Construction of the Belle II TOP counter

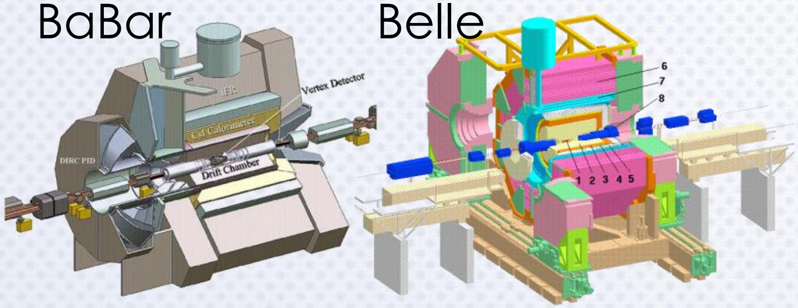
Kodai Matsuoka (KMI, Nagoya University)
for the Belle II TOP group

The 3rd KMI International Symposium (KMI2017)

The Belle II experiment

B-factory experiments

BaBar Belle

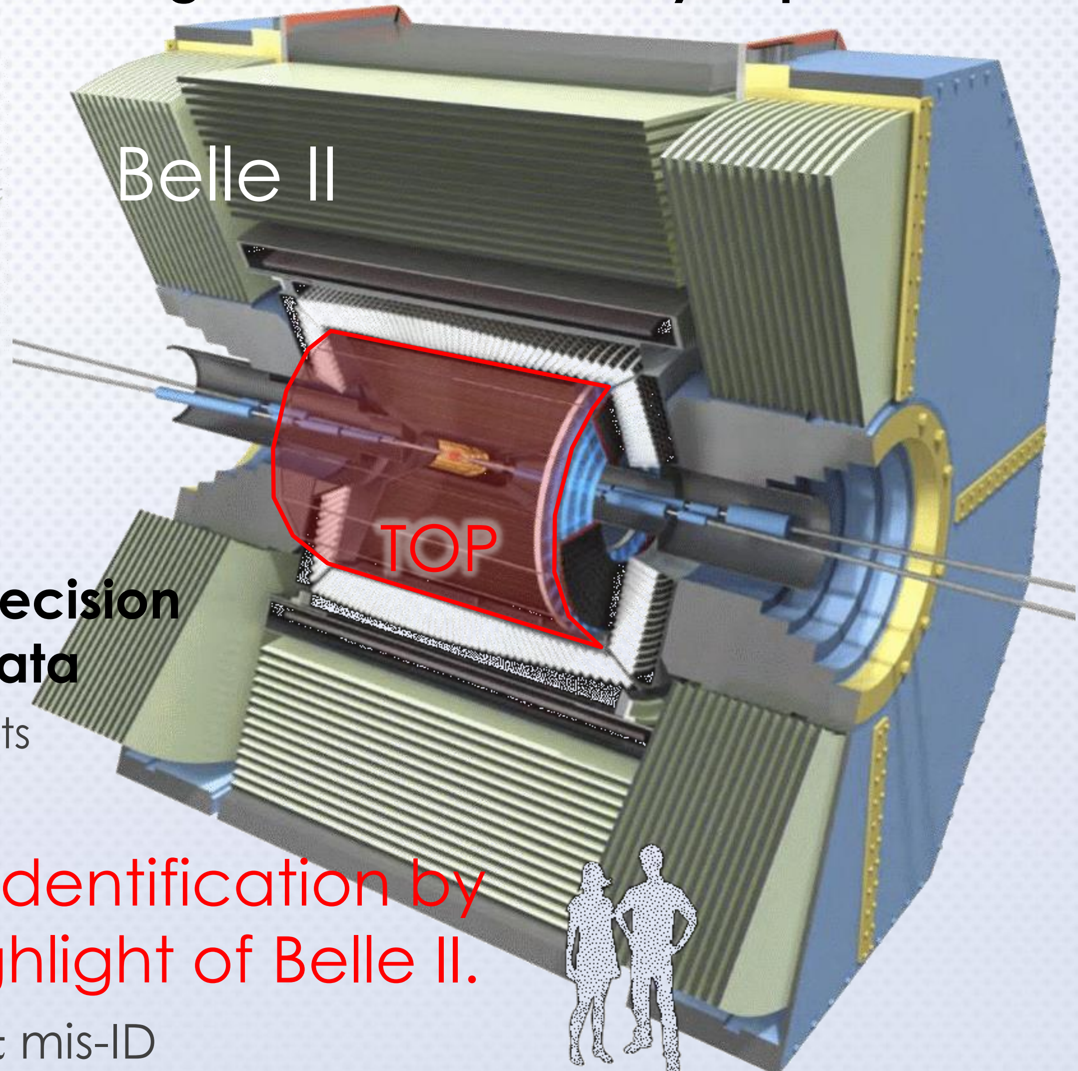


Confirmed Kobayashi-Maskawa theory with > 1 ab^{-1} data

Search for new physics via precision measurements with 50 ab^{-1} data

See A. Gaz's talk on Physics Prospects at SuperKEKB / Belle II

Next generation B-factory experiment

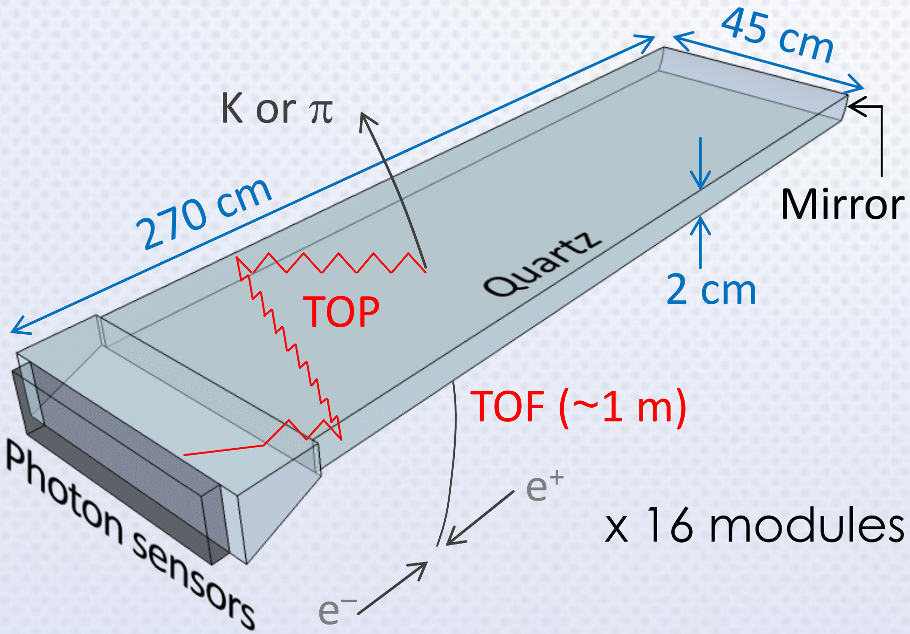


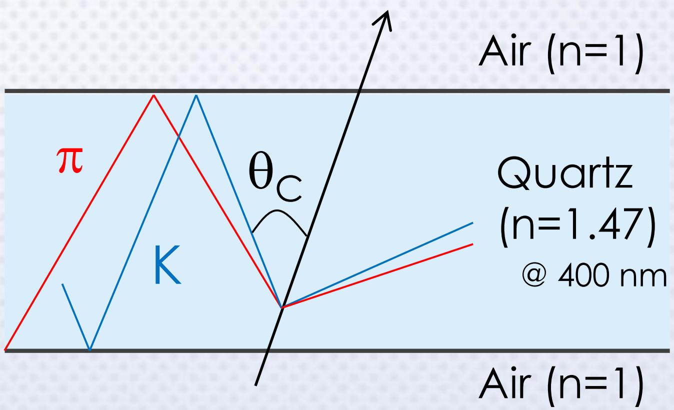
Improvement of particle identification by the TOP counter is the highlight of Belle II.

e.g. ~10% (Belle) → ~3% (Belle II) π mis-ID at 86% efficiency of 1-2 GeV/c K for $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$

TOP (Time-Of-Propagation) counter

