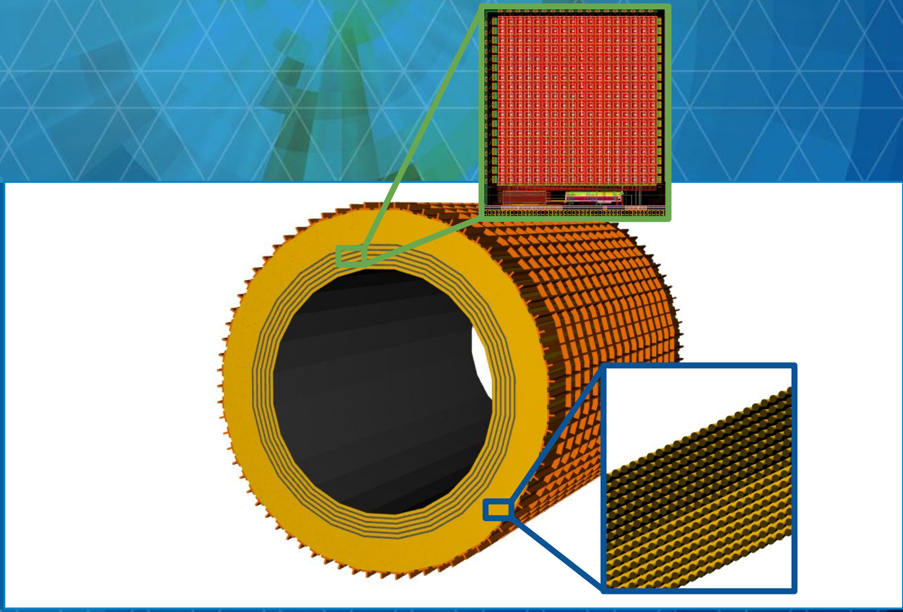
ePIC TIC Meeting, June 19, 2023

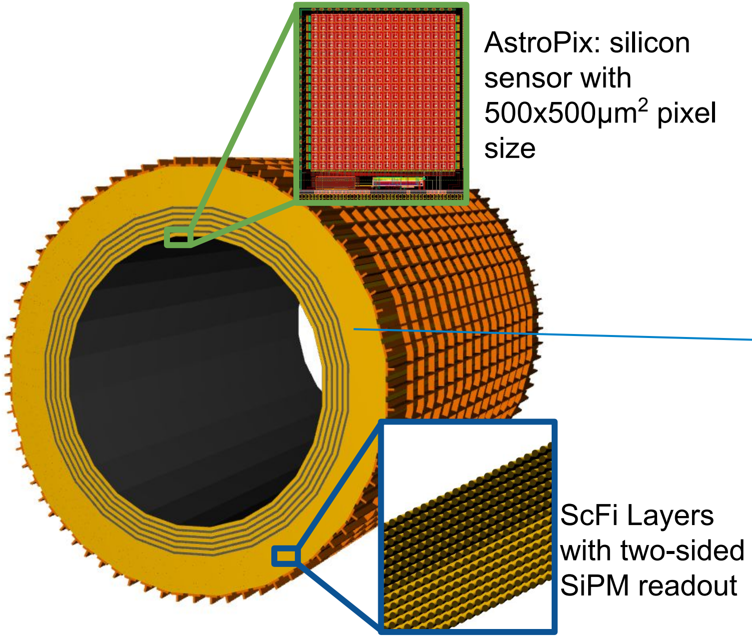
The Barrel Imaging Calorimeter
Status

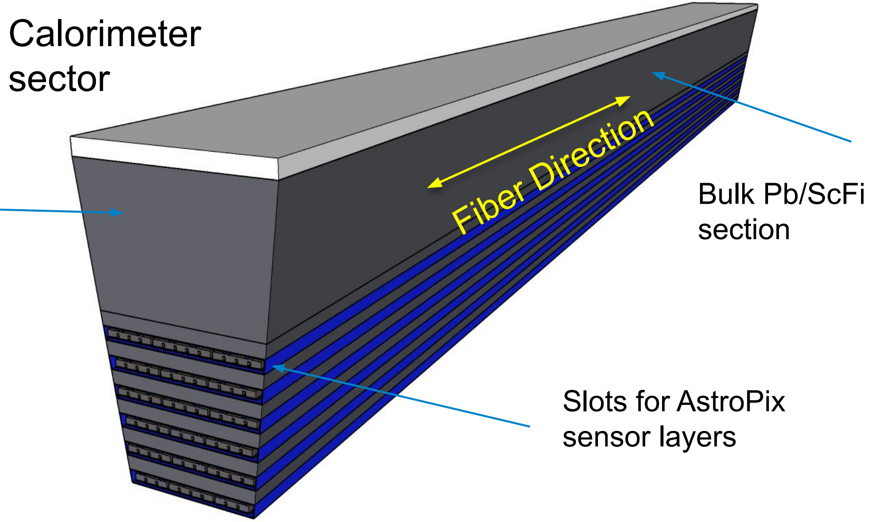


Sylvester Joosten & Maria Żurek
PHY, Argonne National Laboratory

Geometry

- **4(+2) layers of imaging Si sensors** interleaved with **5 Pb/ScFi layers**
- Followed by a **bulk section of Pb/ScFi section**

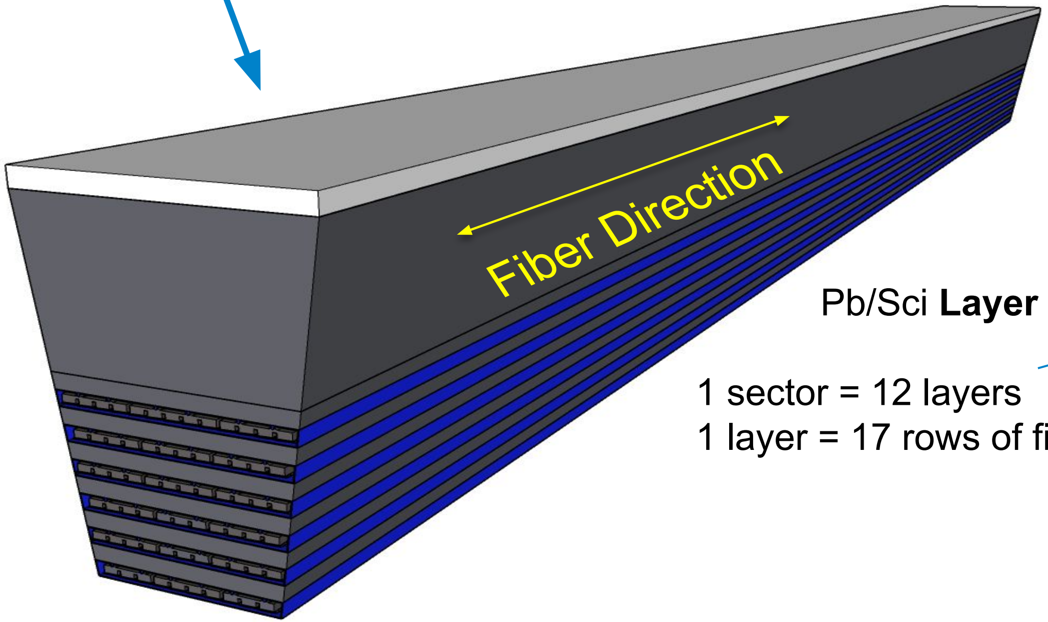




Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-side Pb/ScFi readout and radial segmentation)

Geometry and Naming Scheme

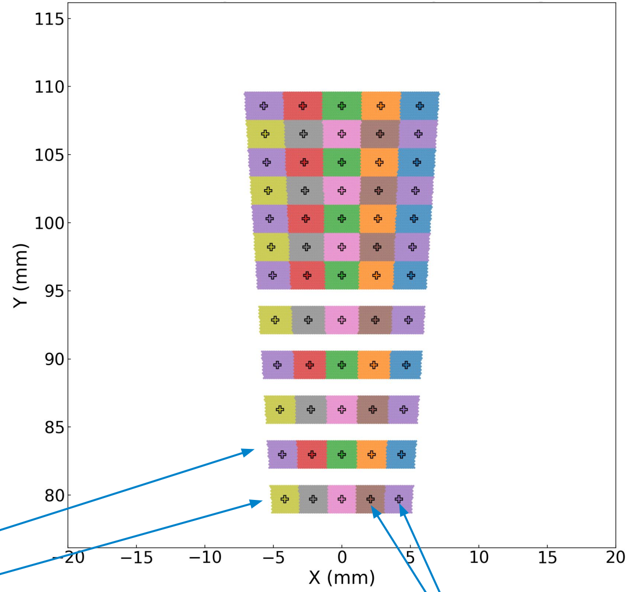
Sector
Whole Barrel: 48 Sectors



Pb/Sci **Layer**

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

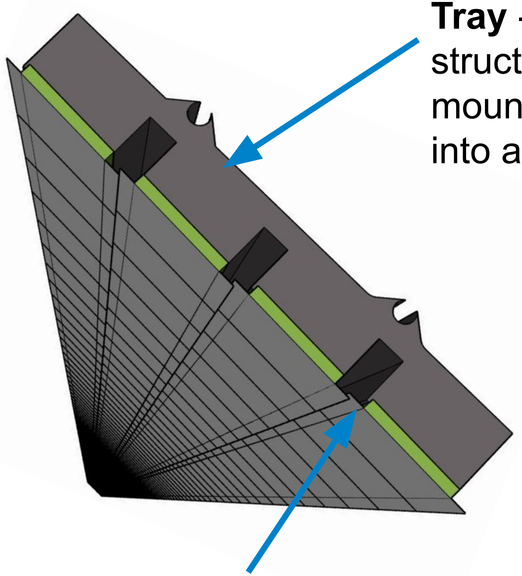
Sector End View
(x-y plane view)



