International Symposium on the Development of Detectors, 2006/4 at SLAC

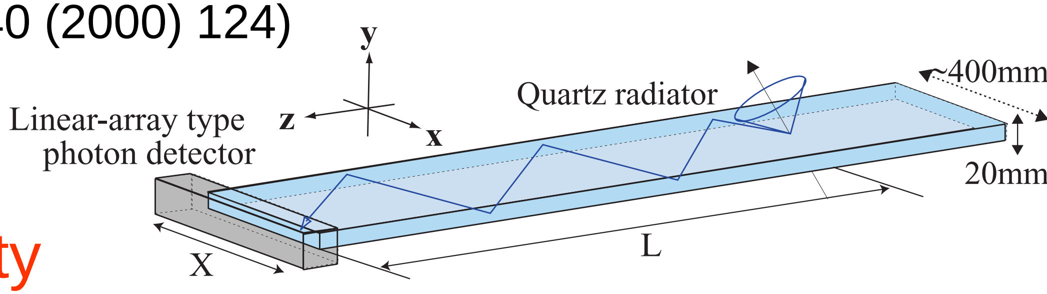
Time of Flight measurements with MCP-PMT

- Very high resolution TOF counter
- Lifetime of MCP-PMTs

T.Ohshima, K.Inami, N.Kishimoto, M.Nagamine
(Nagoya university, Japan)

Introduction

- Photon device for TOP counter
  - Cherenkov ring imaging counter with precise time measurement (NIM A 440 (2000) 124)
    - 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
for TOP counter

- MCP-PMT is a good solution.

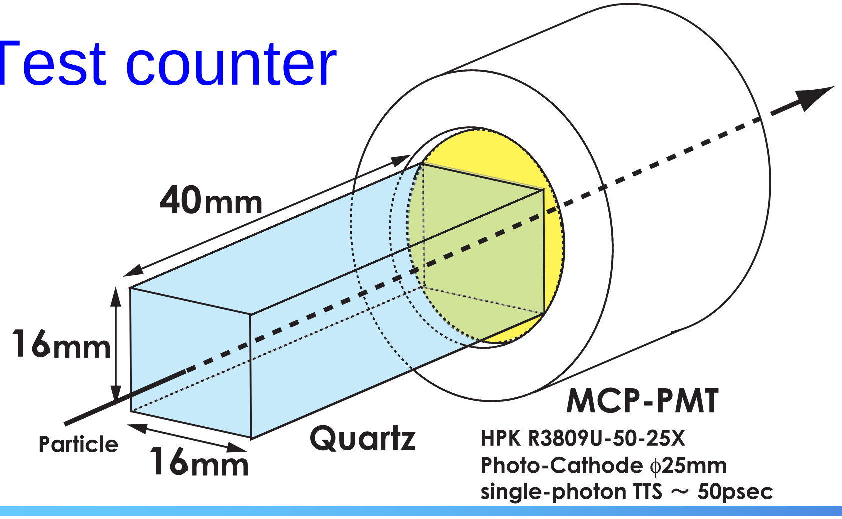
In the course of R&D,

- Idea of a few psec resolution TOF

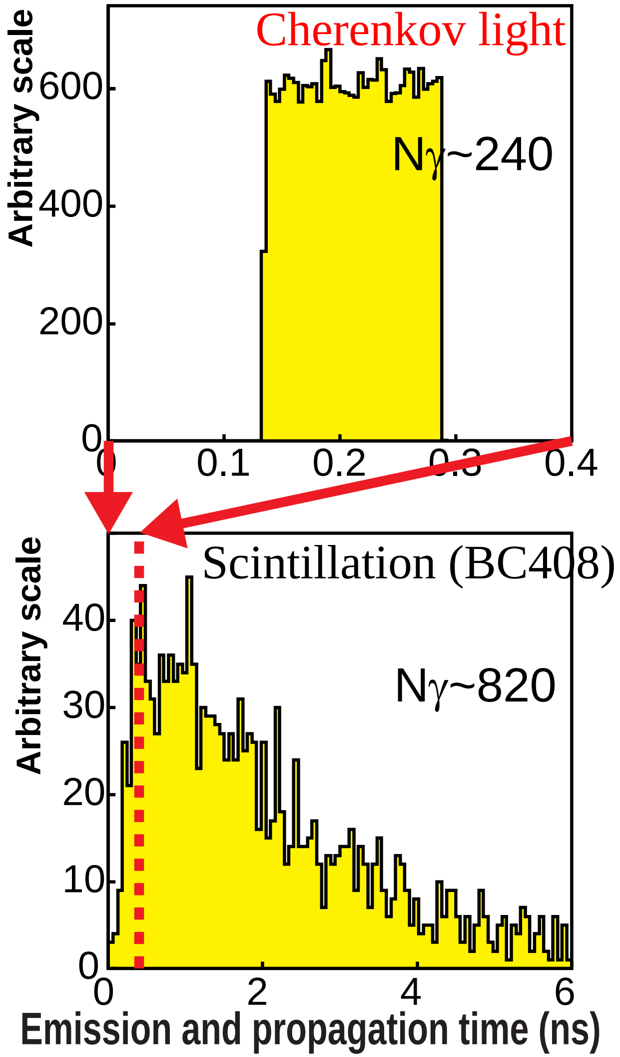
High resolution TOF

- 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



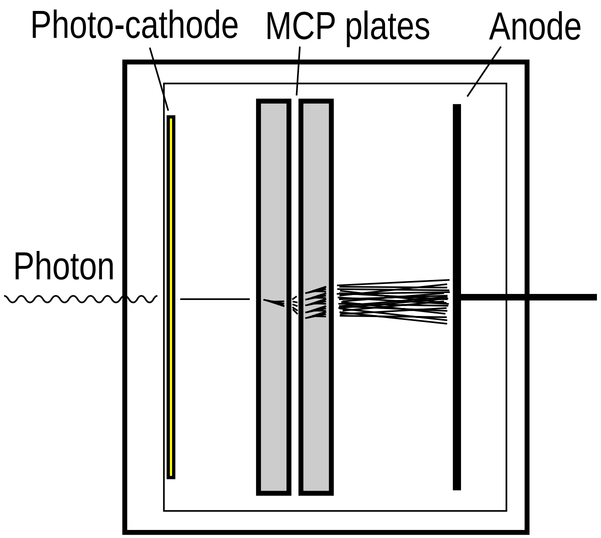
Simulation

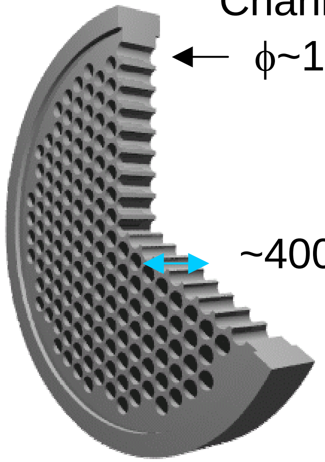


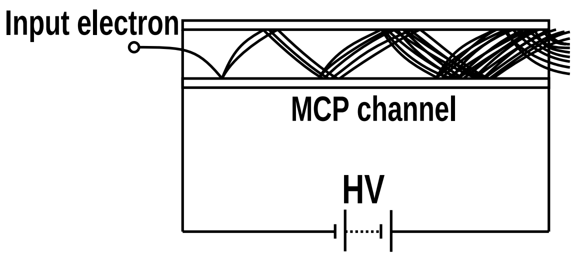
MCP-PMT

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

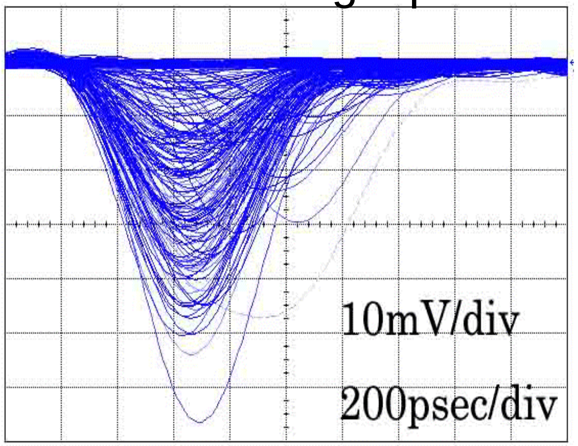
    Pulse raise time ~500ps, TTS < 50ps
  - can operate under high magnetic field (~1T)







