The Progress of TOF on BESIII

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A new general detector, BESIII, is under-construction for the Beijing Electron Positron Collider II (BEPCII) operated at a center of mass energy of 2-5 GeV with a designed highest luminosity of 1x1033cm-2s-1. The Barrel TOF on BESIII is designed as two layers of scintillator bar directly coupled with fine-mesh PMTs at two ends. TOF's main target is to identify the pion and kaon with its good time resolution of 90 ps. Some experiments and testing are submitted: the radiation damage character of scintillator, the properties of fine-mesh PMT under high magnetic field, the beam test on the TOF module and the electronics property.

1. DESIGN OF TOF

Four detectors, Drift Chamber, Time Of Flight (TOF), Electromagnetic Calorimeter and Muon detector, will be installed on the new Beijing Spectrometer (BESIII)[1]. TOF is placed between DC and EMC(see Fig. 1). It is made of barrel and endcap. The solid coverage of the barrel TOF is 0.82, and that of the endcap TOF is from 0.85 to 0.95. The radius of barrel TOF is from 81 cm to 92.5 cm, and its effective length is 232 cm.

The barrel TOF is designed to use two layers of plastic scintillator bar directly coupled with FM-PMT. The endcap TOF will use the fan-shaped scintillators instrumented with PMTs at inner radius. The scintillator of BC-408 by Saint-Gobain will be used for barrel because of its longer attenuation length and BC404 will be for endcap because it is shorter and has larger light output and faster time response.

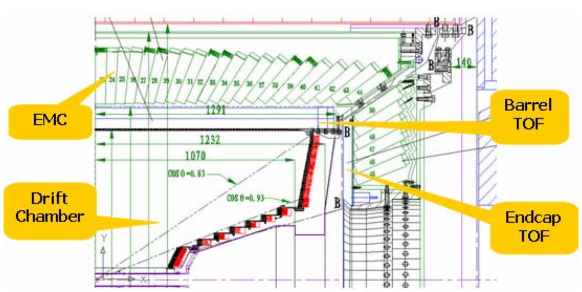


Fig. 1 Schematics of TOF on BESIII

TOF is to measure the flight time of charged particles for particle identification (PID) by comparing the measured time against the predicted time, which can be obtained from the charged particle track and the momentum given by Drift Chamber. Its capability of PID is determined by the flight time difference of particles of different types and time resolution. The former is determined by the flight path and the latter is related to many items as listed in table 1.

Table 1 Analysis of time resolution for PID

Item	Barrel time reso.	Endcap time reso.
Intrinsic time reso. of one TOF layer for 1 GeV muon	80~90 ps	80 ps
Uncertainty from bunch length	15 mm , 35 ps	15 mm , 35 ps
Uncertainty from bunch time	~20 ps	~20 ps
Uncertainty from Z position	5 mm,25 ps	10 mm,50 ps
Uncertainty from electronics	25 ps	25 ps
Resolution of expected time of flight	30 ps	30 ps
Time walk	10 ps	10 ps
Total time reso, one layer of TOF for 1 GeV muon	100~110 ps	110~120 ps
Total time reso, double layer of TOF for 1 GeV muon	90 ps	

The target of the time resolution of one layer for 1 GeV muon is about 100 ~ 110 ps. For kaon and pion, it will increase by 20% because of strong interaction as experienced at BESI, BESII and BELLE. For the double TOF, intrinsic time resolutions are reduced by a factor of $\sqrt{2}$. Fig. 2 shows the K/π separation capability for one layer or double TOF. The momentum of 2σ K/π separation can go up to 0.8 GeV/c or 0.9 GeV/c for single and double layer of TOF respectively.

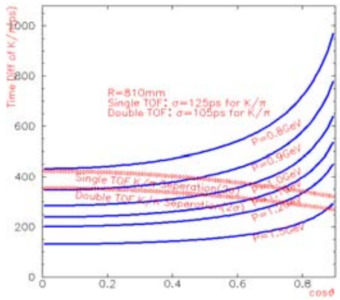


Fig.2 Kaon and pion separation capability.

2. RADIATION DAMAGE ON PLASTIC SCINTILLATORS

Three samples of scintillator, EJ-200, BC408 and BC404, were measured after different dose of radiation[2]. Each sample was machined to be a cylinder with a length of 6 cm and a diameter of 3 cm. Their transverse sections were polished , and cleaned with lower alcohols before every measurement, but the side surfaces were left intact. Moreover, all the samples were stored, irradiated and measured in air. They were irradiated by two 60Co sources, 1 Ci and 5 M Ci. The dose rate, duration time and the total irradiation dose of each exposure are listed in table 2.

