Workshop on timing detectors at Saclay, 8-9 March 2007

Timing properties of MCP-PMT

- Time resolution
- Lifetime
- Rate dependence
- Applications (TOF, TOP)

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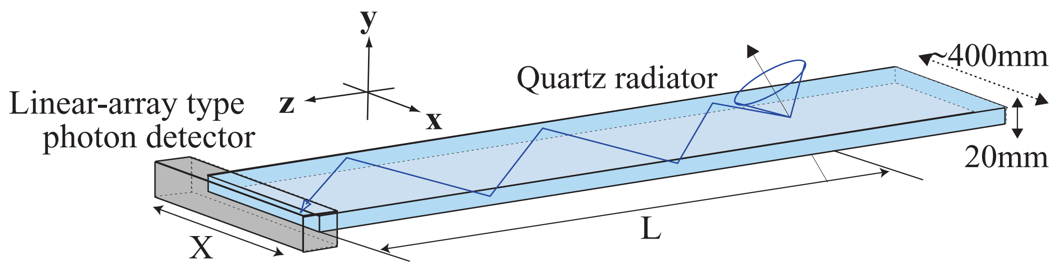
Introduction

- Photon device for TOP counter
  - Cherenkov ring imaging counter with precise timing measurement (NIM A 440 (2000) 124)
    - Barrel PID upgrade for Super B factory



- Single photon sensitivity
- Good transit time resolution (<50ps)
- Operational under 1.5T B-field
- Position sensitive (~5mm)
- High detection efficiency

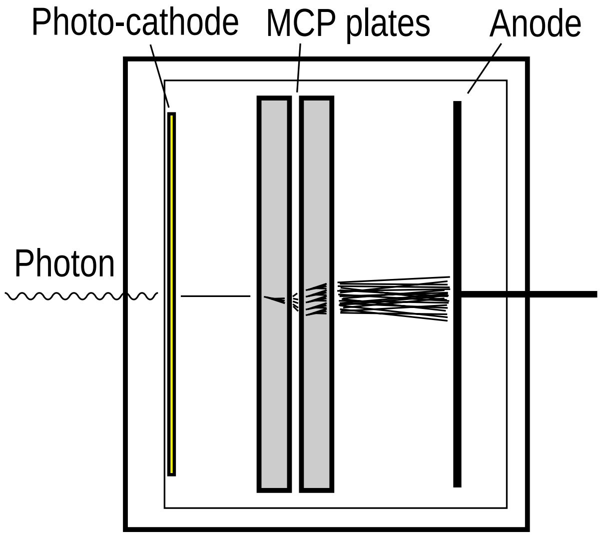
- MCP-PMT is a best solution!

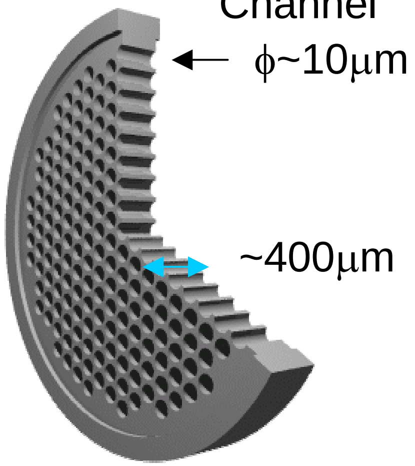
MCP-PMT

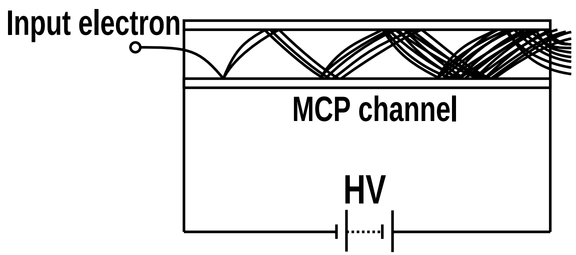
- Micro-Channel-Plate
  - Tiny electron multipliers
    - Diameter ~10μm, length ~400μm
  - High gain
    - ~10^6 for two-stage type

  → Fast time response

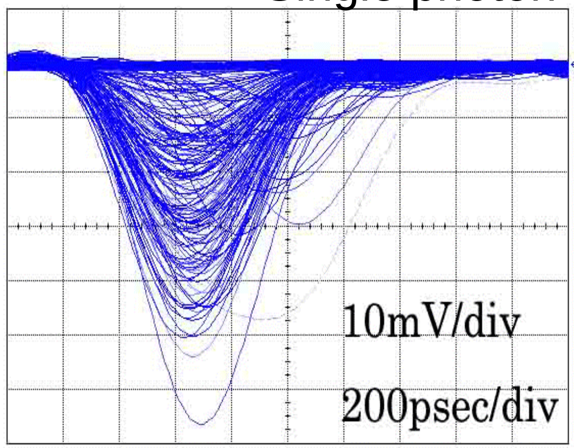
  Pulse raise time ~500ps, TTS < 50ps
  - can operate under high magnetic field (~1T)





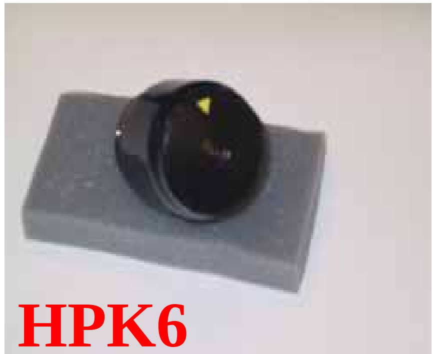


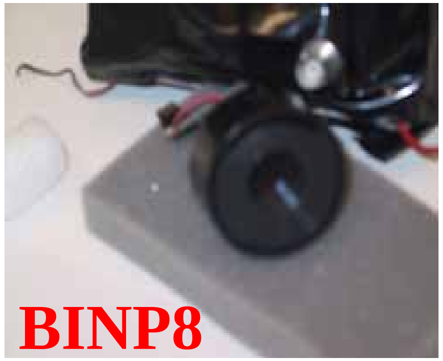
Single photon

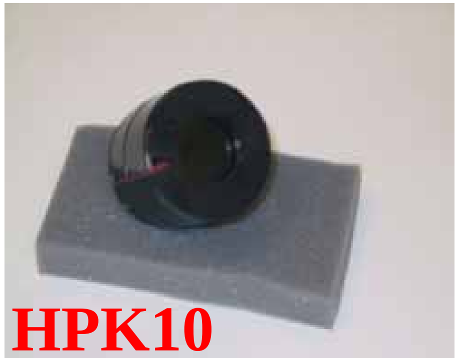


MCP-PMT for single photon

- Timing properties under B=0~1.5T parallel to PMT



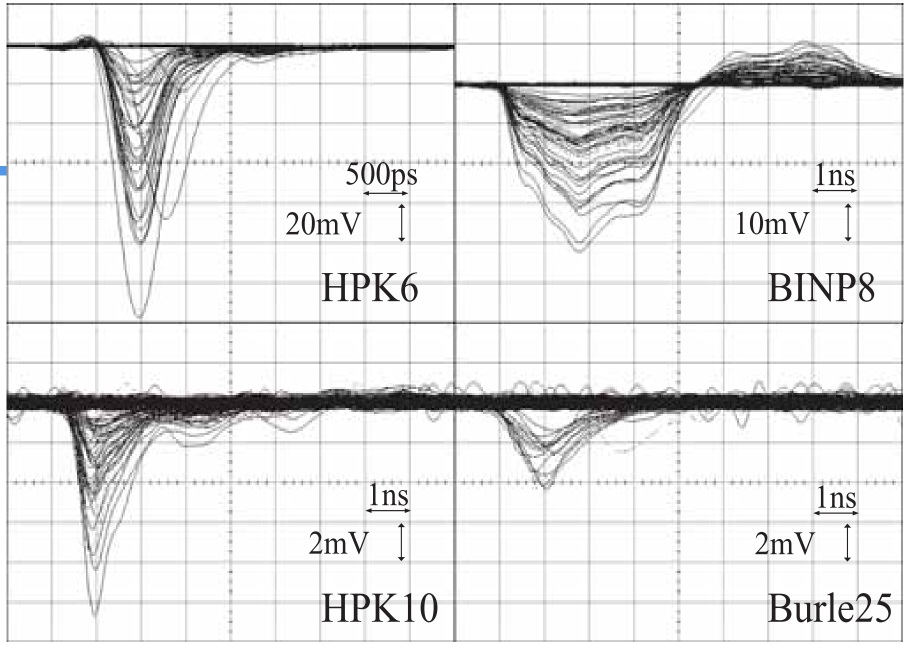


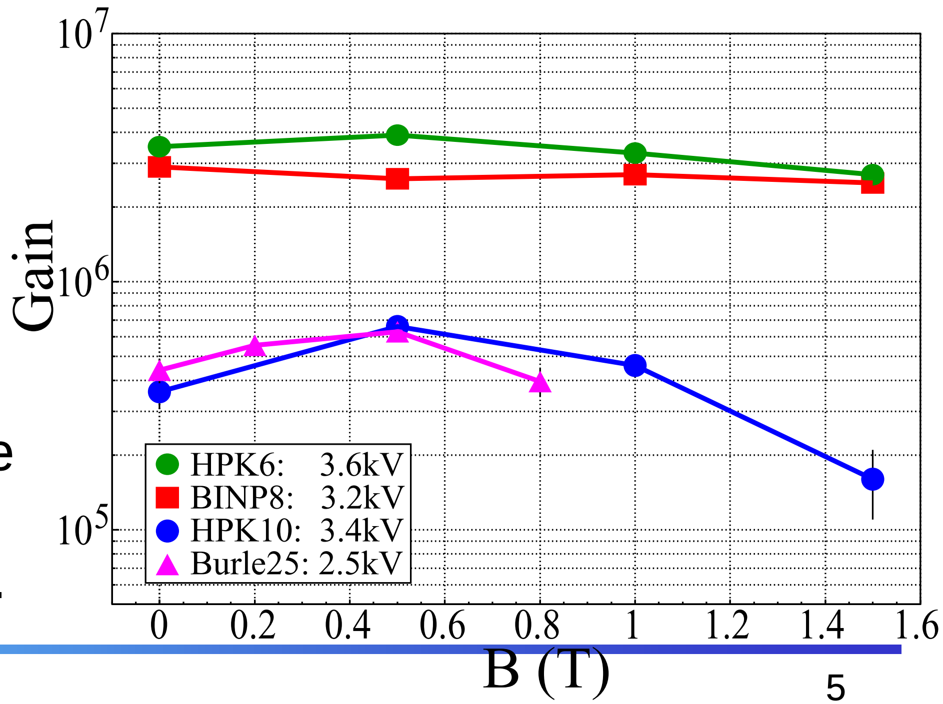


MCP-PMT	HPK6 R3809U-50-11X	BINP8 N4428	HPK10 R3809U-50-25X	Burle25 85011-501
PMT size(mm)	45	30.5	52	71x71
Effective size(mm)	11	18	25	50x50
Channel diameter(μm)	**6**	**8**	**10**	**25**
Length-diameter ratio	40	40	43	40
Max. H.V. (V)	3600	3200	3600	2500
photo-cathode	multi-alkali	multi-alkali	multi-alkali	bi-alkali
Q.E.(%) (λ=408nm)	26	18	26	24

