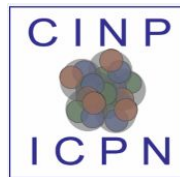


# CAP 2026

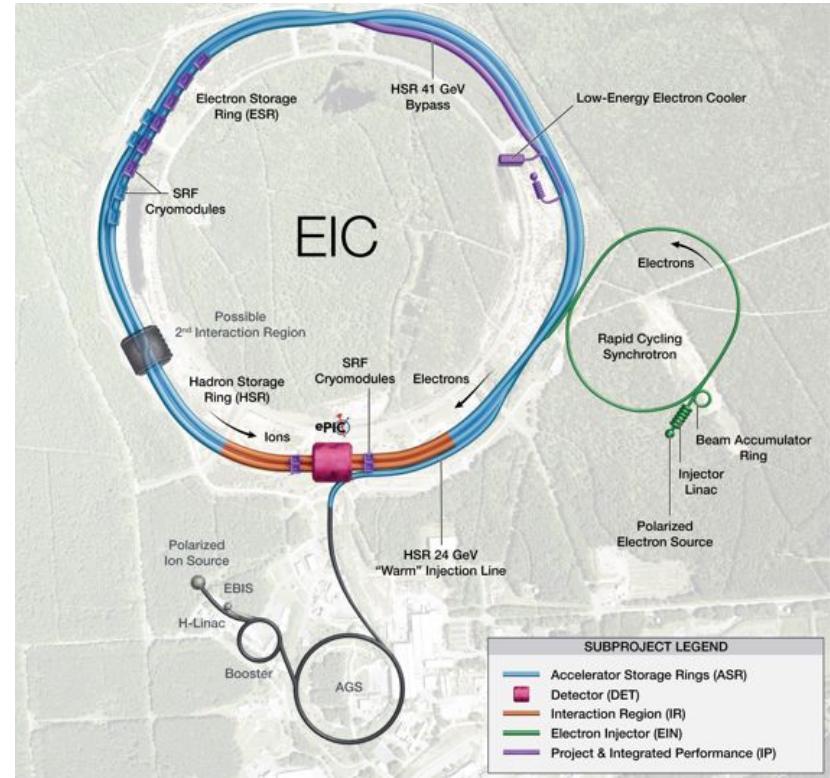
## Scintillating Fiber (ScFi) Testing and Hybrid Cluster Algorithm for the Barrel Imaging Calorimeter (BIC) at the Electron Ion Collider (EIC)

Akshaya Vijay, Dr Wouter Deconinck  
June 23, 2026



# The Electron-Ion Collider (EIC) will be the world's first polarized electron-ion collider to answer fundamental questions about the structure of matter and the strong force.

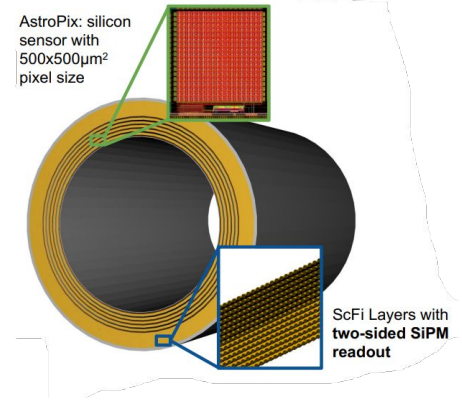
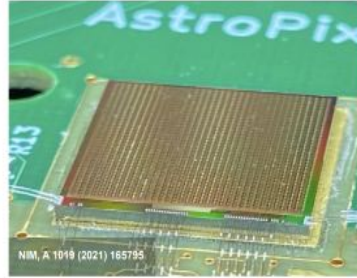
- ❖ Highly polarized electron, proton.
  - center-of-mass energy ( $E_{CM}$ ) range from ~20-100 GeV (140 GeV upgradeable)
  - Ion beams from deuteron to the heavier nuclei
- ❖ High collision luminosity :  $10^{33}$  to  $10^{34}$   $\text{cm}^{-2} \text{sec}^{-1}$ .
- ❖ More than one interaction region



EIC layout

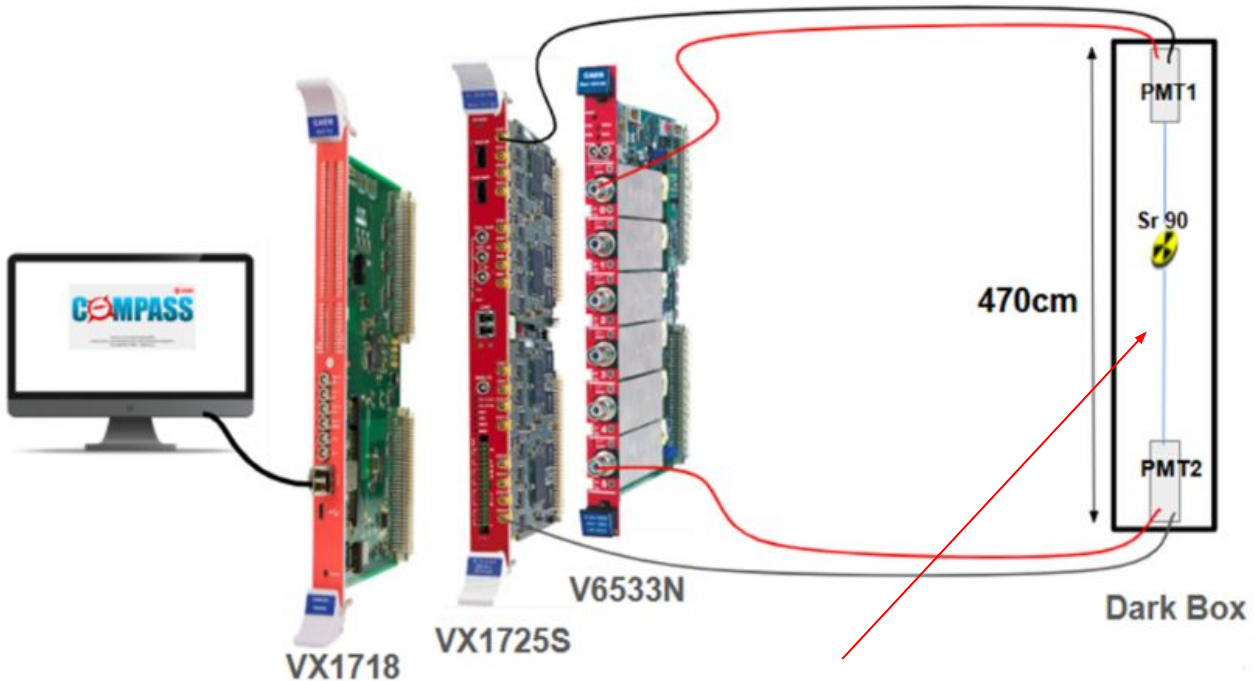
# BARREL IMAGING CALORIMETER (BIC)

EIC will use the hybrid EM calorimeter by combining the Pb/ScFi technology used in the GlueX calorimeter and the AstroPix sensors developed for NASA's Amegoo-X Mission.



