# My study in internship

PMT calibration

GATE simulation study

19 / 12 / 13

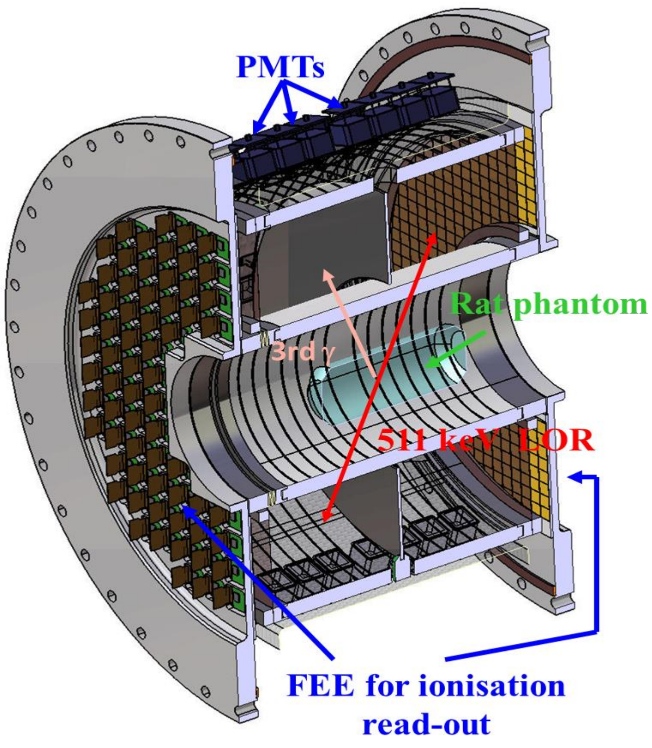
**Ryo HAMANISHI**

KEK HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

Subatech

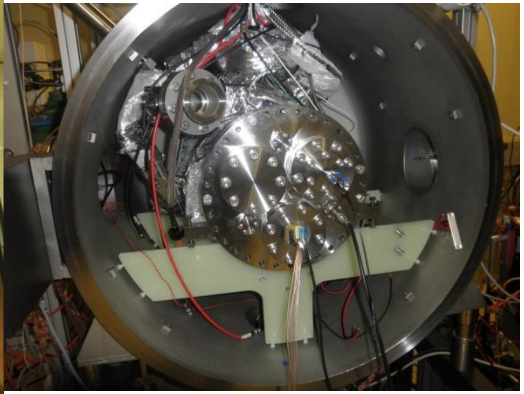
# Background

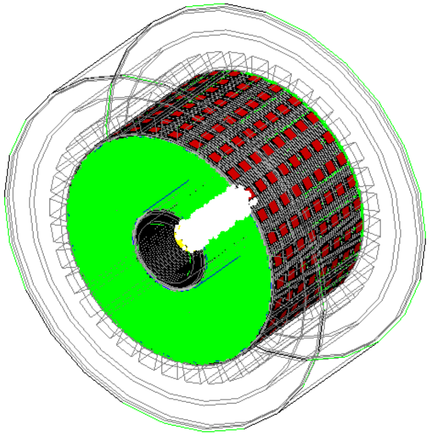
- XEMIS2 (**XE**non **M**edical **I**maging **S**ystem)
  - Characteristics of PMTs (array of 8 X 32)
    - GAIN calibration
    - Temperature dependency
    - linearity
    - Noise etc
  - Evaluate trigger for TPC
    - Number of photoelectron
    - Threshold and uphold

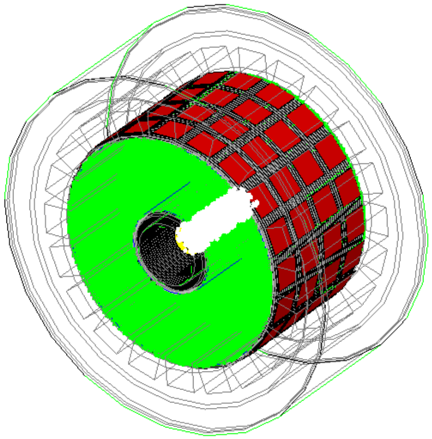


# Contents

- PMT calibration (with black box or cryostat)
  - Setting up
  - Getting pulse
  - Analyzing data
  - Results and conclusion
- GATE simulation study
  - New geometry
  - Analysis programs
  - Conclusion

