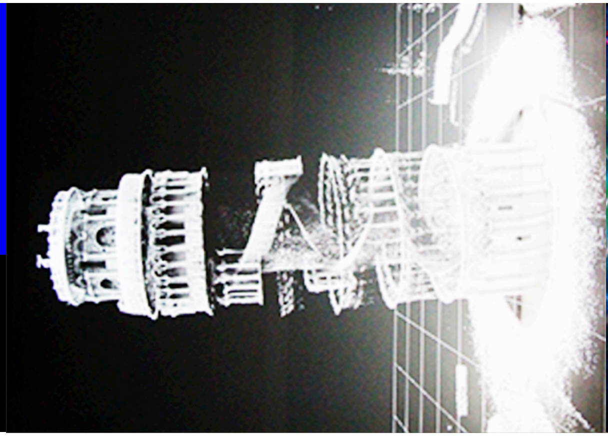


Particle identification with the TOP and AEROGEL detectors at Belle II

Ezio Torassa for the Belle II PID Group

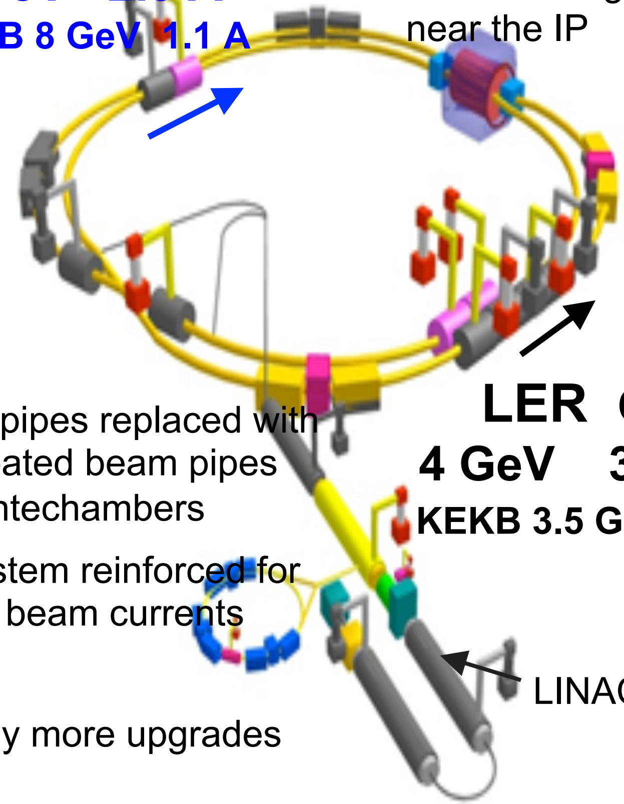
Frontier detectors for frontier physics
13th Pisa meeting on advanced detectors
24-30 May 2015 – La Biodola, Isola d’Elba (Italy)

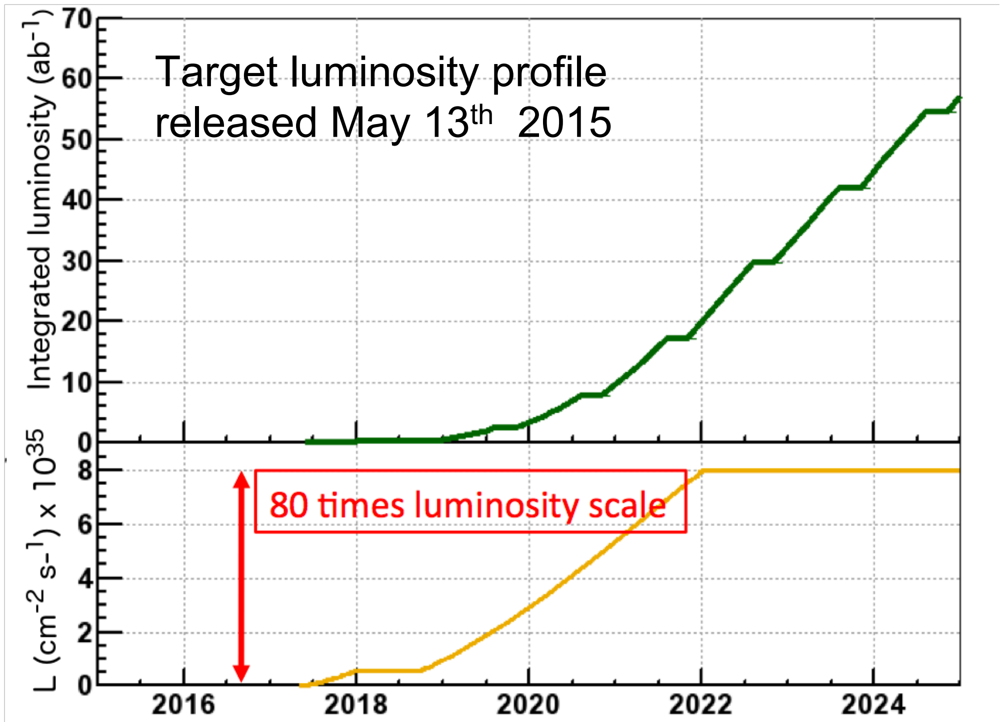
Overview

- SuperKEKB and Belle II vs Belle
- The Time Of Propagation Detector (TOP)
  - TOP detector concept
  - Cherenkov radiator
  - Micron channel plate PMTs
  - Front-end readout electronics
  - Control and calibration systems
  - TOP production
  - Physics performance
- Aerogel RICH
- Schedule for detector and accelerator
- Conclusions

The SuperKEKB Collider

The nano beam design: small beam-size and a large crossing angle at the interaction point, instead of a high current

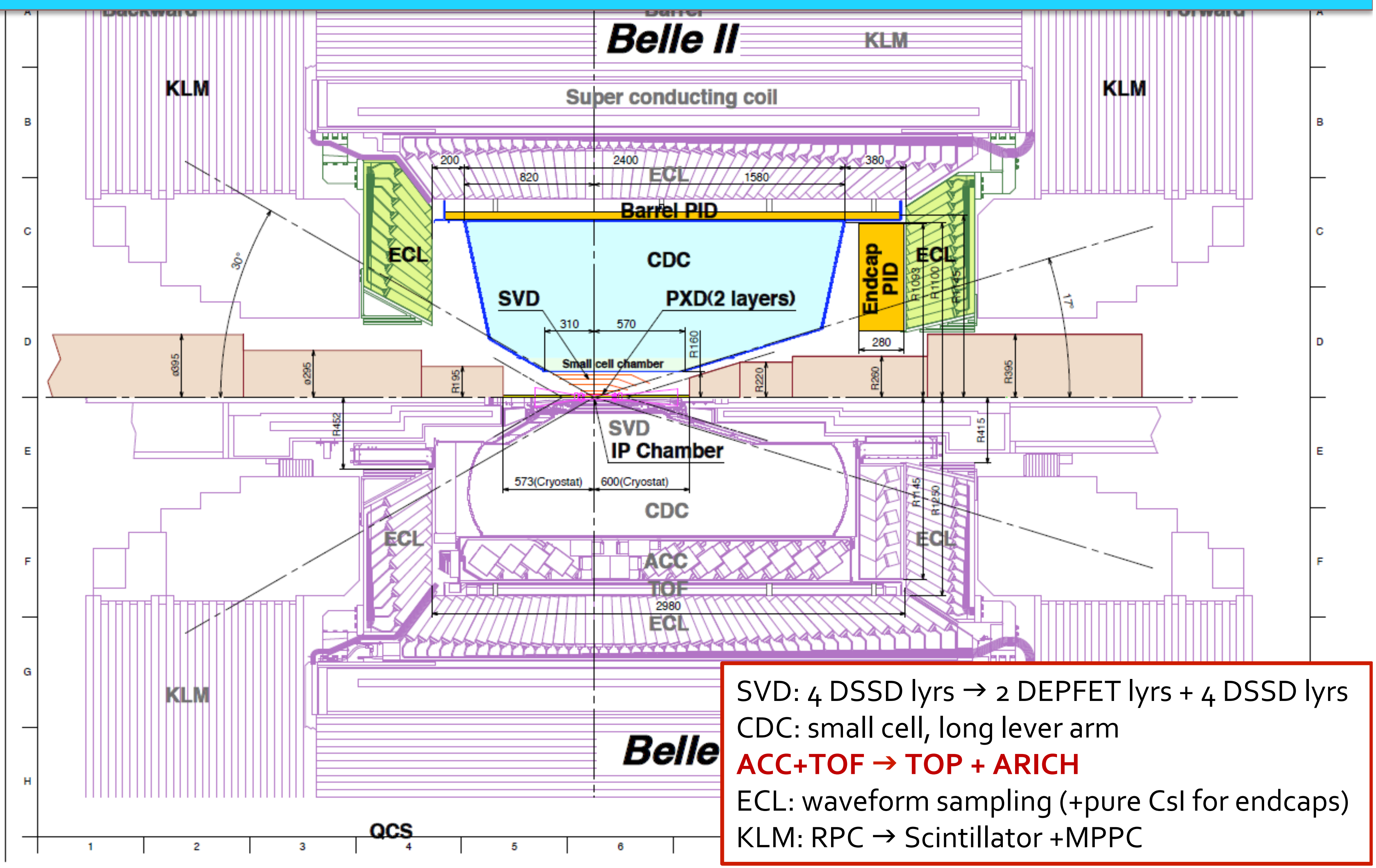




Upgraded KEK accelerator:

