10 psec Time-Of-Flight Counter

T. Ohshima (Nagoya U.)

- Points for TOF counter

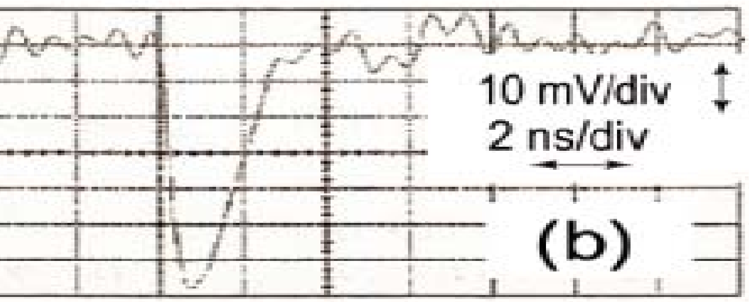
  Photo-detector

- Measurements - Beam tests
- New Approaches
- Know-how

Footnote: MCP-PMTにもとずく 10 psec TOF counter R&Dの報告である。

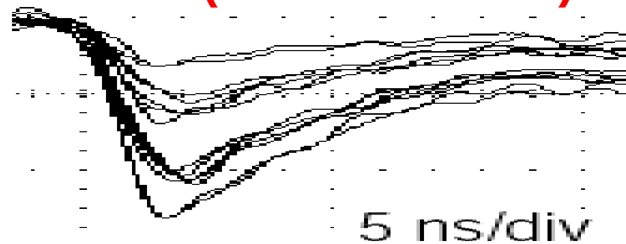
1.Points for TOF counter/ Photo-detectors

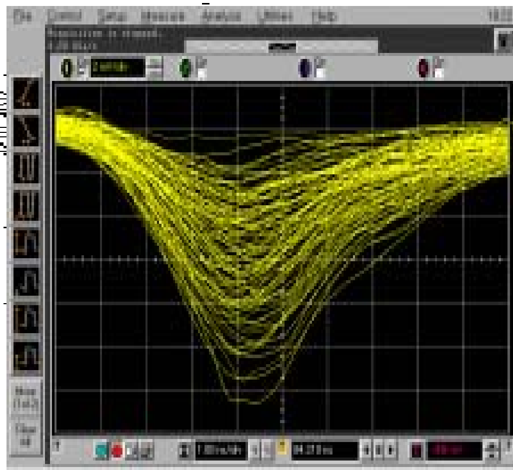
	(Transite Time Spread) **TTS**
●Multi-anode linear-array PMT (L16 & L24)	70-80; 120 ps
●Hybrid Avalanche Photo-Diode	150 ps
●Micro-Channel-Plate PMT	30-40 ps



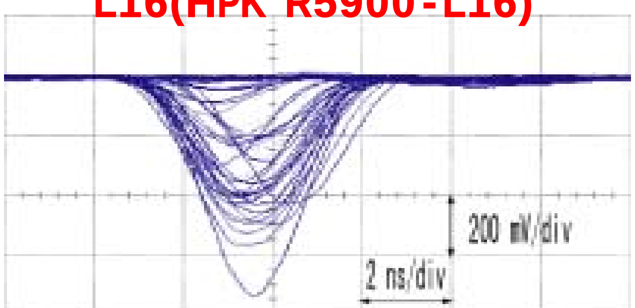
L16(HPK R5900-L16)

HAPD(HPK R7110U-07)

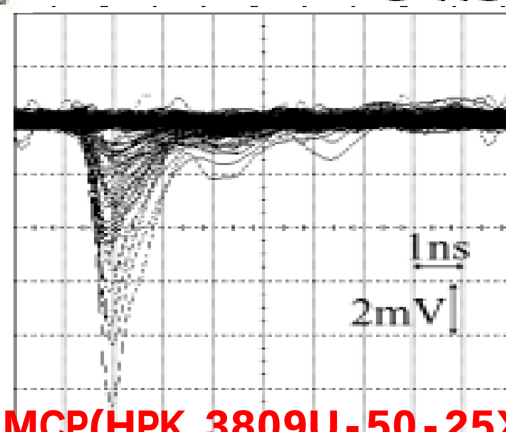




PMT(HPK H7195)
1 ns/div



L24(HPK R6135-L24X)



MCP(HPK 3809U-50-25X)

