T. Abe
2008/03/06
NP08

CHALLENGE TO REALIZE HUGE UNDERGROUND DETECTOR - WATER CHERENKOV DETECTOR CASE-

Introduction

- There are various difficulties to realize next generation huge underground detector.
- High cost is obvious one in the difficulties.
- Photo sensor gives a sizable portion in the cost.
- We will report current R&D status of photo sensors to reduce the cost.

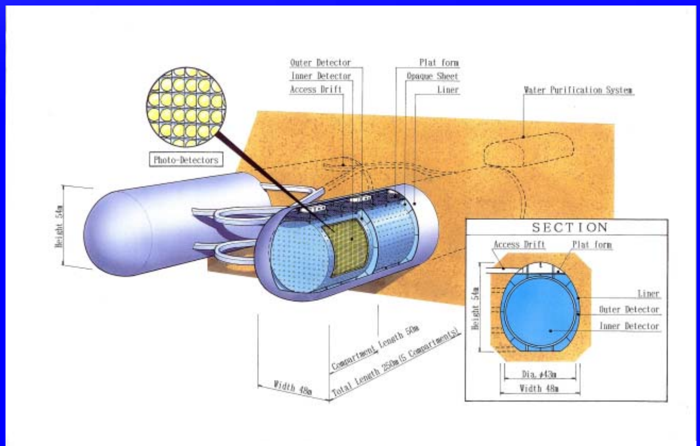
Theme

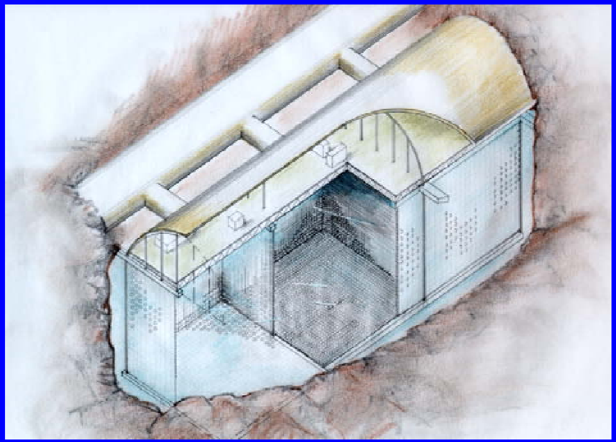
- Huge underground water Cherenkov detectors and their difficulties. – talk given by M Shiozawa
- Two photo sensor developments
  1. PMm^2 – talk given by JE Campagne at NNN07
  2. HAPD
- Summary

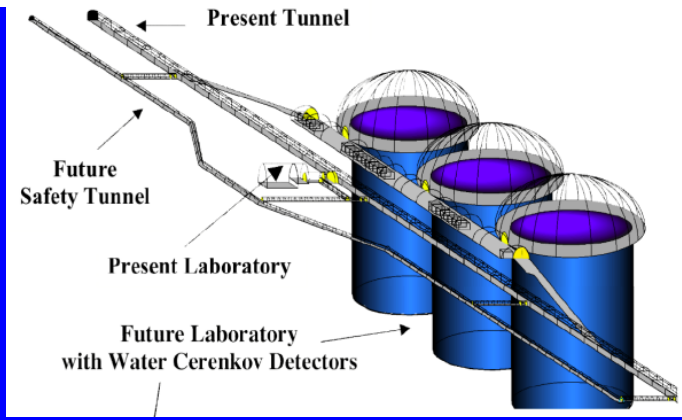
Thanks to M Shiozawa(ICRR) and JE Campagne (LAL)

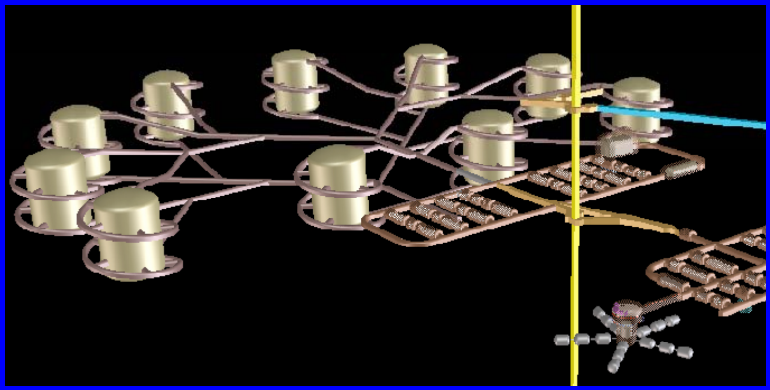
Next-generation water Cherenkov neutrino detectors

- Water Cherenkov: Hyper-Kamiokande, UNO, MEMPHYS, 3M(～0.5Mton)

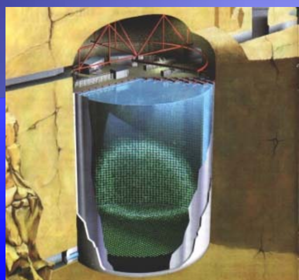




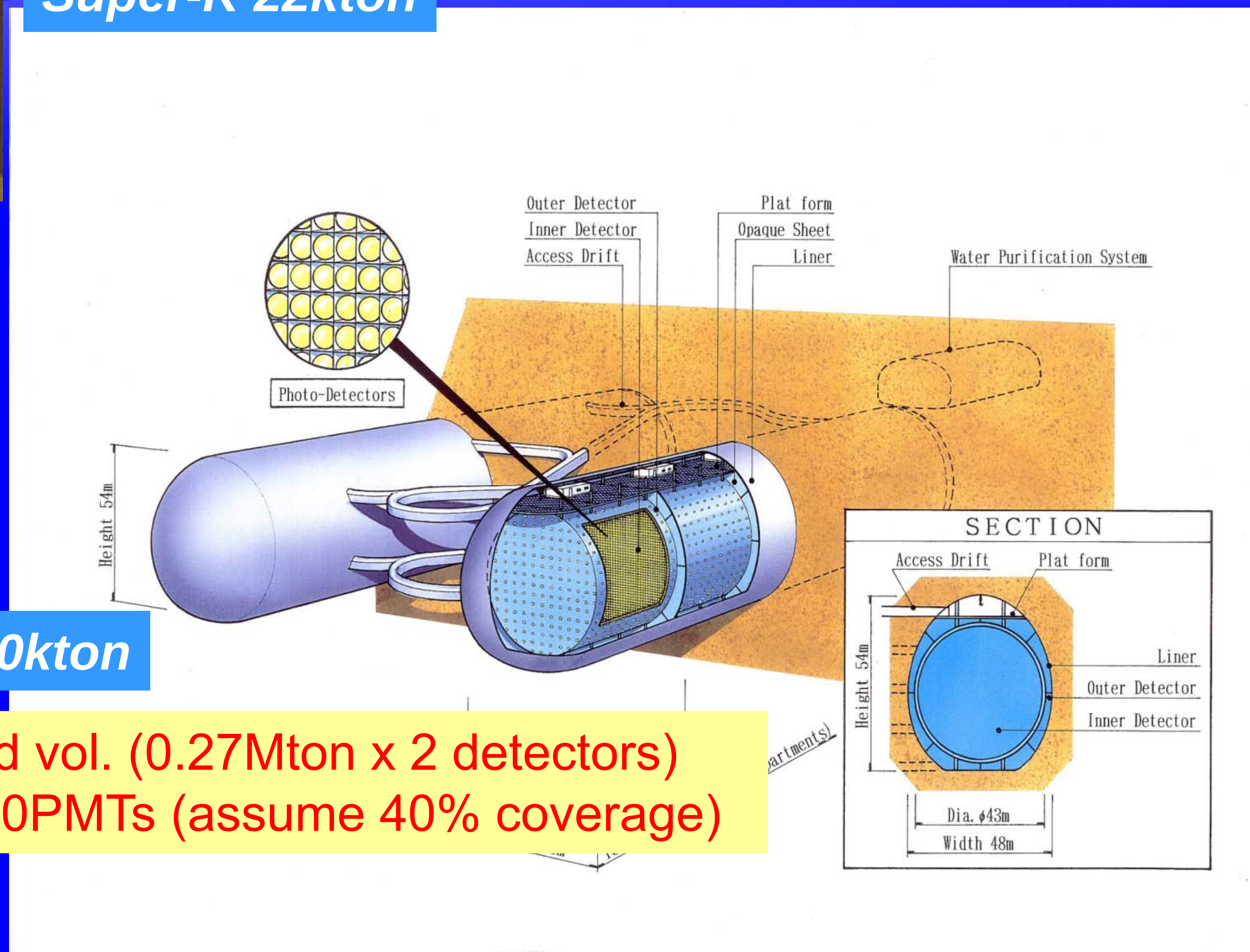




Baseline design of Hyper-K



Super-K 22kton



Hyper-K 540kton

~0.5Megaton fid vol. (0.27Mton x 2 detectors)
Needs ~200,000PMTs (assume 40% coverage)

Key issues for realizing the next generation detector (Shiozawa's opinion)

- Maximize physics motivations
  - Optimize design and maximize physics sensitivities
  - Discovery of nonzero large θ_{13}
  - Discovery of SUSY at LHC or DM search, fine prediction of (hopefully short) proton lifetime…
- Detector technology
  - Large cavity, excavation cost and speed
- Photo sensor
  - Reduce cost (<50%), high production speed, case…

Key issues for realizing the next generation detector (Shiozawa's opinion)

- Maximize physics motivations
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→Well covered by other talks

- Detector technology
  - Large cavity, excavation cost and speed

→Well discussed so far

- Photo sensor
  - Reduce cost (<50%), high production speed, case…

→Main topic of this talk

Photo sensor solution

- Photo sensor gives a sizable portion in the total cost of the experiments.
- There are two propositions to give the solution

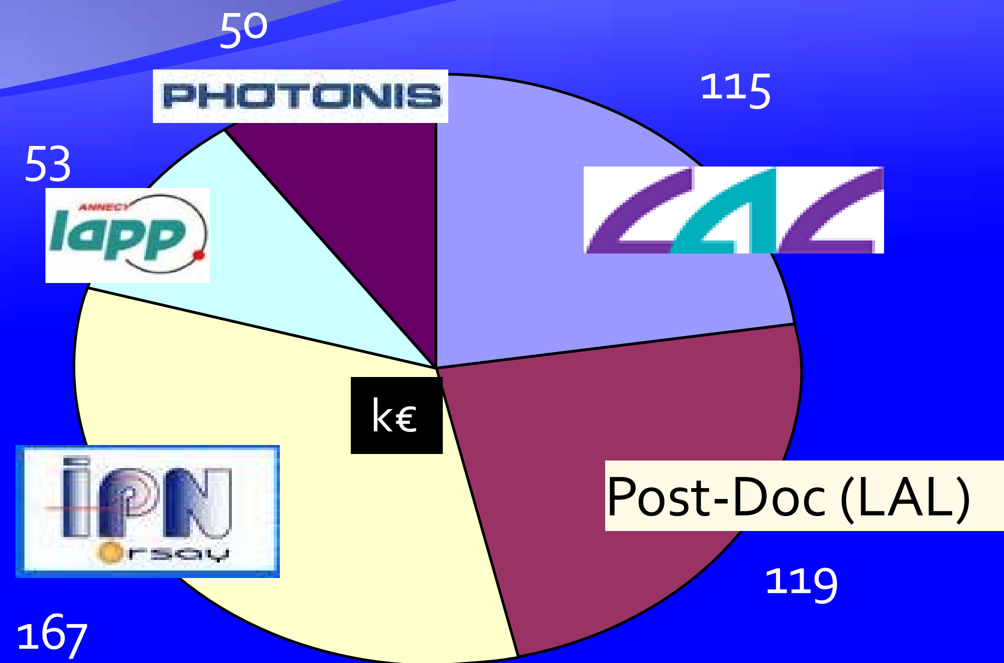
1. PMT with small size (conservative approach)

   by French team (PMm²) with PHOTONIS

2. New photo sensor (aggressive approach)

   by Japanese team with Hamamatsu

PMm^2



500k€/3yrs

funded by new French Agency (ANR)

Starts officially 25 Jan. 07

The team: 5 FTE (Ing.), 1 post-doc

- LAL
  - P. Barillion, S. Blin, Th. Cacérès, J.E Campagne*, Ch. de La Taille, G. Martin-Chassard, N. Seguin-Moreau
  - Wei-Wei (Chinese post-doc since Sept. 07 for 6 months)
- IPN Orsay
  - B. Genolini, Th. Nguyen Trung, J. Peyré, J. Pouthas,E. Rindel, Ph. Rosier
- LAPP
  - N. Dumont-Dayot, D. Duchesneau, J. Favier, R. Hermel, J. Tassan-Viol
- Photonis

PHOTONIS oussan

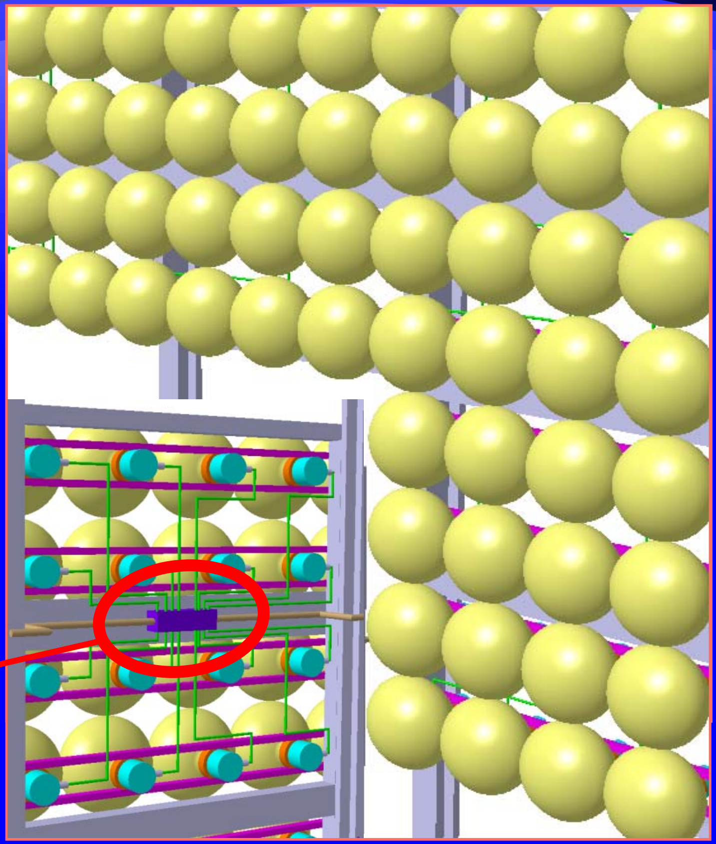
*: coordinator

http://pmm2.in2p3.fr

Large optical surface detector

Huge amount of
very large photodetectors

(PMTs of 20" size)



Proposition : PMm^2

Replace large PMTs (20")
by groups of smaller
ones (12")

Integrated electronics (Multichannel, close to the PMTs)

Cost approach

Photonis at NNN05

C. Marmonier, NNN05, France, April 2005
LIGHT06, Israel, January 2006

Size (Diameter)	20	20(17)	12	Inch
Photocathode area	1660	1450	615	cm^2
Quantum efficiency	20	20	24	%
Collection efficiency	60	60	70	%
Cost	2500	2500	800	€
	12.6	14.4	7.7	€ $/PE_U/cm^2$

Cost/cm^2 per useful photoelectron

Cost / (cm^2 x QE x CE)

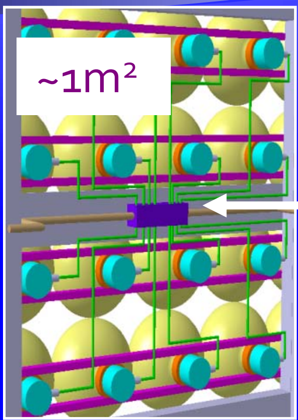
12" is better in SER and timing

12" provides a higher granularity

But, the number of channels is increased

PMm^2 philosophy for large detectors*:

