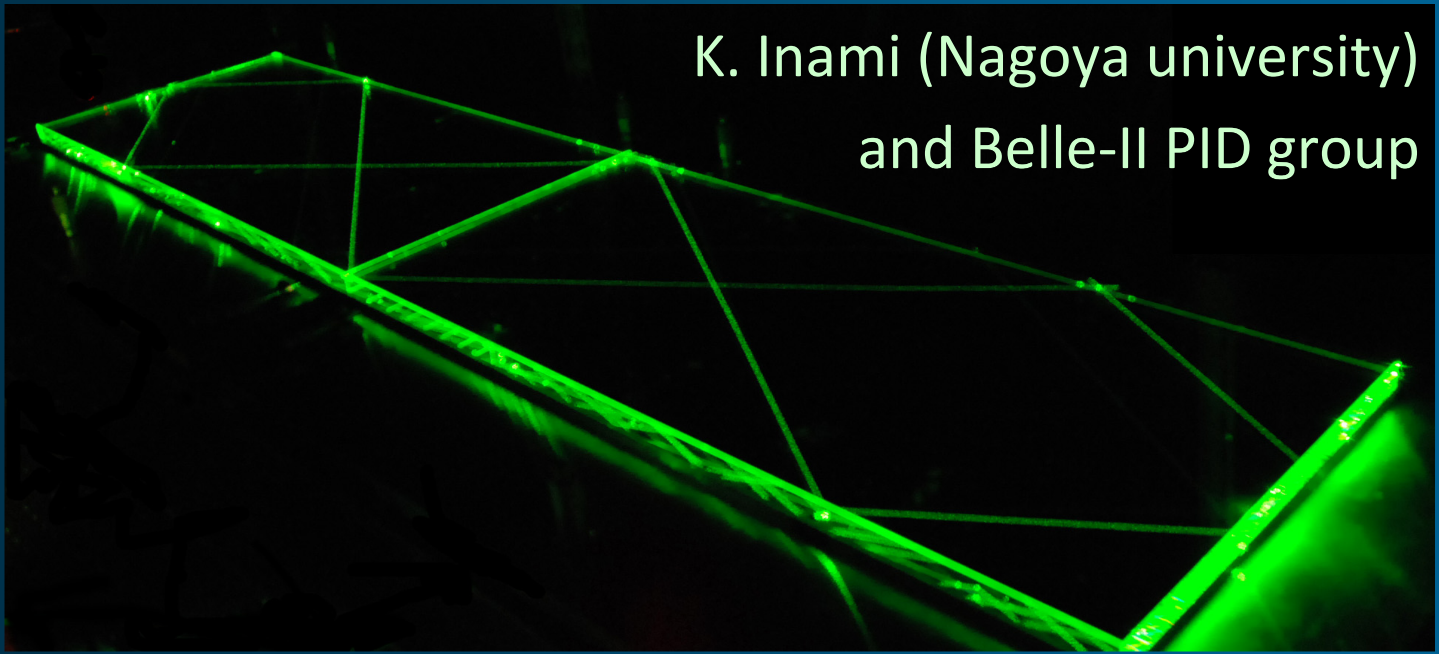
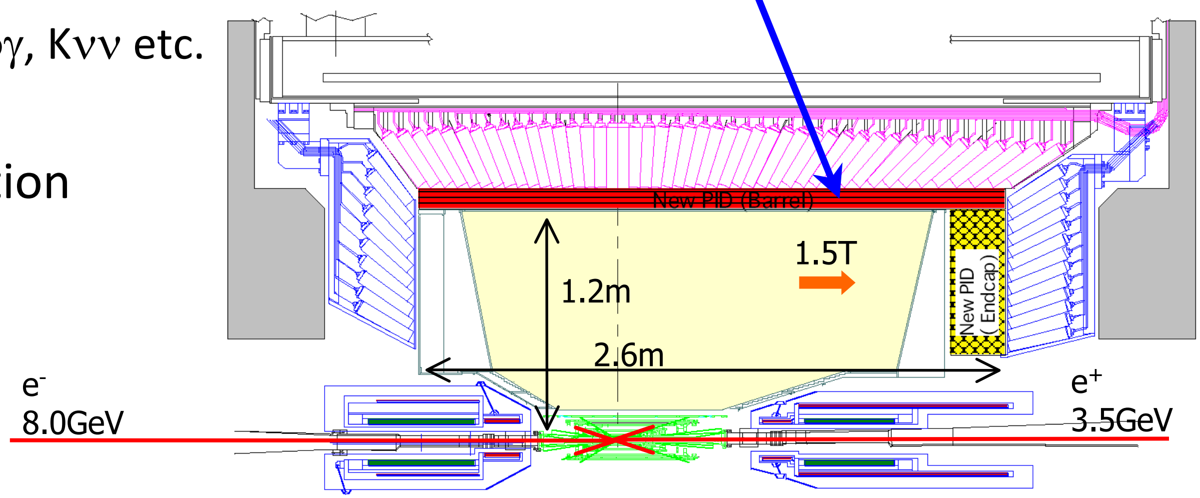
TOP counter prototype R&D



K. Inami (Nagoya university)
and Belle-II PID group

Introduction

- TOP (Time Of Propagation) counter
  - Developing to upgrade the barrel PID detector
  - For super KEKB/Belle-II
    - L_{peak}~$8x10^{35}/cm^2/s$, ~40 times higher than present
      - Need to work with high beam BG
  - To improve K/π separation power
    - Physics analysis
      - B→ππ/Kπ, ργ, Kνν etc.
    - Flavor tag
    - Full reconstruction

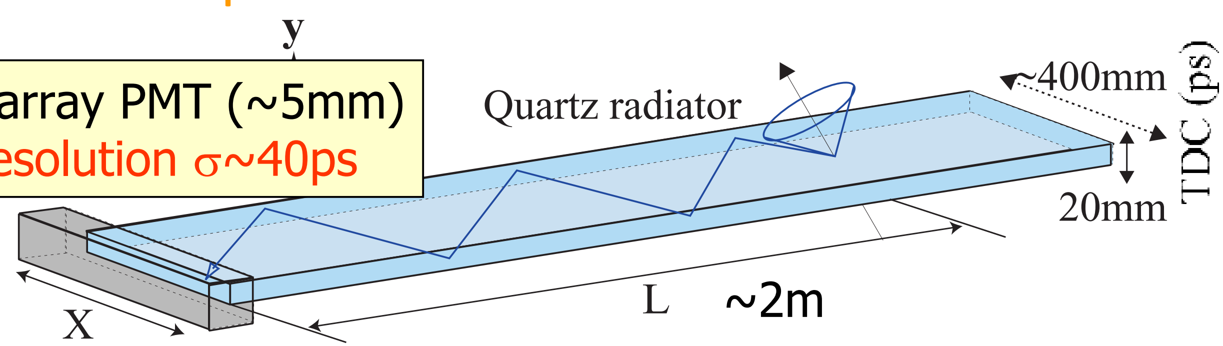


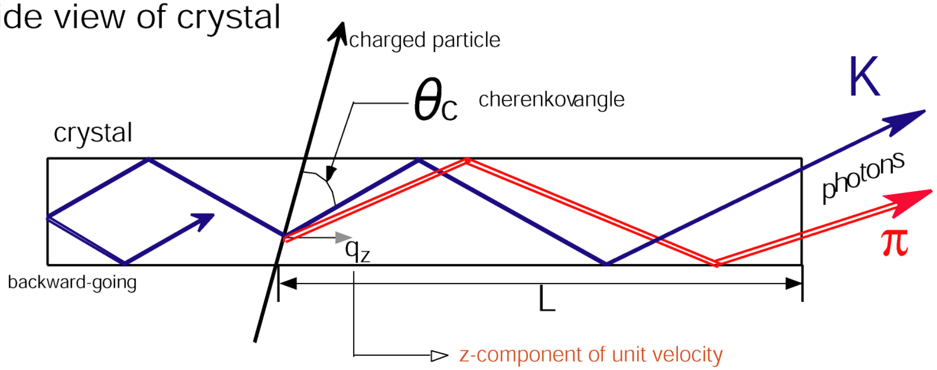
Side view of **Belle II** detector

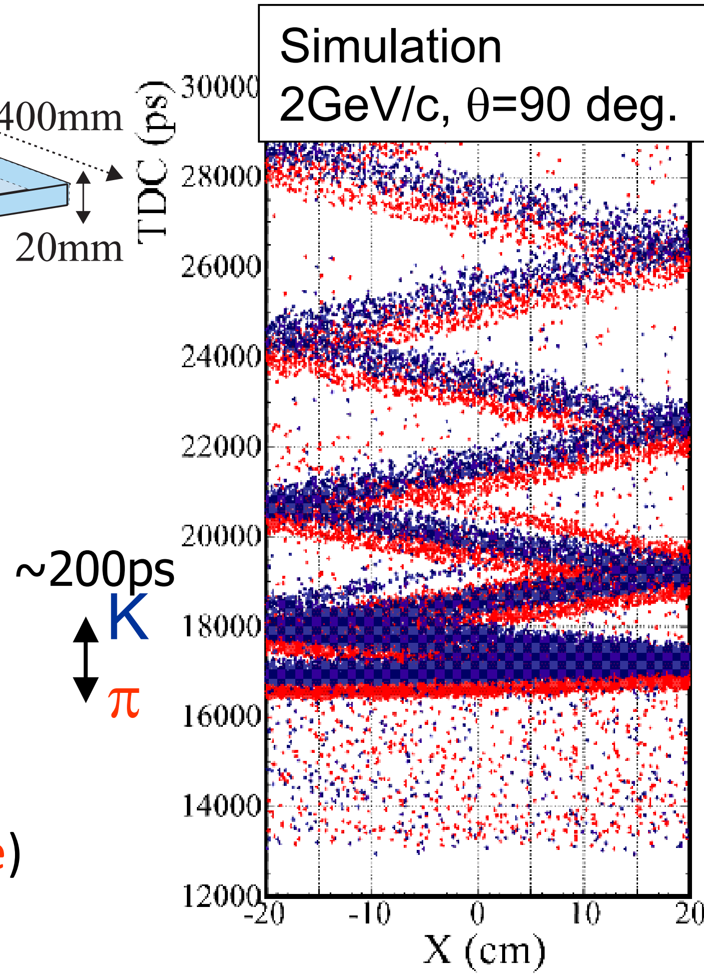
TOP counter

- <u>Position+Time</u> of arrival Cherenkov photons
  - Compact detector!