- State-of-the-art Cherenkov ring imaging detector
- K/π identification by means of β reconstruction using precise timing measurement of internally reflected Cherenkov photons





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

Key techniques:

✓ Propagate the "ring" image undistorted

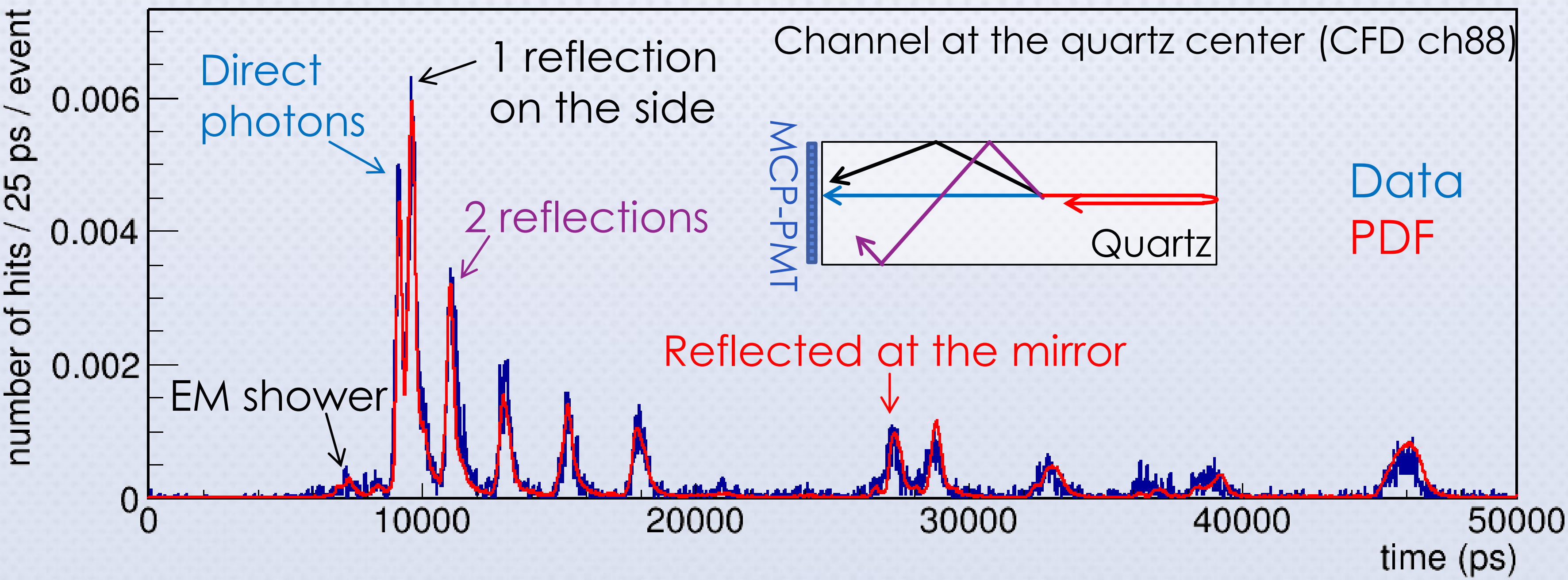
✓ Detect the photons with a high efficiency (~20 hits/track) and with an excellent time resolution (<50 ps)

Major milestones in the past

- TOP counter proposed at Nagoya in 2000.
- Developed the MCP (Micro-Channel-Plate) PMT at Nagoya in collaboration with Hamamatsu.
  Mass production of 512 (+spare) MCP-PMTs started in 2011.

MCP-PMT

- Proved the principle of the TOP counter with a full-scale prototype at the beam test in 2013.
- 32 (+2 spare) quartz bar (pre)production started in (2012)2014.



Quartz bar (synthetic fused silica)

