Development of a Hybrid Photo-Detector (HPD) for a Next Generation Water Cherenkov Detector

ICEPP Symposium 2005

Feb 23th, 2005

Hakuba

H. Nakayama, A. Kusaka, H. Kakuno,
H. Aihara, M. Iwasaki, T. Abe (Tokyo)
M. Shiozawa (ICRR)
M. Tanaka (KEK)
Y. Kawai (HPK)

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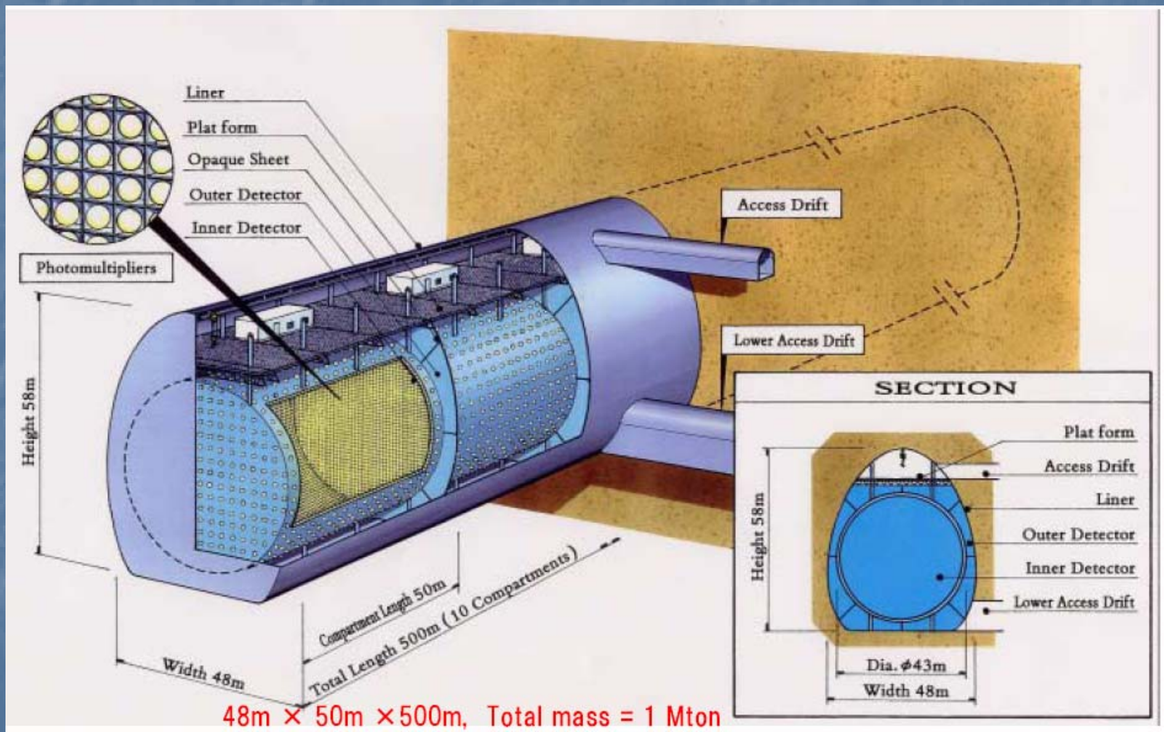
- 1. Introduction

Next Generation Water Cherenkov Detectors

Example: Hyper Kamiokande (HK)



Total Mass ~ 1Mt.

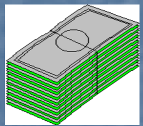
(Super Kamiokande = 50kt)

HUGE!!

# of photo sensors:

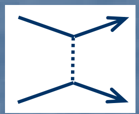
~200,000

Requirements to a New Photo Sensor

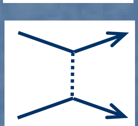


Simple structure

→ *Low cost, quality control (We need many photo sensors!)*

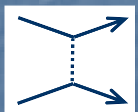


Large sensitive area



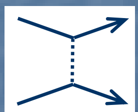
Single photon sensitivity

→ *Advantage in Cherenkov ring reconstruction*



***Wide dynamic range** (up to ~300p.e.)*

→ *Dynamic range of detectable neutrino energy*



***Good timing resolution** (~1ns)*

→ *Good resolution of neutrino vertex ($\Delta x \sim c\Delta t$)*

requirements

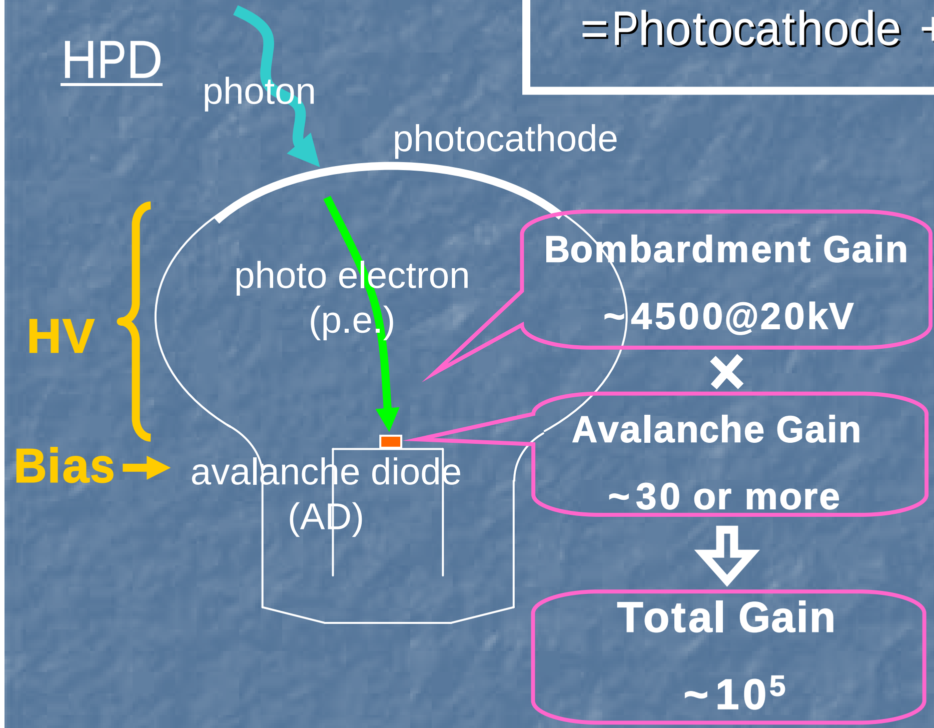
- simple
- large area
- 1p.e.
- ~300p.e.
- good Δt

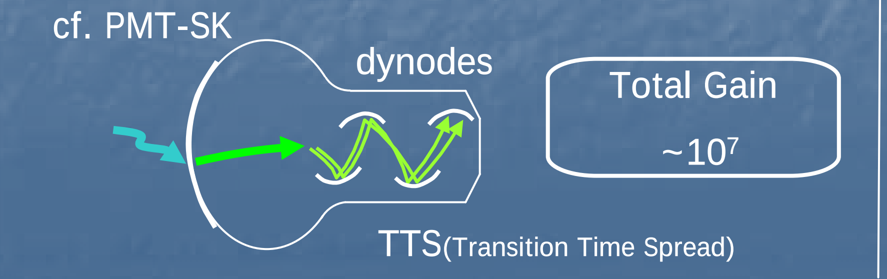
Our Solution: **HPD** (Hybrid Photo-Detector)

The Principle of a HPD

requirements
- simple
- large area
- 1p.e.
- ~300p.e.
- good Δt

"Hybrid"
=Photocathode + Silicon device (AD)





☺ Simple structure without dynodes

# of parts:1/10 of PMT-SK

☺ Single photon sensitivity

sufficient total gain

☺ Wide dynamic range(>1000p.e.)

limited by AD saturation

☺ Good timing resolution(~1ns)

cf. PMT-SK: ~2.3ns (mainly TTS)

☹ Challenging HV (~20kV)

to focus onto small AD (5mmϕ)

☹ Smaller Gain than PMTs

R&D of low-noise readout needed

5inch prototype

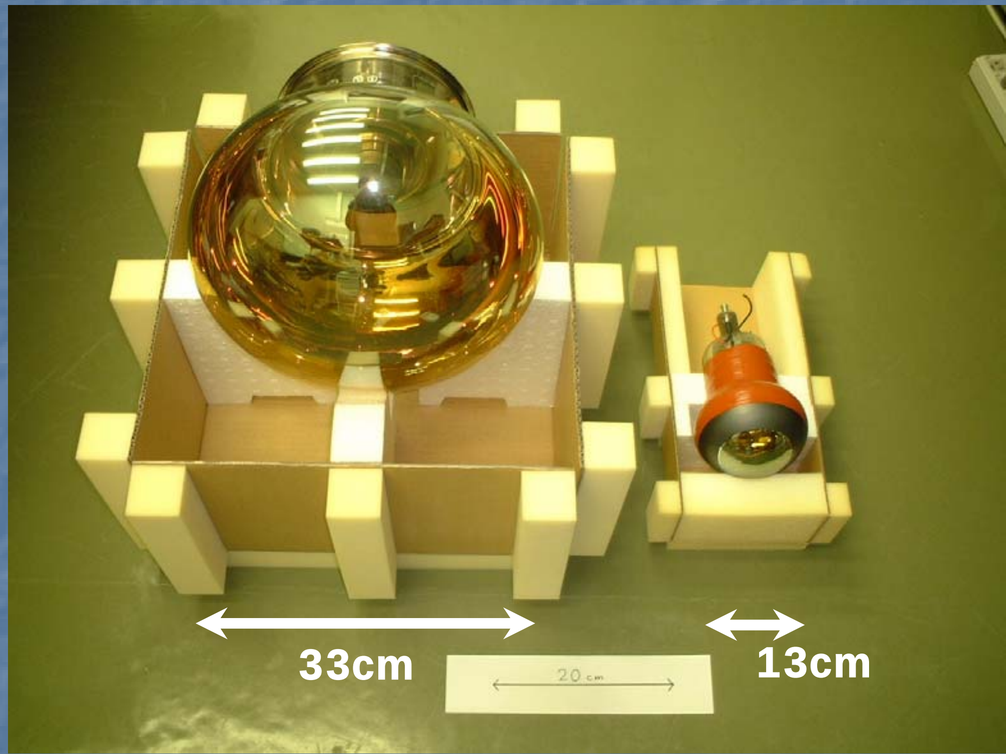
Avalanche Gain	~30 @350V
Bombardment Gain	1000 @-8.5kV
Total Gain	44,000 @-8.5kV, 350V
Single photon	Sensitive（S/N~21）
Timing resolution	~1ns @1p.e.

