CsI crystal comparison and performance study
---Update of EicC ECal Study

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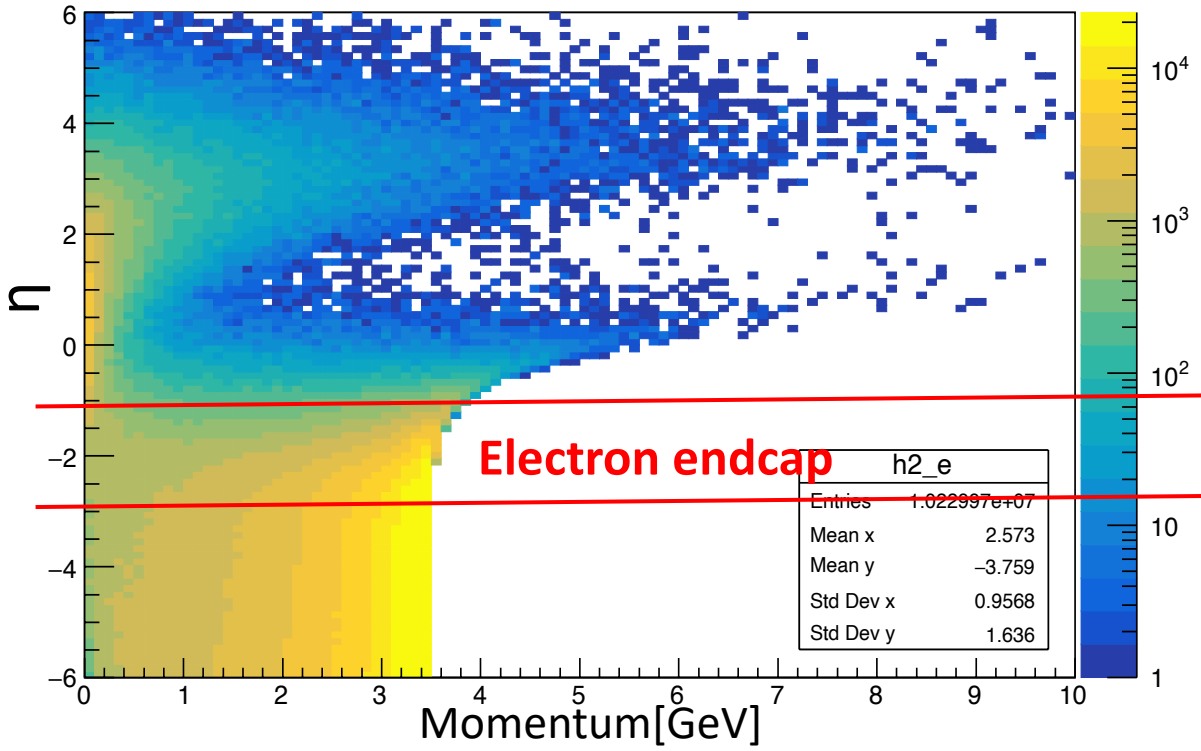
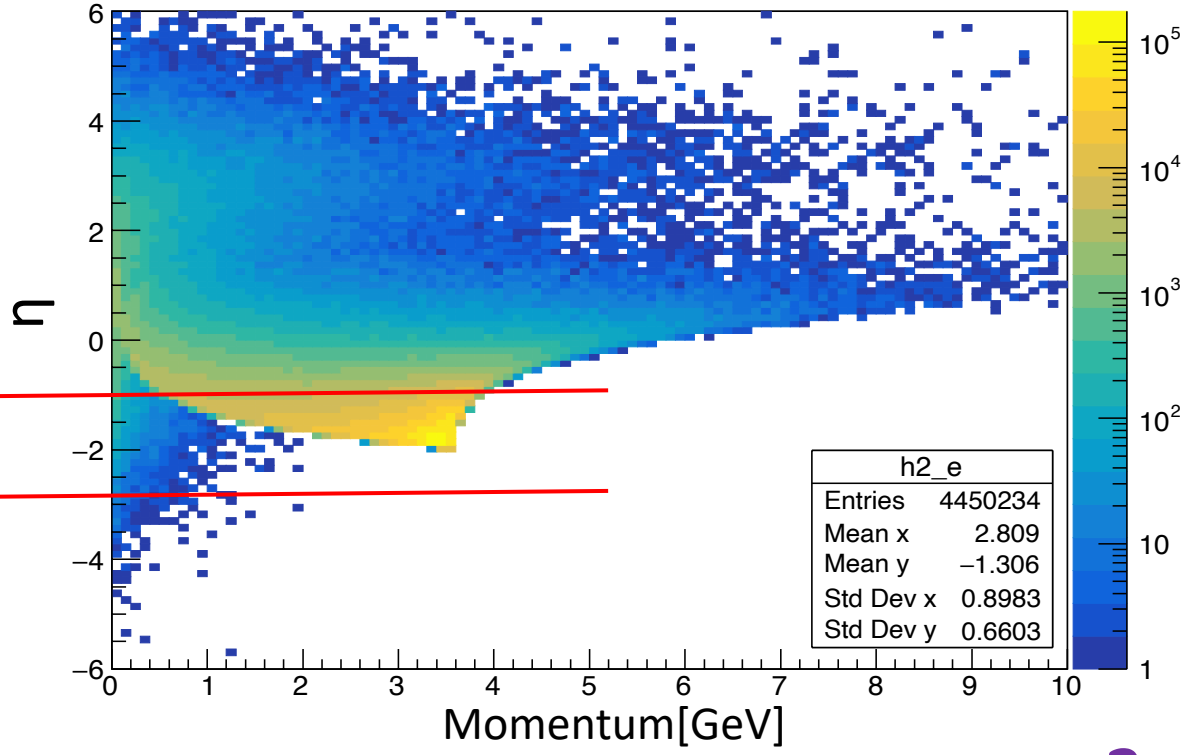
e- distribution in final state

