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

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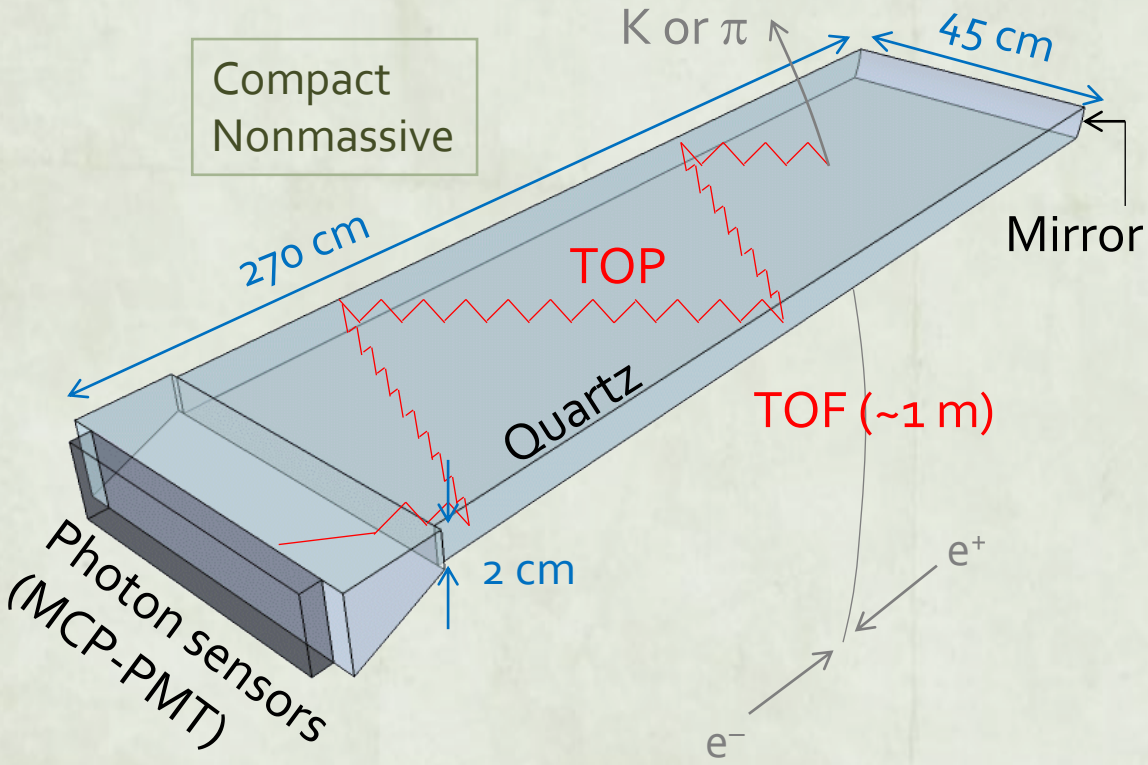
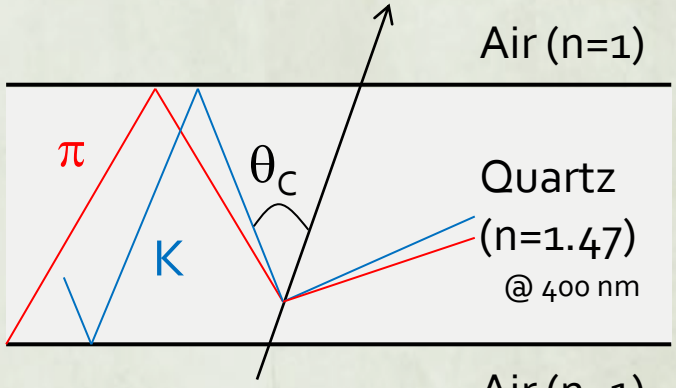
TOP (Time Of Propagation) counter

- A novel Ring Imaging Cherenkov detector for PID in Belle II
  - π 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.



$$\mathrm{TOP} \propto \cos\theta_C = \frac{1}{n\beta}$$

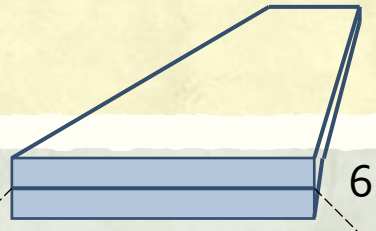
To identify K/π, measure TOP of ~20 photons with a time resolution < 50 ps (as well as TOF).

Key of the TOP counter

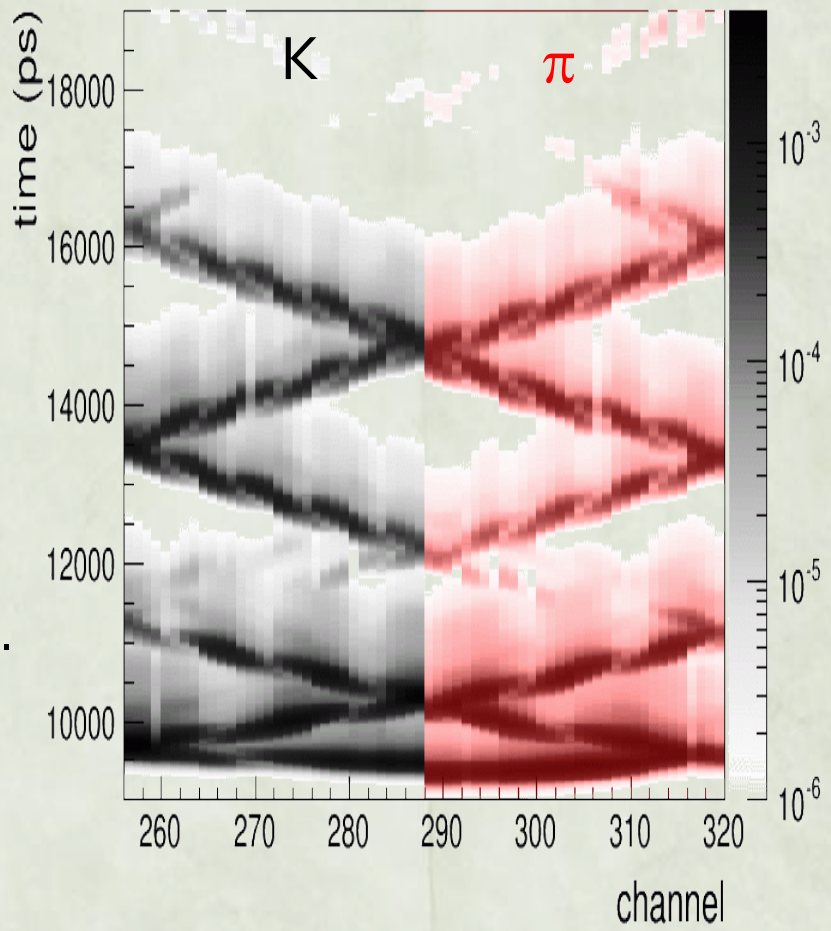
- The Cherenkov 'ring' image has to propagate undistorted along the bar.
  → **Polished quartz bar** with smooth and parallel surfaces
- Distinguish TOP difference of ~100 ps between K and π.
  → **MCP (Micro Channel Plate) PMT** and **readout electronics** with time resolution < 50 ps.

