



中国科学技术大学

University of Science and Technology of China

CEPC AHCAL Prototype Status

Yukun Shi

On behalf of the CEPC Calorimeter Group

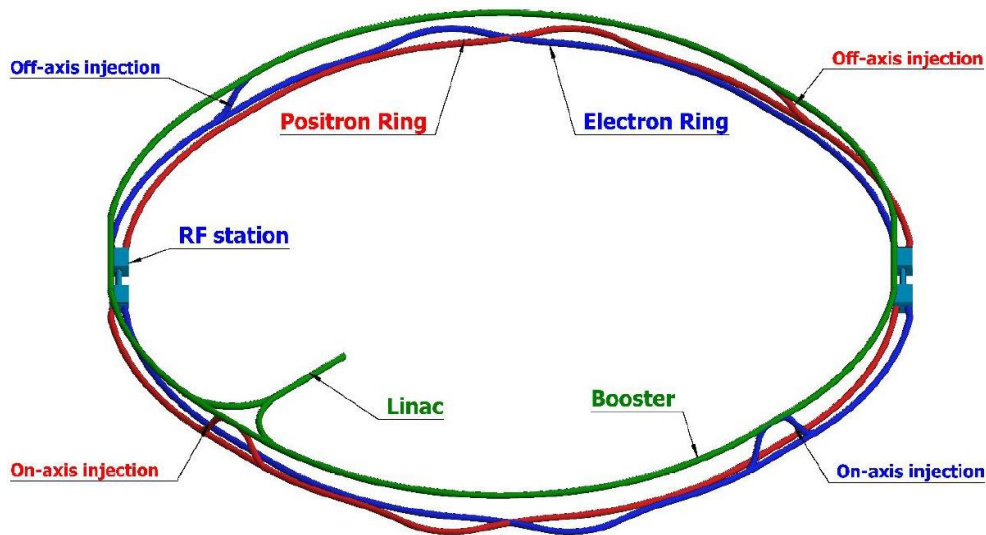
CALICE Collaboration Meeting 2021.3



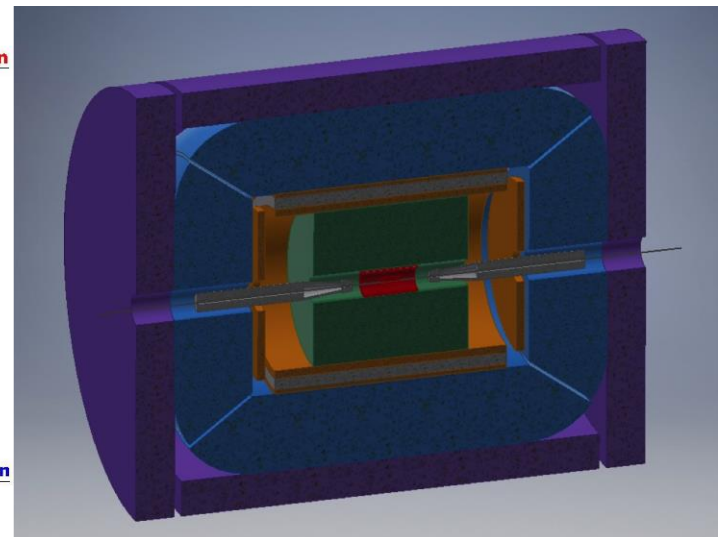
- **Background**
- Prototype optimization
- Scintillator and SiPM
- HCAL Board Unit
- Summary and outlook

- CEPC

- The CEPC is designed as the Higgs factory
- The baseline detector option for the CEPC is guided by the particle flow algorithm(PFA)

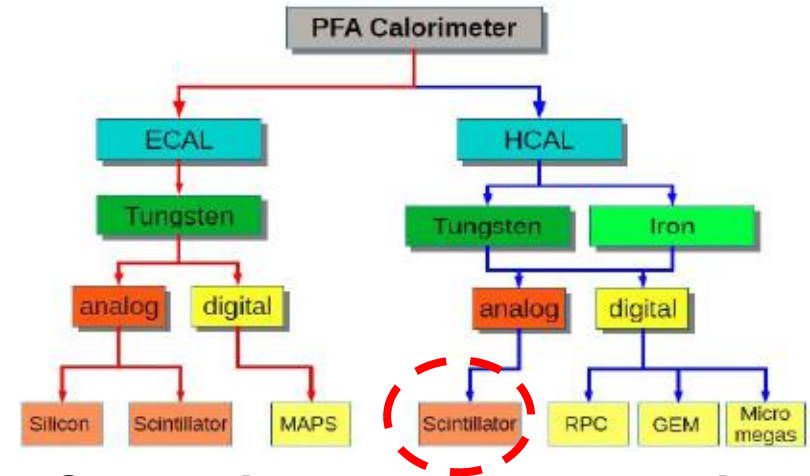


Design of the CEPC Accelerator

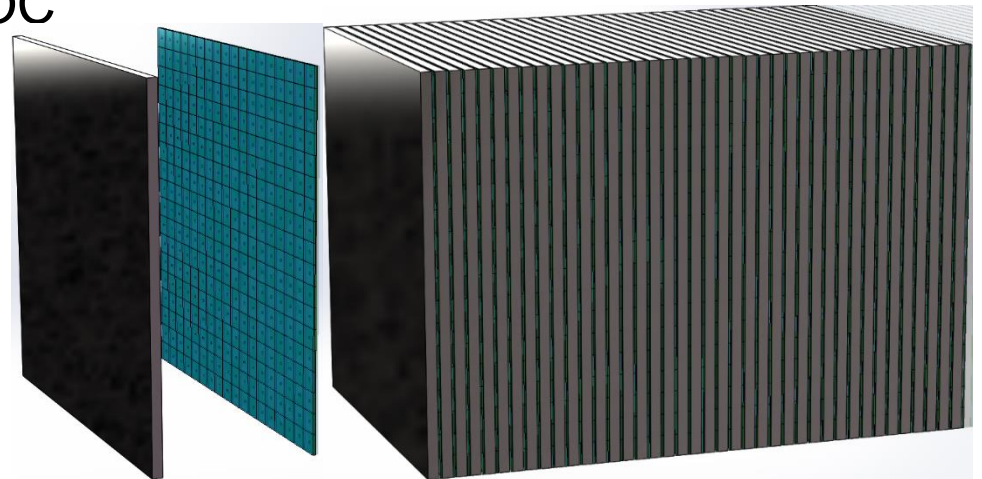
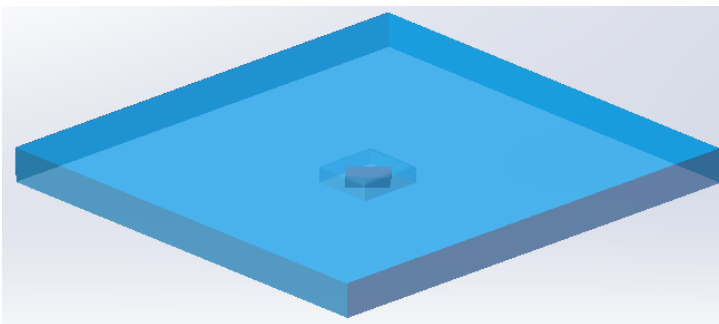


CEPC baseline detector

- The Scintillator-Steel AHCAL
 - PFA oriented: high granularity
 - 40mm cell size
 - 40 sampling layers
 - 20mm Steel
 - 3mm scintillator
 - 2mm PCB
 - Analog readout: SiPM+SPIROC



CEPC baseline calorimeter options

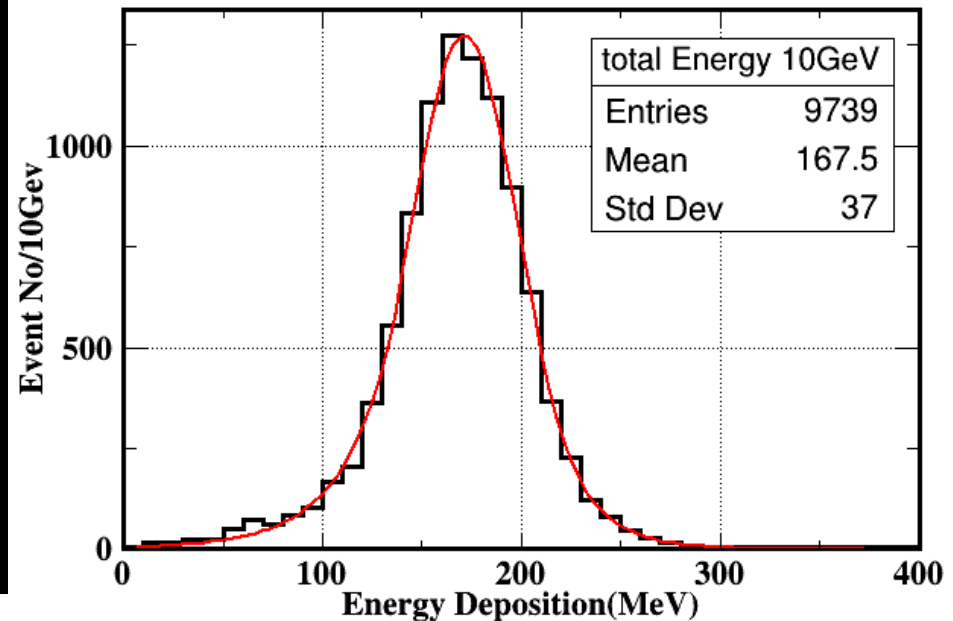




- Background
- **Prototype optimization**
- Scintillator and SiPM
- HCAL Board Unit
- Summary and outlook

- Simulation Setup

- CEPC Simplified Geometry: only AHCAL is implemented
- Prototype Transverse size: $72 \times 72\text{cm}^2$
- 40 layers: each layer has 20mm steel, 3mm scintillator and 2mm PCB
- Incident particle: Klong which's energy ranges from 10GeV to 80GeV

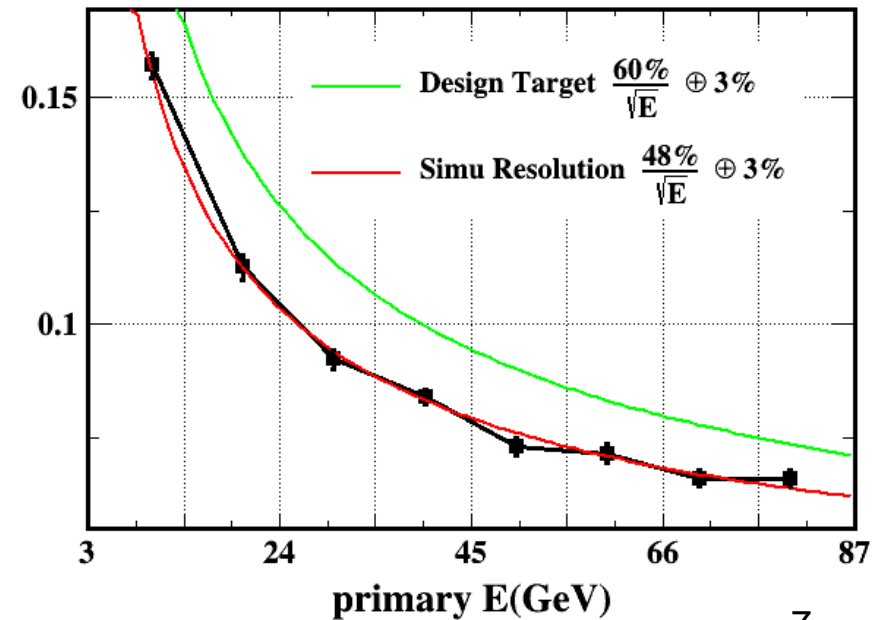
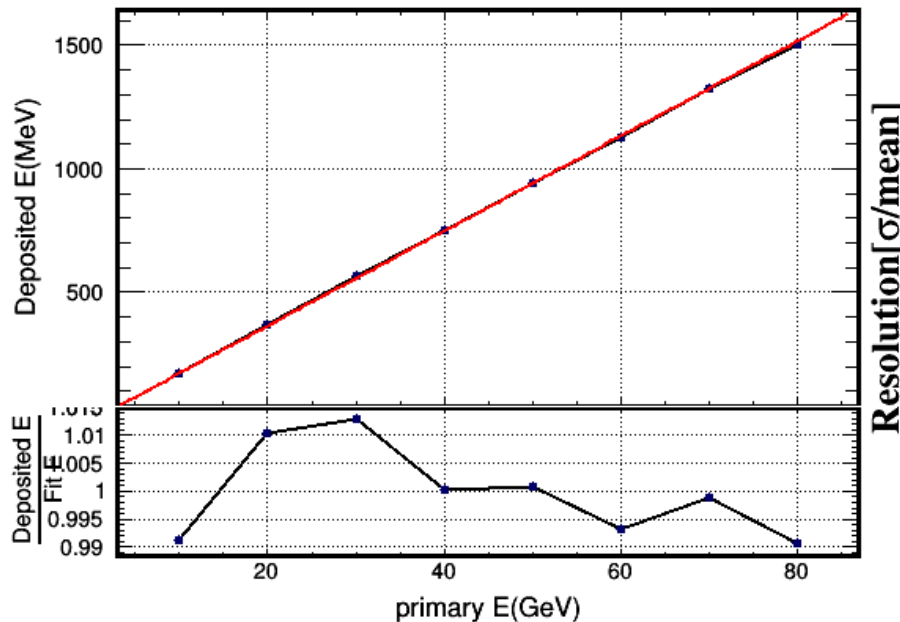


Event Display and Energy deposition for 10GeV KL

- Analysis

- Fit by double side crystal ball function

- Energy resolution as a function of incident particle's energy is described by $\frac{a}{\sqrt{E}} \oplus b$

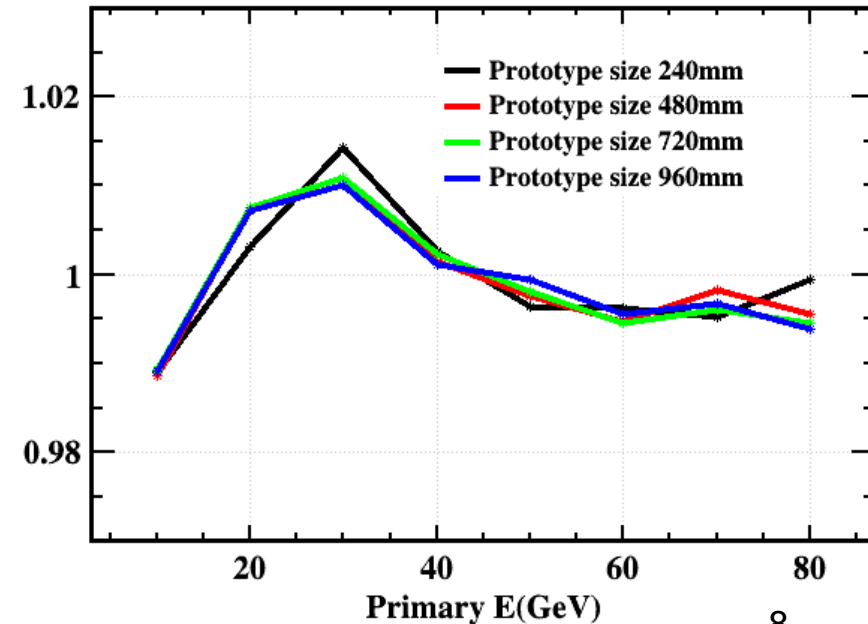
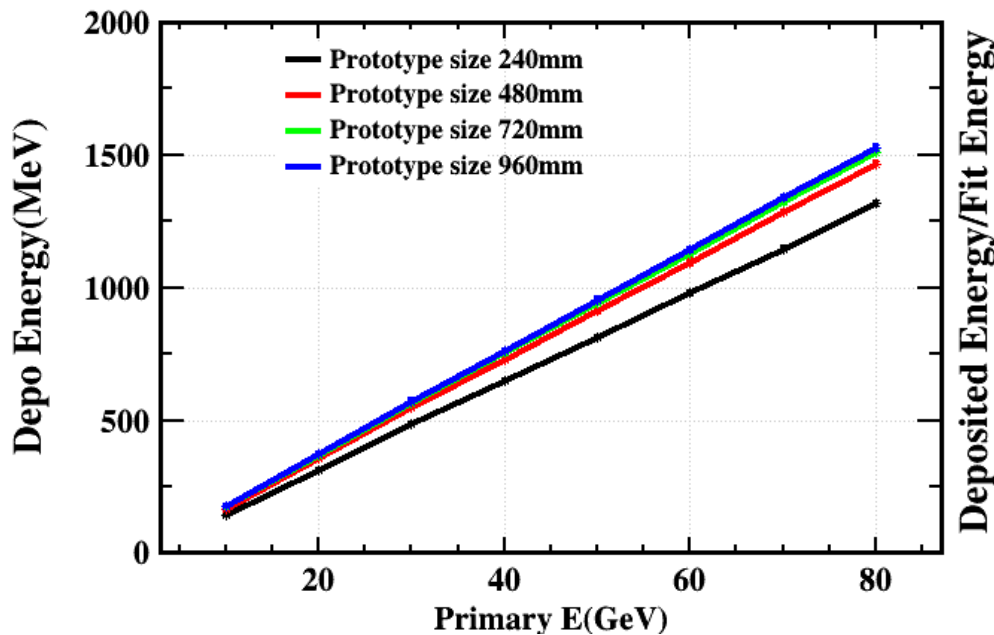


Linearity and resolution for HCAL prototype

Prototype optimization

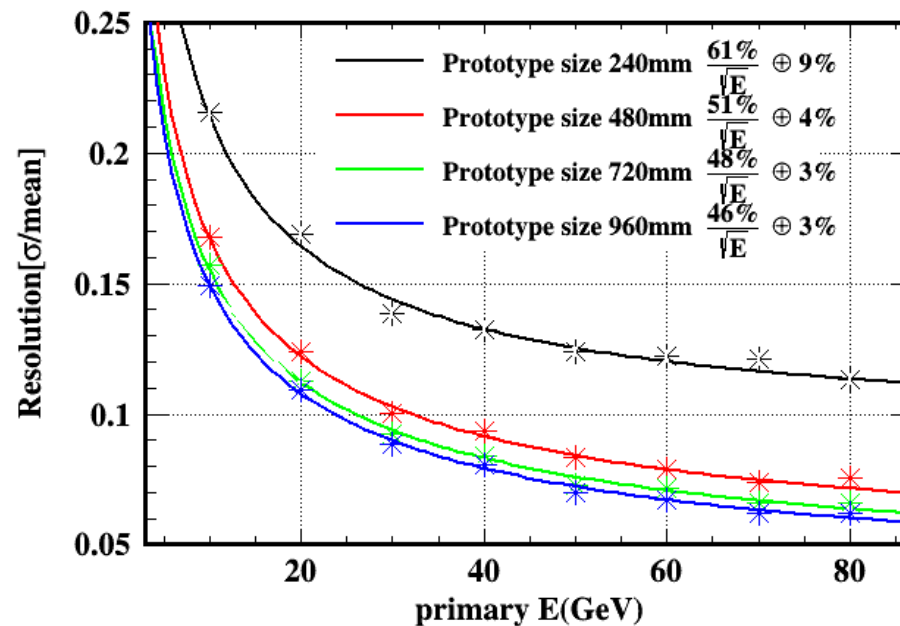


- Prototype size optimization
 - 40 sampling layer, each layer has 20mm steel, 3mm scintillator and 2mm PCB
 - The transverse prototype size ranges from 240mm to 960mm
 - All have a linearity $< \pm 3\%$



Linearity for different prototype transverse size

- Prototype size optimization
 - Larger prototype size has less energy leakage and better resolution
 - Prototype size has a strong impact on the cost and power consumption of the prototype
 - 720mm is chosen to be the prototype transverse size

