R&D Status of the CEPC ScW ECAL

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On behalf of the CEPC calorimeter working group

Outline

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

Requirements of CEPC ECAL

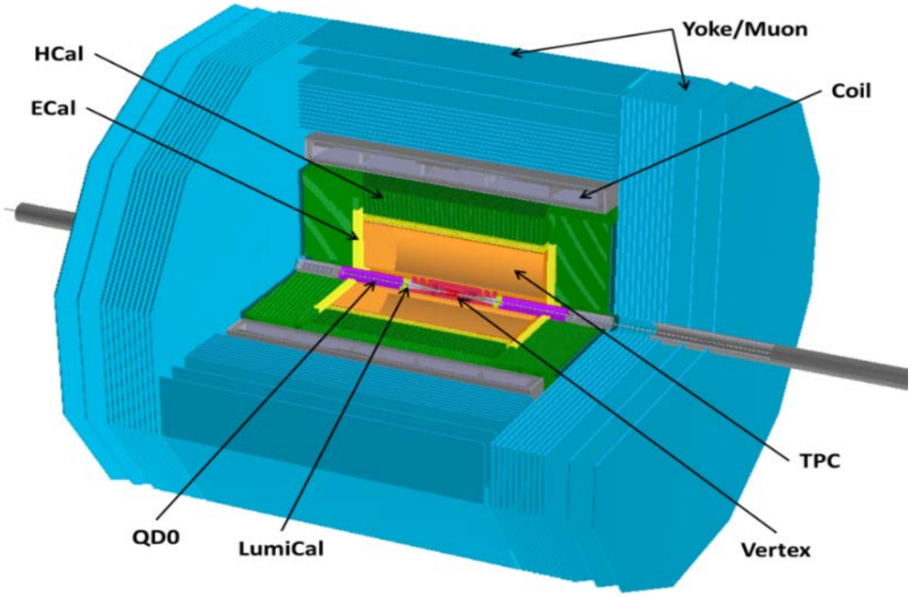
- Precise measurements of electrons and photons with energy resolution of :

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

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

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

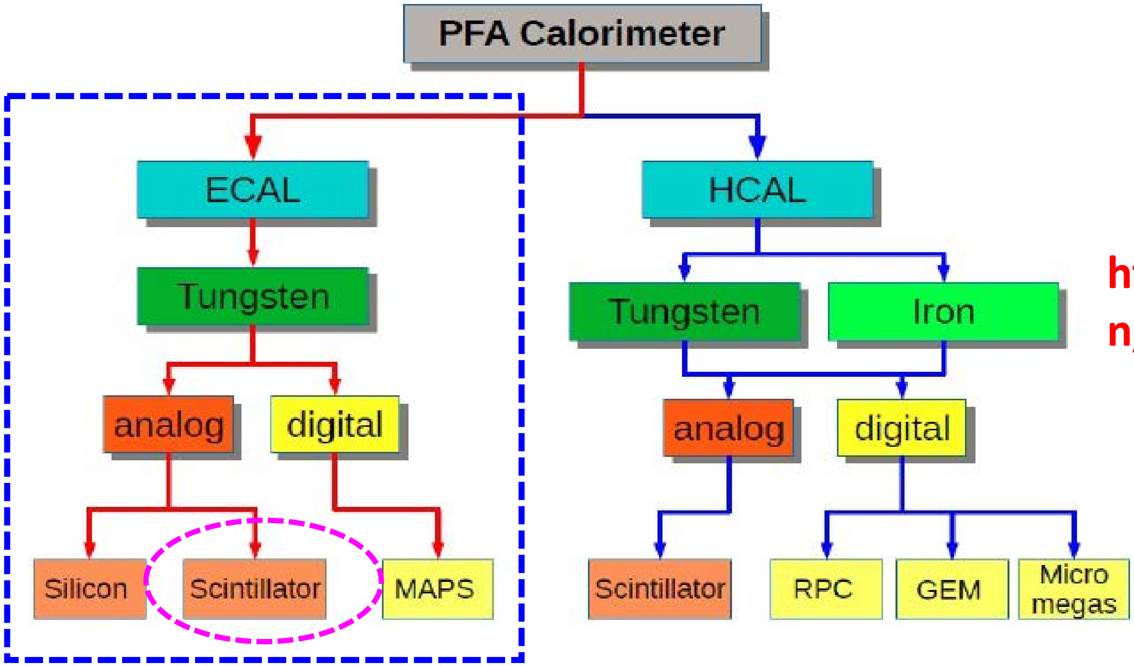
- Can give detailed information of showers: high granularity



Particle Flow Algorithm (PFA) calorimetry system is considered

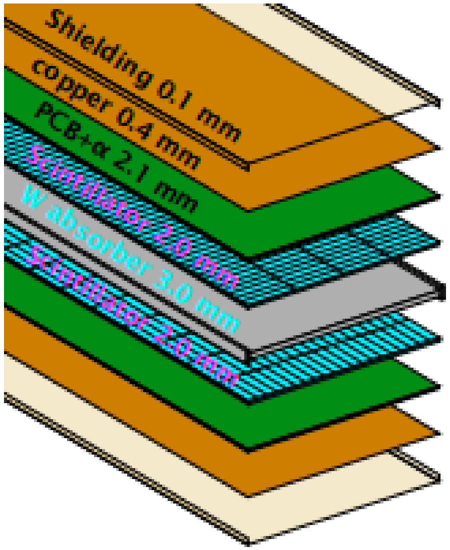
- High granularity
- Compact showers(small radiation length X_0, and small Moliere radius R_M)
- Minimum dead materials

Scintillator-tungsten ECAL



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

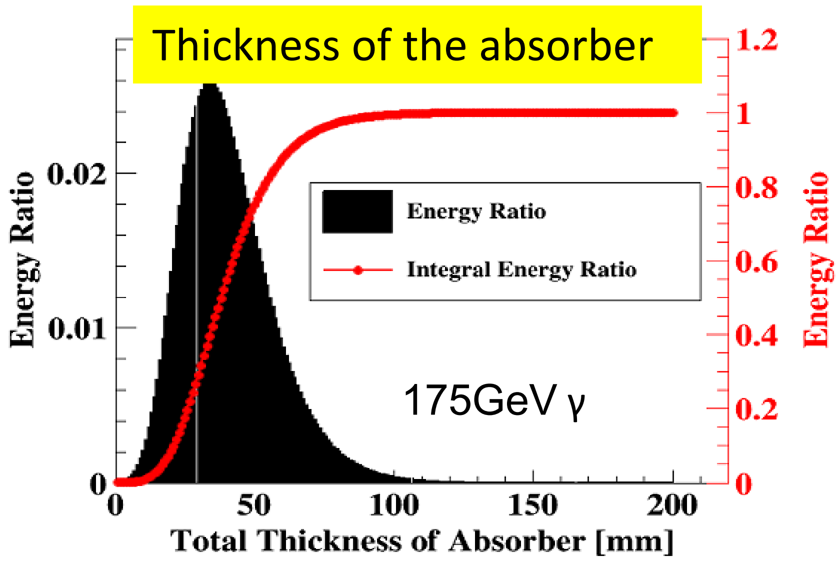
- A sampling calorimeter with scintillator-tungsten sandwich structure (ScW) is one of the ECAL options
- Sandwich structure
  - Absorber + scintillator module + readout electronics(PCB)
- Scintillator readout module
  - Scintillator + SiPM
- Absorber
  - Tungsten