Succeeded in developing each component.

Integrate them and confirm the performance of the TOP counter.



PDF for 3 Gev/c K and π



Quartz bar

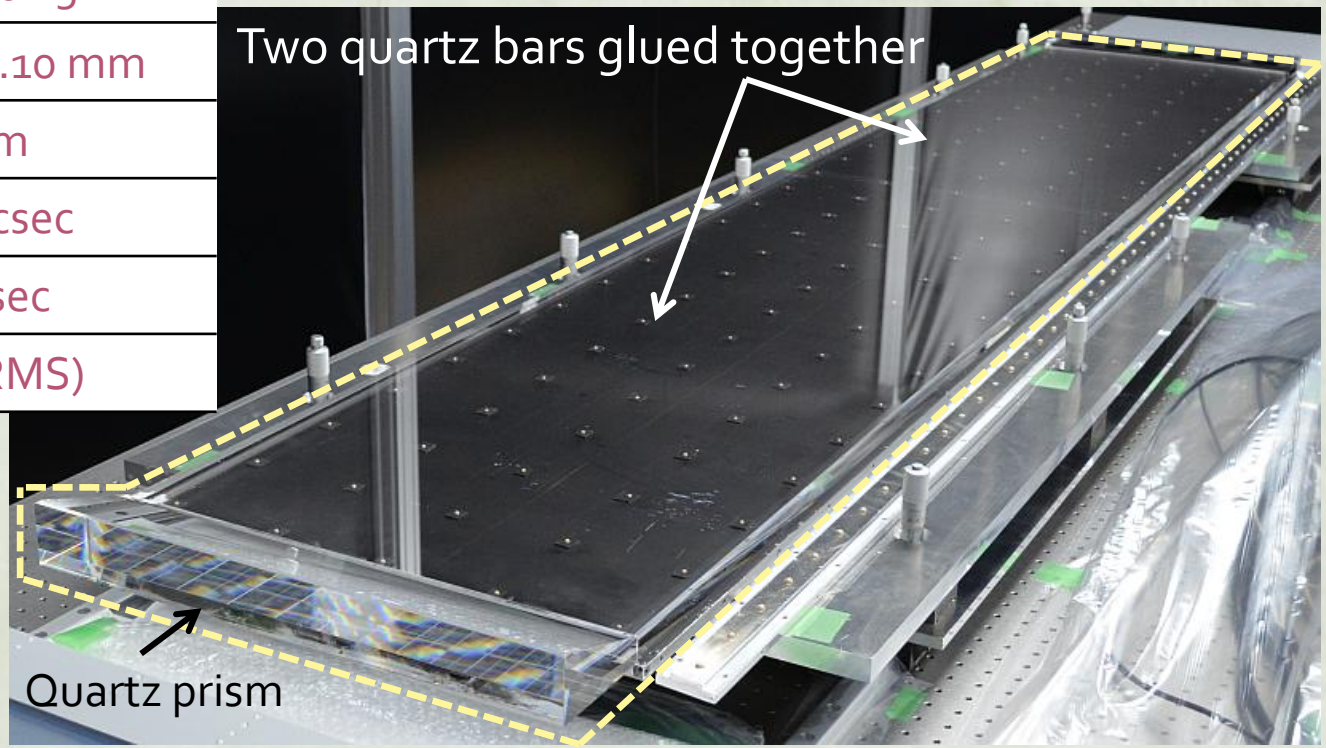
- The quality of Cherenkov ring image has to be maintained after O(100) reflections on the quartz surface.

Requirements (for the largest surfaces)

Length	1250 ± 0.50 mm
Width	450 ± 0.15 mm
Thickness	20 ± 0.10 mm
Flatness	< 6.3 μm
Perpendicularity	< 20 arcsec
Parallelism	< 4 arcsec
Roughness	< 5 Å (RMS)

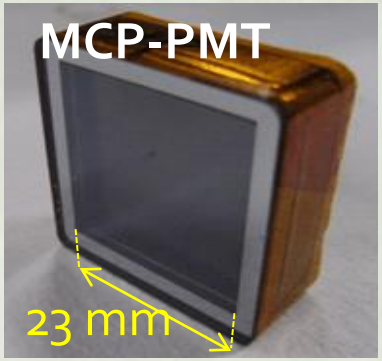
Internal surface reflectance > 99.90%

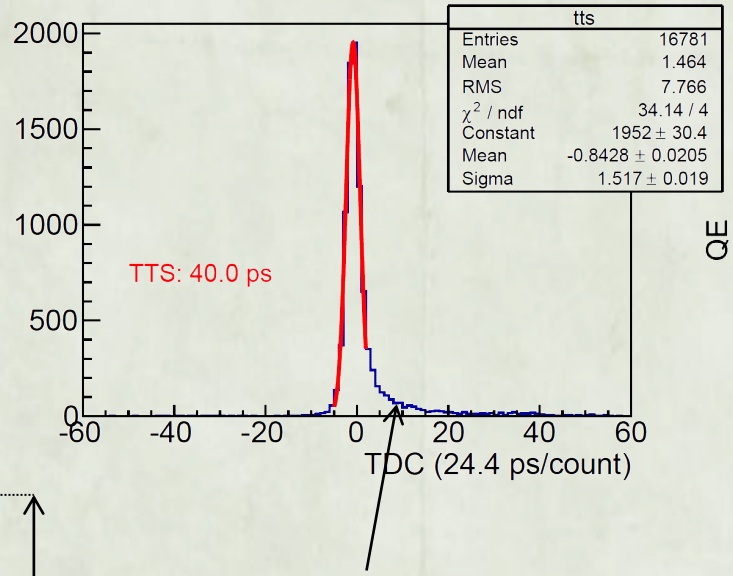
Bulk transmittance > 98.5%/m

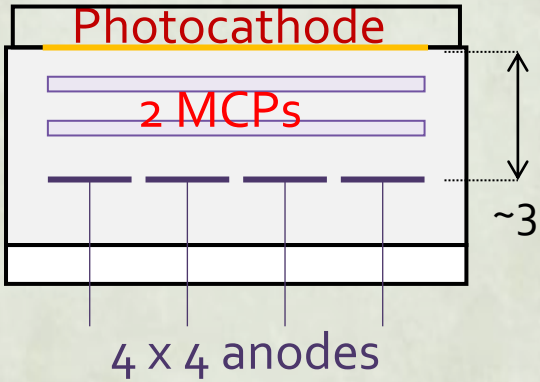


MCP-PMT (Micro Channel Plate PMT)

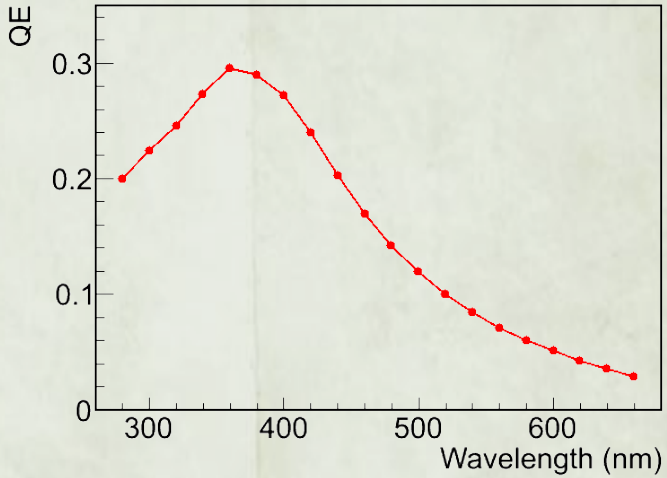
- Square shape to cover the bar edge with small dead region.
- Enough gain (> 5 x 10^5 in 1.5 T) to detect single photon
- Transit Time Spread (TTS) < 40 ps
- QE ~28% at λ 380 nm with NaKSbCs photocathode







