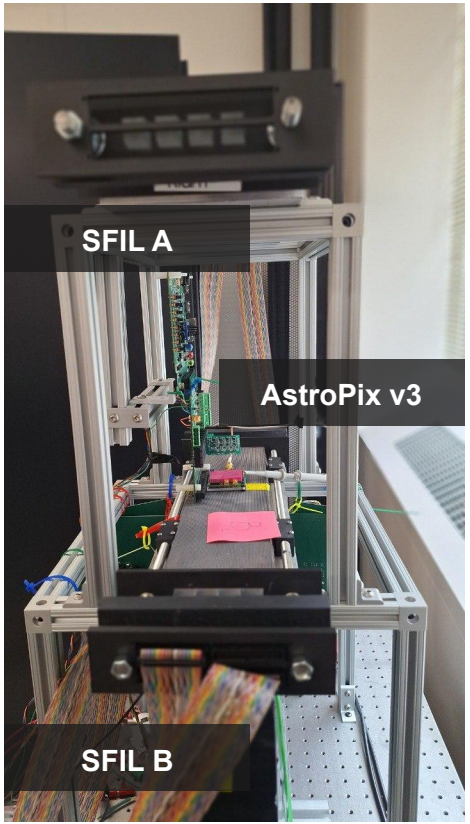


How to synchronize AstroPix w/ SFIL?

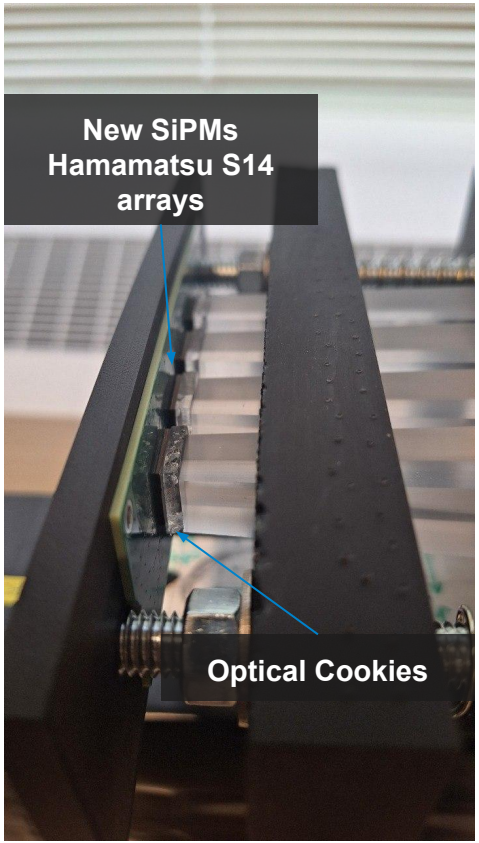
- Plan A (for CODA based JLab readout)
  - LVDS MISO0/1 signals that generated from Astropix used as trigger IN for Baby BCAL



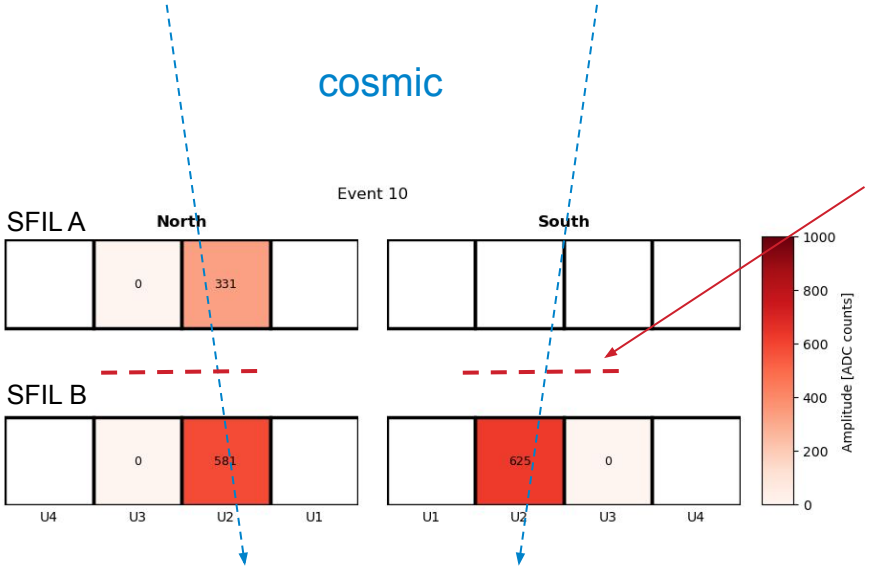
- Plan B (for HGCROC) - for PED phase
  - Provide up to 10 MHz LVDS external clock to Astropix chip via PMOD

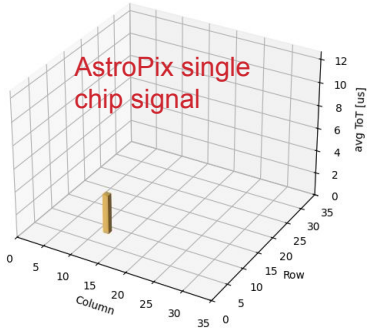


R&D Phase II & III - AstroPix/SFILs Integrations



- SFILs: new S14 SiPM arrays, optical cookies, 8 cm machined light-guides
  - Test station for optical coupling and improvements
- Delays and hiccups delivery to Argonne (broken package, lost SiPM boards)
- Setup successfully commissioned at bench with cosmics (as of yesterday!)





Quad-chip successfully tested with sources and beam

As of yesterday, multiple daisy-chained chips working with a **9-chip PCB module** with one pixel injection test

Milestones Summary

R&D Milestones

*Assuming Start of Funds in Q1 FY24 (funds available from March 2024)

Milestone	Original Timeline*	Status
M1: Integrated setup with Baby BCal and AstroPix chip designed and built at Argonne	t0 + 3 months Q1 FY24*	Done ✅
M2: AstroPix chips prepared at the bench for integrated tests with Baby BCal	t0 + 3 months Q1 FY24*	Done ✅
M3: Data Acquisition (DAQ) for the integrated system of Baby BCal and AstroPix chip designed and tested	t0 + 5 months Q1-Q2 FY24*	Done ✅ • Proof-of-concept tested in the beam and bench
M4: Integrated prototype system tested at the bench with cosmics and/or source	t0 + 6 months Q2 FY24*	Done ✅ • Proof-of-concept tested in the beam and bench
M5: SciFi Inter-Layer (SFIL) delivered by the University of Regina, integrated, and tested at the bench	t0 + 7 months Q2-Q3 FY 24*	Done ✅
M6: Integrated system commissioned at the beam test facility with protons	t0 + 9 months Q3 FY24*	Done ✅ • Single AstroPix v3 chip with Baby BCal • Two AstroPix v3 chips daisy-chained
M7: Response to pions tested in the beam environment and e/pi separation benchmarked in simulations	t0 + 12 months Q3-Q4 FY24*	Done ✅ • Within the available beam test time

P6 Milestone

eRD115 (Barrel EM Cal)
Characterize the integrated AstroPix and SciFi/Pb system with a mixed e/π beam and MIPs, benchmarking the response to charged pions, benchmarking the electron-pion separation capability, and testing the new generation SiPMs. [Summer 2025]

Project completed in FY25. The GlueX Baby BCal, equipped with a single-layer AstroPix sensor, was tested and benchmarked at the Fermilab Test Beam Facility (FTBF) in FY24 using a mixed electron/pion beam and MIPs, despite very limited beam time availability. The data have been analyzed, benchmarking the response to electrons and pions, as well as the e/π separation performance in the SciFi/Pb section of the prototype. AstroPix v3 was extensively tested against design requirements (presented at PDR2 review). A proof-of-principle integration was successfully demonstrated both in the beam and on the bench. Thin SciFi/Pb layers with a new SiPM readout were also commissioned in a bench setup. No beam tests are expected at FTBF in FY25. Larger-scale readout integration studies beyond the scope of the R&D effort and are instead part of the ongoing PED program.

