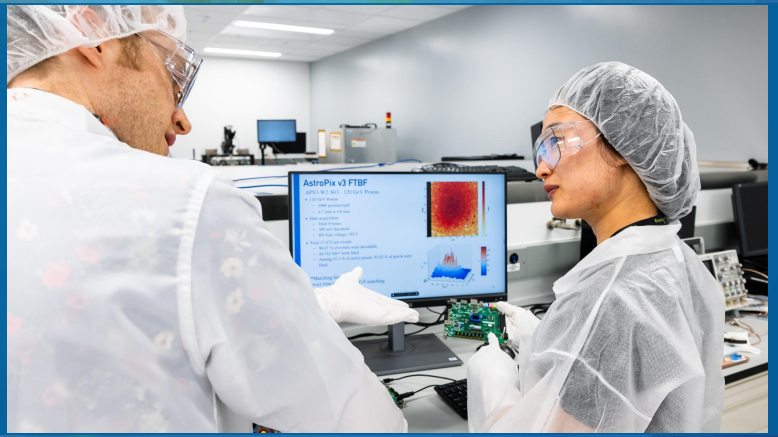
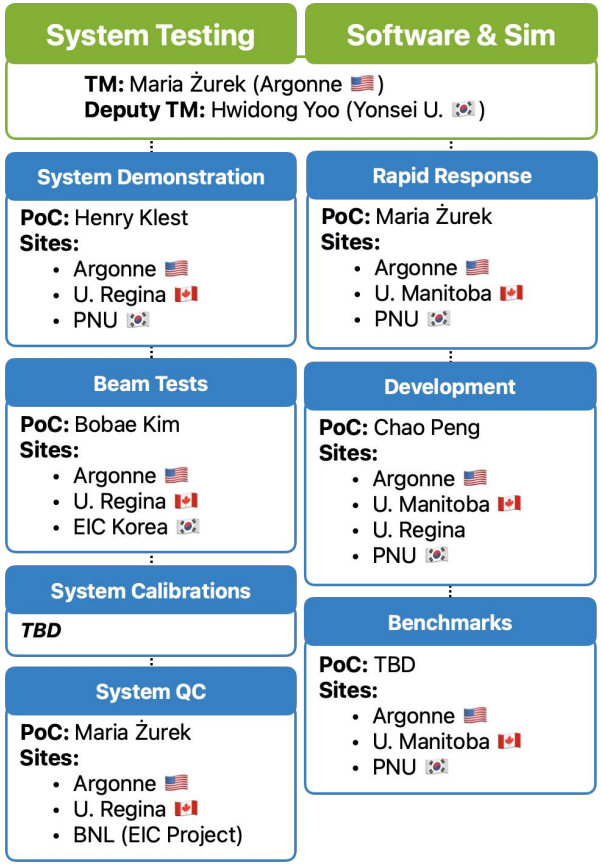
The ePIC Barrel Imaging Calorimeter

System Testing



Maria Żurek
Argonne National Laboratory

Outline



What I will be talking today about?

- Our work structure
- Test Article Evolution
- What do we want to test and how?
- Overview (Hey, what is going on now? A lot!)

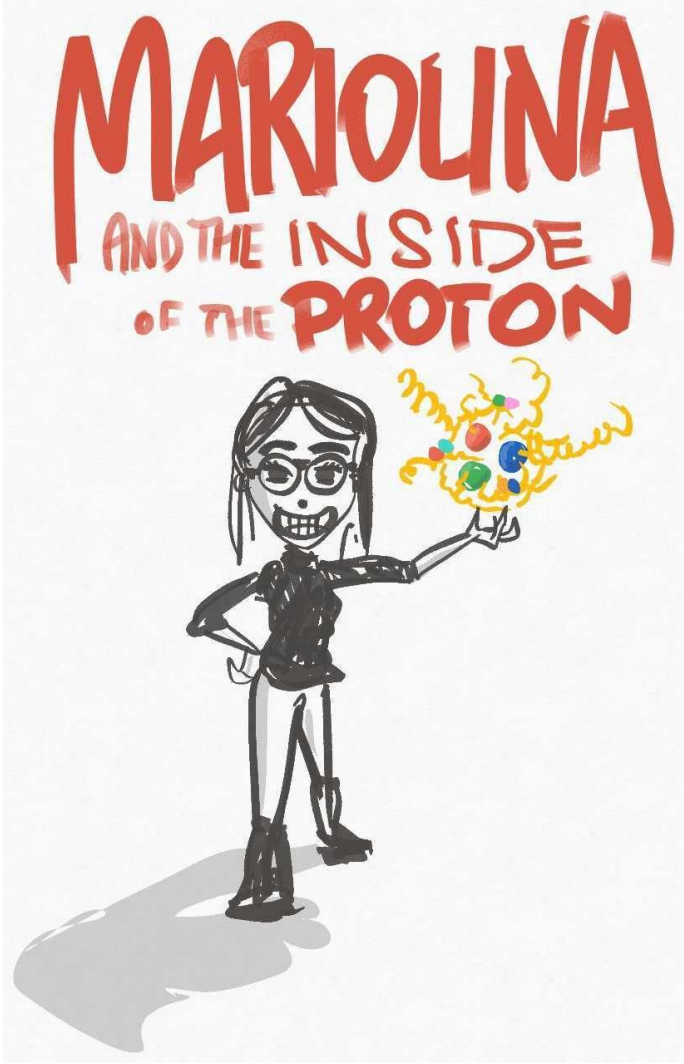
Bio

https://www.anl.gov/profile/maria-zurek

- Joined ANL mid 2021: since then working on BIC concept and design
- FY22: ANL LDRD (Jadhav, Żurek): Can AstroPix be used in calorimetry-like environment?
- FY22: Generic EIC R&D (Papandreou, Żurek): Can SciFi/Pb measure well energies we want to measure in EIC?
- March 2023: (ePIC review) deputy DSC for BIC

I do fun physics with protons (trying to understand where their spin come from?)

