# Fermilab Beam Test Update

HENRY KLEST

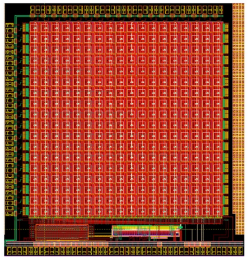


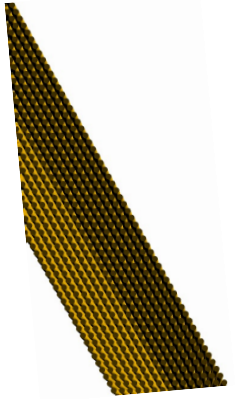

U.S. DEPARTMENT OF ENERGY
Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

May 14, 2024

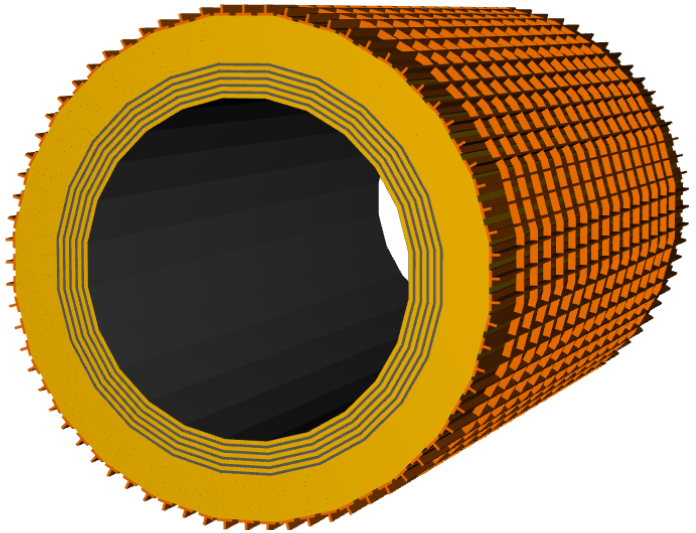
# Test Beam R&D Goals

Benchmark detector performance in as realistic a configuration as possible with different beams at FNAL





- Study e/$\pi$ separation and overall $\pi$ response
- Characterize SciFi energy resolution & linearity at higher energy than GlueX
- Demonstrate ability to operate AstroPix & SciFi in tandem

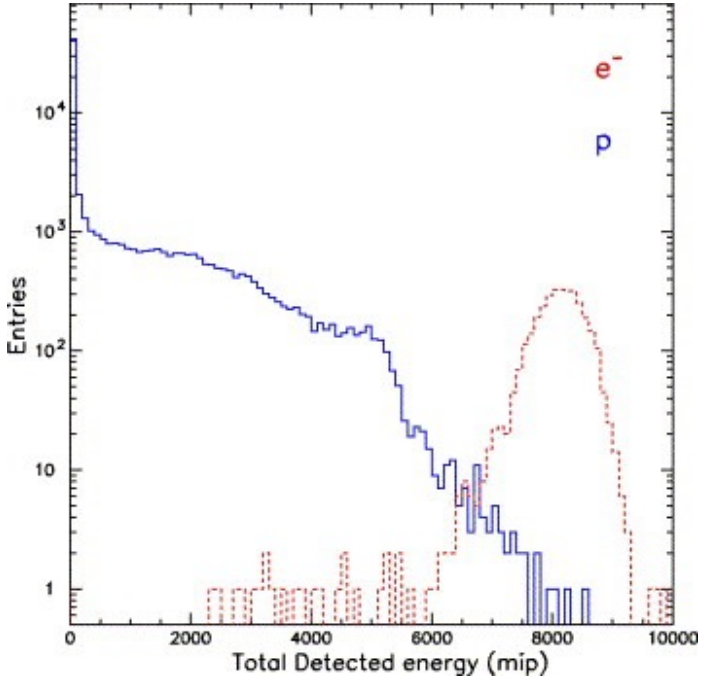


# Fermilab Test Beam Plans

Benchmark simulation results for hadronic response

- EM response well-known from GlueX & PS beam tests
  - Anyhow more likely to be well-described by GEANT
- Crucial to verify hadronic response at energies relevant for EIC
  - Necessary to determine electron/pion separation power

Compare measured energy distributions for pions and electrons to those from a simulation of the Baby BCal (See Jared's talk)




Example energy distribution in an EM calorimeter from hadrons and electrons

# Fermilab Test Beam Plans

Study Baby BCal for the first time at higher energies

- Extensively studied at energies available at JLab
  - See Jon's talk about the Hall D tests
- However, higher energy = better constraint on constant term

Stretch goal of measuring an electromagnetic energy resolution with the higher energy FTBF electron beam

# General setup

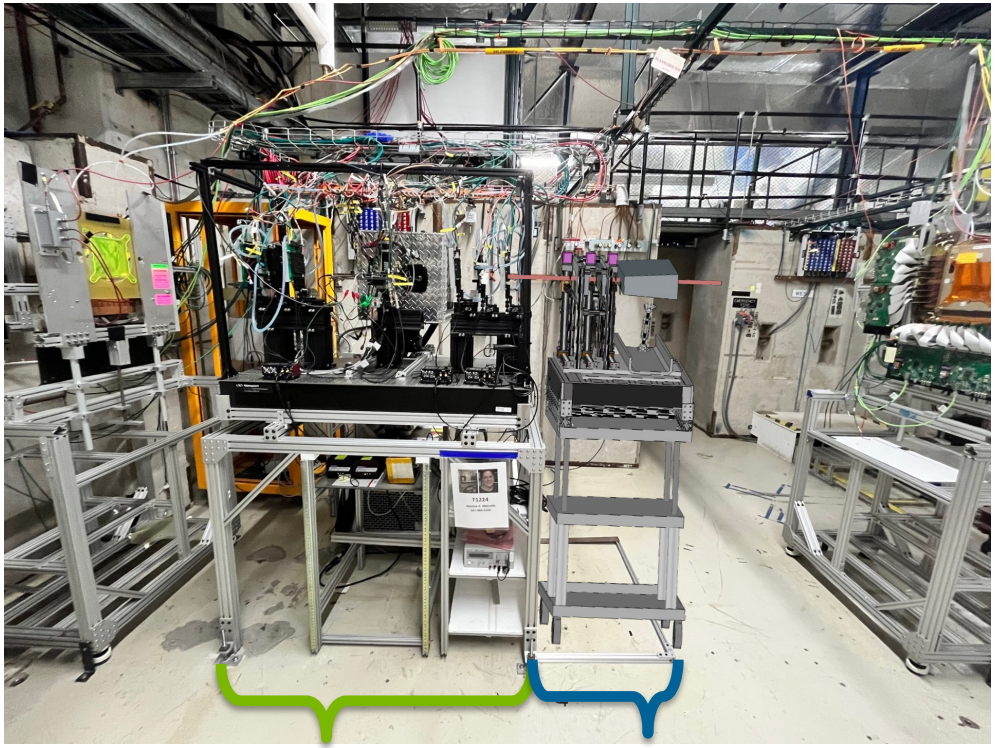
Slide from January

Add BIC prototype calorimeter behind existing Argonne ATLAS Pixel telescope with AstroPix setup at MTest

Rotating stage to simulate particles incident at angles up to 45° ($\eta \sim 1$)

Ability to lower BIC setup out of the beam, no need to uninstall for other experiments to run

- Proximity to Argonne enables occasional opportunistic running



Current ANL AstroPix Telescope Setup

Planned BIC Setup

Drawings by Tom O'Connor

# General setup

Add BIC prototype calorimeter behind existing Argonne ATLAS Pixel telescope with AstroPix setup at MTest

Rotating stage to simulate particles incident at angles up to 45° ($\eta \sim 1$)

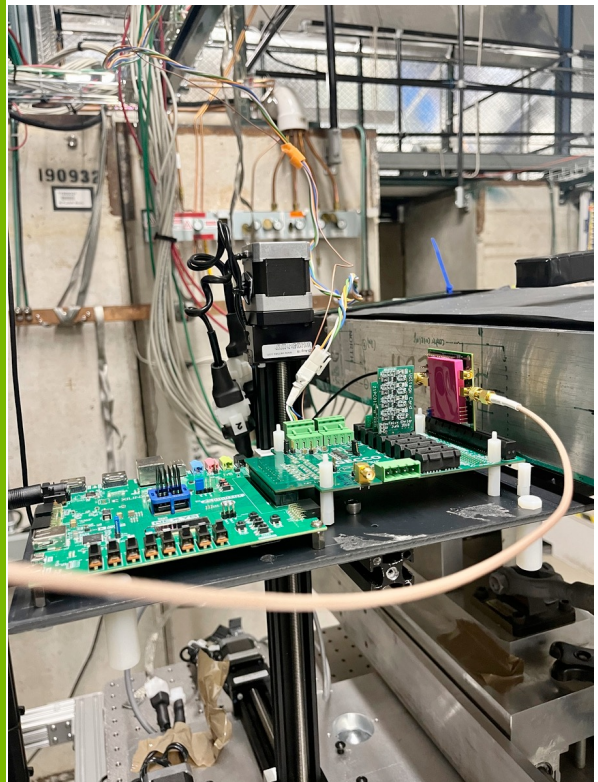
Ability to lower BIC setup out of the beam, no need to uninstall for other experiments to run

- Proximity to Argonne enables occasional opportunistic running

Current ANL AstroPix Telescope Setup

Planned BIC Setup!

# Present Setup Status



# FTBF Beam & Detector Info

Nominal beam is 120 GeV proton beam from the Fermilab Main Injector

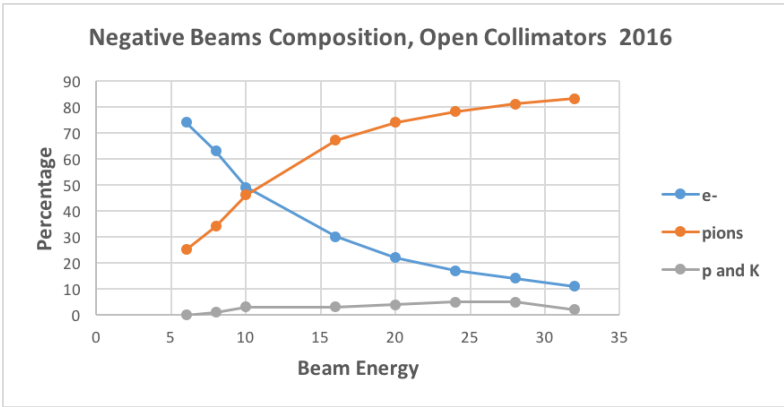
Mixed beams of lower energy electrons, pions, etc. available

- Target placed in beam to produce secondaries

Plan to run with 120 GeV protons & 10 GeV electron/pion mixed beam

- 10 GeV mixed beam has approximately equal rates for electrons and pions

| Energy | Mode[1] | Protons | Pions[2] | Highest Intensity[3] | Muons | Kaons | electrons | Spot Size[4] | Δp |
|---|---|---|---|---|---|---|---|---|---|
| 120 GeV | Protons | 100% | 0 | 5E5 | 0 | 0 | 0 | 6mm | 2% |
| 60 GeV | pions + | | | | | | | | |
| 50 GeV | pions + | | | | | | | | |
| 40 GeV | pions + | | | | | | | | |
| 32 GeV | pions +/- | | | 500,000 | | | | | |
| 30 GeV | pions +/- | | | 500,000 | | | | | |
| 25 GeV | pions +/- | | | 600,000 | | | | | |
| 20 GeV | pions +/- | | | 500,000 | | | | | |
| 16 GeV | LEπ +/- | | 87% | 1,000,000 | 100% | | | 10mm | <4.5% |
| 15 GeV | LEπ +/- | | | | | | | | |
| 12 GeV | LEπ – | | | 500000 | | | | | |
| 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% |

