R&D of a Large Format Hybrid Photo-Detector (HPD) for a Next Generation Water Cherenkov Detector

Tokyo - HPK joint R&D program

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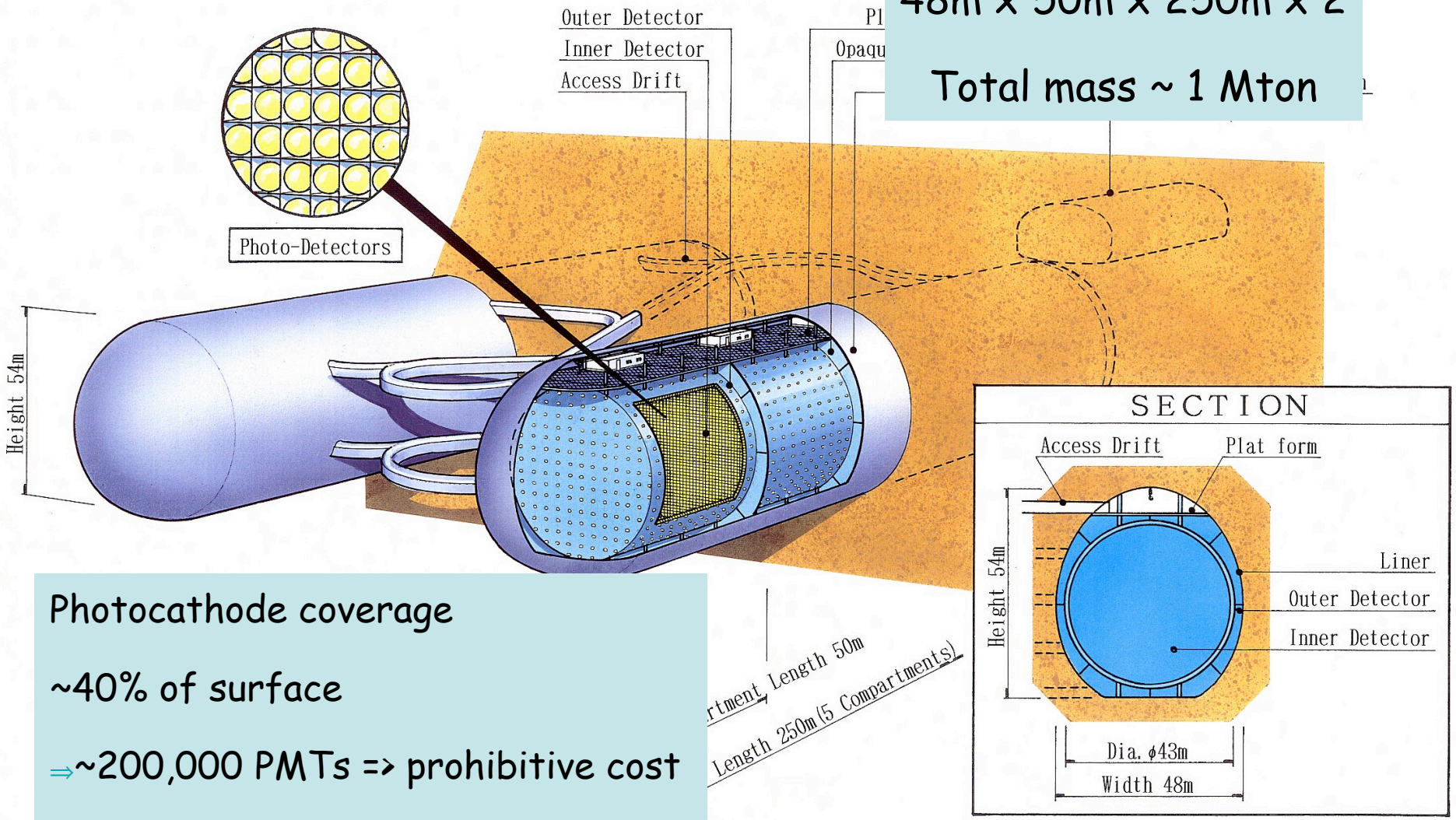
HPK =Hamamatsu Photonics

presented at Next Generation of Nucleon Decay and Neutrino Detectors 7-9 April 2005 Aussois, Savoie, France

Concept of Hyper Kamiokande (20 times Super K)

48m x 50m x 250m x 2

Total mass ~ 1 Mton



Photocathode coverage

~40% of surface

⇒~200,000 PMTs => prohibitive cost

(~10,000 PMTs for SK)

Requirements to a New Photo Sensor

Simple structure

→ *Suited for mass production : Low cost, Ease of quality control*

Large sensitive area

Single photon sensitivity

→ *Advantage in Cherenkov ring reconstruction*

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

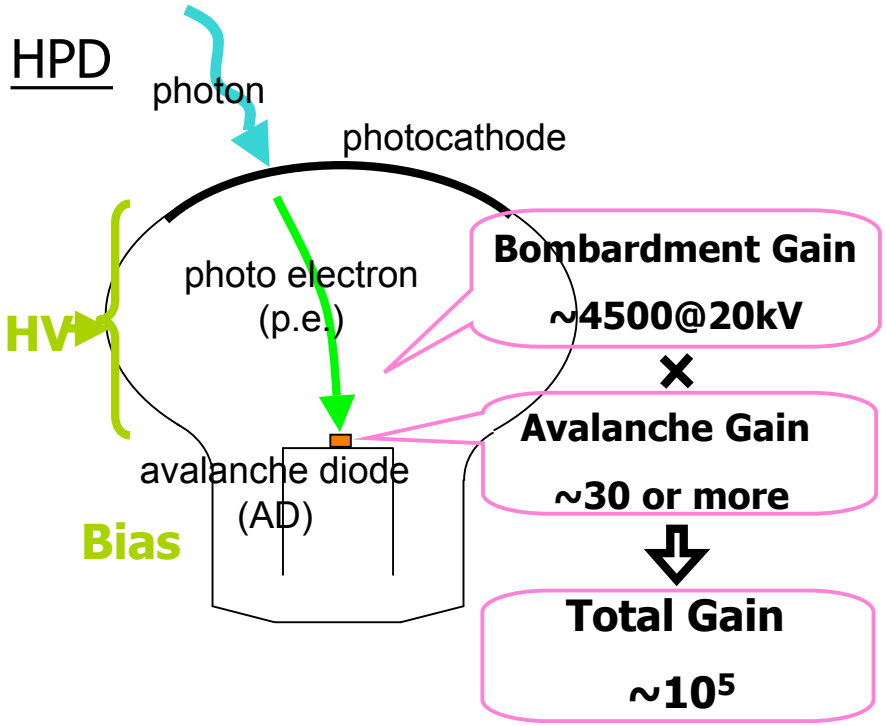
Good time resolution (~1ns)

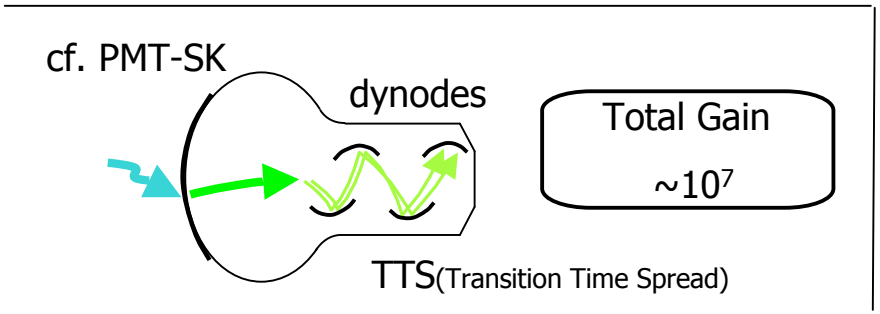
→ *Good resolution of neutrino event vertex ($\Delta x \sim c\Delta t$)*