Pulse response

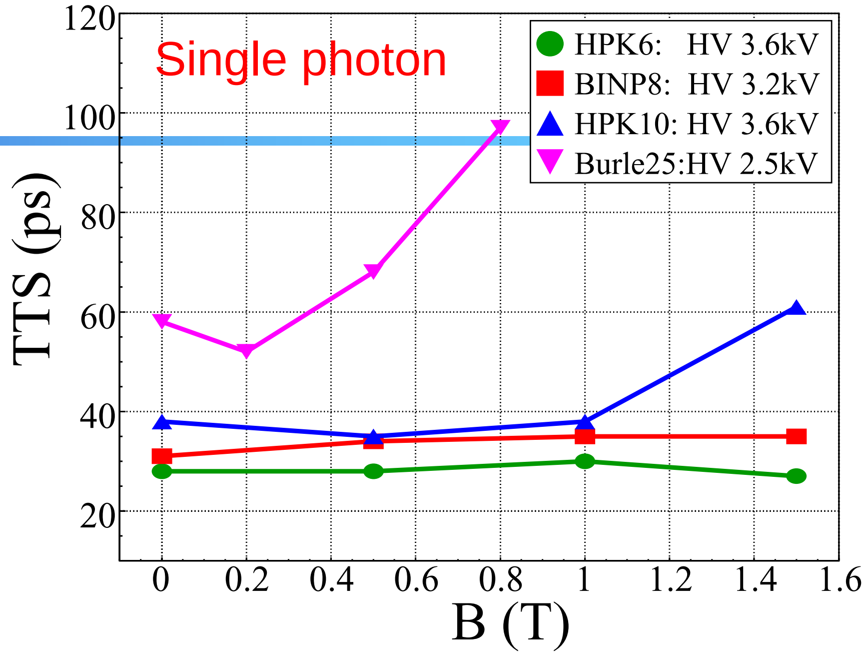
- Pulse shape (B=0T)
  - Fast raise time (~500ps)
  - Broad shape for BINP8
    - Due to mismatch with H.V. supply divider
    - No influence for time resolution
- Gain v.s. B-field
  - Small channel diameter shows high stability against B-field.
  - Explained by relation btw hole size and Larmor radius of electron motion under B-field.

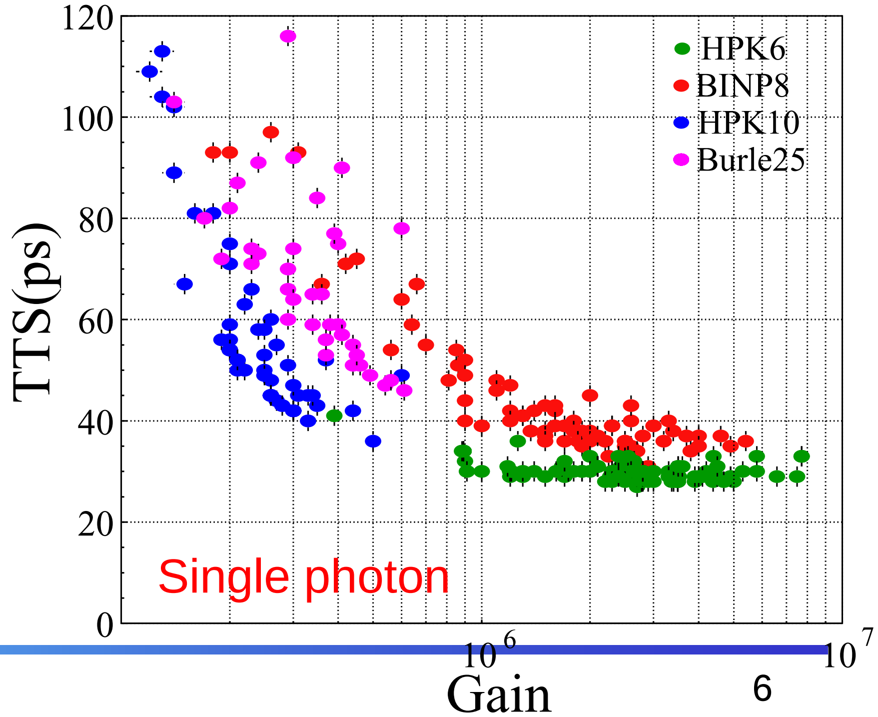




Time response

- TTS v.s. B-field
  - Small channel diameter shows high stability and good resolution.
- TTS v.s. Gain
  - For several HV and B-field conditions
  - 30~40ps resolution was obtained for gain>10^6
- Hole size need <~10μm
  - to get time resolution of ~30ps under 1.5T B-field.

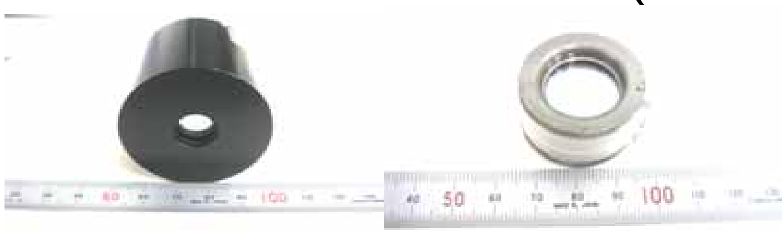




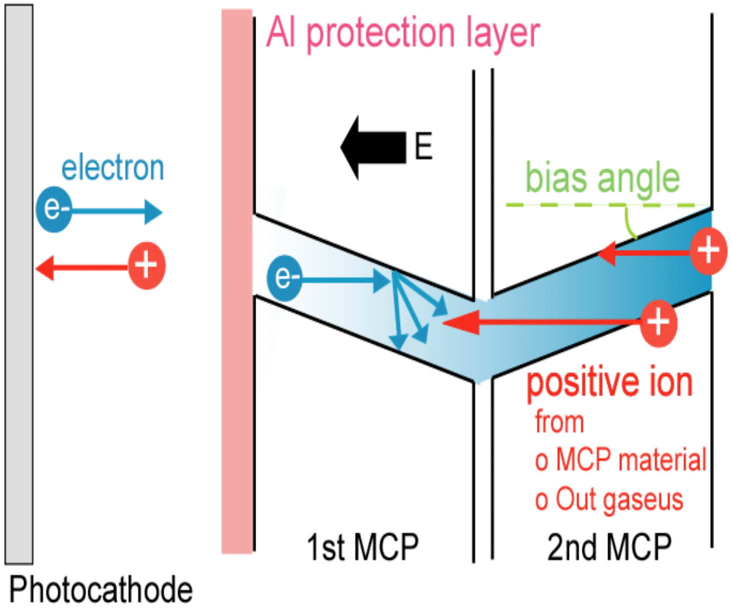
Lifetime

- How long can we use MCP-PMT under high hit rate?

(Nucl. Instr. Meth. A564 (2006) 204.)



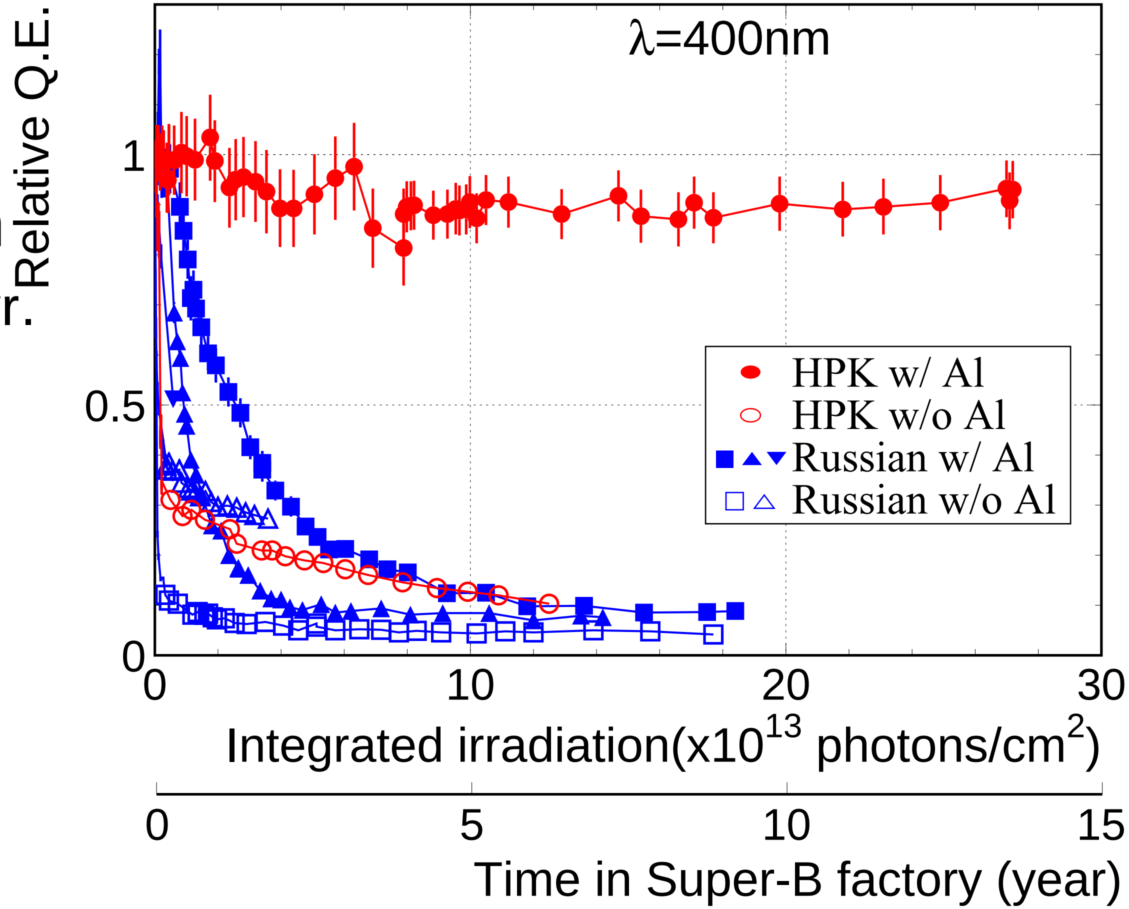
	HPK (x2)		Russian (x5)	
Al protection	**O**	**X**	**O**	**X**
Correction eff.	**37%**	**65%**	**40-60**	**55-60%**
Effective area	11mmϕ		18mmϕ	
Gain	1.9×10^6	1.5×10^6	$3\sim4\times10^6$	
TTS	34ps	29ps	30~40ps	
Photo-cathode	Multi-alkali (NaKSbCs)			
Quantum eff. at 400nm	21%	19%	16-20%	
Bias angle	13deg		5deg	



