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Study of the TOP counter performance with the 2 GeV/c positron beam at LEPS

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The TOP (Time-Of-Propagation) counter is a novel ring-imaging Cherenkov detector developed for particle identification in Belle II. A prototype of the TOP counter with almost the final design was tested with the 2 GeV/c positron beam at LEPS (Laser Electron Photon facility at SPring-8). With these beam data, the optics of the TOP counter and the performance of the photodetector, MCP-PMT (Micro-Channel-Plate Photomultiplier Tube), were studied.

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1. The TOP counter in Belle II

The Belle II experiment [1] is a Super B flavor factory experiment at the SuperKEKB accelerator [2]. It aims to search for contributions from new physics, which could appear in discrepancies from the Standard Model expectation. To extend the physics reach, a novel Cherenkov detector, TOP counter [3, 4, 5, 6, 7, 8], is used for particle identification in Belle II. The goal is to identify up to 3 GeV/c kaons and pions with a pion efficiency of 95% and a fake-pion rate of 5% or better.

The TOP counter mainly consists of a 2.7 m long quartz radiator bar, two rows of 16 micro-channel-plate photomultiplier tubes (MCP-PMTs) [9, 10, 11, 12] at the end of the quartz and a spherical mirror at the other end as shown in Fig. 1. The Cherenkov light generated in the quartz by a charged particle is internally reflected on the quartz surfaces and is propagated toward the MCP-PMT array. The time of propagation depends on the Cherenkov angle and it is different by ~ 100 ps between a 3 GeV/c kaon and pion. By measuring the time of propagation of the Cherenkov light as well as the time of flight of the charged particle, the TOP counter identifies a kaon and pion. Therefore it is essential for the TOP counter to propagate the Cherenkov light without distortion and to detect each photon with a time resolution better than 50 ps. The propagation without distortion is realized by polishing the quartz bar to have a flatness of 6.3 μm or less and a roughness of 5 Å rms or less (for the largest surfaces). The MCP-PMT is capable of detecting single photons with less than 40 ps transit time spread. It has a NaKSbCs photocathode and the quantum efficiency is about 28% at 380 nm. To study the TOP counter performance, a prototype TOP counter was tested with the 2 GeV/c positron beam at LEPS (Laser Electron Photon facility at SPring-8) [13].

2. Beam test at LEPS

The prototype TOP counter was close to the final design. The major differences were the shorter quartz bar length by 61 mm and the readout electronics. For this beam test, a front-end readout electronics based on a constant fraction discriminator (CFD) and VME TDCs (CAEN V1290A) were used. The time resolution of the TDC is about 20 ps with dedicated calibration. Figure 2 shows the CFD front-end readout with 2×16 MCP-PMTs mounted on the quartz bar. Due to the limited number of the TDC modules, the sixteen channels of each MCP-PMT were

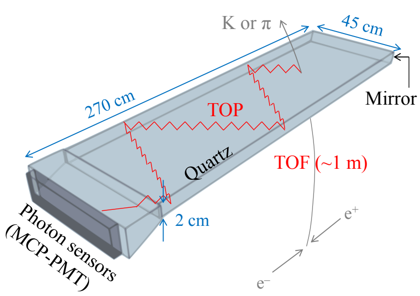

Figure 1: Schematic view of the TOP counter. An example of a charged particle (kaon or pion) trajectory and one path of the Cherenkov light in the quartz is indicated in this figure.

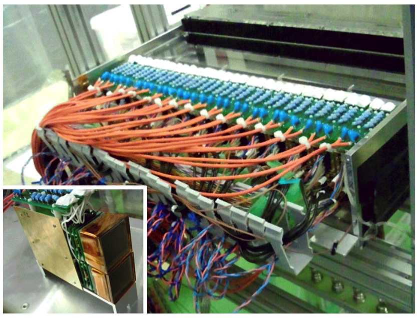

Figure 2: Photograph of the CFD front-end readout. The inset shows one of the readout module with two MCP-PMTs.

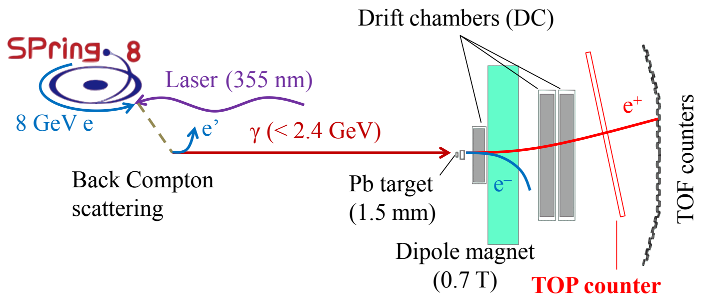

Figure 3: Schematic view of the LEPS beam line and the setup of the beam test.

