ECal simulation and hardware

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On behalf of EicC ECal group

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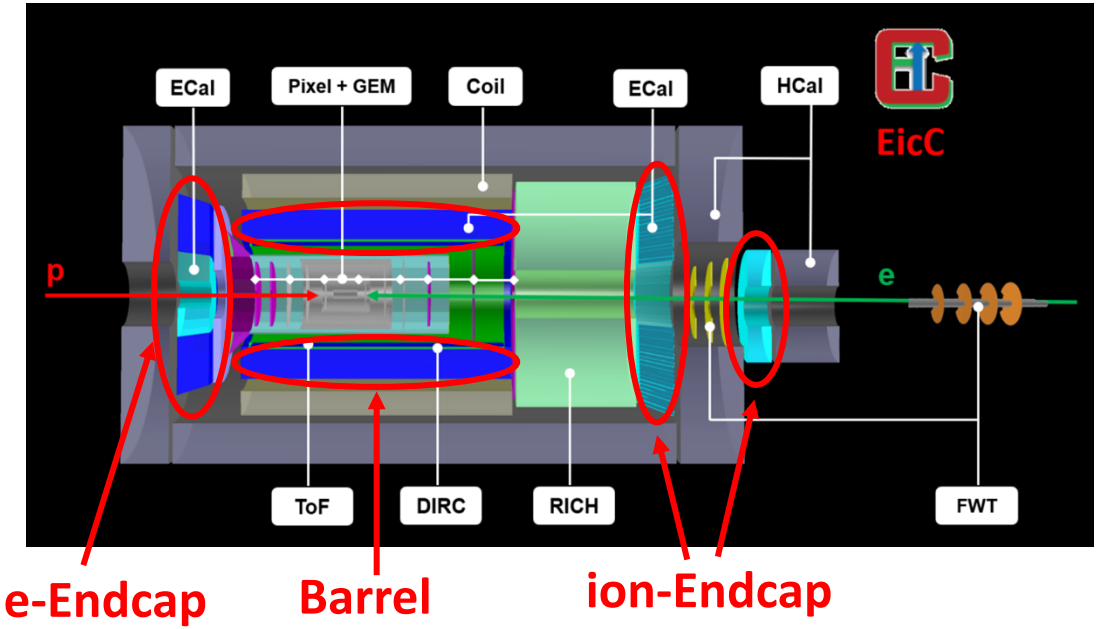
Outline

- EicC ECal detector introduction
- ECal detector simulation
- Shashlik prototype and CsI crystal test
- ECal CDR outline and discussion
  - e^-/π^- separation
  - ECal DAQ

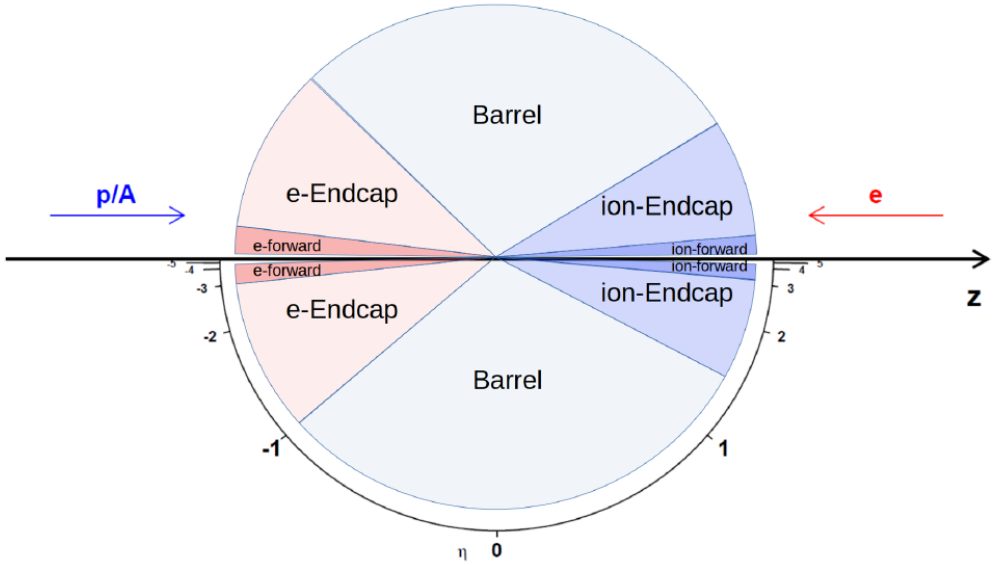
Design of the ECal for EicC

- Essential requirement
  - **e&γ detection and measurement**
  - **e^-/π^- separation**
- Detailed requirement
  - Large solid angle[-3, 3] and energy dynamic range
  - Energy and angle resolution
  - π^0 reconstruction
  - γ/n separation
- Other requirement
  - Short barrel radius -> area difference between front and rear
  - Time resolution
  - ……

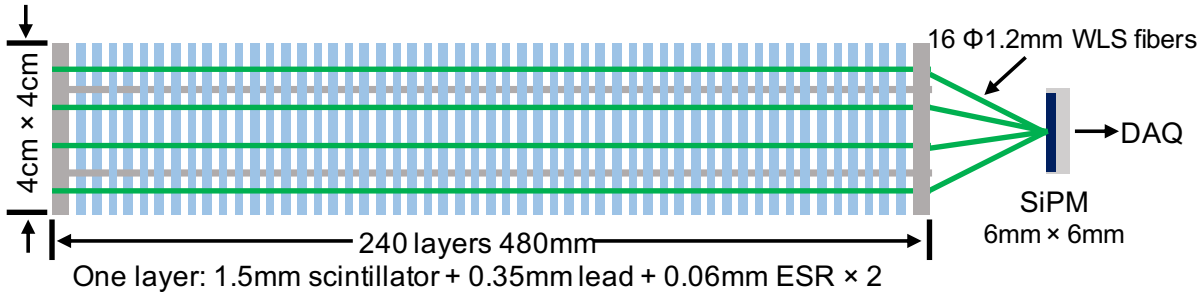


Basical ECal special requirement:

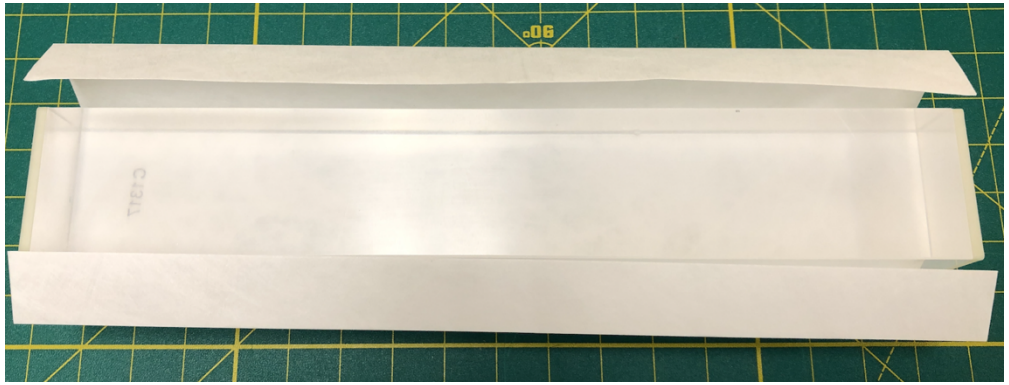
- **E-endcap:** good energy resolution
- **Barrel:** short radius, good angle resolution
- **Ion-endcap:** angle resolution, π^0 reconstruction, PID. Need additional small angle detector.



ECal design and simulation

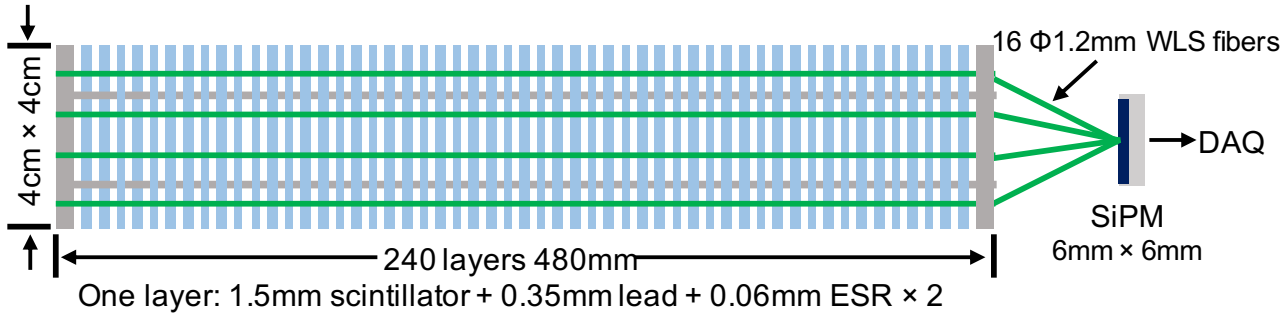


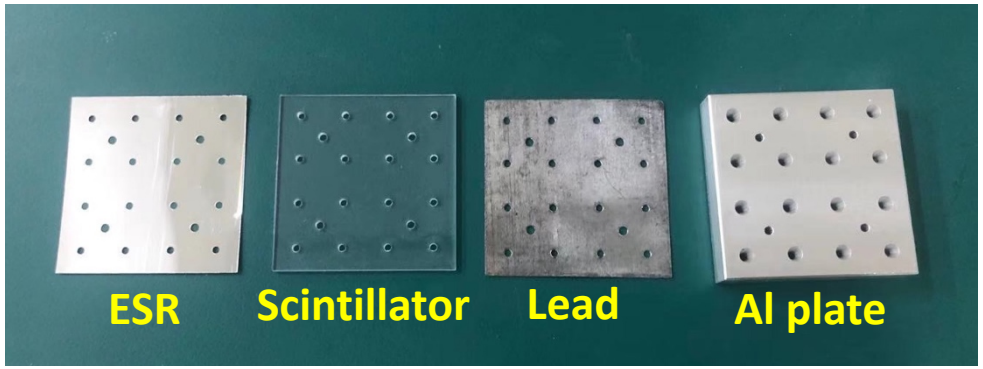
EicC Shashlik ECal



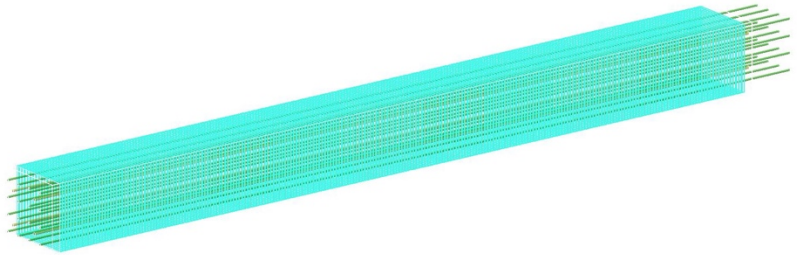
CsI Crystal

Shashlik ECal design



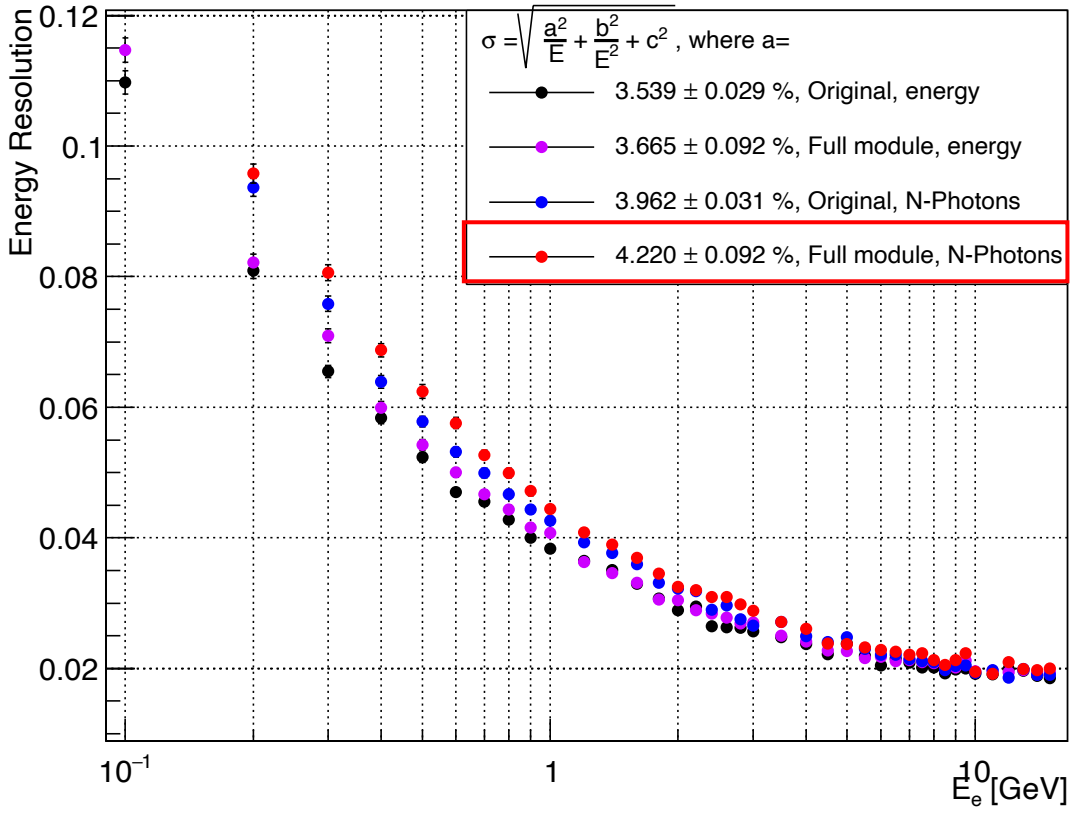


- **Longitudinal:**
  - (1.5 mm scintillator + 0.35 mm lead+ 65 μm reflector *2) * 240 layers
  - **Sampling ratio**: 0.33
  - **Radiation length**: total 16 X_0 (X_0: 2.81 cm)
  - **Length**: 15 mm external fiber, 6 mm Al Plate + 470 mm + 8 mm Al Plate + 45 mm fiber bundle + 15 mm SiPM readout = **560 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

