PETに使える3Dガンマ検出器

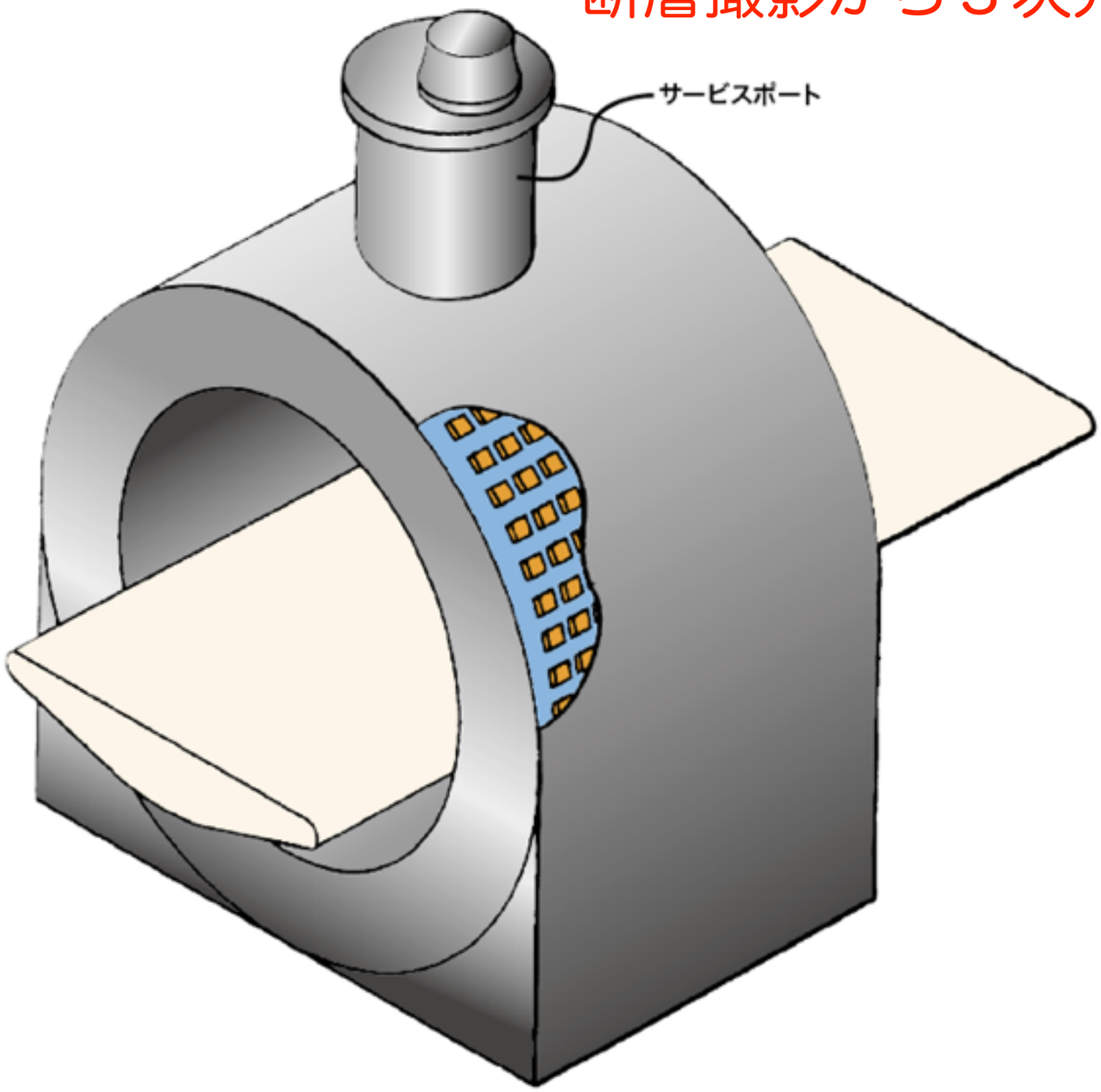
液キセノンTPC

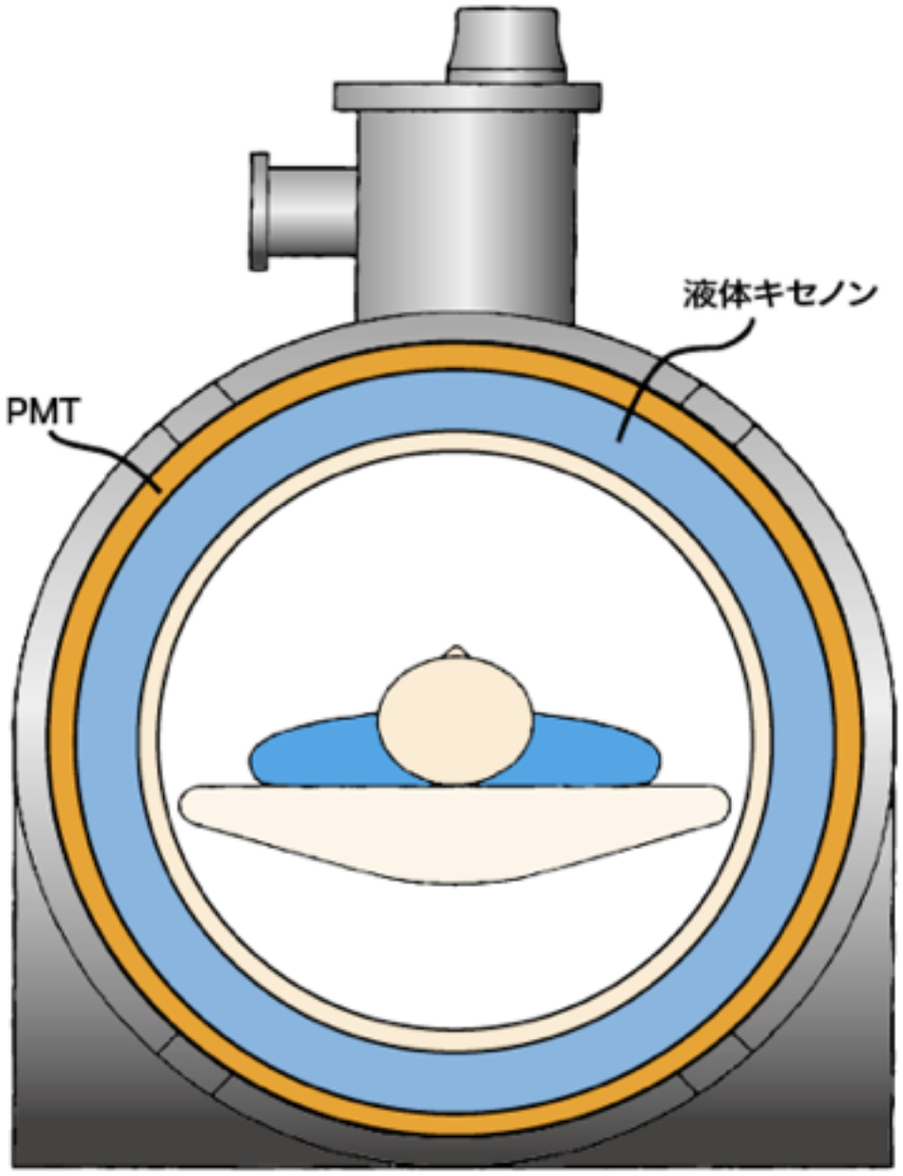
田内利明 (KEK)

アクティブ媒質TPC開発座談会、2017年4月22日

TXePETイメージ（液体キセノン検出装置のみ）

断層撮影から３次元立体撮影へ





XEMIS2 : Small animal PET, which will be tested for 2017 -2020 in CHU-Nantes, France, Subatech group

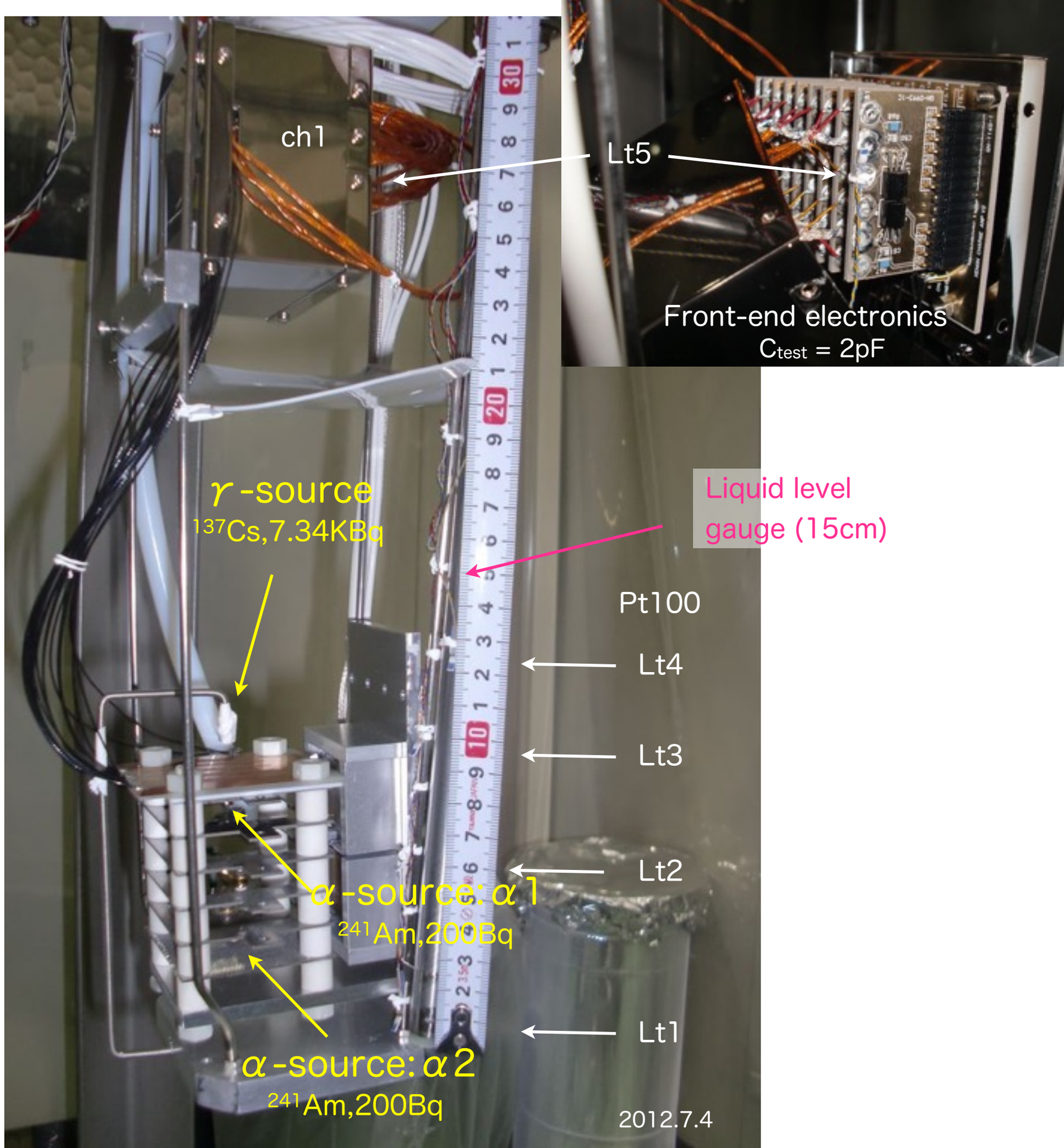
LXeTPC

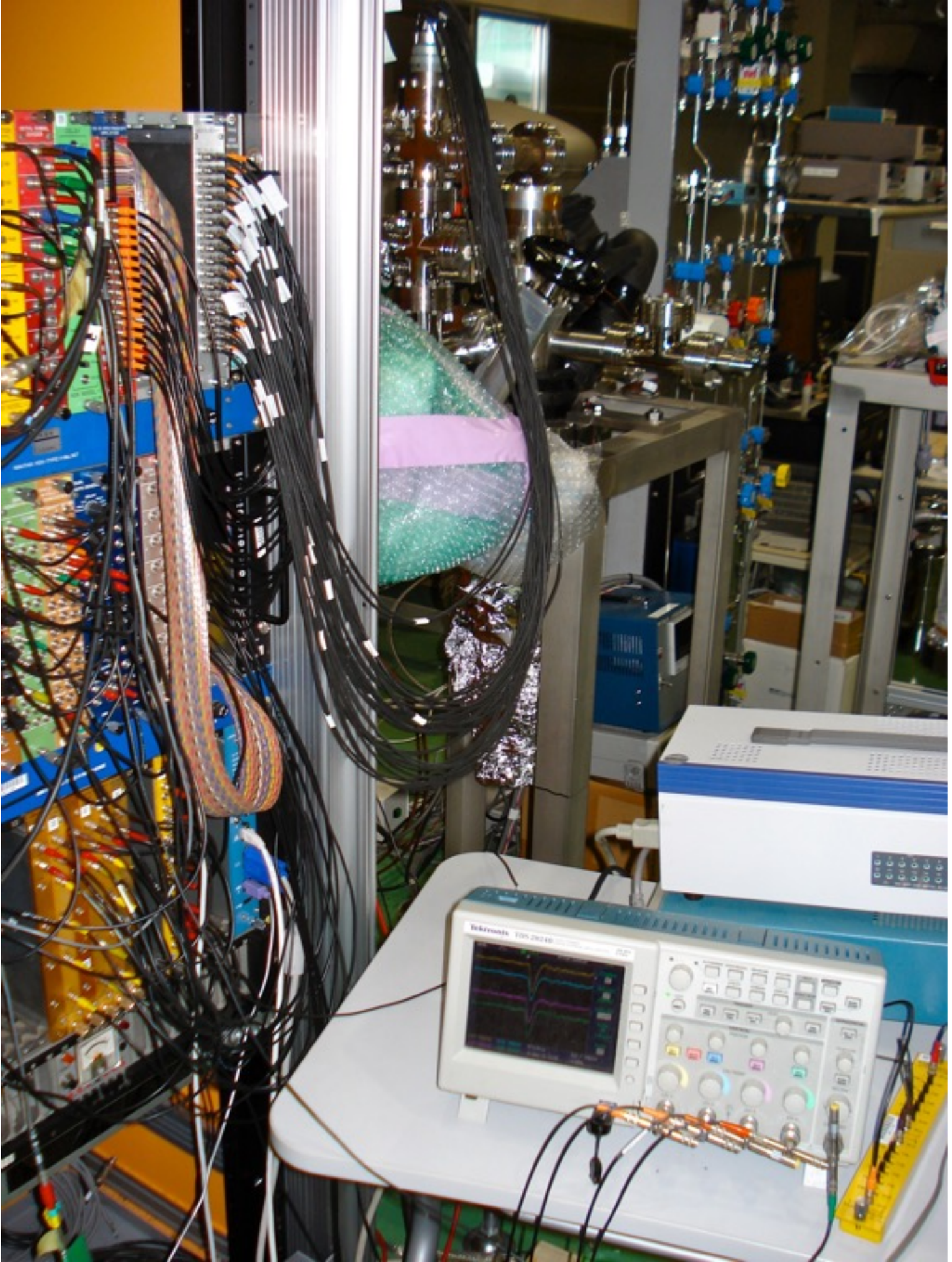
prototype -1

5cm drift, mesh grid
with1mm gap
4x4 pads readout,
7.5x7.5mm/pad

PMT1 (up) : R5900; DY1 - 12
20.7uA at +900V(max)
Q.E.=20%@175nm
(2003.11.28)

PMT2 (down) : R7600; DY1 - 10
23.9uA at +900V(max)
Q.E.=30%@175nm
(2009.06.15)



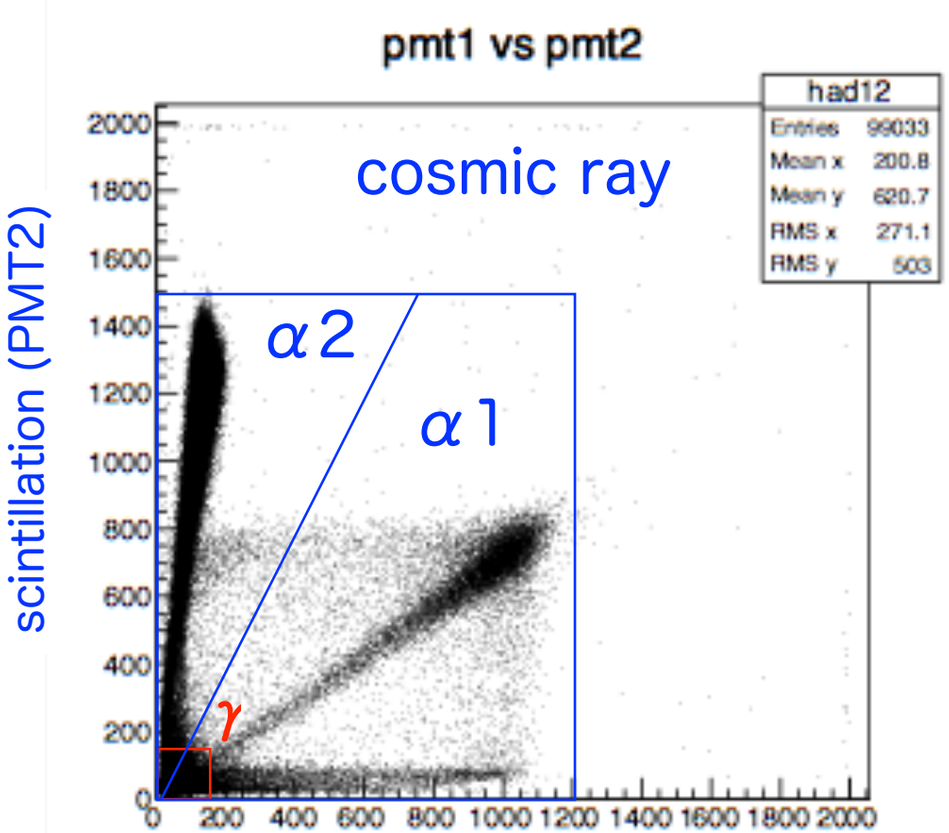


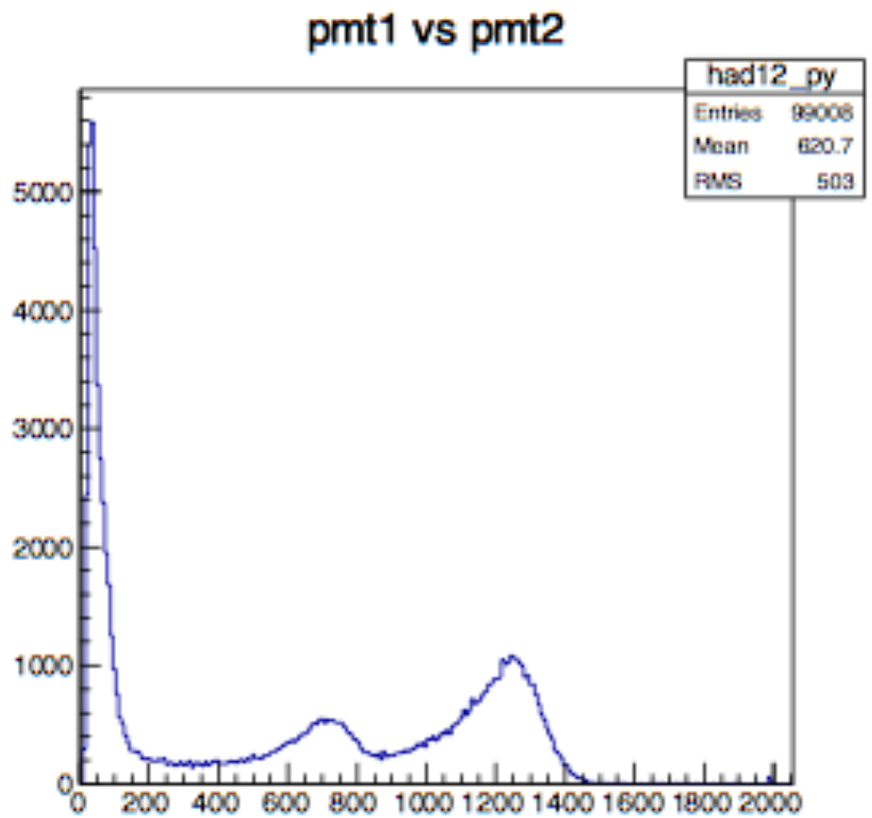
Pre-amp (A250) NIM 16ch
post amp CAEN/N568B 16ch
(shaping amplifier)

