Commissioning of the Belle II Time-Of-Propagation counter

Maeda Yosuke (N-lab)
for the Belle II TOP group

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KMI topics

content

- introduction
  - role of particle identification
  - Belle II Time-Of-Propagation (TOP) counter
- operation test before installation
- commissioning after installation
- summary and prospects

Belle → Belle II

- The Belle experiment finished data taking at Jun, 2010
  →upgrade to Belle II is on-going
- Belle II
  - ×40 luminosity by accelerator upgrade (KEKB → SuperKEKB)
  - integrated lumi. : 1 ab^{-1}(Belle) → 50 ab^{-1}
  - detector upgrade
    - outer structure is reused
    - to handle higher rate and improve performance

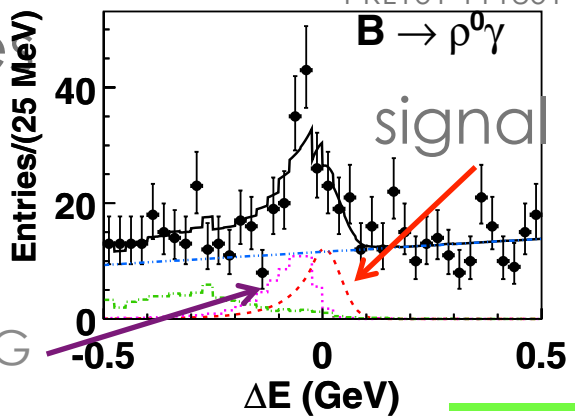
Particle ID in Flavor Physics

- B mesons have various decays modes
- need to identify particle flavor of each observed track to examine various B meson decays precisely
  - example of problematic case
    - B→Kπ / B→ππ
    - B→K*γ→Kπγ / B→ργ→ππγ
    - smaller decay rate in pion modes ($|V_{ub}|$)

B^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
Semileptonic and leptonic modes				
$\ell^+\nu_\ell$ anything	[a]	(10.99 ± 0.28) %		–
$e^+\nu_e X_c$		(10.8 ± 0.4) %		–
$D\ell^+\nu_\ell$ anything		(9.8 ± 0.7) %		–
$\overline{D}^0\ell^+\nu_\ell$	[a]	(2.27 ± 0.11) %		2310
$\overline{D}^0\tau^+\nu_\tau$		(7.7 ± 2.5) × 10^{-3}		1911
$\overline{D}^*(2007)^0\ell^+\nu_\ell$	[a]	(5.69 ± 0.19) %		2258
$\overline{D}^*(2007)^0\tau^+\nu_\tau$		(1.88 ± 0.20) %		1839
$D^-\pi^+\ell^+\nu_\ell$		(4.2 ± 0.5) × 10^{-3}		2306
$\overline{D}_0^*(2420)^0\ell^+\nu_\ell$, $\overline{D}_0^{*0}\to D^-\pi^+$		(2.5 ± 0.5) × 10^{-3}		–
$\overline{D}_2^*(2460)^0\ell^+\nu_\ell$, $\overline{D}_2^{*0}\to D^-\pi^+$		(1.53 ± 0.16) × 10^{-3}		2065
$D^{(*)}n\pi\ell^+\nu_\ell(n\geq 1)$		(1.87 ± 0.26) %		–
$D^{*-}\pi^+\ell^+\nu_\ell$		(6.1 ± 0.6) × 10^{-3}		2254
HTTP://PDG.LBL.GOV	Page 7	Created: 10/1/2016 20:05		

from Review of Particle Physics, ~15 pages for B^+

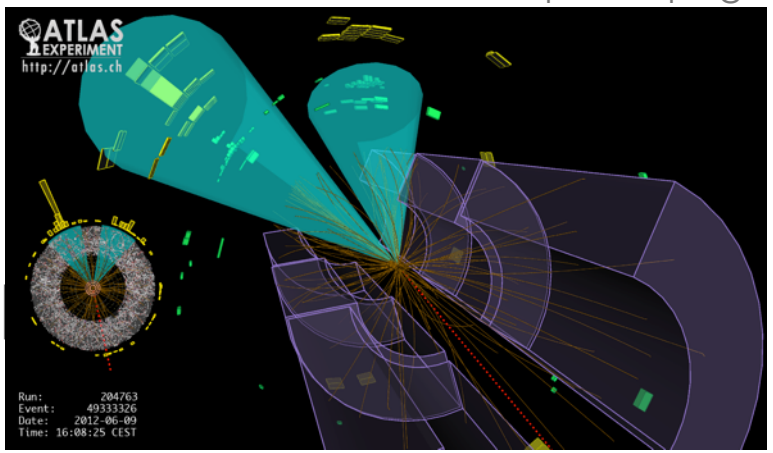
PRL101 111801

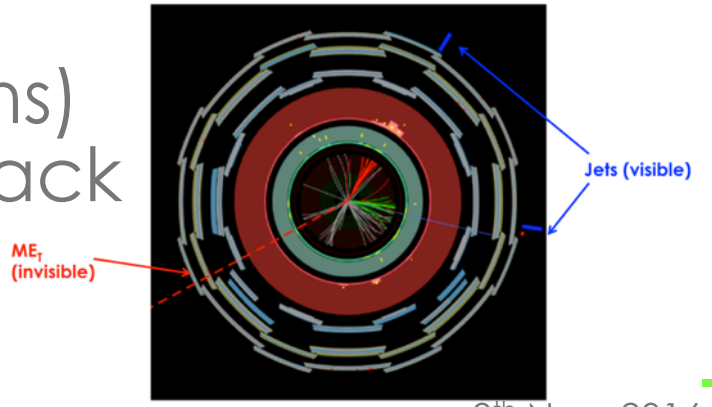


energy frontier case

- high energy pp collision (ATLAS, CMS,...)
  - Most hadronic objects are observed as a bundle of particle trac →do(can) not identify track by track
  - leptons (especially muons) are identified track by track

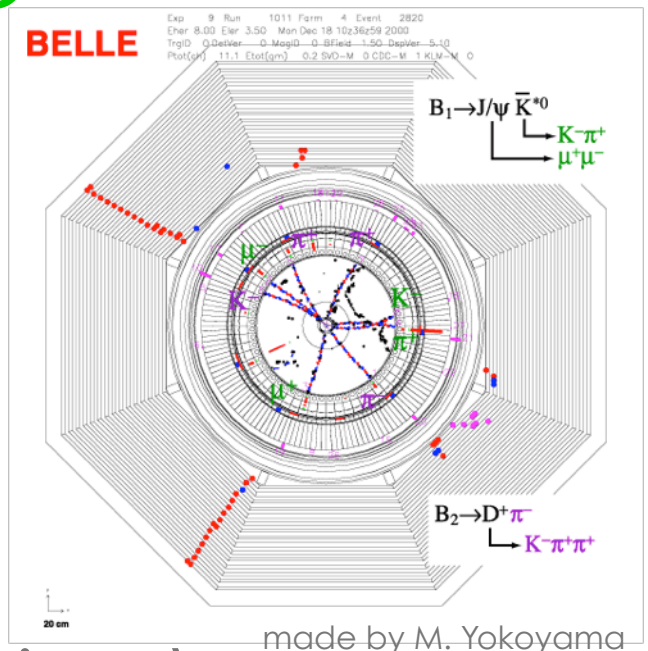
from ATLAS public page





PID algorithm in general

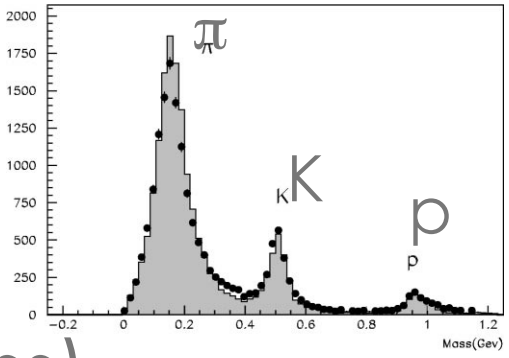
- muon
  - penetrating track through the outer detector
- electron
  - energy in calorimeter (E/p)
- hadrons (protons, kaons, pions)
  - time of flight, dE/dx → protons
  - Identification of high-p kaons and pions is achieved with dedicated PID detectors.