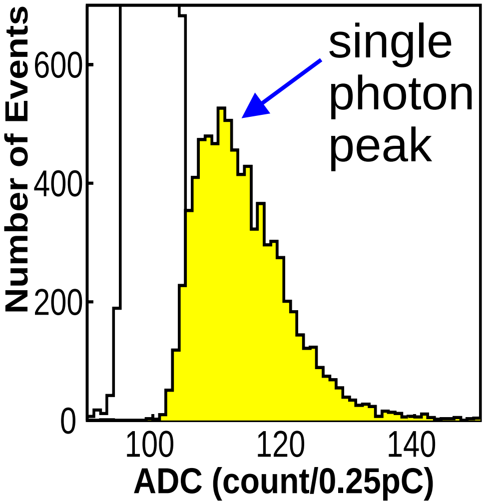
Single photon

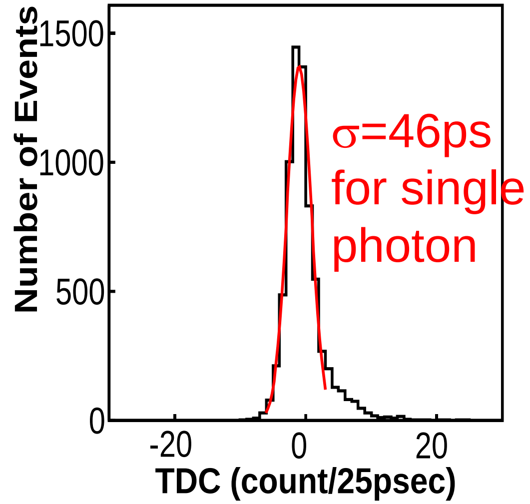


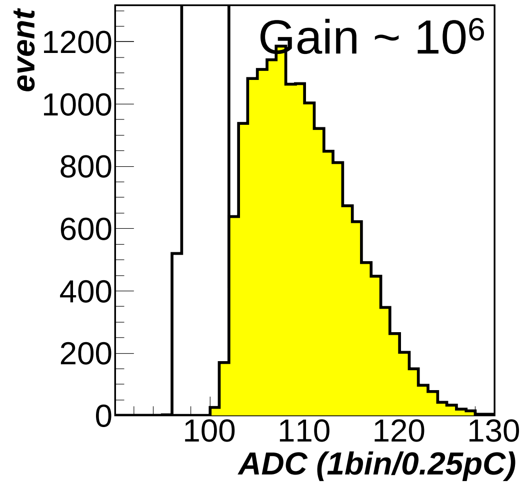
MCP-PMT (2)

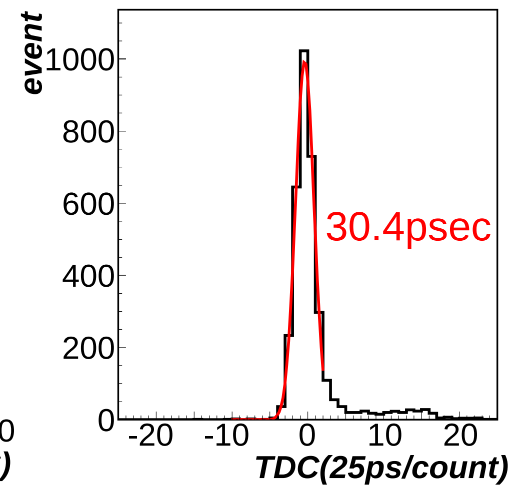
- Hamamatsu R3809U-50 (multi-alkali photo-cathode)

