Progress on the study of CEPC ScECAL

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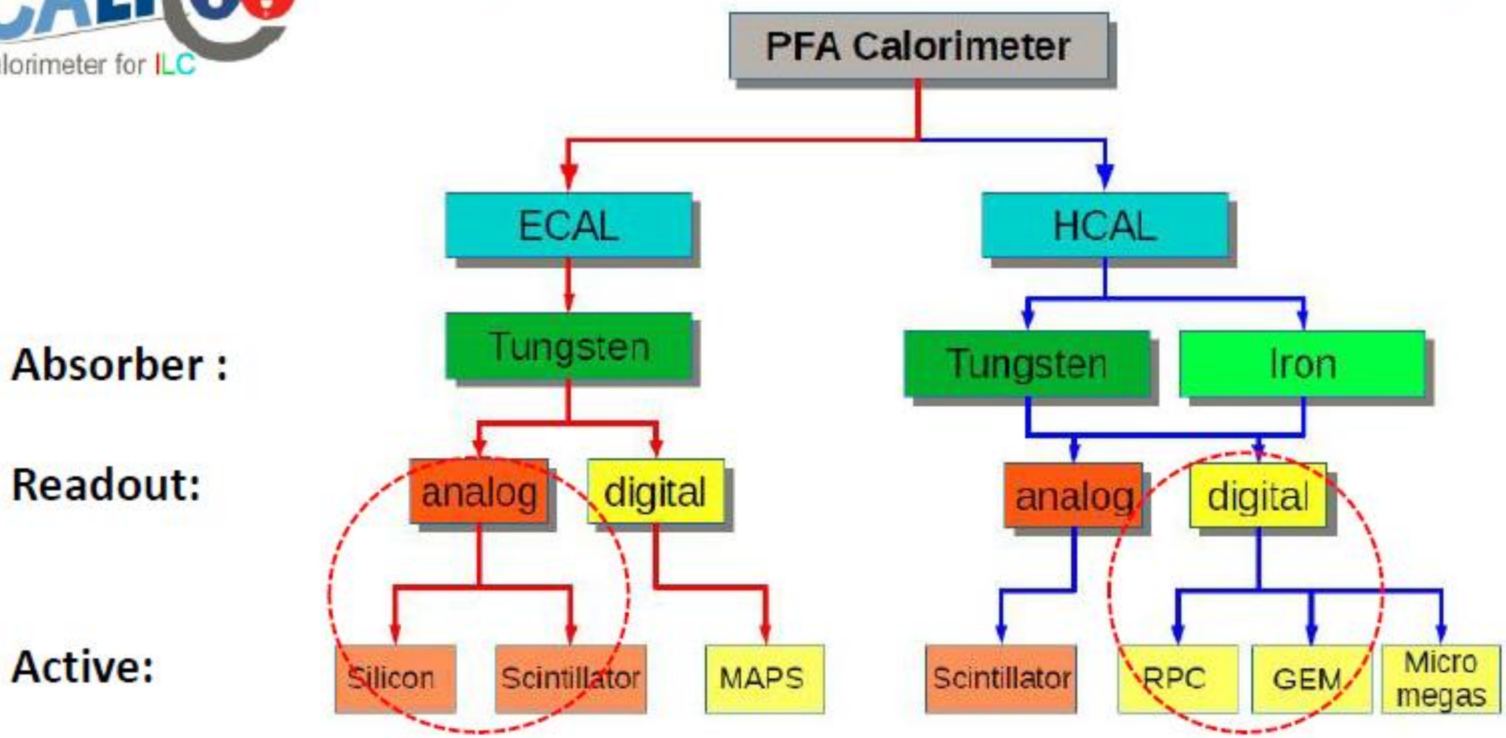
OUTLINE

- Introduction
- Optimization of ECAL Geometry
- Detector cell study
  - Scintillator
  - SiPM
- Beam test of a mini prototype
- Summary

Global R&D of Imaging Calorimeters

Calorimeter for ILC

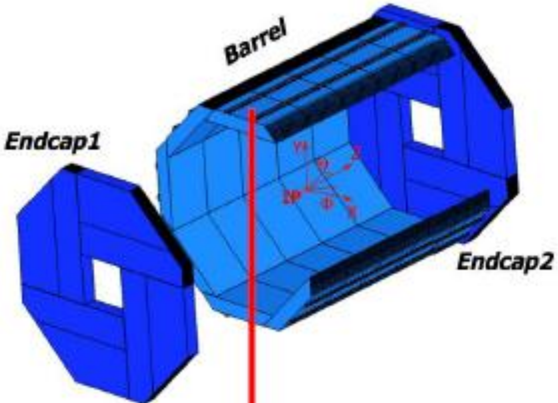
https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers



Readout cell size: 144 - 9 cm^2 → 4.5 cm^2 → 1 cm^2 → 0.25 cm^2 → 0.13 cm^2 → 2.5x10^{-5} cm^2

Technology: Scintillator + SiPM/MPPC; Scintillator + SiPM/MPPC; Gas detectors Silicon; Silicon; Silicon; Silicon (MAPS)

Structure of the CEPC ScECAL



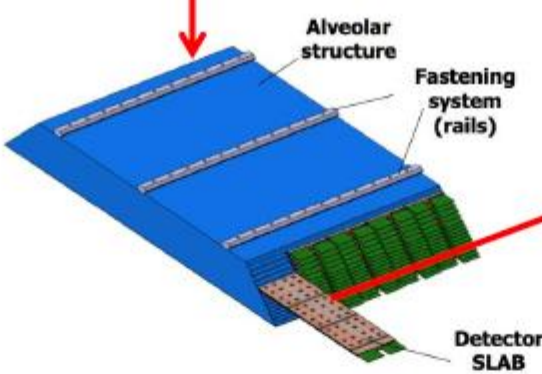
The CEPC ECAL consist of a cylindrical barrel system and two end caps.

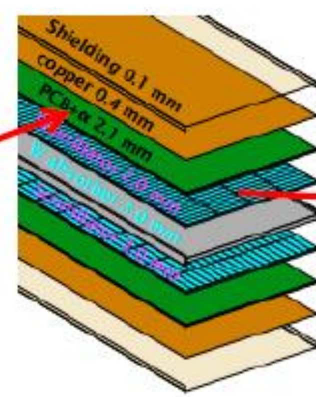
One of the proposal for CEPC ECAL is based on scintillator strip with SiPM readout.

Total readout channel: ~8 Million

Two scintillator layers make a sandwich structure with a tungsten absorber.

The strips in adjacent layers are perpendicular to each other to achieve a 5×5 mm2 transverse size.