Linear array PMT (~5mm)
Time resolution σ~40ps



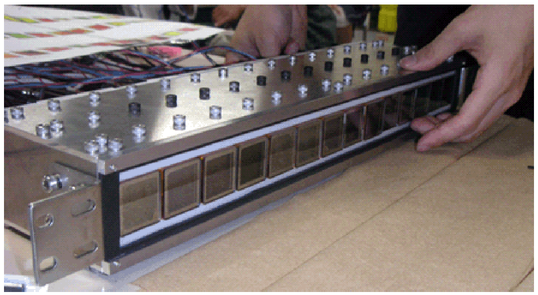


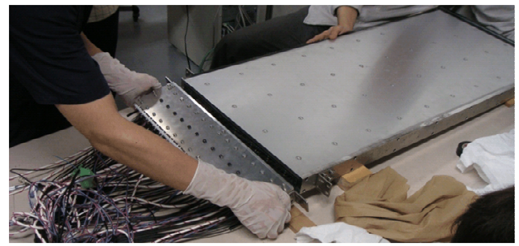


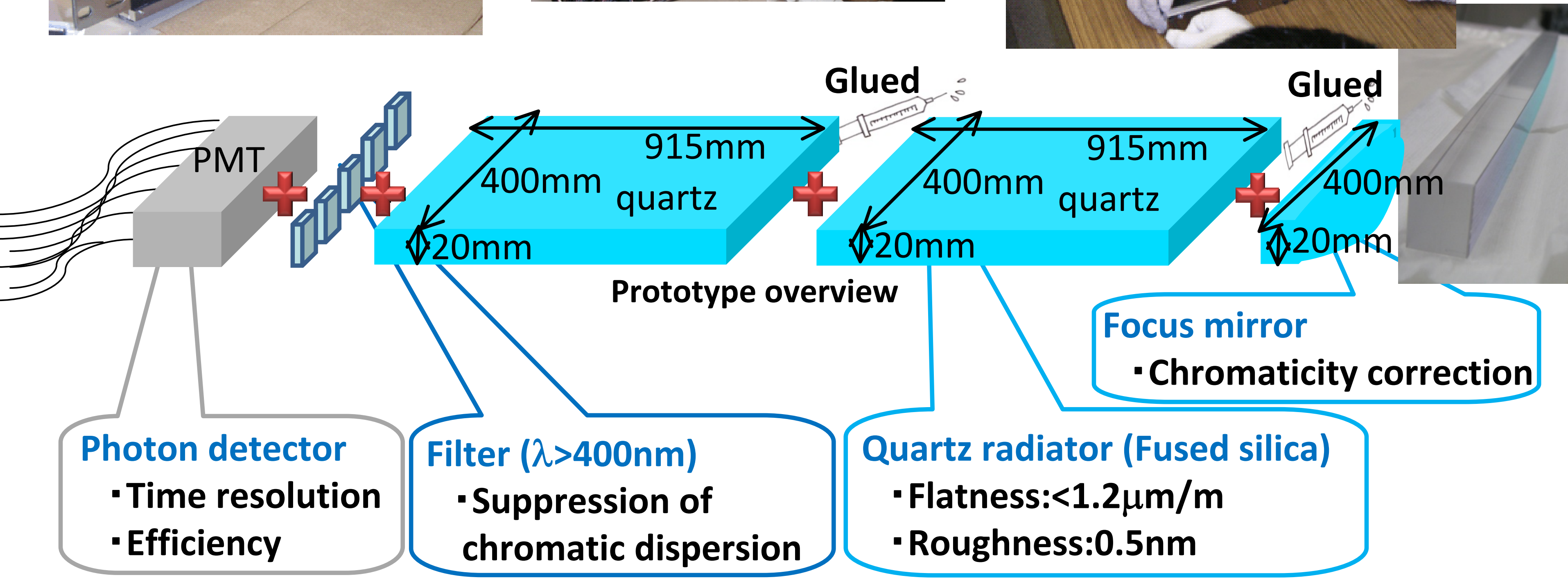
Different opening angle for the same momentum
→ Different propagation length(= propagation time)

+ TOF from IP works additively.

- Demonstration of the performance

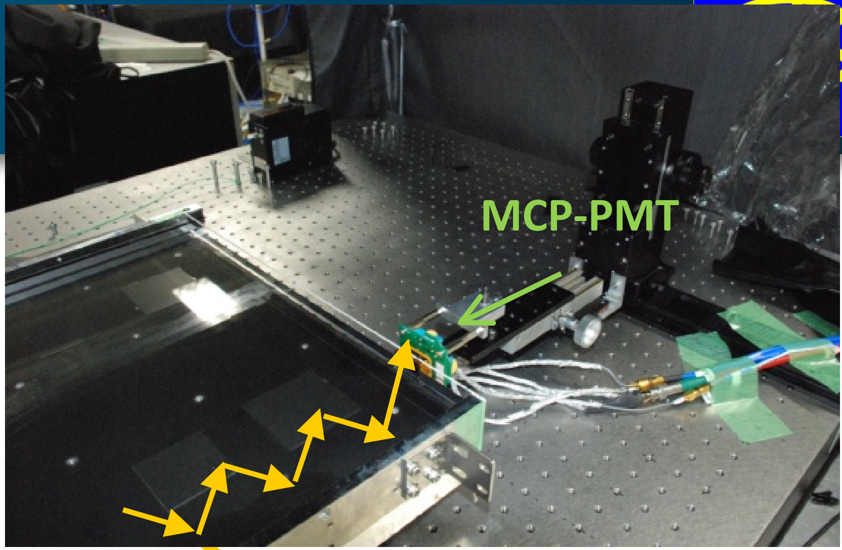


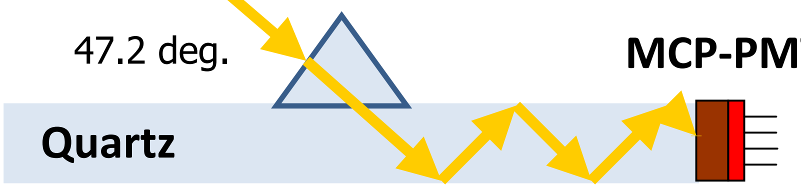


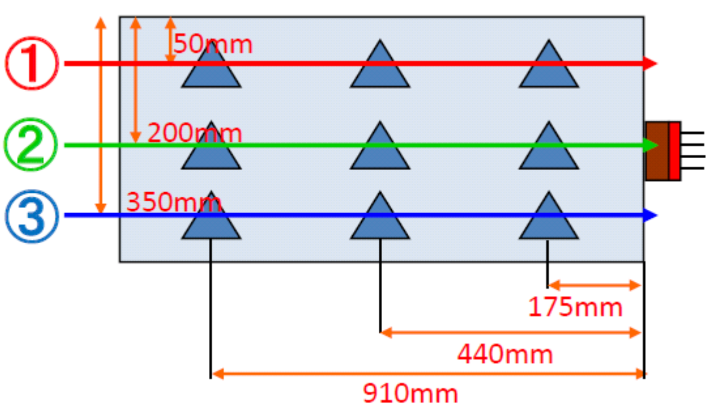


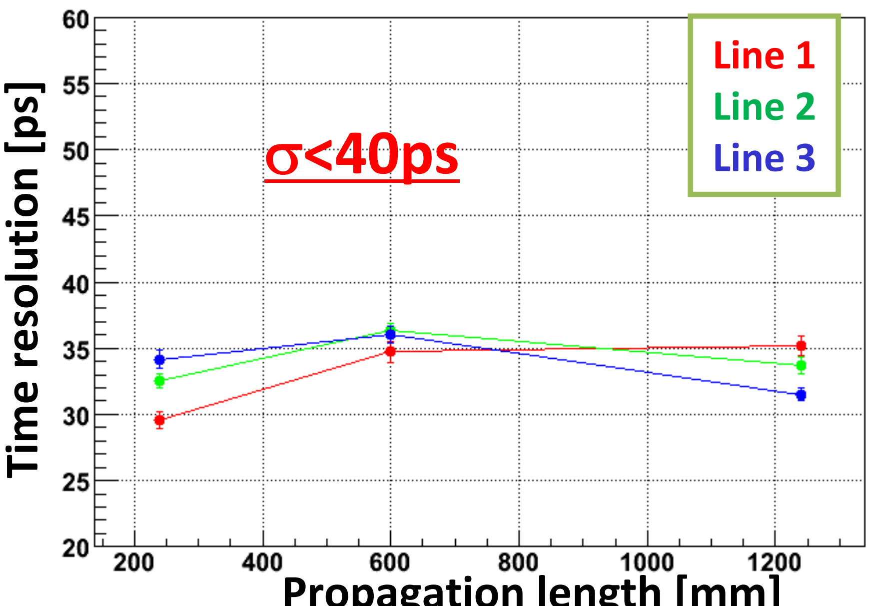
Quartz radiator

- Made by Okamoto optics
  - Size; 91.5 x 40 x 2 cm^3
  - Flatness: <1.2μm/m
  - Roughness: <0.5nm
- Check the quality for time resolution
  - Single photon pulse laser
    - λ=407nm
  - MCP-PMT
  - Several incident position
- → No degradation of time resolution
  - Enough quartz quality

