MEG II実験液体キセノンガンマ線検出器性能のモニタリング (THE MONITORING FOR THE PERFORMANCE OF THE MEG II LIQUID XENON GAMMA RAY DETECTOR)

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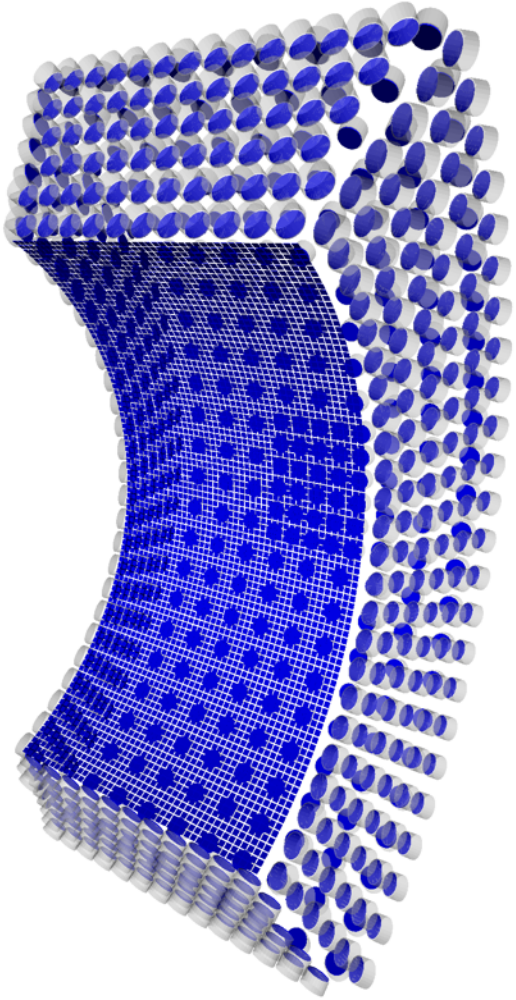
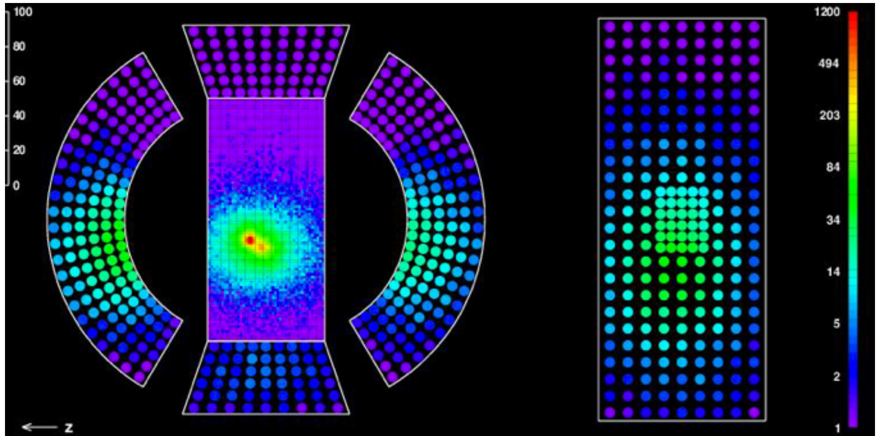
LIQUID XENON GAMMA RAY DETECTOR

- We use 900L liquid xenon detector to measure the energy, position and timing of gamma-ray from $\mu \rightarrow e\gamma$ decay
- 4092 MPPCs on the gamma-ray entrance wall
- 668 PMTs on the other walls
- MPPCs and PMTs detect scintillation light of liquid xenon from gamma-ray



event example (simulation)



LIQUID XENON MONITORING

- Monitoring is needed to confirm the stability of liquid xenon detector to achieve the aimed energy resolution
- The examples of monitoring:

1. Stability of PMT & MPPC characteristics against temperature; for detector performance stability
2. **Purity of liquid xenon; for light yield stability**

LIGHT YIELD PROCESS

- There are two kinds of scintillation process for liquid xenon;

1. Excitation process:

$$\mathrm{Xe}^* + \mathrm{Xe} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Xe},$$
$$\mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + h\nu,$$

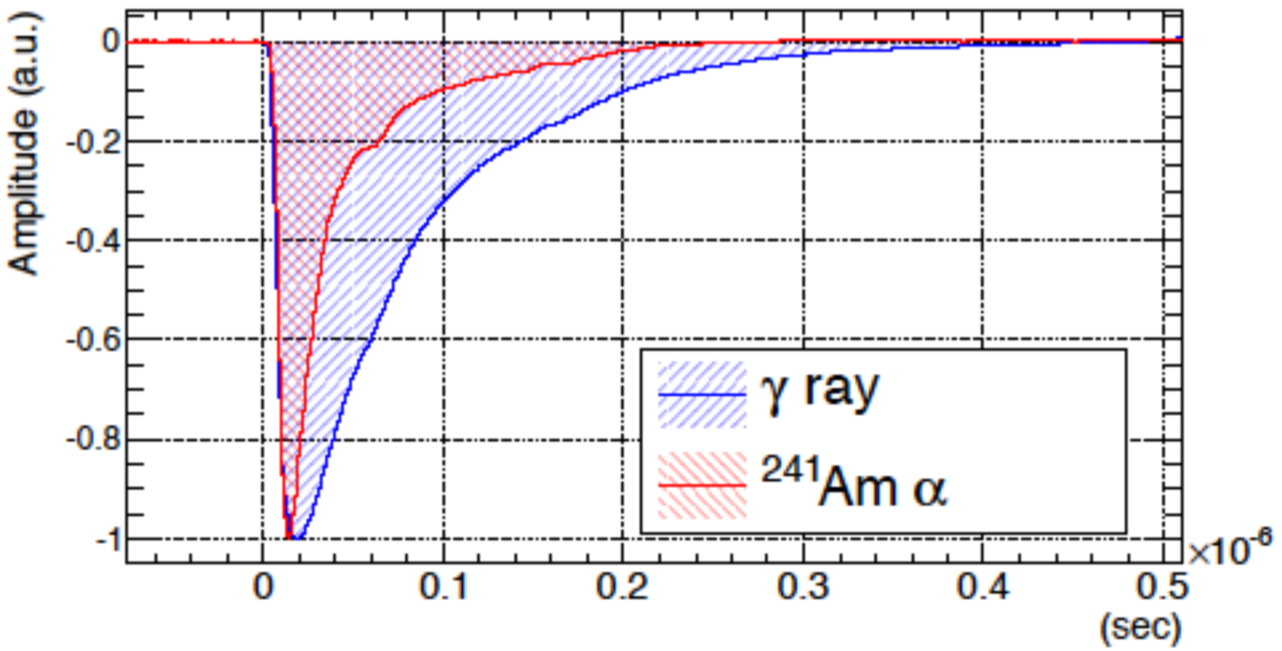
   - Two components of excimers Xe_2^* decay with singlet state $^1\Sigma_u^+$ (4.2ns) and triplet state $^3\Sigma_u^+$ (22ns)

2. Recombination process: dominant in scintillation by electrons and gamma rays
   - Time for decay component = 45ns
   - slower than 1. due to the time to make excimers

$$\mathrm{Xe}^+ + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^+,$$
$$\mathrm{Xe}_2^+ + e \rightarrow \mathrm{Xe}^{**} + \mathrm{Xe},$$
$$\mathrm{Xe}^{**} \rightarrow \mathrm{Xe}^* + \mathrm{heat},$$
$$\mathrm{Xe}^* + \mathrm{Xe} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Xe},$$
$$\mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + h\nu,$$