- Electron distribution in both high Q2 and low Q2 cut.
- Maxumum energy is about 4 GeV for electron endcap.

Low Q2 lower limit(>1e-6)

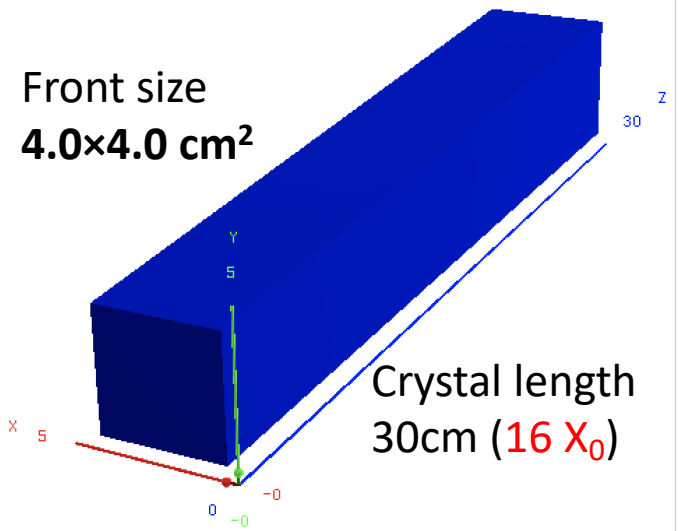


High Q2 lower limit(>1)

