PET development at KEK

Liquid Xenon TPC for a gamma detector

(TXePET)

T. Tauchi (KEK)

1 February 2010

LXeTPC project

since 2007.4 as a KEKDTP project

Detection of KeV-MeV “gammas” with 3D positions and energy of high resolutions

Applications：Gamma ray astronomy; Single Photon Emission Computed Tomography (SPECT), Positron Emission Tomography (PET)；Dark matter, Double β decay experiments

KEK : liquefaction & purification , PMT, TPC, DAQ

T.Tauchi, A.Maki, T.Haruyama, S.Tanaka, S.Mihara, T.Saeki

K.Kasami, S.Suzuki

Saga univ. : TPC, simulation, FE ASIC chip, test

A.Sugiyama, T.Higashi(D3)

Tokyo univ. : TPC, PMT, simulation, test

T.Mori, Y.Fujii(M1)

National Institute of Radiological Science : PET

M.Kumada, T.Tomitani, C.Toramatsu

Yokohama National univ. : PMT, Xe-property

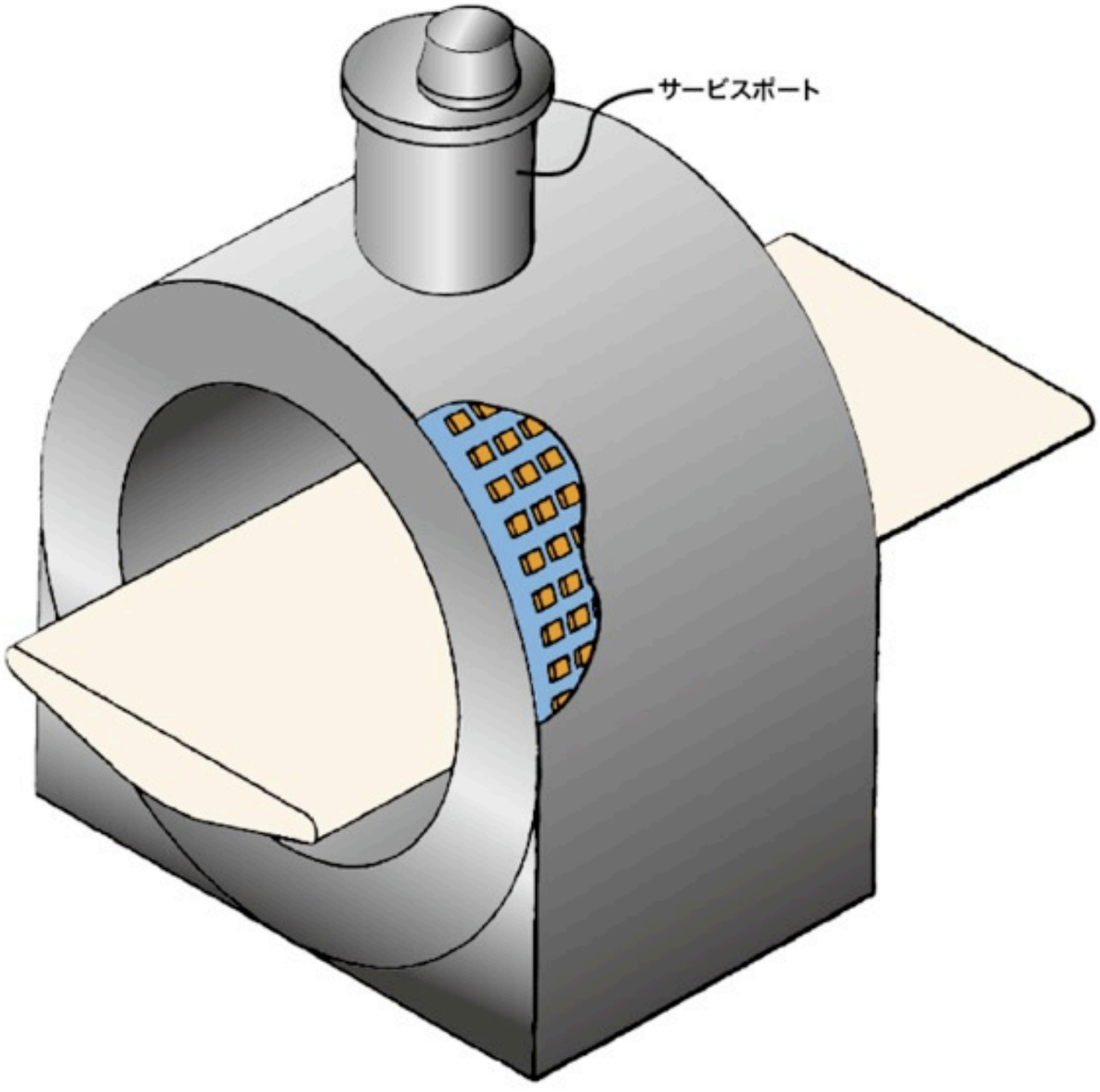
S.Nakamura

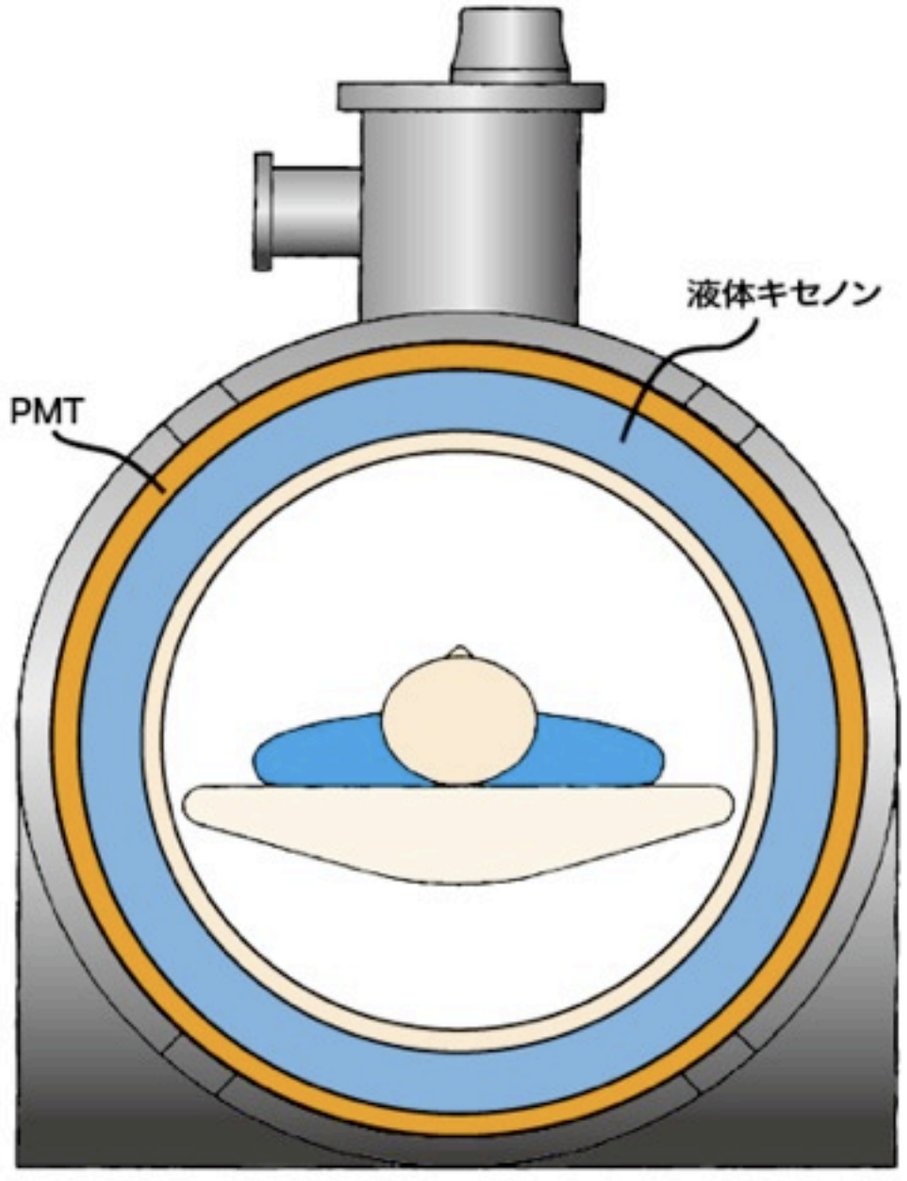
Cooperation : KEK electronics system group , DAQ

M.Tanaka et al.

Next-generation PET with LXeTPC

TXePET





Electronics System

Pipeline readout (digital processing)

Scintillation light
Photomultipliers

FADC
300 MHz

FPGA
Precise time
Rough position

Time Stamp
(t_0)

Fast
memory
(SRAM)

Charge
Anode pads
(1mm x 1mm)

ASIC-FEXE08

FADC
or TOT etc
10-30MHz

FPGA
Precise
position &
Energy

Imaging

under development

supported by ASIC education & fabrication program, KEK

Previous Activities

2007.4　Proposal to KEKDTP
2007.4 - Preparation of prototype
2008.2　New laboratory was completed
2008.4.30　Refrigerator system was completed
2008.5.7　Chamber was filled with liquid Xenon
in the first time w/o a detector.
2008.5.22　First scintillation signal was observed
2009.2.25　First charge signals from cosmic rays(11)
2009.3.31　First charge signals from α sources(45)
Improving vacuum system and 4ch pad readout
2009.4.24　This experiment

(days since purification/circulation)

LXe Cryogenic system at KEK , operation since May 2008

Gas handling panel

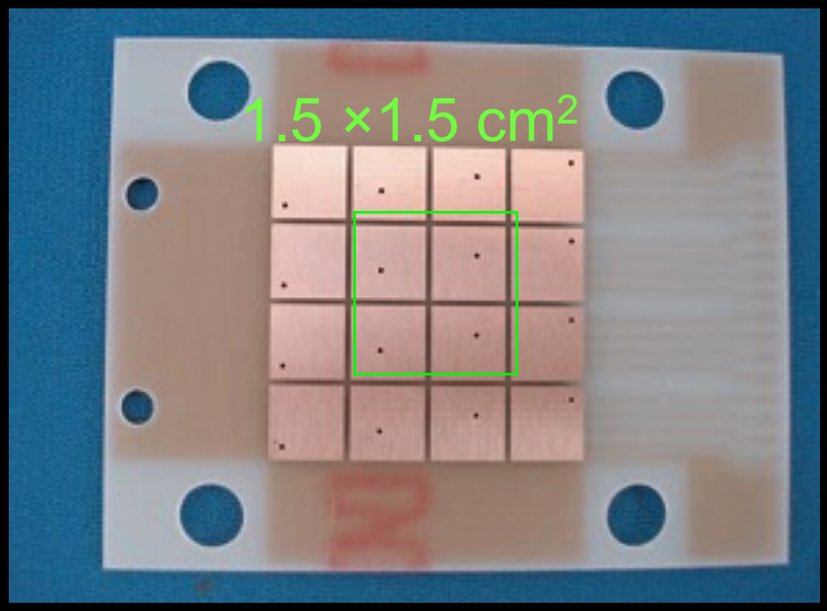
PTC (24W@165K)

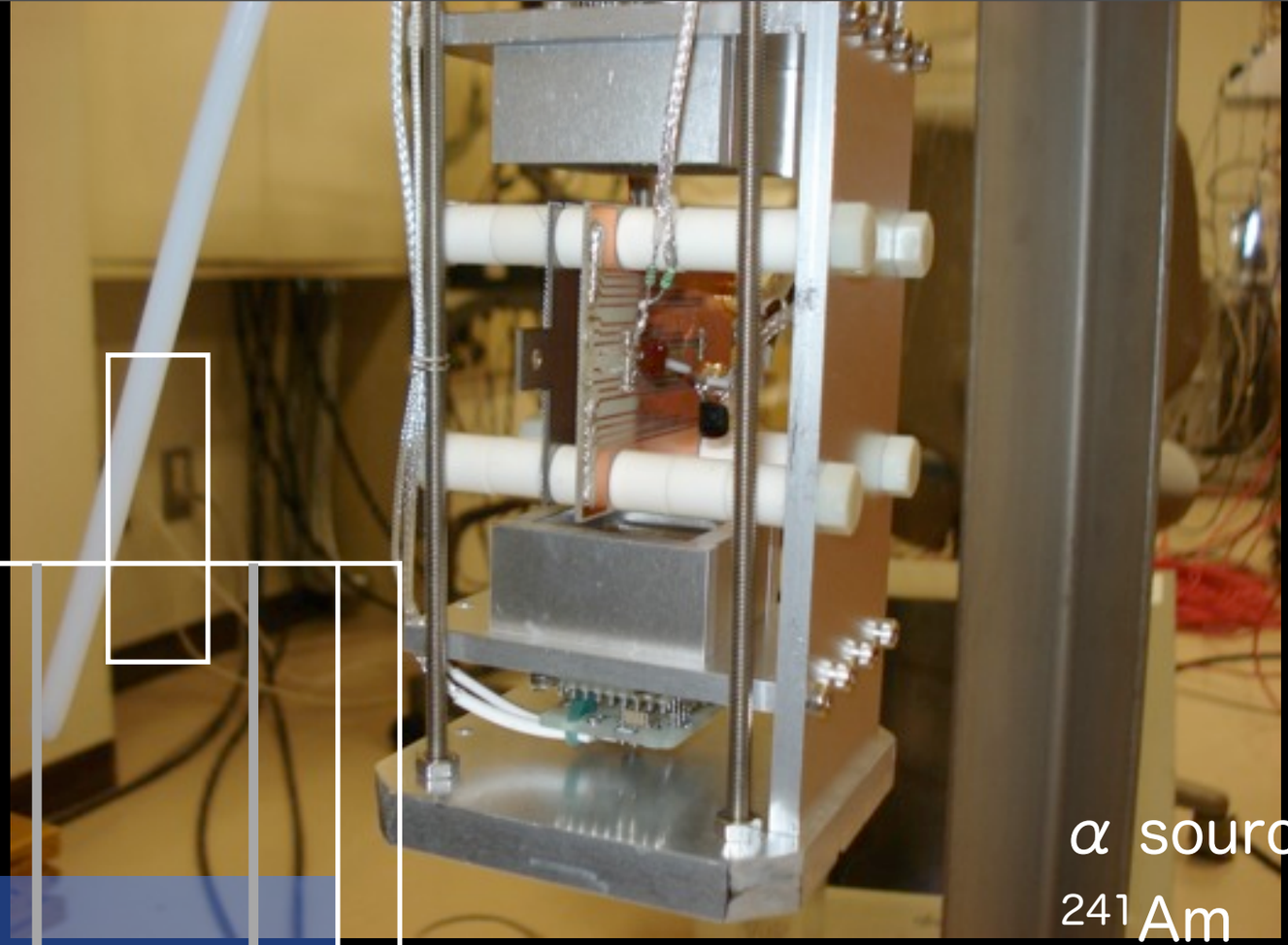
0.75m^3 Tank

700W compressor

Test chamber 1.5L-Xe

Experimental setup





α source of
^{241}Am (200Bq)

