EicC中的电磁量能器

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On behalf of EicC ECal group

超级陶粲装置研讨会
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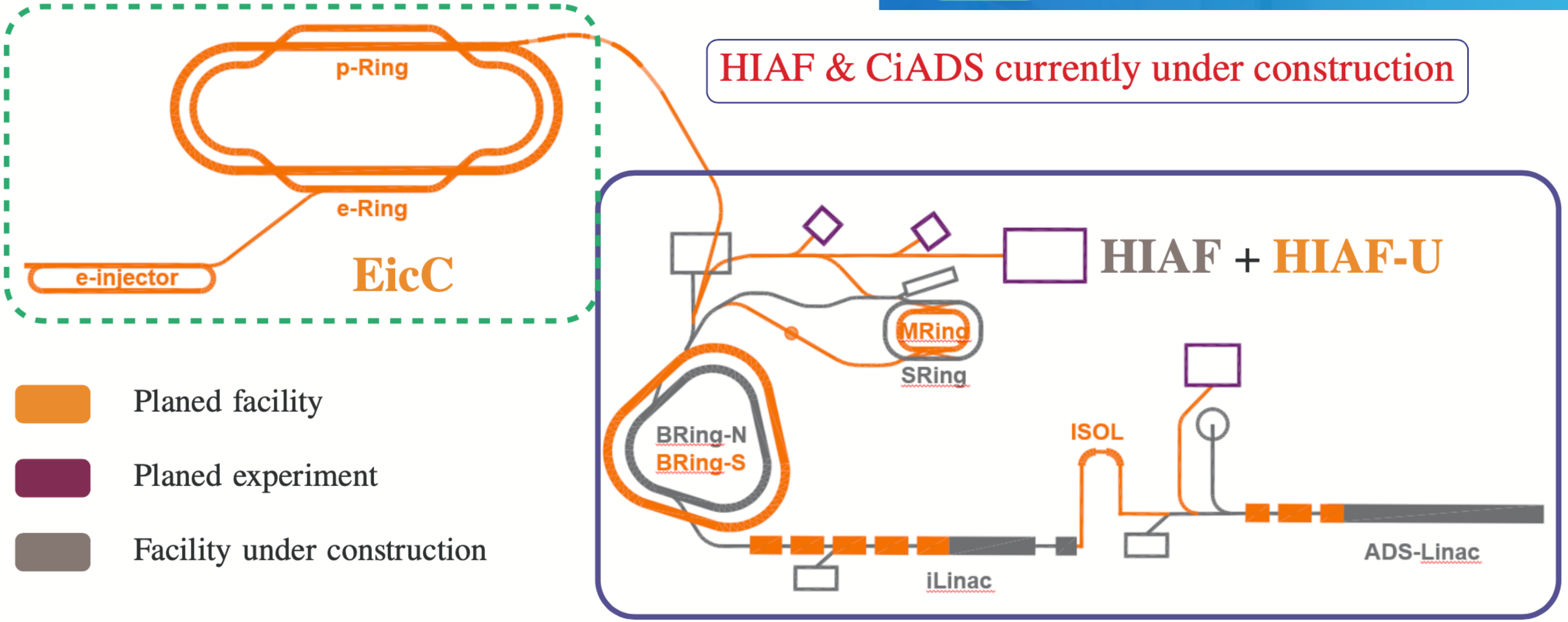
Outline

- ❖EicC 介绍和电磁量能器需求
- ❖Shashlik和碘化铯模块的设计和阵列模拟
- ❖整体量能器的模拟
- ❖Shashlik和碘化铯的硬件测试工作
- ❖总结和展望

EicC and HIAF introduction

中国极化电子-离子对撞机
Polarized electron ion collider in China



HIAF: High Intensity heavy-ion Accelerator Facility in Huizhou, Guangdong

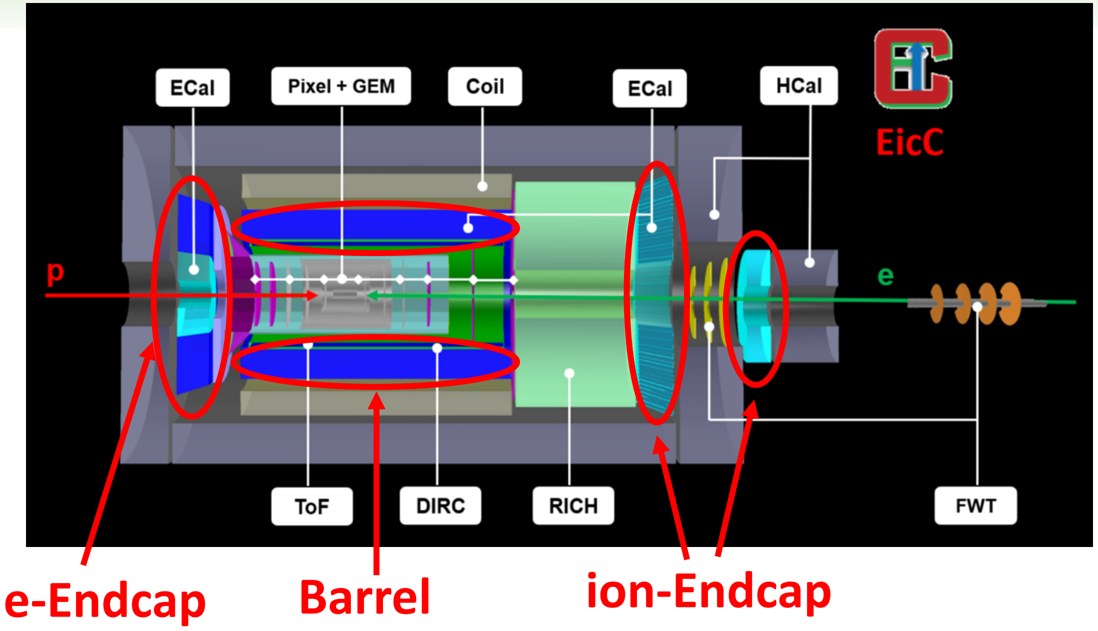
EicC is based on HIAF

- Electron: 3.5 GeV, polarization ~ 80%
- Ion: p, d, $_{3}He^{++}$, $_{7}Li^{3+}$, $_{12}C^{6+}$, $_{40}Ca^{20+}$, $_{197}Au^{79+}$, $_{208}Pb^{82+}$, $_{238}U^{92+}$

Main: 3.5 GeV e +20 GeV p, 2.0 x10^{33} $cm^{-2}\cdot s^{-1}$

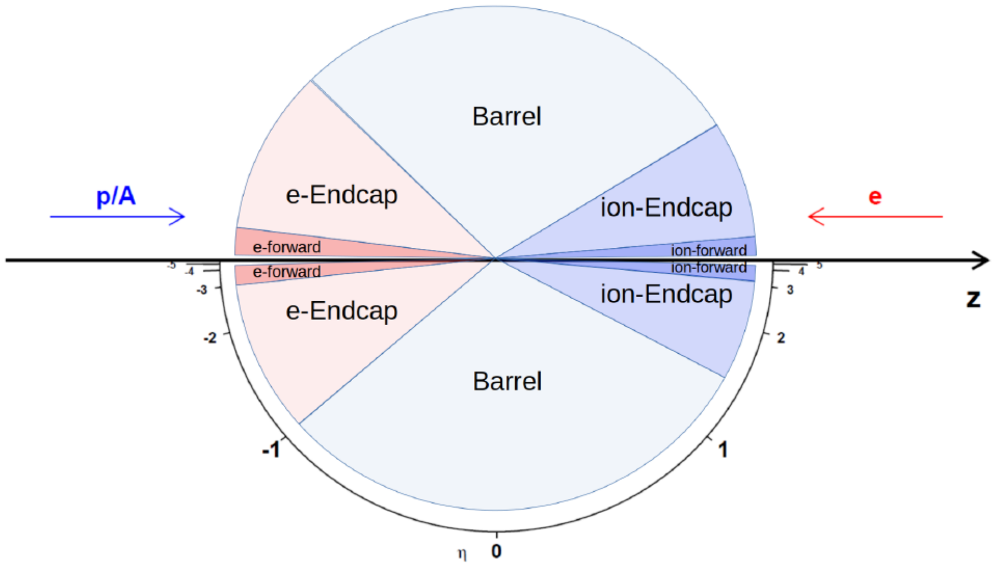
ECal Design for EicC

- Essential requirement
  - Scattered e- measurement
  - e-/π- separation
  - γ measurement (π^0 decay & DVCS)
- Detailed requirement
  - Large solid angle[-3, 3] and energy dynamic range
  - Energy and angle resolution
  - π^0 reconstruction
  - γ/n separation



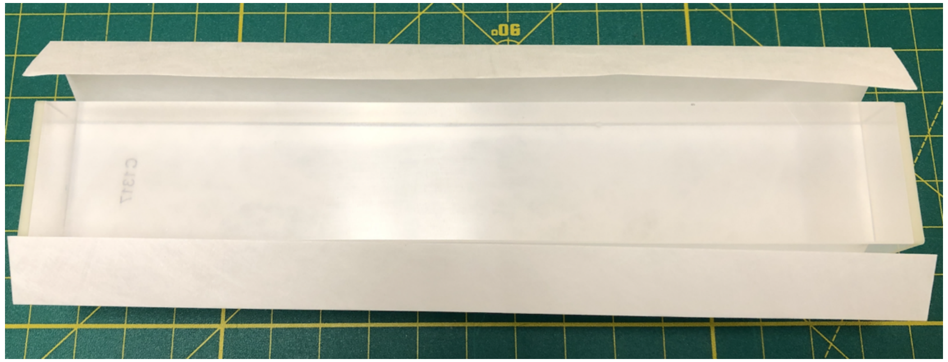
Requirement for different locations:

- **E-endcap:** good energy resolution
- **Barrel:** short radius(90cm), good angle resolution
- **Ion-endcap:** angle resolution, π^0 reconstruction, PID. Need additional small angle detector.

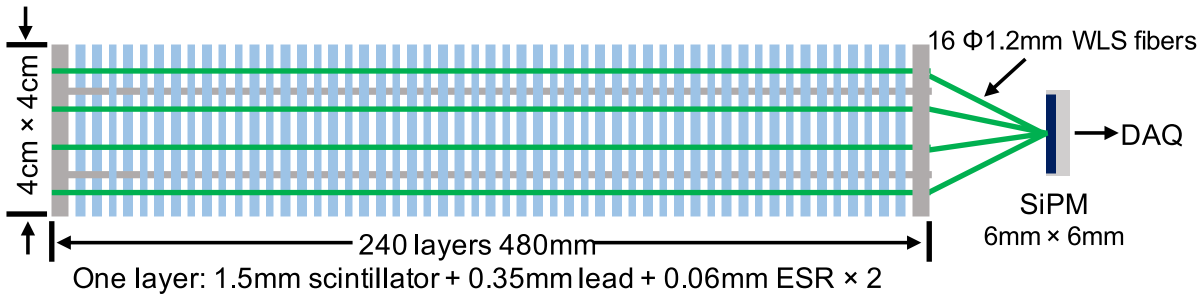


ECal module design and simulation

pCsI Crystal



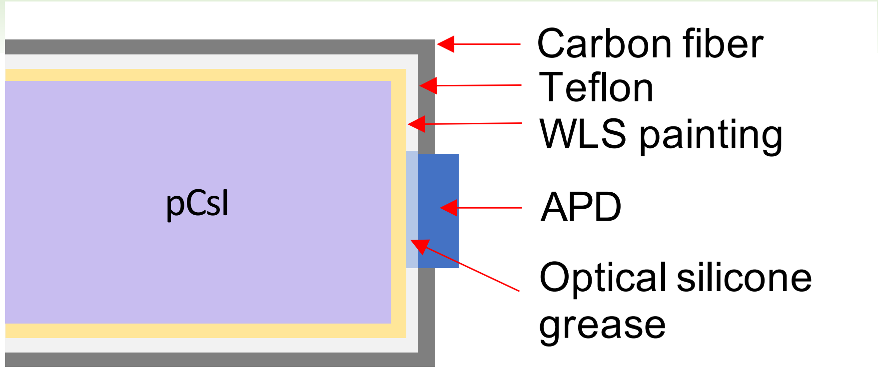
EicC Shashlik ECal

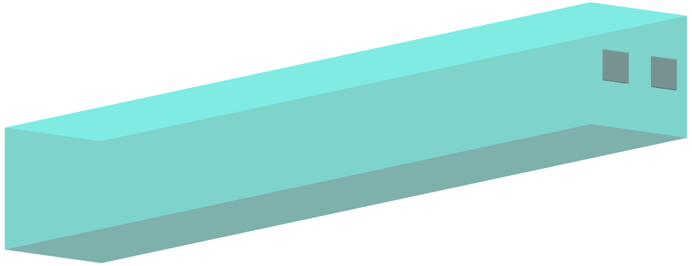


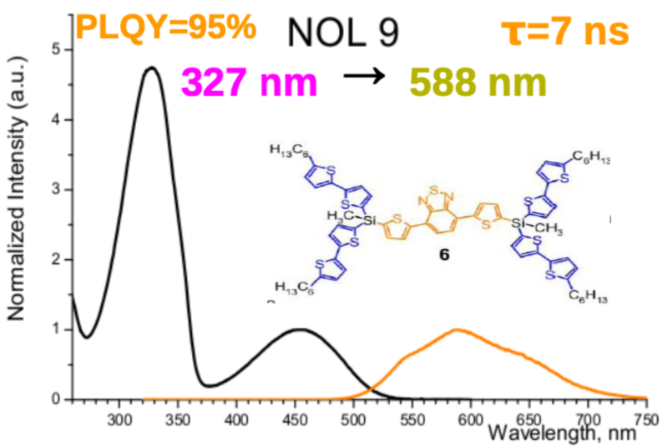
pCsI Module Design

- Preferred to use **pCsI**
- **Module size**: 4 x 4 x 30 cm (16X_0)
- **pCsI manufacturer**: SICCAS(硅酸盐所)、Hamamatsu、IMP
- **Readout** photoelectric device: two 10 x 10 mm APDs (Hamamatsu S8664-1010)
- **Wrapping**: Teflon, fixed by carbon fiber.
- **WLS painting**: NOL 9
- **Couple**: Optical grease between APD and crystal for avoiding air gap

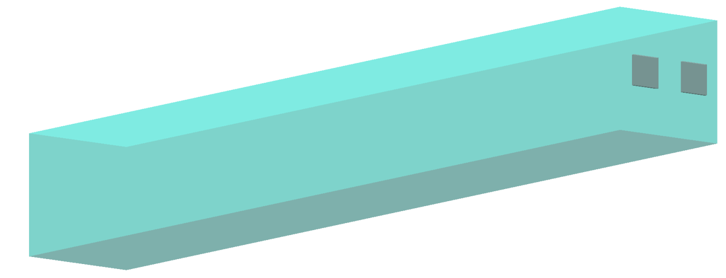
About 150 NPE/MeV light yield is expected.