Longitudinal shower information from the ScFi system and fine spatial imaging from AstroPix measures **3D image of electromagnetic showers!**

# FIBER TESTING WITH PMTs : Setup to measure the attenuation length of ScFi



VX1718

VX1725S

V6533N

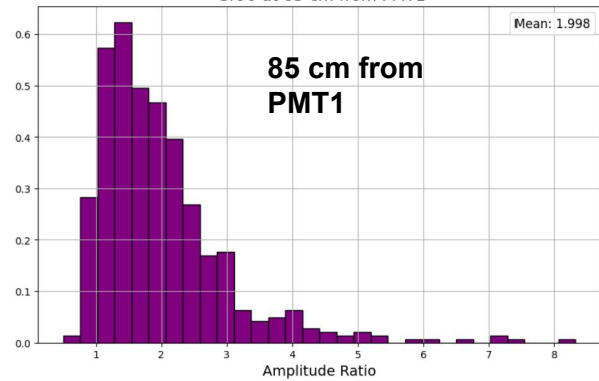
Dark Box

470cm

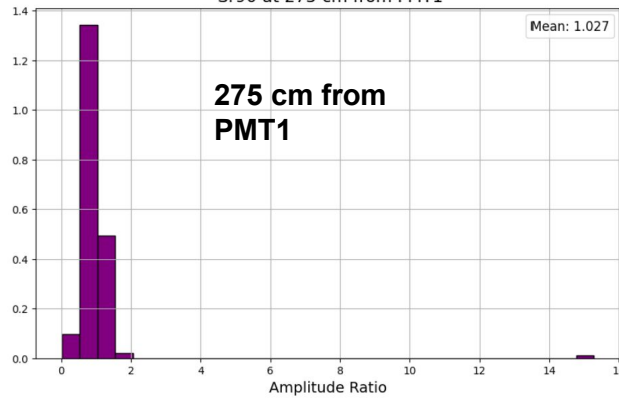
### KURARAY SCINTILLATING FIBER:

- Type : SCSF - 78 MJ
- Multi Clad
- Length: 4.1m
- Size: 1.0mm Dia

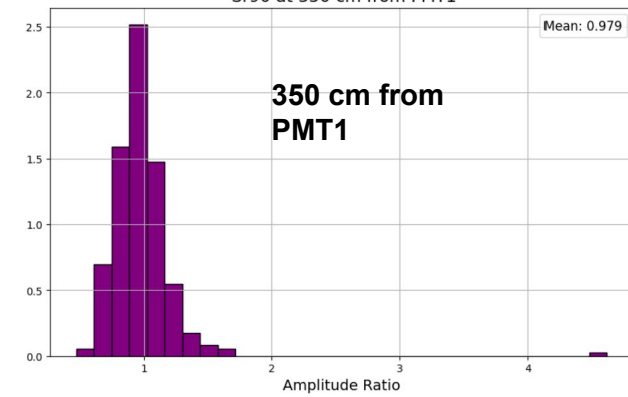
Histogram of Amplitude Ratio (PMT1/PMT2)  
Sr90 at 85 cm from PMT1



Histogram of Amplitude Ratio (PMT1/PMT2)  
Sr90 at 275 cm from PMT1



Histogram of Amplitude Ratio (PMT1/PMT2)  
Sr90 at 350 cm from PMT1



$I_1$  and  $I_2$  are the intensity corresponding to PMT1 and PMT2 respectively.

$$I = I_1 / I_2 = \exp(-2x) / \lambda$$

$$I' = (I_1' / I_2') = \exp(-2x') / \lambda$$

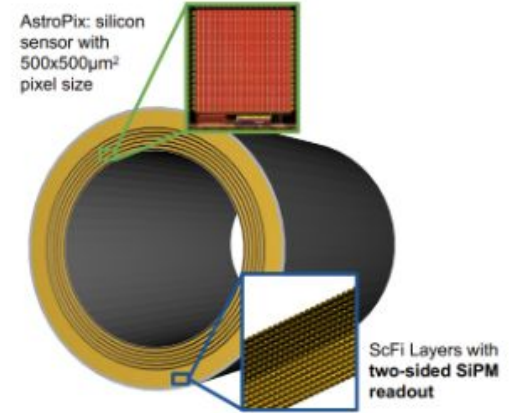
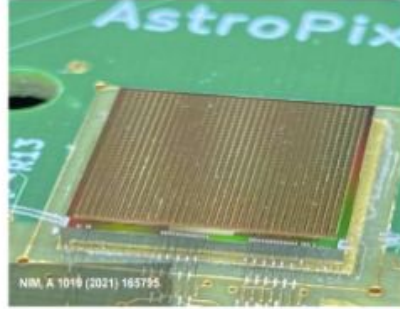
$$(I / I') = \exp(-2(x - x')) / \lambda$$

$$\ln(I / I') = -2(x - x') / \lambda$$

Source position from PMT1	Amplitude ratio
85 cm	1.998
275 cm	1.02
350 cm	0.979

$(x - x')$ cm	$\ln(I / I')$	$\lambda$ (cm)
85-350 = -265	$\ln(1.998/0.979) = 0.713$	743.338

Measured attenuation length is in agreement with the value reported by Kuraray



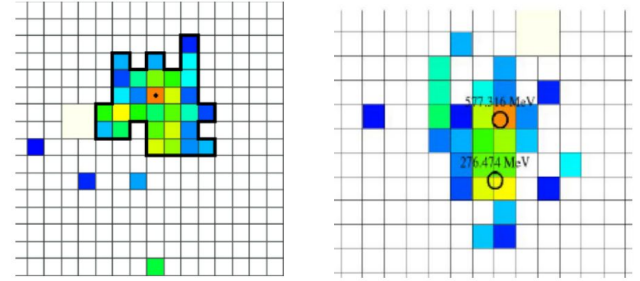
1. Fiber Testing ✓
2. Clustering Methods :
  - i. ScFi system : Island Clustering Algorithm
  - ii. Imaging system : Topological Clustering Algorithm

# ScFi Hits : Island Clustering Algorithm

1. Identify the seed hit : (hits with energy above threshold)
2. Breadth-First Search (BFS) Grouping : Connects adjacent hits meeting a distance threshold
3. Find Local Maxima - Identifies energy peaks within each group:

-If one maximum found: All hits form a single cluster

-If multiple maxima found: splits clusters in the spatial distributions of energy



Plots by Chao Peng (ANL)