Replace large PMTs (20") by groups of smaller ones (eg. 12");
originally proposed by Photonis Co. at NNN05



x16

"Local"

FE-ASIC | Monitoring | HV

FPGA + µC

Network Controller

"No possible local coincidence"
(low energy event 10PMs/MeV over 81000 PMs)

⇓

TRIGGER LESS

Twisted pairs
cables for
Clock sync.
- Digitized Data -
Power

"Outside"

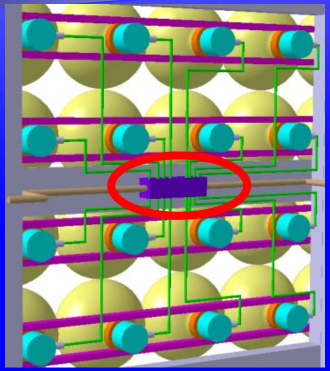
Ethernet switches + server

DAQ

GPS receiver

*: MEMPHYS ~ 3 x 81,000 PMTs; LENA & GLACIER ~ 20,000 ÷ 30,000 PMTs

Front-End Electronics Requirements



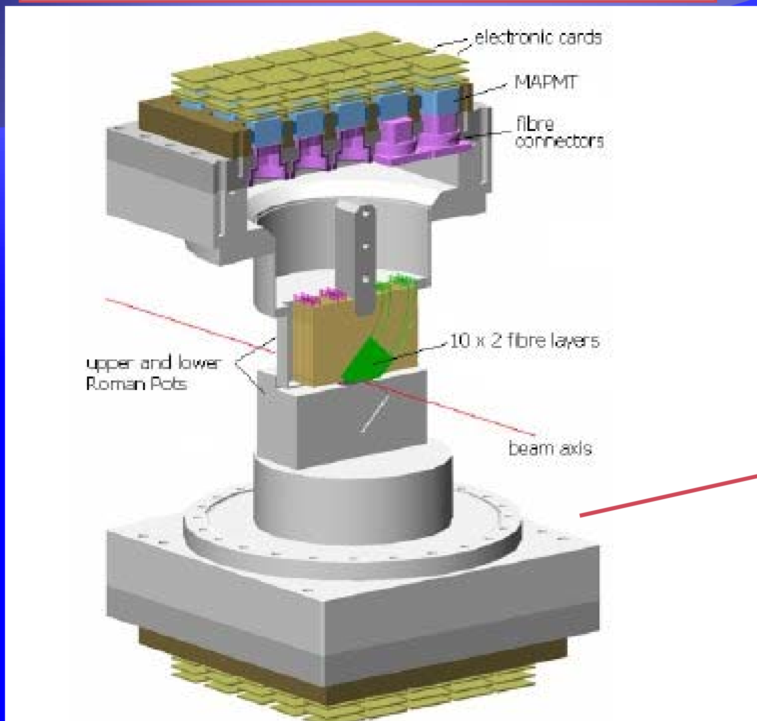
- Auto trigger
- 100% trigger efficiency @ 1/3 p.e (50fC)
- Excellent time resolution < 1ns
- Dynamic range up to 300 p.e
- Provide digitized signals
- Scalability
- Low cost

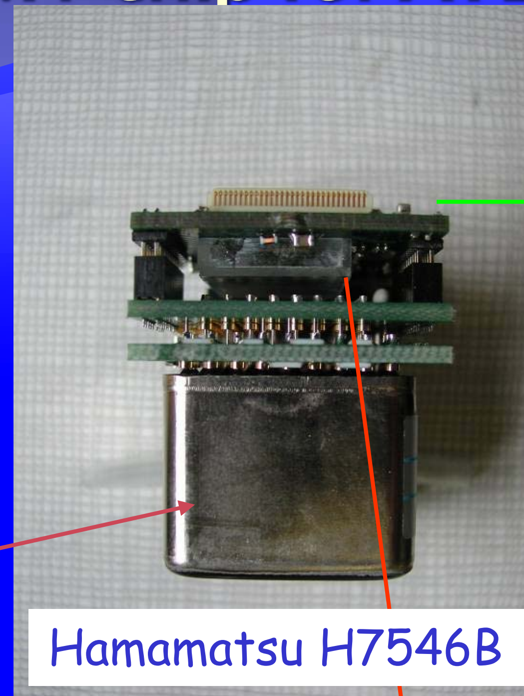
- Profit from progress in micro-electronics and DAQ !

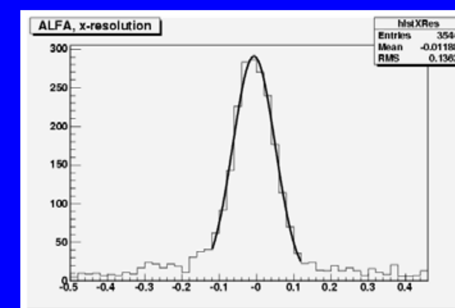
- Many issues in common with HPD or large PMs developments by KEK (see M. Tanaka)

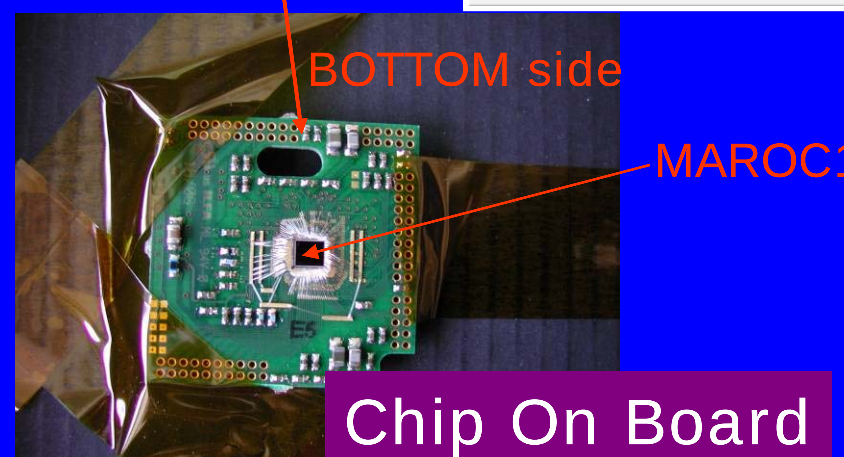
MAROC : 64 ch MaPMT chip for ATLAS lumi

5x5 array of 64 anodes PMT

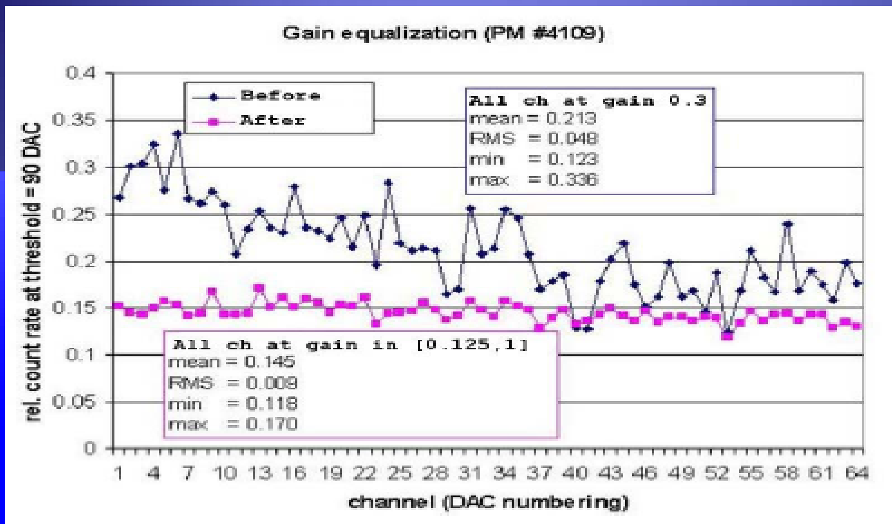


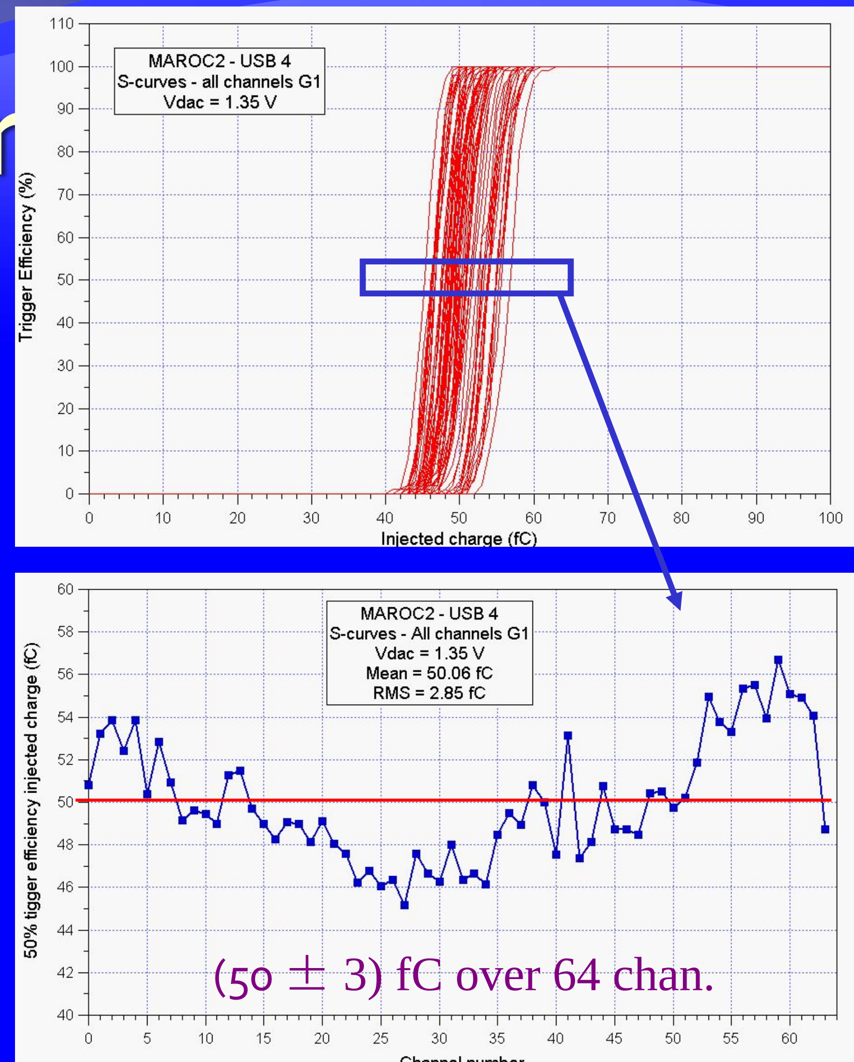






LAL has a solid expertise in micro-electronic developments and we will reuse efficiently the existing and validated blocs.

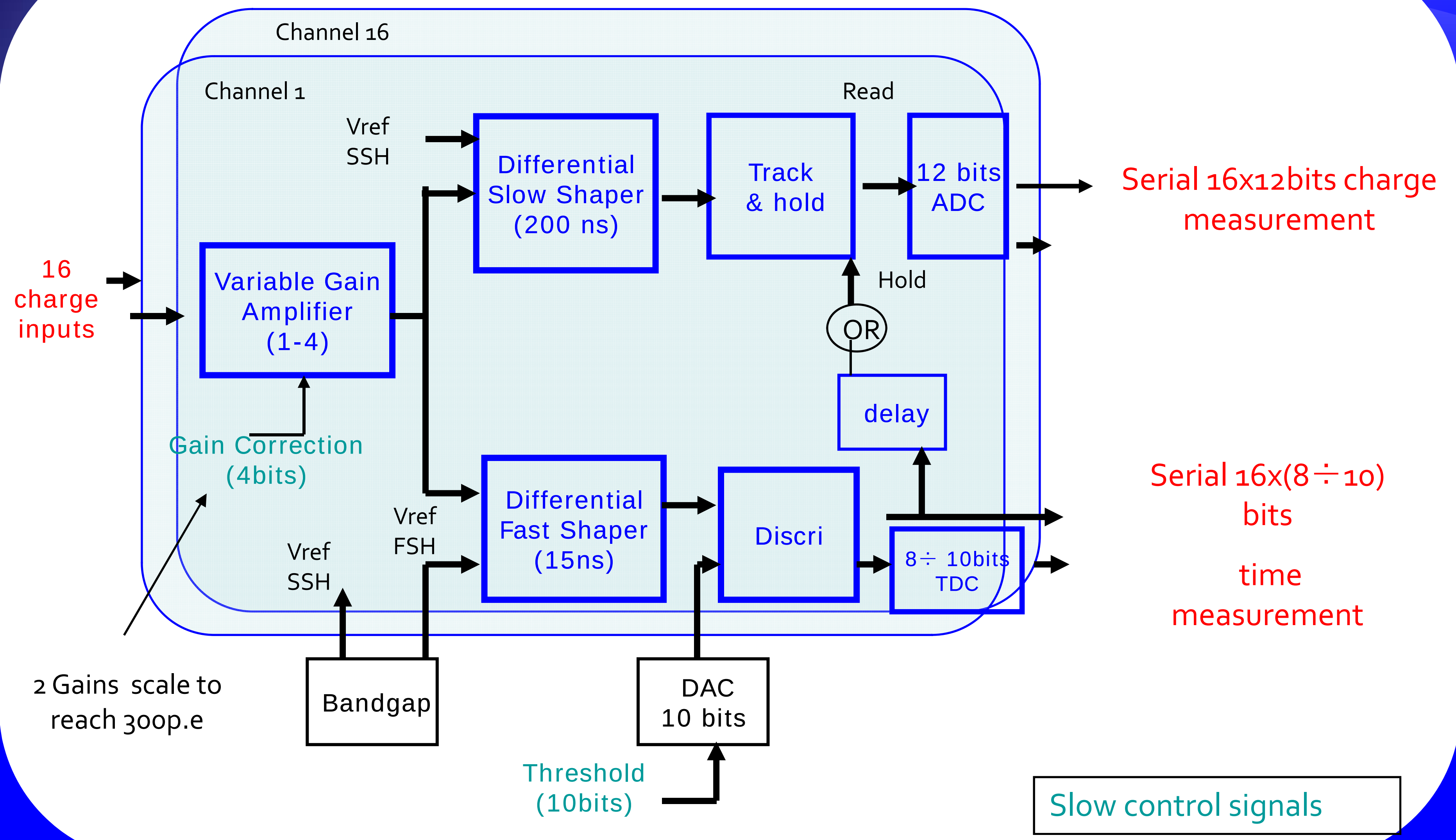




- Gain adjustment
- Trigger efficiency 100% @ 50fC (1/3 p.e @ 10^6)
- Can be lower down to 10fC

P. Barillon et al., « MAROC: *Multi-Anode ReadOut Chip for MaPMTs* », IEEE 2006, October 29 – Nov. 4, 2006 · San Diego, California
P. Barrillon's talk at TWEPP07

New ASIC Architecture



PMm² summary

- PMm² takes small PMT with their intelligent ASIC technology to save cost.
- There is a cost estimation (not finalized) showing cheaper than 20 inch PMT solution.
- Readout system is a key and they have a solid expertise in ASIC development.

→probably a guaranteed realization for next WC.