At first, using the small size HPD (5inch), we establish the fabrication techniques and check the basic specifications

→ Next R&D stage: 13inch

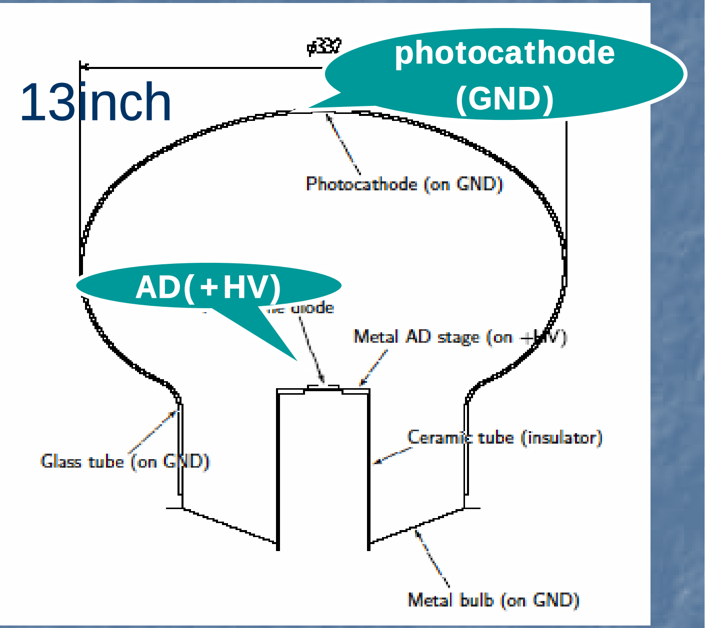
Photos of the 13inch HPD

13inch HPD



13inch 5inch

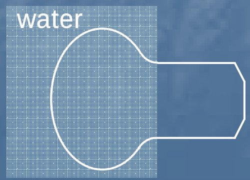
New! 13inch prototype



	13inch	5inch
Diameter	332mm	128mm
Effective area	240mmϕ	-
AD size	5mmϕ	3mmϕ
AD type	Low capacitance (~25pF)	Low capacitance (~30pF)
Bias max	370V	350V
HV max	+12kV (goal: +20kV)	-8.5kV

Upgrades from 5inch

- HV (-8.5kV→+12kV)
- +HV mode (photocathode=GND) ← use in water



- 2. Measurement Results of 13inch-Prototype HPD

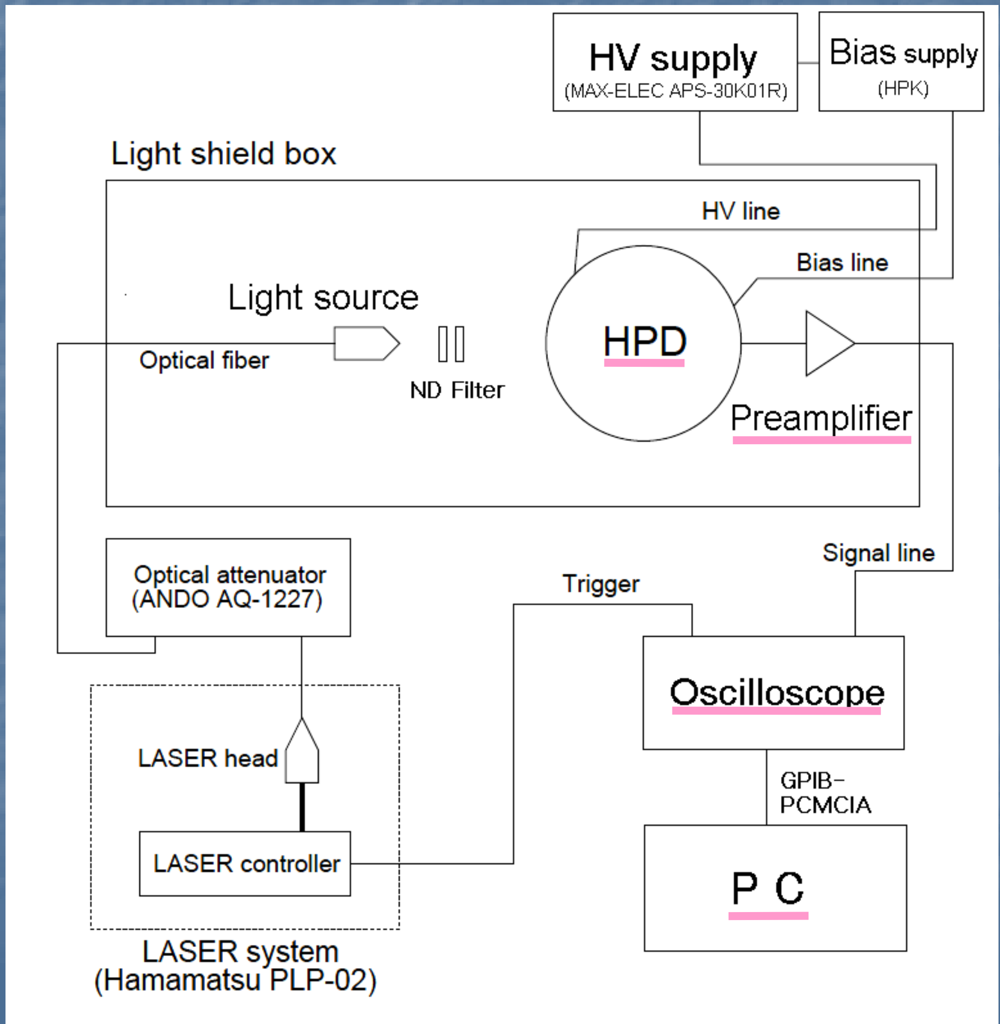
    2-a. basic parameters

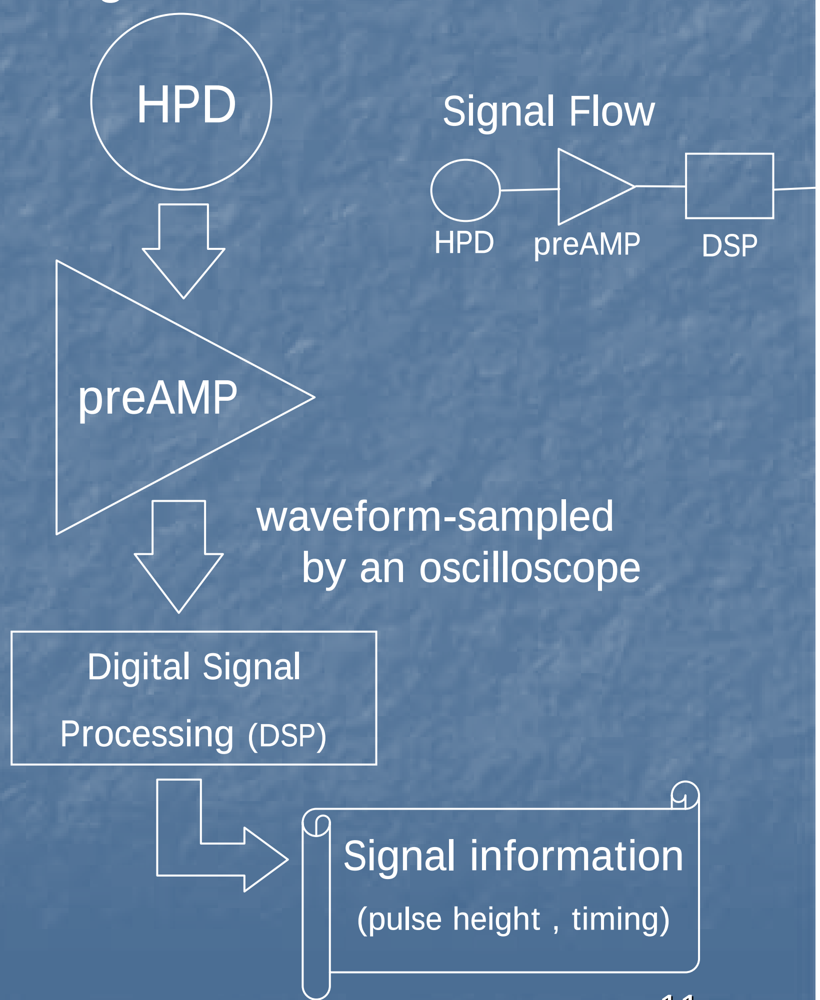
    2-b. single photon sensitivity, gain linearity