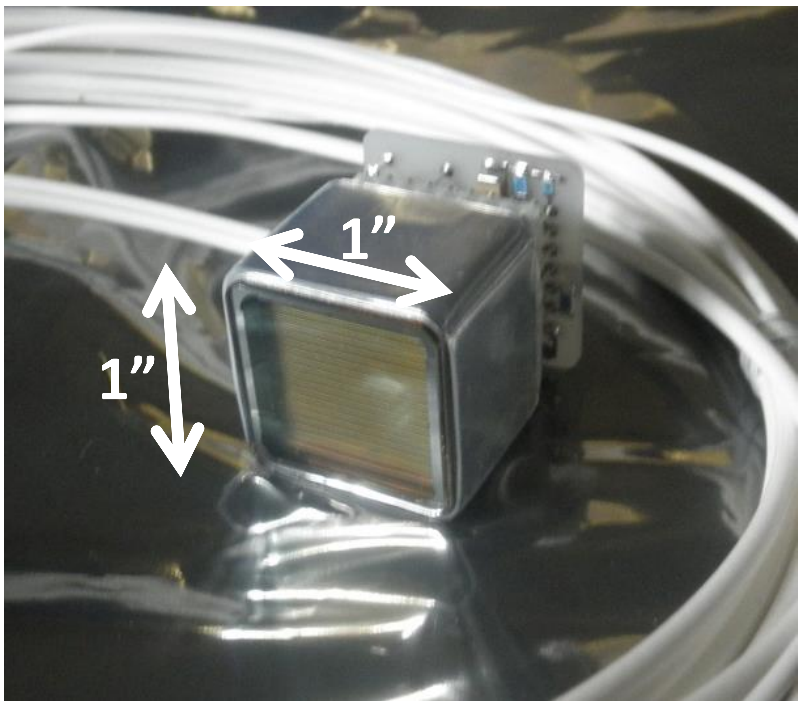




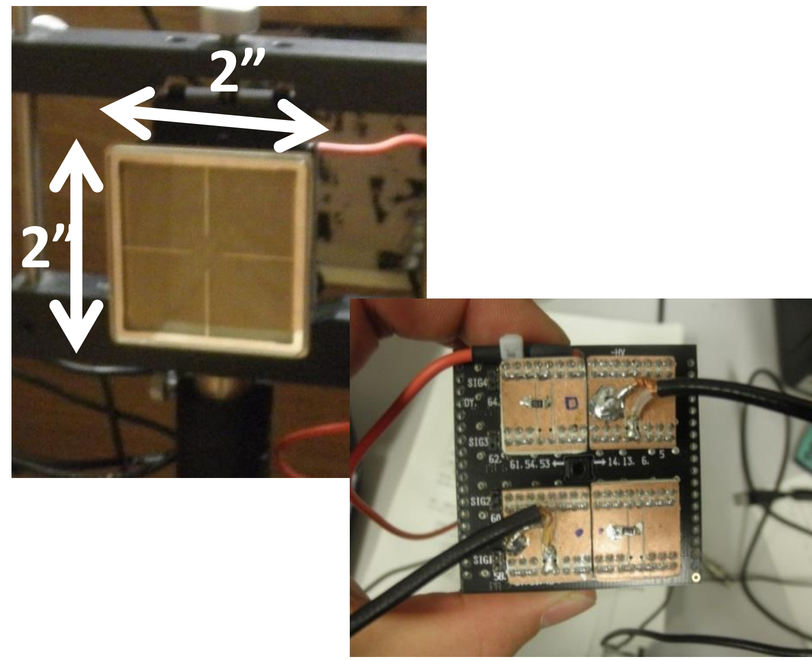


# PMTs

R7600
HAMAMATSU




R10551
HAMAMATSU



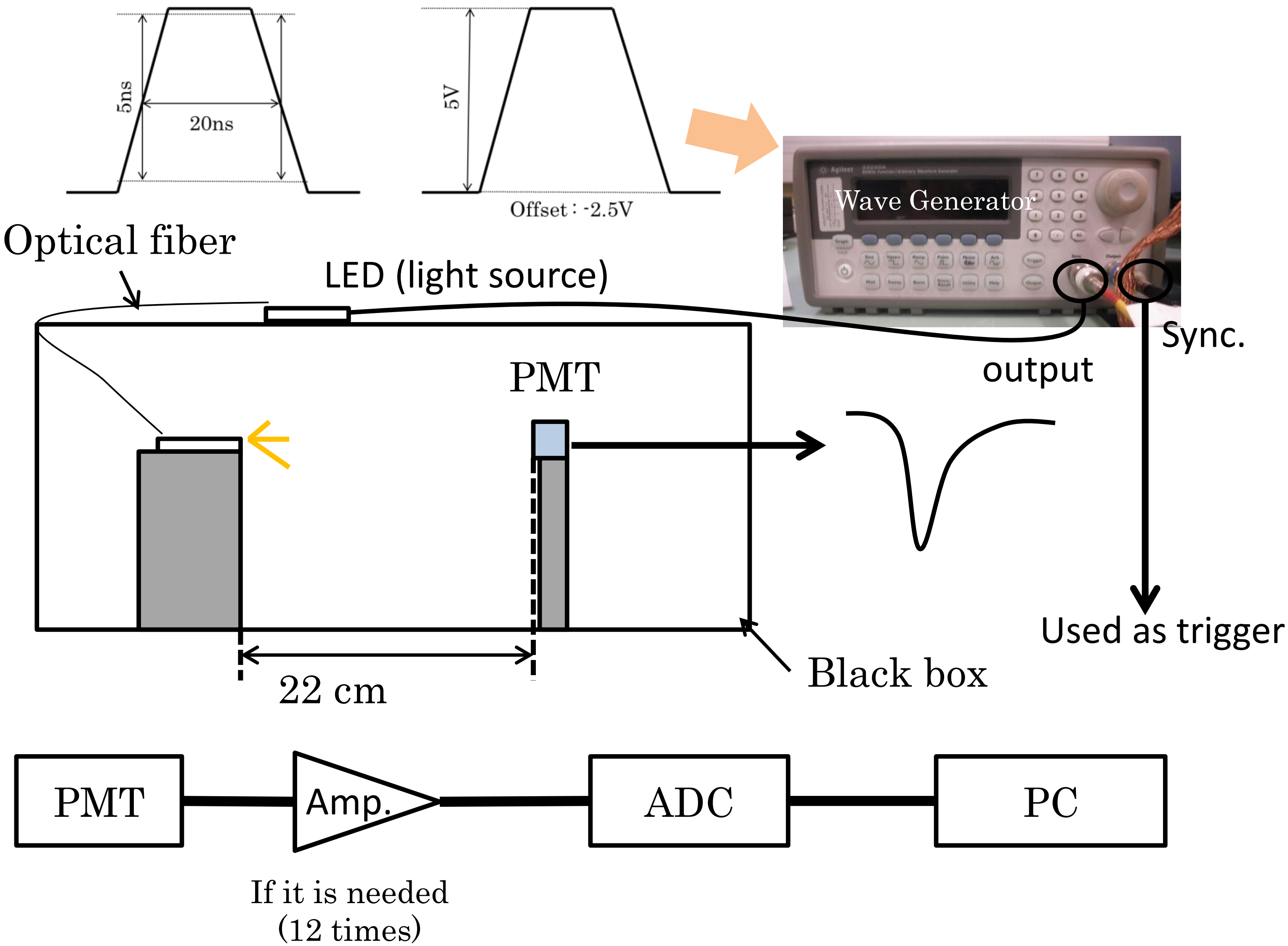

Total : 64 channels
Divided by 4 : 16 channels per 1 ch

# PMT calibration (with black box)

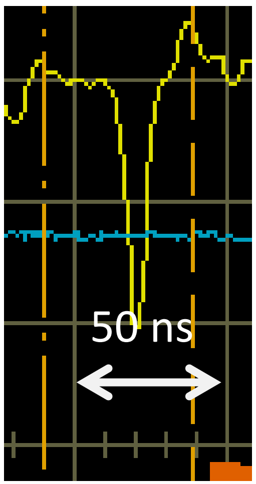
# PMT calibration with black box

- We used black box (room temperature).
- Light source was yellow region LED.
- Supply voltage of R7600 was set to 700 - 780 V (each 10 V) .
- Supply voltage of R10551 was set to 900 - 1000 V (each 10 V).
- We got linearity of GAIN.

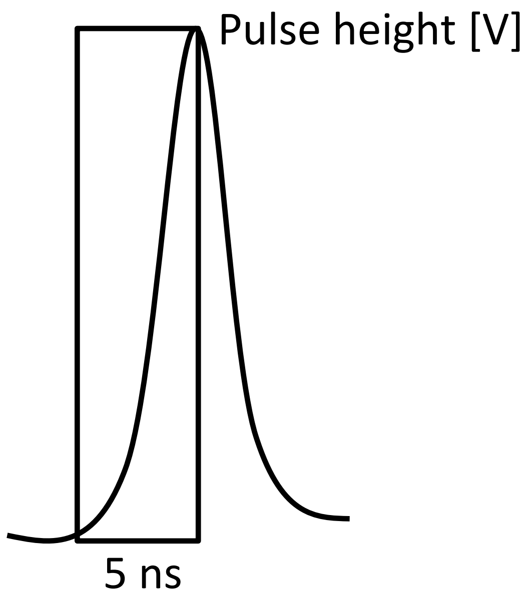
# Set up


5ns
20ns
5V
Offset : -2.5V
Wave Generator
Optical fiber
LED (light source)
PMT
output
Sync.
Used as trigger
Black box
22 cm
PMT
Amp.
ADC
PC
If it is needed
(12 times)

# Calculating GAIN



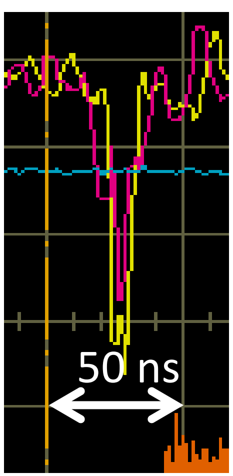

R7600




$$Q_1 = \int \frac{V}{R}\, dt$$

$$GAIN = Q_1/Q_e$$

$$\int V dt = (\text{Pulse height}) \times 5\ \text{ns}$$




R10551

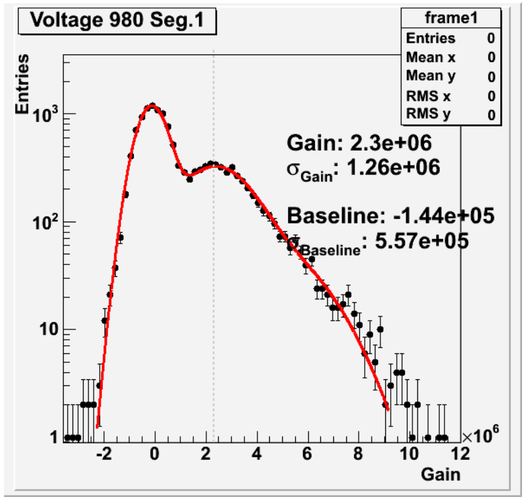
In this measurement, because I measured the pulse height,
I calculated  the charge  of pulse like figure.
So, these experiments are approximate measurement.

# Fitting function

- I used three gauss function when I analyze the histogram.

$$S_G = A_N exp\left(-\frac{(x-x_N)^2}{2\sigma_N{}^2}\right) + A_1 exp\left(-\frac{(x-x_1)^2}{2\sigma_1{}^2}\right) + A_2\ exp\left(-\frac{(x-2x_1)^2}{4\sigma_1{}^2}\right).$$

Pedestal — Single photoelectron — two photoelectrons

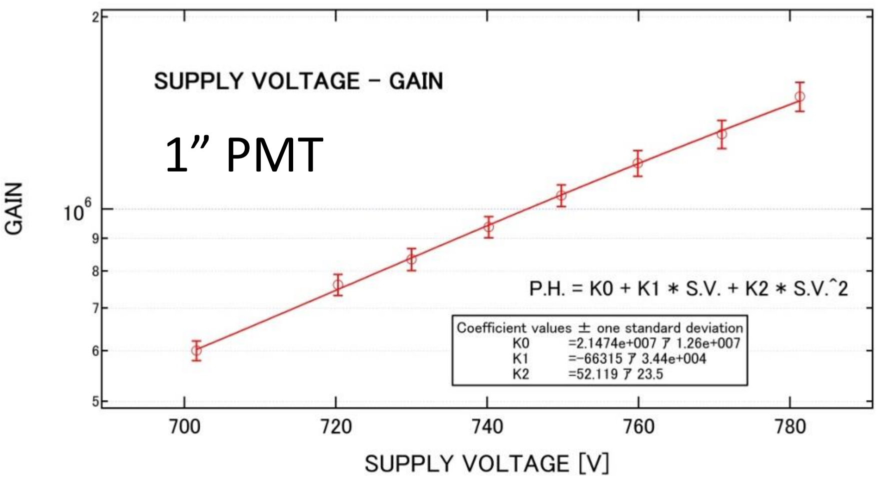


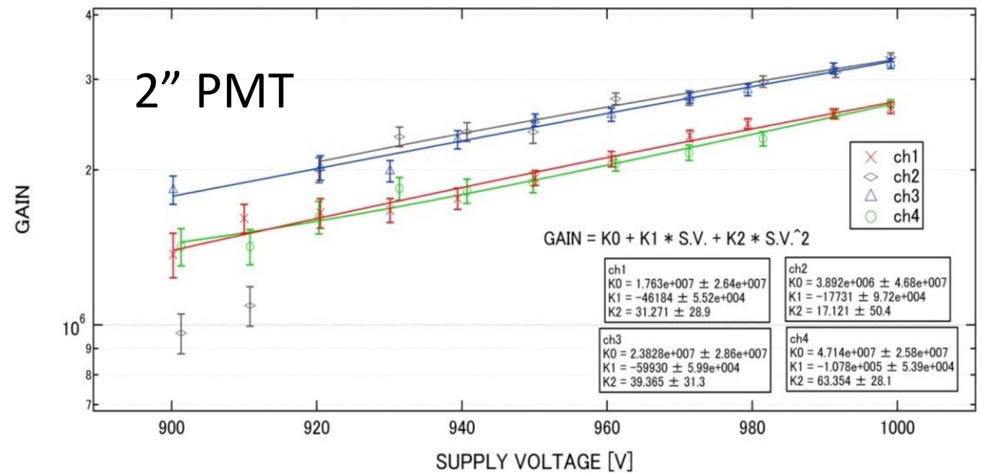

- I used polynomial function when I analyze the GAIN.

