

液体キセノン検出器TPPCのR&D

次世代PETに向けて

(TXeTPC)

高エネ研：田内利明

KEK測定器開発室・液体キセノングループ

佐賀大学、東京大学、放医研、横浜国大、KEK

研究会『電離及びシンチレーション検出器の基礎物理と暗黒物質探索への応用』，早稲田大学、2009年9月18日

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：冷凍・純化システム、PMTシステム、TPC、テスト

田内利明、真木晶弘、春山富義、田中秀治、三原智、佐伯学行
笠見勝裕(冷凍システム構築)、鈴木祥仁 (モニター:Labview)

佐賀大：TPC、TPC/PETシミュレーション、テスト

杉山 晃、東貴俊 (D3)

東大：TPCテスト

森俊則、藤井祐樹 (M1)

放医研：PETとしての性能仕様とシミュレーション

熊田雅之、富谷武浩、寅松千枝

横浜国大：液体キセノン基本特性

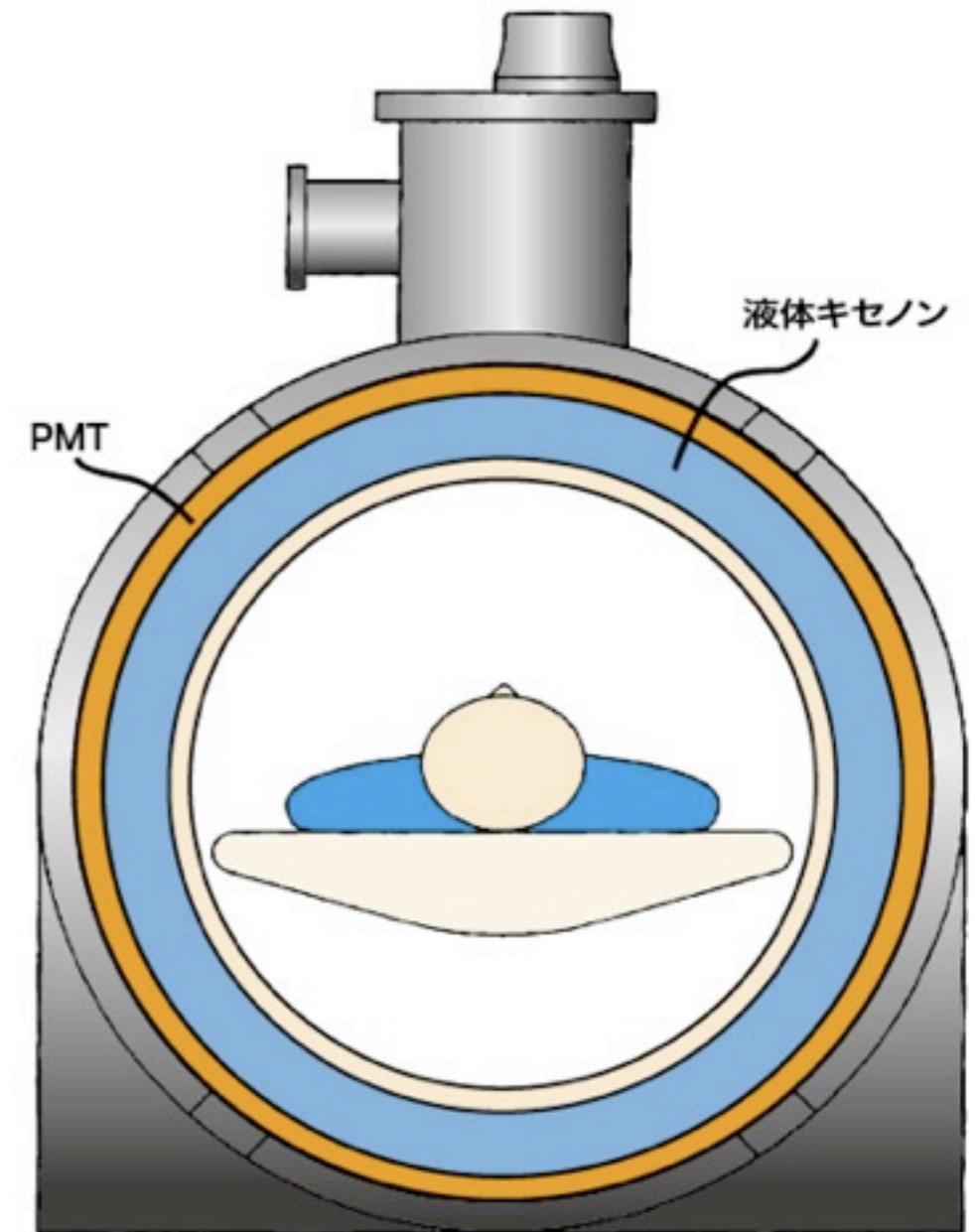
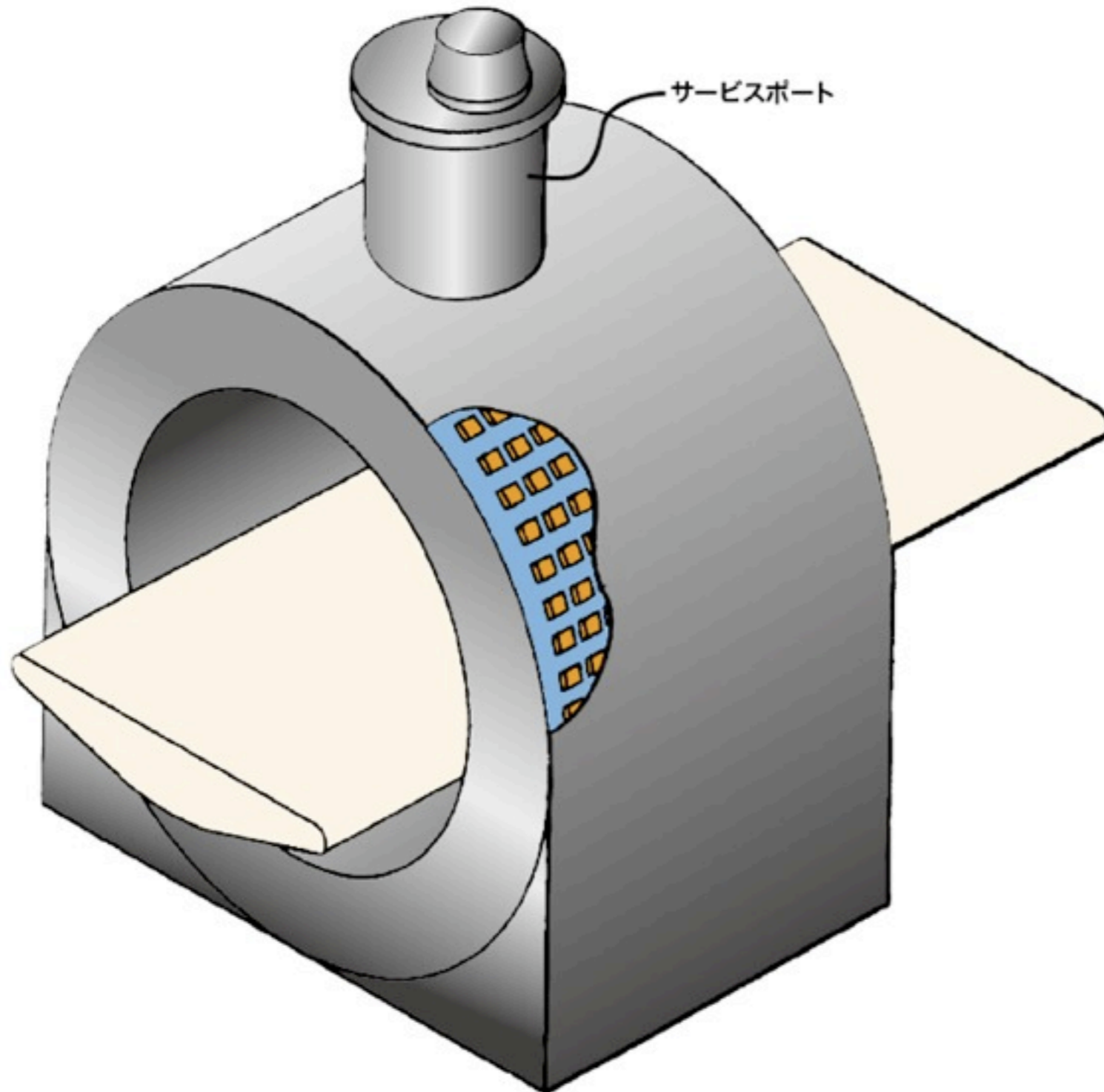
中村正吾

協力支援：KEKエレクトロニクスシステムG、田中真伸氏

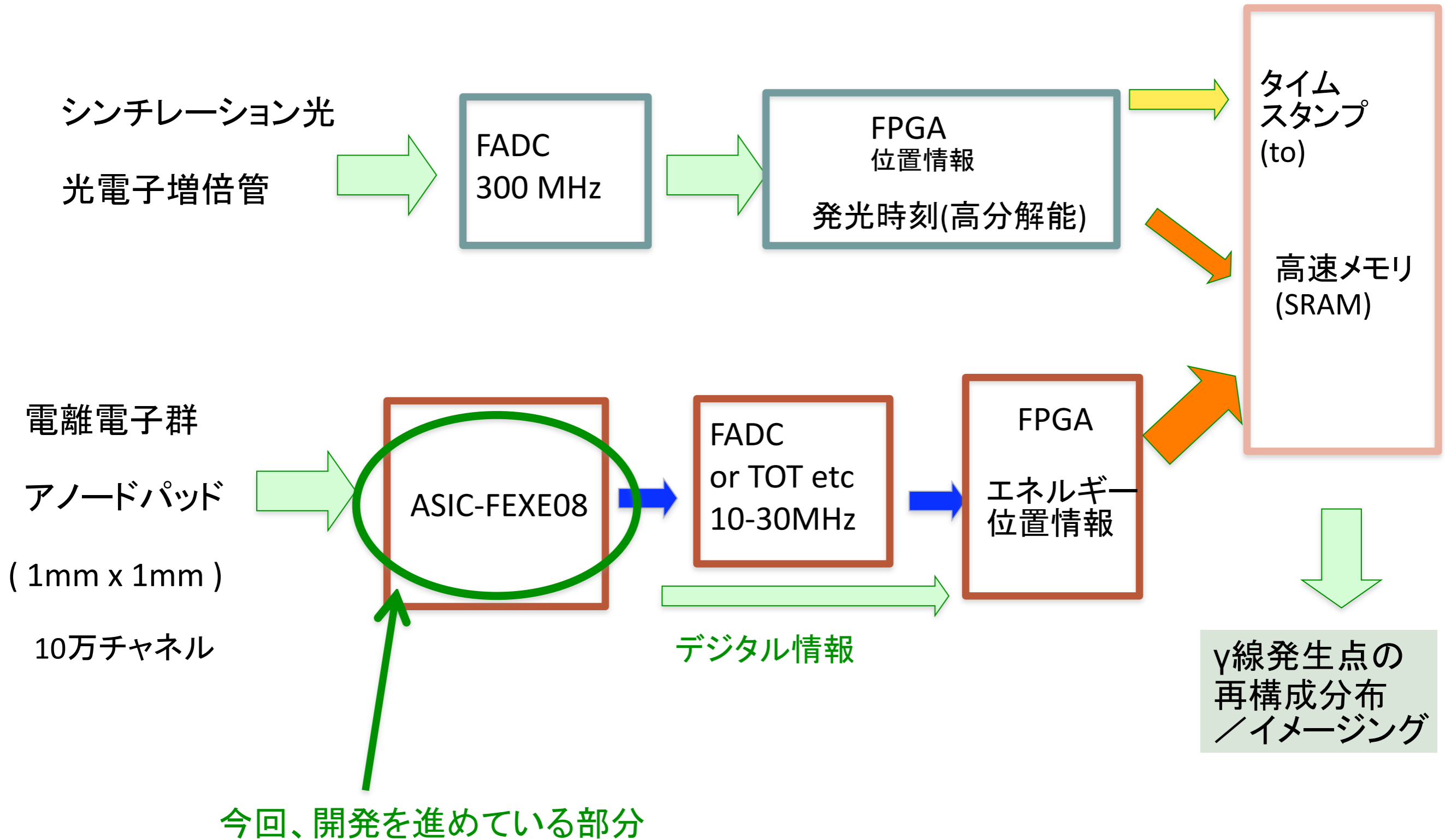
レビュワー：宮島光弘氏 (早稲田大)、海野義信 (KEK)

Next-generation PET with LXeTPC

TXePET



エレクトロニクスシステム



支援：KEKエレクトロニクスシステムグループによるASIC製作教育プログラム

Previous Activities

2007.4 Proposal to KRKDTP

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

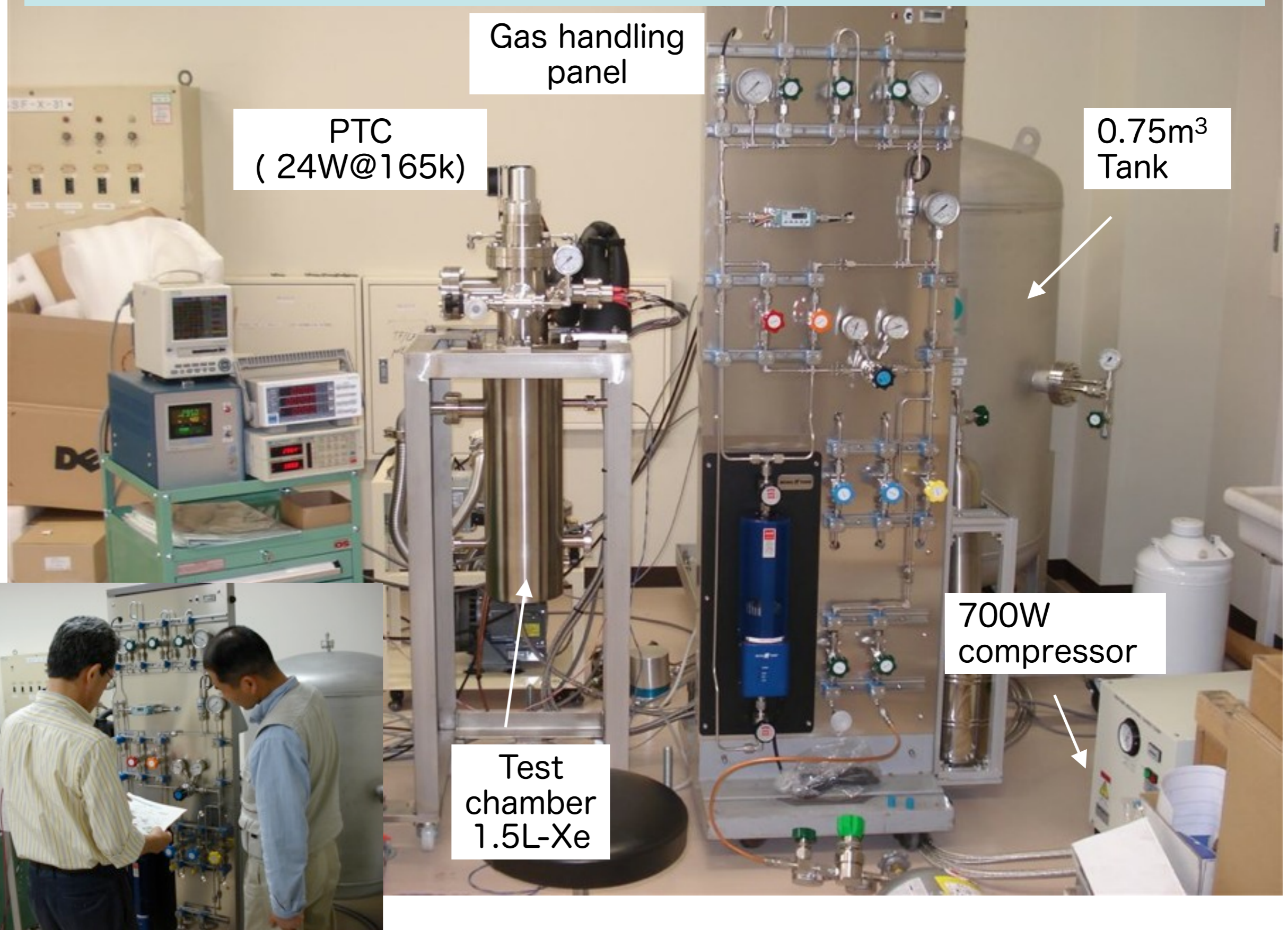
2009.2.25 First charge signals from cosmic rays(11)

2009.3.31 First charge signals from α sources(45)

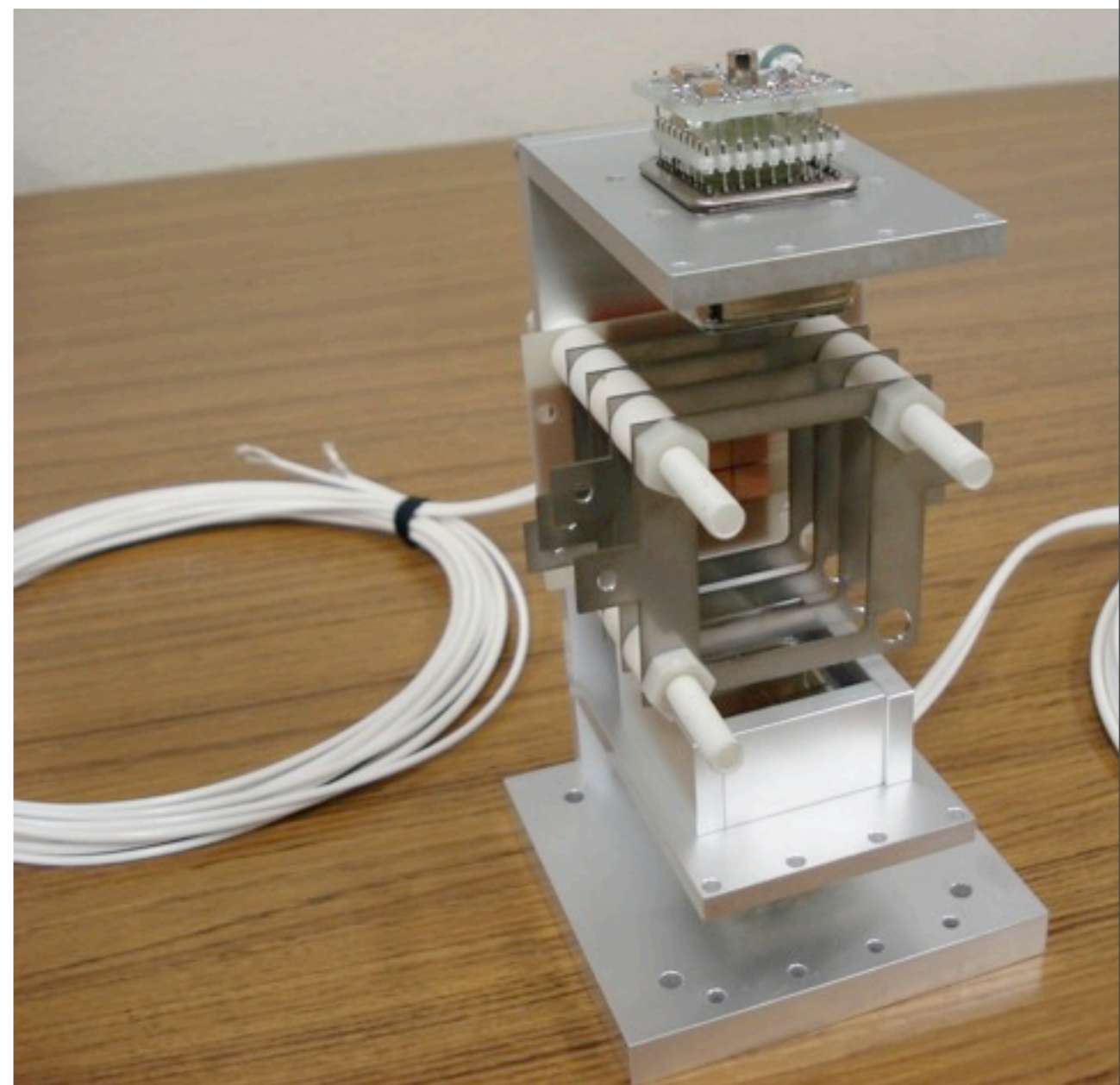
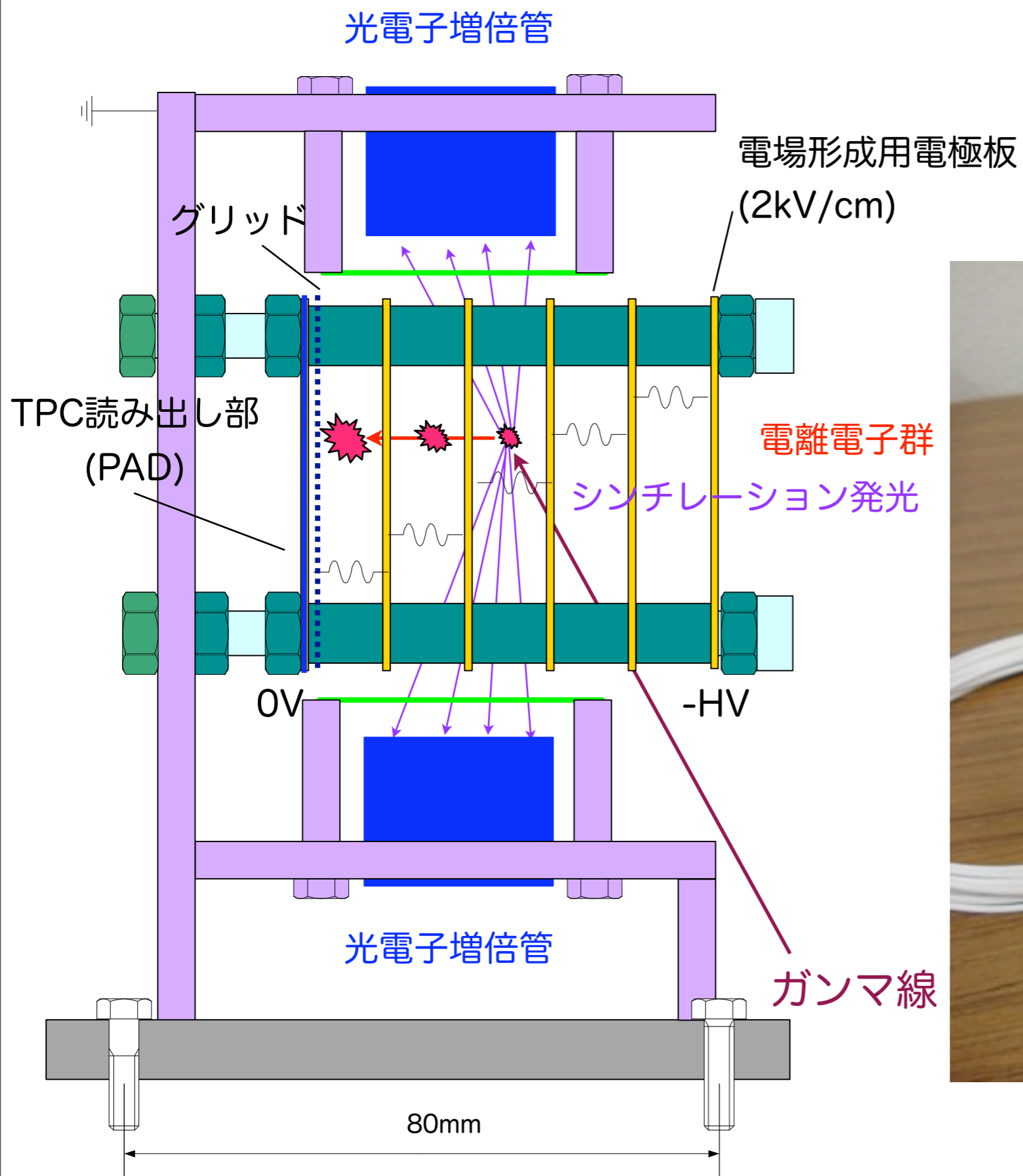
Improving vacuum system and 4ch pad readout

