The TOP Project at Belle II

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for Belle II B-PID group
2015.11.12

Belle II

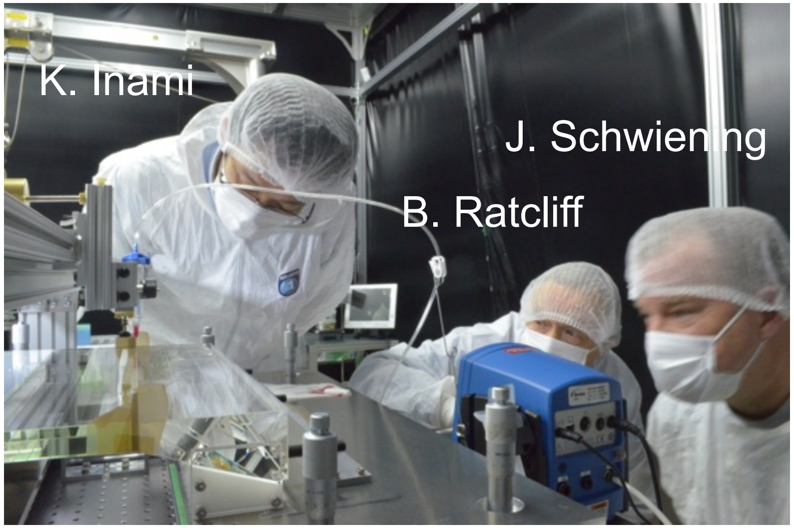
NAGOYA UNIVERSITY

Kobayashi-Maskawa Institute for the Origin of Particles and the Universe

Talk Outline

- Status of Belle II
- Overview of the Belle II TOP Counter
- Status of detector construction
  - Module production
  - Quartz optics
  - Mechanics
  - MCP-PMT
  - Readout electronics
  - Calibration system
- Summary

Detailed information available via webpages of "BPAC review" meetings.
→ belle2.kek.jp



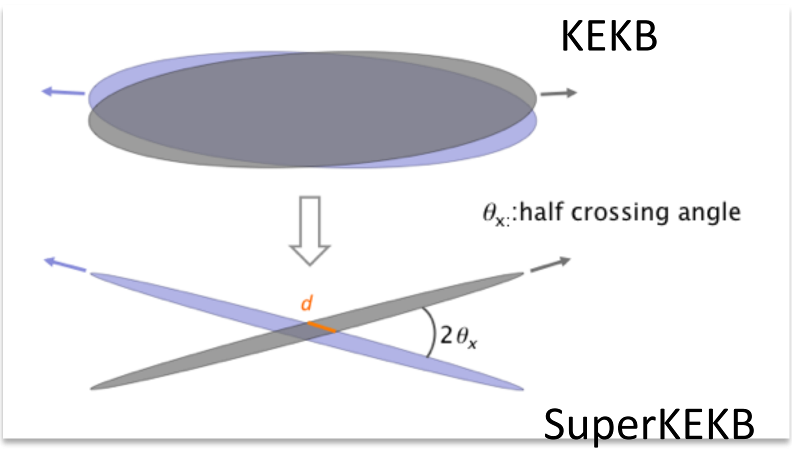
SuperKEKB/Belle II

- New intensity frontier facility
- Target luminosity ;
  - L_{peak} = 8 x $10^{35}cm^{-2}s^{-1}$
  - L_{int} > 50 ab^{-1} by early 2020's.

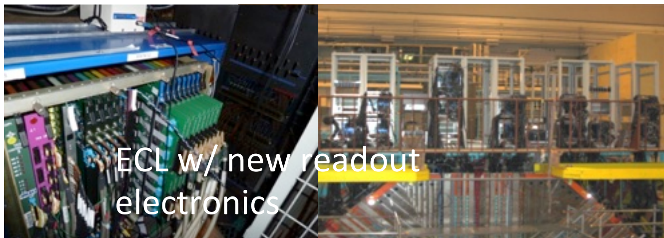
⇒ ~10^{10} BB, τ+τ- and charms per year !

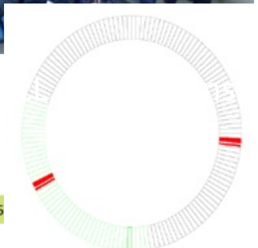
	SuperKEKB LER/HER	KEKB LER/HER
E(GeV)	4.0/7.0	3.5/8.0
ε_x (nm)	3.2/4.6	18/24
βy at IP(mm)	0.27/0.30	5.9/5.9
βx at IP(mm)	32/25	120/120
Half crossing angle(mrad)	41.5	11
I(A)	3.6/2.6	1.6/1.2
Lifetime	~10min	130min/ 200min
L($cm^{-2}s^{-1}$)	80×10^{34}	2.1×10^{34}

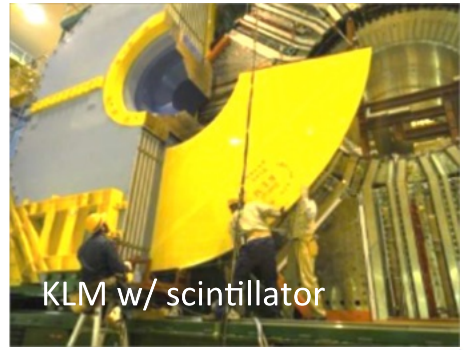
"Nano-beam" scheme
proposed by P.Raimondi

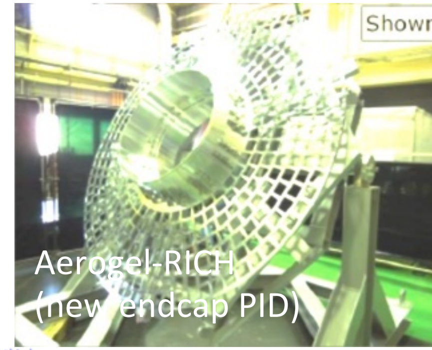


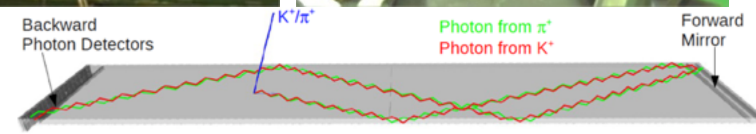
Belle II collaboration (>600 from 99 institutes)

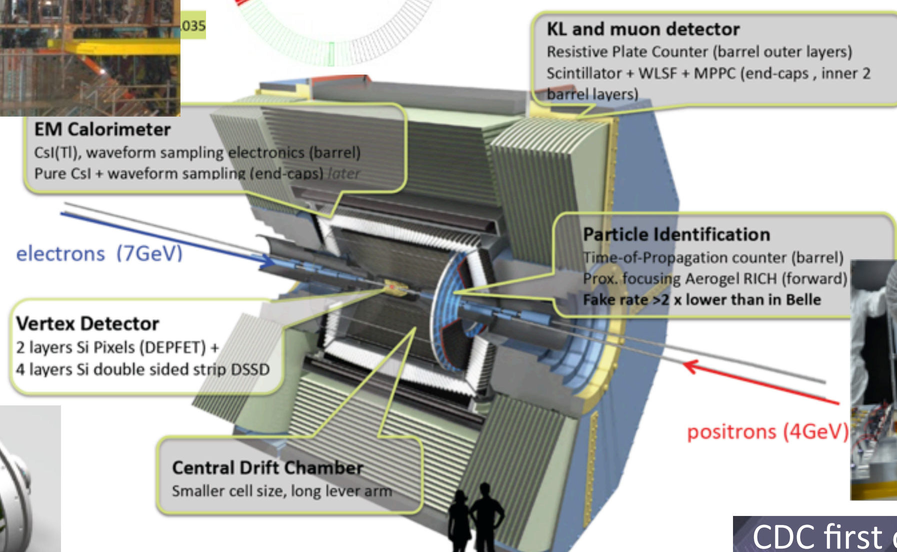


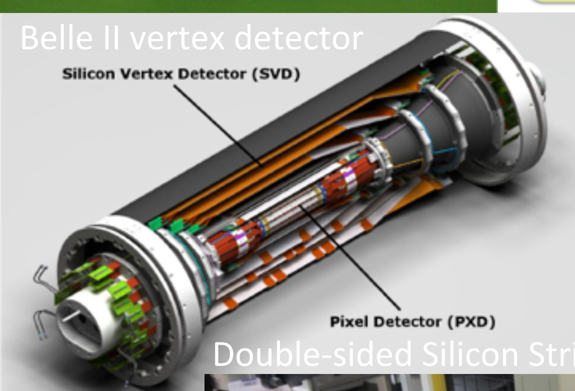


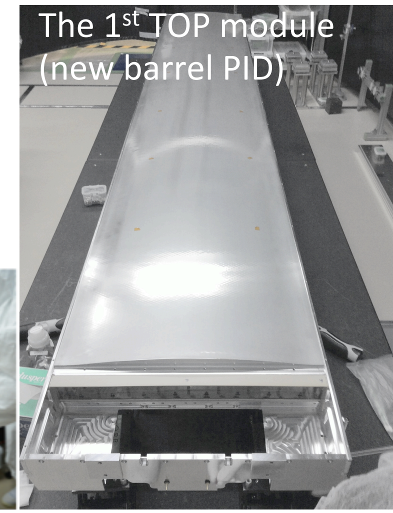


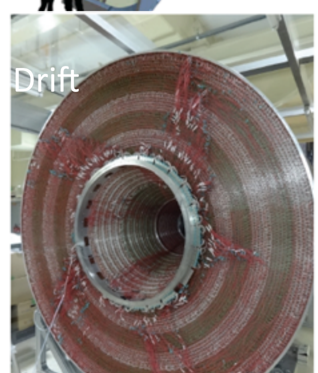


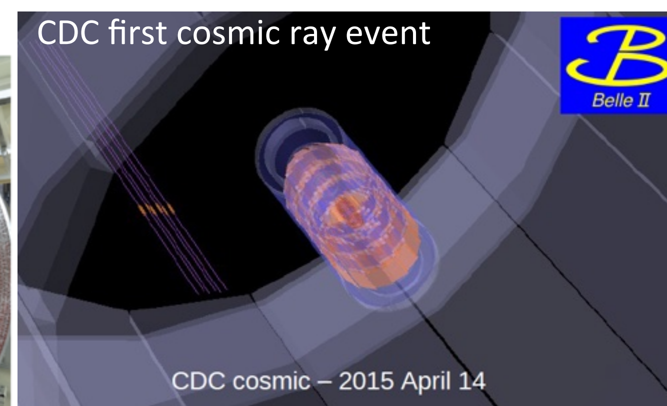




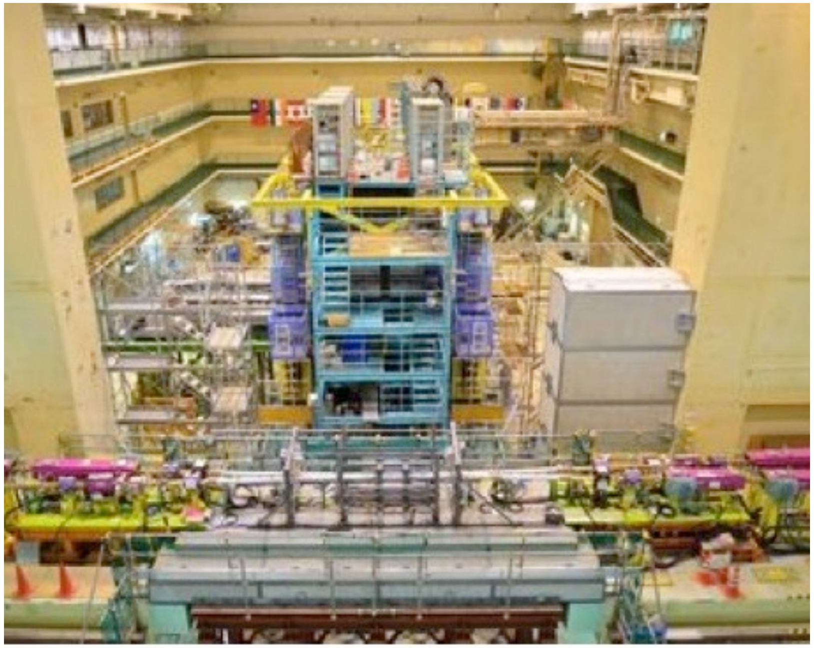


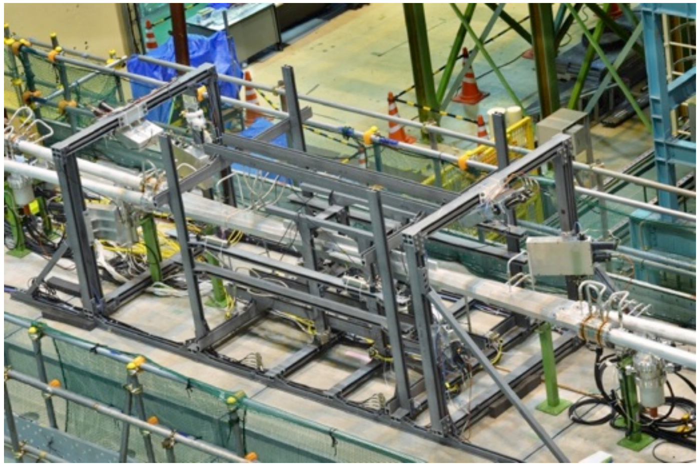






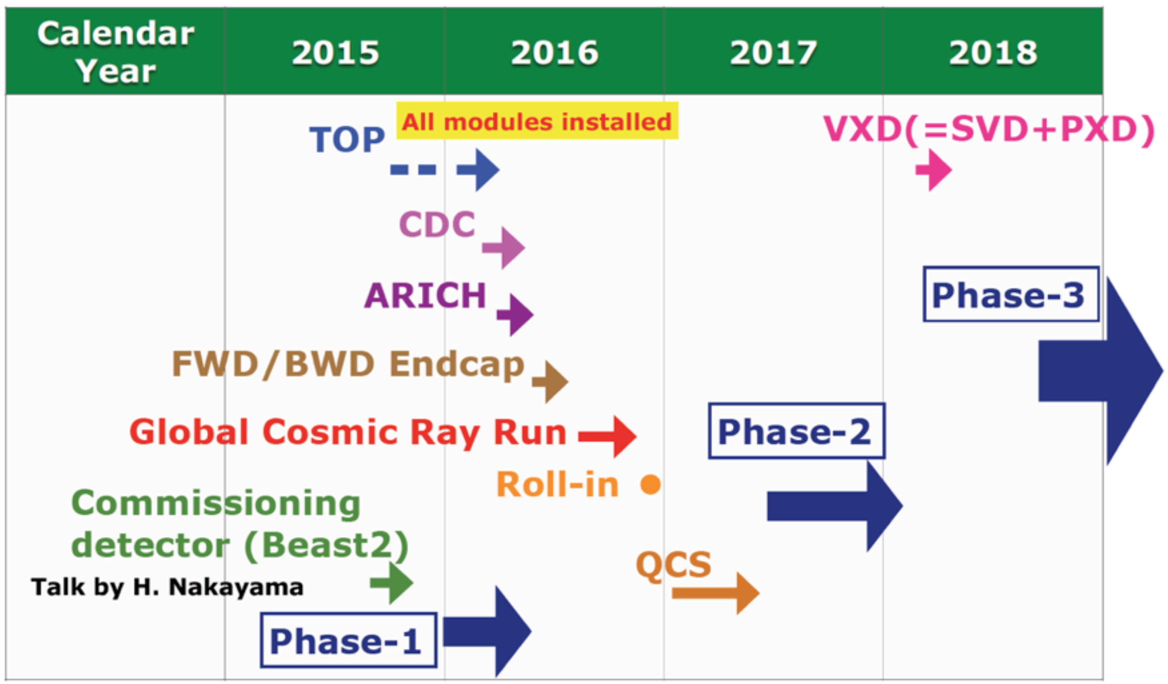
Getting Ready for Phase 1





Schedule

- 2016.1: start beam commissioning
- 2017: data taking without vertex detector
- 2018: data taking with full detector



BEAST phase 1	2016	BEAST/SuperKEKB & cosmics
BEAST phase 2	Mid 2017- Early 2018	BEAST with Partial Belle II
Full physics	Oct 2018-	Full detector

Belle II TOP counter

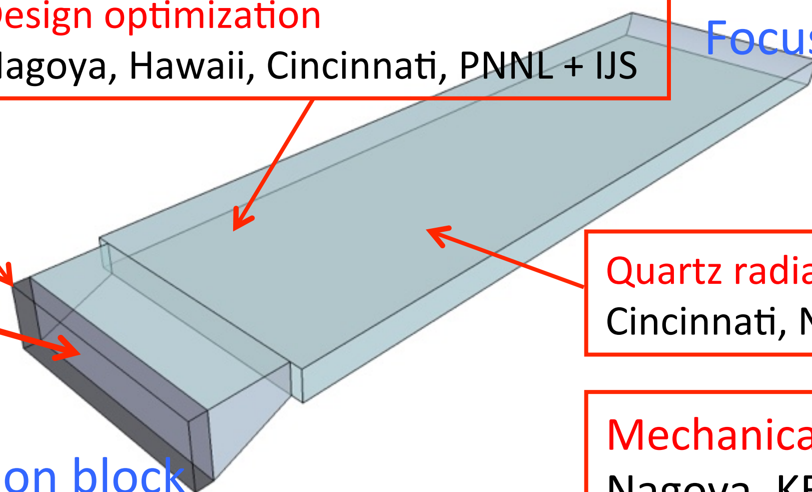
- Cherenkov ring imaging using precision timing (σ_{TTS} < 50ps/photon).
- Very compact, suitable for collider geometry.
- Focusing mirror for correcting chromatic dispersion effect.
- Imaging w/ expansion block + 2-layer MCP-PMT.