$$GAIN = K0 + K1\ \times S.V. + K2\ \times S.V.2$$

(S.V. : SUPPLY VOLTAGE)

# Results



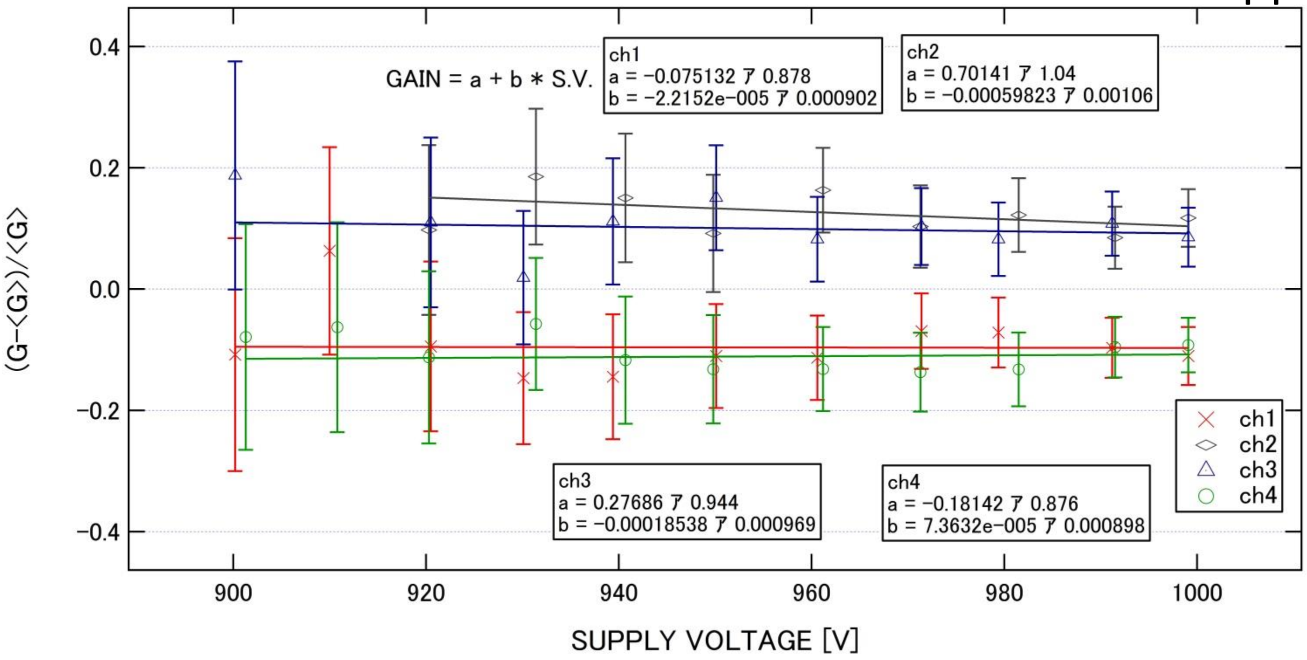




Both 1” PMT and 2” PMT show good linearity of GAIN.
And each channels of 2” PMT shows a little difference.
I guess this is due to the different intensity between each (64) channels.

# (G - <G>) / <G> (for R10551)

I calculated differences from average (of all channels) in each SUPPLY VOLTAGE.

line approximation




Only ch2 shows the slop, but others show the flat.

# PMT calibration (with cryostat)

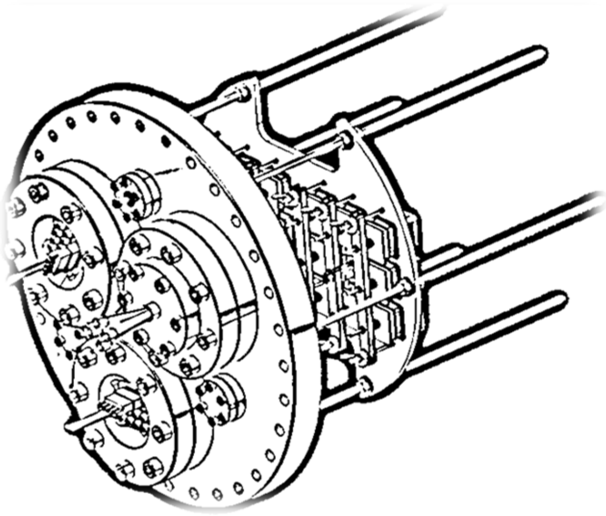
# PMT calibration (with cryostat)

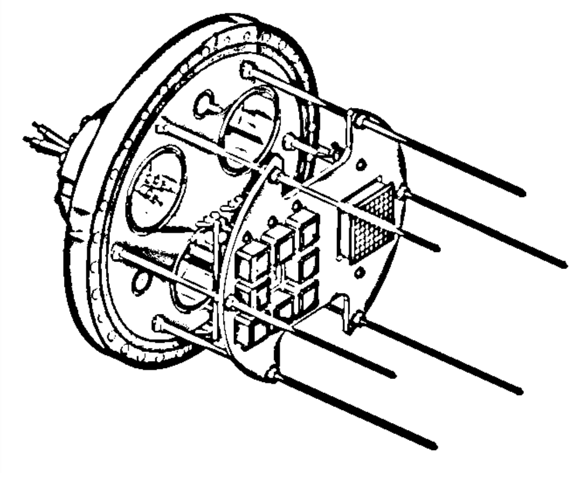
- We used **PMT test station**.

($T_{set}$ **: -110 – -106℃**, $T_{real}$ : **-103.2**, **-101.5**, -**99.9**℃)

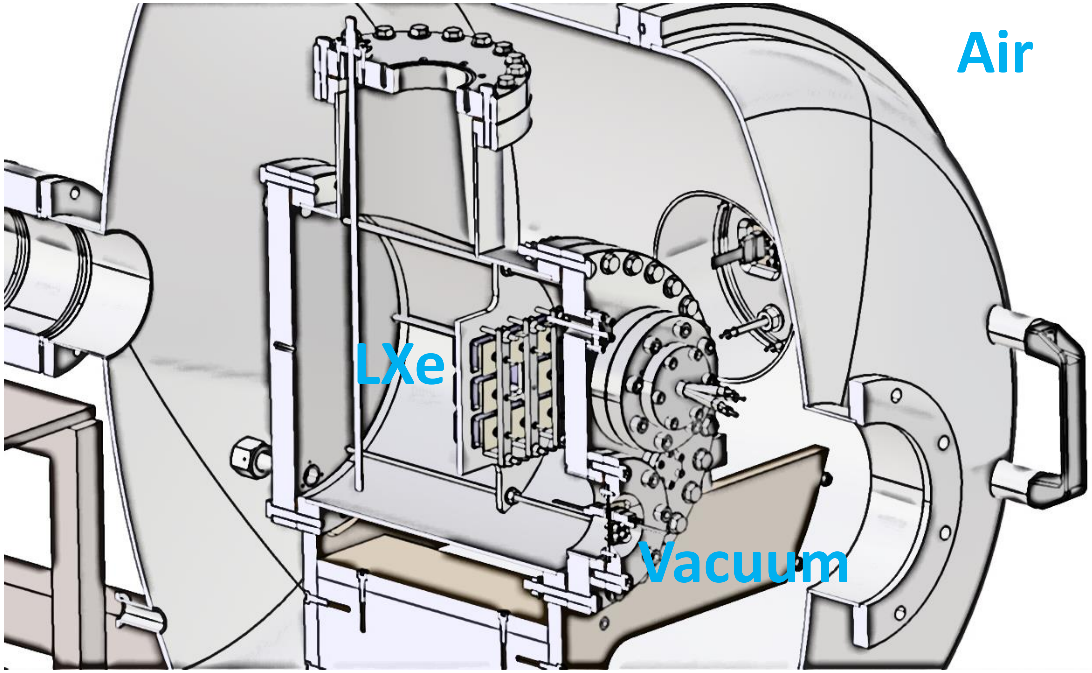
- We used same LED.
- Supply voltage of R7600 was set to **740 - 900** V.
- Supply voltage of R10551 was set to 900 - 1000 V.
- We got linearity of GAIN.
- **We checked the dependency of range of integral, frequency of light source, and temperature of Xenon.**