    2-c. timing resolution

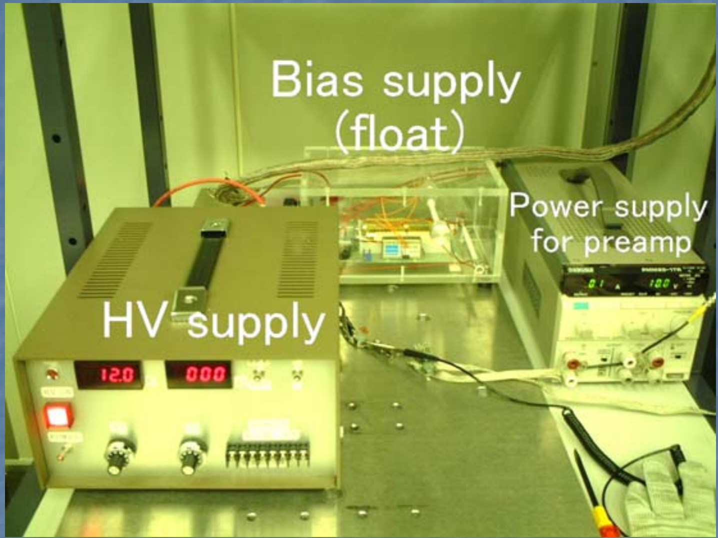
    2-d. gain/timing uniformity on 13-inch photocathode

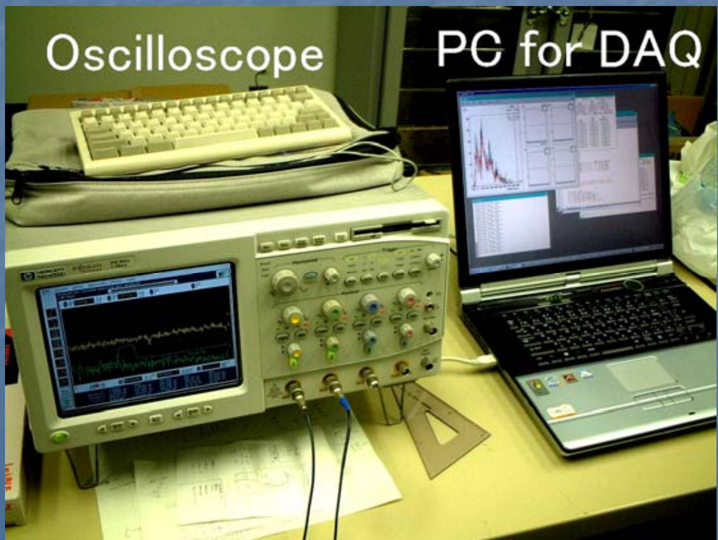
Measurement Setup





Measurement Setup (Photos)





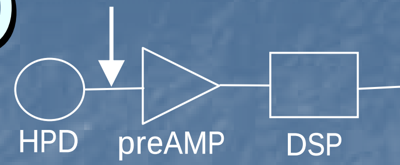
→ 2-a. basic parameters

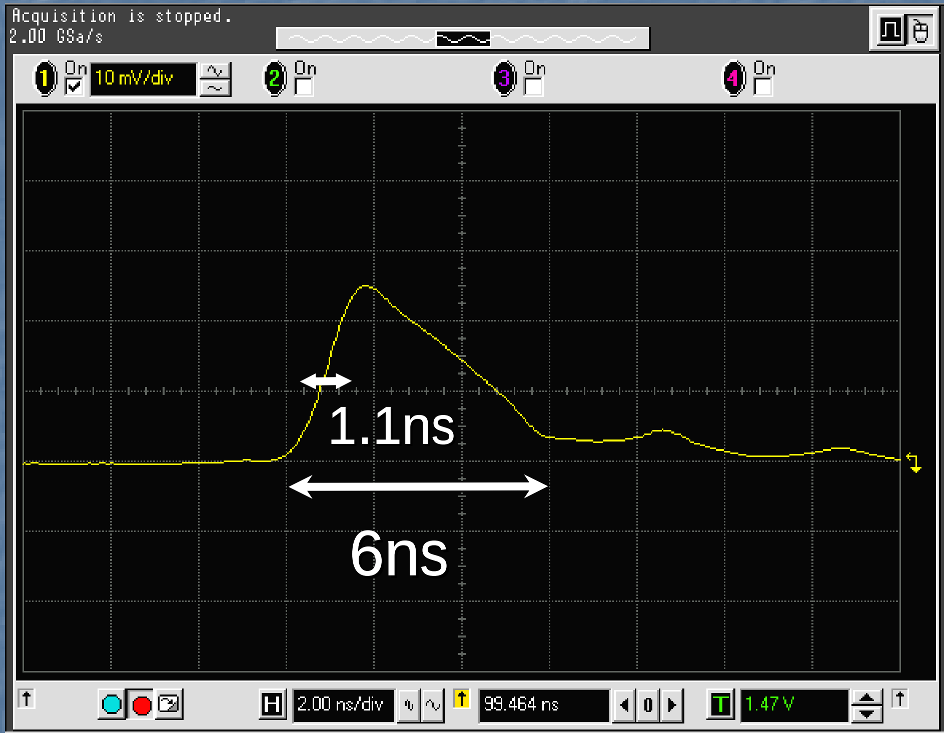
2-b. single photon sensitivity, gain linearity

2-c. timing resolution

2-d. gain/timing uniformity on 13inch photocathode

Raw Signal of the HPD





10mV/div, 2ns/div

LHP30

HV, Bias: Max(12kV, 370V)

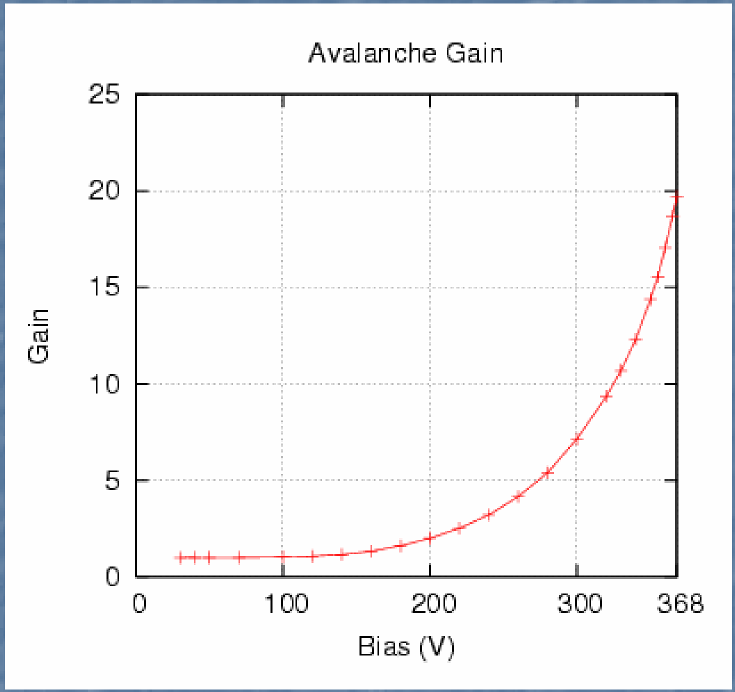
Input light: ~30p.e.

- Fast signal response
  - Rise time ~ 1.1ns
  - Pulse width ~ 6ns

Avalanche/Bombardment Gain

- Avalanche Gain

HV=12kV(fixed), Bias=sweep



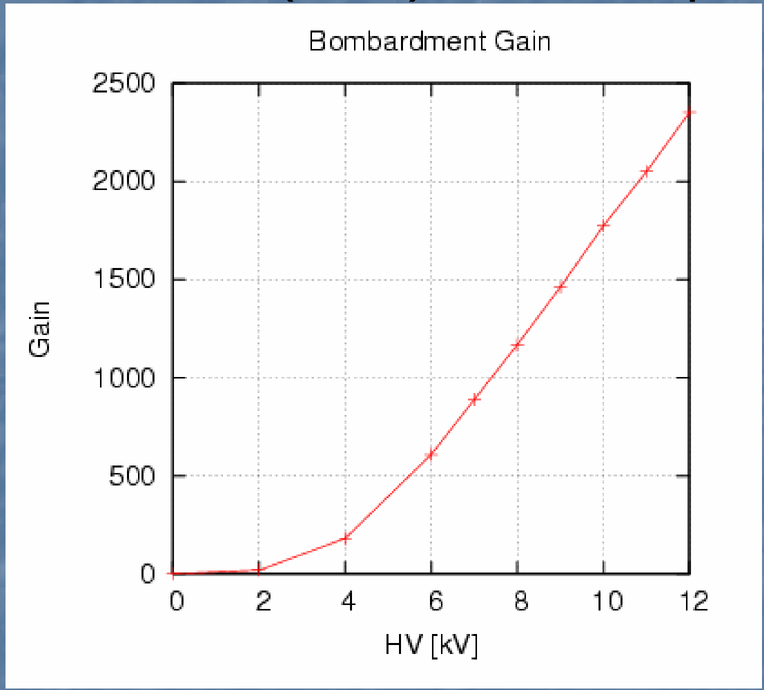
Gain≡1@Bias=40V

(no avalanche effect ≲40V)