made by M. Yokoyama

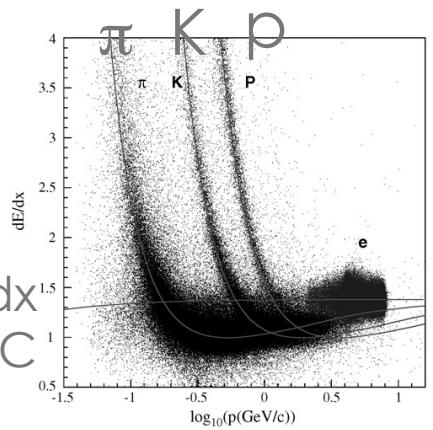
tools to identify particles

- Time Of Flight
  - TOF = L/v
- dE/dx (energy loss)
  - Bethe-Bloch formula
- Cherenkov radiation
  - cos θ = 1/(nβ)
  - radiator is chosen for mom. range of interest

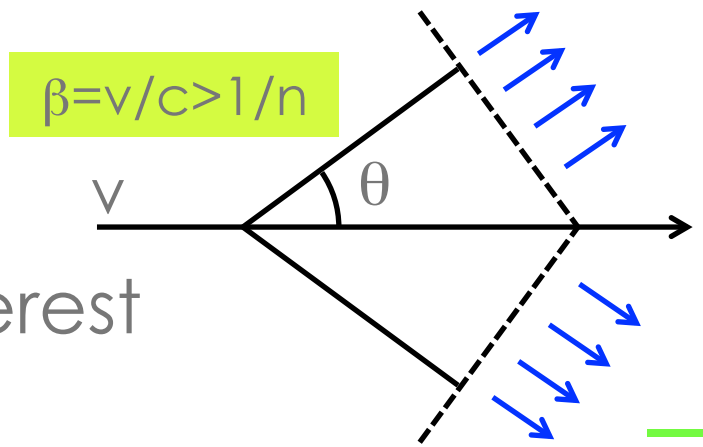


TOF distribution in Belle (<1.2 GeV/c)

NIMA494 402-408



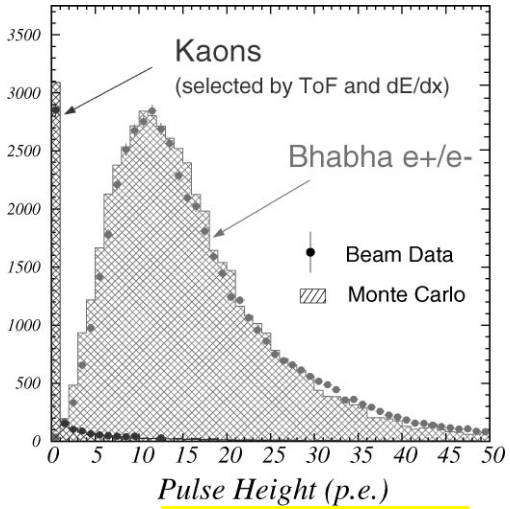
Belle dE/dx in CDC



Cherenkov radiation for PID

- threshold type
  - use Cherenkov threshold; see “hits” or “no hits”
  - ex) Aerogel Cherenkov Counter (ACC) in Belle
- ring imaging Cherenkov counter
  - measure the Cherenkov angle to get velocity information

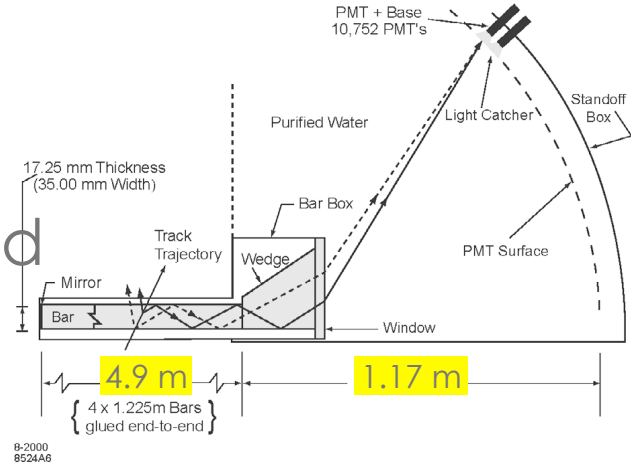
NIMA453 321-325

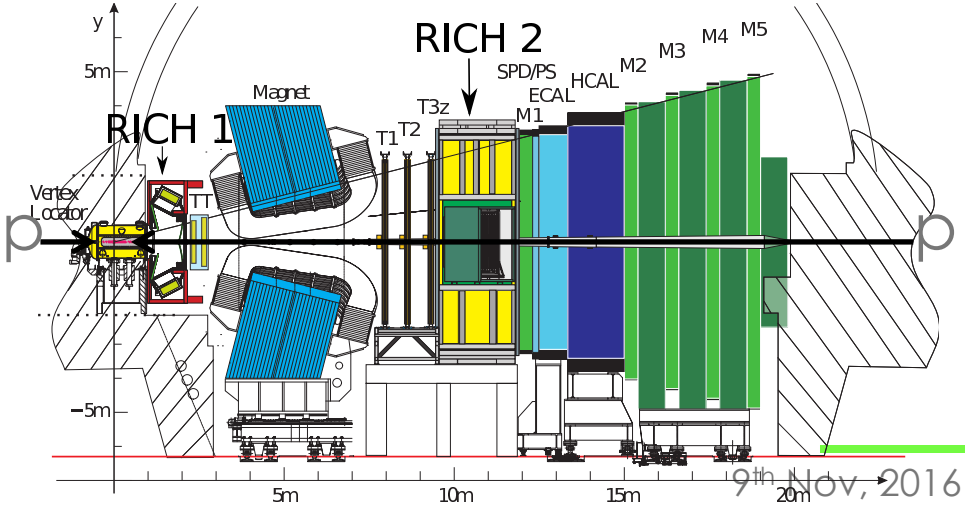


Belle ACC

RICH type PID detector

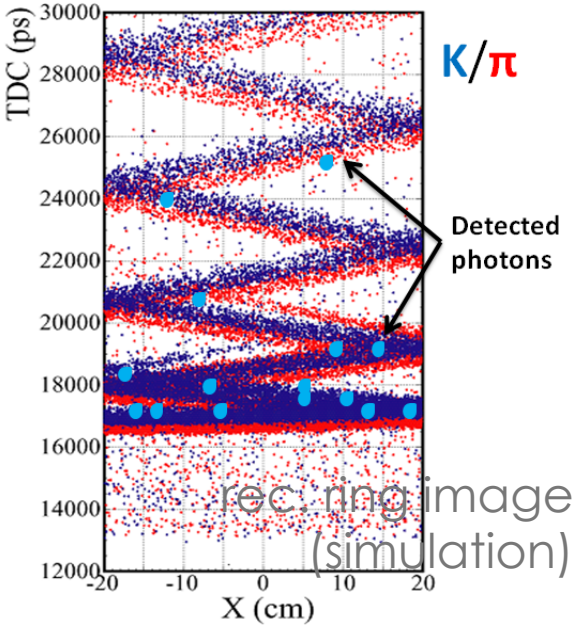
- BaBar DIRC
  (Detection of Internally Reflected Chrenkov light)
  - quartz bar
    + “standoff box” (image expansion, filled with water)
- LHCb RICH
  - C_4F_{10} or CF_4 gas



