Timing Performance of Plastic Scintillators of Various Sizes in a Beam Test*

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Abstract The time-of-flight detector of the Beijing Spectrometer III(BESIII) is built with long and narrow plastic scintillator bars, with each being 2.3m long and 6cm wide. The time resolution of prototypes wrapped with aluminum film has been studied for various thickness of the scintillator using a test beam at the Institute of High Energy Physics in Beijing, China. In this paper, the position-dependent time resolution of the scintillator with a thickness of 4cm, 5cm and 6cm is presented and compared with a Monte Carlo simulation, the results show that the bar with a thickness of 5cm has the best performance.

Key words time resolution, time of flight, BESIII, scintillator, Monte Carlo

1 Introduction

The time-of-flight detector (TOF)[1] using plastic scintillation bars is powerful for particle identification (PID) of K/π with a momentum less than 1GeV/c, as in the Belle experiment[2] and the Beijing Spectrometer (BESIII)[3] currently under construction. The TOF detector can provide also the fast trigger and event timing. The PID capability mainly depends on the intrinsic TOF time resolution, which is determined by the scintillator properties, the photomultiplier tube (PMT) and electronics. The scintillator bar must be thick enough to provide the necessary light yield for the required time resolution while the bar should be as thin as possible to reduce the bremsstrahlung, the multiple-scattering, and the straggling of flying particles, as well as their energy-loss. In this paper, the timing performance of the scintillator bars with different thickness has been investigated using an 800MeV/c electron beam at the Institute of High Energy Physics (IHEP), Beijing, China.

2 Experimental setup

The layout of the apparatus of the test beam experiment and the coordinate system are shown in Fig. 1. A total of four scintillator bars with a length of 2.3m were tested, three BC-408[4] with cross sections of 4cm×6cm, 5cm×6cm, and 6cm×6cm respectively; and one EJ-200[5] with a cross section of 5cm×6cm.

The two lateral and two end surfaces of the scin-

Received 8 December 2005, Revised 13 January 2006
*Supported by BEPCⅡ Project, CAS Knowledge Innovation Program (U-602 and U-34) and National Science Foundation of China (10491305, 10225524)

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tillator bars were diamond-milled by manufacturers in order to minimize losses due to surface imperfections; the other lateral surfaces were kept intact as its casting form. A phototube (R5924, Hamamatsu) was placed at each end of the bar without silicon grease. The scintillator was wrapped with aluminum film (shiny aluminum side in contact with the scintillator), and then with black plastic fabric for light-tight.

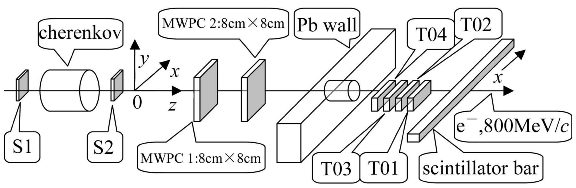

Fig. 1. Experimental setup for the TOF beam test.

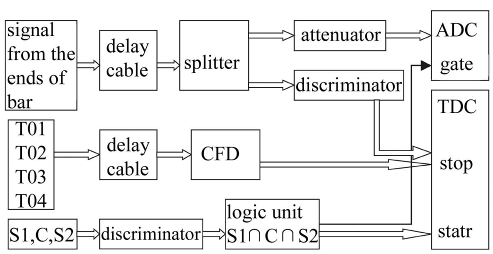

Fig. 2. Schematics of the readout system.

