XEC pre-engineering run 2017 -Noise reduction & timing resolution-

S.Ogawa for LXe group,

Global Developments of Researches in Lepton Flavor Physics with Muons,

2018.04.05

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Beam test analysis status

Topics		Reports on collab. meeting
Calibration & monitor	MPPC gain & correlated noise	@ 2018/Jan. meeting
	PMT gain	**This talk**
	PDE & LXe light yield	**This talk**
Position	Position resolution	**Satoru**
Energy	Energy scale	@ 2018/Jan. meeting
	Energy uniformity & resolution	gave up due to noise issue
Timing	Calibrations & Even-odd resolution	**This talk**
	Time offset meas.	**Rina**
Noise study	Effect to energy resolution (low freq.)	**Kei**
	Effect to timing resolution (high freq.)	**This talk**
etc...		

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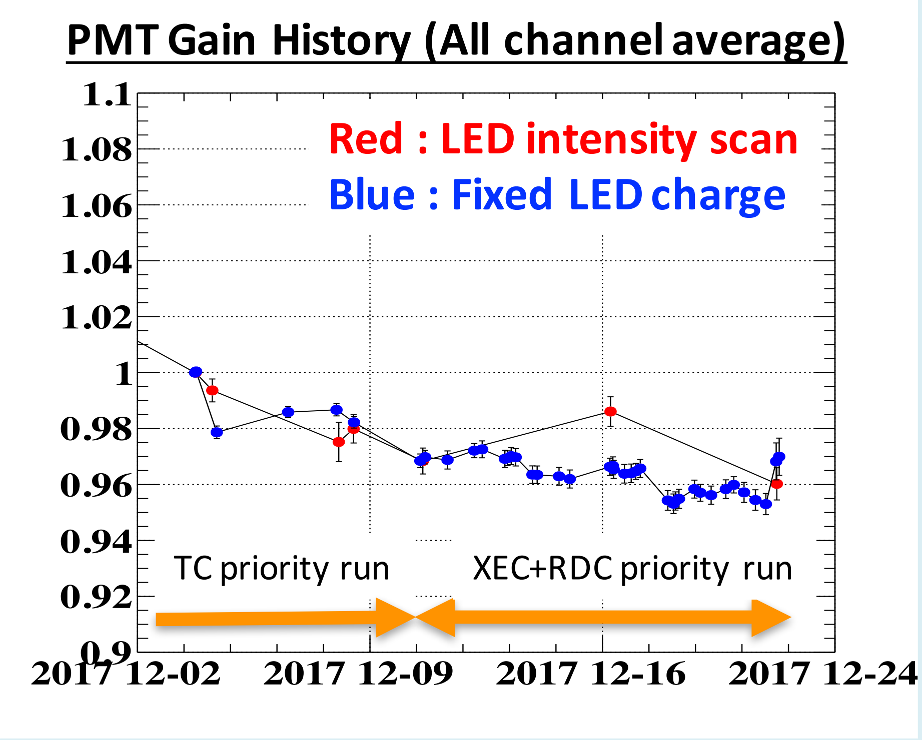
PMT gain monitor

By Satoru

- PMT gain was monitored by the same method with MEG.
  1. By LED intensity scan.
  2. By charge of LED at fixed light intensity.

→ **Two method was consistent.**

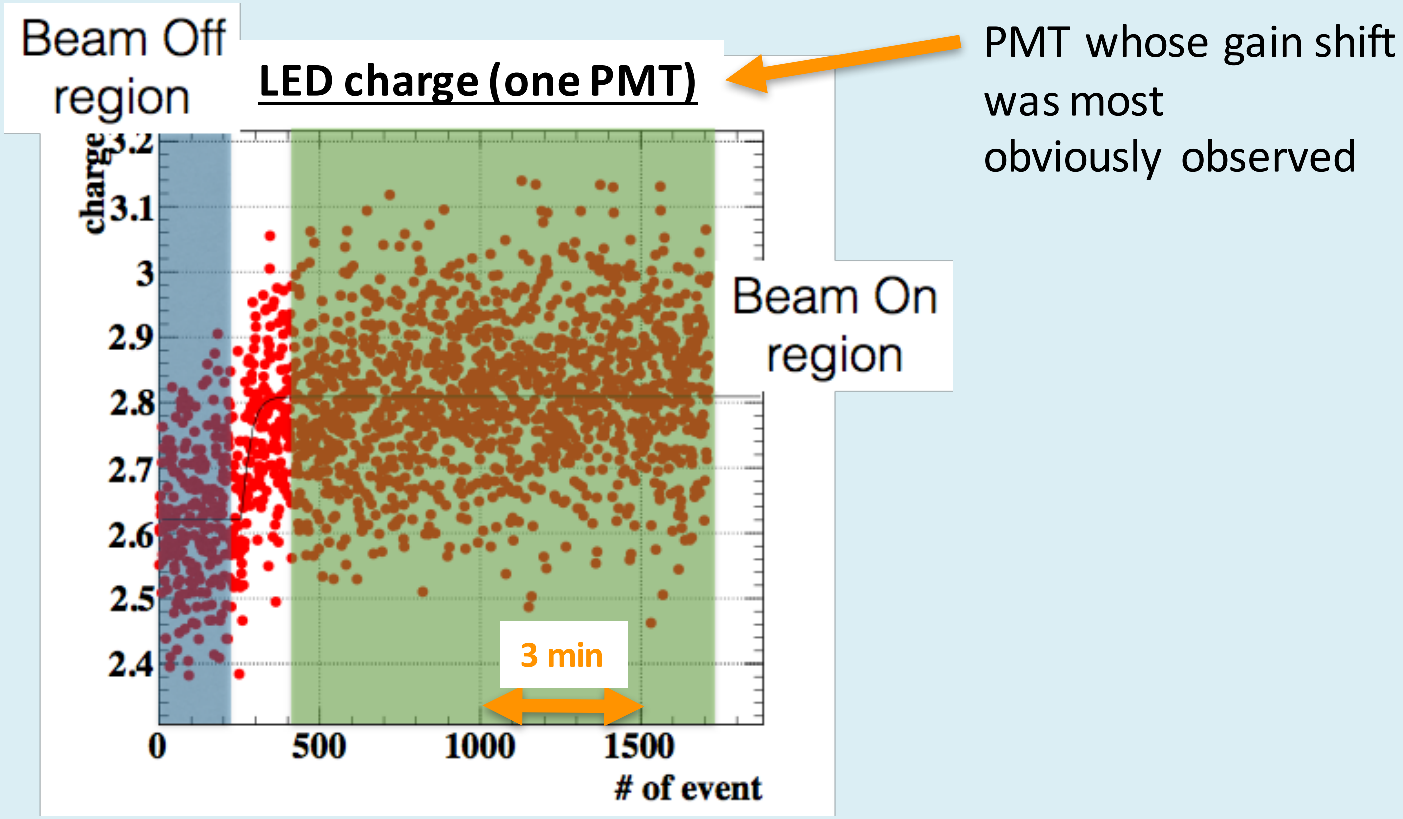
→ Gain decreased by 4% in 3 weeks. (aging effect of beam).



PMT gain monitor

By Satoru

- Gain shift when we open beam blocker was also observed.
  - measured by fixed intensity LED run during BB open/close.
- DAQ rate was not enough to discuss about the shape (time dependence) of this shift.
  → Will be discussed after DAQ rate improvement.



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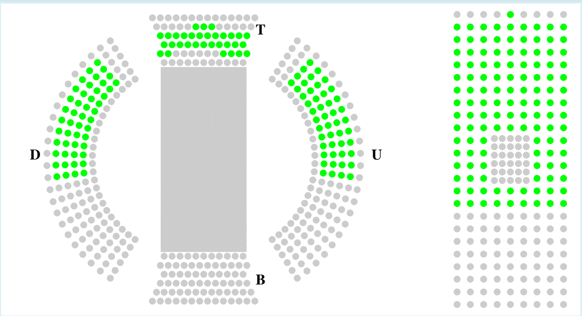
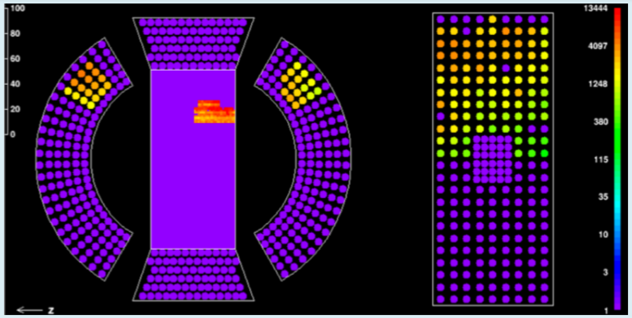
Alpha monitor configurations

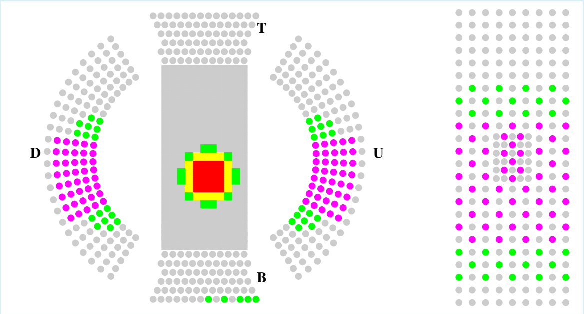
- Light yield was monitored from July to Dec.
  - Configuration changed 3 times.