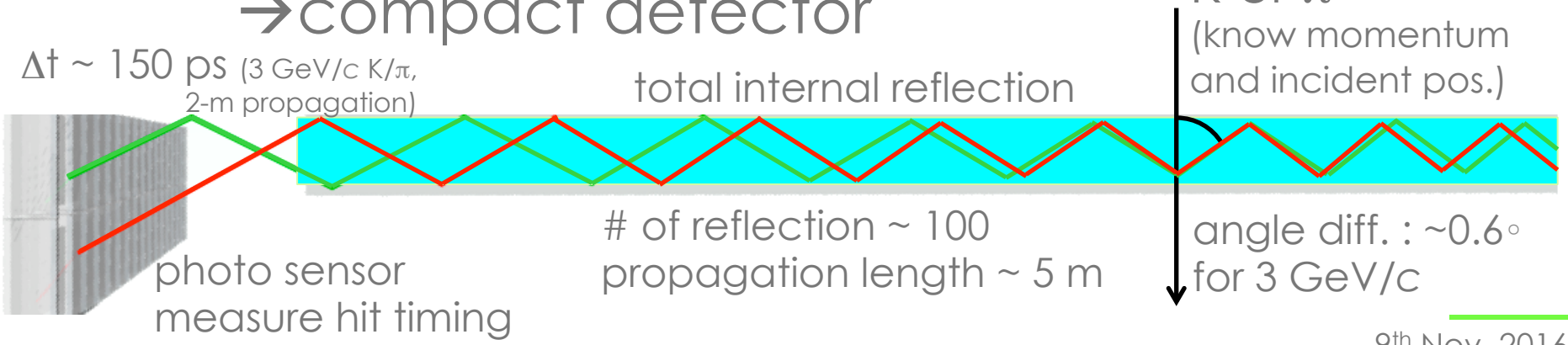


Time-Of-Propagation counter

- new idea :
  use propagation time
  of Cherenkov light
  to reconstruct ring images
  - do not need large space
    to expand ring images
    →compact detector



rec. ring image
(simulation)

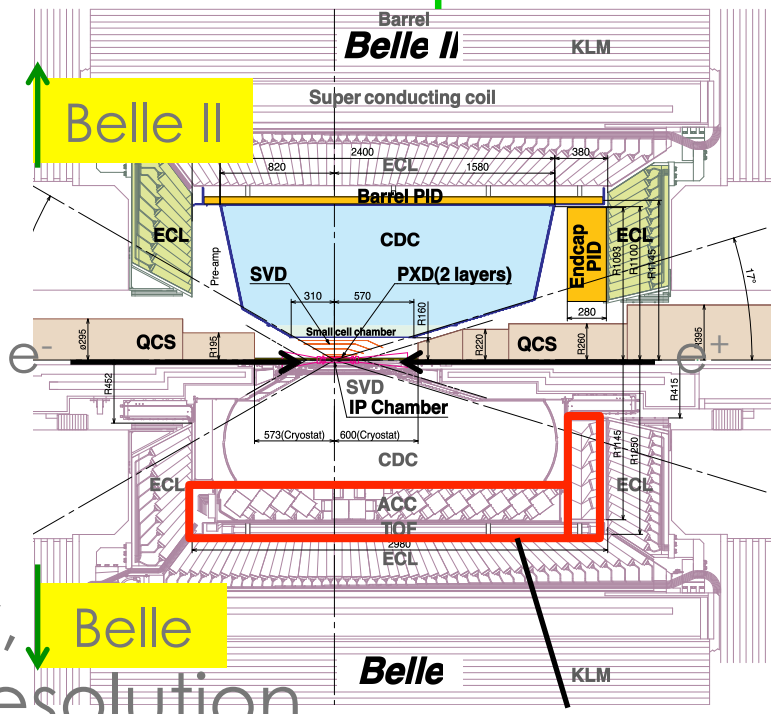


challenges

- extreme timing resolution for each single photon (<50 ps)
  - not only for photo sensor, but also for readout electronics
- mechanical property of radiator
  - flatness, alignment…
- radiation tolerance

TOP counter in the Belle II exp't

- replacement of ACC
  - higher performance threshold type → RICH type
  - compact large tracker detector, improve momentum resolution
  - less material less scattering, better energy resolution for calorimetry



Belle PID system (ACC + TOF)

detector overview

- 2-cm-thick quartz bar
- aluminum honeycomb structure
- photo sensor : micro channel plate (MCP) PMT
- 16 identical modules to form barrel structure

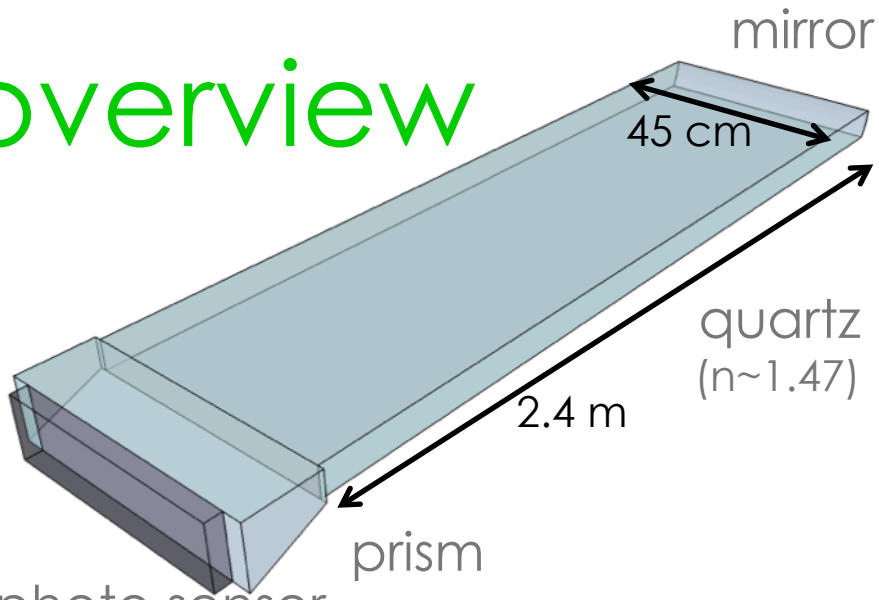
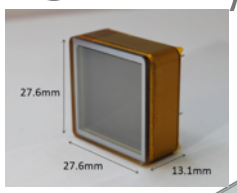
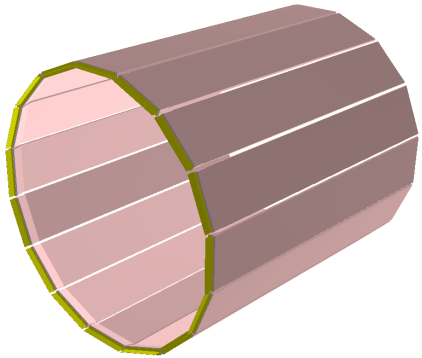


photo sensor (MCP-PMT)

