Design and Study of Electromagnetic Calorimeter for Super Tau-Charm Facility

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Abstract

Modern e^+e^- colliders will reach an exceedingly high level of luminosity, like SuperKEKB, Super Charm-Tau Factory (SCTF) proposed by Russia, and Super Tau-Charm Facility (STCF) proposed by China. Under such a high event rate and additional beam background, the electromagnetic calorimeter should be capable of maintaining good energy and position resolution while dealing with pile-up pulses and fake signals. A calorimeter system based on fast pure CsI crystal, read out by avalanche photodiodes, highlighting good time resolution and high granularity is designed for STCF. This poster will expand from three aspects: Tests of the scintillation counter; Geometry optimization and simulated performance of calorimeter system; Severe performance deterioration caused by beam background with possible solutions.

Introduction

The proposed **S**uper **T**au **C**harm **F**acility in China is a symmetric double ring electron-positron collider. It is designed to have a center-of-mass energy ranging from 2 GeV to 7 GeV, and peaking luminosity beyond $0.5 \times 10^{35}\,\text{cm}^{-2}\text{s}^{-1}$ at $\sqrt{s} = 4$ GeV. It also maintains the potential for luminosity upgrade and beam polarization in the future.

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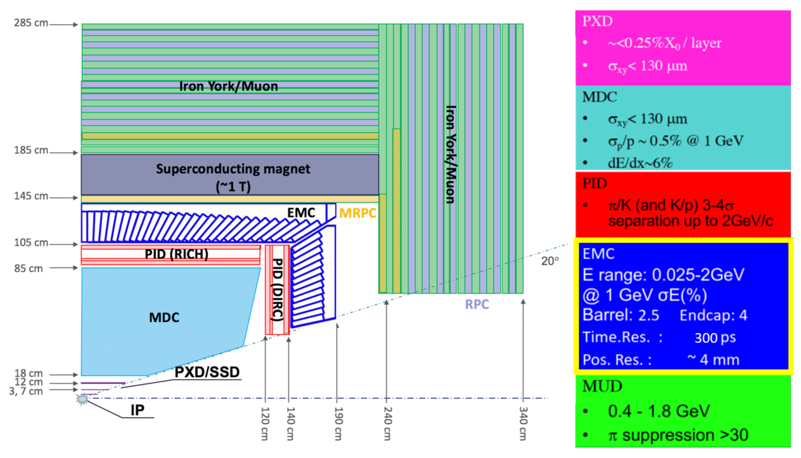


(b)

Figure 1. (a) Layout of STCF accelerator; (b) Detector layout and performance requirements for sub-detectors.

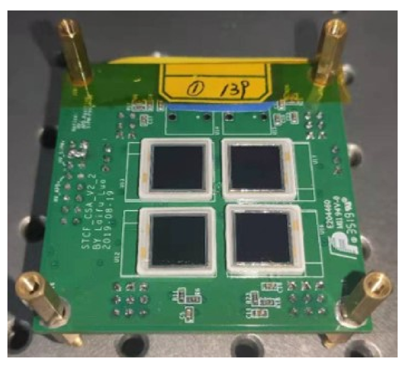
Electro**M**agnetic **C**alorimeter undertakes the tasks of 4-momentum measurement and particle identification for neutral particles. Due to large beam background induced by high luminosity, how to balance the precision of energy, position and time measurement under high background takes priority in EMC design.

Tests of the scintillation counter

STCF EMC is a homogeneous calorimeter consisting of more than 8000 scintillation counters. The main components of one counter are listed below:

- **Pure CsI crystal**: $5 \times 5 \times 28\,\text{cm}^3$, $\tau \approx 10$ ns, can tolerate more than 1×10^5 rad TID.
- **Avalanche photodiode**: $4 \times 10 \times 10\,\text{mm}^2$, QE = 70% (@ 420 nm), Gain = 50.
- **Tetratex** 3 × 75 µm thickness, reflectance >90% @ 300 nm.
- **CSA based electronics**: By using 3 JFET in parallel, the total electronic noise is 1025 electrons under room temperature[1].