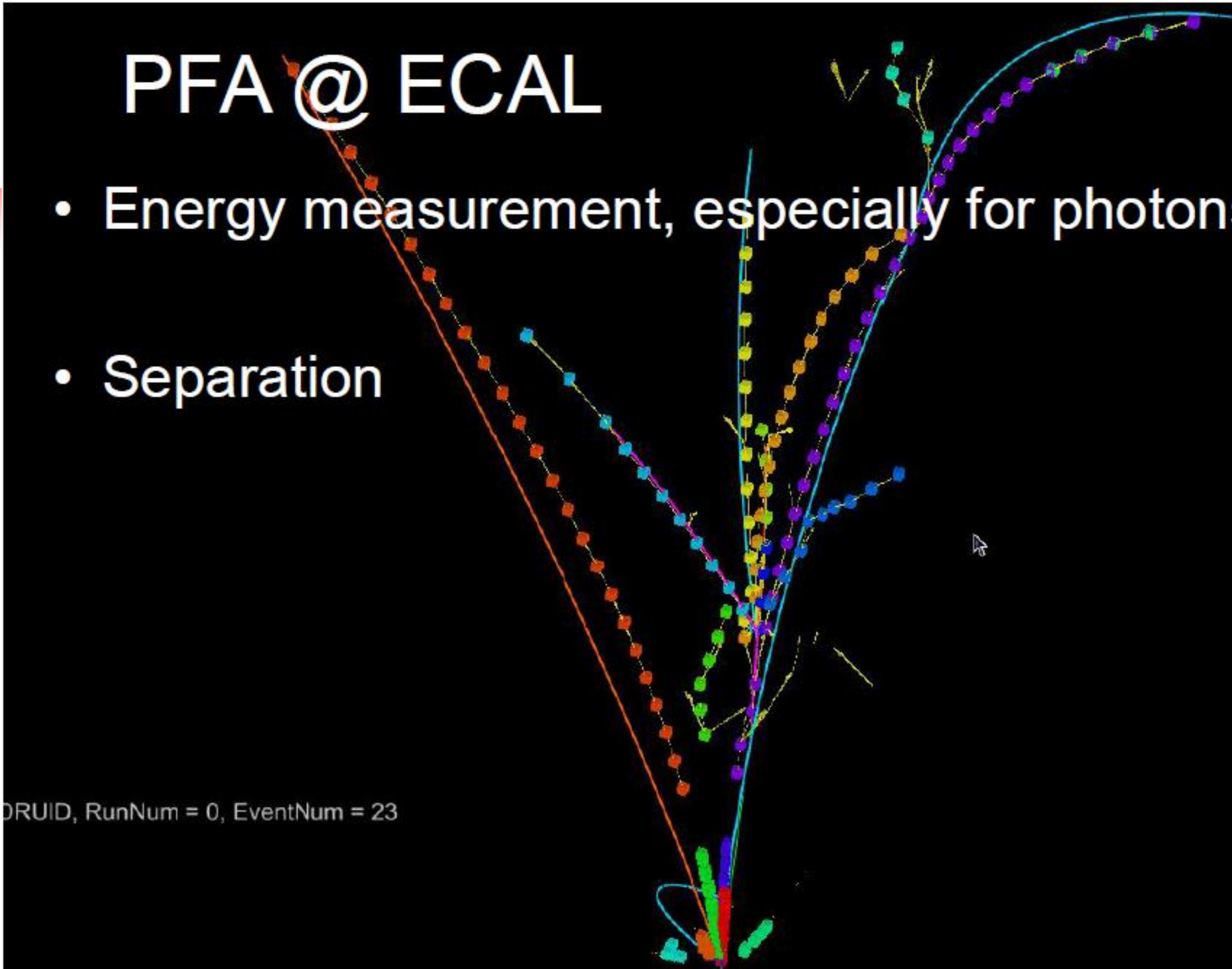


Baseline design of scintillator and SiPM

PFA @ ECAL

- Energy measurement, especially for photons

- Separation



Study on cell size

Nearby Photon Showers in Physics Objects

Z->tau tau
(at Zpole Energy)

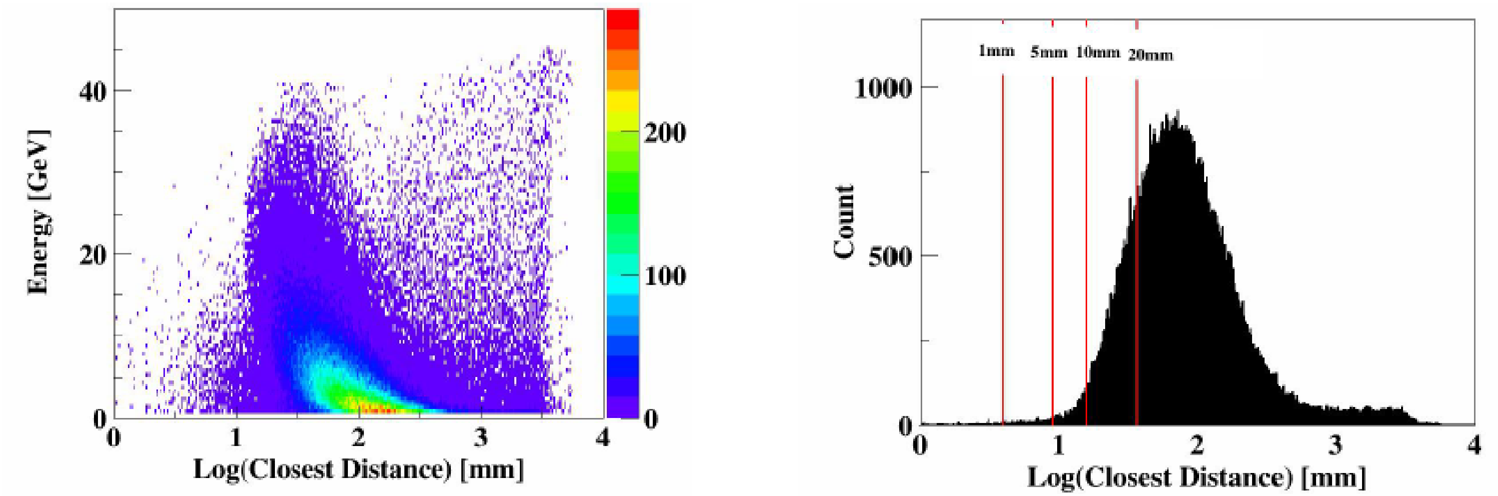
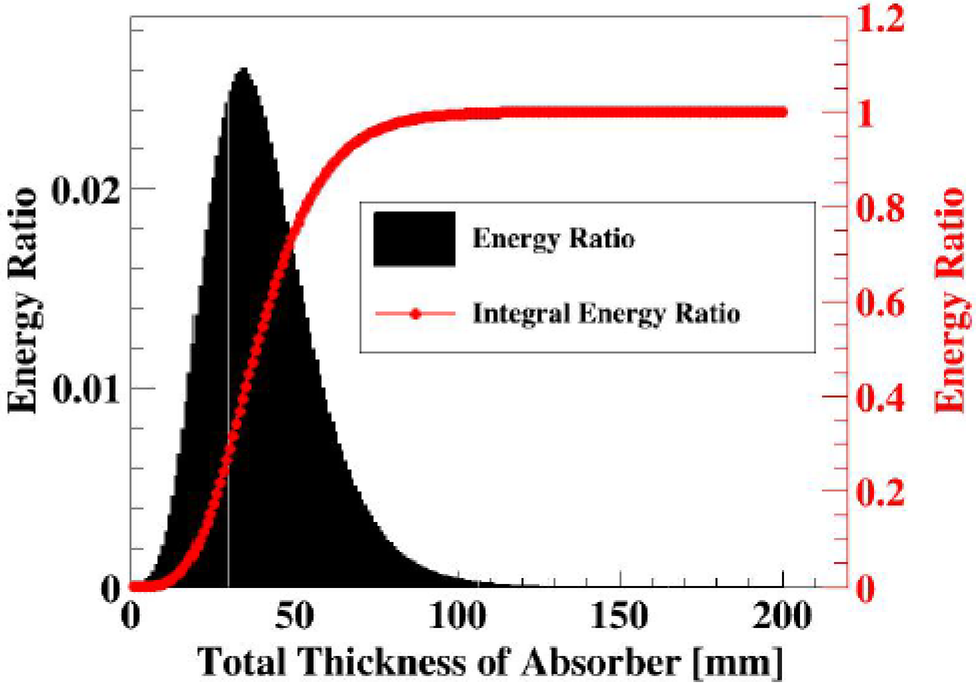