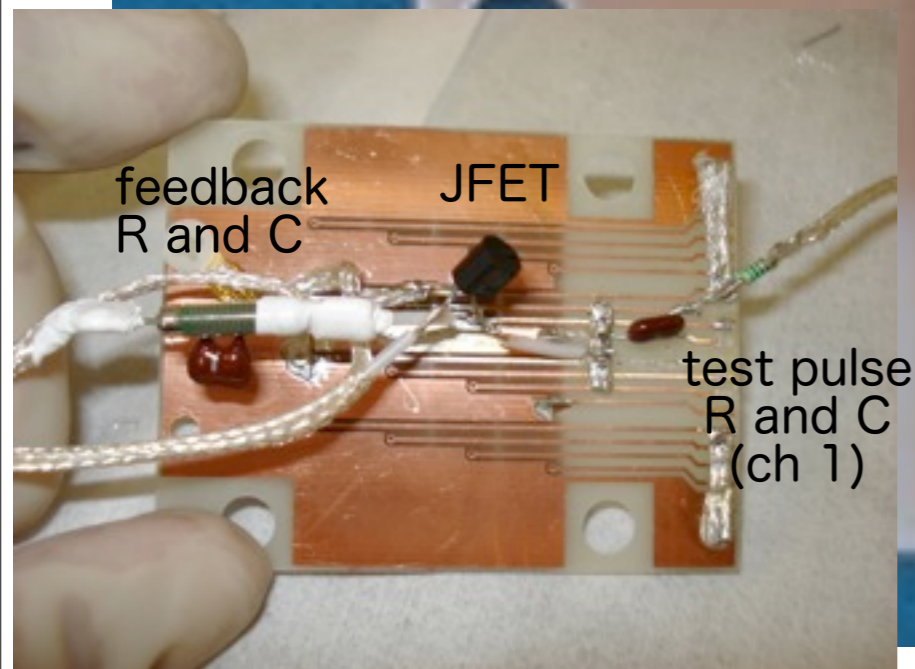
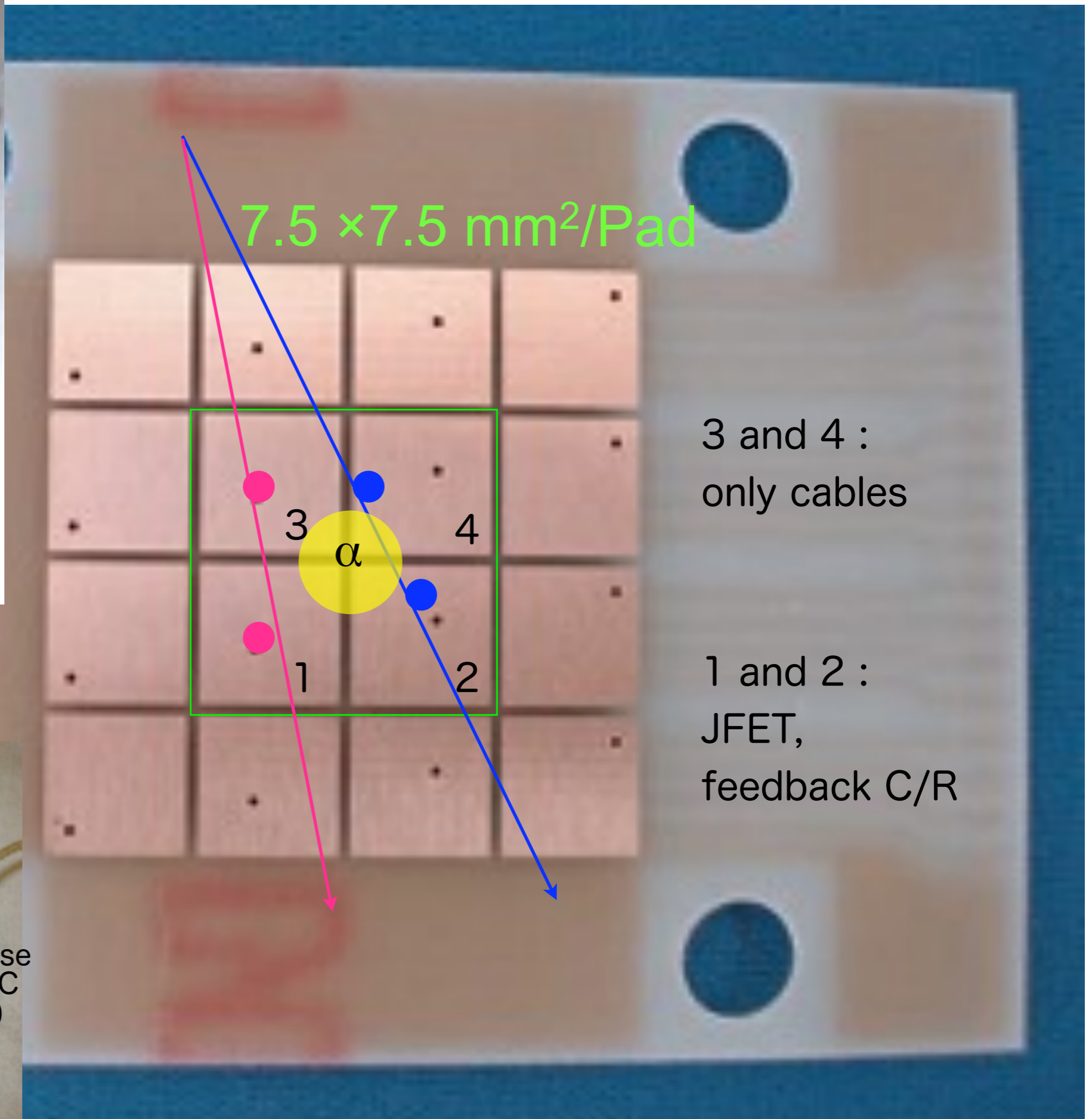
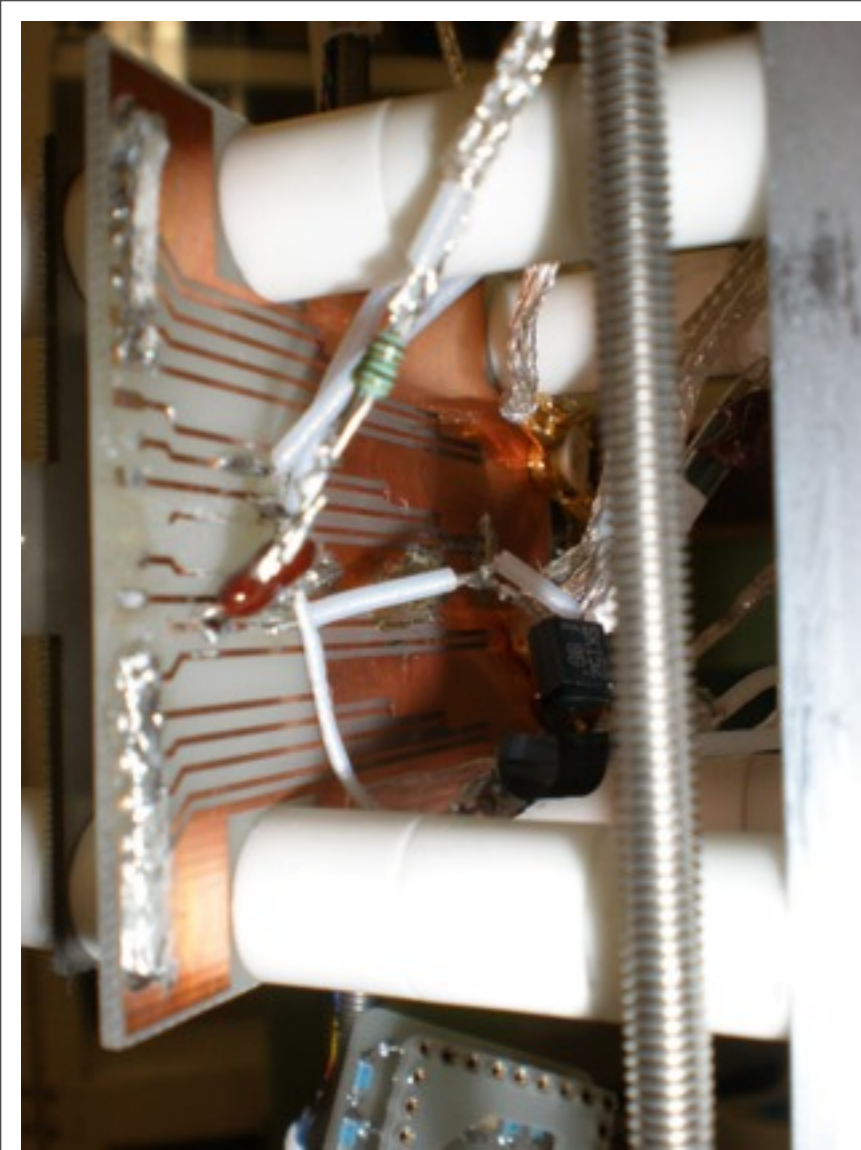
2009.4.24 This experiment

LXe Cryogenic system at KEK , operation since May 2008

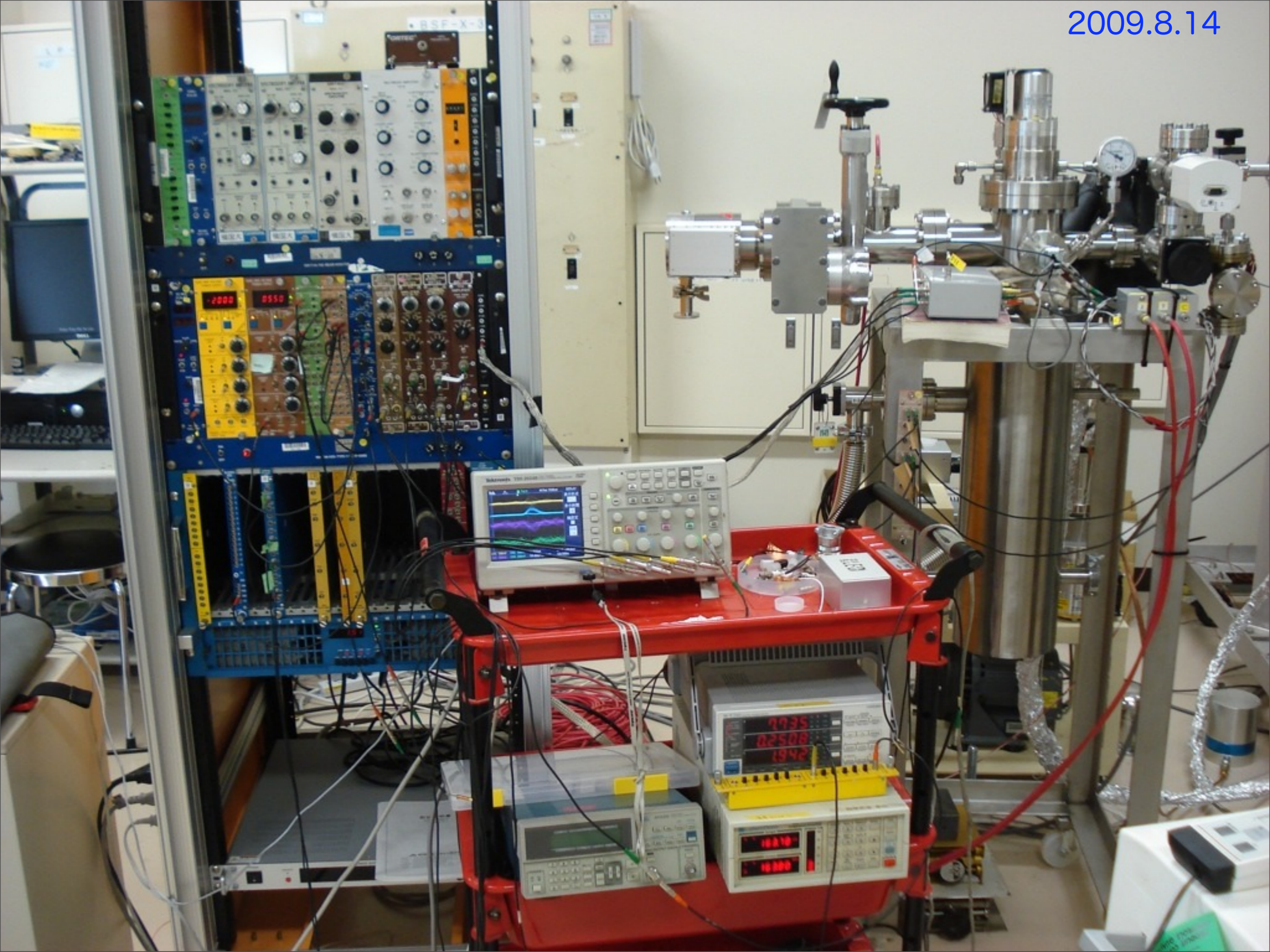


LXeTPC : プロトタイプで原理実証





2009.8.14



2009年 9月 19日 土曜日

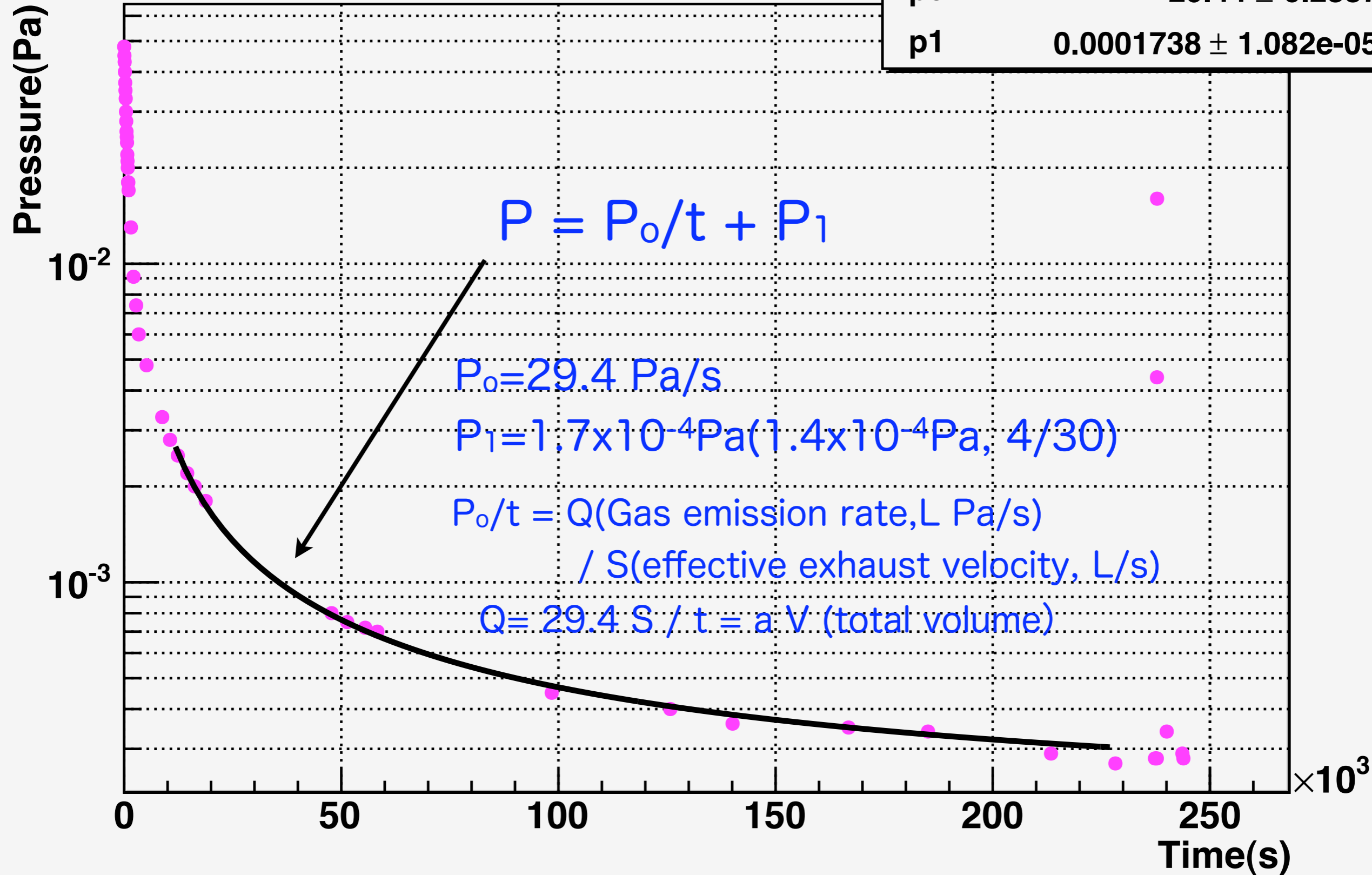
This Experiment in 2009

- 4/24 15:04 Start of evacuation in the chamber
- 4/27 -30 Vacuum build up tests in three times @ 1.4×10^{-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

Evacuation Curve(2009.4.24 - 4.27 - 4.30)

