Liquid Xenon TPC for a gamma detector (LXeTPC)

T. Tauchi (KEK)

DTP International Review
10-11 December 2013
KEK, Japan

KEK : liquefaction & purification , PMT, TPC, DAQ

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

K.Kasami, S.Suzuki

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

A.Sugiyama

Tokyo univ. : TPC, PMT, simulation, test

T.Mori

National Institute of Radiological Science : PET

M.Kumada, T.Tomitani, C.Toramatsu

Yokohama National univ. : APD test, Xe-property

S.Nakamura, R.Hamanishi(M1) , Y.Iwasaki (M1)

Cooperation : KEK electronics system group , DAQ

M.Tanaka et al.

Previous Activities (1)

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

~ 2008.12　Cooling tests 7 times; gas circulation, charge signal detection (1ch)

2009.2.25　First charge signals from cosmic rays at the 7th test (11)

2009.3.31　First charge signals from α sources at the 7th test (45)

Improving vacuum system;

2009.4.24　First TPC prototype w/ 1cm drift w/o grid and 4ch readout

2009.5.10 First observation of charge signals from cosmic rays (8)

2009.5.22　First observation of α charge signals (20mV) (20)

(days since purification/circulation)

Previous Activities (2)

2009.4.24 -9.10 First prototype w/ 1cm drift w/o grid and 4ch pad readout

2009.9.10 Y.Fujii presented results of Cosmic ray events at JPS meeting

~ 2010.3 Preparation of 2nd prototype w/ 5cm drift, grid and 16ch readout

2010.4 - 12.3 Problem of the AD829 pre-amplifier system, i.e. large oscillation

2010.12.4 give-up it and switched to the A250 pre-amplifier system

~ 2011.3.4 Optimization of the A250 system with JFET of 2SK152

2011.3.11 M9.0 Tohoku Earthquake

2011.4.28 Pressure test of a ceramic plate for the endcap (ASIC chip readout)

2011.5.13 Resume the 2nd prototype test at liquid Xe

~ 2011.9.21 Unstable operation was mitigated with additional molecular sieve at output of the helium compressor

~ 2012.1 No charge signal except for once when the PTR stopped accidentally.

2012.2 - 3 Appearance of charge signals by increasing the liquid level of Xe

2012.4 - 7 Preparation of next run, e.g. replacement of dead electronics

2012.7.18 Resume the liquefaction

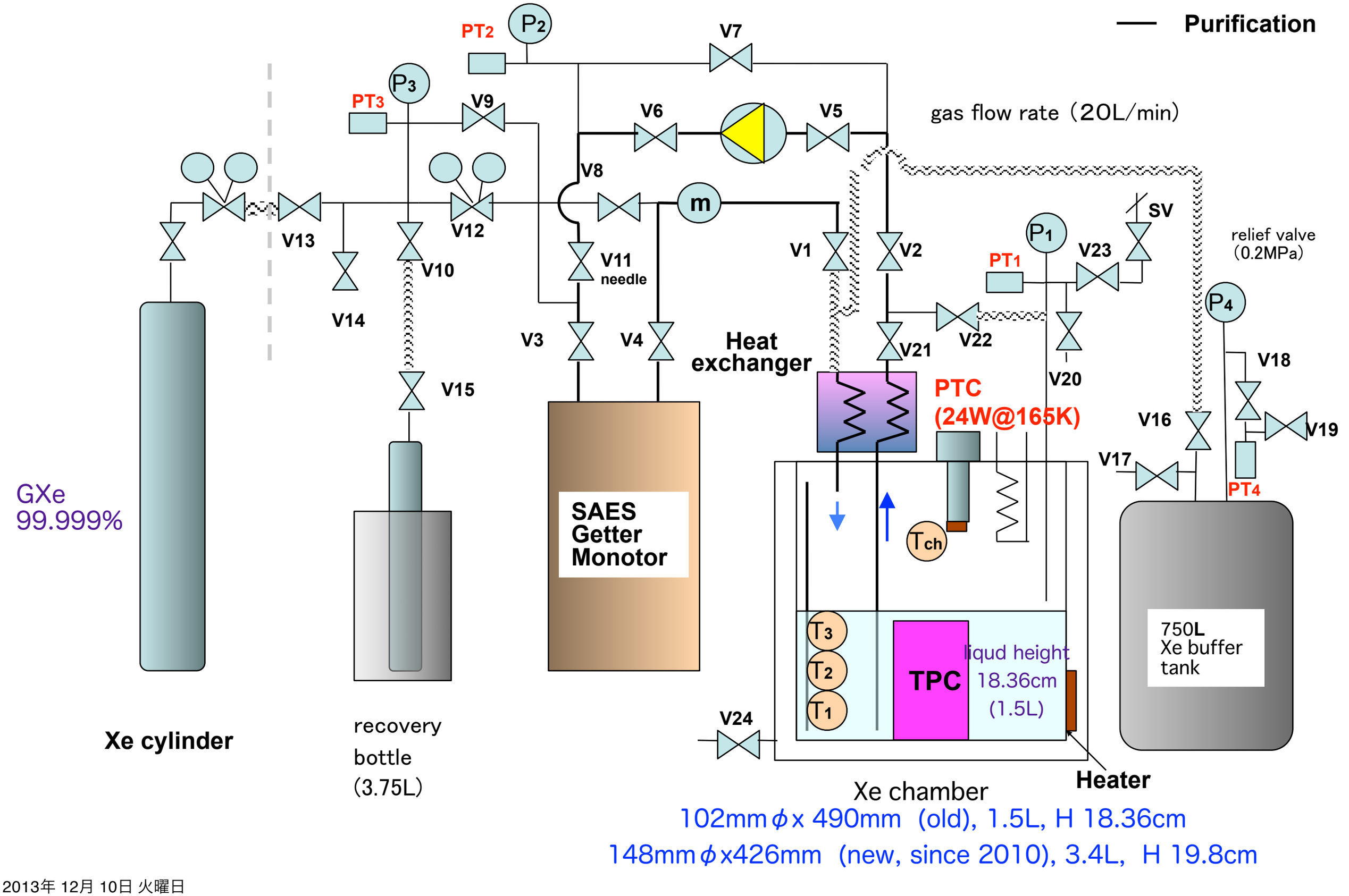
~ 2013.6 Taking data with various conditions and results are reported here.

2013.1 ~ Preparation of front-end electronics by TPCFE09 (ASIC).

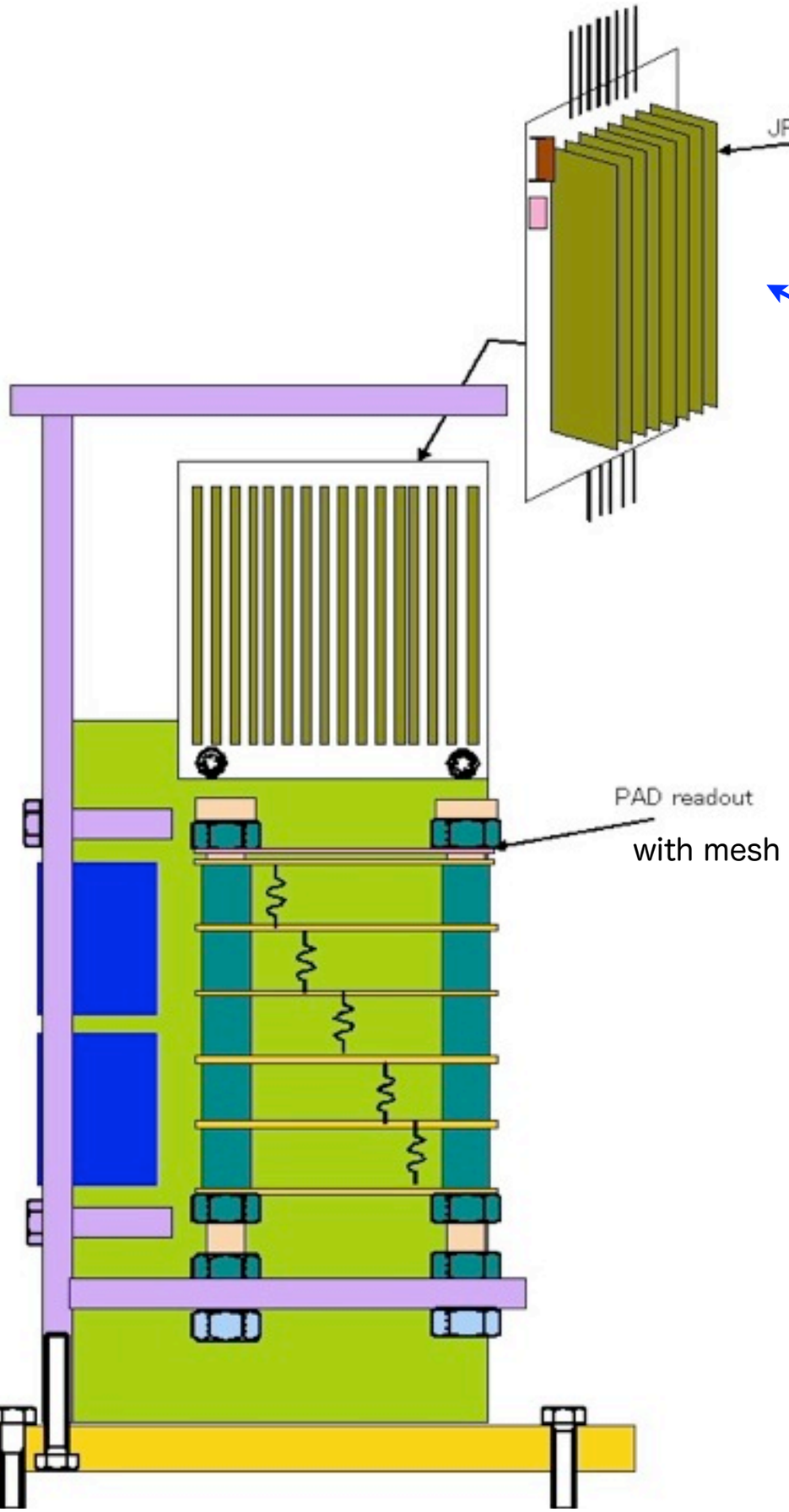
LXeTPC : Liquefaction / purification

since June 2008

Circulation by an oil-free diaphram pump (Enomoto co.)



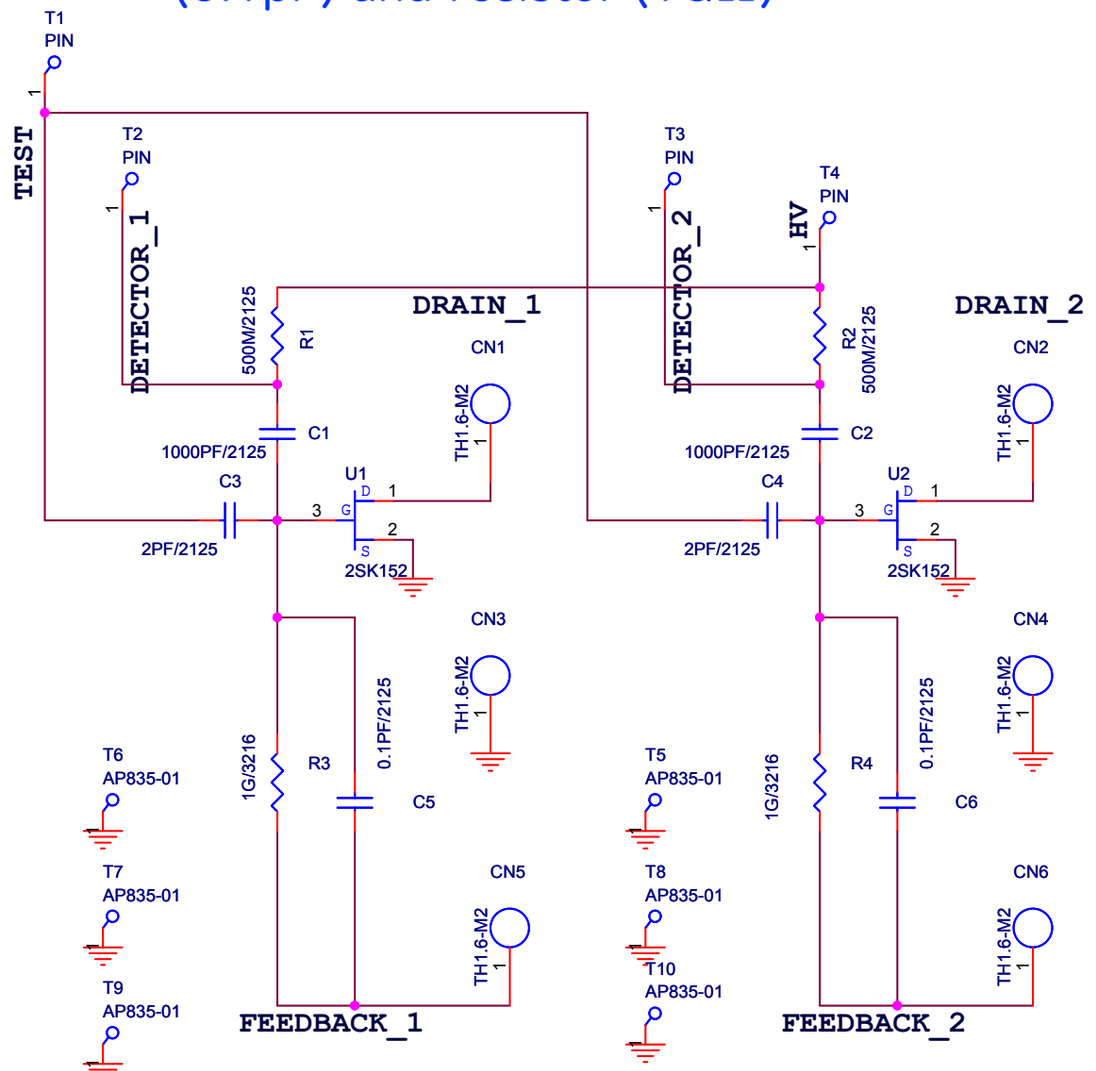
2nd Prototype, 2010~ 2013

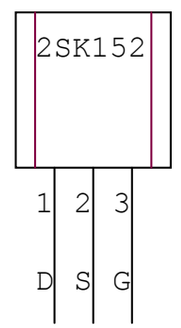


5cm drift with grid(mesh)
&16 pad readout

cold part of the preamplifiers :

8 daughter cards (2ch/card) consisted of JFET(2SK125), feedback capacitor (0.1pF) and resistor (1GΩ)



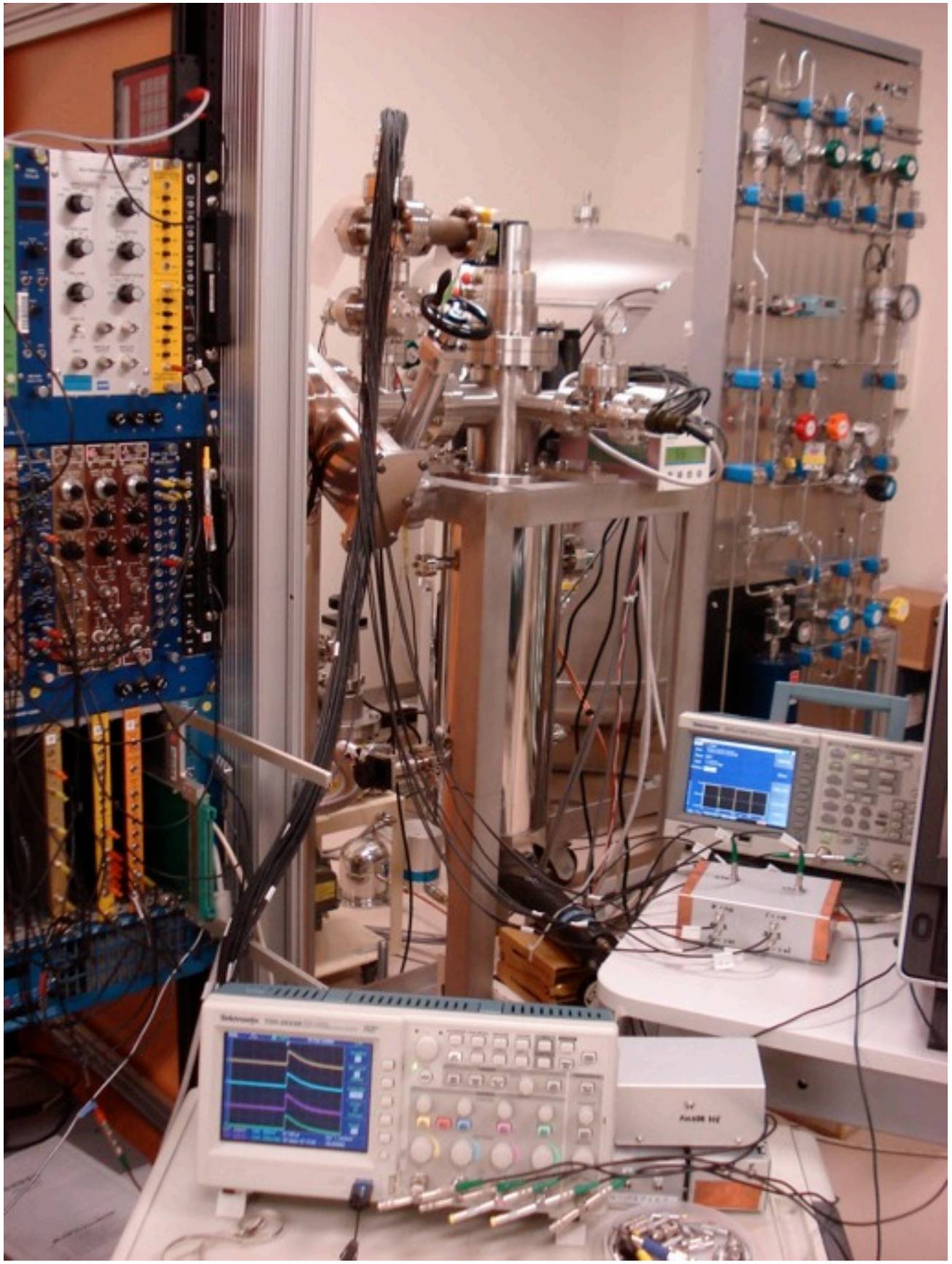


Getter Pump

(CapaciTorr D400-2)

additional installation of gate valve and chamber, July, 2012

Experimental Setup in 2011



TPC prototype

ch1

Lt5

Teflon tube
for circulation

γ-source
^{137}Cs,7.34KBq

Liquid level gauge (15cm)

Lt4

Lt3

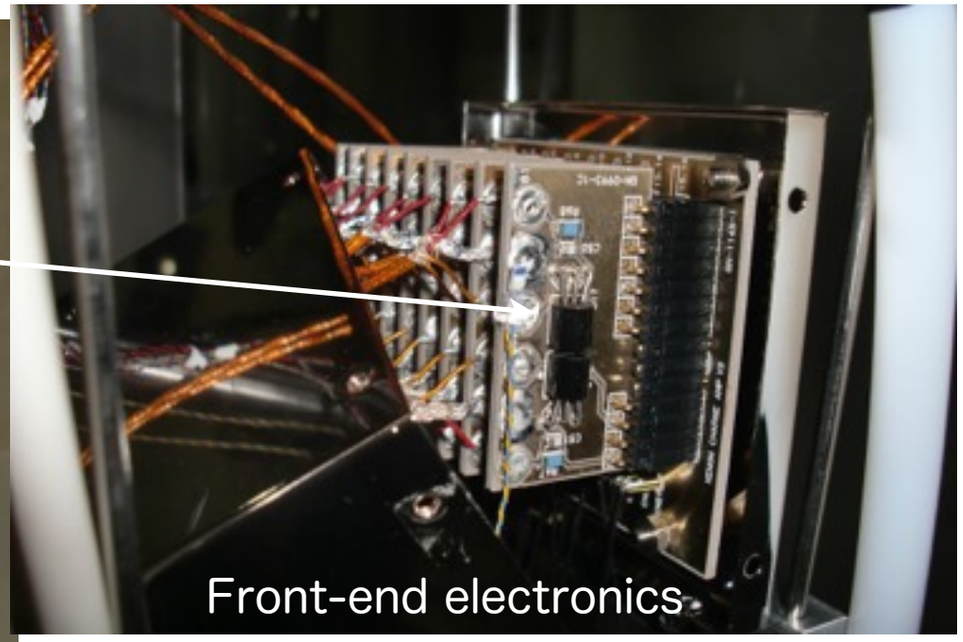
2 PMTs

Lt2

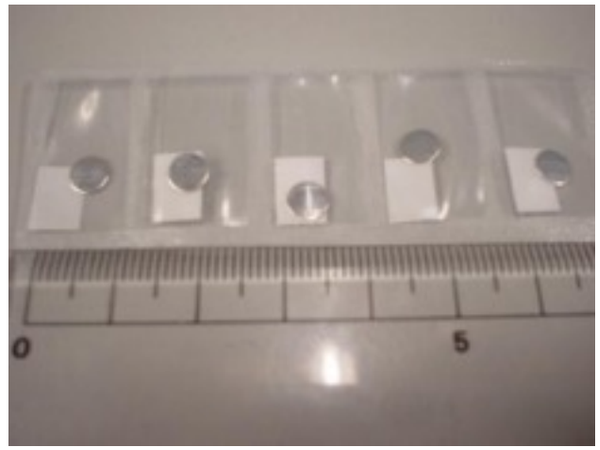
α-source: α1
^{241}Am,200Bq

Lt1

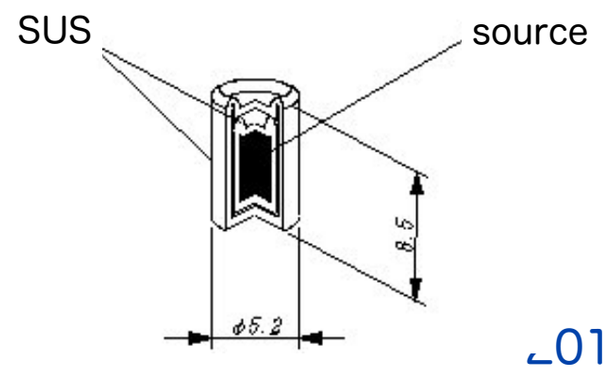
α-source: α2
^{241}Am,200Bq



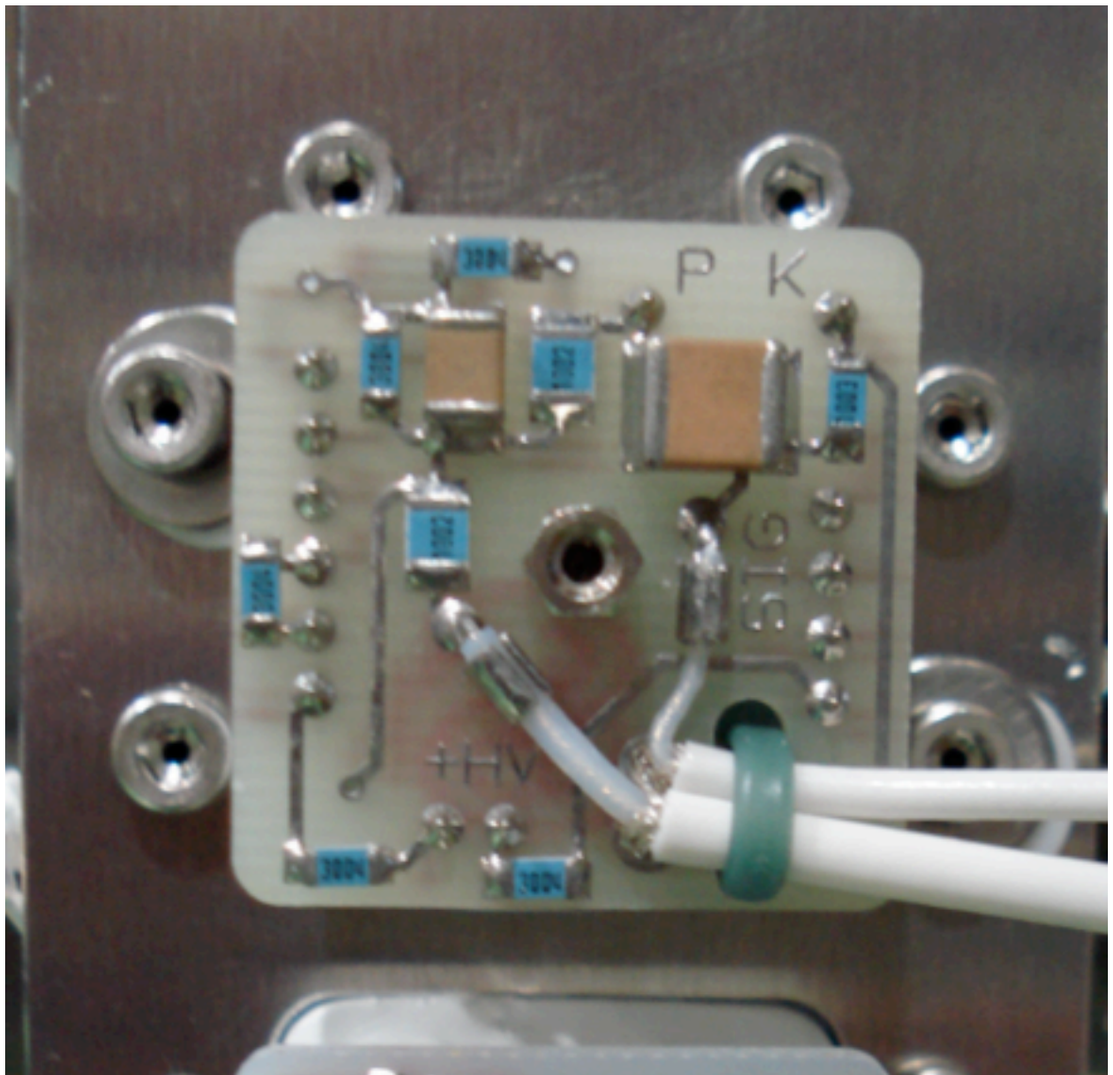
α : Am-241, 5.49MeV, 200 Bq



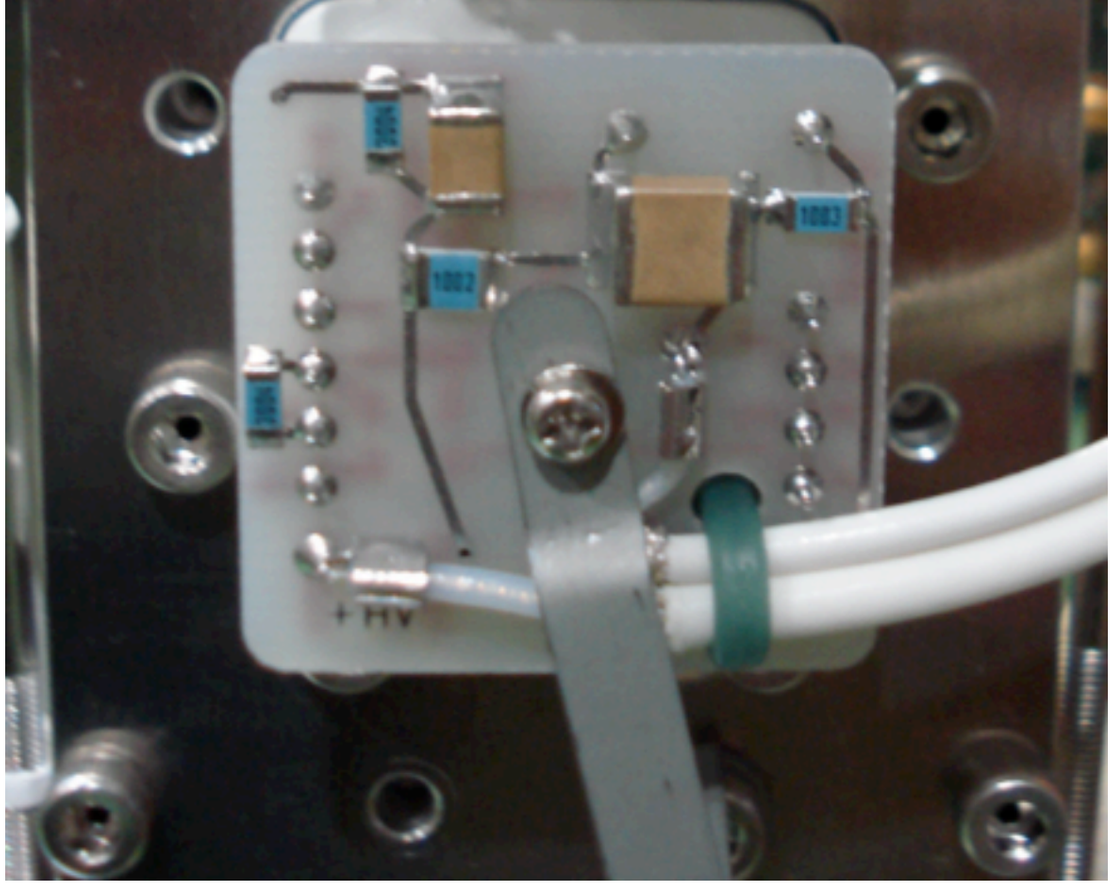
γ : Cs-137, 0.66MeV, 7KBq (CS516)



2012.7.4

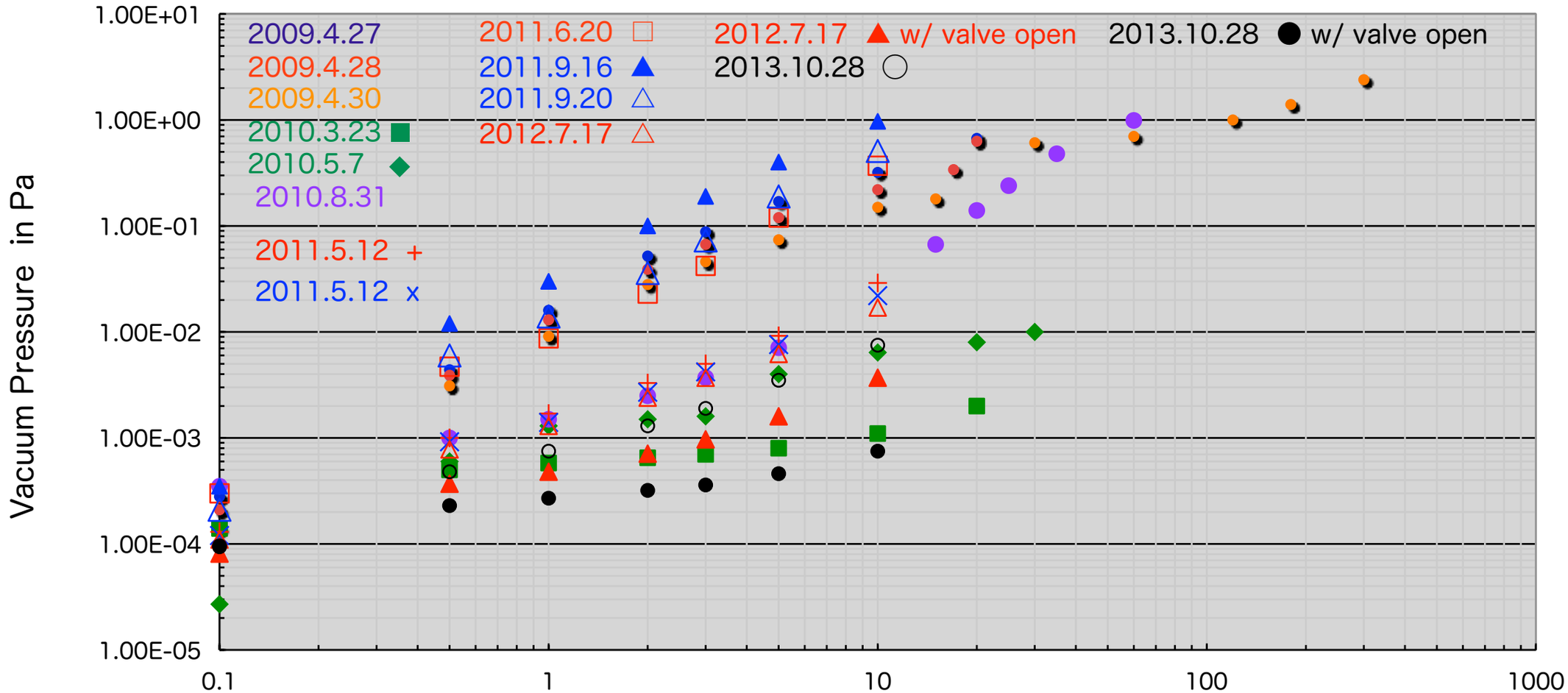


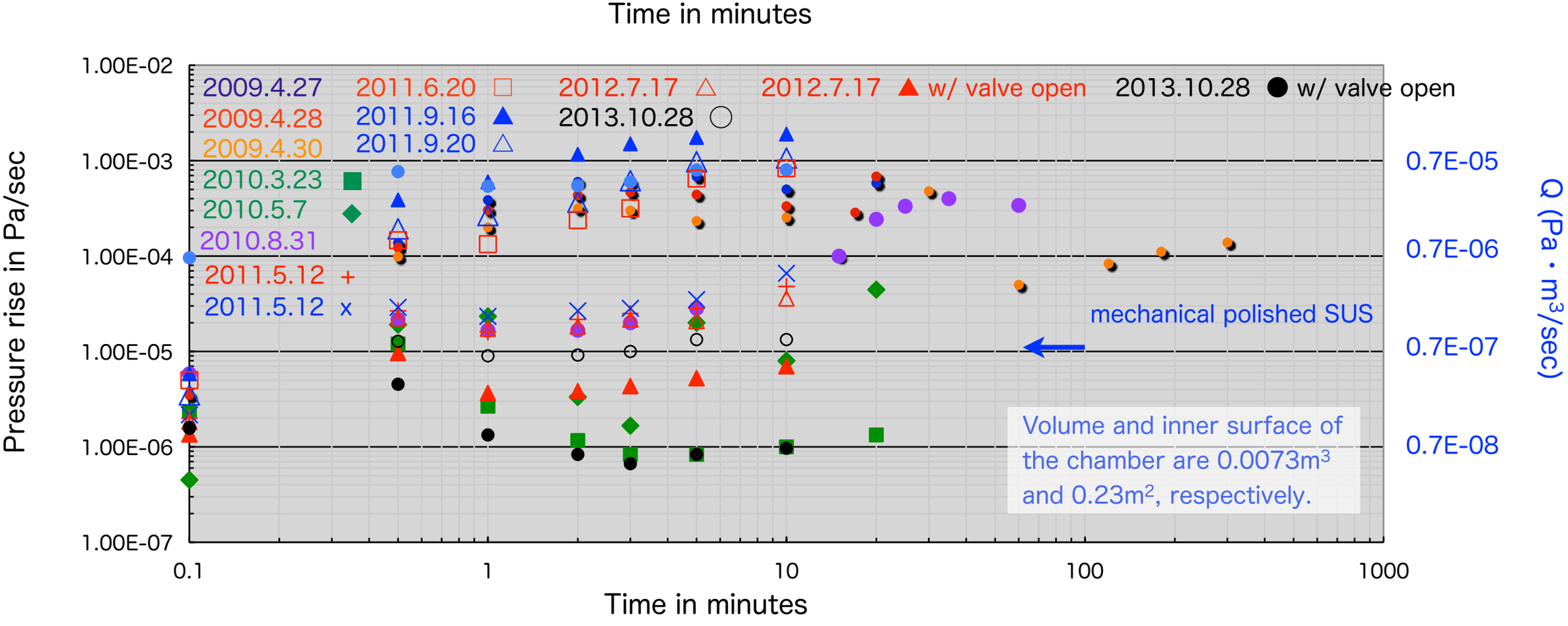
PMT1 (up) : R5900; DY1 - 12
20.7uA at +900V(max)
Q.E.=20%@175nm
(2003.11.28)