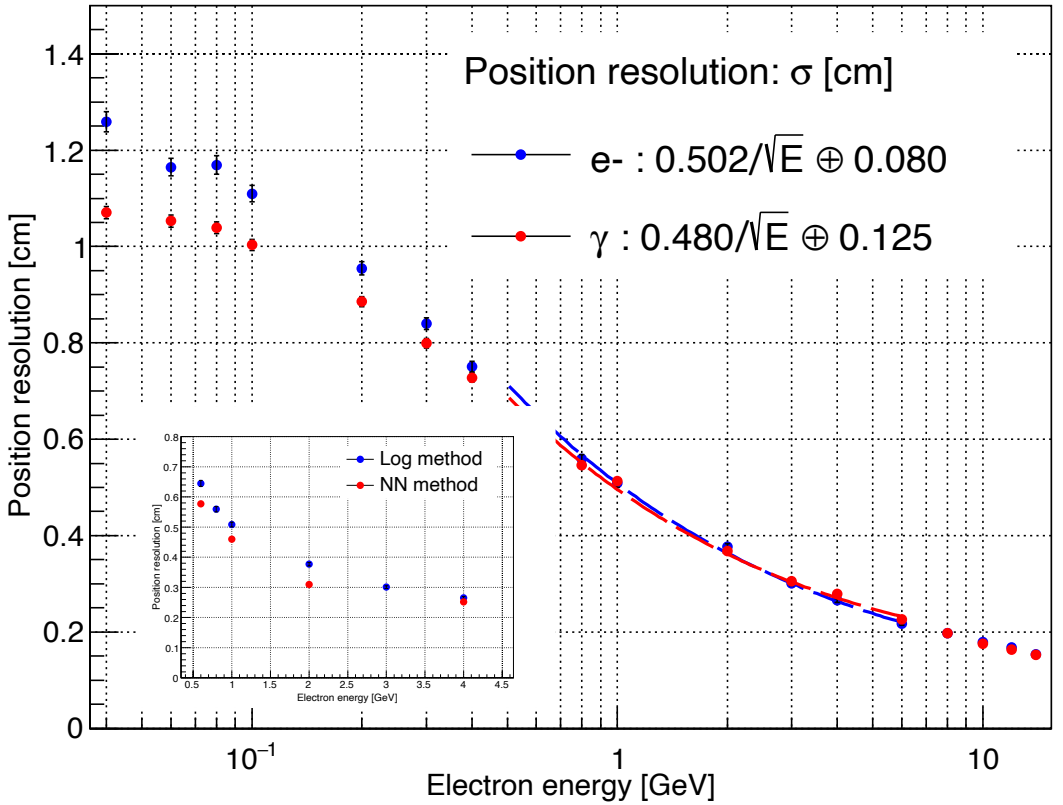


Shashlik array simulation result

Energy resolution



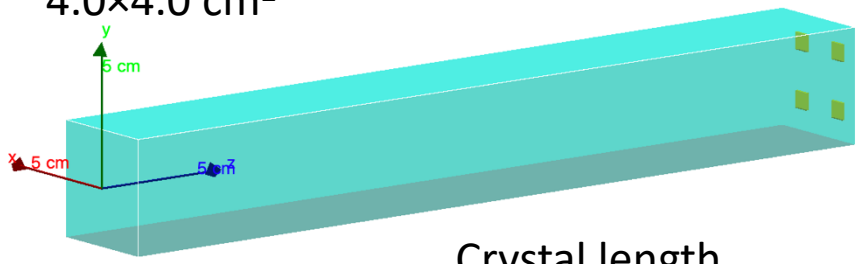
Position resolution



CsI module array simulation result

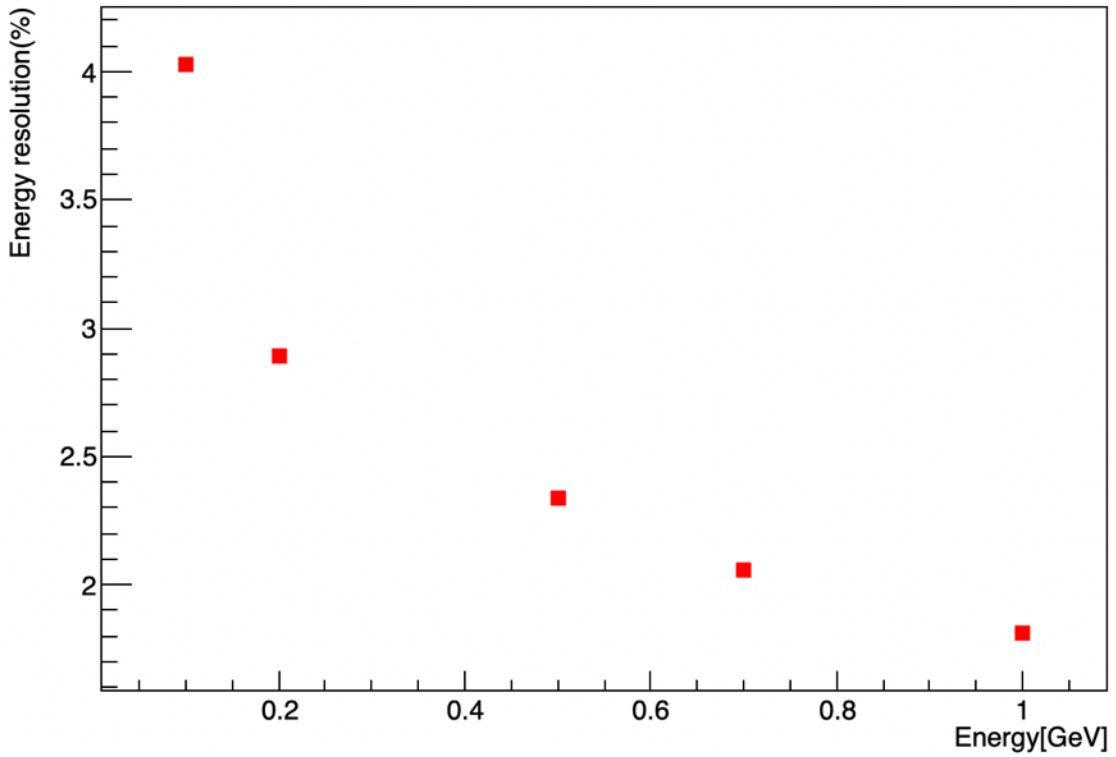
- Preferred to use pCsI, readout by APD
- Very good energy resolution: 1.8%@1GeV
- Better position resolution(0.48cm@1GeV) than shashlik(0.5cm@1GeV)

Front size
4.0×4.0 cm^2

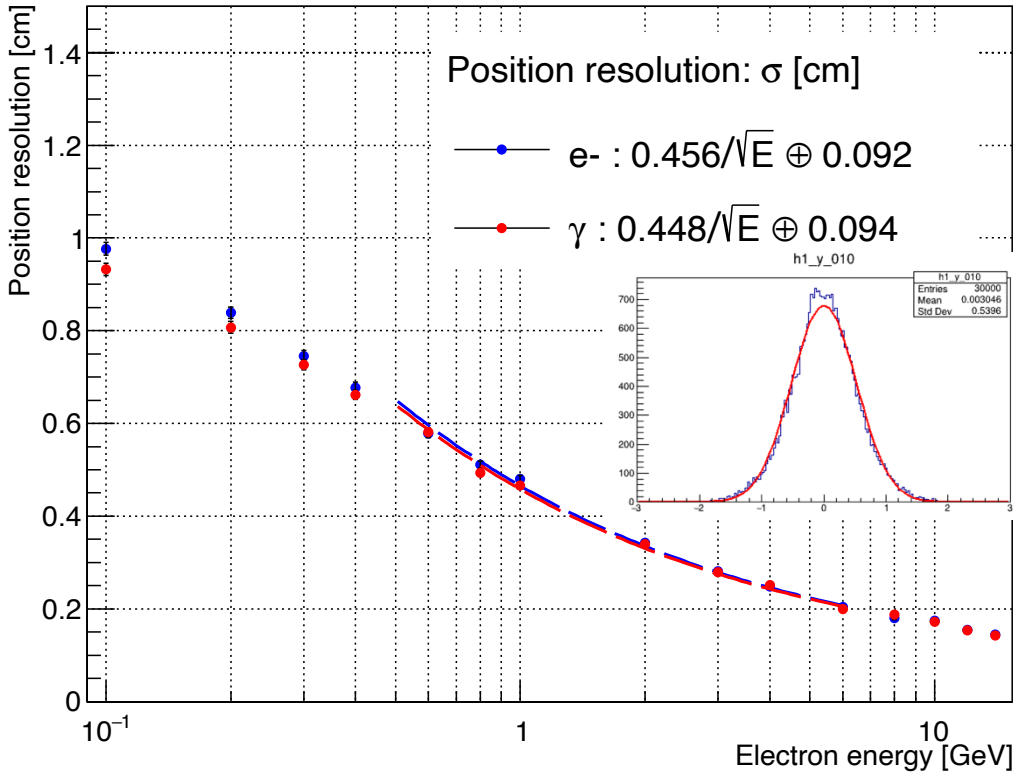


Crystal length
30cm (16 X_0)

Energy resolution

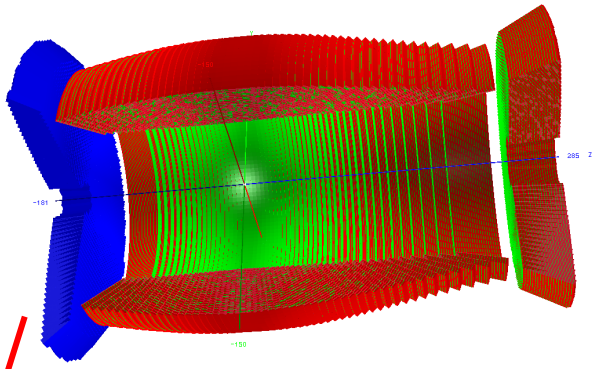


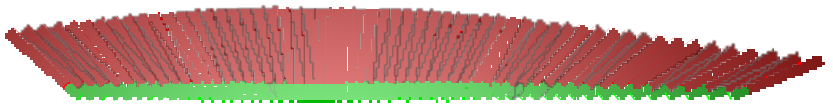
Position resolution

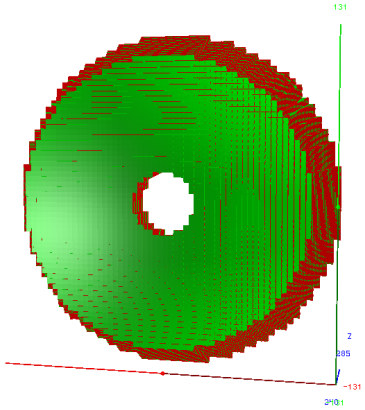


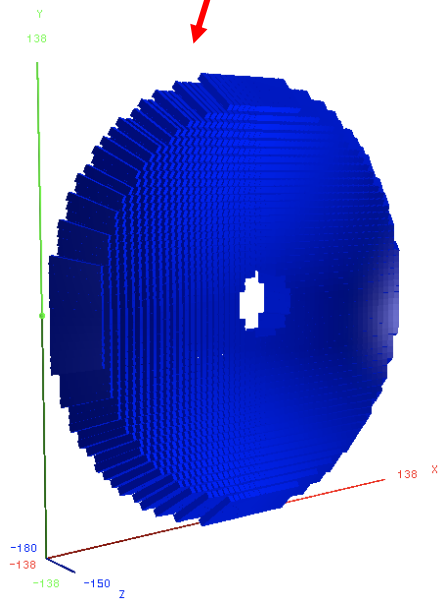
ECal detector design

The design in EicC ECal simulation.







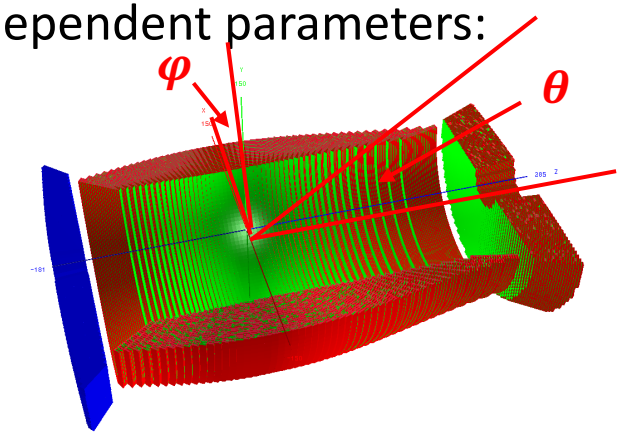


Parameter	value
Distance to IP	1.5 m
η acceptance	(-3, -1)
Inner radius	15 cm
Outer radius	128 cm
length	30 cm
Radiation length	16 X_0
Front size	4×4 cm^2
Rear size	4.8×4.8 cm^2
Photon detector	APD
Total modules	~2700

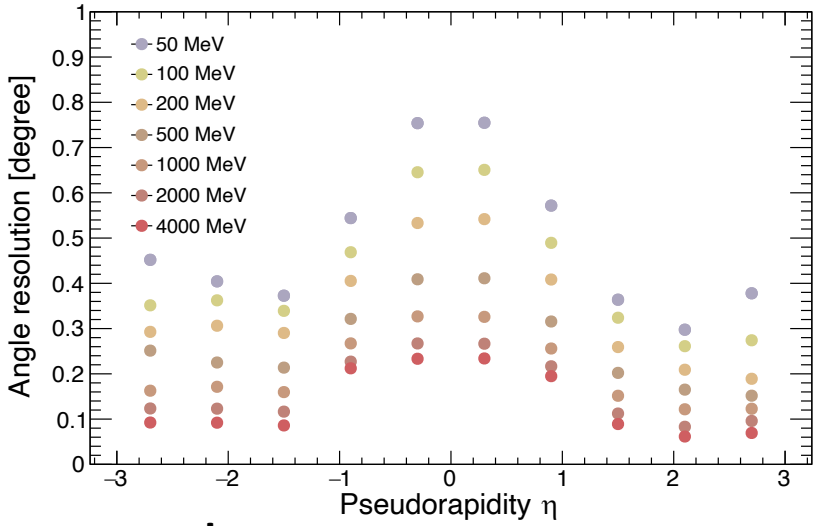
Parameter	**Barrel**	**Ion-Endcap**
Distance to IP	2.4 m	
η acceptance	(-1, 1.5)	(1.5, 3)
length	60 cm	
Radiation length	16 X_0	
Molière radius	5.02 cm	
Front size	4×4 cm^2	
Rear size	5.7×5.7 cm^2	4.7×4.7 cm^2
N layers	240	
Scintillator thickness	1.5 mm	
Lead thickness	0.35 mm	
Reflector thickness	0.065 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

Single e- reconstruction

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

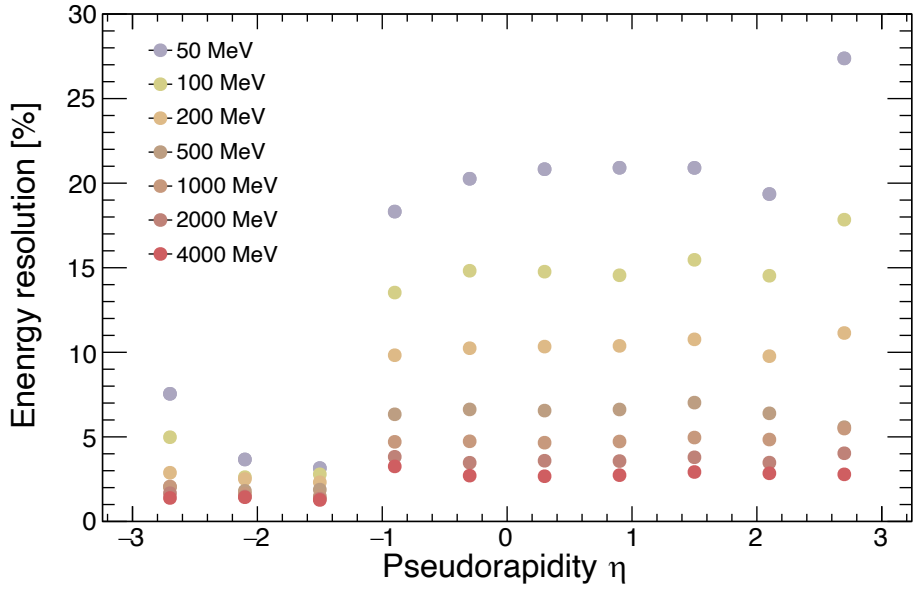


Reconstructed angle $\Delta\theta$ vs. Pseudorapidity η



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

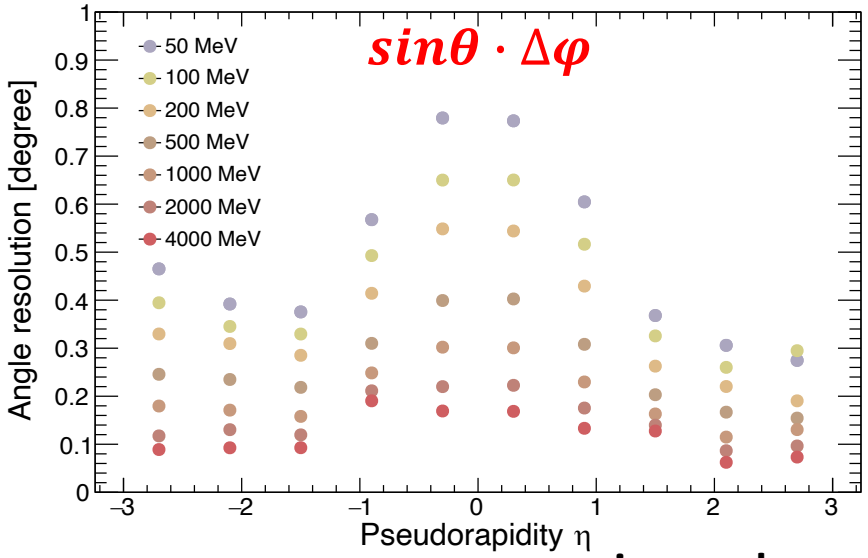
e- energy ΔE & resolution v.s. Pseudorapidity