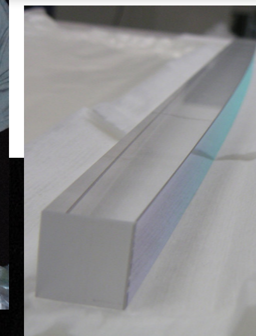


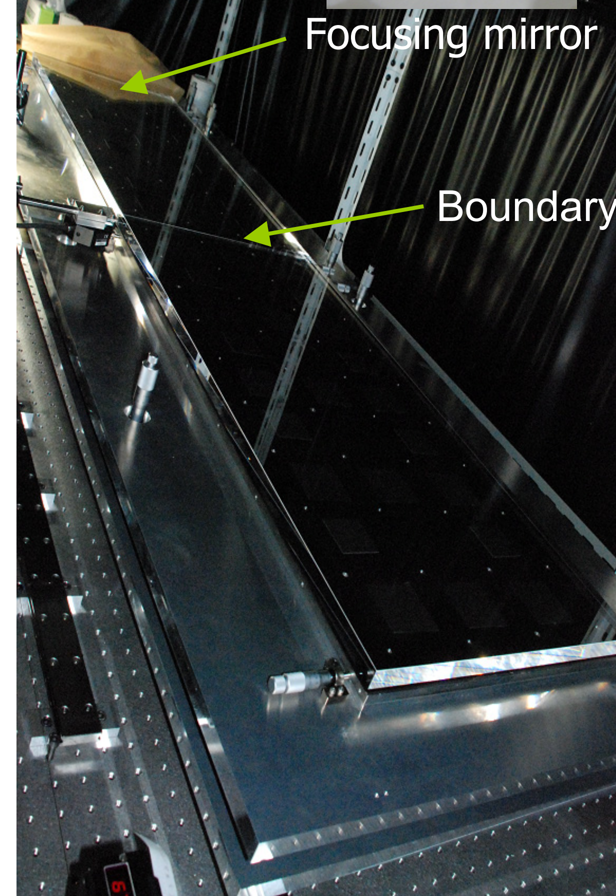




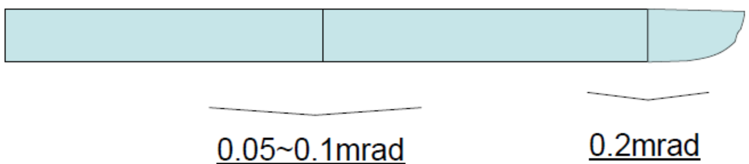


Quartz radiator

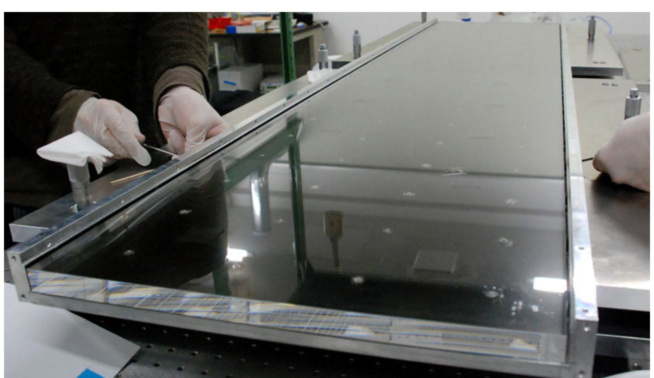




- Two fused silica bars
- Focusing mirror (R=5m)
- Glued
  - UV cure type (NOA63)
  - Flatness; ~0.2mrad
    - Laser depth meter
    - Laser reflection at mirror



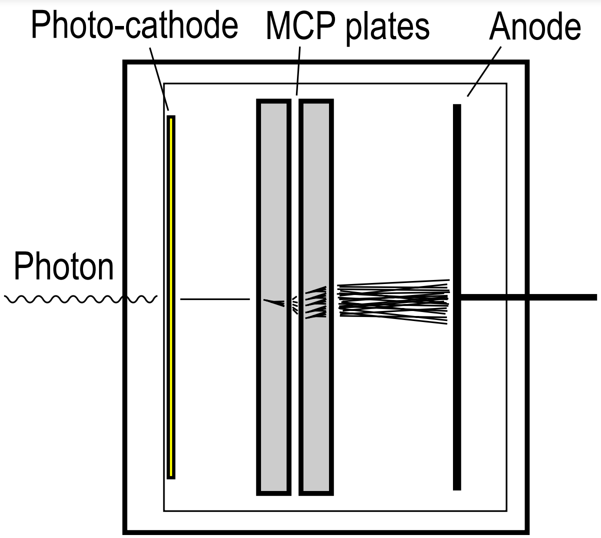
- Supported by aluminum honeycomb board

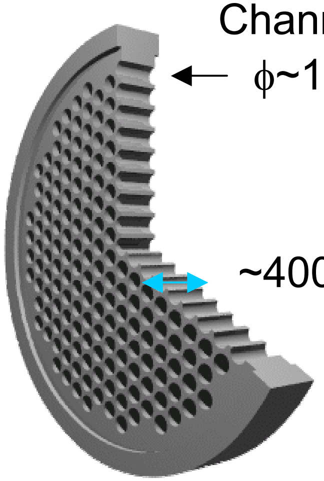


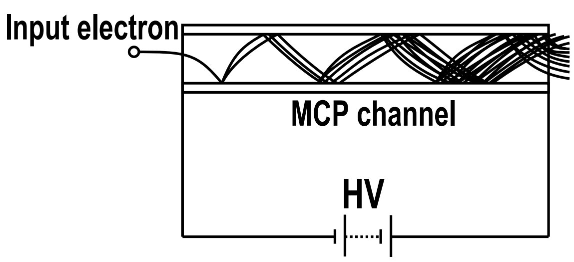
MCP-PMT

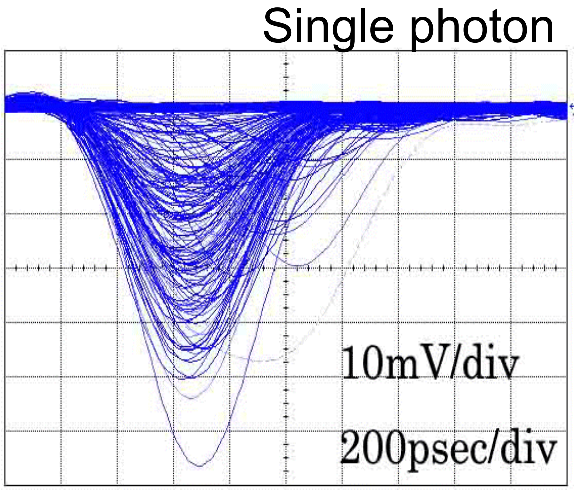
- Micro-Channel-Plate
  - Tiny electron multipliers
    - Diameter ~10μm, length ~400μm
  - High gain
    - ~10^6 for two-stage type
  - → Fast time response

    Pulse raise time ~500ps, TTS < 50ps
  - can operate under high magnetic field (~1T)

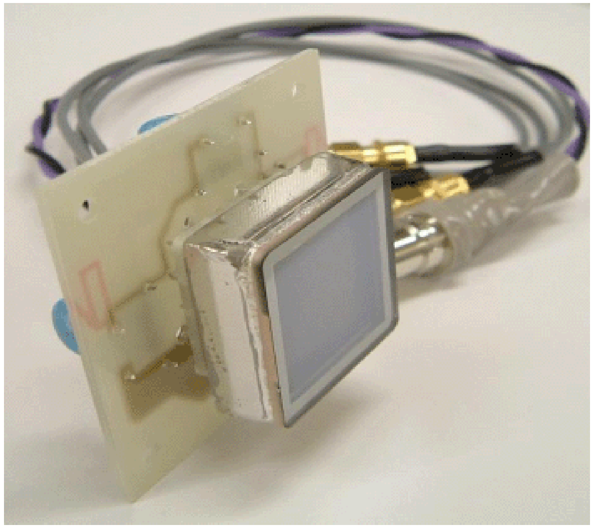


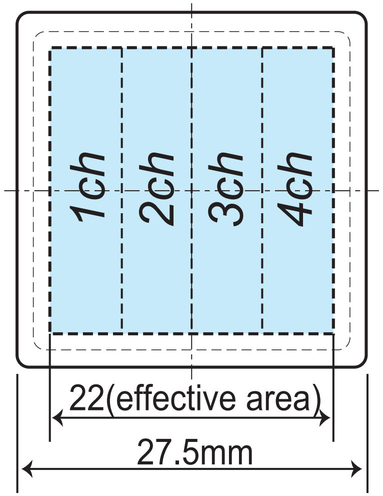






Multi-anode MCP-PMT





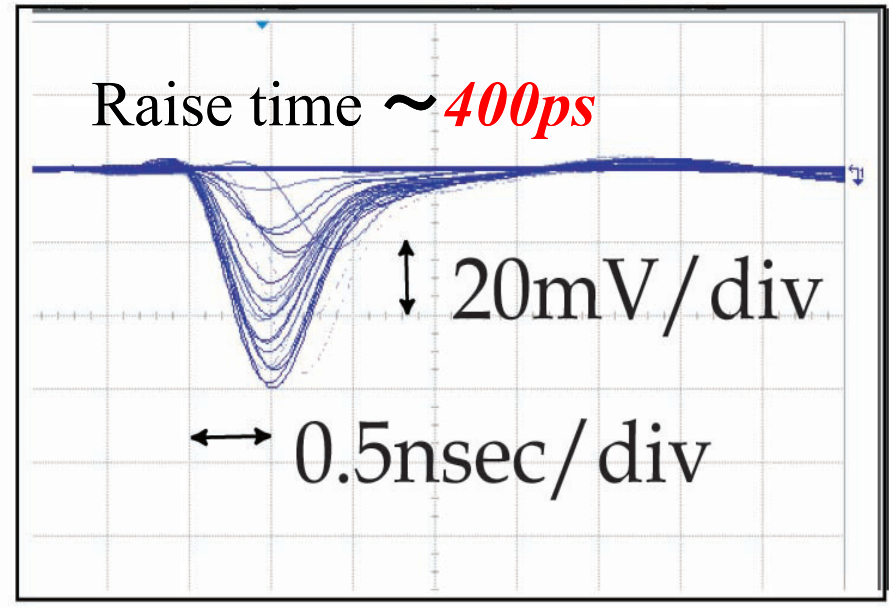
R&D with Hamamatsu

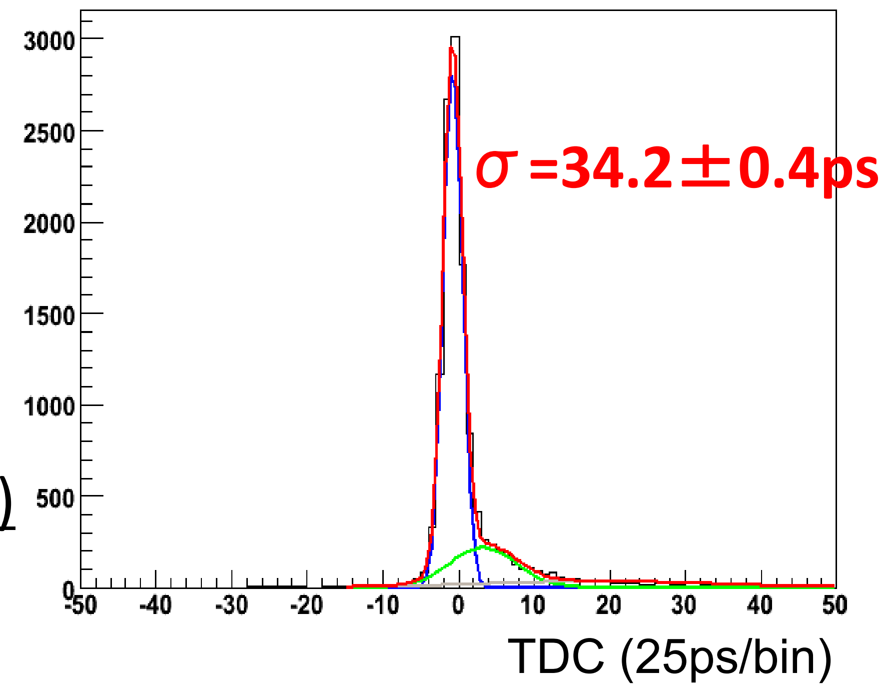
Size	27.5 x 27.5 x 14.8 mm
Effective area	22 x 22 mm(64%)
Photo cathode	Multi-alkali
Q.E.	~20%(λ=400nm)
MCP Channel diameter	10 μm
Number of MCP stage	2
Correction efficiency	~60%
Anode	4 channel linear array
Anode size (1ch)	5.3 x 22 mm
Anode gaps	0.3 mm