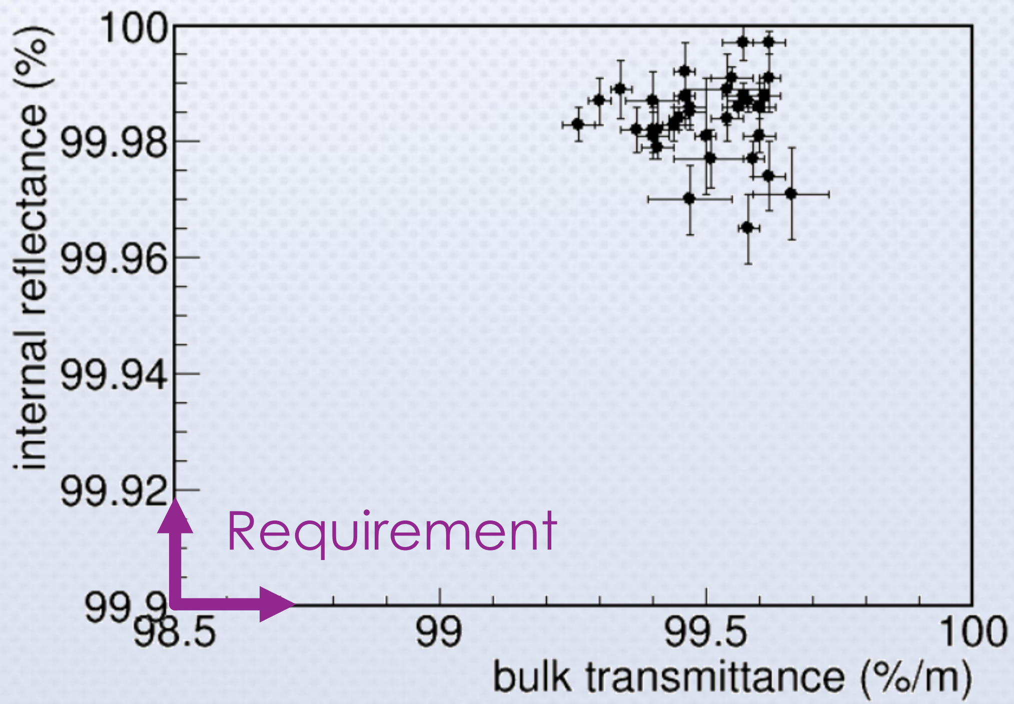
- Two 1250 x 450 x 20 mm^3 bars per TOP module glued together to make a 2500 mm long bar
  - Material: Corning 7980
  - 30 bars polished by Zygo and 2 (+2 spares) by AOS/Okamoto

Specifications

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)

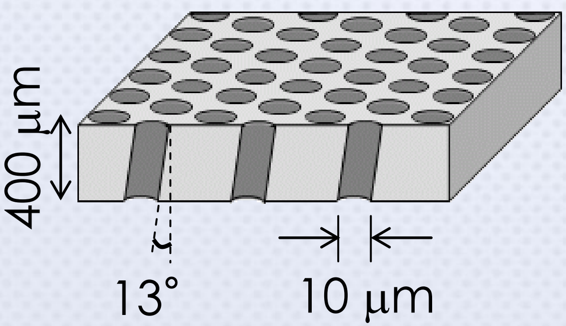
(for the largest surfaces)

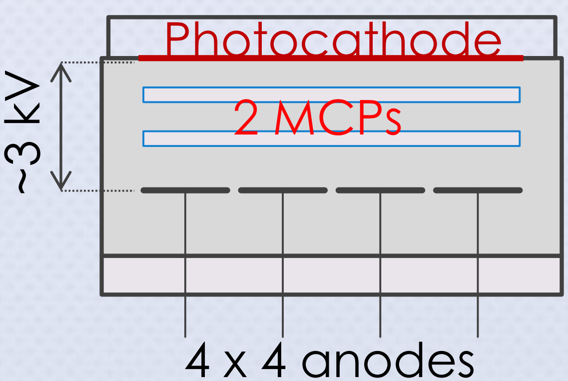
QA results



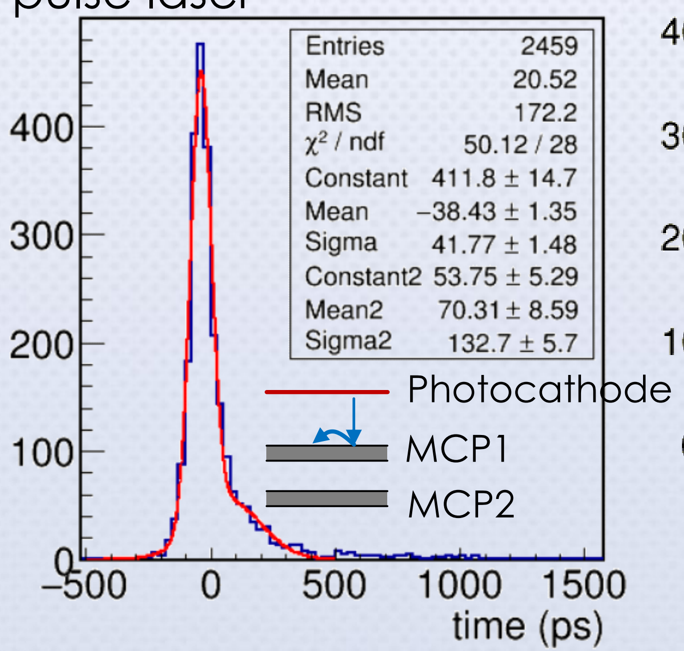
MCP-PMT

- Square shape to cover the bar edge (fill factor: 73%)
- Enough gain (> 5 x 10^5 in 1.5 T) to detect single photon
- Transit Time Spread (TTS) < 40 ps
- QE = 29.3% (average) at $\lambda \approx 360$ nm with NaKSbCs photocathode

