Status of installation and commissioning for the Belle II time-of-propagation counter

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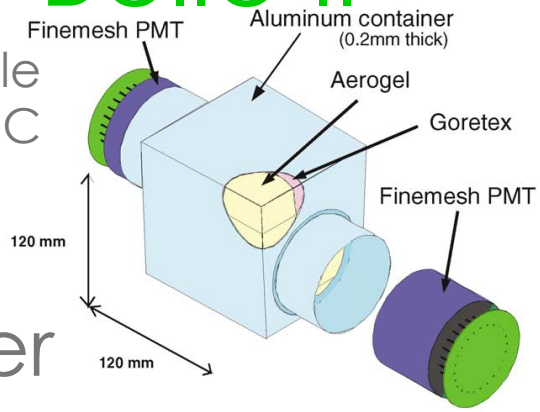
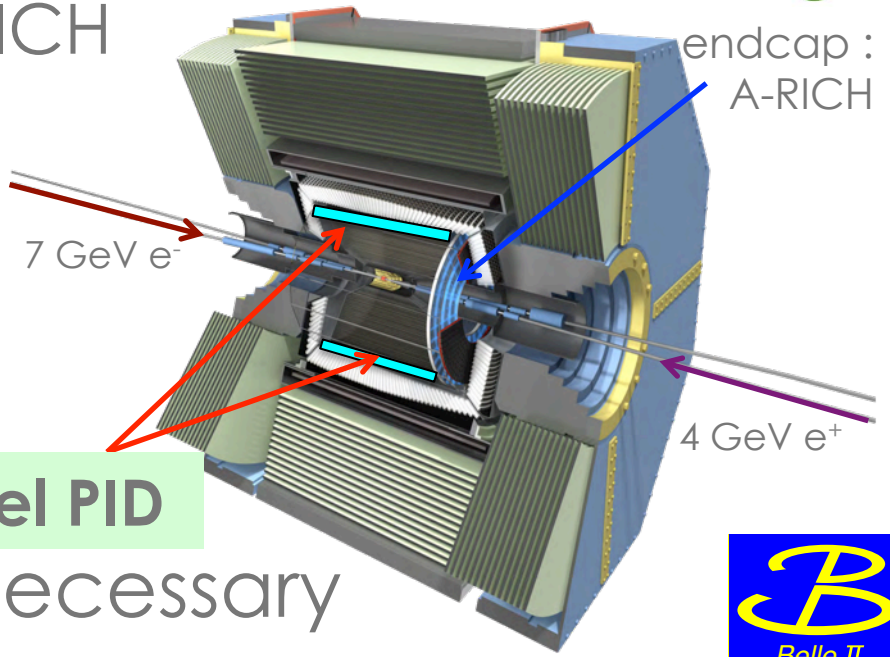
PID upgrade in Belle → Belle II

- Belle PID : threshold-type aerogel Cherenkov counter
- upgrade to RICH-type counter
  - end-cap : Aerogel-RICH (talk by L. Santelj)
- challenge for barrel PID upgrade
  - limited space
  ←Belle structure is reused
  - large area

→new technology is necessary

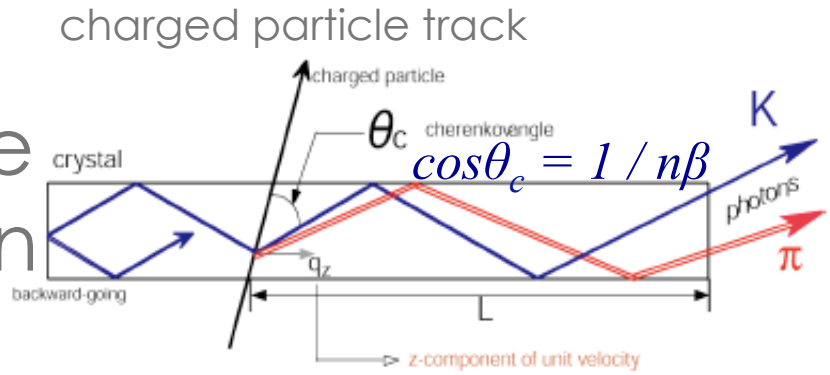
Belle ACC

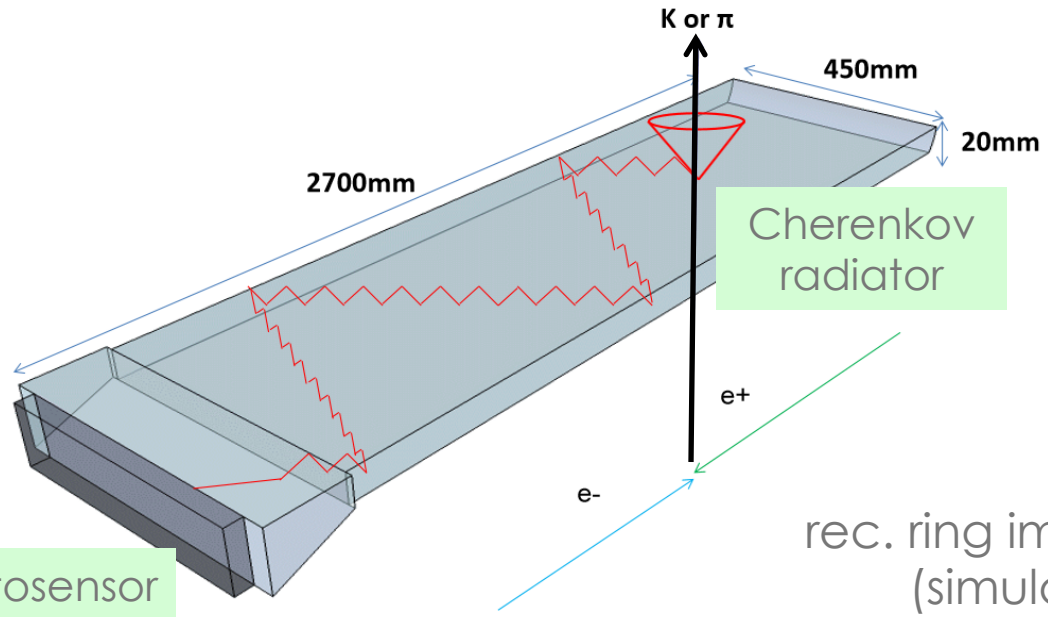


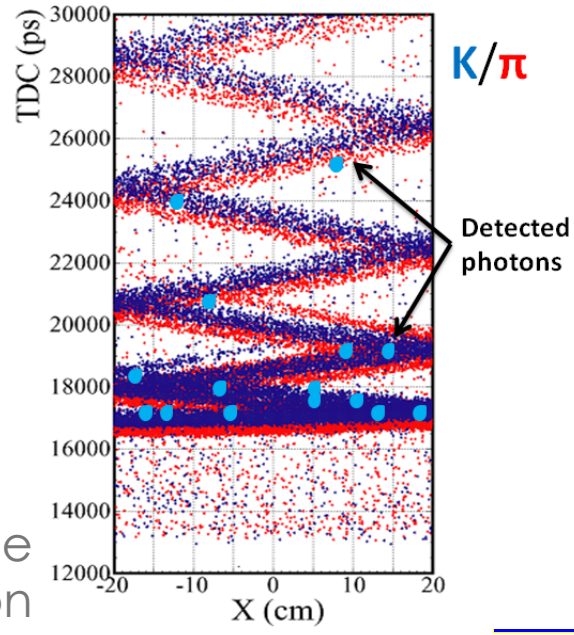


new technique : Time-Of-Propagation

- reconstruct ring image with **timing** information
  - high performance



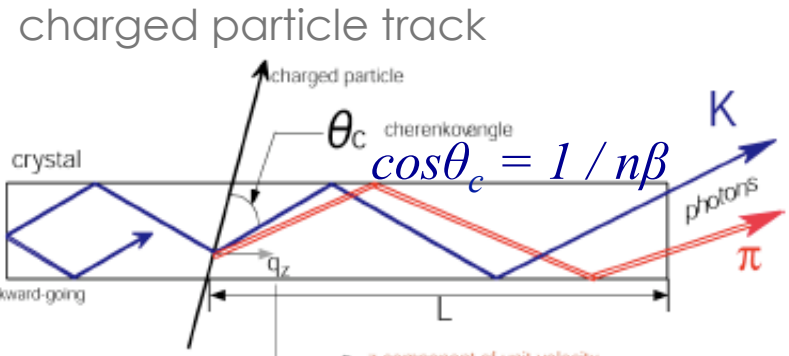


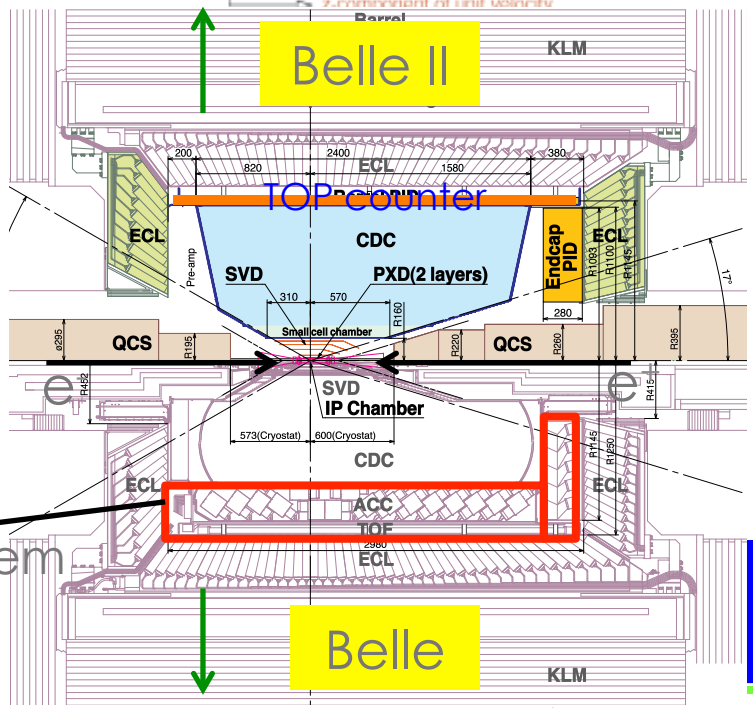


rec. ring image (simulation 2 GeV/c, θ=90°)

new technique : Time-Of-Propagation

- reconstruct ring image with **timing** information
  - high performance
  - homogeneous
  - compact
    →larger inner tracker
  - lower amount of material
    →less effect
    for calorimeter

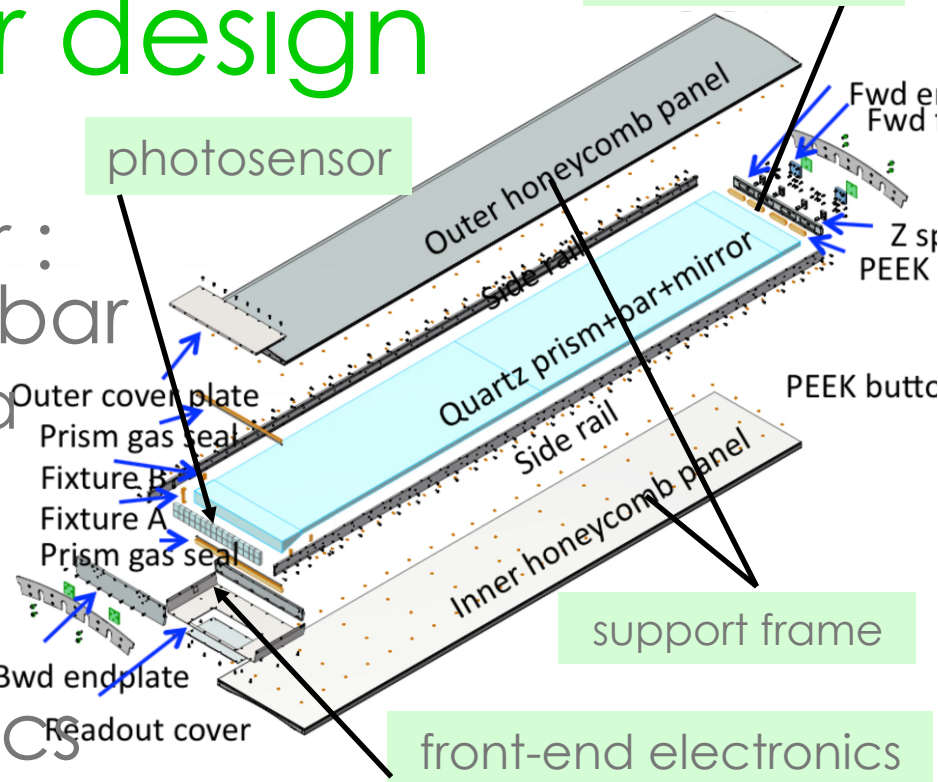


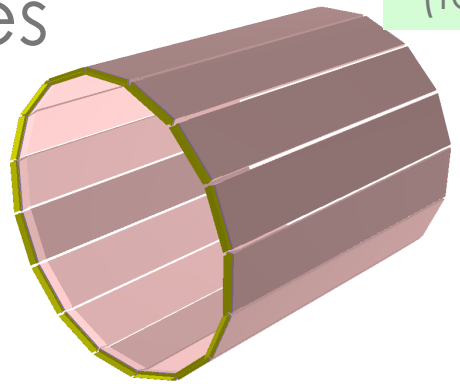


Belle PID system
(ACC + TOF)

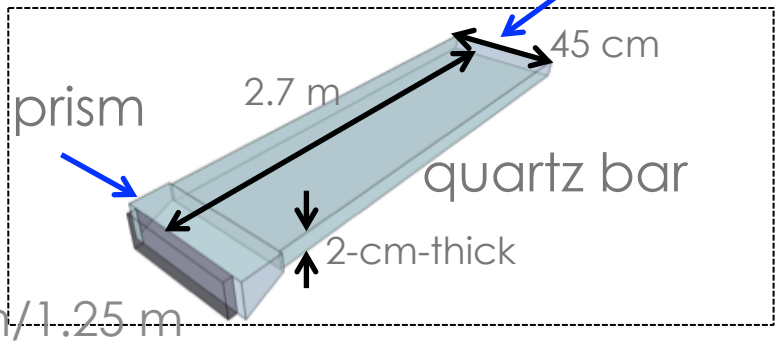
detector design

- Cherenkov radiator : high-quality quartz bar
  - synthetic fused silica
  - n=1.47 (@λ=400 nm)
- high-speed photo -sensor(MCP-PMT) + readout electronics
- 16 identical modules to form a barrel structure

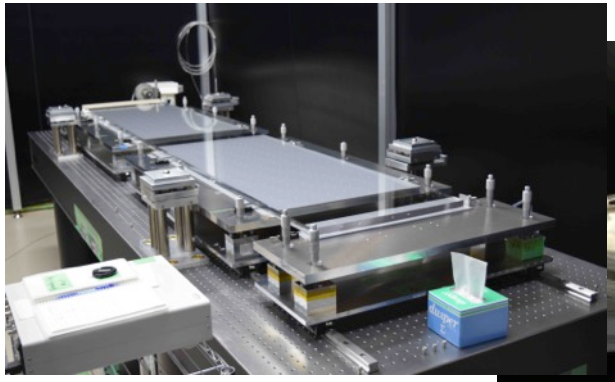


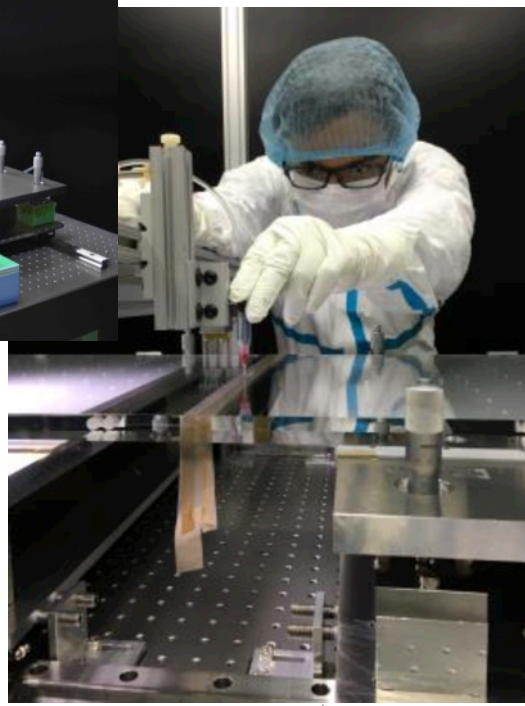


quartz bar



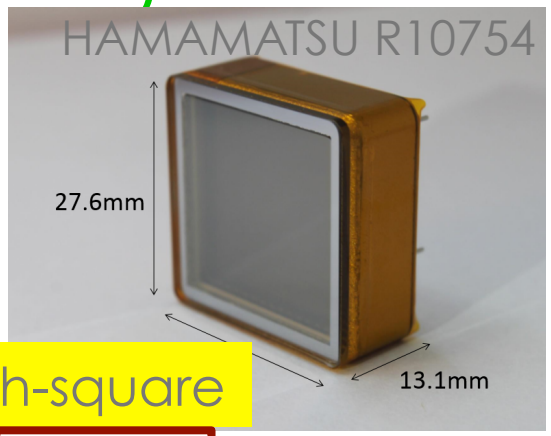
- challenging specification
  - roughness <6 Å (RMS)
  - parallelism <4 arcsec =24 μm/1.25 m
  - flatness < 6.3 μm
  - chamfers < 0.2 mm
  - …
- two 1.25-m-long bars are glued as well as a prism and a mirror
- results of quality assessment
  - transmittance >98.5%/m
    reflectance >99.9%