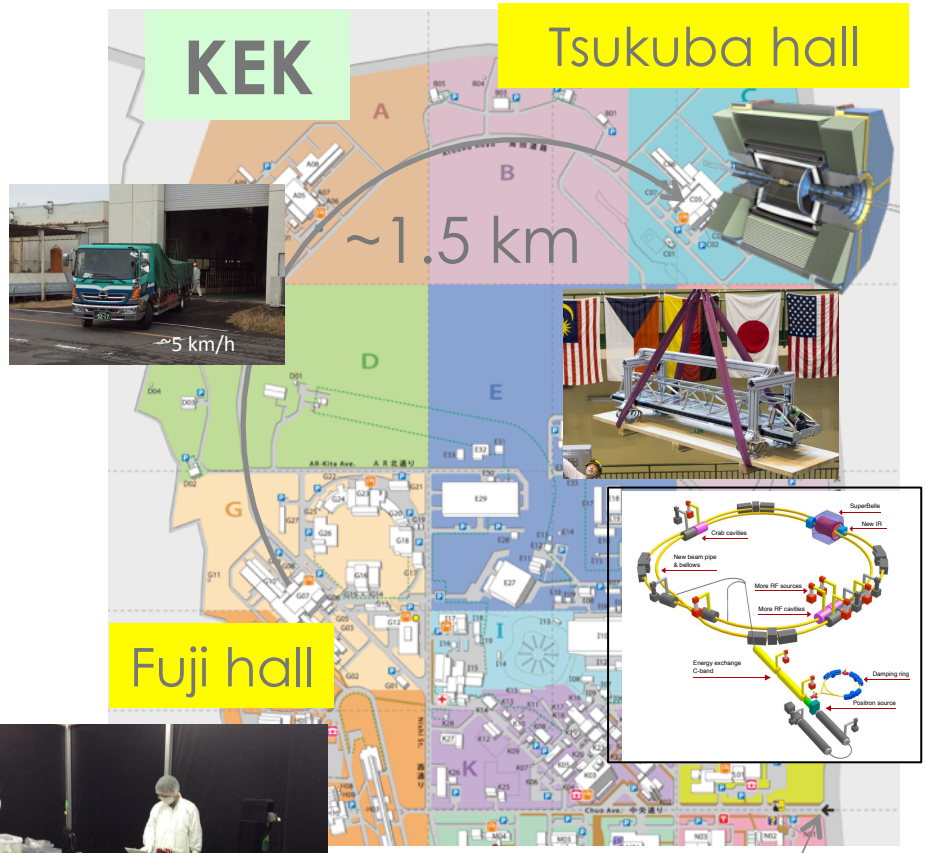




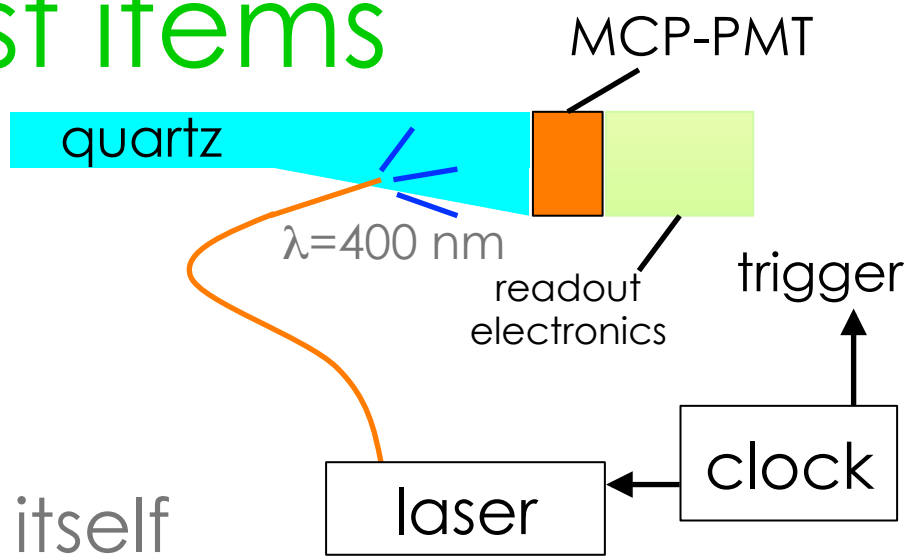
support structure

from production to installation

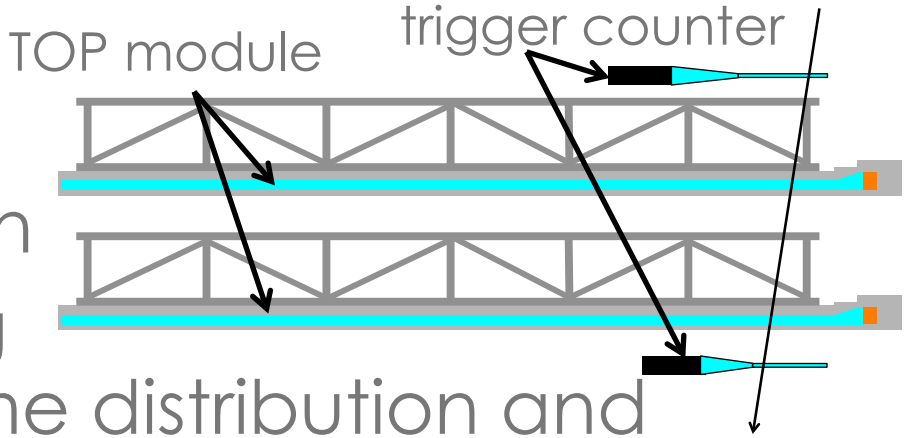
- module production at Fuji hall
  →initial operation test
- transportation to Tsukuba hall
  →2nd check before installation
- commissioning after installation



initial test items

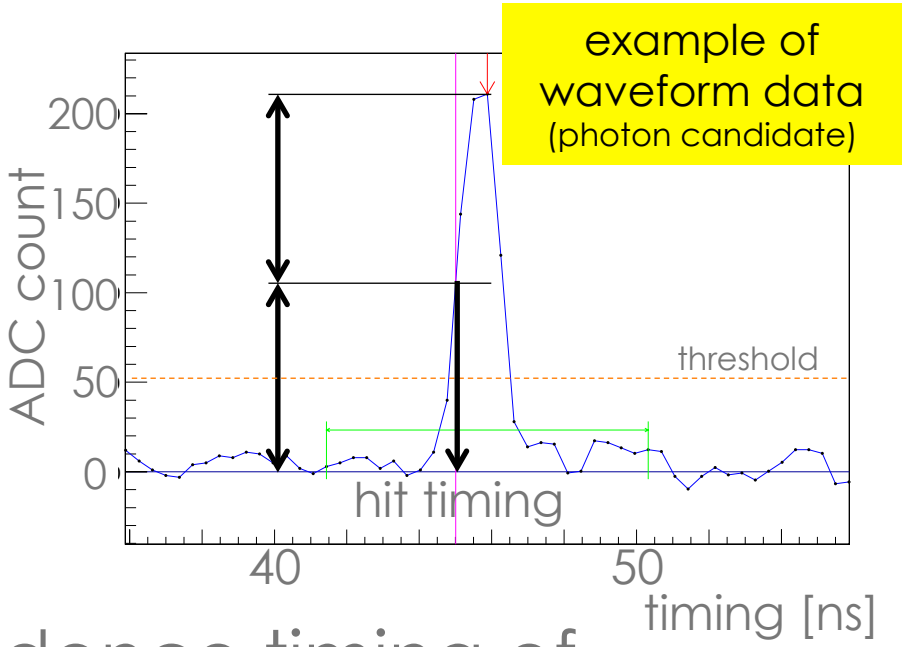


- laser
  - PMTs and readout electronics
  - test of laser system itself
- cosmic ray
  - response to real Cherenkov emission
  - no precise tracking
    →check only hit time distribution and the number of hits per event



data analysis scheme

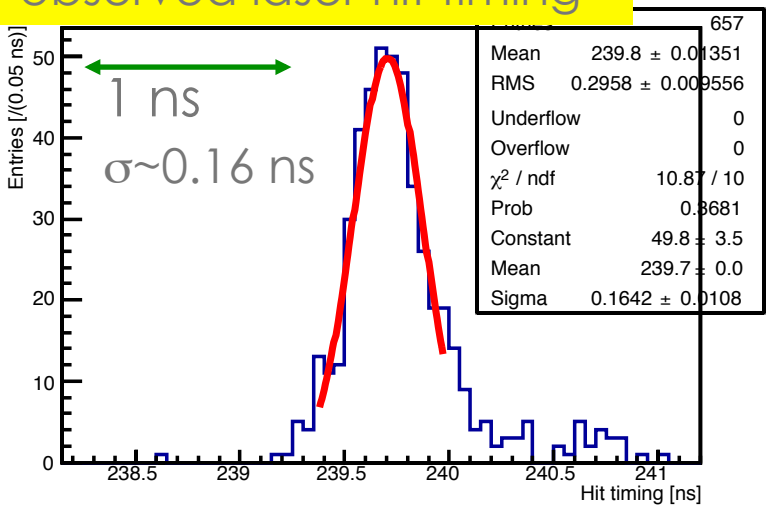
- waveform readout
  - ~3 GHz sampling
    →offline analysis
    to extract hit timing
  - external trigger
    (laser timing, coincidence timing of cosmic ray counters)
  - this is temporary readout scheme;
    in the real experiment, only energy and timing information is read