MCP hole 10μmφ



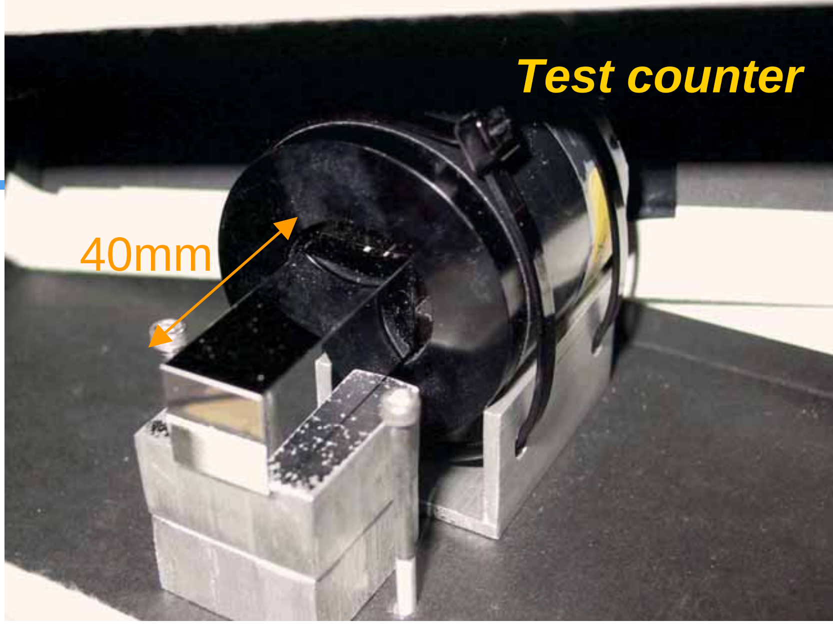




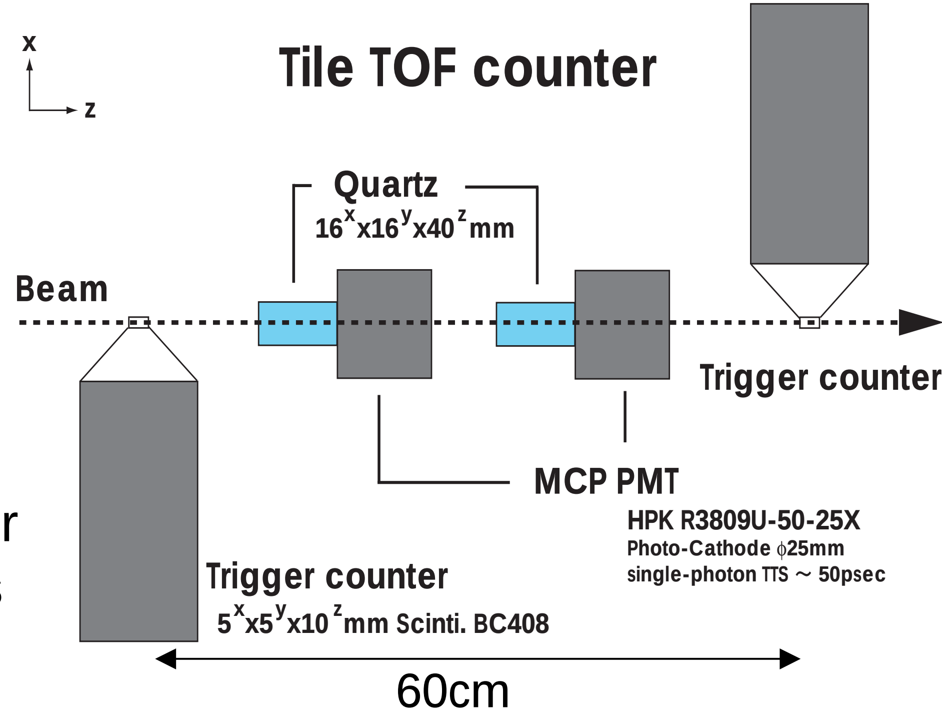


Beam test 1

- 3GeV/c π^- beam
  - at KEK-PS π2 line
- PMT: R3809U-50-25X
- Quartz radiator
  - 16x16x40mm with Al evaporation

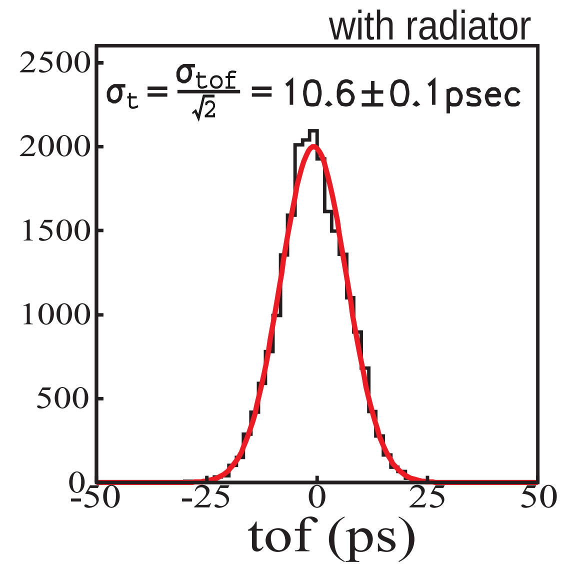


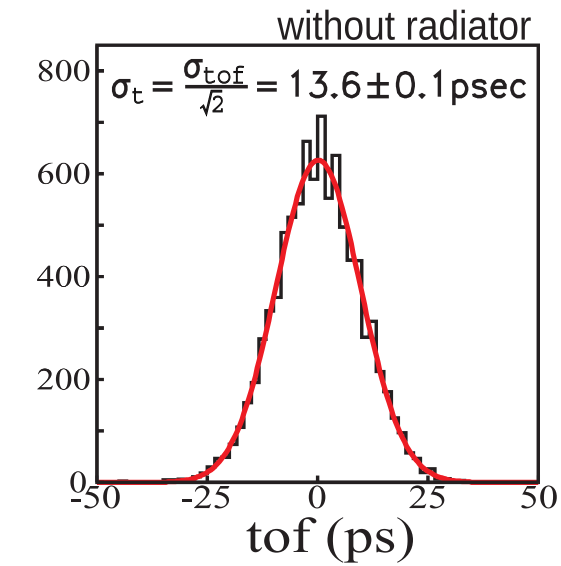
- TOF between two counters
  - evaluate the time resolution
- TOF counter with and without quartz radiator
  - To confirm MCP-PMT's behavior for passage of charged particles



Beam test 1 result

- With quartz radiator
  - Number of photons ~ 250
    - agree with expectation of simulation ~240
  - Time resolution ~ 10.6ps
- Without radiator
  - Number of photons ~ 50
    - Cherenkov light from PMT window
  - Time resolution ~ 13.6ps
- Resolution is limited by readout electronics. (σ_{elec}~8.8ps)
  - Expected intrinsic resolution ~5.9ps

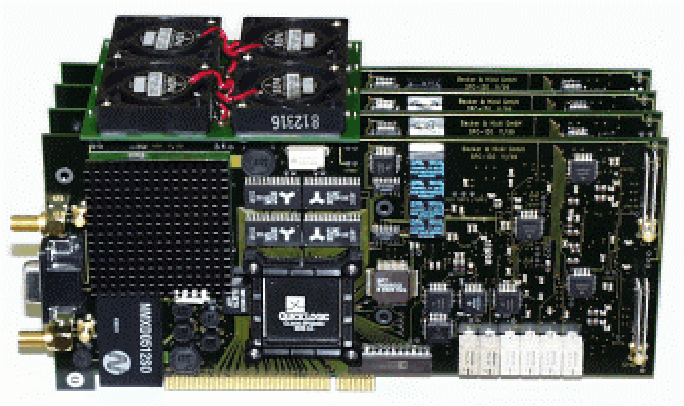




Beam test 2

- Confirmation of intrinsic time resolution

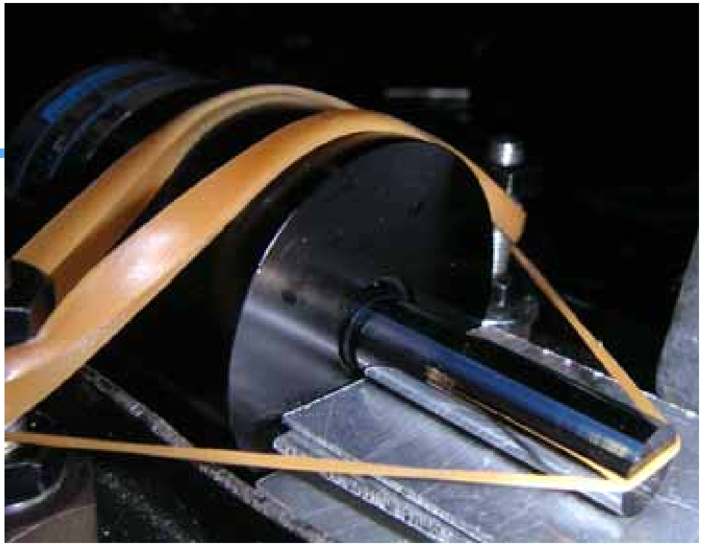
- Improvements
  - Readout electronics
    - $\sigma_{elec.}$: 8.8ps → 4ps
    - Time-correlated Single Photon Counting Modules (SPC-134, Becker & Hickl GMbH's)
      - CFD, TAC and ADC
      - Channel width = 813fs
      - Electrical time resolution = 4ps RMS