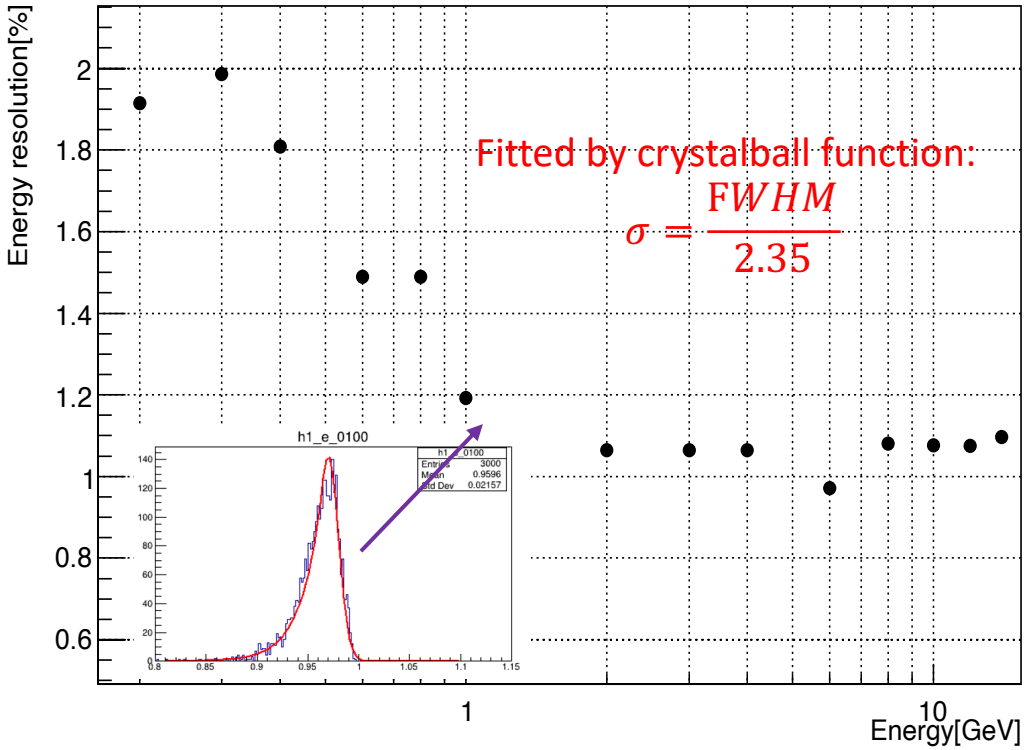


CsI module array energy deposit simulation result

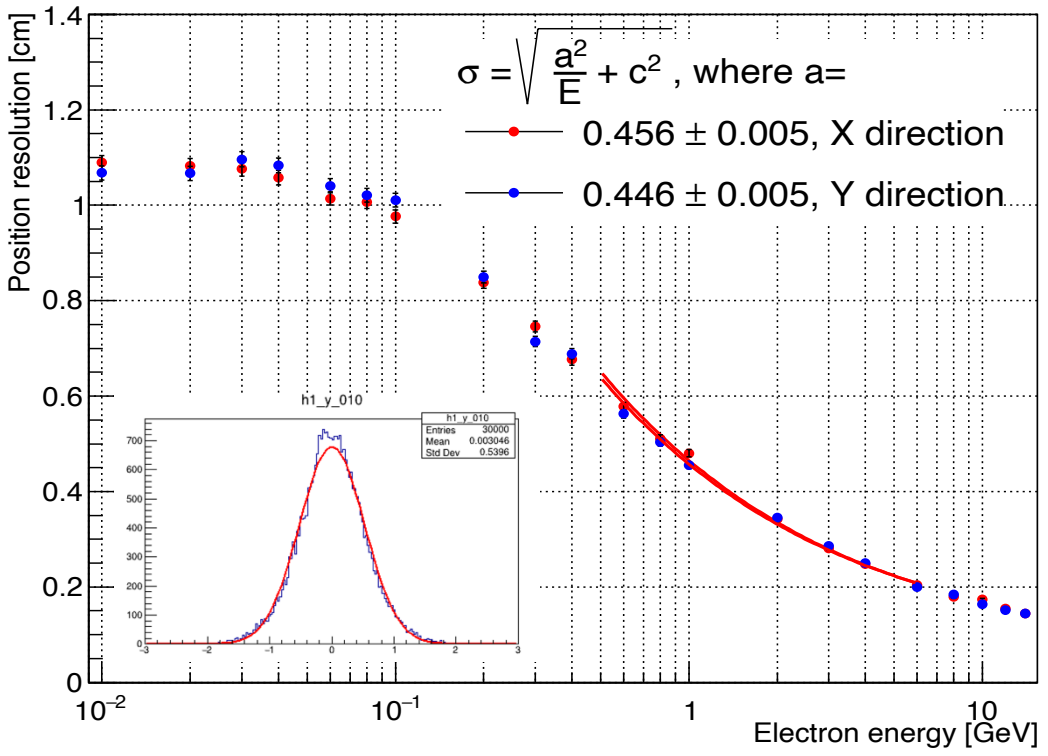
- Very good energy resolution: 1.2%@1GeV
- Better position resolution(0.48cm@1GeV) than shashlik(0.53cm@1GeV)