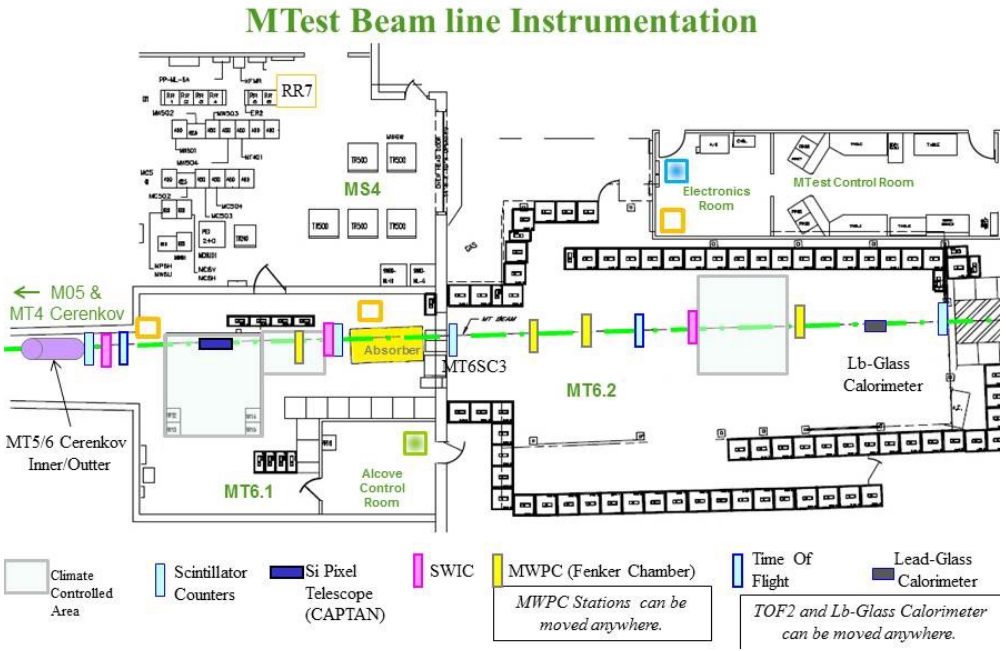


# FTBF Beam & Detector Info

Beam provides ~1 particle per 11 microseconds

- At 100 kHz, ~35% of bunches have > 1 particle in them
- This is a very long time for the Baby BCal
- Reasonably long time for AstroPix (few 10s of coarse clock ticks)

At low intensity (where we plan to run), pileup of events is no issue



# FTBF Beam & Detector Info

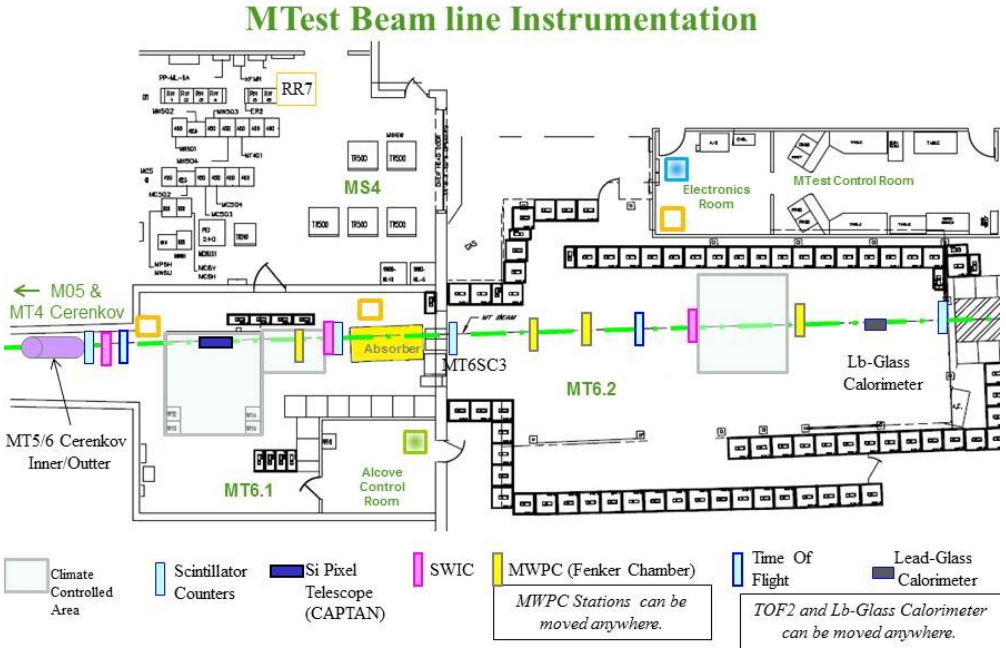
Various ancillary detectors allow for good knowledge of the beam

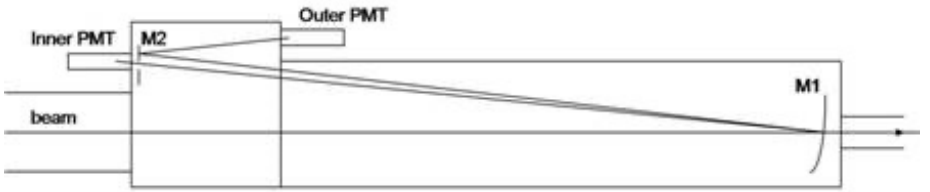
Two long O(3m) gas Cherenkov detectors upstream of enclosure

- Necessary to tell us which signals in the Baby BCal came from pions and which from electrons
- One has two PMTs, allowing differential operation
  - E.g. pion rings hit PMT 1, electron rings hit PMT 2

Three upstream scintillating paddles for triggering

MWPCs for beam profile



# FTBF Beam & Detector Info

Various ancillary detectors allow for good knowledge of the beam

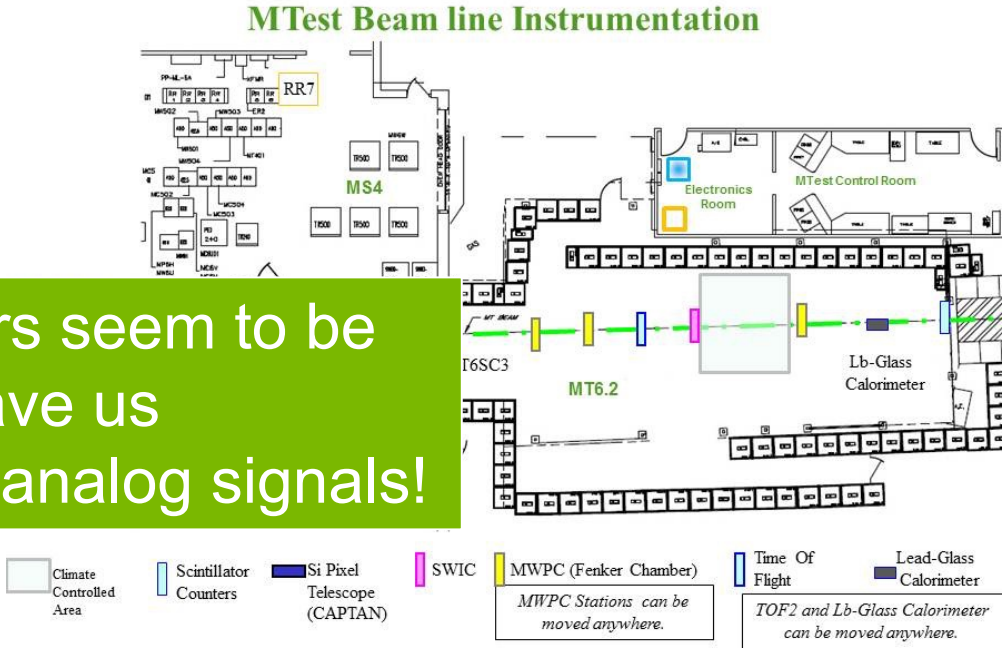
Two long O(3m) gas Cherenkov detectors upstream of enclosure

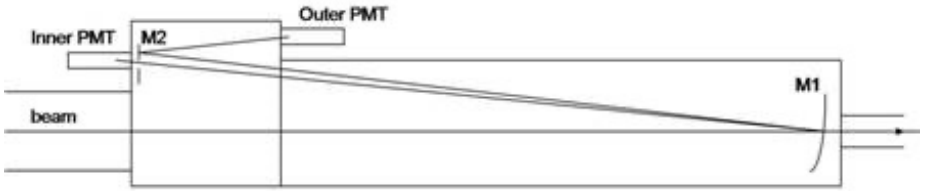
- Nec… sign… from… elec…
- One… differential operation
  - E.g. pion rings hit PMT 1, electron rings hit PMT 2

All of these detectors seem to be in working order, gave us reasonable looking analog signals!

Three upstream scintillating paddles for triggering

MWPCs for beam profile

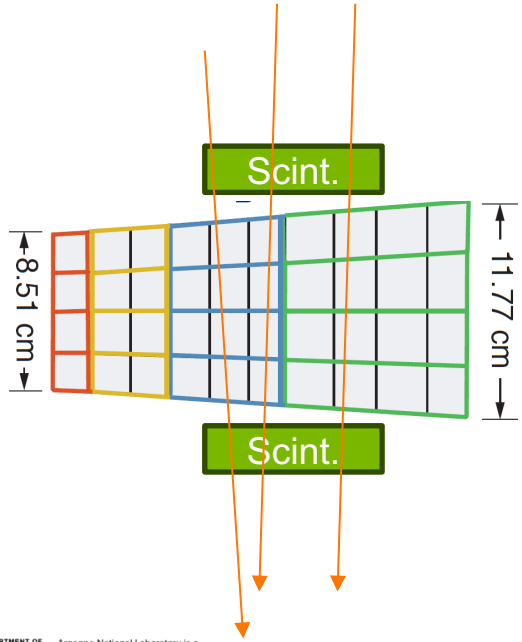


# Cosmic Ray Data

4x Scintillating paddles above and below for triggering on straight cosmic tracks

Slight complication arises from the fact that the Baby BCal is on its side w.r.t incidence direction of cosmics passing through both paddles





# Electronics

Plan to use 2 JLab FADC boards to readout the Baby BCal

One FADC board to read out ancillary detectors

- FTBF Cherenkov, FTBF Scintillators, Cosmic ray paddles

250 MHz sampling

- Various readout modes, integral, pulse height, etc.