13inch HAPD

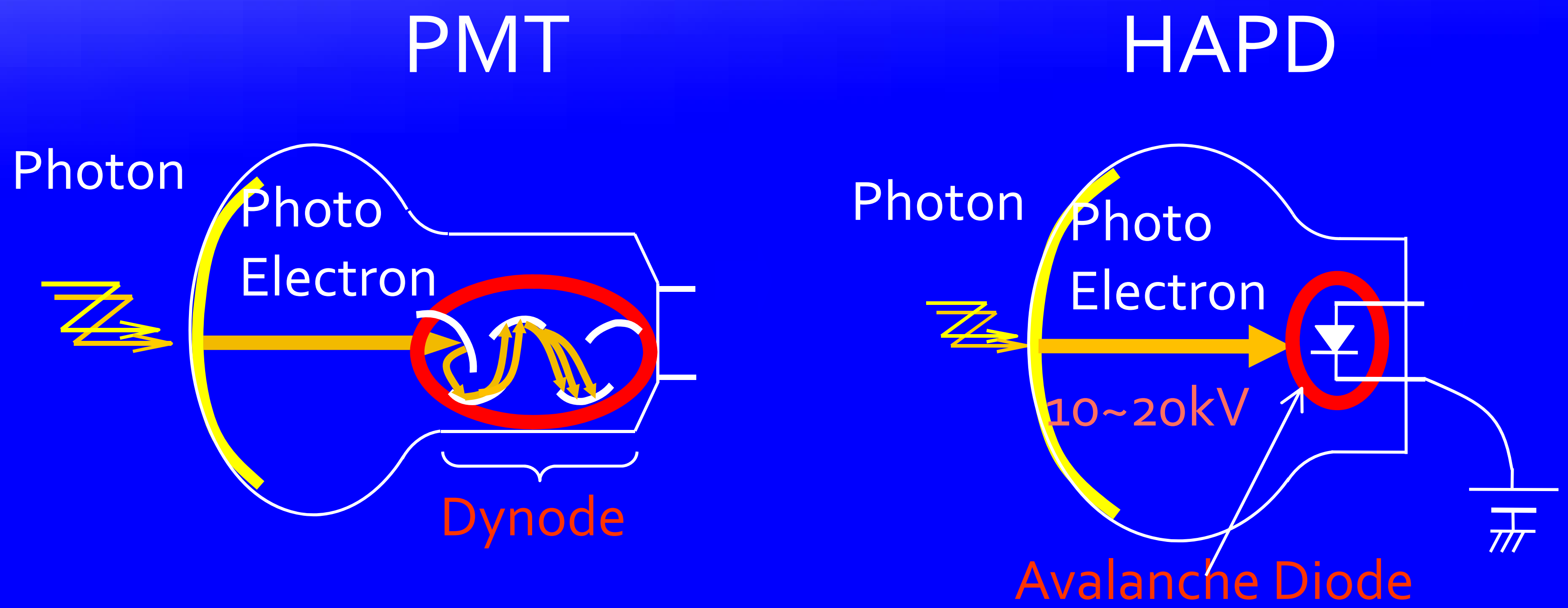
HAPD team

T. Abe, H. Aihara, M. Iwasaki, H. Miyatake, T. Uchida
(University of Tokyo)
M. Tanaka
(KEK)
Y. Kawai, H. Kyushima, M. Suyama
(Hamamatsu Photonics)
M. Shiozawa
(ICRR)

HAPD's theme

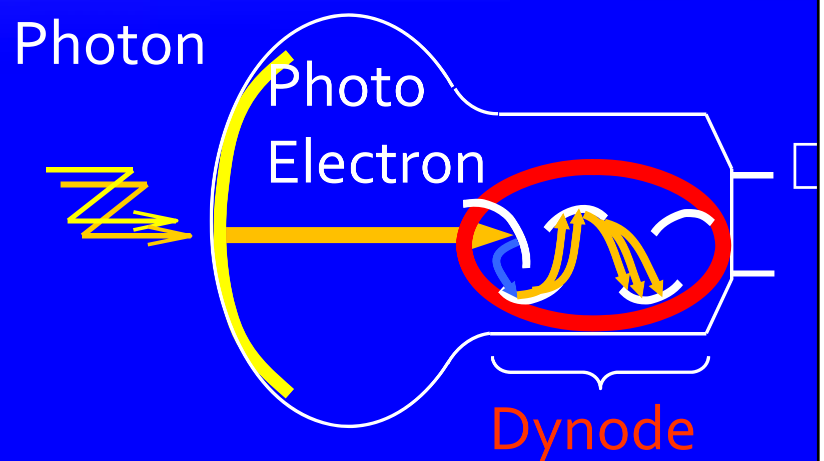
- PMT vs. HAPD
- Excellent HAPD performances
  - Energy resolution
  - Timing resolution
- Status of readout system
  - AMC, FINENET
  - System test
- Summary

Operation Principle



Operation Principle

PMT

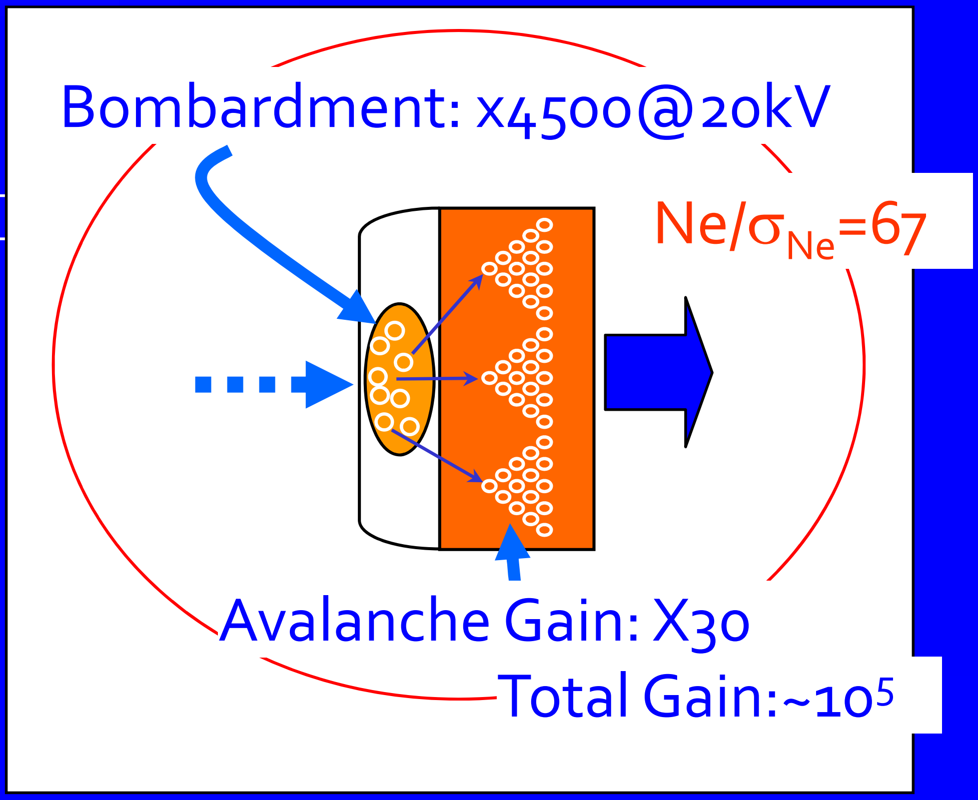


1^{st} Dynode Gain: x5

$Ne/\sigma_{Ne}=2.2$

Total Gain: $\sim 10^7$

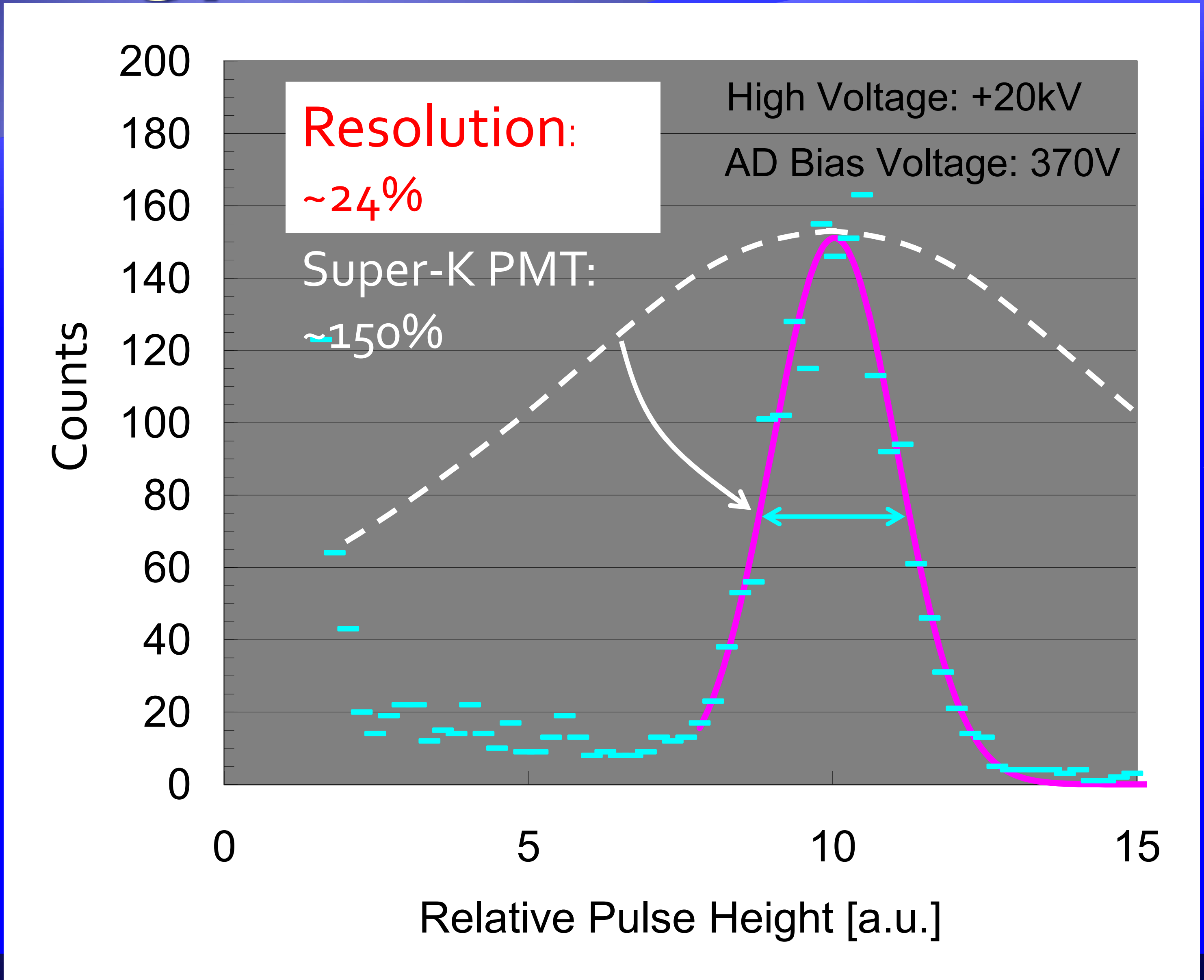
HAPD



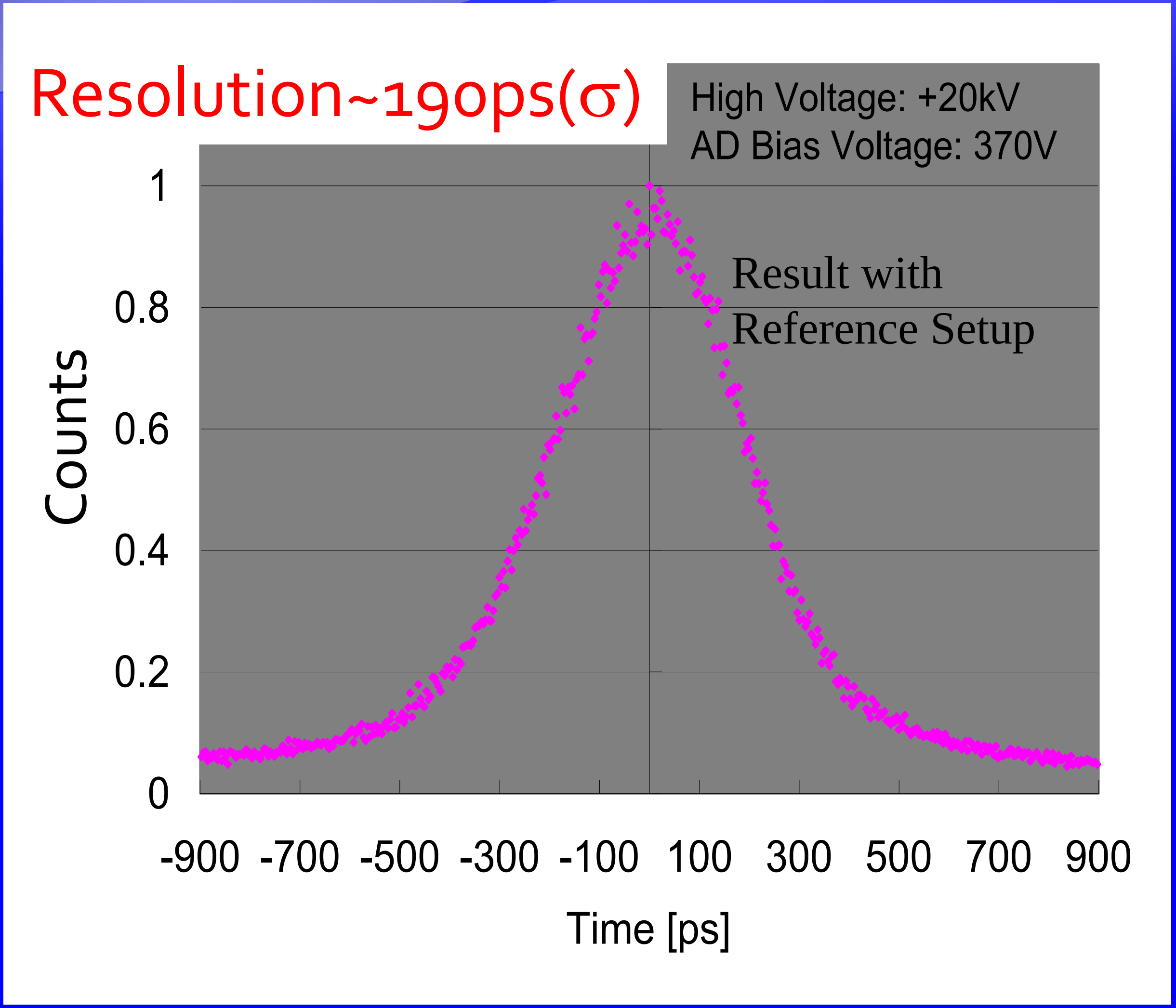
HAPD features

- Large gain at the first electron multiplication
  → Good single photon energy resolution and detection efficiency
- No dynode
  → Good time resolution
  → Cost reduction and easy quality control
- Low gain
  → Need dedicated readout system
- High voltage (10kV~20kV)

Energy resolution at 1P.E.