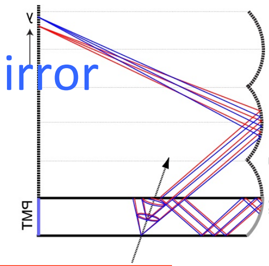
Calibration system
Italy (Padova/Torino)

Design optimization
Nagoya, Hawaii, Cincinnati, PNNL + IJS

MCP-PMT
Nagoya

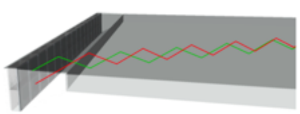
Readout Electronics
US (Hawaii, PNNL, …)





Quartz radiators
Cincinnati, Nagoya, PNNL

Mechanical Issues
Nagoya, KEK, PNNL

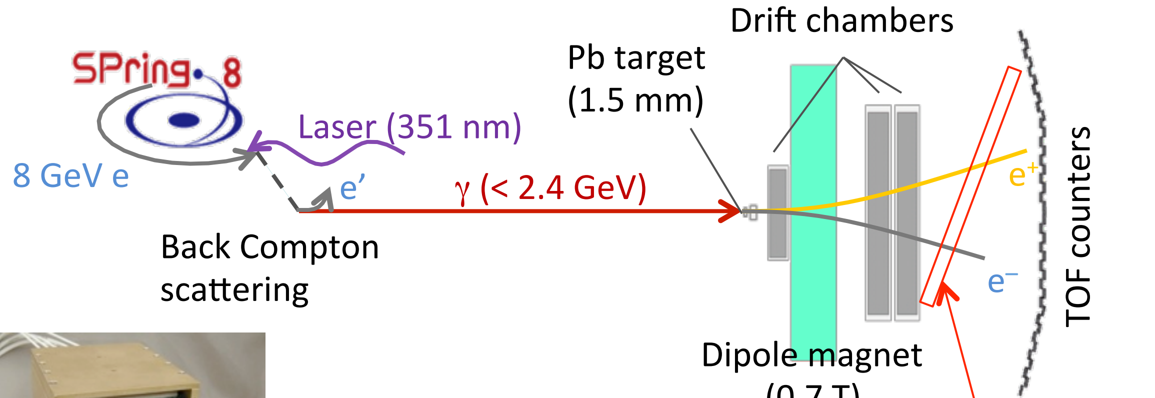


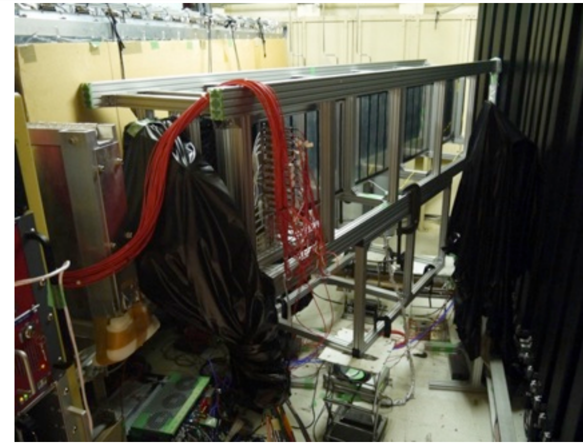
Expansion block
+ MCP-PMT array

Collaboration of Japan + US + Slovenia + Italy

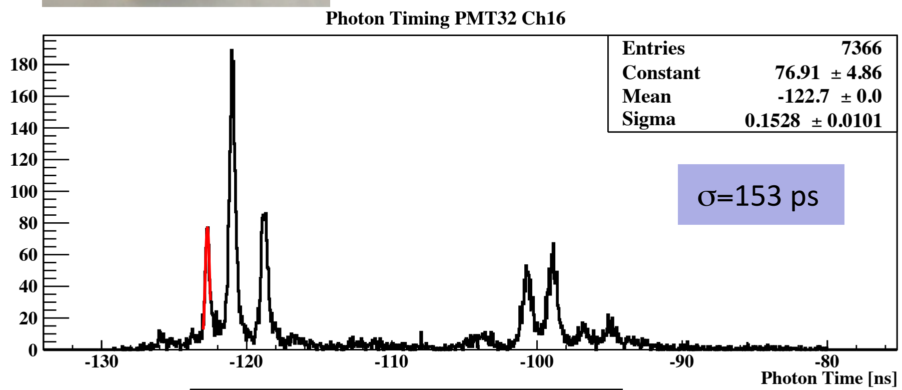
Group leader : Jim Fast (PNNL), sub-leader: T.I.

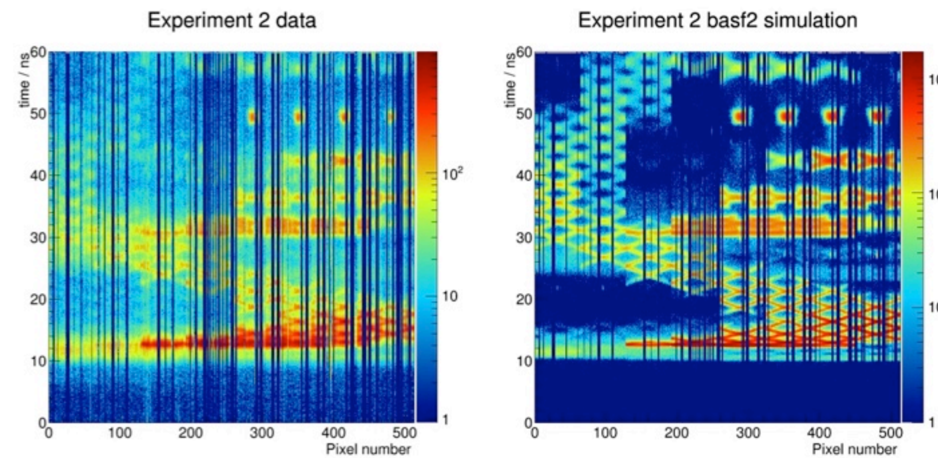
Beam Test @ Spring-8/LEPS (June 2013)





IRS3B readout





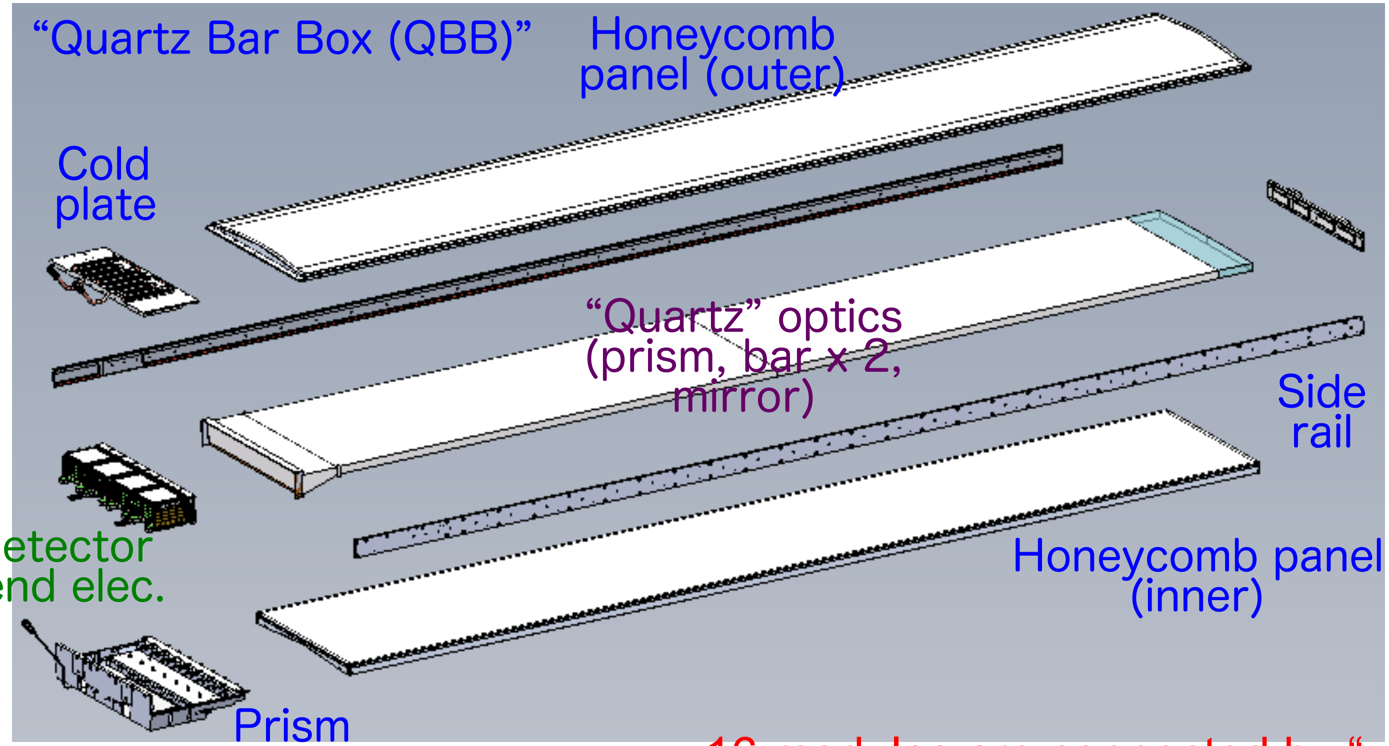
$$\sqrt{(120\,ps)^2 + (100\,ps)^2} = 156\,ps$$

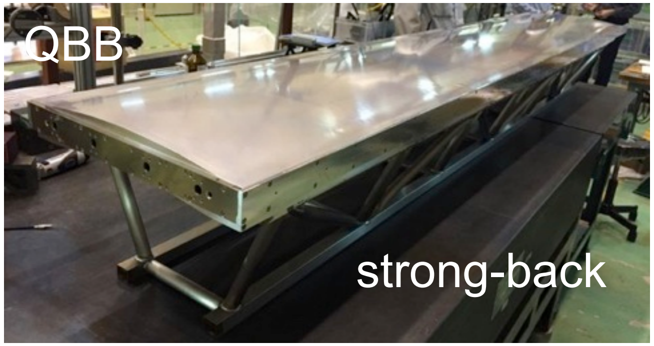
ITOP Physics — IRS3B, PMTs, CAMAC, FTSW, RF, …

Performance demonstrated with final form of optics, PMT and readout (IRS).

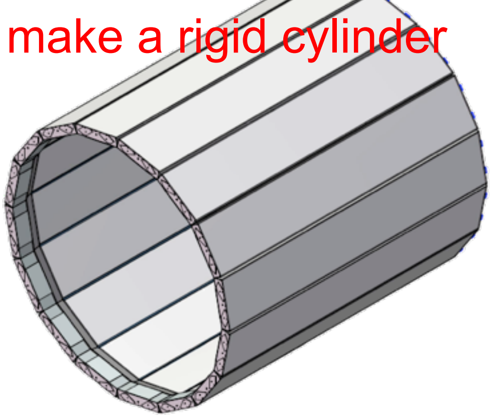
More results (also with conventional CFD readout) → talks by K. Inami @ RICH2013, K. Matsuoka @ TIPP2014

Belle II TOP Quartz Bar Box (QBB)



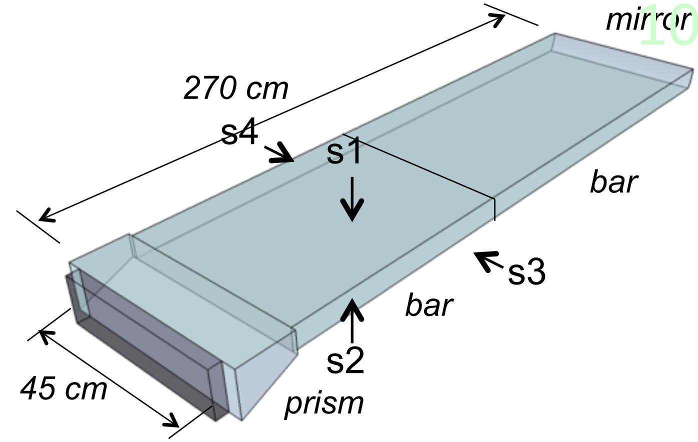


16 modules are connected by "z beam" to make a rigid cylinder



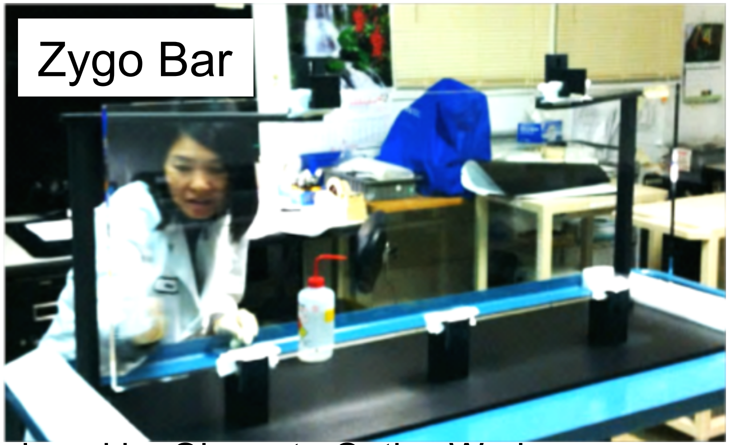
sag < 0.5 mm required

Belle II TOP Quartz Optics



Bar (photon propagation)

- L=1250 ± 0.5mm
- W = 450 ± 0.15mm
- H = 20 ± 0.1mm
- Flatness (S1,S2) ≤ 6.3μm
- Local flatness (S1, S2) ≤ 1.8μm (200mm area)
- Surface roughness ≤ 5 Å rms (S1-S4)
- S1 ⊥ S3,4 ≤ 20 arcsec, S1 // S2 ≤ 4 arcsec



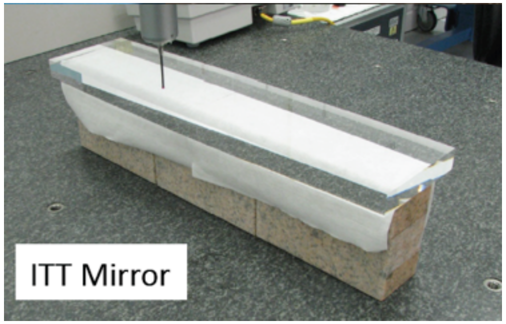
4 bars produced by Okamoto Optics Works
29 of 34 bars are at hand (completed by Feb. 2016)

Mirror (image focusing)

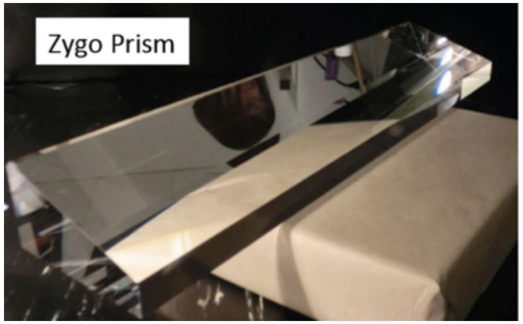
- L = 100 ± 0.15 mm
- R = 6500 ± 100 mm

Prism (image expansion)

- L = 100 +0.1/ -0.25 mm
- W = 456 ± 0.15 mm
- H = 51 ± 0.1 mm (PMT side)
- Angle (S1-S2) = 18.07 ± 0.04 deg.