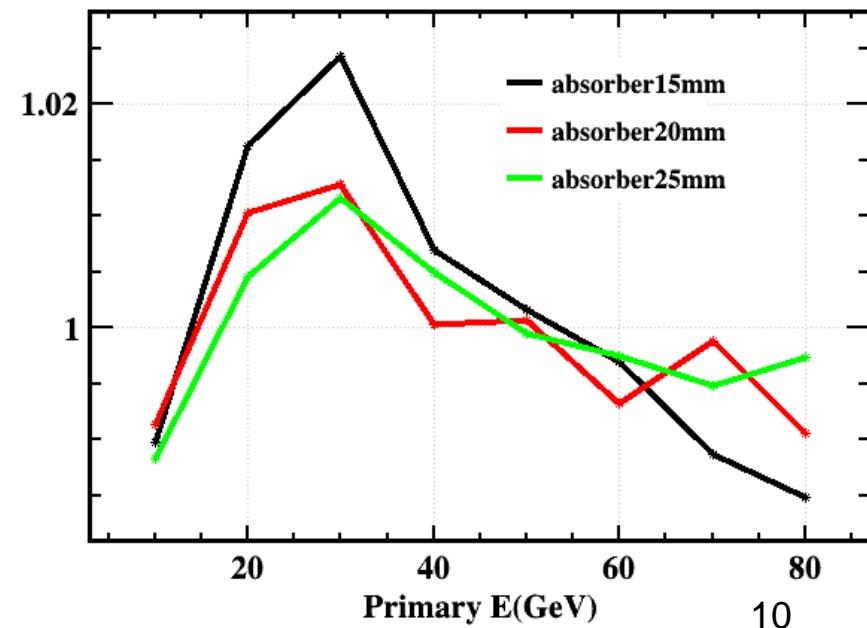
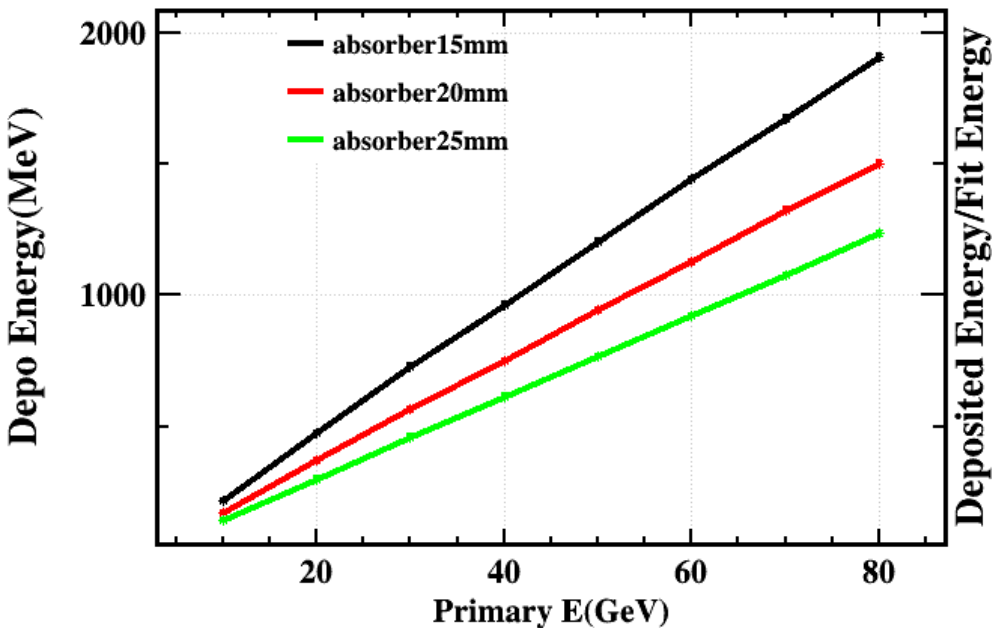


resolution for different Prototype size

Prototype optimization

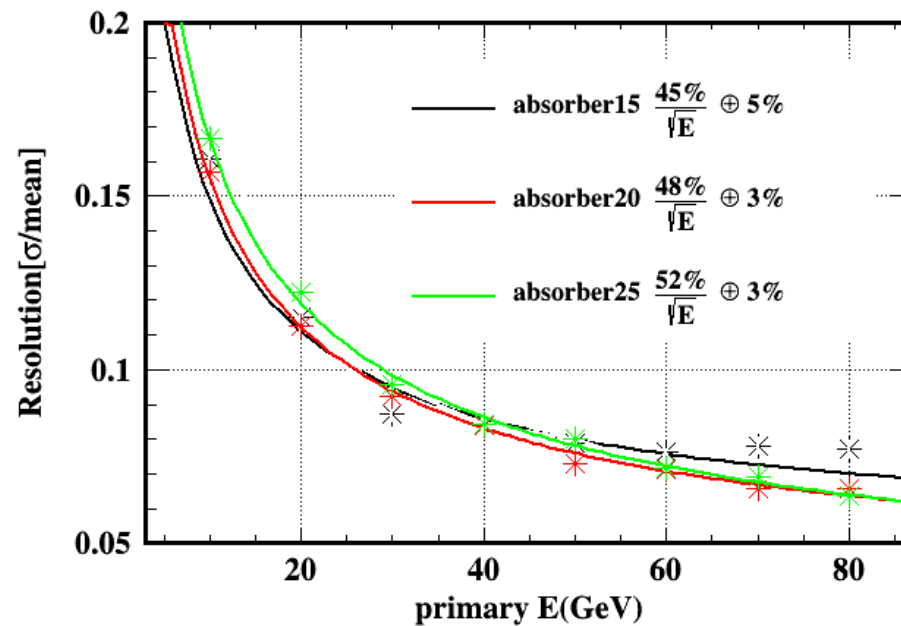


- Absorber thickness optimization
 - Prototype Transverse size: $72 \times 72\text{cm}^2$
 - 40 sampling layer, each layer has 3mm scintillator and 2mm PCB
 - Absorber thickness for each layer ranges from 15mm to 25mm
 - Total absorber thickness ranges from 3.8λ to 6.3λ
 - All have a linearity $< \pm 3\%$



Linearity for different absorber thickness

- Absorber thickness optimization
 - Thinner absorber has a better sampling ratio resulting a smaller statistical term
 - Thinner absorber has more leakage resulting a bigger constant term
 - The 20mm absorber is a balanced choice



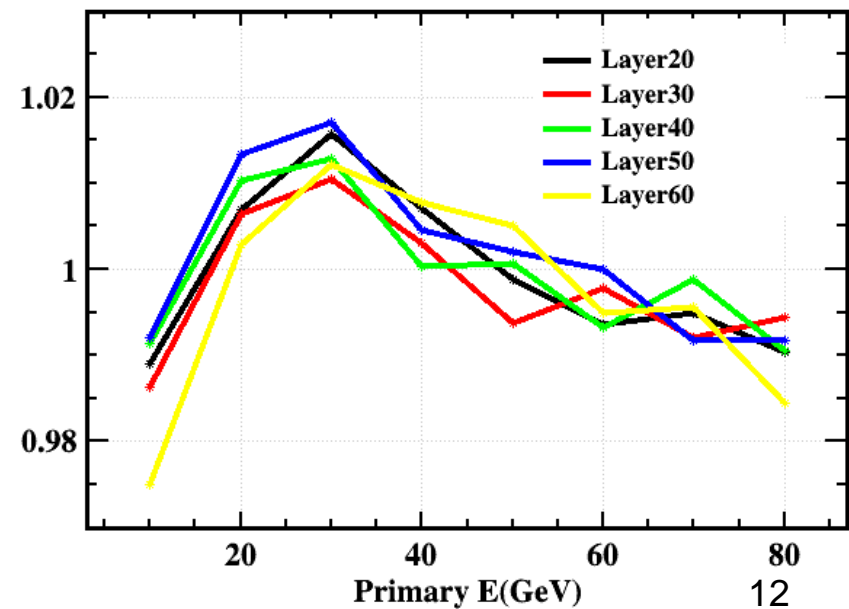
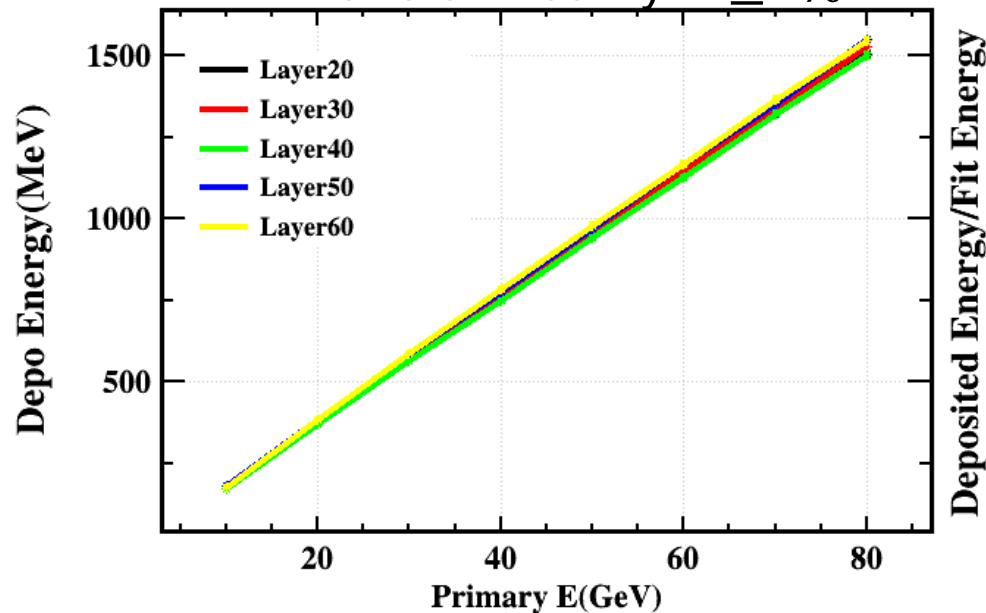
resolution for different absorber thickness

Prototype optimization



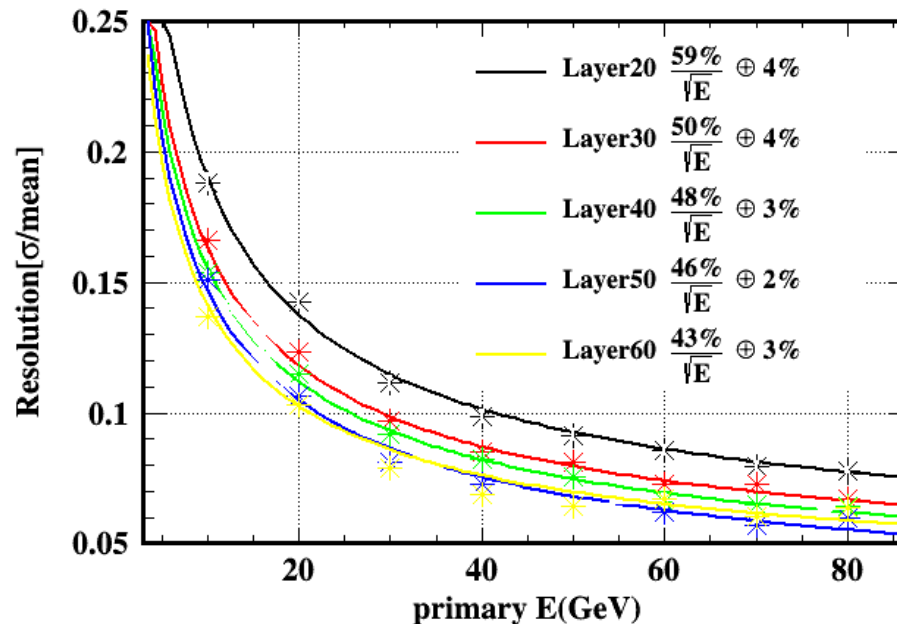
- Sampling Layer optimization

- Prototype Transverse size: $72 \times 72\text{cm}^2$
- Total absorber thickness is fixed as 800mm and total scintillator thickness is fixed as 120mm
- The thickness of PCB for each layer is 2mm
- The number of sampling layers ranges from 20 to 60
- All have a linearity $< \pm 3\%$



Linearity for different sampling layers

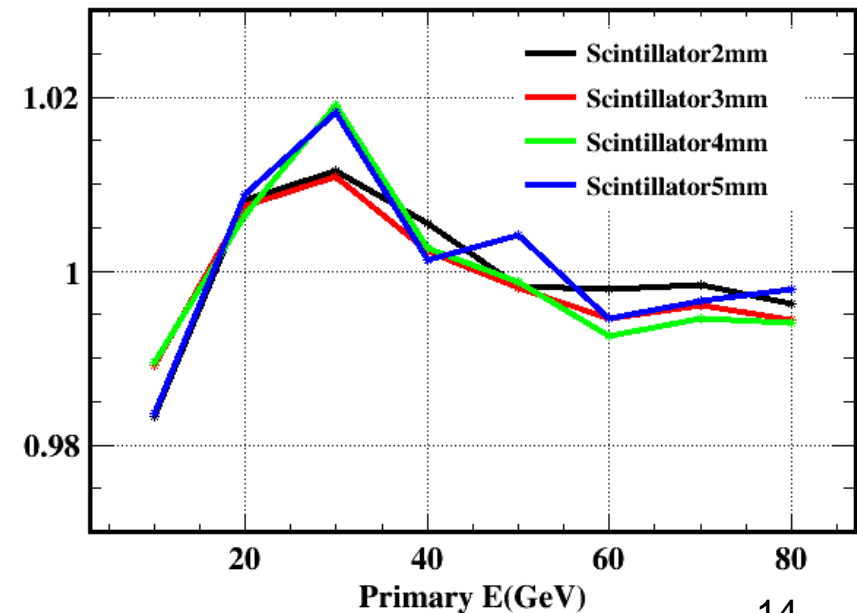
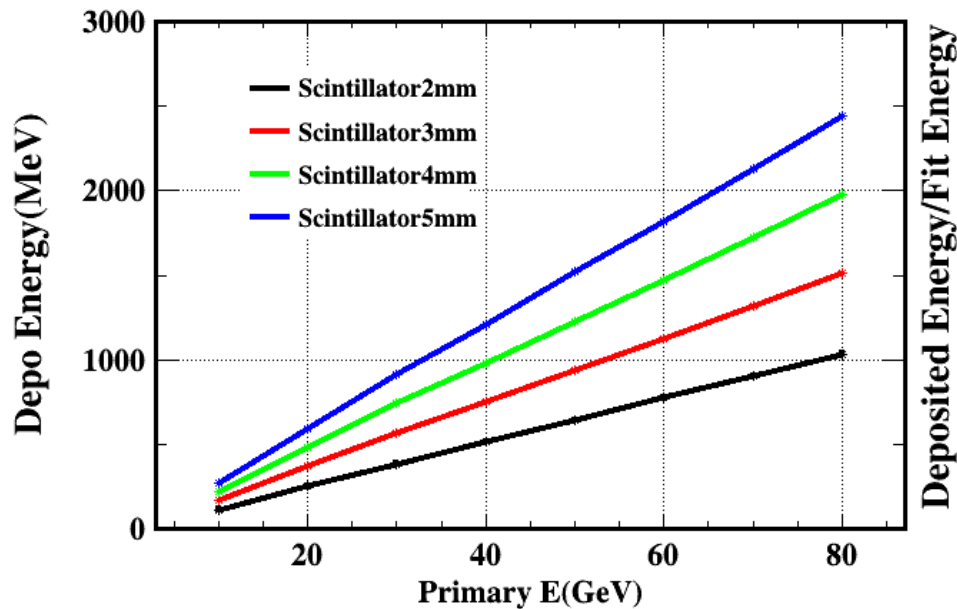
- Sampling Layer optimization
 - More sampling layers have less statistical fluctuation
 - Since PCB thickness for each layer is fixed, it could be a problem for more sampling layers in the prototype
 - 40 layers is reasonable for the prototype



Resolution for different sampling layers

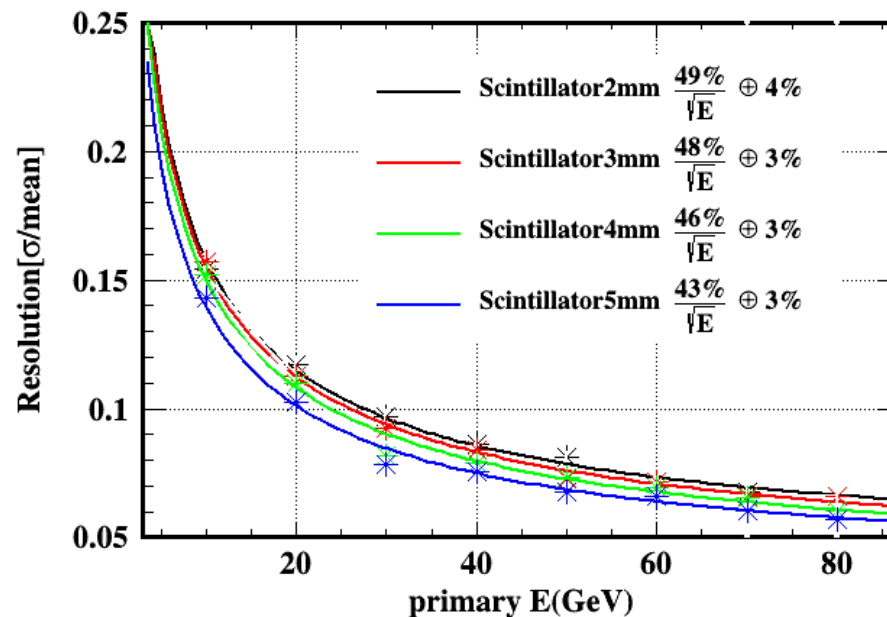
- Scintillator thickness optimization

- Prototype Transverse size: $72 \times 72\text{cm}^2$
- 40 sampling layer, each layer has 20mm steel and 2mm PCB
- The scintillator thickness for each layer ranges from 2mm to 5mm
- All have a linearity $< \pm 3\%$



Linearity for different scintillator thickness

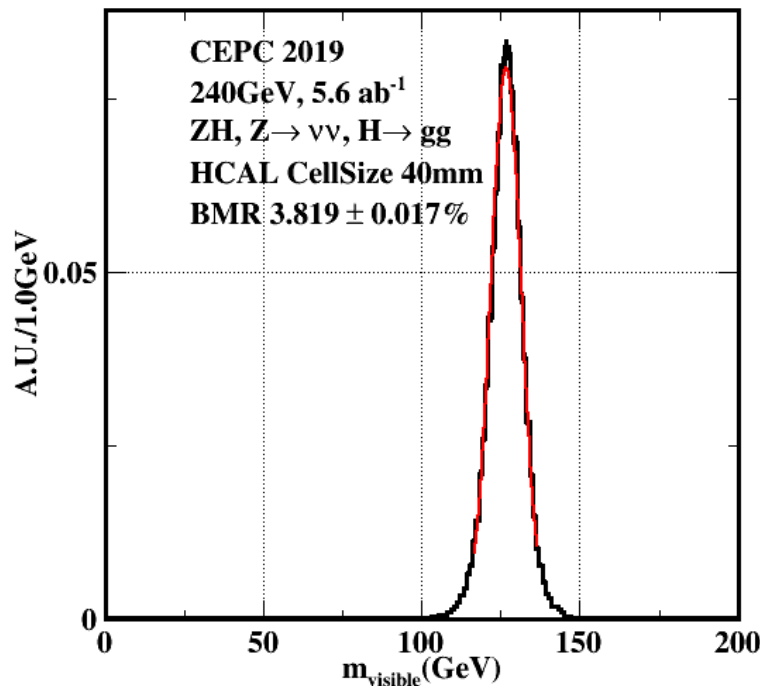
- Scintillator thickness optimization
 - Thicker scintillator has better resolution but the improvement isn't obvious
 - Thicker scintillator will increase total thickness and manufacture cost
 - 3mm scintillator is chosen for the prototype



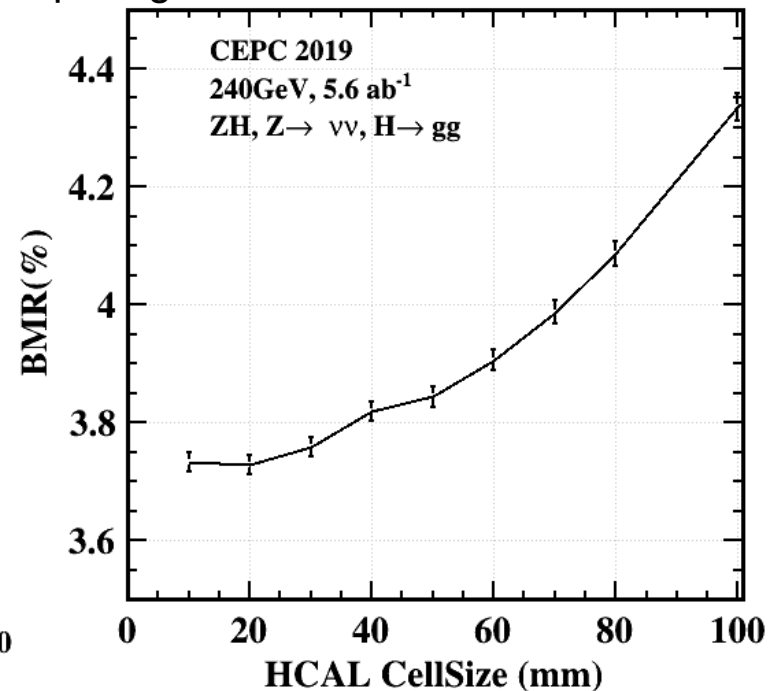
Resolution for different scintillator thickness