Keep large photocathode and replace dynodes with an avalanche diode

=>Hybrid (Avalanche) Photodetector : H(A)PD

Principle of HPD





Simple structure without dynodes

# of parts:1/10 of PMT-SK

Single photon sensitivity

large gain at the first stage

Wide dynamic range(>1000p.e.)

determined by AD saturation

Good timing resolution(~1ns)

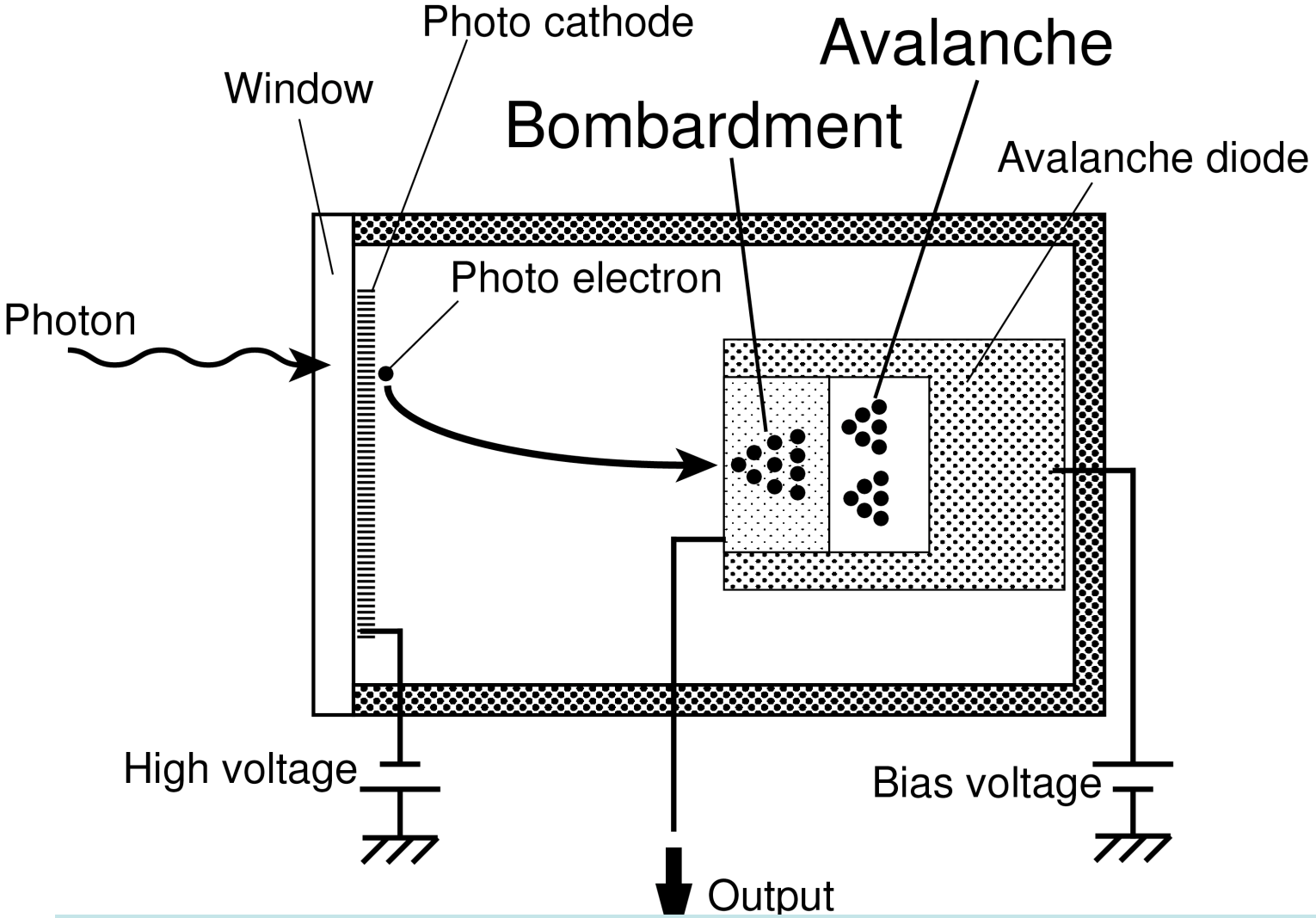
cf. PMT-SK: ~2.3ns (mainly TTS)

Challenging HV (~20kV)

to focus onto a small AD (5mmϕ)

Smaller Gain

low-noise readout needed



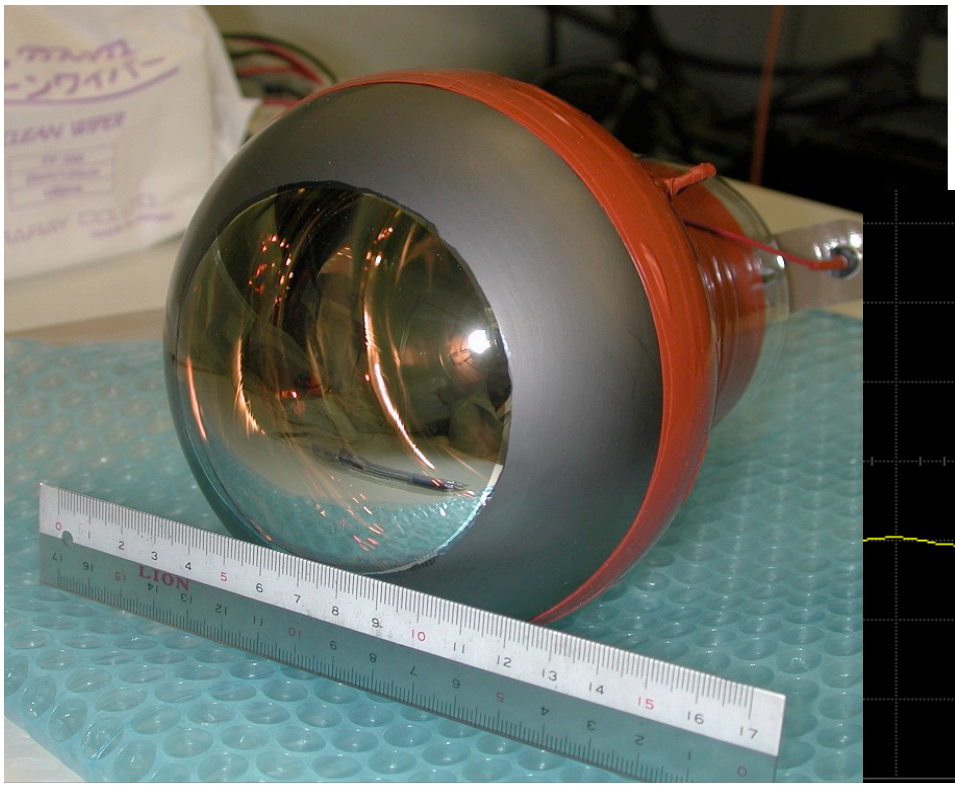
Bonbardmend Gain (dE/dX in Si / 3.6 eV) ~4,500@20kV

× Avalanche Gain (~30-50)