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

Vacuum Build-up Test





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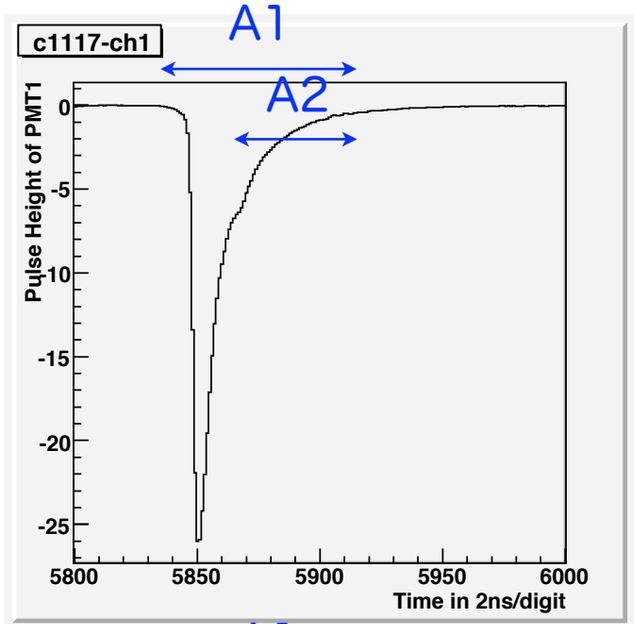
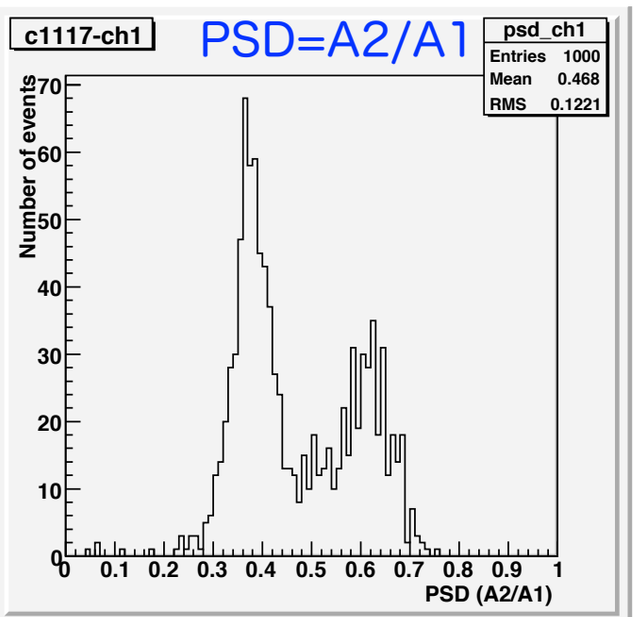
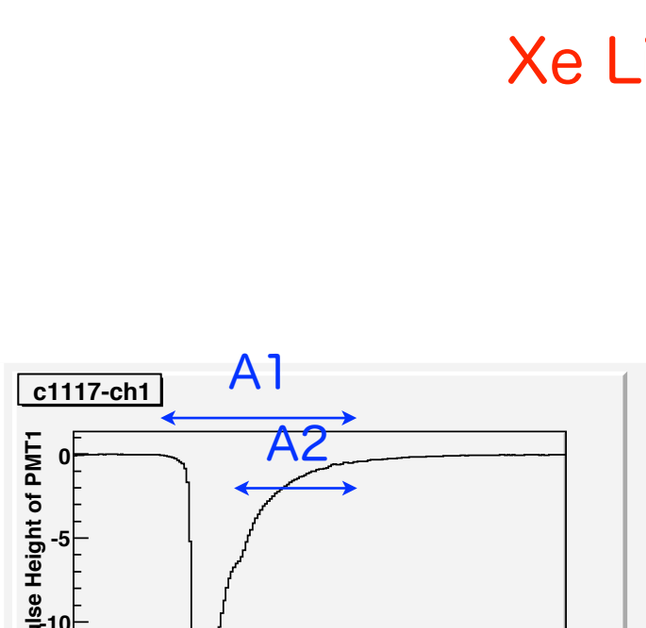
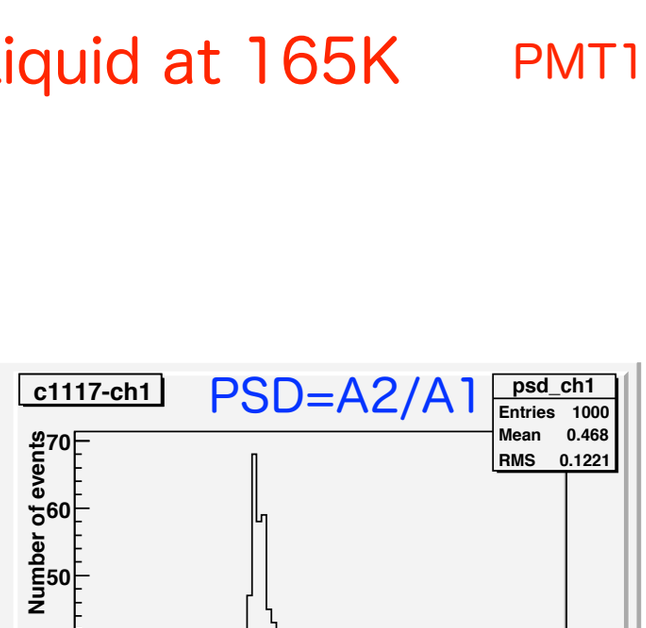
Xe Liquid at 165K PMT1=PMT2=+720V 2011.10.6.1832

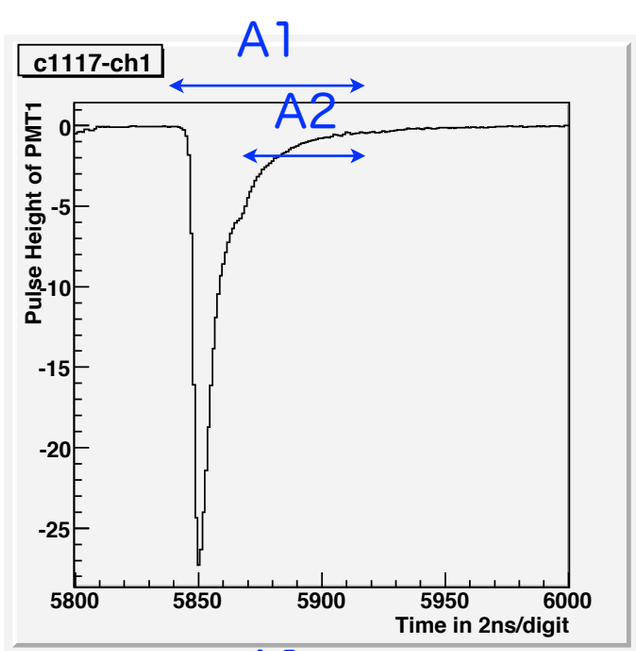


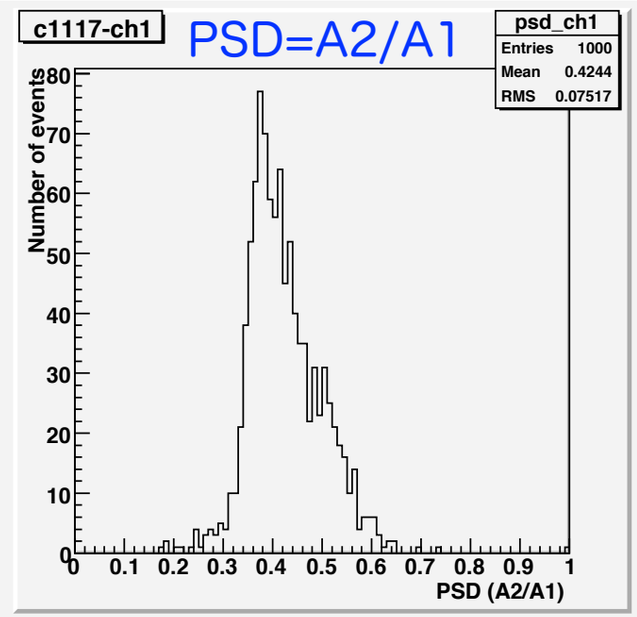


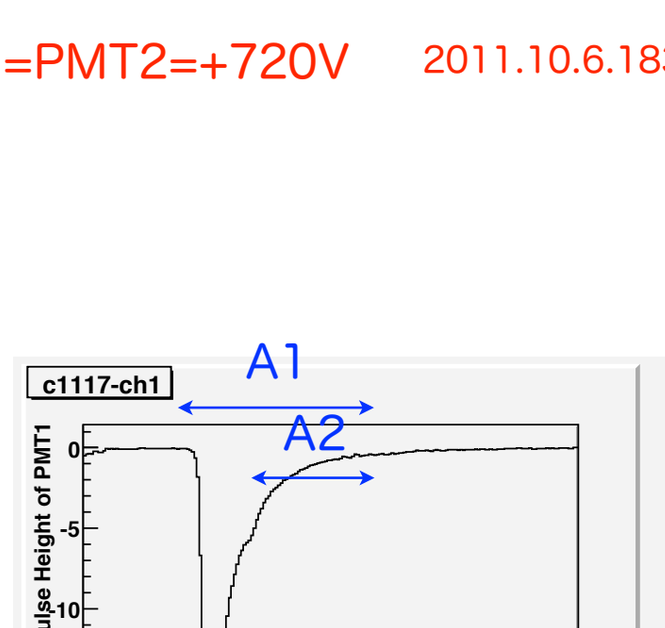


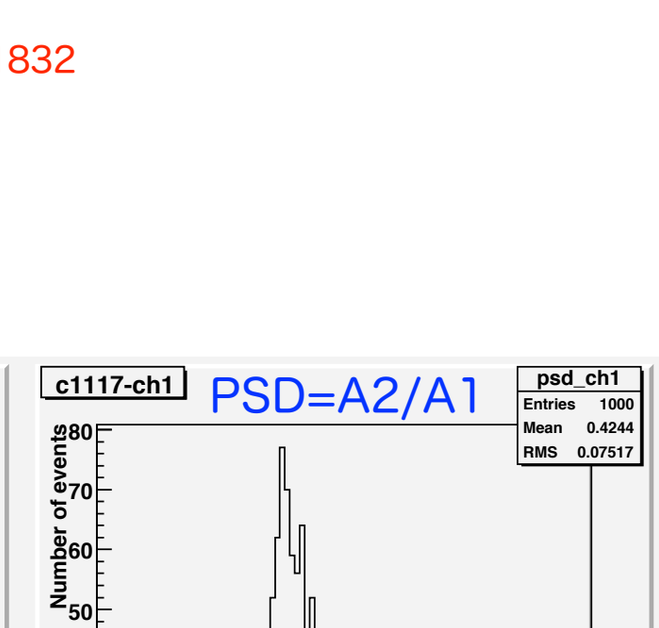


TPC cathode =0V, anode=0V



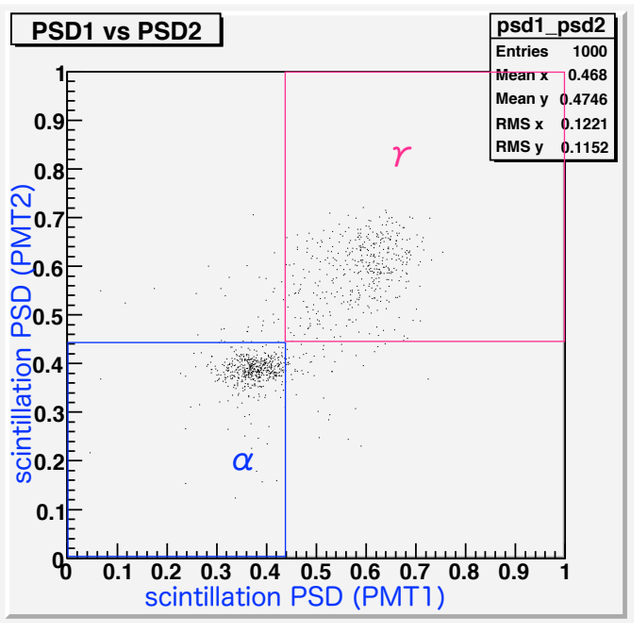


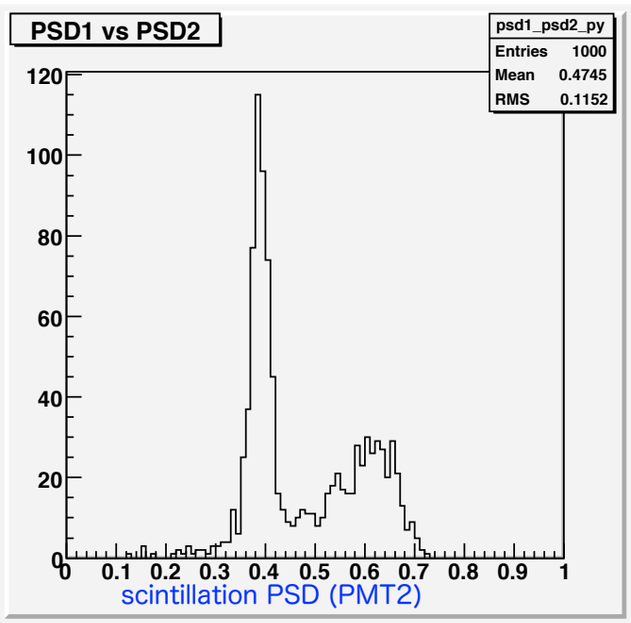


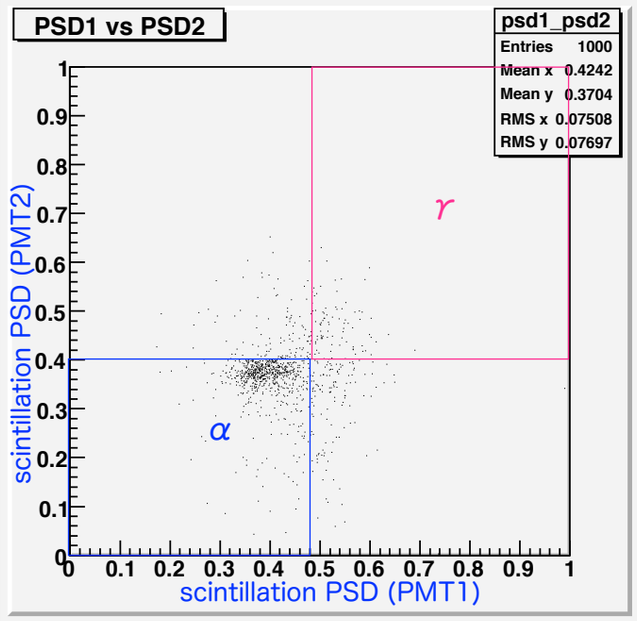


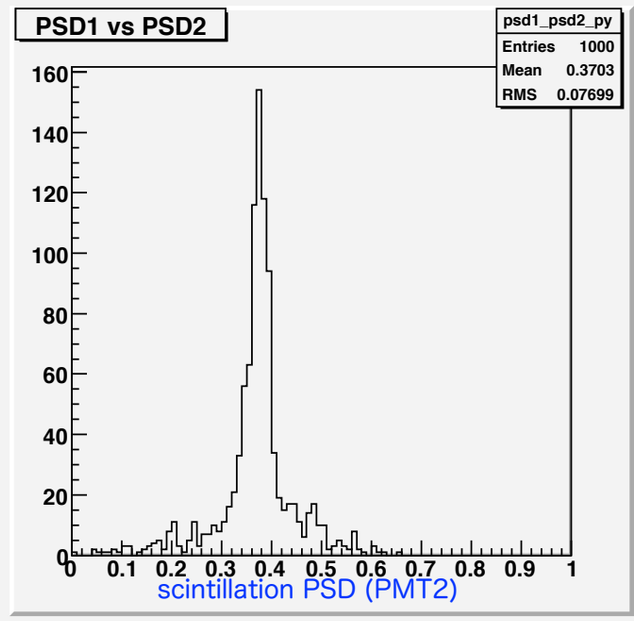
TPC cathode =-2.5kV, anode=+255V

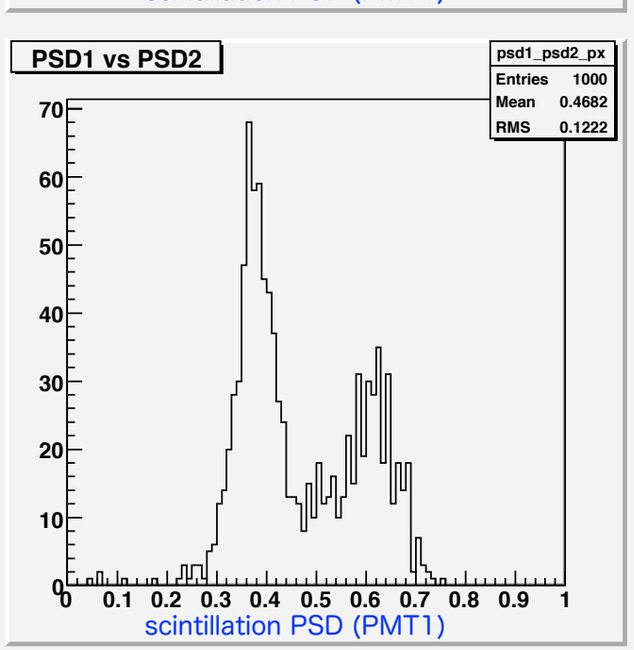
Xe Liquid at 165K　　PMT1=PMT2=+720V　　2011.10.6.1832

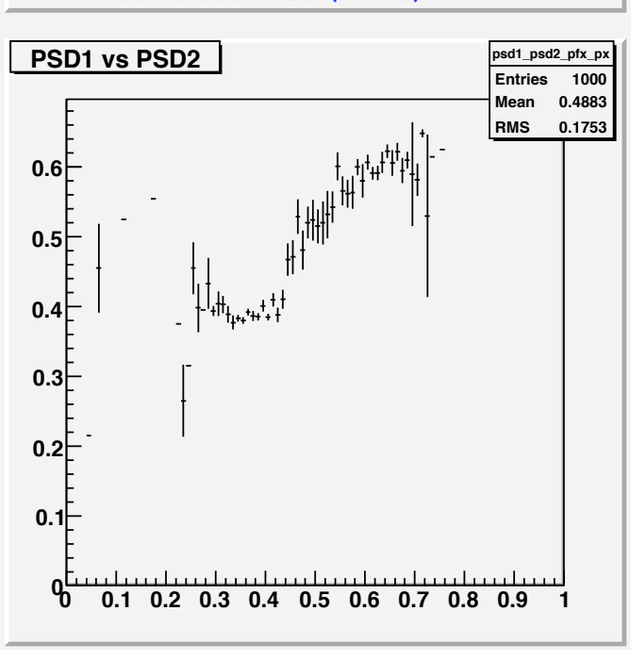


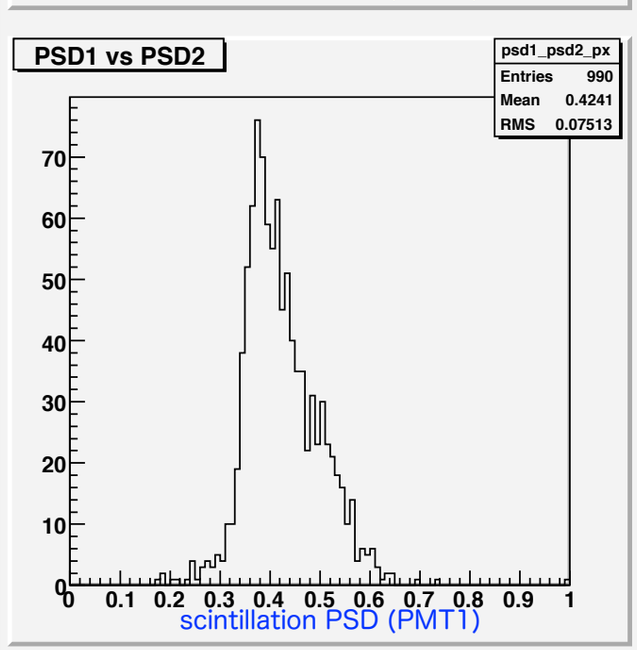


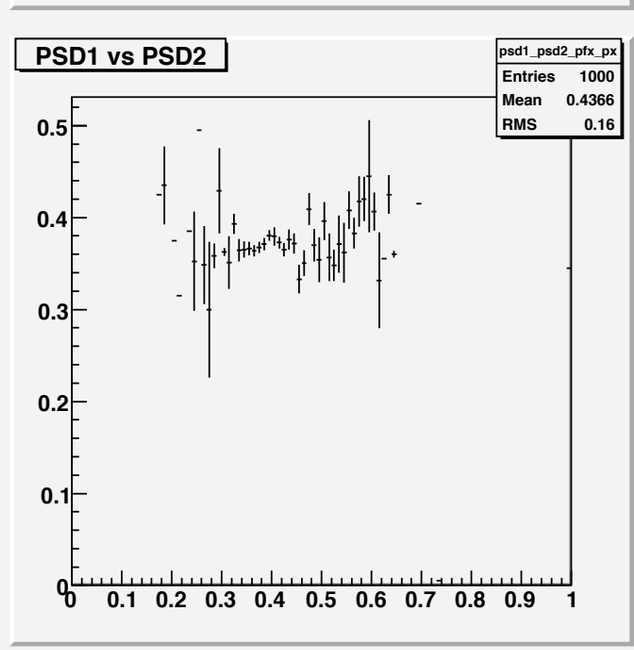












TPC cathode =0V, anode=0V

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

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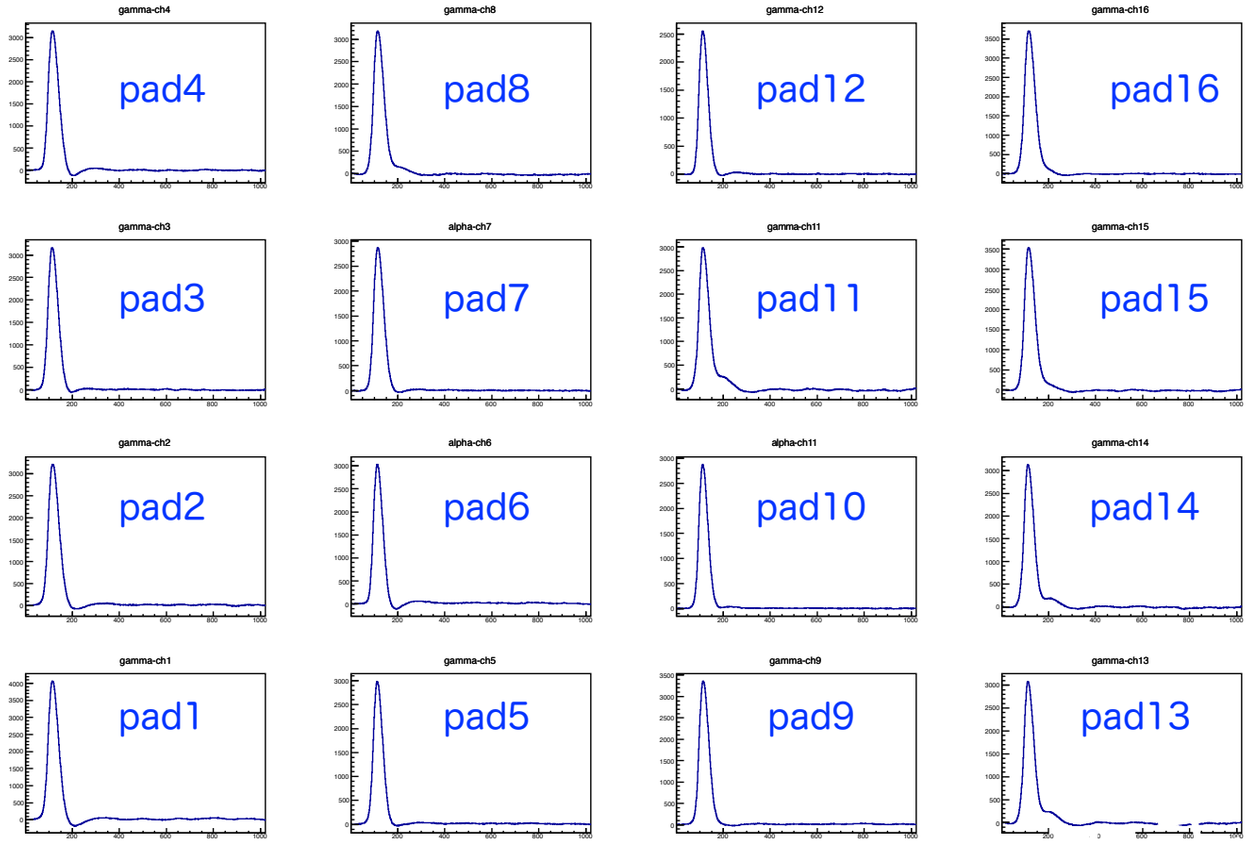
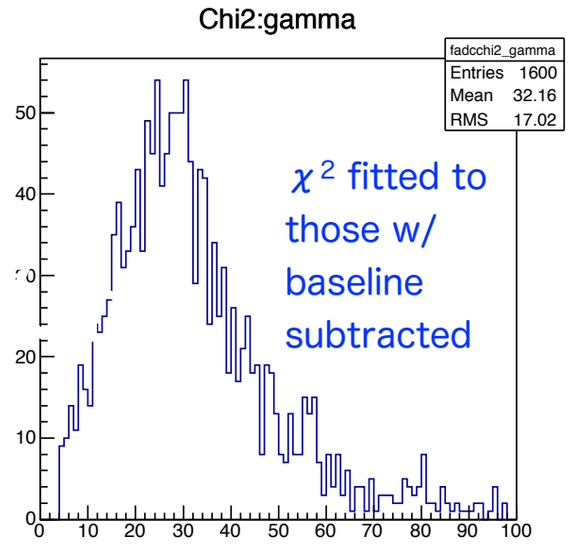
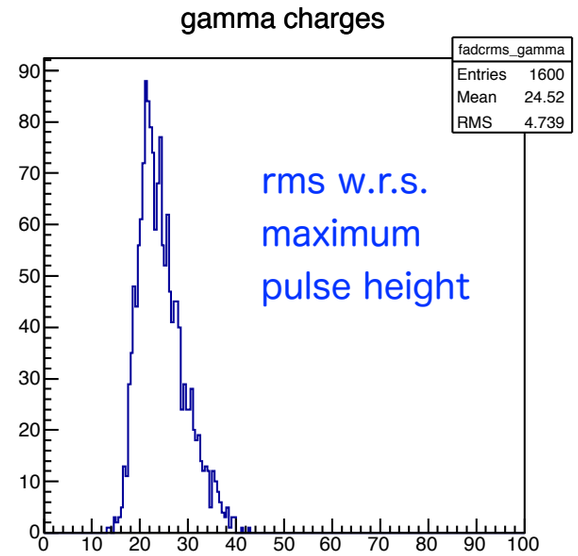
Performances of test pulse run 2012.8.23 18:35

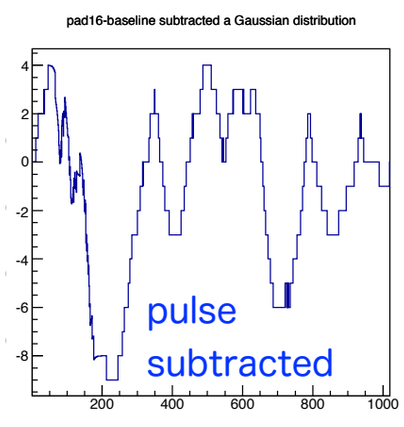


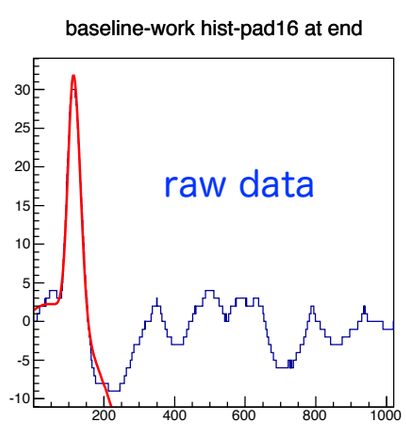
Test pulse : 50Hz, 0.025V w/ 31dB, 0.7mV, C_i=2pF, i.e. injected charge =1.4fC;
Preamp gain = 10mV/fC w/ C_fb=0.1pF ->14mV, but output impedance=100Ω instead of 50Ω@the scope, so 14/2=7mV expected ;
Observed : 5mV@preamp, 240mV@shaper-amp
FADC20MHz : 240/7.8=31 counts expected

So, 240mV/1.4fC =171mV/fC or 22 count/fC

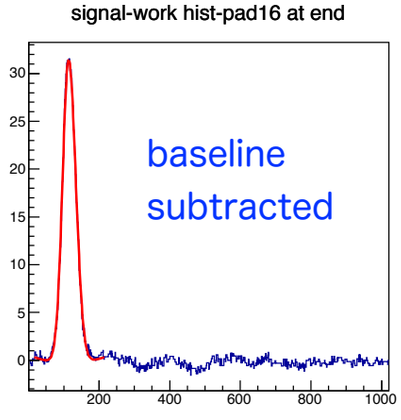


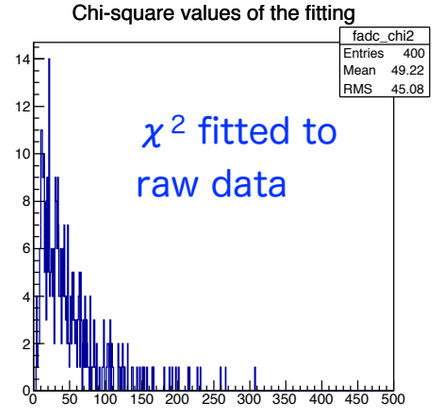


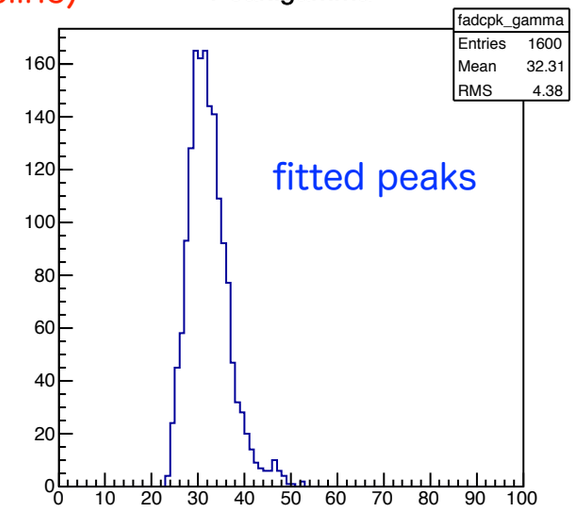


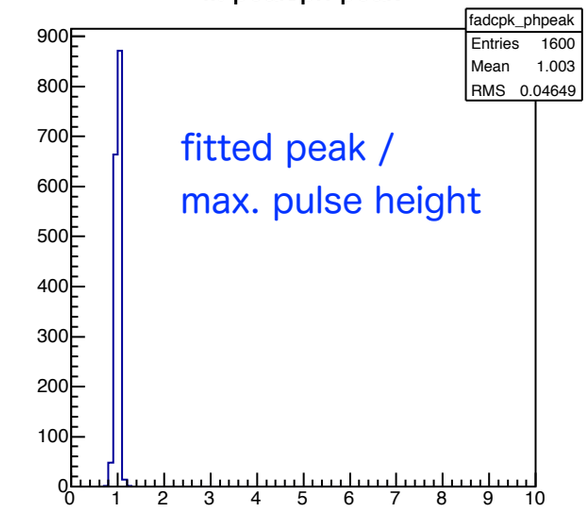


pulses are fitted with dual-Gaussian and 2nd order polynomial (baseline)

