MEG実験用液体Xeγ線検出器用光電子増倍管についてI

東京大学素粒子物理国際研究センター

森研究室修士2年

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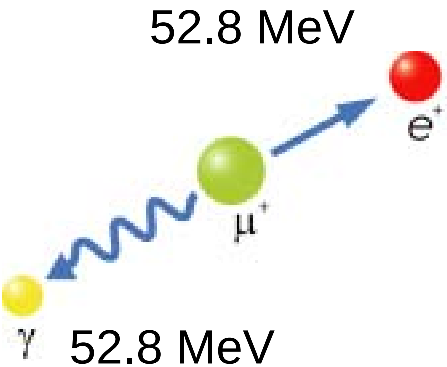
Abstract

- About MEG Experiment
- PMT for MEG photon detector
- Works on Final Design of PMT
- PMT test at Univ. of Tokyo
- Summary

MEG Experiment



$\mu^+ \longrightarrow e^+ \gamma$

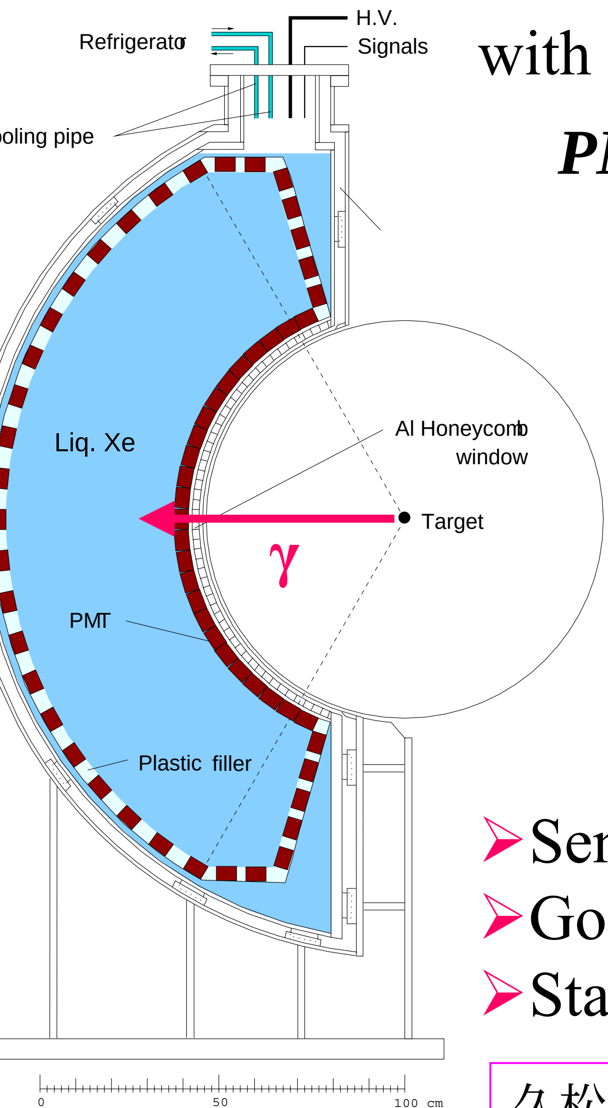
- beyond SM
- SUSY-GUT promising

MEGA(~1999)
Br $1.2*10^{-11}$

MEG
Br 10^{-14}

- Approved by Paul Scherrer Institut
- Using intense muon beam @PSI
  $1*10^8$/sec
- Start of Physics Run : 2006

MEG Liq. Xe γ detector



Detect scintillation light with 800 Liter liq.Xe and with 830 PMTs

PMT for liq.Xe detector needs to be/have…

- Short
- Able to operate under magnetic field
  - ➡ Metal Channel Dynode
- Do not contaminate Xe
- Able to stand high pressure; up to 0.3MPa
  - ➡ Metal Cover ⟶ Positive HV
  - ➡ Parts on Bleeder Circuit
- Sensitive to VUV (Liq.Xe scintillation light)
- Good performance at 165K (Liq.Xe temperature)
- Stable under high rate background

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PMT performance @165K

Temperature ⬇
surface resistance of photocathode ⬆
Quantum Efficiency ⬇

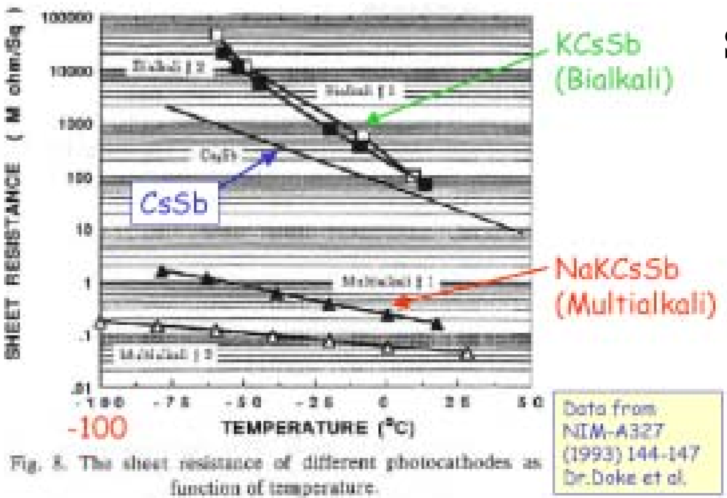

Fig. 8. The sheet resistance of different photocathodes as function of temperature.

First Ver.

Second Ver.