Table 2. Percentage of photons that would be polluted by neighbor particle

Cell Size	Crucial Separation Distance with Arbor	Percentage of $H\rightarrow\gamma\gamma$		Percentage of $Z\rightarrow\tau\tau$
		$\geq$30GeV	$\leq$30GeV	
1mm	4mm	0%	0.06%	0.068%
5mm	9mm	0.007%	0.352%	0.388%
10mm	16mm	0.097%	1.12%	1.70%
20mm	37mm	0.404%	6.41%	18.6%

At least ~10mm×10mm effective cell size

Study on ECAL Absorber Thickness



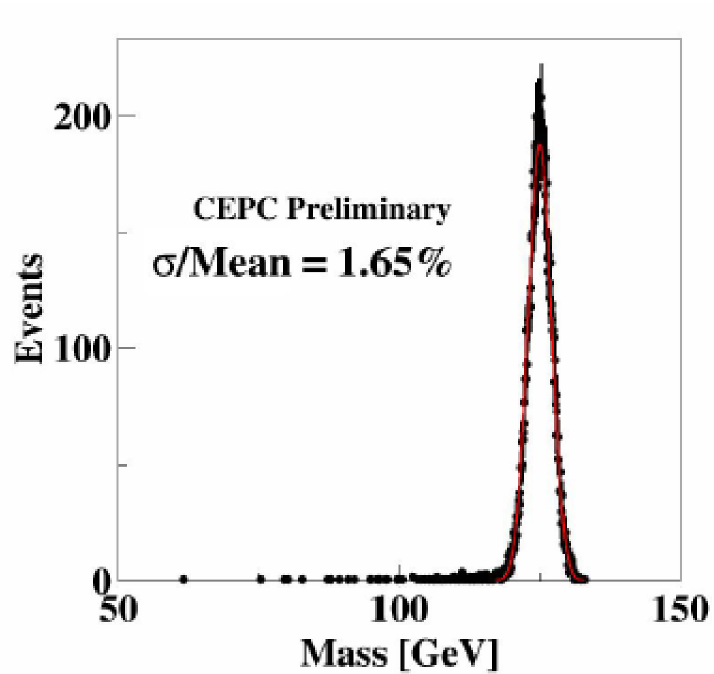
80-90mm Total Tungsten Thickness is resonable

175GeV photon shower energy deposit in each 1mmW ($0.35X_0$)

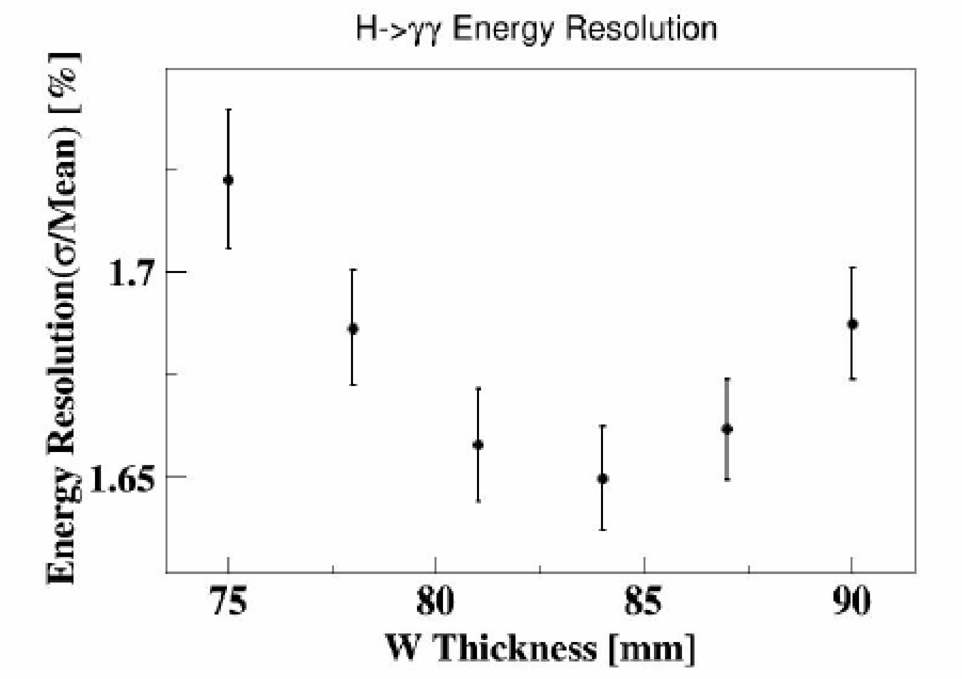
	95mm W	90mm W	85mm W	80mm W
175GeV	99.0%	98.6%	97.9%	96.9%
120GeV	99.2%	98.8%	98.2%	97.3%
45GeV	99.4%	99.1%	98.7%	98.1%

vvHiggs->diphoton Reconstruction

the reconstruction accuracy is mainly decided by the photon energy resolution because the spatial resolution is negelectable.

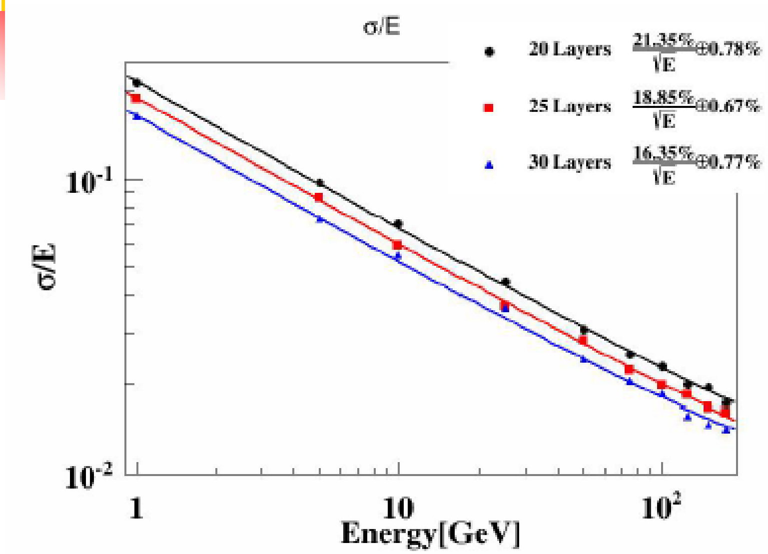


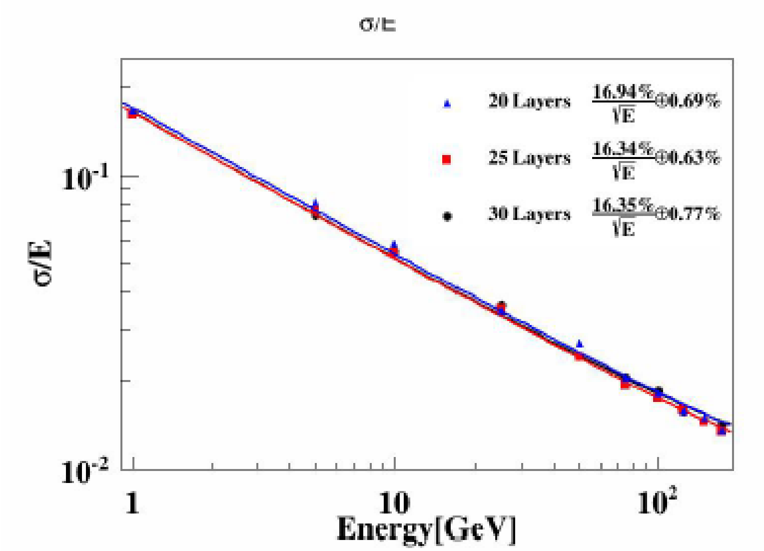
30layers ECAL with 2.8mmW+0.5mmSi in each layer



