Workshop on timing detectors at Lyon, 15-16 Oct. 2008

Tests of MCP-PMT for TOP counter

- Prototype production
- CFD readout
- Protection for ion-feedback

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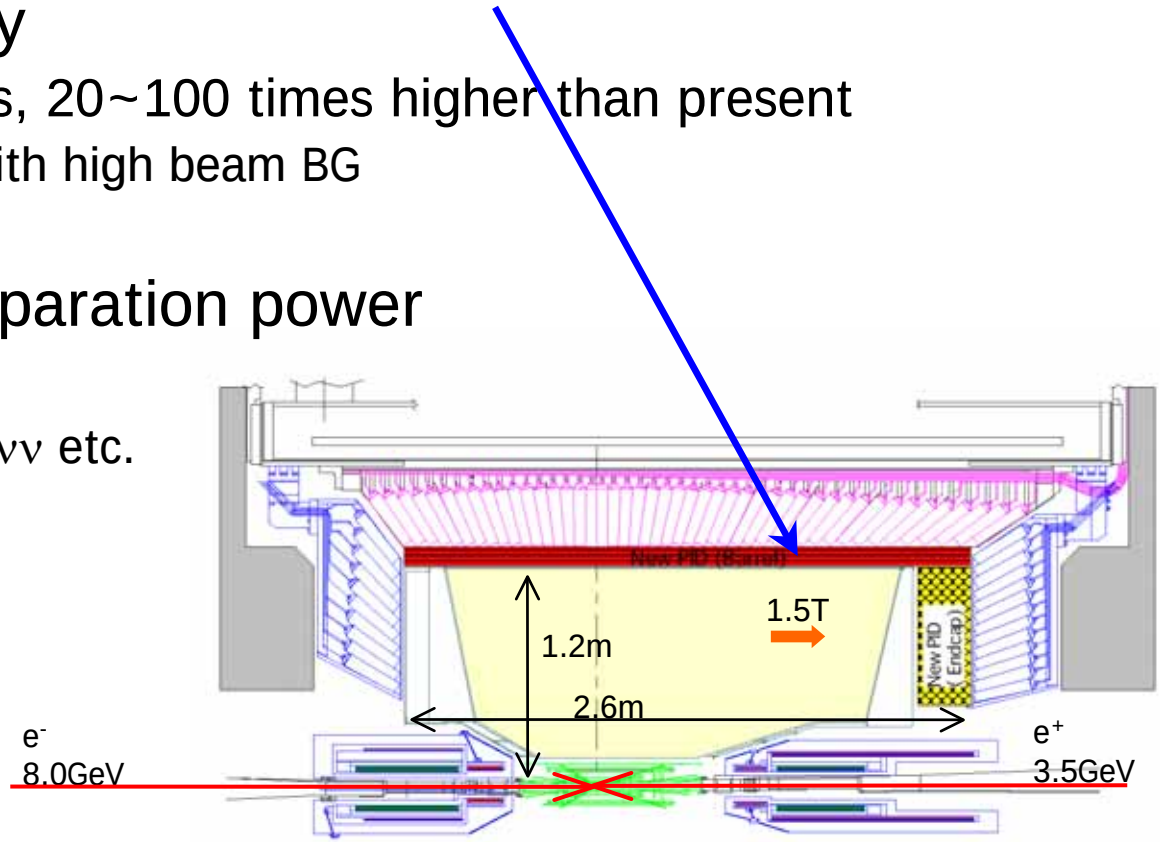
Introduction

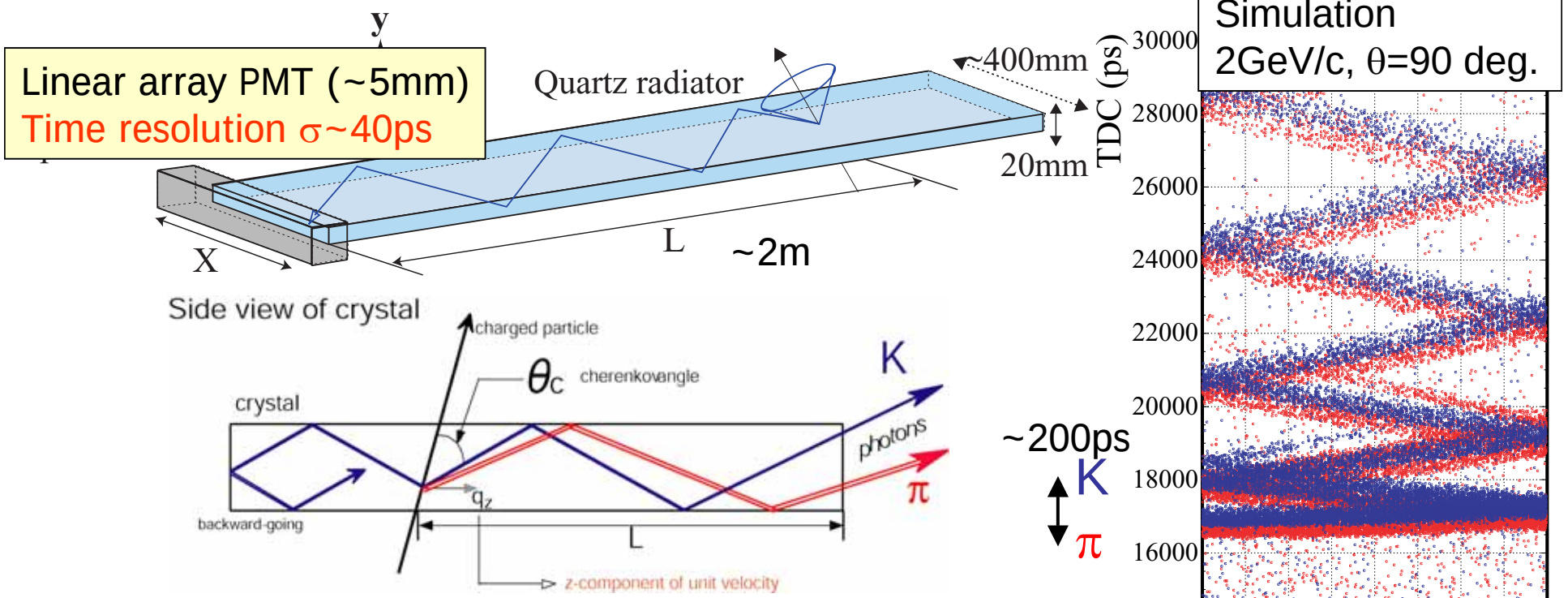
- TOP (Time Of Propagation) counter
  - Developing to upgrade the barrel PID detector
  - For Super B factory
    - L_{peak}~$10^{35\sim36}/cm^2/s$, 20~100 times higher than present
      - Need to work with high beam BG
  - To improve K/π separation power
    - Physics analysis
      - B→$\pi\pi$/Kπ, $\rho\gamma$, K$\nu\nu$ etc.
    - Flavor tag
    - Full reconstruction
  - Target; 4σ for 4 GeV/c



Side view of Super Belle detector

TOP counter

- Position information → Position+Time
  - Compact detector!



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

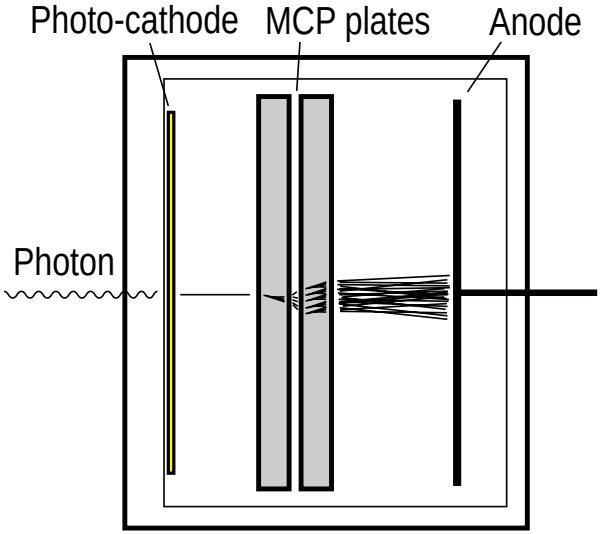
+ TOF from IP works additively.