(a)

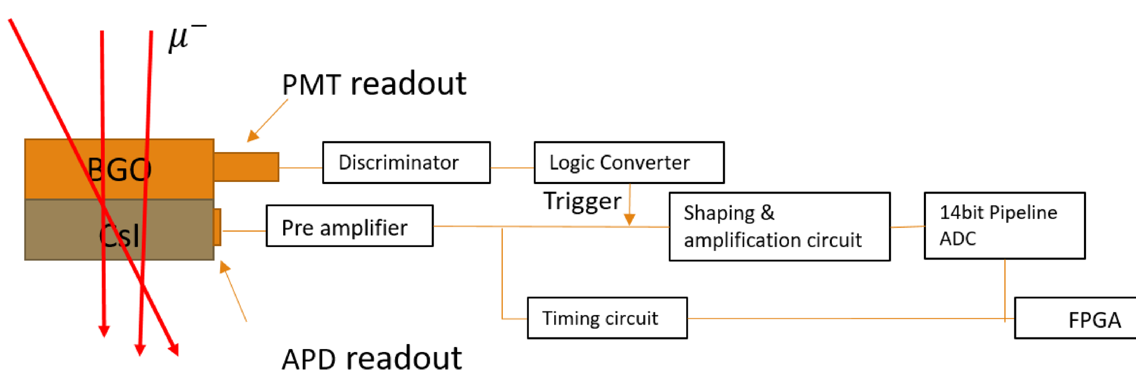


(b)

(c)

Figure 2. Figure of (a) Crystal and wrapping material; (b) APD and FEE; (c) The whole scintillator counter

Cosmic ray test shows the light yield for one counter is **155 pe/MeV** while the equivalent noise energy is **1.2 MeV**.



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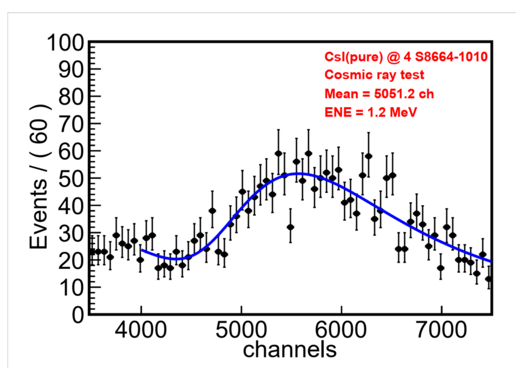

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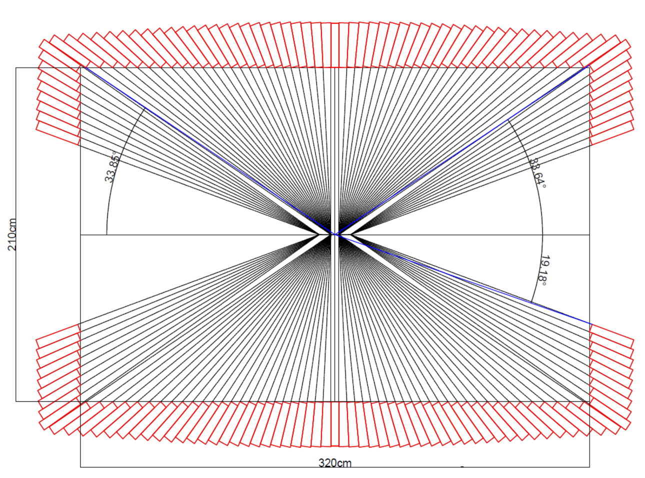
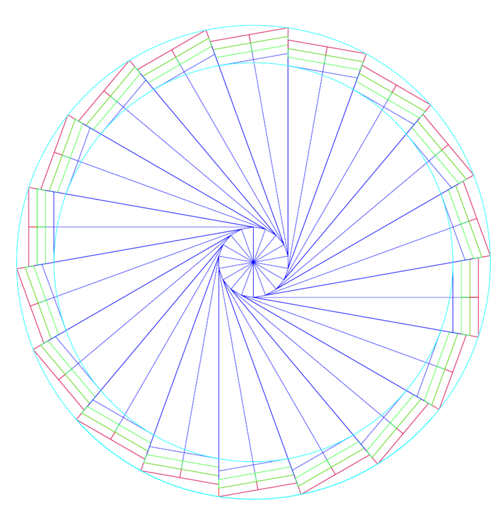
Figure 3. Schematic diagram (a) and a typical energy spectrum (b) of cosmic ray test

Geometry design and simulated performance of ECAL system

To mitigate the effect of energy leakage in gap between crystals, a defocusing ECAL geometry is proposed. In both x-y plane and x-y plane, the direction of gaps are tuned away from interaction point.