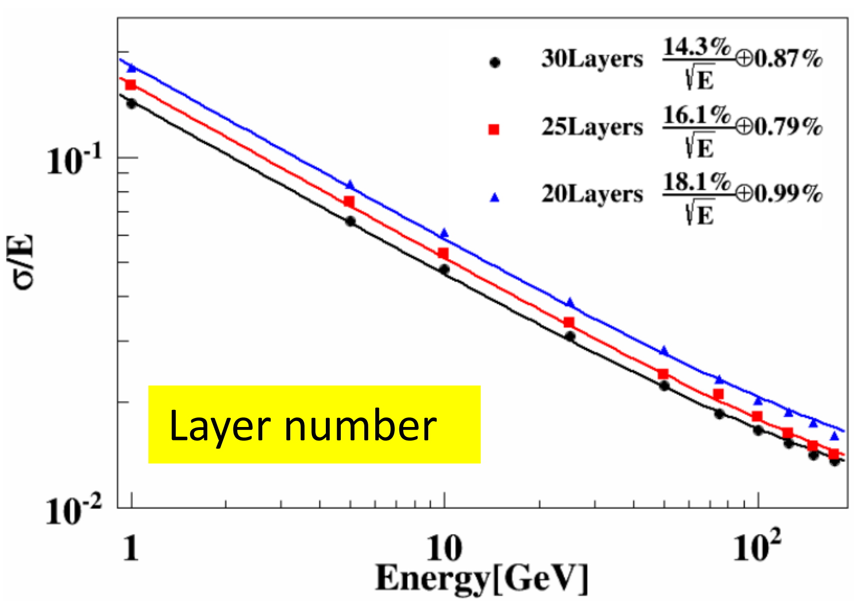


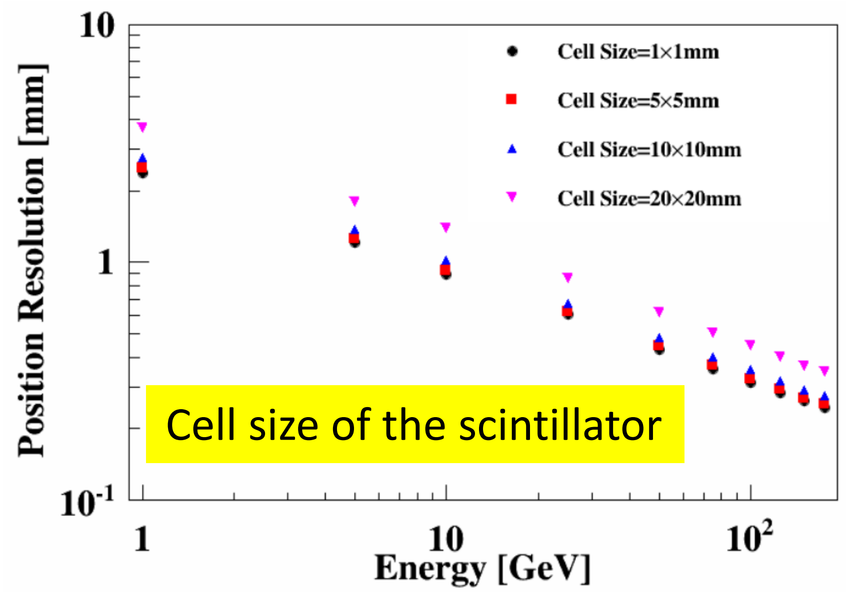
Optimization of ScW ECAL

- Simulation and optimization of the structure and geometry to determine the key parameters
  - Total Thickness of the absorber: 80~90mm
  - Layer number: 25
  - Granularity: 5mm × 5mm
  - Thickness of the scintillator: 2mm

More details in Dr. Hang Zhao's talk

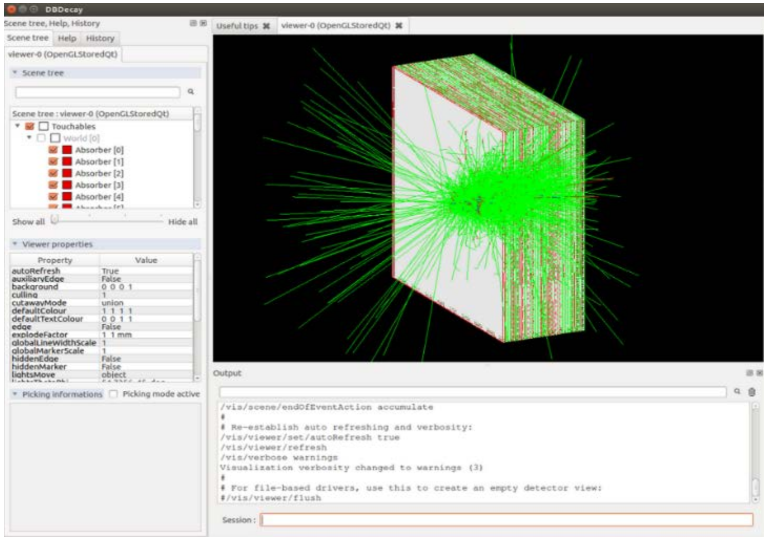


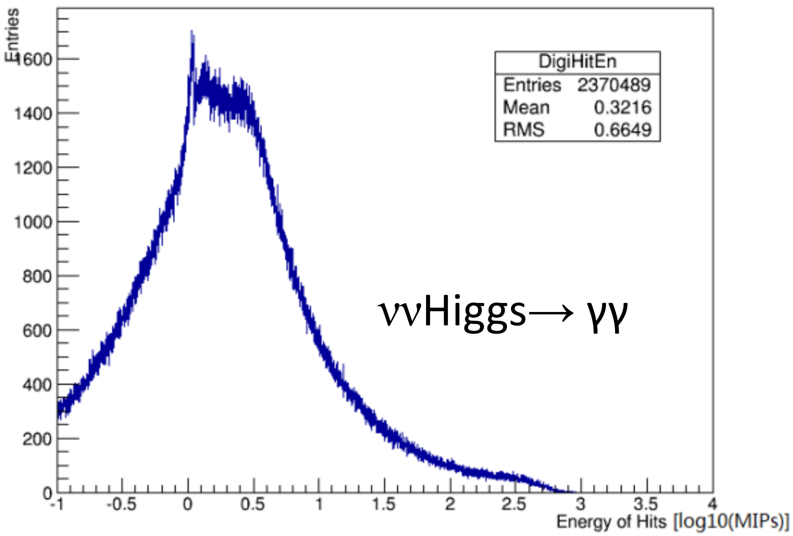


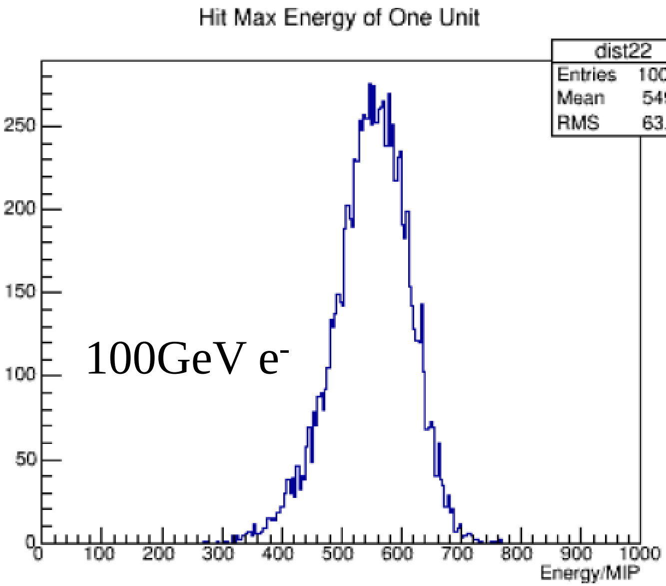


ECAL Optimization II

- Dynamic range of ECAL scintillator module
  - 1MIP – ~800 MIPs
- ~15 p.e. @ 1 MIP
  - SiPM >10k pixels







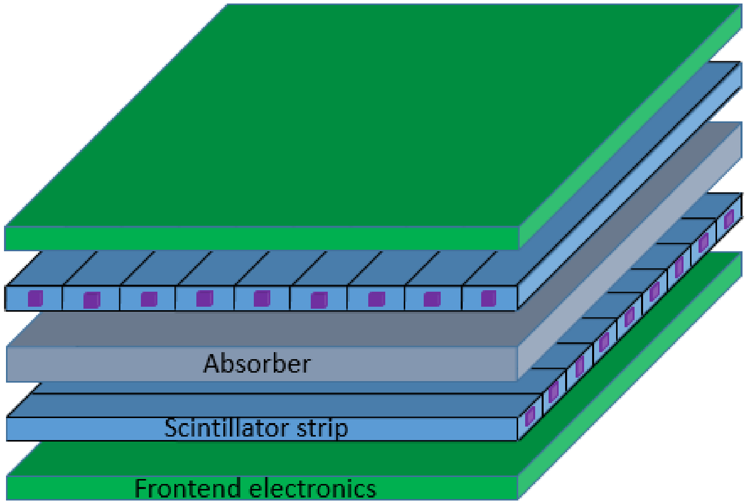
Key parameters of scintillator module

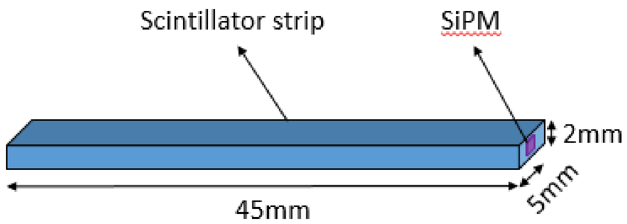
The scintillator module : Scintillator + SiPM