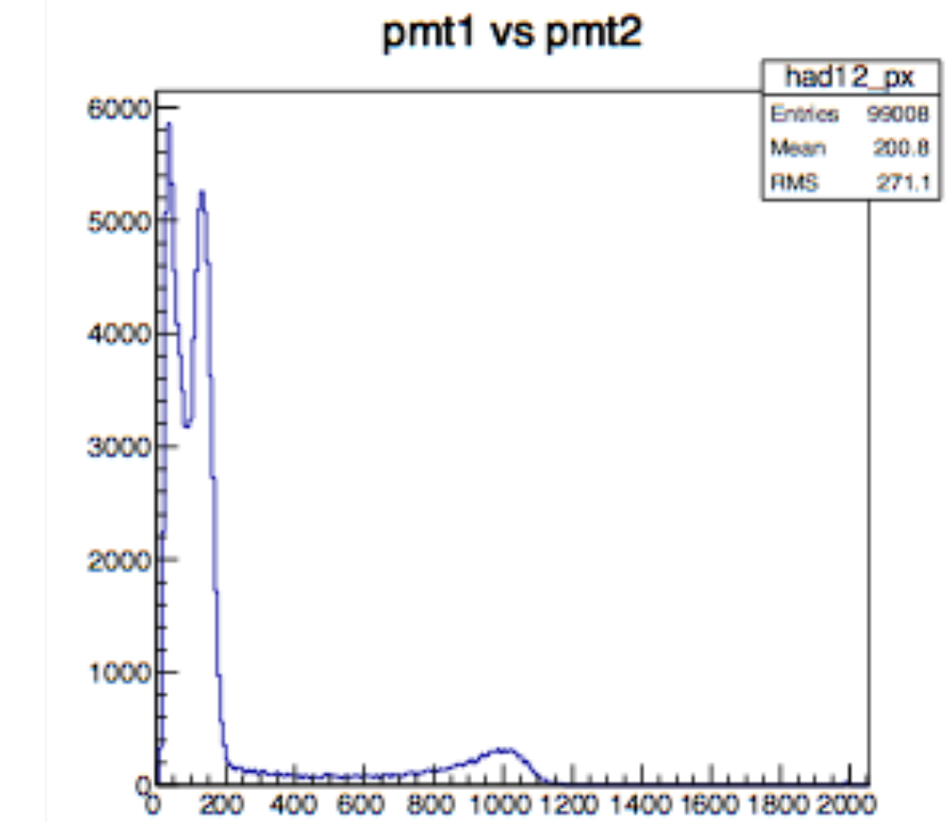
Trigger: pmt1xpmt2, test pulse, cosmic
HV power supplies
- positive (brown) : PMTs
- negative cathode, PMT3(cosmic)

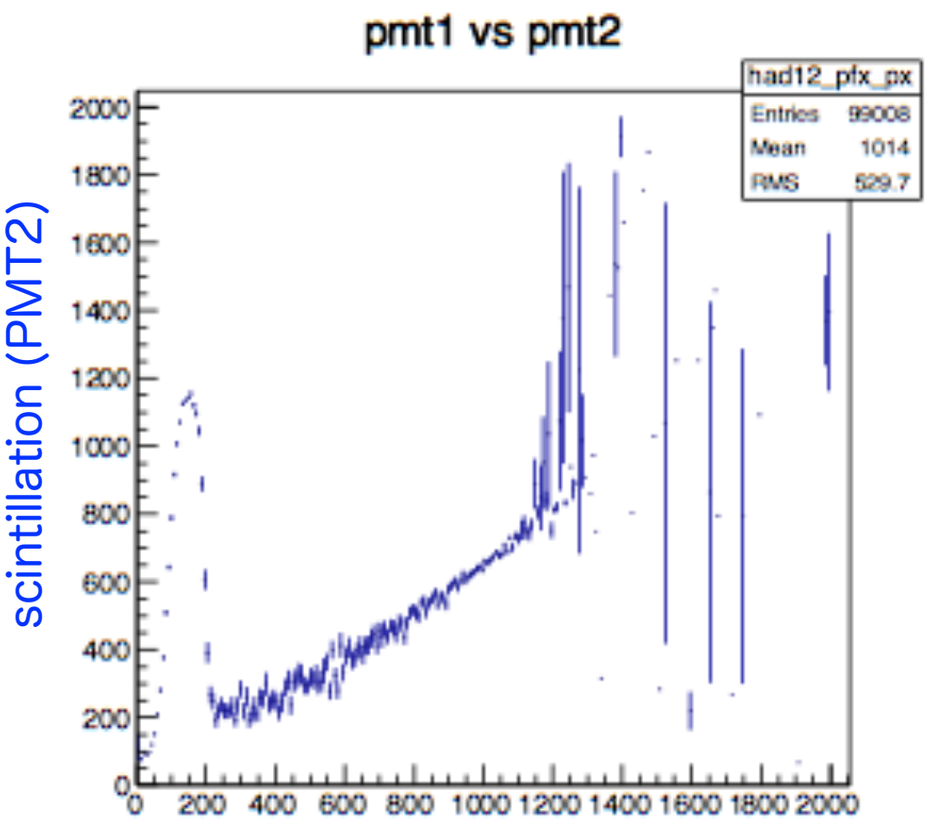
DAQ : CAMAC
FADC 500MHz 2ch/module
8bits/3.3V, 8k words/ch
FADC 20MHz 16ch/4modules
8bits/2V, 1k words/ch
ADC 2249W 12ch, 11bit integrated ADC
0.25pC/count, 800nsec gate