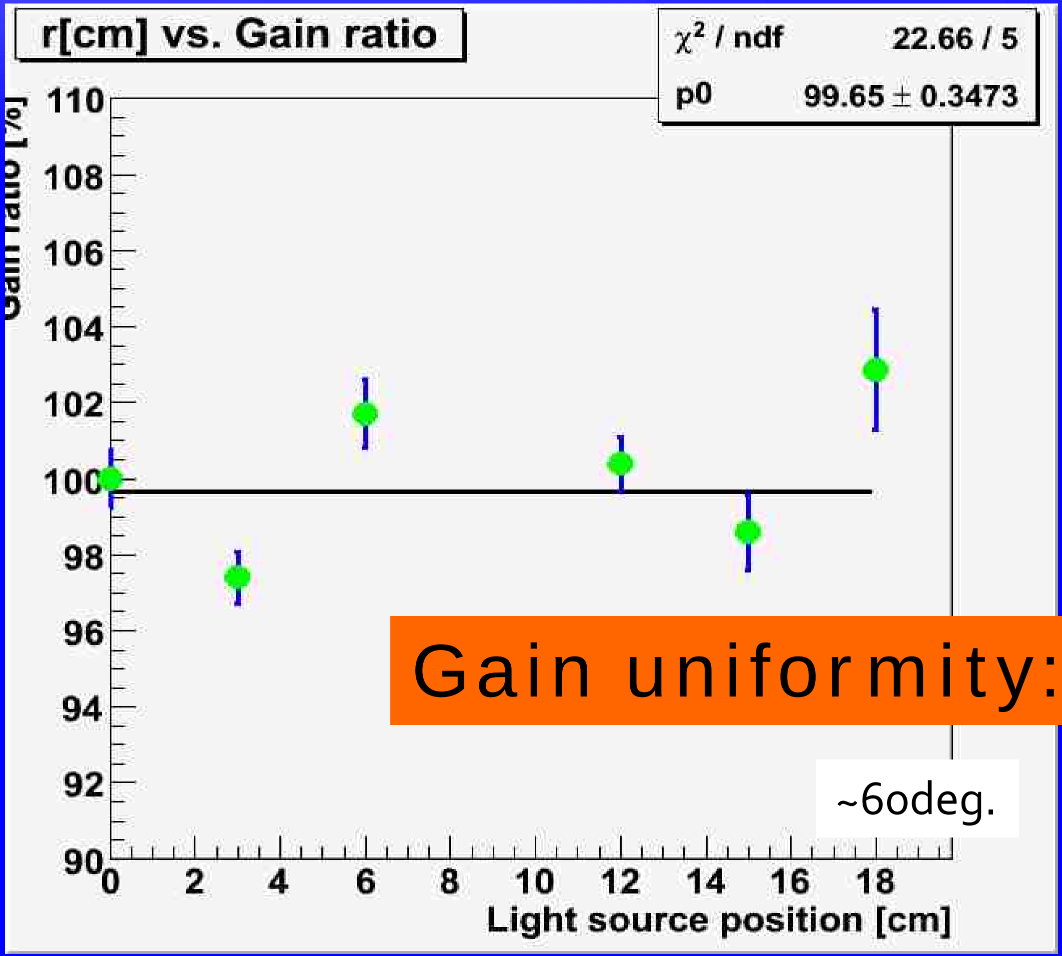


Time resolution at 1P.E.



Gain uniformity

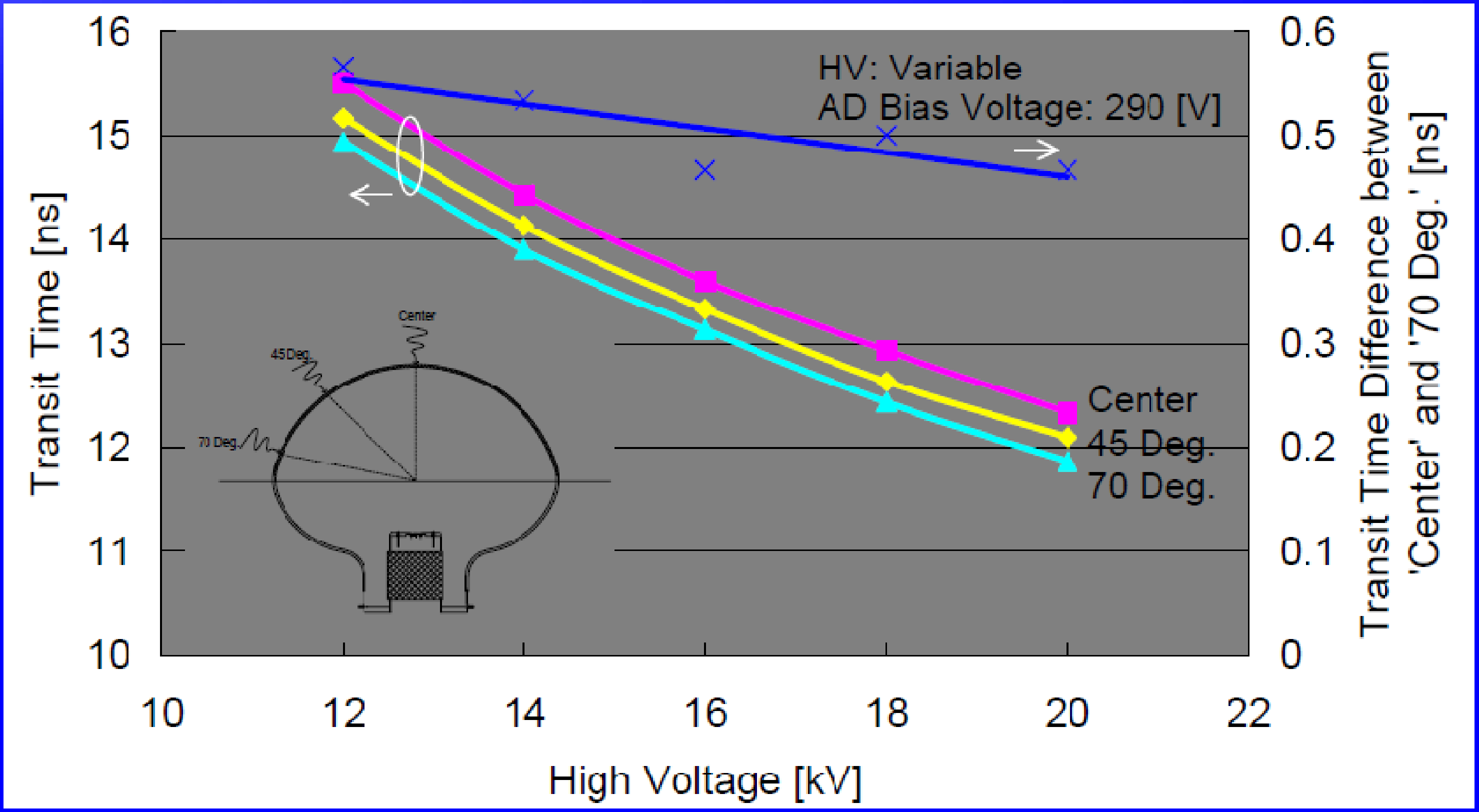
for photons<5



Gain uniformity:σ~2%

~60deg.

Photoelectron transit time



Dark count rate

- We find weakness of dielectric strength in HAPD (16kV<).
- Dark count rate at 16kV = ~25kHz
  →same order as the dark rate of SK PMT
  →factor 2 larger than that of 13inch PMT
- The problem might be fixed in the next production.

HAPD vs. PMT

Parameters*		13inch HAPD	13inch PMT (R8055)	20inch PMT (for SK)
Single Photon Time Resolution (s)		190ps	1400ps	2300ps
Single Photon Energy Resolution		24%	70%	150%
Pulse Respon se	Rise Time	1ns	6ns	10ns
	Pulse Width	2.2ns	10ns	20ns
Transient Time		12ns	100ns	95ns
Dynamic Range (Signal Intensity in p.e.)		3000 p.e.	2000 p.e.	1000 p.e.
Order of Gain		10^5	10^7	10^7

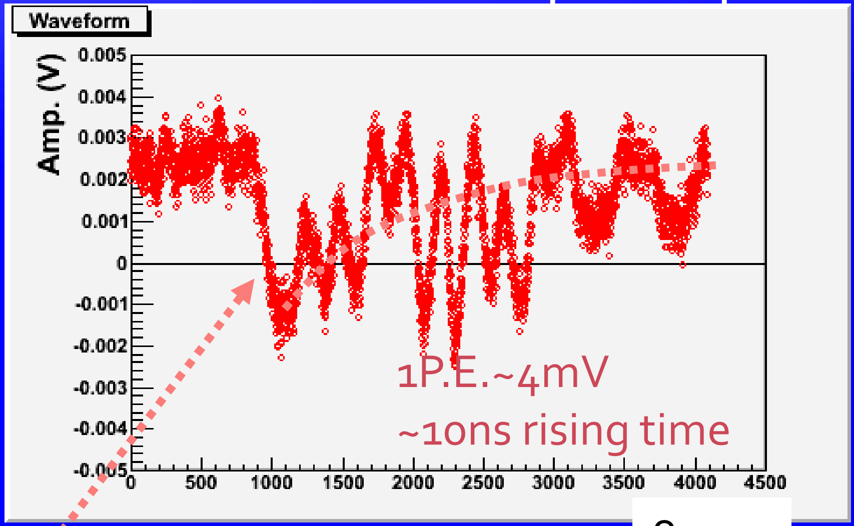
Readout system requirements

- HAPD has 100 times lower gain than that of PMT
- Low noise
- Excellent signal to noise ratio under various environment

→Digital signal processing

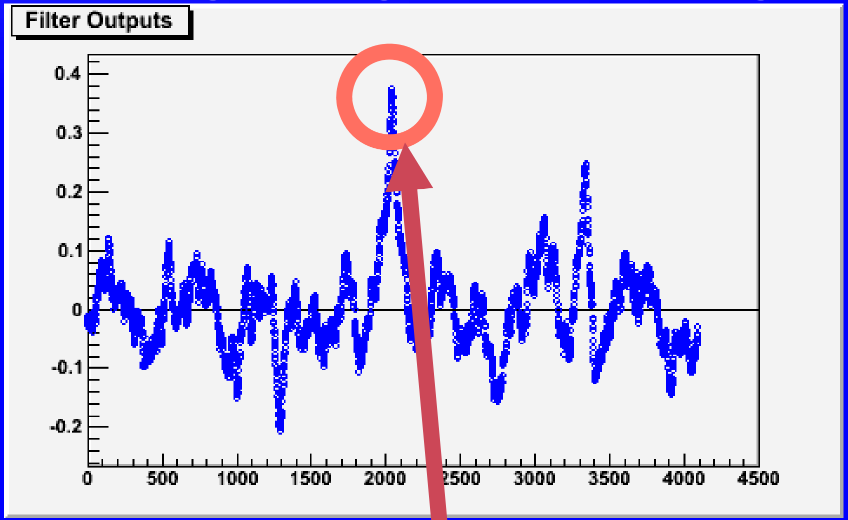
Digital signal processing

Waveform after preamp.



