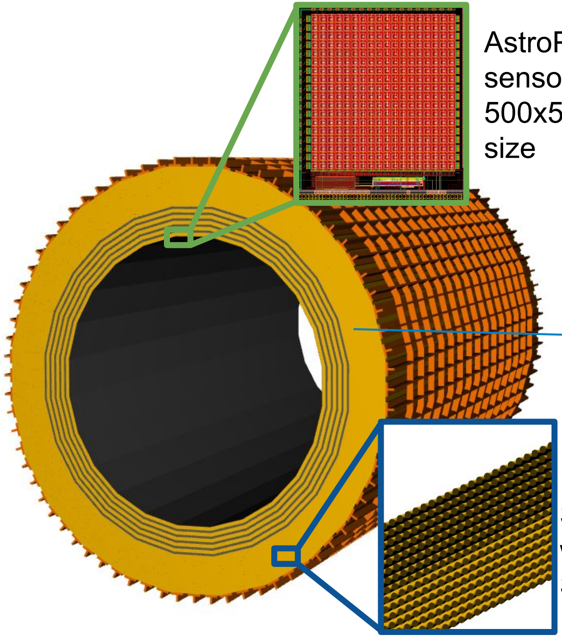
ePIC Barrel ECal Meeting - 06/12-16/23

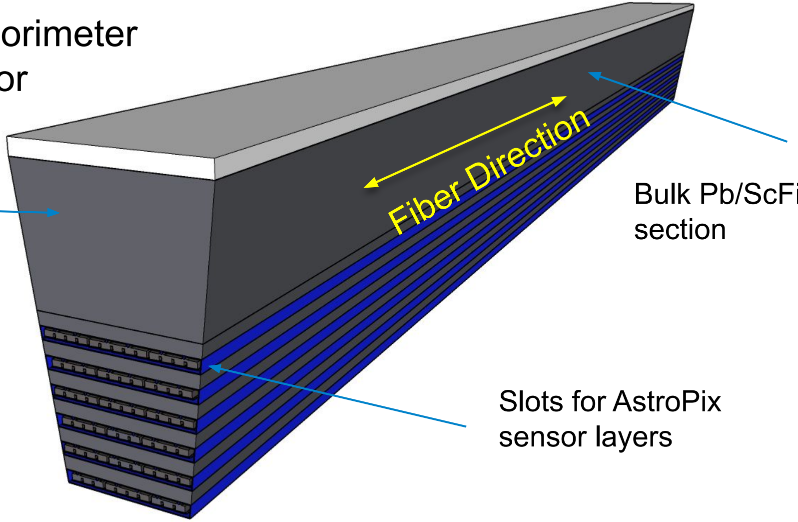
ePIC Imaging Calorimeter Intro: Facts & Figures

Maria Zurek
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**

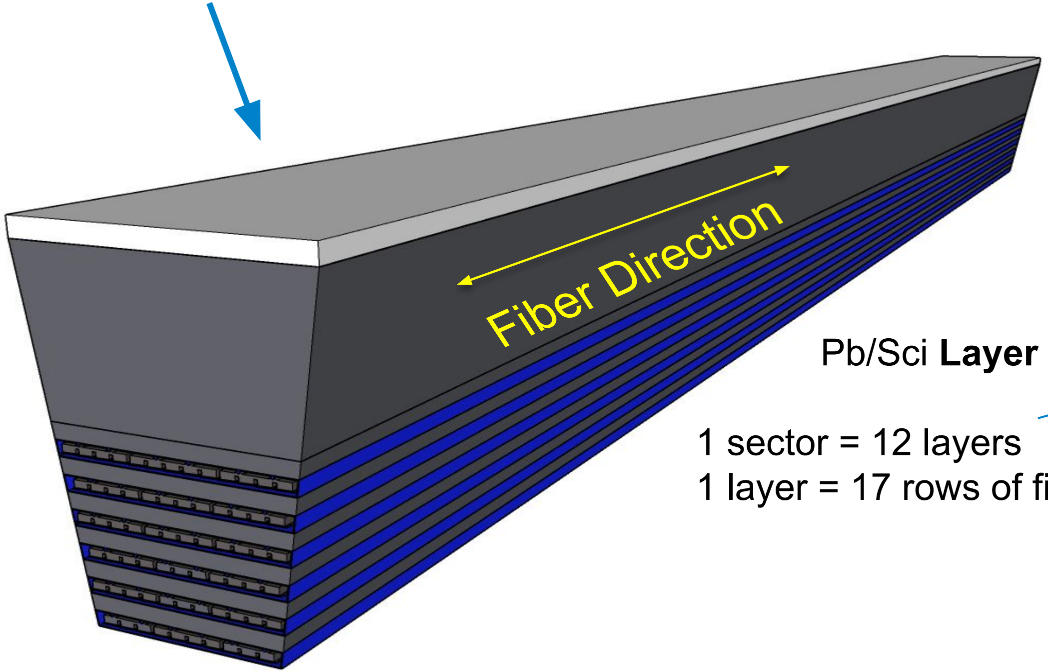




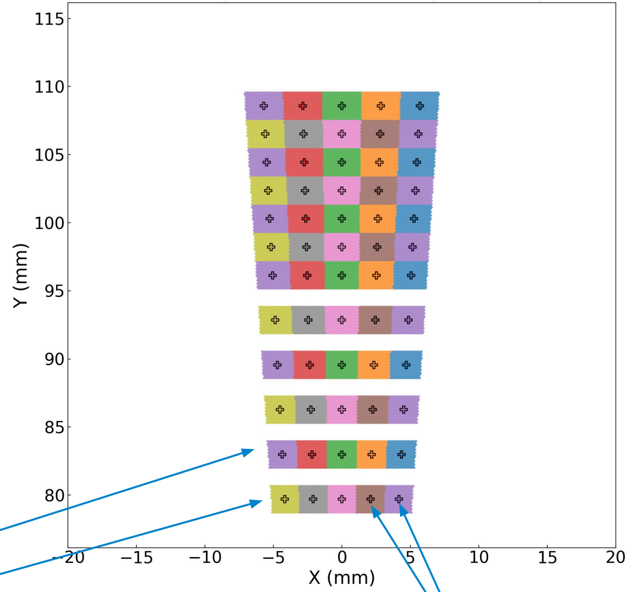
Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-side Pb/ScFi readout and radial segmentation)

Geometry and Naming Scheme

Sector
Whole Barrel: 48 Sectors



Sector End View
(x-y plane view)