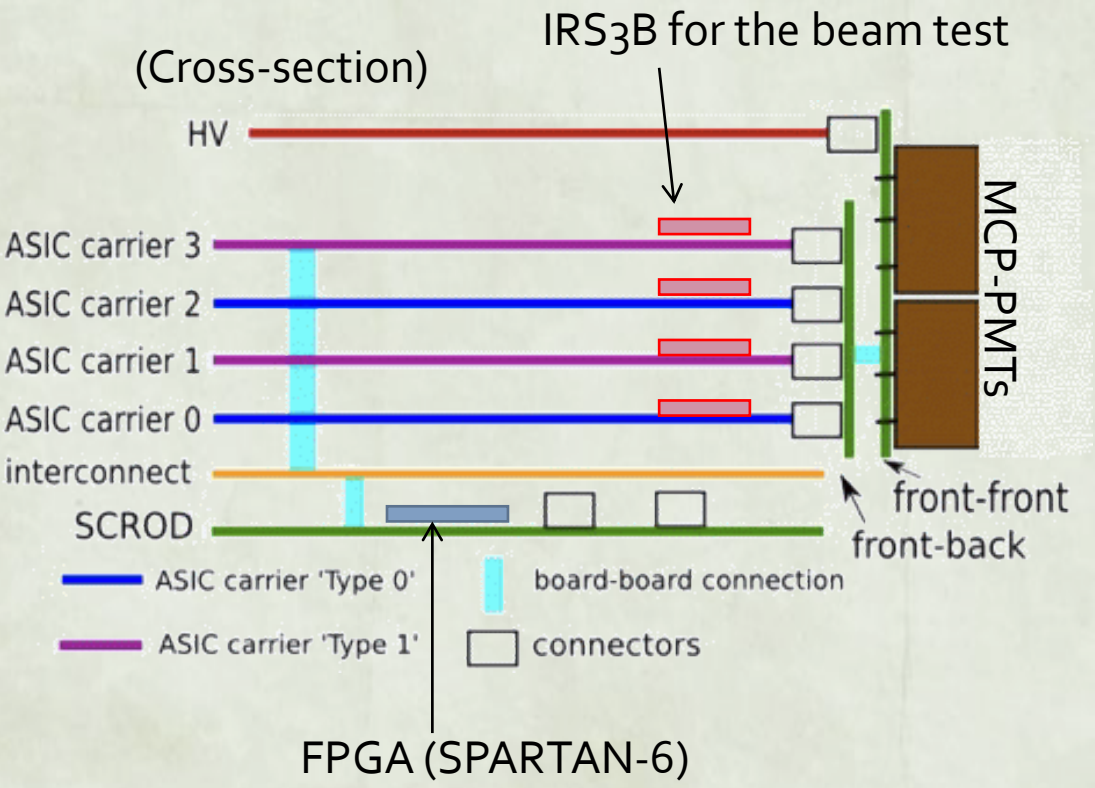
Tail due to bounce on the 1st MCP surface



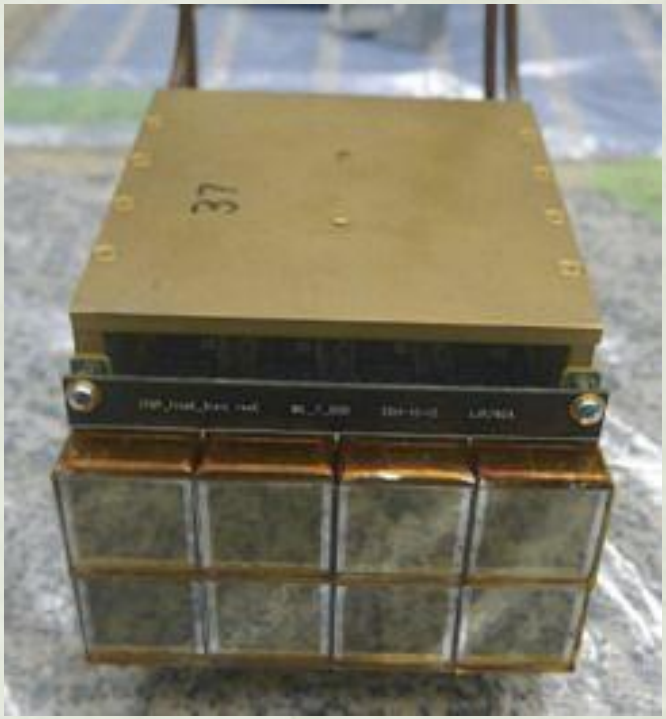
Detail → Talk by T. Yonekura (I.d Photon, Session 2)

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



Front-end readout with 8 PMTs

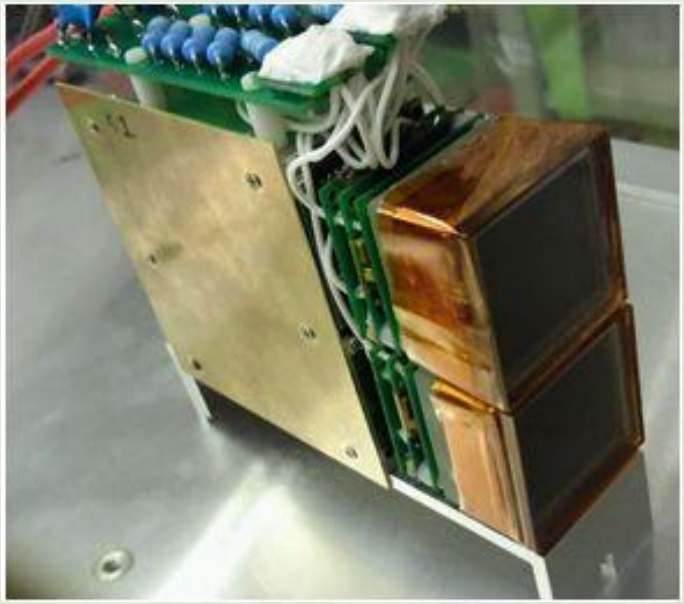


Detail → Talk by M. Andrew (III.a FE & ASICs, Session 1)