800ns

After digital signal processing



Signal

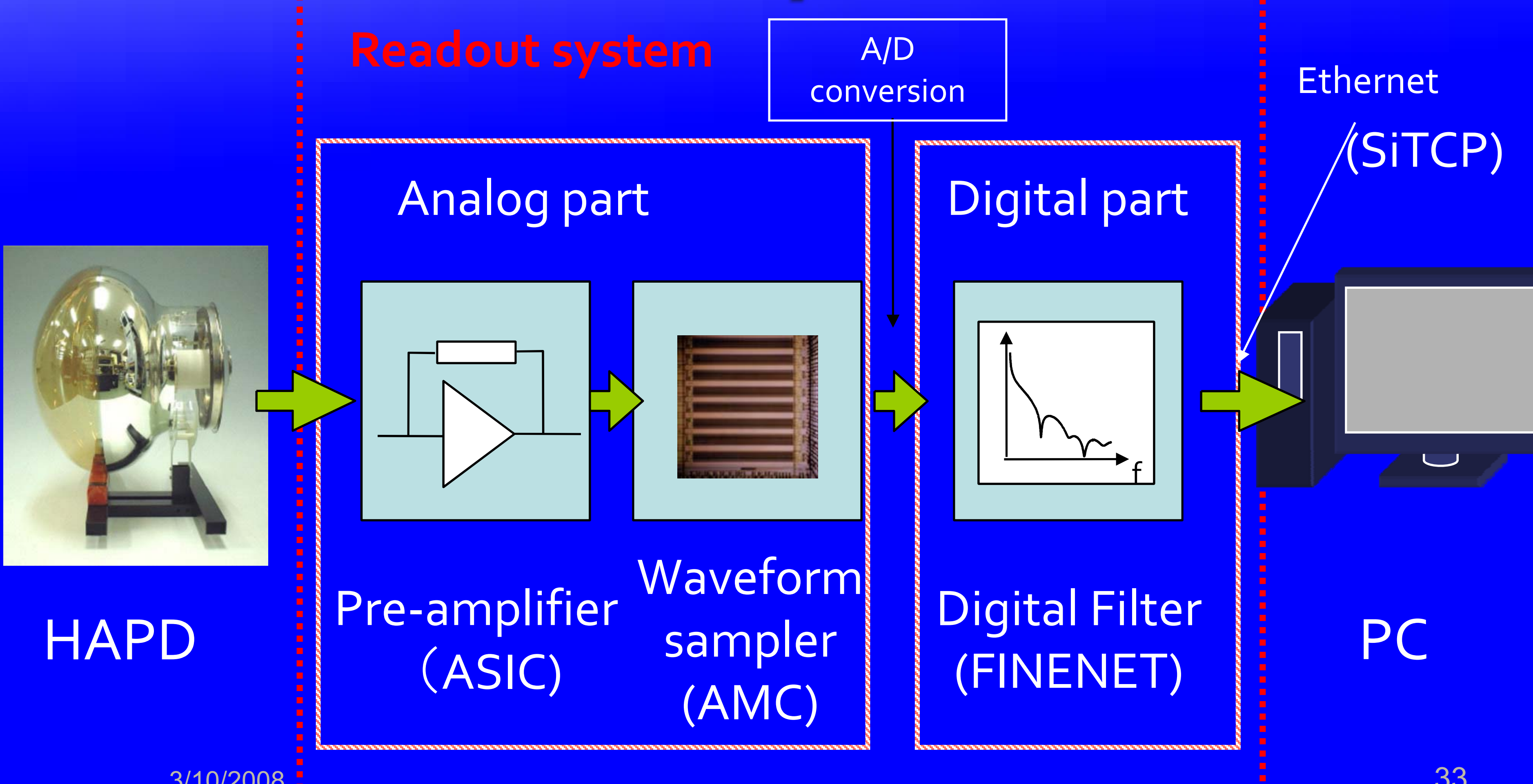
5GS/s 4096pts

Signal separation

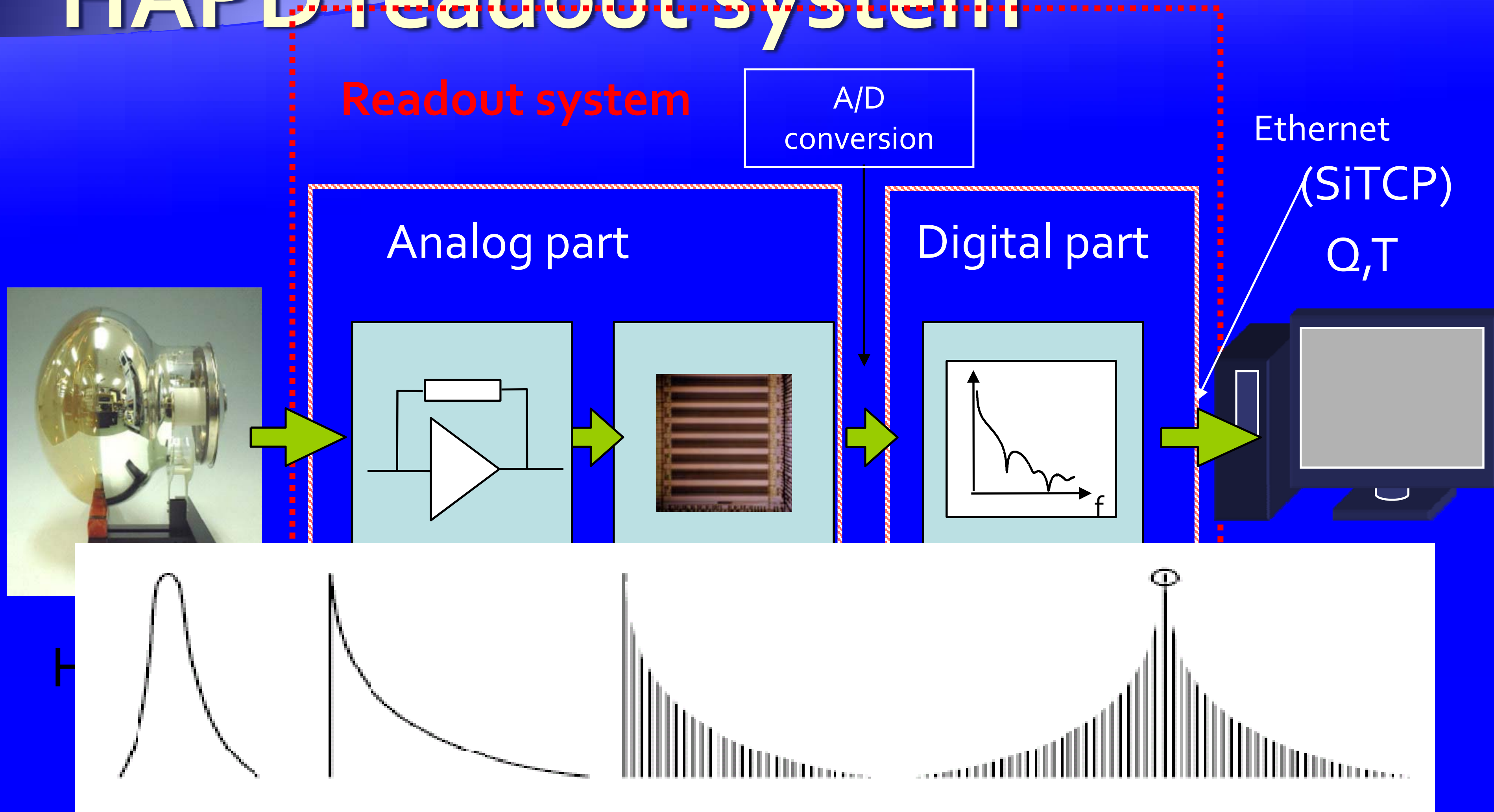
- Robust again noise

→meet HAPD usage

HAPD readout system



HAPD readout system



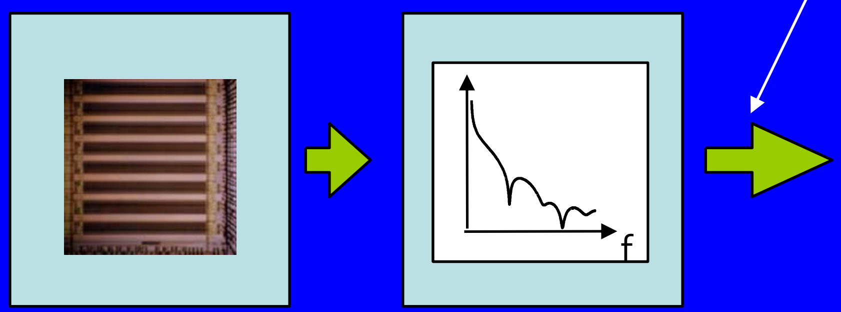
HAPD readout system

Ethernet

(SiTCP)

AMC

FINENET



1GS/s Low power

Digital Filter
Controller
Ethernet I/F

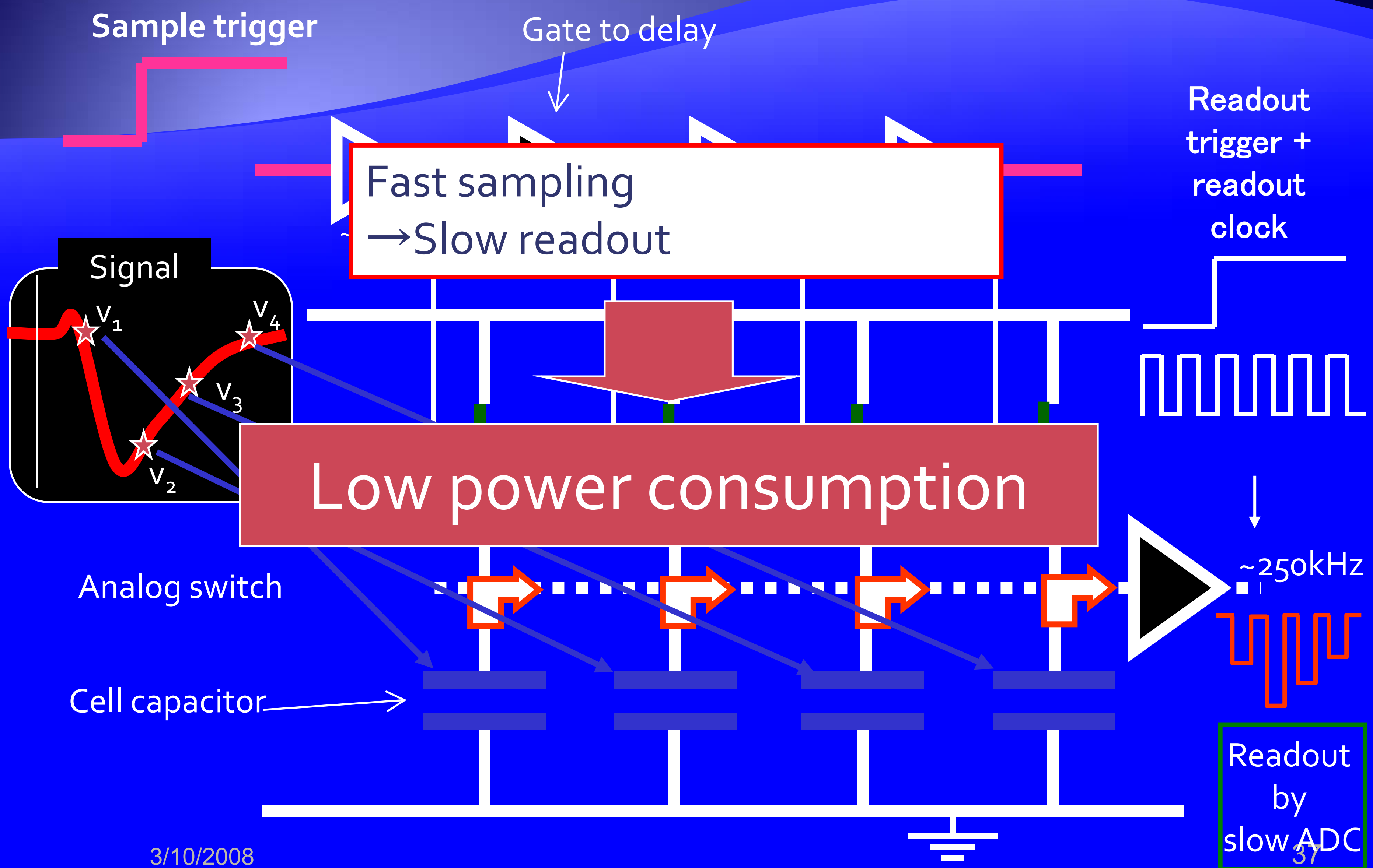
AMC

- Requirements
1. Low power consumption
2. Fast sampling of 1GHz
- Analog memory cell

→Sampling time by delay buffer

→No fast clock

AMC operation and readout system



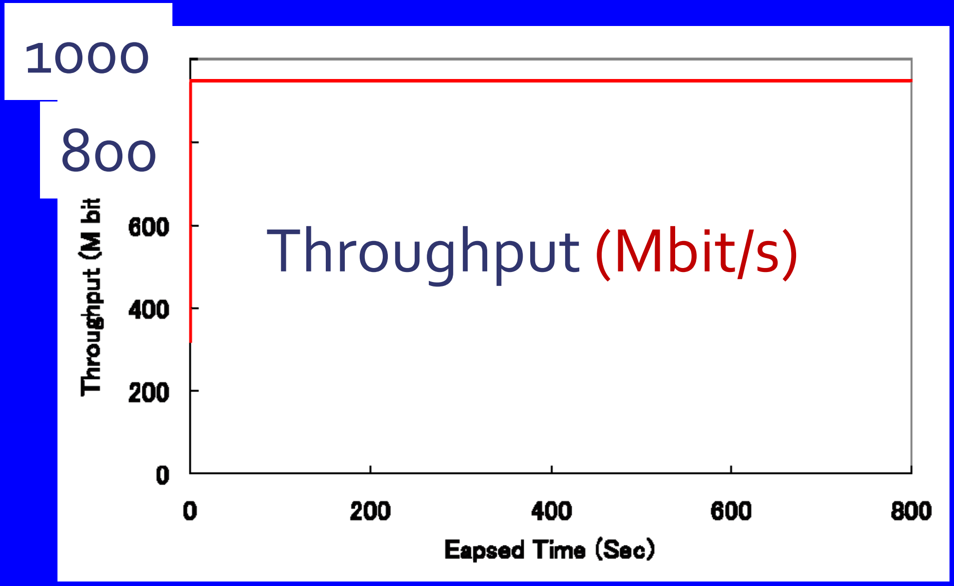
AMC vs. 1GHz FADC

	AMC (+slow FADC)	FADC (ADC081000 N.S.)
Sampling rate	~1GHz	1GHz
Supply voltage	+5V	+1.9V
Power/channel	72mW(*) (+160mW FADC)	1.45W
Resolution	≥10bit	~8bit

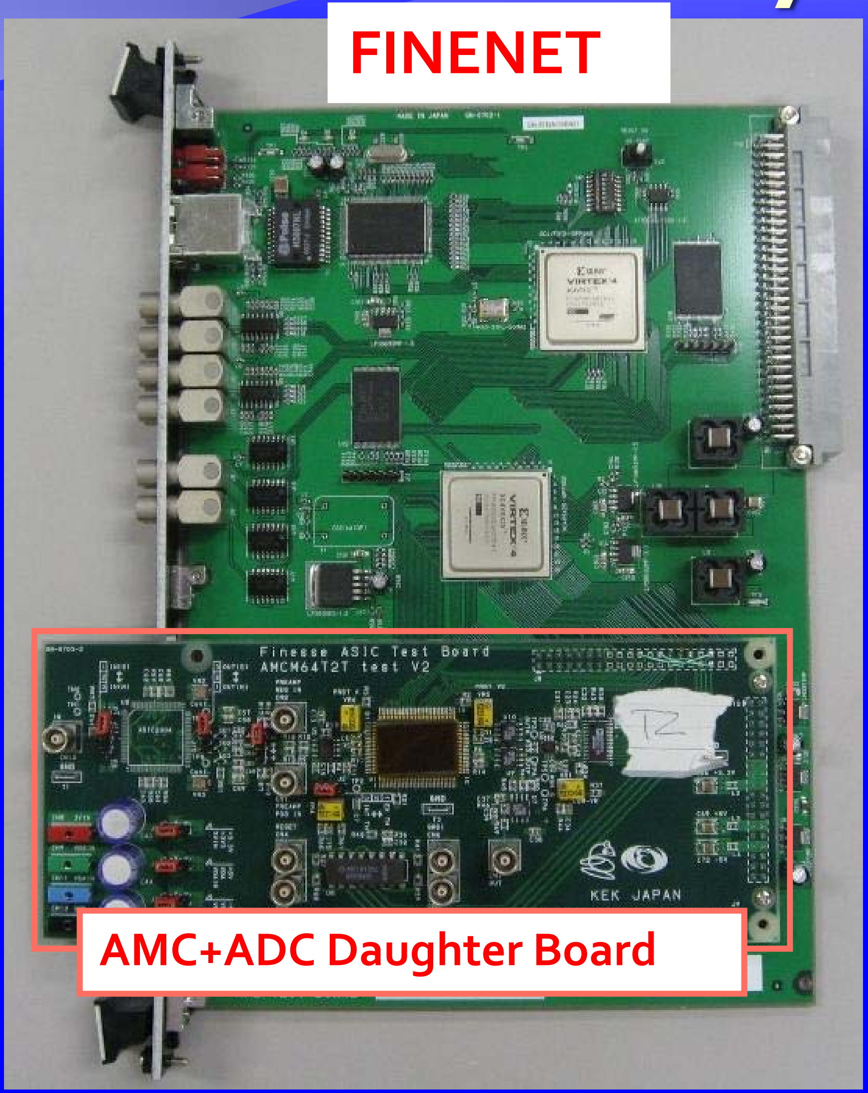
(*) readout clock=200kHz

FINENET (+SiTCP)

- Mounting two FPGAs
- Real-time signal processing
- Digital signal processing (DSP)
- High speed data transfer with SiTCP (<1Gbps)



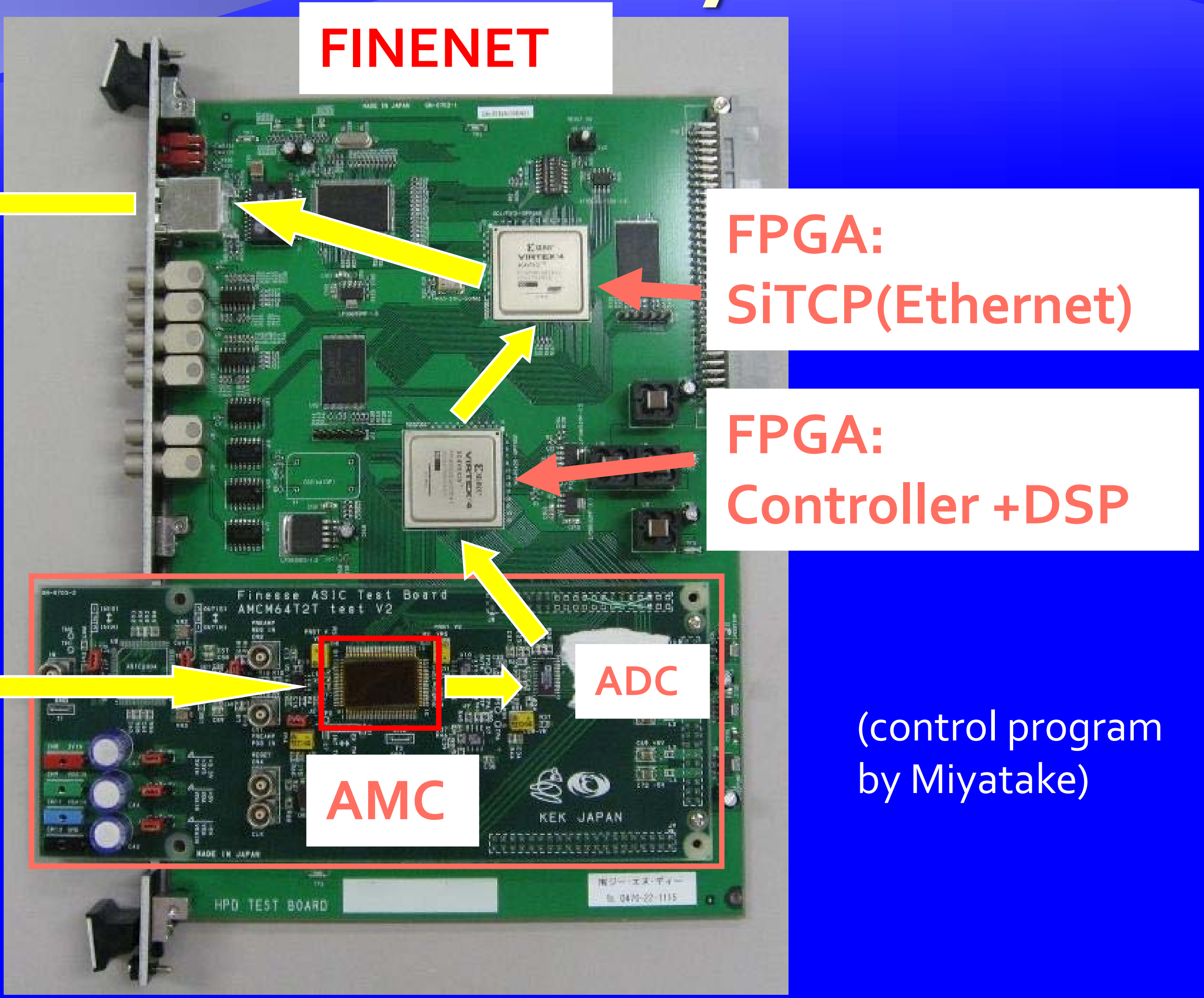
Prototype of readout system



(Uchida)