- Light load by LED pulse (1~5kHz)
  - 20~100 p.e. /pulse (monitored by normal PMT)

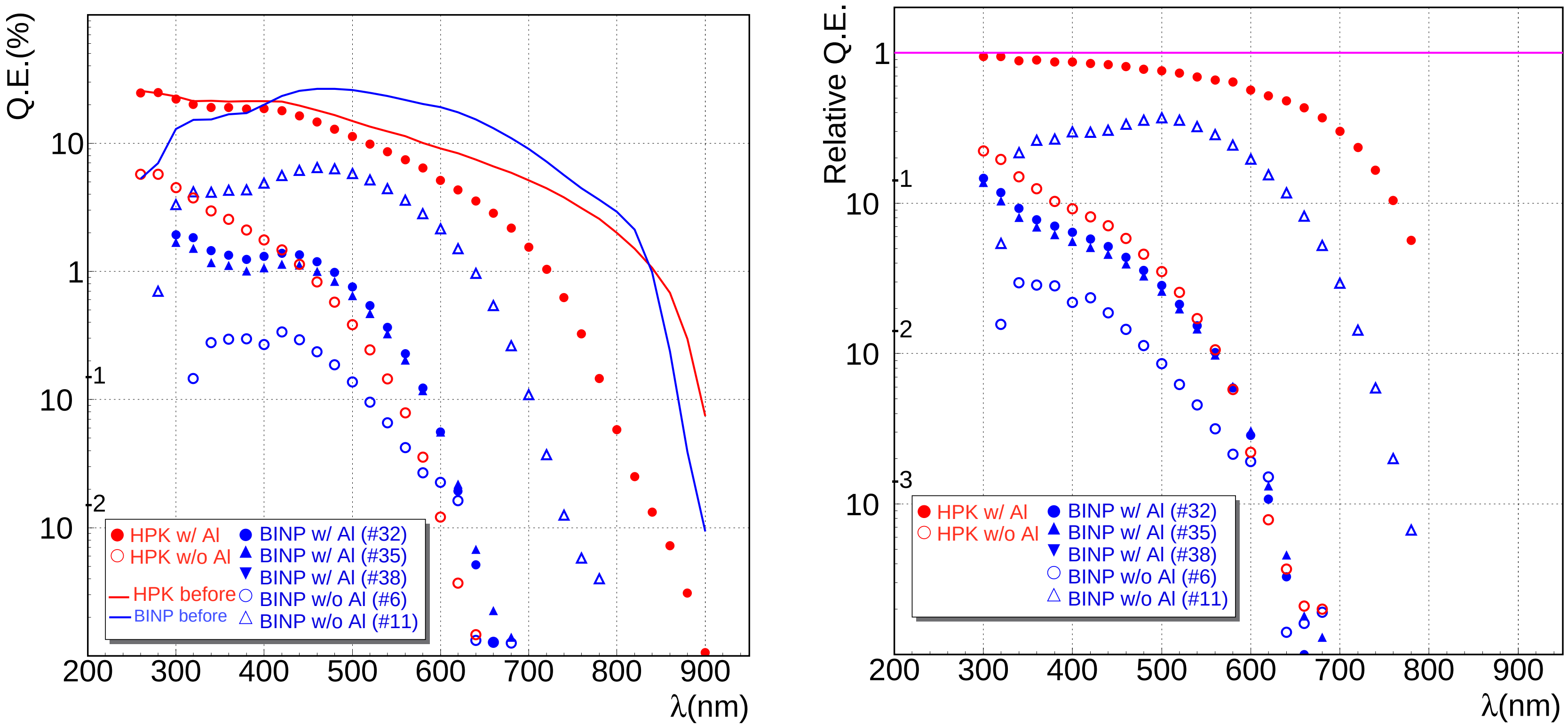
Lifetime - Q.E. -

- Relative Q.E. by single photon laser
- Without Al protection
  - Drop <50% within 1yr.
- With Al protection
  - Long life
  - Not enough for Russian PMTs
- Enough lifetime for HPK's MCP-PMT with Al protection layer



Lifetime - Q.E. vs wavelangth -

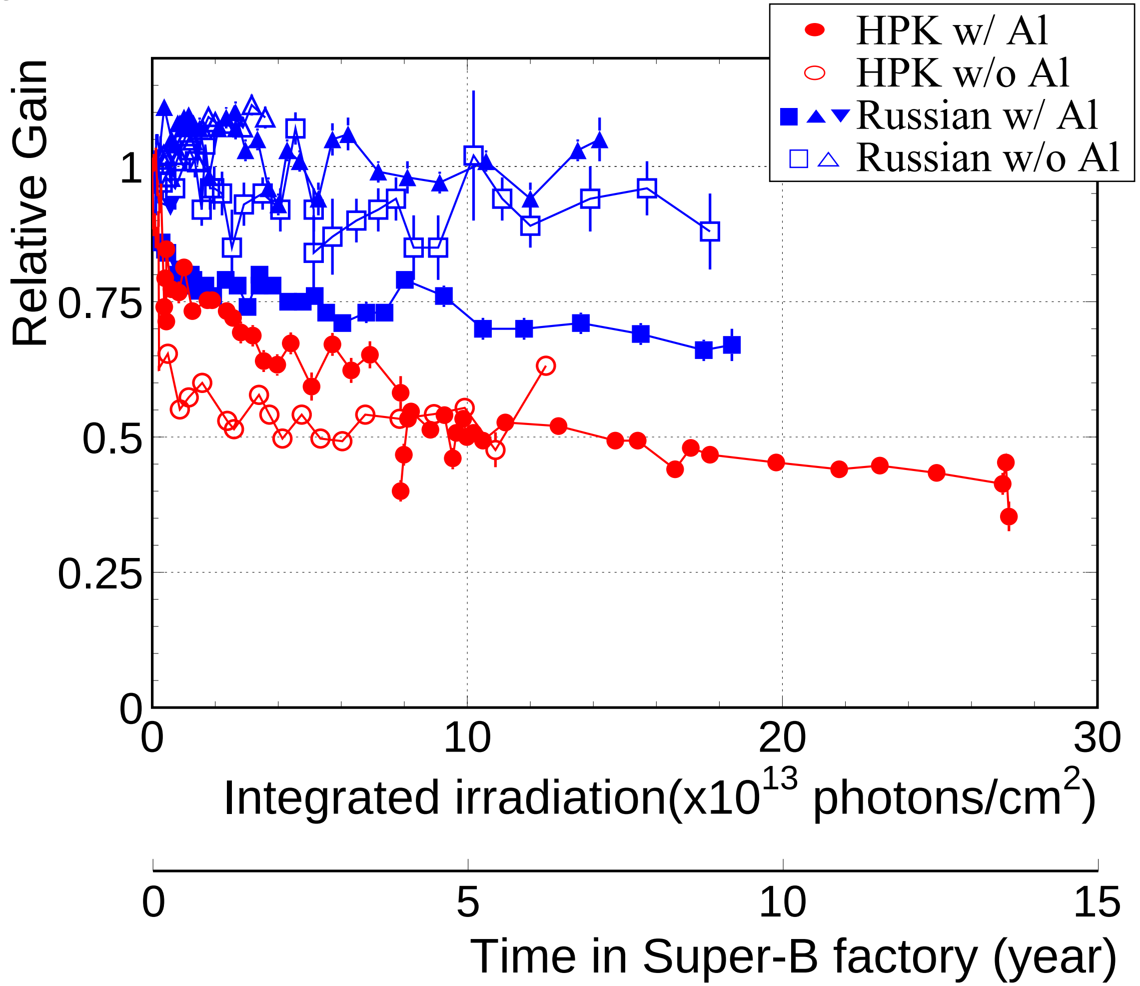
- Q.E. after lifetime test (Ratio of Q.E. btw. before,after)



- Large Q.E. drop at longer wavelength
- Number of Cherenkov photons ; only 13% less (HPK w/Al)
  - Number of generated Cherenkov photon: $\sim 1/\lambda^2$