- Was a convener of Cold/QCD group at STAR (proton spin and jets!)
- Now work with CLAS12 experiment at JLab (proton spin structure and single hadrons :))



Bio

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  EIC?
- March 2023: (ePI

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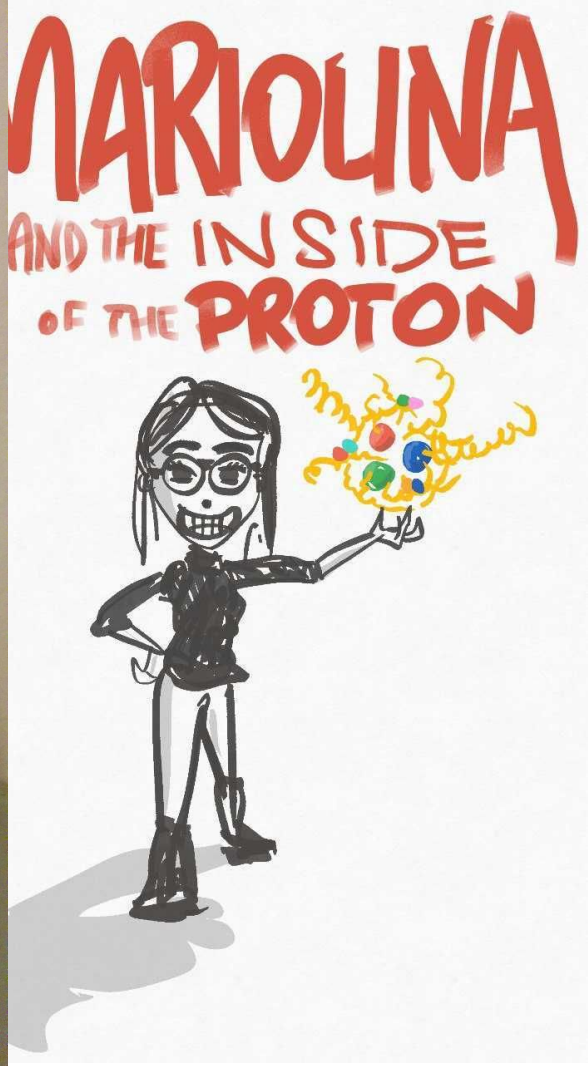
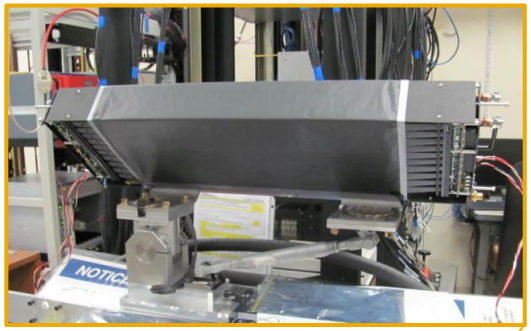
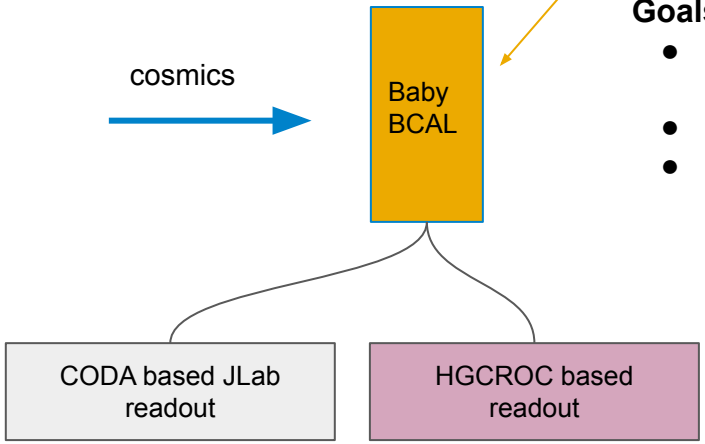


Test Article Evolution - PED

What do we test and why?

