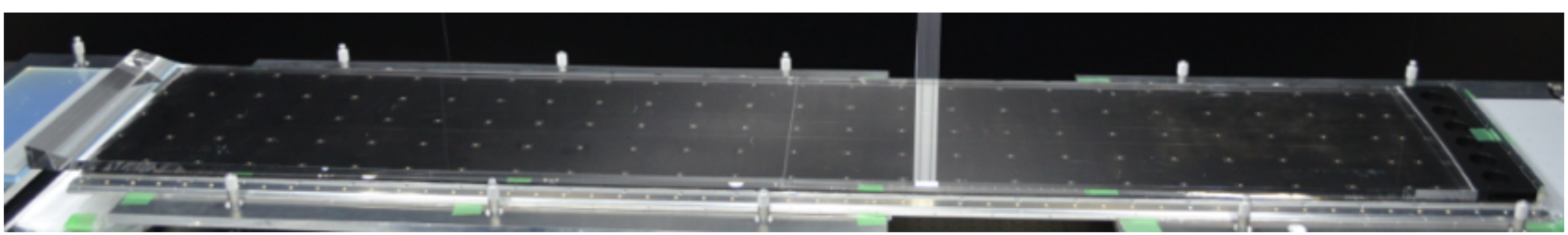
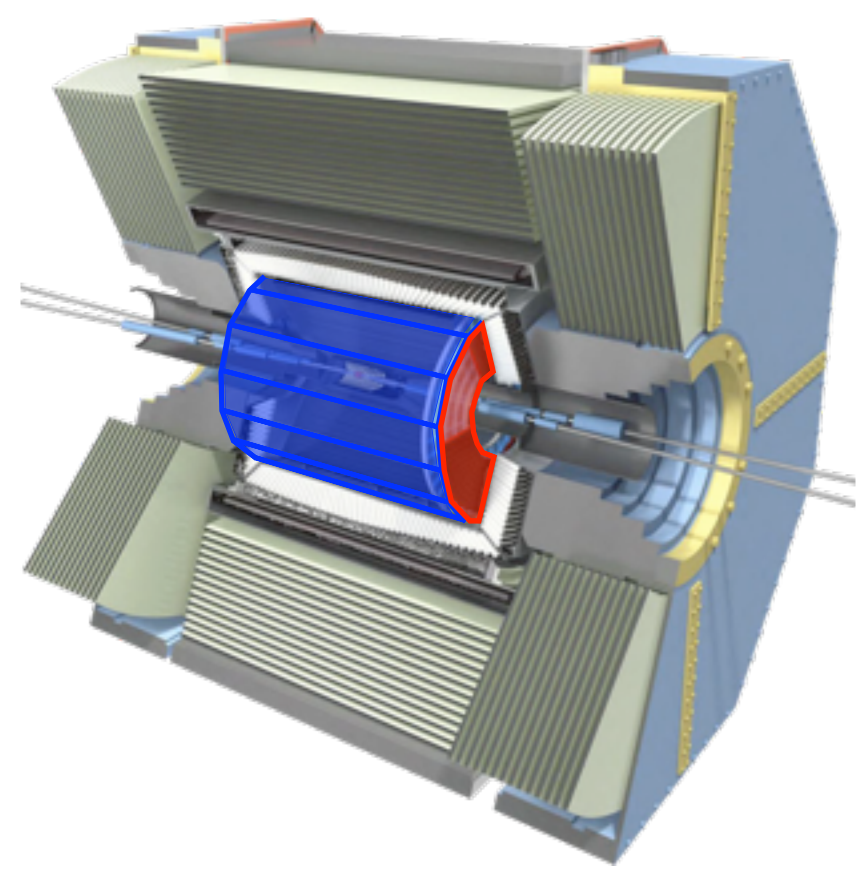
TOP Detector for Particle Identification at the Belle II Experiment

Y. Horii (Nagoya University)
on behalf of the Belle II PID Group



Belle II Experiment and PID

- Belle II experiment
  - e^+e^- collision at Υ resonances.
  - Target integrated luminosity of 50 ab^{-1} (×50 of Belle).
  - Precision studies on B, c, τ, ... for searching for new physics.

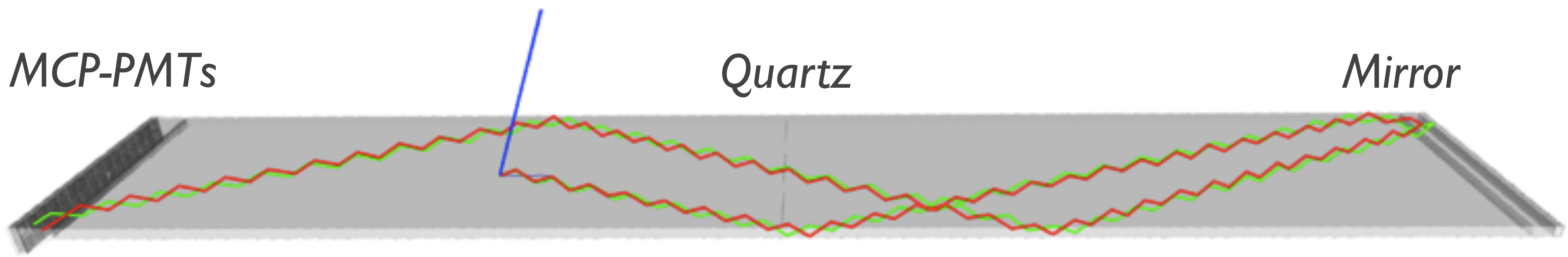


- Particle identification (PID) at Belle II
  - K/π efficiency > 95% (~90% at Belle),
  - K/π fake rate < 5 % (10-15% at Belle).

Barrel PID: TOP detector
Endcap PID: ARICH detector

TOP (Time-of-Propagation) Detector

- Cherenkov photons are propagated in the quartz, and detected by the MCP-PMTs (~20 photons detected).
- Velocity β is measured by the position and the time of the photons.

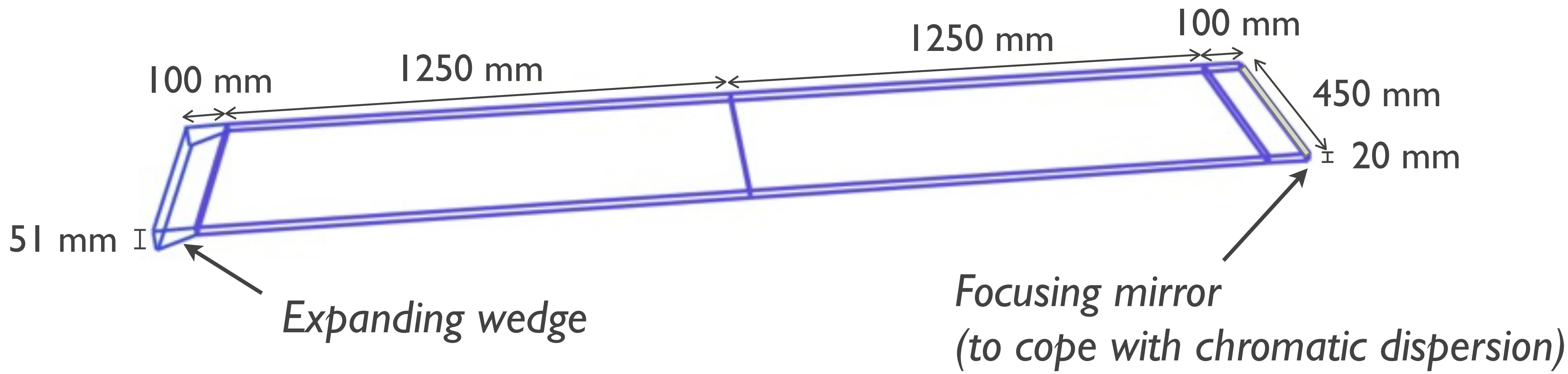


Example of Cherenkov-photon paths for 2 GeV/c $\pi^{\pm}$ and $K^{\pm}$.