Photocathode	Rb-Cs-Sb	K-Cs-Sb
Material to reduce surface R	Mn layer	Al Strip
Q.E. @ 165K	~6%	?
Gain control	Difficult	Easy

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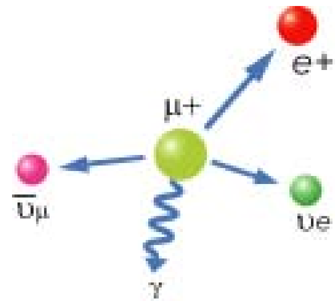
Major Background for PMT

- muon radiative decay
- Gamma from positron annihilation
- Neutrons from proton beam

T.Iwamoto, 27aSB-6

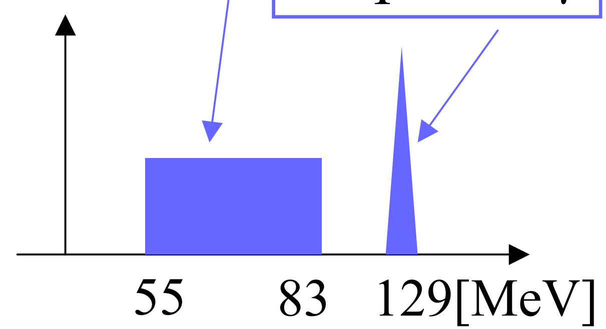


$\pi^- p \rightarrow \pi^0 n$

$\pi^0 \rightarrow \gamma\gamma$

$\pi^- p \rightarrow n\gamma$

- neutrons from pion's CEX reaction (@calibration run)

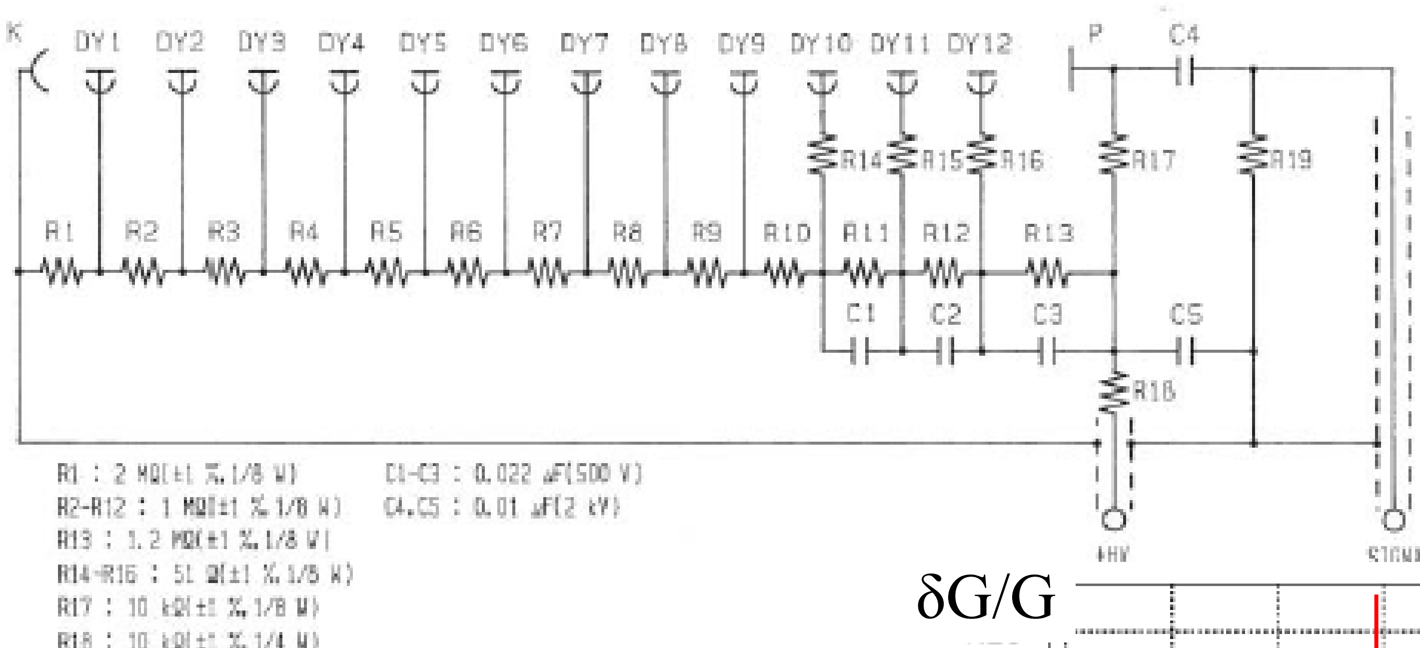


γ energy spectrum

c.f. muegamma event

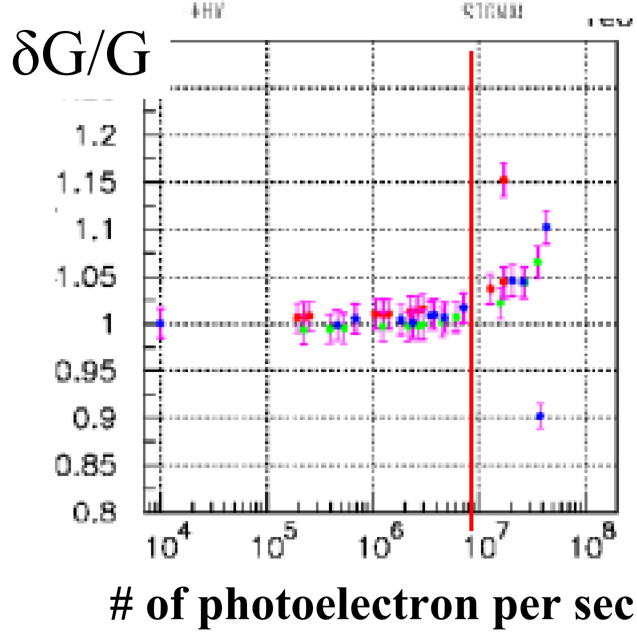
BG level ~ 2μA @10^6gain (~10^7p.e./sec)

PMT performance under high rate B.G.



