# R&D Status of the CEPC scintillator-tungsten ECAL

Mingyi Dong
dongmy@ihep.ac.cn
On behalf of CEPC calorimeter working group

# Outline

- Introduction of CEPC scintillator-tungsten ECAL
- Scintillator module test and optimization
- SiPM performance study
- Design and development of readout electronics
- Summary

# Requirements of CEPC ECAL

- Precise measurements of electrons and photons with energy resolution of :

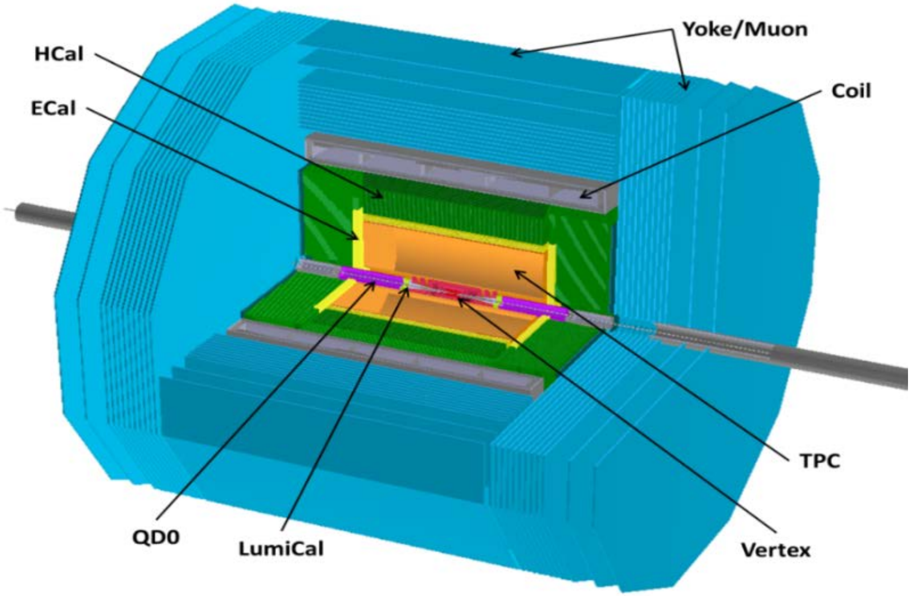
  $\sigma_E/E \approx 16\%/\sqrt{E} \oplus 1\,\%$

- Jet energy resolution (ECAL combined with HCAL and tracker):

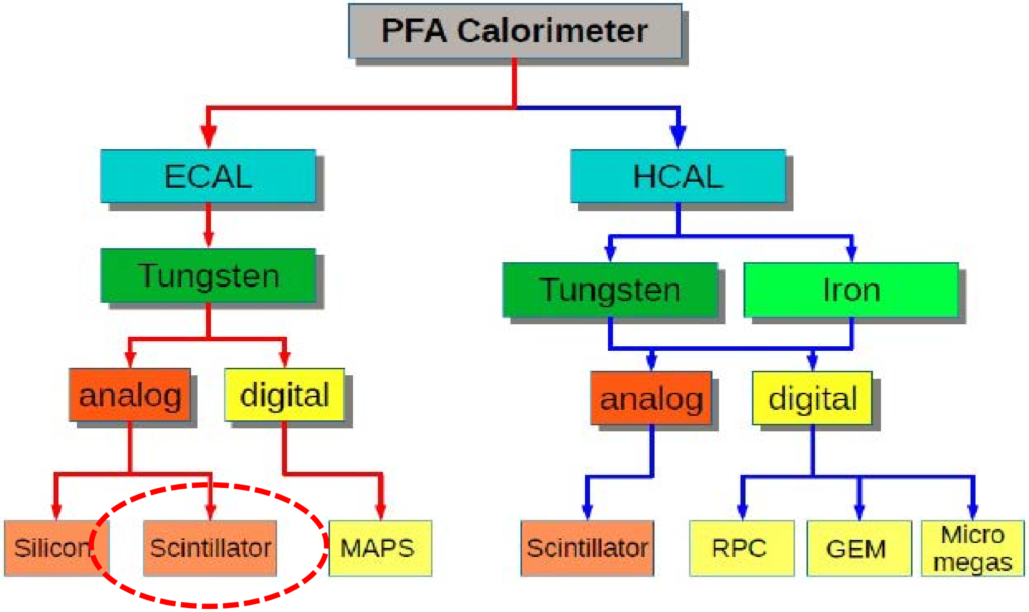
  $\sigma_E/E \approx (3\% - 4\%)$

- Can give detailed information of showers

- Be designed as high granularity , with compact showers(small radiation length $X_0$, and small Moliere radius $R_M$), and minimum dead materials

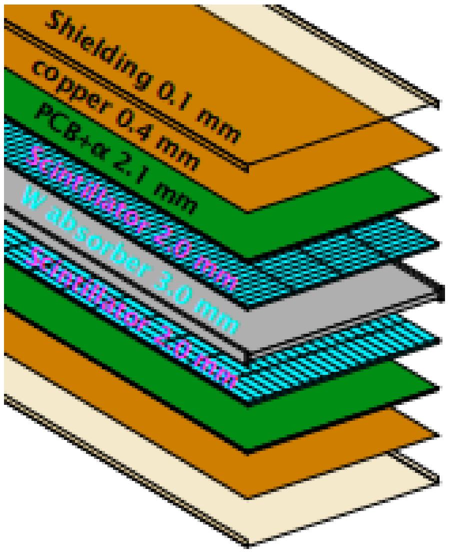


# Scintillator-tungsten ECAL



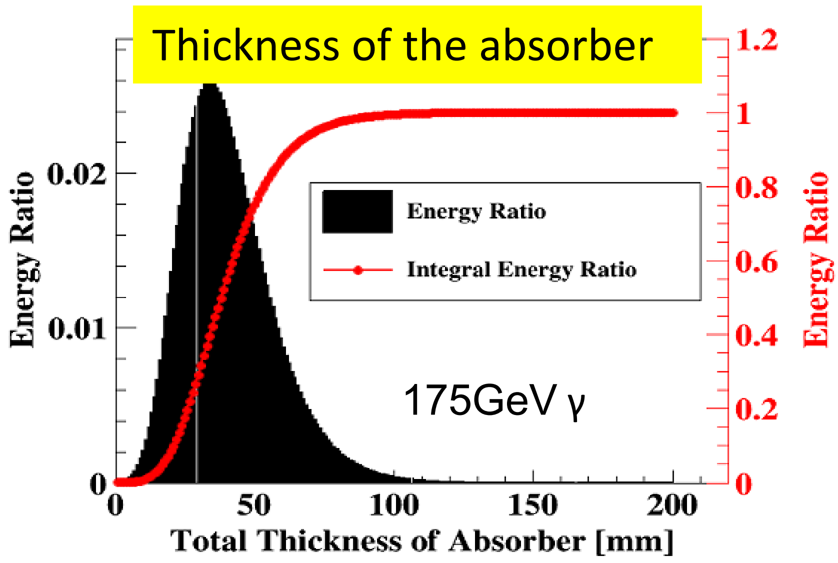

https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers

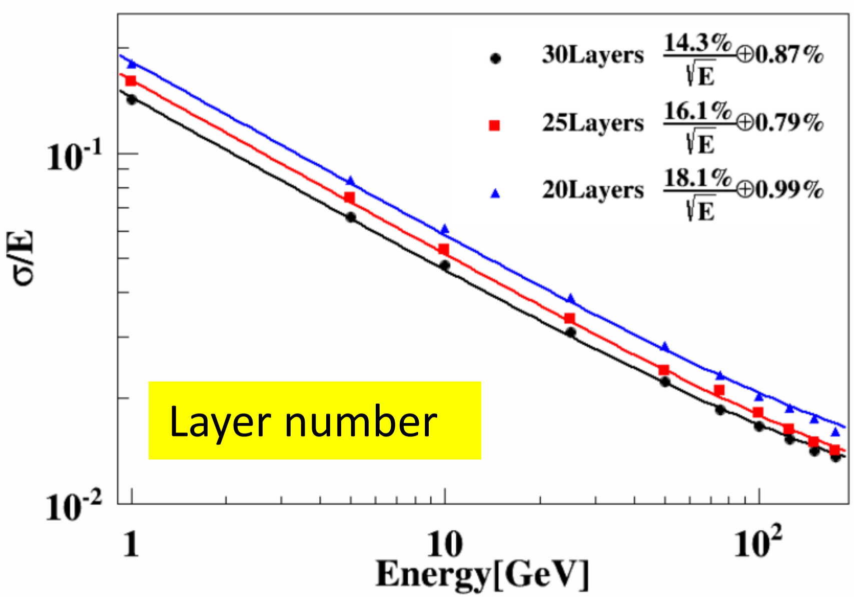
- A sampling calorimeter with scintillator-tungsten sandwich structure (ScW) is one of the ECAL options
- Sandwich structure
  - Absorber + scintillator readout module + PCB
- Scintillator readout module
  - Scintillator + SiPM
- Absorber
  - Tungsten (total thickness : 80~90mm)