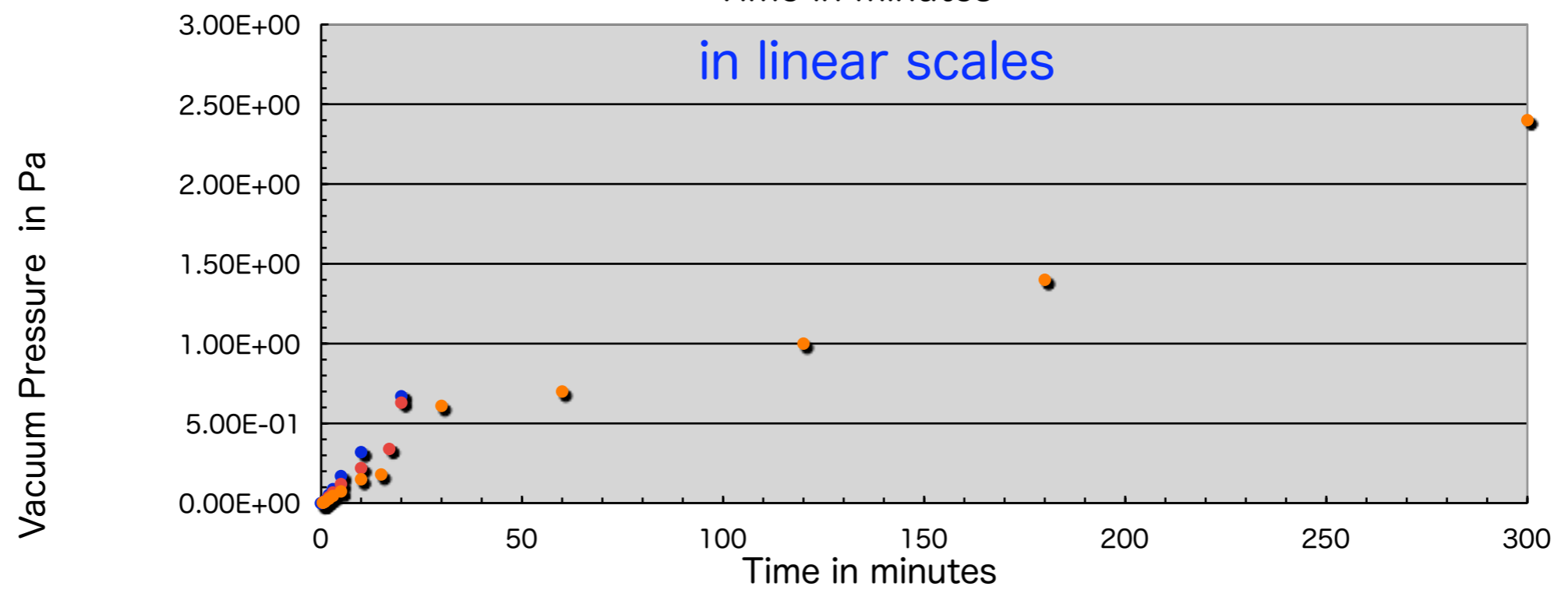
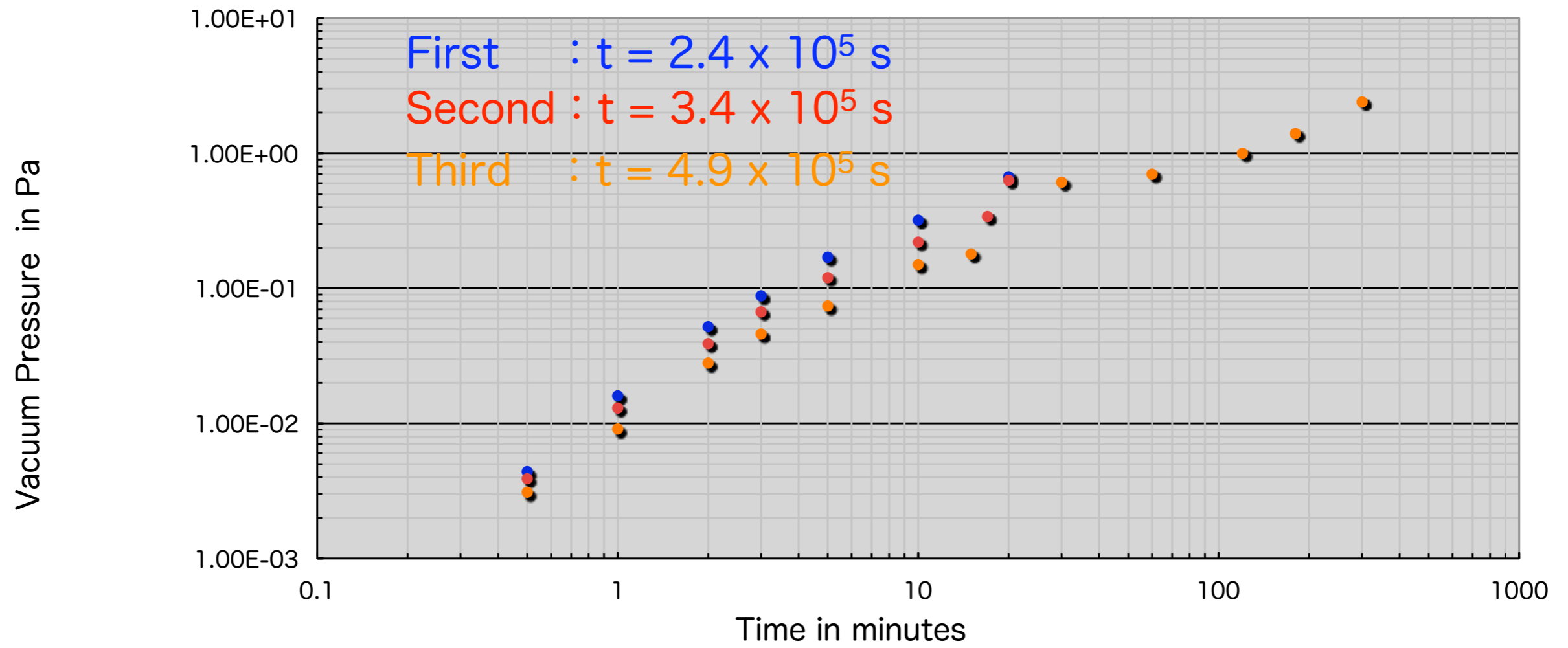
Graph

χ^2 / ndf	9.259e-09 / 12
p0	29.44 ± 0.2887
p1	0.0001738 ± 1.082e-05



Vacuum Build Up Test

"Less than 1 Pa overnight", 道家先生 Golden rule -> 10Pa for us



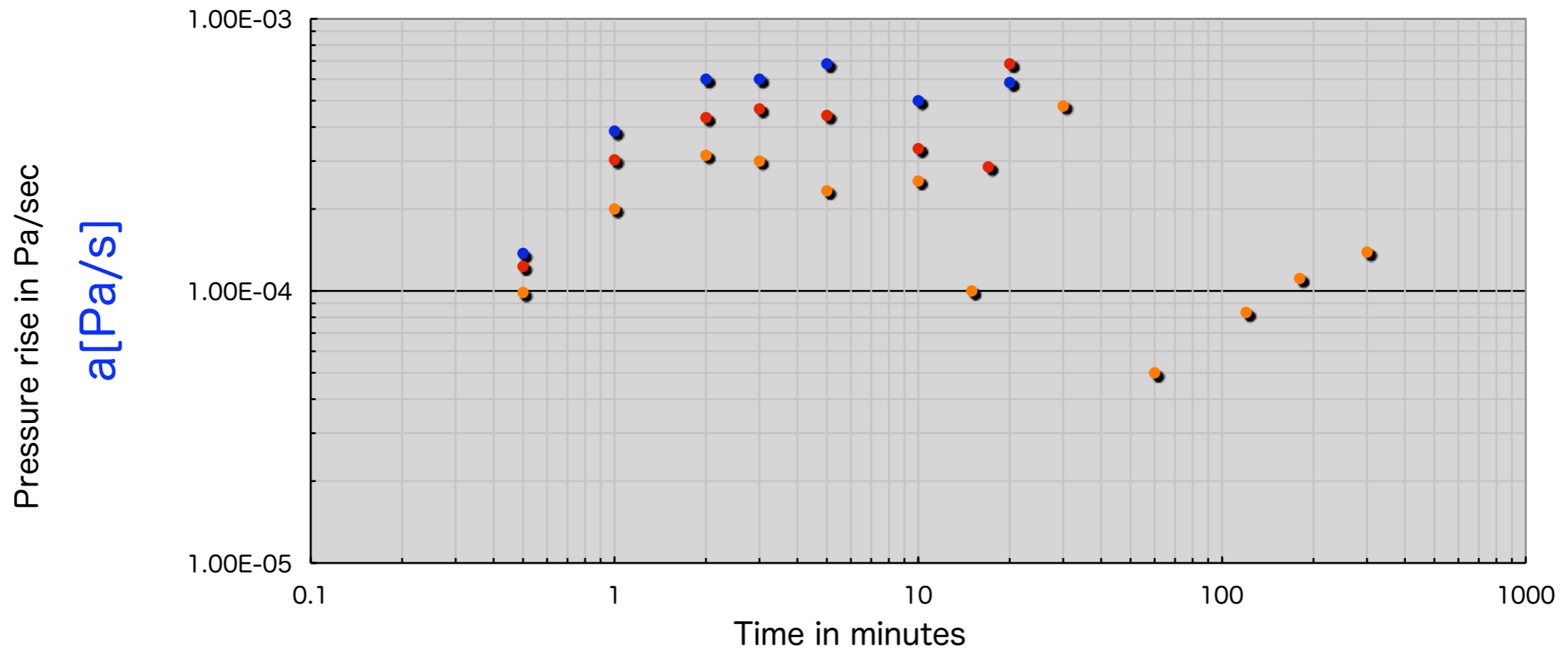
Vacuum Build Up Test (2)

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

First : $t = 2.4 \times 10^5 \text{ s}$

Second : $t = 3.4 \times 10^5 \text{ s}$

Third : $t = 4.9 \times 10^5 \text{ s}$

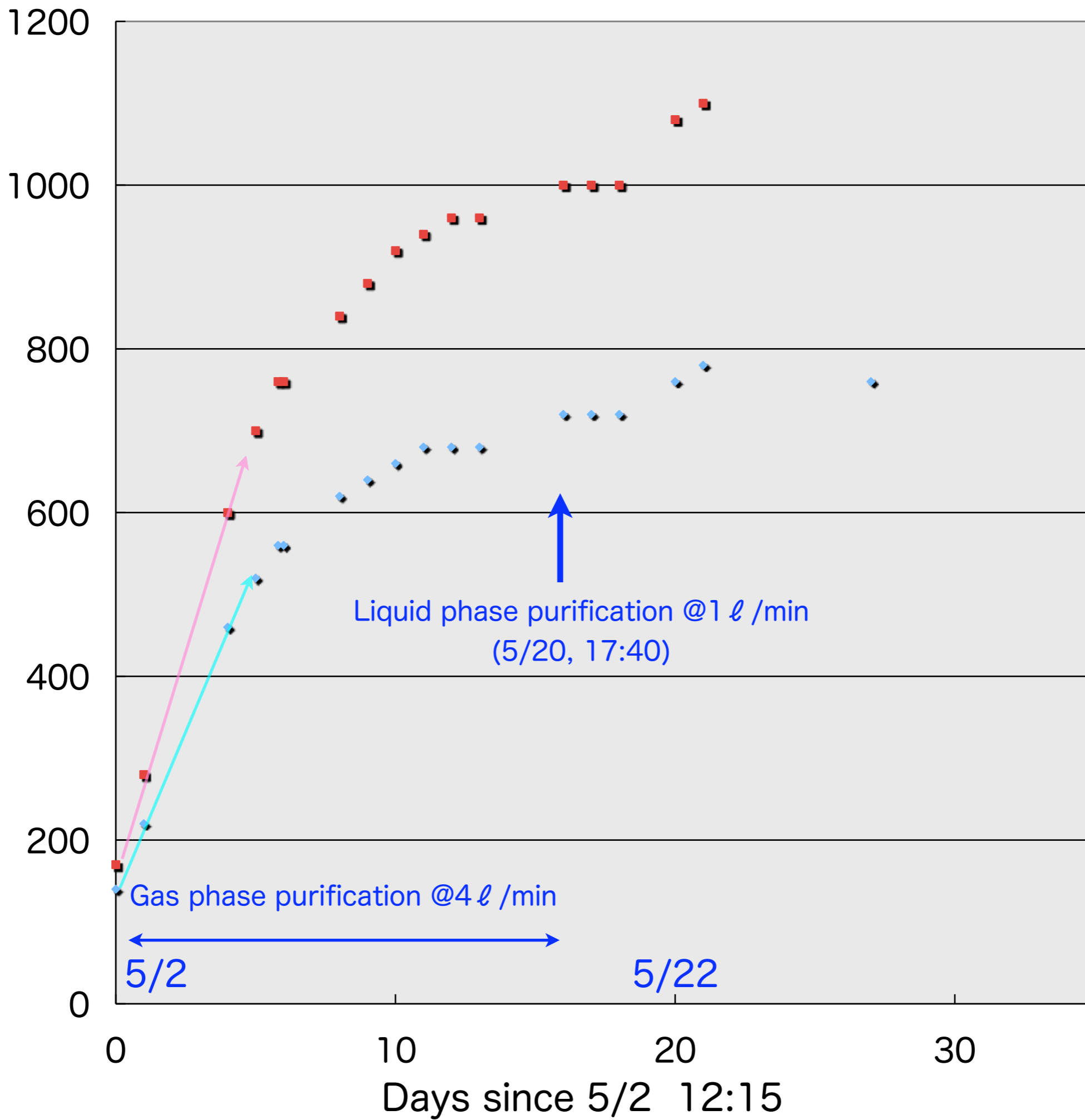


SUS vacuum chamber : 102mm ϕ , 490mm length , 4 ℓ , inner surface of 0.17m²

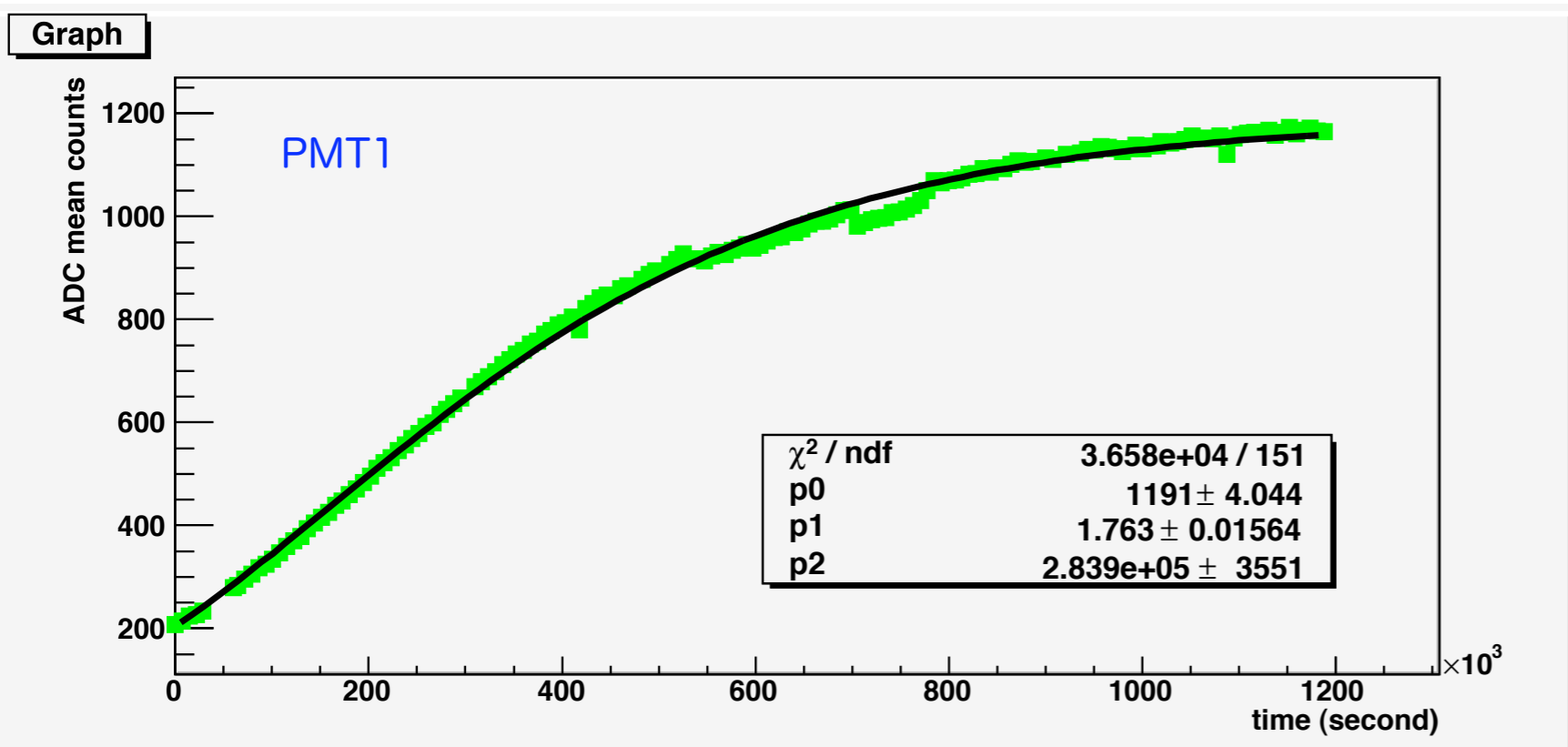
Assuming total volume $V=10\text{L}$ and $Q=a \times 10$ [L Pa/s] ,

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

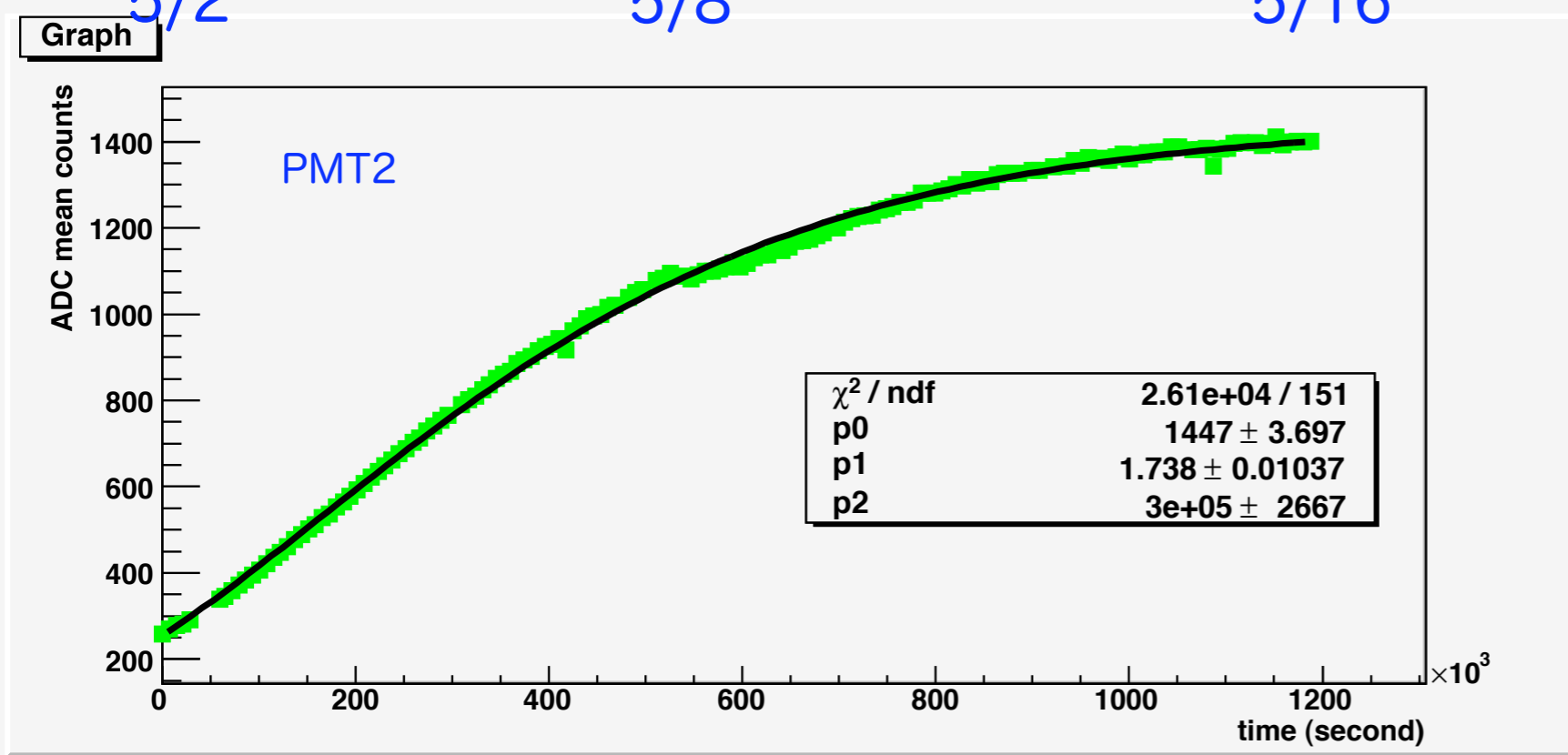
Scintillation Lights
Pulse Height (mV)