**Island Clustering is 2D Clustering : Thus cannot be used for Imaging layers of BIC**

# Imaging Hits : Topological Clustering Algorithm

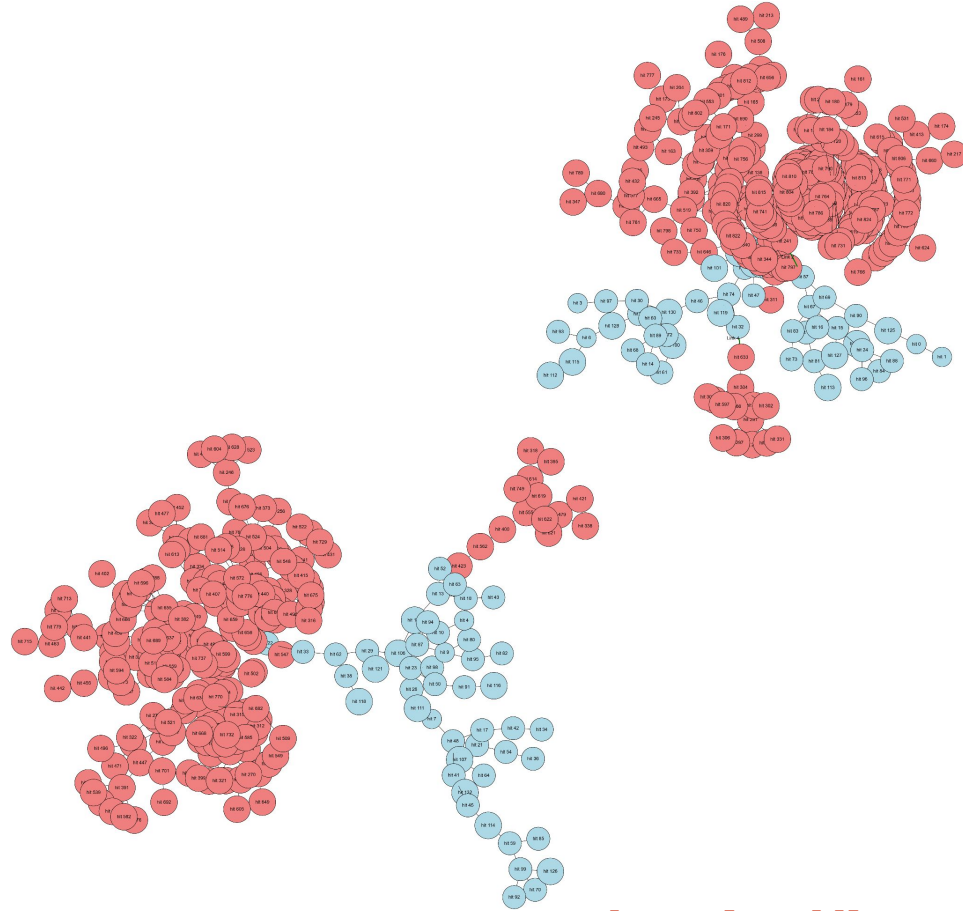
1. Starts with seed hit
2. Breadth-First Search (BFS) - Expands outward, adding neighboring hits to the cluster.
3. Neighbor criteria depend on the layer configuration:
  - Same layer Mode
  - Different layer Mode (within neighbour Layers Range)
  - Different sectors

# Hybrid Clustering For BIC

- ❖ **Topological clustering:**
  - **On Imaging Hits**
  - **On Scfi Hits**
- ❖ **Cross System Clustering**

# Cross-System Clustering

- Start from an Imaging cluster
- Search for neighboring ScFi clusters
- If a neighbour is found → combines Imaging and ScFi clusters
- Check whether other Imaging clusters connect to the same ScFi cluster
- Repeat the neighbour checks for all Imaging clusters
- Keep unused clusters unchanged



Imaging Hits  
ScFi Hits

This is just for demonstration and are not real detector hits and clusters

Optimizing the Hybrid clustering : based on simulation of 2 Photon at different opening angles and with energy of 500 MeV.

Penalty score :

**Cluster Count** :  $P_{\text{count}} = |N_{\text{clusters}} - N_{\text{true}}|$

**Cluster Energy** :  $P_{\text{energy}} = \frac{1}{N} \sum_{i=1}^N \frac{|E_{\text{cluster}} - E_{\text{true}}|}{E_{\text{true}}}$

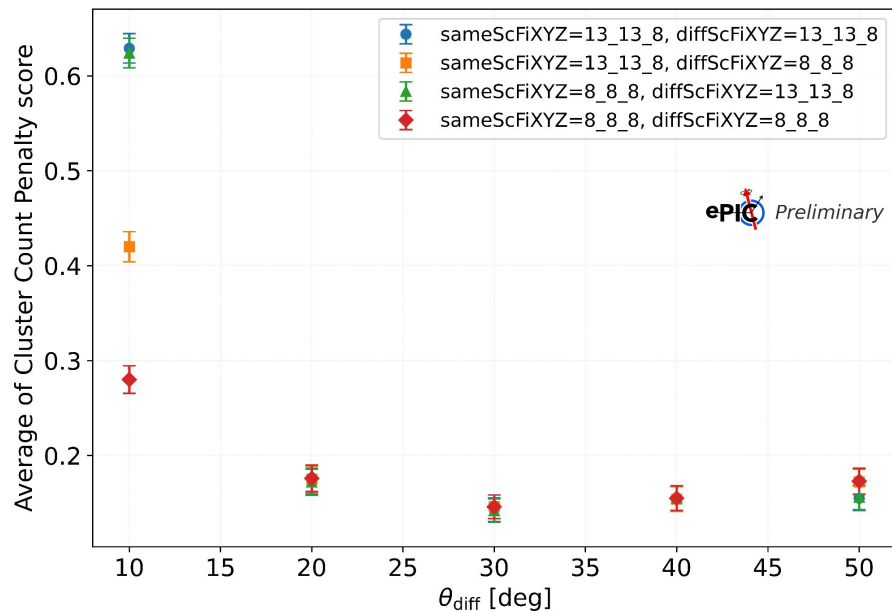
Distance parameters are optimized by minimizing the penalty score; lower values indicate better clustering performance.