Backup readout electronics for the beam test

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

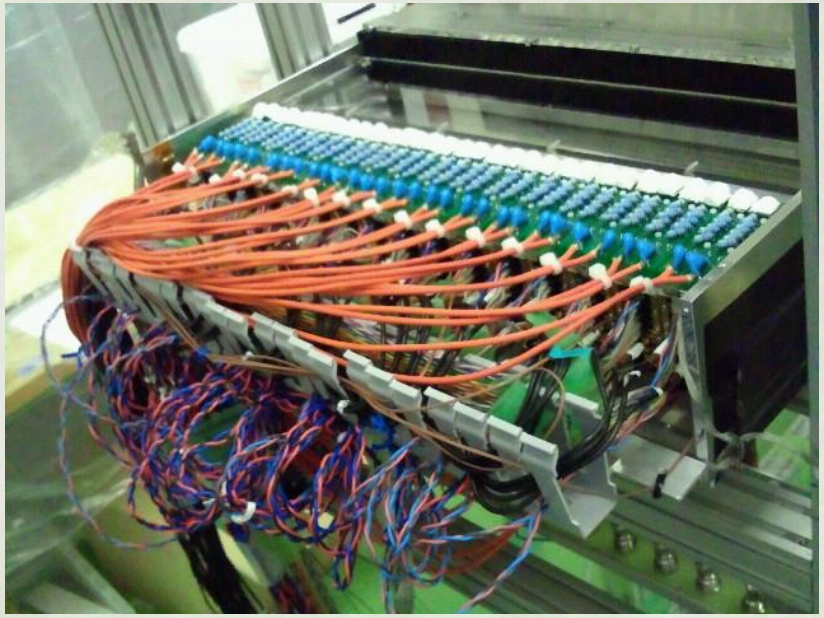
CFD front-end with 2 PMTs



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)

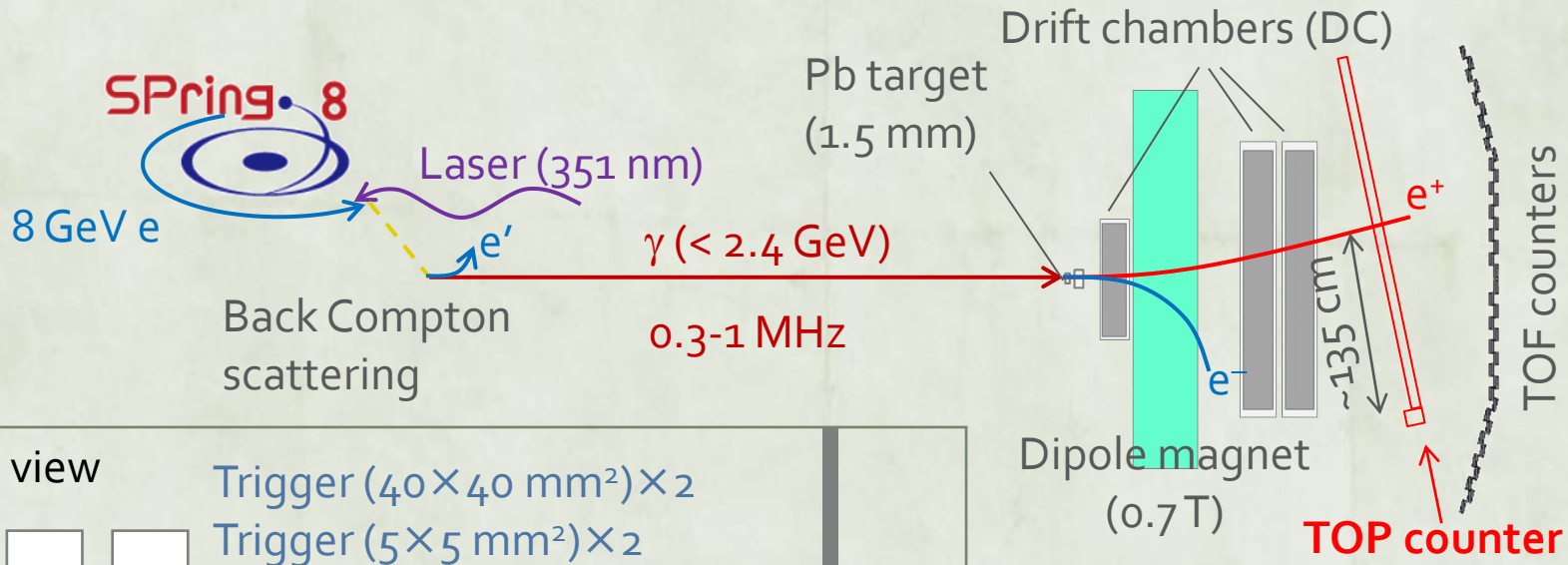
CFD board

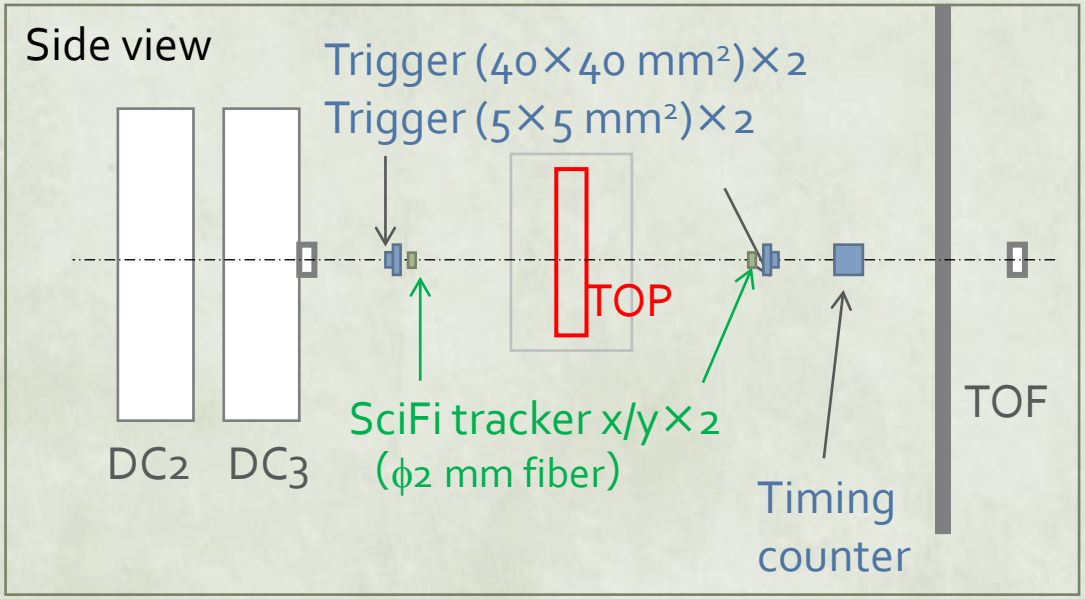
Full 32 PMTs and the CFD mounted on the quartz