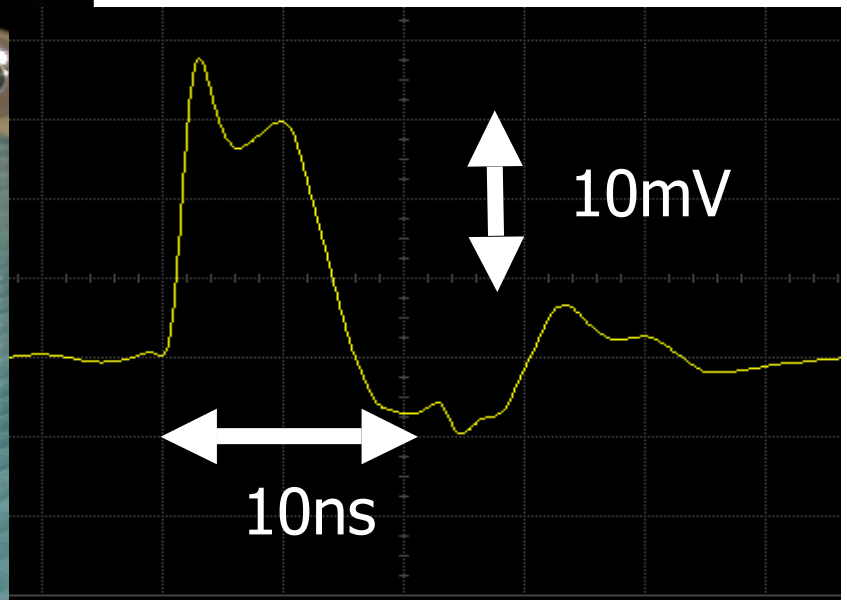
Total Gain ~ $10^5 < 10^7$ of SK-PMT

5 inch prototype HPD

5 inch prototype HPD (HY0010)