Summary

Successful R&D program in FY24/FY25:

- **Baby BCal commissioned** with proton, pion, and electron beams during the June 2024 FBTF test
- Data allows **benchmarking the response to pions and electrons** in simulations
- Proof-of-concept **synchronization of AstroPix and Baby BCAL** was achieved
- Building on the extensive AstroPix tests previously conducted at FTBF, we continued to collect **high-quality data with the v3**

Thank you

Backup

August, 2024 Detector Day, Close-Out Report:

eRD115 - Barrel EM Calorimeter

- First year of R&D which combines Pb/Scifi technology with a high-precision position detector(Astropix).
- Despite many problems (funding, test beam) FY24 R&D progressing very well.
- Successful integration of Astropix and BabyCal has been achieved on the readout side adding one Astropix board to the DAQ stream in the first phase, and two boards in parallel in the second phase.
- Not all tasks completed - integration of BabyCal and Astropix with the short Pb/Scifi sections (SFils): fundamental to clarify needs for final detector configuration (#position sectors, π/e, π^0/γ disc.)

- First results from latest test beam at FTBF but not enough details on π/e, π^0/γ separation.
- Did not see results on BabyCal energy resolution and response from ANL 2023 test beam.
- No assessment of the efficiencies of the AstroPix ASICs shown.
- In general the AstroPix development may need further scrutiny.

ongoing tests during PED

- We commend the team for the work done since summer 2023, and we provide our full support for an extension of the R&D period to FY 2025. (Not clear if this should be supported by R&D or PED?)
- Extend the R&D to horizontal arrangements of AstroPix to mimic better the situation in the experiment. Check reproducibility of layer production.
- Carry out tests on the efficiency of the AstroPix ASIC with the multilayer setup. → see above
- Confront early AstroPix performance with specs.
- Data-simulation comparison should still be completed. Similarly, linearity tests should be carried out to decide an eventual selection of other SiPM models.
- Keep working on detector mechanical integration and cooling., and robust procedures for detector construction. → PED

- π/e separation from SciFi obtained
- Response to π/e benchmarked
- SFILs integrated with cosmics
- No more beam at FTBF in FY25 (large-scale integrations during the PED phase)
- High-level performance (e/π, γ/π^0) simulated with realistic simulations benchmarked with real daya

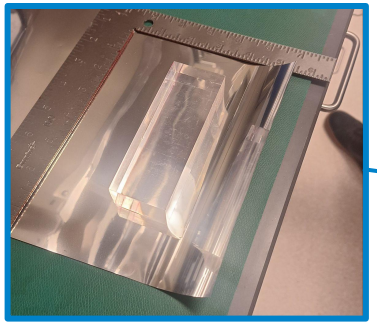
FY23 beam test took place at Hall D and the results presented during the talk

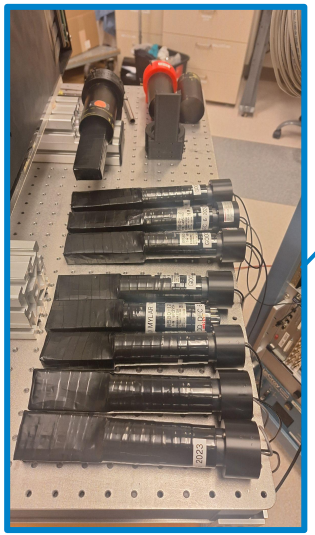
Test with 9 chip module and/or quad-chip ongoing for PED

- Data/MC comparison from FTBF beam test completed
- Linearity measured up to 10 GeV
- Response with new SiPMs and optical coupling simulated (PDR2 review)
- SiPM boards with S14 SiPMs will be tested during the PED

Phase I - Preparations

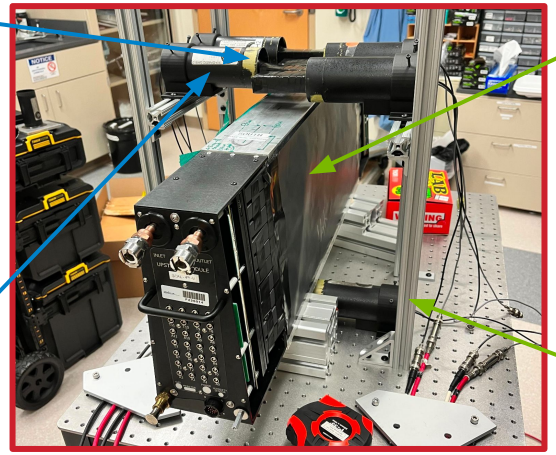
FY24 R&D Phase I - Cosmic Setup





Preparation and testing of trigger paddles

Baby BCal Setup for Cosmics at Argonne

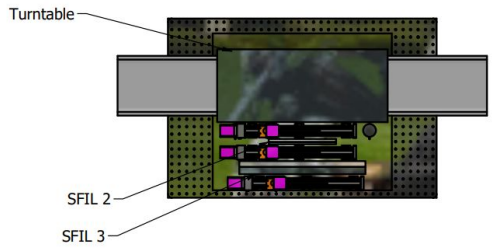


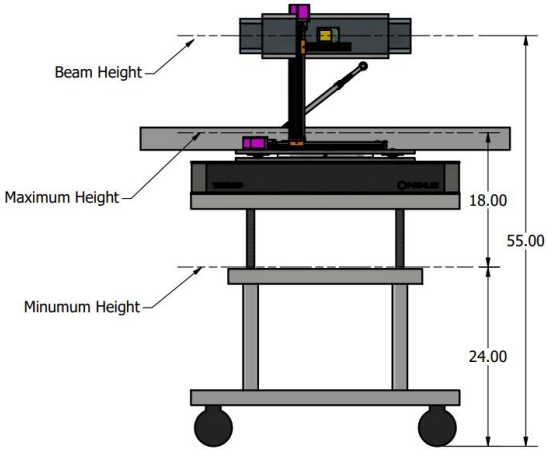
Baby BCal arrives from JLab

Shipment and assembly of the setup

FY24 R&D Phase I - Beam Test Setup

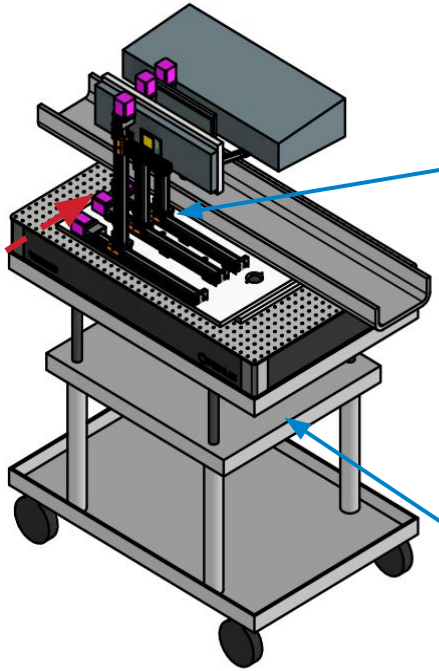
top view

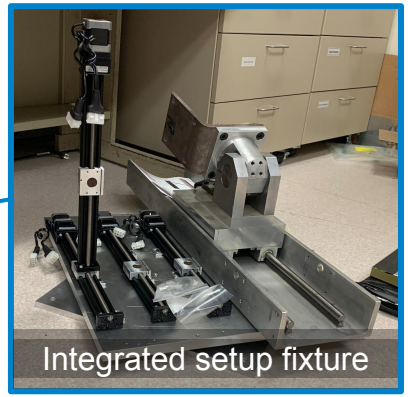




side view

Beam





FY24 R&D Phase I - Baby BCal Cosmic Tests

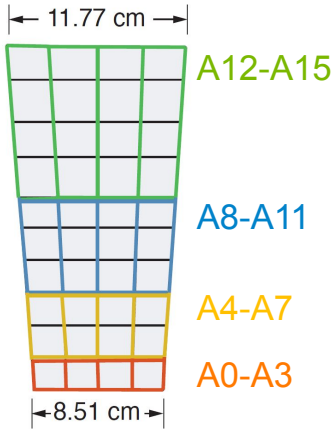
All channels tested on oscilloscope: Upstream (U) and Downstream (D) channels in coincidence

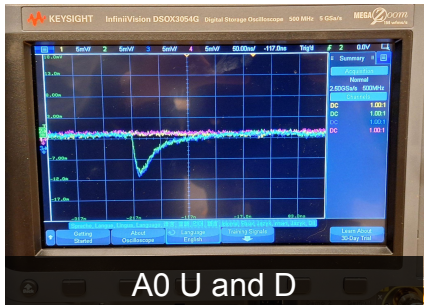
- S12045(X) SiPMs signal summed as shown below
- Only S10 channel has output (known) issue

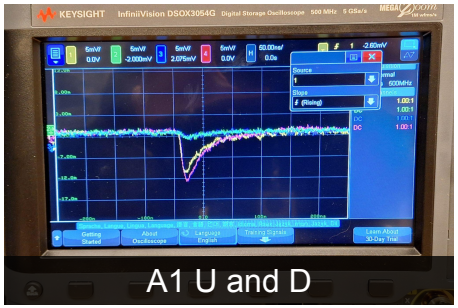
Work in progress on integration within JLab DAQ with fADC