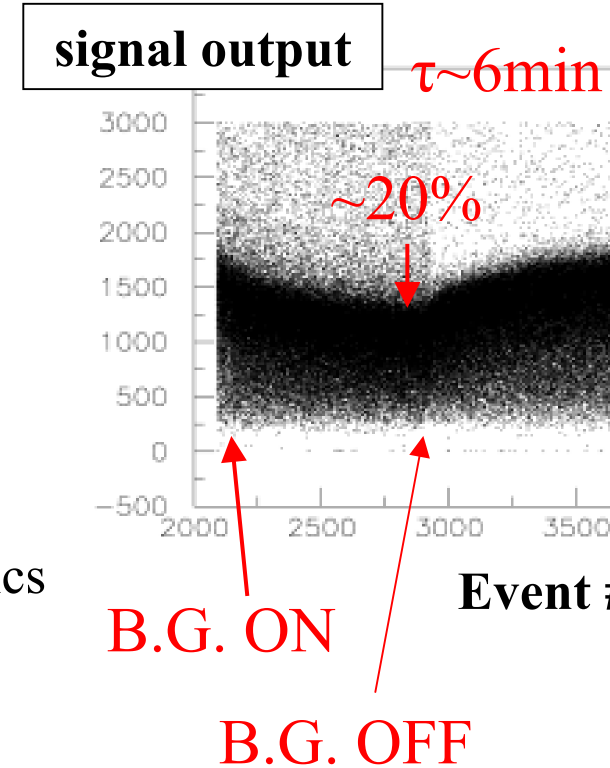
- *Base Circuit for MEG PMT*

Gain fluctuation due to high rate background



PMT performance under high rate B.G.

- Output from some First version PMTs deteriorates under high rate background.



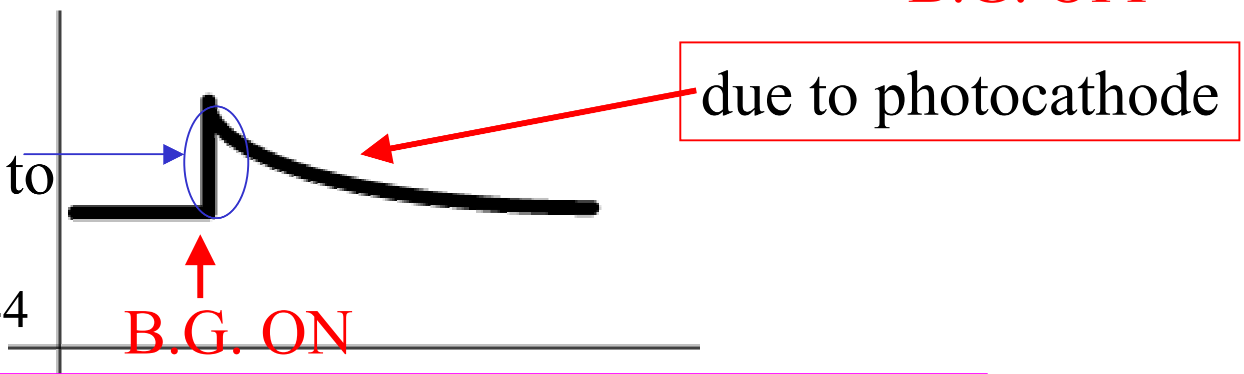
Related to the characteristics of photocathode in the low temperature

- ➢Rb-Cs-Sb + Mn Layer @ First version PMT
- ➢To obtain "higher" gain, added more alkali
- ➢Larger fraction of alkali changed the characteristics of photocathode

PMT outputs deterioration from two reasons:

Gain Variation due to base circuit

A.Yamaguchi 29aSB-4



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PMT for MEG

	First Ver.	Second Ver.	Final Ver.
Photocathode	Rb-Cs-Sb	K-Cs-Sb	K-Cs-Sb
Material to reduce surface R	Mn layer	Al Strip	Al Strip (doubled)
Gain controll	Difficult	Easy	Easy
Q.E. @ 165K	~6%	?	??

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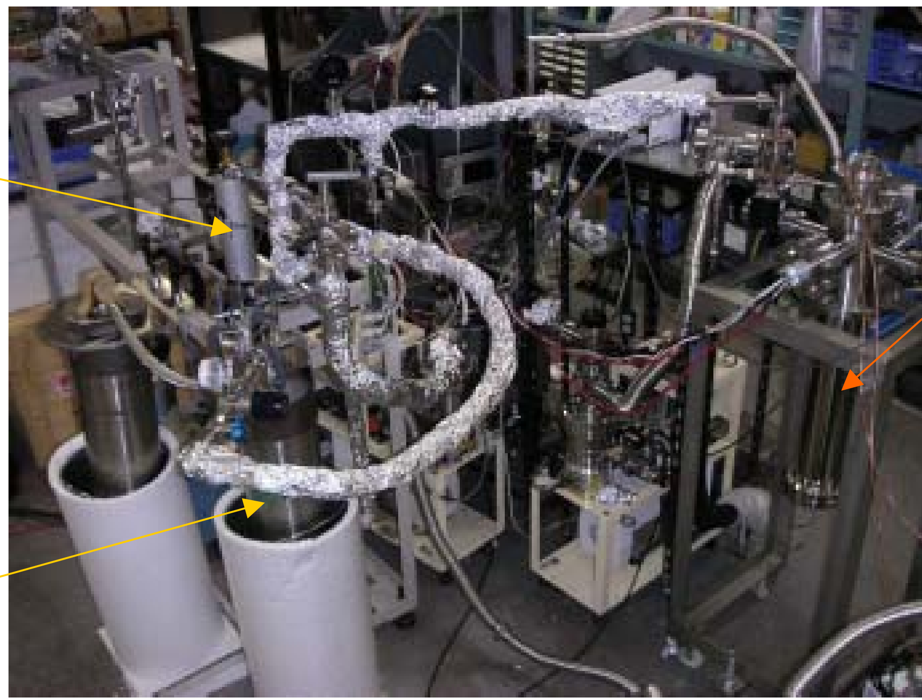
PMT Test @ Univ. of Tokyo

- How much has Q.E. improved?
- Will PMT survive the high background environment?