Raw signal

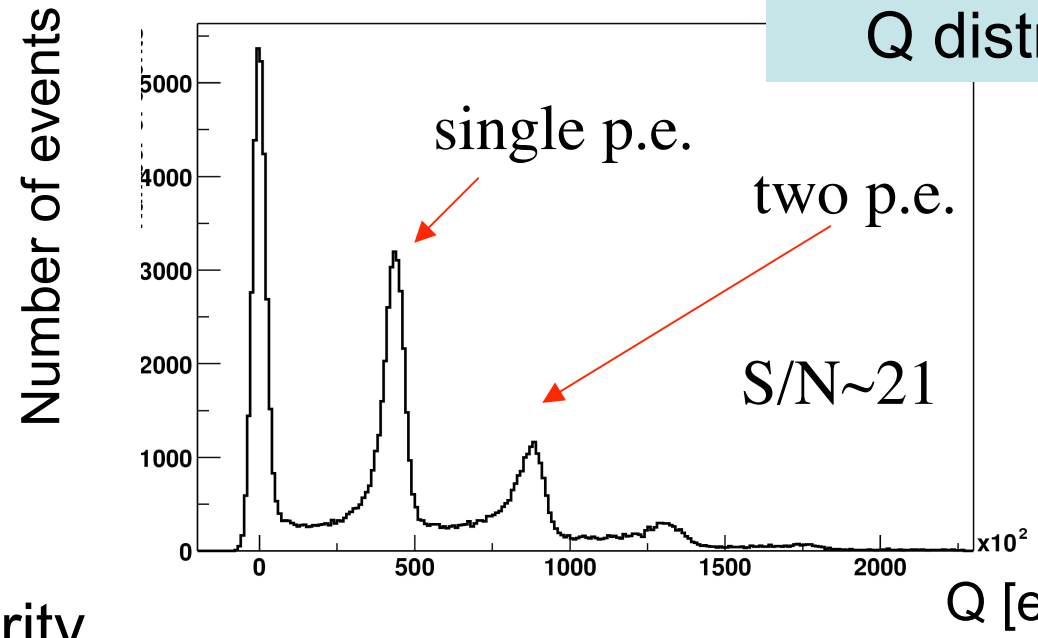


Proof of principle using 5 inch prototype

Total Gain

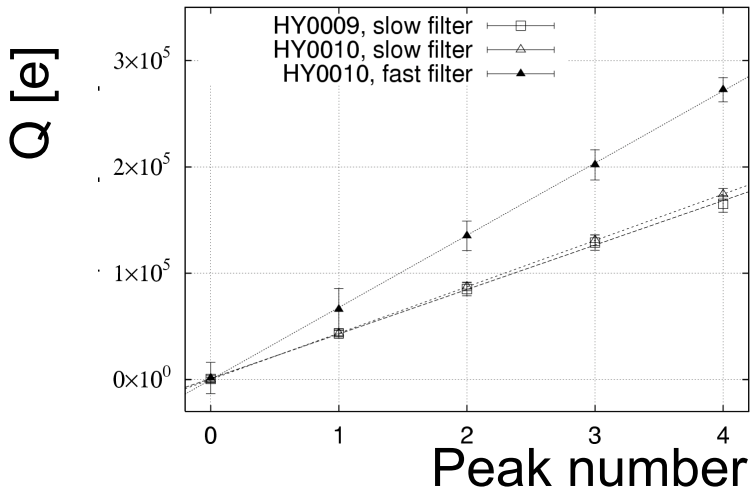
~44,000

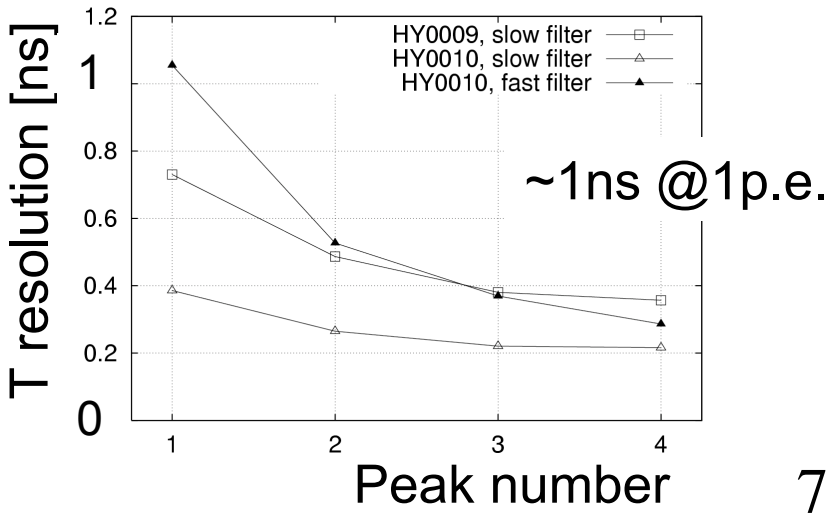
Q distribution



3mmϕ AD
~30pF
Bias: 350V
HV:-8.5kV

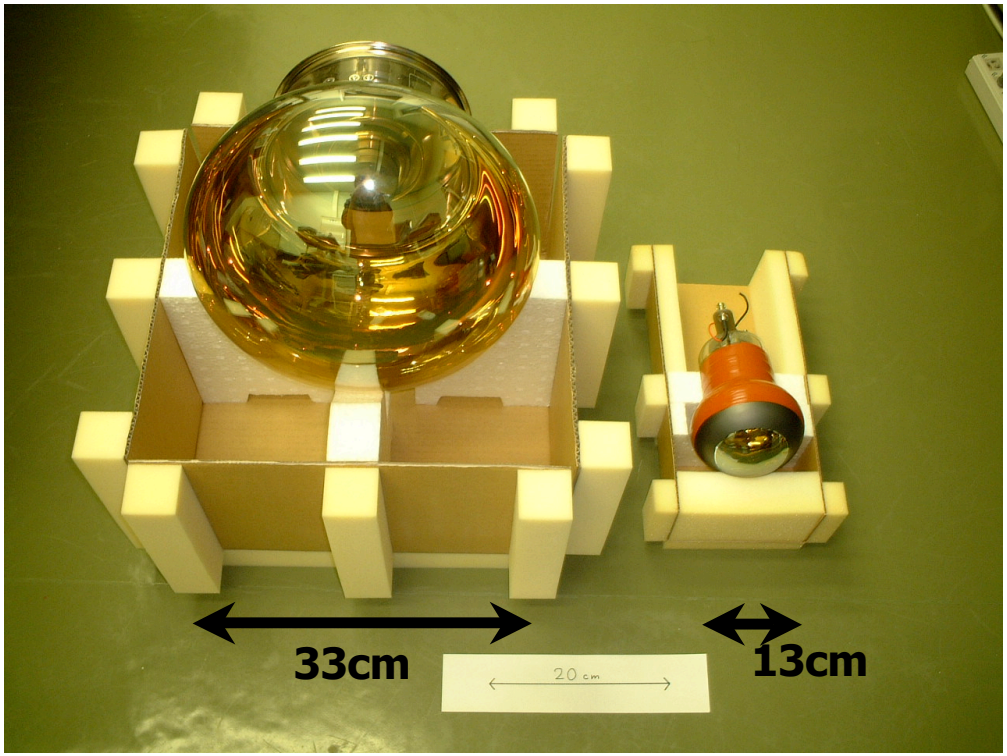
Linearity





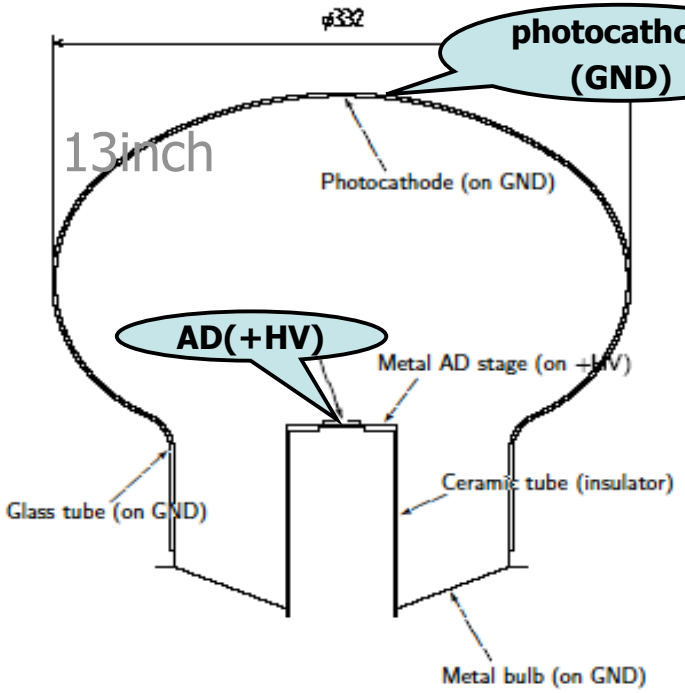
Photos of 13inch HPD

13inch HPD



13inch 5inch

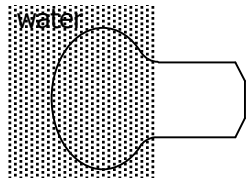
New! 13inch prototype



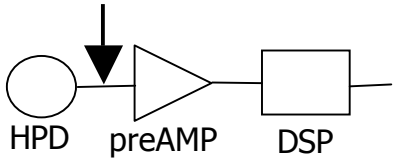
	13inch	5inch
Diameter	332mm	128mm
Effective area	240mmϕ	-
AD size	5mmϕ	3mmϕ
AD type	Low capacitance (~25pF)	Low capacitance (~30pF)
Bias max	370V	350V
HV max	+12kV (goal:+20kV)	-8.5kV

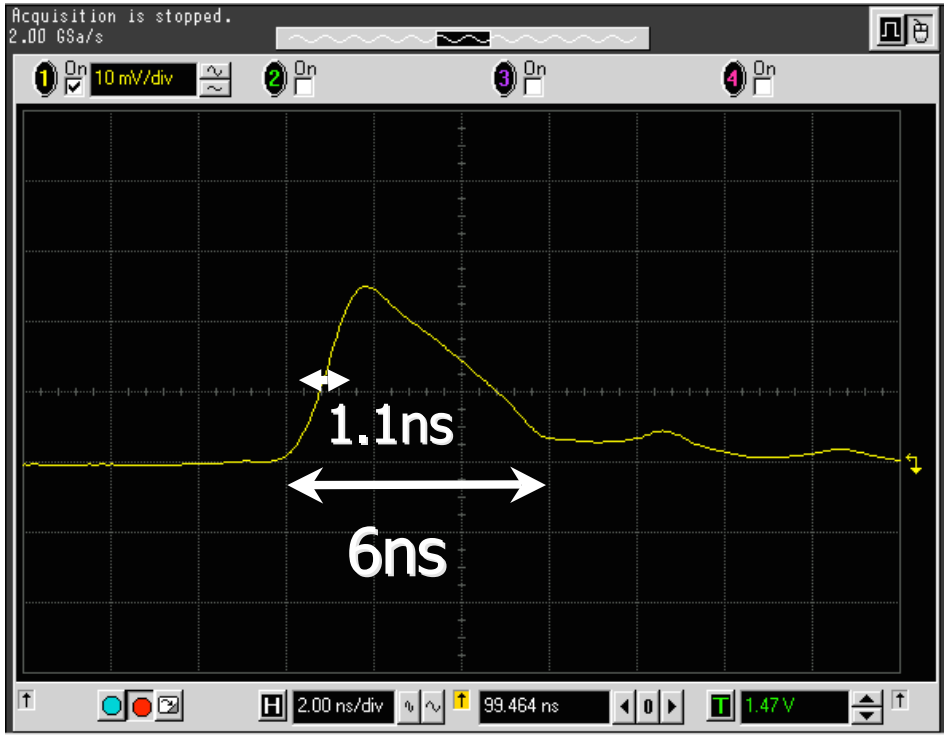
Change from 5inch

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



Raw Signal of the HPD





10mV/div, 2ns/div

LHP30

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

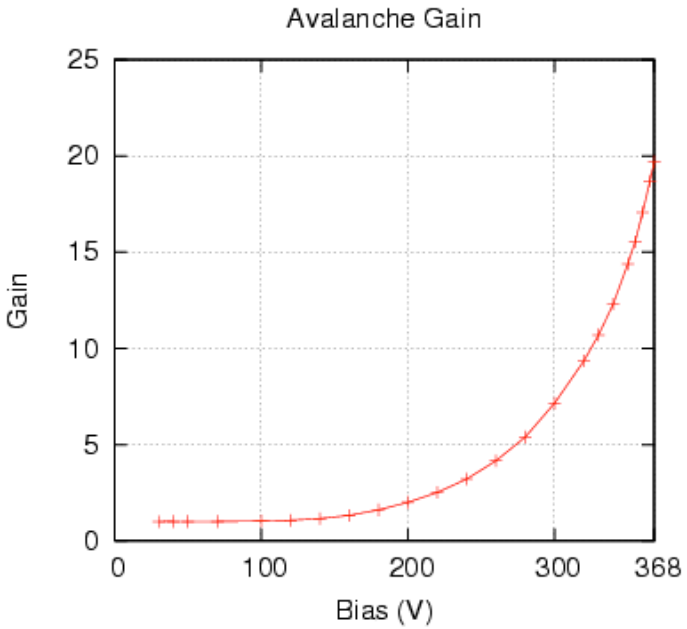
Input light: ~30p.e.