Energy resolution

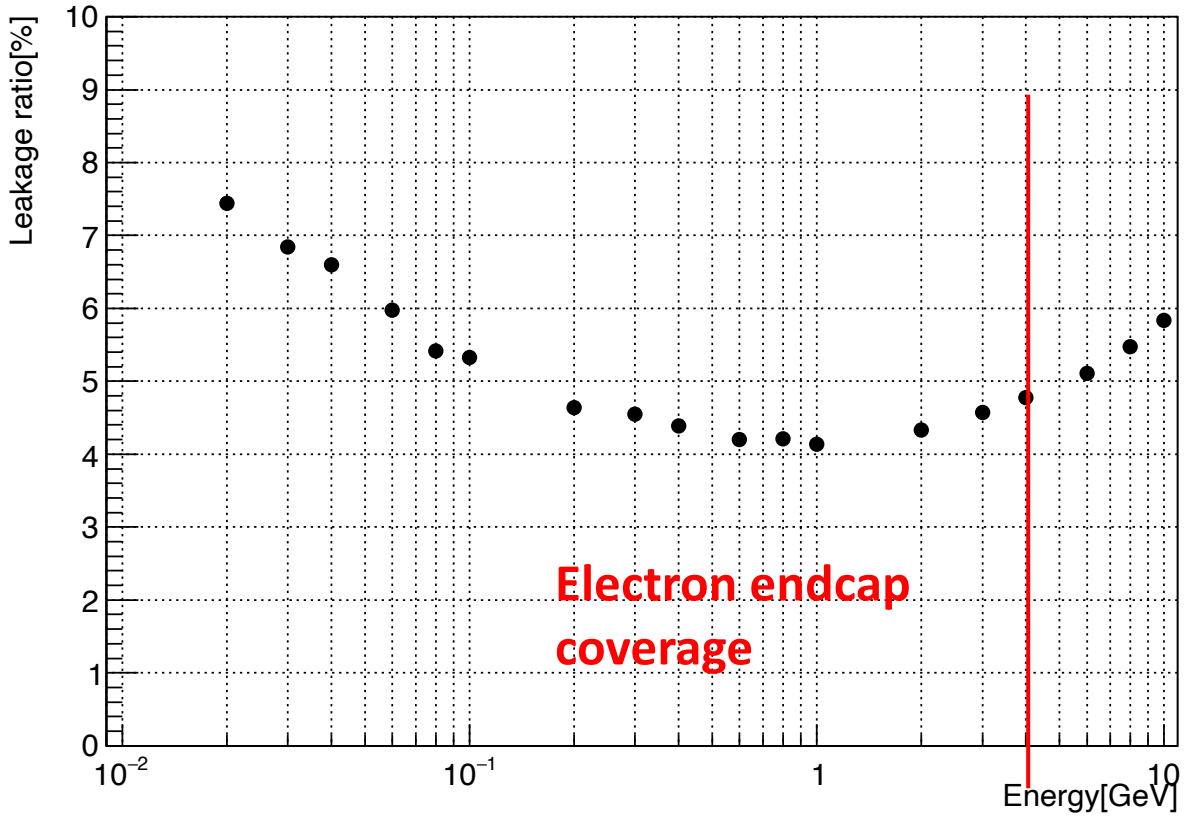


Position resolution



Energy leakage for all energy(7x7 CsI Array)

- Definition: (**energy) – (average energy deposit)**
- The cluster reconstruction algorithm is applied.
- With 16 X_0 radiation length, the energy leakage for 4 GeV electron is **4.7%**.



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

Pure CsI or CsI(Tl)

- Two CsI crystals are considered: **pCsI** and **CsI(Tl)**.
- From white paper, the interaction rate is 83.2 kHz with L=4x$10^{33}$$cm^{-2}s^{-1}$, which means ~11 μs/event, so CsI(Tl) could cope with this low rate

Crystal	X_0 (cm)	λ_{em} (nm)	n	N_{ph}/MeV	τ (ns)
CsI(Tl)	1.86	550	1.8	52 000	1000
CsI	1.86	305/400	2	5000	30

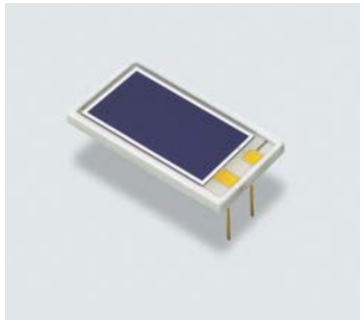
Crystal	Photons collection device	Radiation hardness	Price	Absorption length	Hygroscopic	Application
Pure CsI (pCsI)	APD, UV SiPM	good	¥35/cc(IMP), purity related	1 – 1.5 m	Slightly	High rate experiemnt
CsI(Tl)	PD, APD	normal	Lower than pCsI	*30cm @450nm (<50cm)	Slightly	Commonly used