Purification process by scintillation lights in 2 weeks



5/2 5/8 5/16



fitted by

$$\rho(d,t) = \rho_0 e^{-d/\lambda}$$

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

,where

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

$$\rho_1 = d / \lambda_0 = 1.75$$

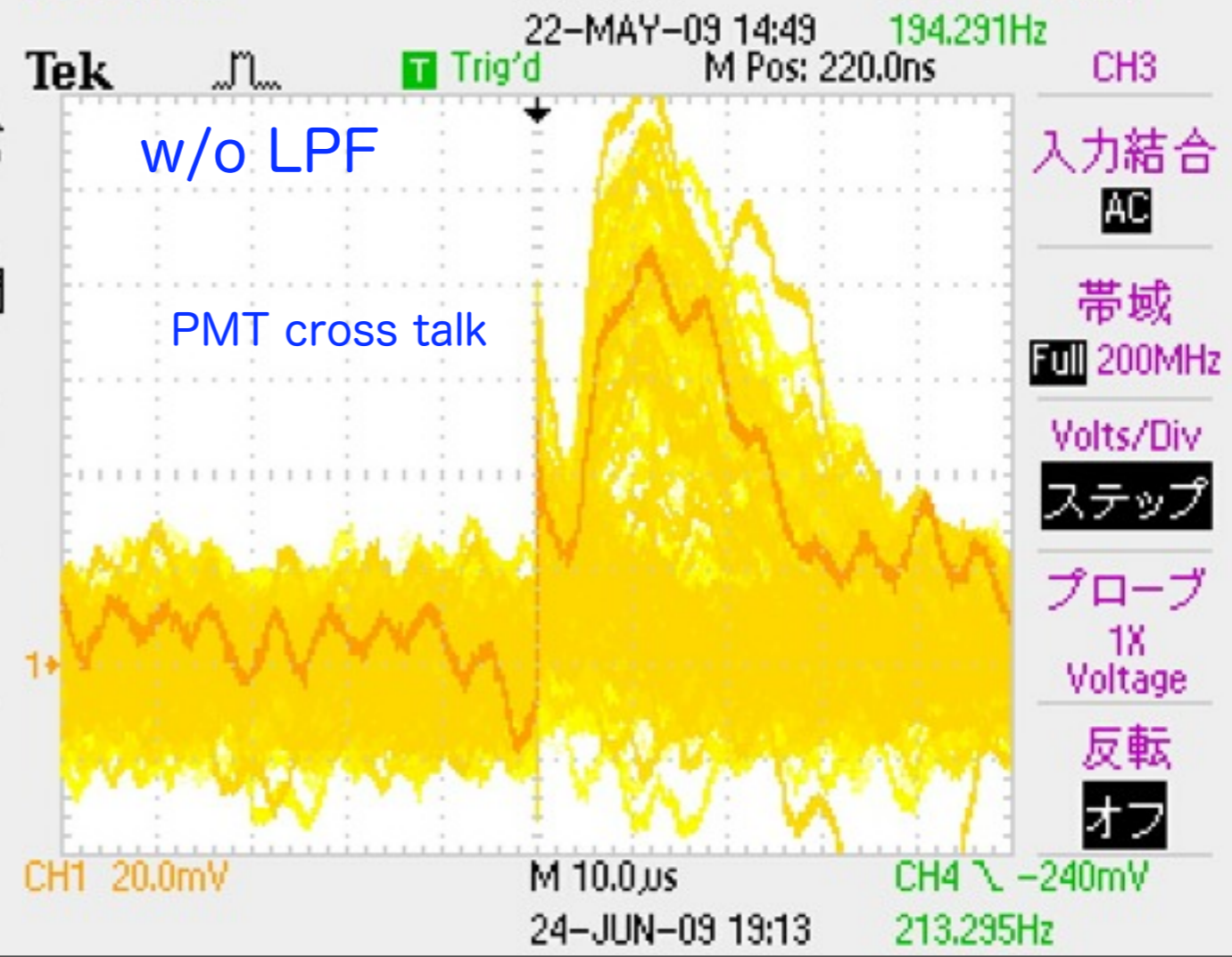
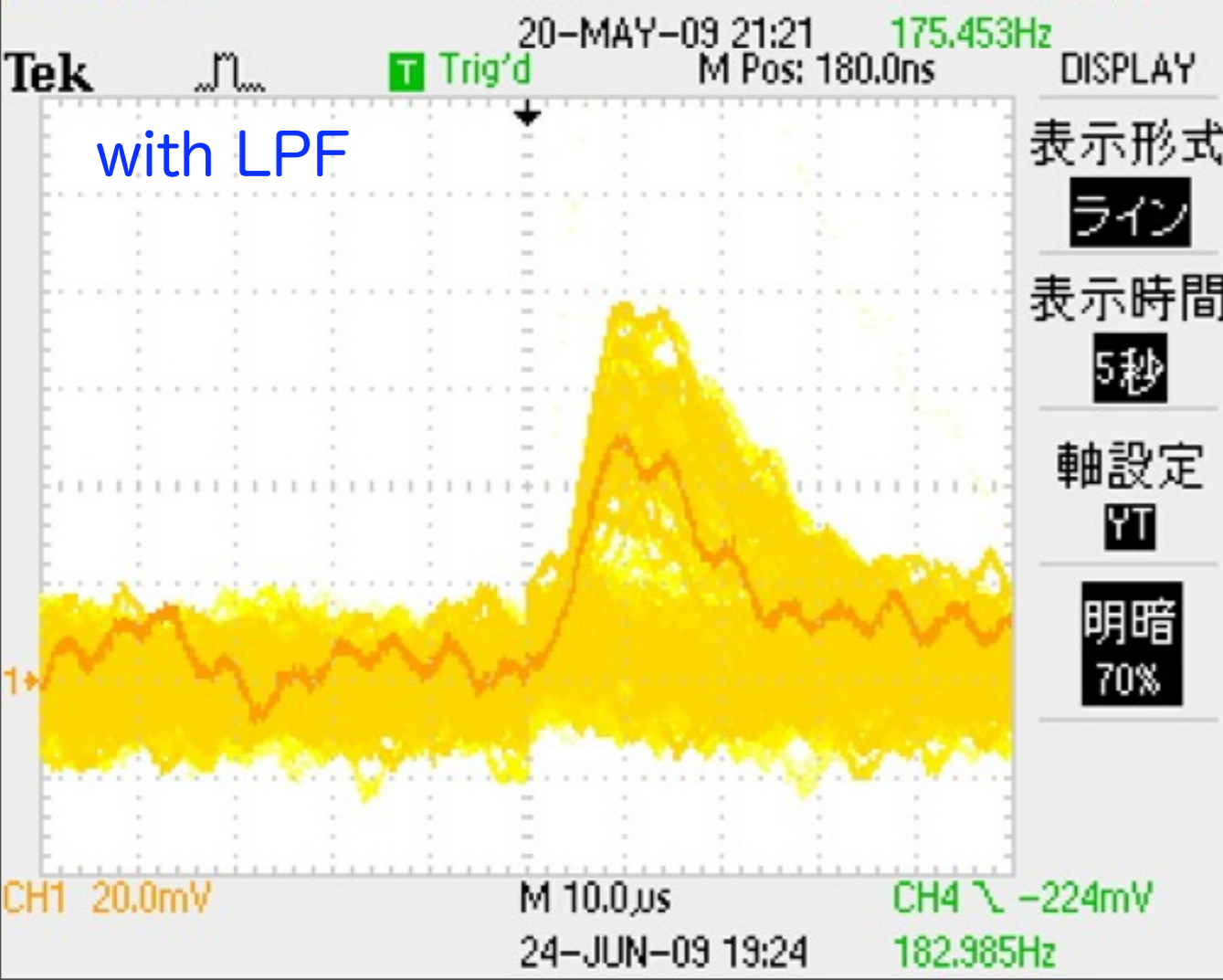
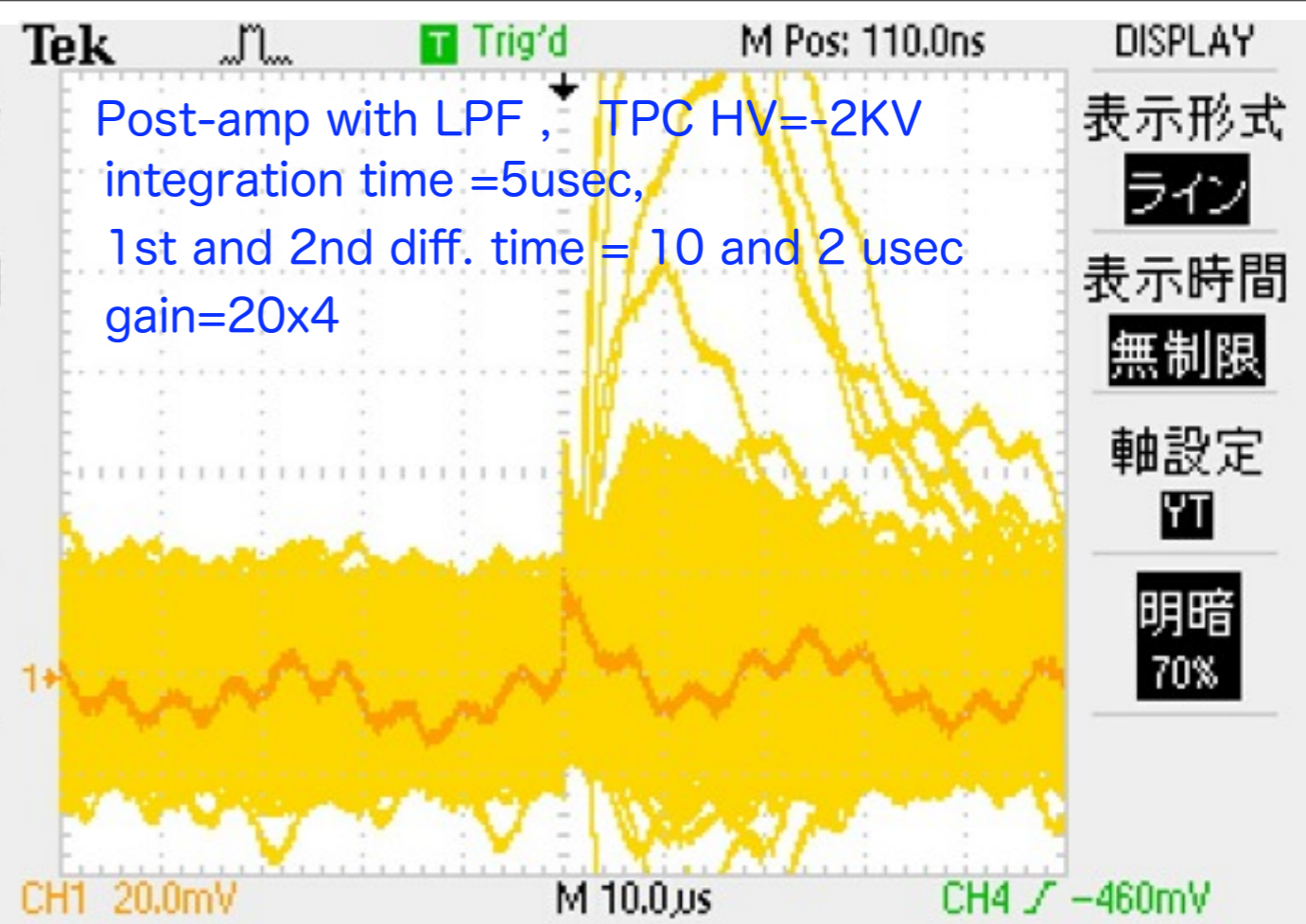
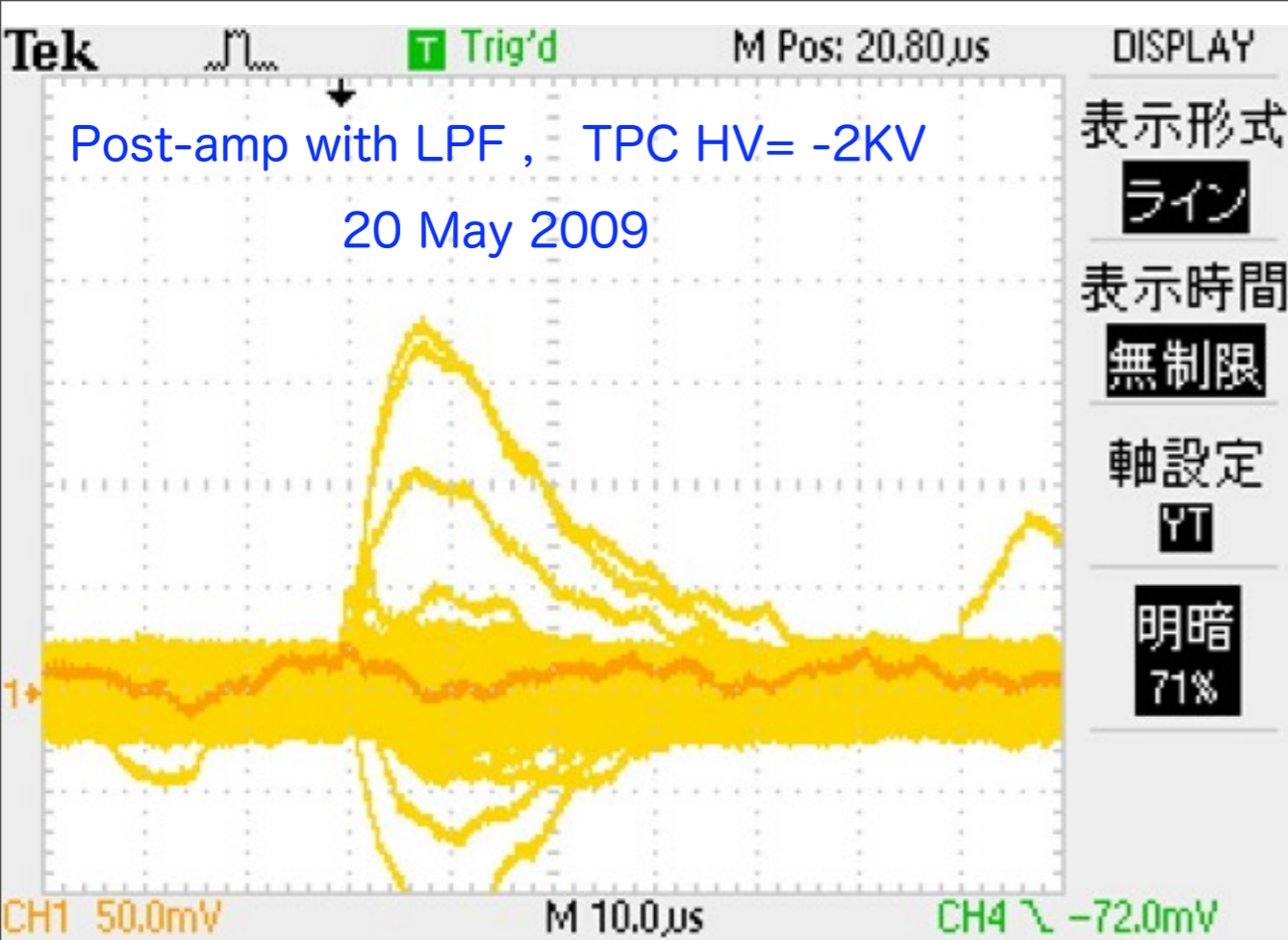
$$\rho_2 = \tau = 2.9 \times 10^5 \text{ sec}$$

$$\tau = 3.4 \text{ days}$$

$$\text{put } d = 5 \text{ cm}$$

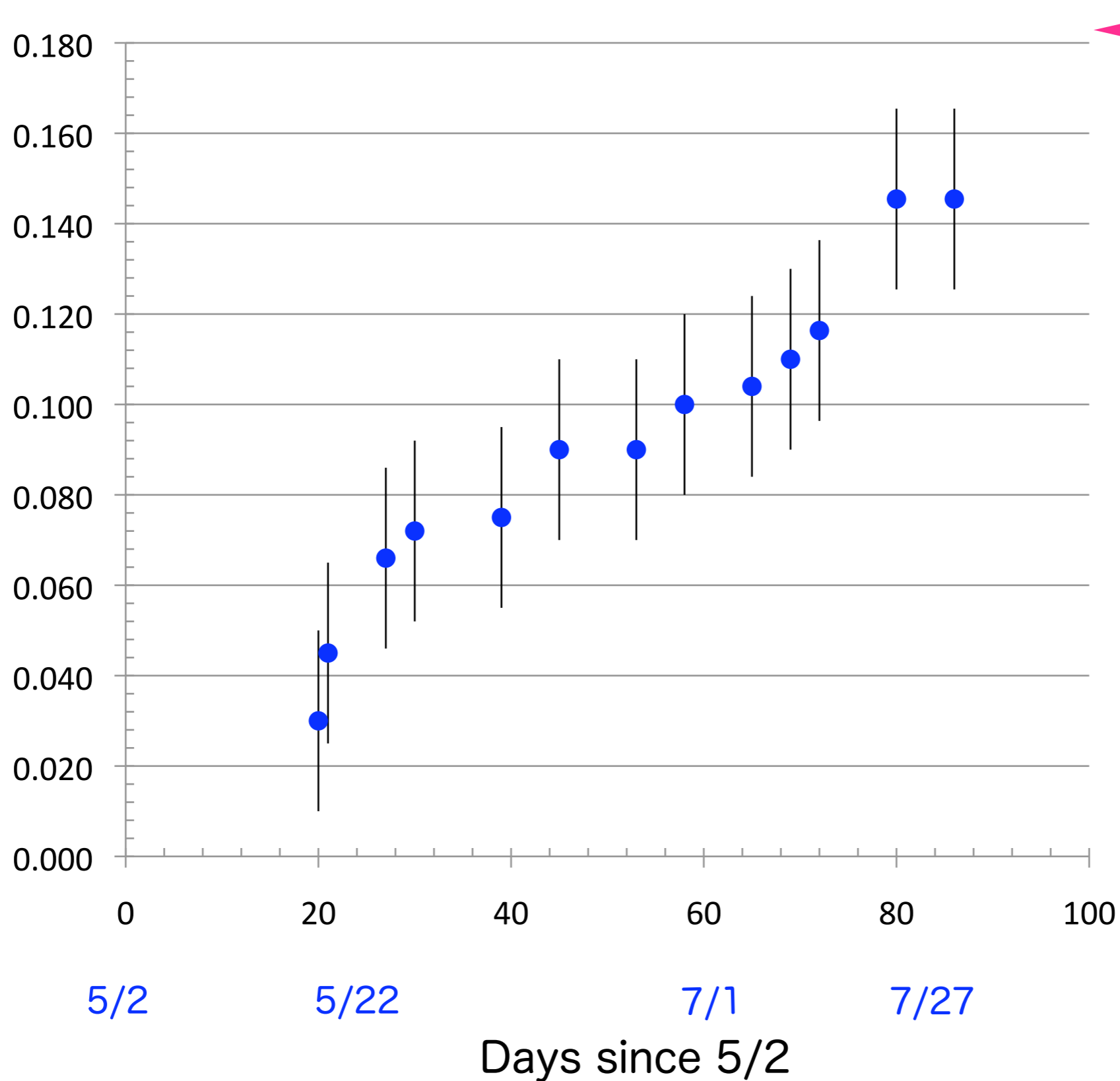
$$\lambda_0 = 2.9 \text{ cm}$$

$$\lambda = 160 \text{ cm at 14 days}$$



α 線シグナル (ch1, x80)

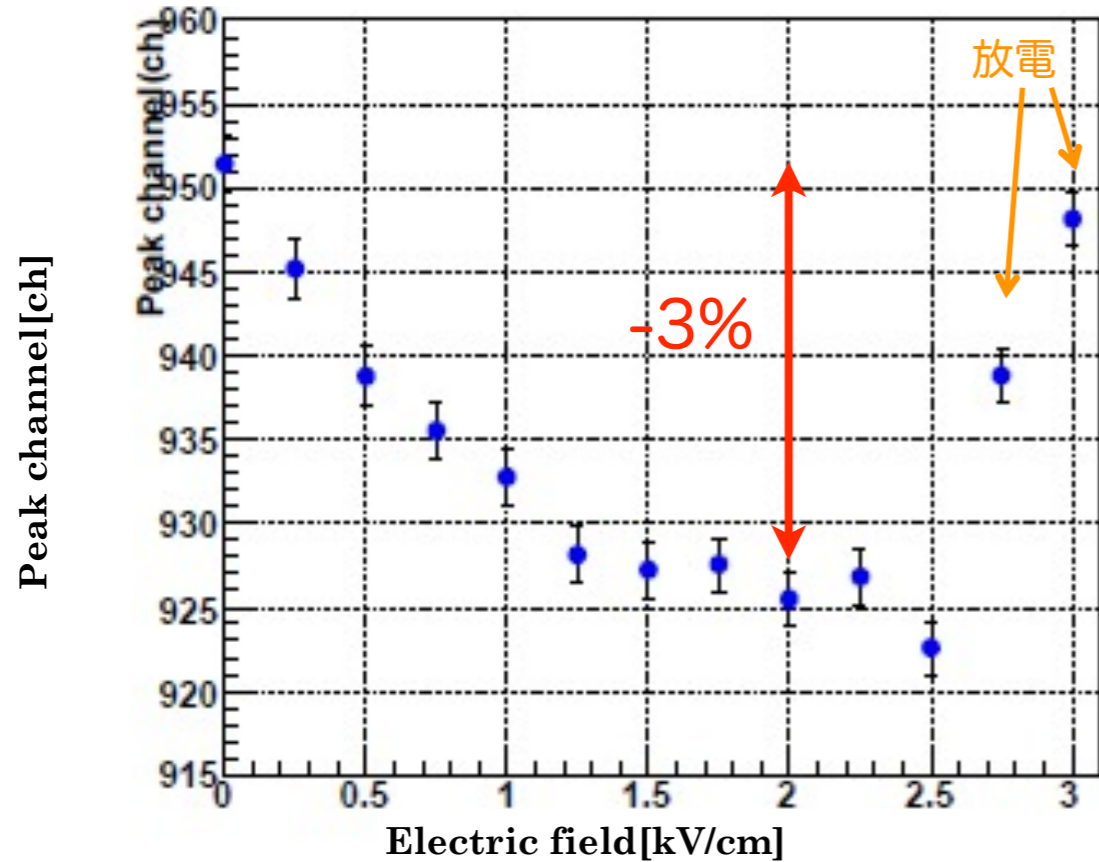
“Peak” Pulse Height at post-amp w/o LPF (V)