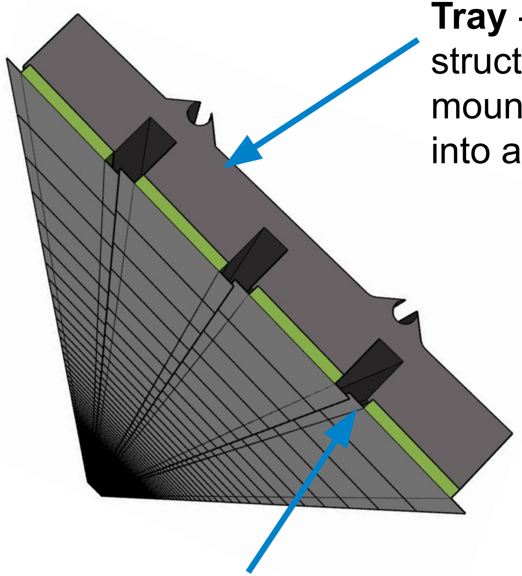
Pb/Sci **Layer**

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

Readout **Cell**
Layer = 5 cells

The area 1 light guide is attached

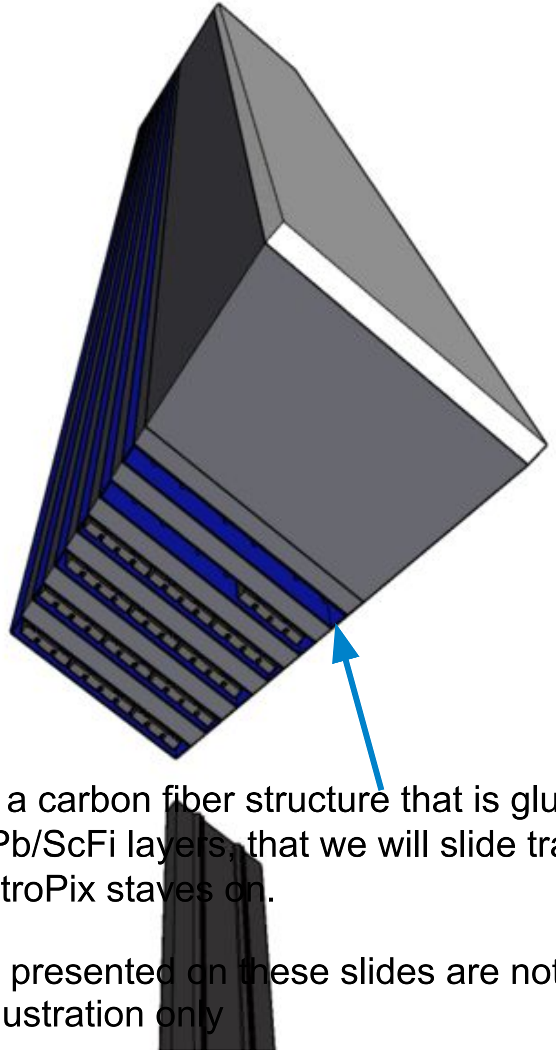
Geometry and Naming Scheme



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

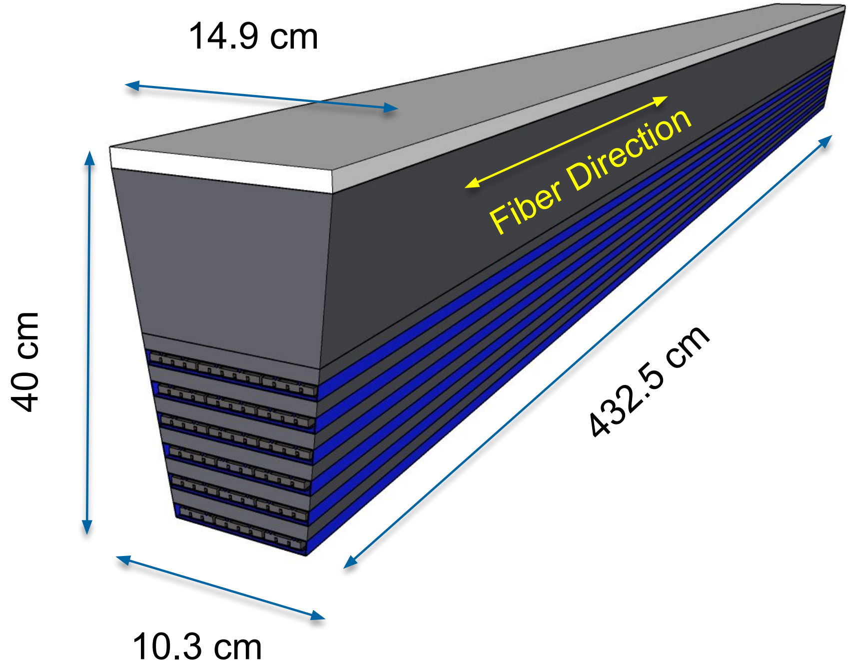
AstroPix **Module**
Subset of chips that will be mounted on one stave support structure



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

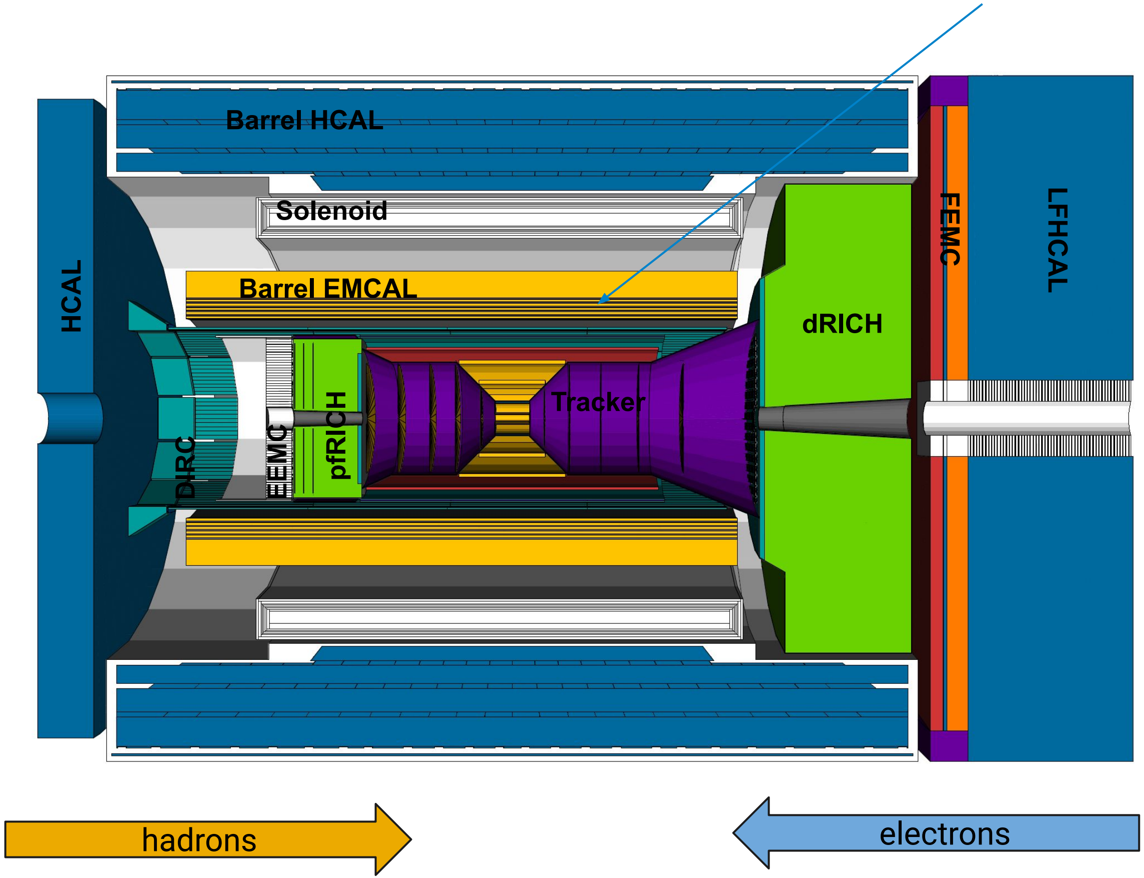
Dimensions



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

Barrel ECal in ePIC Detector



Tracking:

- New 1.7 T solenoid
- Si MAPS Trackers
- MPGD layer before DIRC

Particle ID:

- DIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

- Si and Pb/ScFi Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal + HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