Readout **Cell**
Layer = 5 cells

The area 1 light guide is attached

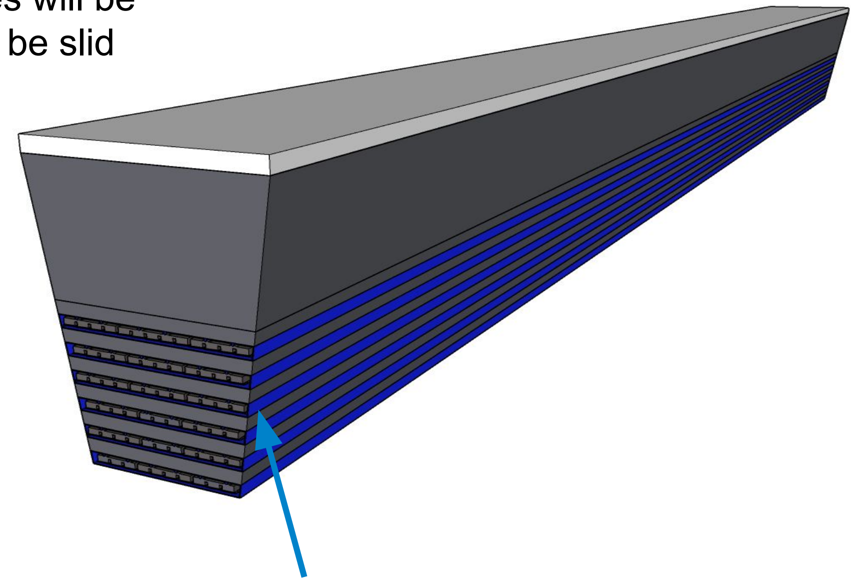
Geometry and Naming Scheme



Tray - a carbon fiber structure the staves will be mounted on. It will be slid into a shelf.

AstroPix **Stave**
Consists of 1 x 108 chips with the support structure

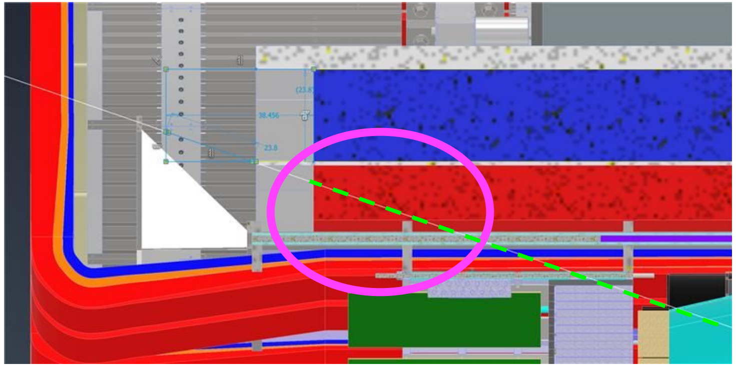
AstroPix **Module**
Subset of chips that will be mounted on one stave support structure



Shelf - a carbon fiber structure that is glued to the Pb/ScFi layers, that we will slide trays with AstroPix staves on.

*The designs presented on these slides are not final but for illustration only

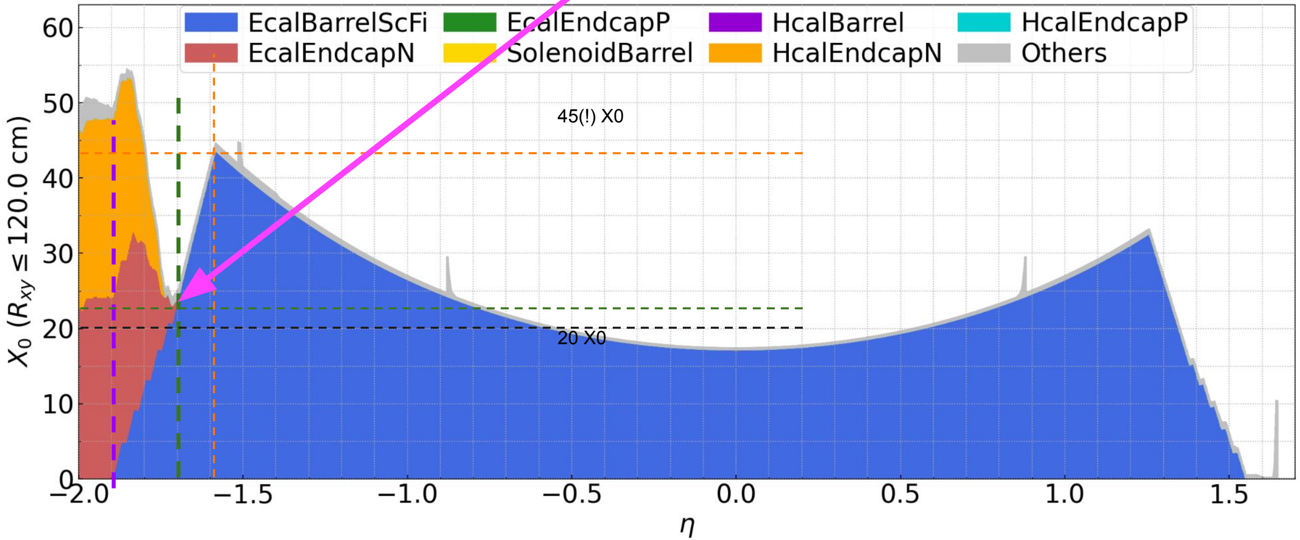
Backward integration and impact of “shorter” depth



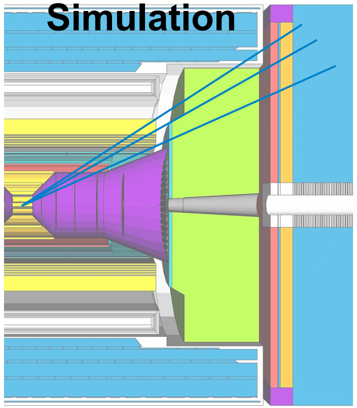
Reduced calorimeter depth to ~17.1X0 at central rapidities since the review, did not impact performance metrics!

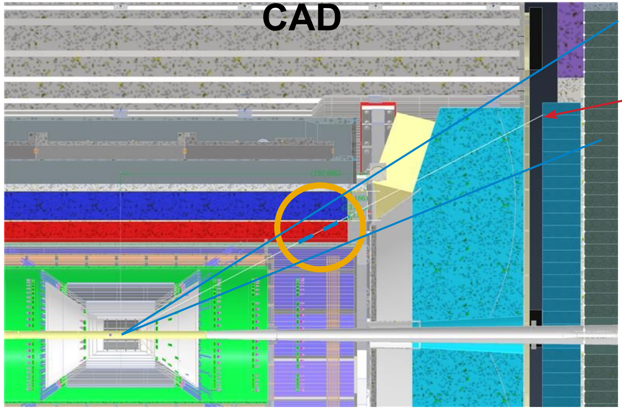
Particles passing at steeps angle pass through *much* more material than at central rapidities (up to 45 X0).

We never dip below ~24 X0 when transitioning to the backward calorimeter.