Basic structural and functional block of the active layers of the ScW ECAL

- Granularity → Number of the readout channels → Cost
- Light output → Scintillator, Reflector, PDE of SiPM
- Homogeneity → Scintillator, SiPM coupling mode, Reflector
- Dynamic range → light output, Number of pixels of SiPM
- Dead material /area →Thickness of the reflector, SiPM coupling mode

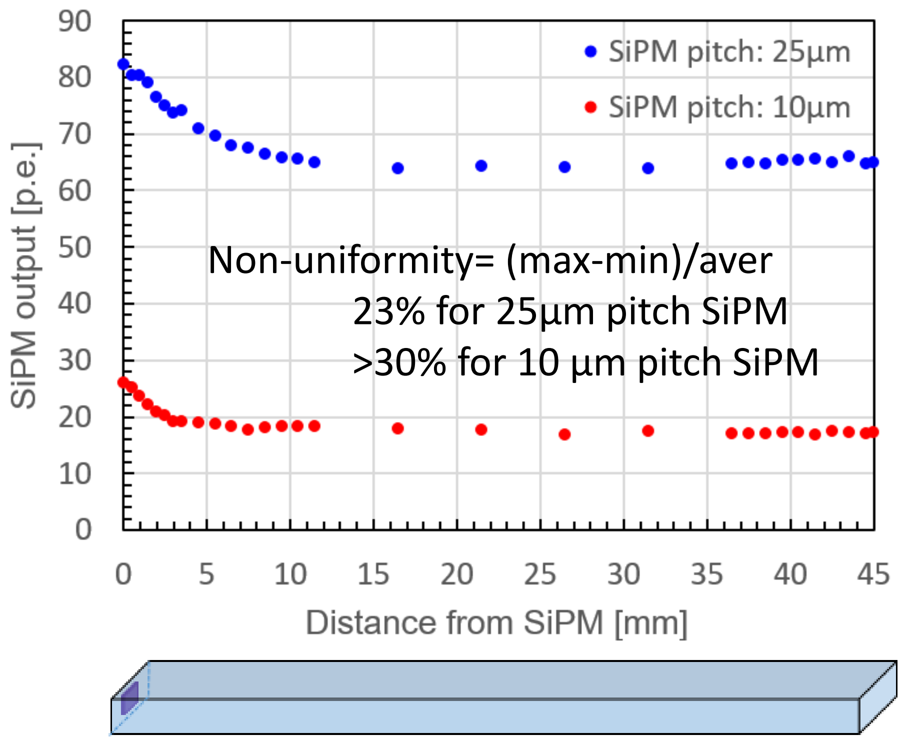
Design of scintillator module





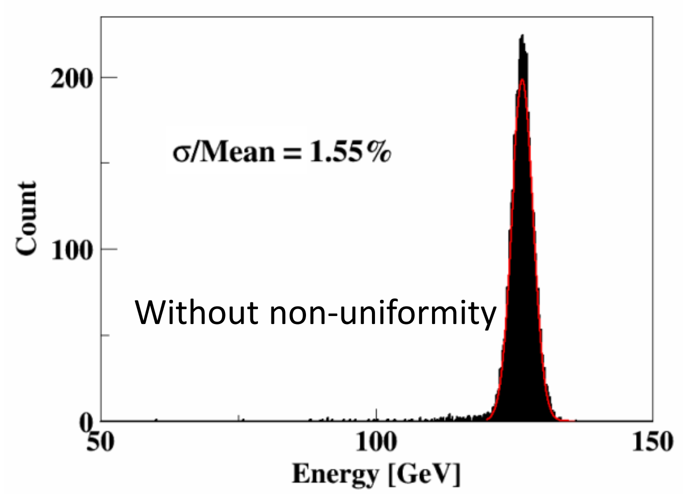
- Scintillator strip module is designed as strip wrapped with enhanced specular reflector (ESR)
- Scintillator dimension : 5mm × 45mm × 2mm
- Cross arrangement of neighboring layers → a transverse readout cell size of 5 × 5 mm^2
- Reduction of the readout channels → low cost
- SiPM coupled at the side or the bottom of the scintillator strip → few or negligible dead area

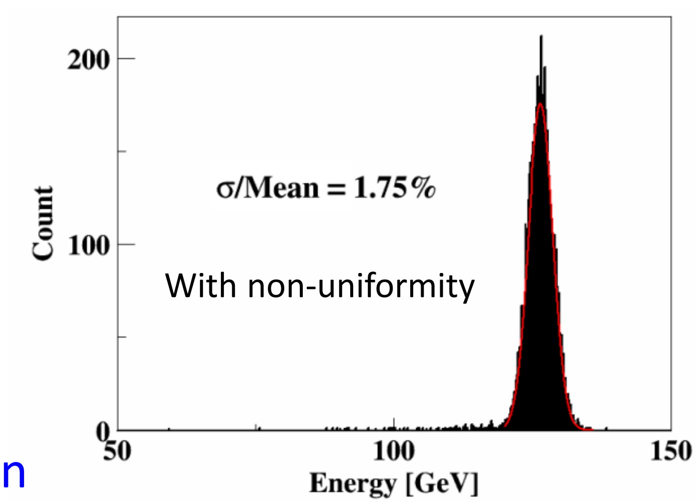
Light output and uniformity test



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

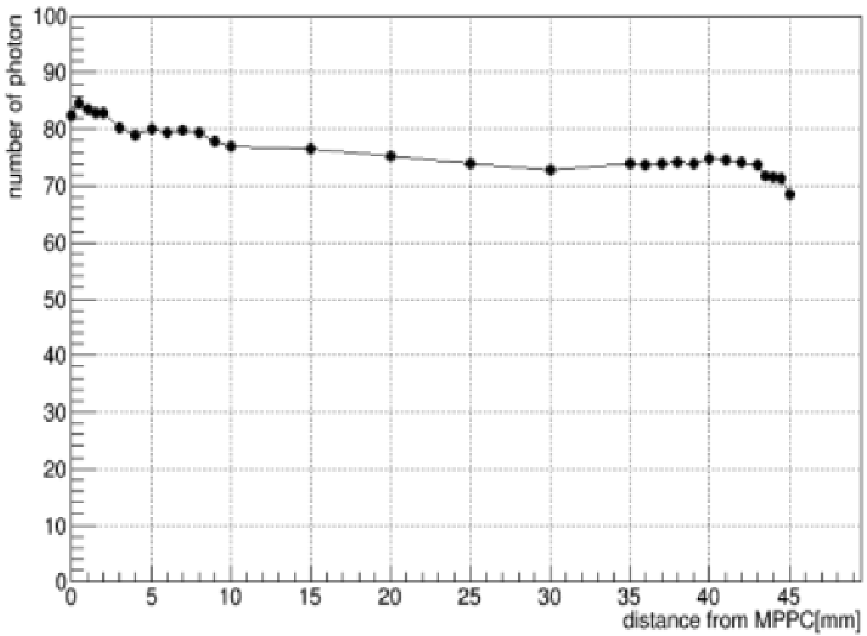
- Light output is non-uniformity along the length of the scintillator, degrades the energy resolution
- Need to be optimized



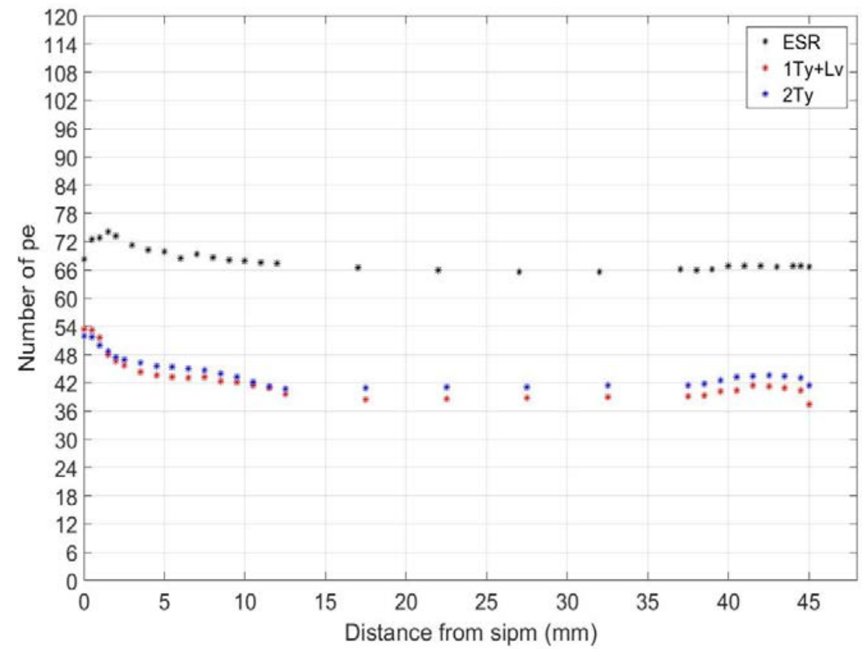


Energy reconstruction of $\nu\nu$Higgs$\rightarrow\gamma\gamma$

Module optimization (reflective layer)