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

About 5%[1GeV]

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

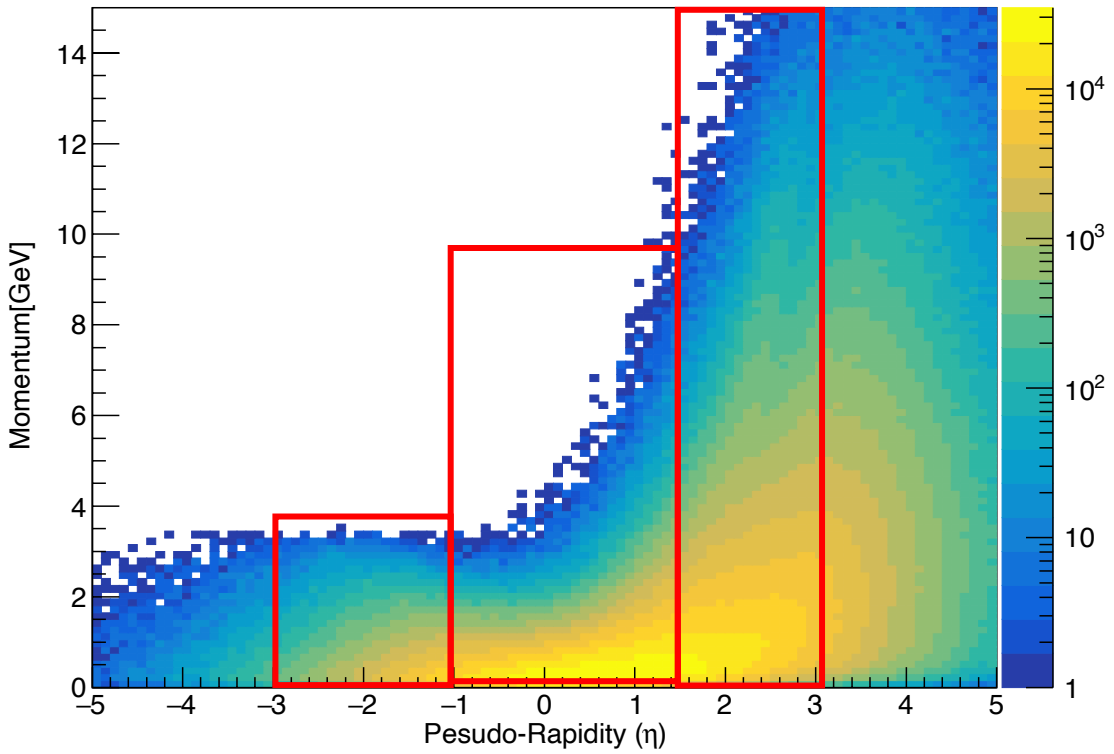


e-endcap **barrel** **ion-endcap**

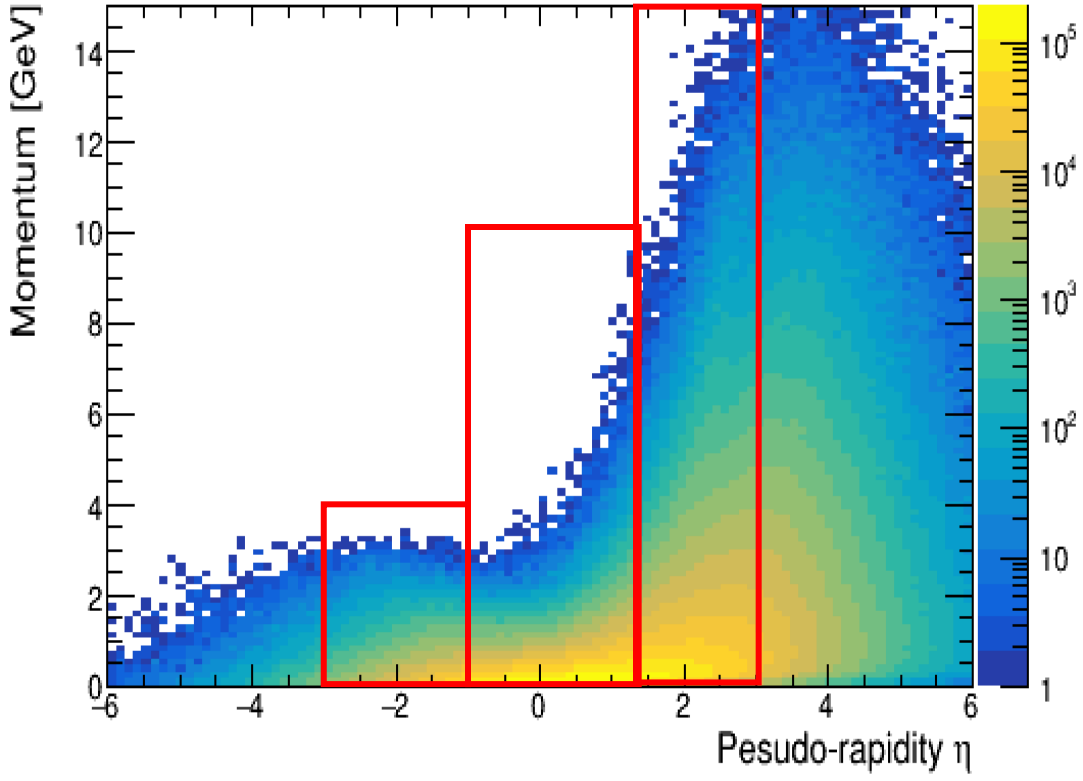
π^0 and γ distribution

- 90% gammas are generated from π^0 decay.
- Max momentum 3.5 GeV(e-endcap crystal), 10 GeV (barrel), 15 GeV (ion-endcap)

π^0 distribution



Final state γ distribution



π^0 acceptance

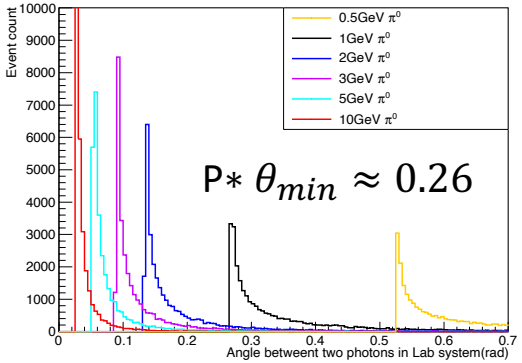
➢ **π^0 detection efficiency:**

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

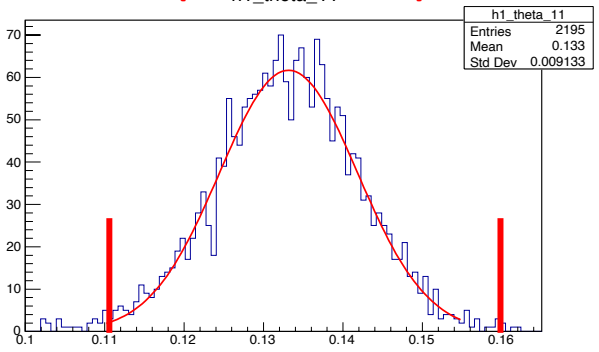
Intrinsic

Design and algorithm

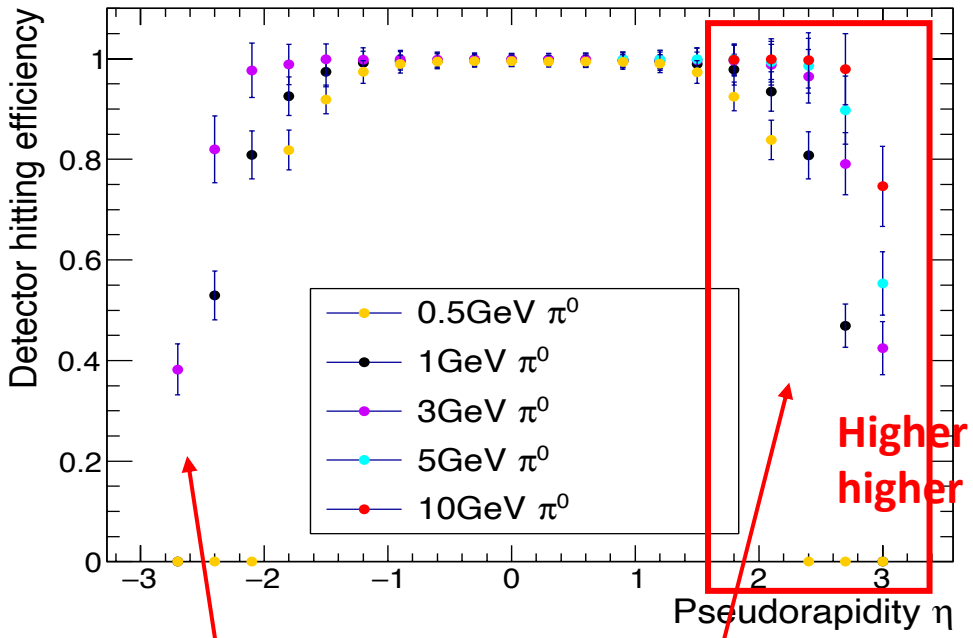
Angle of two photon in Lab system



π^0 invariant mass cut (110-160MeV)