← <期待値>
2.3fC
assume $Q/Q_0=4\%$
at $E=-2\text{kV/cm}$

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

シンチレーション光



α線による電場依存性の測定

注：不純物による減衰効果とドリフト時間の電場依存性も含まれる

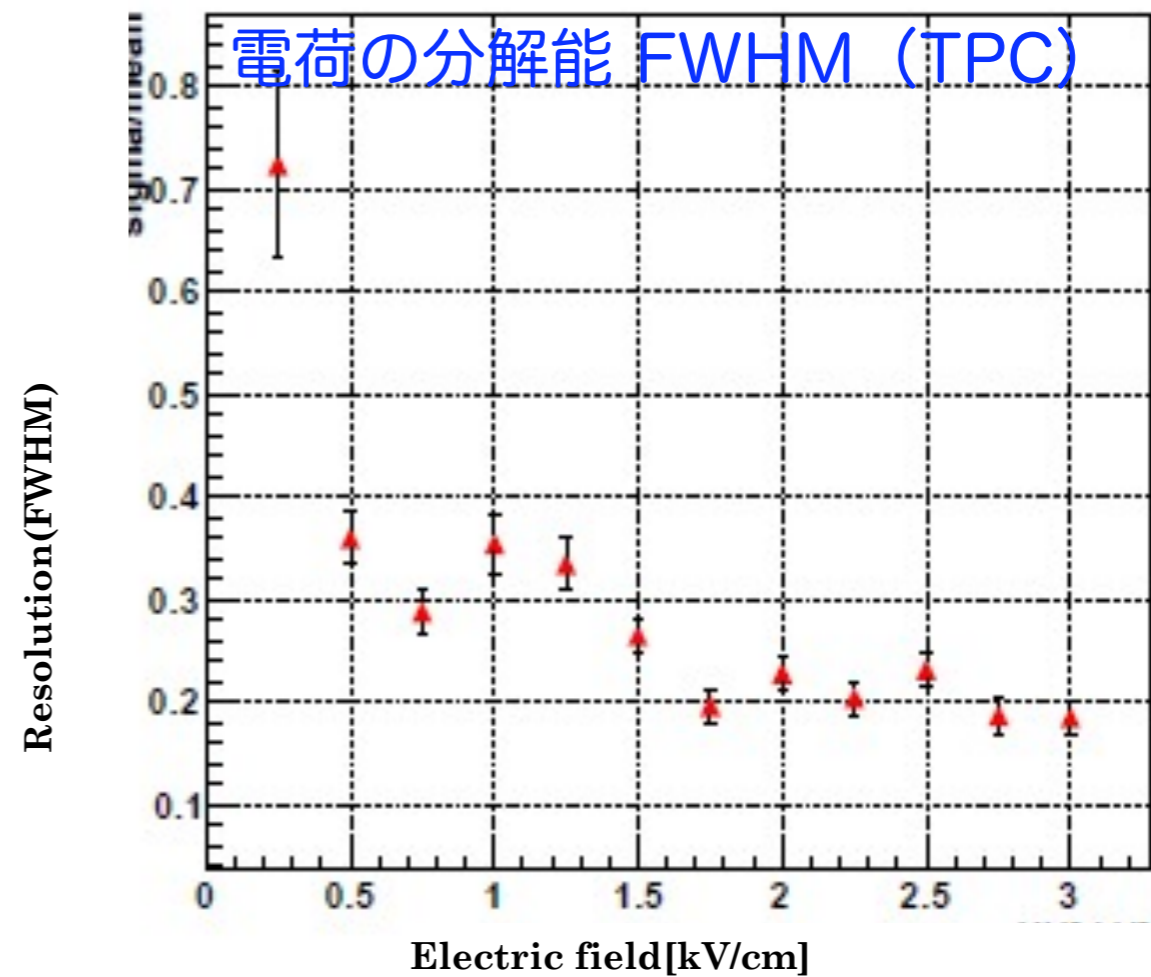
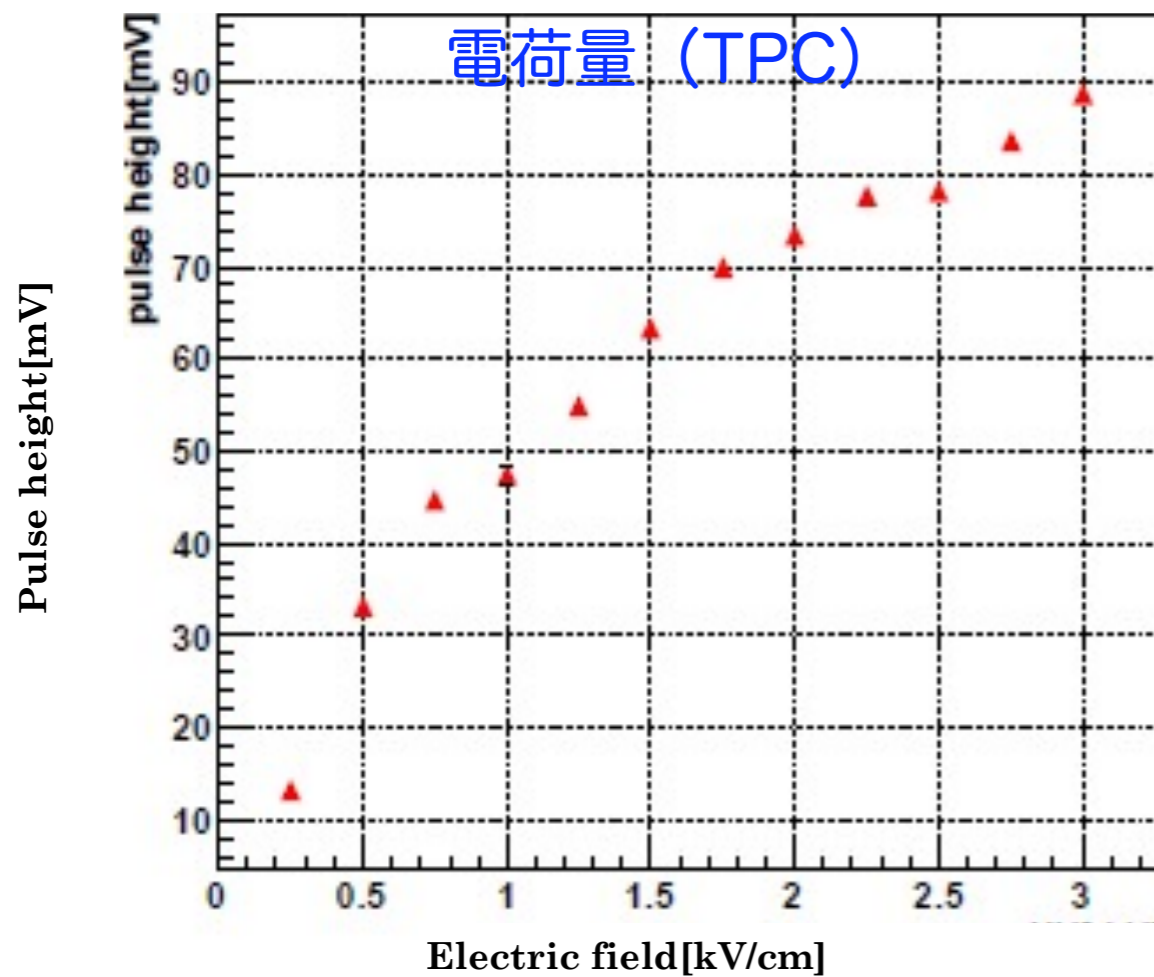
電場 = - 2kV / 1kV

シンチレーション光 -3% / -2%

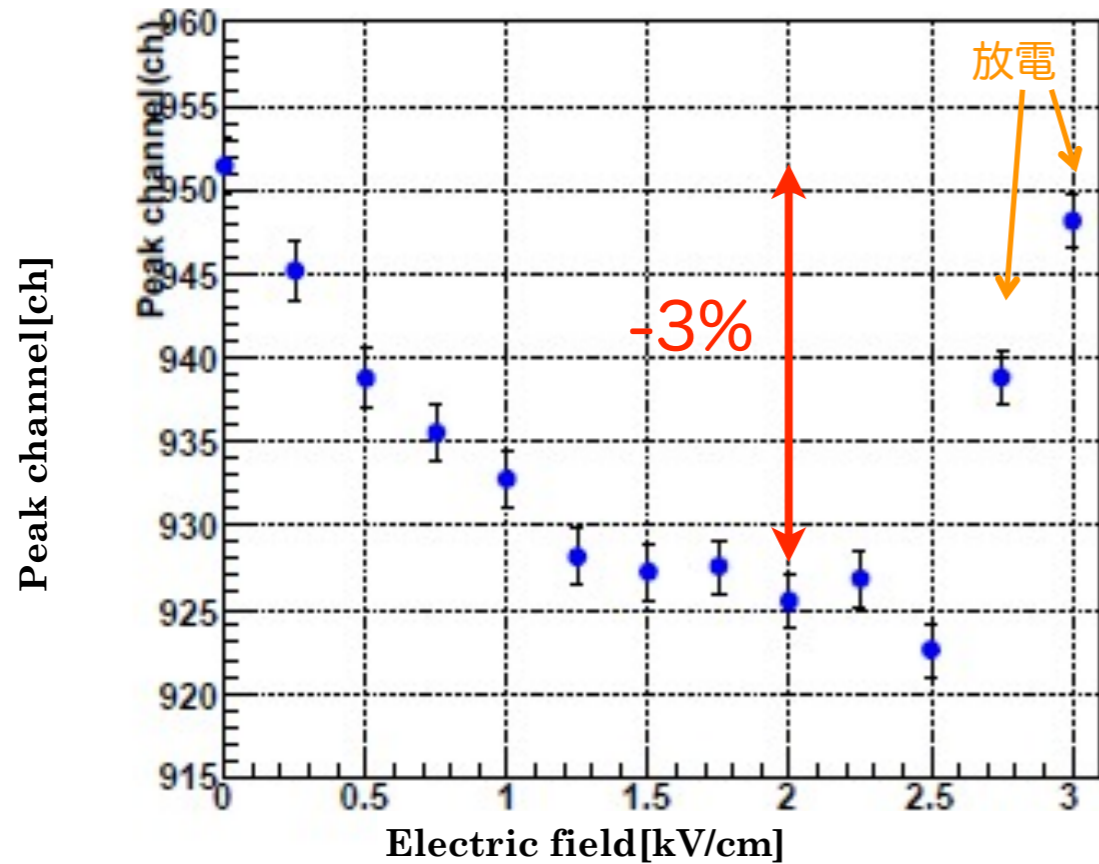
電荷量 73mV / 46mV = 1.6

電荷量分解能 FWHM 0.22 / 0.35 = 0.6

HV vs resolution



シンチレーション光



α線による電場依存性の測定

注：不純物による減衰効果とドリフト時間の電場依存性も含まれる

電場 = - 2kV / 1kV

シンチレーション光 -3% / -2%

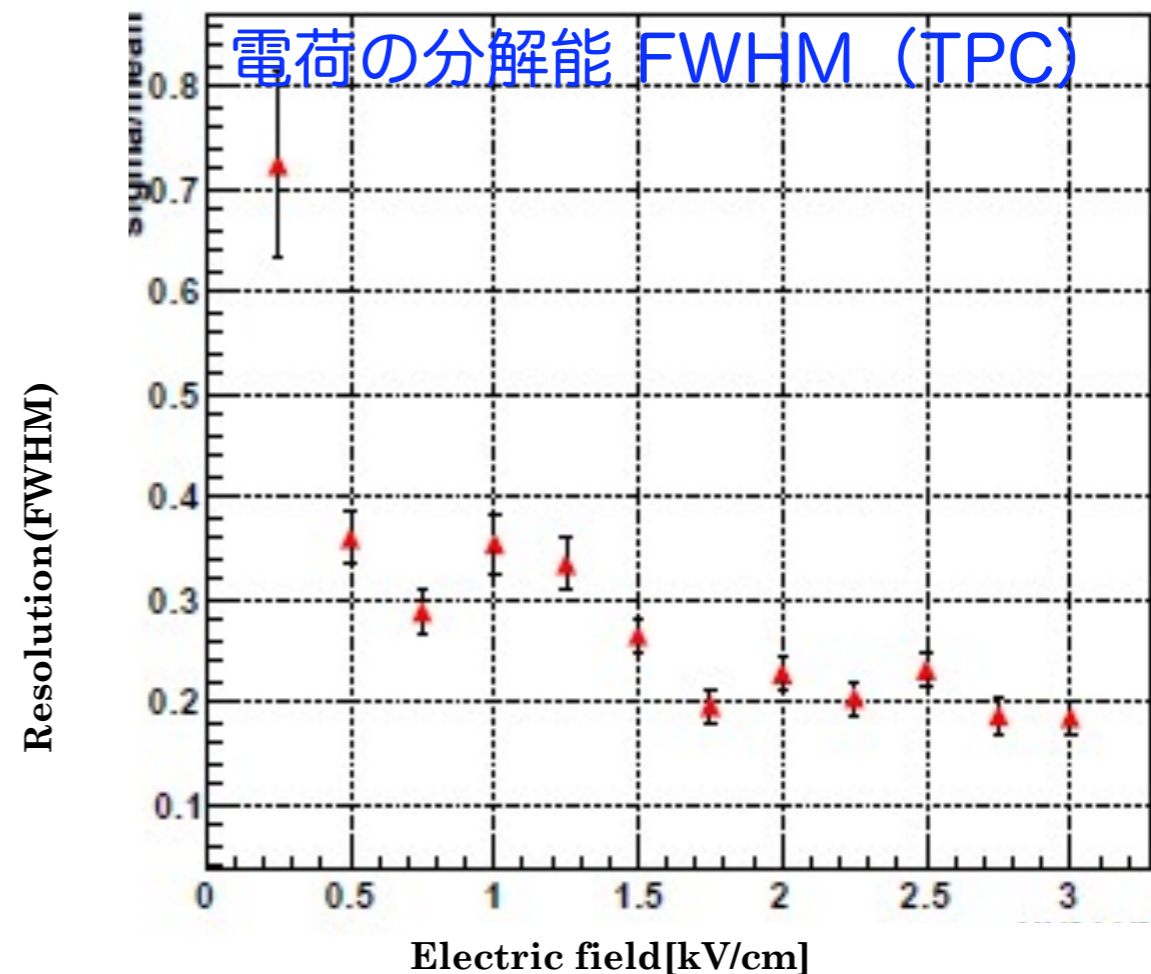
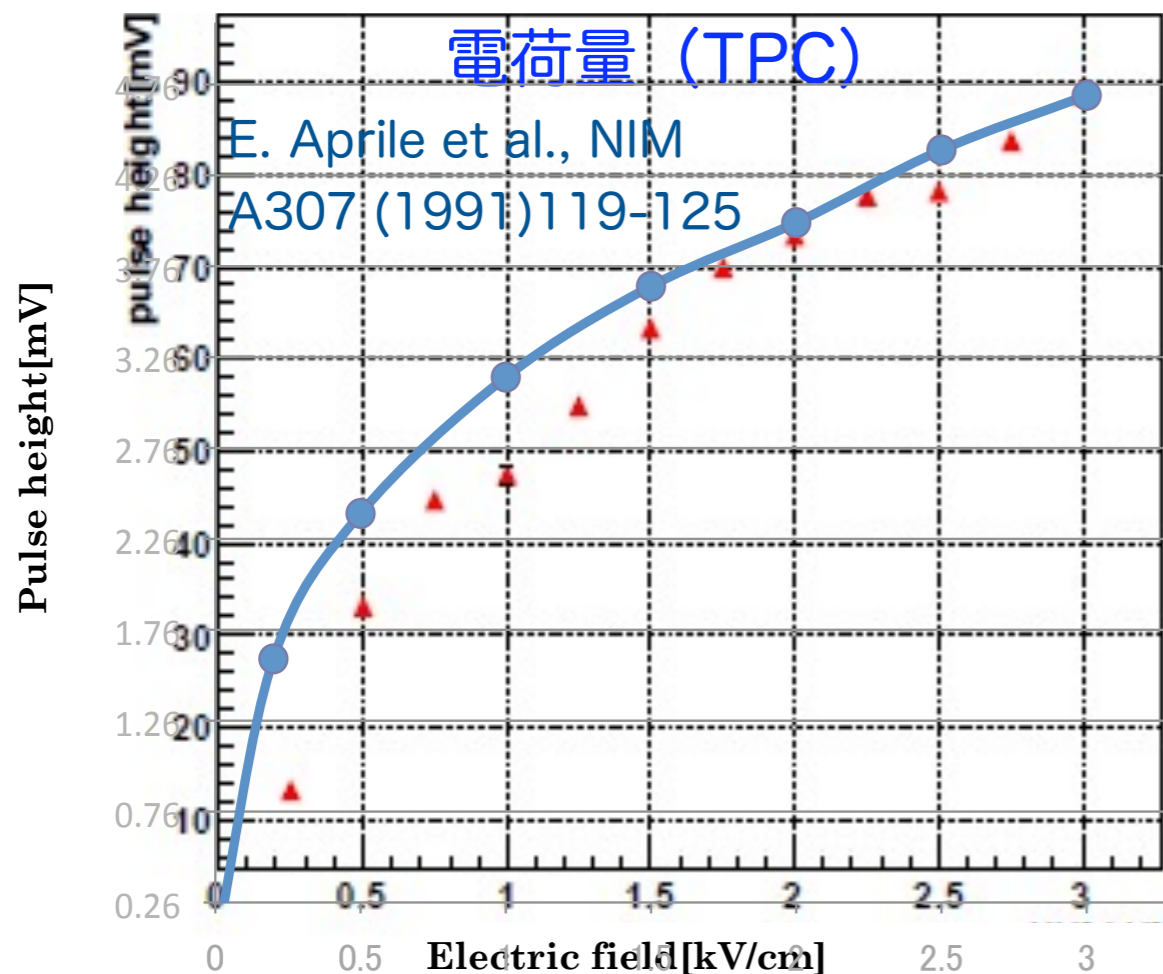
電荷量 73mV / 46mV = 1.6

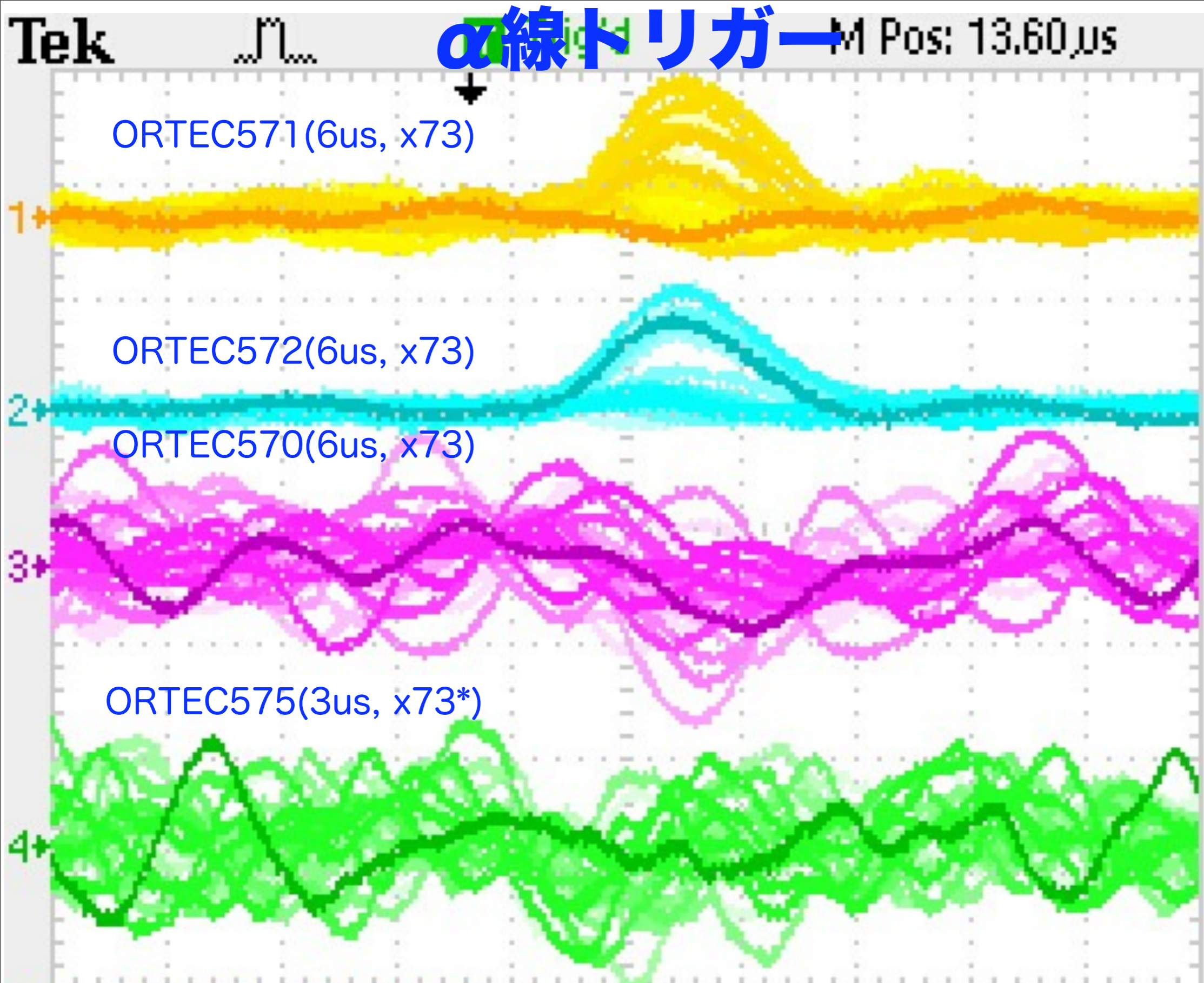
1.27

電荷量分解能 FWHM 0.22 / 0.35 = 0.6

0.05/0.05 = ~1

HV vs resolution



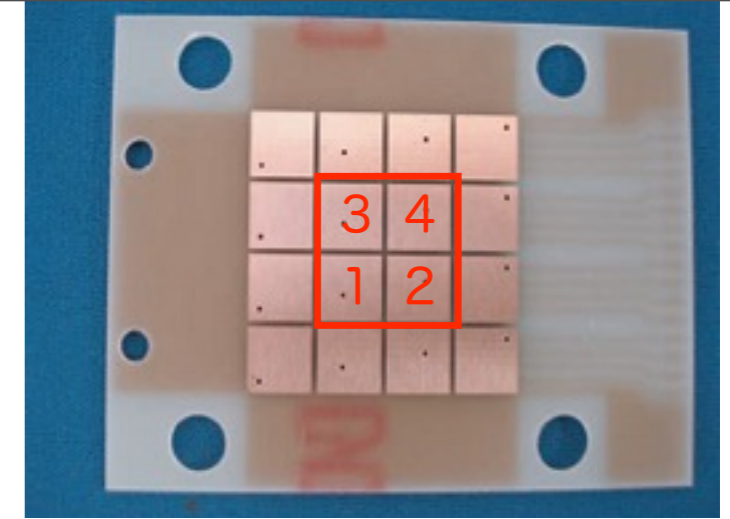


表示形式
 ライン
 表示時間
 1秒
 軸設定
 YT
 明暗
 56%

CH1 100mV CH2 100mV M 10.0 μs Ext \sim -88.0mV
 CH3 200mV CH4 200mV 12-AUG-09 19:26 86.1659Hz