The 800MeV/c electron (e^-) beam shoots into the bar along z axis perpendicular to its lateral surface and passes through the scintillator with different thickness of 4cm, 5cm, and 6cm respectively. The origin of the x coordinate is defined at the center of the scintillator bar along its long axis. The beam is triggered by scintillation counters, S1 and S2, together with a Cherenkov detector to select electrons, as shown in Fig. 1. The two multiwire proportional chambers (MWPC) can define the position of incident particles. A lead brick wall is built to shield background particles from entering the scintillator. The reference start time is given by plastic scintillators of the type BC-420, T01, T02, T03 and T04, located close to the scintillator bar. With a cross section of 2.5cm×8.0cm and a thickness of 0.3cm, they are coupled to the Hamamatsu phototube H6533 with silicon grease. Signals from reference scintillators, T01, T02, T03 and T04, are fed into the constant fraction discriminators (CFD), which can correct the time-walk effect. The centers of the apparatuses except the scintillator bar are all on the beam line, and the bar can be moved along the x axis on a table. The readout system is shown in Fig. 2, including four ORTEC 583B CFDs, two LeCroy 623B discriminators, two CAEN N109 attenuators, a LeCroy 365AL logical unit, a LeCroy 2249A ADC and a CAEN C414 TDC.

3 Results and discussions

3.1 Time resolution of the reference start

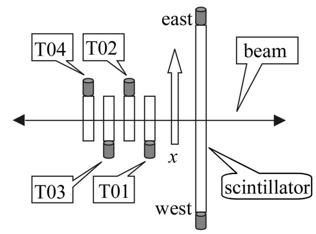

Fig. 3. The arrangement of T01, T02, T03, T04 counters.

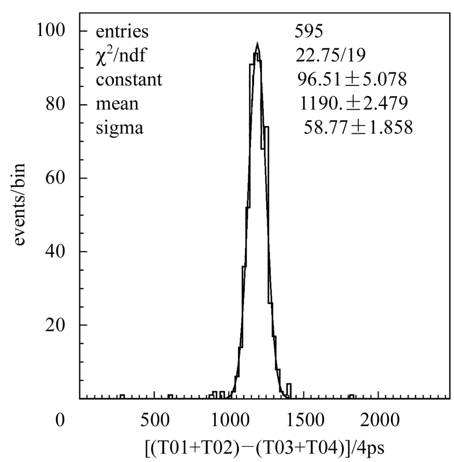

Fig. 4. Time resolution of the reference start (T0).

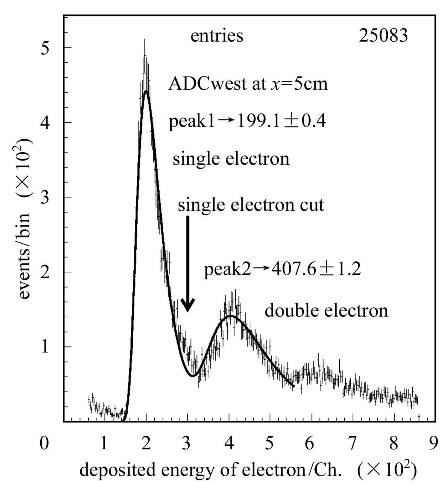

Fig. 5. Deposited energy spectrum(ADCwest) of e^- for BC408 (5cm×6cm) at x=5cm.

The reference time scintillators, T01, T02, T03, T04, are arranged as shown in Fig. 3, and located as close as possible from each other.

The resolution of the reference time,

$$T0=(T01+T02+T03+T04)/4, \tag{1}$$

can then be obtained as shown in Fig. 4. After a selection to single electrons by using signal amplitude as shown in Fig.5, a Gaussian fit gives

$$\sigma_{T0}=59\pm2\text{ps}.$$

3.2 Intrinsic time resolution

The measured average time as a function of incident position x is shown in Fig. 6. A linear fit yields the effective speed of light of scintillators along x-axis. The BC-408 and EJ-200 with the same dimension have the same speed of light within experimental errors.

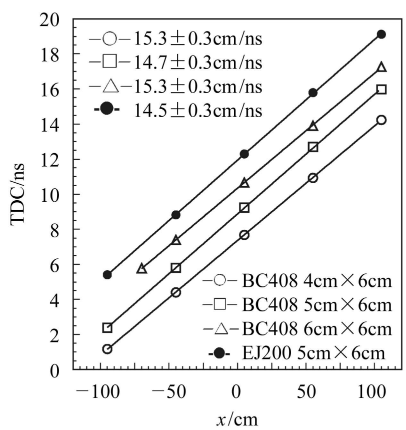

Fig. 6. The average TDC time as a function of x.