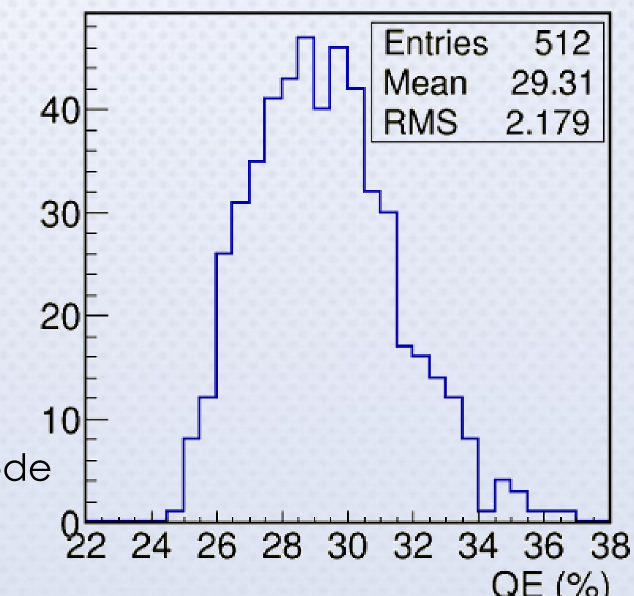




TDC distribution for single photons from picosecond pulse laser



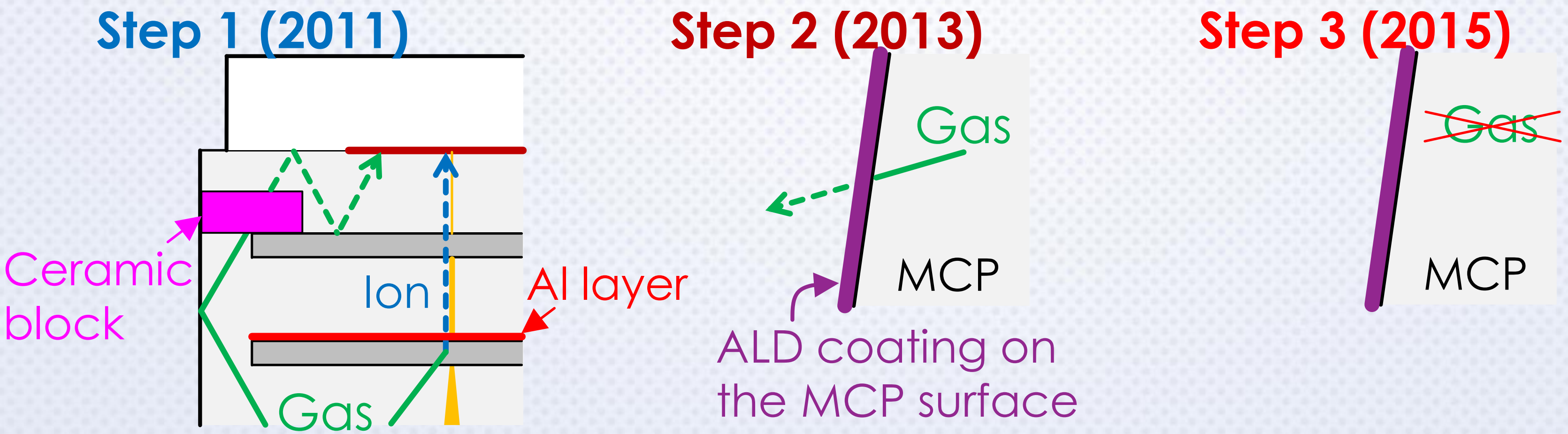
QE at peak (~360 nm)

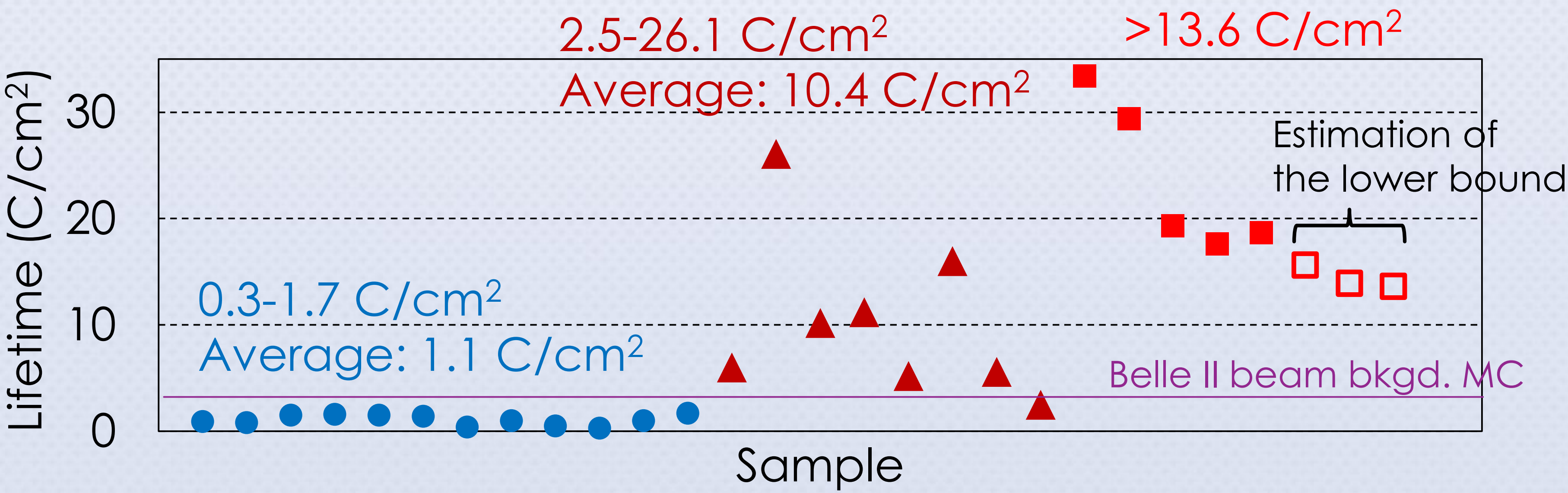


Requirement:
24% min, 28% average

Lifetime extension of the MCP-PMT

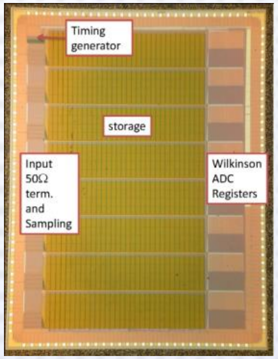
- Outgassing from the MCP deteriorates the photocathode and the QE drops as a function of the integrated output charge.