Event classifications by scintillation lights



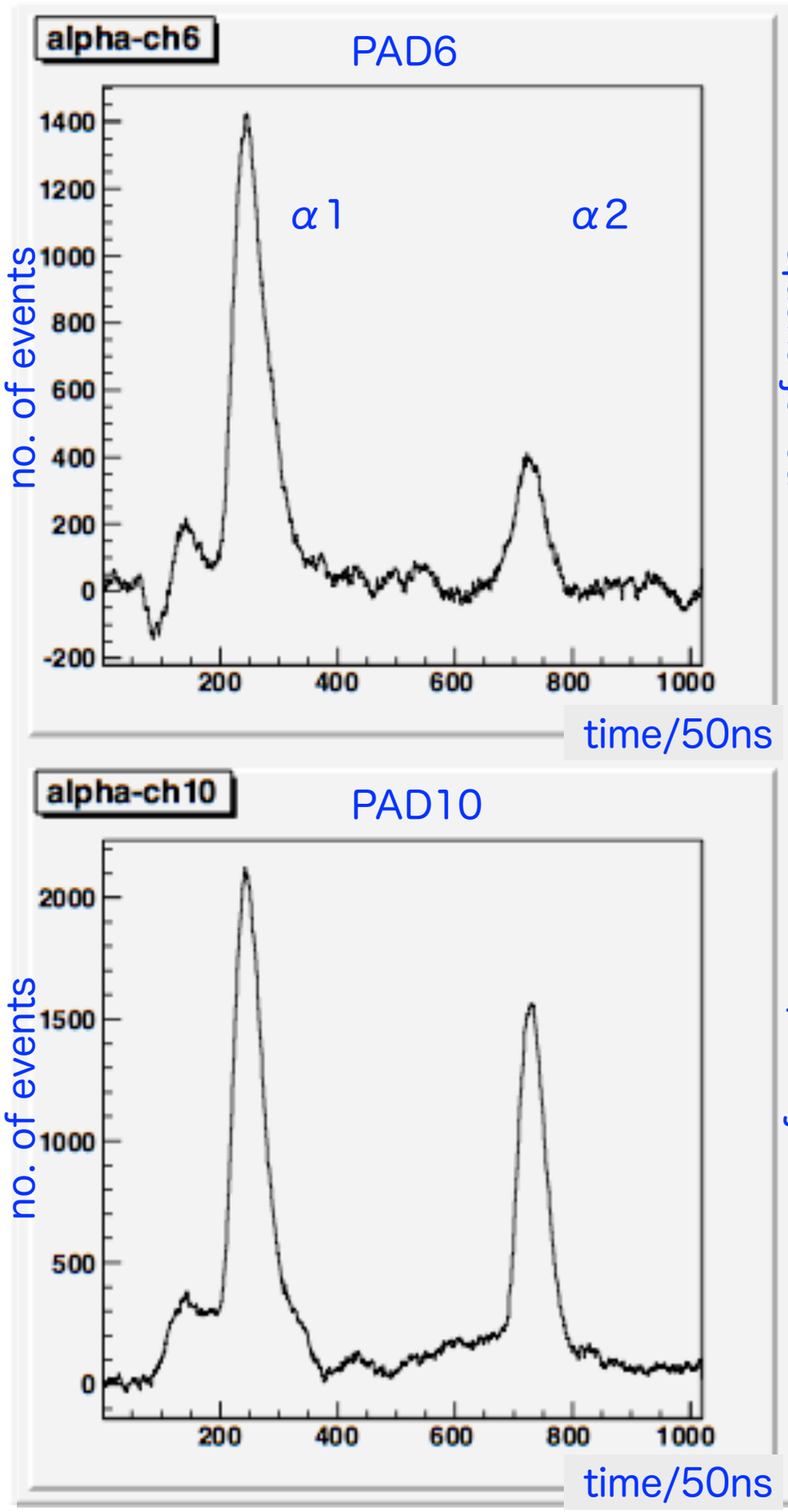


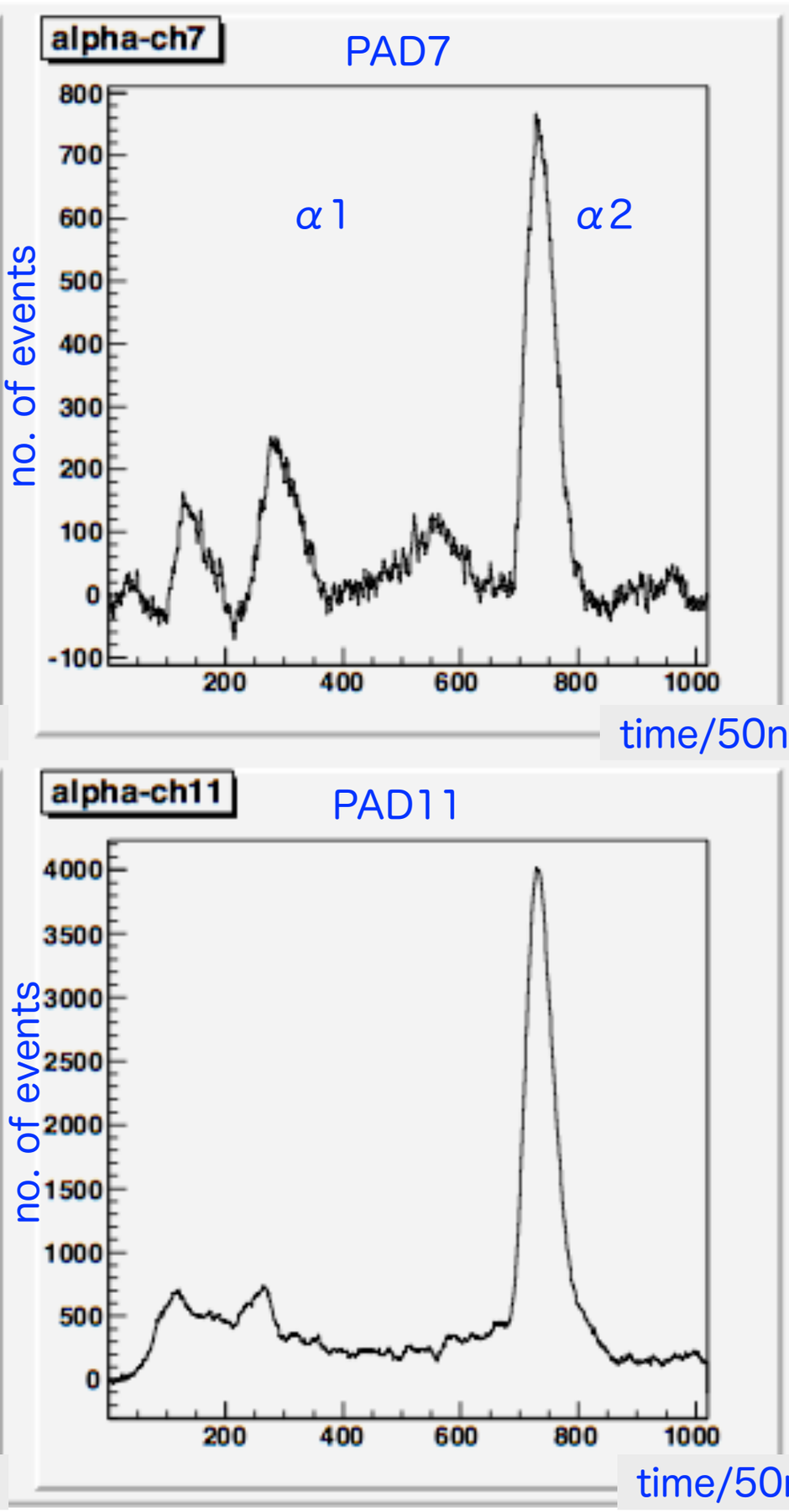




2012.12.10-
2013.1.19

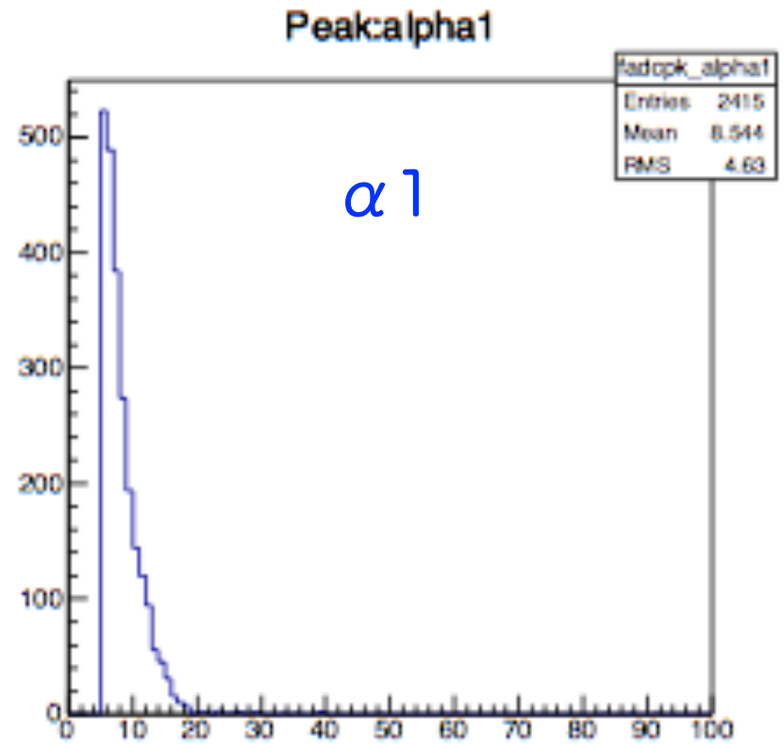
Raw signal charges

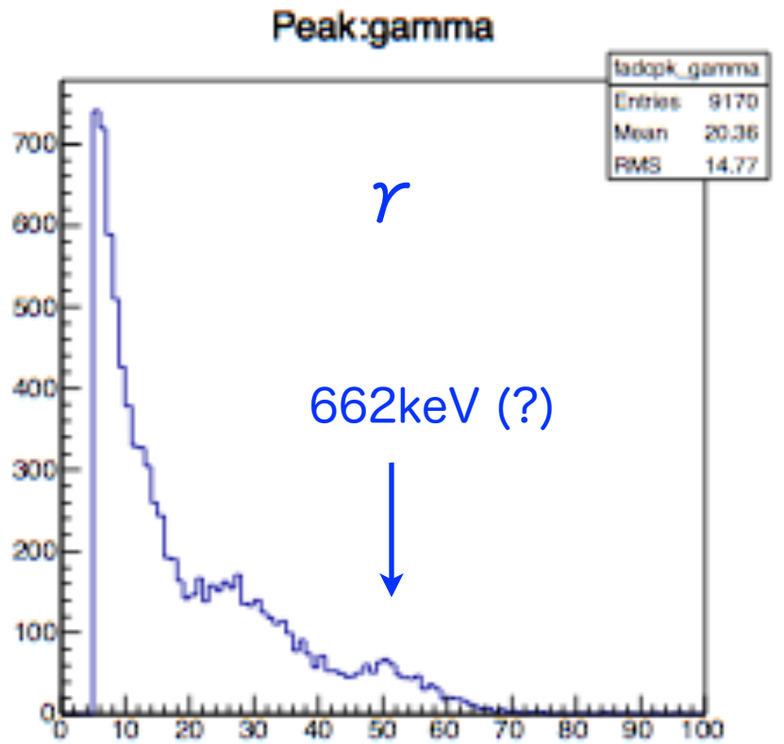


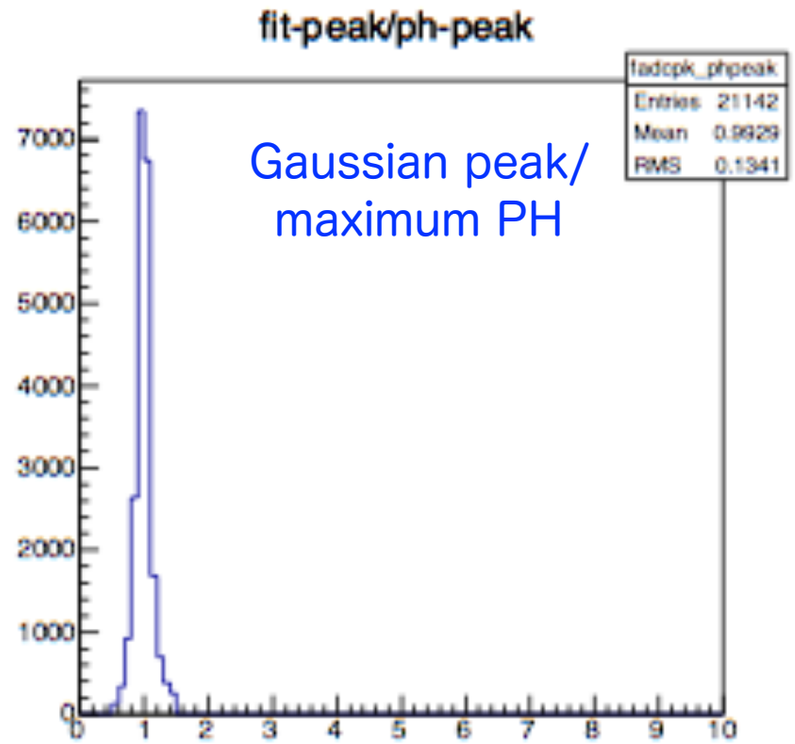


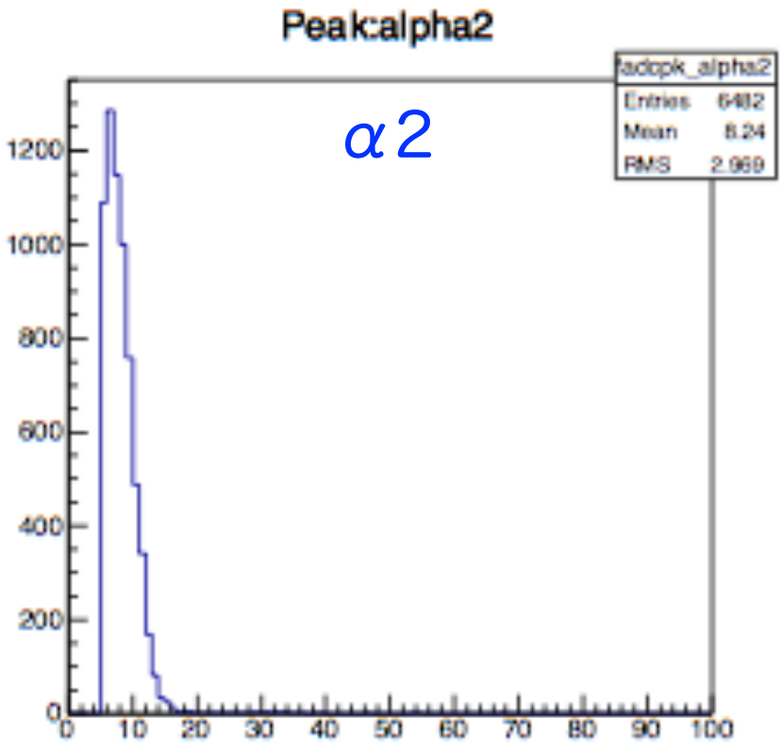
2012.9.18

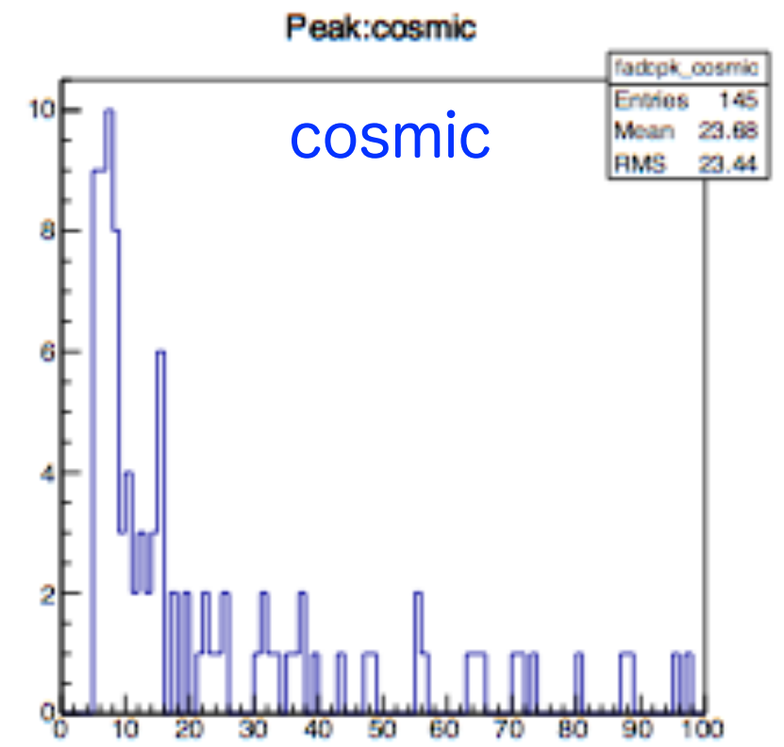
Charges/pad (peak of D-Gaussian fit) of $\alpha 1, \alpha 2$ and γ, 2012.12.20-12.31 (8 days)