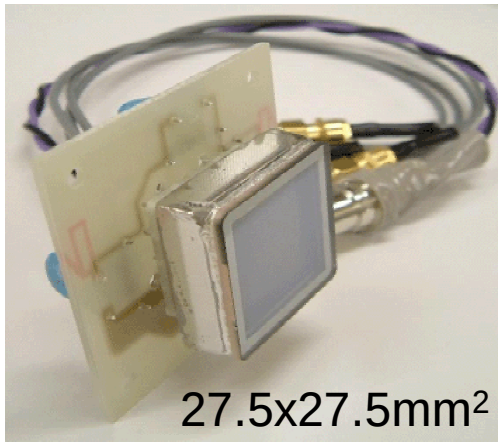
Photo-device for TOP counter

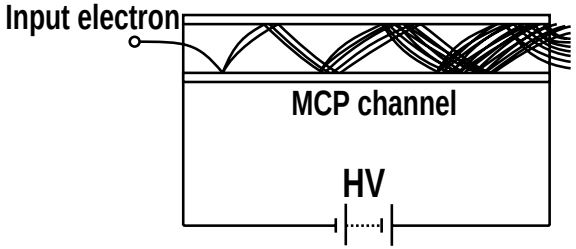
- Micro-Channel-Plate (MCP) PMT
  - Square shape, 4 linear anodes
  - MCP; two stage
    - Diameter 10μm, length 400μm
    - Tiny electron multipliers
    - High gain; ~10^6

      → Fast time response

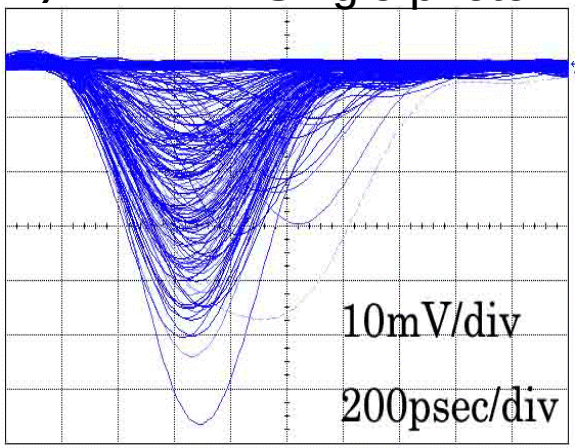
      Pulse raise time ~500ps, TTS < 40ps
  - Operational under high magnetic field (~1.5T)





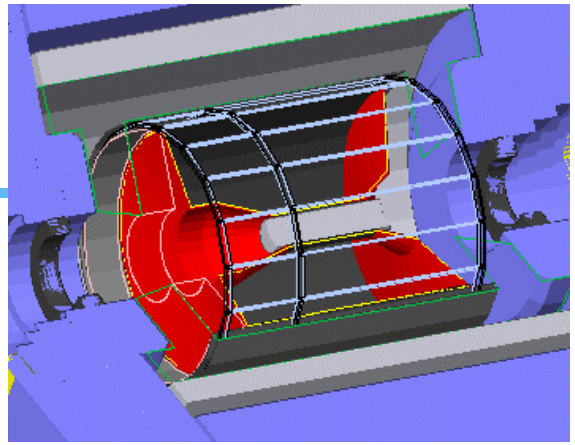


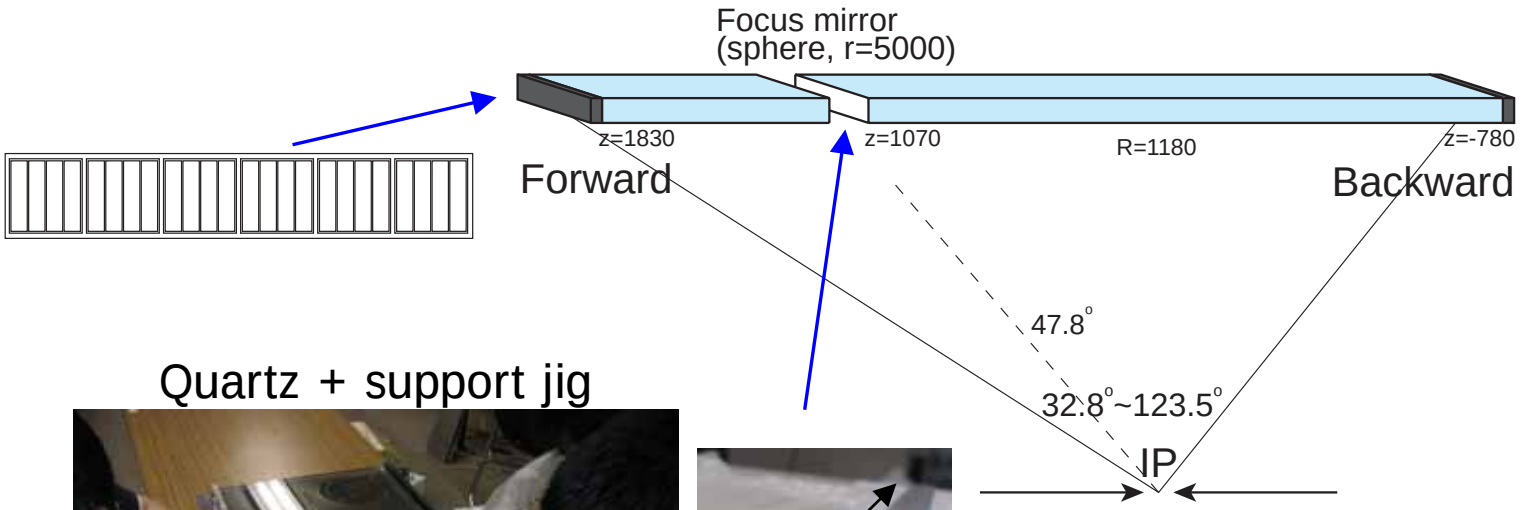
Single photon



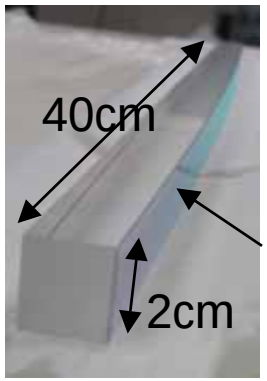
TOP counter Prototype

- Quartz radiator + mirror
- MCP-PMT (square shape, 4ch)



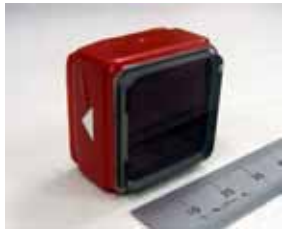


Quartz + support jig

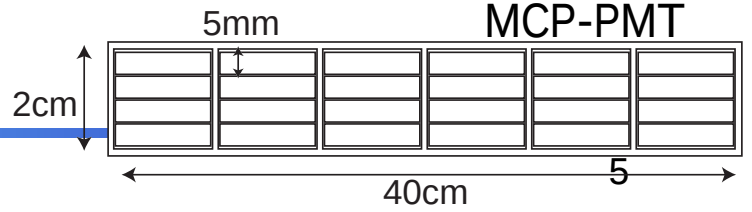


mirror (R=5 m)