PMT

TPC

Cathode

1cm

Pad

GND

50Ω

Test pulse

1KΩ

2pF

JFET

to Pre-amp IN

100MΩ

to Pre-amp
feedback

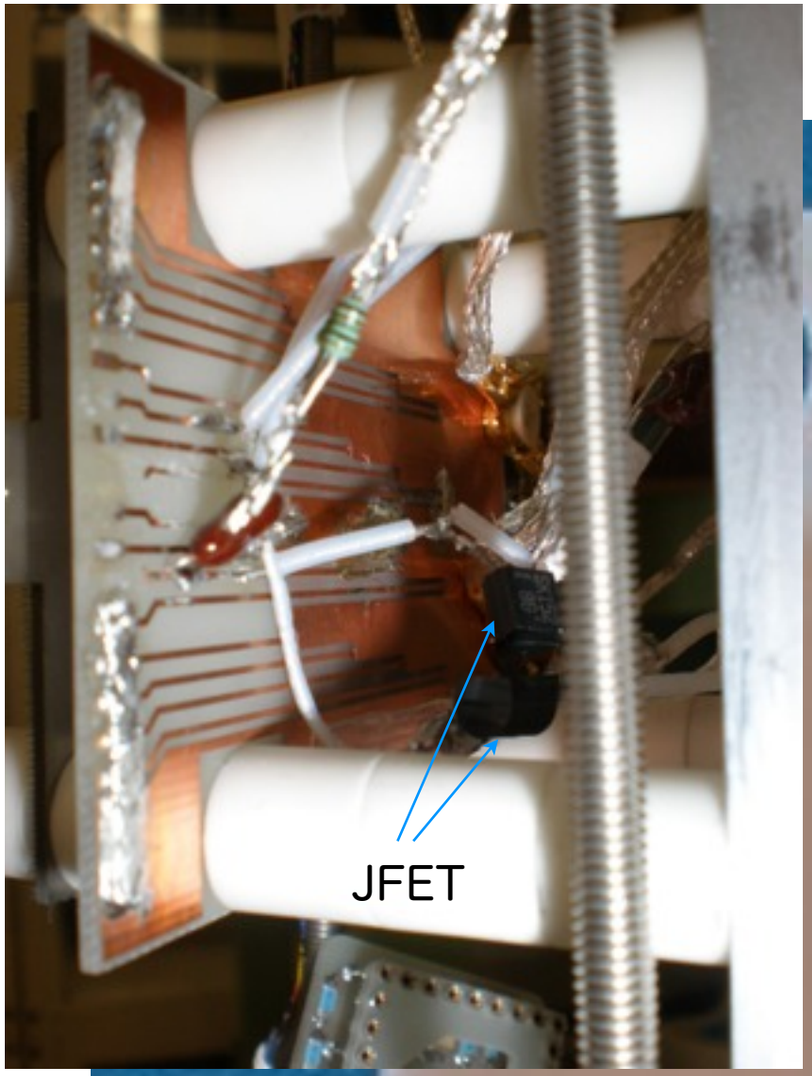
1pF

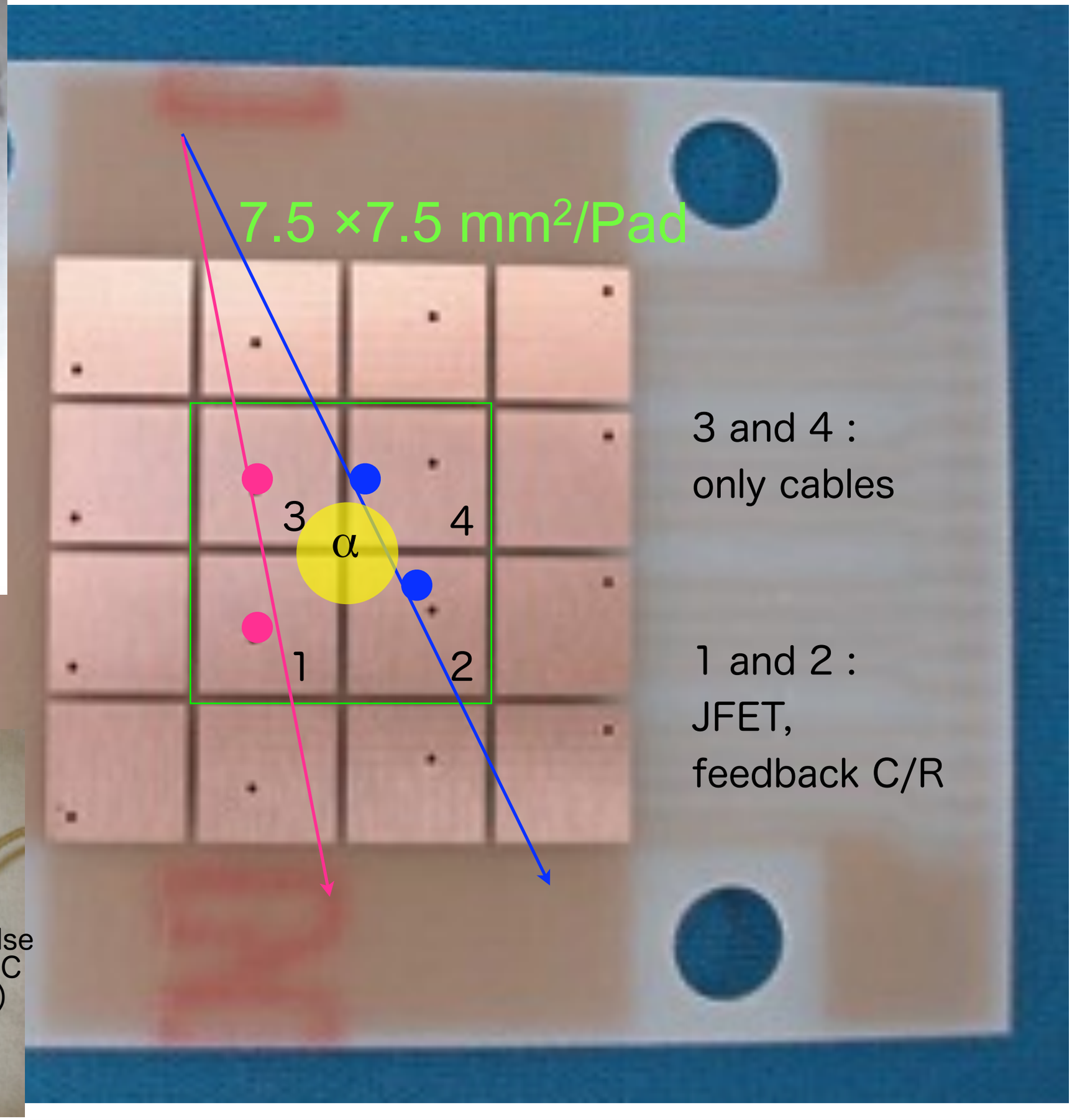
- H.V.

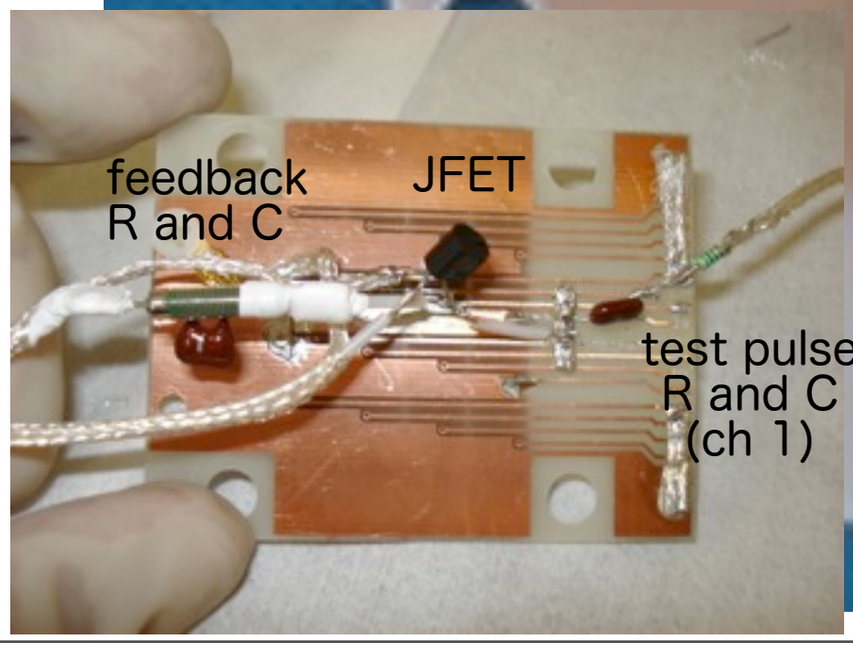
100MΩ

GND

Pre-amp :AMP-TEK
A250 (1V/pC)


JFET


7.5 ×7.5 mm²/Pad
3
4
α
1
2
3 and 4 :
only cables
1 and 2 :
JFET,
feedback C/R


feedback
R and C
JFET
test pulse
R and C
(ch 1)

2009.8.14

2010年 3月 9日 火曜日

This Experiment in 2009

4/24 15:04 Start of evacuation in the chamber

4/27 -30 Vacuum build up tests in three times @ 1.4 x 10^{-4}Pa

5/2 12:15 Gas phase purification/circulation with 4L/min

5/10 16:52 First observation of charge signals from cosmic rays(8)

5/20 17:40 Liquid phase purification/circulation with 1L/min

5/22 14:44 First observation of α charge signals (20mV)(20)

6/29 17:15 α charge signals to 100mV w/o LPF

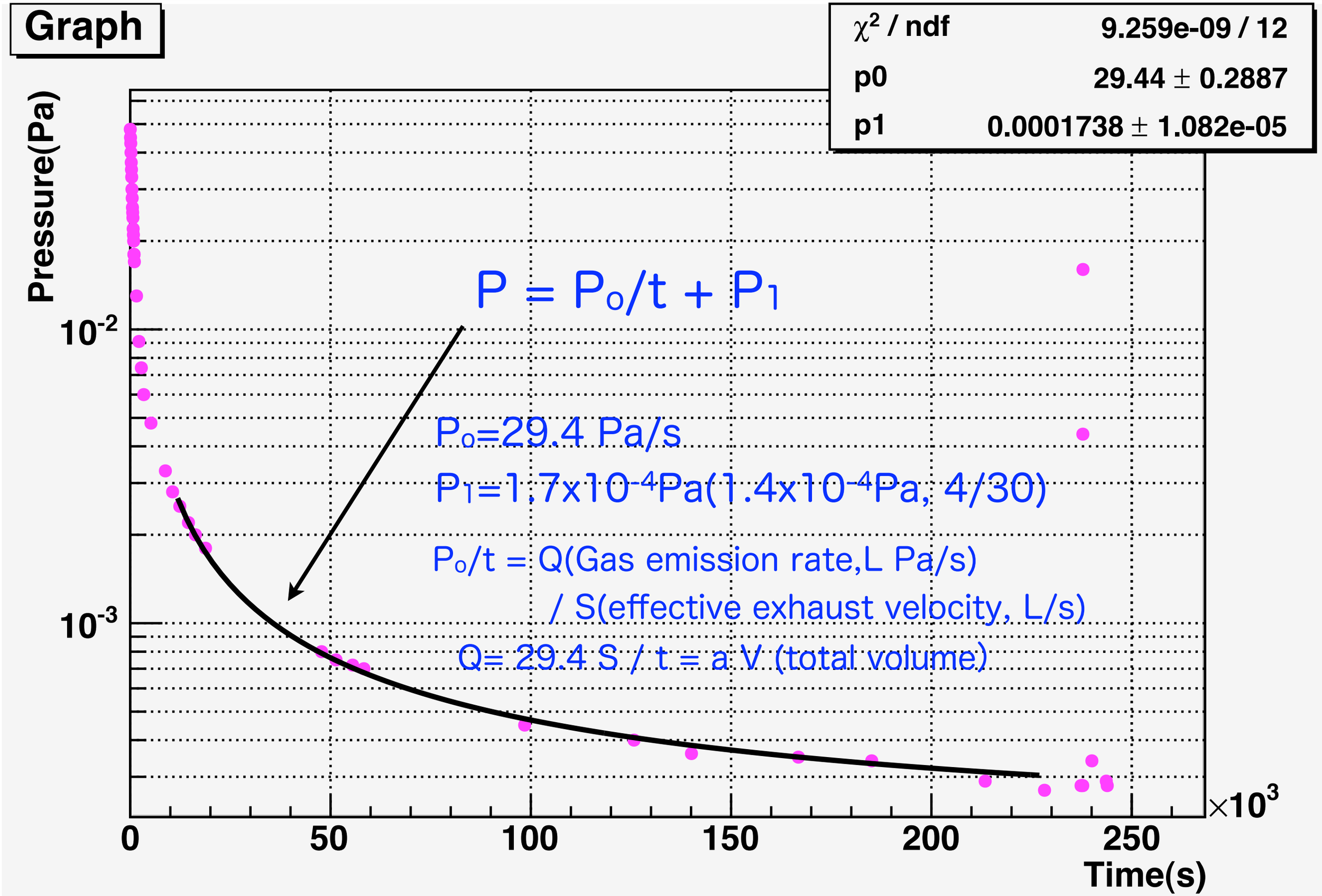
6/25 -7/9 Electric field dependence of charge and light signals

7/23 - 31 4ch Pre-amplifier setup and test

8/14 -17 Data taking with Cosmic ray trigger, about 1/min

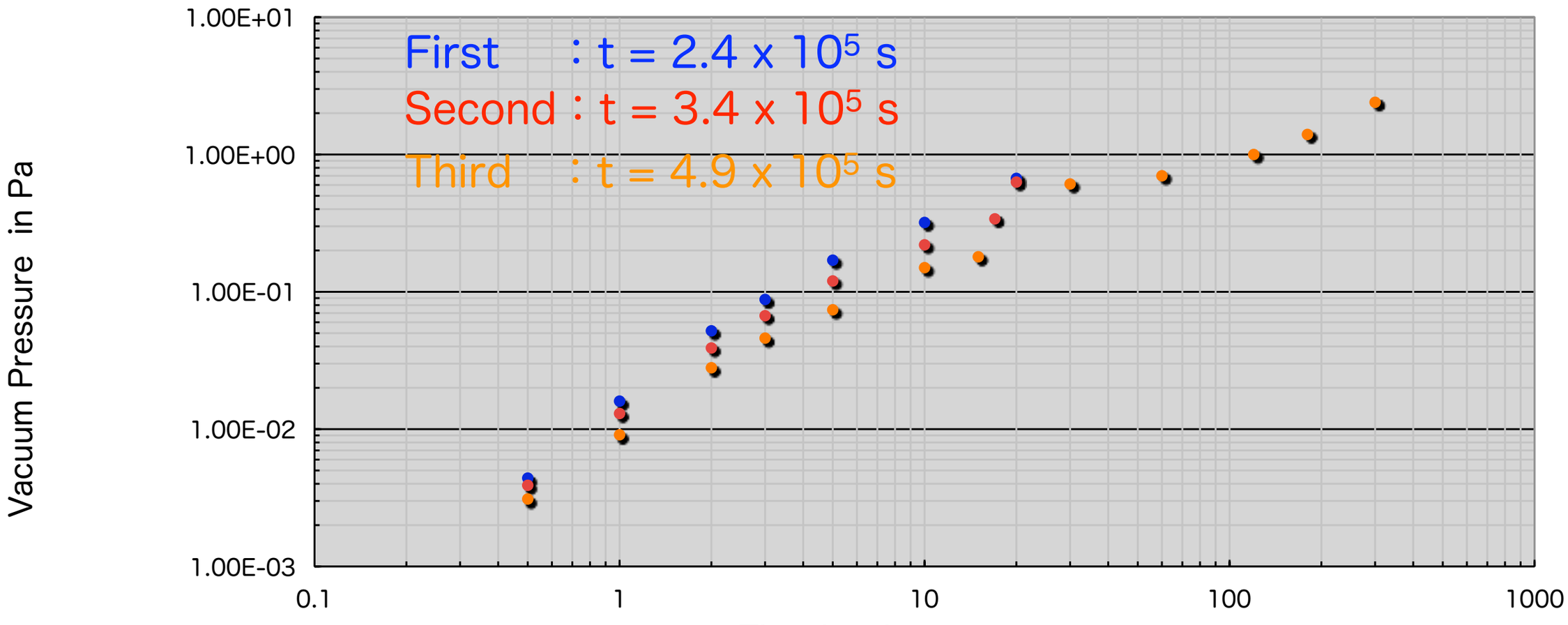
(days since purification/circulation)

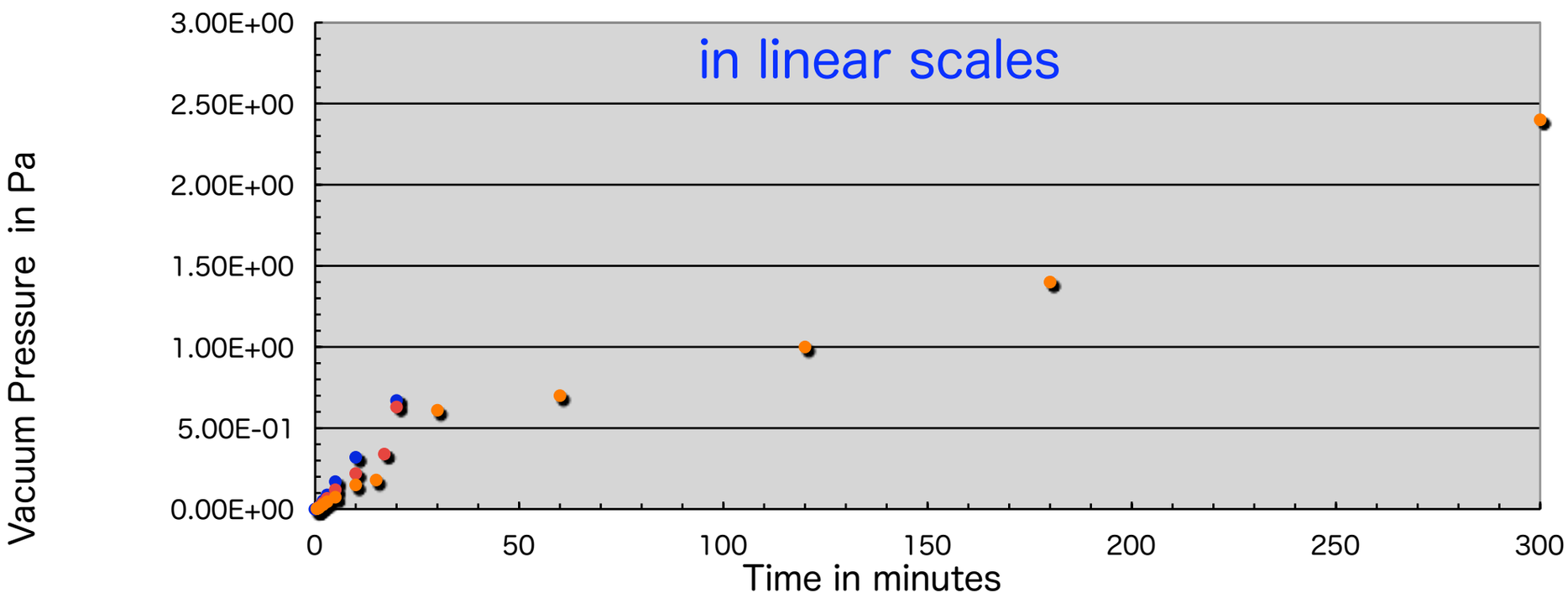
Evacuation Curve(2009.4.24 - 4.27 - 4.30)



Vacuum Build Up Test

"Less than 1 Pa overnight", Douke's Golden rule -> 10Pa for us





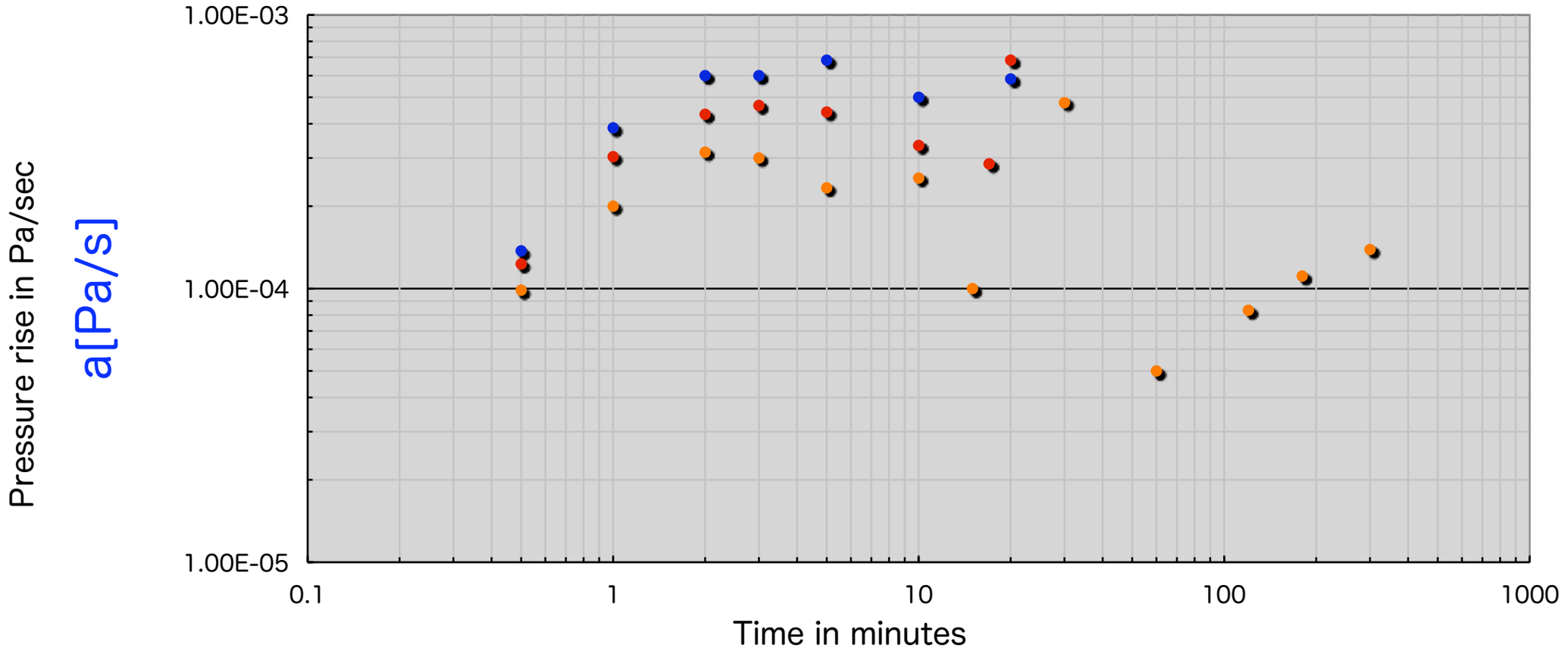
Vacuum Build Up Test (2)