- Cell size optimization

- The boson mass resolution(BMR) is reconstructed by arbor under CEPC V4 environment
- BMR is suggested to be smaller than 4% considering the Physics on CEPC(Manqi Ruan,IHEP)
- 40mm cell size can satisfy the BMR requirement while reducing about half of the readout channels comparing to 30mm



cell size 40mm: BMR



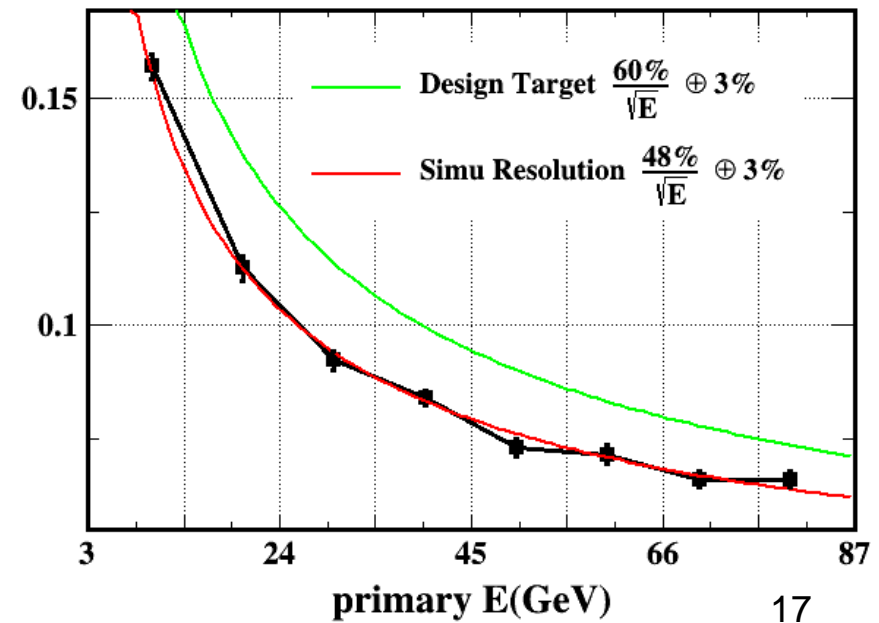
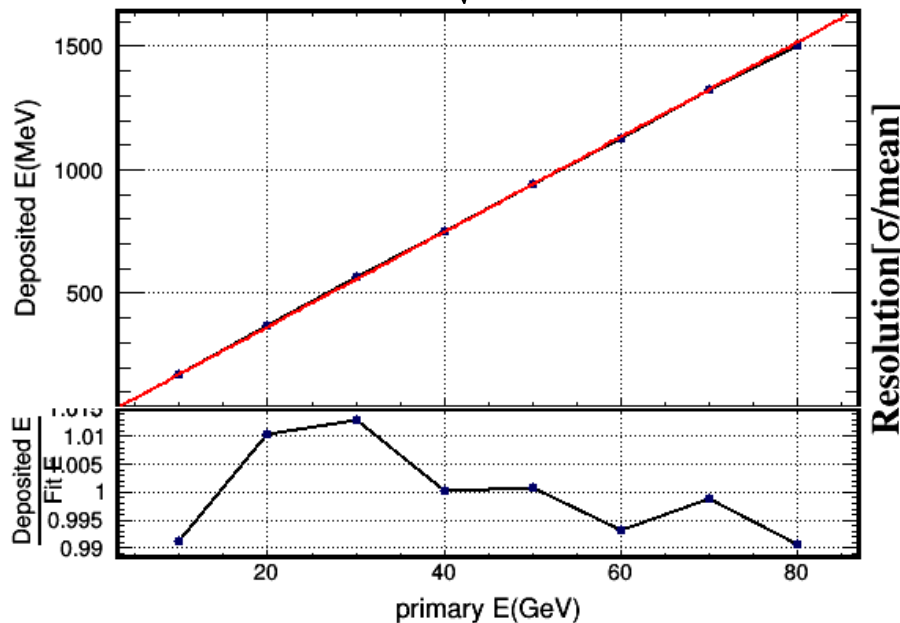
CEPC ACHAL cell size vs BMR

Prototype optimization



– Prototype design and performance

- Transverse size: $72 \times 72\text{cm}^2$
- 40 layers: each layer has 20mm steel, 3mm scintillator and 2mm PCB
- Cell size: 40mm
- Linearity: $\sim \pm 1\%$
- Resolution: $\frac{48\%}{\sqrt{E(\text{GeV})}} \oplus 3\%$



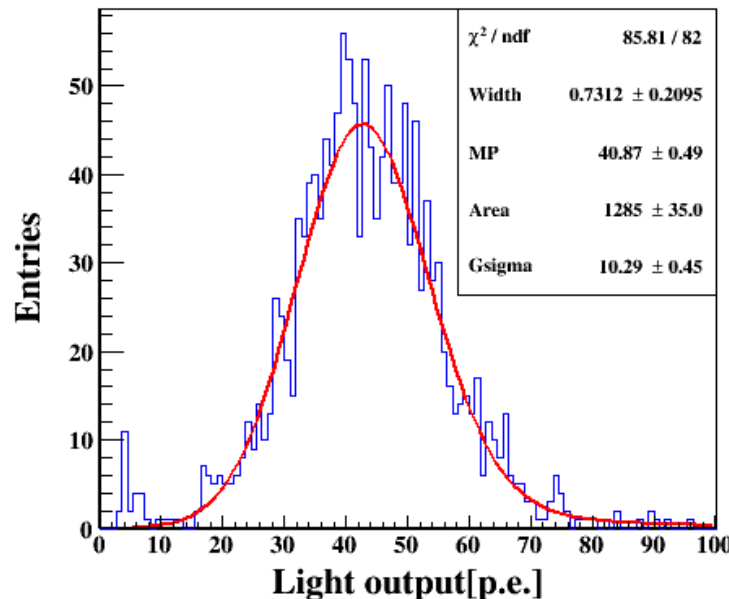
Linearity and resolution for HCAL prototype



- Background
- Prototype optimization
- **Scintillator and SiPM**
- HCAL Board Unit
- Summary and outlook

- 11000 scintillators have been produced using the injection molding technique
- The light yield of one scintillator is about 40 p.e. test by NDL-22-1313-15S

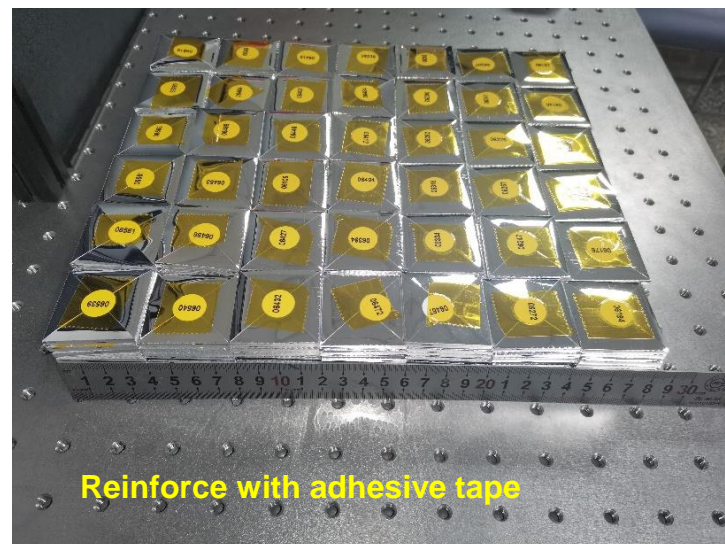
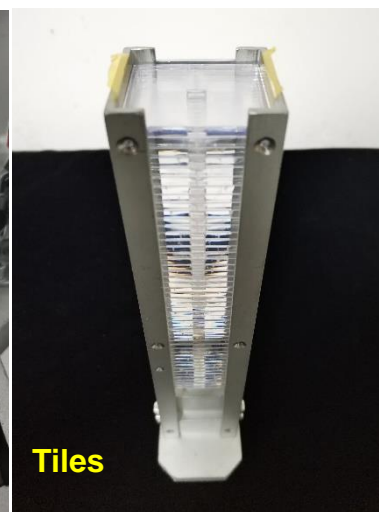
Light output:41p.e.



Wrapping of scintillators

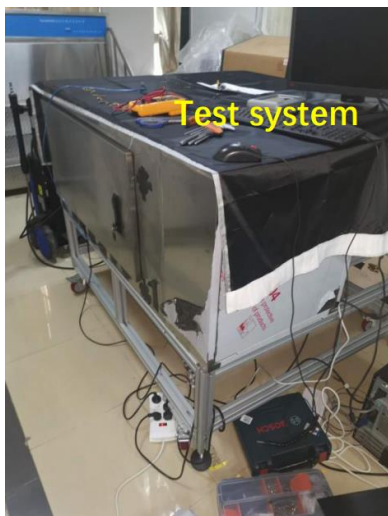
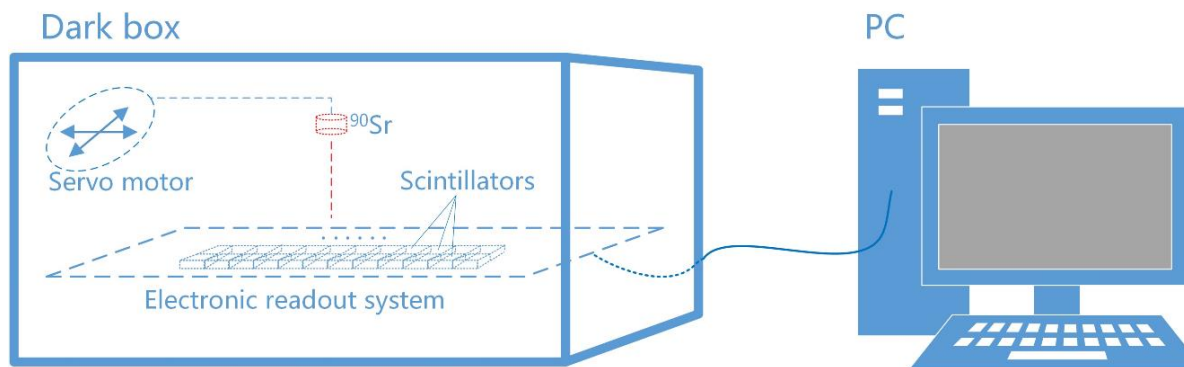


- The material of the wrapper is ESR
- The whole wrapping and labelling procedure is automatic
- 100 scintillators cost 75min once



Batch Testing Platform

- Test the uniformity of all scintillators
- 144 channels one platform
- Auto-moving
- 3 batch testing platforms



USTC

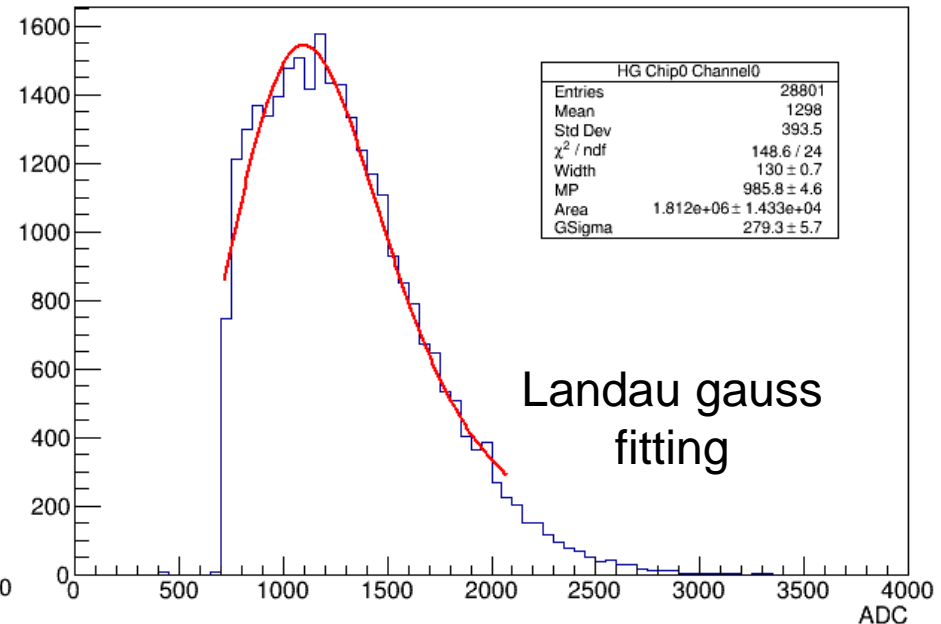
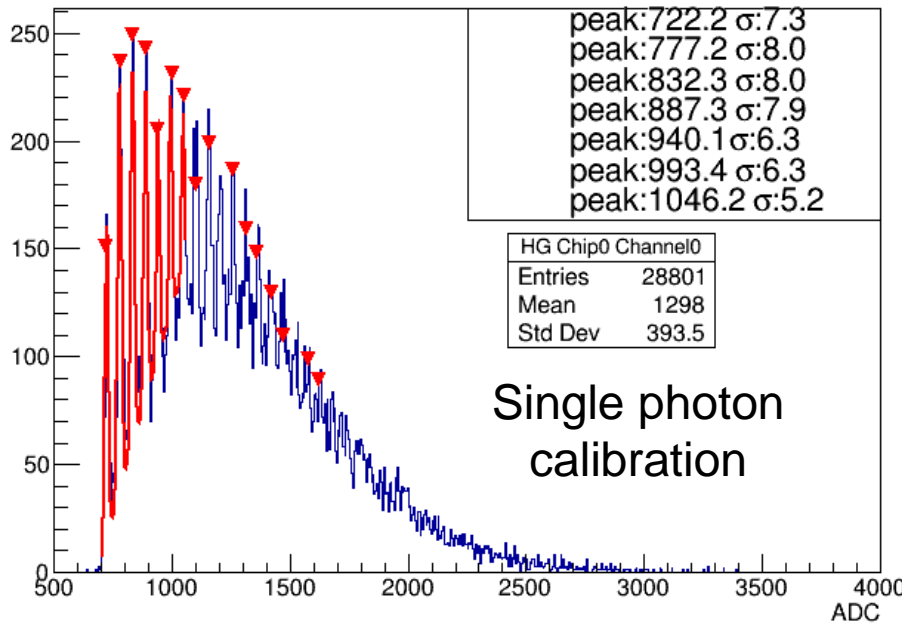


SJTU



IHEP

- MIP source : Sr 90
- The scintillator light is detected by the SiPM 13360-1325PE working at the 5V overvoltage
- The SiPM signal is read by the SPIROC2E chip

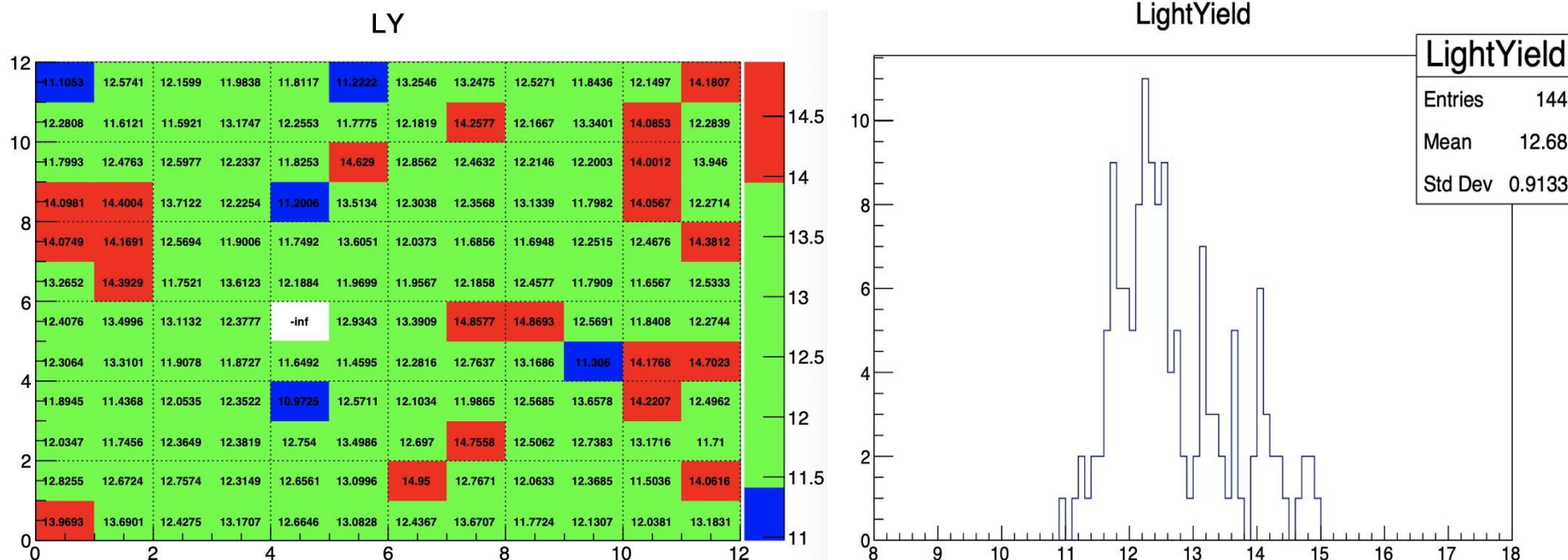


The MIP Spectrum

Batch test of scintillators



- Uniformity within $\pm 15\%$
- The differences between channels will be calibrated
- The differences between 3 platforms will be calibrated



The light yield(test in SJTU)