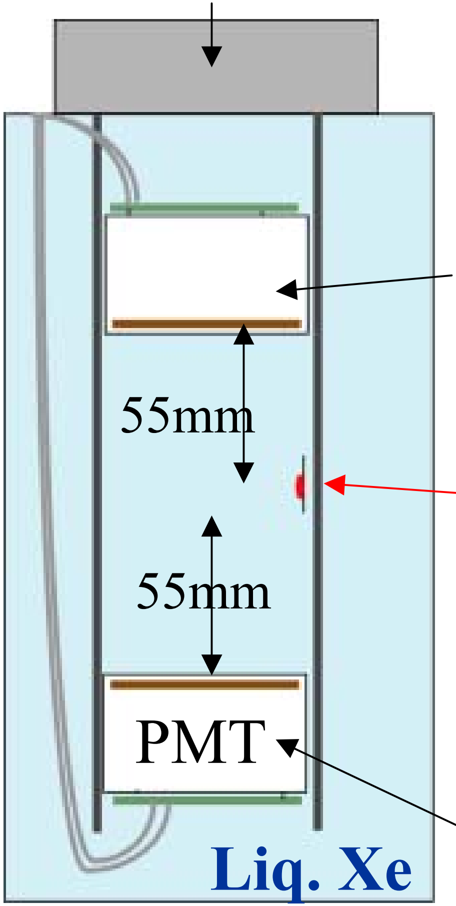
  low temperature effect on photocathode

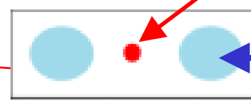
  bleeder circuit current A. Yamaguchi

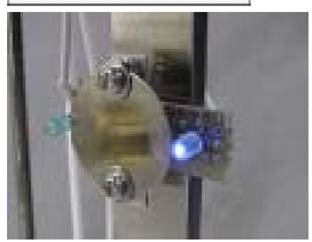
PMT Test facility @Univ. of Tokyo



PMT Test Set up *Q.E. measurement*







Observe 5.5MeV alpha event

Gain calibration using LED

$$g = \frac{c\,\sigma^2}{eM}$$

$$\sigma^2 = g\frac{e}{c}(M - M_0) + \sigma_0^2$$

g: gain

c: ADC least count

σ : standard deviation

M: mean of ADC spectrum

e: elementary electric charge

Gain :10^6

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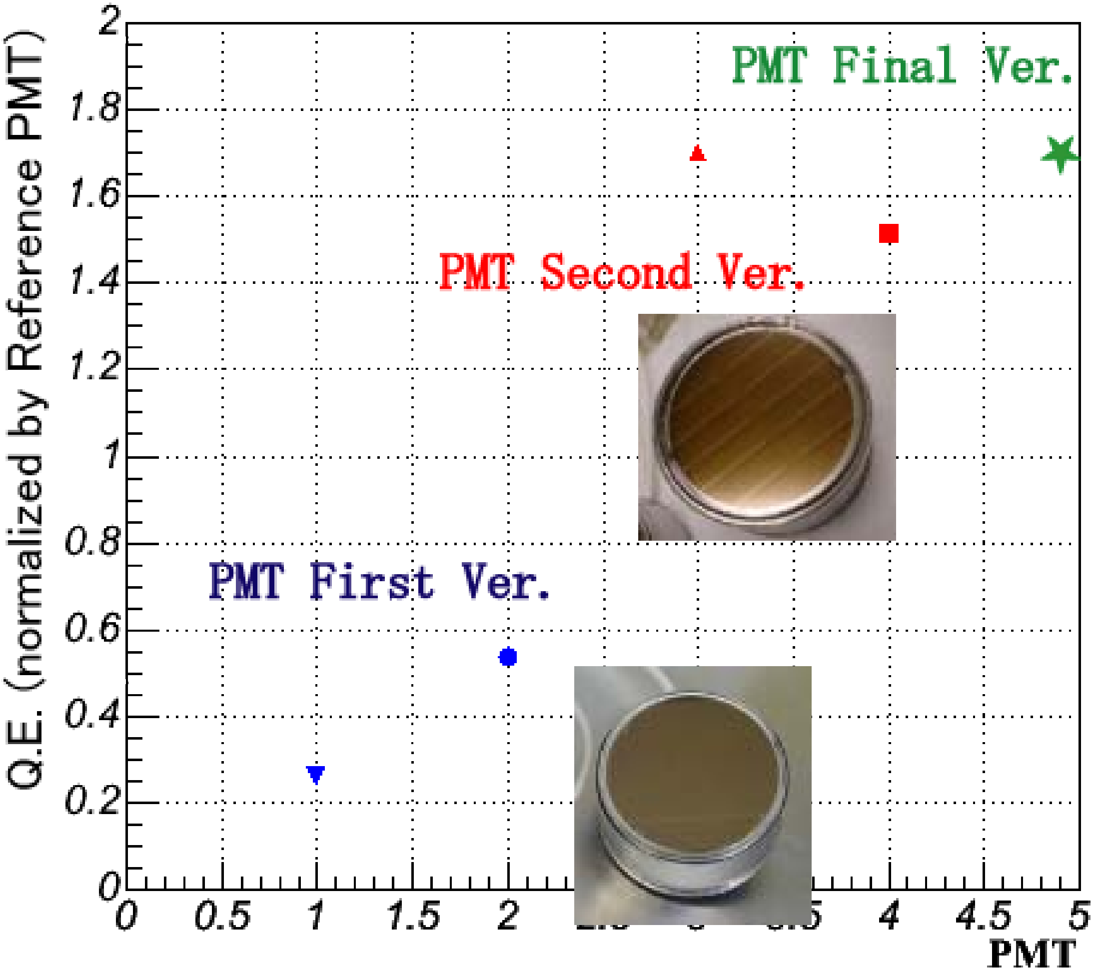
Q.E. measurement



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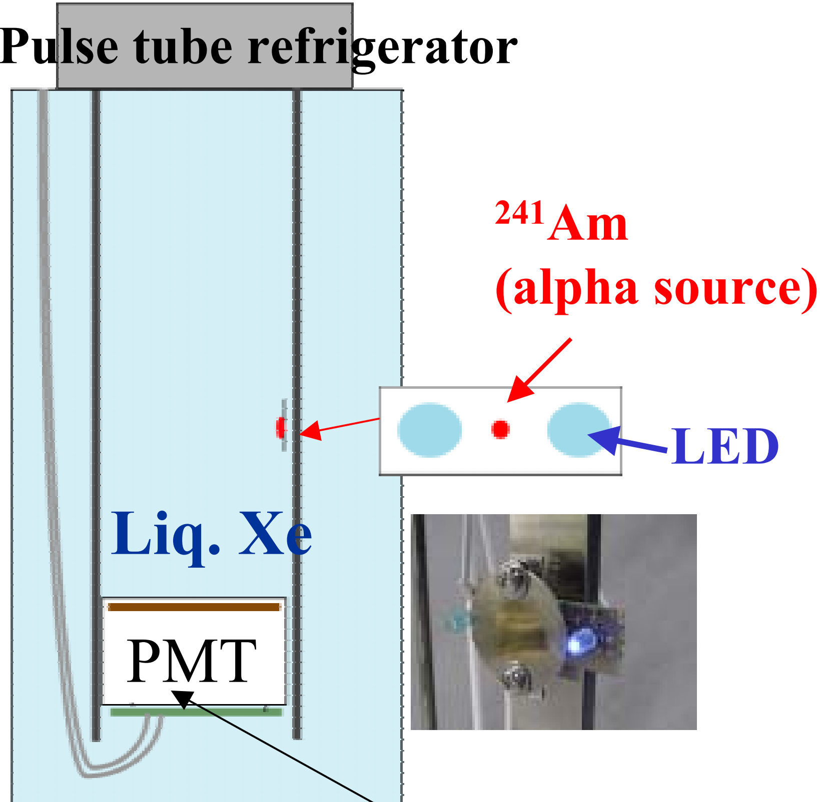
PMT Test Set up *Rate dependence test*



