Stereo Crystal Ecal: Input Materials

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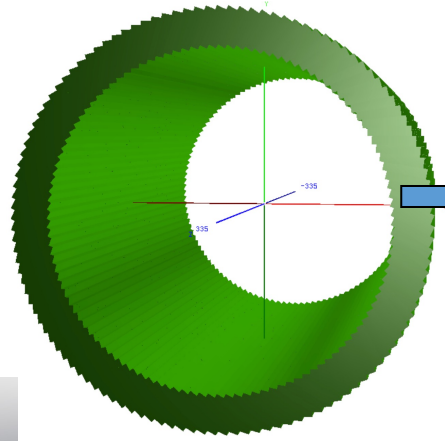
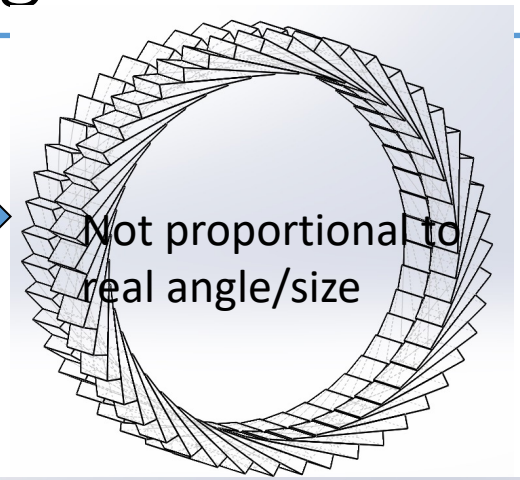
For Stereo Crystal Ecal study team

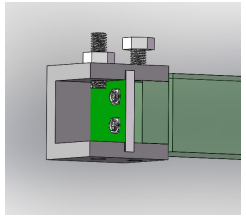
Stereo Crystal Electromagnetic Calorimeter: Design

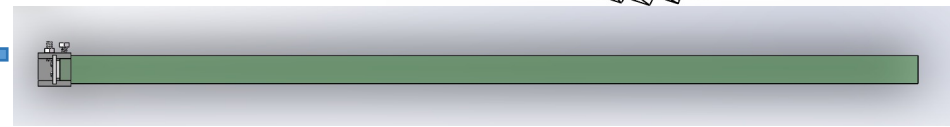
- To improve the 3D position resolution
  - Pointing angle of even layers alone Z: α
  - Pointing angle of odd layers alone Z:

  $\alpha' = -\alpha$
- Benchmark design:
  - α=20 degrees
  - R segmentation = 10
  - Crystal: (8-8.1)*10*284 mm^3
  - Readout: SiPM or PD + electronics
  - Cooling pipe planted into the outside of the mechanical support
  - 24X0+10mm electronics+10mm support + 10 mm contingency = 300mm