GlueX Baby BCal





Existing:

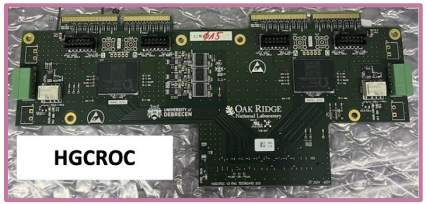
- Baby BCAL: ~60 cm long, 15.5 X_0 deep GlueX BCAL prototype with 40 SiPMs on each side (S12 Hamamatsu)
- CODA Based Readout: 250MHz fADCs, to TDC currently

To be upgraded:

- HGCROC Based readout
- New SiPM Board with BIC SiPMs (S14 Hamamatsu) and optical cookies

Goals:

- Test performance of Baby BCAL (response to muons) with new SiPMs, optical coupling (cookies) and HGCROC readout
- Benchmark against performance with previous readout (CODA based)
- Benchmark improvement in performance thanks to the new SiPMs

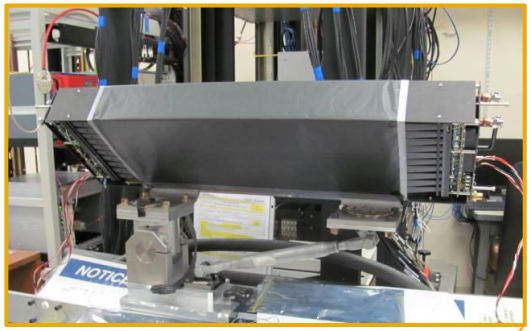


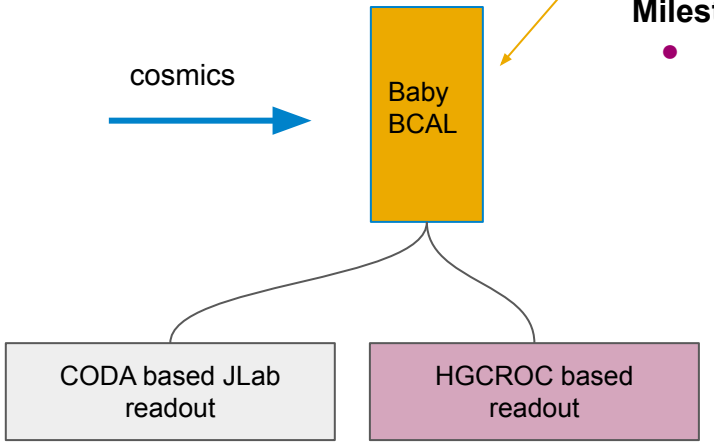
Beam Test Opportunity:
EM (e/ɣ) beam with range of energies up to > 10 GeV (ideally)
Goal: linearity of response

Test Article Evolution - PED

What do we test and why?

GlueX Baby BCal





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- HGCROC Based readout
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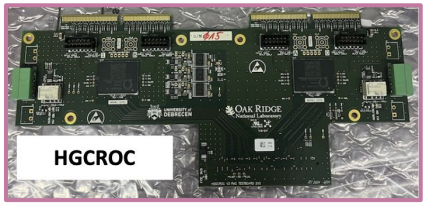
Milestone:

- ***Milestone: BabyBCAL with new SIPMs and HGCROC tested and benchmarked against previous results (August 2025)***



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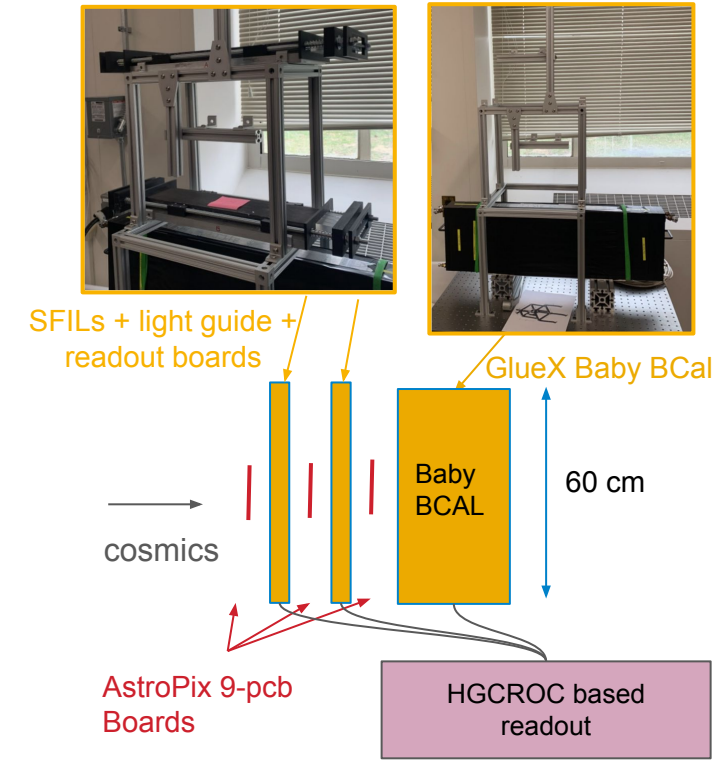
Test Article Evolution - PED

What do we test and why?