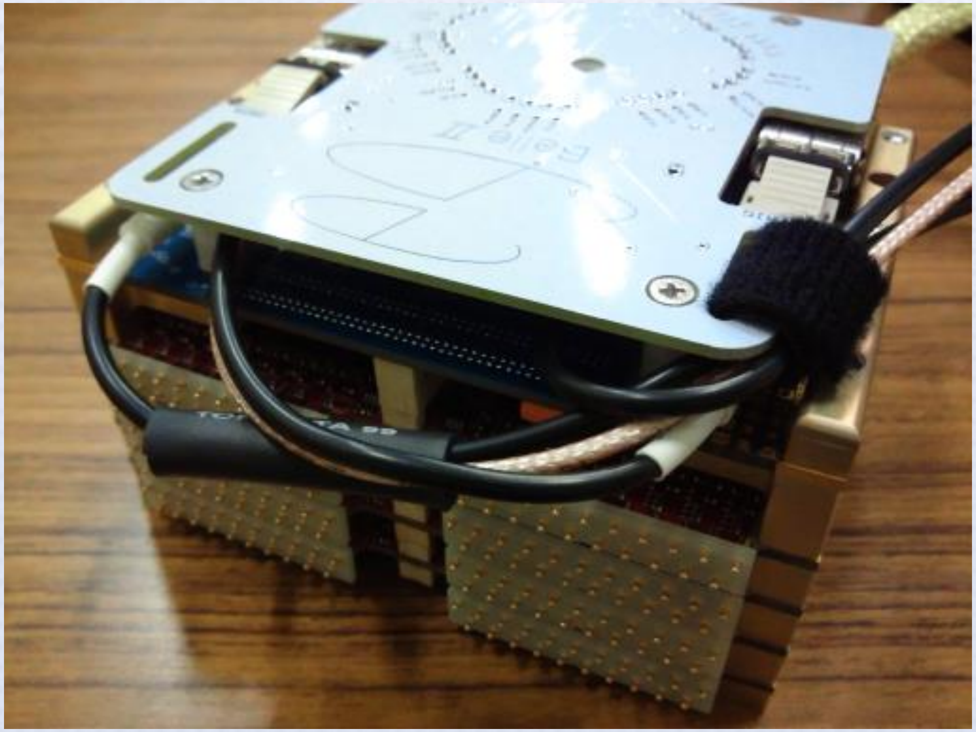
Front-end electronics

- 8-channel, multi-giga sample/sec, transient waveform recorder ASIC (IRSX) developed at Hawaii Univ.
  - 2.8G sample/sec for TOP
  - 32k (11.6 μs) storage per channel

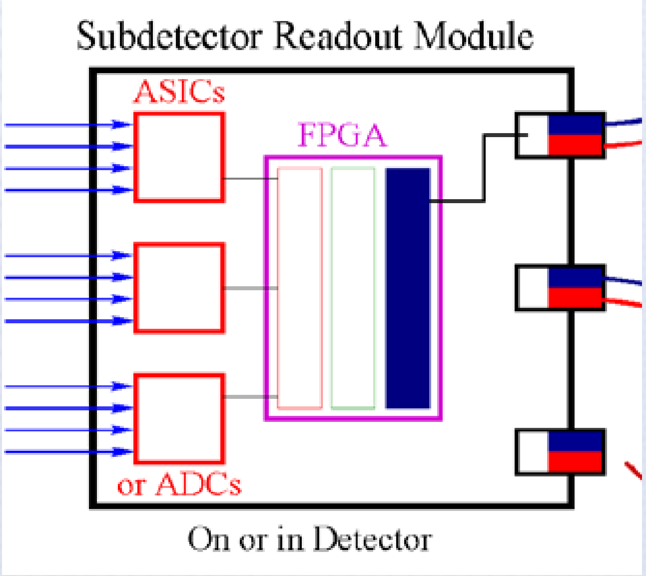


ASIC die photograph

Board stack:
4 carriers + SCROD (master FPGA etc.)

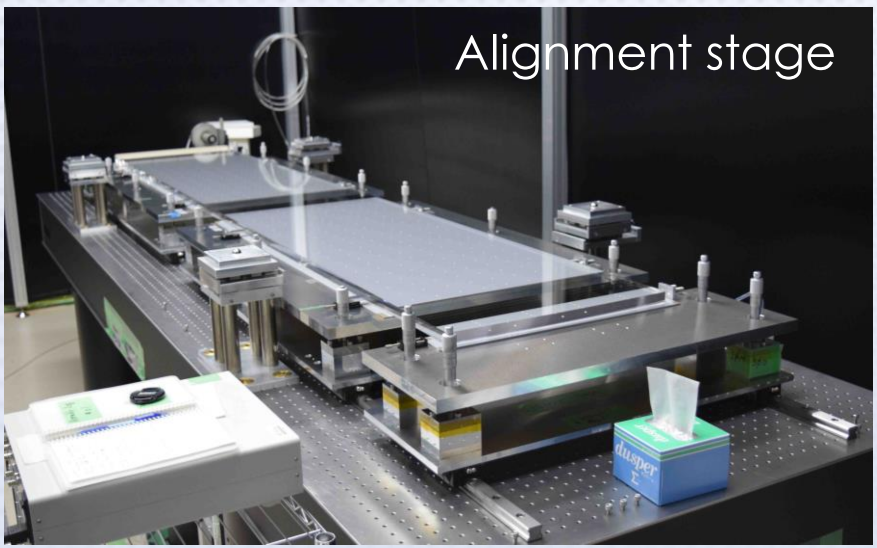


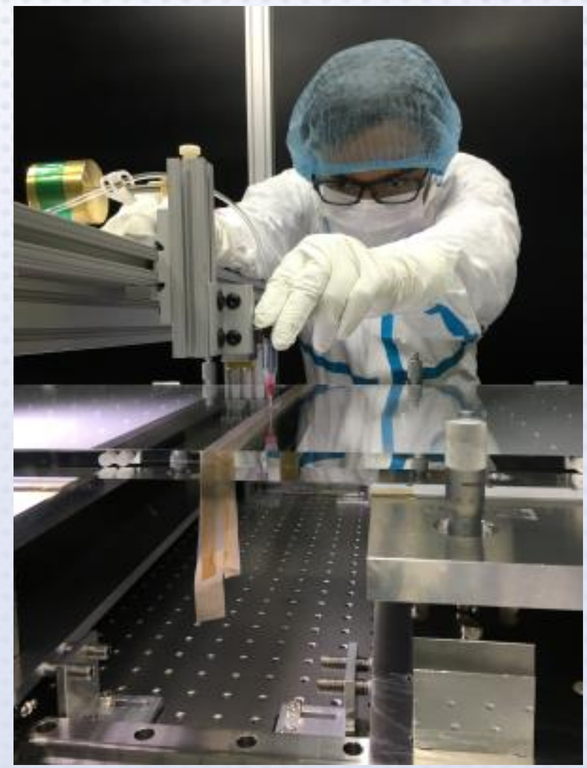
Carrier board: 4 ASICs + Xilinx FPGA

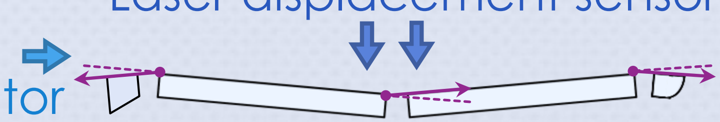


Module assembly 1 (Gluing optics)

- Assembly of 16 production TOP modules started in Mar. 2015.
- Alignment and gluing of prism-bar-bar-mirror:
  1. Insert shims to adjust the gap for glue.
  2. Adjust surface positions using a laser displacement sensor and micrometers.
  3. Adjust surface angles using an autocollimator and micrometers.
  4. Iterate 2-3 several times.
  5. Tape joints and apply epoxy (EPOTEK 301-2).