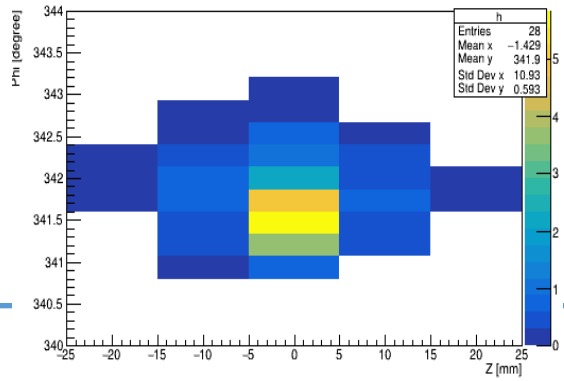






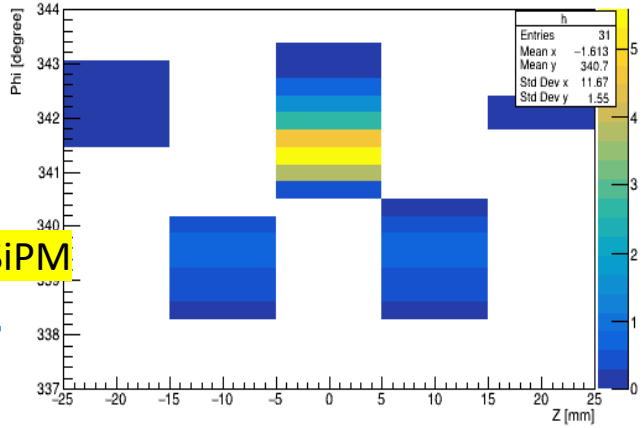


Traditional Crystal Ecal



BGO+SiPM

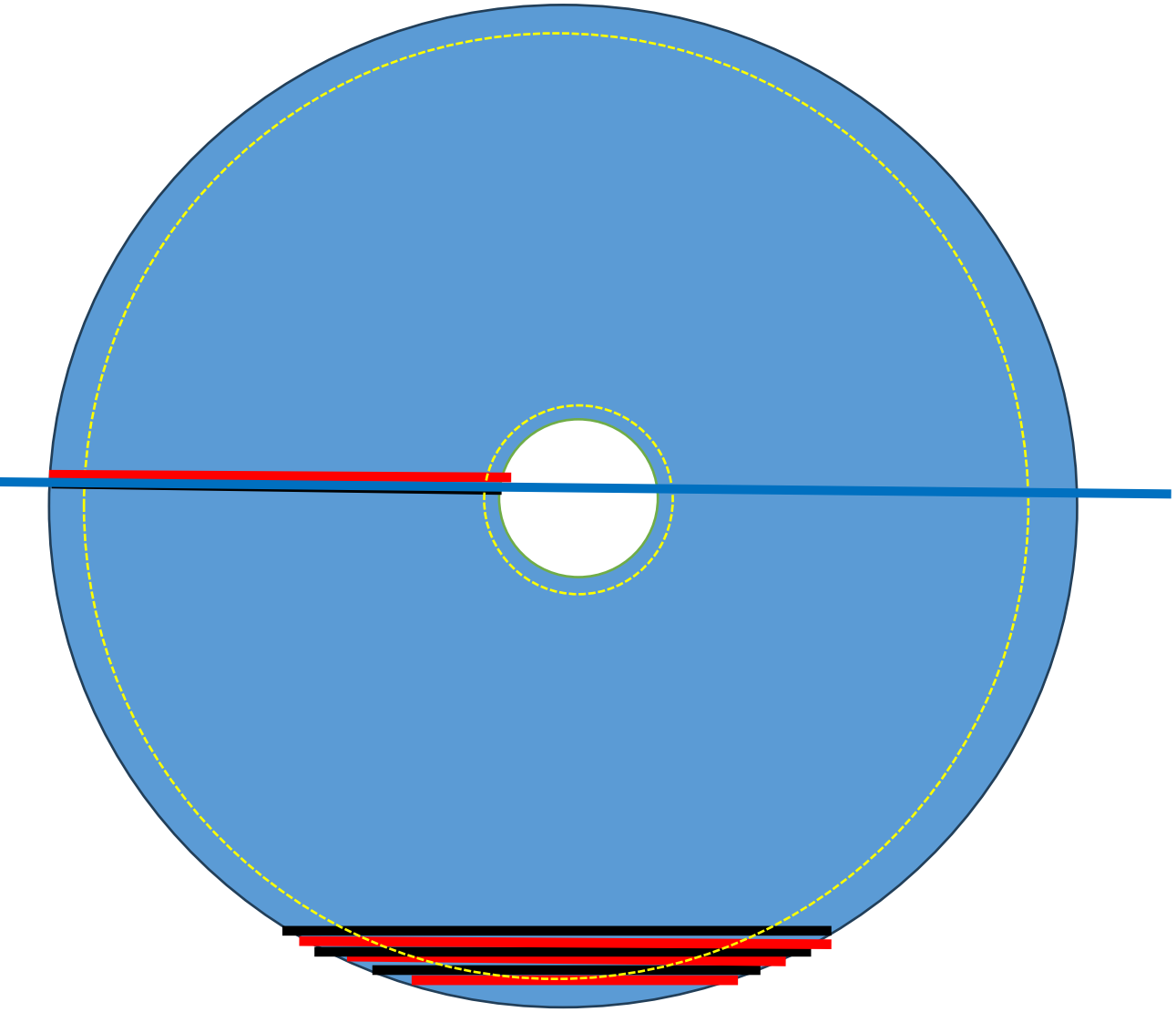
SCEcal



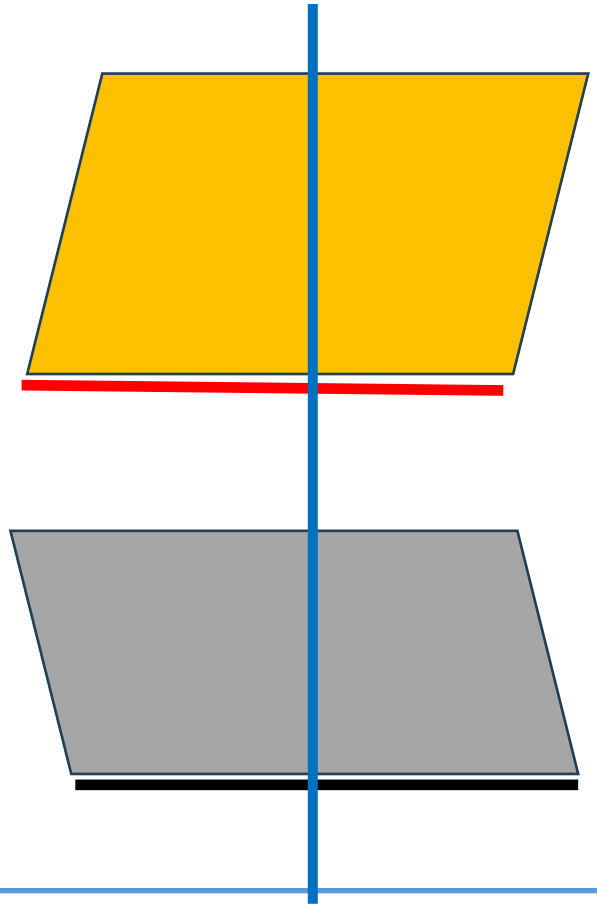
Left eye

Right eye

Endcap design



Crystal: 8*10*284mm
Horizontal layers has same point angle
Pointing angle defined as angle w.r.t. beam in the horizontal plane: 20 degree