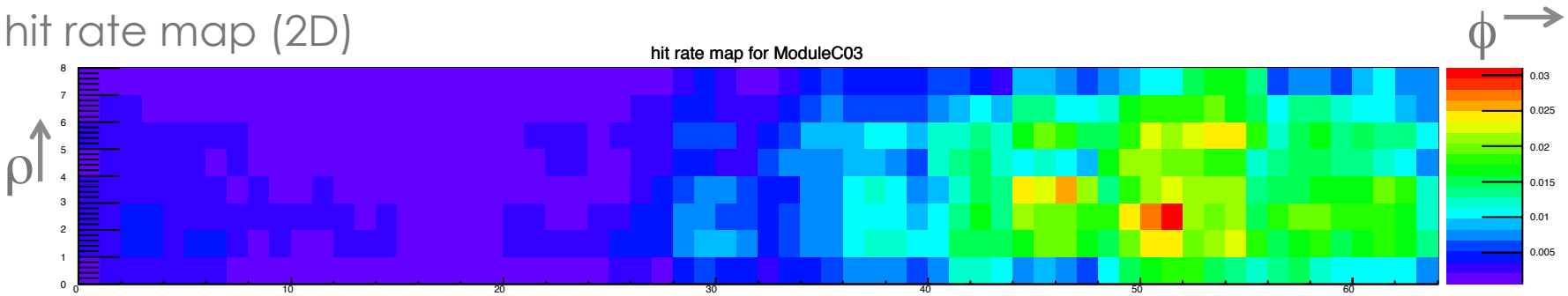
first complete laser data

- clear sharp peak
- All channels (512 ch.) are working.

observed laser hit timing



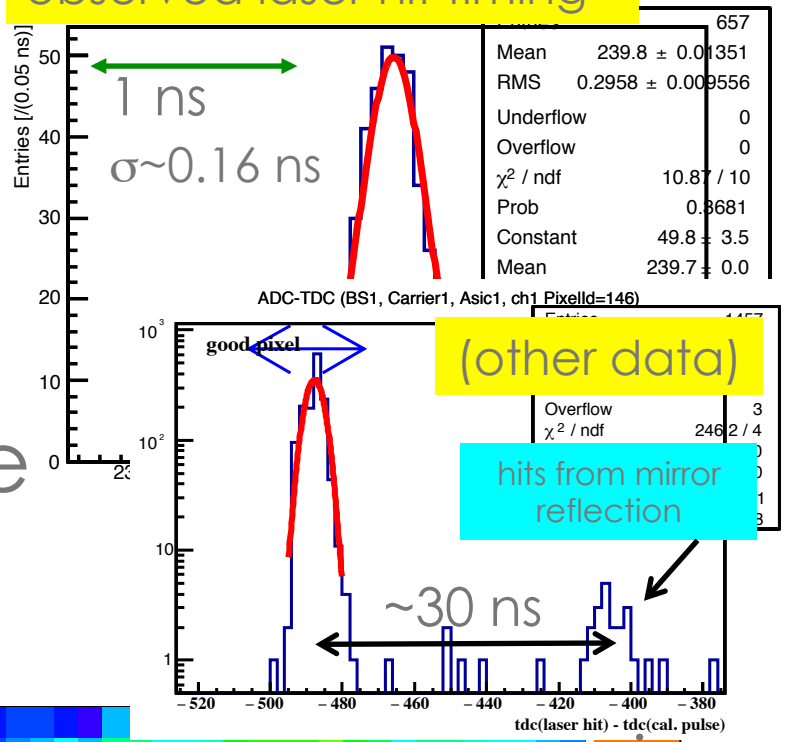
hit rate map (2D)



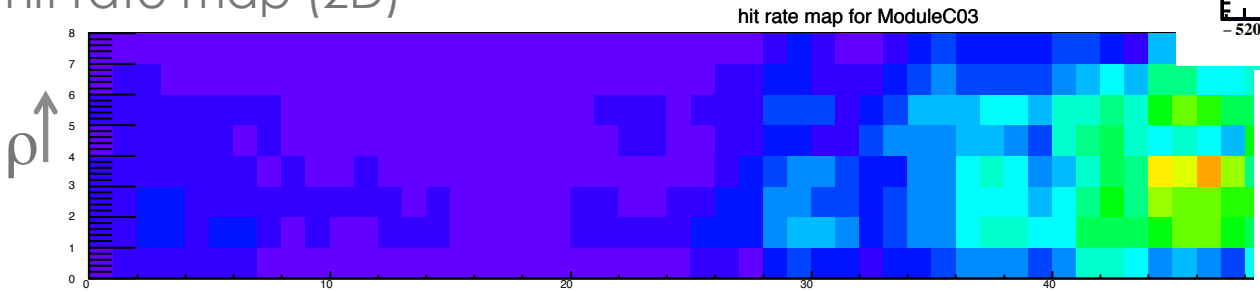
first complete laser data

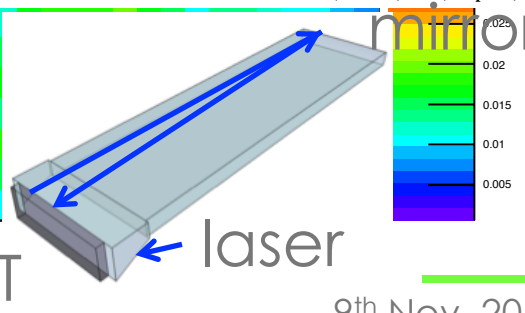
- clear sharp peak
- All channels (512 ch.) are working.
- Reflected signals were also observed.

observed laser hit timing



hit rate map (2D)

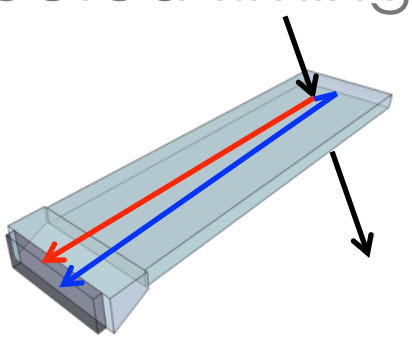




cosmic ray data

- timing distribution (to trigger timing)
  - clear hit peak of cosmic ray
  - reflection by the mirror is seen in the expected timing

