Beam test results of high-density glass scintillator tiles

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Abstract. To achieve the physics goal of precisely measuring the Higgs, Z, W bosons and the top quark, future electron-positron colliders, such as the Circular Electron Positron Collider (CEPC), require that their detector systems have unprecedented high jet energy resolution. Based on the particle flow algorithm (PFA), a new high-granularity hadronic calorimeter with glass scintillator tiles (GSHCAL) has been proposed, focusing on the significant improvement of hadronic energy resolution with a notable increase of the energy sampling fraction by using high-density glass scintillator tiles. The Glass Scintillator R&D Collaboration group is dedicated to developing high-performance glass scintillators to meet the requirements of high-energy physics experiments. The minimum ionizing particle (MIP) response of a glass scintillator tile is crucial to the hadronic calorimeter, so a dedicated test system was developed for testing the performance of glass scintillator tiles. Two beam tests on large glass scintillator tiles at CERN and DESY have been carried out, and the MIP response of glass scintillator tiles was demonstrated to reach ∼ 100 p.e./MIP, which essentially meets the design requirements of the GSHCAL. This contribution will introduce the dedicated test system and also present highlighted beam test results.

1 Introduction

A new PFA-oriented CEPC 4^{th} detector system with highly granular calorimeters has been proposed for the Circular Electron Positron Collider (CEPC), including a electromagnetic calorimeter with long crystal bars [1] and a hadronic calorimeter with high-density glass scintillator tiles (GSHCAL) [2]. The GSHCAL with a higher energy sampling fraction can achieve better hadronic energy resolution, to further improve the Boson Mass Resolution (BMR). Finely segmented calorimetry with silicon photomultiplier (SiPM) readout would be a new option to be compatible with PFA. The MIP response of scintillator cells with SiPM readout is crucial for calorimetry, and the CEPC GSHCAL requires it to achieve 100 p.e./MIP.

Simulation studies indicate that the energy threshold significantly affects the hadronic energy resolution of the GSHCAL, and it is hoped that GSHCAL can achieve a low energy threshold. However, it is also necessary to consider the impact of SiPM dark noise, and the test results reveal that the dark noise of the Hamamatsu H13360-6025PE SiPM can be ignored when the threshold exceeds 4.5 p.e.. Therefore, a higher MIP response would help to achieve a lower energy threshold. On the other hand, considering the difficulties in developing glass scintillator materials, the target for the MIP response is set at 100 p.e./MIP. This means that the energy threshold for 0.1 MIP (10 p.e.) can effectively suppress the impact of noise and achieve better hadronic energy resolution.

As glass scintillator materials are still under development, a dedicated testing system has been developed to evaluate the MIP response of the latest glass scintillator tiles. Two beam tests have been conducted on two batches of large-sized glass scintillator tiles at the European Organization for Nuclear Research (CERN) and the Deutsches Elektronen-Synchrotron (DESY). The first beam test was conducted at CERN in May 2023 [3], testing the first batch of large-sized glass scintillator samples developed by the Large Area Glass Scintillator Collaboration Group. The subsequent beam test was carried out at DESY in October 2023, testing the second batch of large-sized glass scintillator tiles. In this proceedings, experimental setup and results will be introduced. Section 2 focuses on CERN beam test, followed by Section 3 with DESY beam test. Conclusions and outlooks will be covered in Section 4.

2 CERN beam test with muon

The first beam test was carried out at CERN Proton Synchrotron (PS) T09 beamline in May 2023, where the facility can provide muons, electrons (up to 5 GeV/c) and charged hadrons (up to 15 GeV/c). The first batch of 11 glass scintillator tiles were tested using 10 GeV muon beam. These glass tiles have various tile dimensions, with widths ranging from 25.6 to 40.3 mm and thicknesses within the range from 5.0 to 10.2 mm, as shown in Figure 1(a). All glass tiles were wrapped with Teflon reflector films, and read out by individual SiPM with 6×6 mm^2 sensitive area. As shown in Figure 1(b), 4 tiles can be tested simultaneously, including 1 plastic scintillator tile as a reference and 3 glass scintillator tiles.