Performance

Items	Priority	Results / Status	Remarks
Boson Mass Resolution	A	H→di-photon: 0.3%(1.3%) with 2MeV(50MeV) thr. H→gg is under study	BMR < 4%
Intrinsic EM/hadronic energy resolution	A	Stochastic term: 0.9%(3.2%)/sqrt(E) with 2MeV(50MeV) thr.	CEPCSW fullsim
Separation power		5 GeV gamma/gamma, >80%@15mm 5 GeV gamma/10 GeVPi: coming	CEPCSW fullsim
Lepton ID in jets		preparing	Clear shape difference seen(backup)
Timing capability		Could have, accuracy depending on the sensitive material	No showstopper
π^0 reconstruction		Studying	soon
Pile-up at Z-pole		-	No showstopper

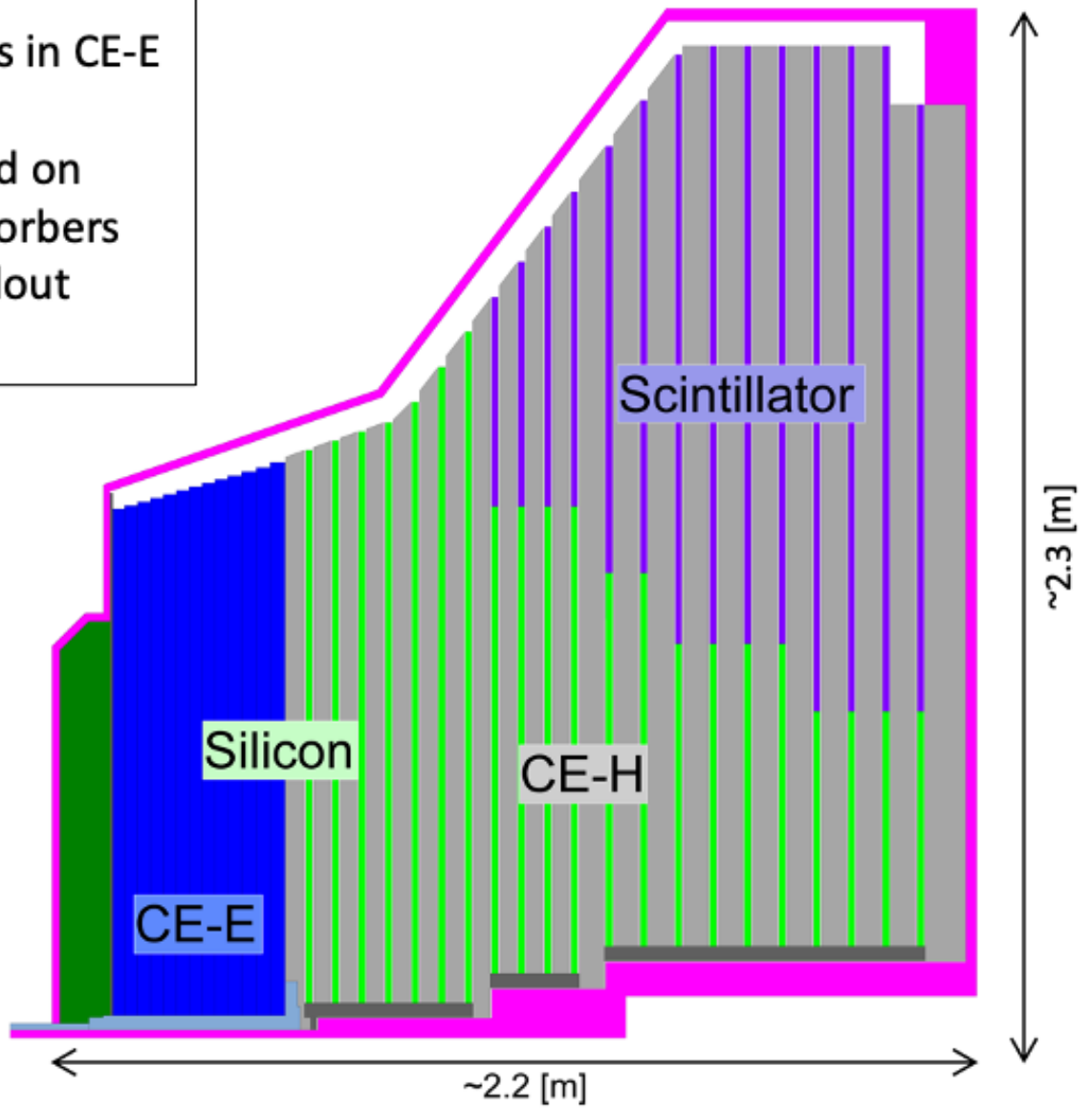
- Priority/importance for performance requirements: (A) must-have; (B) plus; (C) not essential

Active Elements:

- Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
- "Cassettes": multiple modules mounted on cooling plates with electronics and absorbers
- Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H

Key Parameters:

Coverage: $1.5 < |\eta| < 3.0$
~215 tonnes per endcap
Full system maintained at -30°C
~620m^2 Si sensors in ~26000 modules
~6M Si channels, 0.6 or 1.2cm^2 cell size
~370m^2 of scintillators in ~3700 boards
~240k scint. channels, 4-30cm^2 cell size
Power at end of HL-LHC:
~125 kW per endcap



Electromagnetic calorimeter (**CE-E**): **Si**, Cu & CuW & Pb absorbers, 26 layers, 27.7 X_0 & ~1.5λ
Hadronic calorimeter (**CE-H**): **Si** & **scintillator**, steel absorbers, 21 layers, ~8.5λ

Cost from CMS HGCal (kCHF)