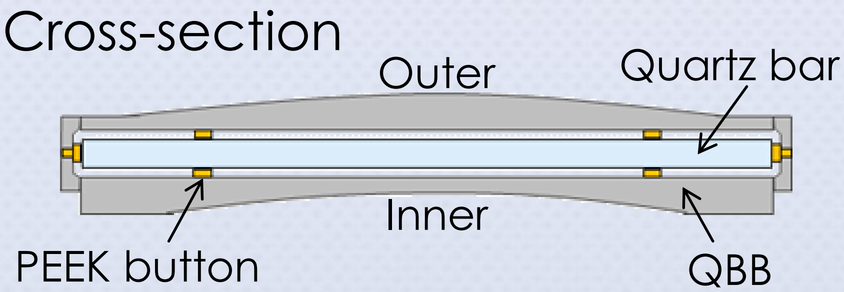


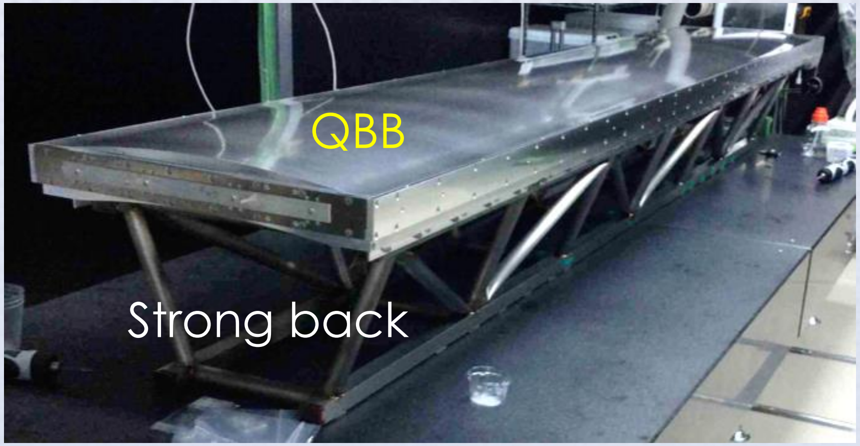
Aligned with $|\theta| < 20$ arcsec

Module assembly 2 (Quartz bar box)

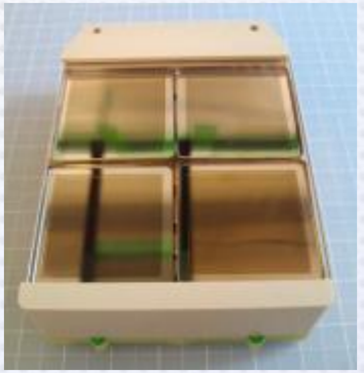
- Quartz Bar Box (QBB) to contain the optics keeping flat
- QBB needs high rigidity ↔ low mass
  - Aluminum honeycomb panels for low mass
  - Round shape to have high rigidity
- PEEK buttons to support the optics
  - Button height was tuned ($\sigma < 0.02$ mm) with ring shims or bond thickness according to the optics alignment.
- Truss support (strong back) for handling
  - Keep module sag < 0.5 mm to securely support the optics

PEEK button

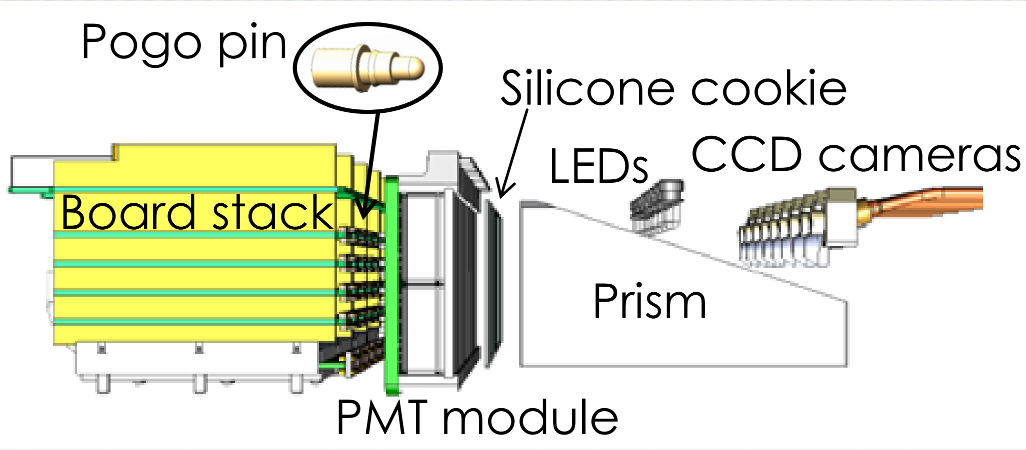


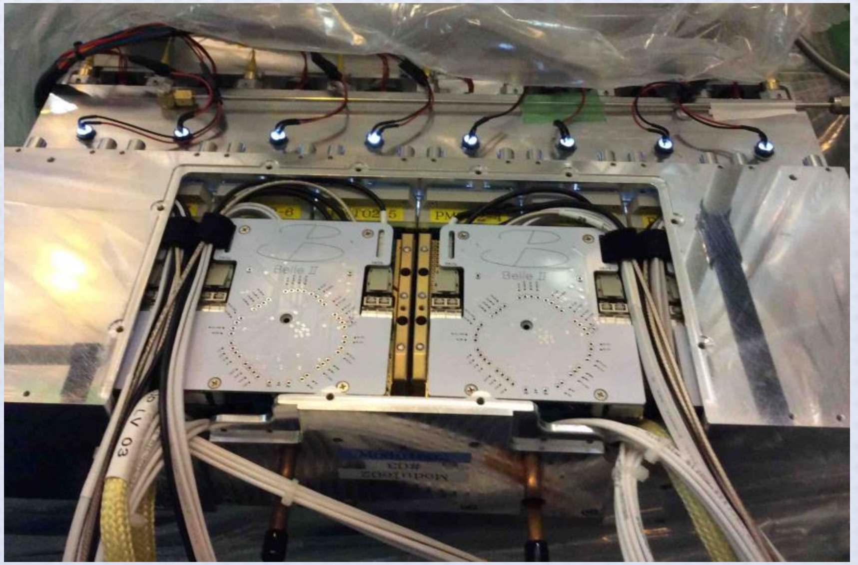


Module assembly 3 (PMT and front-end readout)



- 4 MCP-PMTs are assembled in a PMT module.
  - PMT window is glued on a wavelength filter.
  - Wavelength filter cuts $\lambda \leq 340$ nm to suppress chromatic dispersion.
- Optical contact of the PMT module on the prism is made by a soft cast silicone cookie.
  - It makes bubble free contact and PMT module replaceable.
  - The optical contact was checked by the CCD cameras.