- will operate at 40x Belle luminosity
- will obtain $8 \cdot 10^{35}$ cms^{-2} s^{-1} , 20 ab^{-1} by 2022, $O(10^{10})$ B

Belle II vs Belle



SVD: 4 DSSD lyrs → 2 DEPFET lyrs + 4 DSSD lyrs
CDC: small cell, long lever arm
ACC+TOF → TOP + ARICH
ECL: waveform sampling (+pure CsI for endcaps)
KLM: RPC → Scintillator +MPPC

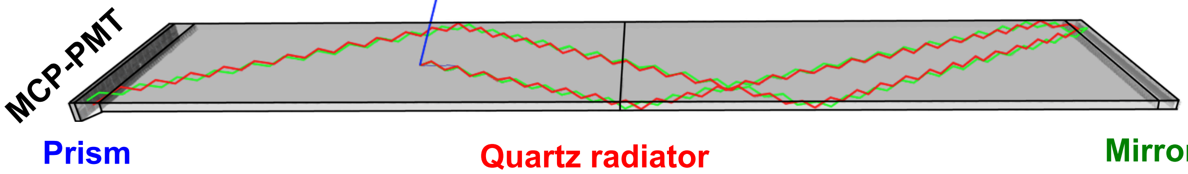
Time Of Propagation (TOP)

3 key elements in each TOP module:

16 TOP modules

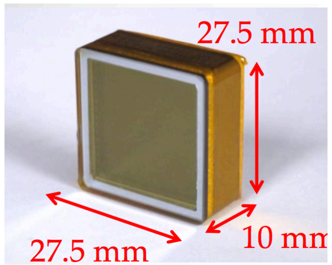
L = 100+2500+100 mm   W = 450 mm   H = 20 – 50 mm

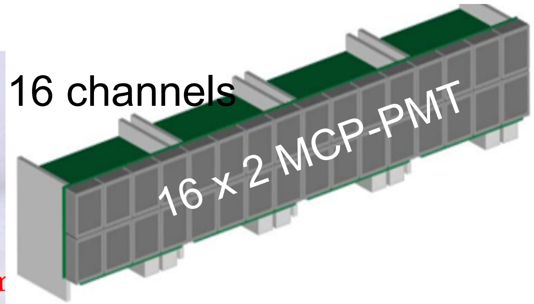
1) Cherenkov radiator



2) micro channel plate (MCP) PMT

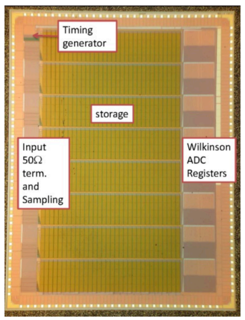
10^6 gain, 40 ps resolution



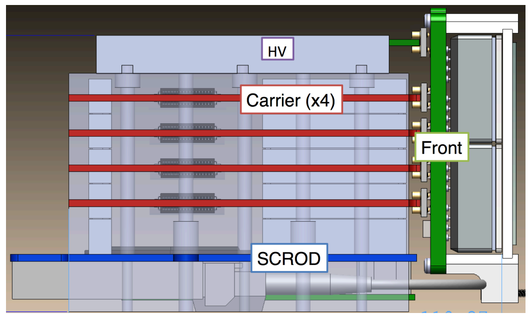


3) front-end readout electronics

design goal: < 50ps time resolution



ASIC

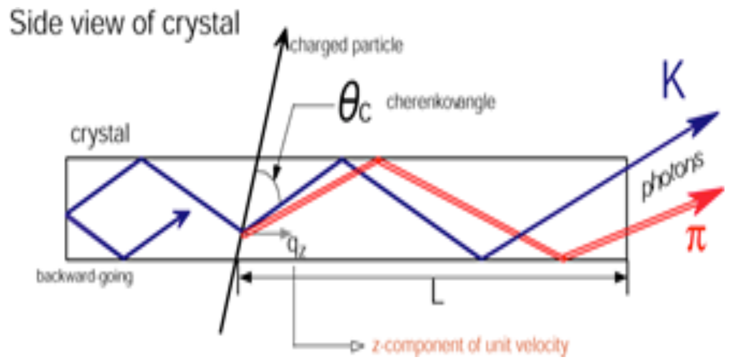


4 carrier boards x 4 ASICs

TOP detector concept

Use of the arrival time and position of the Cherenkov photons.

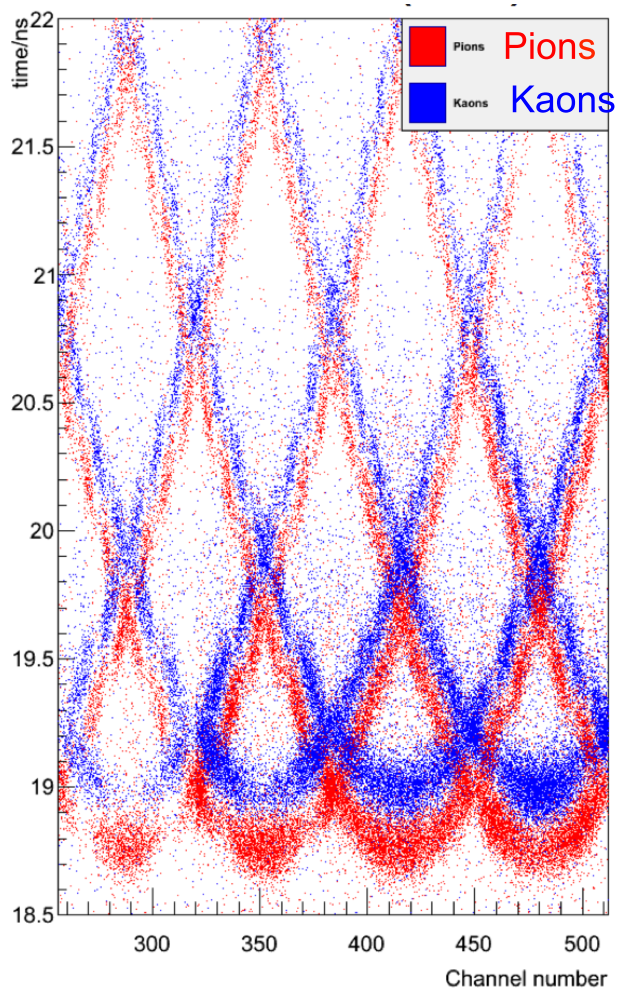
The different Cherenkov angle for photons from kaons leads to a later arrival time than for photons from pions.



A 2-dimensional PDF can be constructed based on detection time and detection position of Cherenkov photons.

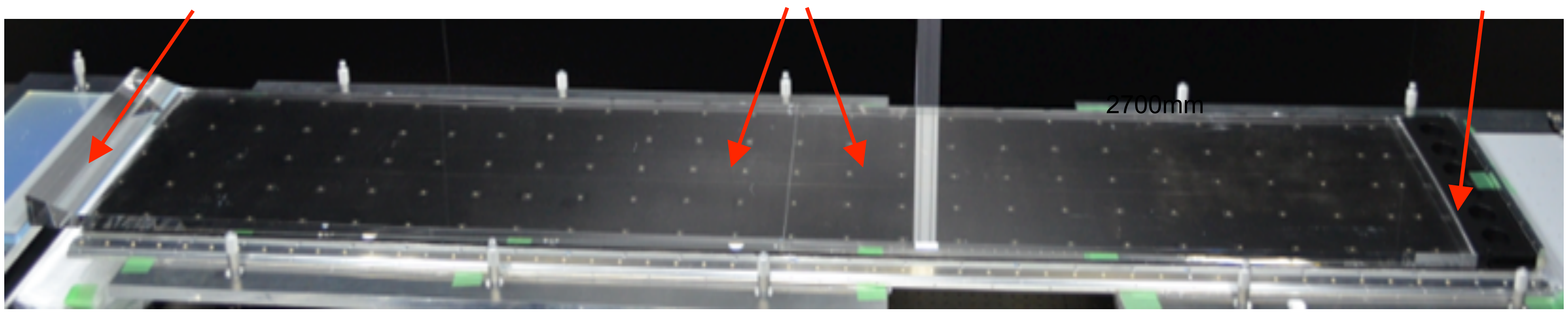
The primary use for the TOP will be to discriminate between kaons and pions.