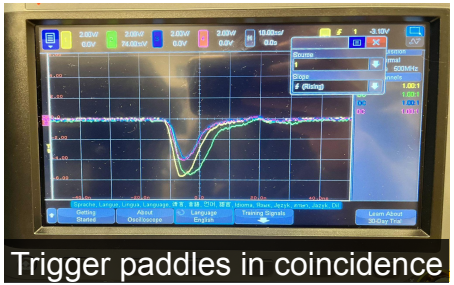
Baby BCal testing and data analysis:
Henry Klest, Jonathan Zarling

Channel numbering

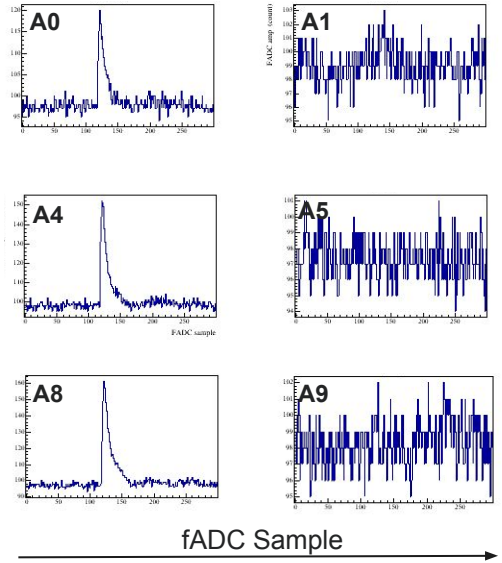








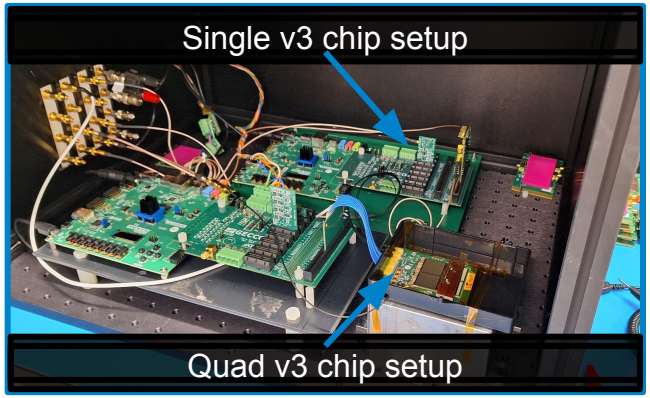
Example fADC amplitudes from a cosmic in Baby BCal



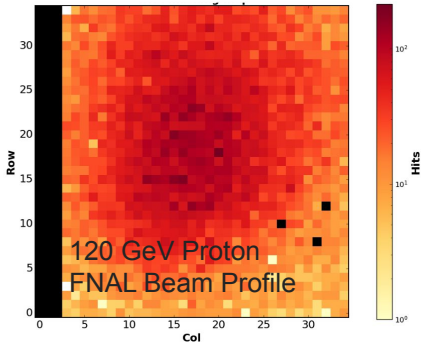
FY24 R&D Phase I - AstroPix Preparations

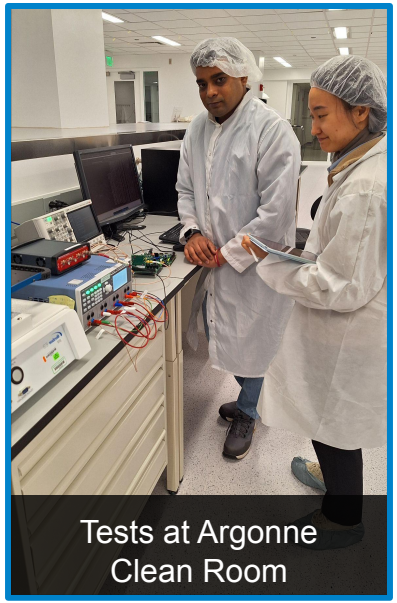
- AstroPix v3 chips preparation: masking maps and optimal threshold studies
- Calibration with sources in progress and initial tests for the quad chip