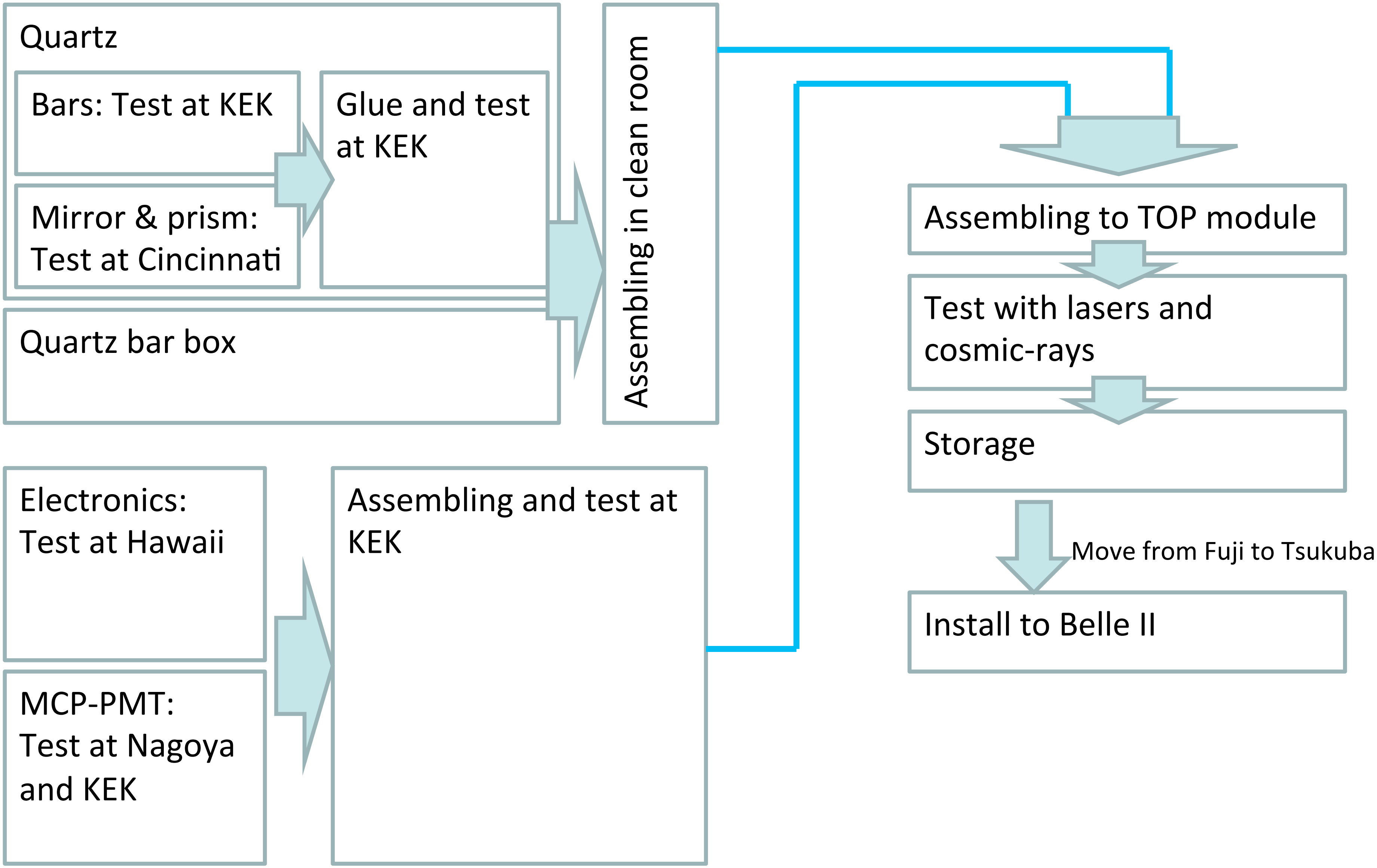


Delivery completed



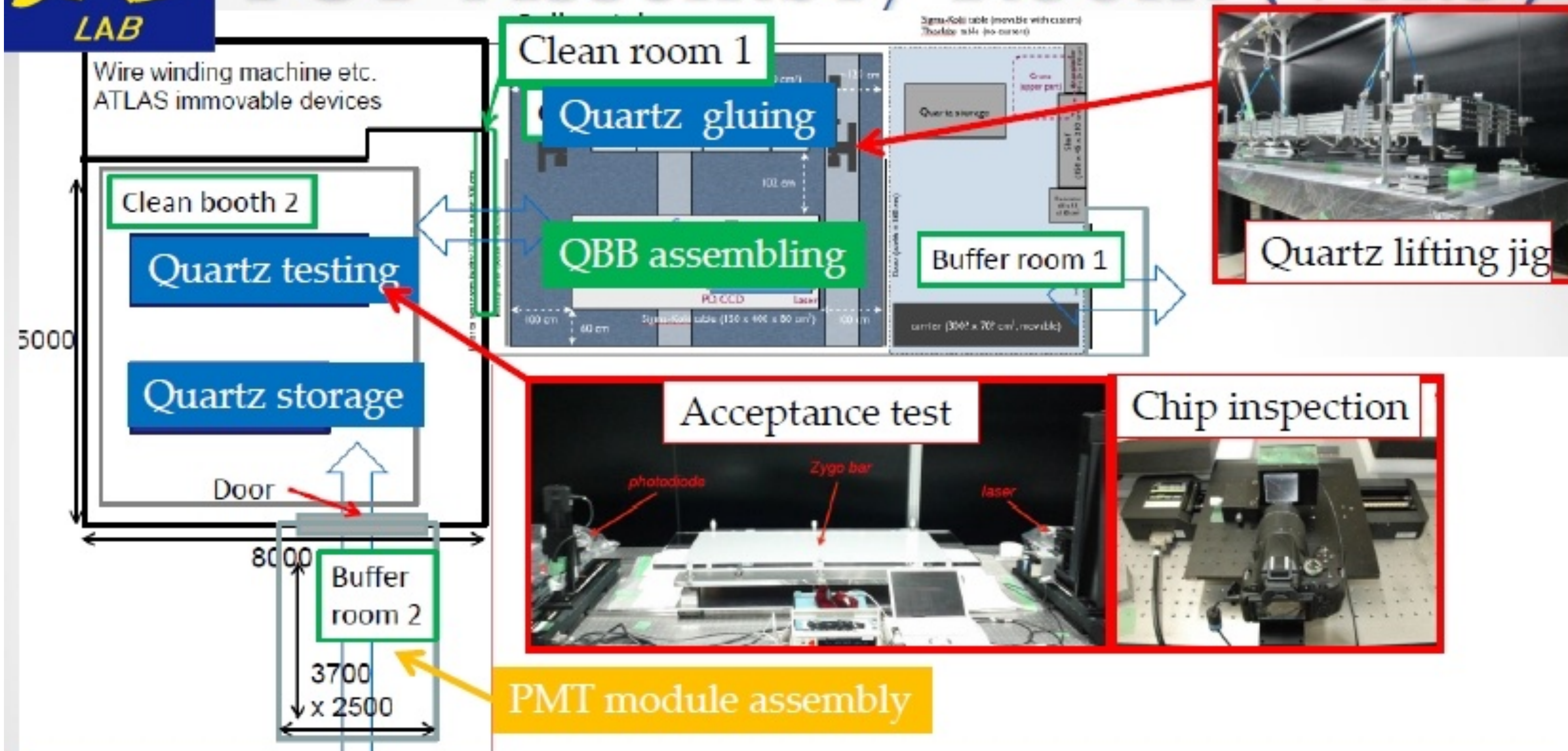
Delivery completed

Construction flow overview



TOP Assembly Facility @ Fuji B4

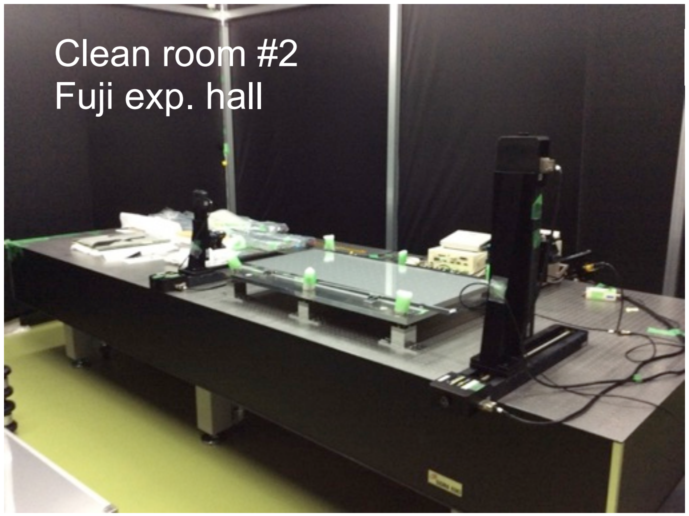
TOP Assembly Room (ver.3)

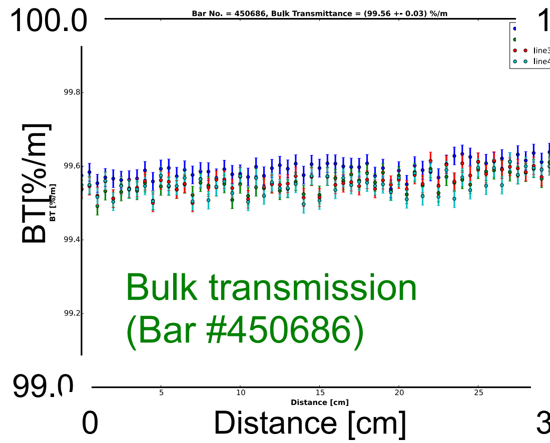


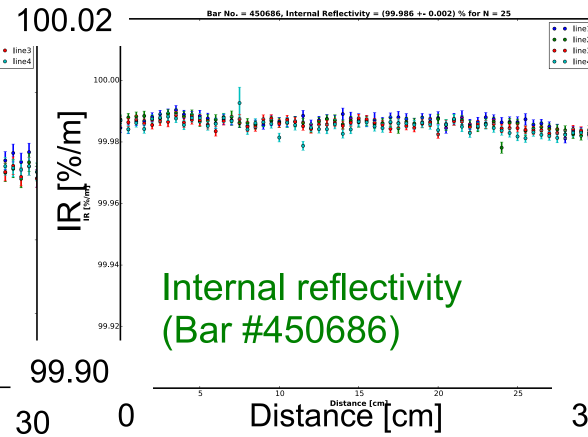
- TOP assembly room (ver.3) managed by Nagoya / KEK team
  - Class 100-1,000 large cleanrooms + class <5,000 buffer room + booth
  - Cleanroom 1: Quartz gluing / QBB assembly
  - Cleanroom 2: Quartz testing / Temporal(?) quartz storage
  - 2nd buffer booth: PMT Assembly / cleaning space for QBB parts

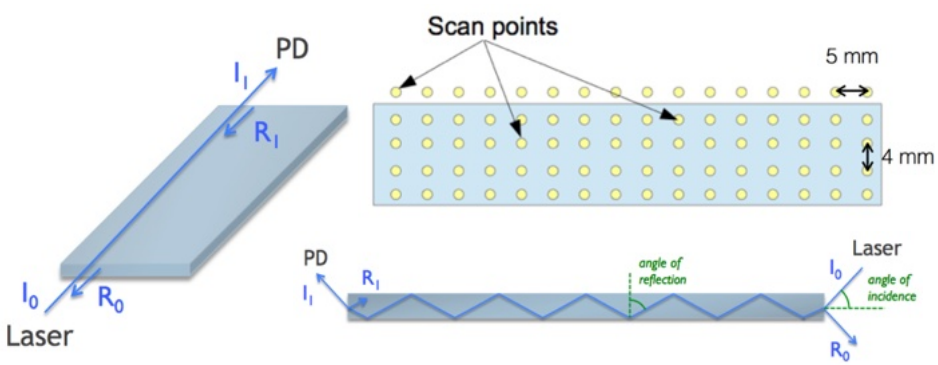
Optics QA : Bars

- QA measurements are made in the clean room #2 at KEK.
- Inspect bulk transmission, reflectivity and chips.









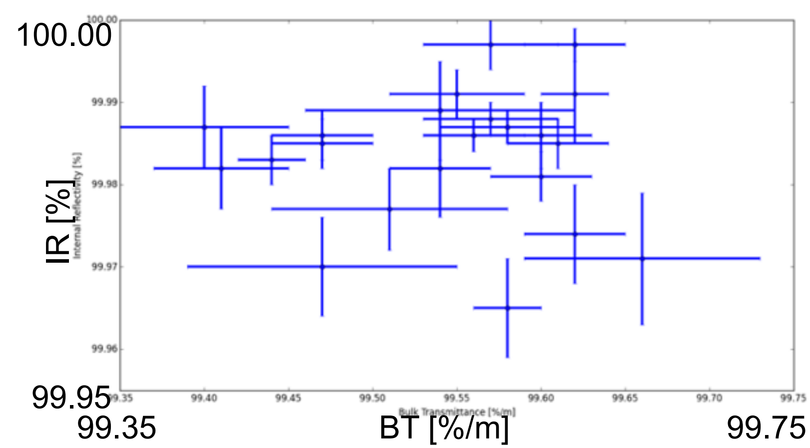
$I_0(1 - R_0)\tau(1 - R_1) = I_1$

Bulk Trans.

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

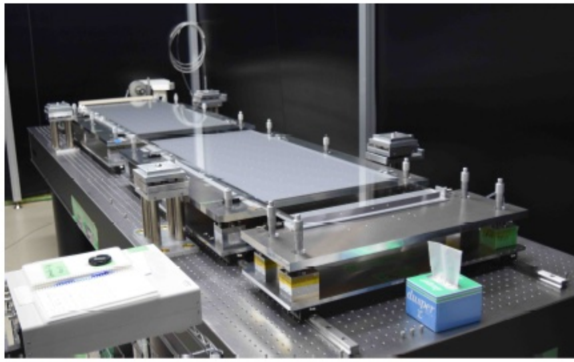
Internal Reflect.

R_0, R_1: Calculated by Fresnel equations. Laser is polarized as S-wave for reflectivity measurement.



Laser wavelength: 405 nm
Ave. Bulk Trans.: (99.55 ± 0.07) %/m
Ave. Internal. Reflect.: (99.984 ± 0.008) %

Assembling steps

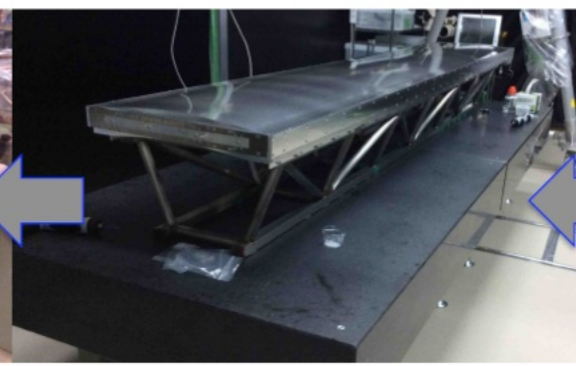


Optics: alignment, gluing, curing and aging (~2 weeks).

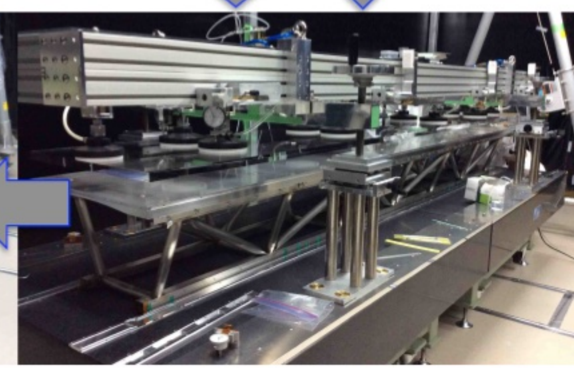
Enclosure: gluing CCDs and LEDs, integrating fiber mounts.

QBB: strong back flattening, button & enclosure gluing.

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



QBB assembly and gas sealing.



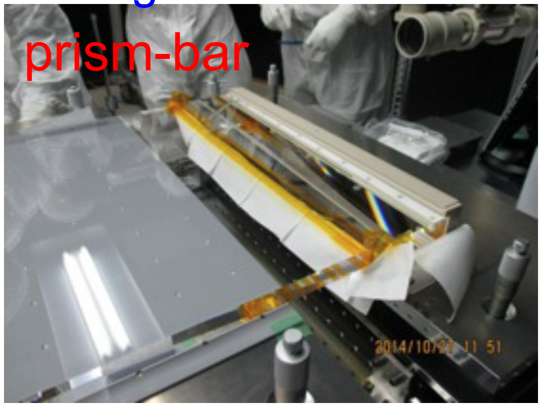
Move optics to QBB using the "lifting jig".

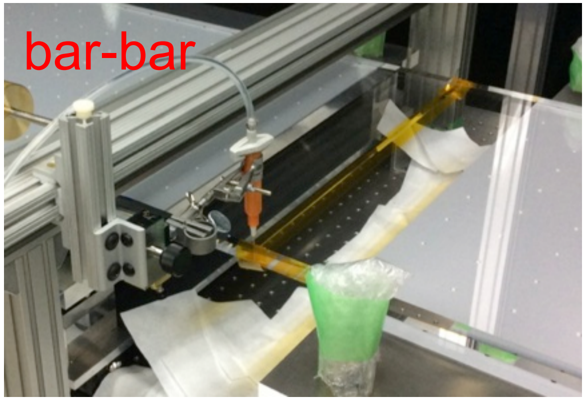
Quartz Gluing

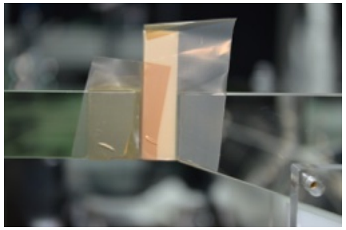
- We use EPOTEK-301 for all joints.
- Gluing procedure is based on dry runs + some R&D for details
  - Taping (+ curtain for prism-bar joint)
  - Centrifuge for eliminating bubbles
  - Glue injection with a trolley
  - Cleaning, curing, …

Remove extra glue after ~6hrs
Remove tape and clean optics after ~27hrs

Gluing for module 01



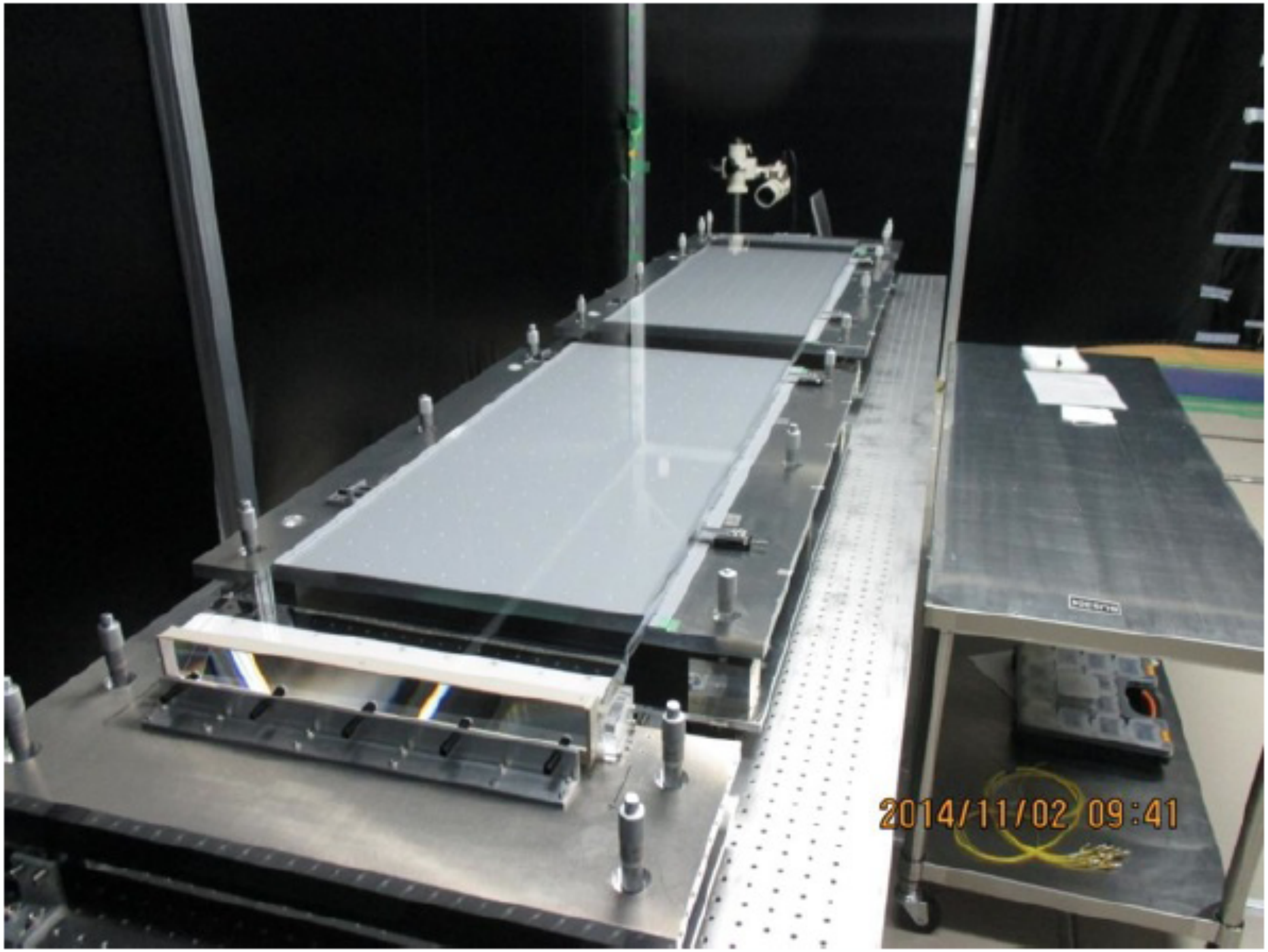




We use Teflon tapes for later modules

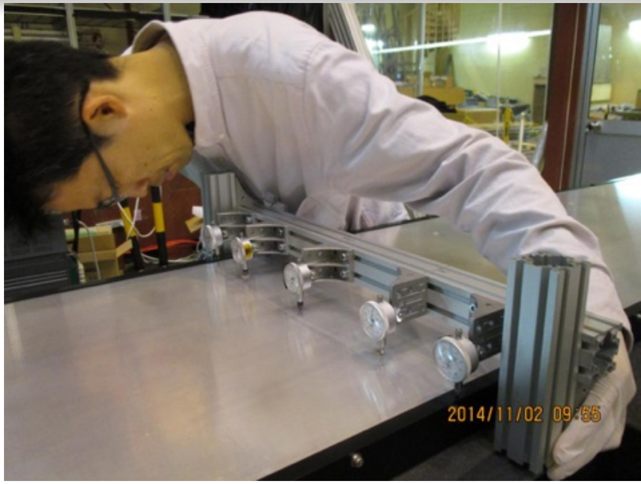
- Small delamination observed in prism-bar joint for the module01.
- Gluing procedures were revisited, and many studies were made.
- We haven't seen similar phenomena for later modules.