LED

- simulate the high rate background
- pulse height:4000~7200 p.e./event
- pulse shape: ~10nsec
- rate: 500Hz ~ 10KHz

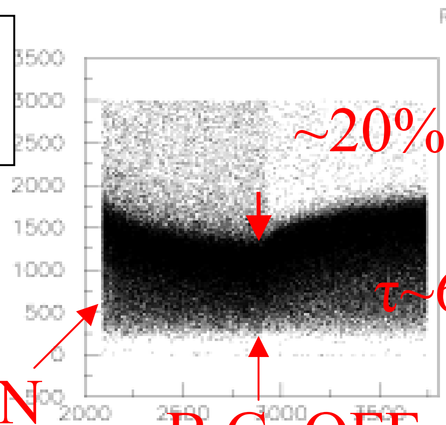
Background Level Upper limit :
2μA, $1*10^7$ p.e./sec

alpha

Observe 5.5MeV alpha event,
~200Hz

PMT for MEG final version *Rate Dependence @ Liq. Xe*

signal output

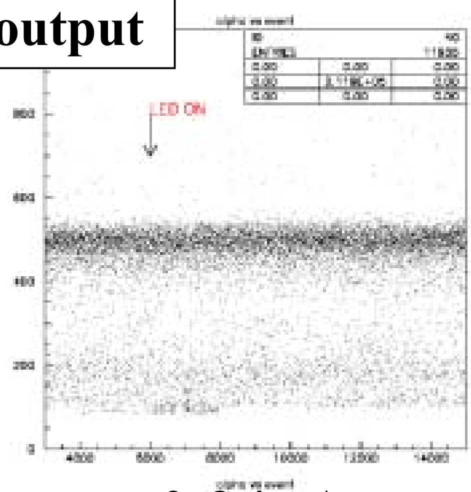


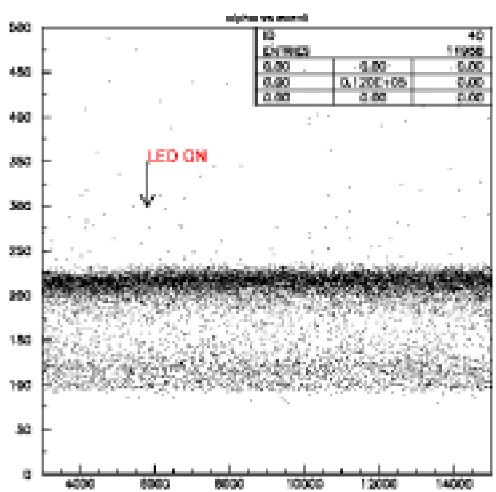
Event #

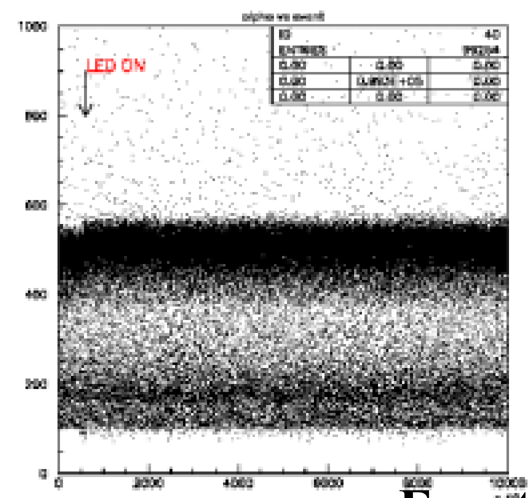
Background Level Upper limit :
2μA, $1*10^7$ p.e./sec

c.f. First Version PMT

signal output







Event #

Background:	0.34μA	1.2μA	2.2μA
	$2.0*10^6$p.e./sec	$7.2*10^6$p.e./sec	$1.3*10^7$p.e./sec

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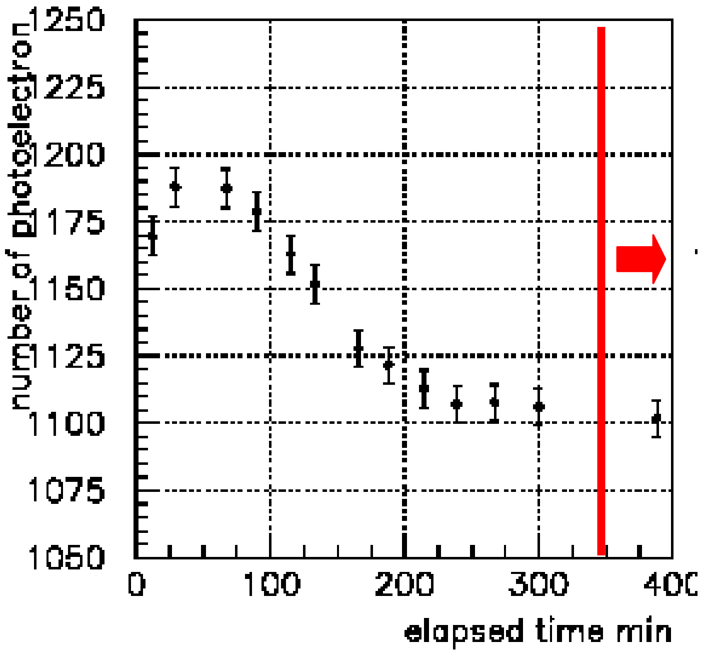
Summary