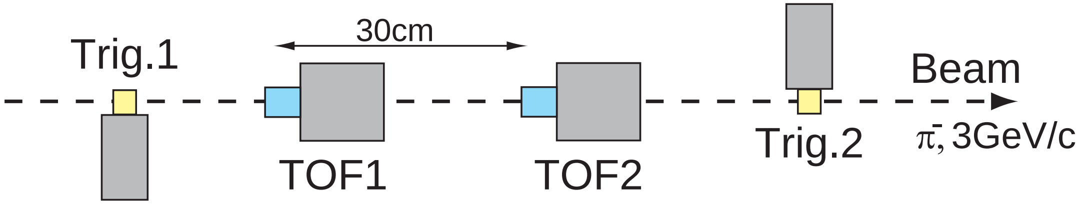


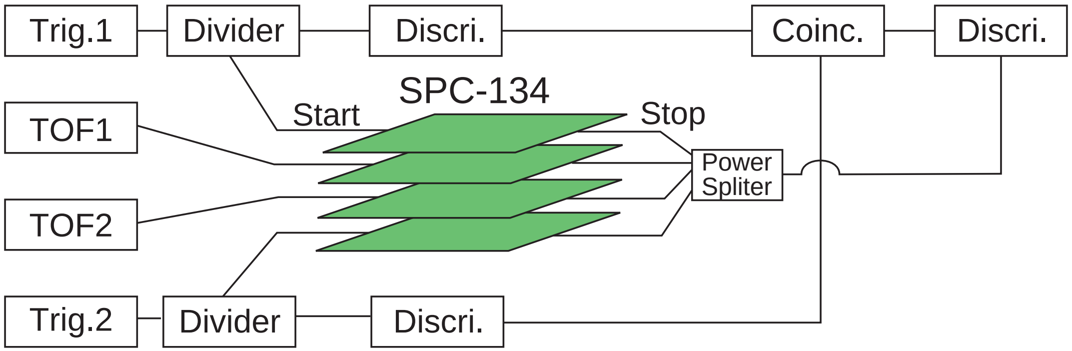
  - MCP-PMT
    - TTS: ~46ps → ~30ps
    - 10μm hole → 6μm hole
      - R3809U-50-25X → -11X

