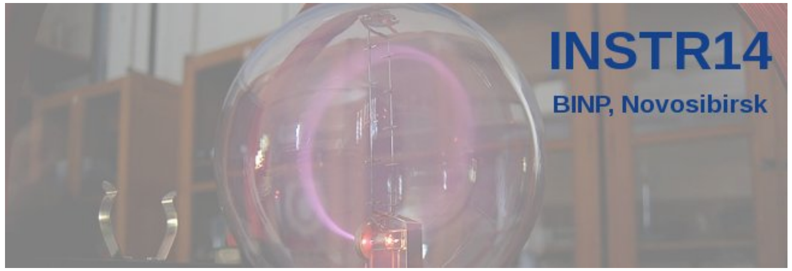


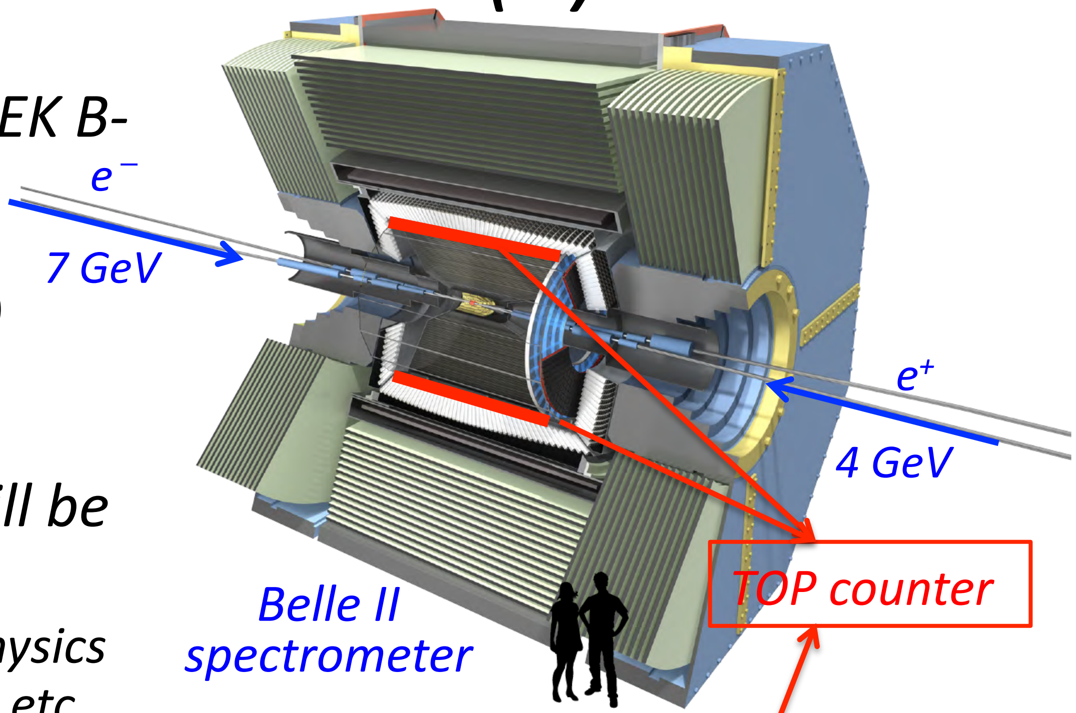
Development and Construction of the Belle II TOP Counter

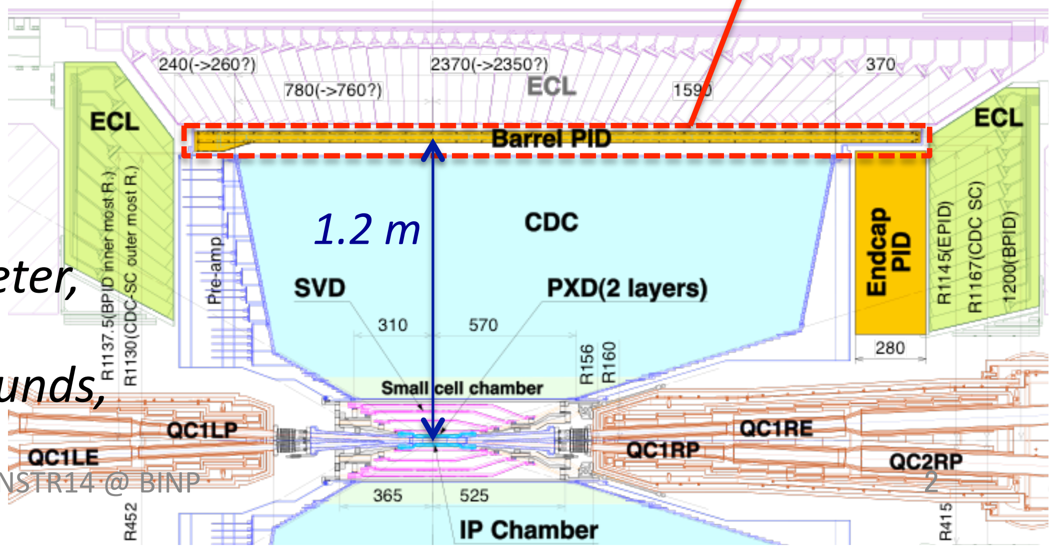
Kazuhito Suzuki (Nagoya Univ.)

on behalf of the Belle II TOP Group

Belle II TOP counter (1)

- *SuperKEKB/Belle II project*
  - *Luminosity upgrade of the KEK B-factory.*
    - ➢ *∫Ldt ~50 ab^{-1} (x50)*
    - ➢ *L~$8x10^{35}$ $cm^{-2}s^{-1}$ (x40) (BG: x20)*
    - ➢ *Commissioning in 2015-2016.*
    - ➢ *Data taking will start in 2016.*
  - *Various physics programs will be carried out.*
    - ➢ *Rare decay searches for new physics hunt, exploring exotic particles, etc.*
- *Barrel PID device*
  - *TOP counter (16 modules)*
    - ➢ *Good PID performance*
      ex.) ε_{π}~99%, f_K~1% in B→ργ
    - ➢ *Less material inside the calorimeter,*
      c.f. Belle: ACC+TOF
    - ➢ *Operative under higher backgrounds,*
    - ➢ *To be installed in Feb. 2015.*

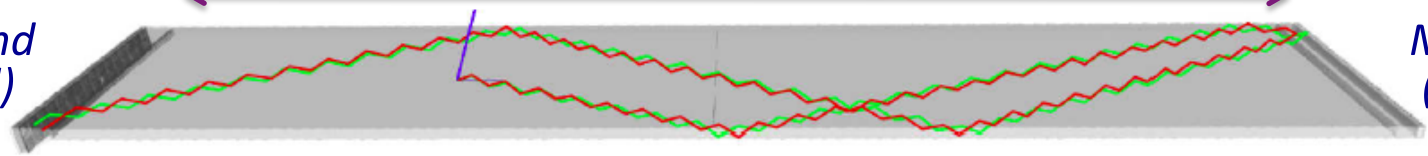




Belle II TOP counter (2)

"Quartz" optics (2700 mm)

Read-out end (backward)

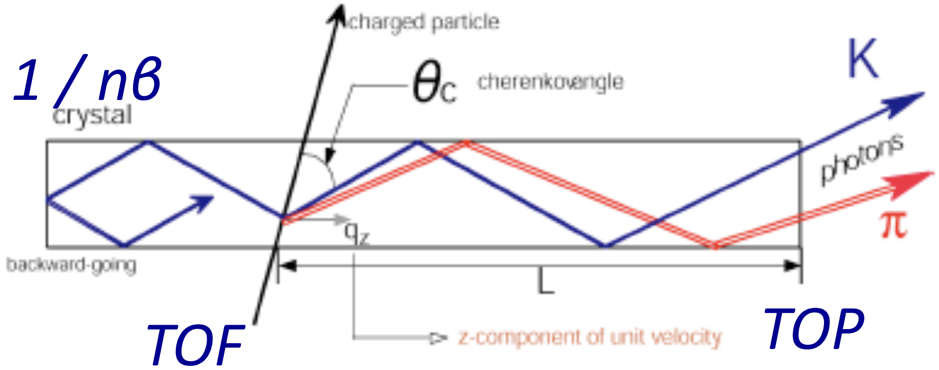


Mirror end (forward)

w: 450 mm, t: 20 mm

Internally reflected Cherenkov photons bounce off ≥ 100 times at the large faces.

$\cos\vartheta_c = 1 / n\beta$



$$S = \frac{\Delta TOF + \Delta TOP}{\sigma_{TOP}} \sqrt{N_{det}} \qquad \sigma_{TOP} = \sqrt{\sigma_{opt}^2 + \sigma_{PD}^2}$$

N_{det}: number of photons detected

[target: 20-30 photons]

σ_{opt}: chromatic dispersion (> ~50 ps)

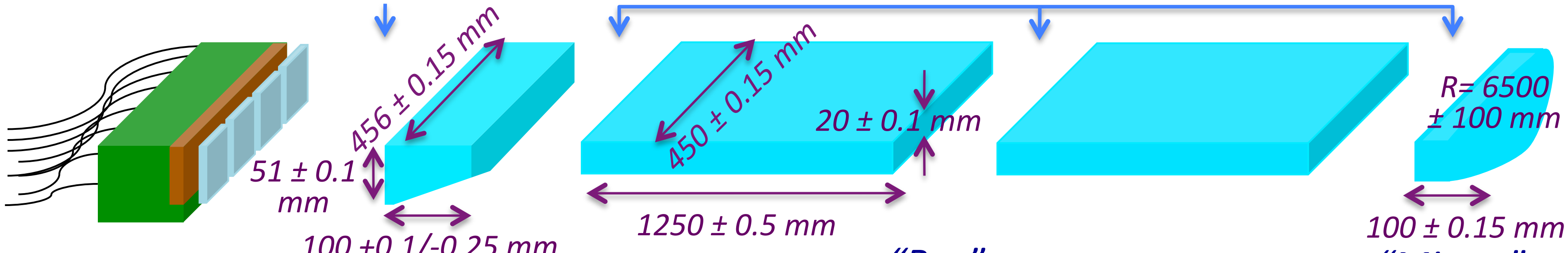
σ_{PD}: time resolution (TTS and elec.)