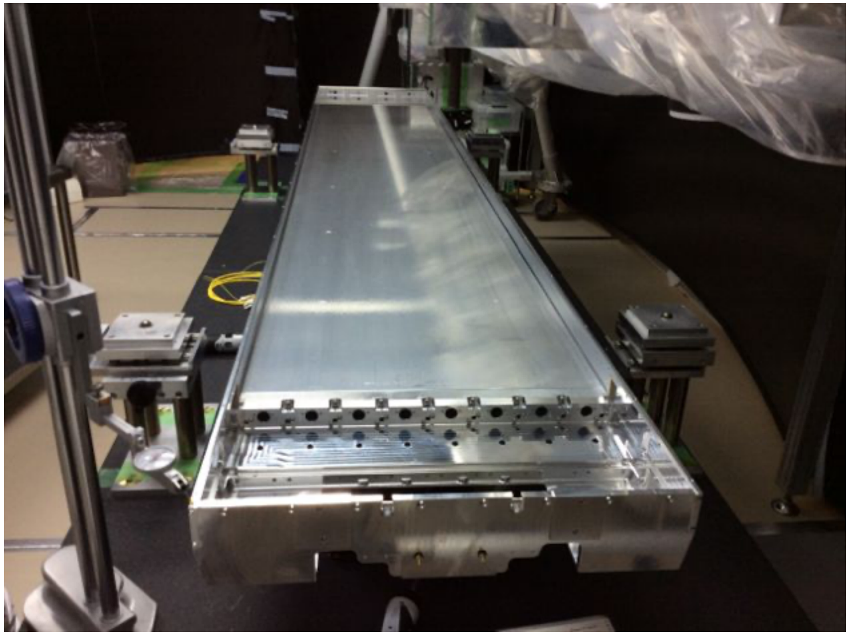
Glued Optics (Module 01)

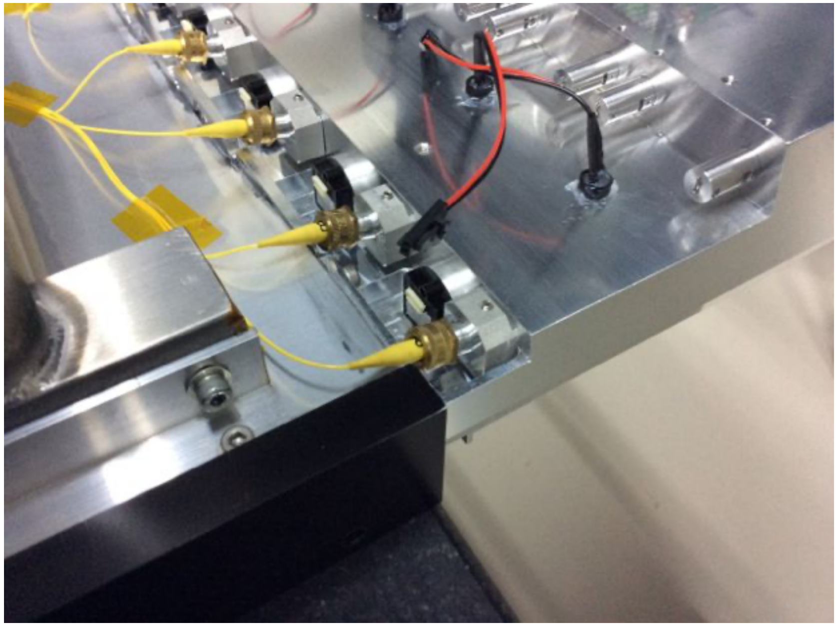


QBB preparation

- Measure flatness of the honeycomb panels.
- Attach strong-back, tune and test stability.
- Assemble enclosure
  - Align inner-panel and enclosure < 0.06mm.
- Install LEDs, cameras, spring holders, fiber holders

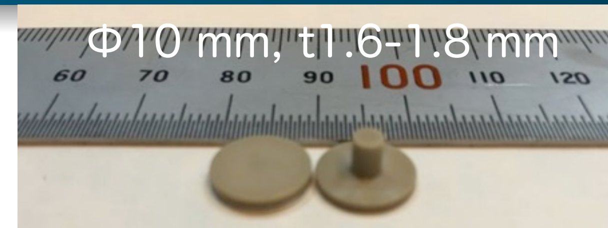


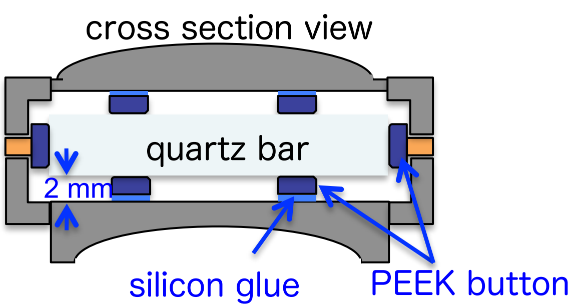


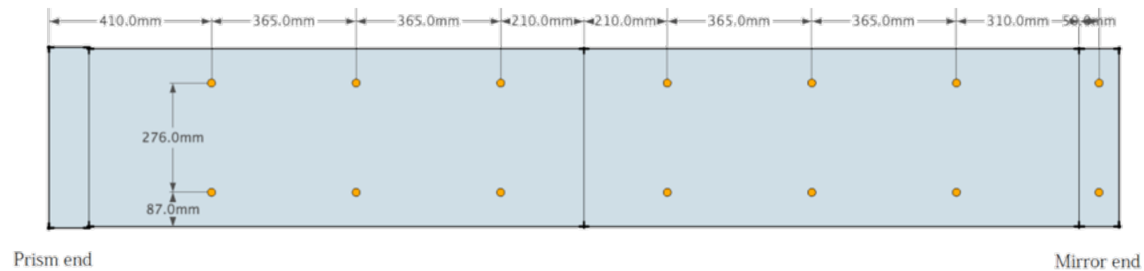


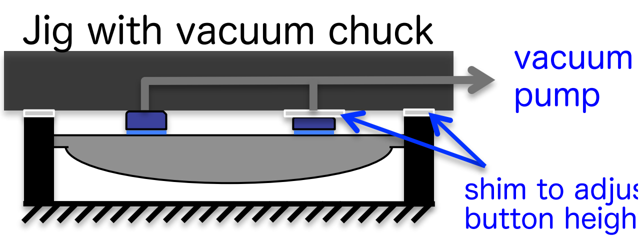
QBB Preparation (PEEK button)

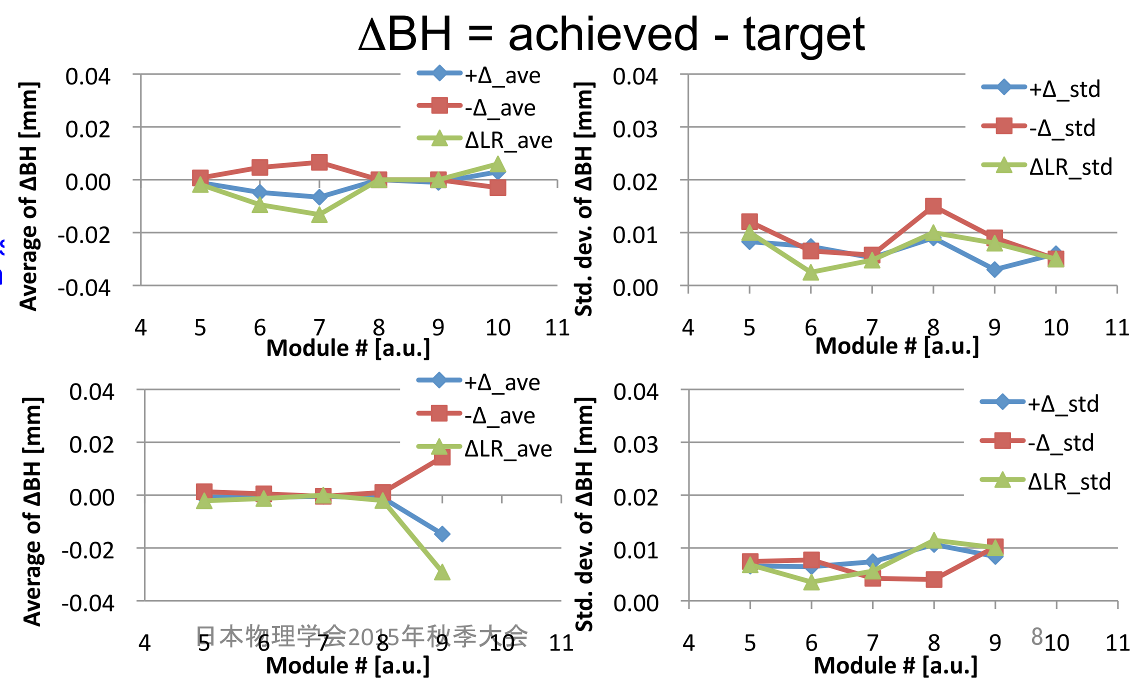
- Quartz are supported by PEEK buttons.
- Height of the PEEK buttons need be adjusted very carefully.