Hit-time difference between $\pi^{\pm}$ and $K^{\pm}$ due to

- difference of time of flight btw $\pi^{\pm}$ and $K^{\pm}$ from IP to TOP: ~50 ps/m,
- difference of time of propagation of the Cherenkov photon: ~75 ps/m.

Quartz Bar



Key issues: 1) ensure photon efficiency and 2) maintain the photon angles.

- Requirements for polishing

Flatness	< 6.3 μm
Perpendicularity	< 20 arcsec
Parallelism	< 4 arcsec
Roughness	< 5 Å (RMS)

- Additional requirements

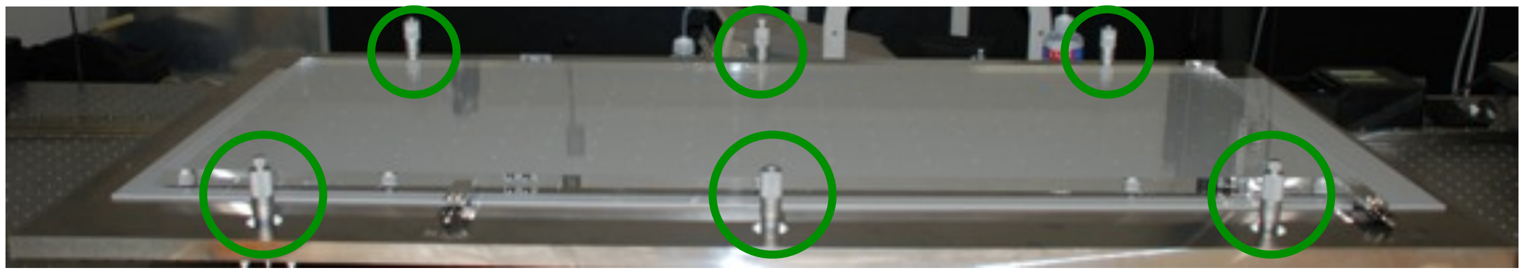
Bulk transmittance (τ)	> 98 %/m
Surface reflectance (R)	> 99.9 %/bounce

For a Corning 7980 0D prototype bar,

$\tau = (99.4 \pm 0.2)$ %/m,
$R = (99.92 \pm 0.01)$ %/bounce at Ref. angle 56°.

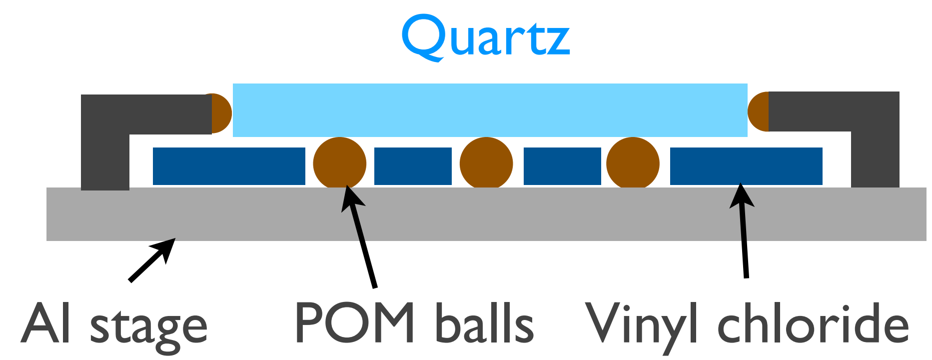
Glue for Quartz Bars

Alignment using micrometer heads.

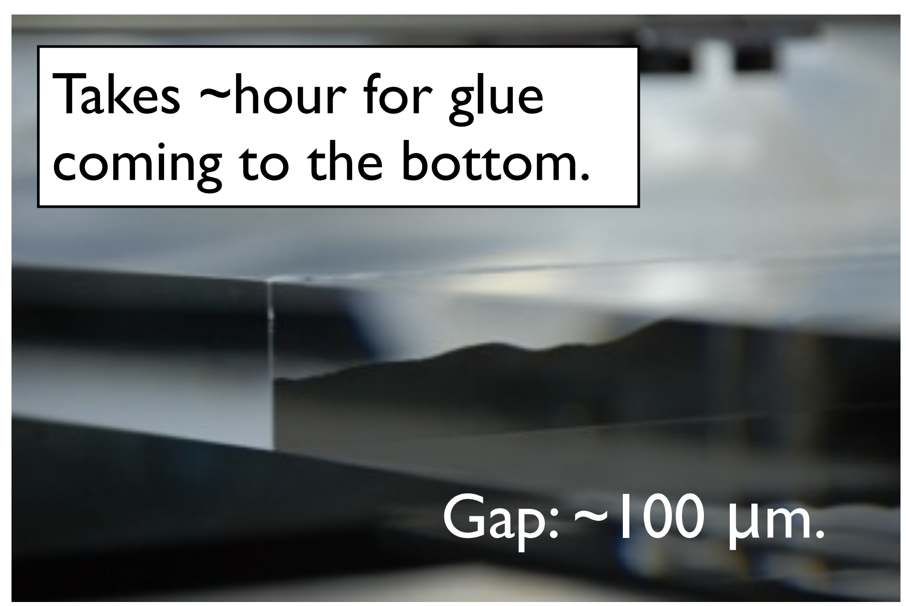


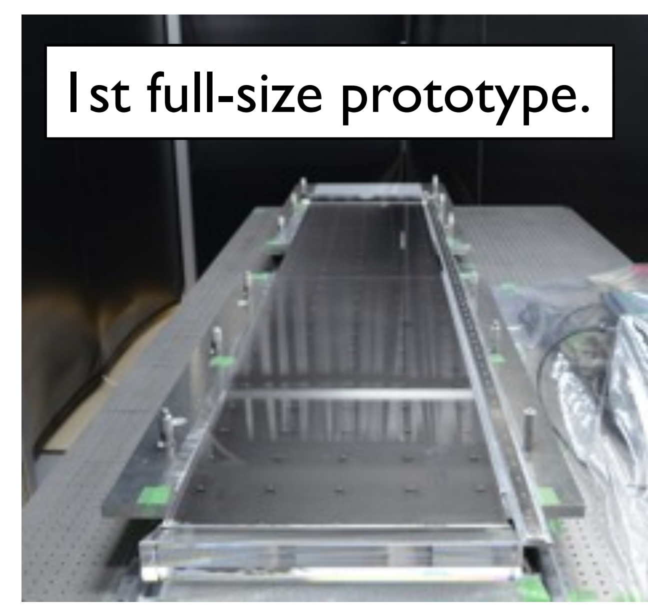
Position and angle adjustable
by O(10) μm and O(10) μrad, respectively.
(One-order better than the requirements.)

Quartz supported by plastics.