[target: ~50 ps]

Quartz optics (1)

- *Optical components*
  - *Tight requirements on material quality and dimensional tolerances.*

Optical coupling *Optical glue*

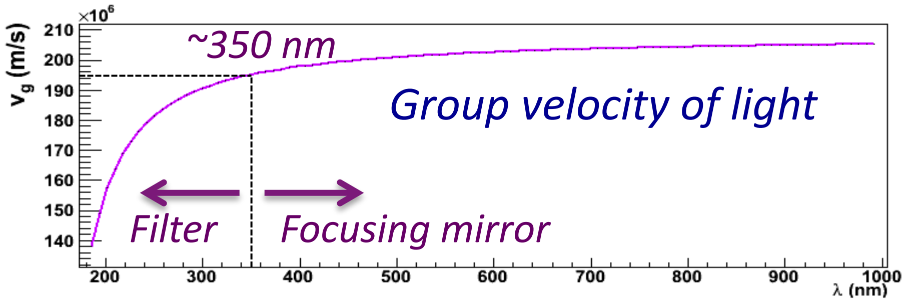


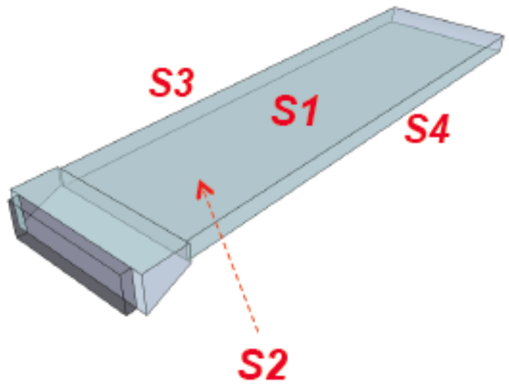
PMTs + opt. filter + front-end elec.

"Prism" (image expansion)

"Bar" (radiator/propagator)

"Mirror" (focusing)



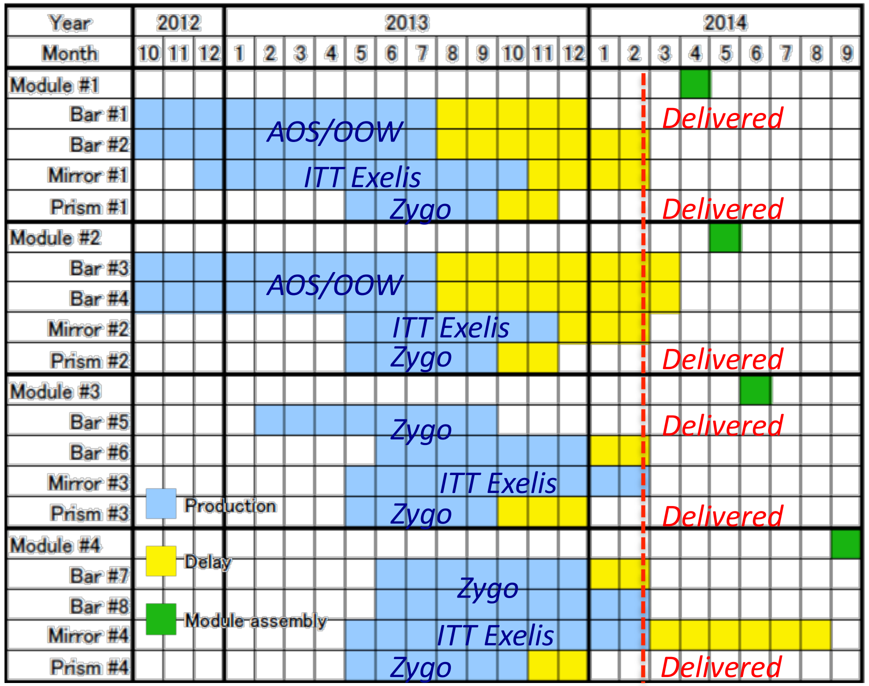


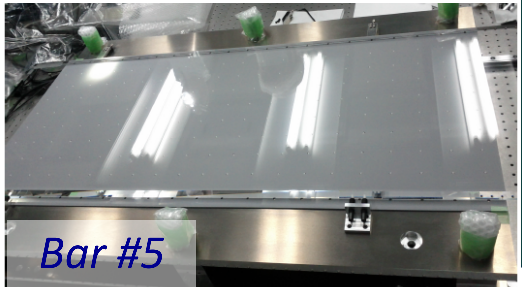
Synthetic silica (Corning 7980 class 0, grade F or better)	
Homogeneity	< 5 ppm
Radiation hardness	> 10k gray (γ), 10^{12} n/cm^2 (n)
Straia	< 5 straia/thickness direction
Bifringence	≤ 1 nm/cm

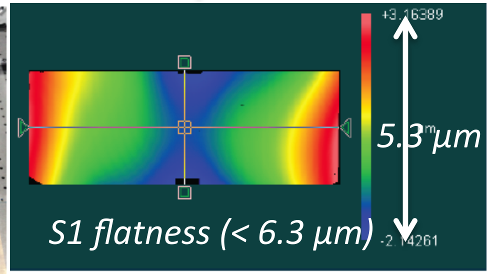
Bar dimensional tolerances	
Flatness	≤ 6.3 μm (10 waves) for S1-S4
Roughness (RMS)	≤ 0.5 nm for S1-S4
Parallelism	≤ 4 arcsec (24 μm) for S1 // S2
Perpendicularity	≤ 20 arcsec (2 μm) for S1 ⊥ S3, S4

Quartz optics (2)

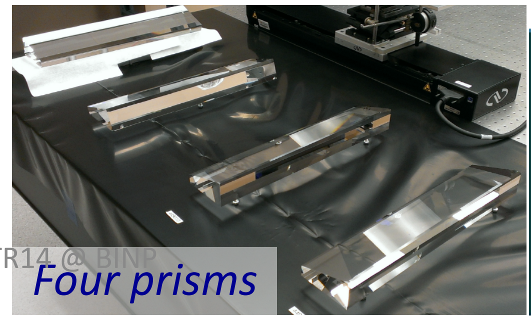
- *Procurement*
  - *Optical components for the first 4 modules have been in process.*
    - *Multi-vendor production to assure the delivery rate.*
  - *2 bars and 4 prisms have been delivered so far.*
    - *Bar #5 was delivered in Oct. 2013, and has been inspected.*
    - *The other ones have been delivered recently and are under inspection.*
  - *Component production for the rest of the modules will start in May 2014.*
    - *After a review for the US funding to be held in Mar. 2014.*

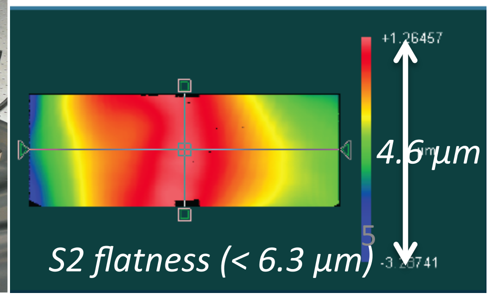






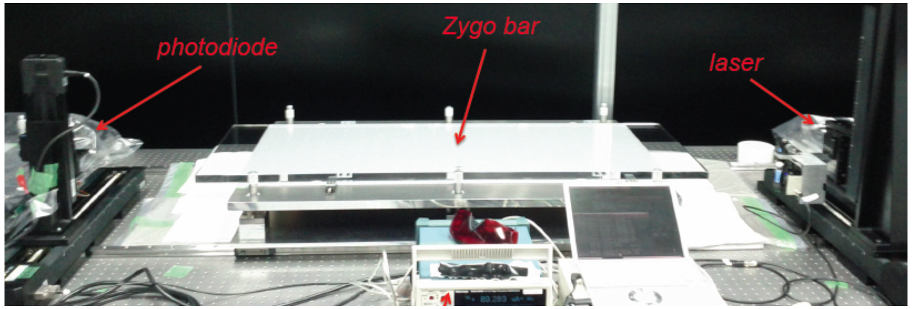
(S1 Surface Flatness)

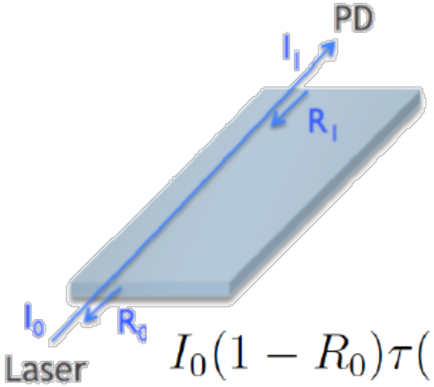


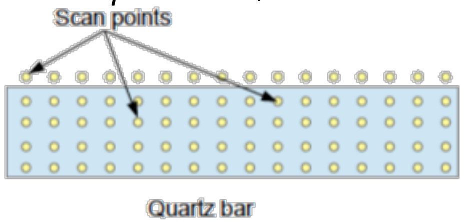


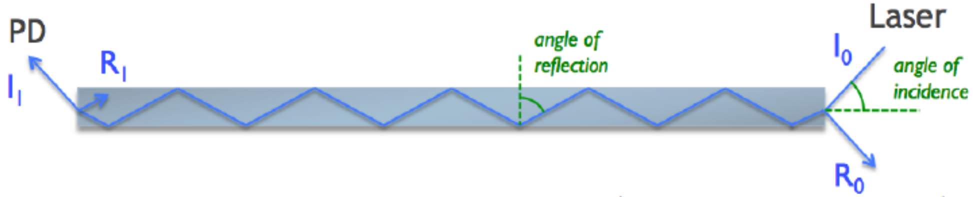
Quartz optics (3)

- Bar inspection
  - Measured the bulk transmittance and surface reflectivity.
  - Bar #5 meets the requirements.









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

I_0, I_1: Measured with PD.

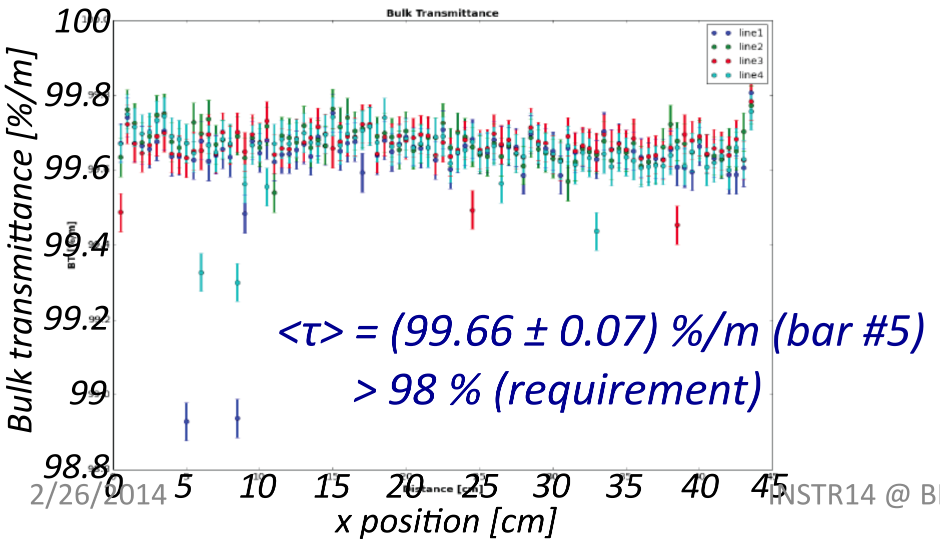
R_0, R_1: Calculated via Fresnel eqs.