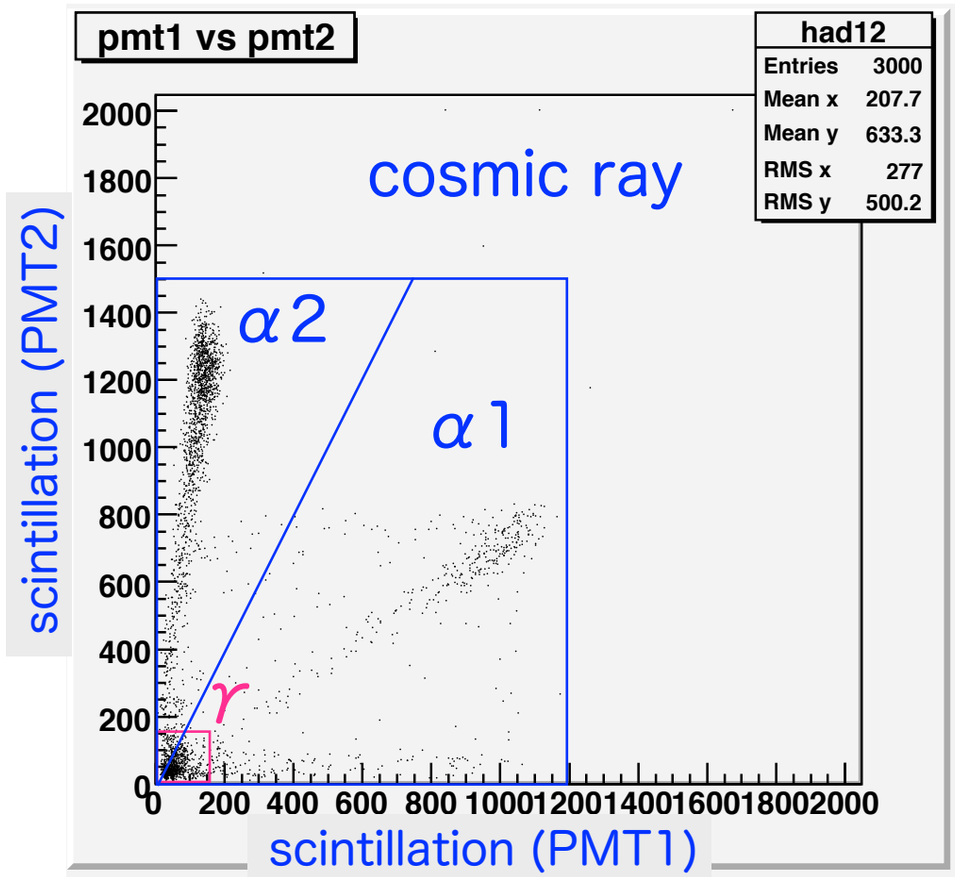


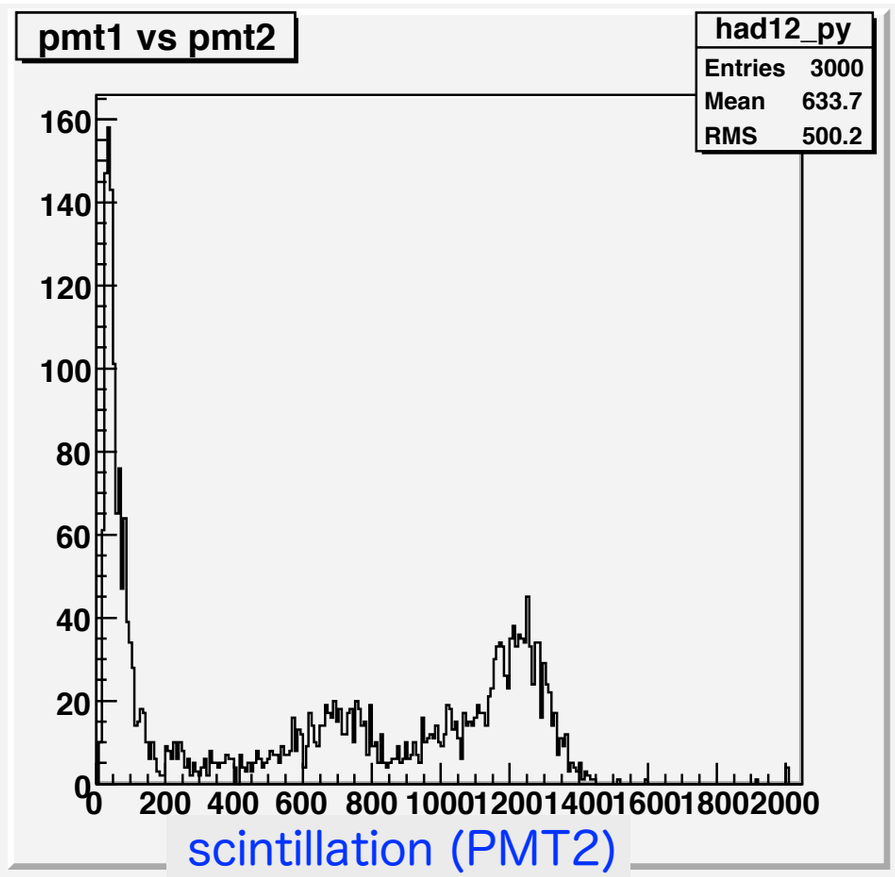


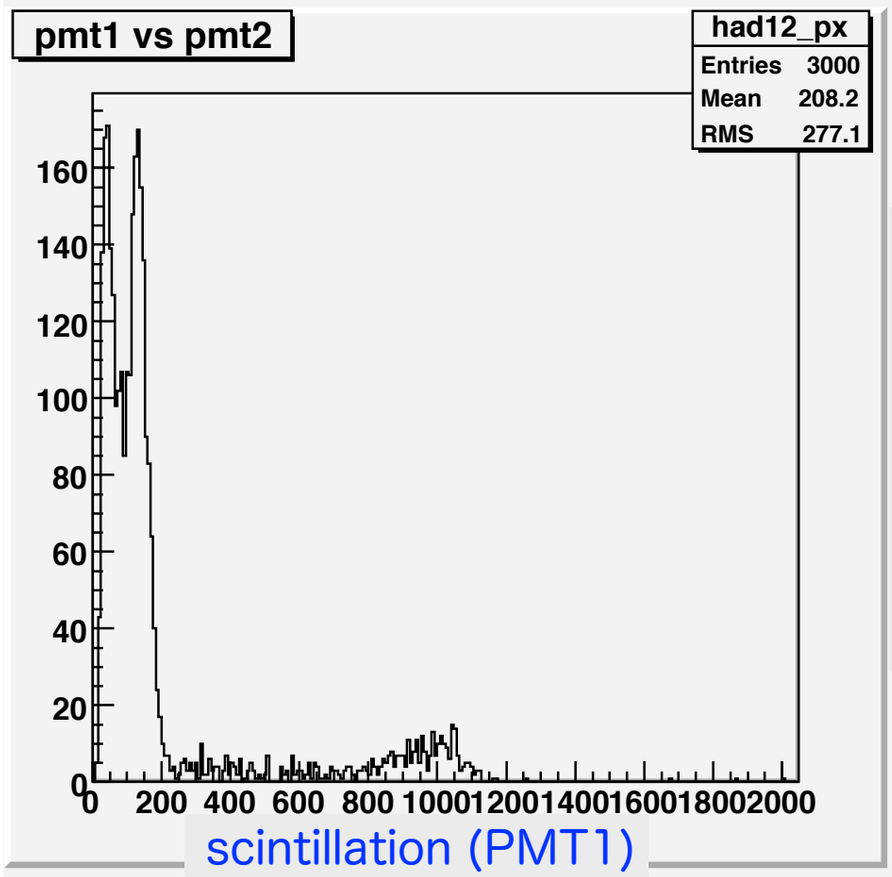


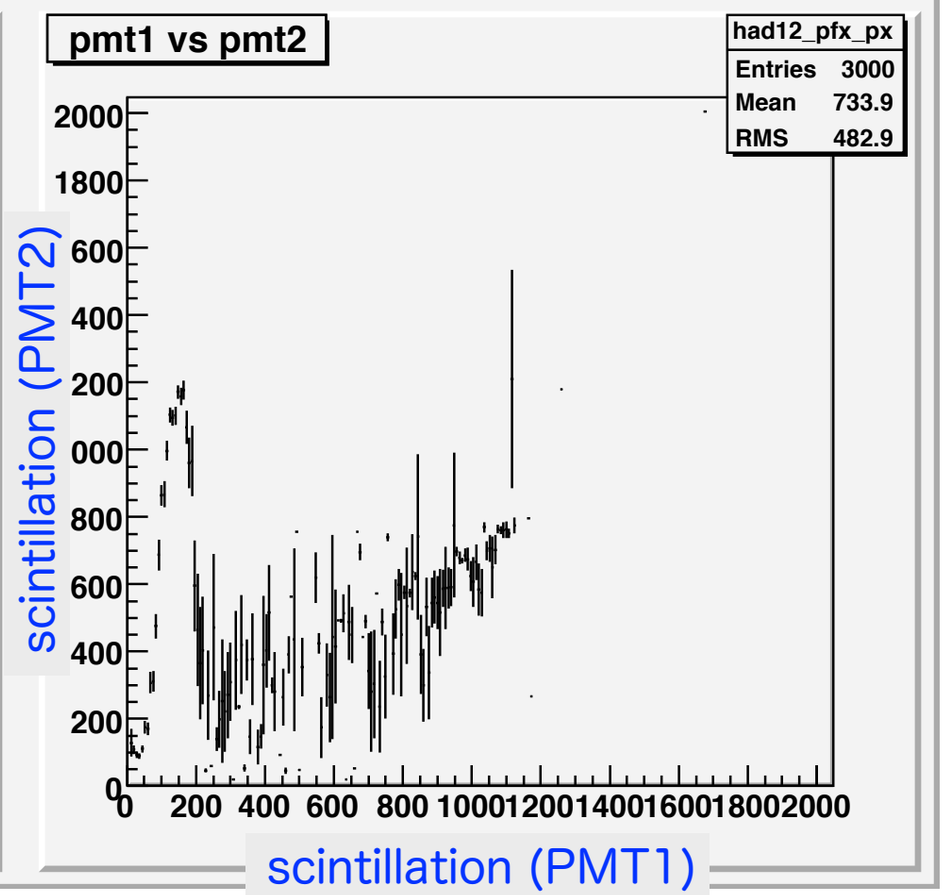


Event classifications by scintillation lights



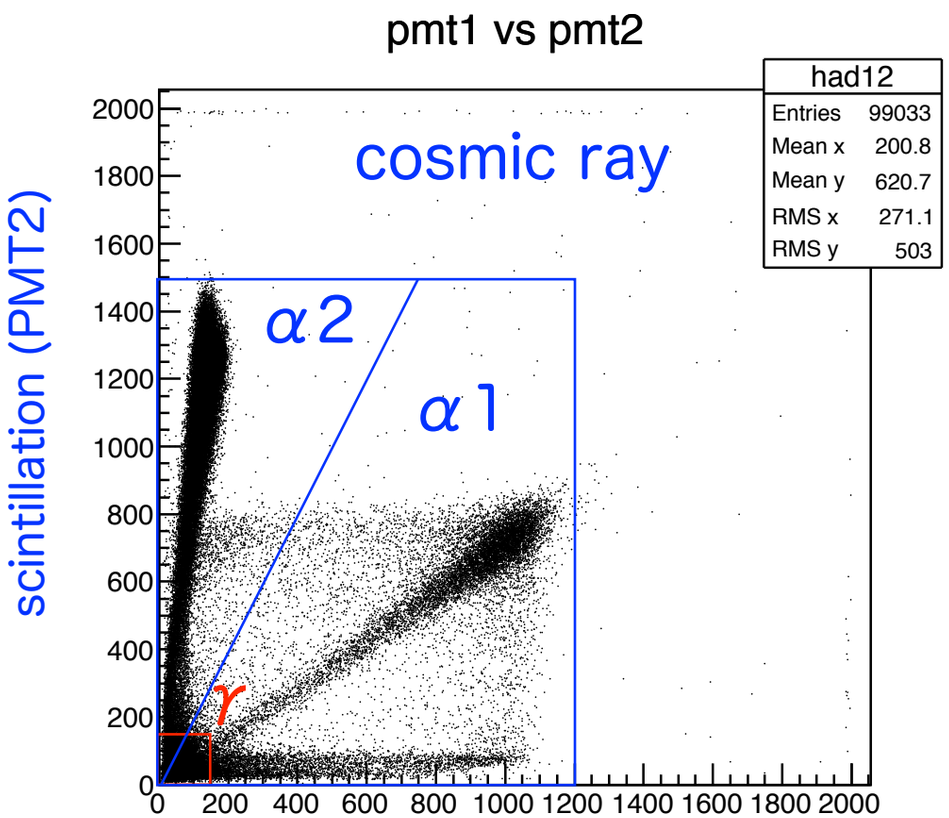


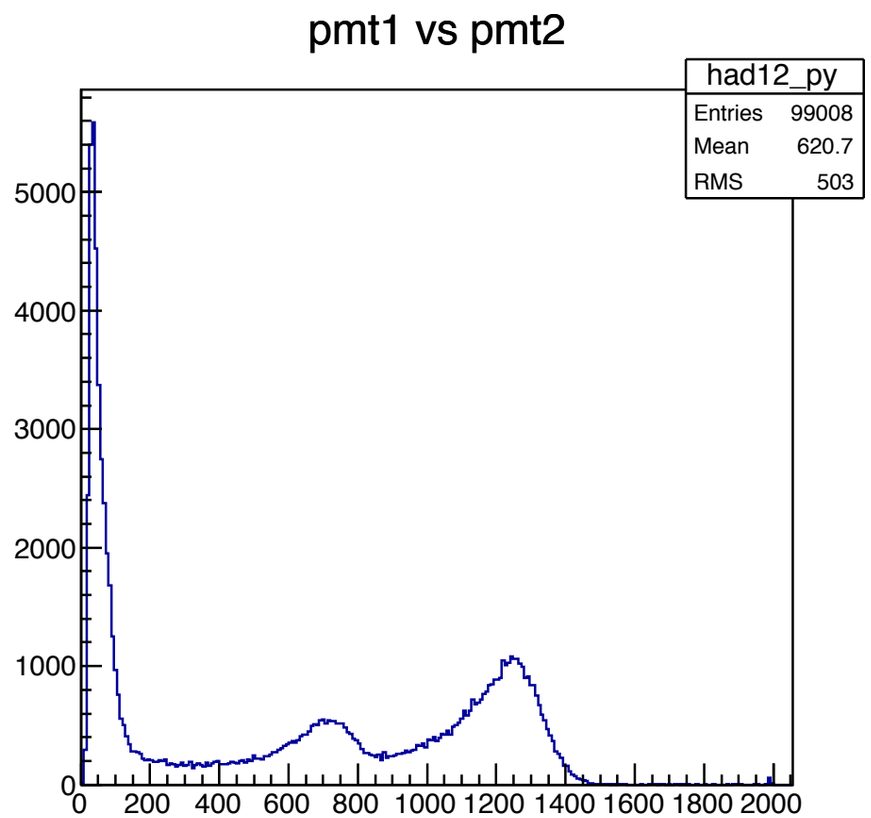




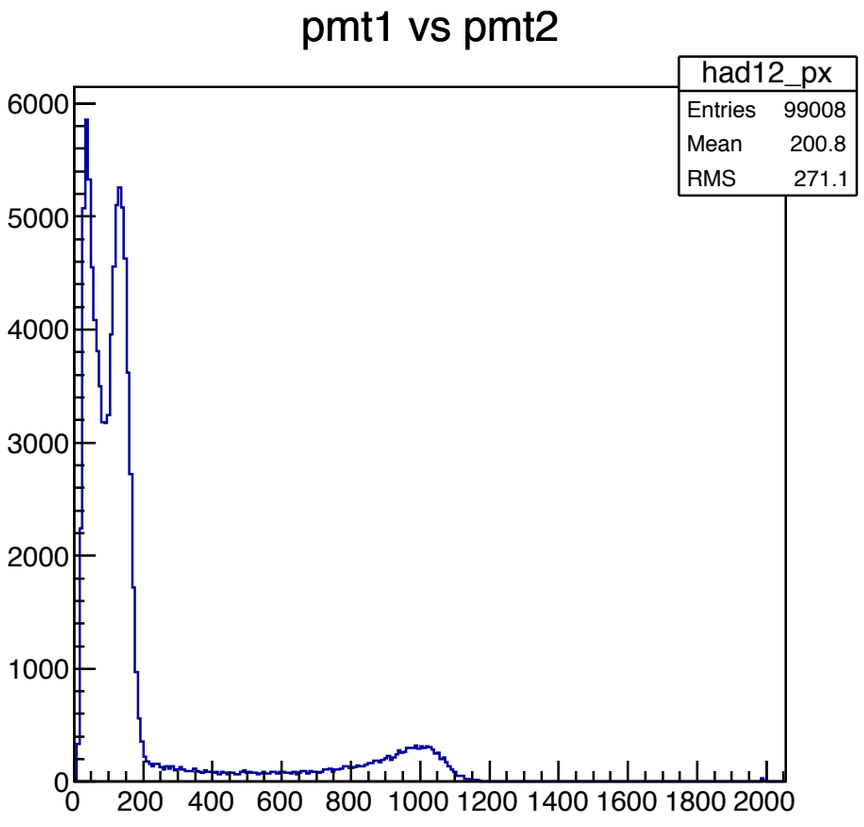
2012.8.28

Event classifications by scintillation lights

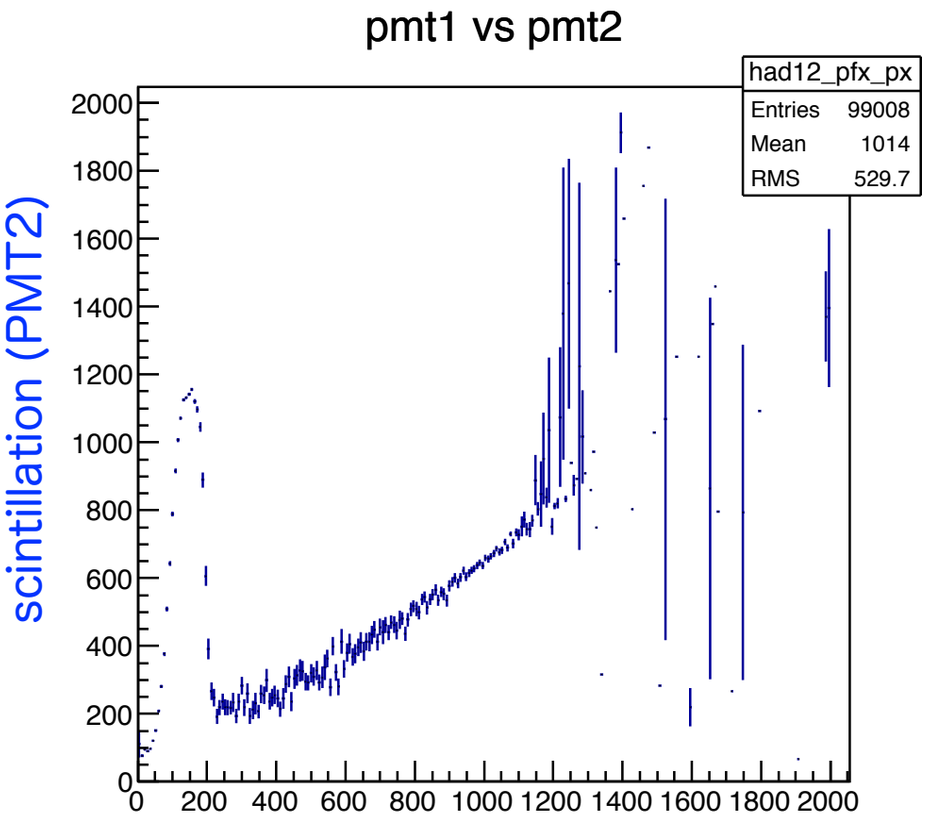




scintillation (PMT1)

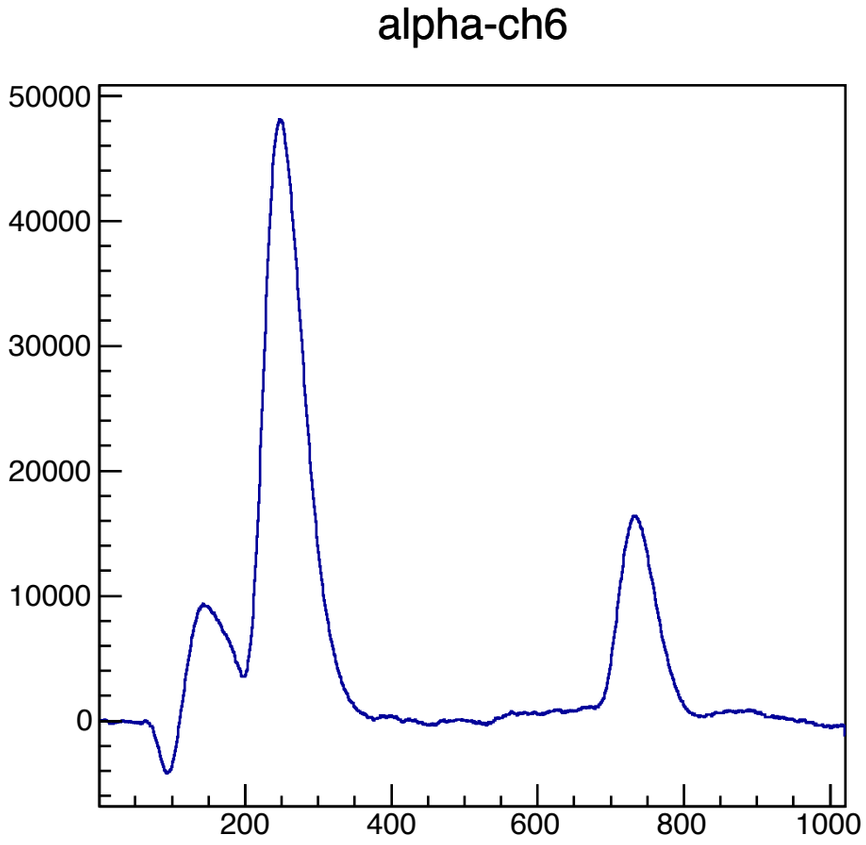


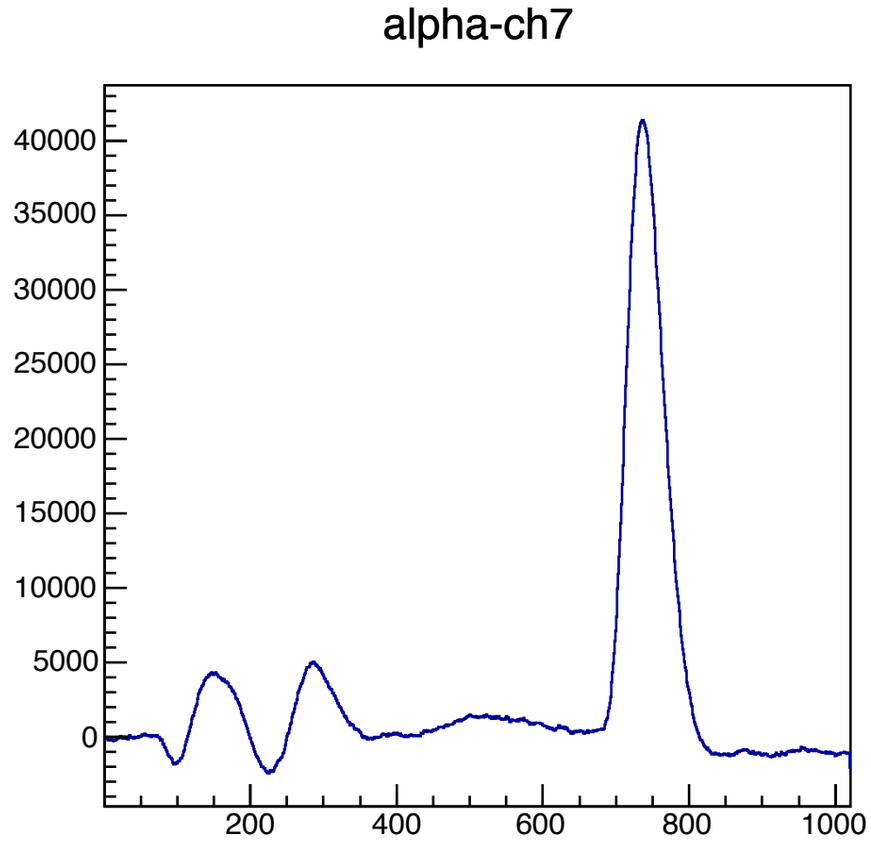
scintillation (PMT2)

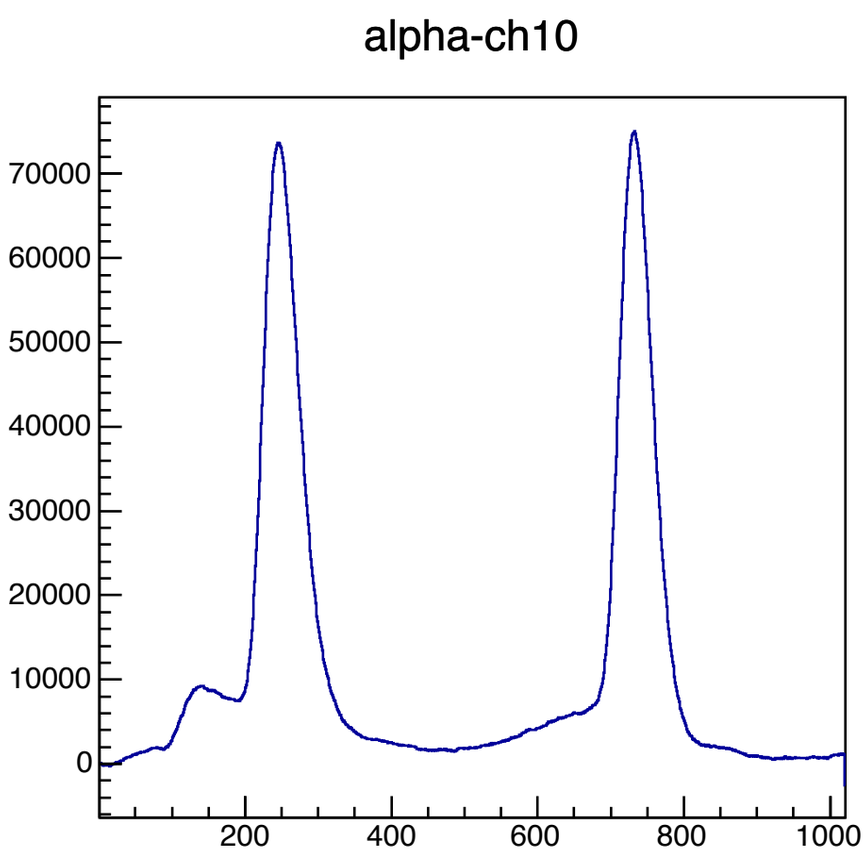


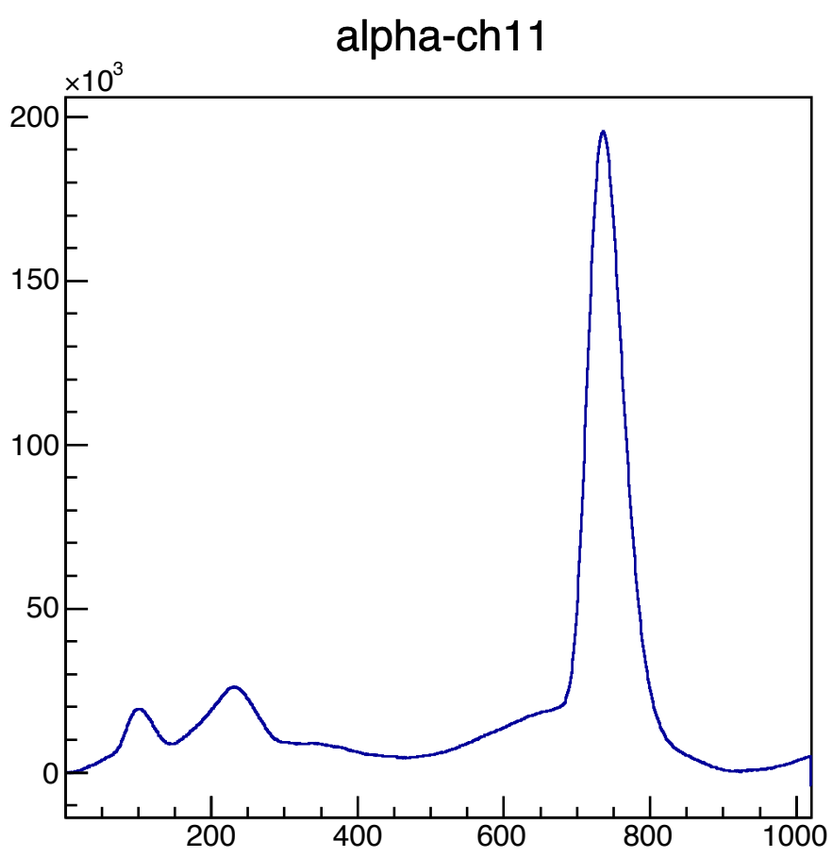
scintillation (PMT1)