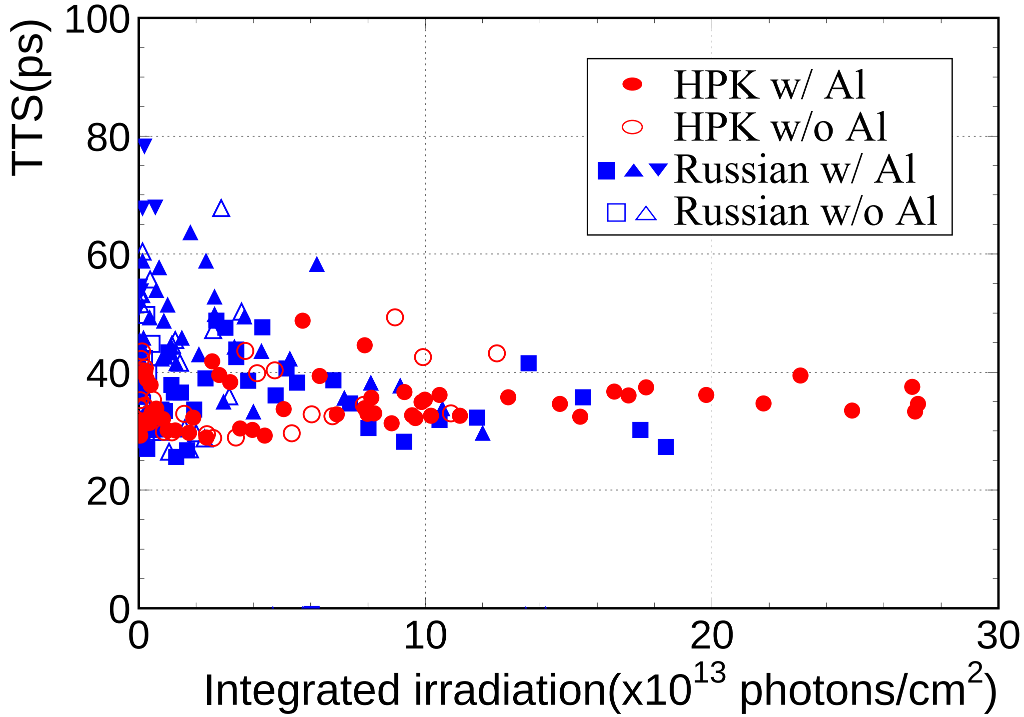
Lifetime - Gain -

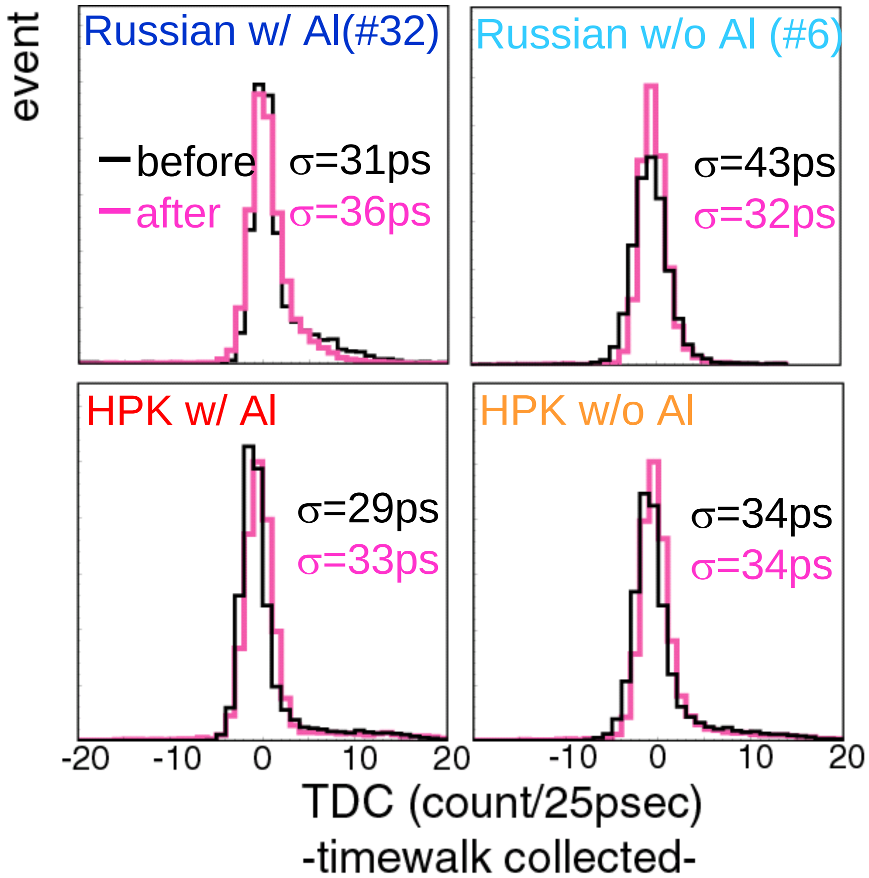
- Estimate from output charge for single photon irradiation
- $<10^{13}$photons/cm^2
  - Drop fast
- $>10^{13}$photons/cm^2
  - Drop slowly
- Single photon detection: OK
- Can recover gain by increasing HV



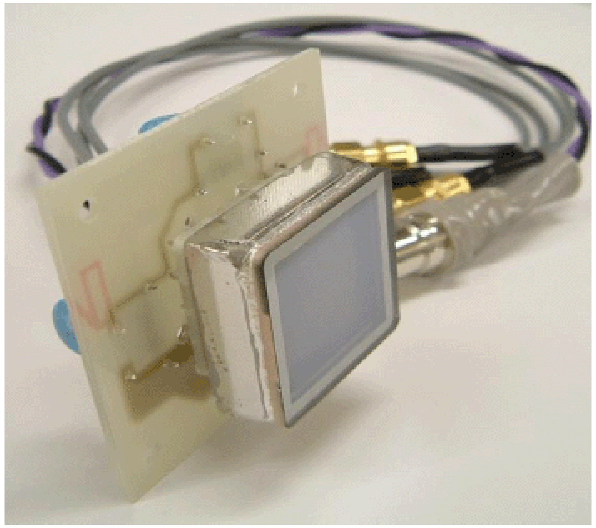
Lifetime - T.T.S. -

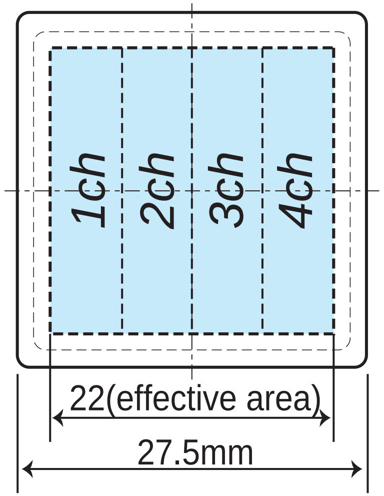
- Time resolution for single photon
  - →No degradation!
    - Keep ~35ps





Multi-anode MCP-PMT (1)





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=350nm)
MCP Channel diameter	10 μm
Number of MCP stage	2
Al protection layer	No
Aperture	~60%
Anode	4 channel linear array
Anode size (1ch)	5.3 x 22 mm
Anode gaps	0.3 mm

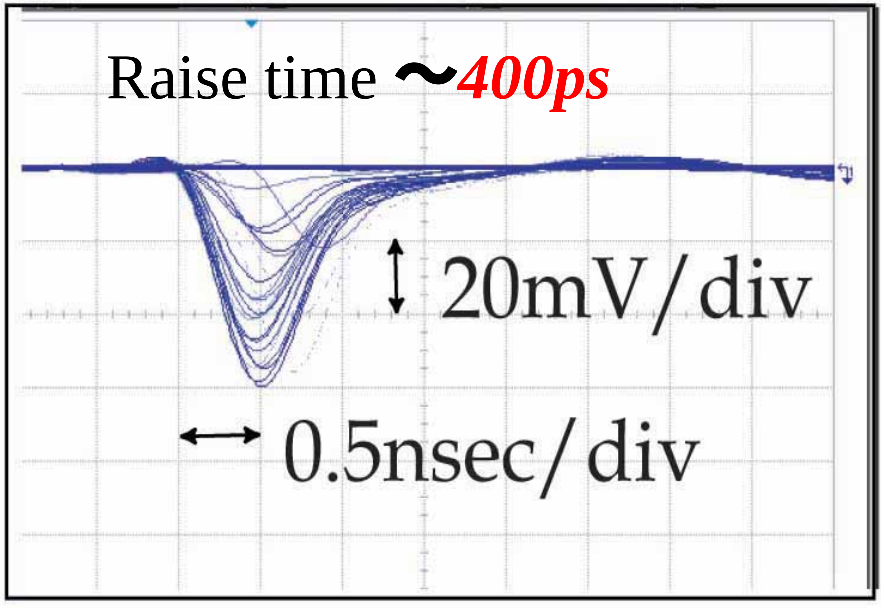
SL10

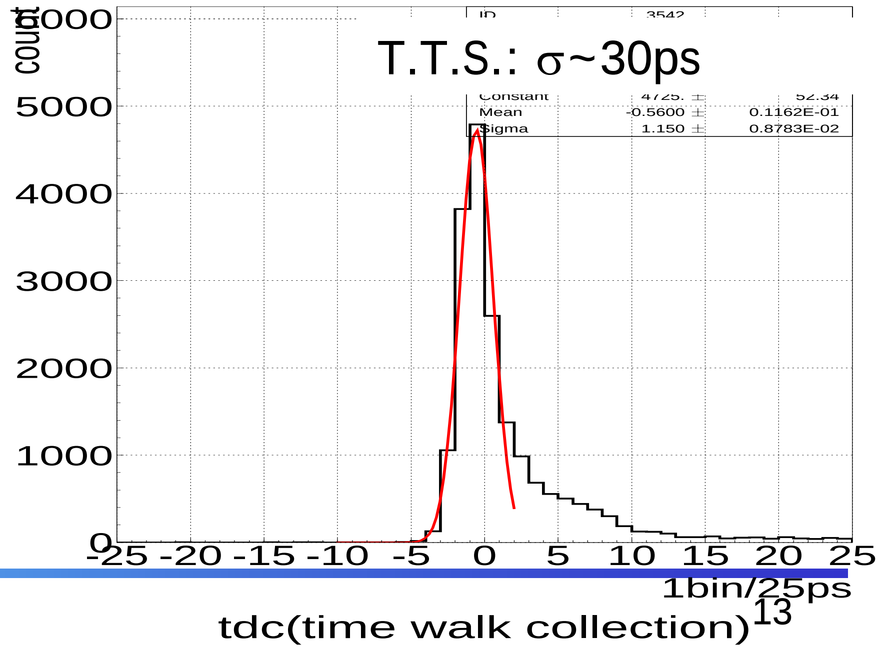
R&D with Hamamatsu
for TOP counter

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

Multi-anode (2)