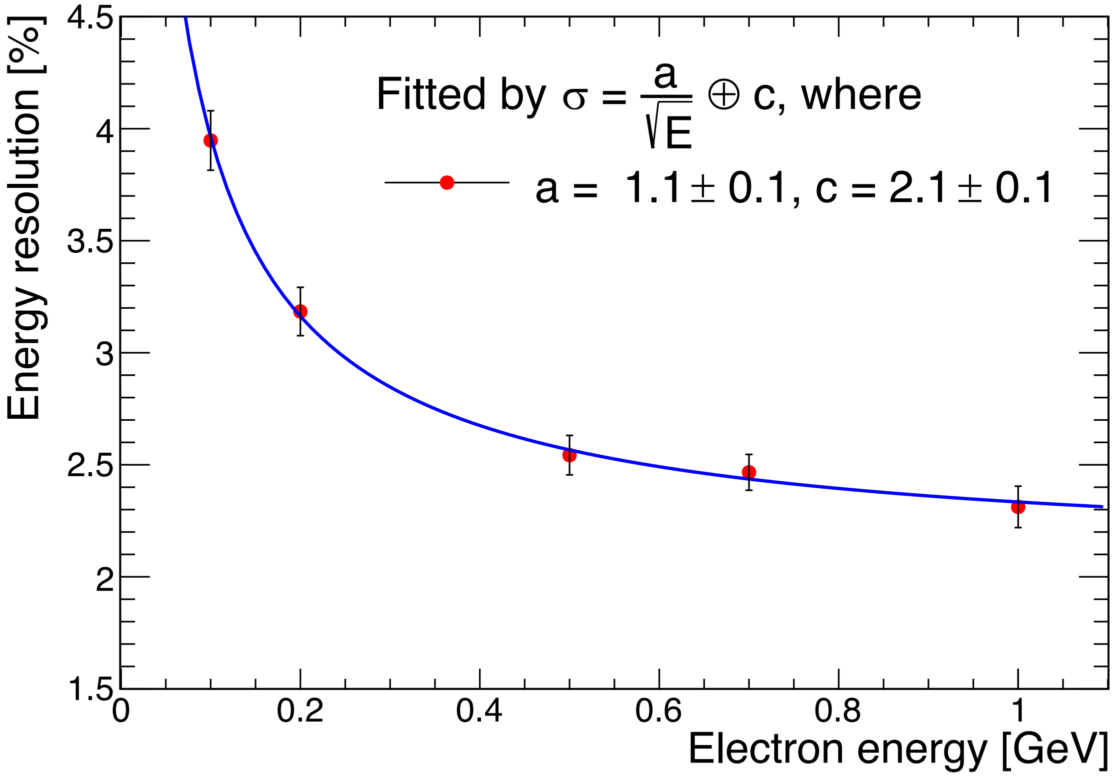


CsI module array simulation result

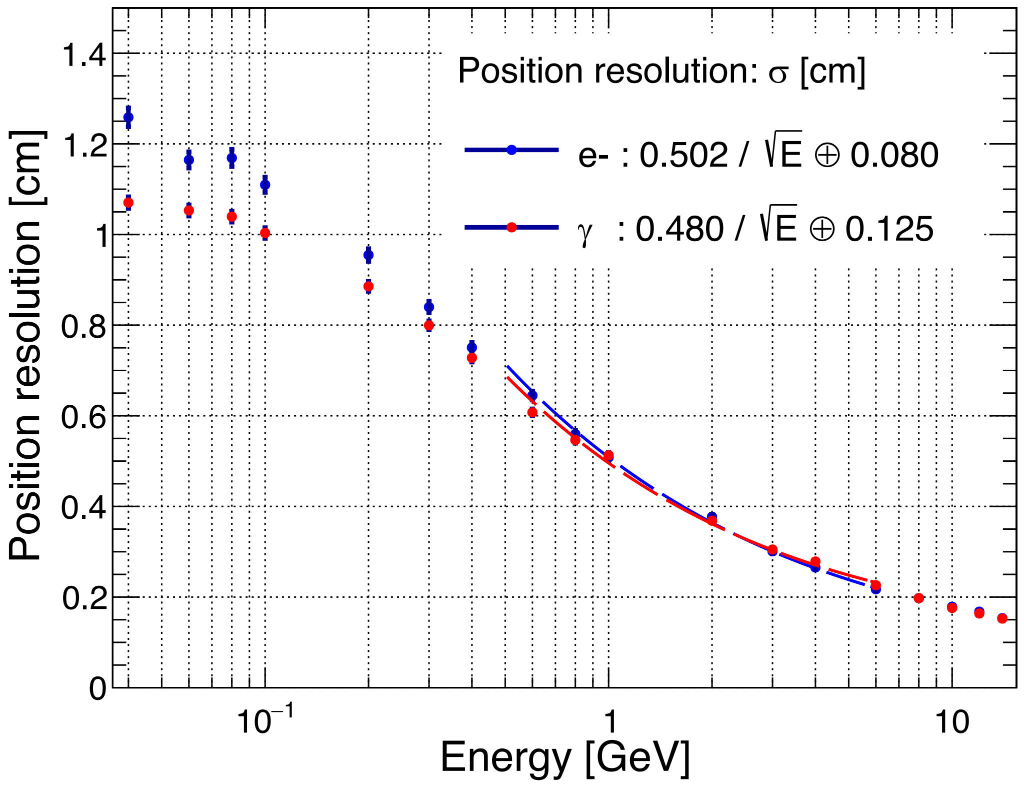


- Simulation with 7x7 array
- Very good energy resolution: **2.4%@1GeV**
- Position resolution(0.48cm@1GeV)

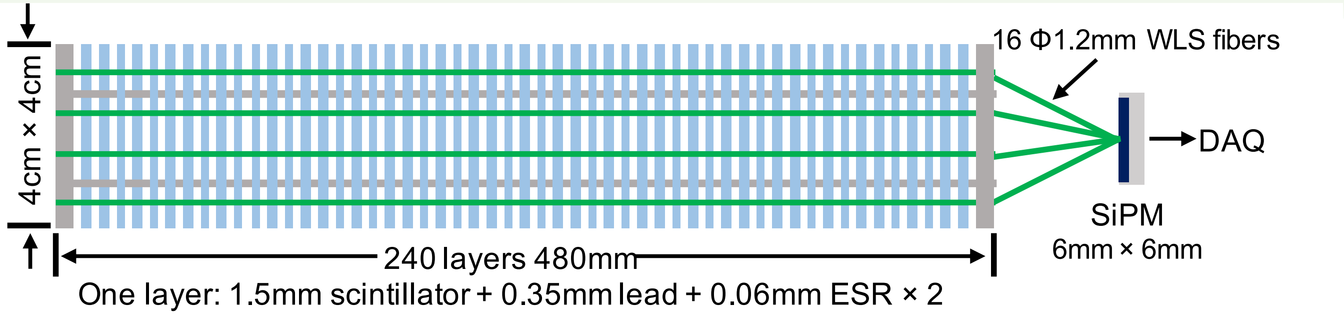
Energy resolution

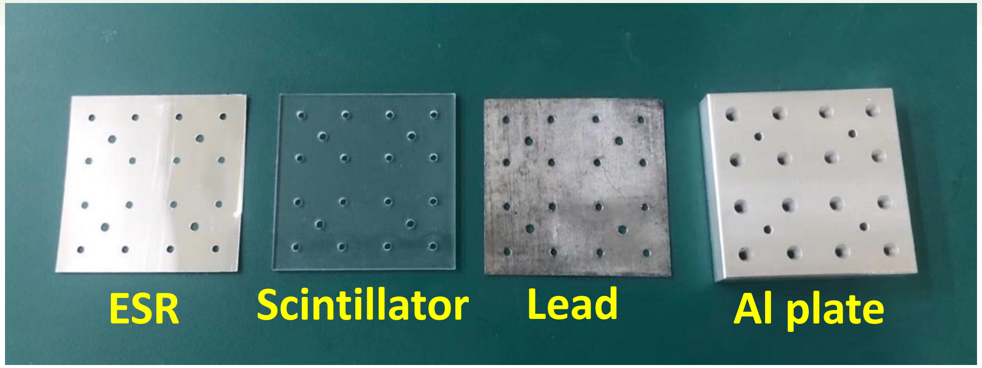


Position resolution

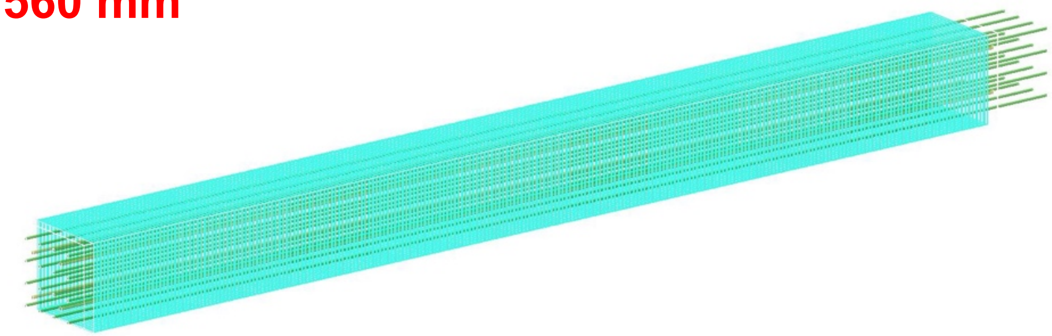


Shashlik ECal design





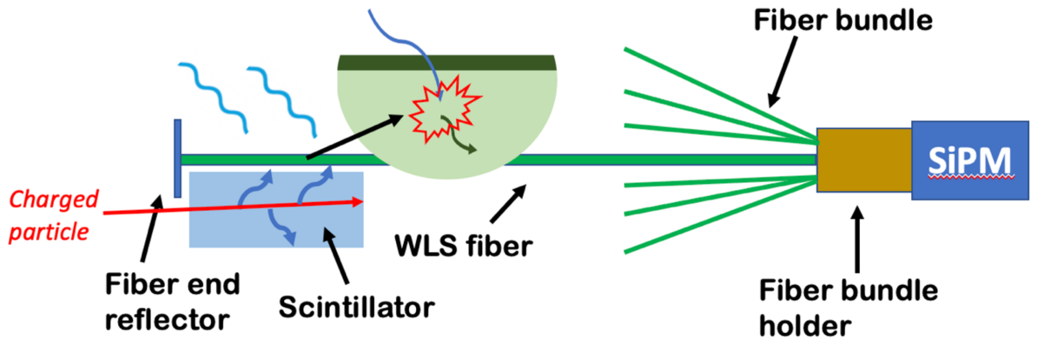
- **Longitudinal:**
  - (1.5 mm scintillator + 0.35 mm lead+ 65 μ m ESR *2) * 240 layers
  - **Sampling ratio**: 0.3
  - **Radiation length**: total 16 X_0 (X_0: 2.81 cm)
  - **Length**: 15 mm external fiber, 6 mm Al Plate + 470 mm + 8 mm Al Plate + 45 mm fiber bundle + 15 mm SiPM readout = **560 mm**
- **Lateral:**
  - 4.0 × 4.0 cm^2
  - 16 × Φ1.2 mm WLS fbers to collect light
  - 4 × Φ1.5 mm steel rods as module support
- **Other supplyment**
  - ESR as fiber end reflector
  - 6.0×6.0 mm^2 S13360-6025 SiPM as readout
  - TiO_2 coating

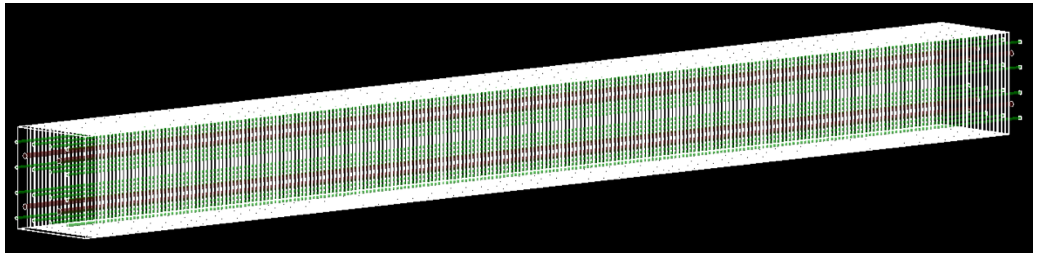


The Geant4 simulation of Shashlik module

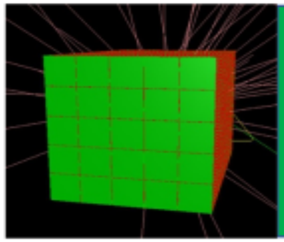
Takes into account the effects of **light generation** and **propagation** inside the scintillator tiles and in the WLS fibers.

- ➢ **Time consuming**
- ➢ **Important to extract parameters for the simplified simulations**





Parameterization of light yield



Geant4 Energy depoisted in scintillator → N_photon generated in scintillator → N_photon absorbed in fiber → N_photon trapped by WLS fiber → Attenuation in fiber → SiPM quantum efficiency → N_photon detected by SiPM

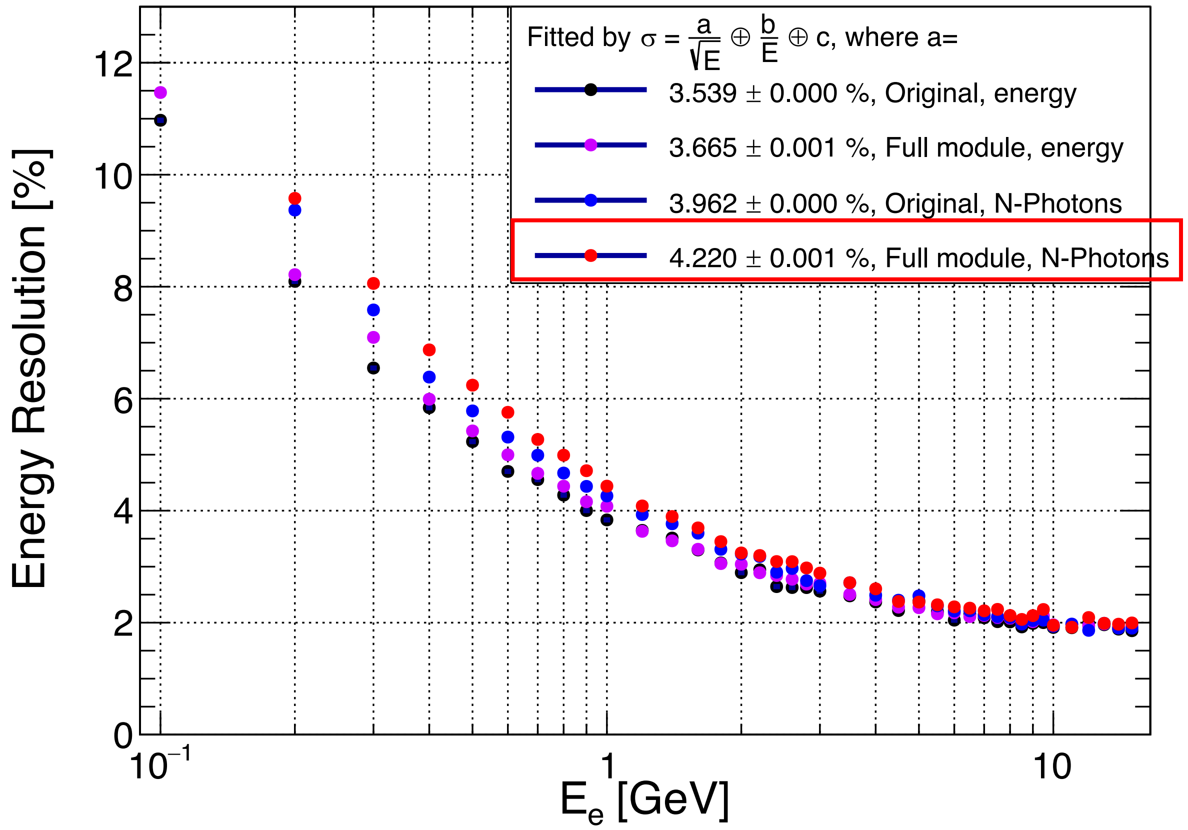
~10000/MeV | **~10%** | **~10%** | **~85%** | **~20%**