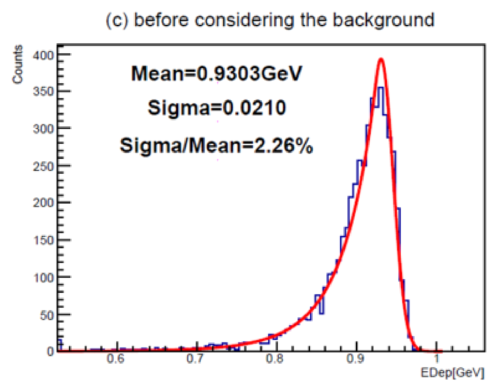
(a)



(b)

Figure 4. Schematic diagram of crystal arrangement viewed from (a) x-z plane (b) x-y plane

Based on GEANT4, simulation result shows that the front end size of crystal should be smaller than **3 × 3 cm²** to achieve a position resolution better than 4 mm. Meanwhile, no apparent deterioration of energy resolution is observed for smaller crystal.



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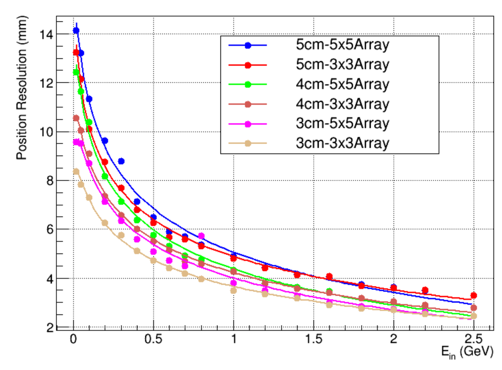

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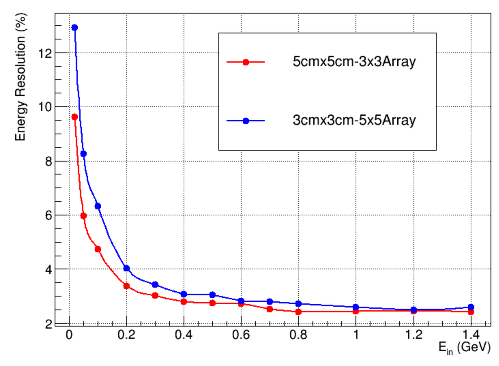
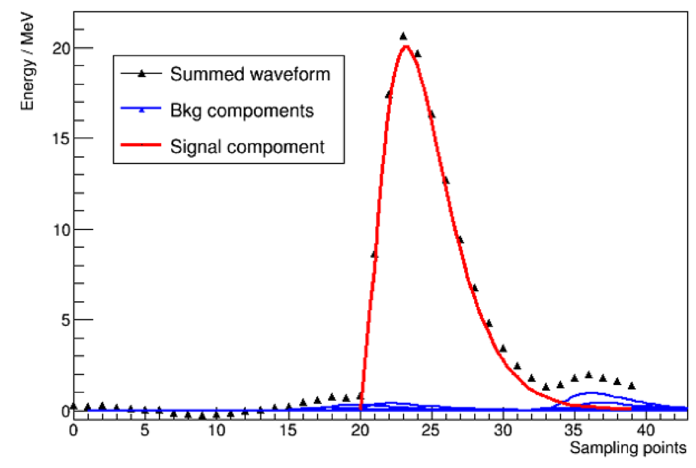


(c)

Figure 5. (a) Energy spectrum and fit result for 1 GeV γ ($5 \times 5 \times 28\,\text{cm}^3$ size crystal); Simulated performance of position resolution (b) and energy resolution (c) for crystals with vary size

Effect of pile-up and possible solution

On STCF, the event rate of secondary photons induced by beam background exceeds 1×10^9 Hz[2]. This will result in large fake photon rate and severe pile-up effect. According to GEANT4 simulation, energy resolution get **4 times worse under 50 MeV**.