1 crate.
Jul – Oct
PMT Gain : ~8 × 10^6



0.5 crate.
Nov/8 – 20
PMT Gain : ~8 × 10^6

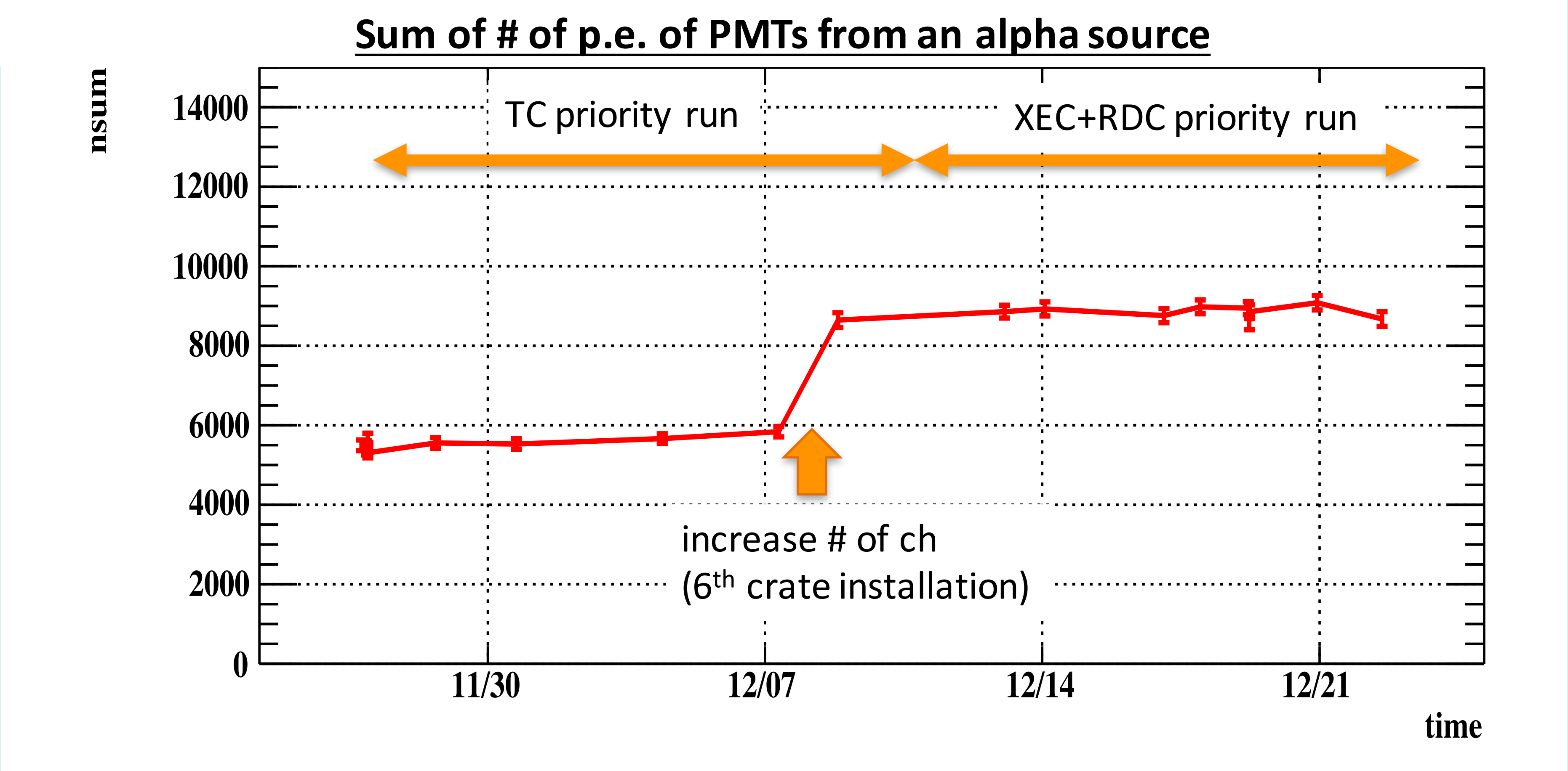


0.5 crate.
Nov/25-Dec/8
PMT Gain : ~1.6 × 10^6

0.75 crate.
Dec/8-Dec/21
PMT Gain : ~1.6 × 10^6

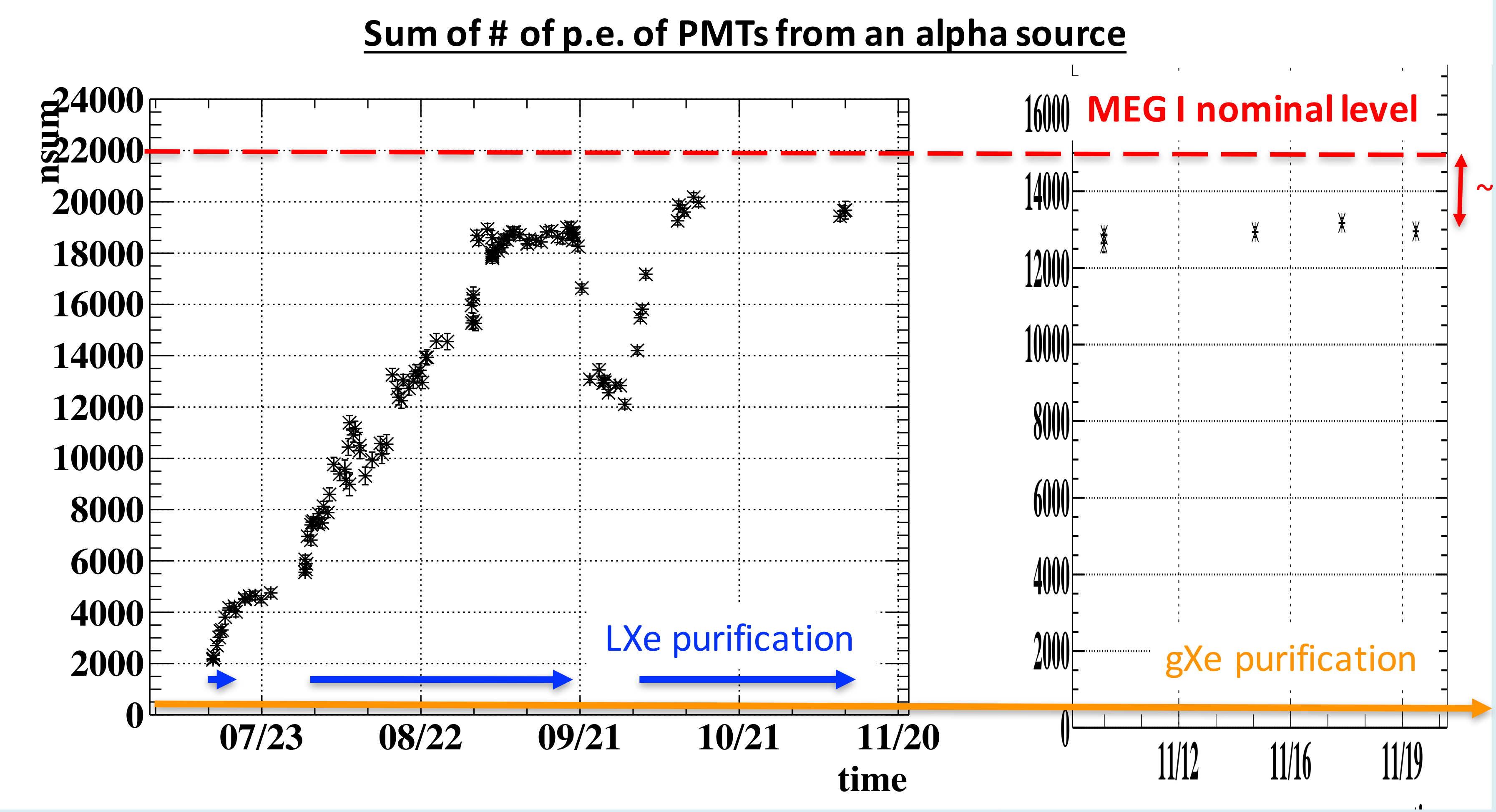
Light yield stability during beam time

- LXe light yield monitored by alpha run.
- **Stability was OK during beam time**.