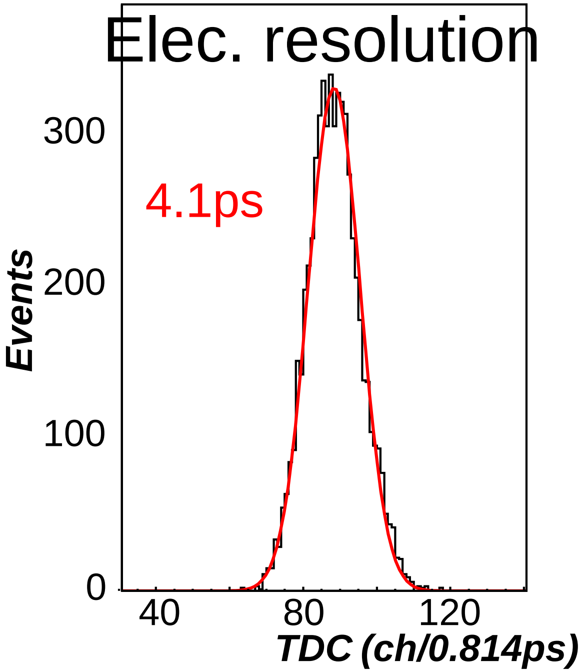
Beam test 2 setup

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

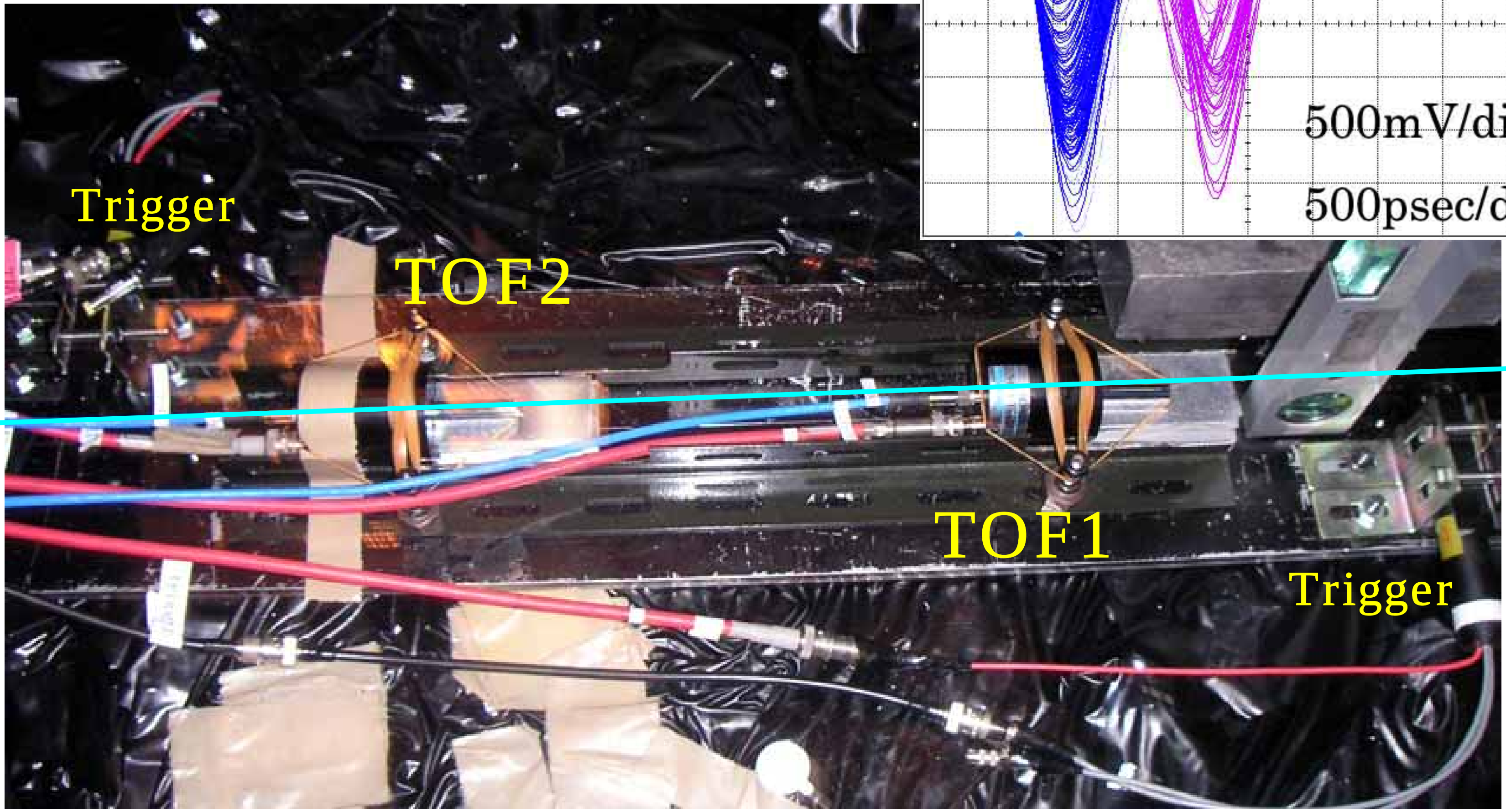


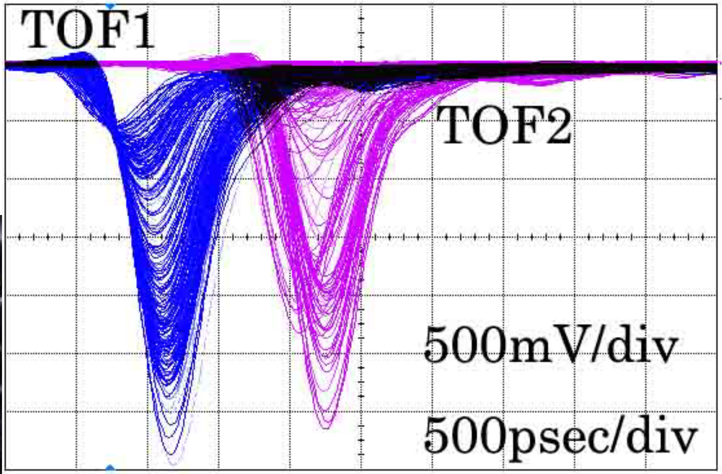






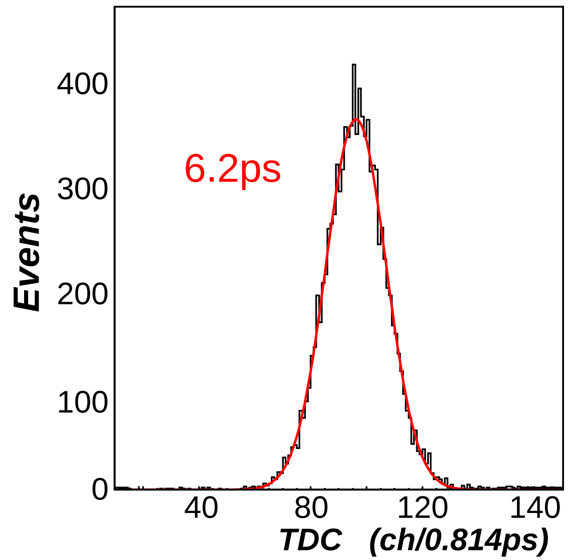
Beam test 2 setup photo



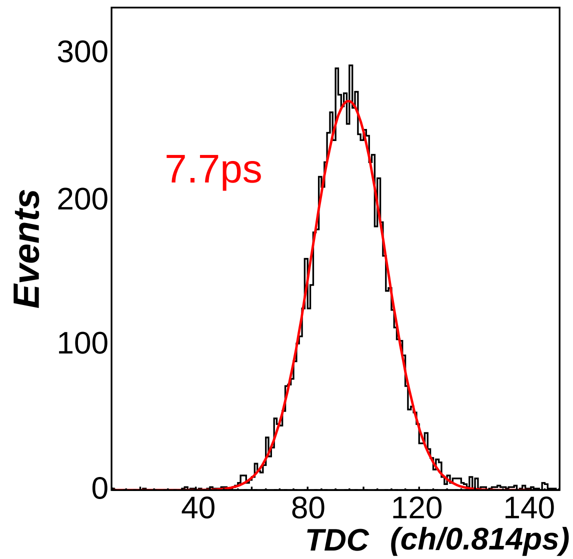


Beam test 2 result

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

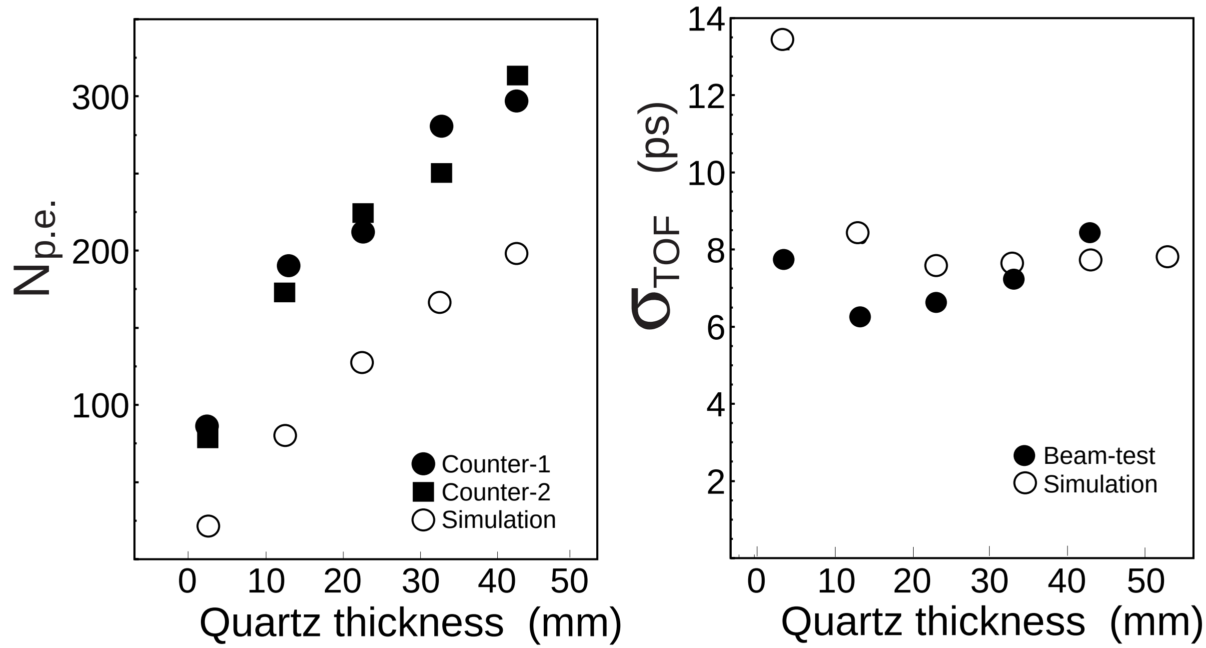


- Without quartz radiator
  - 3mm quartz window
  - Number of photons ~ 80
    - Expectation ~ 20 photo-electrons
  - Time resolution = 7.7ps



Beam test 2 result (cont'd)

- Nγ, σ_{TOF} v.s. radiator thickness

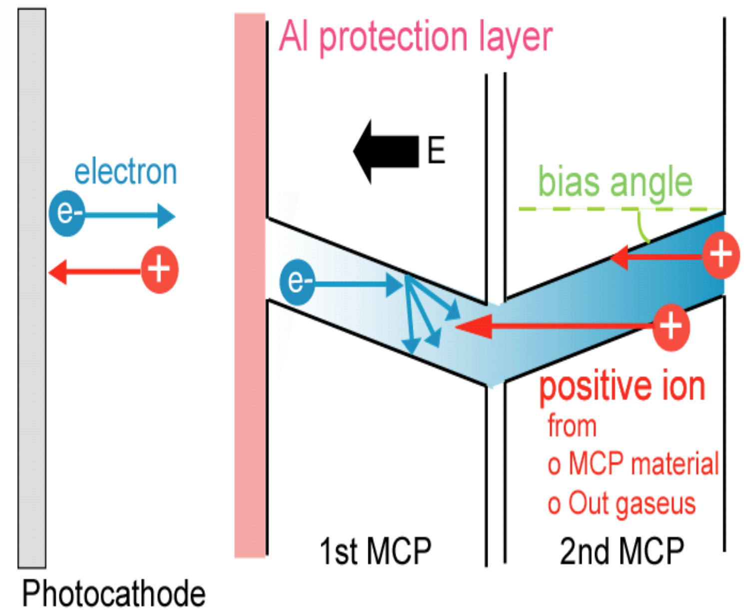


- Extra photo-electrons
  - $N_{p.e.}$ from short distance is larger than that of expected.
- Time-resolution behavior
  - Resolution is gradually worse.
  - → Extra p.e. would affect the resolution dependence.