Focusing mirror

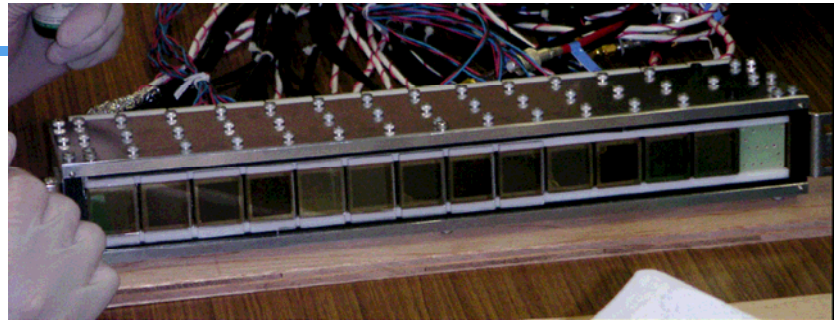


MCP-PMT

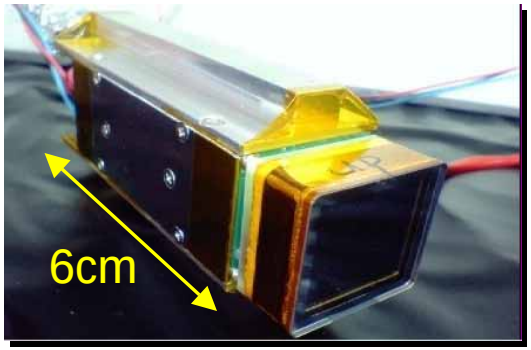


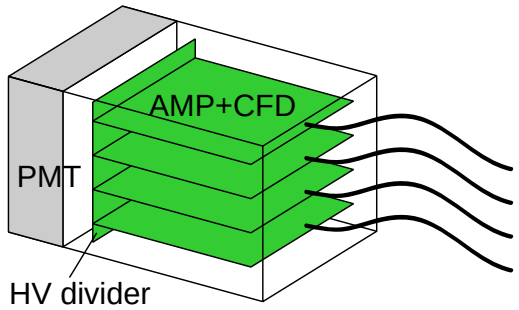
PMT box

- Support PMT modules
- Attach to quartz support

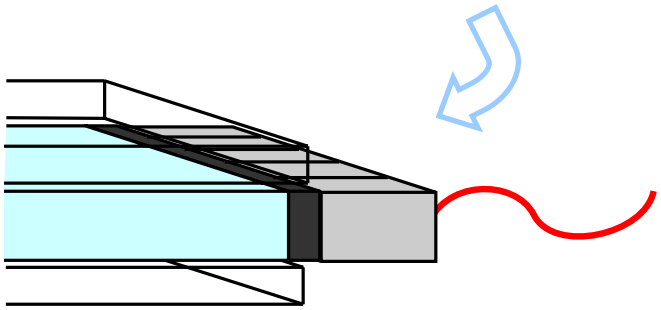


- PMT module
  - MCP-PMT
  - PMT base
    - HV divider
    - AMP



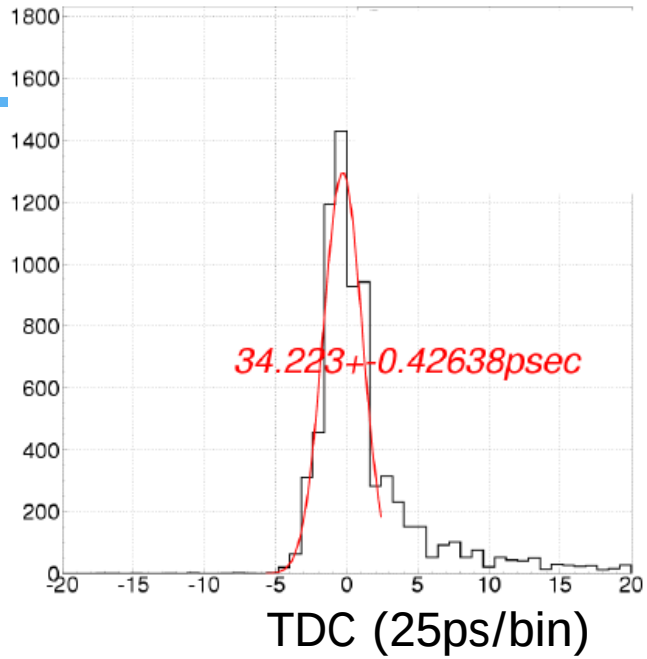


- MCP-PMT
  - Multi-alkali photo-cathode
    - 13 PMTs without Al protection
    - 10 additional PMTs with Al protection; in production

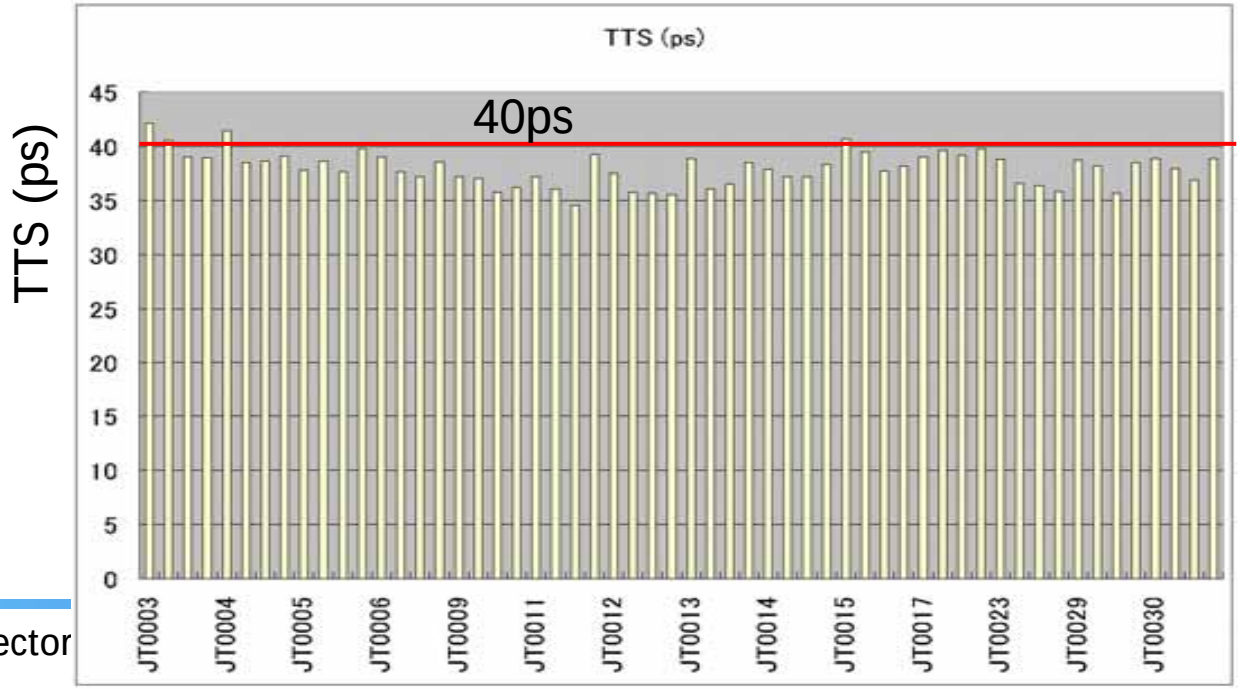


PMT performance (TTS)

- Test with pulse laser
  - single photon level
- Readout
  - PMT base
    - HV divider, AMP
  - LED (Philips, 350MHz)
  - CAMAC TDC (25ps/bin)

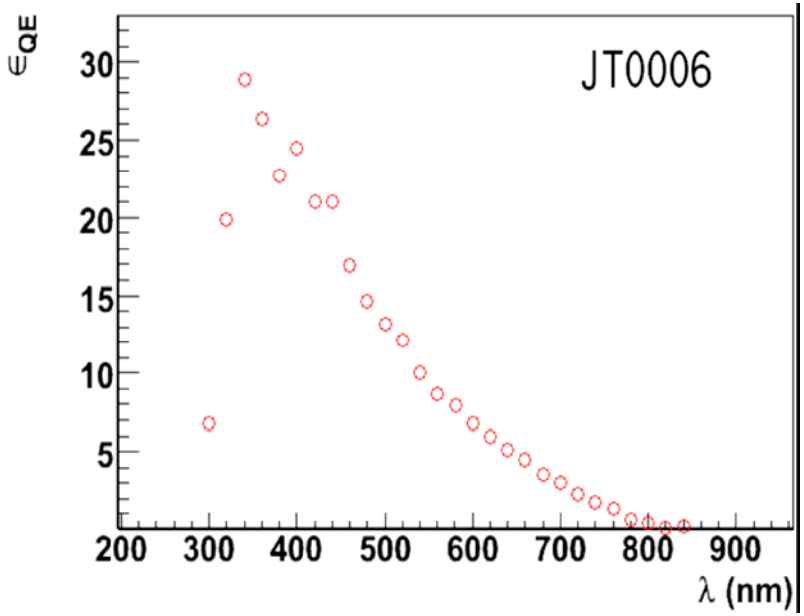


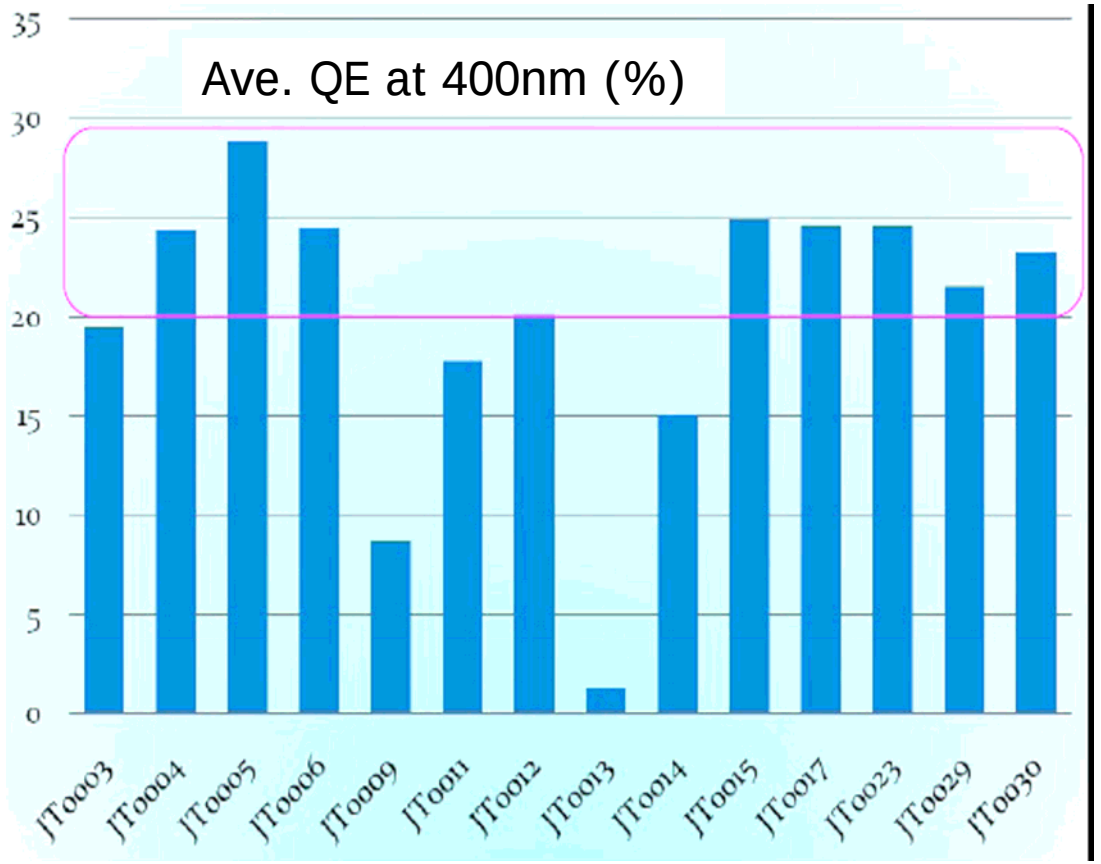
- Result
  - 35~40ps
  - Stable



PMT performance (QE)