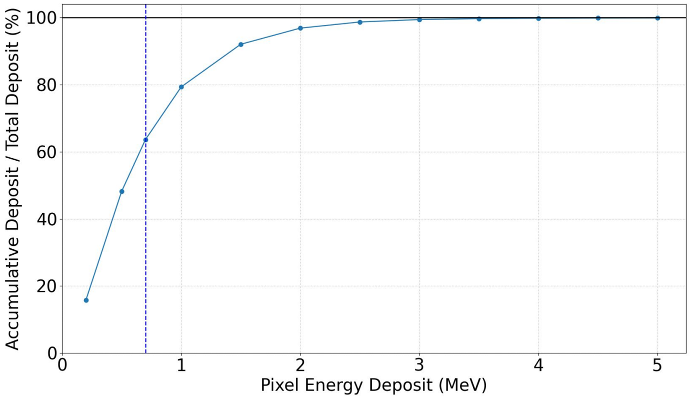
AstroPix for ePIC - Numbers

Estimates based on the current design

shelf number	shelf width [cm]	number of staves	number of chips (108 chips per stave)	number of pixels (40x36 pixels per chip)
1	10.3	12	1296	1.87E+06
2	10.8	-	-	-
3	11.3	12	1296	1.87E+06
4	11.9	12	1296	1.87E+06
5	12.4	-	-	-
6	12.9	14	1512	2.18E+06
	sum per barrel sector:	**50**	**5400**	**7.78E+06**
	sum per barrel:	**2400**	**259200**	**3.73E+08**

AstroPix for ePIC

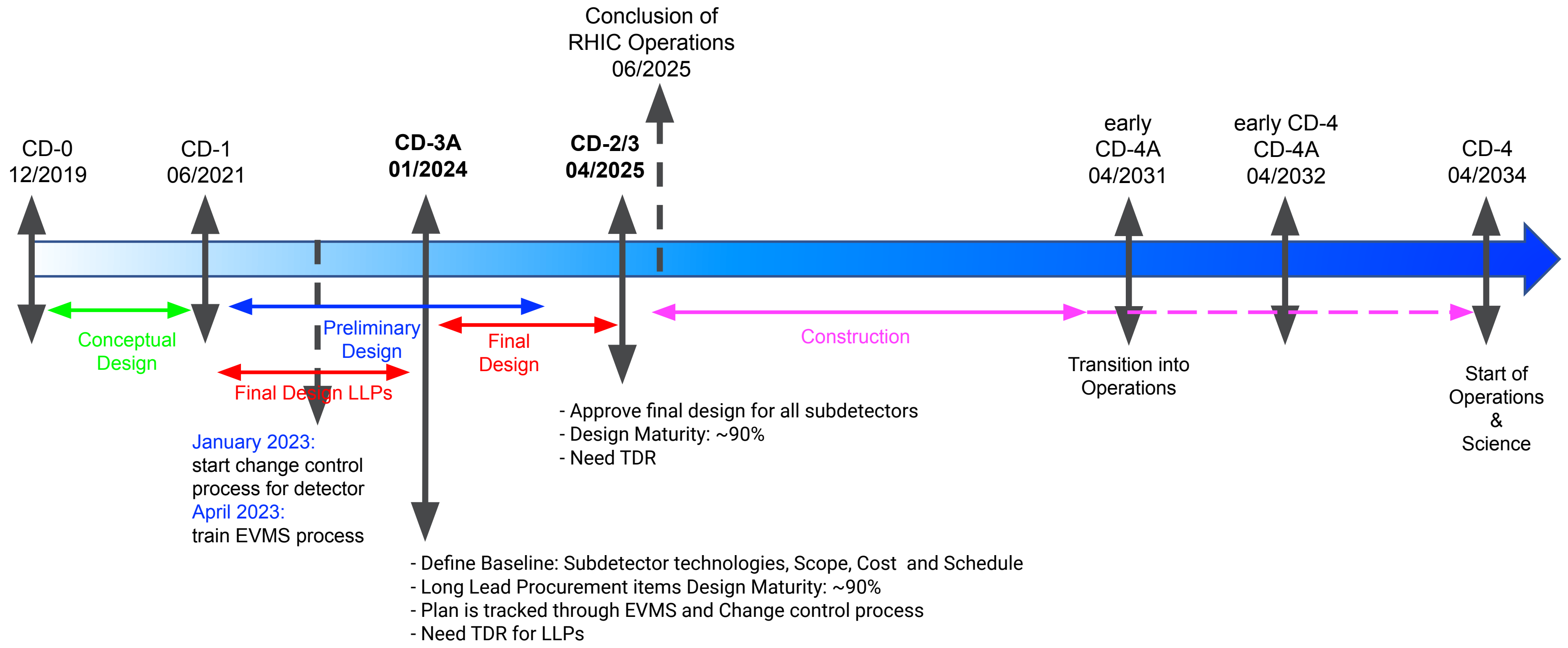
1. Low rates
   a. The expected hit rate for **all imaging layers together** is well below < 3 x 10^7 Hz
   b. This translates to a maximum hit rate per tracker stave (1 x 108 chips) < 36 kHz
2. Dynamic range (see plot for 2 GeV electron) **~ 3 MeV**
3. **Zero suppression threshold of 20 keV** well suited for EIC electromagnetic showers
4. Low Ionization radiation dose and neutron flux
   a. The maximum **ionizing radiation dose < 1 kRad/year** for the barrel region
   b. Max neutron flux is at the order of **10^9 neutrons/cm^2 per year**
5. Timing requirement: 3.125 ns (v4) - **driven by 10 ns bunch** crossing

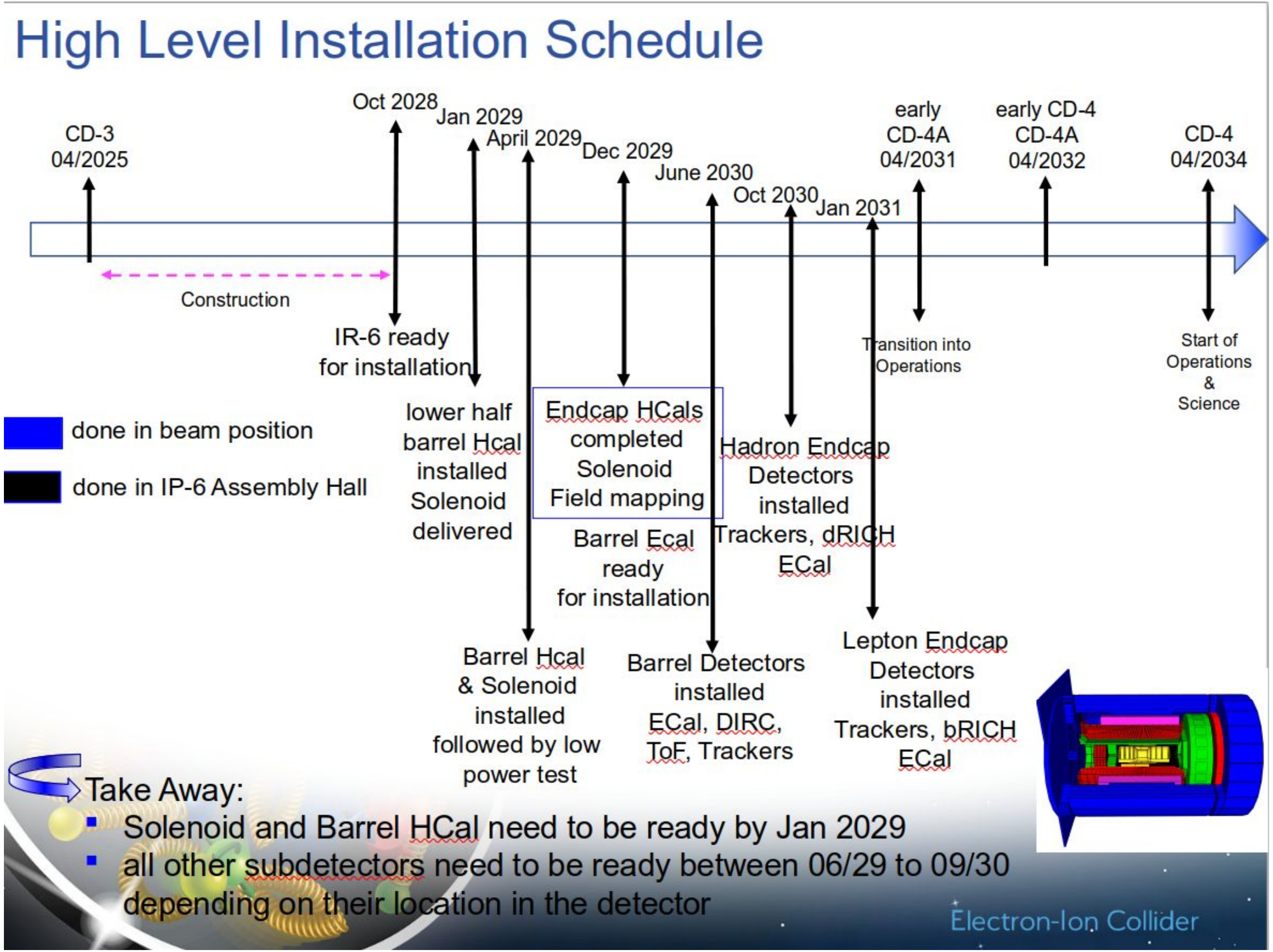


Accumulative energy deposit to the total energy deposit for 2 GeV electrons.