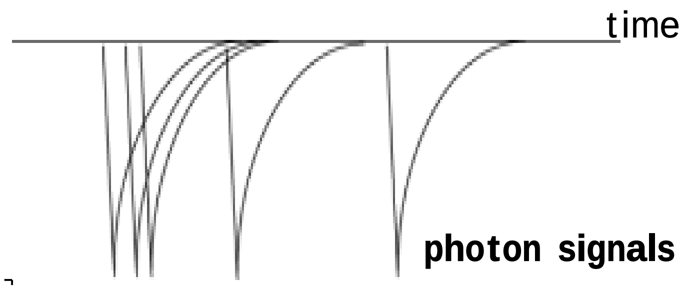
Footnote: これまで開発研究した光検出器の1光子に対する信号と測定TTS。信号の立ち上がりの速さを比較せよ。

1.Points for TOF counter

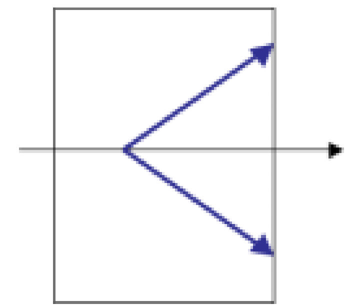
<u>Fluctuations of</u>

1. TTS
2. Decay-time ($T_d \leq$ TTS)
3. Light-path ($T_\gamma \leq$ TTS)
4. N_γ

Photo-statistics $1/\sqrt{N_\gamma}$ is varied only at Td, T_γ << TTS.



quartz: n=1.47;
$\theta=45^o$ (for GeV/c particles)



1. 30-40 ps (MCP-PMT), 70-80 ps (L16)
2. Cherenkov light
3. Normal incidence

$\Rightarrow \sigma = (30x2–30)$ ps /1cm/($\sqrt{12N_\gamma}$**)** = 9 ps/ $\sqrt{N_\gamma}$ **/** 1 cm)

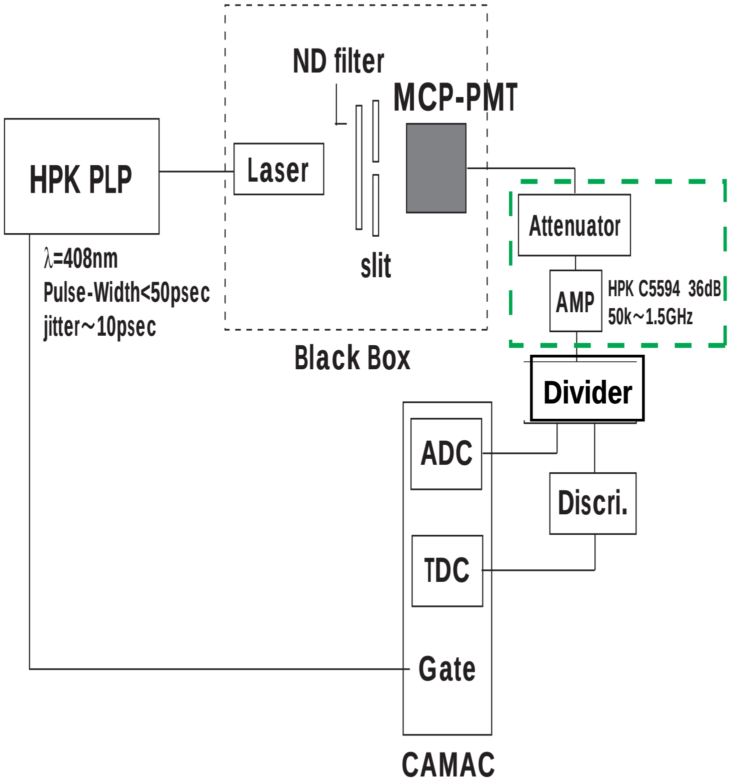
4. 50 detected photons/1 cm quartz

For short path, no chromaticity effect.