resolution(σ/mean) with different total tungsten thickness

Study on ECAL layer number





0.5mm thick silicon in each layer

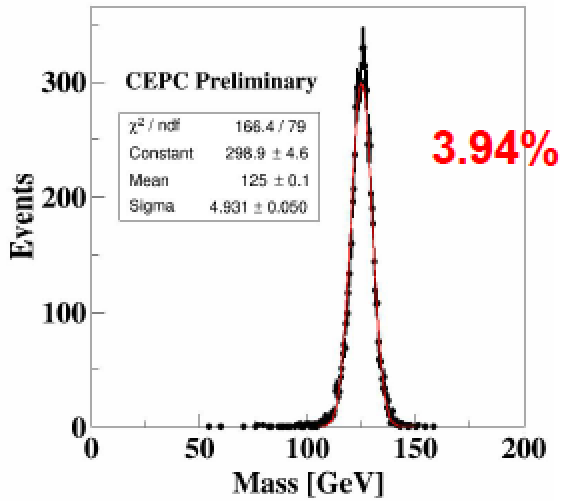
less layer gets worth photon energy resolution, due to the less sensor/absorber ratio

thicker sensor can compensate photon energy resolution

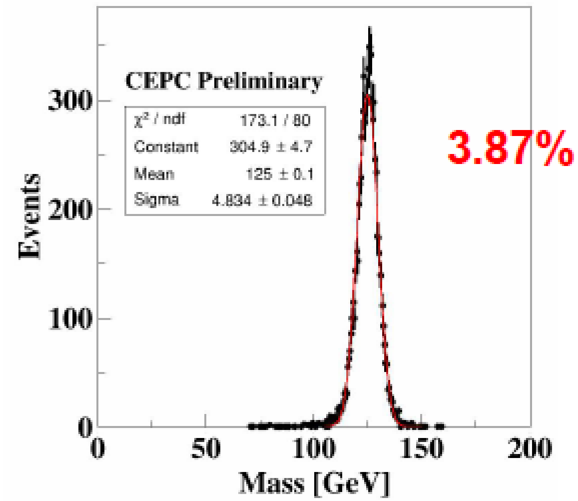
30layers 0.5mm silicon
25layers 1mm silicon
20layers 1.5mm silicon