Estimation of gas emission rate (Q) : Q = a V

First : t = 2.4 x 10^5 s

Second : t = 3.4 x 10^5 s

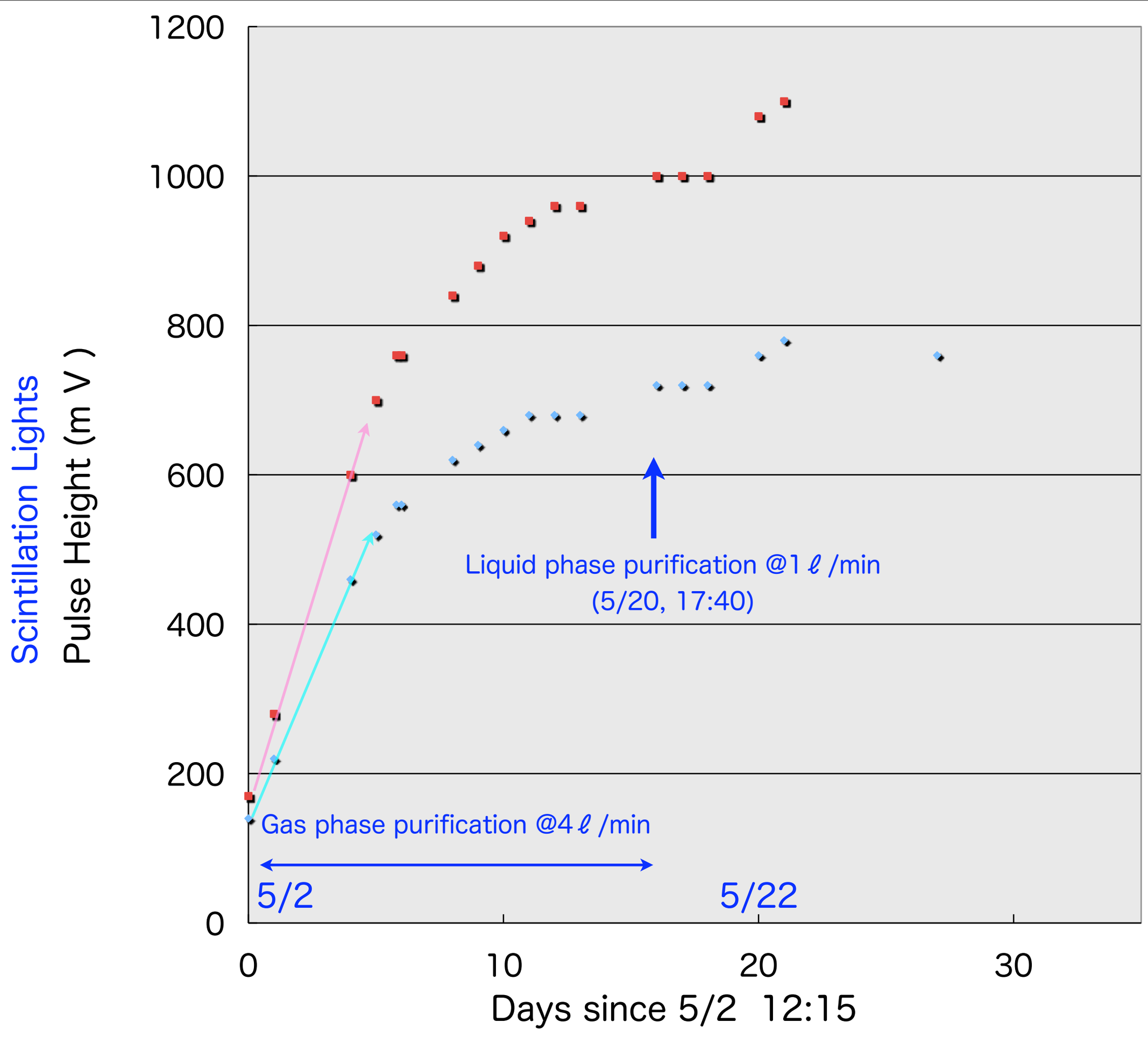
Third : t = 4.9 x 10^5 s



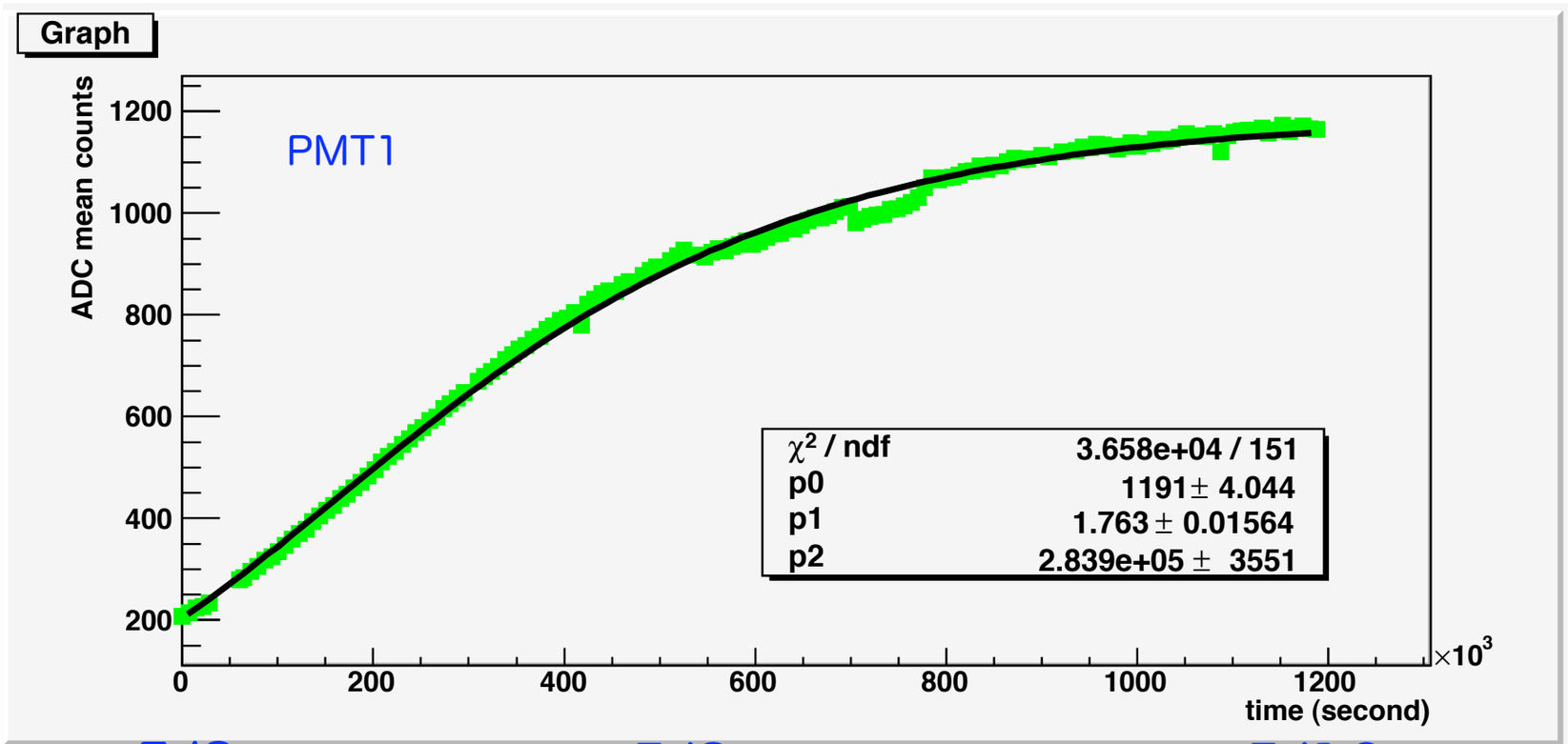
SUS vacuum chamber : 102mmϕ, 490mm length ,4ℓ , inner surface of 0.17m^2

Assuming total volume V=10L and Q=a x10 [L Pa/s] ,

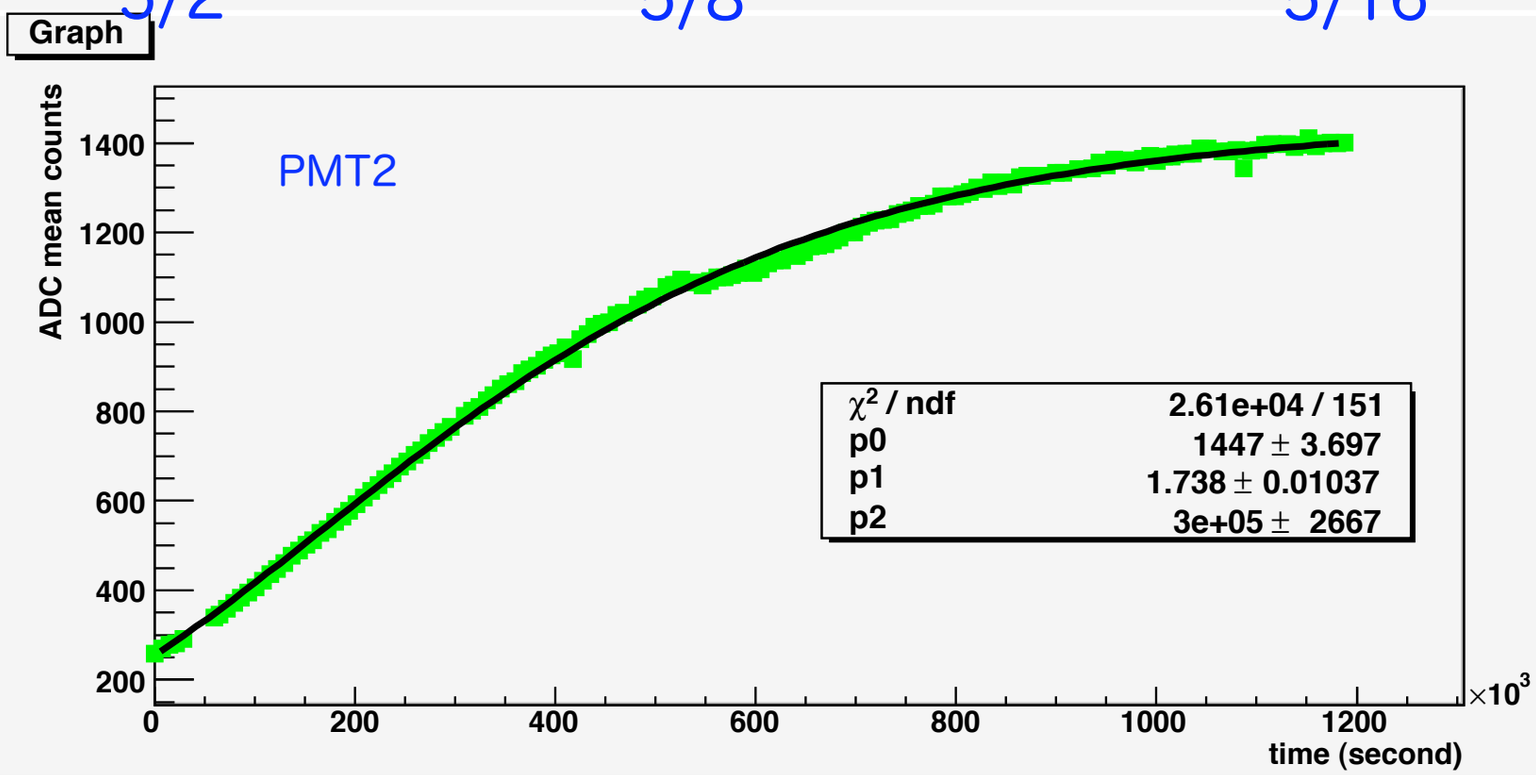
Gas emission rate at the third test is estimated to be Q= 1.4 x 10^{-3}L Pa/s


Scintillation Lights
Pulse Height (m V)
1200
1000
800
600
400
200
0
0
10
20
30
Days since 5/2 12:15
Liquid phase purification @1 ℓ /min
(5/20, 17:40)
Gas phase purification @4 ℓ /min
5/2
5/22

Purification process by scintillation lights in 2 weeks



5/2 5/8 5/16



fitted by

$p(d,t) = p_0 e^{-d/\lambda}$

$\lambda = \lambda_0 e^{t/\tau}$

,where

λ_0 = initial attenuation length and τ = time constant of purification

$p_1 = d/\lambda_0 = 1.75$

$p_2 = \tau = 2.9 \times 10^5$sec

τ = 3.4 days

put d = 5 cm

λ_0 = 2.9 cm

λ =160cm at 14days

Post-amp with LPF , TPC HV= -2KV

20 May 2009

CH1 50.0mV M 10.0µs CH4 ∖ −72.0mV

20-MAY-09 21:21 175.453Hz

Post-amp with LPF , TPC HV=-2KV

integration time =5usec,

1st and 2nd diff. time = 10 and 2 usec

gain=20x4

CH1 20.0mV M 10.0µs CH4 ∕ −460mV

22-MAY-09 14:49 194.291Hz

with LPF

CH1 20.0mV M 10.0µs CH4 ∖ −224mV

24-JUN-09 19:24 182.985Hz

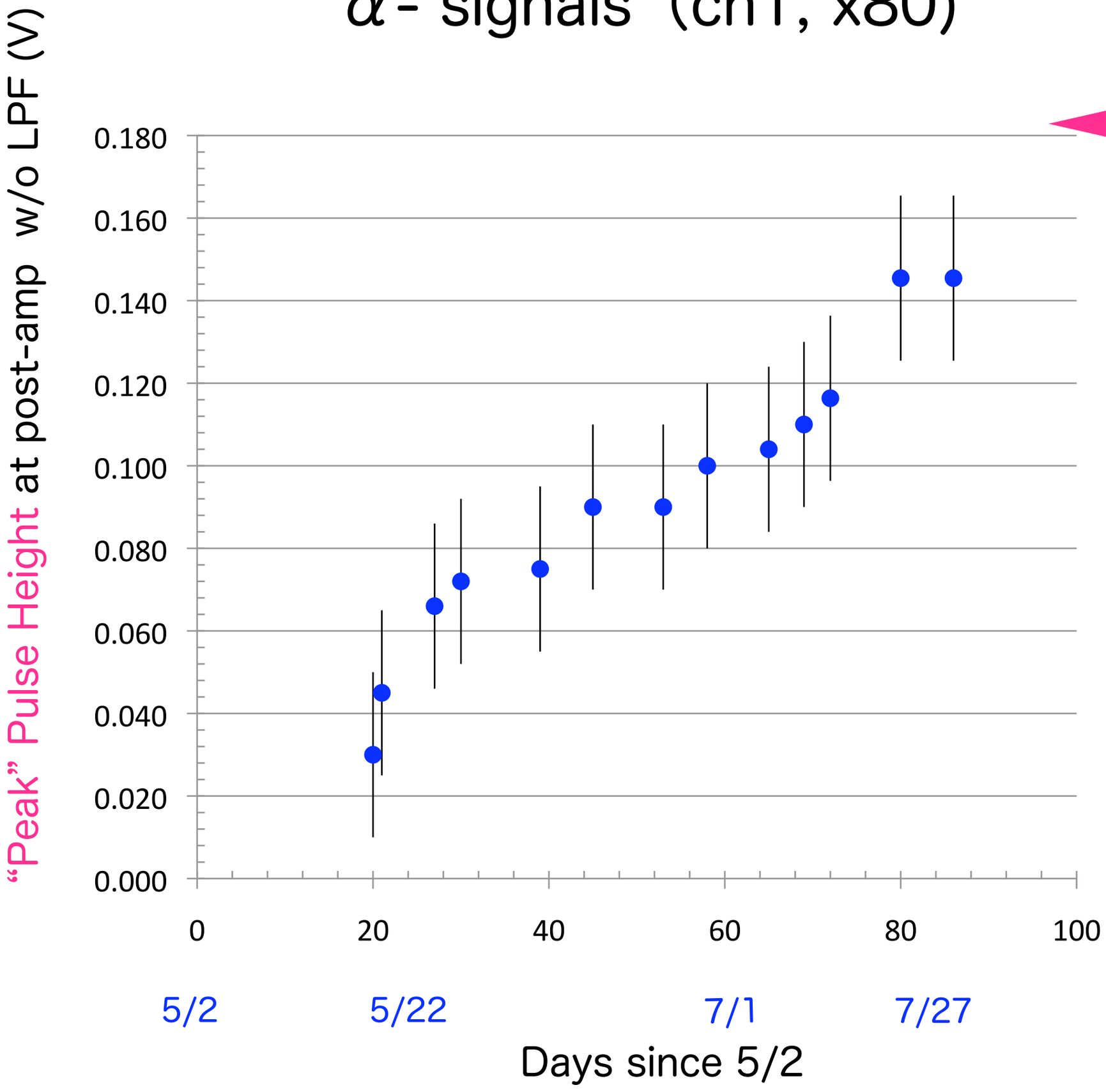
w/o LPF

PMT cross talk

CH1 20.0mV M 10.0µs CH4 ∖ −240mV

24-JUN-09 19:13 213.295Hz

α- signals （ch1, x80)