trigger counter in mirror side

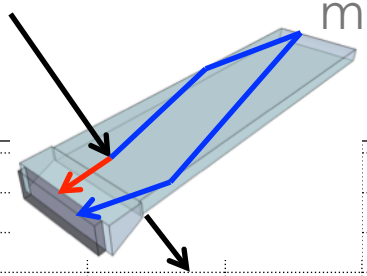


hit timing

single peak

Module#06

trigger counter in prism side



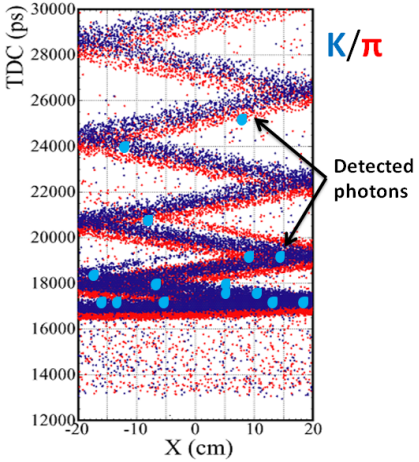
~34 ns

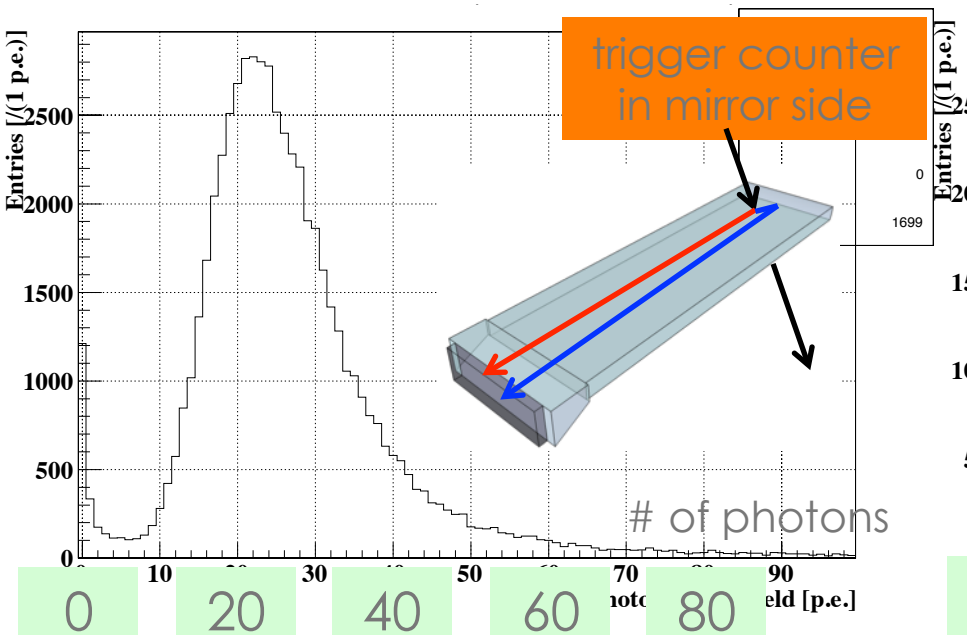
hit timing

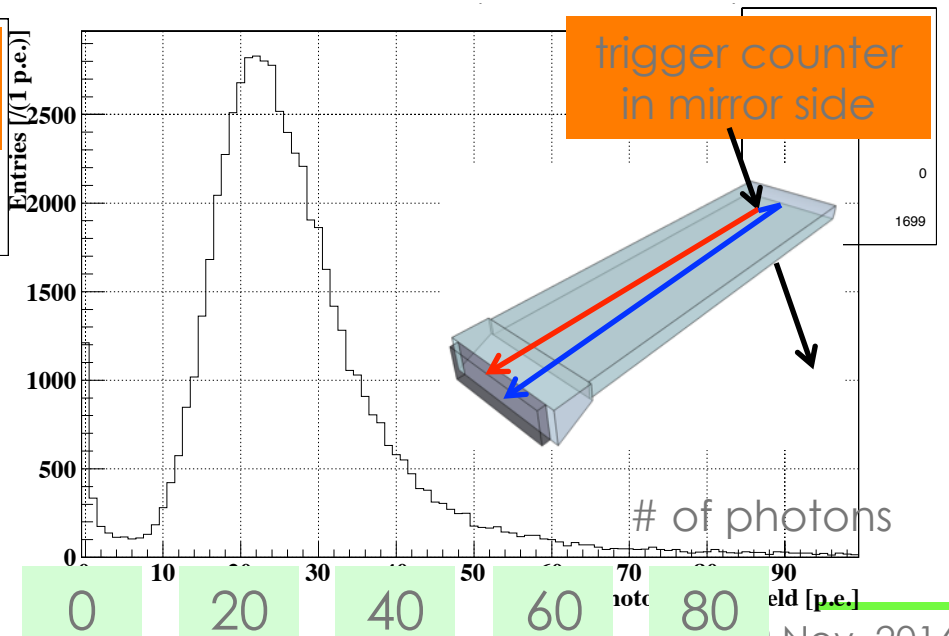
double peak

cosmic ray data

- count # of hits in each event
- consistent with simulation expectation (~20)







module test schedule

- Testing should finish in 5 months
  - all the 16 modules
  - in both Fuji and Tsukuba

Date (JST)	Major Activity	KEK Expert	KEK shifters	Remote/Data shifter
Mon Apr 18	Fuji M16	Tao, Maeda	Dmitri, Kichimi, Umberto	Hulya
Tue Apr 19	Install M07	Tao, Maeda	Dmitri, Umberto	Hulya
Wed Apr 20	Install M14	Maeda	Dmitri, Kichimi, Umberto	Hulya
Thu Apr 21	Install M02/M15	Maeda	Dmitri, Kichimi, Ale	Boqun
Fri Apr 22	Tsukuba M11	Maeda	Dmitri, Ale, Umberto	Boqun
Sat Apr 23		Maeda	Dmitri, Ale	Hulya
Sun Apr 24		Maeda	Dmitri, Ale	Hulya
Mon Apr 25	Tsukuba M10	Maeda	Kichimi, Ale	Kichimi
Tue Apr 26		Maeda	Kichimi, Ale	Hulya
Wed Apr 27		Tao, Maeda	Hulya	Hulya
Thu Apr 28	Tsukuba M16	Tao, Maeda	Kichimi	Kichimi
Fri Apr 29		Maeda	Kichimi	Hulya
Sat Apr 30		Maeda	Hulya	Hulya
Sun May 01	Tsukuba M17	Maeda	Hulya	Hulya
Mon May 02		Maeda	Ale	Bryan
Tue May 03		Maeda	Ale	Bryan
Wed May 04		Maeda	Ale	Bryan
Thu May 05		???	Ale, Hulya	Hulya
Fri May 06		???	Ale, Hulya	Hulya
Sat May 07		???	Kichimi, Ale	Kichimi
Sun May 08		???	Kichimi, Hulya	Kichimi

last production module

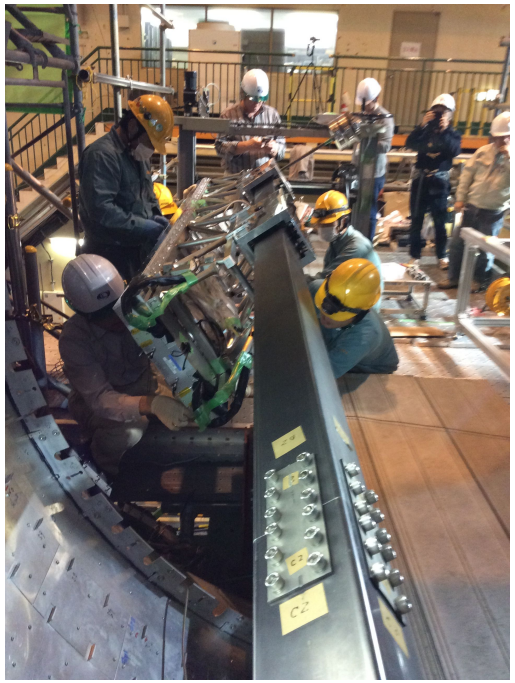
Fuji test stand

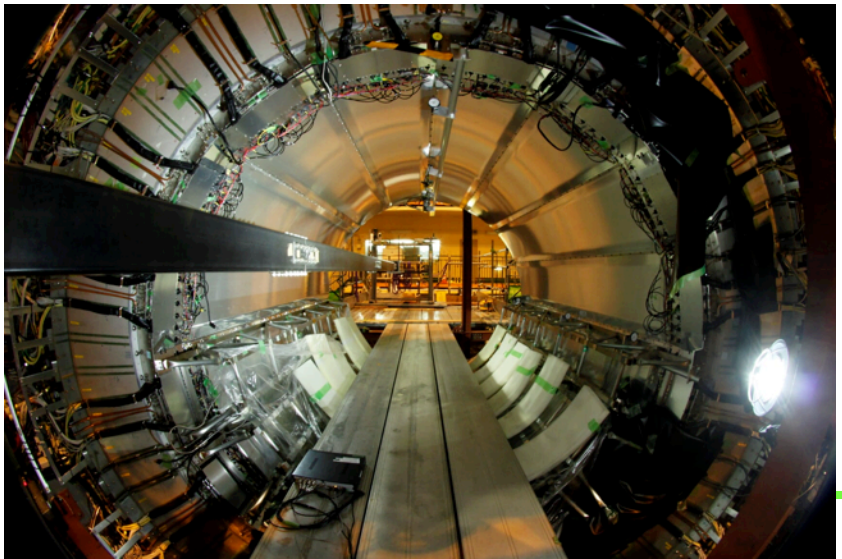
Two modules can be tested at the same time.