- Works on Final Design of PMT have finished,
  Adopting new photocathode material: K-Cs-Sb
  Adding Al Strip Pattern : reduction of surface resistance
- Final Version of PMT is tested @ liq.Xe.
- New photocathode mentioned above works quite well;
- Q.E. is expected to be ~4 times bigger than that of R6041Q.
- Stable output under the estimated background level in MEG

PMT stability, DAQ Procedure

DAQ started after all chamber
components become low temperature



Trigger : alpha self trigger

DAQ Procedure :

Pedestal Run
→ Gain Calibration
→ alpha run

Condition and Procedure

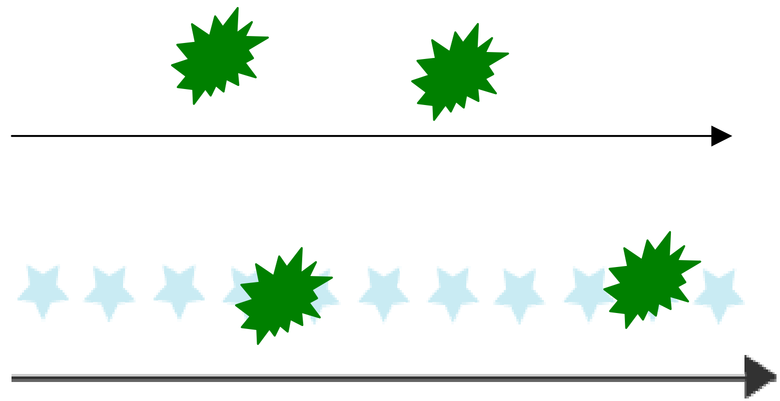
- Gain $1*10^6$
- Trigger: alpha self trigger (veto by LED driver pulse)
- Procedure