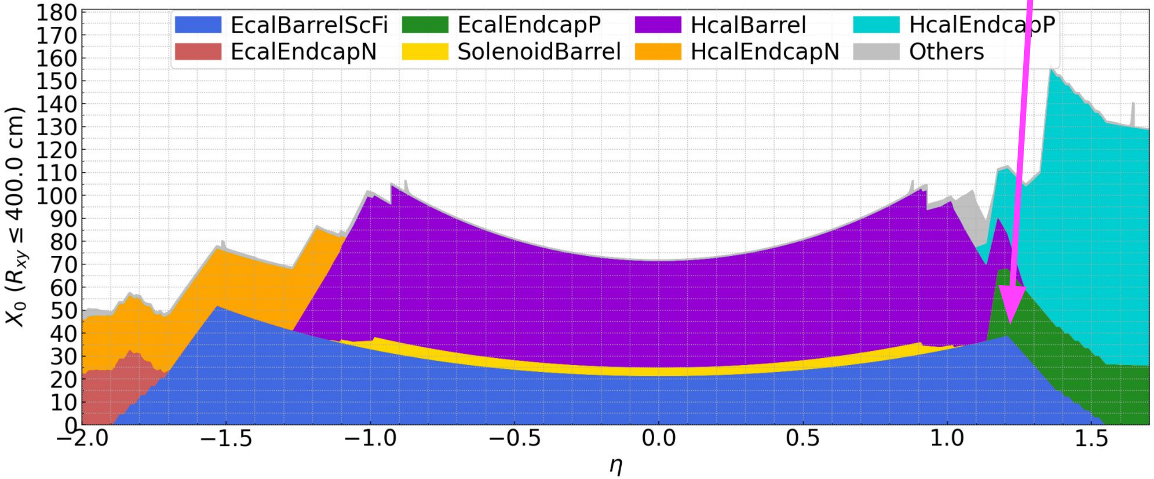
Forward integration





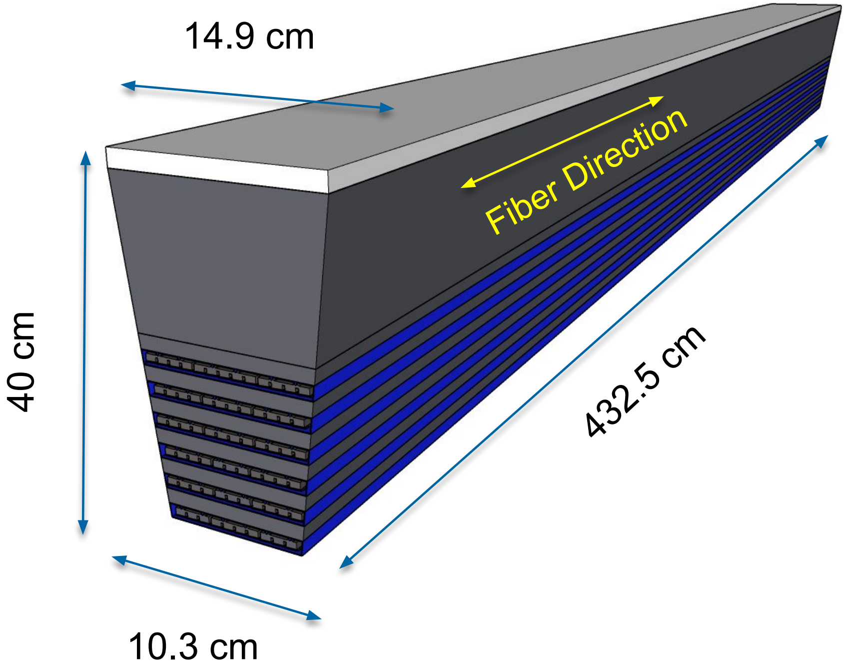
η = 1.31

Very good continuous coverage in the forward region, up to ~ 33 X0



at η = 1.31
~25 X_0

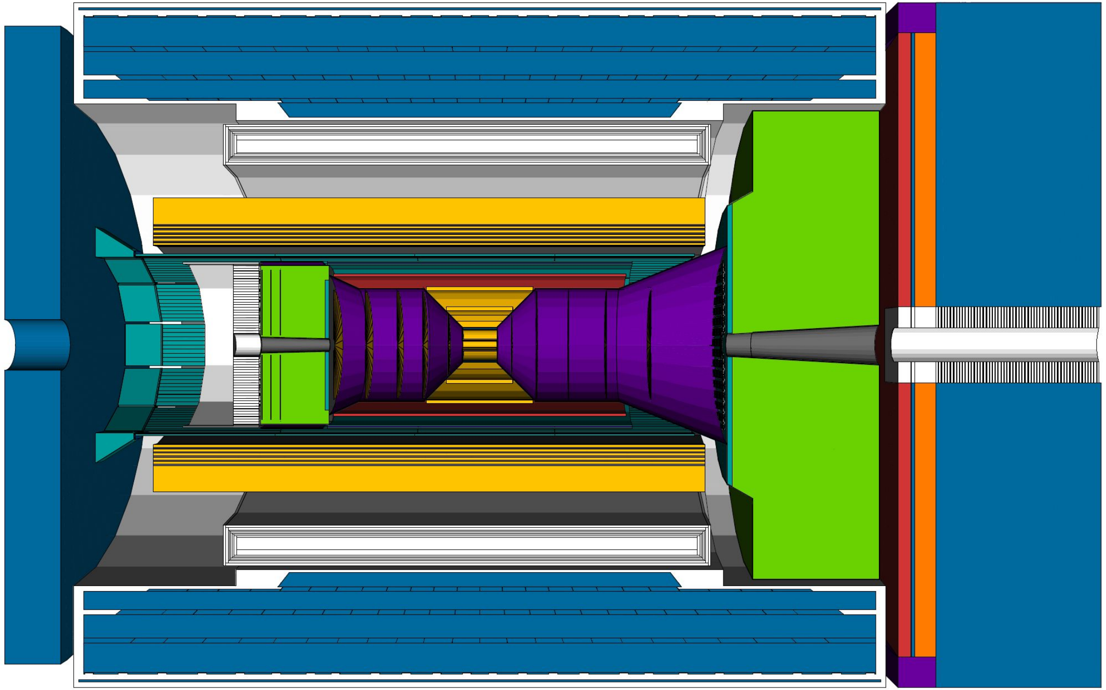
Dimensions



Dimensions a the current stage of the design

inner barrel radius	78.3 cm
nb of sectors	48
length	432.5 cm
AstroPix slot thickness	2 cm
SciFi/Pb Layer 1-5 thickness	2 cm
Total weight	~36 t
1 sector weight	~750 kg

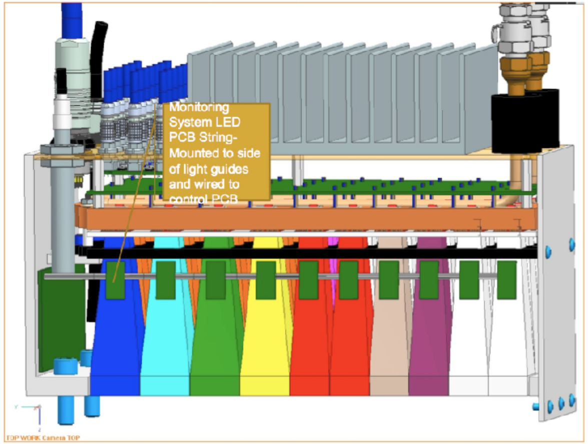
Overall space considerations



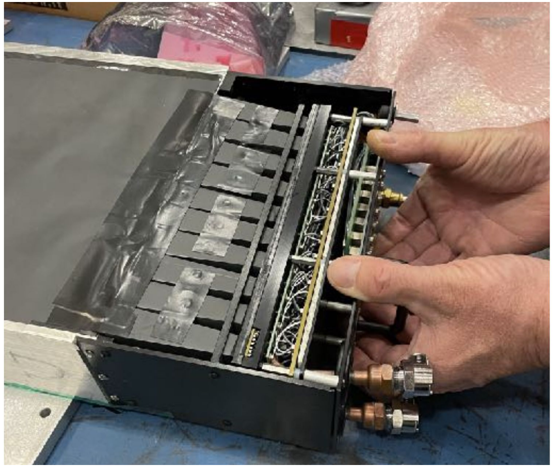
- Lots of space between the barrel EMCal and the solenoid crystat (~ 20 cm)
- Forward region under heavy pressure, space needed for:
  - Barrel EMCal readout box
  - Inner detector services
  - Barrel EMCal and inner detector support
  - dRICH
- Situation a bit more relaxed in the backward region

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.