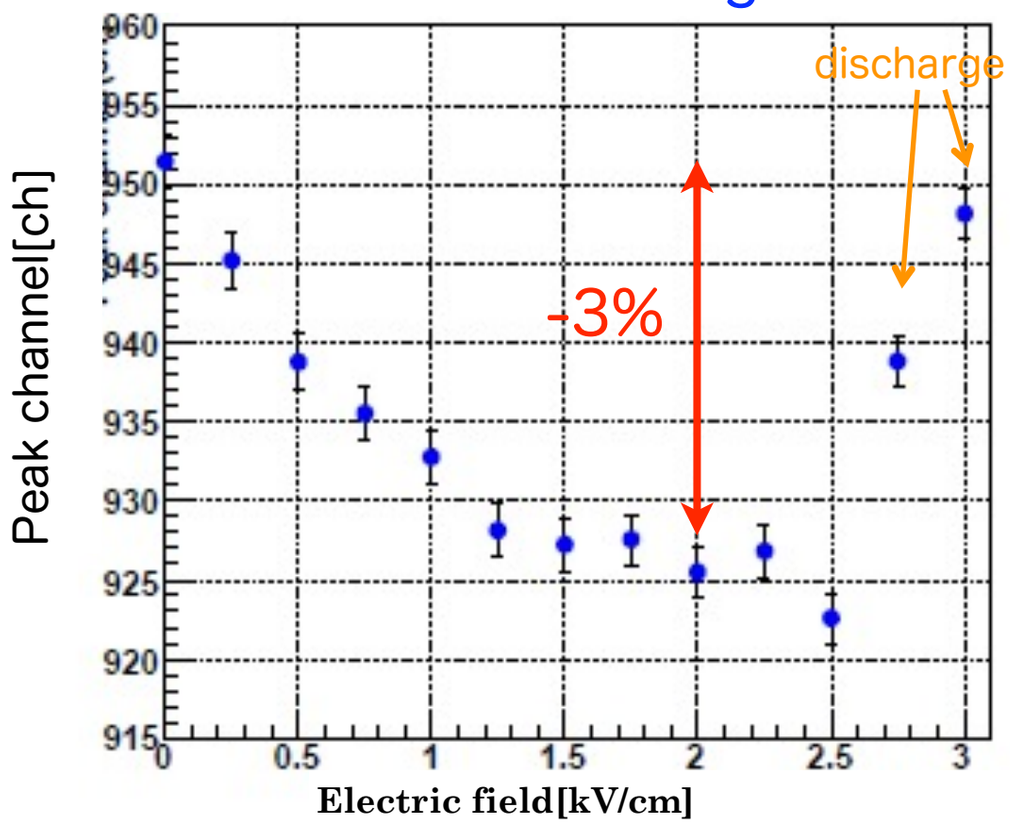
< expectation >
2.3fC
assume Q/Qo=4%
at E=-2kV/cm

note - pulse height : w/o : w LPF = 1.5 : 1

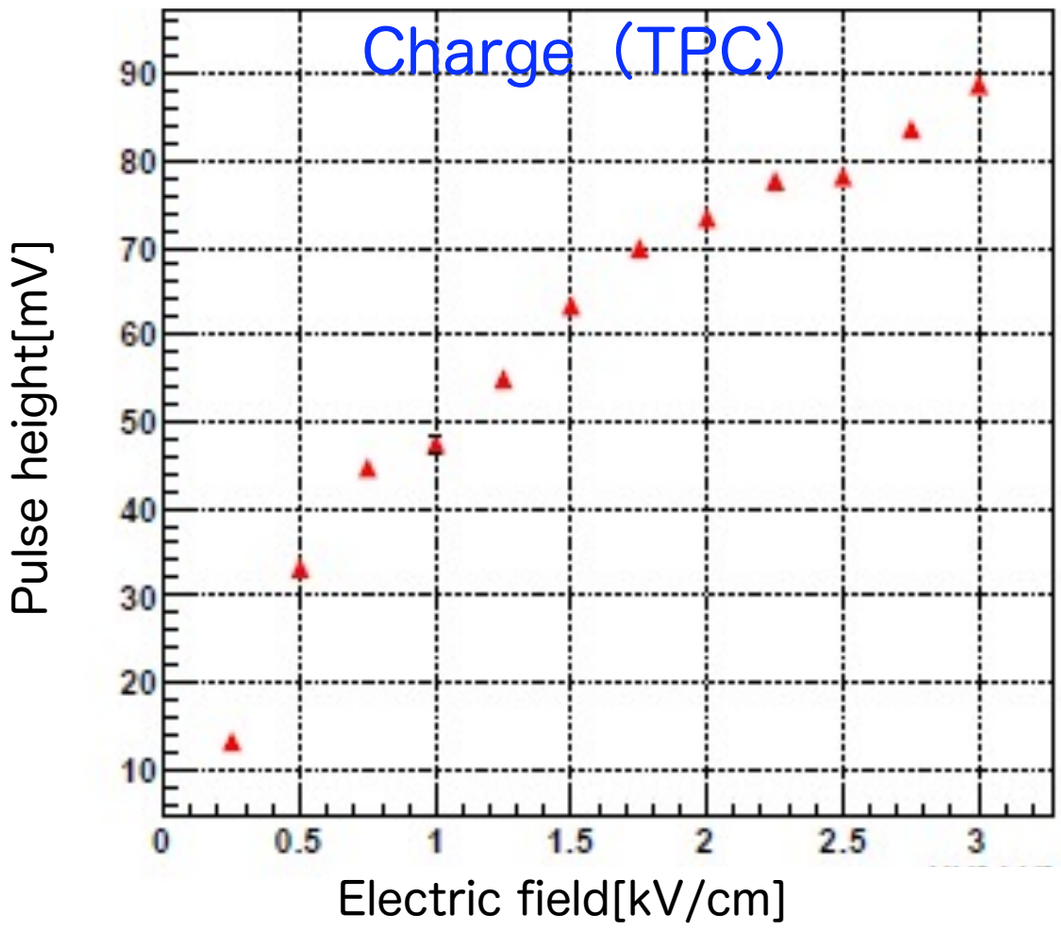
Electric field dependence (α)

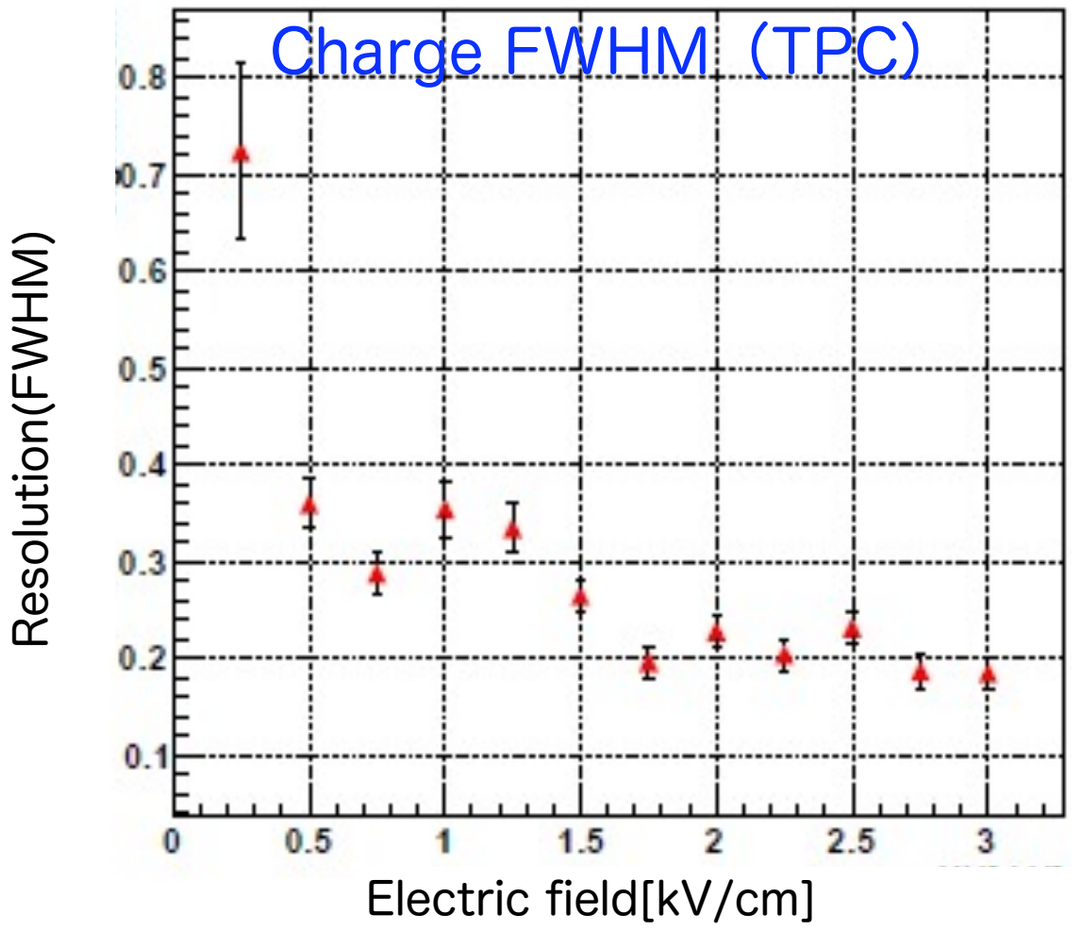
including attenuation due to impurity and drift time (E-field)

Electric field	2kV / 1kV
Scintillation lights	-3% / -2%
Charge	73mV / 46mV =1.6
Charge res. FWHM	0.22 / 0.35 = 0.6

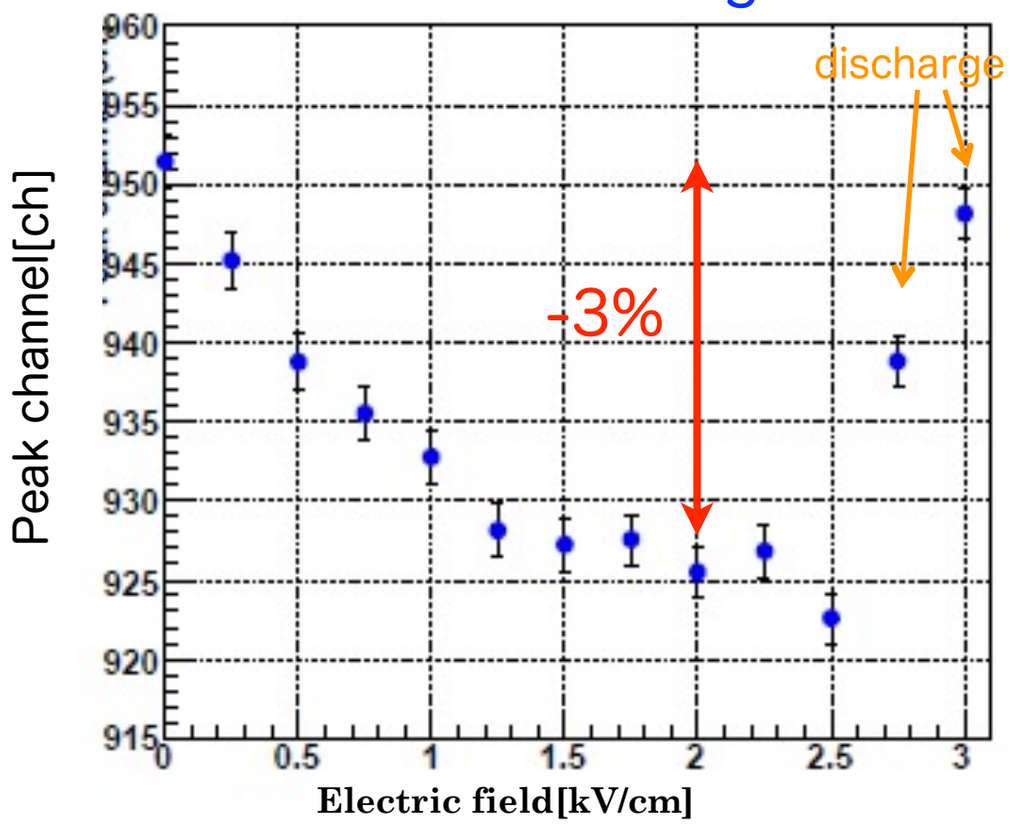


HV vs resolution





Scintillation Lights



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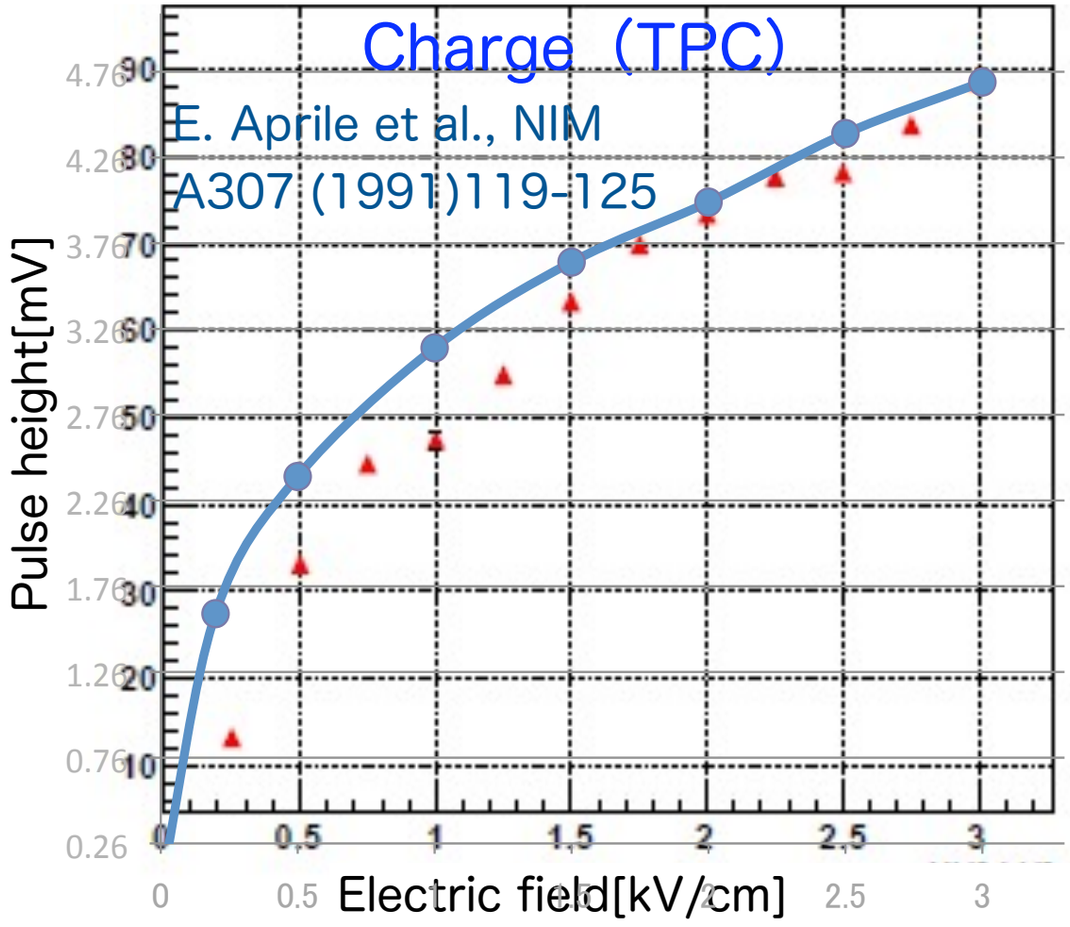
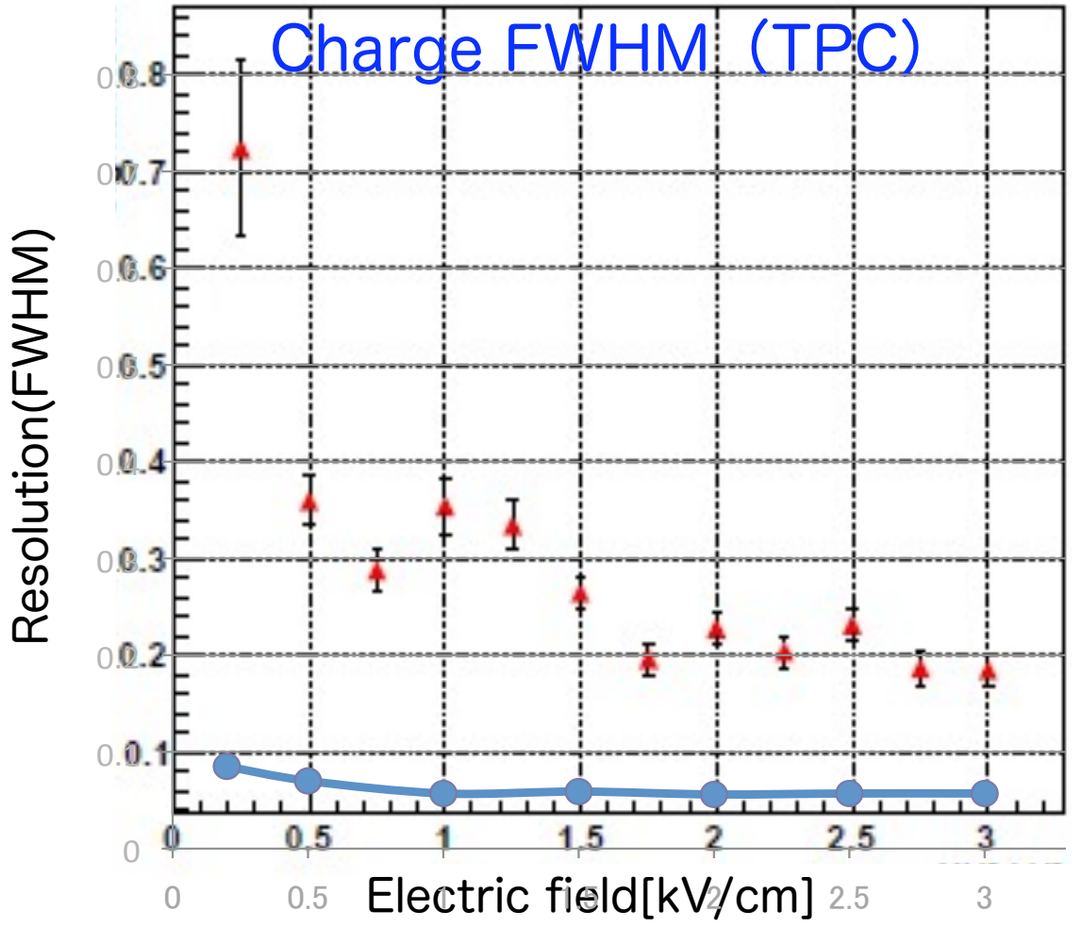
	1.27
Charge res. FWHM	0.22 / 0.35 = 0.6

0.056/0.057= ~1

HV vs resolution





α Trigger

Tek

M Pos: 13.60µs

ORTEC571(6us, x73)

ORTEC572(6us, x73)

ORTEC570(6us, x73)

ORTEC575(3us, x73*)