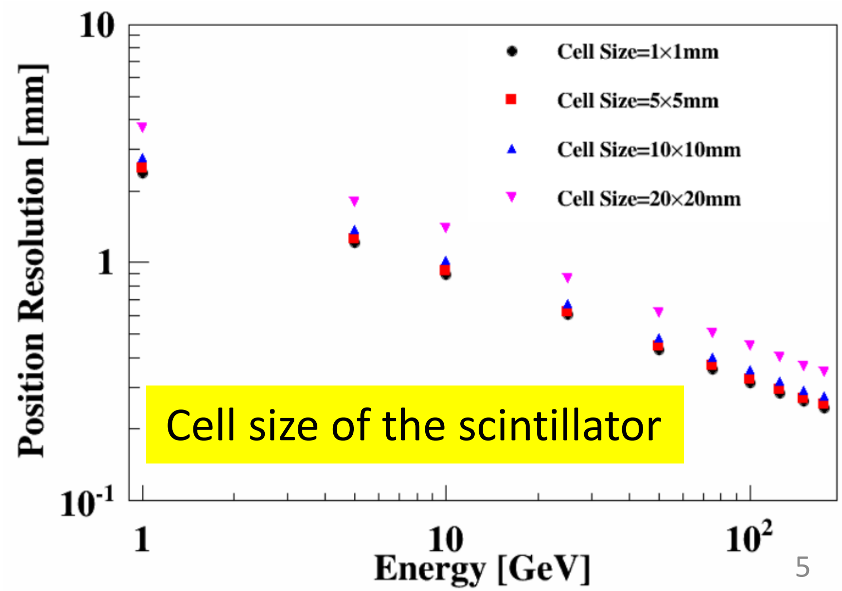


# Optimization of Scintillator-tungsten ECAL

- Simulation and optimization of the structure and geometry to determine the key parameters
- Thickness of the absorber, layer number, cell size and thickness of the scintillator

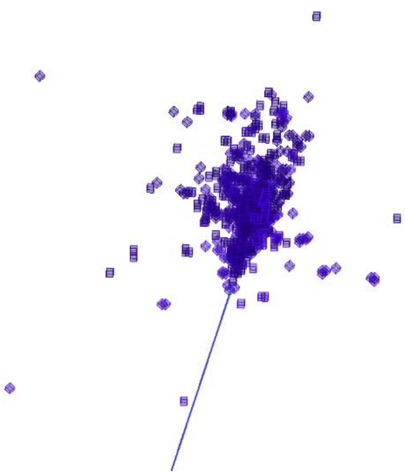


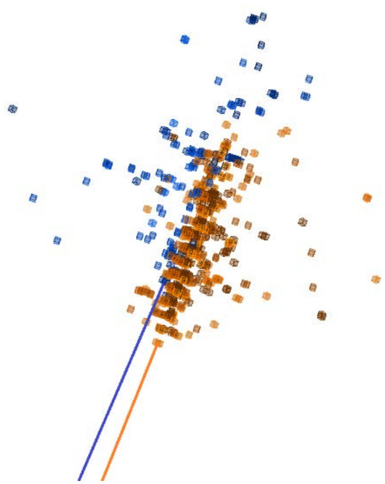



# Nearby EM-Shower Separation

- Lots of nearby EM-showers exist in jets, the separation and reconstruction of them are important for some physics objects
- The reconstruction efficiency of two parallel 5GeV photons was studied. The distance between these photons ranges from 1mm to 80 mm.

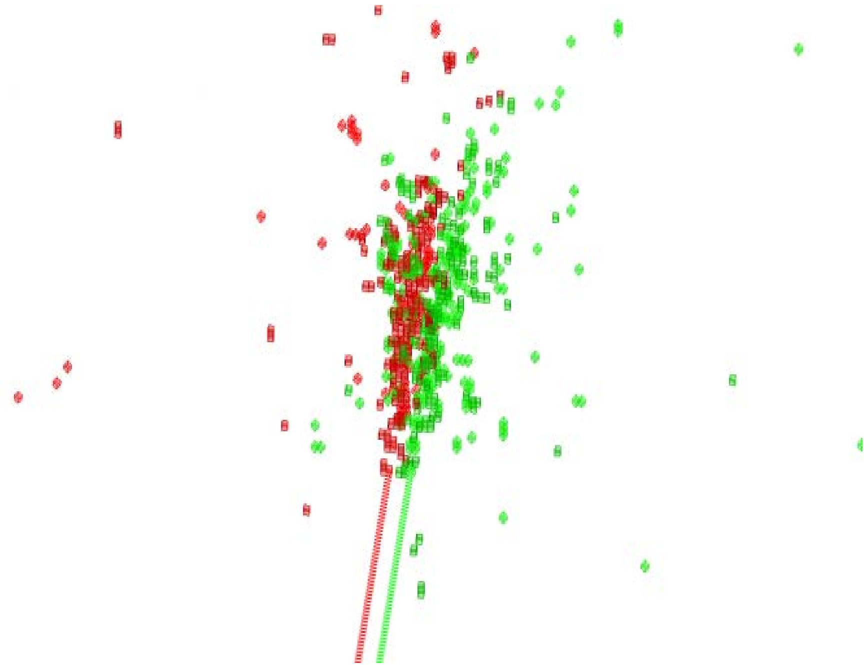


failed



failed

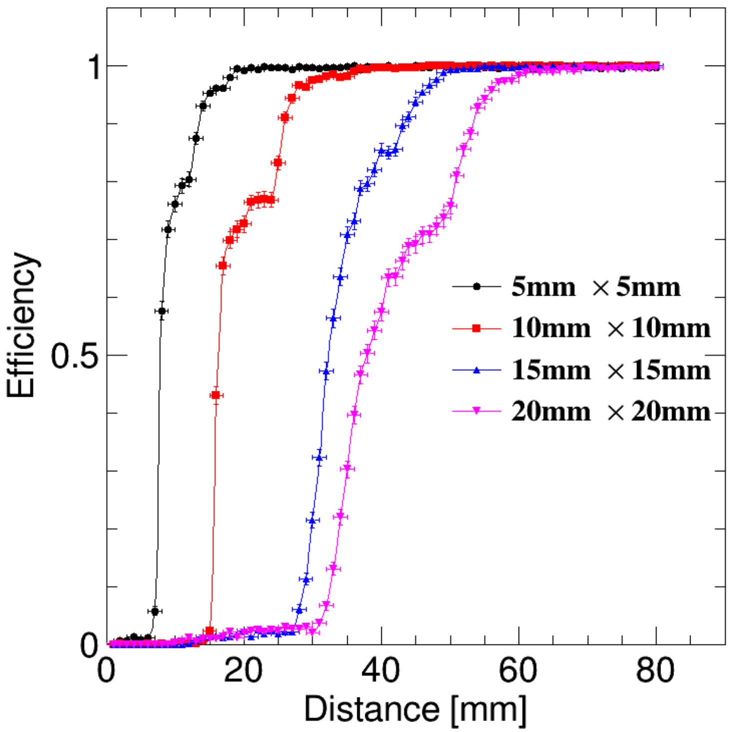
($E_{\text{blue cluster}} \approx 1/6 E_{\text{orange cluster}}$)



succeeded

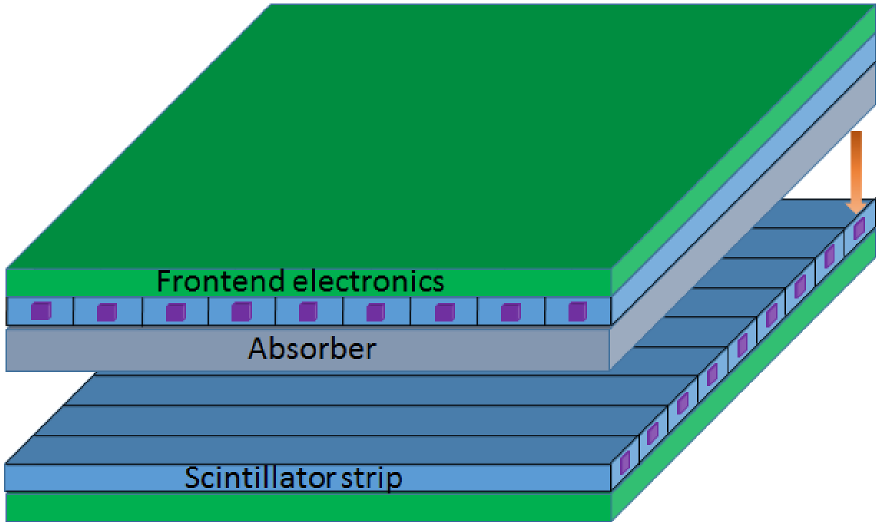
Succeeded conditions: $1/3E_{All} < E_{photon1} < 2/3E_{All}$ && $1/3E_{All} < E_{photon2} < 2/3E_{All}$

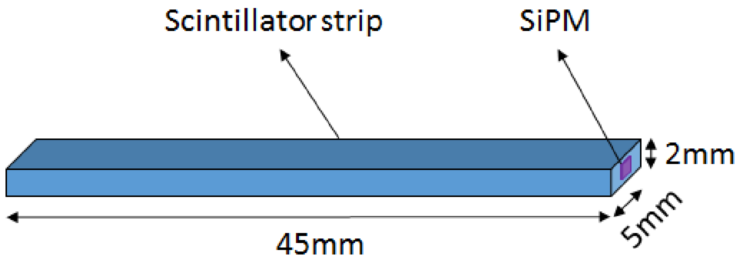
# Nearby EM-Shower Separation




- Efficiency with different cell size was checked
- The reconstruction efficiency converges to 1 for the two showers with large distance
- For the showers with very close distance, the reconstruction efficiency drops significantly
- 30 layer ScW ECAL is used, with 2.8mm W and 2mm Scintillator in each layer