Crystal calorimeter readout: Si photon detector

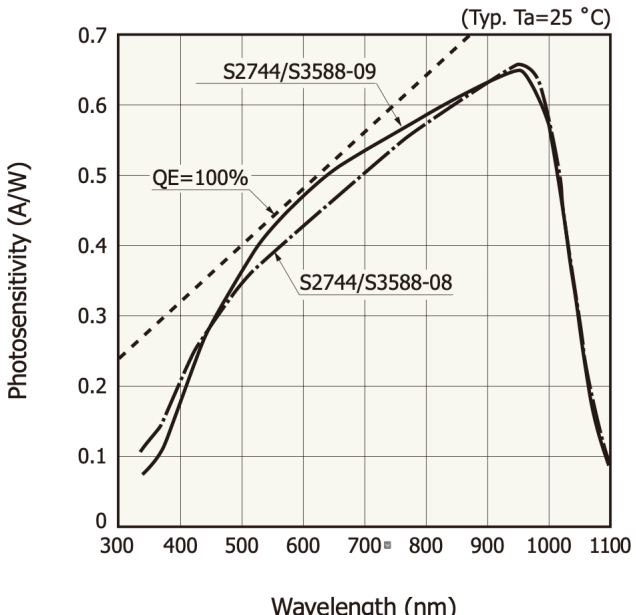
- **N photons dynamic range: PD > APD > SiPM**
- **Gain: SiPM(10^6) > APD(50) > PD(1)**

Photodiodes(PD)

For CsI(Tl)

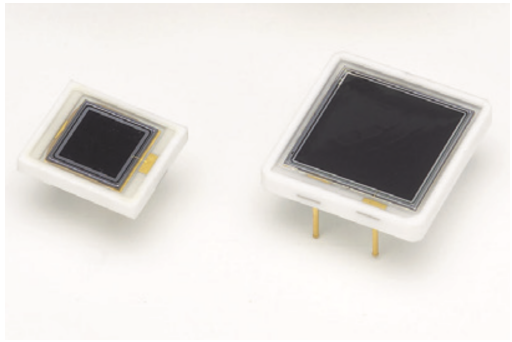


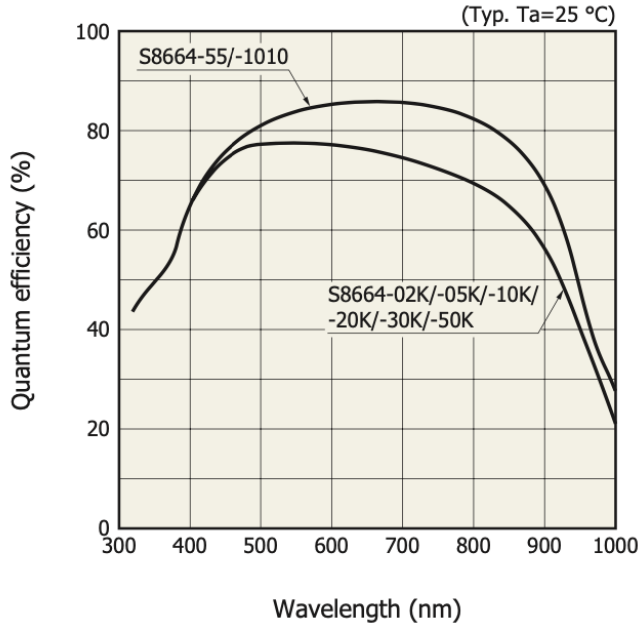
[S2744/S3588 series]



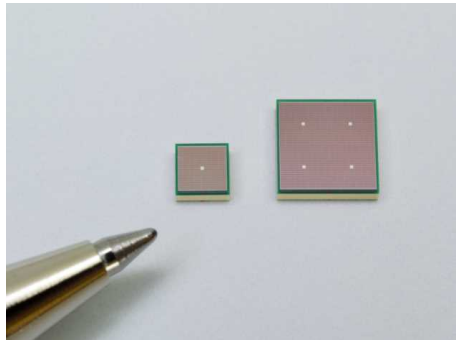
Avalanche Photodiodes(APD)