Gain ~20 @368V

- Bombardment Gain

Bias=50V(fixed), HV=sweep



Gain ~2400 @12kV

Gain rises >3kV (energy loss in an insensitive layer on AD)

→ *Total gain ~50,000 (current mode)*

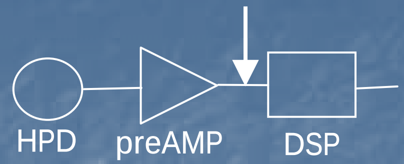
2-a. basic parameters

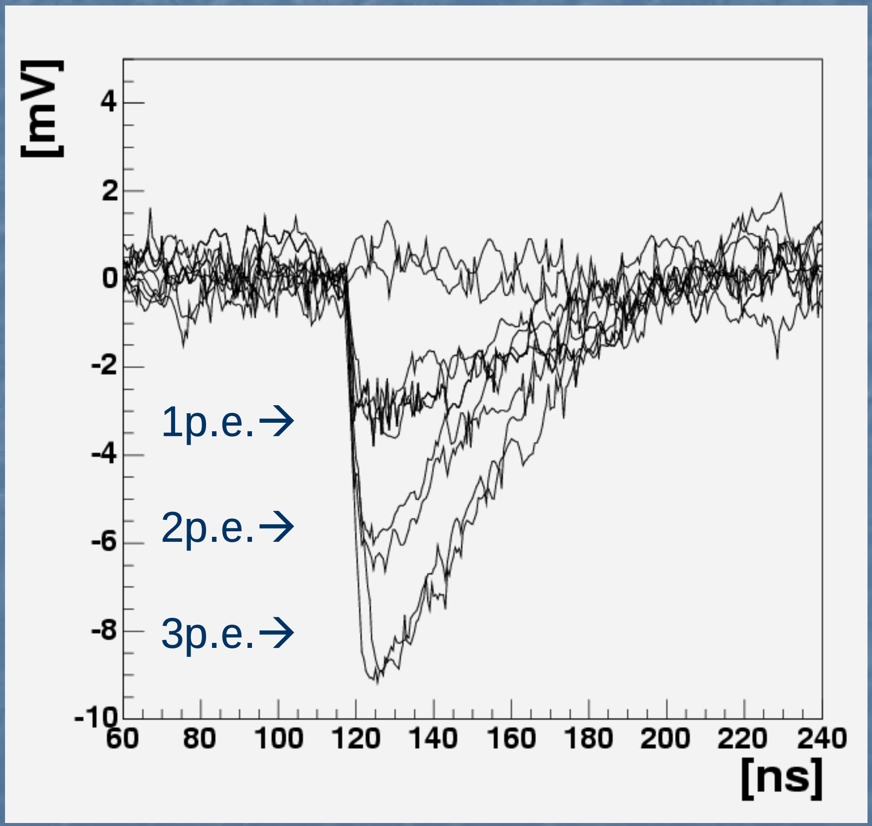
→ 2-b. single photon sensitivity, gain linearity

2-c. timing resolution

2-d. gain/timing uniformity on 13inch photocathode

Signals at preamplifier output





HV, Bias: MAX(12kV, 370V)

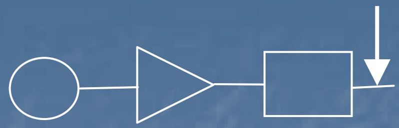
Light input: ~2p.e.(average)

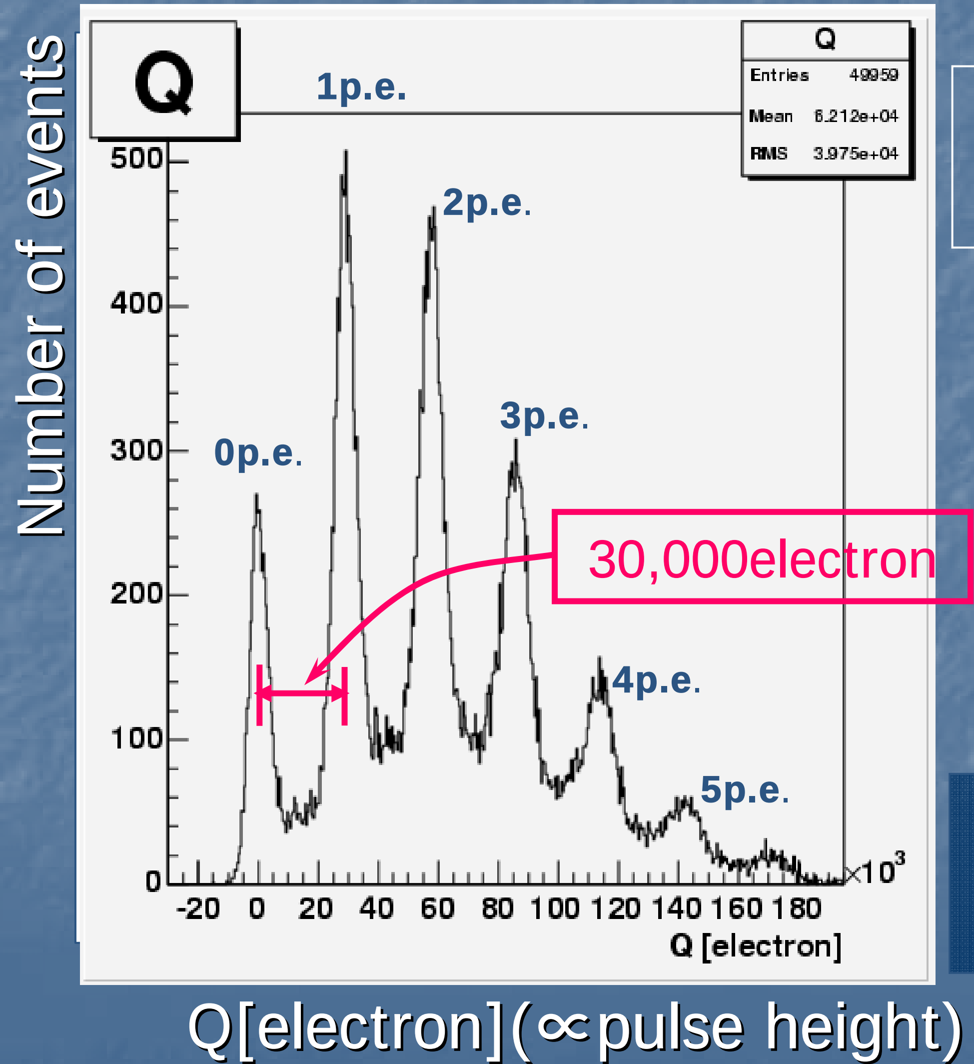
Pulse height

1p.e. ~3.2mV
Noise RMS ~0.5mV

LHP25

Single Photon Sensitivity





Pulse height distribution after DSP

→ very clear 1, 2, .. p.e. peaks

Gain ~30,000 (pulse mode)

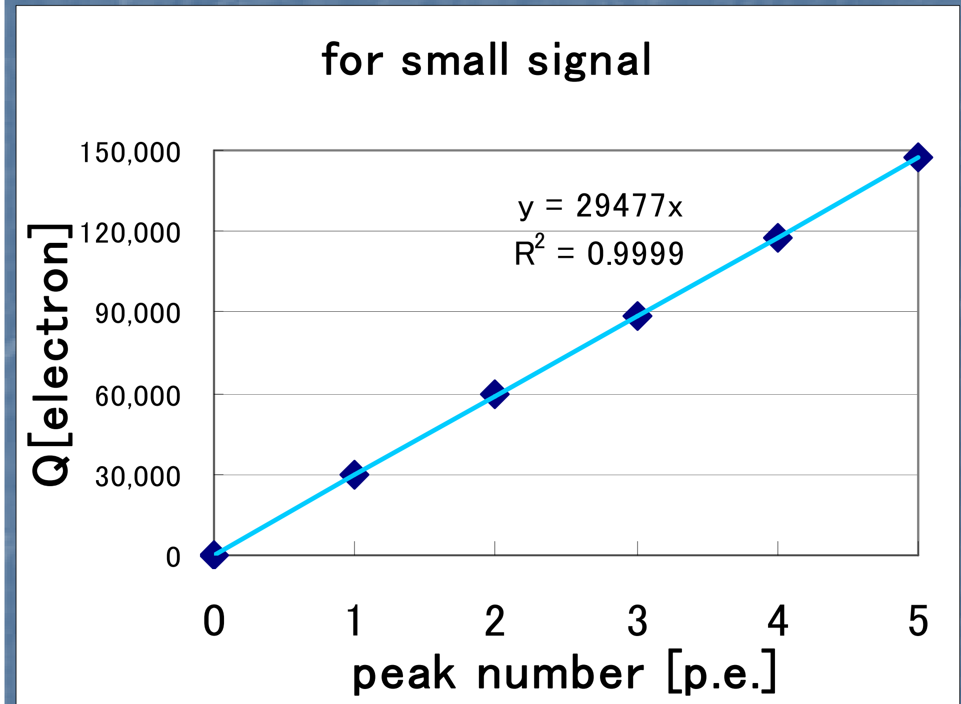
ENC ~3,000[electron]