- Measure by monochrometer

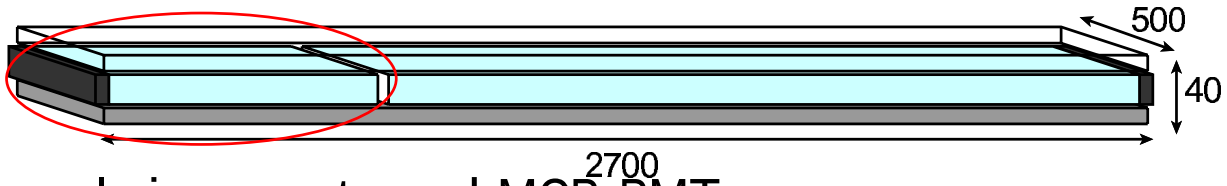




- Result
  - Typical QE distribution
    - Multi-alkali p.c.
  - Enough QE
    - Some of them are bad. Need to improve.

Beam test

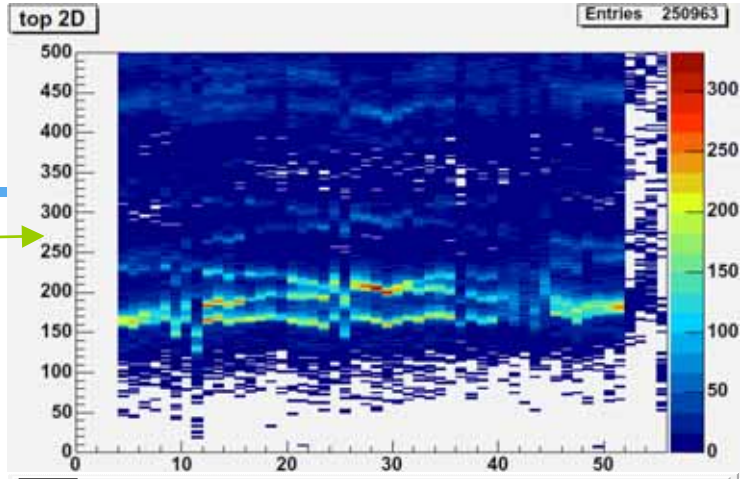
- 2GeV/c electron beam at KEK Fuji test beam line in June
- Prototype of forward part

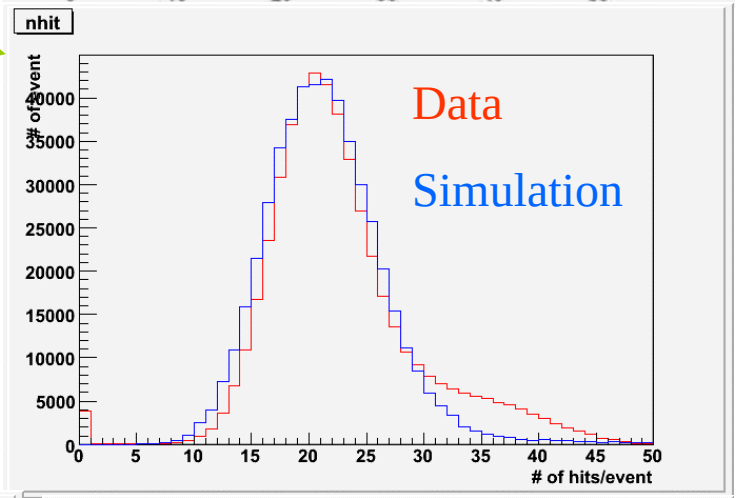


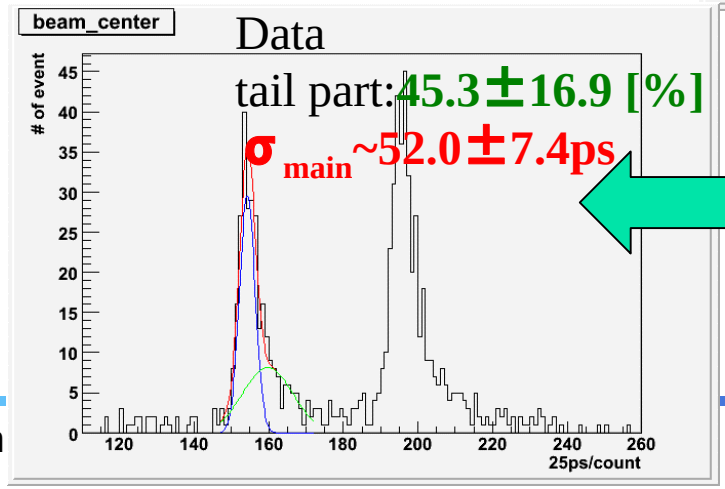
  - Using real size quartz and MCP-PMT
    - MCP-PMT: Multi-alkali p.c., C.E.=60% (no Al protection)
- Check items
  - Ring image
  - Num. of detected photons
  - Time resolution
- Set up
  - TOP (915x400x20mm^3)
  - Timing counters (σ<10ps)
    - MCP-PMT+10mm quartz
  - MWPCs, triiggers

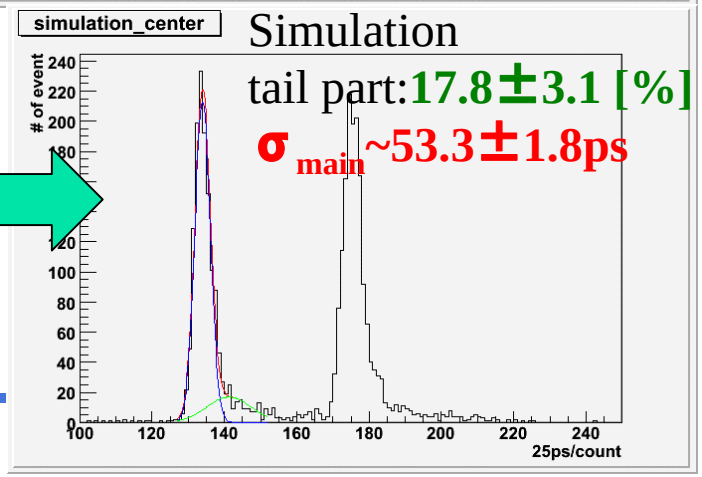
Beam test (2)

- Ring Image
  - Similar with Simulation
- Number of photons
  - N~20; as expected
    - Tail due to EM shower in triggers
- Time resolution
  - Main part; OK.
  - Rate of tail seems large.
    - Not in MCP-PMT and readout