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

Avalanche/Bombardment Gain

- Avalanche Gain

HV=12kV(fixed), Bias=sweep



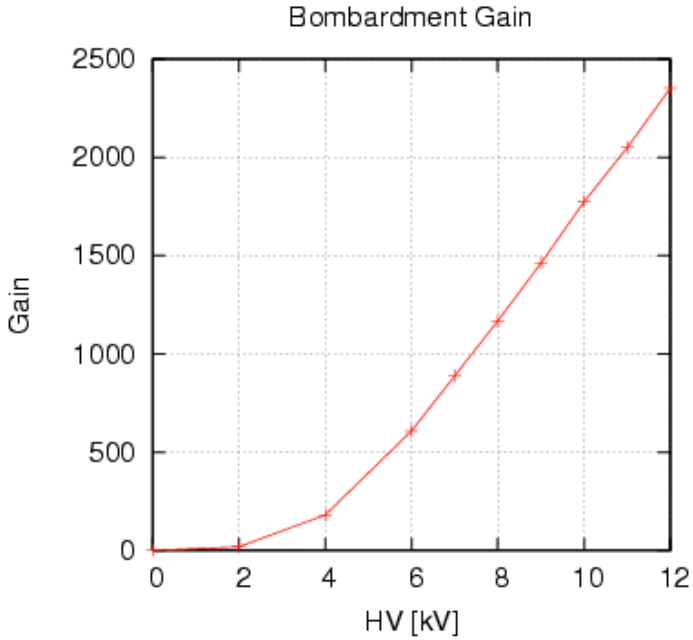
Gain≡1@Bias=40V

(no avalanche effect ≲40V)

Gain ~20 @368V

- Bombardment Gain

Bias=50V(fixed), HV=sweep



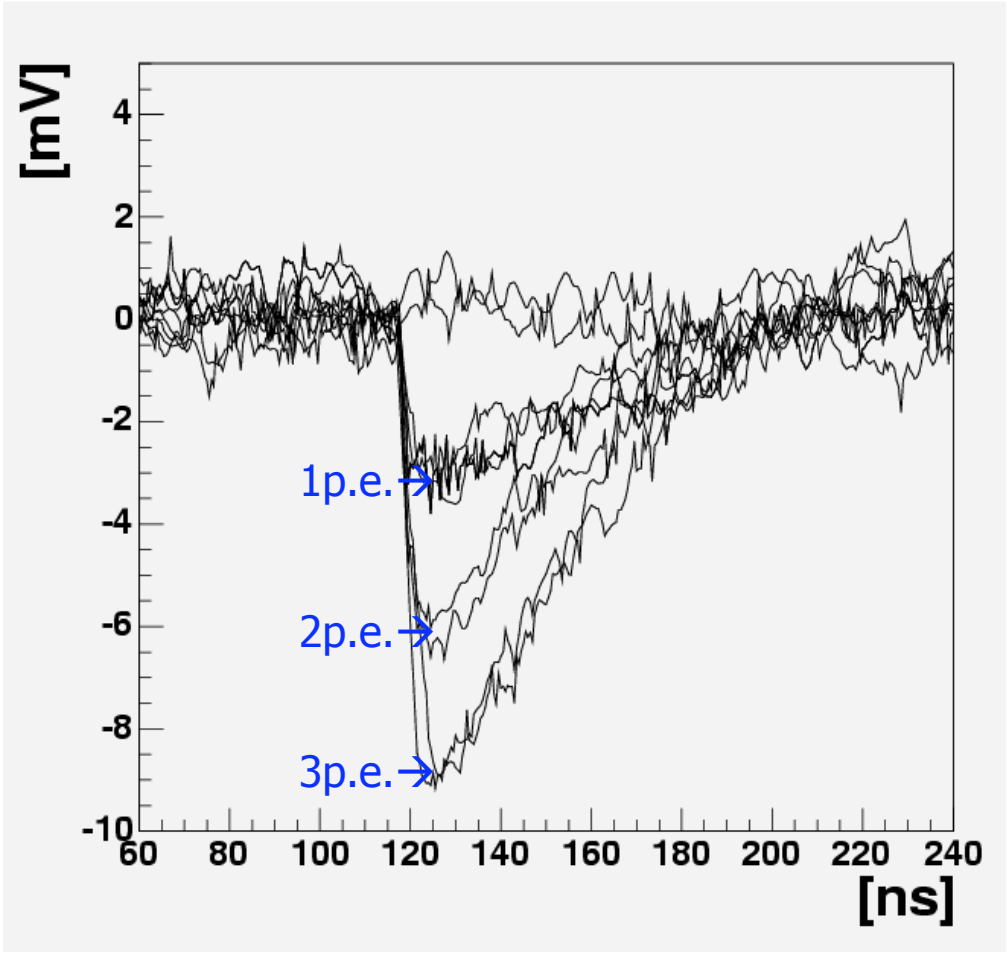
Gain ~2400 @12kV

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

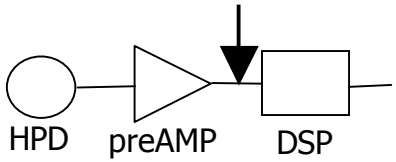
→ Total gain ~50,000

LHP25
current mode

Signals at preamplifier output



LHP25



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

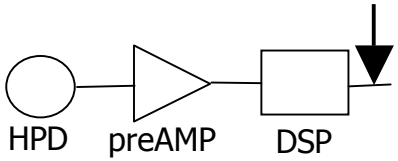
Light input: ~2p.e.(average)