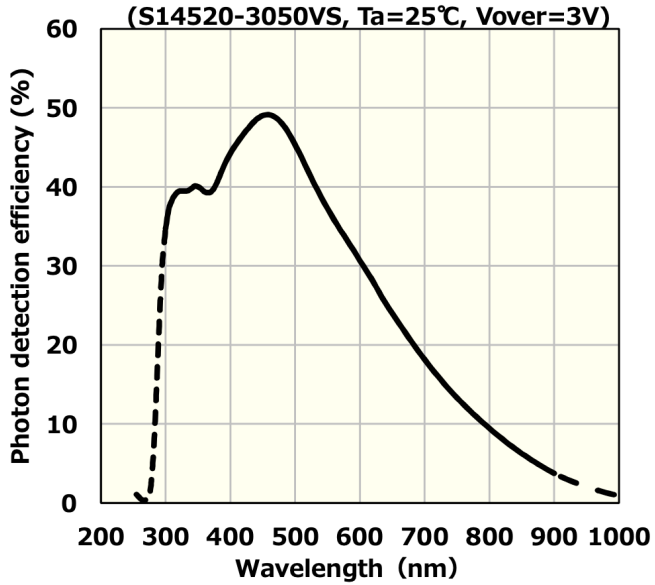
For pure CsI





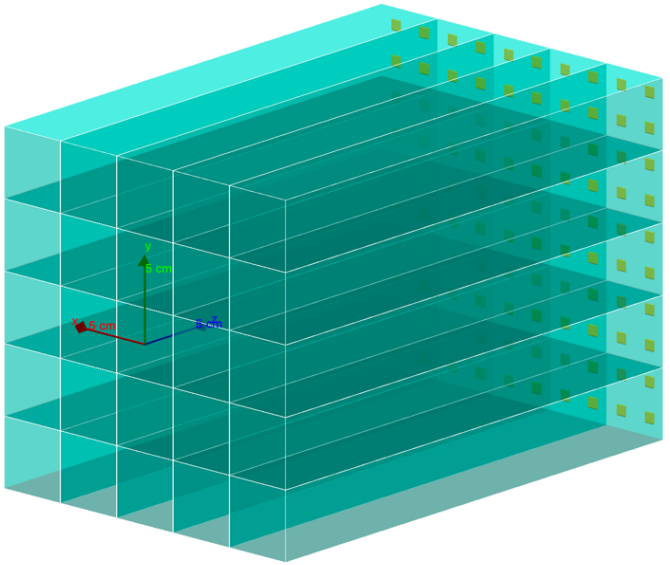
Silicon photomultiplier(SiPM)





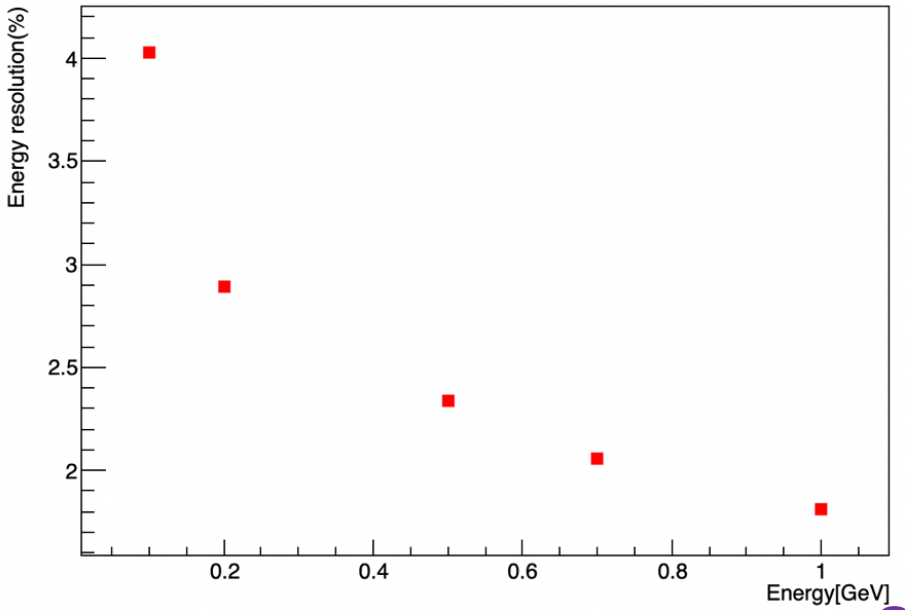
5*5 CsI array optical simulation

- 5*5 CsI array, read out by four 6mmx6mm SiPMs
- 250 μm **carbon fiber** and 70 μm **tyvek** is used for wrapping
- Actual light yield x10, better energy resolution
- The **absorption length** is assumed as 100cm
- Both 5k/MeV(CsI(Tl)) and 50k/MeV(CsI) light yield are simulated



e enenrgy (GeV)	Initial light yield(N.P.E./MeV)	N.P.E. collected by SiPMs	Enenrgy resolution (%)
0.1	5000	6200	3.16
0.2		12400	3.01
0.5		31200	2.43
0.7		43900	1.87
1		62800	**1.81**
	20000	255000	**1.79**
	50000	621500	**1.80**