2012.12.10-
2013.1.19









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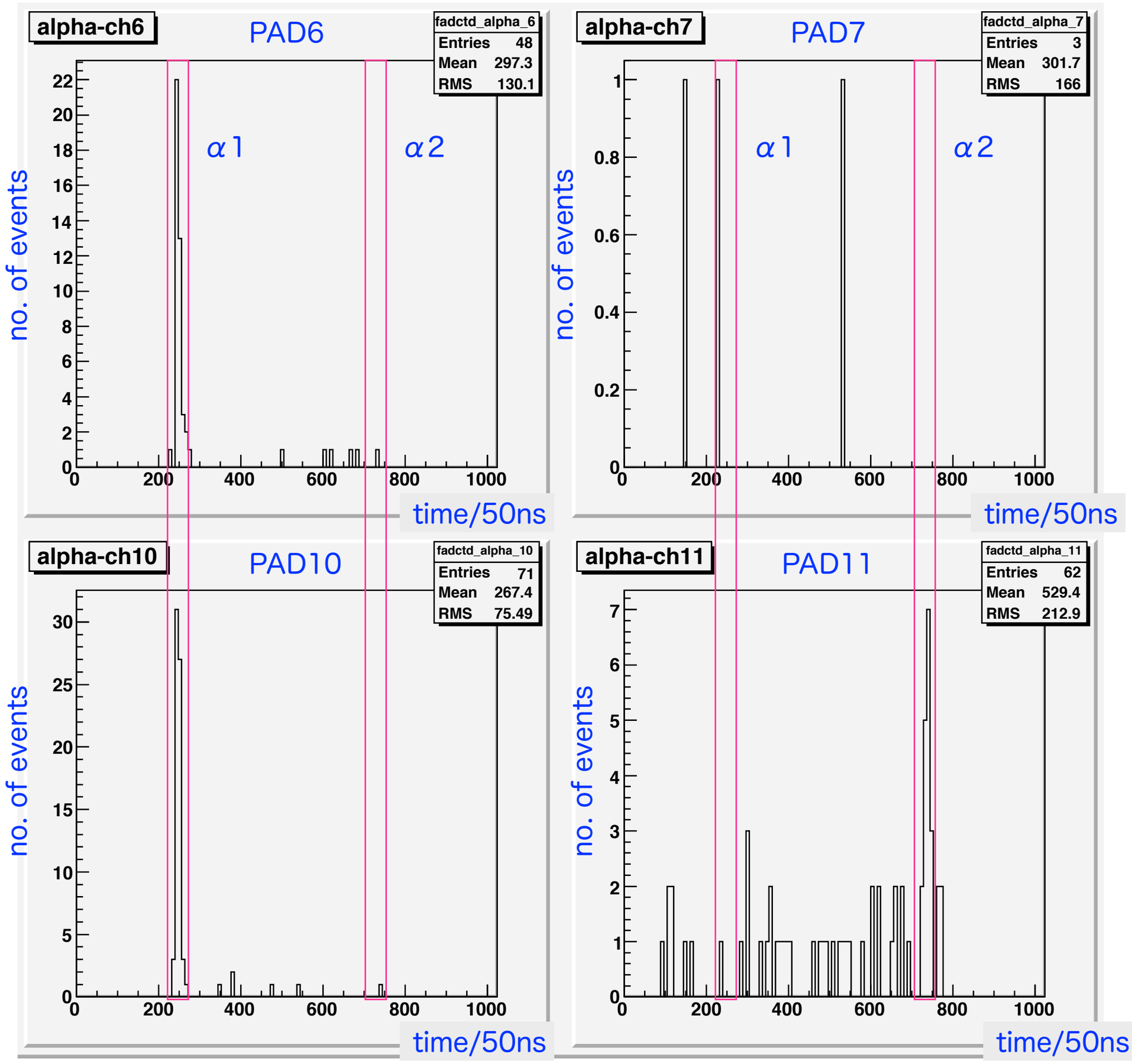
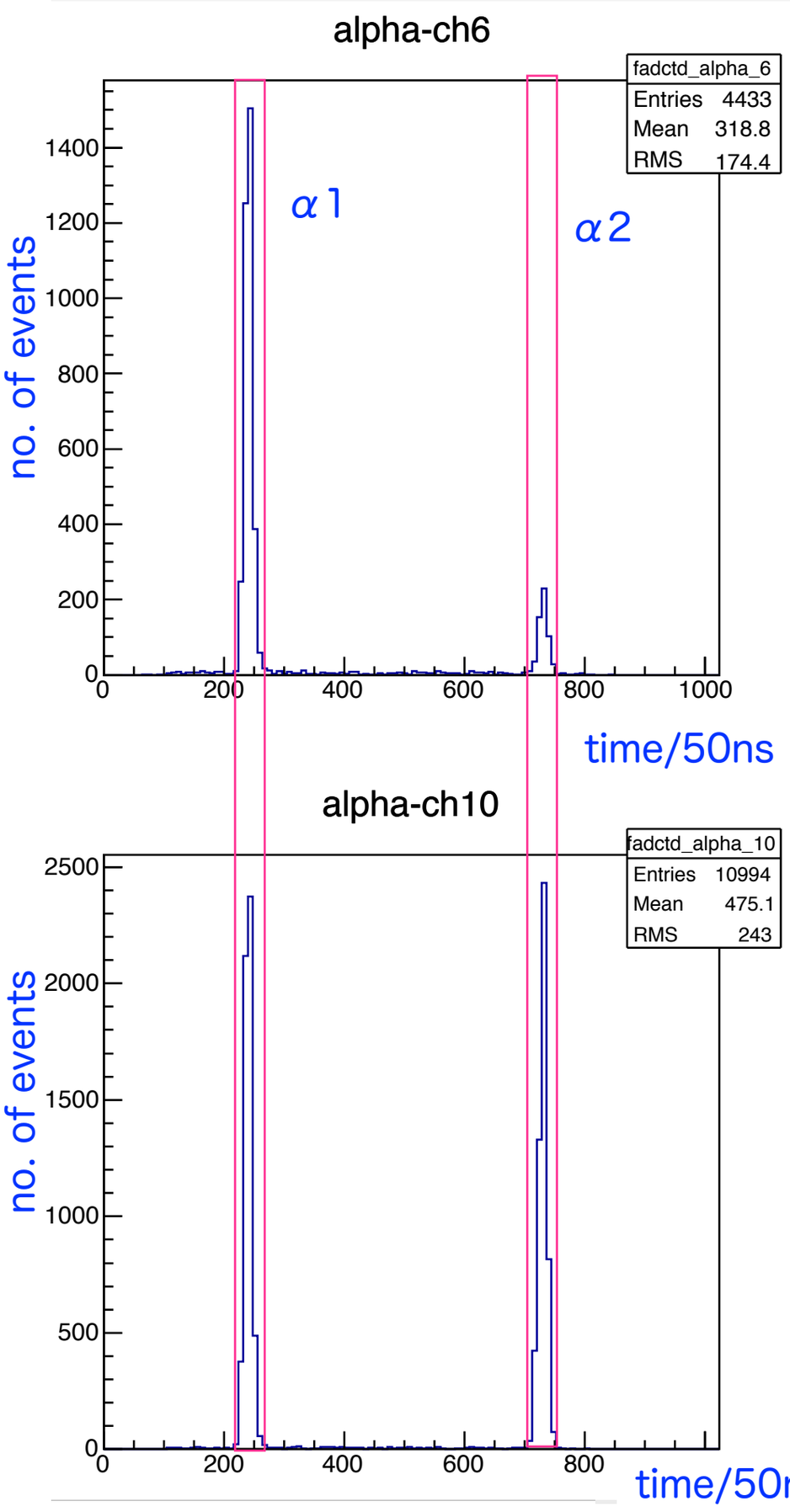
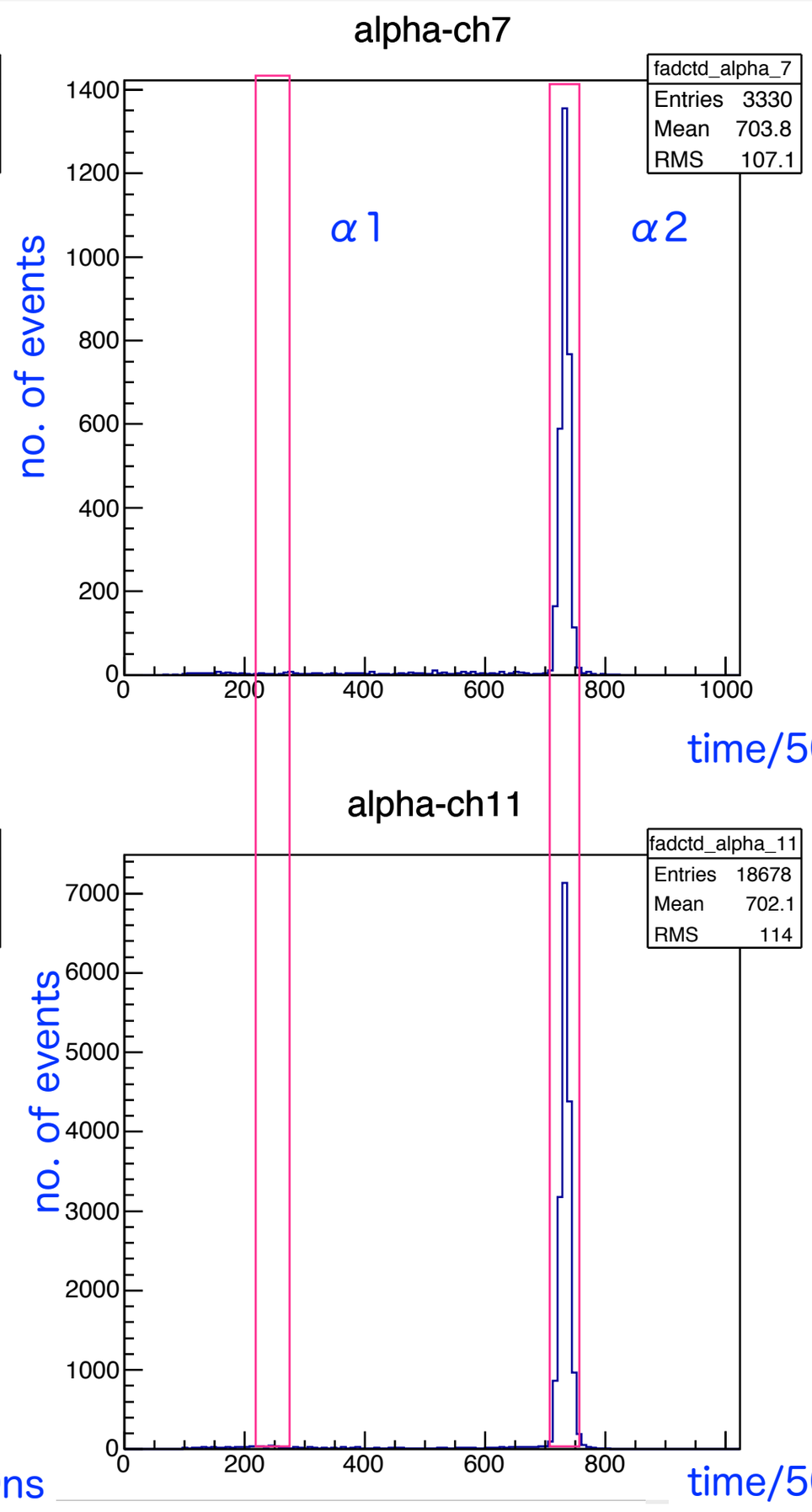
Fitted peak charges



2012.8.28

Fitted peak charges



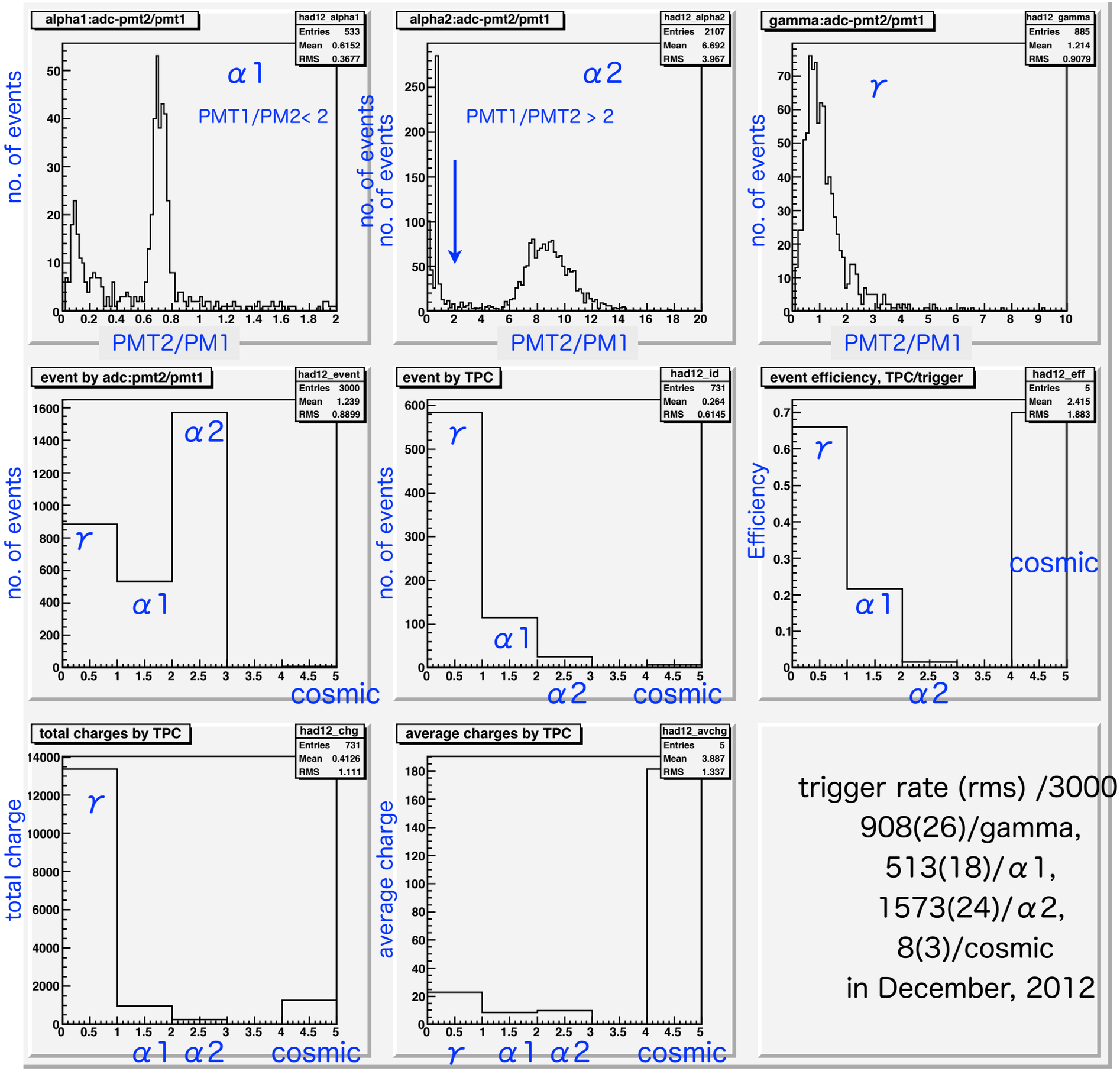


2012.12.10-
2013.1.19

scintillation ratio :
PMT2/PMT1

Statistics :
triggered,
identified,
efficiency

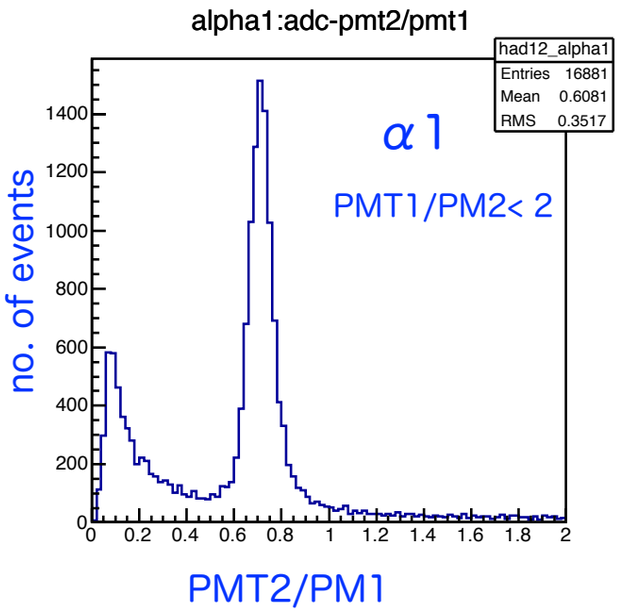
Charges :
pulse height
peak fitted,
averages

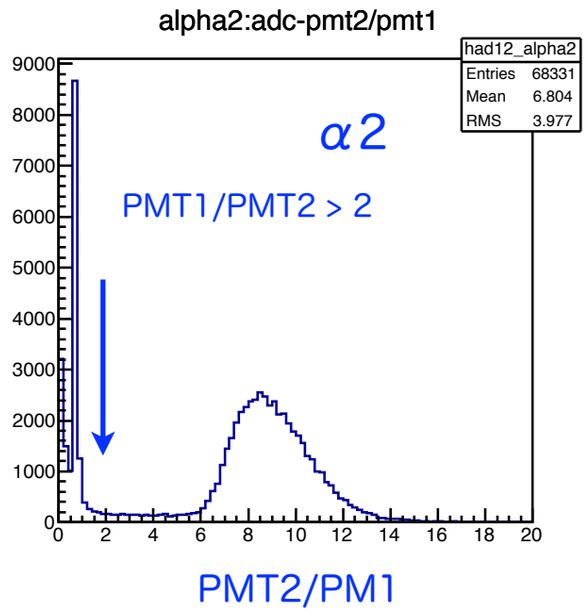


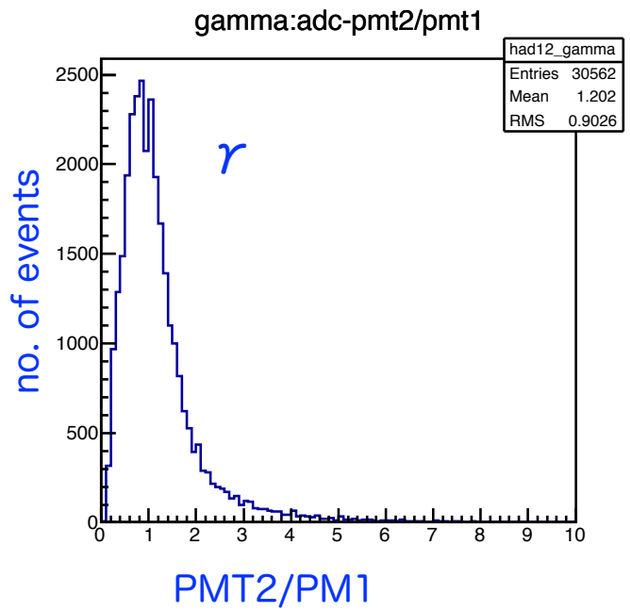
trigger rate (rms) /3000 :
908(26)/gamma,
513(18)/α1,
1573(24)/α2,
8(3)/cosmic
in December, 2012

2012.8.28

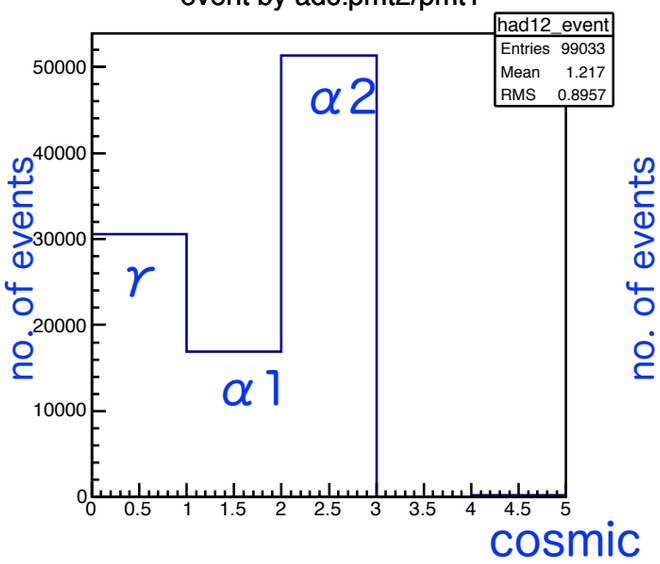
scintillation ratio :
PMT2/PMT1

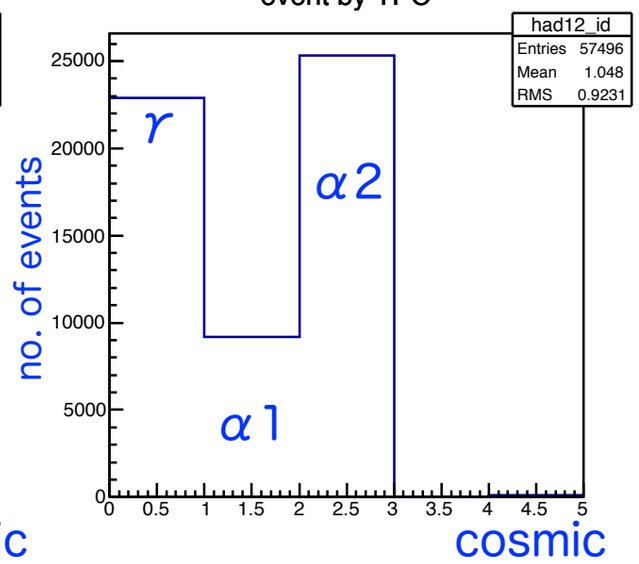


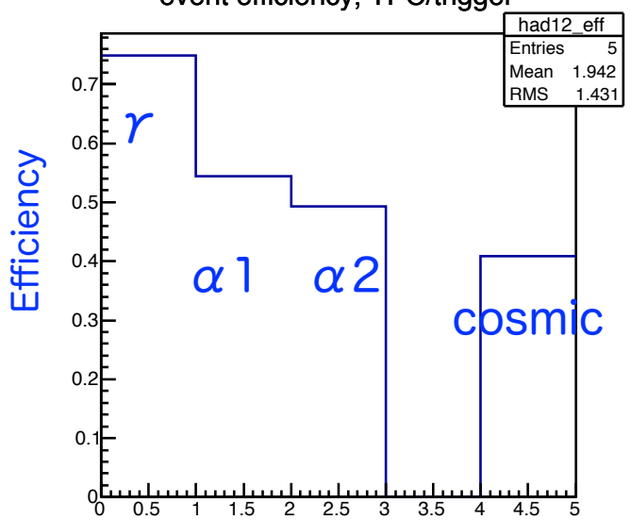




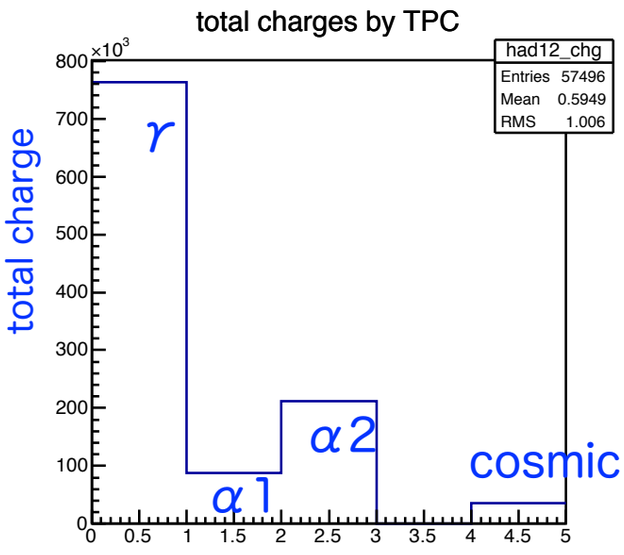
Statistics :
triggered,
identified,
efficiency

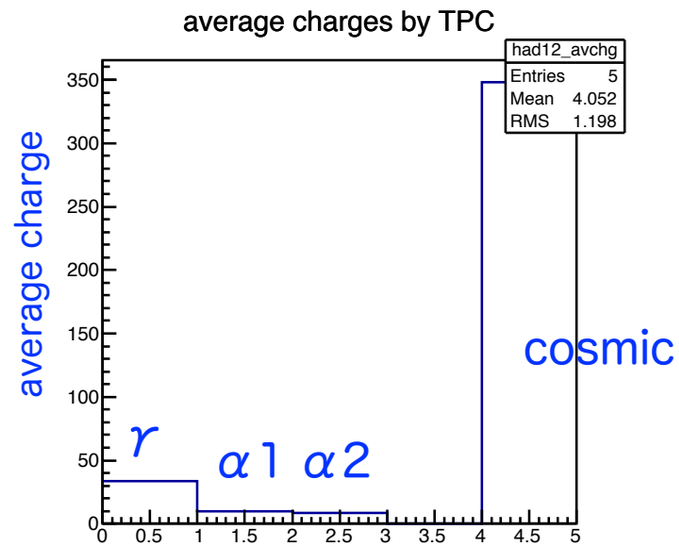






Charges :
pulse height
peak fitted,
averages





trigger rate (rms) /3000 :
908(26)/gamma,
513(18)/α1,
1573(24)/α2,
8(3)/cosmic
in December, 2012

2012.12.10-
2013.1.19

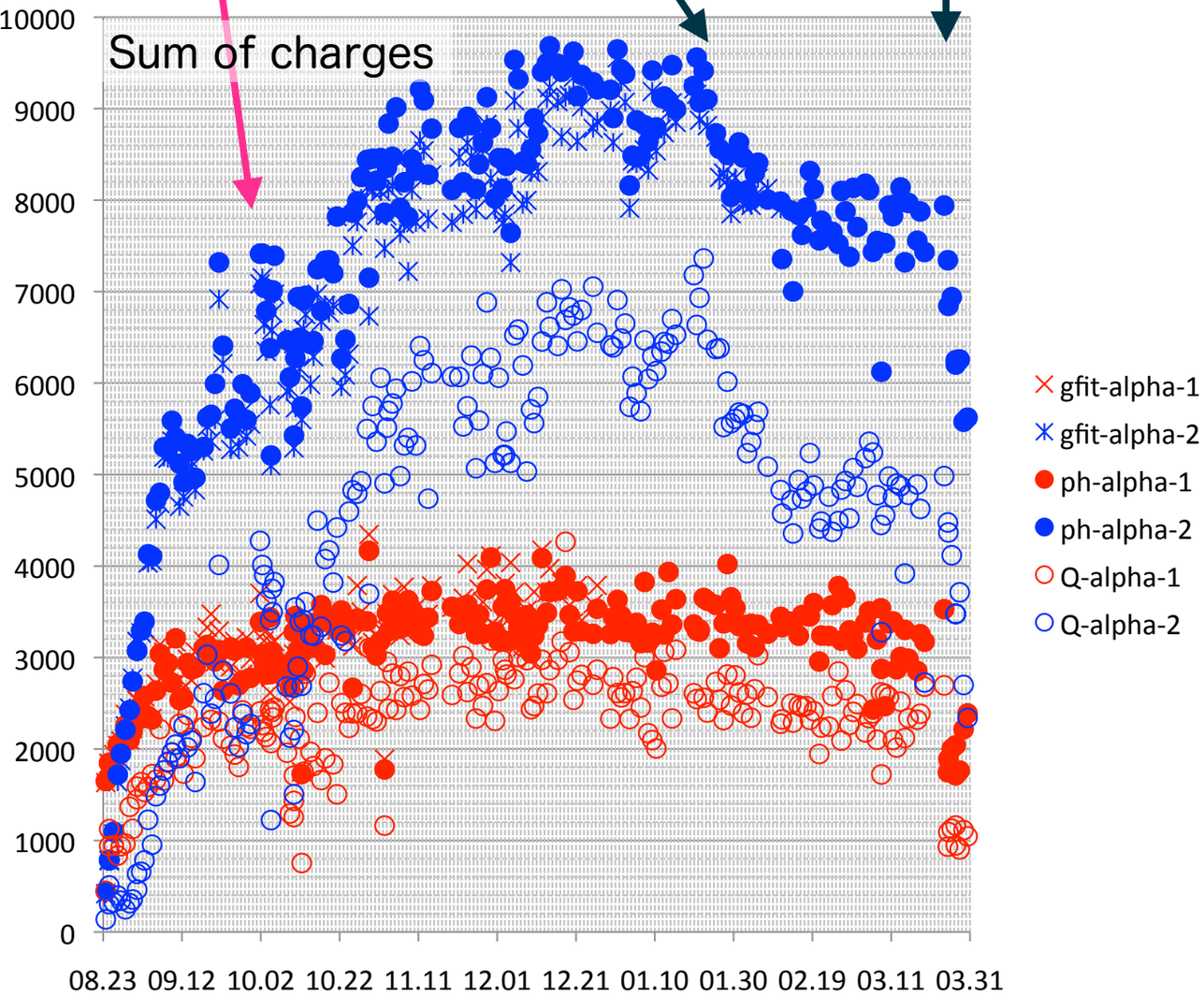
TPC charge signals

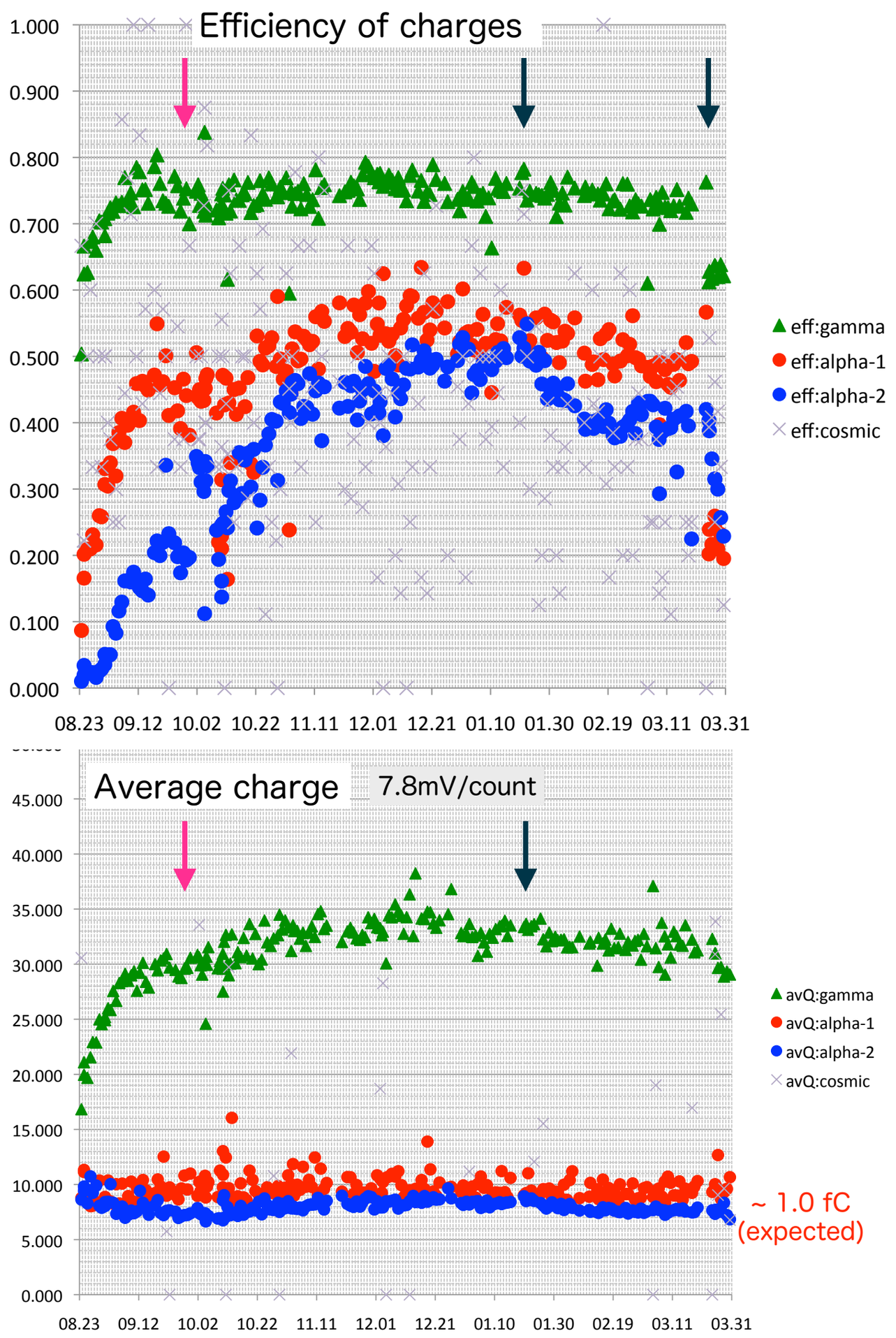
23 August 2012 to 31 March 2013

Since 1 October, 2012, a warm up of CH /day
except for weekends

On 20th January, 2013, stop the warm up

On 25th March, 2013,
stop the gas circulation





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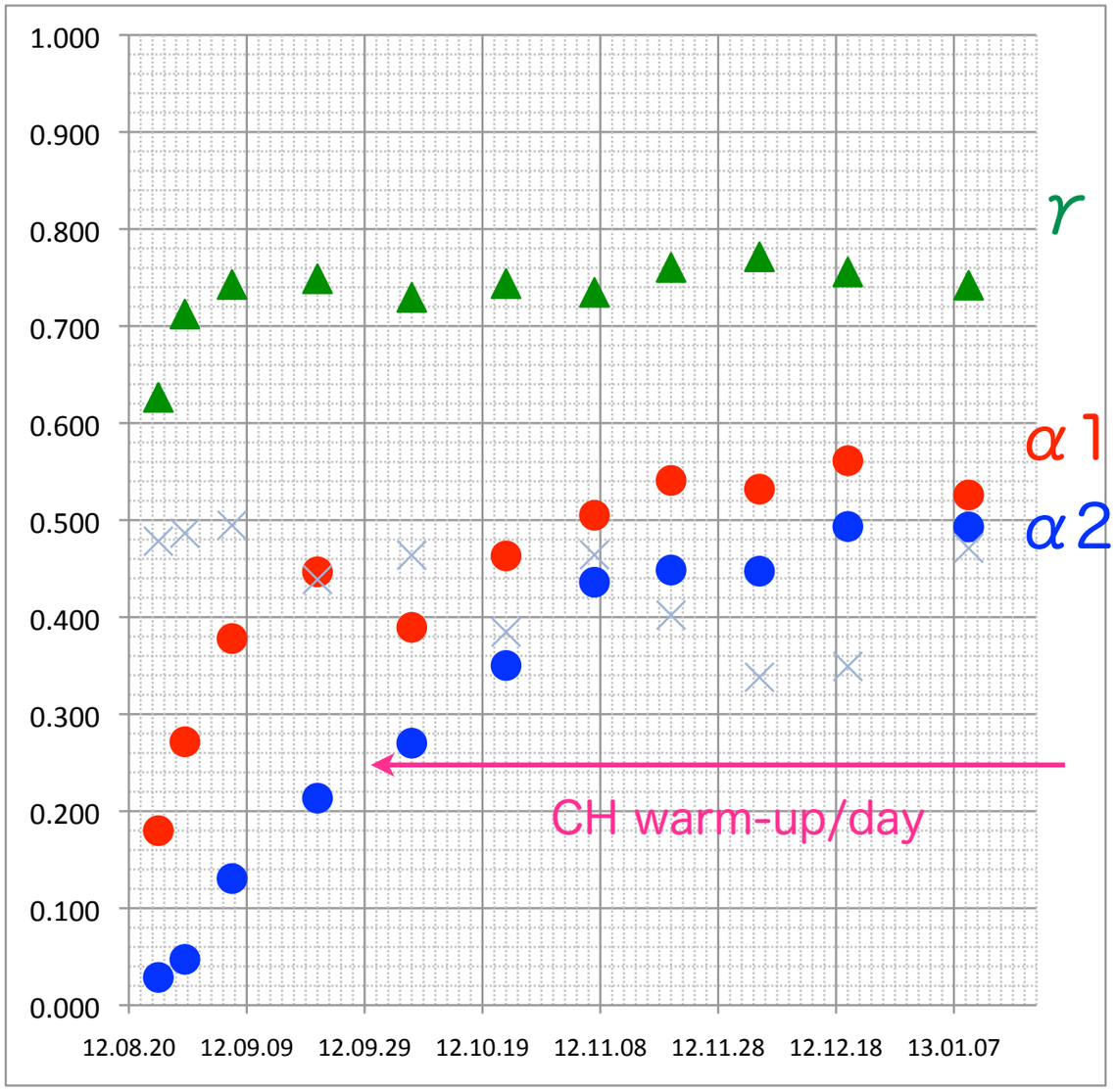
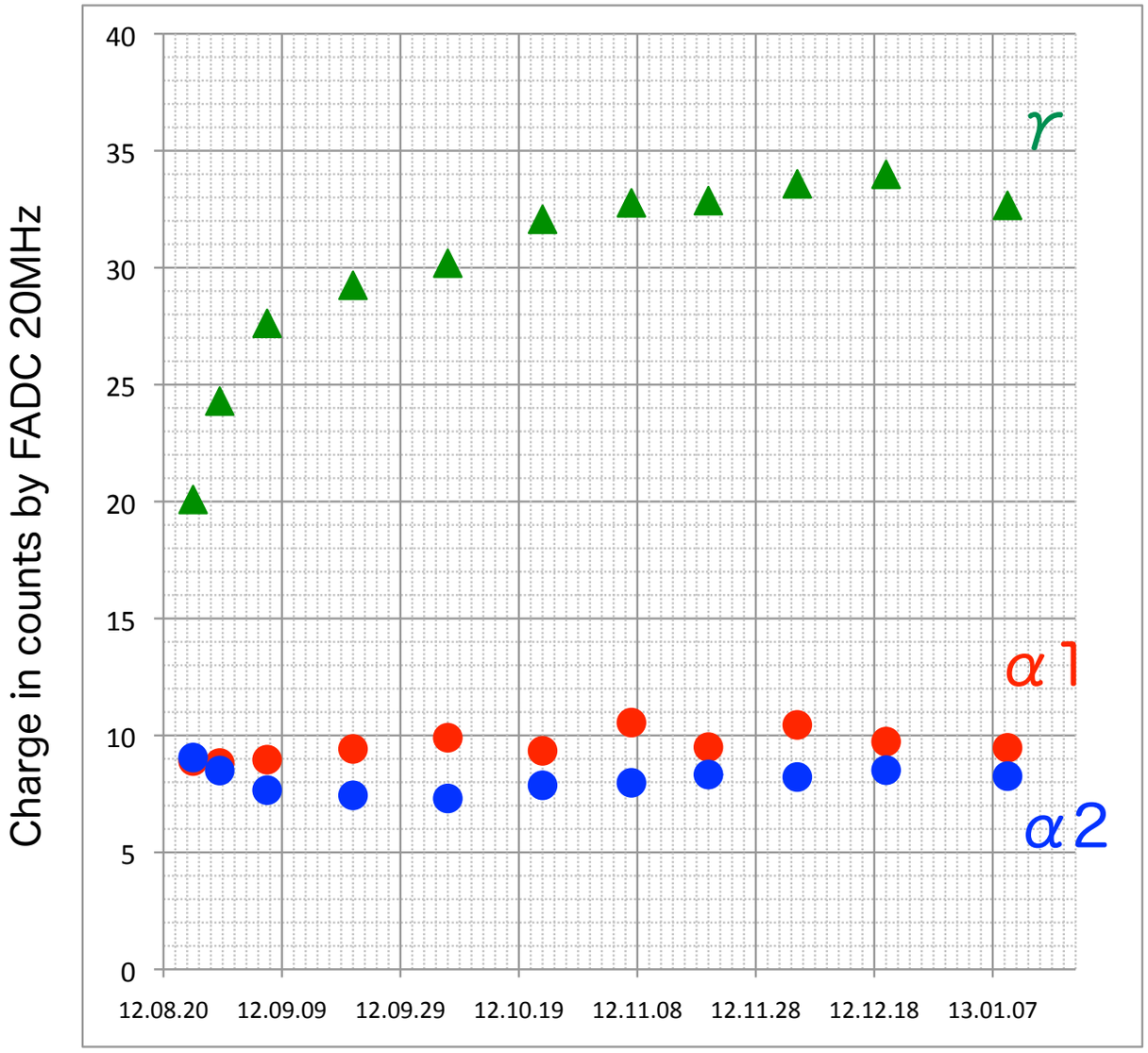
Efficiency