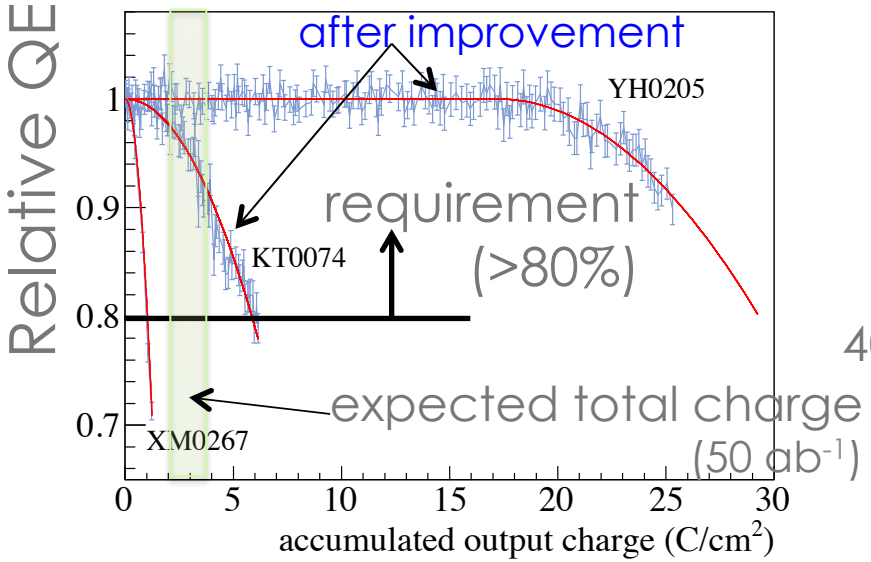


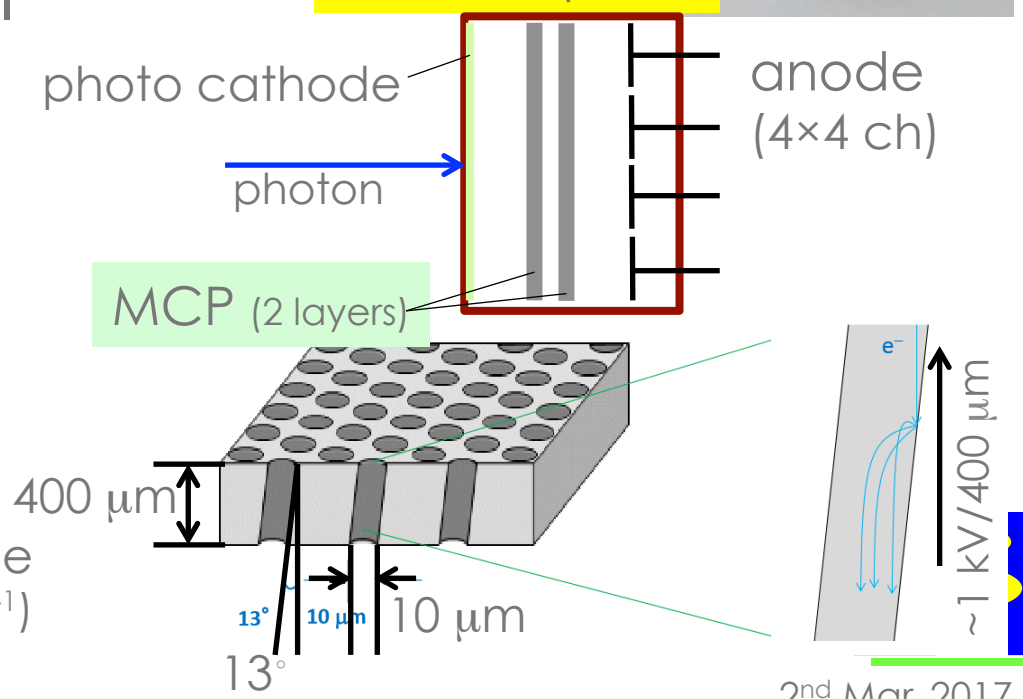
Micro-Channel-Plate (MCP) PMT

- excellent timing resolution for single photon (~30 ps)
- 512 PMTs in total
- lifetime R&D



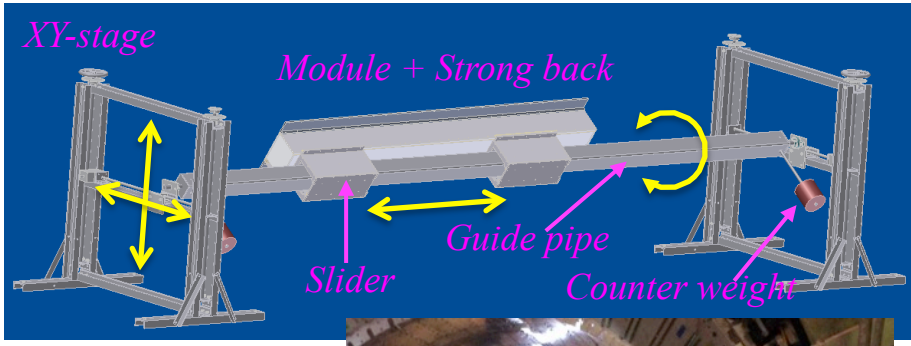
1-inch-square



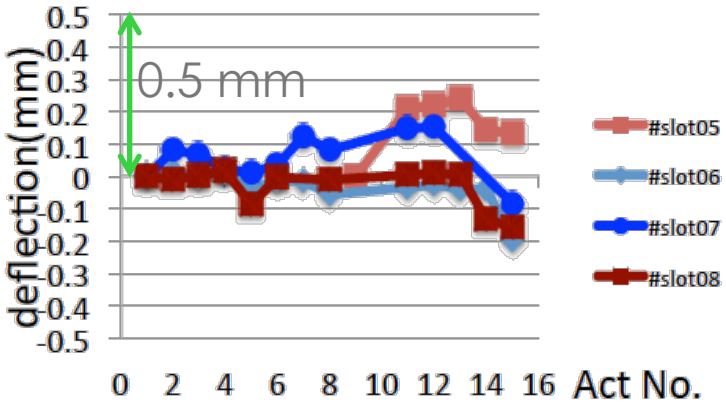


installation

- module production late 2014 – Apr 2016
- installation : Feb – May, 2016
  - sag during the period was <0.5 mm, within requirement



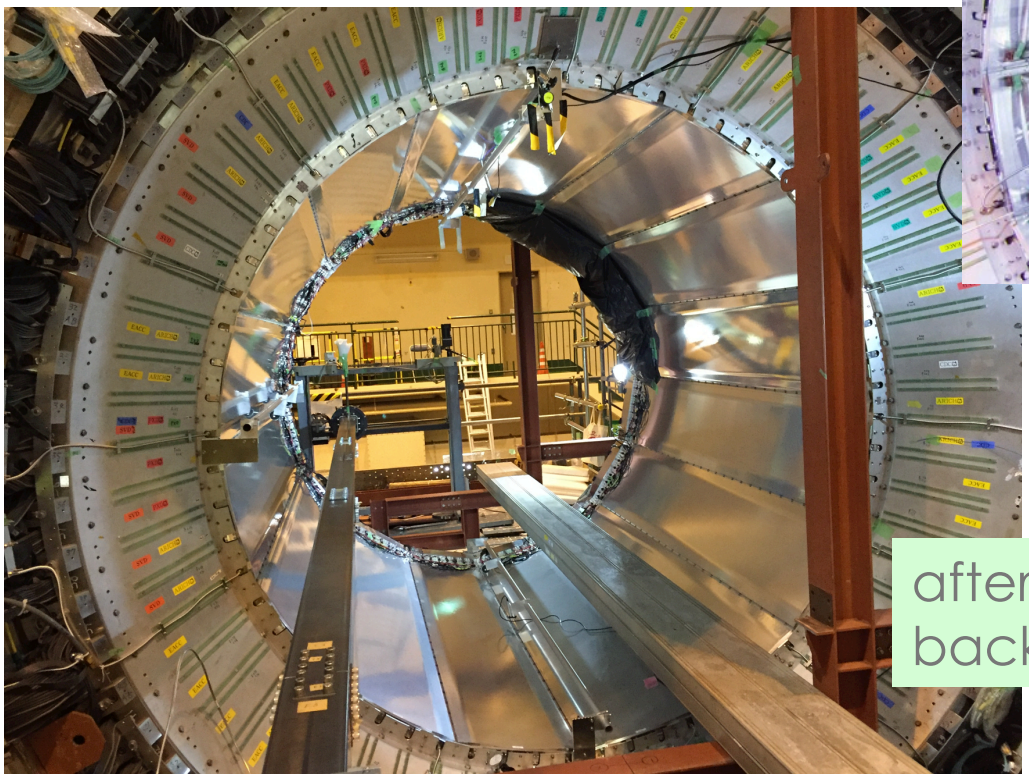
monitored sag



installation

- module production
  late 2014 – Apr 2016

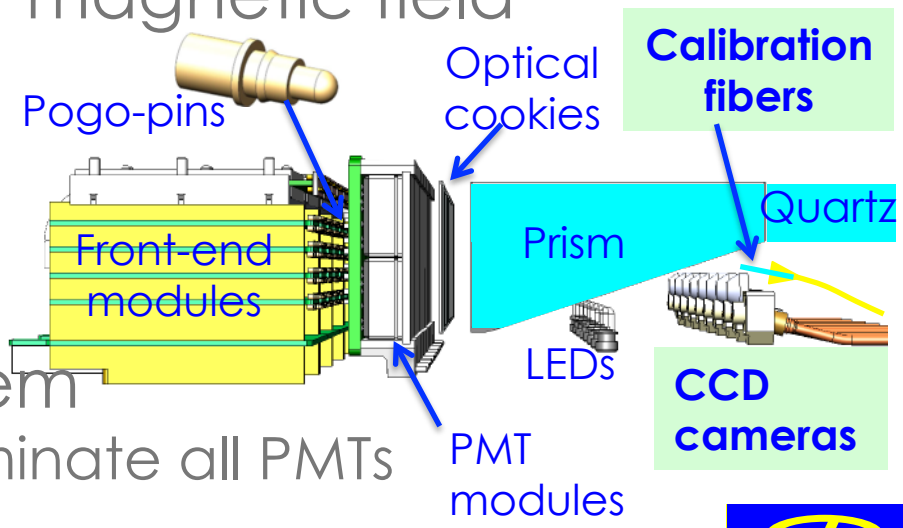
installation completed
at 11th May, 2016



after strong
back removal

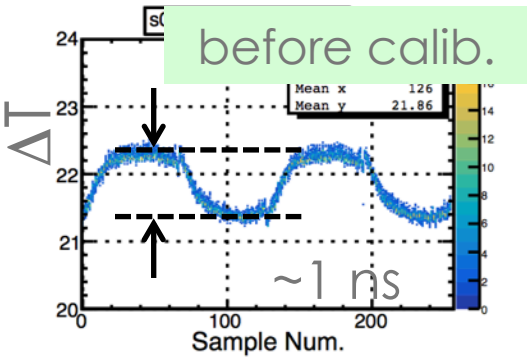
performance study after installation

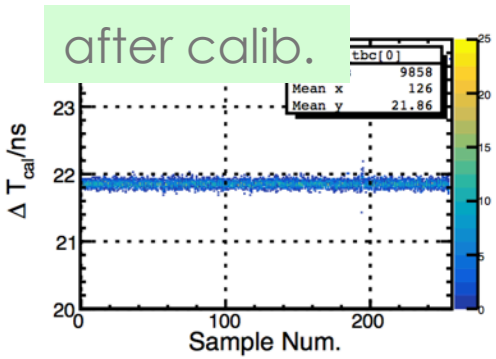
- items to be checked
  - healthiness of each component
  - calibration to achieve full performance
  - operation in the 1.5-T magnetic field
- available tools
  - CCD camera
    - directly check quartz -PMT optical coupling
  - laser calibration system
    - picosecond laser illuminate all PMTs
  - cosmic ray data

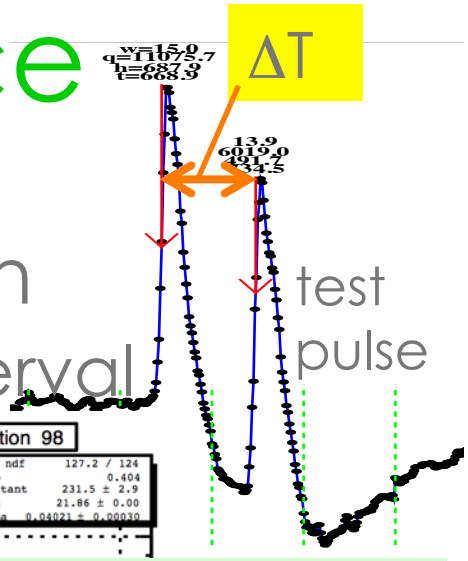


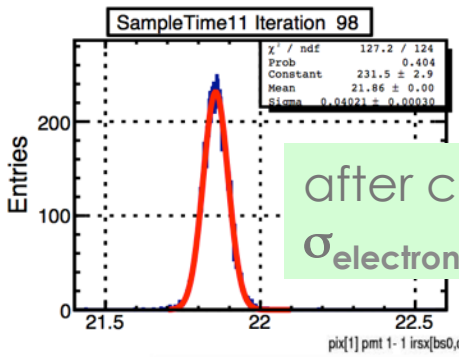
timing performance

- waveform time base calibration
  - calibrate non-uniform sample interval





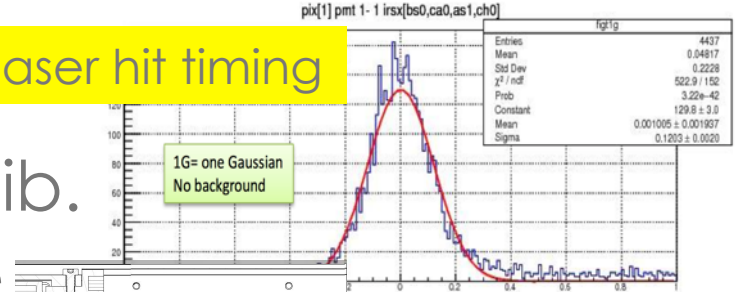


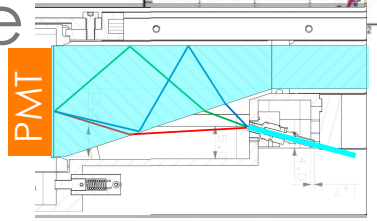


after calibration
$\sigma_{electronics}$ = 30 ps

- response to laser
  - σ ~ 120 ps with above calib.
  - understanding of multiple laser path is necessary

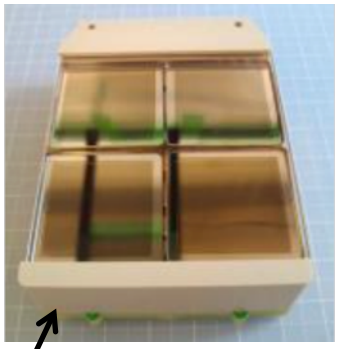
laser hit timing



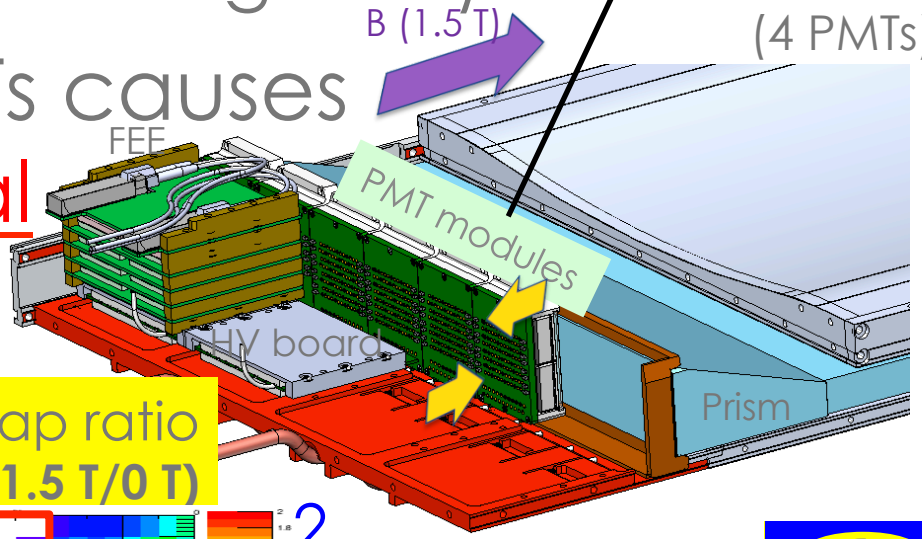


"PMT rotation" problem

- slight tilt of the magnetic field
  →strong magnetic force to PMTs
  (side tube of the PMT is magnetic)
- Movement of PMTs causes bad and electrical optical contact



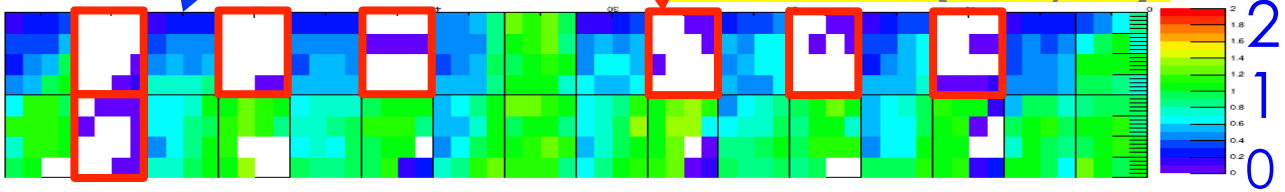
PMT modules
(4 PMTs)



low hit ratio

no entries as no HV

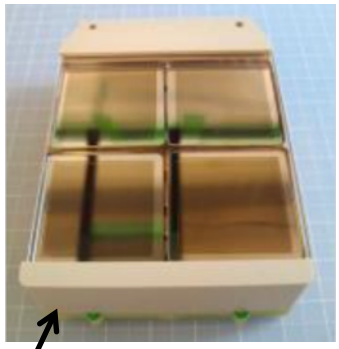
laser hit map ratio
(1.5 T/0 T)



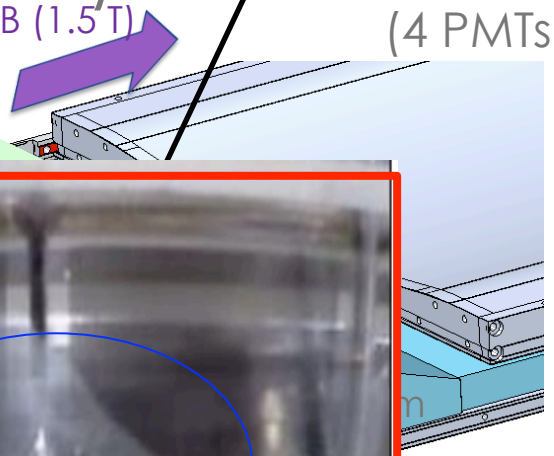
"PMT rotation" problem

- slight tilt of the magnetic field
  →strong magnetic force to PMTs
  (side tube of the PMT is magnetic)

direct inspection with CCD camera

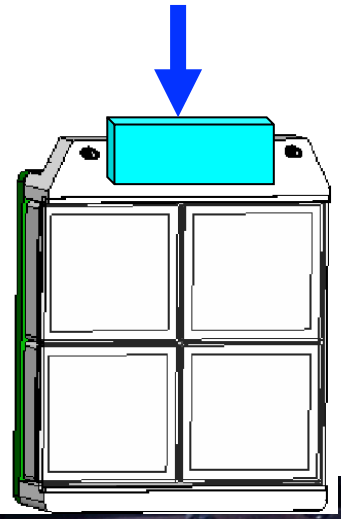


PMT modules
(4 PMTs)