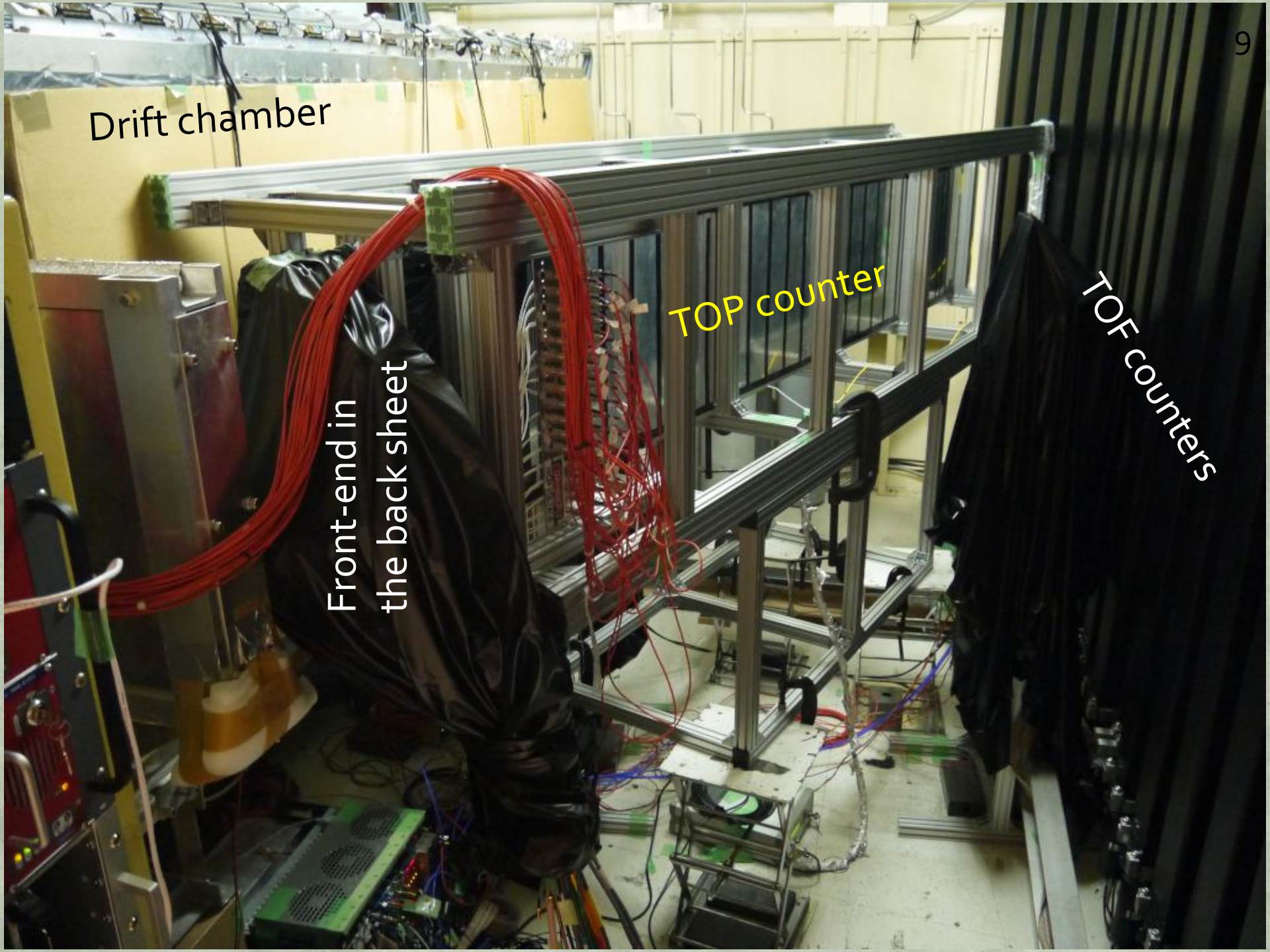
Beam test at LEPS (Laser Electron Photon beamline at SPring-8)

- 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 $N_{TOF}=1$

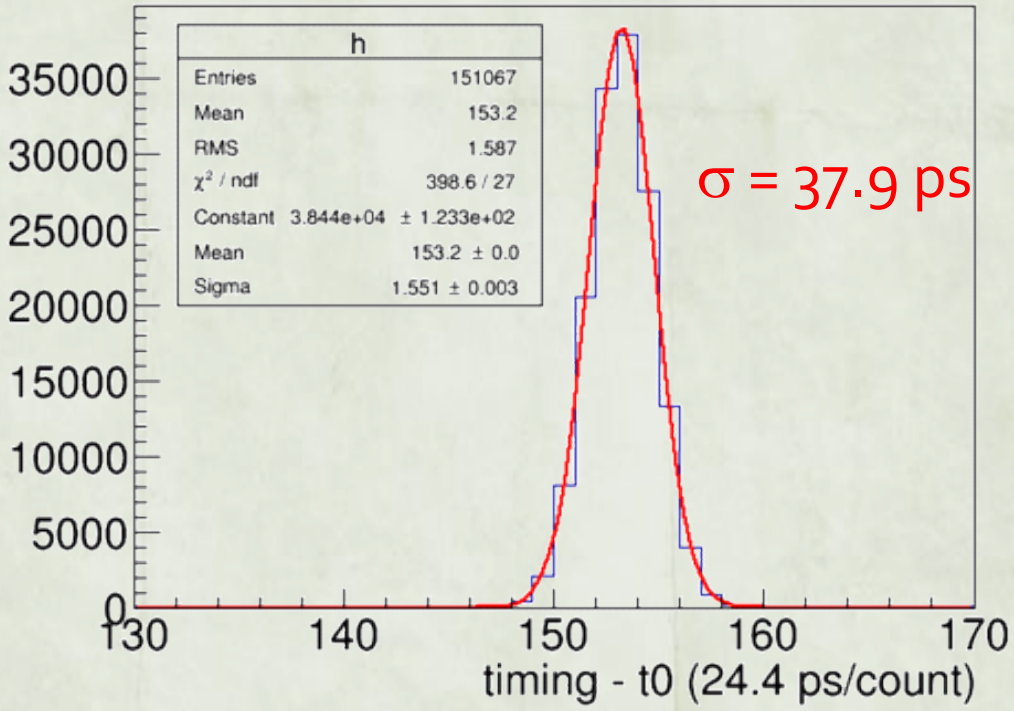

Drift chamber
Front-end in the back sheet
TOP counter
TOF counters

Beam timing

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

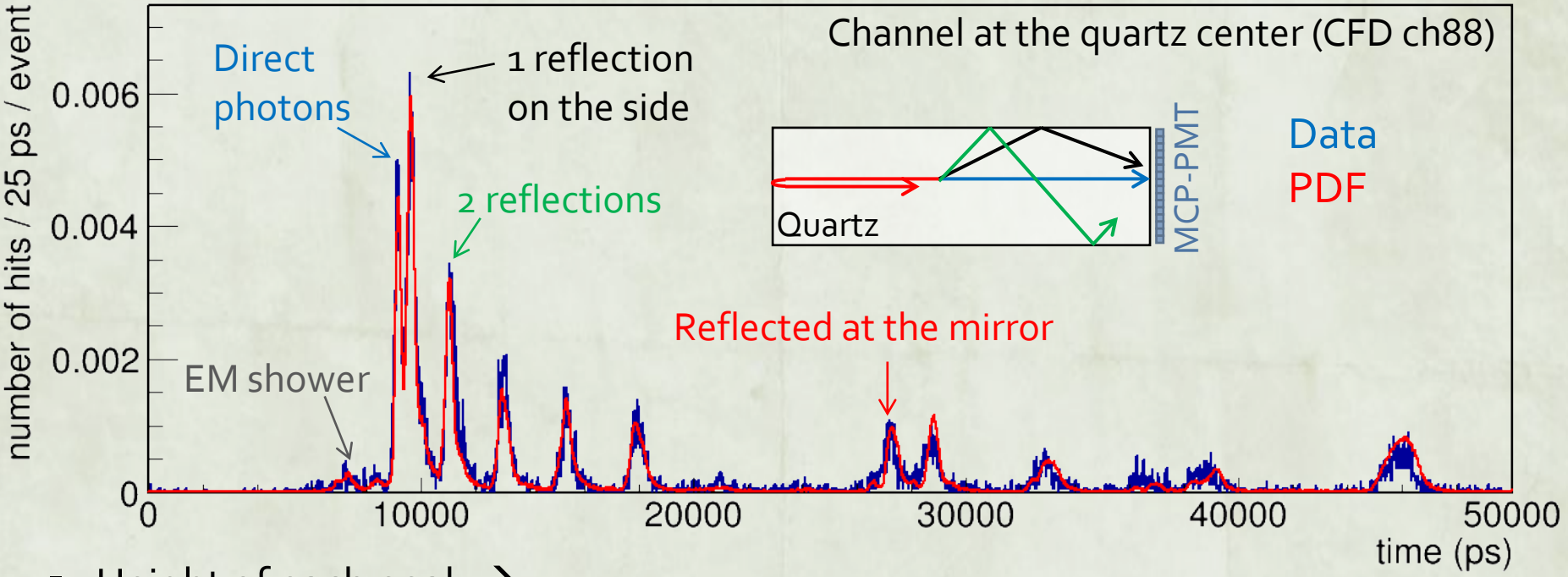
Cherenkov timing counter
(10 mm ϕ quartz + MCP-PMT)