DISPLAY

表示形式

ライン

表示時間

1秒

軸設定

YT

明暗

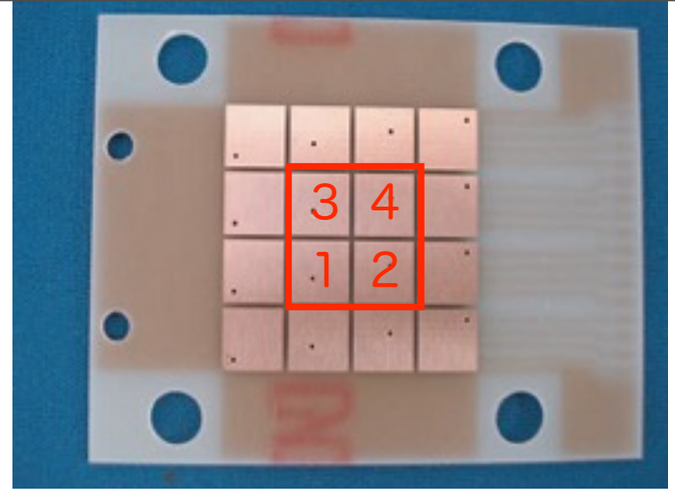
56%

CH1 100mV CH2 100mV M 10.0µs Ext ⌥ -88.0mV

CH3 200mV CH4 200mV 12-AUG-09 19:26 86.1659Hz

2010年 3月 9日 火曜日

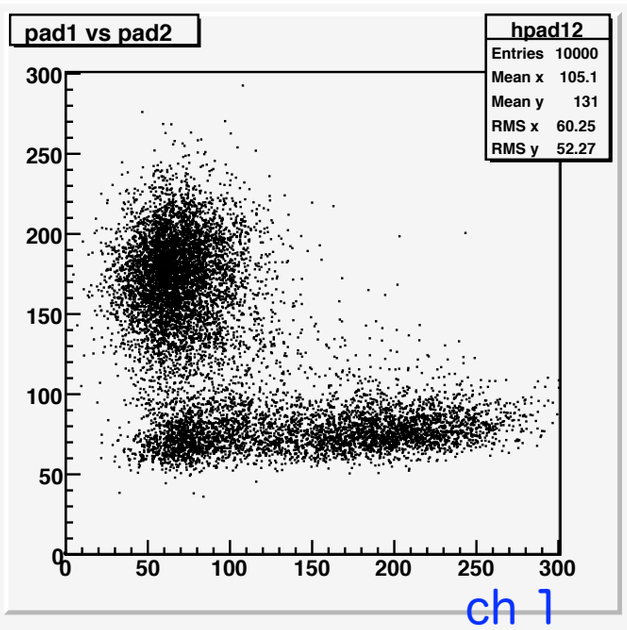
α events

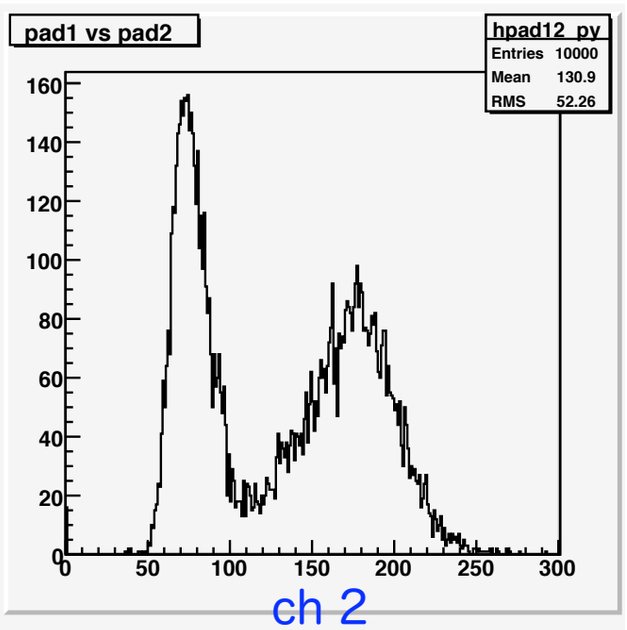


1.1fC measured at the α peak

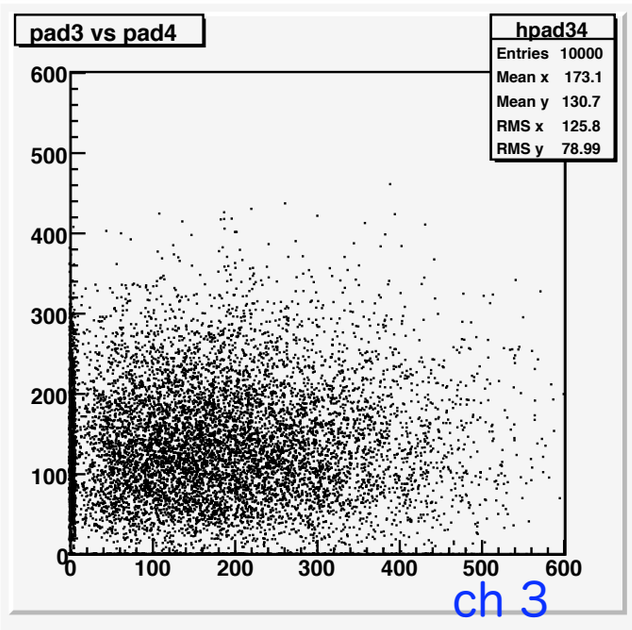
(about 91ppb O_2 eqiv., λ_{att}=15.3mm)