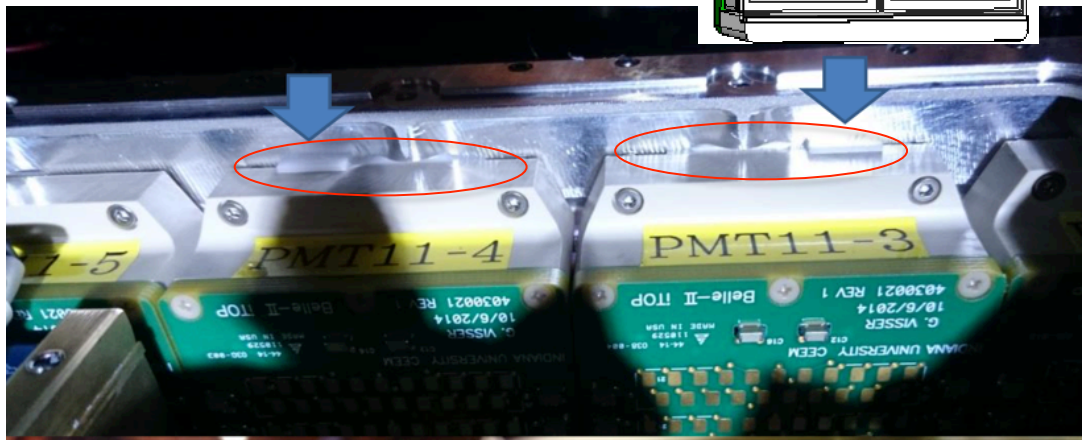


no entrie
as no HV

fix the problem

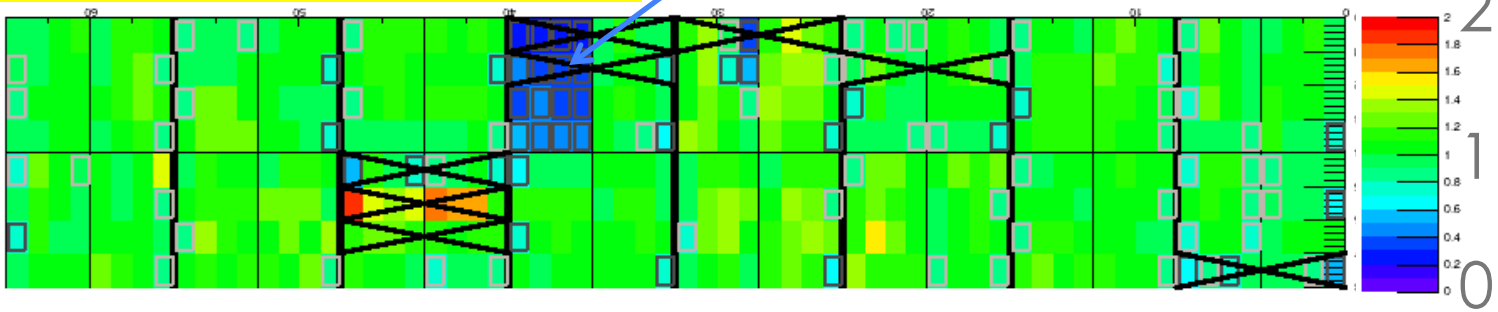


- inserting spacer to prevent the rotation
  - no rotation of PMT modules



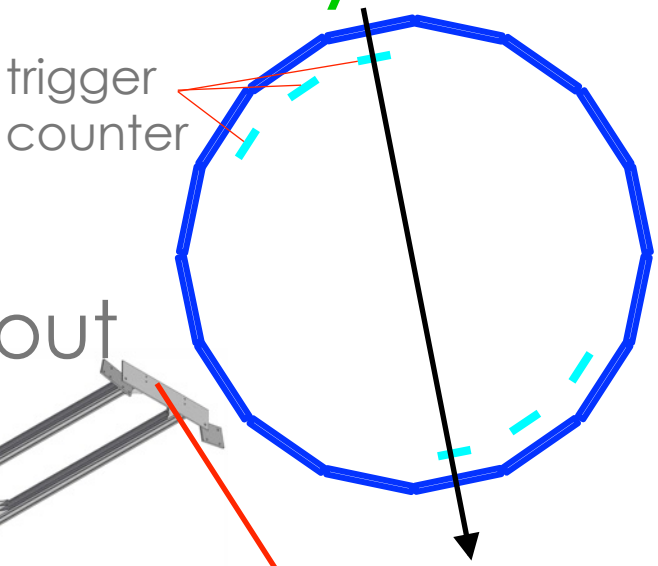
laser hit map ratio **(1.5 T/0 T)**

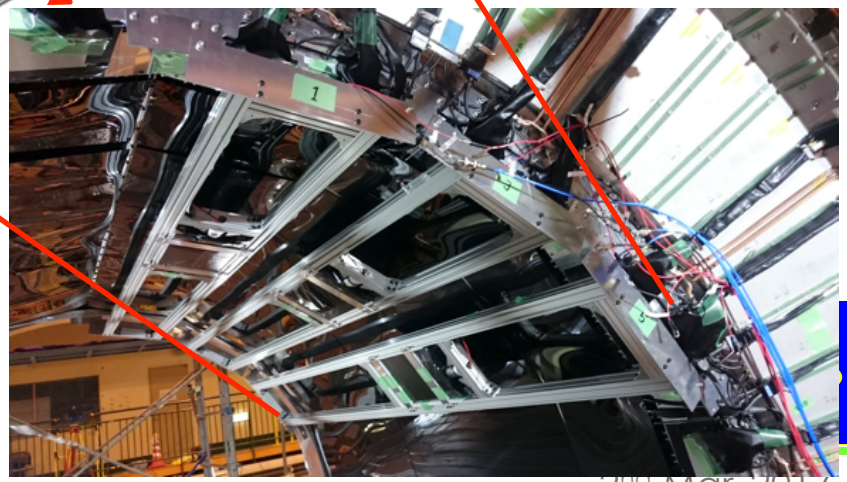
temporal failure in applying HV

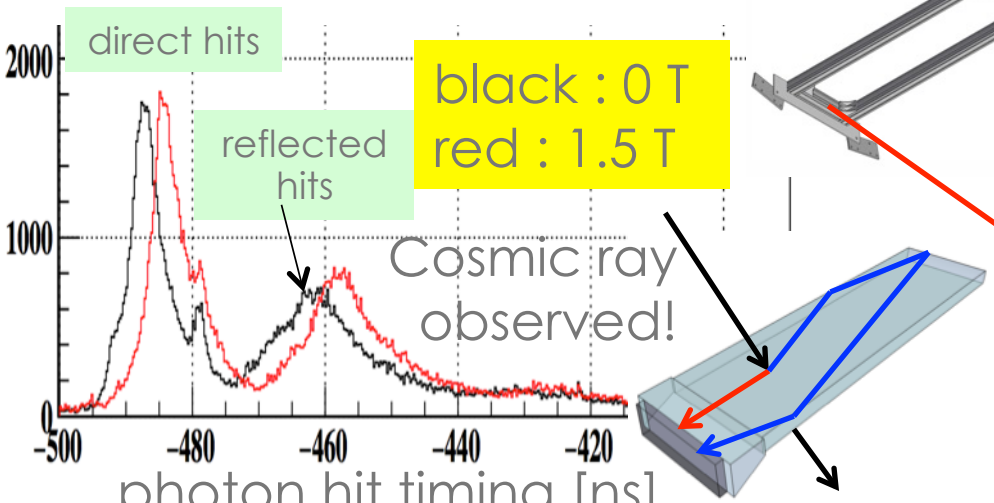


response to cosmic ray

- install trigger counter
  - No tracking
- data taking with and without magnetic-field
  - confirm the counter -measure is valid



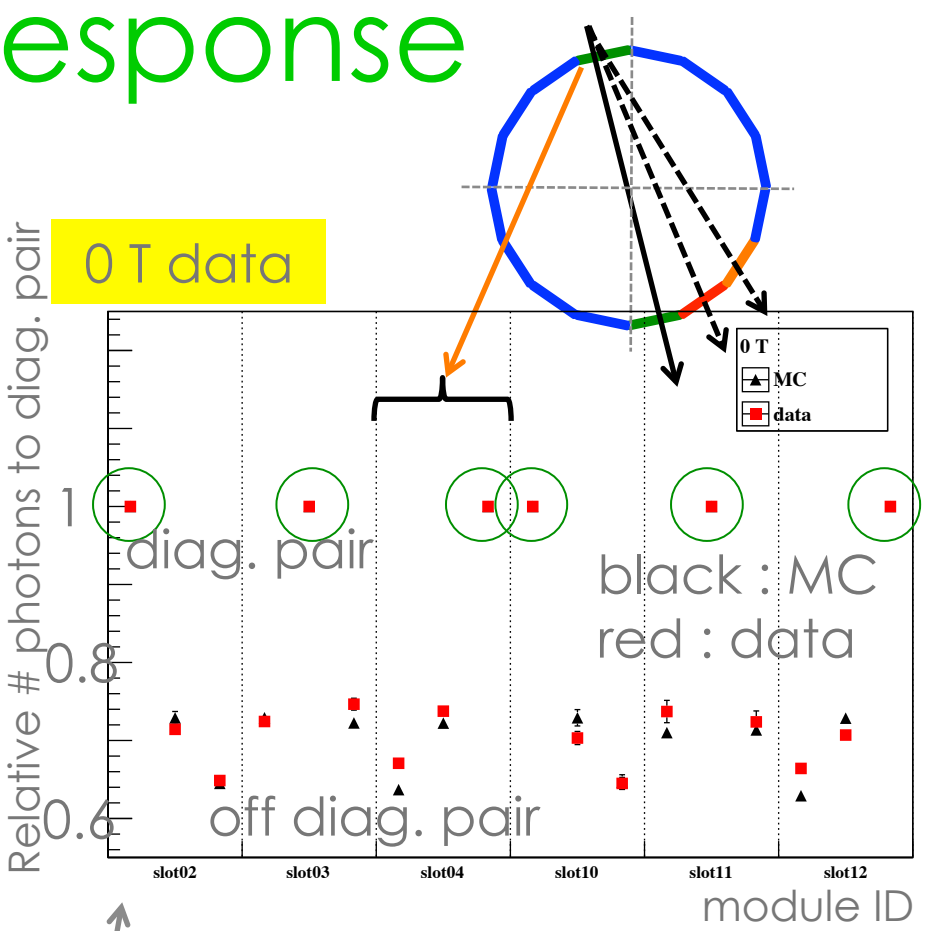




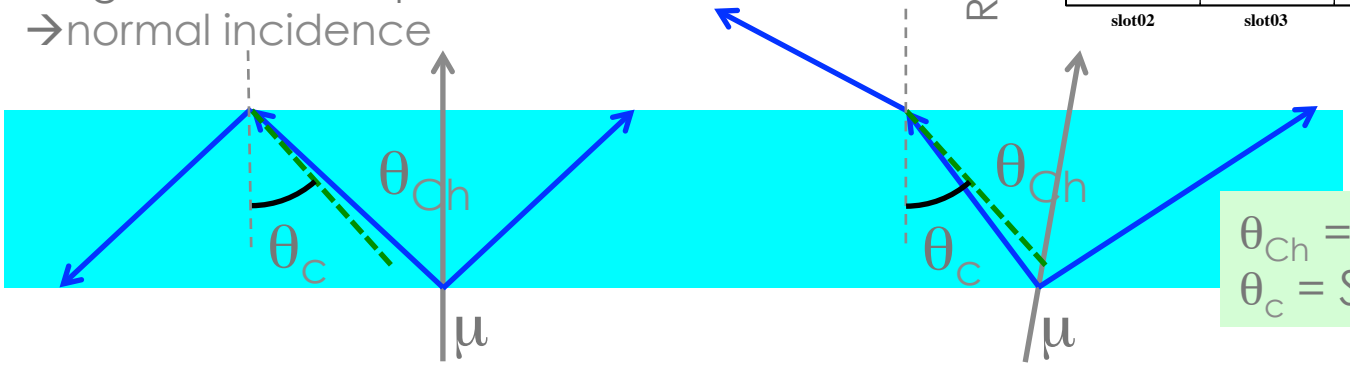
Cosmic ray observed!

angular response

- photon yield with diagonal and off–diagonal hit event
  - less hits when muon penetrate off-diag. pair of modules
  - well reproduced by simulation



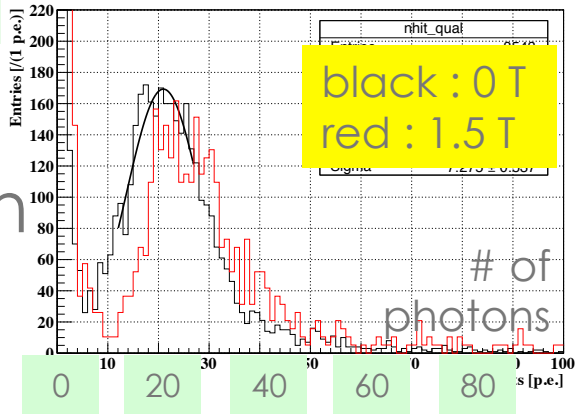
diagonal module pair
→normal incidence



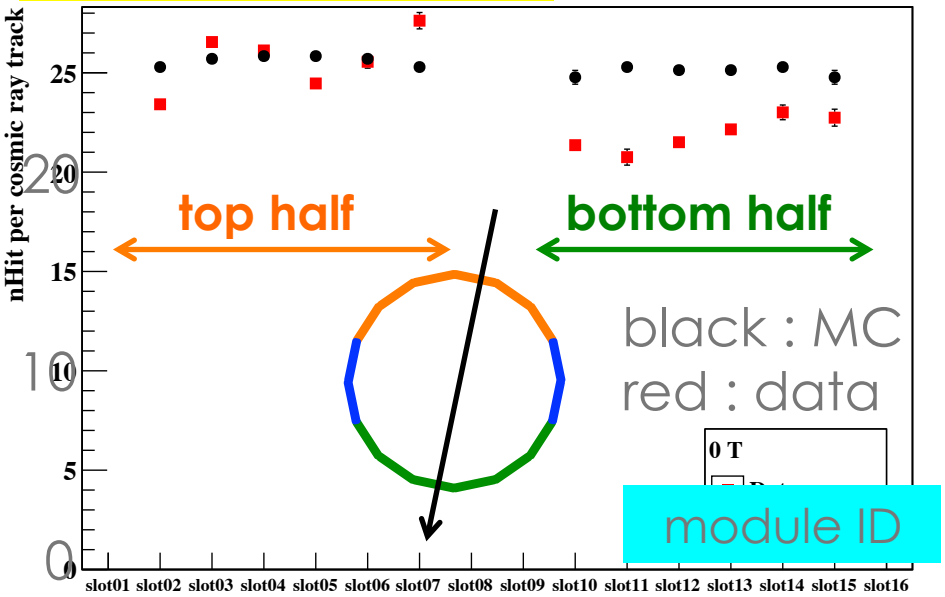
$\theta_{Ch} = \mathrm{Cos}^{-1}(1/n) \sim 47^\circ$
$\theta_c = \mathrm{Sin}^{-1}(1/n) \sim 42^\circ$

photon yield

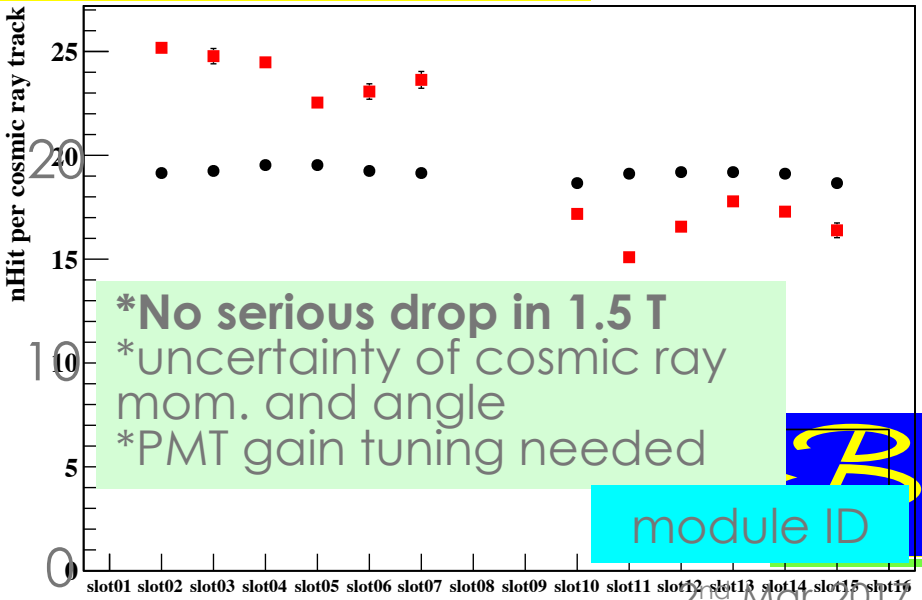
- comparison of absolute photon yield between data and MC
- agree within ~20% level
- Further study on hit efficiency is on-going.



0 T (diag. pair only)



1.5 T (diag. pair only)



current status


CDC installation (Oct, 2016)

- after fixing the PMT problem, inner tracking detector (**CDC**, talk by N. Taniguchi) as well as backward end-cap EM calorimeter (ECL) was installed
- preparation of data taking with other detectors is on-going
  →more detailed analysis is possible with track information

summary & prospects

- The Belle II Time-Of-Propagation (TOP) counter was successfully installed last May, and commissioning is on-going
- We faced PMT rotation problem in the magnetic field, it is immediately fixed.
- Cosmic ray data (without tracking) showed reasonable data-MC agreement. Still more understanding of hit efficiency is necessary.
- More detailed performance evaluation will be possible using coming "global" cosmic ray data with track information.

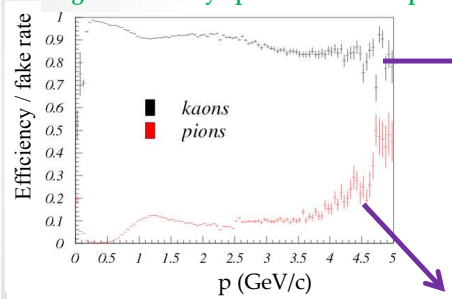
backup slides

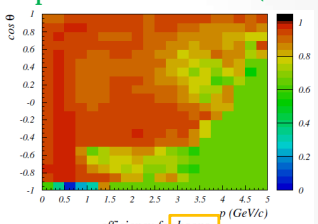
expected performance

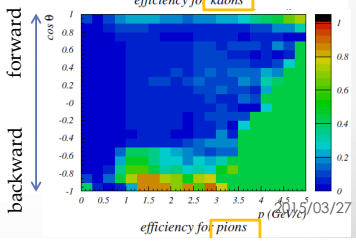
- e.g. ~10% (Belle) → ~3% (Belle II) π mis-ID at 86% efficiency of 1-2 GeV/c K for $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$

K/π separation: efficiency

- **Belle II PID (TOP+ARICH+dE/dx) performance**
- TOP / ARICH event reconstruction software already working well.
- + dE/dx (CDC) information to cover the backward region
- → **a.v.g. K efficiency / pion fake rate improved as expected. c.f. Belle PID (88%/9%)**



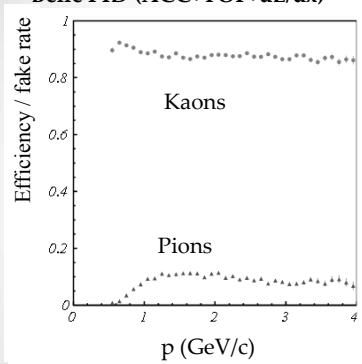




	Belle II PID
Averaged K efficiency	94%
Pion fake rate	4%

K/π separation: efficiency

Belle PID (ACC+TOF+dE/dx)

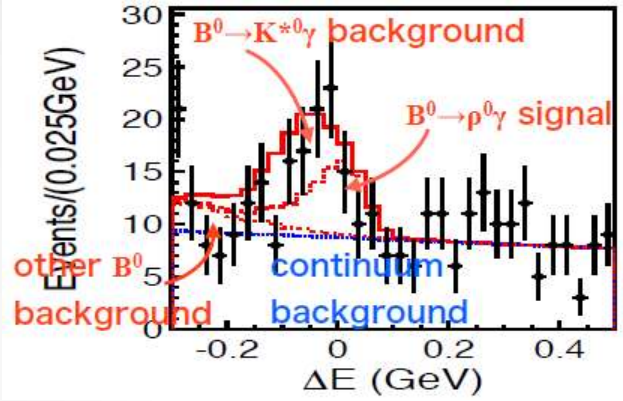


	Belle PID
Averaged K efficiency	88%
Pion fake rate	9%

slides from K. Hayakawa (2015)

expected performance

PID impact on physics analysis

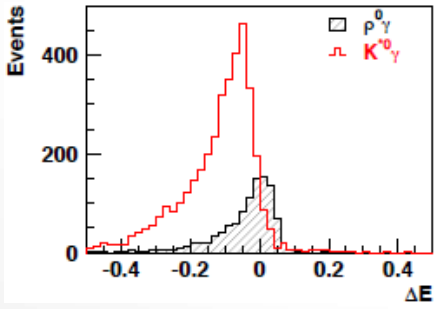


Belle experimental data (657 million BBbar sample)