- Electronics： 6M Si + 240k Sc

4.6.1	Front-end System (Silicon sensors)	5,778
4.6.2	Front-end System (Scintillator/SiPM sensors)	872
4.6.3	Front-end System (Common to Silicon and SiPM)	4,164
4.6.4	Clock and Control	500
4.6.5	Power Distribution	4,448
4.6	**Electronics and Electrical Systems**	**15,762**
4.7.1	DAQ	2,447
4.7.2	Trigger	3,779
4.7	**Backend System (Trigger and DAQ)**	**6,226**
4.8.1	DCS	257
4.8.2	DSS	341
4.8	**Slow control**	**598**

SiPM + Sc. (4-30 cm2 cell, 240k ch, 370 m2, X mm thick)

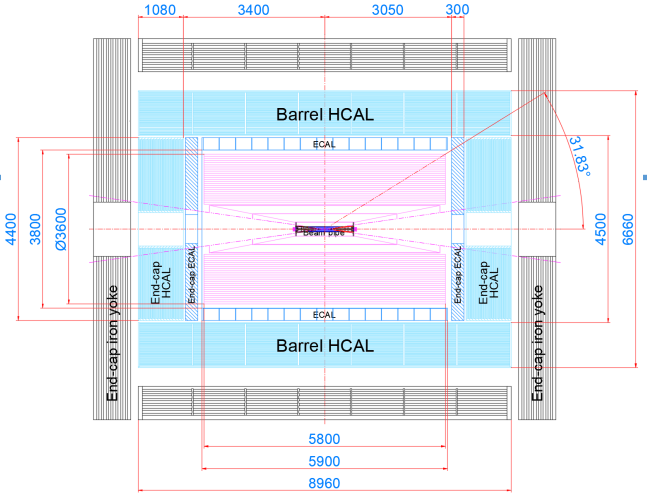
4.5.1	SiPM - Photosensors	1,718
4.5.2	Plastic scintillator	832
4.5.3	Wrapping (ESR film)	111
4.5.4	Assembly Centre and Tooling	270
4.5.5	Scintillator/SiPM Module Production	14
4.5	**Scintillator/SiPM Modules**	**2,945**

Si sensors: 620 m2

4.3	Silicon Sensors	**21,513**

item	Power	SiPM	Plasic Sc. Mat.	FE	BE+Slow C.	Si
numbers	40 mW/ch	7.2CHF/ch	0.22CHF/cm2	2.5CHF/ch	1.1CHF/ch	3.5CHF/cm2
remarks	Half? in e+e	3*3 mm2	No wrapping			

Cost



Cost table template for ECAL

Parameter Name	Barrel	Endcaps (x2)	Sum
Inner Radius for ECAL	1900 mm	400 mm	NA
Length for barrel; Outer radius for endcap	5900 mm	1900 mm + $24X_0$	NA
Longitudinal Depth	$24X_0$ (Thickness depends on each option)		NA
Modularity	#modules in phi, #rings along Z	Assuming ideal geometry if no design?	NA
Material Volume (m^3)	20.3	7.2	27.5
Readout channels	827180	317,248	1,144,428
Power dissipation (kW)	16.5kW	6.3kW	22.8kW
Cost: sensitive materials	579M RMB	205M RMB	784M RMB
Cost: electronics	74.4M RMB	28.6M RMB	103M RMB
			887 MRMB

SiPM + Electronics from HGCal
- SiPM: 7.2CHF/piece
- Electronics: 3.6CHF/ch
- Total～90RMB/ch

BGO:
- BGO: 4USD/cc (4000RMB/kg)

Power:
- 20mW/ch(Half of HGCal/ch)

Technical readiness level

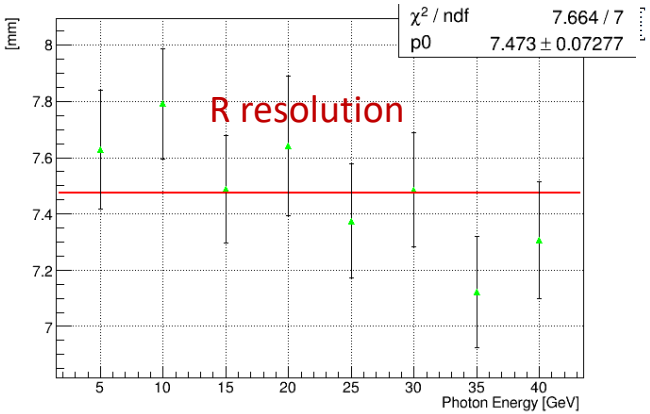
- Status and plans of simulation studies and R&D (a table template)
- Person power: Xiao ZHAO, Chaochen Yuan, Han WANG, Liheng Huang, Lianyou Shan, Huaqiao ZHANG

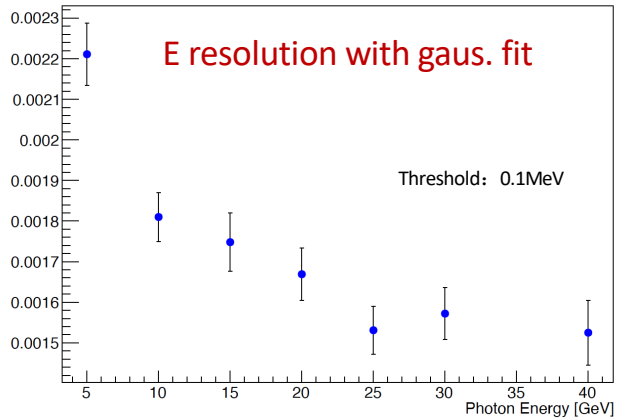
Category	Status	Design 1	Other Alternative Design (if any)
Technical Readiness Level	Full Simulation (system level)	V1 Implemented in CEPCSW	
	Full Simulation (module level)	V1 Implemented in CEPCSW	
	Prototyping R&D (common)	L3 Ecal, CEPC 4D crystal Ecal	
	Prototyping R&D (modules, units)		No BGO module, GEO with Sc. In preparing

