2018年 第十届高能物理学术年会

Status of CEPC ECAL R&D

Yazhou Niu

On behalf of CEPC calorimeter working group

State Key Laboratory of Particle Detection and Electronics, China

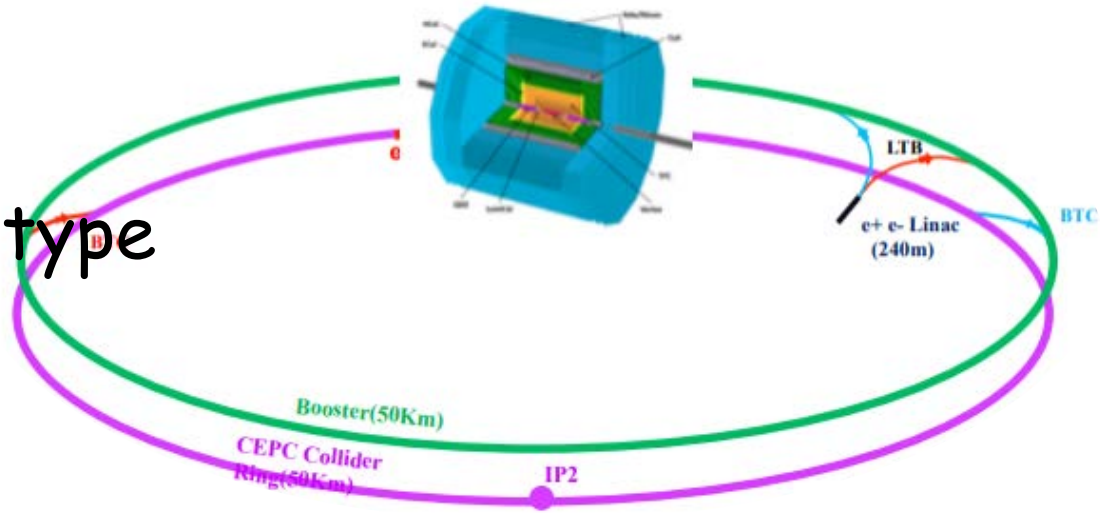
University of Science and Technology of China

CEPC-MOST Project

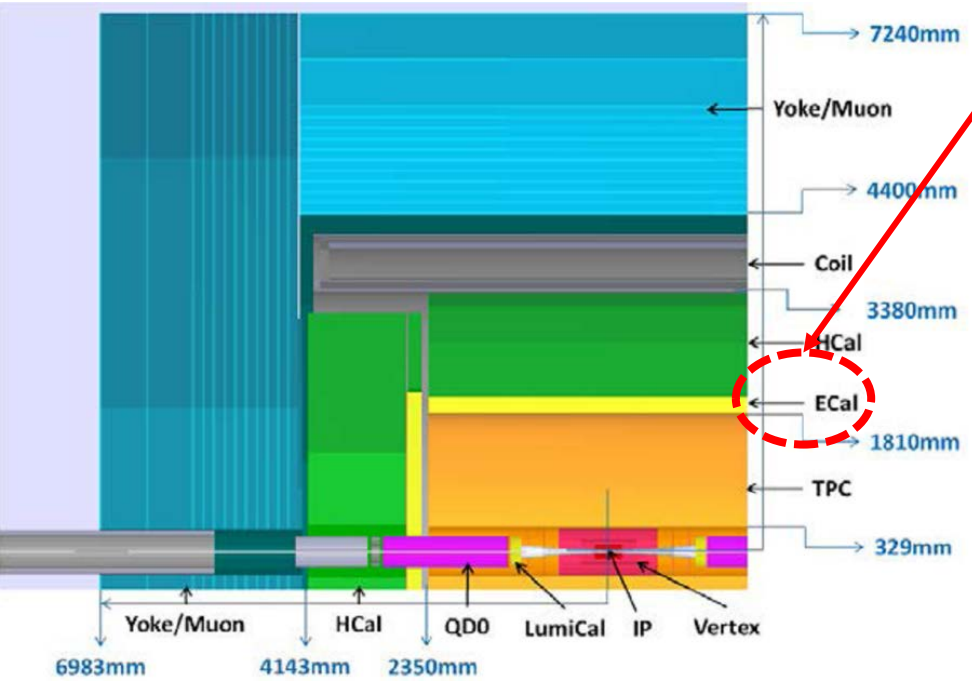
- It is a CEPC R&D project funded by Ministry of Science and Technology of China in 2016-2021 (No.2016YFA0400404)
- The proposed tasks and goals for CEPC ECAL R&D
  - Choose appropriate technology option for CEPC ECAL
  - Build a small ECAL physics prototype with cell size of $5mm \times 5mm$
  - Design an active cooling system prototype using CO_2, towards active cooling design for ECAL operating with continuous mode

Outline

- Motivation : PFA and Imaging Calorimetry
- ECAL Unit Study and Optimization
  - Simulation and Optimization
  - Photon sensor
  - Scintillator strip
  - Readout Electronics
- Single Layer Prototype
- Summary



Motivation



Requirements of CEPC ECAL:

- Energy resolution of γ

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

- Jet energy resolution (combined tracker, ECAL and HCAL)

  $\sigma_E/E \approx (3\%\sim4\%)$

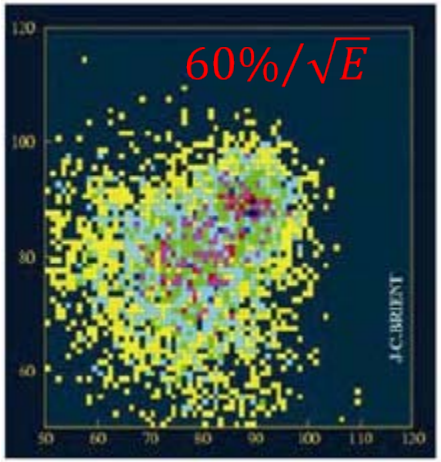
The Particle Flow Algorithm (PFA) calorimetry concept was proposed:

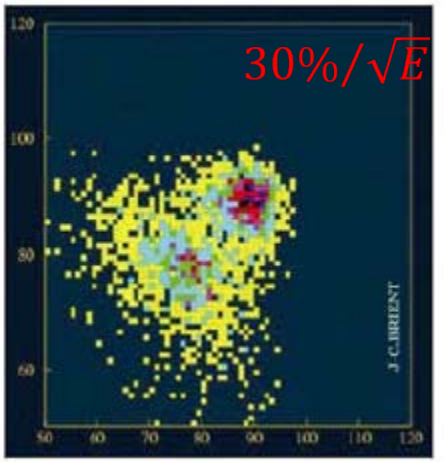
Reconstruct each individual final state particle in the most suitable sub-detector

Motivation

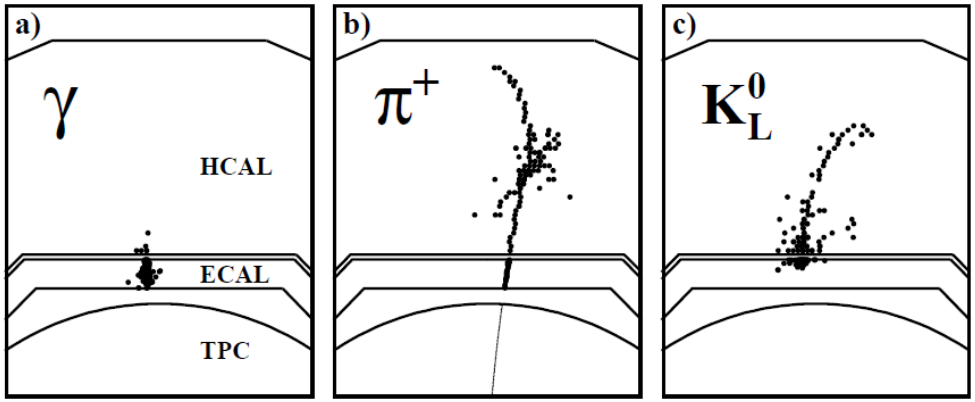
PFA and Imaging Calorimetry

- Simulation of WW and ZZ separation for the events in 4jets





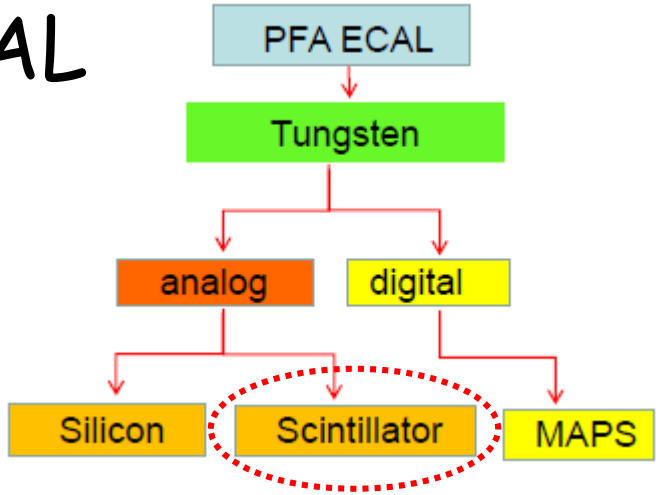
$$\sigma_{jet}^2 = \sigma_{h^\pm}^2 + \sigma_\gamma^2 + \sigma_{h^0}^2 + \sigma_{confusion}^2 + \sigma_{threshold}^2 + \sigma_{losses}^2$$

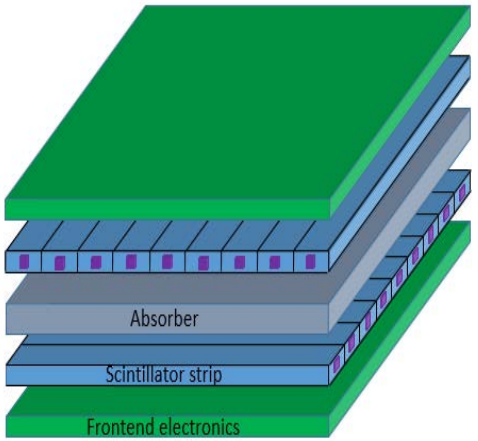


- High granularity
- Good shower separation
- Good energy resolution

ECAL Options

- ✓ Scintillator-tungsten ECAL
  - Larger detector PFA
    - Sandwich structure
    - Absorber + SD + Electronics
  - Smaller Moliere radius
    - Tungsten
  - Larger dynamic ranger
    - Scintillator + SiPM
    - SPIROC Chip





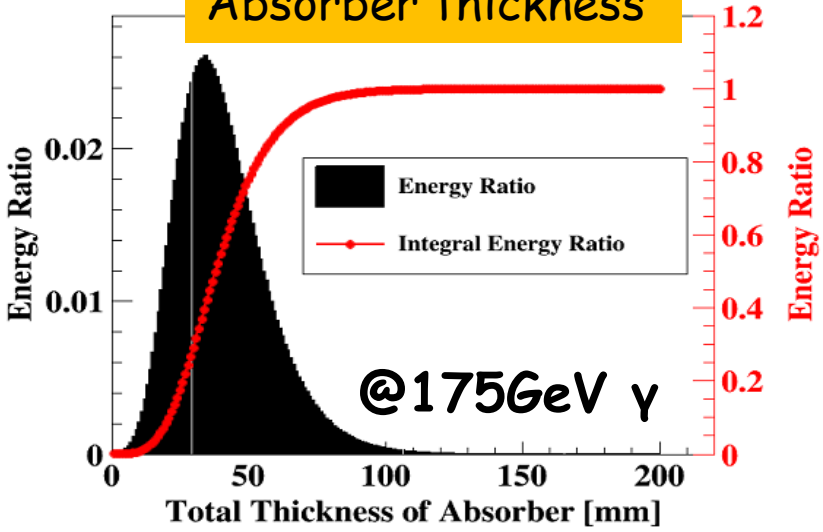
ECAL Optimization I

Scintillator-tungsten ECAL:

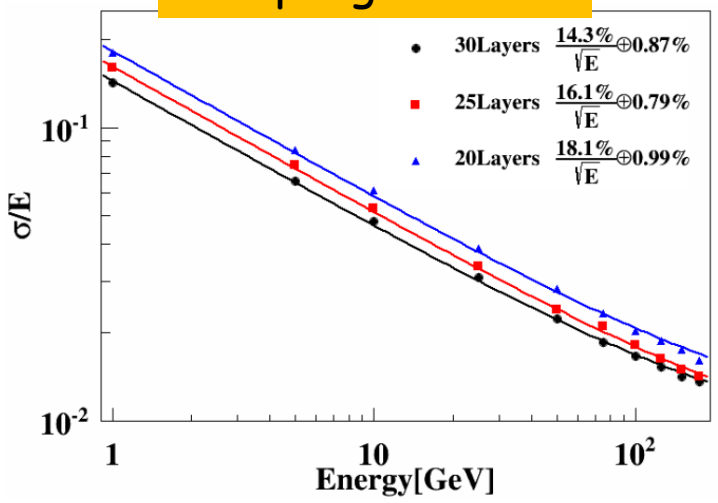
- Absorber thickness: 24 X_0
- Sampling number: 30 layers
- Cell size: <10mm*10mm

see more@arXiv:1712.09625v3

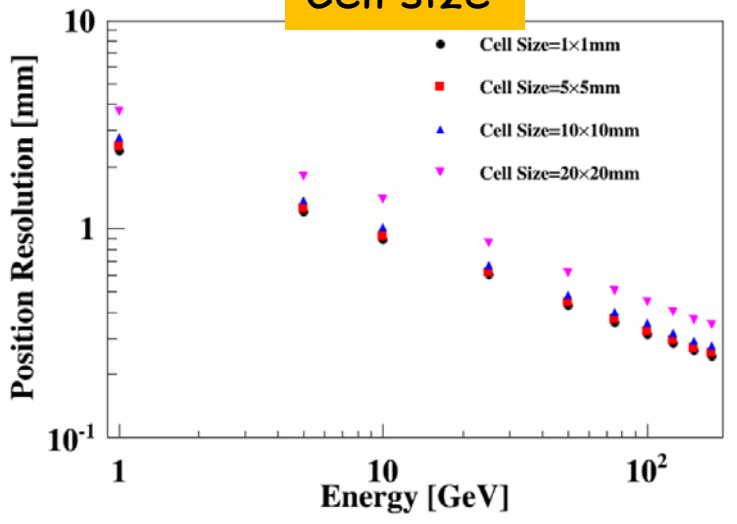
Absorber thickness



Sampling number

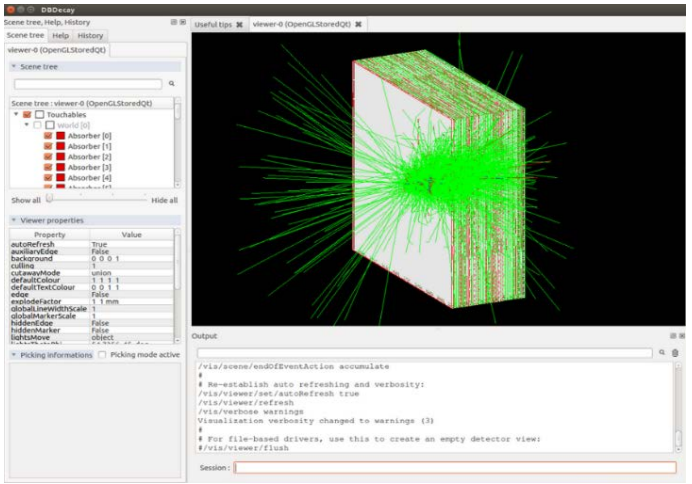


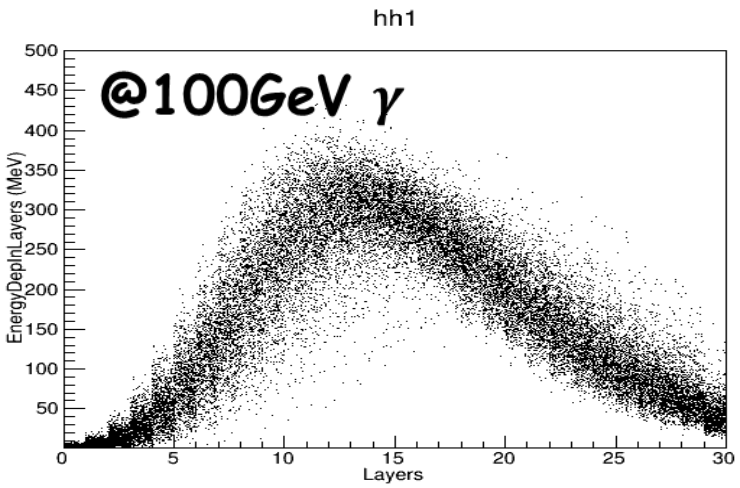
Cell size

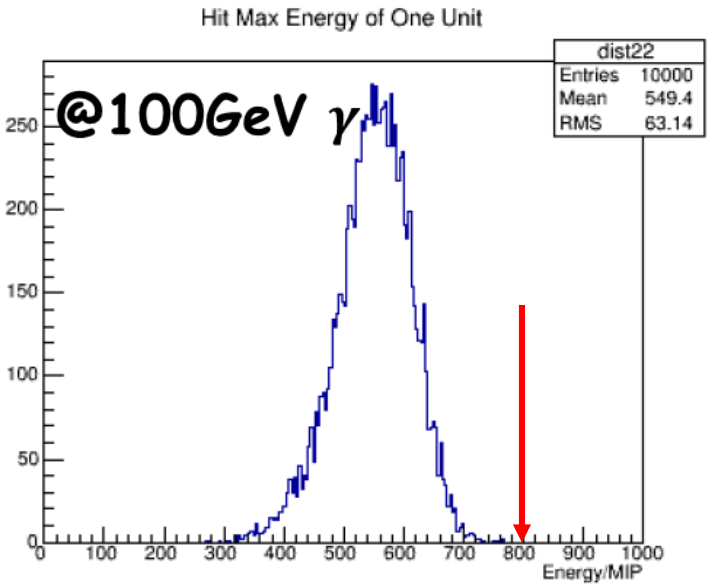


ECAL Optimization II

- Dynamic range of one SD
  - 1MIP~800MIPs
- ~15p.e. @ 1 MIP
  - Photon sensor : >12,000
- Gain :$\sim 10^5$
  - Electrics: 240fC~200pC



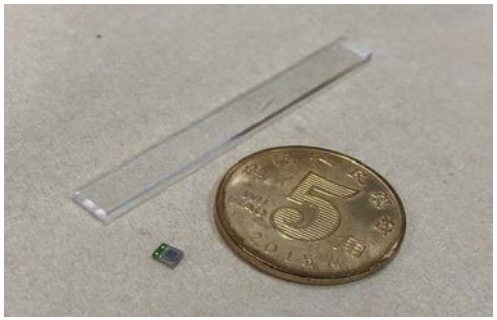


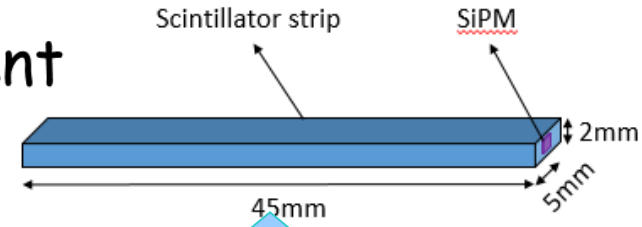


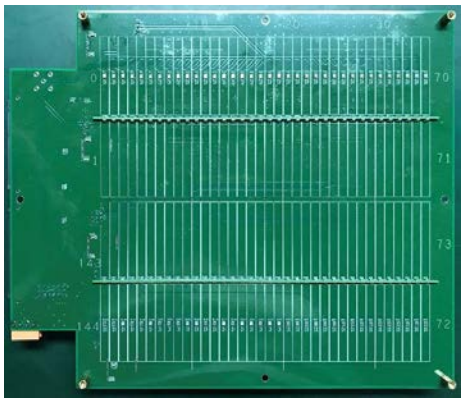
Shower profile in ECAL

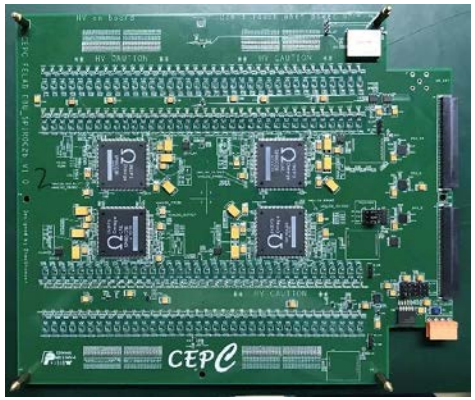
Scintillator-tungsten ECAL

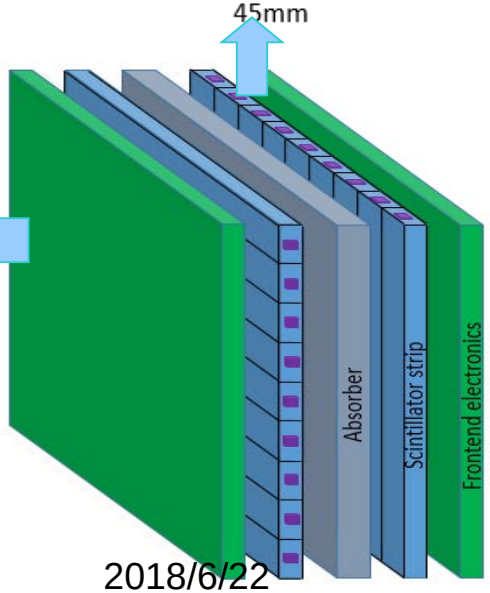
- Scintillator strip:$45mm \times 5mm \times 2mm$
- High pixel SiPM: 10k
- Frontend electronics chip: SPIROC
- Assemble scintillator module in the other side of EBU
- Orthogonal arrangement of adjacent layers: achieve $5mm \times 5mm$ cell