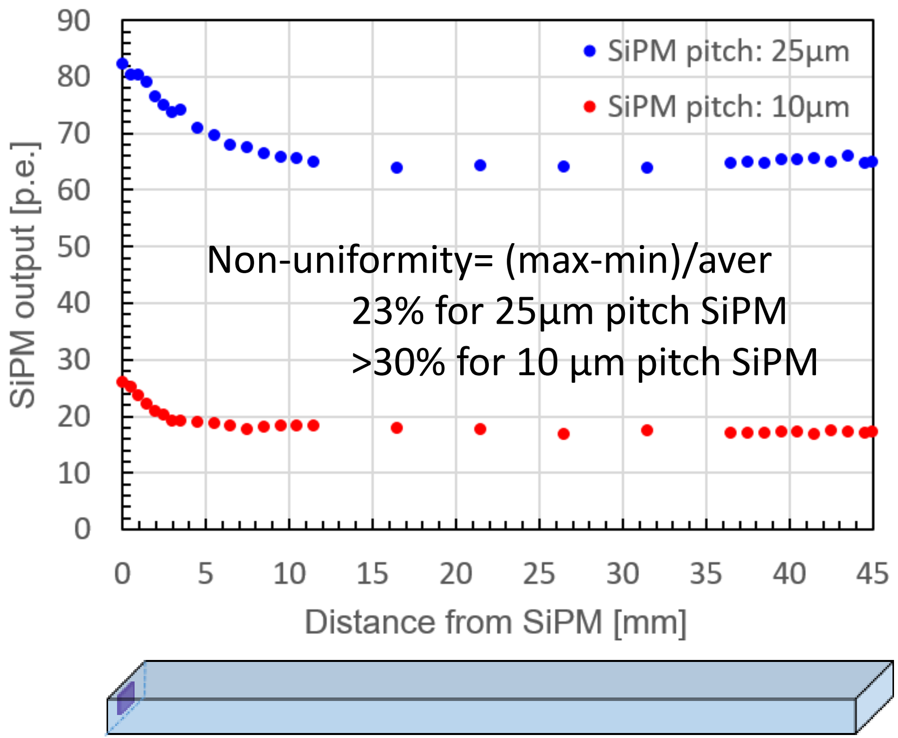
# Scintillator module



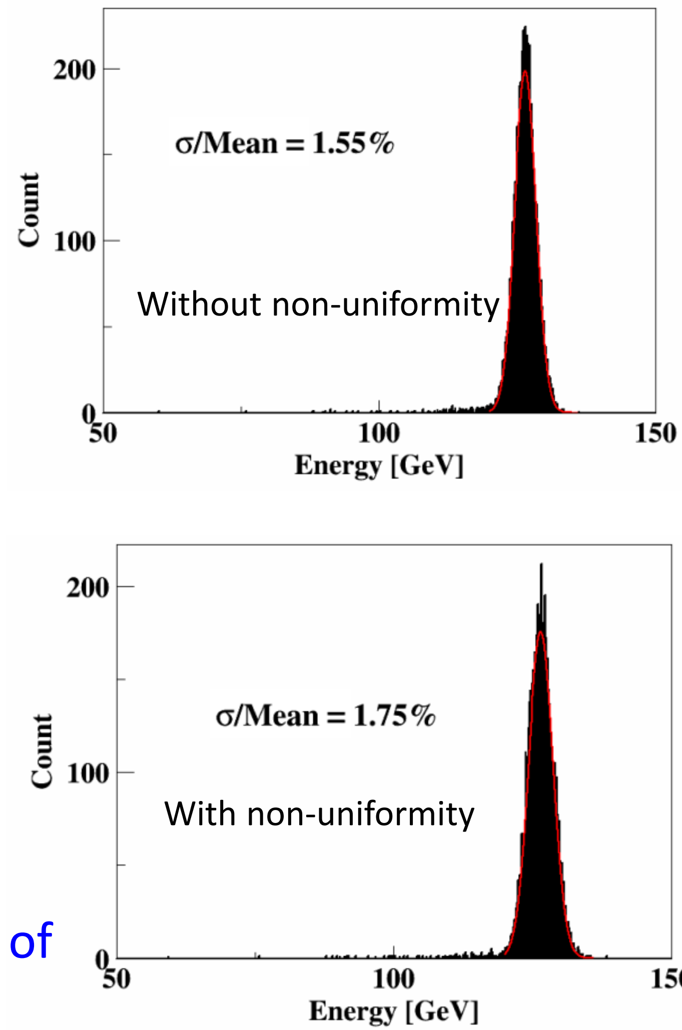




- The scintillator module is basic structural and functional block of the active layers of the ScW ECAL.
- Based on the simulation, Scintillator strip module is designed as strips with a dimension of : 5mm×45mm×2mm
- Cross arrangement of the neighboring layers to realize a transverse readout cell size of $5 \times 5mm^2$
- Reduction of the readout channels, low cost
- SiPM coupled at the side or the bottom of the scintillator strip, negligible dead area

# Module test



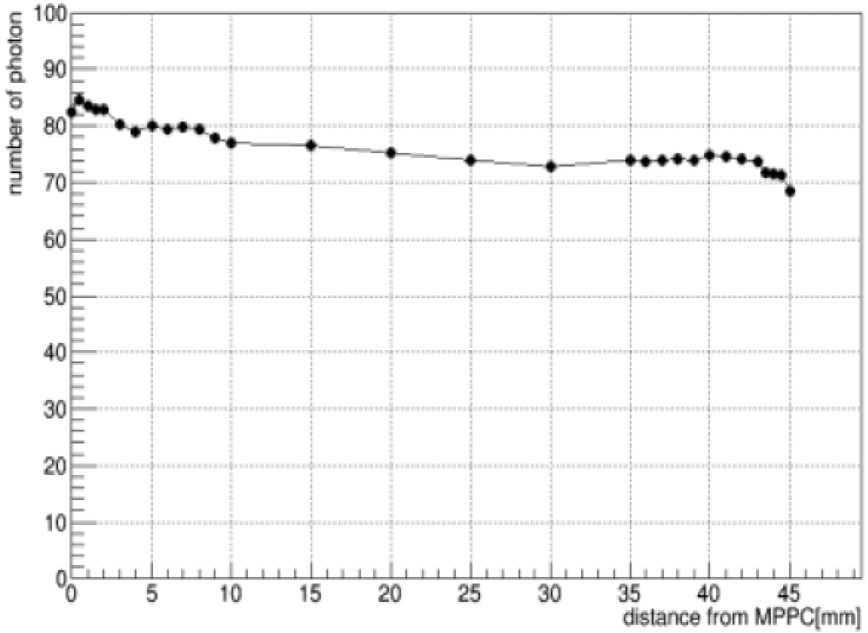

Typical output with SiPM (Hamamatsu S12571-025P or 010P) coupled at the side of the scintillator



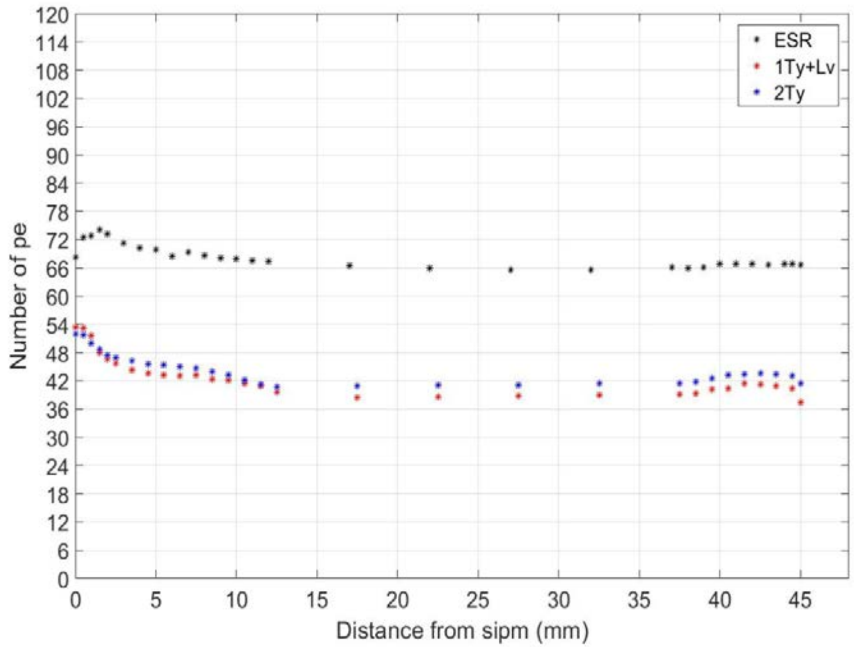

Energy reconstruction of ννHiggs→ γγ

- Light output is non-uniformity along the  length of the scintillator, which will impact the energy resolution
- The uniformity of the output needs to be optimized