Strip with rough reflective surfaces

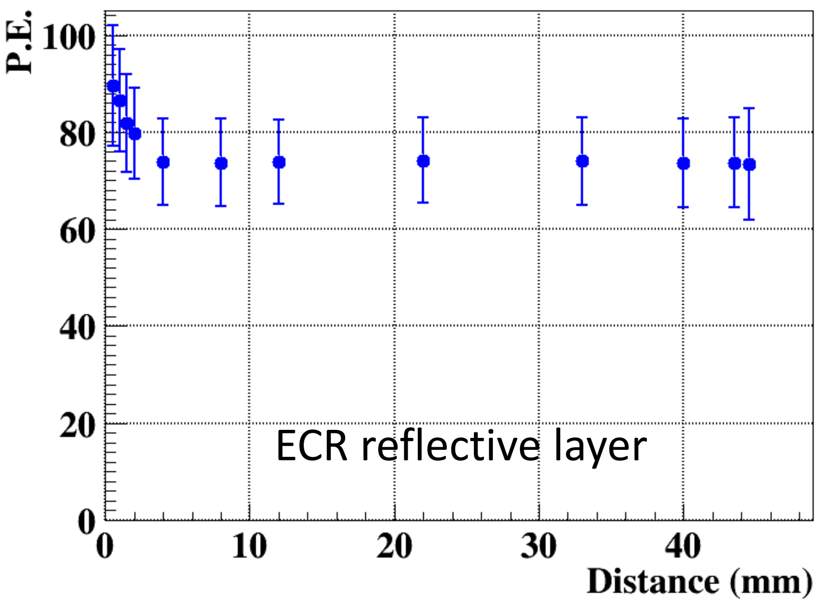


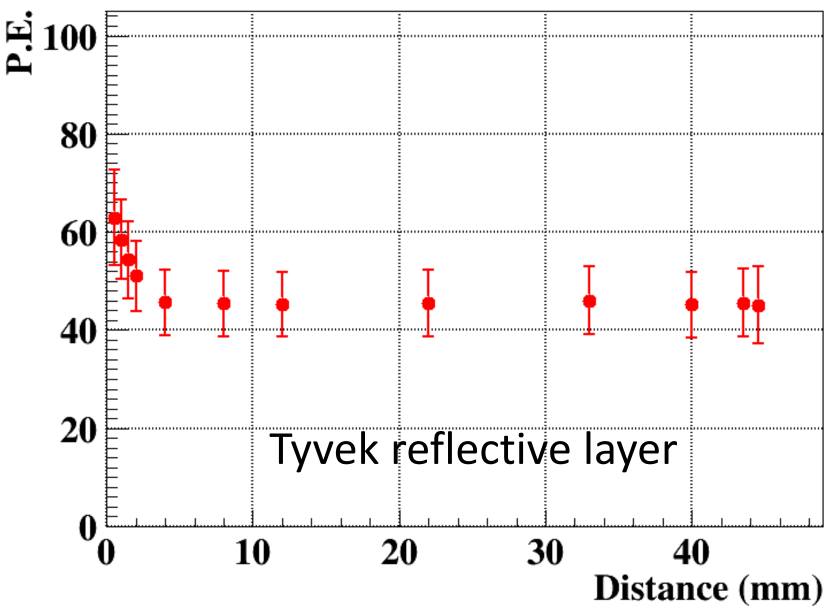
Strip wrapped with different reflective layer

- Rough reflective surfaces vs. polished surfaces
- Diffuse reflective layer vs. ESR
- Slightly improve the uniformity, but not good enough.

Scintillator module output simulation

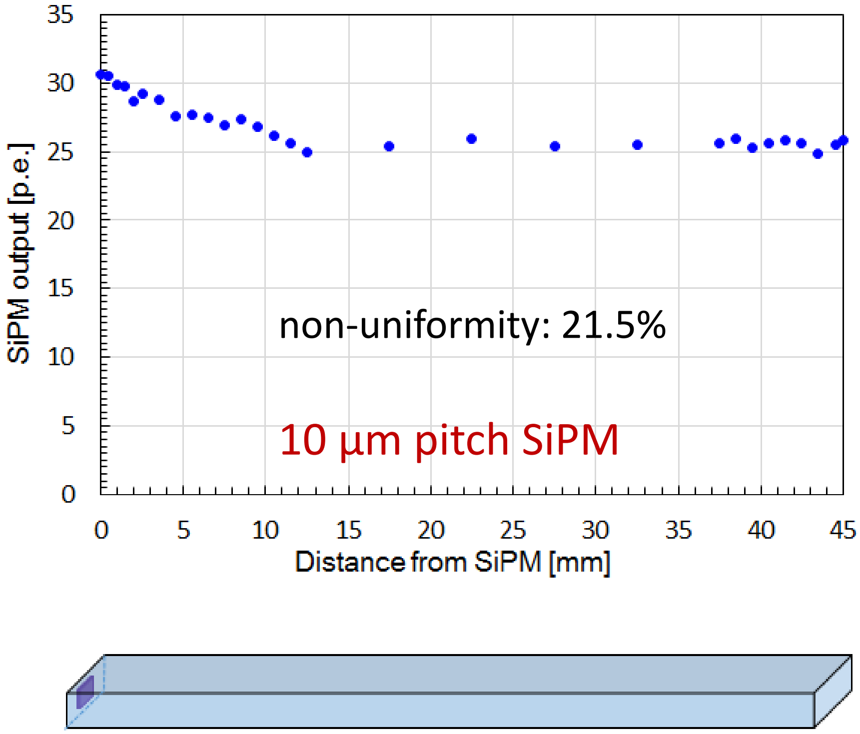
- Simulation is performed to optimize the scintillator module
  - PhysicsList: QGSP_INCLXX + Standard Geant4 Optical Physics (Geant4 Version: Geant4.10.3)
  - Scintillator Strip: BC408, dimension: 45×5×2mm^3
  - SiPM: 1×1×0.1mm3 , Pitch size 25μm, 1600pixel
  - Cladding: ESR, Tyvek
  - Particle source: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