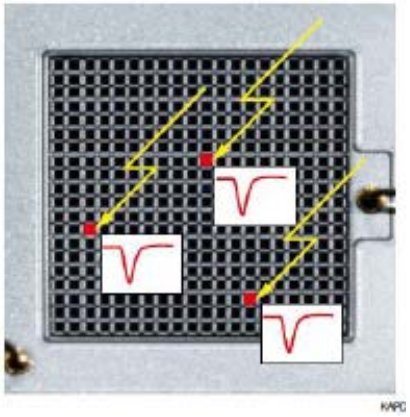


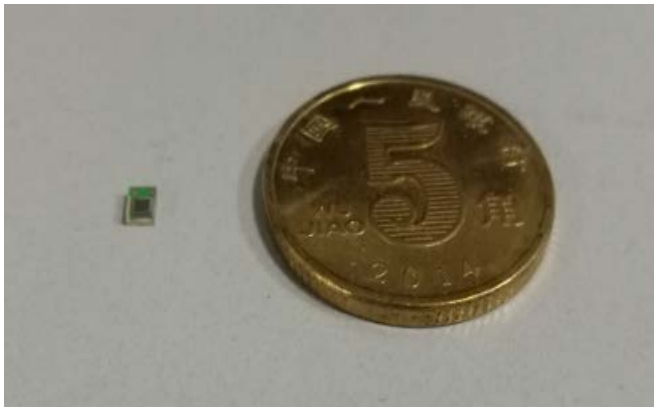


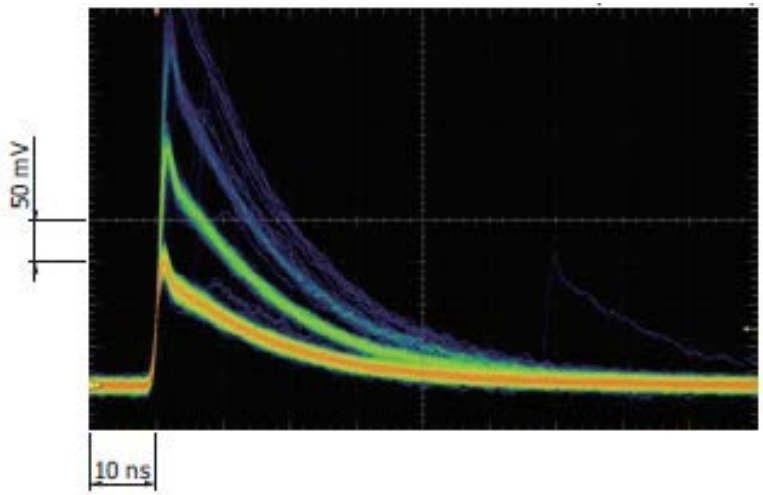
SiPM Study

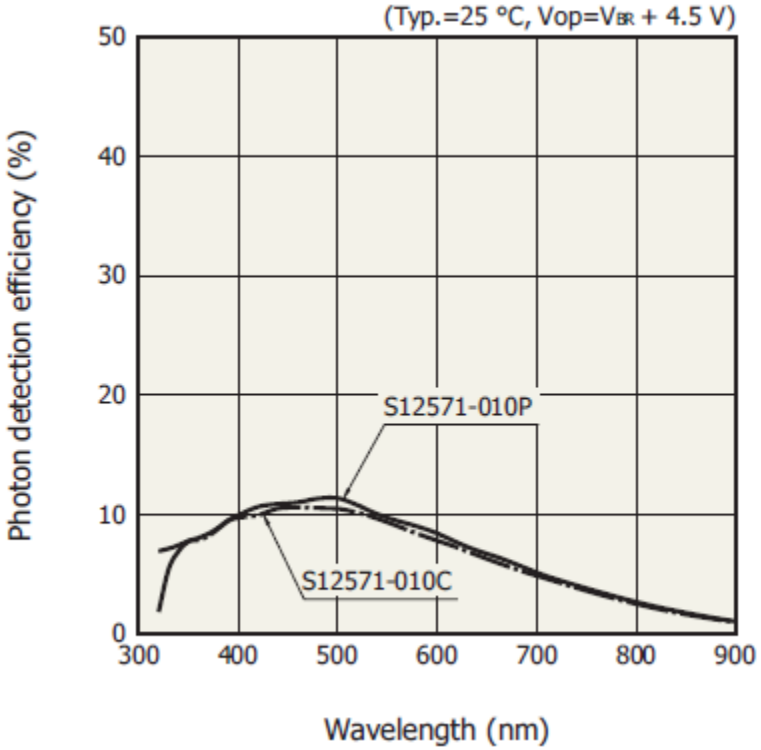
SiPM Features

- High gain
- Low power
- Small size
- Large dynamic range





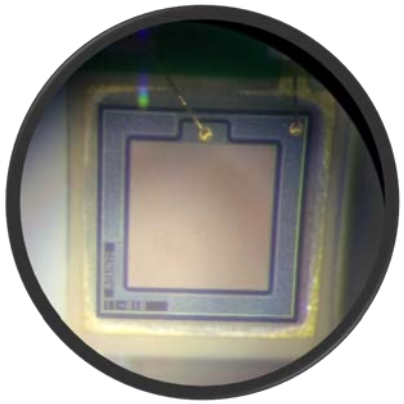




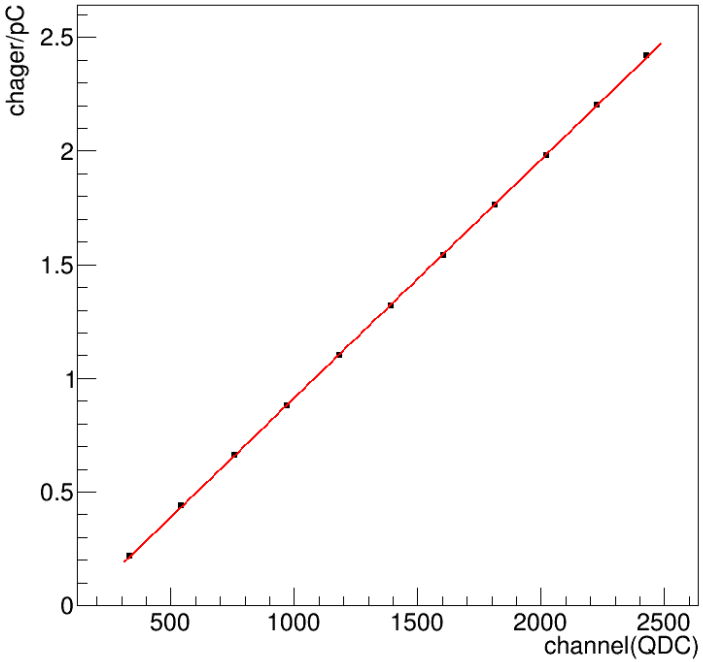
SiPM Gain

Hamamatsu S12571-010P

- sensitive area: $1mm \times 1mm$
- size: 10 um
- number: 10 K
- gain: 1.35e5

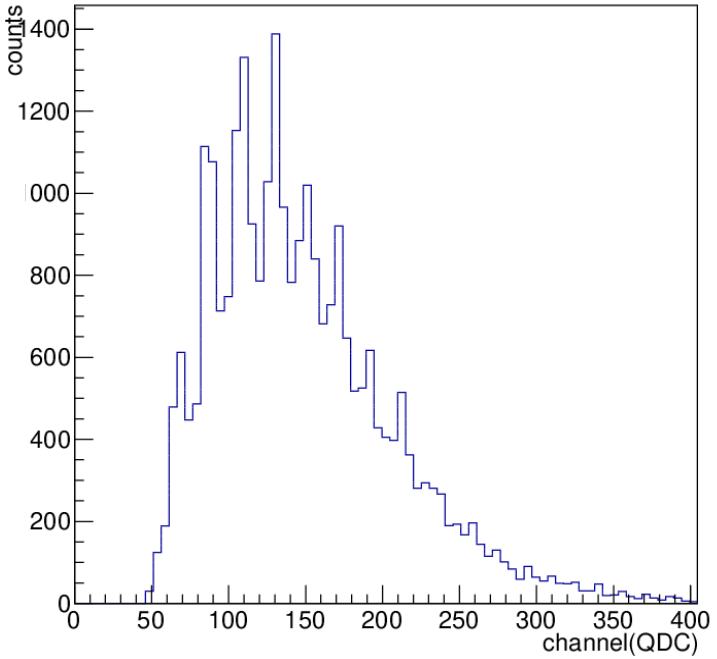


Calibration of the test system



$$Q(pC) = 0.00105 \times Ch - 0.134$$

single photon distribution

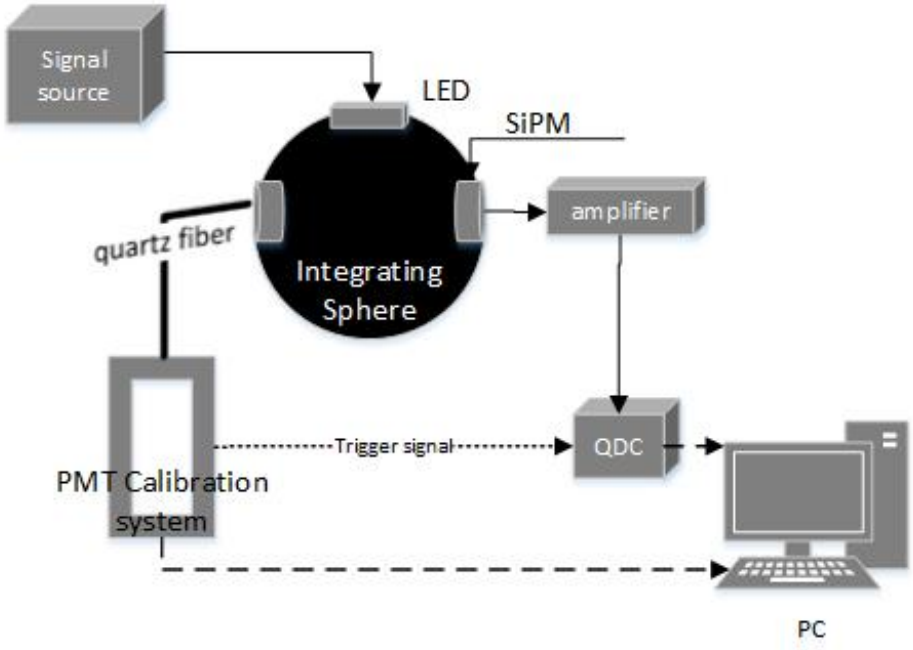


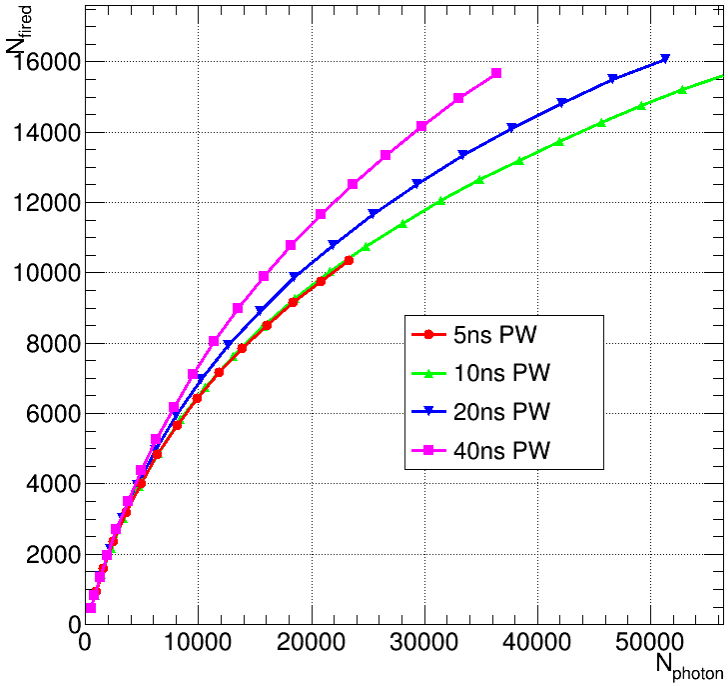
$$Ch = 20.5 \times N(p.e.)$$

$$Gain = 1.34 \times 10^5$$

SiPM Linearity

Test with different Photon Width(PW):
5ns, 10ns, 20ns and 40ns





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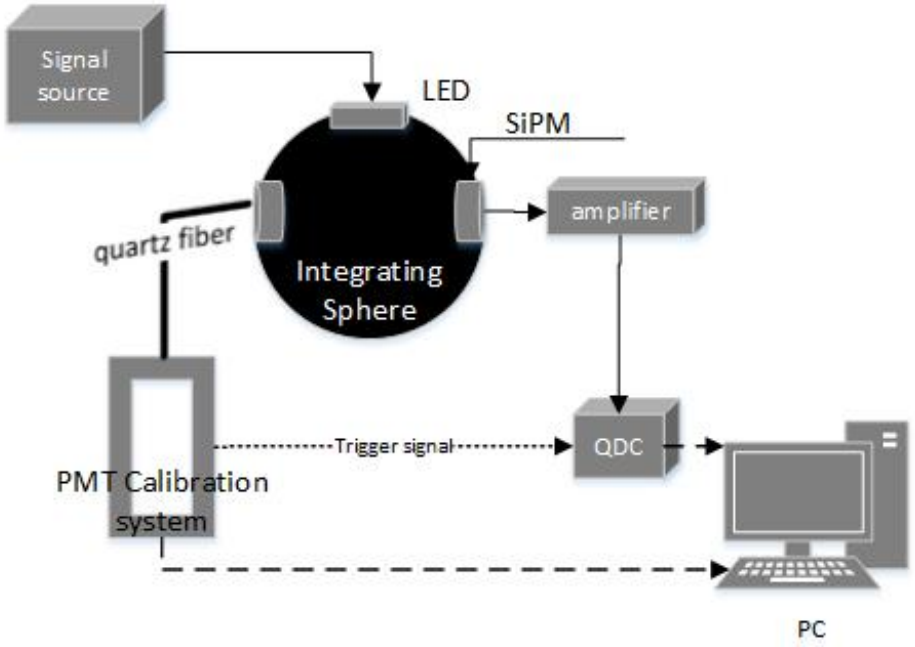
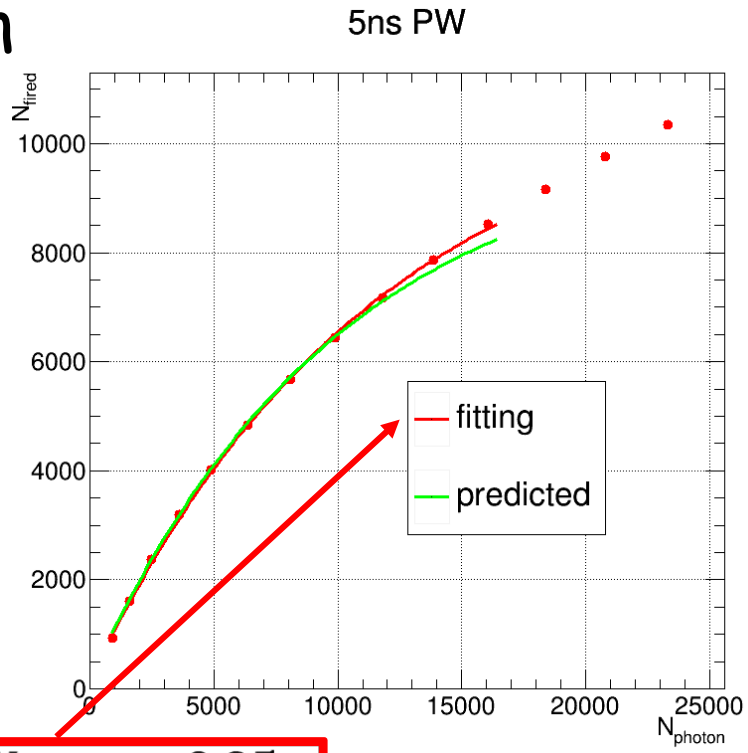
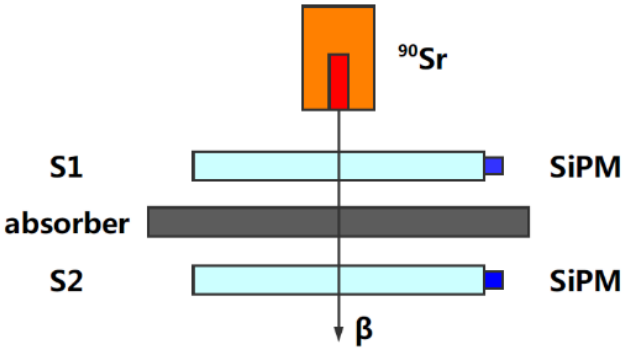