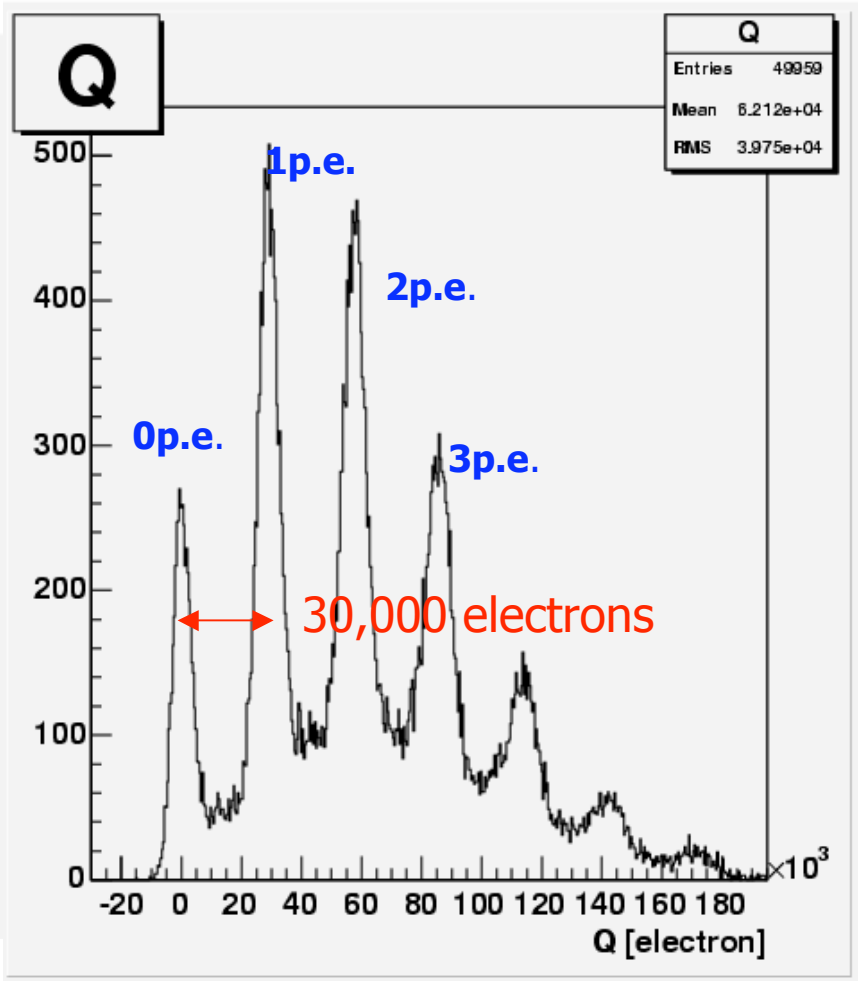
Pulse height

1p.e. ~3.2mV

Noise RMS~0.5mV

Single Photon Sensitivity





Pulse height distribution after DSP

→ very clear 1, 2, .. p.e. peaks

Gain ~30,000

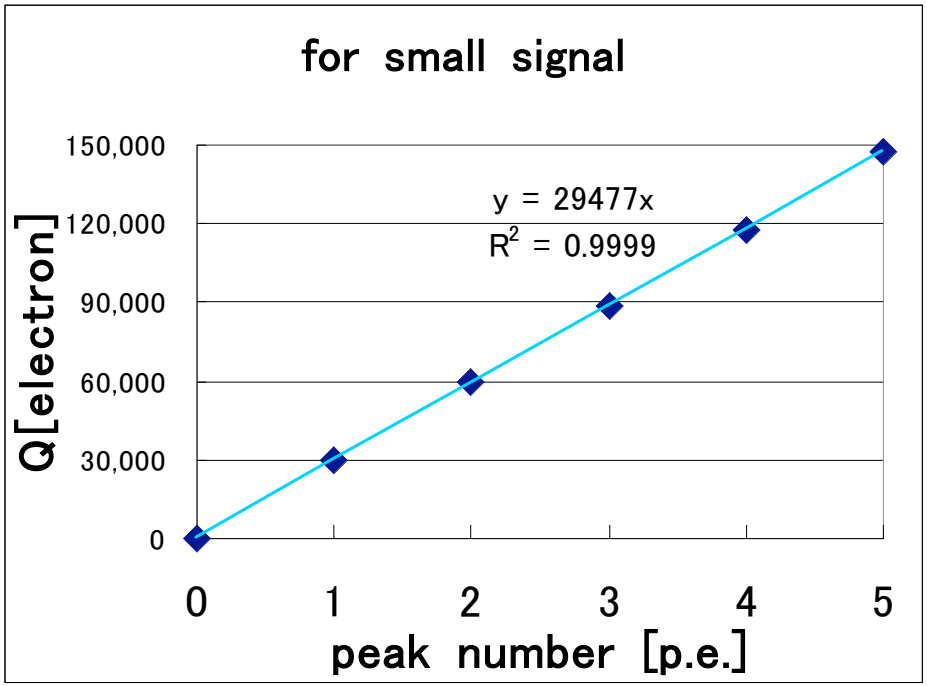
ENC~3,000

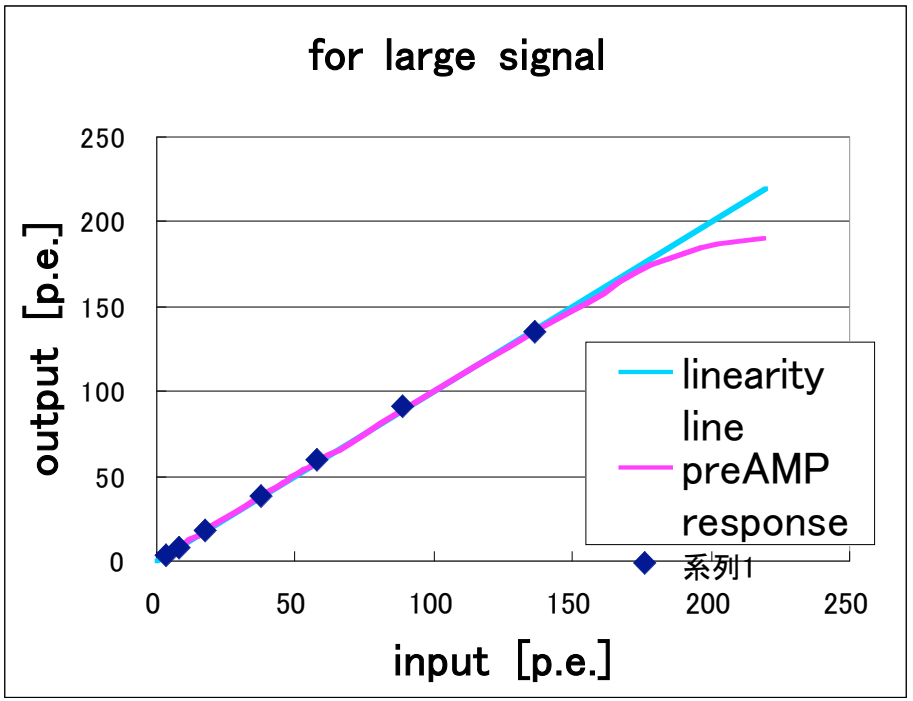
→ S/N = 10 @1p.e.

Single Photon Sensitivity!

Gain Linearity

Peak positions in the Q-histogram





Linearity is quite good

~5p.e.

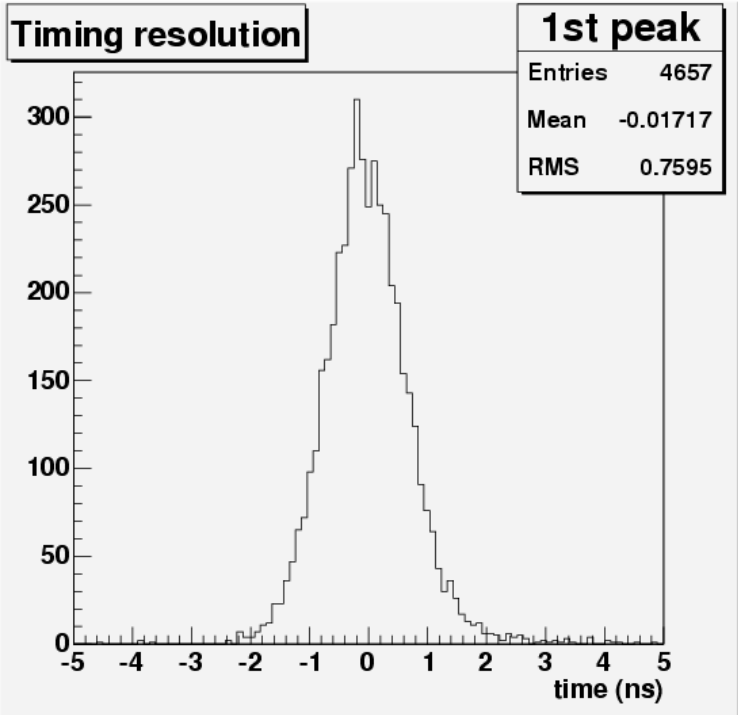
Good linearity up to

~150p.e.(preAMP limit)

Timing Resolution for 1p.e.