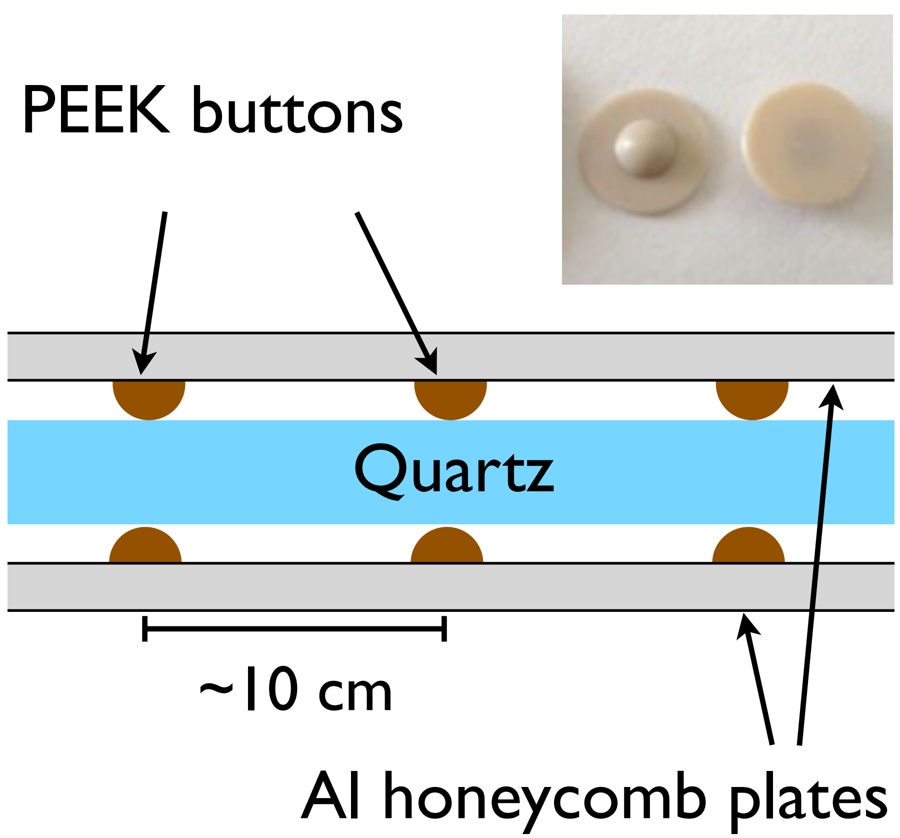
Quartz flatness ~10 μm.

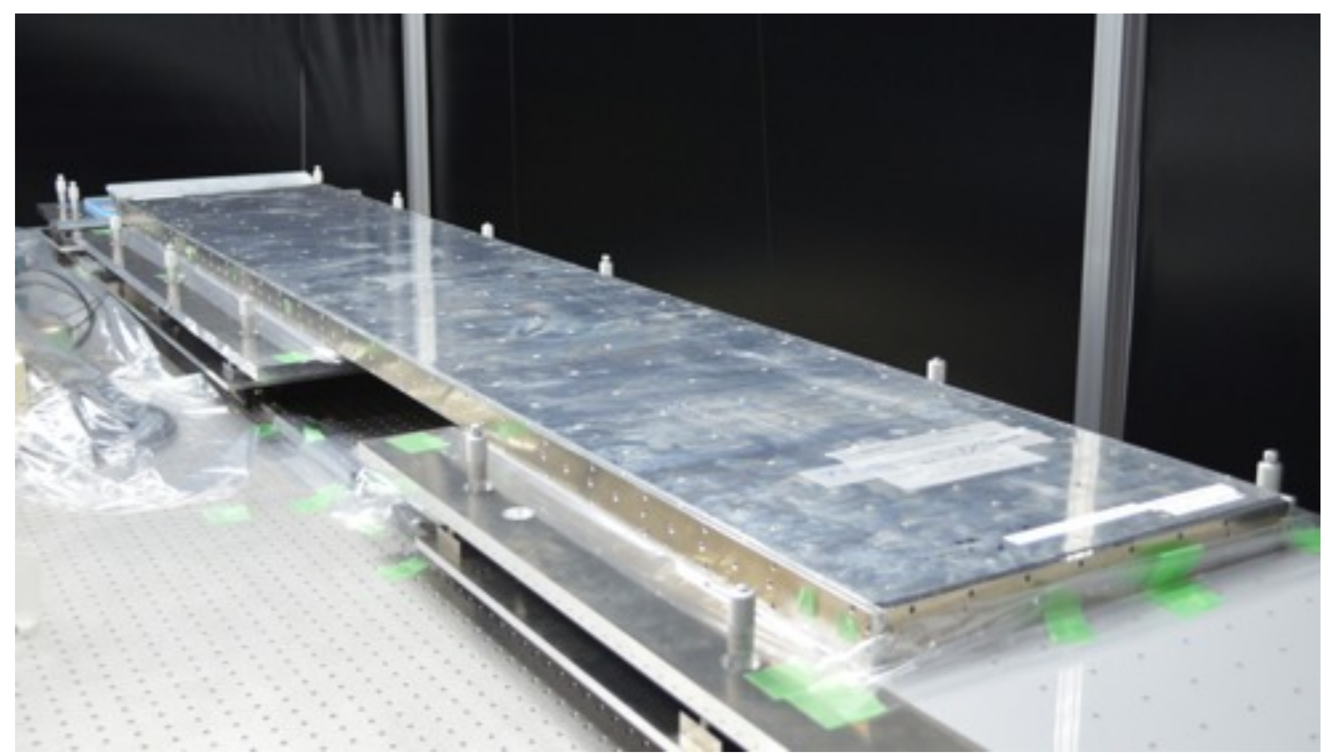




Quartz Bar Box

- Support quartz bar with PEEK buttons, enabling total reflection at the quartz surface.
- Box made of aluminum honeycomb panels (low mass).

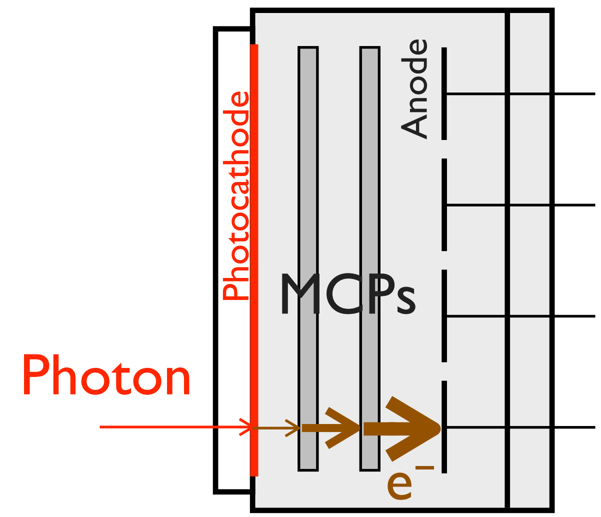




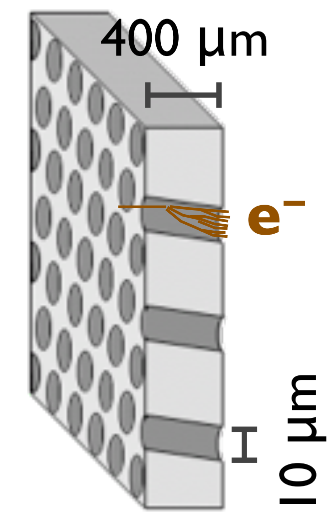
MCP-PMTs (Micro Channel Plate PMTs)