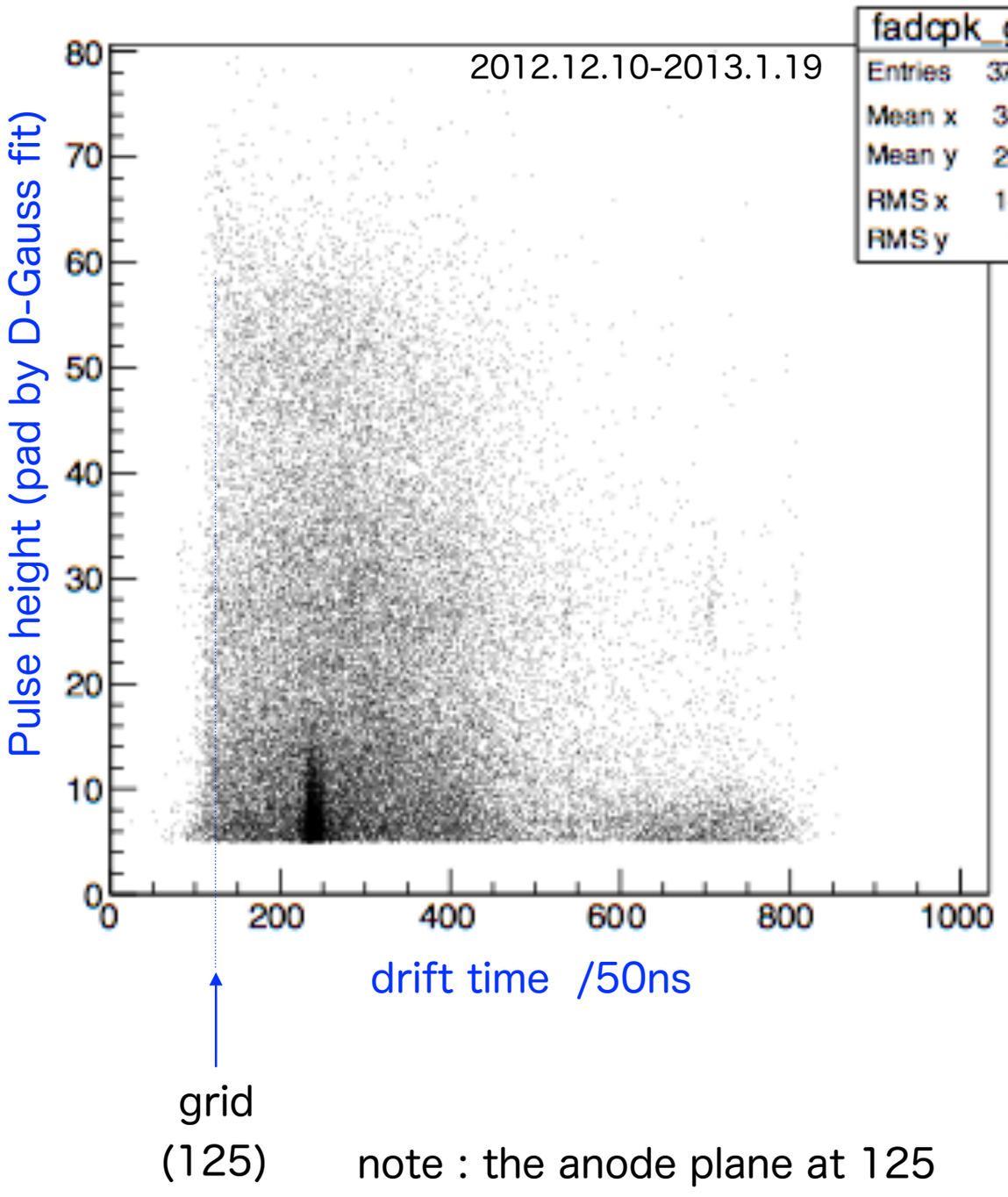


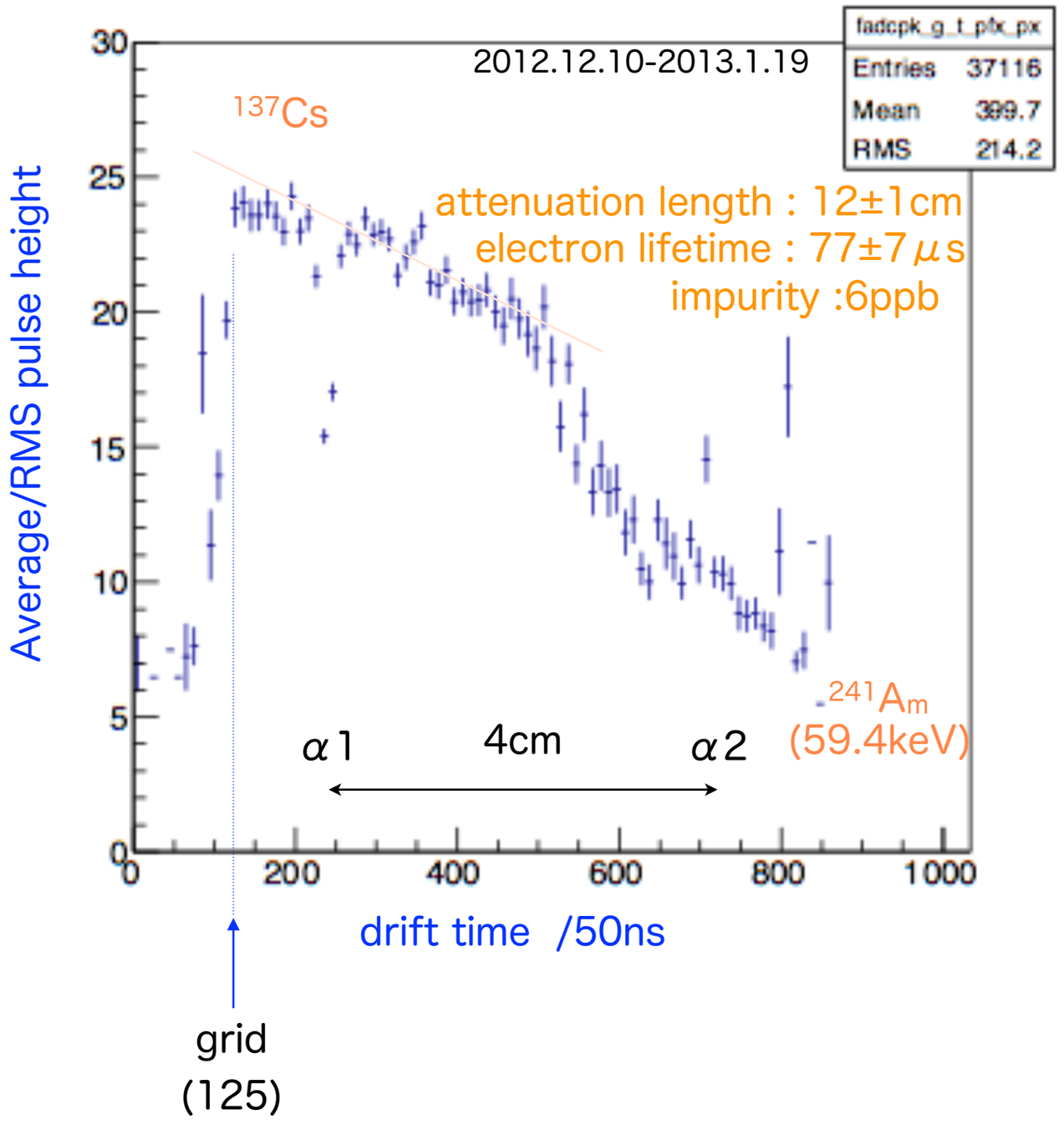




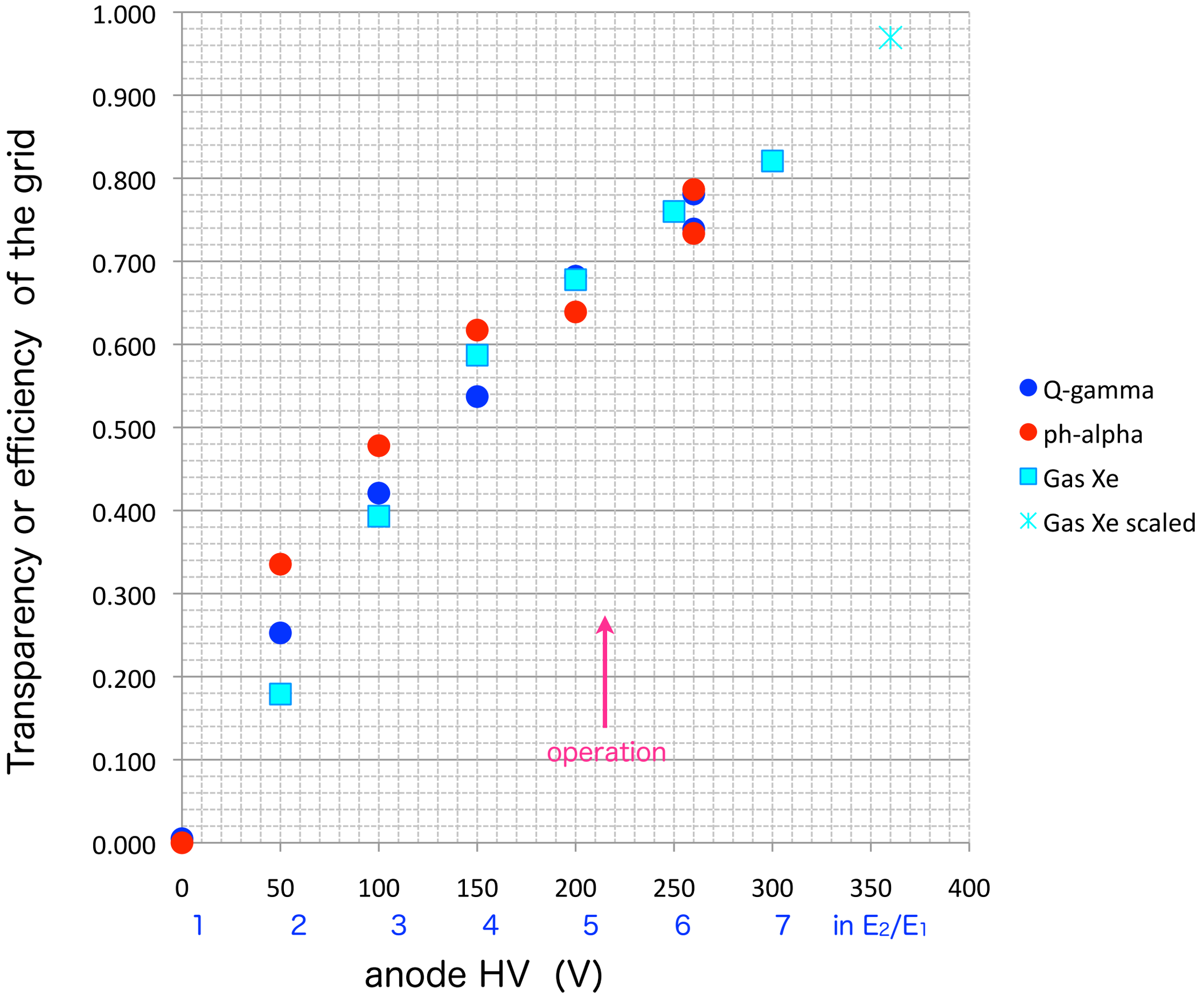


Gamma's （subtracted peaks of α1 and α2）

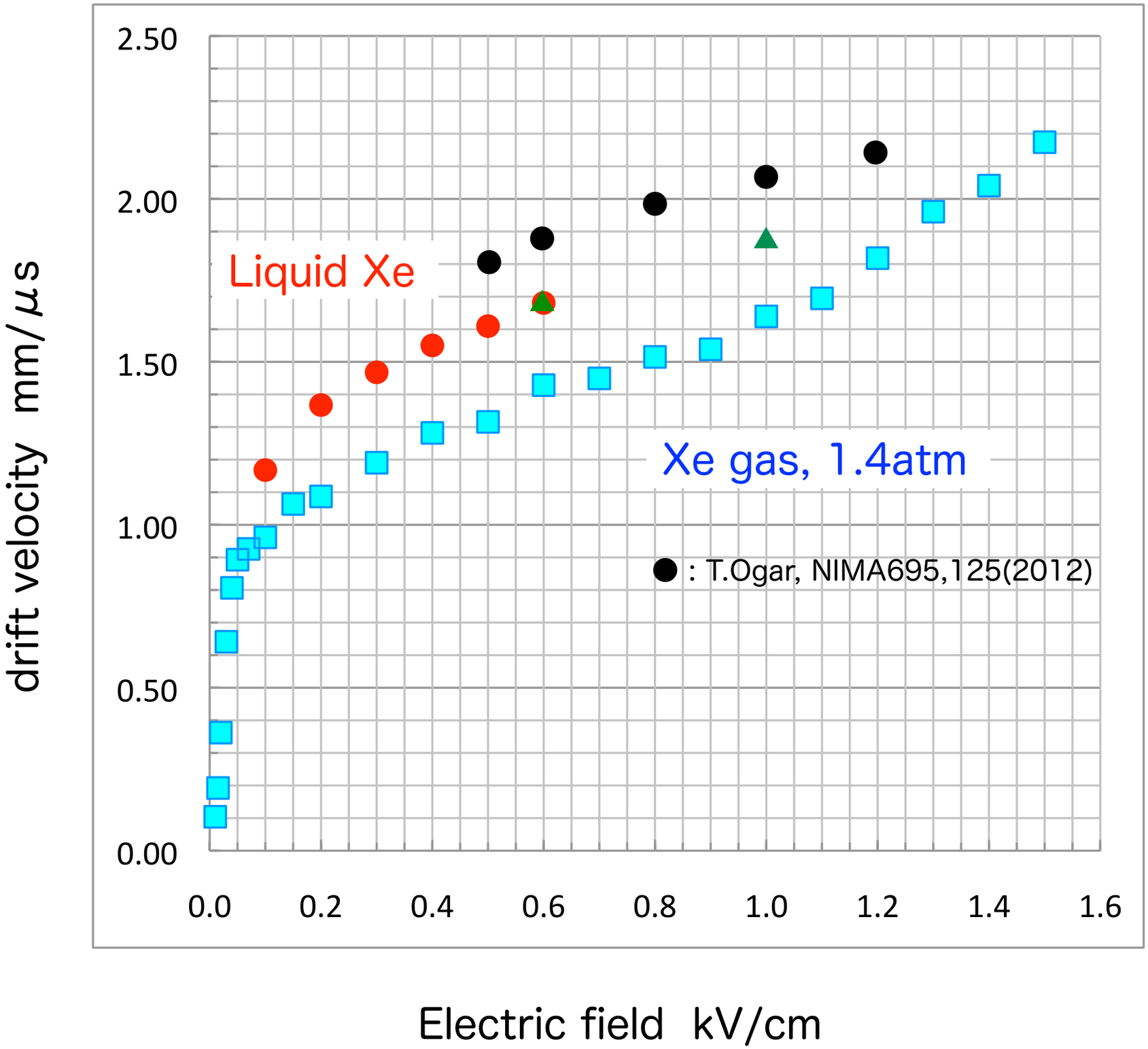




Grid Transparency

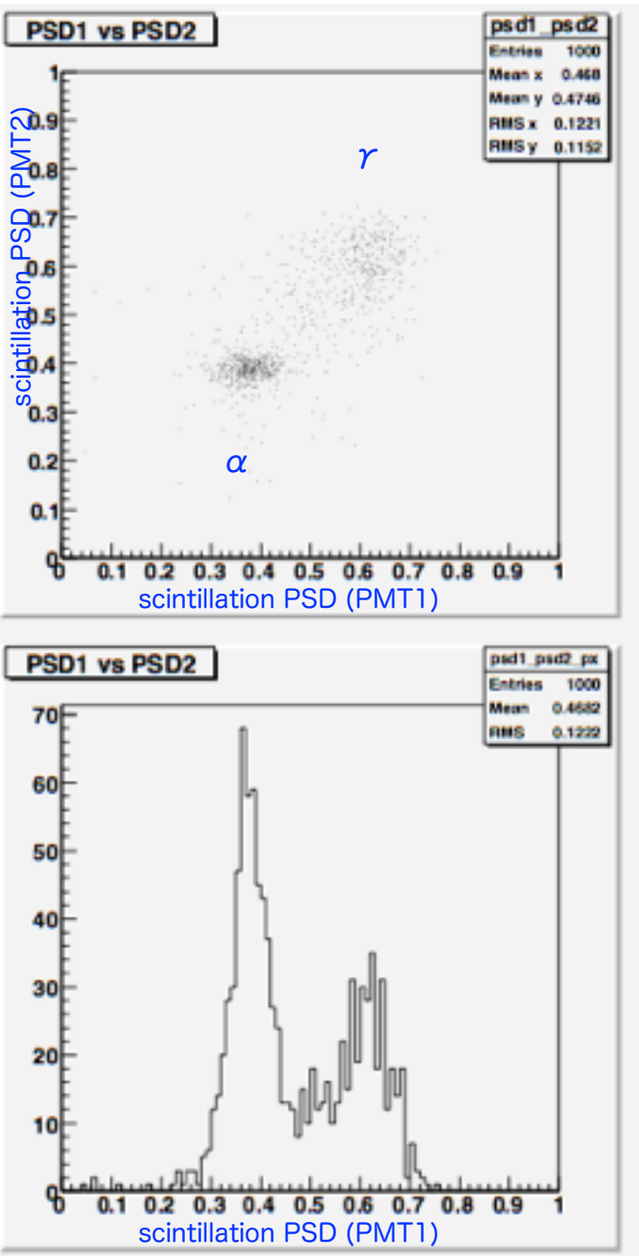


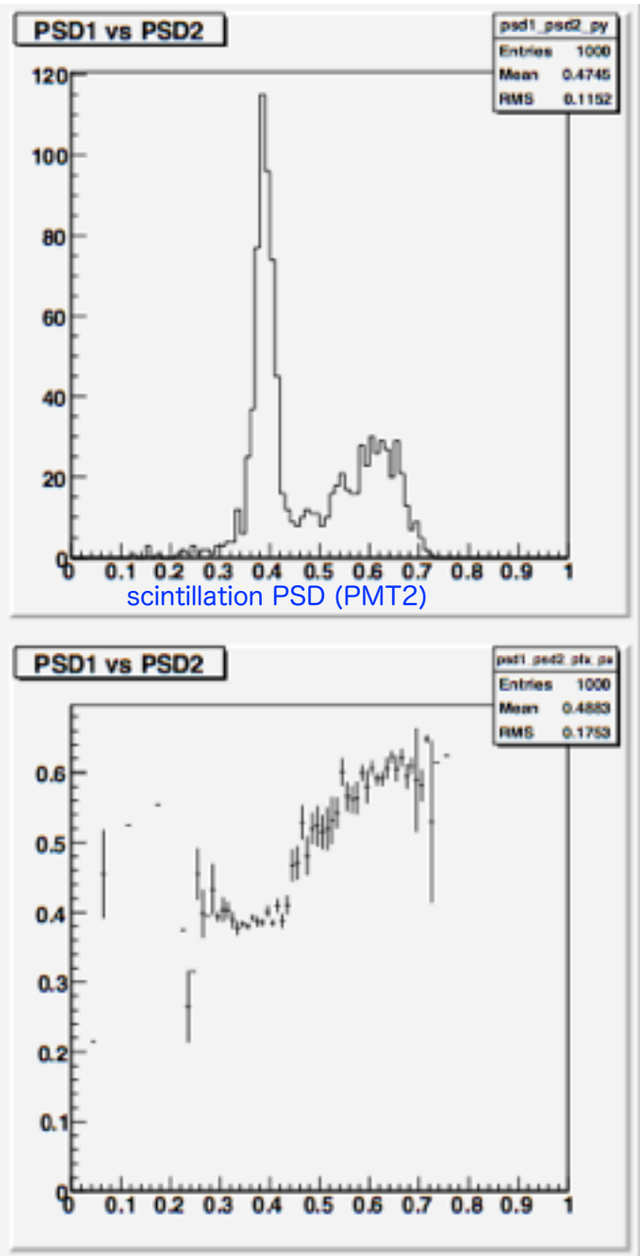
Drift velocity in Liquid Xe



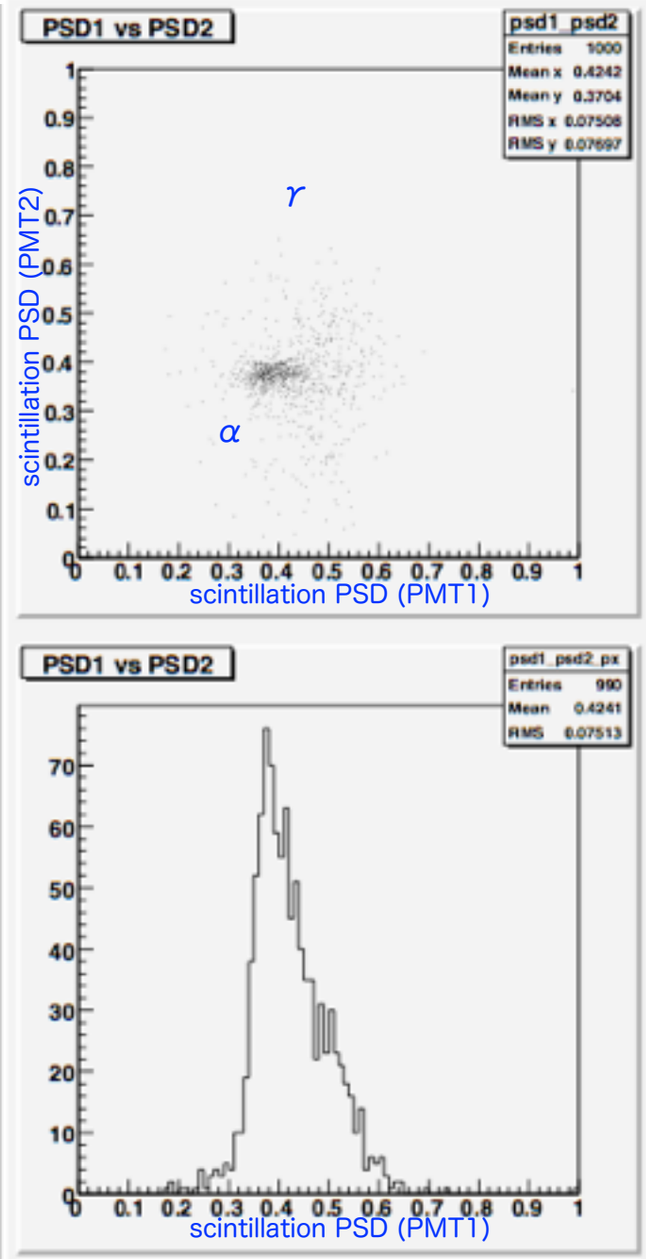
Pulse Shape Discrimination (PSD)

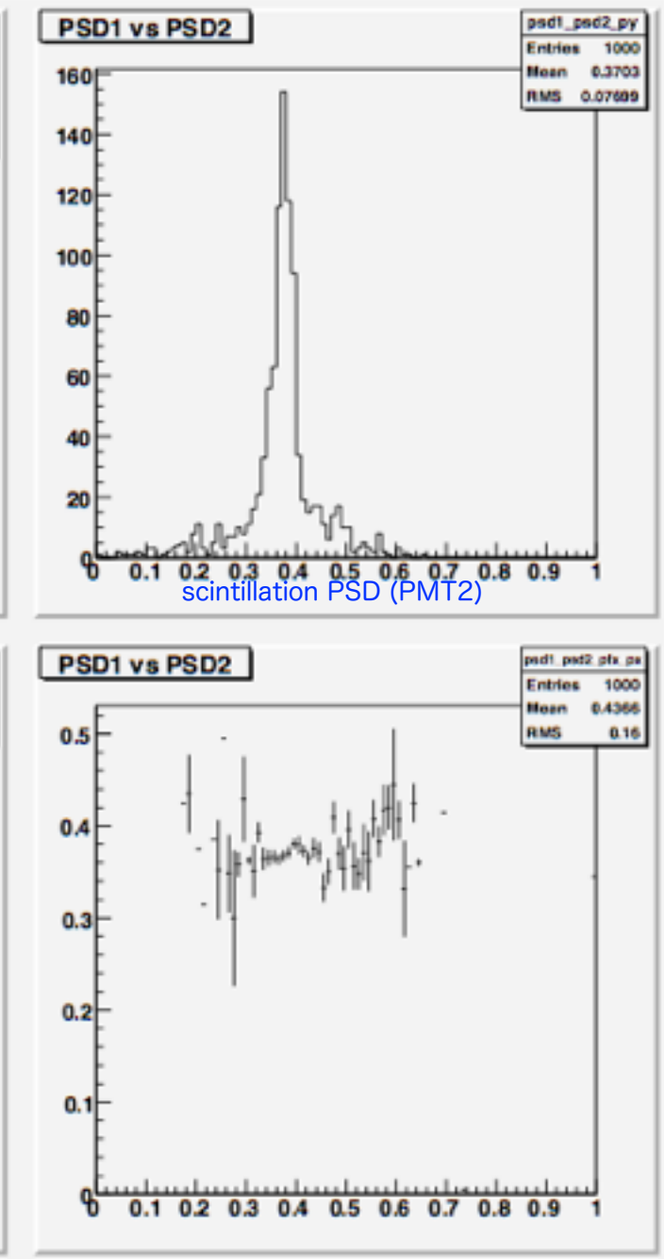
Xe Liquid at 165K PMT1=PMT2=+720V 2011.10.6.1832





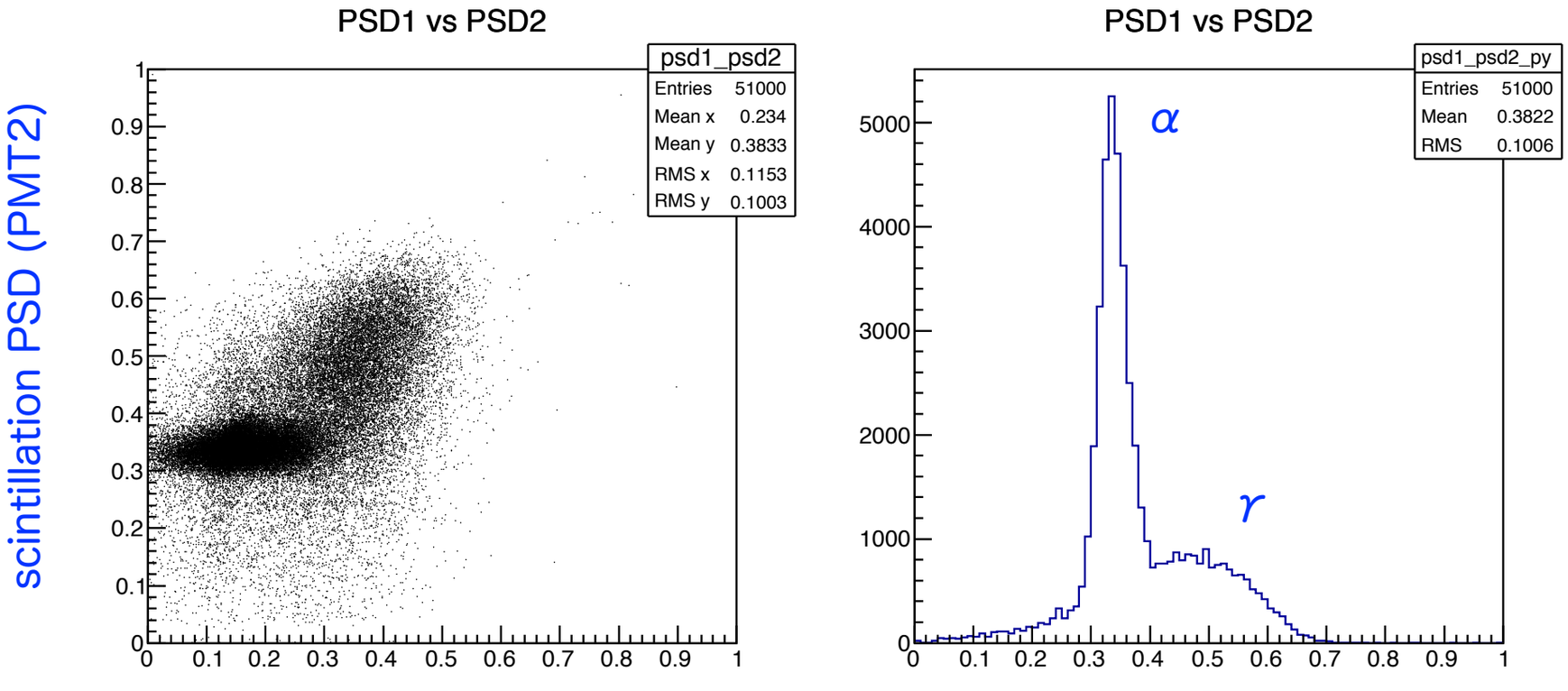
TPC cathode =0V, anode=0V





TPC cathode =-2.5kV, anode=+255V

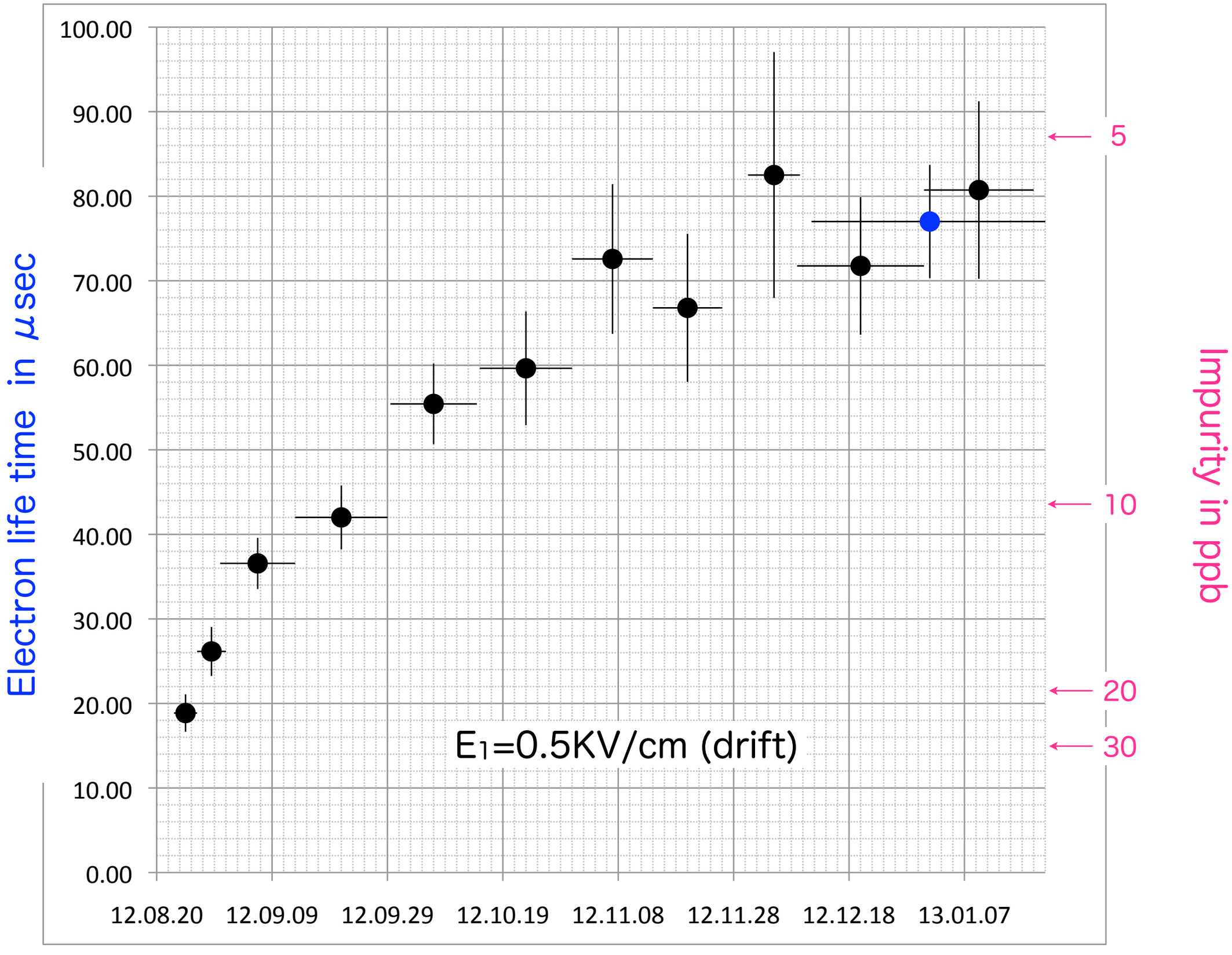
TPC cathode =-2.5kV, anode=+255V



16:04 16 Oct. ~ 13:49 19 Dec. 2016

Electron life time and impurity in Liquid Xe

2012.8.23-2013.1.19



Summary : LXeTPC prototype -1

1. Preamp : AI 16 ch OK (2012 July - 2013 May)
2. Purification : gas circulation at 1.3 ℓ /min for about three months

   8/23-9/9 (17days) smooth increase of charge signals followed with saturation

   10/-12/10 (71days) increase with CH warm-up/day followed with saturation
3. Impurity estimated by γ spectrum of ^{137}Cs (662keV, Compton edge)

   after 2nd saturation : life time=77±7 μs, attenuation L.=12±1cm, 6ppb
4. Grid transparency as a function of E_2

   good agreement with the expectation from the micro-megas results

   transparency=0.76 at E_2/E_1=5.2, mesh aperture=0.57
5. Drift velocity as a function of E_1

