CEPC Scintillator-Tungsten ECAL R&D progress

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Outline

• Introduction of CEPC scintillator-tungsten ECAL
• Scintillator module study and optimization
• Single active layer construction and test
• International collaboration
• Summary
Performance requirements of the CEPC ECAL

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

• Jet mass 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

• A sampling calorimeter with scintillator-tungsten sandwich structure (ScW) is one of the ECAL options

• Good energy resolution

• High granularity and minimum dead materials

• Compact showers (small radiation length \(X_0\), and small Moliere radius \(R_M\))
Scintillator module

- The scintillator module: plastic scintillator strip 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
Strip Readout Separation Algorithm

$5 \times 45 \text{mm Cell} \rightarrow 5 \times 5 \text{mm Cell}$

Energies of Neighbor Layer Strips ($2 \times 9$) are used to calculate the splitting weights

**Di-photon Separation**

Distance = 15mm
Module test and optimization

- SiPM coupled at the side-end of the scintillator → bad uniformity
- Optimize the coupling mode: SiPM embedded at bottom-center of the strip
- Uniformity of light output is improved significantly
SiPMs response

ECAL mass reconstruction, using $H \rightarrow \gamma\gamma$ as a benchmark process

<table>
<thead>
<tr>
<th>Pixel number</th>
<th>infinite</th>
<th>10000</th>
<th>4500</th>
<th>1600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch size</td>
<td></td>
<td>$10\mu m \times 10\mu m$</td>
<td>$15\mu m \times 15\mu m$</td>
<td>$25\mu m \times 25\mu m$</td>
</tr>
<tr>
<td>PDE / %</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>MIP LY / p.e.</td>
<td>20</td>
<td>20</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Mean / GeV</td>
<td>124.83</td>
<td>124.79</td>
<td>124.88</td>
<td>111.45</td>
</tr>
<tr>
<td>$\sigma$/Mean</td>
<td>1.55%</td>
<td>1.57%</td>
<td>1.58%</td>
<td>2.62%</td>
</tr>
</tbody>
</table>

Preliminary results:

- SiPM with pixel number larger than 10000 is not required
- Need further study

SiPM non-linearity response correction applied
Single active layer

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

Scintillator strips were produced 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
Cosmic-ray test

Small cracks lead to low light output
SiPM coupling mode

SiPM bottom-center embedded coupling mode is 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 caused by SiPM.
• Easy to operation in the prototype construction.
• Enabling to extend the SiPM area with more pixels if it is demanded.
Optimization of scintillator strips

- 200 BC408 scintillator strips were cut with a runaway shaped groove (without polishing)
- Limited by production technics, the thickness of casting scintillator plate is non uniform (1.8mm-2.5mm), a fraction of strips with thickness larger than 2.3mm were thinned to 2.0mm.
Light output and uniformity

Light output and uniformity of new scintillator strip tested by source 90Sr

- Light output of the strips after thinning is 15-18 p.e./MIP, about 1 p.e. smaller than those strips without thinning.
- A relative good uniformity obtained with thinning.

Injection-molding technique is being developed to make mass production easy and low cost.
Cosmic-ray test of new strips

- 40 new scintillator strips were mounted on electronics readout board and tested with cosmic-ray.
- Preliminary results shown the peak of the MIPs is well separated from the pedestal for most strips.
Technological Prototype

• A technological prototype will be constructed and studied
• The key parameters were optimized by simulation
  – 30 layers, Sandwich structure
  – Each layer has a sensitive dimension of 200mm × 200mm
  – Each layer includes:
    • Tungsten absorber (2.8mm)
    • Scintillator module (2.0mm): scintillator strip (5mm × 45mm × 2mm)
      + SiPM (1mm × 1mm, 10um pixel size), bottom-center coupling
    • Readout electronics (SPIROC2e)
Mechanical structure design

Two sensitive layers merged into a pluggable unit.

Each sensitive layer contains $5 \times 45$ scintillator strips.

Overall structure of the prototype
International collaboration

- Monthly work meeting on Scintillator Ecal with CALICE Sc-W Japanese group
- Application for CAS-JSPS Cooperative research project together with Tohru Takeshita from Shinshu University
- Joint effort to optimize the design of the sensitive layer (scintillator+SiPM)

![Graph 1: SI PM output vs hit position](image)

- Average: 16.96
- Non-uniformity: 12.64%

![Graph 2: ADC count vs relative position](image)

- Preliminary
- $dV=4V$
- Average: 21.1

Read out by Hamamatsu S12571-010P

Read out by Hamamatsu S12571-015P
Schedule in 2019

• 2019.1-4: Development and test of new readout board with SPIROC2e chips
• 2019.4-5: Construction and cosmic-ray test of a new single layer
• 2019.2-5: Mechanical structural design and manufacture of a pluggable layer
• 2019.5-10: Mass production and test of the scintillator strips
• 2019.6-8: Manufacture of the prototype mechanical structure
• 2019.8-12: Mass production and test of the readout electronics
• 2019.8-12: Assembly and test of the pluggable layers
• 2019.9: Application of test beam at DESY for the prototype
Summary

• Scintillator strip modules were studied and optimized.
• A single active layer was constructed and tested with cosmic-ray.
• A technological prototype with 30 layers will be constructed and studied.

Thanks for your attention!