Prototype of readout system

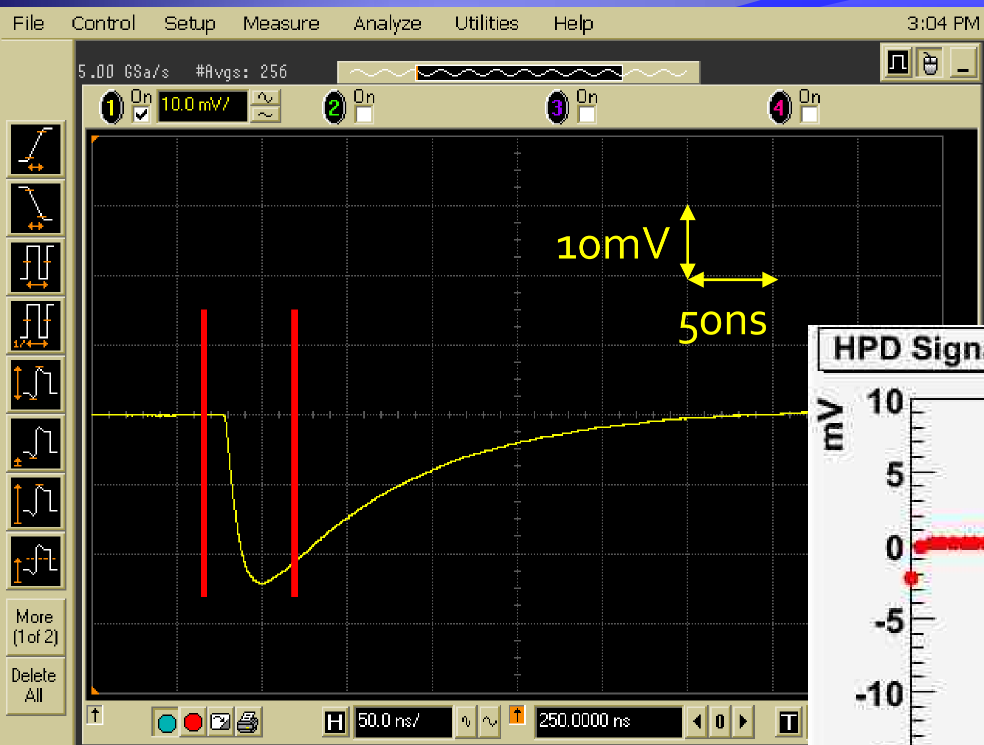
Ethernet(<1Gbps)

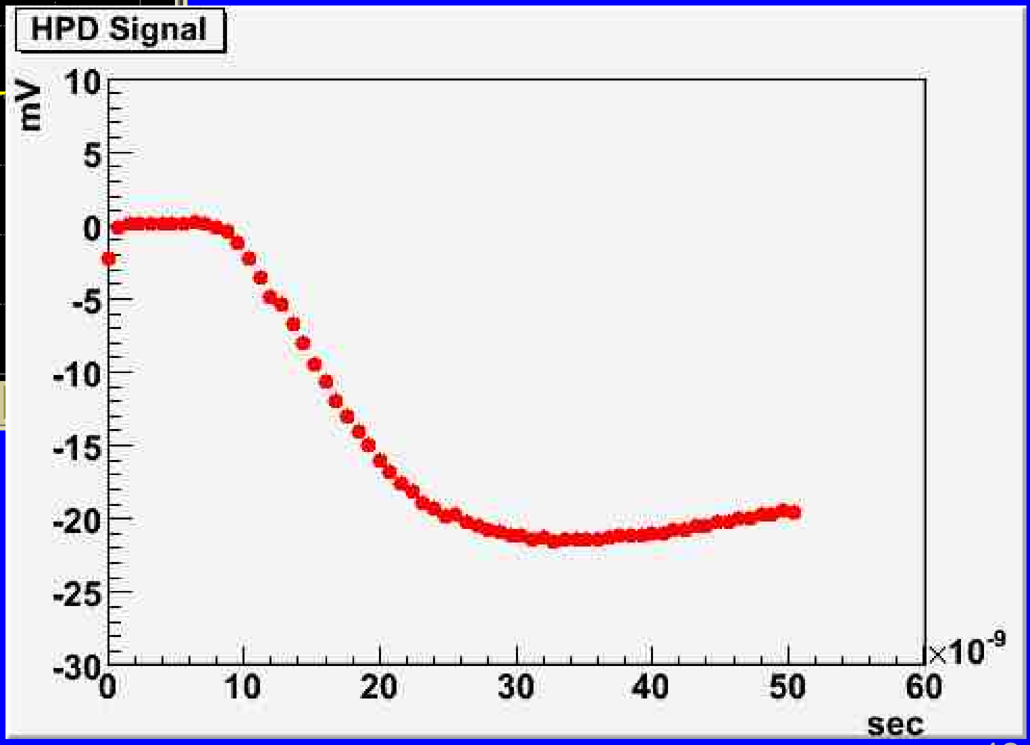


Signals from HAPD

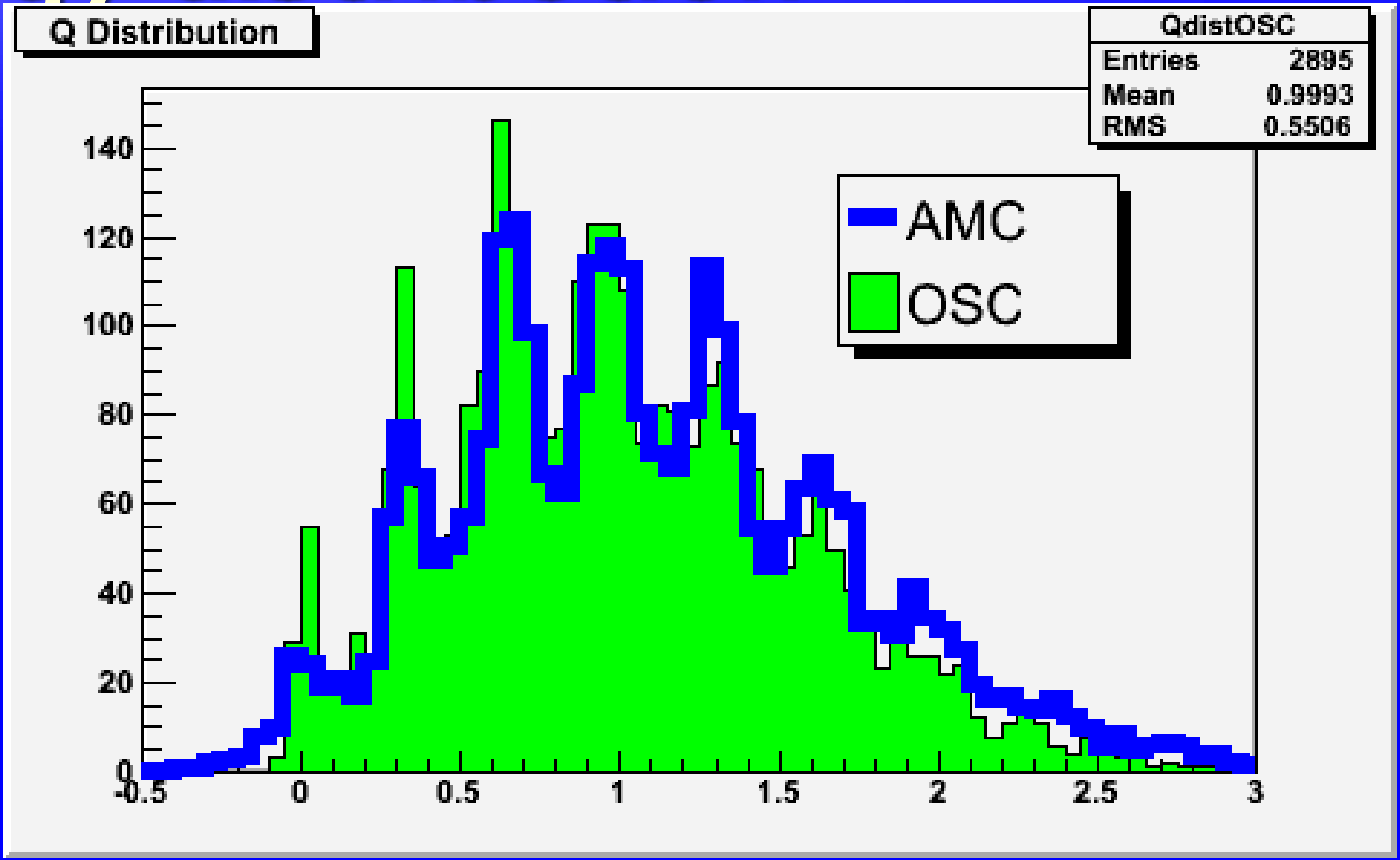
(control program
by Miyatake)