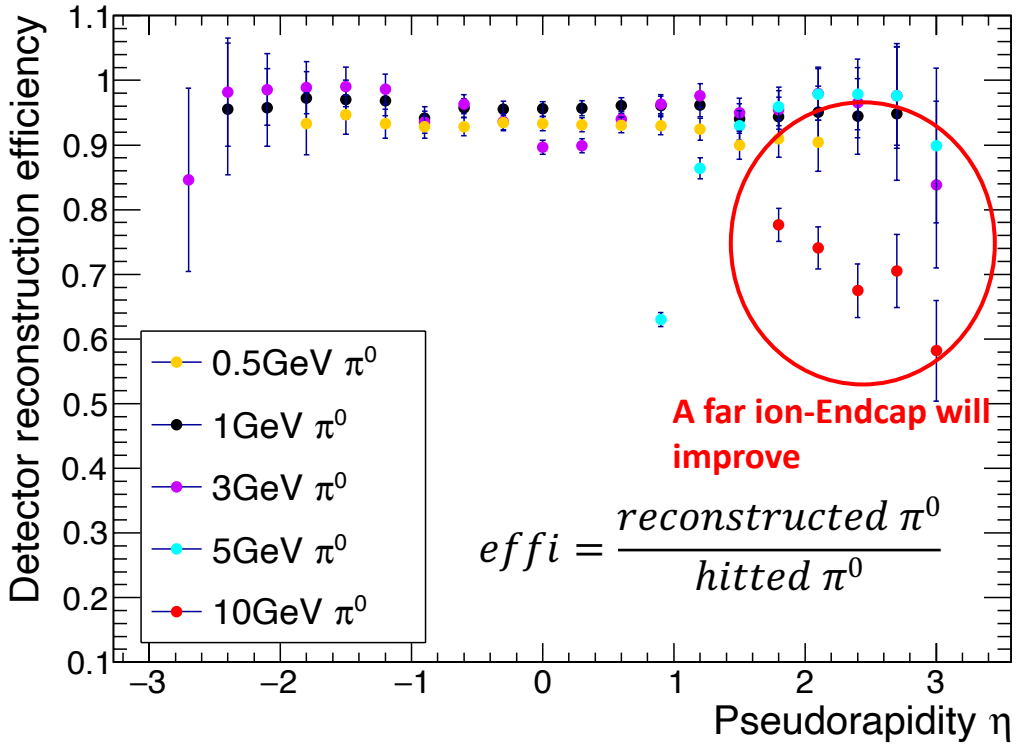
ECal geometry acceptance of π^0



Higher momentum, higher acceptance

Photon escape from hole

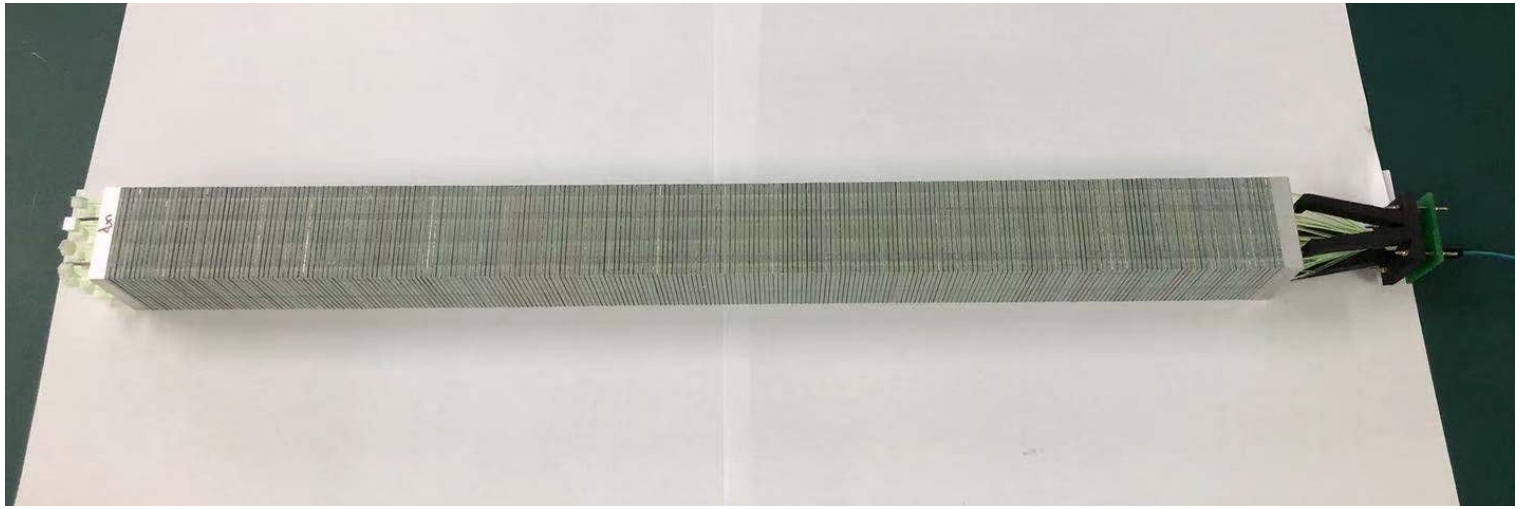
π^0 reconstruction efficiency

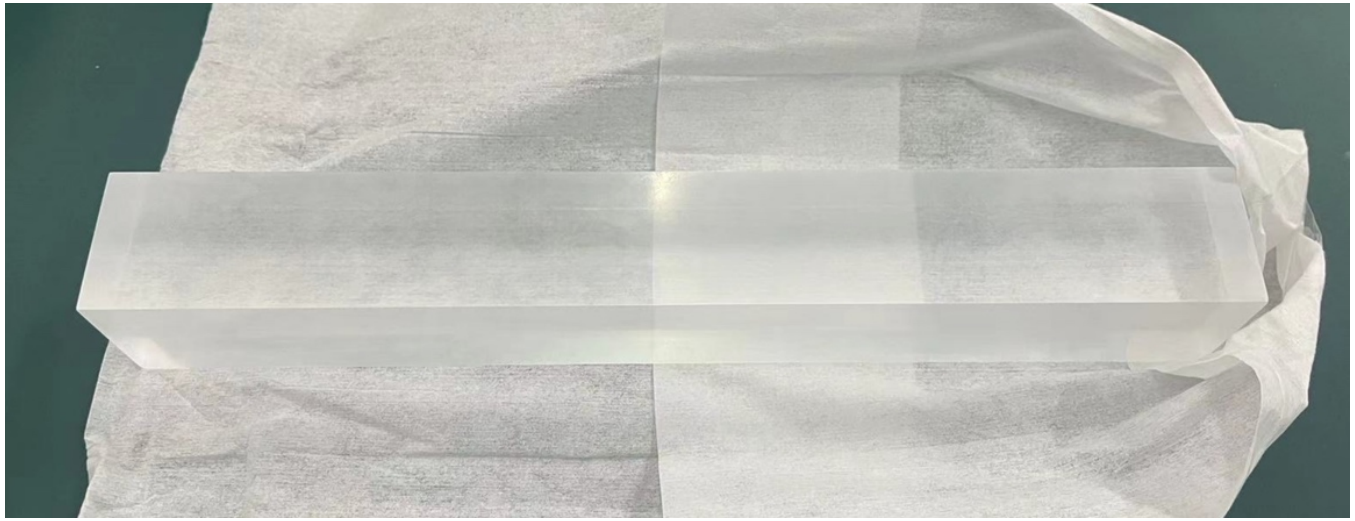


A far ion-Endcap will improve

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

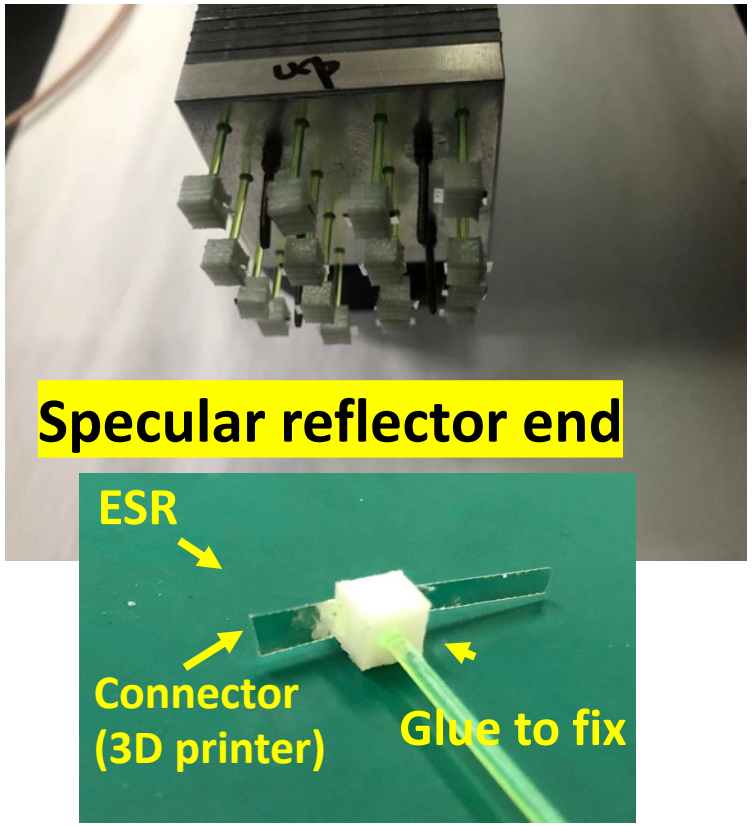
ECal hardware work



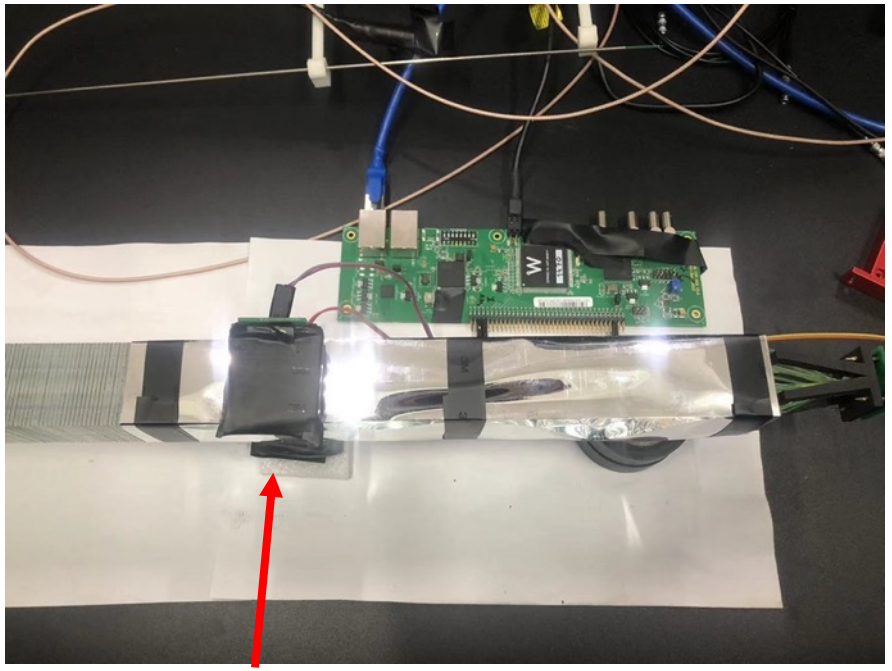


Shashlik horizontal cosmic ray test setup

Add fiber end mirror

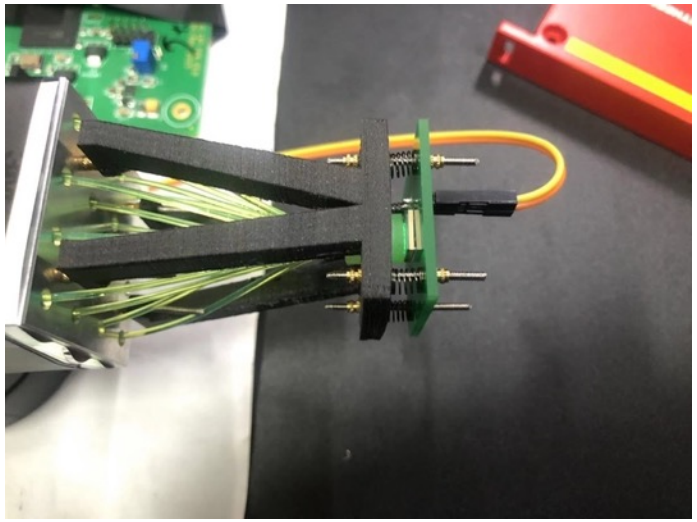


ESR coating(temporary)



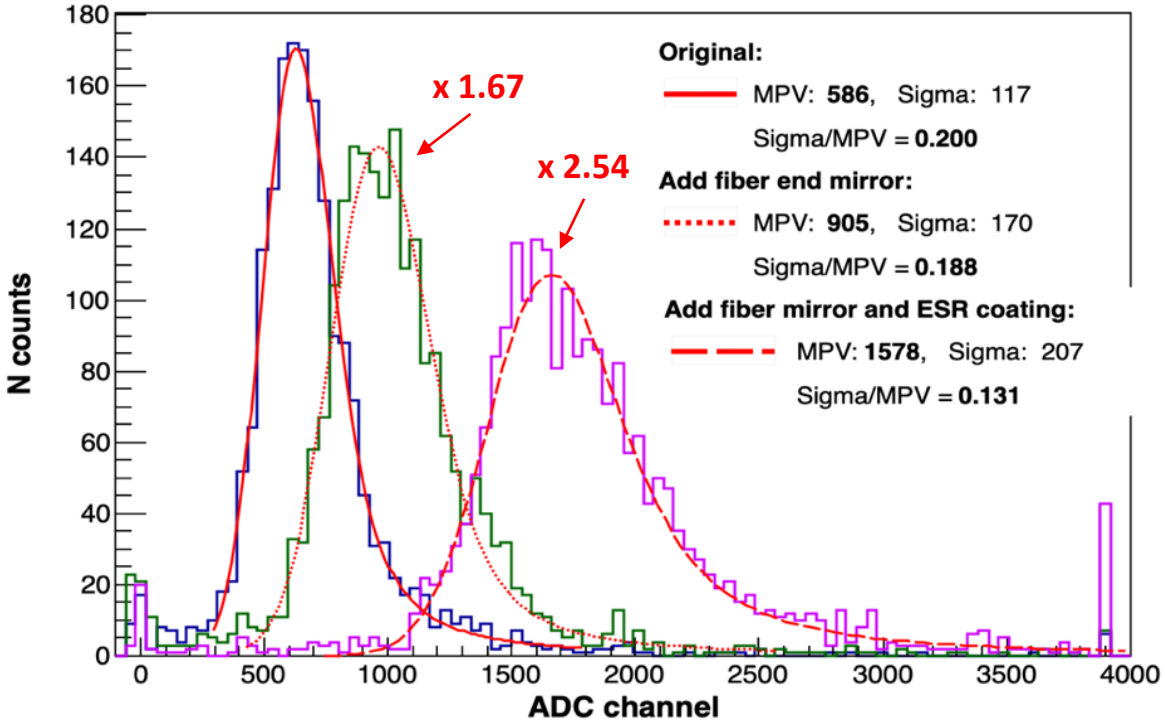
Trigger scintillator that places at the center of module has the same size as module laterral size.

Fiber bundle – SiPM coupling

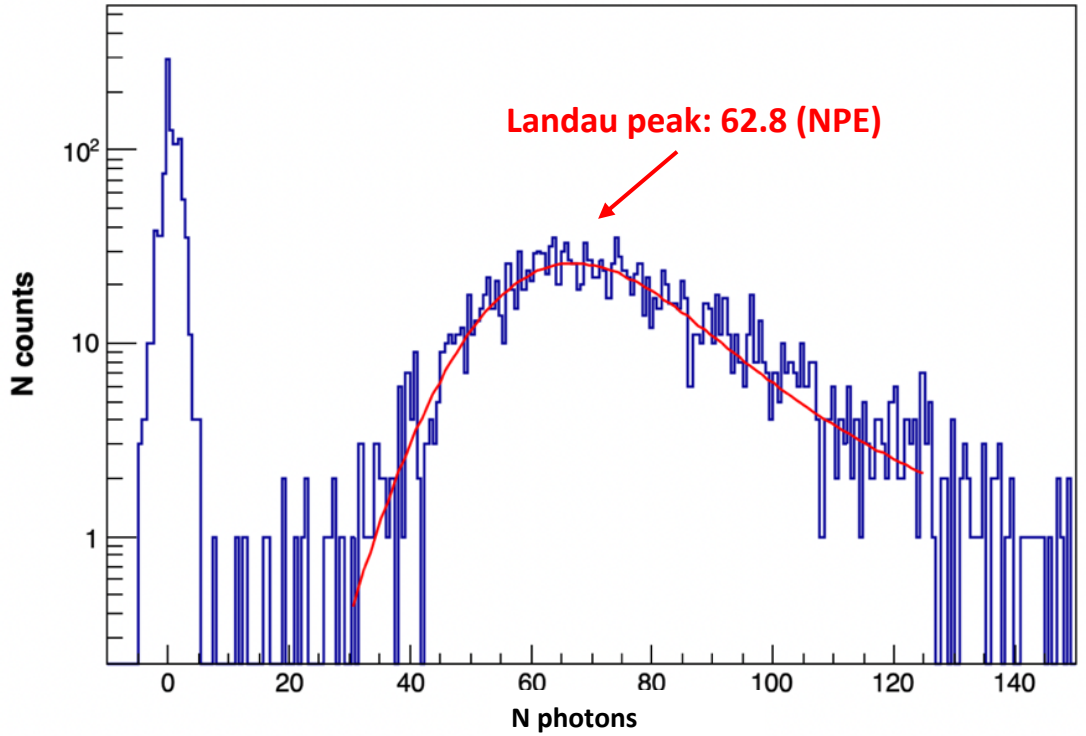


Horizontal test result

Light yield improvement with reflector (SiPM)



N photons spectrum (PMT)

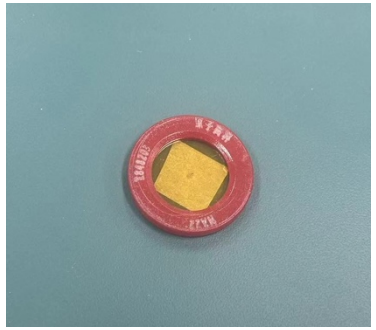


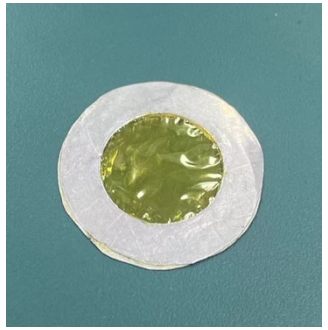
- **62.8** NPEs is acquired, similar to NIKA **63** NPEs that use better scintillator

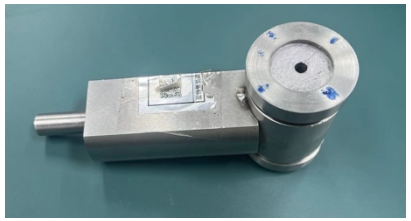
CsI(Tl) and pCsI module

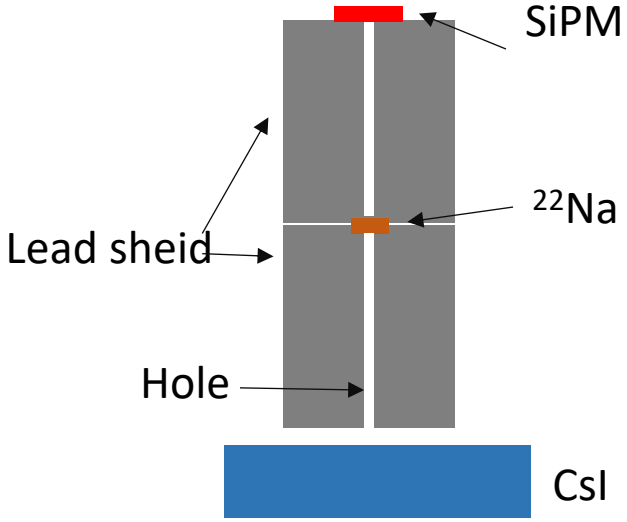
- CsI(Tl)（IMP）：6x6x30 cm, 2.5(3.5)x3.5x25 cm
- pCsI(Hamamatsu): 4x4x30 cm
- pCsI(硅酸盐所): 4x4x30 cm

Radioactive source test setup

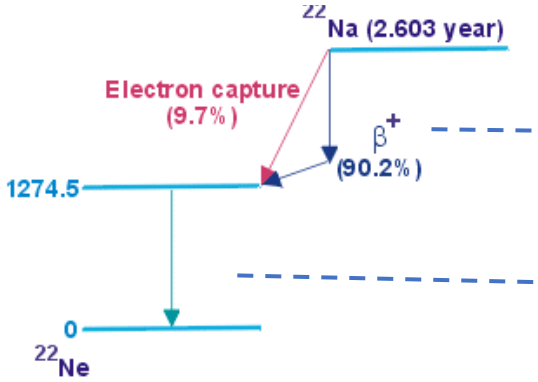




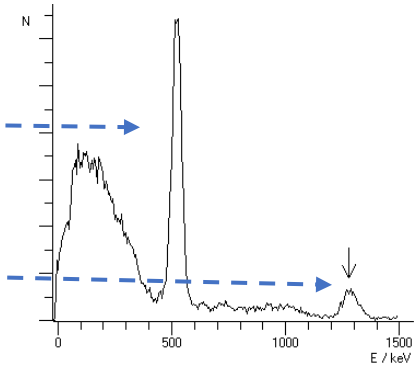


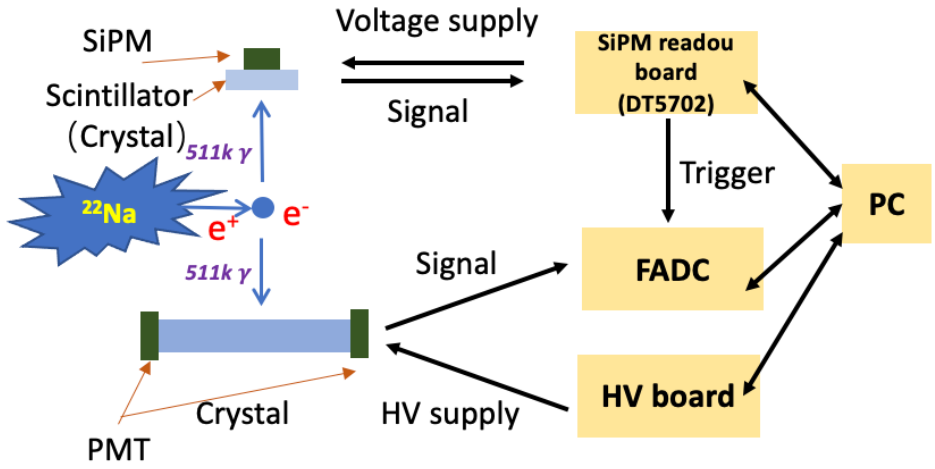


Decay chain



Energy deposit spectrum

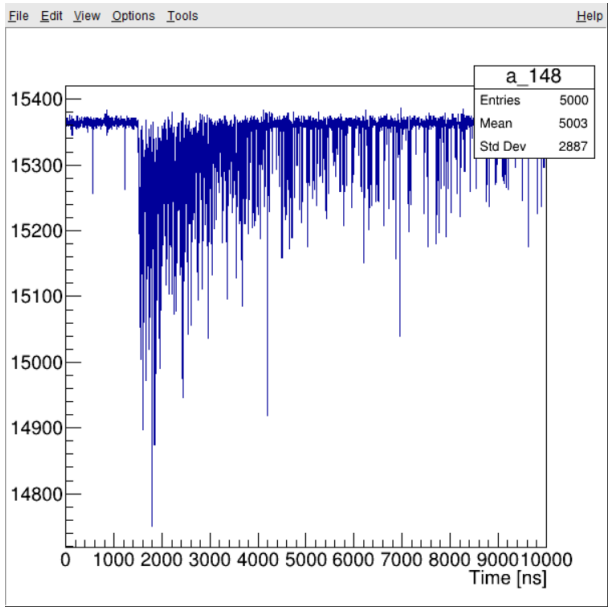




- 22Na borrowed from other group in IMP
- Both sides coupled to PMT
- Optical silicone grease for connection between PMT and CsI
- Wrapped by ESR as reflector