Integration to JLab CODA for DAQ

# DAQ

DAQ has been a challenge due to lack of availability & complicated configuration of ANL VME hardware & FADCs

Lots of hard work from Sylvester has gotten us close, but still some more work to be done before we can fully readout the Baby BCal (+other FTBF detectors and cosmic paddles) in the same data stream

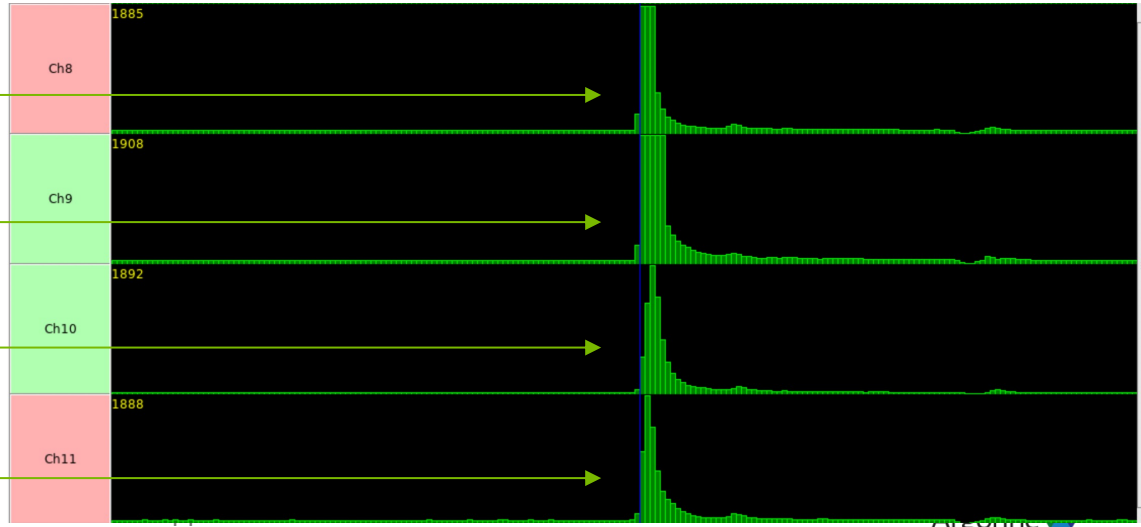
CODA Scope view of pulses

Cosmic ray paddle above North side of Baby BCal

Cosmic ray paddle below North side of Baby BCal

Cosmic ray paddle above South side of Baby BCal

Cosmic ray paddle below South side of Baby BCal



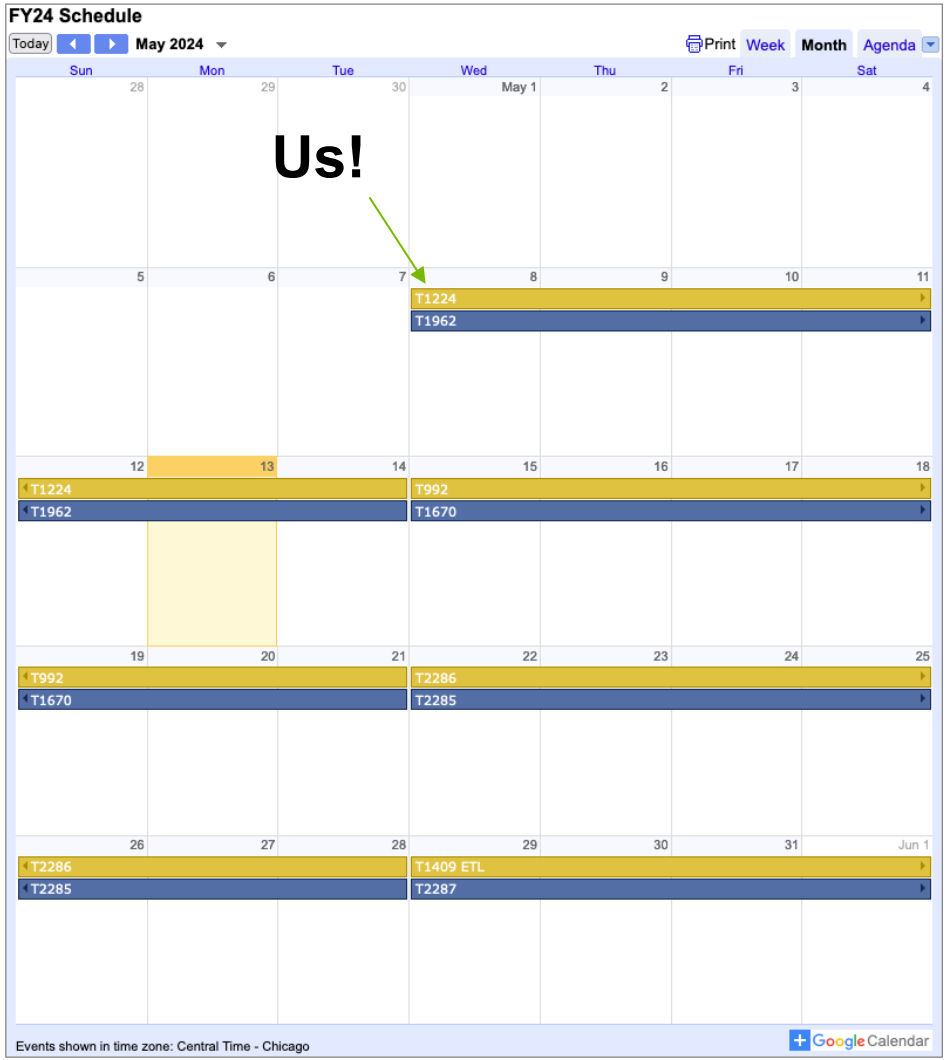
# Schedule

Scheduled to run in the first week of FTBF running

With only one week, planned simply to observe Baby Bcal response to hadrons & collect AstroPix V3 data

Unfortunately, no beam!

- The best laid plans…



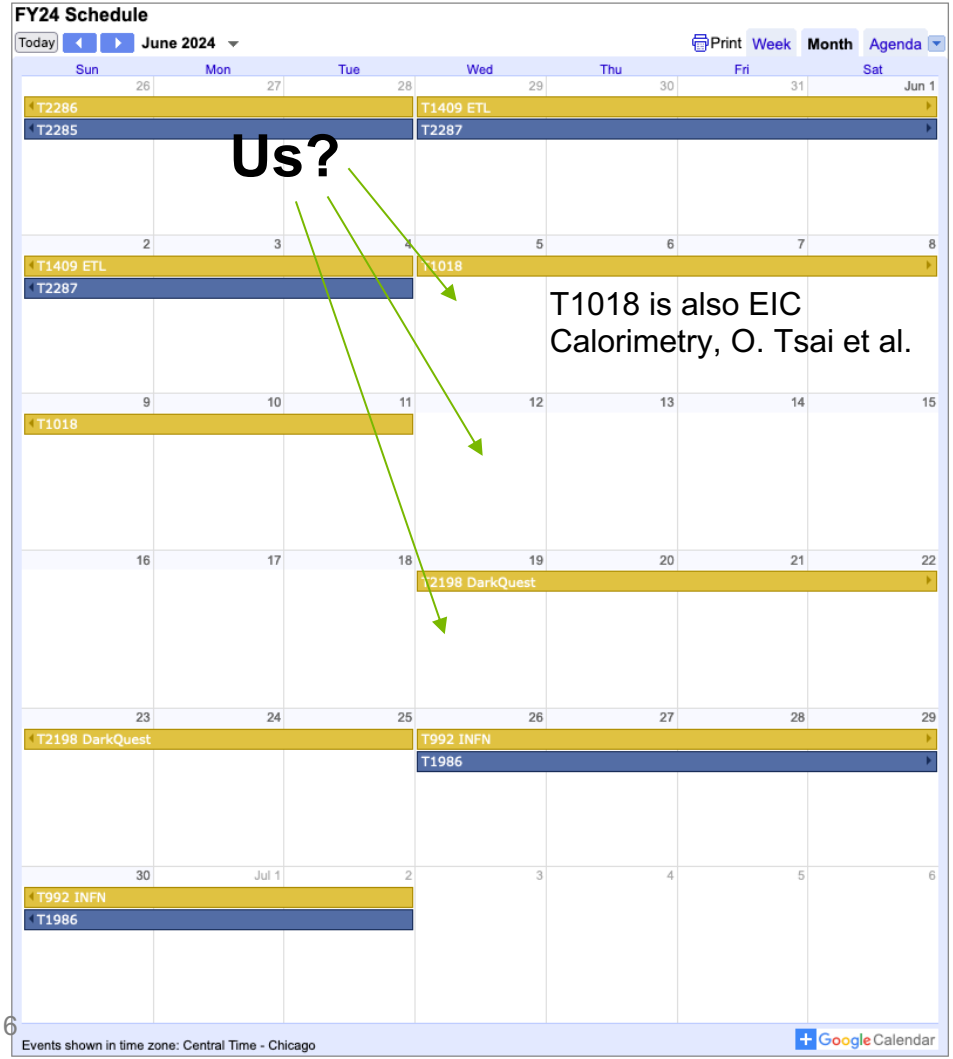
# Schedule

However, FTBF said that we could have some time in June to run
- For a few reasons this is actually advantageous for us

Gives us more time to refine our setup

Can run parasitically if any of the experiments in-between don't need the beam

Can collect cosmic data with Baby Bcal to test full readout chain & perform calibrations



# Schedule

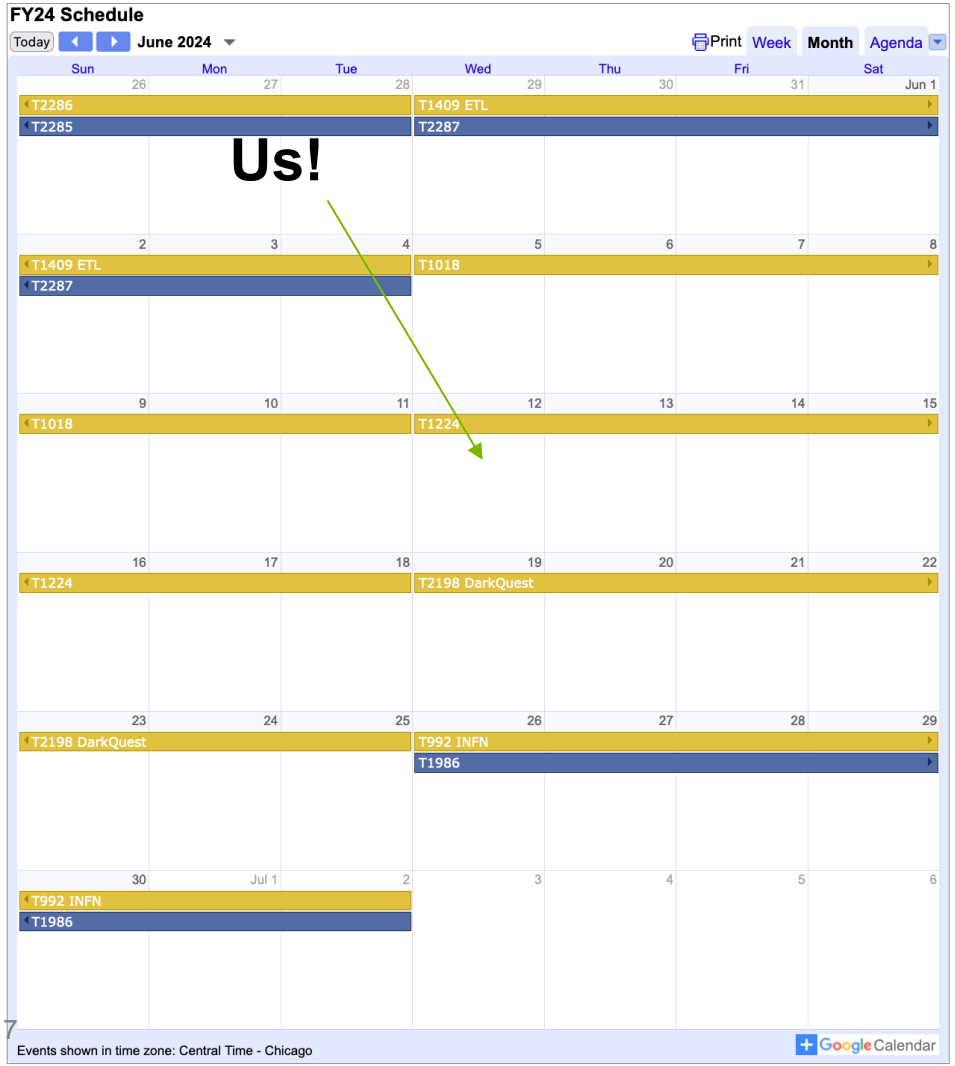
However, FTBF said that we could have some time in June to run

