Progress of the CEPC scintillator-tungsten ECAL

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Outline

• Introduction of CEPC scintillator-tungsten ECAL
• Scintillator module test and optimization
• Design and development of readout electronics
• Single layer prototype construction and test
• Summary
Requirements of CEPC ECAL

- Precise measurements of electrons and photons with energy resolution of:
  \[ \frac{\sigma_E}{E} \approx 16\% / \sqrt{E} \oplus 1\% \]

- Jet energy resolution (ECAL combined with HCAL and tracker):
  \[ \frac{\sigma_E}{E} \approx (3\% - 4\%) \]

- 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
- Good energy resolution
Scintillator-tungsten ECAL

- A sampling calorimeter with scintillator-tungsten sandwich structure (ScW) is one of the ECAL options
- A R&D programme supported by Ministry of Science and Technology of China (MOST)
- Sandwich structure
  - Absorber + scintillator module + readout electronics (PCB)
- Scintillator readout module
  - Scintillator + SiPM
- Absorber
  - Tungsten

https://twiki.cern.ch/twiki/bin/view/CALICE/CalicePapers
Optimization of ScW ECAL

- The key parameters were studied by simulation and optimization of the structure and geometry
  - Total thickness of the absorber: 80~90mm
  - Layer number: 25-30
  - Granularity: about 5mm × 5mm
  - Thickness of the scintillator: 2mm

![Graph showing energy ratio vs. total thickness of absorber](image1)

![Graph showing position resolution vs. energy](image2)

![Graph showing effect of layer number and cell size](image3)
ECAL Optimization II

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

\[ \nu \nu \rightarrow \gamma \gamma \]

100GeV e^−
• The scintillator module: Scintillator wrapped with reflector+ SiPM
• The key parameters: Granularity, Light output, Homogeneity, Dynamic range, Dead material /area
• Scintillator dimension: 5mm × 45mm × 2mm
• Cross arrangement of neighboring layers → a transverse readout cell size of 5 × 5 mm²
• Reduction of the readout channels → low cost
• SiPM coupled at the side or the bottom of the scintillator strip → few or negligible dead area
At the beginning, SiPM (Hamamatsu S12571-010P) coupled at the side-end of the scintillator → bad uniformity

Change the coupling mode: SiPM embedded at bottom-center of the strip

Uniformity of light output is improved significantly
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 15%
- No gap between the scintillators → Avoid the dead area
- Easy to operation in the prototype construction
- Enabling to extend the SiPM area with more pixels and extend the dynamic range of the SiPM
The SiPM output linearity and effective pixels are improved with the incident light width.

SiPM response can be described well with the theoretic formula:

\[ N_{\text{fire}} = N_{\text{eff}} \left( 1 - e^{-\varepsilon N_{\text{in}}/N_{\text{eff}}} \right) \]

where:
- \( N_{\text{fire}} \): number of fired pixels
- \( N_{\text{eff}} \): number of effective pixels
- \( \varepsilon \): PDE (Photo Detection Efficiency)
- \( N_{\text{in}} \): number of incident photons

Saturation effect could be corrected.
- Asic board is developed with SPIROC2b/SPIROC2e 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

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

Test Platform

• Calibration
• Cosmic-ray test with scintillator modules

Cosmic ray test

- Sci+PMT1
- Sci+PMT2

Cosmic

Logic &

Trigger

FEE &

DAQ

FEF

FEE

DAQ

12
Electronics cosmic-ray test

- Different scintillators were tested by cosmic rays
  - Plastic scintillator: BC408, EJ200
  - SiPM: S12571-010P with dimension of 1mm × 1mm and 10k pixels

- The peak of the MIPs is clearly separated from the pedestal
- The electronics worked with good performance
• Single photon-electron can not be used to calibrate each scintillator modules with For S12571-010P SiPM, due to big electronics noise with SPIROC chips
• LED calibration system is considered and designed
Preparation for single layer prototype

- Single layer prototype for the study of module layout, integration, preliminary performance
- 4 SPIROC2b chips, 144 modules
- Half: side-end coupling mode, another half: bottom-center embedded coupling mode

Front End Board
Scintillator modules

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

- 144 modules of scintillator strip coupling with SiPM (S12571-010P)
- I and IV: bottom-center embedded coupling mode, wrapped with ESR
- II: Side-end coupling mode scintillators wrapped with ESR
- III: Side-end coupling mode scintillators wrapped with Teflon
- Working in high gain mode
- SiPM with H.V.
- Long time work stability

Pedestal of single layer

The stability of pedestal position

The stability of pedestal width
Cosmic-ray test

- Small cracks lead to low light output
New scintillator strips
• Scintillator strip modules were tested and optimized
• Readout electronics was designed and developed
• A single layer prototype was constructed and tested with cosmic-ray
• New scintillator module will be prepared to replace the old ones on the single layer prototype

Thanks for your attention !