Time resolution: ~23 ps



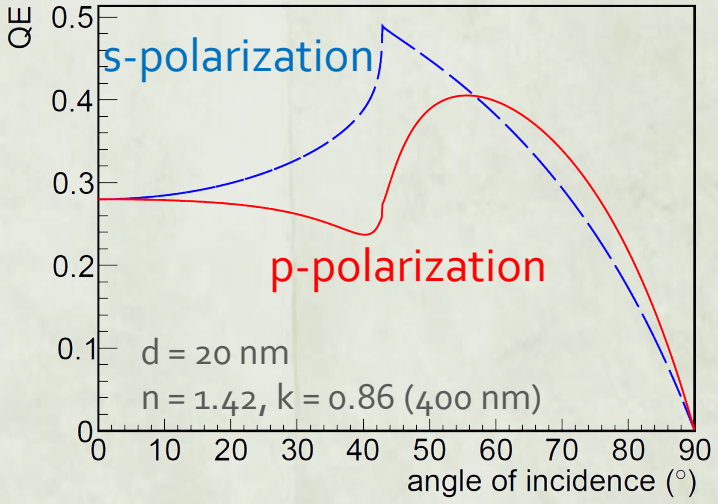
→ t_0 resolution: ~30 ps

Distribution of time of propagation

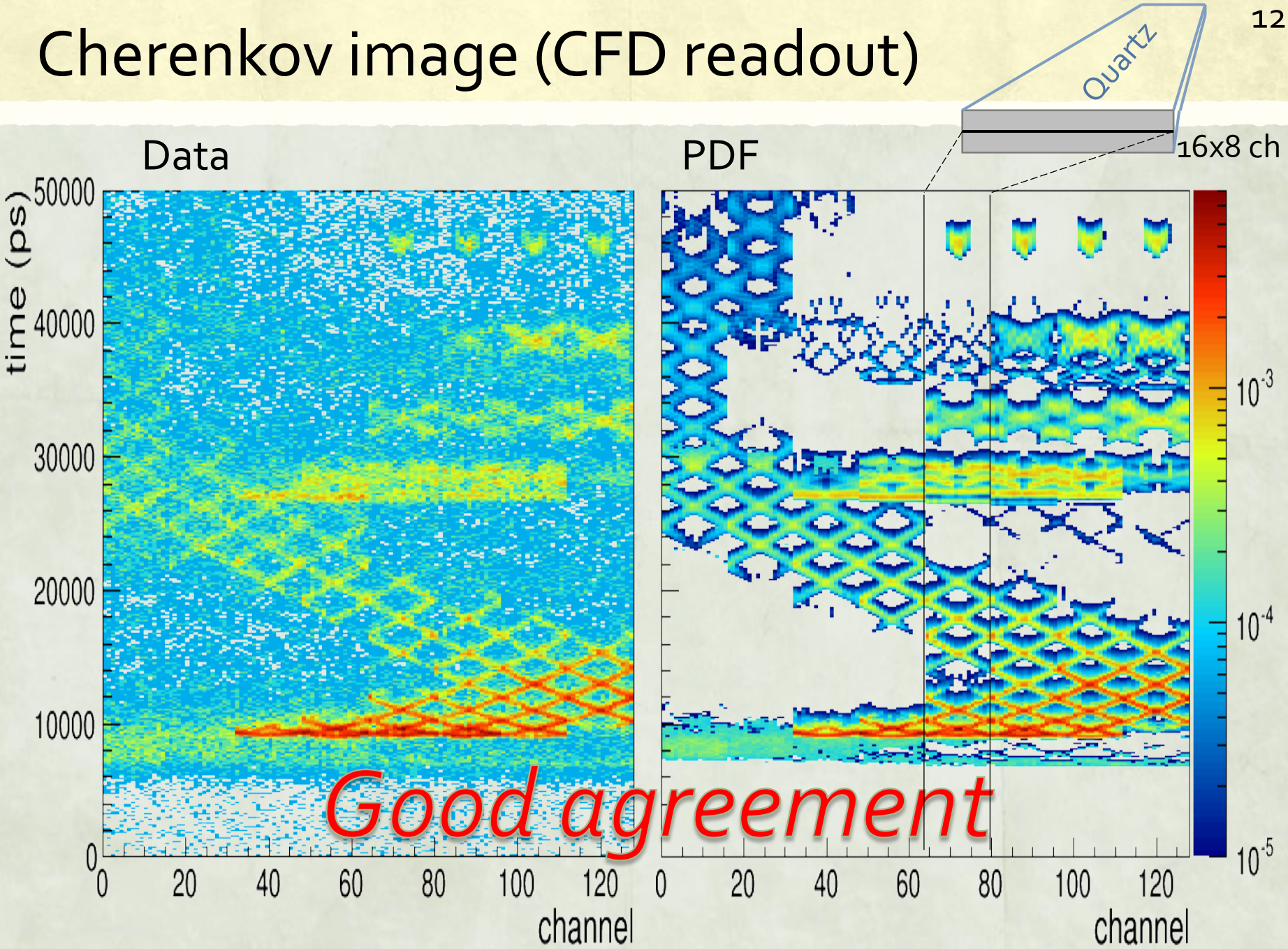


- Height of each peak →
  - Quartz surface reflectance, transmittance
  - QE and its angle/polarization dependence
- Width of each peak →
  - Chromatic dispersion
  - MCP-PMT timing resolution
- Tail of each peak →
  - MCP-PMT (bounce on MCP surface, x-talk)

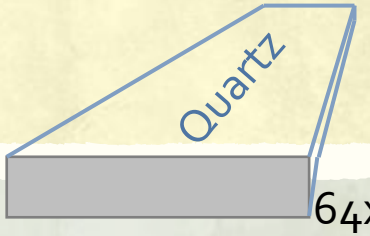
All well understood



Cherenkov image (CFD readout)