The SiPM comparison

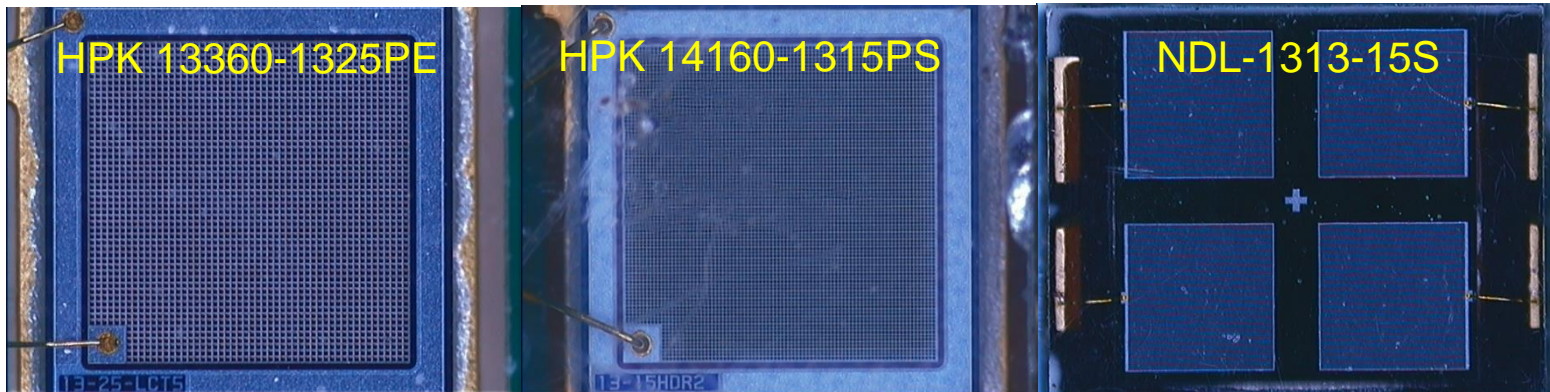


- **HPK-SiPM**

- Low PDE, dark rate and crosstalk
- High breakdown
- High price

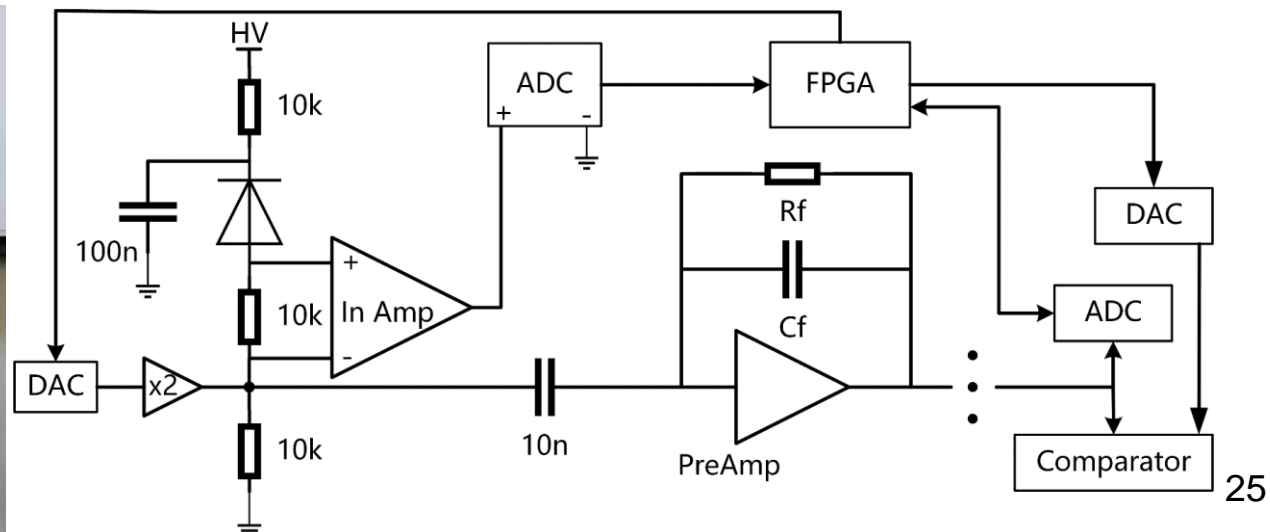
- **NDL-SiPM:**

- High PDE, dark rate and crosstalk
- Low breakdown
- Low price



Company	HPK		NDL
Type	13360-1325PE	14160-1315PS	22-1313-15S
Light output [p.e.]	13	17	40
Crosstalk[%]	1.59	1.17	4.4
Dark Counts [kHz]	120	290	550
Breakdown[V]	53	38	27.5

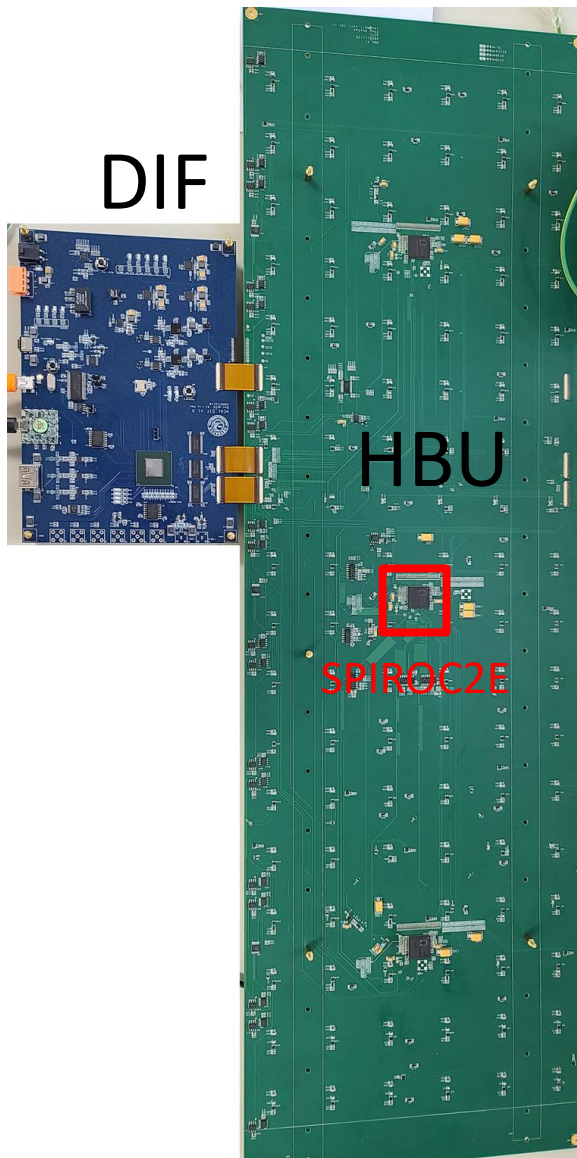
- The design of the SiPM test platform
 - Assure the uniformity of SiPMs
 - A SiPM detachable fixer
 - SKIROC2a readout or discrete-circuit readout
 - Test quality : break down voltage, dark count rate, gain



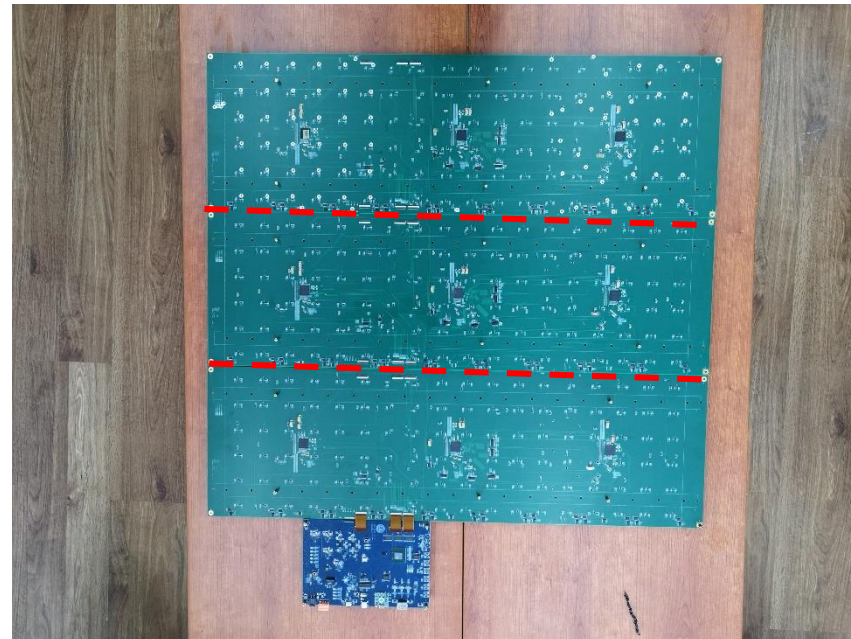


- Background
- Prototype optimization
- Scintillator and SiPM
- **HCAL Board Unit**
- Summary and outlook

HBU(HCAL Basic Unit)

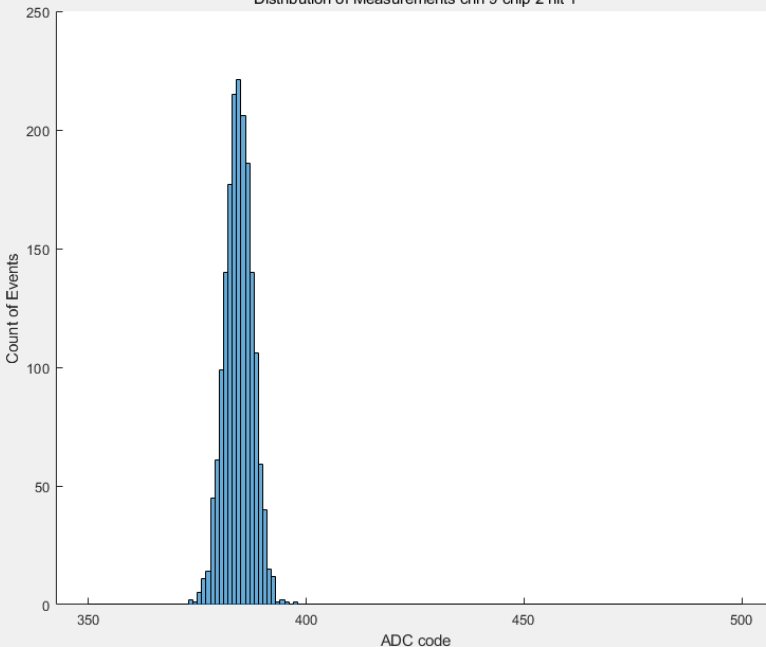


- The sensitive size of one layer is designed as $72 \times 72\text{cm}^2$
- A single layer is equally divided into 3 boards, each HBU is $78.5 \times 24\text{cm}^2$
- One PCB has 108 channels
- Every layer is controlled by one DIF board



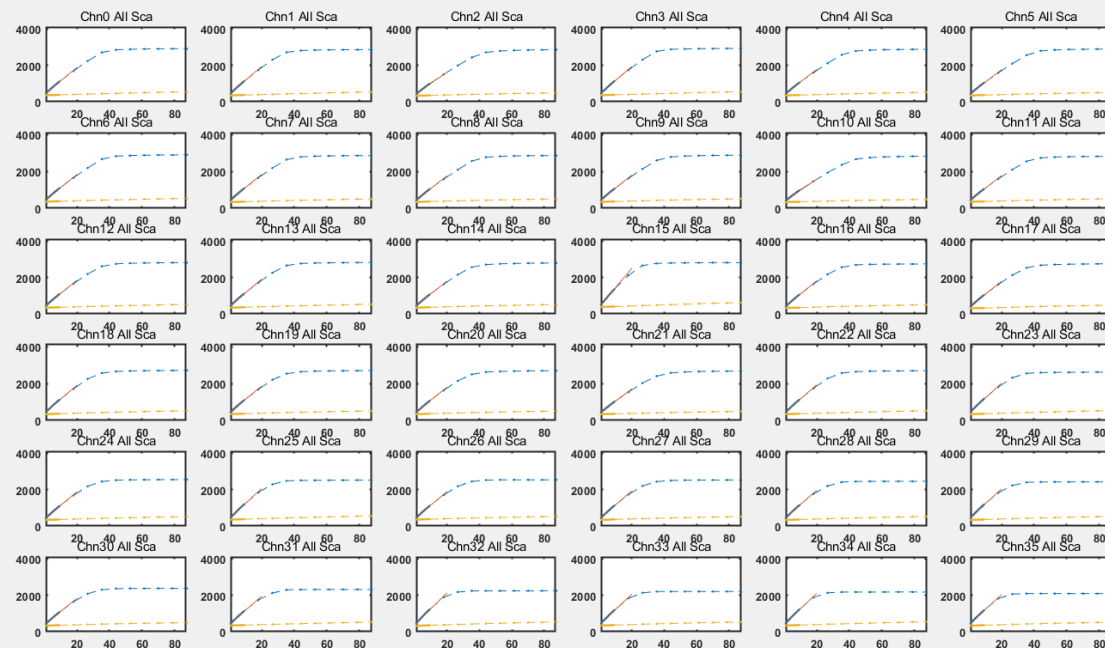
- Electronic test
 - The pedestal and charge calibration results mean that the chips are working normally

Distribution of Measurements chn 9 chip 2 hit 1



pedestal

CHIP1



Charge calibration



- Background
- Prototype optimization
- Scintillator and SiPM
- HCAL Board Unit
- Summary and outlook



- **Summary**

- The final design for the AHCAL prototype has been settled
- 11000 scintillators have been produced and all will be test in a few months
- The BNU SiPM will be used in the prototype after Batch test
- The HBU electronics works normally now

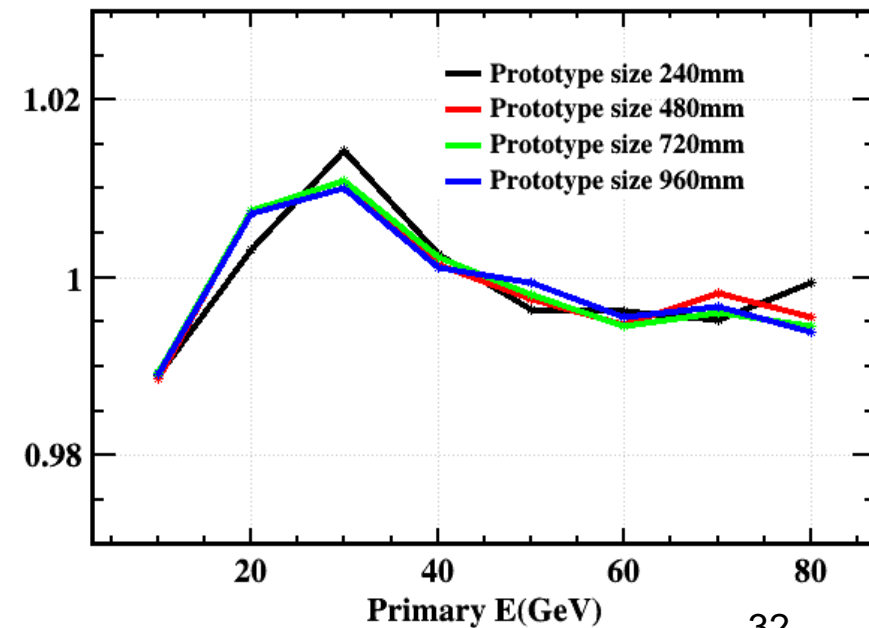
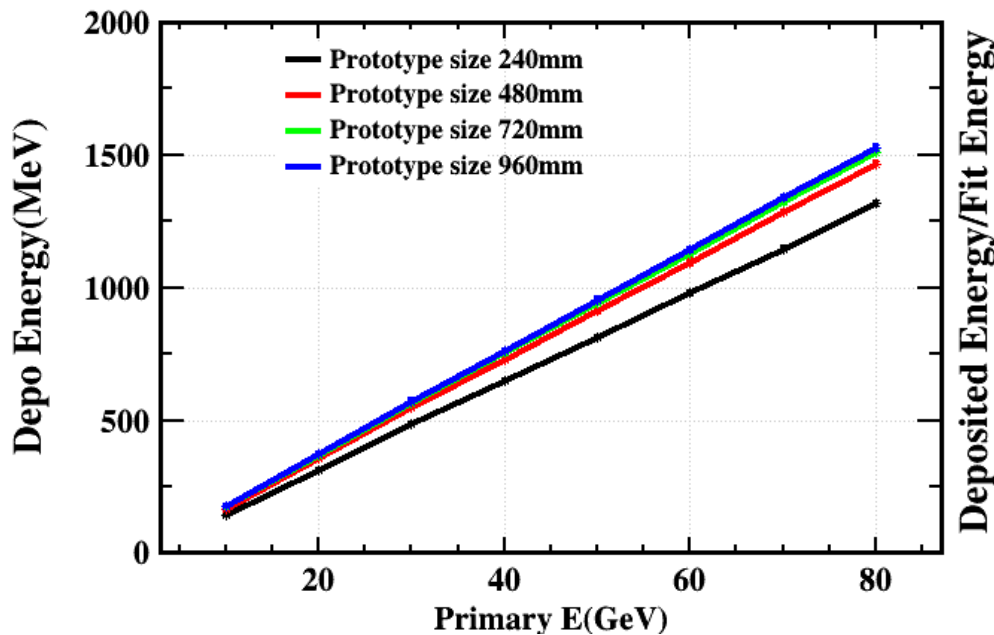
- **Outlook**

- The test platform for SiPMs will be completed before summer
- Production of all 40 prototype layers will be finished this year
- The next step, the whole prototype construction, will start before the end of this year, and the cosmic and beam test is expected next year



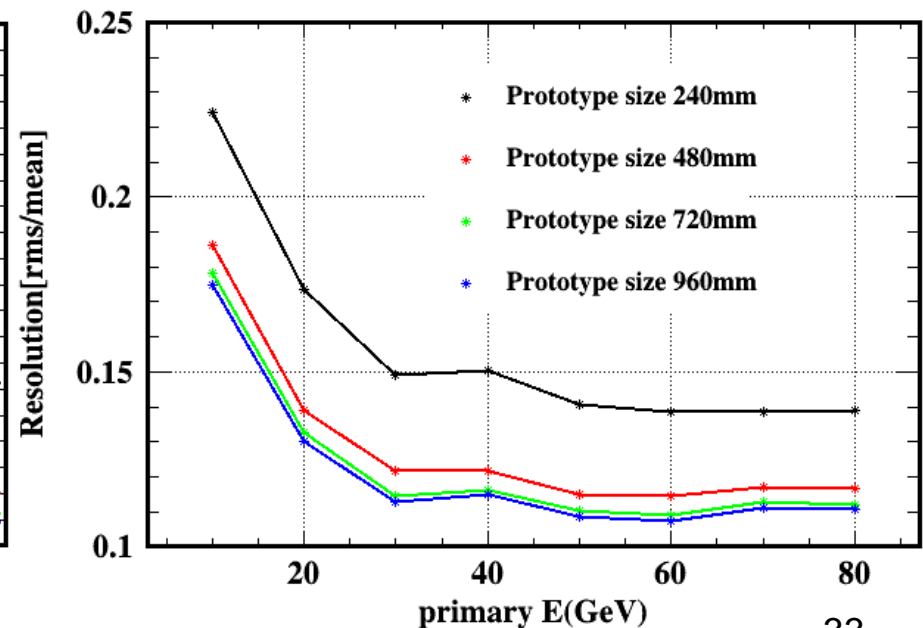
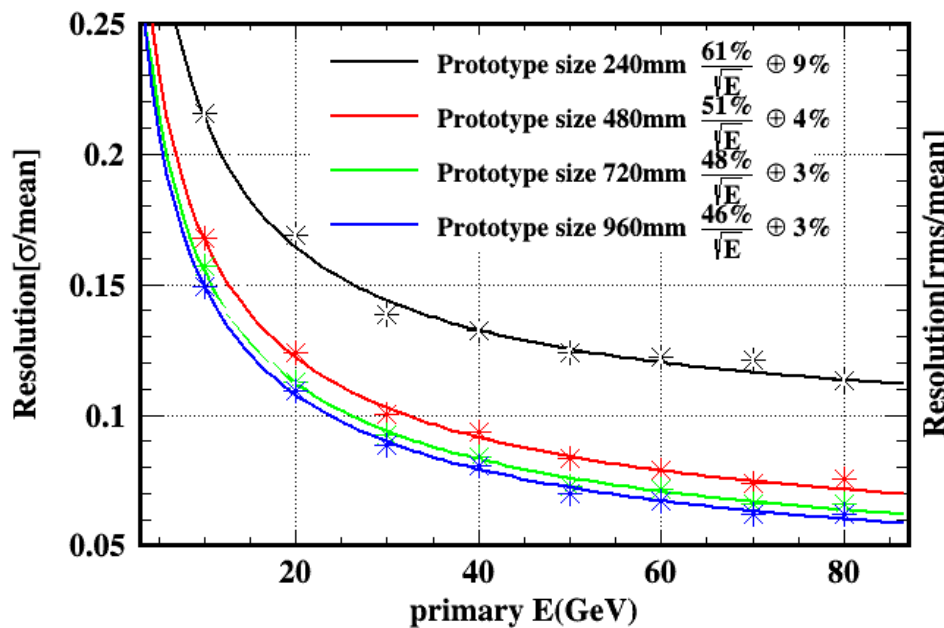
Back up

- Prototype size optimization
 - 40 sampling layer, each layer has 20mm steel, 3mm scintillator and 2mm PCB
 - The transverse prototype size ranges from 240mm to 960mm
 - All have a linearity $< \pm 3\%$