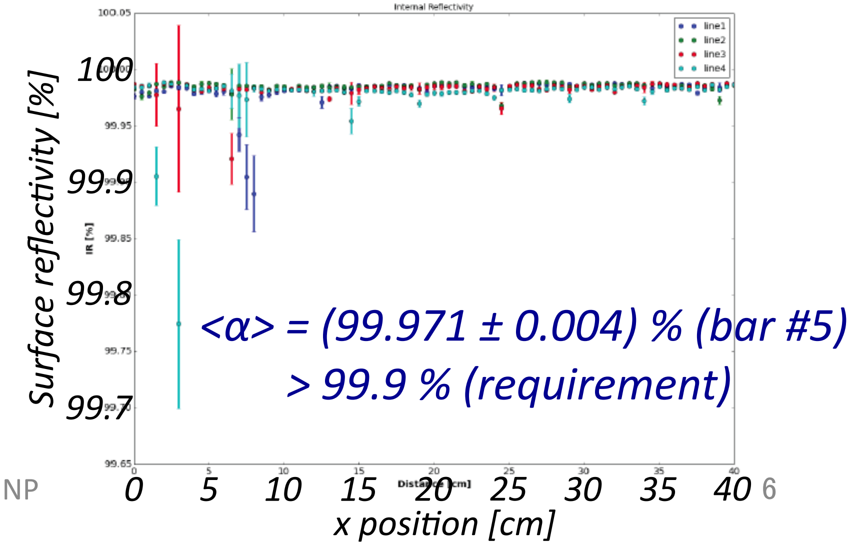
$$(I_1 - R_1) = (I_0 - R_0) \cdot \alpha^N \cdot \exp\left(-\frac{L}{\Lambda} \cdot \sqrt{1 + (Nh/L)^2}\right)$$

N: Number of reflections.

Λ: Attenuation length (> 1000 m @ λ = 530 nm).

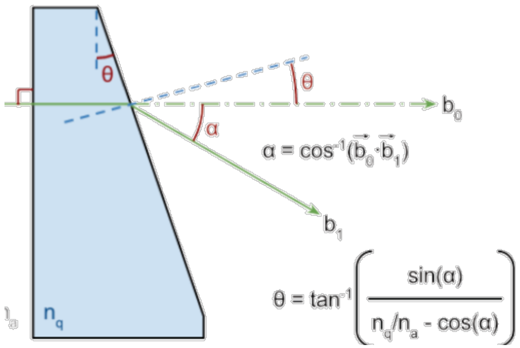
L: Bar length (1250 mm), h: Bar height (20 mm).

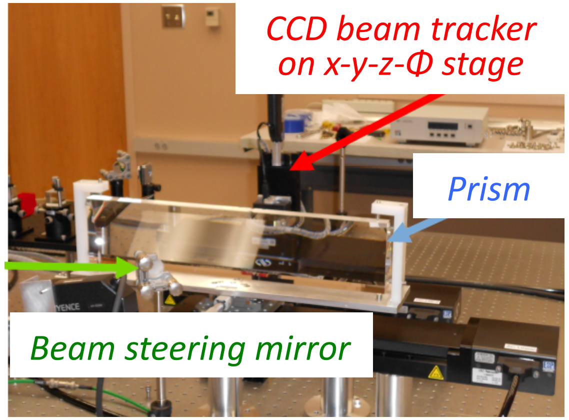


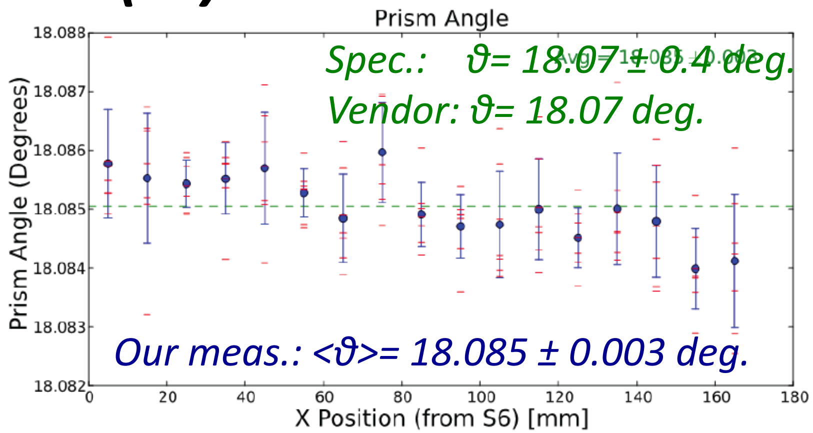


Quartz optics (4)

- *Prism inspection*
  - *Measured the prism angle.*



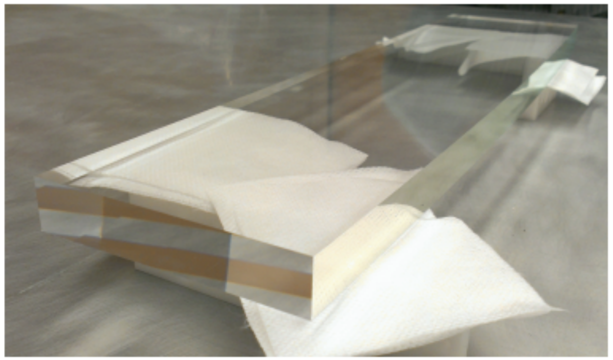


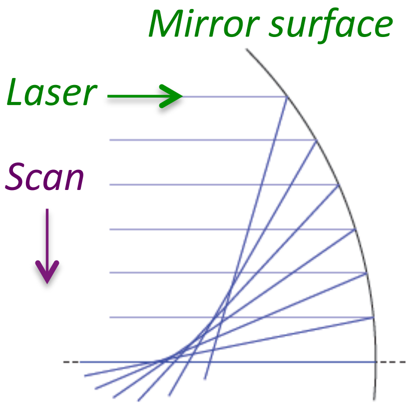


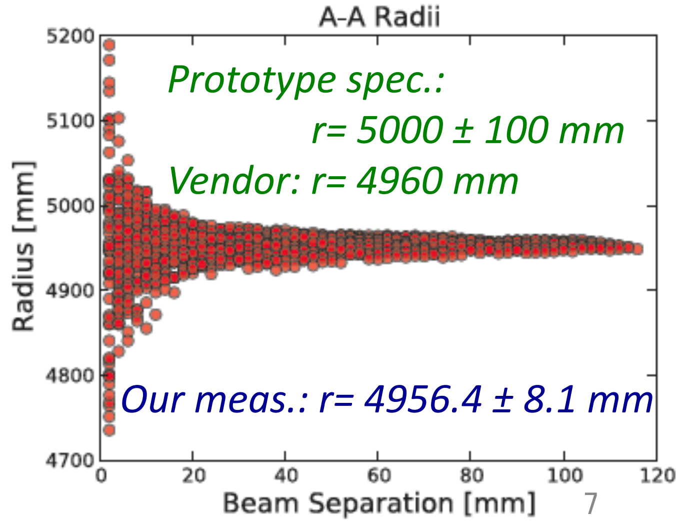
A delivered prism meets the requirement.

- *Mirror focal length*
  - *Established the focal length measurement.*

A prototype mirror

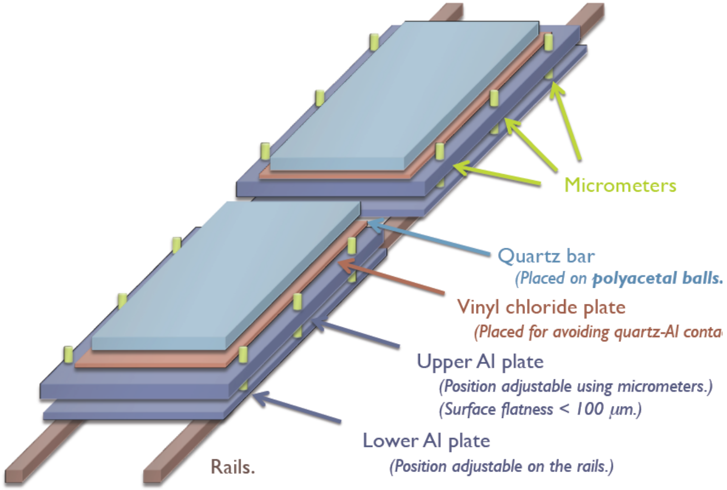




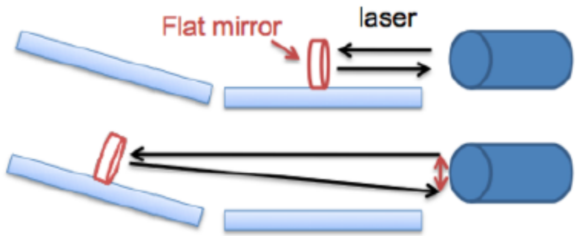


Quartz optics (5)

- *Gluing of the components*

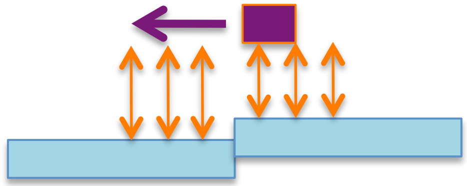


Autocollimator alignment (angle < ±0.2 mrad.)