The average time (T_{av}) and its resolution are calculated as the following[6].

$$T_{\text{av}}=\frac{T_{\text{w}}/\sigma^2_{T_{\text{w}}}+T_{\text{e}}/\sigma^2_{T_{\text{e}}}}{1/\sigma^2_{T_{\text{w}}}+1/\sigma^2_{T_{\text{e}}}}, \tag{2}$$

Where T_{w} (T_{e}) is the measured timing of the pulse from the west (east) end of the bar, corrected to the beam incident position and the signal amplitude by the following relation:

$$T_{\text{w}}(e)-T0=C1+C2\times X+C3/\sqrt{Q}, \tag{3}$$

where X is the incident position of particles on the scintillator bar, and Q the charge of the signal.

In such a way the effect of the start trigger is replaced by the reference time, which can be measured as discussed in Section 3.1. Therefore, the intrinsic TOF time resolution of the scintillator bar is given by

$$\sigma_{T_{\text{w}(e)}}=\sqrt{\sigma'^2_{T_{\text{w}(e)}-T0}-\sigma^2_{T0}}. \tag{4}$$

The average time resolution of the scintillator bar from both ends, after the correction of the reference start time of 59ps, can be obtained by the following relation:

$$\frac{1}{\sigma^2_{T_{\text{av}}}}=\frac{1}{\sigma^2_{T_{\text{w}}}}+\frac{1}{\sigma^2_{T_{\text{e}}}}. \tag{5}$$

The measured intrinsic time resolution $\sigma_{T_{\text{av}}}$ of scintillators as a function of the incident position of particles is shown in Fig. 7. These points are asymmetric due to the difference of two R5924 PMTs. For the same type of scintillator BC-408, the bar with a thickness of 4cm wrapped with the aluminum film has the worst resolution. While the bar with a thickness of 5cm has the best resolution, not the one with a thickness of 6cm, as one naively expected.

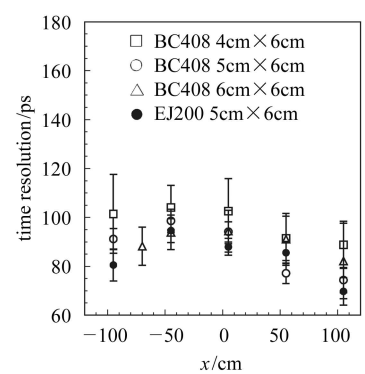

Fig. 7. Intrinsic time resolution as a function of x.

Hence, a study based on Monte Carlo simulation is performed to understand this observation.

3.3 Monte Carlo simulation

A detailed Monte Carlo simulation[7] using the Geant4 package is performed for electrons of 800MeV/c hitting the scintillator of type BC-408. The interaction of particles with matter, their energy deposition, and the light transport (Fig. 8) in the scintillator is taken into account by the Geant4 package. The main parameters in the simulation are listed in Table 1, the index of reflection of the wrapping materials (Al film) used in the beam test, measured at the National Institute of Metrology of China, is 0.85. The electron collection factor[2] of PMT is 0.6, due to the fine mesh dynode structure. The bulk light attenuation length of the scintillator is set according to its effective attenuation length in the beam test.

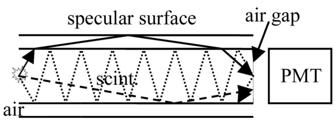

Fig. 8. Photons collection by PMT.

Table 1. Main parameters of scintillator, PMT, air gap and wrapping in the simulation.

scintillator (BC-408)	
base	polyvinyl toluene
density(g/cm^3)	1.032
refractive index	1.58
rise time	0.9ns
decay time	2.1ns
bulk light attenuation length	4.8m
wavelength of maximum emission	425nm
FM PMT (R5924)	
effective photocathode diameter	39mm
transit time spread	440ps
quantum efficiency	~0.21
electron collection factor	0.6
rise time	2.5ns
wrapping (Al film)	
reflective index	0.85
air gap	
from scintillator to wrapping	~0.5mm
from scintillator to PMT	~0.1mm

The effective attenuation length of BC-408 with a thickness of 5cm from simulation and beam test is 357±7cm and 361±5cm respectively, the same within errors. The time resolution of simulation as shown in Fig. 9, is consistent with that of beam test if the difference of the two PMTs in the beam test is considered.