AMC+FINENET output



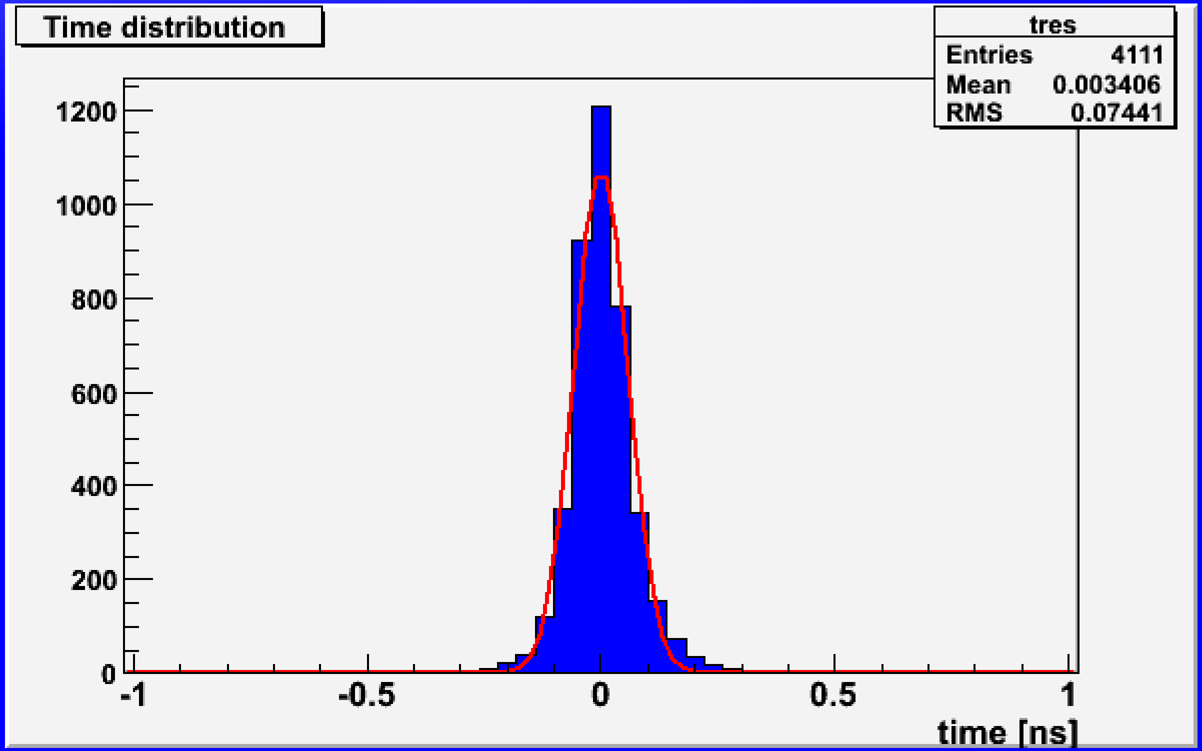


Energy distribution



Timing resolution

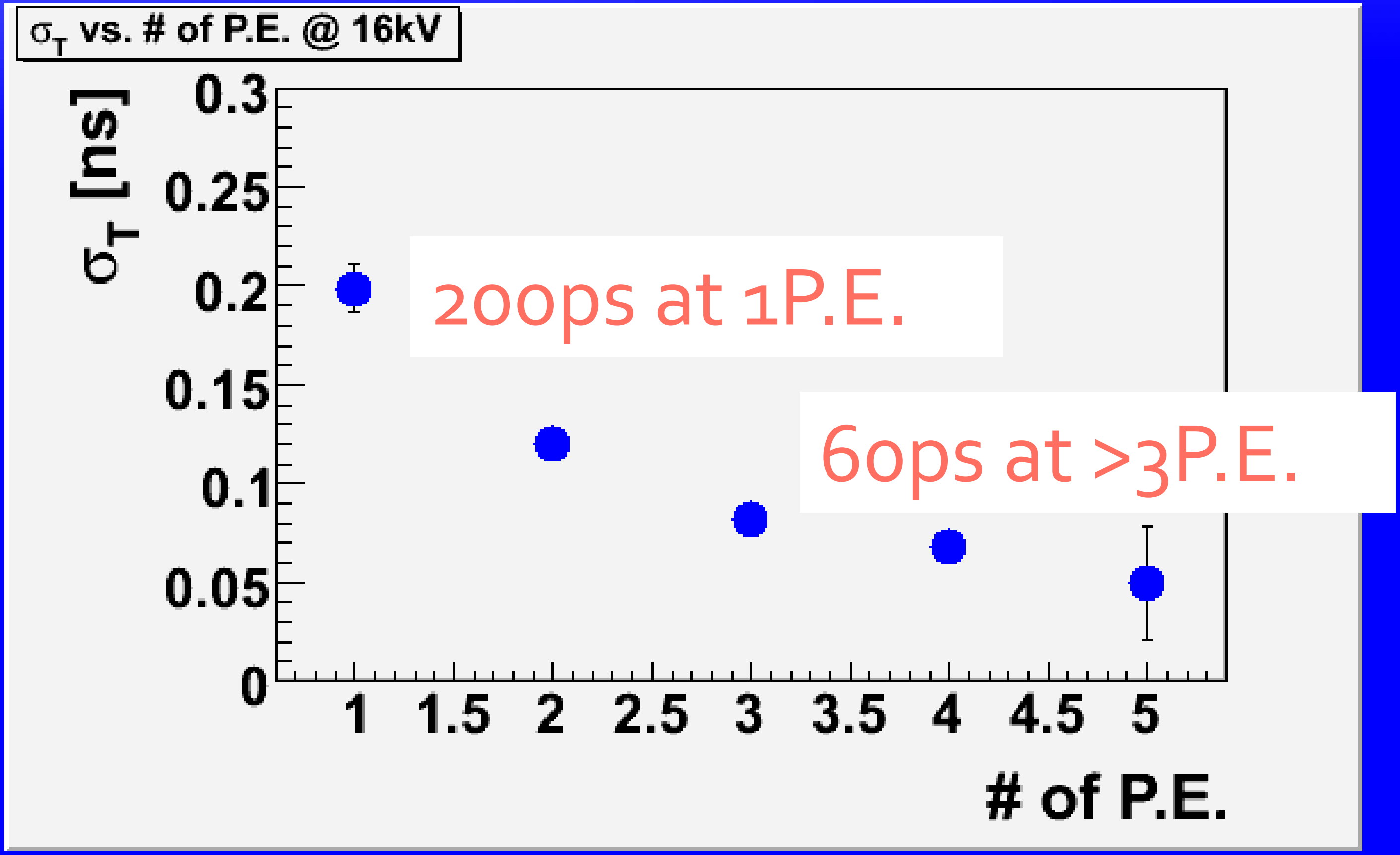
σ_t~60ps



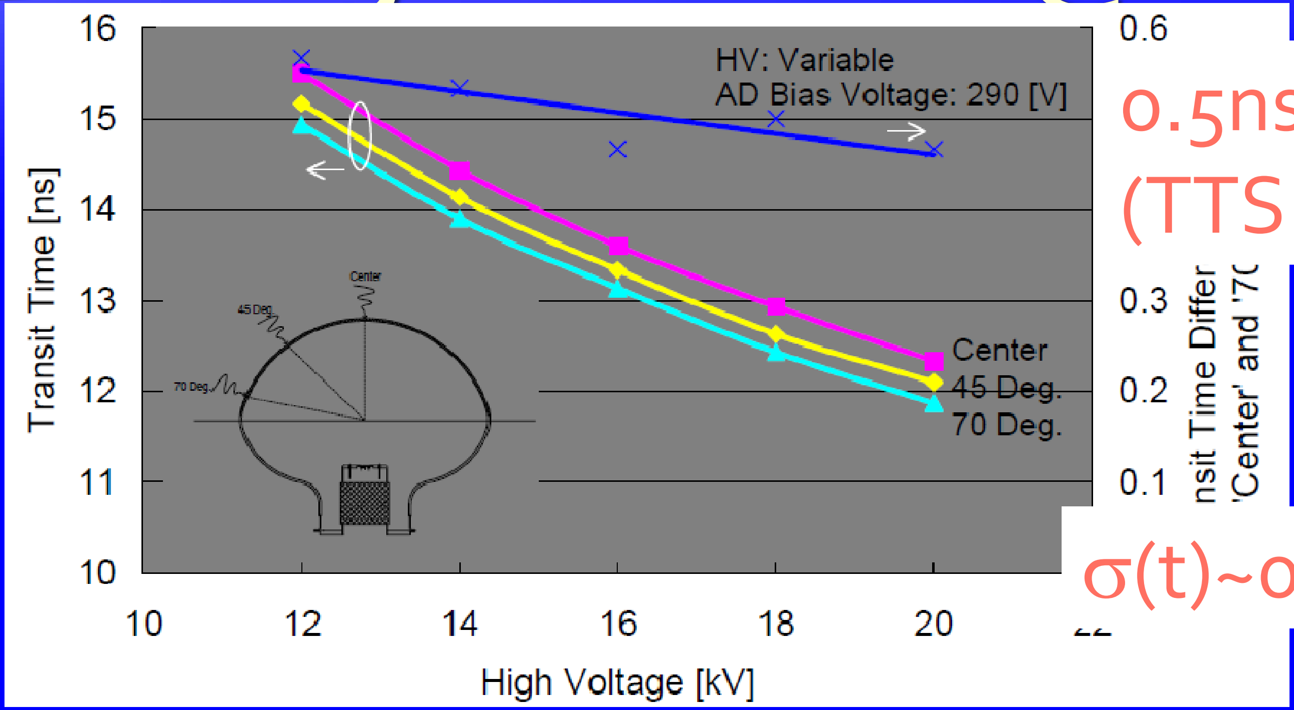
3>P.E.

Timing resolution vs. P.E.

PLP spot illumination (PW: ~70ps, λ:~400nm) HV=16kV bias=240V



Timing resolution @ 1P.E.



0.5nsec
(TTS by position)

σ(t)~0.2nsec

HAPD Summary

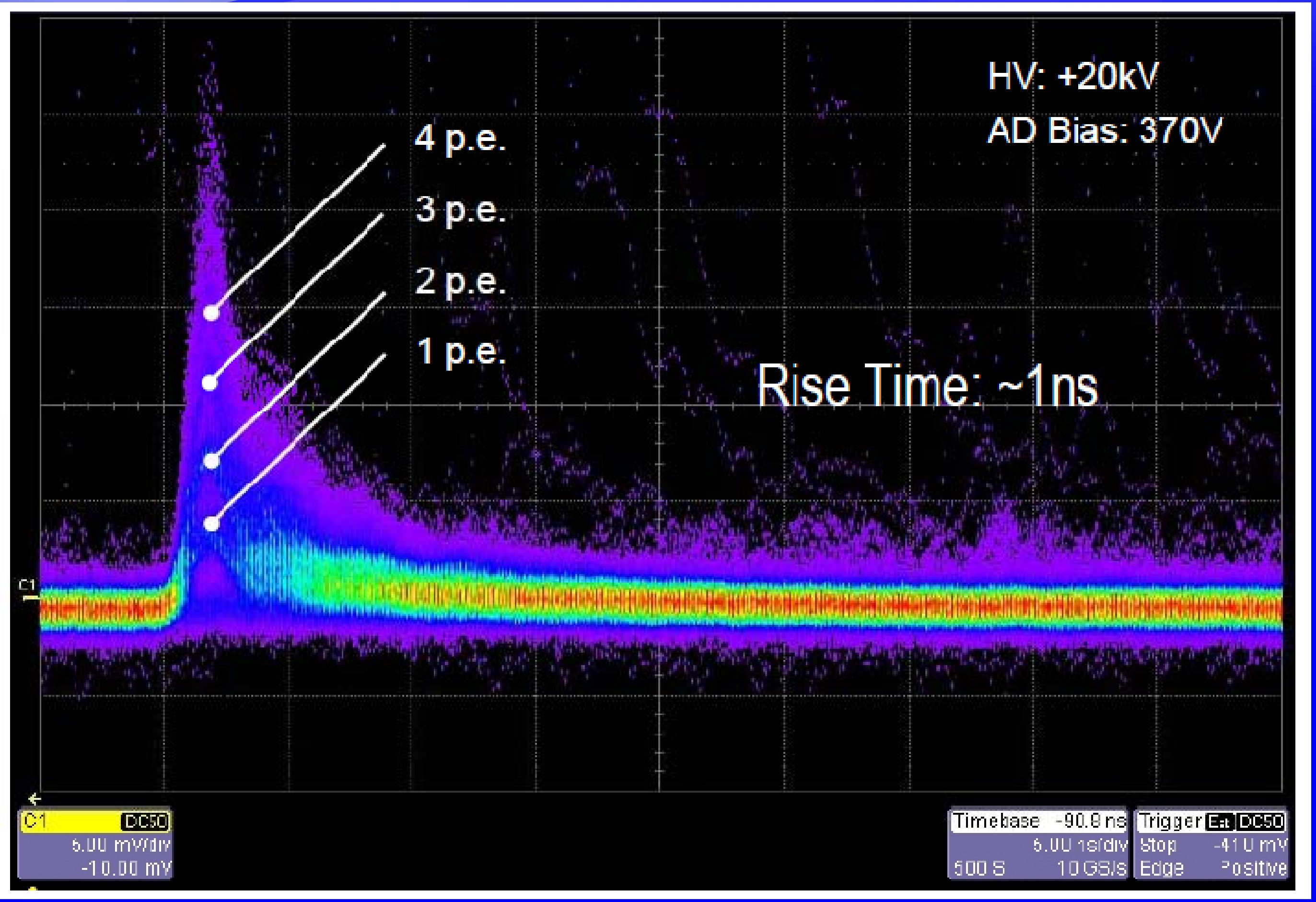
- We develop 13inch HAPD and its readout system.
- HAPD shows superiority than conventional PMTs.
  - 24%(HAPD) vs. 70%(R8055) @ 1P.E.
  - 190ps(HAPD) vs. 1400ps(R8055) @1P.E.
- First full readout system is completed and gives excellent performance.

Summary

- We report two photo sensor developments to save cost for the next water Cherenkov detector.
- PM2 develop small PMT solution with their intelligent ASIC technology and have a cost estimation (not finalized)
- HAPD approach show superb performance compared to PMT. No cost estimation yet.