Lifetime

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

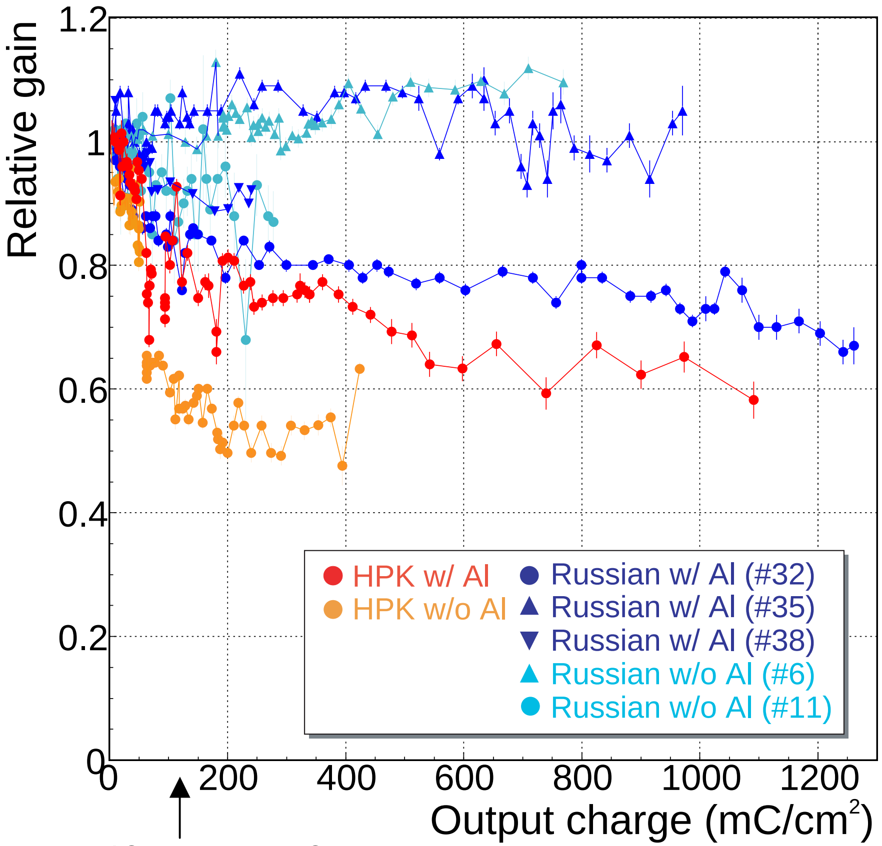
	HPK (x2)		Russian (x5)	
Al protection	**O**	**X**	**O**	**X**
Correction eff.	**37%**	**65%**	**40-60%**	**55-60%**
Effective area	11mmϕ		18mmϕ	
Gain	1.9×10^6	1.5×10^6	$3\text{-}4\times10^6$	
TTS	34ps	29ps	30-40ps	
Photo-cathode	Multi-alkali (NaKSbCs)			
Quantum eff. at 400nm	21%	19%	16-20%	
Bias angle	13deg		5deg	



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

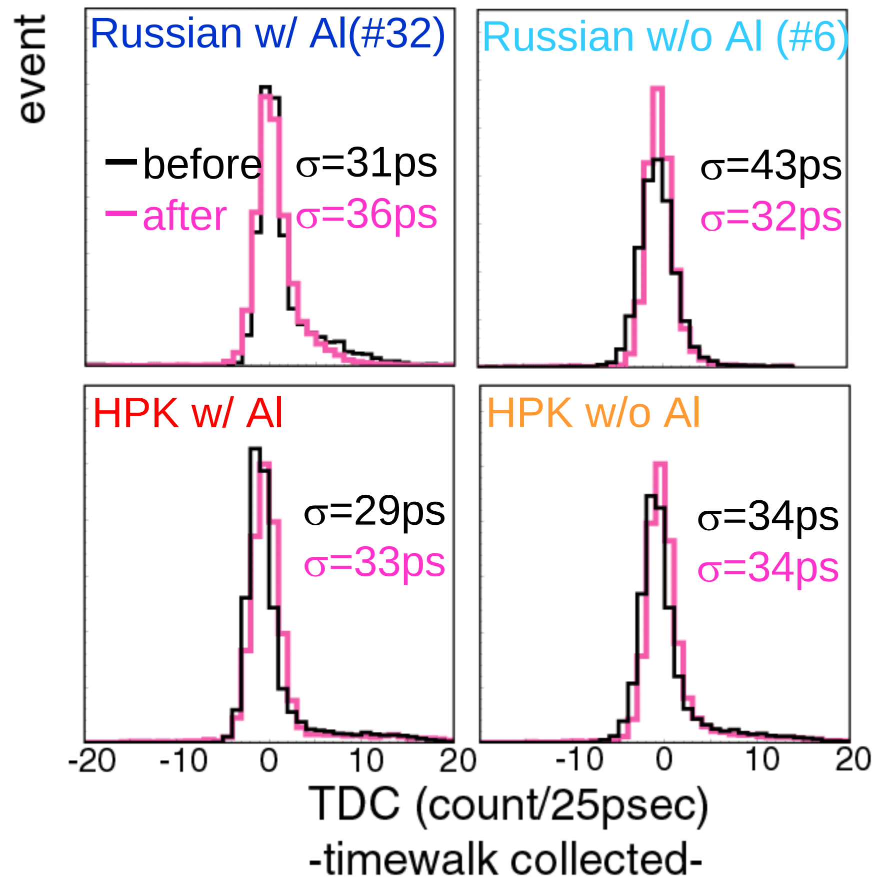
Gain & TTS for single photon

- Gain



~10^{12} p.e./cm^2
with 10^6 gain

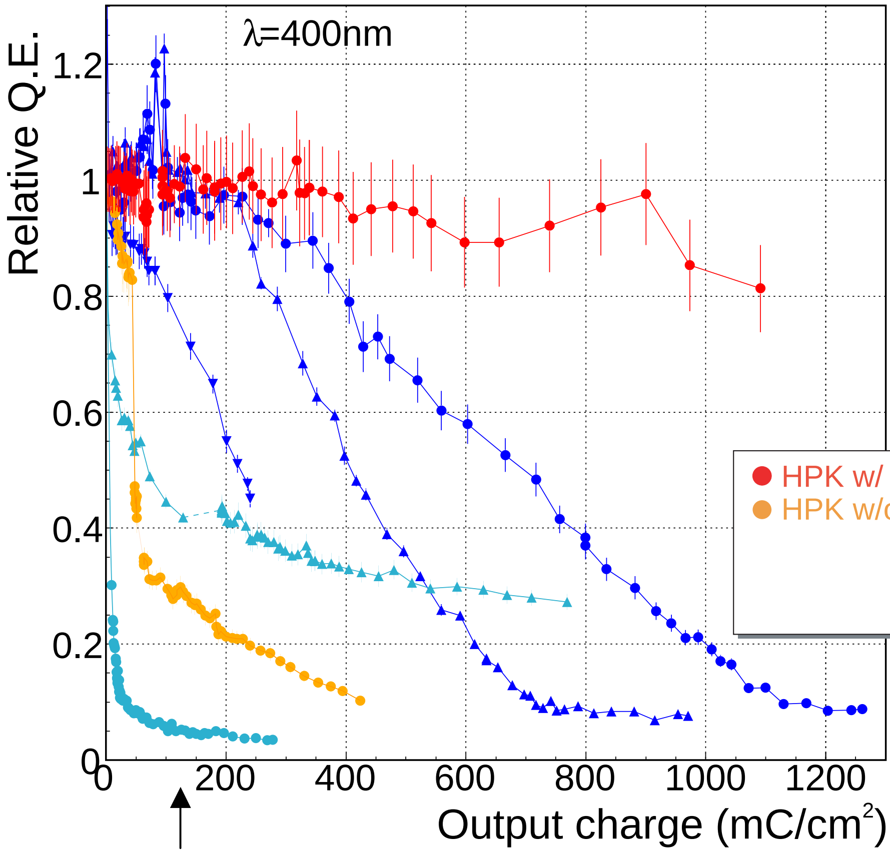
- TTS



TTS is stable within the gain drops.