Observed charges

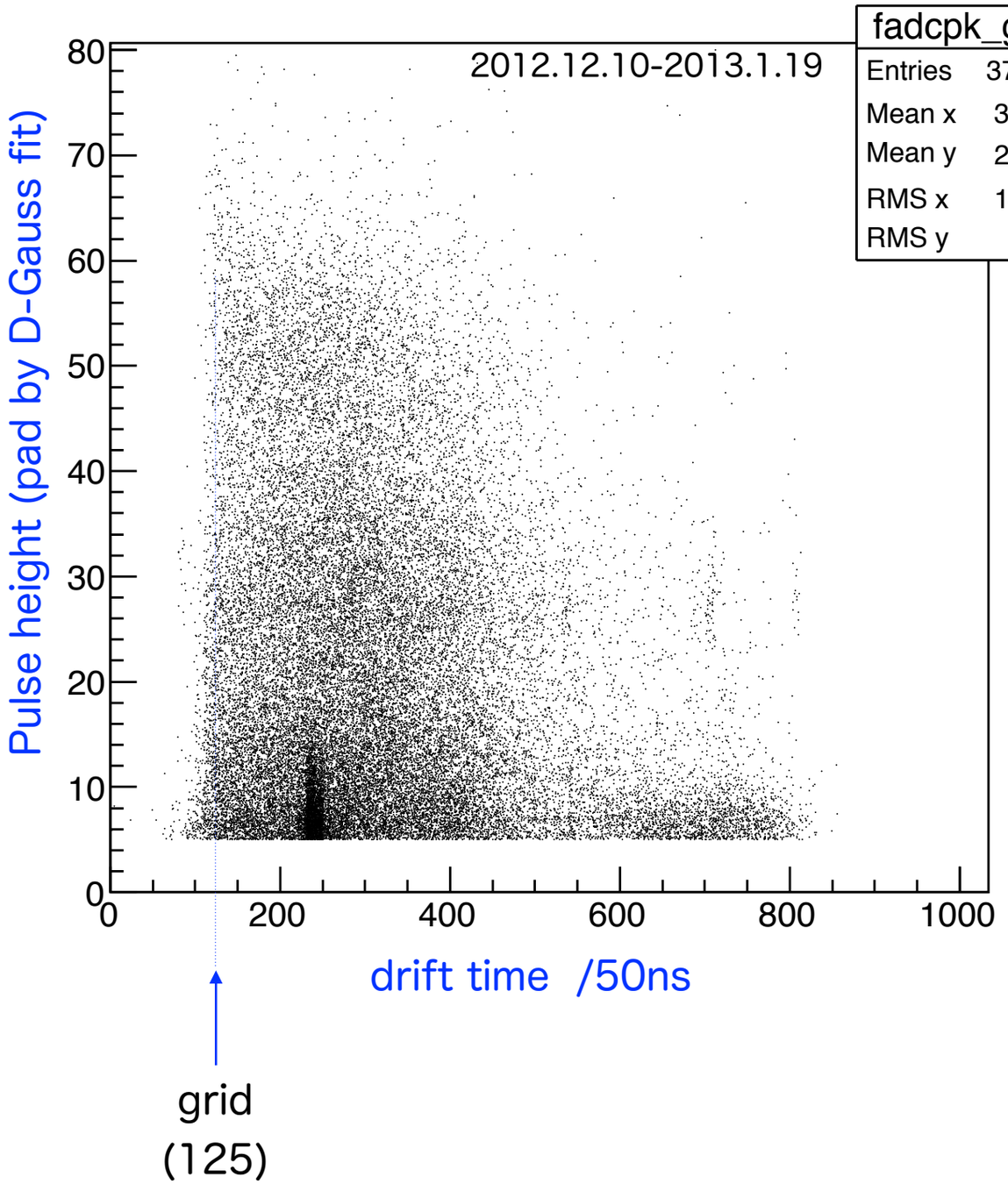


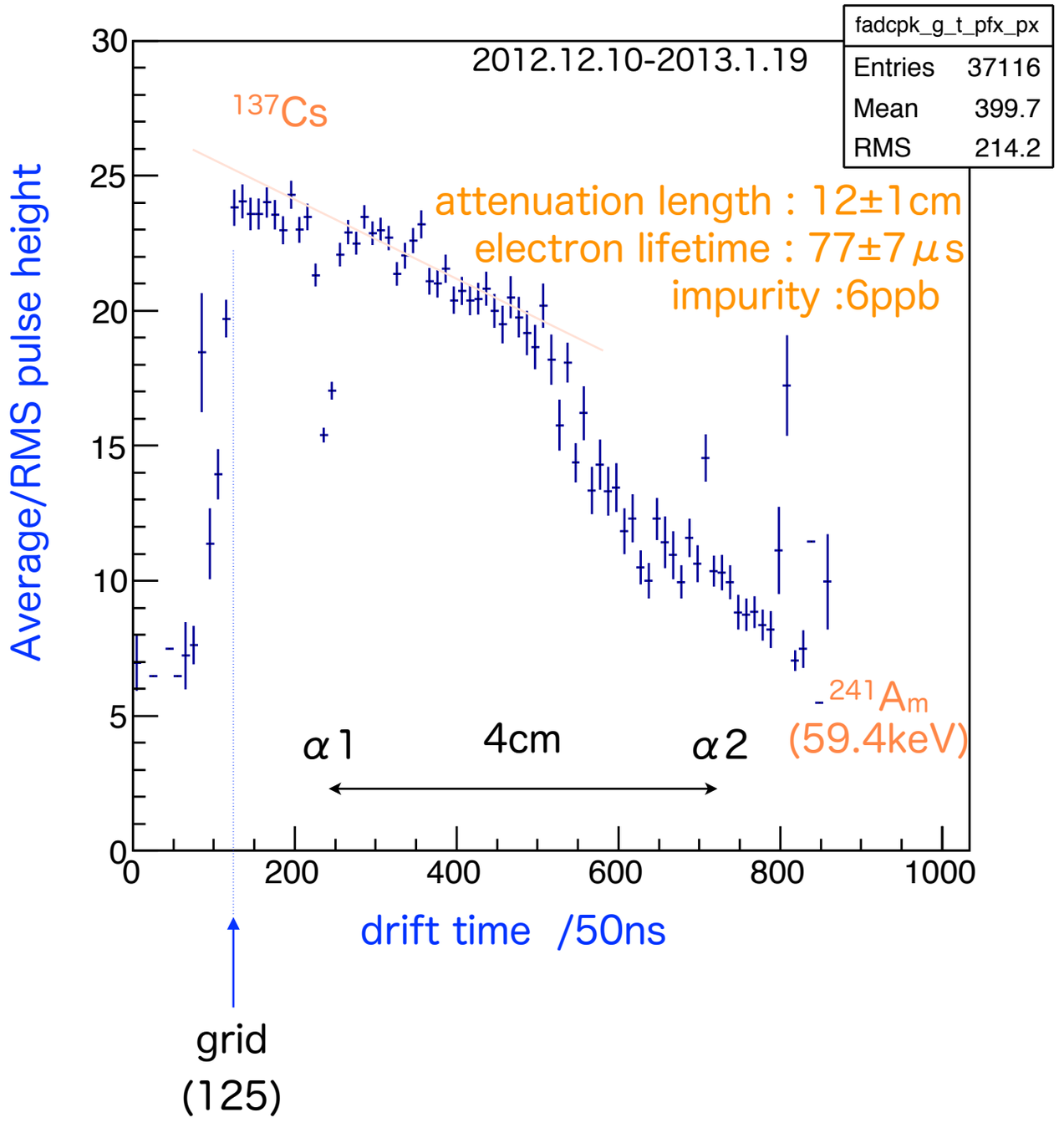
ID	Efficiency by TPC/PMT	Observed charge count	(count by test pulse)	Expected charge
γ-ave	0.76	34		
γ(662keV)	0.76	50	(94)	4 fC = 5.4fC(^{137}Cs,662keV, 80%) x 0.76 (grid)
α1	0.55	10	(21)	0.9 fC = 1.3fC(^{241}Am,5.49MeV, 2.4%) x 0.76(grid) x 0.92(att.@1cm)
α2	0.50	8	(15)	0.7 fC = 1.3fC(^{241}Am,5.49MeV, 2.4%) x 0.76(grid) x 0.66(att.@5cm)

^{137}Cs,662keV, 80% at E=0.5kV/cm, S.Kubota et al., PR B20 (1979) 3486

^{241}Am,5.49MeV, 2.4% at E=0.5kV/cm, E.Aprile et al., NIM A307 (1991) 119-125

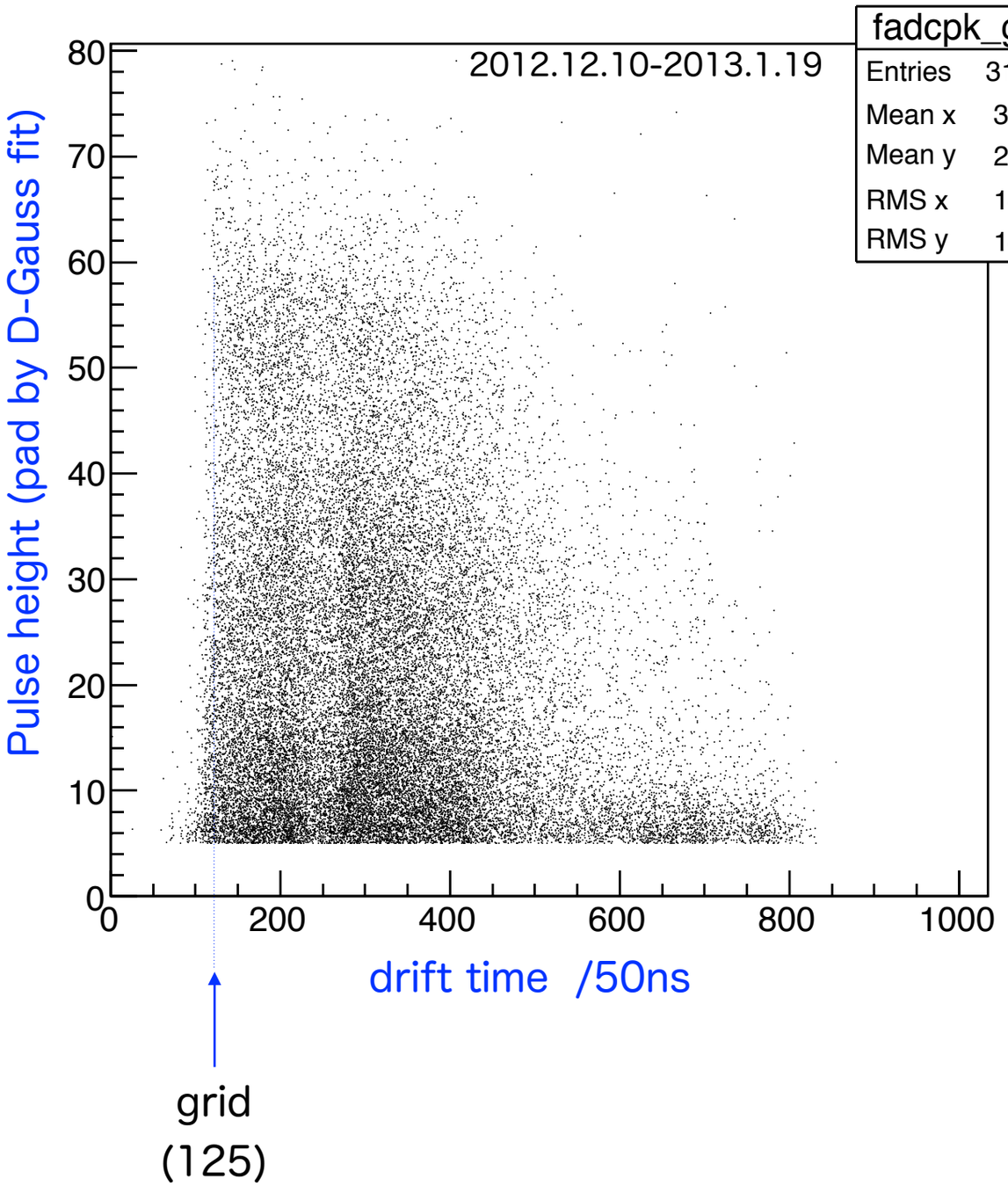
Gamma's （subtracted peaks of α1 and α2）

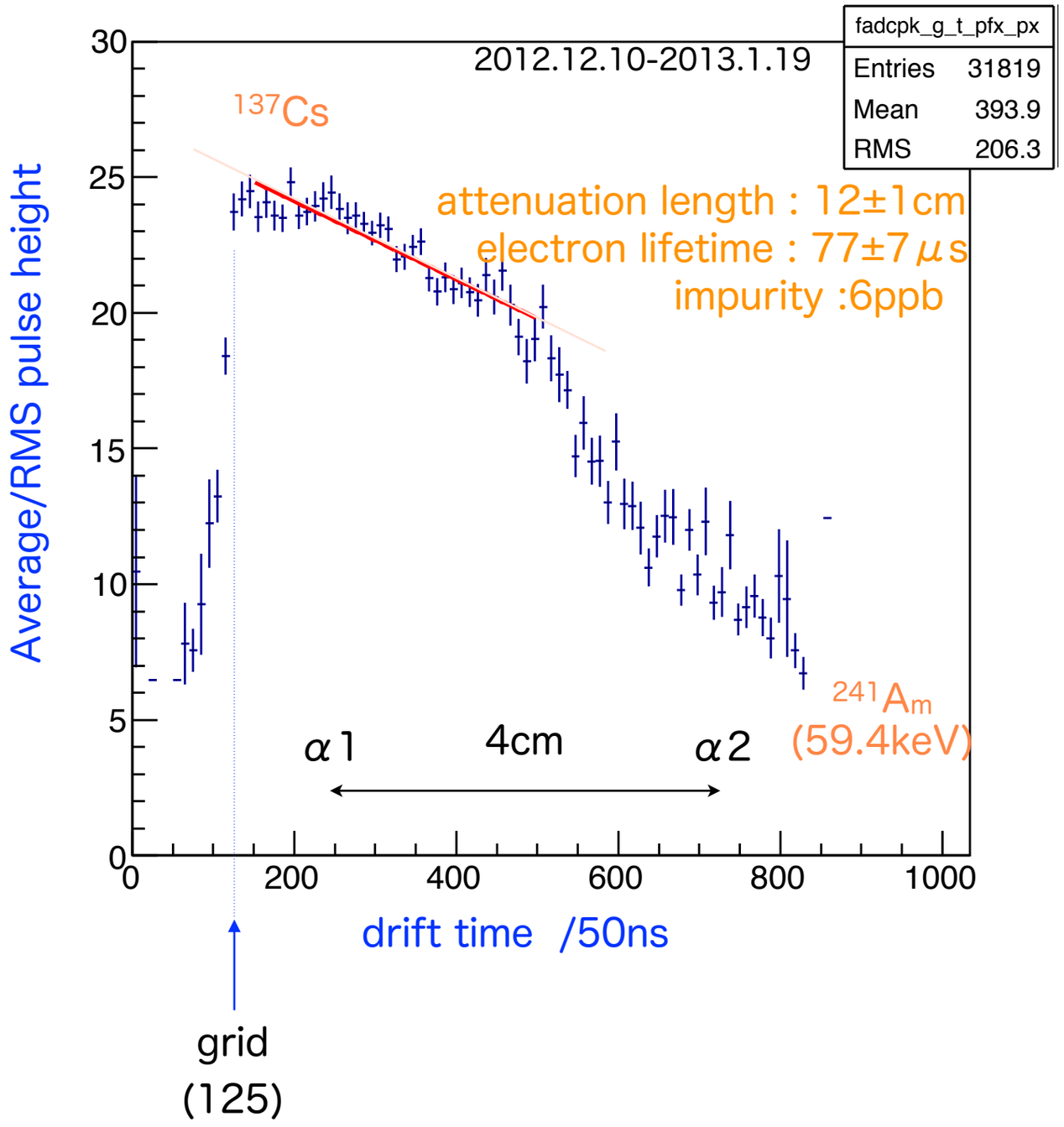




note : the anode plane at 125

Gamma's (subtracted peaks of $\alpha 1$ and $\alpha 2$)

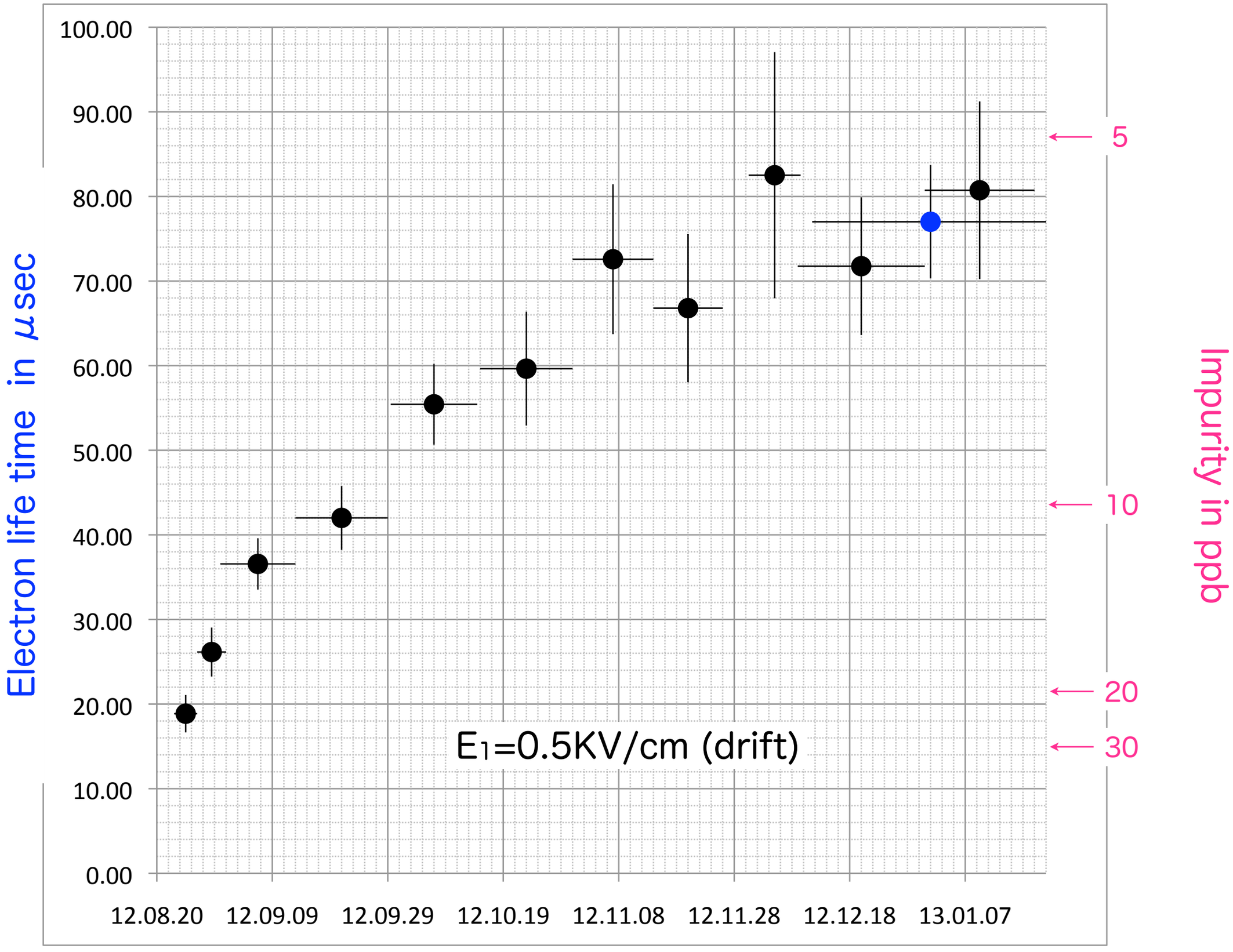




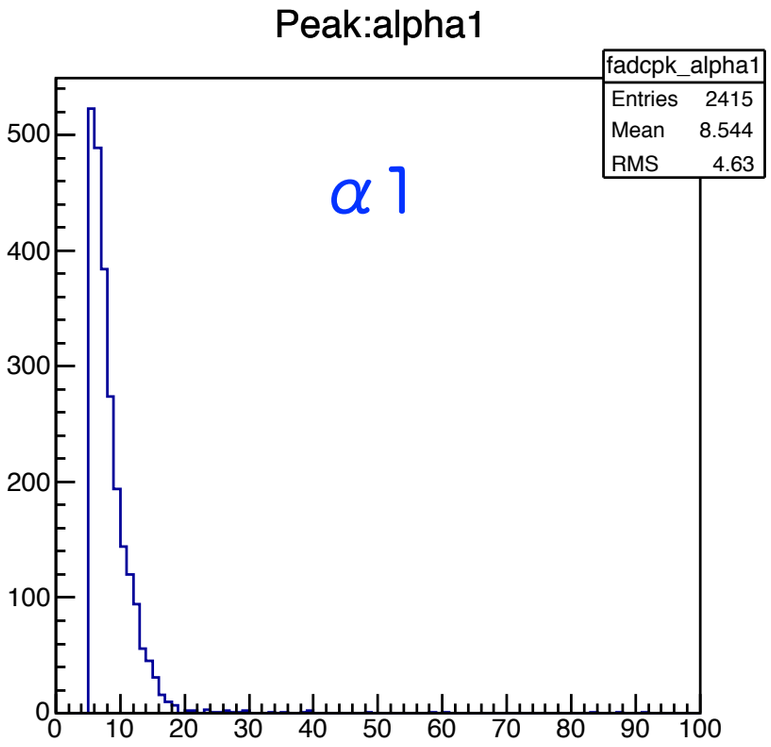
note : the anode plane at 125

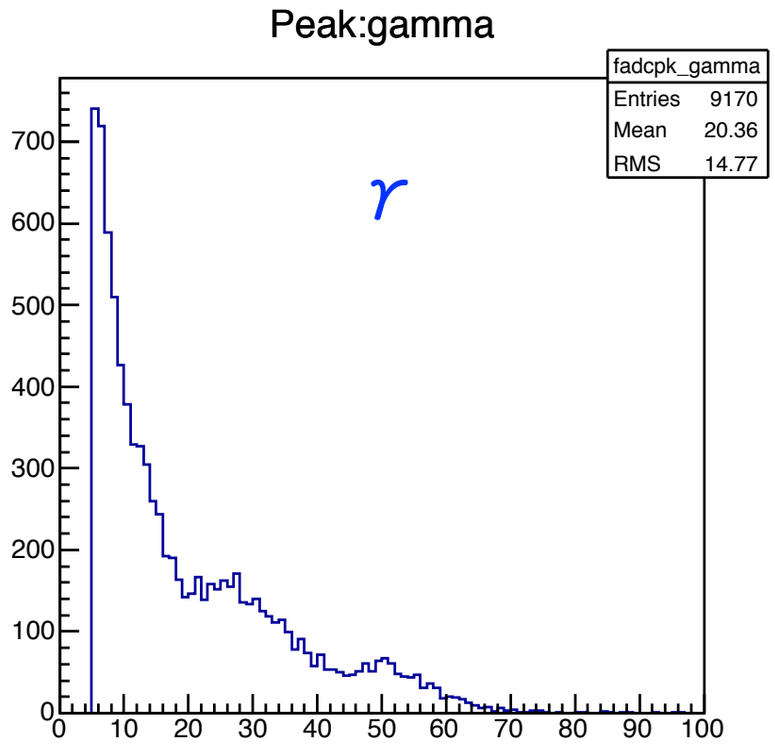
Electron life time and impurity in Liquid Xe

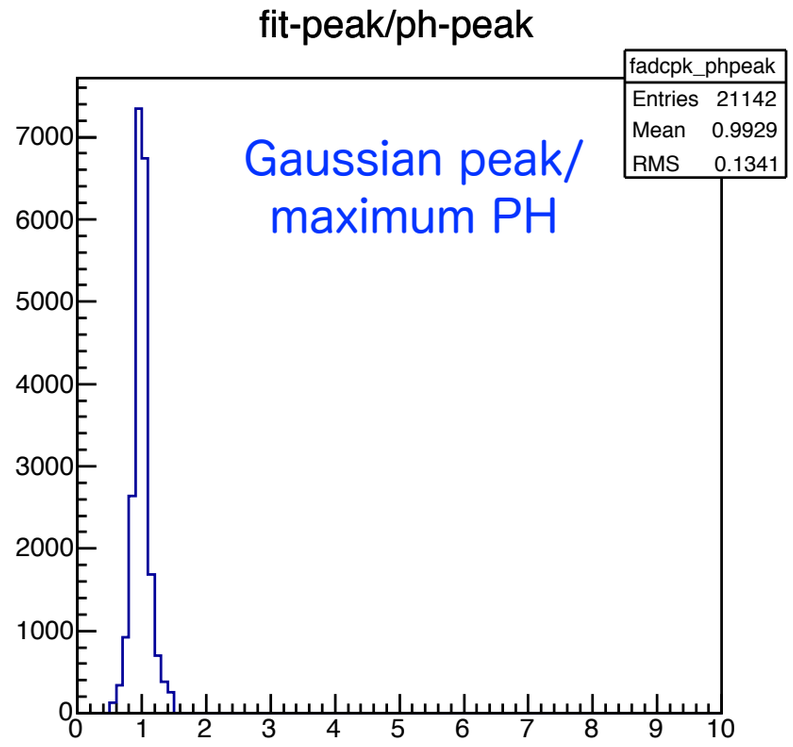
2012.8.23-2013.1.19

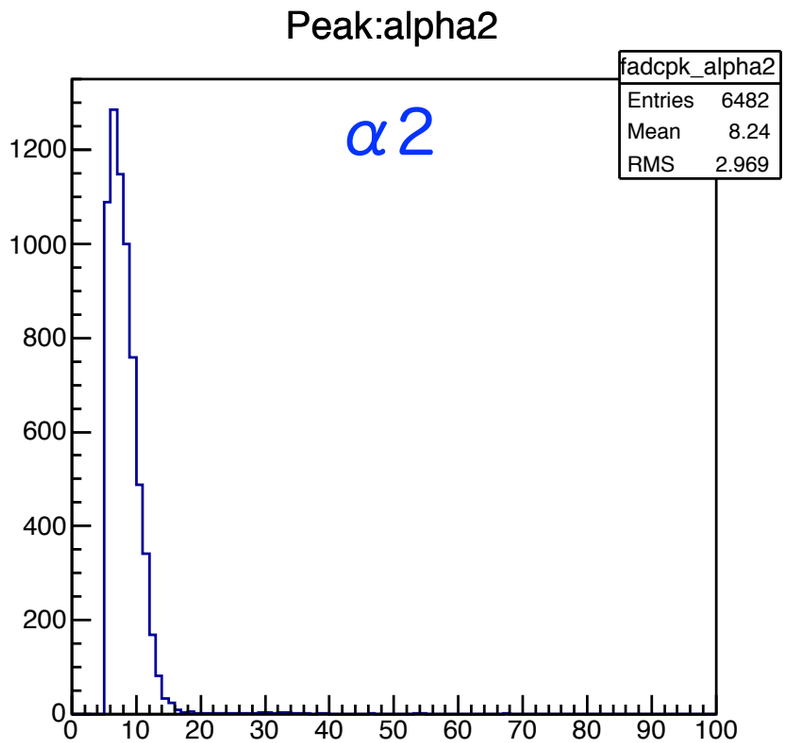


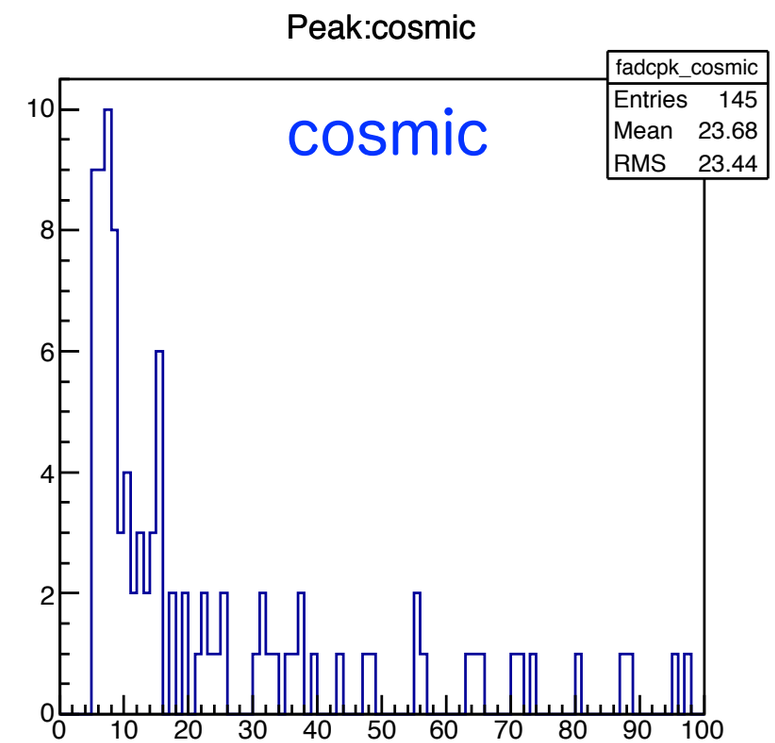
Charges/pad (peak of D-Gaussian fit) of $\alpha 1, \alpha 2$ and γ, 2012.12.20-12.31 (8 days)