SIGNAL FOR MONITORING

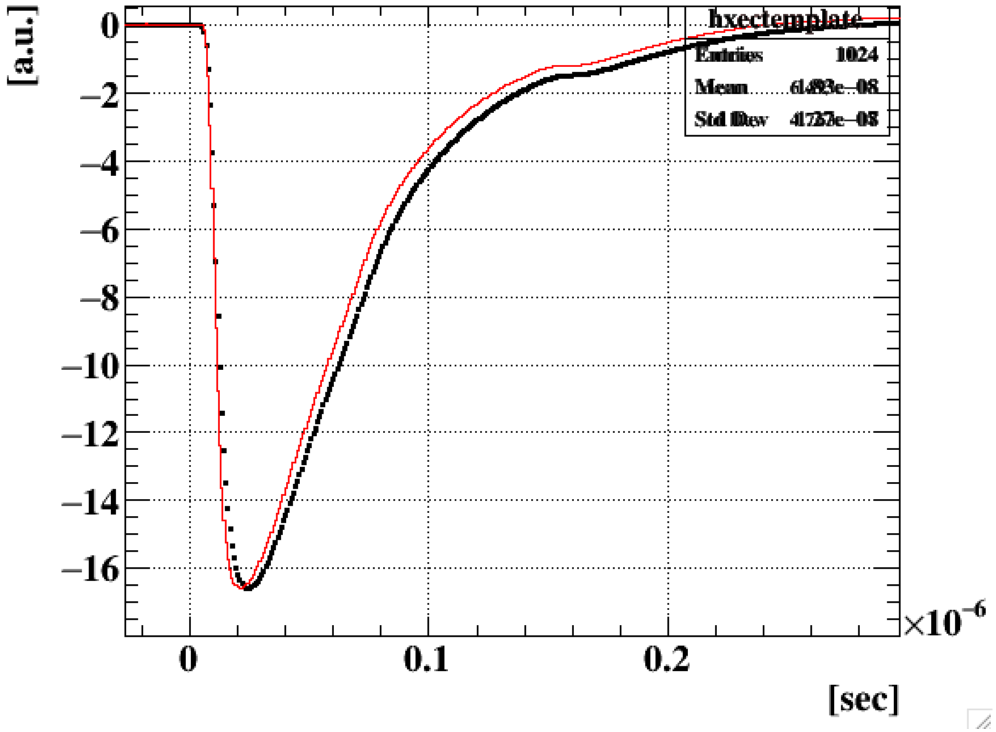
- Purity of liquid xenon was monitored with two kinds of events; **alpha ray** and **cosmic ray**
- Due to the difference of energy deposit density, alpha ray and cosmic ray signal have different response
- Alpha: shorter decay time
  - energy deposit area is small, and Xe^+ & e^- recombine immediately
- Cosmic ray: longer decay time
  - large energy deposit area, and Xe^+ & e^- do not recombine immediately →recombination process



waveform obtained in MEG I

COSMIC RAY

- The role of cosmic ray: **monitoring the impurity that cause quenching**
  - Quenching: energy of excimer is deprived by impurity
  - Slower time component decreases by quenching
- We can monitor the change of pulse shape as the impurity change
- Pulse gets wider (decay time longer) as the purification progresses
- The decay time converges to 45ns; time for recombination process

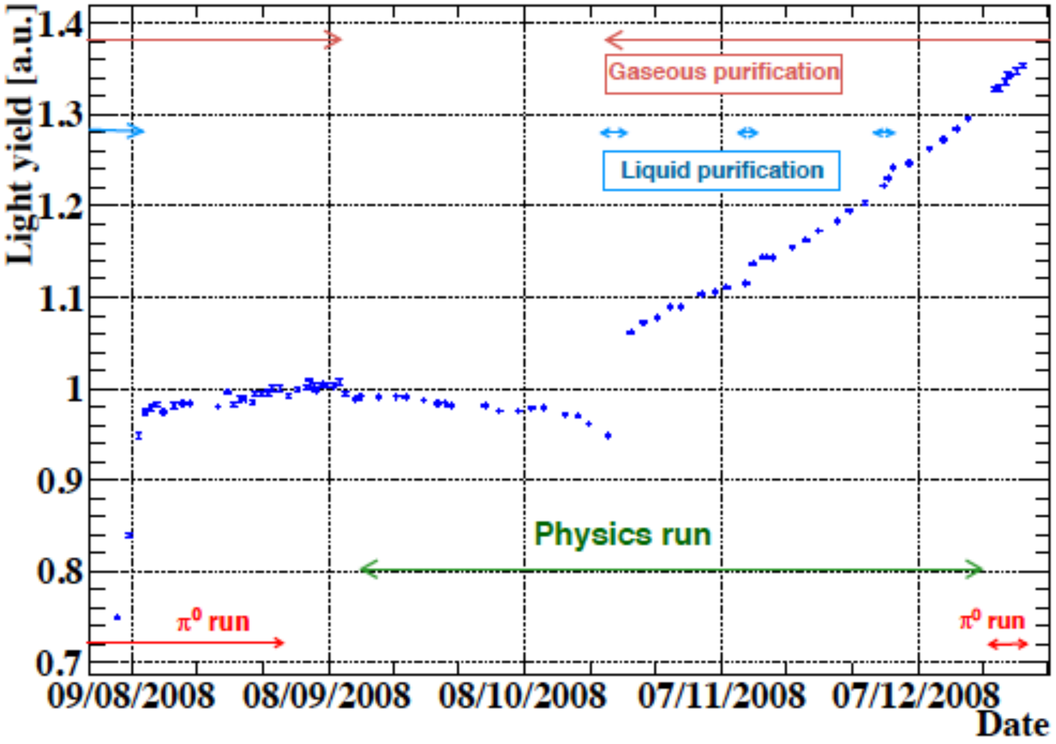


<u>change of PMT waveform</u>

red: just purification started
black: 40 days later

ALPHA RAY

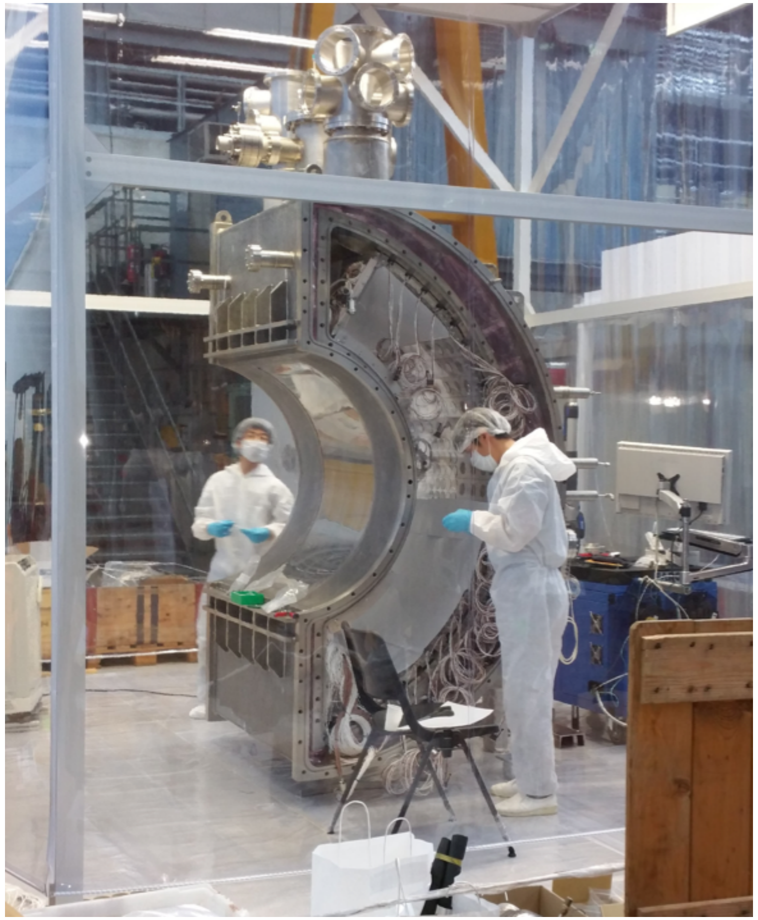
- The role of alpha ray: **monitoring the total light yield of scintillation light**
- Impurity absorb the VUV scintillation light of xenon; small number of photons increases the statistical uncertainty
- Alpha ray from alpha source; fixed energy and easy to monitor the light yield history
- Number of photons and attenuation length can be monitored



light yield change for MEG I (gamma-ray)

LIQUID XENON IMPURITIES

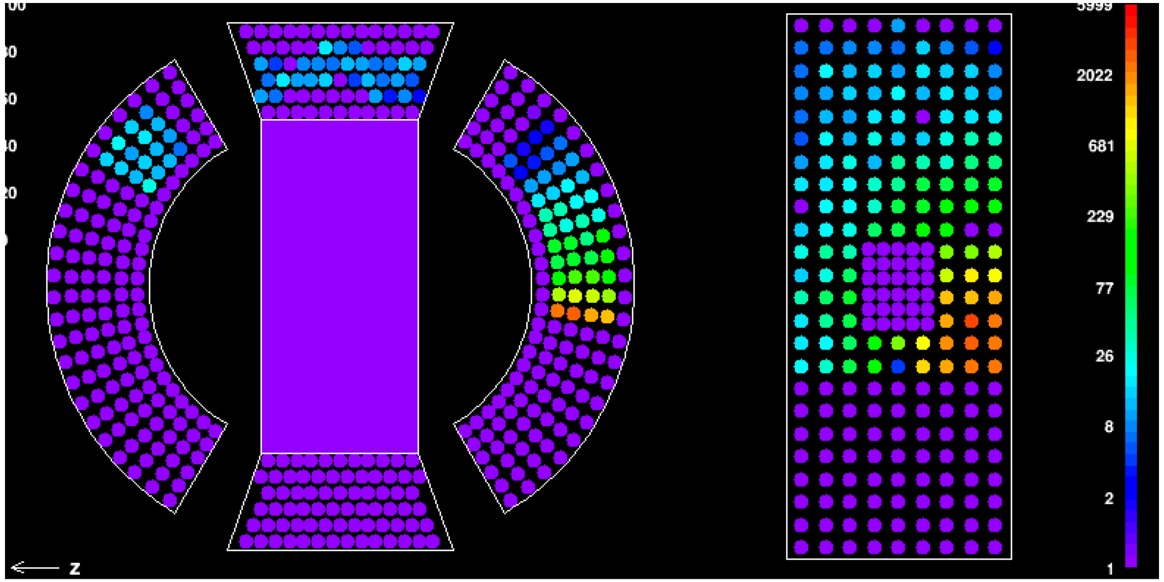
- The main impurity for liquid xenon scintillator:
  1. Quenching: oxygen, nitrogen…
  2. Absorption: water, oxygen…
- The construction of xenon detector was done in the clean room for water and dust not to stick inside the detector
- However, still contamination exists → circulation of xenon with purifier