- For a few reasons this is actually advantageous for us

Gives us more time to refine our setup

Can run parasitically if any of the experiments in-between don't need the beam

Can collect cosmic data with Baby Bcal to test full readout chain & perform calibrations



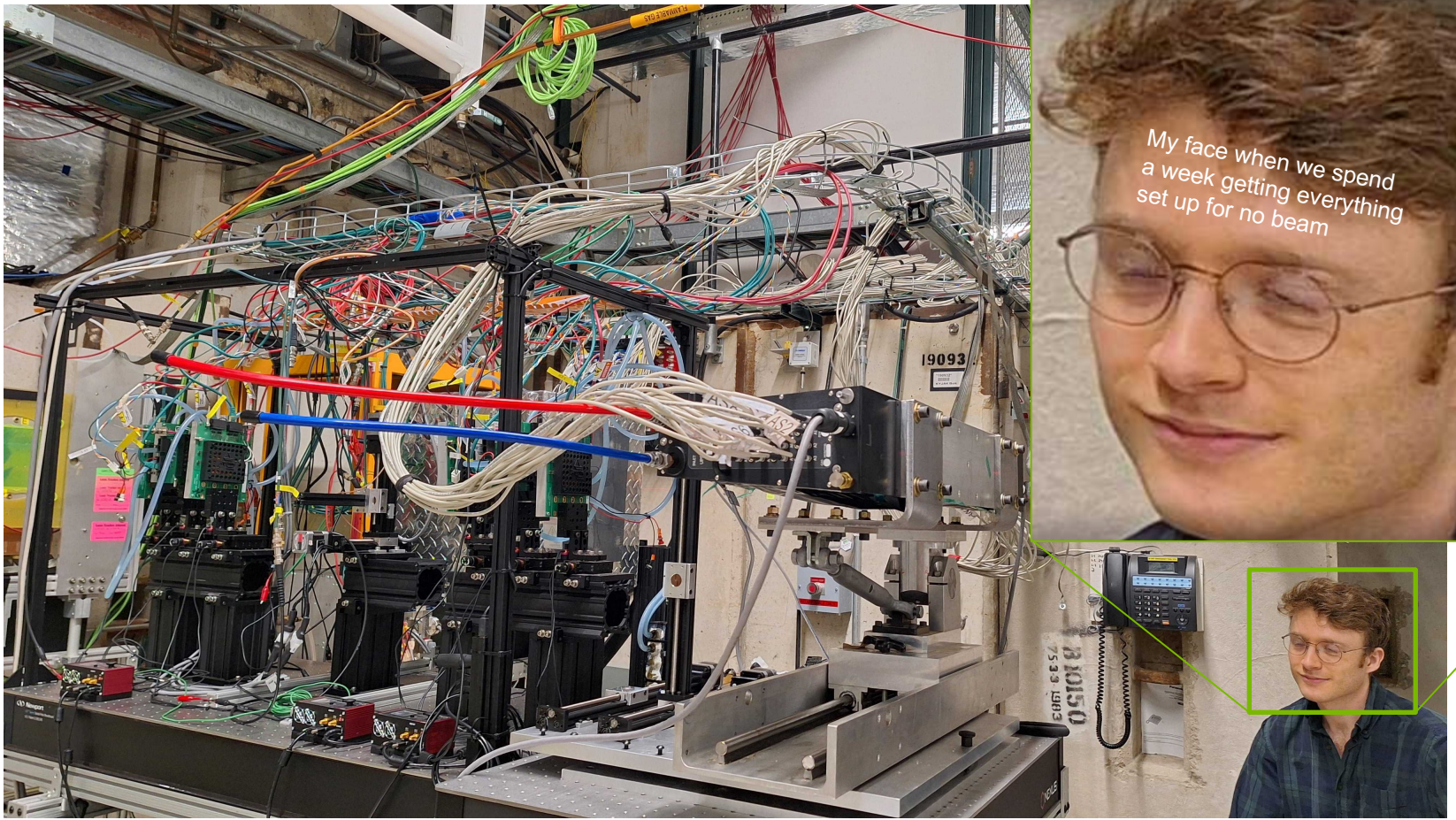
# Conclusion

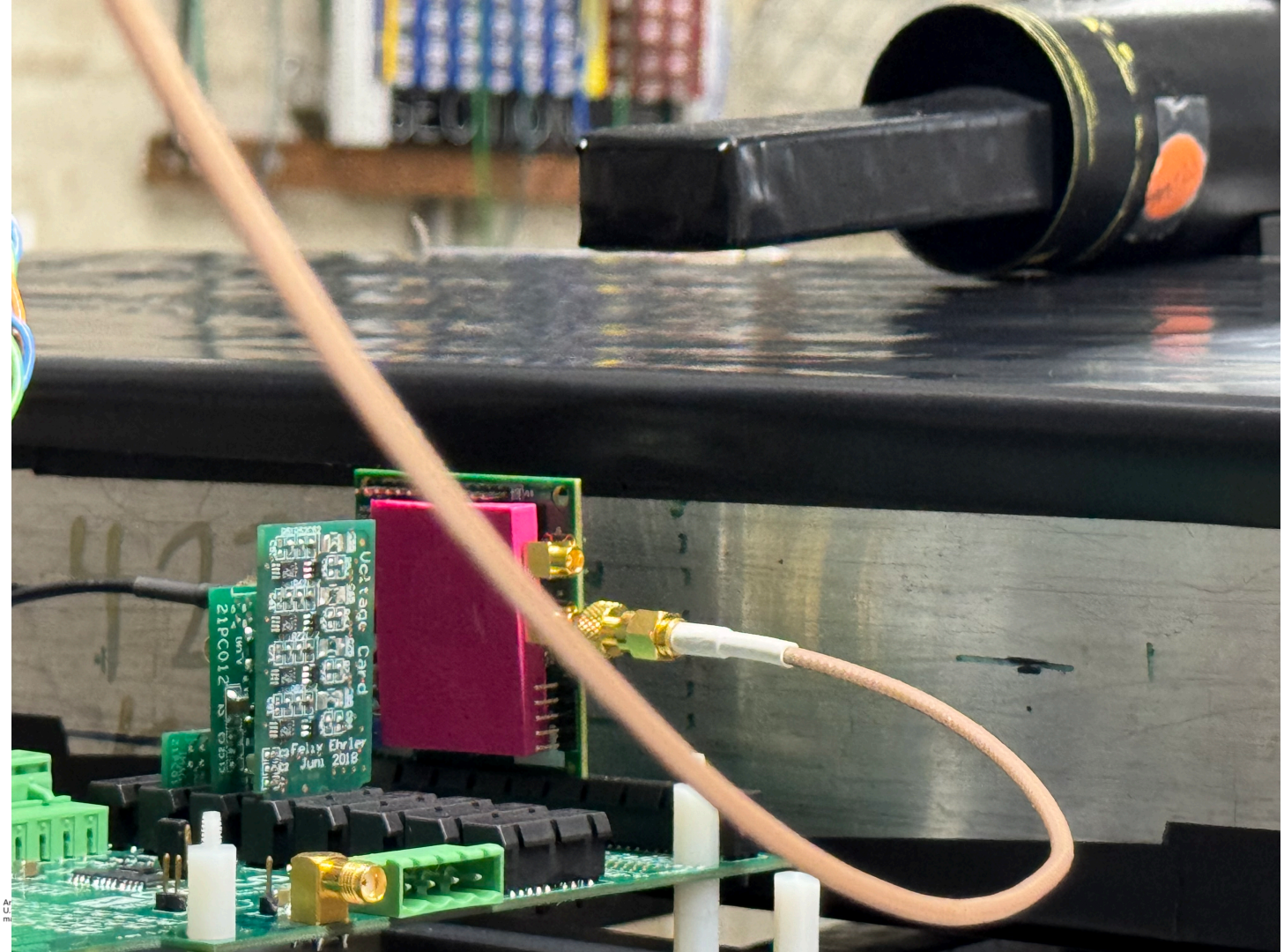
Lots of useful work went into preparing for this week's test beam

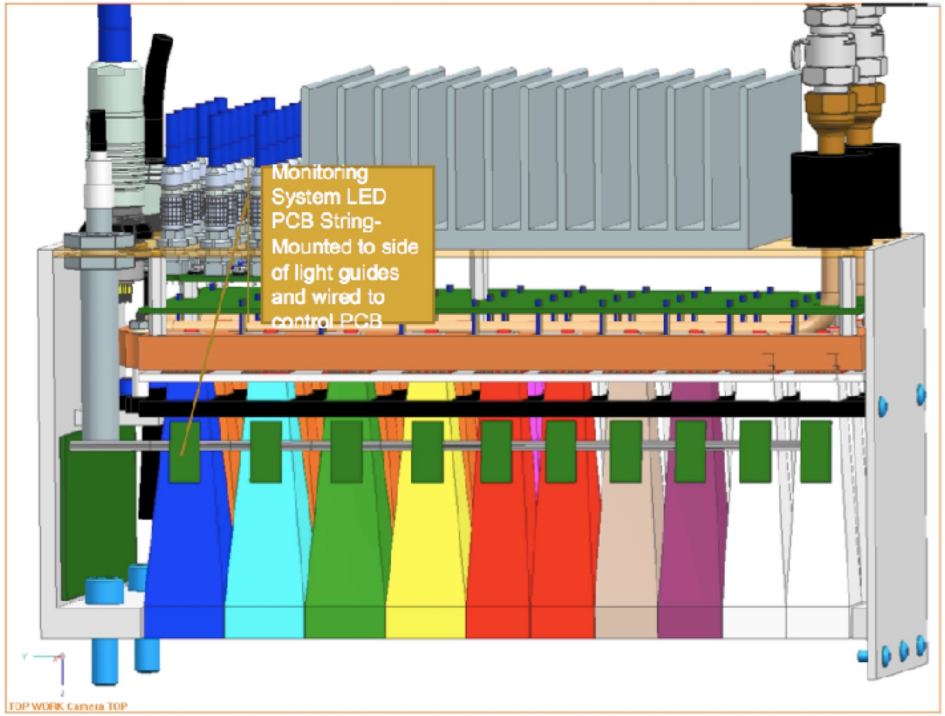
- Thankfully that work isn't lost, still have the opportunity for test beam in June, as well as parasitic running with some other groups

Prior to June, tasks include:

- Getting DAQ up and running
- Tuning FTBF detectors with beam
  - Can be done whenever the beam is available
- Calibrations with cosmic rays

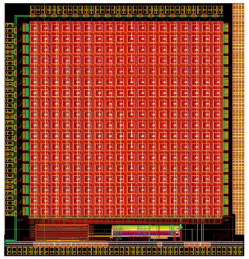

My face when we spend
a week getting everything
set up for no beam

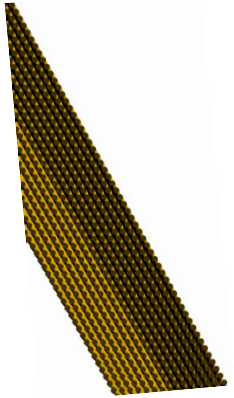

Ucl rage Card
Felix Ehrler
Juni 2018


Monitoring System LED PCB String-Mounted to side of light guides and wired to control PCB
TOP WORK Camera TOP