   1.6mm/μsec at E_1=0.5kV/cm (1.3mm/μsec in Xe gas at 1.4atm)
6. Preparation of TPCFE09 (ASIC) in the chamber

   168mV/fC, -7fC<Q_{in}<+7fC at room temperature by simulation and test bunch

   0.2V/fC expected at 165K (peaking time = 1 μsec)

ASIC ·

TPCFE09

TPCFE09 : 2nd version of FEXE09

Designed by Open-IT ;
Yuta Takagi (Yokohama N. univ.) ,
Takatoshi Higashi (Saga univ.),
Takahiro Fusayasu(NIAS) , Hirokazu Ikeda(JAXA) , Manobu Tanaka(KEK)

Open-It (Open source consortium for detector instrumentation) collaboration

together with the neutron group

Parameters	TPCFE09(TPCFE1x)
dynamic range	-75fC~+25fC -500fC ~ -5fC
gain	2mV/fC 10mV/fC
gain tolerance	~1%
ENC	400+25/pF@0.5us
cross talk	~1%
peaking time	0.5, 1 and 2 us
power dissipation	<10mW/ch
Temperature range	-110 ~ + 25℃
# of channels	16ch
ADC	none (10bit/10MHz)

UMC 0.25um process

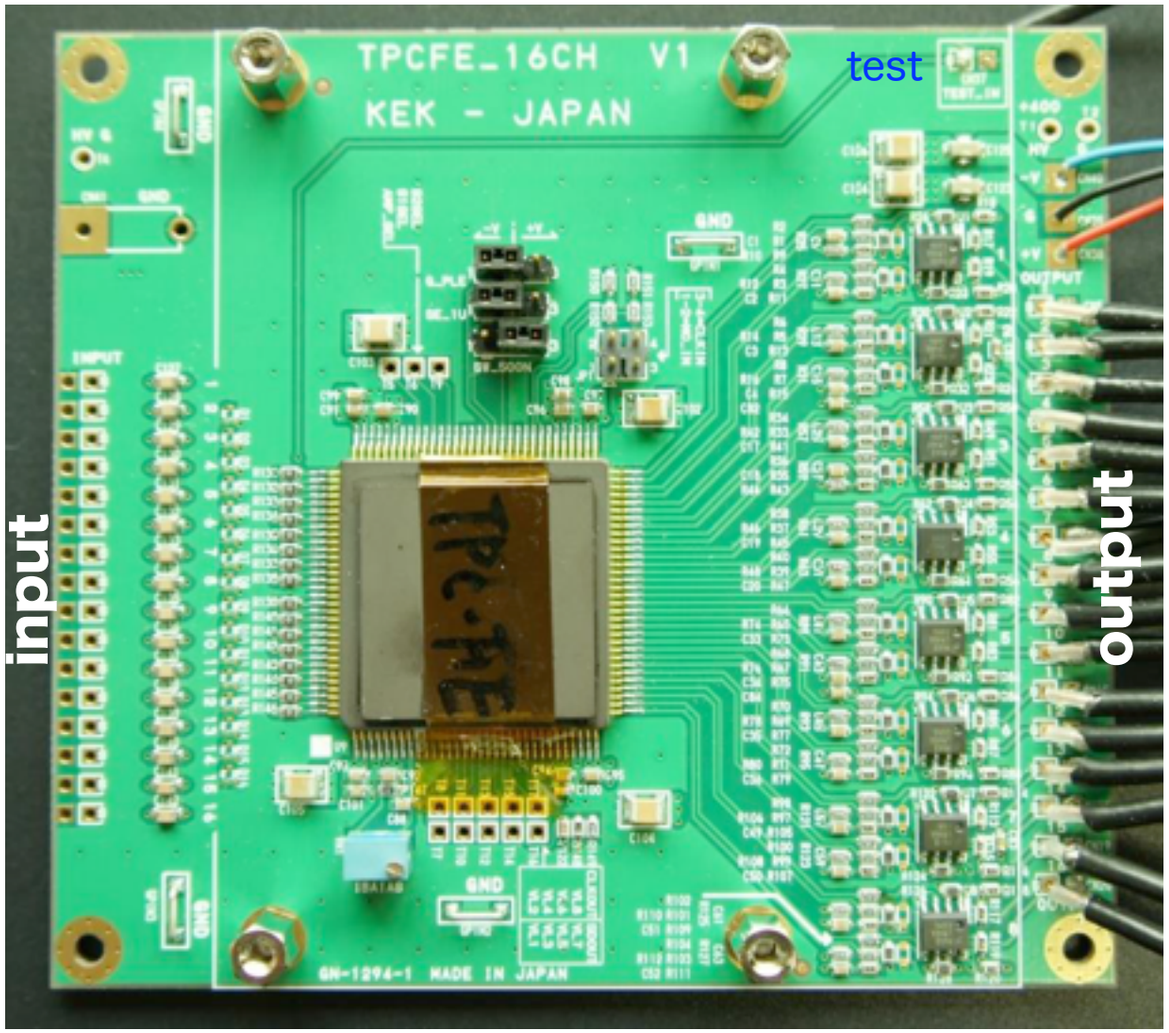
Schedule

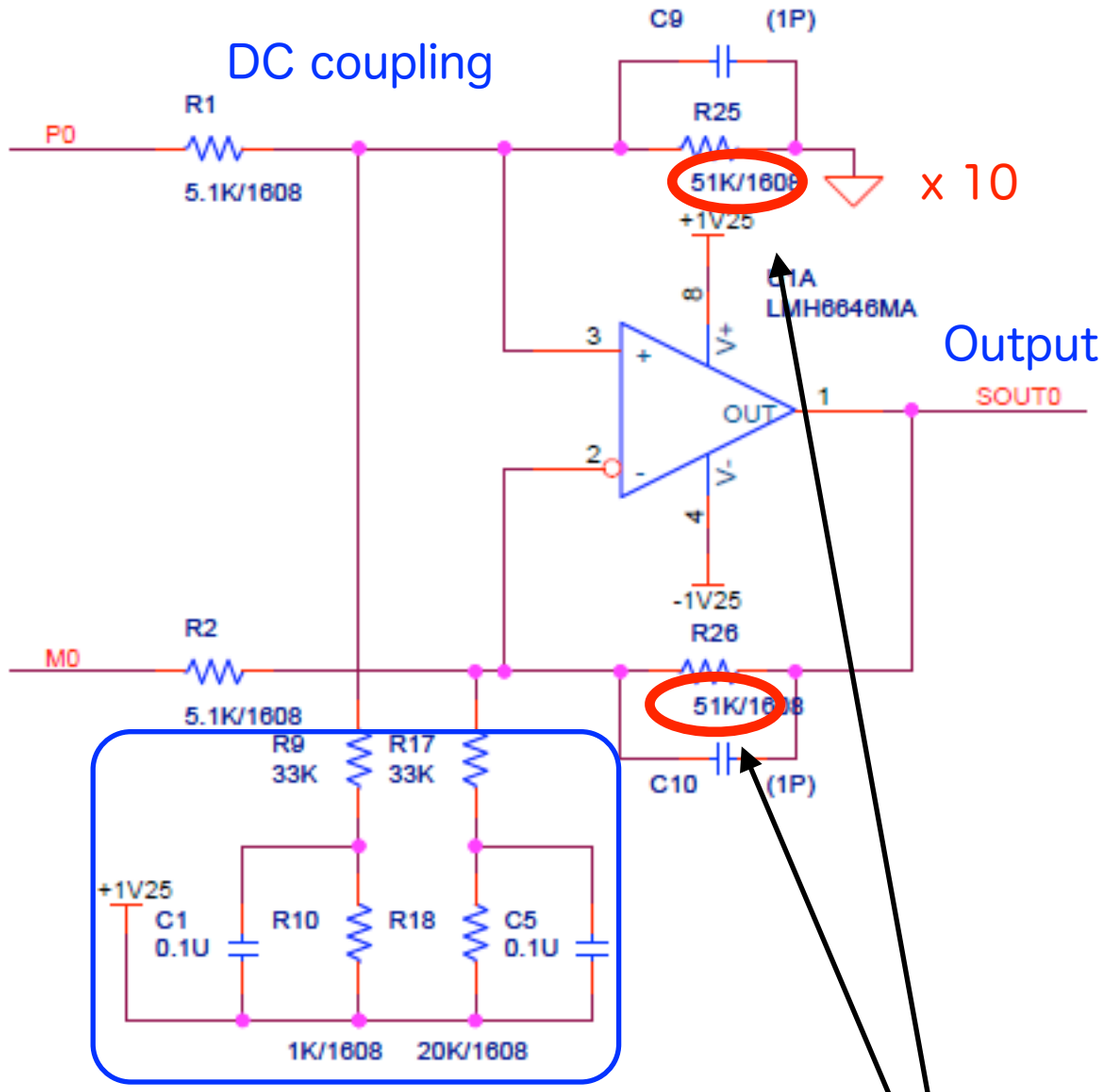
1. Circuit design was completed, Mar.2010
2. Simulation was completed
3. Layout design was passed to the company on 24 Nov.2010
4. Tape out was(?) submitted by end of January 2011
5. Delivery in Summer 2011
6. Test in Autumn 2011

Mother board of TPCFE (16ch), version -1, for test, Jan-Mar 2013

studied by Yuya Iwazaki, Yokohama National University

GN-1294-1(FR4), based on Takagi's M thesis

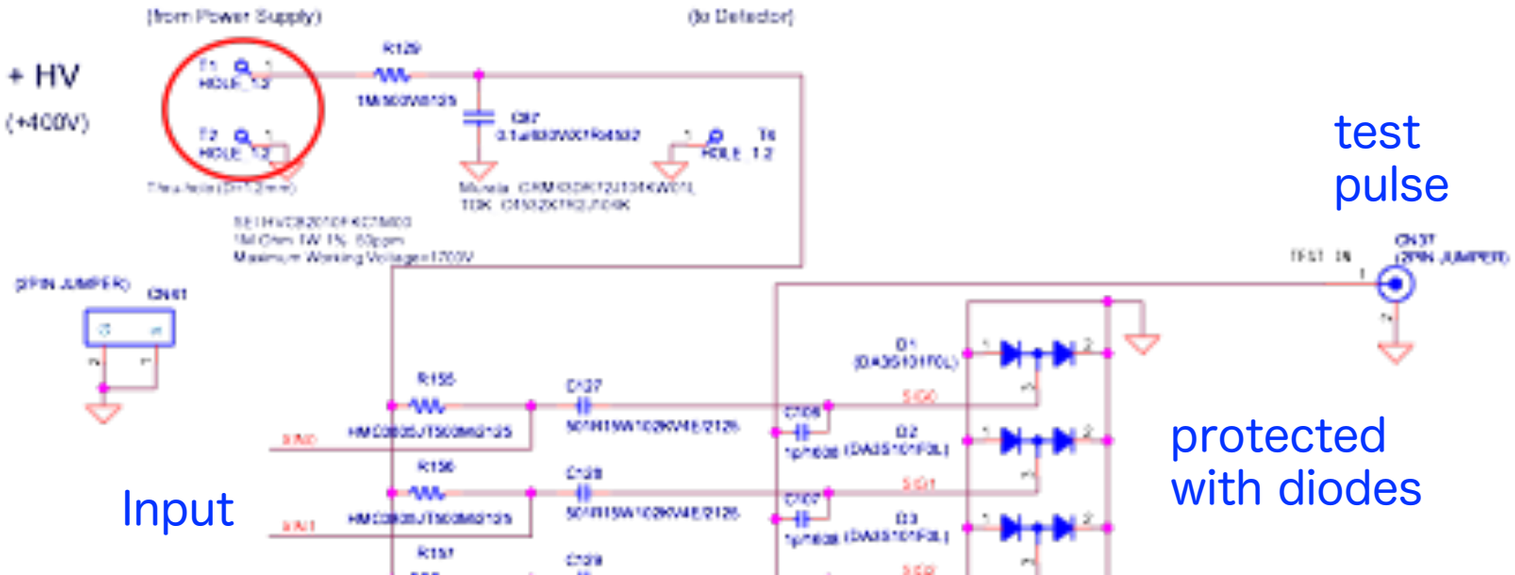


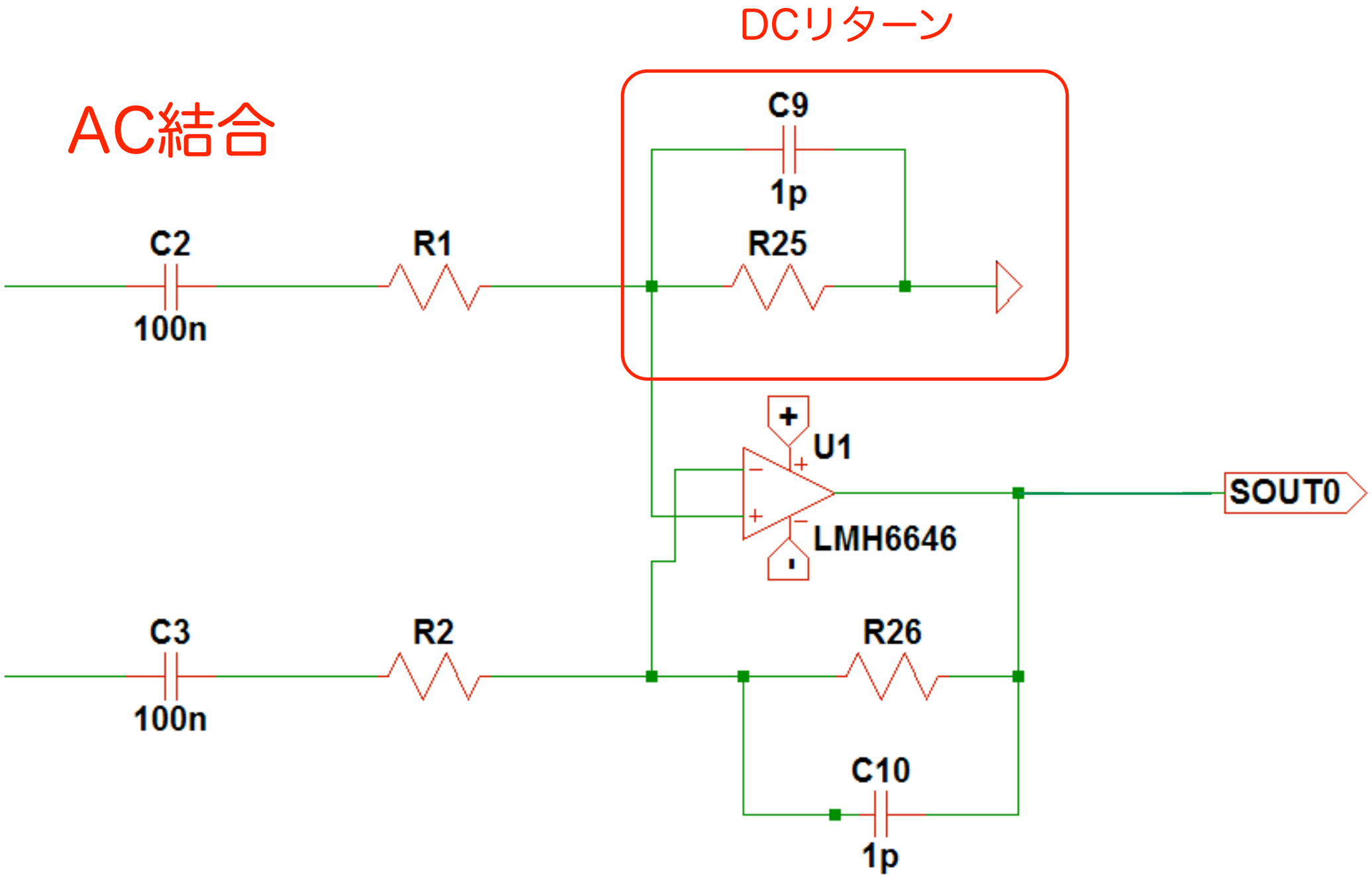


DC offset tuning circuit

changed to AC coupling for prototype-2

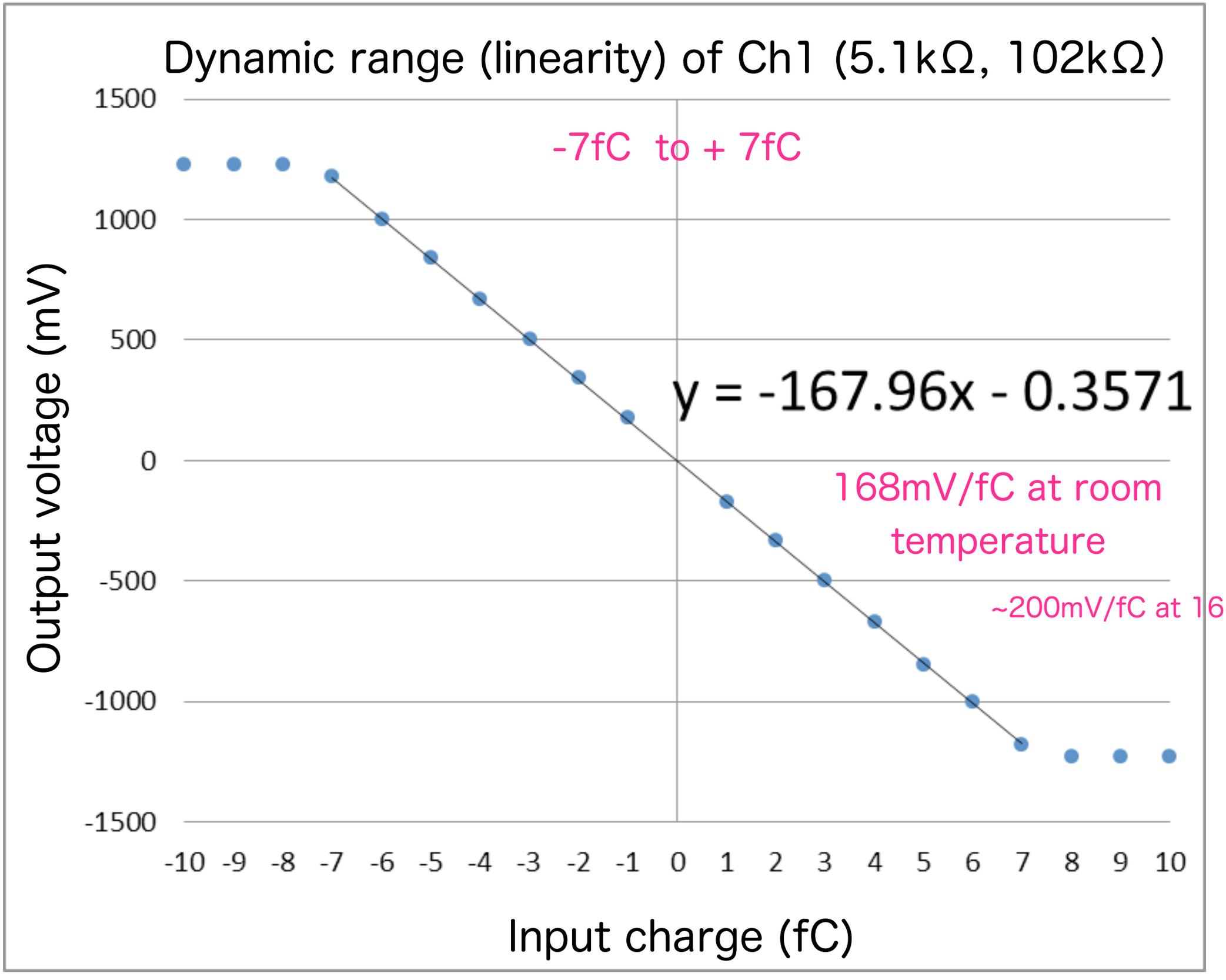
changed to 100kΩ for prototype-2
∴ x 20





R1=R2=5.1kΩ　：　R25=R26=100kΩ　Gain=19.6 → GN-1294-2(LTCC)