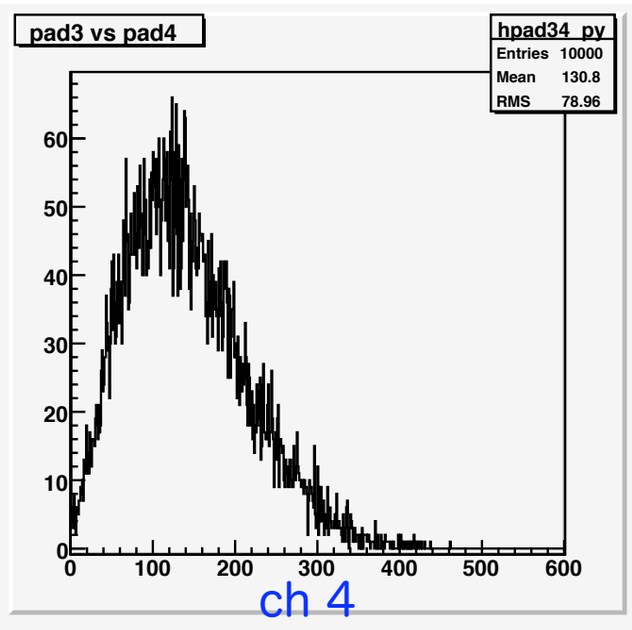
ch 2



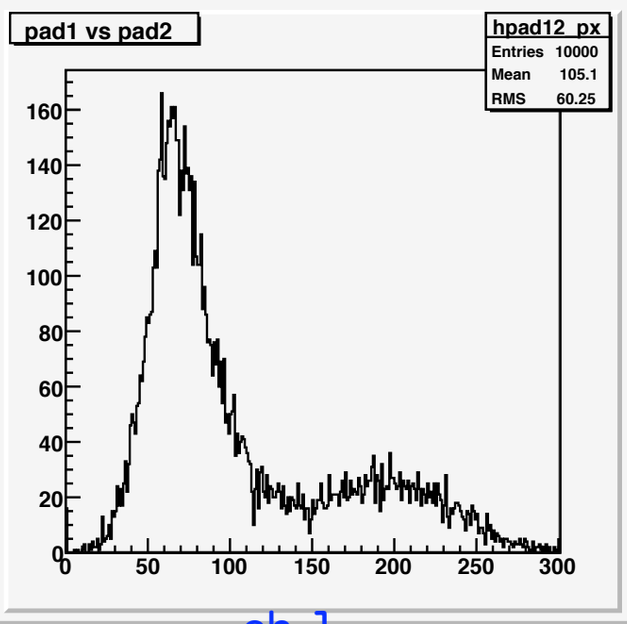


ch 4

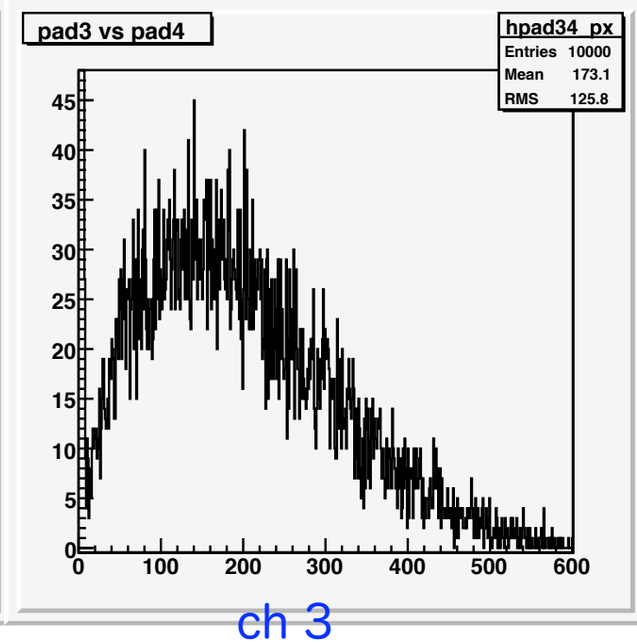




ch 1 ch 2 ch 3 ch 4



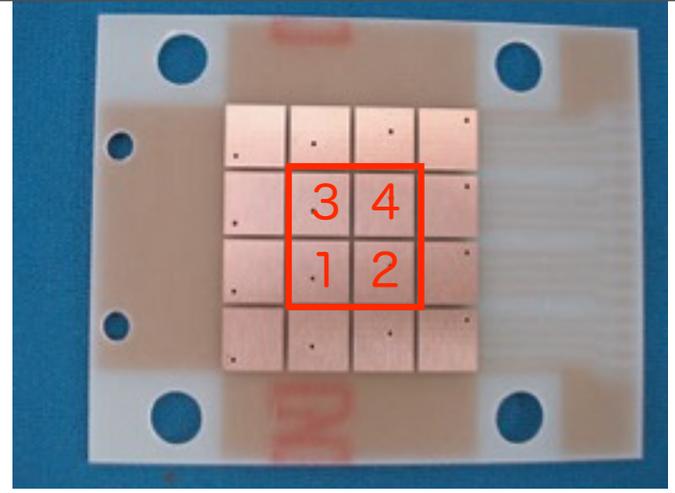
ch 1

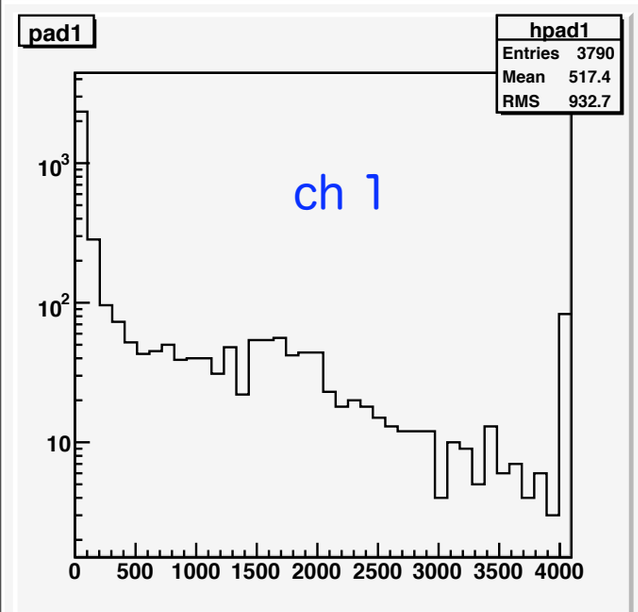


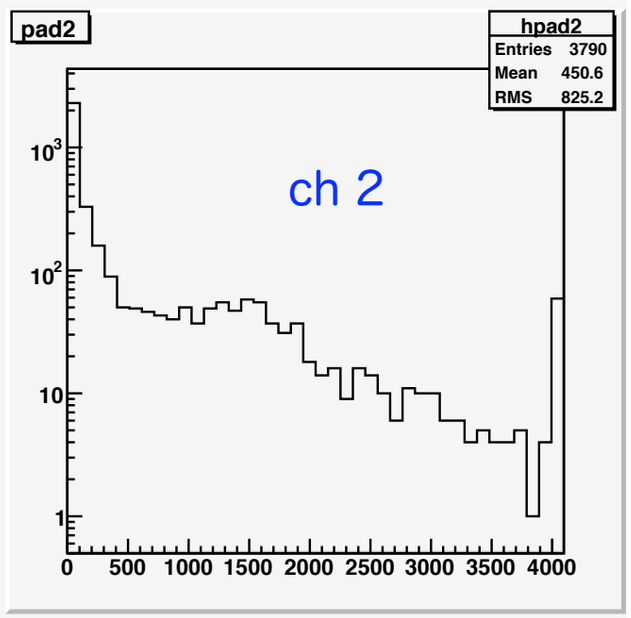
ch 3

Cosmic rays

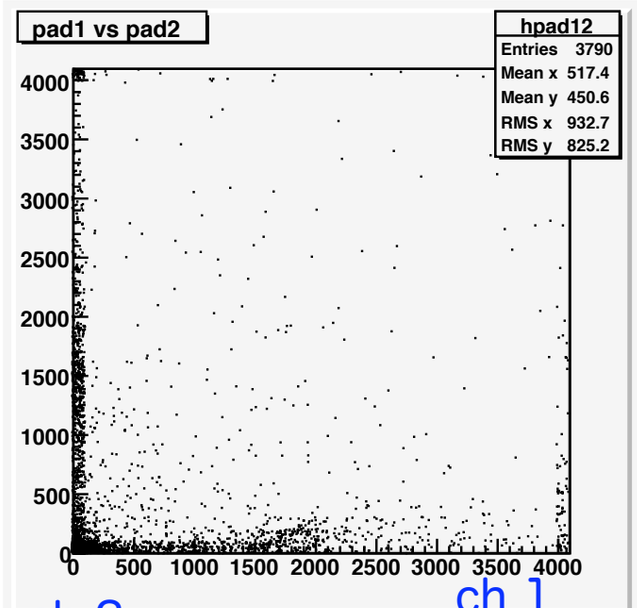
(1) Pulse height





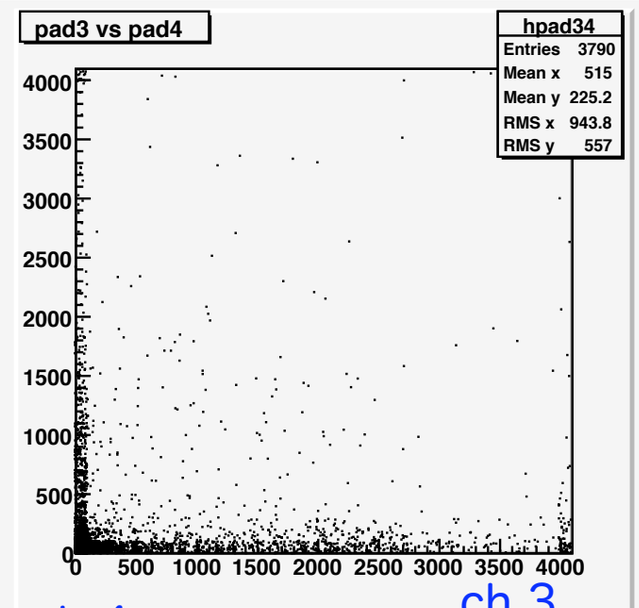


ch 2

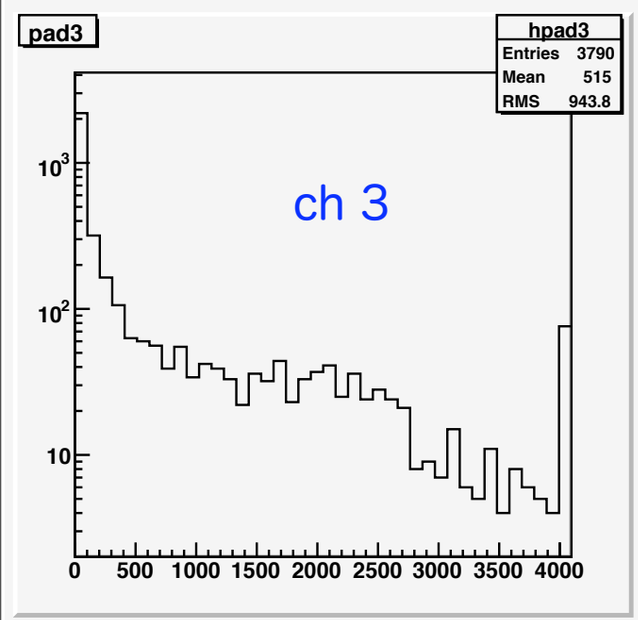


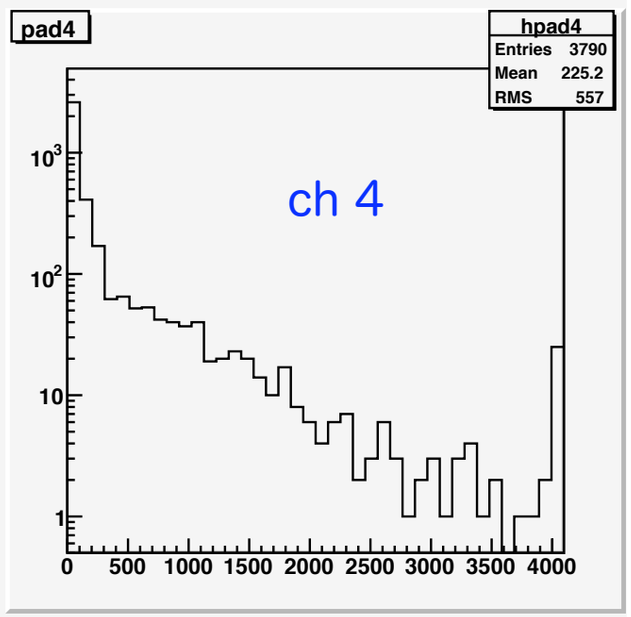
ch 2

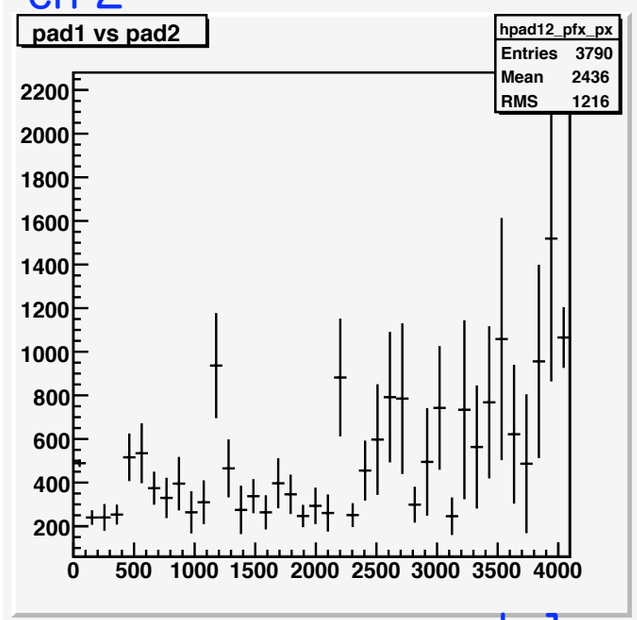
ch 4

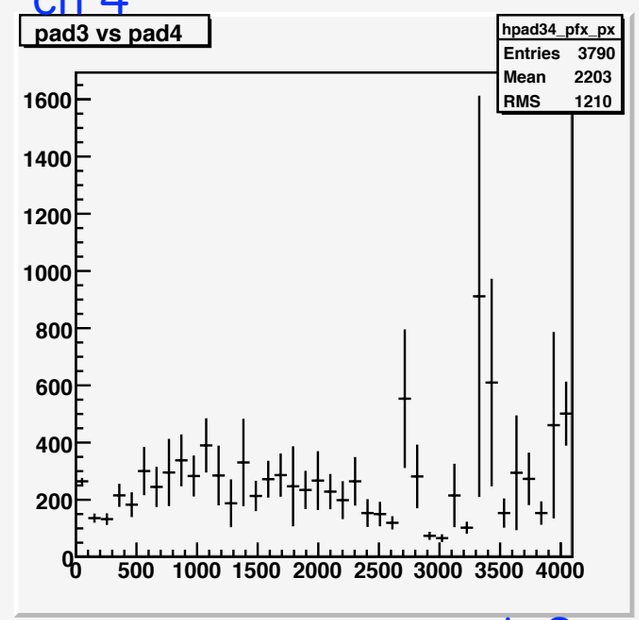


ch 4



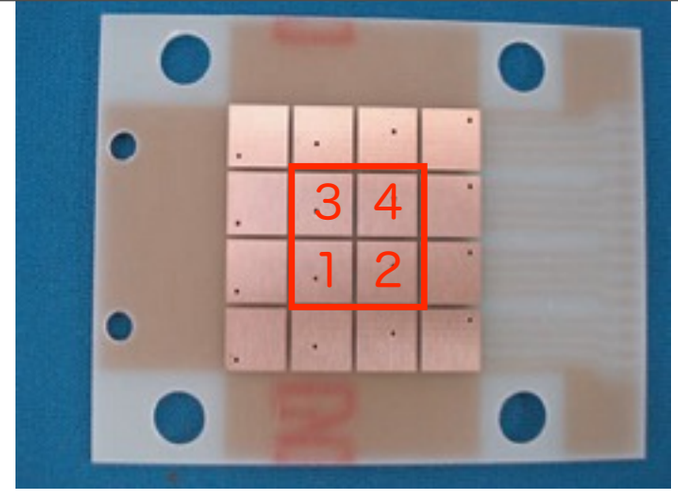




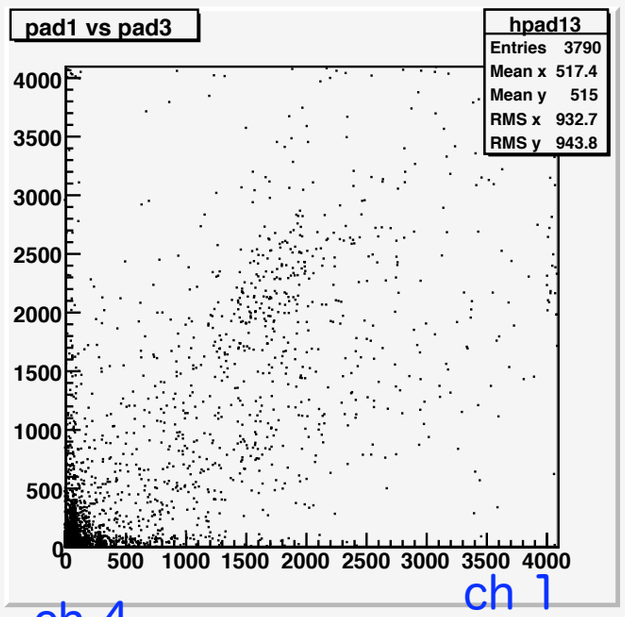


Cosmic rays

(2) Pulse height

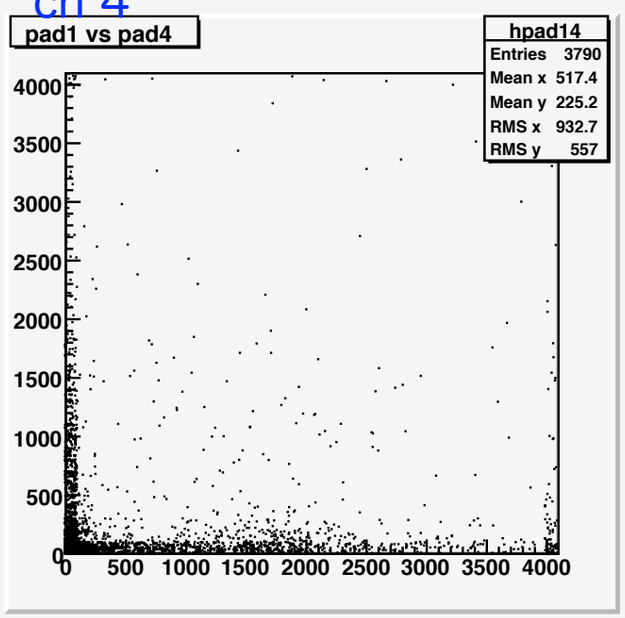


ch 3



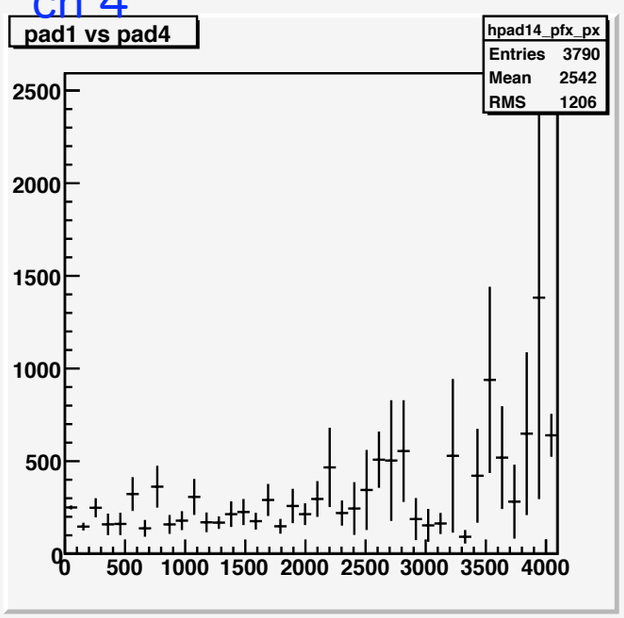
ch 1

ch 4



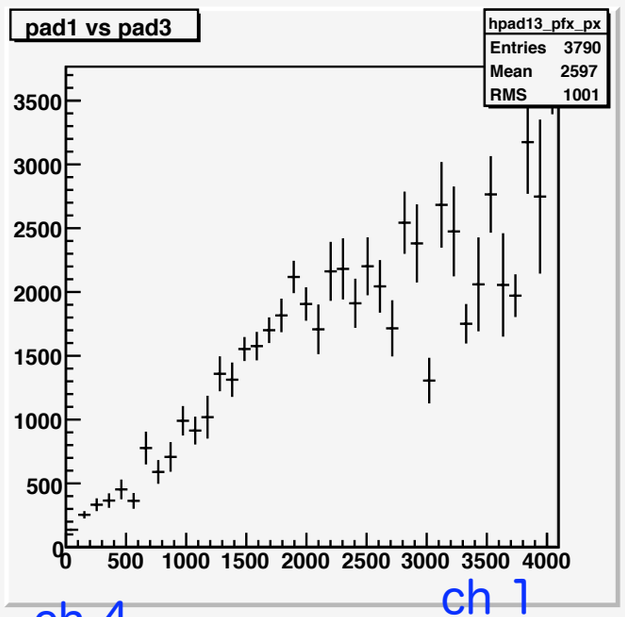
ch 1

ch 4



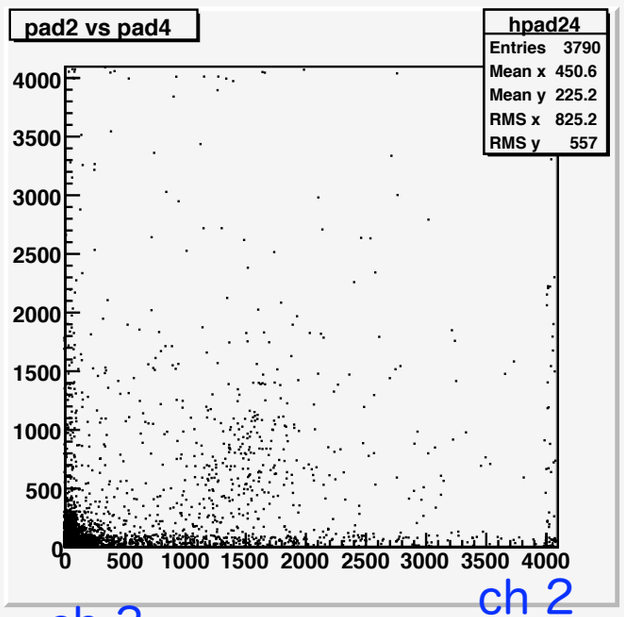
ch 1

ch 3



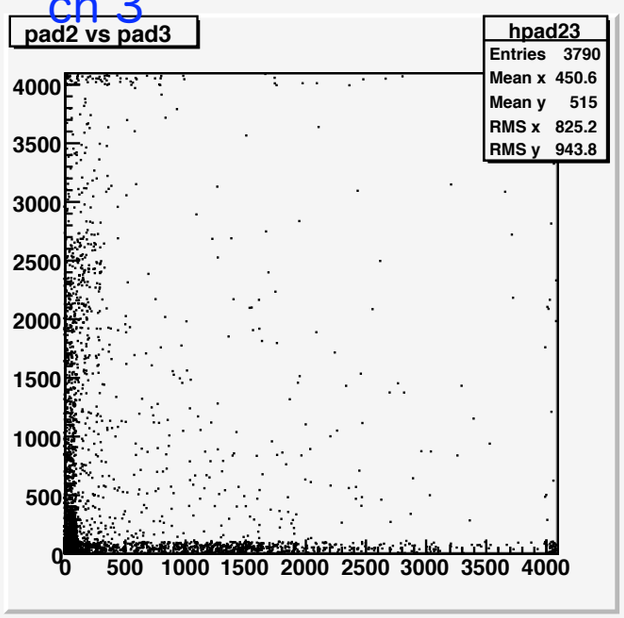
ch 1

ch 2



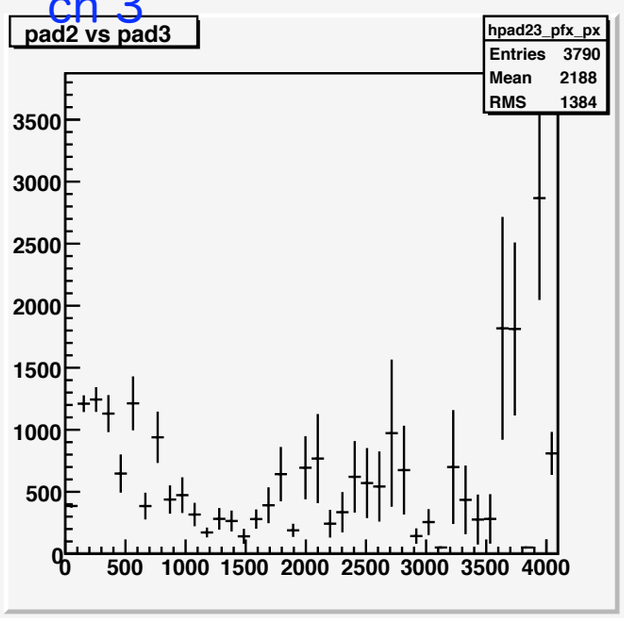
ch 2

ch 3



ch 2

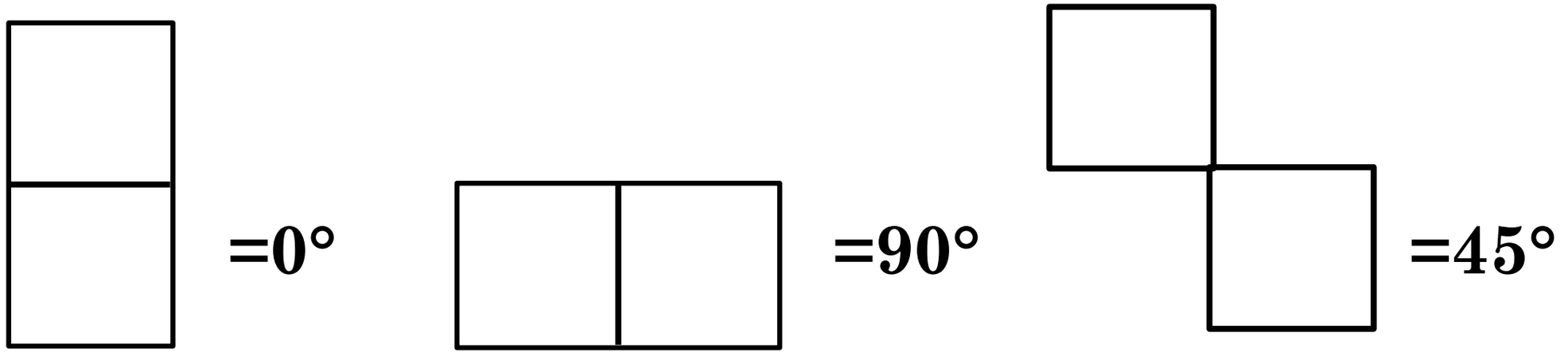
ch 3



ch 2

Demonstration of tracking by using Cosmic Ray Muon (CRM)

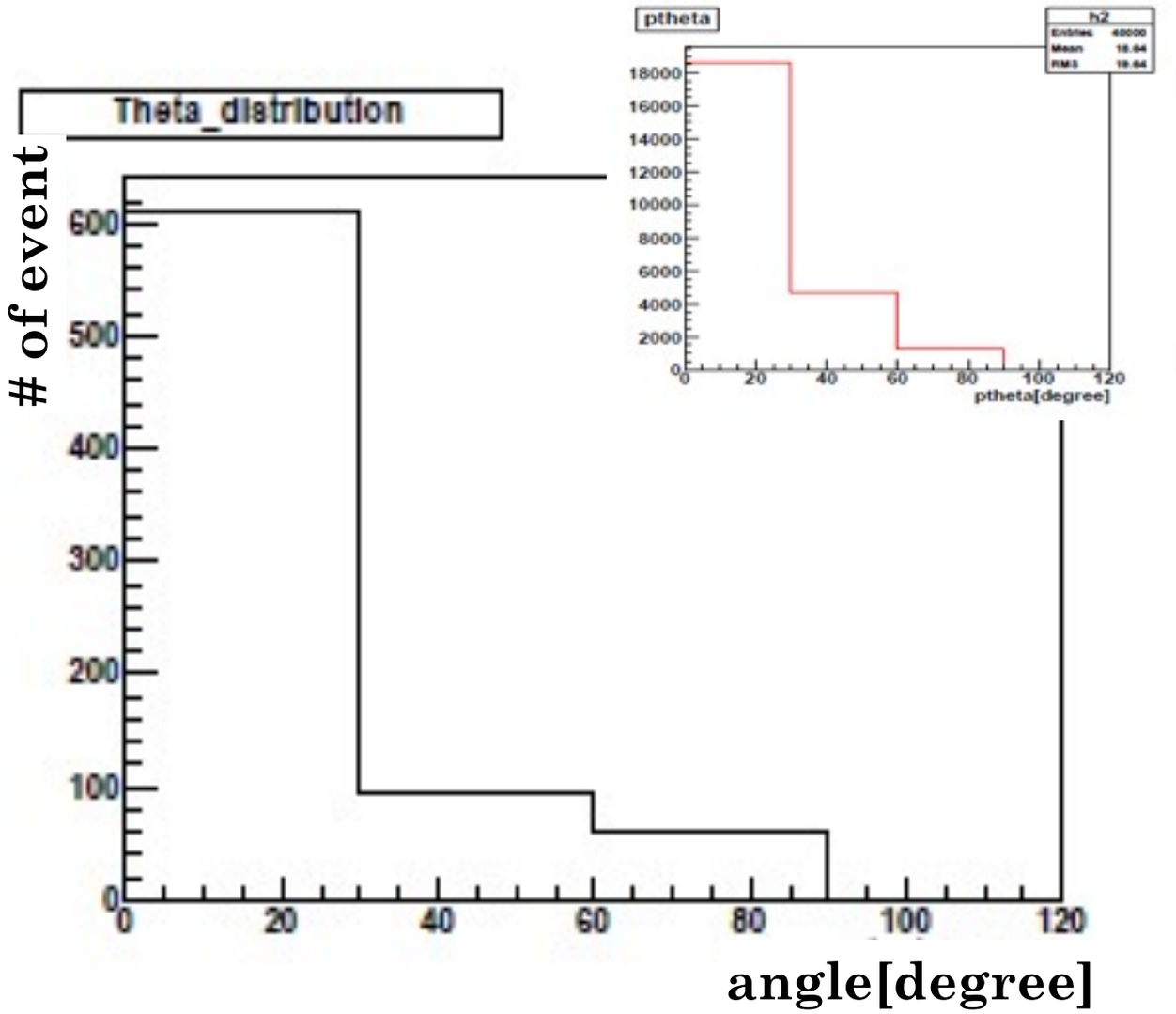
- Analysis of the 4 pad signals
  - Ch 1 and 2 are good, while Ch 3 and 4 are noisy .
  - Cosmic ray muons produce larger signals of > 20fC .
  - Attenuation of charge is small for the 1cm drift-gap .
    - It is about 20% in average for them.
- Zenith angular distribution
  - To show the global characteristics, i.e. compare with $\cos^2\theta$
  - classify events into following 3 patterns



Y. Fujii, JPS fall meeting, Kohnann univ., 9 Oct. 2009

Zenith Angular Distribution of CRM

- Results
  - Sum of charges > 20fC
  - Cosmic ray muons have the zenith angular distribution as a function of $\cos^2\theta$
    - Red histogram shows the distribution with $\cos^2\theta$ (Monte Carlo), where the azimuthal angles are integrated.
  - Consistent distribution was obtained.