- Developed by Nagoya Univ. and Hamamatsu Co.
- 4 x 4 channels per PMT. 32 PMTs per TOP module.

square shape

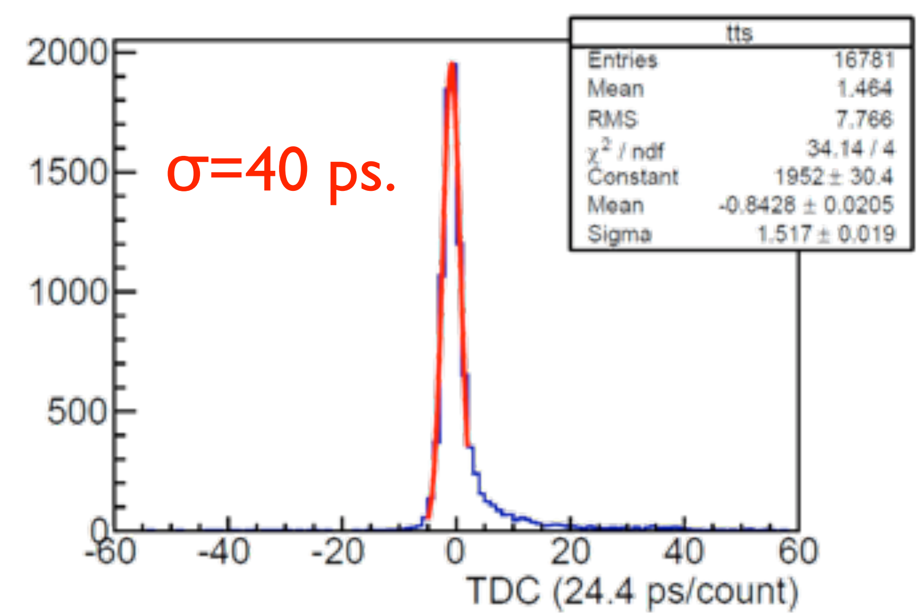


cross-sectional view



MCP

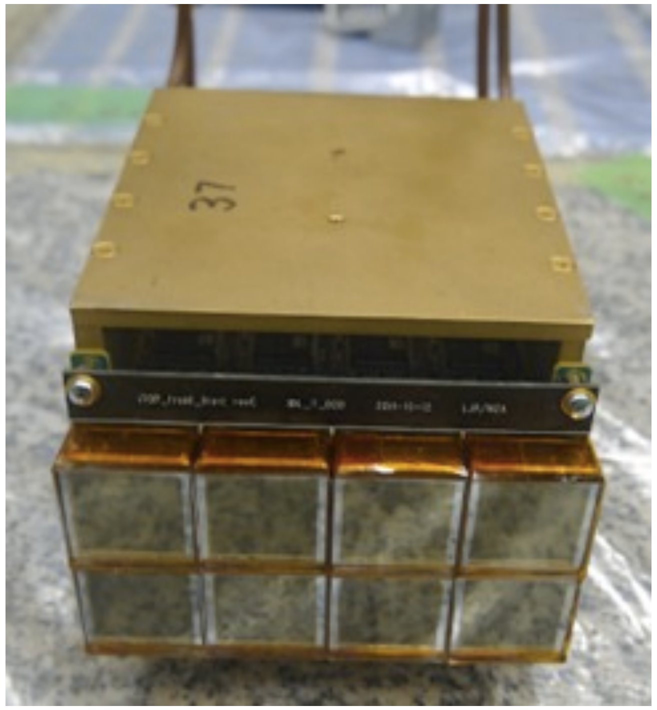
- QE > 24% at 380 nm (NaKSbCs photocathode).
- Collection Eff. = 50-55% (~MCP aperture ratio).
- Gain of 2 x 10^6 at ~3.4 kV; 1 photon detection.
- Transit time spread (TTS) ~ 40 ps.
- Work in 1.5 T magnetic field.



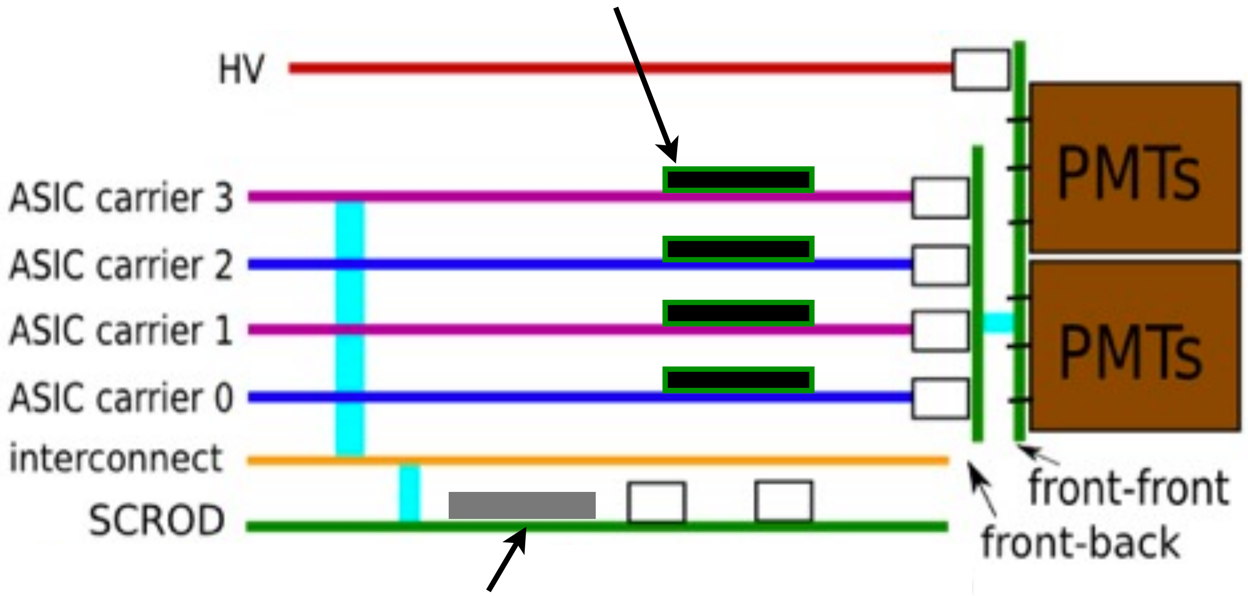
Electronics

Based on a waveform-sampling ASIC.

G.Varner, "Experience with the first generation deep sampling ASICs IRS and BLAB3", Workshop on Timing Detectors: Electronics, Medical and Part. Phys. Appl., Cracow, 2010.
G.Varner, "Deeper Sampling CMOS Transient Waveform Recording ASICs", TIPP 2011.



Currently-tested version of the ASIC: IRS3B



FPGA (SPARTAN-6) for operating readout.

4×10^9 samples / sec. Chip intrinsic time resolution of <25 psec.
Works for >5 μs trigger latency; multi-hit buffering for 30 kHz L1 trigger accept.