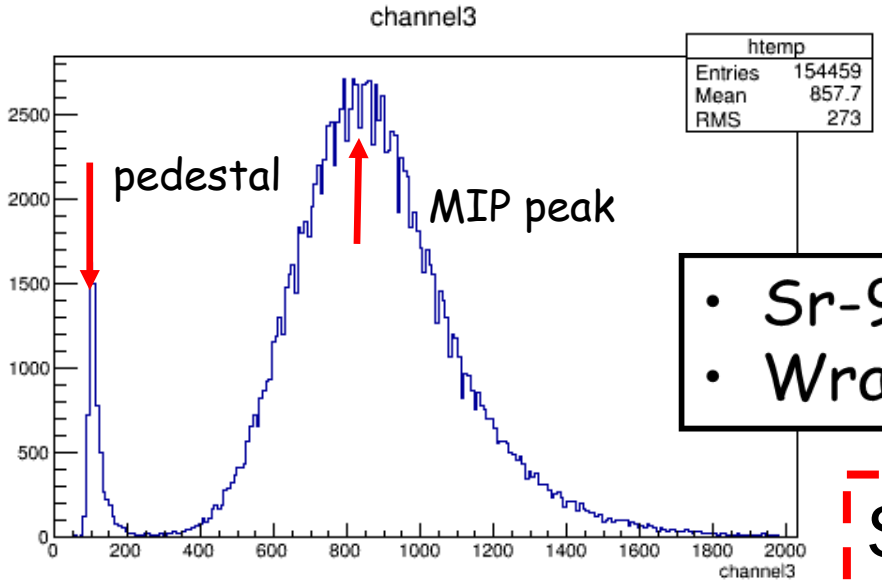


$$N_{fired} = 11010 \cdot (1 - e^{\frac{-N_{photon} \times 0.95}{11010}})$$

- SiPM response can be described well with the theoretic prediction
- Enabling dynamic range up to 16,000 photons through correction

Scintillator Light-Yield



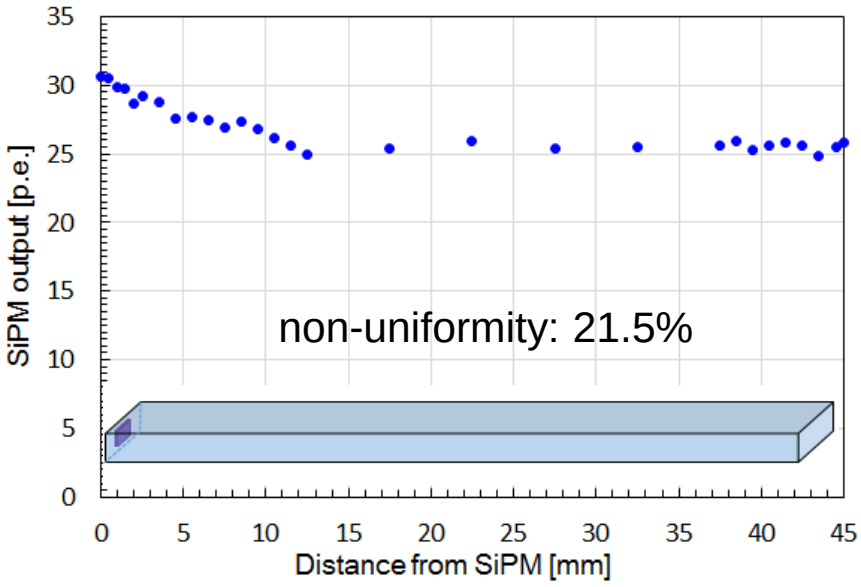


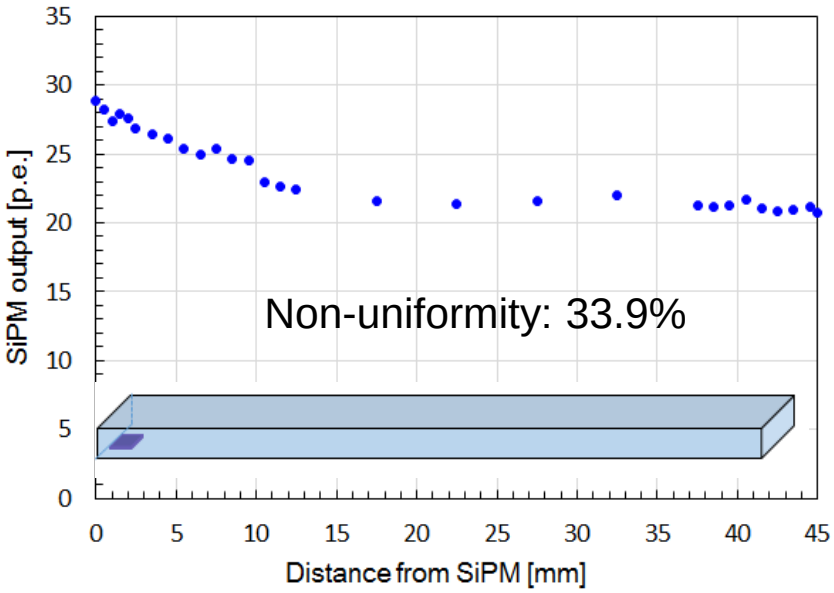
- Sr-90 source provide β ray as MIPs
- Wrapped with ESR or Teflon

Scintillator： BC-408
Light-Yield： ~25 p.e.
Diversity: ~12%

Scintillator non-Uniformity

Two type SiPM coupling mode



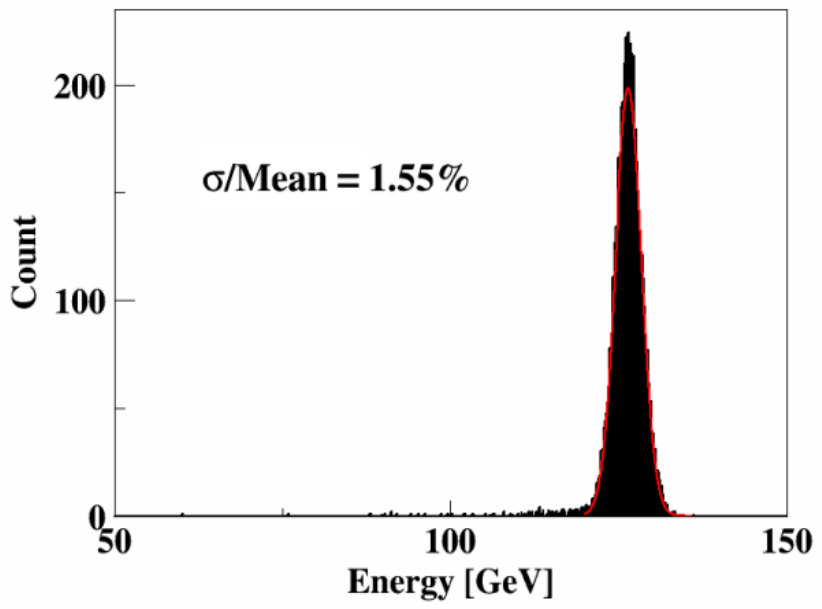


- SiPM (Hamamatsu S12571-010P) embedded at the side-end or the bottom-end of the scintillation strip
- Light outputs along the length of the scintillator strip is non-uniformity, degrades the energy resolution

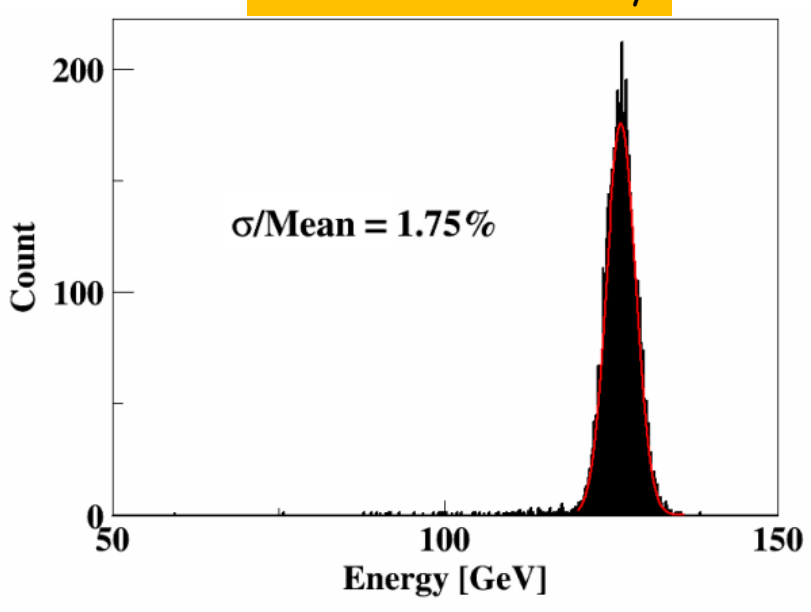
Scintillator non-Uniformity

How much is the effect of uniformity on energy reconstruction?