Table 2 Irradiation data for all the samples

No. radiation	Dose rate (Gy/min)	Time (min)	Total irradiation dose (Gy)
1	3.7×10-4	1540.2	0.57 ± 0.04
2	8.3×10-3	2722.8	22.6 ± 0.1
3	8.3×10-2	865.2	71.8 ± 0.9
4	12.5	48	602 ± 24
5	52.7	273	14387 ± 104

Results of emission and transmittance of all the samples before and after irradiation are presented in Fig.3 The emission peak is located at about 425 nm for BC-408 and EJ-200, while at about 407 nm for BC-404. No changes have been observed before and after irradiation.

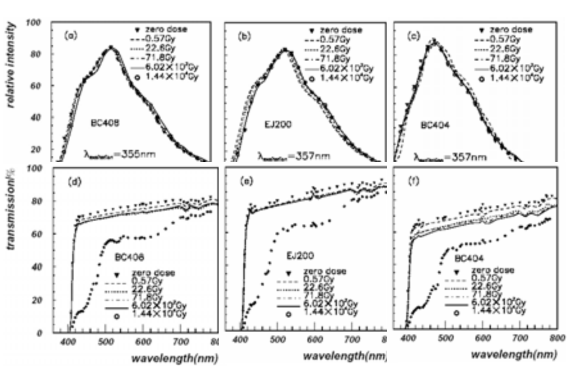


Fig. 3 Emission and transmission spectra before and after irradiation

The absorption edge of BC-408 and EJ-200 is at about 400 nm, while that of BC-404 at about 390 nm. Irradiation has no effect on the transmittance for a dose less than 600 Gy. When irradiation dose reaches 1.4×10^4 Gy at a dose rate of 52.7 Gy/min, the samples are obviously destroyed. They became yellow. However the yellow color tended to disappear with elapsing of the time from outside towards inside.

The actual light yield defined as the number of observed photoelectrons for unit energy deposit (in MeV), is calculated by the following expression $LY = P_P/(P_{SPE}\times E_\gamma)$, where E_γ is the $\gamma - ray$ energy released by ^{241}Am in unit of MeV; P_{SPE} is the peak position of the single photoelectron and P_P is the peak position of full energy.

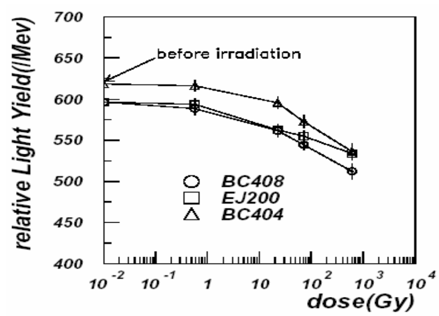


Fig. 4 Light yield versus dose

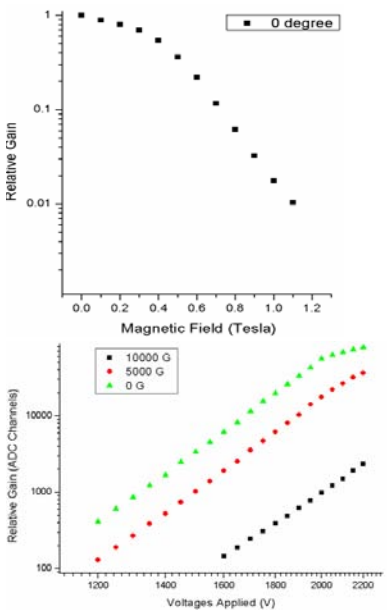
The light yield as a function of radiation dose is presented in Fig. 4. All the samples lose their light yield when radiation dose increase. At 600 Gy, the light yield loss is 14.1% for BC-408, 13.4% for BC-404, and 10.6% for EJ-200. When radiation dose reaches 1.4×10^4 Gy, the light yield of all samples disappear.

The conclusions for the radiation test on scintillator: 1) For irradiation dose up to 600 Gy, the transmittance of the samples is almost unchanged. A substantial change happens at a radiation dose of 1.4×10^4 Gy; 2) After irradiation, the shapes of the emission spectra of all the samples remain unchanged, even after the samples are significantly damaged as irradiation dose reaches 1.4×10^4 Gy; 3) The light yield of all the samples decreases when the radiation dose increases. BC-404 has the maximum light yield, while BC-408 has similar light yield compared with EJ-200.

3. TEST OF PMT UNDER STRONG MAGNETIC FIELD

The gain of PMT is influenced much by magnetic field, which disturbs the transmitting electrons in PMT. But the shield for magnetic field can't be used for PMT on BESIII because its uniformity is needed by Drift Chamber. So fine-mesh PMT R5924 by Hamamatsu is used for TOF. It can keep some gain under strong magnetic field because of its special structure. Its 19 dynodes are made up of fine-mesh, which has many apertures to let electrons go through. Also they are very close and the distance between two adjacent fine-meshes is about 1mm.