Photon detection time vs channel #

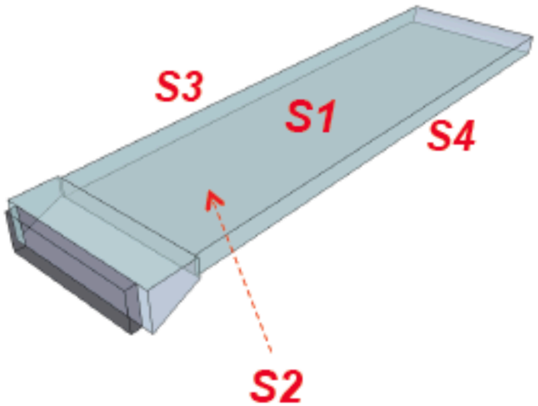


Cherenkov radiator

TOP module contains 2 quartz bars, 1 focusing mirror and 1 expansion block

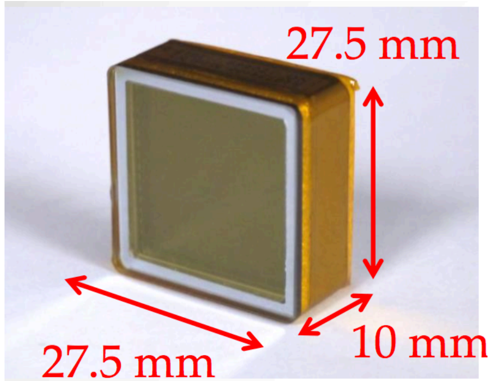


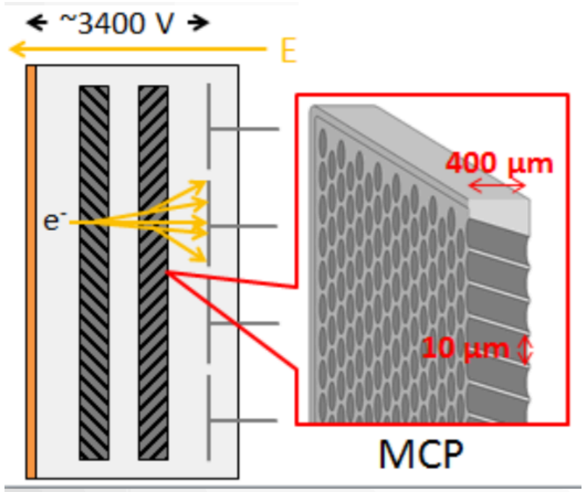
High quality quartz surfaces required for multiple internal photon reflections



○	Flatness	< 6.3 μm	S1,S2,S3,S4
○	Roughness	< 0.5 nm (RMS)	S1,S2,S3,S4
○	Perpendicularity	< 20 arcsec	S1 ⊥ S3,S4
○	Parallelism	< 4 arcsec	S1 // S2

Micro Channel Plate PMTs





MCP-PMT

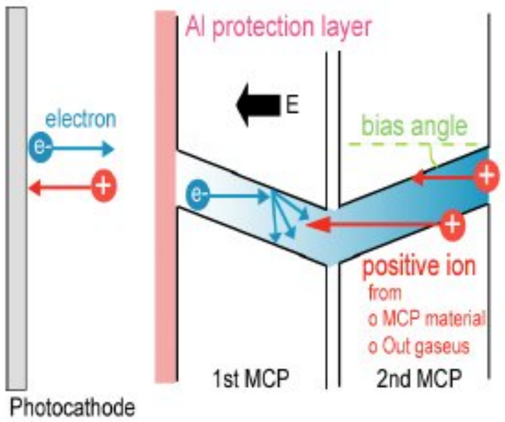
- Square-shape to minimize the dead space
- High-gain for single photon detection
  - ➔ $2x10^6$ at nominal HV
- Fast time response
  - ➔ Transit Time Spread (TTS) < 50 ps
- High quantum efficiency (QE)
  - ➔ QE > 24% (a.v. 28%) @ λ = 380 nm
- Operative in 1.5 T

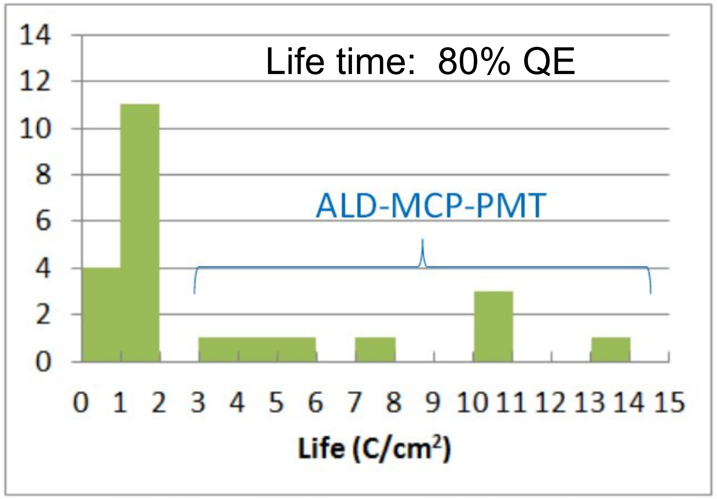
Photo-cathode	NaKSbCs
Anode	4x 4
Collection efficiency	50-55%
Nominal HV	~ 3.4 kV

32 MCP-PMTs / module, 512 total   16 channels / PMT, 8192 total

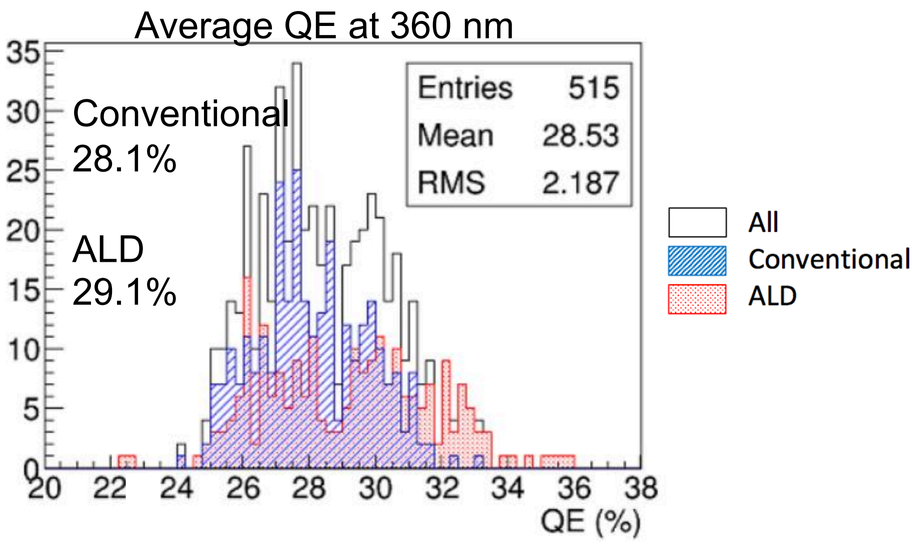
ALD MCP-PMT

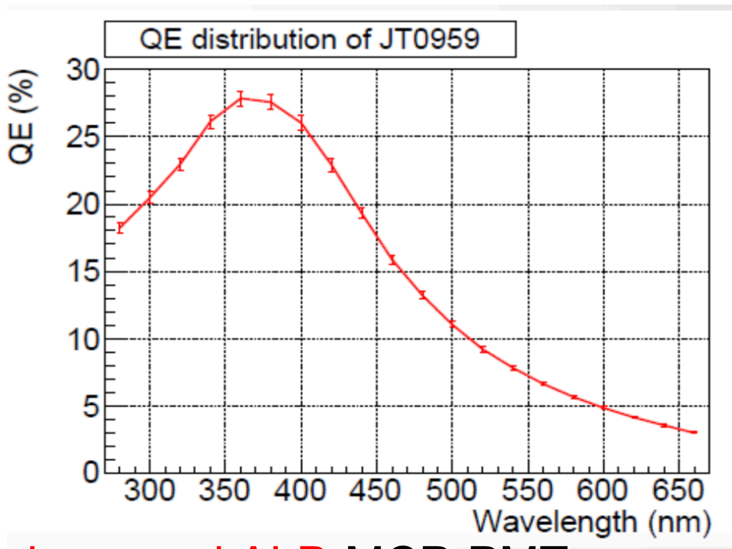
Atomic Layer Deposition (ALD). Protection of the photocathode from the positive ions