# Module test




Strip with rough reflective surfaces

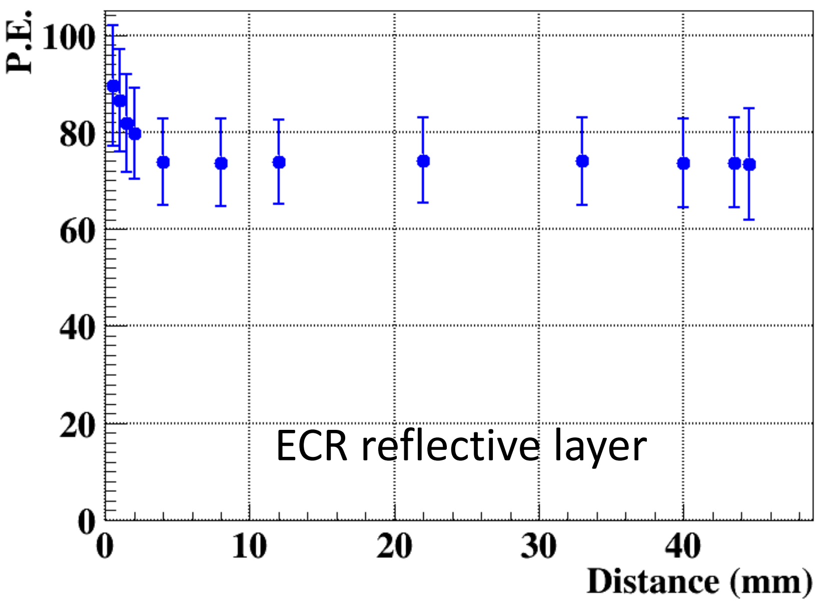


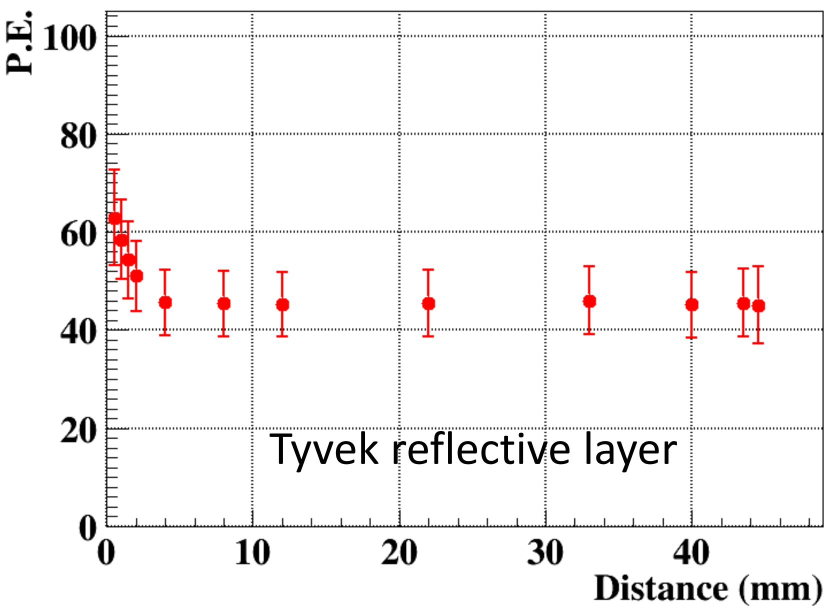

Strip wrapped with different reflective layer

- Rough Reflective surfaces and diffuse reflective layer can slightly improve the uniformity of light output along scintillator strip, but not good enough.

# Scintillator module output simulation

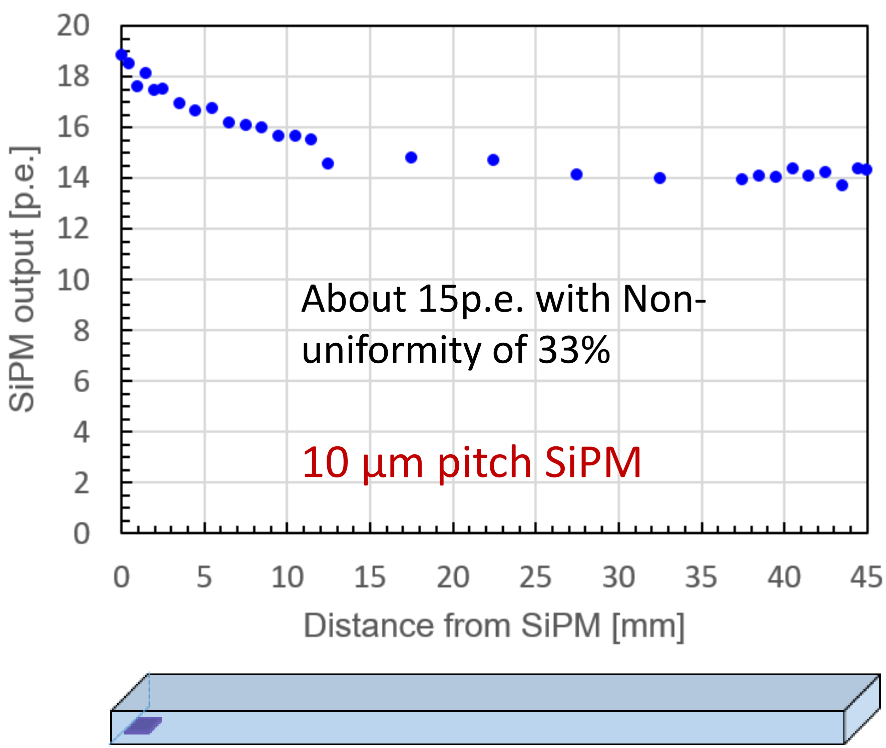
- Simulation is performed for the optimization of the scintillator module
  - PhysicsList: QGSP_INCLXX + Standard Geant4 Optical Physics (Geant4 Version: Geant4.10.3)
  - Scintillator Strip: BC408, dimension: 45×5×2mm$^3$
  - SiPM: 1×1×0.1mm3 , Pitch size 25μm, 1600pixel
  - Cladding: ESR, Tyvek
  - Particle source: Sr-90, Center of the Strip, Vertical incidence

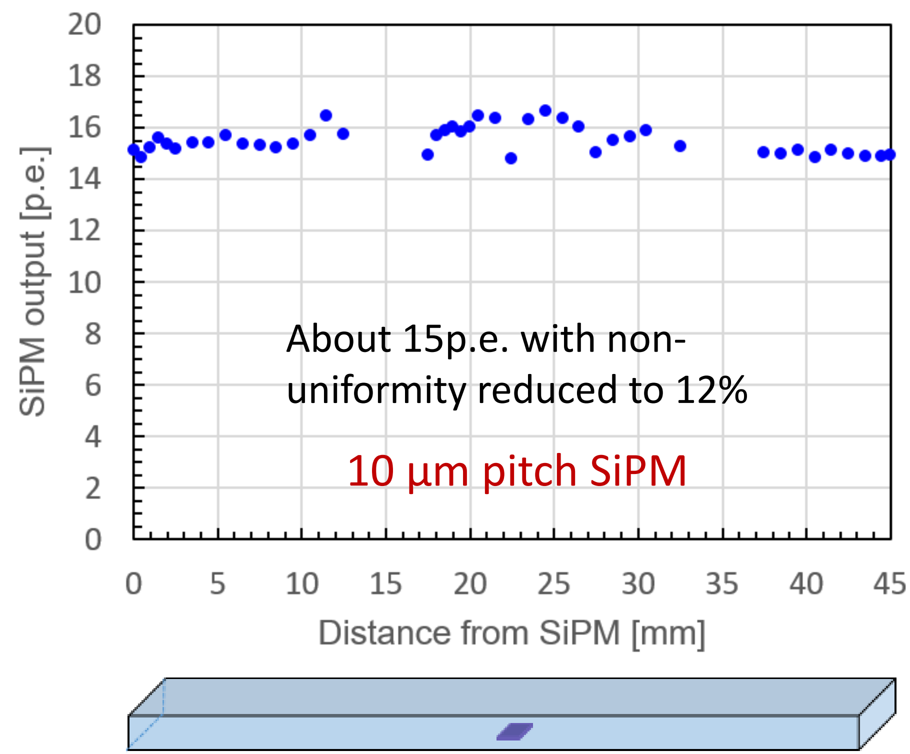



Stand alone G4 simulation. Parameters are still under optimization

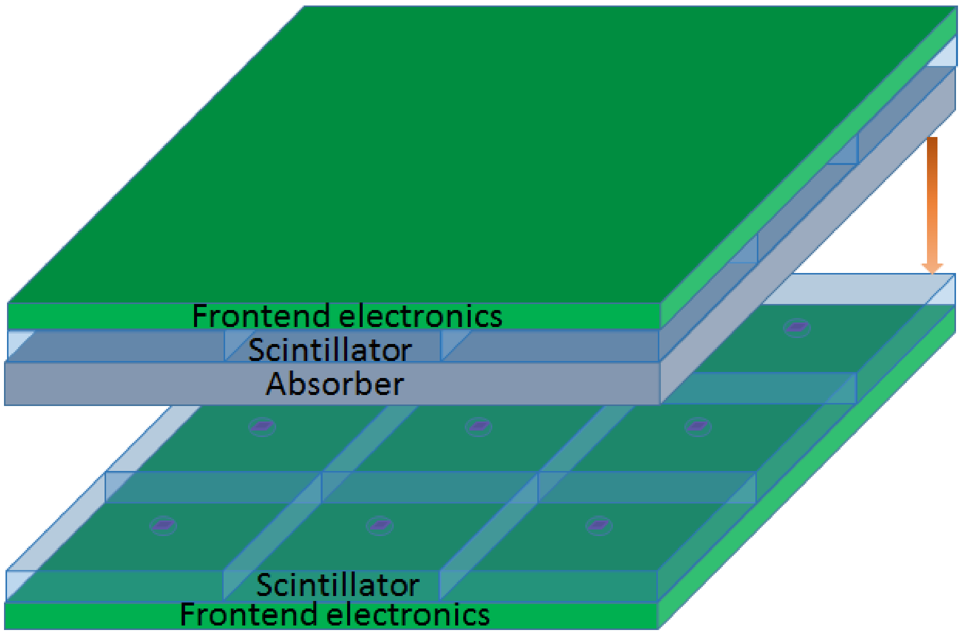
# Module optimization

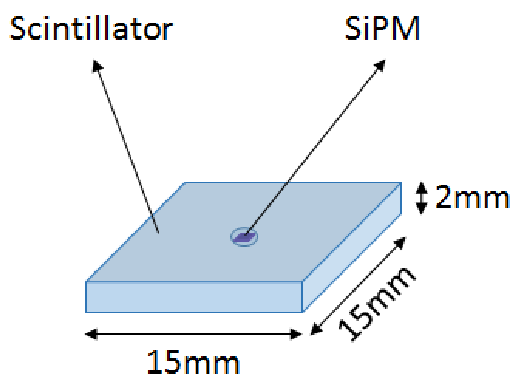



- SiPM embedded at the bottom-end or the bottom-center of the strip
- Uniformity of output has not improved for the former, but has improved significantly for the latter
- The bottom-center coupled mode will be adopted in the prototype construction