σ = 30-40 ps/ $\sqrt{50}$ = 5-6 ps

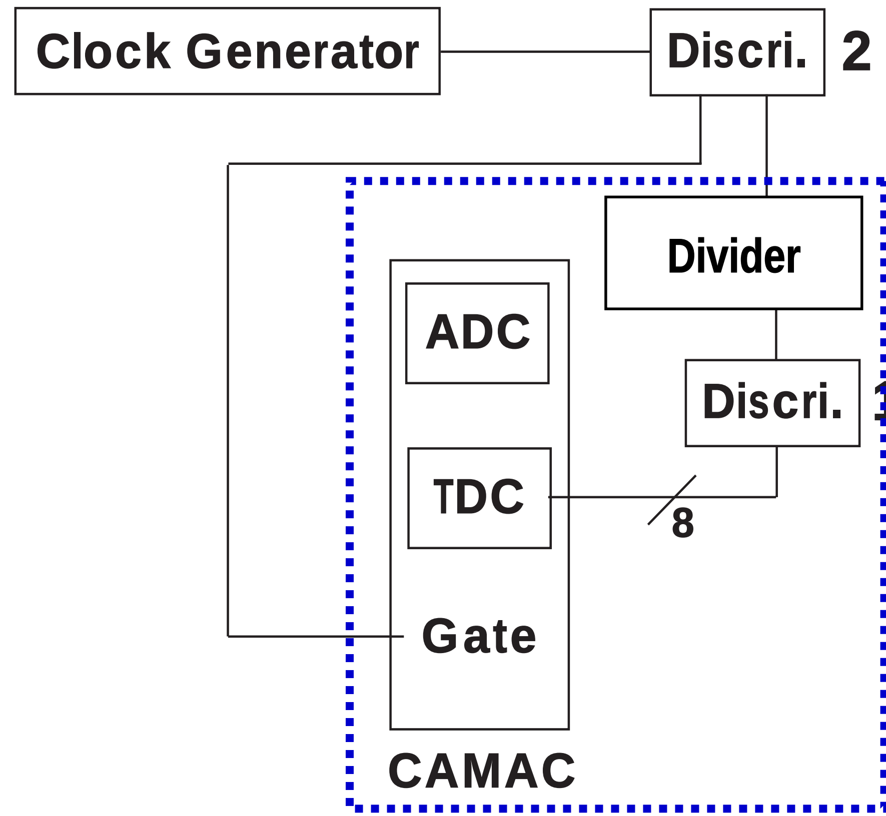
Footnote: TOF**精度を決める要因。⇒**MCP-PMY/Cherenkov/path/# photons （**時間広がりがなく、多量の光子が＝1．＆4．**）

1.Points for TOF counter (continue)



矩形波で測定

測定回路の寄与＝ 8.8psec



Footnote: TOF**精度を決める要因。⇒回路系の精度**（**実測値＝**7-9 psec）。**ビームテストでは**att.&amp**は不要。**

2.Measurements

L16-TOF

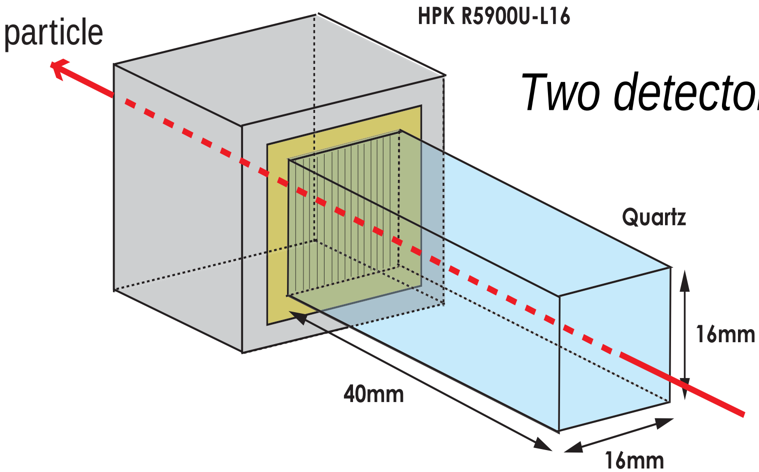
NIM submitted by Y.Enari et al, Cross-Talk of a Multi-Anode PMT and Attainment of a σ sim 10 ps TOF counter