Average lifetime: 1.1 (normal), 8.6 (ALD) C/cm^2



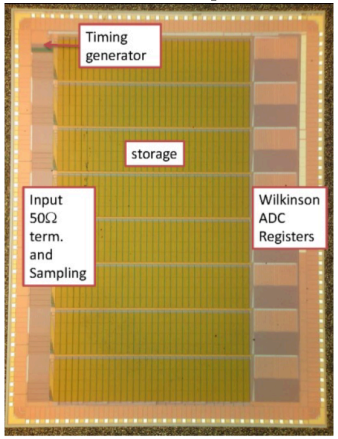


We have 284 conventional, 230 ALD and 54 Life improved ALD MCP-PMTs

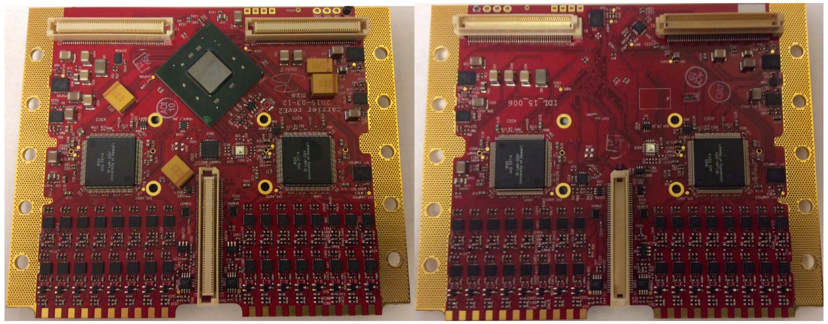
Front-end readout electronics

PMTs instrumented with electronics using high speed waveform sampling ASIC (IRSX)

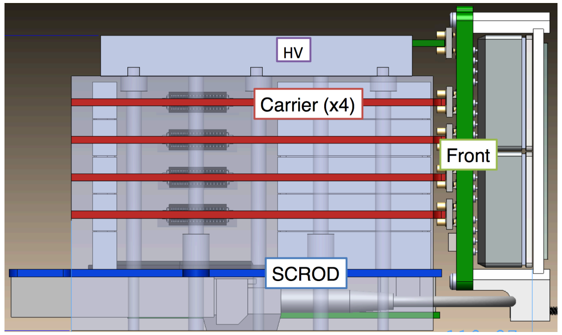
8 channels/chip 4 GHz ASIC



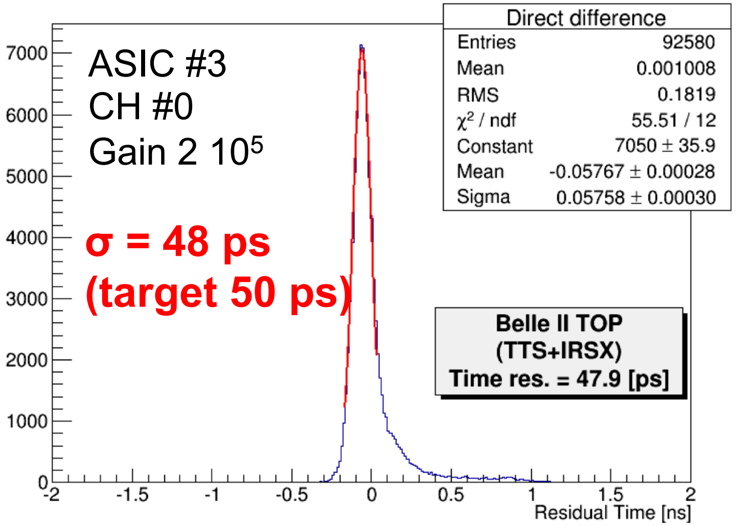
4 ASICs / Carrier board



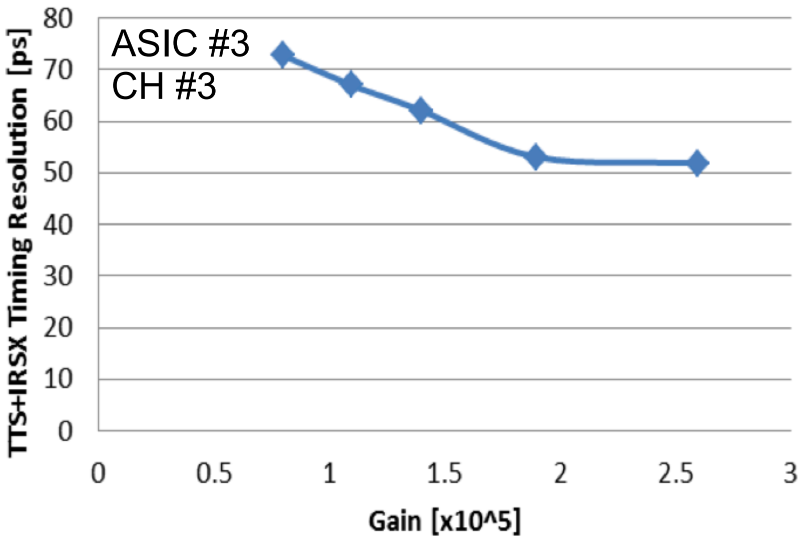
4 Carrier boards / 8 PMT



Time resolution of pulsed laser irradiation



Time resolution as a function of the PMT gain



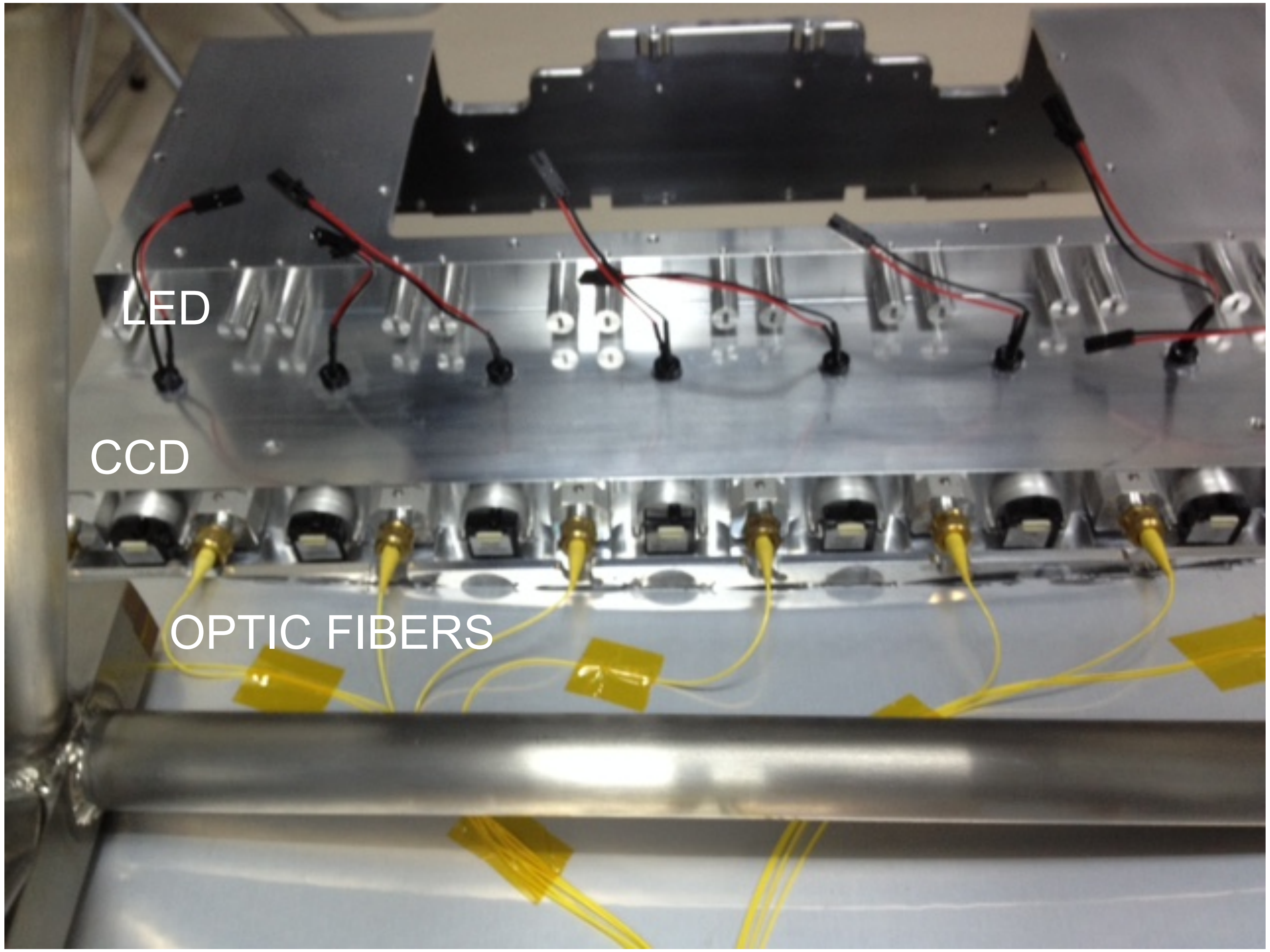
Control and calibration systems

LED and CCD

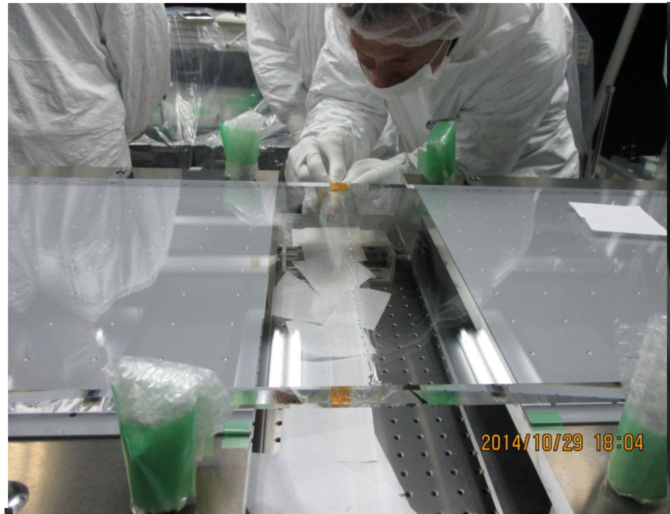
To control the quality of the optical coupling between quartz and PMT