- Single photon detection
- Fast raise time: ~400ps
- Gain=1.5x10^6 @B=1.5T
- T.T.S.(single photon): ~30ps @B=1.5T
- Position resoltion: <5mm
- Correction eff.: ~50%
  - Nucl. Instr. Meth. A528 (2004) 768.
- Basic performance is OK!
  - Same as single anode MCP-PMT

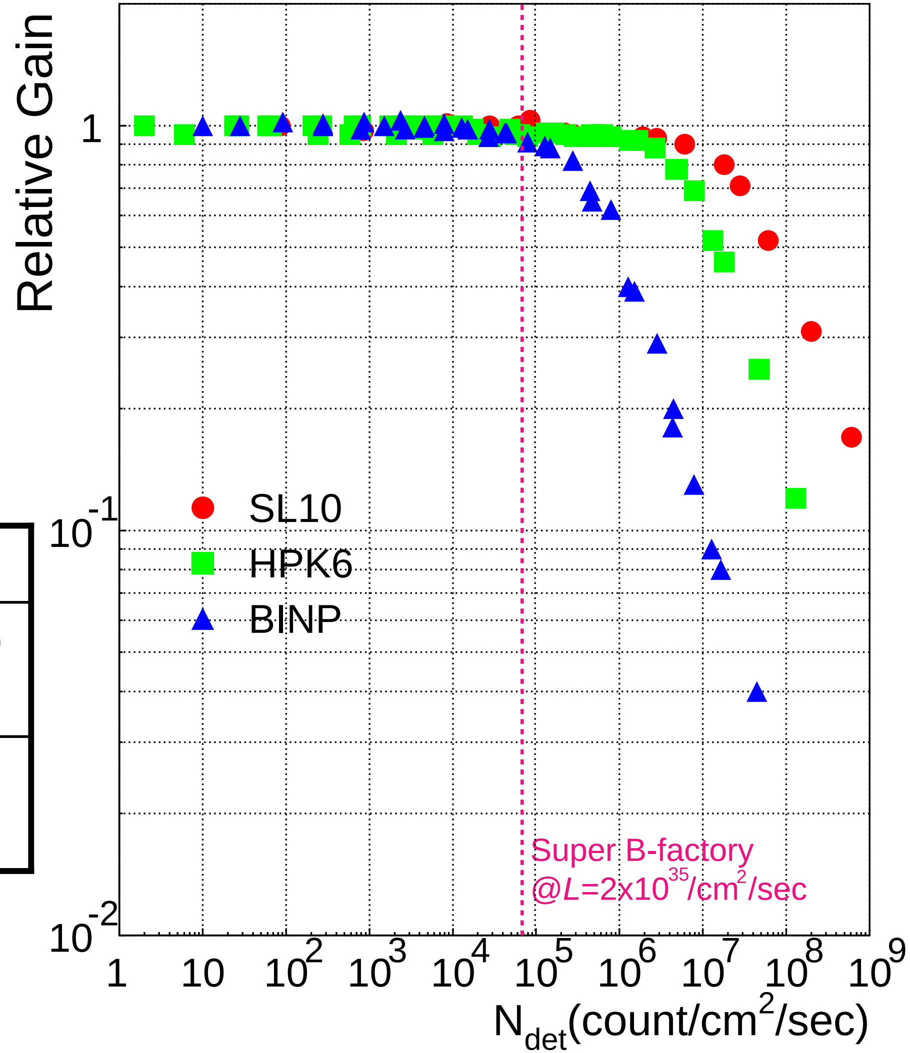


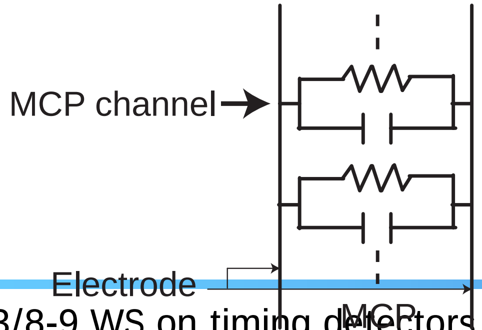


Rate dependence

- Gain vs. photon rate
  - For high intensity beam
- Gain drop for high rate
  - $>10^5$ count/cm^2/s
  - Due to lack of elections inside MCP holes
  - Dep. on RC variables

	SL10	HPK6	BINP
MCP resistance (MΩ cm^2)	96	143	380~1000
MCP capacitance (pF/cm^2)	16	31	24~39





Enough for TOP counter

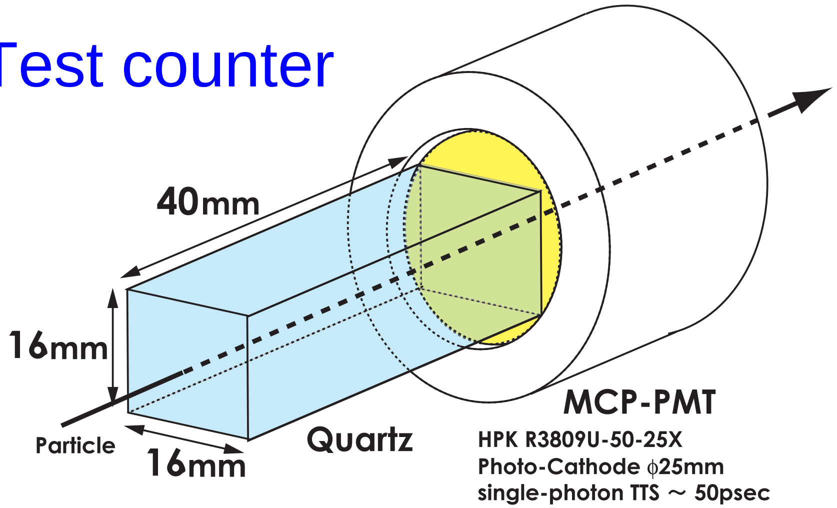
Applications

- 5ps TOF
- TOP counter

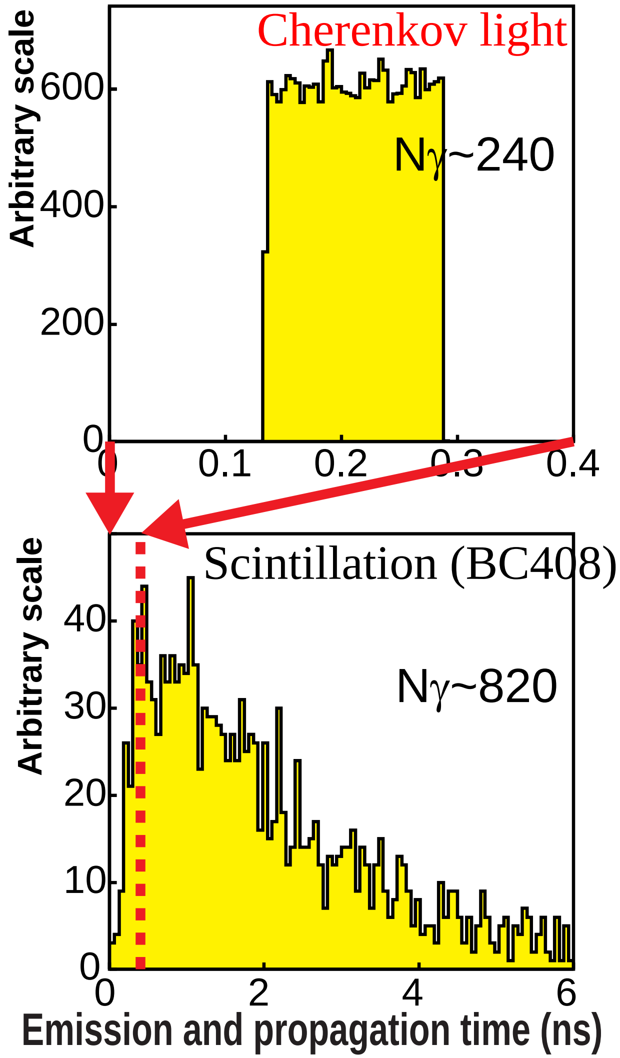
High resolution TOF

- Structure
  - Small-size quartz (cm~mm length)
    - Cherenkov light (Decay time ~ 0) extremely reduce time dispersion compared to scintillation (τ ~ ns)
  - MCP-PMT (multi-alkali photo-cathode)
    - TTS < 50ps even for single photon gives enough time resolution for smaller number of detectable photons

Test counter



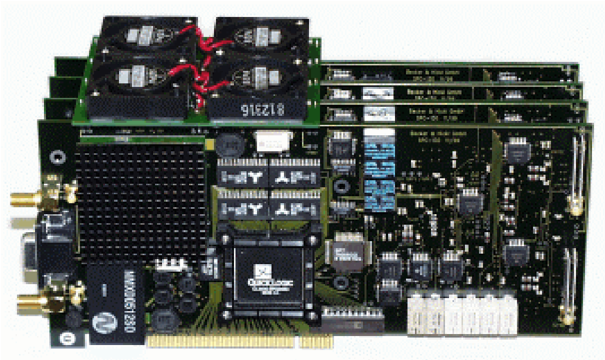
Simulation



Beam test

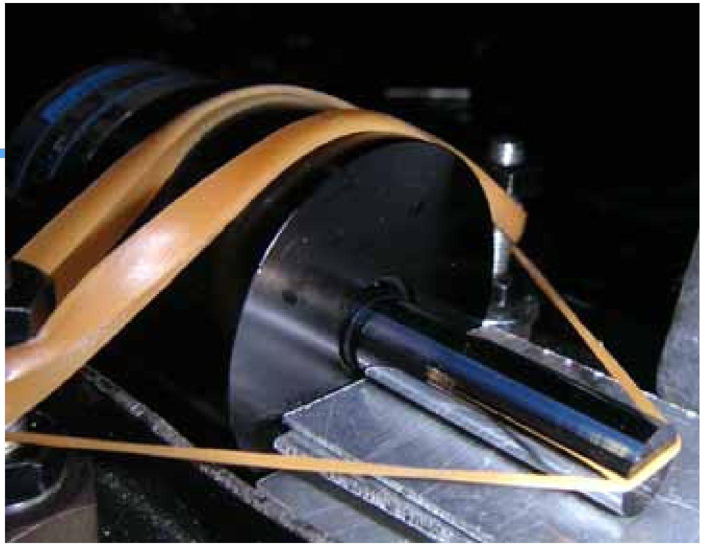
- MCP-PMT (HPK6, R3809U-50-11X)
  - TTS: ~30ps
  - 6μm hole