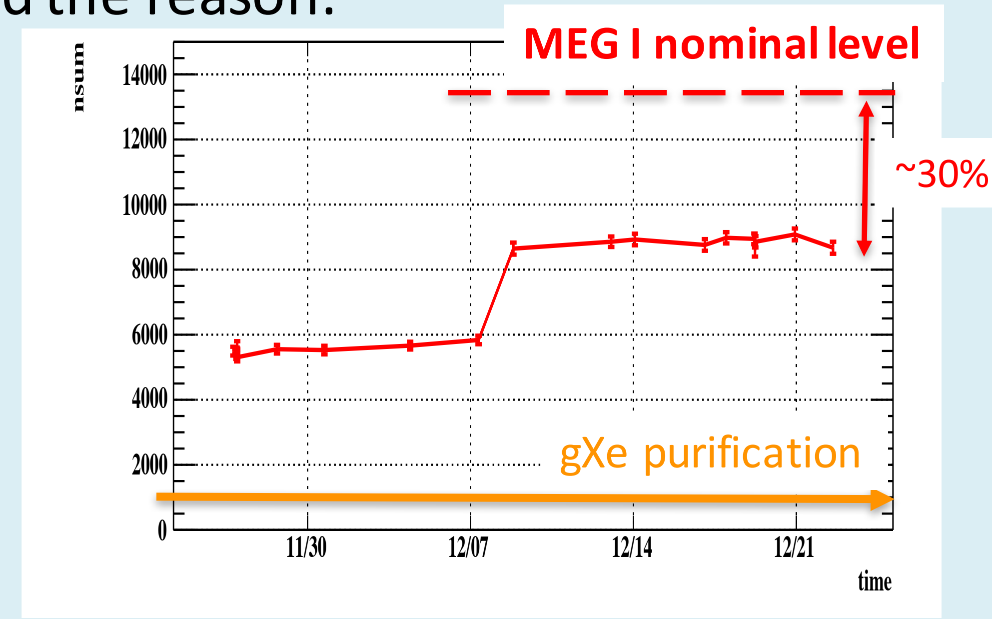
Light yield history before Nov/25

- Before Nov/25, light yield reached **90% of MEG I nominal level.**
  - MEG I nominal level :
    From MC. Assuming 22% PMT QE.



Light yield history after Nov/25

- However, light yield after Nov/ 25 was **70% of nominal level**.
  → **Inconsistent with light yield before Nov/25**.
- Since we changed many parameters at the same time, it seems difficult to understand the reason.
  - Channel assignment
    - PMTs
    - WDBs
    - Alpha source
  - PMT HV.
    - gain
    - QE (CE).



- We will continue purification this year and see what will happen.

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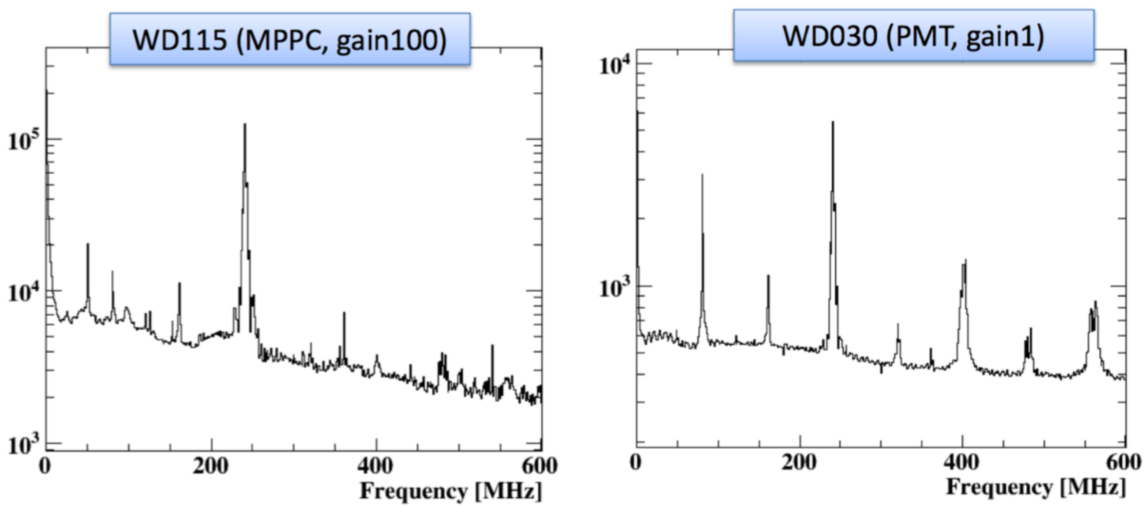
High frequency noise

- We have both low frequency noise & high frequency noise.
  - Low freq. noise-> Can affect charge integration→Energy resolution.
  - High freq. noise-> Can affect timing extraction →Timing resolution.
- We see many noises from system clocks (n * 80MHz).
  → Can we subtract them in the offline analysis?

After both subtraction methods applied

Kei's report @ 2018/Jan. collab. meeting



Low frequency (<5MHz) noise and other frequency peaks still exist.

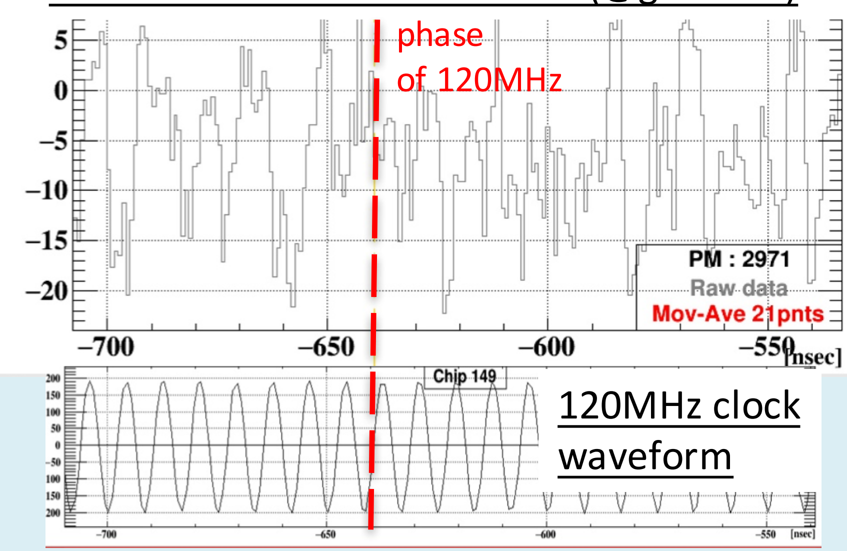
120MHz noise reduction

Reminder

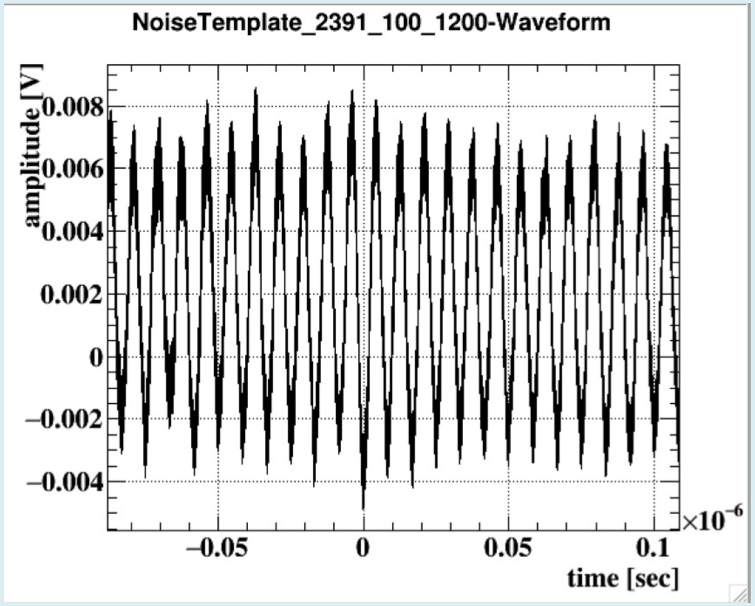
- 120MHz sine wave was recorded in ch 16/ 17 of DRS for offline synchronization.
  - Crosstalk of them is observed as 120MHz noise, on DRS ch 0-15.
- 120MHz noise subtraction procedure
  1. Phase extraction of 120MHz.
  2. Make noise template from Pedestal run.
  3. Apply noise subtraction in γ run.

※Reference :
Masashi's report on 2017/Jul

Pedestal waveform of a MPPC. (@gain 100)



Make noise template (ch by ch)



120MHz noise reduction

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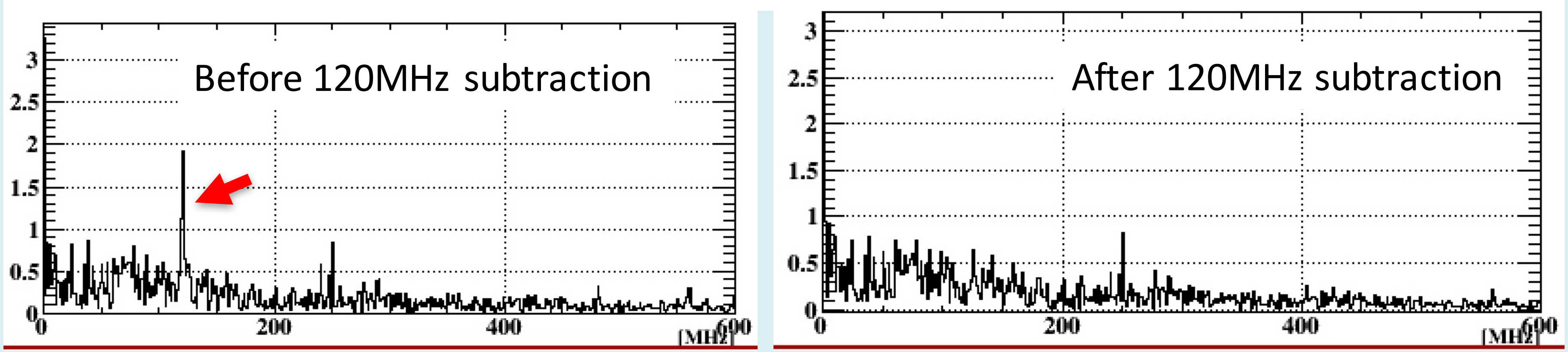
FFT of a MPPC waveform