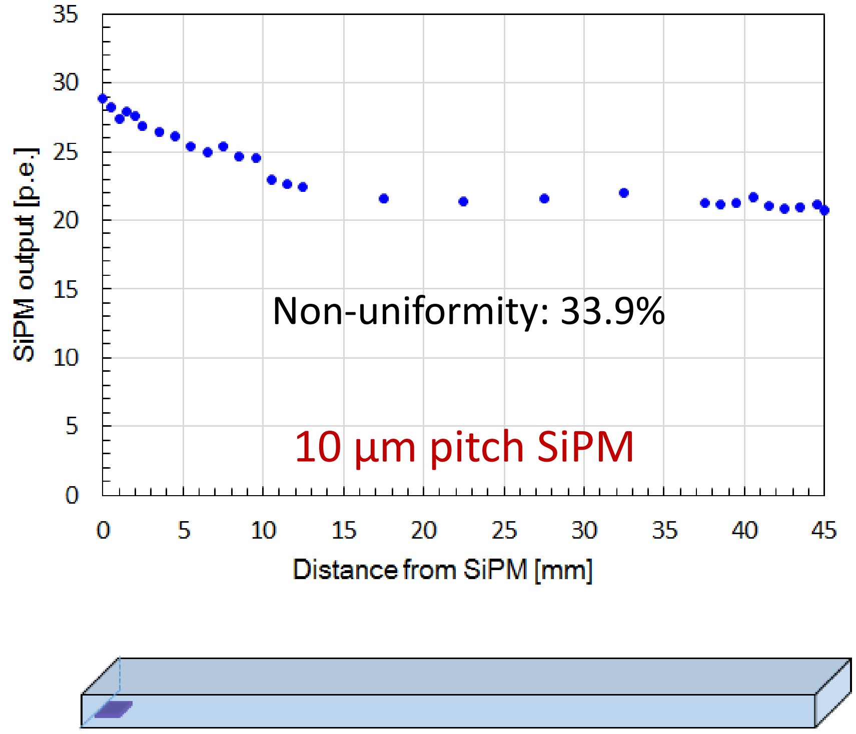




Stand alone Geant4 simulation. Parameters are still under optimization

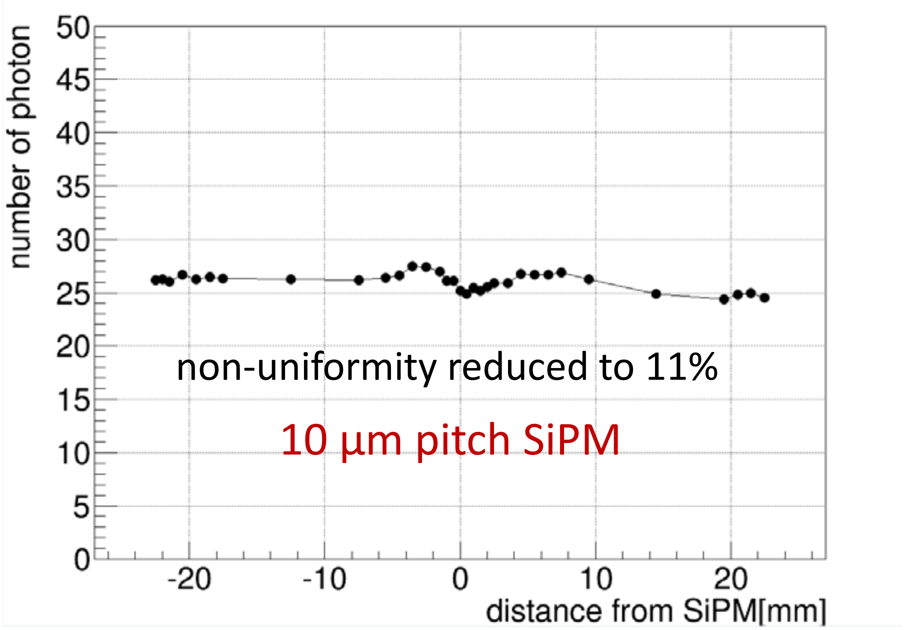
Module optimization (SiPM coupling mode)

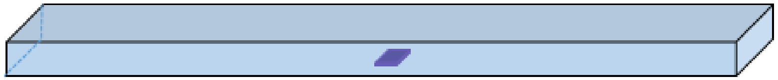




- SiPM (Hamamatsu S12571-010P)embedded at side-end of the strip or the bottom-end of the strip
- Uniformity of light output is not improved

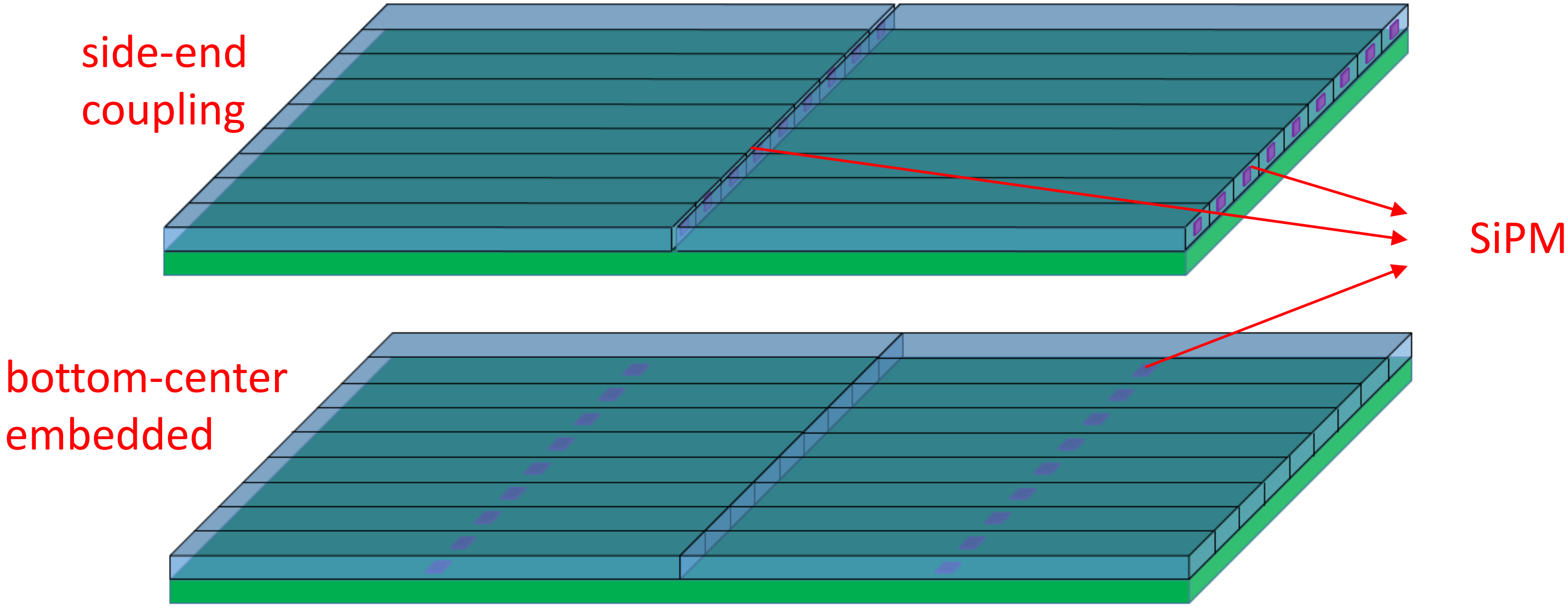
Module optimization (SiPM coupling mode)





- SiPM embedded at bottom-center of the strip
- Uniformity of light output is improved significantly

SiPM bottom-center embedded coupling



SiPM bottom-center embedded coupling mode will be adopted in the construction of the ScW ECAL prototype

- Improve the uniformity → The non-uniformity can reach about 10%
- No gap between the scintillators → Avoid the dead area
- Easy to operation in the prototype construction
- Can use SiPM with larger dimension and more pixels to extend the dynamic range of the SiPM

SiPM dynamic range

- The SiPM is not a linear photon detection device. The effective response pixels can be described by following formula:

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

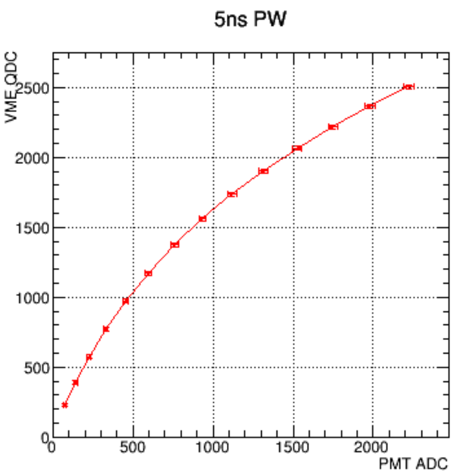
N_{fire}: number of fired pixels, N_{eff}: number of effective pixels,

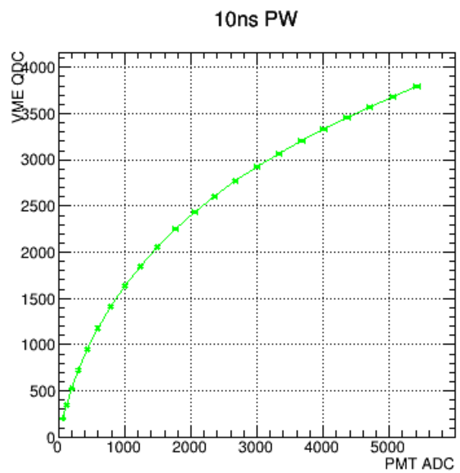
ε : PDE, N_{in} : number of incident photons.