To be upgraded:

- 2 SFILs (Scintillating Fiber/Pb Intermediate (thin) Layers) with S14 SiPMs (existing, but to be compatible with the HGCROC readout)
- 9-chip pcb boards (eventually 3 of them, starting from one)

Goals:

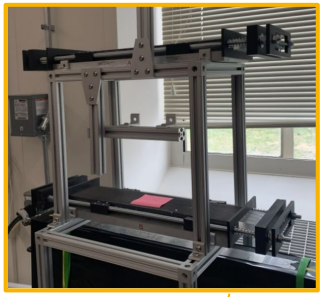
- Show the performance of the Integrated System of AstroPix 9-chip (daisy-chained chips) with SciFi: synchronization is needed
  - Read 3 9-chip PCB boards in sync
  - Read 9-chip PCB board and SciFi (HGCROC) in sync
    - The sync work can start with quad/single chip
- Develop basis for the cross-calibration procedure (position and energy)
- Additionally: Develop basis for the large scale AstroPix energy calibration with sources (AstroPix v4 single chip based)

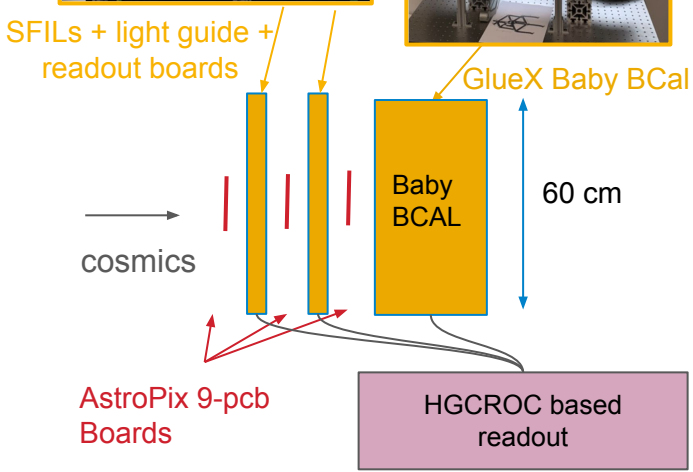
Beam Test Opportunity:

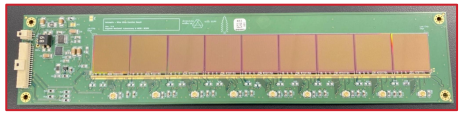
- EM (e/ɣ) beam with range of energies up to > 10 GeV (ideally), **Goal:** linearity of response
- e/π beam with range of energies up to > 10 GeV (ideally), **Goal:** e/π separation

Test Article Evolution - PED

What do we test and why?







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- 2 SFILs (Scintillating Fiber/Pb Intermediate (thin) Layers) with S14 SiPMs (existing, but to be compatible with the HGCROC readout)
- 9-chip pcb boards (eventually 3 of them, starting from one)

Milestones:

- ***AstroPix 9-chip board can be read in sync with SciFi HGCROC readout (Sep 2025)***
- ***3 fully calibrated AstroPix 9-chip boards read in sync with SciFi HGCROC readout (Nov 2025)***
- ***Energy calibration strategy for AstroPix developed (TBD)***

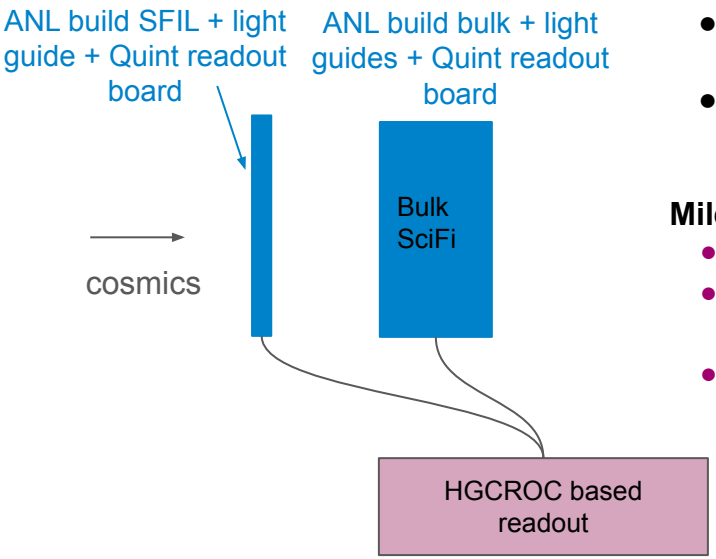
Beam Test Opportunity:

- EM (e/ɣ) beam with range of energies up to > 10 GeV (ideally), **Goal:** linearity of response
- e/π beam with range of energies up to > 10 GeV (ideally), **Goal:** e/π separation

Test Article Evolution - PED

What do we test and why?

GlueX SFIL



To be upgraded:

- SFIL build at ANL
- Bulk SciFi/Pb build at ANL (thicker section)
- New 5 cm lightguides
- Quint board with 5 SiPMs (S14 Hamamatsu)

Goals:

- Test the ANL-build SciFi Matrix with full readout chain and compare light response with MIPs
- Test the uniformity of the Bulk SciFi Matrix with photodiode (based on GlueX QC procedure) and eventually MIPs

Milestones:

- ***First ANL-build SciFi/Pb piece tested at ANL (August 2025)***
- ***ANL-build SciFi/Pb calo bulk response tested electrically and for uniformity (October 2025)***
- ***Optional: And calibrated through several layers with the new SiPM board (January 2026)***

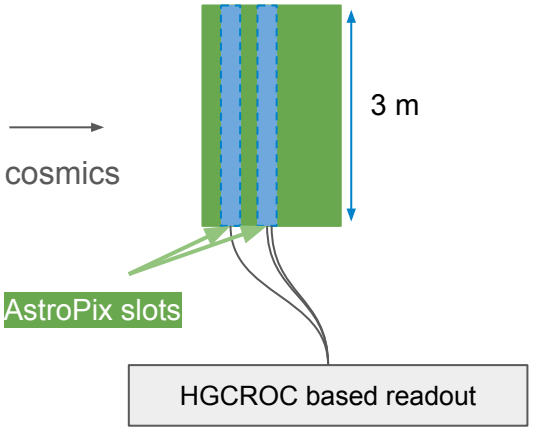
Beam Test Opportunity:

- Can be integrated in previous setups with same goals

Test Article Evolution - PED

What do we test and why?