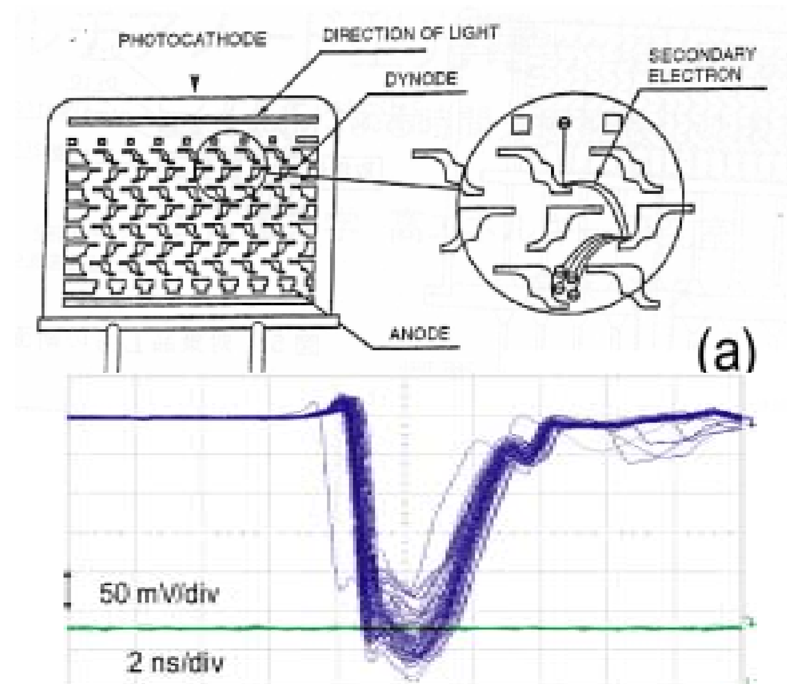
TTS=80 ps, $N\gamma$ = 120-160/ 4 cm quartz,

16 independent measures

σ_0= 80/$\sqrt{}$ 9 (photons/channel) / $\sqrt{16}$ = 7 ps

$\Rightarrow$ $\sigma_{expected}$ = 11 ps
including circuit fluctuation of 9 ps.

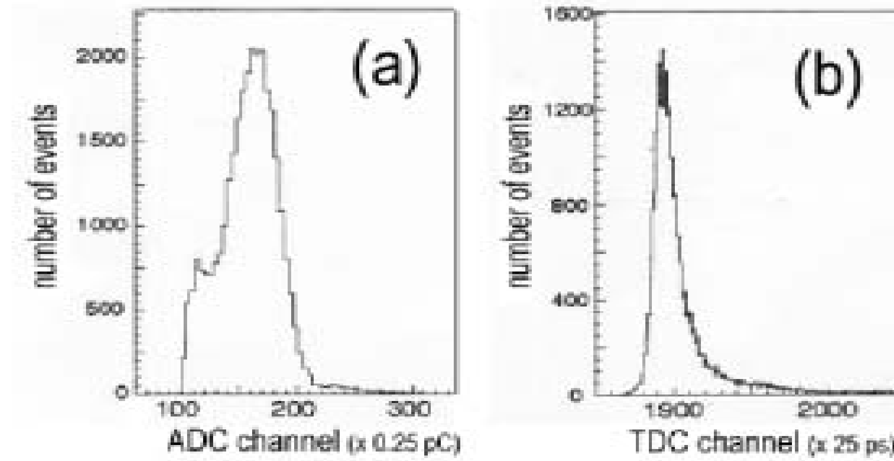




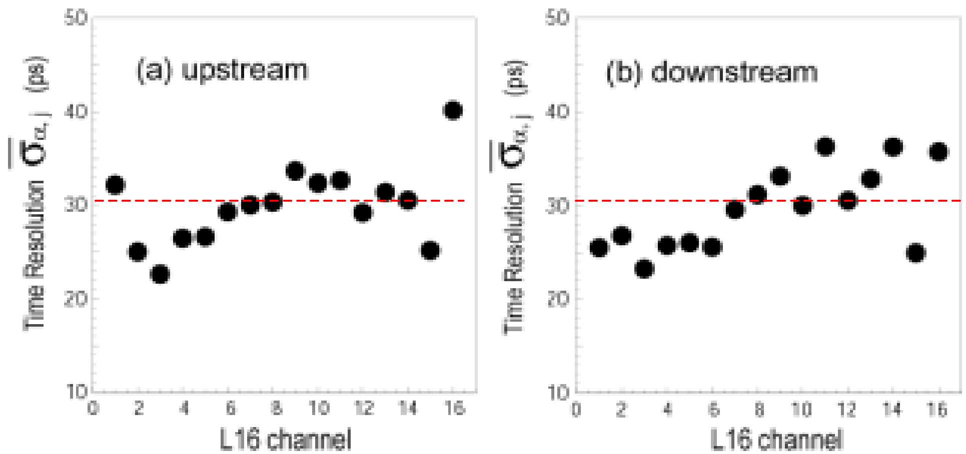
Footnote: L16-PMTによるTOF。16の独立な測定⇒期待値＝11 psec。