WO non-uniformity



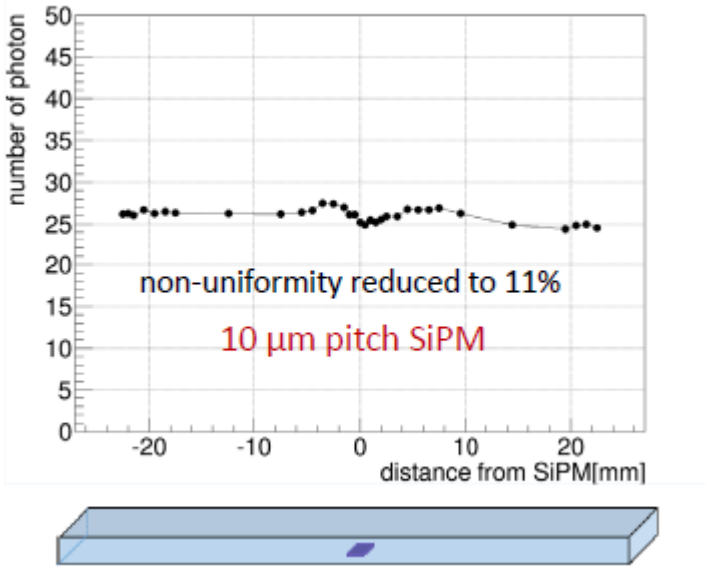
W 25%non-uniformity

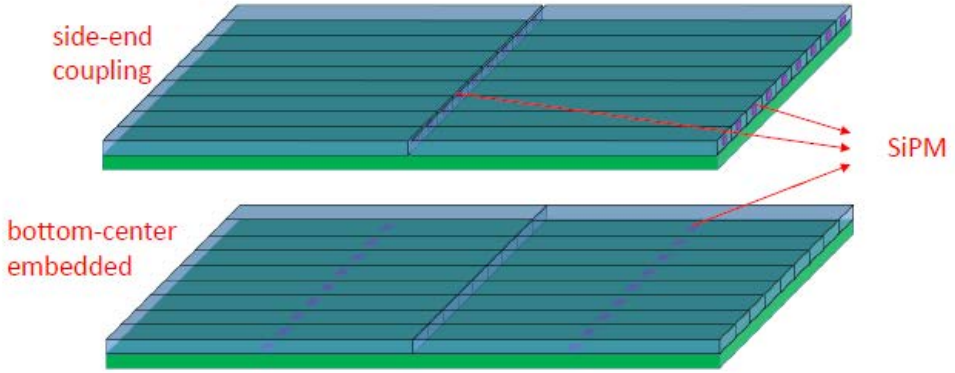


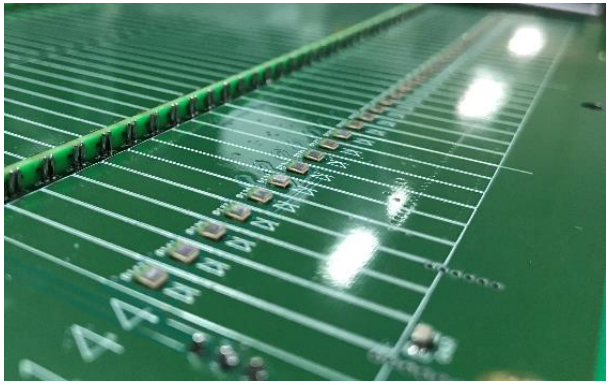
$$\nu\nu Higgs \rightarrow \gamma\gamma$$

New coupling mode

SiPM embedded at bottom-center of the strip





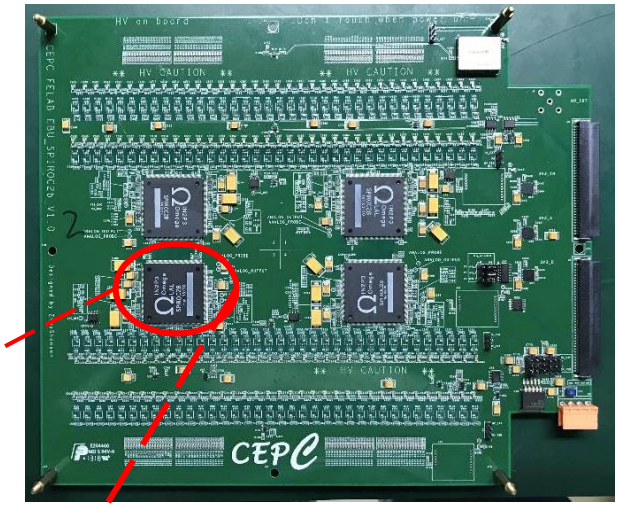


New coupling mode have many merits:

- ✓ Reducing light outputs non-uniformity
- ✓ Avoiding the dead area between scintillators
- ✓ Simplifying process of scintillators assembling
- ✓ Enabling to extend the SiPM area with more pixels

SPIROC2b chip

- SiPM front-end with **ASIC SPIROC2b** of 36 channels
- **FPGA** (Artix-7 200T)
- DIF is **compatible for FEB**
- USB for data upload & cmd sending
- USB for single DIF, and **serial port for DAQ** when using multiple DIF

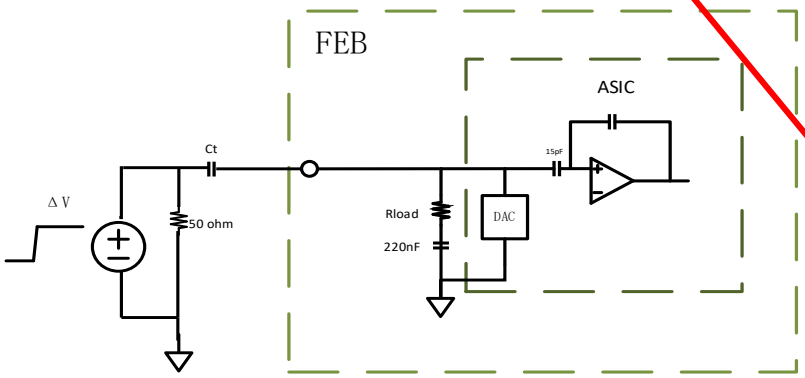


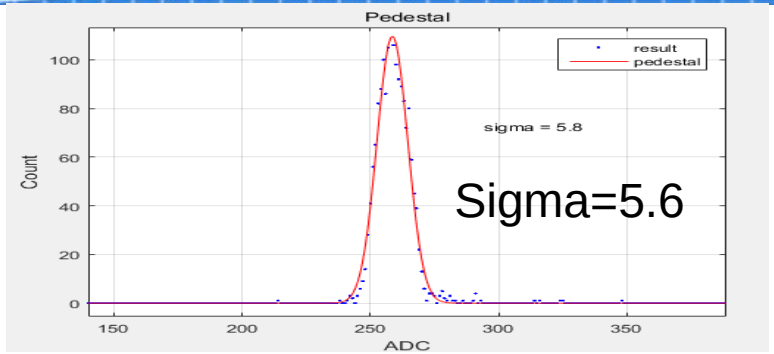
- Switched capacitor array store charge measurement
- 12 bits ADC conversion
- Variable Gain due to:
  - adjustable Cf of pre-amplifer
  - Rload on the board
  - Shaping time and delay

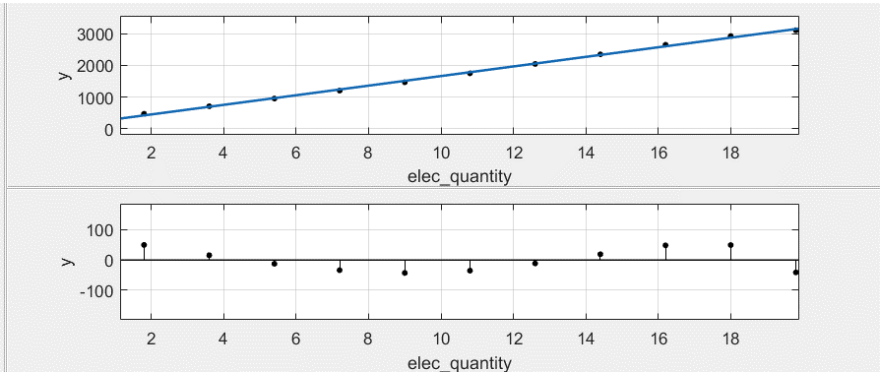
- Dynamic range：~100fC~200pC
- channels：36
- Dead time：2ms
- Polar: positive
- power：8mW/channel

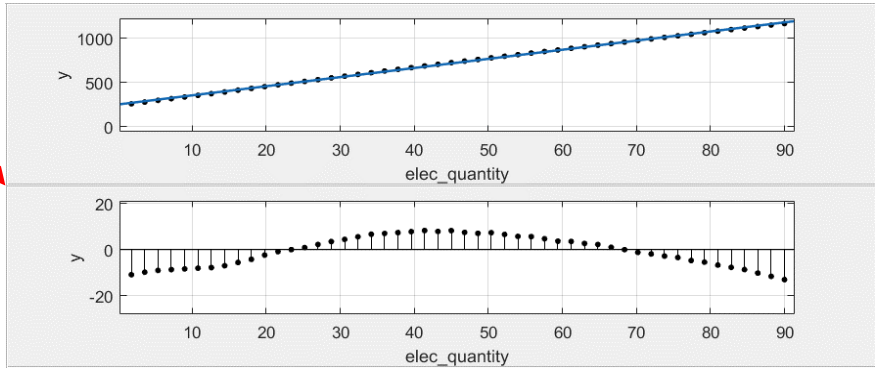
Readout Electronics

- Measurement is also relative with not only Q_{inject} but also waveform
- $\tau_{fall} = C_t * R_{load}$ same to $\boldsymbol{\tau_{SiPM}}$**~3.5ns** (S12571-010P)
- $Q_{inject} = \Delta V * C_t$ (@ τ_{SiPM}~3.5ns)
- R_{load} = **200Ω** , C_t = **18pF**
- High Gain 92fC – 19pC (3% INF, S/N ~ 2)
- Low Gain ~ 350pC (2% INF)



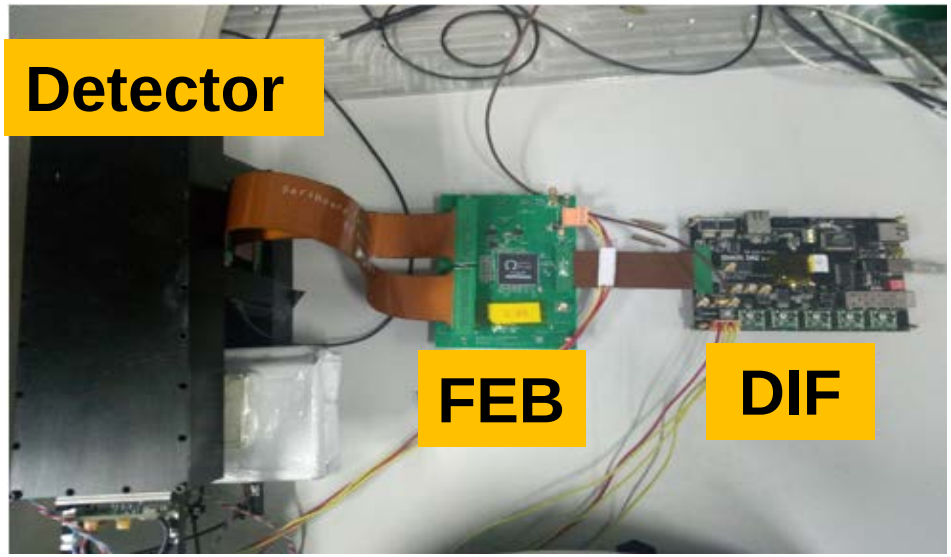


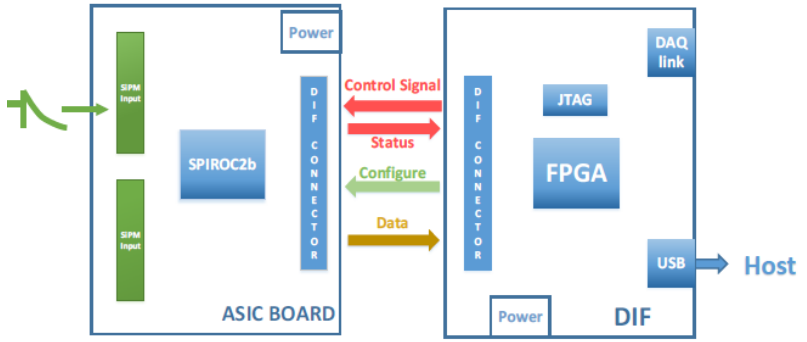




Readout Electronics

- Test platform
  - Signal generator for electronic testing
  - Sci + SiPM detector with cosmic triggers
  - Power supply, oscilloscope and PC