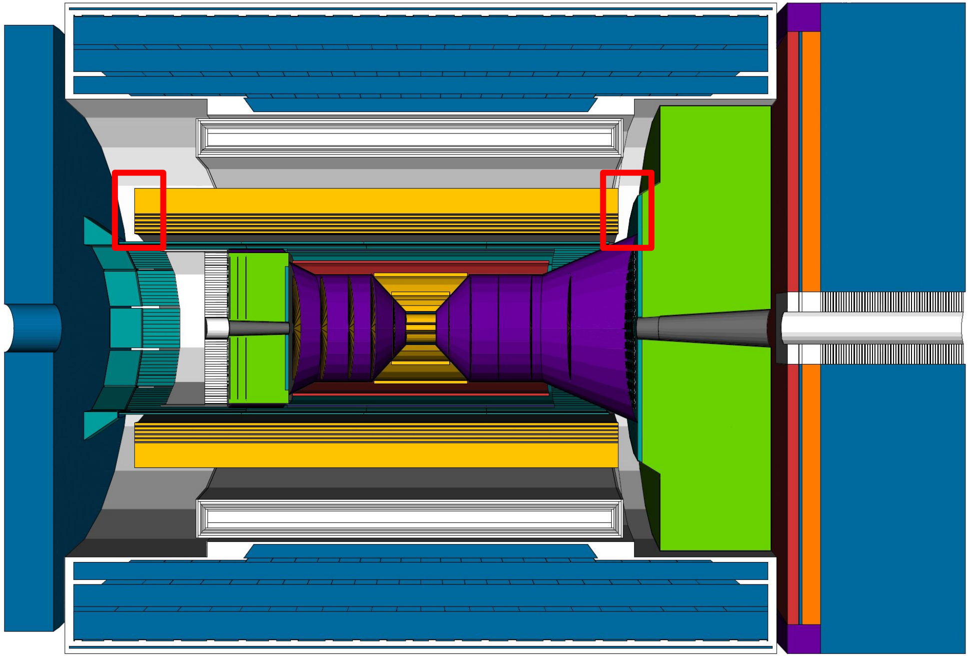


CAD drawing of GlueX readout box



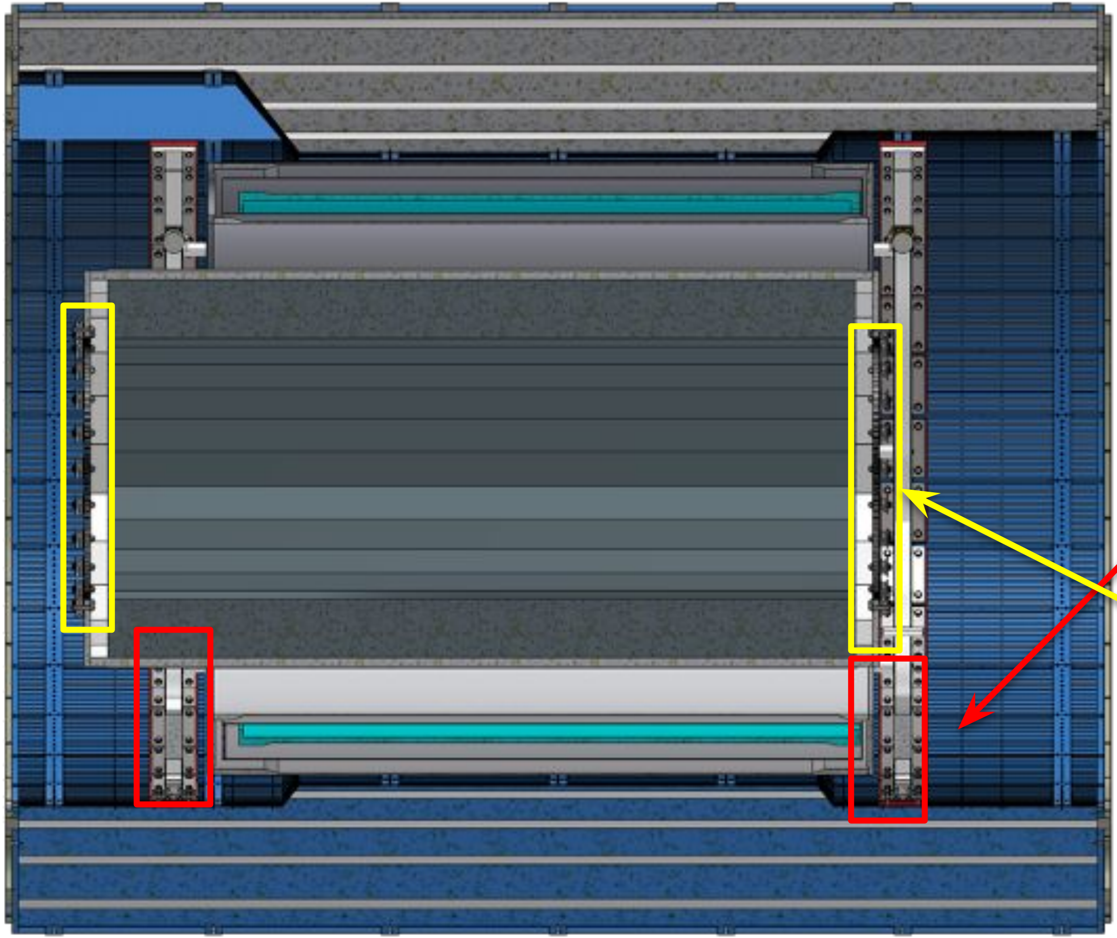
"BabyBCAL" prototype readout box

Barrel ECal Readout & Services



- Nominal 10cm service box at the end of each sector, may have to grow slightly
  - This would put (more) space pressure in the hadron-going direction.
  - May need to shorten calorimeter by a few cm to compensate
- Readout box includes:
  - Pb/ScFi readout components based on the GlueX design (including light-monitoring system)
  - 4 6x6mm2 SiPMs with 50 um pixel per lightguide ("project" Hamatsu meets the performance requirements)
  - 1 x HGCROC per sector-end for SiPM readout
  - End-of-tray FPGAs for each of the silicon layers
- Readout boxes at both sides of the calorimeter are identical.

Support structure



- Support strategy still being evaluated, tightly coupled whole system integration
  - Barrel EMCal may need to support the whole inner detector!
- **Design rapidly evolving**
- Current iteration:
  - Barrel EMCal rests on Barrel HCal support rings
  - Only two points of contact (versus rails in GlueX) requires a bit more work to evaluate rigidity and need for outside support
  - Inner detector suspended off inner support rings at the end of the Barrel EMCal
  - Some issues with install/service access to the imaging layers still being addressed
- Other avenues also being explored

Performance requirements on the BECal

From the EIC Yellow Report: stringent requirements

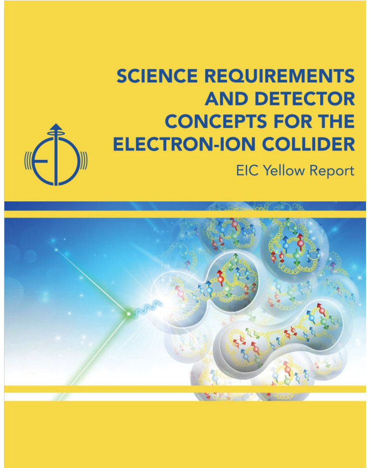
EIC is an **electron scattering** machine and identifying scattered electrons mainly depends on the electromagnetic calorimetry.

The electromagnetic calorimeter is the main detector for **electron-pion separation**. The inclusive physics program requires up to 10^4 pion suppression at low momenta in the barrel.

The exclusive program requires **decent energy resolution** ($< 7\%/\sqrt{E} \oplus 1\%$) **for photon energy reconstruction, and also the fine granularity for good** π^0-γ separation up to 10 GeV.

The bECal should be capable of measuring **low energy photons** down to 100 MeV, while having the range to measure energies well above 10 GeV

The system is space-constrained to very **limited space** inside the solenoid.

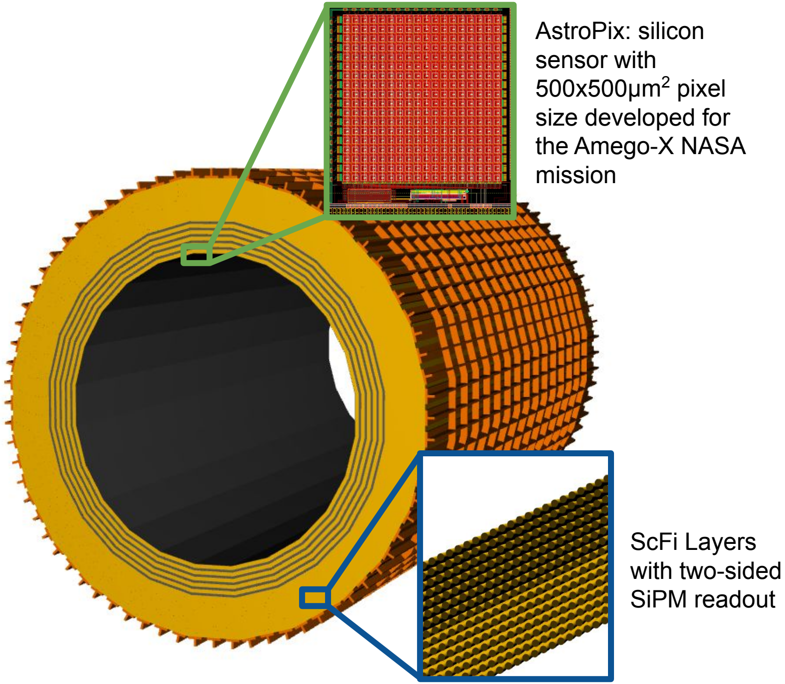


We easily meet the YR requirements

No significant changes in performance compared to the Barrel ECal review

~~6 layers~~ 4(+2) layers of Astropix sensors interleaved with the first 5 Pb/ScFi layers, followed by a large volume of bulk Pb/ScFi layers

- ☑️ Deep calorimeter but still very compact at ~ 40 cm
- ☑️ Excellent energy resolution (5.2% $/\sqrt{E} \oplus$ 1.0%)
- ☑️ Unrivaled low-energy electron-pion separation by combining the energy measurement with shower imaging
- ☑️ Unrivaled position resolution due to the silicon layers
- ☑️ Longitudinal shower profile from the Pb/ScFi layers
- ☑️ Deep enough to serve as inner HCal
- ☑️ Very good low-energy performance
- ☑️ Wealth of information enables new measurements, ideally suited for particle-flow



Checks all the boxes!

Performance overview in backup

https://indico.bnl.gov/event/19689/timetable/#all.detailed

In-person Barrel Imaging Calorimeter Meeting last week

Meeting happened over 5 days, discussion Pb/ScFi part (Mo-Tue), Engineering (We), and AstroPix/silicon (Thu-Fri)

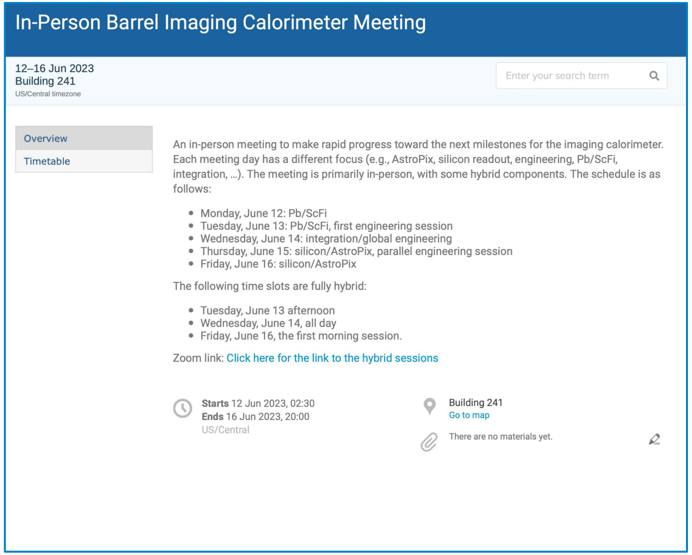
Highly productive meeting, up to > 20 in-person people at the meeting, and with hybrid component for most sessions.

In-person representatives from Project (Sasha) and ePIC management (John), active remote participation by Project engineer (Dan), regular check-ins with Elke & Rolf

~ 30 pages of live notes documenting action items and discussion, many presentations on Indico (still collecting some info).

Collected wealth of information for a bottom-up cost estimate, short-term engineering tasks and needs, realistic production strategy and workforce requirements, timeline, …

Should have everything in hand for Change Control, and to fill out the work packages based on this meeting!