Need other information to confirm

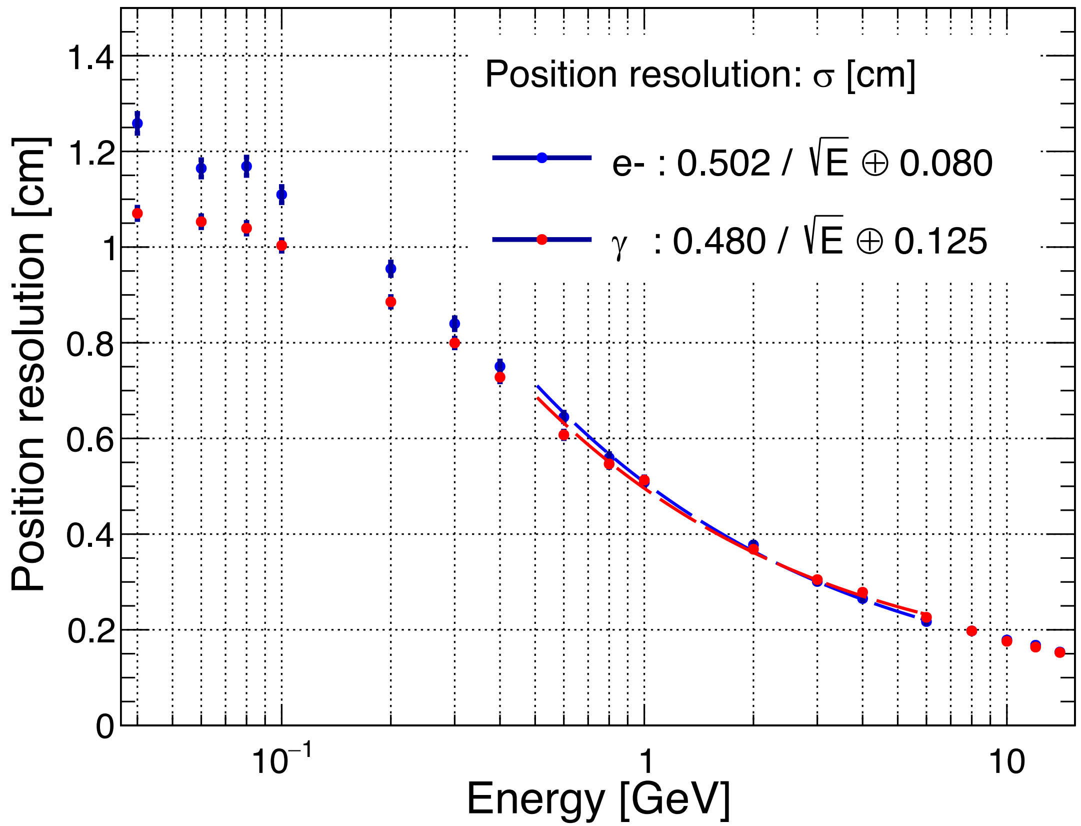
4000 NPE /GeV!

Shashlik array simulation result

Energy resolution



Position resolution

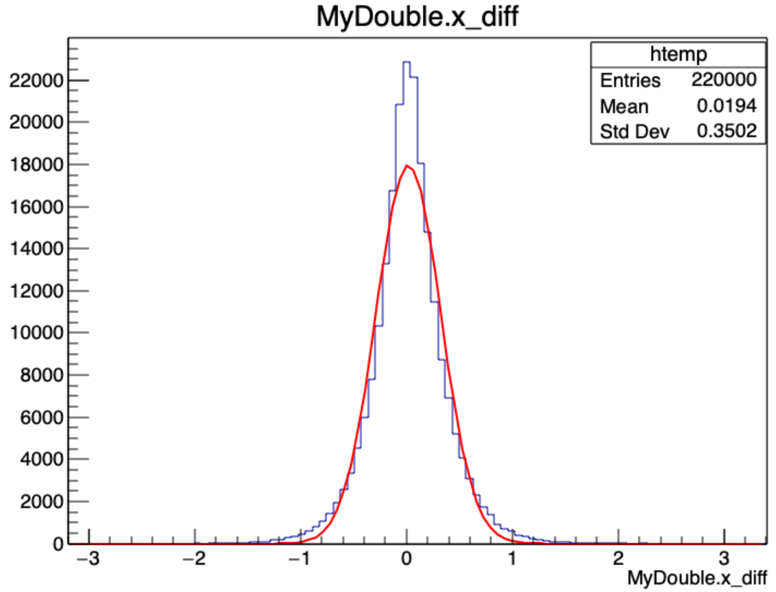


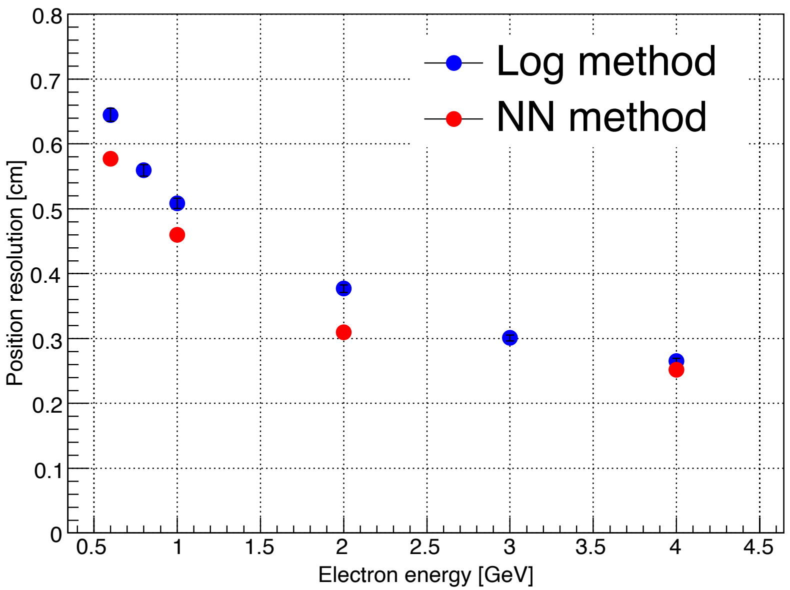
0.5 cm @1 GeV compared to pCsI 0.48 cm@1 GeV

Position reconsturction with NN method (0.5-5 GeV)

Train input: N.P.E. of 49 modules, energy range: 0.5-5 GeV

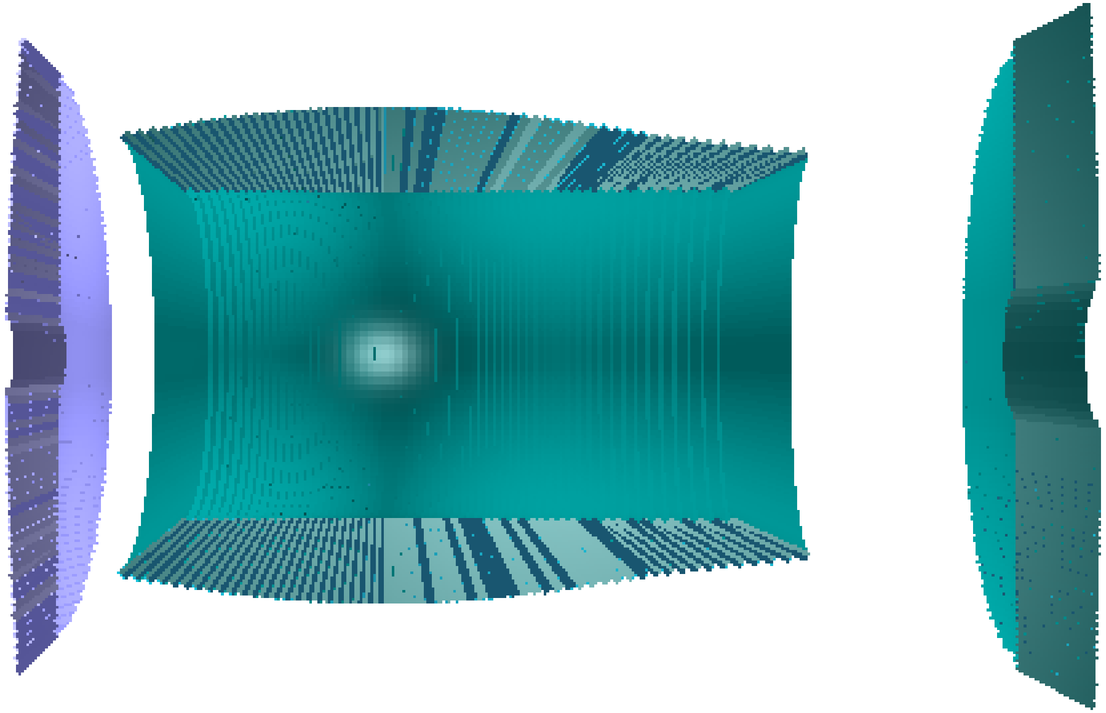
Output ： reconstructed position





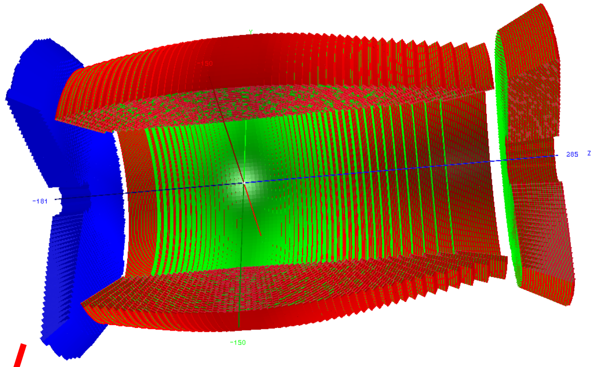
- NN method for position reconstruction is much better than W_0 centroid method.
- NN method is also applied for energy reconstruction and PID, but not work well as ordinary method
- Further details are under investigation

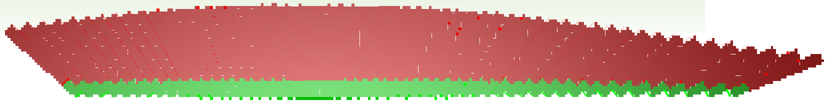
The Overall EicC ECal design

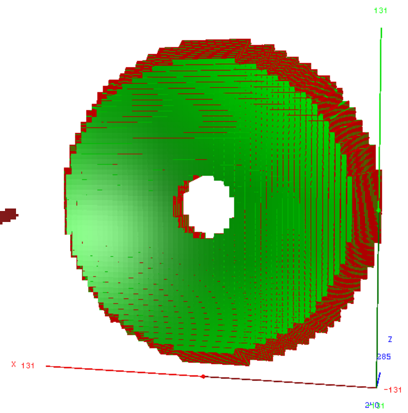


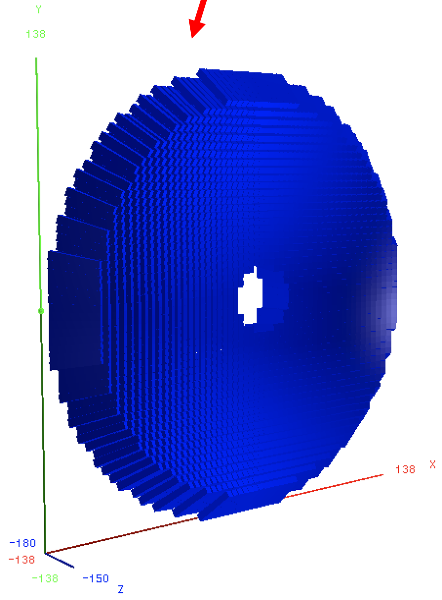
ECal detector design

The design in EicC ECal simulation.









Parameter	value
Distance to IP	1.5 m
η acceptance	(-3, -1)
Inner radius	15 cm
Outer radius	128 cm
length	30 cm
Radiation length	16 X_0
Front size	4×4 cm^2
Rear size	4.8×4.8 cm^2
Photon detector	APD
Total modules	~2700

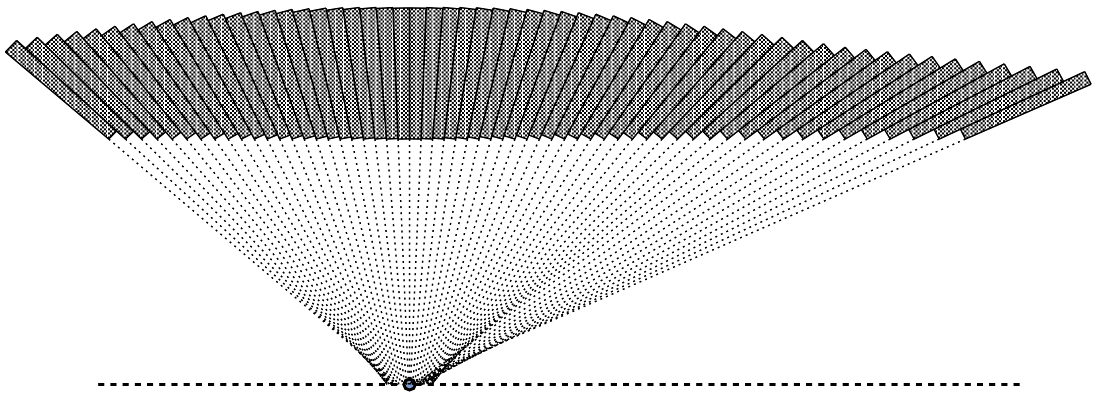
Parameter	**Barrel**	**Ion-Endcap**
Distance to IP		2.4 m
η acceptance	(-1, 1.5)	(1.5, 3)
length	60 cm	
Radiation length	16 X_0	
Molière radius	5.02 cm	
Front size	4×4 cm^2	
Rear size	5.7×5.7 cm^2	4.7×4.7 cm^2
N layers	240	
Scintillator thickness	1.5 mm	
Lead thickness	0.35 mm	
Reflector thickness	0.065 mm	
Sampling ratio	0.33	
Inner radius	90 cm	24 cm
Outer radius	150 cm	113 cm
N fibers(front)	16	
Photon detector	6x6 mm^2 SiPM	
Total modules	~8000	~2300

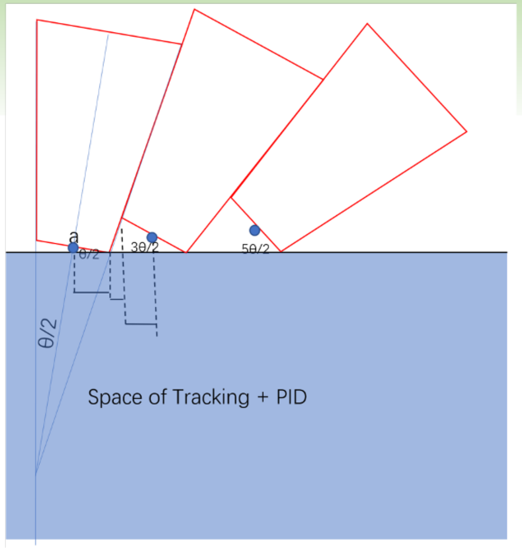
Module θ optimization for barrel

The trapezoid module angle is optimized for two angles:

48 + 10 with 2.1° + 1.3°

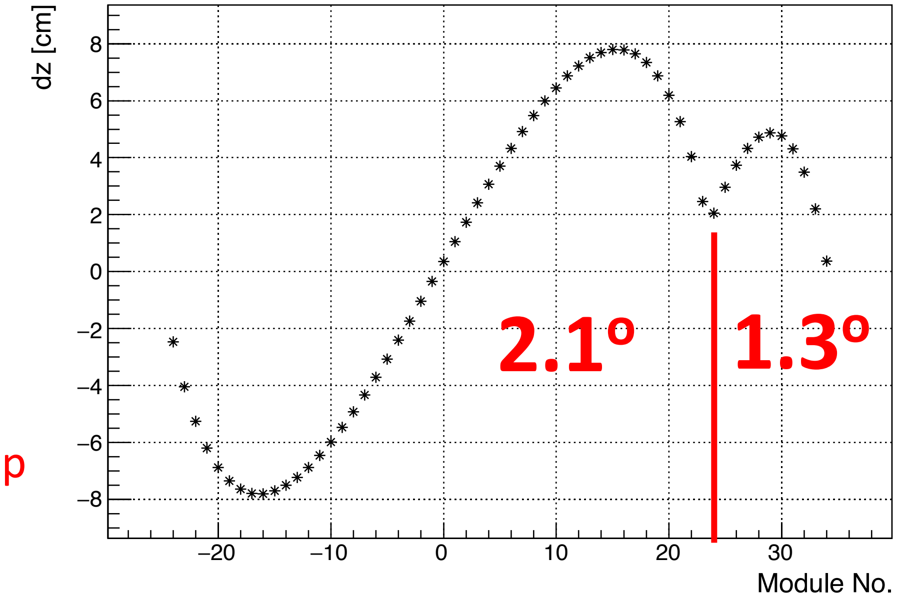
to minimize the dz and the energy leakage between barrel and endcap.



