

A plastic scintillating fiber position detector in vacuum for the test beam facility at BEPC II-LINAC^{*}

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Abstract: Two plastic scintillating fiber position detectors for charged particles have been designed, built and installed inside the vacuum tube near two sides of the DM2 deflection magnet on the E3 beam line of the test beam facility at the BEPC-LINAC. A one-dimensional position resolution of ~ 1 mm with a sensitive area of $60\text{ mm}\times 60\text{ mm}$ has been obtained for this detector.

Key words: plastic scintillating fiber, multi-anode photomultiplier tube, vacuum

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1 Introduction

With flexibility, a fast response time and a high photon yield, scintillating fibers can be used to build tracking detectors [1–3]. When a charged particle penetrates a scintillating fiber detector, photons are produced by the deposited energy of the charged particles inside the plastic scintillating fibers, and the signals of light are read out by a multi-anode photomultiplier tube. We built two plastic scintillating fiber position detectors to measure the positions of charged secondary particles which cross the DM2 [4] deflection magnet on the E3 beam line of the test beam facility at the BEPC-LINAC. These charged secondary particles (electrons, pions, protons) are produced from the interaction of the electron beam with targets such as Cu, Be or C. By using two plastic scintillating fiber detectors located at both the up- and down-stream sides of the DM2 magnet, the position of the charged particles can be measured with a resolution of ~ 1 mm to improve momentum resolution, which is needed to test some of the detectors being installed in the experimental area of the E3 beam line.

2 The construction of the plastic scintillating fiber position detector

The plastic scintillating fiber position detector consists of four layers of BCF-20 fibers, with a fiber diameter of 1 mm, and two fibers of each layer are coupled together to one channel of a multi-anode photomultiplier tube. When a charged particle penetrates the group of fibers, the signal will be read out from the coupled channel of the multi-anode photomultiplier tube. A BCF-20 [5] fiber consists of core material (polystyrene), first cladding material (acrylic), second cladding material (fluor-acrylic) and a white EMA (extra mural absorber). the core refractive index is 1.60, the refractive index of the first cladding material is 1.49, and the second one is 1.42. The output signal of the multi-clad fibers has a 60% increase over conventional single-clad fibers. With the EMA, the optical cross-talk could be eliminated.

234 fibers with a length of 320 mm are glued together, as shown in Fig. 1(a). The glued area is $60\text{ mm}\times 60\text{ mm}$. BC-600 optical cement, which has a refractive index close to that of BCF-20, is used to

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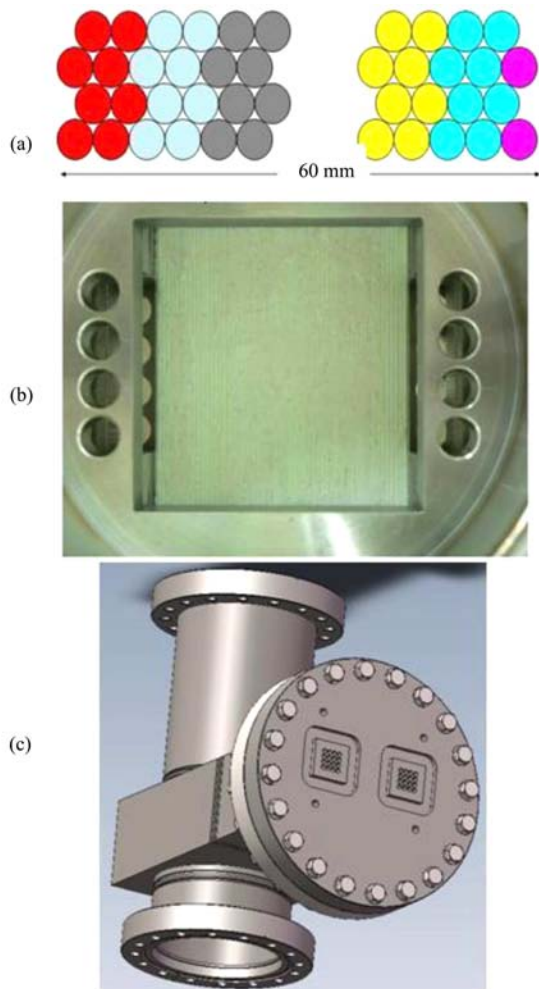