For now only the parameters used for Topological clustering on ScFi hits at the initial stage of Hybrid Clustering are optimized. They are:

- 1) ScFisameLayerXYZ
- 2) ScFidiffLayerXYZ

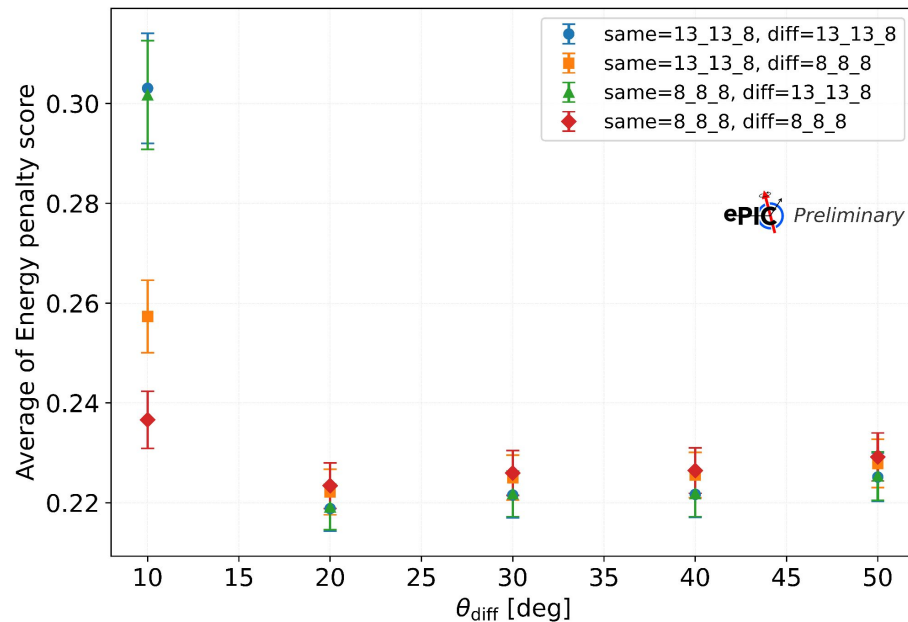
# Hybrid Clustering (2 photons of 500 MeV)

Cluster size penalty comparison for different distance parameters



$$P_{\text{count}} = |N_{\text{clusters}} - N_{\text{true}}|$$

Cluster energy penalty comparison for different distance parameters

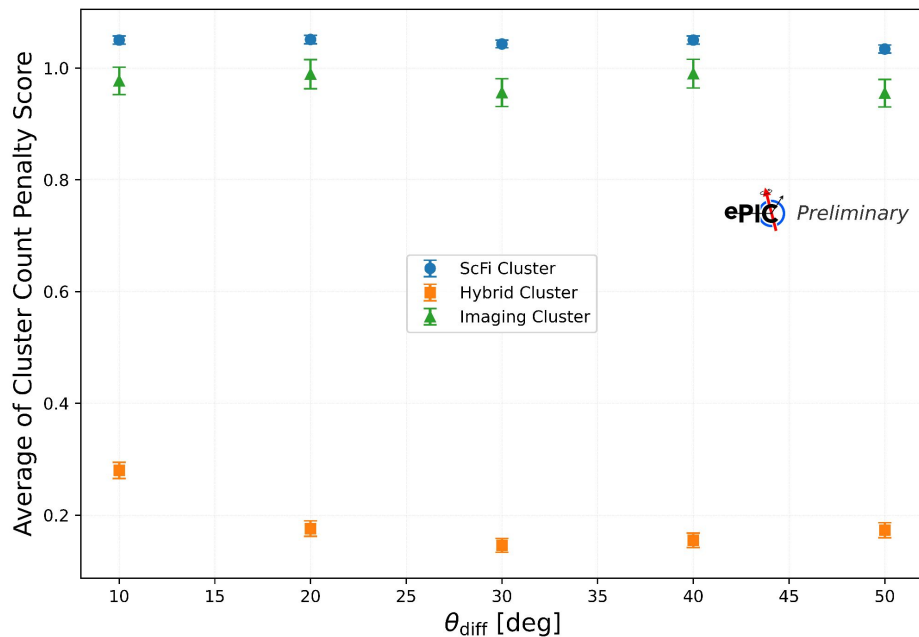


$$P_{\text{energy}} = \frac{1}{N} \sum_{i=1}^N \frac{|E_{\text{cluster}} - E_{\text{true}}|}{E_{\text{true}}}$$

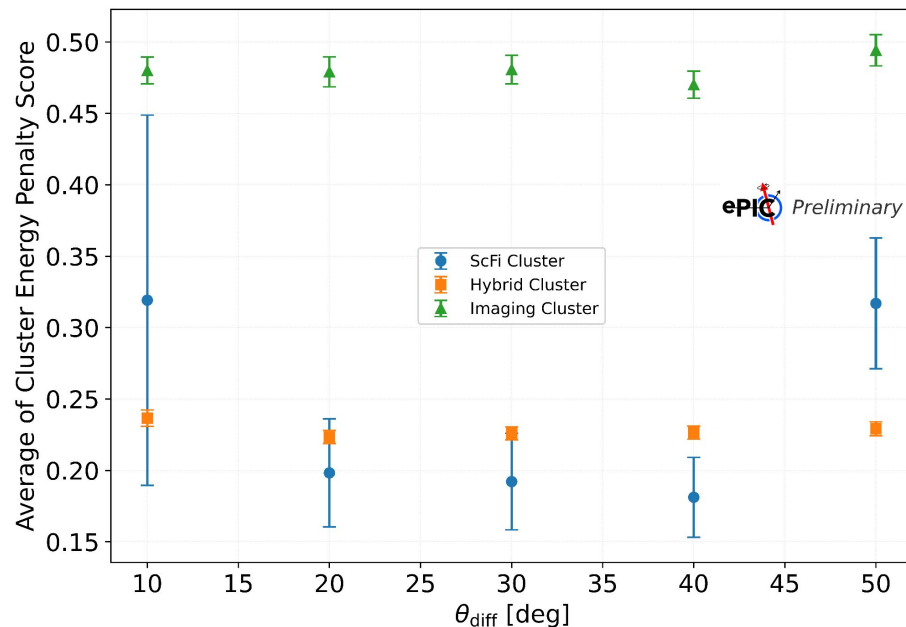
Distance parameter with low penalty is the best choice

# Comparing the 3 Clustering Algorithms

Comparison of clustering methods



Comparison of clustering methods



Lower penalty  $\rightarrow$  better clustering

# Summary :

- BIC have a hybrid concept with Pb/ScFi and AstroPix sensors.
- Initial bench tests with ScFi : attenuation length of Kuraray ScFi ~ 743 cm
- Currently the hybrid nature of the BIC uses two different clustering algorithm for each subsystem : Island Clustering, Imaging Topo Clustering.
- Developed a single clustering method for both subsystems at BIC : Hybrid Clustering Algorithm.
- Hybrid Clustering shows a low penalty score for both cluster count and cluster energy indicating a better performance than separate clustering method.