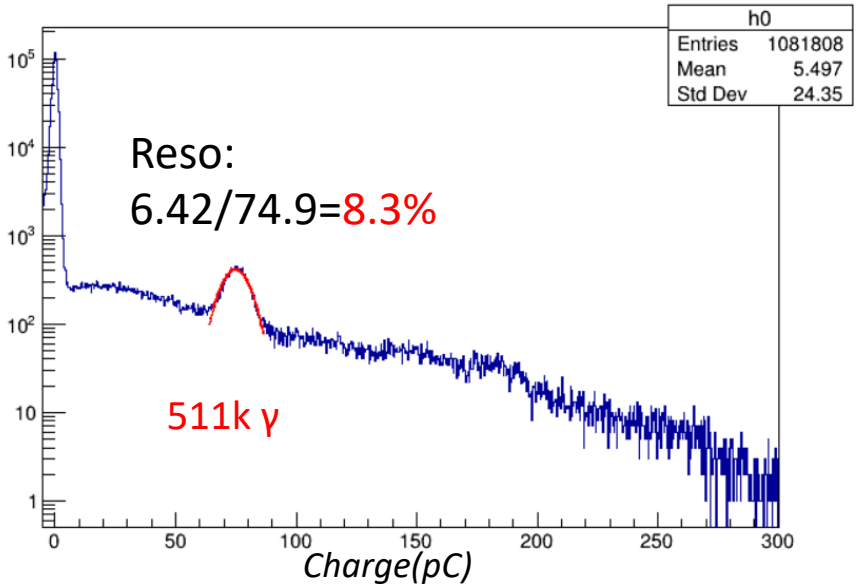
CsI(Tl) ^{22}Na test

Typical CsI(Tl) 511k γ Spectrum



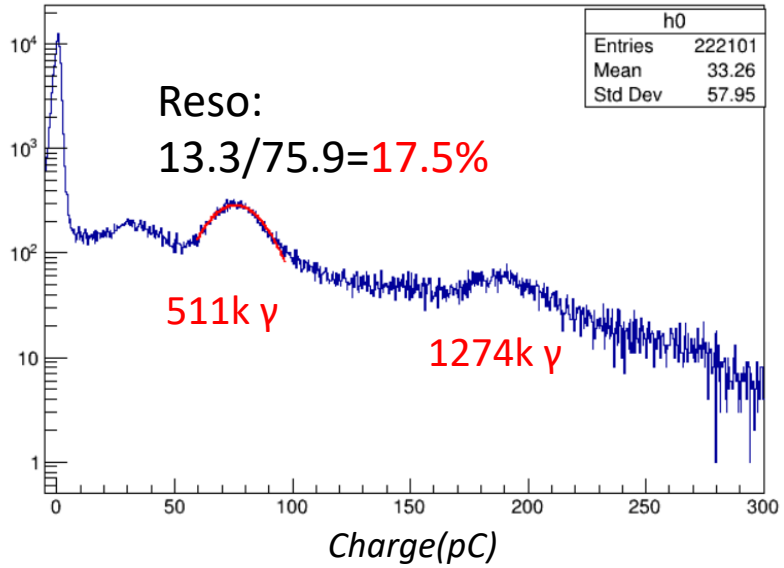
With collimator

(*Two γs back to back*)



No collimator

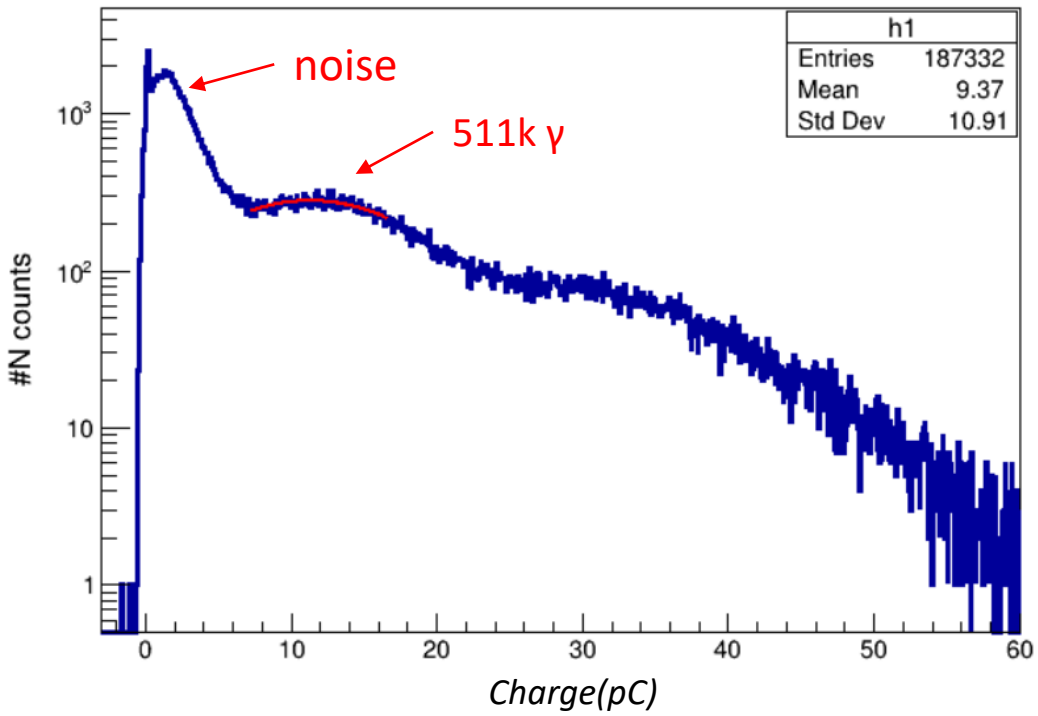
(*^{22}Na close to detector*)



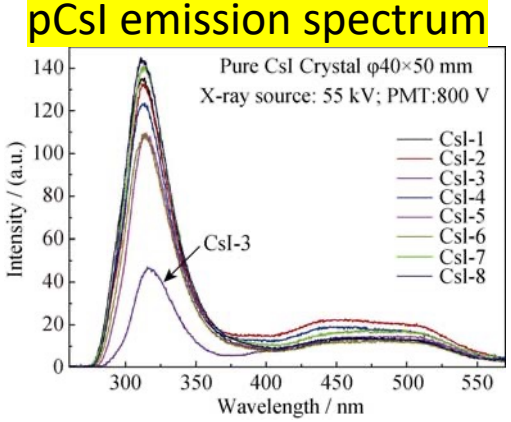
Pure CsI ^{22}Na test

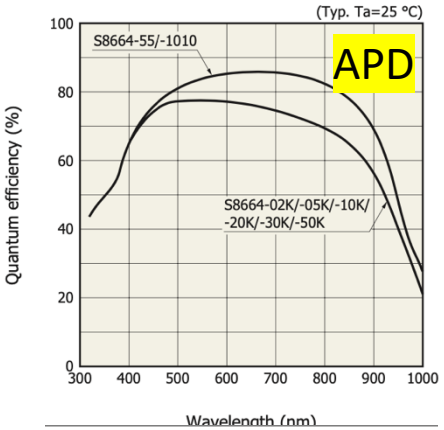
- In theory, 1/10 light yield of CsI(Tl). Very short decay time.
- Light yield is much less than expected for the dis-match pCsI spectrum with PMT
- Will use APD(UV SiPM), or cosmic ray test

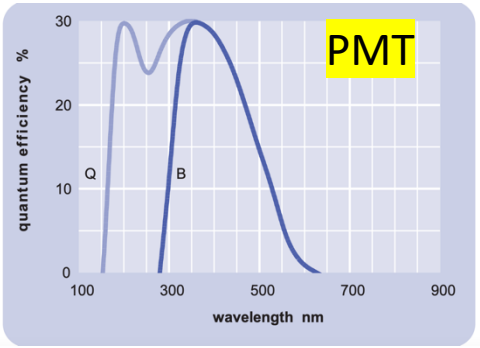
Energy deposit spectrum

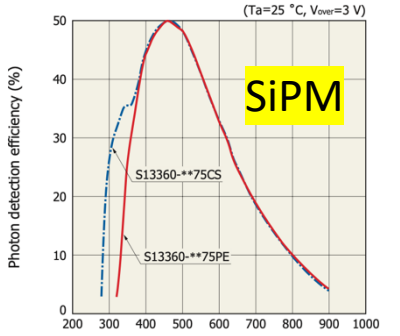


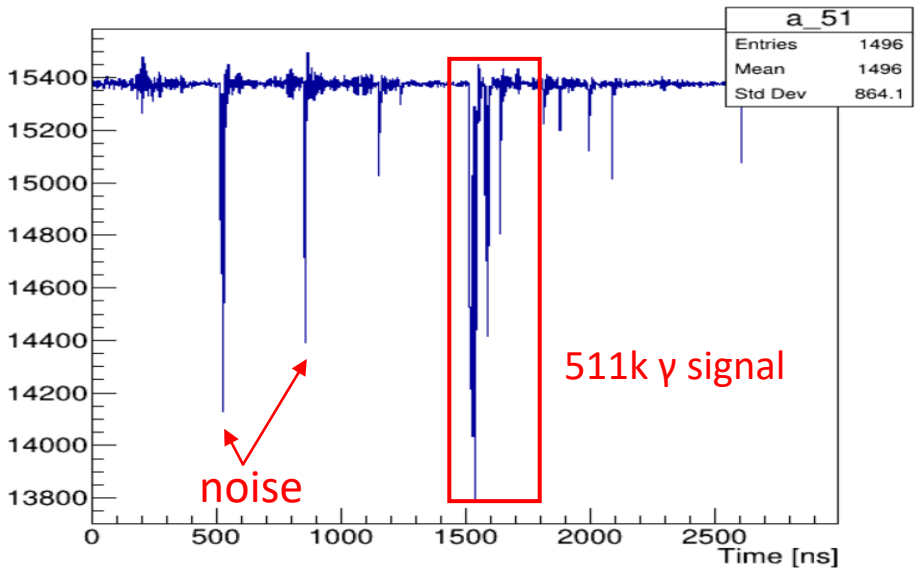
pCsI emission spectrum











ECal CDR outline

Finished:

- ✓General design
- ✓Software and reconstruction
- ✓Performance (energy, position, PID)
- ✓Optical simulation
- ✓Prototype module

On study:

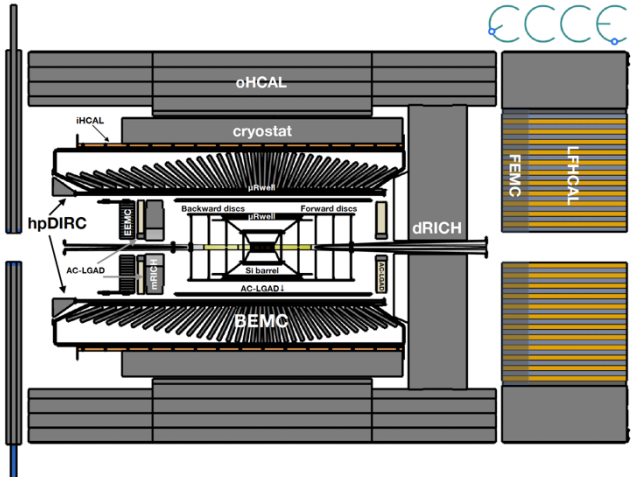
- ➢More detailed performance simulation
- ➢DAQ system
- ➢Shashlik trapezoid design
- ➢CsI crystal and Shashlik module hardware test

Contents

EIC detector e/π separation performance

For e/π PID, EIC detector:

- **e-endcap**: mRICH (0.6-2.5 GeV) + TOF (<0.5 GeV) + ECal
- **Barrel**: (hp)DIRC (0.3-1.2 GeV) + TOF (<0.45 GeV) + ECal
- **Ion-endcap**: dRICH (0.6-15 GeV) + TOF (<0.6 GeV) + ECal



π suppression ratio requirement

Detector subdivision	η coverage	Yellow report	ECCE detector
		π suppression ratio	
E-endcap	-3.5 to -2.5	10^4	10^4
	-2.5 to -1	10^2-10^3	
Barrel	-1 to 1	10^2	10^2-10^4
Ion-endcap	1 to 3.5		

TOF

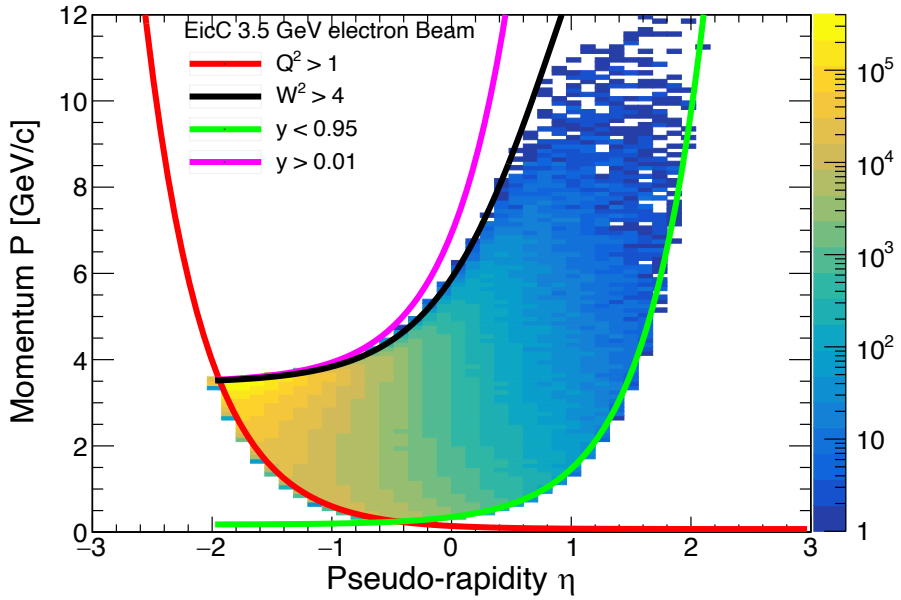
PID	ETTL	CTTL	FTTL
e/π	< 0.5	< 0.45	< 0.6
π/K	< 2.1	< 1.3	< 2.2
K/p	< 3.3	< 2.2	< 3.7