Beam Test FY23 Results: Jihee Kim
Bench Tests FY24: Bobae Kim

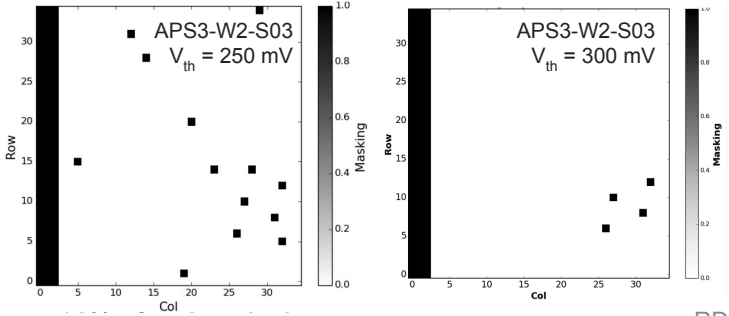


Example Beam Profile
FY23 Beam Test





Example Noise Scans

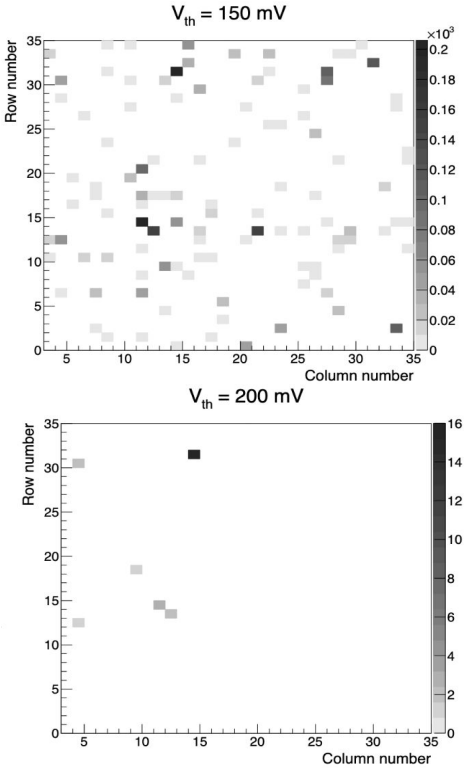


Analog Signal with Injection

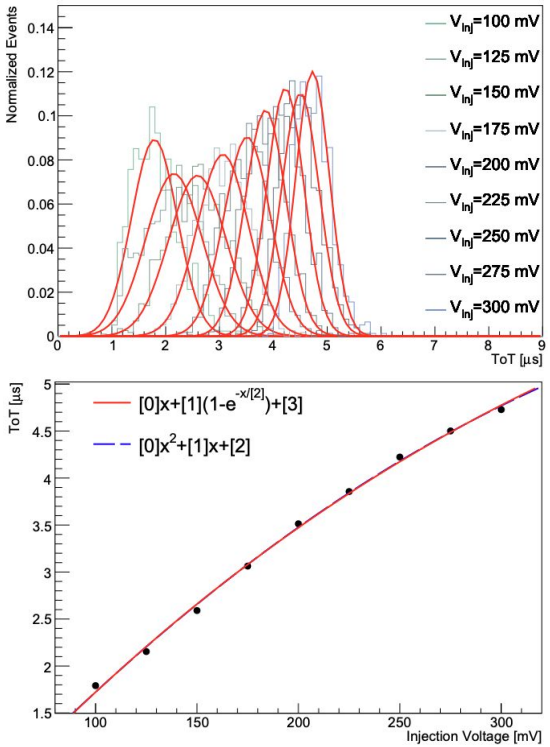
AstroPix v3 single chip testing

Noise scan, injection scan and source test for FY24 beam test

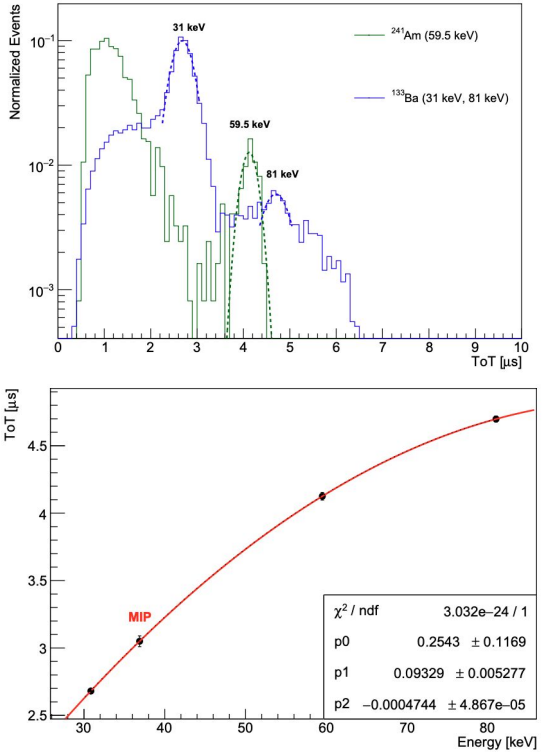
- Noise map w.r.t threshold



- ToT distribution and injection vol. vs ToT



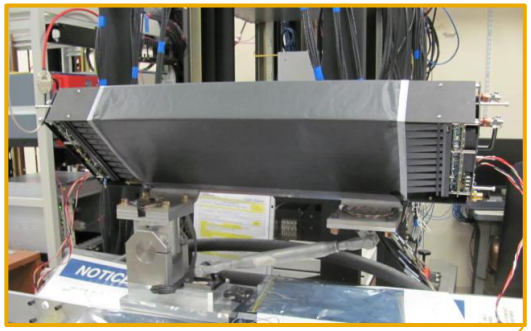
- Calibration curve for beam test result



Modes of Integration

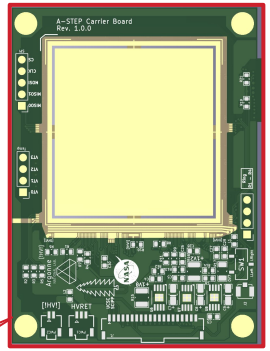
Examples

GlueX Baby BCal

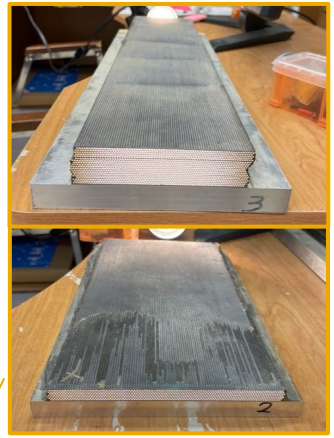


v3 chip (2x2 cm^2) carrier board

v3 quad chip (4x4 cm2) carrier board



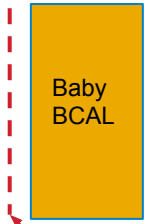
SciFi interlayer (SFIL)



120 GeV proton

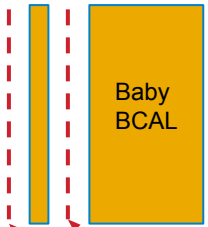
4-10 GeV pion/electron

top view



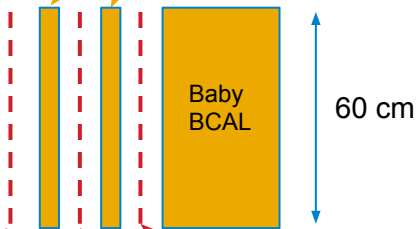
AstroPix*

Mode A



AstroPix*

Mode B



AstroPix*

Mode C

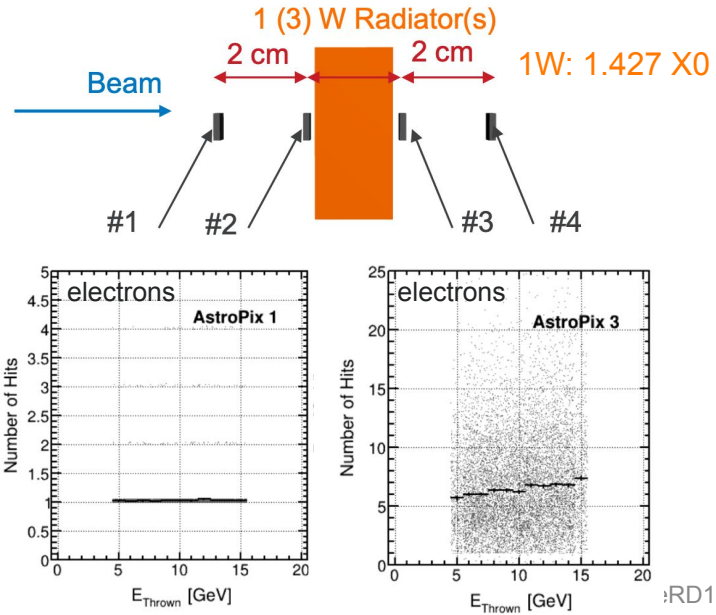
* System flexible for testing single AstroPix chip, quad chip, any any further module test design

FY24 R&D Phase I - Simulations

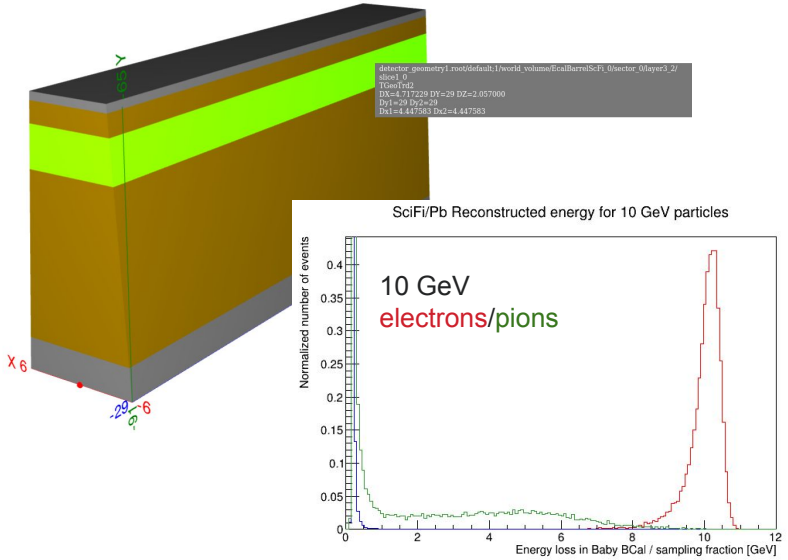
AstroPix Simulations: Jihee Kim
Baby BCal Simulations: Jared Richards

- **Full simulation of AstroPix and Pb/SciFi** matrix implemented for **ePIC**
- Simulation of effective response **including light attenuation and SiPMs responses** implemented
  - Based on measured phe statistics from FY23 Baby BCal beamtest in Hall D
- Current effort on implementing the **Baby BCal and AstroPix Prototype geometry**