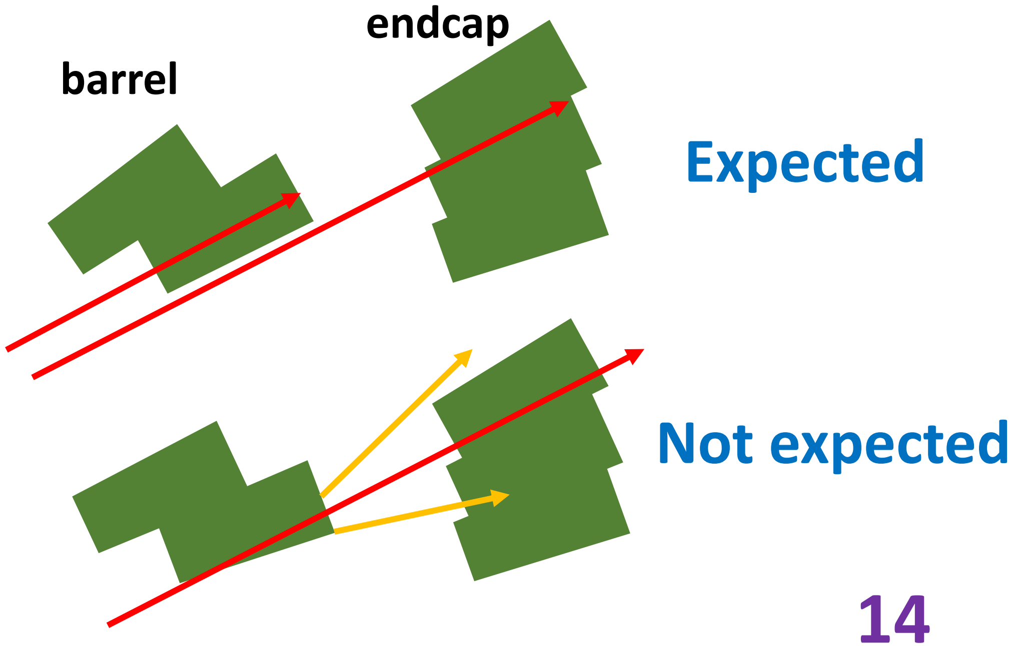


Two angles

E-endcap

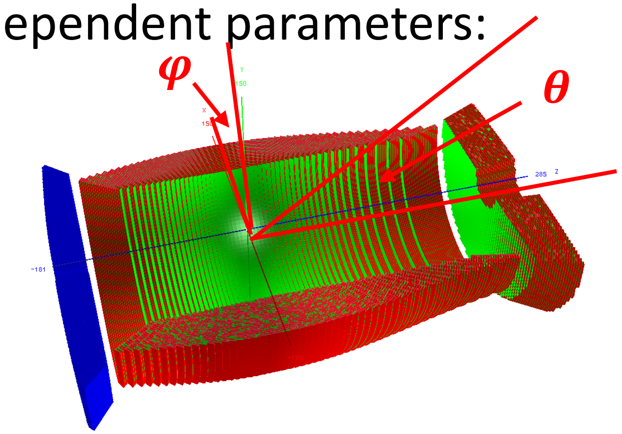


Ion-endcap

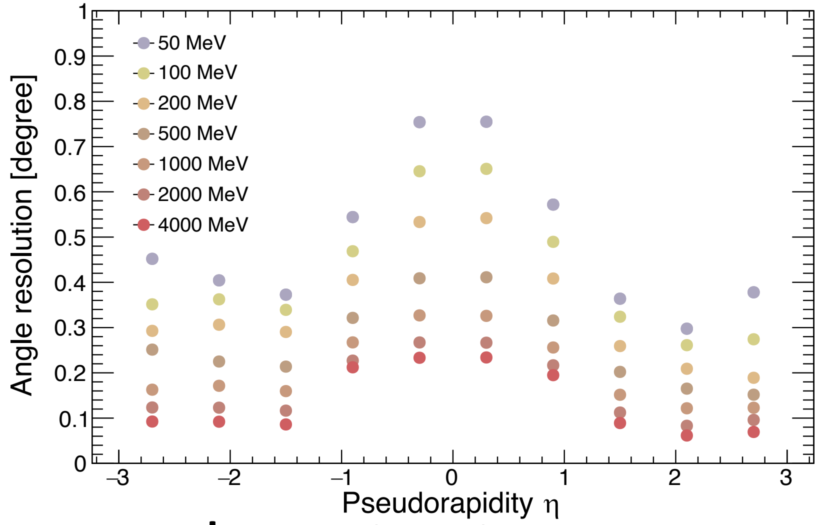


Single e⁻ reconstruction

- Reconstruction based on 3-independent parameters:
  - Energy
  - Two angles (θ and φ).
- **Δ = Reco – Real**

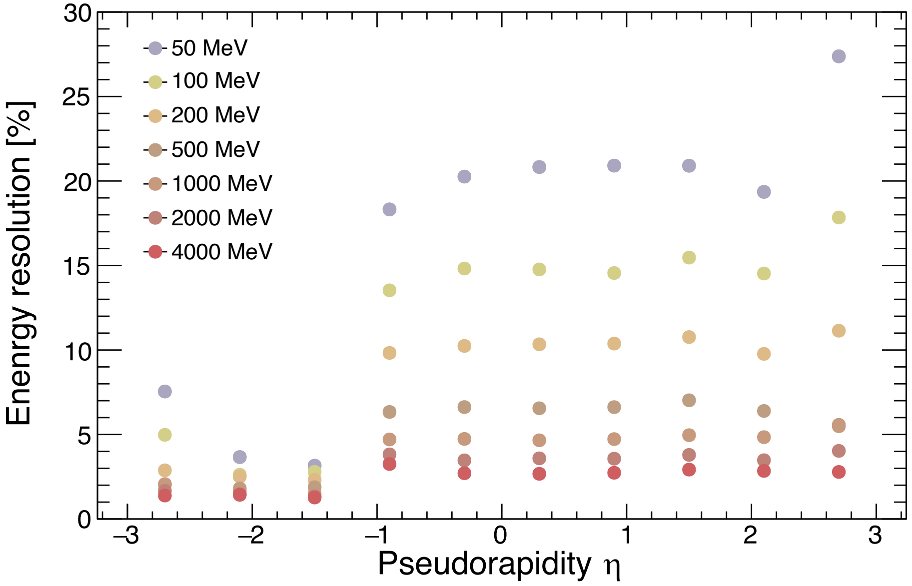


Reconstructed angle $\Delta\theta$ vs. Pseudorapidity η



e-endcap **barrel** **ion-endcap**

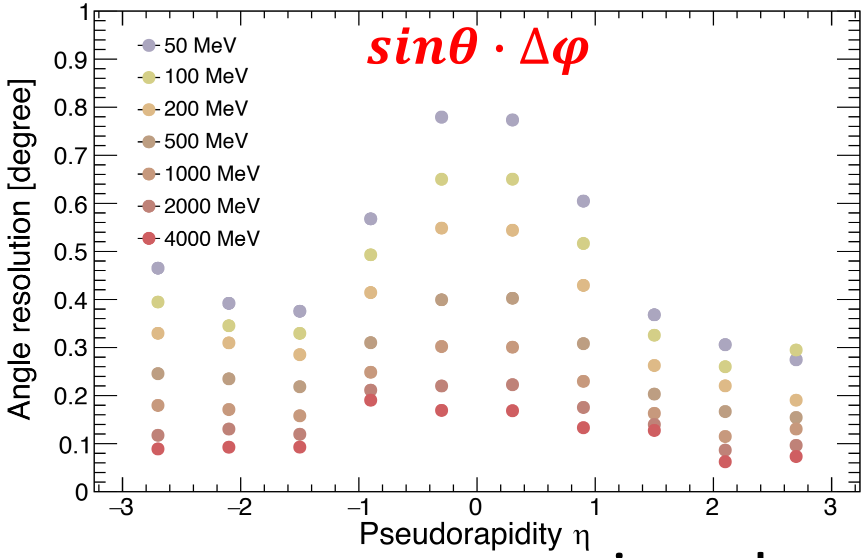
e- energy ΔE & resolution v.s. Pseudorapidity



e-endcap **barrel** **ion-endcap**

About 5%[1GeV]

Reconstructed angle $\Delta\varphi$ vs. Pseudorapidity η



e-endcap **barrel** **ion-endcap**

π^0 acceptance

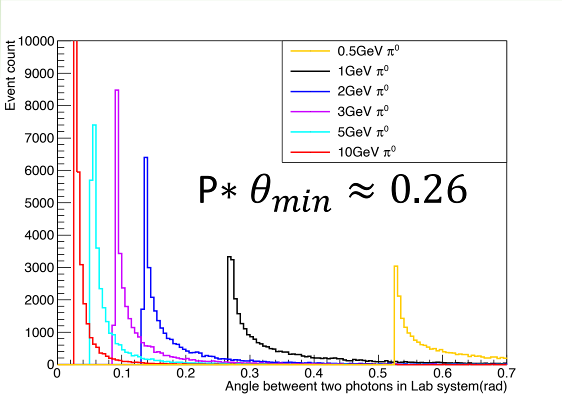
- π^0 **detection efficiency:**

π^0 Kinematic distribution
↓
energy cut (10MeV)
↓
detector acceptance
↓
reconstruction efficiency

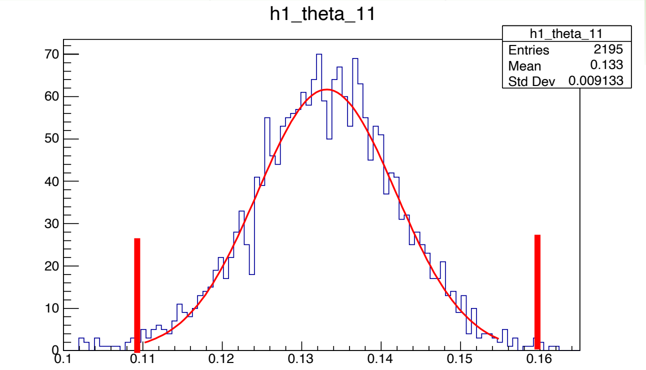
Intrinsic (Kinematic distribution, energy cut)

Design and algorithm (detector acceptance, reconstruction efficiency)

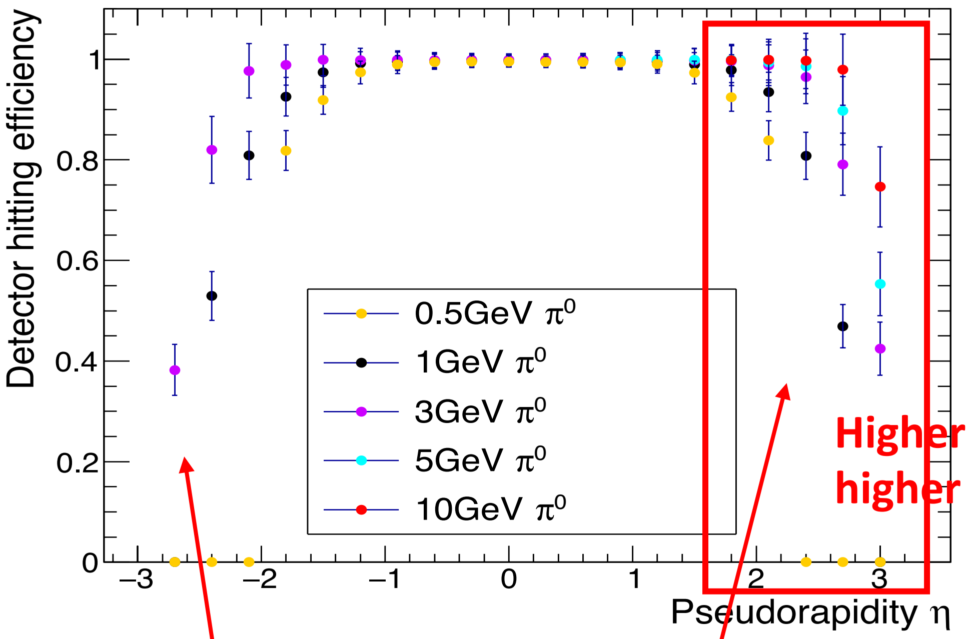
Angle of two photon in Lab system



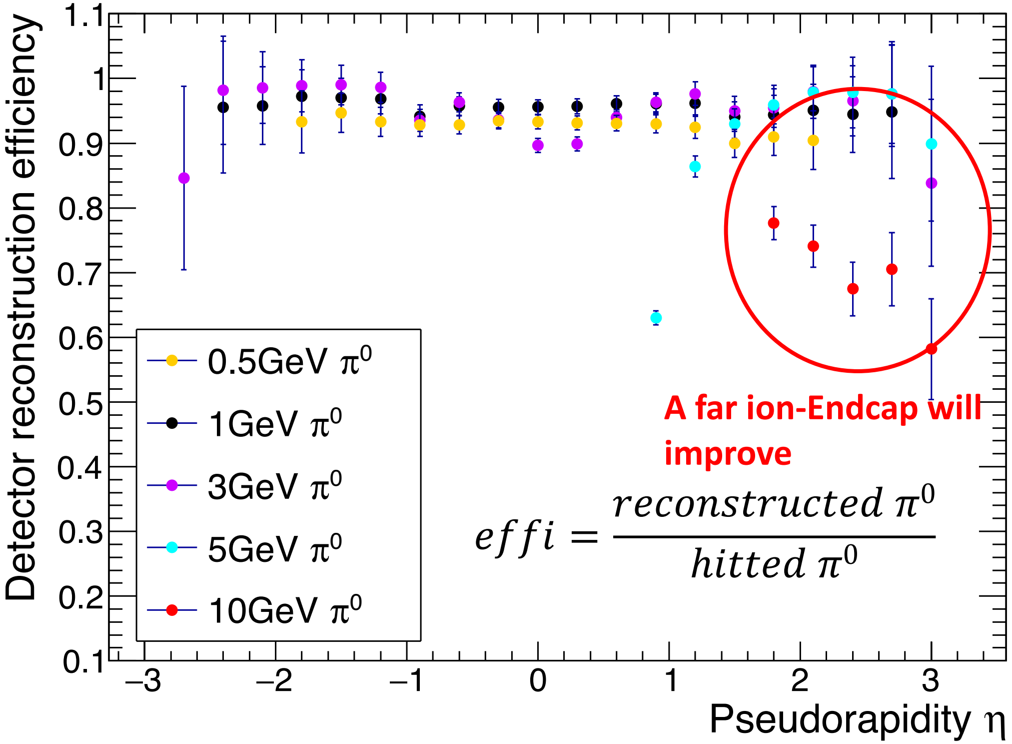
π^0 invariant mass cut (110-160MeV)