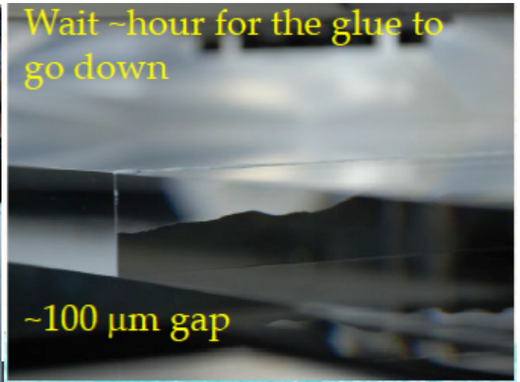


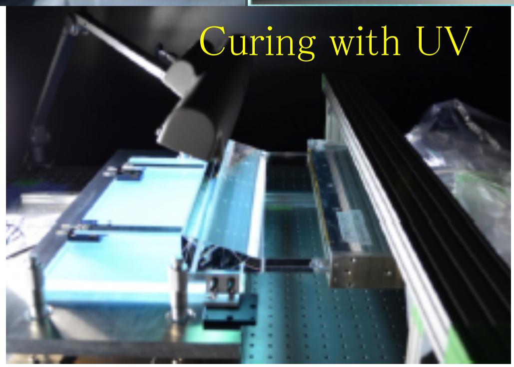
Accuracy: ±0.01 mrad.

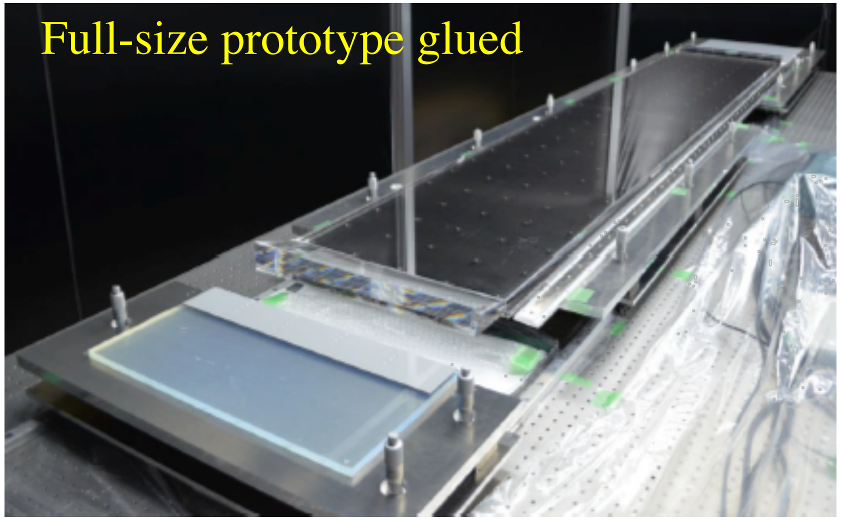
Laser sensor alignment (displacement < ±0.1 mm)



Accuracy: ±5 μm



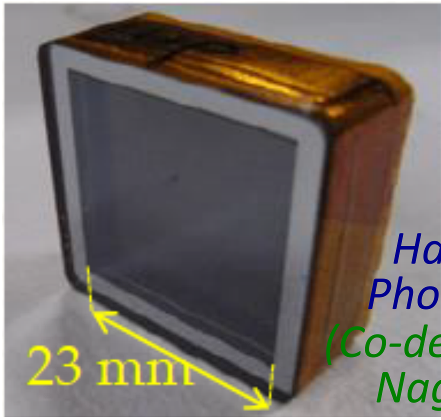




Being prepared for coming module assembly.

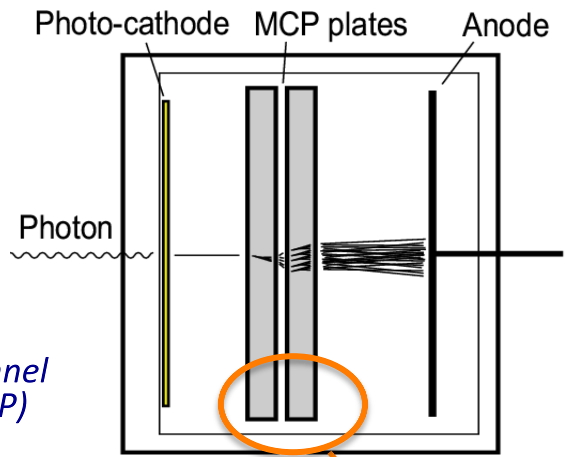
Photodetectors (1)

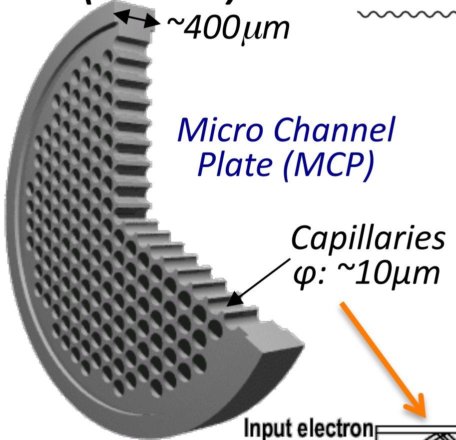
- *Micro channel plate (MCP) PMT*
  - *Square-shape to minimize the dead area.*
  - *High-gain for single photon detection.*
    - ➢ *2×10^6 at nominal HV.*
  - *Fast time response.*
    - ➢ *Transit Time Spread (TTS) < 50 ps.*
  - *Good quantum efficiency (QE).*
    - ➢ *QE ≥ 24% (ave. 28%) @ λ=380 nm.*
  - *Dark noise rate < 100 kHz.*
  - *Operative under a magnetic field (1.5 T).*

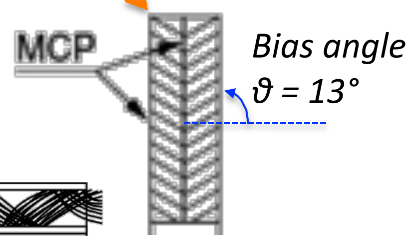


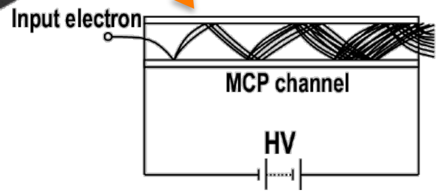
Hamamatsu Photonics SL10
(Co-developed with Nagoya Univ.)

SL-10 Specification	
Photo-cathode	*NaKSbCs*
Anode channels	*4 × 4*
Entrance window	*synthetic silica*
Sensitive region	*69%*
Collection eff.	*50-55%*
Nominal HV	*~ 3.4 kV*



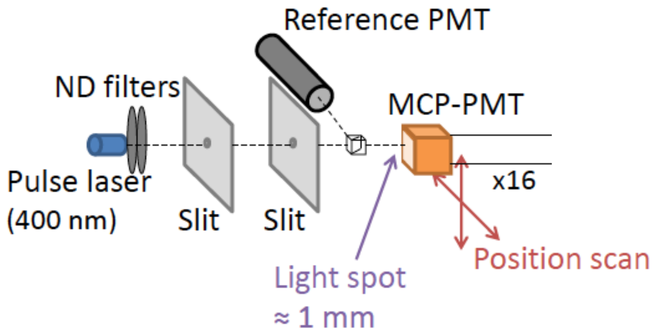


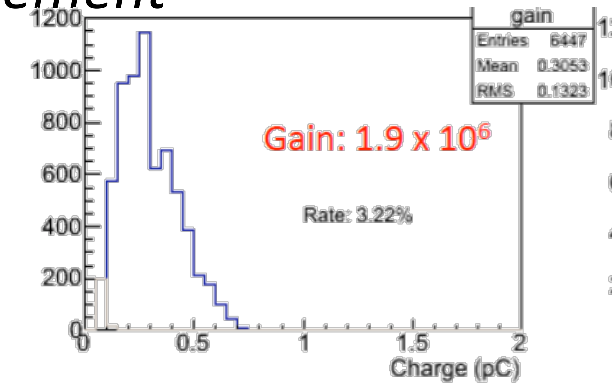


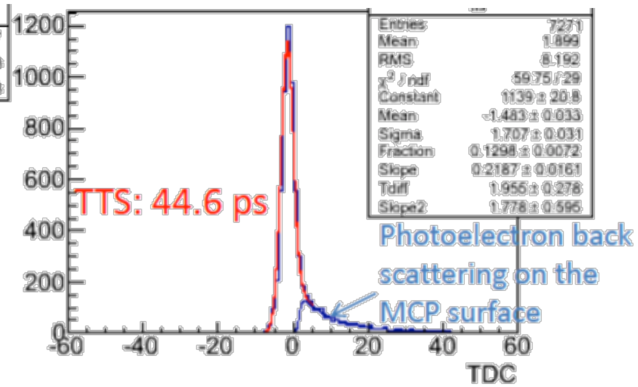


Photodetectors (2)

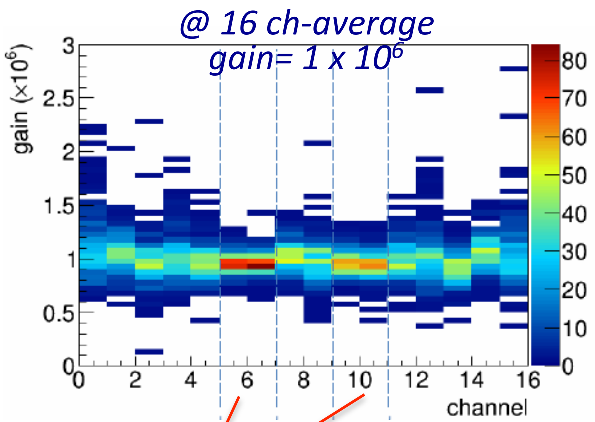
- *Gain and Time Transit Spread (TTS)*
  - *Single photon measurement*

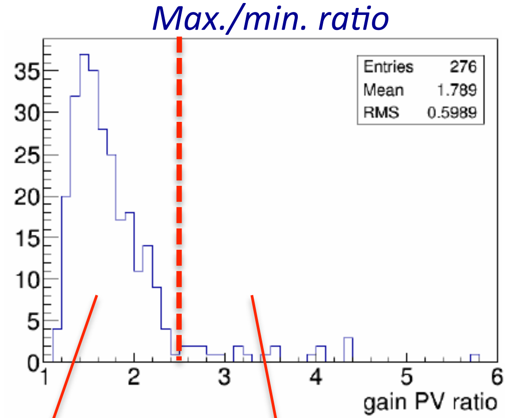




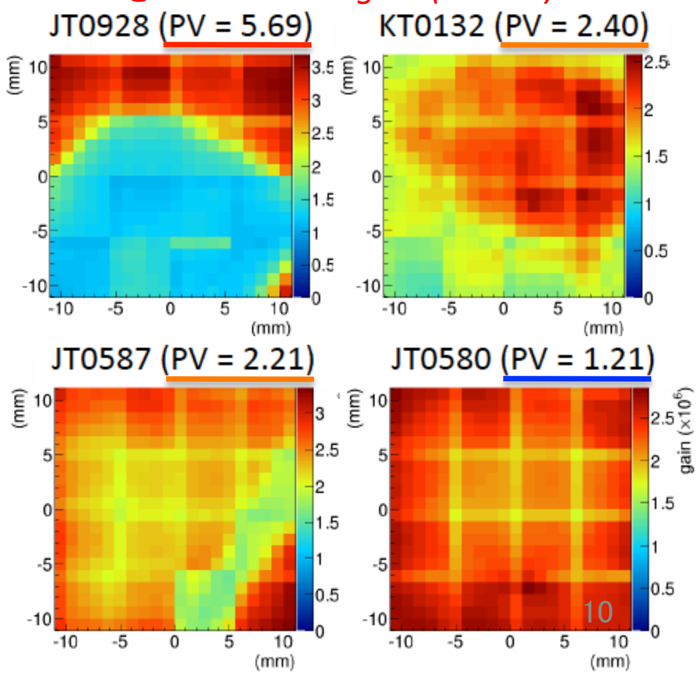


  - *Gain variation over the 16 anode channels*





Fine 2D scan of gain (1.1 mm steps)
@ the nominal gain (2×10^6)



Central 4 channels seem to have smaller variations.