AstroPix telescope simulations w/ and w/o radiator



Baby BCal geometry implementation

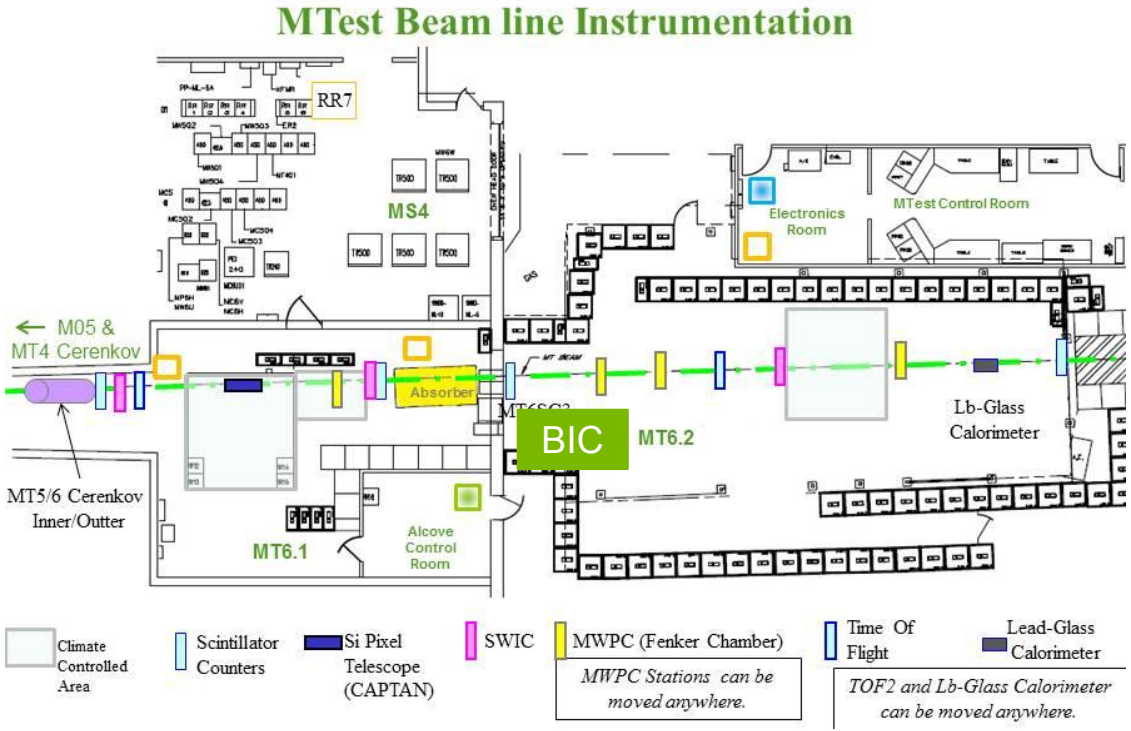


Phase II and III - Beam Test and Data Analysis

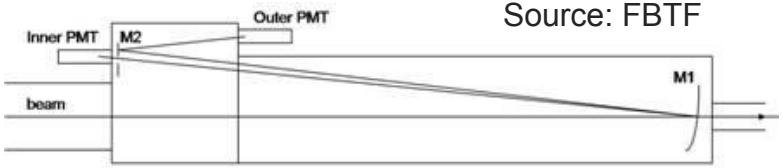
Fermilab Beam Test Facility

- Nominal beam is 120 GeV protons from main injector
- Secondary hadron/electron beam from sending 120 GeV protons on a 30 cm thick aluminum target
- Scintillators provided by FTBF along beamline for trigger
- Two Cherenkovs for PID

Source: FBTF

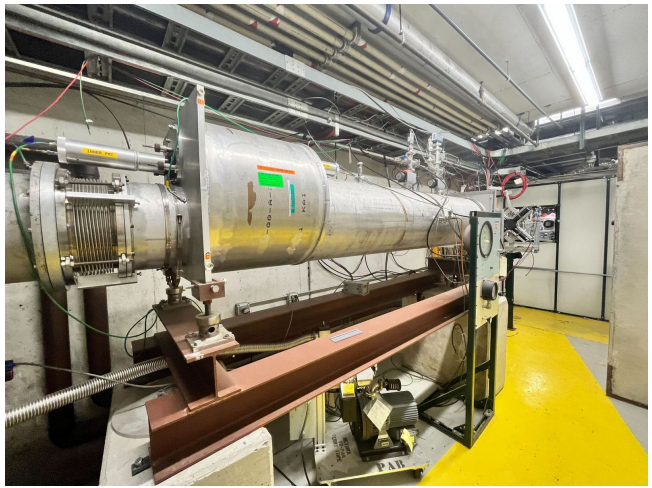


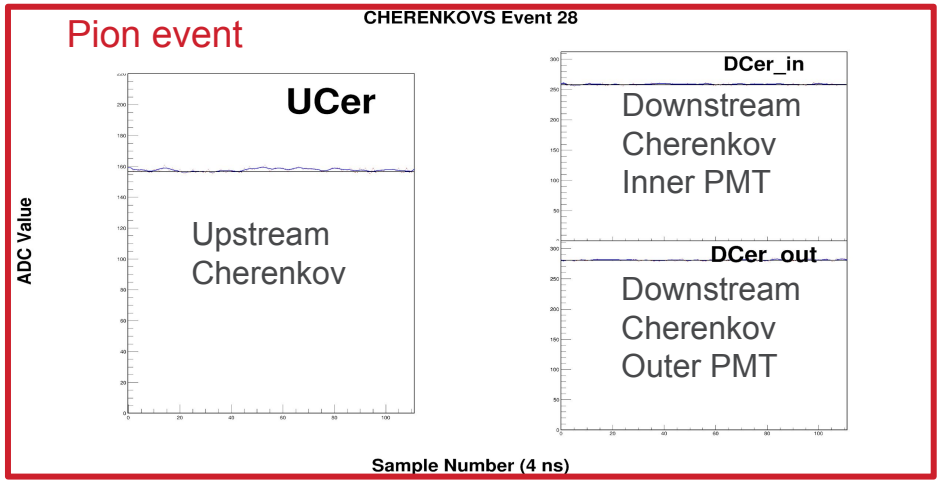
Cherenkov Detectors

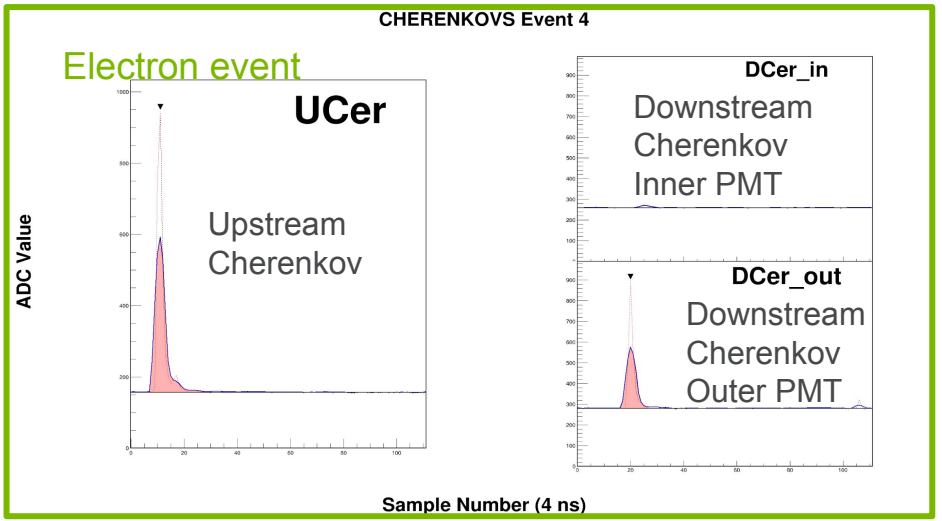


Source: FBTF

Downstream Cherenkov

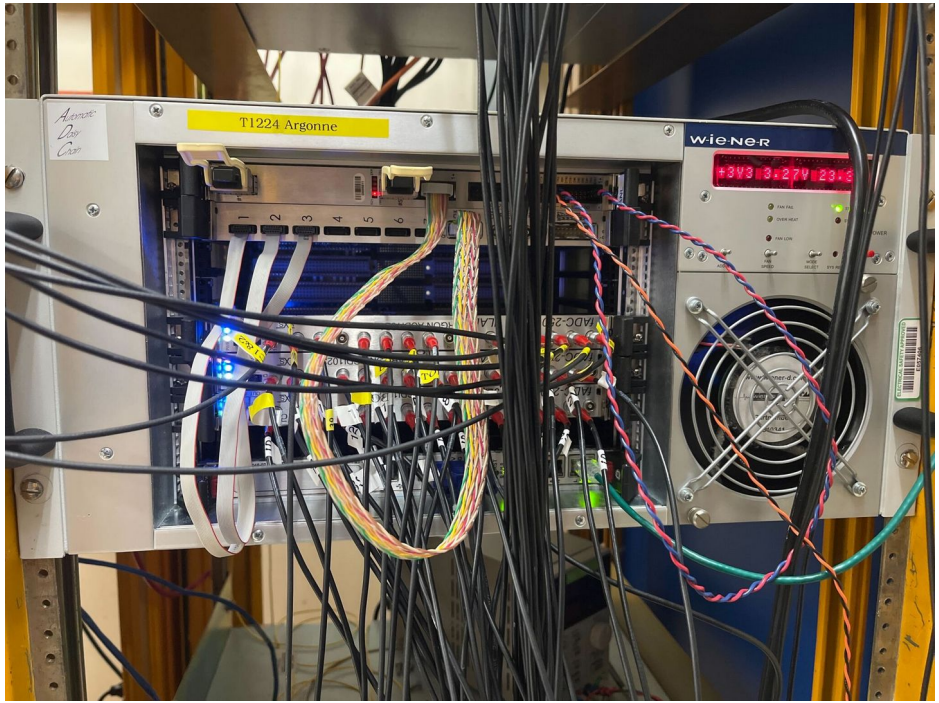






DAQ

- Used 3 x 16 channel JLab 250 MHz fADCs in full waveform readout mode
- Sent analog signals from the North and South sets of 16 baby BCal channels into two blades of fADC
- Remaining blade used for FTBF detectors, cosmic ray paddles, AstroPix analog signal