Pedestal Run & Gain calibration using LED

Alpha Run @ LED OFF 20 min

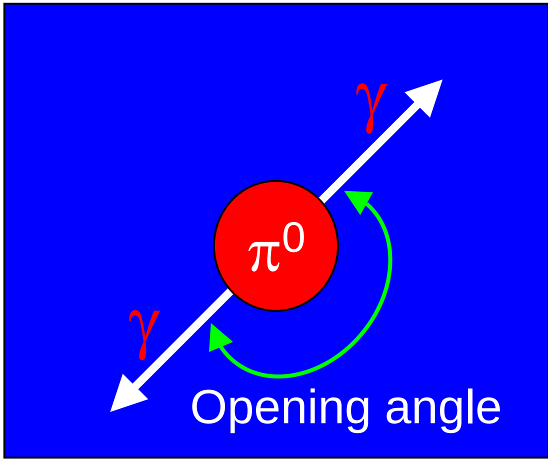
Alpha Run @ LED ON 20 min

-Change LED Pulse height, rate

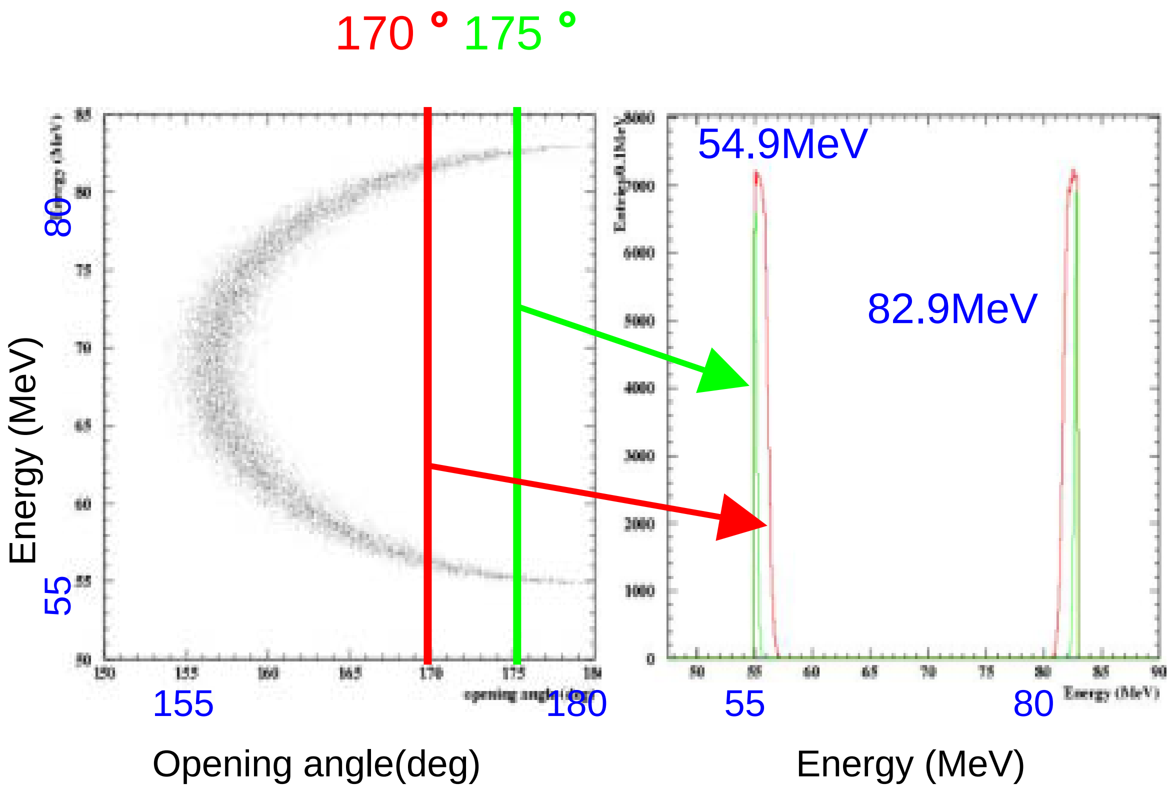


π^0 Beam Test at PSI

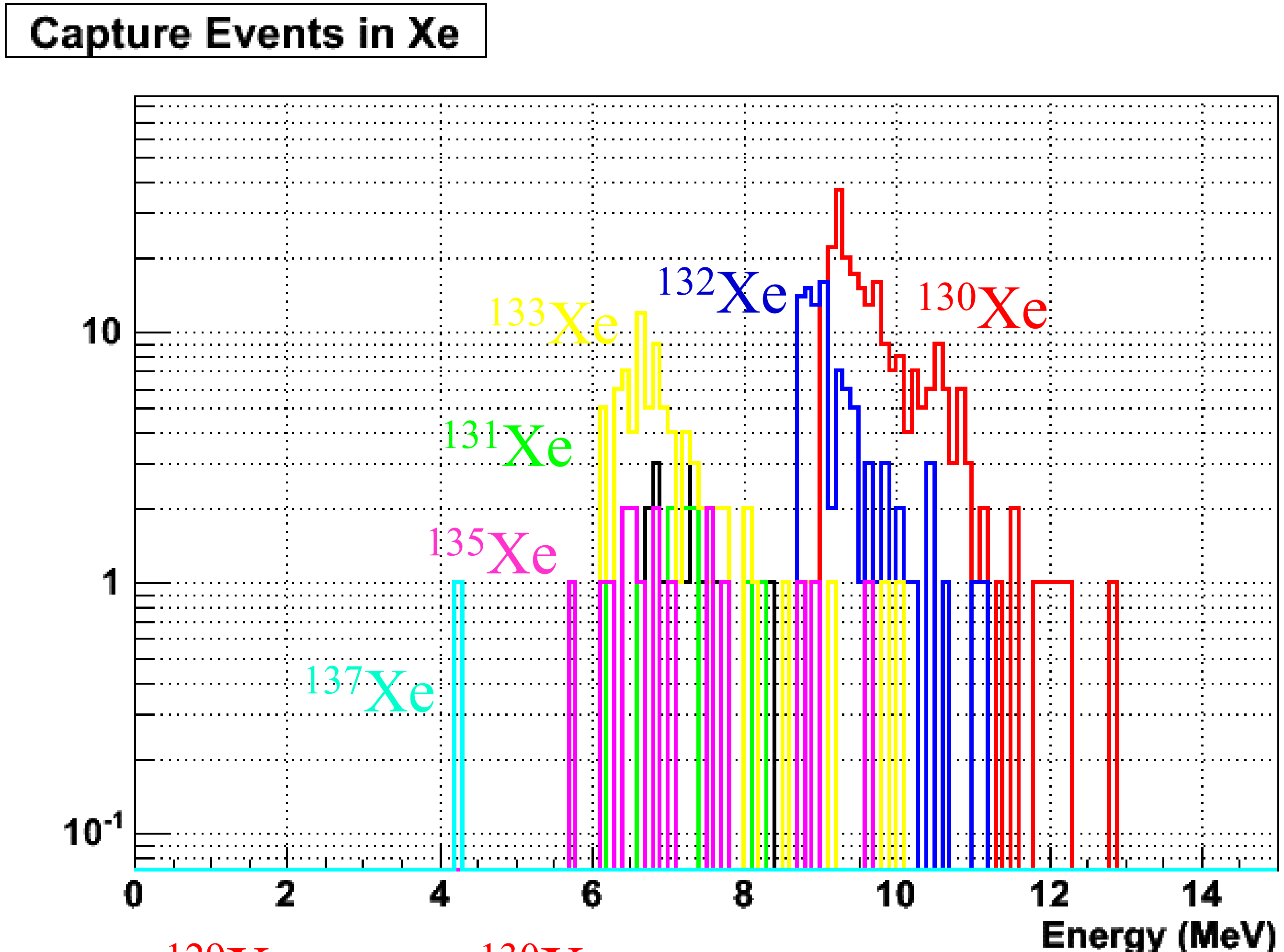
π^- (at rest) + p -> π^0 + n,
π^0(28MeV/c) -> $\gamma + \gamma$
(54.9MeV<Eγ<82.9MeV)
Almost monochromatic γ



π^- + p -> n(8.9MeV)
+ γ (129MeV)
linearity check
55, 83 and 129MeV
neutron response