CEPC Detector Model Results

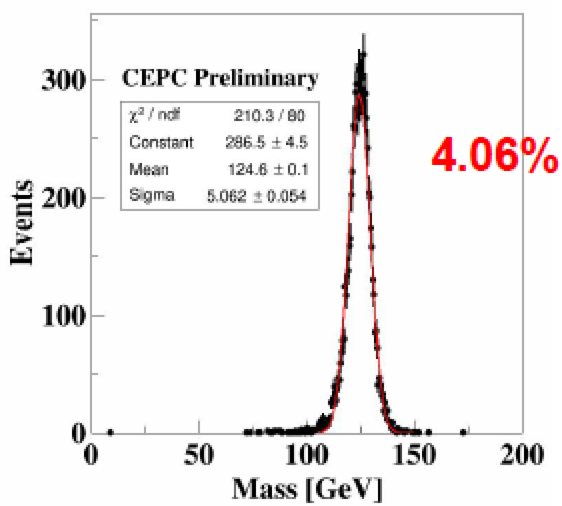
vvHiggs->gluon gluon



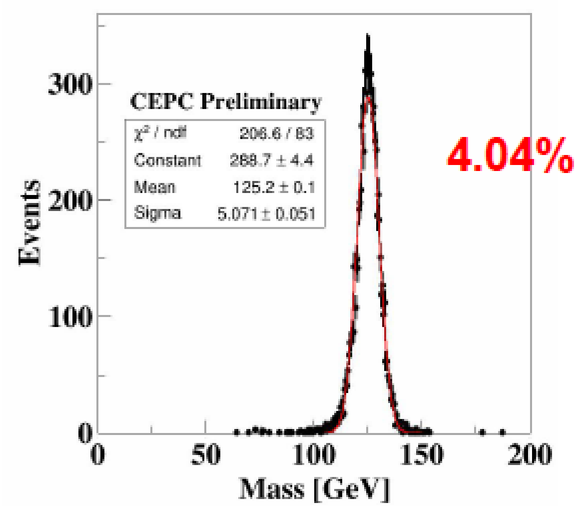
0.5mmSi, 30Layers



1mmSi,30Layers

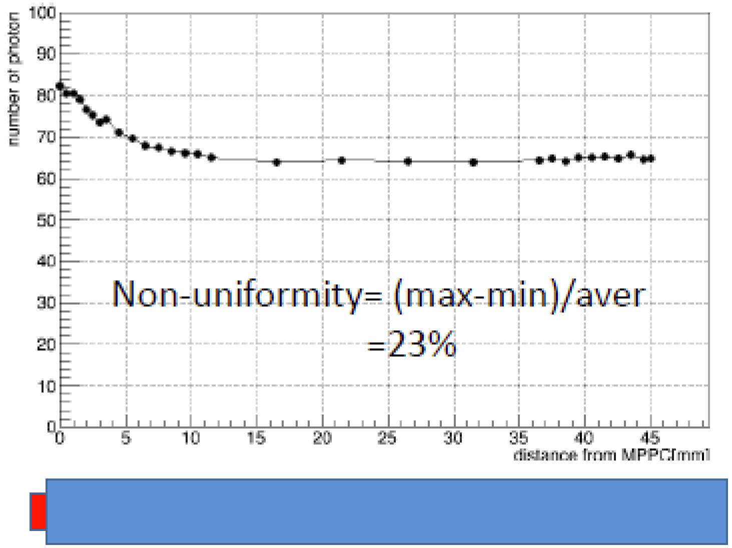


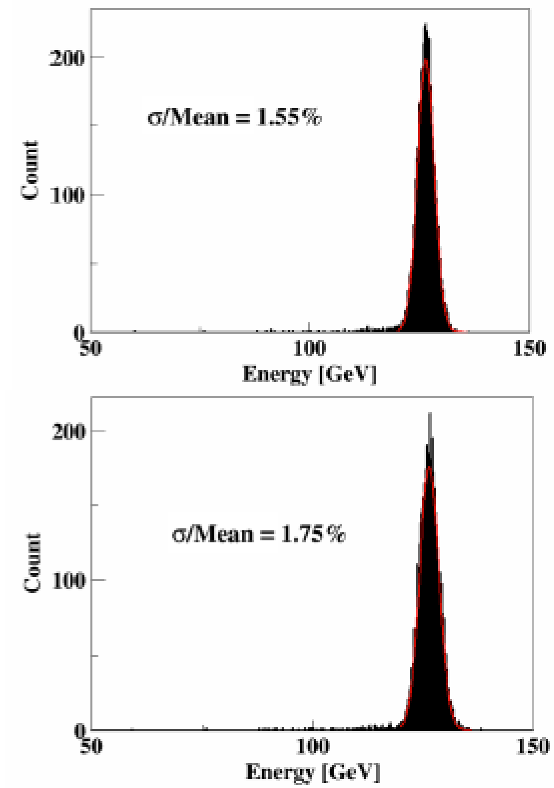
1mmSi,20Layers



1.5mmSi,20Layers

Scintillator strip test





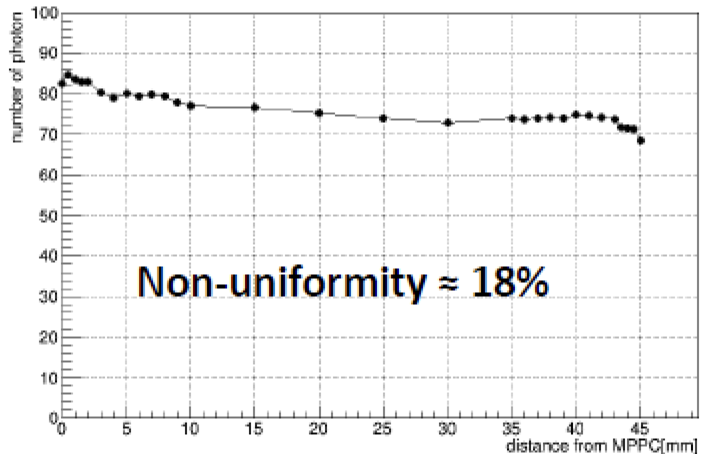
Scintillator strip： 5mm╳45mm╳2mm

SiPM: Hamamatsu S12571-025P

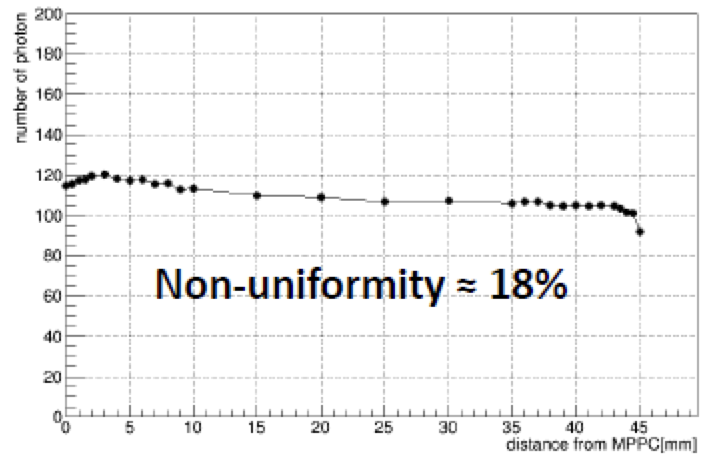
Energy reconstruction of ννHiggs⟶ γγ

- Light output is non-uniformity along the length of the scintillator, which will impact the energy resolution
- Optimize the uniformity of the scintillator
  - Reflective layer
  - Coupling mode of SiPM and scintillator

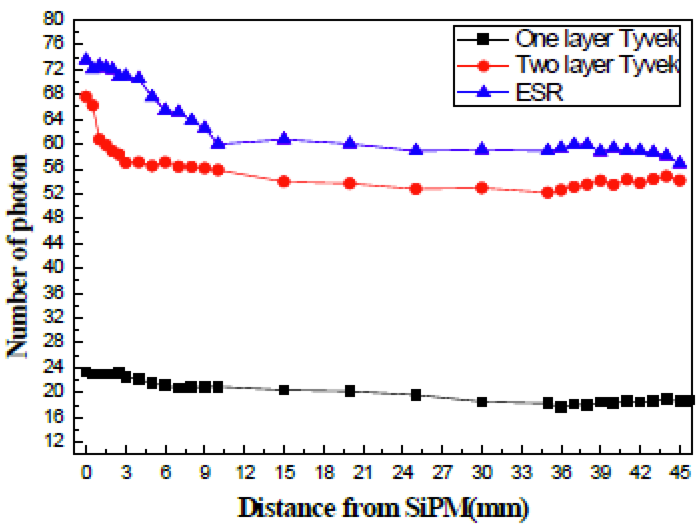
Scintillator structure optimization



Strip with five rough surfaces



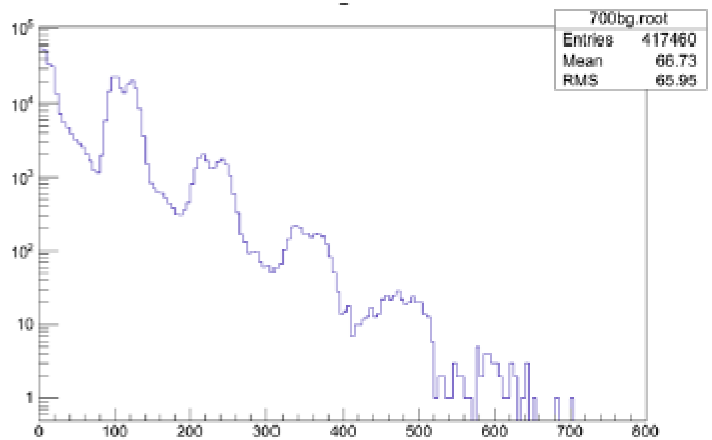
Embed SiPM into scintillator strip



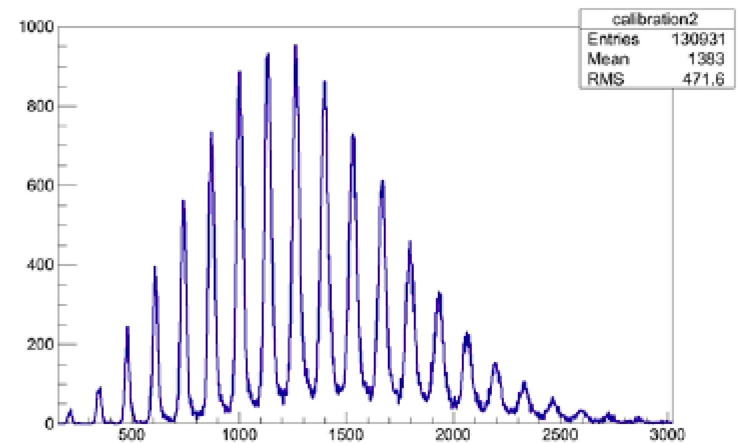
- Rough Reflective surfaces and suitable coupling mode can improve uniformity of light output along scintillator strip.
- Further optimization is under study

SiPM performance study

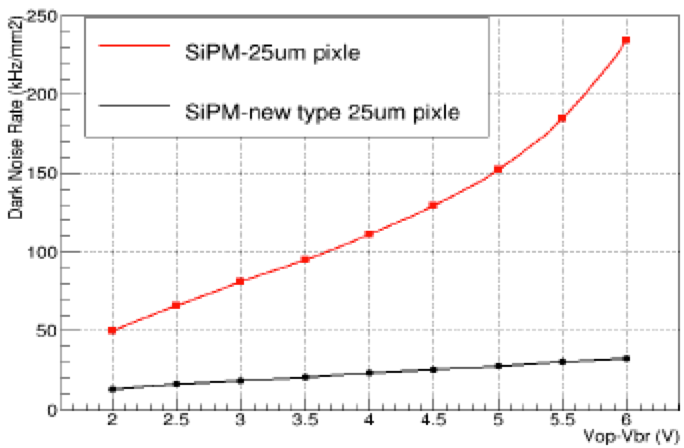
- The SiPM dark noise, pulse height spectrum, and response test