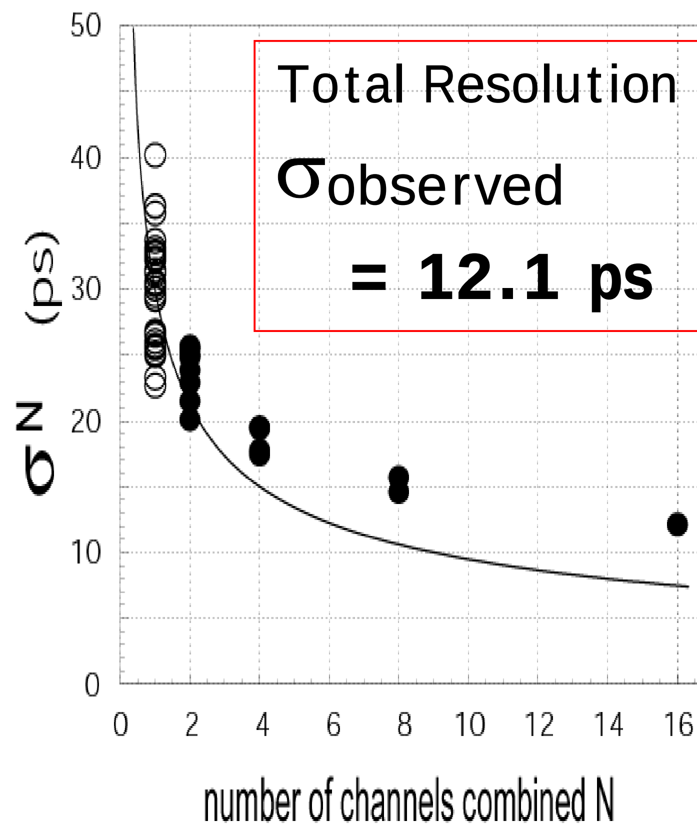
$$TOF = TOF_1 - TOF_2, \quad \text{where}$$

$$TOF_\alpha = \frac{\sum_{j=1}^{16} tof_{\alpha,j}}{16}, \qquad \sigma_\alpha = \frac{\sqrt{\sum_{j=1}^{16} \sigma_{\alpha,j}^2}}{16}$$



Single channel Resolution **σ = 30 ps**





Footnote: **ビームテストのデータ、各チャンネル分解能＝**30 psec**⇒16チャネルでは**12.1 psec。

Intrinsic resolution and systematic ncertainty

In order to examine the origin of the systematic uncertainty, we suppose the measured time-of-flight ($tof_{\alpha,j}$) to be composed of two components: the subjective time ($t_{\alpha,j}$) and the systematic uncertainties (t_x), as

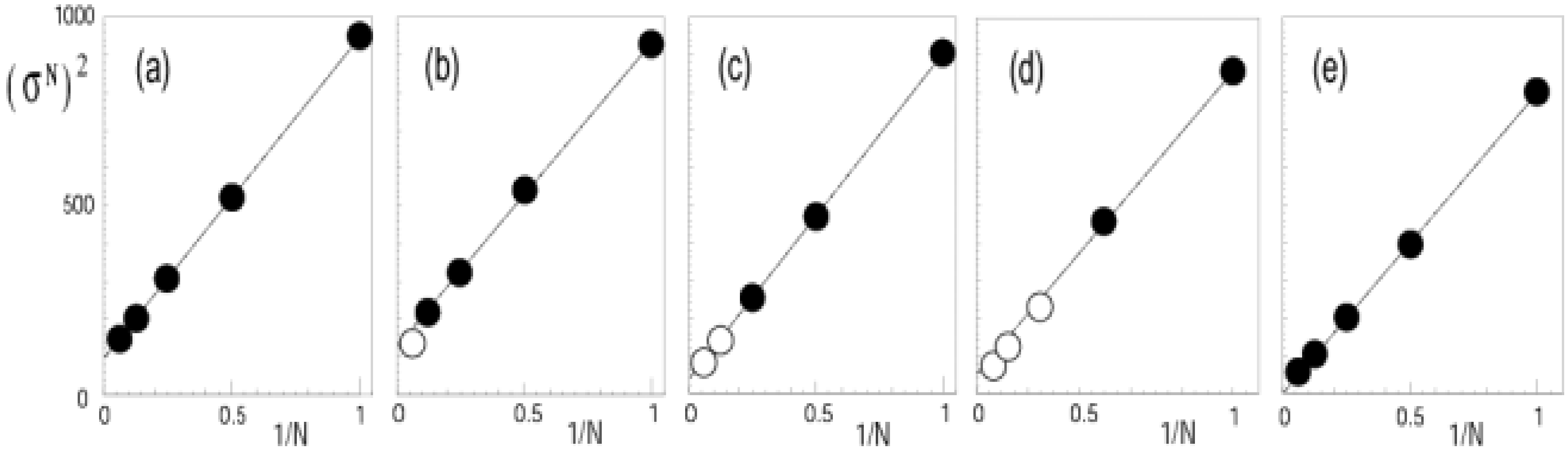
$$tof_{\alpha,j} = t_{\alpha,j} + (t_{32} + t_{16} + t_8 + t_4 + t_2), \qquad (8)$$