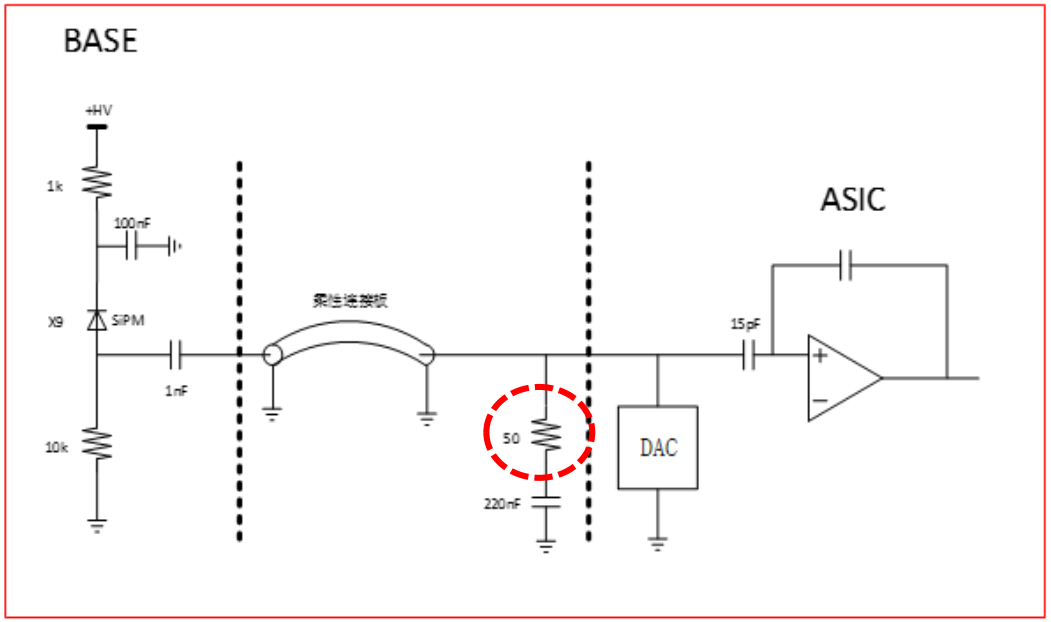




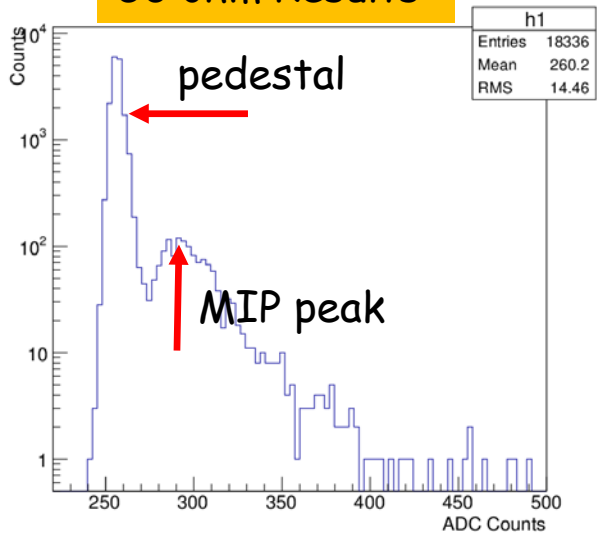
System schematic

Cosmic ray Results

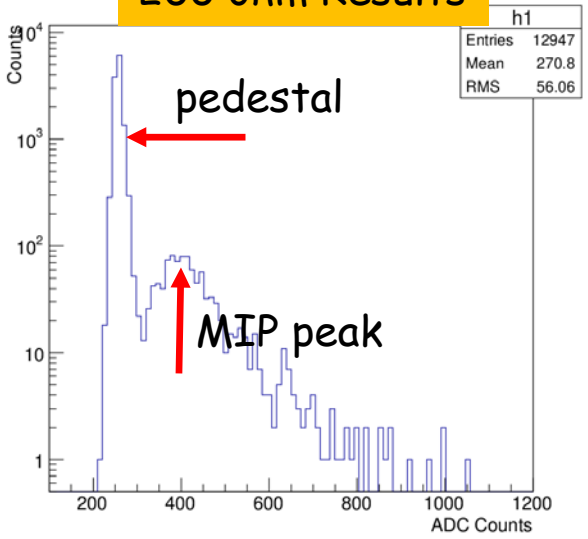
	sigma/ Ch	MIP/Ch	S/N
50ohm	2.7	35.7	13.2
200ohm	6.0	147.2	24.5
1kohm	24.7	389	15.7



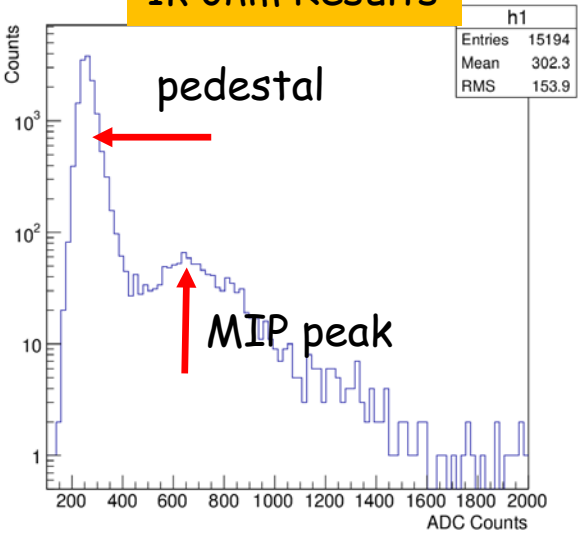
50 ohm Results



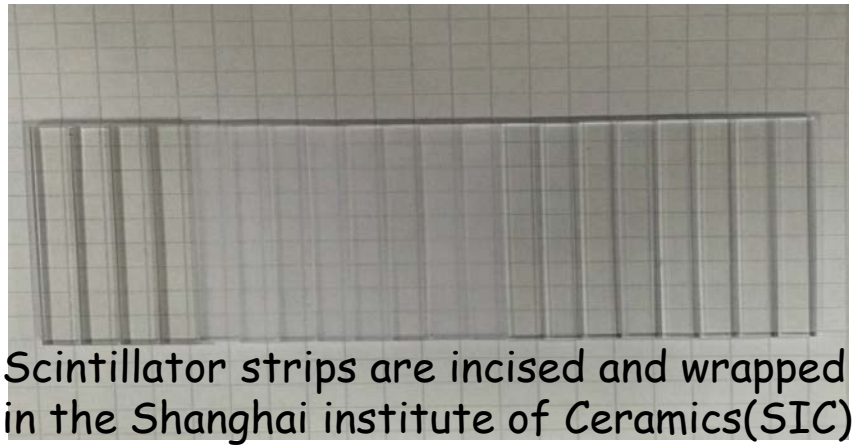
200 ohm Results



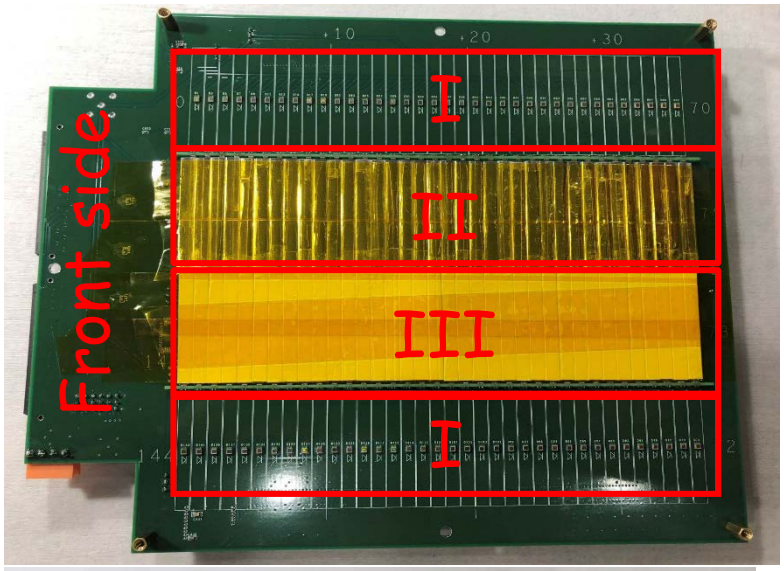
1k ohm Results



Single layer prototype

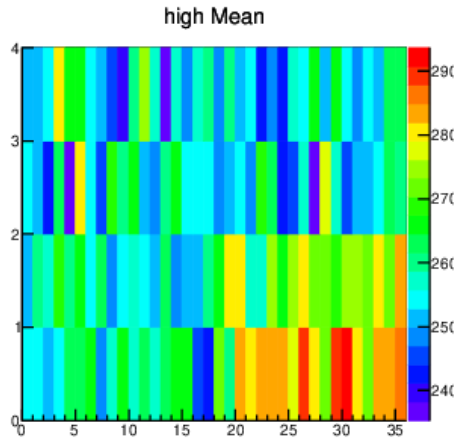


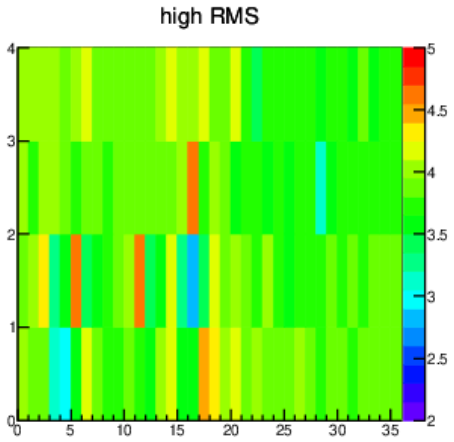
Scintillator strips are incised and wrapped in the Shanghai institute of Ceramics(SIC)



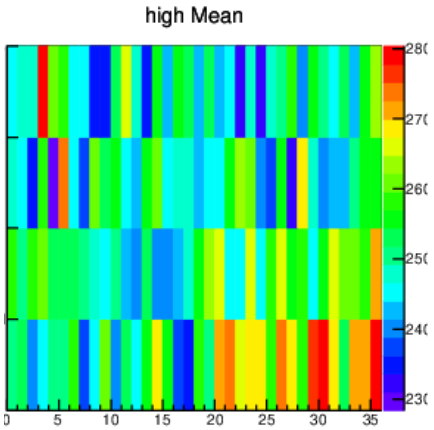
- Single layer prototype for the study of modules layout, integration, preliminary performance
- 144 modules of scintillator strip coupling with SiPM(S12571-010P)
- Half are side-end coupling mode, another half are bottom-center embedded coupling mode(I) unfinished
- Side-end coupling mode scintillators wrapped with ESR(II) or Teflon(III)

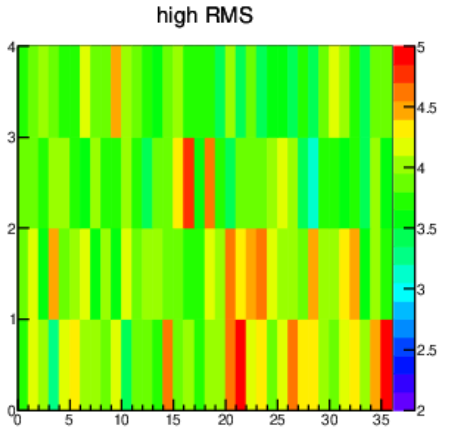
Single layer prototype



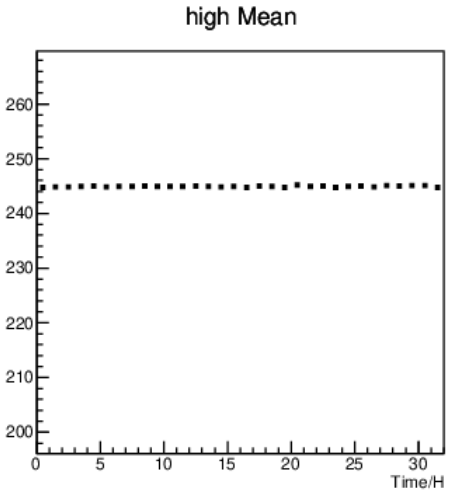


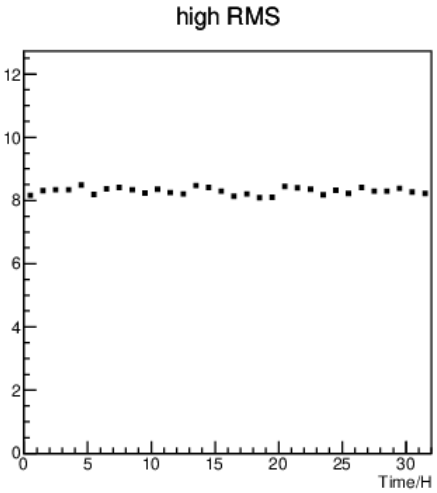
SiPM without H.V.