Spectrum of SiPM dark noise



pulse height spectrum

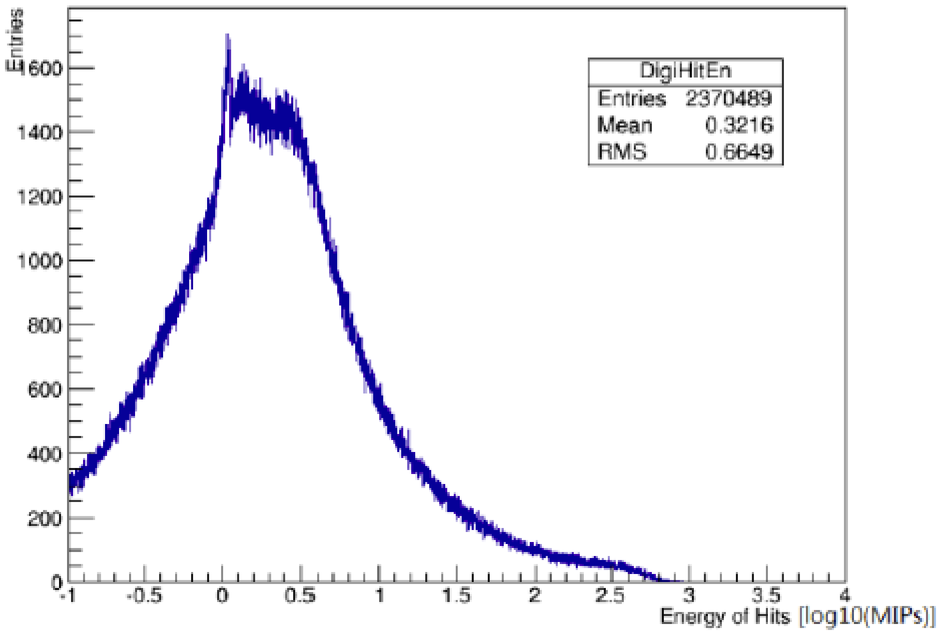


Dark noise rate with over-voltage

The peaks separate clearly from each other. Excellent photon counting ability

Dark noise rate rises exponentially with the applied over-voltage.
New SiPM can reduce dark noise.

SiPM dynamic range



ννHiggs→ γγ

Cell size of scintillator is 5mm×45mm×2mm

- The range of energy deposition in scintillator module is quite large.
- 10k pixel number SiPM is required for big dynamic range (1 MIP>10 p.e.)

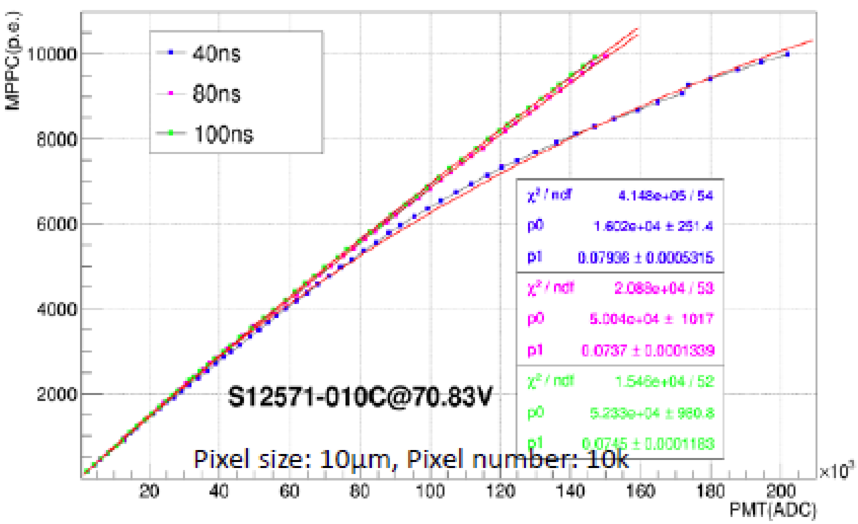
SiPM response test

- When the recovery time of each pixel of SiPM is faster than the duration of one event, some pixels will contribute to an signal more than once. It makes the effective response pixels larger than the real number of pixels, and extend the dynamic range of SiPM
- The effective response pixels can be described by following formula

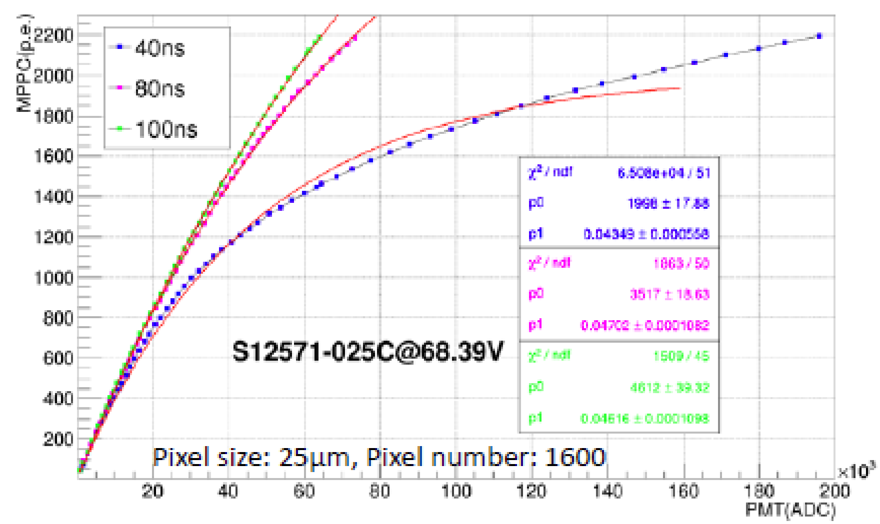
$$N_{fire} = N_{eff}\left(1 - e^{-\epsilon N_{in}/N_{eff}}\right)$$

N_{fire}: the number of fired pixels, N_{eff}: the effective pixel number of pixels

ε : photon detection efficiency, N_{in} : the number of incident photons.