Cherenkov detector

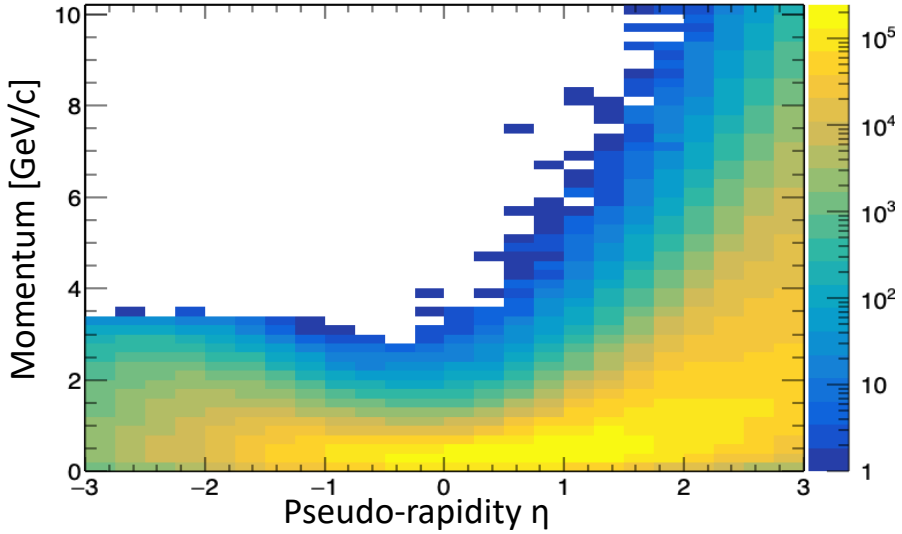
PID	Mode	mRICH	hpDIRC	dRICH aerogel	dRICH gas
π/K	Ring Imaging	$2-9$	$1-7$	$2-13$	$12-50$
	Threshold	$0.6-2$	$0.3-1$	$0.7-2$	$3.5-12$
e/π	Ring Imaging	$0.6-2.5$	< 1.2	$0.6-13$	$3.5-15$
	Threshold	< 0.6	–	< 0.6	< 3.5

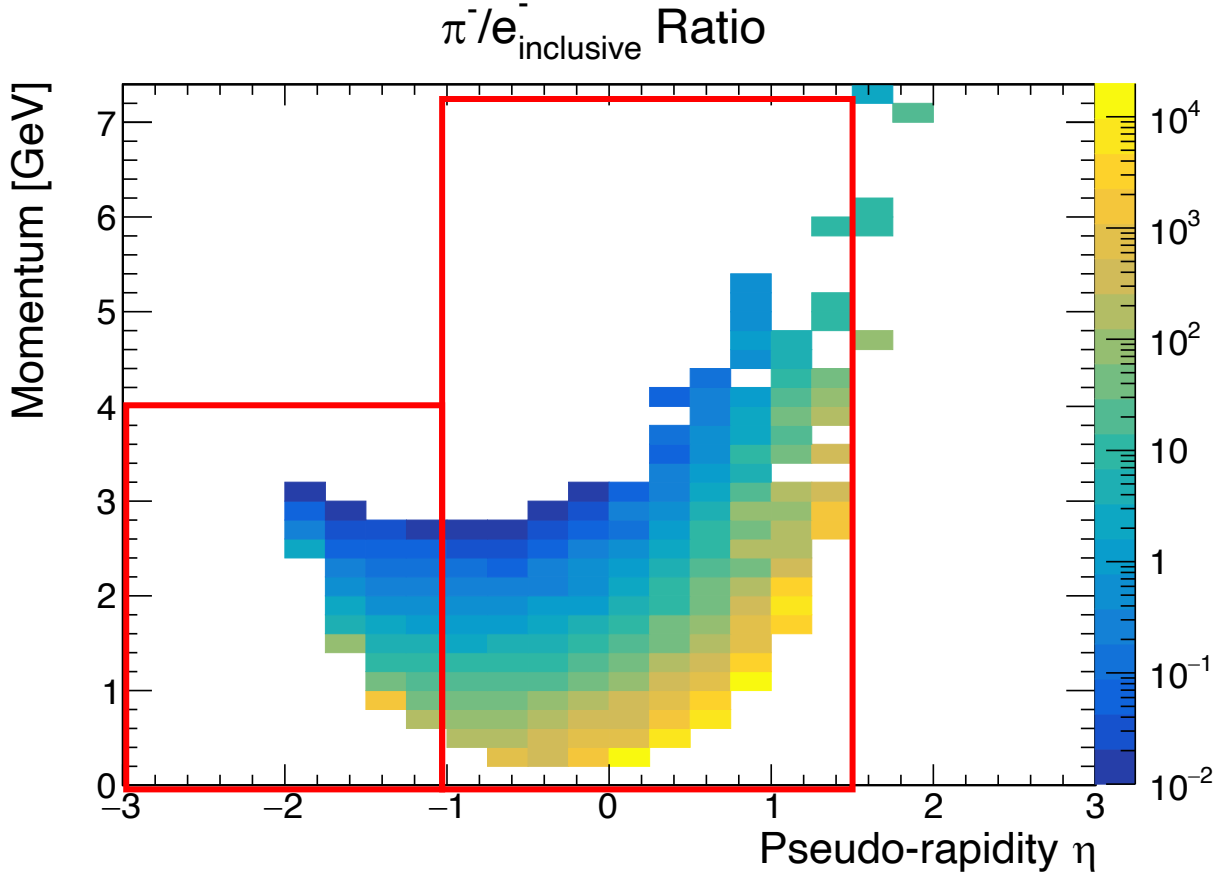
e^-/π^- separation

Inclusive electrons ($Q^2>1$)



Pion background





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

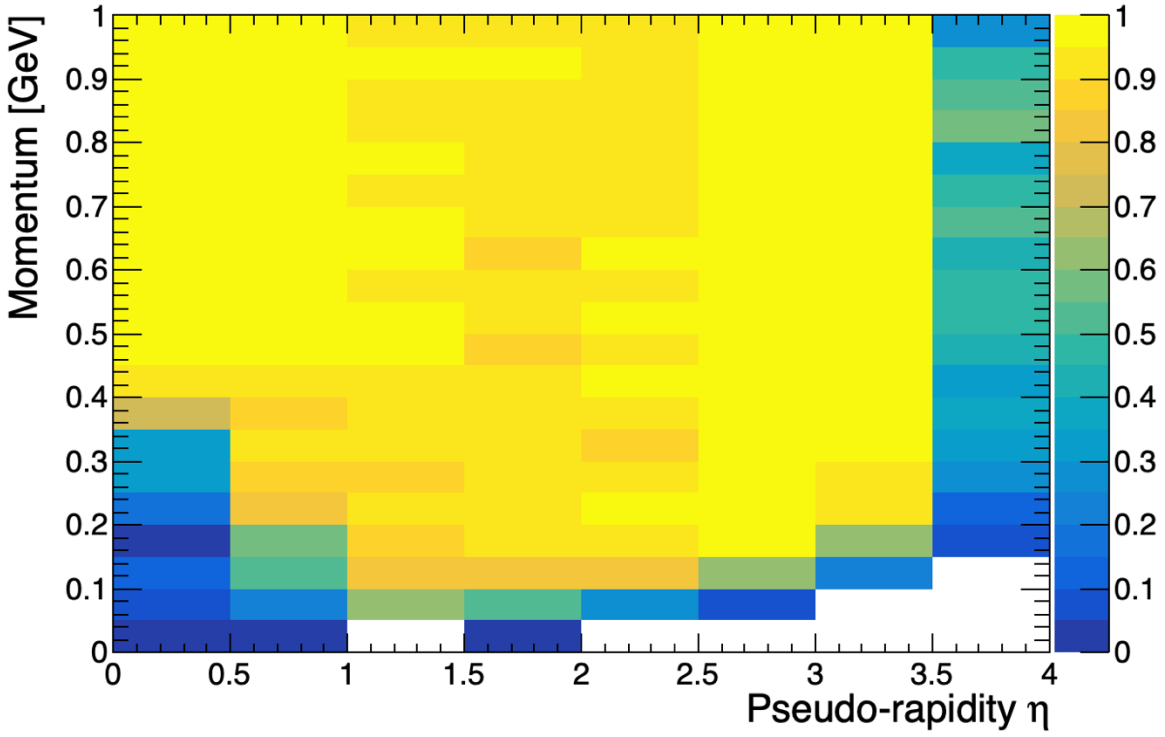
Low momentum electron detection

Influenced by two factors:

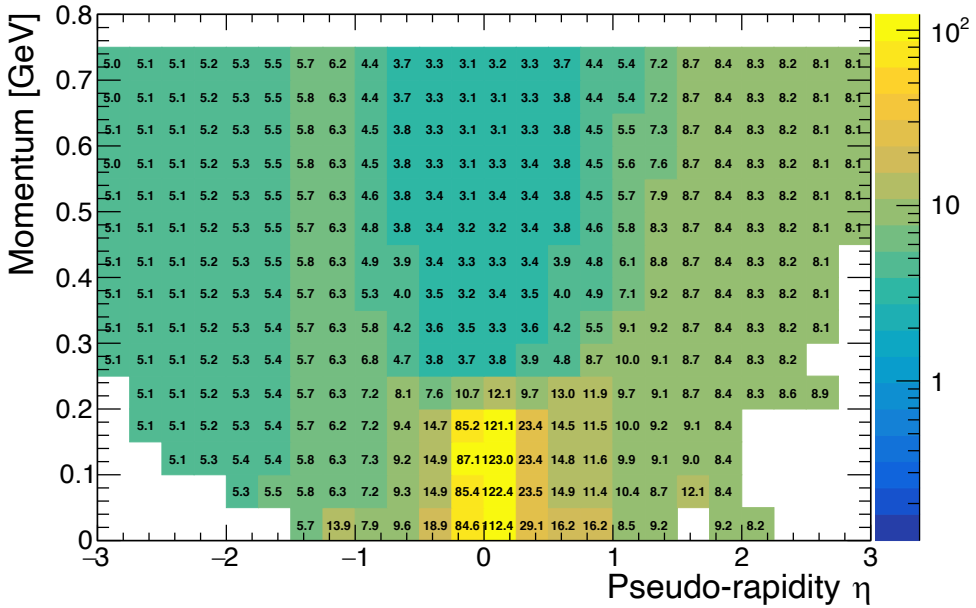
- The tracking reconstruction efficiency.
- Electron response in magnetic field.

Tracking reconstruction efficiency

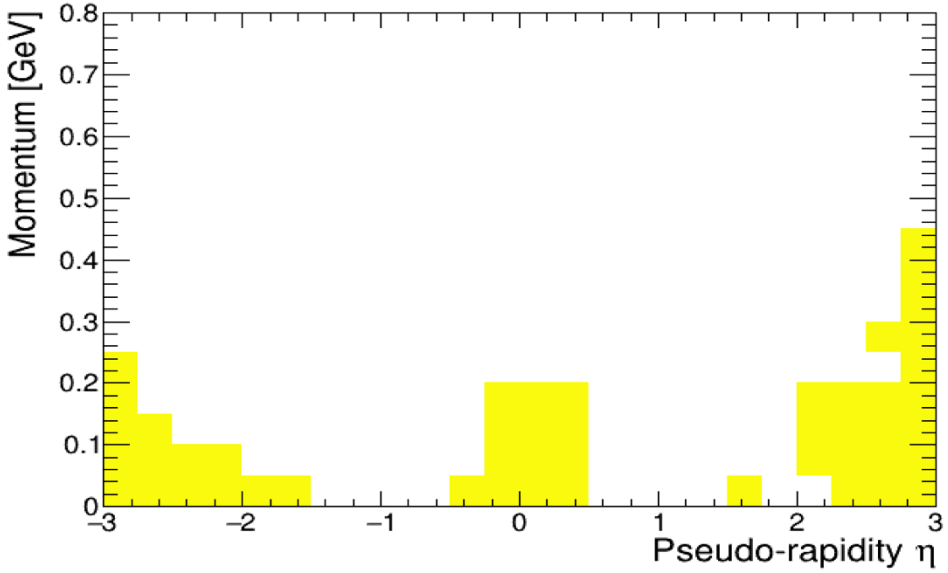
From MA Yuming



Fly time before hit the ECal in 1.5 T



time cut

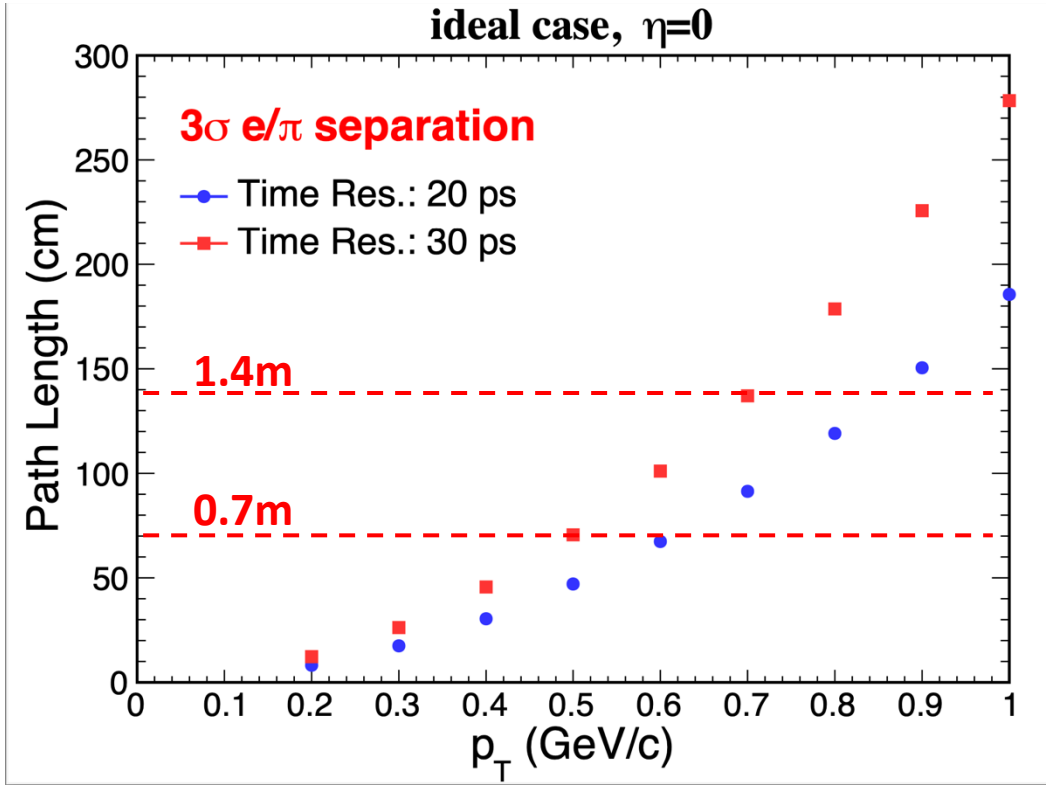


e/π separtion based on TOF

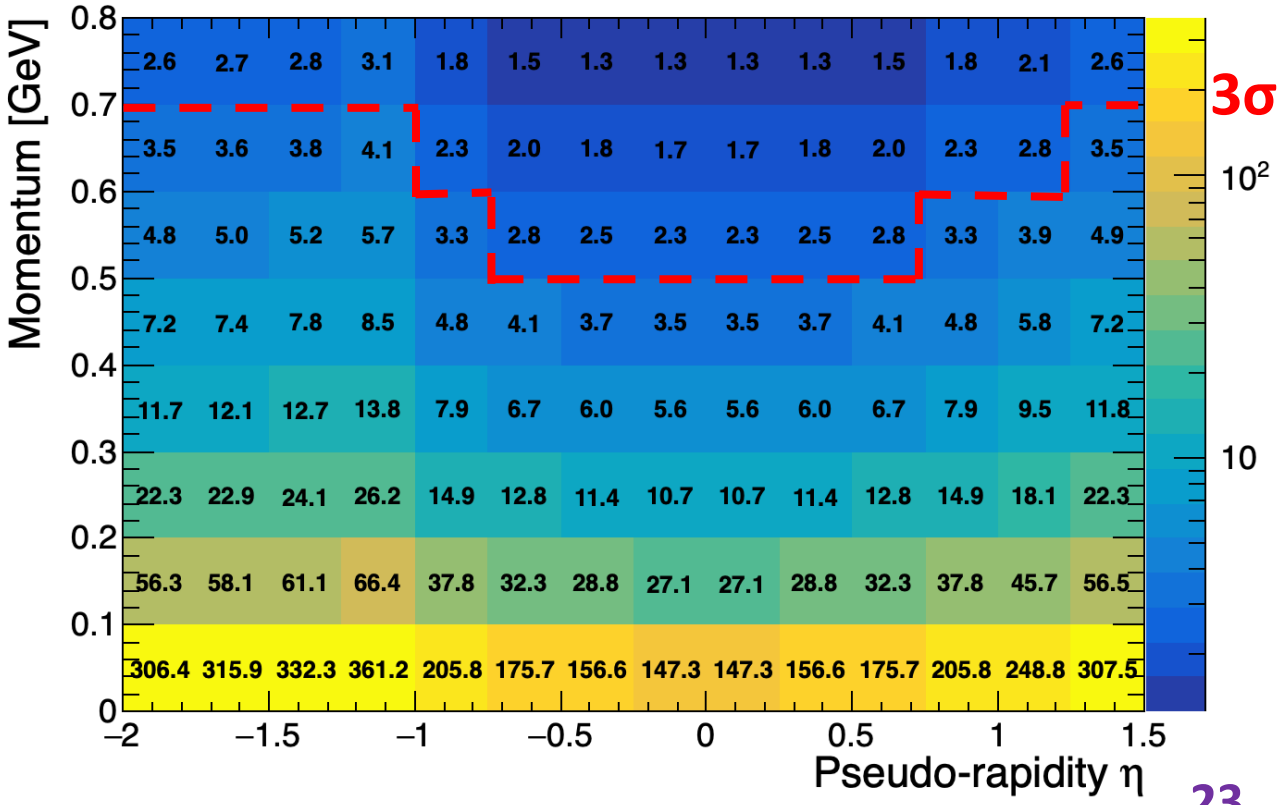
Flight time difference:

$$\Delta t = L\left(\frac{1}{v_\pi} - \frac{1}{v_e}\right) = \frac{L}{c}\left(\frac{1}{\beta_\pi} - \frac{1}{\beta_e}\right)$$

- TOF barrel radius **70 cm**, e-endcap distance **1.4 m**
- Time resolution **30 ps**.