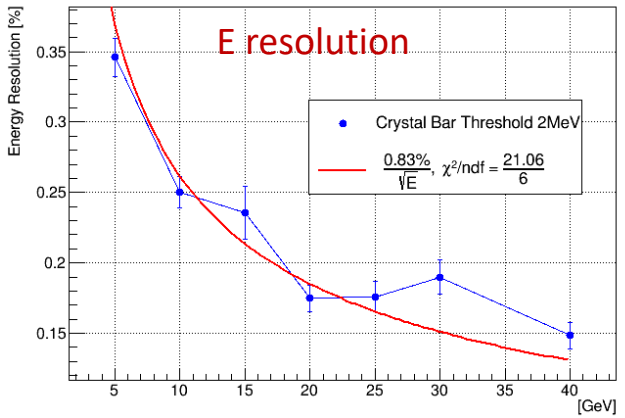
桶部	单位（毫米）				
内部直径	3800	最大外部直	4400	长度	5900
晶体	BGO（24X0=26.88cm）	市场参考价格：	￥4000.00/kg左右		
大小	(8.0-8.1)*10*284	数量	827180=1402*590	体积	20.3m3
重量	144.5吨	价格	5.779亿		
机械设计	纯圆桶				
外径面支撑/悬挂		内径面辅助		沿5？个session	
竖直组装，旋转90度后推入					
端盖*2	单位（毫米）				
内部半径	400	外部直径	3800+2*24X0	厚度	24X0*2
晶体	BGO（24X0）	市场参考价格：	￥4000.00/kg左右		
大小	8*10*284	数量	317248	体积	7.2 m3
重量	51.3吨	价格	2.0534亿		
机械设计					
内径面支撑					
电子学	1,144,428=827180+317248				
前端板	1.6mm	母版	1.6mm	间隙	2mm
功耗	22.8kW(20mw/channel)	电子学价格	3.6CHF/ch		
SiPM	7.2CHF/ch	总价格	103MRMB		

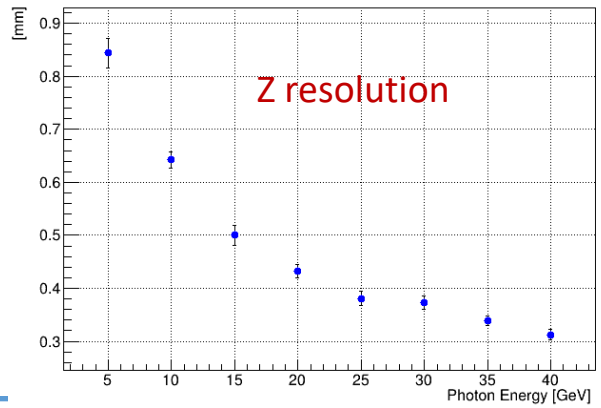
Performance of Energy and 3D positioning resolution

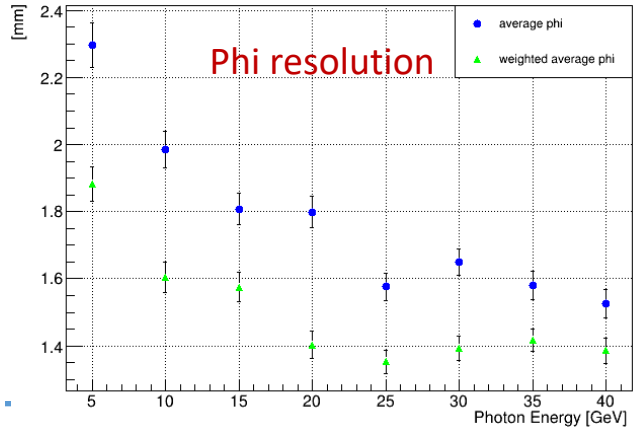
- **5GeV gamma, phi: 10~350°，theta: 90°**
  - Z resolution ~ 0.84 mm;　　Phi resolution ~ 1.9 mm
  - R resolution ~ 7.6 mm;　　Energy resolution as function of energy