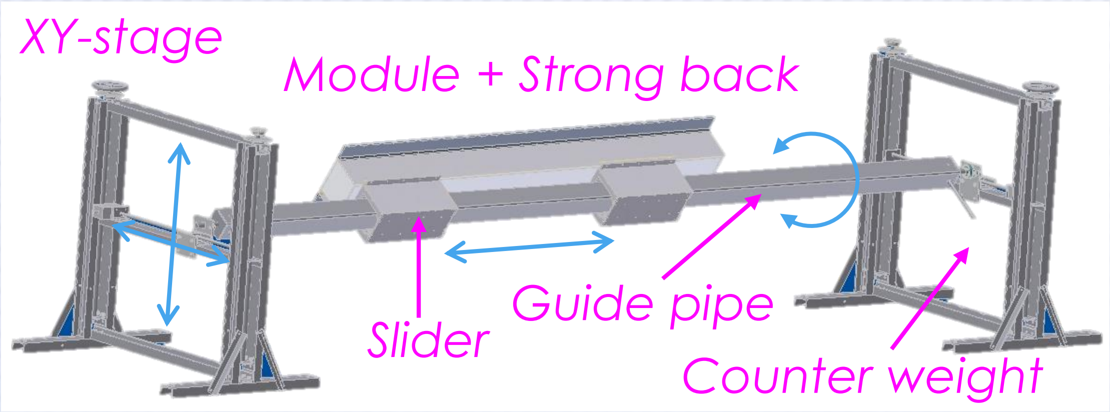




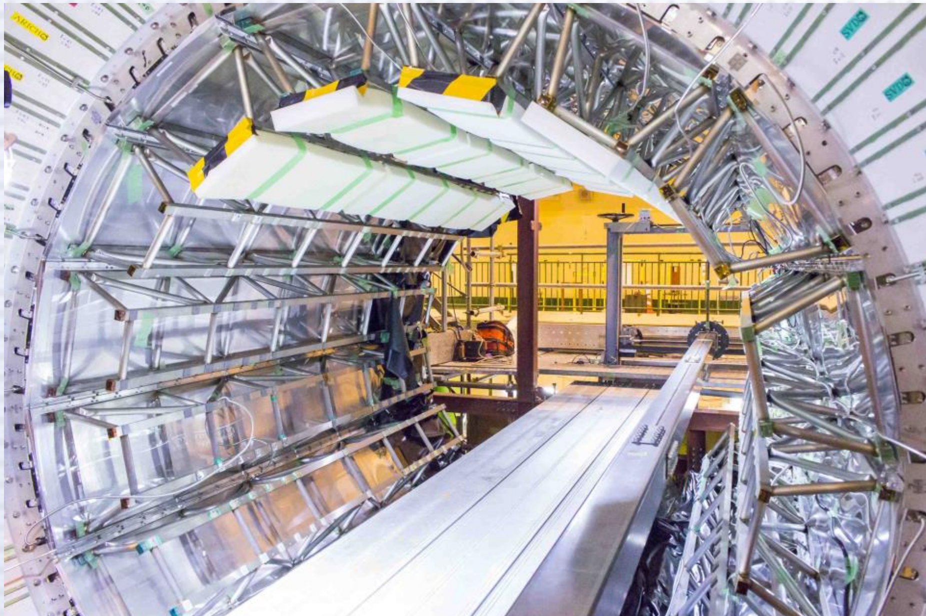
Installation

- 1^{st} module installed on Feb. 10, 2016.
  - Installed one-by-one module with a dedicated installation jig.
- Module deflection was monitored by three types of gauges.
  - The max sag was kept within 0.5 mm.