Fig. 1. (a) Scheme showing 234 fibers with a length of 320 mm glued together. Eight fibers with the same color will be coupled to one channel of a multi-anode photomultiplier tube. (b) A fiber detector located inside a vacuum chamber. (c) Drawing of a vacuum chamber with holes of 4 mm diameter, where eight fibers emerge.

glue the fibers together. The end surface of the glued area is polished, a 3M-ESR foil – whose reflectivity can reach 99% – is attached to the polished end as a reflective layer, and the fibers are finally located inside the vacuum chamber, as shown in Fig. 1(b). Eight fibers come out of a hole with a diameter of 4 mm, as shown in Fig. 1(c), and a Varian Torr Seal high-vacuum expoy is used to seal the fibers within the hole with a diameter of 4 mm. The area with 16 holes is the same as that of a multi-anode photomultiplier tube, so every hole is coupled, respectively, to a $4.2\text{ mm} \times 4.2\text{ mm}$ sensitive area of one HAMAMATSU H8711 multi-anode photomultiplier tube. BC-630 silicone optical grease is used as the coupling compound between the fibers and the multi-anode photomulti-

plier tube. The fibers are located in a vacuum to reduce the background particles which originate from the interaction of secondary particles with residual gas, even in the vacuum chamber. During data taking, the vacuum can reach 8.5×10^{-8} Torr.

3 Experimental setup and electronics

The experimental setup is shown in Fig. 2(a), which is part of the test beam facility located at the end of the BEPC-LINAC. The beam energy is 1.89 GeV and the beam current can reach 910 mA. The pulse width is 1 ns and the repeat frequency can reach 50 Hz. We chose Cu, Be, or C as a target depending on the running of the experiment. 1.89 GeV electrons bombard the target and produce the secondary particles. LQ1 and LQ2 are the two quadrupole magnets used to focus the beam, and DM1 and DM2 are the two dipoles used to deflect the beam. The plastic scintillating fiber position detectors, SH1 and SH2, are at two sides of the DM2. A gas Cherenkov counter ($\check{C}c$), scintillator counters, multi-wire proportional chambers, a silicon strip detector and a BGO crystal calorimeter are installed in the experiment area.

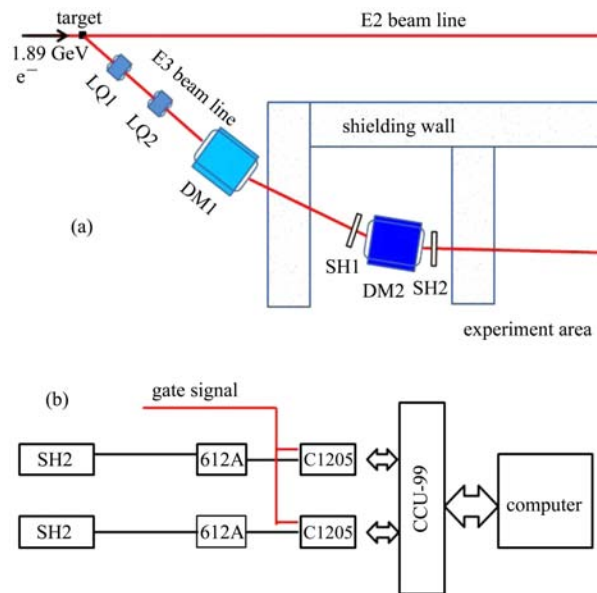


Fig. 2. (a) The experimental setup, and (b) the CAMAC data acquisition system.

When a charged particle penetrates the plastic scintillating fibers, signals from the coupled photomultiplier tube are sent to a LeCroy Model 612A module via a 50 m low-loss RF cable. The LeCroy Model 612A is a 12-channel linear photomultiplier amplifier with a gain of 10. The 16-channel CAEN

QADC (model C1205) is a CAMAC module used to measure the charge of the signal. We use the 650 pc middle range, which is 160 fc per count. The CAMAC data acquisition system is shown in Fig. 2(b). The gate signal comes from the coincidence signal of detectors in the experimental area.