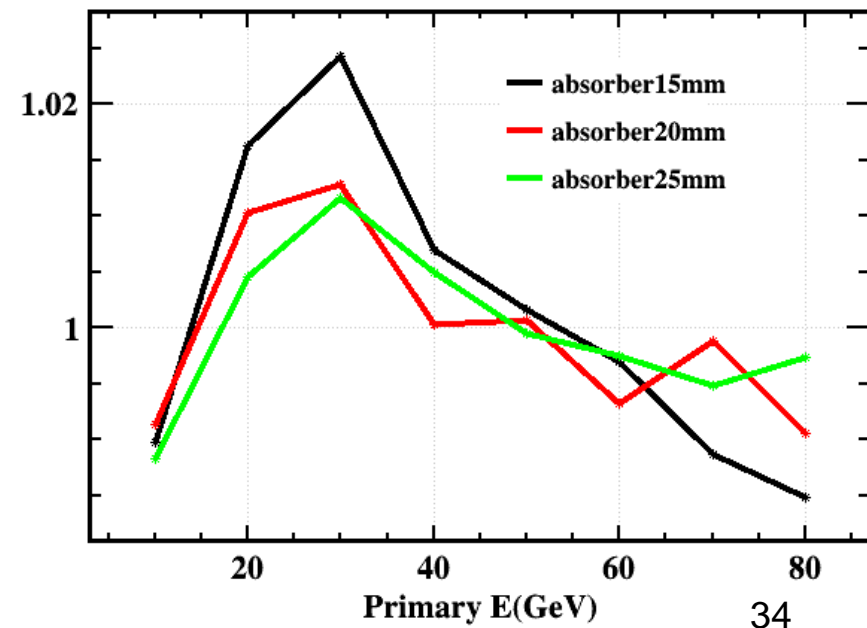
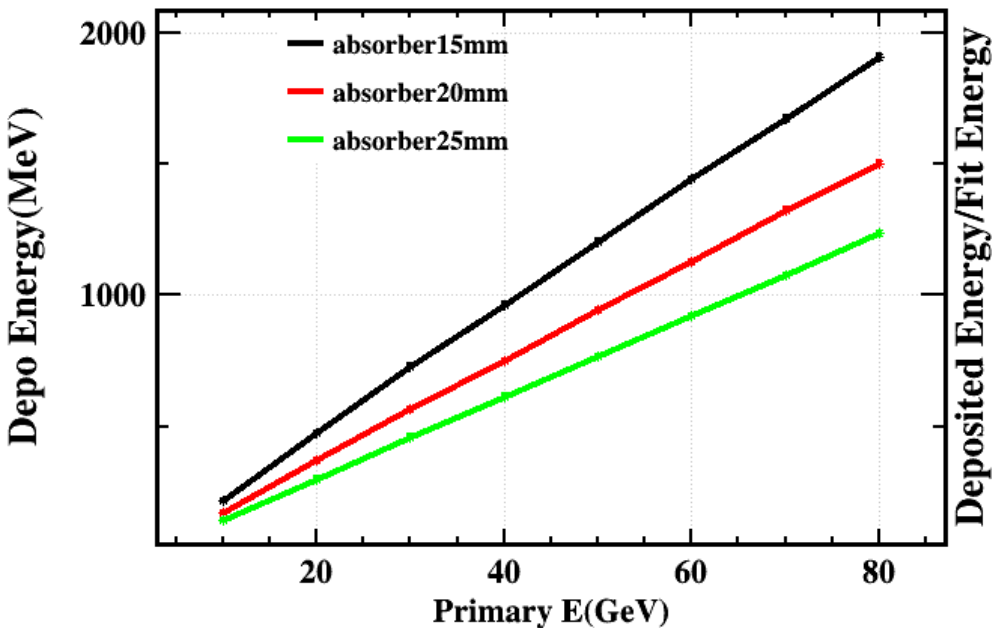
Linearity for different prototype transverse size

- Prototype size optimization
 - Larger prototype size has less energy leakage and better resolution
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 - 720mm is chosen to be the prototype transverse size



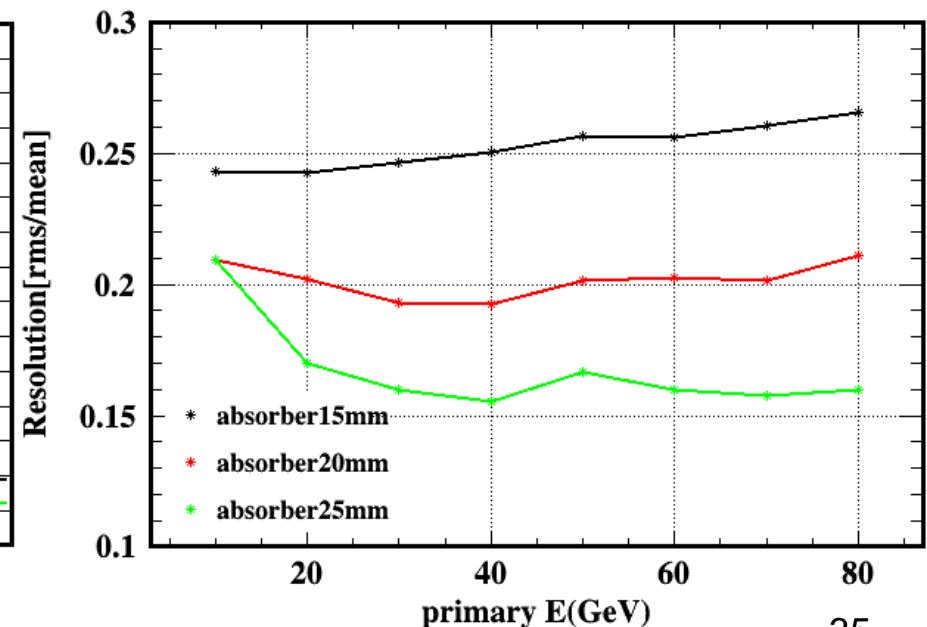
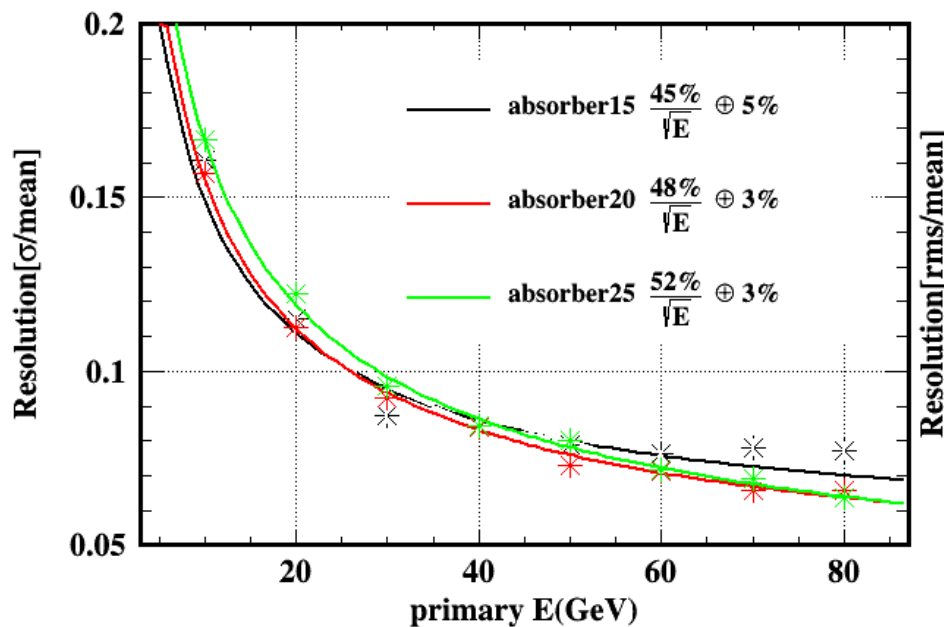
resolution for different Prototype size

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 - Prototype Transverse size: $72 \times 72\text{cm}^2$
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Linearity for different absorber thickness

- Absorber thickness optimization
 - Thinner absorber has a better sampling ratio resulting a smaller statistical term
 - Thinner absorber has larger leakage resulting a bigger constant term
 - The 20mm absorber can satisfy our need



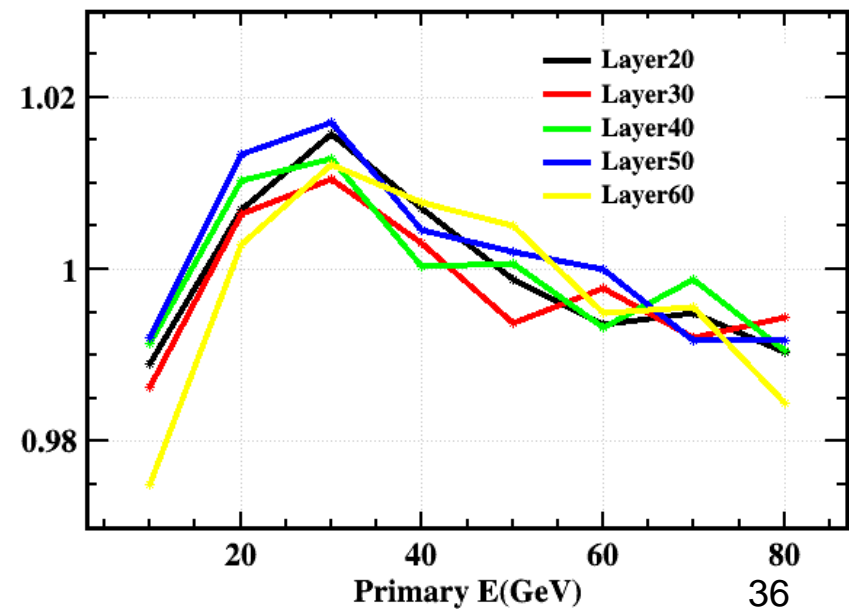
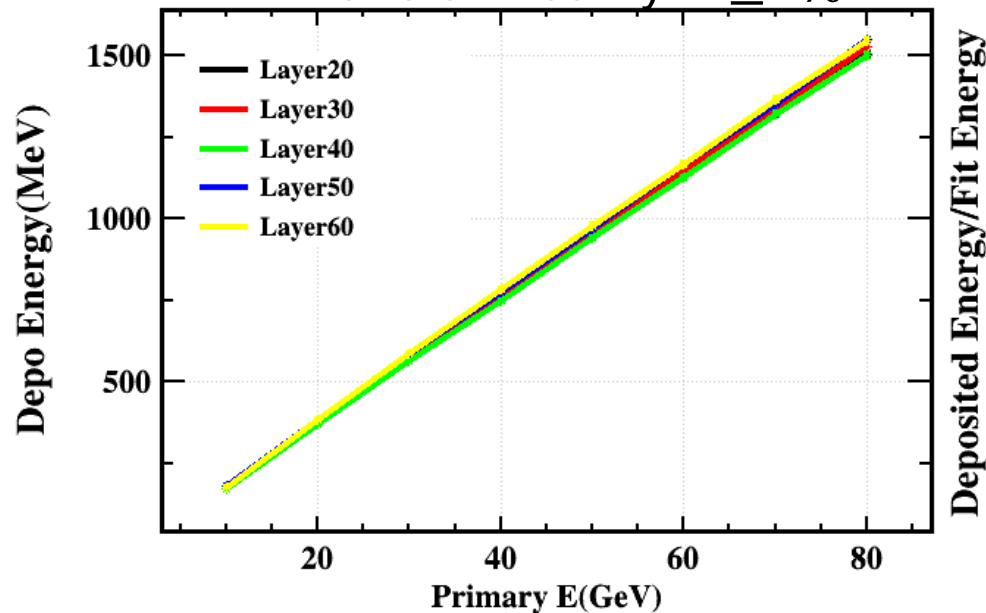
resolution for different absorber thickness

Prototype optimization



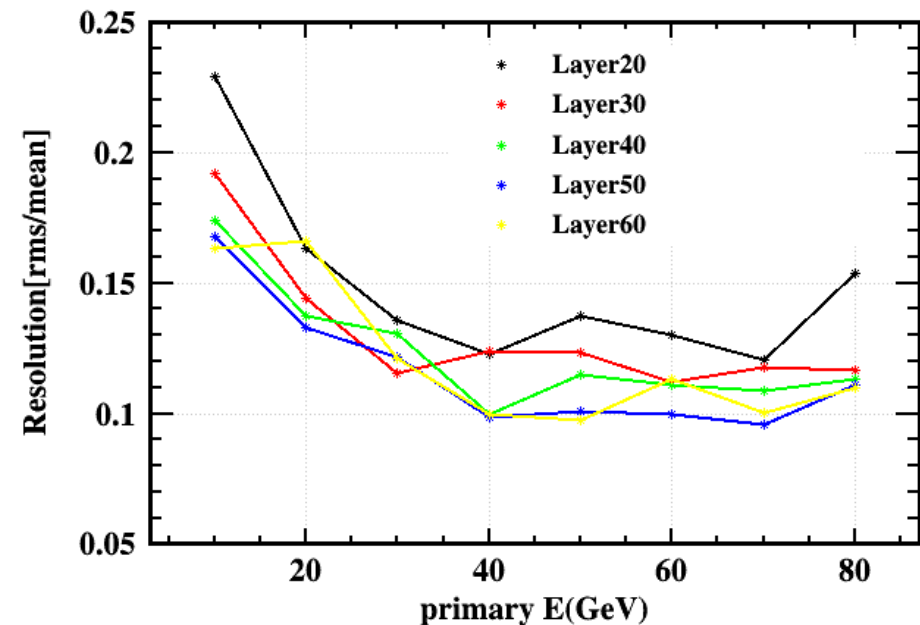
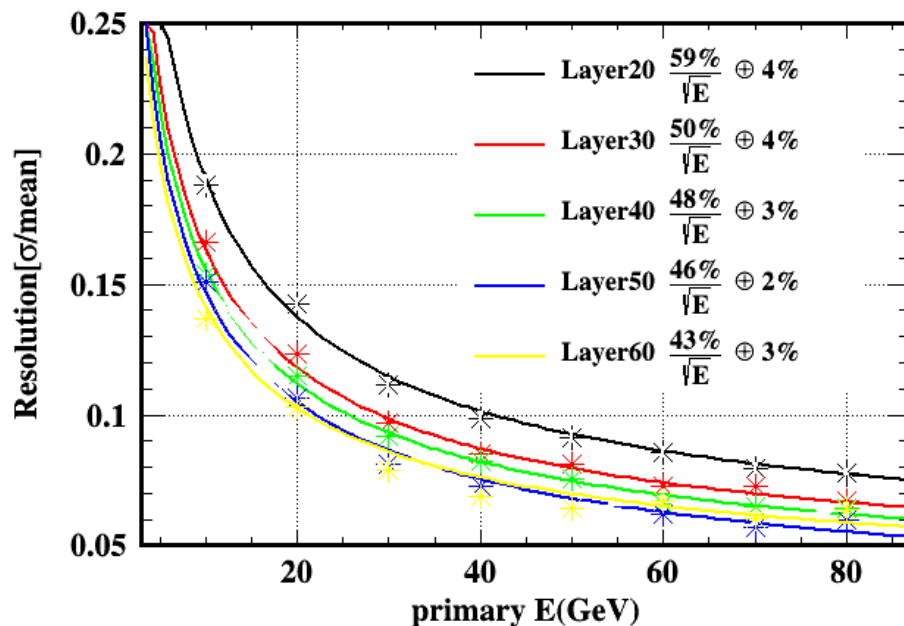
- Sampling Layer optimization

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- Total absorber thickness is fixed as 800mm and total scintillator thickness is fixed as 120mm
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Linearity for different sampling layers

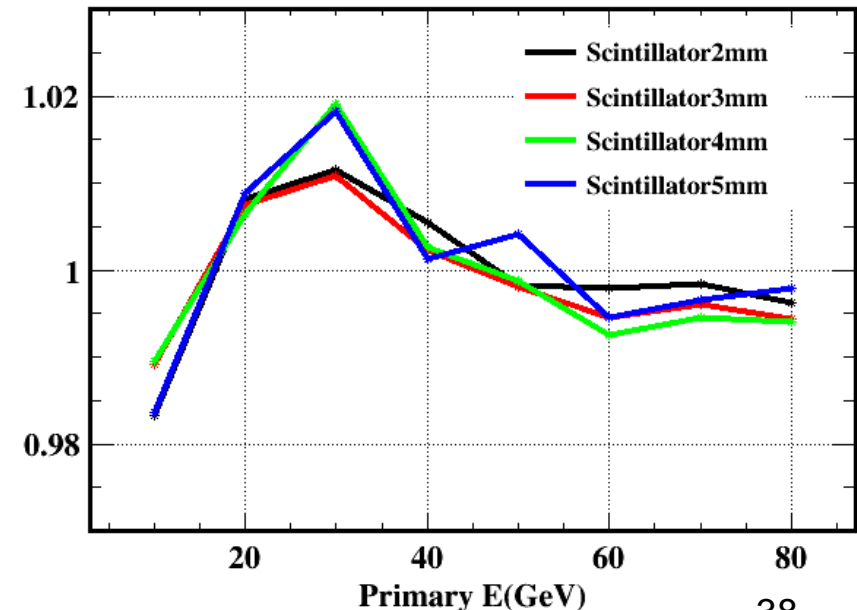
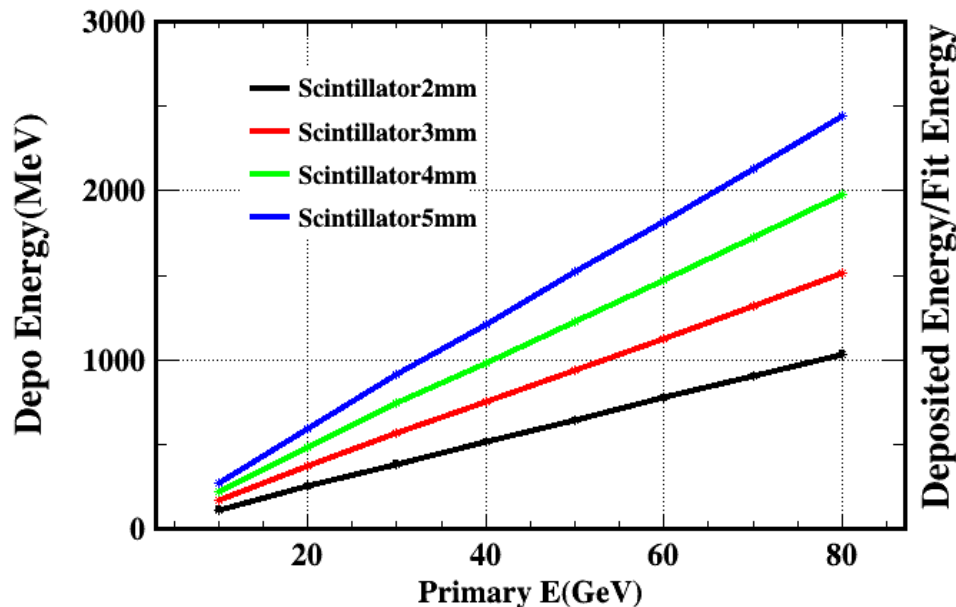
- Sampling Layer optimization
 - More sampling layers have less statistical fluctuation
 - Since PCB thickness for each layer is fixed, it could be a problem for more sampling layers in the prototype
 - 40 layers is reasonable for the prototype