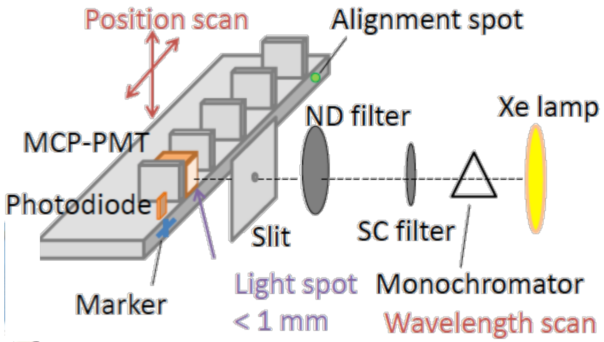
Handled by the front-end electronics.

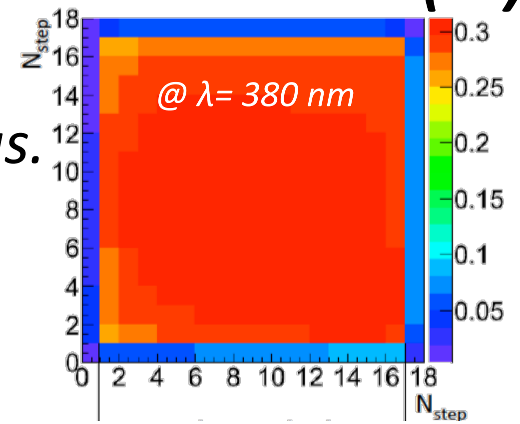
Under negotiation with HPK for replacement

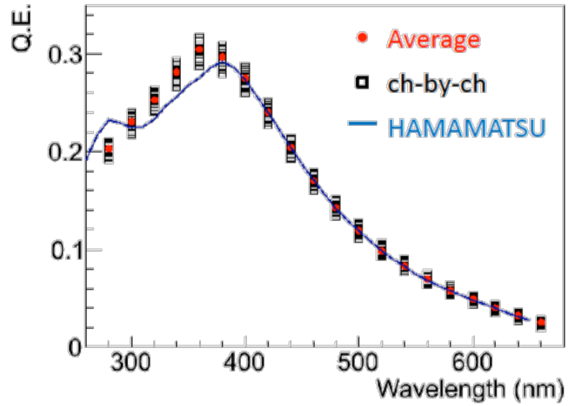
Photodetectors (3)

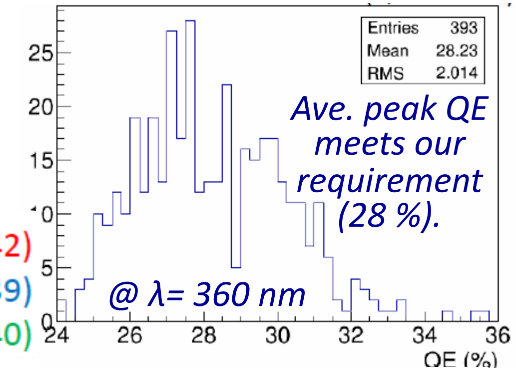
- *Quantum efficiency (QE)*
  - *Photocathode current meas.*

$$QE_{MCP} = I_{MCP} / I_{PD} \times QE_{PD}$$

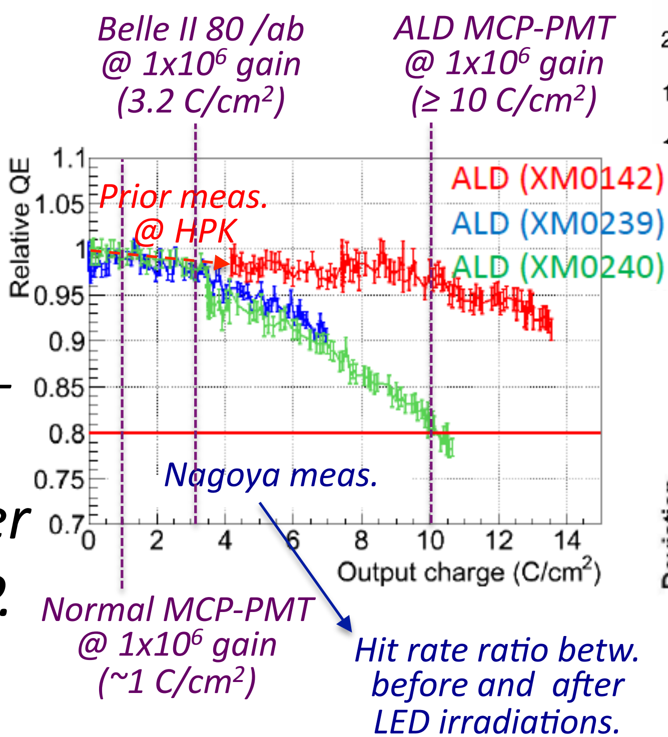


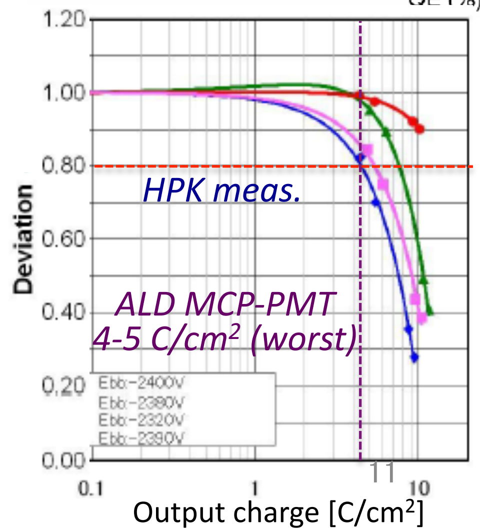






- *Photocathode lifetime*
  - *Deterioration due to the out-gases from MCPs.*
    - *Serious issue under the high-bkg environment of Belle II.*
  - *Improved by Atomic Layer Deposition (ALD) on MCP.*
    - *Still trying to eliminate the variation across the PMTs.*





Photodetectors (4)

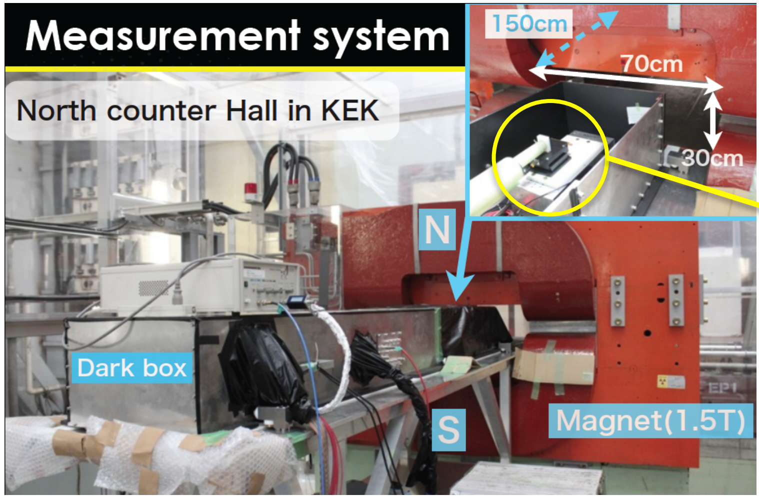
- *Mass production status*
  - *550 PMTs in total to produce.*
    - *~20 PMTs/months are being delivered.*
  - *Inspections are catching up the delivery rate.*
    - *16 normal MCP-PMTs failed so far; to be replaced with the ALD-coated ones.*
    - *~50% (or more) will be the ALD-coated ones.*
    - *Set-up for a 1.5 T field is being upgraded to measure the photon detection efficiency.*

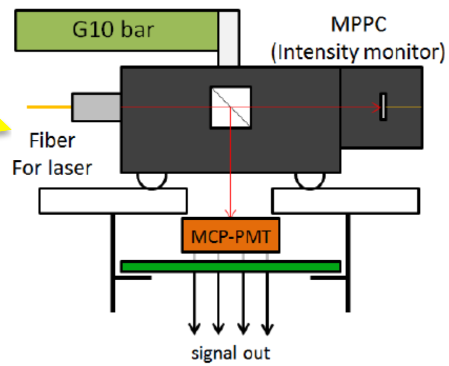
As of 2/02/2014

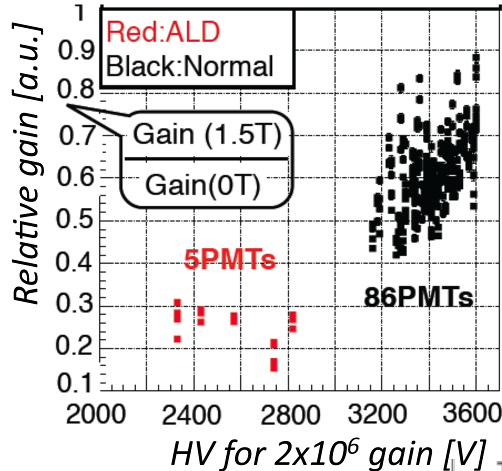
Inspected item	*Normal*	*ALD*
Delivered	*293*	*179*
Visual	*168*	*179*
QE	*285*	*120*
HV test	*265*	*122*
Gain/TTS @ 0 T	*237*	*37*
Gain/TTS @ 1.5 T	*87*	*5*
To be used	*≤277*	*≥273*

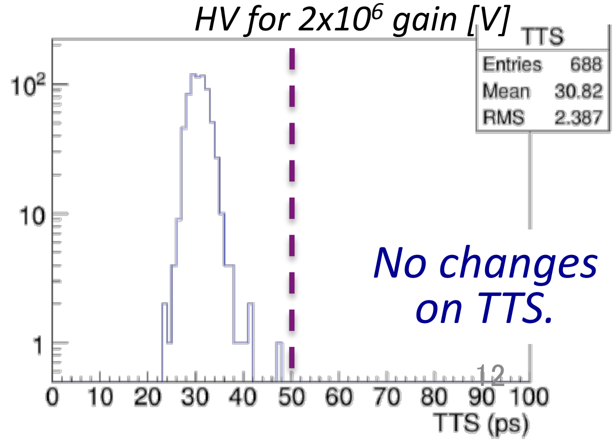
- *Gain and TTS at 1.5T*

Gain drops to 15-90%.