Radiative Capture events in Xe



$^{129}Xe + n \to {}^{130}Xe + \gamma$ etc…

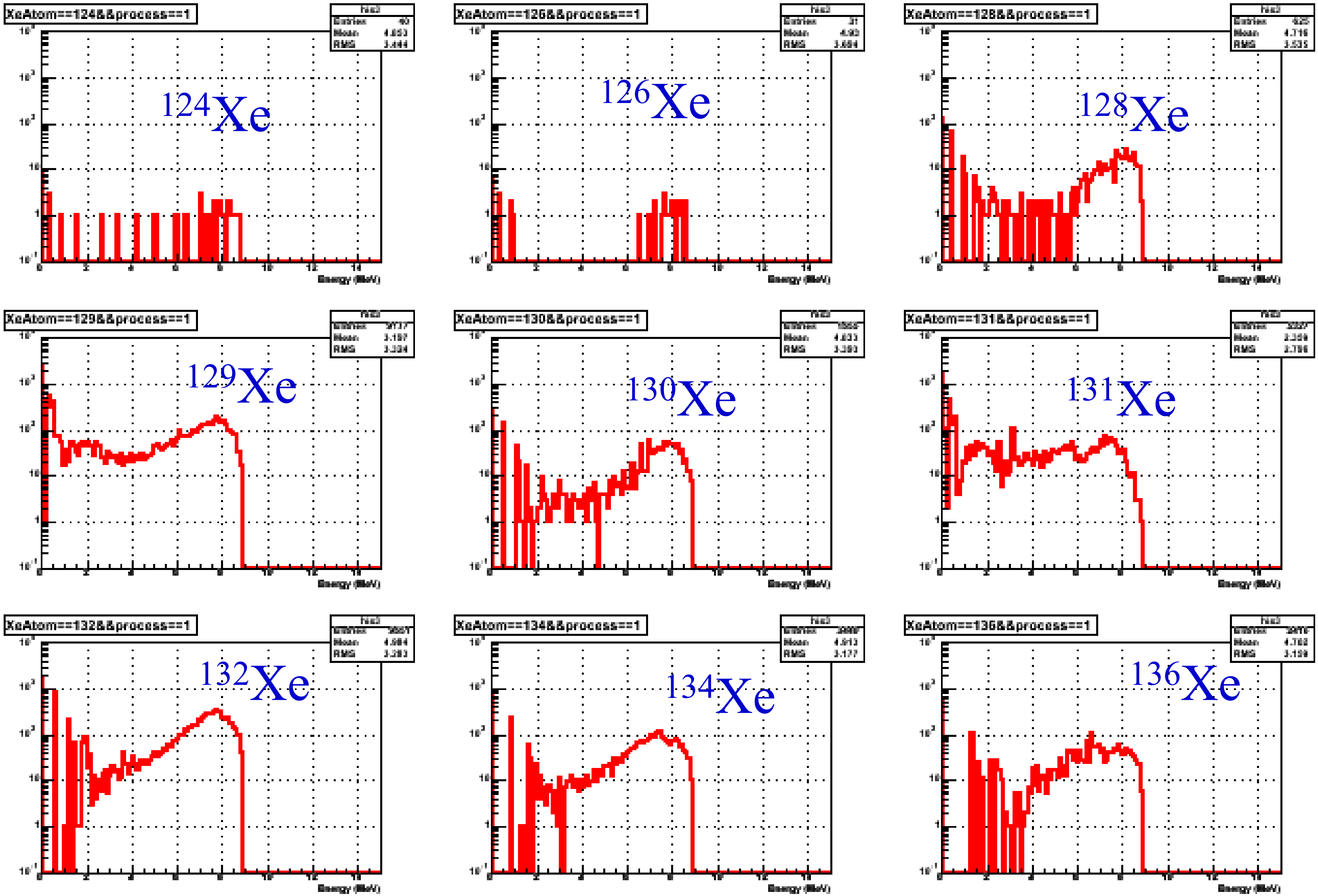
Many γ's are emitted, not one.

γ from radiative muon decay

- $10^8\mu$/s->$10^6\mu e\nu\nu\gamma$/s
- acceptance 10%
- Mean deposit energy 5MeV
- 1photon = 24eV
- Xe detector front face 200PMTs, QE 10%, coverage 50%, photon collection 50%
- $10^6\mu\gamma$x0.1x5x10^6MeVx0.1x10^6x1.6x10^{-19}Cx0.5x0.5/24eV/200PMTs

= 0.4μA

Inelastic reaction of different nuclei in Xe



0MeV 15MeV There are edges for different Xe nuclei around 9MeV.

CRYOGENIC OPERATION FOR LARGE-PROTO DETECTOR

-Heat Load-

Phase	LXe (L)	PMT	Heat Load W@165K			Total (W)
			Static	PMT	Cable	
L.Proto	120	250	24	16	10	50
Final	800	800	20	52	50	122

*Static heat load depends on manufacturers design

*PMT power dissipation 65mW/PMT

*Due to number and length of cables

(R9288) 感度測定

PMT gain calibration 1

How to gain calibration?

PMTに入射した光子が光電面で光電子をたたき出す過程をPoisson分布であるとすると

$$\sigma_{Npe} = \sqrt{Npe} \quad (Npe : \text{光電子数})$$

増幅率GのPMTと1ch当りの電荷量CのADCで見ると

$$G = \frac{C \times M}{e \times Npe} \quad (e : \text{電気素量、} M : ADC\text{スペクトルの平均値})$$

$$\therefore Npe = \frac{C \times M}{e \times G}$$

また、

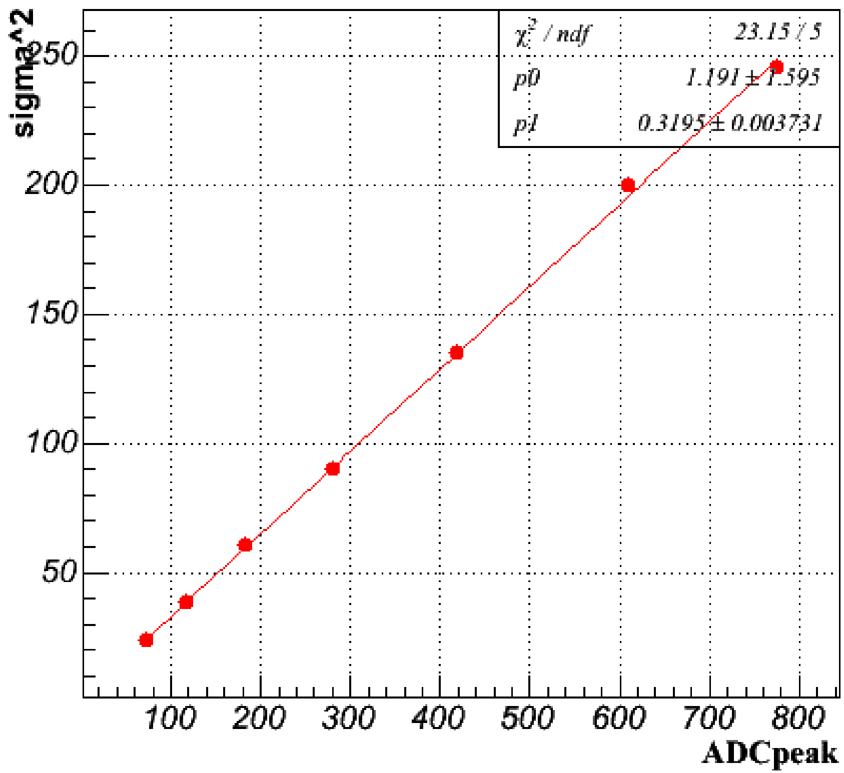
$$\sigma_{Npe} = \frac{C \times \sigma_{ADC}}{e \times G}$$

以上より

$$\sigma_{ADC}{}^2 = \frac{C \times M}{e \times G} = \left(\frac{C \times \sigma_{ADC}}{e \times G} \right)^2$$

$$\therefore \sigma_{ADC}{}^2 = \frac{e \times G}{C} \times M$$

M v.s sigma^2のplotの傾きからgainを算出



gain calibration(sample)