- Large effective area — 64% by square shape
- Position information — 4ch linear anode (5mm pitch)

Multi-anode MCP-PMT

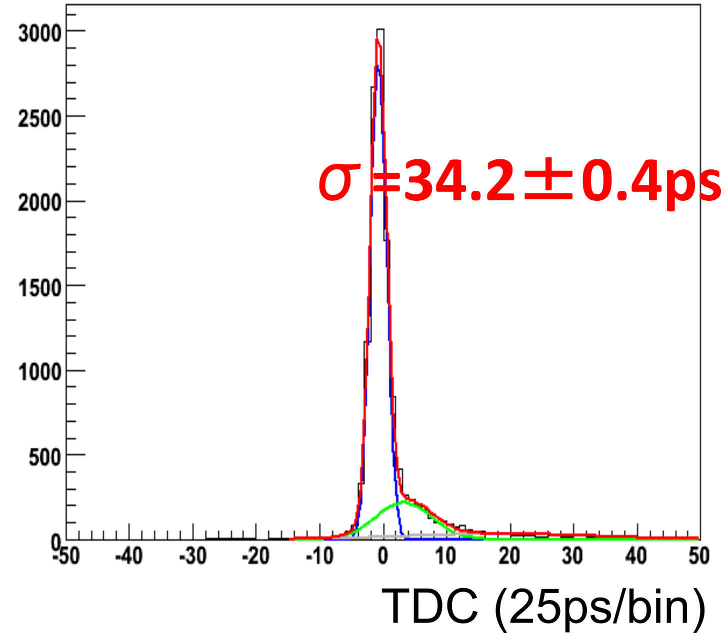
- Single photon detection
- Fast raise time: ~400ps
- Gain: >1x10^{6} at B=1.5T
- T.T.S.(single photon): ~35ps at B=1.5T
- Position resolution: <5mm
  - Nucl. Instr. Meth. A528 (2004) 768.
- Basic performance is OK!
  - Same as single anode MCP-PMT
- <u>Semi-mass production (14 pieces)</u>

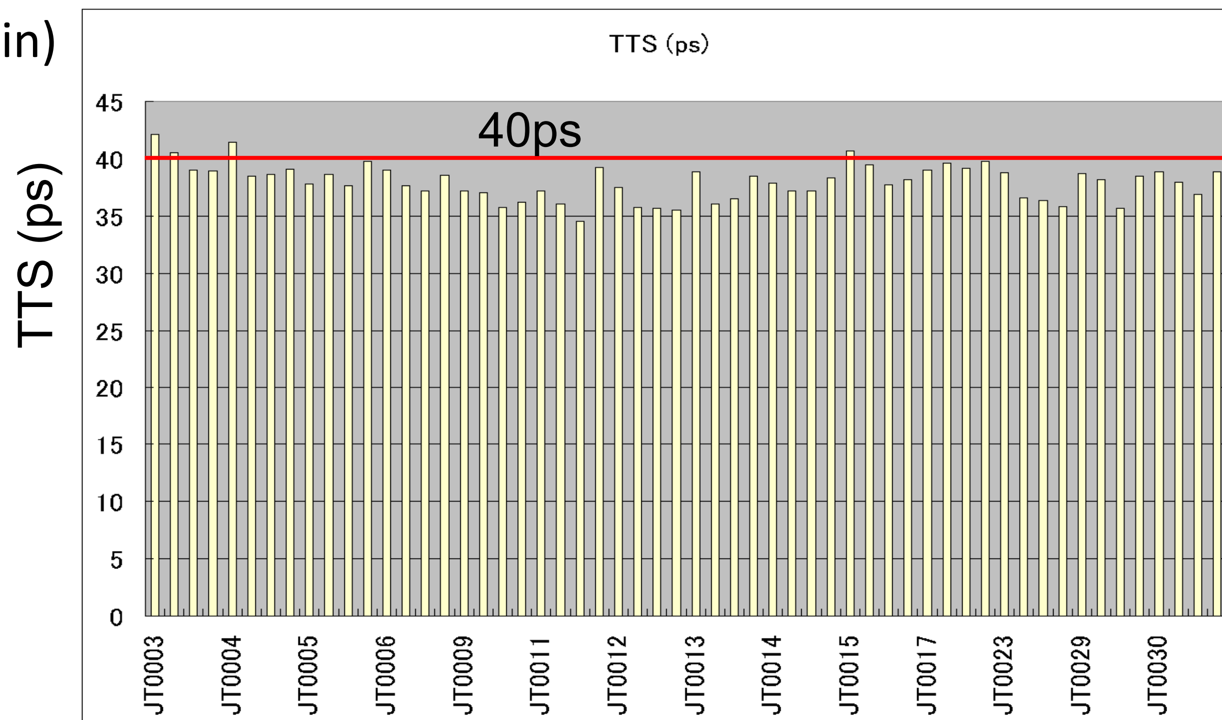




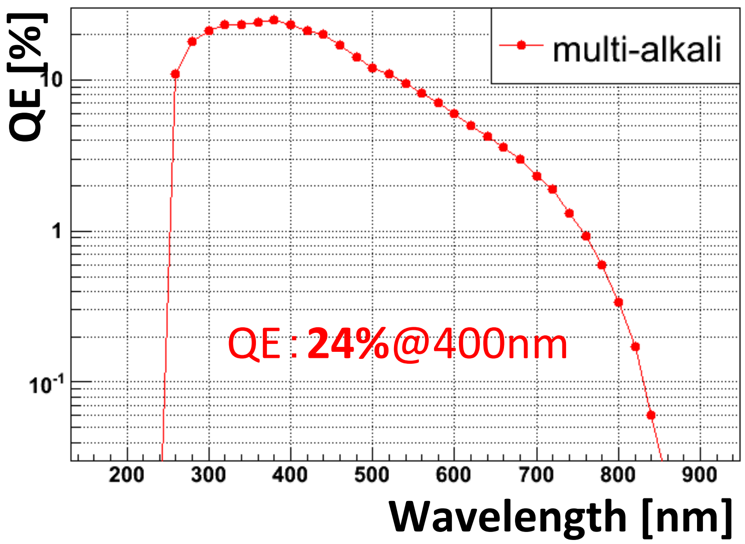
PMT performance (TTS)

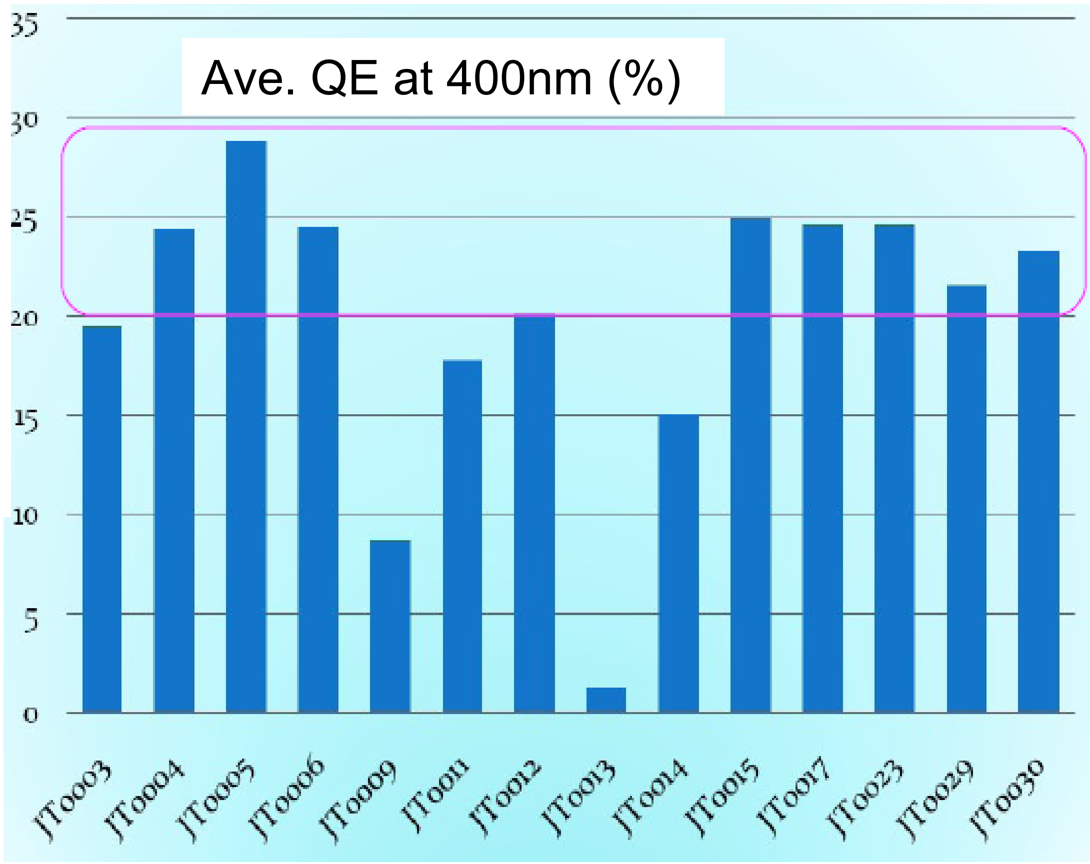
- Test 14 pieces with pulse laser
  - single photon level
- Readout
  - New PMT base
    - HV divider, Fast AMP (1GHz, x20)
  - Discriminator (Philips, 350MHz)
  - CAMAC TDC (25ps/bin)
- Result
  - 35~40ps
  - Stable





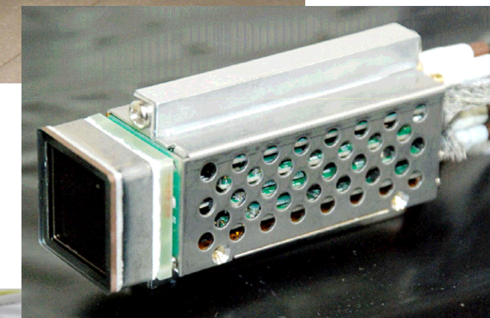
PMT performance (QE)





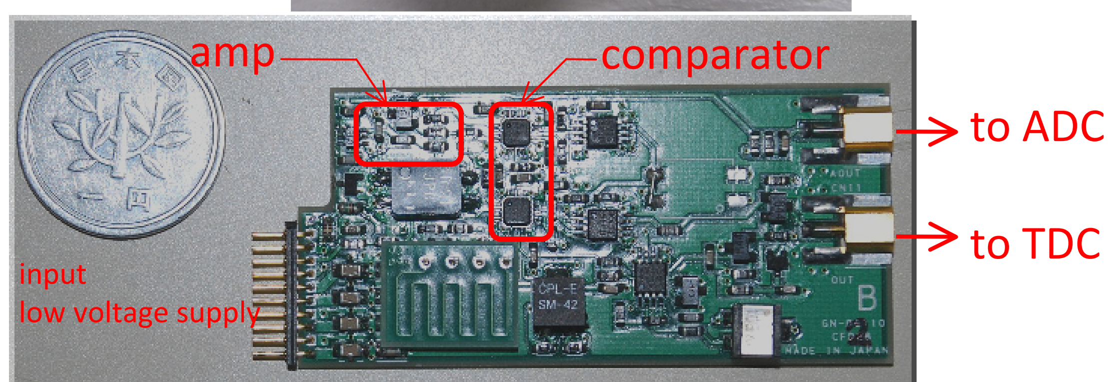
- Typical QE distribution
  - Multi-alkali p.c.
- Enough QE
  - Some of them are bad. Need to improve.