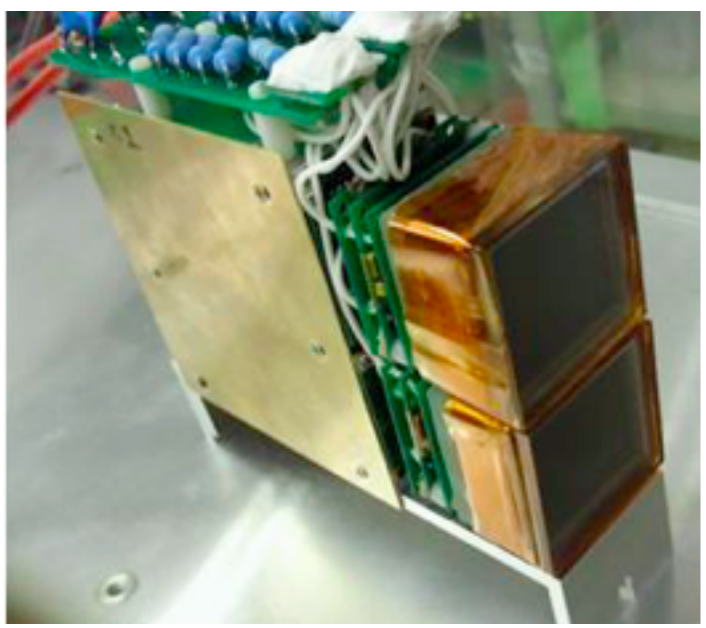
Calibration of the time and the charge requires a significant learning curve.

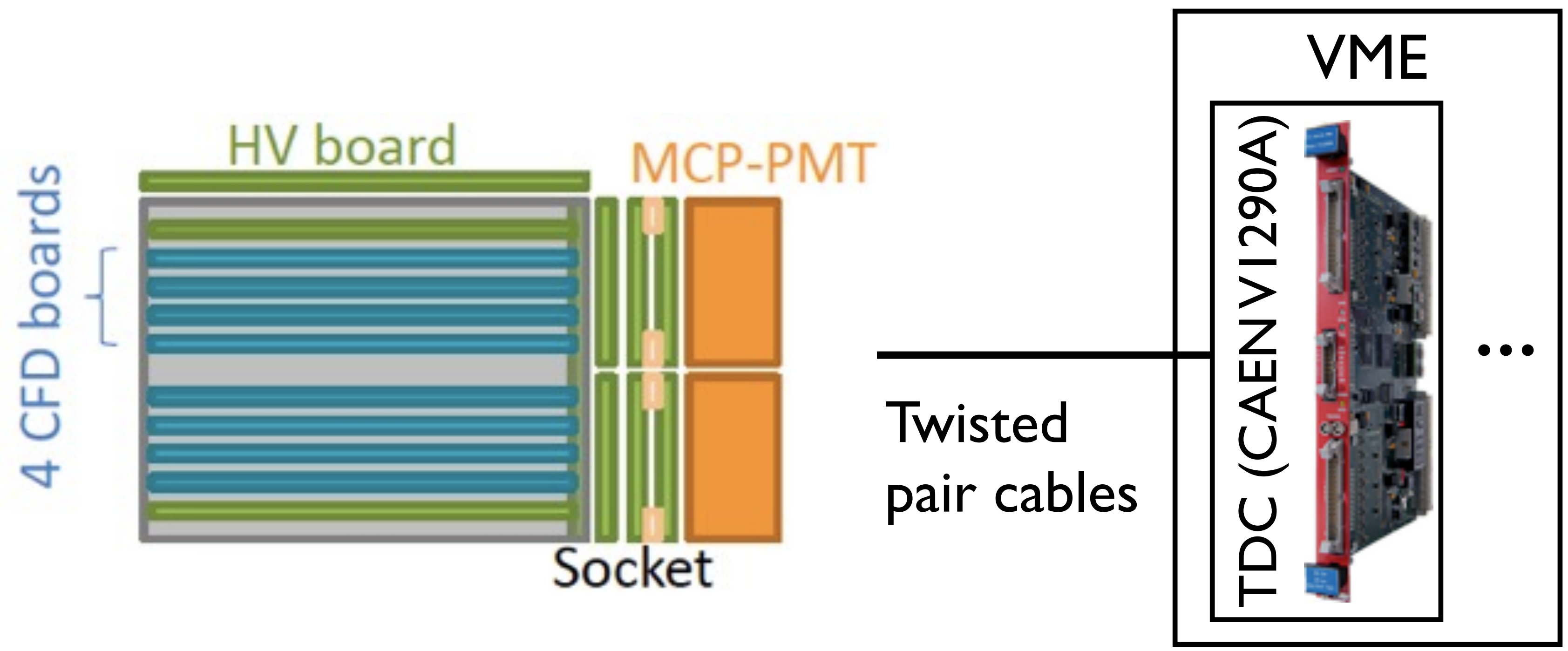
Backup Electronics for Performance Tests

K. Inami, "TOP counter prototype R&D", RICH 2010.

Based on constant fraction discriminator (CFD).

MCP-PMT 16 channels are merged into 4 at the MCP-PMT socket.



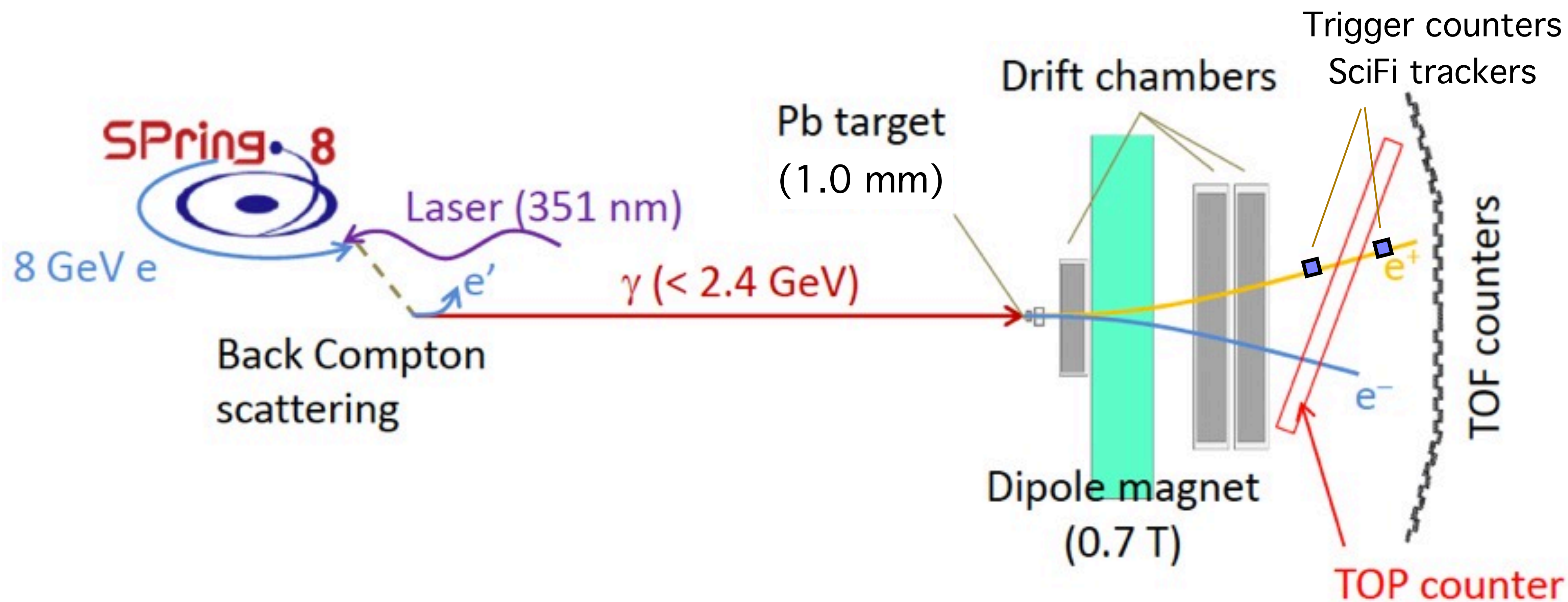


Time resolution ~ 50 psec.