In-Person Barrel Imaging Calorimeter Meeting

12–16 Jun 2023
Building 241
US/Central timezone

Enter your search term

Overview
Timetable

An in-person meeting to make rapid progress toward the next milestones for the imaging calorimeter. Each meeting day has a different focus (e.g., AstroPix, silicon readout, engineering, Pb/ScFi, integration, …). The meeting is primarily in-person, with some hybrid components. The schedule is as follows:

- Monday, June 12: Pb/ScFi
- Tuesday, June 13: Pb/ScFi, first engineering session
- Wednesday, June 14: integration/global engineering
- Thursday, June 15: silicon/AstroPix, parallel engineering session
- Friday, June 16: silicon/AstroPix

The following time slots are fully hybrid:

- Tuesday, June 13 afternoon
- Wednesday, June 14, all day
- Friday, June 16, the first morning session.

Zoom link: Click here for the link to the hybrid sessions

Starts 12 Jun 2023, 02:30
Ends 16 Jun 2023, 20:00
US/Central

Building 241
Go to map

There are no materials yet.

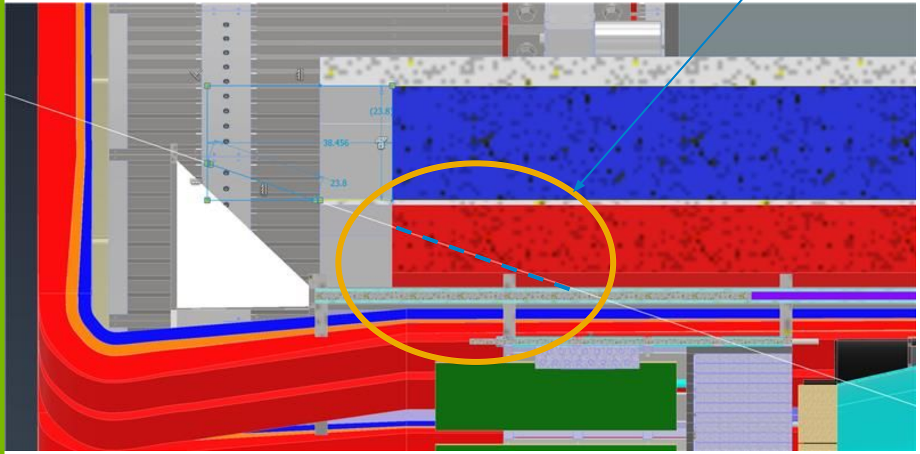
Backup

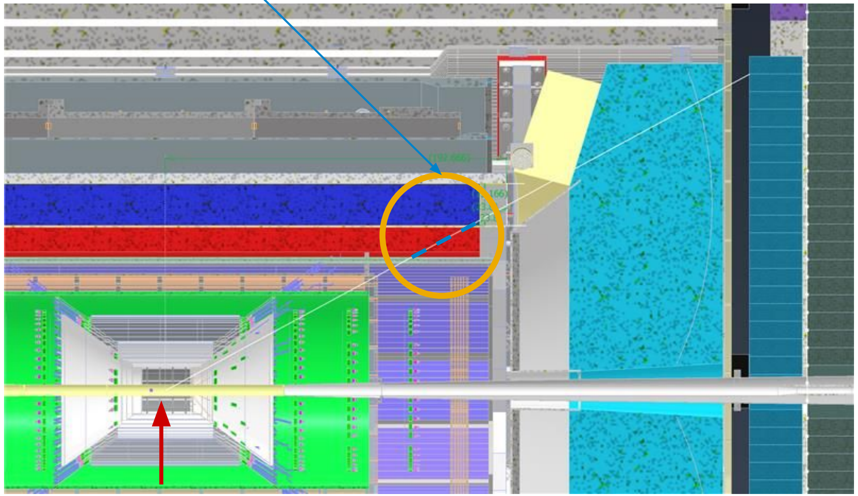
How is your system integrated with the overall ePIC design, i.e., what is the envelope occupied, is there possibly overlap with other subsystems, and is the design consolidated, ...

From Menagerie Tables:

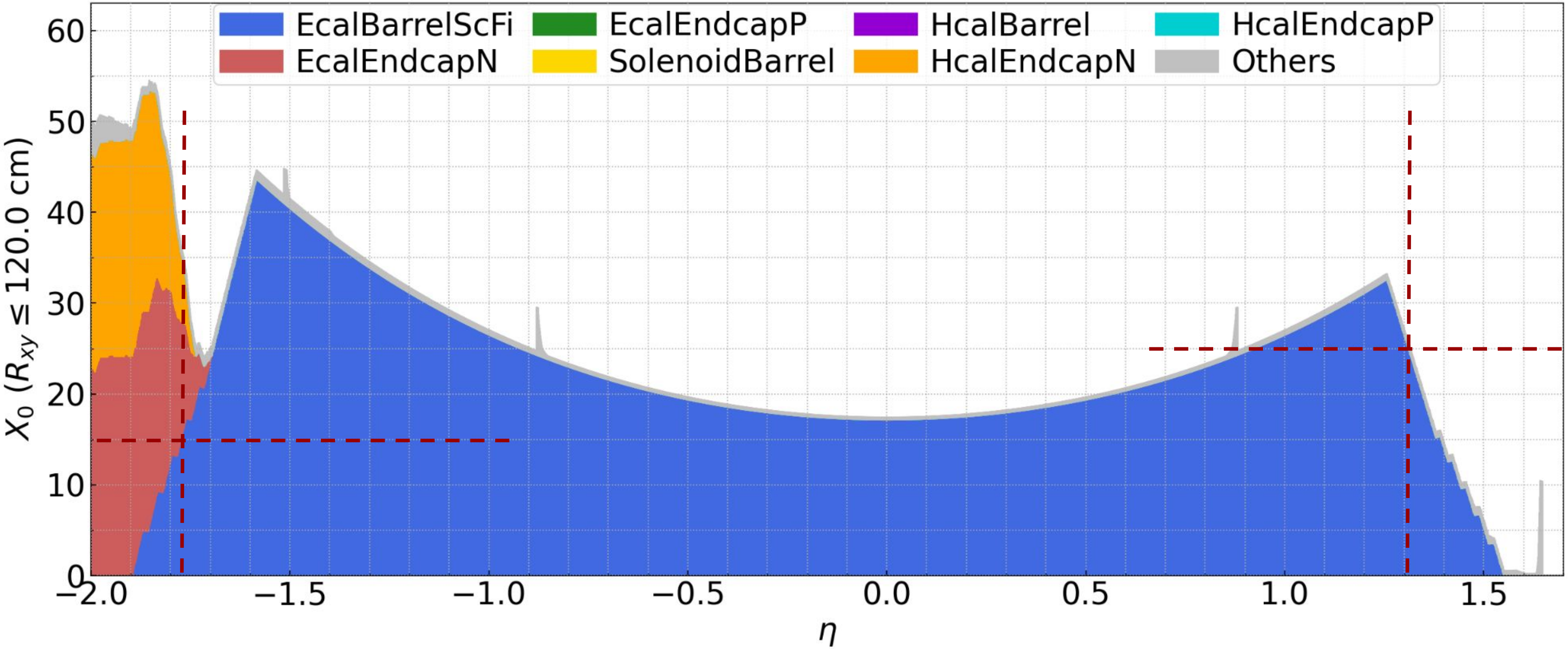
- negative ecal front face at z -174 cm, up to r = 63 cm
- positive ecal front face at z 329.5 cm, up to r = 195 cm
- backward block size = 2 cm, forward module size = 2.5 cm

η = -1.77 and +1.31 for those lines assuming *one block size less than maximum radius*



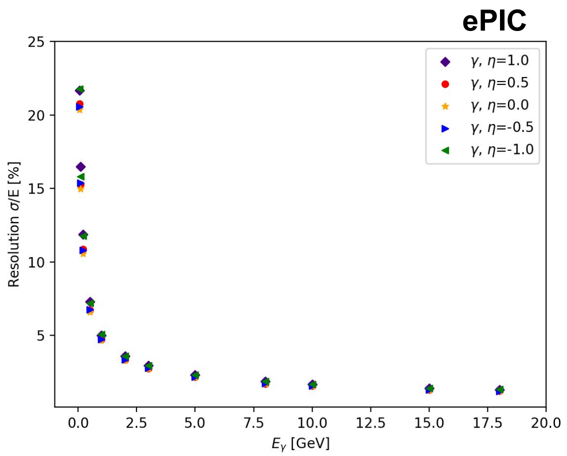


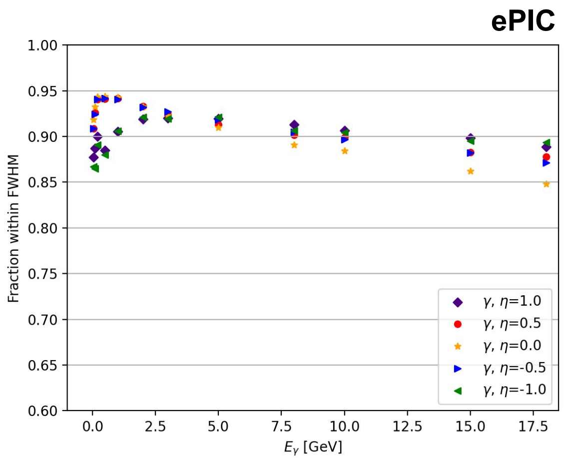
η = -1.77 and +1.31

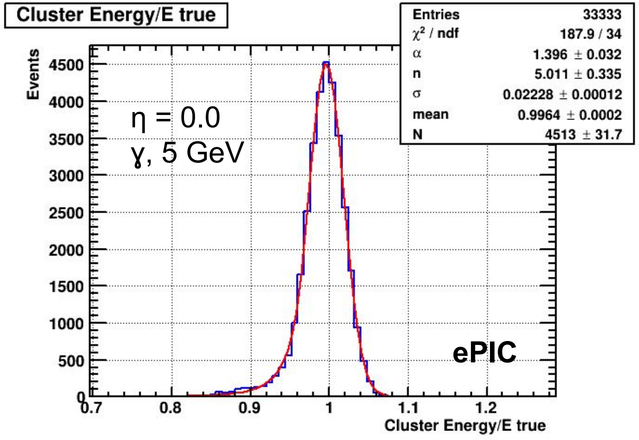


EcalBarrelScFi
EcalEndcapN
EcalEndcapP
SolenoidBarrel
HcalBarrel
HcalEndcapN
HcalEndcapP
Others
X_0 (R_{xy} ≤ 120.0 cm)
η
0
10
20
30
40
50
60
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5