GN-1294-2(LTCC)



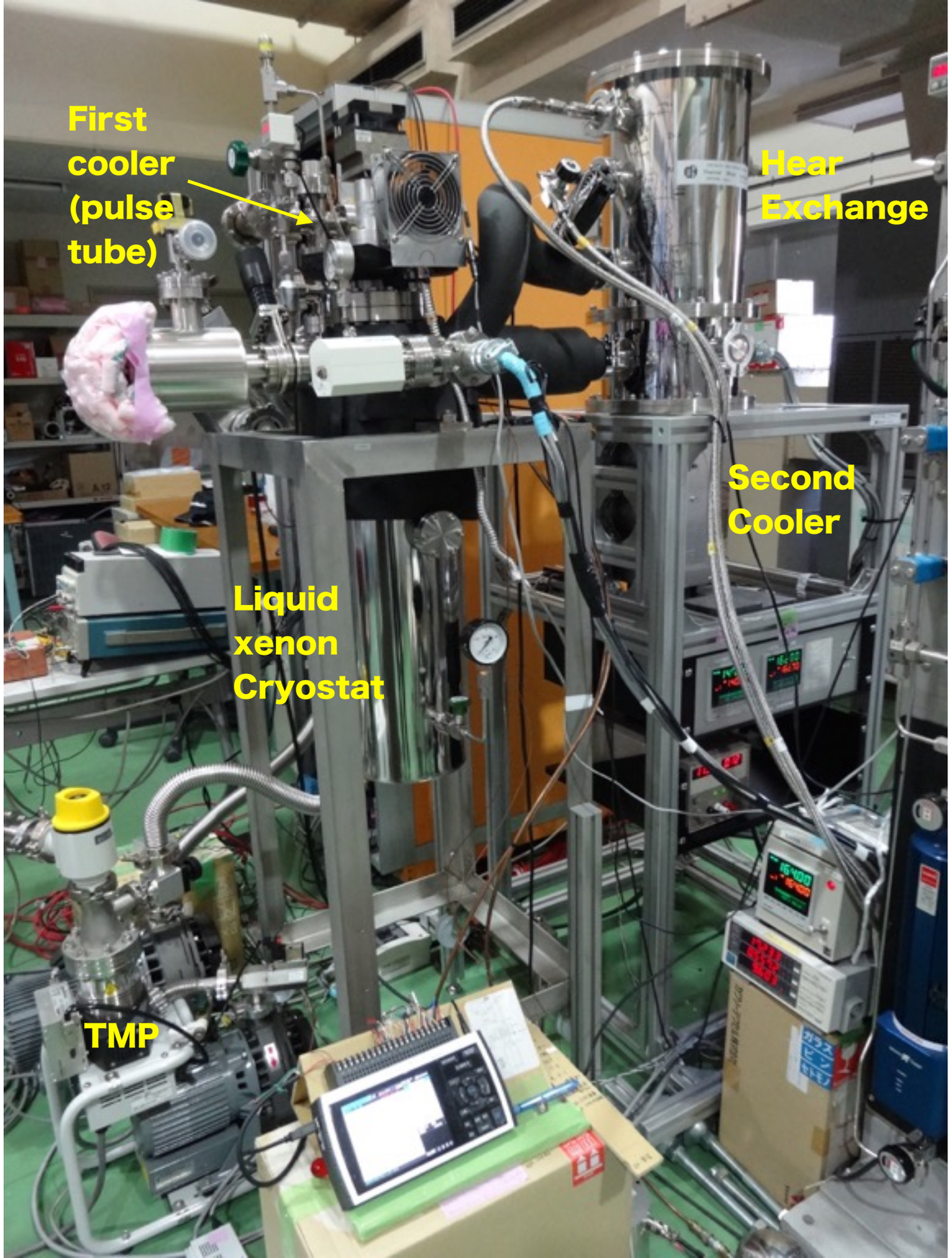
現在のセットアップ

(2015 ~)

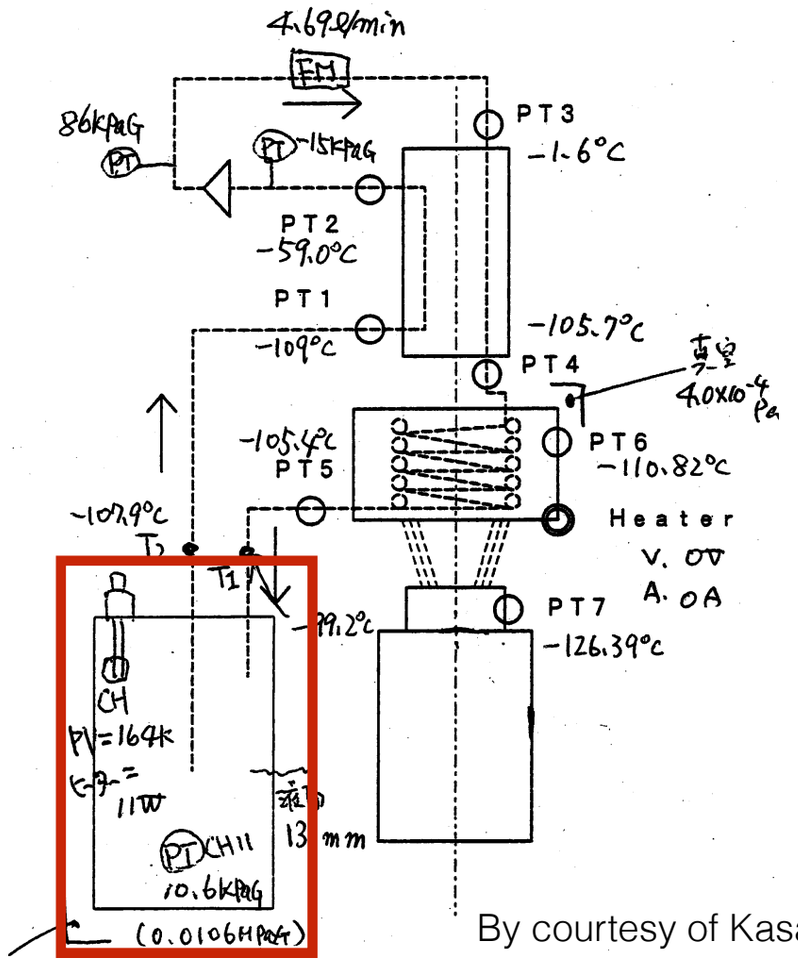
予冷システム（Heat Exchanger +Second Cooler) を構築し、Xe純化のためのガス流量の大幅な増大を期待している。

これまで、最大で1.5ℓ /分であったが、10ℓ /分程度まで安定な自動運転が可能なことが得られた。

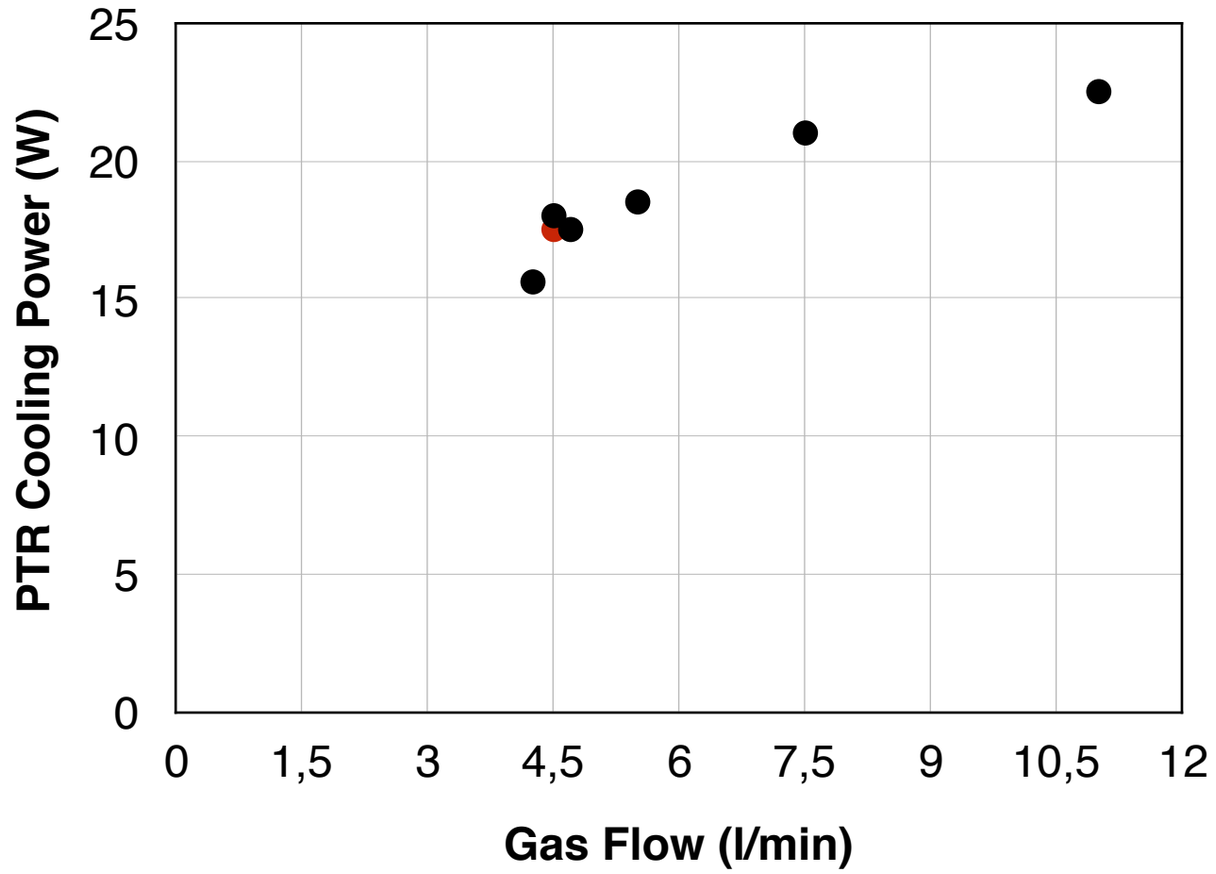
~ 4.5ℓ /分 で定常運転。



KEK Cryogenics Set-up — Data (18 - 26/11/2015)



By courtesy of Kasami-san



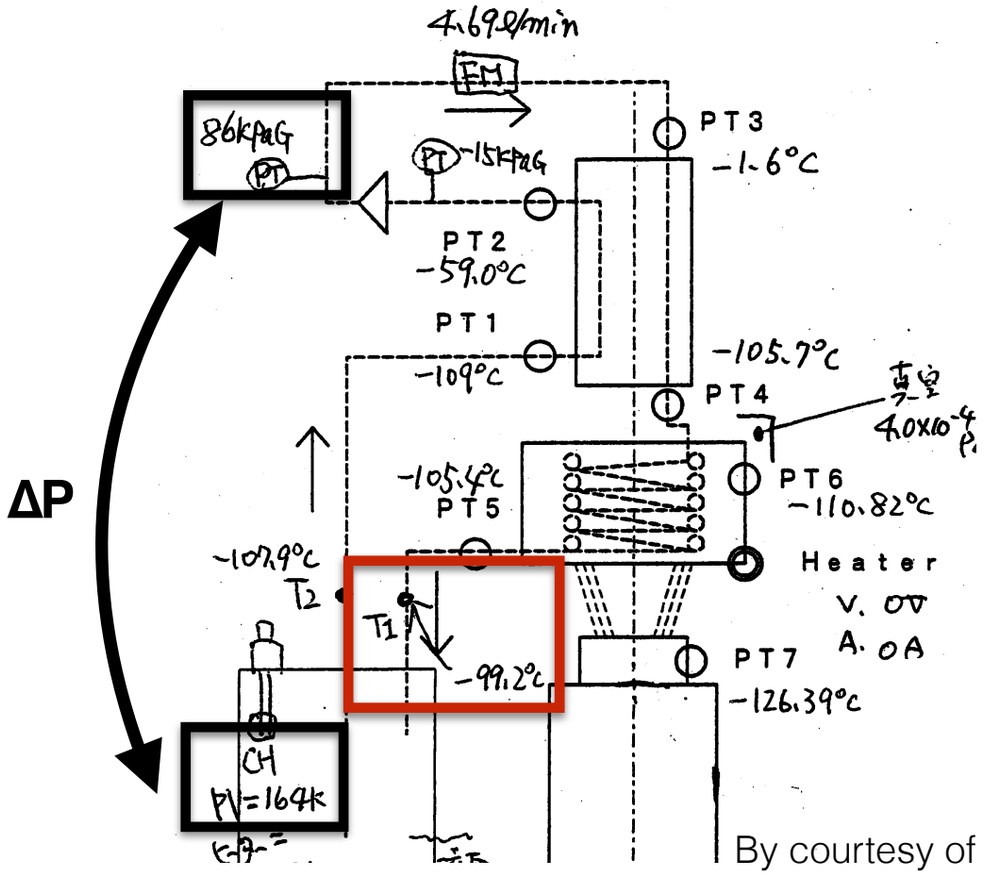
	SUBATECH	KEK		
Gas flow (l/min)	31.3	**4.5**	**7.5**	**11.0**
T inside cryo T2 (°C)	-100.7	-106.9	-106.5	-106.3
PT1 (°C)	-106	-107.9	-107.5	-107.3
PT2 (°C)	18.1	-58.5	-50.3	-44.1
PT3 (°C)	24.5	-1.5	6.7	11.7
PT5 (°C)	-104.4	-104.7	-104.3	-104.0
T1 (°C)	-104.4	-98.6	-98.5	-98.5

	PTR (164 K@24 W)		
Gas flow (l/min)	**4.5**	**7.5**	**11.0**
Cold Head T (°C)	164	164	164
PTR Power (W)	29	29	29
Heater (W)	11	8	6.5
Cooling Power (W)	**18**	**21**	**22,5**

*Average values during stability
*PTR power from KEK measurements

by Sara Diglio and Lucia Gallego (Subatech)