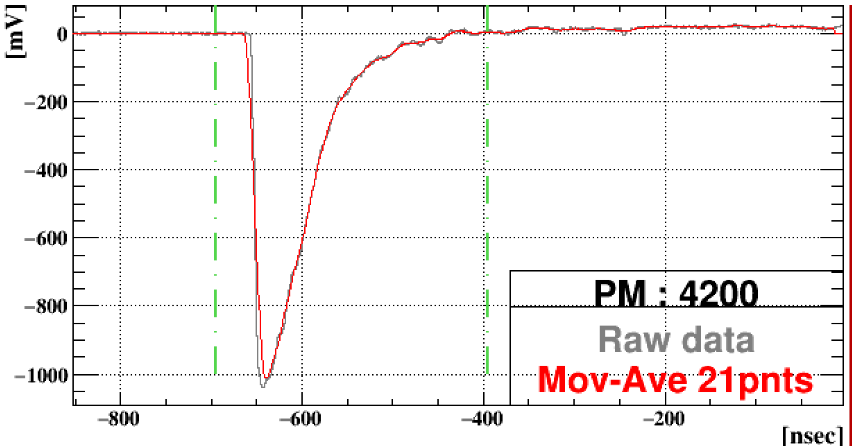


LIQUID XENON PURIFICATION

- Two kinds of purification is ongoing on MEG II liquid xenon gamma-ray detector;
  1. Gaseous xenon purification: removal of oxygen and nitrogen etc. with getter
     - circulation time: ~35 L/min
  2. Liquid xenon purification: removal of water etc. with molecular sieves
     - circulation time: ~40 L/hour

COSMIC RAY MONITORING



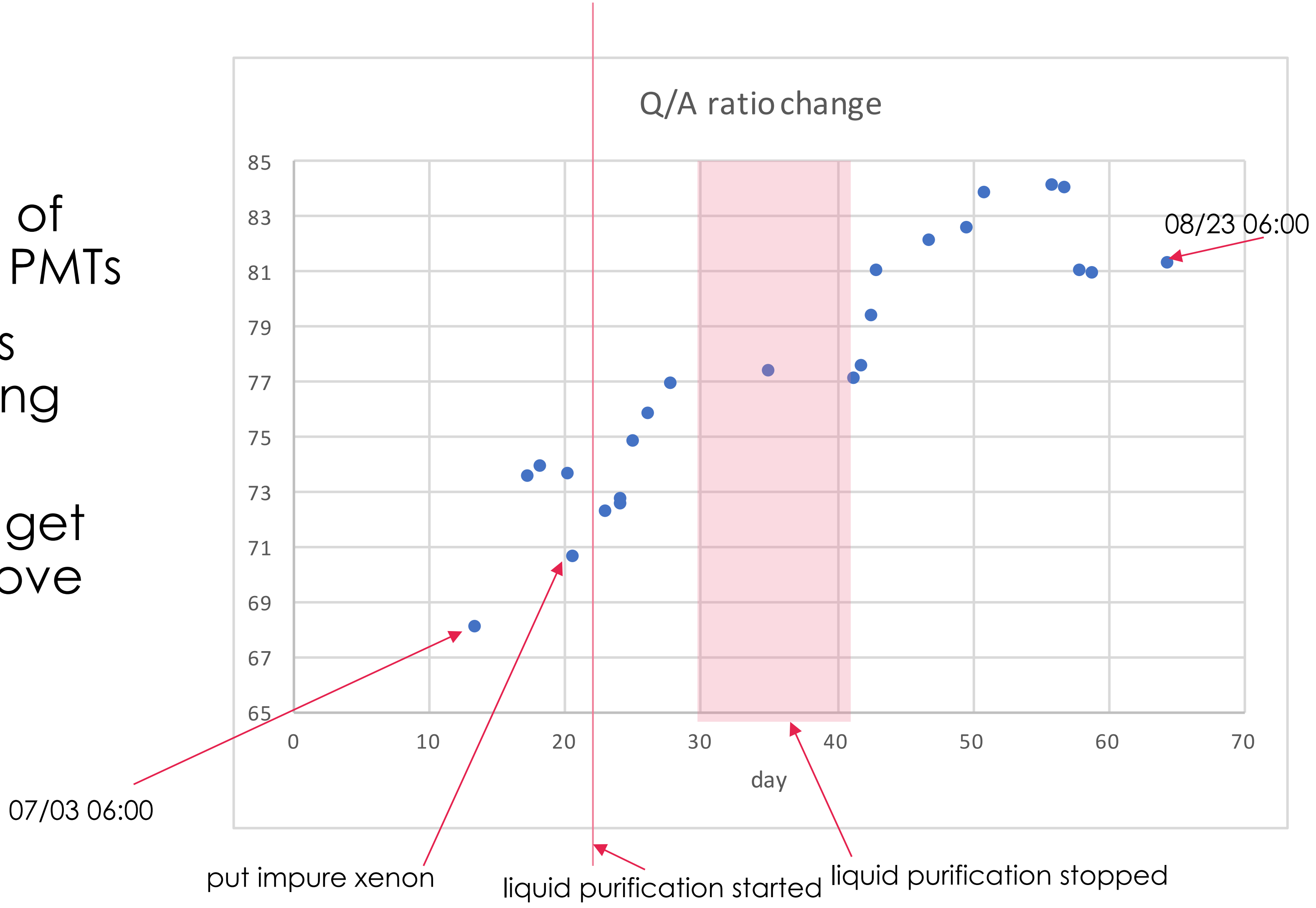


- The pulse shape change of cosmic ray was monitored for 2 months with PMTs
- Pulse selection was done by its height; higher pulse was selected as cosmic ray event
- Waveform of cosmic ray scintillation was averaged for all PMTs and events
- change of charge/height (Q/A) value of averaged waveform was monitored against time

(up) distribution of scintillated photons of cosmic ray event on the detector (purple channel: not used or dead)
(down) typical waveform of cosmic ray scintillation on a PMT