where t_{32} is the uncertainty common to all $32 = 2\times 16$ channels; t_{16} is common to j = 1-16 channels, but different at each counter, α = 1 or 2; t_8 is common to j = 1-8 and also 9-16 channels, but different at 8 individual channels and each counter; t_4 is common to j = 1-4, 5-8, 9-12 and 13-16 channels, but different at 4 individual channels and each counter; t_2 is common to j = 1-2, 3-4, $\cdots$, 15-16 channels, but different at 2 individual channels and each counter.

σ^N can be expressed as

$$(\sigma^N)^2 = \frac{a^2}{N} + b^2, \qquad (9)$$

where a is the time resolution of a single channel, and b is the contribution of the systematic uncertainty. An adequate combination of two channels cancels certain t_x's in the time-of-flight $tof_{\alpha,j} - tof_{\beta,k}$, and its N dependence of $(\sigma^N)^2$ provides a and b.



Footnote: Systematic errorの評価。 j＝16と j＝4での寄与が大きい。

2.Measurements

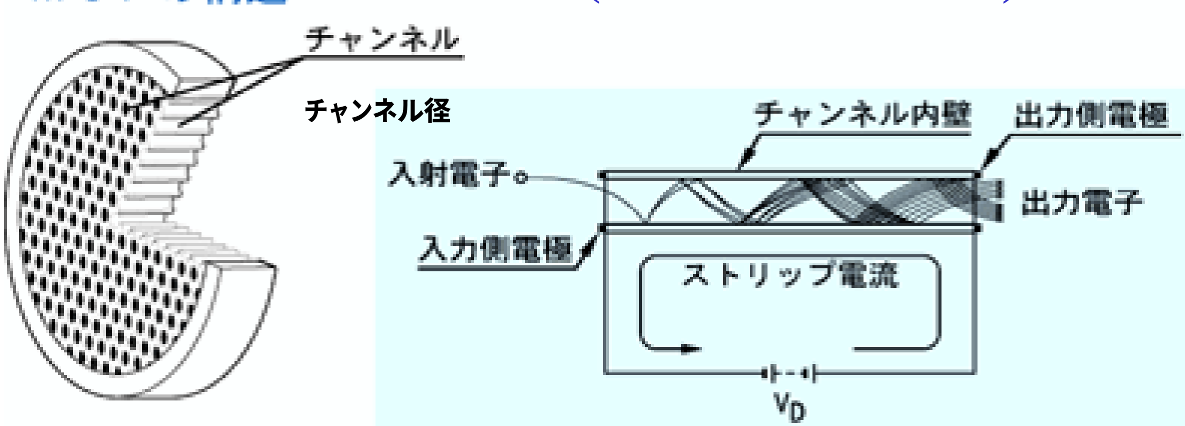
MCP - TOF

NIM A528 (2004) 763-775, by M. Akatsu et al, “MCP-PMT timing property for single photons”

MCP-PMT	HPK6	BINP10	HPK10	Burle25
diameter of MCP-PMT (mm)	45^{ϕ}	30.5^{ϕ}	52^{ϕ}	71×71 ♮1
diameter of effective size (mm)	11^{ϕ}	18^{ϕ}	25^{ϕ}	50×50 ♮2
photocathode	bialkali	multialkali	bialkali	bialkali
gaps (mm)	2 / 0.03 / 1	0.2 / 0.1 / 1.2	1.1 / 0 / 0.94	6.4 / 0.032 / -
D ♮3 (μm)	6	10	10	25
$\alpha = L/D$ ♮3	40	40	43	40
bias angle (°)	13	5	12	10
max. voltage (kV)	3.6	3.2	3.6	2.5
divider ratio	2 : 4 : 1	3.4 : 30 : 1	2 : 4 : 1	1 : 10 : 1
gain	2×10^{6}	$\sim 10^{6}$	$\sim 10^{5}$	6×10^{5}