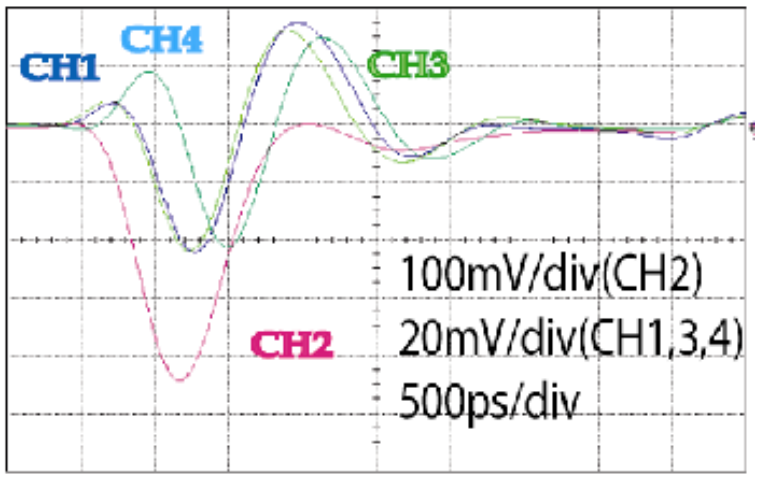


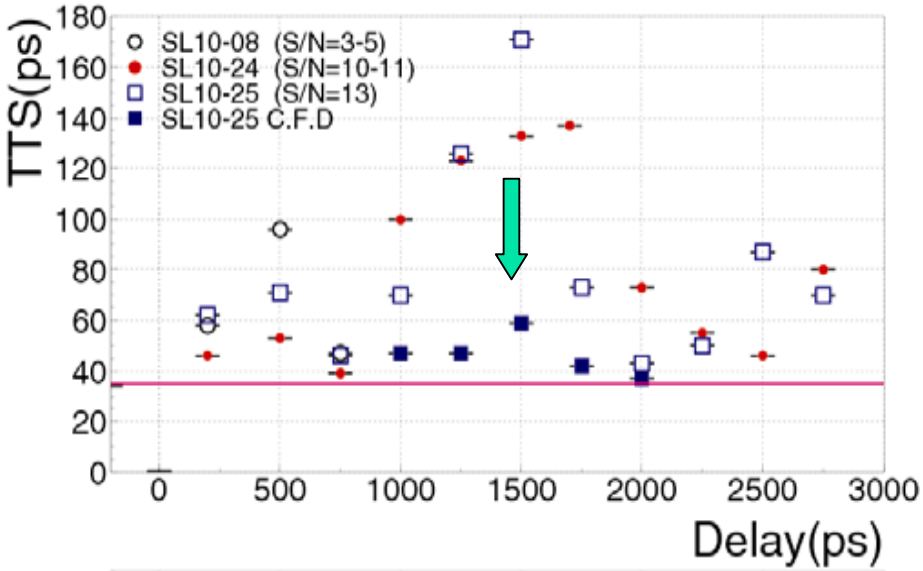


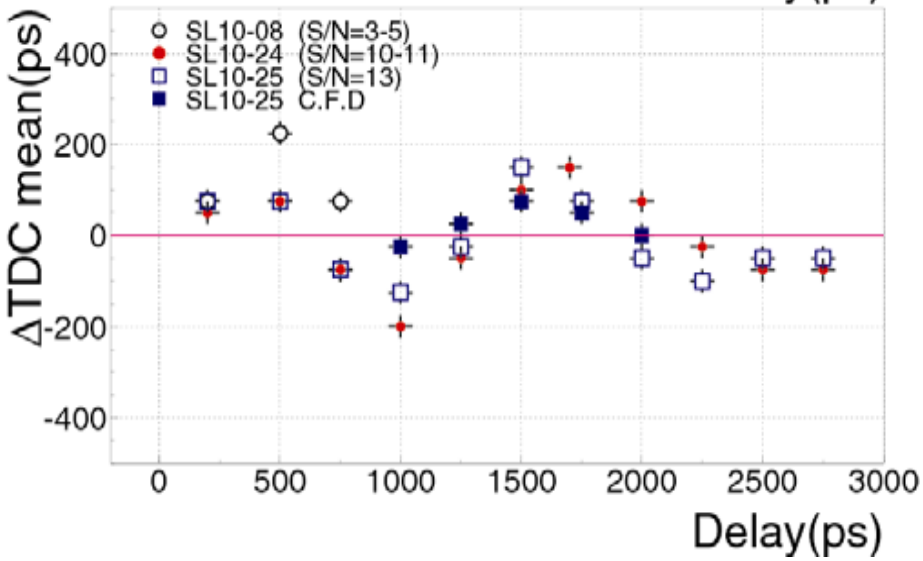


PMT base + CFD

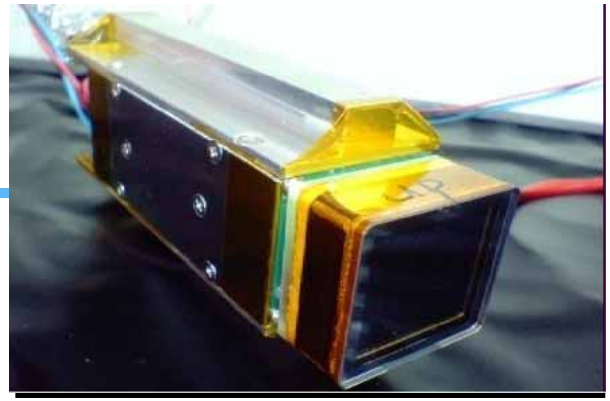
- CFD on PMT base
  - Digitize with low noise
    - Low PMT gain operation
  - Robust against cross-talk
    - Able to determine PMT timing by (approximately) pulse peak.



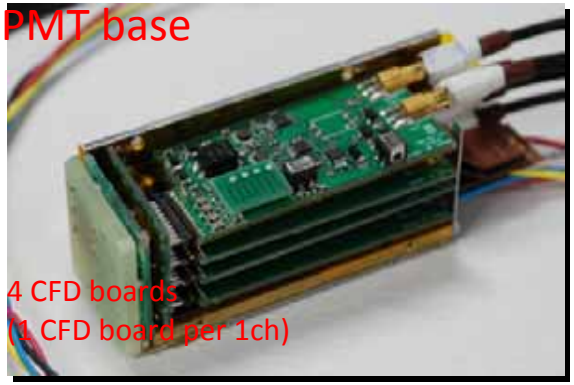




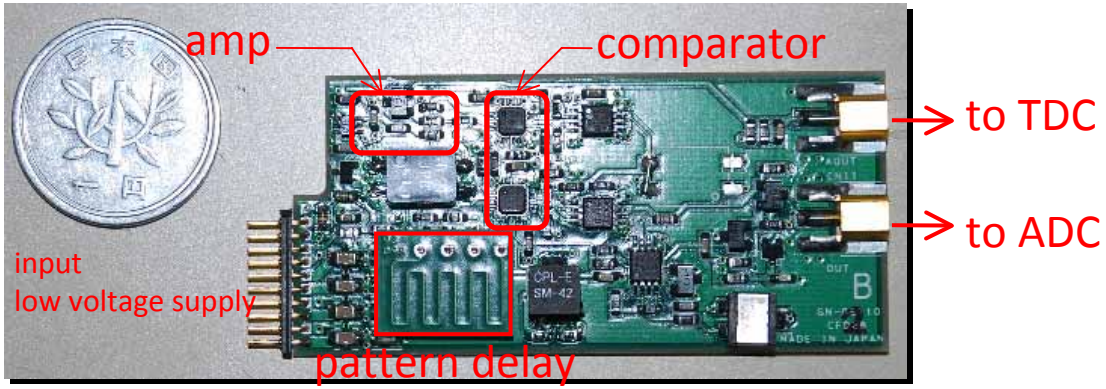
CFD prototype



- HV divider + AMP + CFD
- Small size
  - 29mm^{w} (→28mm^{w} in next version)
- CFD board
  - Fast AMP (MMIC, 1GHz, x20)
  - Fast comparator (180ps propagation)
  - CFD with pattern delay (500ps)
    - Avoid pulse distortion