ECal geometry acceptance of π^0



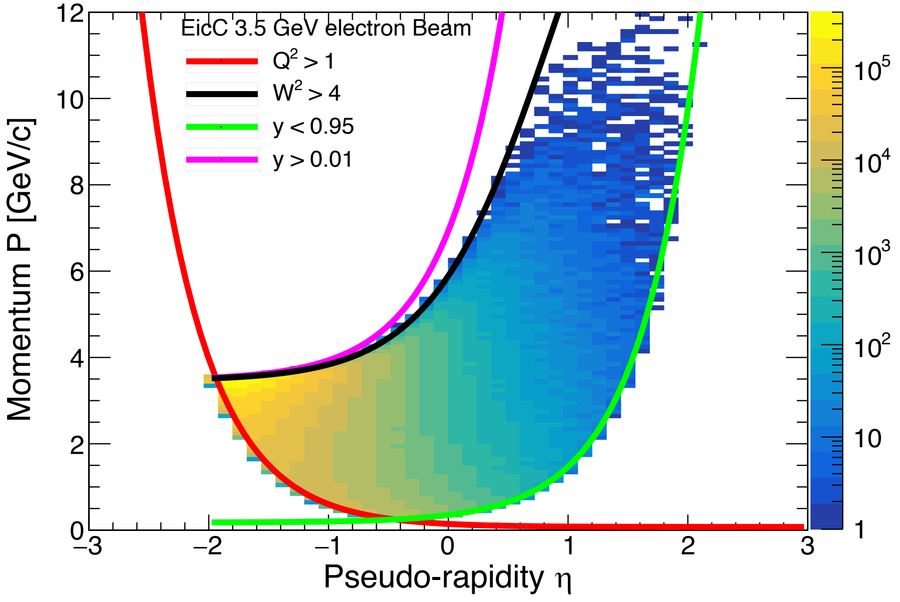
π^0 reconstruction efficiency



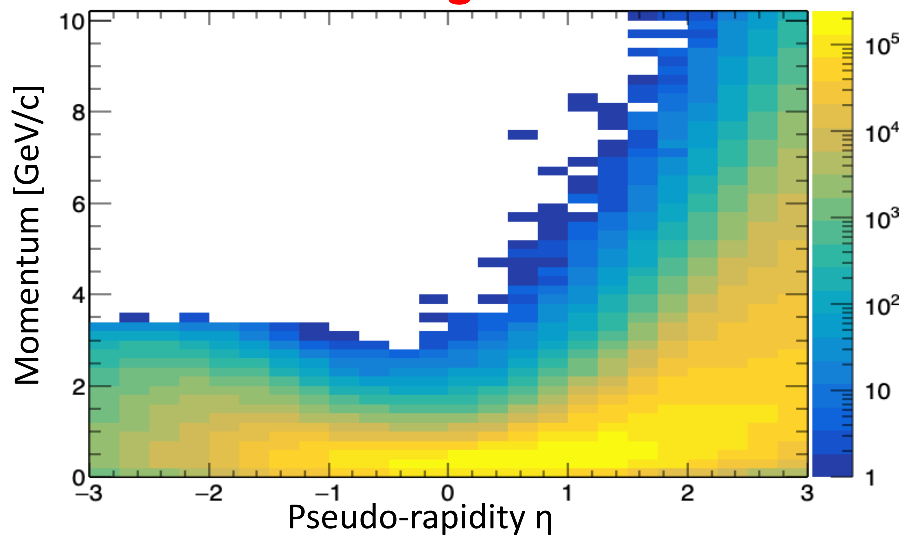
$$effi = \frac{reconstructed\ \pi^0}{hitted\ \pi^0}$$

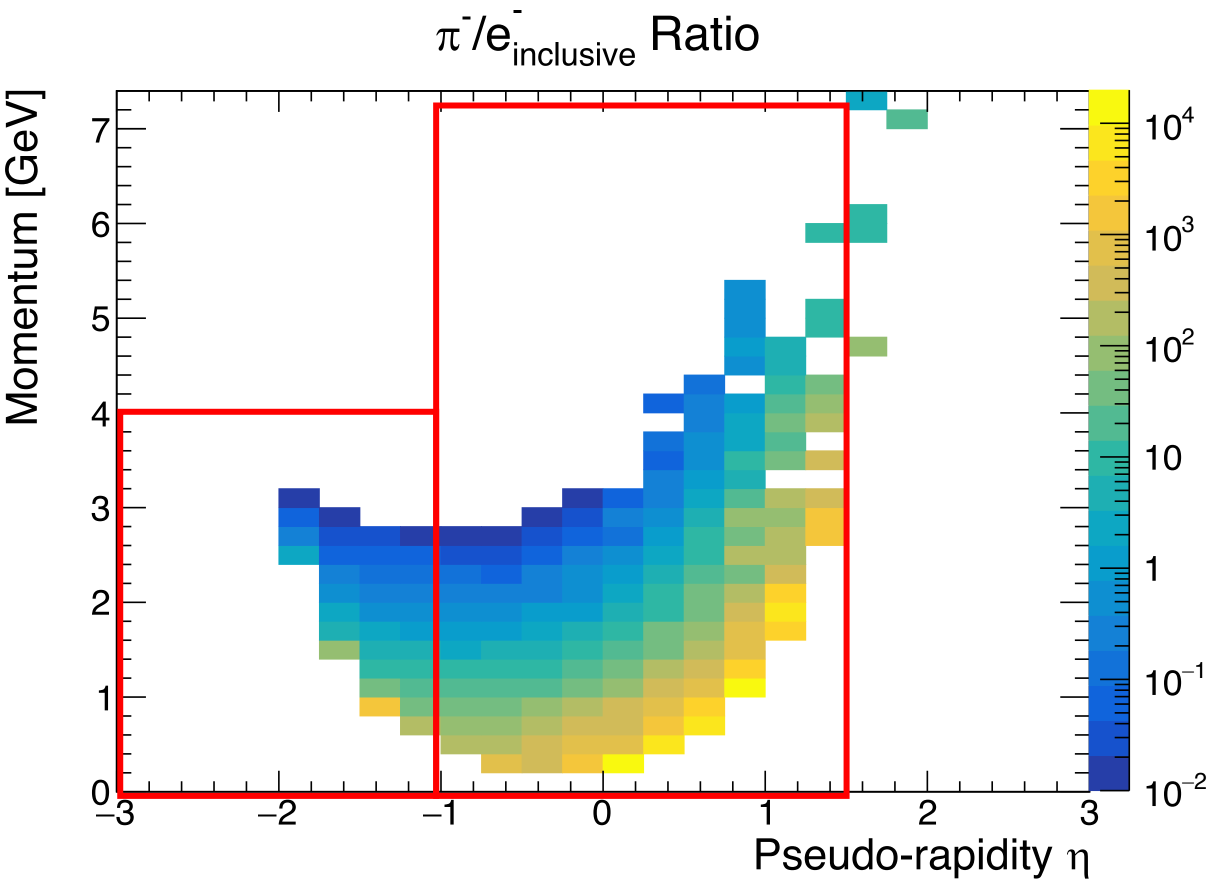
e^-/π^- separation

Inclusive electrons (Q^2>1)



Pion background





e^-/π^- separation focus on e-endcap and barrel !

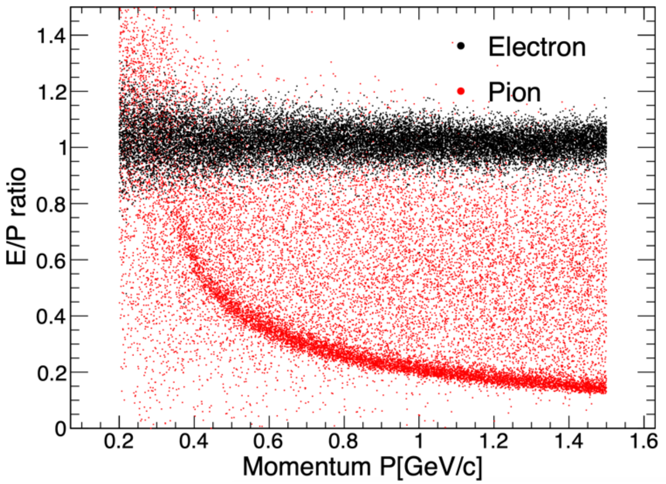
ECal e/π separation performance

- e^-/π^- is separated by **E/p** and **D** in ECal

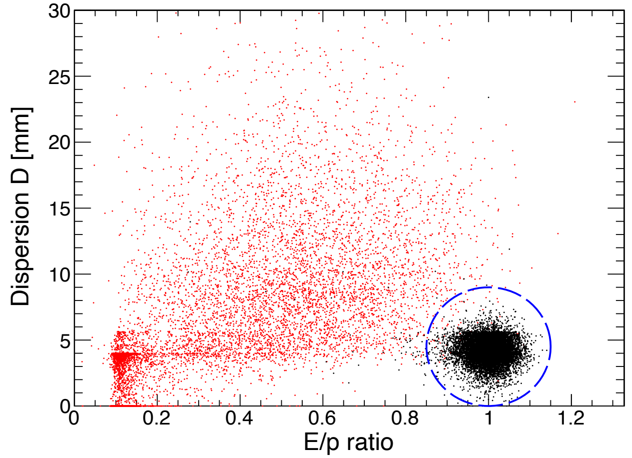
$$D = \sqrt{D_x^2 + D_y^2} = \sqrt{\frac{\sum_i w_i (x_i - x_{com})^2}{\sum_i w_i} + \frac{\sum_i w_i (y_i - y_{com})^2}{\sum_i w_i}}$$

- The cut is affected by e^-/π^- ratio, to achieve good electron efficiency and purity.
- e^-/π^- ratio **1:10** is assumed in this analysis