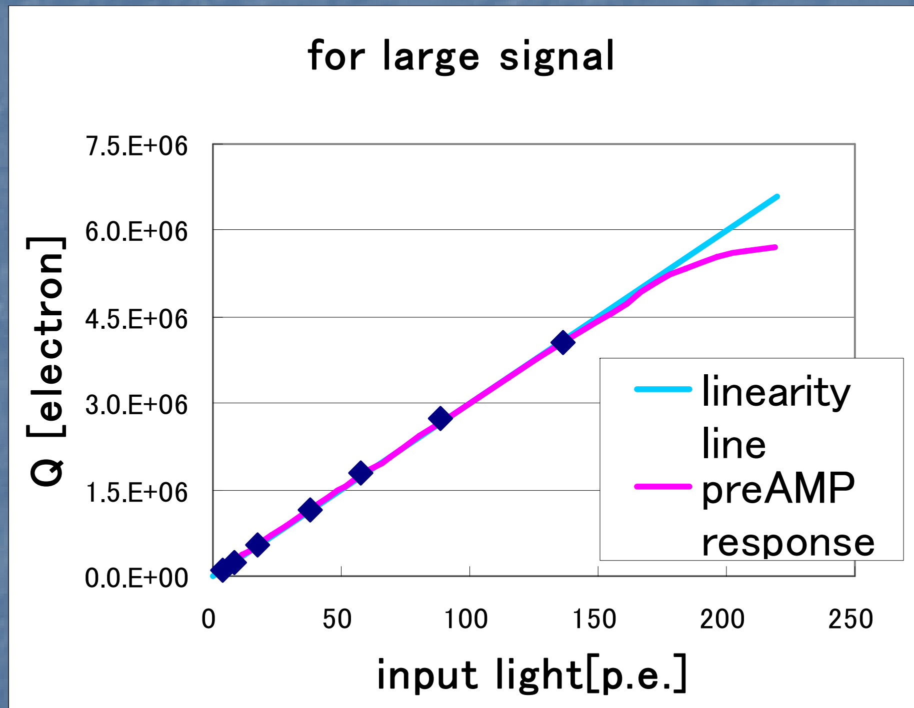
→ S/N ~10 @1p.e.

Single Photon Sensitivity!

Gain Linearity

Peak positions in the Q-histogram





Linearity is quite good ~5p.e.

Good linearity up to ~150p.e.(preAMP limit)

2-a. basic parameters

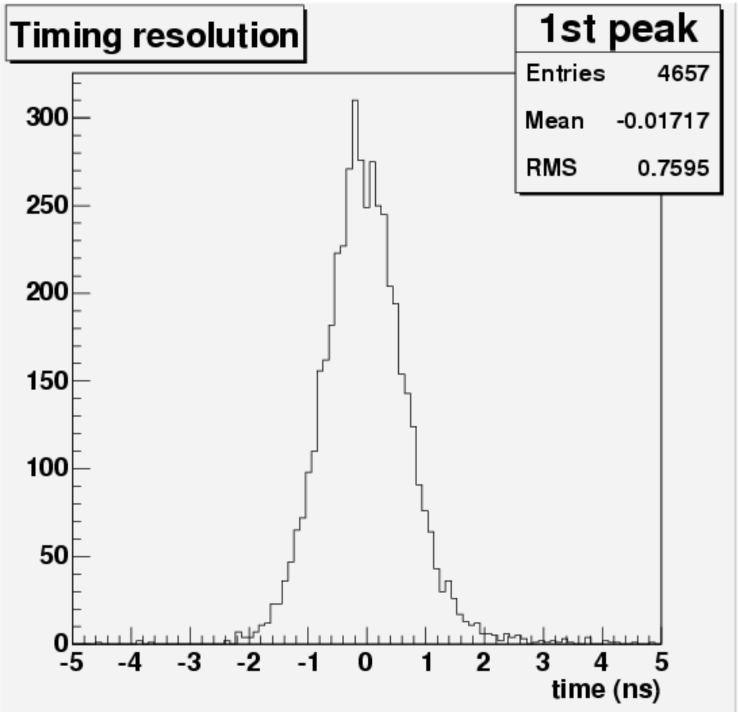
2-b. single photon sensitivity, gain linearity

→ **2-c. timing resolution**

2-d. gain/timing uniformity on 13inch photocathode

Timing Resolution for 1p.e.

Timing resolution directly affects to the neutrino vertex reconstruction performance. ($\Delta x \sim c\Delta t$)



timing (ns)

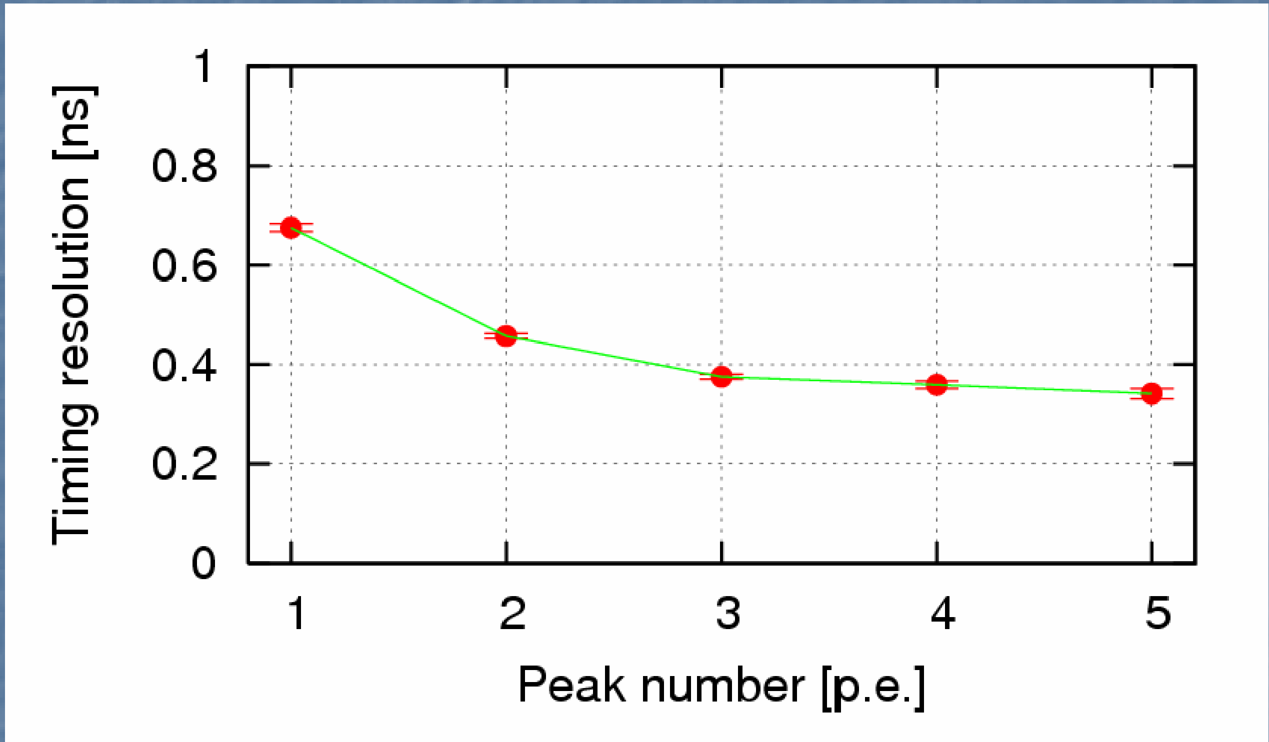
Timing resolution

~0.7ns@1p.e.

cf. PMT-SK

~2.3ns@1.p.e.

Timing Resolution for multi p.e.



Timing resolution $\lesssim$0.5ns for $\geq$2p.e.

➡ **Meet the requirement (~1ns)**

2-a. basic parameters

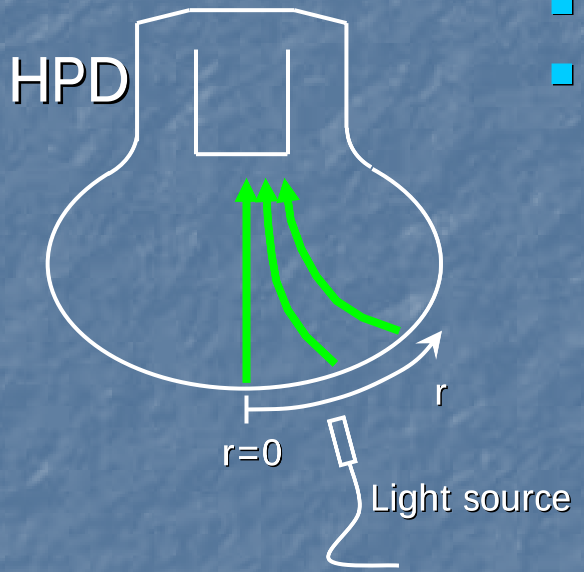
2-b. single photon sensitivity, gain linearity