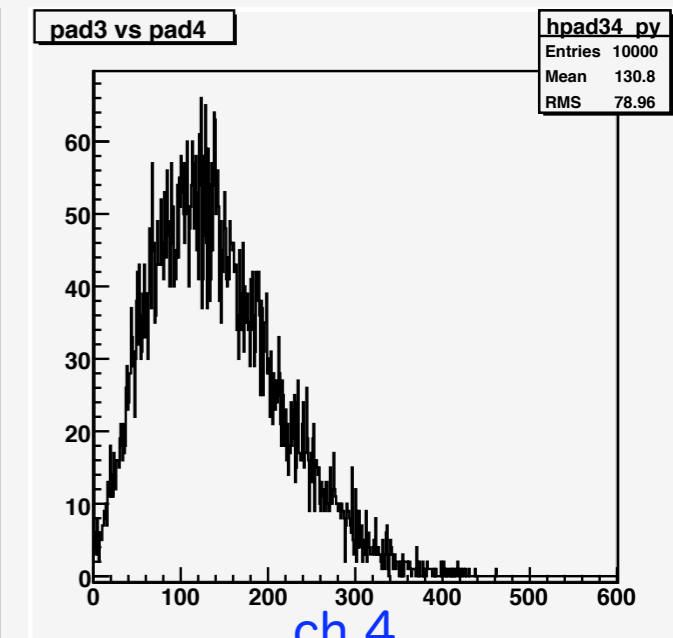
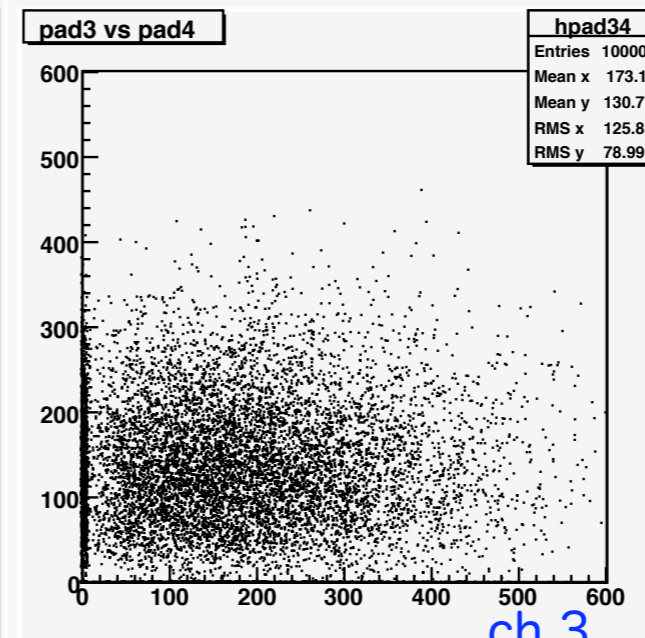
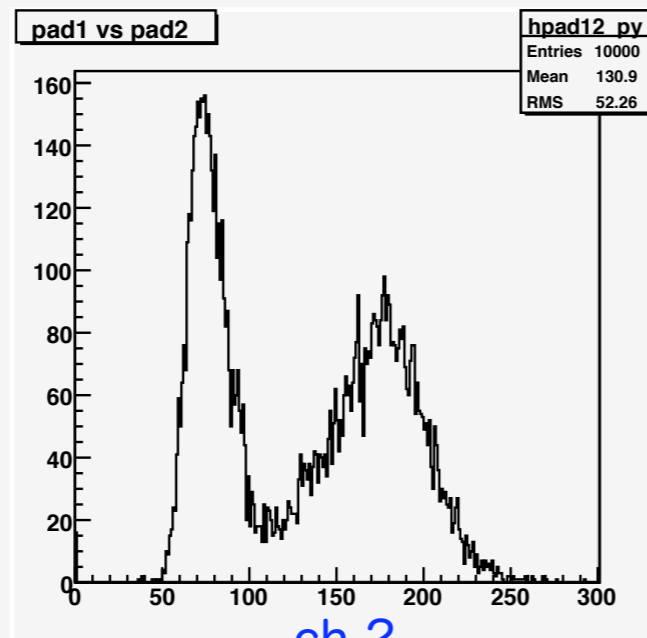
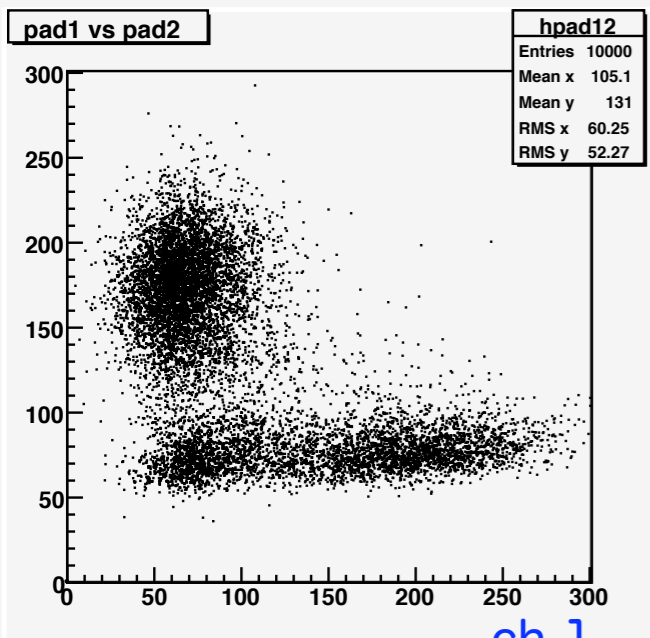
α線イベント

1.1 fC measured at the α peak
(about 91 ppb O₂ equiv., $\lambda_{att}=15.3\text{mm}$)



ch 2

ch 4

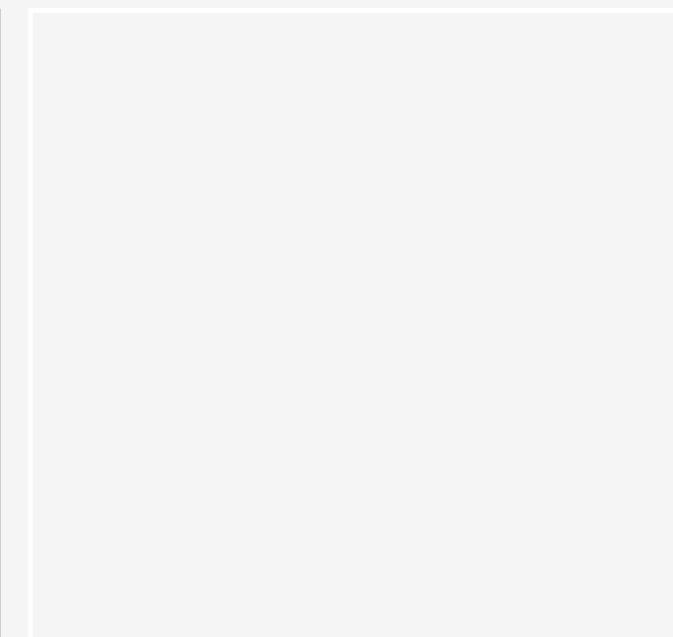
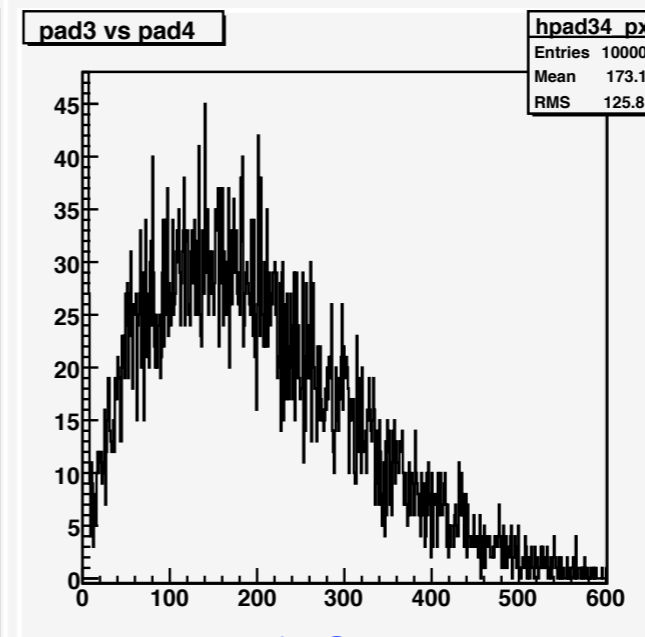
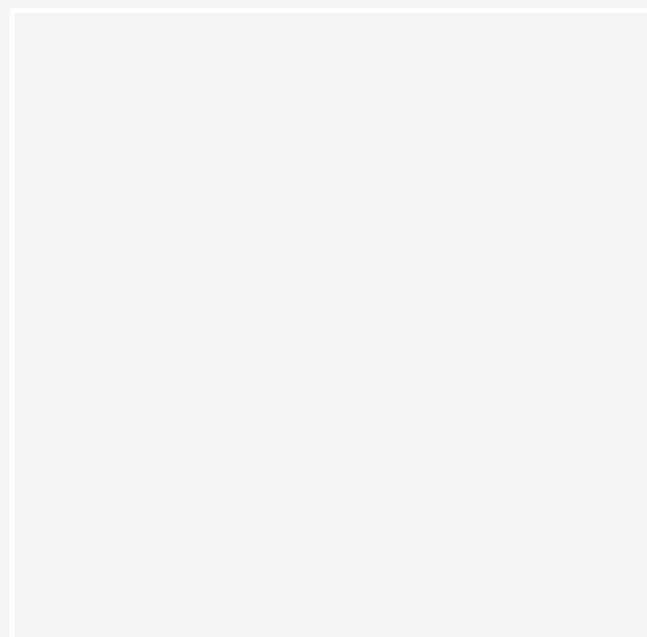
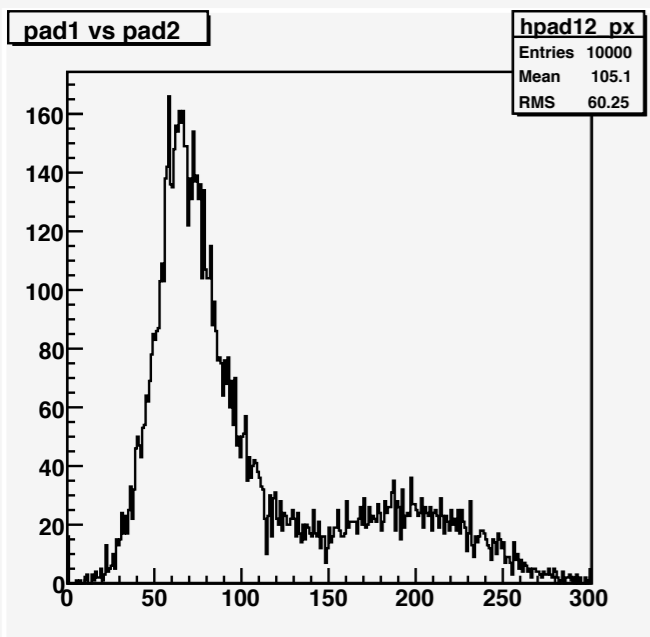


ch 1

ch 2

ch 3

ch 4

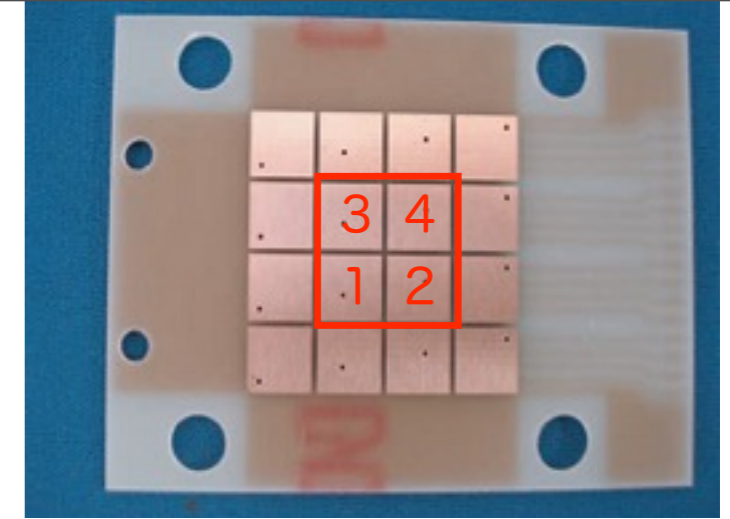


ch 1

ch 3

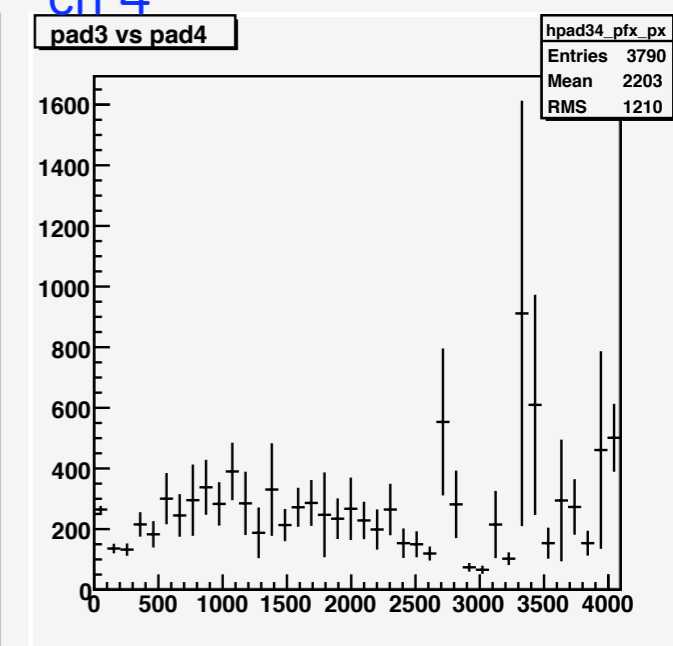
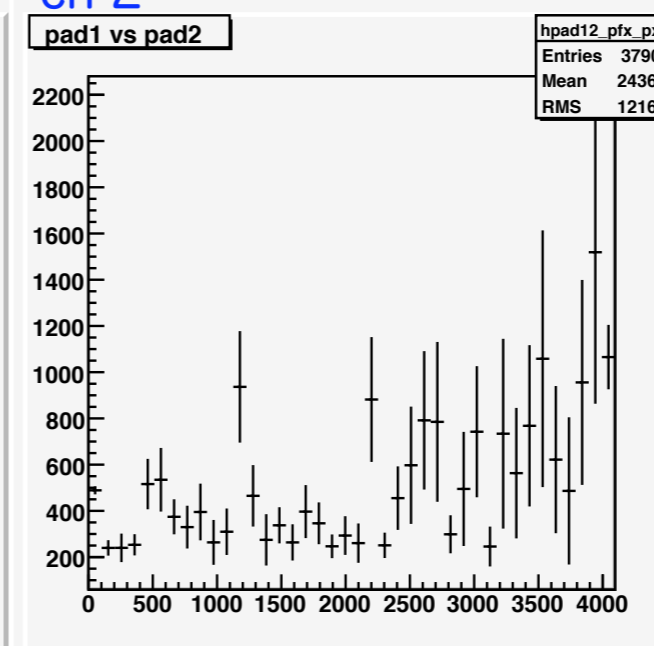
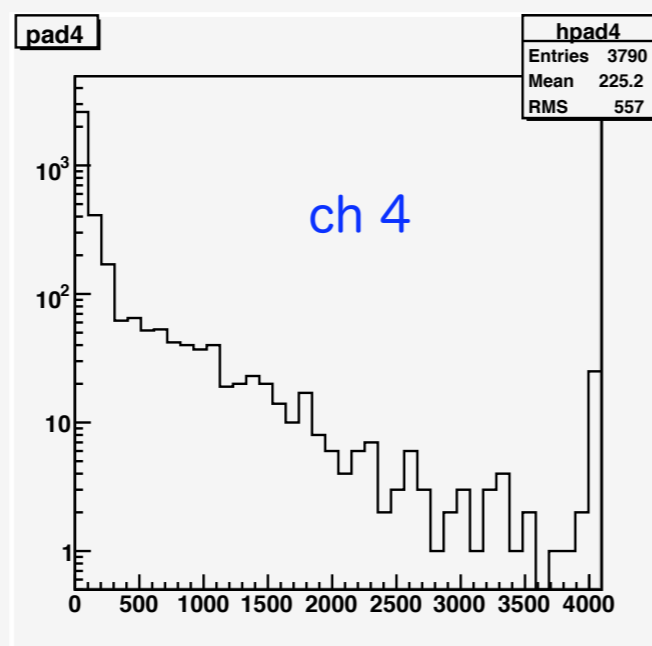
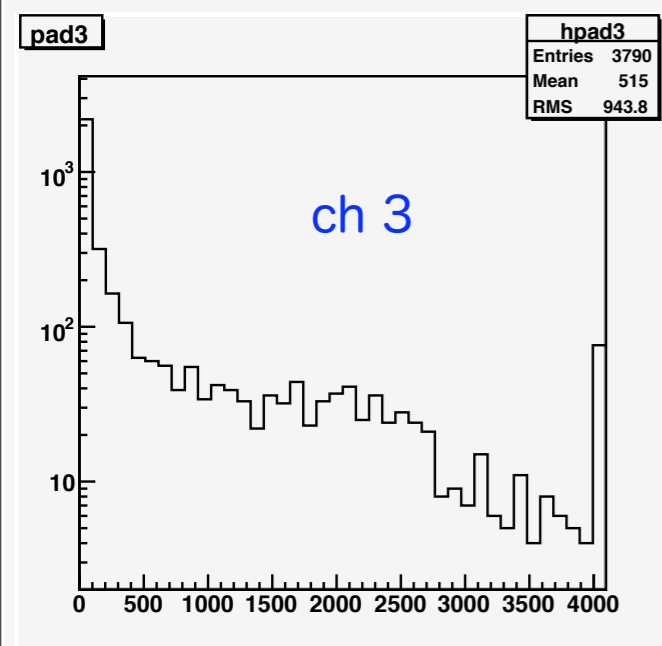
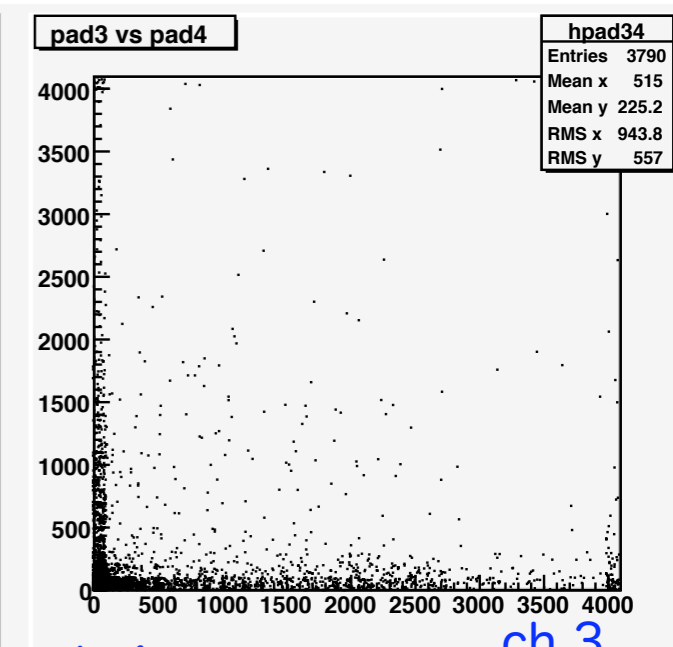
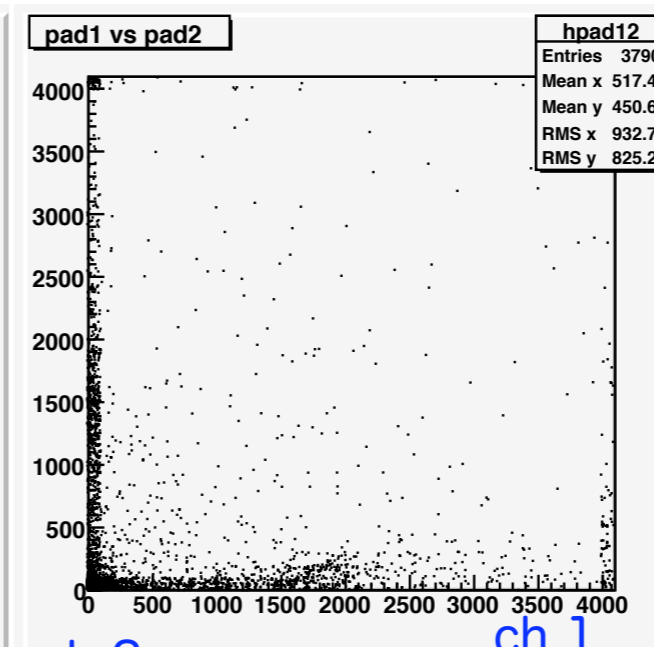
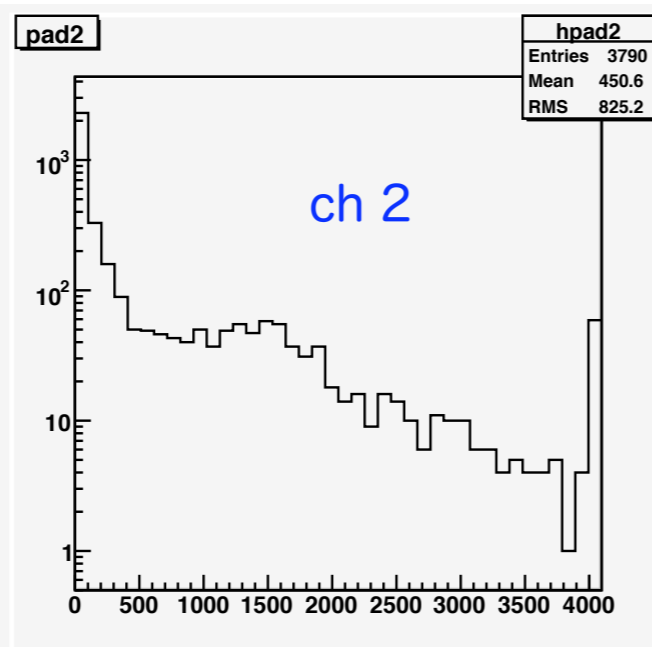
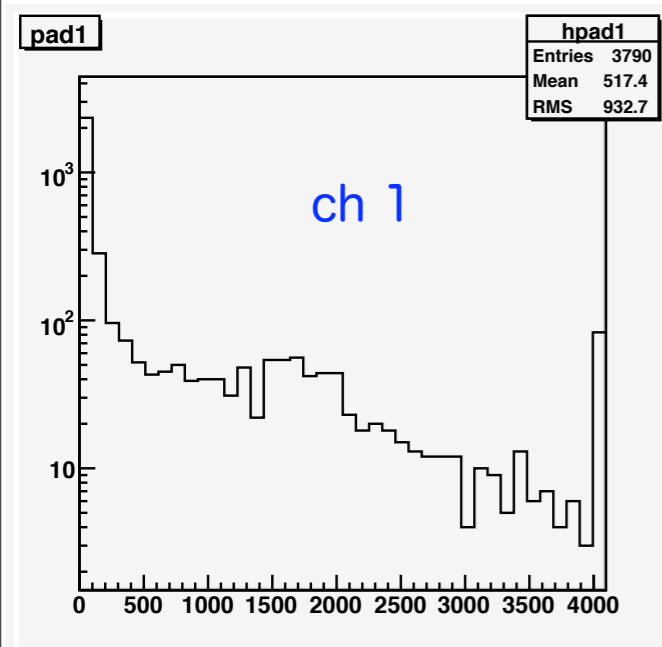
宇宙線イベント