# Backup

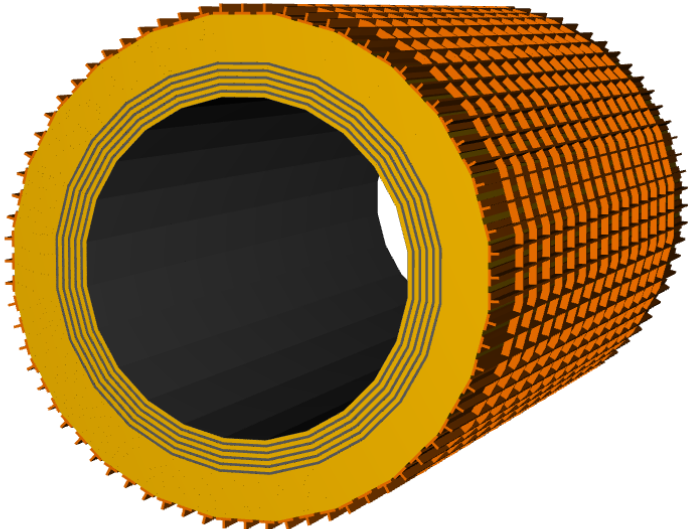
# Test beam R&d goals





Benchmark detector performance in as realistic a configuration as possible with different beams at FNAL

- Demonstrate ability to operate AstroPix & SciFi in tandem
- Study e/$\pi$ separation and overall $\pi$ response
- Characterize SciFi energy resolution & linearity at higher energy than GlueX
- Gain operational experience with the specific SiPM options to be used in ePIC BIC



All of the above highlighted by comprehensive detector review report

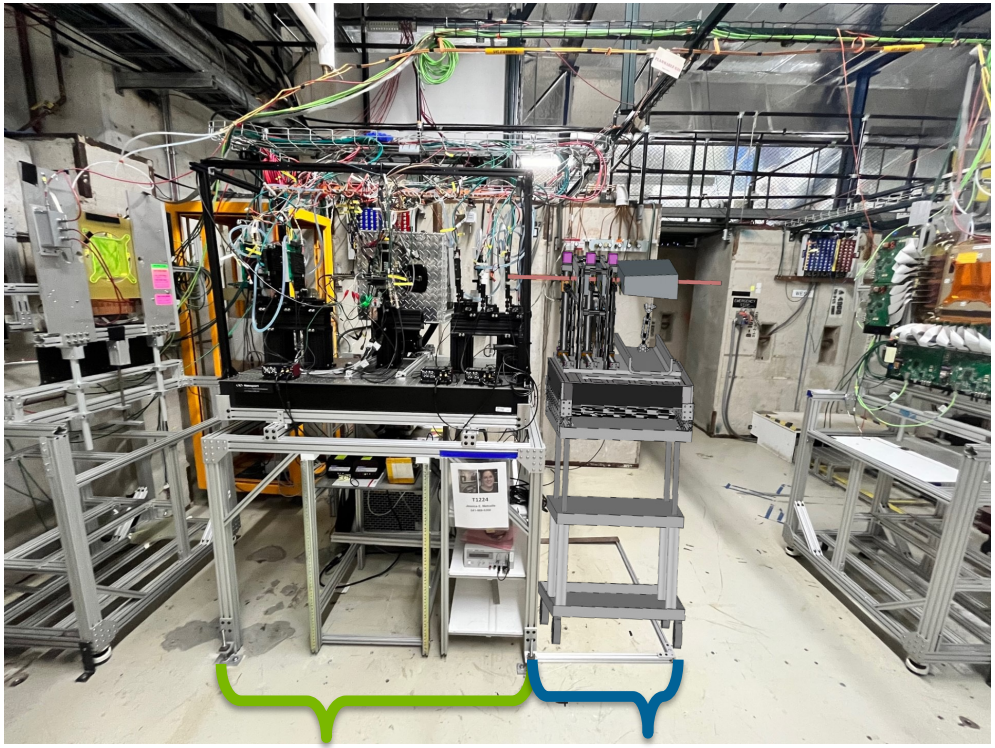
# General setup

Add BIC prototype calorimeter behind existing Argonne ATLAS Pixel telescope with AstroPix setup at MTest

Rotating stage to simulate particles incident at angles up to 45° ($\eta \sim 1$)

Ability to lower BIC setup out of the beam, no need to uninstall for other experiments to run

- Proximity to Argonne enables occasional opportunistic running



Current ANL AstroPix Telescope Setup

Planned BIC Setup

# Gluex bcal prototype

Thick SciFi portion of BIC approximated by the GlueX prototype

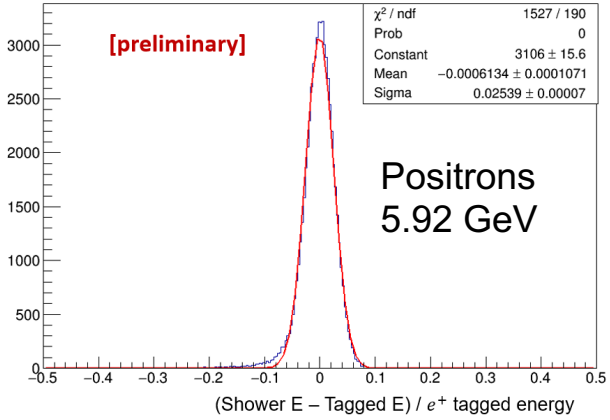
- Studied in March ‘23 with positrons in Hall-D PS
- Cosmic data taken in Hall-D, currently under analysis
- More cosmics planned at ANL prior to installation at FTBF

Baby BCAL in Hall D, 2023

- $e^+$ energy = 5.92 GeV
- Resolution ≈ **2.5**%

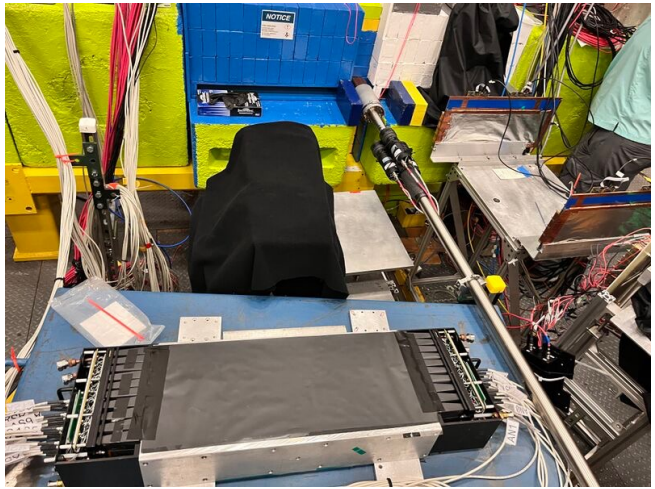
GlueX NIM, extrapolated

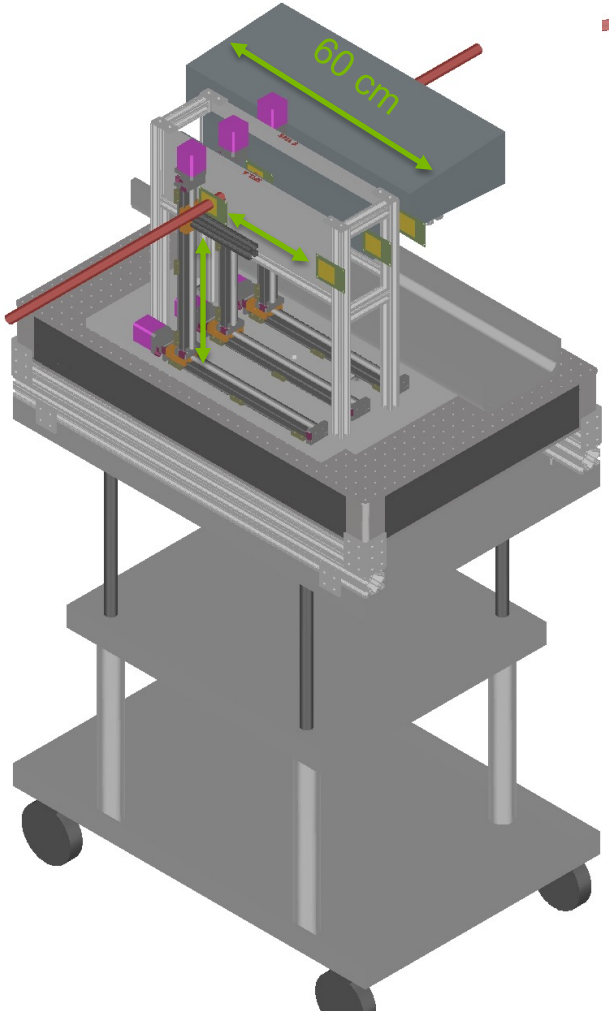
- Expect ≈ **4.2**%

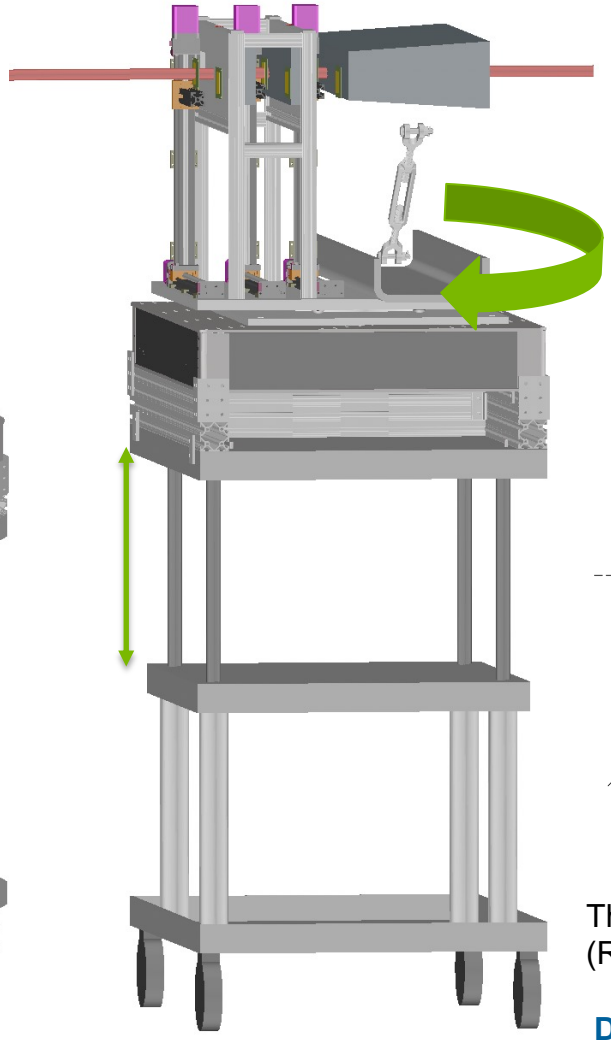



GlueX BCAL: $\frac{5.2\%}{\sqrt{E\ (GeV)}} \oplus 3.6\%$

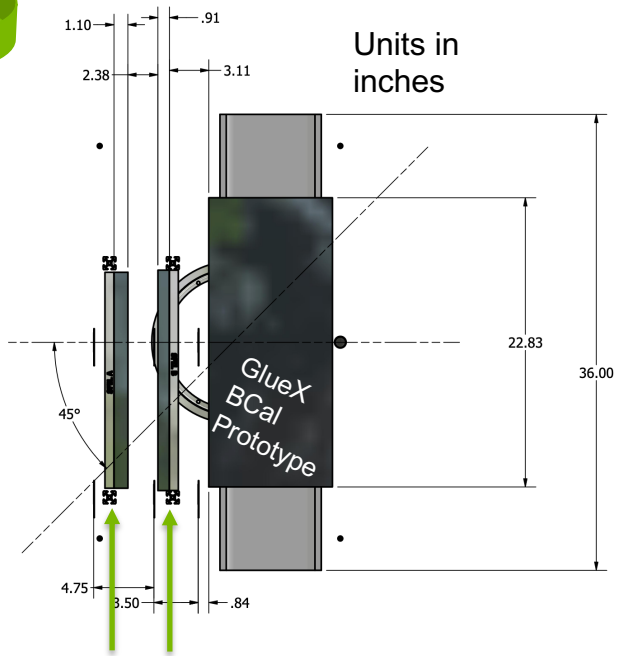
NIM A**896** 24-42 (2018)