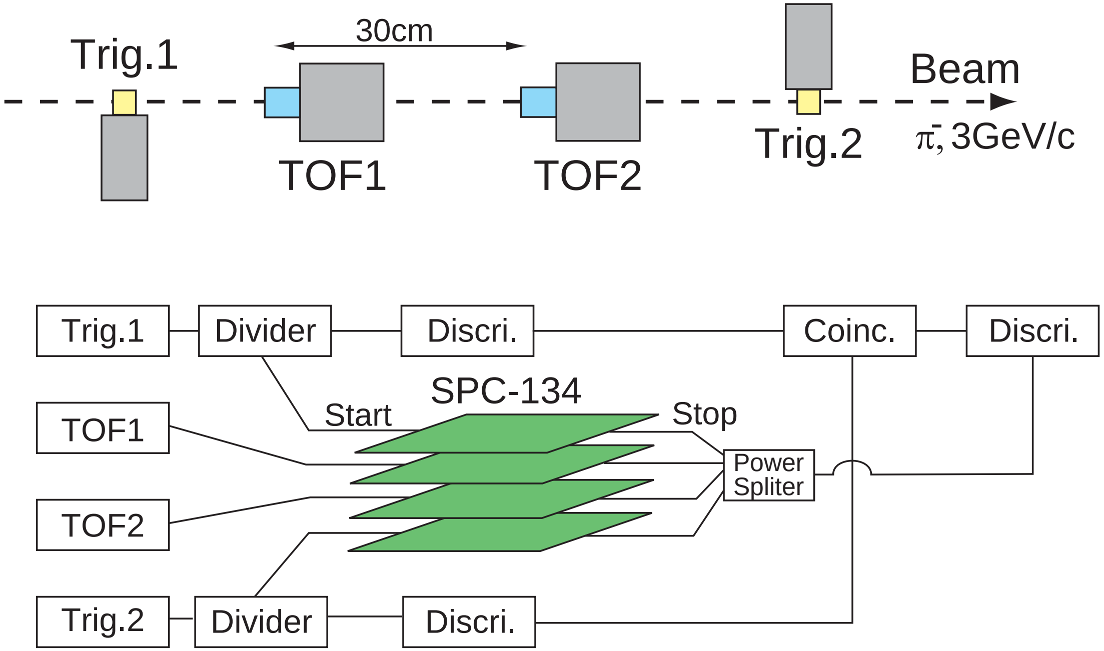
- Readout electronics
  - $\sigma_{elec.}$: 4ps
  - Time-correlated Single Photon Counting Modules (SPC-134, Becker & Hickl GMbH's)
    - CFD, TAC and ADC
    - Channel width = 813fs
    - Electrical time resolution = 4ps RMS

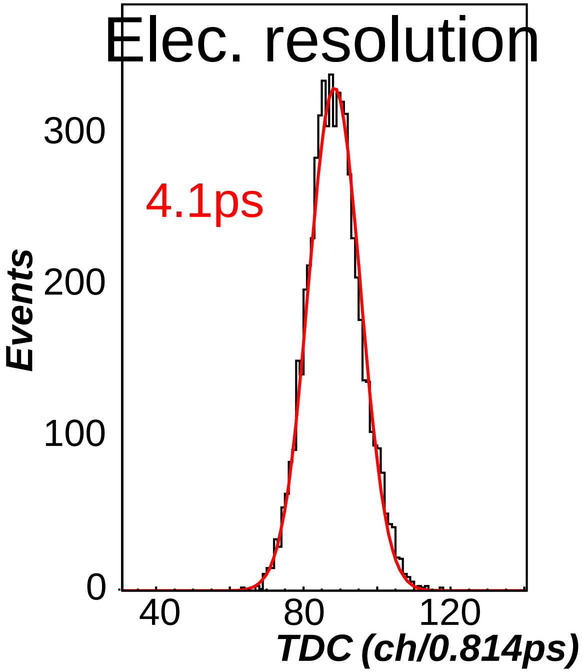


Beam test setup

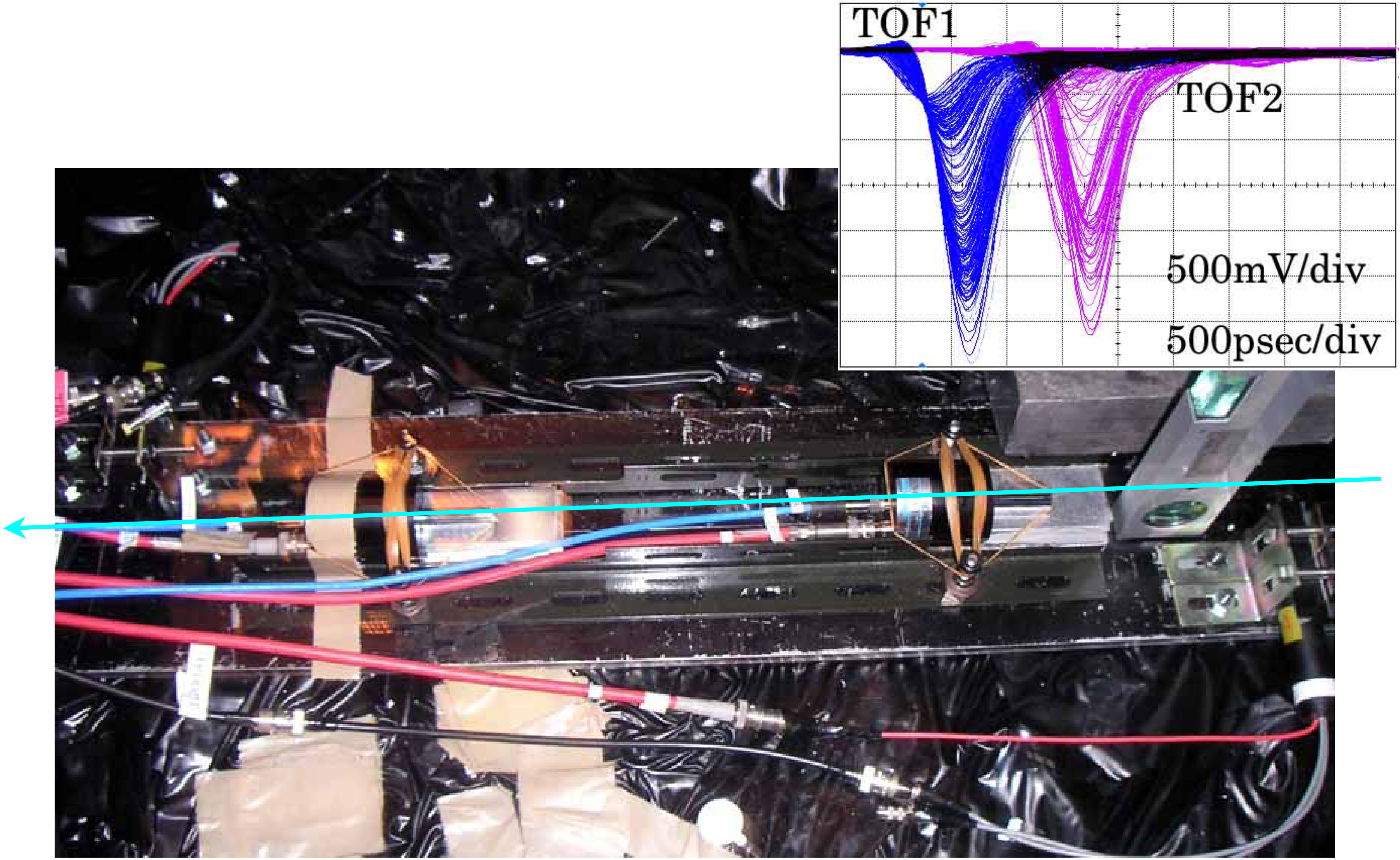
- 3GeV/c π^- beam
  - at KEK-PS π2 line
- PMT: R3809U-50-11X
- Quartz radiator
  - 10^{ϕ}x40^{z}mm with Al evaporation





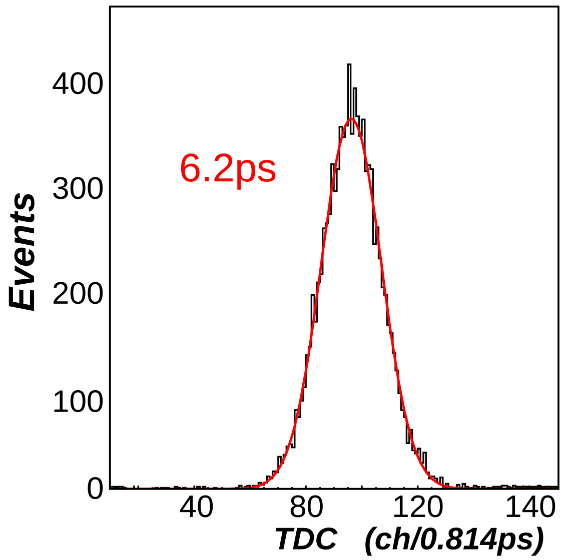


Beam test setup photo

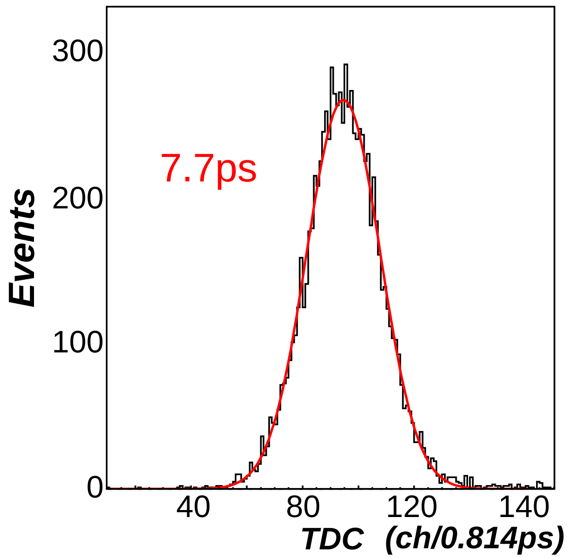


Beam test result

- With 10mm quartz radiator
  - +3mm quartz window
  - Number of photons ~ 180
  - Time resolution = 6.2ps
  - Intrinsic resolution ~ 4.7ps