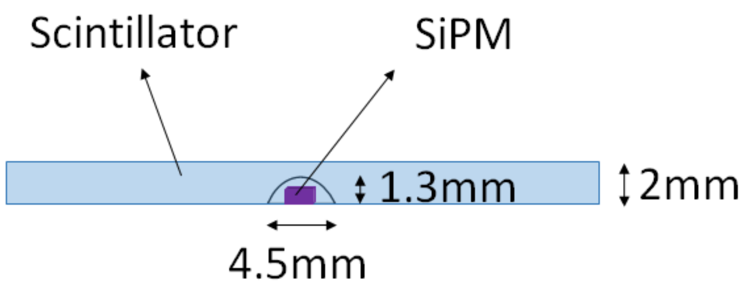
# New shape of the scintillator module

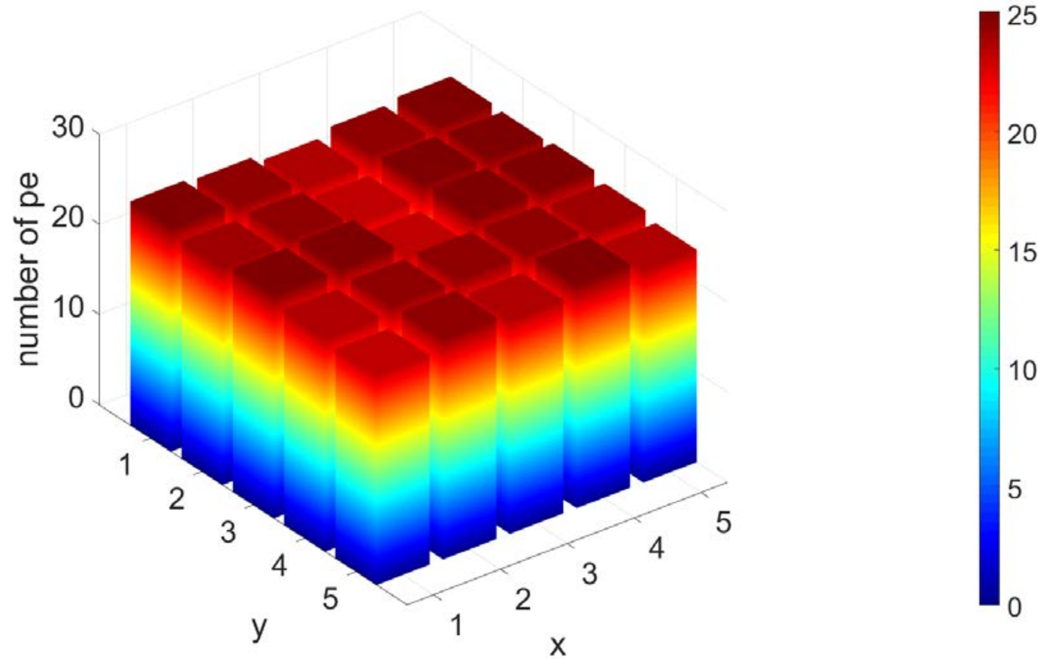



- Based on the simulation results , the cell size of ScW ECAL could be enlarged to 15mm╳15mm
- Square scintillator module is designed and tested
- SiPM embedded into the dome-shaped cavity of the scintillator
- Relative simple reconstruction algorithm
- No dead area
- The total number of the modules is the same as the strip modules

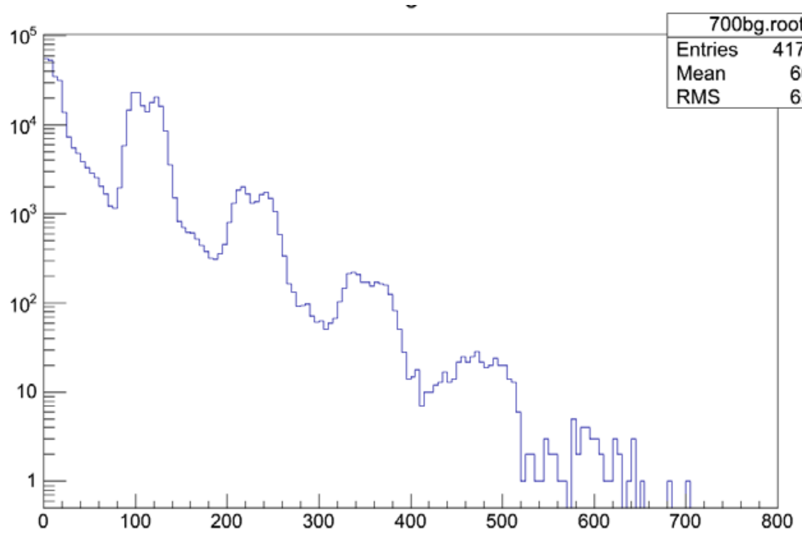
# Module test



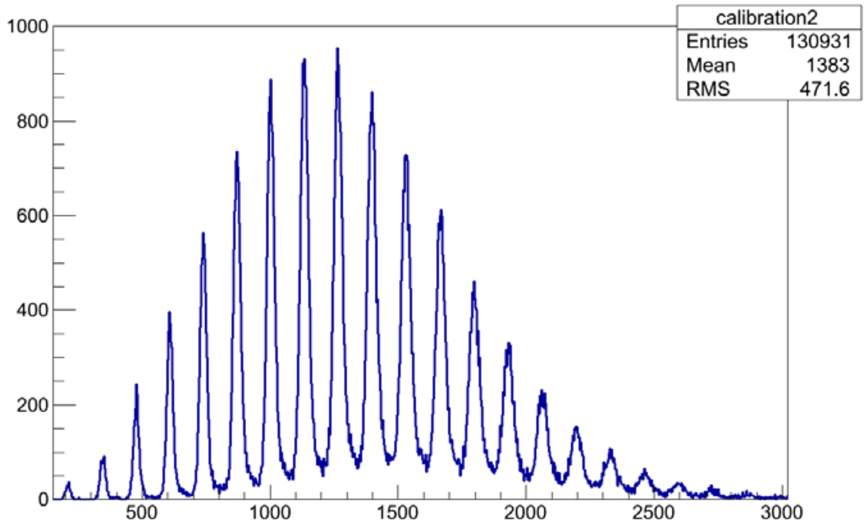




- Module output: 22 p.e. for MIP, little bigger than the strip module
- Better output uniformity（ <10%）than the strip module
- Further tests are needed

# SiPM performance study



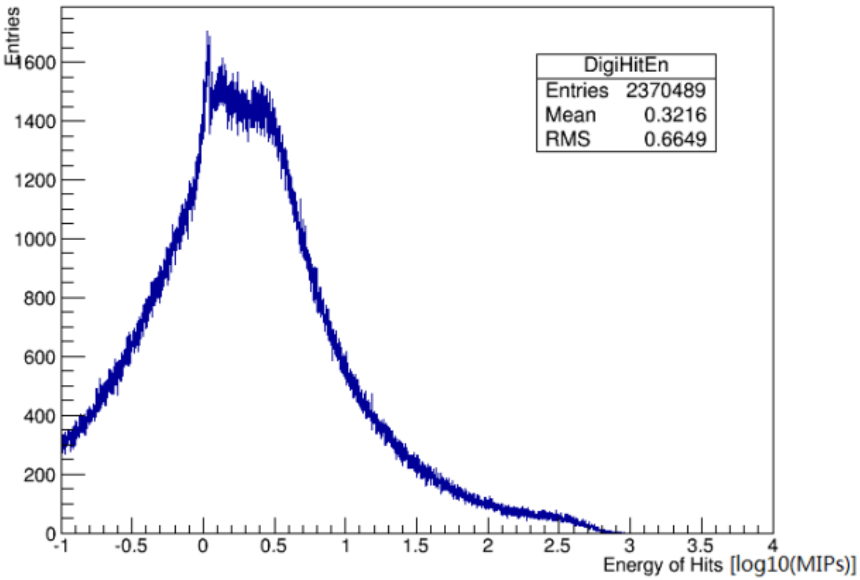

Spectrum of SiPM dark noise



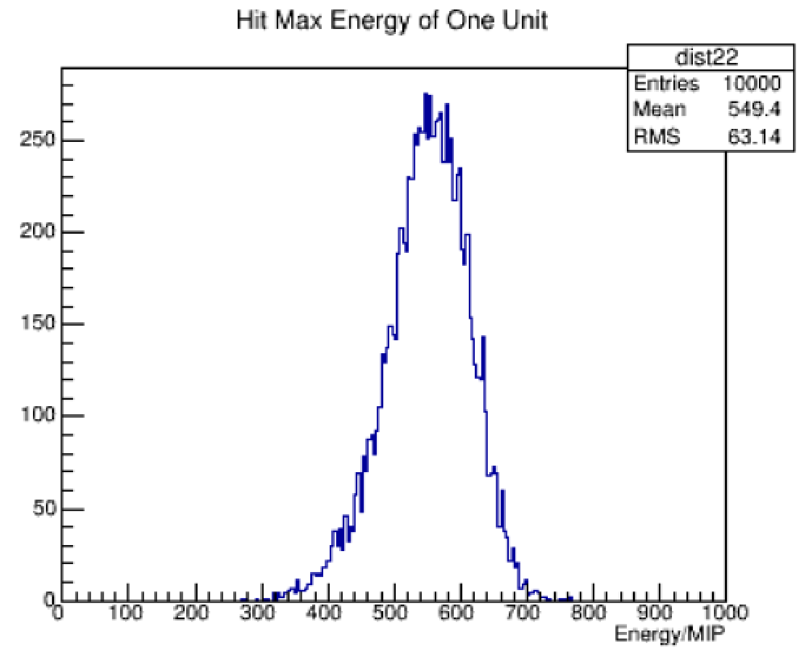

pulse height spectrum

- Hamamatsu S12571-025P and S12571-010P SiPM
- The dark noise, pulse height spectrum, and response test were studied
- The peaks separate clearly from each other
- Excellent photon counting ability