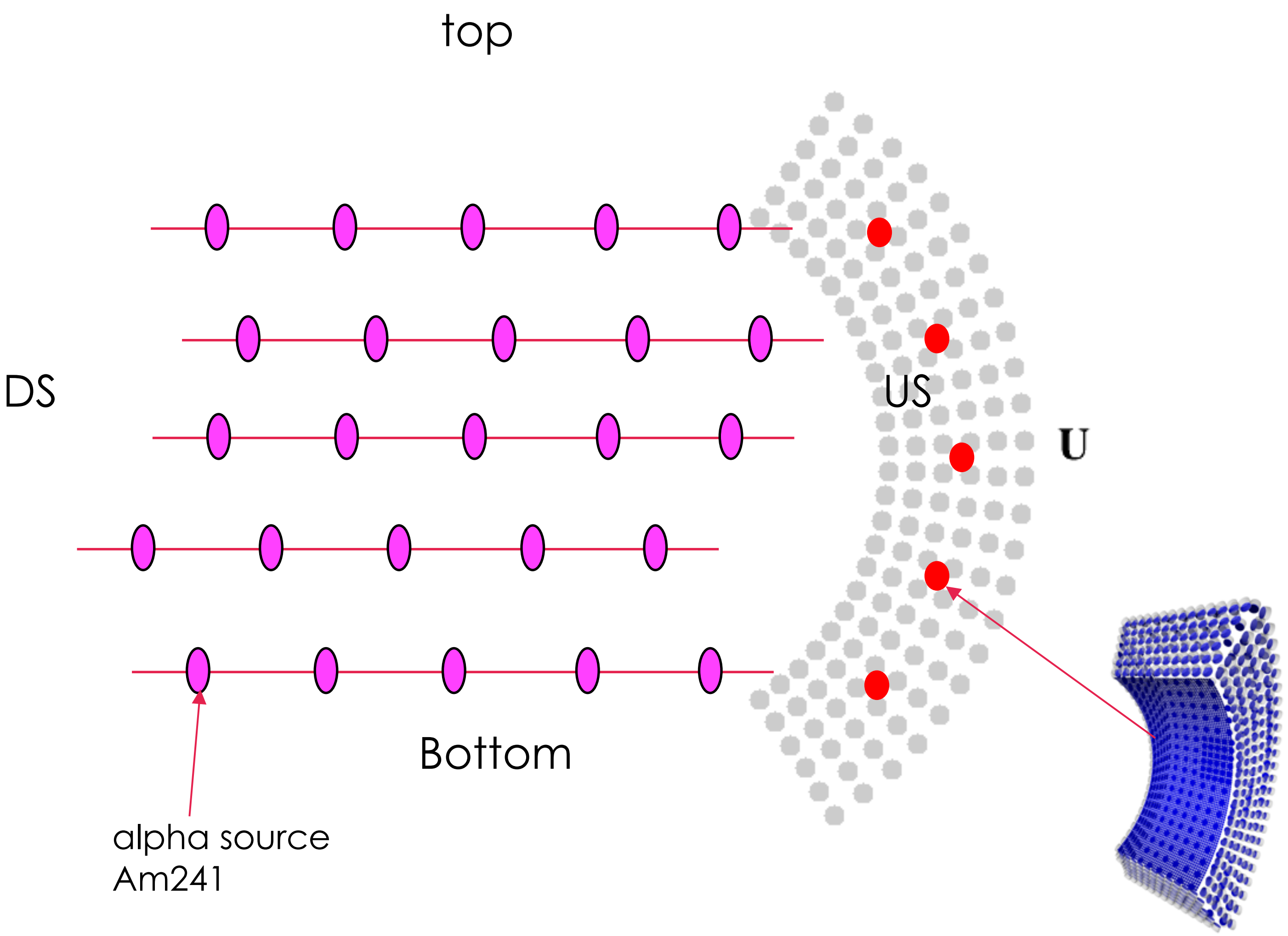
COSMIC RAY MONITORING

- The change of Q/A ratio of cosmic ray detected by PMTs
- Gaseous purification was ongoing before monitoring start (6/30~)
- The decay time of pulse get longer as the purity improve
- Exclusion of quenchable impurities is ongoing



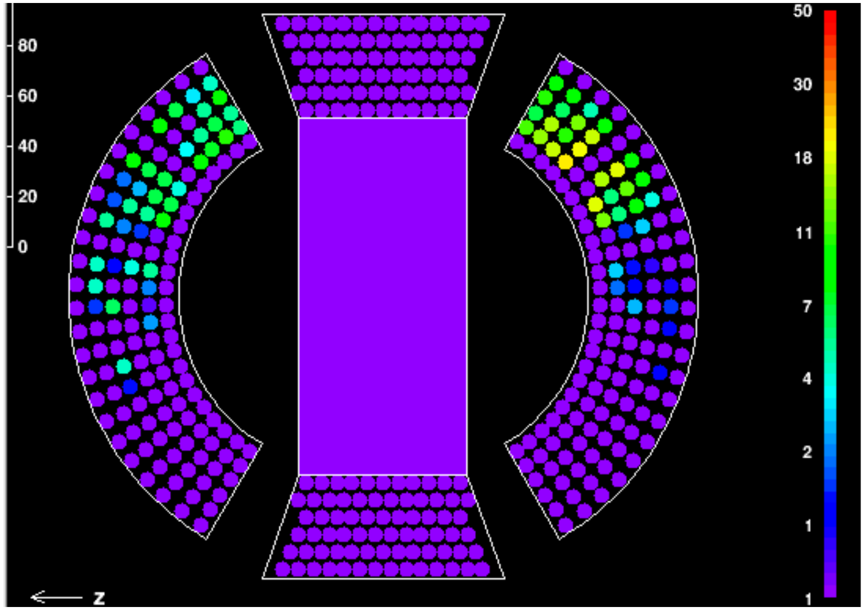
ALPHA MONITORING

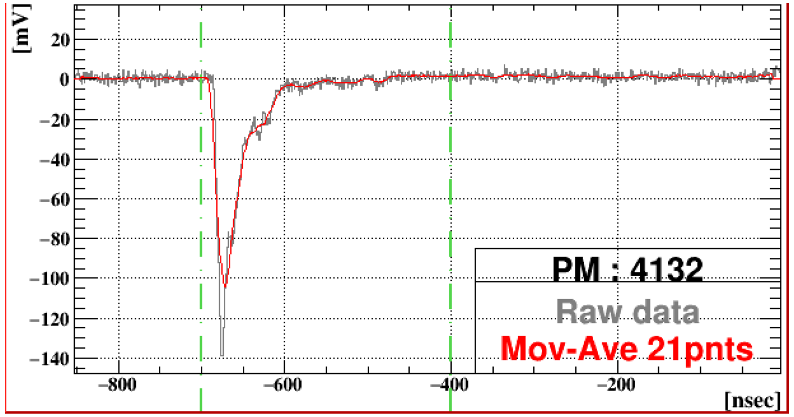
- The characteristics of alpha ray source used in xenon detector:
    1. Am241: 5.485MeV and 5.443MeV energy with 200 Bq activity;
    2. In total 25 sources (5 wire with 5 sources installed)
- Light yield was seen to check the change of the attenuation length; indicator of VUV-absorbent existence



ALPHA MONITORING

- Alpha events from alpha wire source were monitored for 2 months with PMTs
- Event selection: lower Q/A ratio events are selected
- Total number of detected photoelectrons were monitored using particular group of PMTs (not all PMTs were used)
- Number of photoelectrons were calculated from pulse integration and gain of each PMT

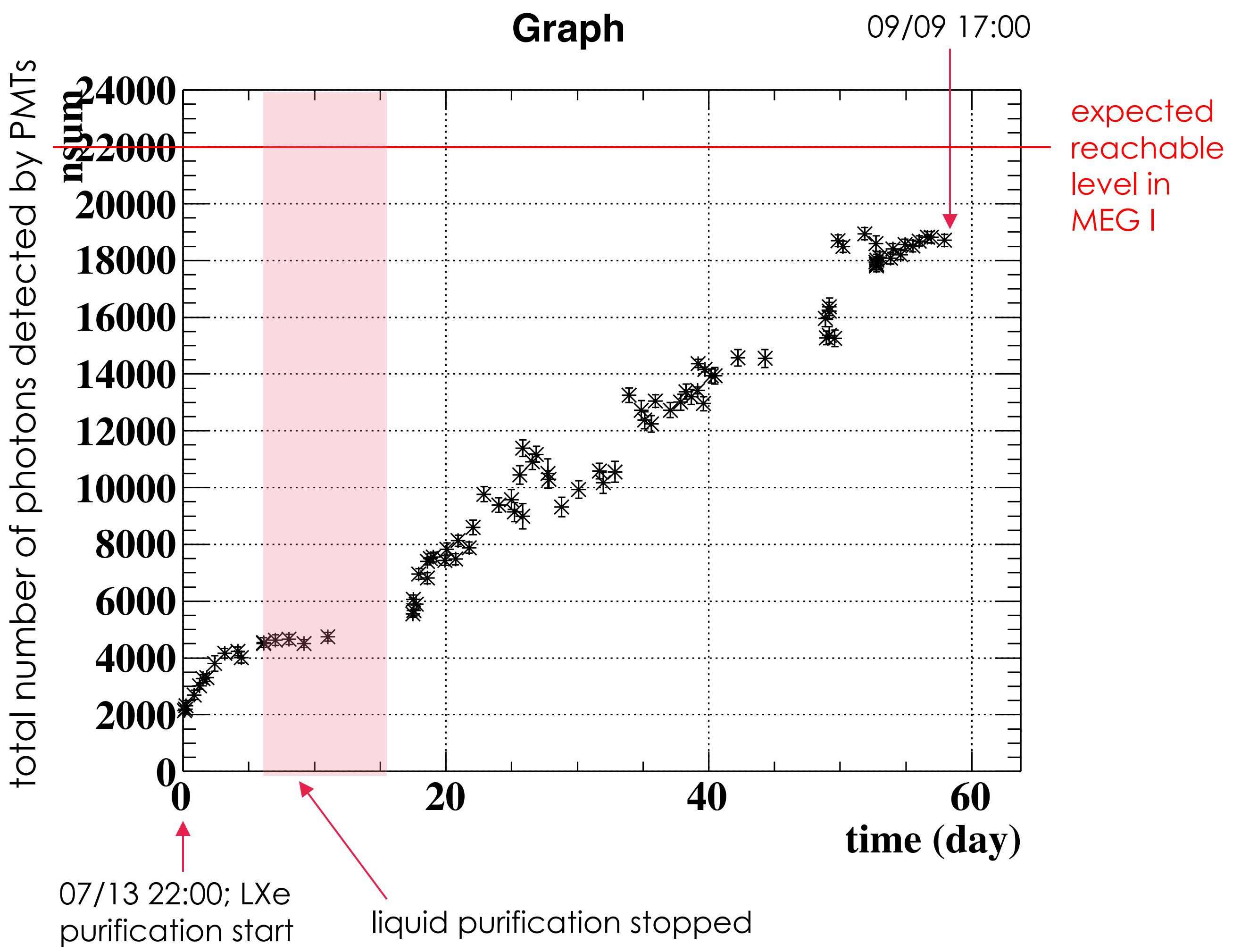




(up) distribution of scintillated photons of alpha event on the detector (purple channel: not used or dead)
(down) typical waveform of alpha scintillation on a PMT