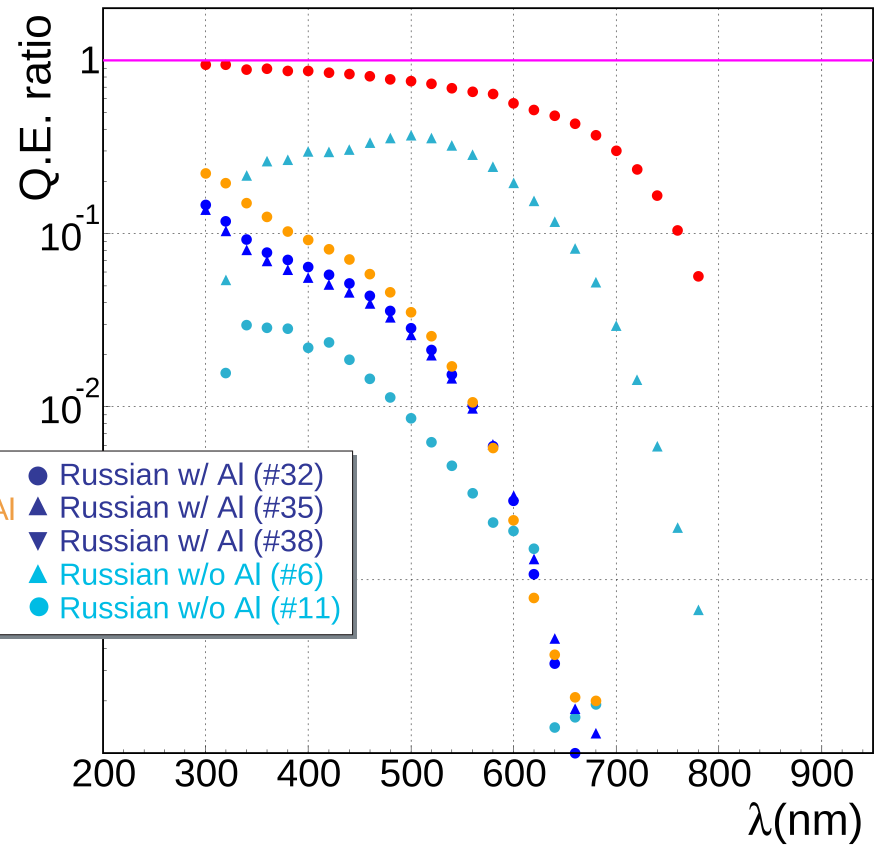
Quantum efficiency

- Q.E.



↑
~10^{12} p.e./cm²
with 10^6 gain

- Before/After

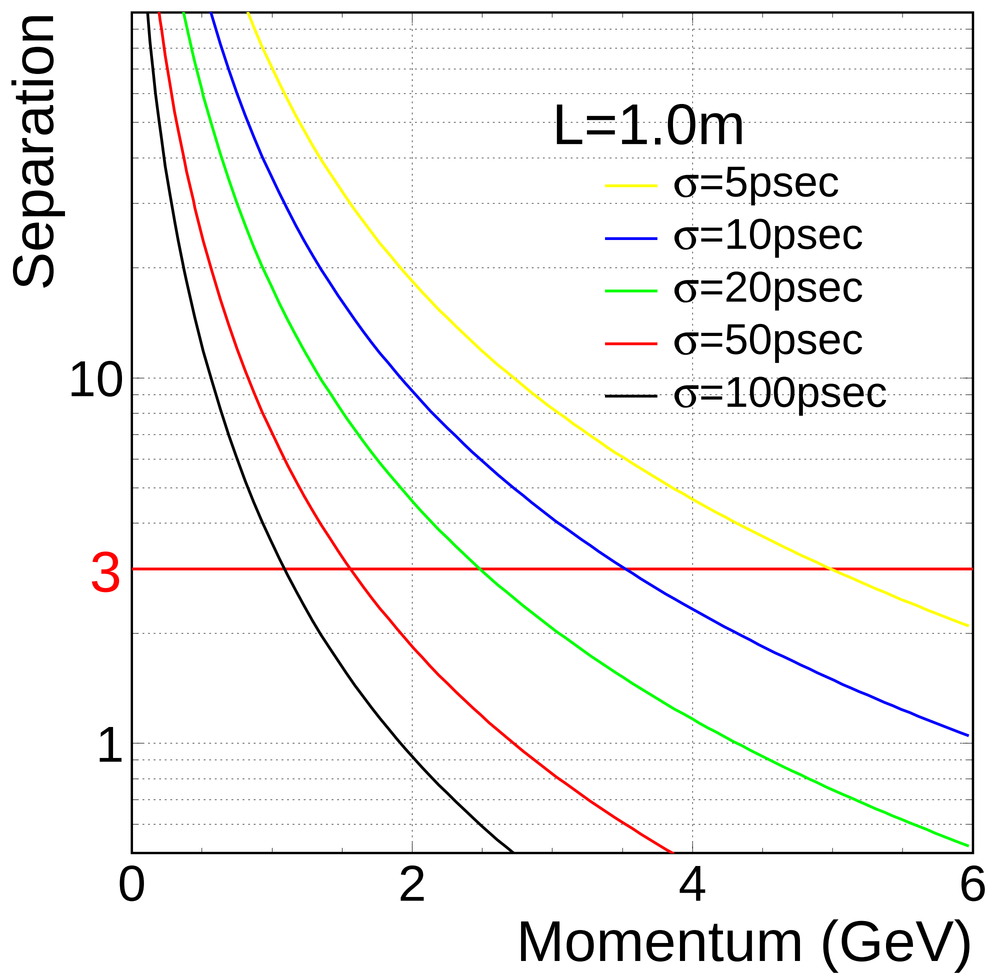


- Small Q.E. drop for HPK with protection
- Fast degradation for longer wavelength

Summary

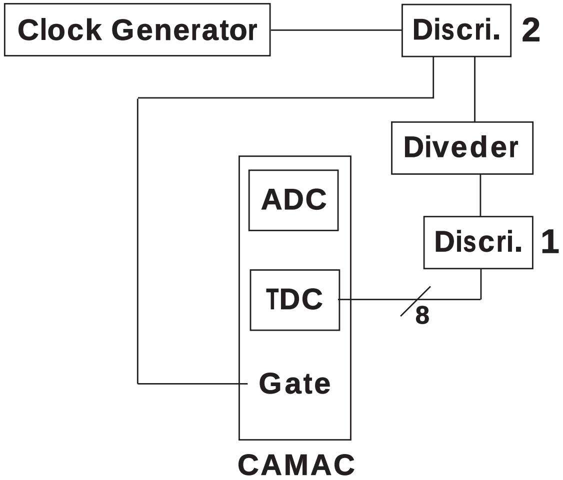
- High resolution TOF counter
  - Small quartz as Cherenkov radiator
  - MCP-PMT (TTS ~30ps for single photon)
  - Readout system (time resolution ~4ps)
  - Time resolution of 6.2ps have been measured.
    - 4.7ps intrinsic resolution
- Lifetime test of MCP-PMTs
  - Al protection layer works well to stop feedback ions.
  - MCP-PMT by HPK with Al layer is best solution.
- For more detail, please refer NIM A 528, 763 (2004) and new paper to be published in NIM A.