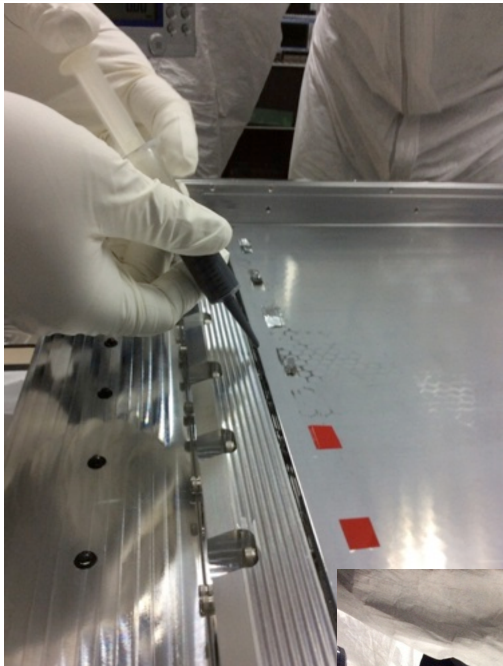


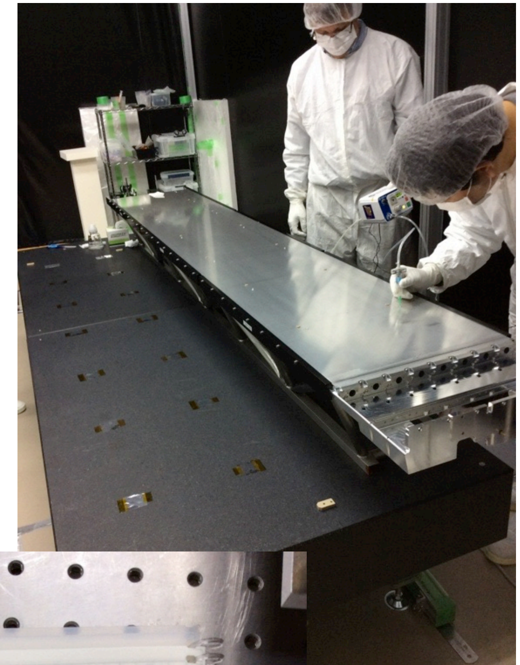


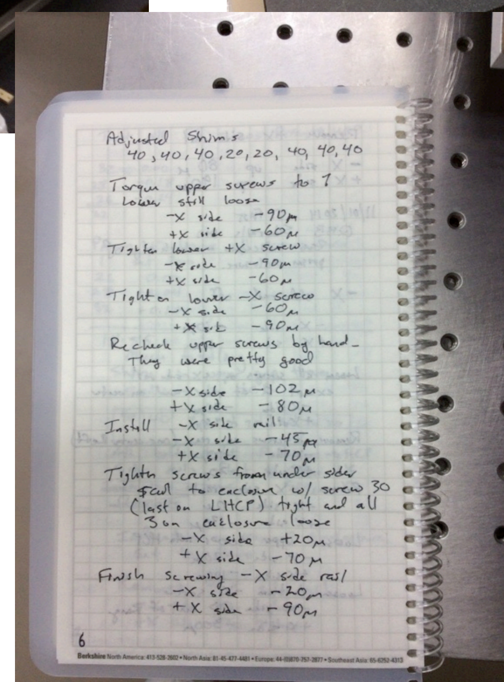




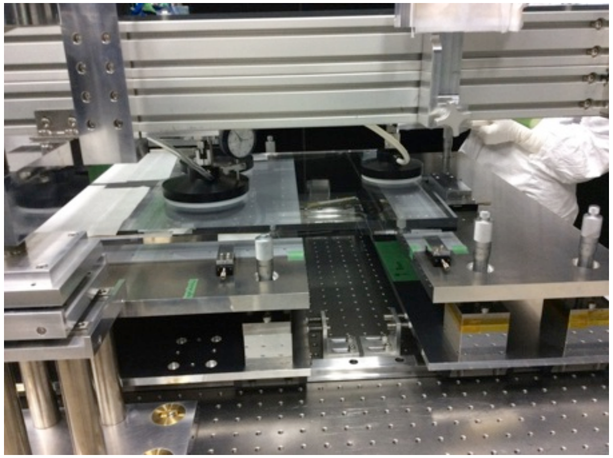
More Pictures from QBB Preparation

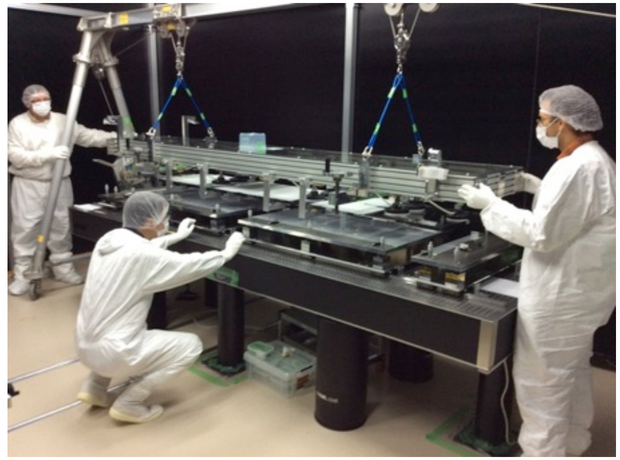


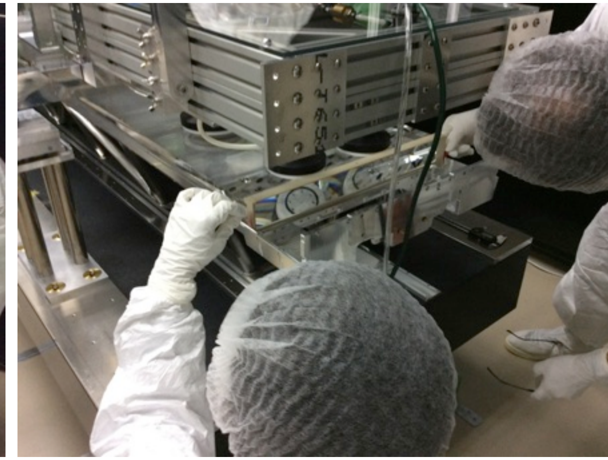


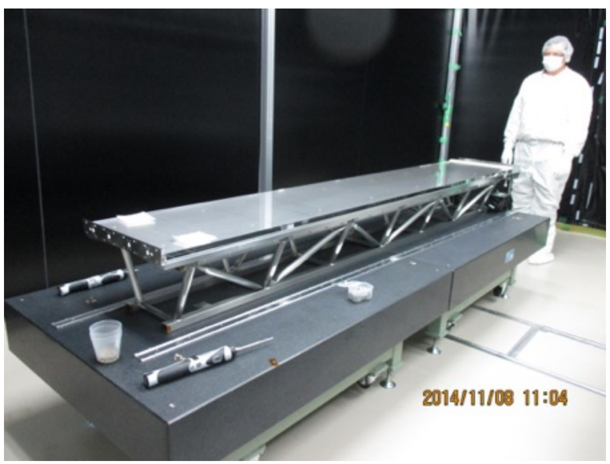


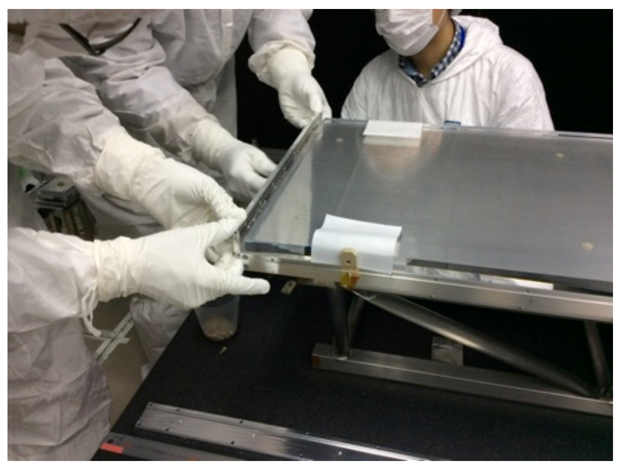
Installation of Optics to QBB

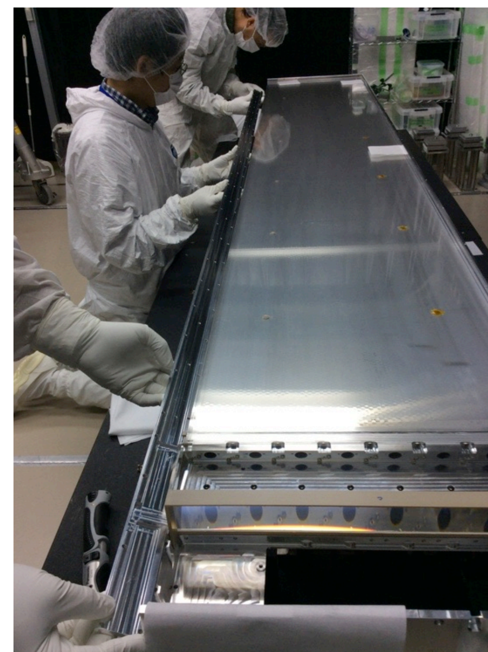




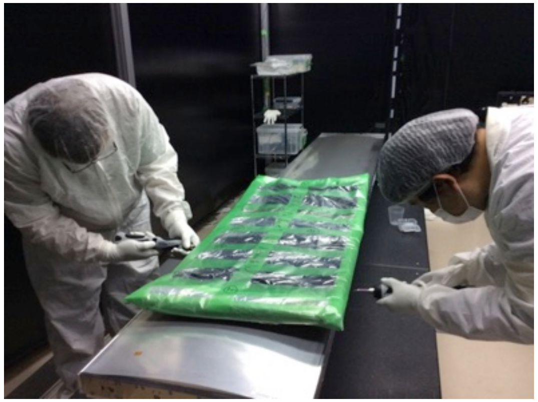


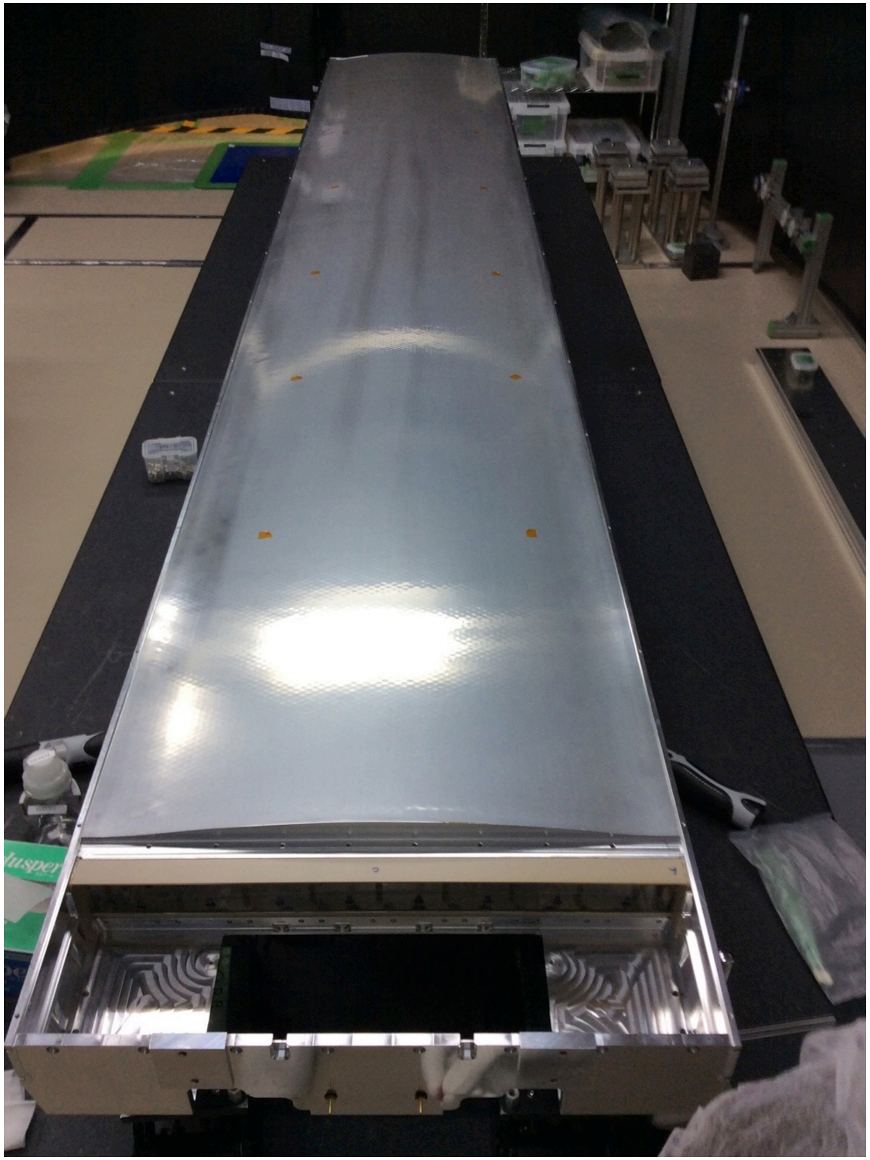






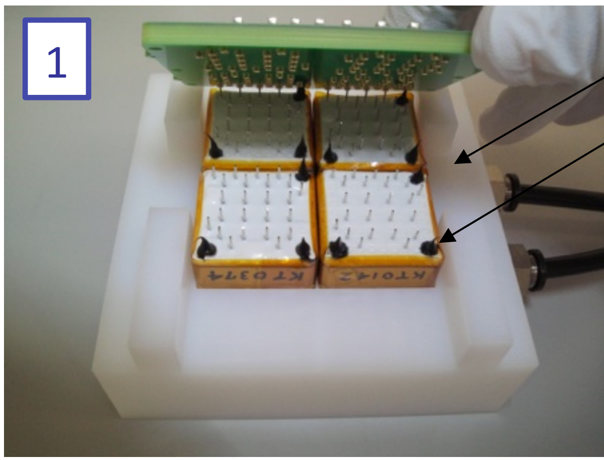
Completion of Optics + QBB (Nov.10)





PMT Module Assembly

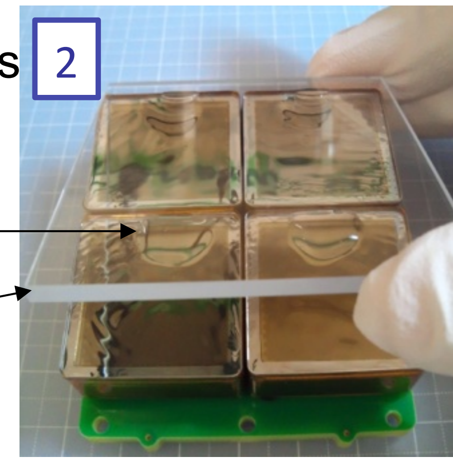
- PMT modules are assembled in the Fuji FI clean booth.
- The assembly procedure has been fixed.
- Every module is tested for HV after assembly.

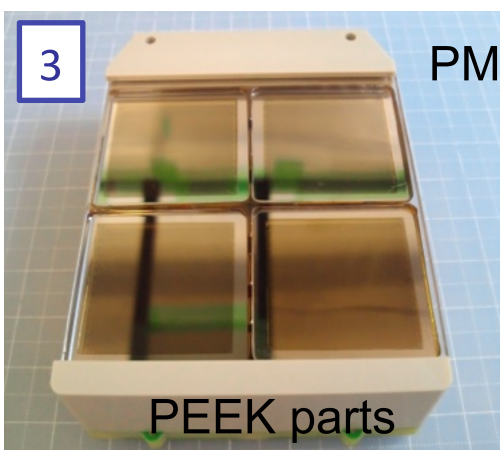


Vacuum chuck to align the PMT faces

RTV silicon rubber to hold the PMTs

Silicon rubber TSE3032 (before curing) to be filled between the PMTs and the wavelength cut filter



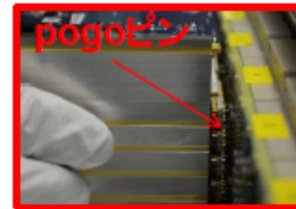


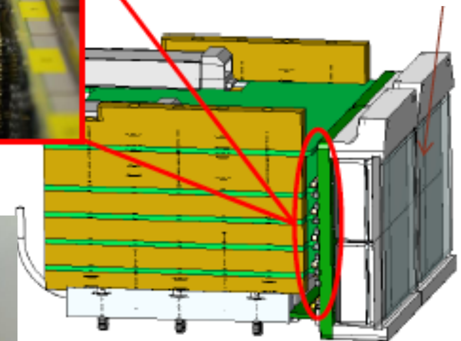
PMT module completed

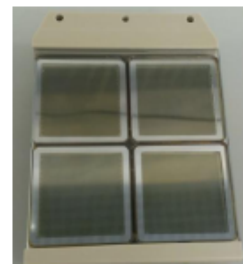
HV test in a dark box

MCP-PMT Mounting

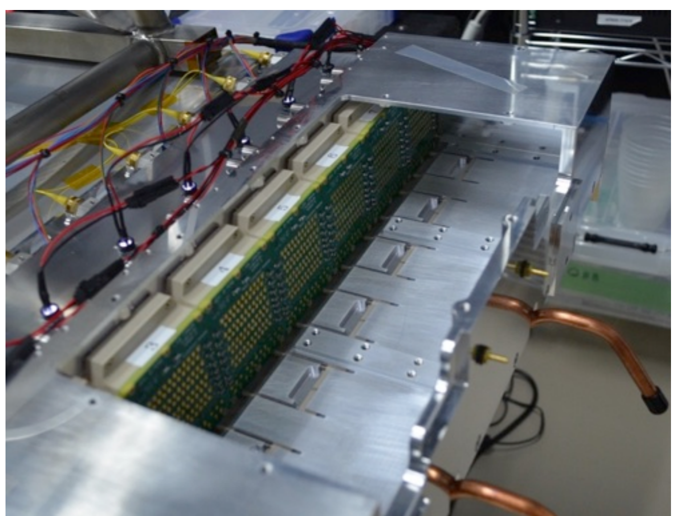
- Designed so that PMT+ readout modules can be replaced from the access hatch.
- Mounting method has been established with the prototype.
  - Optical cookies for WL-filter–Prism interface
  - Pogo pins for PMT – Readout interface







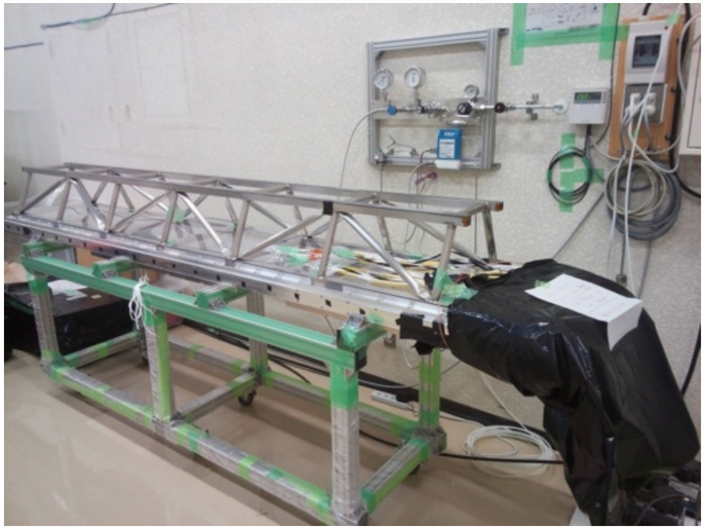
Installation for module 01



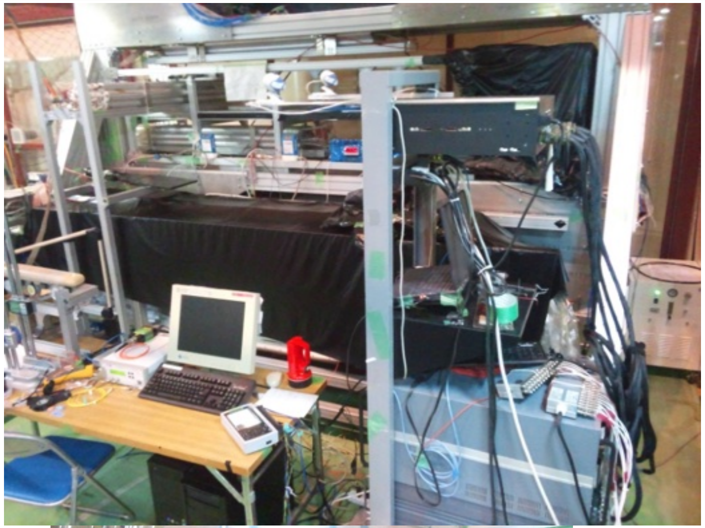
Production schedule

- Module production moves smoothly now. ~3 weeks per module
- Finished Module10 assembly as scheduled

Current status



Module01 at Fuji F1



Module03,04 at Fuji B4 tent in testing for installation

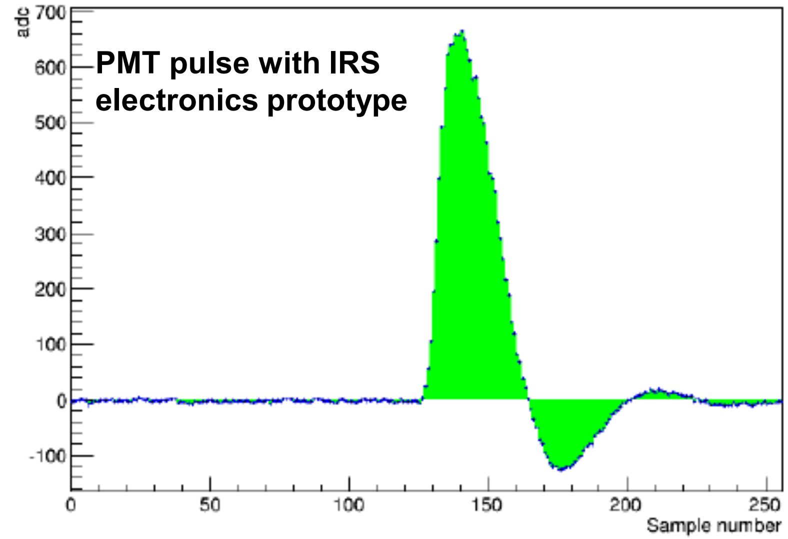
Module02, 05-07 at Fuji B4 tent

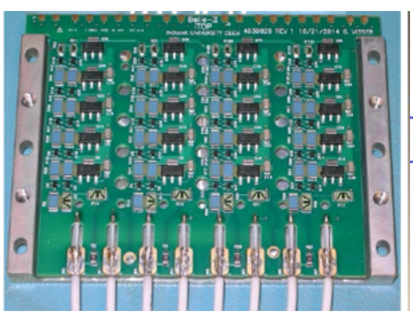
Module08,09 at Buffer2

In clean room,
Module10 gas sealed
Module11 optics glued.

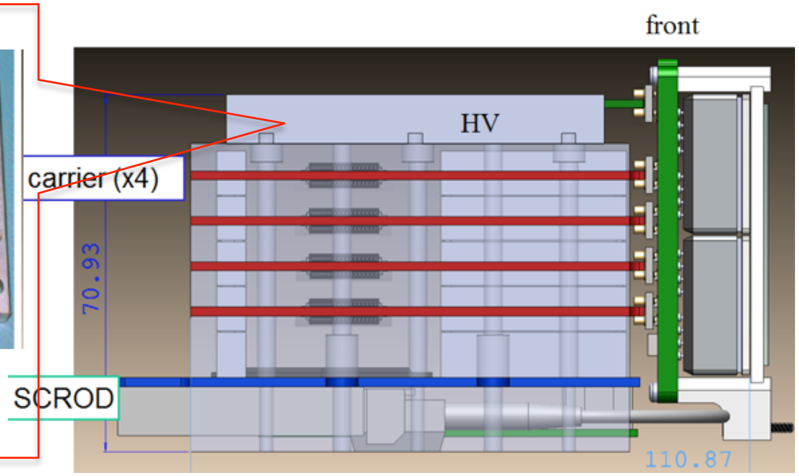
Readout Electronics + HV

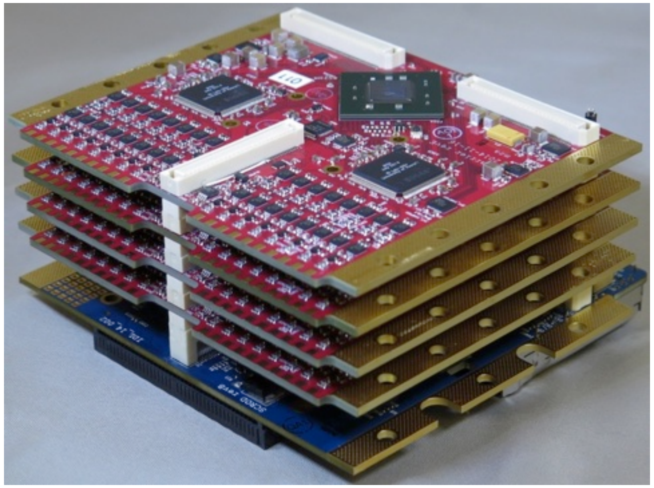
- MCP-PMT signal is readout by newly developed “IRS” ASICs.
  - Waveform sampling
  - High density, multi-hit buffering
    - 512ch/module, 30kHz trigger rate
  - Clock jitter measured with test pulse is 20ps.