4 Simulation of the energy deposition of the protons

Using GEANT4, the energy deposition of protons with an energy of 1.1 GeV in one sector of eight fibers is evaluated with the following methods. First, the proton beam penetrates into the sector that is perpendicular to the bundle axis at the middle point between two fibers of the first layer, as shown in the left picture in Fig. 3(a). Second, the evaluation method is

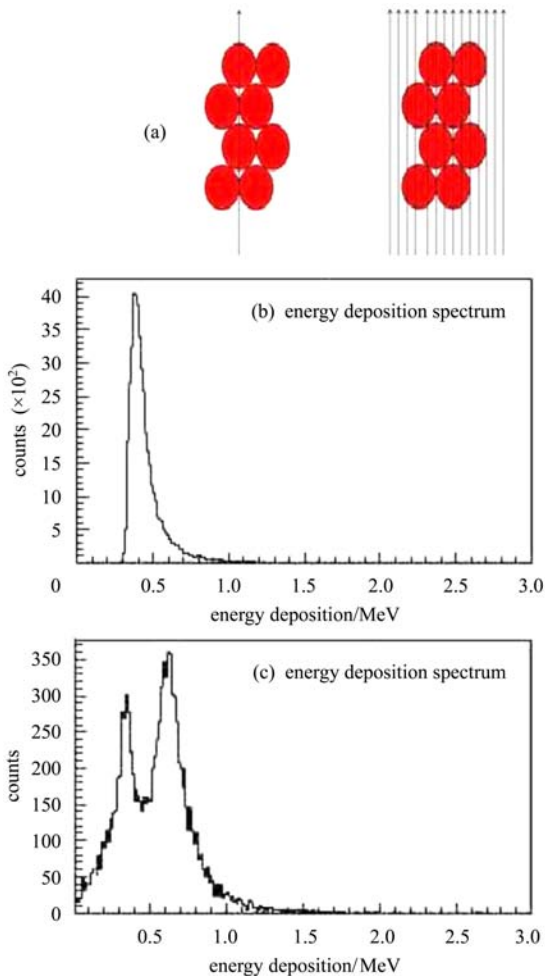


Fig. 3. (a) Two cases of the energy deposition of protons with an energy of 1.1 GeV; (b) the energy deposition spectrum with the proton beam hitting the middle position of two fibers in the first layer; and (c) the energy deposition spectrum with the proton beam hitting the region of eight fibers.

the same as the first case except the proton beam is scanned along the direction shown in the right picture in Fig. 3(a), and covers one sector of eight fibers. For the first case, the energy deposition is shown in Fig. 3(b) with a quasi-Gaussian distribution. For the second case, the energy deposition shown in Fig. 3(c) could be obviously seen, which is associated with just the staggering fiber position. The actual experiment is similar to the second case, where particles penetrate the fibers at different positions and with different lengths of fiber material. Comparing the measured charge spectrum with the maximum energy deposition shown in Fig. 3 (c), the threshold energy deposition can be set to 0.2 MeV. The signal produced by an energy deposition of more than 0.2 MeV can be recorded by the C1205 module. From Fig. 3 (c), more than 93% of the events can produce an energy deposition of more than 0.2 MeV. The detector efficiency can be estimated to about 93% at a 1.1 GeV proton energy.

5 The data-taking results

During data taking, protons with a momentum of 625 MeV/C are studied. Normally a data file includes a few thousand events. Fig. 4(a) shows a charge spectrum of one channel of the C1205 module from a recorded data file, and the peak corresponds to the