PMT module

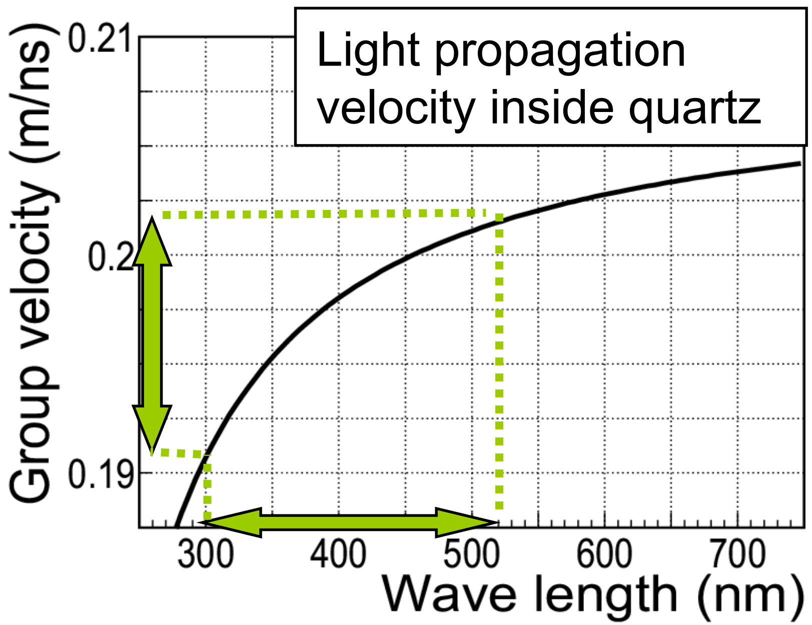


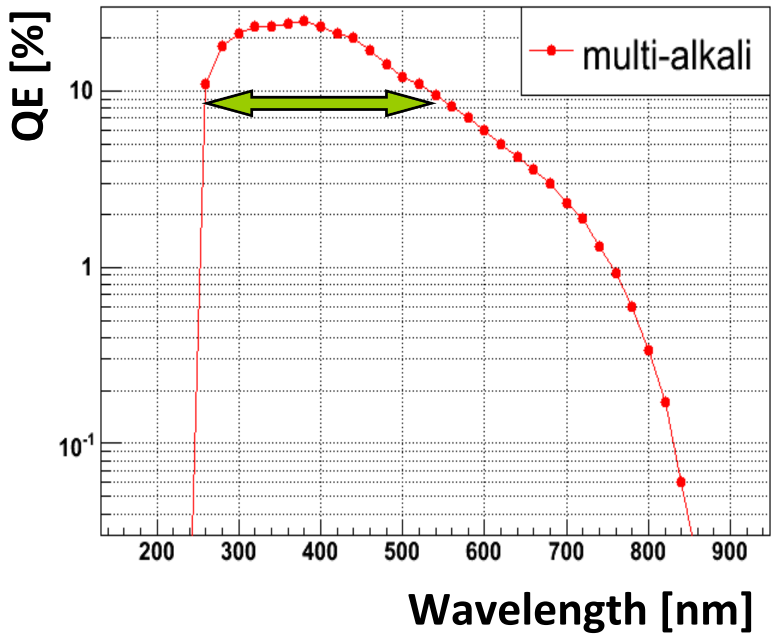
- HV divider + AMP + Discriminator
- Small size (28mm^{W})
- Prototype
  - Fast AMP (MMIC, 1GHz, x20)
  - Fast comparator (180ps propagation)
  - CFD with pattern delay

- Performance
  - Test pulse
    - ~5ps resolution
  - MCP-PMT
    - σ<40ps
    - Working well



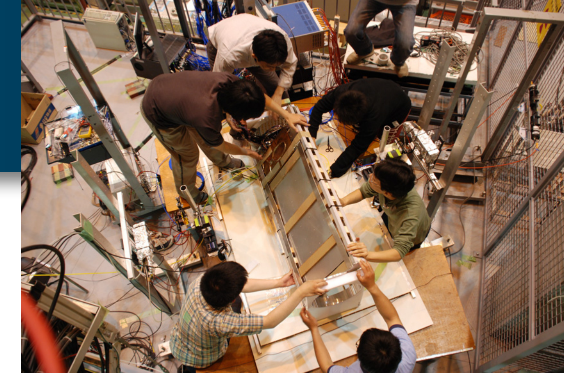
Chromatic dispersion effect





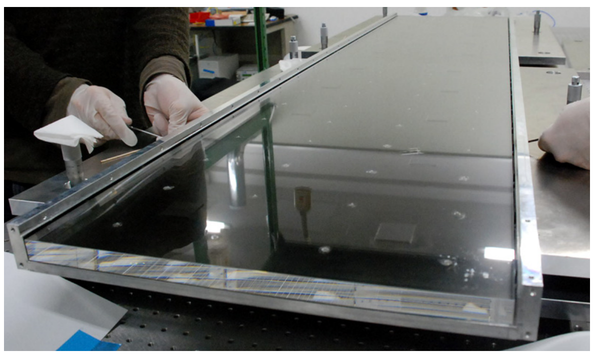
- Range of detectable wavelength of Cherenkov photons
  → Time fluctuation of the Cherenkov ring image
    → Time resolution depends on the propagation length.
- Check the degradation of time resolution by beam test

Beam test



- With electron beam at KEK Fuji test beam line
- Using real size quartz and 10 MCP-PMT
    - MCP-PMT: Multi-alkali p.c., C.E.=55%

Quartz + support jig



TOP counter

Quartz bar
(1850 x 400 x 20mm)

MWPC 1

Timing counter

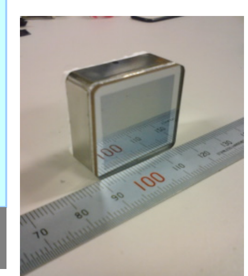
10mm$^{\phi}$ quartz + MCP-PMT
σ_{t0} < 15ps

MWPC 2

Trigger counter

Lead glass +
Finemesh PMT

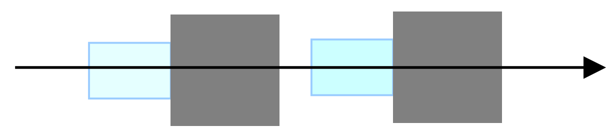
MCP-PMT (10 PMT)



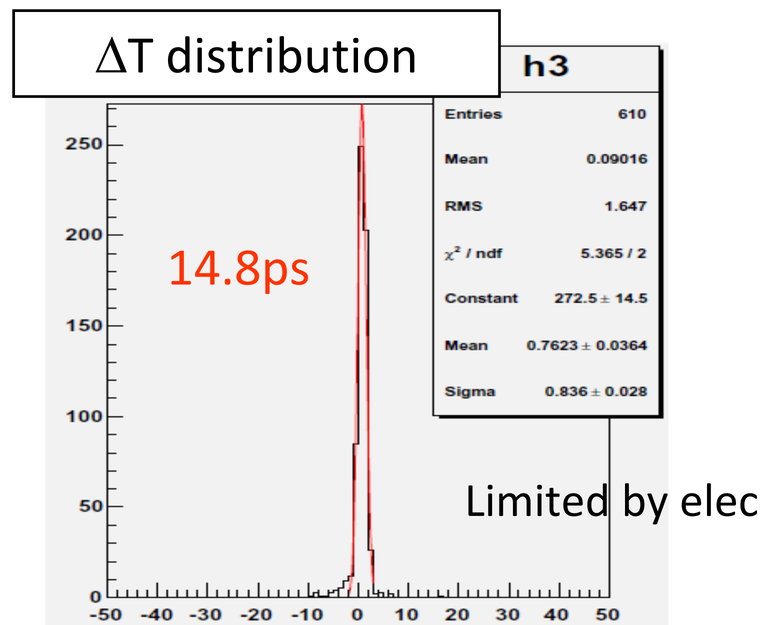
- Check
    - Ring image
    - Number of photons
    - Time resolution