## Future Goal :

Study the physics-performance by applying the hybrid clustering algorithm to neutral pion reconstruction and evaluating how it improves photon separation, merging probability etc

Thank You

**EIC Canada is now open for collaboration!**

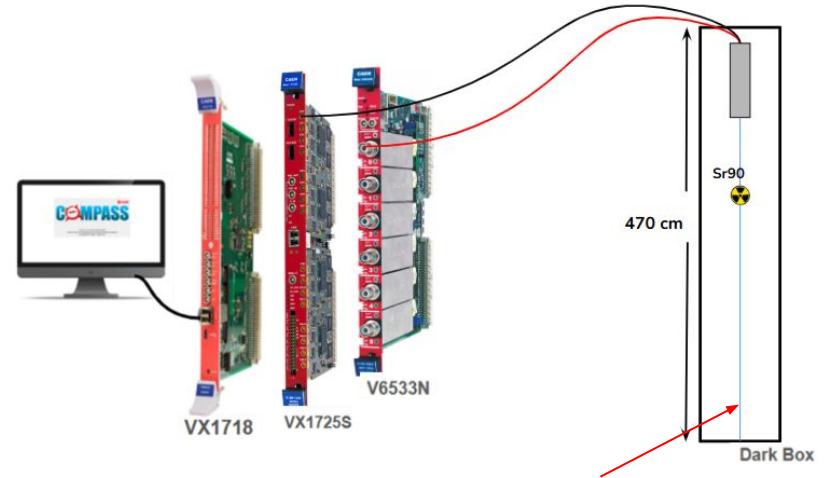
**Back Up**

# FIBER TESTING WITH PMTs : SETUP



Openable cap to get access to the fiber. 2 such caps along the length (4.7m) and at both ends of the dark box to access the PMTs and fiber .

Figure3: Dark box made of ABS Pipe.

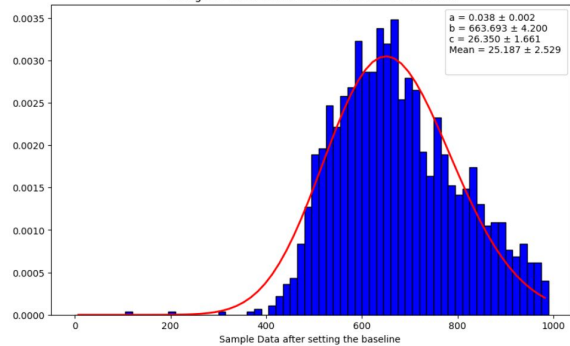


## KURARAY SCINTILLATING FIBER:

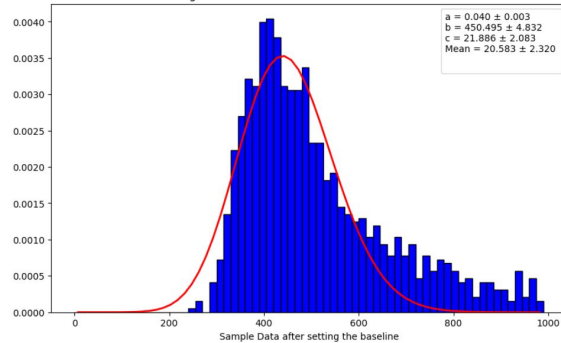
Type : SCSF - 78 MJ  
Multi Clad  
Length: 4.1m  
Size: 1.0mm Dia

# TEST Result with 1 MBq Sr90

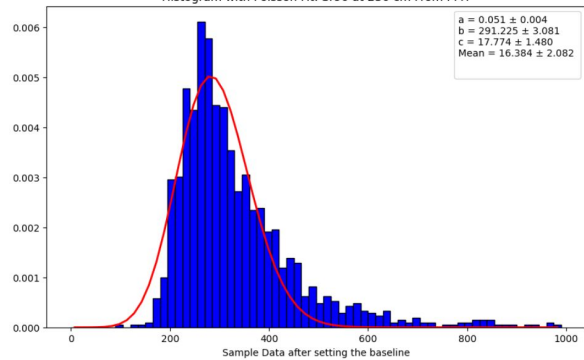
Histogram with Poisson Fit: Sr90 at 25 cm From PMT



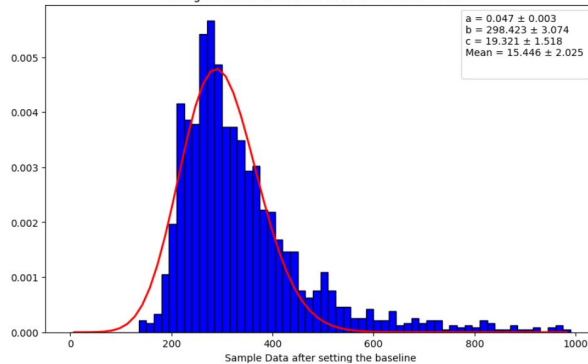
Histogram with Poisson Fit: Sr90 at 210 cm From PMT



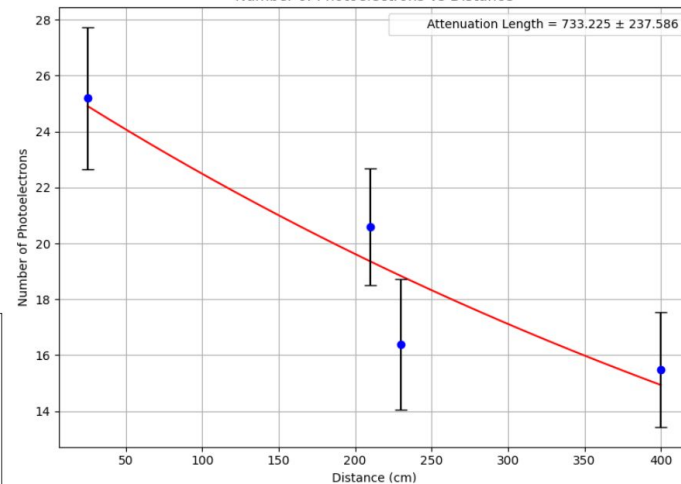
Histogram with Poisson Fit: Sr90 at 230 cm From PMT