Tsukuba test stand

installation

- The first module was installed in Feb, and the rest in Apr-May

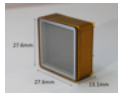




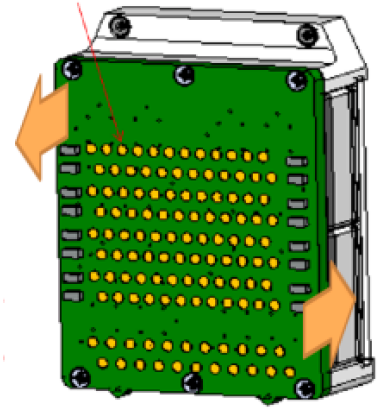
operation after installation

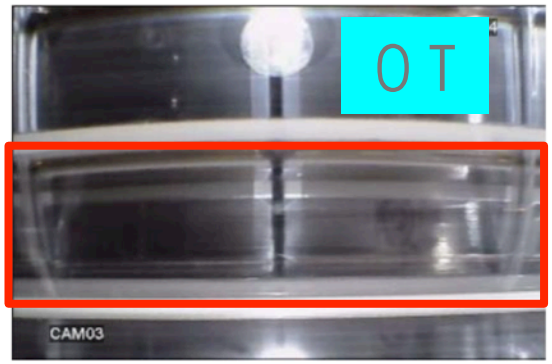
- Many components to be used in the real exp't are available.
- need to find problems before installation of inner detectors
- concern : operation in the magnetic field
  - performance of MCP-PMTs
  - mechanical effect to PMTs

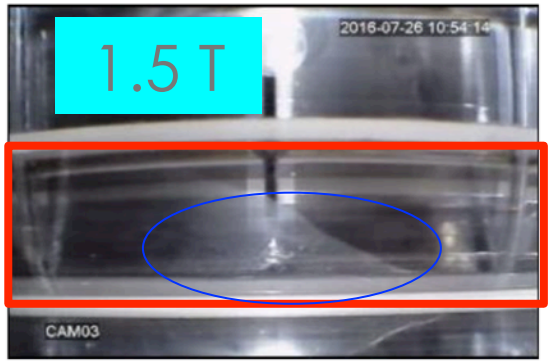
operation in the mag.-field

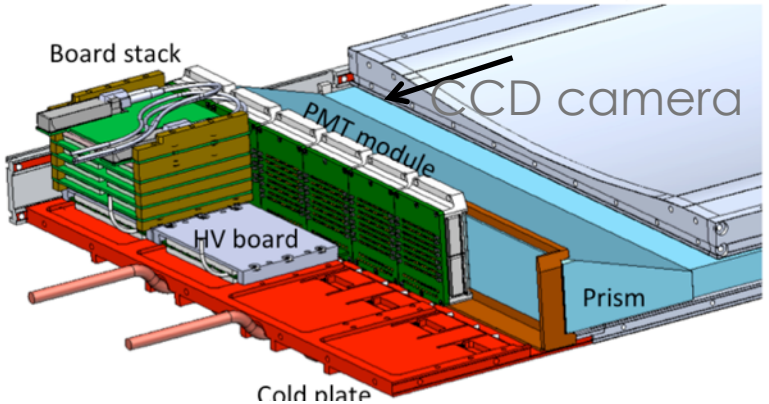


- problems in the first magnet excitation
  - PMT side tubes were magnetic
    →strongly affected by magnetic force in 1.5-T field
    →motion of PMTs broke optical and electrical contant