# Dynamic range




$\nu\nu$Higgs$\rightarrow\gamma\gamma$




100GeV $e^-$

- Based on the simulation, the showers of particles may deposit 1 ~ 800 MIP energy in a single scintillator module
- Key issue of the SiPM: dynamic range must be large enough to match the corresponding light output range
- If the MIP signal is larger than 10 p.e., the SiPM is required to have at least 10k pixels

# SiPM response test

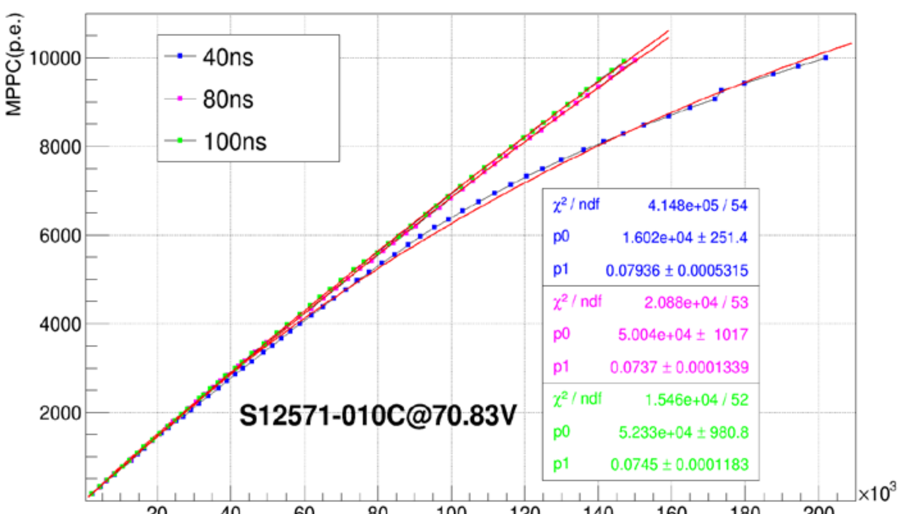
- The SiPM is not a linear photon detection device, when the recovery time of the pixels is smaller than the duration of one event, some pixels can respond more than once. It makes the effective response pixel number larger than the real number of pixels, and thus extends the dynamic range of SiPM
- The effective response pixels can be described by following formula

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

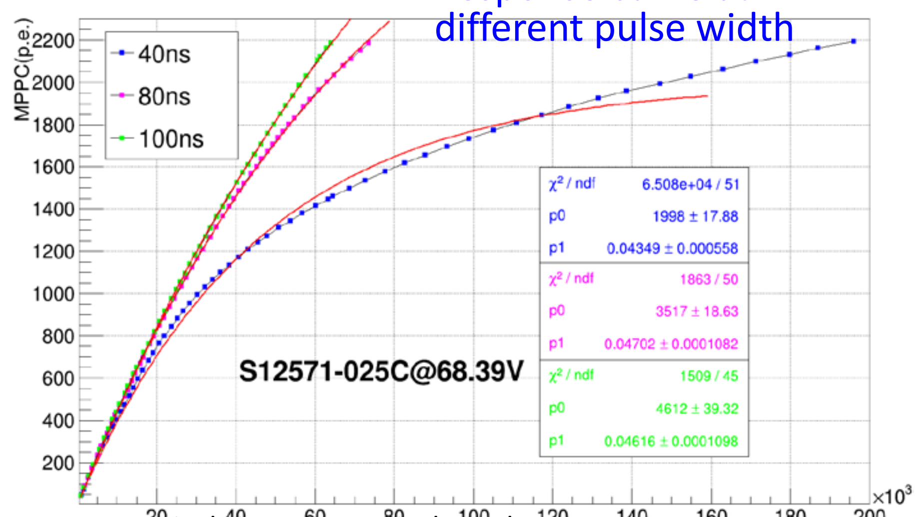
$N_{fire}$: the number of fired pixels, $N_{eff}$: the effective pixel number of pixels

$\varepsilon$ : photon detection efficiency, $N_{in}$ : the number of incident photons.

Response curve at different pulse width



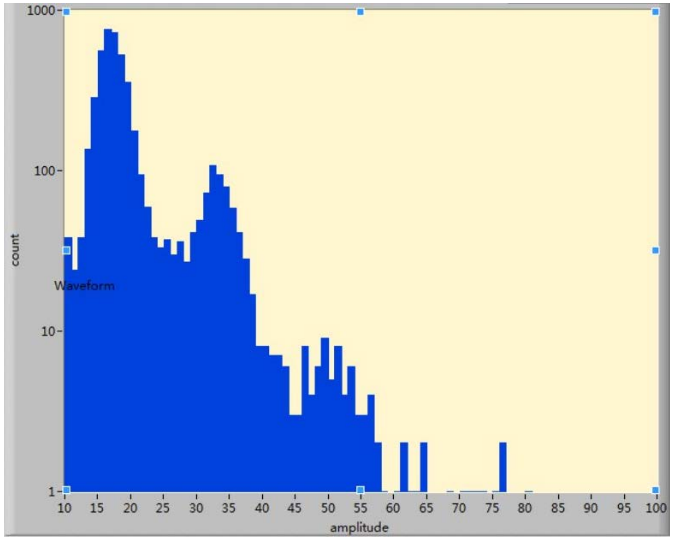

Pixel size: 10µm, Pixel number: 10k



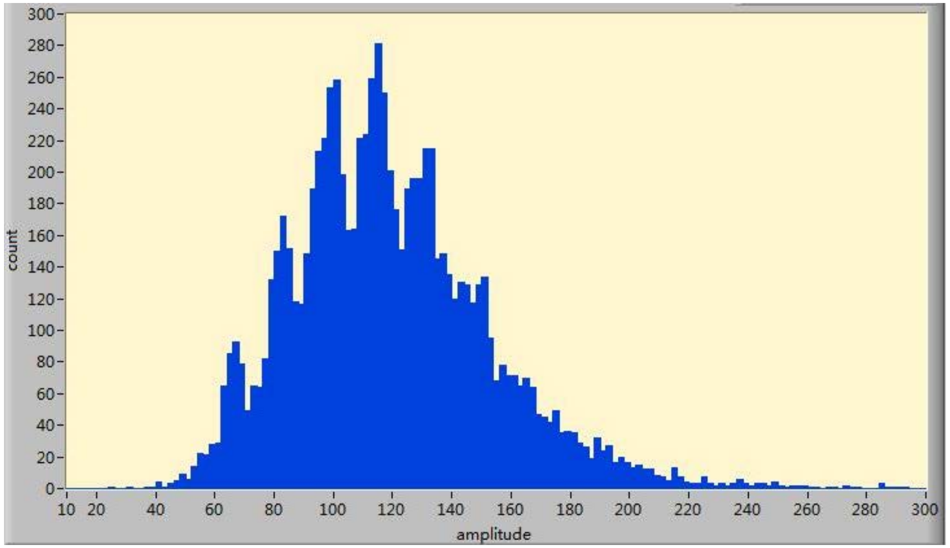

Pixel size: 25µm, Pixel number: 1600

The output linearity of the SiPM are improved with the increase the incident light width.

# Chinese NDL SiPM




Spectrum of dark noise




pulse height spectrum

- Besides Hamamatsu SiPM, we also test Chinese SiPM
- Developed Novel Device Laboratory(NDL) of Beijing Normal University (BNU) with epitaxial quenching resistors(EQR) technologies.
- NDL-EQR SiPM is easy to implement due to its unique structure, featuring intrinsic continuous and uniform cap resistor layer , thus reducing the cost of the fabrication.

# Parameters and performance of NDL SiPM

| | 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 |

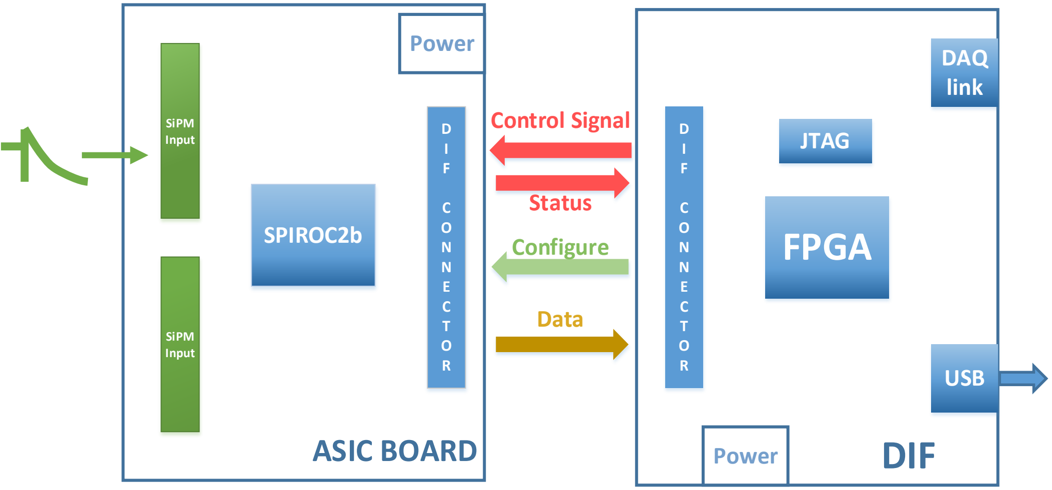
Has good performance, some parameters need improvement