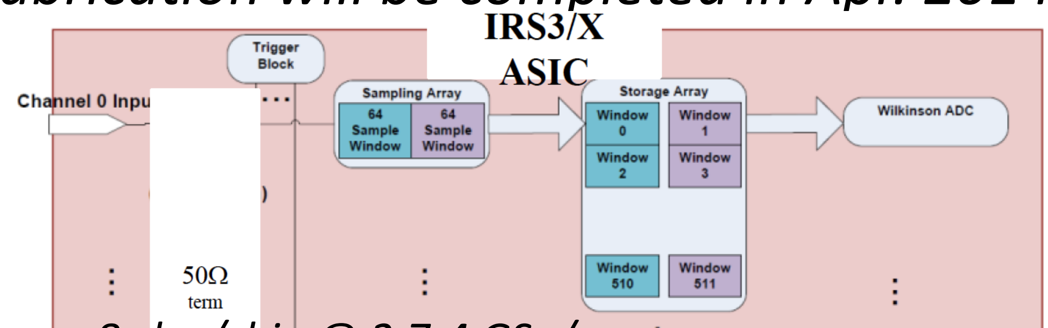


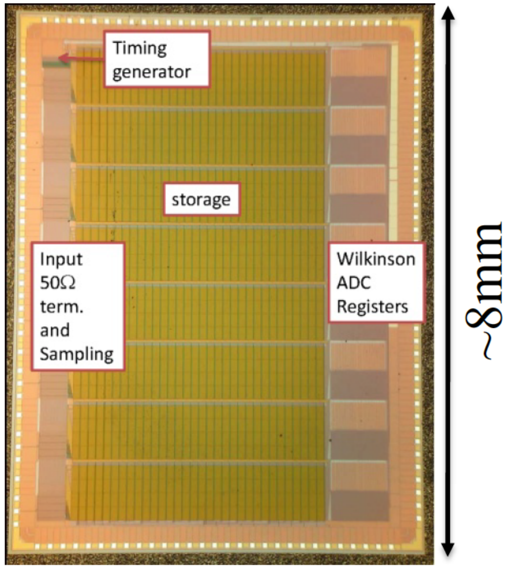


No changes on TTS.

Front-end electronics (1)

- High-speed waveform sampling ASICs ("IRSX")
  - Fabrication will be completed in Apr. 2014.

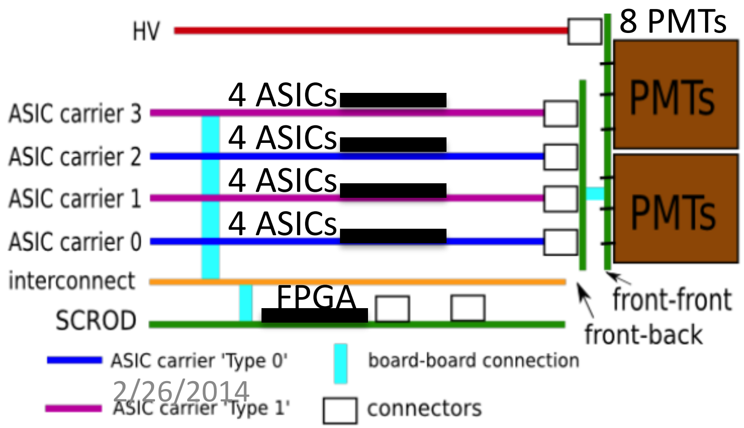


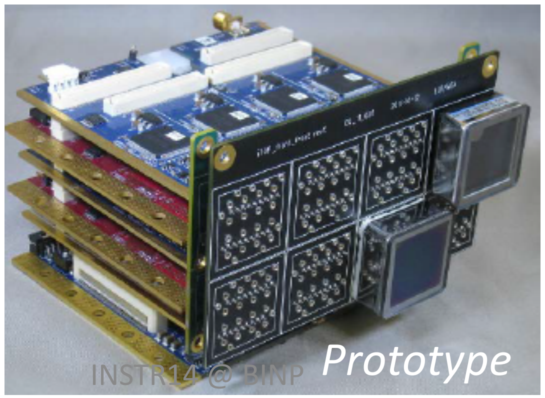


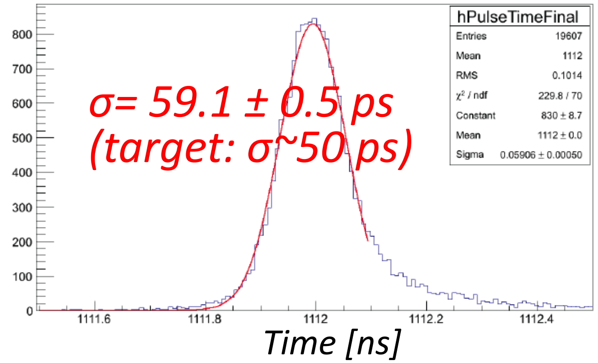
Die Photograph

- 8 chs./chip @ 2.7-4 GSa/s.
- Samples stored, 12-bit digitized in groups of 64.
- 32k samples/ch. (8 μs @ 4 GSa/s).
- Developed by Univ. of Hawaii.

- Front-end module
  - Integrated in a board stack.



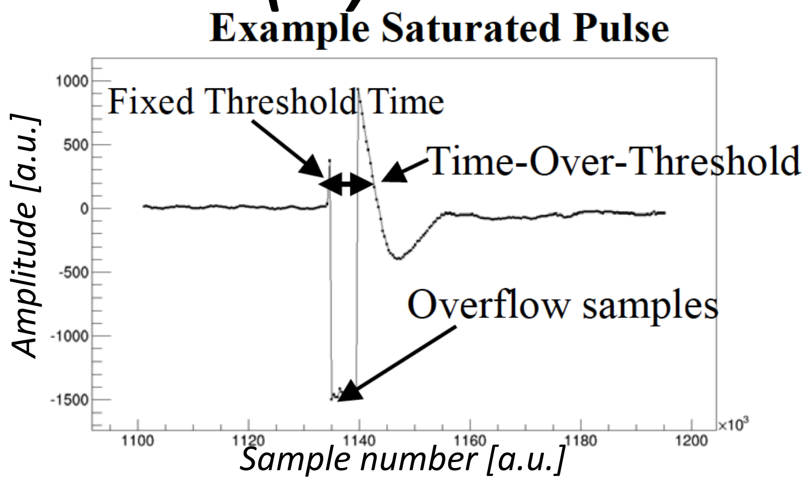


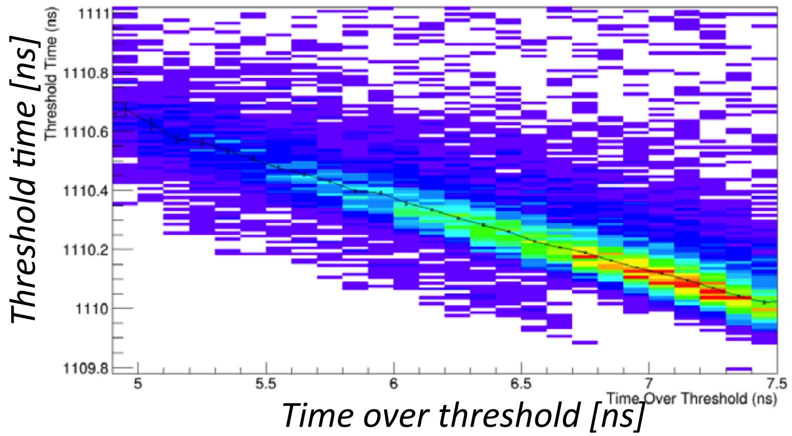


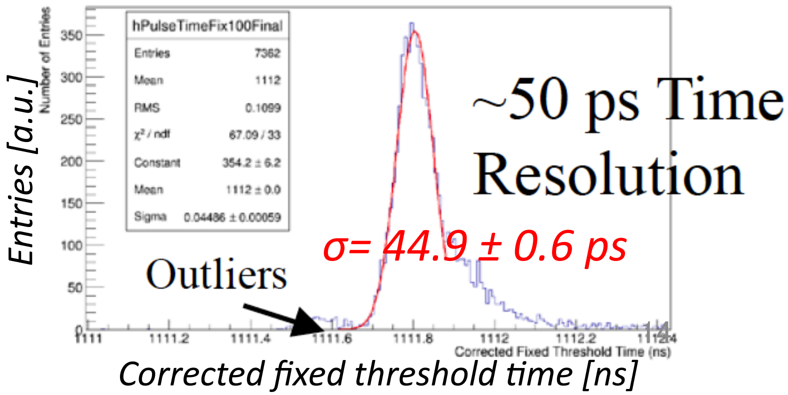
Time resolution of pulsed laser irradiation at a test bench.