Energy Resolution - Photons







Fit parameters

η	a/√(E) [%]	b [%]
-1	5.1(0.01)	0.47(0.03)
-0.5	4.77(0.01)	0.38(0.02)
0	4.67(0.01)	0.40(0.02)
0.5	4.75(0.01)	0.39(0.02)
1	5.1(0.01)	0.41(0.02)

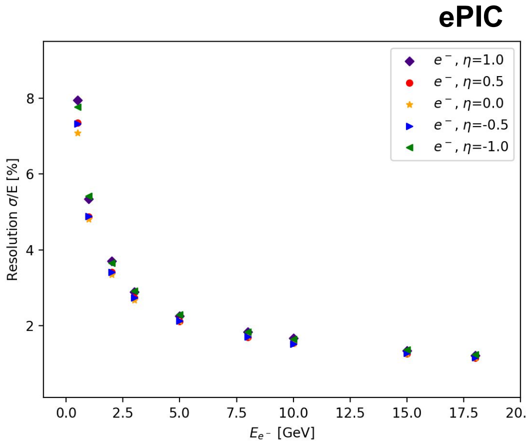
- Based of Pb/ScFi part of the calorimeter
- Resolution extracted from a Crystal Ball fit σ

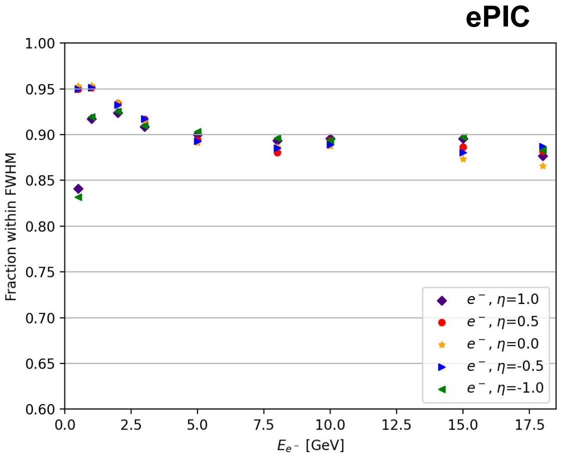
GlueX Pb/ScFi ECal: $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ NIM, A 896 (2018) 24-42

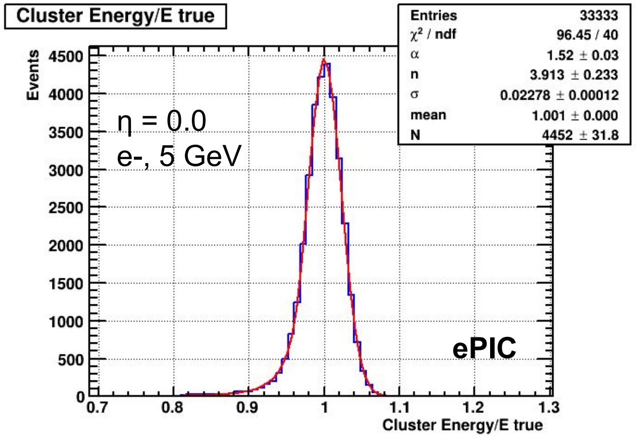
- 15.5 X_0, extracted for integrated range over the angular distributions for π^0 and η production at GlueX (E_γ = 0.5 - 2.5 GeV)
- Measured energies not able to fully constrain the constant term

Simulations of **GlueX prototype** in ePIC environment agree with data at E_γ < 0.5 NIM, 596 (2008) 327−337

Energy Resolution - Electrons







Fit parameters

η	a/√(E) [%]	b [%]
-1	5.22(0.02)	0(0.08)
-0.5	4.88(0.01)	0(0.04)
0	4.81(0.01)	0(0.08)
0.5	4.88(0.01)	0(0.04)
1	5.19(0.01)	0(0.06)

Resolution extracted from a crystal ball fit σ

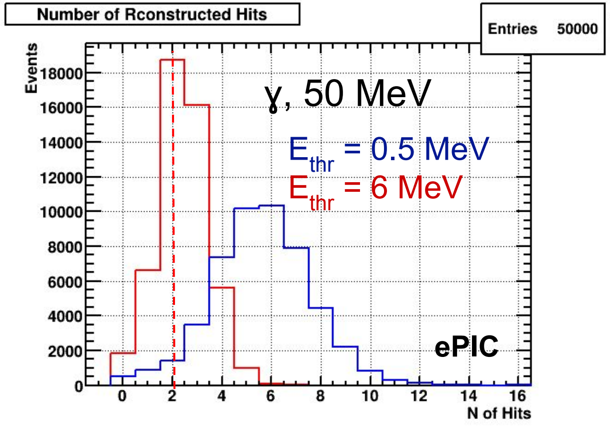
GlueX Pb/ScFi ECal: $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ NIM, A 896 (2018) 24-42

- 15.5 X_0, extracted for integrated range over the angular distributions for π^0 and η production at GlueX (E_γ = 0.5 - 2.5 GeV)
- Measured energies not able to fully constrain the constant term

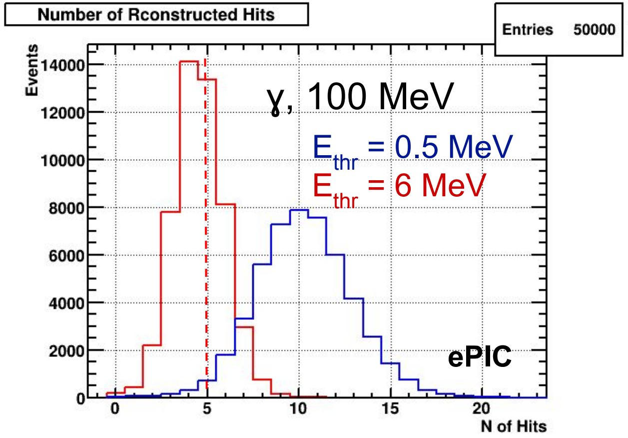
Simulations of **GlueX prototype** in ePIC environment agree with data at E_γ < 0.5 NIM, 596 (2008) 327−337

Low Energy Particles

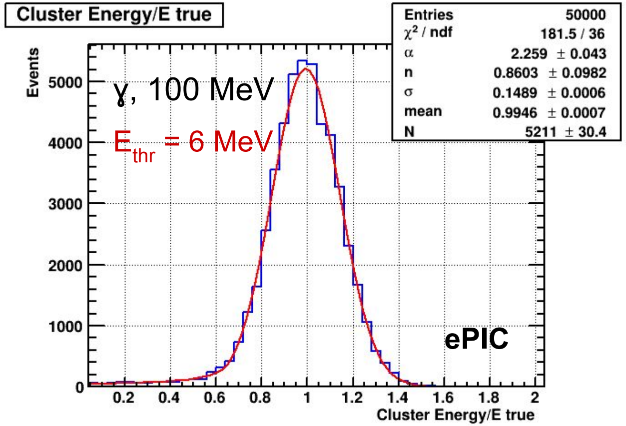
- For electrons: cut out because of the 1.7 T field to reach the calorimeter (p < ~408 MeV)
- For photons shown number of fired readout cells with different thresholds at $\eta = 0$



Thresholds corrected for f_{sam}



Blue threshold very low just to illustrate the distribution shape

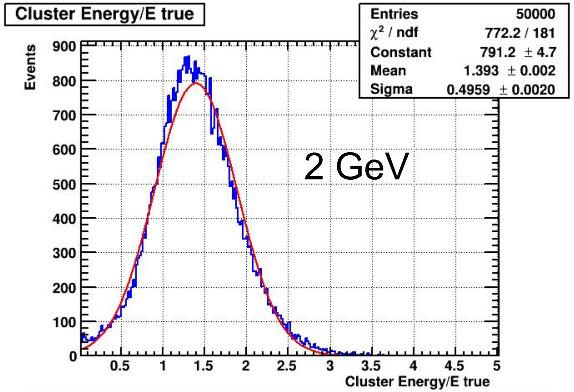


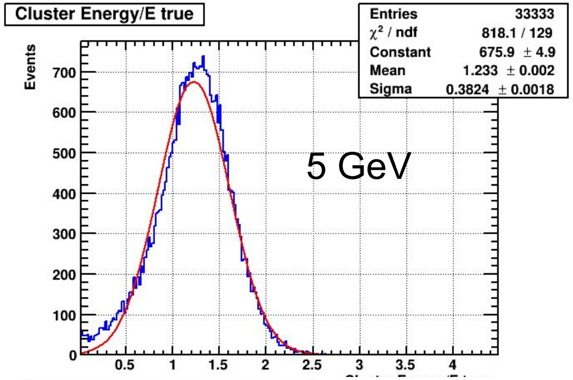
- **From GlueX** studies: cluster/shower threshold is 100 MeV nominal (down to 50 MeV for some analyses, with mostly two cells per event only). Low energy detection threshold studied also with Michel electrons. (NIM, A 896 (2018) 24-42)