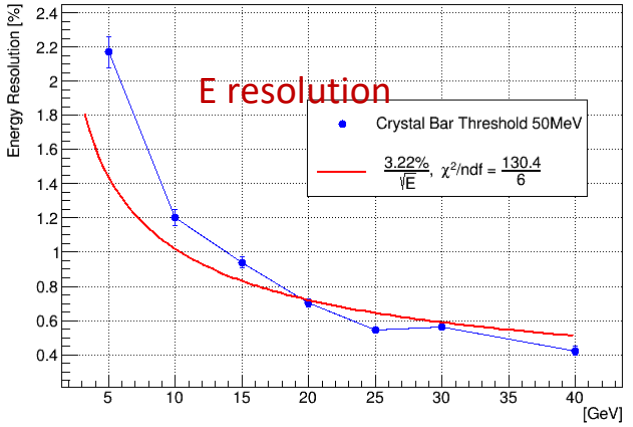






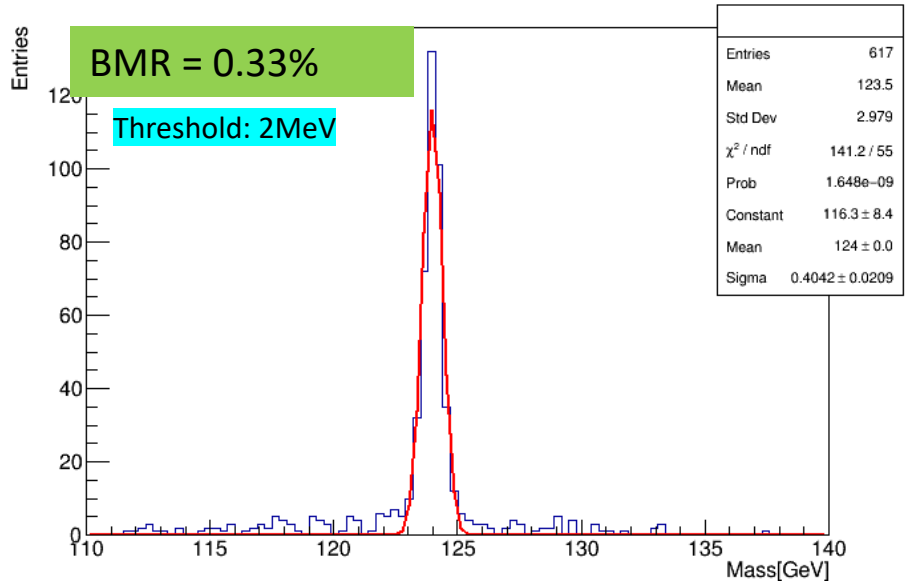


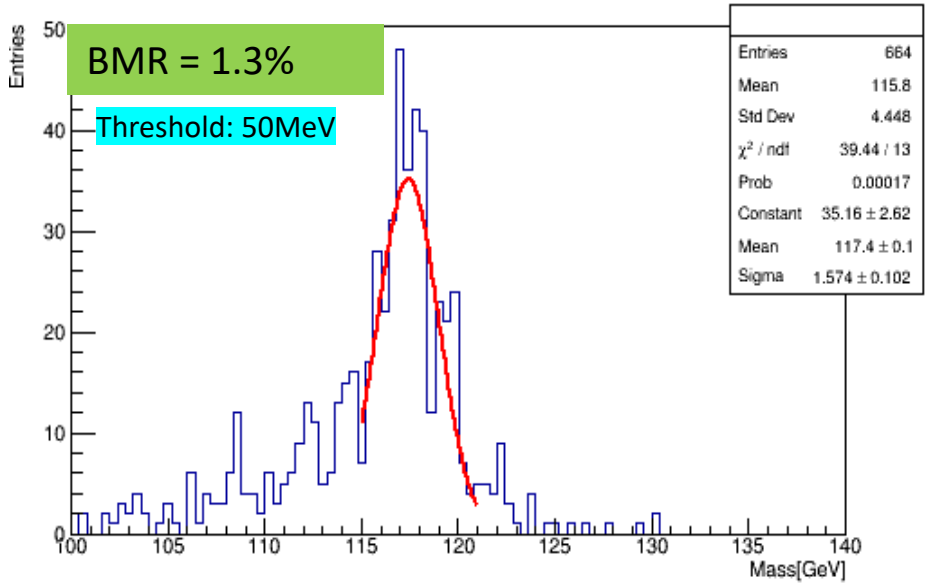




Boson mass resolution in H→ γγ

- Sample: ZH->2neutrinos + γγ at 240 GeV
- Energy, position reconstruction and separation using simplified reconstruction method described above
- Crystal energy threshold: 2 MeV/50MeV