Calibration relatively simpler. Can be used for TOP performance tests.

Beam Test Overview

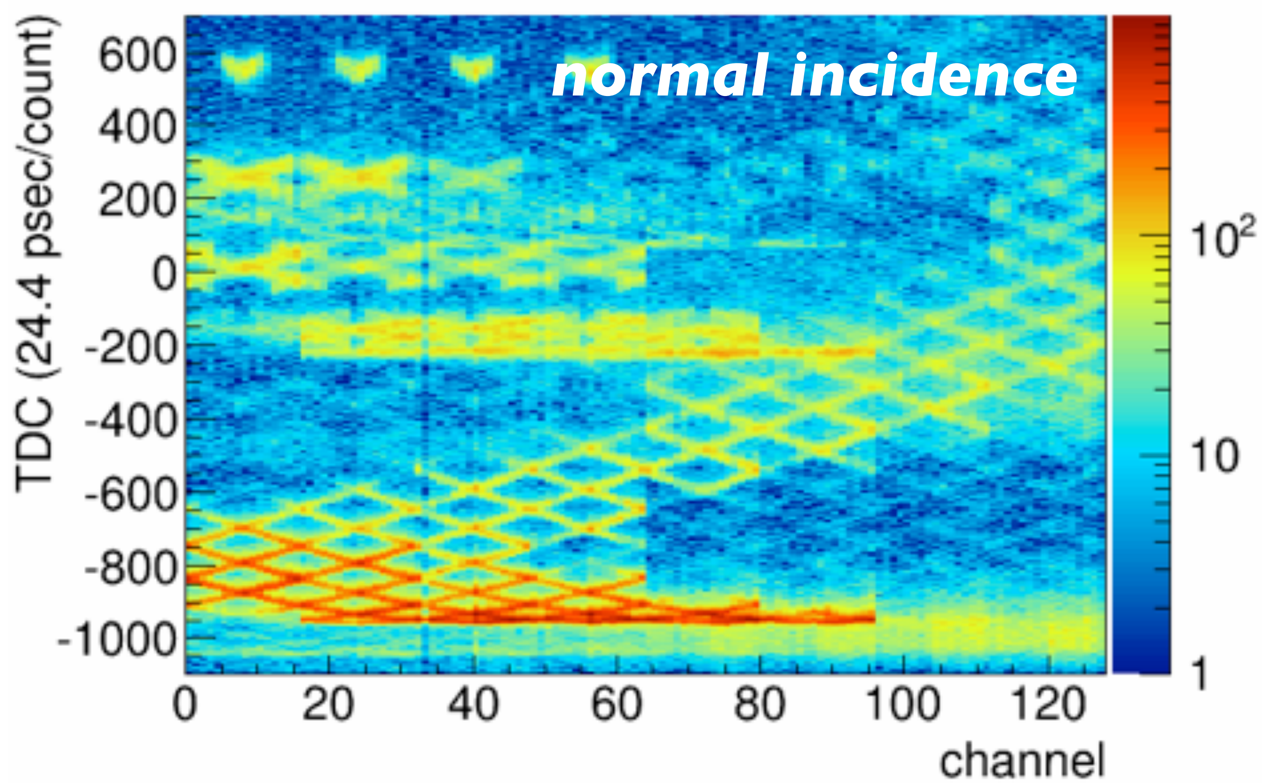
Performance of the TOP detector tested using 2.0 GeV/c e^+ beam at LEPS (Laser Electron Photon beamline at SPring-8).



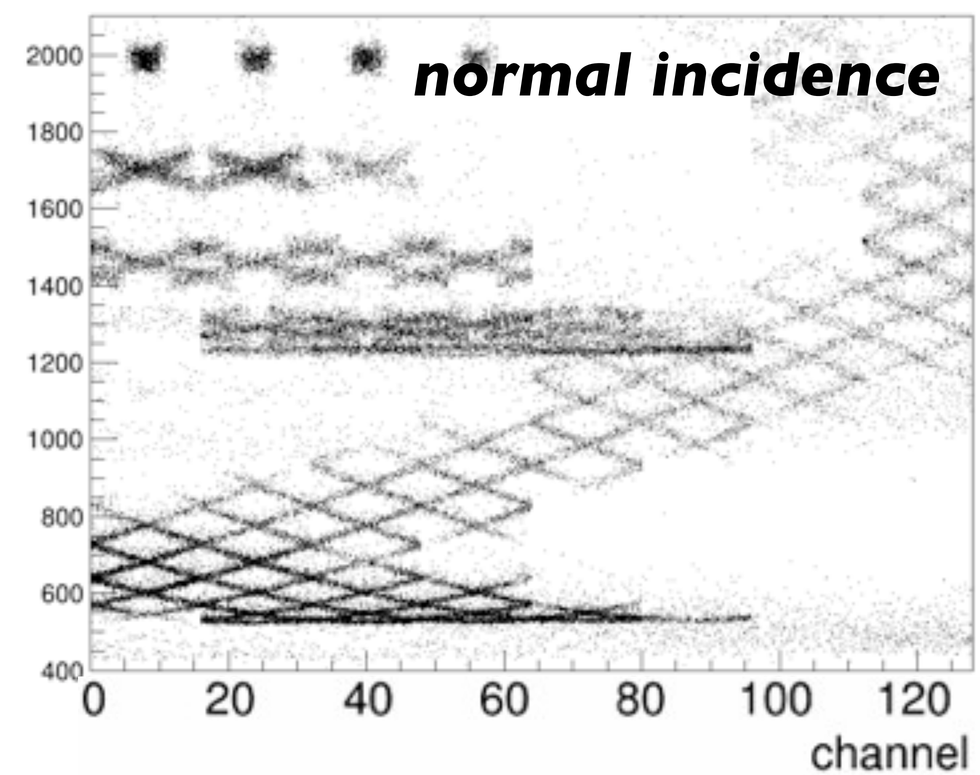
- Data taken for both IRS3B and CFD readout.
- Beam timing from the accelerator RF with a resolution of < 25 psec.
- Test highly supported by the LEPS collaborators.

Beam Test Preliminary Output

Data taken by CFD readout



MC



- Good agreement of the Cherenkov ring image between data and MC.
  - The distribution for data obtained without event selection so far.
  - Channel-by-channel time origin alignment using laser data.
- Will estimate the β resolution for e^+ (directly related to the PID performance).

Analysis ongoing also for the data taken with IRS3B readout.