Separation power (Nσ)



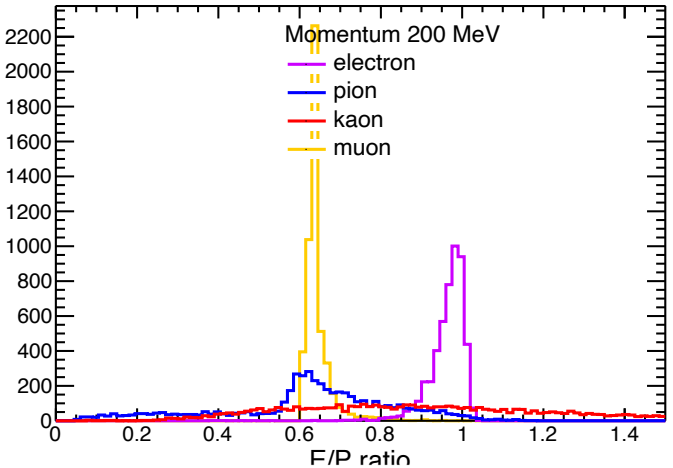
ECal e^-/π^- separation performance

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

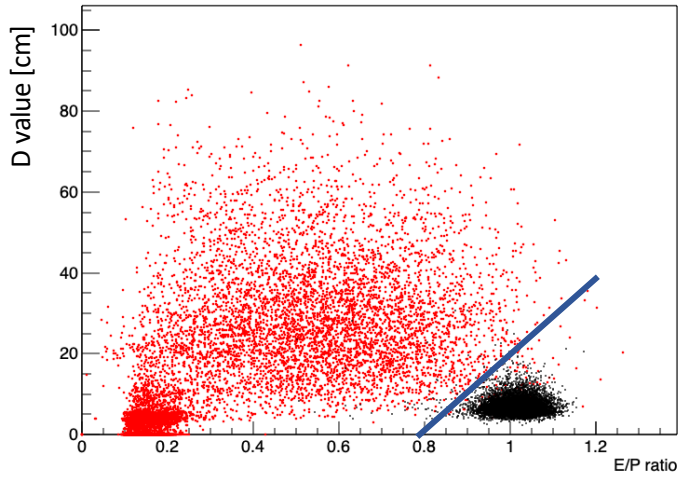
$$D = \sqrt{D_x^2 + D_y^2} = \sqrt{\frac{\sum_i w_i (x_i - x_{com})^2}{\sum_i w_i} + \frac{\sum_i w_i (y_i - y_{com})^2}{\sum_i w_i}}$$

- 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

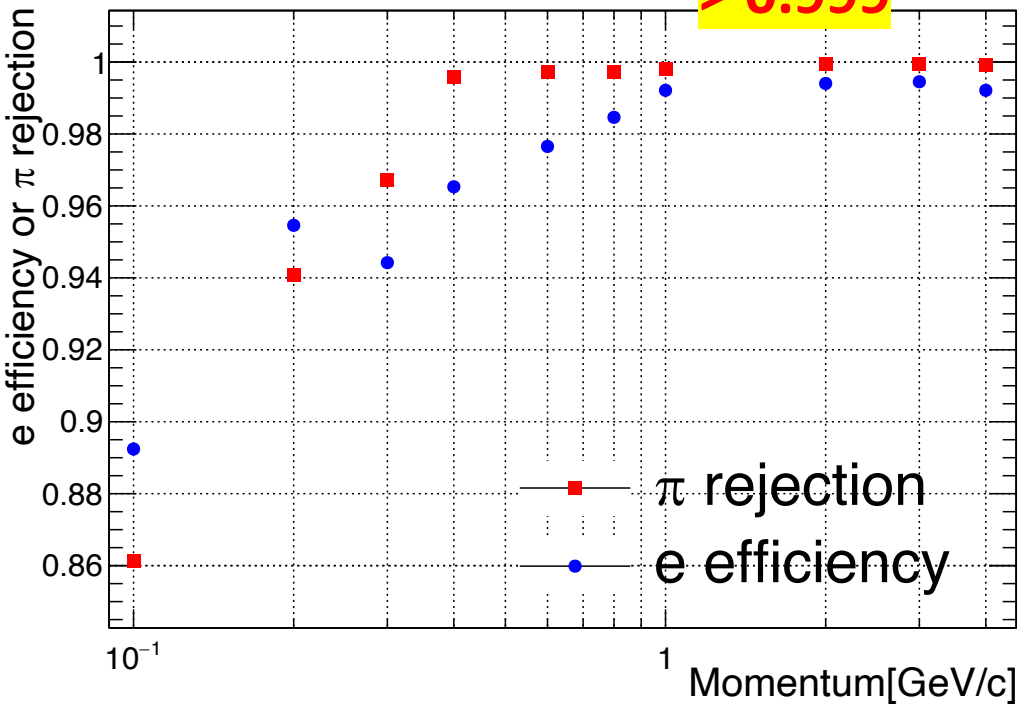
E/P distribution



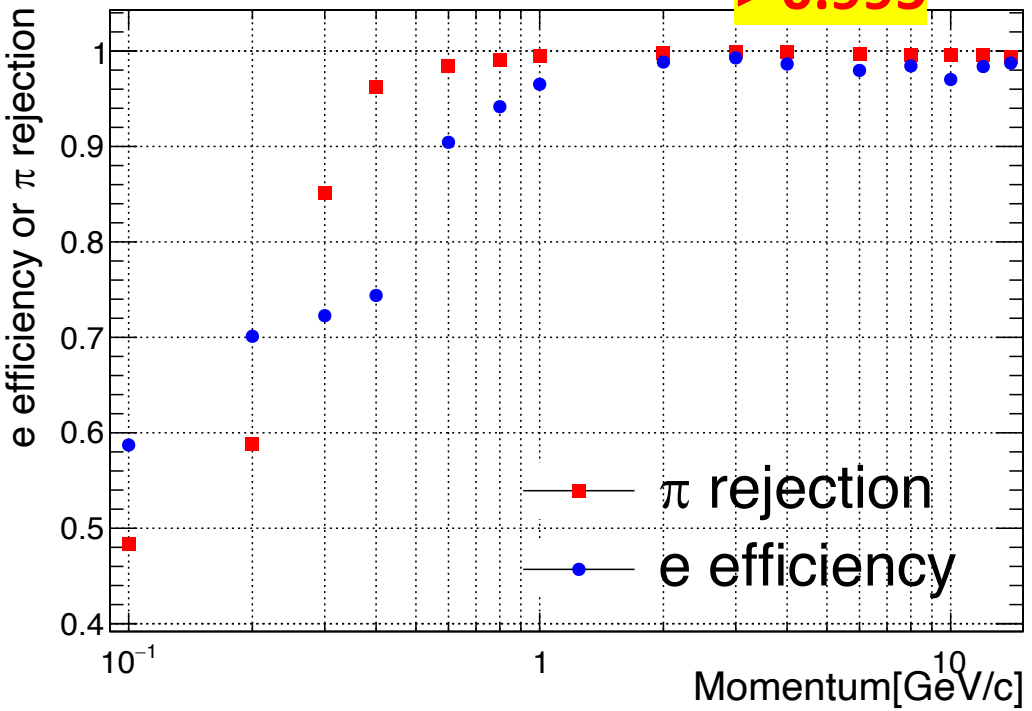
E/P v.s. D distribution



CsI crystal PID **> 0.999**

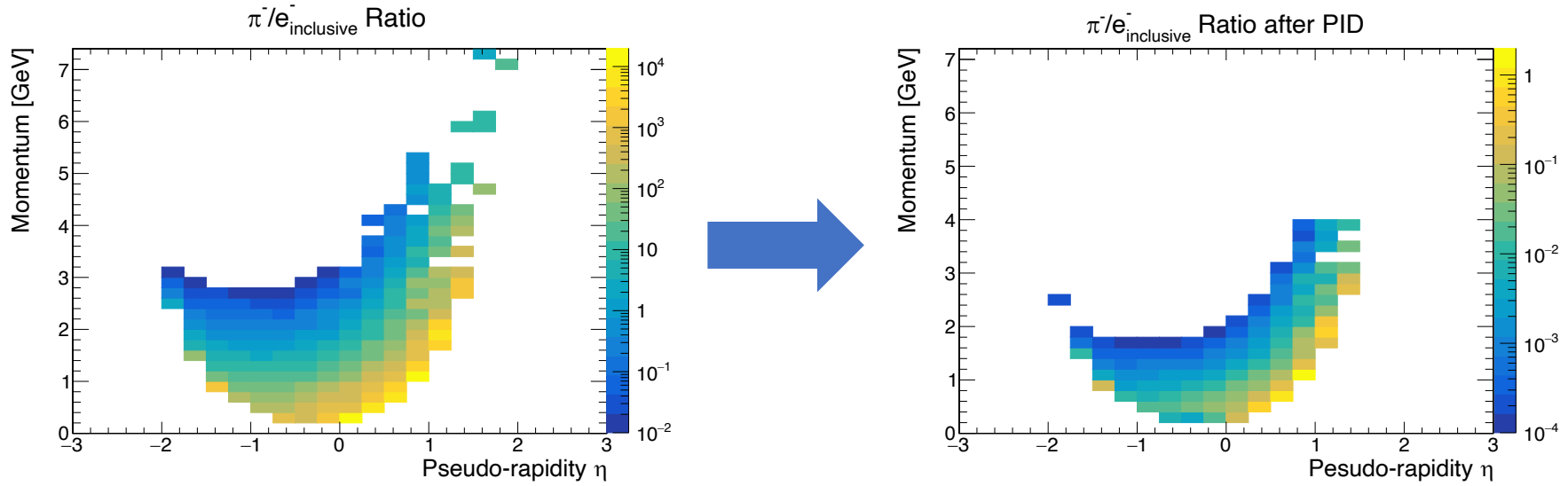


Shashlik PID **> 0.995**



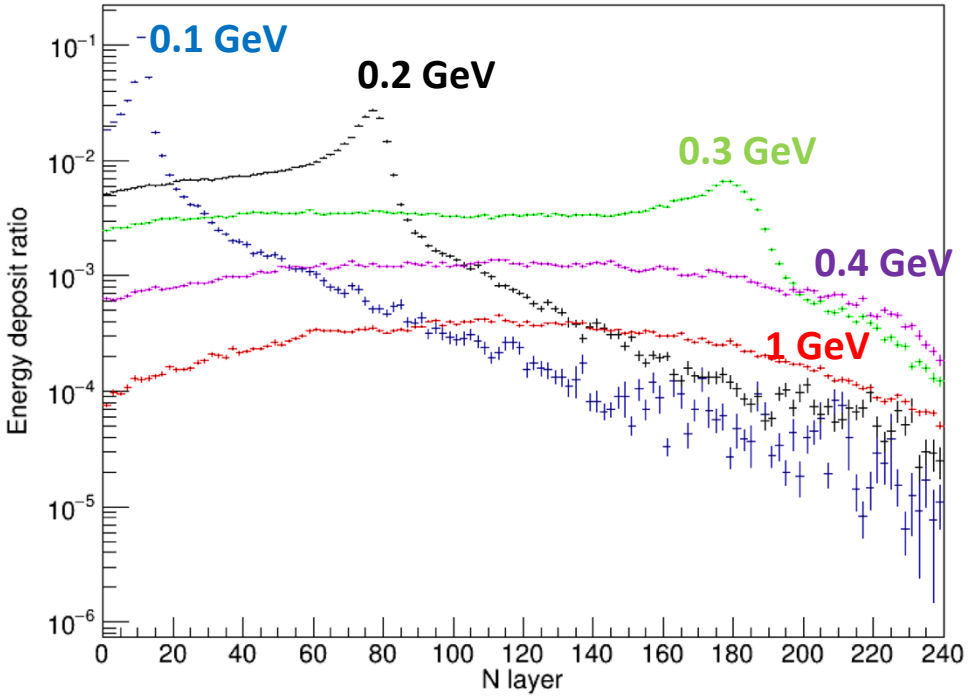
e/π PID Summary

Momentum [GeV/c]	|η|			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**

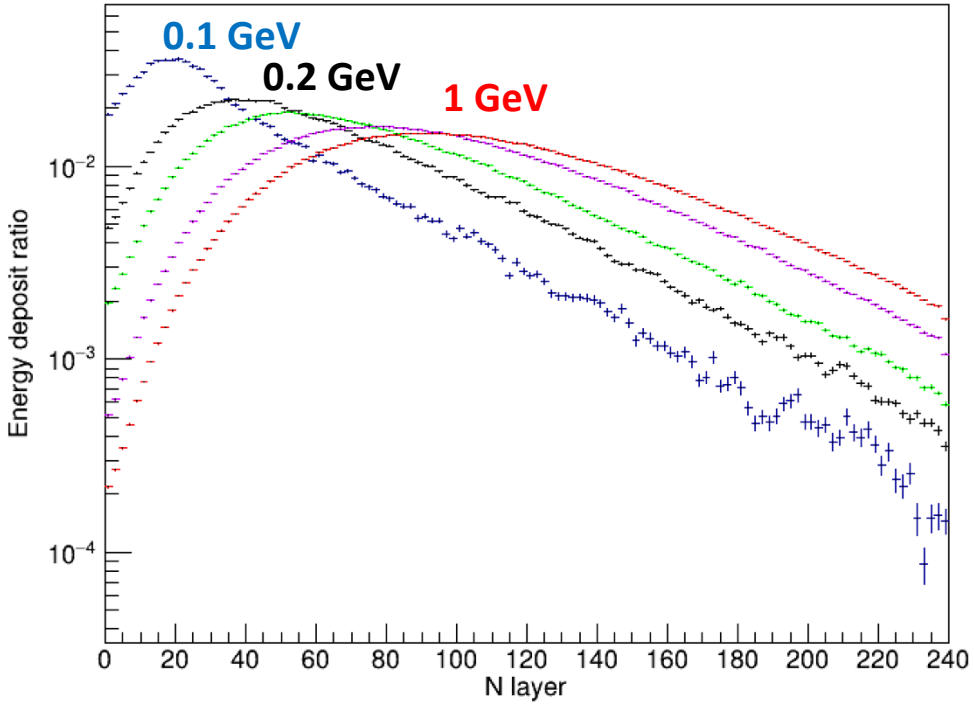


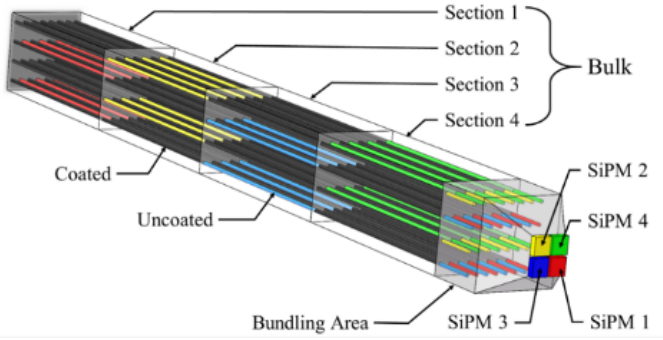
Shashlik trapezoidal design: π^- and e^- PID from longitudinal energy deposit distribution