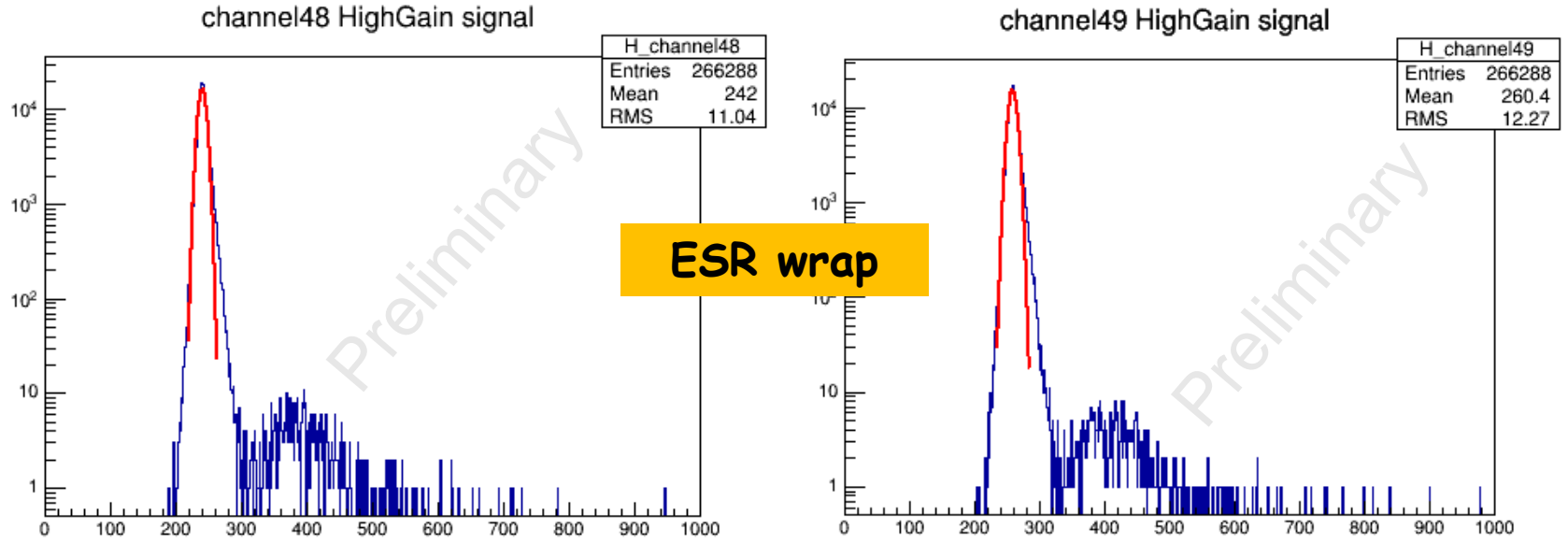
SiPM with H.V.

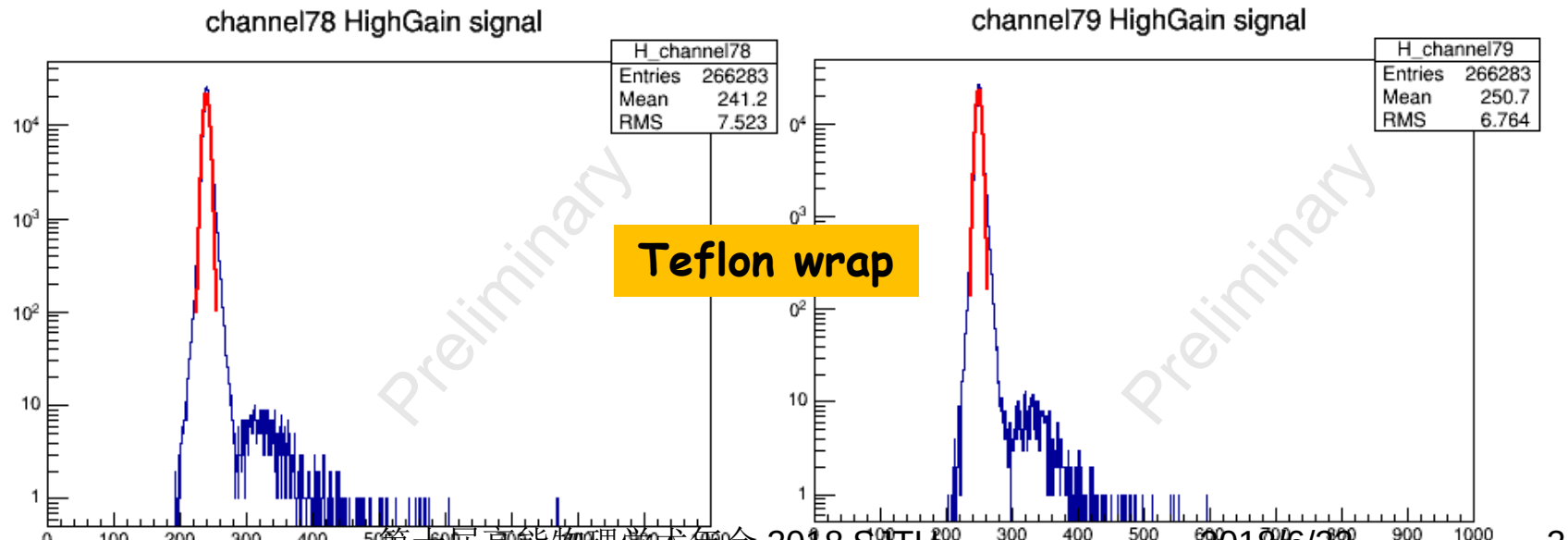




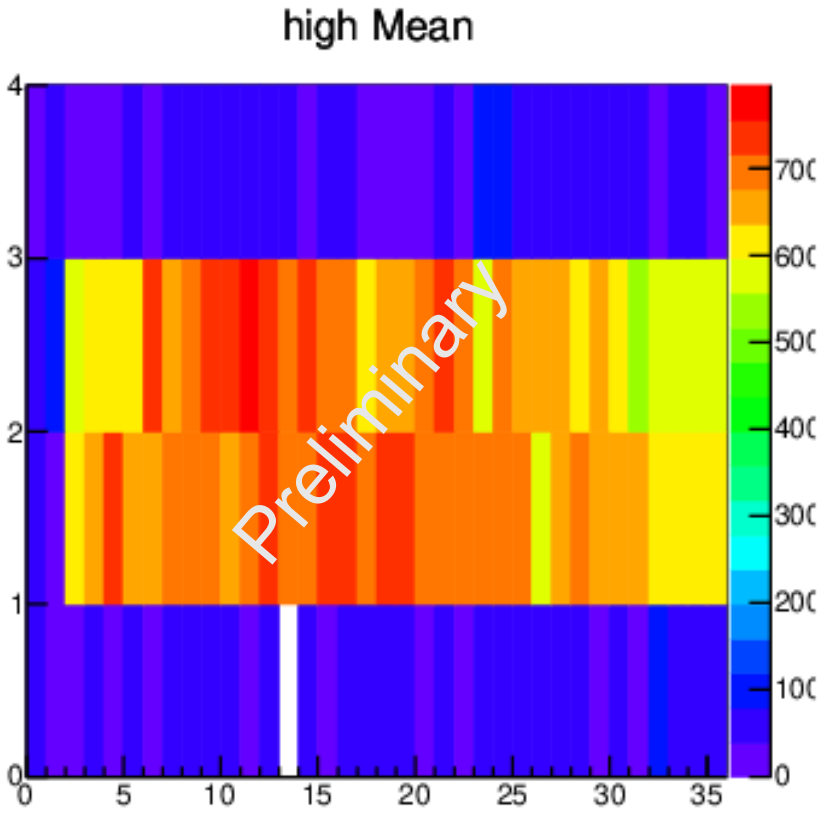
Long time work stability

Preliminary performance

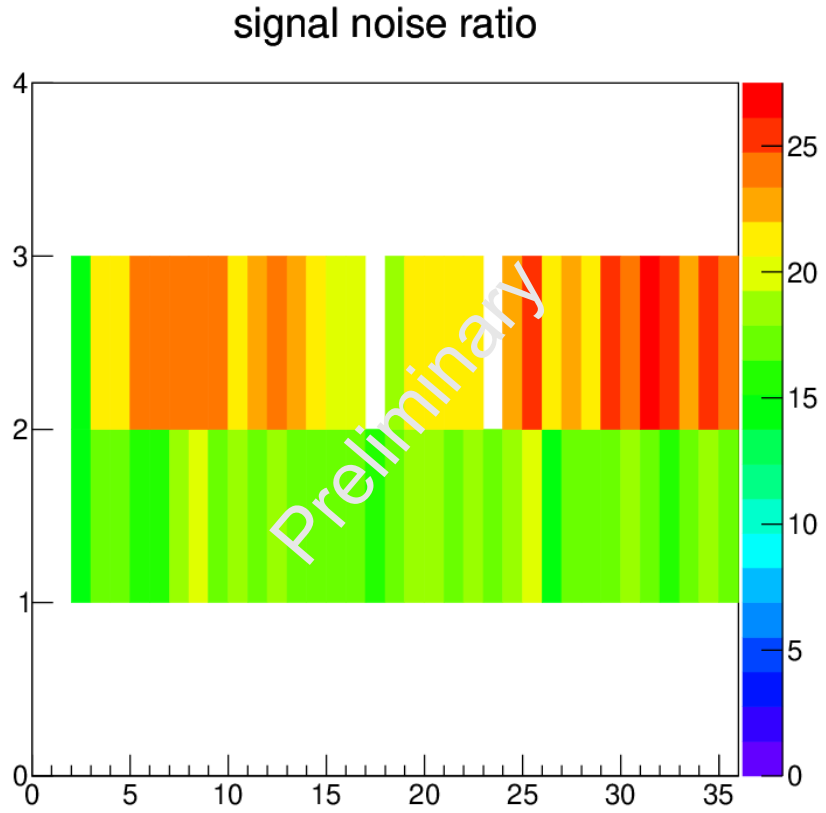




Preliminary performance



Hits number (threshold: 8sigma)



Signal noise ratio

Summary

- Optimized ECAL absorber thickness, active layers and cell size
- Improved uniformity of scintillator strip light output
- Achieved SiPM response function for nonlinearity correction
- Assembled half of single layer prototype and obtained preliminary results
- Great progress has been made, but much more needs to be done ……