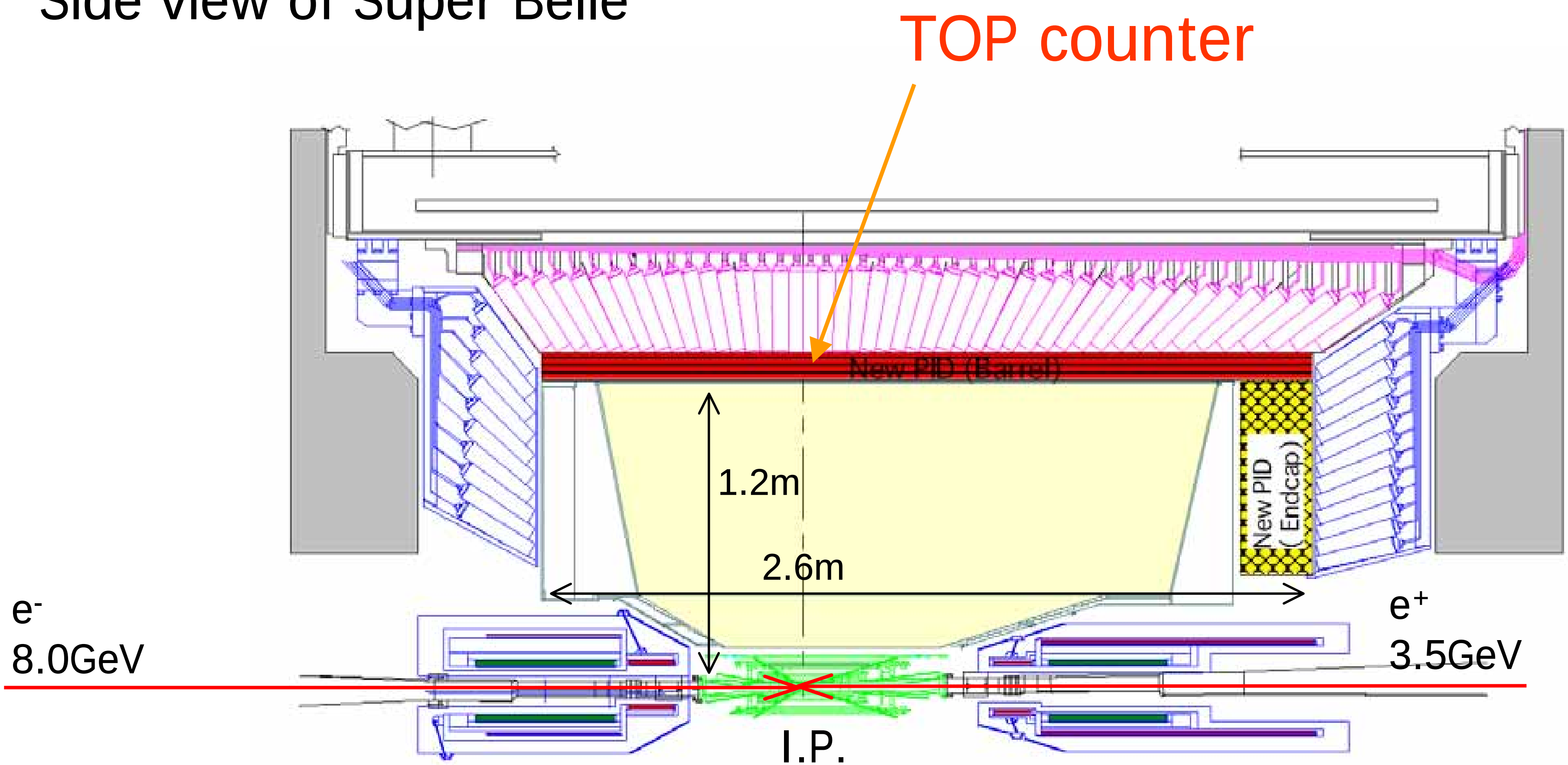


- Without quartz radiator
  - 3mm quartz window
  - Number of photons ~ 80
    - Expectation ~ 20 photo-electrons
  - Time resolution = 7.7ps



TOP counter in Super B-factory

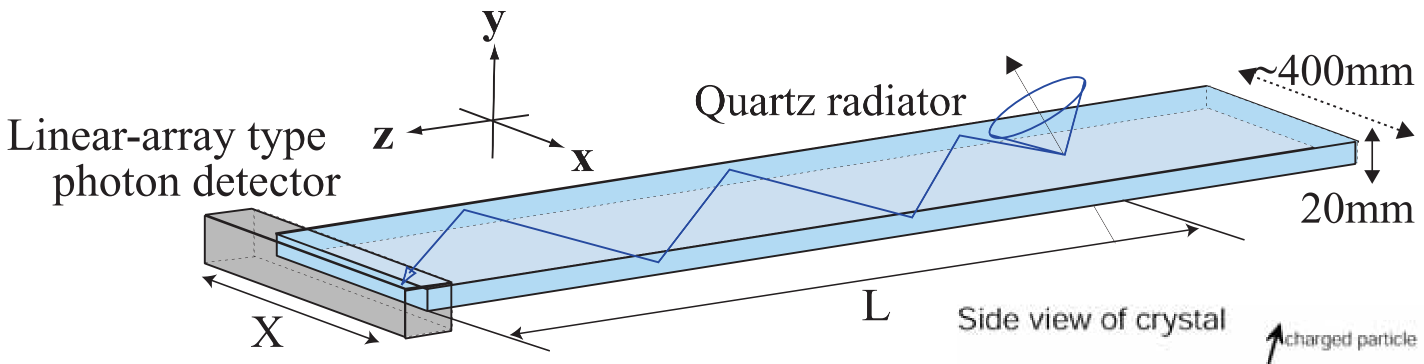
Side view of Super Belle



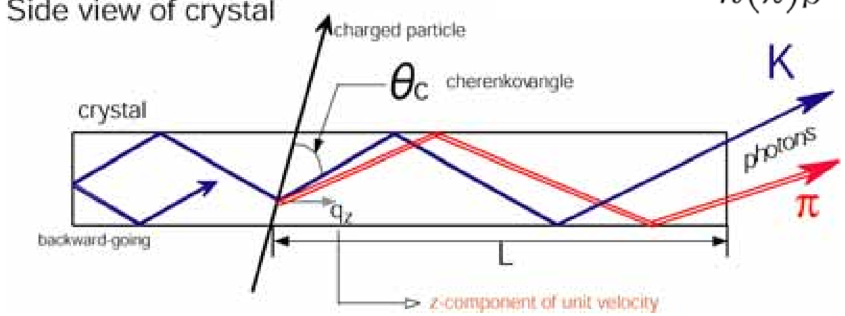
TOP counter should be compact!

TOP counter

- Cherenkov ring imaging using timing information



$$\cos\theta_c = \frac{1}{n(\lambda)\beta}$$



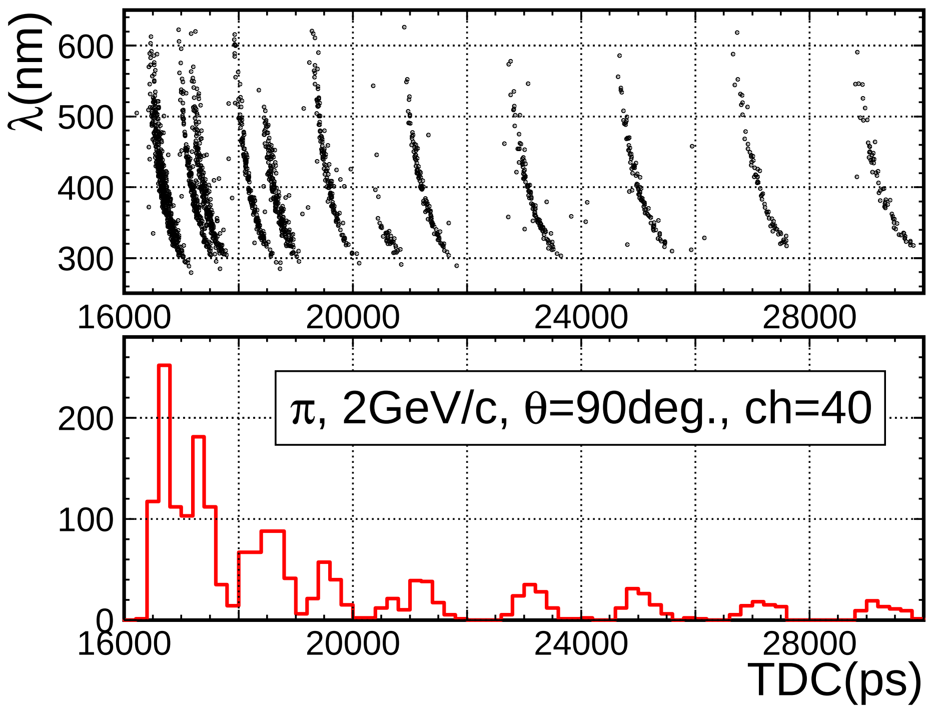
Difference of path length
$\rightarrow$ Difference of time of propagation (TOP)