- About 63% of the energy deposit was made through hits with deposit < 700 keV
- hits with deposit < 3 MeV contribute to 99% of the total energy deposit

EIC Project Schedule





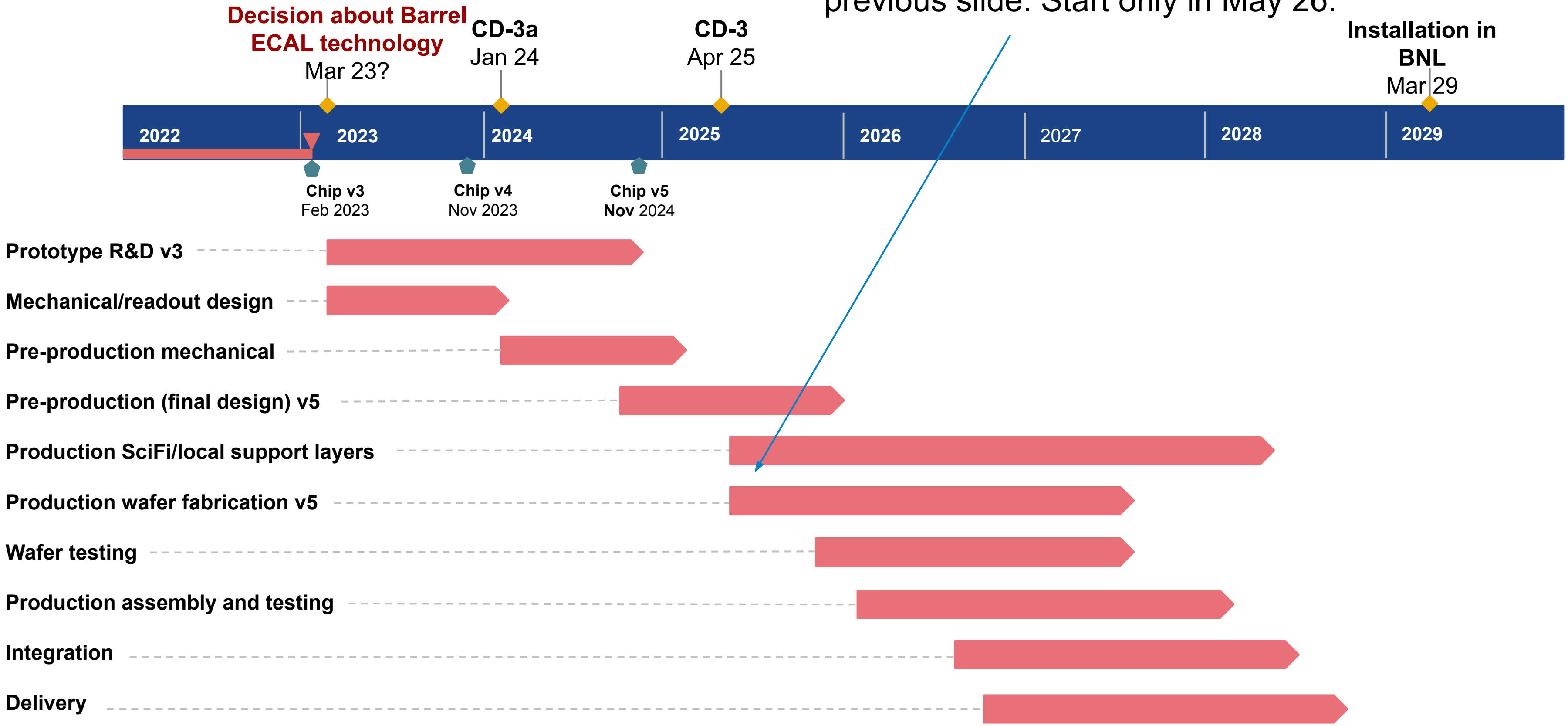
E. Aschenauer, R. Ent,
ePIC General Meeting,
04/14/23

High Level Schedule

Jul 2023 - Oct 2024: Design
Jan 2024 - Oct 2024: Prototyping/First article (*note any beam tests relate to R&D not to EMCal WBS*)
Oct 2024 - Oct 2025: Production development
Feb 2025 - Feb 2026: Procurement process
Feb 2026 - May 2029: Contract Award followed by material delivery
May 2026 - Sep 2029: Production for Pb/SciFi and test & assembly for Si, and ship to BNL
Sep 2029 - Dec 2029: Sector assembly at BNL (light guides, SiPM, etc.)
Dec 2029: Deadline to have all sectors and Si staves ready for integration
Dec 2029 - Feb 2030: Sector assembly in a barrel
Feb 2030 - May 2030: Insert/integrate Si staves

Schedule

Production start needs to be adjusted according to the schedule from the previous slide. Start only in May 26.



Backup

Daisy-chain throughput does not lead to dropped hits: method

Specs:

- One silicon stave is 108 Astropix sensors daisy-chained together, which measures 2 cm x 216 cm (one chip x half calorimeter length).
- Each Astropix sensor has 1360 pixels. The on-chip buffer has the same size as the number of pixels.
- It takes ~ 1 μs to push a hit from the Astropix chip to the periphery. The hit will go onto the hit buffer of the adjacent chip, taking 1 μs hops until it reaches the data aggregator at the end of the chain

Question: *Is there any risk for dropped hits due to traffic jams in the daisy chain?*

Method:

- Simulate the daisy chain for an *absurdly* high upper limit to show there are no issues (we do not have holistic full background+physics simulations available right now). If it works in this upper limit it will not be an issue for realistic operation.
  - Overestimate 1: The expected hit rate for all imaging layers together is well below < 3×10^7 Hz based on physics + background simulations done with an energy threshold of 0.4keV (correct threshold is 20keV so likely 1 or more orders of magnitude too large).
  - Overestimate 2: This corresponds to a raw hit rate of <36kHz per stave (high occupancy staves), let's assume this is not the *hit* rate but rather the *event* rate.
  - Overestimate 3: Let's assume every one of these events is a highest occupancy event (max occupancy/stave is <25hits/stave, which we found in the Pythia8 NC Q^2 > 1000 GeV^2 samples).
  - **Hence: highly conservative (unrealistically high) upper limit would be an event rate of 36kHz per stave with a multiplicity of 25 hits/stave.** This is what we simulated.*

* Note that the numbers we are simulating corresponds to a hit rate of 900kHz per stave, which is a dramatic overestimate.

Daisy-chain throughput does not lead to dropped hits: Results

Highly conservative (unrealistically high) upper limit would be an event rate of 36kHz per stave with a multiplicity of 25 hits/stave. This corresponds to assuming every hit is really an outlier high-multiplicity event. This is what we simulated.