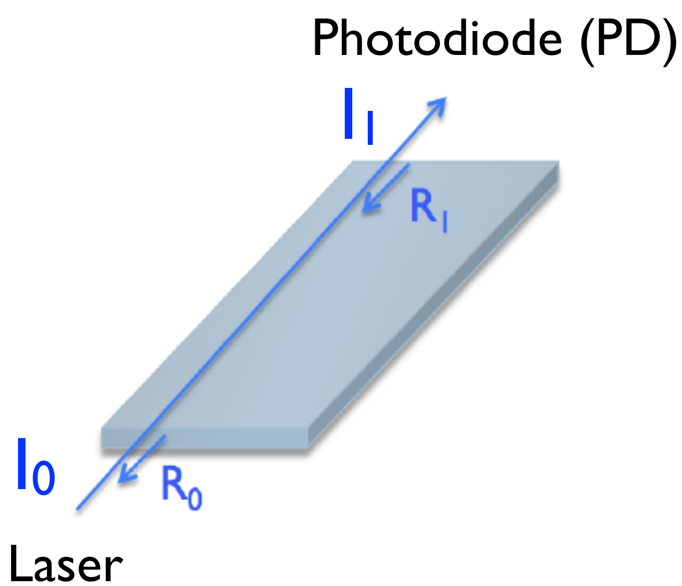
Summary

- TOP detector developed for barrel PID at Belle II.
  - Quartz: maintain Cherenkov-photon efficiency and paths.
  - MCP-PMTs: detect photons with QE > 24% and TTS ~ 40 psec.
  - Electronics: waveform sampling, CFD for performance test.

- Performance test using full-size prototype at LEPS/SPring-8.
  - Good agreement of Cherenkov-ring image btw data and MC.
  - Analysis ongoing for evaluating PID performance.

Backup Slides

Bulk transmittance measurement

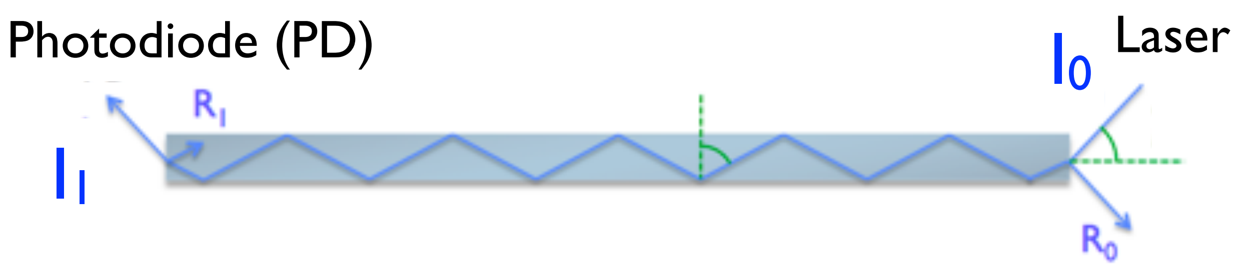


$$I_0(1-R_0)\tau(1-R_1) = I_1$$

τ: bulk transmittance
I_0, I_1: laser intensity (Meas. by PD)
R_0, R_1: intensity for reflection (Calc. by Fresnel's Eq.)

Requirement: > 98%/m

Surface reflectance measurement

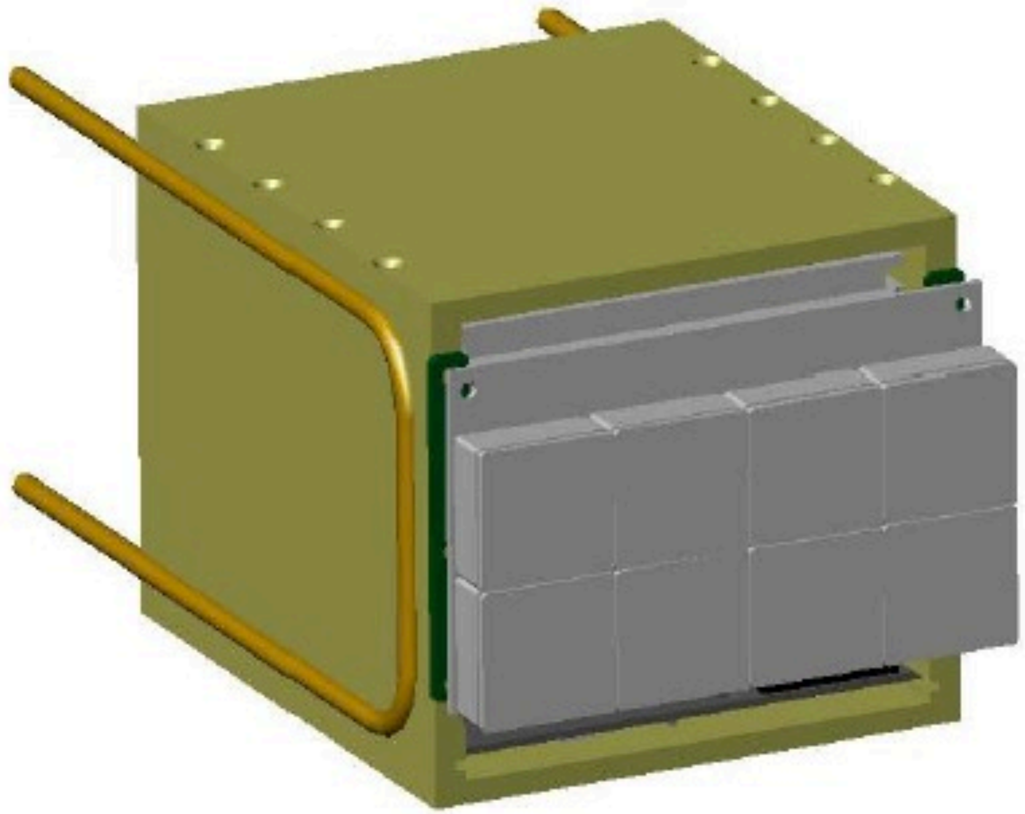


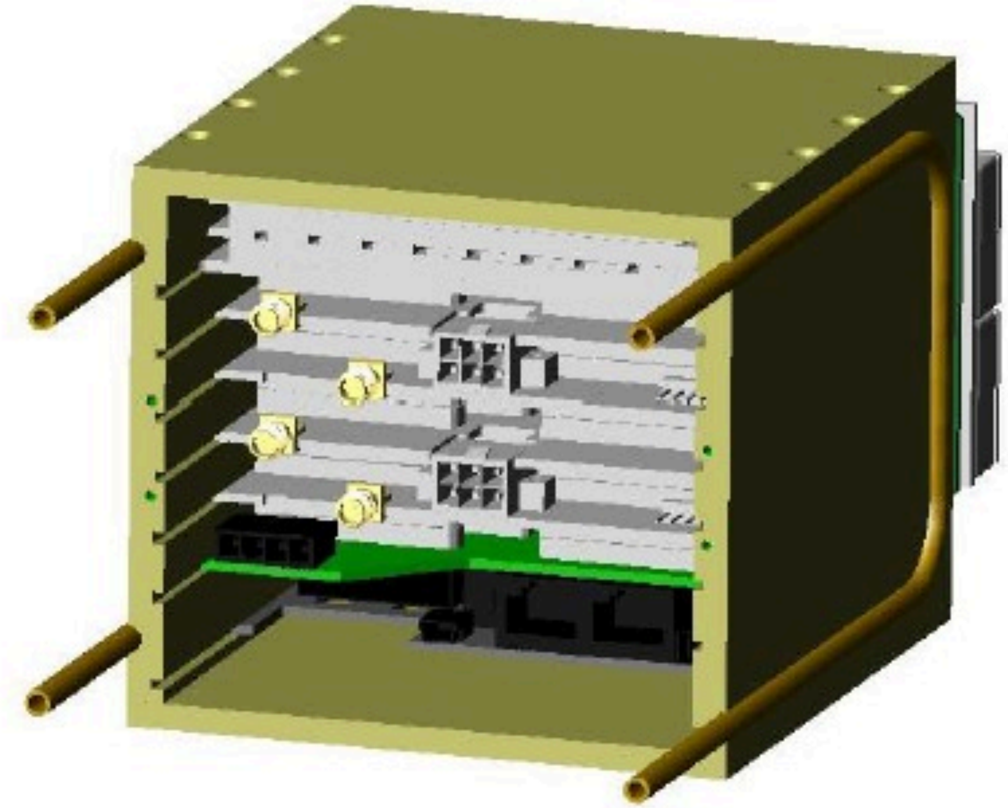
$$I_0(1-R_0)\alpha^N e^{-\frac{L}{\Lambda}\sqrt{1+\left(\frac{bN}{L}\right)^2}}(1-R_1) = I_1$$