**Rotatable up to 45°!**




Thin SciFi Insert Layers (Removable)

**Drawings by Tom O'Connor**

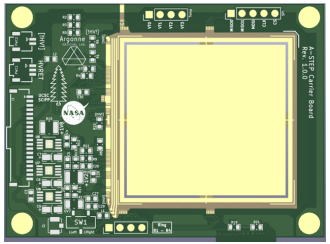
Argonne NATIONAL LABORATORY

# Planned staged setup – Stage 1

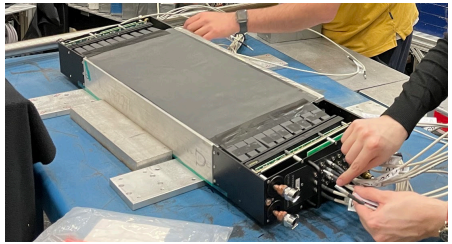
Start with GlueX BCal prototype with one AstroPix v3 quad in front

Prior to installation at FTBF:

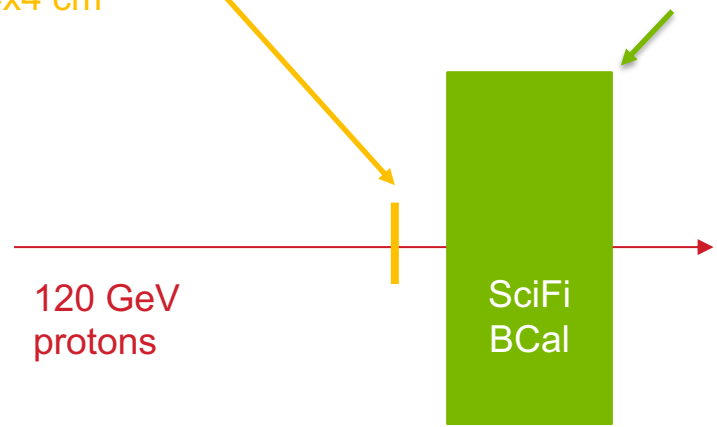
- Characterize AstroPix v3 Quad sensor on the bench, noise scans, calibration, etc.
- Take cosmics with GlueX prototype at ANL
- Gain a good understanding of both systems individually



AstroPix v3 Quad
4x4 cm



GlueX Prototype

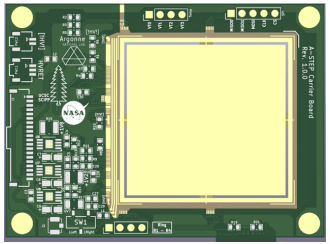


# Planned staged setup – Stage 1

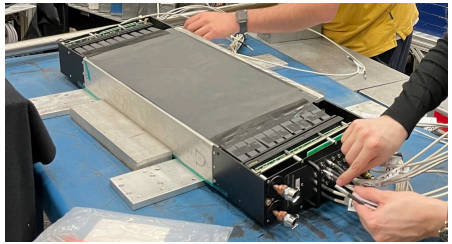
Once beam is available, work on combining information between the systems

- Bringing the two detectors into time coincidence
- Use AstroPix hit position information to seed clusters in the SciFi

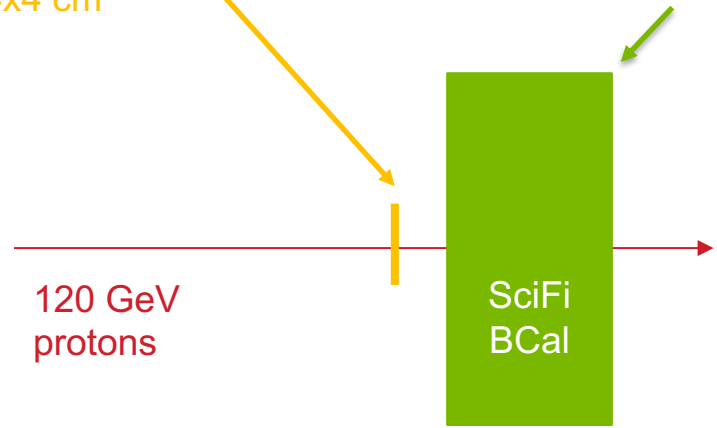
Test response of SciFi at different incidence angles



AstroPix v3 Quad
4x4 cm



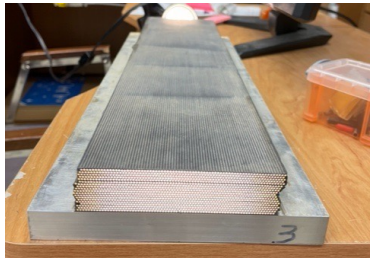
GlueX Prototype



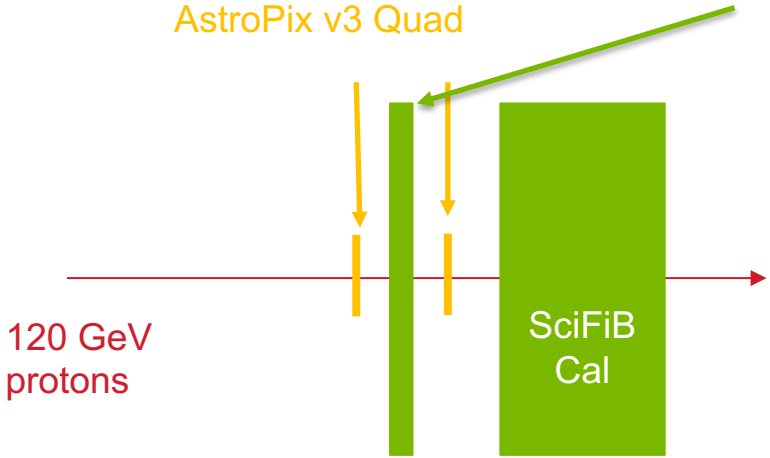
# Planned staged setup – Stage 2

Add thin layer of SciFi from GlueX
- Layers of SciFi in thickness similar to ePIC already exist, currently no SiPMs attached

Opportunity for testing of SiPMs planned for use in the final design
- Protons to test response to MIPs
- Measure pulse shape & timing response with fast electronics



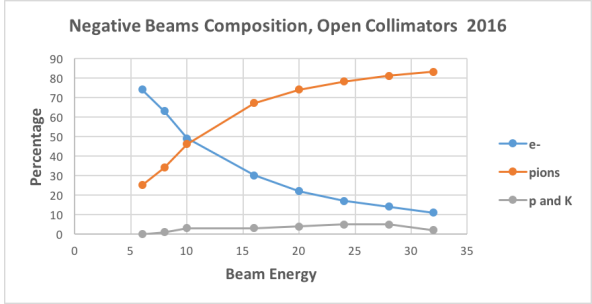
SciFi Insert Layer

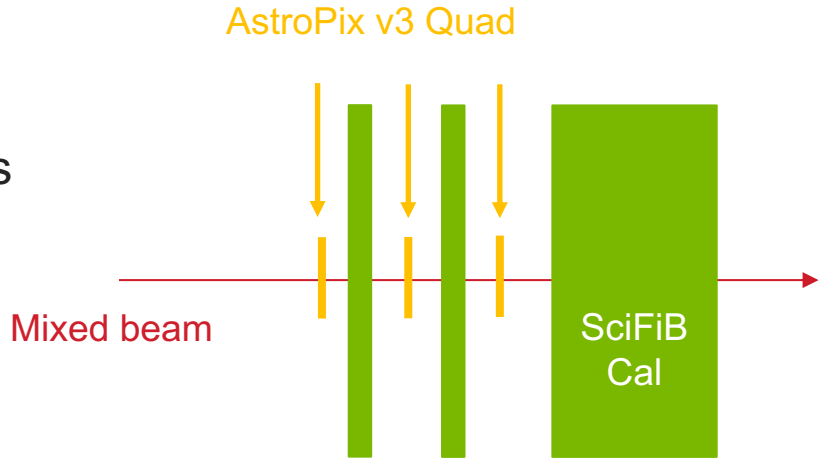


# Planned staged setup – Stage 3

Add second thin layer of SciFi
- Approach ePIC design

Test e/$\pi$ separation with mixed beam
- Run at low rates to avoid pile up in SciFi
  - Possibility with AstroPix to tag two-particle events
- Use FTBF beamline instrumentation to tag electrons
- Possibly tag hadronic showers with detectors behind BCal

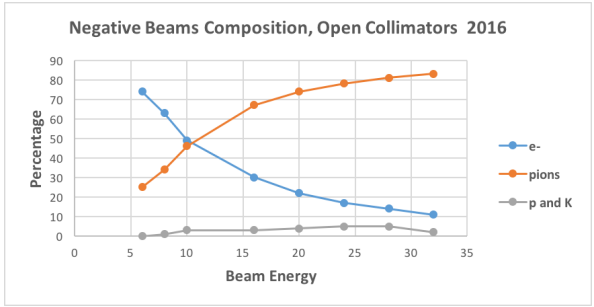


# Planned staged setup – Stage 3

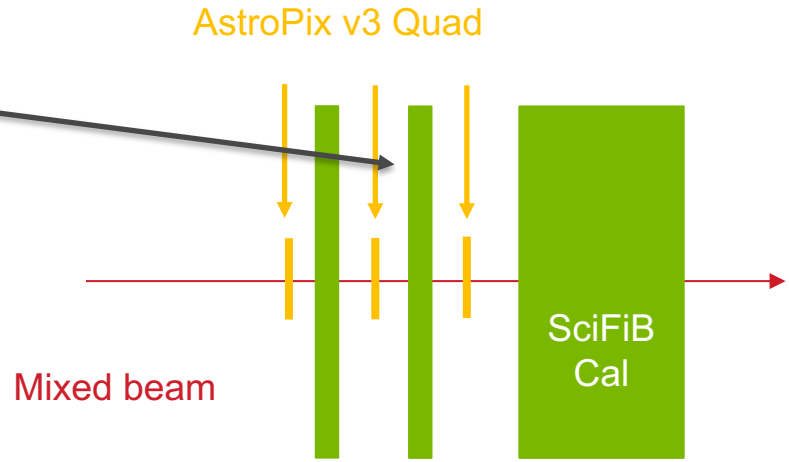
Test energy resolution & linearity up to 32 GeV

- Near upper limit of what will be seen at EIC

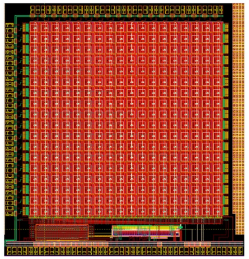


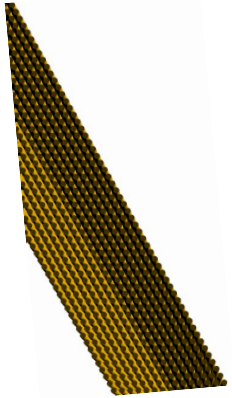

Second (downstream) SciFi layer should see significant energy deposits from 32 GeV electrons (especially at large angles)