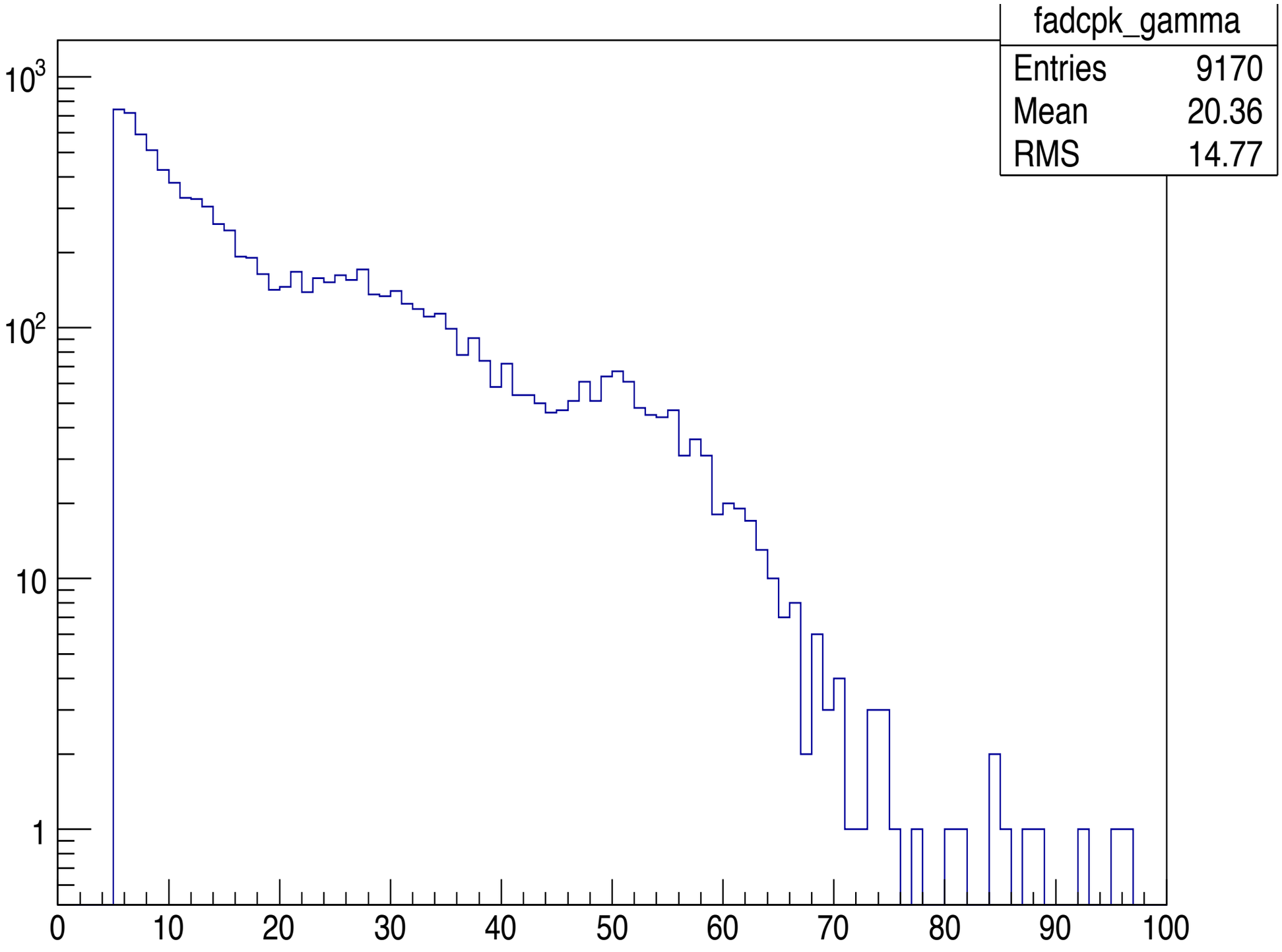




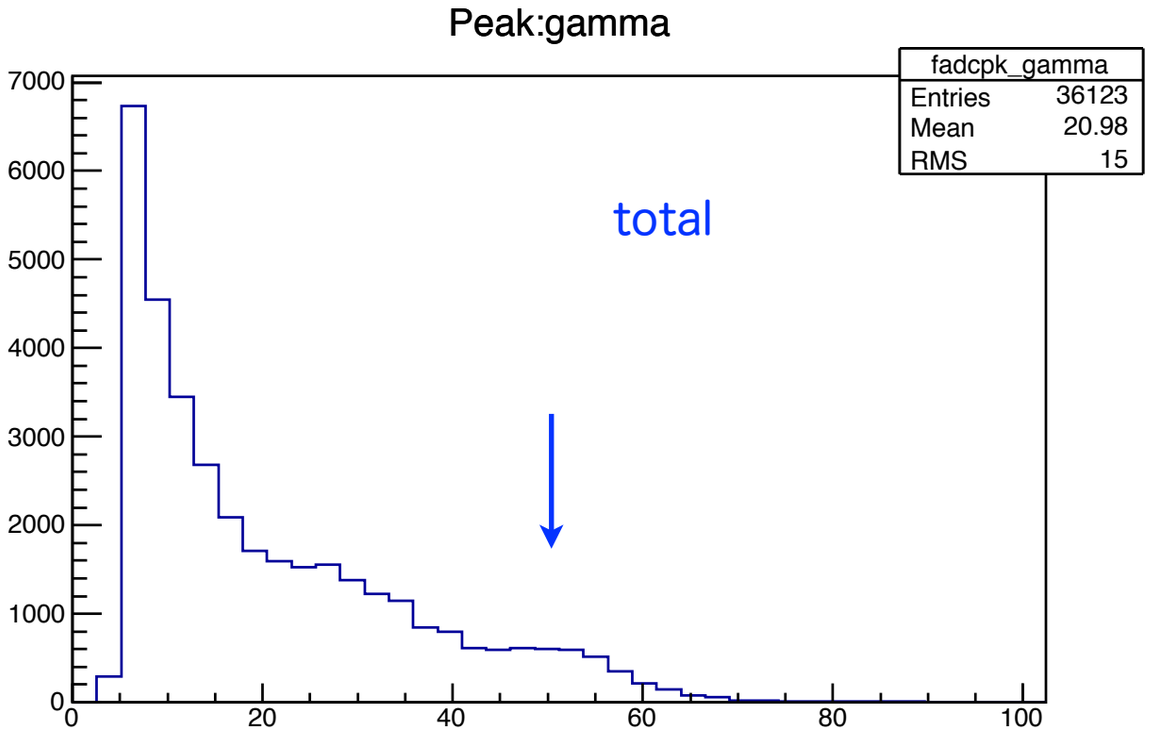


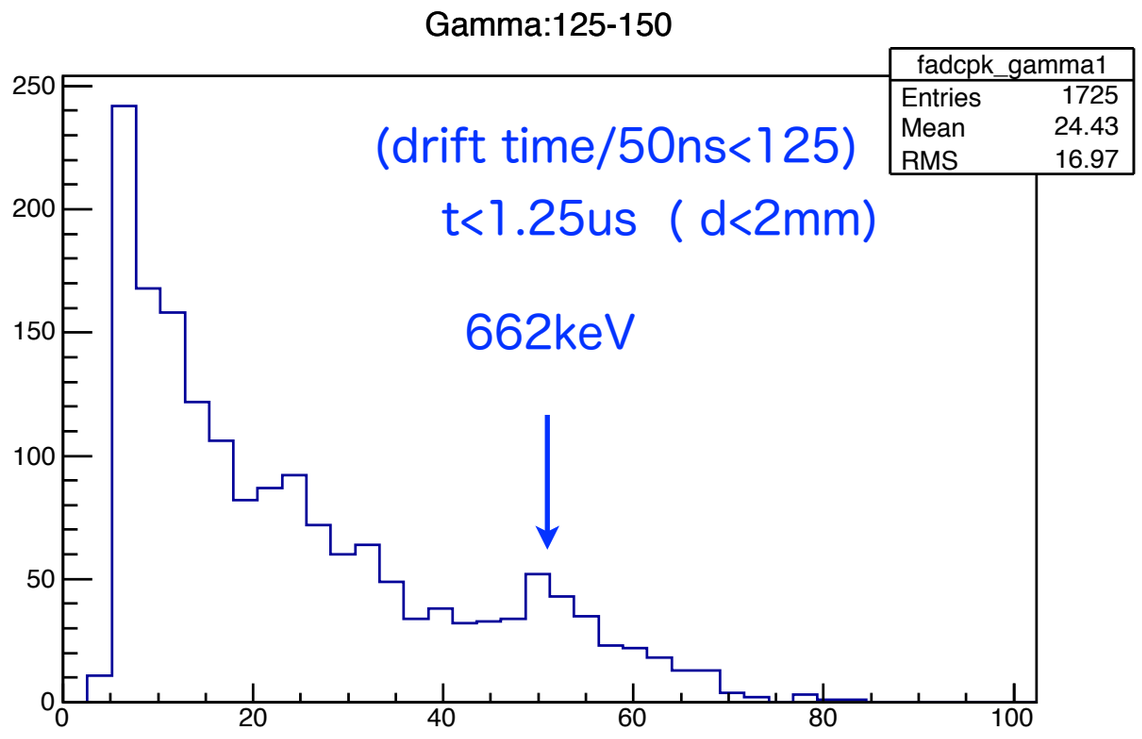


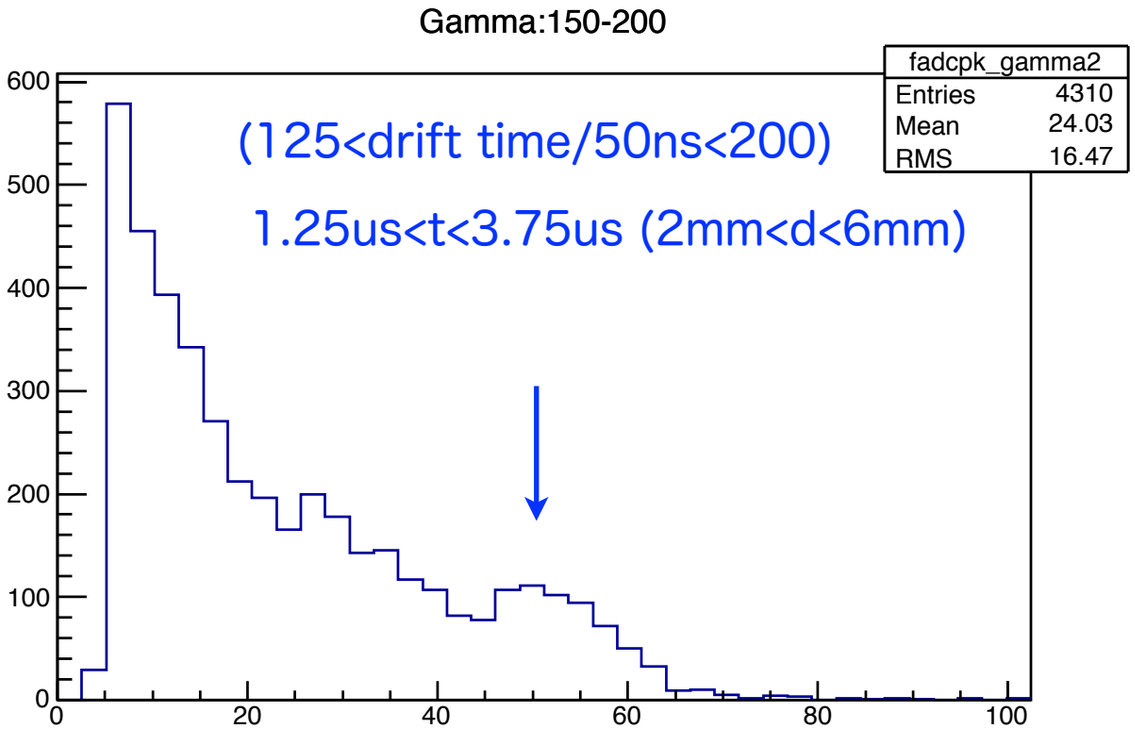
Charges/pad (peak of D-Gaussian fit) of γ, 2012.12.20-12.31 (8 days)

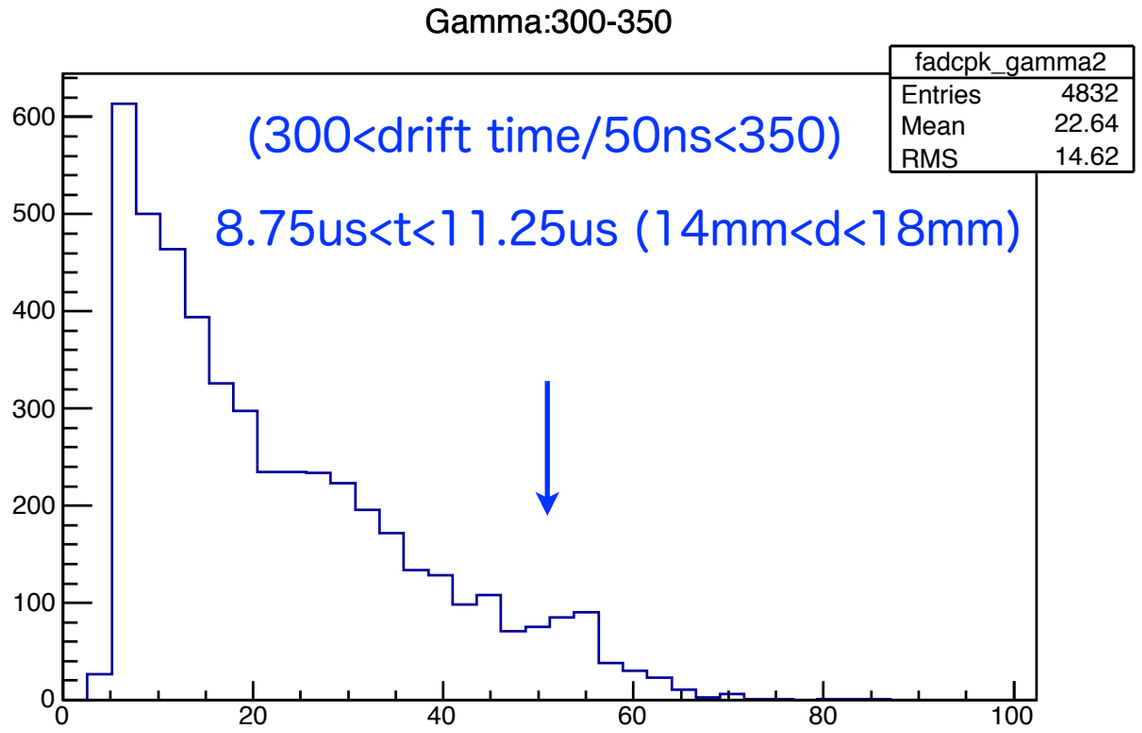


Charges/pad (peak of D-Gaussian fit) of γ, 2012.12.10-2-13.1.19



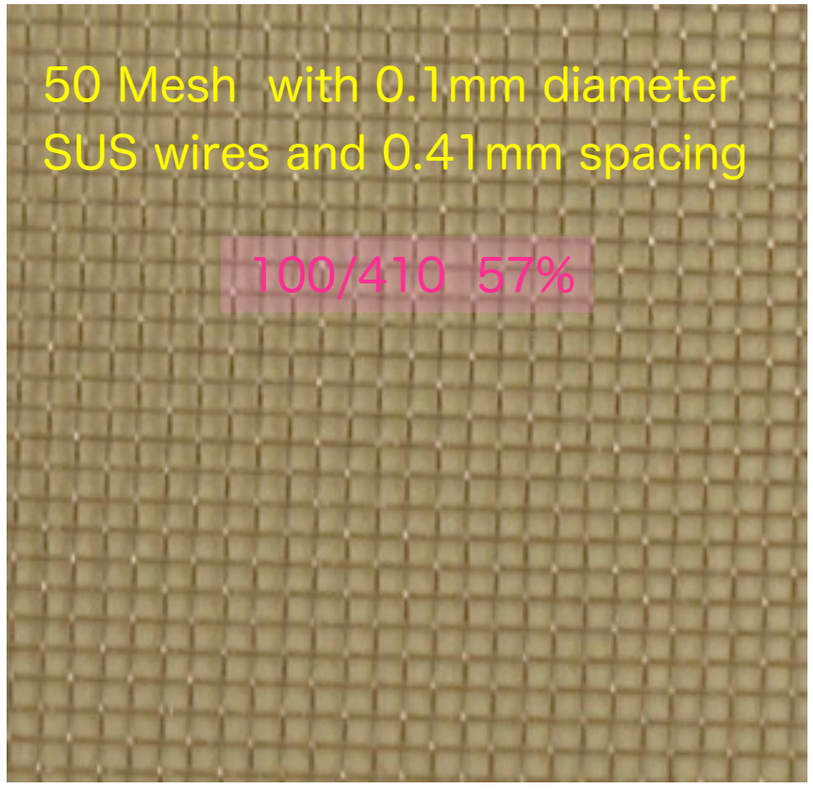




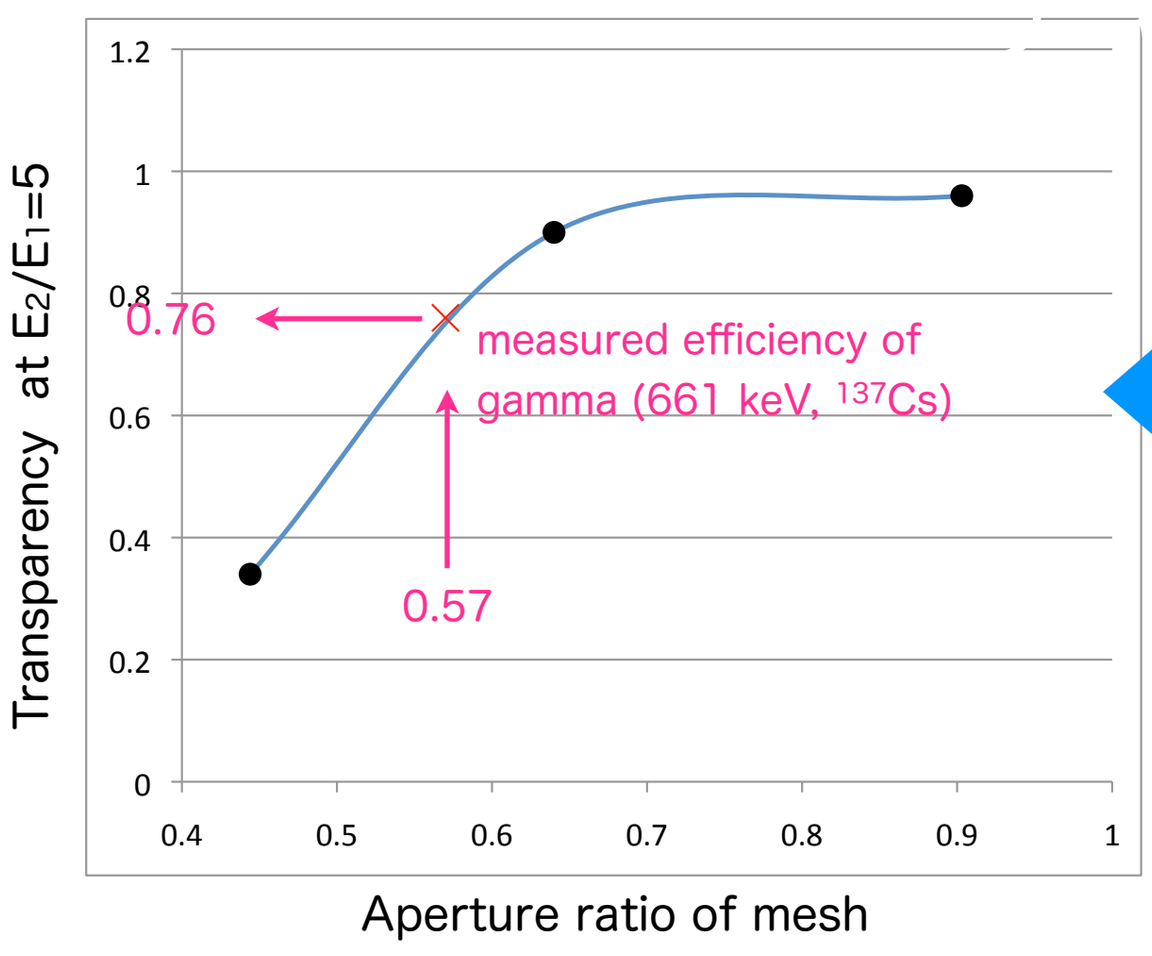


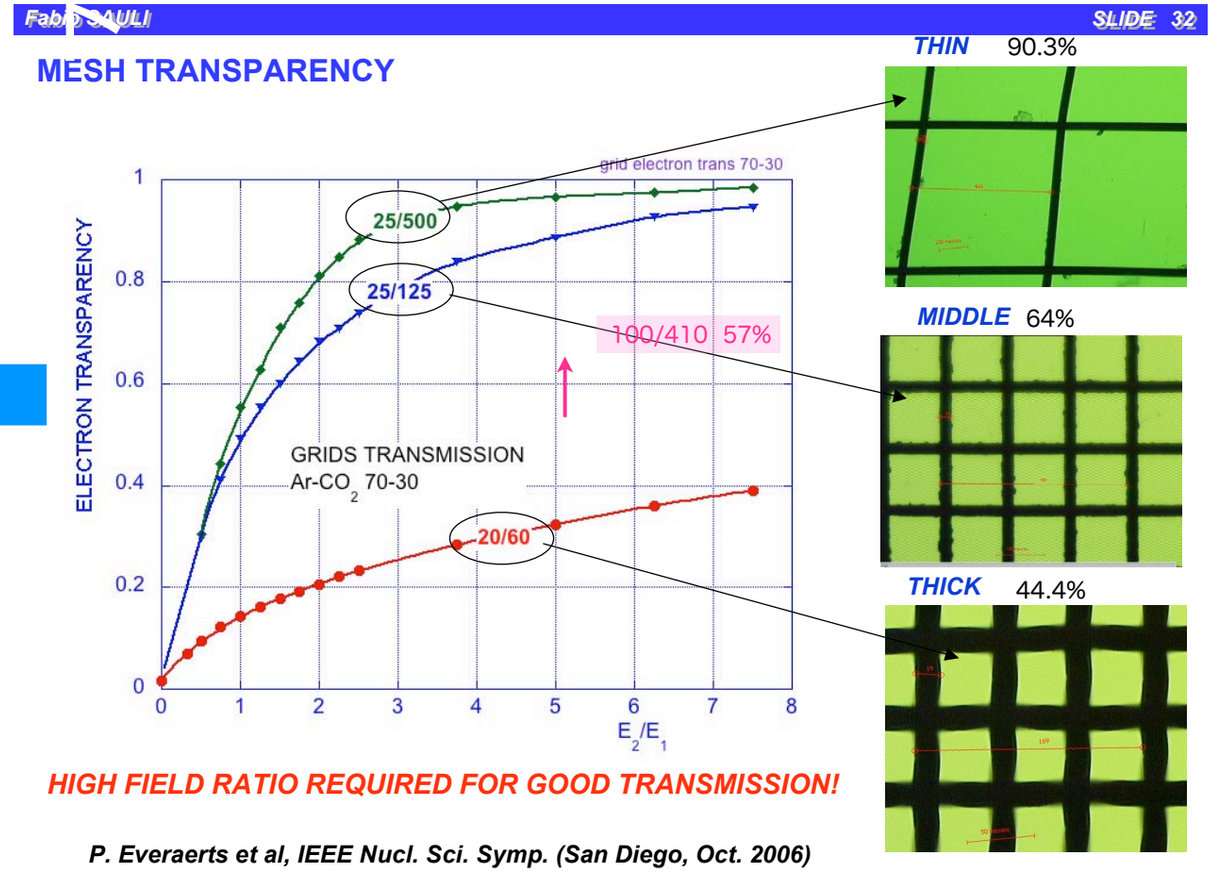
Estimation of the grid transparency

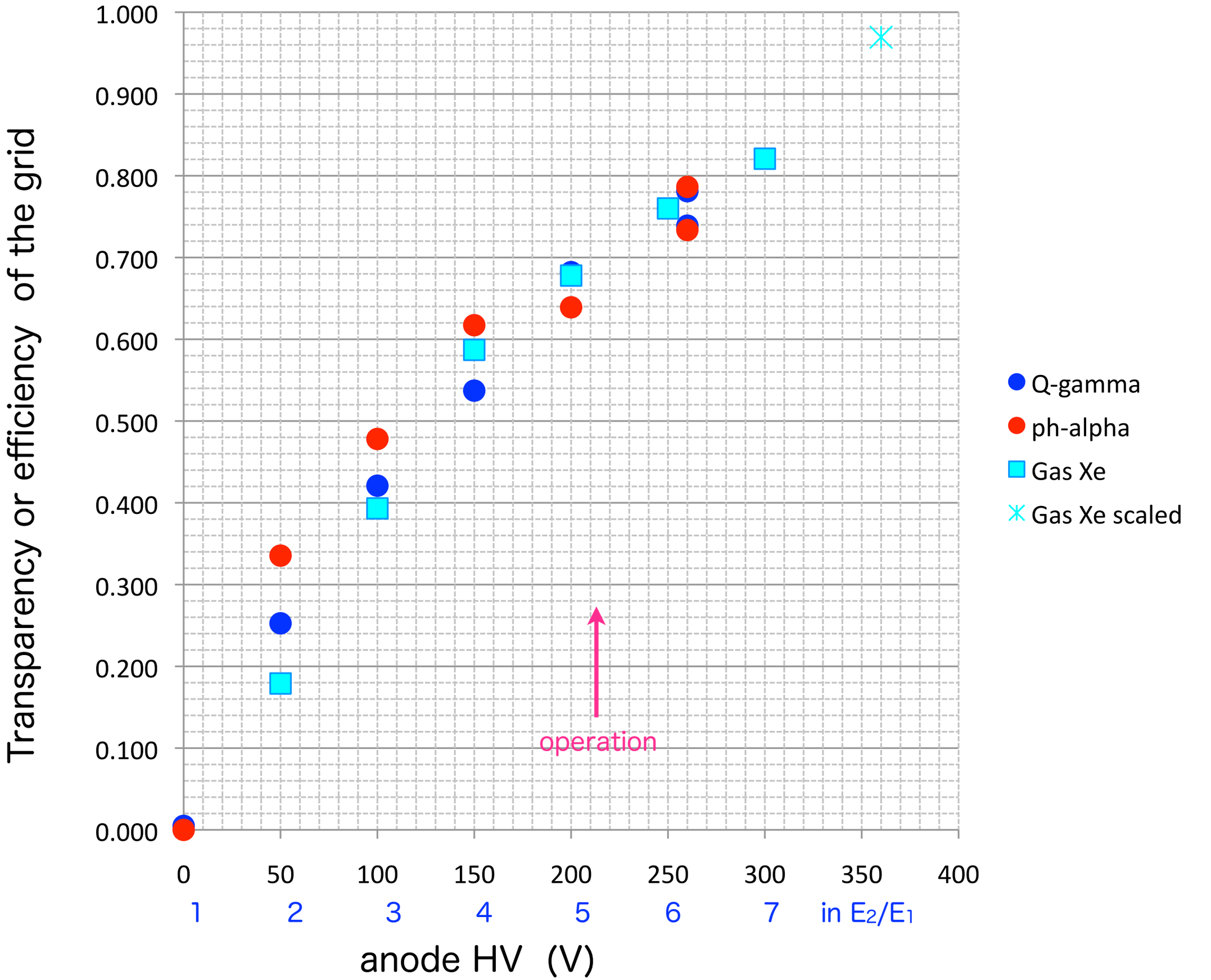
Our mesh for the grid



Expectation of our grid/mesh



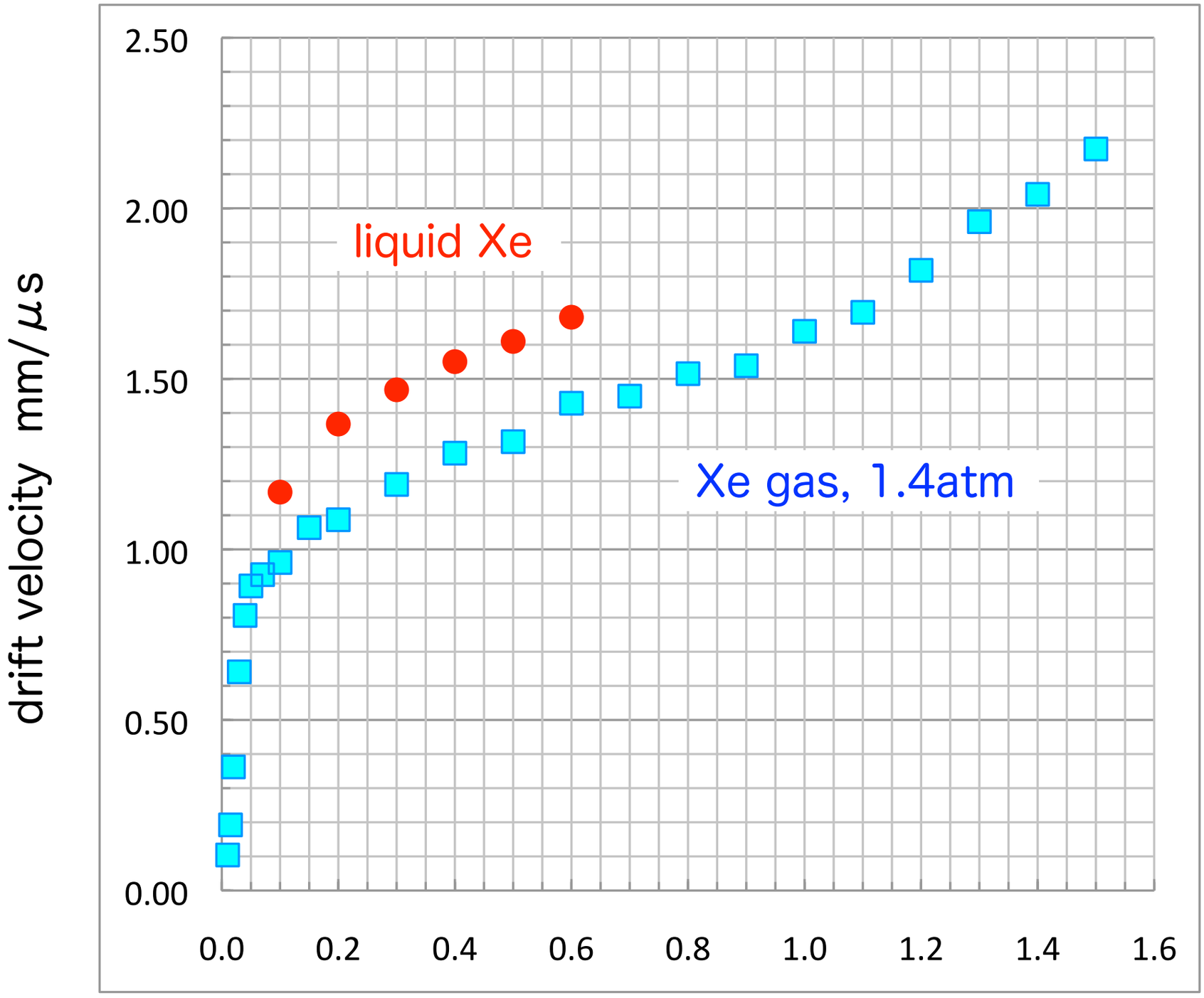




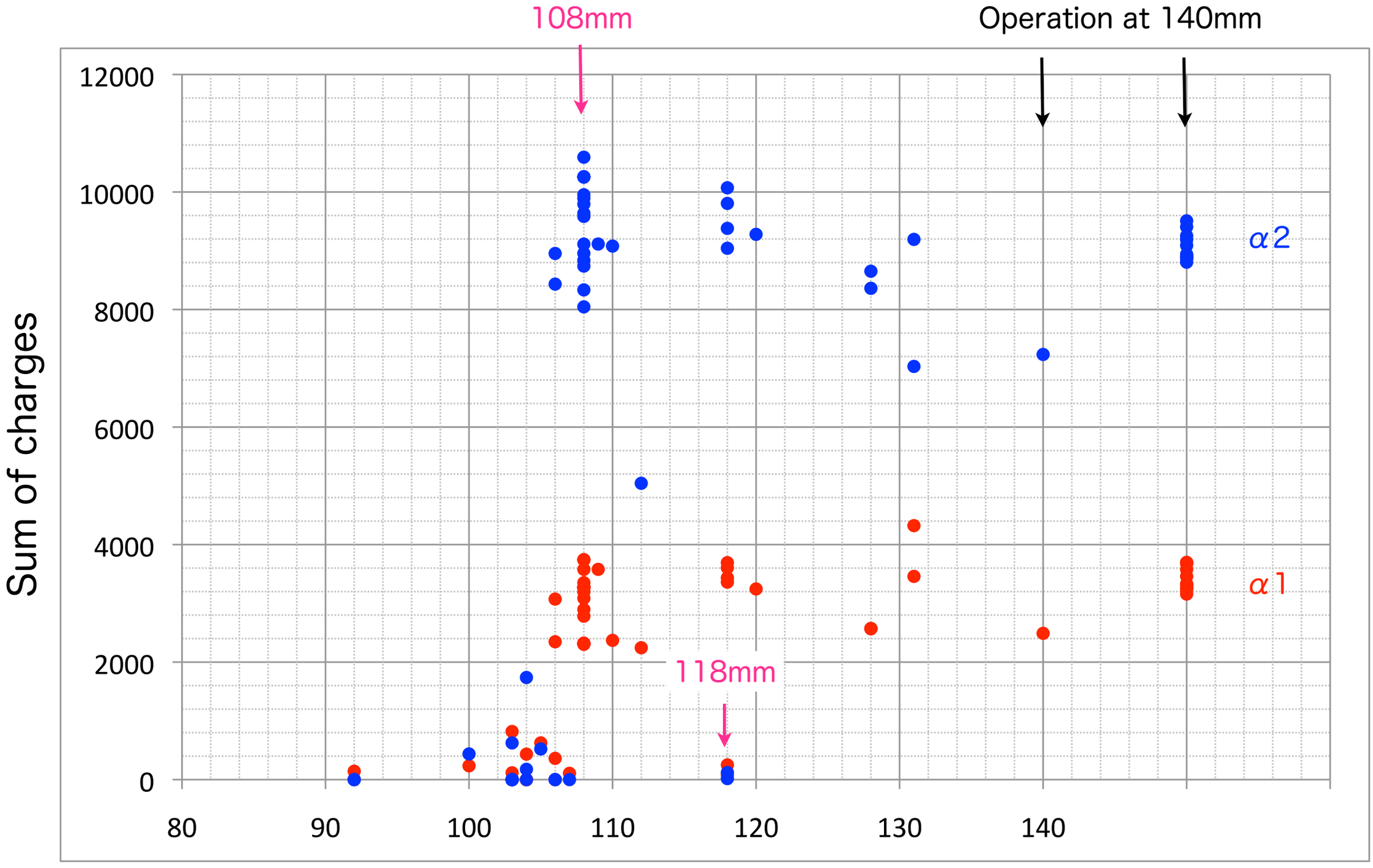
each normalized to be 0.76 at anode-HV=250V