ALPHA MONITORING

- The change of total number of photon against time (progress of purification)
- The light yield increased; attenuation decline
- It seems that light yield is still increasing (not yet saturated)
- We need to continue purification and monitoring

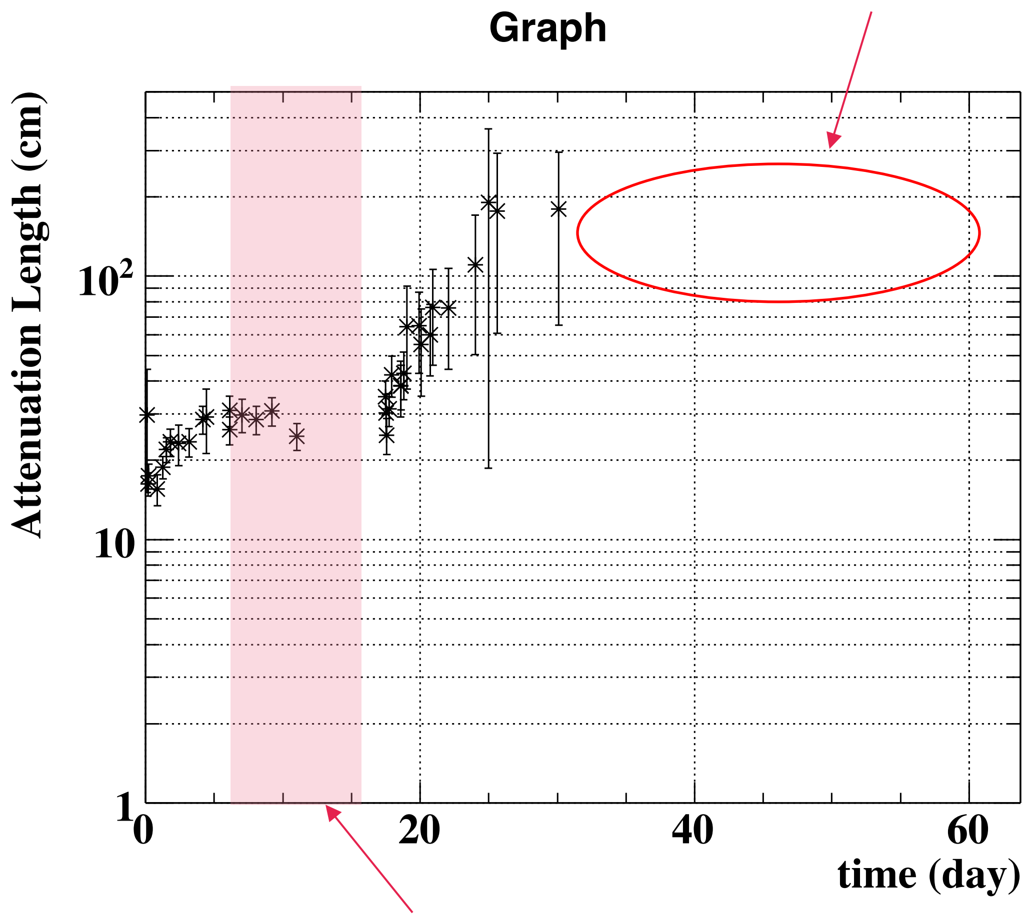


ALPHA RAY MONITORING

- Attenuation length of scintillation light in xenon detector
- Attenuation length is calculated by comparing measured data and MC simulation: $l = \frac{x}{\log(\frac{N_{MC}}{N_{measure}})}$
- It is impossible to obtain the attenuation length with proper value if the length is too long

→ the attenuation length now is longer than the detector size!

cannot be defined



liquid purification stopped

NEXT TO DO

- Continue the monitoring of purity improvement
- Monitor the stability of the gamma ray detector
- Stability is now monitored with LED, but still the detector is unstable
  - Detector instability: sudden pressure & temperature change due to stop of purification pump etc.
  - Stability should be checked when the stability is confirmed

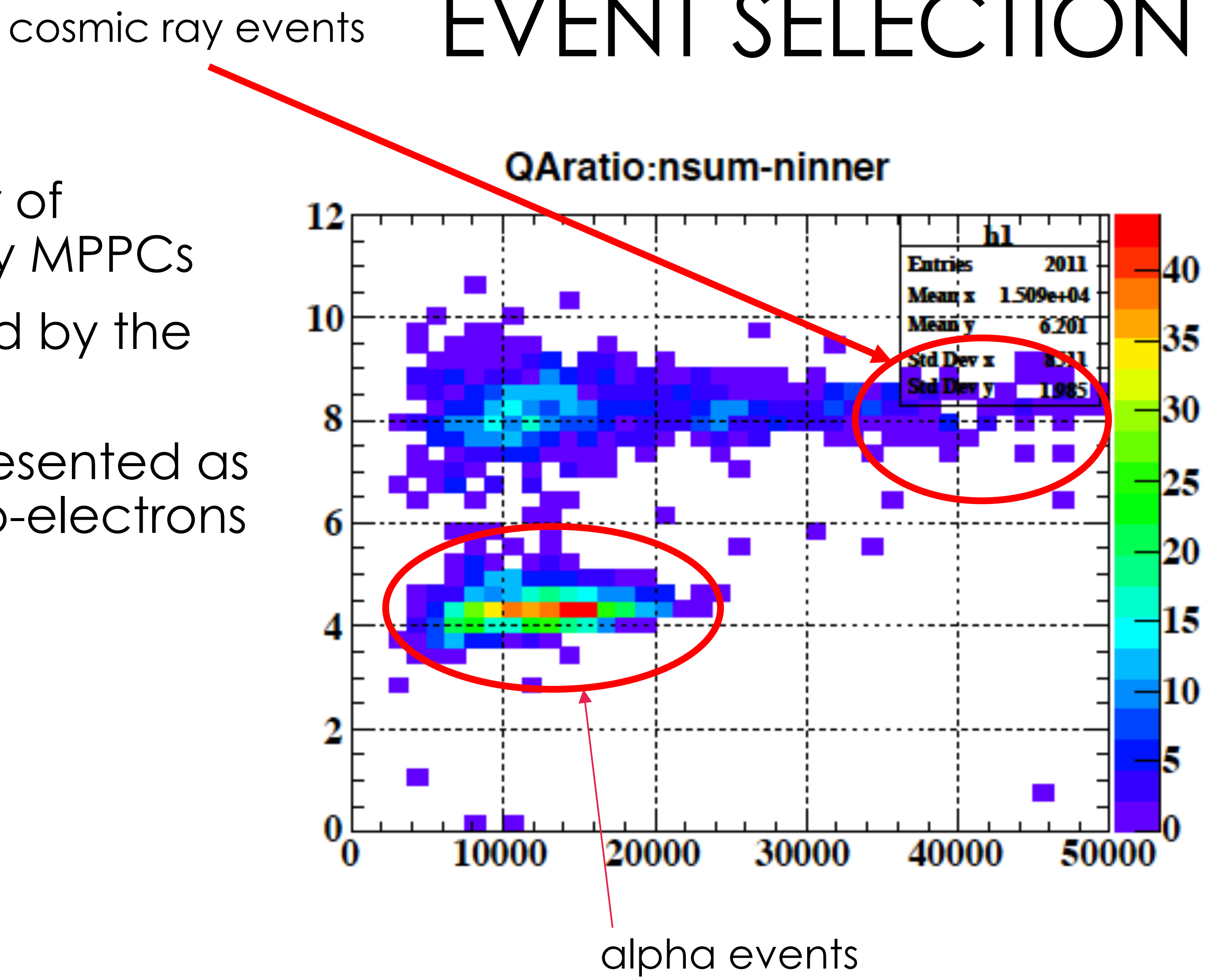
SUMMARY

- The purity of liquid xenon is important to obtain high light yield
- Purification of xenon is ongoing with gas & liquid phase
- The purification of liquid xenon is monitored using cosmic ray & alpha ray
- Impurities that cause attenuation & quench is being removed
- The stability of the detector performance should be checked next
    - it is impossible to discuss now because the detector is unstable now