LankyTeenagerBIC



Beam Test Opportunity:

- Can be integrated in previous setups with same goals + impact of longer sector tested (z-dependent calibration)

To be upgraded:

- LankyTeenagerBIC (3-m long, ANL build test article with slots for AstroPix layers) (AVAIL: Jan 27) + Bulk Section for integration might be separate
- ESB Test Article
- 3 9-chip pcb (AVAIL: Aug 25)
- first QC'ed module (AVAIL: July 25); ½ stave (AVAIL: Mar 26)

Goals:

- Test the long ANL-build SciFi Matrix with full readout chain and compare light response with MIPs
  - measure attenuation length, SciFi position resolution, cross calibration
- Develop the SciFi uniformity QC procedure (most probably with photodiode)
- Test fully integrated system with MIPs: cross calibration for energy and position/timing
- Eventually repeat the procedure with fully integrated first v5 modules

Milestones:

- ***Integration of Lanky with ESB and 9-chip PCB and testing accomplished (Mar 2026)***
- ***Integration with first stave (modules) accomplished (May 2026)***

Test Article Evolution - PREP

What do we test and why?

Test Articles:

- First Tested PREP staves (~ Dec 2026)
- PREP Test with Lightguides + ESB (~Jan 2027)

Goals:

- Tray + ETC Card:
  - Connection
  - Energy Calibration: Test the full chain calibration for the flow tray with tooling (reiterate on tooling if needed)
  - Timing calibration verification/ synchronization and system timing
  - Electrical Stress Test

First Tray fully tested and calibrated ready to be integrated with the Sector (March 27)

- SciFi/Pb Sector
  - Bench test for the full SciFi Sector with ESB (with LMS: Light Monitoring System): Relative calibration with MIPS and temperature dependence with LMS
  - Reception QC procedure development on sector SciFi (check that LMS works on sector, check that SiPMs work, check that readout works)
  - Global tests: light output (nphe), attenuation measurement for full system

All subprocedures developed, all aspects of SciFi/Pb tested (June 2027)

Test Article Evolution - PREP

What do we test and why?

Test Articles:

- First Tested PREP staves (~ Dec 2026)
- All Tested PREP staves (~ May 2027)
- PREP Test with Lightguides + ESB (~Jan 2027)

Goals:

- Full integration with 1 tray
  - Thermal performance in the full system (trays + sector + ESB)
  - Verify full system response with MIPs: Read out both systems in sync
    - Position calibration for AstroPix
    - Cross-calibration between SciFi/Pb and AstroPix (energy, timing, position)

Milestone: Full Sector with 1 tray tested (July/August 27)

- Trays (All 5) + ETC Card (assumed happening in parallel):
  - Repeat the tests for 5 remaining trays
  - Fully develop (reiterate) receiving QC procedures at BNL

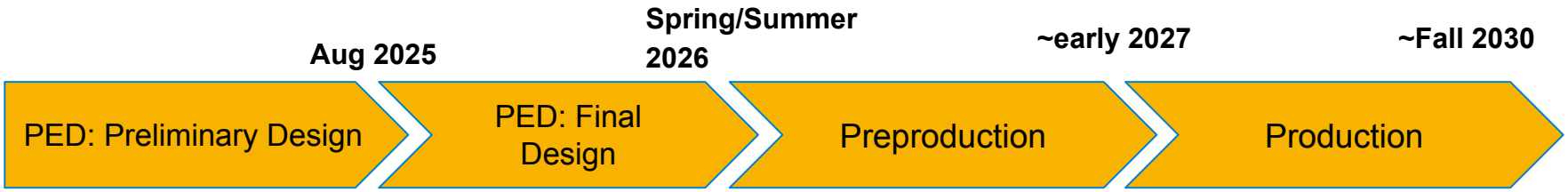
5 trays fully tested and calibrated ready to be integrated with the Sector (Aug 27)

Beam Test Opportunity:

- This would be a fantastic opportunity to perform a full dressed rehearsal of the system integration and reception QC procedure ideally nearby the construction side (FNAL?)
- ***Milestone: Perform full system energy response with beam and expected EIC occupancies. Test full system (sector) assembly procedure and testing.***

PED/preliminary and final design

Milestones



BabyBCAL with new SIPMs and HGCROC tested and benchmarked against previous results (August 2025)

AstroPix 9-chip board can be read in sync with SciFi HGCROC readout (Sep 2025)
3 fully calibrated AstroPix

3 9-chip boards read in sync with SciFi HGCROC readout (Nov 2025)

ANL-build SciFi/Pb calo bulk response tested electrically and for uniformity (October 2025)

Optional: And calibrated through several layers with the new SiPM board (January 2026)

Integration of Lanky with ESB and 9-chip PCB and testing accomplished (Mar 2026)

Integration with first stave (modules) accomplished (May 2026)