Installation jig

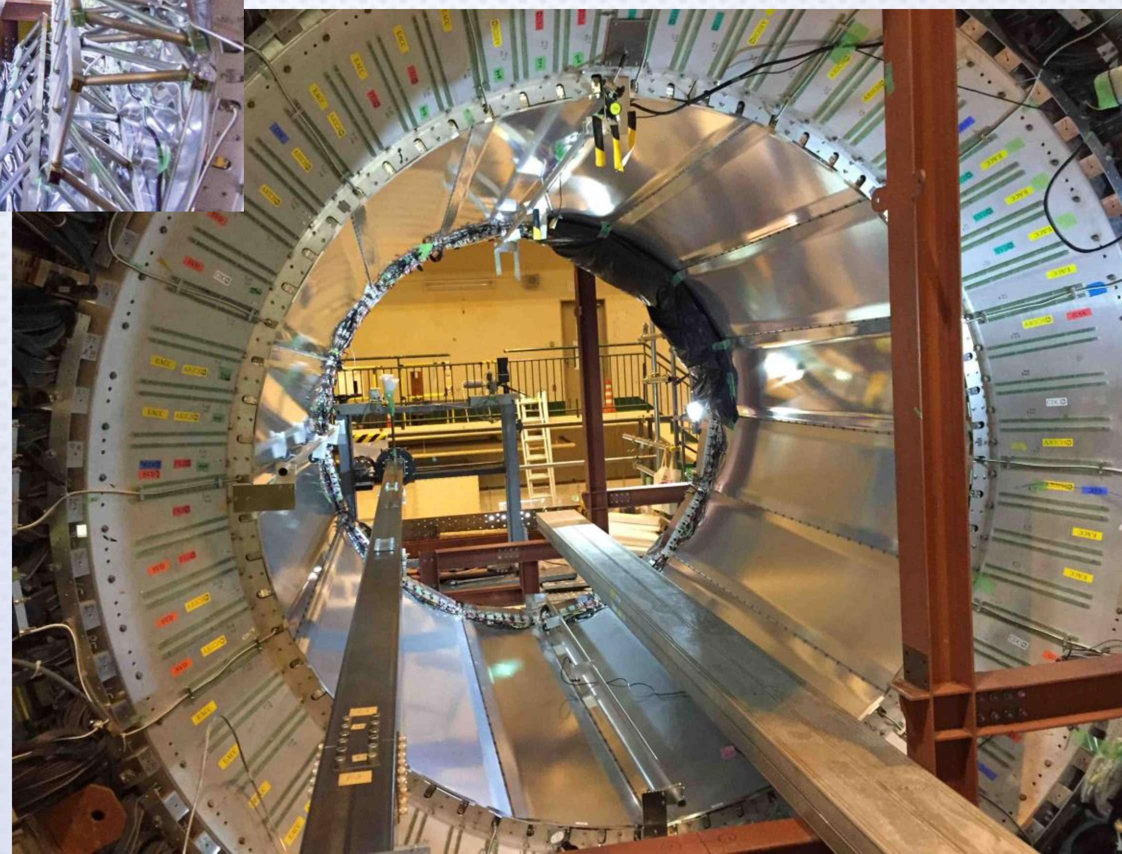


Installation completed successfully



Last (16^{th}) module installed on May 11

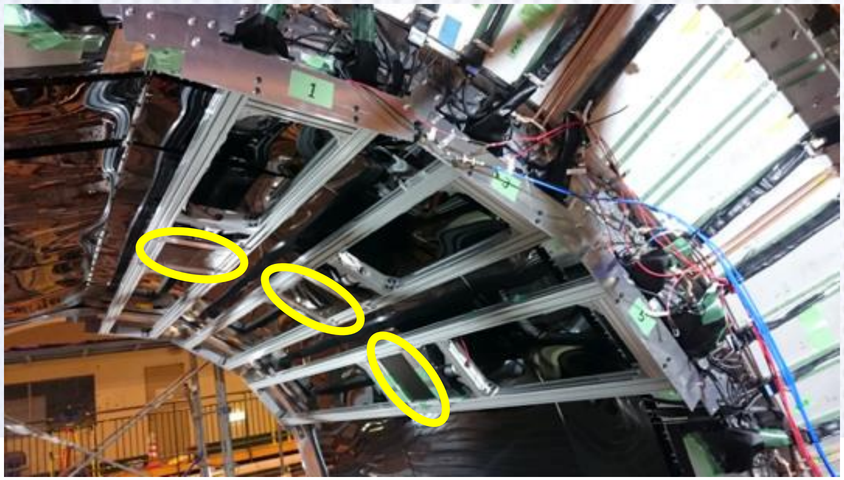
- Side-by-side modules were joined by 2.65 m long Al z-beams for structural integrity.

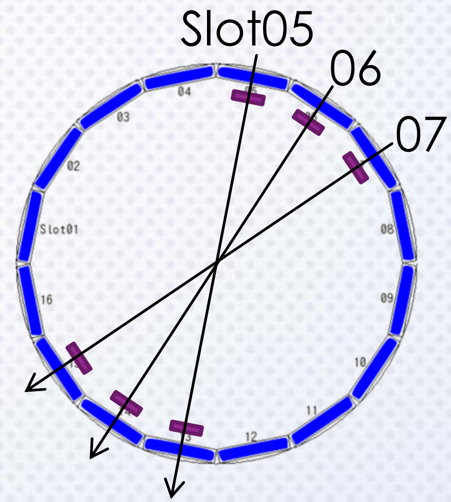


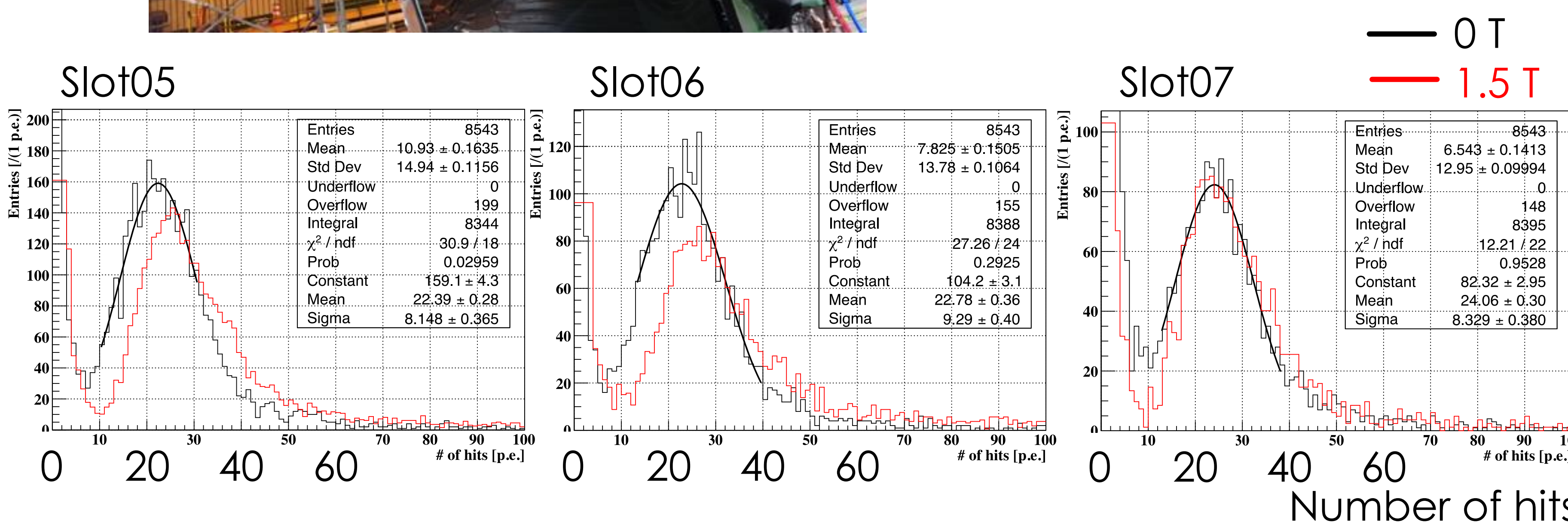
Strong back removed on May 20

Preliminary commissioning with cosmic rays

Temporary scintillator paddle triggers







Detailed calibration in progress

Summary

- The TOP counter is a key device in Belle II.
- After the long R&D of more than a decade and 2-3 years production/construction, we finally succeeded in
  - Producing the 32 (+2 spare) quartz bars and the other optics
  - Producing the 512 (+spare) MCP-PMTs and extending the lifetime
  - Assembling the 16 (+1 spare) TOP modules
  - Installing 16 TOP modules
- Commissioning/calibration of the installed modules is ongoing toward
  - Phase 2 (SuperKEKB commissioning with Belle II) from Jan. 2018
  - Physics run from Dec. 2018

→ See poster by R. Omori, N. Tsuzuki and G. Muroyama