# PMT test station



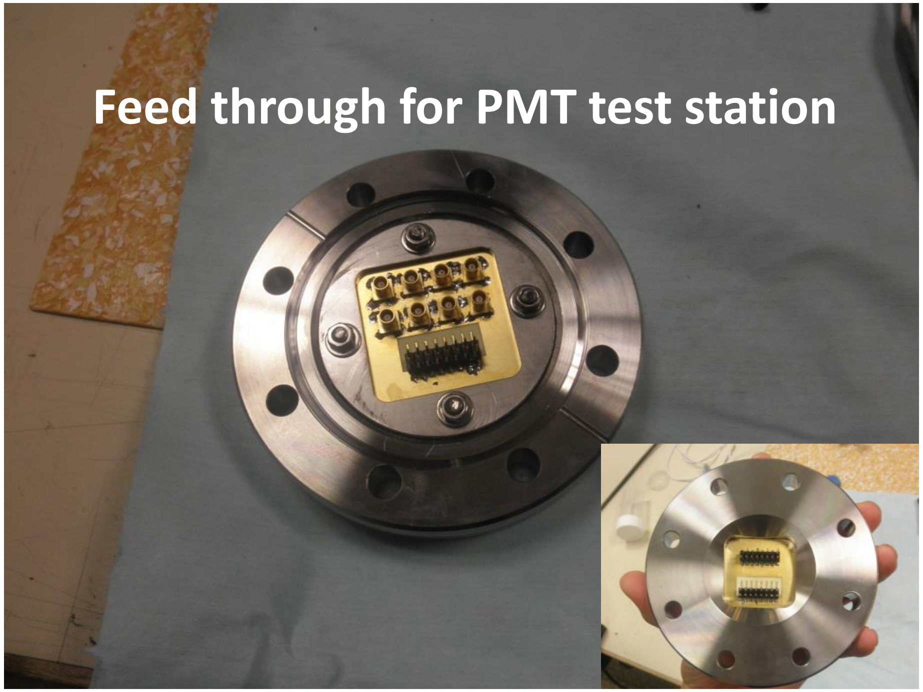


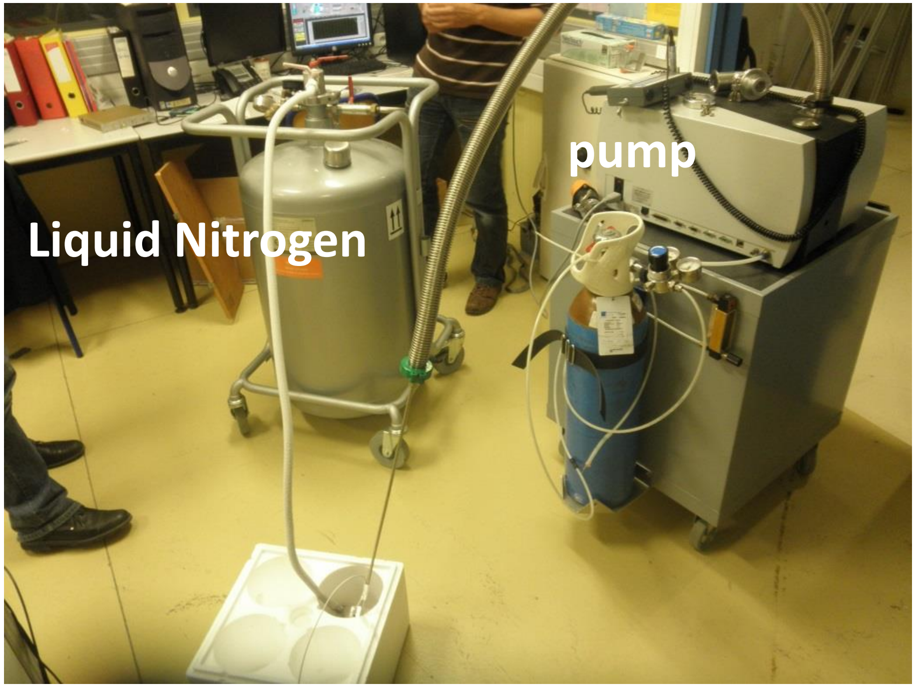
This time, 1 x 2”PMT and 4 x 1”PMTs were set to PMT test station.



# Feedthrough test

We tested the feedthrough for PMT test station at first.
By using liquid Nitrogen, we put it into low temperature condition and checked leak of vacuum.

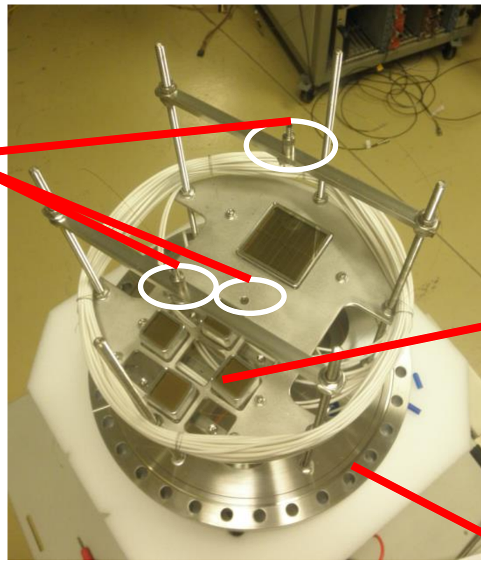


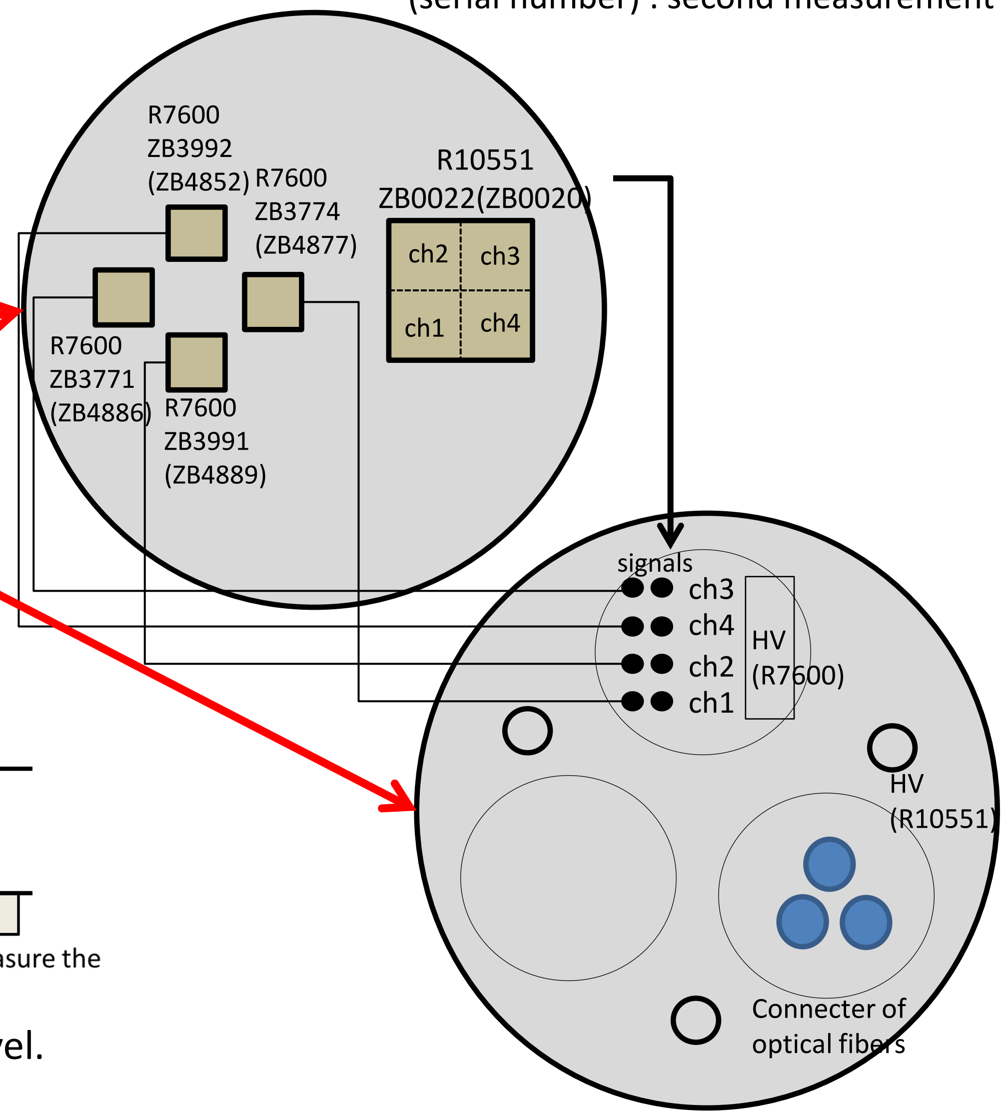




No issues found.

# Set up

(serial number) : second measurement

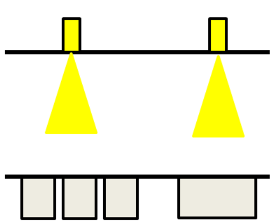




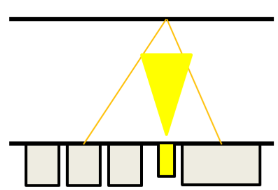

Light source : LED (yellow right)

Position : front

horizontal
side view



Position : inverse



In this position, we measure the reflex light.