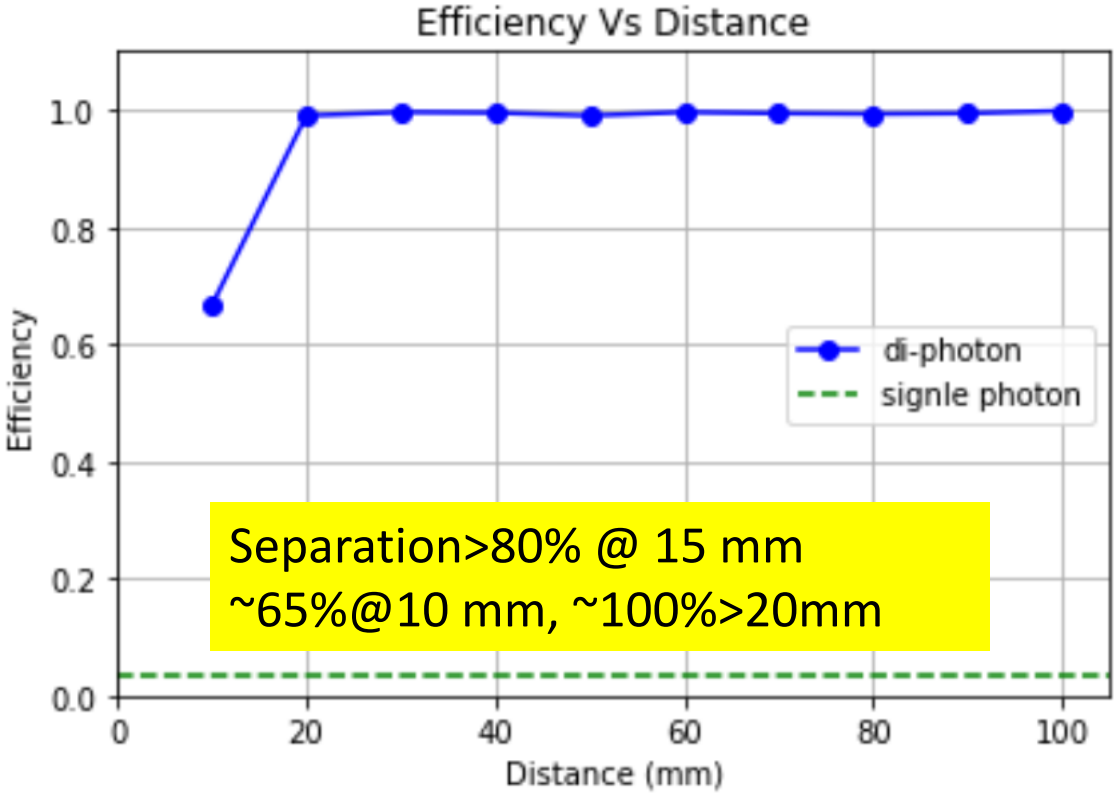


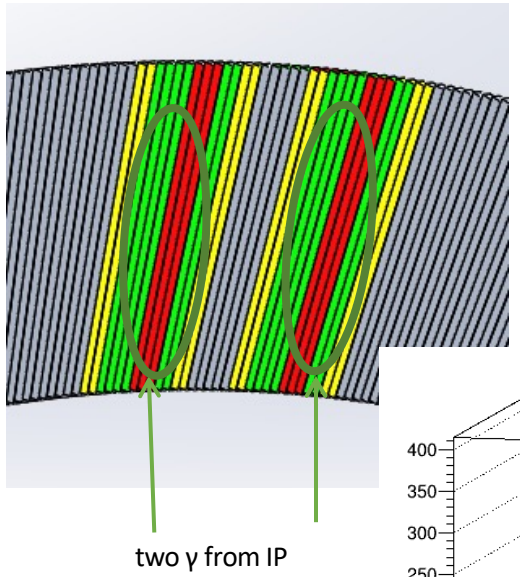


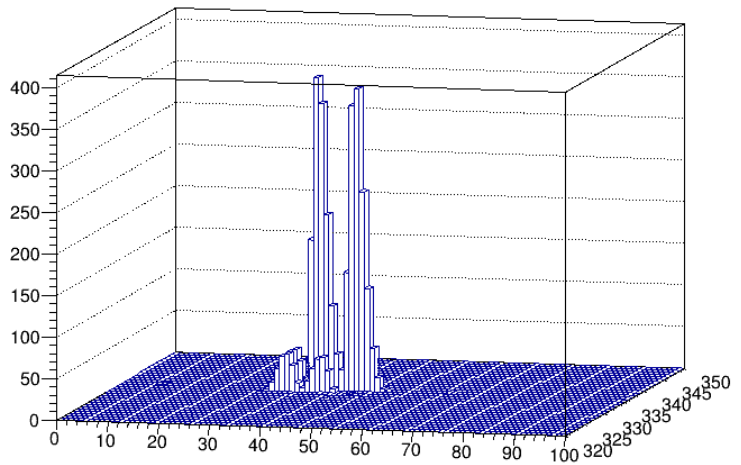
Separation between two 5 GeV photons

- Two 5 GeV photons, vary distance along phi between them
- Success reconstruction: 2 neutral particles, 3.3GeV<Eγ<6.6GeV for each photon
- **Separation and energy regression using end-to-end NN**
  - trained with flat distributed photon energy and distances

https://journals.aps.org/prd/pdf/10.1103/PhysRevD.108.052002

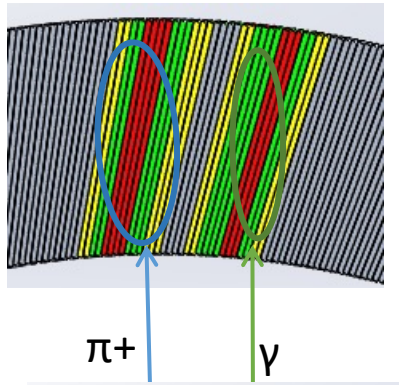


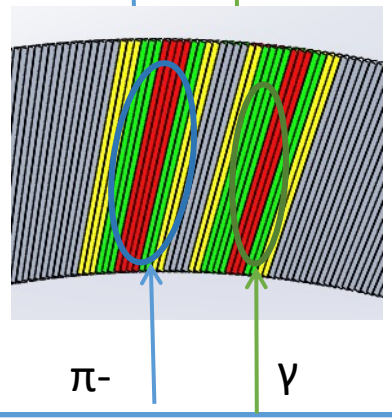




Separation between γ/π

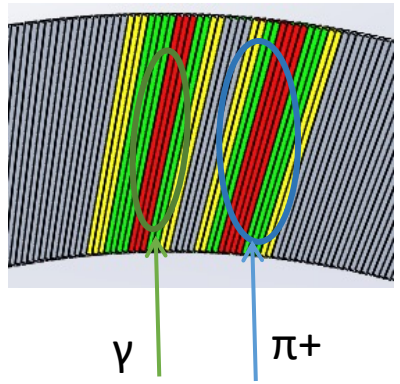
- 5 GeV γ/10GeV π, vary distance along phi between them
- Success reconstruction: $3.3GeV<E_{\gamma}<6.6GeV$
- Different π/γ separation power: pointing angle / magnetic field