HV board





Production Workflow

	Design/ Procure	Custom Assembly	Initial Test	Assembly/ Test	Shipping	Integration Test	Module Assembly
Front Boards	**Indiana (Visser)**	Press-fit HV pins (IU)	Probe and HV test (IU)	To KEK	MCPPMT installation (Nagoya)	Test (Nagoya)	
HV Boards	**Indiana (Visser)**	Pogo pins, potting (IU)	HV test (IU)	Hi-pot test (IU)	To KEK		
SCROD	**Hawaii (Andrew)**	Cable harnesses (Pitt)	FTSW + COPPER (Pitt)	Board Stack Assy/Test (UH)	To KEK	Retest at KEK (USC)	
Carrier Boards	**Hawaii (Andrew)**	Pogo pins (PNNL)	Ref. SCROD, DAQ (SC)	Board Stack Assy/Test (UH)	To KEK	Retest at KEK (USC)	

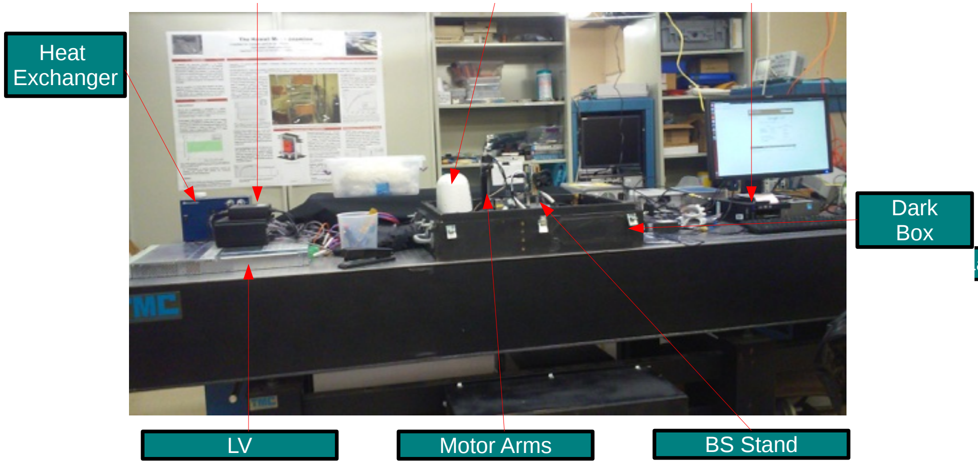
Industry Std PCB, SMT assy

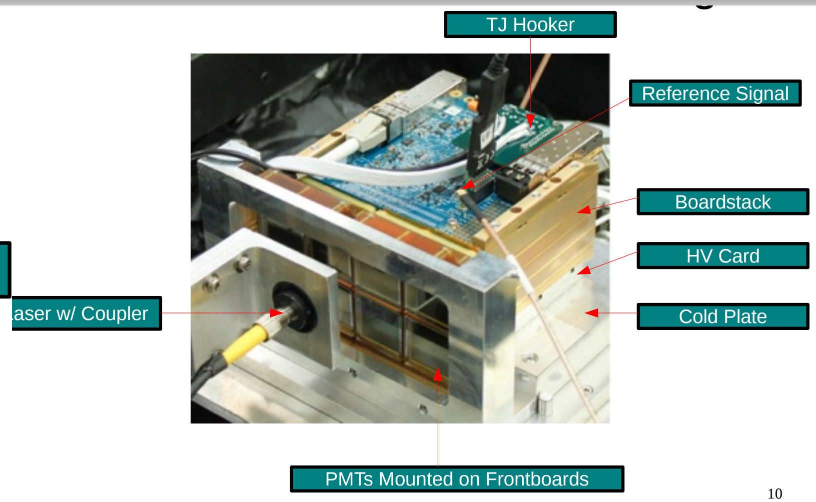
Laser scan Verification

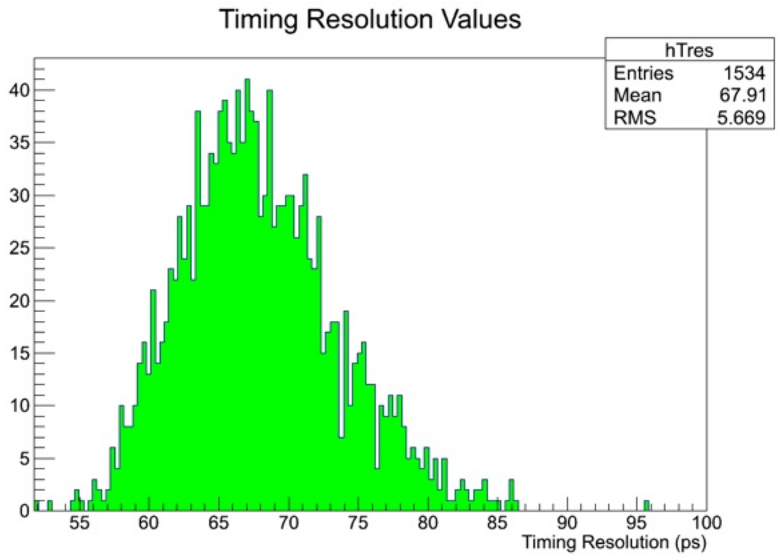
Acceptance Verification

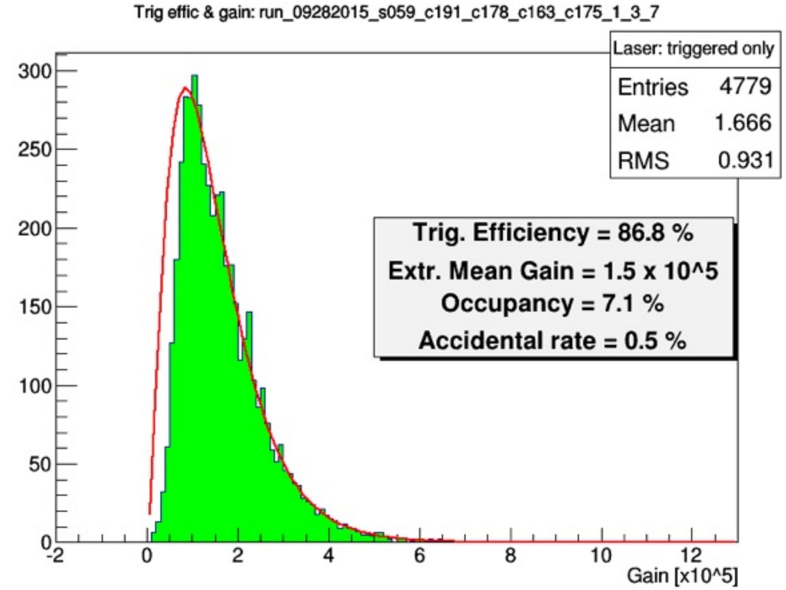
All circuit boards fabricated, assembled
Cable harnesses in fabrication, HV board PoGO pins & potting

Production Laser Testing (at UH)





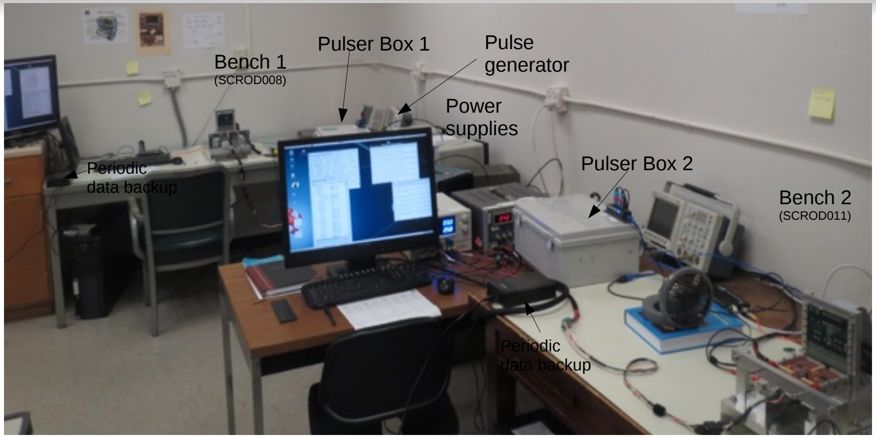




Readout meets experiment needs

Production status

Test bench at U. South Carolina



- Testing is going well.
- More manpower for HVB going to IU in November.
- Rework is needed to get sufficient number of SCROD.

Board	# Required	# Fabbed	# Grade A*	# Grade B**	# Grade F***	Untested
Front	136	164	125	15	13	11
High Voltage	68	90	17 **28**	0 **1**	0	73 **61**
SCROD	68	77	63	0	14	0
Carrier	272	332	213 **247**	41 **74**	18 **9**	63 **2**

Update (G. Varner)

* Grade A = perfect

** Possibly usable

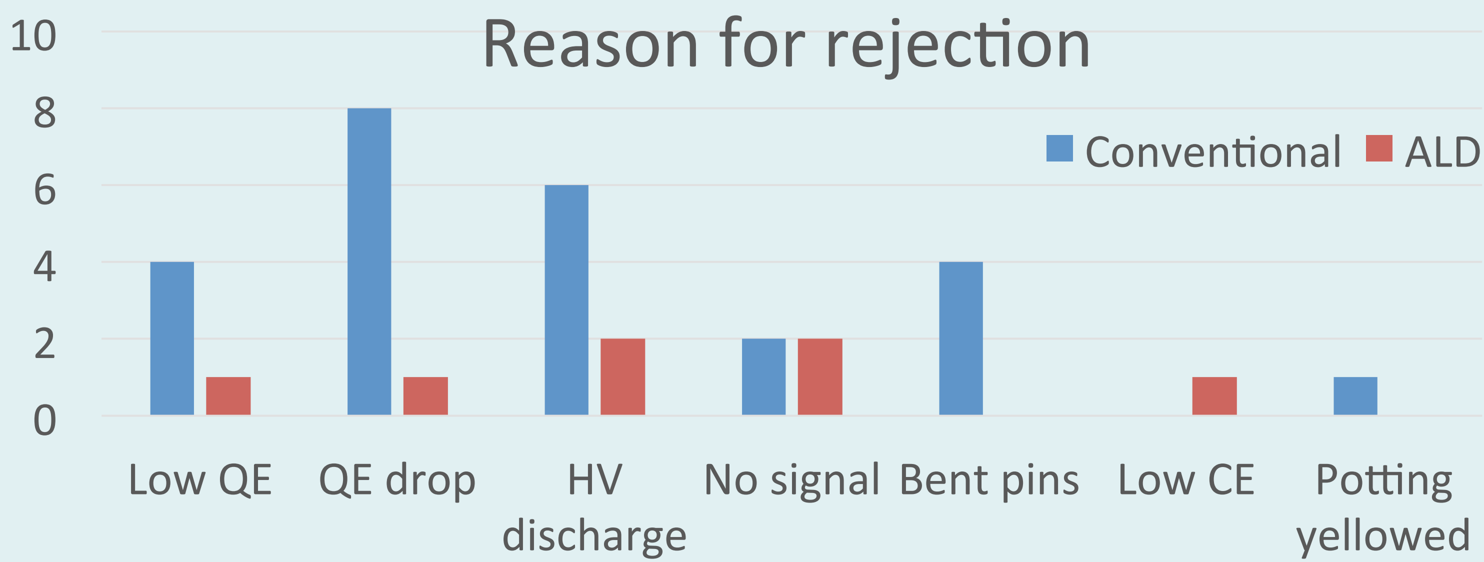
*** Requires rework prior to using

MCP-PMT Production

Hamamatsu 1”
16-ch MCP-PMT

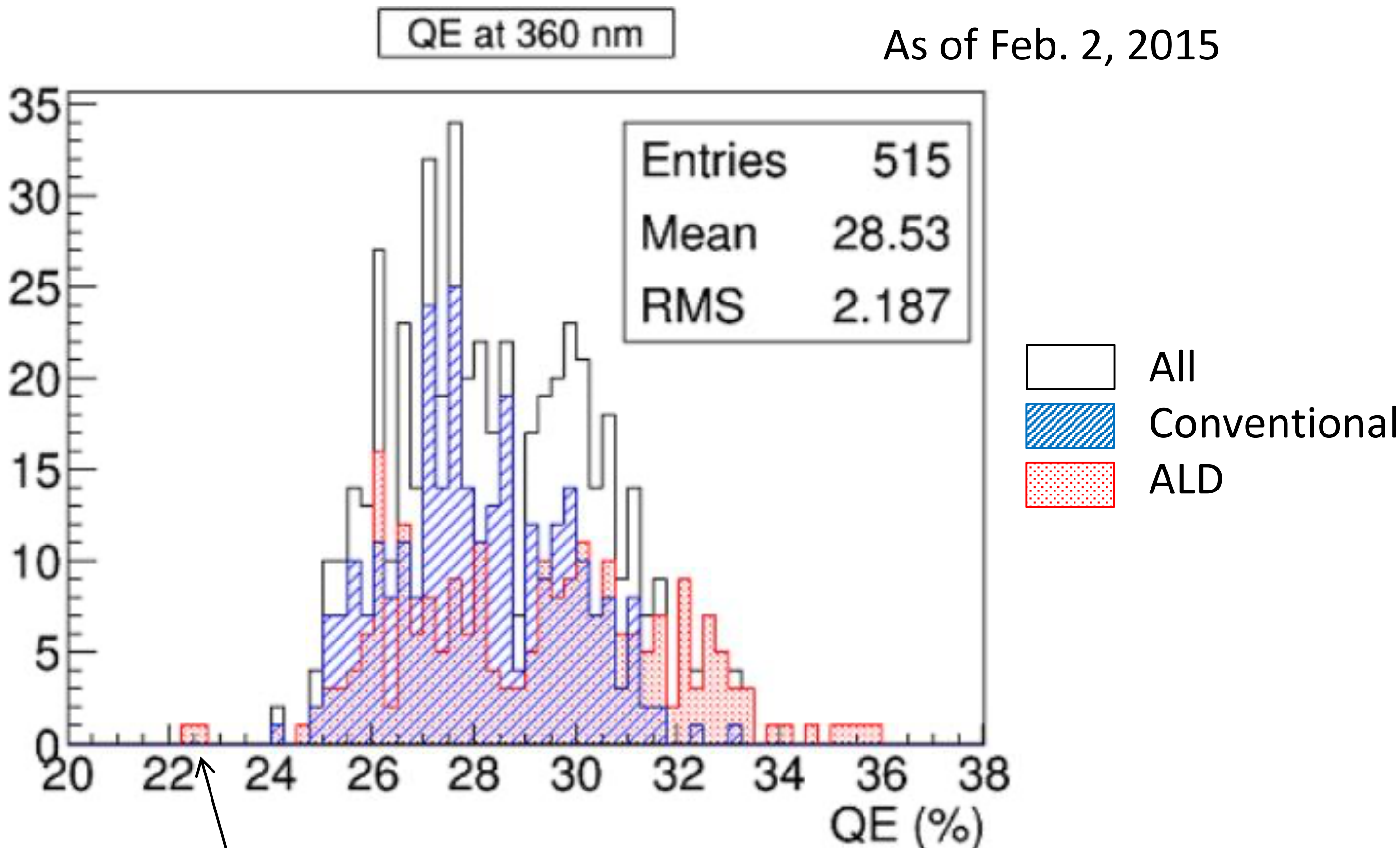
- Total of 611 MCP-PMTs have been ordered
  - Phase1 production completed: 515 total (285 conventional, 230 ALD)
  - Lifetime extension R&D is using 42 (will not be used in Belle II)
  - Phase 2 production of extended lifetime tubes will produce final 54
  - Belle II will have a total of 569 tubes (512 + 57 spares).

We have repeated the PMT measurements to confirm no performance degradation.