Front-end electronics (2)

- *Handling of the large gain variation over the PMT anodes*
  - *Design for smallest pulses and handle overflow.*
    - ➢ *Use time-over-threshold method for saturated pulses.*
    - ➢ *Fixed threshold time is highly correlated with pulse width.*
  - *Obtained ~50 ps time resolution for saturated pulses.*
    - ➢ *Slightly better than the total time resolution (~60 ps) as no small pulses.*
    - ➢ *Need to understand outliers in time distribution.*

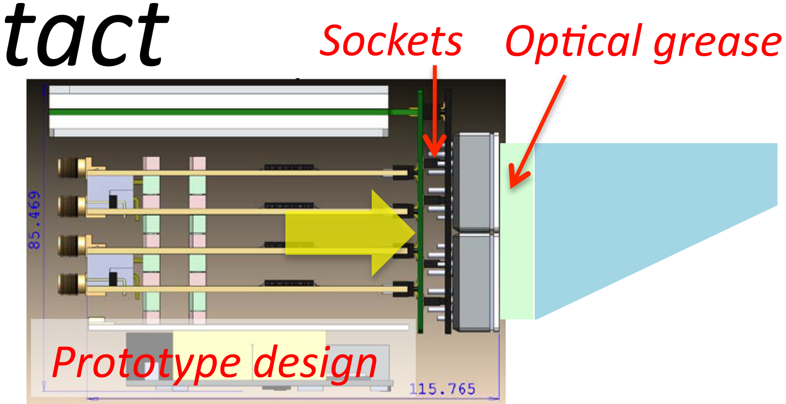


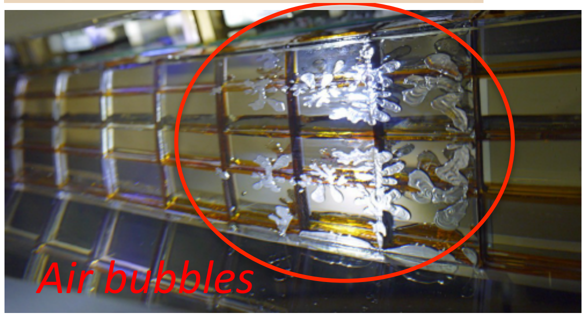


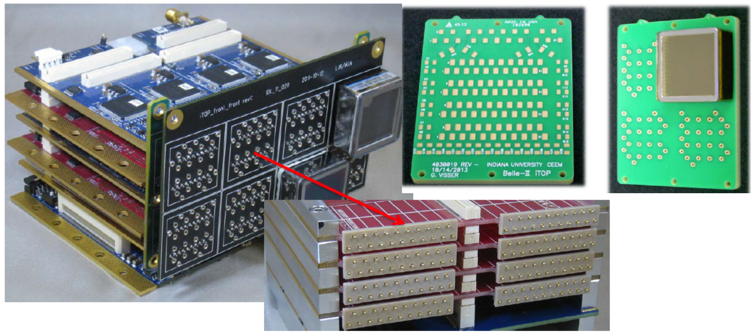


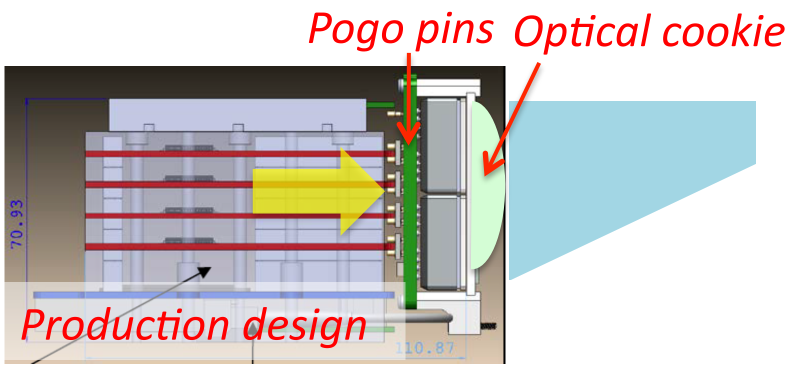
Optical contact

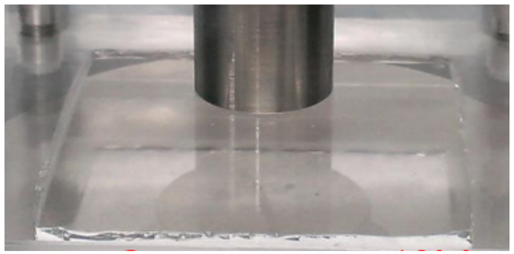
- *Pogo pins*
  - *Separate the mechanical function from the front-end module.*
- *Optical cookie*
  - *Utilize the elasticity of Si rubber.*
    - ➢ *"TSE3032" (refractive index= 1.406, elongation= 210%).*
  - *Semi-cylindrical shape to easily eliminate air.*
    - ➢ *Peak-to-valley: 0.05 mm,*
    - ➢ *thickness: 2-3 mm.*









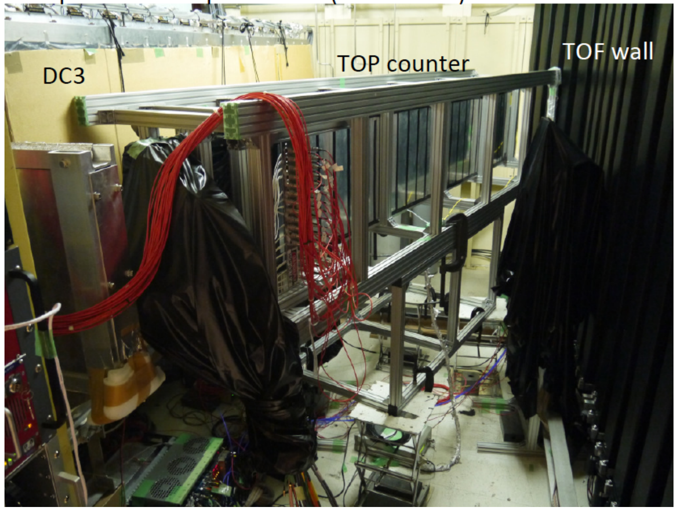


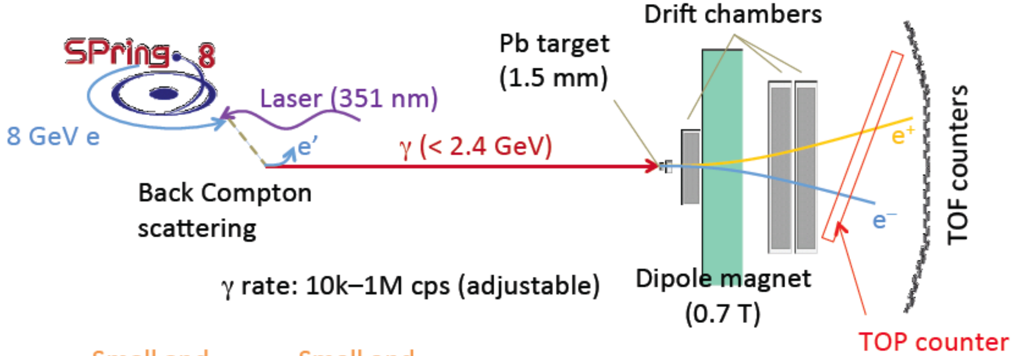
A 3 mm-thick cookie can stick to a glass plate with 40 N (~1 kgf/PMT).

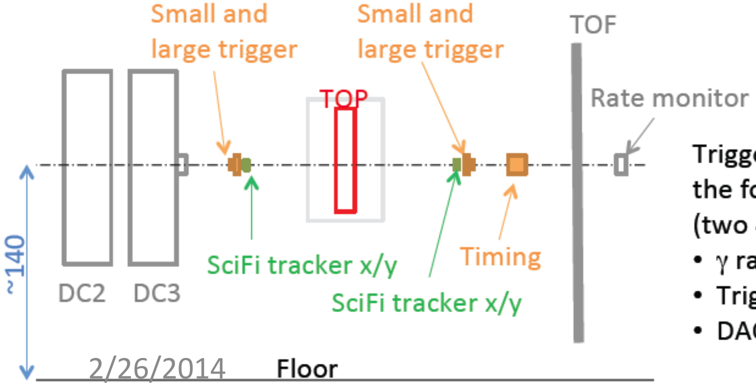
Beam test (1)

- *Beam test at the LEPS beam line in SPring-8.*
  - *Having nearly the final optics.*
    - *Nearly full-size optics.*
    - *Prototype prism was glued for the first time.*
  - *Having 32 PMTs for full coverage.*
  - *Using a prototype front-end electronics.*
    - *"IRS3B" (prototype ASIC).*

Setup for IRS3B Experiment 3 (cosθ = 0.43)







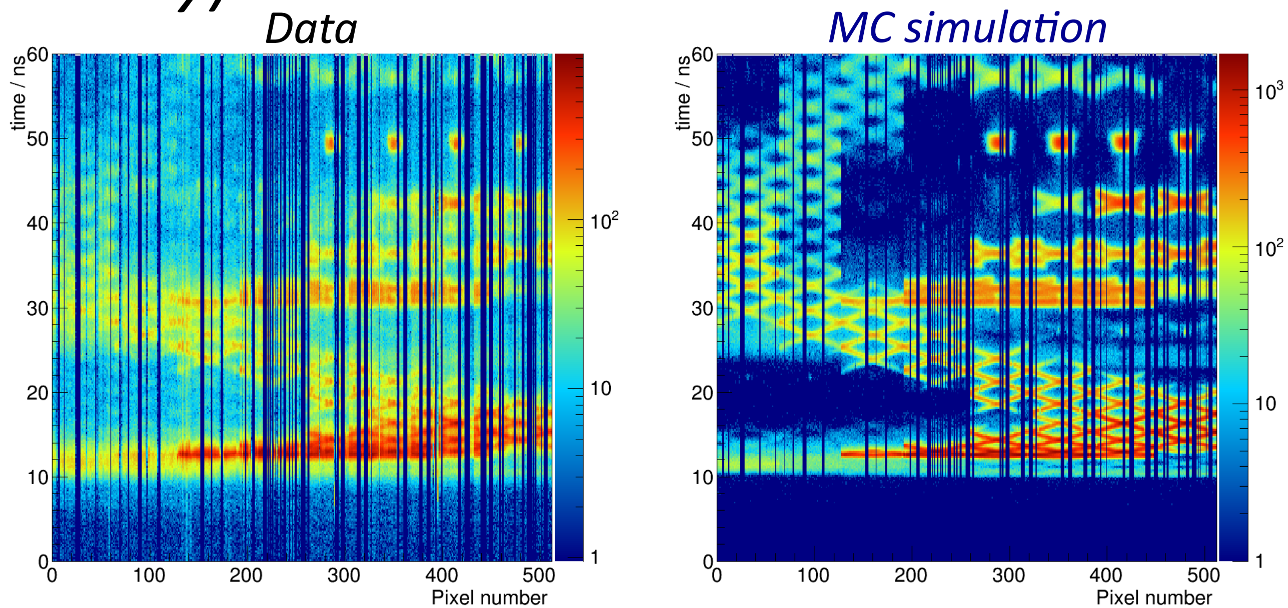
Triggered the 2 GeV/c e^+ beam with the four trigger counters (two 40 x 40 mm^2 and two 5 x 5 mm^2)
- γ rate: ~30 kHz
- Trigger rate: ~10 Hz
- DAQ rate: ~5 Hz (IRS3B)

