Performance study of the TOP counter with the 2 GeV/c positron beam at LEPS

K. Matsuoka (KMI, Nagoya Univ.) for the Belle II PID group
**TOP (Time Of Propagation) counter**

- A novel Ring Imaging Cherenkov detector for PID in Belle II
  - $\pi$ efficiency > 95% and K fake rate < 5% for < 3 GeV/c

Cherenkov photons generated in the quartz bar travel in the bar as they are totally reflected on the quartz/air boundaries.

To identify $K/\pi$, measure TOP of ~20 photons with a time resolution < 50 ps (as well as TOF).
Key of the TOP counter

- The Cherenkov ‘ring’ image has to propagate undistorted along the bar.
  - Polished quartz bar with smooth and parallel surfaces
- Distinguish TOP difference of ~100 ps between K and π.
  - MCP (Micro Channel Plate) PMT and readout electronics with time resolution < 50 ps.

Succeeded in developing each component.

Integrate them and confirm the performance of the TOP counter.
Quartz bar

- The quality of Cherenkov ring image has to be maintained after \(O(100)\) reflections on the quartz surface.

Requirements (for the largest surfaces)

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Length</td>
<td>1250 ± 0.50 mm</td>
</tr>
<tr>
<td>Width</td>
<td>450 ± 0.15 mm</td>
</tr>
<tr>
<td>Thickness</td>
<td>20 ± 0.10 mm</td>
</tr>
<tr>
<td>Flatness</td>
<td>&lt; 6.3 (\mu)m</td>
</tr>
<tr>
<td>Perpendicularity</td>
<td>&lt; 20 arcsec</td>
</tr>
<tr>
<td>Parallelism</td>
<td>&lt; 4 arcsec</td>
</tr>
<tr>
<td>Roughness</td>
<td>&lt; 5 Å (RMS)</td>
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</tbody>
</table>

Internal surface reflectance > 99.90%
Bulk transmittance > 98.5%/m
**MCP-PMT** (Micro Channel Plate PMT)

- **Square shape** to cover the bar edge with small dead region.
- **Enough gain** (> $5 \times 10^5$ in 1.5 T) to detect single photon
- **Transit Time Spread (TTS)** < 40 ps
- **QE ~28%** at $\lambda$ 380 nm with NaKSBcCs photocathode

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**Image Description**

- **Photocathode**:
  - 2 MCPs
  - 4 x 4 anodes

- **MCP-PMT** dimensions: 23 mm

- **Transit Time Spread (TTS)**: 40.0 ps

- **QE Plot**

- **Talk by T. Yonekura (I.d Photon, Session 2)**
Readout electronics for Belle II

- Waveform-sampling ASIC (IRS) being developed at Hawaii Univ.
  - Multi-G sample / sec to measure the fast MCP-PMT waveform

(Cross-section)

IRS3B for the beam test

Front-end readout with 8 PMTs

FPGA (SPARTAN-6)

Detail \(\rightarrow\) Talk by M. Andrew (III.a FE & ASICs, Session 1)
Backup readout electronics for the beam test

- Front-end: CFD (constant fraction discriminator) board
- Back-end: VME TDC (CAEN V1290A) … time resolution ~ 20 ps

16 outputs of each PMT were merged into 4 at the PMT socket to reduce the number of channels (little impact on the PID performance)
Beam test at LEPS (Laser Electron Photon beamline at SPring-8)

- Evaluate the performance of the TOP counter with the 2 GeV/c \(e^+\) beam at LEPS with both ASIC and CFD.

- Coincidence of the 4 triggers
  - Beam fluctuation \(~1.5\) mrad
- Trigger rate \(~10\) Hz
- \(e^+\) momentum measured by the LEPS spectrometer
- EM shower cut by requiring \(N_{\text{TOF}} = 1\)
Drift chamber

Front-end in the back sheet

TOP counter

TOF counters
Beam timing

- Used the accelerator RF clock to obtain the beam timing ($t_0$).
- Checked the $t_0$ resolution with a Cherenkov timing counter.

Cherenkov timing counter (10 mm $\phi$ quartz + MCP-PMT)

Time resolution: $\approx 23$ ps

$\sigma = 37.9$ ps

$t_0$ resolution: $\approx 30$ ps
Distribution of time of propagation

- Height of each peak →
  - Quartz surface reflectance, transmittance
  - QE and its angle/polarization dependence

- Width of each peak →
  - Chromatic dispersion
  - MCP-PMT timing resolution

- Tail of each peak →
  - MCP-PMT (bounce on MCP surface, x-talk)

All well understood
Cherenkov image (CFD readout)

Data

PDF

Good agreement
There are dead channels (90/512) due to some problems.
Beam correlated EM shower and uncorrelated background also have to be understood since they affect the TOP performance.

ASIC readout

- MC (no background)
- MC (with background)
- Data (IRS)

CFD readout

- 50 ns window
- 40 ns window
- Bad channels are removed
- Tail by EM shower from the upstream counters and in the quartz
- Peak shift by uncorrelated background

Preliminary

<table>
<thead>
<tr>
<th>Data (IRS)</th>
<th>MC (no background)</th>
<th>MC (with background)</th>
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<tbody>
<tr>
<td>Entries</td>
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<tr>
<td>Mean</td>
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<tr>
<td>RMS</td>
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<table>
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<tr>
<th>Data (CFD)</th>
<th>MC</th>
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<tr>
<td>Mean</td>
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<tr>
<td>RMS</td>
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Event by event reconstruction (CFD)

Reconstructed $\beta$

Preliminary

<table>
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<th></th>
<th>data</th>
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<tbody>
<tr>
<td>Entries</td>
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<tr>
<td>Mean</td>
<td>1.00</td>
</tr>
<tr>
<td>RMS</td>
<td>0.006</td>
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</table>

$\beta_{\text{mean}} = 1.00$

$\beta_{\text{RMS}} = 0.006$

PID by the likelihood ratio of 2 GeV/c $e^+$ ($\beta=1$) to 3 GeV/c $K$ ($\beta=0.987$)

Fake rate = 6.2%

Obtained the TOP counter performance as expected.
TOP counter is a novel Ring Imaging Cherenkov detector for $K/\pi$ identification in Belle II.
- Polished quartz bar as a radiator and propagator
- MCP-PMT and readout electronics of good time resolution (< 50 ps)

Constructed a prototype TOP counter (almost the same design as the final one) and tested it with the 2 GeV/c $e^+$ beam at LEPS.
- A beautiful pattern of the Cherenkov image was obtained as expected.
- Understood the TOP optics and MCP-PMT performance.
- Succeeded in evaluating the PID performance.
  - The result was consistent with the MC simulation.