Summary

- Optimized ECAL absorber thickness, active layers and cell size
- Improved uniformity of scintillator strip light output
- Achieved SiPM response function for nonlinearity correction
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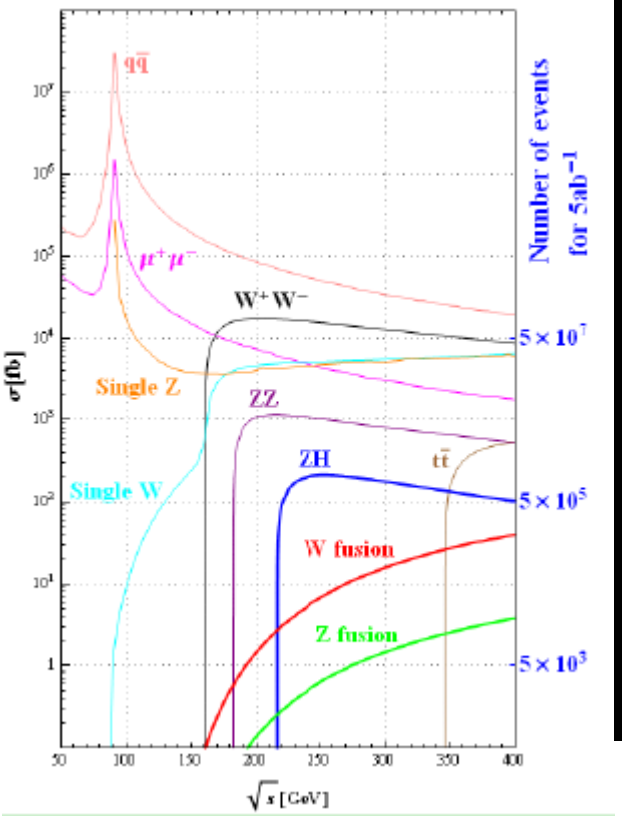
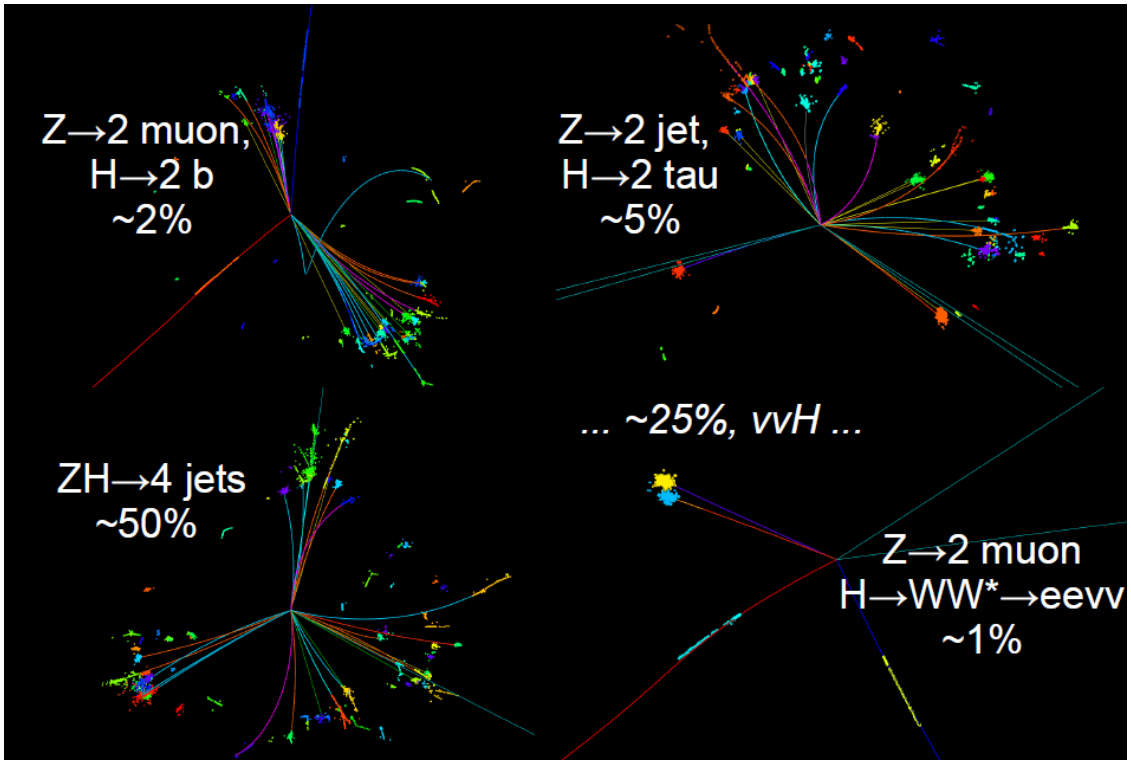
Thanks for your attention!

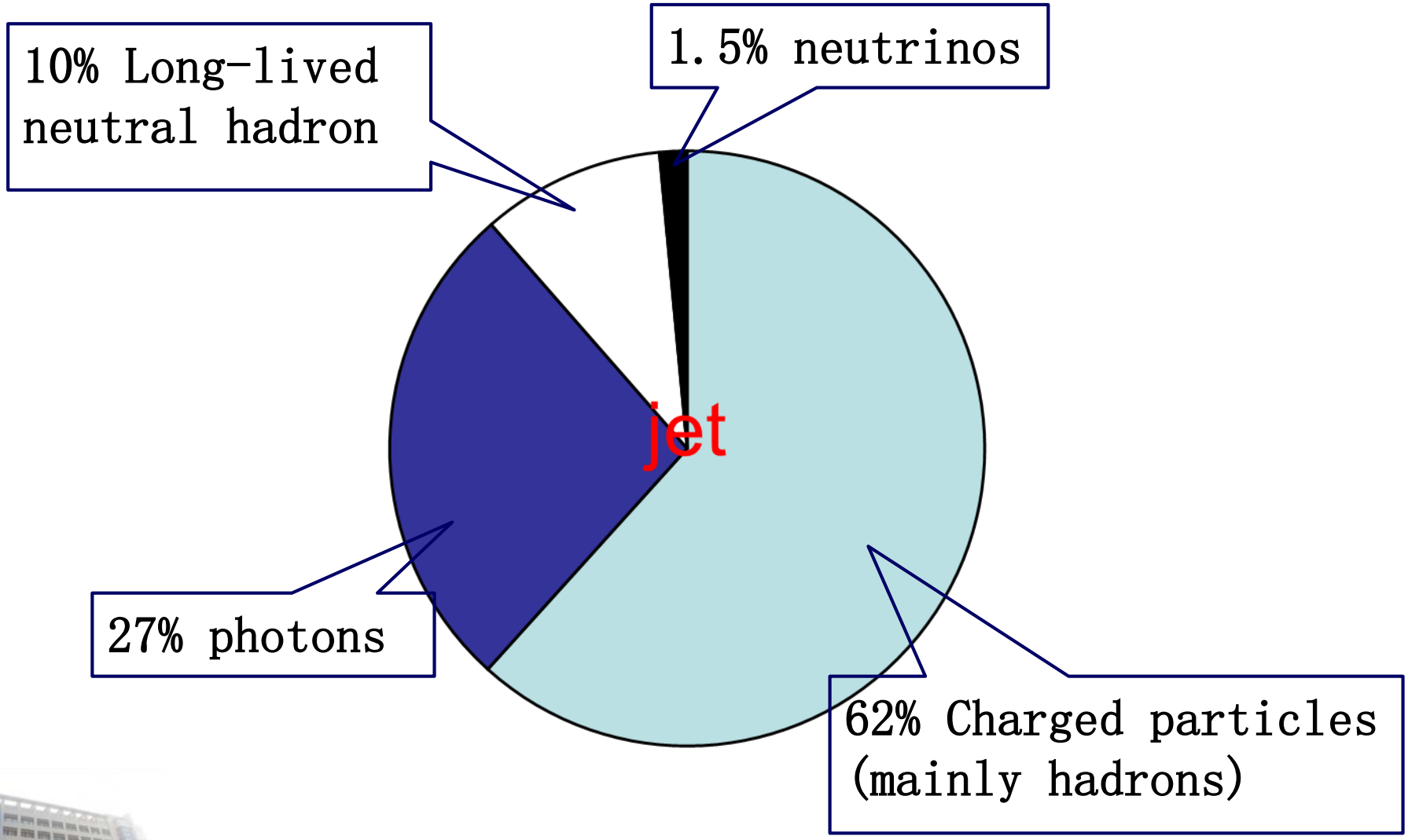
backup

Higgs产生与衰变

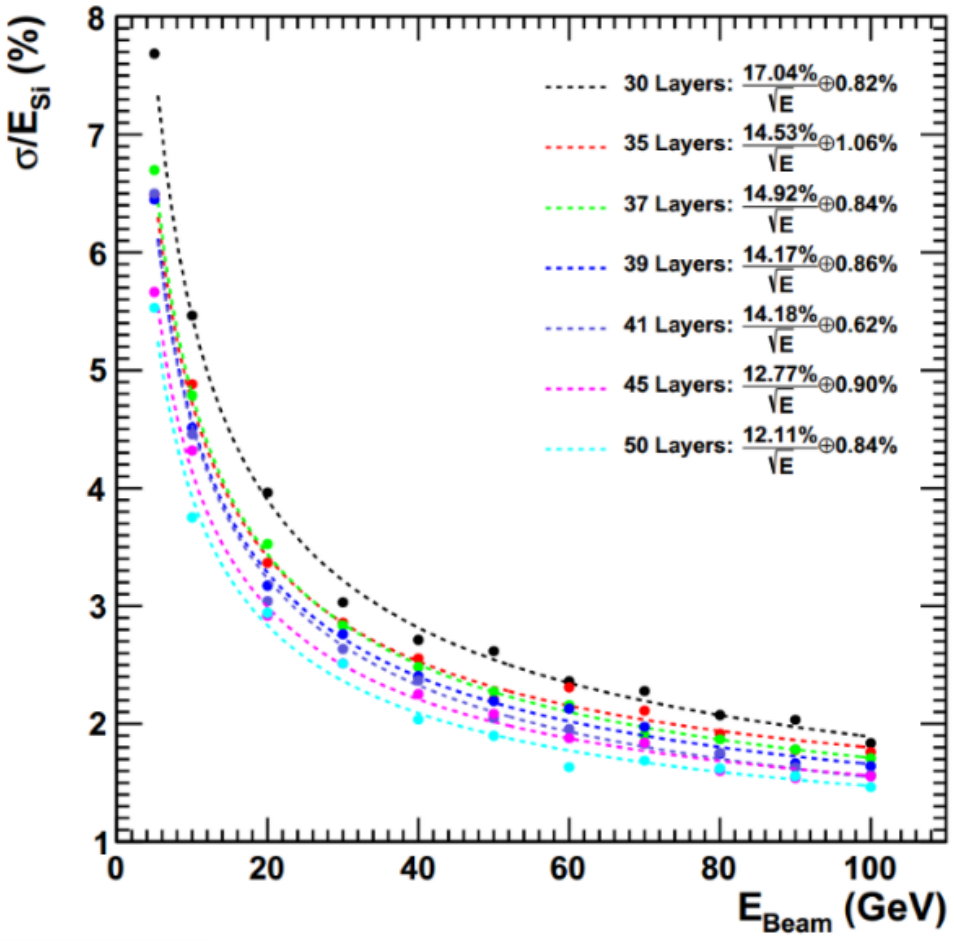

$q\bar{q}$
$\mu^+\mu^-$
W^+W^-
Single Z
ZZ
ZH
$t\bar{t}$
Single W
W fusion
Z fusion
σ[fb]
Number of events for 5ab^{-1}
5×10^7
5×10^5
5×10^3
$\sqrt{s}$ [GeV]


Z→2 muon,
H→2 b
~2%
Z→2 jet,
H→2 tau
~5%
... ~25%, vvH ...
ZH→4 jets
~50%
Z→2 muon
H→WW*→eevv
~1%

➢ Jet的组成

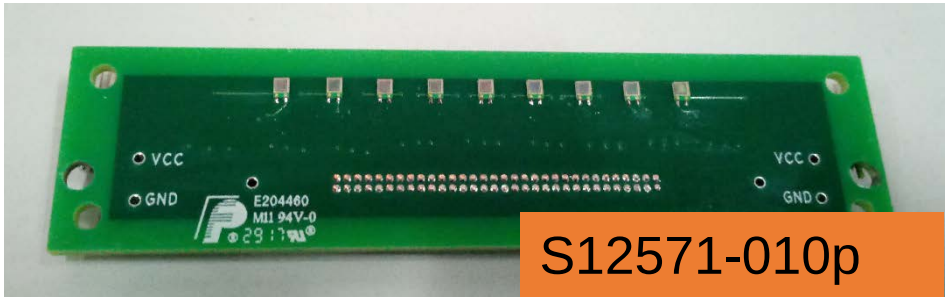

10% Long-lived neutral hadron
1.5% neutrinos
jet
27% photons
62% Charged particles (mainly hadrons)

W+Silicon

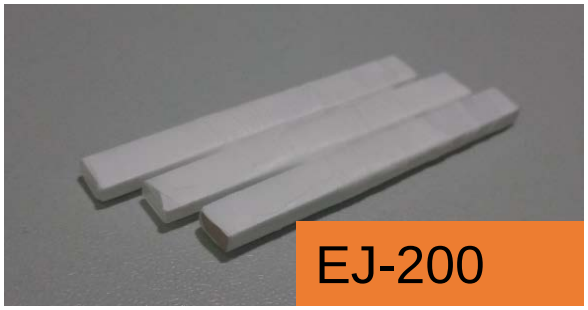


- 死区大
- 信噪比小
- 对电子学要求高
- 对Silicon生产工艺要求高

探测单元的研制



S12571-010p


EJ-200

- 闪烁体：BC408
- 包装：Teflon / ESR
- MIP：^{90}Sr
- 数据采集: QDC