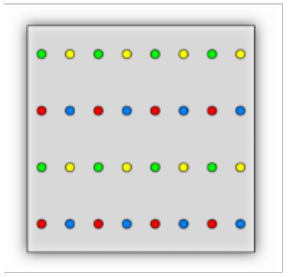
π^- (after E/P cut)



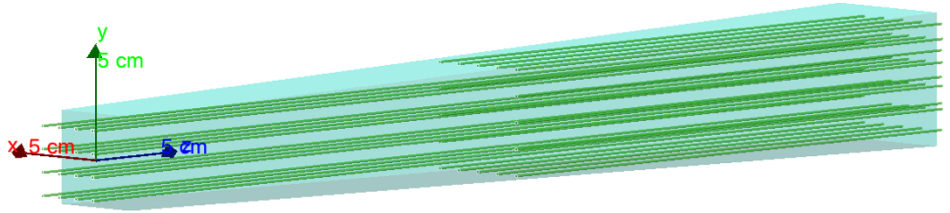
e^-

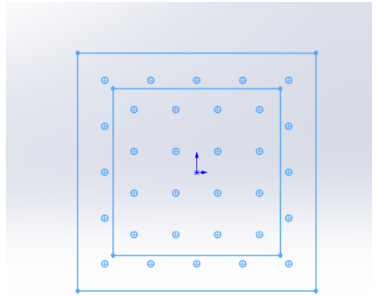






From WANG Yi





ECal DAQ

Upper limit: maximum energy
Lower limit: low momentum photons,
electronic noise,
background particle

pCsI：APD (refer to STCF)

- **? – 4 GeV**
- two 10x10 mm^2 APD

Shashlik：SiPM

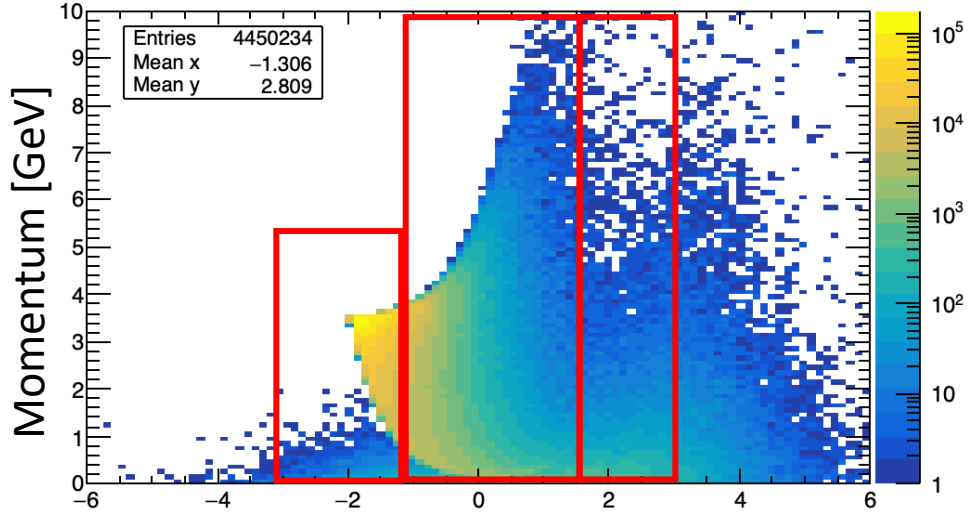
- **? - 15GeV**(barrel up to 10GeV， endcap up to **15GeV)**
- **need 1-4 SiPMs**

In common:

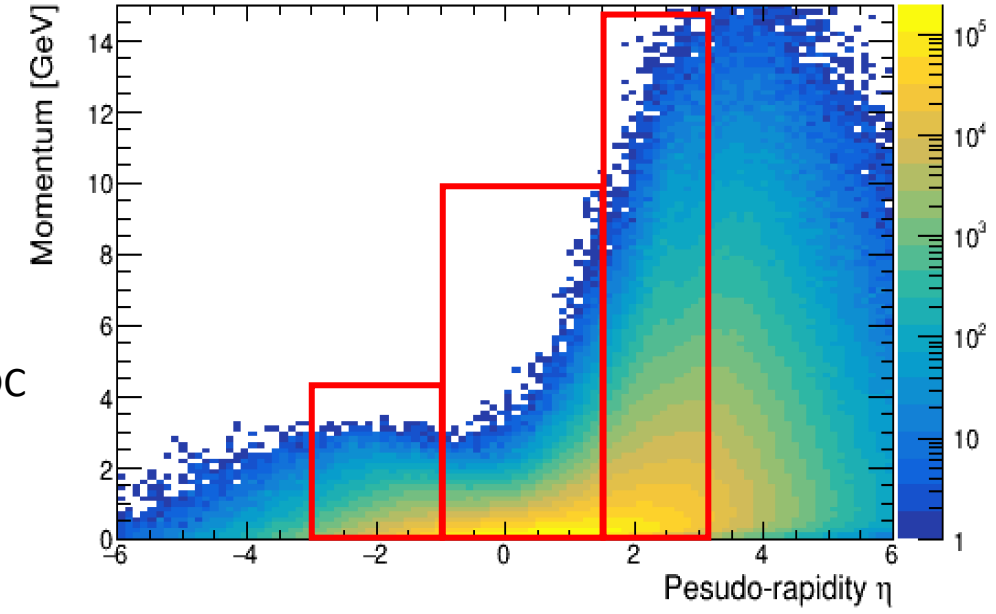
- Dual gain (preamplifier)
- Noise
- Time resolution < 1 ns
- Rate acceptance for single module: < 100 k Hz
- Store waveform by FADC or store peak time by TDC and amplitude by ADC
- LED calibration
- Cooling (<20 degree)

Will collaborate with USTC DAQ group.

Electron distribution



γ distribution



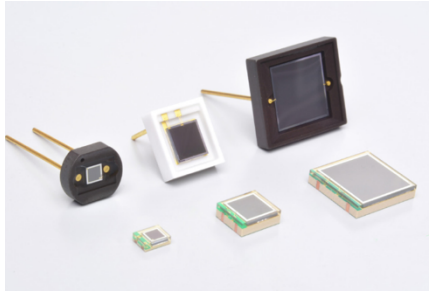
CsI and Shashlik calorimeter collected electro-photon number

Calorimeter Style	Initial light yield	N photons hitted on APD/SiPM	Collected by APD/SiPM	Max Energy	Max NPE for a shower	Max for a module (70%)	Max for a single photoelectric sensor
Pure CsI crystal	5000 /MeV	**127/MeV**	100 NPE/MeV	**4 GeV**	400k	280k	**140k**
Shashlik	8000 /MeV	**17.4/MeV**	4000 NPE/GeV	**15 GeV**	60k	42k	**42k**(30k if use two segmented readout)

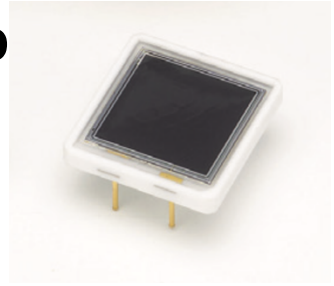
SiPM and APD model introduction

Type no.	Pixel pitch(um)	Size(mm)	Number of pixel	Peak PDE
SiPM: S13360-6025PE	25	6x6	**57.6k**	26%
北师大6015	15	6x6	**160k**	45%
APD: S8664-1010	-	10x10	-	85%

SiPM

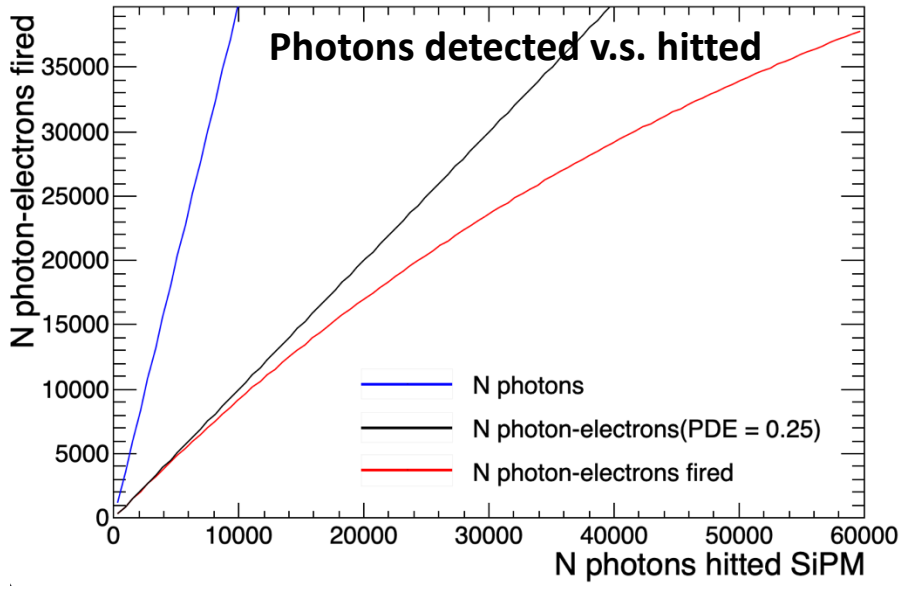


APD



SiPM linearity problem

Hamamatsu SiPM (60k pixels)



Conclusion and outlook

Finished:

- ✓Gneral design
- ✓Software and reconstruction
- ✓Performance
- ✓Optical simulation
- ✓Prototype module
- ✓Priliminary test setup and result

Next Step:

- ➢More precise simulation and reconstruction
- ➢More work on Shashlik prototype assembly, test and Lab setup
- ➢The pure Crystal and CsI(Tl) test
- ➢DAQ, SiPM and APD test
- ➢Finish radioactive source test setup for crystal
- ➢Crystal and other optical material reflectance and transmittance performance

THANK YOU!

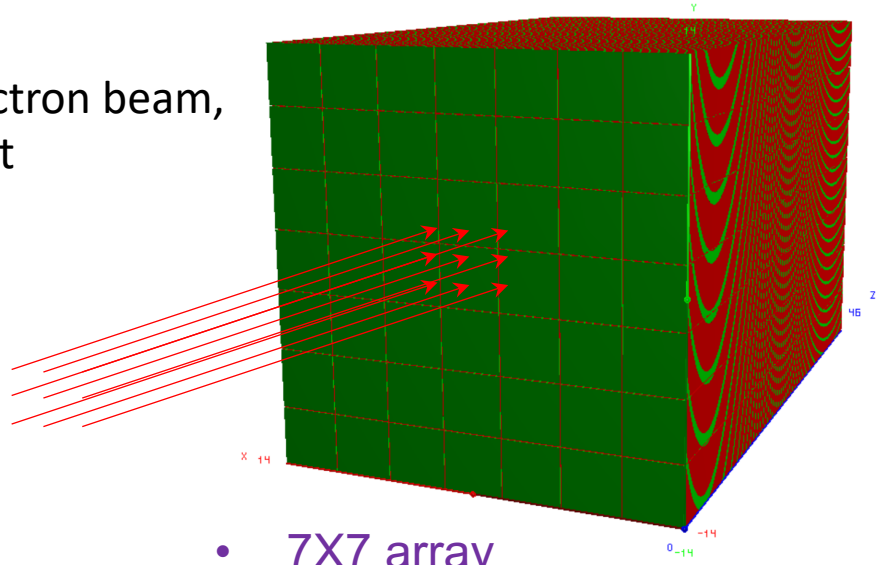
Crystal clorimeter comparison

	CsI	CsI(Tl)	CsI(Na)	NaI(Tl)	BGO	BSO	PWO	LSO(Ce)	LYSO(Ce)	BaF2	CeF3
					$(Bi2O3)2(GeO2)3$	$(Bi_2O_3)_2(SiO_2)_3$	PbWO4	$Lu2(SiO4)O$	$Lu2(1-x)Y2xSiO5$		
Density[g/cm^3]	4.51	4.51	4.51	3.67	7.13	6.8	8.3	7.4	7.1	4.89	6.16
Radiation length[cm]	1.85	1.85	1.85	2.59	1.12	1.15	0.89	1.14	1.16	2.06	1.68
Moliere radius	3.5	3.5	3.5	4.8	2.3	2.18	2	2.07	2.07	3.4	2.6
Interaction length	37	37	37	41.4	21.8	22	18	20.9	20.3	29.9	26.2
Refractive index(peak)	1.95	1.79	1.84	1.85	2.15	2.06	2.2	1.82	1.8	1.5	1.62
Hygroscopicity	Slightly	Slightly	Yes	Yes	No	No	No	No	No	No	No
Emission specturm(peak)	310	560	420	410	480	480	510	420	420	300/220	340
light yield rel. to NaI(%)	5.6	45	85	100	9	4	0.3	85	75	21/2.7	7
Decay time[ns]	35	1300	600	230	300	100	50	40	35	630/0.9	30
Price per cc($, 1m^3 batch)	4.6				8	8.5	9		34	12	
Price * X0, rel. to CsI	1				1.05	1.07	0.97		5.89	2.84	
Experiment	BELLE2, mu2e	CLEO, BaBar, BELLE, BES III		Crystal Ball	L3, BELLE		CMS, ALICE, PrimEx, Panda	SuperB, KLOE			

Choice: CsI > CsI(Tl) > BGO

The Geant4 simulation of Shashlik module

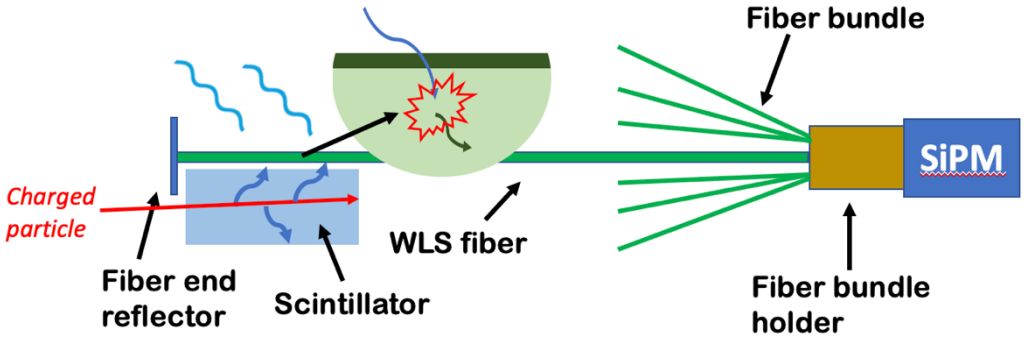
0.1-15 GeV electron beam, verticle incident



- 7X7 array
- 4X4 cm^2 area source

Simulation method

Module	Energy deposit	N photons
Simplify: Lead+Scin	Geant4	Geant4+**parameterization**
Full module	Geant4	• Geant4+**parameterization** • Geant4+**optical photon**



Parameterization of light yield