Laser calibration system (optic fibers and lens)

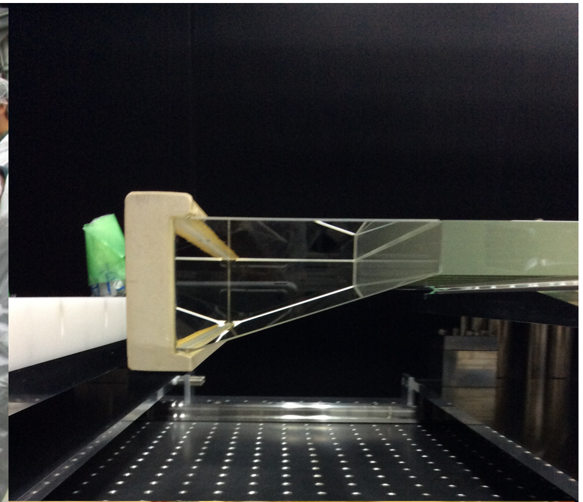
To control the PMT and the front-end electronic stability and to measure the relative QE of PMTs



TOP production



TOP module #1 quartz gluing

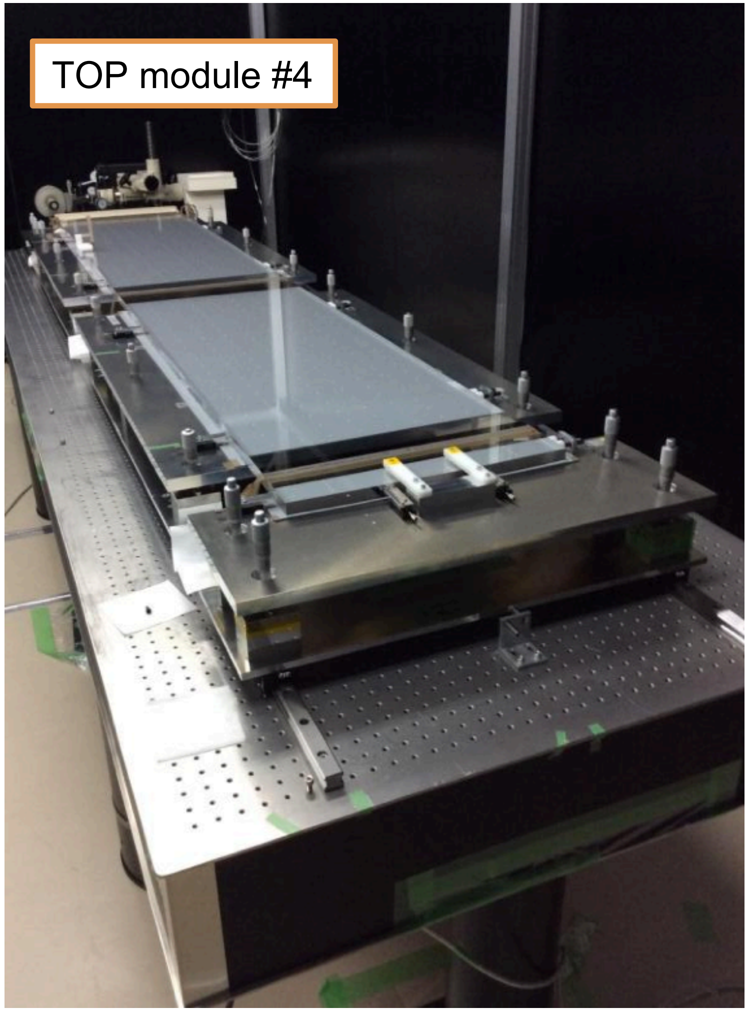


TOP module #1 completed

TOP module #1 inside CRT

TOP production

	Mechanical Assembly		Electronics Integration
	Start	Finish	Complete
Module 01	Oct 2014	Nov 2014	Feb 2015
Module 02	Mar 2015	April 2015	
Module 03	April	April	
Module 04	May	May	
Module 05	June	June	
Module 06	June	July	
Module 07	July	Aug	
Module 08	Aug	Sept	
Module 09	Sept	Oct	
Module 10	Oct	Oct	
Module 11	Nov	Nov	
Module 12	Nov	Dec	
Module 13	Jan 2016	Jan 2016	
Module 14	Jan	Feb	
Module 15	March	March	
Module 16	March	April	
Module 17	April	May	
Module 18	May	May	



Physics performance

The TOP readout needs to have excellent time resolution to distinguish between particle types, with a requirement of better than 100 ps, and a goal of 50 ps.

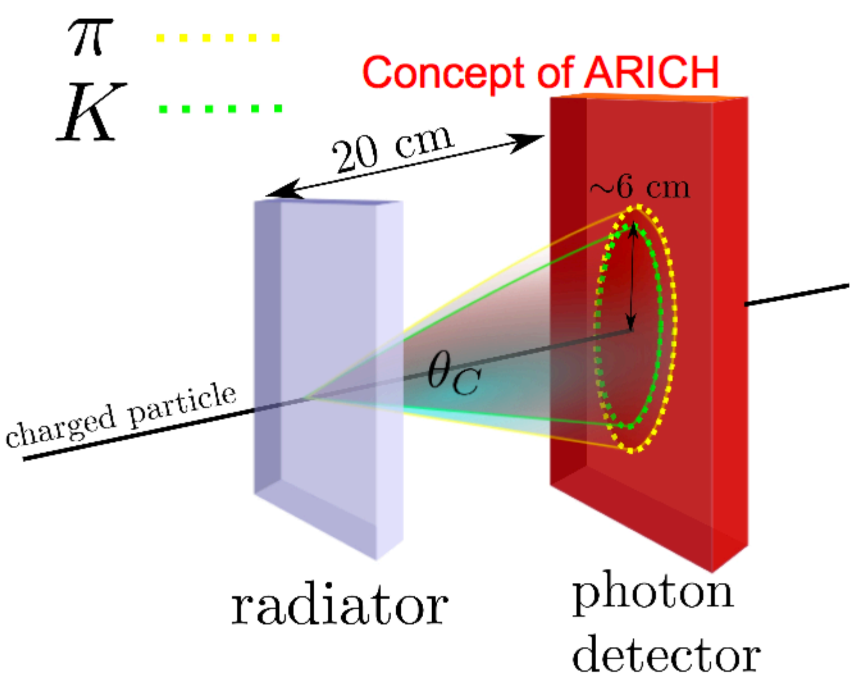
Final PID performance will also include information from other subdetectors, e.g. dE/dx to form a likelihood for each particle hypothesis.