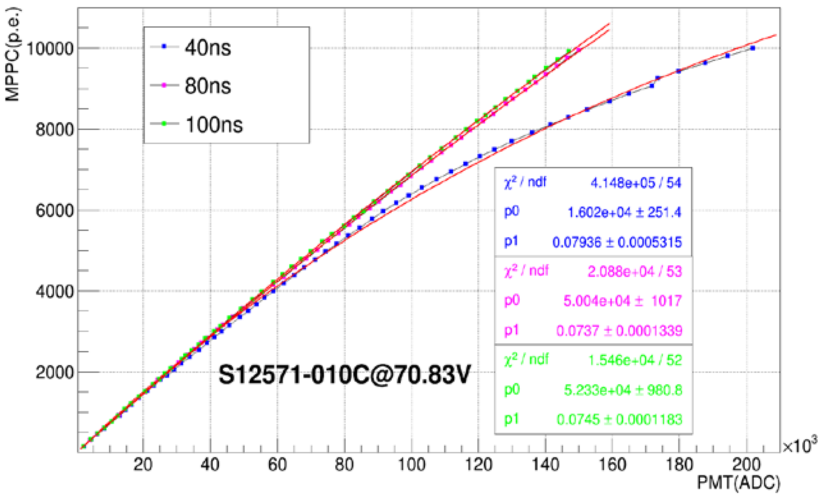
$N_{eff} > N_{real}$, thus extends the dynamic range of the SiPM

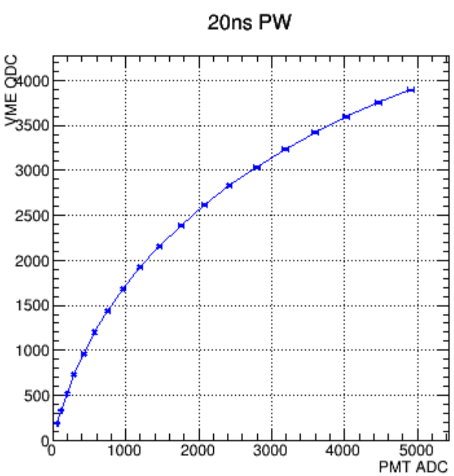
- SiPMs used in the preliminary test
  - Hamamatsu S12571-025P/025P
  - Hamamatsu S12571-025P/010P
  - 1mm×1mm sensitive area, 25μm/10μm pitch, 1600 /10k pixels
- SiPM with more pixels is needed, → larger sensitive area. **SiPM bottom-center embedded coupling mode make it possible**

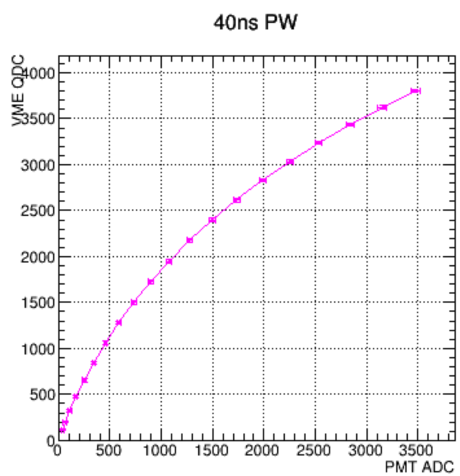
SiPM linearity vs pulse width

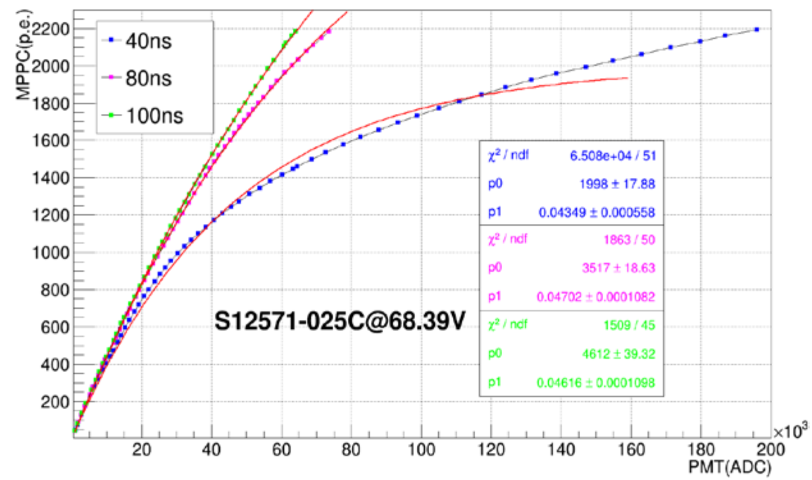






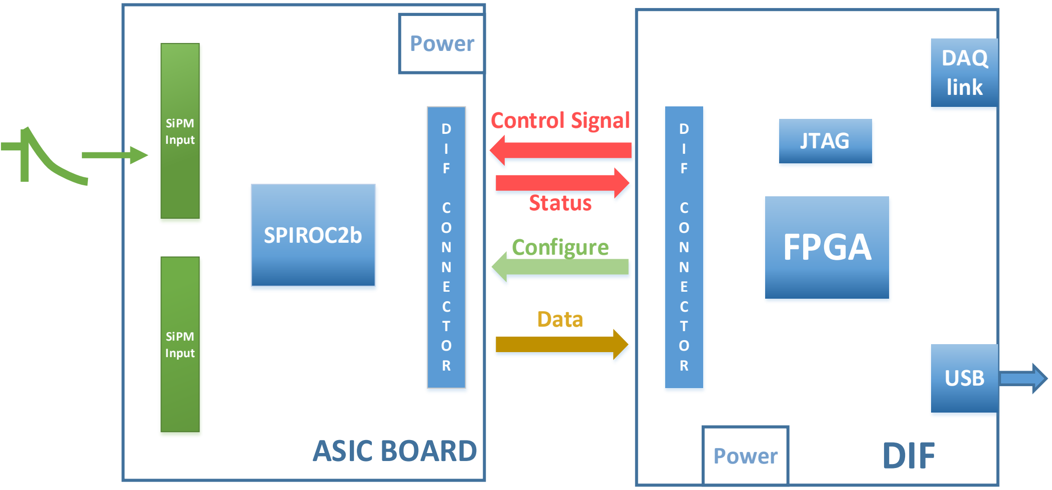






- The width of LED light are: 5ns - 400ns
- The SiPM output linearity is improved with the incident light width

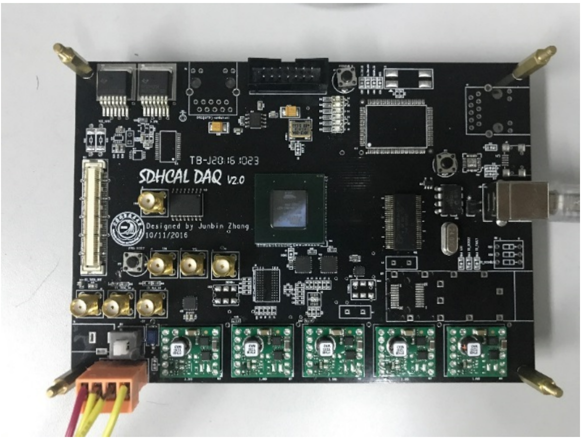
Electronics Development



System schematic

- Asic board is developed with **SPIROC2b** chip, which performs amplification, auto-triggering, digitization and zero-suppression
- DIF initializes chips and collects data
- USB for data upload & commands sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