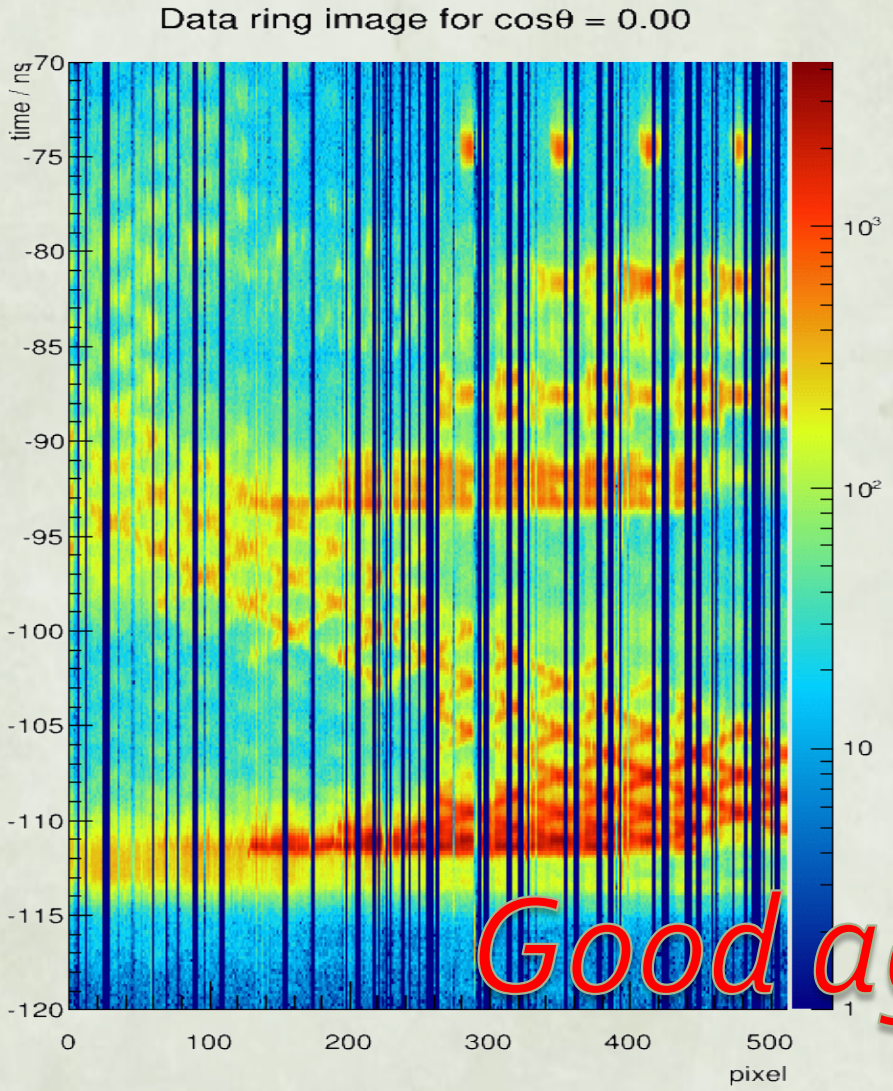


Cherenkov image (IRS readout)