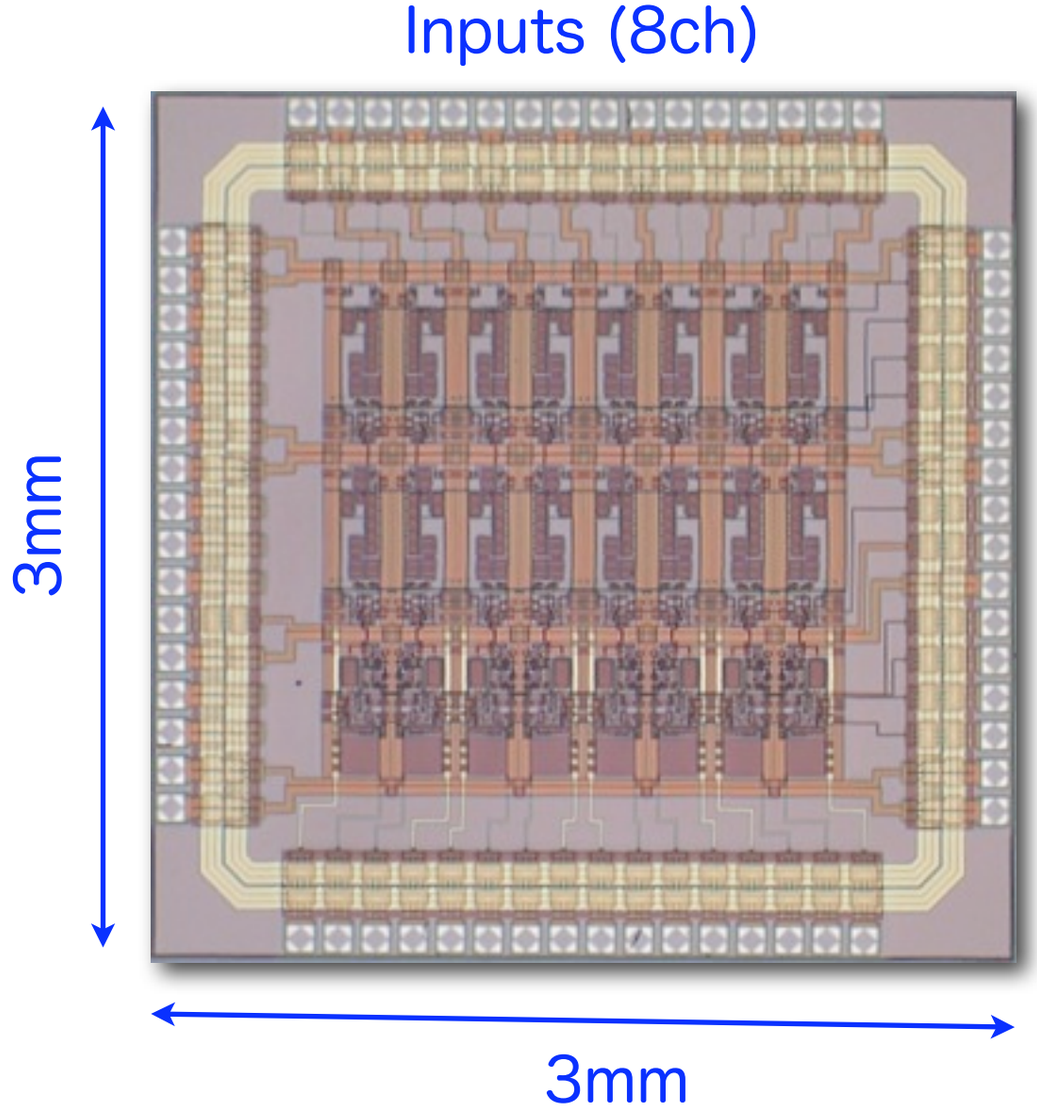


Y. Fujii, JPS fall meeting, Kohnann univ., 9 Oct. 2009

Front-end ASIC chip R&D

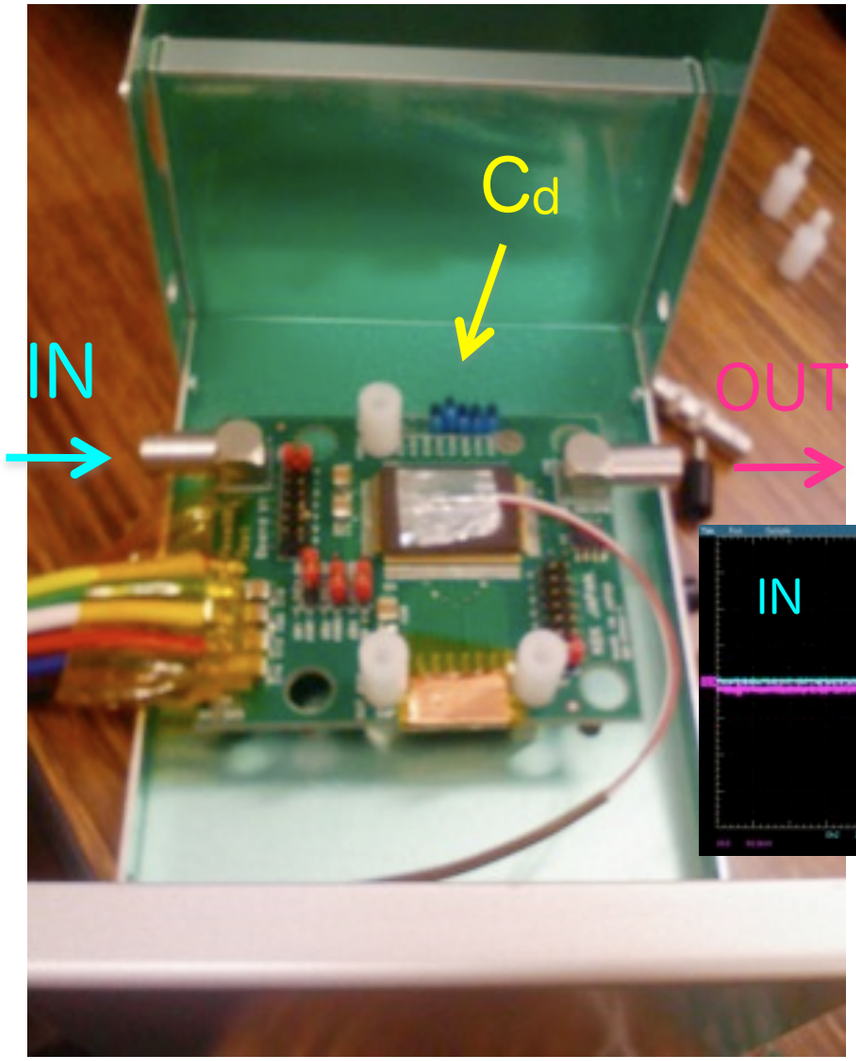
Pre-amp. to PZC to shaper - output all analog channels

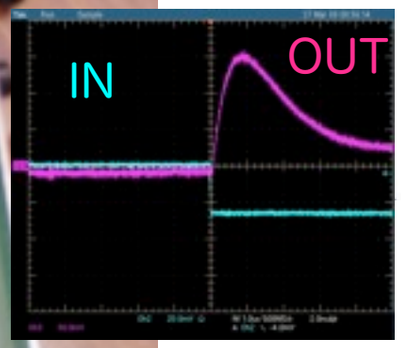
PARAMETER	SPECIFICATION	Achieved
chip size	3mm x 3mm	
channel number	8	
power supplies	±2.5V	
dissipation power	<10mW/ch	
gain	8.2V/pC	6.0±0.5V/pC
Input charge	±25fC	-60~100fC
peaking time	0.5, 1us, variable(>1us)	
prod. process	0.5um CMOS	
ENC	2,000e (C_d=1pF)	400e (C_d=1pF)

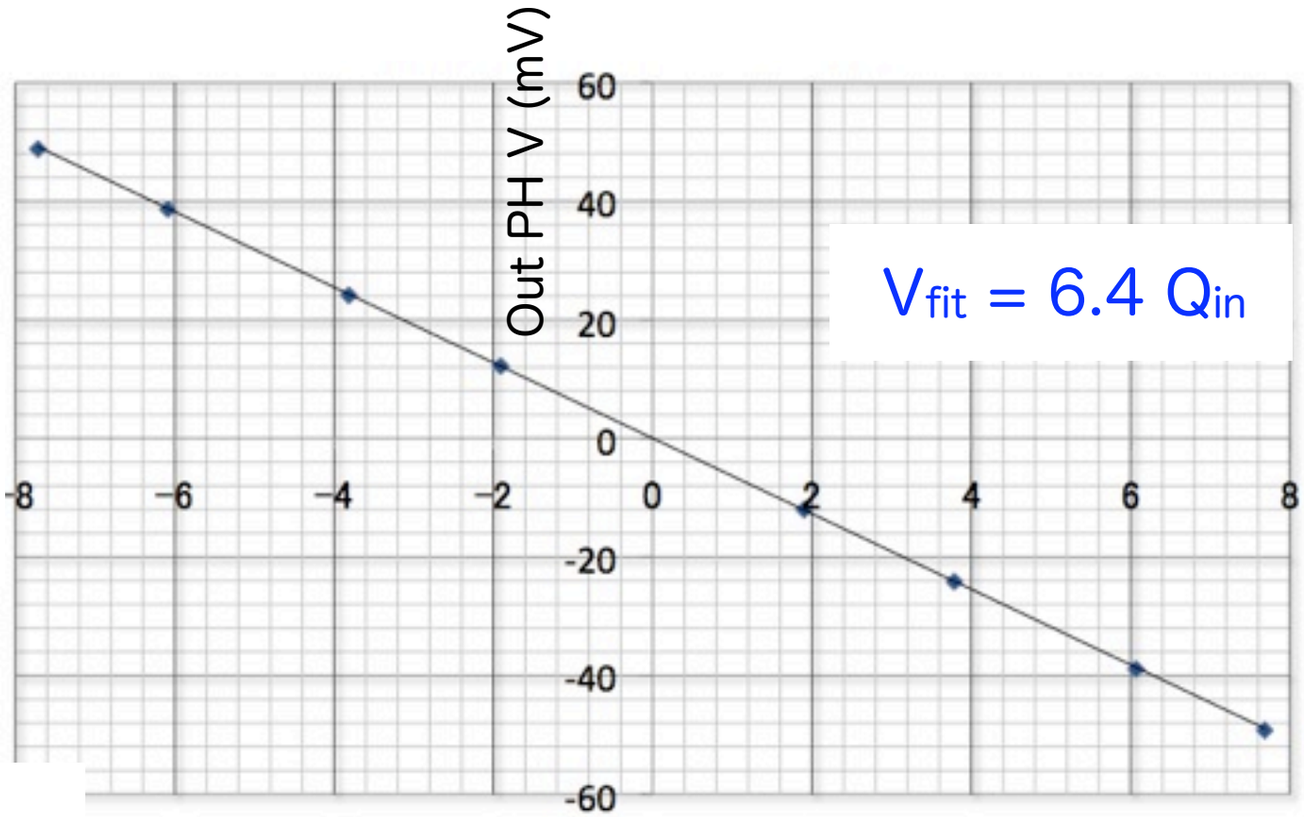


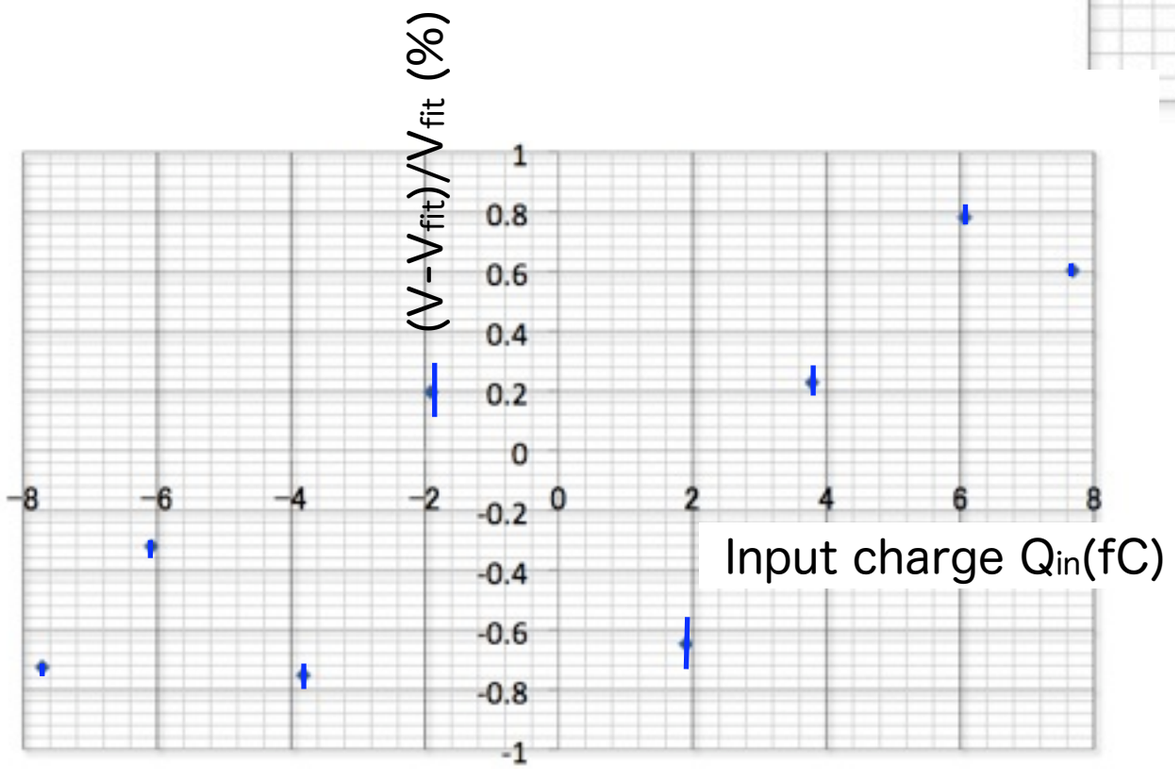
T. Higashi, JPS fall meeting, Kohnann univ., 9 Oct. 2009

Test results : Linearity









Since σ of V (out) is about 1mV ;

σ=1mV/(6.4mV*Qin)

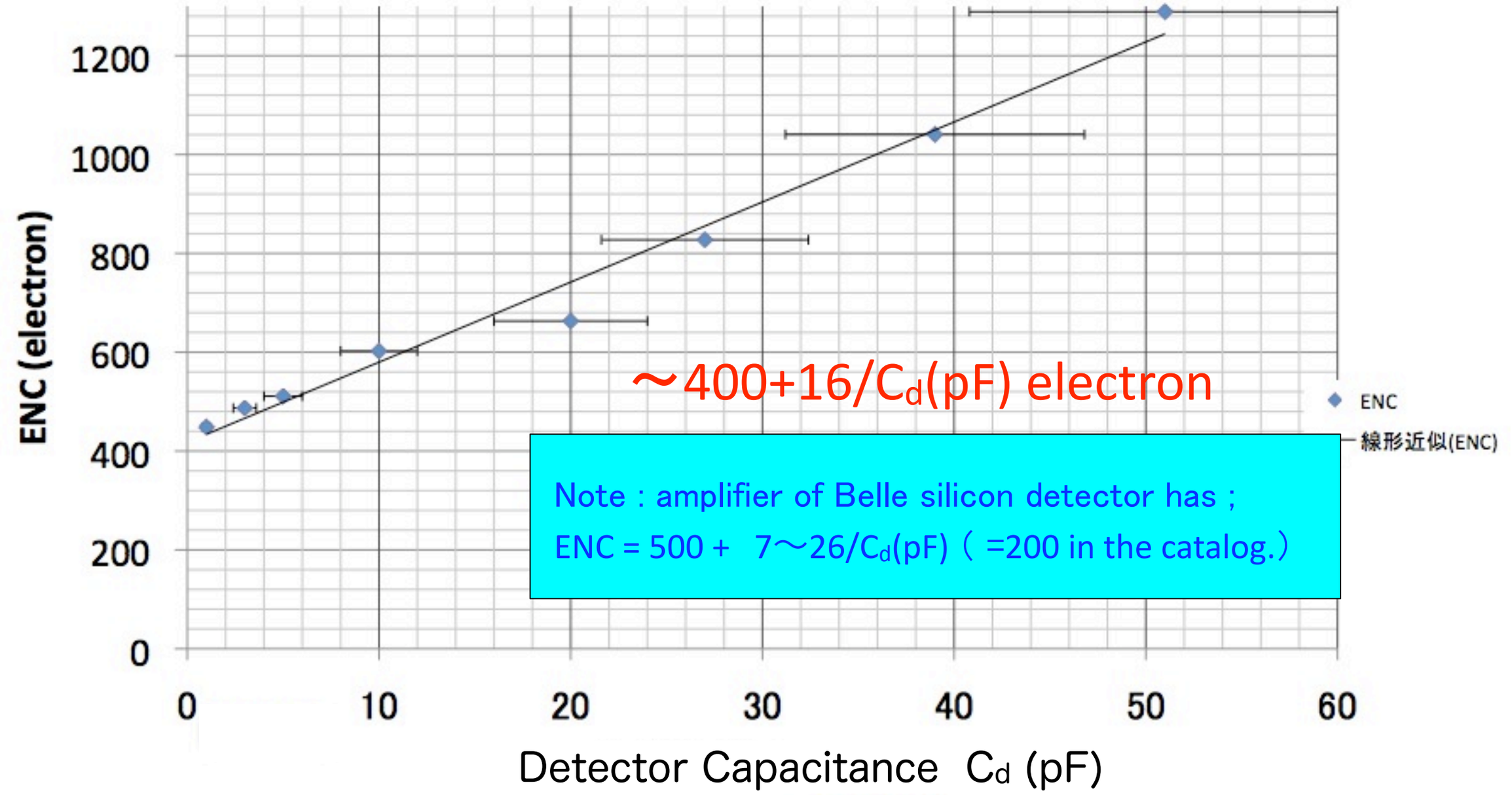
σ= 0.16/Qin[fC]

In Qin of -8 ~ 8 fC ,

Non-linearity is less than 0.8%.