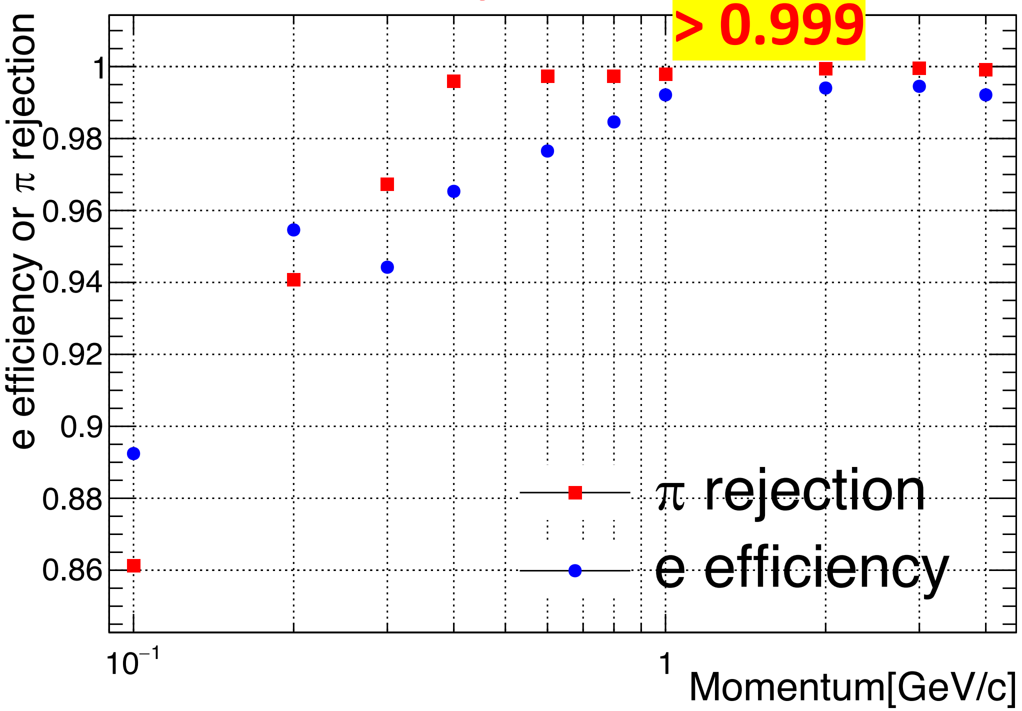
E/p distribution



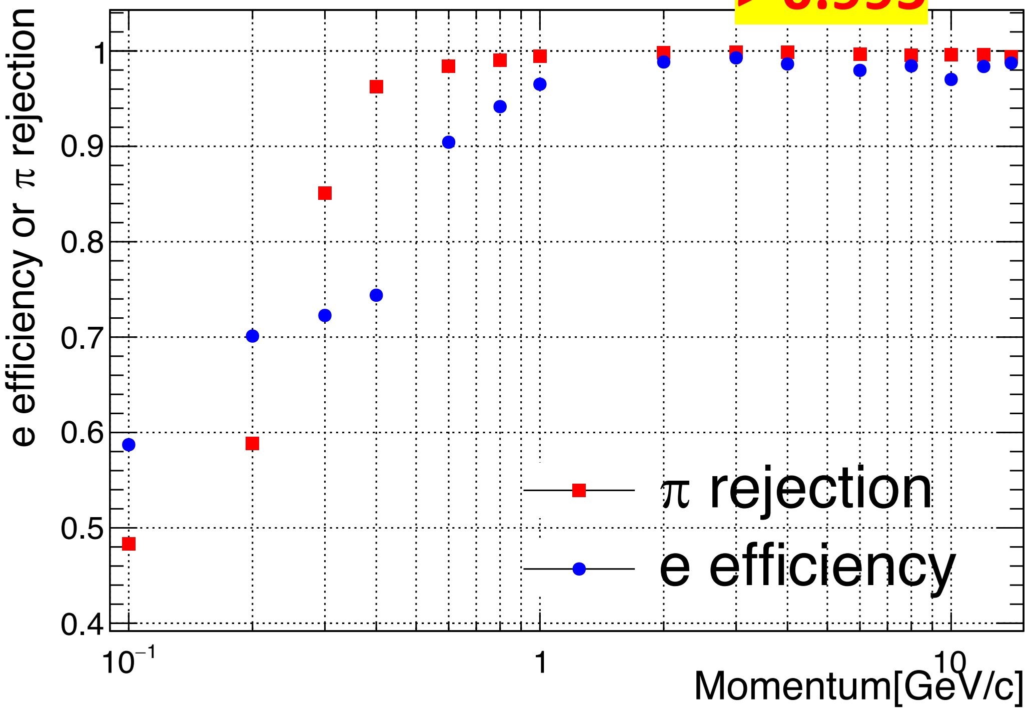
E/p v.s. D distribution



CsI crystal PID **> 0.999**

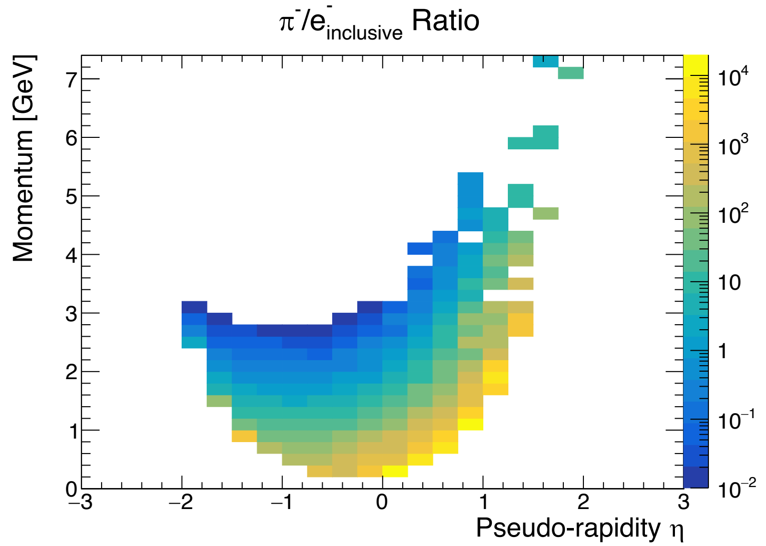


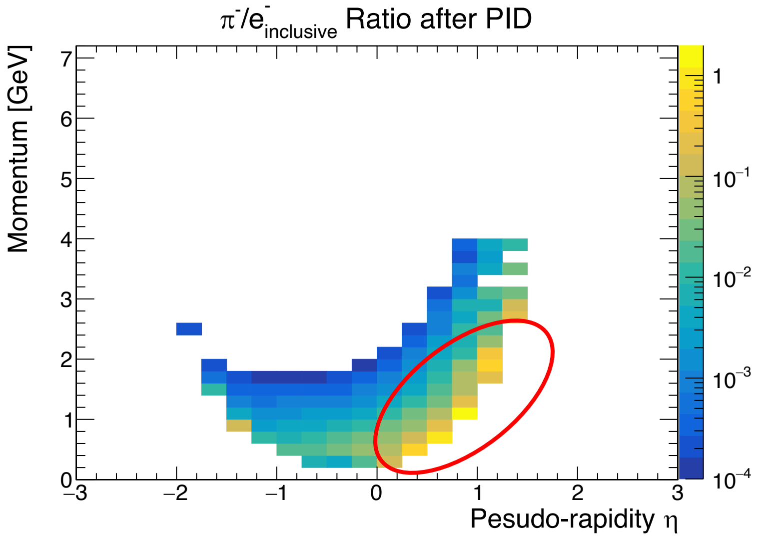
Shashlik PID **> 0.995**



EicC e/π PID Summary

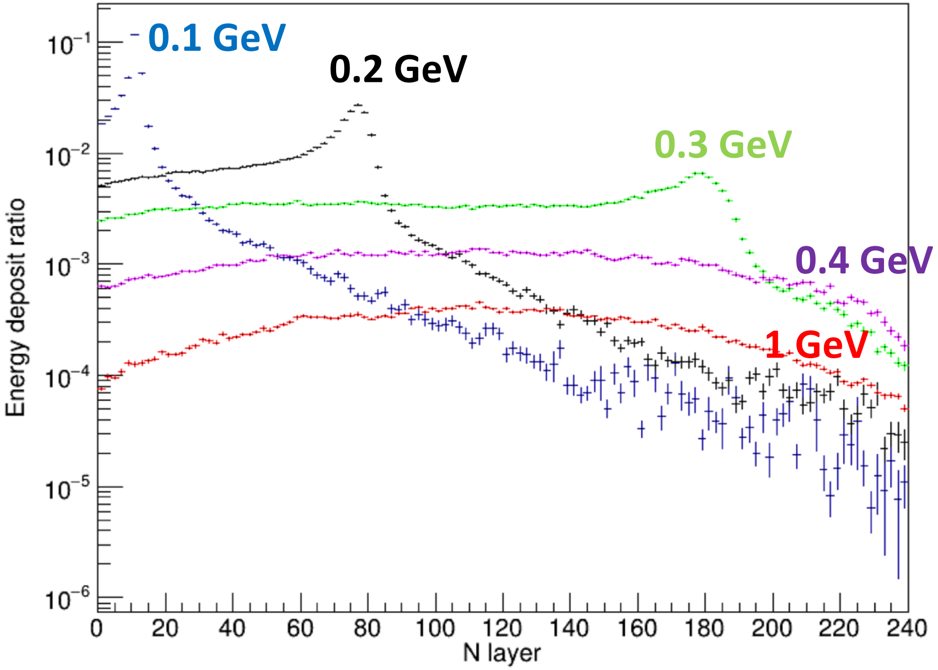
Momentum [GeV/c]	Eta $\lvert\eta\rvert$			π^- suppresion ratio
[0, 0.1]	Tracking efficiency low, discard			-
[0.1, 0.2]	[0, 1]	[1, 2]	[2, 3]	
	Long flight time + tracking efficiency low, discard		EMC no hit+ tracking efficiency low, discard	-
[0.2, 0.5]	Excellent e/π separation from TOF + below RICH π Cherenkov threshold			**> 10^5:1**
[0.5, Cherenkov upper limit]	RICH / DIRC + ECal + TOF			**10^4:1**
> Cherenkov upper limit	ECal			**10^3:1**



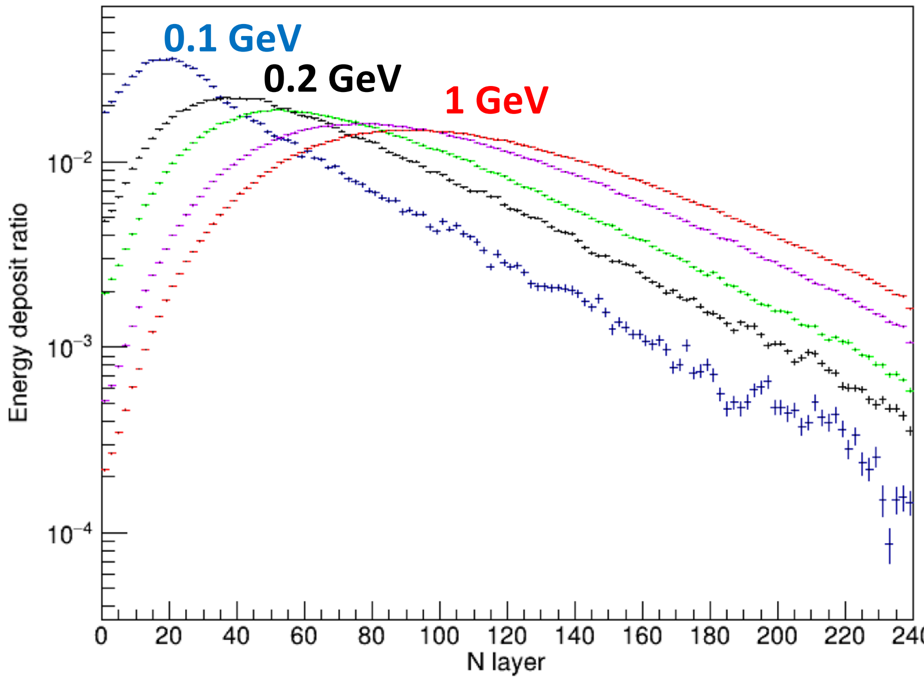


Shashlik longitudinal design with improved e^-/π^- separation

π^- (after E/P cut)