Timing resolution directly affects to

the neutrino vertex reconstruction performance. ($\Delta x \sim c\Delta t$)



timing (ns)

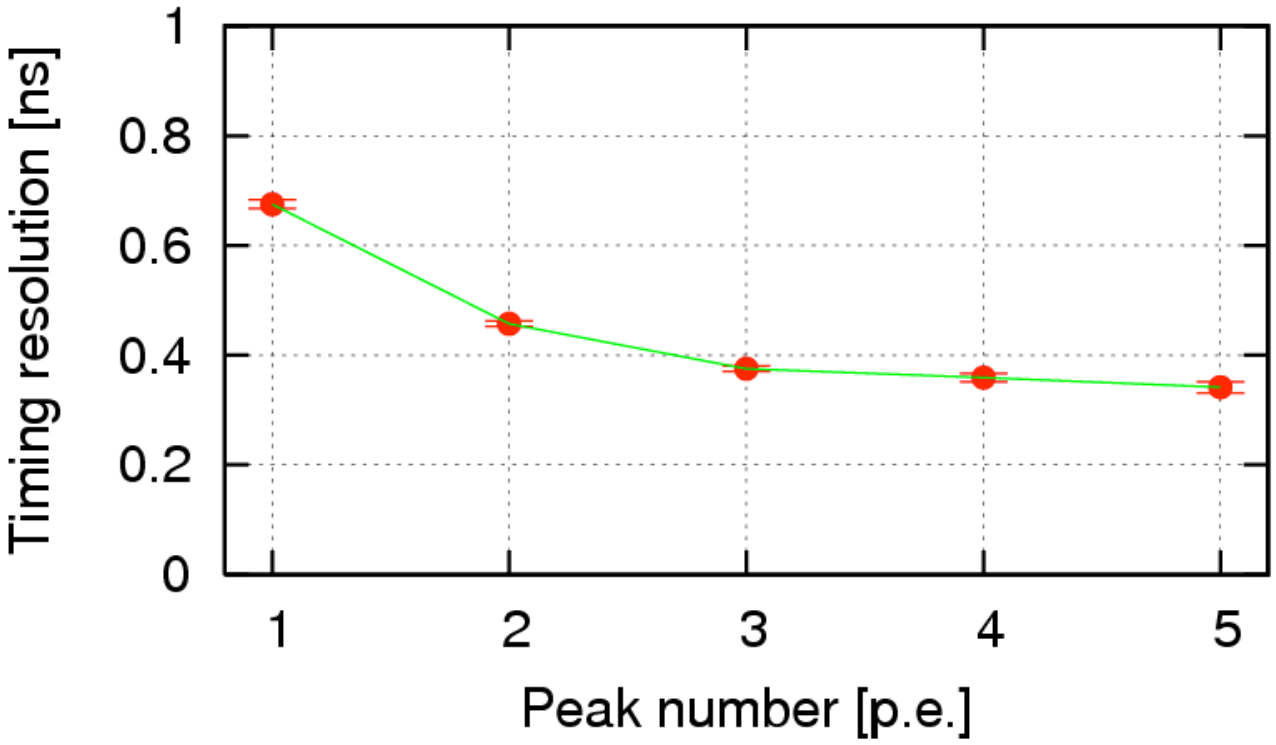
Timing resolution

~0.7ns@1p.e.

cf. PMT-SK

~2.3ns@1.p.e.

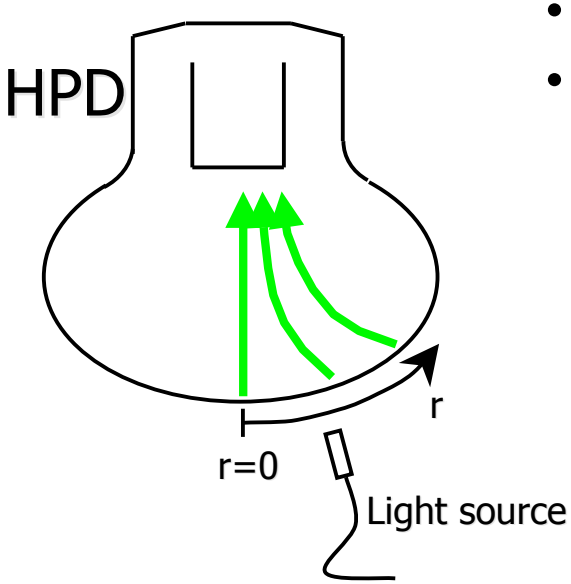
Timing Resolution for multi photoelectrons



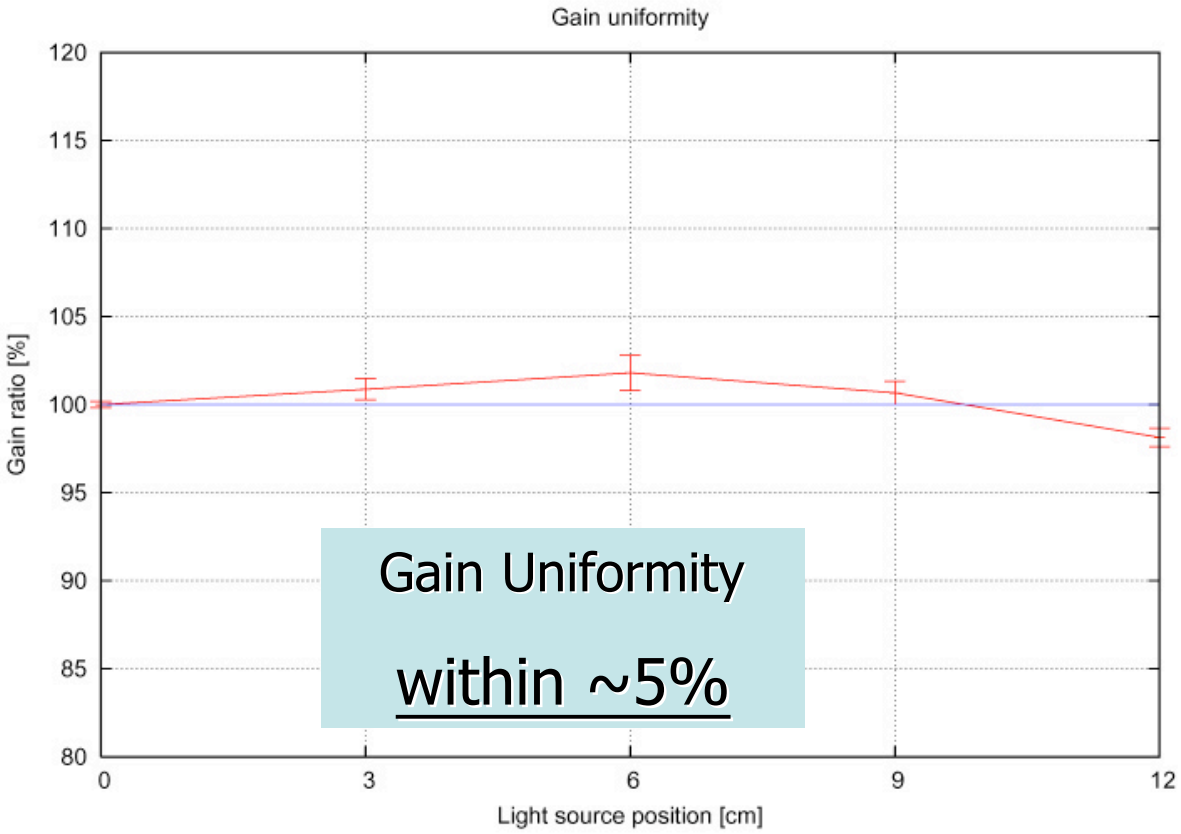
Timing resolution $\lesssim$0.5ns for $\geq$2p.e.