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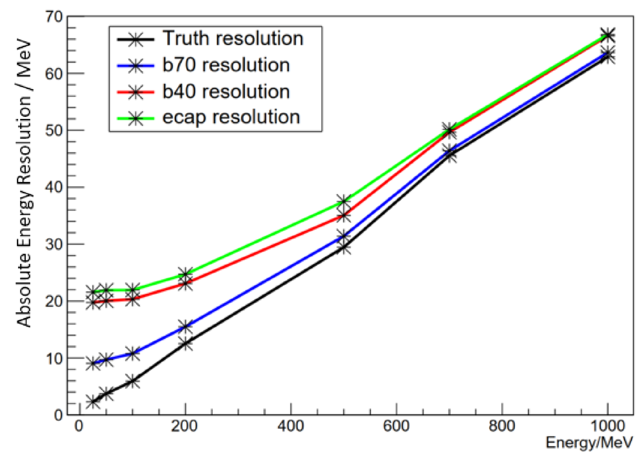
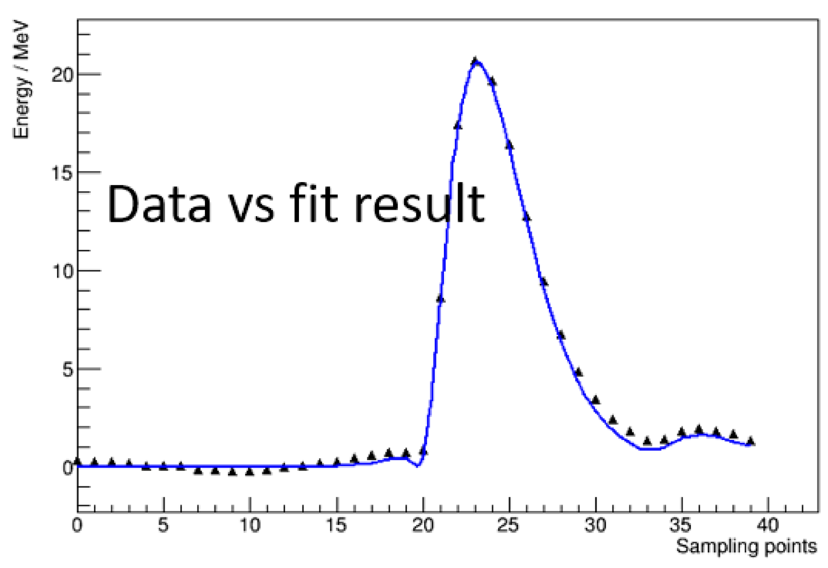


(b)

Figure 6. (a) An example of piled electronic waveform; (b) Energy resolution at different θ direction (relative to beam direction), b70: $\theta = 70°$, b40: $\theta = 40°$, ecap: $\theta = 20°$

Based on *fnnls* algorithm[3], apply a multi-pulse fit to deal with pile-up effect. By waveform simulation, for signal with electronic noise $\sigma = 0.3$ MeV:

- Signal amplitude resolution **2 times** better than peak finding method
- Signal amplitude bias reduced by **10 times**



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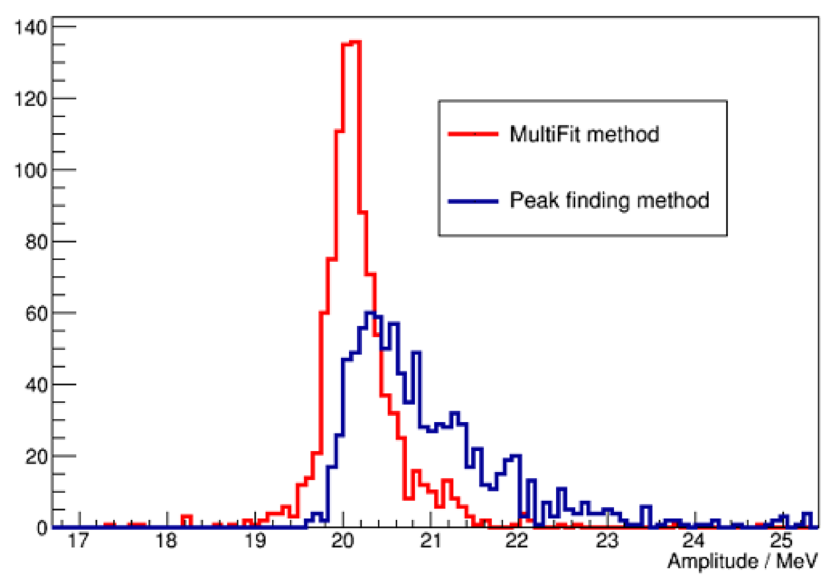

(b)

Figure 7. (a) Comparison between piled waveform and fit result; (b) Amplitude spectrum of 20 MeV signal with Multifit method and peak finding method

Conclusion

- A light yield of 155 pe/MeV is achieved based on a pure CsI scintillation counter.
- The overall geometry design and performance simulation are finished, indicating the crystal with a size of $3 \times 3 \times 28\,\text{cm}^3$ satisfies position resolution requirement.
- *fnnls* based multi-pulse fit shows decent performance to deal with pile-up effect under small electronic noise.
- Further work on improving counter SNR, counter timing performance and mitigating pile-up effect are undergoing.

References

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