BACK UP

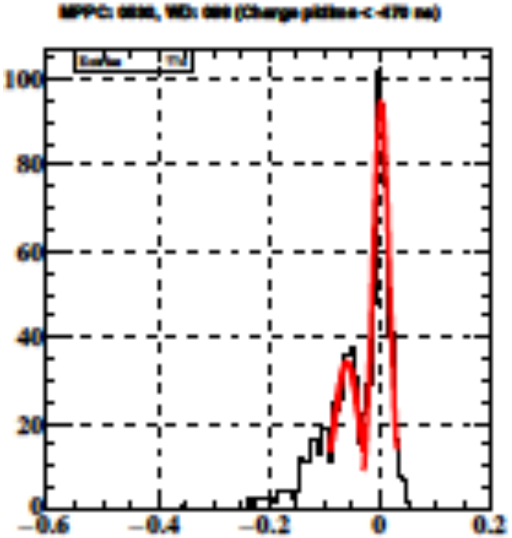
EVENT SELECTION

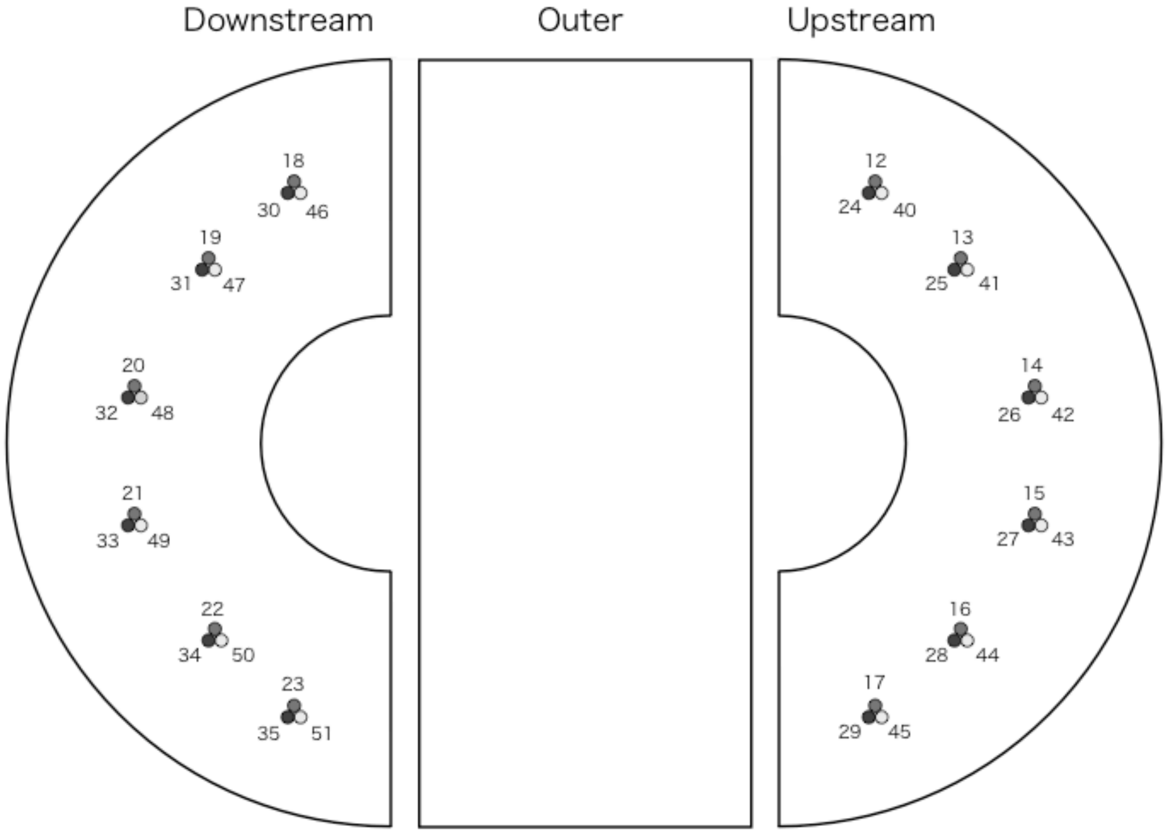
- Q/A value v.s. total number of photoelectrons obtained by MPPCs
- Events are clearly separated by the difference of pulse shape
- Cosmic ray events are represented as high Q/A & high total photo-electrons number



SENSOR STABILITY

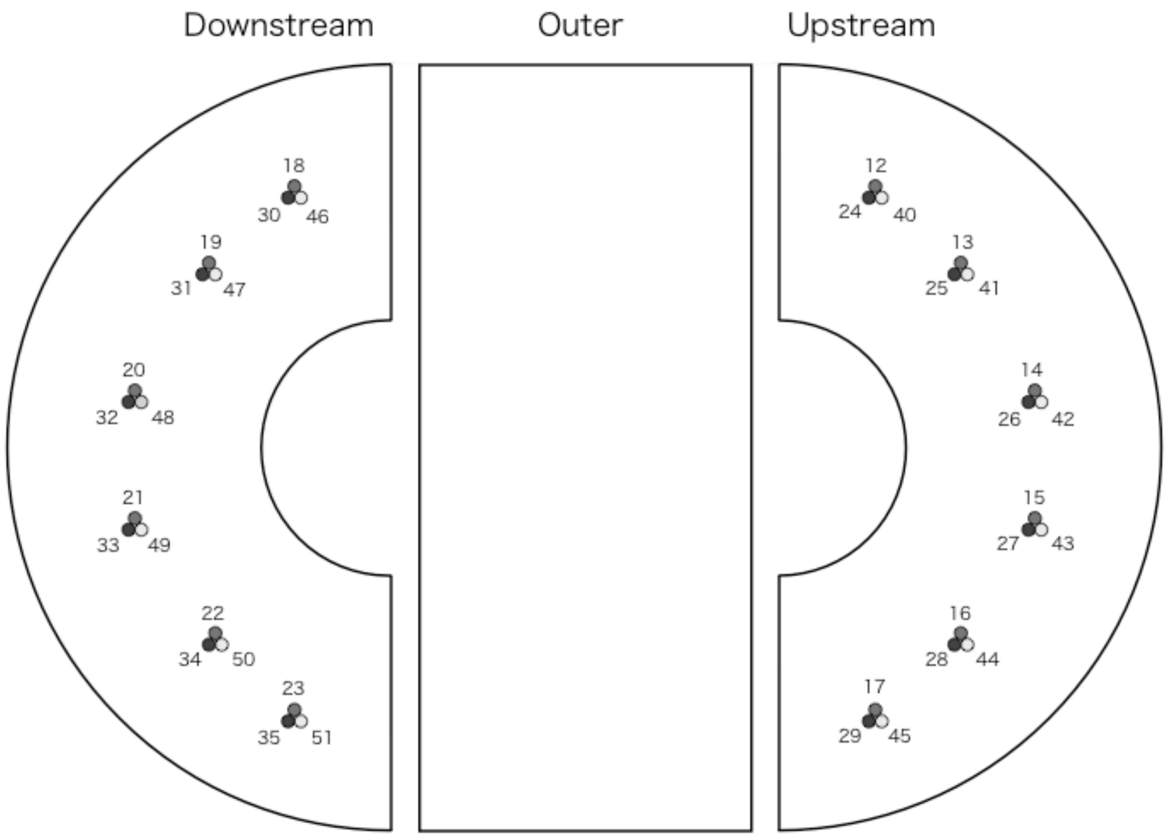
- The sensor stability against time is checked using LEDs inside the detector; gain and light yield
- The gain of sensors: obtained from interval of photoelectron peak