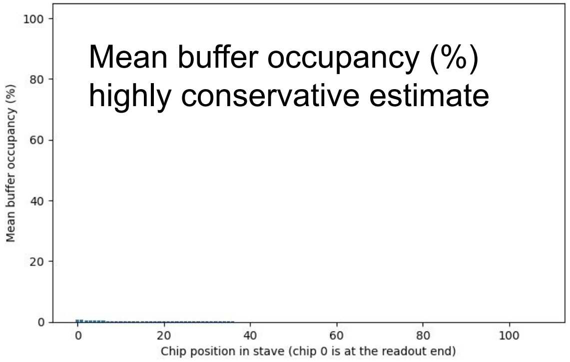
We ran the simulation until the results stabilized.

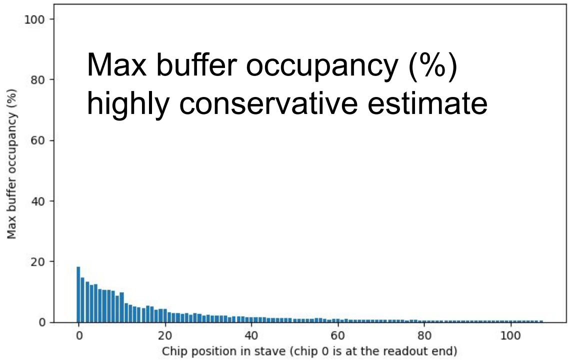
The mean buffer occupancy is very low.

The maximum buffer occupancy (highest-seen buffer usage for each of the chips) increases as we go towards the readout end of the daisy chain.

In this upper limit scenario, we never exceeded 20% buffer occupancy and **never dropped a hit**.

Realistic estimates will be orders of magnitude lower.





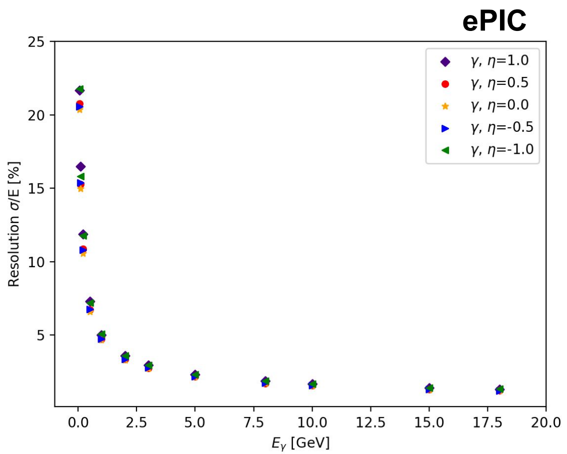
Project Schedule

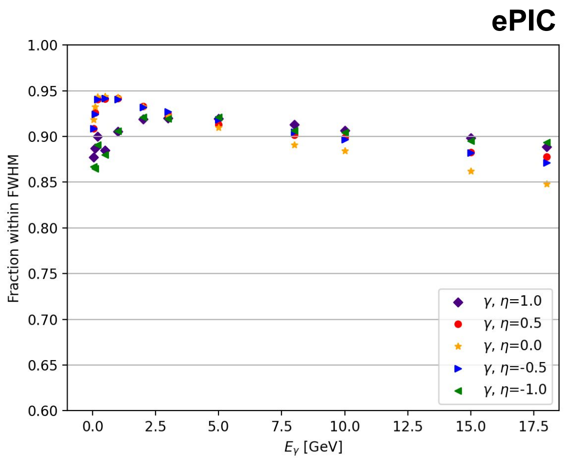
E. Aschenauer, R. Ent, ePIC General Meeting, 05/11/23

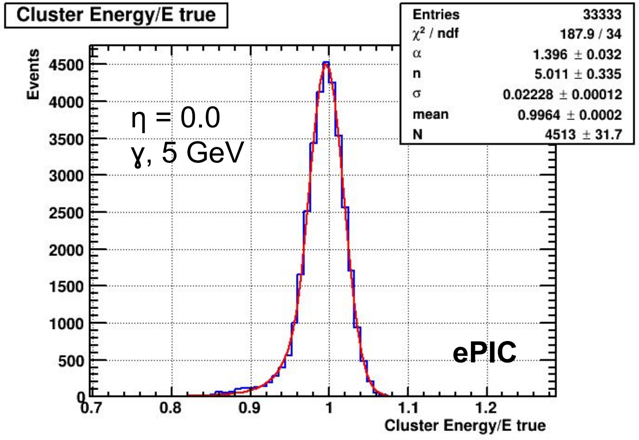
DOE OPA Status Review	**October 19-21, 2021(A)**
FPD Status Update at BNL	June 28, 29, 30 2022(A)
Technical, Cost, and Schedule Scrutiny Meeting	July – Sept 2022 (A)
Project, Detector & Infrastructure Advisory Meeting	October 2022(A)
DOE OPA Status Review	**Jan. 31-Feb 2, 2023(A)**
Project Advisory Meeting	February 22, 23 2023(A)
Infrastructure Advisory Meeting	March 22, 23 2023(A)
1st RRB Meeting	April 4,5 2023 (A)
Begin LLP EVMS (practice 3 months data)	**July 2023**
CD-3A Director's Review (Co-Chaired by M. Reichanadter / S. Cousineau)	**October 10-12, 2023**
DOE CD 3A OPA Review	**November 2023**
DOE CD 3A ESAAB Approval	**January 2024**
Final Design Reviews for all ePIC subsystems	**April – October 2024**
DOE CD 2/3 OPA Review and ICR	January 2025 (TBC)
DOE CD 2/3 ESAAB Approval	April 2025
RHIC Operations Concludes	June 2025

Perfomance

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)

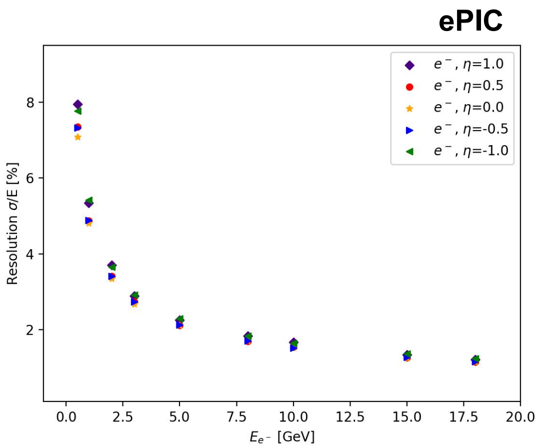
- Based of Pb/ScFi part of the calorimeter
- Resolution extracted from a Crystal Ball fit σ

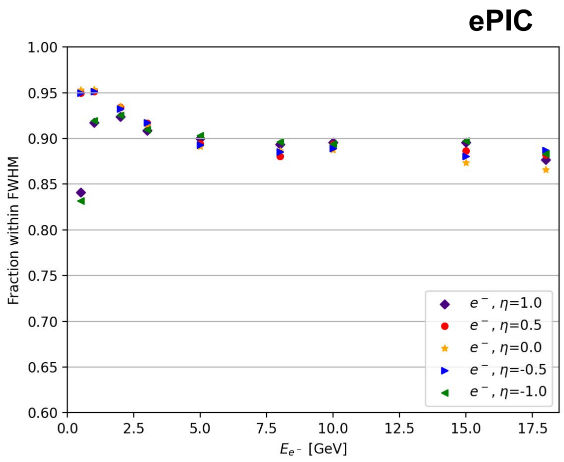
GlueX Pb/ScFi ECal: $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ NIM, A 896 (2018) 24-42