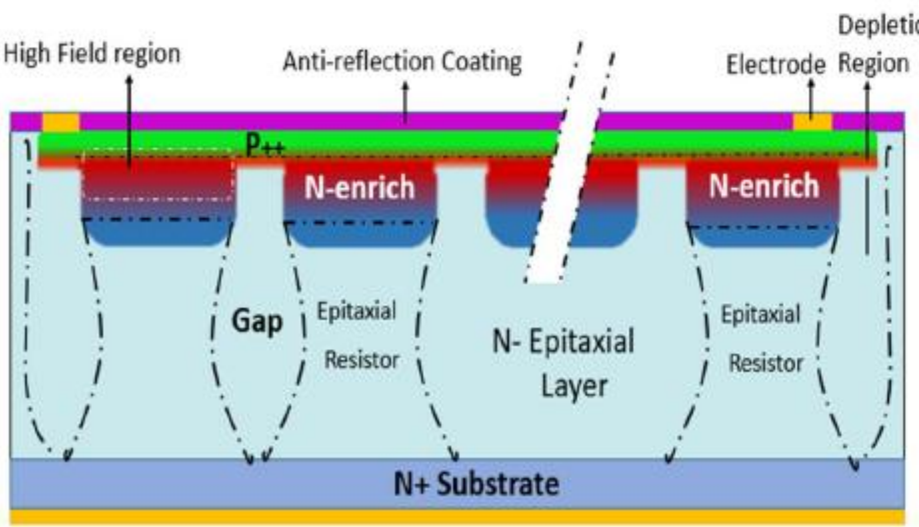
Response curve at different pulse width



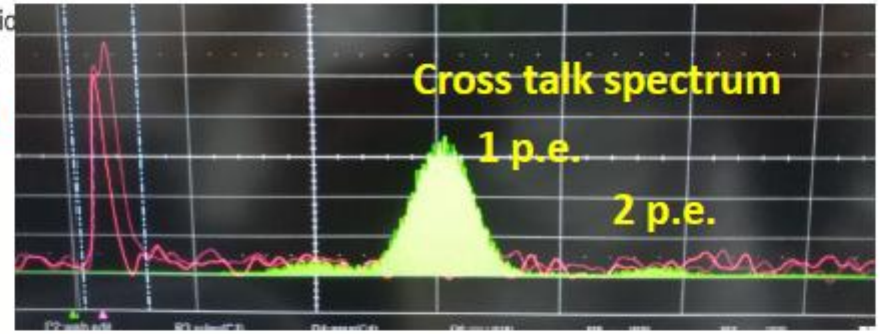
Response curve at different pulse width

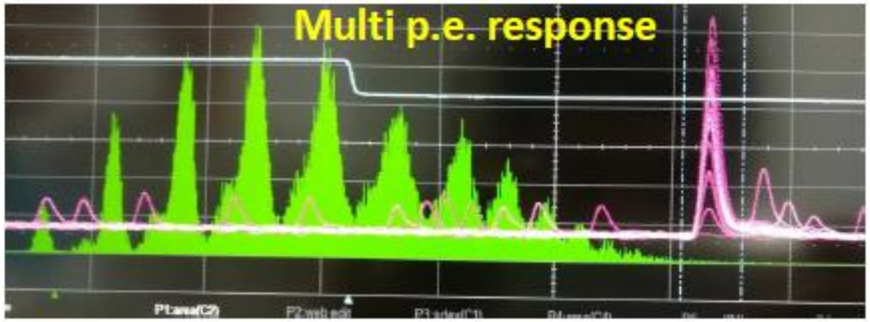
Chinese SiPM（by BNU）

- Chinese **Beijing Normal University** (BNU) has developed silicon photomultiplier (SiPM) technologies with epitaxial quenching resistors (EQR).
- NDL EQR-SiPM is easy to implement owning to its unique structure featuring intrinsic continuous and uniform cap resistor layer, **thus reducing the cost of the fabrication.**



Schematic structure of EQR SiPM





BNU SiPM performance

	NDL SiPM	
Effective Active Area	11-3030 B-S	22-1414 B-S
	3.0×3.0 mm^2	1.4×1.4 mm^2 (2×2 Array)
Effective Pitch	10 μm	10 μm
Micro-cell Number	90000	19600
Fill Factor	40%	40%
Breakdown Voltage (V_b)	23.7±0.1V	23.7±0.1V
Measurement Overvoltage (V)	3.3	3.3
Peak PDE	27%@420nm	35%@420nm
Max. Dark Count (kcps)	< 7000	<1500
Gain	2×10^5	2×10^5
Temp. Coef. For V_b	17mV/° C	17mV/° C

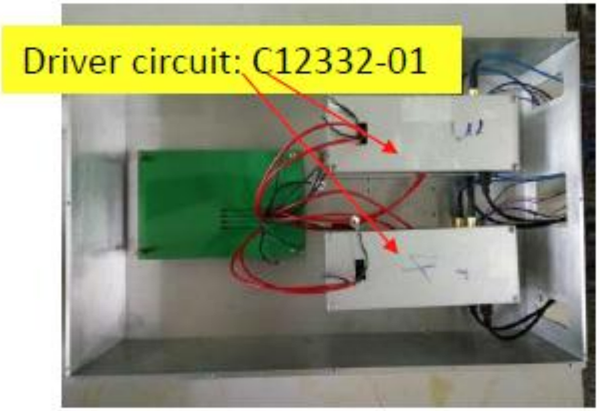
- Chinese SiPM already can work with some good performance
- Some performance need more improvements

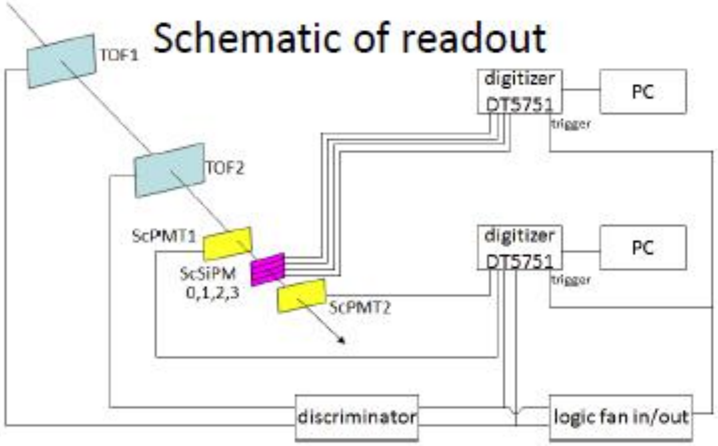
Higher dynamic range
Higher fill-factor

High Dark count rate

A little low Gain

Beam test of a mini prototype

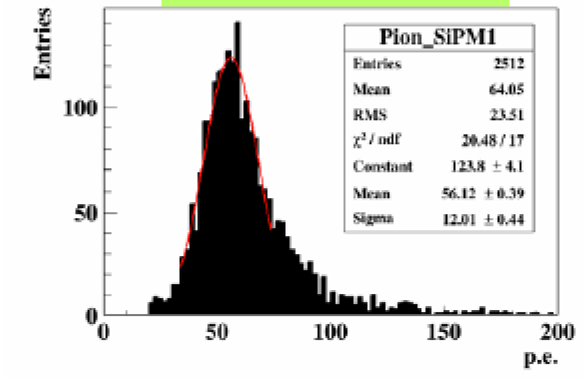




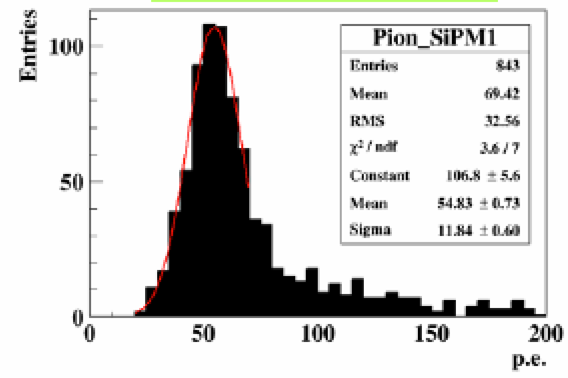
- To study the layout and the coupling mode of the scintillator and SiPM, a mini prototype was constructed and tested by test beam
- Carried out at E3 beam at IHEP in June 2017, Proton and pion mixed irradiation, the momentum of the particles are from 400MeV to 1.1GeV