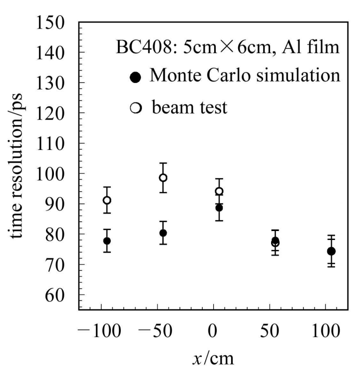

Fig. 9. Time resolution of simulation as function of x.

All the input parameters except the thickness of scintillator remain unchanged; the number of photoelectrons collected by PMT as a function of thickness of the scintillator bar is shown in Fig. 10. Although the bar with a thickness of 6cm emits more photons as the particles pass through it, the number of photons accepted by PMT does not increase largely since the area of the photocathode of PMT is fixed. This is the reason why the 5cm thick scintillator has the best resolution.

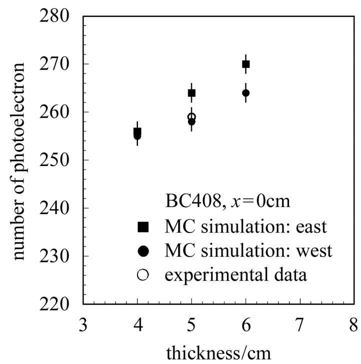

Fig. 10. The number of photoelectron as a function of thickness of scintillator.

4 Conclusions

A beam test of the scintillator with different thickness has been performed. The results are summarized as the following:

1) The effective speed of light BC-408 (5cm×6cm) and EJ-200 (5cm×6cm) is 14.7cm/ns and 14.5cm/ns respectively, the same within experimental error.

2) The BC-408 scintillator bar with a cross section of 5cm×6cm has the best time resolution. Both BC-408 and EJ-200 bars with the same dimension reach 90ps at the middle of the bar.

3) The results of simulation show that the effective cathode area of PMT limits the improvement of time resolution of the bar with a thickness of 6cm, and the scintillator bar with a cross section of 5cm×6cm fits best to the R5924 PMT.

Therefore the scintillator with a cross section of 5cm×6cm is selected for the BESIII TOF detector.

References

1 Klempt W. Nucl. Instrum. Methods, 1999, **A433**: 542

2 Nam J W et al. Nucl. Instrum. Methods, 2002, **A491**: 54

3 BESIII Preliminary Design Report. http://epc.ihep.ac.cn/epc/design/design1.htm

4 http://www.detectors.saint-gobain.com/Media/Documents/S0000000000000000003/organics_brochure_2001.pdf

5 http://www.eljentechnology.com/ej-200.html.

6 Denisov S et al. Nucl. Instrum. Methods, 2002, **A478**: 440

7 ZHANG Li-Ming et al. Meas. Sci. Technol., 2004, **15**: N54-57

束流实验中不同尺寸塑料闪烁体的时间特性*

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摘要 北京谱仪(BESⅢ)中的飞行时间探测器将采用长2.3m宽6cm的长条形塑料闪烁体. 利用北京高能物理研究所的实验束流对铝膜包装的不同厚度闪烁体的本征时间分辨进行了研究, 给出了4cm, 5cm和6cm闪烁体的时间分辨, 而且用蒙特卡罗模拟做了比较, 结果表明5cm厚的闪烁体具有最佳性能.

关键词 时间分辨率 飞行时间 北京谱仪Ⅲ 闪烁体 蒙特卡罗

2005 – 12 – 08 收稿, 2006 – 01 – 13 收修改稿

*北京正负电子对撞机重大改造工程项目, 中国科学院知识创新基金(U-602和U-34)和国家自然科学基金(10491305, 10225524)资助

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