ＭＣＰの構造

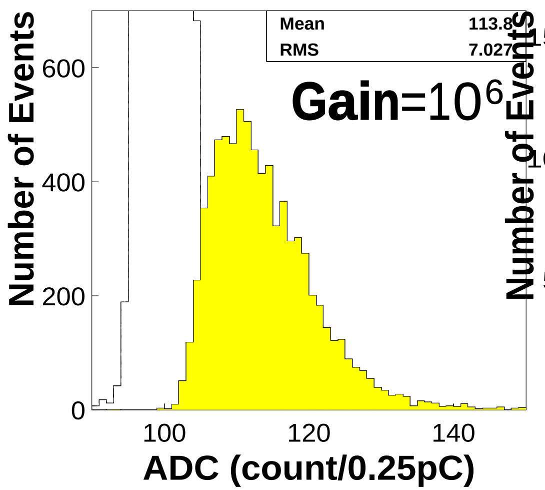
MCP(Micro-Channel Plate)



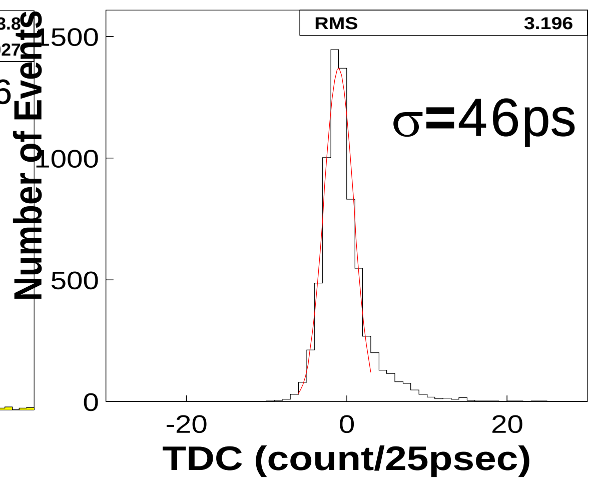
Footnote: 開発研究のMCP-PMT性能比較。

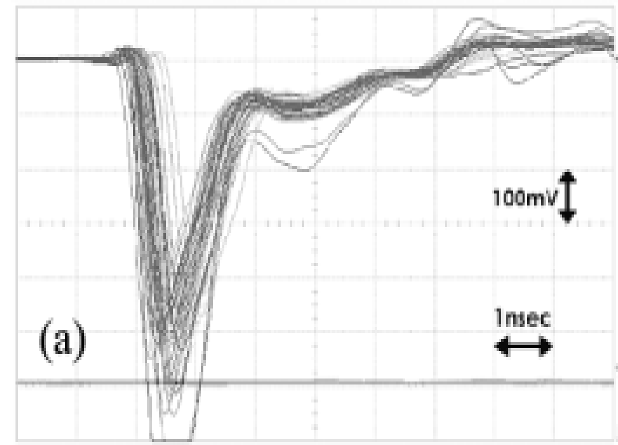
2.Measurements / MCP spectra

- HPK R3809U-50-25X

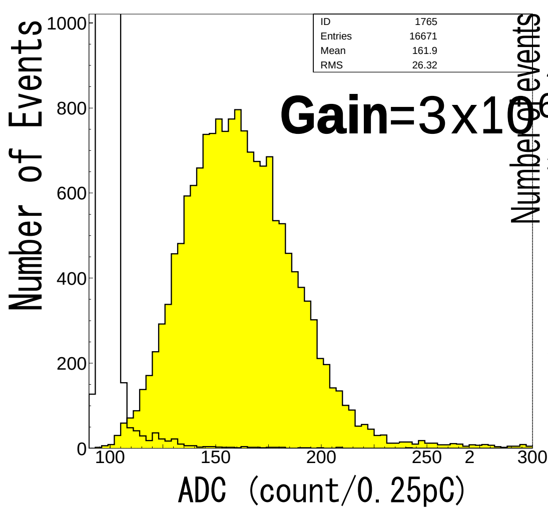


(pedestal = 100count)

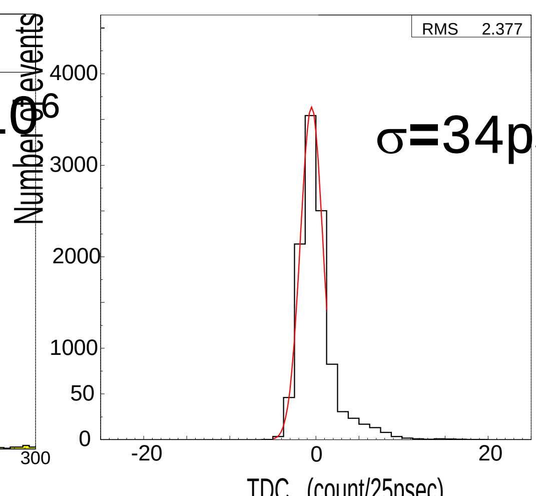




- BINP N4963



(pedestal = 100count)