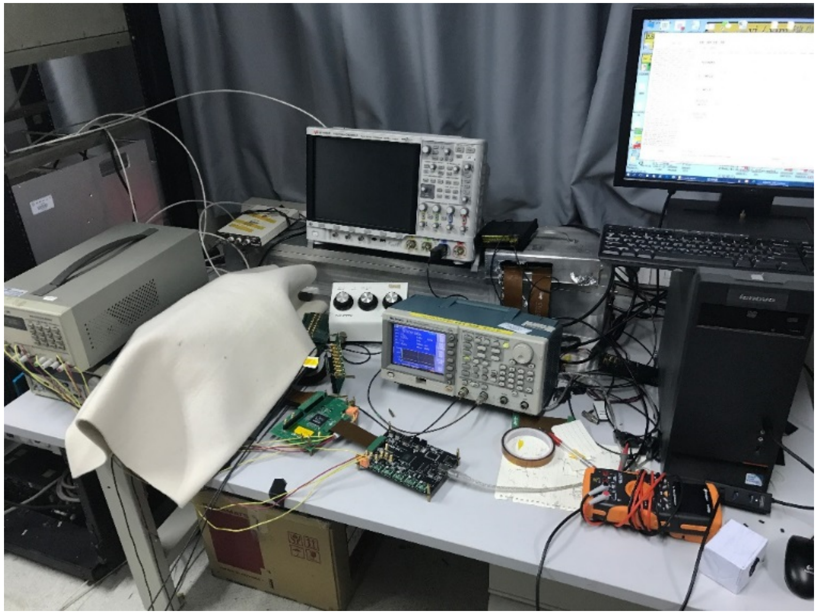
FEB



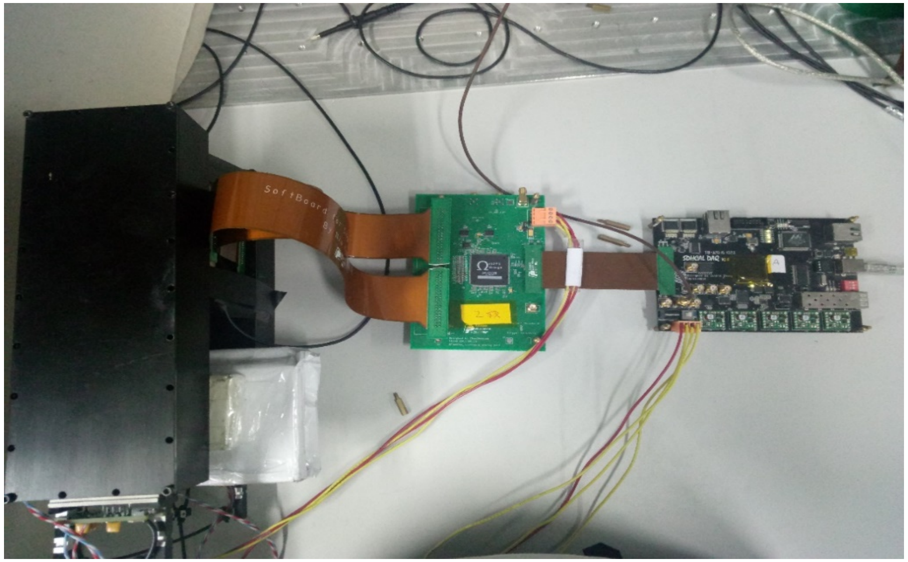
DIF

- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable Cf of pre-amplifer
  - Rload on the board
  - Shaping time and delay

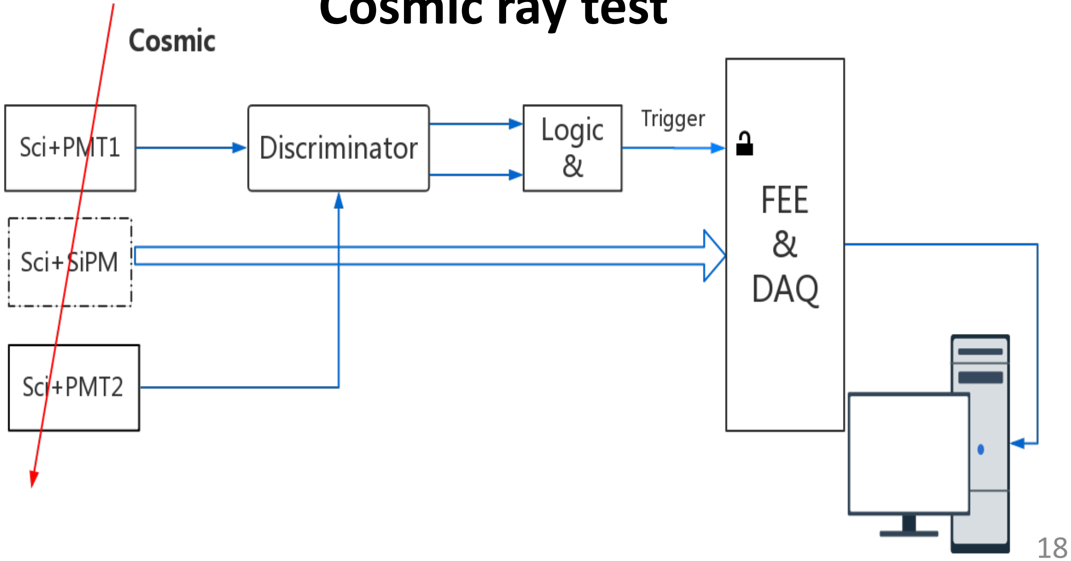
Electronics test



Test Platform



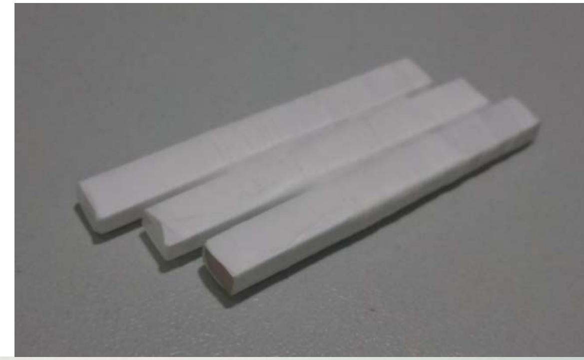
Cosmic ray test

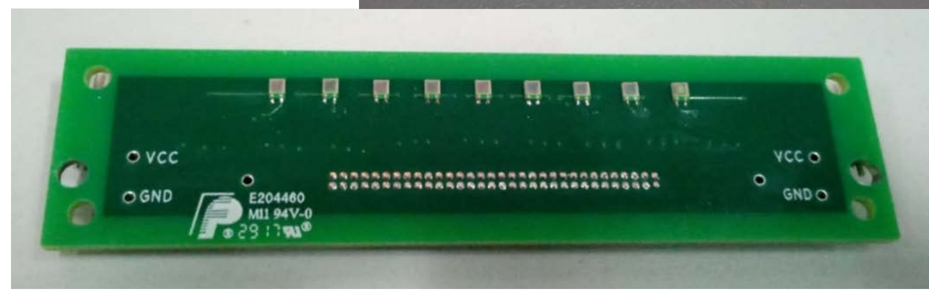


- Calibration
- Cosmic-ray test with scintillator modules

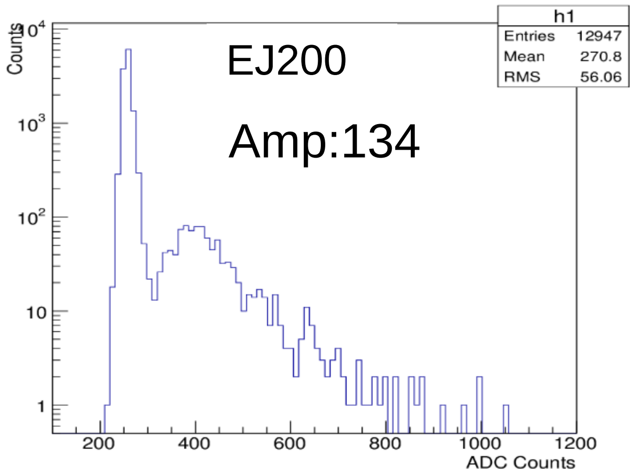
Electronics cosmic-ray test

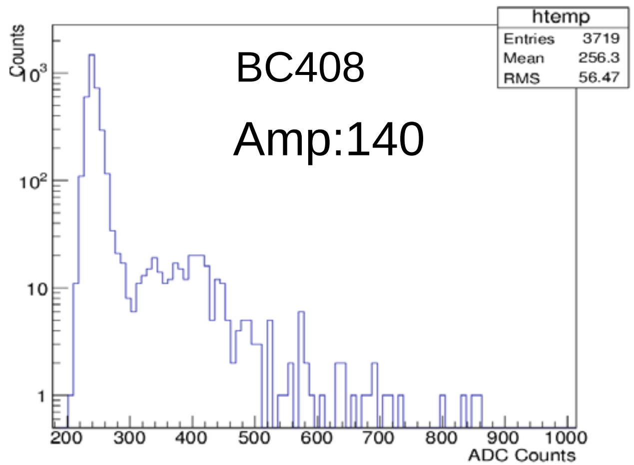
- Different scintillator materials were tested by cosmic rays
  - Plastic scintillator
    - BC408
    - EJ200
  - Crystal
    - BGO crystal
- SiPM
  - S12571-010P
  - 1mm×1mm
  - 10k pixels