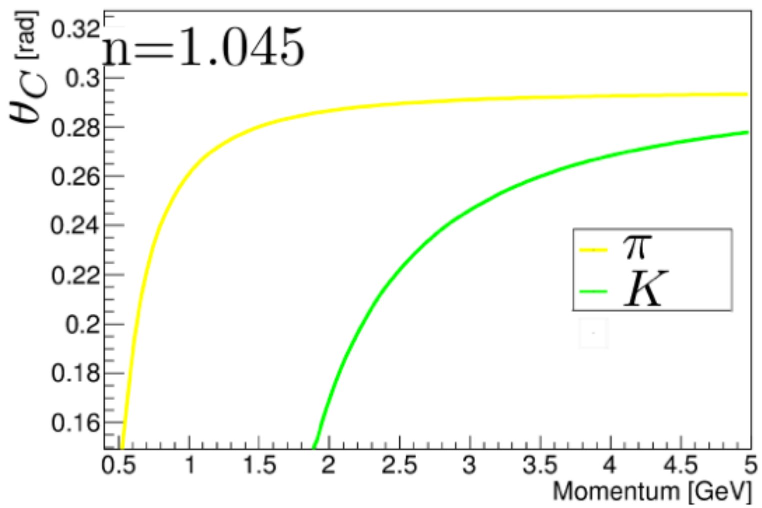
Decay mode	π efficiency with 2% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 50ps electronics jitter
$B \to \pi\eta\gamma$ vs $K\eta\gamma$	84.28 +/- 0.91	94.13 +/- 0.57	93.22 +/- 0.52
$B^+ \to \rho\gamma$ vs $K^*\gamma$	80.71+/-1.07	93.19+/-0.67	92.55 +/- 0.62
$B^0 \to \rho\gamma$ vs $K^*\gamma$	81.50+/- 0.78	92.63+/-0.49	92.13 +/- 0.46
$B^+ \to \pi\pi\pi^0\gamma$ vs $K\pi\pi^0\gamma$	83.55+/-0.76	94.03+/-0.46	93.47 +/- 0.43
$B^0 \to \pi\pi\gamma$ vs $K\pi\gamma$	79.50 +/- 0.67	91.48+/-0.45	92.56 +/- 0.38
$B^+ \to \pi\pi\pi\pi^0\gamma$ vs $K\pi\pi\pi^0\gamma$	75.00+/-0.72	90.50 +/-0.44	91.01 +/- 0.38
$B^0 \to \pi\pi\pi\gamma$ vs $K\pi\pi\gamma$	76.33+/-0.37	90.00+/-0.33	92.20 +/- 0.31

ARICH

Goal:
4σ separation, at 1.0 - 3.5 GeV

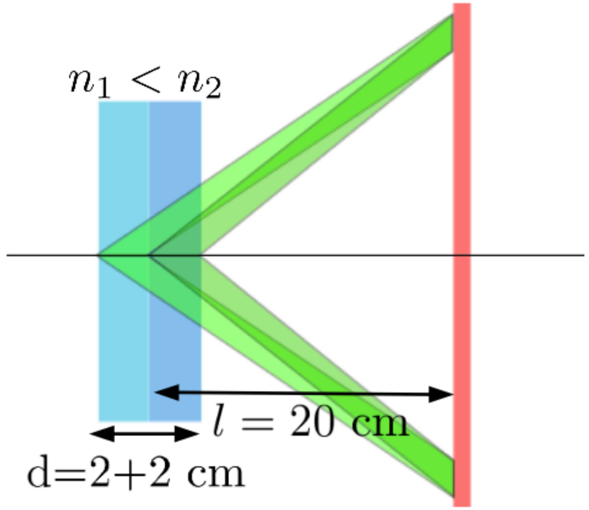
Constraints:
- in 1.5 T magnetic field.
- limited available space ~ 28 cm.
- radiation hardness (n, γ).





$\theta_C(\pi) - \theta_C(K) \sim 30$ mrad @ 3.5 GeV

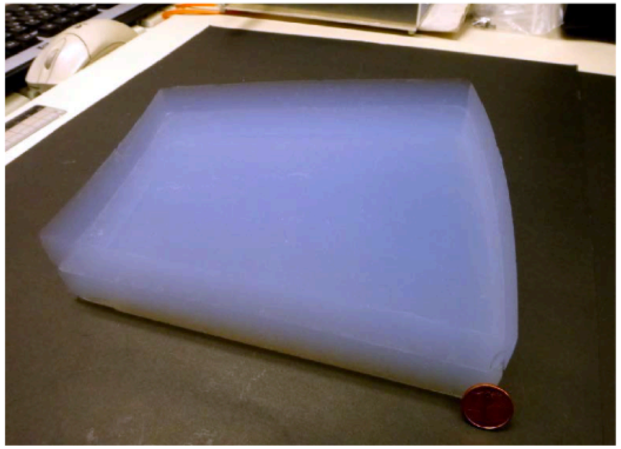
ARICH

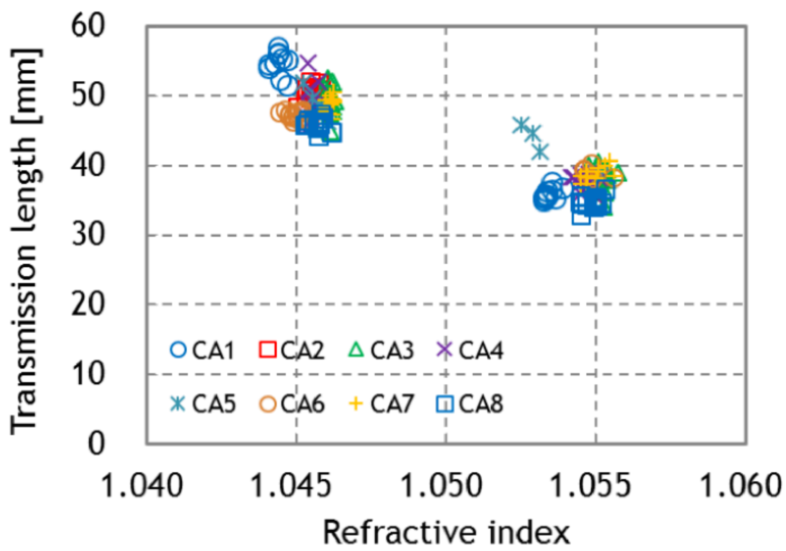


Two aerogel layers in focusing configuration:
n_1=1.405 , n_2=1.055
Overlapping rings from 1st and 2nd layer
High transmission length is required (>30 mm).

Mass production is ongoing, with relatively stable transmission length and refractive index

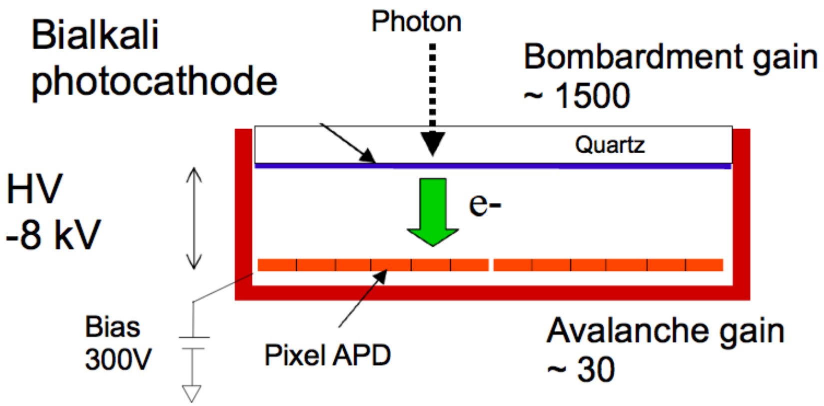
Minimize photon loss on tile edges
→ large tiles (~ 18 x 18 cm)

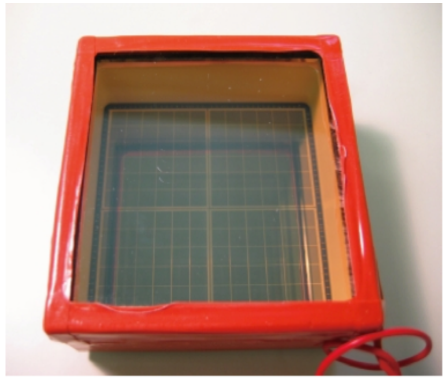


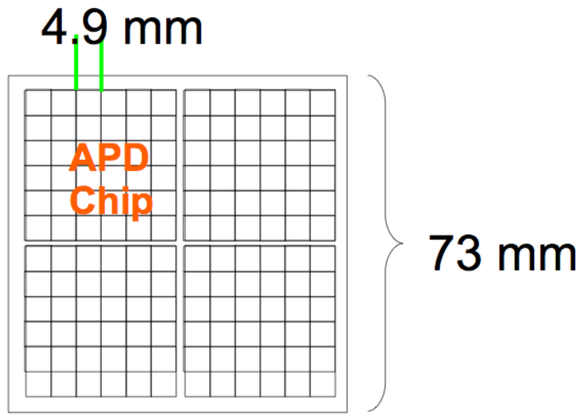


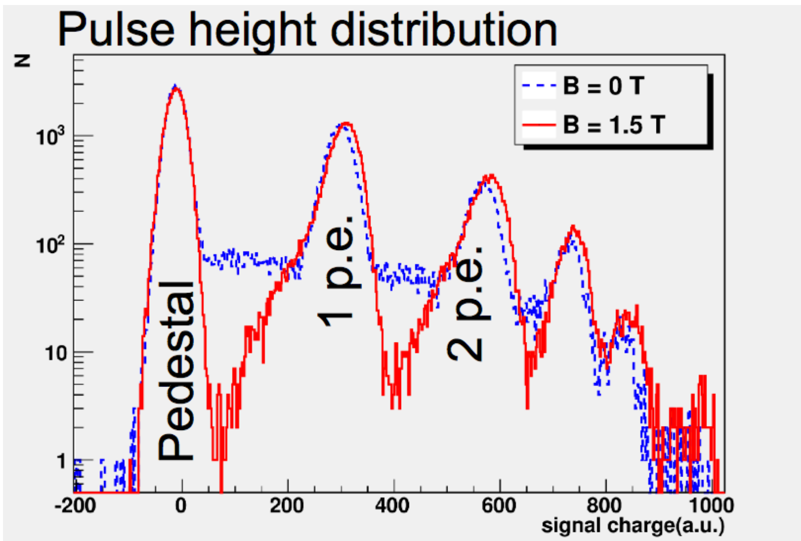
ARICH

Photon detector HAPD (Hybrid Avalanche Photo-Detector)