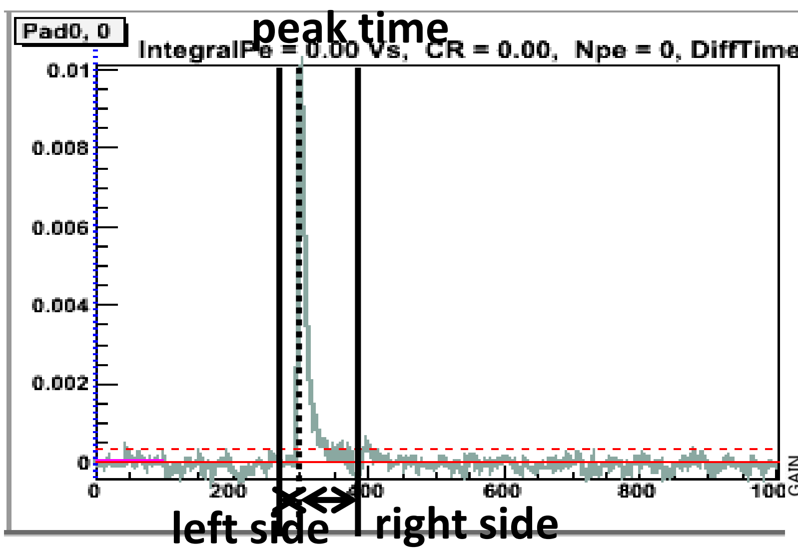
Light source is set to single photo electron level.

# Analysis contents

- Integrating range
- SUPPLY VOLTAGE vs GAIN
- Checking stability
  - Dependency of frequency of light source
  - Dependency of LXe temperature

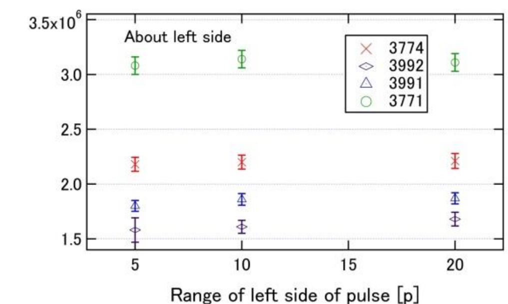
# Integrating pulse

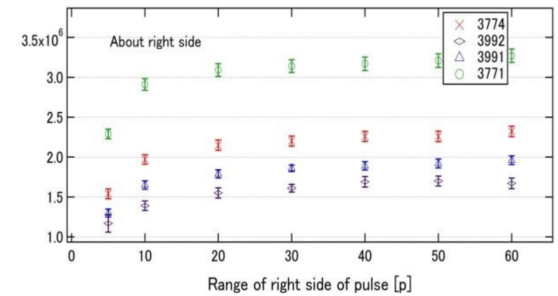
- First, finding the peak time of each pulse
- Second, setting the range of left side and right side of each pulse from peak time



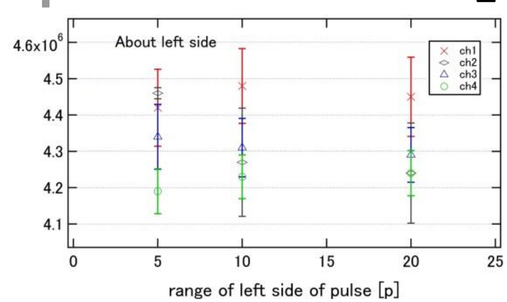

1” PMTs

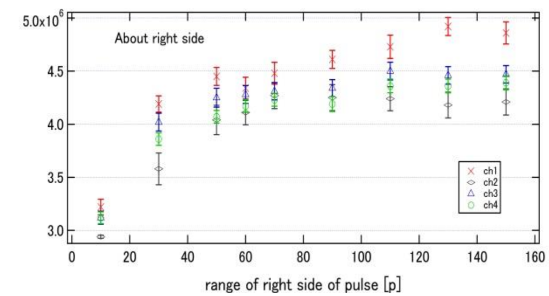
1 p = 0.5 ns




2” PMT



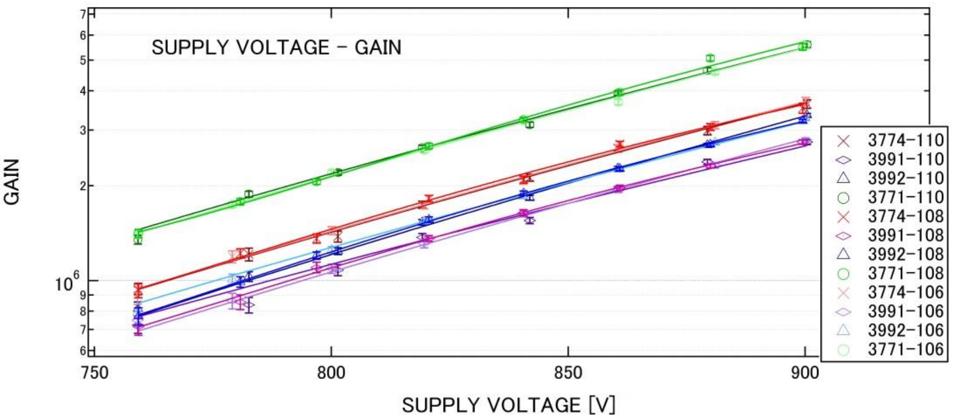



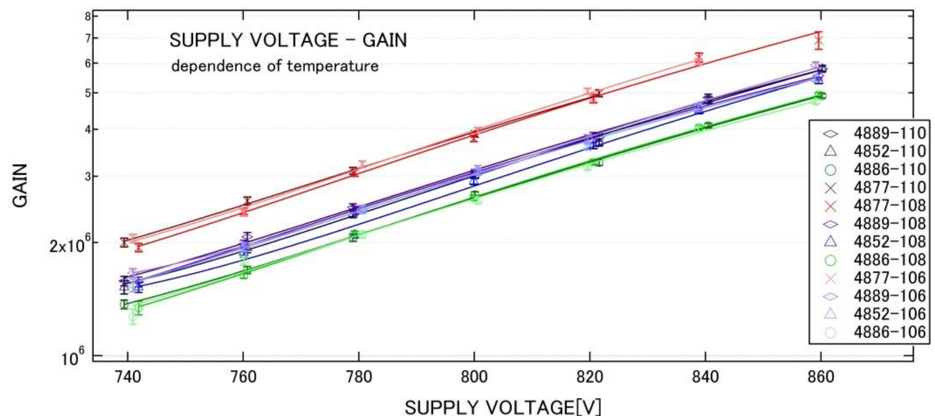

1” PMTs : left = 10 p, right = 30 p

2” PMT : left = 10 p, right = 60 p

# SUPPLY VOLTAGE vs GAIN

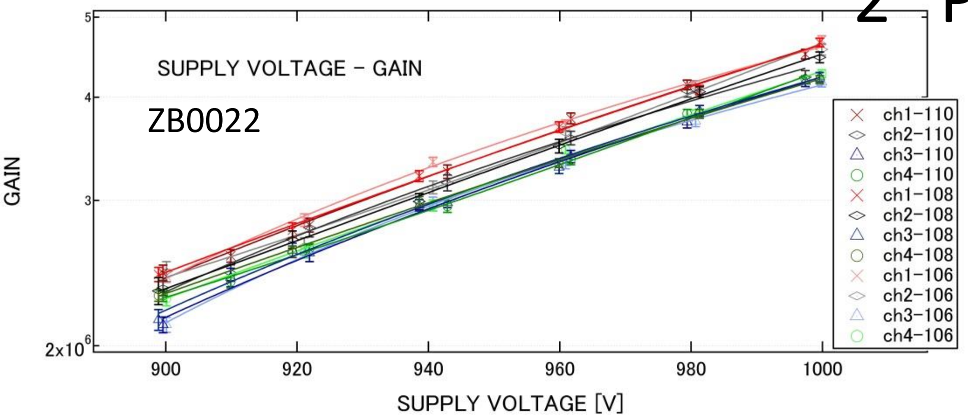
## 1” PMTs

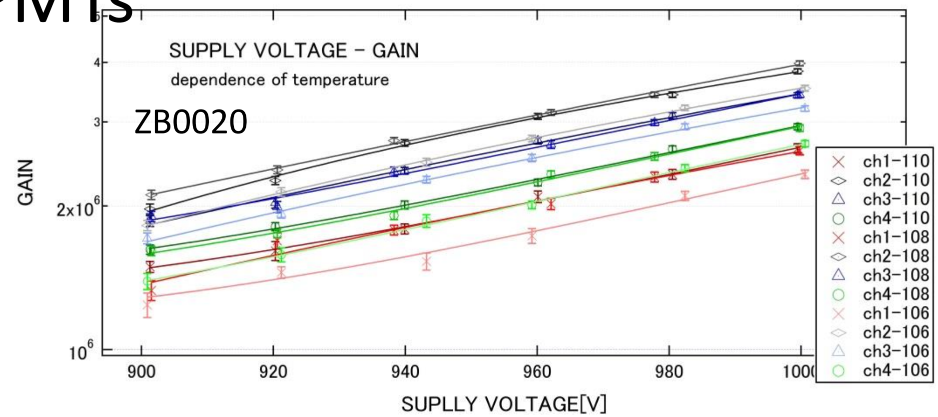



| | | |
|---|---|---|
| -106 (-99.9) : light color | -108 (-101.5) : in-between color | -110 (-103.2) : dark color |