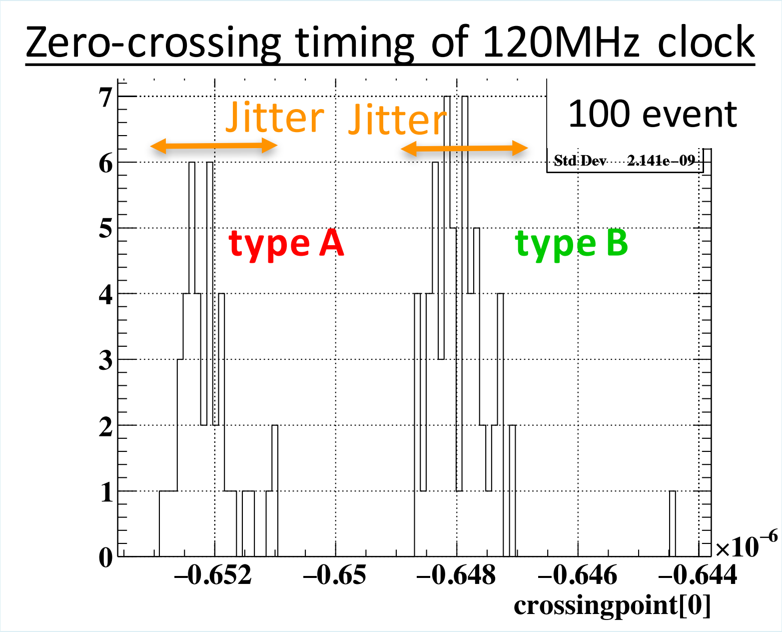


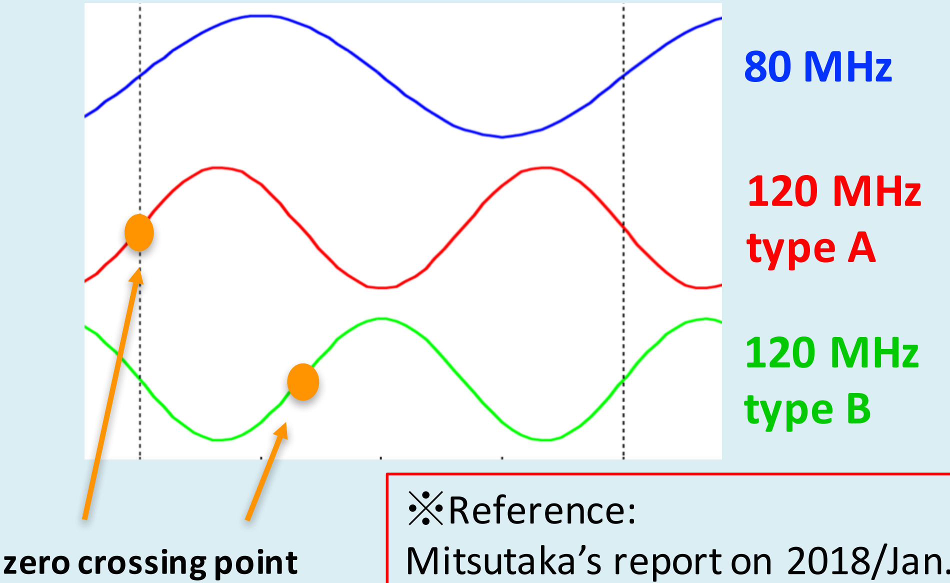
→We can reduce "n*80" MHz noise if we can know the phase of them.

Phase of 80MHz clock

- We need to know phase of 80MHz clock event by event.
  → Absolute timing of DRS waveform should be synchronized with 80MHz clock.
  - Trigger generation from 80MHz clock.
- We need to know event-by-event jitter to subtract high frequency noise.
  → Use phase of 120MHz clock to know the jitter,
  since they are partially synchronized with 80MHz clock.

→ "Phase of 80MHz" = "Absolute DRS timing (e.g. -650 ns)"
+ "Jitter correction (by 120MHz clock)"

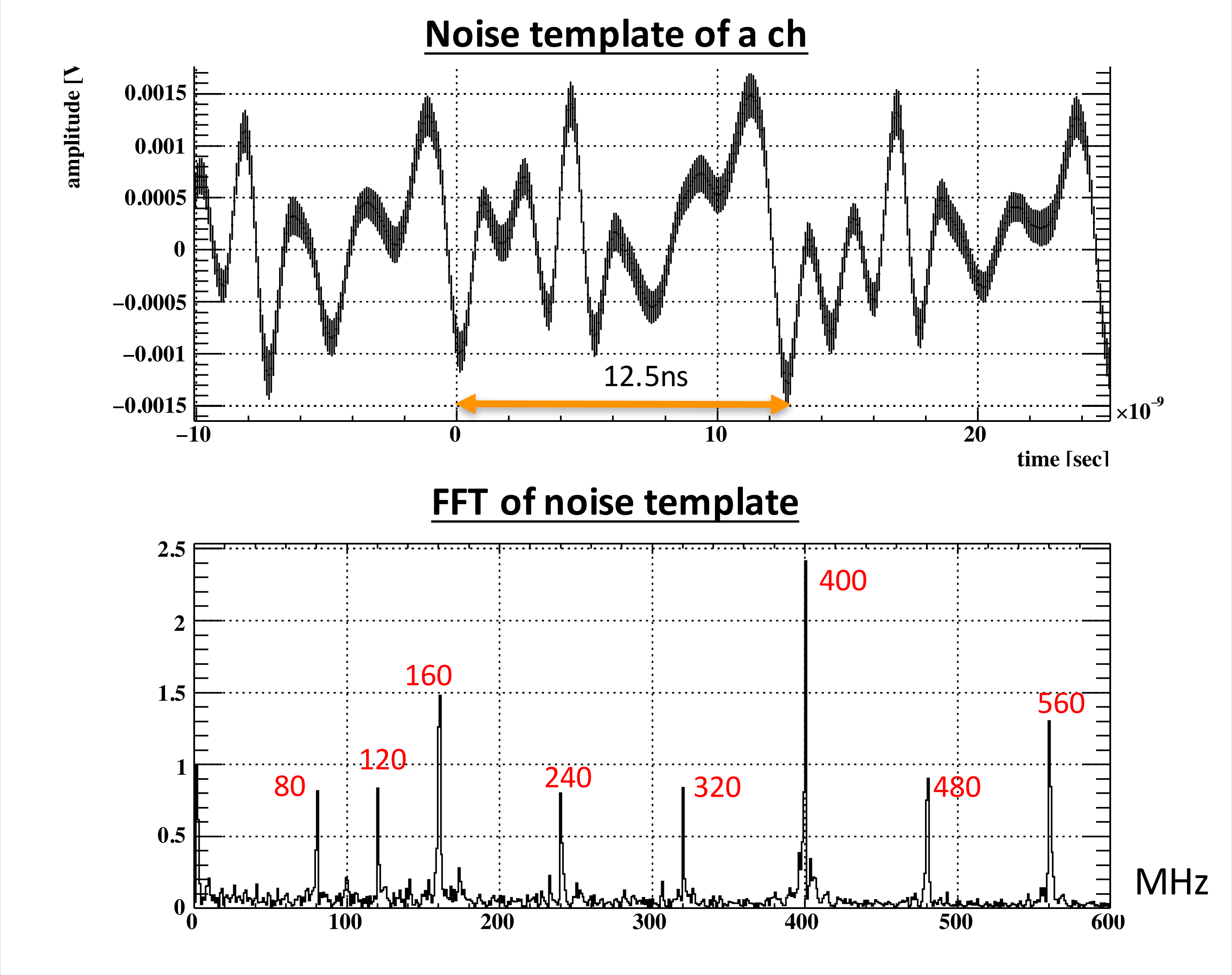




※Reference:
Mitsutaka's report on 2018/Jan.

Noise template (80MHz sync.)