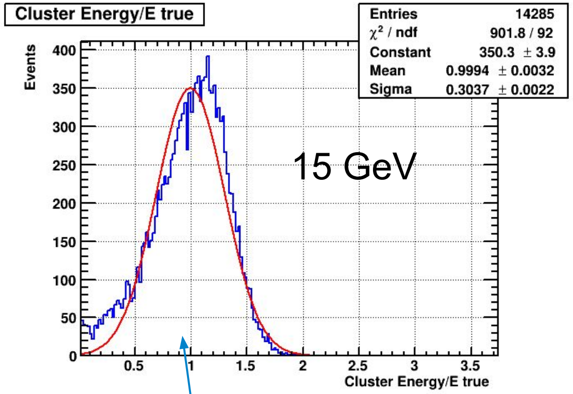
Energy resolution of AstroPix Layers

- **Sampling fraction < 0.5 %**
- Example Energy Lineshapes for photons at $\eta = 0$

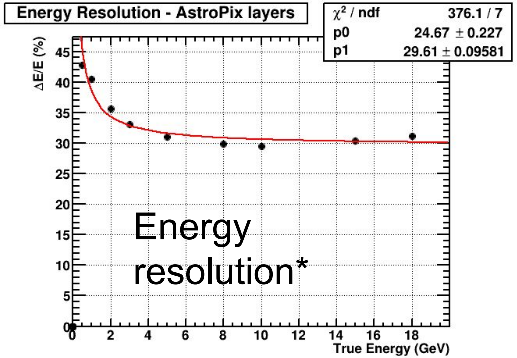
with 6 AstroPix Layers

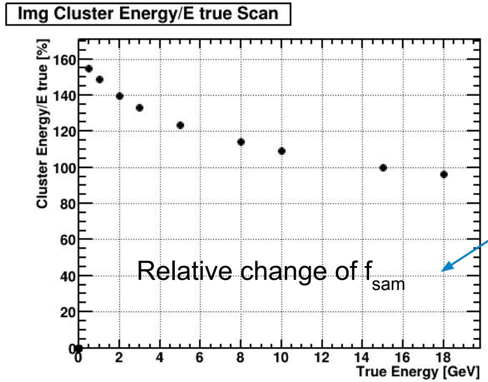






non-gaussian





strong dependence in this geometry

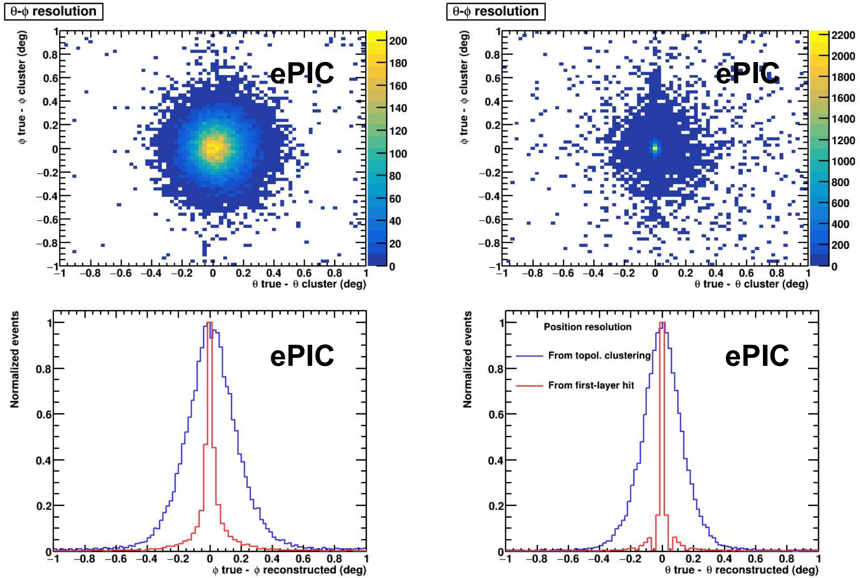
*Assuming perfect calibration (but! huge sampling fraction energy dependence)

Position Resolution

with 6 AstroPix Layers

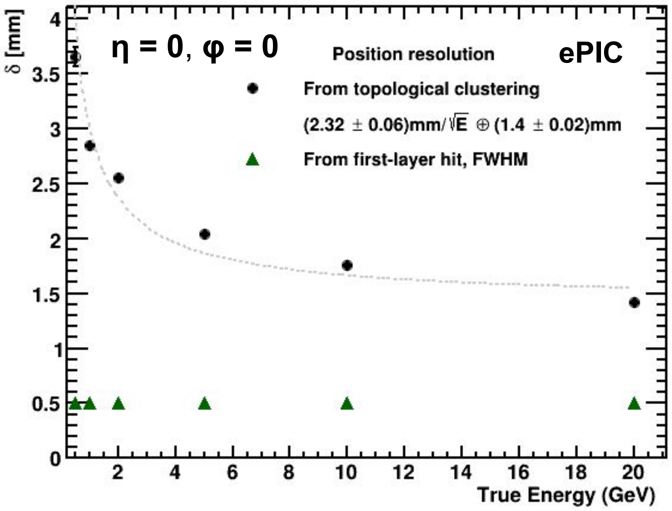
Example of θ - φ resolution for 5 GeV photons

Only information from **clusters** | **Clusters + first-layer hit**



Position resolution for photons

Particles thrown perpendicular to the calo surface



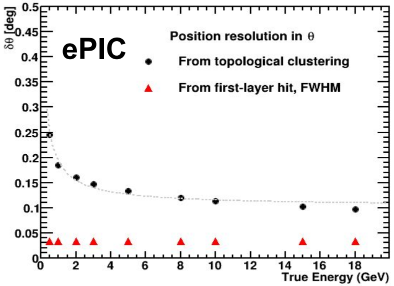
- Clusters from Imaging Si layers reconstructed with 3D topological algorithm
- Cluster level information: $\sigma_{position}$ = (2.32 ± 0.06) mm/√E ⊕ (1.4 ± 0.02) mm at η=0
- First-layer hit information added: $\sigma_{position}$= **~0.5 mm (pixel size)**

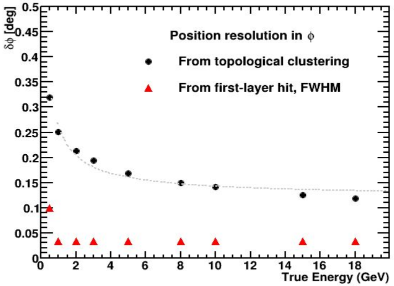
Position resolution studies

with 6 AstroPix Layers

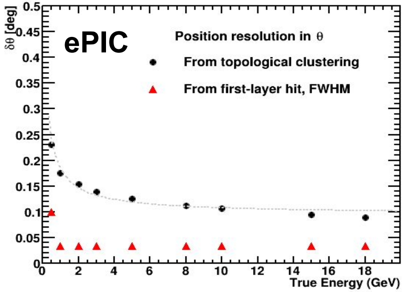
Angular resolution for different η

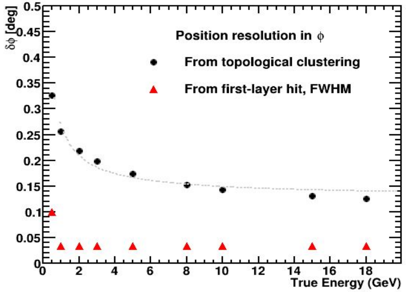
η = 0, φ = (0,2π)



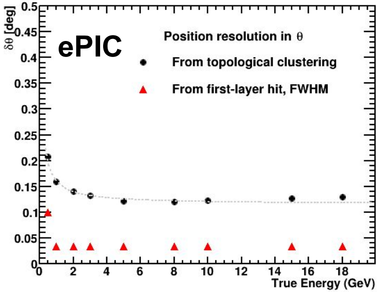


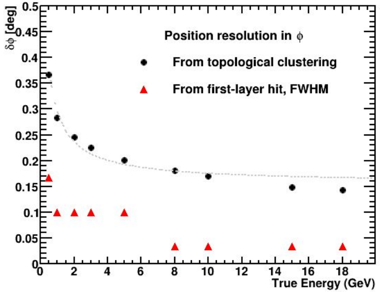
η = 0.5, φ = (0,2π)





η = 1, φ = (0,2π)

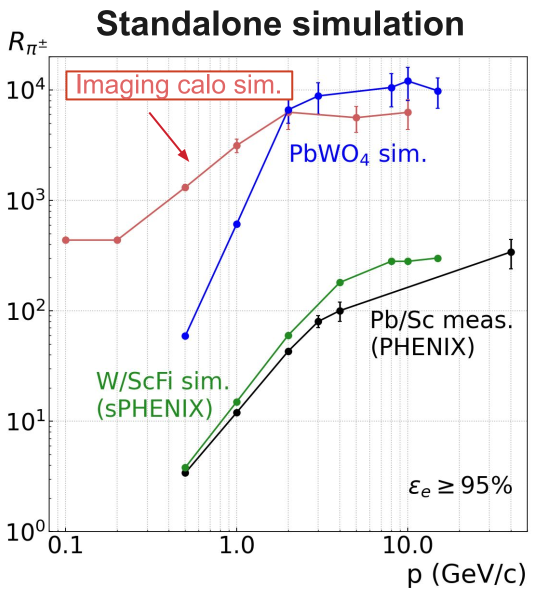


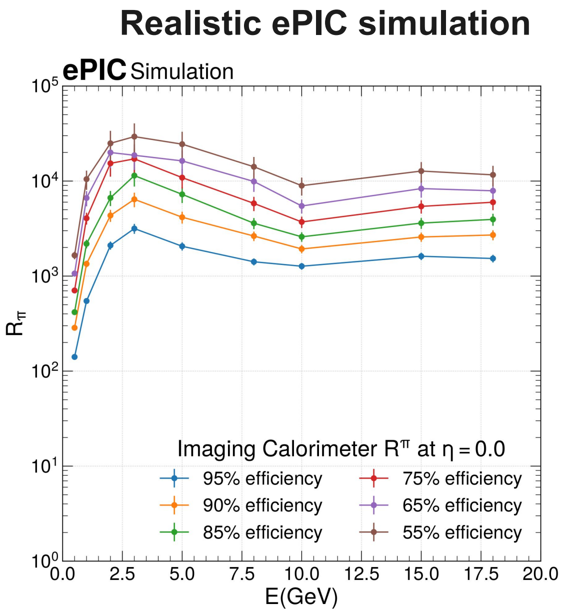


- Small dependence seen with changing η
- Angular resolution in all regions well below 0.1 deg (in majority regions on the level of single pixel resolution)
- Results well below any tower-like calorimetry