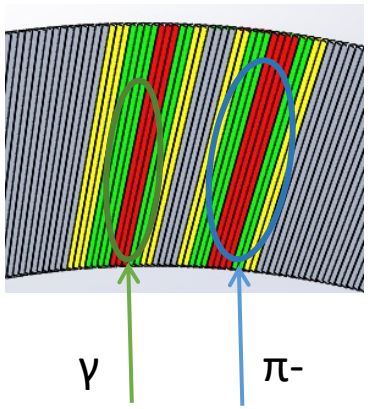




Separation using NN will come soon

Threshold: 2MeV



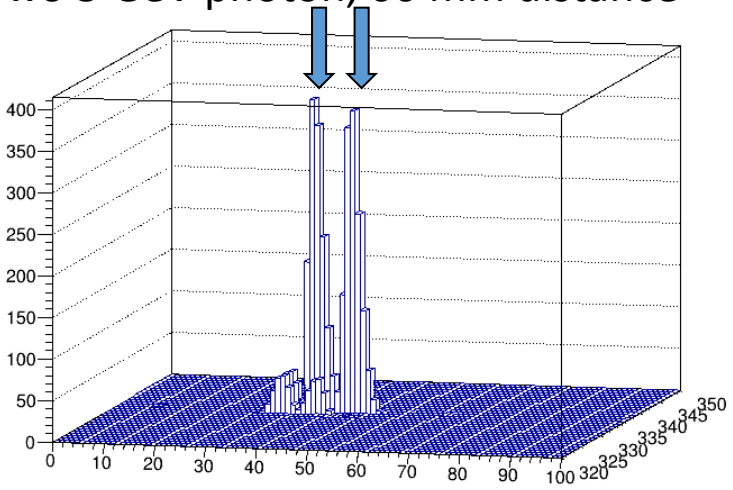


Pi0→2phton invariant mass

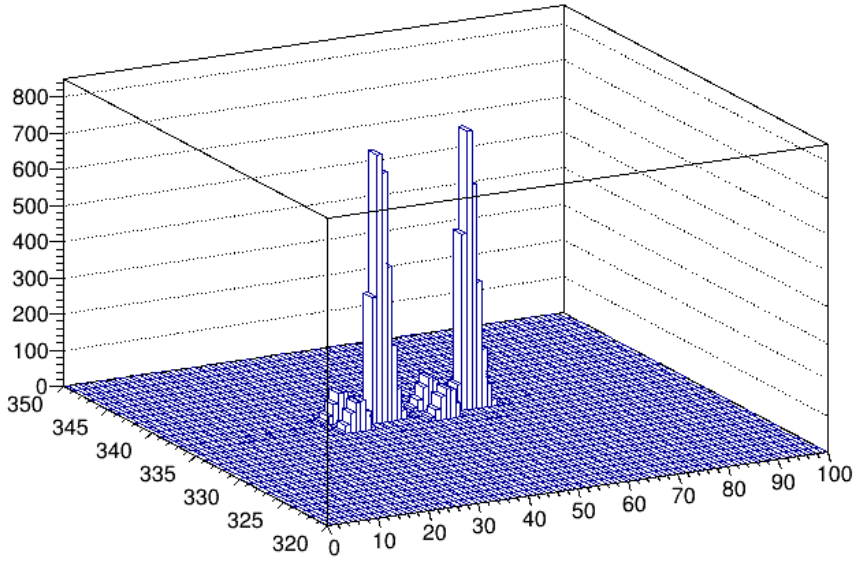
- End-to-end NN regression is on going, coming soon

Event display of shower separation/ID

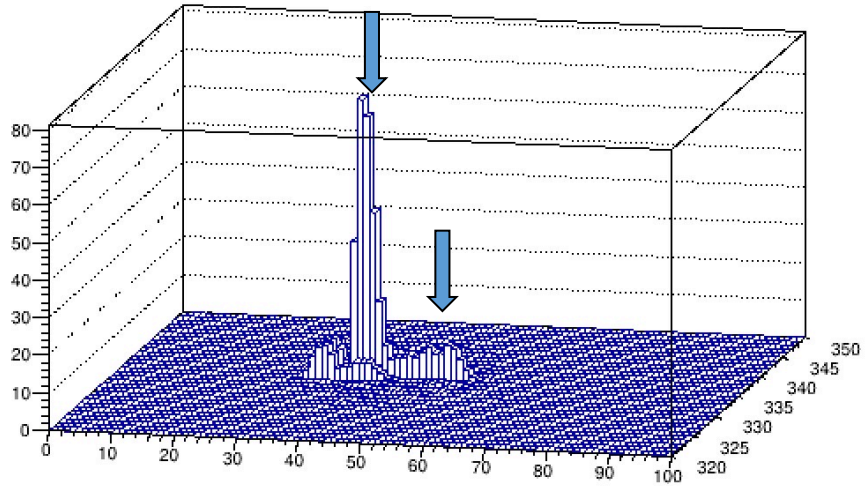
Two 5 GeV photon, 66 mm distance



Two 5 GeV photon, 165 mm distance



5 GeV photon and 10 GeV pi-, 66mm



5 GeV photon and 10 GeV pi-, 195mm