Datasets

- Due to heat issues at FNAL, only ran for ~30% of our allotted week
- DAQ limited to ~7 kHz due to full waveform readout
- **120 GeV protons**
  - Mostly parasitic overnight
  - Large dataset, few million events
- **10 GeV e/pi**
  - Also large dataset, but mostly taken with FADC jumpers set in the wrong positions, so gain is 2x higher than it should be
  - After the jumper repositioning, took an hour and a half of e/pi at 10 GeV (540K)
- **10 GeV mu/pi**
  - Taken with a lead sheet in the beam to absorb electrons
  - Provides a large MIP calibration dataset
- **Energy scan e/pi**
  - 4 GeV (1.4M), 6 GeV (440K), and 8 GeV (320K)
  - Took a larger 4 GeV because pions are rarer at low energies

Energy Calibration

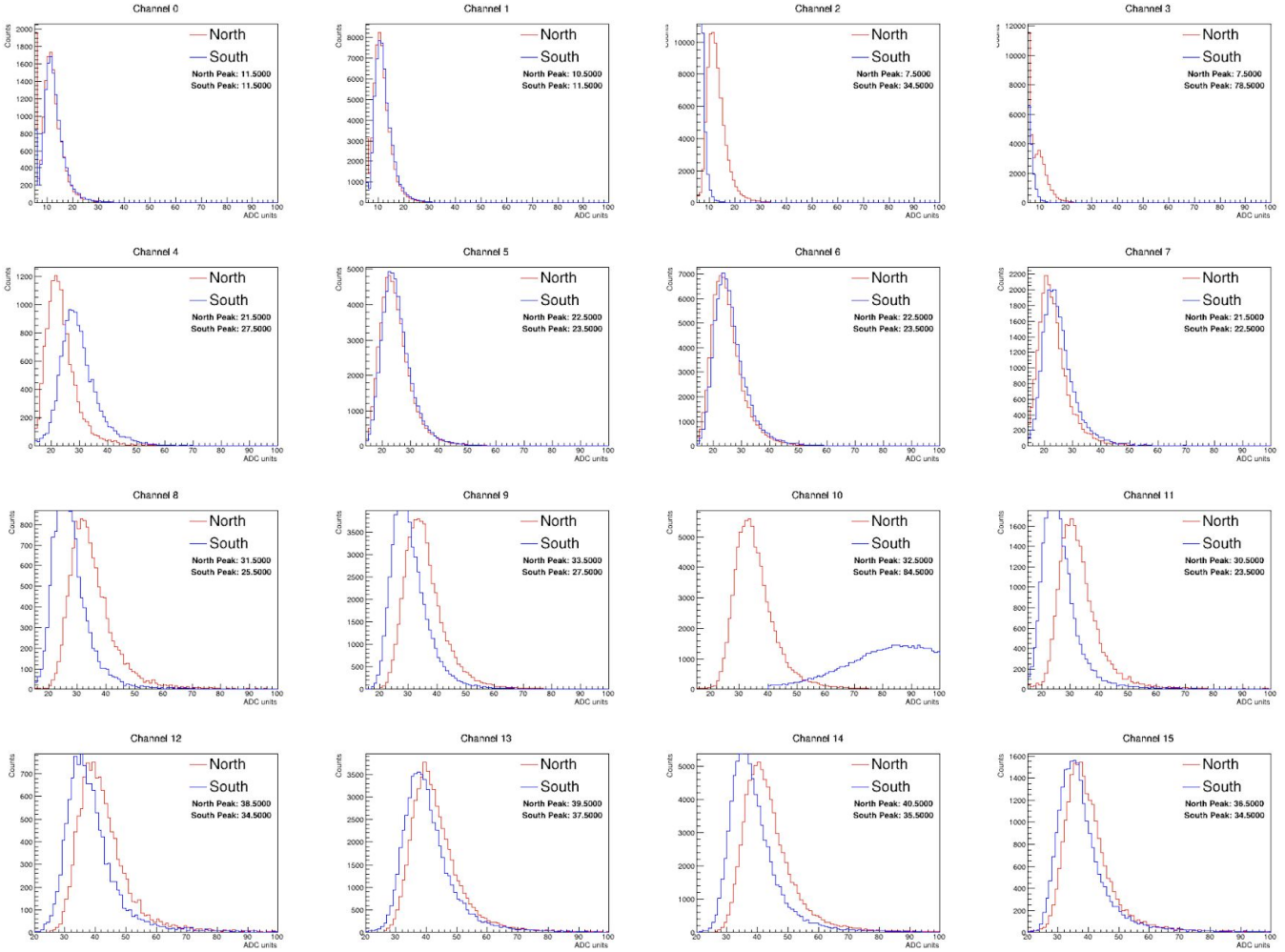
- Employ two complementary calibration techniques

- **MIP technique** – use MIP peak to align all channels
  - Pro: Each channel has an independent calibration constant, one single solution
  - Con: MIP sampling fraction is different from electrons! Needs an additional sampling fraction correction.

- **Electron technique** – minimize difference of sum of all channels with respect to a known input electron energy
  - Pro: Better energy resolution achievable
  - Con: No unique solution, 16 (or 32) unknowns and one known, different combinations of calibration constants can give the same result

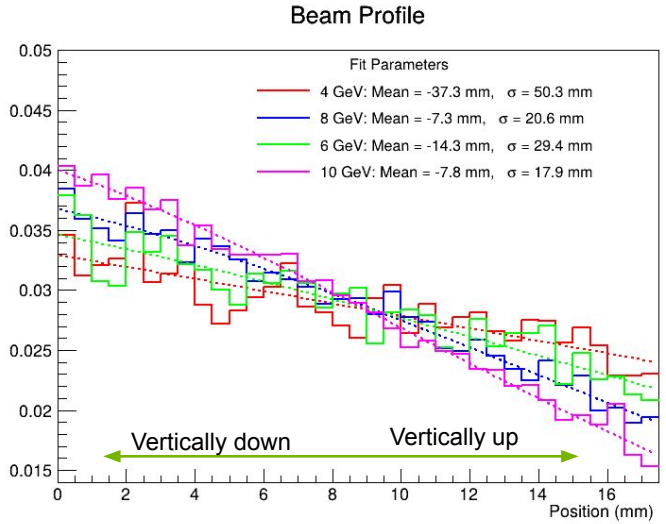
Energy Calibration

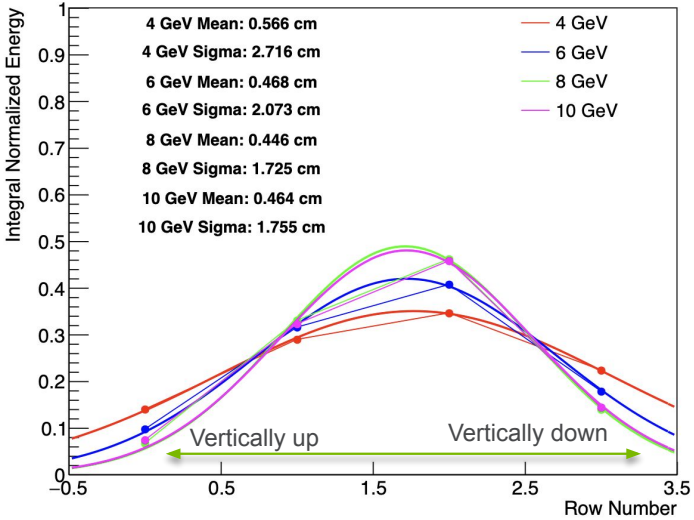
- Plot pulse heights in ADC units for events which left energy only in a line through the calorimeter
- Use muon/pion run to get clean MIP sample
- Nice MIP peak visible in all channels except for South 2&3



Beam Profile

- For calo analysis, want to know the profile of the beam in the vertical direction
  - Determines amount of leakage
- Not much info from FTBF detectors
  - MWPCs were out of gas
  - SWICs showed poor performance for secondary beams
- Have AstroPix & Calo information
  - Thanks to Bobae and Manoj for taking nice AstroPix data for us ☺
- Both detectors agree beam widens at lower energy, both agree the beam center is vertically below the center of the calorimeter





Beam Δp

- An important factor in understanding the energy response is the beam momentum spread
- This term enters as a constant term on the energy resolution
- Quoted beam spread is 2.7% at low energies, improving to 2% at 120 GeV
  - However, statement from Joe at FTBF is that: ”every calo group is telling me it looks like the momentum spread is higher than the website indicates it should be.”