Timing counter

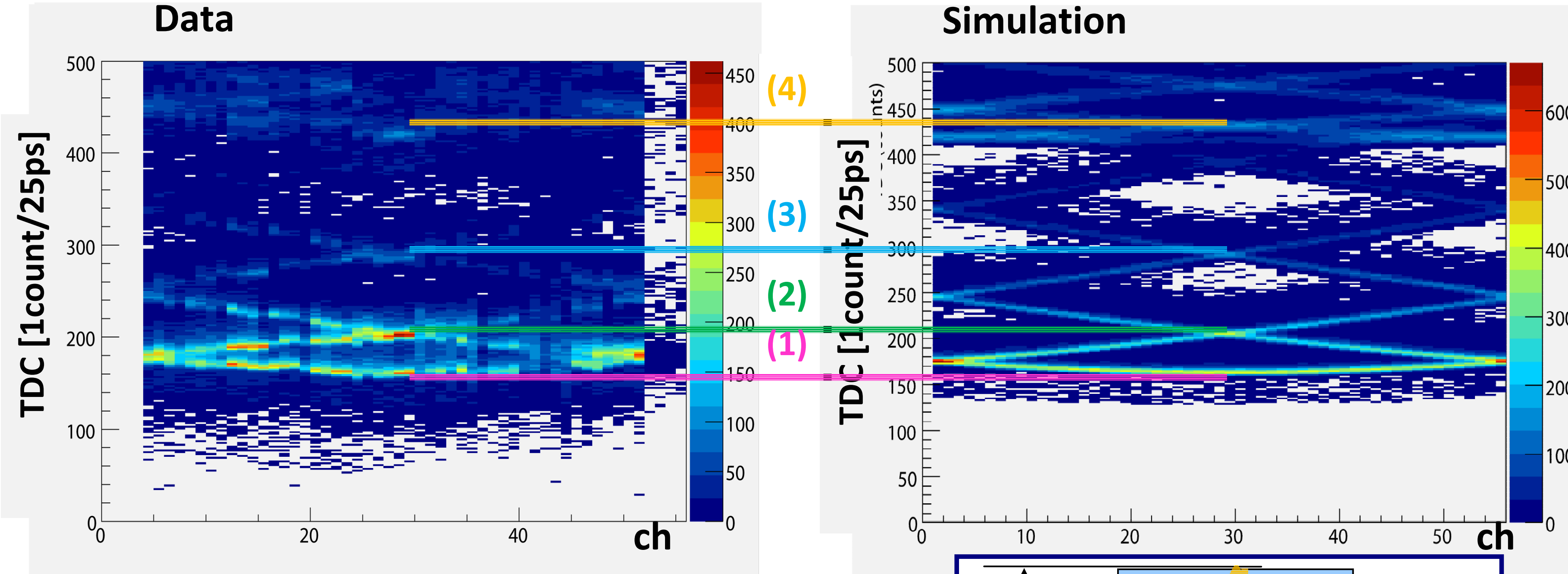
- Based on our high resolution TOF
  - σ=6.2ps with 6μm MCP-PMT, Cherenkov light in quartz and special electronics [NIM A560,303(2006)]
- Time difference between two counters
  - Check time resolution

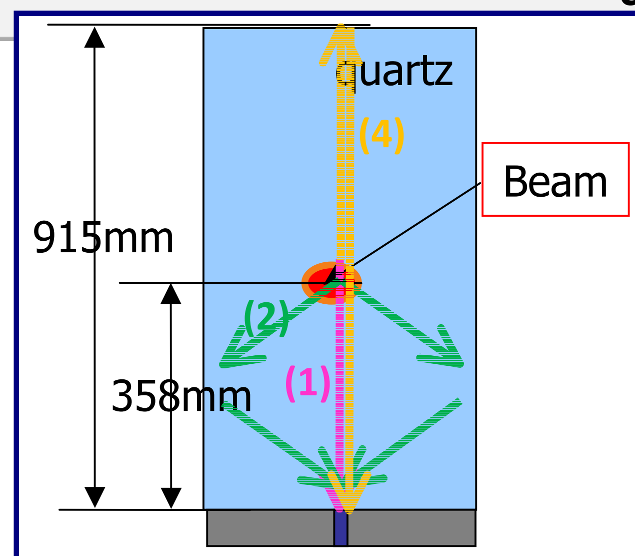


10mm$^{\phi}$ quartz + MCP-PMT



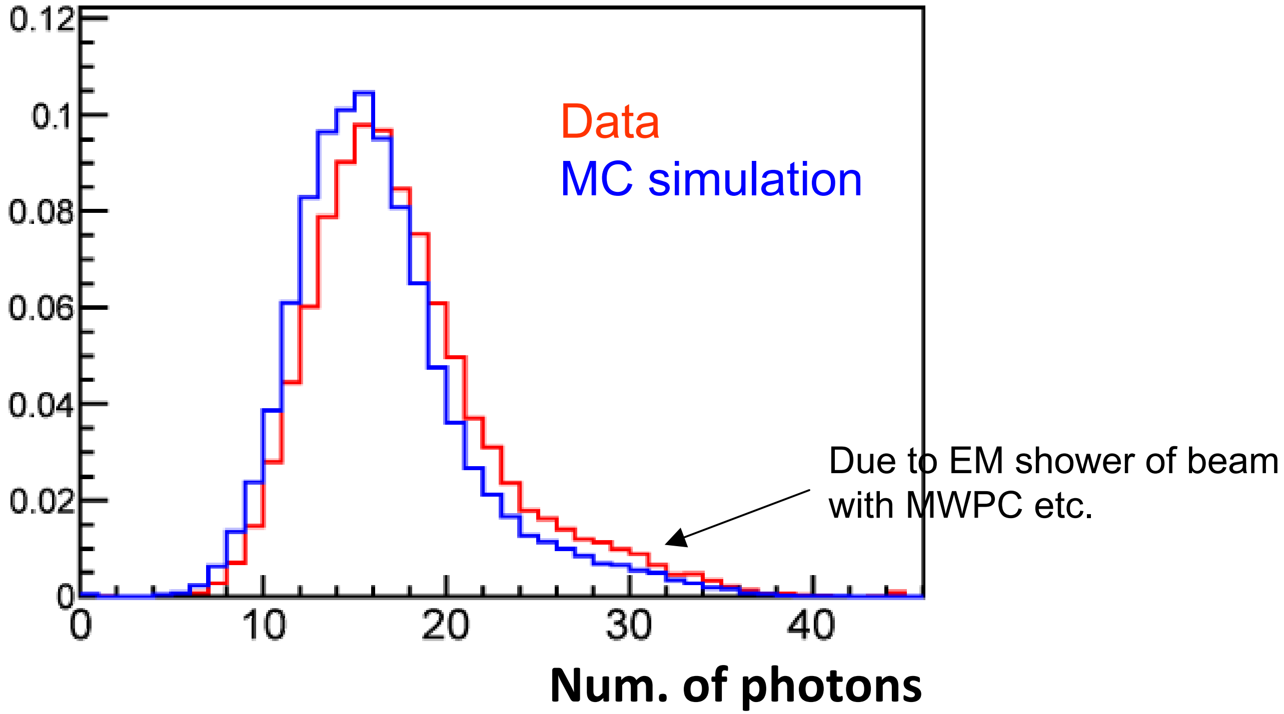
Ring image





- Proper ring image
  - Same time interval with simulation

Number of detected photons

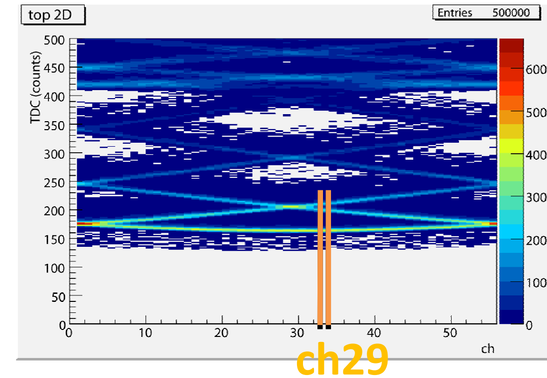


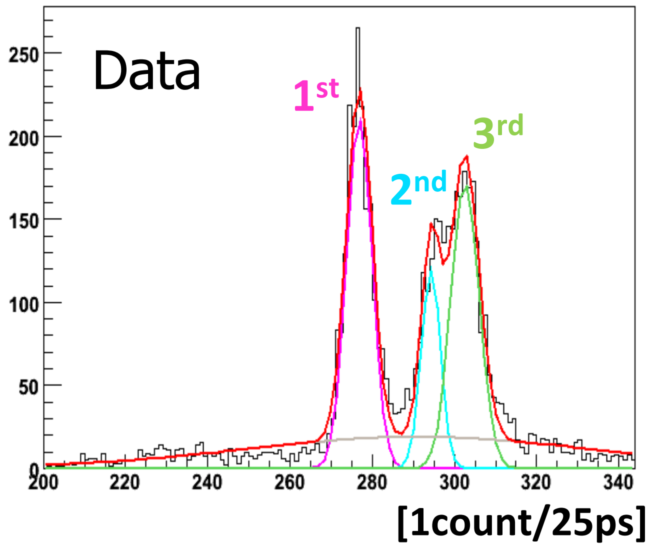
- Normal incidence (90 deg.)
- Obtained number of photons as expected

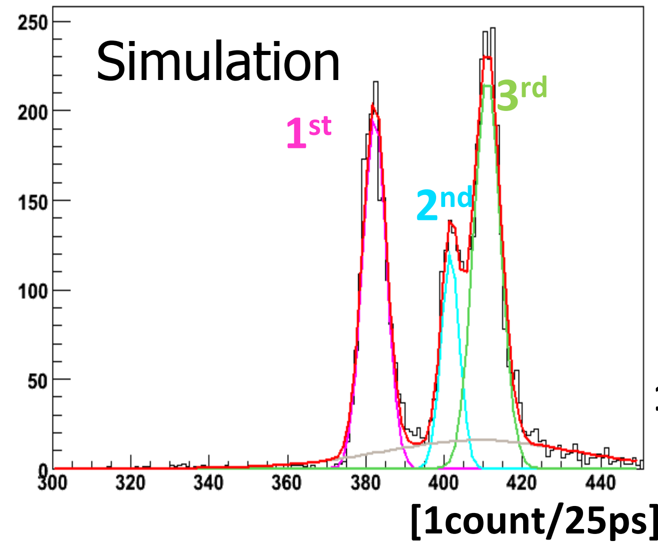
- → We can expect ~26 photons/event, if we use full 16 PMTs.
  - Normalized by active area (10→16 PMTs)

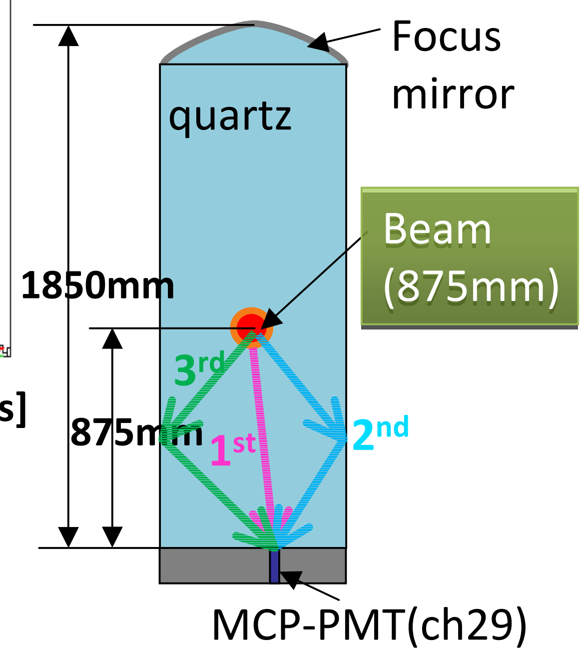
Time resolution

- TDC distribution of ch.29
  - Compare with the distribution expected by a simulation including PMT resolution and chromatic dispersion effect