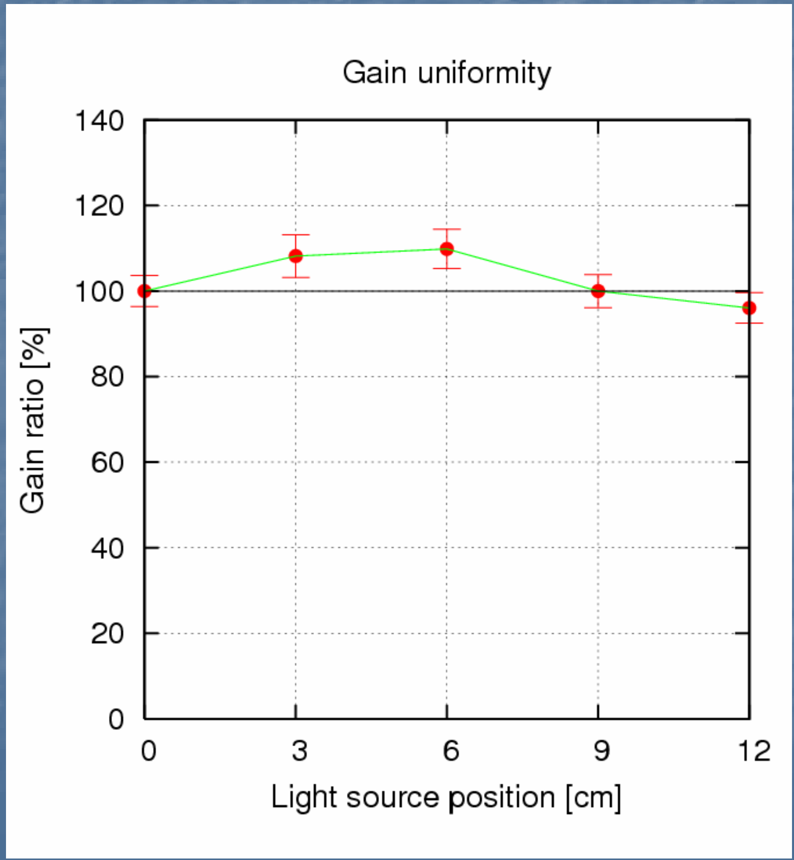
2-c. timing resolution

→ 2-d. gain/timing uniformity on 13inch photocathode

Gain Uniformity

- Gain vs. position on the photocathode
- Light input: 1p.e.



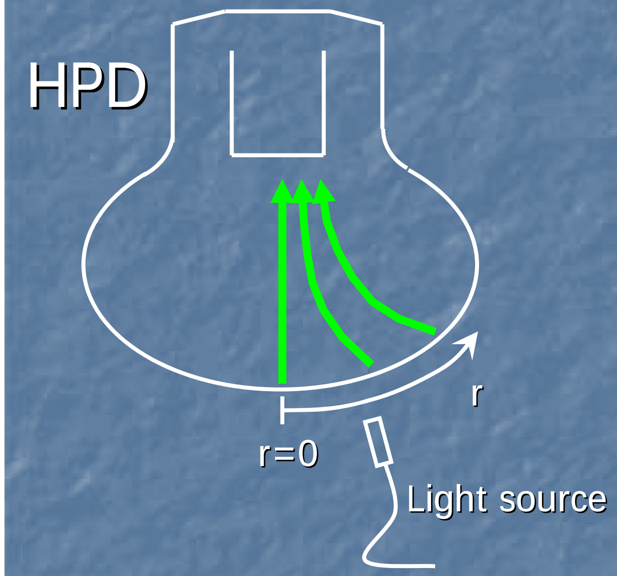


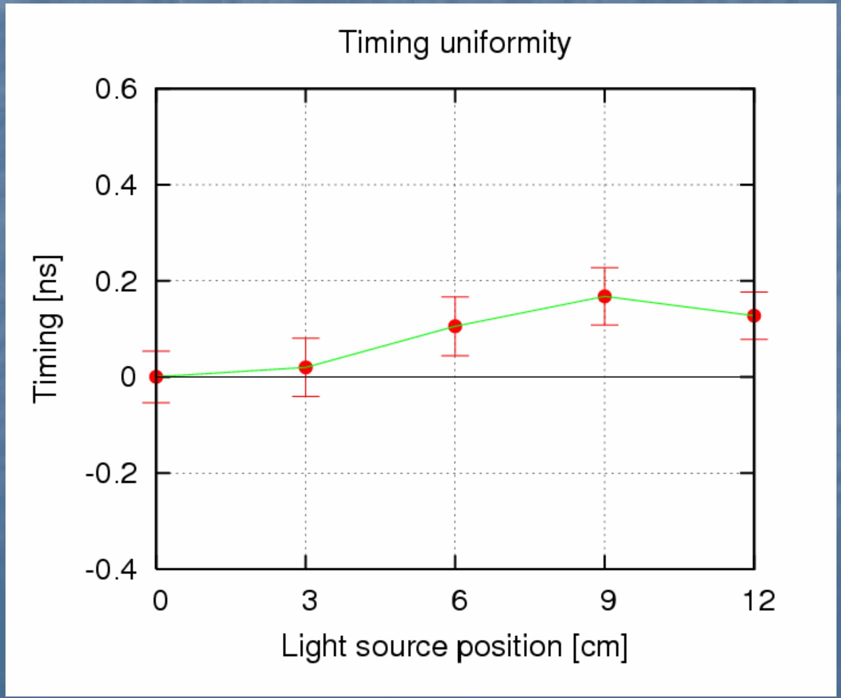
Gain Uniformity

within ~10%

Timing Uniformity

- T.O.F (photocathode~AD) vs. position on the photocathode
- light input: ~30p.e.
  (timing resolution: 0.06ns@30p.e.)





Timing uniformity

<u>~0.1ns</u>

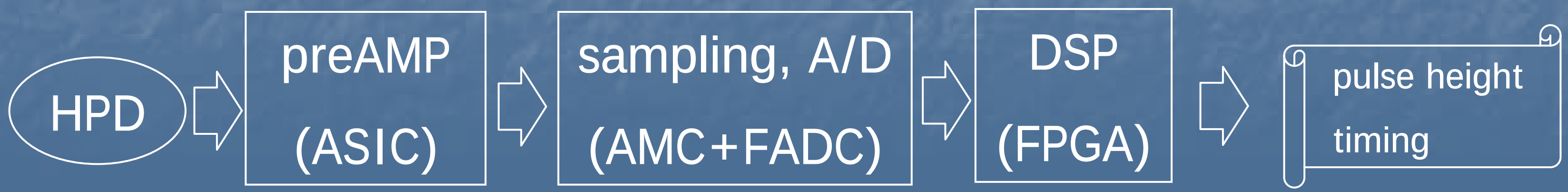
- 3. Current status & Future Plans of R&D

Current status

Requirements	Current	Task
Simple structure	units:1/10 of PMT	OK!!
Large sensitive area	13inch, good uniformity	OK!!
1.p.e. sensitivity	S/N~10@1p.e.	OK!!
Dynamic range (~300p.e.)	limited by the preAMP (~150p.e.)	upgrade preAMP (detector limit >1000p.e.)
Timing resolution (~1ns)	0.7ns@1p.e.	OK!!

Future R&D Plans

- preAMP (dynamic range)
  → confirm our HPD meets all the requirements
- New type AD (back illuminate)
  → small detector capacitance → better S/N
- Tube structure (Max HV: 12kV → 20kV)
  → wide effective area & gain increase
- Readout system (ASIC/FPGA implementation)
  → quality control on mass production



- 4. Summary

Summary

- We develop a 13inch prototype HPD to be meant for the next generation WCD.
- We study basic responses of the 13inch HPD:
  Timing resolution(~1ns), single photon sensitivity,…
- Our study shows the HPD is in good shape as a photo sensor for the next generation WCD.

- backup

Gain loss at readout

- Gain loss @ readout

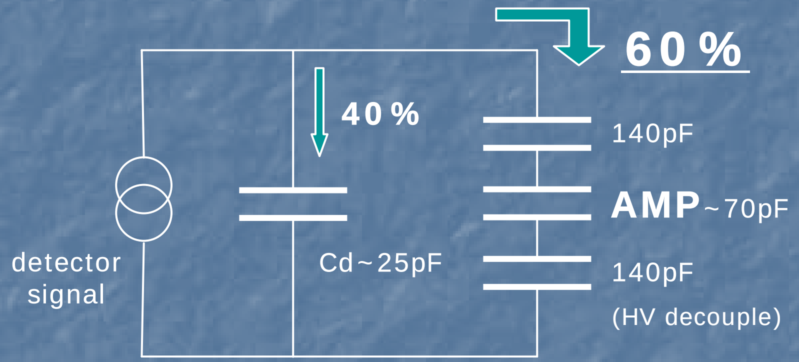
Gain=50,000

(detector itself)

↓

Gain=30,000

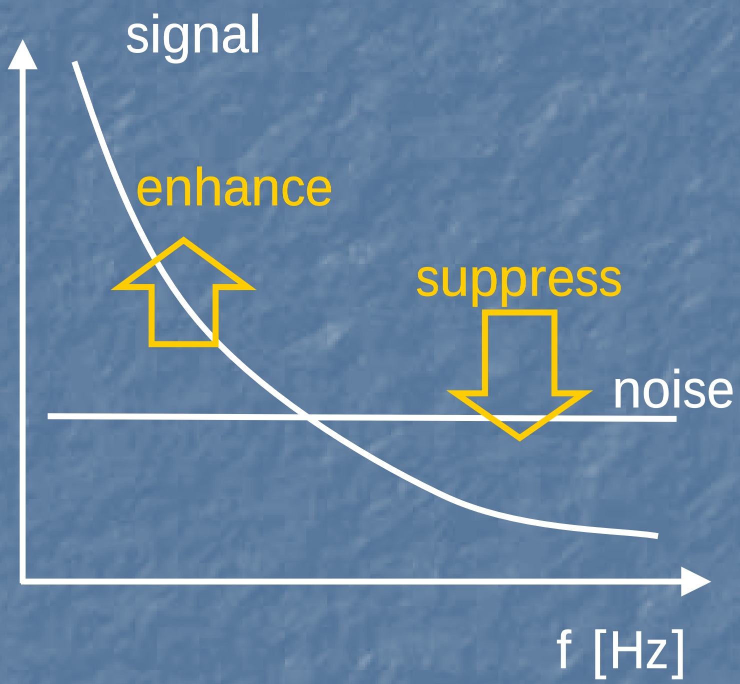
(at readout)