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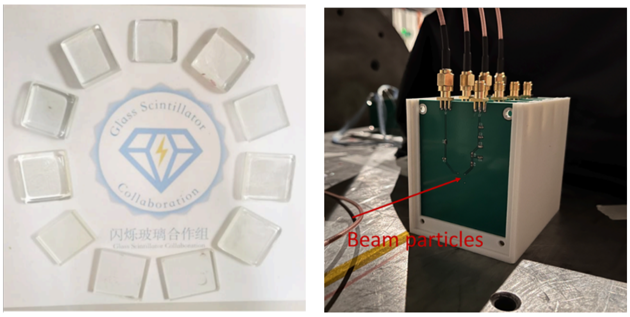


(a) (b)

Figure 1. (a) The first batch of glass scintillator tiles before wrapping and (b) CERN beam test setup.

Clear MIP signals were observed in all glass scintillator tiles. The MIP response is defined as the most probable value (MPV) obtained by fitting spectrum with Landau convoluted Gaussian function. Figure 2 shows the MIP response spectrum of the #11 glass scintillator tile measured at CERN, with an MPV is 73 p.e./MIP at a thickness of 8.7 mm. Figure 3 shows the MIP response of all glass scintillator tiles tested at CERN. The magenta points represent the measured values for glass scintillator tiles with different thicknesses. The GSHCAL requires a thickness of 10 mm for the glass scintillator tiles. To assess the performance of these tiles, assuming that the MIP response is proportional to the thickness in the ideal case, we scaled the MIP response linearly to a 10 mm thickness. As shown by cyan points in Figure 3, the scaled MIP responses of all glass scintillator tiles range from 23 to 107 p.e./MIP. In addition, a huge variation was observed between the different tiles, which were attributed to different components, molar fractions, and preparation processes.

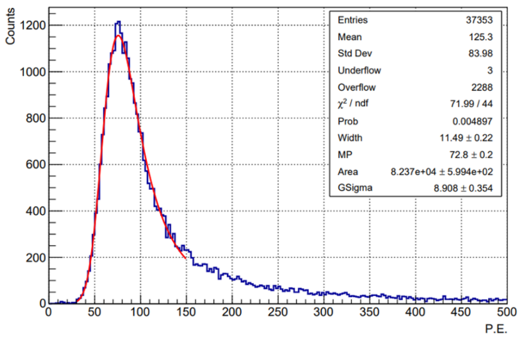


Figure 2. MIP response spectrum for the #11 glass scintillator tile tested by 10 GeV muon beam at CERN.

3 DESY beam test with electrons

The subsequent beam test was conducted at DESY TB22 beamline in October 2023, where the facility can provide an electron beam with 1-6 GeV. The second batch of 9 glass scintillator tiles, each with standard dimensions of

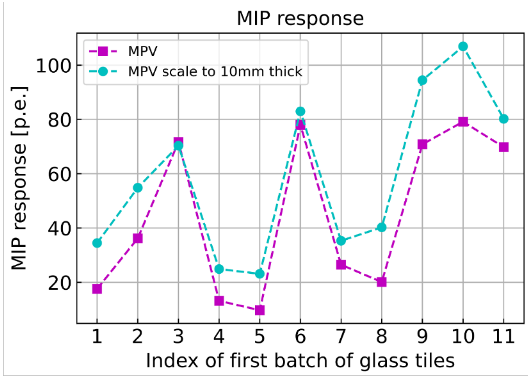
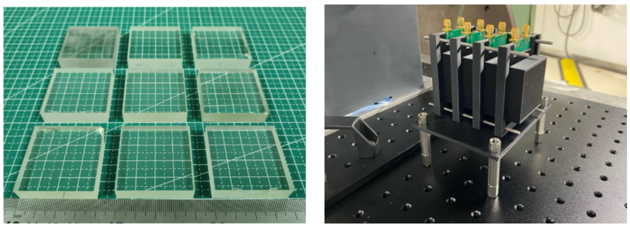