(1光子照射,HV:3.2kV)

Footnote: ADC & TDC spectra

2.Measurements I
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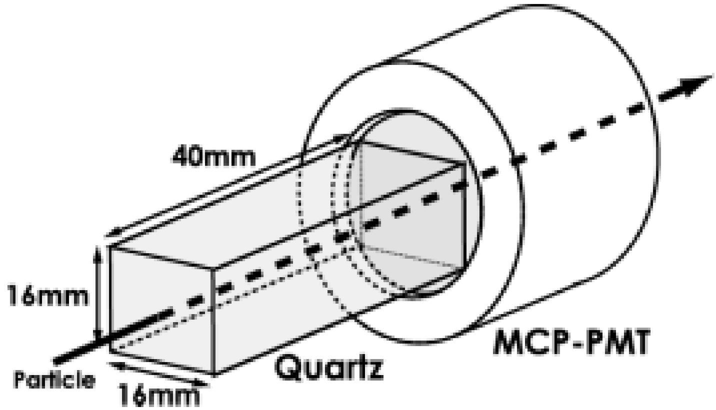
TOF by HPK10
TOF by HPK10



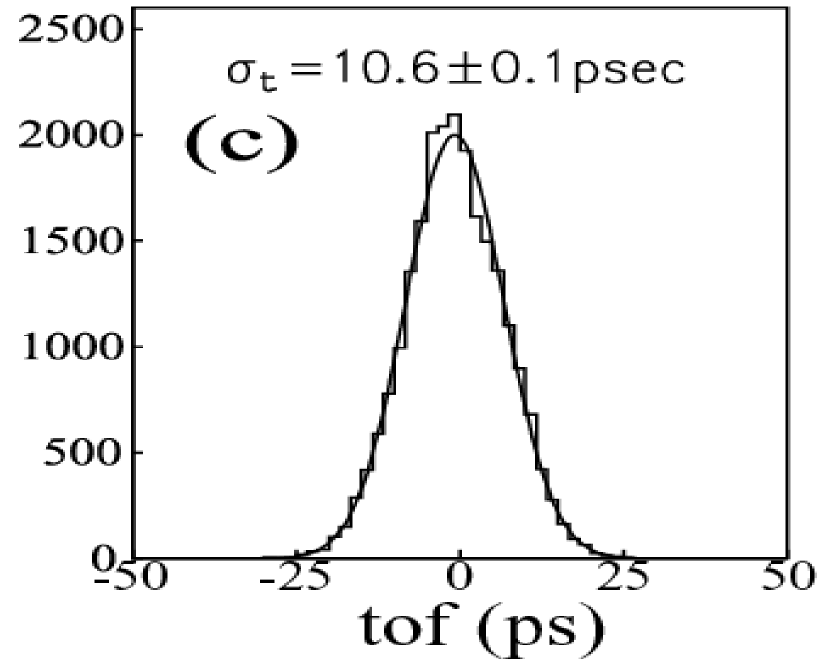
TTS=46 ps, $N\gamma$ = 200/ 4 cm quartz,

$\sigma_0 = 46/\sqrt{200}$ = <u>3 ps</u>

⇒ $\sigma_{expected}$ = 9 ps

including circuit fluctuation of 9 ps.

$\sigma_{observed}$ = 10.6 ps



⇒ With different TTS [L16(TTS=80 ps) & MCP(TTS=46 ps)] and similar $N\gamma$'s, $\sigma_{observed}$ = 11-12 ps is attained,where the circuit fluctuations (7-9 ps) dominate the ambiguity.

Footnote: HPK10 TOFのビームテスト。期待値＝9 ps vs。測定値＝10.6 ps。

Summary

1. TOF resolution = 10 ps achieved !
2. K/pi separation at Belle (Belle is a relatively small spectrometer)

   ⇒ ~ 4 σ at 4 GeV/c

3. Issues to be solved:

   (1) MCP-PMT lifetime

   (2) enlargement of radiator

   (3) precise circuit

K/π separation (σ) for Belle with 10 ps