## 2” PMTs

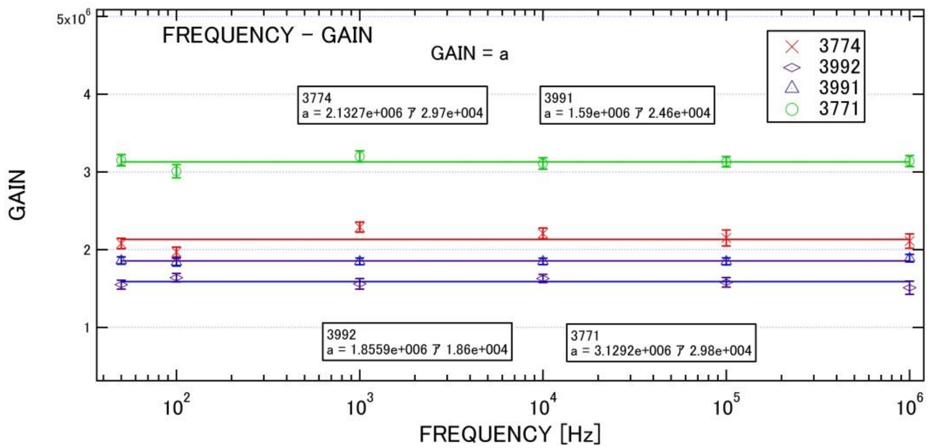


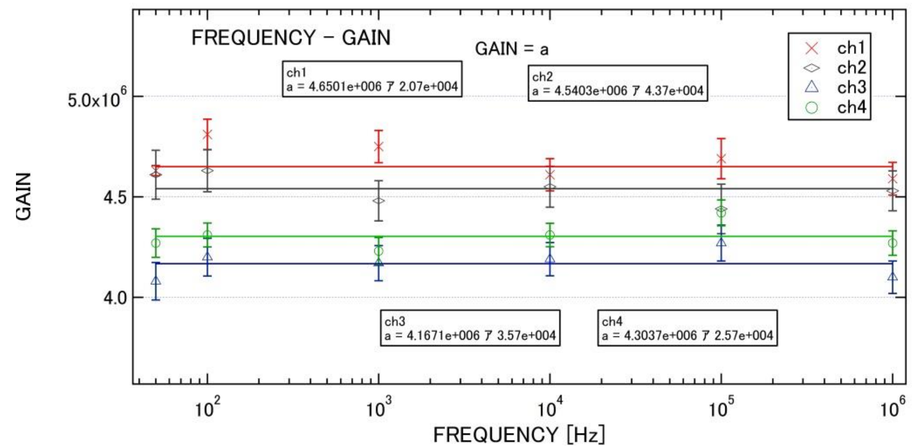

We got good linearity.

# Dependency of trigger rate

1” PMT




2” PMT

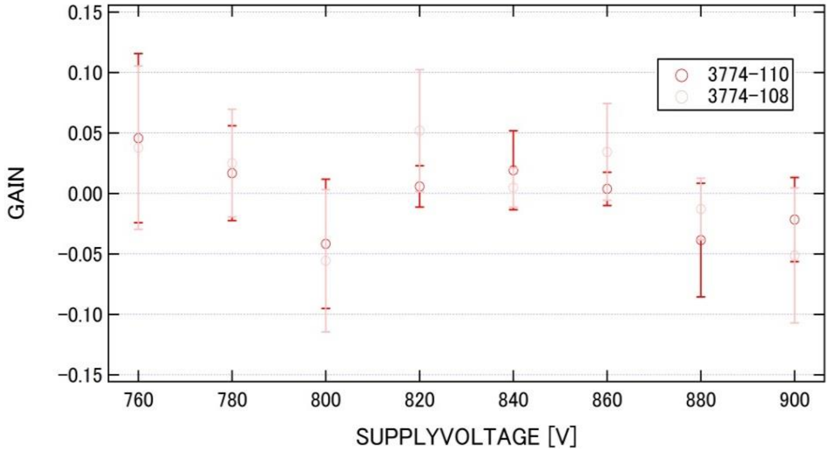



GAIN doesn’t depend on the frequency of light source in 50 Hz – 1 MHz range.

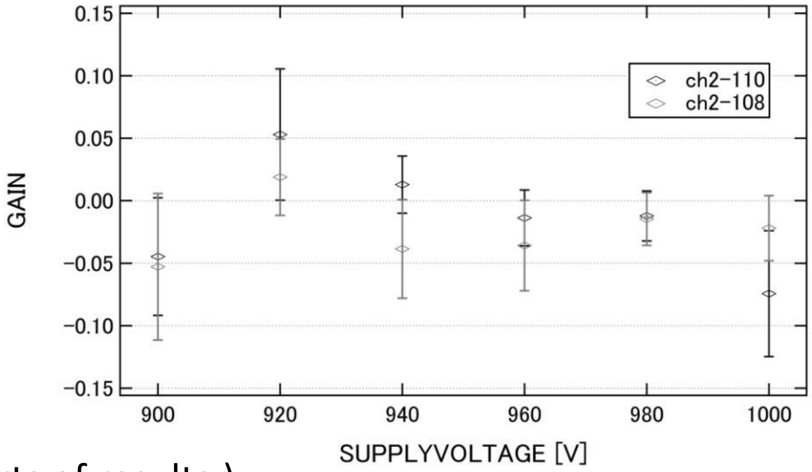
# Dependency of T ($(G_{110or108}-G_{106})/G_{106}$)

By setting data of -106℃ to standard, I calculated the difference of each temperatures.

1" PMT




2" PMT




(These are parts of results.)

GAIN doesn't depend on the temperature of LXe in -103.2 – -99.9 ℃ range.

# Conclusion

- PMT calibration

We tested 8 x 1” PMTs and 2 x 2” PMTs for XEMIS2.

This time, all of them worked perfectly from room temperature to liquid Xenon one. Then, we got the very nice single photoelectron signal spectrums and measured the good linearity.

We didn’t find the dependency of frequency of light source and temperature of liquid Xenon.

Next, we will test other PMTs and check the dark current rate, noise…..

# GATE simulation study

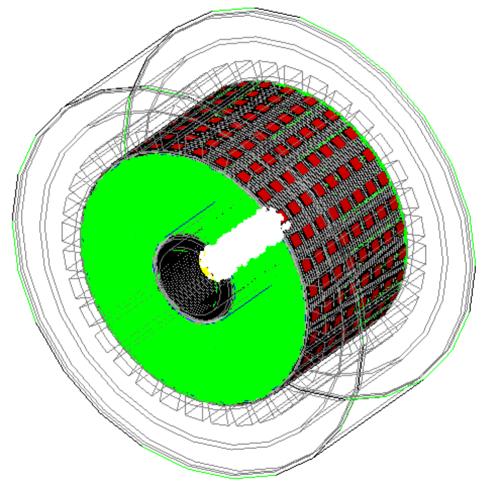
# About GATE

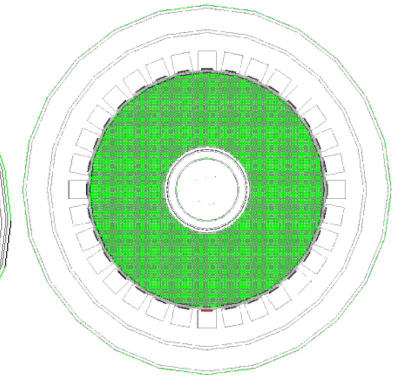
- In each simulation, user has to :
  1. define the geometry, source, and parameter (e.g. Q.E.)
  2. set up the physics process
  3. initialize the simulation
  4. specify the data output format

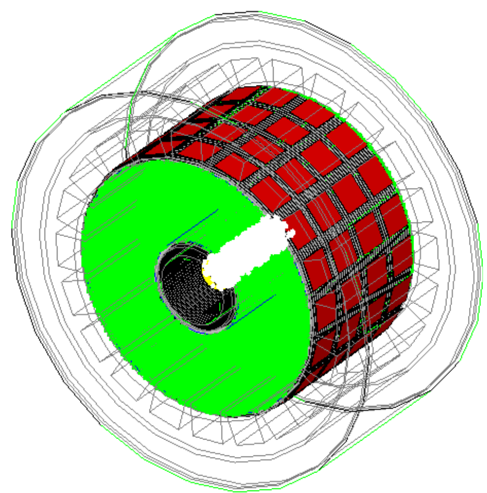
- This time, I changed geometry, source, and analysis programs.
- I mainly studied how to analyze the data by using ROOT Trees which are generated by Gate and evaluate the trigger which is decreased by electric field.

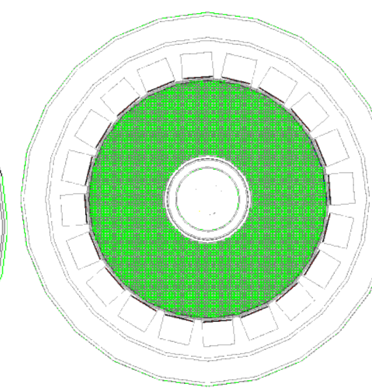
# Geometry

- radial 7 < r < 19 cm
- axial (z) Length = 2 × 12 cm (divided by cathode)
- Electric Field in z direction 2 kV/cm
- FEE 3.175 x 3.175 $mm^2$
- Source $^{44}Sc$ ($\beta^+$, $\gamma$ : 1.157 MeV)
- Size of source (cylinder : R = 2.5 cm z = 15 cm)
- PMTs
    - 1 inch : 8 x 32 (1.8 x 1.8 $cm^2$)
    - 2inch : 4 x 20 (4.624 x 4.624 $cm^2$)









# Source

- In GATE simulation, we can use Geant4 library for $\gamma$-source.
- This time, I used $^{44}Sc$ source of Geant4 library.
- Main decay process

$$^{44}Sc \rightarrow {}^{44}Ca + \beta^{+} + \nu_e$$

- In this process, electron capture is sometimes occurred.
- Geant4 library follows many processes of $^{44}Sc$.