Energy resolution



STCF: 156 p.e./MeV for pCsI

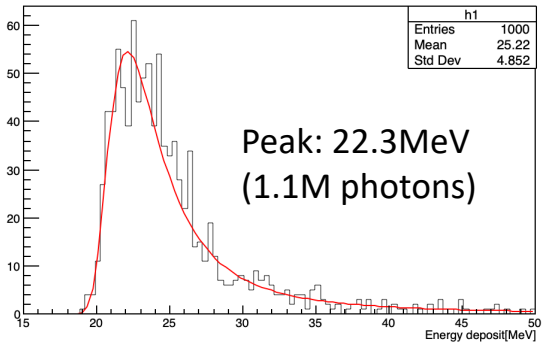
CsI(Tl) module cosmic test

- Test purpose: get the CsI(Tl) waveform and attenuation length
- CsI(Tl) bar: 4(3) *4 *25 cm, made by IMP
- Each end coupled with a PMT, waveform is collected by FADC
- Cosmic ray is triggered by two 4*4*0.6 cm scintillator tile that placed upper and lower side

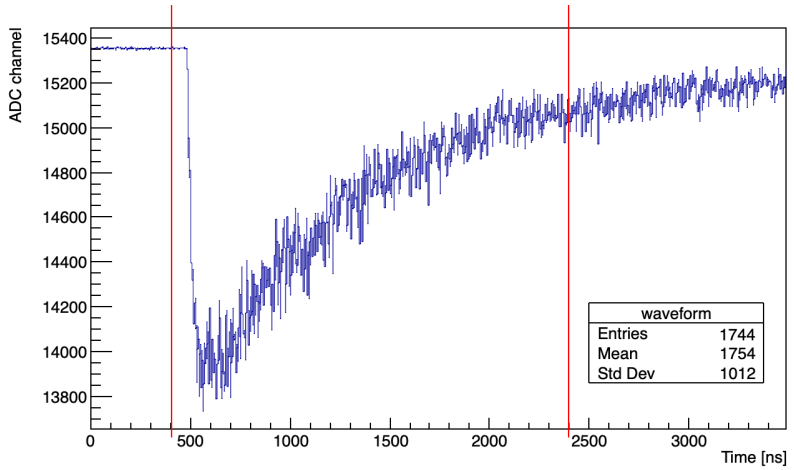
Cosmic ray test result

- A 2 μs window is used as time window to integrate the signal.
- Simulation shows 22.3 MeV energy deposit in CsI, created 1.1M photons.