Measured QE

As of Feb. 2, 2015

- 

QE peak at 420 nm

- KT0275 (26.0%)
- KT0309 (26.0%)

Average QE at 360 nm

- Conventional: 28.1%
- ALD: 29.1%

Photoelectron flux, accumulated charge

1 MHz/PMT at 5 10^5 gain at design luminosity

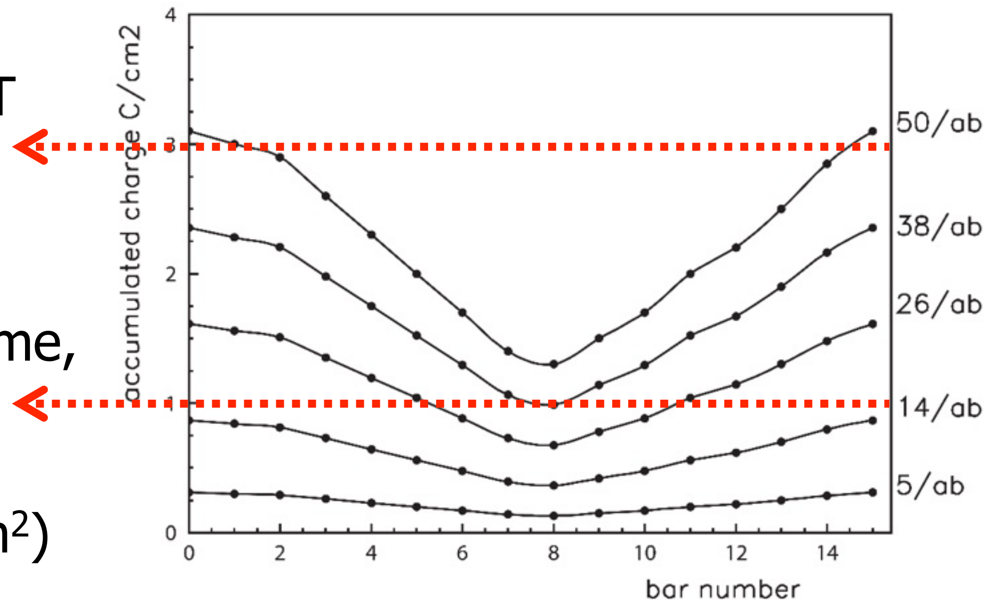
→ about 1 $C/cm^2/50ab^{-1}$ normal type MCP PMTs

Rate plot can be turned into an accumulated charge (C/cm^2) plot

Plot the accumulated charge for expected summer shutdown luminosities

Min. lifetime, ALD MCP PMT (>3 C/cm^2)

Average lifetime, Conventional MCP PMT (0.3-1.8 C/cm^2)



2023: 50/ab

2022: 38/ab

2021: 26/ab

2020: 14/ab

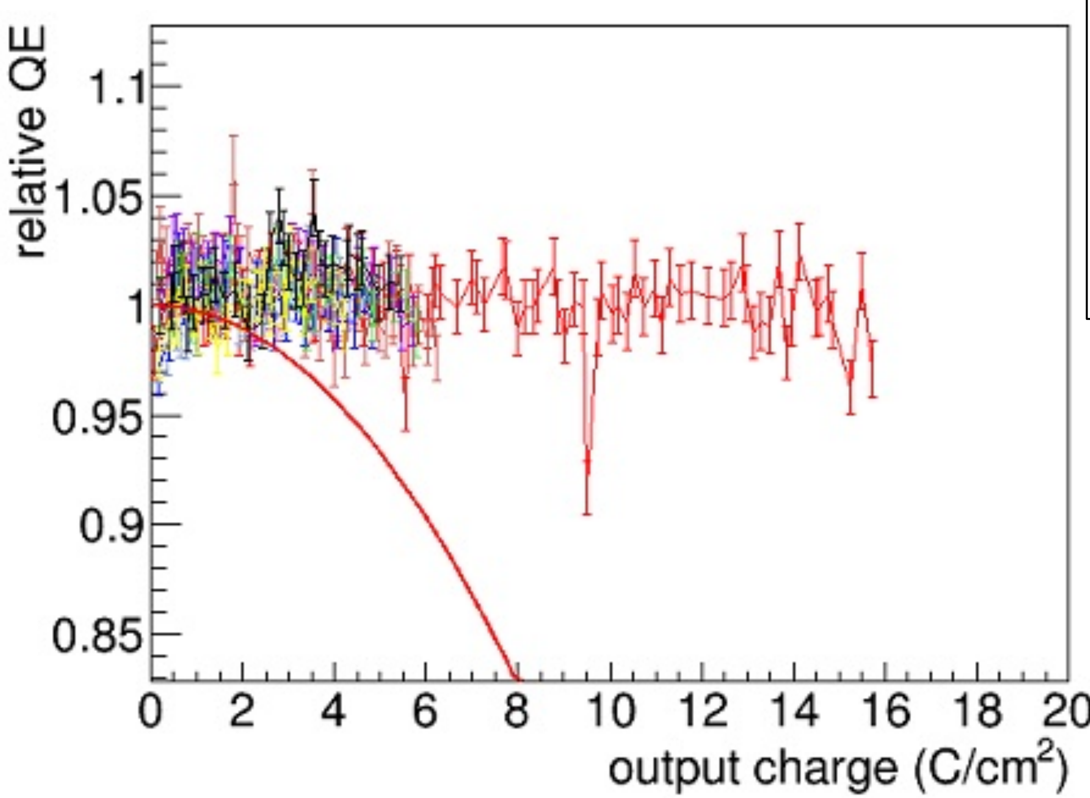
2019: 5/ab

P. Krizan

Conventional MCP-PMTs have to be replaced at some point.

Recent Lifetime R&D

- Test 6 methods of processing to improve the lifetime.
- Produce 6 samples of each method for life test.
  - Test 4 samples at Nagoya and 1 at HPK.
- Produce 8 samples with the good methods combined, and measure their lifetime for confirmation.



- Estimated integrated output charge in Belle II: 1.5-3 [C/cm^2 /50 ab^{-1}/5 x 10^5 gain]
- We measured the lifetime for some MCP-PMTs.
  - Conventional: 0.3-1.8, average 1.1 C/cm^2
    - We will exchange them with new ones when their QEs drop.
  - ALD: 3-13.5 (or longer), average 8.6 C/cm^2

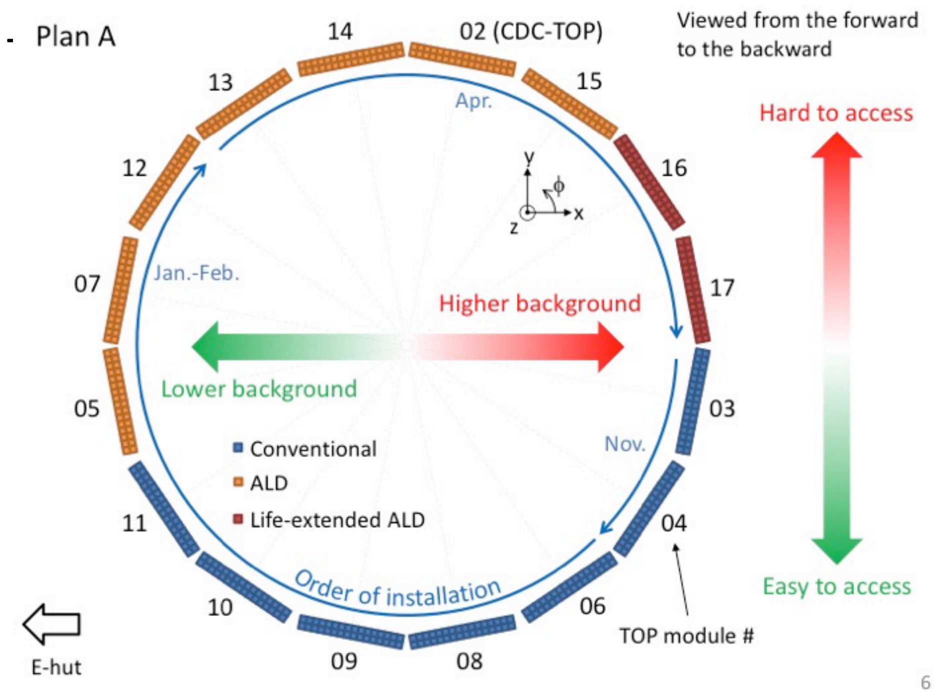
    ↑We want to improve this for future use.

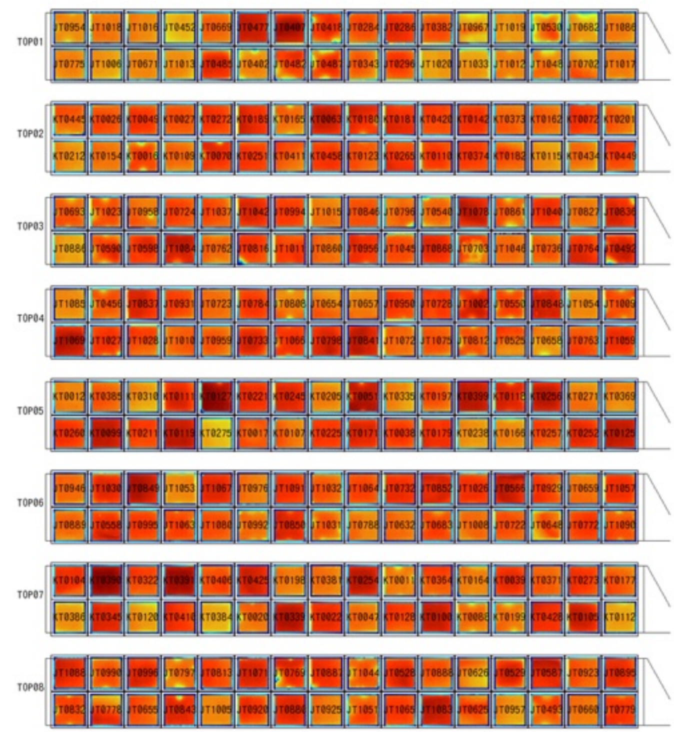
The lifetime of every sample is expected to be longer than 15 C/cm^2.

Plan for MCP-PMT Installation

- We have three types of MCP-PMTs:
  - 283 conventional MCP-PMTs (lifetime: 0.3-1.8 C/cm^2, average 1.1 C/cm^2)
  - 231 normal ALD MCP-PMTs (>3 C/cm^2, average 8.6 C/cm^2)
  - 65 life-extended ALD MCP-PMTs under production (at least 15 C/cm^2)

  (cf. Predicted output charge: 1.5-3.1 C/cm^2/50 ab^{-1} at 5 x 10^5 gain)
- Conventional ones have to be replaced in 2020 or 2021 summer.
- Average QE of each module is almost the same.

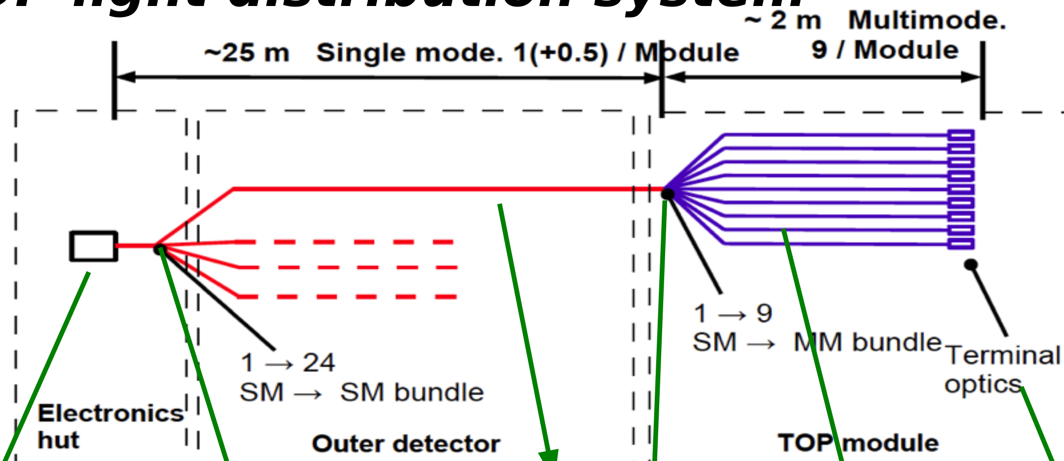




Laser Calibration System

- Developed by Italian group (Padova/Torino)
- w/ PiLas laser, PLC splitter, SM fiber, MM fiber, GRIN lens.

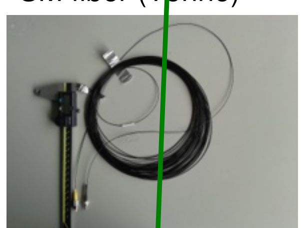
TOP light distribution system



PiLas laser (Torino)

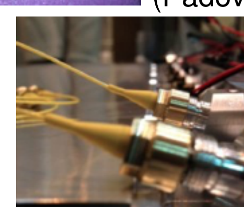
NEW: Splitter 1-24 via Planar Light Circuit (Padova)

SM fiber (Torino)

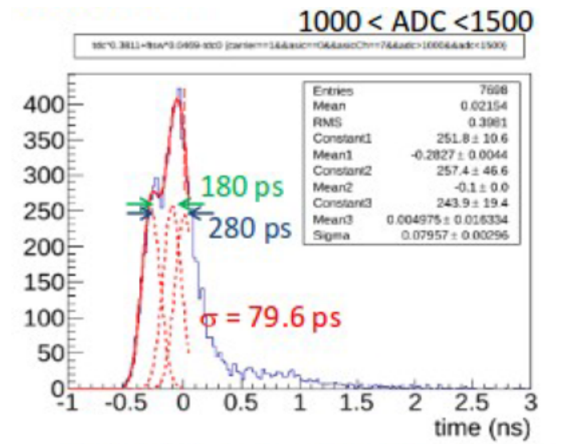


Connector SM-MM: (Torino)

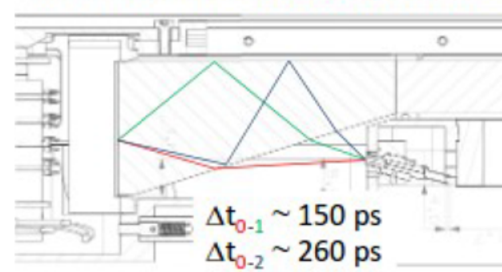
GRIN Lenses (Padova)



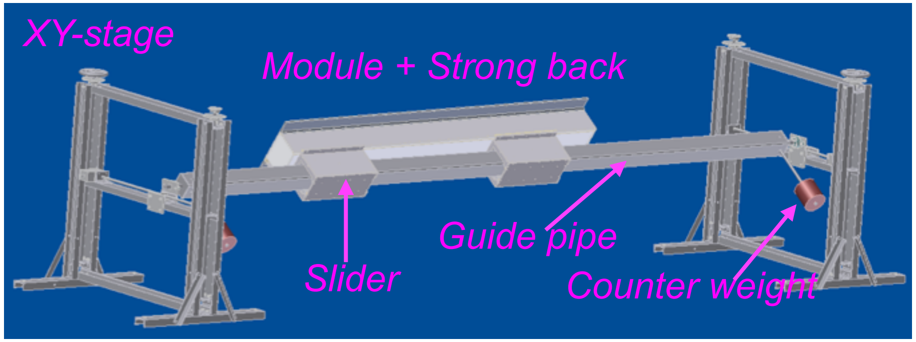
2

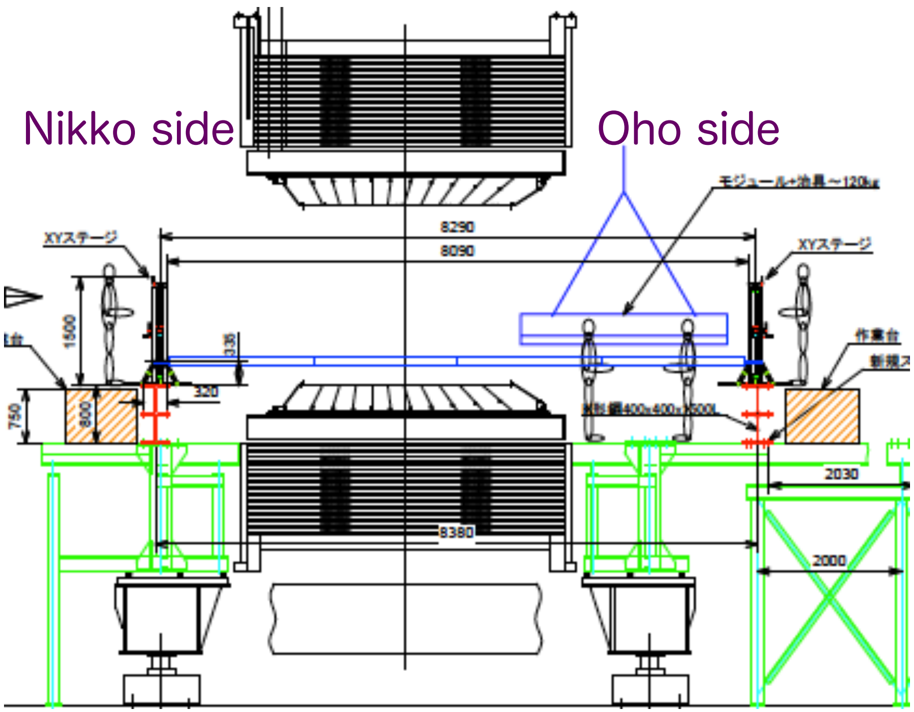


Probably three peaks by direct photons and those reflected once and twice



Module Installation



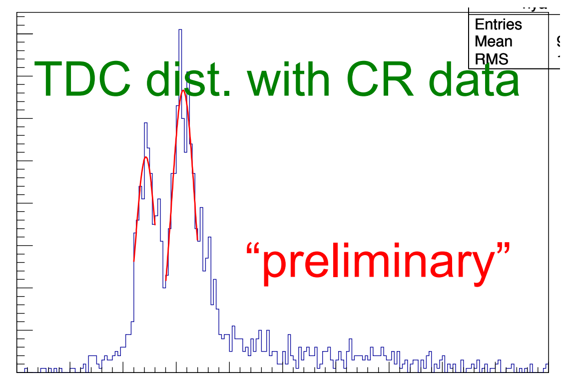


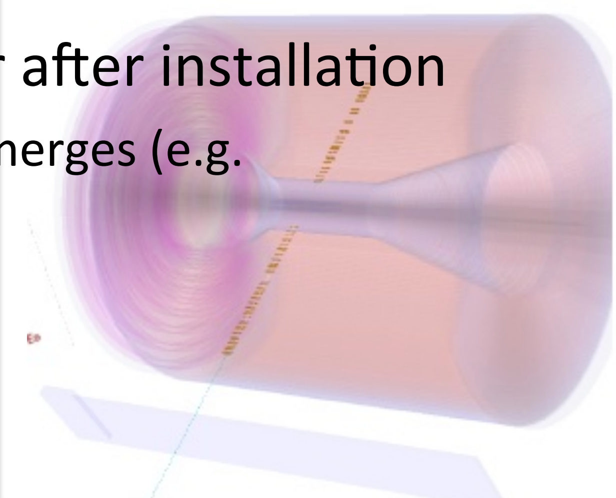
Module installation practice went extremely well.

Module Testing Plan

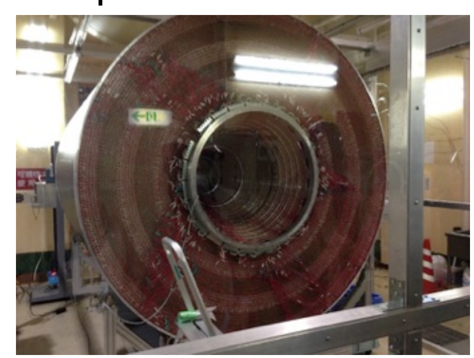
- Primary test for every module
  - Electronic charge injection
  - Laser test in modules
  - Cosmic test without tracking
- Cosmic test with precision tracking for subset of modules (one or two)
  - Use CDC for precision tracking
  - Also as an integration test of Belle II DAQ
- Global cosmic ray test after installation
- A beam test could occur after installation
  - If a compelling reason emerges (e.g. calibration of p.d.f.)