α: surface reflectance
N: number of bounces
L/b: quartz length/thickness

I_0, I_1: laser intensity (Meas. by PD)
R_0, R_1: intensity for reflection (Calc. by Fresnel's Eq.)
Λ: absorption factor (Calc. from bulk transmittance)

Requirement: > 99.90%

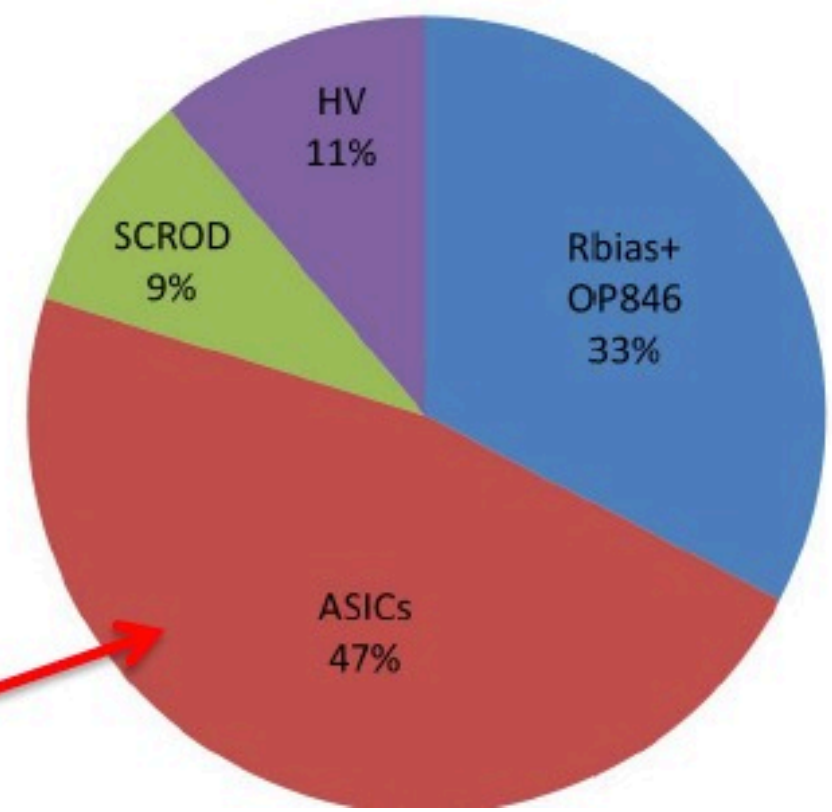




About 31W per board-stack module

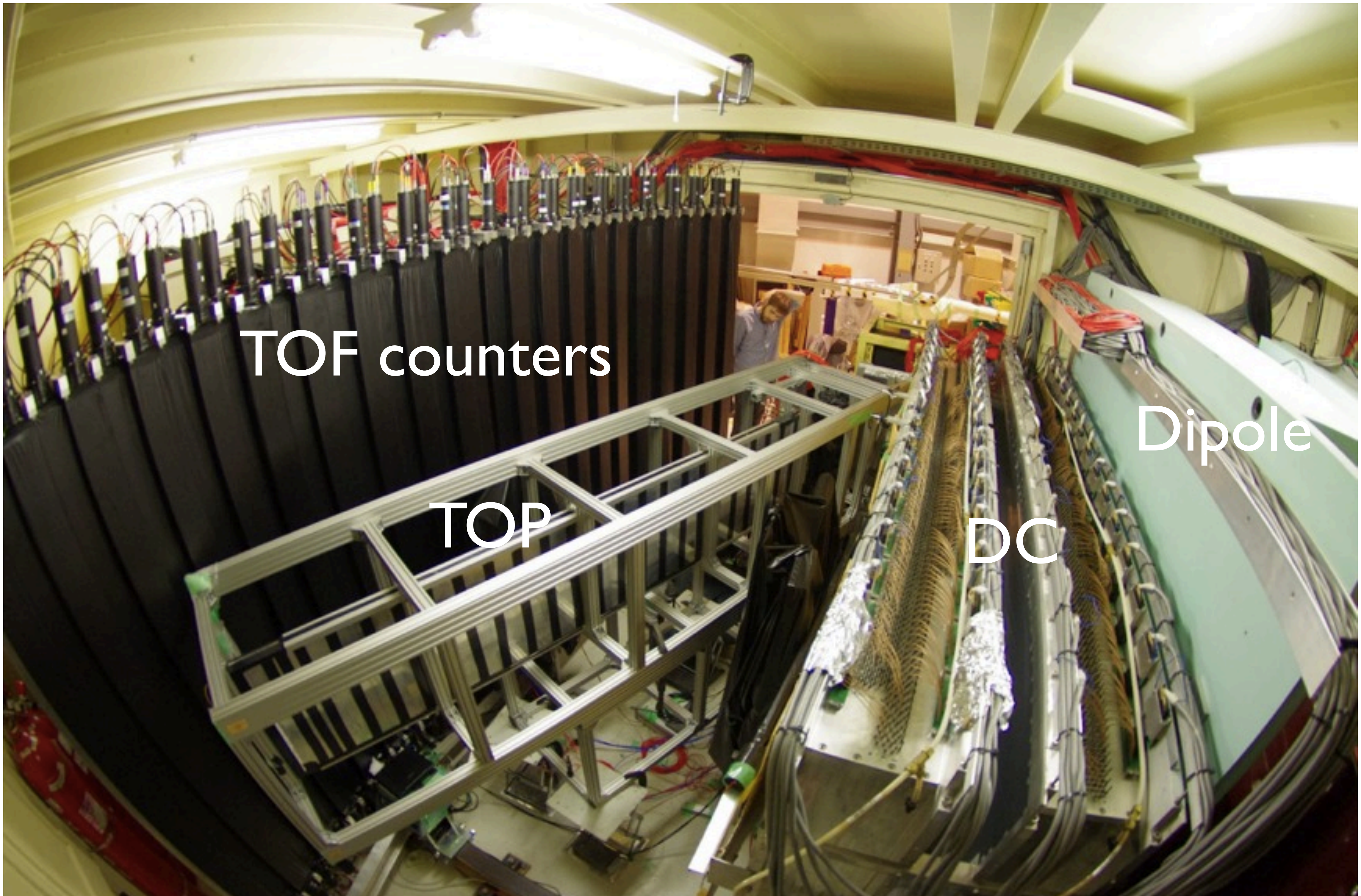
Full TOP, measured numbers

Rbias+OP846	40 W
ASICs	57.6 W
SCRODs	11.2 W
HV	13.6 W
Total	122.4 W



May be possible to tune biases lower

Beam Test at LEPS



Time Origin Calibration Using Laser Data

Preliminary

Channel-by-channel time origin alignment
using the first peak of the TDC distribution.

Laser image after time origin alignment