We did some tests to check the variation of its gain under magnetic field [3]. Fig. 5(a) shows that the gain will decrease about a factor of two. This is why we put a preamp for the PMT. It is known that the relationship of the gain and the HV is exponential and the gain goes to near saturation when the HV is high enough. Fig. 5(b) shows that the HV of saturation becomes higher with magnetic field than that without it. Thus the HV for fine-mesh PMT can be set bigger under magnetic field and so the gain can increase some. Page numbers are included to assist authors with page length. However, page numbers may change upon compilation of the entire volume of the Proceedings.



(a)

(b)

Fig. 5 The variation of relative gain of fine-mesh PMT with magnetic field and HV.

4. BEAM TEST OF TOF PROTOTYPE

The measurements were performed[4] on a test beam setup at the Institute of High Energy Physics, Beijing, China. The experimental setup and electronics are shown in Fig.6.

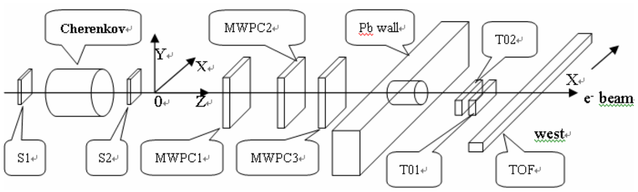


Fig. 6 Experimental setup for TOF on test beam

Electron beam with a momentum of 800 MeV/c was selected. The scintillator, 230 cm long with a cross-section of 5×6 cm^2 was coupled with R5924 PMT at each end without silicon grease. Two reference time plastic scintillators, T01 and T02, were coupled with H6533 PMTs with silicon grease. The time resolution of reference and electronics were measured to be 58 ps and 20 ps.

Five different wrapping materials, Al film (used by BESII), Tyvek (two layers), Teflon, Millipore and ESR[5] (Vikuiti^{TM} Enhanced Specular Reflector), were used for the experiment.

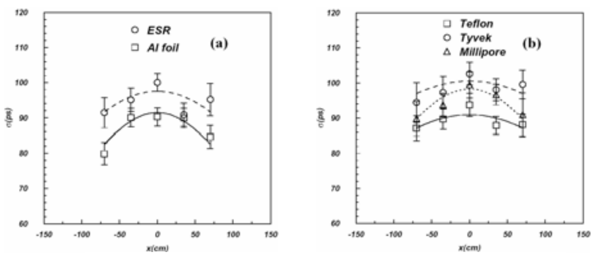


Fig. 7 The time resolution for barrel TOF with different reflection wrapping: (a) specular (b) diffusion reflection.

After correction to amplitudes and positions, the time resolutions can be obtained. They are shown in Fig. 7 (a) and (b). The time resolution wrapped with Al film or Teflon is better than that wrapped with other materials. Similar results using Al foil and Tyvek are observed in [6]. Fig. 8 (a) and (b) show the amplitude spectra of the scintillator wrapped with different reflective materials. Fig. 8 (c) illustrates the reflectivity spectra of the materials and the transmission spectrum of scitillator. Although the reflectivity of ESR, Teflon, Tyvek and Millipore are similar, the signal amplitude of the scintillator wrapped with ESR is the highest. It is obvious that the PMT can collect more photons when the bar is wrapped with a specular reflective material.

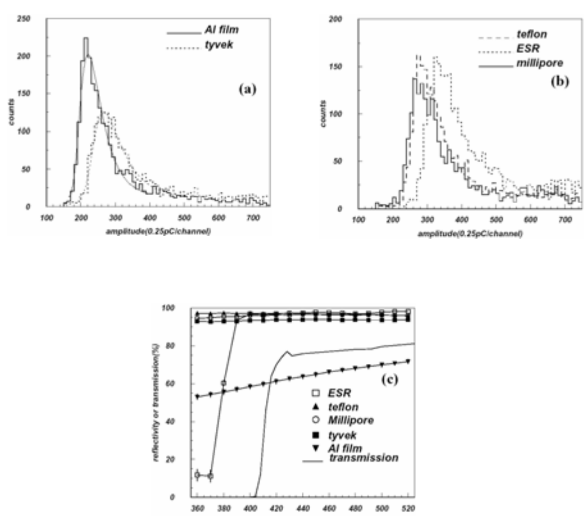


Fig. 8 Comparisons of (a) (b) amplitudes and (c) reflectivity for different wrapping materials.