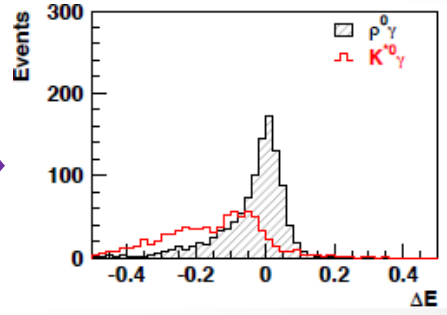
ΔE: energy difference between reconstructed B^0 and beam

Belle II 7.5 ab-1 expectation from MC

with Belle PID



with Belle II PID (TOP+ARICH)



quartz specification

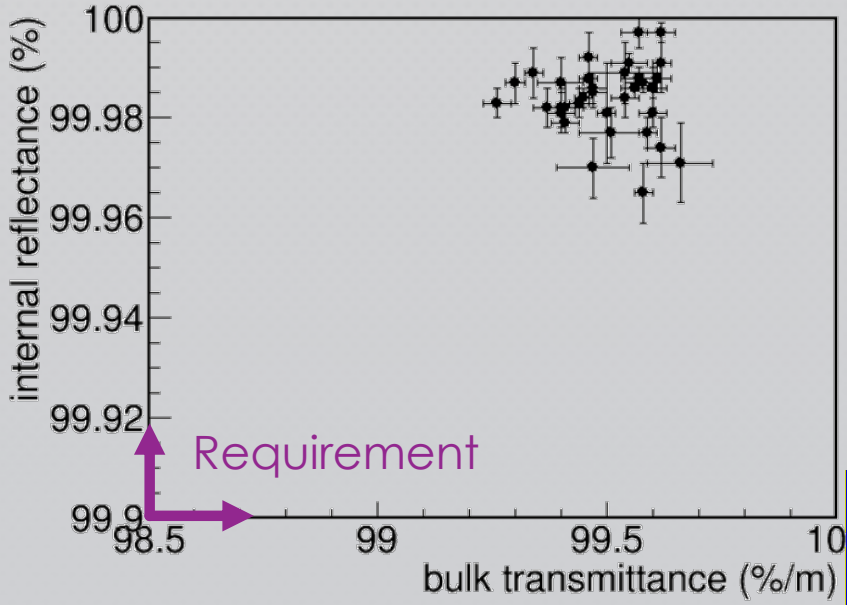
- Two 1250 x 450 x 20 mm^3 bars per TOP module glued together to make a 2500 mm long bar
  - Material: Corning 7980
  - 30 bars polished by Zygo and 2 (+2 spares) by AOS/Okamoto

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)

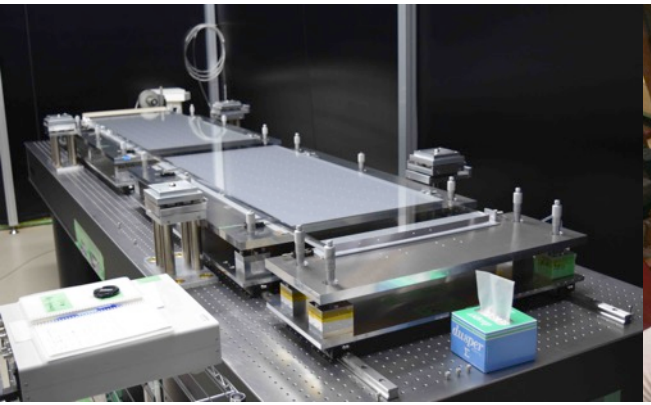
(for the largest surfaces)

QA results



module assembly

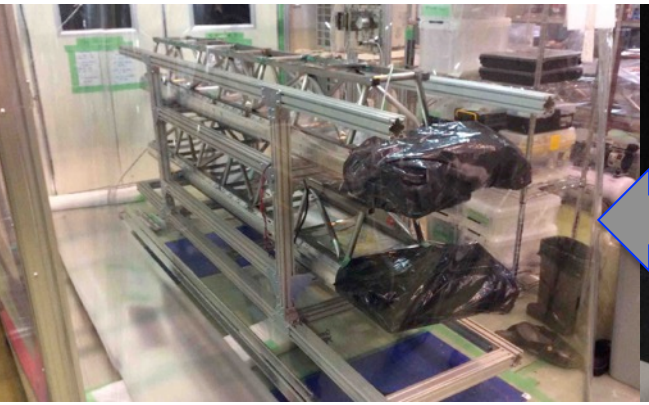
K. Suzuki
(@RICH2016)



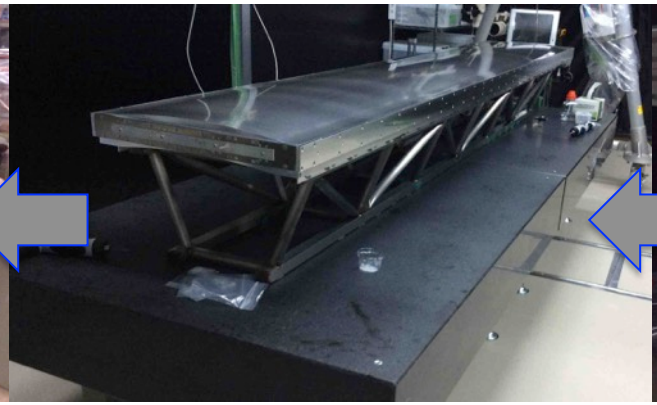
Optics: alignment, gluing, curing and aging (~2 weeks).

Enclosure: gluing CCDs and LEDs, integrating fiber mounts.

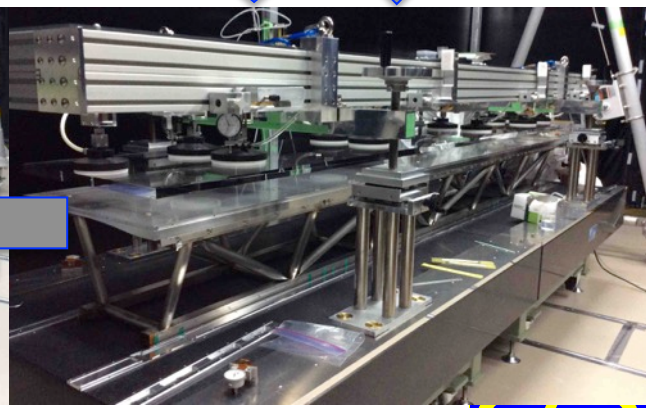
QBB: strong back flattening, button & enclosure gluing.



Put on a cart. PMT and front-end integration, performance check.

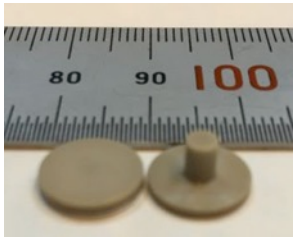


QBB assembly and gas sealing.

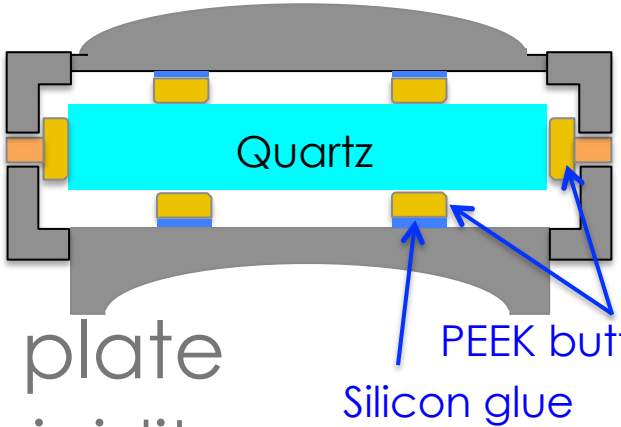


Move optics to QBB using the "lifting jig".

mechanics



Module cross section

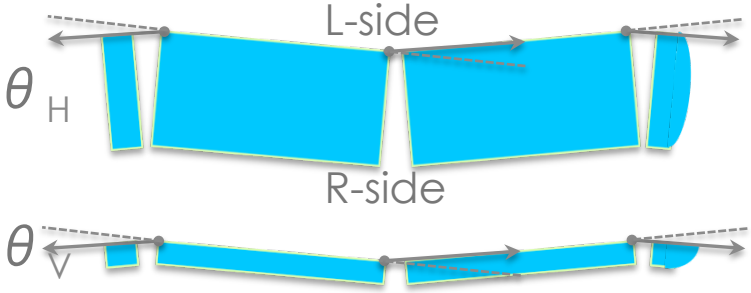


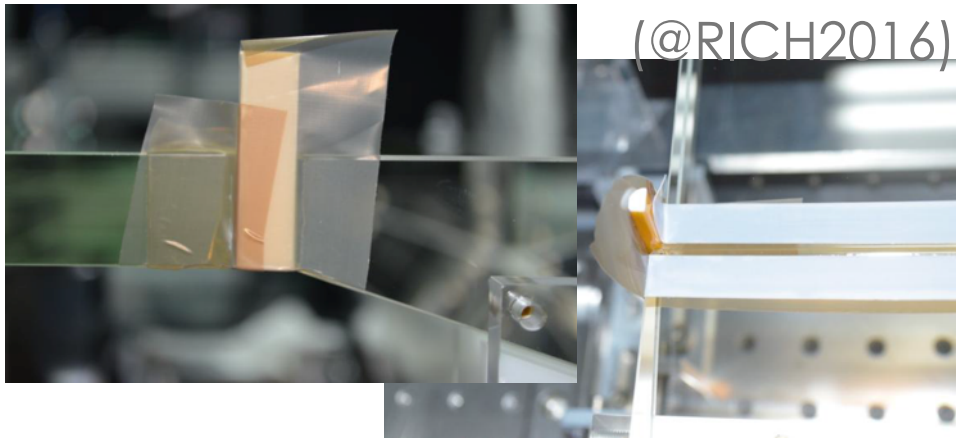
- requirement for Quartz Bar Box (QBB): light but rigid
  →aluminum honeycomb plate
  - round shape to have high rigidity (×2.8 rigidity than square)
- strong back
  - support frame
  - removed after connecting to adjacent modules

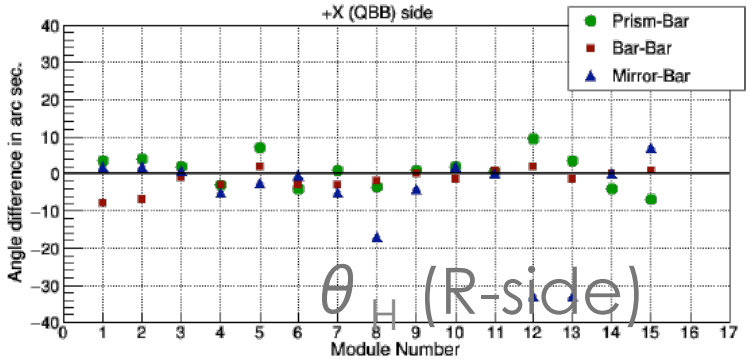
QBB

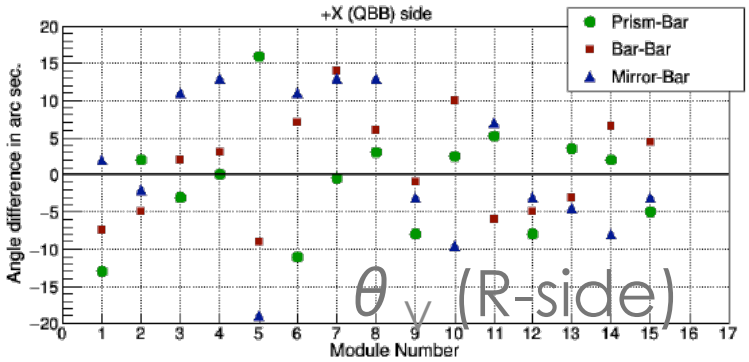
K. Suzuki (@RICH2016)

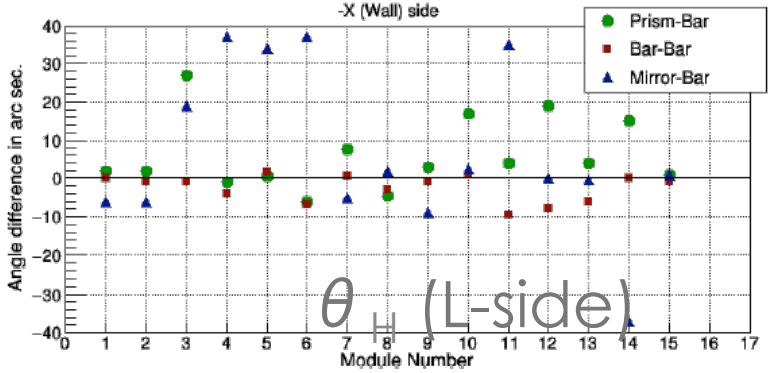
Optics: alignment, gluing.

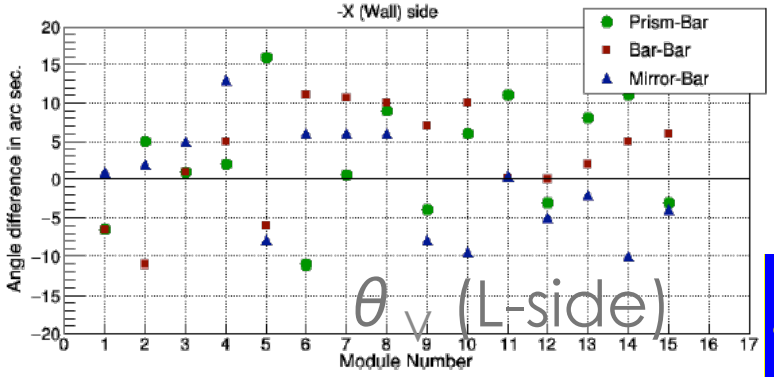










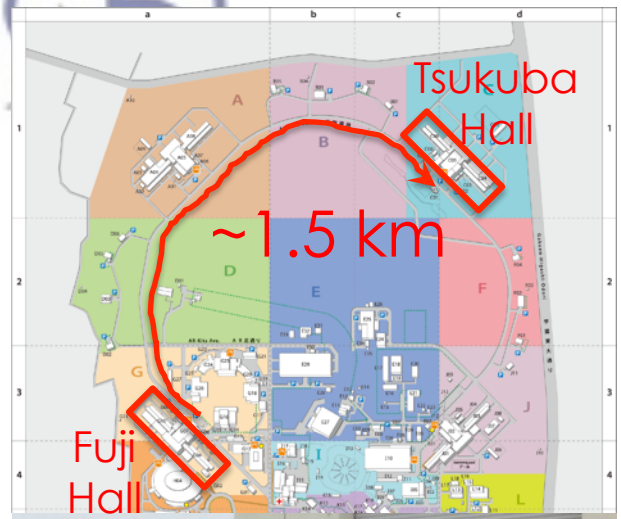


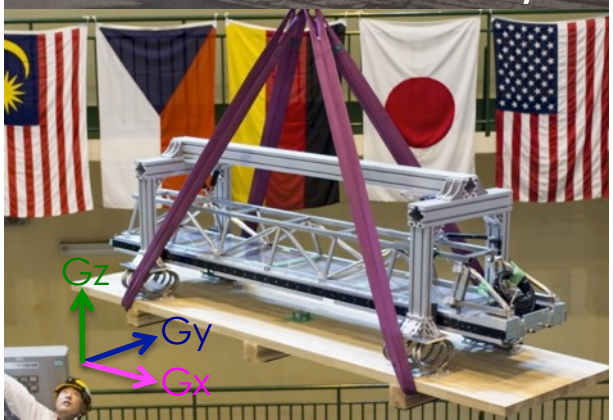
$|\theta_H| < 40$ arcsec.

$|\theta_V| < 20$ arcsec.

Belle II

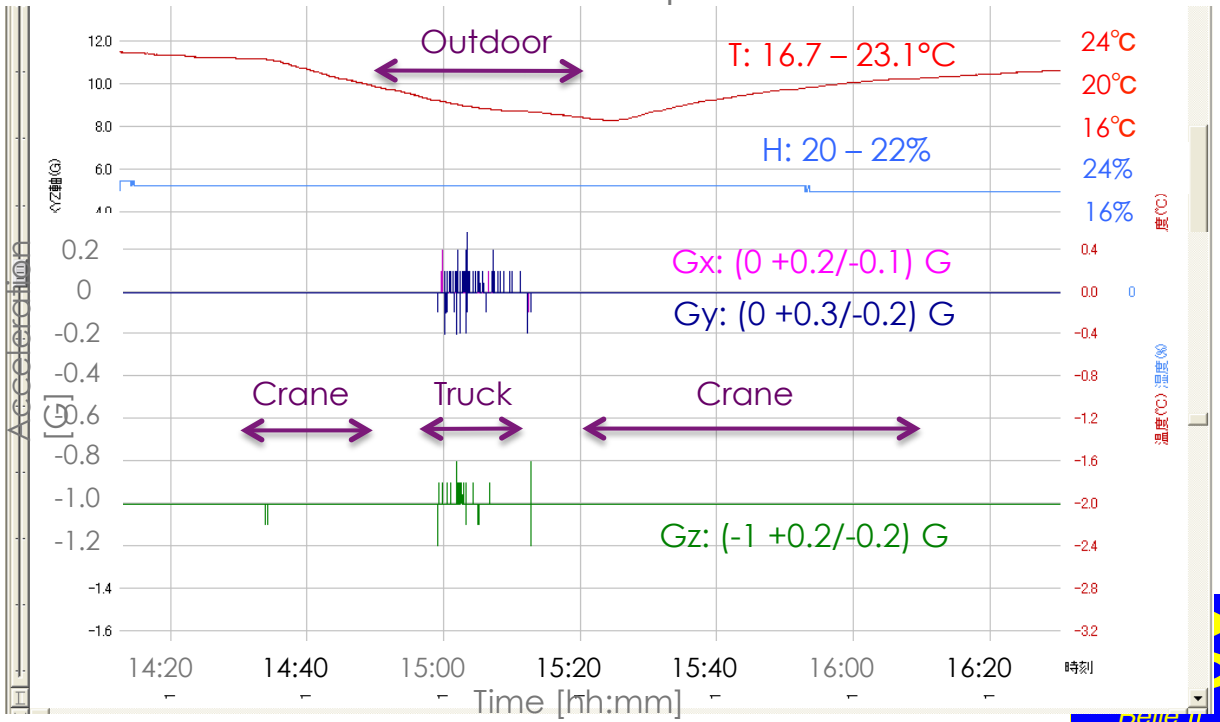
Module transportation





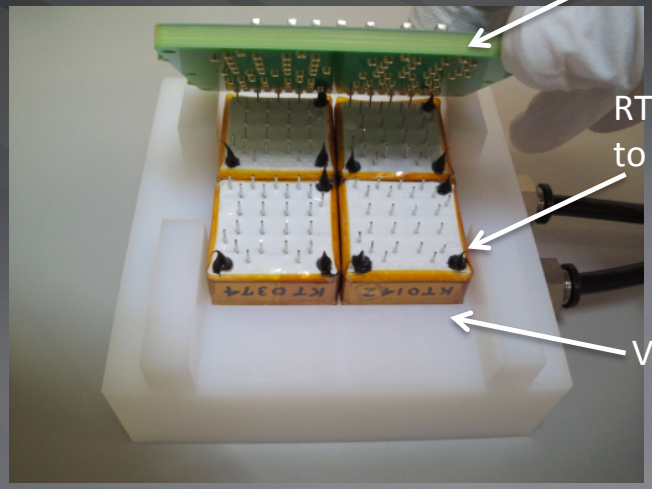
- From the assembly site to the installation site.
  - Using a transportation pallet, crane and truck (~1.5 km @ ~5 km/h).
  - Gently done for all modules.