Resolution for different sampling layers

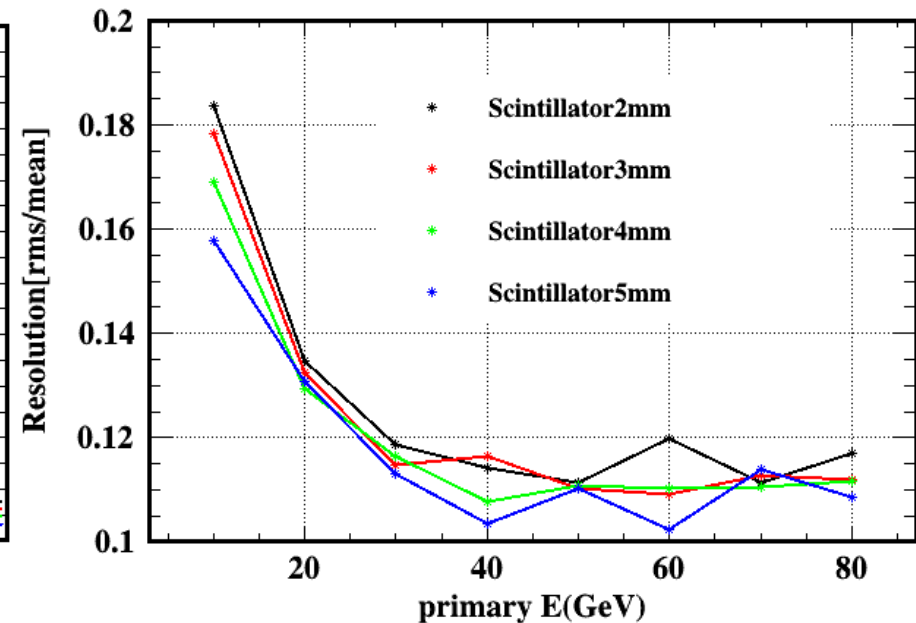
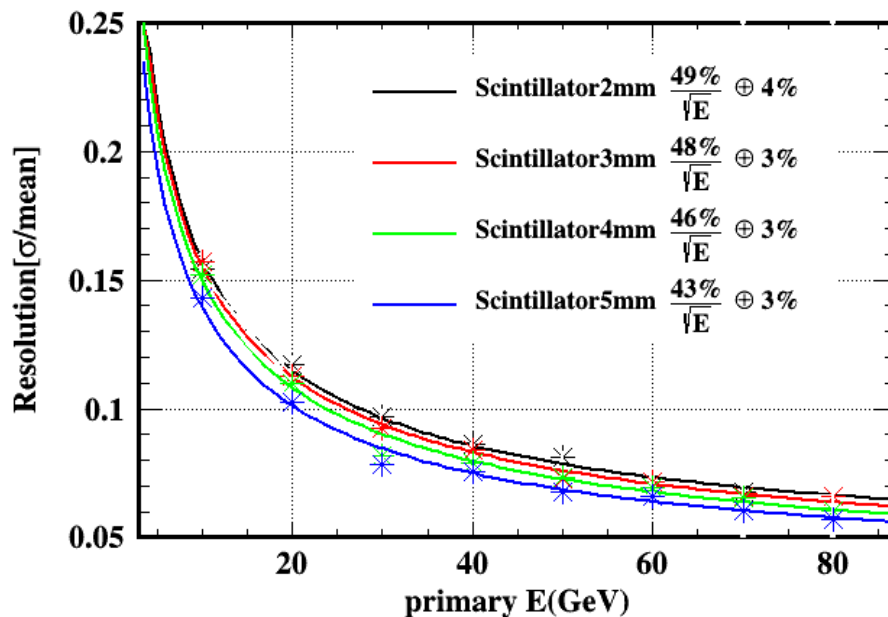
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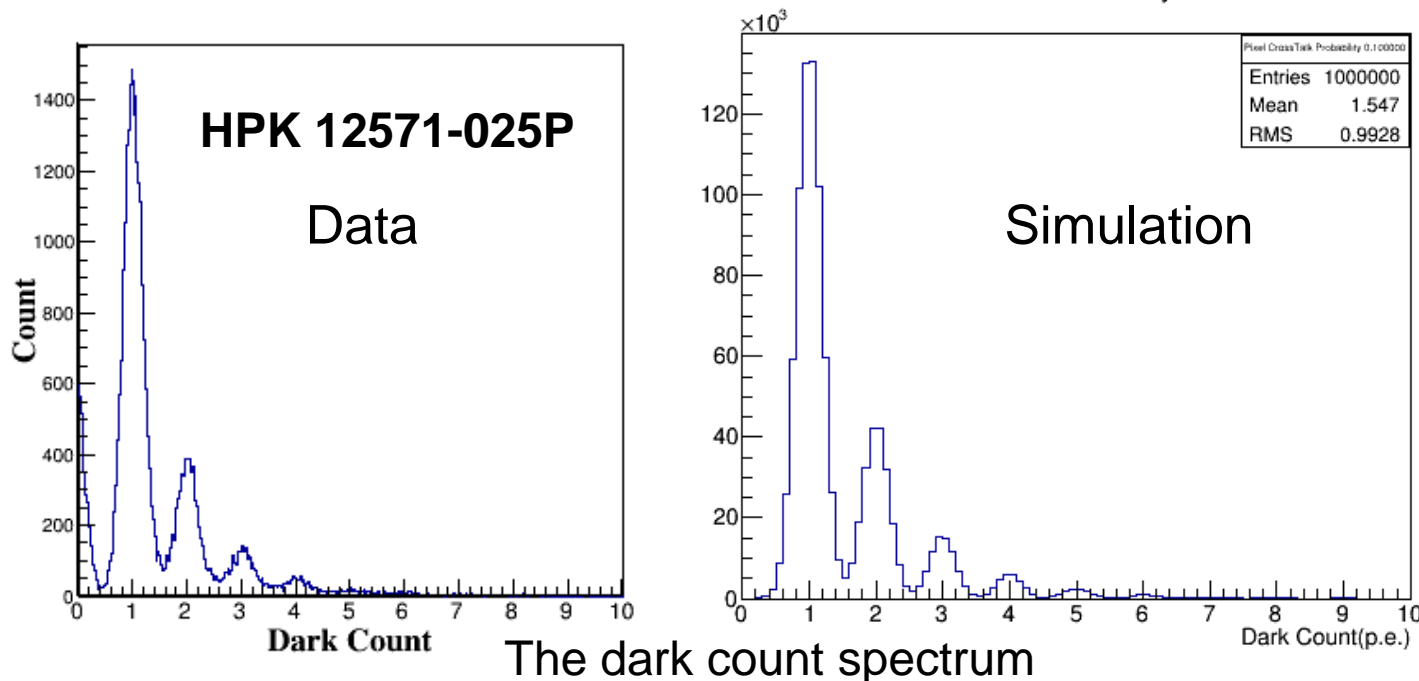
Linearity for different scintillator thickness

- Scintillator thickness optimization
 - Thicker scintillator has better resolution but the improvement isn't obvious
 - Thicker scintillator will increase total thickness and manufacture cost
 - 3mm scintillator is chosen for the prototype



Resolution for different scintillator thickness

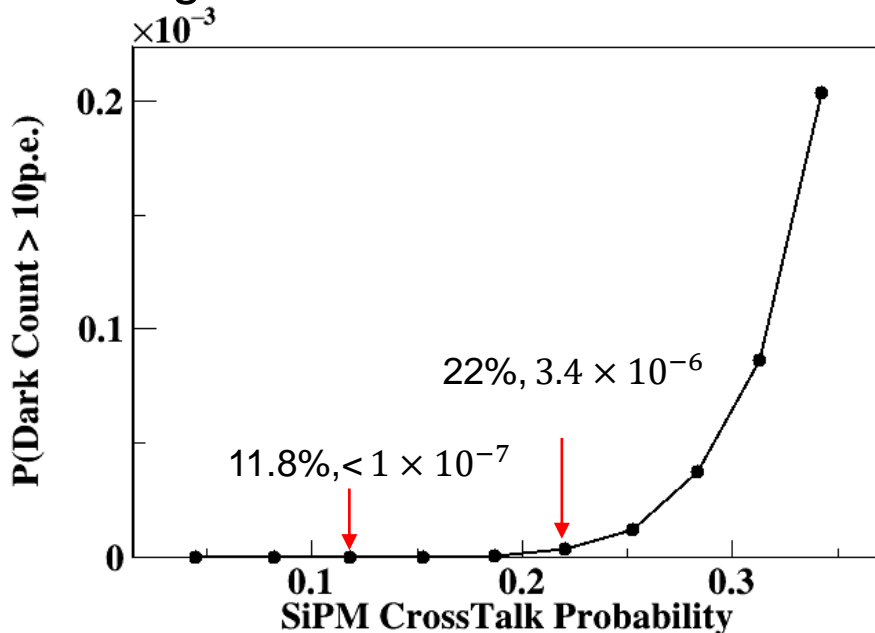
- The dark count and threshold
 - The dark count spectrum has been simulated
 - The SiPM is S12571-025P
 - Crosstalk probability is 22.6%



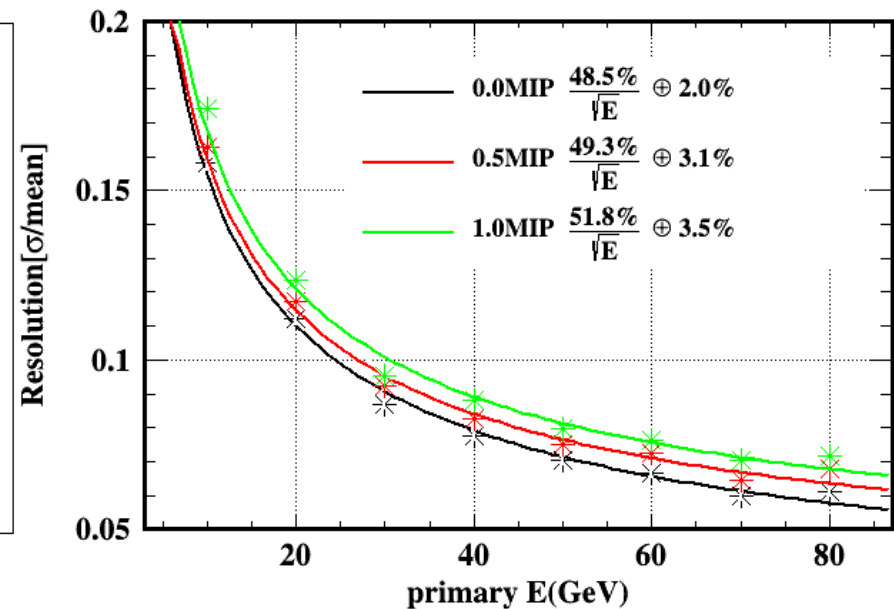
The SiPM simulation



- For the BNU SiPM, the 0.5MIP equals 20p.e. while for the HPK SiPM, the 0.5MIP equals 10p.e.
- The probability that a Dark count is over 10p.e. is quite low, not to mention the 20p.e.
- From this point of view, PDE is dominant in the threshold issue
- High PDE also means the fluctuation is lower

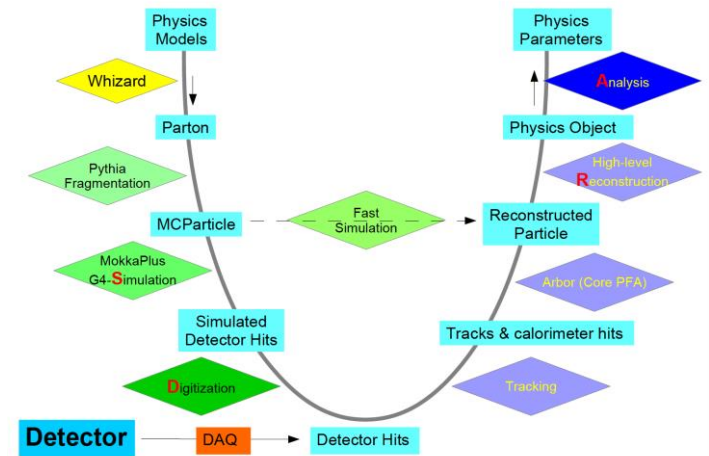
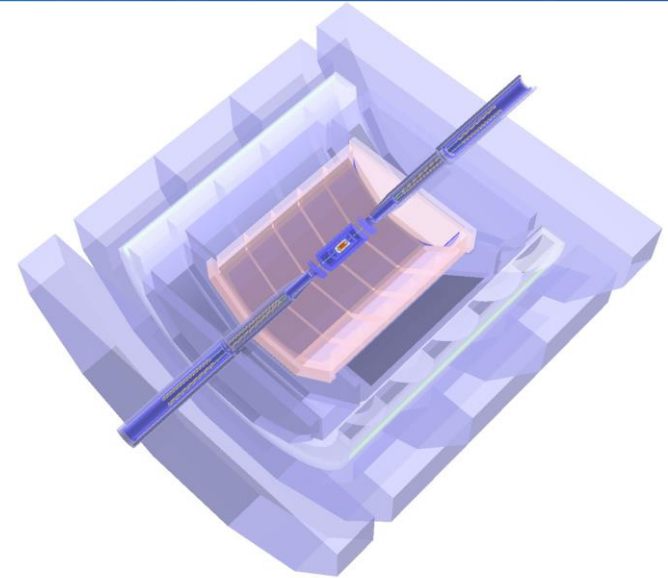


The cross talk probability and threshold efficiency

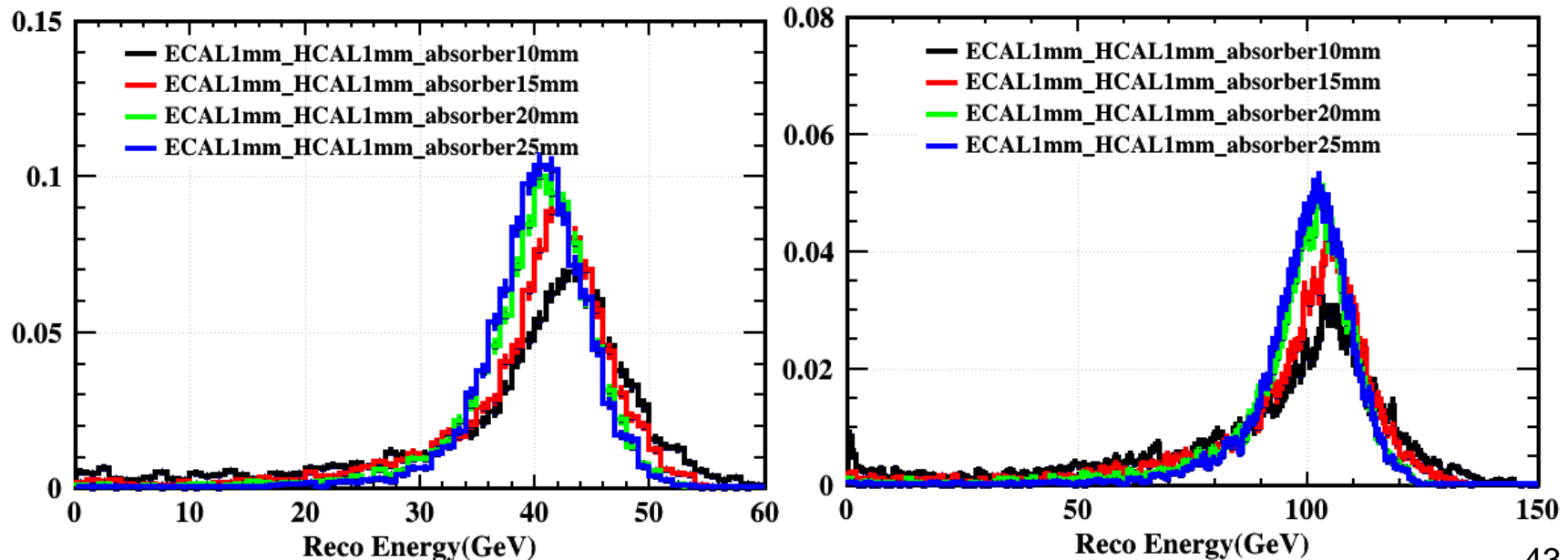


The threshold and energy resolution

- CEPC software environment
 - CEPC V4 geometry
 - Tracker and magnet field
 - ECAL and HCAL
 - Muon detector
 - PFA reconstruction
 - Detect particles with optimal detector
 - Higgs boson mass could be reconstructed with the recoil mass method
 - Physics benchmarks
 - $\nu\nu H - gg$
 - Zuds: $e^+e^- - q\bar{q}(q = uds)$ via Z

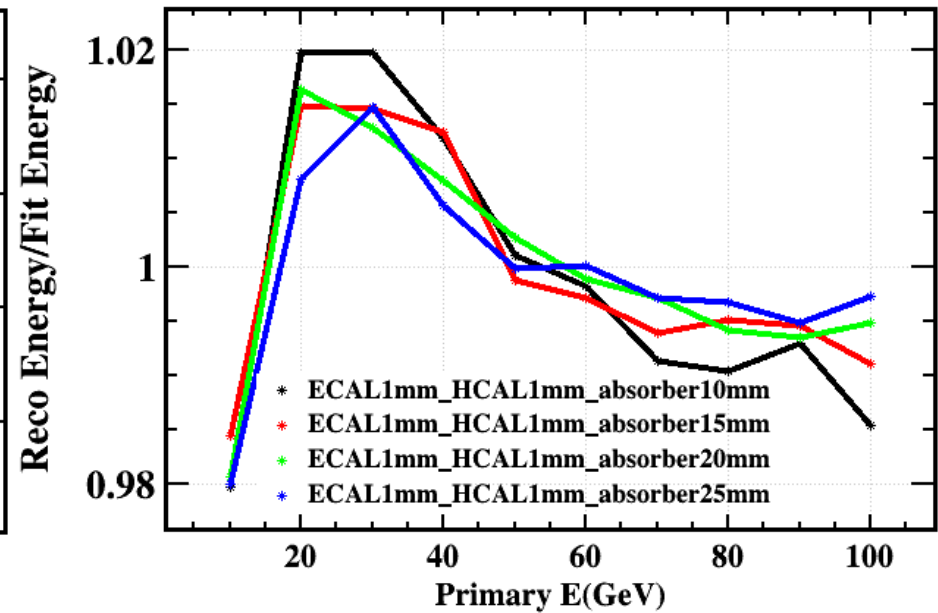
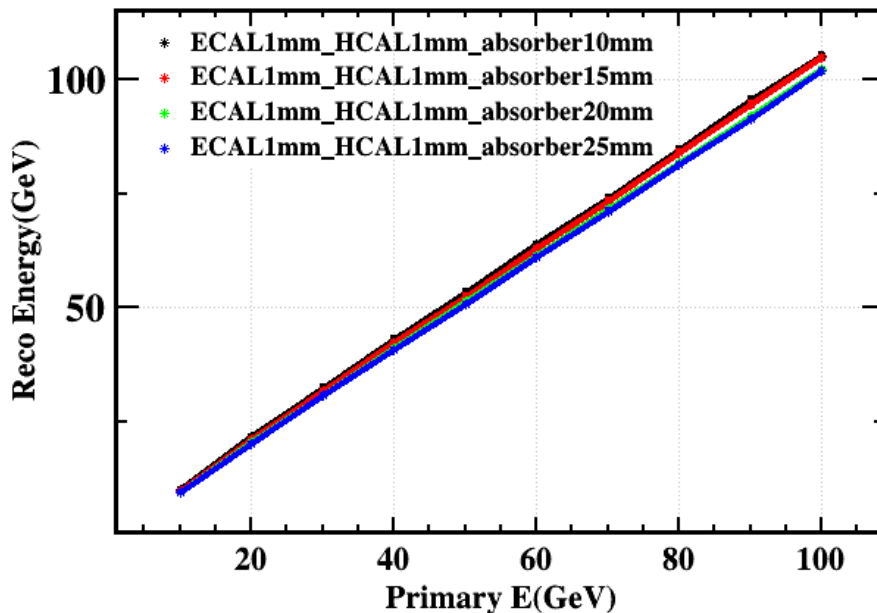


- Absorber thickness optimization
 - Klong with energy from 10 to 100GeV
 - Absorber thickness ranges from 10mm to 25mm
 - KL energy is reconstructed from ECAL and HCAL energy



KL reconstructed energy at different absorber thickness

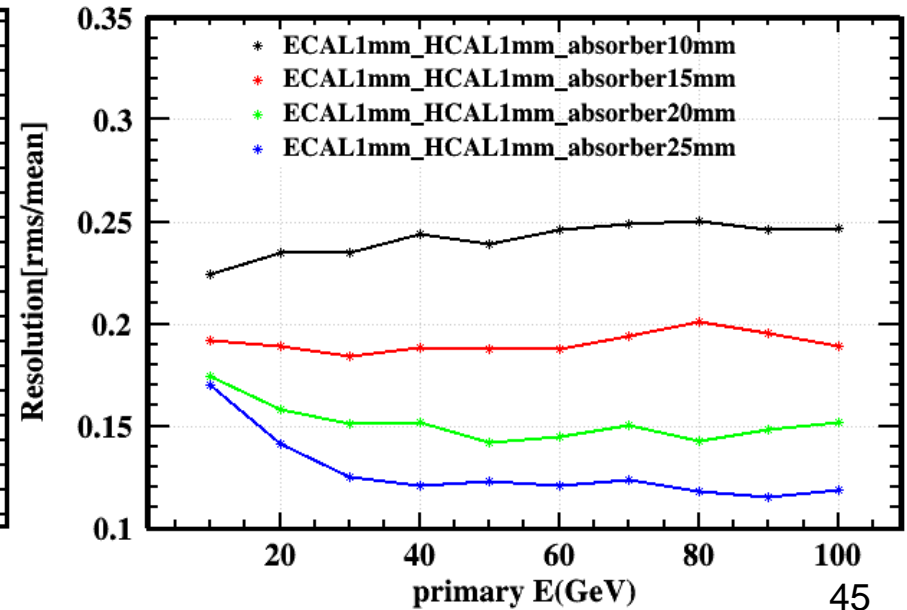
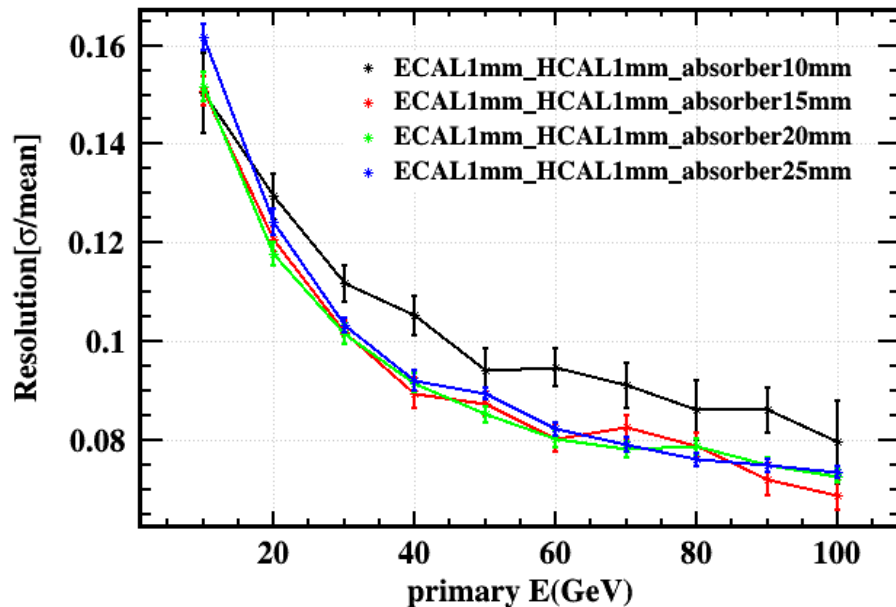
- Absorber thickness optimization
 - Use crystal ball function as fitting function
 - The linearities are all within $\pm 3\%$ for different absorber thickness