- Allow for characterization of ePIC BIC SiPMs with large $N_{Ph.}$



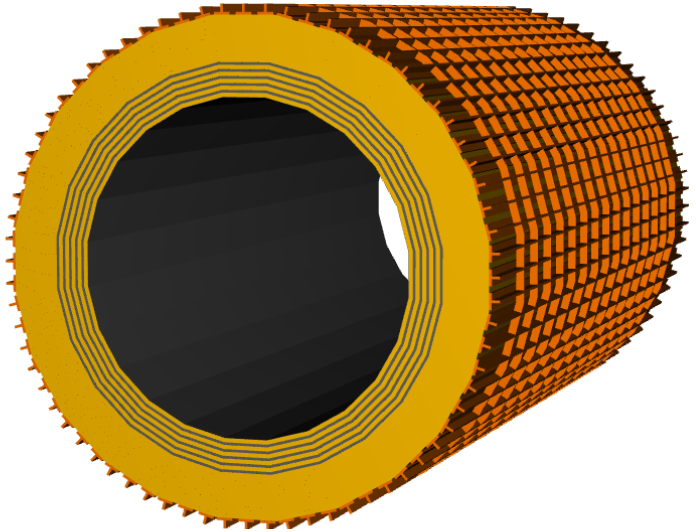
# Test beam R&d goals





Benchmark detector performance in as realistic a configuration as possible with different beams at FNAL

- Demonstrate ability to operate AstroPix & SciFi in tandem
- Study e/$\pi$ separation and overall $\pi$ response
- Characterize SciFi energy resolution & linearity at higher energy than GlueX
- Gain operational experience with the specific SiPM options to be used in ePIC BIC



All of the above highlighted by comprehensive

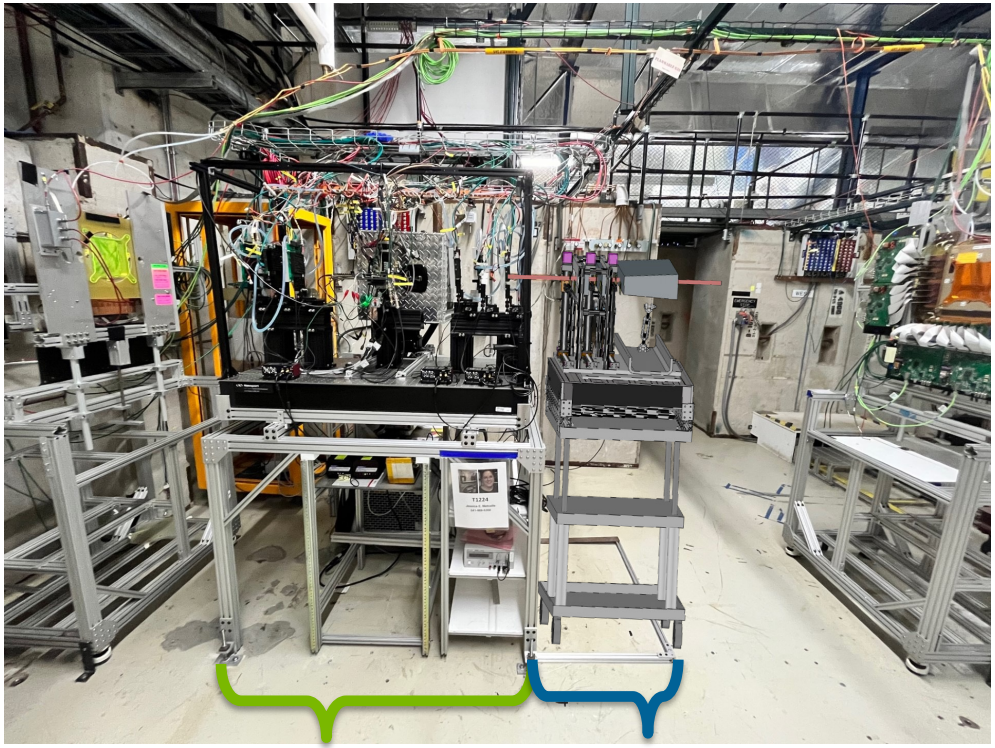
# General setup

Add BIC prototype calorimeter behind existing Argonne ATLAS Pixel telescope with AstroPix setup at MTest

Rotating stage to simulate particles incident at angles up to 45° ($\eta \sim 1$)

Ability to lower BIC setup out of the beam, no need to uninstall for other experiments to run

- Proximity to Argonne enables occasional opportunistic running



Current ANL AstroPix Telescope Setup

Planned BIC Setup

# Gluex bcal prototype

Thick SciFi portion of BIC approximated by the GlueX prototype

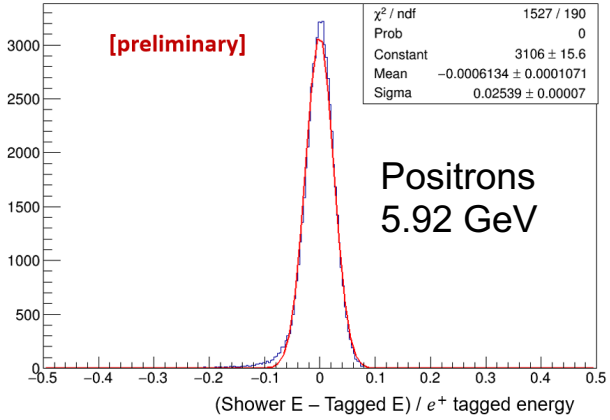
- Studied in March ‘23 with positrons in Hall-D PS
- Cosmic data taken in Hall-D, currently under analysis
- More cosmics planned at ANL prior to installation at FTBF

Baby BCAL in Hall D, 2023

- $e^+$ energy = 5.92 GeV
- Resolution ≈ **2.5**%

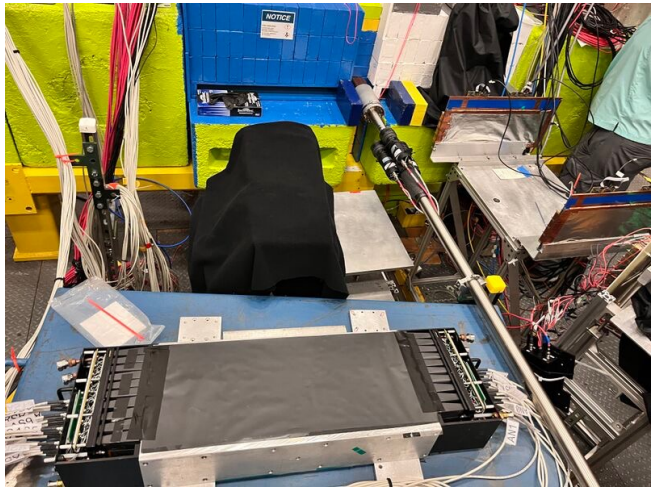
GlueX NIM, extrapolated

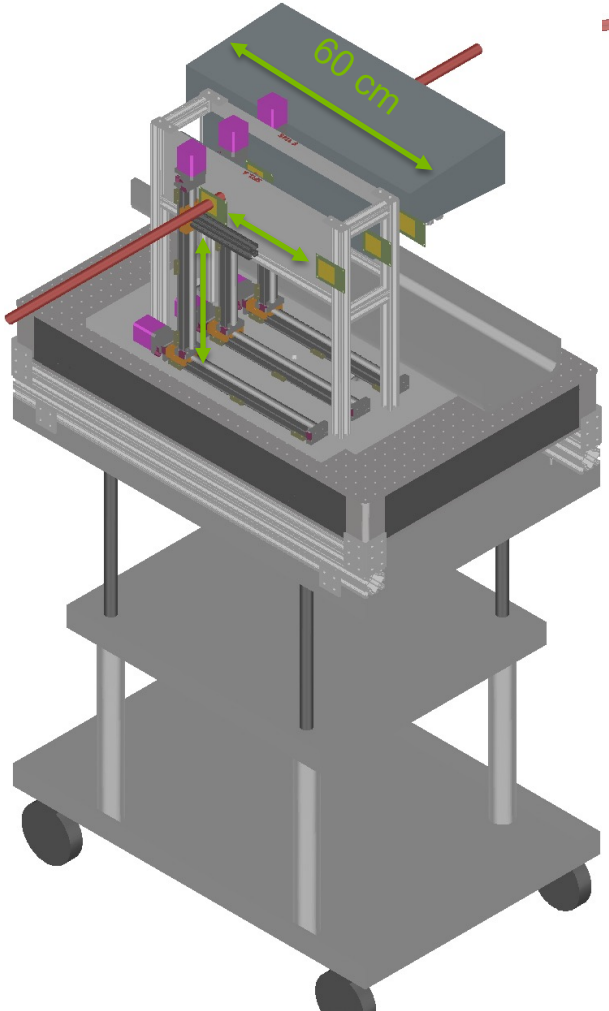
- Expect ≈ **4.2**%

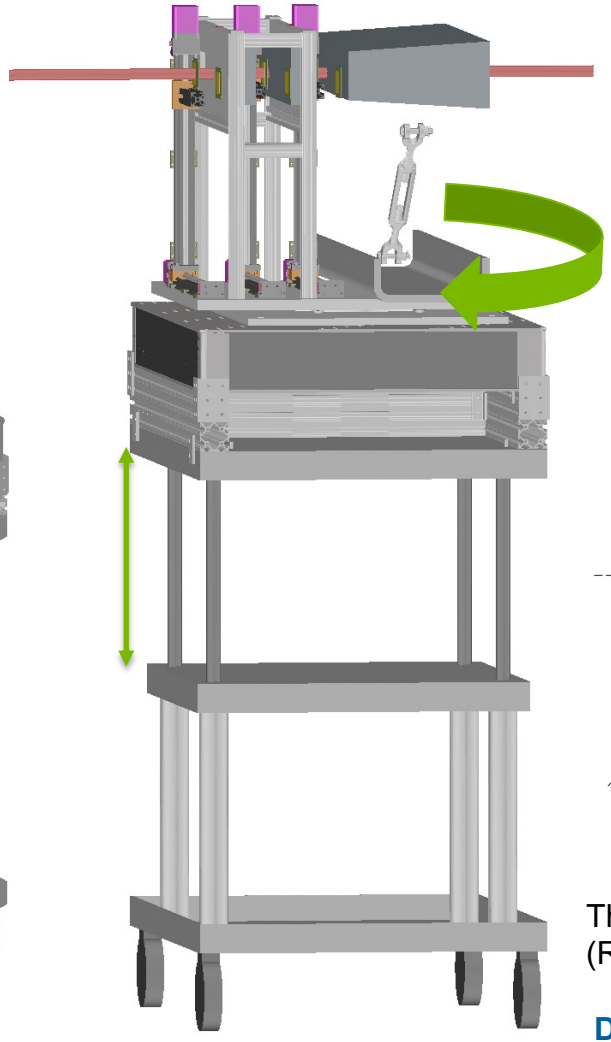



GlueX BCAL: $\frac{5.2\%}{\sqrt{E\ (GeV)}} \oplus 3.6\%$

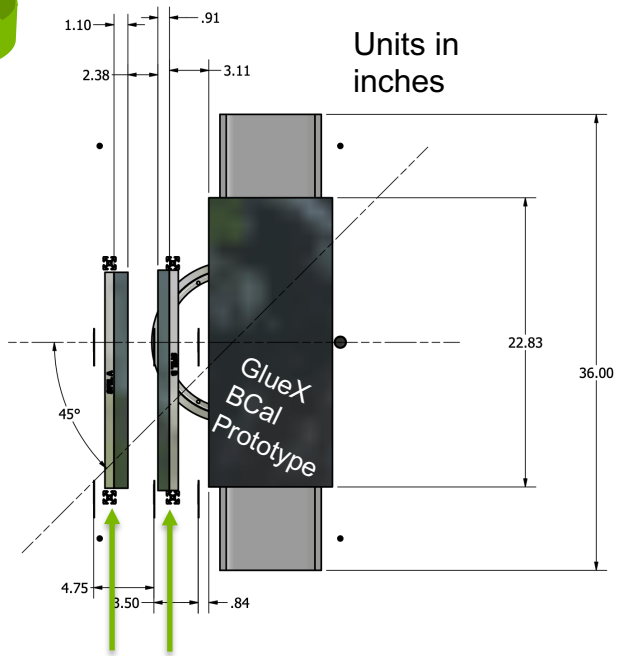
NIM A**896** 24-42 (2018)