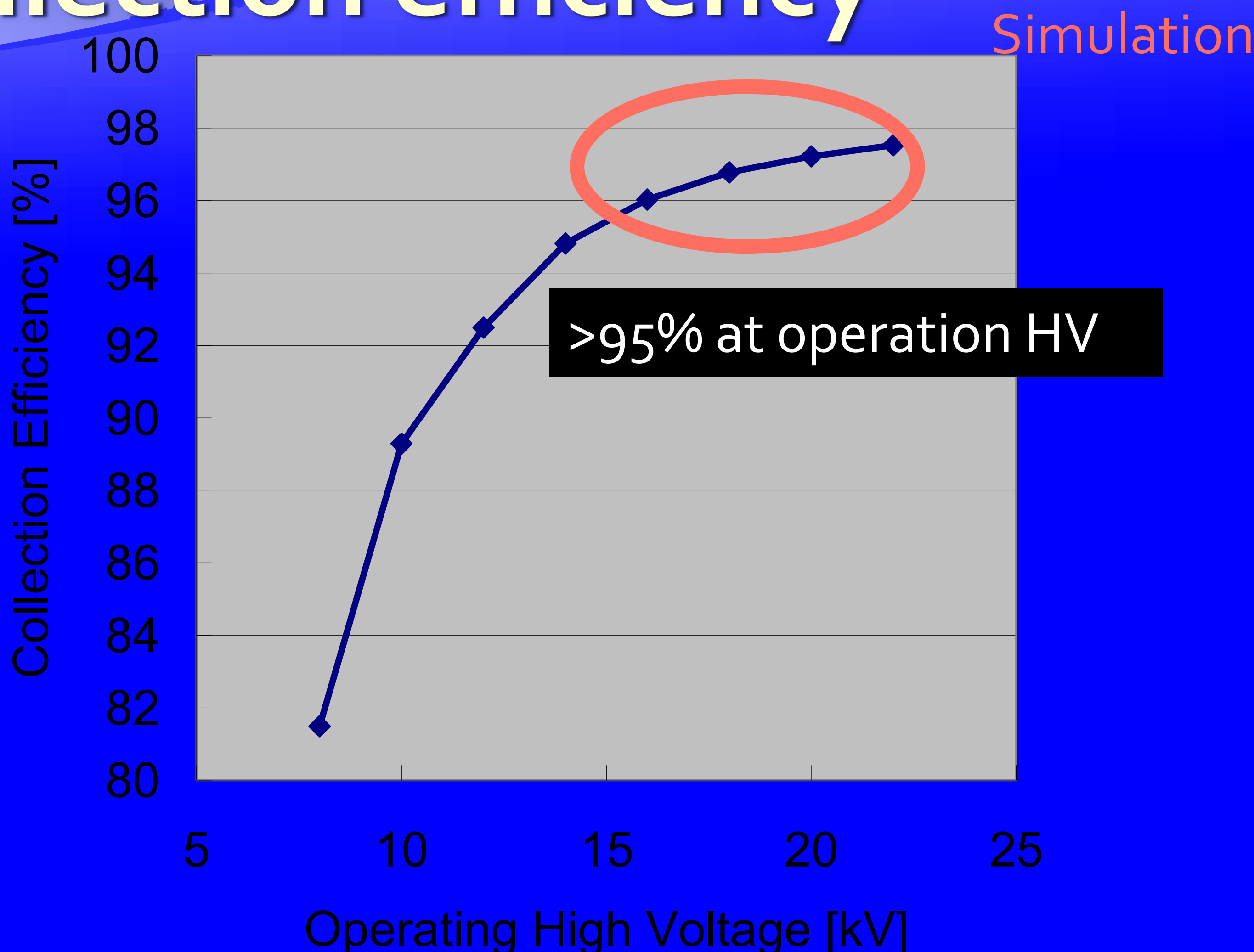
Backup slides

Raw signal of HAPD



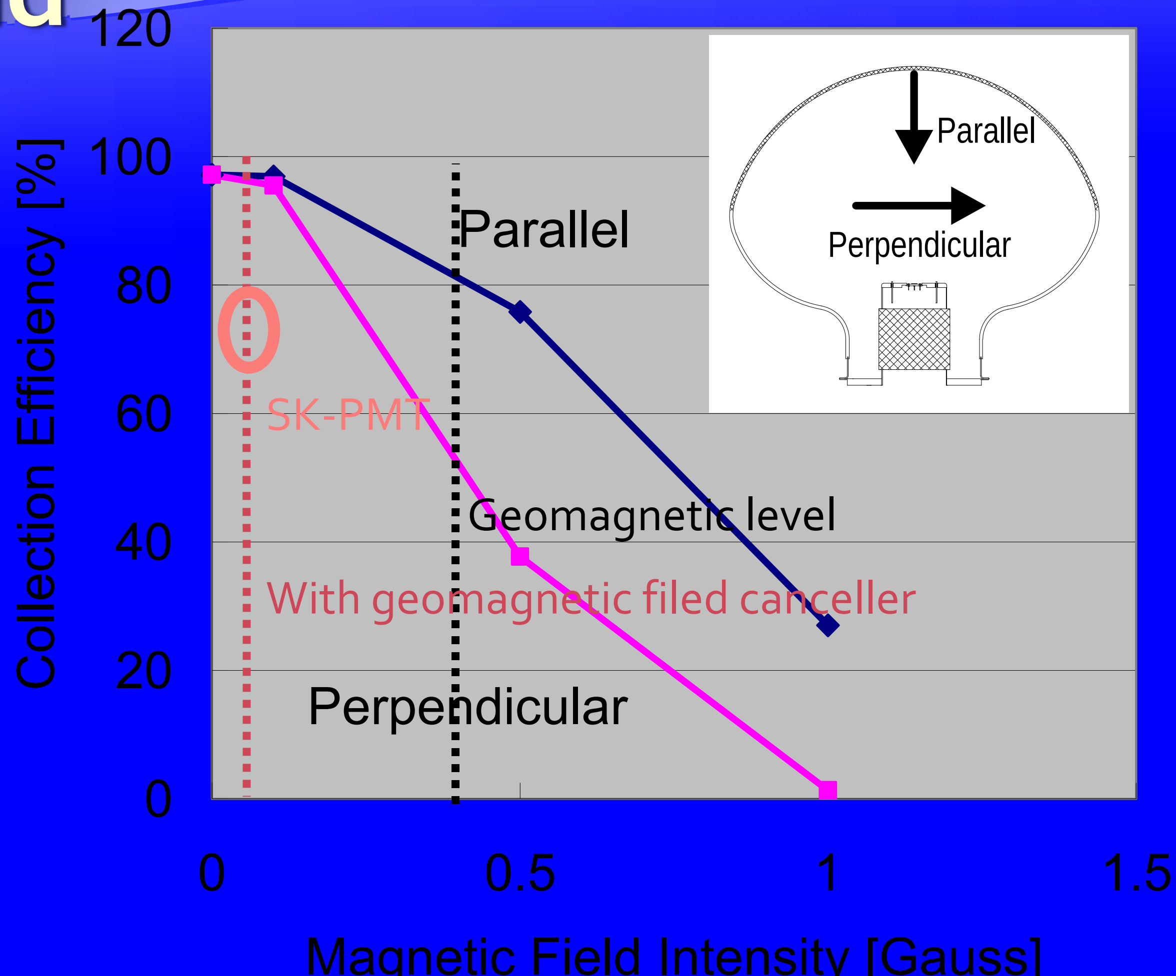
3/10/2008
50

P.E. collection efficiency



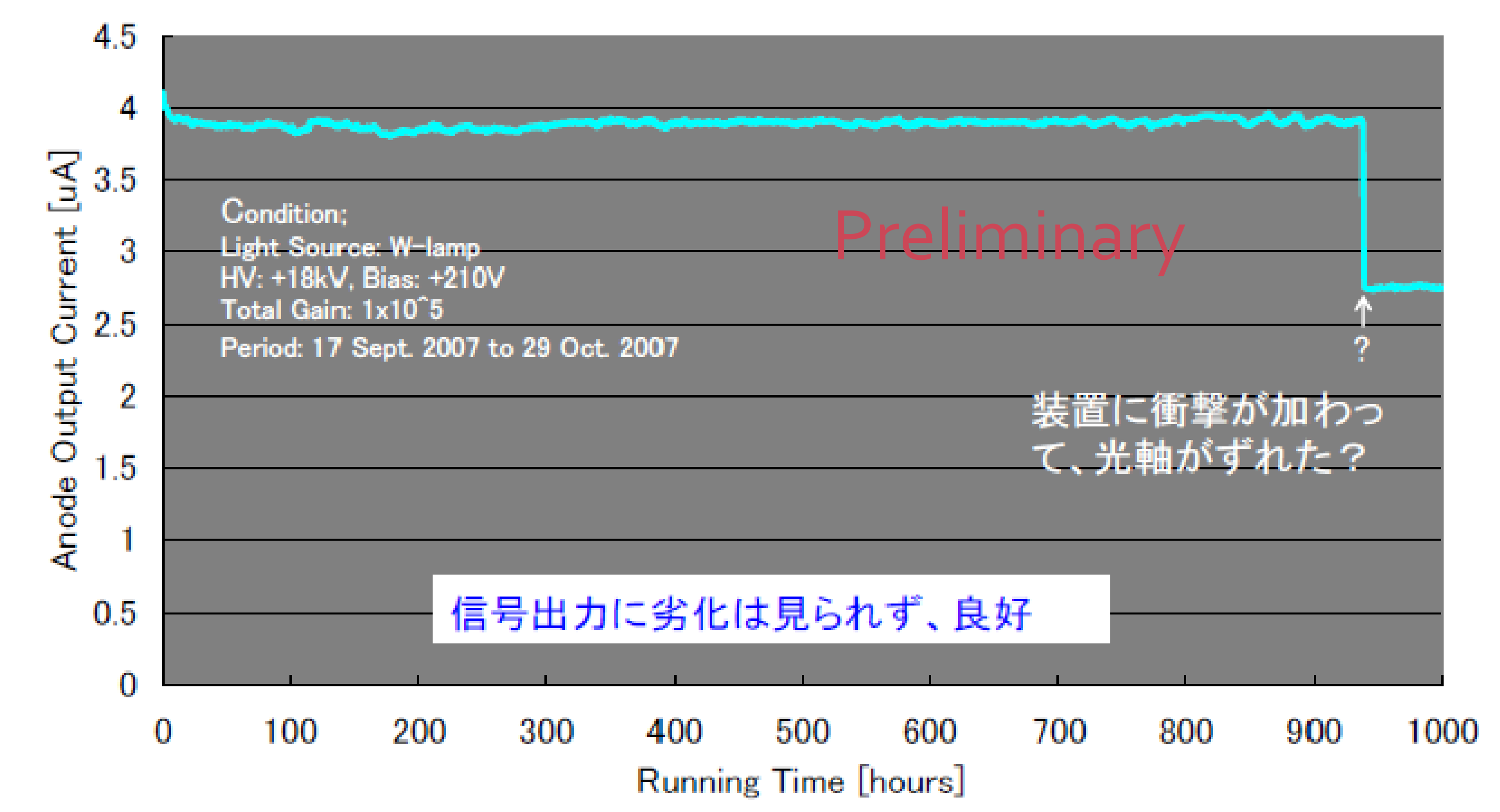
Collection efficiency vs. magnetic field

Simulation



<2%degradation with canceller

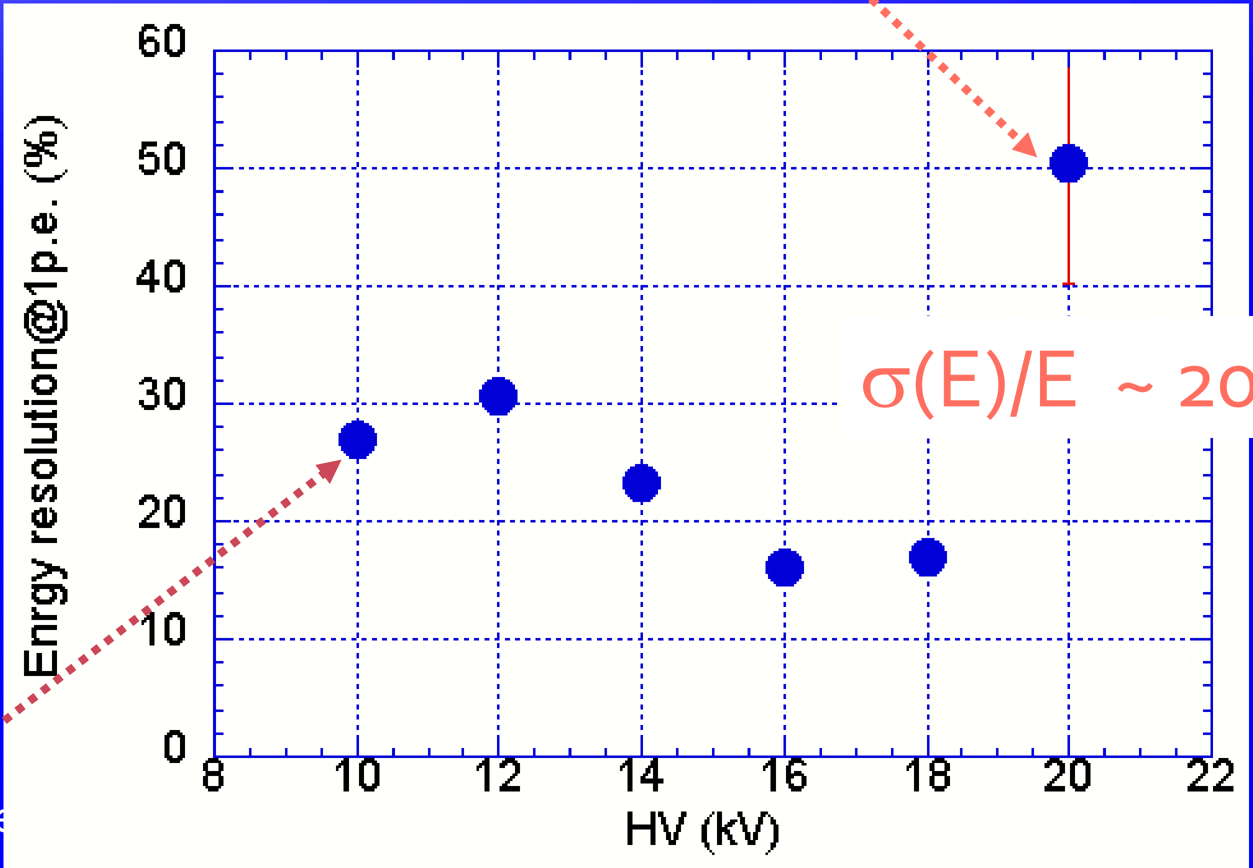
Long term stability test



全フォトエレクトロン数: ~9x10[14], JHF前置検出器で20年間にADが受ける光電子量は宇宙線ミューオン　100p.e. x 1e5Hz x 86400sec x 365days x 20years ~ 6x10[14]

Energy resolution @ 1P.E.

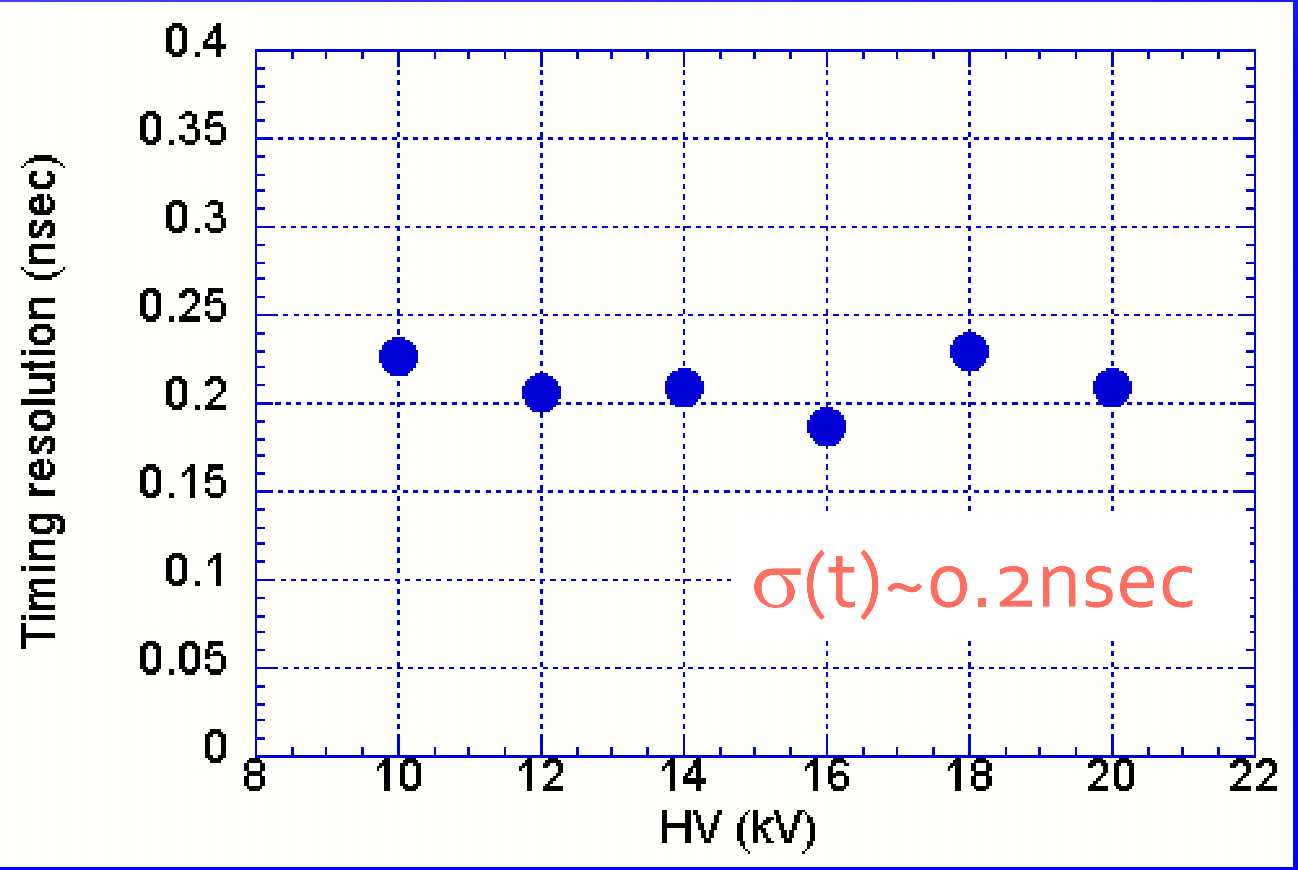
Noise due to weakness of dielectric strength in HAPD



σ(E)/E ~ 20%

Measured in diffe

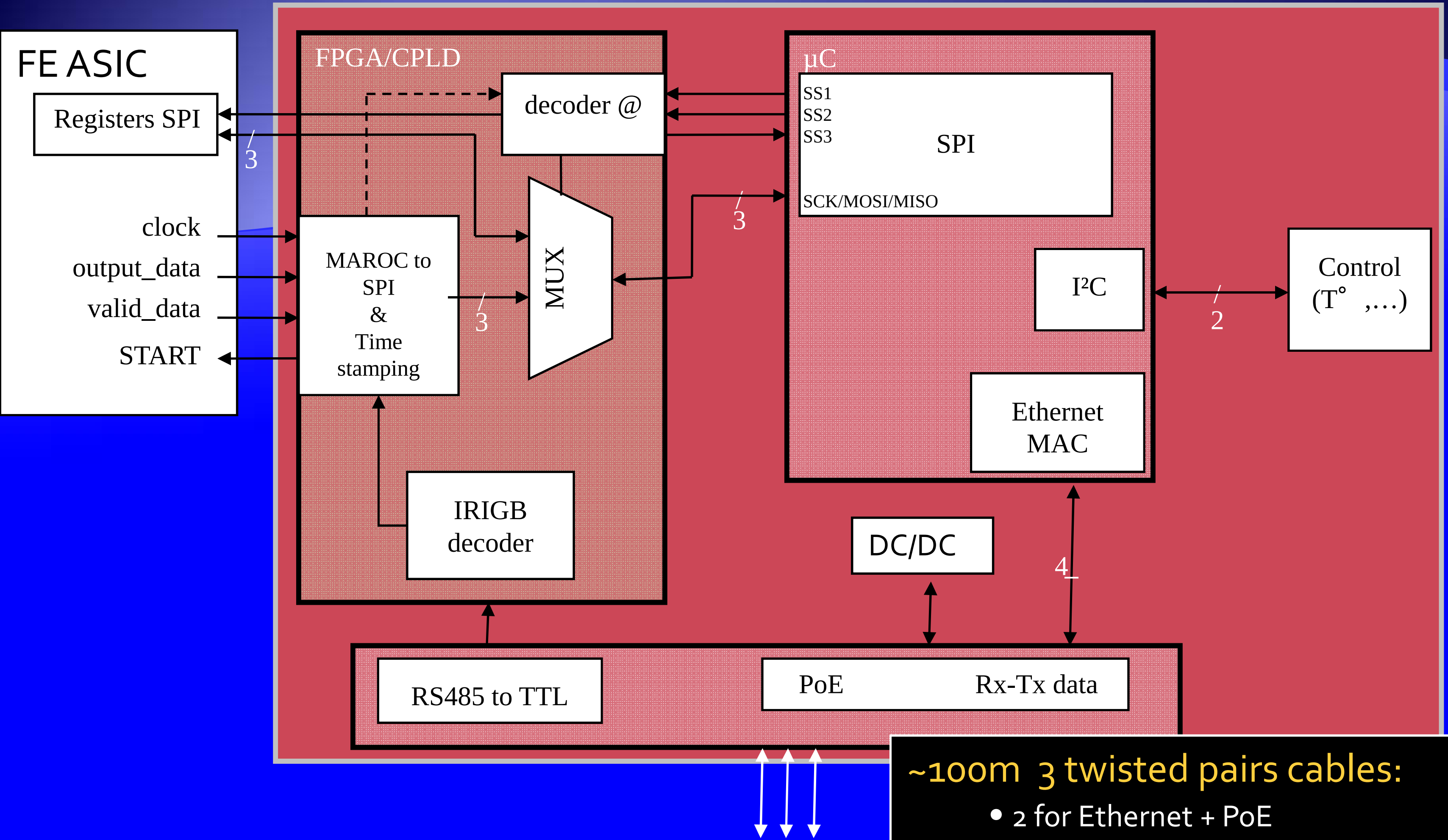
Timing resolution @ 1P.E.



Comments on the readout system

- We can make dead timeless readout system with AMC.
- AMC can speed its readout time up because:
  - Multiple outputs ([0-15] [16-31]...).
  - Tandem AMC system
- It is a trade off business between fast readout and power consumption.

Digital part details



~100m 3 twisted pairs cables:
- 2 for Ethernet + PoE
- 1 for GPS synchronisation

SPI bus : Dialog with FE ASIC, Read IRIGB time stamping (UTC + pps)

I2C bus : Monitoring and control

Ethernet (data) + Power Over Ethernet (power supply):
- ~50V for HV generation locally
- Ok at least for 40 Mb/s @ 5kHz/PM Dark Current