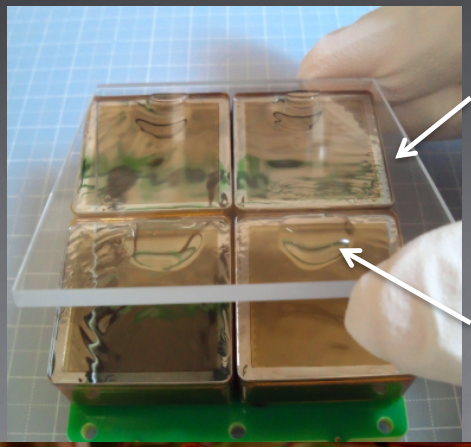
Temp. (T), Humidity (H) and Acceleration (G) in the M01 transportation.

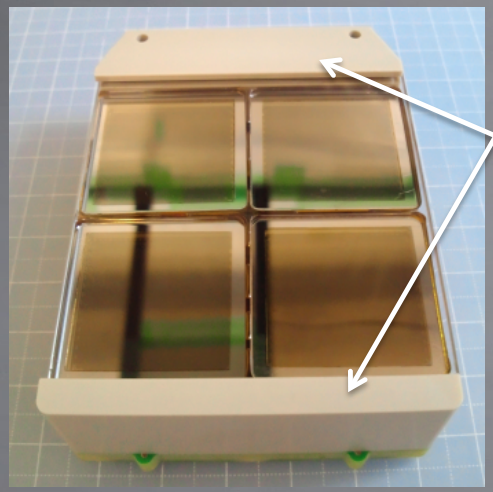


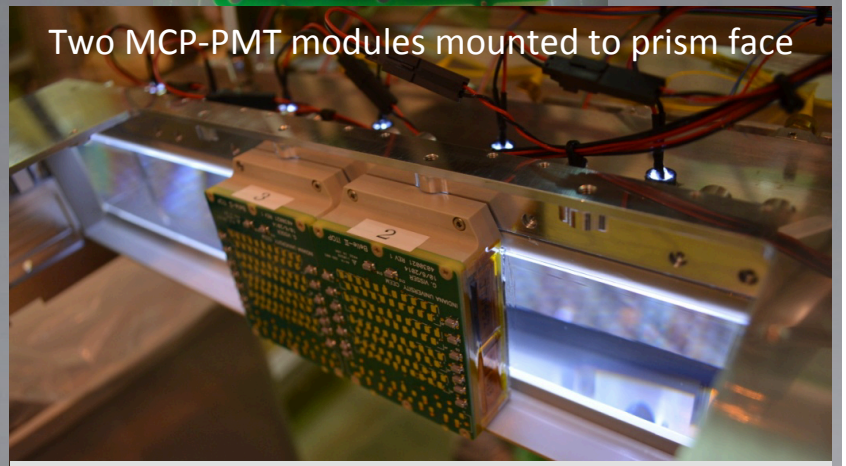
MCP-PMT modules

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965





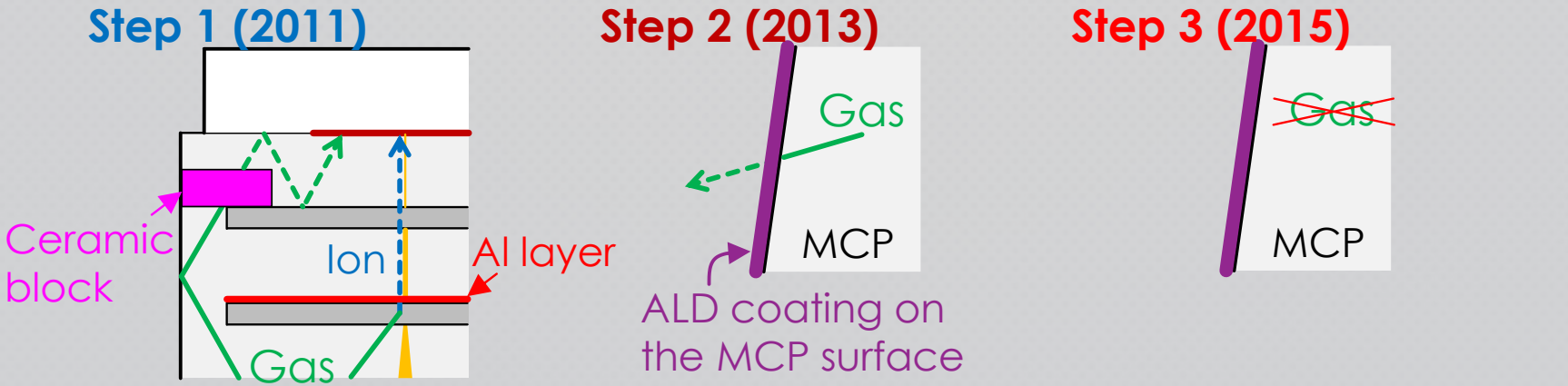


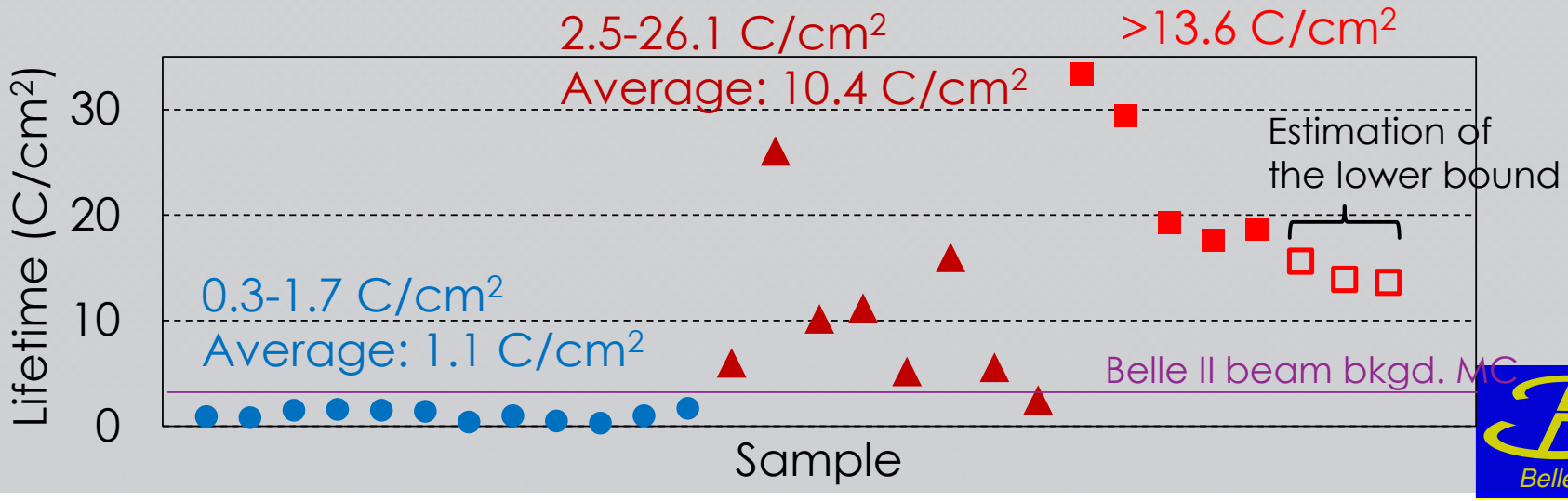


Removable optical coupling is made using a soft cast silicone cookie with a drop of optical oil to make a “bubble free” contact

Lifetime extension of the MCP-PMT

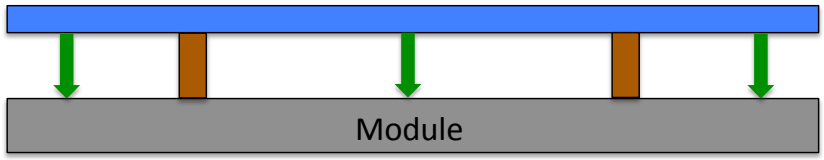
- Outgassing from the MCP deteriorates the photocathode and the QE drops as a function of the integrated output charge.

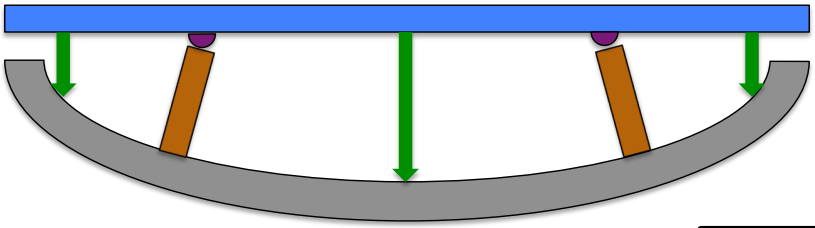




deflection measurement

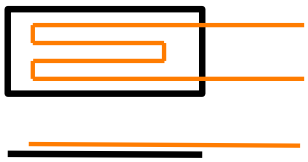
- Portable Pipe gauge

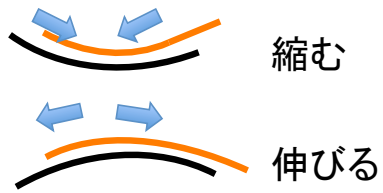


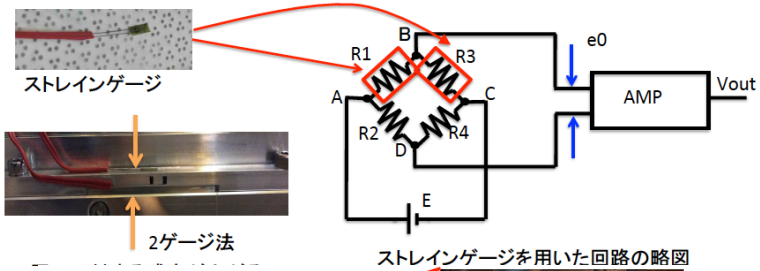


Used gau

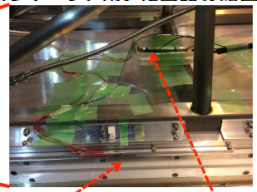
- strain gauge

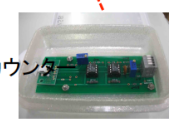






ストレインゲージを用いた回路の略図



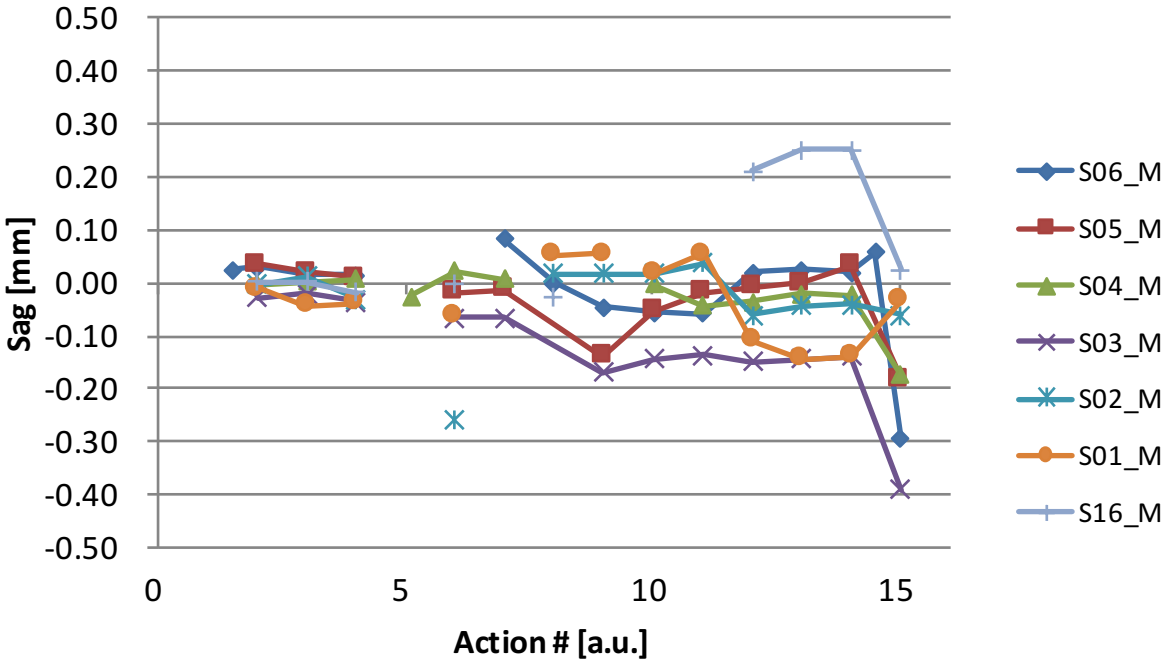


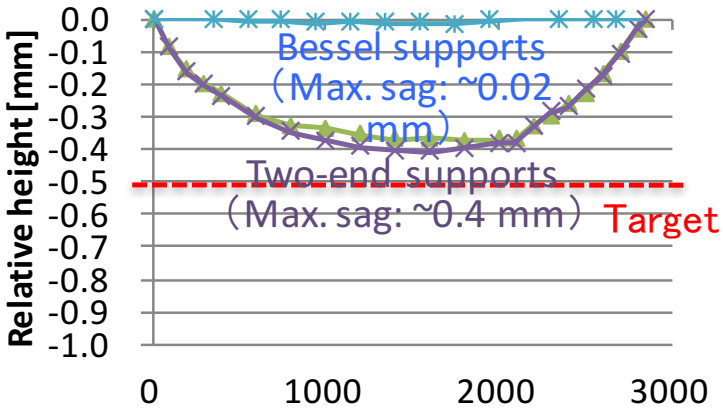
アルミ棒
表裏にゲージが貼ってある

本体回路

deflection measurement

Act. #	Action
1	Before the slider approach.
2	Sliders joined.
3	Lifted up.
4	Set the weights.
5	Rotated to the top position.
6	Removed OP spacers.
7	Rotated to the slot position.
8	Moved to a lower position.
9	Slid in the barrel.
10	Tightened the shoulder bolts.
11	Tightened the flange bolts.
12	Removed the weights.
13	Removed the slider bolts.
14	Removed the upper L-fixtures.
15	Removed the lower L-fixtures.



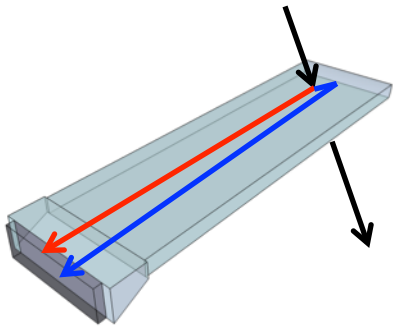


K. Suzuki (24th B2GM)

宇宙線データ (タイミング分布)

- トリガーカウンターの場所を変えながら応答を確認
- 想定通りの直接光/反射光の時間差

trigger counter in mirror side

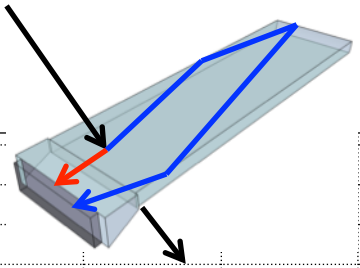


hit timing

single peak

Module#06

trigger counter in prism side



~34 ns

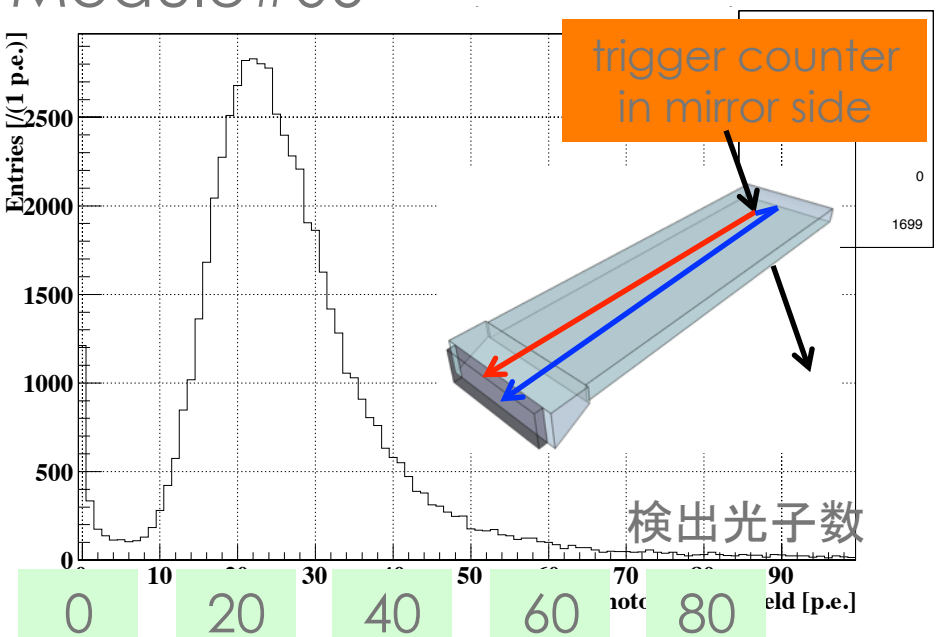
hit timing

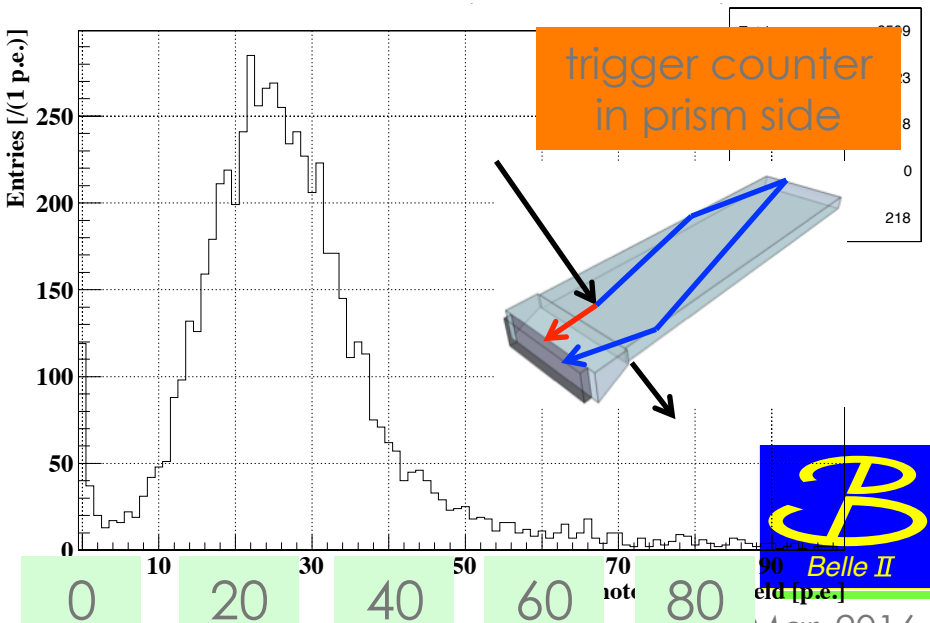
double peak

宇宙線データ (ヒット数)