Electron Identification

with 6 AstroPix Layers





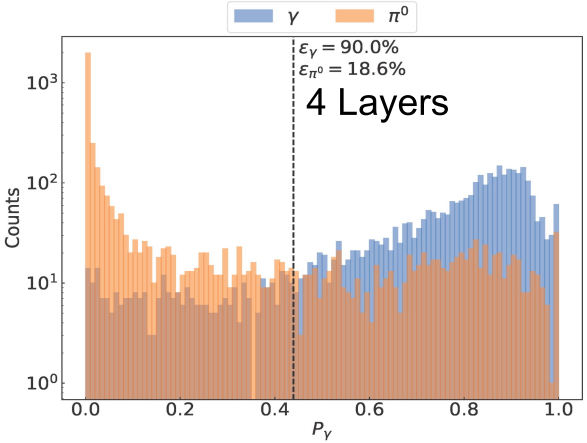
- **Goal:** Separation of electrons from background in Deep Inelastic Scattering (DIS) processes
- Method: **E/p cut (Pb/ScFi) + Neural Network** using 3D position and energy info from imaging layers

- e-π separation exceeds **10^3** in pion suppression at **95% efficiency** above 1 GeV in realistic conditions!

Performance with reduced number of layers

γ/π^0 separation

Momentum	Configuration	γ efficiency	π^0 rejection
10 GeV/c	6-layer default	90%	11.5
10 GeV/c	4-layer alternate	90%	5.4



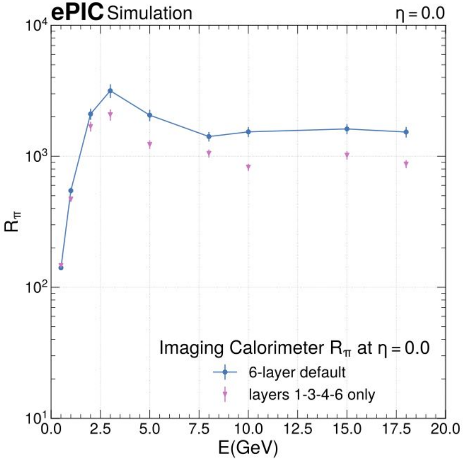
Significant reduction in π^0 rejection at larger energies when reducing the number of layers (where π^0 rejection is the hardest).

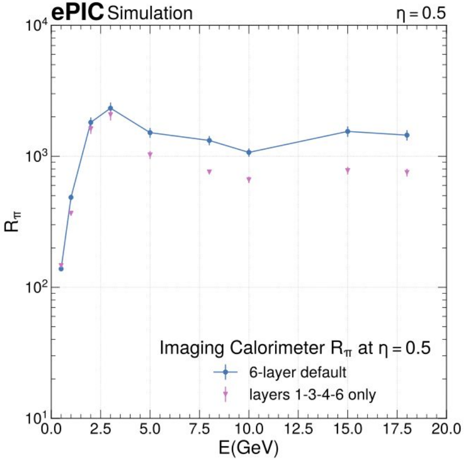
4-layer configuration, sees a reduction in π^0 rejection at high energies by a factor of 2.

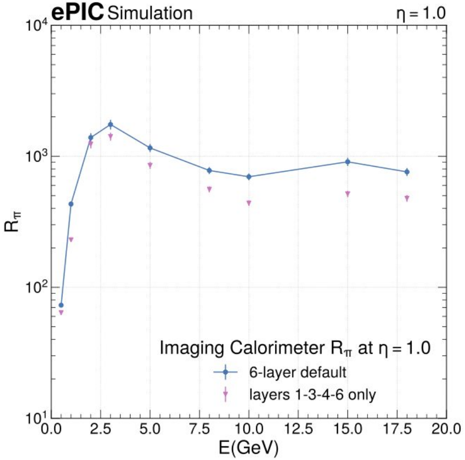
4-layer alternate is workable (still better than theoretical limit on a crystal calorimeter!), but significantly reduced π^0 performance versus the default 6-layer configuration.

Performance with reduced number of layers

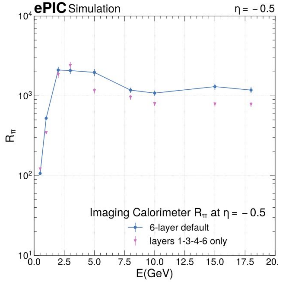
e/π separation at 95% efficiency

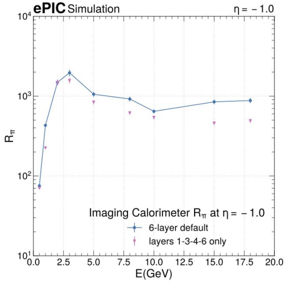






4-layer alternate: layers 1-3-4-6





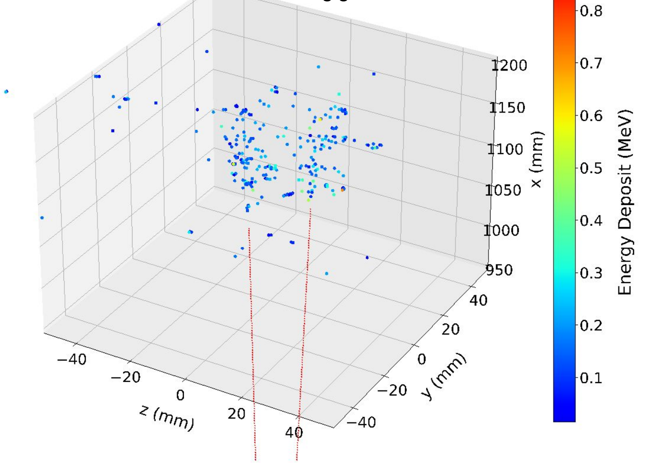
Default configuration exceeds 10^3 pion rejection almost everywhere

4-layer alternate still performs relatively well at lower energies (where most rejection is needed), larger degradation at higher energies

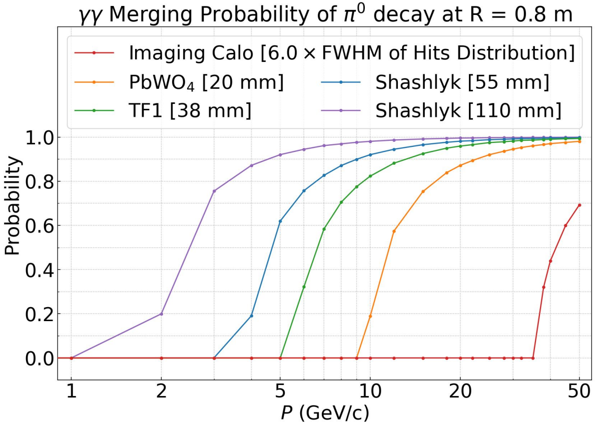
4-layer alternate seems workable compromise.

Neutral Pion Identification

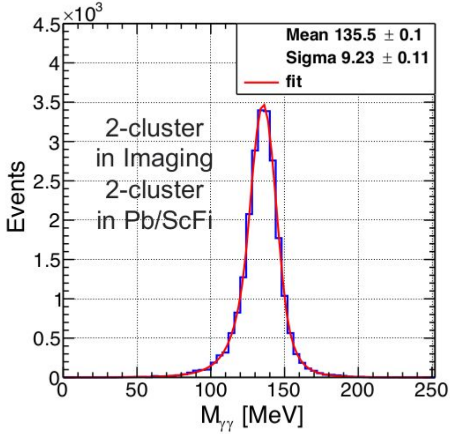
15 GeV $\pi^0 \rightarrow \gamma\gamma$



Separation of γ/π^0 (upper limit)



M_{inv} reconstruction 2 GeV π^0



- **Goal:** Discriminate between π^0 decays and single γ from DVCS, neutral pion identification
- Precise position resolution allow for excellent separation of γ/π^0 **based on the 3D shower profile**
- Reconstruction of 2 GeV π^0 invariant mass as a testing ground for cluster energy splitting

Separation of two gammas from neutral pion well above required 10 GeV

γ/π^0 Separation - Exploratory Studies

Convolutional neural network utilizing energy and spatial information from AstroPix layers

- Started from **10 GeV/c at η = 0** - the upper limit for γ/π^0 from YR

No proper **topological clustering algorithm** in the ePIC reconstruction yet

With a quick study we easily achieved

10 GeV/c particles - **91.4%** rejection of π^0 at **90%** efficiency of γ (better than $PbWO_4$ crystal with 20mm block size)

Full study is ongoing:

- Implementing optimized topological clustering for AstroPix layers
- Significant improvements expected