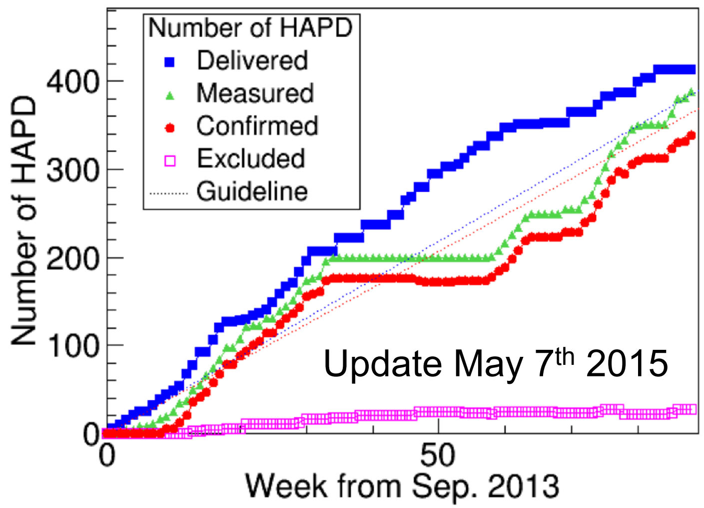




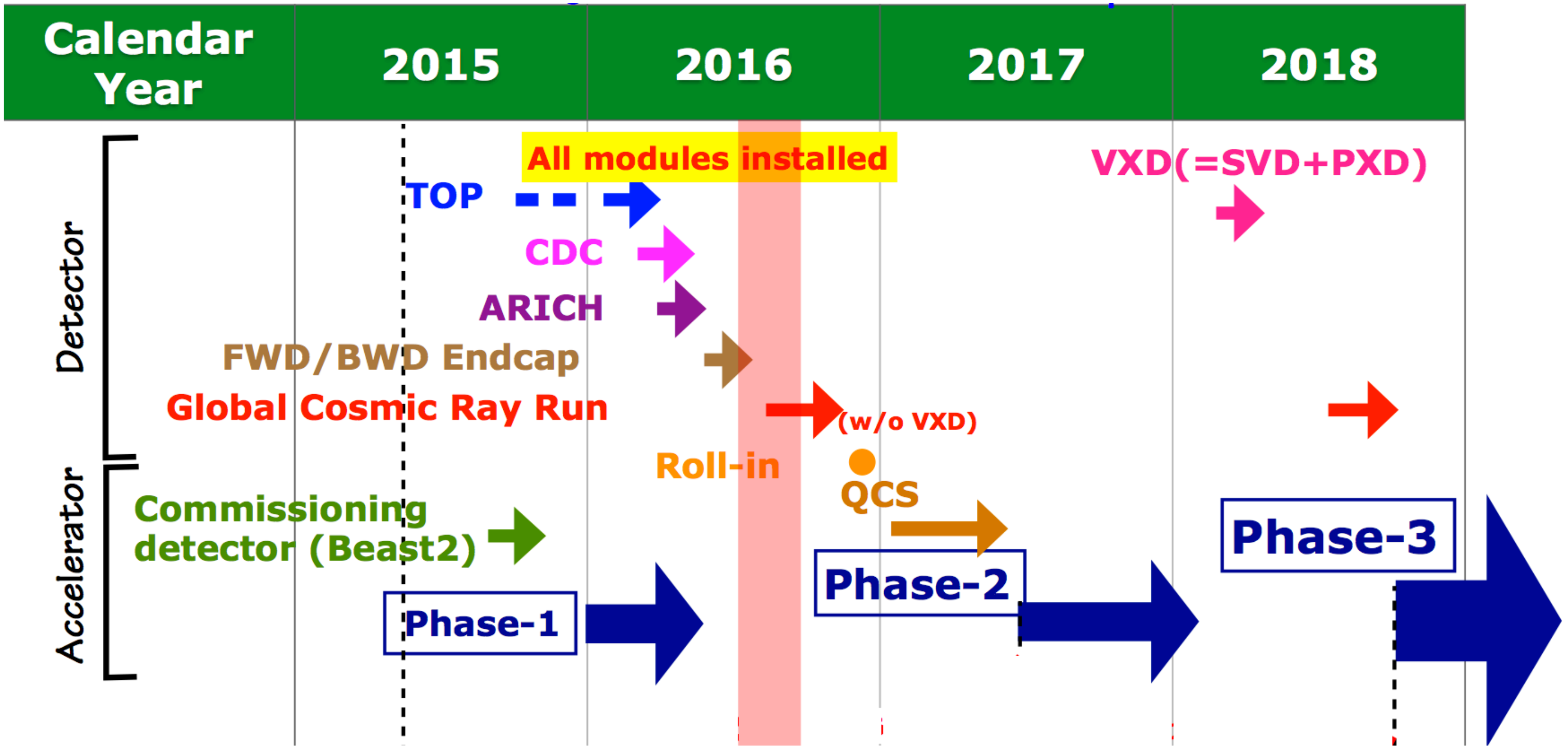




Delivered = 413 of of 450 +26



Schedule


Calendar Year
2015
2016
2017
2018
All modules installed
TOP
CDC
ARICH
FWD/BWD Endcap
Global Cosmic Ray Run
(w/o VXD)
VXD(=SVD+PXD)
Roll-in
QCS
Commissioning detector (Beast2)
Phase-1
Phase-2
Phase-3
Detector
Accelerator

Conclusions

- Belle II will be equipped with 2 new PID detectors: TOP and ARICH
- Quartz components have been produced with the expected time schedule and with the required specifications
- New MCP-PMTs (improved ALD) with a life time increased by a factor 10 have been developed in collaboration with Hamamatsu
- TOP Module #1 is complete and under test at the CRT station, 4 modules have the quartz elements already glued
- Mass production of the Aerogel is ongoing and HAPD production is close to the end

Backup

Lorentz factor

Beam current

Beam-beam parameter

$$L = \frac{\gamma_{e\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

correction coefficient

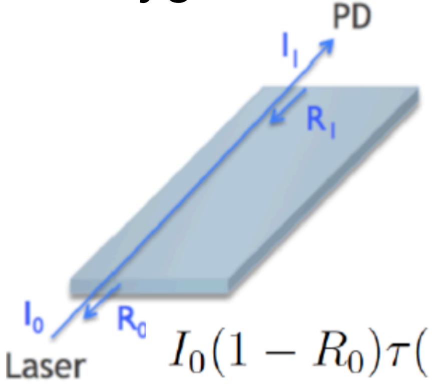
σ: Beam size

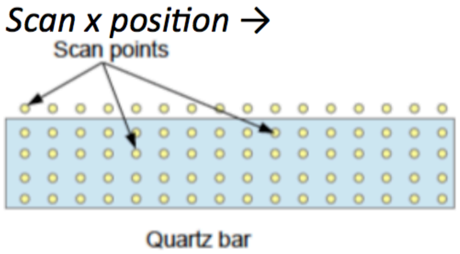
β function: aperture of beam

parameters		KEKB		SuperKEKB		units	
		LER	HER	LER	HER		
Beam energy	E_b	3.5	8	4	7.007	GeV	
Half crossing angle	ϕ	11		41.5		mrad	
# of Bunches	N	1584		2500			
Horizontal emittance	ε_x	18	24	3.2	5.3	nm	
Beta functions at IP	β_x^*/β_y^*	1200/5.9		3.2/0.27	2.5/0.30	mm	×20
Beam currents	I_b	1.64	1.19	3.6	2.6	A	×2
Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um	
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$	

for the Belle II experiment

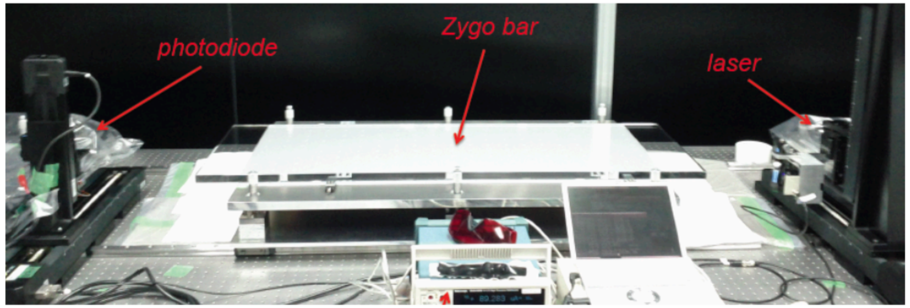
- *Bar inspection*
  - *Measured the bulk transmittance and surface reflectivity.*
  - *Zygo bar #4 measurements*