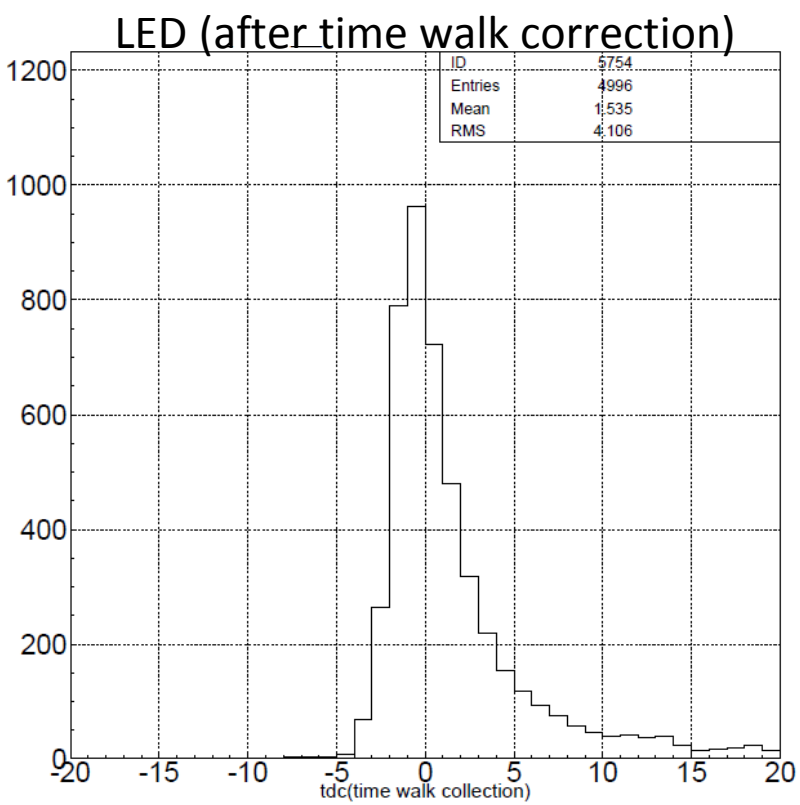


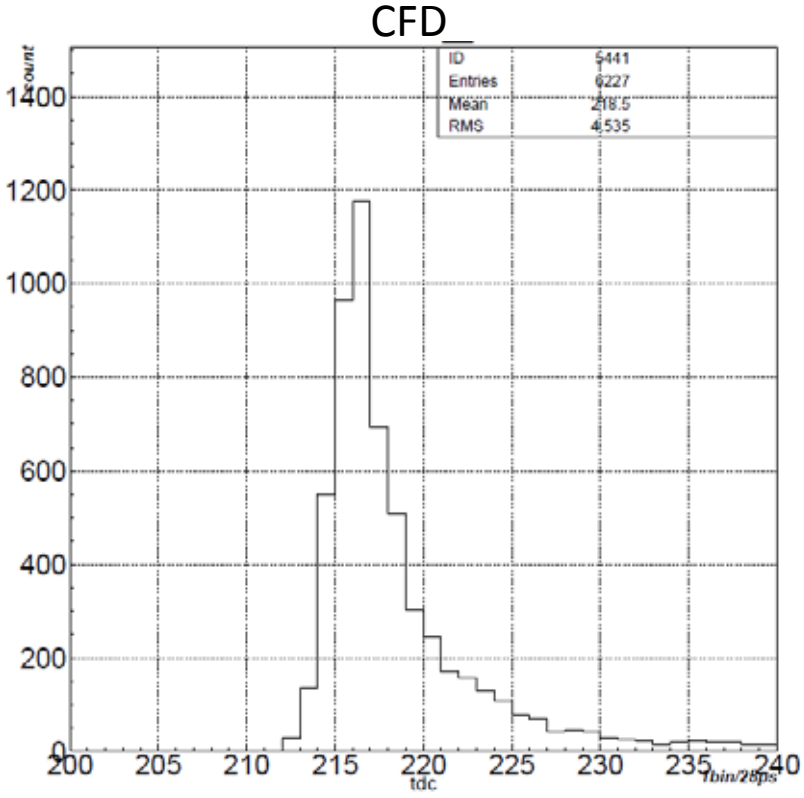
- 5ps resolution
  - 20mV test pulse



CFD performance with MCP-PMT

- LED with time walk correction and CFD



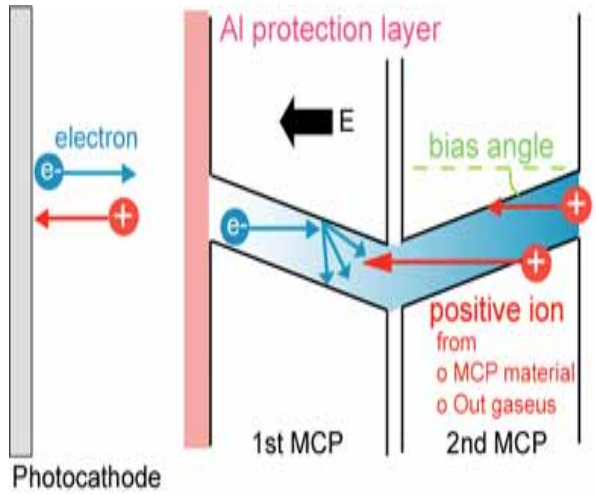


Good TDC distribution

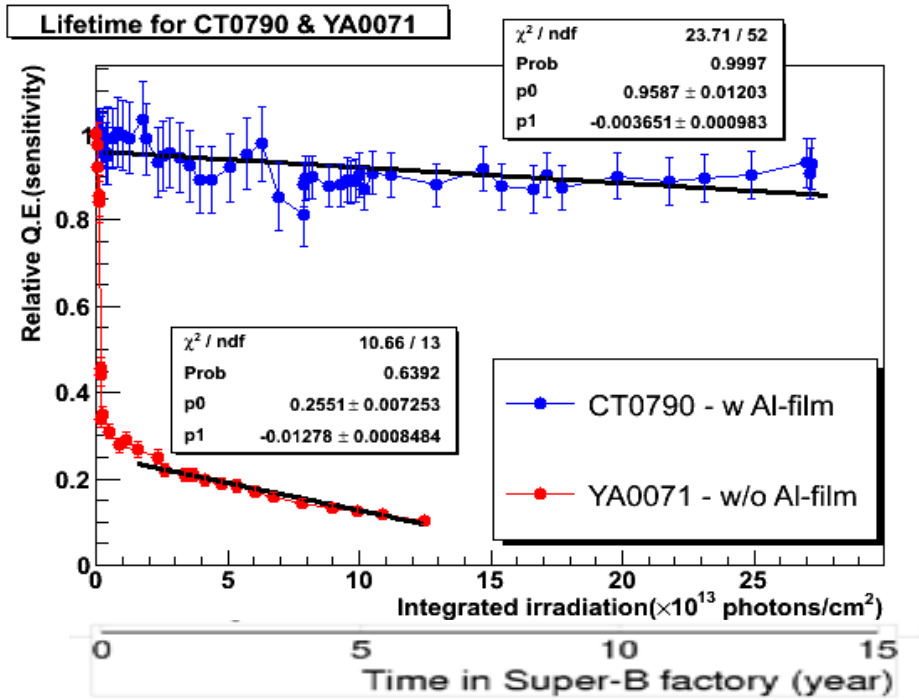
CFD prototype has enough ability for MCP-PMT.

Protection for ion-feedback

- Long lifetime against high hit rate
  - Cherenkov photons from beam BG
- Lifetime test
  - Hamamatsu round-shape MCP-PMT
    - With/without Al protection layer
    - Enough lifetime of QE for PMT with Al protection layer

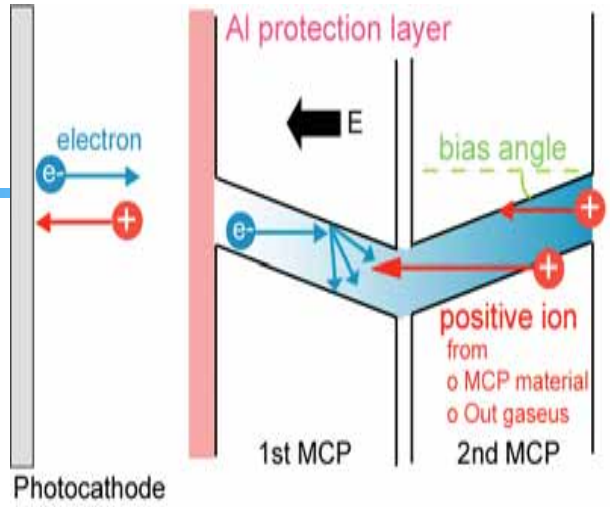


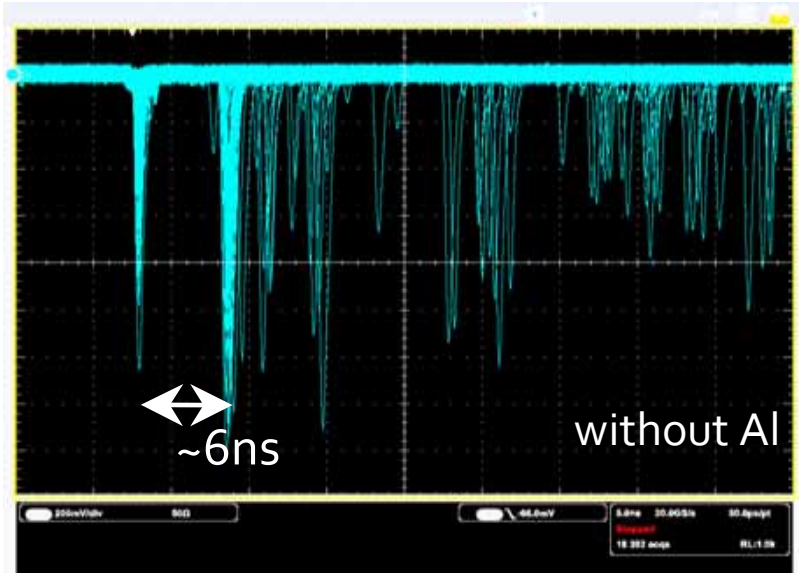
Al protection	O	X
Correction eff.	37%	65%
Effective area	11mmϕ	
Gain	1.9×10^6	1.5×10^6
TTS	34ps	29ps
Photo-cathode	Multi-alkali (NaKSbCs)	
Quantum eff. at 400nm	21%	19%
Bias angle	13deg	

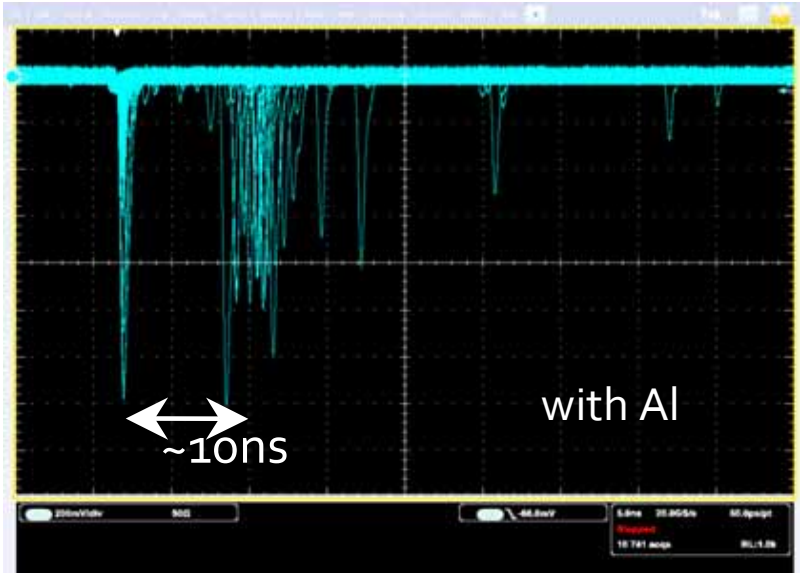


Source of ion

- Measure timing of after pulse
  - Dark pulse (←single photon level)
  - By oscilloscope (2.5GHz)
  - → H^+ from MCP surface