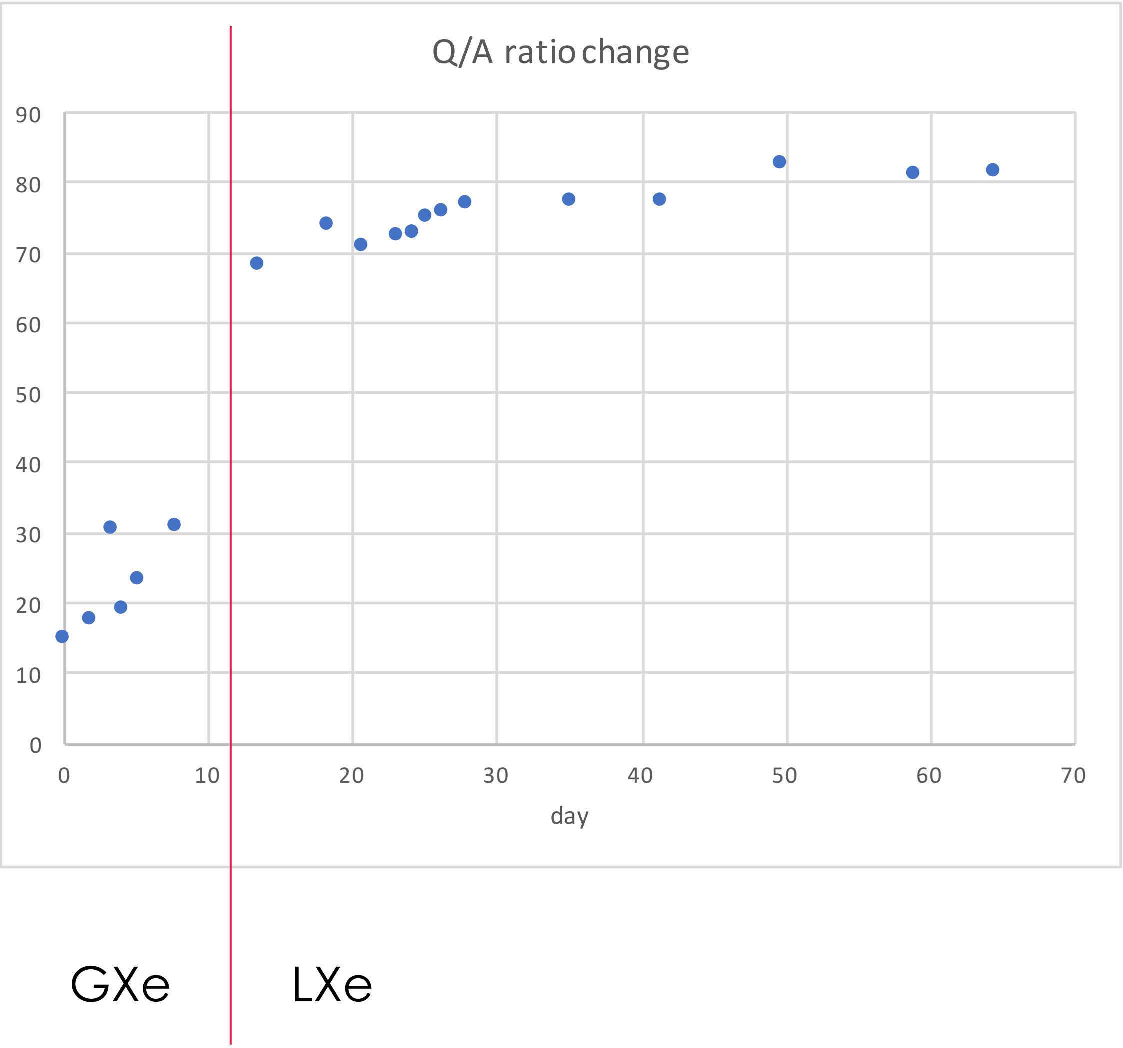
SENSOR STABILITY

- The sensor stability against time is checked using LEDs inside the detector; gain and light yield
- The light yield of sensors; obtained by monitoring with a few tens of photons
- The detection efficiency of sensors are monitored by direct light measurement



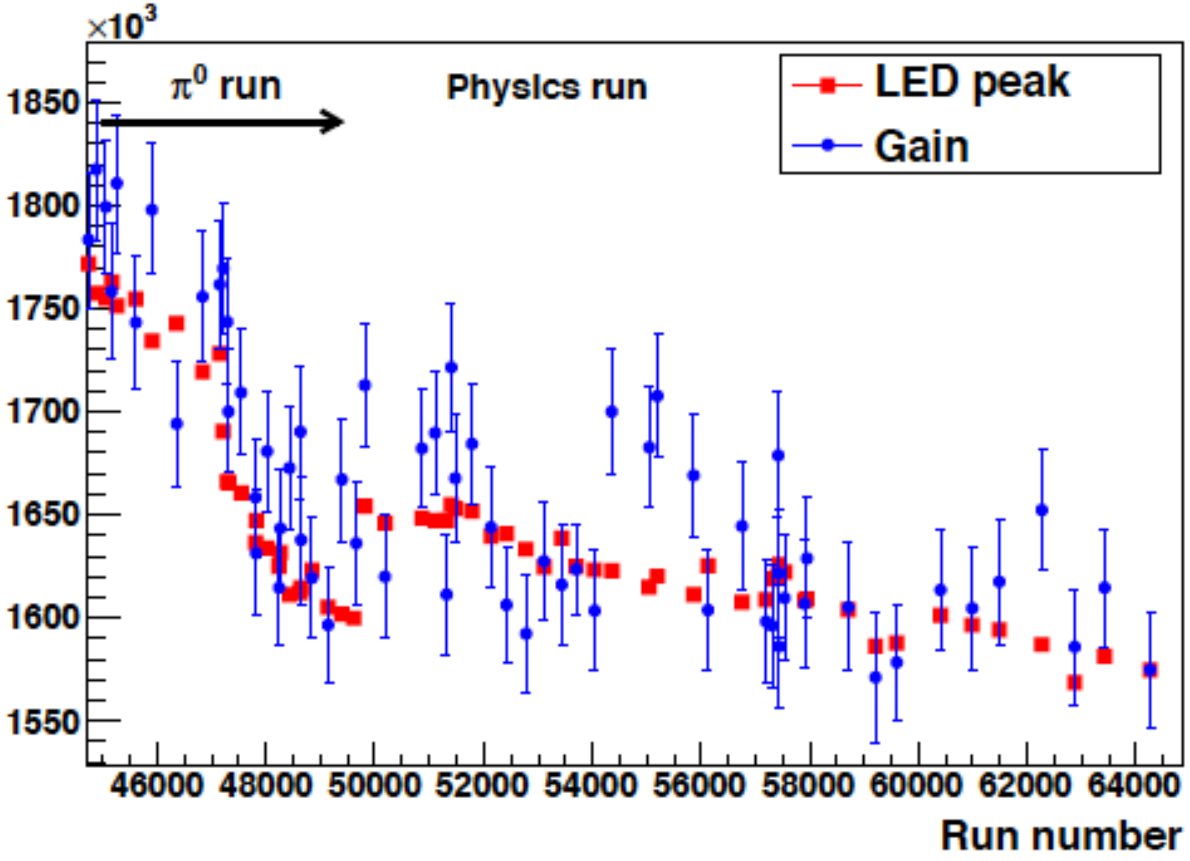
COSMIC RAY MONITORING

- The change of Q/A ratio to check the pulse shape for PMTs
- Soon after purification was started, Q/A ratio increases as the purification progresses
- The pulse get wider, which means events with 45ns decay time increase as the purity increases



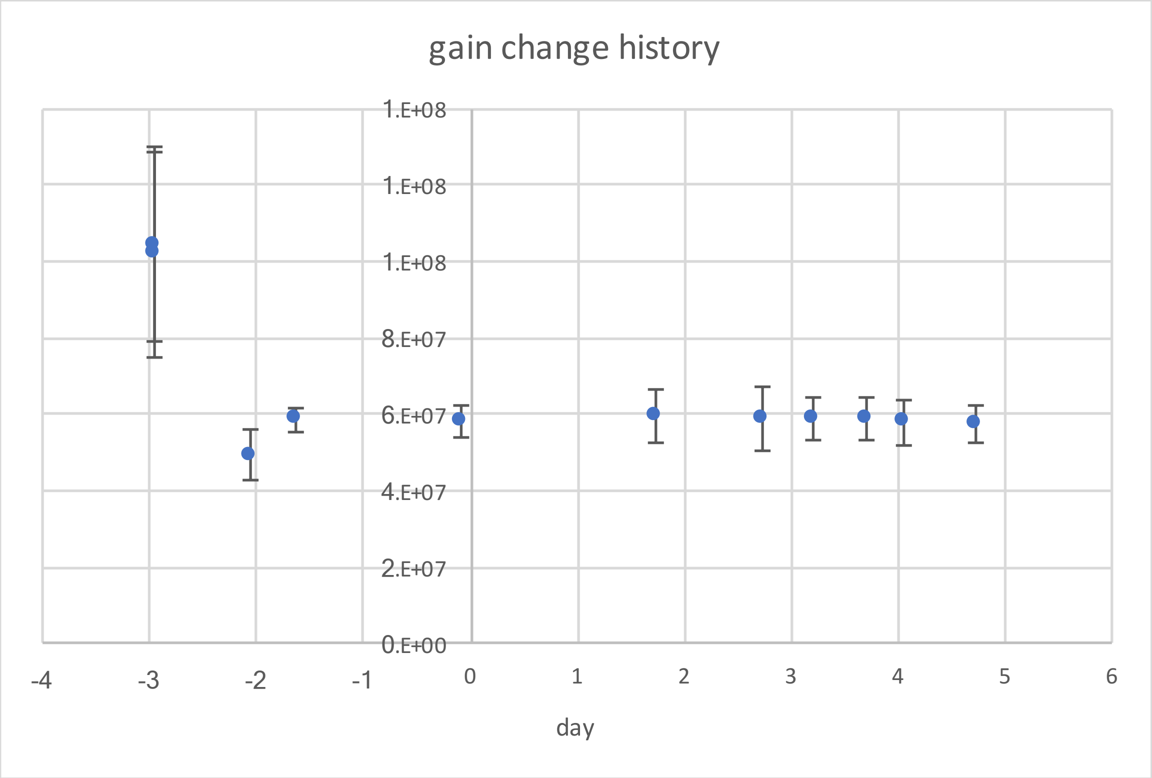
STABILITY CHECK

- It is important to confirm the stability (or unevenness) of photo-sensors
- Gain change leads to misunderstanding of detected number of photoelectrons