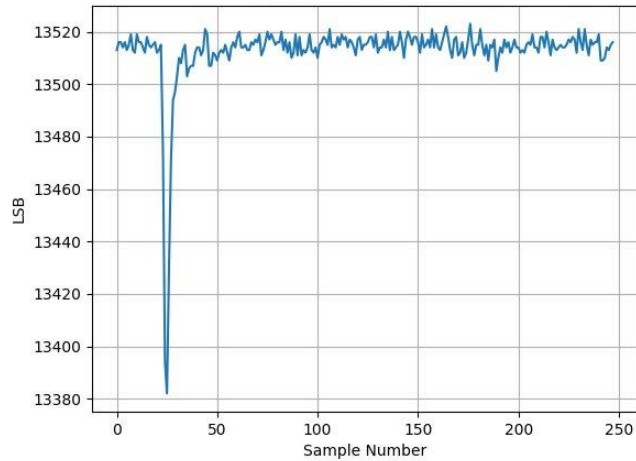


Histogram with Poisson Fit: Sr90 at 400 cm From PMT



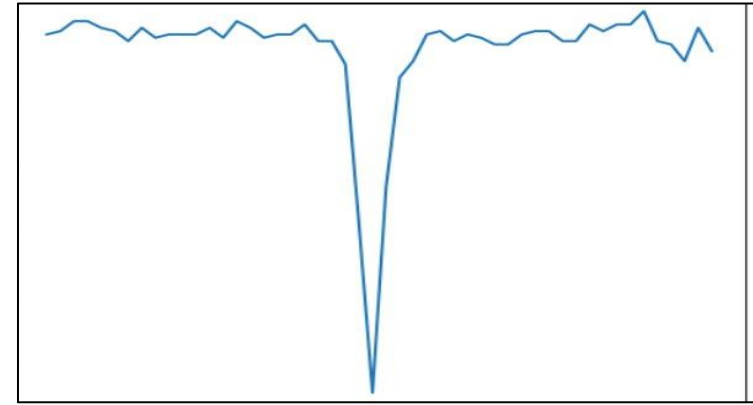
Number of Photoelectrons vs Distance





Signal shape from the data

Set the mean of the initial samples (before the signal) as a threshold and then subtracted this mean value from the samples to set a clear baseline to the sample data.



Signal shape After Correcting the Baseline

Mean of the poisson fit of the data gives the number of photoelectrons

**Poisson Distribution :**

$$P = a * (b/c)^{(x/c)} * \exp\left(-\frac{b}{c}\right) * \frac{1}{\Gamma\left(\frac{x}{c} + 1\right)}$$