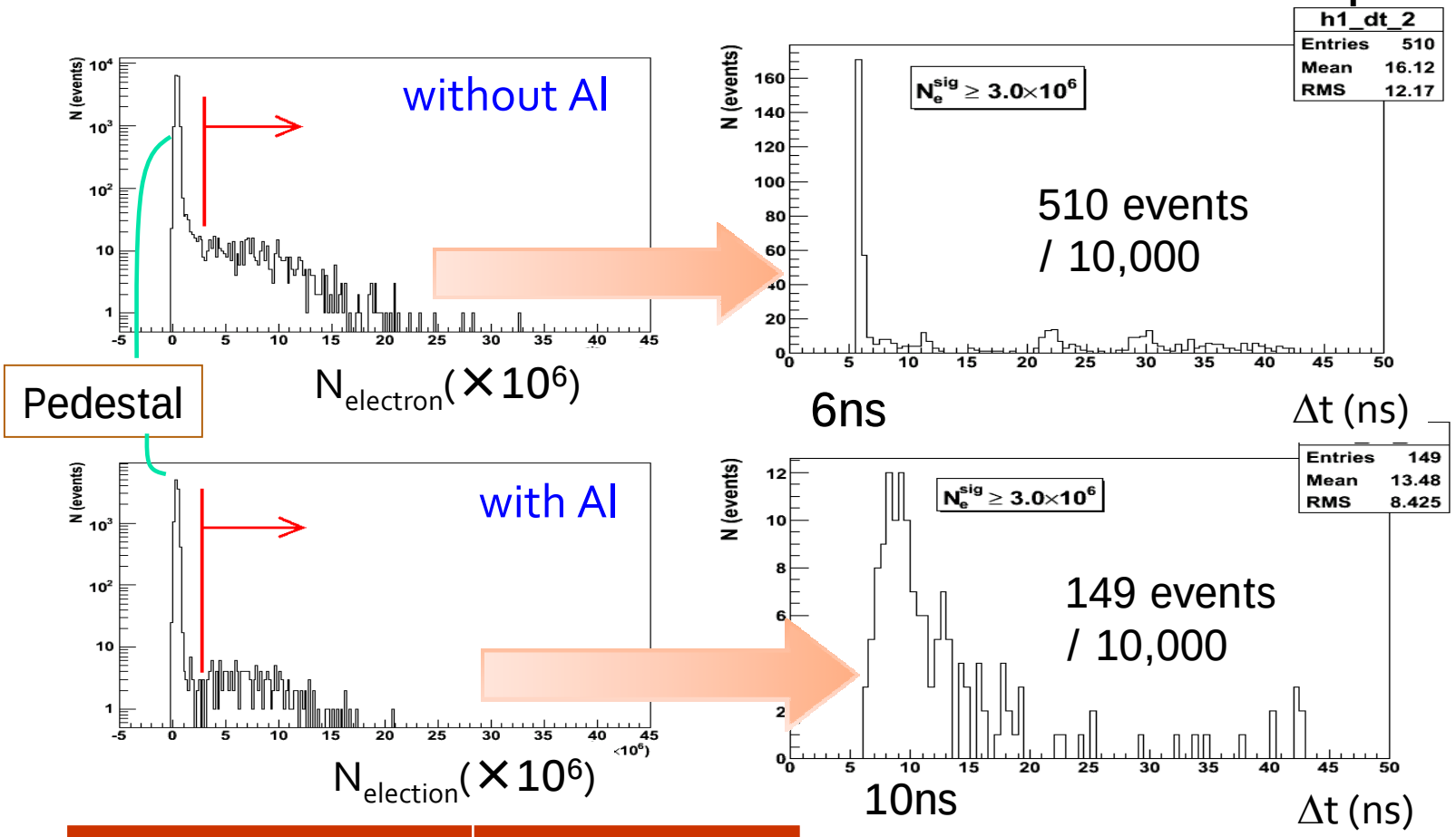




		HPK without Al	HPK with Al
ΔT(calc.)	H^+	5.4ns	10.7ns
	H_2^+, He^{2+}	7.2ns	15ns
ΔT(data)		~6ns	~10ns

Lifetime vs. rate

- Check correlation between lifetime and rate of after pulse

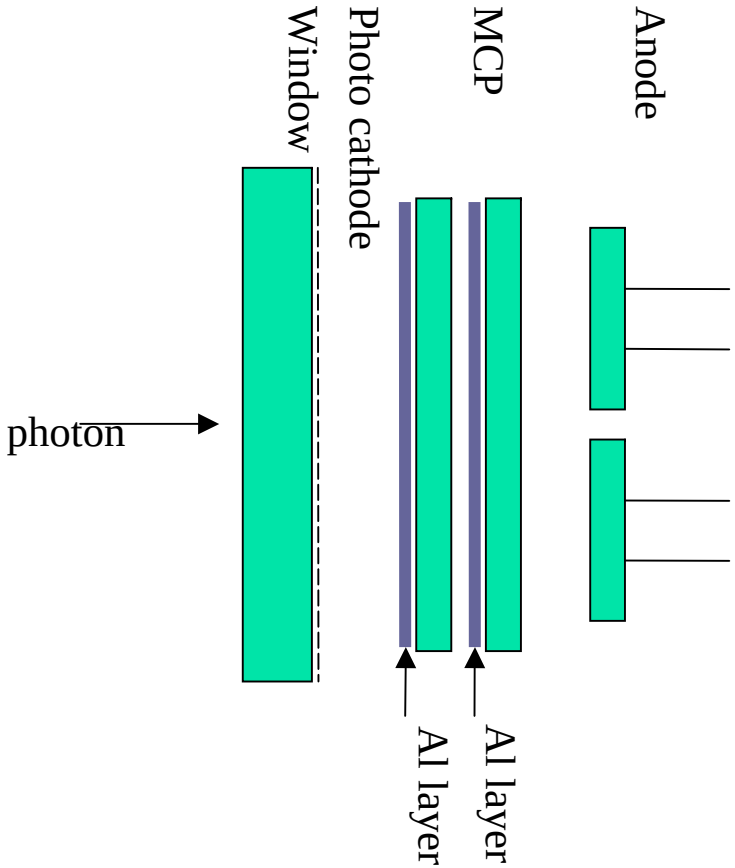


Al protection	without / with
Lifetime of QE	3.5 / 1
Rate of after pulse	3.4 / 1

Similar tendency

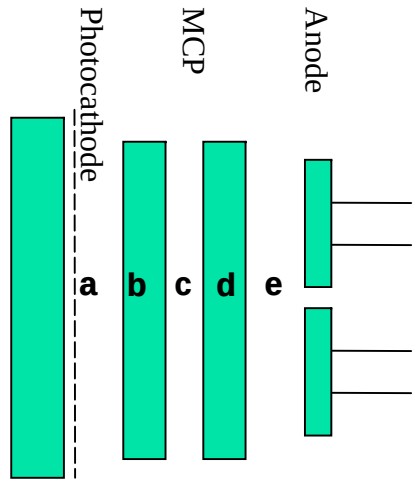
Protection with Al layer

- Ion feed-back
  - Protected by Al layer on 1st MCP
    - Reduce correction efficiency
      - 60% → 36%
  - H^+ from 2nd MCP layer?
    - Many elections hit MCP surface
      - Difference; ~10^3
- Put Al layer on 2nd MCP
  - Recover CE; ~2 times
  - Keep lifetime?
  - Lower effective gain?