Besides the above beam tests on wrapping material, a prototype test for Barrel TOF had been finished, which included two layers of scintillator with Al foil wrapping, PMT, preamp, 18 m cables and electronics. Also the test was done while other system, like DC and EMC, were working. The results of time resolution are shown in Fig. 9, electron: 94±3ps, π: 104±11ps, proton: 70±2ps.

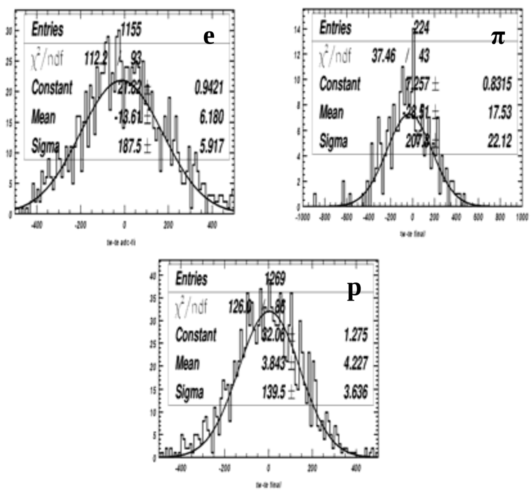


Fig. 9 Beam test of prototype of barrel TOF of double layers. The time resolution of one layer can be extracted from the two layers' subtracting.

The above test is for barrel scintillator which is a long bar. For shorter fan-shaped scintillator of endcap, the beam test had been performed too and the results were different. The scintillator of BC 404 and the wrapping material of ESR can give better time resolution for endcap

5. ELECTRONICS OF TOF

TOF electronics system composes of Pre-Amplifiers, Front End Readout Modules (FEE) and its corresponding FEE_Rear Modules, Clock Generator and Fanout Modules, and the Fast Control Fanout Modules (Fig. 10).

1) Differential Pre-Amplifiers

The Pre-Amplifier drives the differential output to FEE module, it provides the advantage of common noise resist and a large linearity dynamic range (0 ~ 4 V). The Pre-Amplifier is designed with the factor of 10, big bandwidth (rising time lower than 2 ns), low noise (equivalent input noise level less that 1mV P-P).

2) HPTDC and online Compensation

The TDC chip employed in FEE module is HPTDC version 1.3, developed in the Micro-electronics group at CERN. The very high mode resolution (25 ps) and high integration level of 32 channels per TDC chip provide the way of time resolution. But the internal crosstalk caused by logic core leads to the great Integral-Nonlinearity, which makes the time resolution in very high mode resolution bad (about 58 ps). The online compensation of FEE module can correct it to the acceptable time resolution, less than 25 ps .

3) Charge-to-Time Converter

The Charge-to-Time Converter Circuit in FEE module transforms the pulse's charge information to the time interval. Then, the pulse height dependence information of 16 channels can be measured by a HPTDC, instead of 16 ADCs. This makes the FEE modules' integration level very high, and the power consume low.

4) Clock System

TOF electronics provide the very strict clock synchronous with the beam. The clock system fans 28 channels clock signal in PECL level to FEE modules, with jitter lower than 20ps, and provide a fiber channel for other BES III electronics system clock.

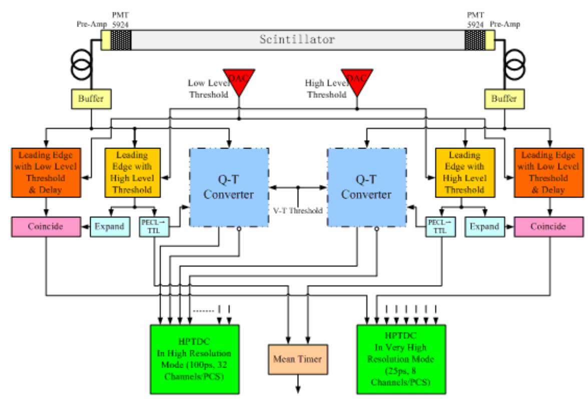


Fig. 10 Diagram of TOF Electronics (Barrel)

6. SUMMARY

The TOF on BESIII is under construction and many tests have been done. The plastic scitillator can endure ten years for a dose rate of about 100~1000 rad/year. The 19-dynode FM PMT R5924 connecting a preamp with a factor of 10 can work under 1 Tesla. The scintillator and its wrapping are chosen to be different for barrel and endcap TOF because of their different shape, size and PMT-coupling method. BC408 with Al foil wrapping is used for barrel and BC404 with ESR for endcap. Beam test shows that the prototype can give a about 90 ps time resolution for 800 MeV electron. The preamp with fast response and low noise are finished and the time jitter of electronics is less than 25 ps.

Acknowledgments

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