Spectrum of Pion and Proton

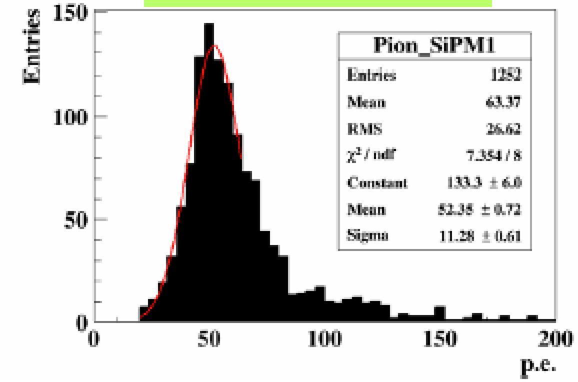
400MeV/c Pion



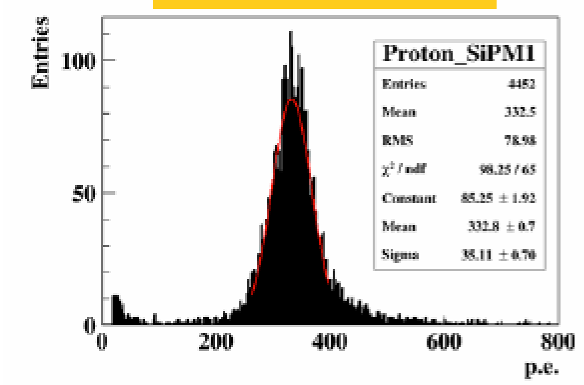
700MeV/c Pion



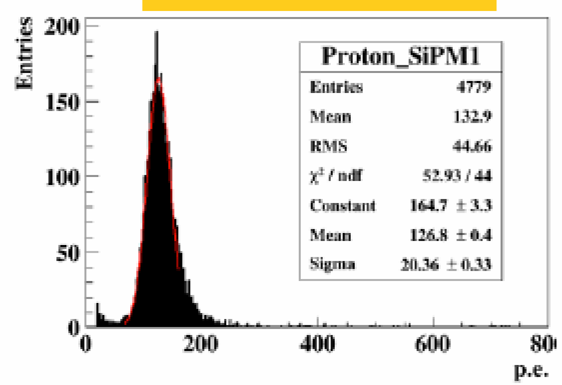
1000MeV/c Pion



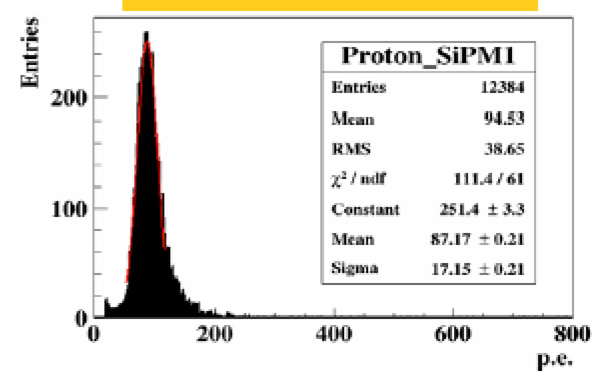
400MeV/c Proton



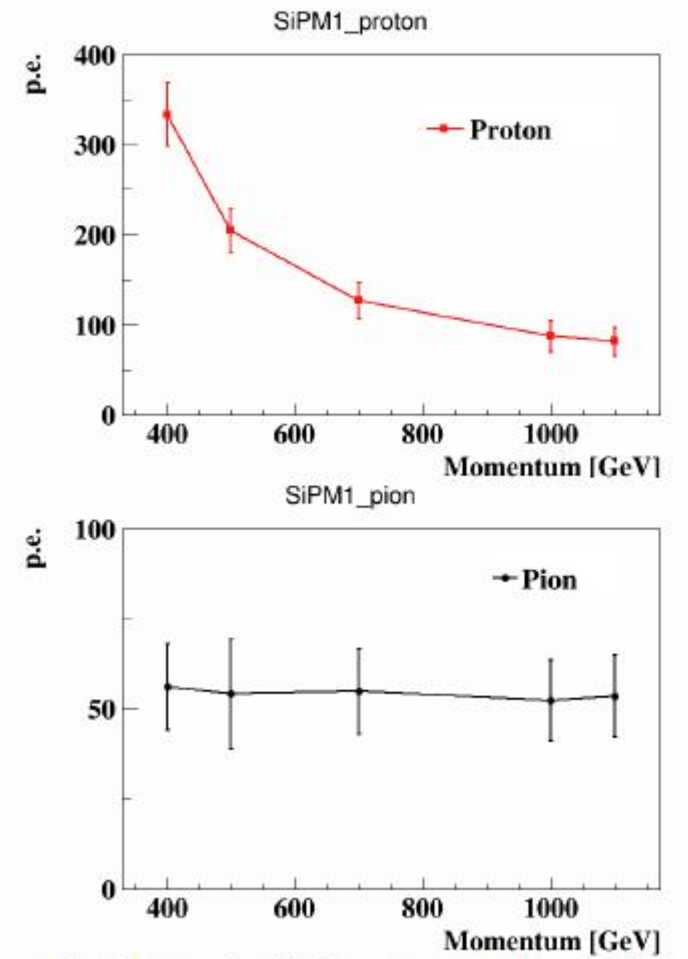
700MeV/c Proton



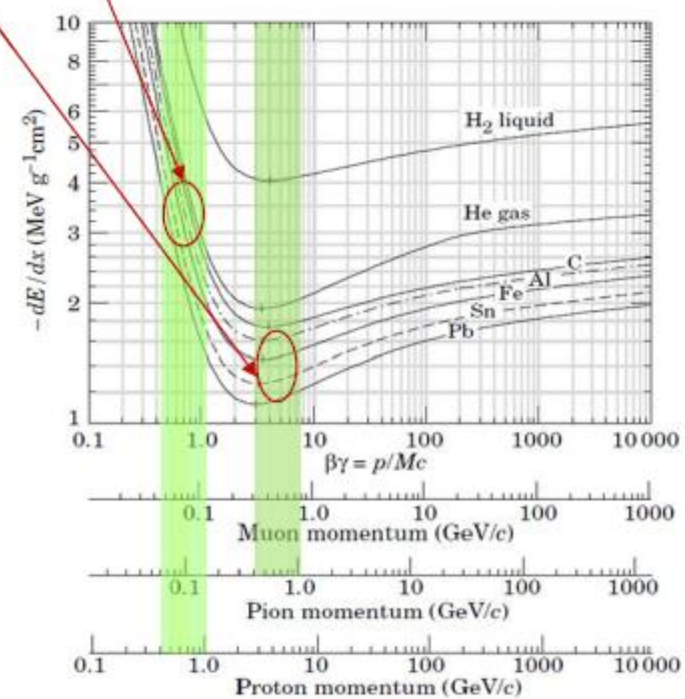
1000MeV/c Proton



dE/dx vs momentum



Momentum (MeV/c)	400	500	700	1000	1100
βγ(proton)	0.43	0.53	0.75	1.07	1.17
βγ(pion)	2.87	3.59	5.02	7.17	7.89



Minimum ionizing energy loss: $\beta\gamma=3.2$

dE/dx (proton and pion) is consistent with the expected value

Summary

- ✓ Optimization of ECAL Geometry
- ✓ Detector cell include
  Scintillator light output/uniformity and
  SiPM dynamic range studied
- ✓ A mini prototype constructed and test at
  IHEP E3 beam and the result is consistent
  with expected value

- ➢ A prototype will be built. Supported by MOST

谢谢！