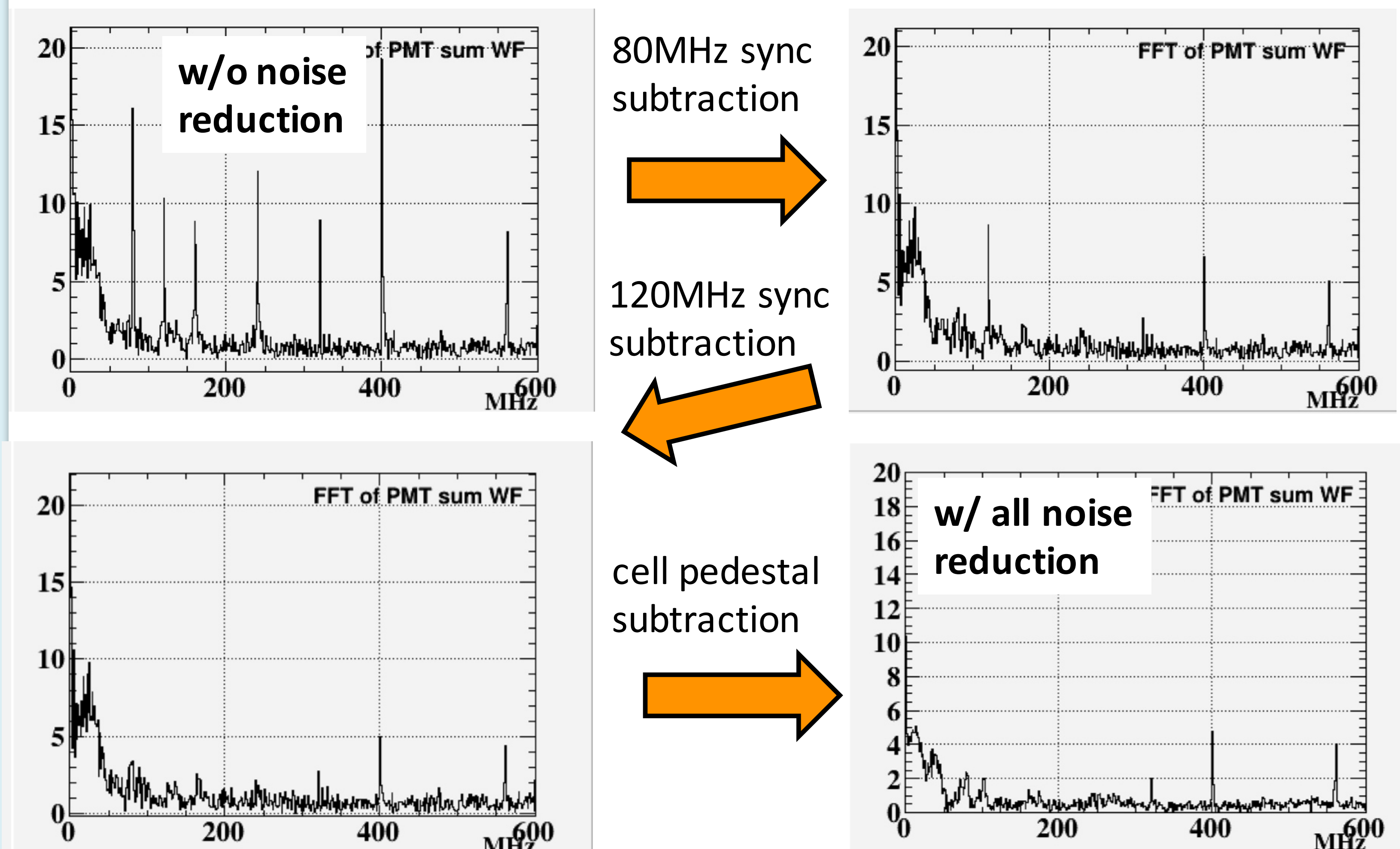
- Template of noises synchronized with 80MHz clock.



High freq. noise reduction

- **High frequency peaks in FFT spectrum have been subtracted.**

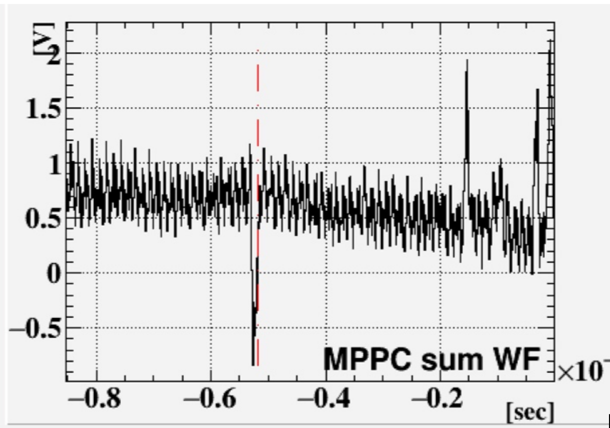
FFT spectrum of PMT sum waveform



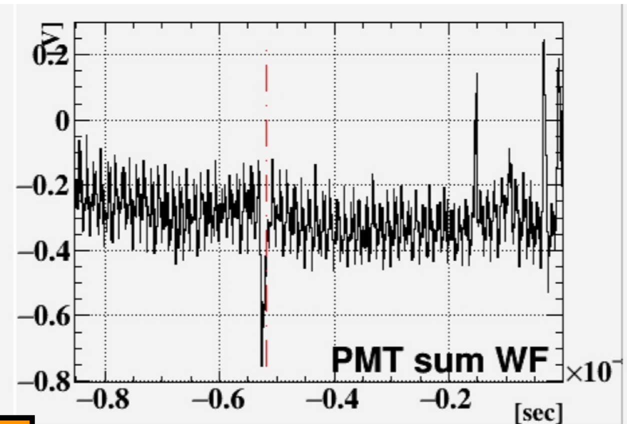
High freq. noise reduction

- High frequency peaks in FFT spectrum have been subtracted.

Sum waveform of MPPC

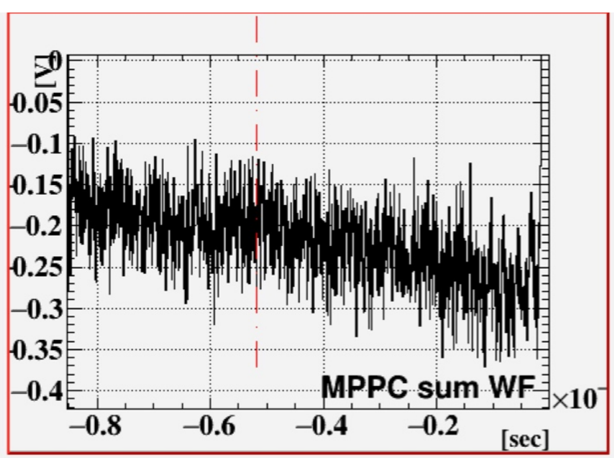


Sum waveform of PMT

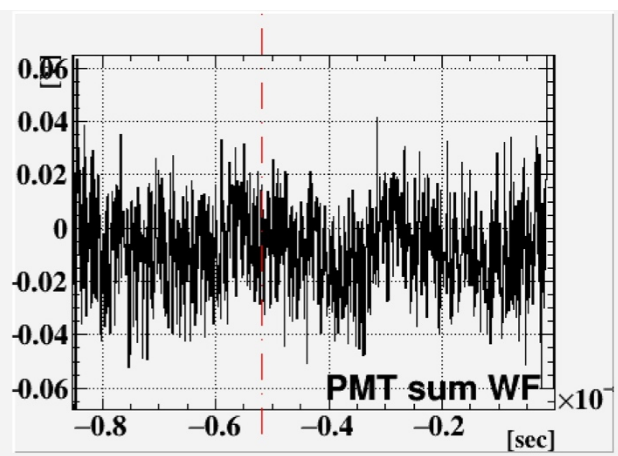


Noise reduction.

Sum waveform of MPPC

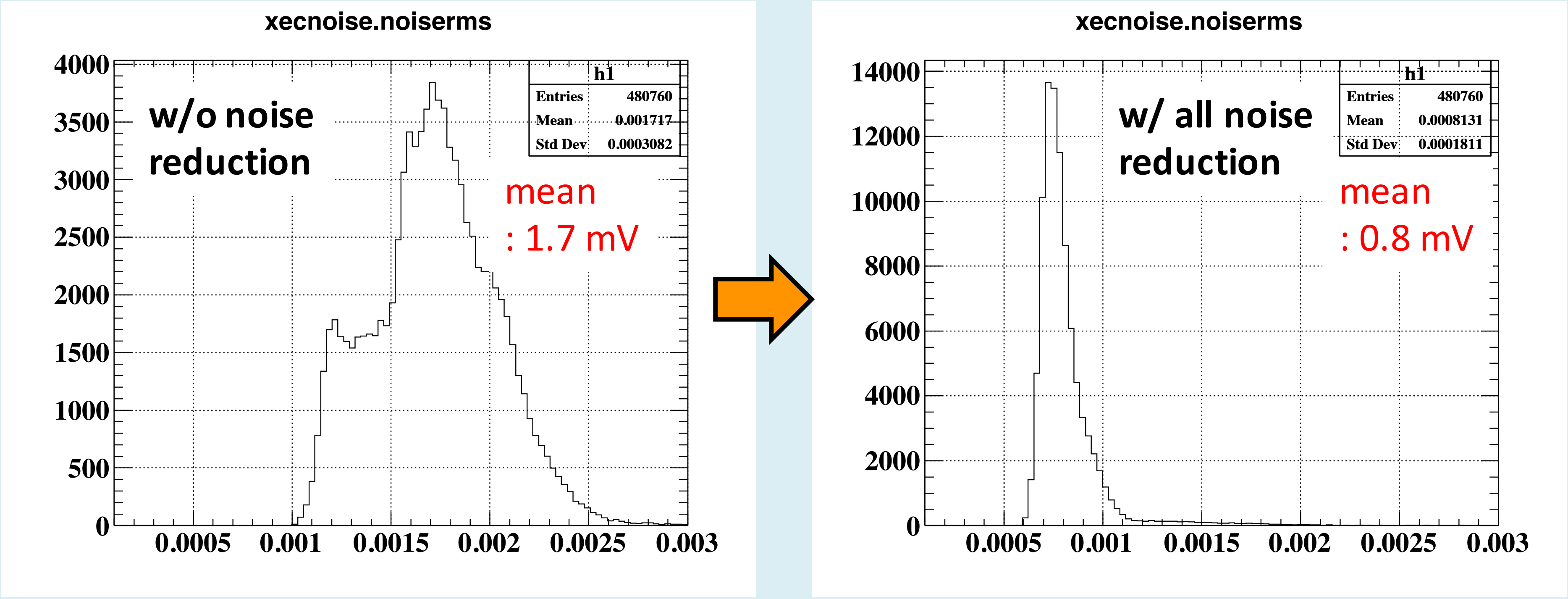


Sum waveform of PMT



High freq. noise reduction

- Noise level (noiserms) has been improved from 1.7mV to 0.8mV.
  - Though it is still larger than MEG I(~0.4mV).