Status Overview

June 24 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

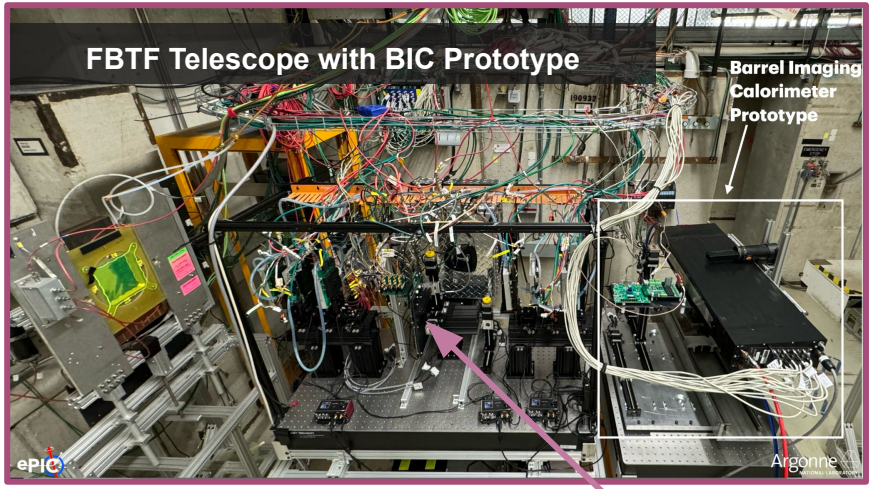
- **Setup 2:** AstroPix multi-channel board with successful daisy chain readout of v3

Beam Test goal:

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

Deliverable: Prototypes commissioned in beam and data collected

- *See talk by Jeongsu Bok on KEK beam test deliverables*



Status Overview

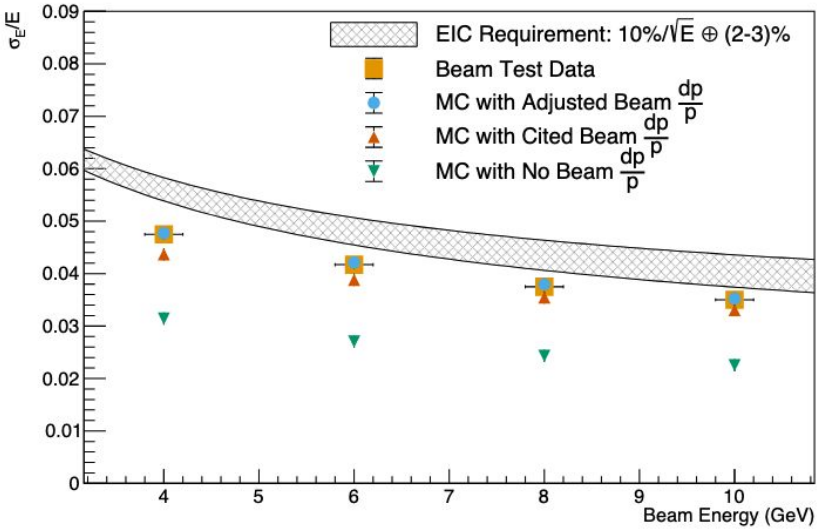
SciFi/Pb results

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% (affected by beam dp/p measurement precision)
- Simulations describe the electron and pion data well
- e/pion separation extracted within the full system in the test beam environment

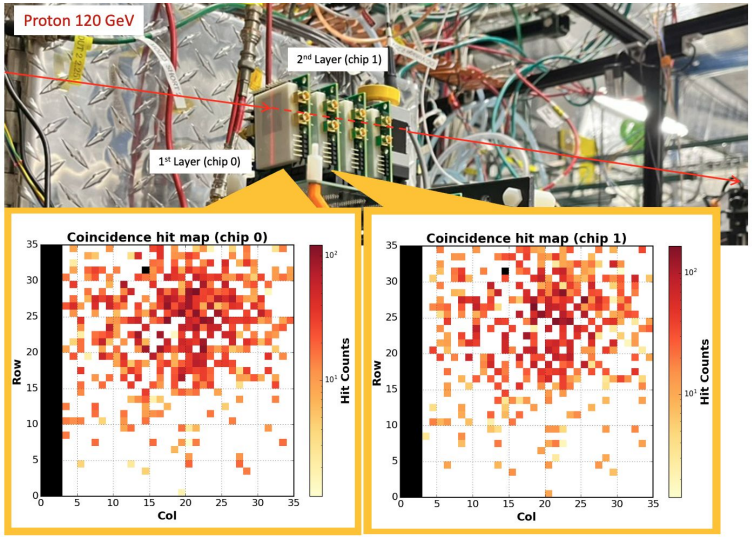
- *See talk by Henry Klest*

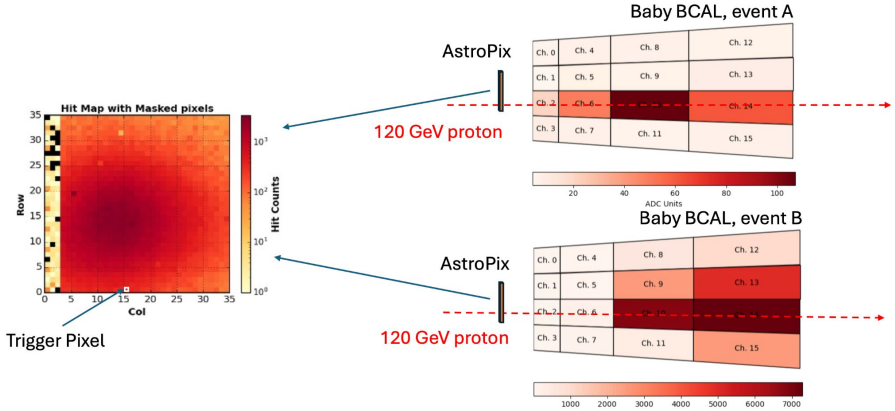


Energy resolution (sigma of the Gaussian core of Crystal Ball fit) from data with past "cited" dp/p (interpolation between 2 values given by FTBF), adjusted to the data dp/p as well as expected resolution with no dp/p.