- 1トリガーあたりのhit数：~20
- およそシミュレーションの予想と一致

Module#06





0 20 40 60 80

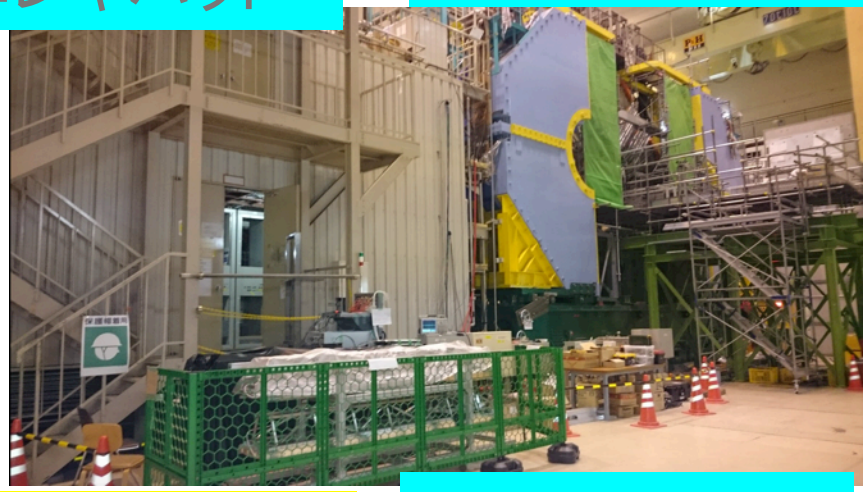
0 20 40 60 80

筑波実験棟への輸送後のデータ

- エレキハット前でインストール前に再度測定を行う
- 輸送時に大きな問題がないことを確認

エレキハット

Belle II検出器

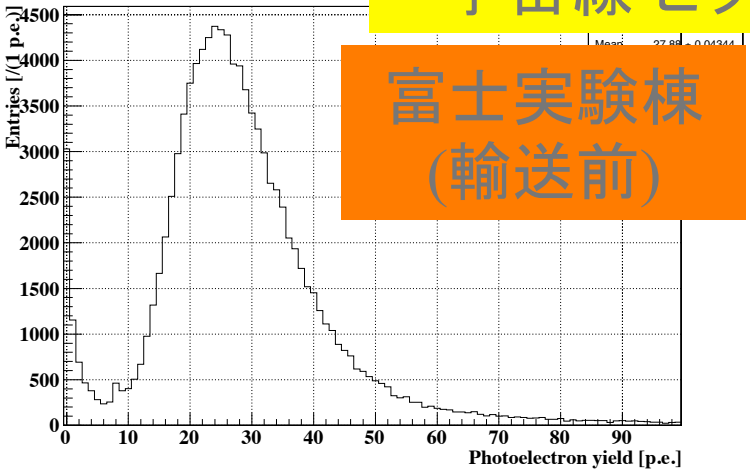


TOPモジュール

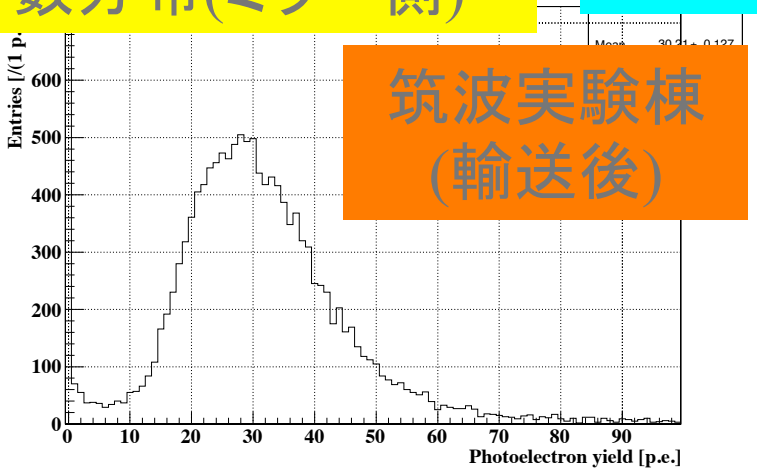
Module#09

宇宙線 ヒット数分布(ミラー側)

富士実験棟
(輸送前)

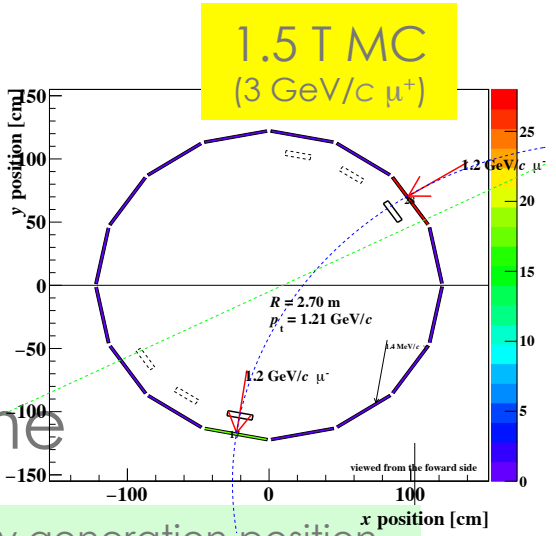


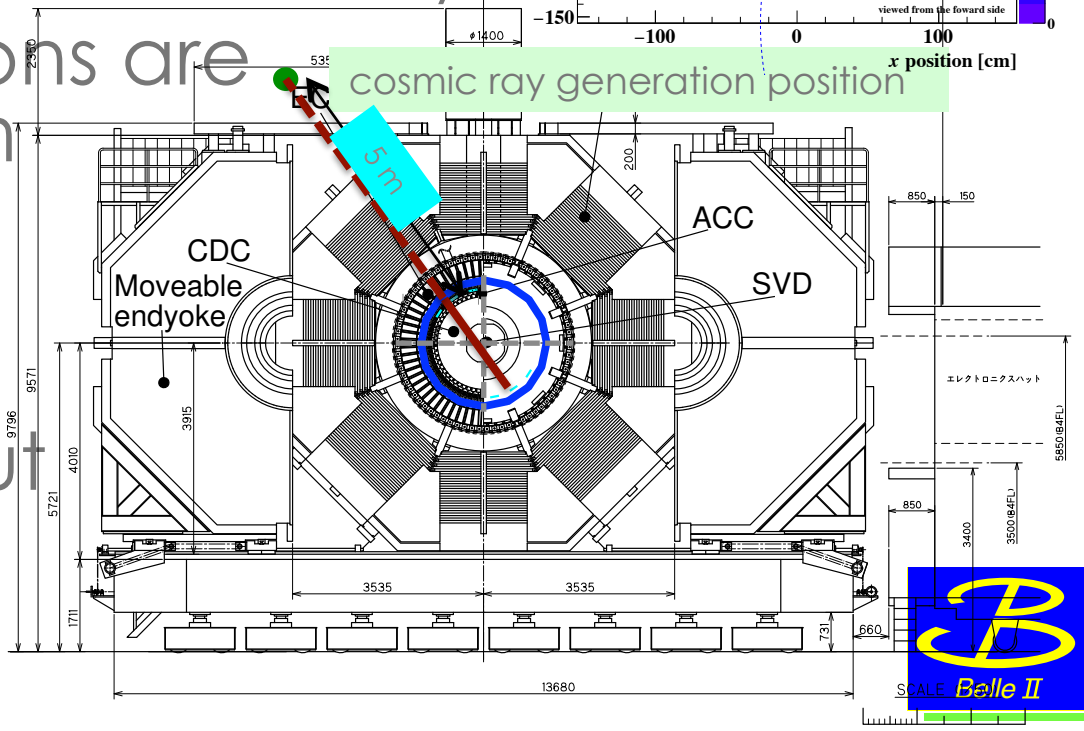
筑波実験棟
(輸送後)



MC simulation

- TOP, ECL and KLM as well as trigger counters were setup
  - prepared by Marko, scinti. by me
- cosmic ray muons are generated from the outside of the Belle II detector
- with and without magnetic field





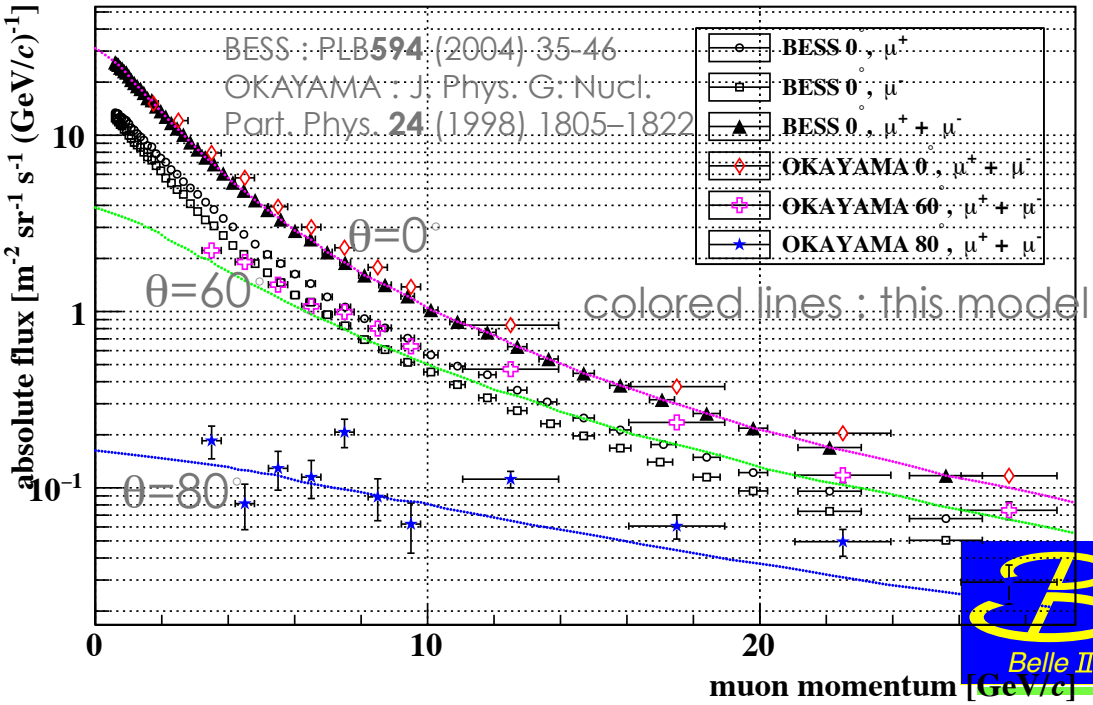
cosmic ray model

- correlation between angular and momentum distribution (from hep-ph/0604145)

$$I(p_\mu, \theta) = \cos^3(\theta) I_{\mathrm{V}}(\zeta)$$

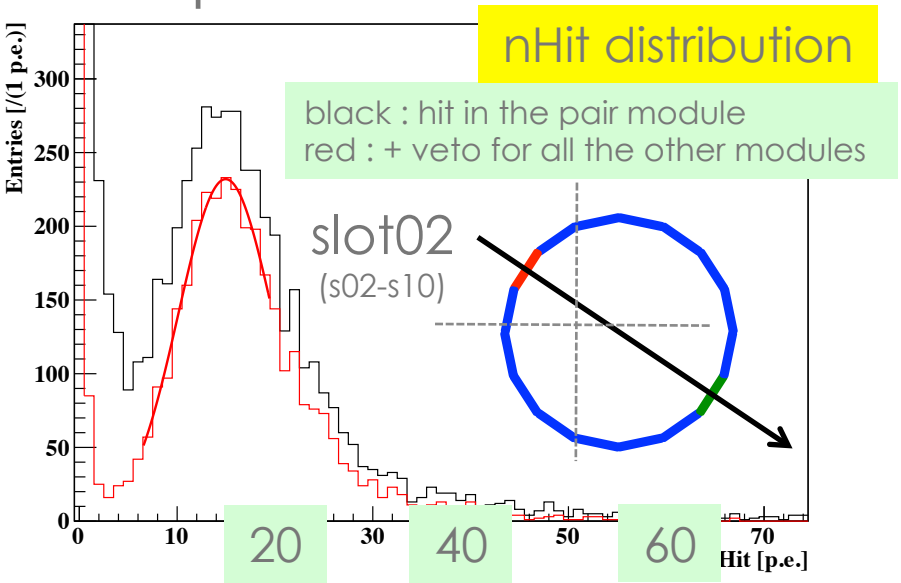
$$\zeta = p_\mu \cos(\theta)$$

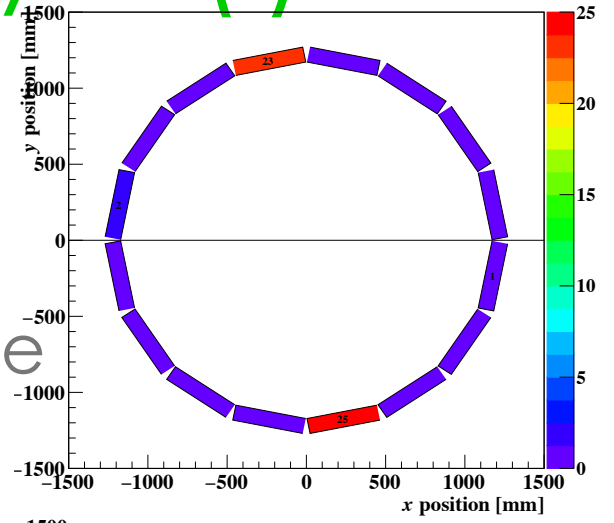
  - I_V : spectrum for θ=0
    - BESS results were used

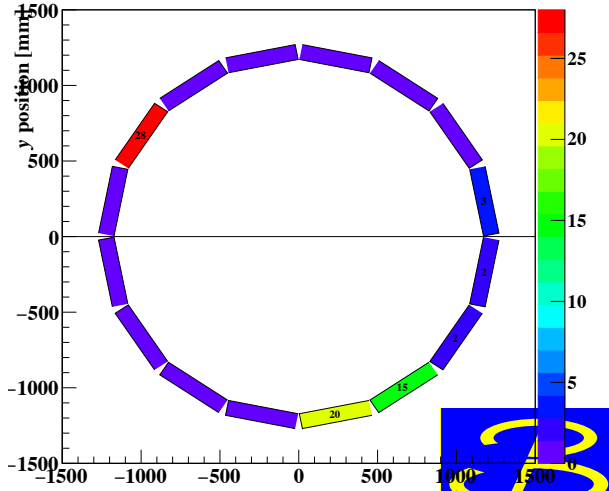


highlights of analysis (i)

- event selection using TOP hit itself is possible
  - require hit in a partner module and no hits in all the others
  - clear peak structure



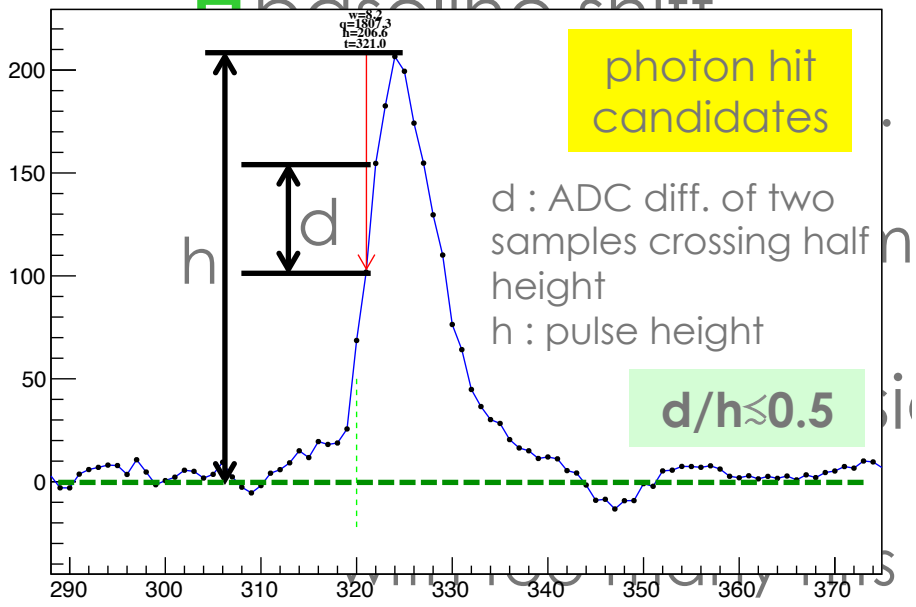


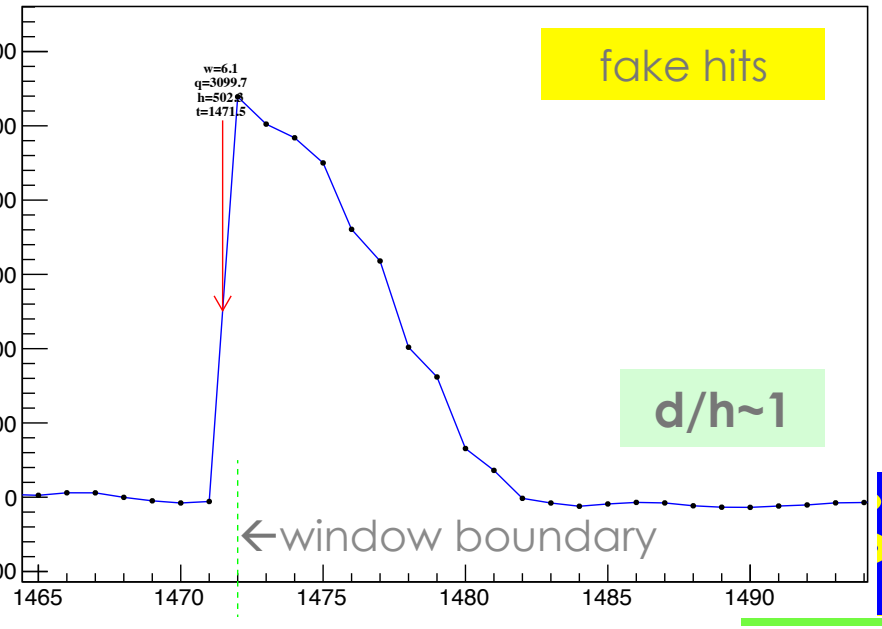


hits in >2 modules shower event?

highlights of analysis (ii)

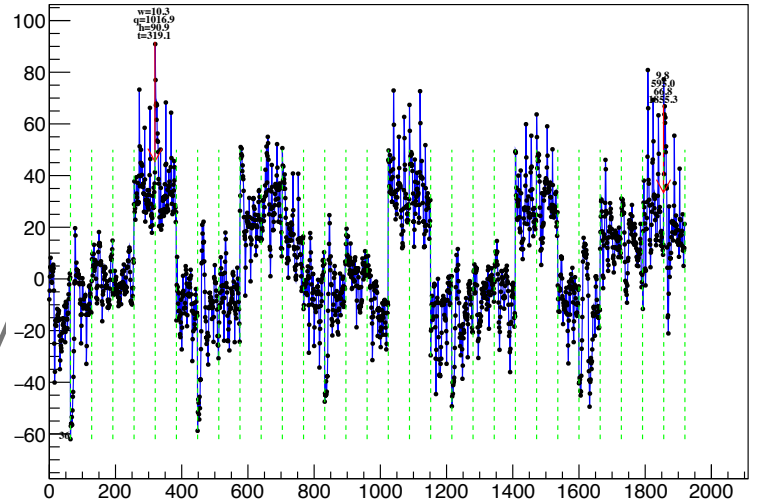
- reduction of artifacts
  – waveform analysis
    - new cut at the window boundary
    - baseline shift