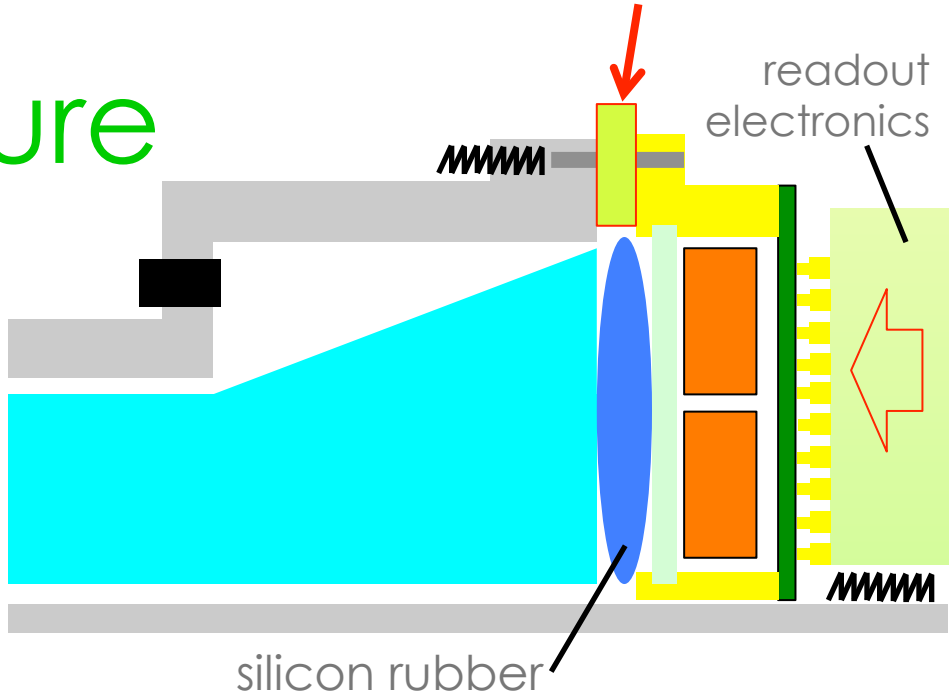


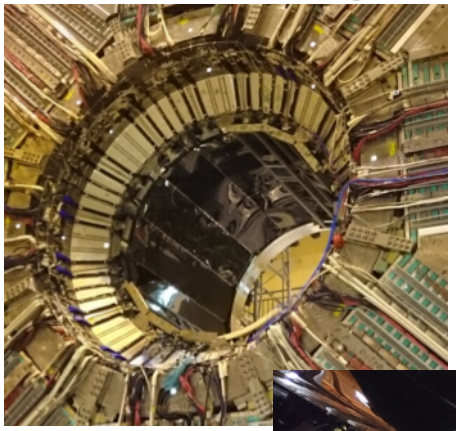




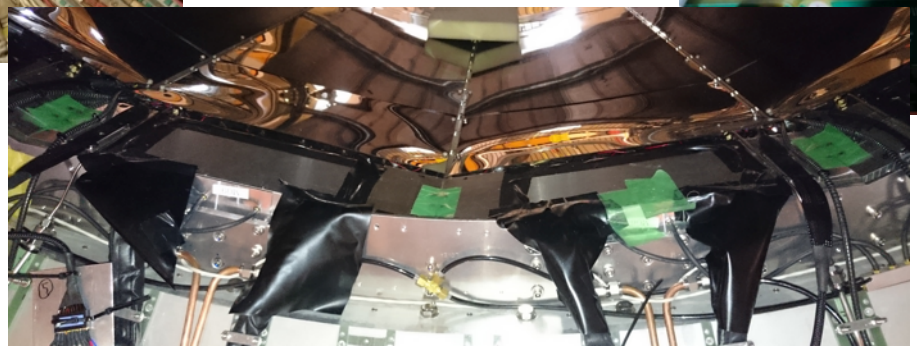
countermeasure

- protection to the movement in the magnetic field



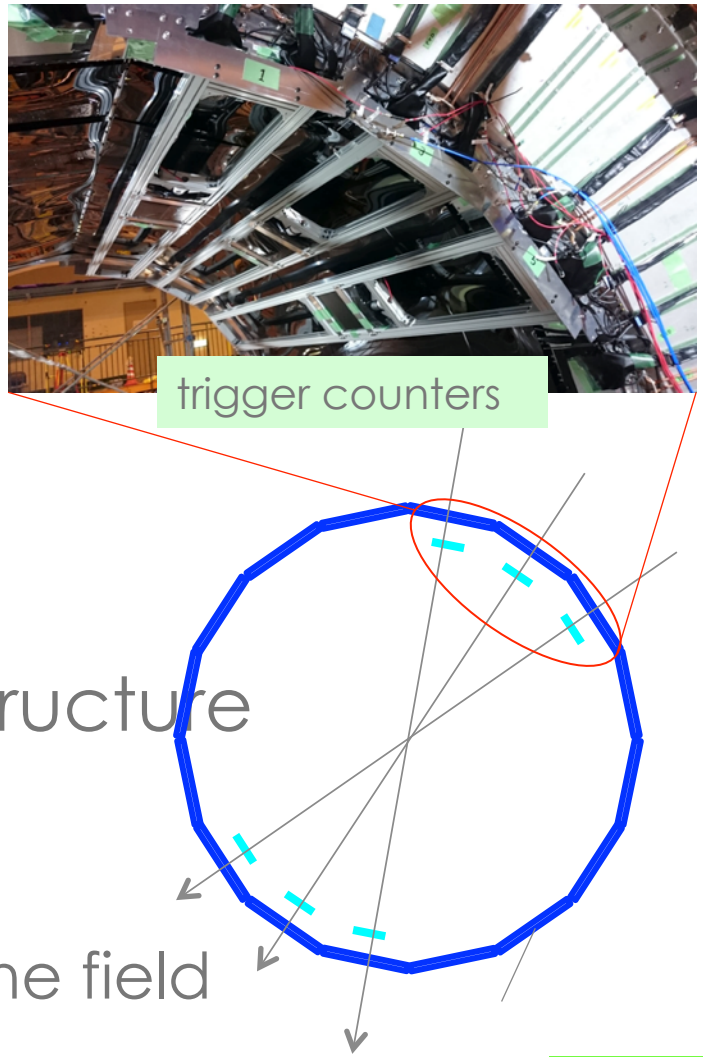


insert plastic spacer



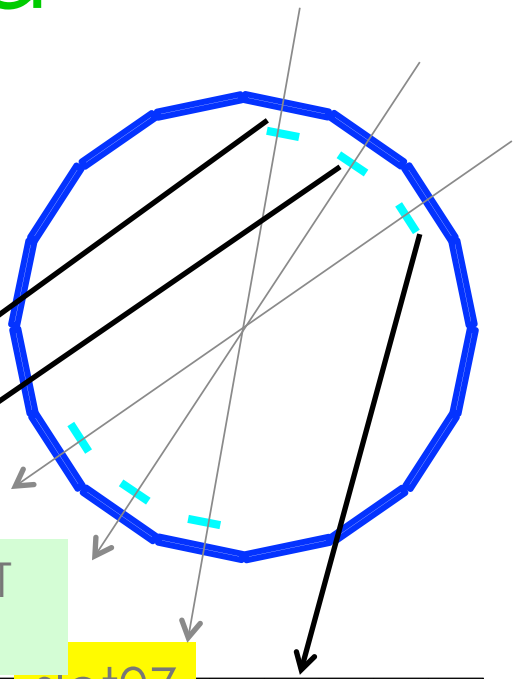
in-situ cosmic ray data taking

- trigger counters were prepared for the in-situ cosmic ray data taking
  - reuse of scintillator bars and PMTs from the Belle TOF counter
  - non-magnetic support structure
  - trigger rate
    - ~0.05 Hz in the 1.5-T field
    - 2-week data taking with the field



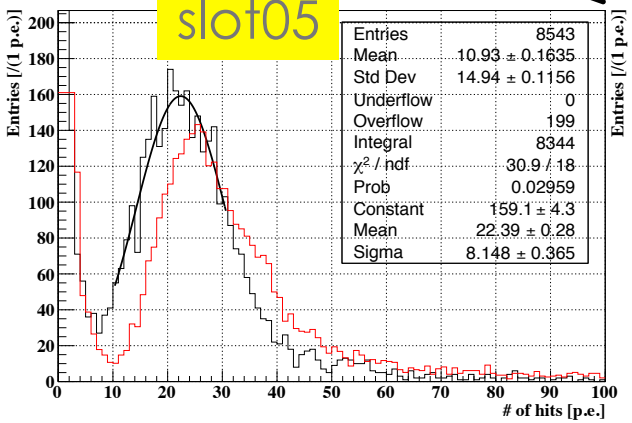
cosmic ray data

- cosmic ray signals are successfully observed in both 0-T and 1.5-T field
- no drastic drop in # of photons

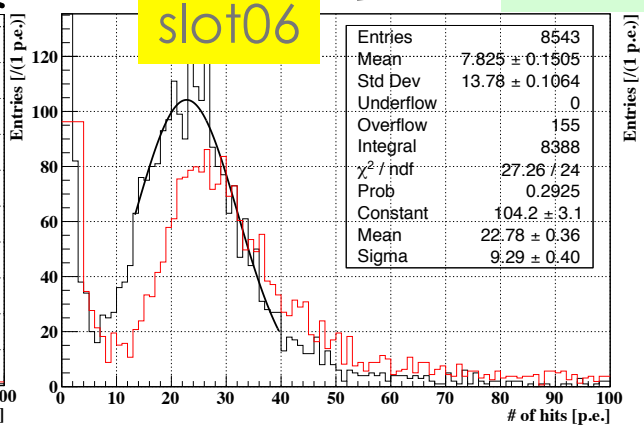


black : 0 T
red : 1.5 T

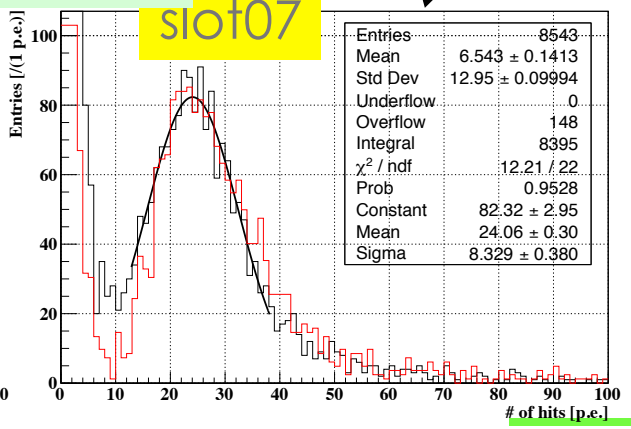
slot05



slot06



slot07



current status

- After the performance test in the magnetic field, no serious problems were found
  →inner detector (CDC) was installed

summary and prospect

- PID is an essential part of flavor physics.
- The Belle II TOP counter is a novel PID detector, using propagation time to reconstruct Cherenkov ring image
- We successfully finished detector installation and commissioning, where we confirmed good
- Still, we do not succeeded in evaluation of PID performance.
  →will be done in Belle II global cosmic data taking.