Higher dynamic range
Higher fill-factor

**High Dark count rate**

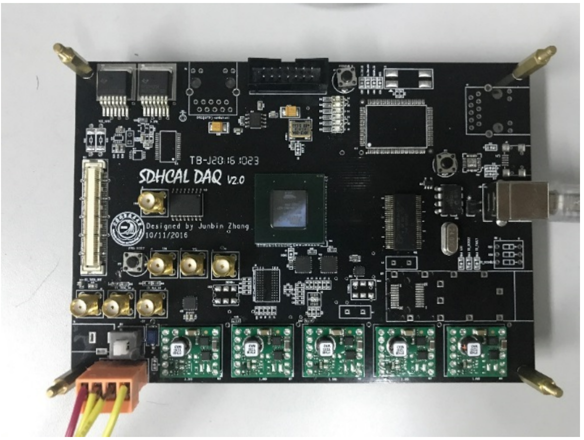
**A little low Gain**

# Electronics Development




System schematic

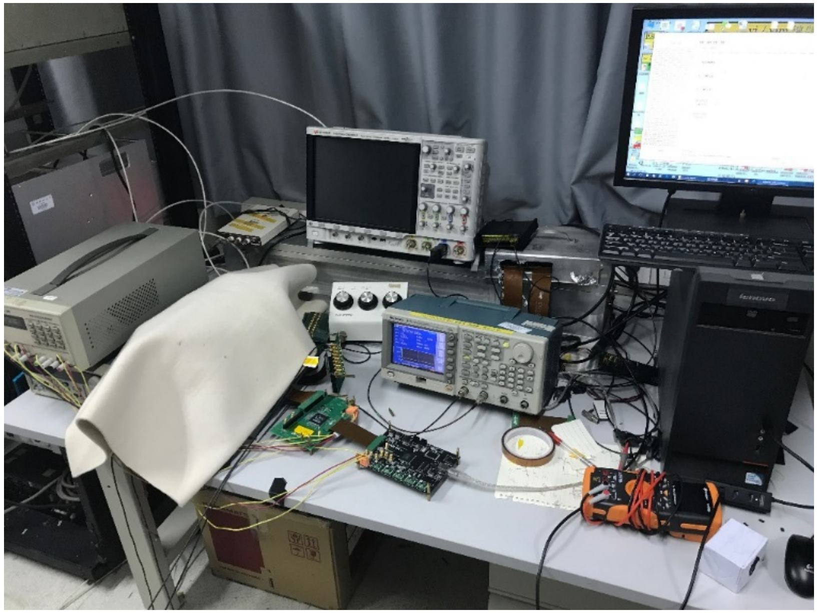
FEB



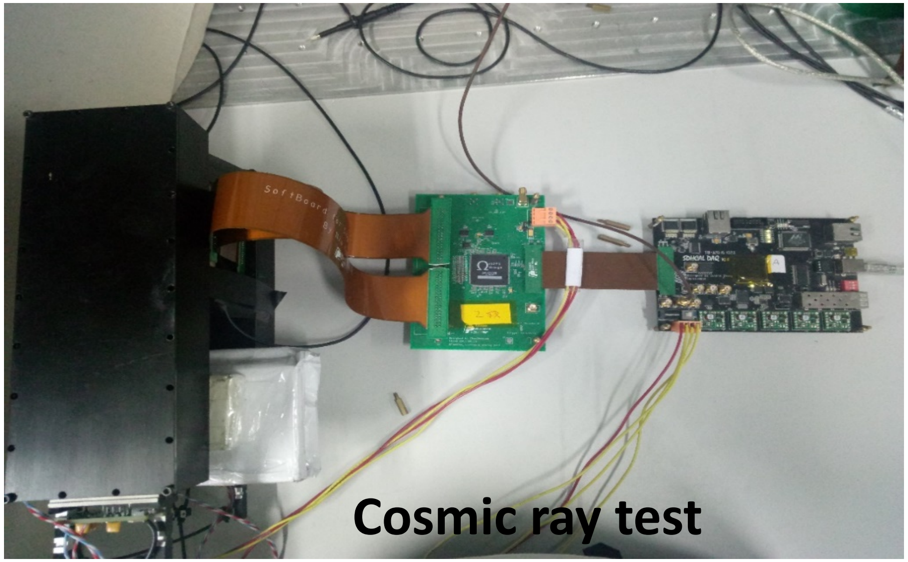
DIF

- Asic board is developed with **SPIROC2b** chip, which performs amplification, auto-triggering, digitization and zero-suppression
- DIF plays the role of collecting data and configuring chip before the system running
- USB for data upload & commands sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

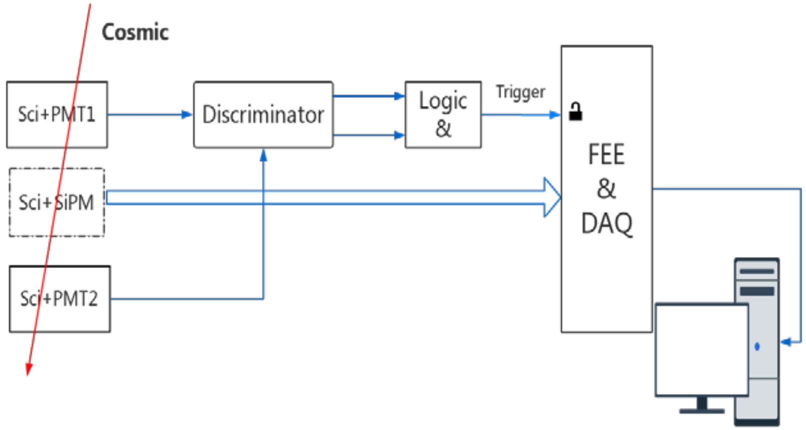
# Electronics test



**Test Platform**

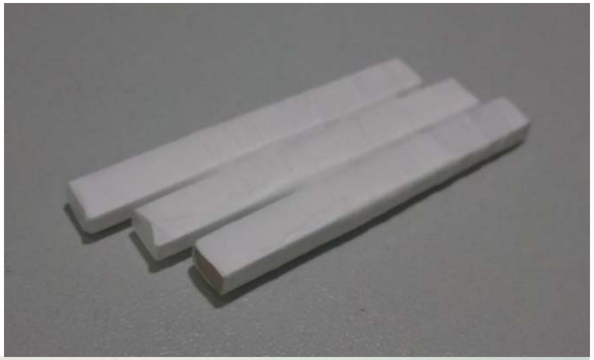


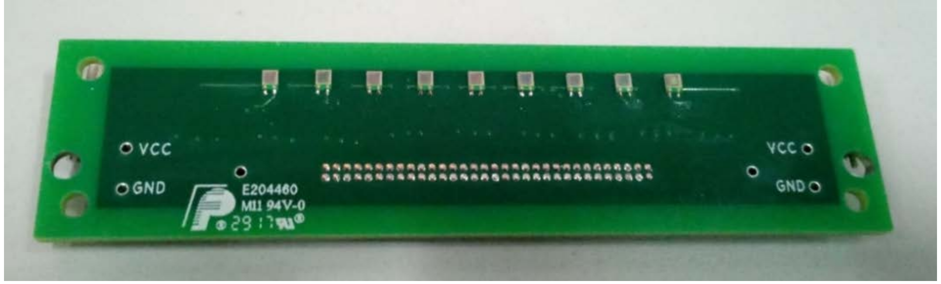

- Calibration
- Cosmic ray test with scintillator module



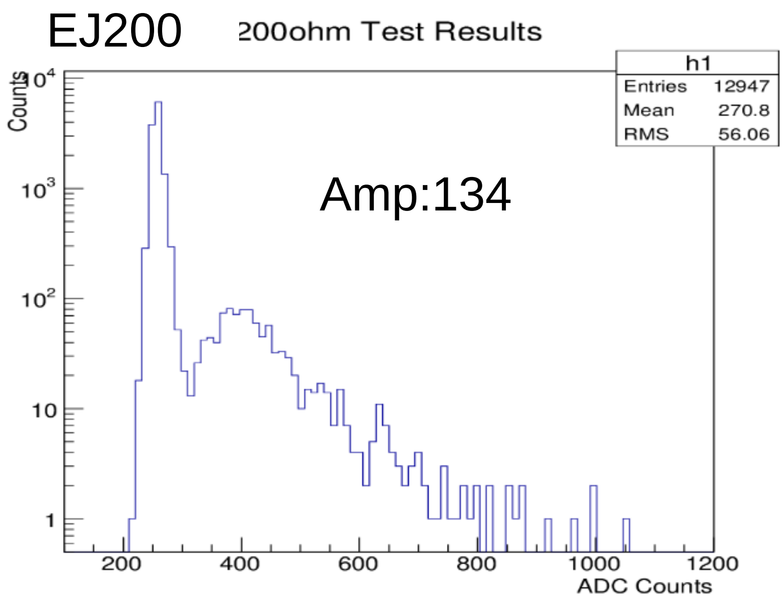
# Electronics cosmic ray test

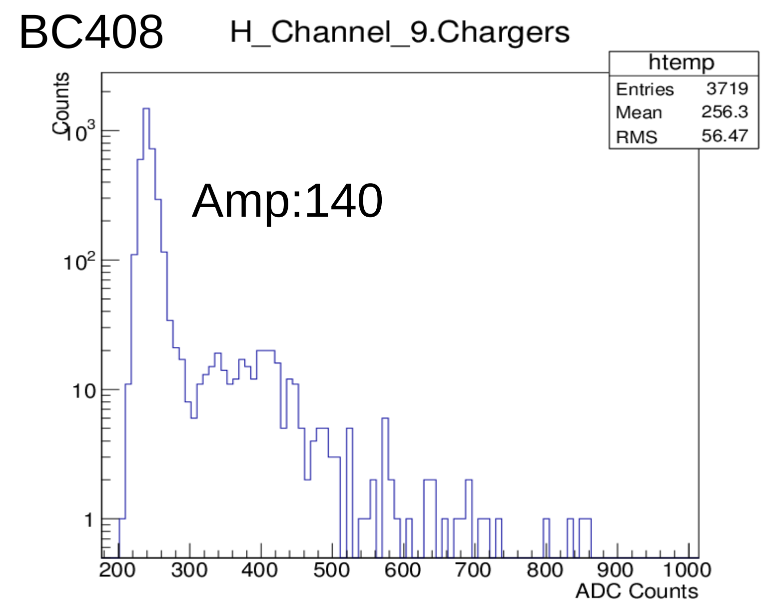
- Three different scintillator materials were tested by cosmic rays
  - Plastic scintillator
    - BC408
    - EJ200
  - Crystal
    - BGO crystal
- SiPM
  - S12571-010P
  - 1mm×1mm
  - 10k pixels