Meet the requirement (~1ns)

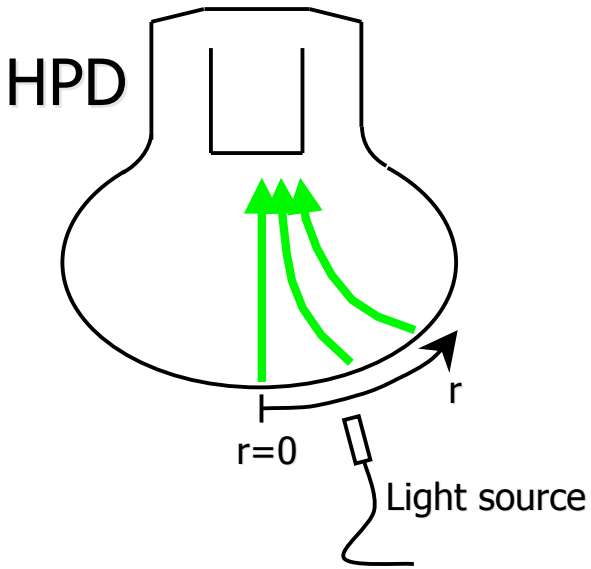
Gain Uniformity



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

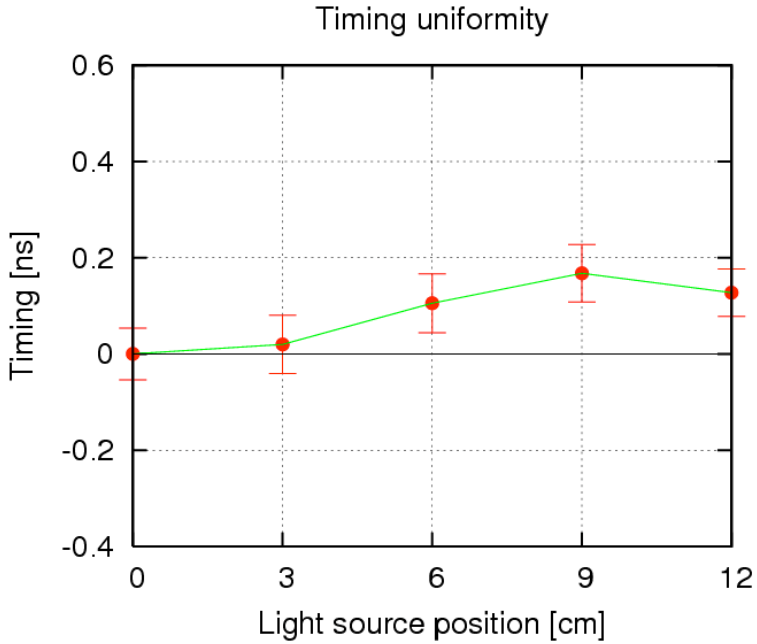


Timing Uniformity



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

  (timing resolution: 0.06ns@30p.e.)

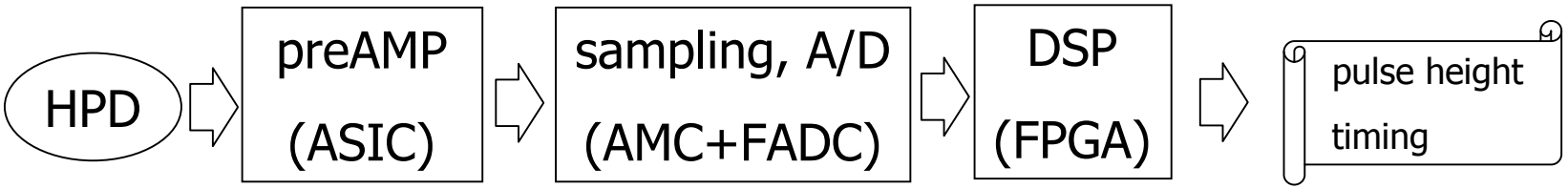


Timing uniformity

~0.1ns

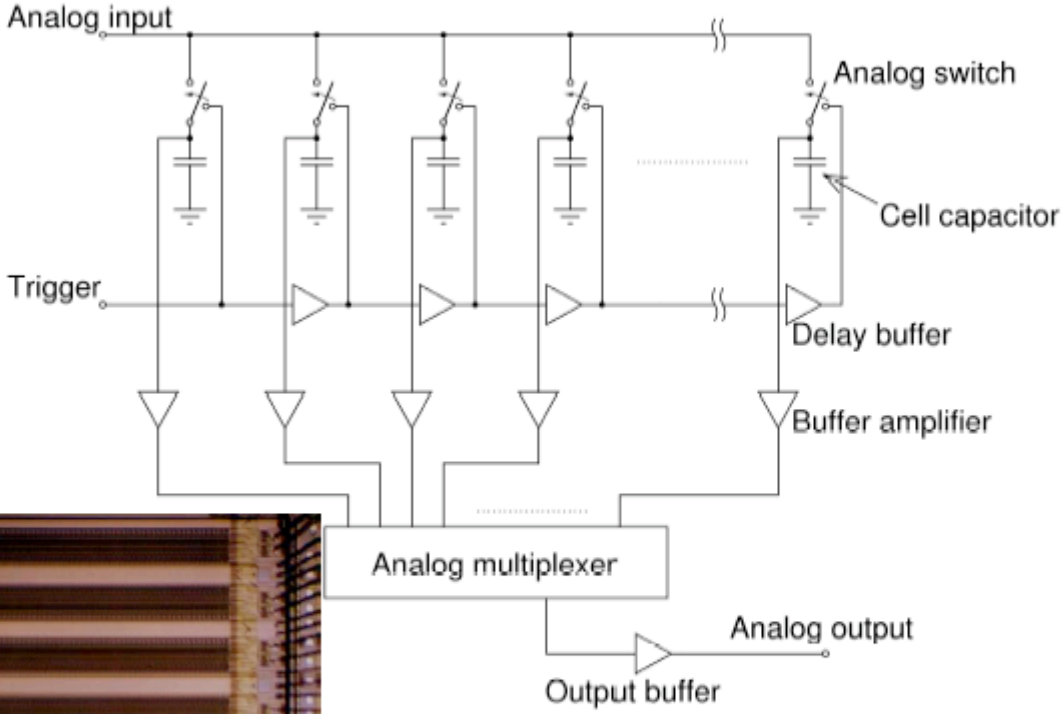
Immediate plans

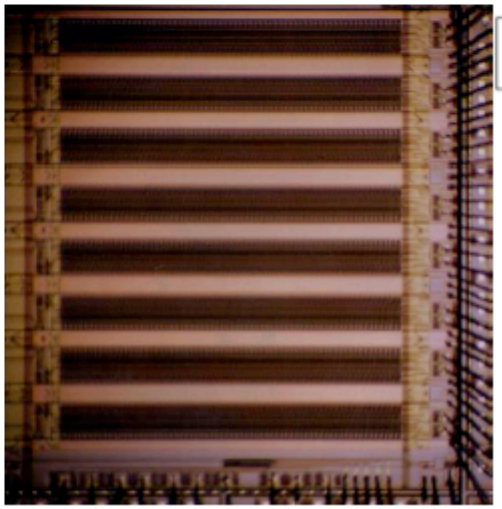
- New type AD (back illuminating)
  → smaller detector capacitance
- New Bulb (Max HV: 12kV → 20kV)
  → wide effective area & gain increase
- Readout (mass production, low-noise preAMP)
  → ASIC/FPGA implementation



Analog Memory Cell (AMC)

Wave form
sampling
without a fast clock
inexpensive
low power
consumption





512 cell prototype
(size : 7mm X 7mm)

Work with KEK

Summary

- R&D for a large format hybrid photo detector has started.
- Initial study shows excellent performance:
  - ✓ Single photon sensitivity
  - ✓ Wide dynamic range (up to the readout limit)
  - ✓ Good time resolution (better than 1ns)
  - ✓ Good uniformity (over a large photocathode)
- Promising