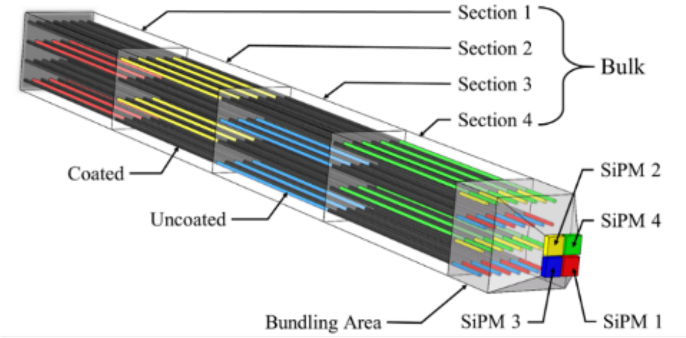


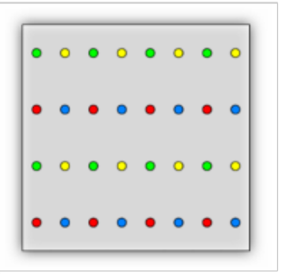
e^-



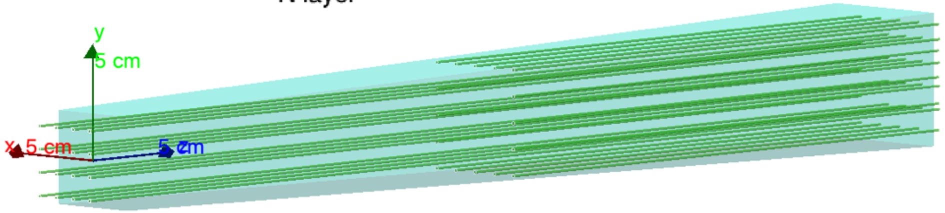
5D design

From 王义

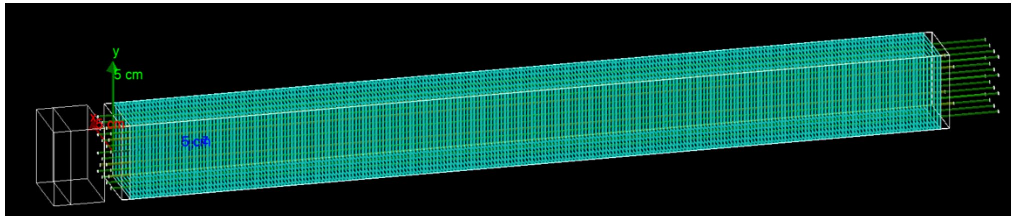




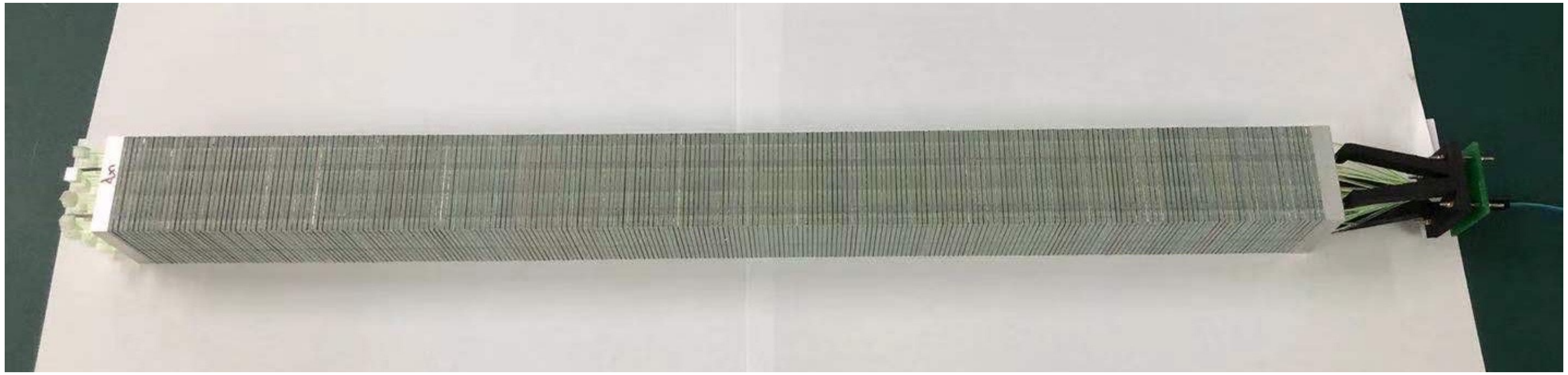
Trapzoid

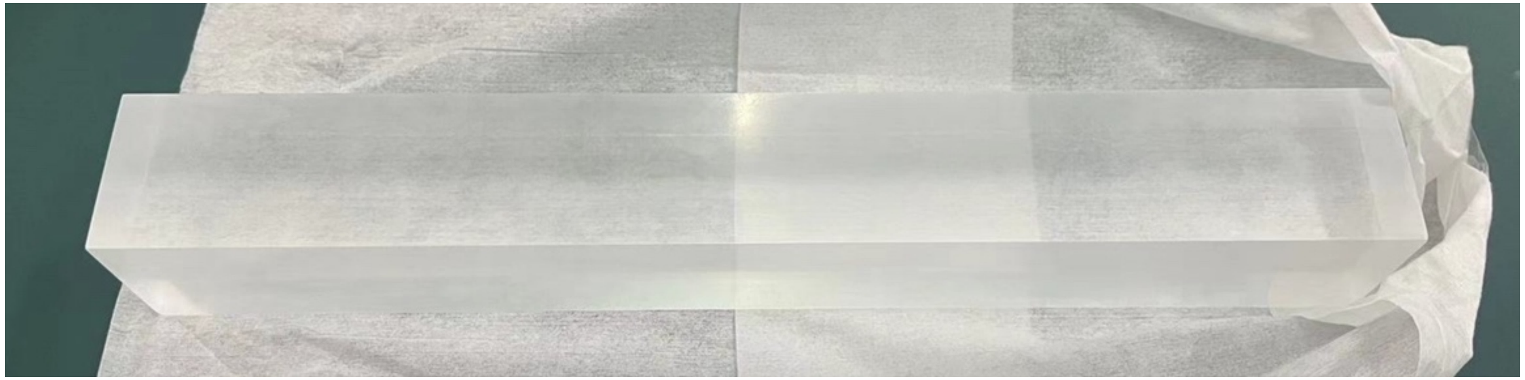


Preshower



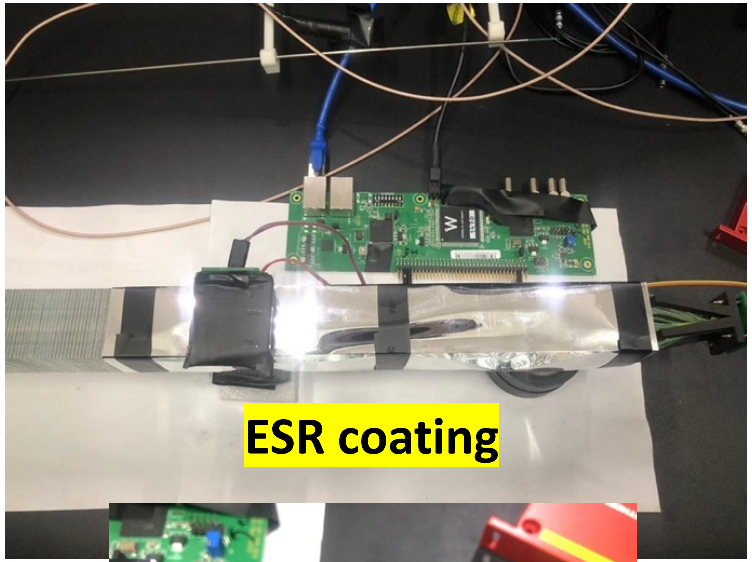
ECal hardware work



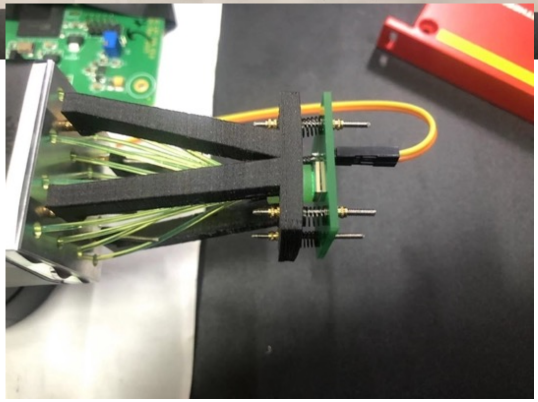


Module prototype

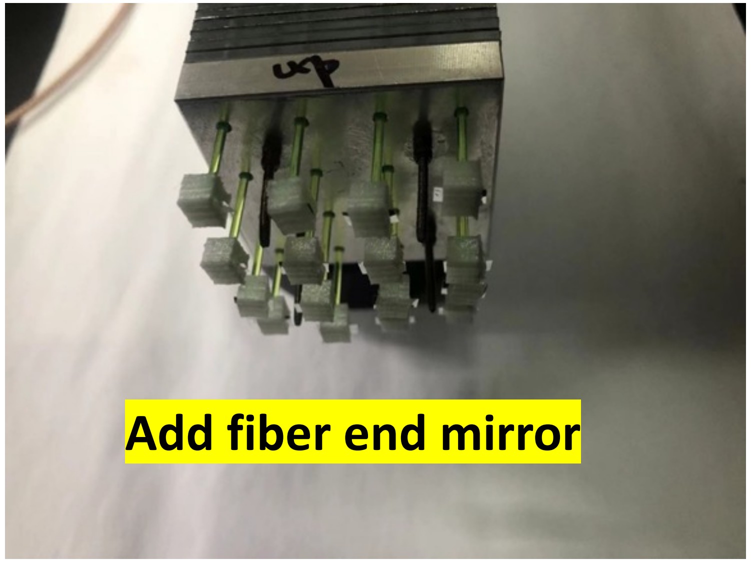
Shashlik module



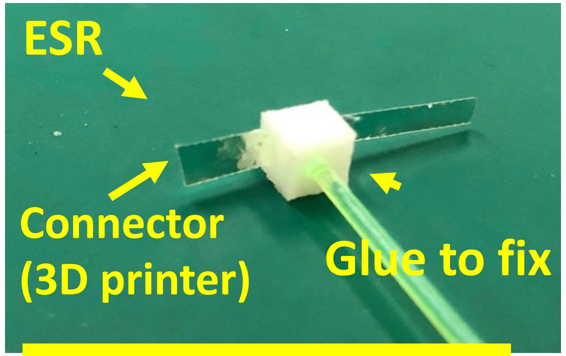
ESR coating



Fiber – SiPM coupling



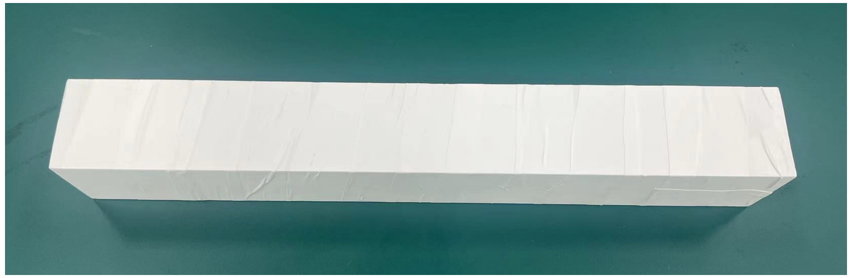
Add fiber end mirror

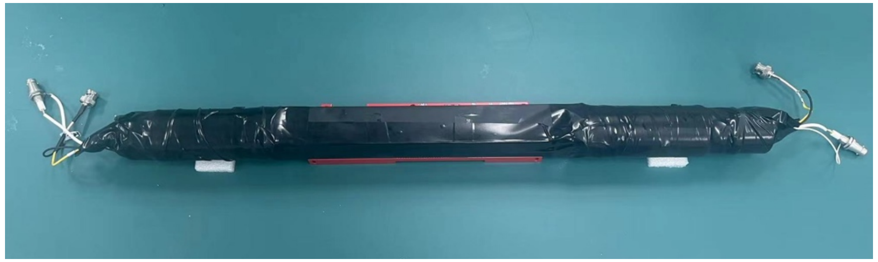


Specular reflector end

pCsI module

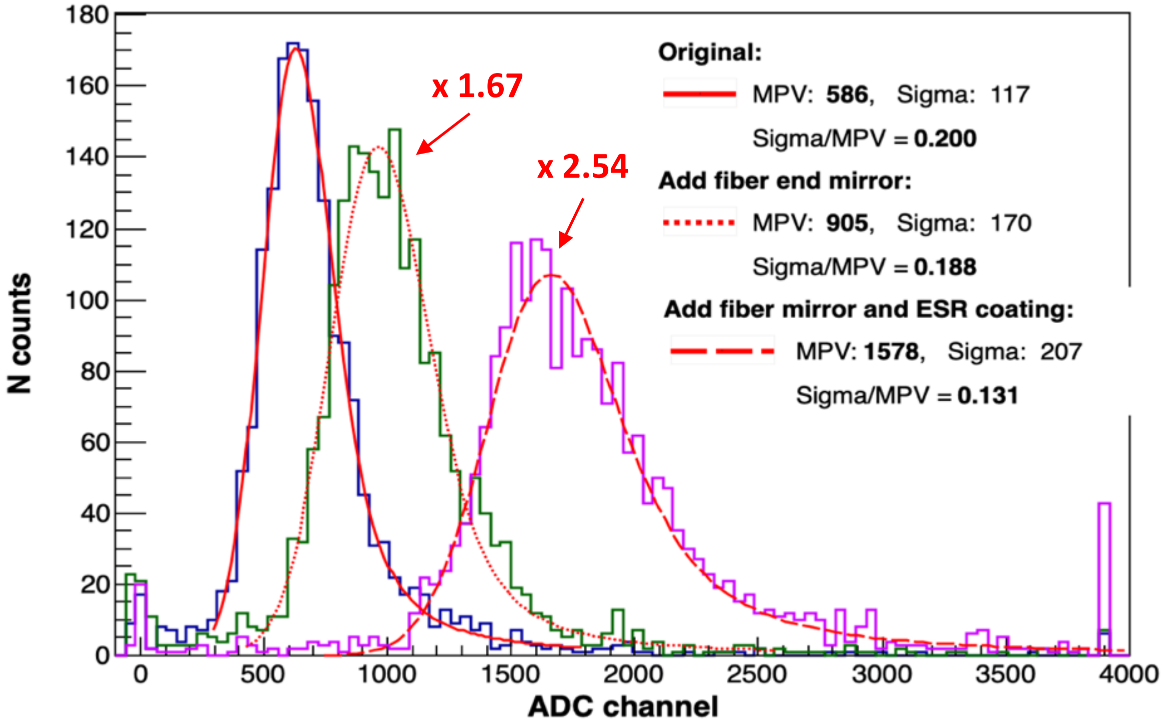
Wrapped by teflon



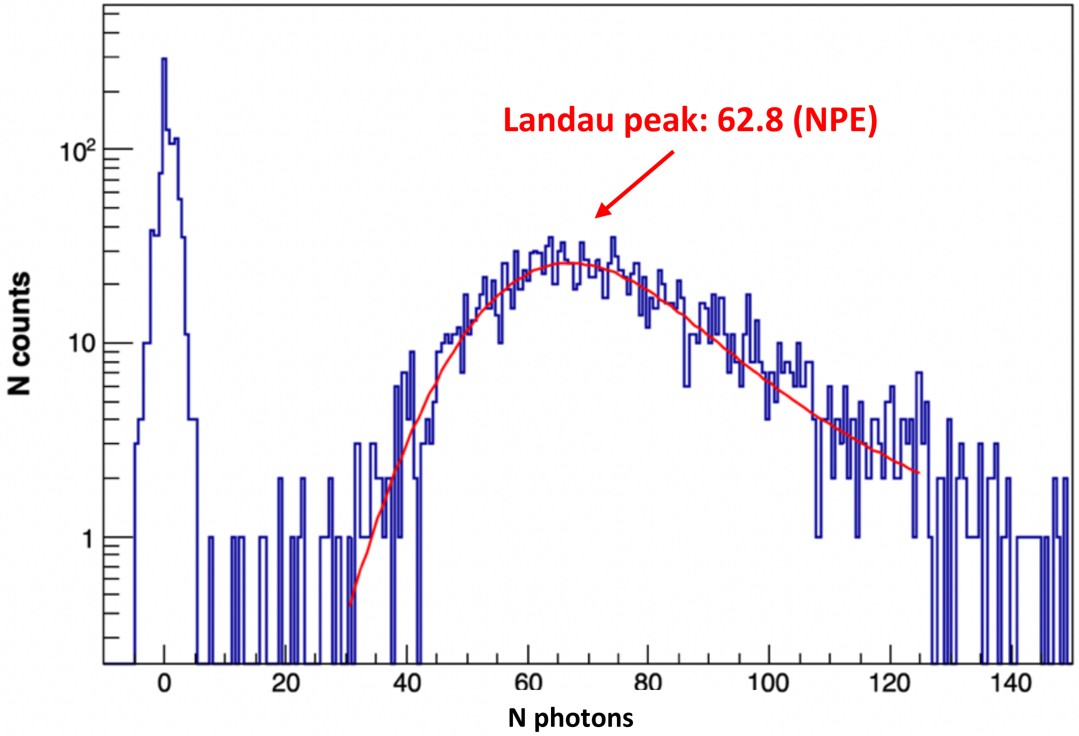


Shashlik module horizontal test result

Light yield improvement with reflector (SiPM)



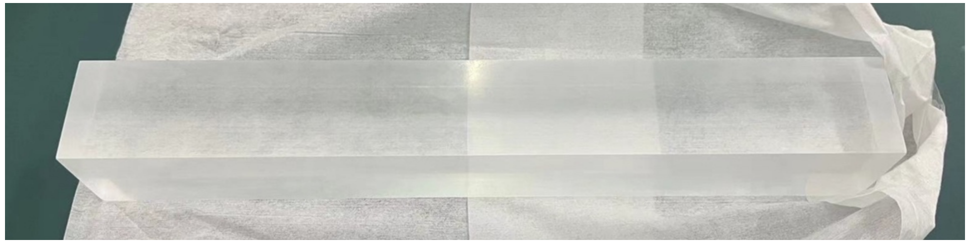
N photons spectrum (PMT)



- 62.8 NPEs is acquired, similar to NIKA 63 NPEs that use better scintillator

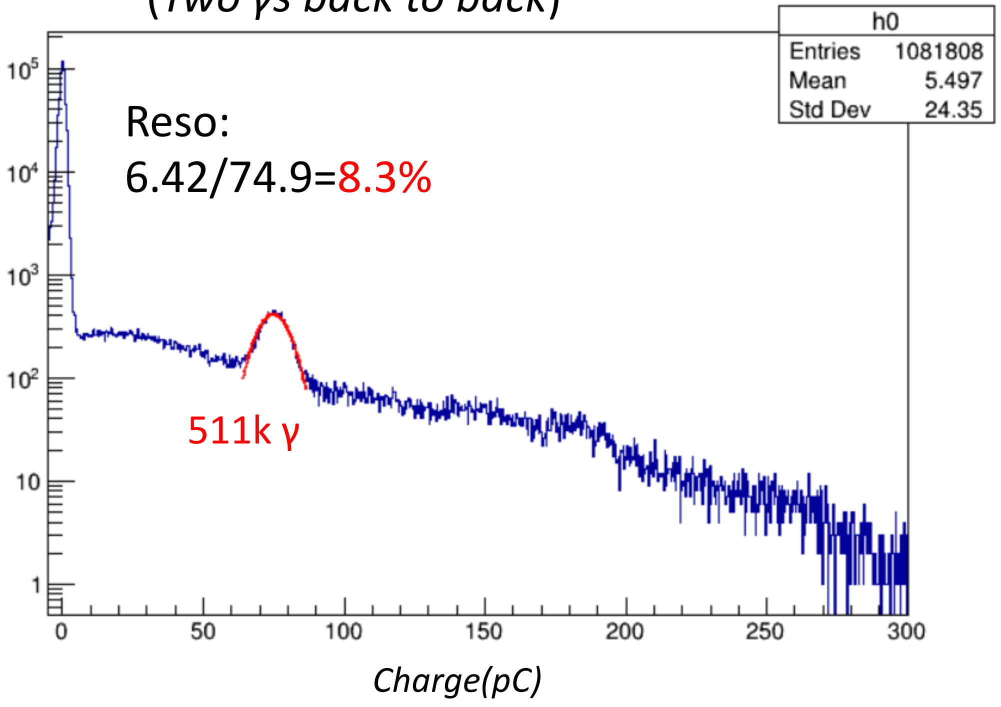
CsI(Tl) Crystal test with Radioactive Source

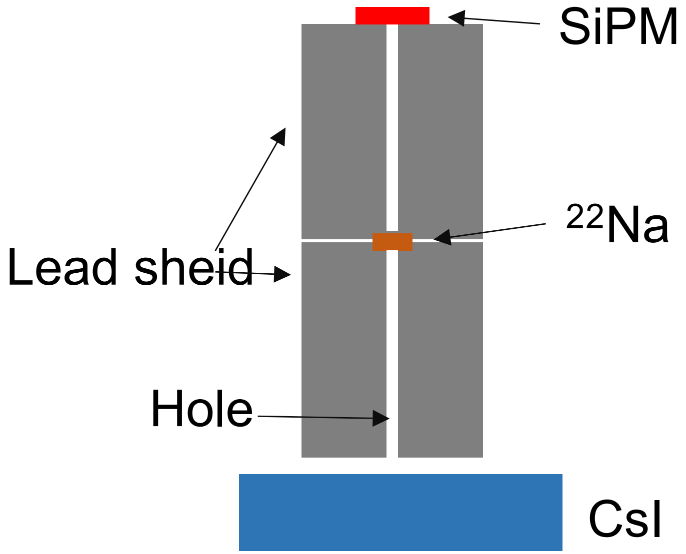
- Study the optical properties of the crystal with ^{22}Na radioactive source
- Two gammas with 0.511 MeV energy emitted back-to-back through positron annihilation,
- Detail studies for pCsI are preparing.