Status Overview

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.



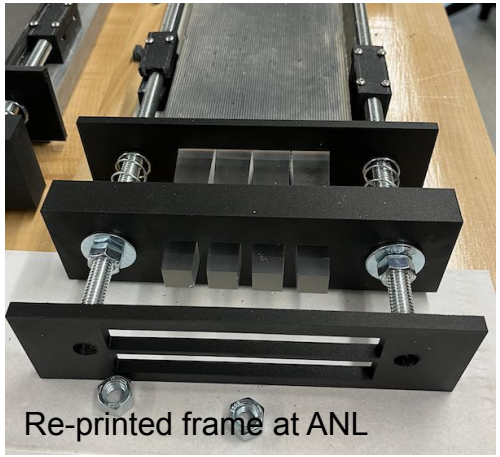


The multilayer AstroPix v3 setup which we tested at FTBF, and an example of the recorded **120 GeV proton beam events from the first two layers, read in coincidence**

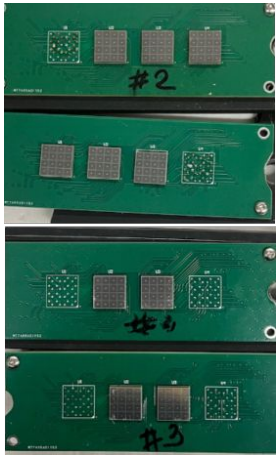
Baby BCal event triggered on AstroPix signal from 120 GeV proton. Event A shows MIP-like behavior, event B shows hadronic shower behavior.

Integrations and R&D news

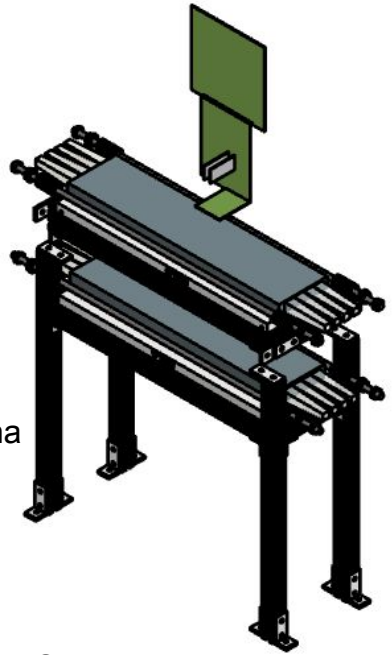
SFILs (~~almost finally!~~) at ANL



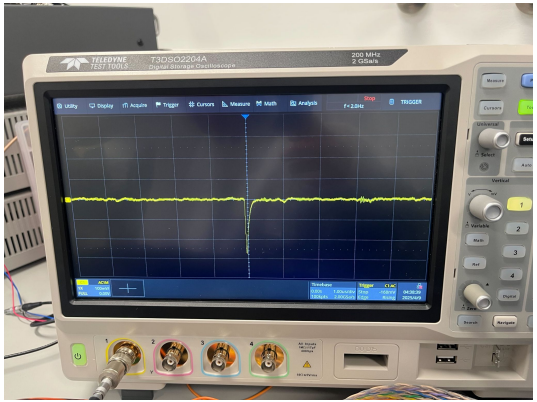
Re-printed frame at ANL



Re-send to U.Regina



Support structure design in progress by Tom.



First signals from the boards read at ANL delivered yesterday by Bobae!

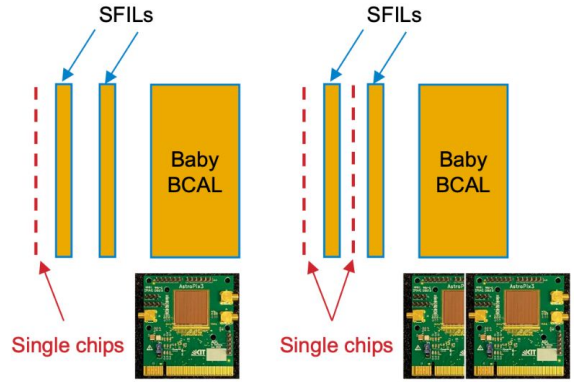
Last stretch to integrate SFILs with Baby BCAL in JLab DAQ and sync with AstroPix

Integrations and R&D news

System Testing Plan

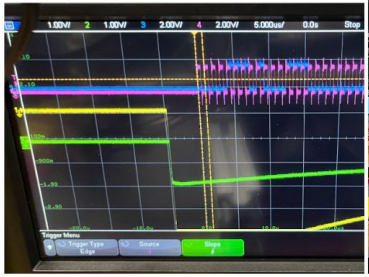
Plan for Synchronization

Possible setup of system integration at bench test in ANL:

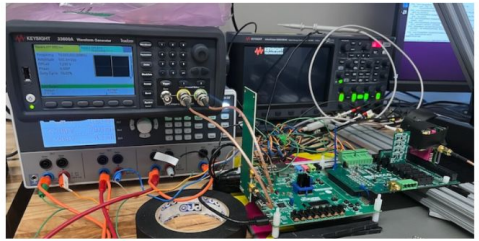


How to synchronize?