(1) 波高分布



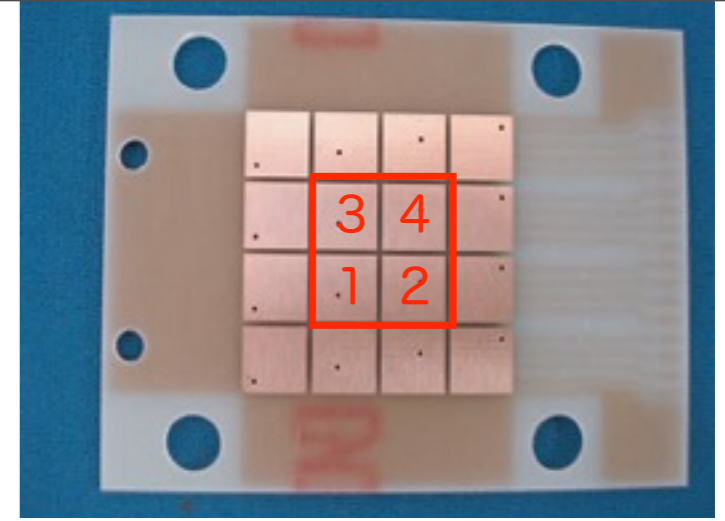
ch 2

ch 4



宇宙線イベント

(2) 波高分布

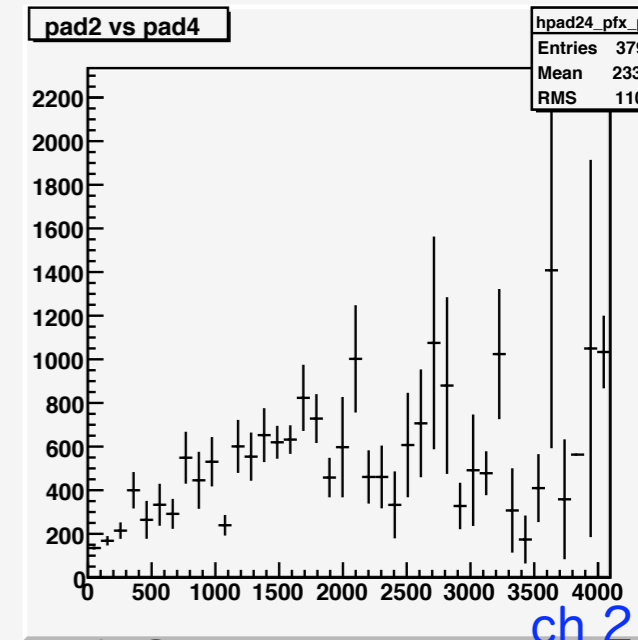
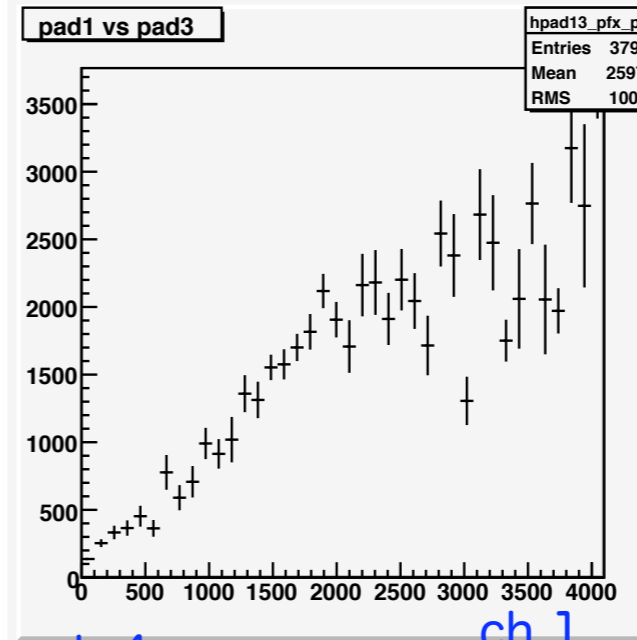
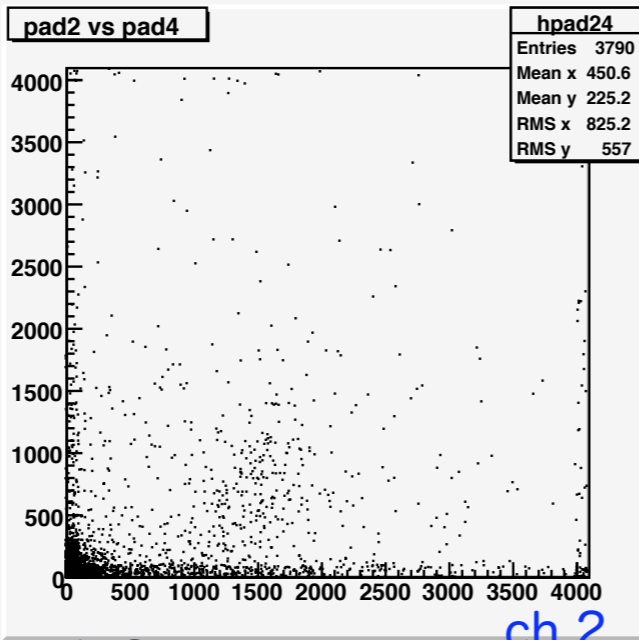
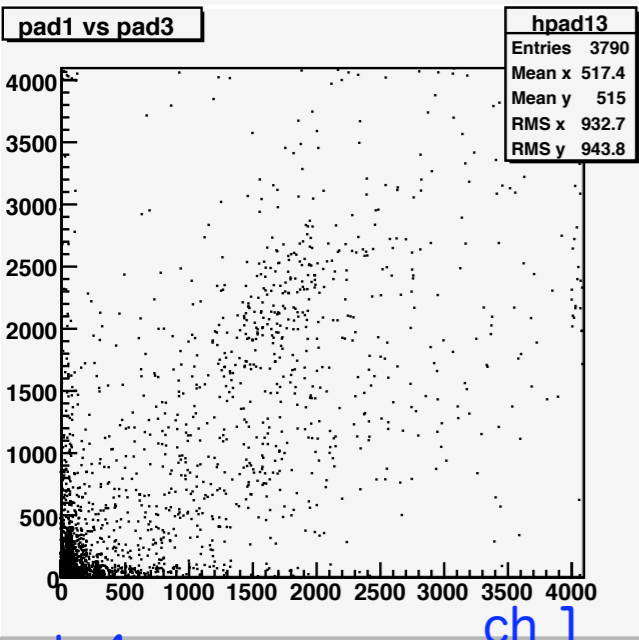


ch 3

ch 4

ch 3

ch 4



ch 1

ch 2

ch 1

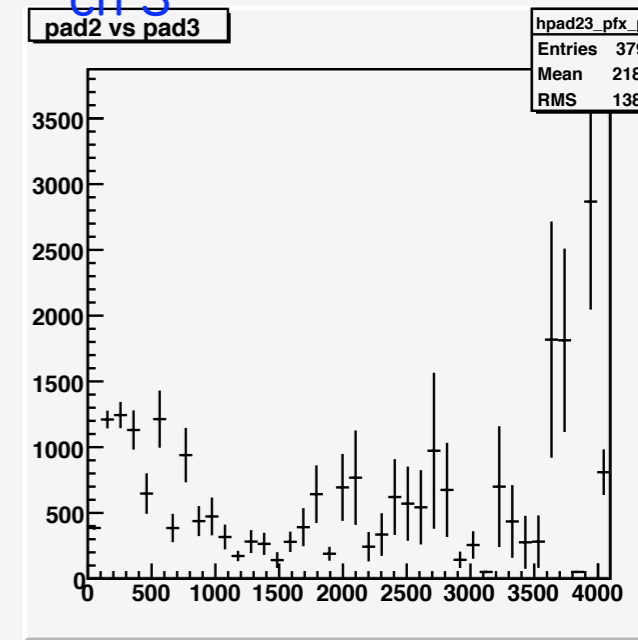
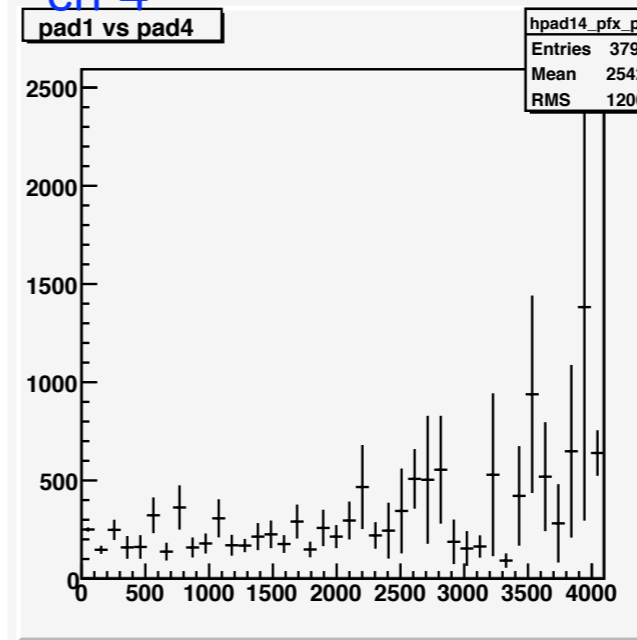
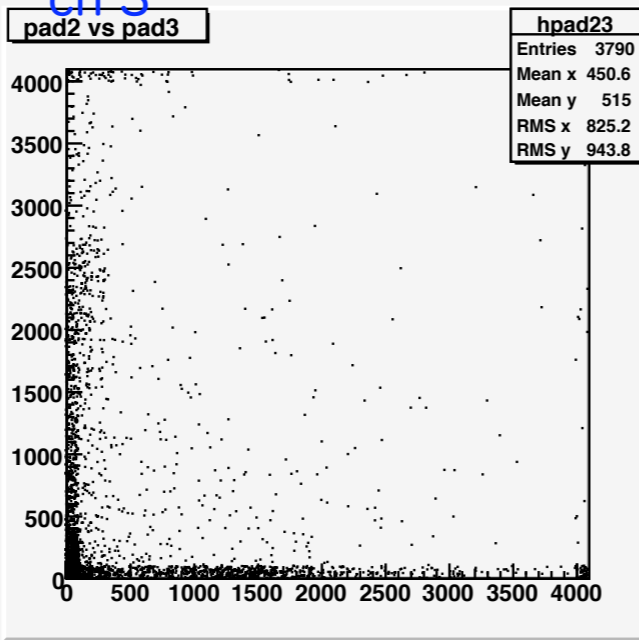
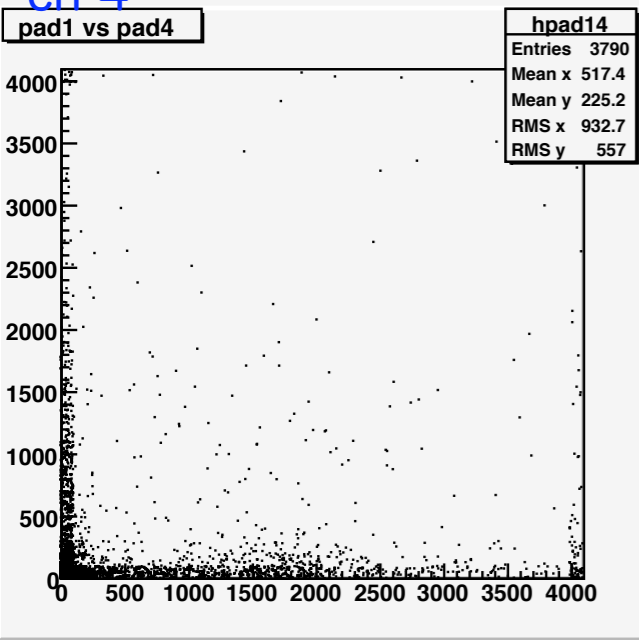
ch 2

ch 4

ch 3

ch 4

ch 3



ch 1

ch 2

ch 1

ch 2

DEMONSTRATION OF TRACKING BY USING COSMIC RAY MUON (CRM)

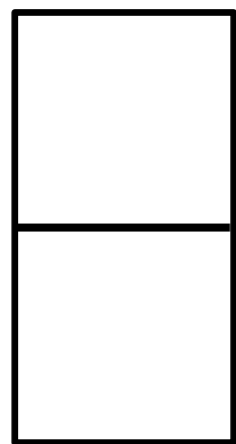
○4chを用いた宇宙線ミュオン信号の解析

- 複数パッドで電荷信号を検出できる
- 再結合による電離電子の損失が少ない
- パッドに近い場所で反応が起きるため、不純物の影響を減らせる
 - ▶ 1 cm で50% の電荷減少とすると、宇宙線の場合は平均で25% の減少のみ
- ノイズの多い3,4 channelでも十分大きな信号が期待される

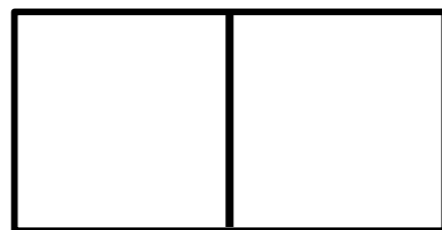
○天頂角での角度分布

Cosmic ray muons >20fC

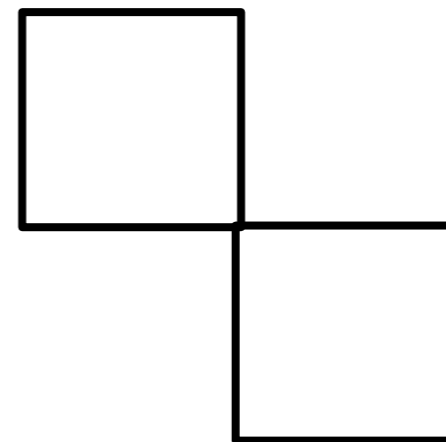
- パッド4枚でノイズもあり、宇宙線のイベントレートもかなり小さいため、正確な角度を求めるのは難しい
- 今回は以下の3通りにイベントを分ける -> 誤差は30%程度である



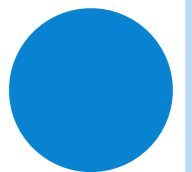
=0°



=90°



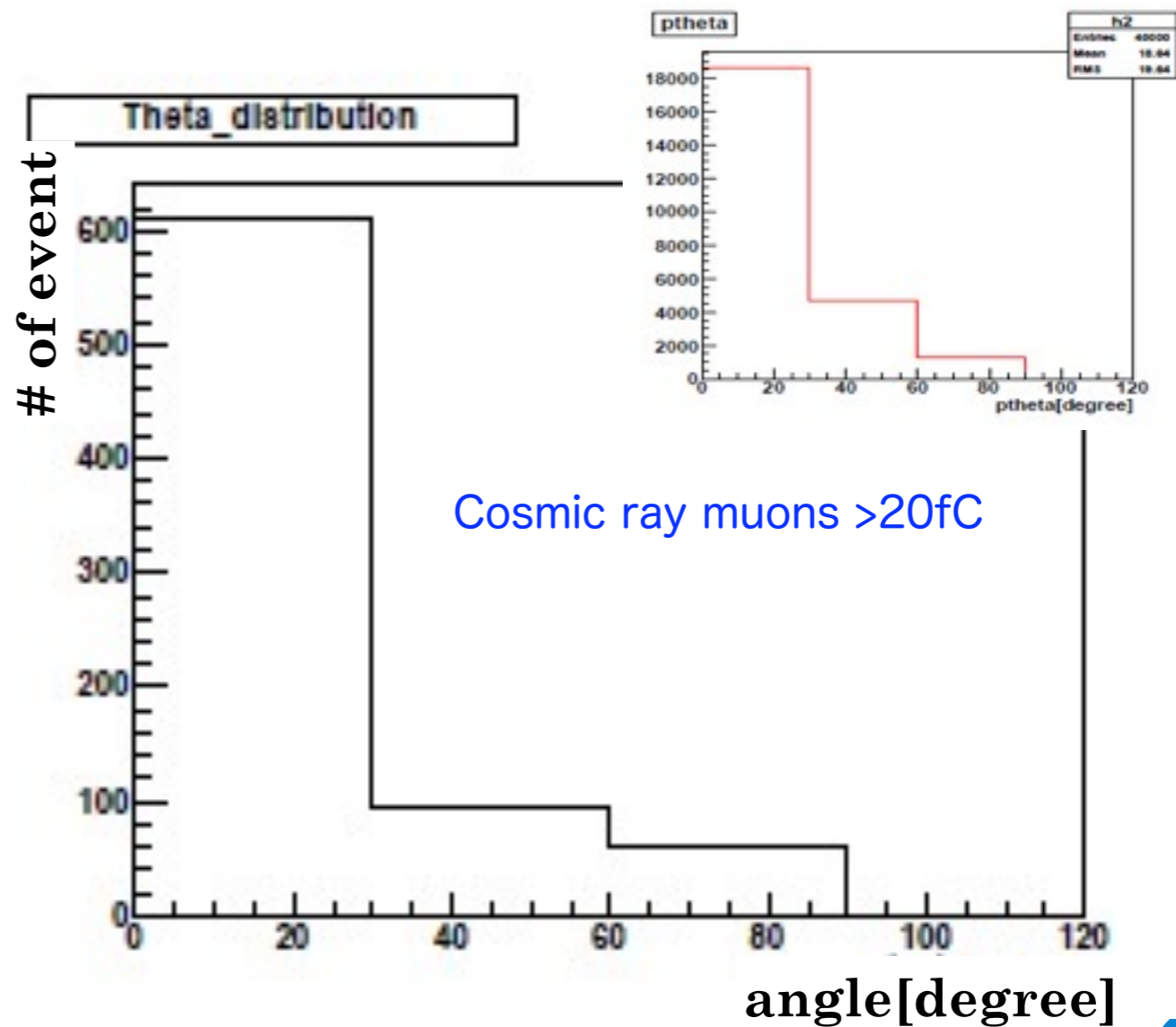
=45°



ZENITH ANGLE DISTRIBUTION OF CRM

○結果

- 右図の天頂角分布が得られた
- 宇宙線ミュオンは天頂角で $\cos^2 \theta$ に従うことが知られている
 - ▶ パッド上で角度を求めているので、 $\cos^2 \theta$ の分布を経面に射影した分布と比較する
 - ▶ 赤い線のヒストグラムが $\cos^2 \theta$ を平面に射影したときの分布 (monte carlo)
 - ▶ 不完全ではあるが理論と近い傾向が見られる