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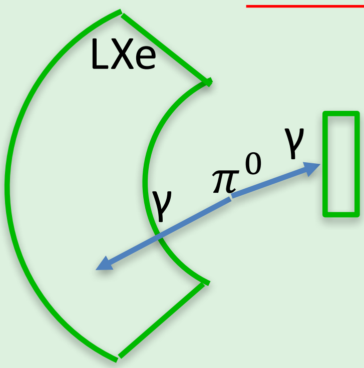
Motivation of Tγ study

- In MC, Tγ resolution was estimated to be **40-70ps**.
  - This is **sensitive to the noise level**.
    - Reference: My report on 2015.Dec & 2016.Jul etc...

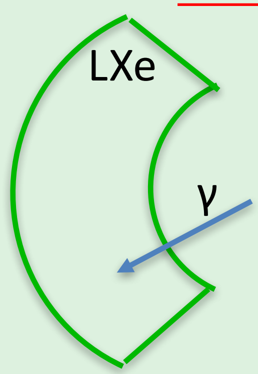
- **Goal : Check timing resolution in real noise environment.**
  →Perform even-odd analysis.

Absolute resolution



- Use coincident 2γ & reference counter.
- $\sigma(T_\gamma) = \sigma(T_\gamma - T_{ref}) \ominus \sigma(T_{ref})$

Even-odd resolution



- Reconstruct Tγ from even/odd ch separately.
- $\sigma(T_\gamma) = \sigma(T_{EVEN} - T_{odd})/2$

- MEG II $T_{e\gamma}$ resolution is dominated by T_γ resolution, thanks to the T_e improvement from MEG.
  - Affects physics sensitivity by ~ 20%.

Tγ reconstruction

Reminder same as MEG I

- Tγ reconstruction : χ^2 min fit of time information from all ch.
- In MEG I, pre-shower counter in CEX run was used as a reference of calibration.
  - For this analysis, reconstructed Tγ was used instead (iterative calibration).

Tγ reconstruction

χ^2 minimization fit of all ch time information

$$\chi^2 = \sum_{MPPC,PMT} \left(\frac{t_{pm} - t_{walk} - t_{prop} - t_{offset} - t_{\gamma}}{\sigma} \right)^2$$

Time info from each MPPC, PMT with time calibration

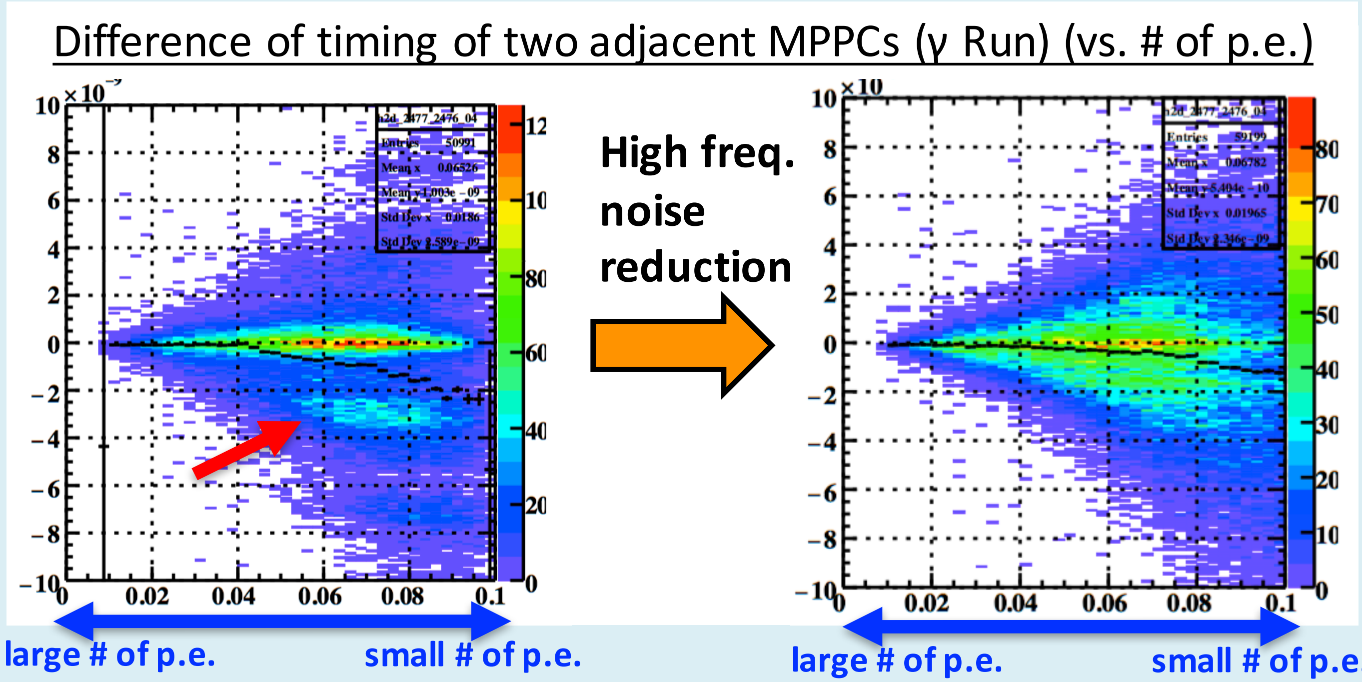
Gamma hit timing (fitting parameter)

Calibration parameters : extracted from data

- Time walk
- Propagation time of scintillation light.
- Time offset of each channel

Timing extraction from waveform

- Reducing noise effect is important to have good resolution.
  - Timing extracted by constant fraction method.
    - Optimal threshold is 5%.
  - Offline reduction of high freq. noise.
  - Apply moving average low-pass filter.
- Without offline noise reduction, strange peak structure was observed in the difference of timing of adjacent two MPPCs. → Fixed by noise reduction.



Timing calibrations

same as MEG I

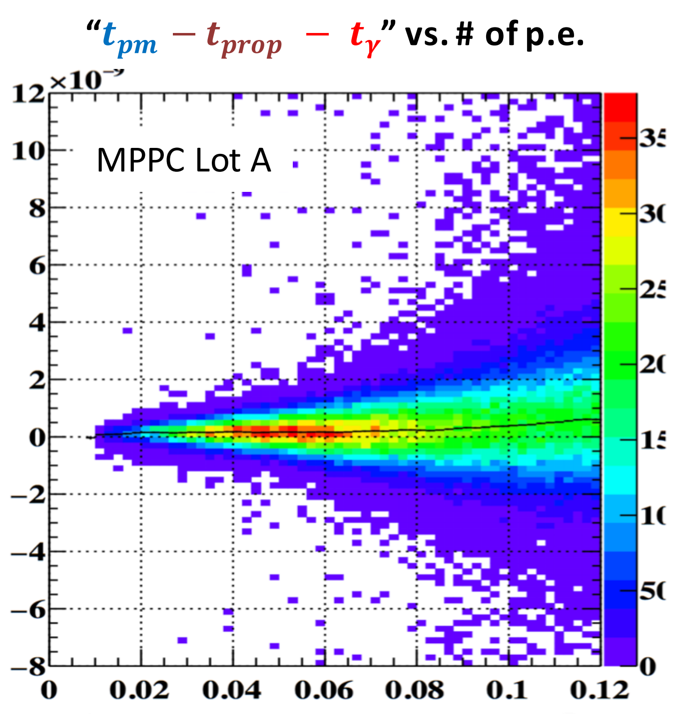
$$\chi^2 = \sum_{MPPC,PMT} \left(\frac{t_{pm} - t_{walk} - t_{prop} - t_{offset} - t_{\gamma}}{\sigma} \right)^2$$

t_{prop} : **Propagation time of scintillation light.** (as a function of distance)

- Simply calculated from effective velocity. (11 cm/ ns)

t_{walk} : **Time walk effect** (as a function of # of p.e.)

- Estimated from # of p.e. dependence of "$t_{pm} - t_{prop} - t_{\gamma}$".
- Different parameters for different MPPC Production lots.
  - Due to different after pulse probability.



large # of p.e. ⟷ small # of p.e.