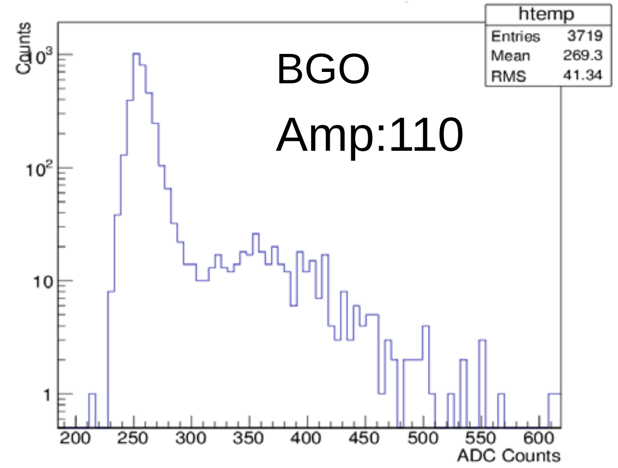




Cosmic ray test results

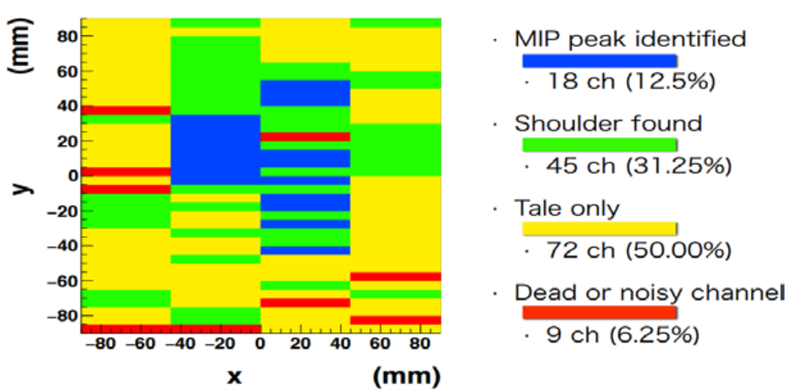




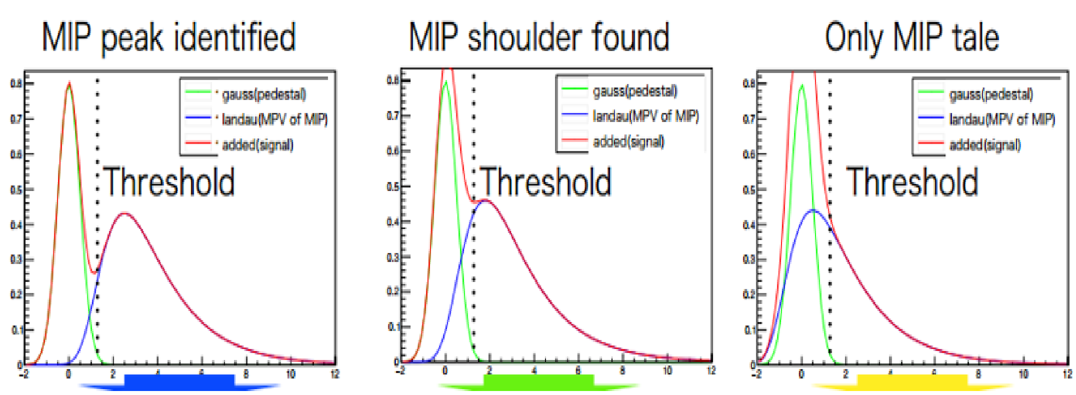


- The peak of the MIPs is clearly separated from the pedestal
- The electronics worked with good performance

Compared with CALICE-EBU ECAL

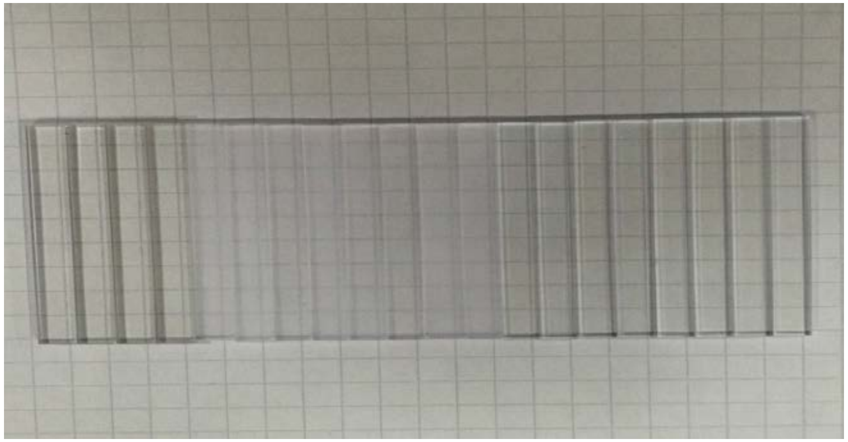


Peak identified channels are only 12.5%.
MIP peak identification with 10k pixel MPPC is not easy.

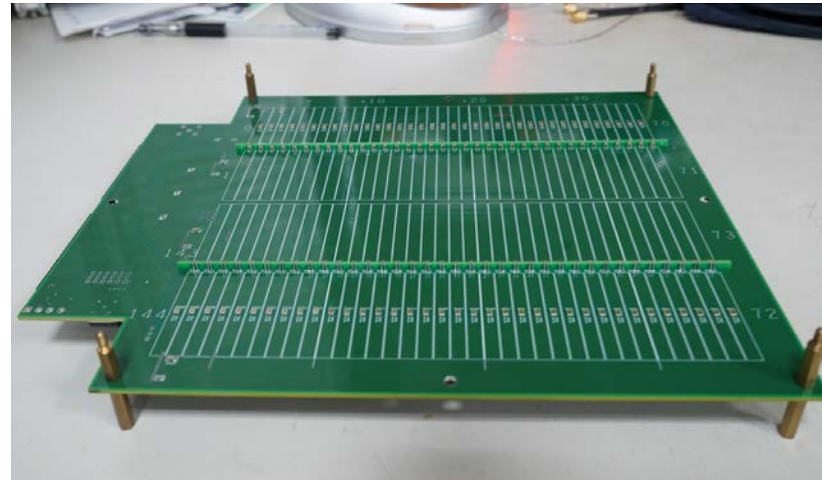


CALICE-EBU ECAL Results

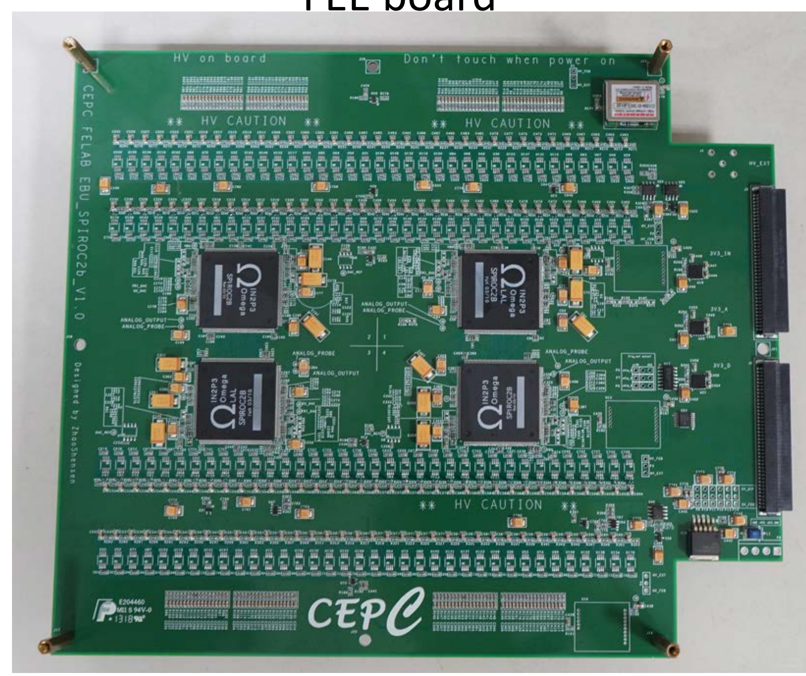
Preparation for single layer prototype



Scintillator strips are incised and wrapped in the SIC (Shanghai Institute of Ceramics)



FEE board



- Single layer prototype for the study of module layout, integration, preliminary performance
- Includes 144 scintillator modules (5mm╳45mm╳2mm) with S12571-010P SiPMs
- Half are side-end coupling mode, another half are bottom-center embedded coupling mode

Summary and Plan

- Optimization of ECAL: thickness of the absorber, layers, cell size, scintillator thickness etc.
- Scintillator strip module test and optimization
- Design and development of readout electronics

- Preparing the first layer of the Scintillator tungsten ECAL prototype

Thanks for your attention !