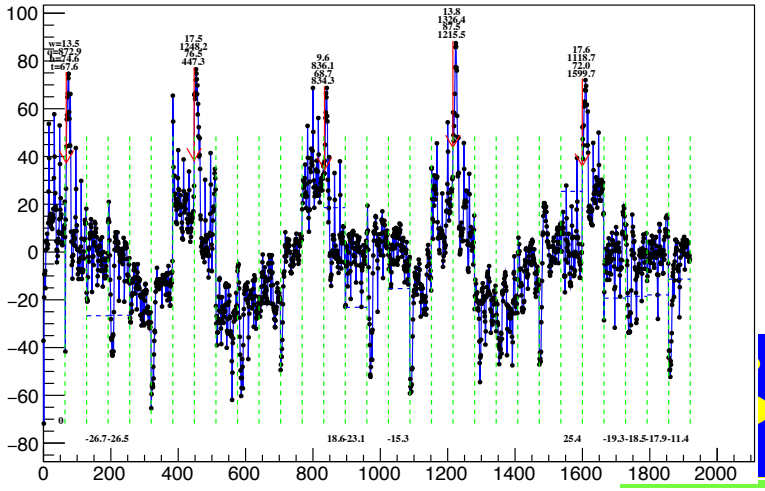




highlights of analysis (ii)

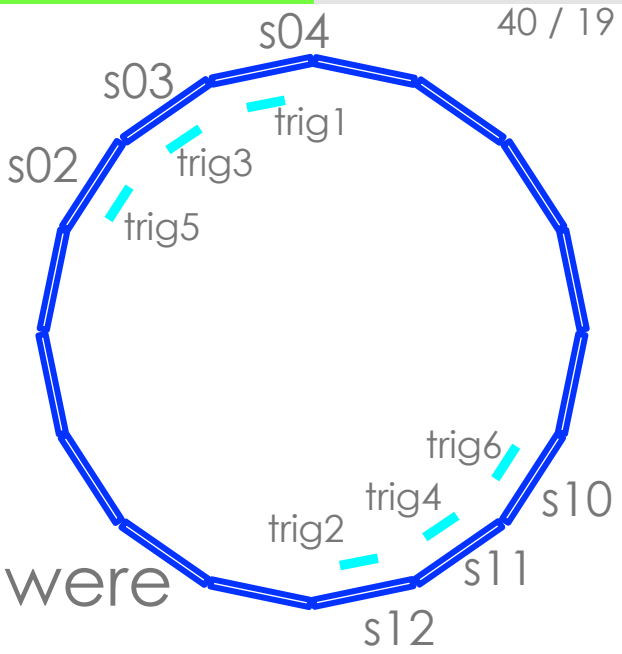
- reduction of artifacts – waveform analysis
  - new cut at the window
  - baseline shift
    - fit ADC count dist. for each window (take very long time to process…)
  - mis-configured asics
    - discard asic data with too many hits

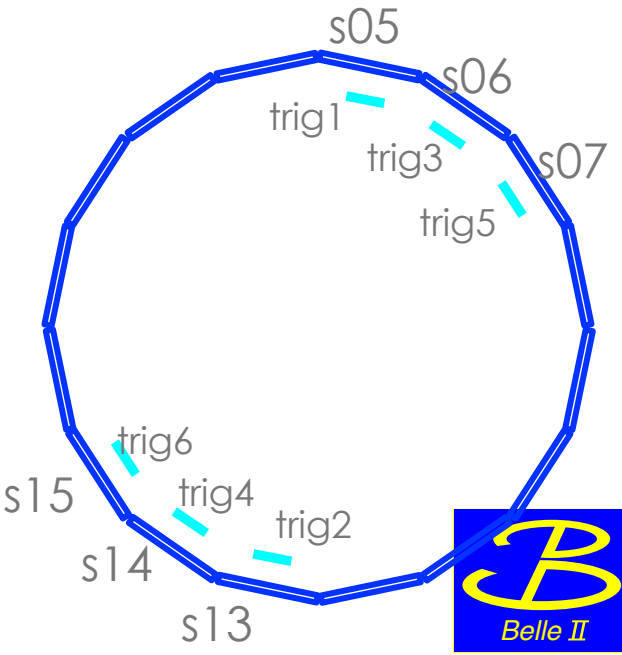




data taking

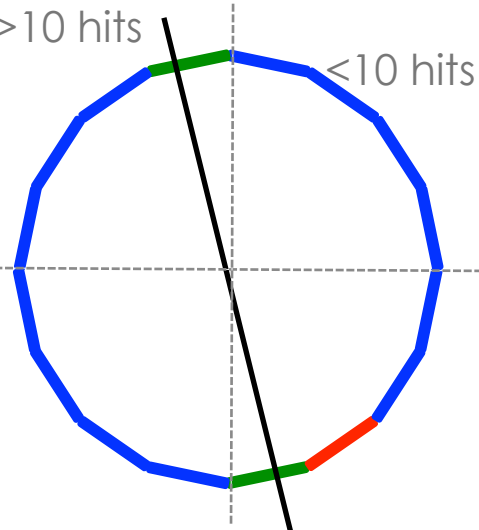
- PocketDAQ with full-waveform firmware (20-21)
  - "Vbias" and "Vbias2" values were swapped
    →hard to analyze timing-related issues, but able to evaluate # of photon hits
  - all the 16 slots were readout
- two kinds of trigger layout
  - manually changed

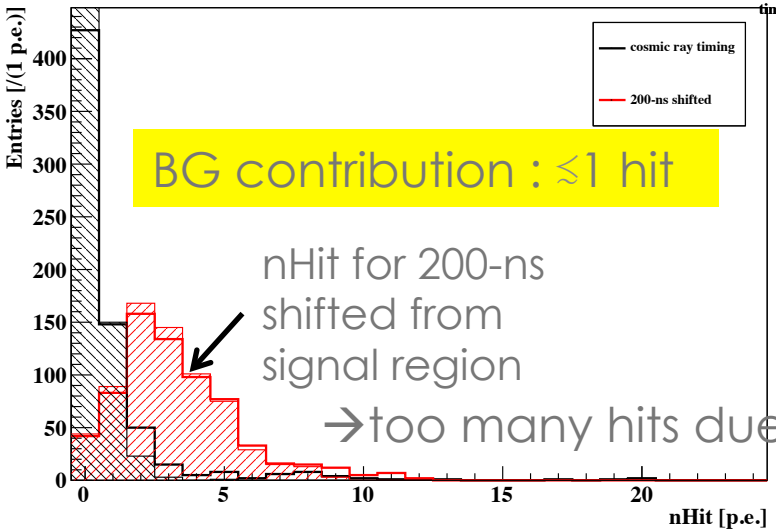




estimation of BG components

- BG sample
  - require hits in a pair of modules and no hits in all the others except the module of interest

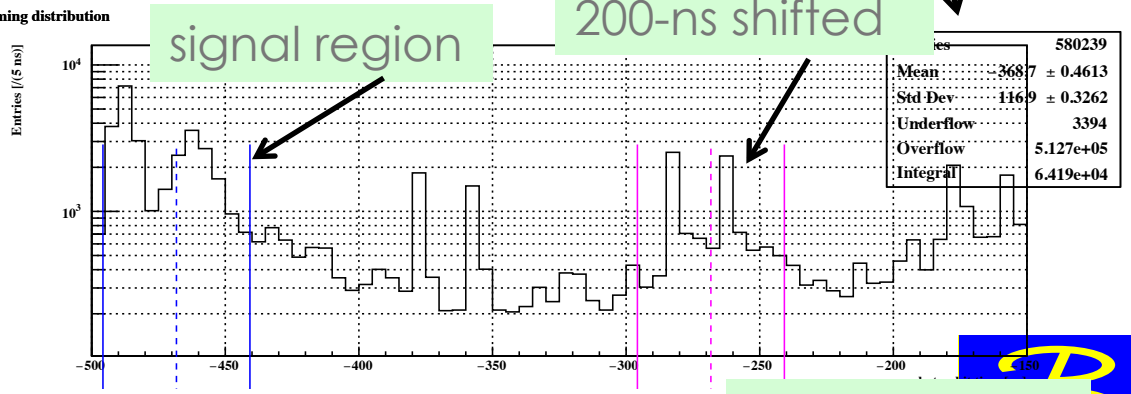




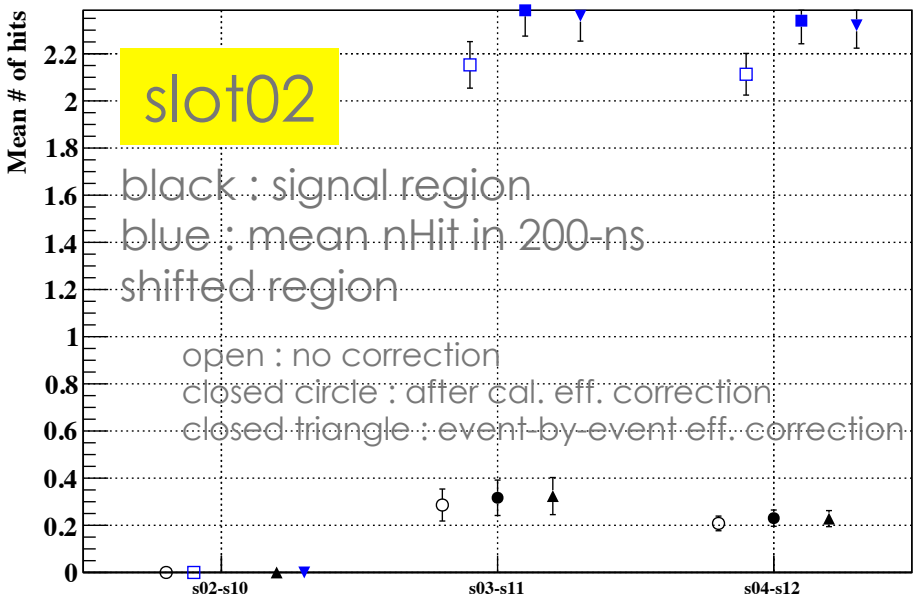
BG contribution : ≲1 hit

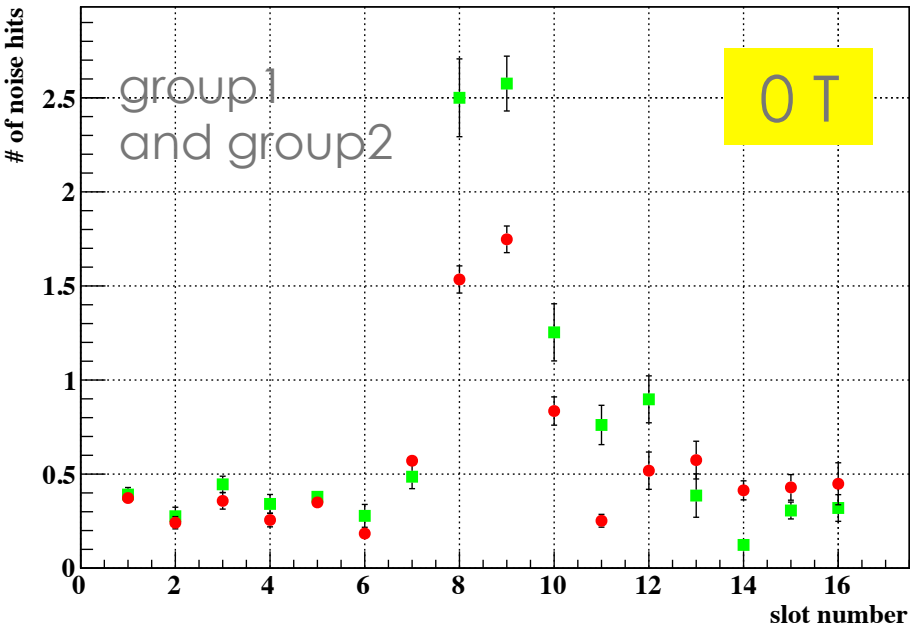
nHit for 200-ns shifted from signal region

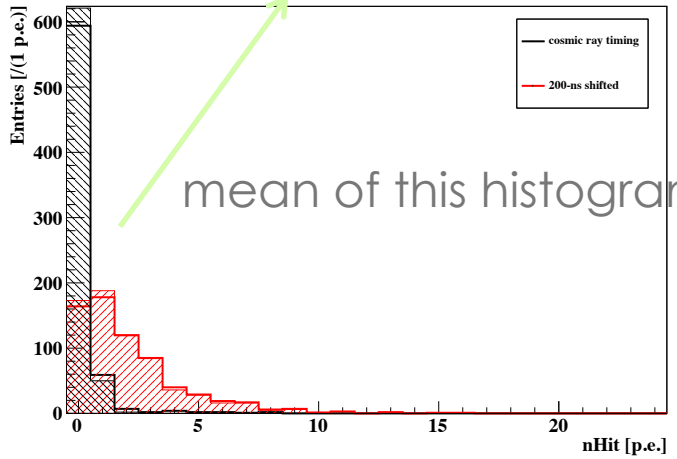
→too many hits due to artifacts



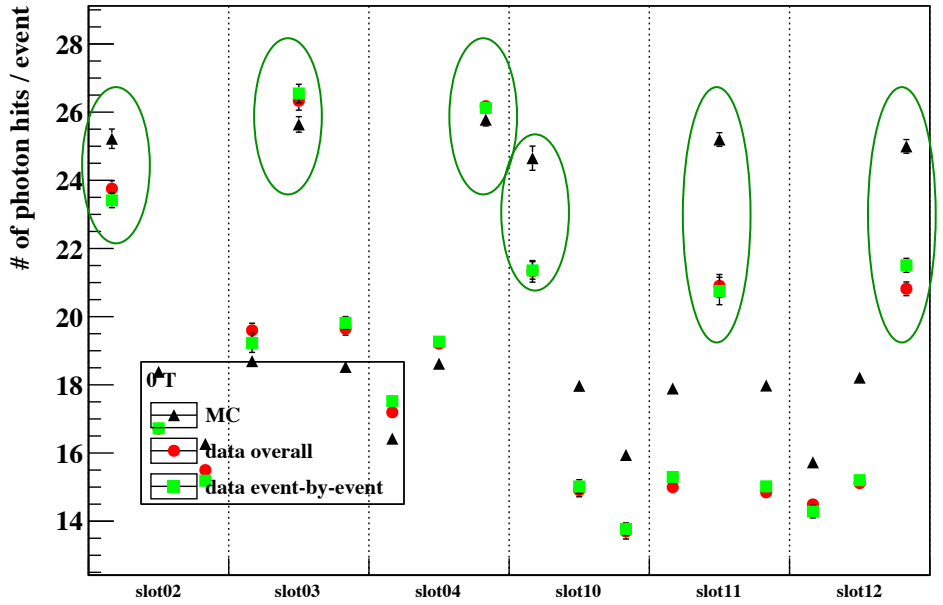
BG contribution







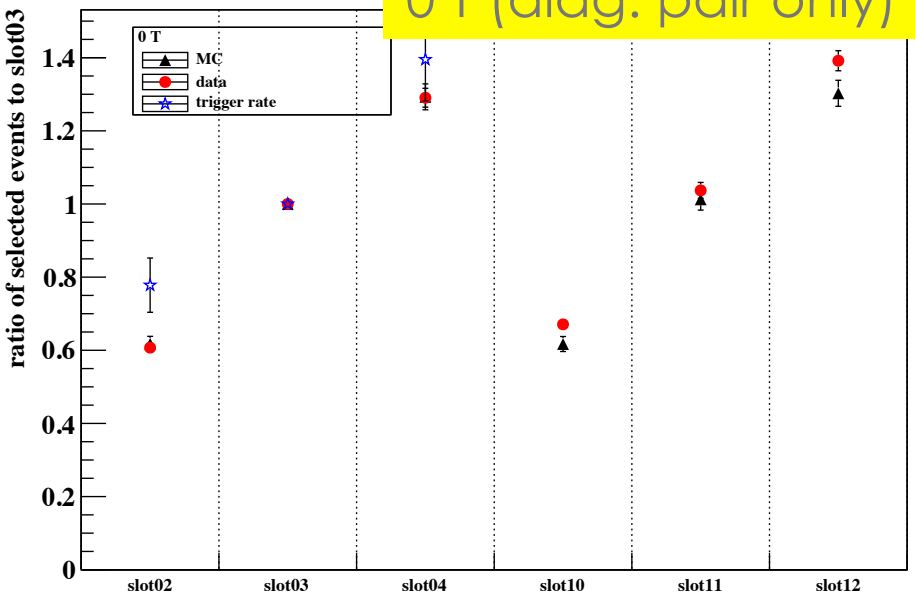
- d


# of photon hits / event
28
26
24
22
20
18
16
14
0 T
MC
data overall
data event-by-event
slot02
slot03
slot04
slot10
slot11
slot12

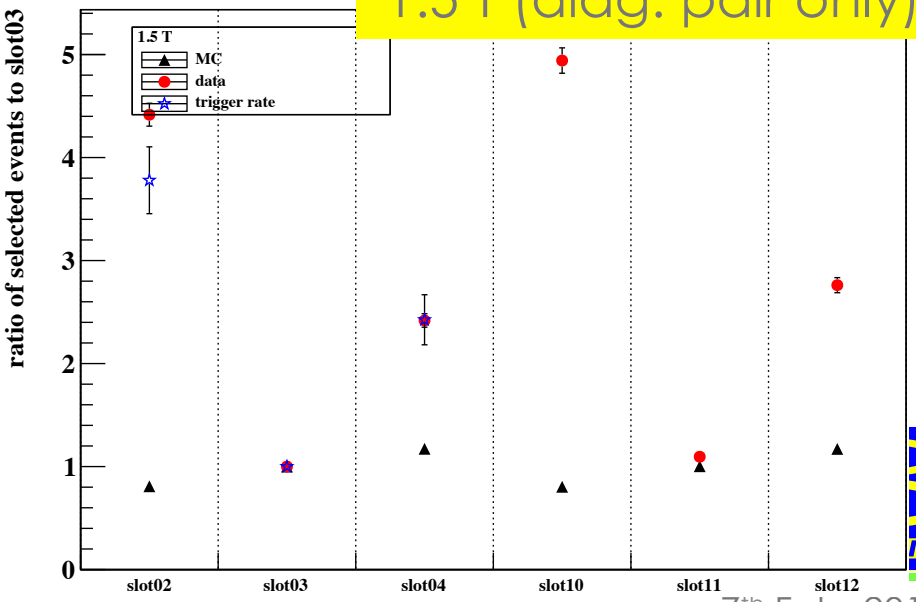
issues – trig. rate in data/MC

- reasonable agreement in 0-T case
- not reproduced in 1.5-T case
  - wrong model? bad trig. counter eff?