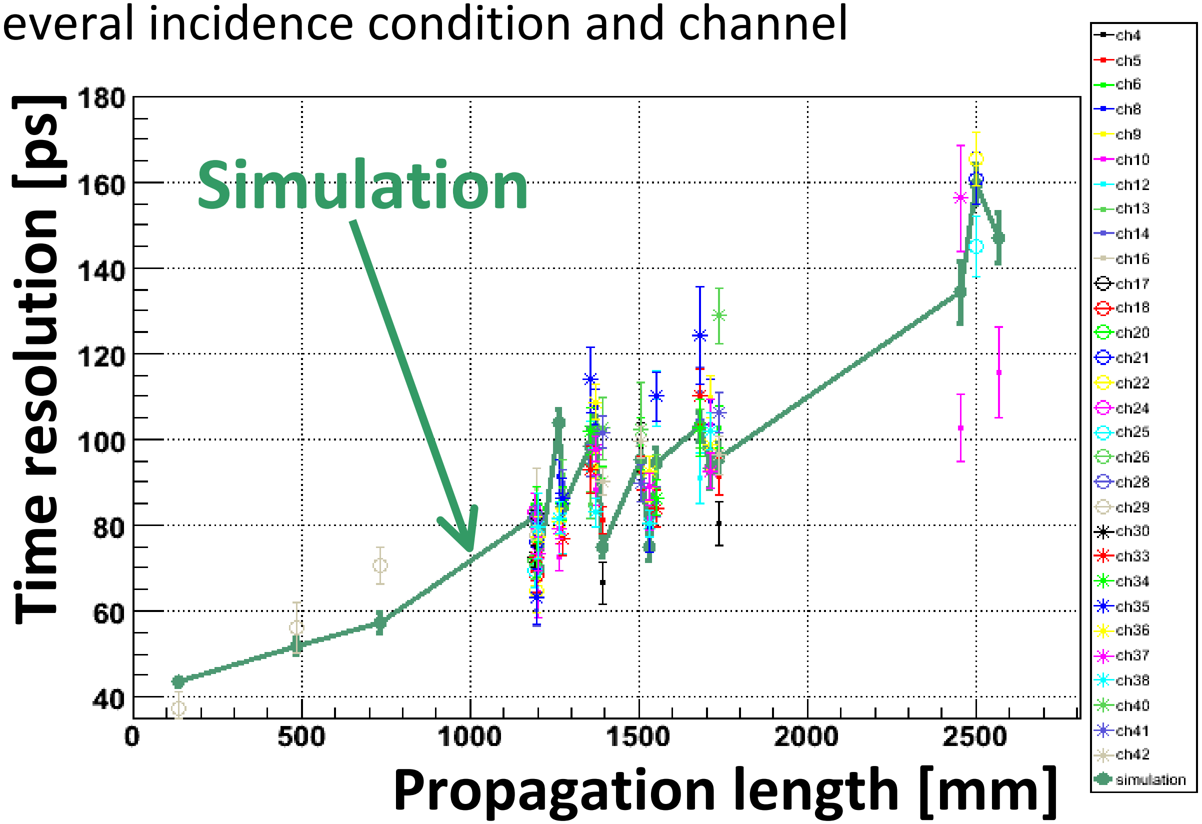




	Resolution(1^{st} peak)
Data	76.0±2.0 [ps]
Simulation	77.7±2.3 [ps]

Time resolution vs. propagation length

- Check time resolutions
  - For several incidence condition and channel



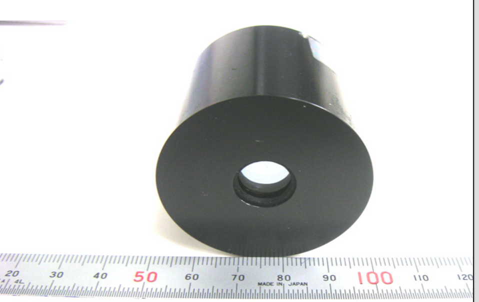
- Data agrees well with simulation expectation.
  → Confirmed the level of chromatic dispersion effect

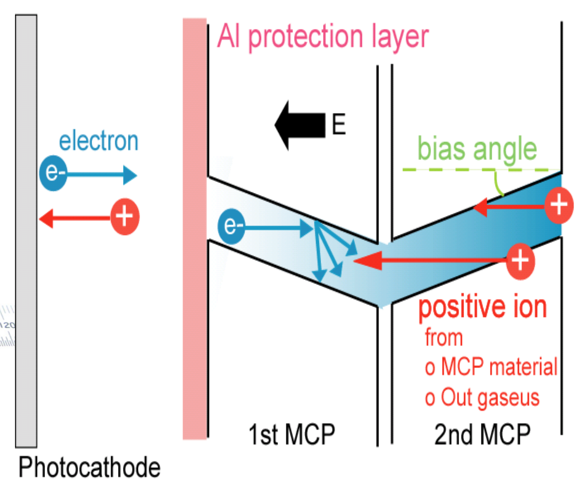
MCP-PMT lifetime

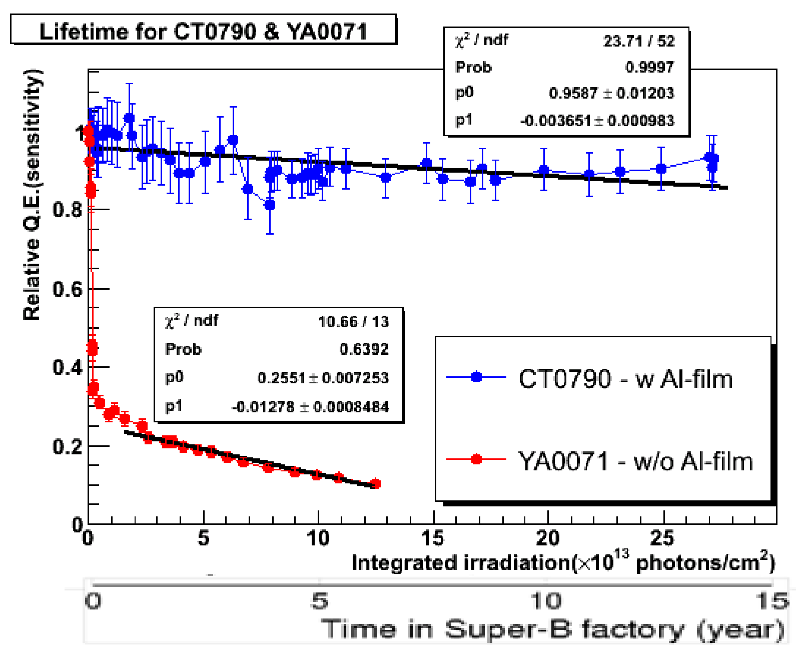
- Very high luminosity at Belle-II experiment
  - Expect 20 times more background rate than current Belle

	Belle	Belle-II
Luminosity (/cm^2/s)	1×10^{34}	8×10^{35}
Num. of detected photons (/cm^2/s)	3400	68000
Output charge (mC/cm^2/year)	~6	~120

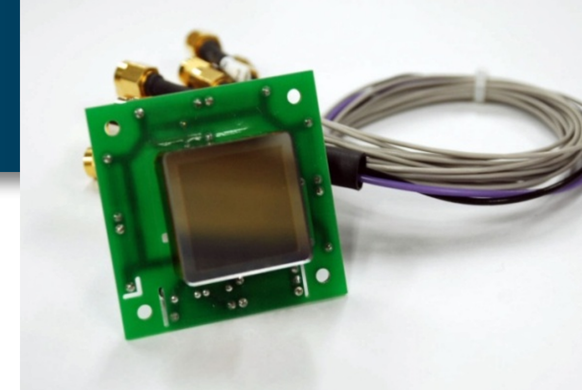
- Round-shape MCP-PMT with Al protection layer
  - Good lifetime property
  - Correction efficiency ~35%



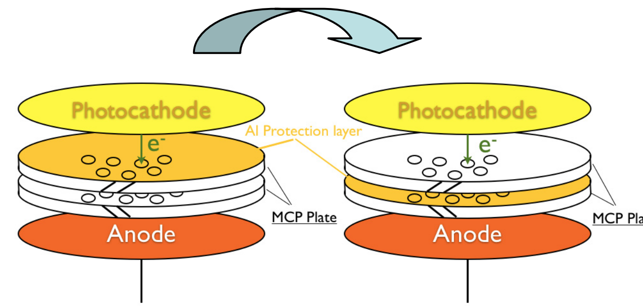




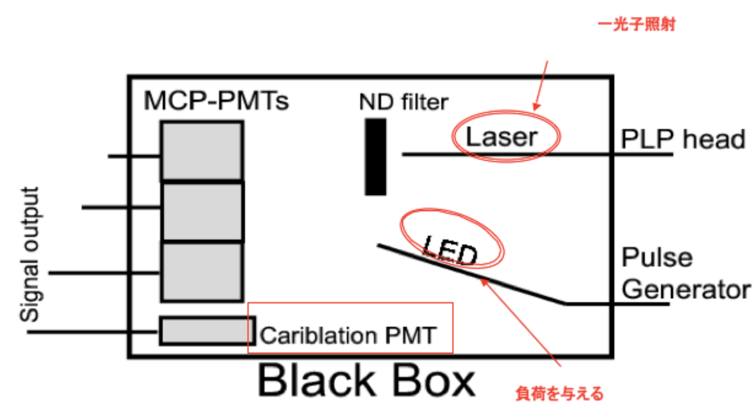
MCP-PMT lifetime



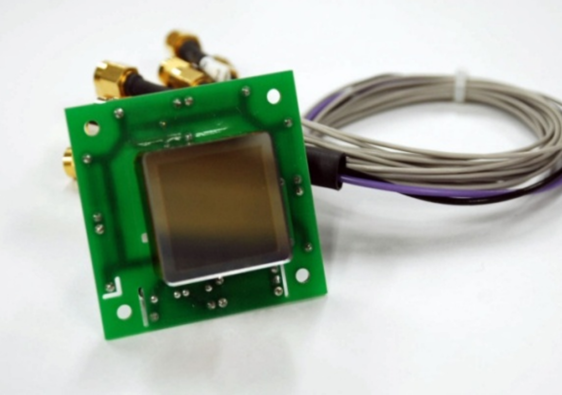
- Square-shape MCP-PMT
  - Develop new version with Hamamatsu
    - Change of internal structure and cleaning method
  - Change to put Al protection layer on 2nd MCP
    - Recover correction efficiency (35%→60%)
    - Expect less effect of 1st MCP to lifetime
      - Because of $1/10^3$ smaller number of electrons