T. Higashi, JPS fall meeting, Kohnann univ., 9 Oct. 2009

Equivalent Noise Charge (ENC) in room temp

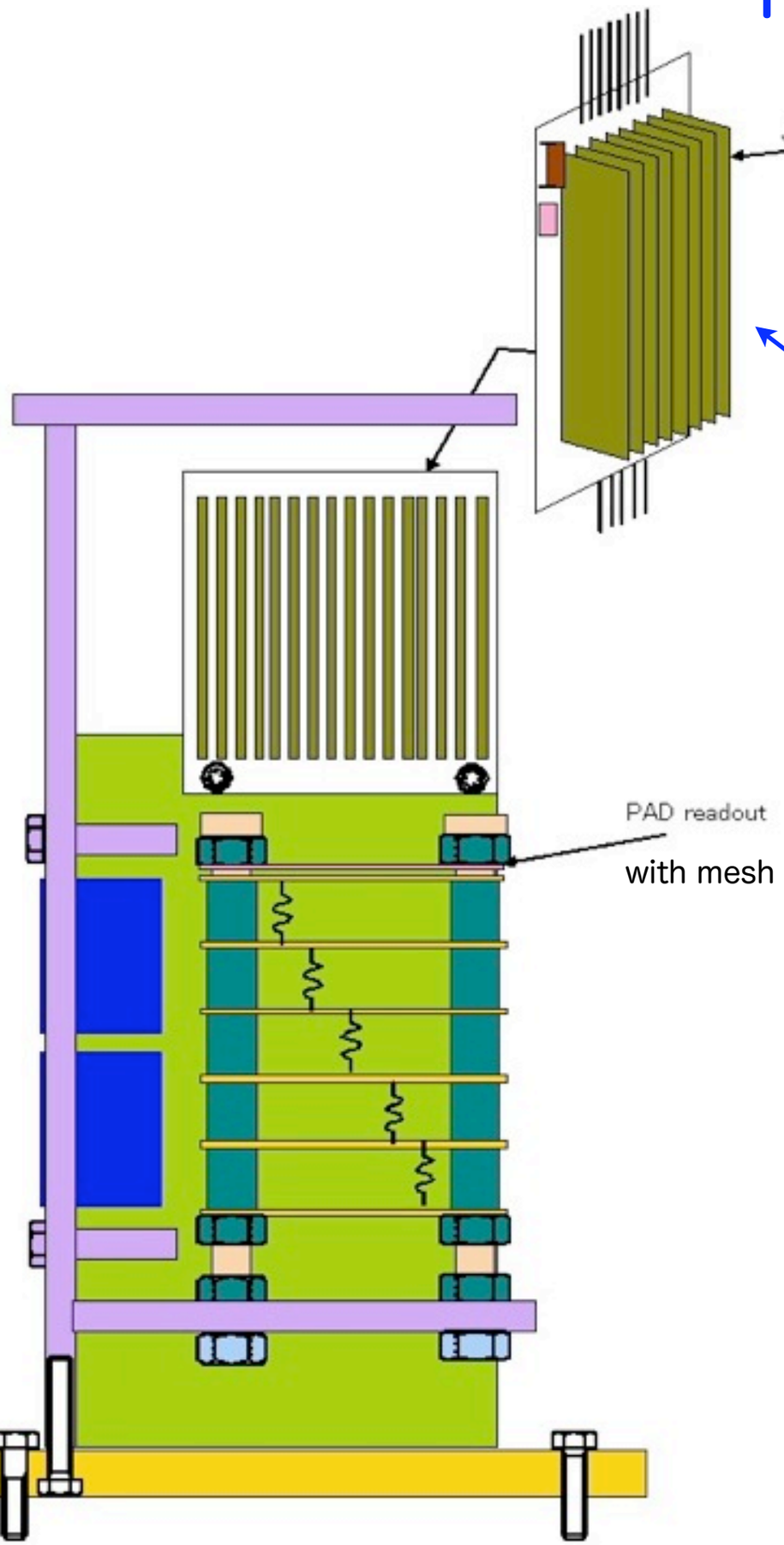


note : accuracy of ceramic condenser is ±20%

note : ENC ∝ $C_d / \tau^{1/2}$, where τ =1us

T. Higashi, JPS fall meeting, Kohnann univ., 9 Oct. 2009

Next Experiment



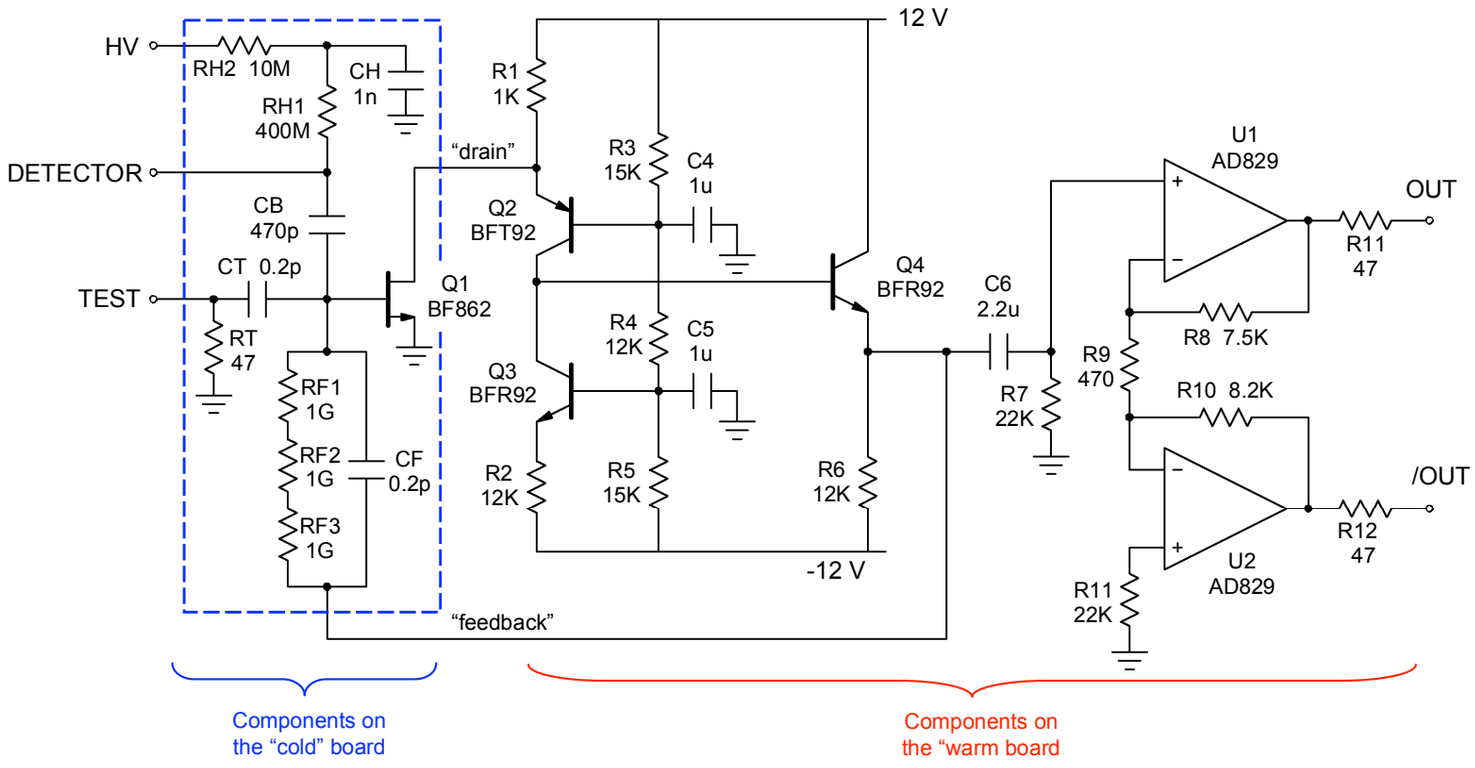
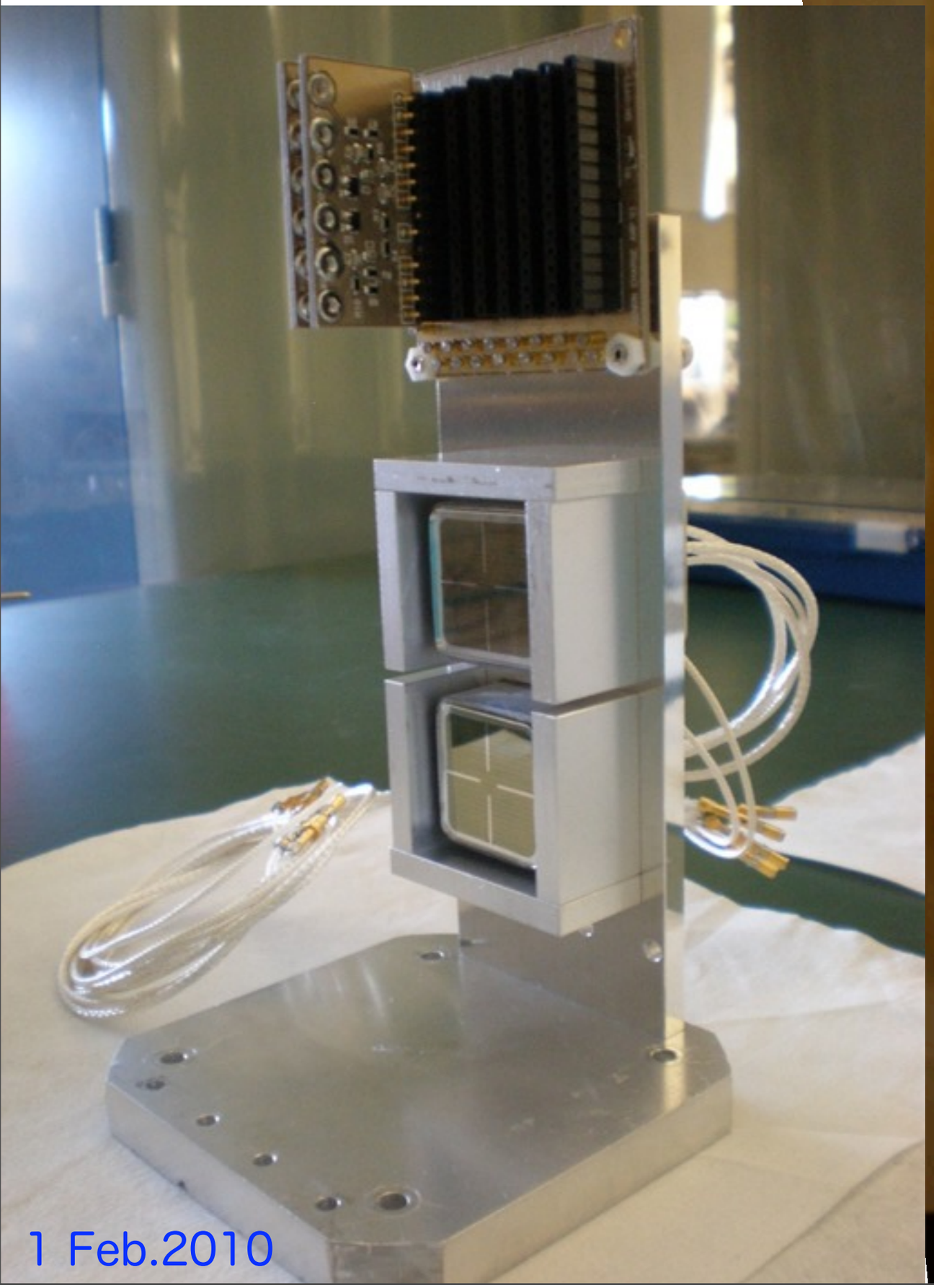
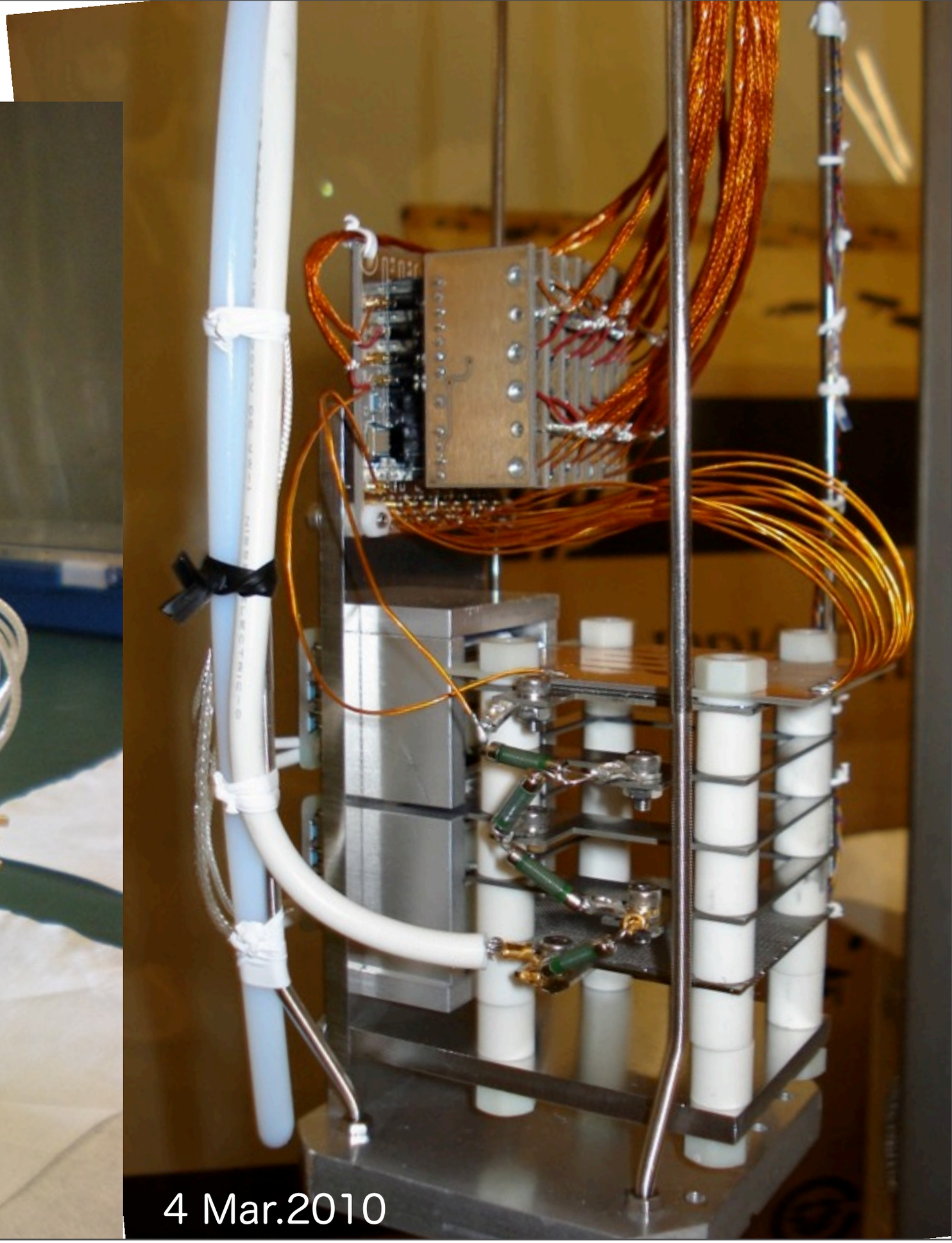


Fig. 3. Simplified schematic diagram of the charge sensitive preamplifier.

"A Cold Low Noise Preamplifier for Use in Liquid Xenon", A. Pullia et al.

Present Status





Next run : 5cm drift with grid(mesh) &16 pad readout

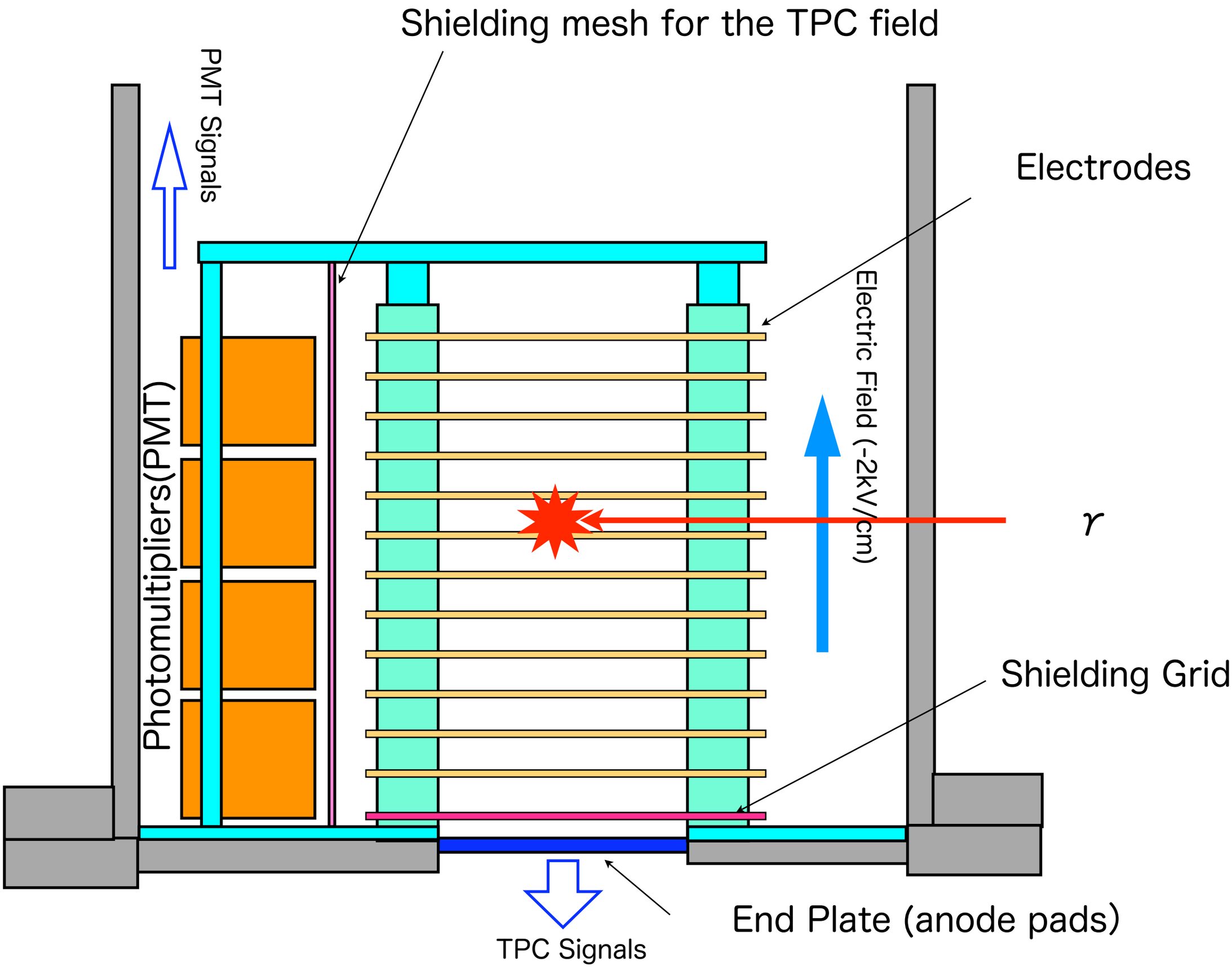
Jan. Feb. Mar. 2010

ID	タスク名	期間
1	**作業準備**	**5日**
2	クリーンブース片付け	1日
3	配管取り外し	1日
4	外真空容器取り外し	1日
5	クライオスタット移動	1日
6	内真空容器取り外し	1日
7	**検出器解体**	**5日**
8	電気配線取り外し	1日
9	検出器取り外し	2日
10	検出器解体	2日
11	**PMTフレーム取り付け**	**5日**
12	部品準備、確認	1日
13	フレーム、ネジ洗浄	1日
14	PMT取り付け	3日
15	**電極組み上げ**	**5日**
16	部品準備、確認	1日
17	部品洗浄	1日
18	電極取り付け	3日
19	**内部配線**	**8日**
20	部品準備、確認	1日
21	部品洗浄	1日
22	**はんだ付け**	**5日**
23	PMT	1日
24	パッド→プリアンプCold Pa	1日
25	プリアンプColdPart入出力	3日
26	洗浄	1日
27	**プリアンプCold Part**	**18日**
28	納品	0日
29	検品	1日
30	常温試験	10日
31	プリアンプ取り付け	2日
32	**検出器取り付け**	**5日**
33	支持用スタッド調整	1日
34	取り付け	1日
35	フィードスルー配線準備	2日
36	内部配線	1日
37	**試験準備**	**18日**
38	内真空容器取り付け	1日
39	クライオスタット移動	1日
40	外部配線	3日
41	常温試験	5日
42	外真空容器取り付け	1日
43	真空引き	7日

2010年 3月 9日 火曜日

Conclusions

1. Charge signals of both cosmic ray and α sources were detected with a commercial pre-amplifier.
2. Purification process was monitored and understood by scintillation light and charge signals. The preliminary estimation is about 90 ppb (O_2 equiv.) with circulation in 2 months, which will be improved in next time.
3. Next, we will measure 16ch-pads with 5cm drift in TPC .


Shielding mesh for the TPC field
PMT Signals
Electrodes
Photomultipliers(PMT)
Electric Field (-2kV/cm)
r
Shielding Grid
TPC Signals
End Plate (anode pads)

TXePET prototype image

PMT 4 x 8
Matrix
24cm drift