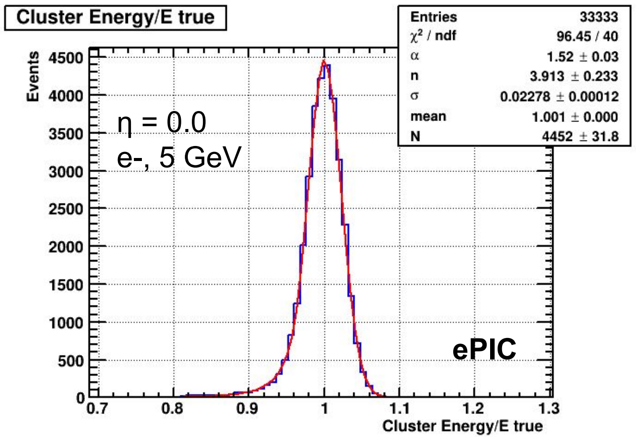
- 15.5 X_0, extracted for integrated range over the angular distributions for π^0 and η production at GlueX (E_γ = 0.5 - 2.5 GeV)
- Measured energies not able to fully constrain the constant term

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

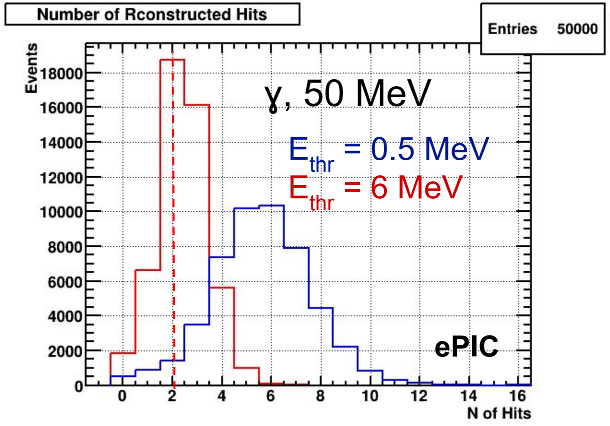
GlueX Pb/ScFi ECal: $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ NIM, A 896 (2018) 24-42

- 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

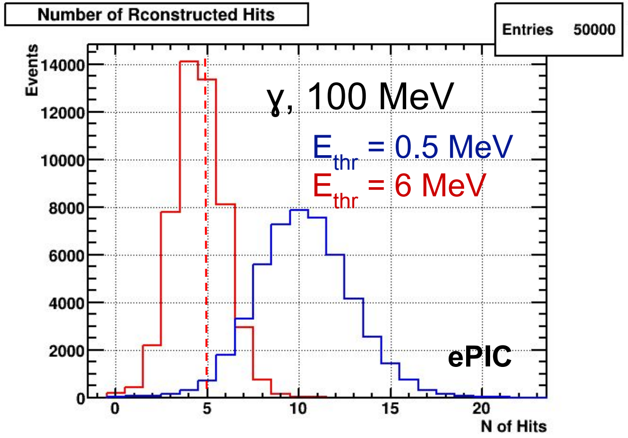
Simulations of **GlueX prototype** in ePIC environment agree with data at E_γ < 0.5 NIM, 596 (2008) 327−337

Low Energy Particles

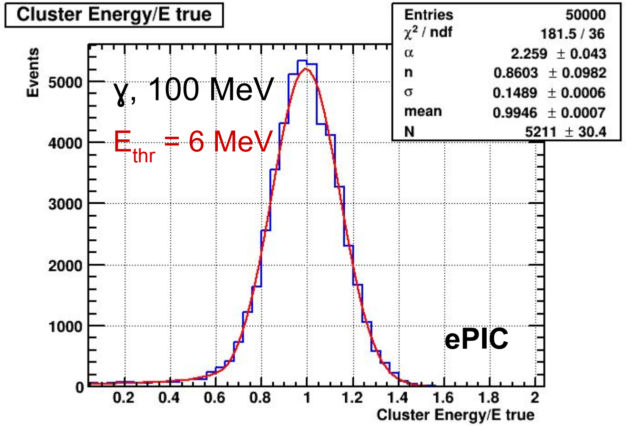
- For electrons: cut out because of the 1.7 T field to reach the calorimeter (p < ~408 MeV)
- For photons shown number of fired readout cells with different thresholds at η = 0



Thresholds corrected for f_{sam}



Blue threshold very low just to illustrate the distribution shape

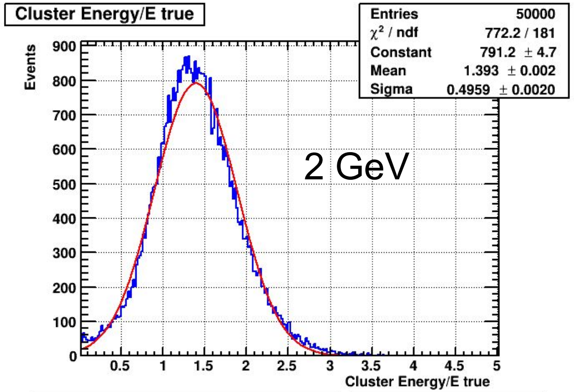


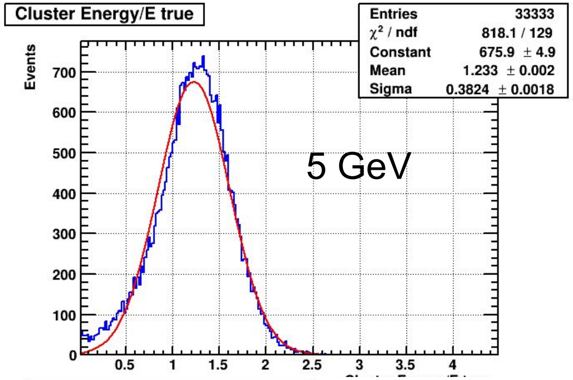
- **From GlueX** studies: cluster/shower threshold is 100 MeV nominal (down to 50 MeV for some analyses, with mostly two cells per event only). Low energy detection threshold studied also with Michel electrons. (NIM, A 896 (2018) 24-42)