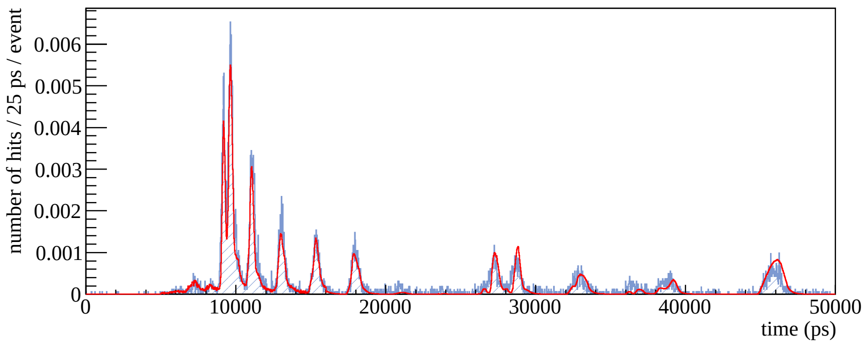

Figure 4: Distribution of the time of propagation for the central channel measured in the beam test (hatched histogram). The PDF (solid line) is overlaid. The vertical axis is normalized to the number of hits in an event.

combined into four by wiring four channels together at the PMT socket. Thus there were 8×16 channels in total for the readout.

The setup of the beam test is shown in Fig. 3. In the LEPS beam line, the high energy photon beam (less than 2.4 GeV) is produced by the backward Compton scattering of 355 nm laser photons on the 8 GeV electron beam in the SPring-8 synchrotron. In this beam test the photon beam impinged on a 1.5 mm thick Pb target to create electron and positron pairs. The momentum of the pairs was measured by the LEPS spectrometer; a dipole magnet operated at 0.7 T, three drift chambers and a wall of TOF counters. To trigger on 2 GeV/c positrons, two pairs of 40×40 mm^2 and 5×5 mm^2 scintillation counters were placed between the drift chamber and the TOF counters. The prototype TOP counter was put between the scintillation counter pairs. The largest surface of the quartz was normal to the triggered beam. The beam hit position on the quartz was 135 cm away from the MCP-PMT array. The TOF counters were used to reject events with electromagnetic showers: events where only one of the TOF counters had a hit by the beam were used for the analysis. The beam timing was obtained from the accelerator RF signal.

Figure 4 shows the distribution of the time of propagation for one of the MCP-PMT channels at the center of the quartz bar. The first peak around 9 ns consists of hits by the Cherenkov photons generated toward this MCP-PMT channel; the second, third, fourth peaks correspond to the Cherenkov photons generated in the other directions and reflected on the quartz bar side once, twice, three times, respectively; the Cherenkov photons reflected on the mirror make the peaks after 27 ns. The hits earlier than the first peak originate from the Cherenkov photons by the electromagnetic showers generated at the material in front of the TOP counter and in the quartz bar.

The probability density function (PDF) calculated analytically is overlaid in Fig. 4. It agrees with the beam data. With the agreement of the height of each peak, one can conclude that the following parameters are well understood; the internal surface reflectance and bulk transmittance of the quartz bar, the quantum efficiency of the MCP-PMTs and its dependence on the photon incident angle and polarization [14]. The width of each peak corresponds to the chromatic dispersion of the quartz and the timing resolution of the MCP-PMT and electronics.

To evaluate the performance of the TOP counter, the incident particle velocity β is reconstructed event-by-event by calculating the likelihood with the PDF as a function of β. The analysis is ongoing.

3. Conclusion

The TOP counter is a novel Cherenkov detector for particle identification in Belle II. A prototype of the TOP counter whose design was close to the final one was built and tested with the 2 GeV/c positron beam at LEPS. In the test, the CFD and the VME TDC were used for the readout. The distribution of the time of propagation was obtained as expected. Therefore it can be concluded that the optics of the TOP counter and the performance of the MCP-PMT are well understood.

References

[1] T. Abe, et al., KEK-REPORT-2010-1, 2010.

[2] Y. Ohnishi, et al., *Prog. Theor. Exp. Phys.* **2013**, 03A011.

[3] M. Akatsu, et al., *Nucl. Instr. and Meth. A* **440** (2000) 124.

[4] T. Oshima, *ICFA Instrumentation Bulletin* **20** (2000) 2.

[5] T. Oshima, *Nucl. Instr. and Meth. A* **453** (2000) 331.

[6] Y. Enari, et al., *Nucl. Instr. and Meth. A* **494** (2002) 430.

[7] Y. Enari, et al., *Nucl. Instr. and Meth. A* **547** (2005) 490.

[8] K. Matsuoka, For the Belle II PID Group, *Nucl. Instr. and Meth. A* **732** (2013) 357.

[9] M. Akatsu, et al., *Nucl. Instr. and Meth. A* **528** (2004) 763.

[10] K. Inami, et al., *Nucl. Instr. and Meth. A* **592** (2008) 247.

[11] N. Kishimoto, et al., *Nucl. Instr. and Meth. A* **564** (2006) 204.

[12] T. Jinno, et al., *Nucl. Instr. and Meth. A* **629** (2011) 111.

[13] T. Nakano, et al., *Nucl. Phys. A* **64** (2001) 71.

[14] K. Matsuoka (For the Belle II PID group), *Nucl. Instr. and Meth. A* (2014), http://dx.doi.org/10.1016/j.nima.2014.05.003.