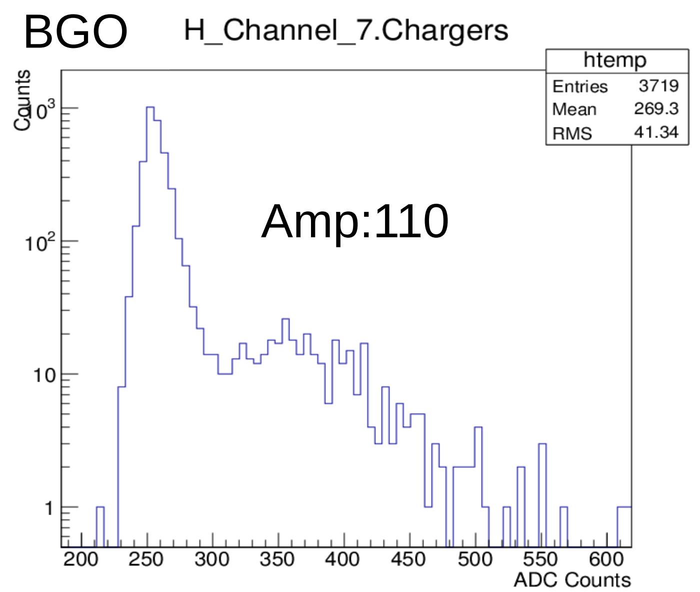





# Cosmic ray test results

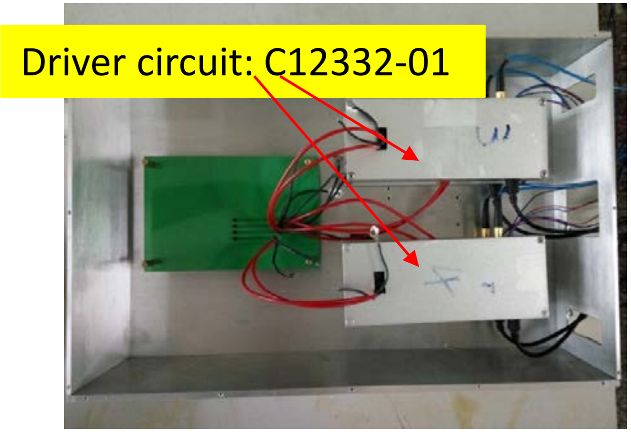


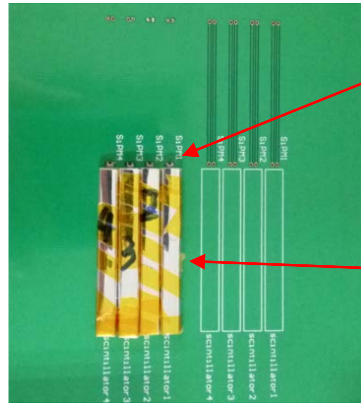



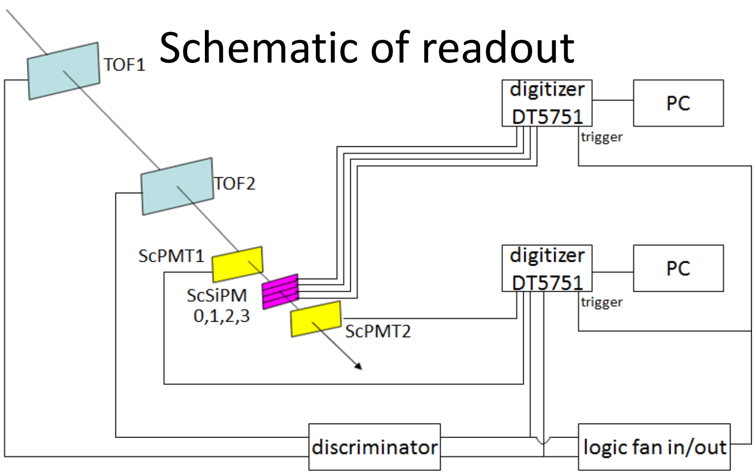




- The peak of the MIPs is clearly separated from the pedestal
- The electronics worked with good performance

# Beam test of a mini prototype

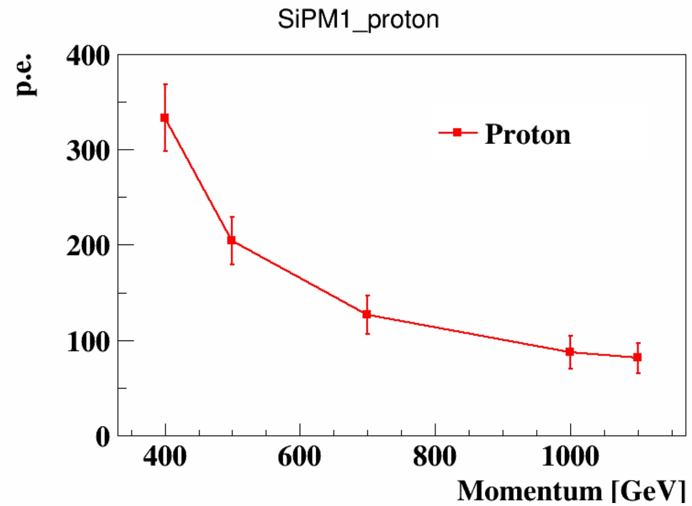


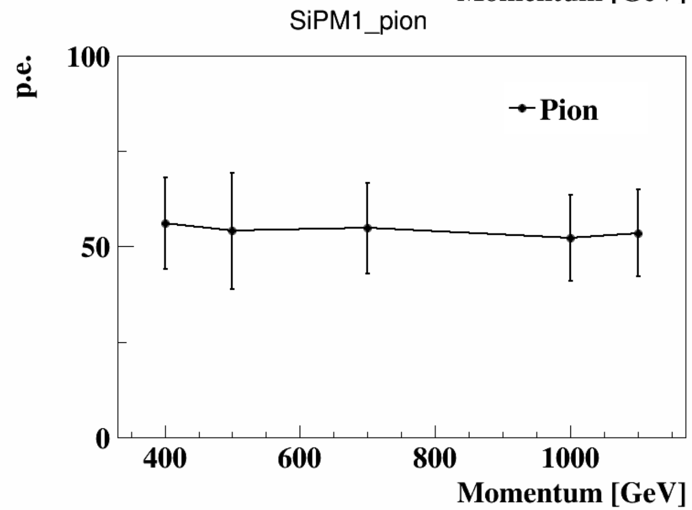



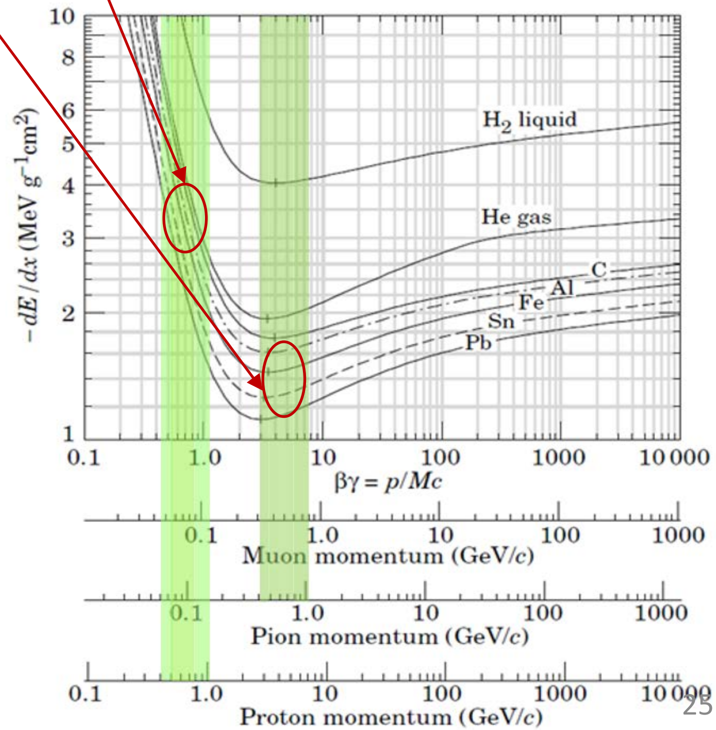

- To study the layout and the coupling mode of the scintillator and SiPM, a mini prototype was constructed and tested by test beam
- Performed at E3 beam at IHEP, Proton and pion mixed irradiation, the momentum of the particles are from 400MeV to 1.1GeV

# Energy deposition 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 |




- dE/dx (proton and pion) is consistent with the expectation

# Summary and Plan

- Optimization of ECAL: layers, Cell size, Scintillator thick etc.
- Scintillator strip test and uniformity optimization
- SiPM test and performance study
- Design and development of readout electronics

- Preparing for Scintillator tungsten ECAL prototype construction and beam test

*Thanks for your attention !*