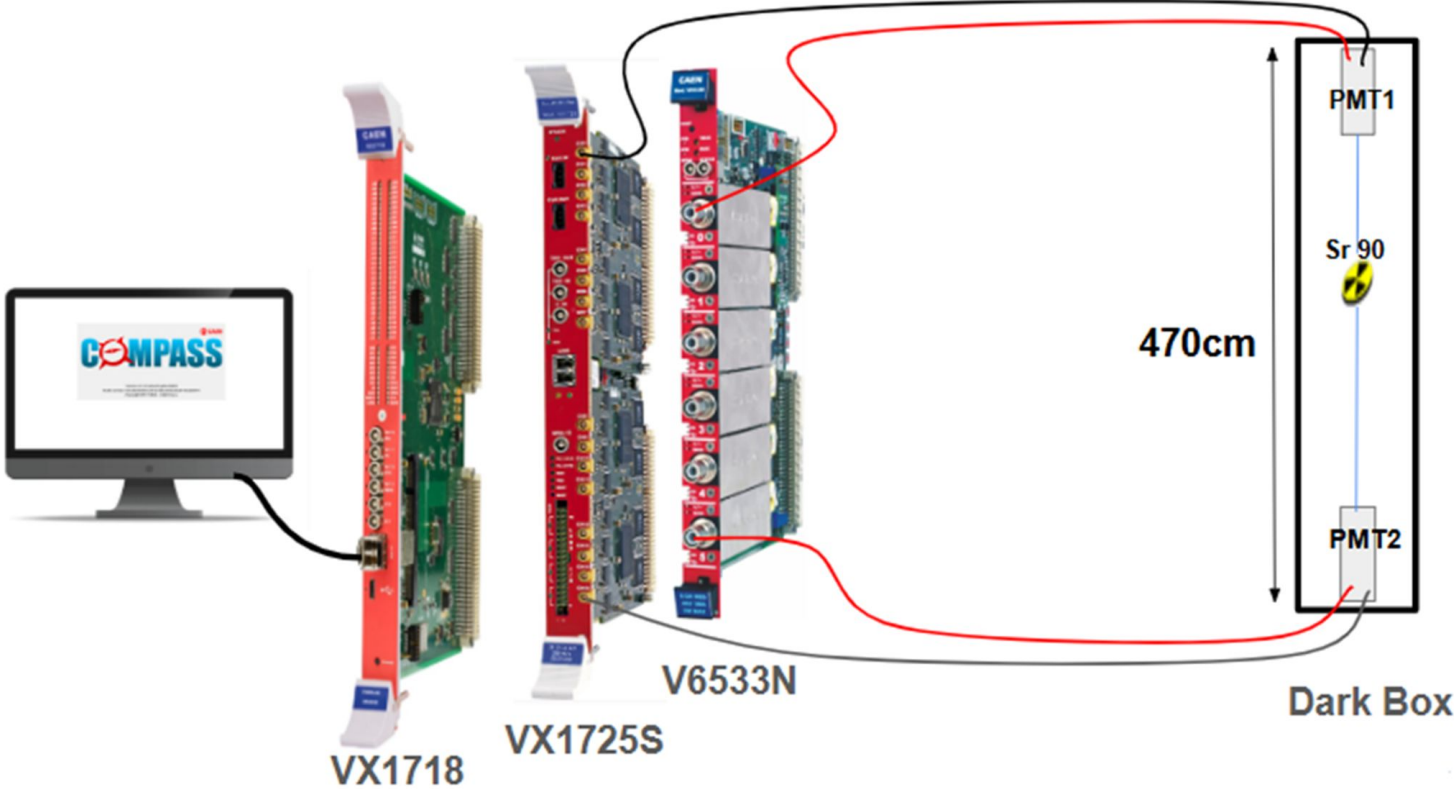
**a = Normalizing parameter**

**(b/c) = mean** [ comparing with :  $P(n; \lambda) = (\lambda^n e^{-\lambda}) / n!$  ]

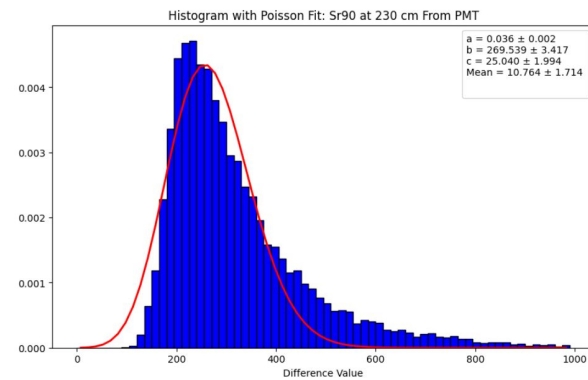
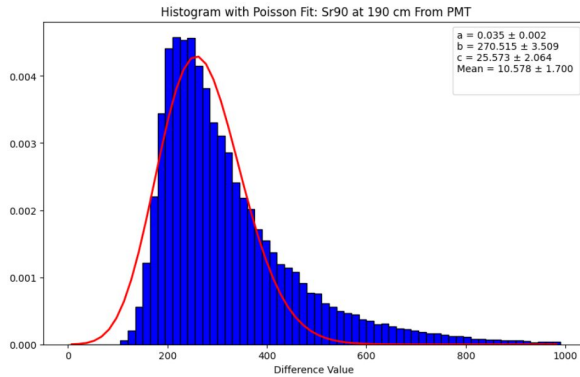
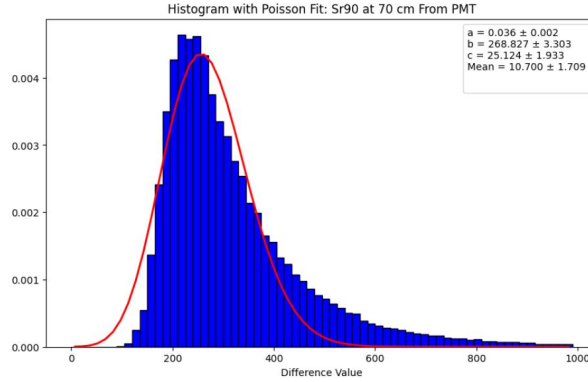
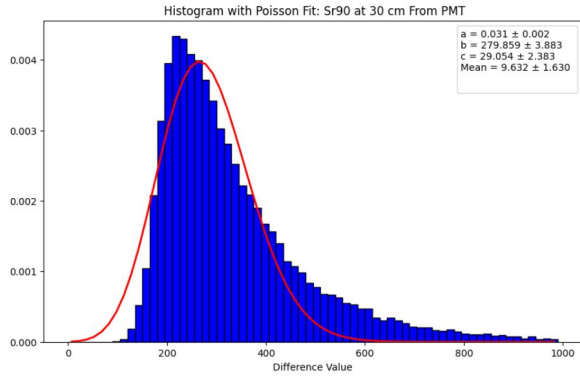
**(x/c) = n**

**$\Gamma\left(\frac{x}{c} + 1\right)$  = factorial (x/c)**

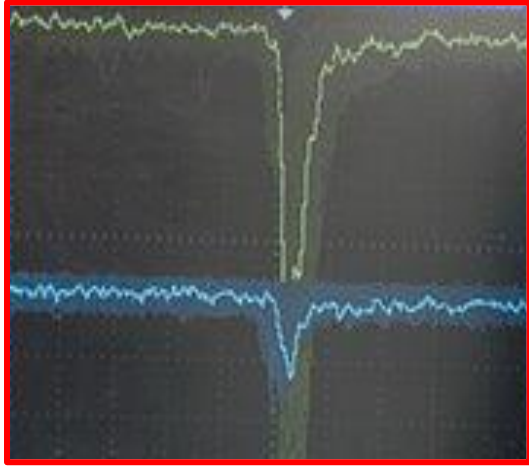
# Coincidence Test Setup



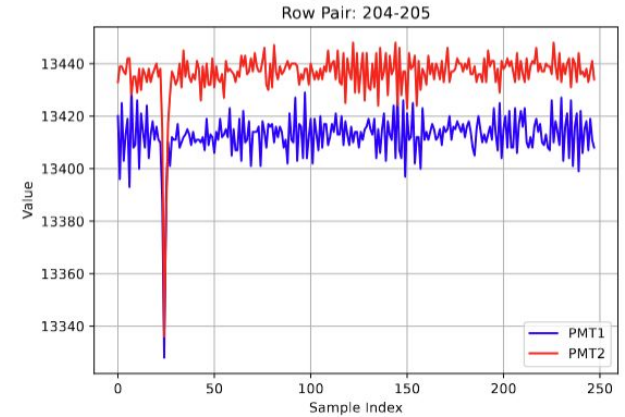
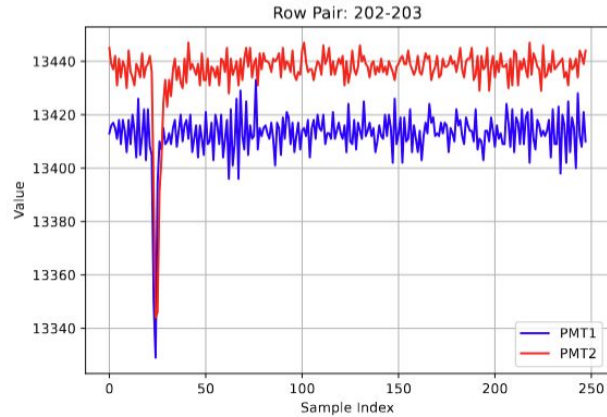
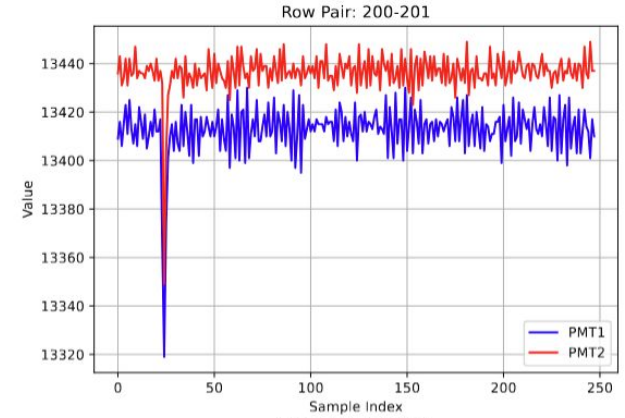
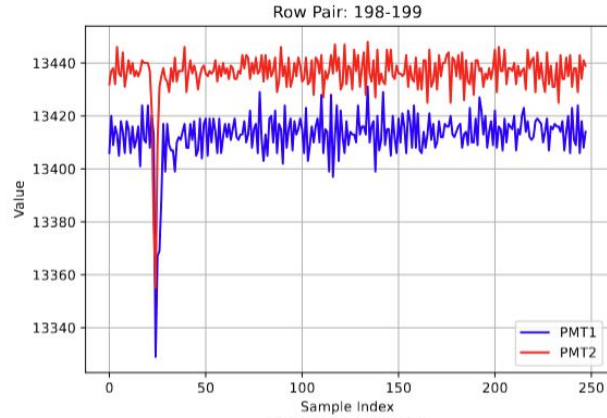
# TEST Result with 0.01 $\mu$ Ci Sr90 (0.00037 MBq)