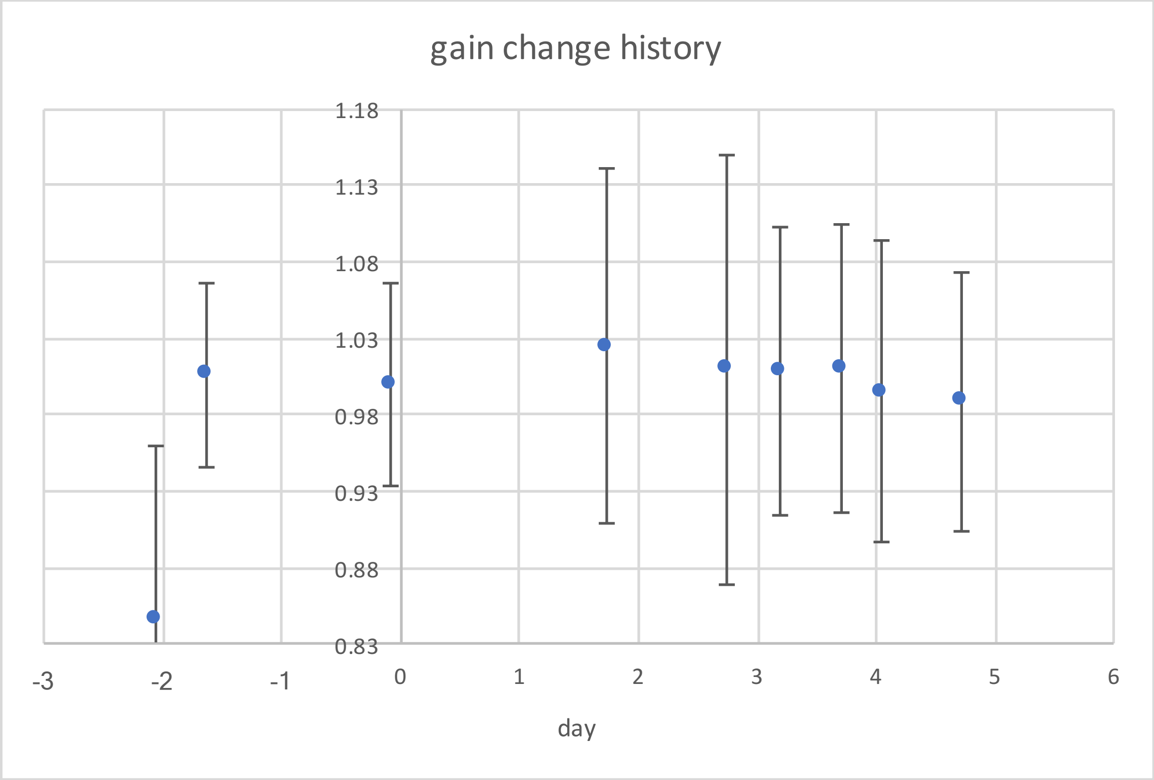
STABILITY

- The time change of gain detected by a part of MPPCs by weak LED (~ one or no photons) for a week
- Gain was obtained by fitting 0p.e. and 1p.e. peak
- Gain is stable around 6E+7 except first a few days



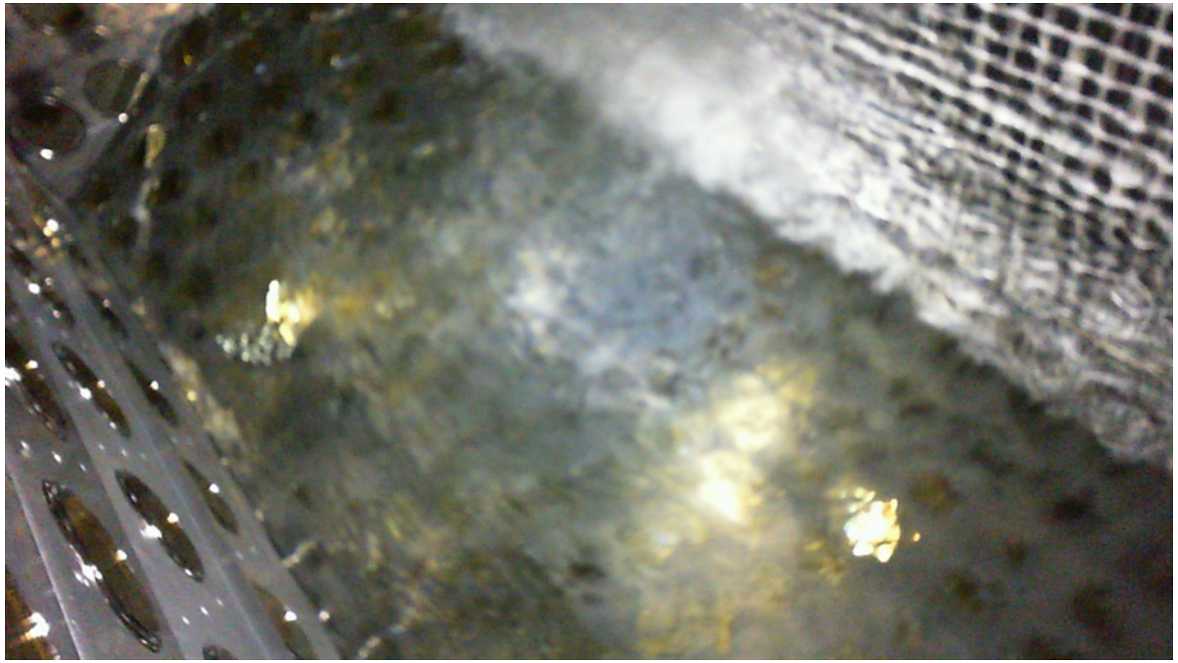
STABILITY

- The time change of gain detected by a part of MPPCs by weak LED (~ one or no photons) for a week
- Gain was obtained by fitting 0p.e. and 1p.e. peak
- Normalized so that charge for day 0 is 1



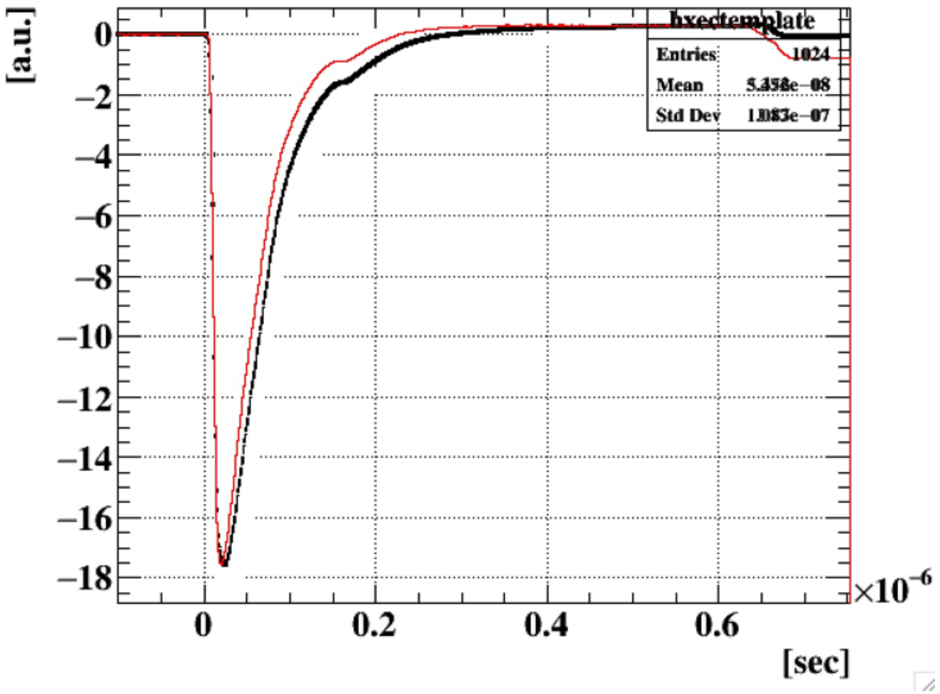
LIQUID XENON

- The scintillator used for MEG II gamma-ray detector
- Noteworthy characteristic
  - High density, which leads to short radiation length
  - High light yield (80% of NAI(Tl))
  - Fast response time for gamma ray (45ns)
  - Scintillation light will not be absorbed by liquid xenon itself
  - Uniformity due to liquid mobility



COSMIC RAY MONITORING

- The pulse shape change



black: after a month since purification started,
red: just purification started