0 T (diag. pair only)

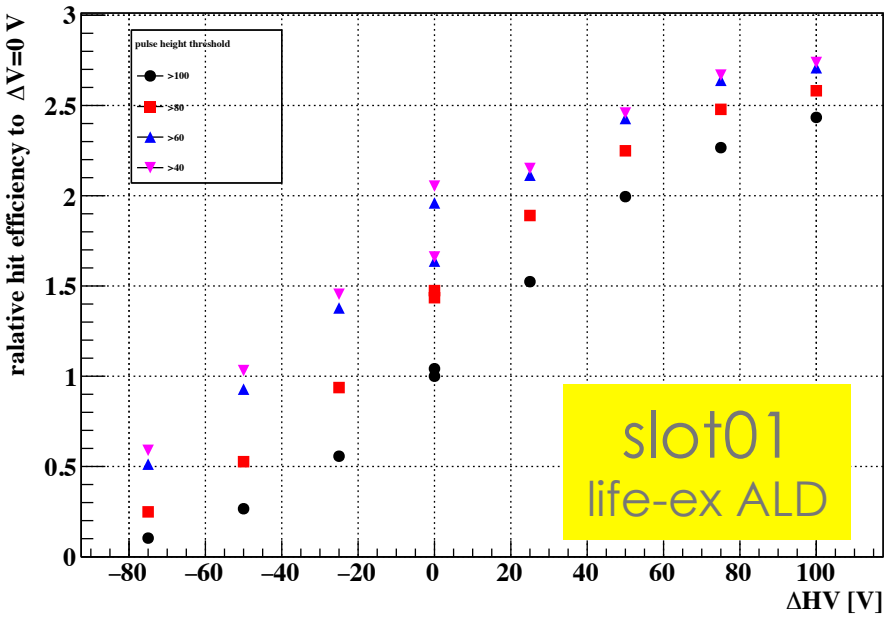


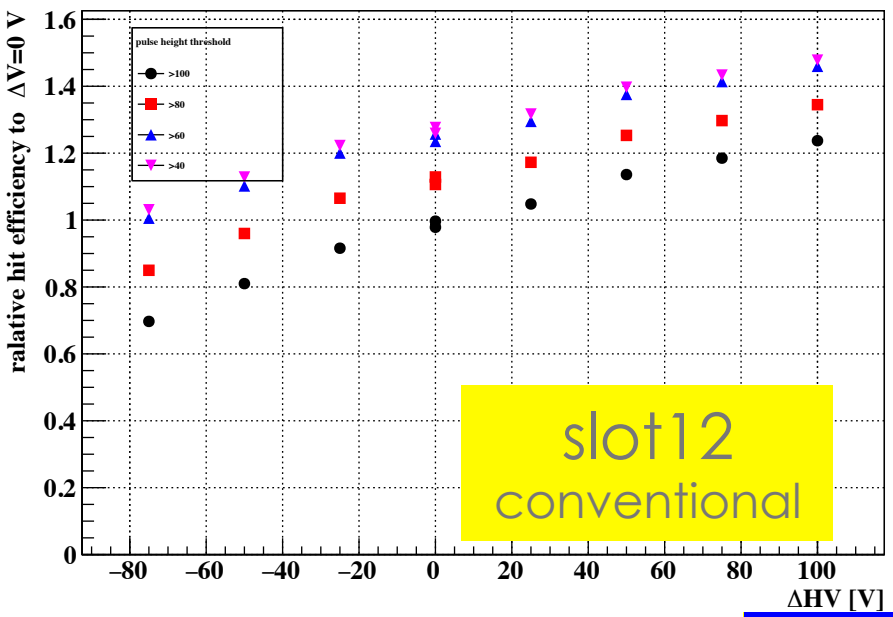
1.5 T (diag. pair only)



eff. vs HV and thre. (0 T)

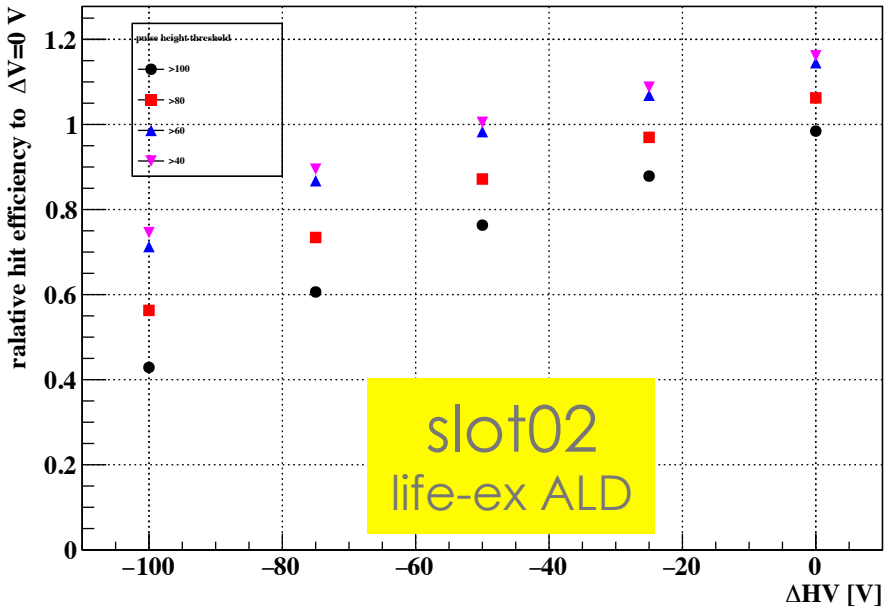
- ΔV = [-80,+100]

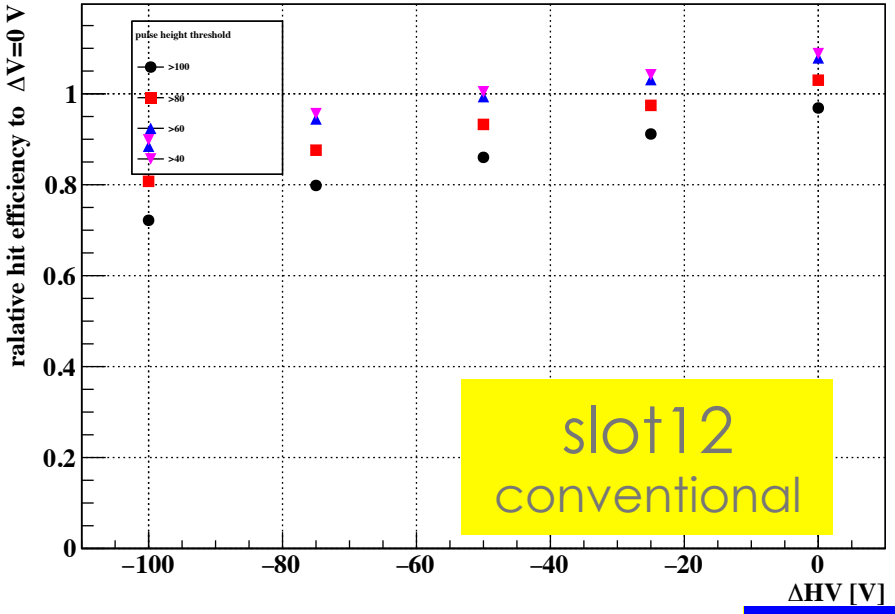




eff. vs HV and thre. (1.5 T)

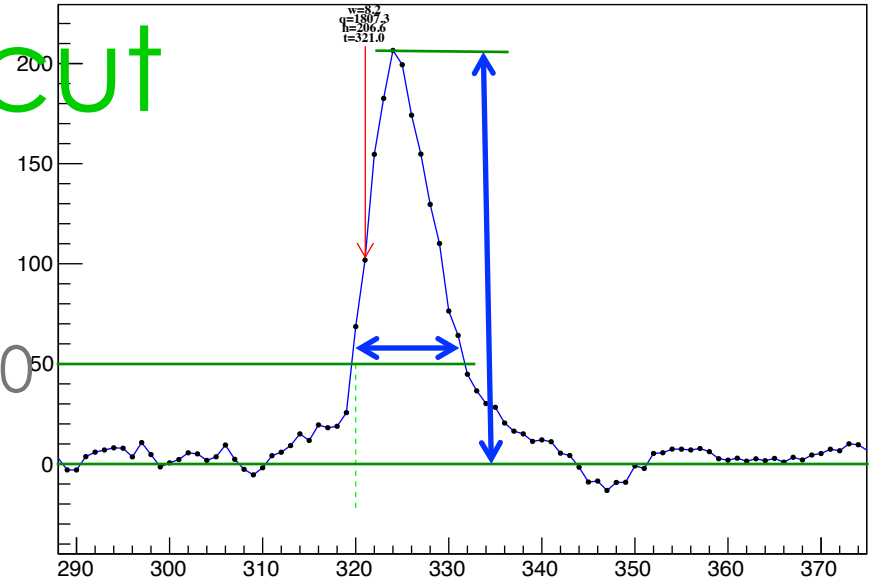
- ΔV = [-100, 0]



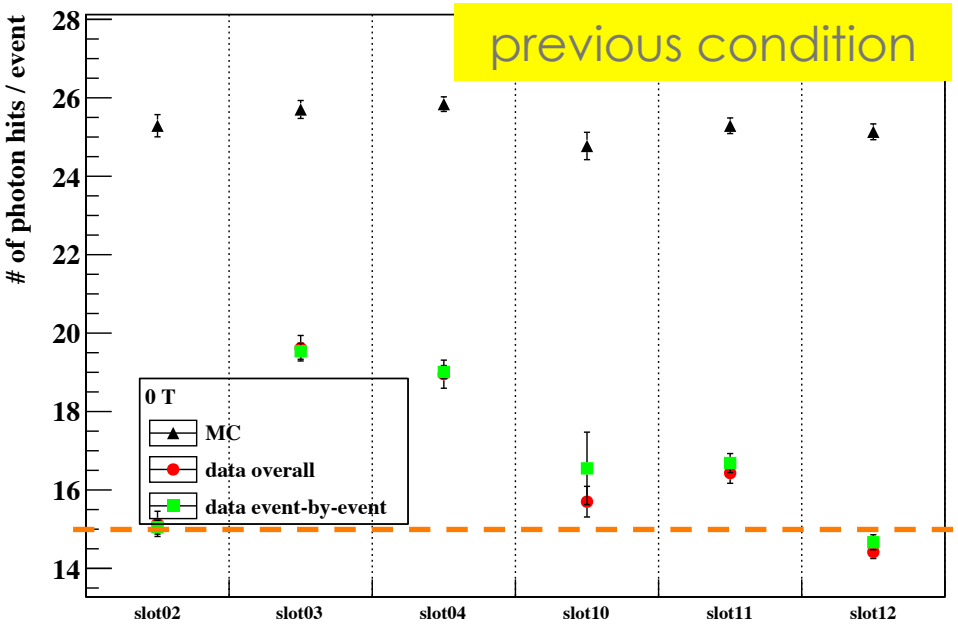


nHit with loose cut

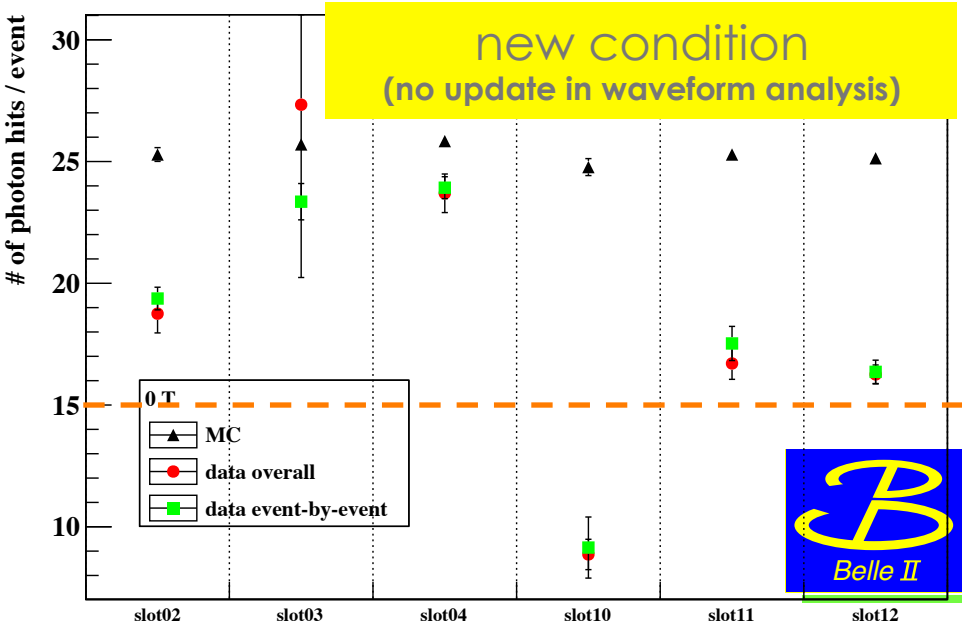
- prev.
  - $nBins_{>50} \geq 3$, height > 100
- new condition
  - $nBins_{>50} \geq 2$, height > 70



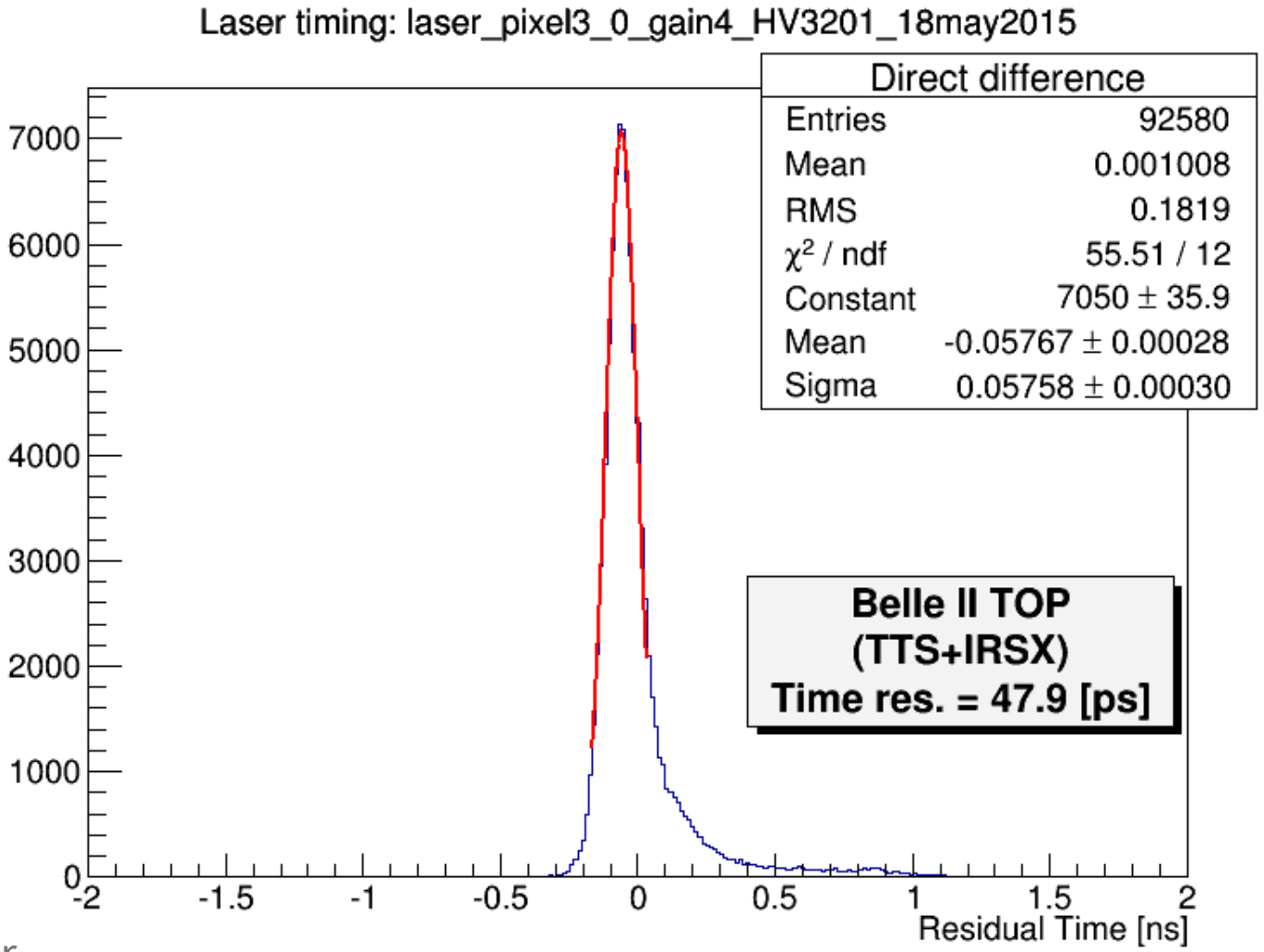
previous condition



new condition
(no update in waveform analysis)



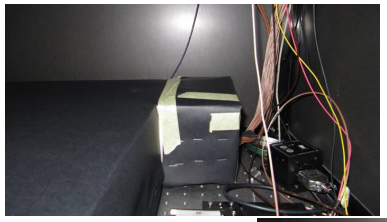
test in Hawaii

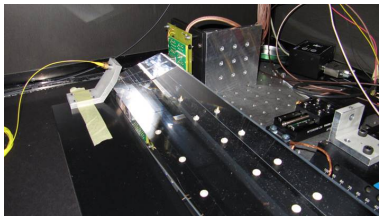


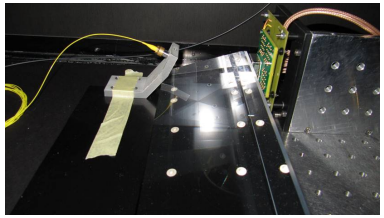
laser system test bench

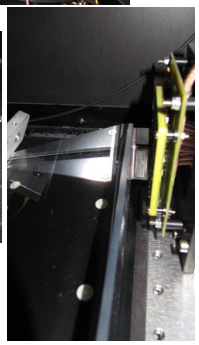
Setup in Padova - I

Quartz prism equal to those installed in KEK (rejected 'cause of production damage on a corner)







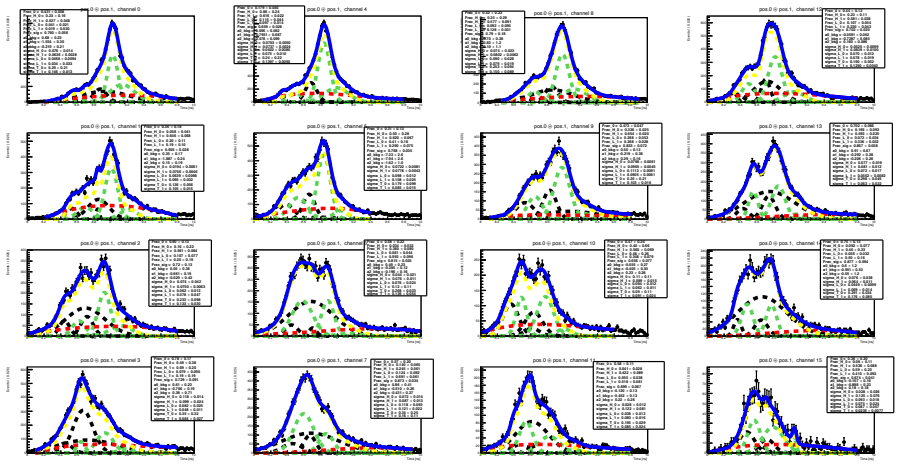


A dedicated support for the fibers is being produced

current precision on fiber position $\sim$ mm

Fit results - pos.0 $\cup$ pos.1 - x-axis range [8,10] ns

pos.0 & pos.1 signal PDFs, full signal PDF, bkg PDF, full PDF



One-two evident peaks, very large tails

pos. 0 & 1 components no more distinguishable without fit