Heat Exchanger Efficiency



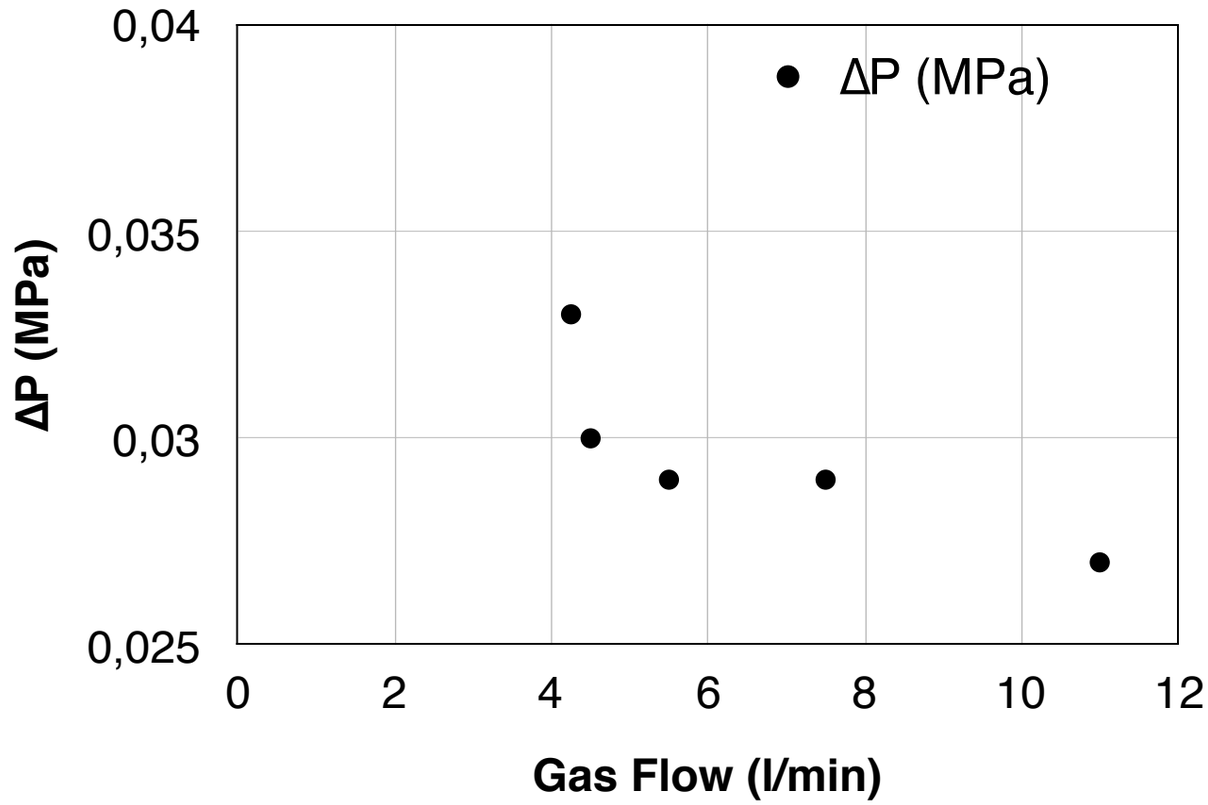
By courtesy of Kasami-san

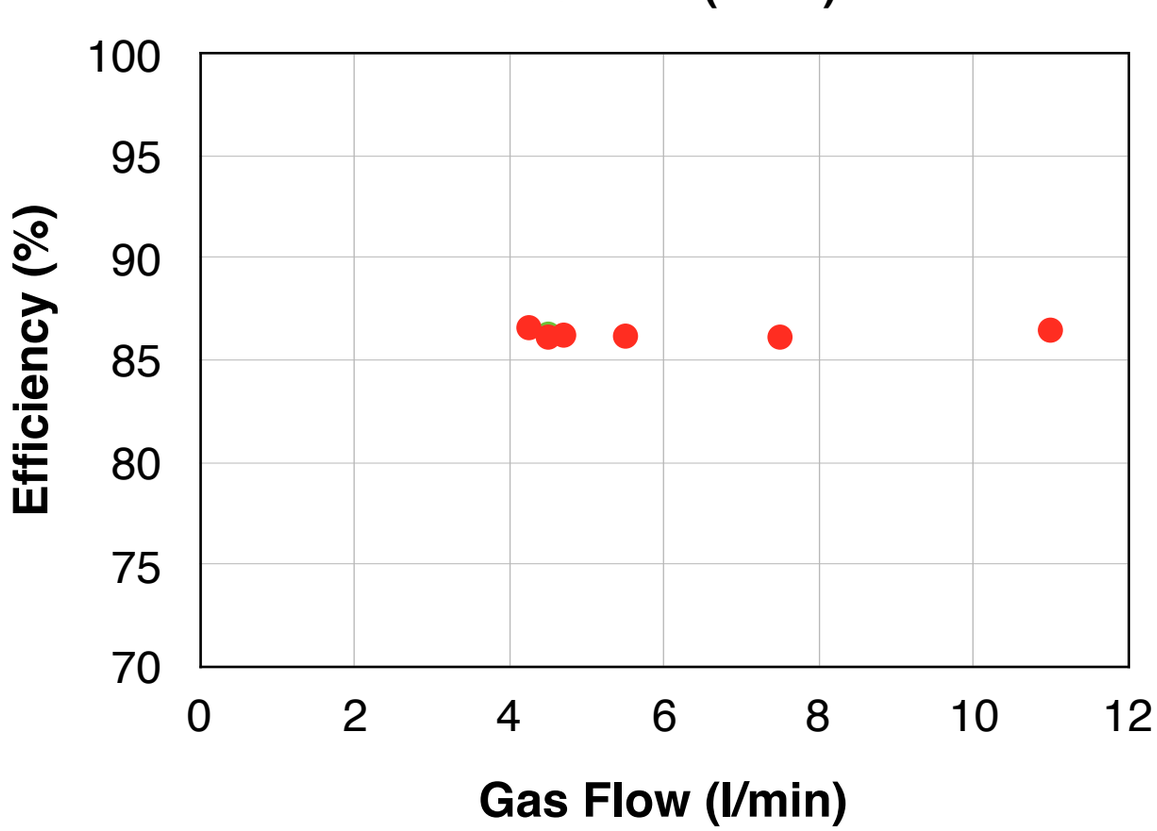
	SUBATECH	KEK			
Gas flow (l/min)	31.3	**4.5**	**7.5**	**11.0**	**4.5**
PT2 (°C)	18.1	-58.5	-50.3	-44.1	-58.5
PT3 (°C)	24.5	-1.5	6.7	11.7	-2.1
Efficiency (%)	**99.0**	86.1	86.1	86.5	86.3

Cp (J/g/K)	0.34
Lp (J/g)	96.26

$$\varepsilon = 1 - \frac{C_p \times \Delta T_{warm} \times F(\mathrm{g/s})}{Q\,(\mathrm{W})}$$

$$\Delta T_{warm} = PT3 - PT2 \qquad Q(W) = (L_p + C_p \times \Delta T) \times F$$





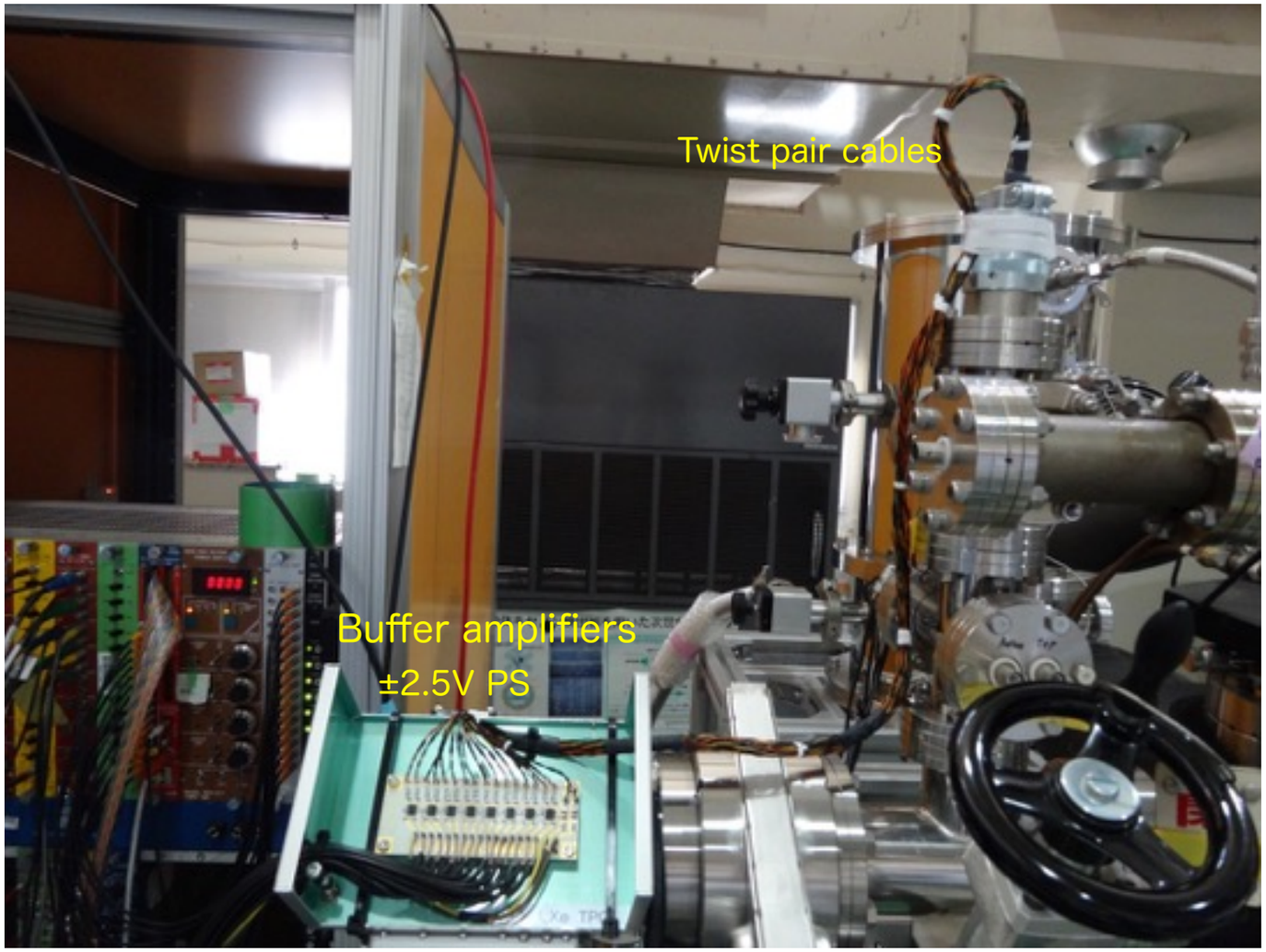
by Sara Diglio and Lucia Gallego (Subatech)

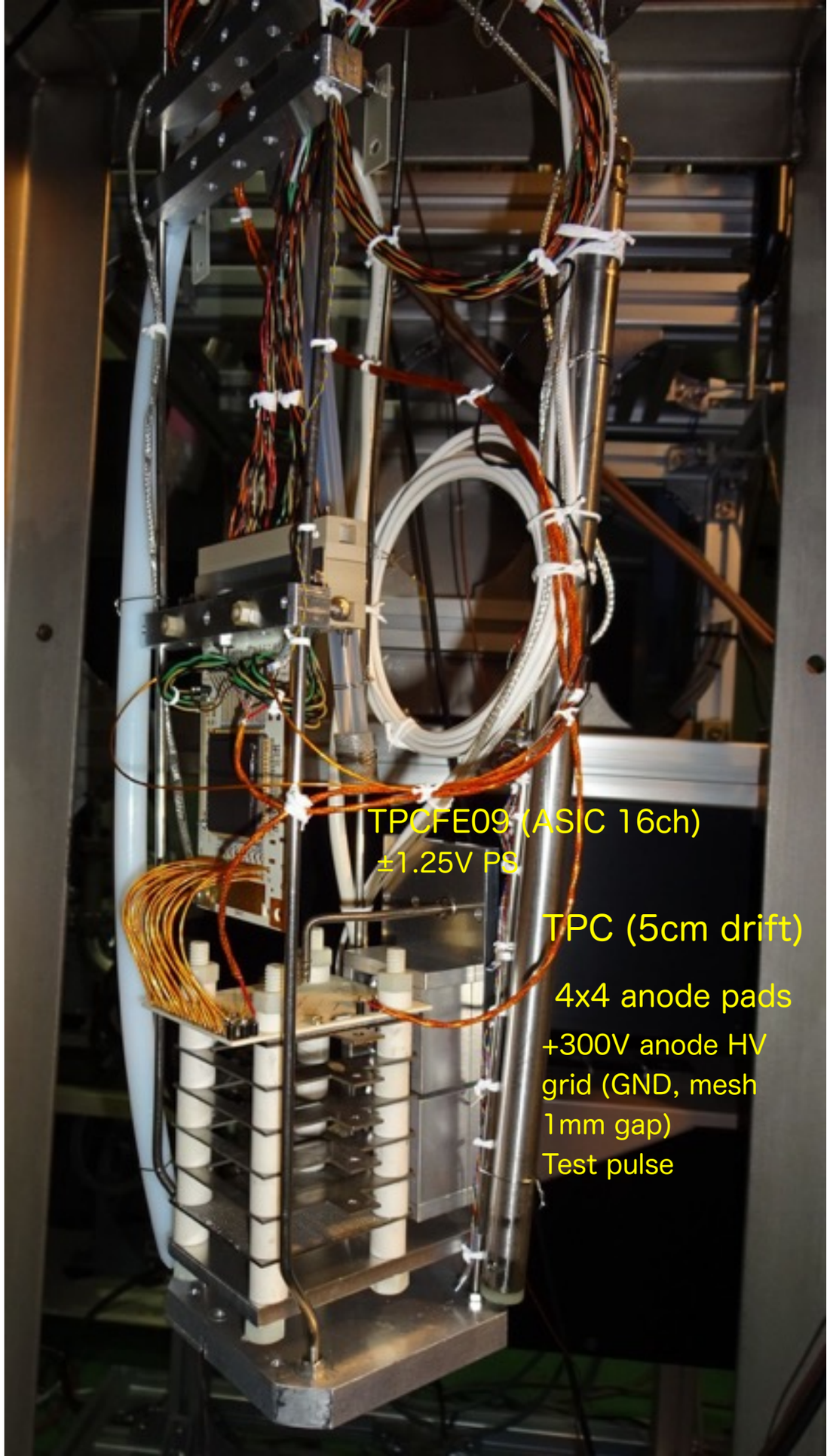
LXeTPC

prototype -2

Frontend Electronics

Optimized setup, 22 October, 2015





TPCFE09

BUFFER AMP

ASIC

AC coupling

BUFFER AMP

x 20

SIG OUTPUT

TPCFE09 :

HV , TEST SIGNAL, GROUND
INDIPENDENT CABLE

+ HV

(+400V)

(from Power Supply)

(to Detector)

Thru-hole (D=1.2mm)

SEI HVCB2010FKC1M00
1M Ohm 1W 1% 50ppm
Maximum Working Voltage=1700V

Murata_GRM43DR72J104KW01L
TDK_C4532X7R2J104K

TEST IN

C_{test} =1pF

Performances of test pulse run

Test pulse : the input charge with 50Hz, 0.025V w/ 31dB, 0.7mV, C_{test}=1pF, i.e. 0.7fC;

FETPC09+buffer amp. gain / 2 = ~ 200mV/fC with each 50Ω in series in the output

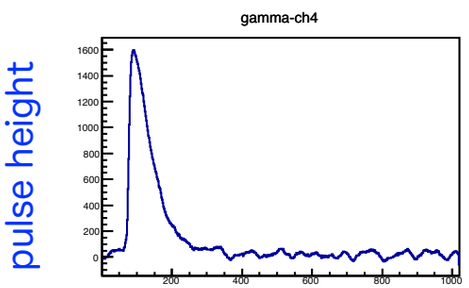
∴ The output voltage at the buffer amp = ~140mV

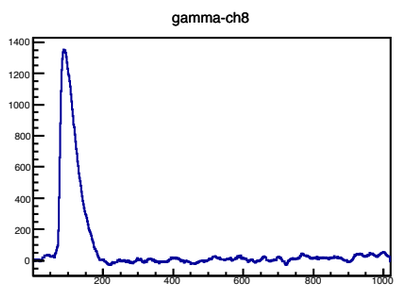
∴ FADC20MHz : 140/7.8=18 counts expected

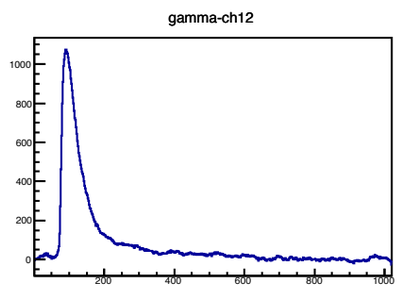
results of the test pulse runs for 100 triggers 2016.11.7