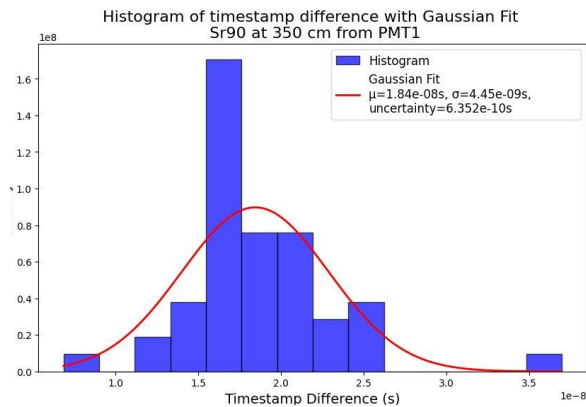
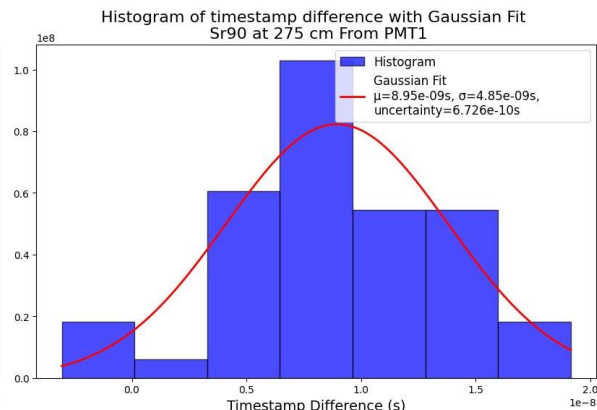
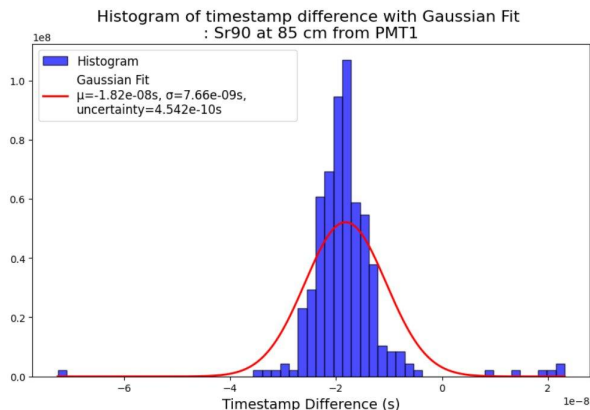
Distance From the PMT	Mean Value From the Fit	Uncertainty
30	9.632	1.630
70	10.7	1.709
190	10.578	1.7
230	10.764	1.714



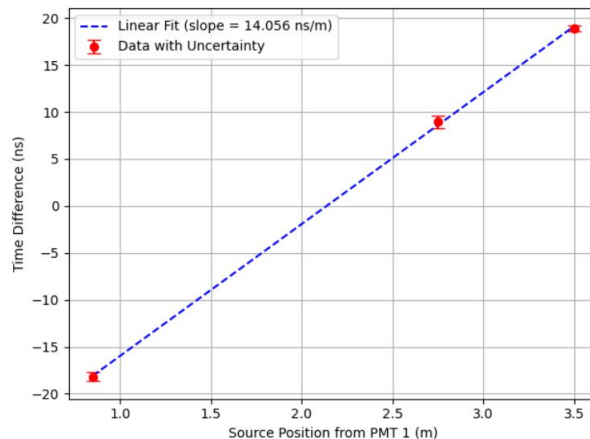
Coincidence Signal in the Oscilloscope.



Coincidence Signal plotted from the collected data



Position of Sr90	Mean Time difference	uncertainty
85 cm	-18.2 ns	0.4542 ns
275 cm	8.95 ns	0.6726 ns
350 cm	18.95 ns	0.2633 ns



Speed of signal in ScFi :

$$c/n = (3 \times 10^8) / 1.59 \text{ m/s} = 0.1886 \text{ m/ns}$$

From plot :  $0.1423 \text{ m/ns} \approx c/n$

where  $c$  is the speed of light in vacuum and  $n$  is the refractive index of SciFi

# Barrel Imaging Calorimeter



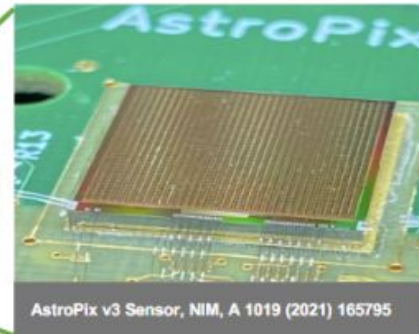
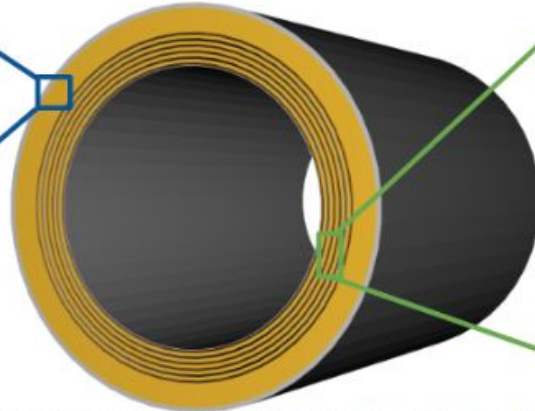
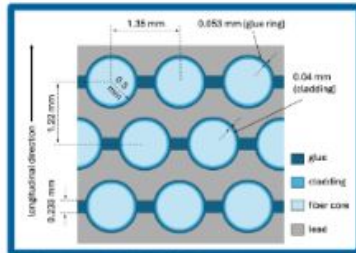
Combination of a high-performance sampling calorimeter with silicon sensors for EM shower profiling

**Pb/SciFi sampling calorimeter** with two-sided SiPM readout

Mature technology based on the GlueX/KLOE barrel calorimeters, with demonstrated detector performance

→ Energy resolution at GlueX:  $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$  [\[NIMA 896 \(2018\) 24\]](#)

→ 1.1cm/ $\sqrt{E}$  position resolution in z-direction [\[NIMA 596 \(2008\) 327\]](#)



Imaging layers with **AstroPix** MAPS (Monolithic Active Pixel Sensor) in the first half of the calorimeter to capture a **3D image of the developing shower**

→ Developed for NASA AMEGO-X space mission [arXiv:2109.13409](#)

→ 500  $\mu\text{m}$  pixel pitch ( $\sim 144 \mu\text{m}$  intrinsic position resolution in z-direction)

→ Good energy resolution (10% at 112 keV) and low power consumption

# Hybrid Clustering For BIC

## ❖ **Topological clustering:**

### ➤ **On Imaging Hits:**

- `Img_sameLayermode - tz`
- `Img_diffLayermode - etaphi`
- `Img_sectorDist`

### ➤ **On Scfi Hits:**

- `ScFi_sameLayermode - XYZ`
- `ScFi_diffLayermode - XYZ`
- `ScFi_sectorDist`

## ❖ **Cross System Clustering:**

- `cross_system_DistXYZ`
- `cross_system_sectorDist`