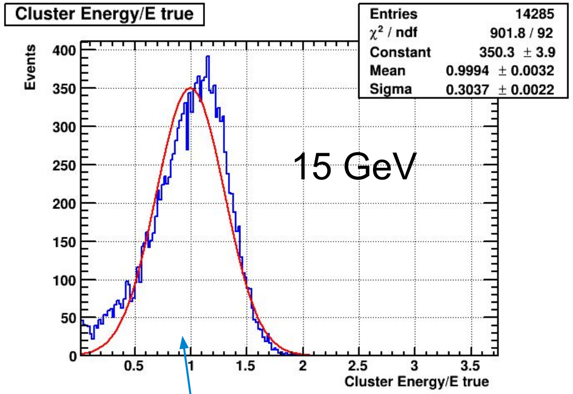
Energy resolution of AstroPix Layers

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

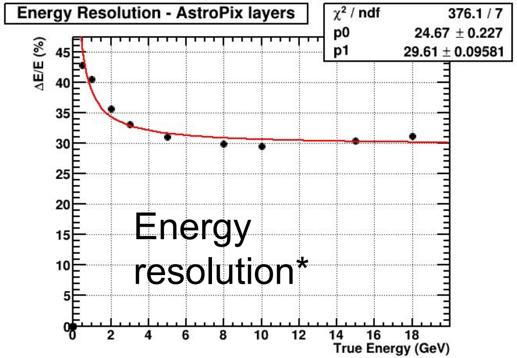
with 6 AstroPix Layers

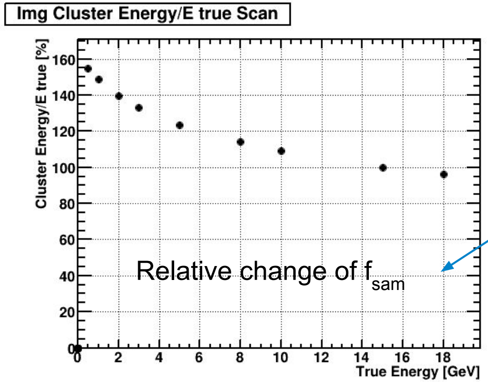






non-gaussian





strong dependence in this geometry

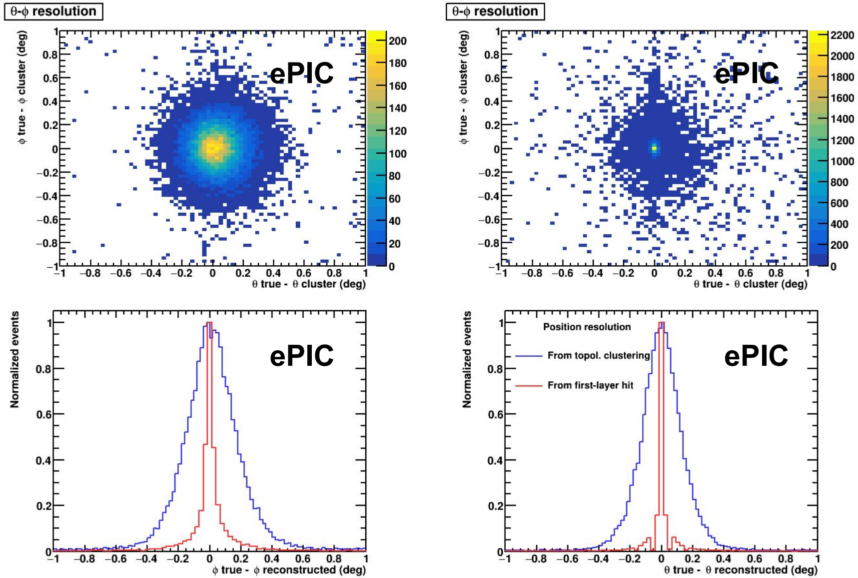
*Assuming perfect calibration (but! huge sampling fraction energy dependence)

Position Resolution

with 6 AstroPix Layers

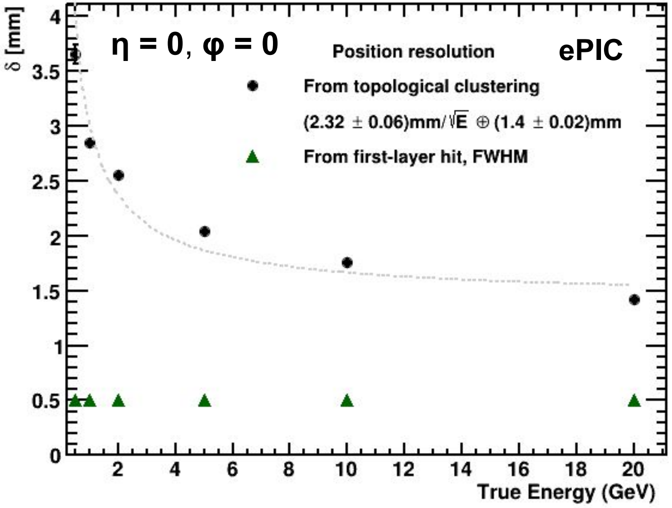
Example of θ - φ resolution for 5 GeV photons

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



Position resolution for photons

Particles thrown perpendicular to the calo surface



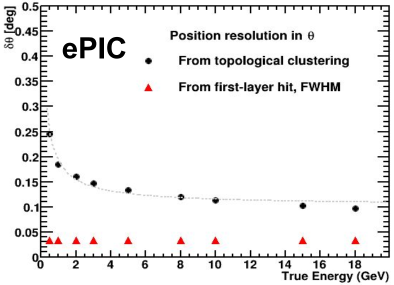
- Clusters from Imaging Si layers reconstructed with 3D topological algorithm
- Cluster level information: $\sigma_{position}$ = (2.32 ± 0.06) mm/√E ⊕ (1.4 ± 0.02) mm at η=0
- First-layer hit information added: $\sigma_{position}$ = **~0.5 mm (pixel size)**

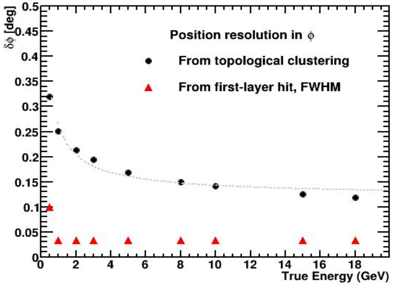
Position resolution studies

with 6 AstroPix Layers

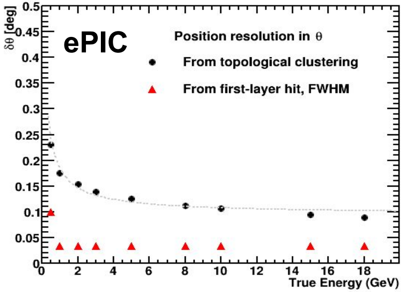
Angular resolution for different η

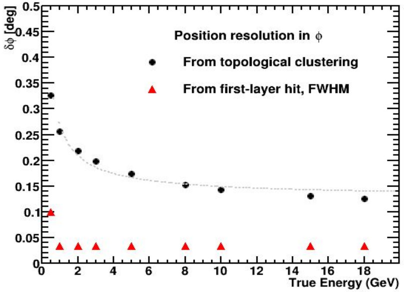
η = 0, φ = (0,2π)



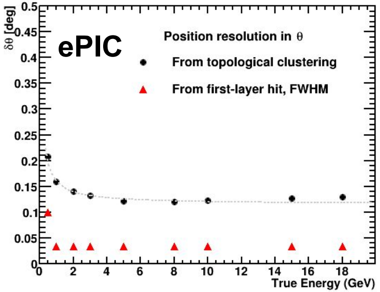


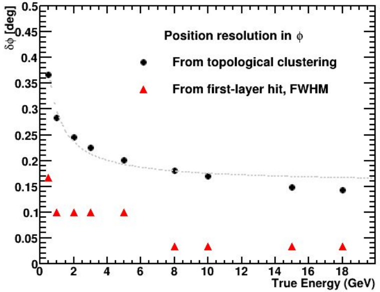
η = 0.5, φ = (0,2π)





η = 1, φ = (0,2π)

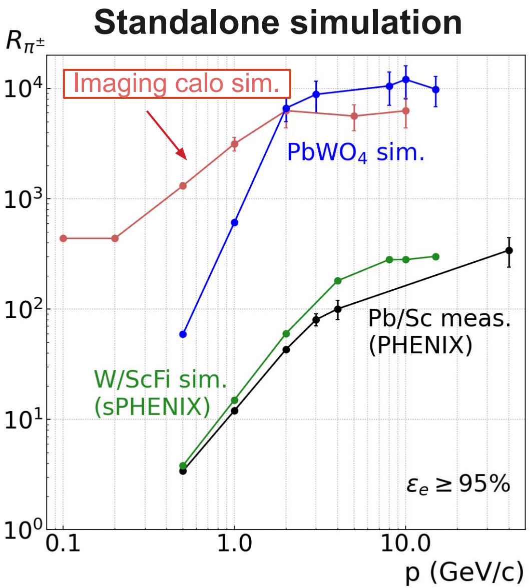


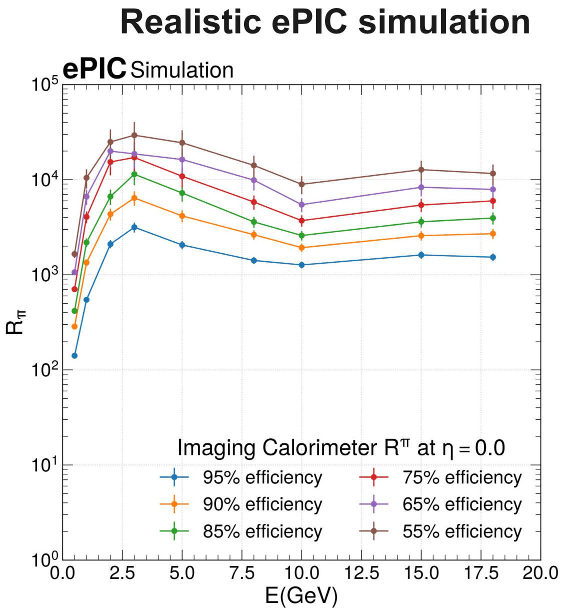


- Small dependence seen with changing η
- Angular resolution in all regions well below 0.1 deg (in majority regions on the level of single pixel resolution)
- Results well below any tower-like calorimetry