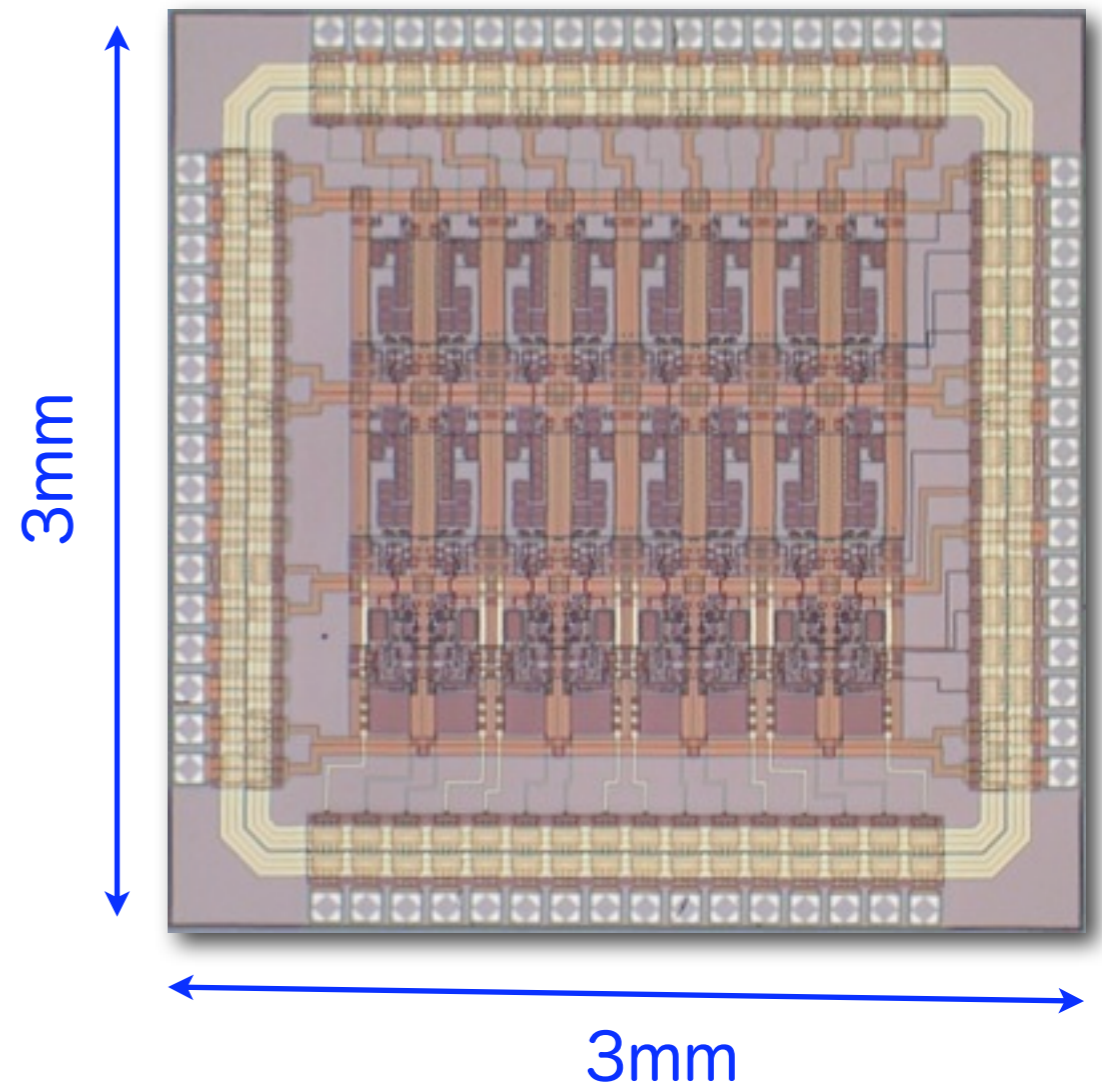


Front-end ASIC chip R&D

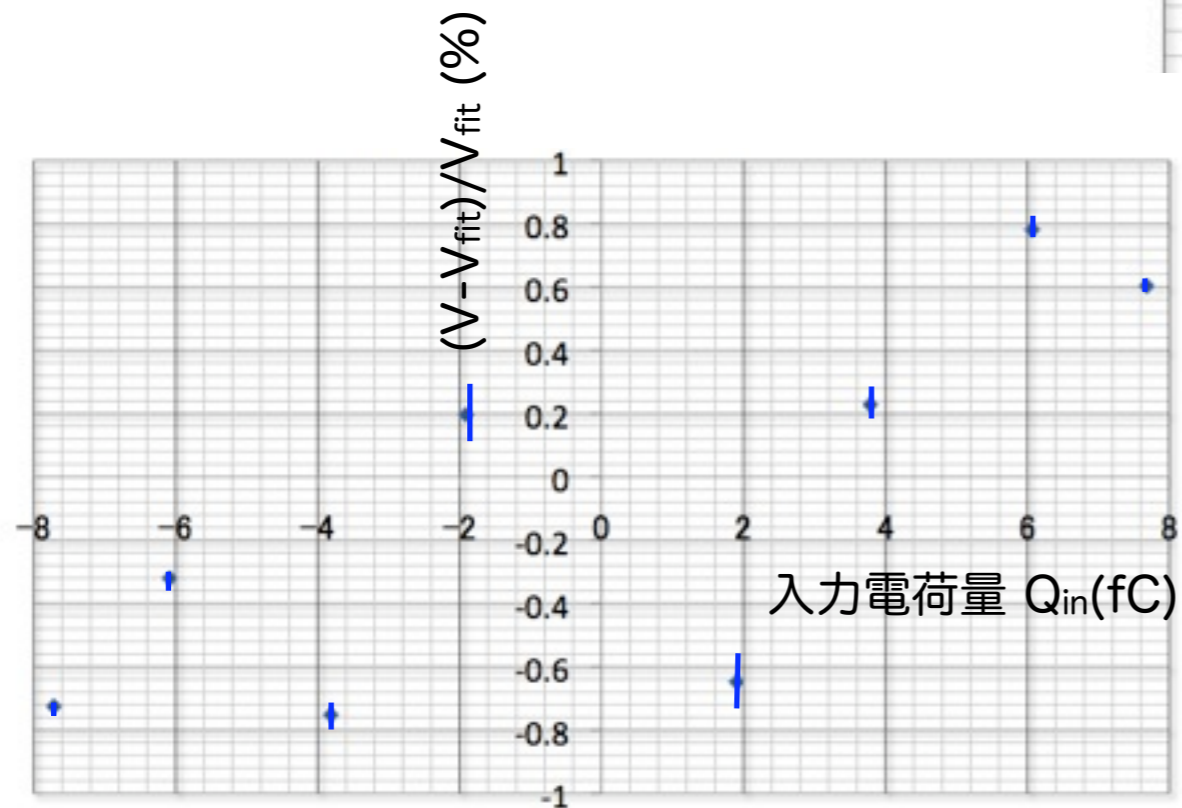
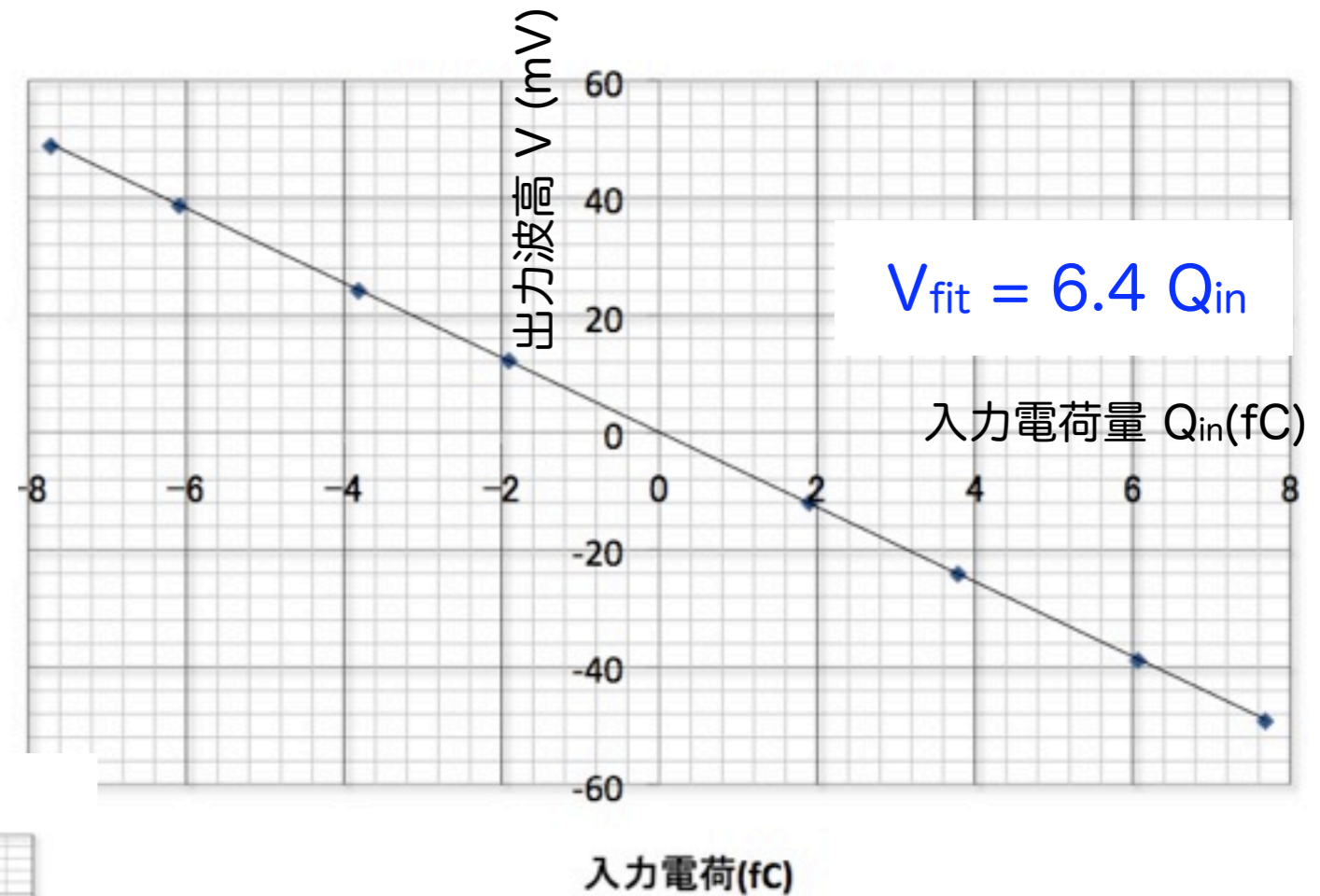
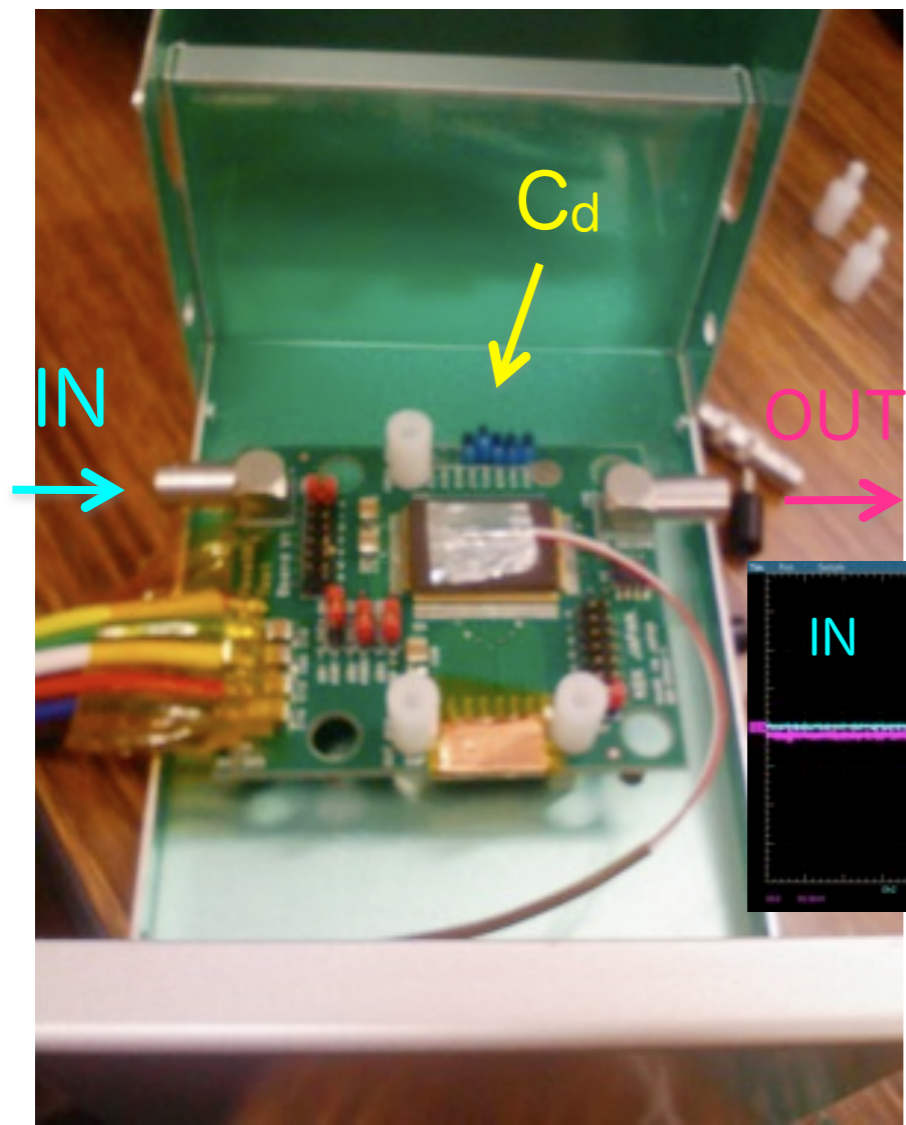
Pre-amp. to PZC to shaper - output all analog channels

Inputs (8ch)

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



試験結果：Linearity



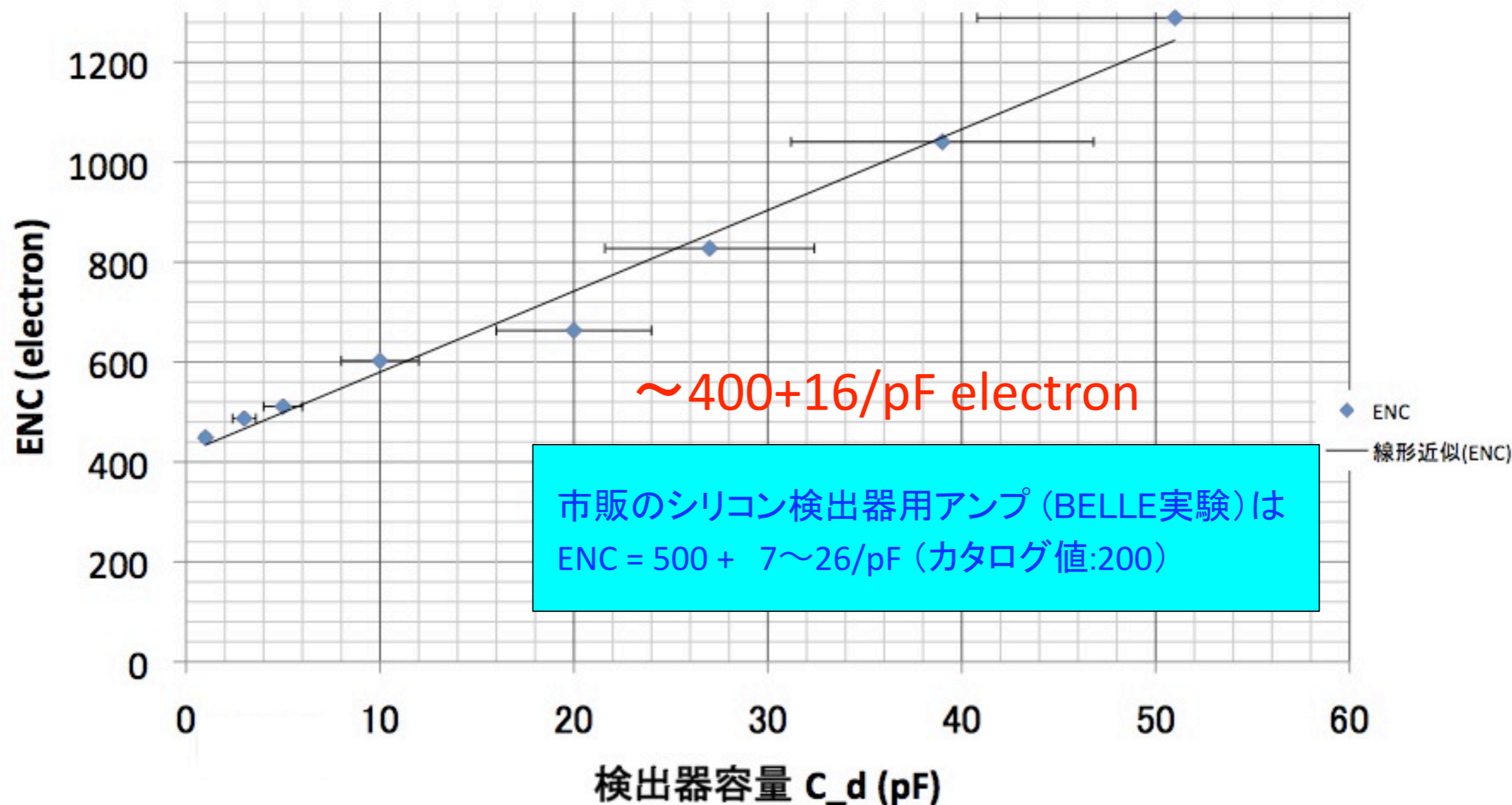
出力電圧の σ 値は1mV前後

$$\sigma = 1 \text{ mV} / (6.4 \text{ mV} * Q_{in})$$

$$\sigma = 0.16 / Q_{in} [\text{fC}]$$

入力電荷 -8 ~ 8 fCの範囲で
非線形性は少なくとも0.8%以下。

ノイズ(ENC)測定 - 常温 -



セラミックコンデンサ容量誤差 = $\pm 20\%$

note : ENC \propto (検出器容量) / (時定数)^{1/2}, 測定データの $\tau = 1 \mu\text{s}$

展望

今後、アナログ-デジタル変換部も含めるためにさらなる低消費電力化を考慮したシステムASICを製作する必要がある。

そのため、プロセスを0.25 μm へ変更し改良型ASIC開発を開始。

- ・ 高ゲイン化
- ・ 高密度多チャンネル化、32チャンネル
- ・ S/N比が10以上の低ノイズアンプ
- ・ 低温(-110)で安定動作

	目標値
入力電荷範囲	- 0.025 ~ 0.025 pC
ゲイン	10 V/pC
ピーキングタイム	1 us, 500ns, variable (外部スイッチで変更可)
消費電力	5mW/ch 以下
ノイズ(ENC)	2000e (Cd = 1pF)以下
チップ(ダイ)の大きさ	3 mm x 3mm
電源電圧	+ 2.5V, -2.5 V
チャンネル数	32 ch
プロセス	0.25 μm CMOS
動作温度	~ -110°C

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 90ppb (O_2 equiv.) with circulation in 2 months, which will be improved in next time.
3. We will confirm the purification and measure the 4ch charge signals (pads).
4. Next, we will measure 16ch-pads with 5cm drift in TPC .