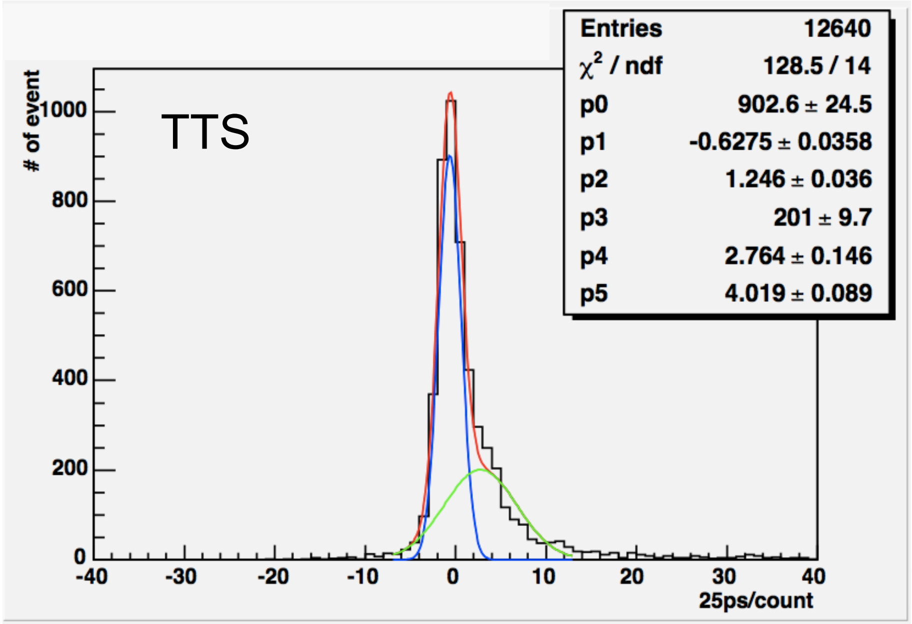
- Lifetime measurement
  - Light load by LED pulse (1~20kHz)
    - 20~50 p.e. /pulse
  - Relative efficiency, gain and TTS
    - By pulse laser at single photon level
    - Monitored by standard PMT

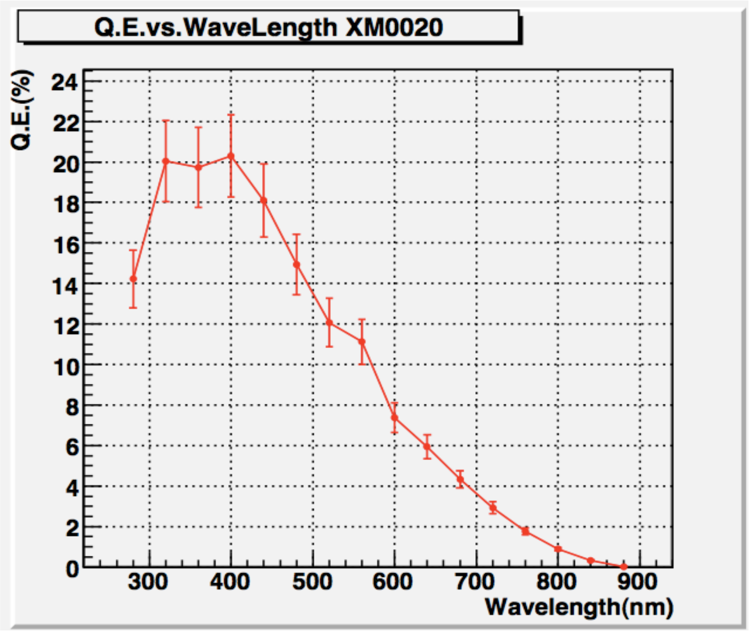


MCP-PMT lifetime



- Basic performance of new version
  - Before aging

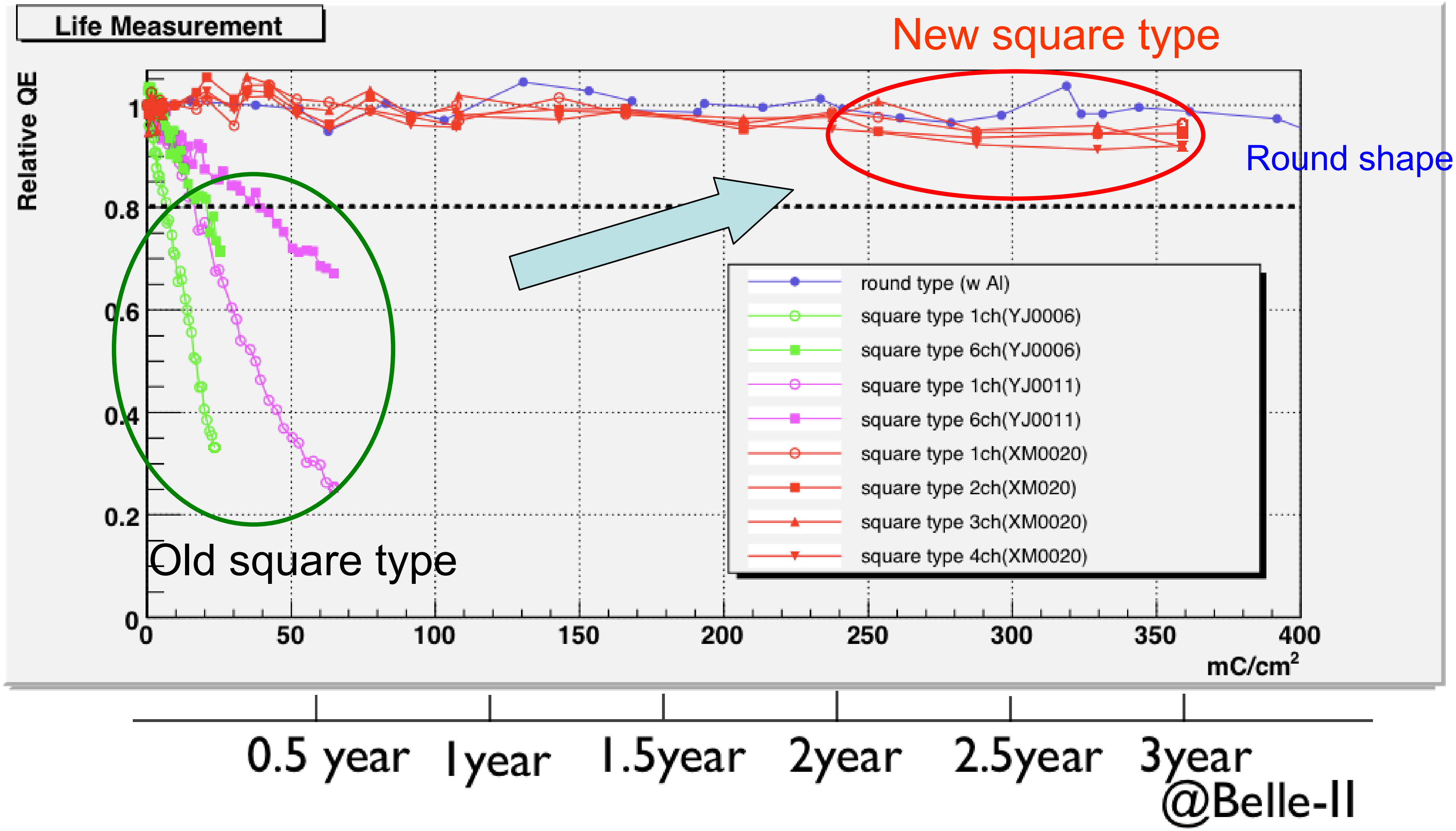




Ch Number	1ch	2ch	3ch	4ch
Gain(Mean)	1.2×10^6	1.2×10^6	1.2×10^6	2.7×10^6
TTS(1st peak)	$31.2 \pm 0.9ps$	$32.9 \pm 1.1ps$	$33.4 \pm 1.1ps$	$31.3 \pm 1ps$

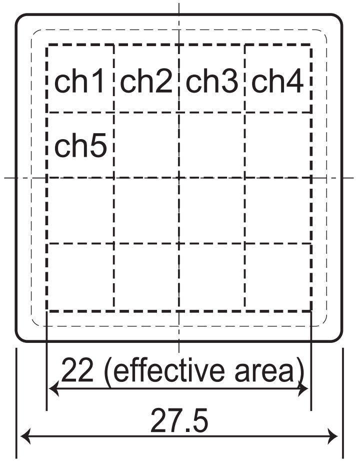
MCP-PMT lifetime result

- QE variation
  - <10% drop at 350mC/cm^2 ; <u>sufficient lifetime</u>

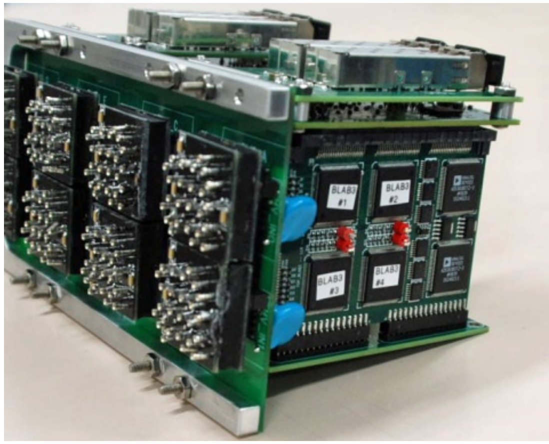


For final system

- MCP-PMT
  - 4x4 channel anodes
    - Reduced occupancy and improve number of detected photons
    - Already have good prototype PMTs
  - Super-bialkali photo-cathode
    - Better QE than multi-alkali p.c.
      (20% → 30~35% at 400nm)



- Electronics
  - New ASIC chip (BLAB3) for very high-speed waveform sampling by Hawaii
  - Beam test in this autumn



Summary

- R&Ds of TOP counter are in progress!
- Prototype developments
  - Quartz radiator
    - Enough quartz quality for single photon propagation
  - Multi-anode MCP-PMT
    - Developing with Hamamatsu photonics
    - Very good TTS (<40ps) and sufficient efficiency and gain
- Performance test with electron beam
  - Proper ring image, number of detected photons (16 photons)
  - Time resolution as expected by simulation

    → Confirmed level of chromatic dispersion effect
- MCP-PMT lifetime for Belle-II
  - Obtained sufficient lifetime (>3 Belle-II years) with improved version