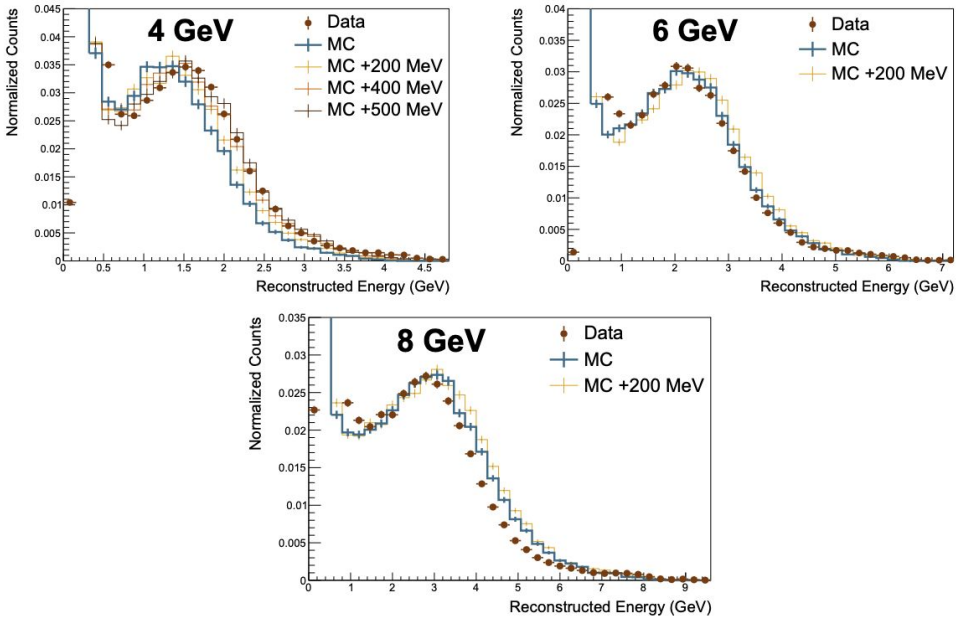
Source: FBTF

- This number depends on beam tune, which can vary from run to run
- We see the 4 GeV beam is physically wider, which suggests it also has a larger momentum spread

Energy	Mode[1]	Protons	Pions[2]	Highest Intensity[3]	Muons	Kaons	electrons	Spot Size[4]	Δp
10 GeV	LEπ +/-								
8 GeV	LEπ +/-		55%	750,000	98%			12mm	2.3%
6 GeV	LEπ +								
4 GeV	LEπ +/-		31%	400,000	74%			13mm	2.7%
3 GeV	LEπ +/-								2.7%
2 GeV	LEπ +/-		<30%	450,000				13mm	2.7%
1 GeV	LEπ +/-		<30%	69,000					2.7%

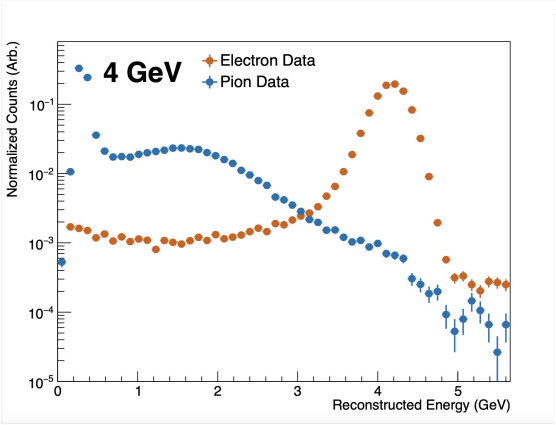
Pion Data

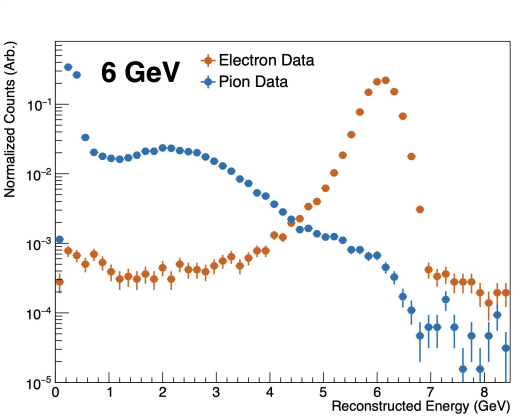
- Observed offset in beam energy, attempt to include in simulation
- Data and simulation agree for 6 GeV pions
- 4 GeV pions in data shifted to the right wrt simulation, 8 GeV pions in data slightly shifted to the left
- Physics lists, Birks' constant, beam position spread, and energy shift simulated
- A possible contributor: beam momentum and its spread. A direct confirmation is not possible with the available dataset.
- Given the constraints of the FTBF dataset, this level of agreement represents the best achievable precision.

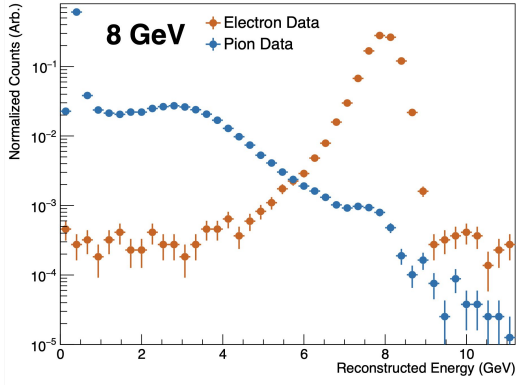


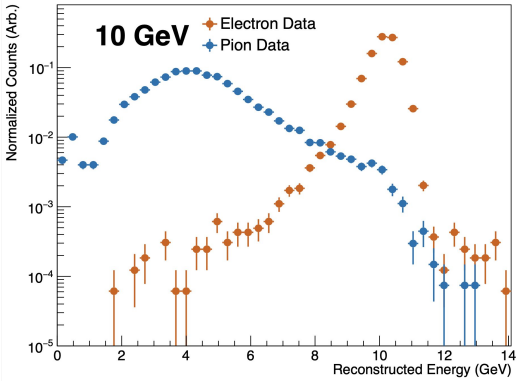
e/π SEPARATION

- Measured energy distributions of events with Cherenkovs firing (electrons, orange) and Cherenkovs not firing (pions, blue)
- Electrons and pions well separated, but both have tails
  - Electron tail – showers upstream, horizontal leakage
  - Pion tail – electron misID, pileup
- The tail of the electron distribution is an artifact of the measurement setup
  - Predict the true performance by fitting crystal ball or gaussian to the electron peak







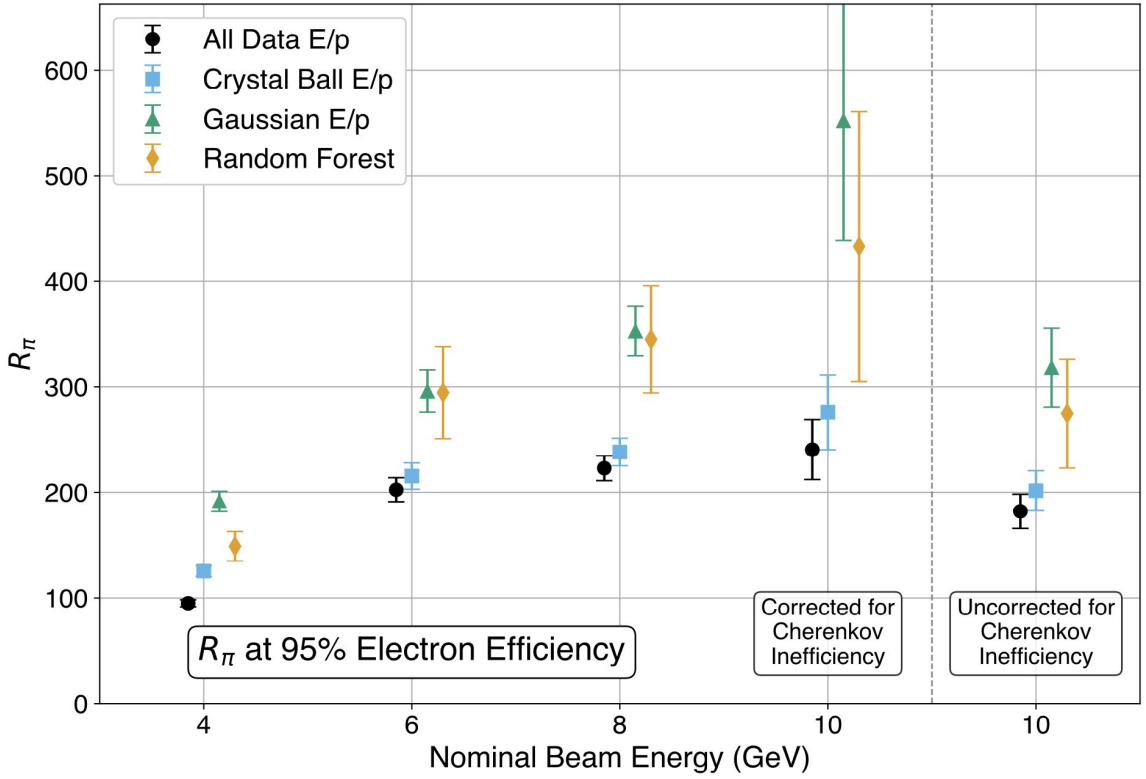


e/π SEPARATION

Presented methods in various degree incorporate artifacts of the test beam setup: beam momentum smearing, effects of upstream material, possible pileup, and beam profile variations