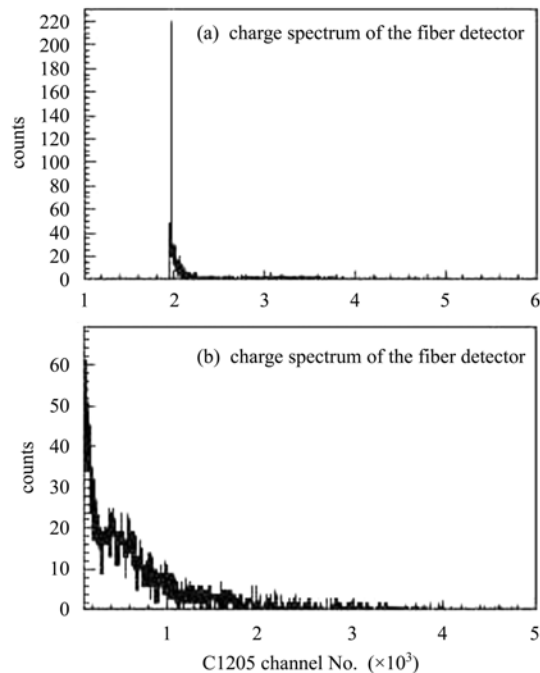


Fig. 4. (a) A charge spectrum of one channel of the C1205 module from a recorded data file; and (b) a charge spectrum of one channel of the C1205 module from 12 recorded data files.

pedestal. When a gate signal is coming, the readout of the C1205 channel without a signal is the pedestal, and the readout of the C1205 channel with a signal is a value more than the pedestal. Deducting the pedestals, the charge spectrum of one channel of the C1205 module from 12 recording files is shown in Fig. 4(b).

The threshold is set to 100. After deducting the corresponding pedestal from the readout value and

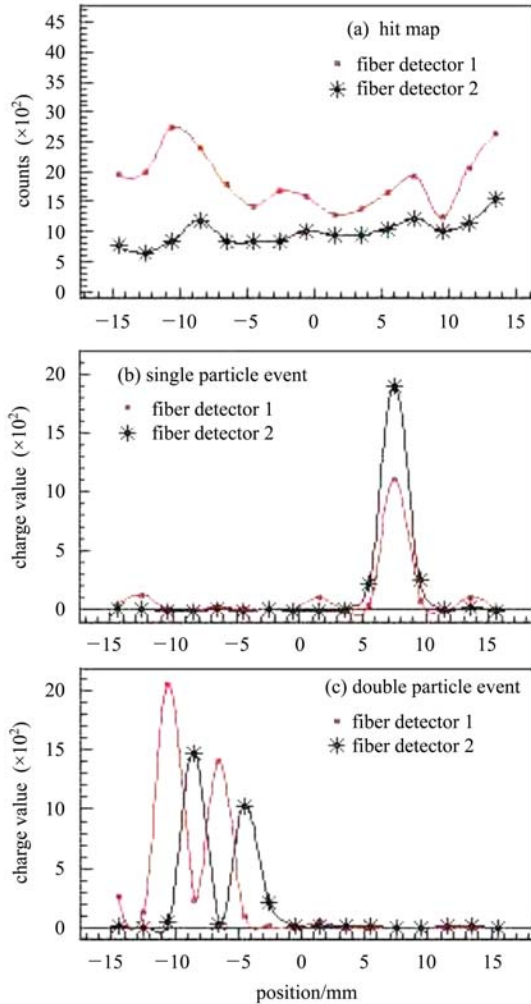


Fig. 5. (a) The hit spectra of the two fiber detectors; (b) the single particle event; and (c) the double particle event.

the net value over 100, this signal can be taken into account as a hit. The hit spectra of two fiber detectors from a recorded file are shown in Fig. 5(a). More particles hit the first fiber detector, and after the DM2, obviously less charged particles penetrate the second fiber detector. In this case, some scattered particles cannot reach the second fiber detector.

When a real event is recorded, the first and second fiber detectors record their charge information. Fig. 5(b) shows a charged particle penetrating the first and second fiber detector. This is called a single particle event, and the square and star stand for the first and second fiber detectors, respectively. The measured charge values show where the charged particle penetrates. When a particle hits the group of fibers, the charge of the signal from the coupled channel is obviously different from the other channels. The position of the group of fibers is given by the middle position of the two fibers of their first layer. Fig. 5(c) shows a double particle event, where two charged particles penetrate the first and second fiber detectors. From Figs. 5(b) and (c) we can easily discover the position where the charged particles penetrate the fibers. This shows that the positive effect of a vacuum environment is very obvious, and that the cross-talk of the multi-anode photomultiplier tube is very low. A position resolution of 1 mm can be reached.

6 Conclusion

Two plastic scintillating fiber position detectors have been installed and have proved to work well at the E3 beam line of the test beam facility at the BEPC-LINAC. The detectors provide one-dimensional particle position information with a position resolution of 1 mm, improving the momentum resolution of the magnetic spectrometer.

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