We can ease this gain loss by the combination following:

- smaller AD capacitance
- larger preAMP input capacitance
- larger HV-decouple capacitance

DSP



A kind of low-pass filter,

but in a more fashioned way

"matched optimal filter"

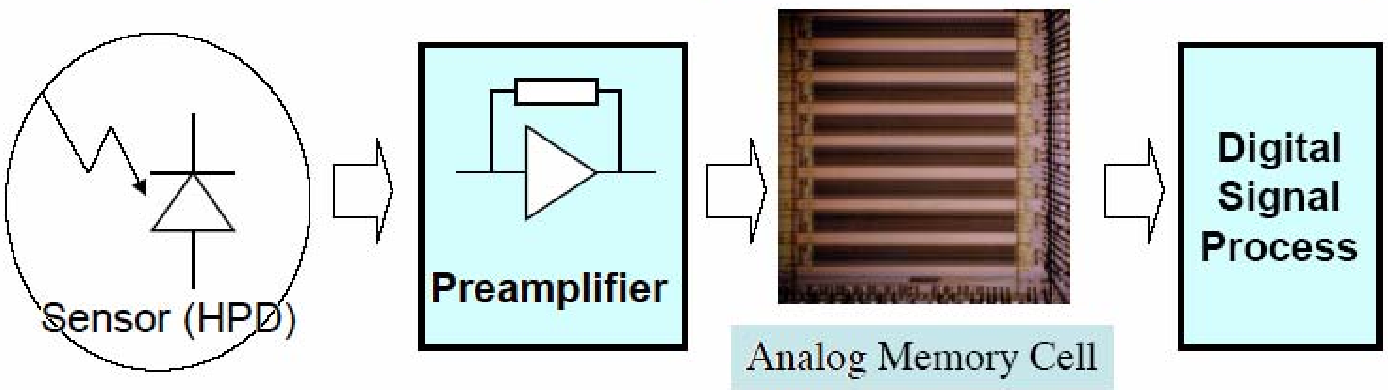
We can design the filter to maximize S/N, for any given f-domain distribution of signal & noise.

読み出し回路の全体

- Timing resolution : <1ns
- Dead time : 7.5ns
- Single photon detection

高エネルギー加速器実験で
よく使われる技術

- Low noise で高速なpreamplifier
- Waveform sampling



Fast signal
(<10ns)

Rise time が短く(<5ns)
Decay time が長め
(Charge アンプを
Shaper無しで用いる)

Waveform
sampling
(~1GHz)

Digital filterをかけ
波高、時間情報を
抽出する

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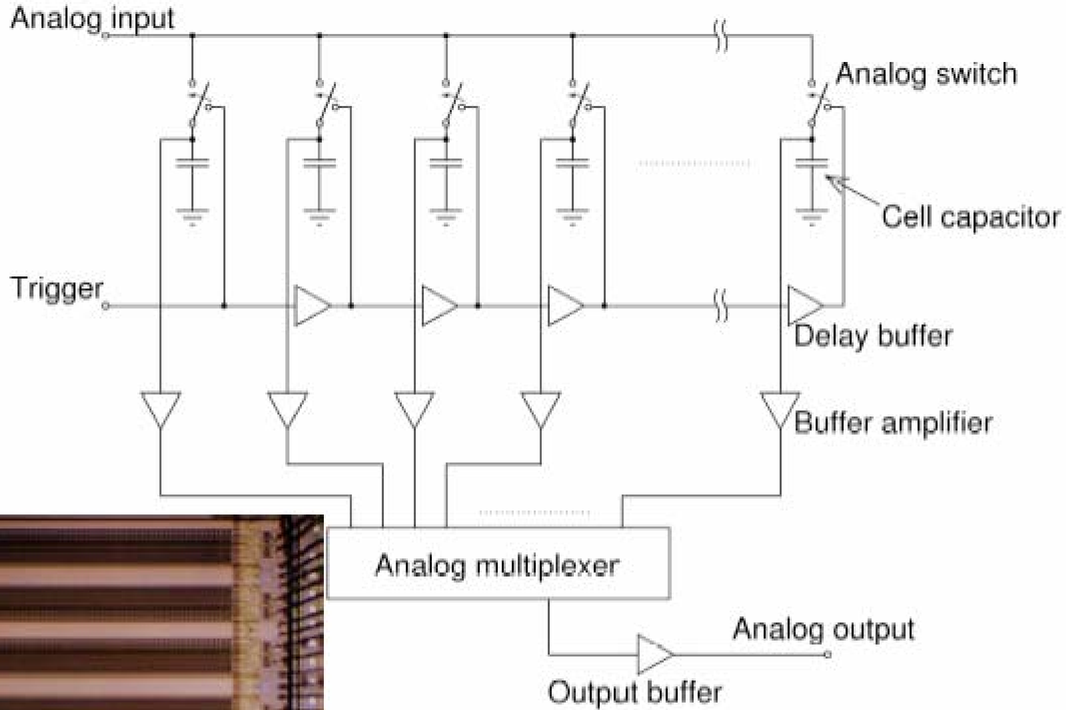
プロトタイプ製作進行中

Analog Memory Cell (AMC)



AMC:
高速クロックなし
　で高速な
waveform sample
が可能

特徴
- 低コスト
- 低消費電力

512 cell prototype
(サイズ：7mm X 7mm)

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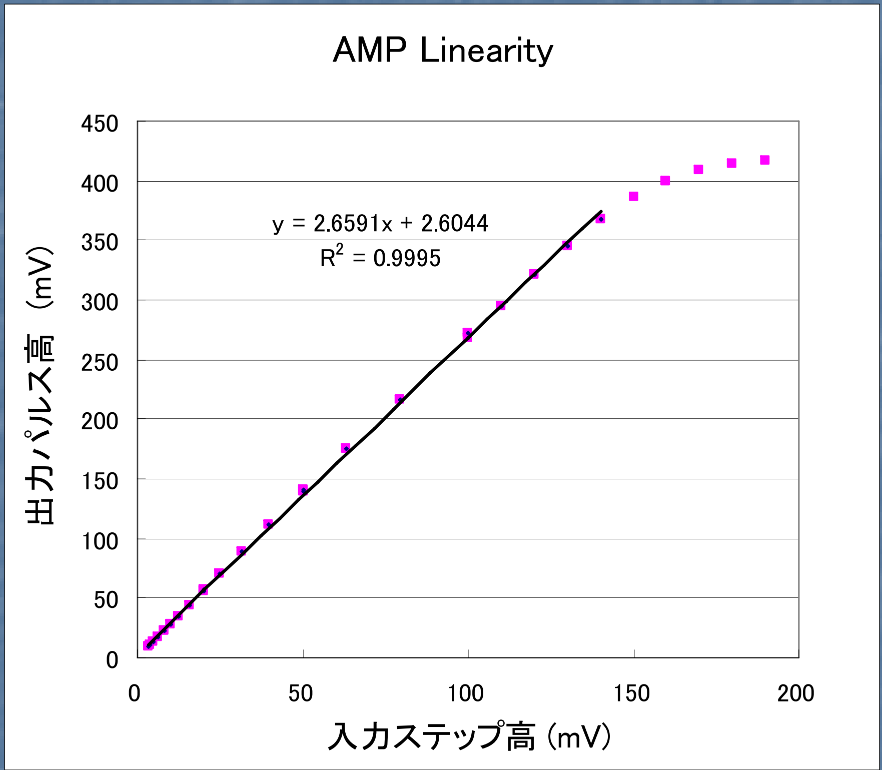
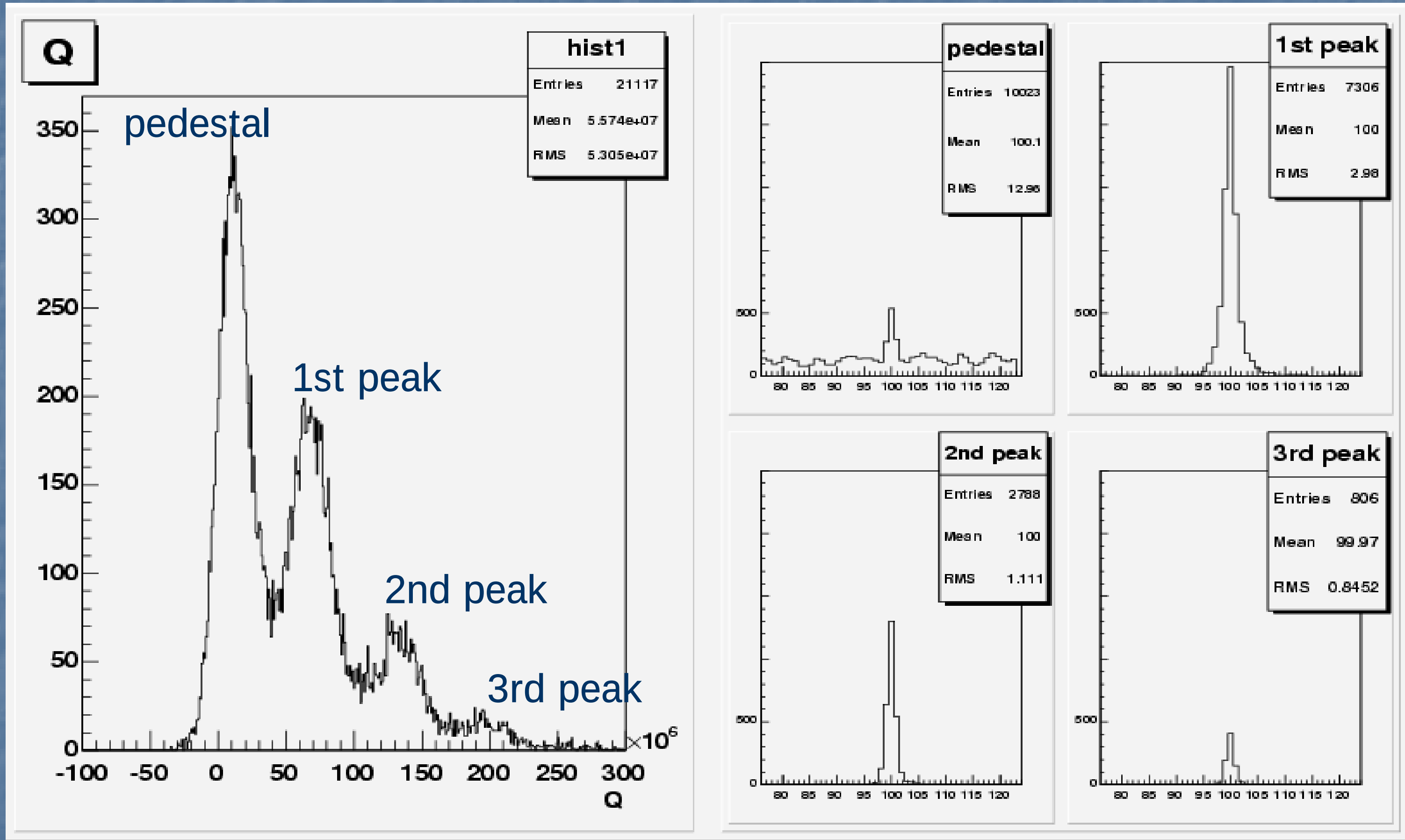
アンプのリニアリティ