Figure 3. MIP responses of the first batch of glass scintillator tiles measured at CERN, with magenta points representing measured values and cyan points representing values scaled to 10 mm thickness. [3]

$4 \times 4 \times 1$ cm^3 as shown in Figure 4(a), was tested using 5 GeV electron beam. All glass tiles were wrapped with Teflon reflector films, and read out by individual SiPM with 6×6 mm^2 sensitive area. As shown in Figure 4(b), due to electrons not being true MIP particles, only 2 tiles could be tested simultaneously, with one plastic scintillator tile placed upstream as a reference and one glass scintillator tile placed downstream.



(a) (b)

Figure 4. (a) The second batch of glass scintillator tiles with standard dimensions before wrapping and (b) DESY beam test setup.

Due to the small substance of the plastic scintillator, high-energy electrons can be considered Minimum Ionizing Particles in the first glass scintillator tile. Besides, Geant4 simulation results also show that the energy spectrum of a glass scintillator tile exhibits similar MPV for muons and electrons, but the electron spectrum is broader. Figure 5 shows the quasi-MIP response spectrum of the #4 glass scintillator tile at DESY, and its MPV is 96 p.e./MIP. Figure 6 shows the MIP response of second batch of glass scintillator tiles, ranging from 72 to 96 p.e./MIP. In standard dimensions, the MIP response of glass scintillator tiles is very close to CEPC GSHCAL requirement of 100 p.e./MIP.

4 Conclusions and outlook

The development of glass scintillator materials specifically for the CEPC GSHCAL is in progress, with two batches of

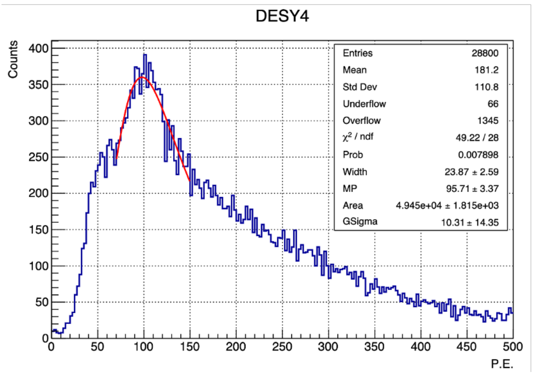


Figure 5. Quasi-MIP response spectrum for the #4 glass scintillator tile tested by 5 GeV electron beam at DESY.

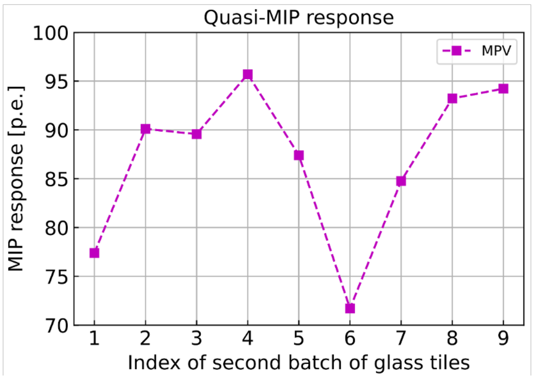


Figure 6. Quasi-MIP responses of the first batch of glass scintillator tiles with $4 \times 4 \times 1$ mm^3 size.

large-sized glass scintillator tiles were produced in 2023. A dedicated beam test system was developed and used to test glass scintillator tiles in two beam tests. All two batches of glass scintillator tiles were successfully tested and their distinct MIP signals were observed. In the first beam test, the MIP response of the best tile reached up to 80 p.e./MIP, and the scaled MIP response exceeded 100 p.e./MIP. In the second beam test, the MIP response reached up to 96 p.e./MIP with standard dimensions. The two beam test results show that it is very promising to realize the CEPC GSHCAL requirements of 100 p.e./MIP. In the future developments, our group will focus on optimizing the mass production process of glass scintillator tiles to improve the uniformity between different tiles.

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