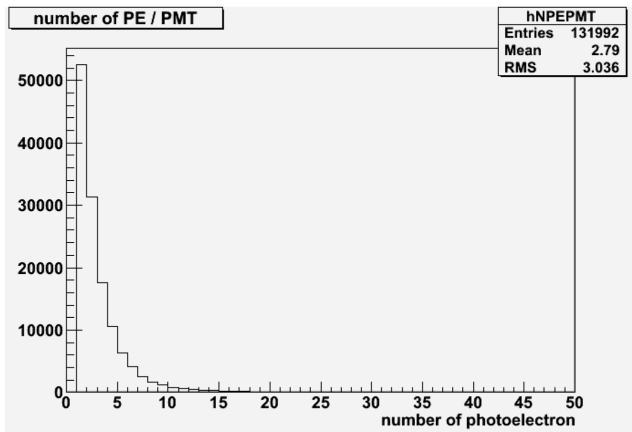
# Analysis programs

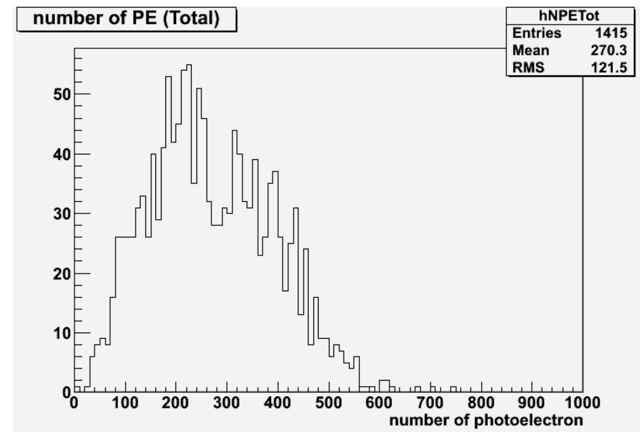
- I made some histograms for evaluation of trigger.
- First one shows how much photoelectron is detected by one PMT (or all PMTs) in each event.
- Second one shows how long time it takes between detection of optical photon and interaction in liquid Xenon.
- Finally, I made the graph which shows the information of uphold and threshold.

# Histogram of nb of PE

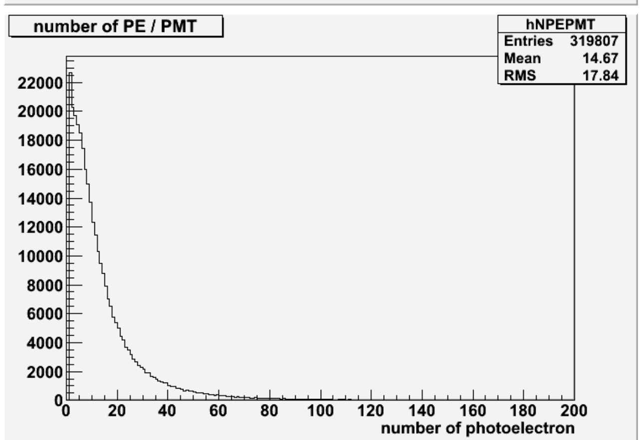
- At first, I made the histogram of number of photoelectron.

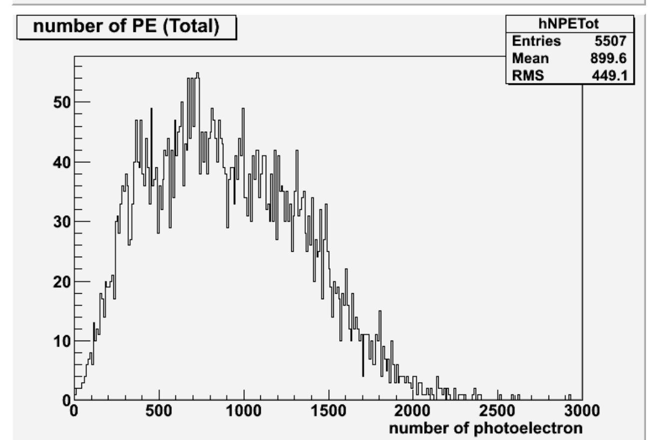
1” PMTs



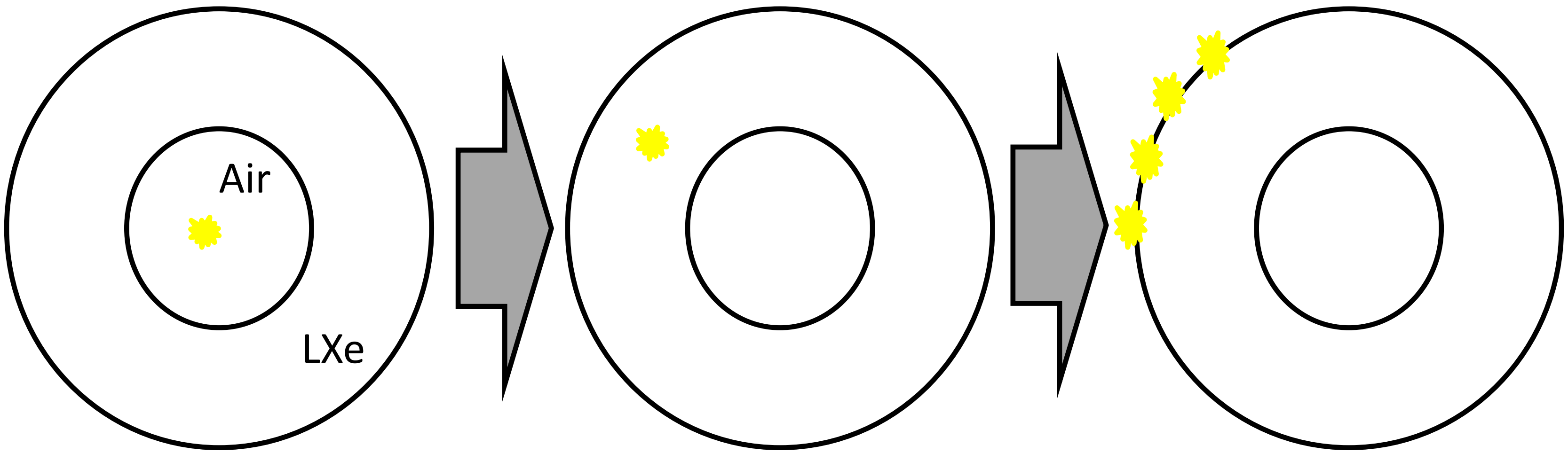

2” PMTs




Mean : 2.79 -> 14.67

# Histogram of delta time



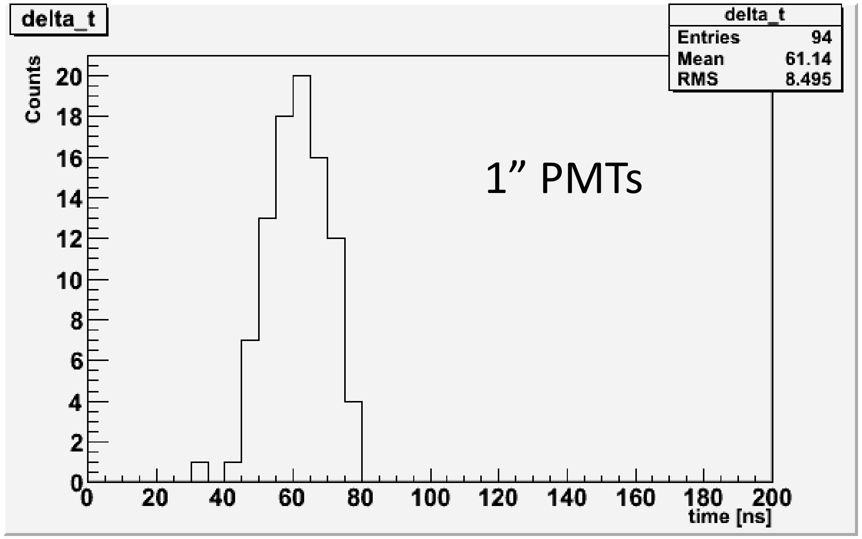

| | | |
|---|---|---|
| Gamma-ray is generated. In this time, eventID is generated, too. | Gamma-ray interacts with liquid Xenon. In this time, measurement of time is started. | Optical photons are detected by PMTs. In this time, measurement of time is stopped. |

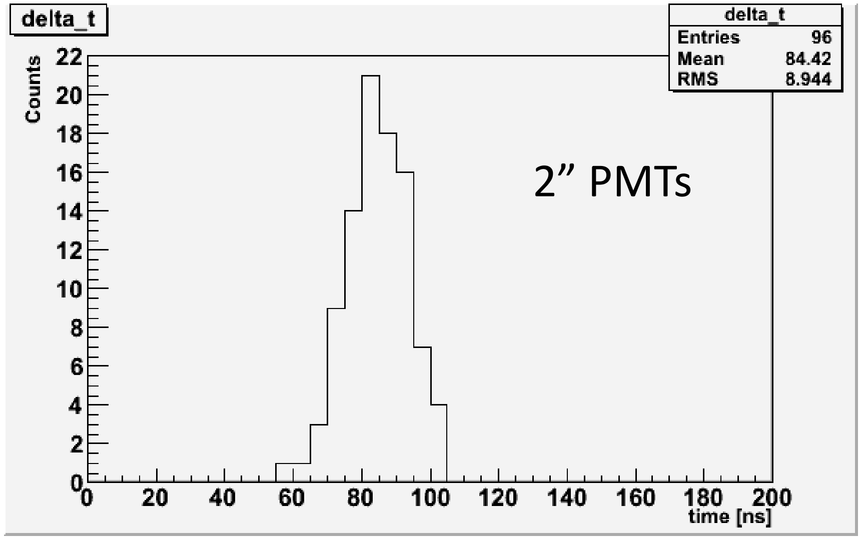
$$\Delta t = < t_{detected} > - t_{generated}$$

If particles have same eventID, I execute this measurement.