Drift velocity in Liquid Xe

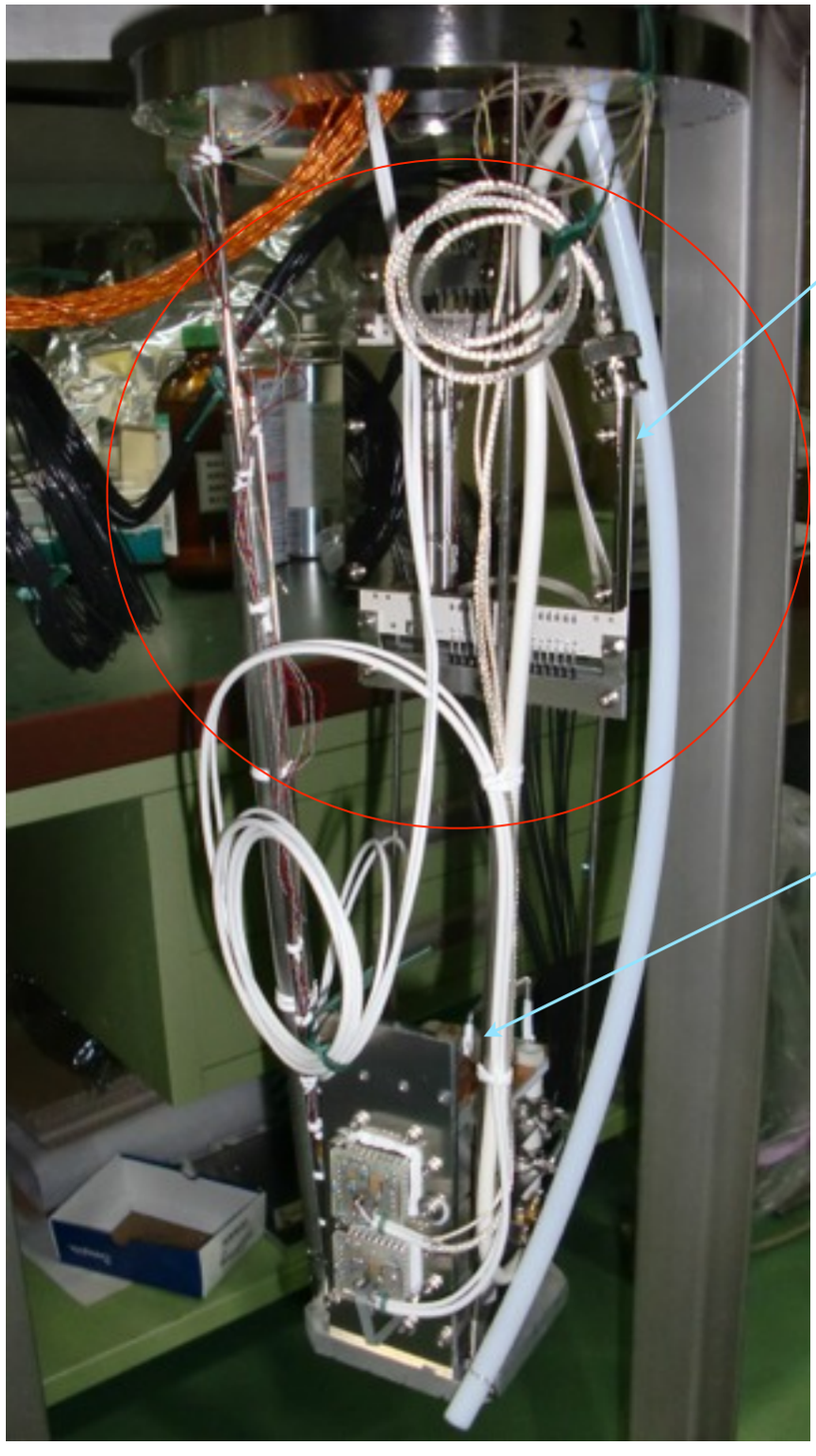
estimated by $\alpha 1$ and $\alpha 2$ in liquid Xe
by α signals without grid in Xe gas



Surface level of liquid Xe,　June, 2013



New Setup with the FETPC (ASIC-chip) , September 2013



LTCC board

^{22}Na
(100kBq)

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(IPNS)

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

together with the neutron group

Parameters	TPCFE09(TPCFE1x)
dynamic range	-75fC~+25fC -500fC ~ -5fC
gain	2V/pC 10V/pC
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

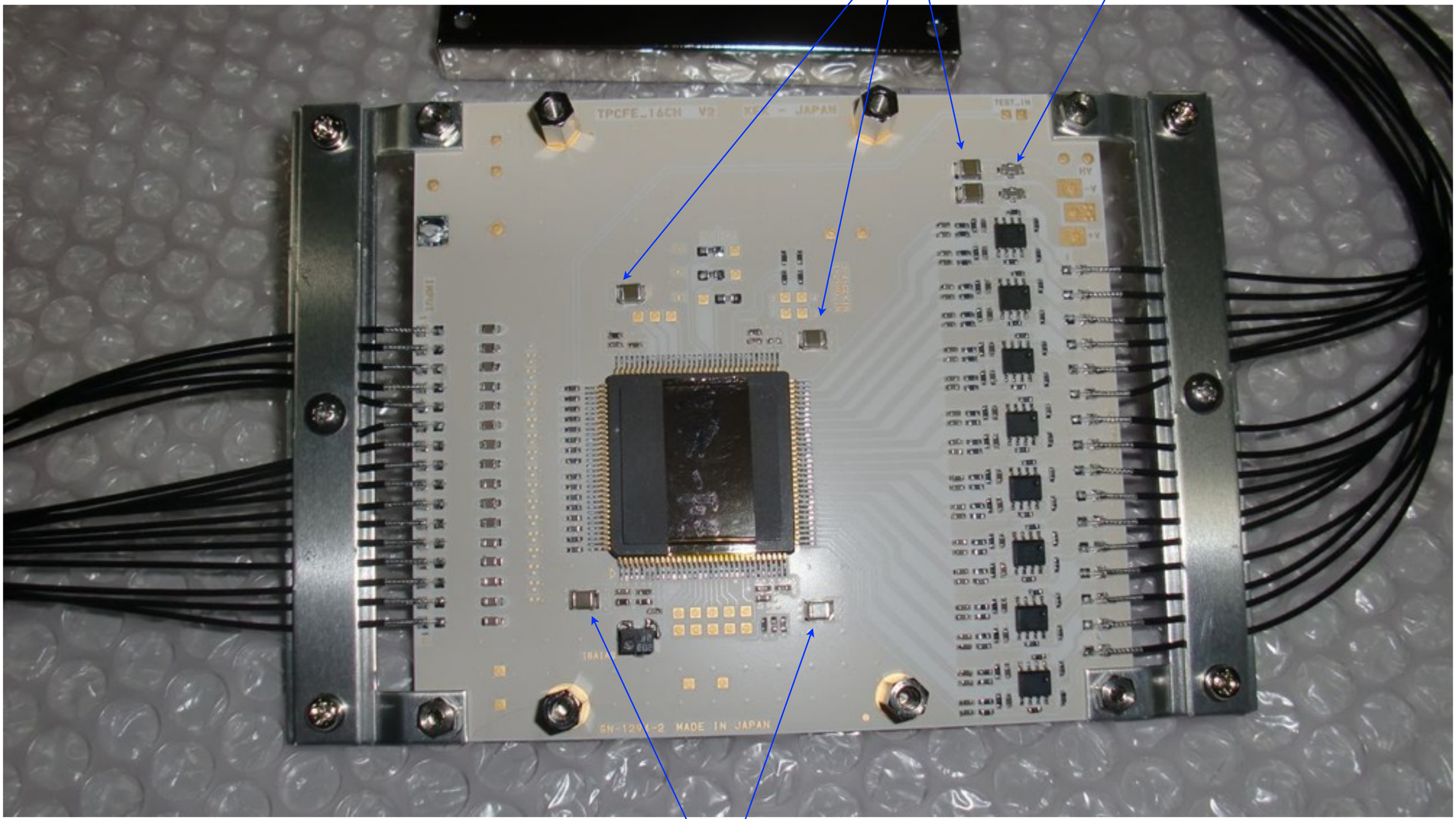
Schedule

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

Decoupling Capacitor or Bypass Capacitor

Filter (60-80dB/0.4-200MHz, 27uF)

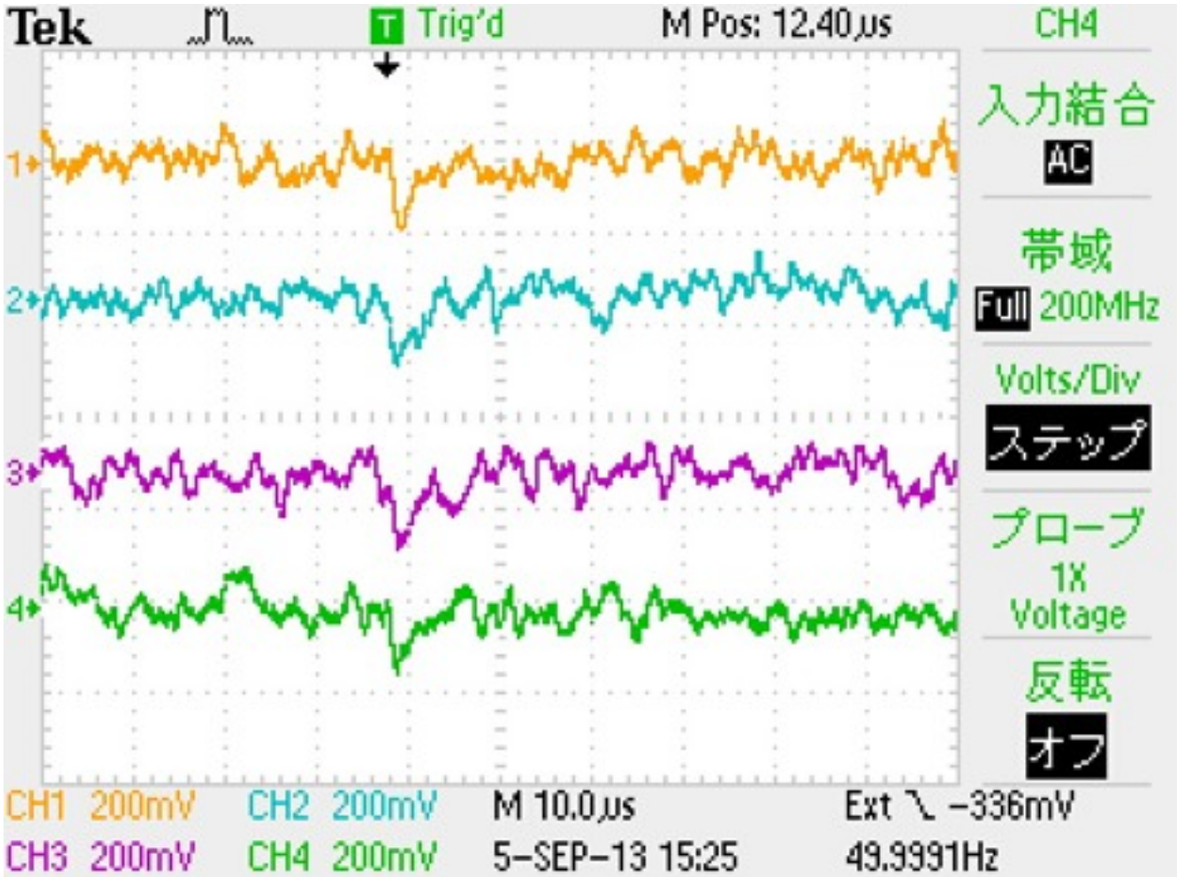
Multilayer Ceramic (JMK325AC6107_M,100uF)



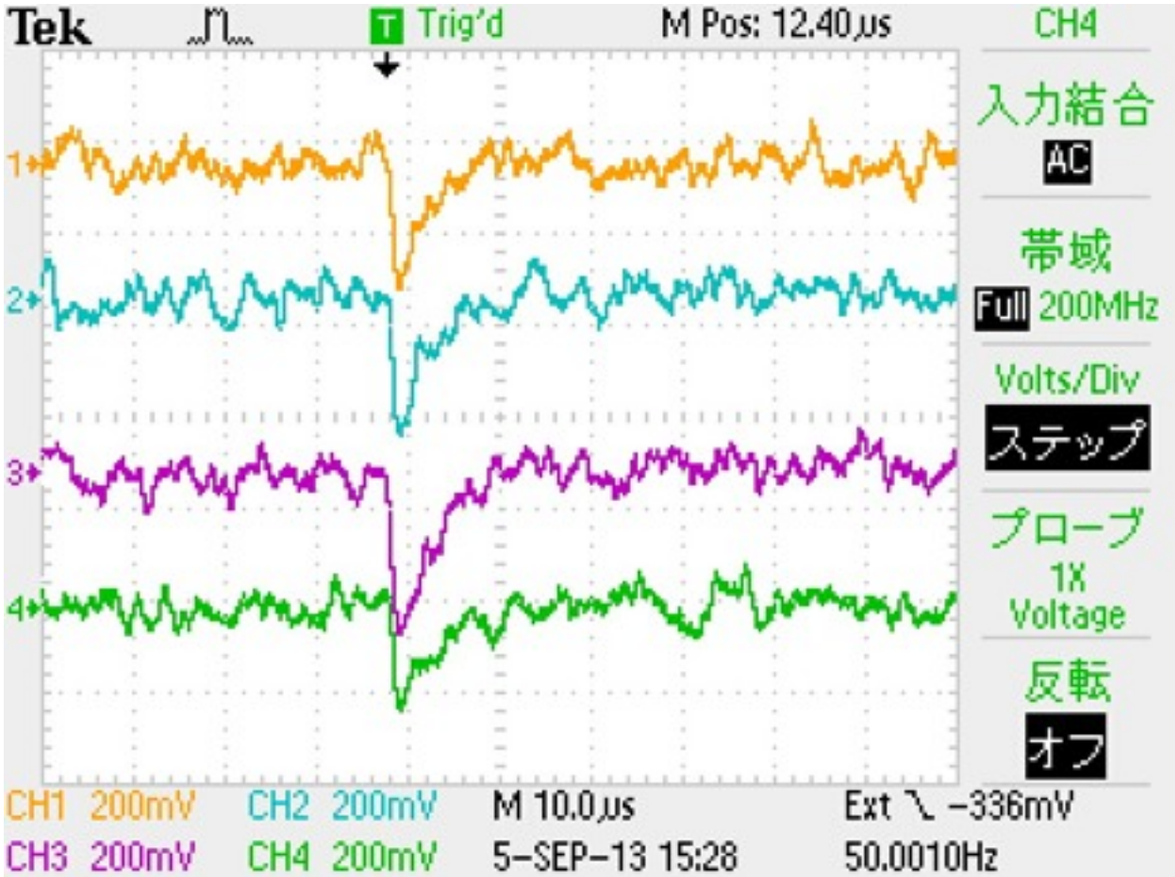
Multilayer Ceramic (JMK325AC6107_M,100uF)

2013年 12月 10日 火曜日

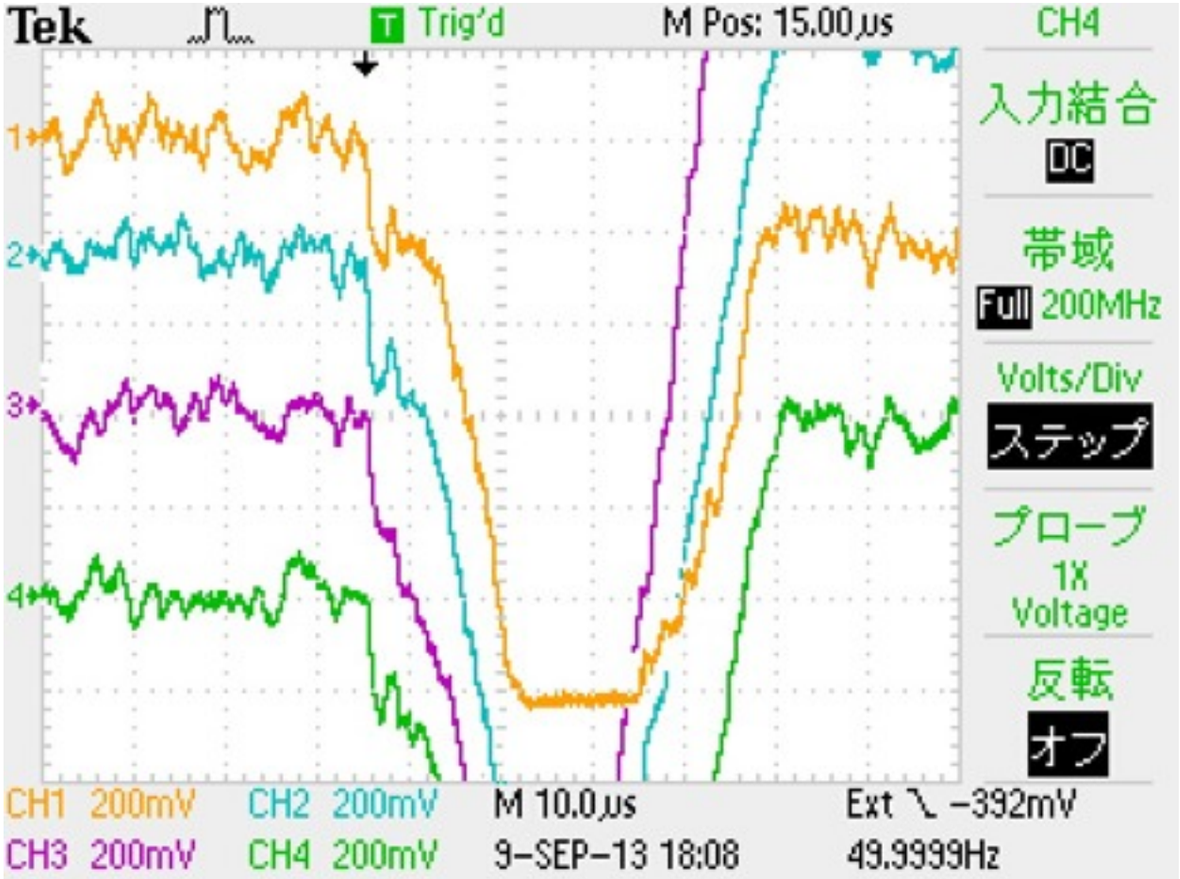
Test pulse, square, 50Hz, 0.025V, 31dB



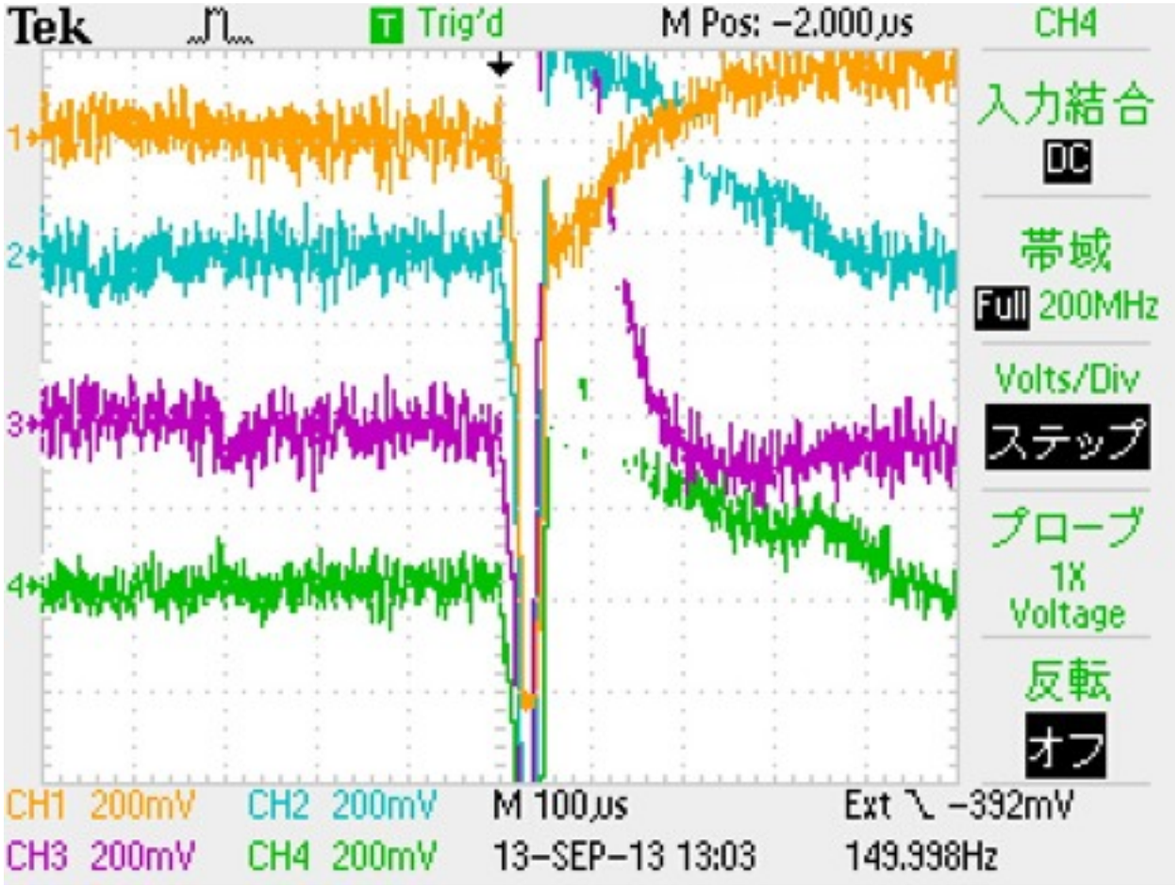
Test pulse, square, 50Hz, 0.025V, 25dB

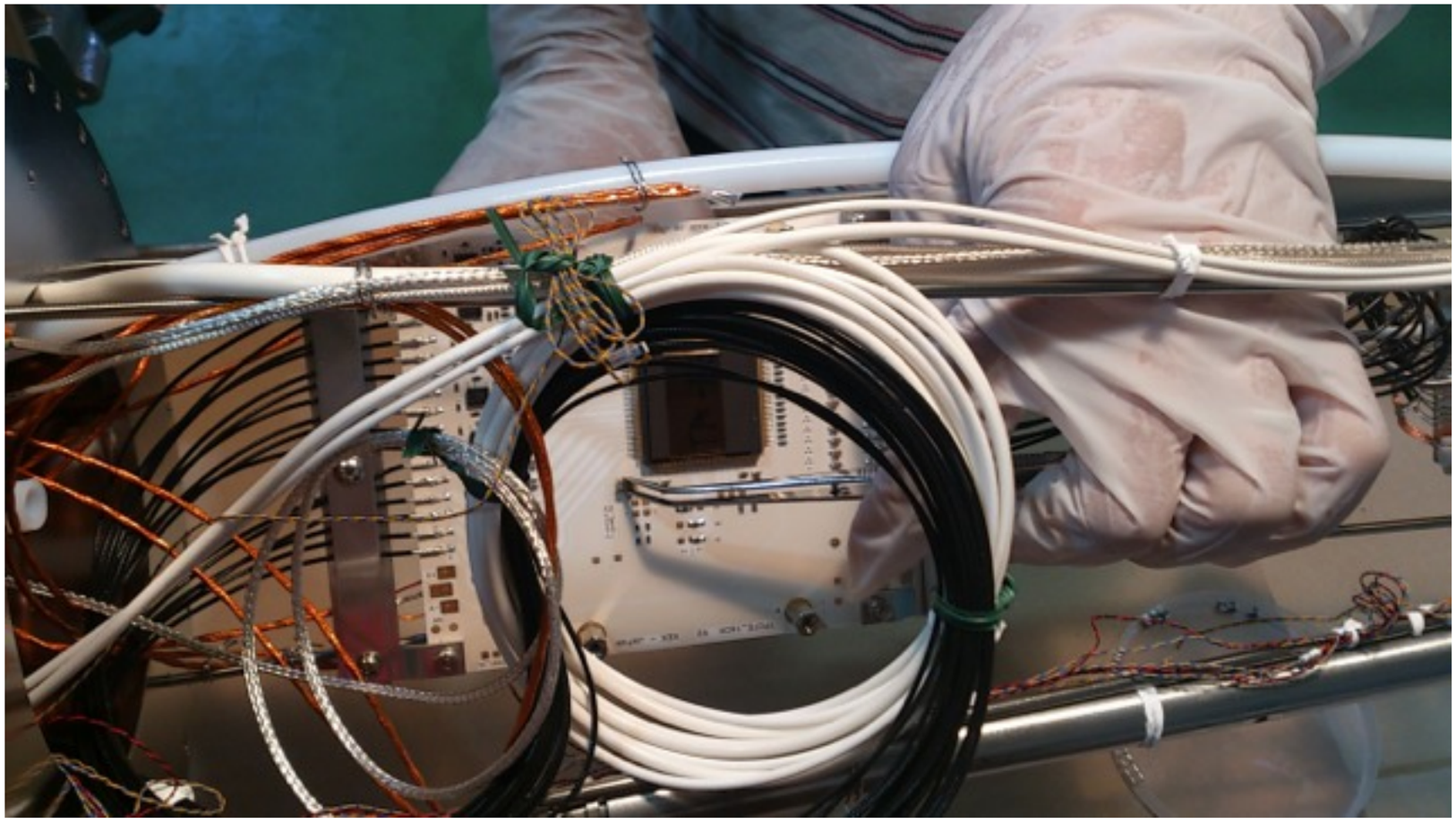


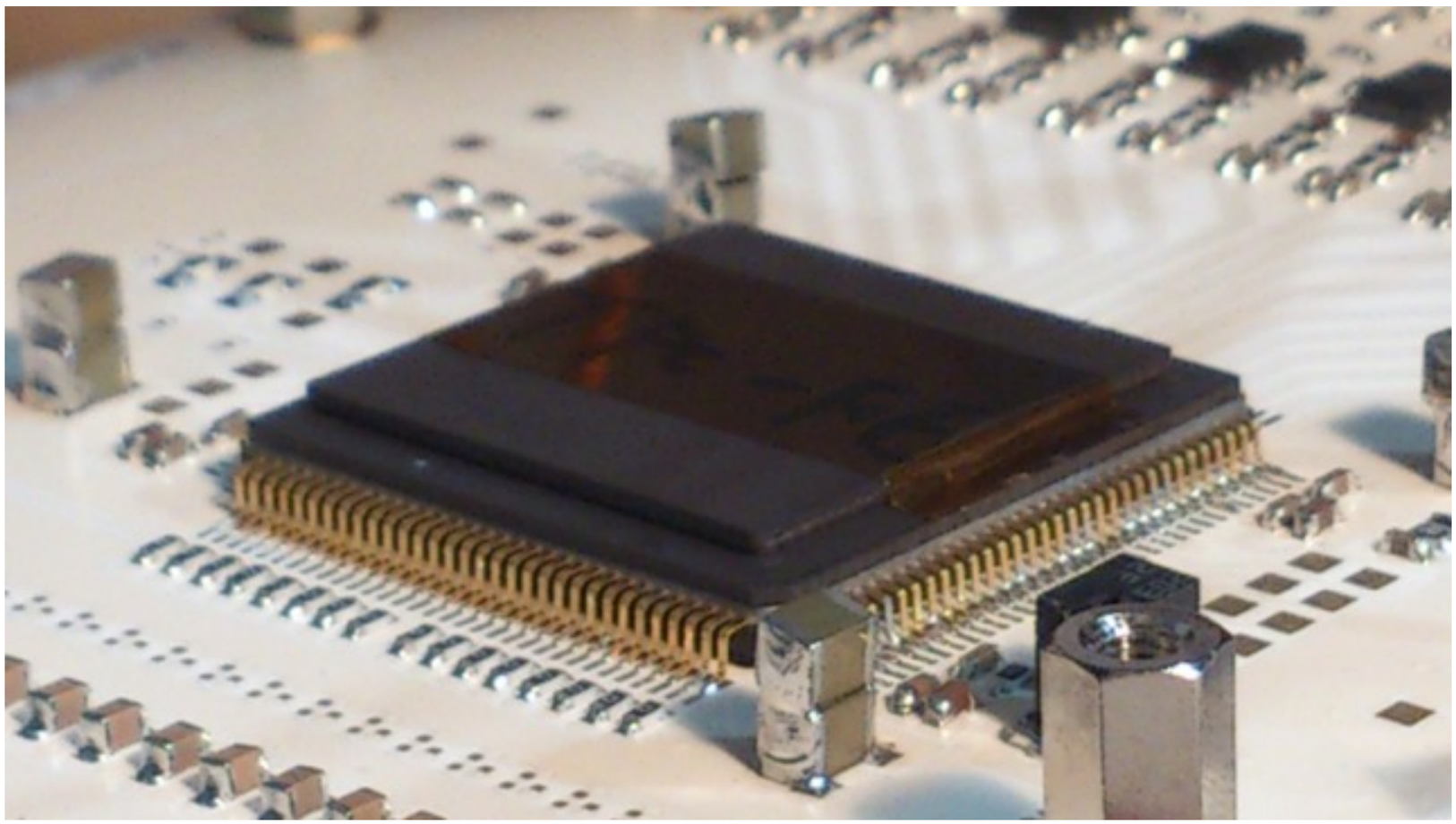
> 12ch of outputs terminated with 50 Ohm