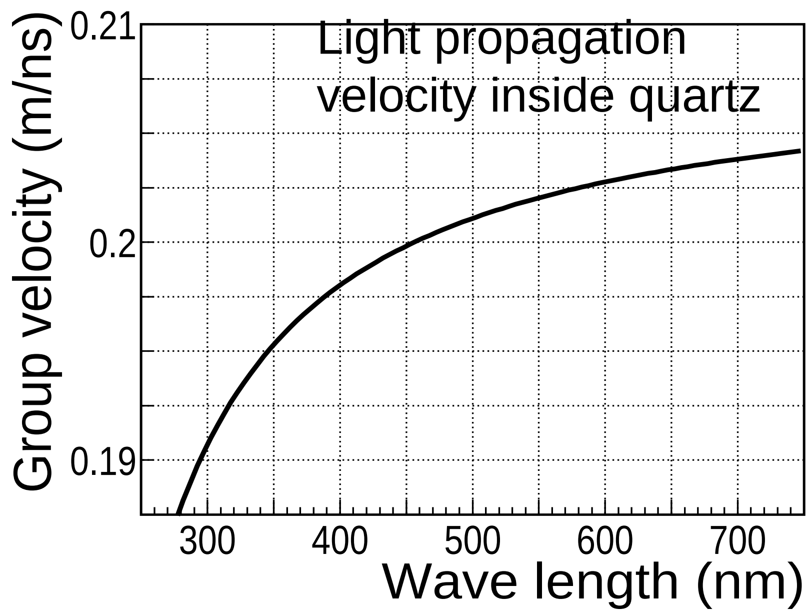
150~200ps from TOP + TOF from IP
with precise time resolution (σ~50ps) for each photon

Chromaticity

- Detection time is depending on the wavelength of Cherenkov light.
  - Due to light propagation velocity depending on the wavelength.
- Time resolution become worse.

$\rightarrow$ Separation of TOP ring image become worse.





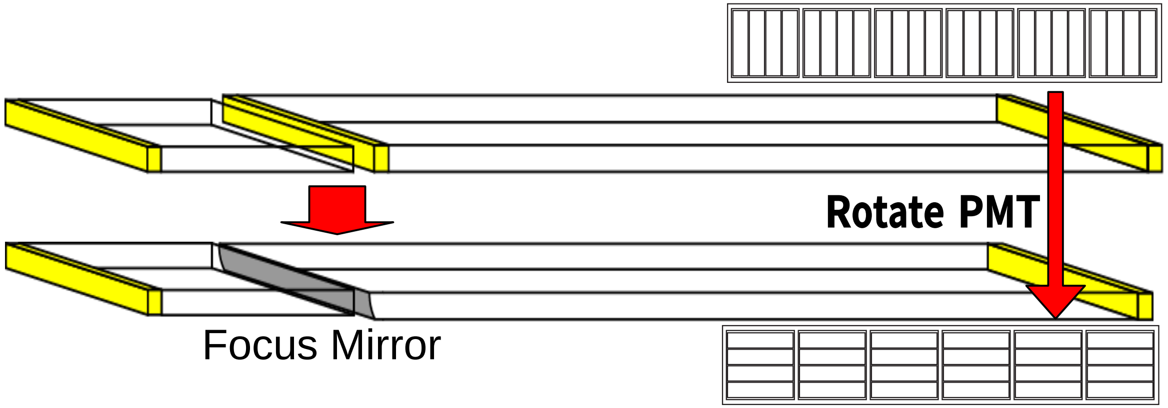
Focusing TOP

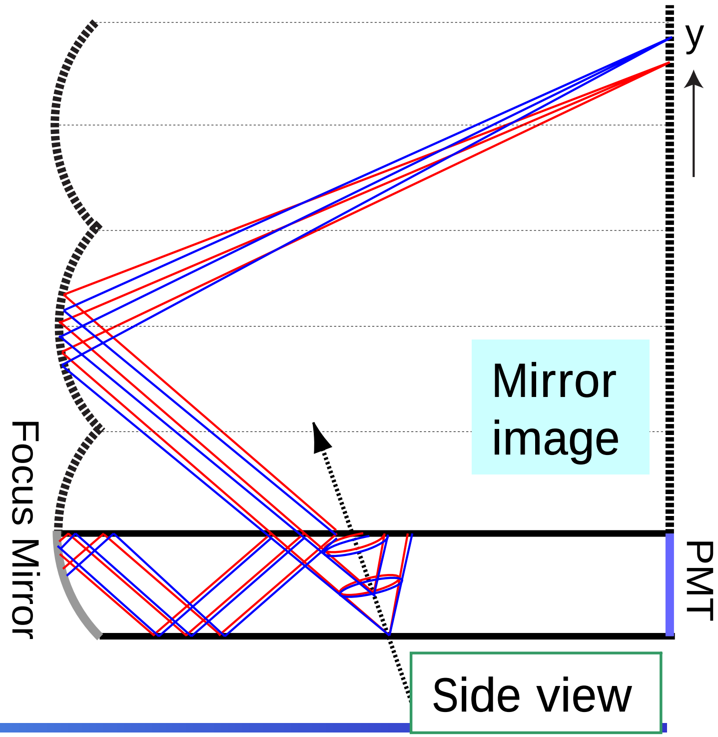
- Chromatic effect makes ~100ps fluctuation for TOP.
- Use λ dependence of Cherenkov angle to correct chromaticity

➔ Focusing system to measure θ_c

- $\lambda \leftarrow \theta_c \leftarrow$ y position
- Reconstruct ring image from 3D information (time, x and y).

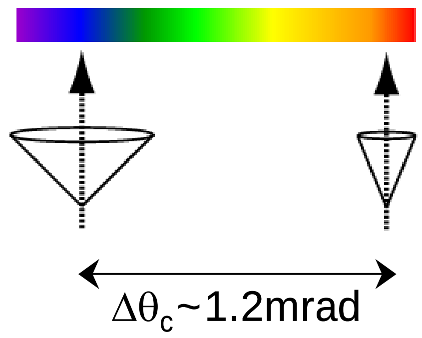
$$\theta_c(\lambda) = \cos^{-1}\left(\frac{1}{n(\lambda)\beta}\right)$$



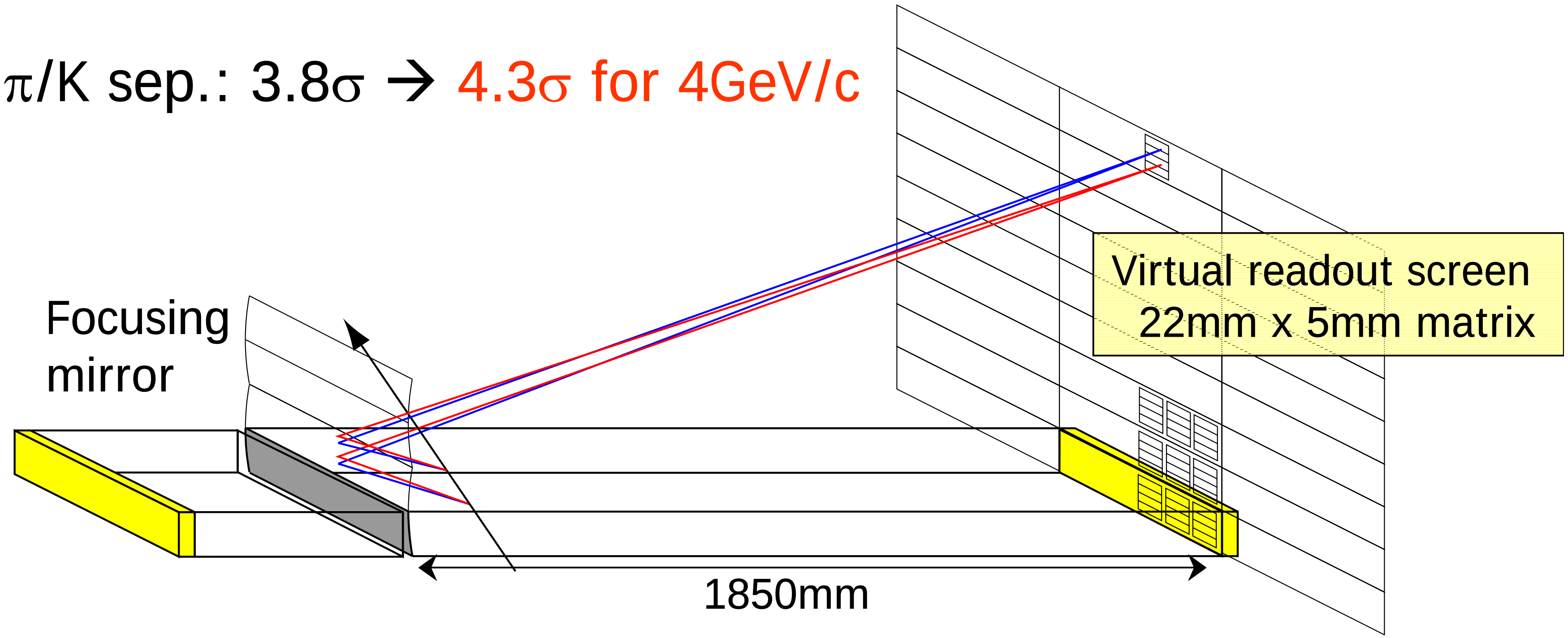


Focusing TOP (2)

- Use λ dependence of Cherenkov angle to correct chromaticity
  - Good separation even with narrow mirror and readout plane because of long propagation length



- π/K sep.: 3.8σ → 4.3σ for 4GeV/c



Summary

- MCP-PMT studies
  - Good time resolution of ~35ps for single photon
    - Even under B=1.5T
  - Gain~10^6 with <10μm MCP hole
  - Long lifetime (<10% QE drop) until 3×10^{14}photons/cm^2
  - Gain degradation if N_{det} >10^5 counts/cm^2/s
    - Enough performance for TOP counter in super B factory

- Applications
  - TOF counter with quartz
    - 5ps intrinsic time resolution in beam test
  - TOP counter
    - To reduce chromatic error, introduce compact focusing mirror.
    - Focusing type improves π/K separation in Super Belle.