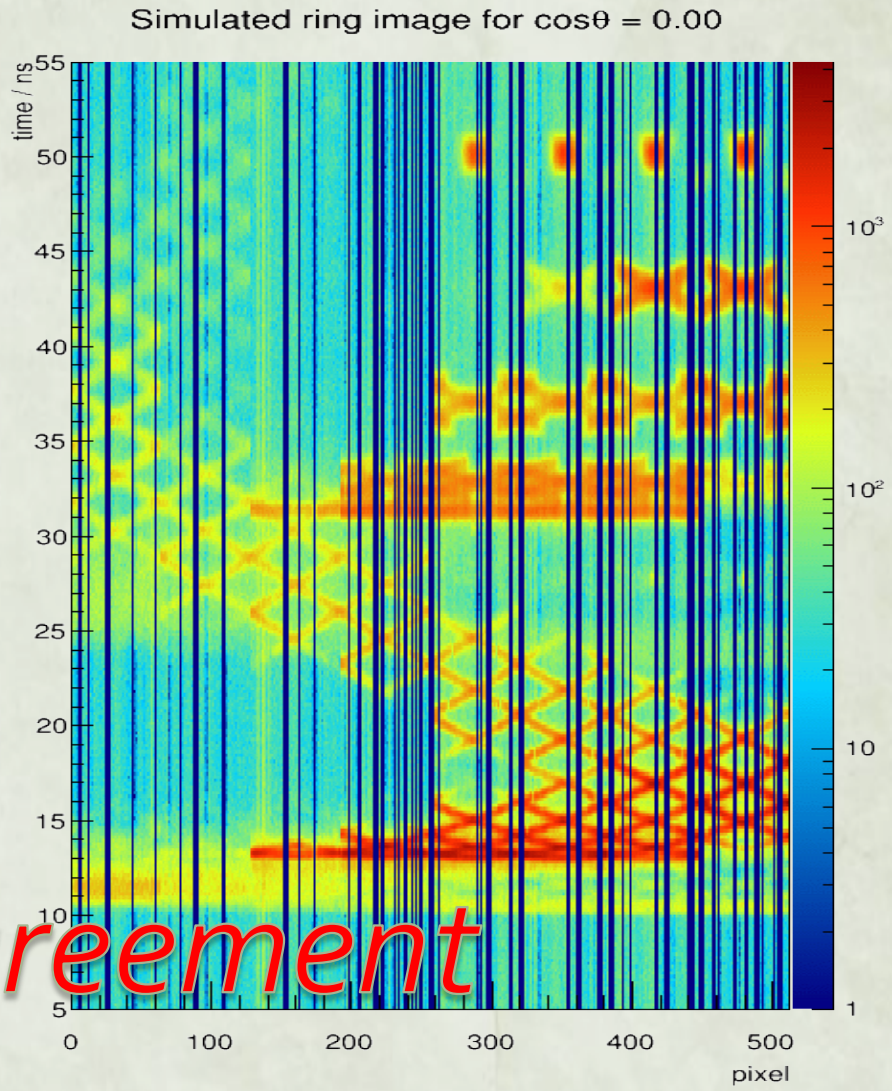


64x8 ch

Data



MC



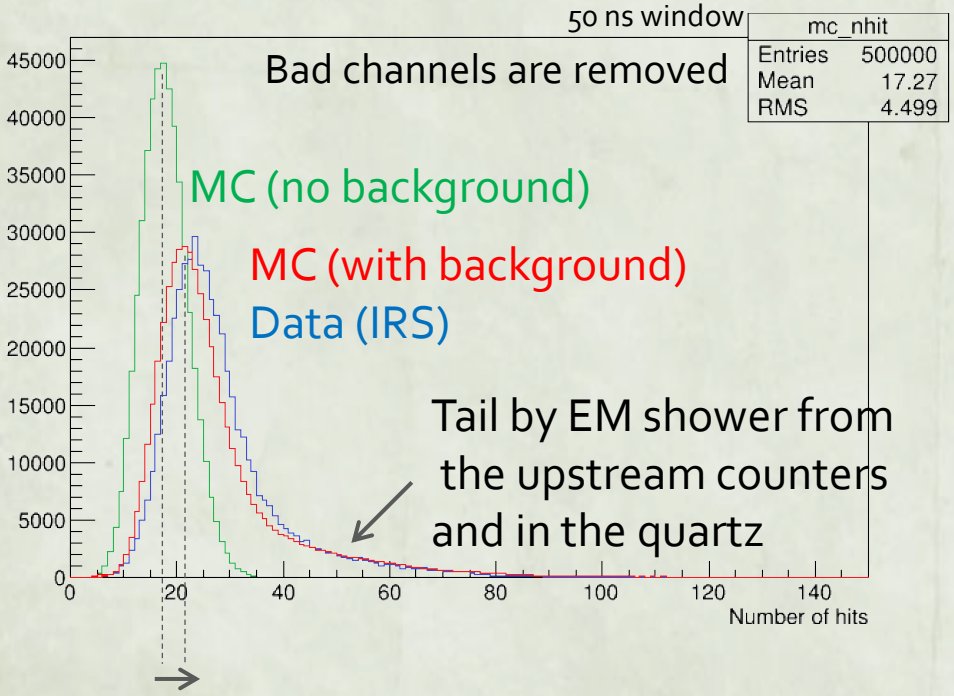
Good agreement

There are dead channels (90/512) due to some problems.

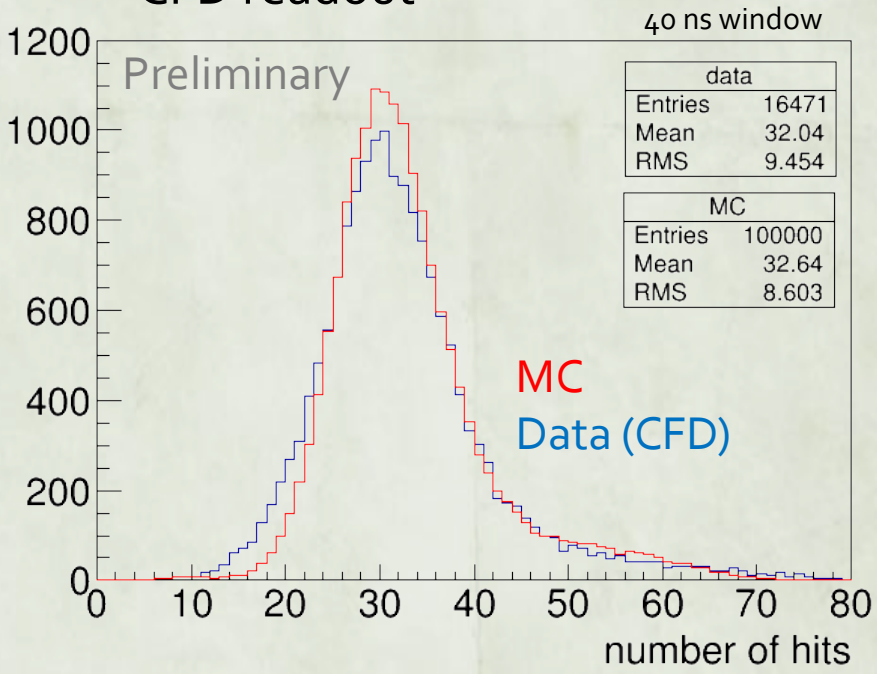
Number of hits per event

- Beam correlated EM shower and uncorrelated background also have to be understood since they affect the TOP performance.

ASIC readout



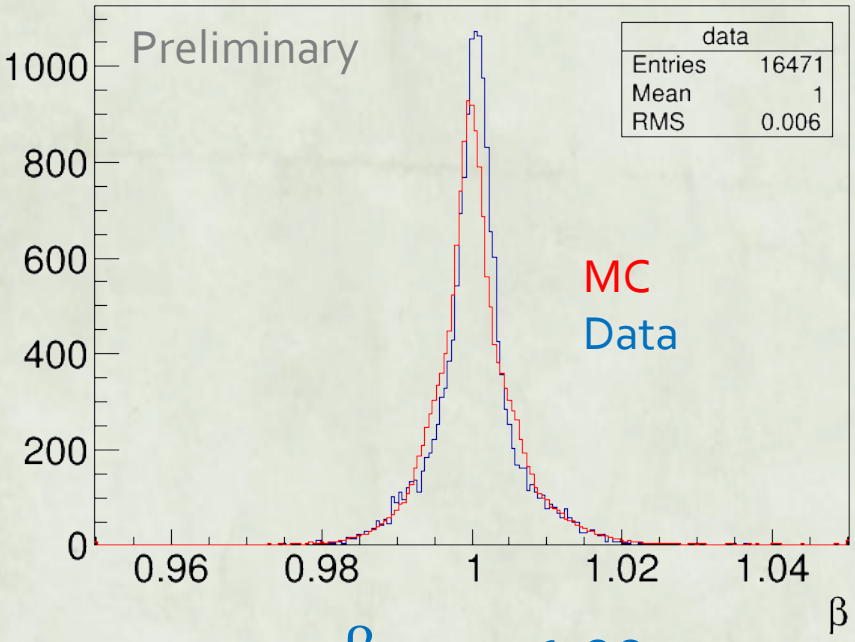
CFD readout



Nearly consistent

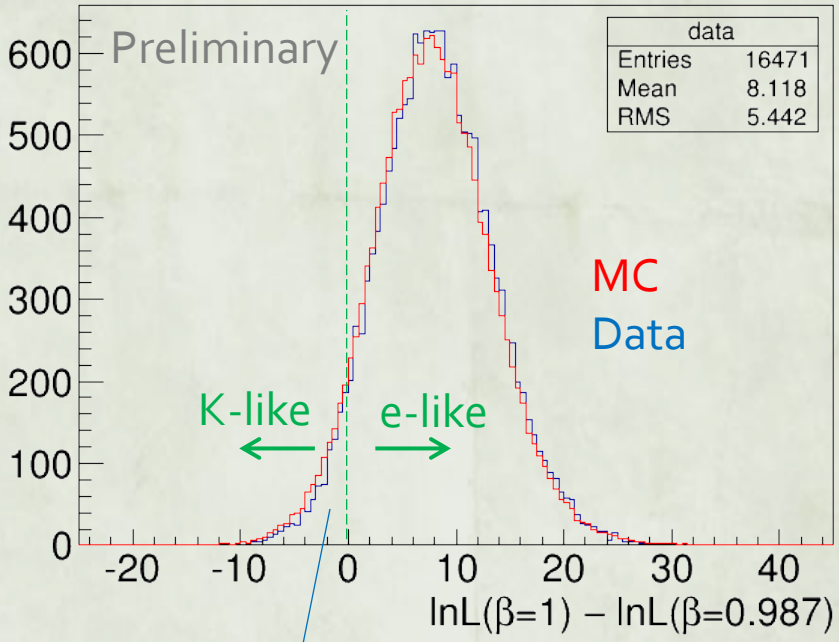
Event by event reconstruction (CFD)

Reconstructed β



β_{mean} = 1.00
β_{RMS} = 0.006

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



Fake rate = 6.2%

Obtained the TOP counter performance as expected.

Summary

- TOP counter is a novel Ring Imaging Cherenkov detector for K/π 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.