KL Linearity at different absorber thickness

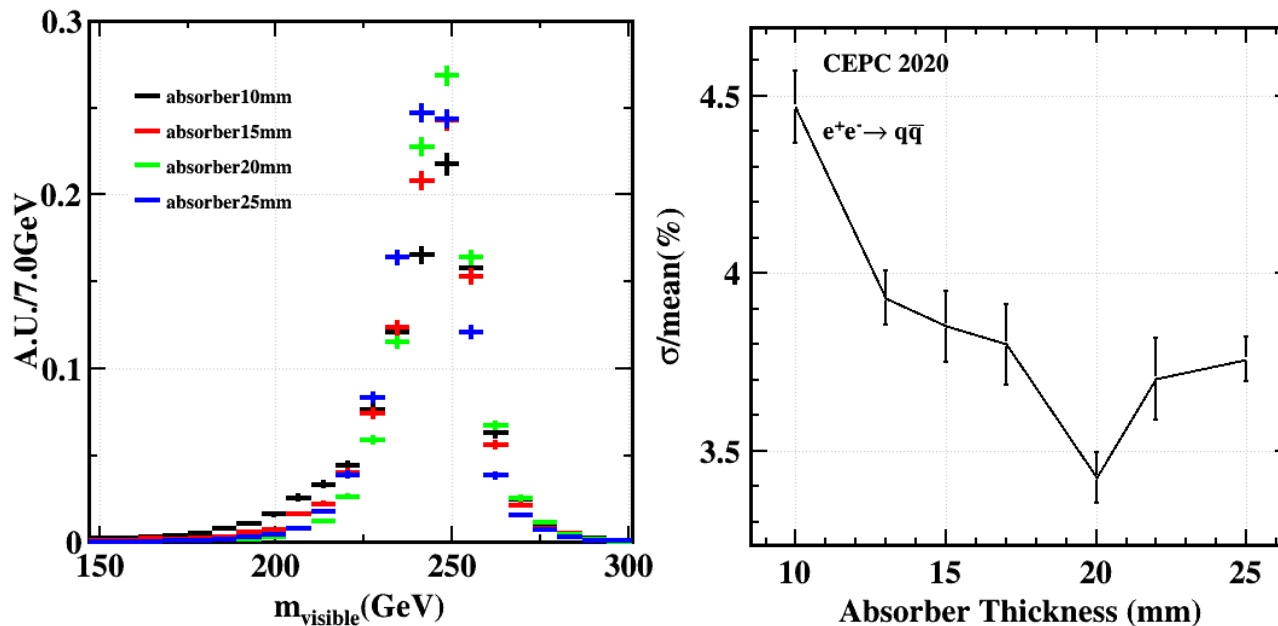
• Absorber thickness optimization

- ECAL introduce more material comparing to Simplified geometry
- The 10mm absorber has a worse resolution than others
- The rms/mean reflects the leakage for different absorber



KL resolution at different absorber thickness

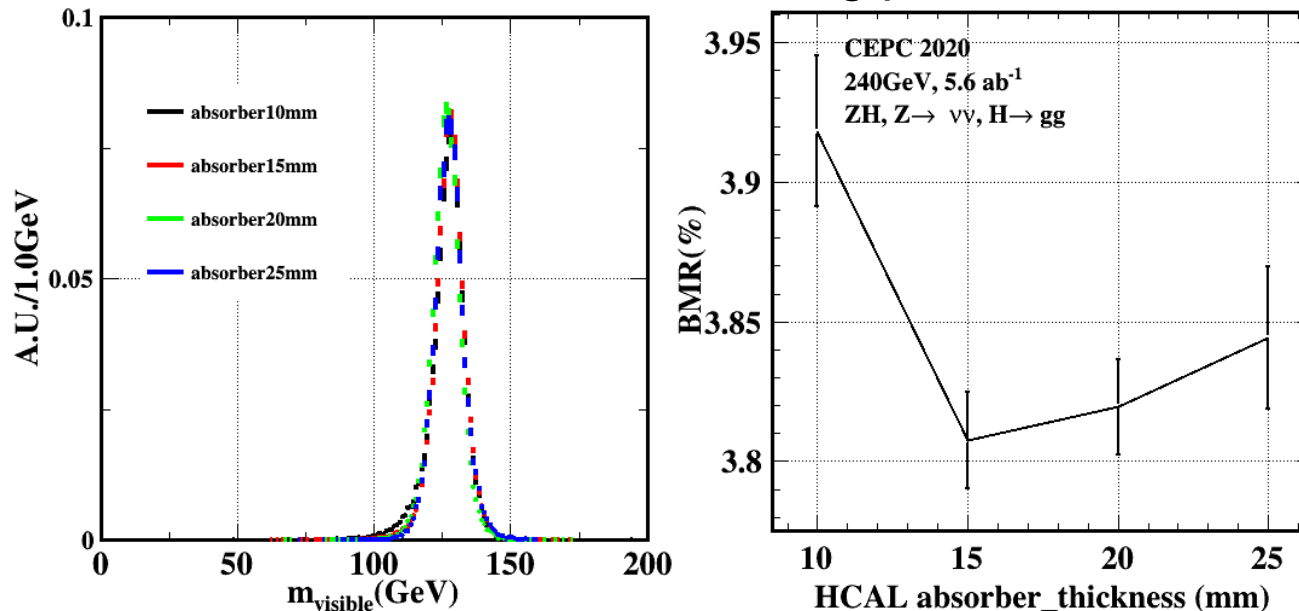
- Absorber thickness optimization
 - The $m_{visible}$ is reconstructed for each Zuds event
 - The resolution of $m_{visible}$ as a function of absorber thickness shows that 20mm is a turning point



Zuds events for different absorber thickness

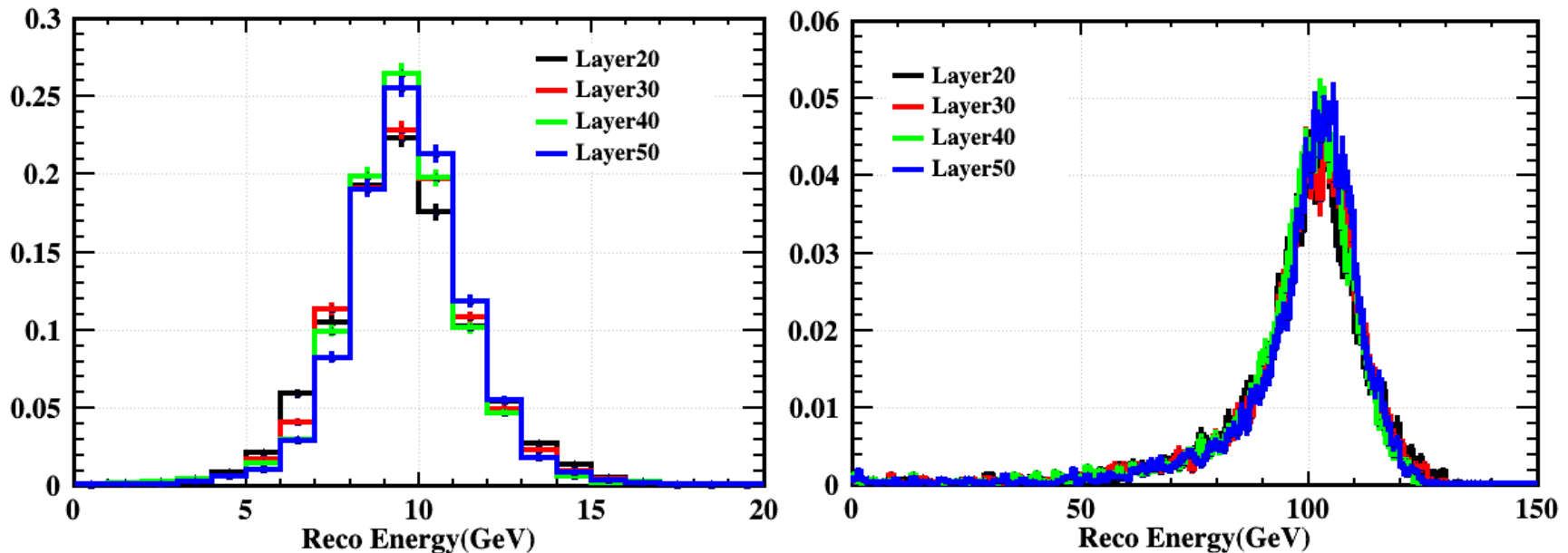
- Absorber thickness optimization

- The jets in $\nu\nu H - gg$ events have lower energy comparing to the jets in Zuds events
- The Higgs mass is reconstructed as $m_{visible}$ in $\nu\nu H - gg$ events
- The boson mass resolution(BMR) as a function of absorber thickness shows 15mm is the turning point



$\nu\nu H - gg$ events for different absorber thickness

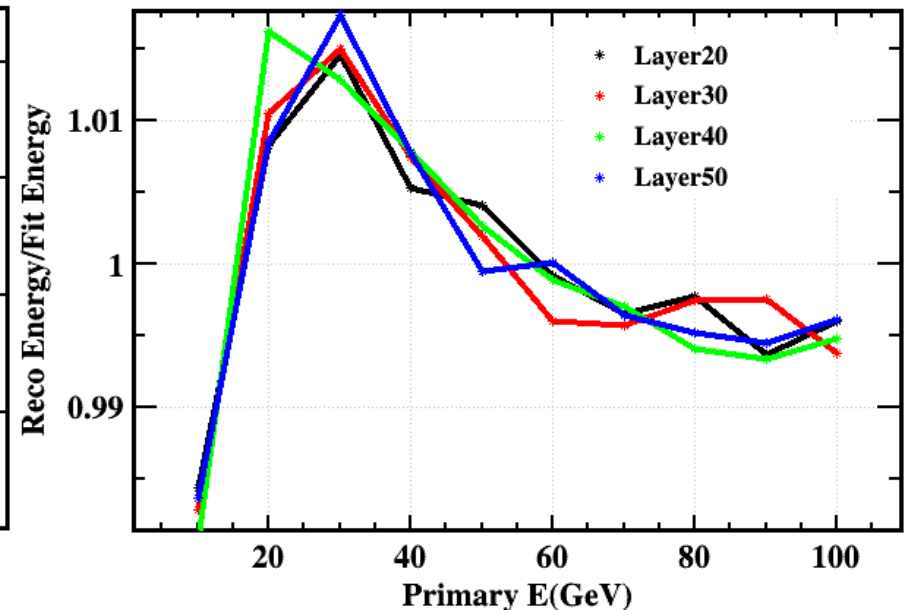
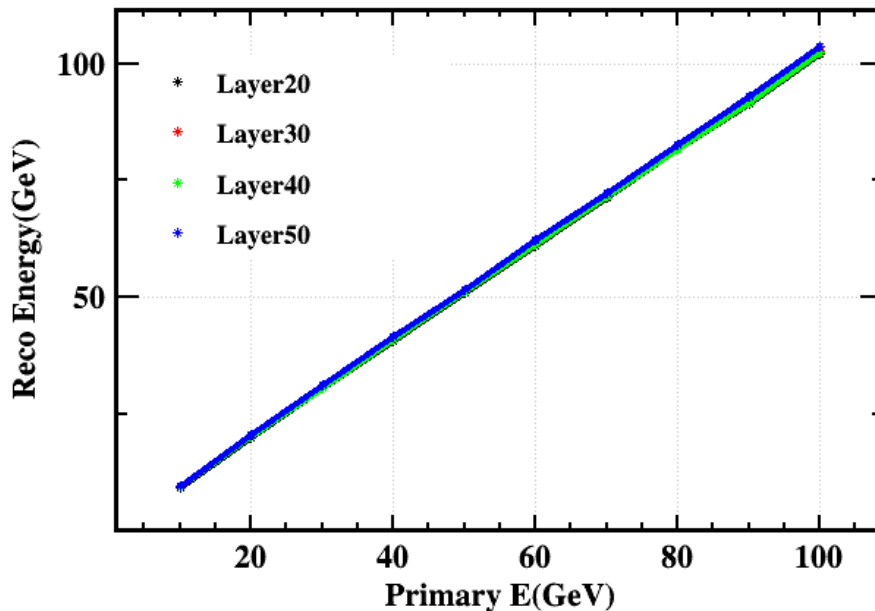
- Sampling Layer optimization
 - Total absorber thickness is fixed as 800mm and total scintillator thickness is fixed as 120mm
 - The thickness of PCB for each layer is 2mm
 - The number of sampling layers ranges from 20 to 50



KL reconstructed energy at different sampling layers

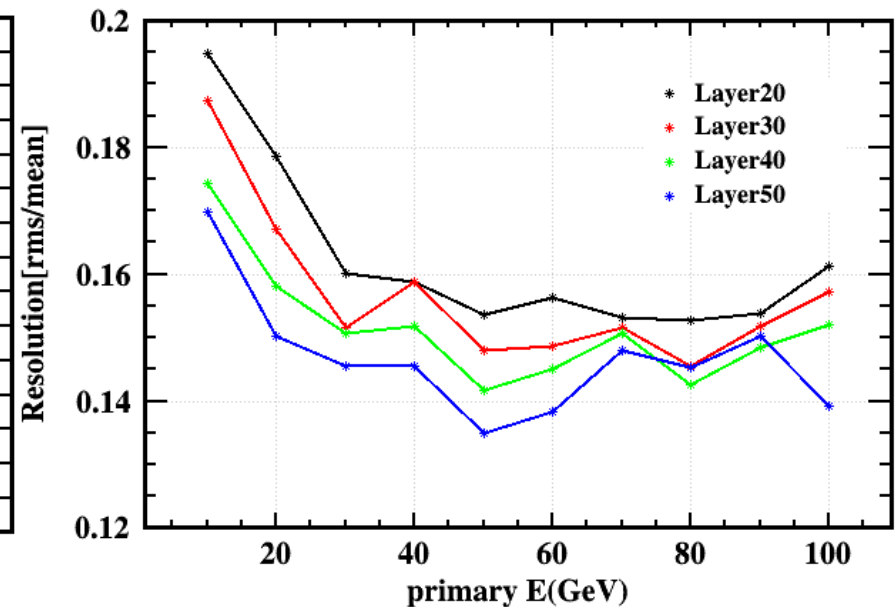
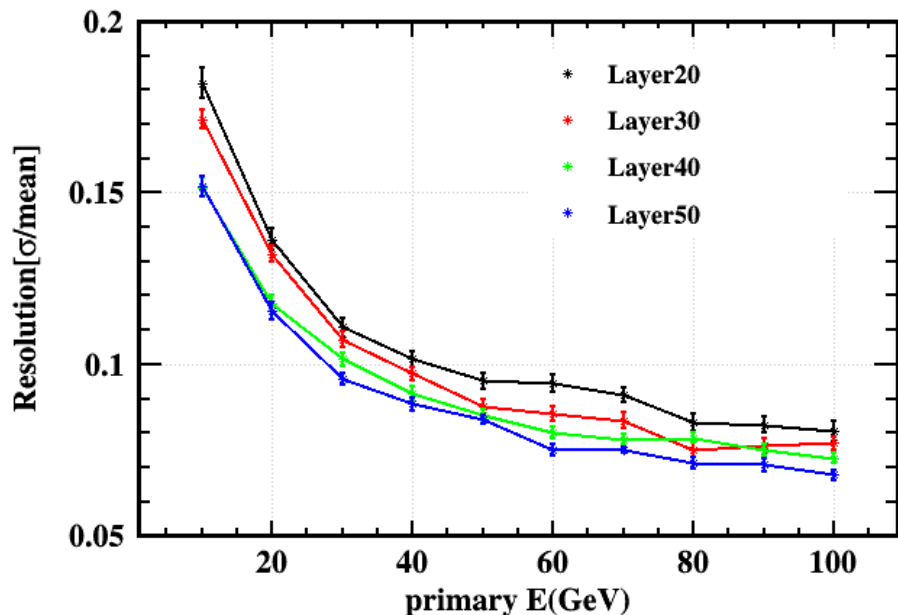
- Sampling layer optimization

- The linearities are almost the same for different sampling layers
- The linearities are all within $\pm 2\%$ for different sampling layers



KL Linearity at different sampling layers

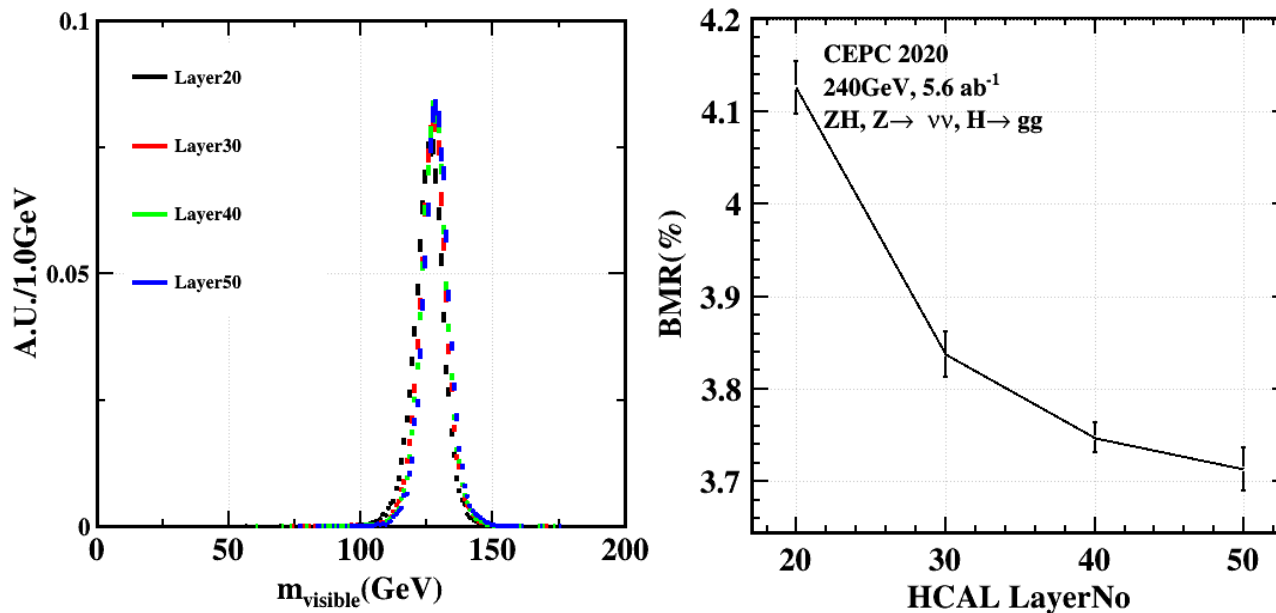
- Sampling layer optimization
 - More sampling layers have better energy resolution