Separation power



Fluctuation of Readout elec.

- 8 TDC channels with logic pulse

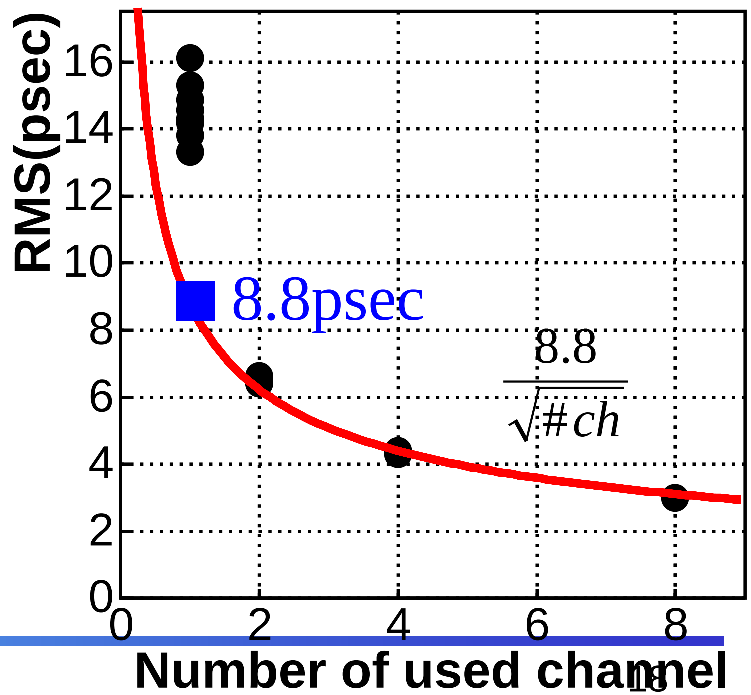


$$T1 = t_{stop1} - t_{start}$$
$$T2 = t_{stop2} - t_{start}$$
☹
$$T8 = t_{stop8} - t_{start}$$

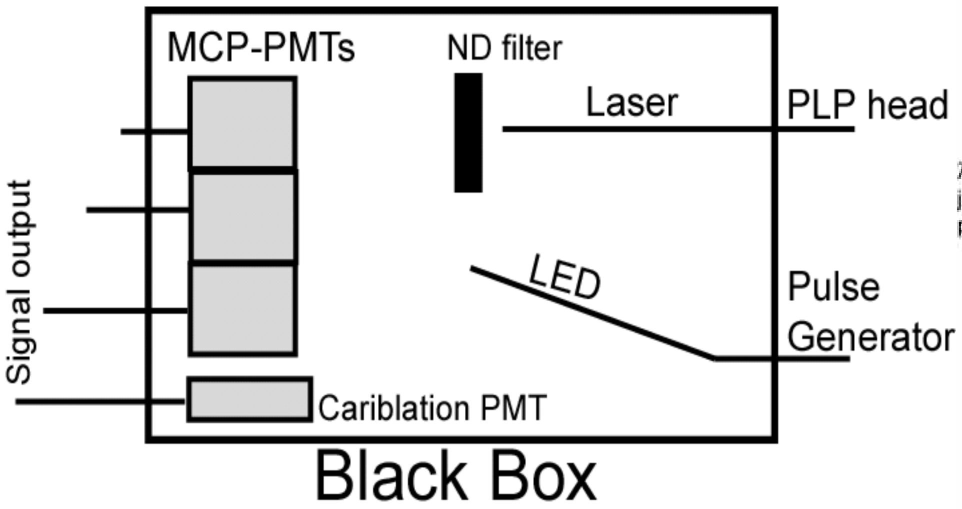
$$T1 - T2 = t_{stop1} - t_{stop2}$$
$$\rightarrow \sigma_{T1-T2} = \sqrt{\sigma_{stop1}^2 + \sigma_{stop2}^2}$$
$$\sigma_{stop} \cong \frac{\sigma_{(T1-T2)/2}}{\sqrt{2}}$$

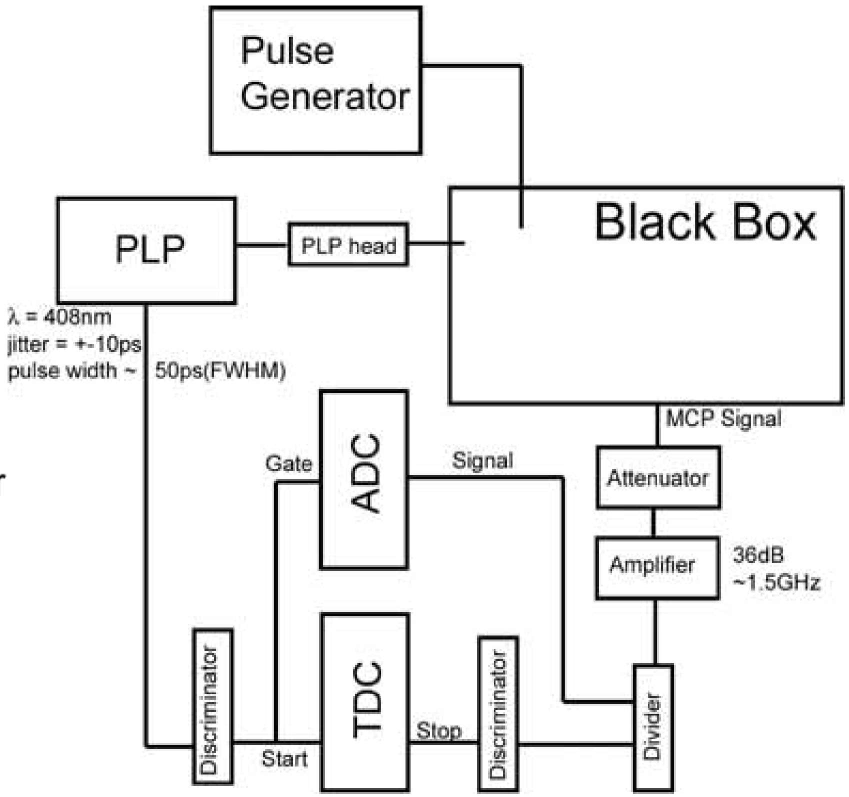
$$\frac{(T1+T2)-(T3+T4)}{2} = \frac{(t_{stop1}+t_{stop2})-(t_{stop3}+t_{stop4})}{2}$$
$$\rightarrow \sigma_{stop} \cong \frac{\sigma_{(T1+T2-T3-T4)/2}}{\sqrt{4}}$$

$$\sigma_{module} = 8.8\text{psec}$$



Lifetime test (setup)





Quantum efficiency