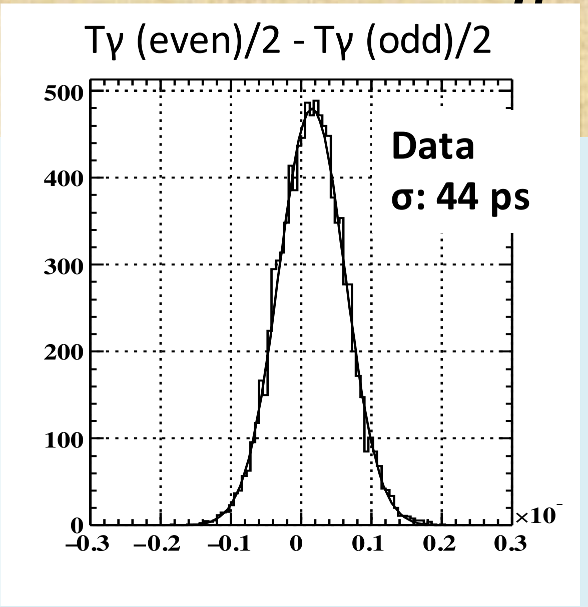
t_{offset} : **Time offset of each channel**

- Estimated from ch by ch difference of "$t_{pm} - t_{walk} - t_{prop} - t_{\gamma}$"-> Rina's report.

σ : **Resolution of one ch** (as a function of # of p.e.)

- Estimated from the sigma of "$t_{pm} - t_{walk} - t_{prop} - t_{offset} - t_{\gamma}$".

Timing resolution



- **Even-odd timing resolution is 44 ps @ ~50MeV.**
- This is **consistent with MC** which reproduces last year's situation.
  - Same channel assignment (25% of whole detector)
  - Reduced PDE to reproduce p.e. statistics in data.
  - Same level of high frequency noise. (0.7mV, white noise)

Tγ resolution	Even-odd	absolute
Data	44 ps	???
MC	44 ps	50-52 ps

※ MEG I: 39 ps 62 ps

- **Absolute Tγ resolution is estimated to be 50 ps** with this MC (all ch readout).
  → **Indicates ~15% sensitivity improvement** from Design Paper (assumption: 78 ps).
  → **Will be measured by CEX this year.**

Summary

- PMT gain was successfully monitored during the beam time.
- Absolute light yield was stable but it was 30% smaller than nominal level.
  - We have not yet understood, why it is not consistent with previous data.
  - We will continue purification this year, and see what will happen.
- High frequency noise synchronized with 80MHz system clock is successfully subtracted in the offline analysis.
  - Peak in the FFT spectrum disappeared,
    and noise level improvement by factor 2.
- Gamma hit timing is reconstructed with iterative calibration.
  - Obtained 44 ps by even-odd analysis (consistent with MC).
  - We can expect 50ps for absolute T_γ resolution.

WDB request before September

- WDB request before September (i.e. arrival of XEC full electronics) to start discussion about WDB assignment.
- LXe purification from beg. of Mar.
  + possible X-ray meas.
  + possible calibration by γ-ray source (AmBe, n gene etc...).
- We request a 2-4 crates for XEC until September.
  - 1-3 crate for PMT + 1-2 crate for MPPC.
  - We do NOT need all four TCBs.
- We will start cabling at the end of Apr.
  → We would like to decide WDB assignment (# of WDBs and position of crate) before end of Apr.

BACKUP

XEC PreEng Run 2017

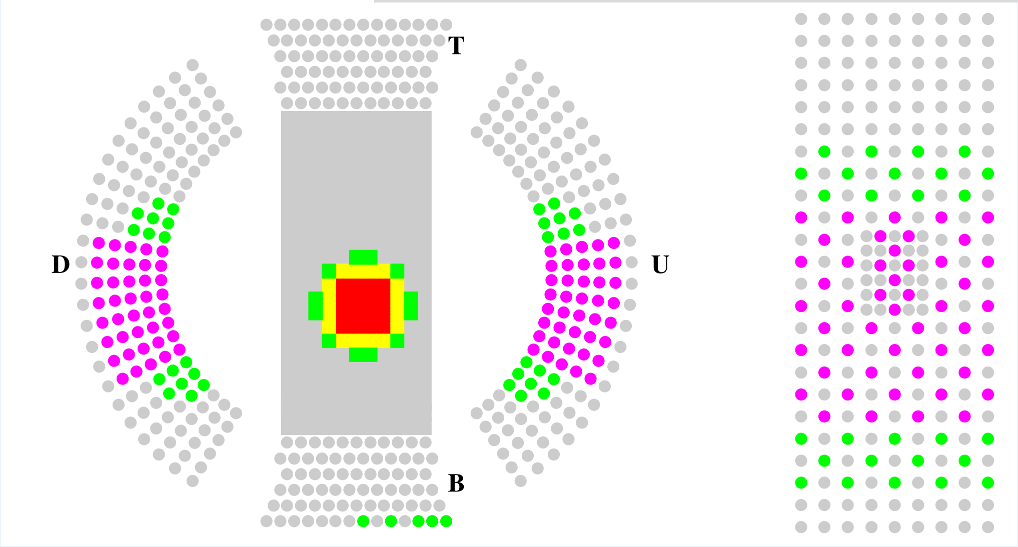
- Calibration & monitor data
  - Gain calibration for MPPC & PMT
  - Relative gain monitor by strong LED run
  - Alpha run for monitor & QE estimation
  - Noise level monitor
- γ from muon beam
  - 2 types of trigger
    - MPPC sum
    - MPPC + PMT sum
  - Lead collimator run.
- γ for calibration
  - AmBe
  - neutron generator

					Nov/25 5th crate ready **Sensor calib. commissioning**	26
27 TC run start	28 **periodical monitoring**	29	30	Dec/1	2	3
4	5 **periodical monitoring**	6 CW failure	7	8 6th crate ready	9	10
11 XEC run start	12 **muon beam DAQ**	13 **AmBe**	14	15	16 **AmBe**	17 **AmBe**
18 circuit breaker down **muon DAQ w/ collimator**	19	20 **n generator** **muon beam DAQ**	21	22 Refrigerator stop		

Photo sensor used for beam test

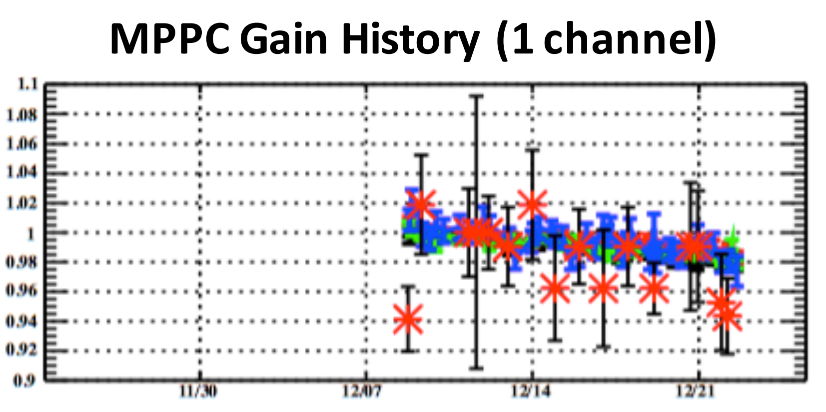
- We read out 704 MPPCs + 192 PMTs.
  - Due to the event rate issue, we are reading out 4 crate at the same time.
  - MPPC @ over voltage 7V
  - PMT @ gain 1.6×10^6 (~ same w/ MEG I)
- Several dead channels found.
  - 8 dead MPPCs
  - 4 dead PMTs

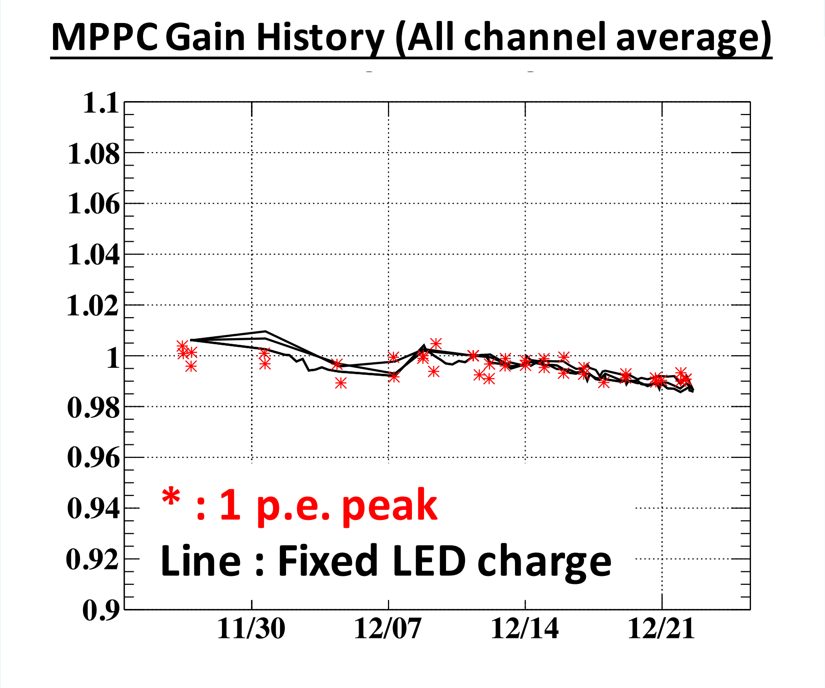
w/ TRG : red, yellow, magenta
w/o TRG : green



MPPC gain history

- MPPC gain history from
  1 p.e. peak & fixed intensity charge.
- Both methods is very nicely consistent each other.
  - precision : < 1%
  - except for several outliers.
- Some coherent change was observed.