**Rotatable up to 45°!**




Thin SciFi Insert Layers (Removable)

**Drawings by Tom O'Connor**

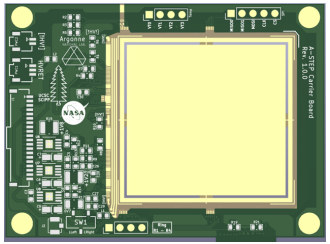
Argonne NATIONAL LABORATORY

# Planned staged setup – Stage 1

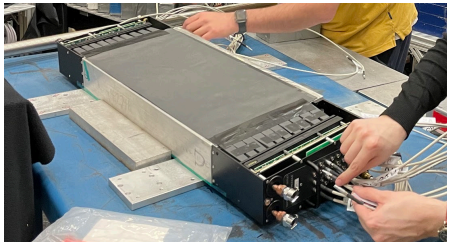
Start with GlueX BCal prototype with one AstroPix v3 quad in front

Prior to installation at FTBF:

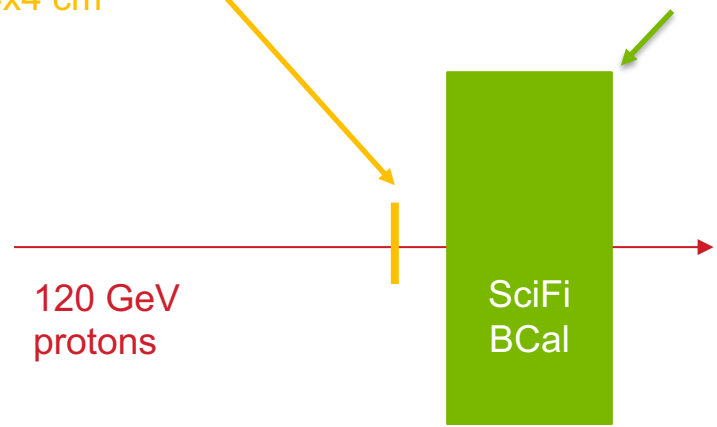
- Characterize AstroPix v3 Quad sensor on the bench, noise scans, calibration, etc.
- Take cosmics with GlueX prototype at ANL
- Gain a good understanding of both systems individually



AstroPix v3 Quad
4x4 cm



GlueX Prototype

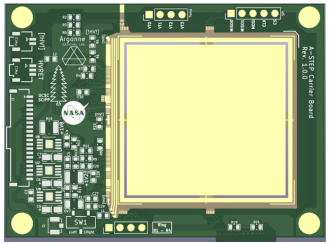


# Planned staged setup – Stage 1

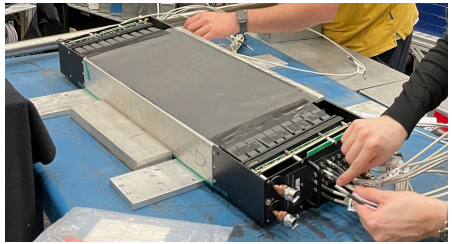
Once beam is available, work on combining information between the systems

- Bringing the two detectors into time coincidence
- Use AstroPix hit position information to seed clusters in the SciFi

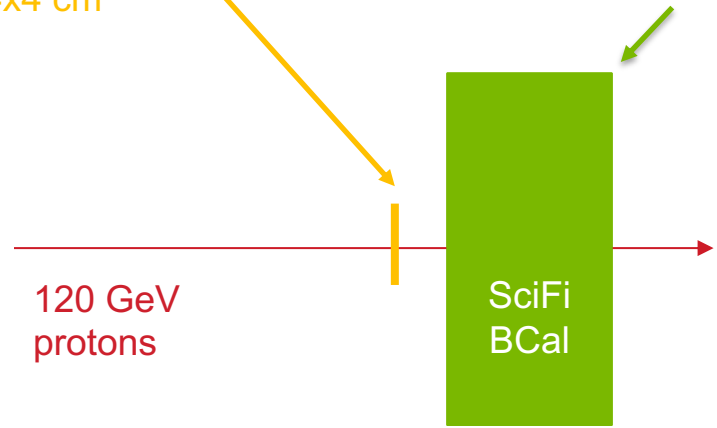
Test response of SciFi at different incidence angles



AstroPix v3 Quad
4x4 cm



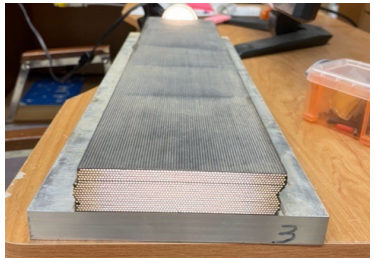
GlueX Prototype



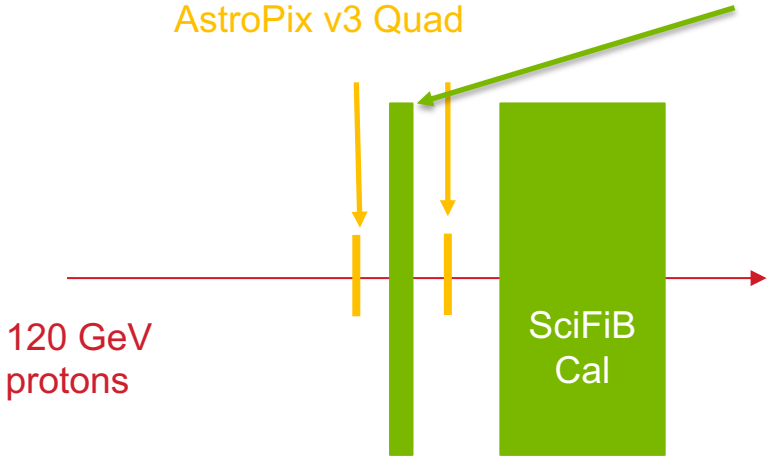
# Planned staged setup – Stage 2

Add thin layer of SciFi from GlueX
- Layers of SciFi in thickness similar to ePIC already exist, currently no SiPMs attached

Opportunity for testing of SiPMs planned for use in the final design
- Protons to test response to MIPs
- Measure pulse shape & timing response with fast electronics



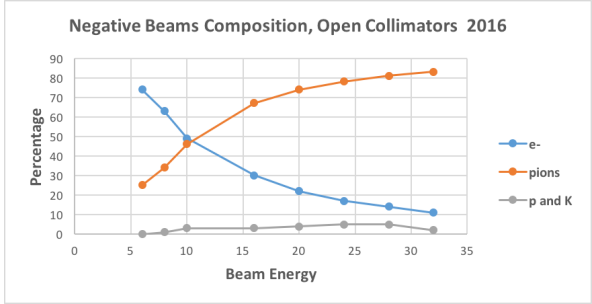
SciFi Insert Layer

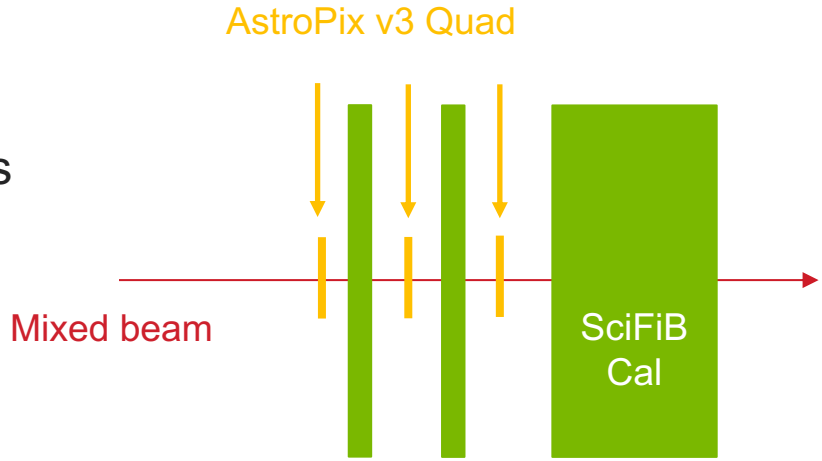


# Planned staged setup – Stage 3

Add second thin layer of SciFi
- Approach ePIC design

Test e/$\pi$ separation with mixed beam
- Run at low rates to avoid pile up in SciFi
  - Possibility with AstroPix to tag two-particle events
- Use FTBF beamline instrumentation to tag electrons
- Possibly tag hadronic showers with detectors behind BCal

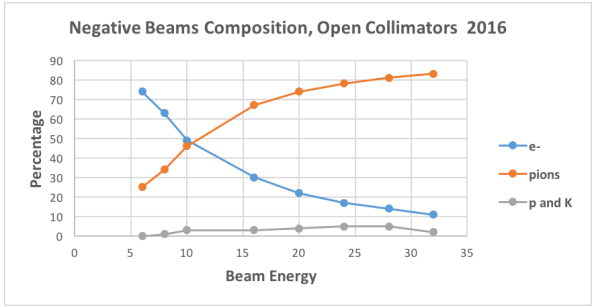


# Planned staged setup – Stage 3

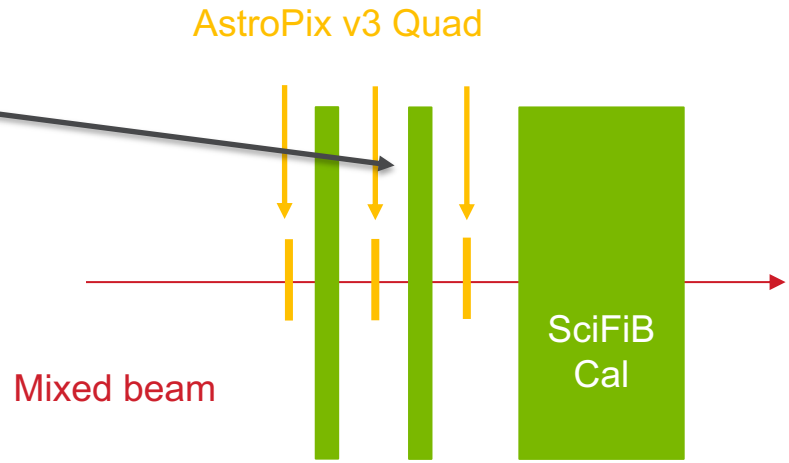
Test energy resolution & linearity up to 32 GeV

- Near upper limit of what will be seen at EIC




Second (downstream) SciFi layer should see significant energy deposits from 32 GeV electrons (especially at large angles)

- Allow for characterization of ePIC BIC SiPMs with large $N_{Ph.}$




Lufkin