MCP-PMT with Al on 2nd MCP

- Prototype by Hamamatsu
  - Square-shape Multi-alkali p.c.
  - Check performance with following HV ratio
    - Take MCP HV as reference
    - Additional HV between MCPs
      to pass through Al layer



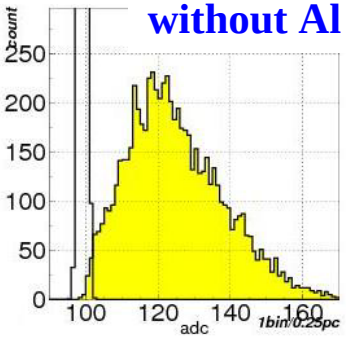
HV for each gap

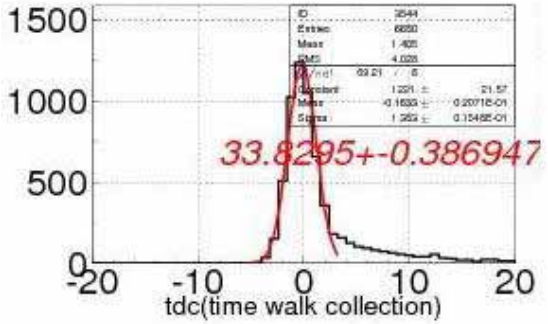
	a) K-MCPIN	b) MCPIN-Mid	c) Middle	d) Mid-MCPOUT	e) MCPOUT-Anode	Max HV (by HPK)
Without Al	200	1000	0	1000	600	2800V
With Al on 1st MCP	1000	1000	0	1000	600	3600V
With Al on 2nd MCP	200	1000	1000	1000	600	3800V

ADC, TDC distributions

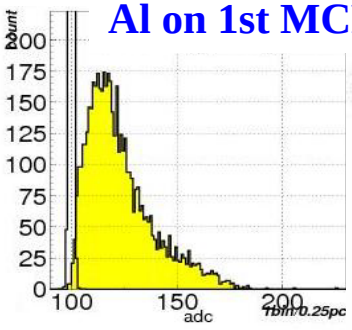
- For single photon
  - Gain=(1.4~1.9)x10^6
- Result
  - Enough gain
    - Good single photon peak
  - Enough TTS
    - ~34ps

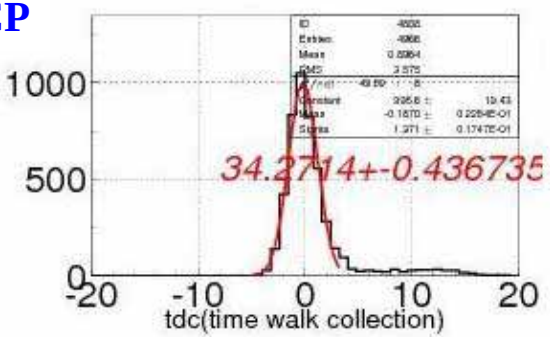
YJ0004/964.3V,Gain=1.9✕10^6



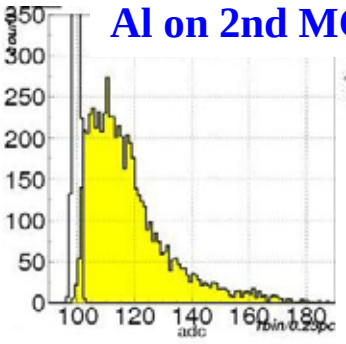


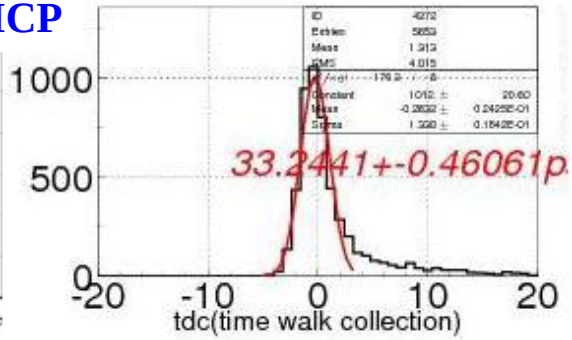
YJ0007/972.2V、Gain=1.6✕10^6



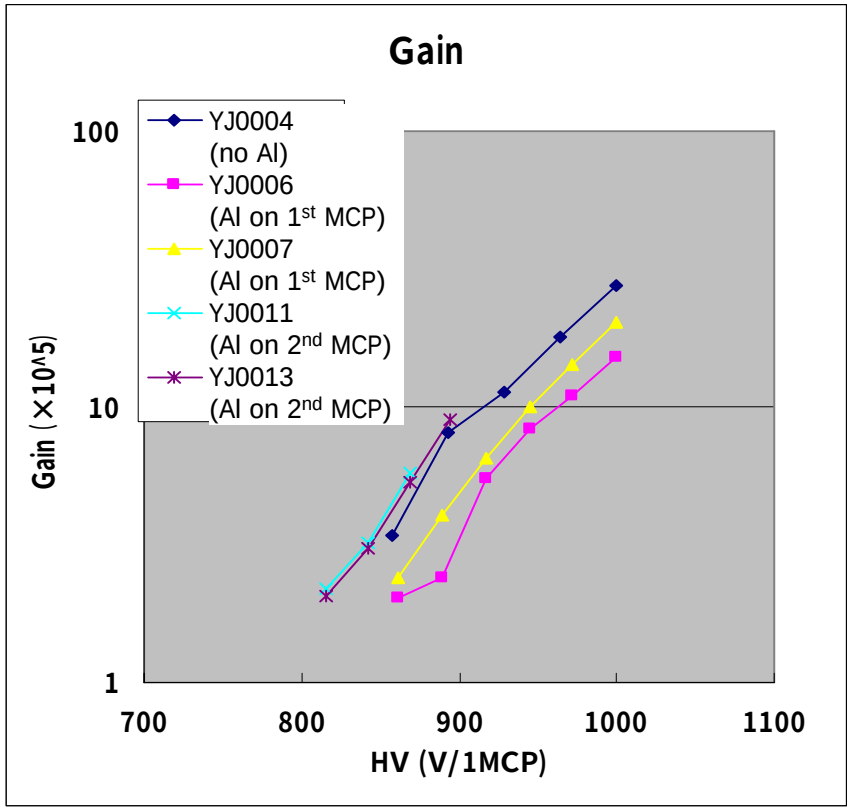


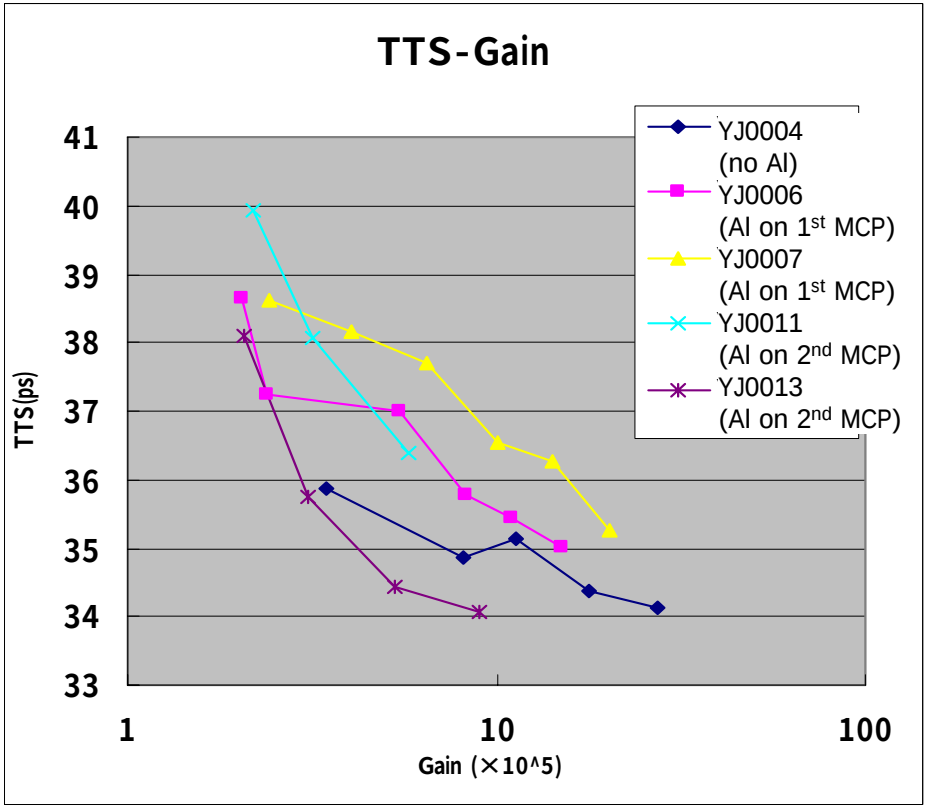
YJ0013/894.7V,Gain=1.4✕10^6





Gain and TTS





- Similar gain dependence on HV
  - HV between MCPs makes some gain
- Similar correlation between TTS and gain
- Enough performance → check after-pulse and lifetime

Summary

- TOP counter prototype
  - MCP-PMT (semi-)mass production, 13 pieces
    - Stable for TTS performance, Need to improve QE
  - Beam test
    - Ring image, number of photons, time resolution as expected
    - Next; check with Focusing system
  - CFD board
    - Good performance with MCP-PMT
- Protection for ion-feedback
  - Measure timing and rate of after-pulse
    - Confirmed that ion is H^+ from MCP surface
    - Correlation between lifetime and rate of ion-feedback
  - Prototype with Al layer on 2nd MCP
    - To improve correction efficiency
    - Enough TTS and gain
    - Next; measure lifetime and after-pulse