Electron Identification

with 6 AstroPix Layers





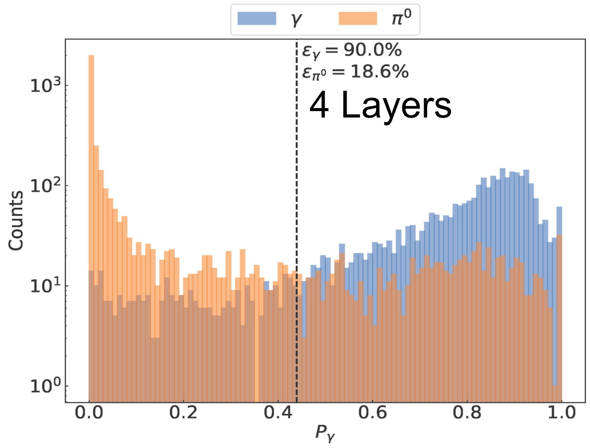
- **Goal:** Separation of electrons from background in Deep Inelastic Scattering (DIS) processes
- Method: **E/p cut (Pb/ScFi) + Neural Network** using 3D position and energy info from imaging layers

- 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

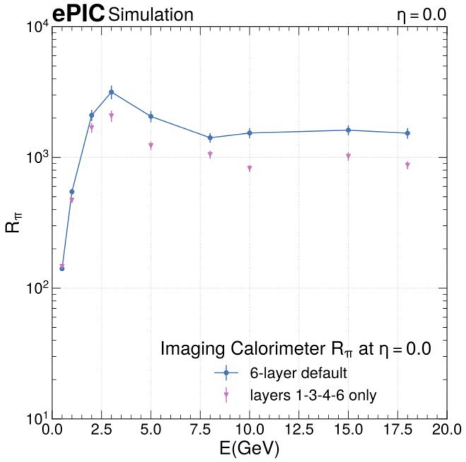


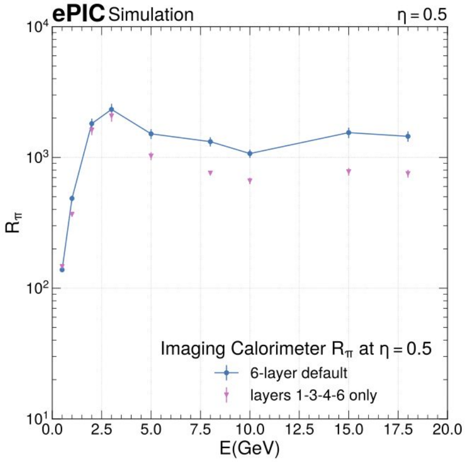
Significant reduction in π^0 rejection at larger energies when reducing the number of layers (where π^0 rejection is the hardest).

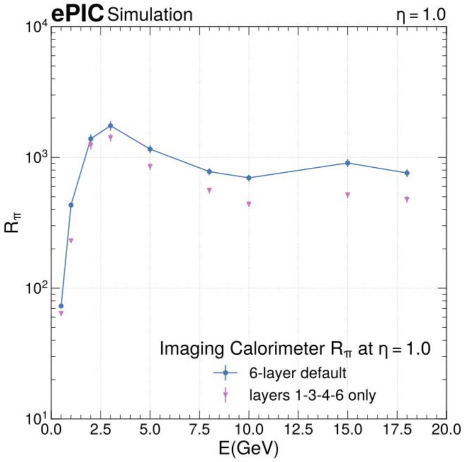
4-layer configuration, sees a reduction in π^0 rejection at high energies by a factor of 2.

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.

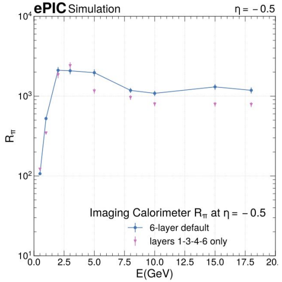
Performance with reduced number of layers
e/π separation at 95% efficiency

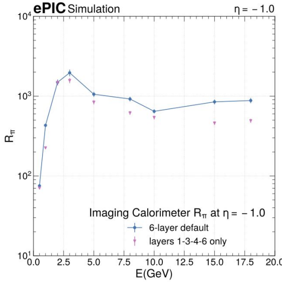






4-layer alternate:
layers 1-3-4-6





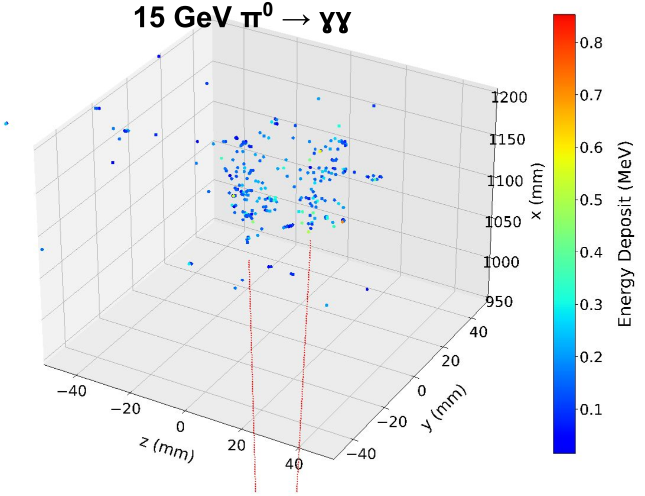
Default configuration exceeds 10^3 pion rejection almost everywhere

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

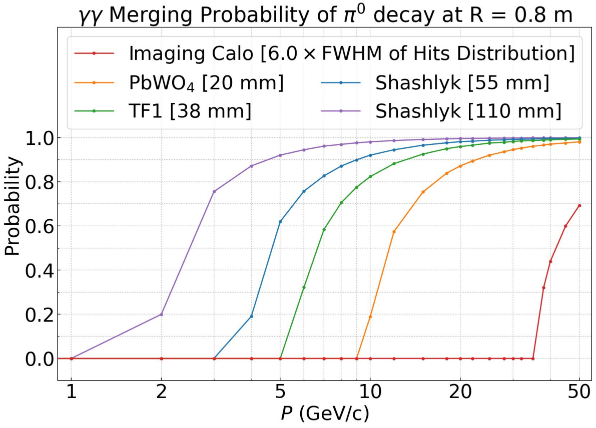
4-layer alternate seems workable compromise.

Neutral Pion Identification

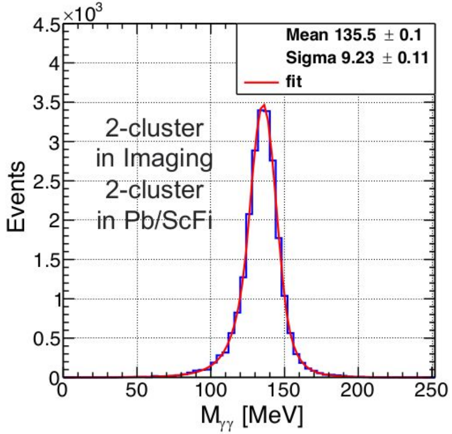
15 GeV $\pi^0 \rightarrow \gamma\gamma$



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