With collimator

(*Two γs back to back*)





ECal DAQ

pCsI : APD

- **Up to 4 GeV**
- two 10x10 mm^2 APD
- 100 NPE/MeV, up to 140k NPE/each APD

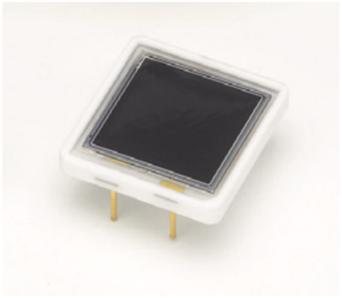
Shashlik : SiPM

- **Up to 15 GeV**(barrel up to 10GeV， endcap up to **15GeV)**
- **need 2 SiPMs**
- 4 NPE/MeV, up to 35k NPE/each SiPM

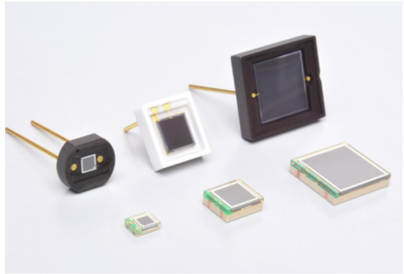
In common:

- Dual gain (preamplifier)
- Time resolution < 1 ns
- Max rate acceptance for single module: 100 k Hz
- Store waveform by FADC

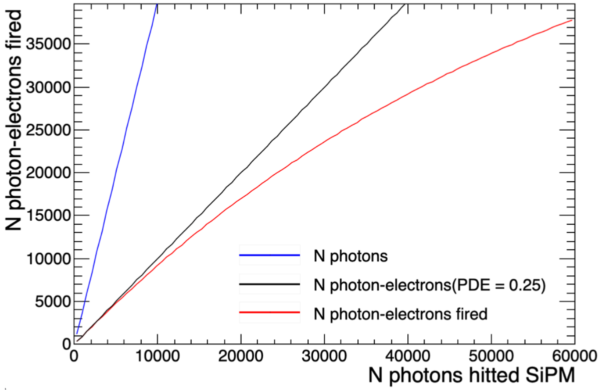
APD



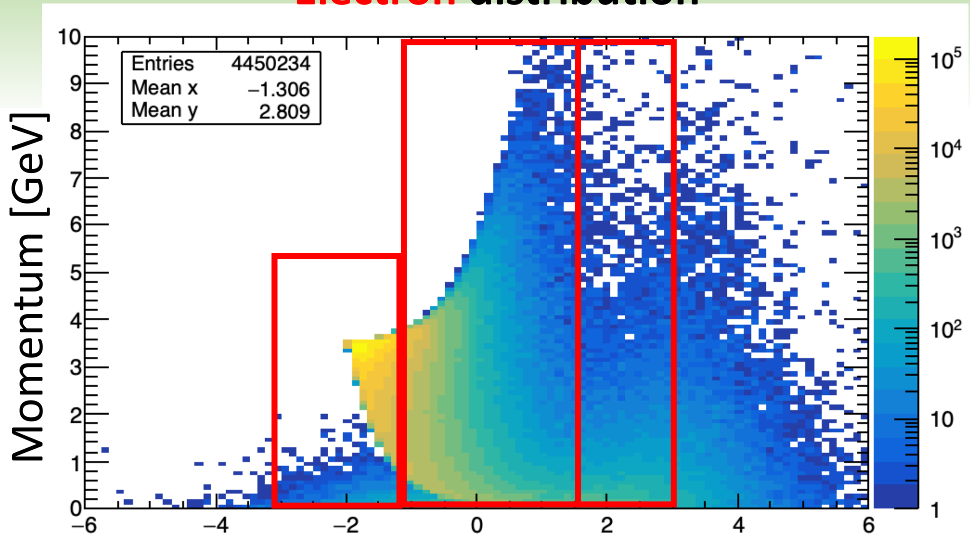
SiPM



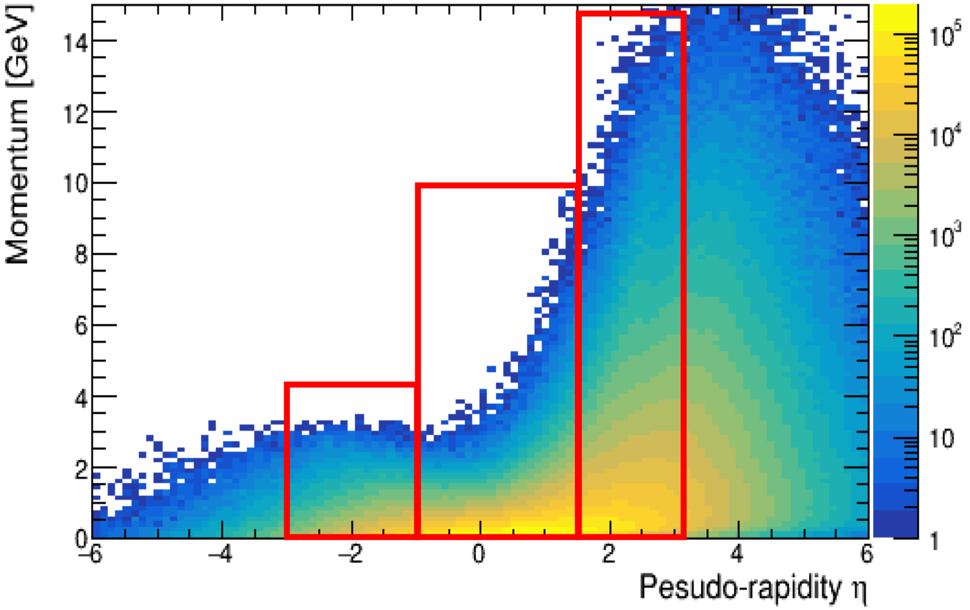
Hamamatsu SiPM linearity (60k pixels)



Electron distribution



Photon distribution



Summary and Outlook

- Homogeneous EMC with **pCsI crystal** for the **electron endcap**
- Sampling EMC with **Shashlik** design for the **central barrel** and **hadron endcap**
- Simulation and event reconstruction are available based on current design, more details is considering to meet the EicC physics requirements
- Hardware research and development is ongoing in the laboratory

Work ongoing:

- Design and light yield optimization for both Shashlik and crystal prototypes
- Test platform setup and upgrade
- DAQ, SiPM and APD test

Thanks!

Welcome to join: dxlin@impcas.ac.cn , tianye@impcas.ac.cn

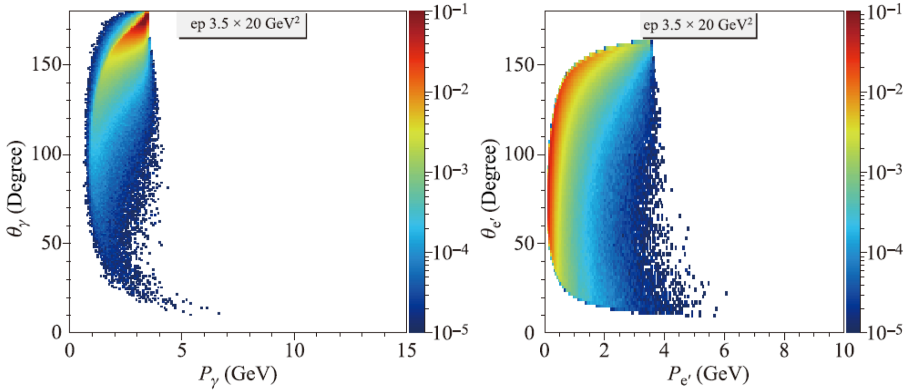
THANK YOU!

EicC requirement on ECal

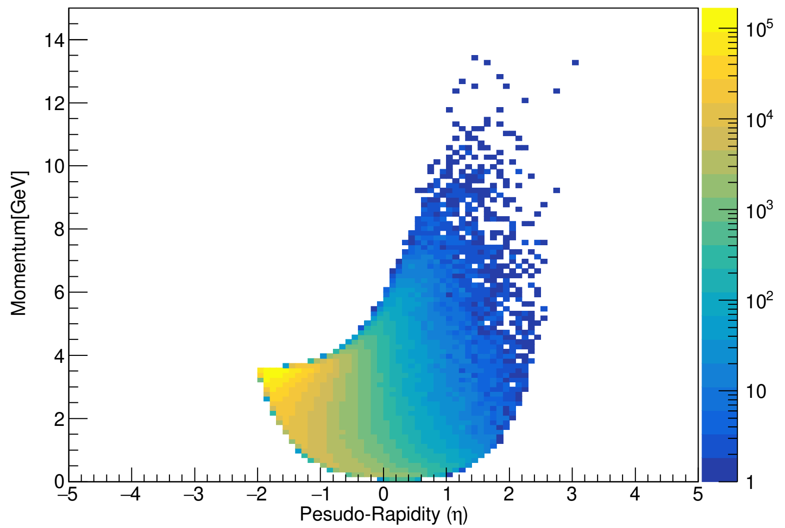
EicC need a general purpose spectrometer, in which the Ecal plays important role to detect and identify:

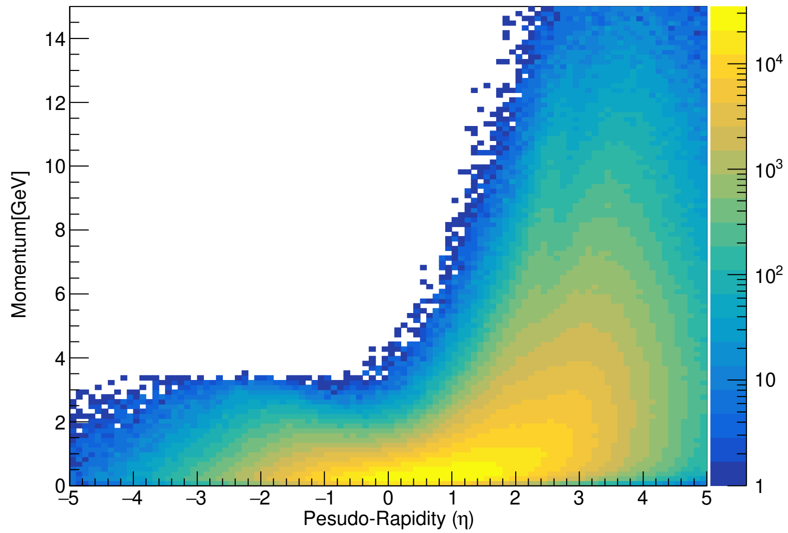
- **Scattered electrons** (especially in the electron forward region)
- **Photons** (eg. photon from DVCS or π^0 decay…)

> ➢ **Ecal@EicC**: large solid angle coverage, good resolution, momentum up to 15 GeV/c



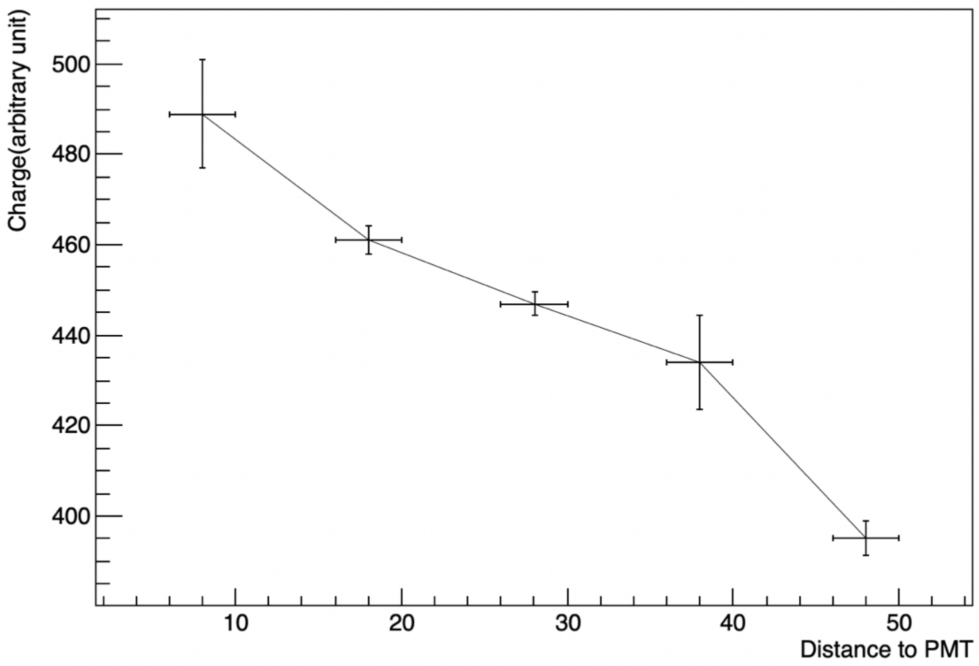
Distribution of photon and electron in DVCS





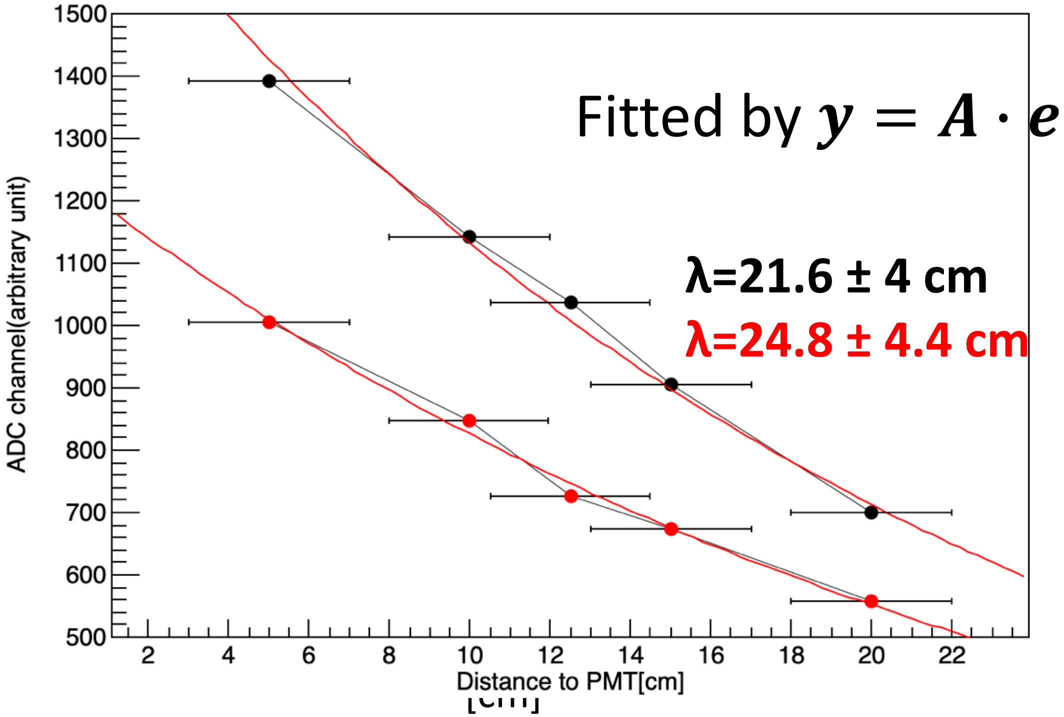
Attenuation length test

Shashlik signal for different locations



The attenuation of Shashlik at different positions is not significant, the maximum is 20%, which is mainly affected by the attenuation length of WLS fiber.

CsI(Tl) crystal for different locations



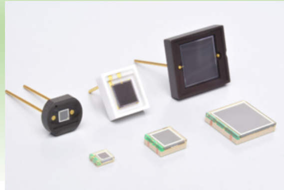
Short attenuation length confirmed, even though the appearance of crystal is transparent!

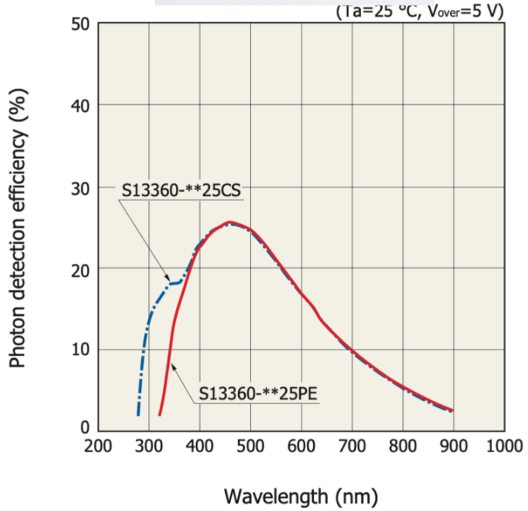
Estimation of replacing APD by SiPM

- SiPM : low price, low noise(high signal/noise ratio), no amplification required
- For 4 GeV electron detection
  - **APD** (two 100 mm^2): total Np.e.: 4GeV * 150 p.e./MeV = 600 kp.e (3 kp.e/mm^2)
  - **SiPM** : take into QE difference, 2.15 kp.e/mm^2 is required, need 6 SiPMs
    - **6 um** : 27 kp.e/mm^2 (max 3 x 3 mm^2 北师大)
    - **10 um** : 10 kp.e/mm^2 (max 3 x 3 mm^2)
    - **15 um** : **4.5 kp.e/mm^2** (6 x 6 mm^2 product is available from 北师大)

	Pixel [μm]	Max sensitive area [mm]	Pixel/area [pixel/mm²]	Gain [x10⁵]	Max Quantum Efficiency (QE)	Drak noise rate [kHz/mm²]
SiPM 北师大	15	6.14	4.4k	4	45%	250
	10	3	10k	1.7	36%	400
	6	3	2.7k	0.8	30%	276
SiPM 滨松	15	3	4.4k	—	32%	—
	10	3	10k	—	18%	—
APD滨松		10		0.0005	85%	

SiPM





APD