- Plan A
  - MISO signal that generated from Astropix used as trigger IN for baby bcal



- Plan B
  - Provide external clock to Astropix chip via PMOD



- *See talk by Bobae Kim*

FY24 R&D Milestones

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
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
M5: SciFi Inter-Layer (SFIL) delivered by the University of Regina, integrated, and tested at the bench	t0 + 7 months Q2-Q3 FY 24*	In progress (almost there) 🚧
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 the simulations	t0 + 12 months Q3-Q4 FY24*	Done ✅ (with as much beam as we had available)

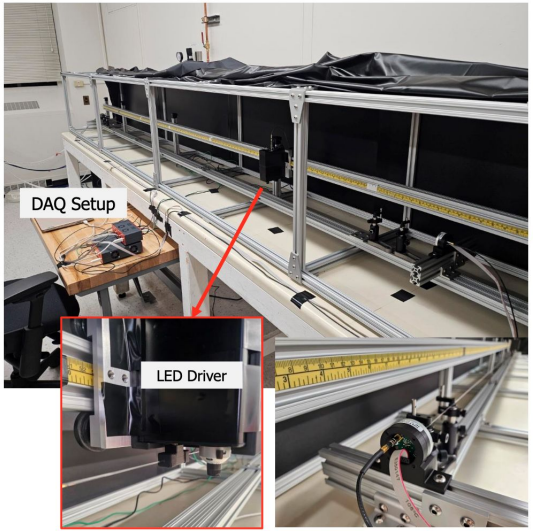
***Assuming Start of Funds in Q1 FY24 (funds available from March 2024)**

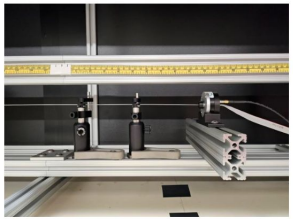
Backup

SciFi Testing

System Testing Meeting: https://indico.bnl.gov/event/26284/ (Seoyun, Bobae)
URegina discusses protocols, the team is in the middle of measurements (Zisis, Tegan, Aram)
Meeting with the project regarding fiber evaluation and decision in progress

SciFi Measurement
Updated Setup



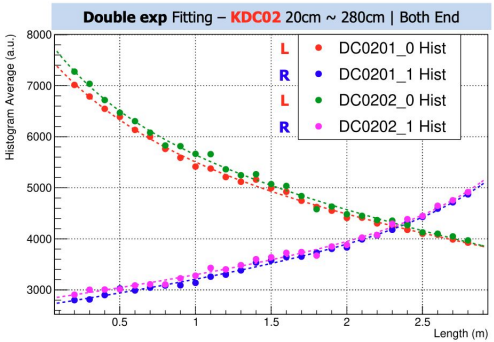


SiPM on both end
S13360-1350CS

13

SciFi Measurement
Measuring both end

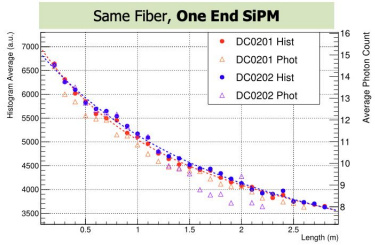
*Only result of **histogram avg.**
**Not proper fitting



$1st\ L: \lambda_{short} = 0.64 \pm 0.18\ m, \lambda_{long} = \mathbf{6.38 \pm 0.84\ m}, ch_{val} = 0.629$
$2nd\ L: \lambda_{short} = 0.50 \pm 0.20 m, \lambda_{long} = \mathbf{5.51 \pm 0.64\ m}, ch_{val} = 0.644$

$1st\ R: \lambda_{short} = 0.52 \pm 0.18\ m, \lambda_{long} = \mathbf{5.94 \pm 0.56\ m}, ch_{val} = 0.616$
$2nd\ R: \lambda_{short} = 0.50 \pm 0.18 m, \lambda_{long} = \mathbf{6.50 \pm 0.73\ m}, ch_{val} = 0.667$

$ch_{val} = (Signal\ at\ 20cm)/(Signal\ at\ 200cm)$



$1st^{**}: \lambda_{short} = 0.78 \pm 0.23\ m, \lambda_{long} = \mathbf{8.22 \pm 2.46\ m}$
$\lambda_{long(o100)} = \mathbf{5.41 \pm 0.19}, ch_{val} = 0.614$
$2nd^{**}: \lambda_{short} = 1.18 \pm 0.12 m, \lambda_{long} = \mathbf{10.00 \pm 15.0\ m}$
$\lambda_{long(o100)} = \mathbf{5.16 \pm 0.19}, ch_{val} = 0.625$

- Similar values of measured points (ch_{val}) with one end SiPM, but large fluctuation on fitting results.

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