Including longitudinal energy profile (4-sections only in Baby BCAL) helps significantly with separation

All things considered, separating electrons and pions is pretty easy in this detector! (even with beam momentum spread & some leakage)



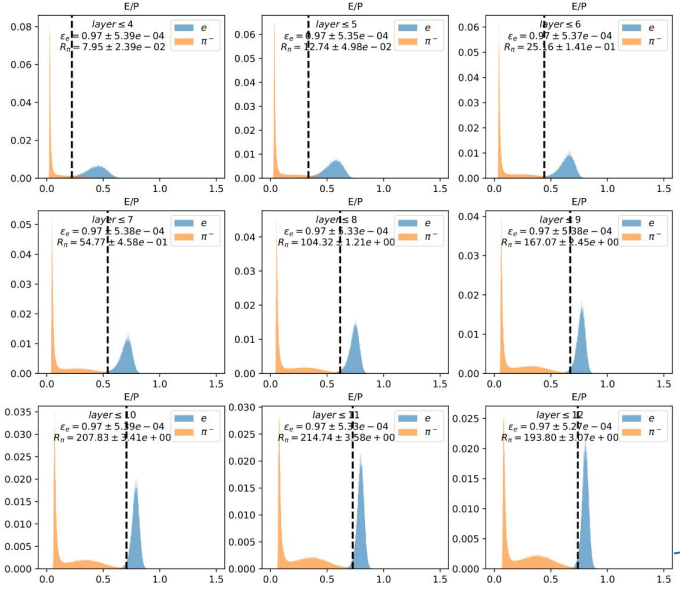
Other

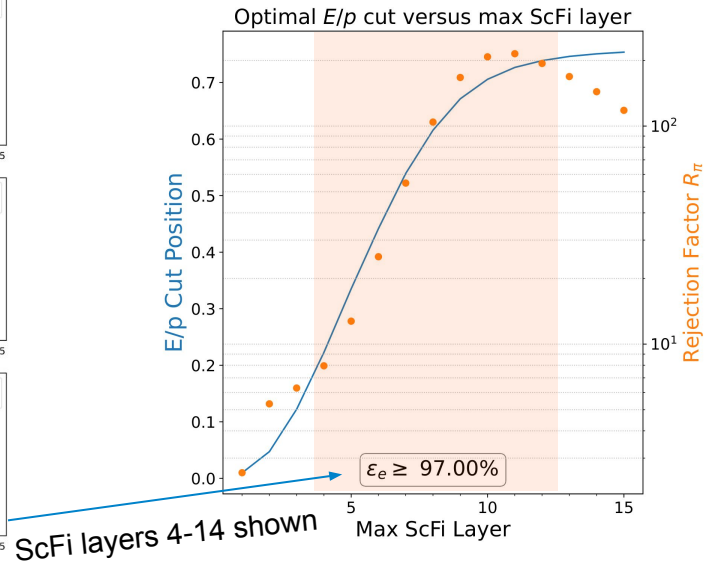
e/π Separation in Barrel ECal - Method

Steps:

1. **Optimized cut on E/p** from different depth of Pb/ScFi layers at very high electron efficiency
2. **Convolutional neural network** utilizing energy and spatial information for shower (see backup slides for details)

Example for 2 GeV e/π

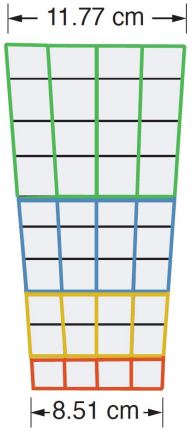




SiPM Readout

- **2-side SiPM readout**
- **Lightguides** attached to the sector sides
  - inner surface ~2×2 cm^2
  - output face 1.3×1.3 cm^2
- SiPMs: S14161-6050-04 array (4x4 array of 3×3 mm^2, 50×50μm^2 pixels)
- 12 layers x 5 cells x 2 sides x 48 sectors = 5760 channels

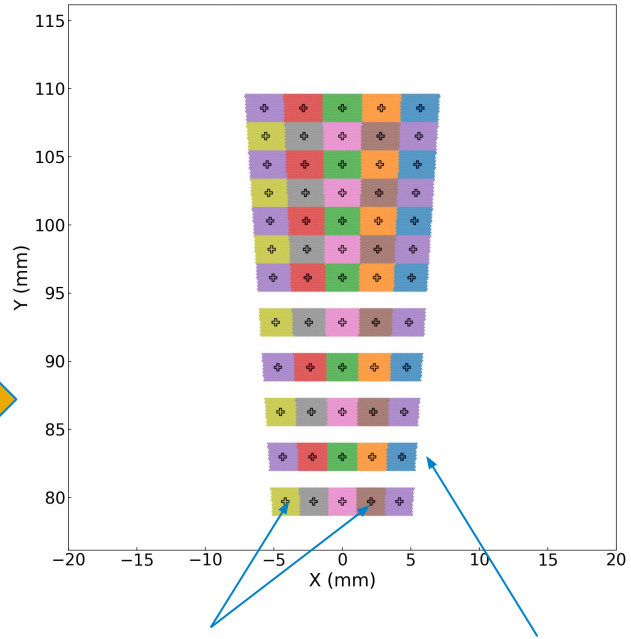
GlueX
1/48th of the barrel end view



Hamamatsu S12045(X)
4×4 array of 3×3 mm^2
50×50μm^2 pixels

16 FADC per side
12 TDC per side

ePIC Sector End View
(x-y plane view)



Readout **Cell**
Layer = 5 cells

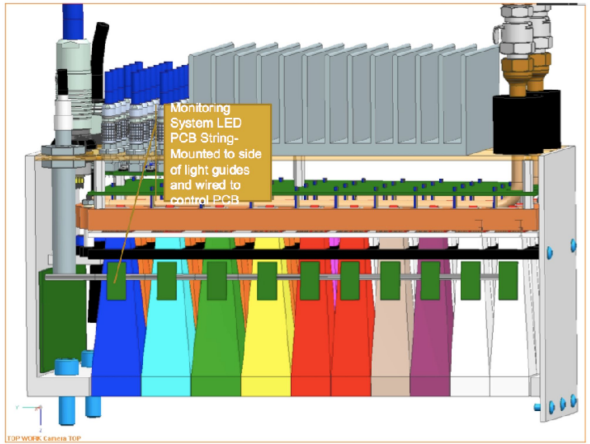
The area 1 light guide is attached

Pb/Sci **Layer**

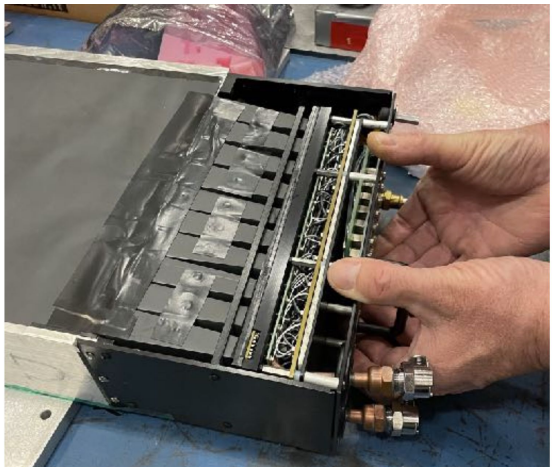
1 sector = 12 layers
1 layer = 17 rows of fiber

GlueX BCAL Readout Design

- Pb/ScFi readout based on the GlueX BCAL readout
- Footprint excluding external connectors of GlueX BCAL readout box about 14cm
  - Dominated by light guides (~ 8 cm)
- We will likely be able to shrink this somewhat to < 12 cm
  - Space pressure in the forward direction, where space is limited.



CAD drawing of GlueX readout box



Baby BCAL prototype readout box