~10 Hz (RFD)

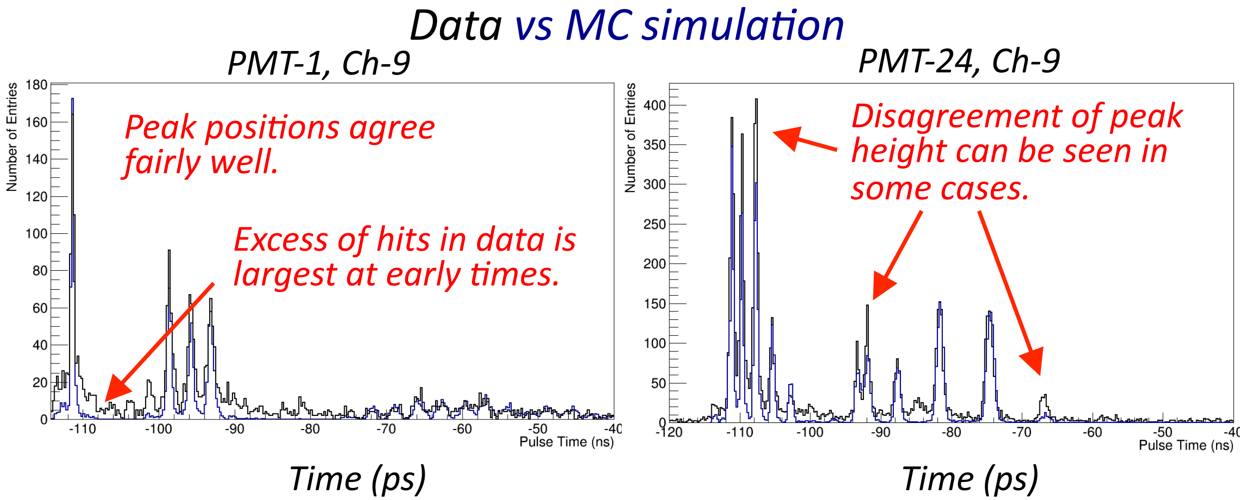
IRS3B module

Beam test (2)

- Ring images (preliminary)
  - Dead channels are simulated in MC.

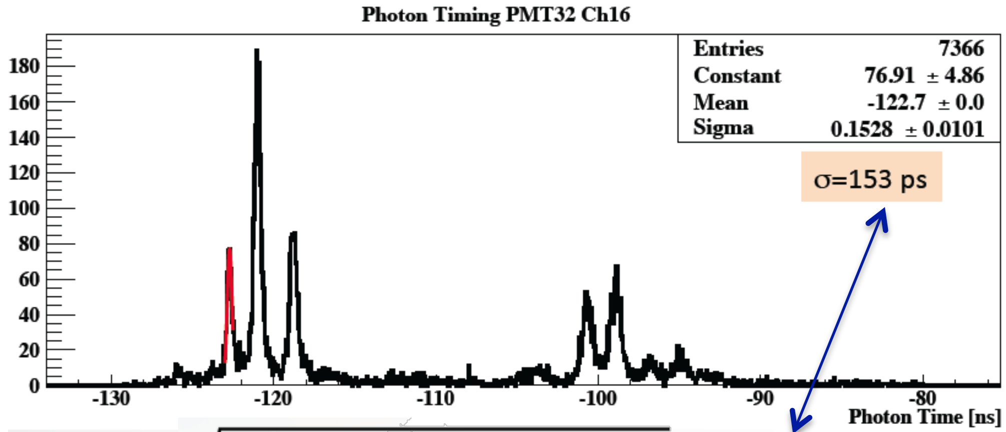


- Time projections (preliminary)
  - Discrepancy in the peak regions:
    - ➢ Alignment, geometry.
    - ➢ Incident angle dependence on QE.
  - Discrepancy in the tails and off-peak regions:
    - ➢ Event selection.



Beam test (3)

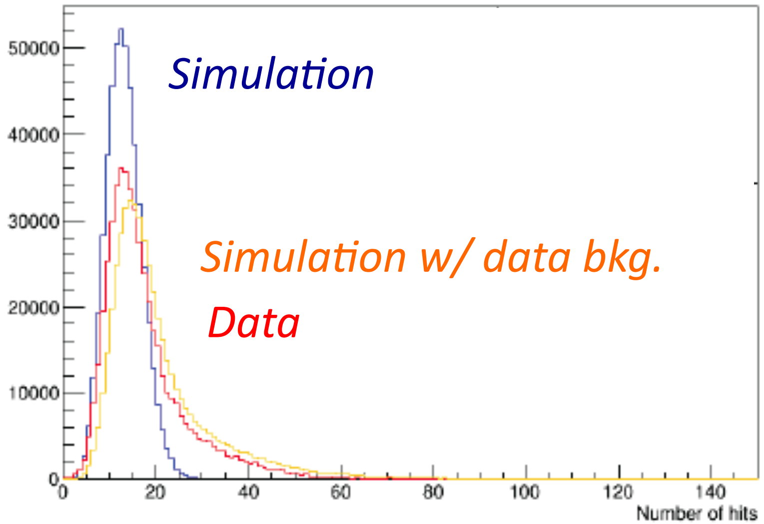
- *Time resolution (preliminary)*
  - *Further improvements can be expected.*
    - ➢ *Various calibrations,*
    - ➢ *Firmware updates,*
    - ➢ *Final hardware design.*



$$\sqrt{(120\,ps)^2 + (100\,ps)^2} = 156\,ps$$

Intrinsic term (simulation) *PMTs, IRS3, back-end modules, etc.*

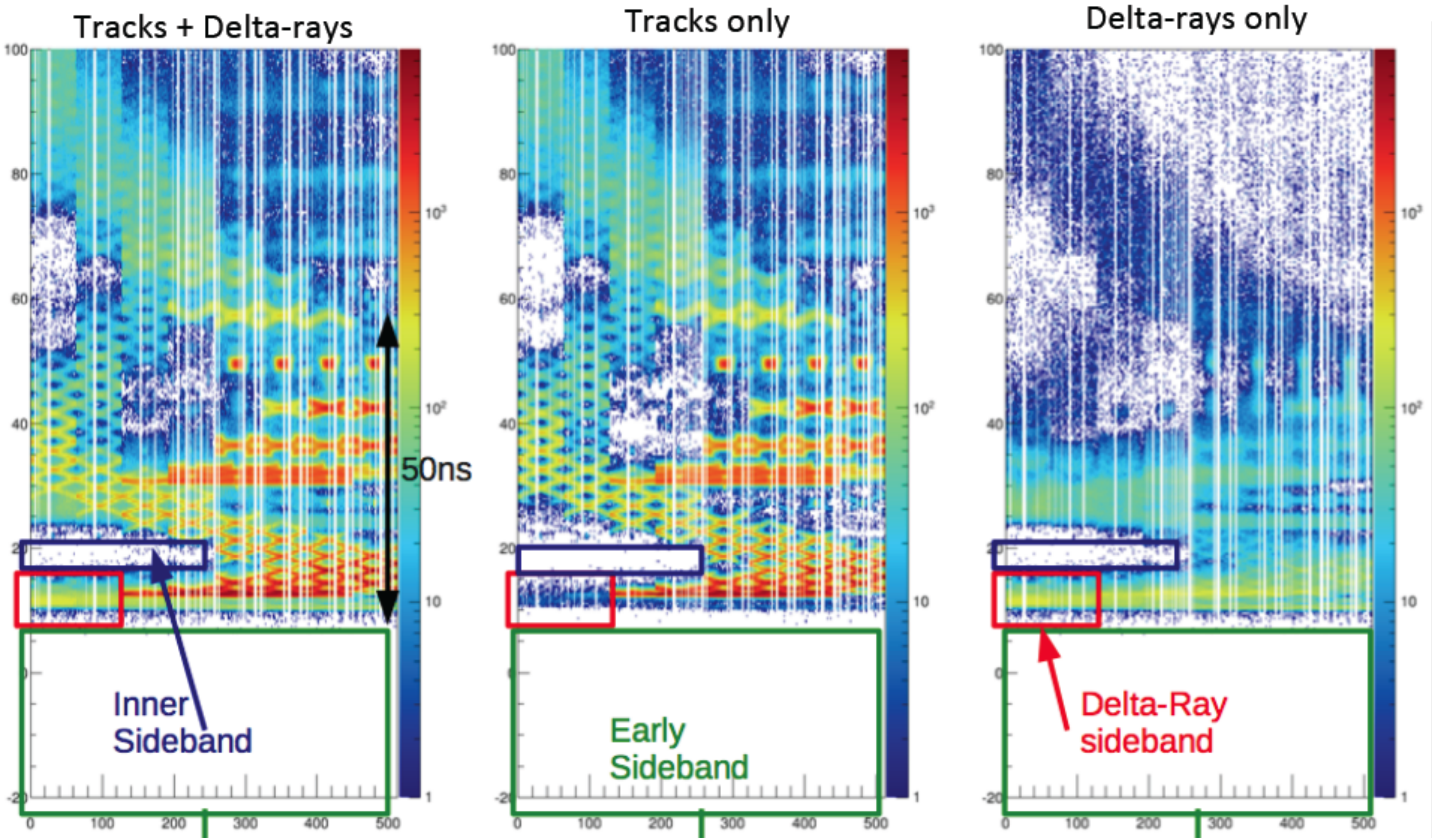
- *Number of photon hits (preliminary)*
  - *For the photon arrival time < 50 ns.*
  - *Adding the data bkg. into simulation.*
    - ➢ *Scaled based on the entries in sidebands.*
  - *Reasonable agreement can be seen.*
    - ➢ *Tail component can be reproduced in simulation.*



Summary

- *Production of the quartz optics is in progress.*
  - *Procedures for the inspection and assembly are being developed.*
  - *Various efforts are being made to recover the delay of the delivery schedule.*
- *Production of the MCP-PMTs is going well.*
  - *Inspection procedure is mostly established.*
  - *ALD-coating greatly improved the lifetimes.*
- *Beam test data is giving better understanding of the detector.*
  - *Various feed-backs have also been obtained to the front-end elec. and the associated opt-mechanical components.*
- *Detector development is being finalized.*
  - *Turning into the construction phase targeting the installation in Feb. 2015.*

Beam test (4)


Tracks + Delta-rays
Tracks only
Delta-rays only
50ns
Inner Sideband
Early Sideband
Delta-Ray sideband