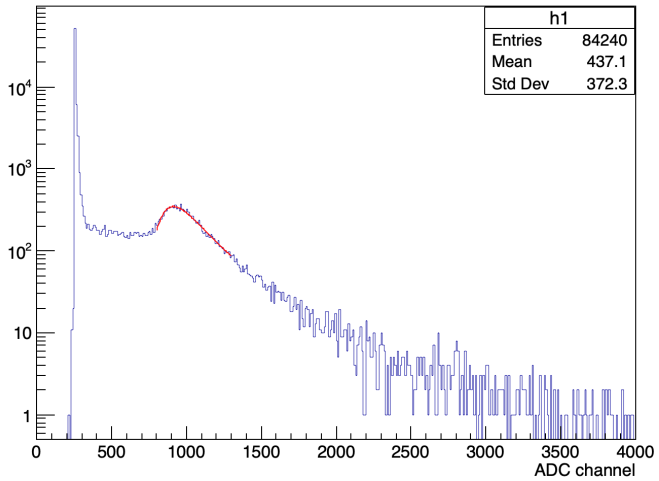
Energy deposit simualtion

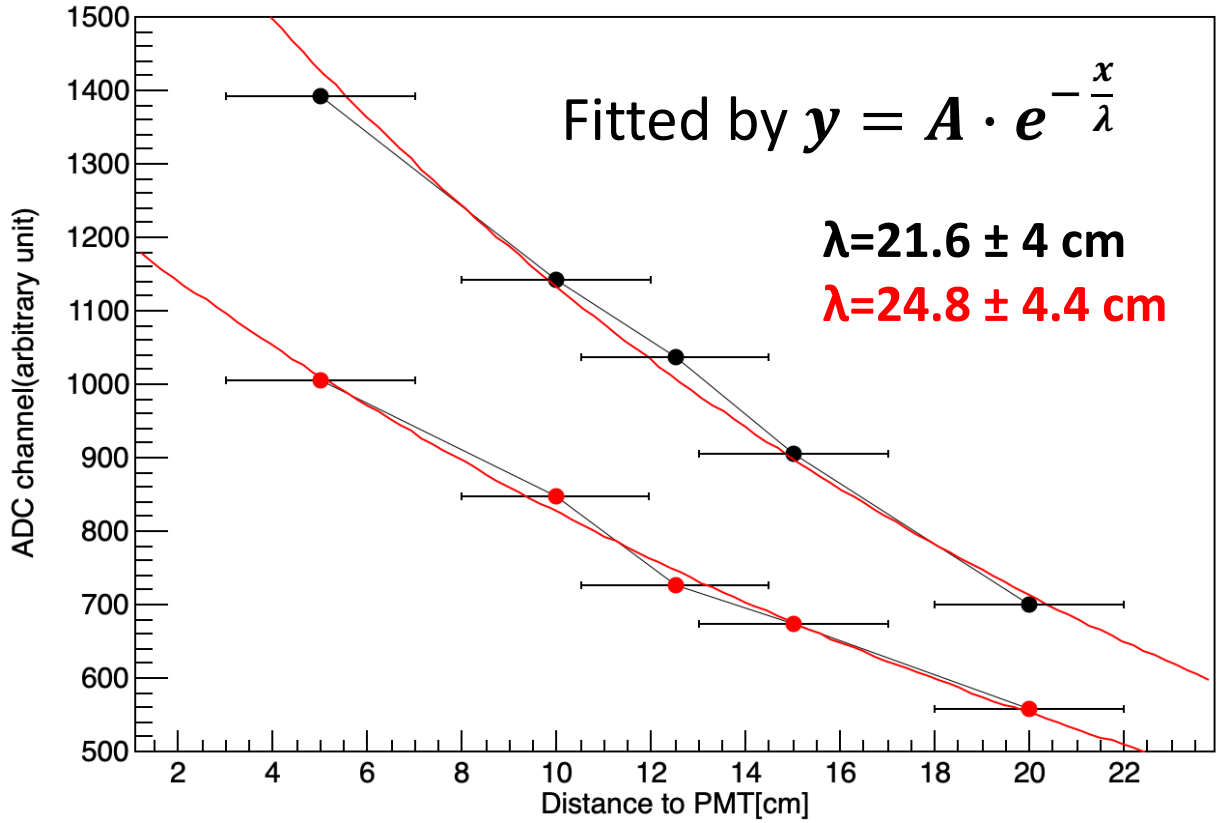


Cosmic ray signal sample



ADC channel spectrum





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

Conclusion and outlook

- The increase of photon number of CsI(Tl) has less significant contribution to energy resolution than CsI
- The attenuation length of CsI(Tl) is rather low, which influence the crystal uniformity
- The pCsI is a better choice, and need higher purity that means higher cost

Next work plan

- Crystal tech is mature, more study and test on crystal calorimeter
- Buy more crystal sample: pCsI(Hamamatsu, 硅酸盐所), Cherenkov crystal, others.
- APD/PD and related electronics research and test

THANK YOU!

CsI caorimeter comparison

Detector	crystal	Photon sensor	p.e./MeV	Year of publishing
STCF	pCsI	APD	**156** p.e./MeV (with two S8664-1010 APDs).	2022
Belle2	**CsI(Tl) + endcap** pCsI upgrade	pCsI： Two-inch vacuum photopentodes PPs (PMT) CsI(Tl) ：PIN-Photo-diodes		2010
Mu2e （100MeV）	pCsI	UV SiPM （SiPM surface add additional coating）	Light output: > 100 p.e./MeV with 200 ns integration gate	2018
BESIII	CsI(Tl)	PD(2* 1cm*2cm)		