KL resolution at different sampling layers

- Sampling layer optimization

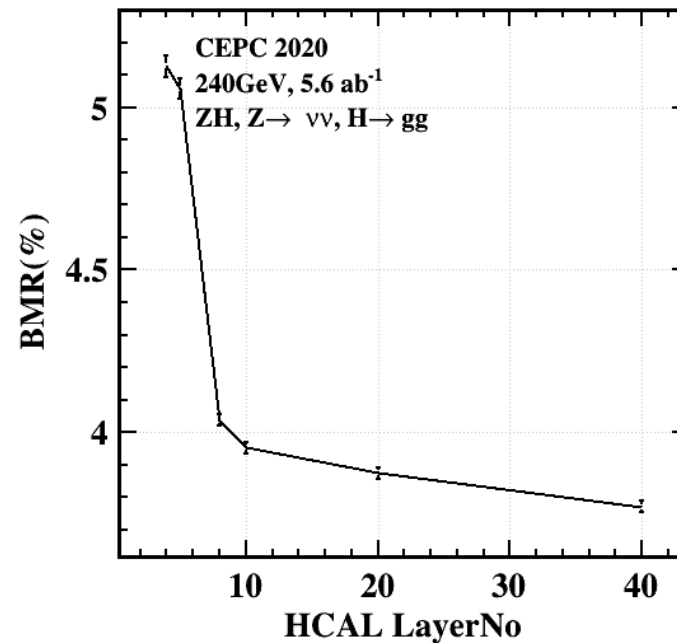
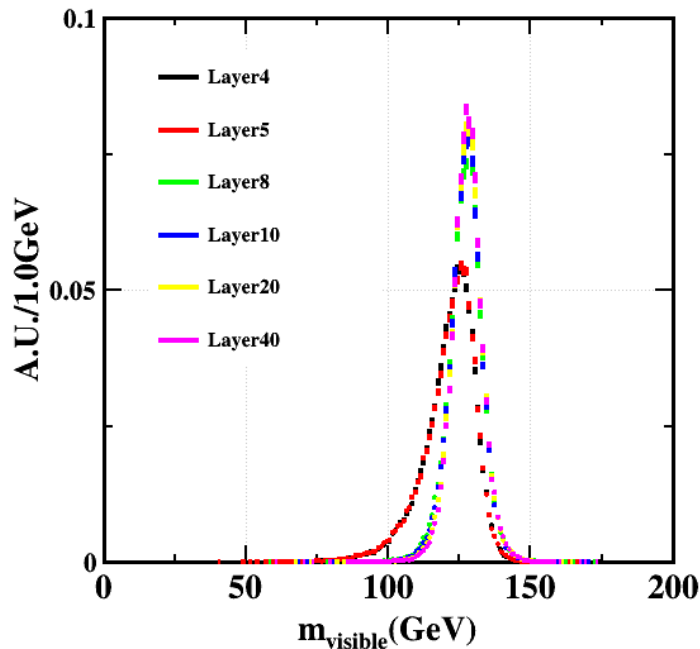
- $\nu\nu H - gg$ events are reconstructed for different sampling layers
- 30 sampling layers can satisfy the 4% BMR requirement but prototype needs 40 sampling layers to fulfill the design target



$\nu\nu H - gg$ events for different sampling layers

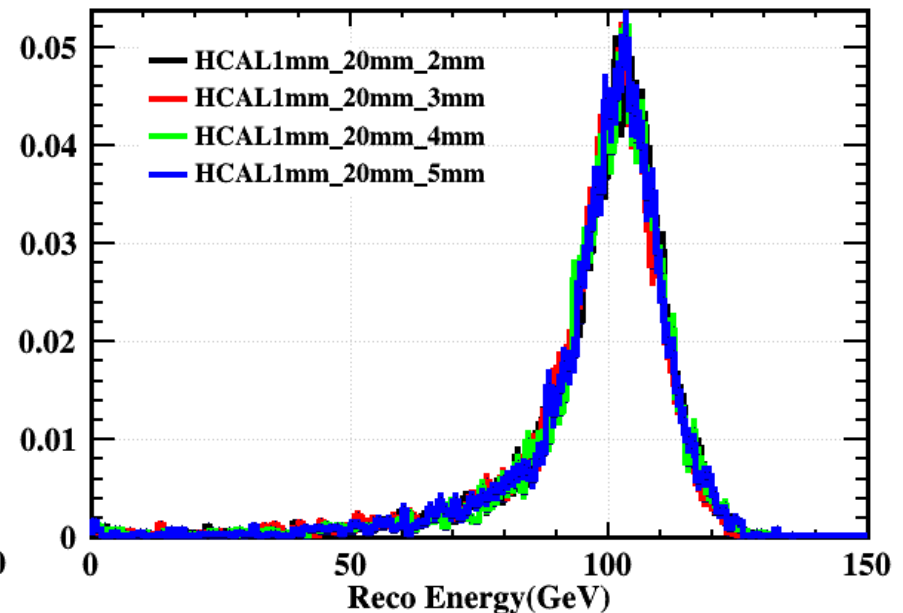
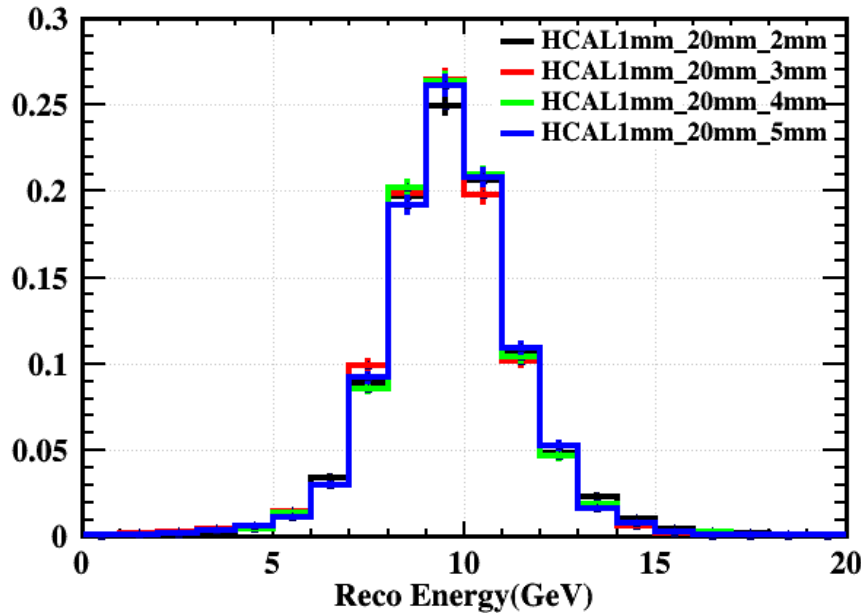
- Merge layer optimization

- The number of sampling layers is fixed as 40
- Combine the hits from adjacent layers to change the longitudinal segmentation without affecting the energy resolution



$\nu\nu H - gg$ events for different readout layers

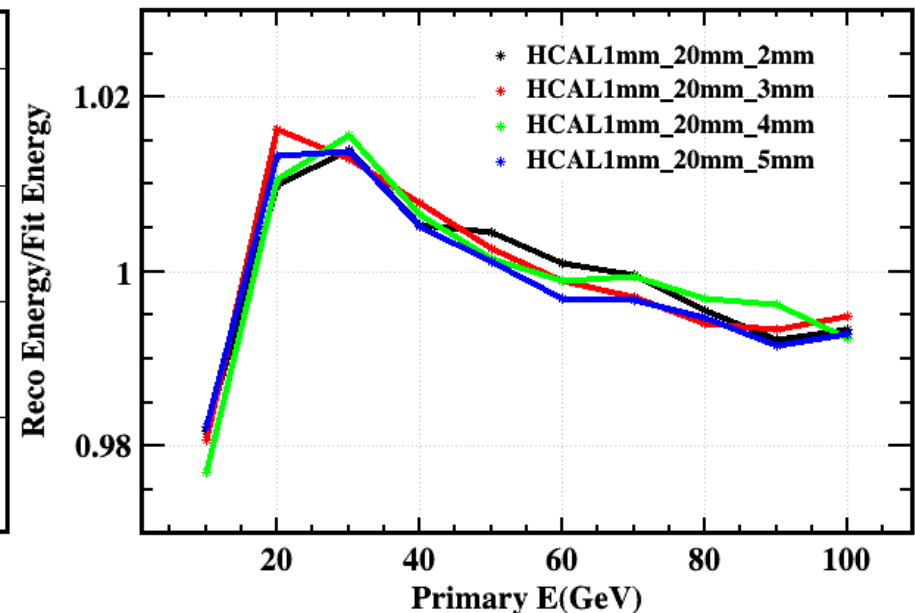
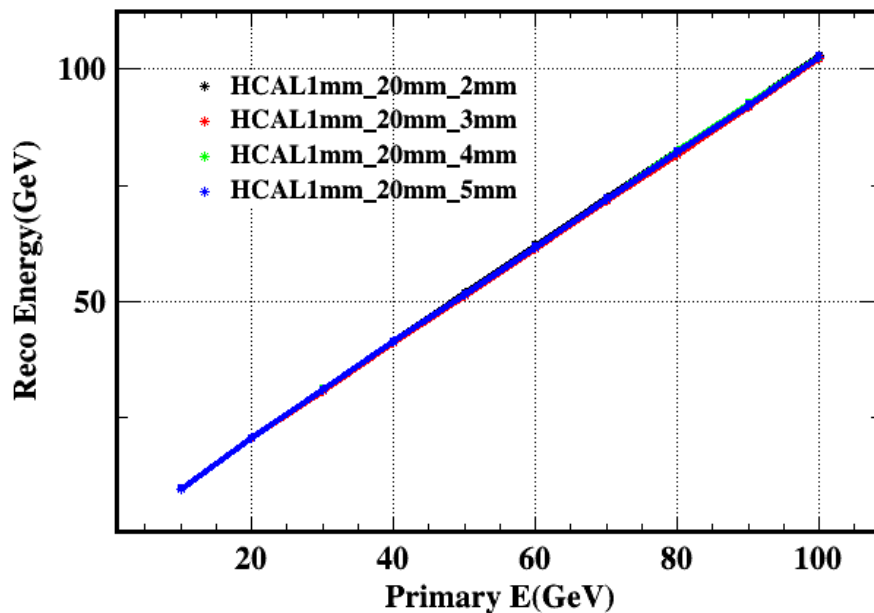
- Scintillator thickness optimization
 - 40 layers: each layer has 20mm Steel and 2mm PCB
 - Scintillator thickness for each layer ranges from 2 to 5mm



KL reconstructed energy at different scintillator thickness

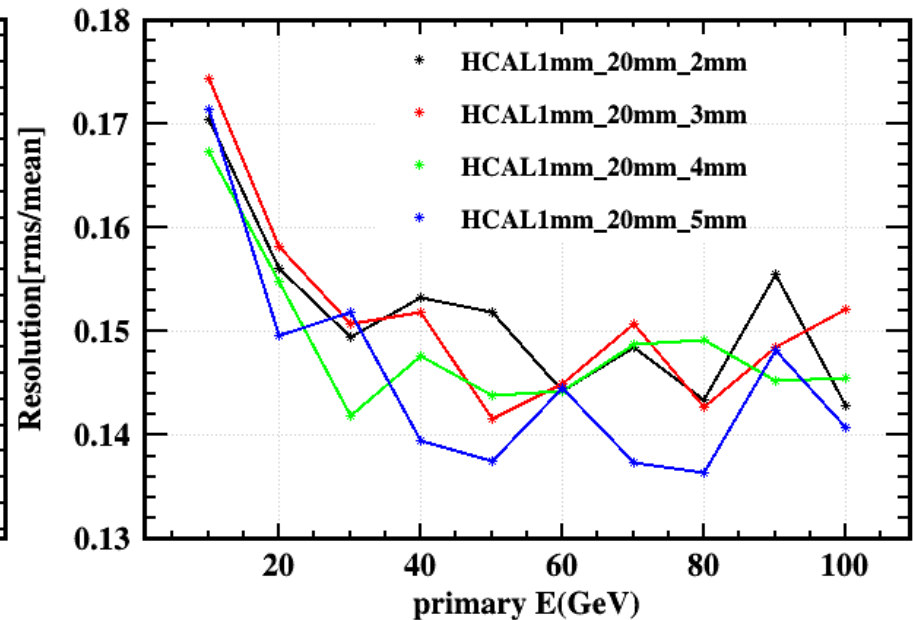
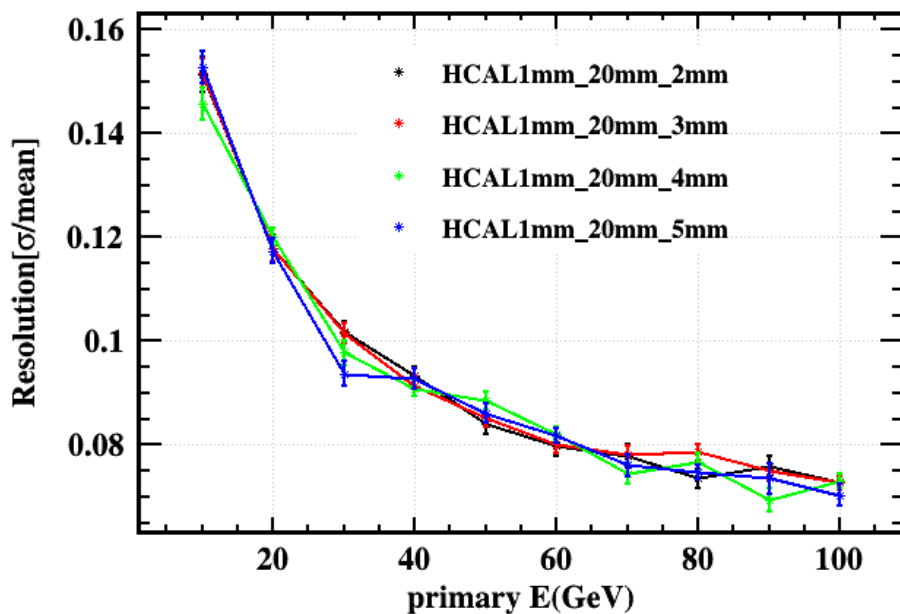
- Scintillator thickness optimization

- The linearities are almost the same for different scintillator thickness
- The linearities are all within $\pm 3\%$ for different scintillator thickness



KL Linearity at different scintillator thickness

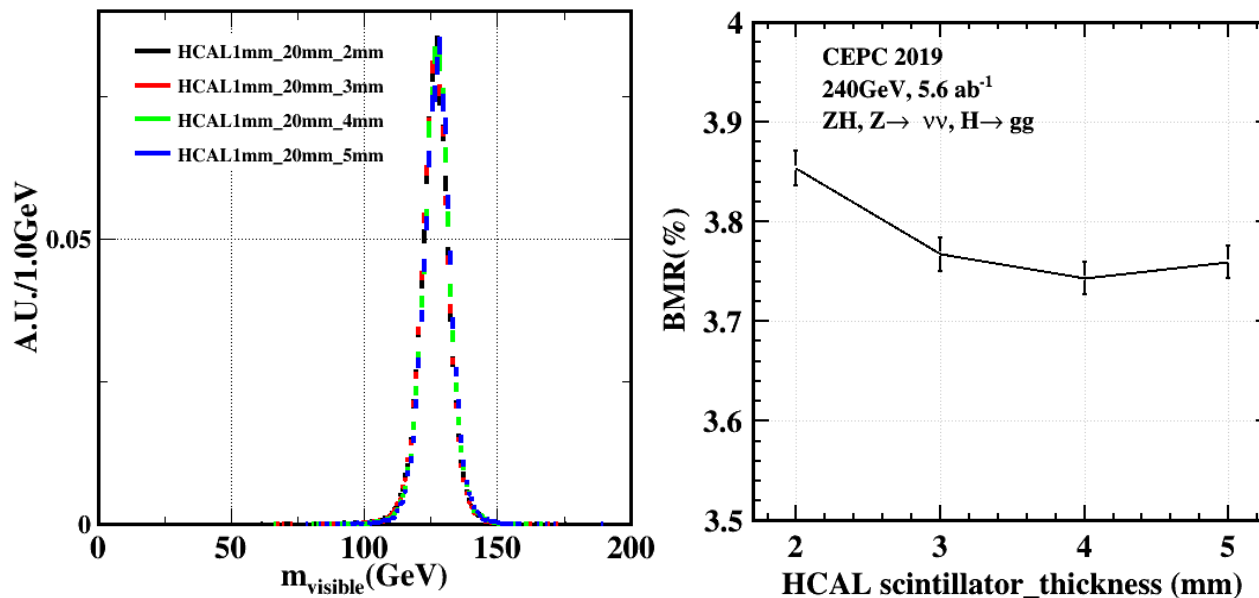
- Scintillator thickness optimization
 - Different scintillator thickness doesn't have much difference on resolution



KL resolution at different scintillator thickness

- Scintillator thickness optimization

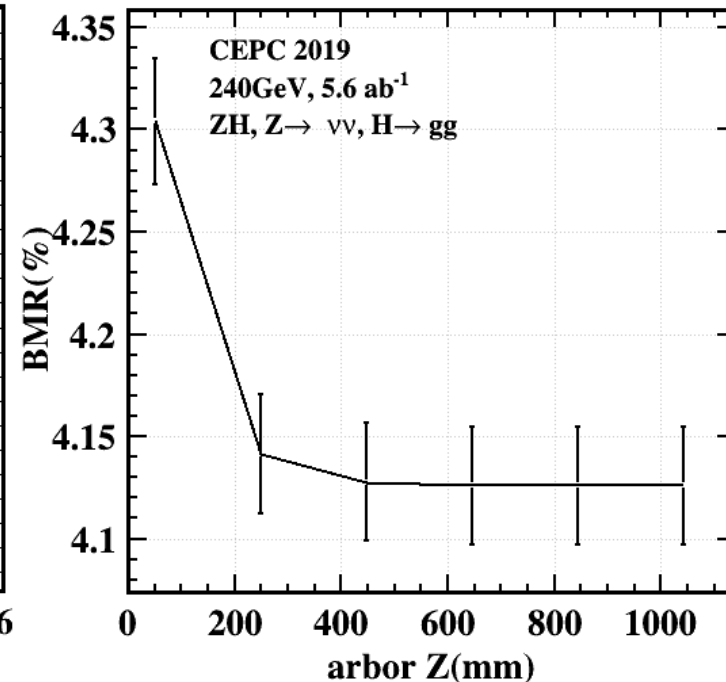
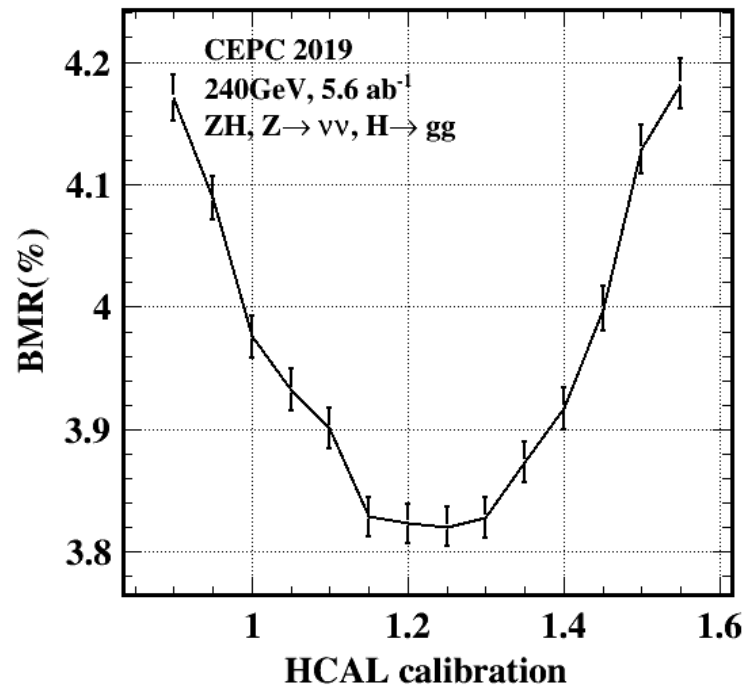
- $\nu\nu H - gg$ events are reconstructed for different scintillator thickness
- The difference of BMR is within 0.1%
- The 3mm scintillator is a reasonable choice



$\nu\nu H - gg$ events for different scintillator thickness

- Cell size optimization

- Cell size is the key parameter for PFA oriented HCAL
- Cell size has a strong impact on both detector performance and cost
- Careful optimization has been done to reconstruction parameter



Parameter optimization in terms of BMR