# Histogram of delta time

- These histogram show the time difference between detection of optical photon and interaction in liquid Xenon.

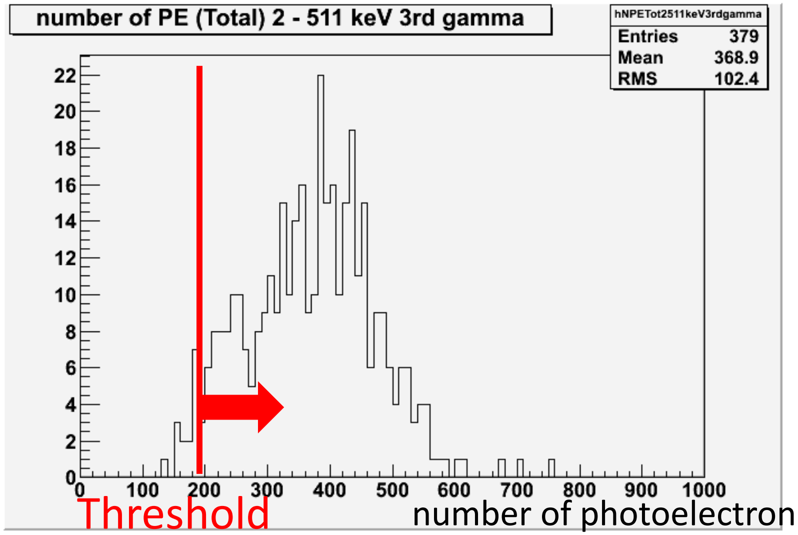


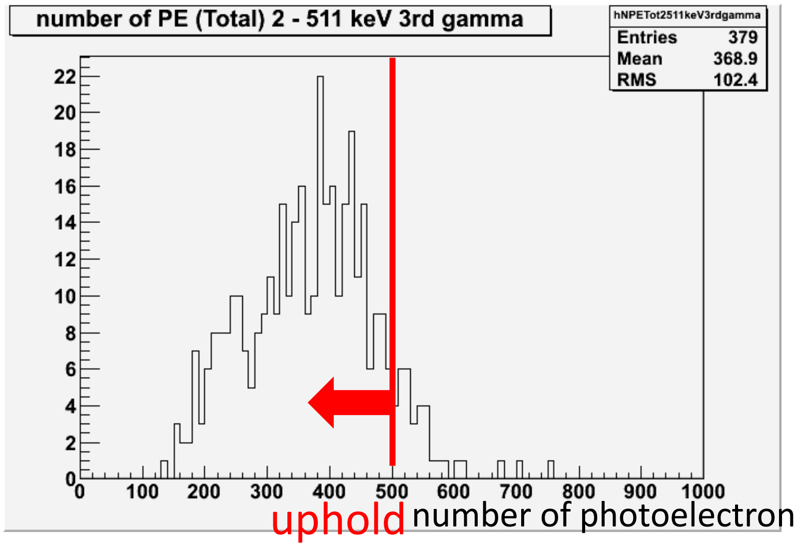

- There is 20 ns difference between the mean of 1” PMTs one and 2” PMTs one. I will modify the method to measure the time on each PMTs. (leading edge, CFD, DTD, …)

# Uphold and threshold

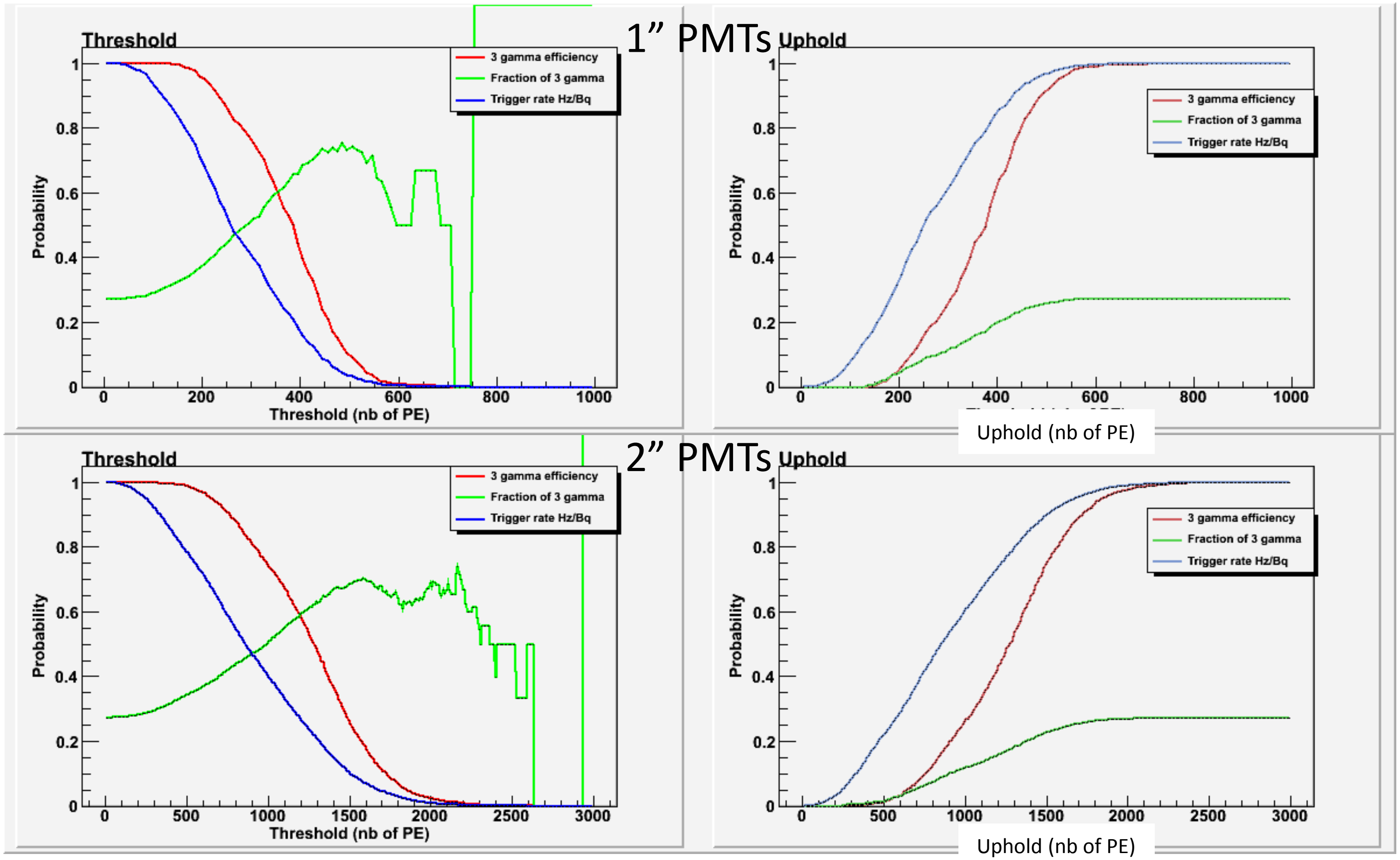
- In this program, I considered the events which generate two gamma (back to back) and 3rd gamma at the same time as good event.
- This program set the threshold and uphold (number of photoelectron) and calculated the integral of good events and total events (and these ratio) from threshold or until uphold.




or



# Uphold and threshold




- 2” PMTs one shows higher value, which is useful for setting threshold, but about ratio (green line), 1” PMTs one shows higher maximum.

# Conclusion

- Gate simulation study

I changed the geometry and made some histograms for evaluating trigger.

In all cases, the results of 2” PMTs shows better value than 1” PMTs one. So, the 2” PMTs will be very adapted to upgrade XEMIS2.

Next, we will consider how to decide the threshold of trigger and establish precious simulation program for reconstruction of source.

# General conclusion

- Through internship

I learned a lot of things and modified many my skills.

It was very nice for me to be able to engage in research.

For the next, I surely learn French.

This experience will be very important for my life. In the future, I will never forget this internship.

Good luck for future study.

# Merci beaucoup