CR test stand at Fuji





CDC at Tsukuba exp. hall



Summary

- Belle II TOP is the first realization of a detector using internally reflected Cherenkov lights with precise Time-Of-Propagation measurement.
  - After >15 years of R&D + very large efforts.
- Construction is progressing very well, after solving many many problems.
- Many many experiences (quartz optics, MCP-PMT, mechanics) have been accumulated.
  - We are happy to share knowledge, know-hows, …
- Many more to learn (probably) for stable operation, analysis, etc.

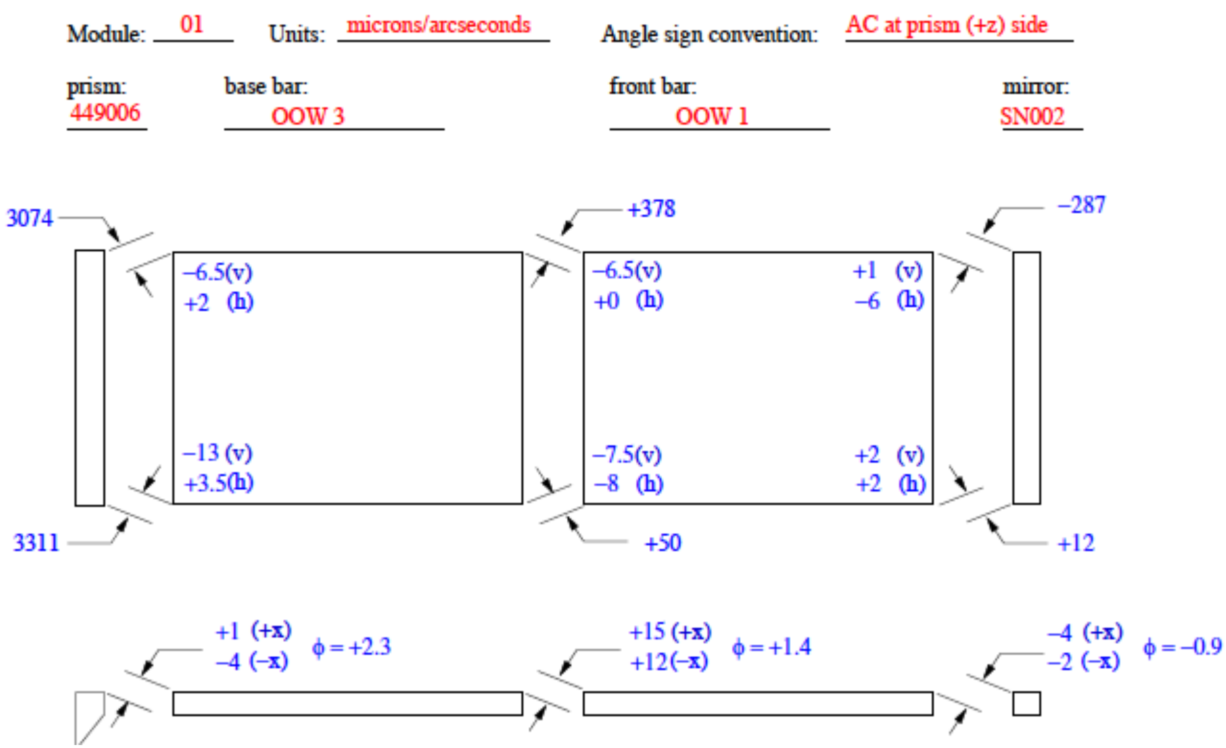
Stay tuned ! & Let's keep in touch !

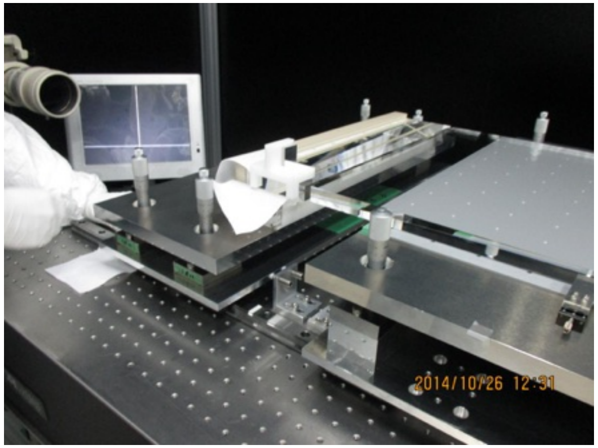
Danke schön !

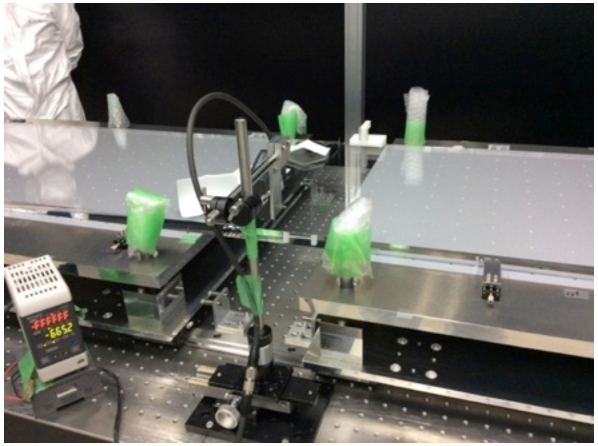
Backup

Quartz Alignment

- Quartz alignment is done with a gluing stage, autocollimator, and laser sensors.



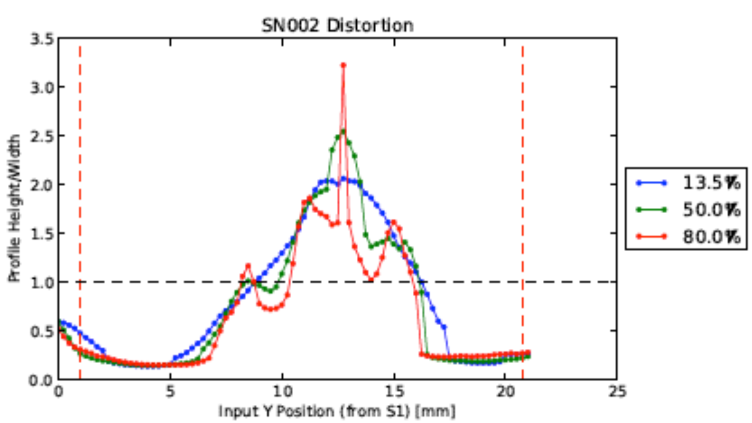


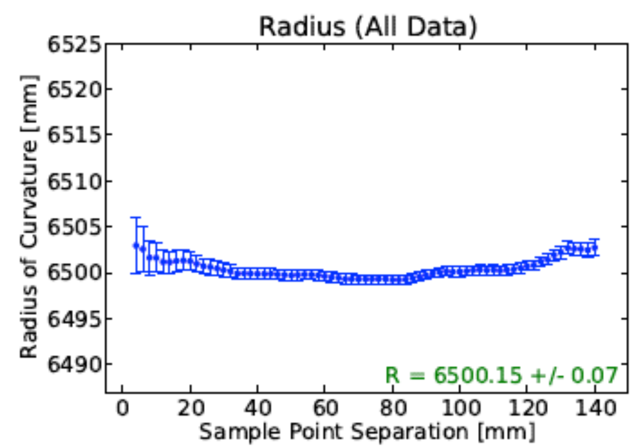


Optics QA : Mirror (SN002)

- Measured at Cincinnati (M. Belhorn, B. Pal, A. Schwarz)

Test (Specification)	Vendor Measurement	Cincinnati Measurements		
		Date	Location	Measurement
Edge Chips (< 20 /m)	16 ("Chippy")	03/15/2014		0 additional
Reflectivity (> 85 % for 300 $-$ 600 nmλ)	87.26 %	06/10/2014	$y = 8.8$ mm	88.29 ± 0.03 %
		06/10/2014	$y = 10.0$ mm	88.09 ± 0.02 %
		06/13/2014	$y = 12.5$ mm	87.81 ± 0.03 %
Transmittance		07/21/2014		99.921 ± 0.052 %/m
Radius (6500 ± 100 mm)	"Approx. 6497 mm"	06/10/2014	$y = 8.8$ mm	6501.38 ± 0.15 mm
		06/10/2014	$y = 10.0$ mm	6500.15 ± 0.15 mm
		06/13/2014	$y = 12.5$ mm	6499.04 ± 0.14 mm
			Overall Fit*:	6500.15 ± 0.07 mm



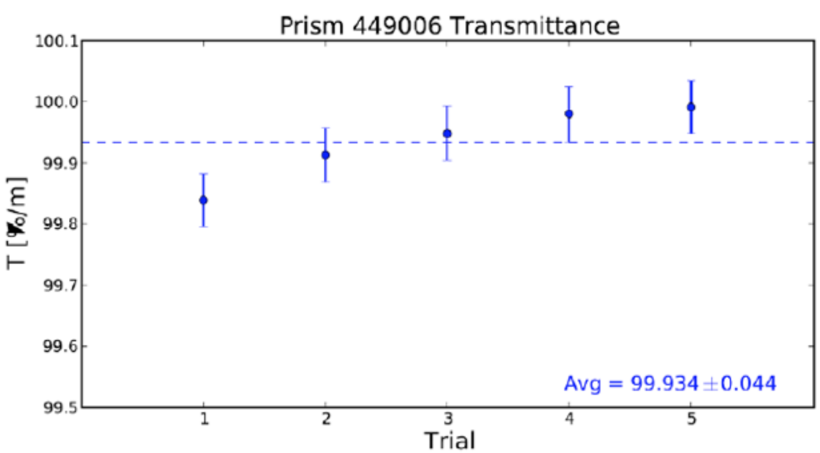


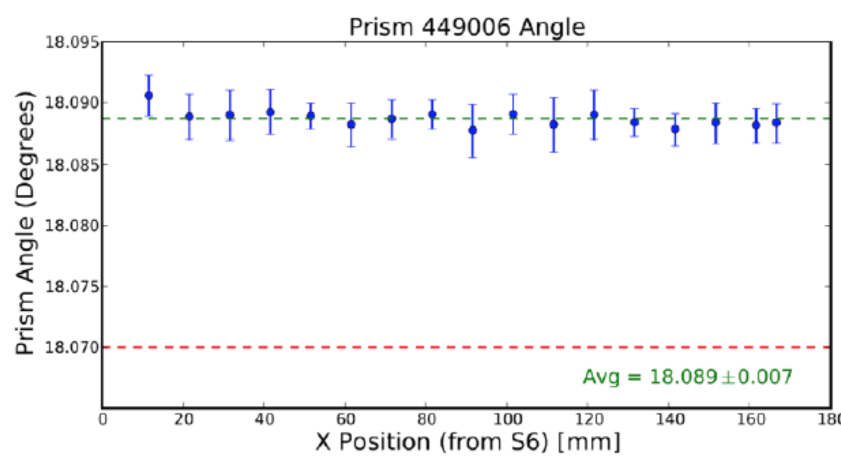
* Statistical error only, applies to following tables.

Optics QA: Prism

- Inspected for chips, angle and transmittance at Cincinnati (M. Belhorn, B. Pal, A. Schwarz)

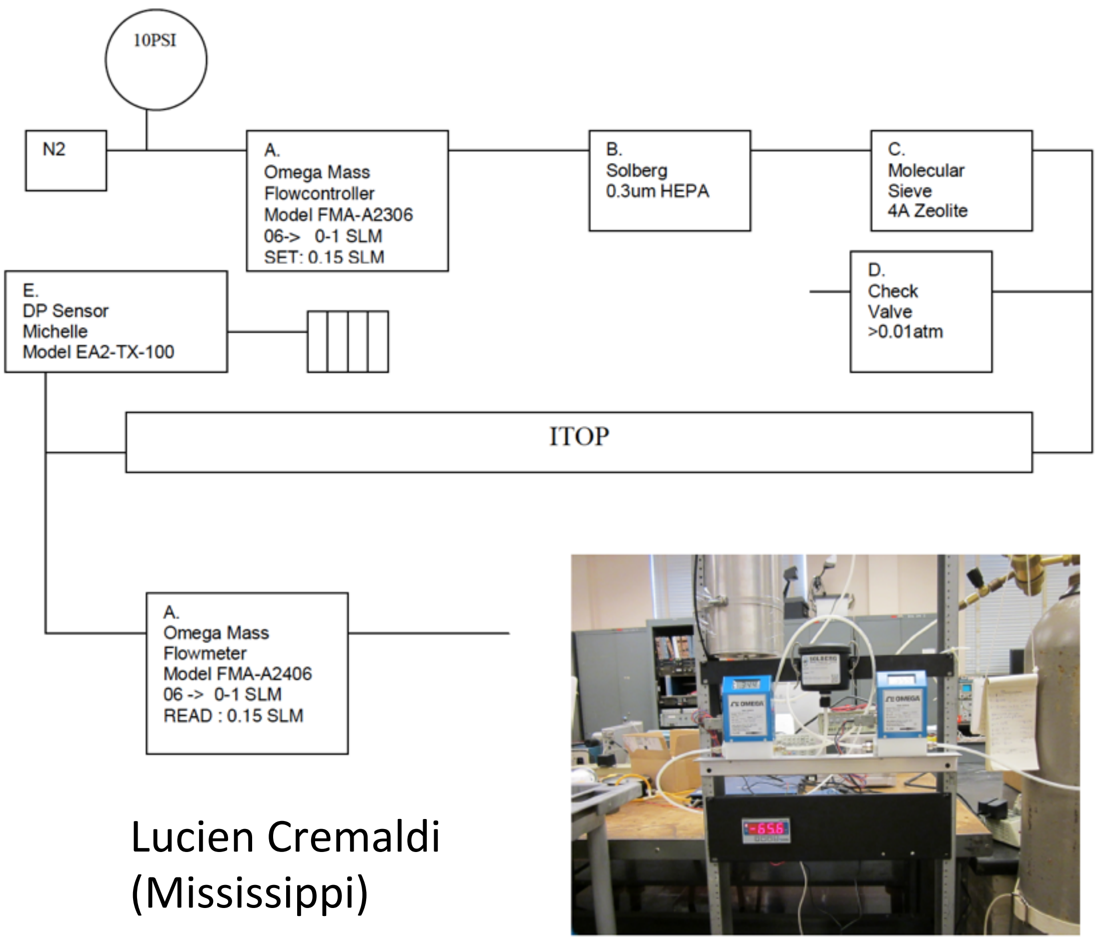
Prism	Chips	Transmittance	Angle
449006	0	99.934 ± 0.044 %/m	$18.089^\circ \pm 0.007^\circ$
449008	0	99.774 ± 0.043 %/m	$18.091^\circ \pm 0.007^\circ$
449009	0	99.935 ± 0.044 %/m	$18.073^\circ \pm 0.007^\circ$
449010	0	99.703 ± 0.043 %/m	$18.086^\circ \pm 0.005^\circ$



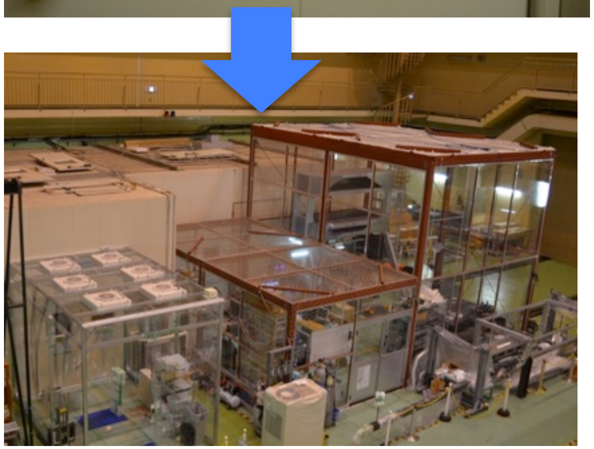


High Purity N2 System

- We will seal QBB and test leak.
- High purity N2 system is ready in Fuji hall

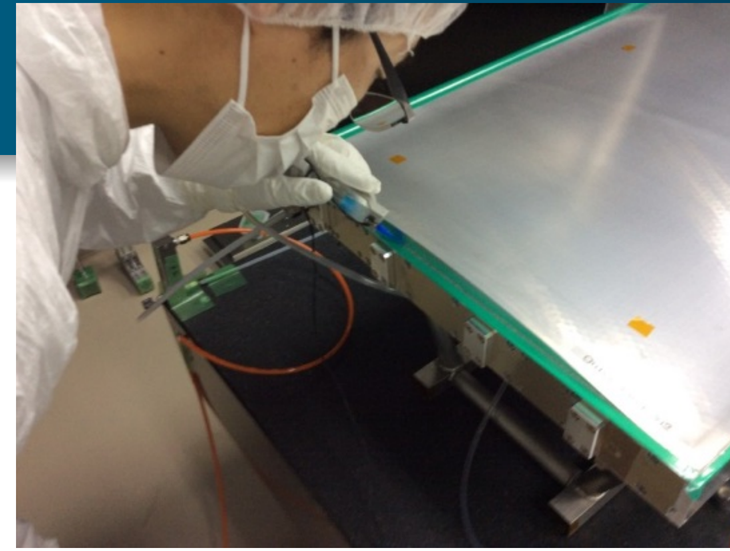


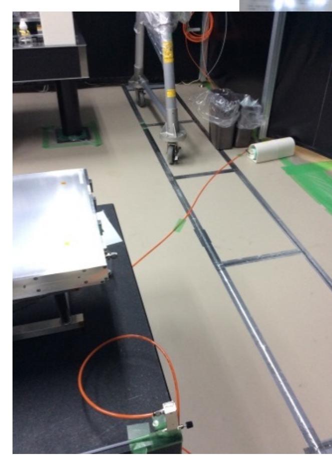
Lucien Cremaldi
(Mississippi)



Gas sealing

- QBB panels, side Rails, FWD endplate, prism enclosure were sealed with Si glue.
- Tested with Restek Electronic Leak Detector + Pure N2 (& G1 Ar)
  - Significant leaks were found in the prism enclosure through the mounts for CCD cameras, LED, fibers and others (fixed now).
- Started to flow pure N2, and measure dew point.
  - < -51 degC. (34.31ppm) achieved
  - Target is - 60 deg (11 vol.ppm) with the inlet flow rate of 0.5L/min. and pressure < 1kPa.





Plastic tubing is used for outlet-module