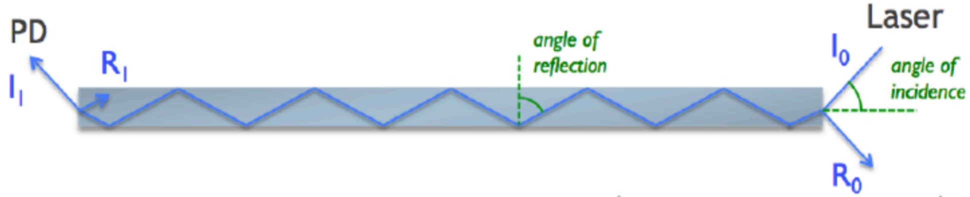




$$I_0(1 - R_0)\tau(1 - R_1) = I_1$$

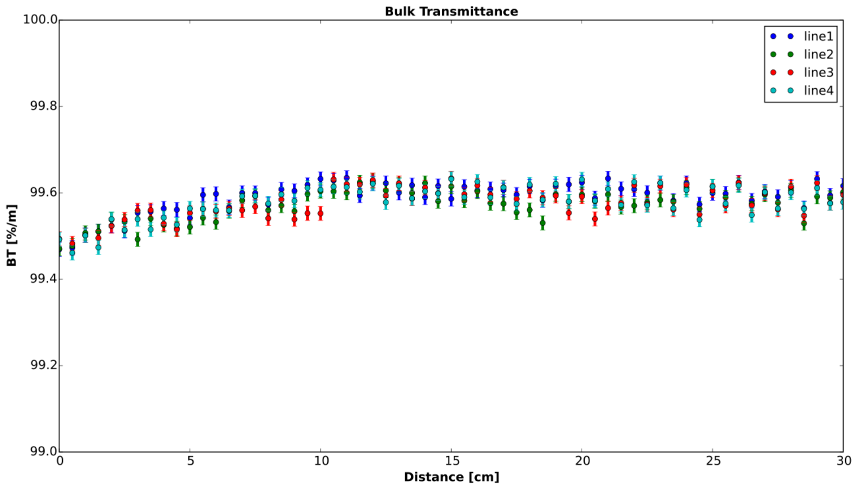
I_0, I_1: Measured with PD.
R_0, R_1: Calculated via Fresnel eqs.

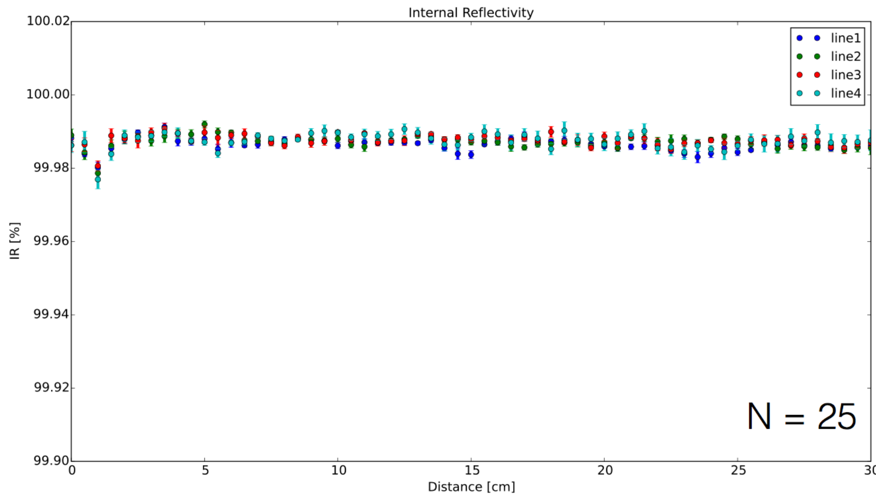




$$(I_1 - R_1) = (I_0 - R_0) \cdot \alpha^N \cdot \exp\left(-\frac{L}{\Lambda} \cdot \sqrt{1 + (Nh/L)^2}\right)$$

N: Number of reflections.
Λ: Attenuation length (> 1000 m @ λ = 530 nm).
L: Bar length (1250 mm), h: Bar height (20 mm).





Bulk Trans. = (99.58 ± 0.04) %/m

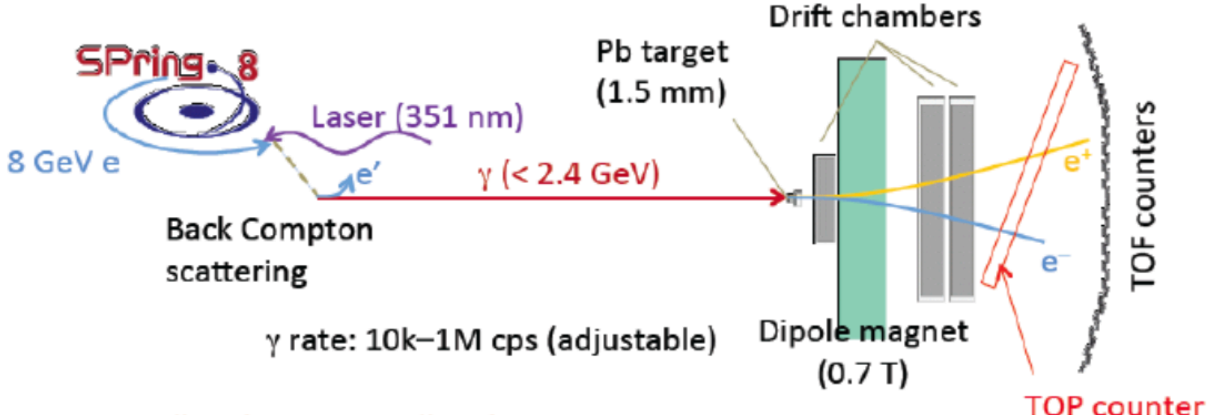
> 98 % (requirement)

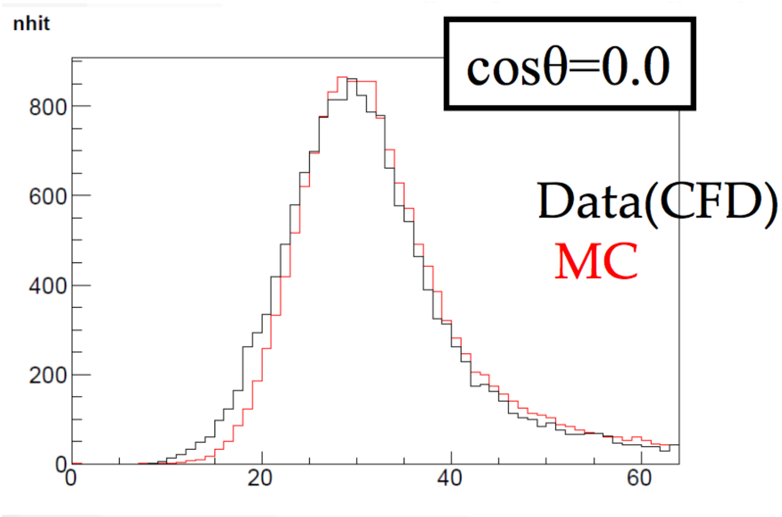
Internal Reflect. = (99.987 ± 0.002) %

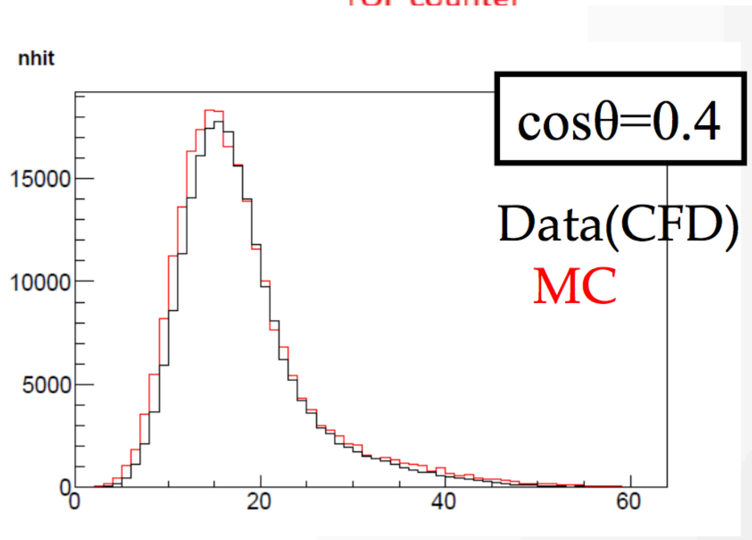
> 99.9 % (requirement)

Beam Test Data/MC

Tested TOP prototype at the LEPS beamline at SPring-8 in Japan







Good agreement in # of hits distribution