> 12ch of outputs terminated with 50 Ohm







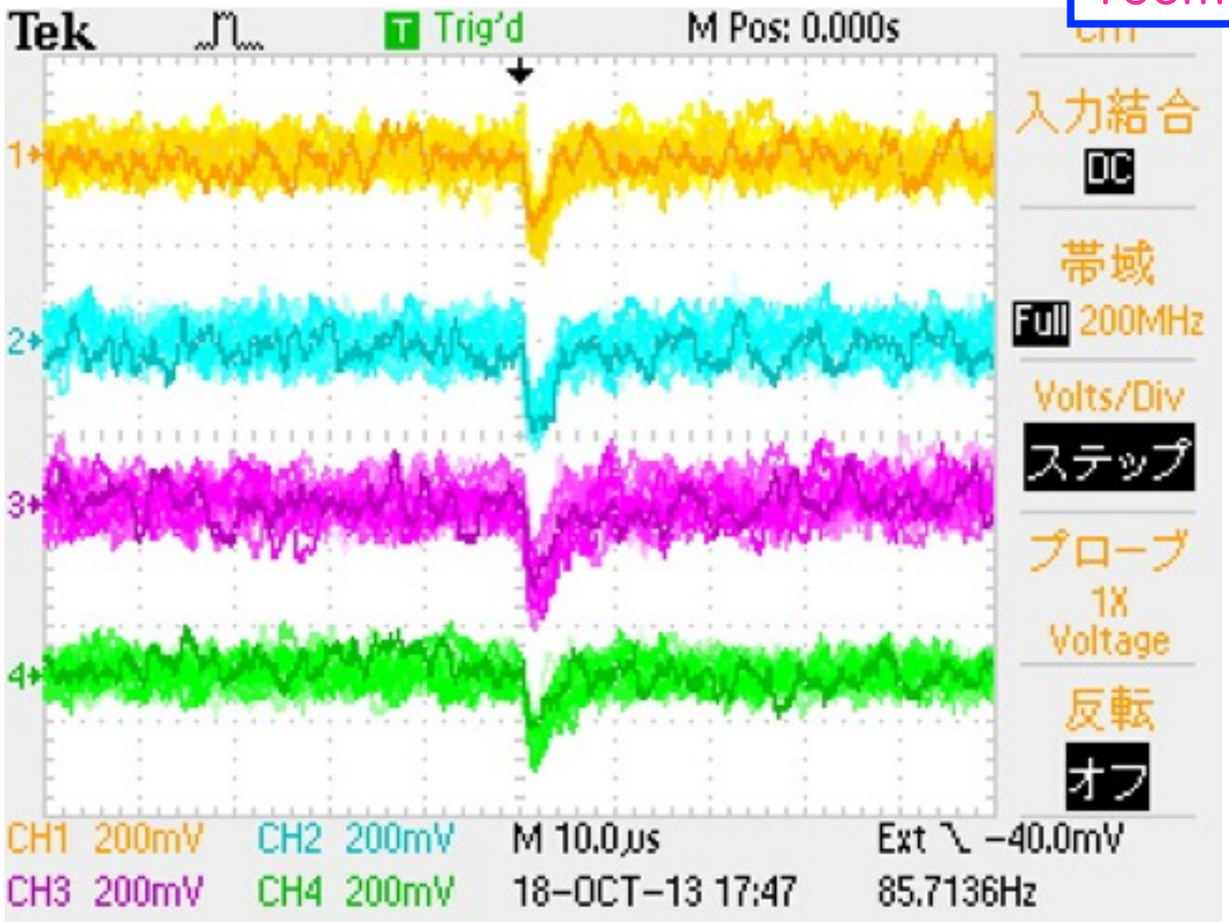
Multilayer Ceramic (
AMK324ABJ337MM,
330uF x 2, ESR=0.002Ω)
at each ±1.25V ,
i.e. 6 points in total

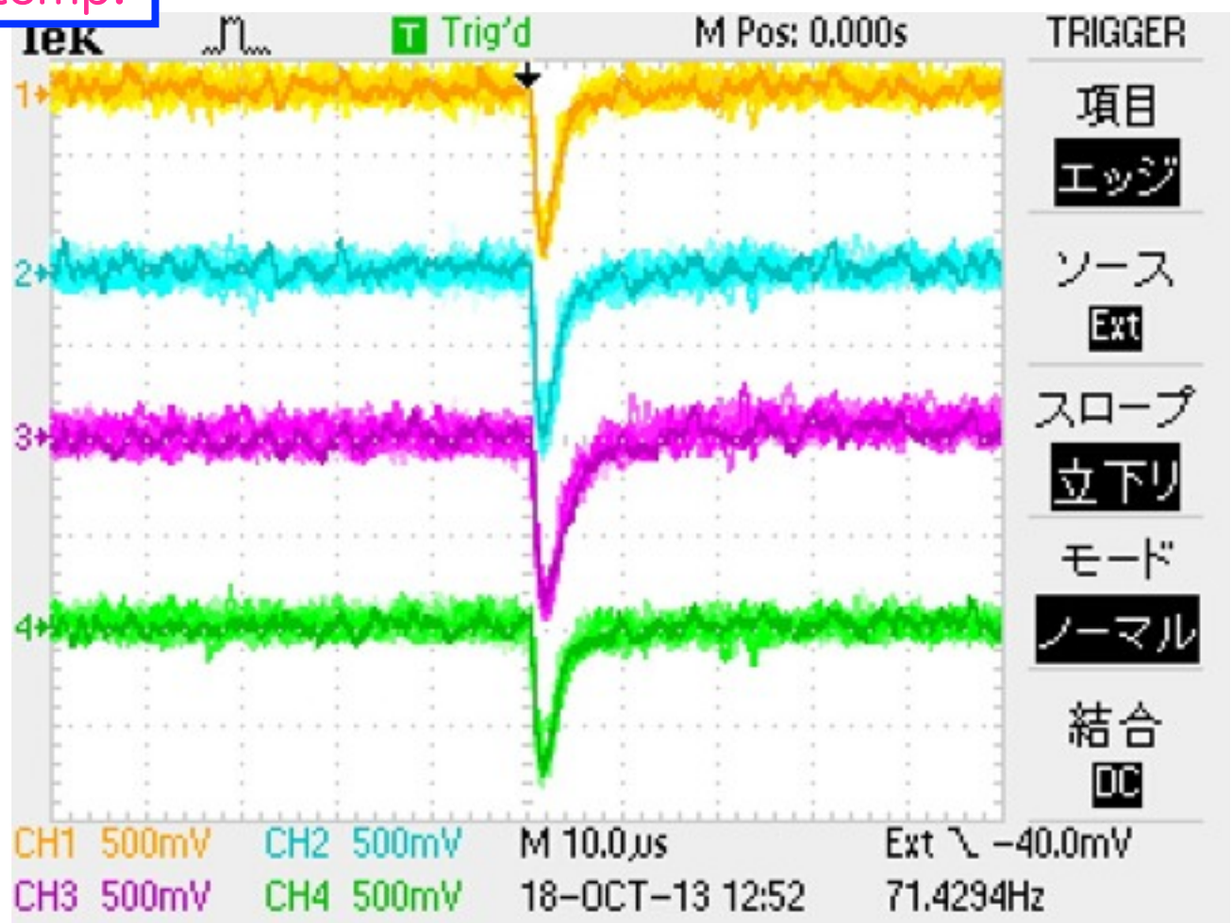
2013.10.18

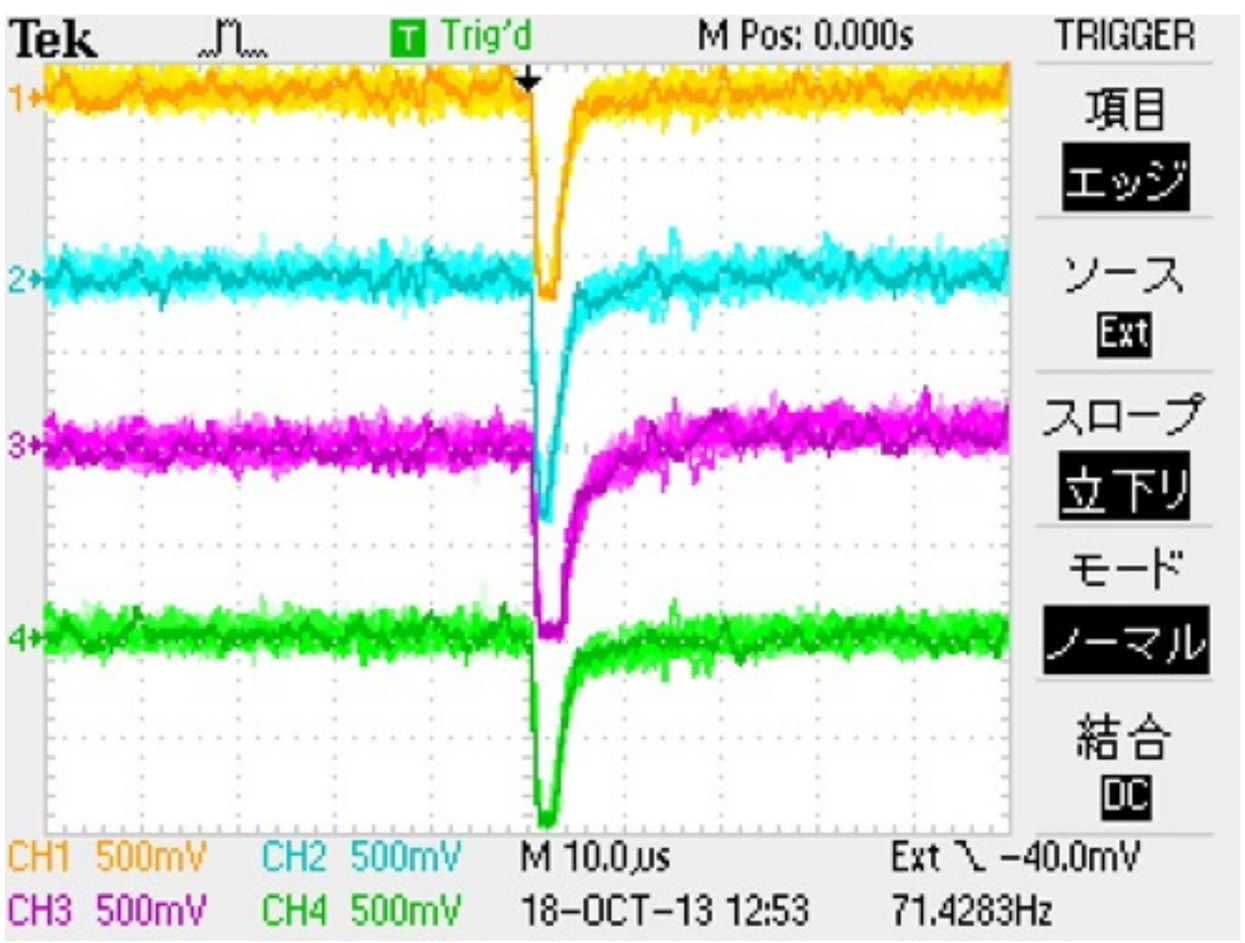
Test pulse, square, 50Hz, 0.025V, 31dB

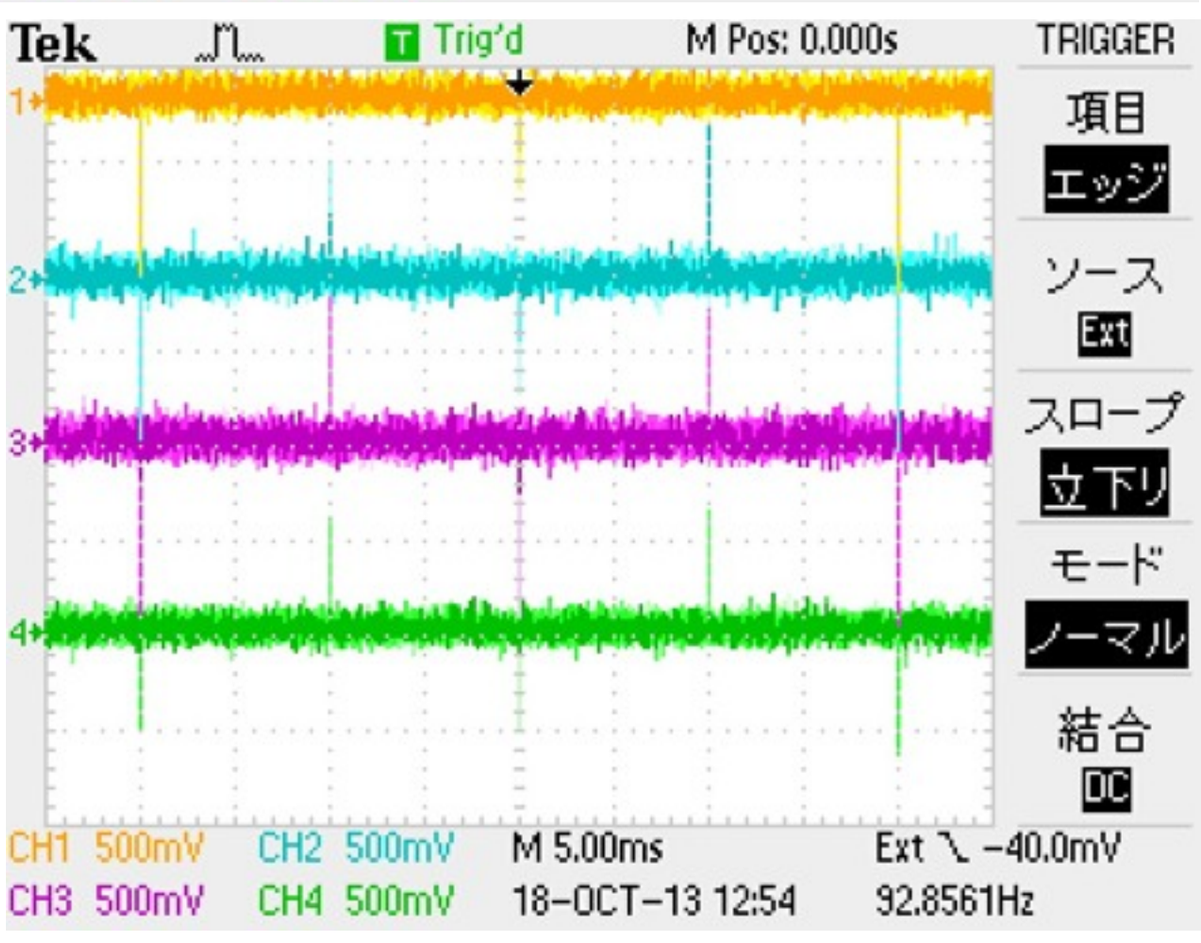
room temp.

Test pulse, square, 50Hz, 0.025V, 25dB



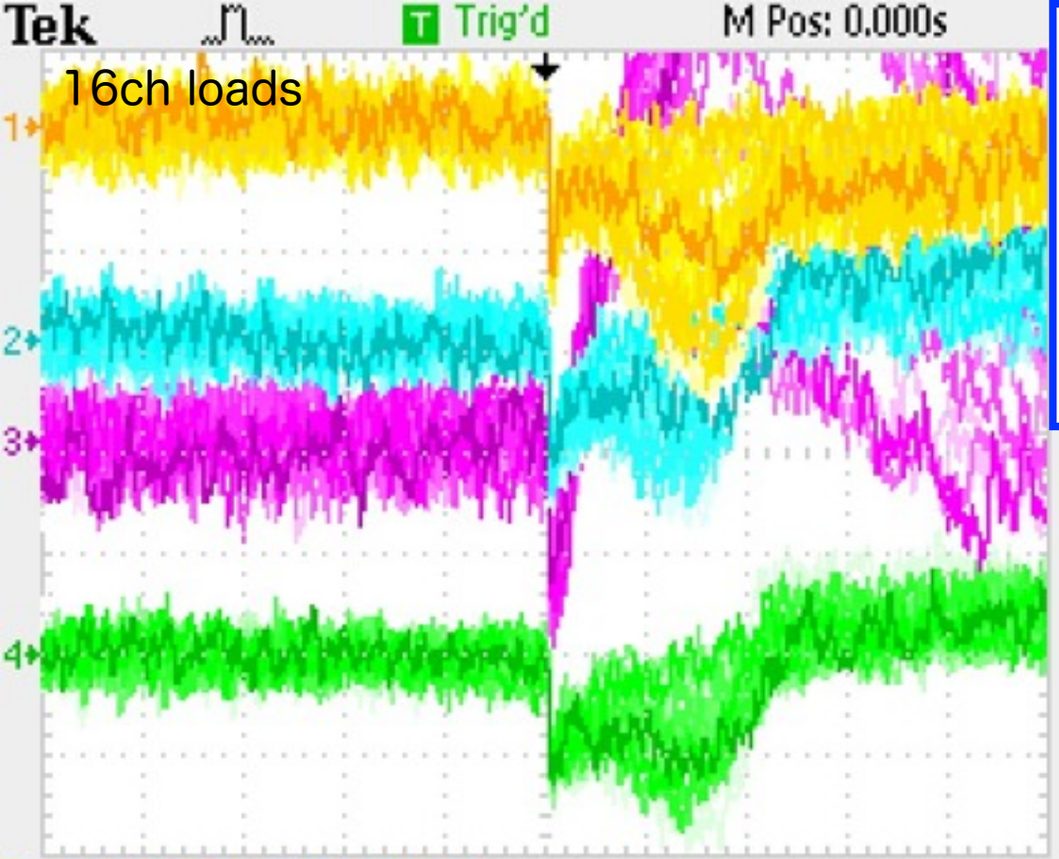


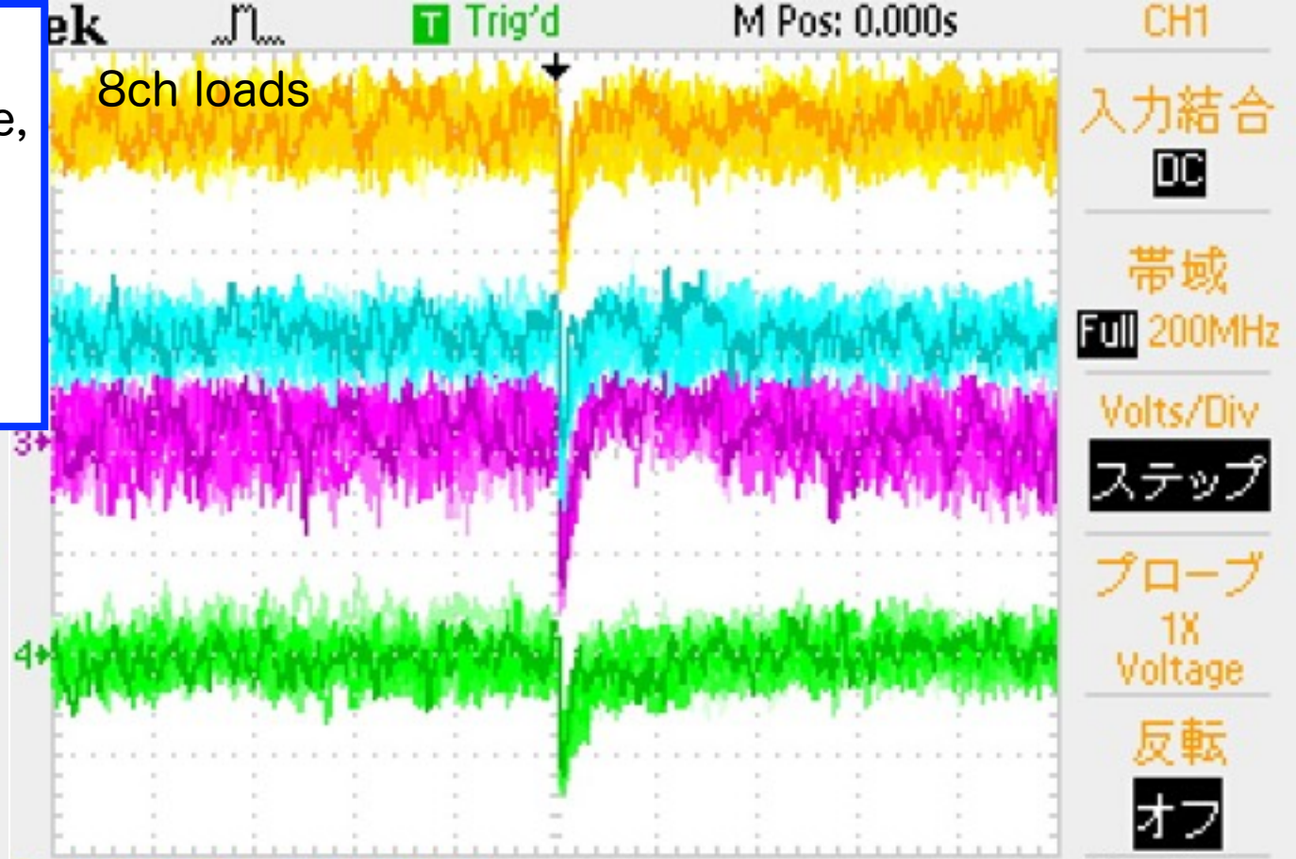


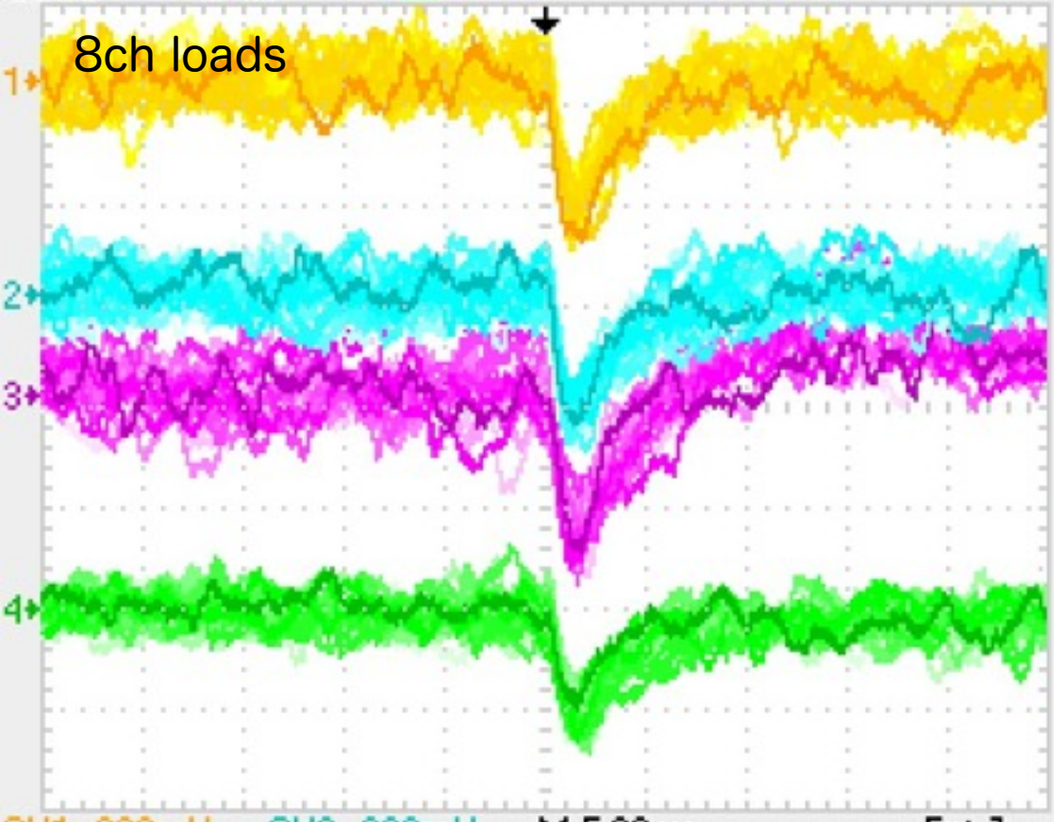


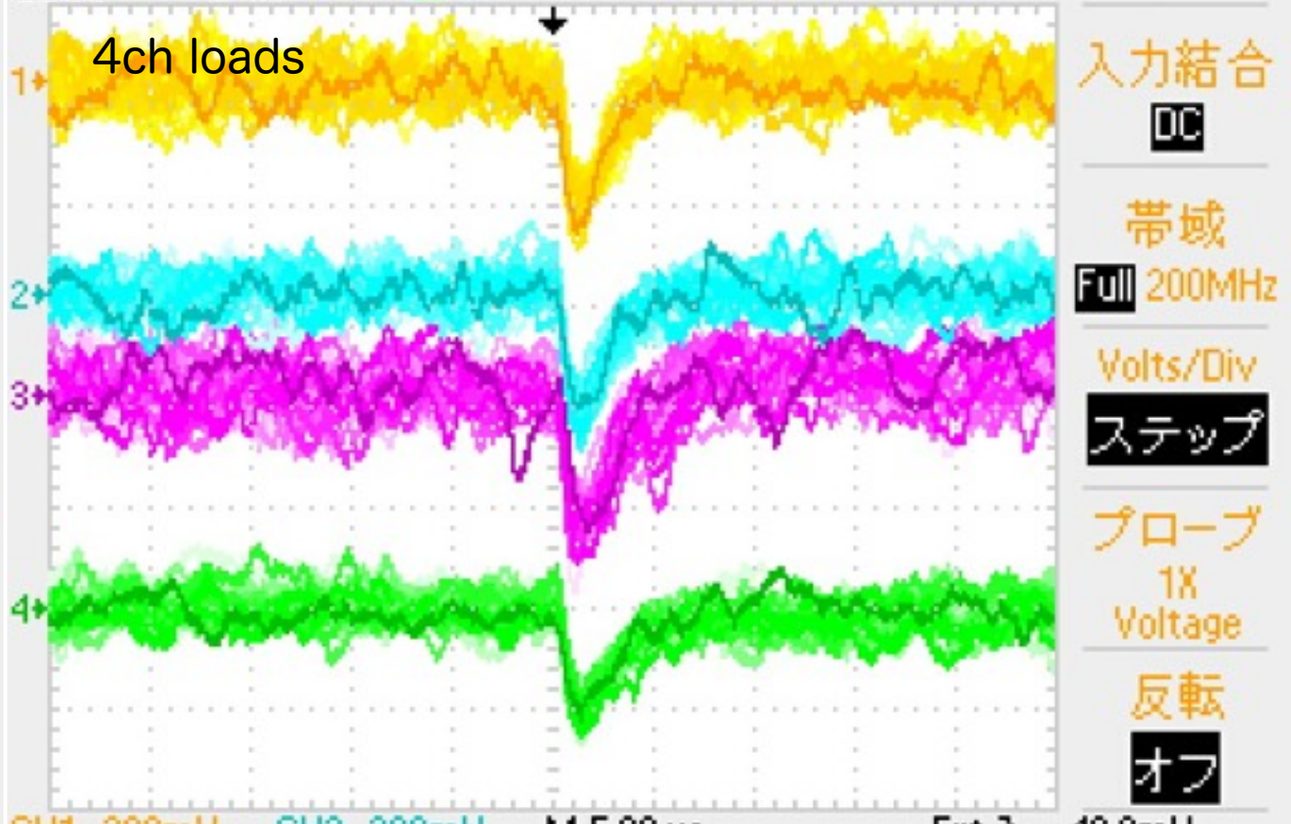
2013年 12月 10日 火曜日

Liq.Xe
Test pulse,
square,
50Hz,
0.025V,
31dB









2013年 12月 10日 火曜日

TPCX R&D in 2013

(1) Noise reduction by isolation of He compressor as much as possible

(2) Readout of 16ch with TPCFE09

radiation sources: ^{22}Na above the anode, α2@cathode

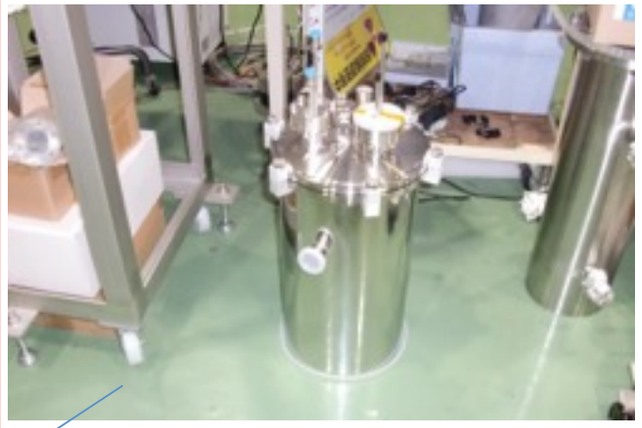
(3) Increase of gas circulation by adding a PTR

(4) In addition, heat exchanger with vacuum insulation will be used

Control system
of cryogenics

pump if the gas circulation

Heat exchanger with
vacuum insulation

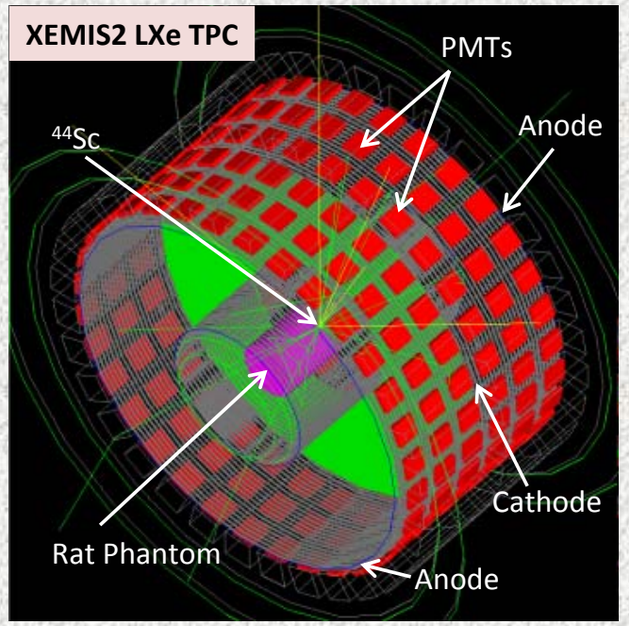


LXe Cryostat

Additional cooler

TWINBIRD SC-UE15
173K@30W

XEMIS2 pre-design study for small animal imaging with GATE



Cylindrical camera XEMIS2 (~ 100 kg LXe)

- radial 8 < r < 20 cm
- axial (z) Length = 2×12 cm
- Electric Field in z direction 2 kV/cm
- 192 PMTs
- Micromegas ionization read-out
- FEE Idef-X, pixels 3.175x3.175 mm^2 (~25k channels)

TPC characteristics

- Intrinsic energy resolution: 5% @ 511 keV
- Spatial resolution: 0.5 mm (X, Y and Z)

Performances (simulation in progress, *PhD student: A.F. Mohamad Hadi*

- Efficiency to measure LOR: 30%
- Efficiency to measure 1.157 MeV γ-rays: 43%
- 3 photons efficiency (after selection): ~5 %
- Precision on localization along LOR ~ 1 cm (FWHM)

Simulation status:

- LXe Compton Telescope already implemented in GATE
- Future => Simulation of test Phantoms (NEMA, Derenzo…) wit

Collaboration with Subatech group led by D.Thers

Exchange students

(1) January ~ March, 2010
2 weeks/each

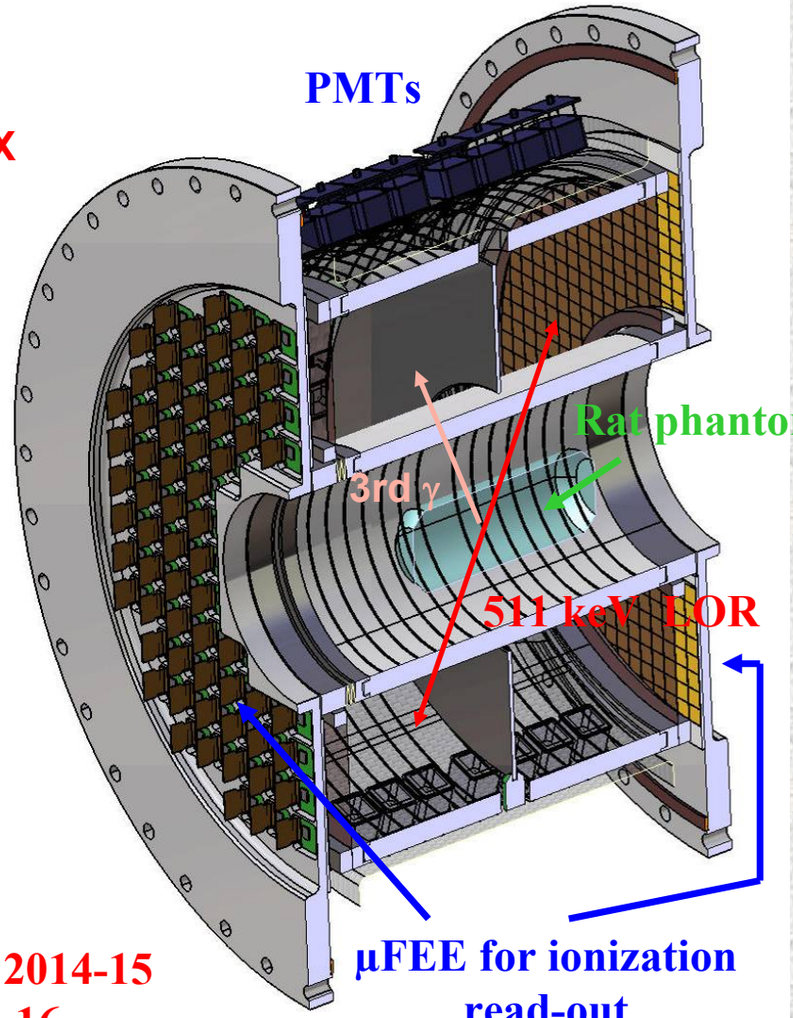
(2) July ~ December, 2013
3 months/each

Funding issues almost adressed with the ARRONAXPLUS EQUIPEX

Improved reliability and safety :
ReStoX (liquid xenon station)

Subatech

AIR LIQUIDE
TECHNIQUES AVANCEES



Expected to run at Subatech in 2014-15
→ Nantes Hospital in 2015-16

R&D on liquid Xenon detector technology, presented by Wan-Ting Chen, FJPPL2012, Clemond-Ferrand, France, 28-29 May, 2012

Summary

1. Charge signals are very sensitive to the liquid level. It should be greater than 120mm, when the anode is at about 90mm of the liquid level.
2. The noise from the He compressor remains the same level even after it was pushed away about 10m from the cryostat.
3. The impurity has reached to 6ppb, which is estimated from the charge attenuation, for operation in several months. It is limited by the gas circulation rate.
4. The ceramic end-plate can be used as a “window” between vacuum and liquid xenon, which was verified by the pressure capacity test.
5. As the front-end electronics, TPCFE09 (ASIC, 16ch/chip) on the LTCC board has problem concerning with the power lines.
6. We are preparing to increase the gas circulation rate in order to improve the impurity with a second cooler and a heat exchanger with vacuum insulator.
7. We have a good collaboration with a French group at Subatech, especially for a small animal PET application (XEMIS2). Also, we exchanged students twice, whose period are two weeks and three months.