- 2pFキャパシタをはさんでステップテストパルス(立ち上がり~5ns)を入力した。
- 出力側で、350mVまで線形。およそ100p.e.に相当。

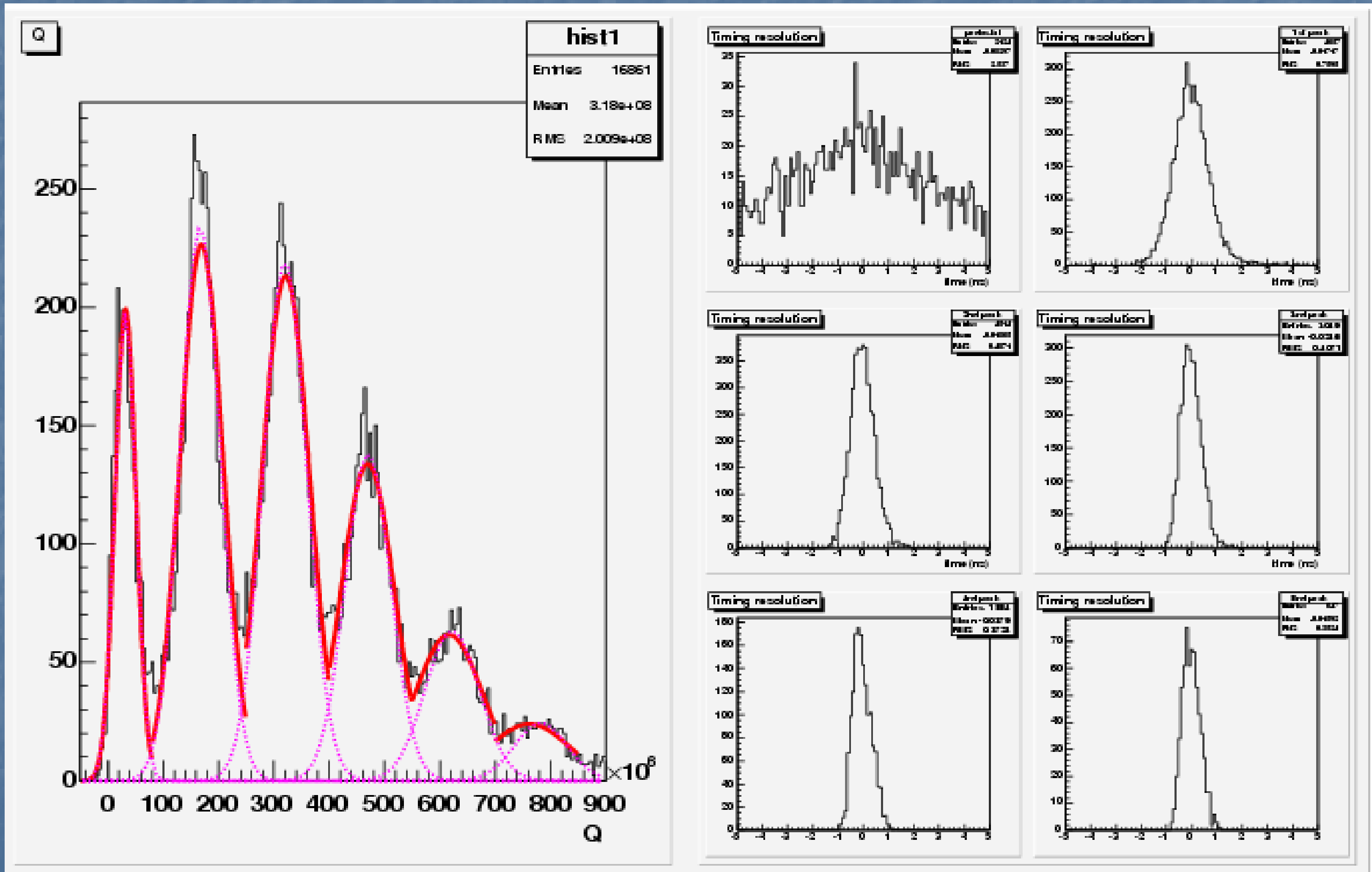
時間分解能

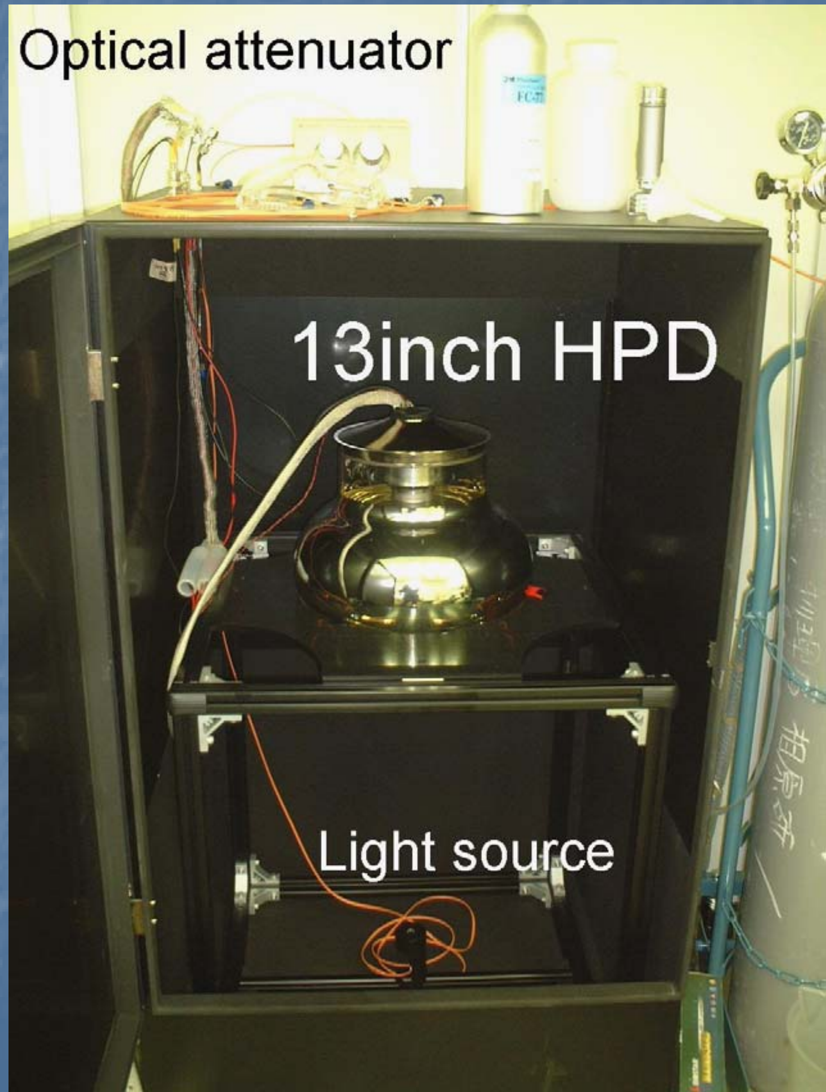


1.p.e.で時間分解能は~0.7ns。

大きい信号ほど時間分解能は良くなる。

Multi photon




Optical attenuator
13inch HPD
Light source