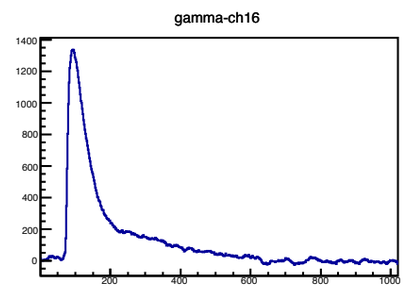
pulse height

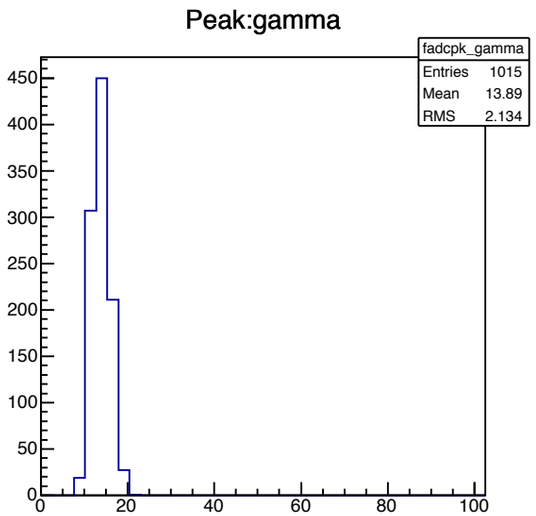
time, 50ns/ch

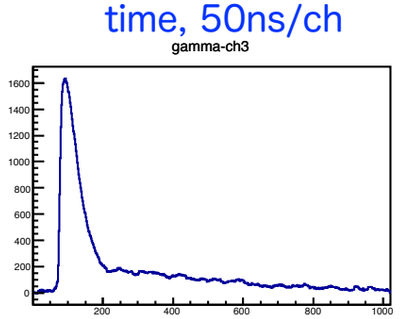


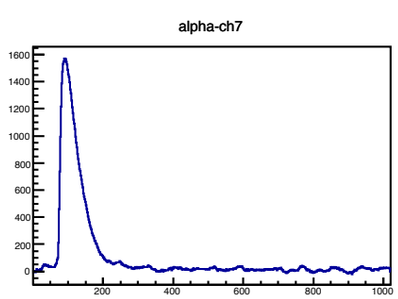


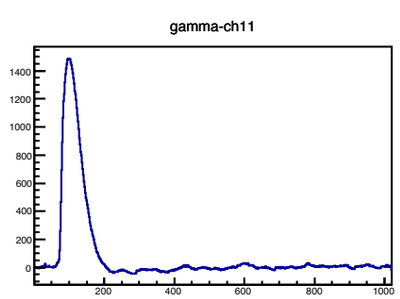


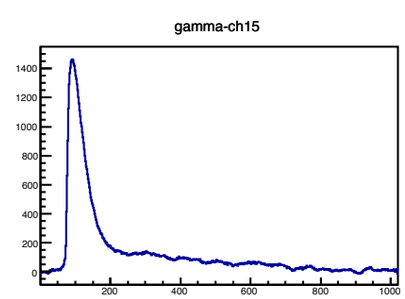


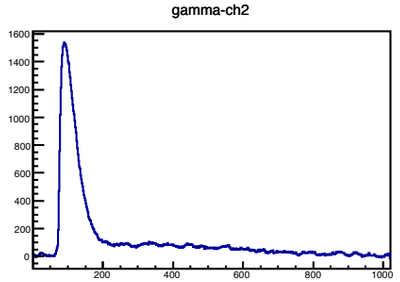


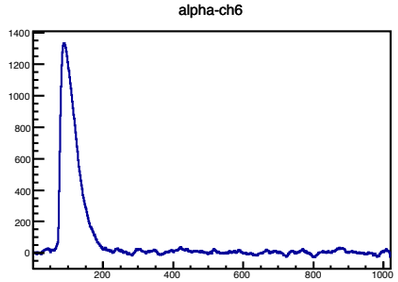


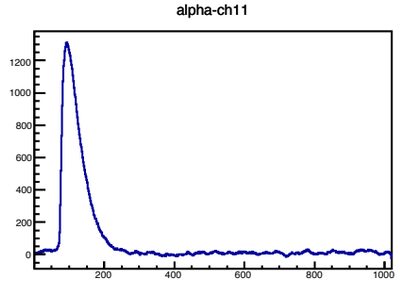


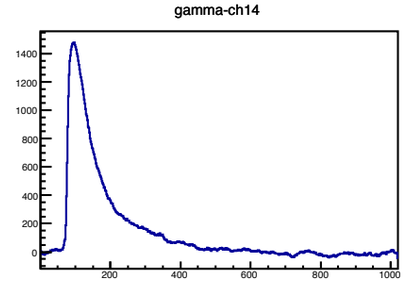


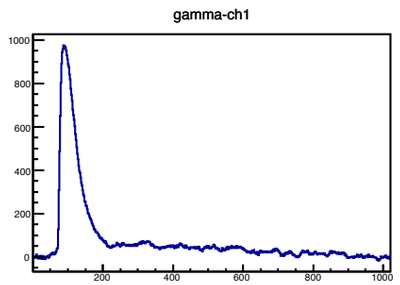


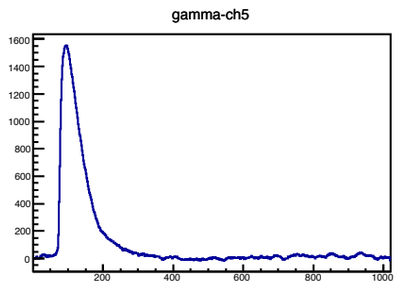


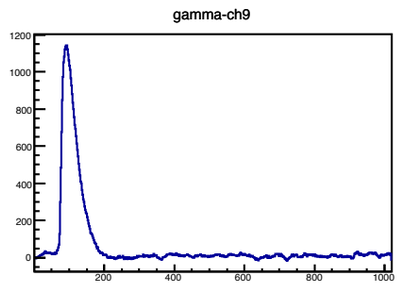


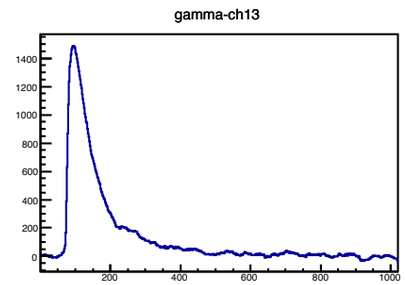




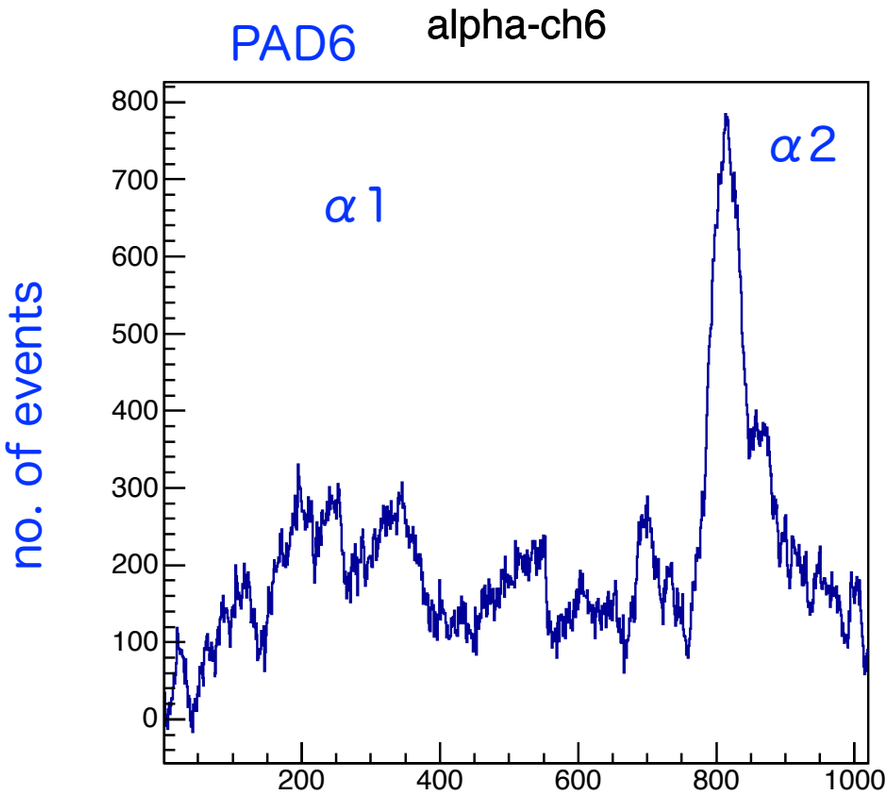


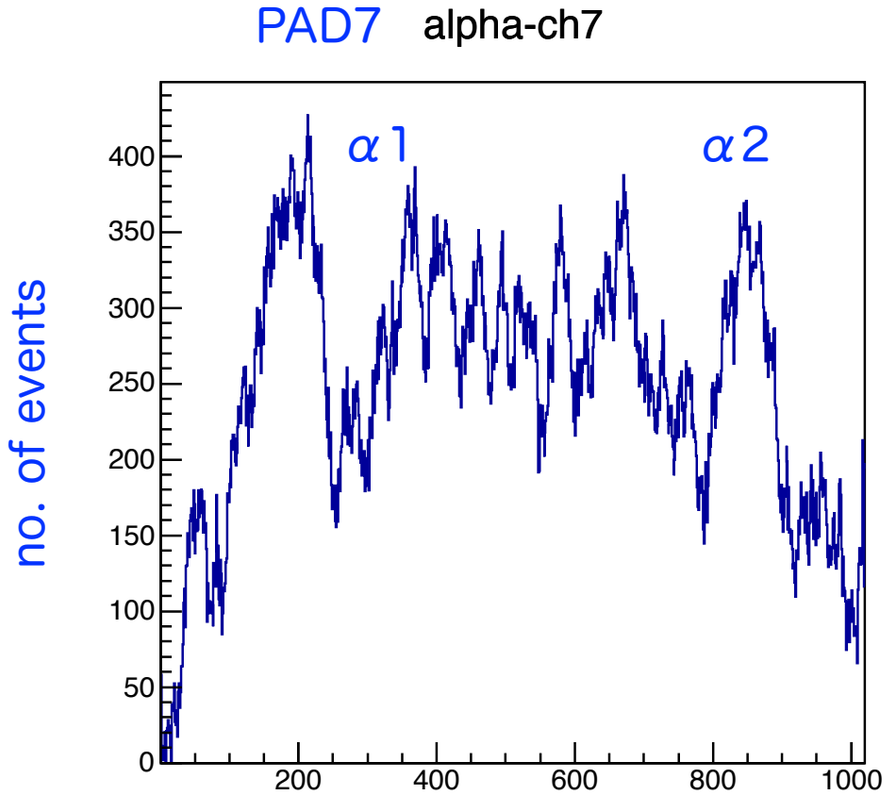


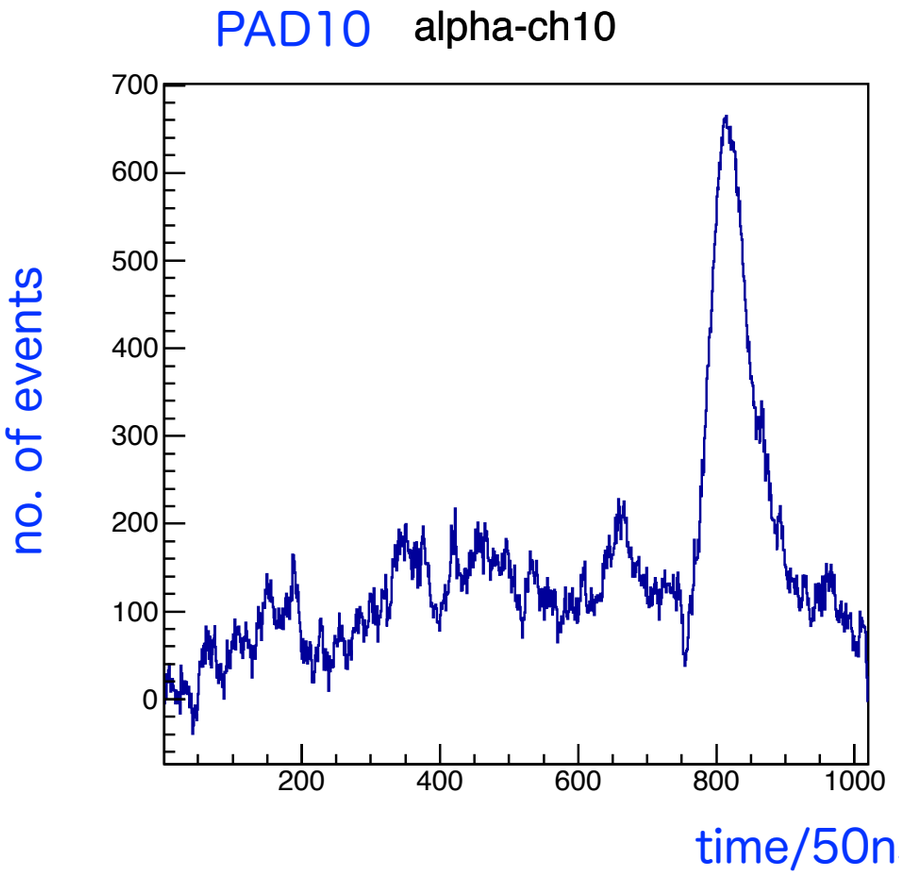


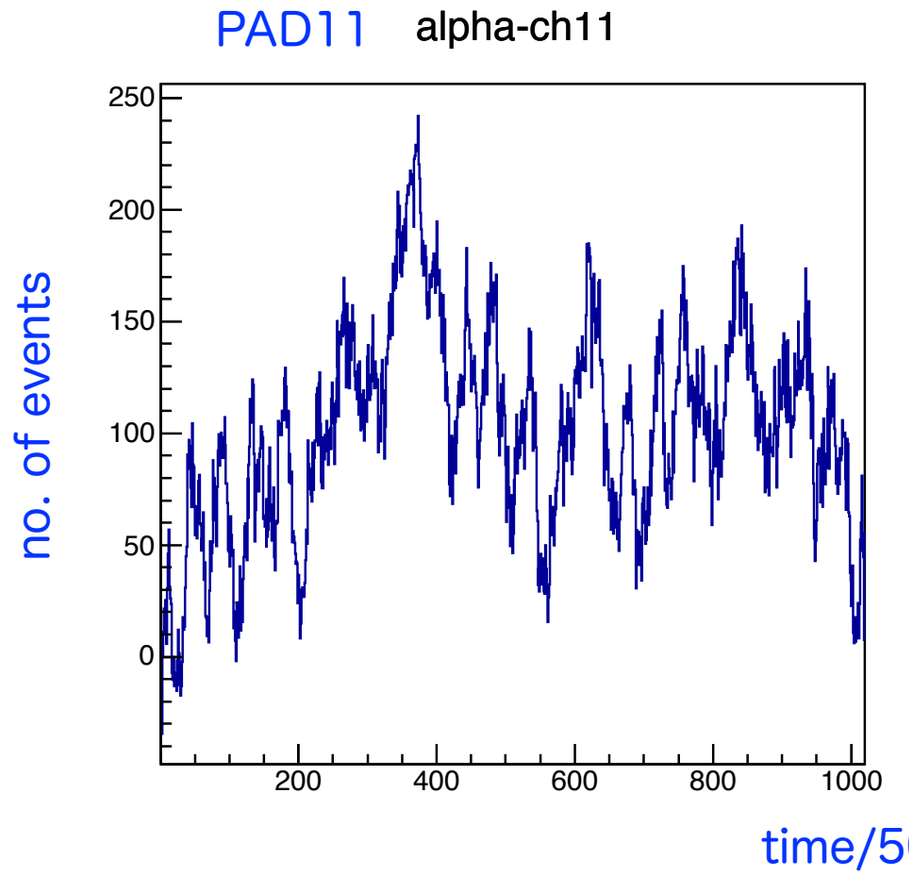


Raw signal charges



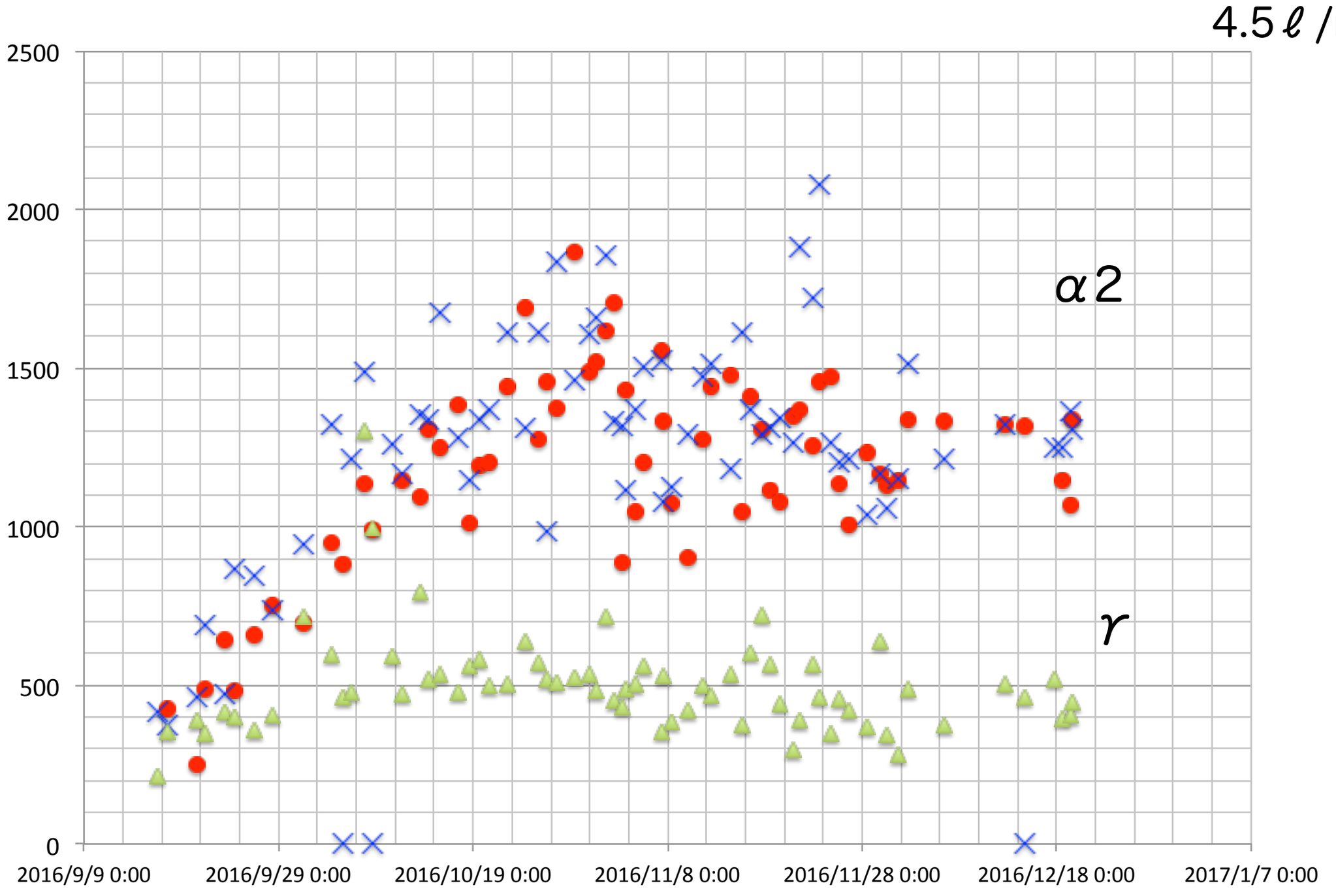




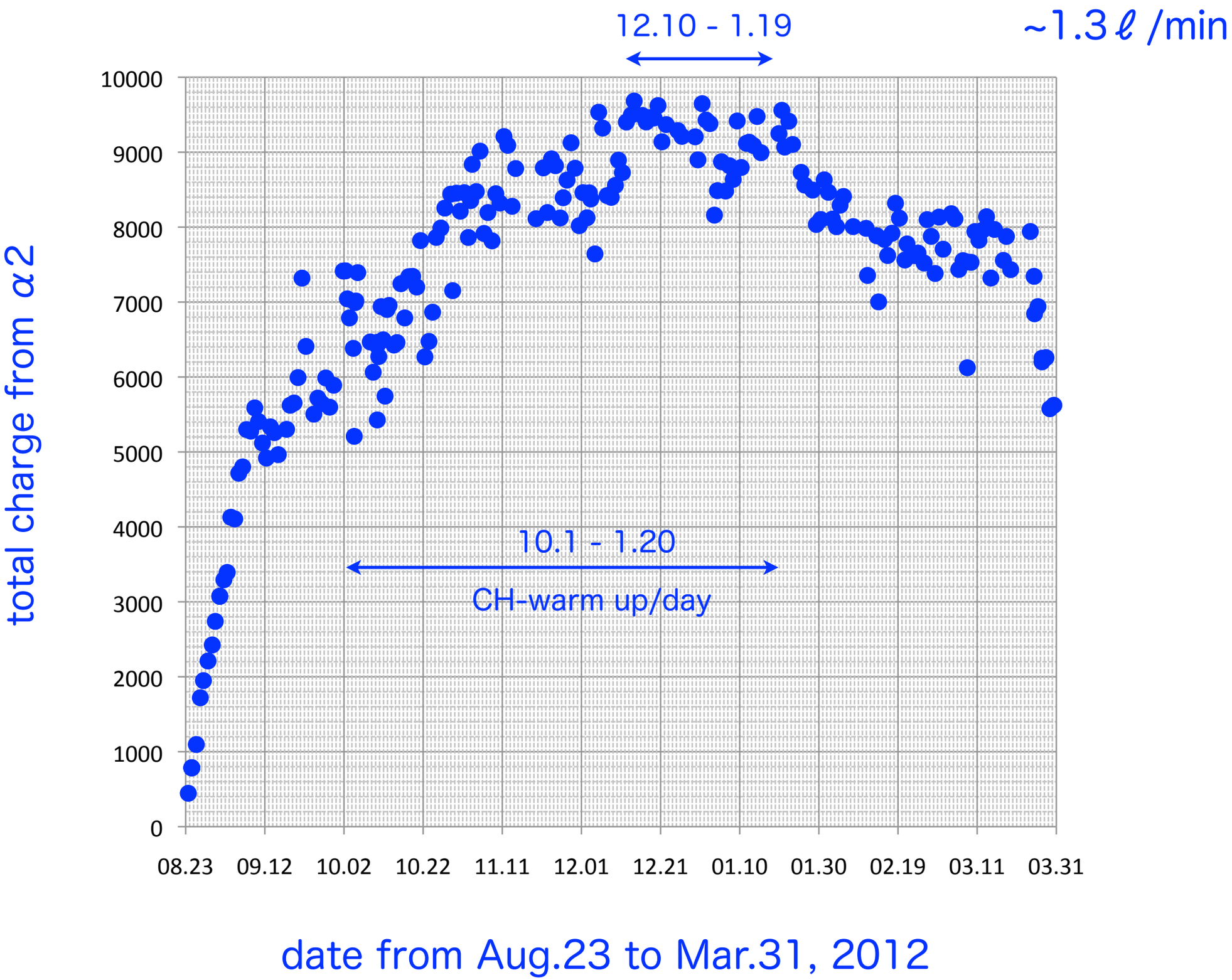


2016.11.08

Prototype-2 : The signal growth in LXeTPC, Sep.-Dec.2016



Prototype-1 : Growth of charge signals (α2)



Summary : LXeTPC prototype -2

(2013 April - 2017 April)

1. New front-end electronics system, all 16 channels, is working since April 2016.
   TPCFE09 is in the Liquid Xe chamber,
   while the buffer amplifier is outside of the chamber.
   TPCFE09 AC-coupled to the buffer amplifier, the total gain is ~ 200mV/fC

2. Very stable operation of the cooling and the gas circulation/purification system
   the gas flow rate is ~ 4.5 ℓ /min.

3. The signal growth is very slow compared to the prototype-1,
   although the gas flow rate incresed from 1.3 ℓ /min to 4.5 ℓ /min.

4. We will try to increase the prufication by adding a getter.

5. The best solution must be to set all the frontend electronics and cables outside the chamber as much as possible.