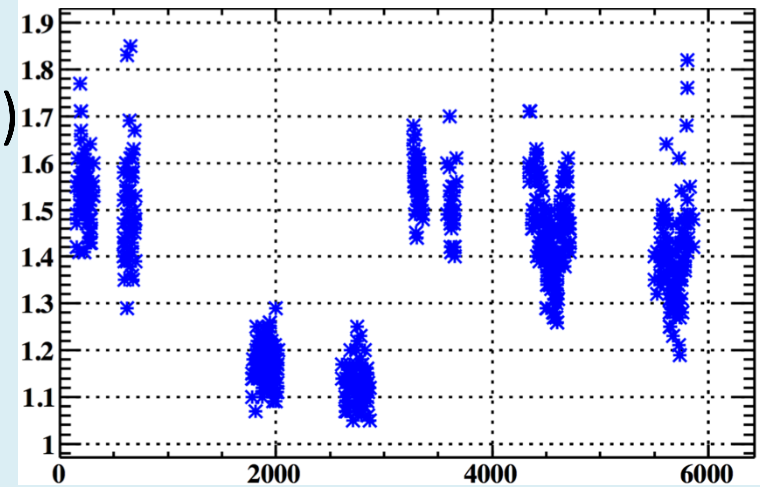




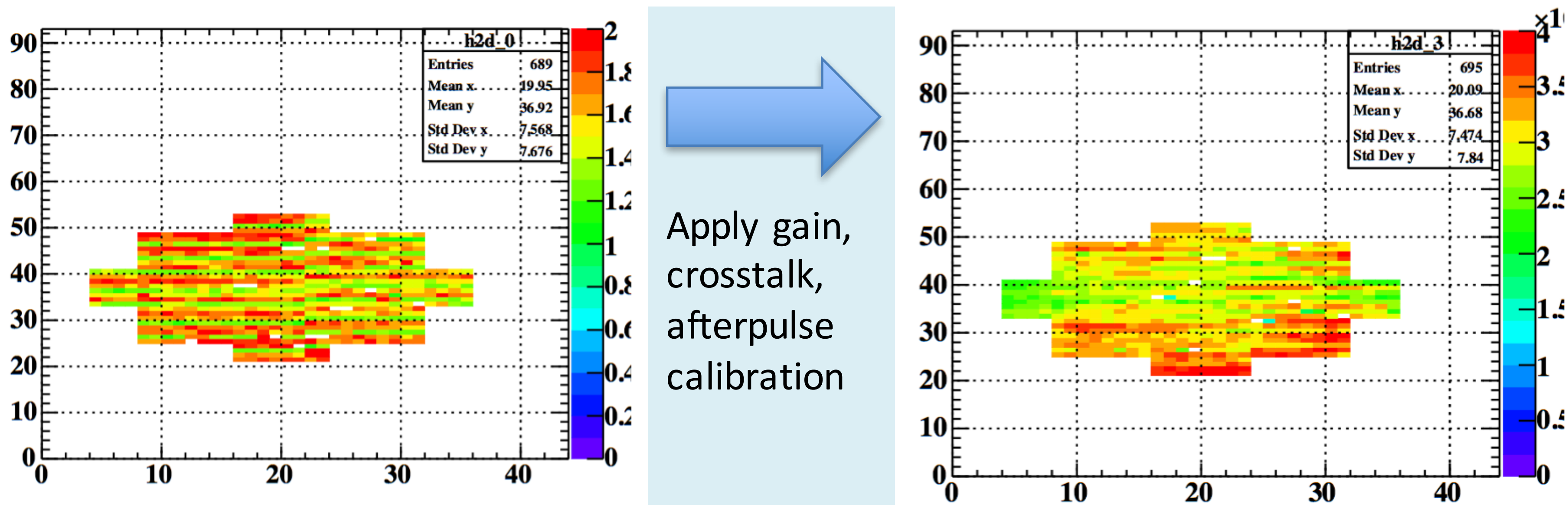
MPPC crosstalk & afterpulse

- Production lot dependence is observed (as is expected from R&D)
- Charge variation b/w production lot is largely suppressed by applying calibration.

Crosstalk & after pulse vs. MPPC serial



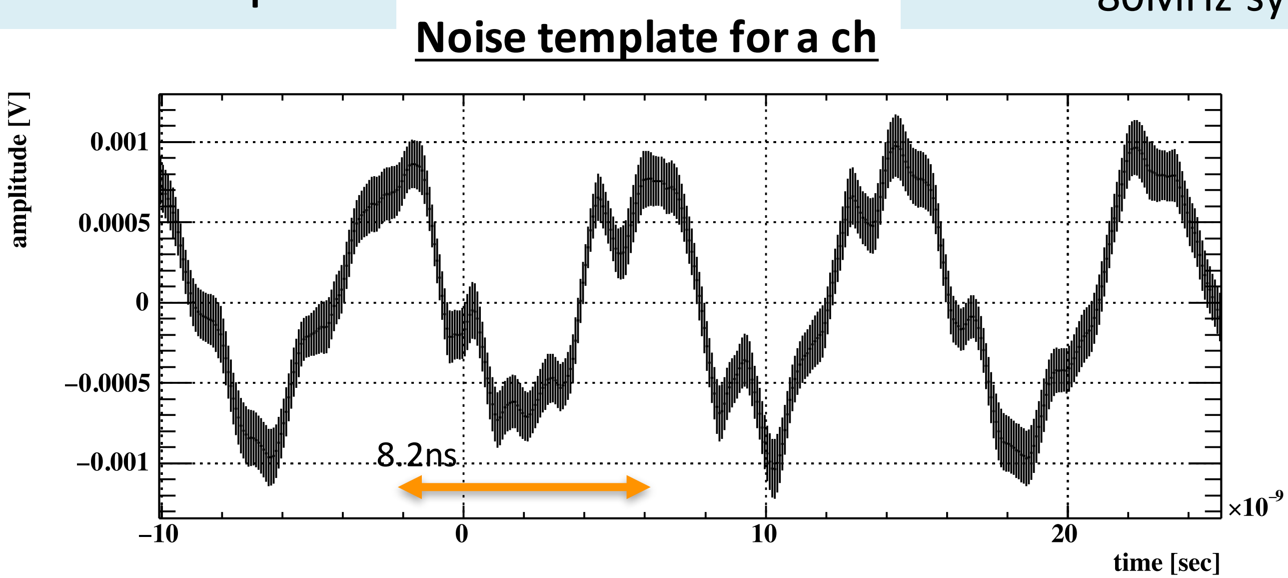
Charge distribution (average) from a LED run

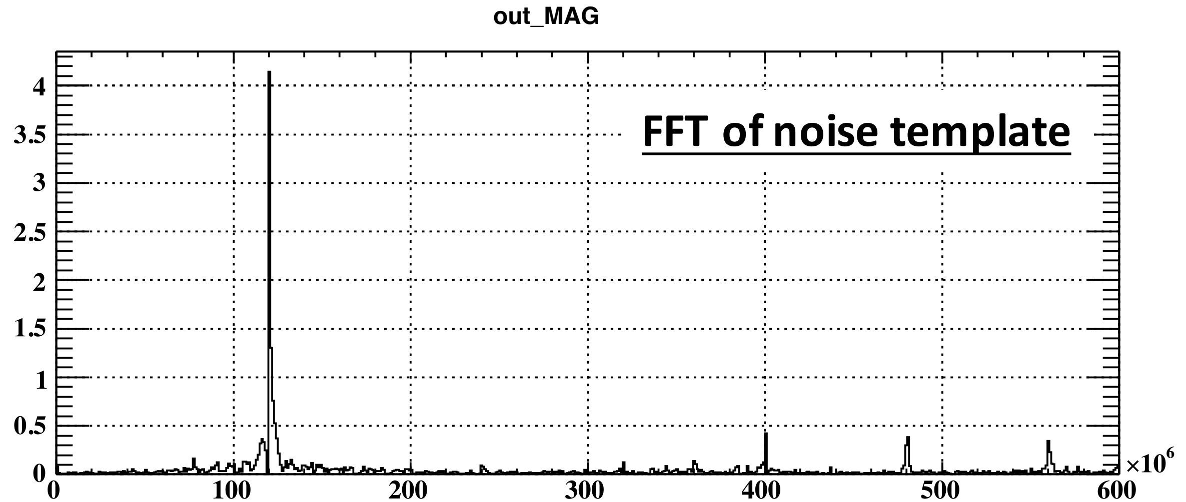


120 MHz noise template

- 120*n MHz component can be extracted.

after extract & subtract
80MHz sync



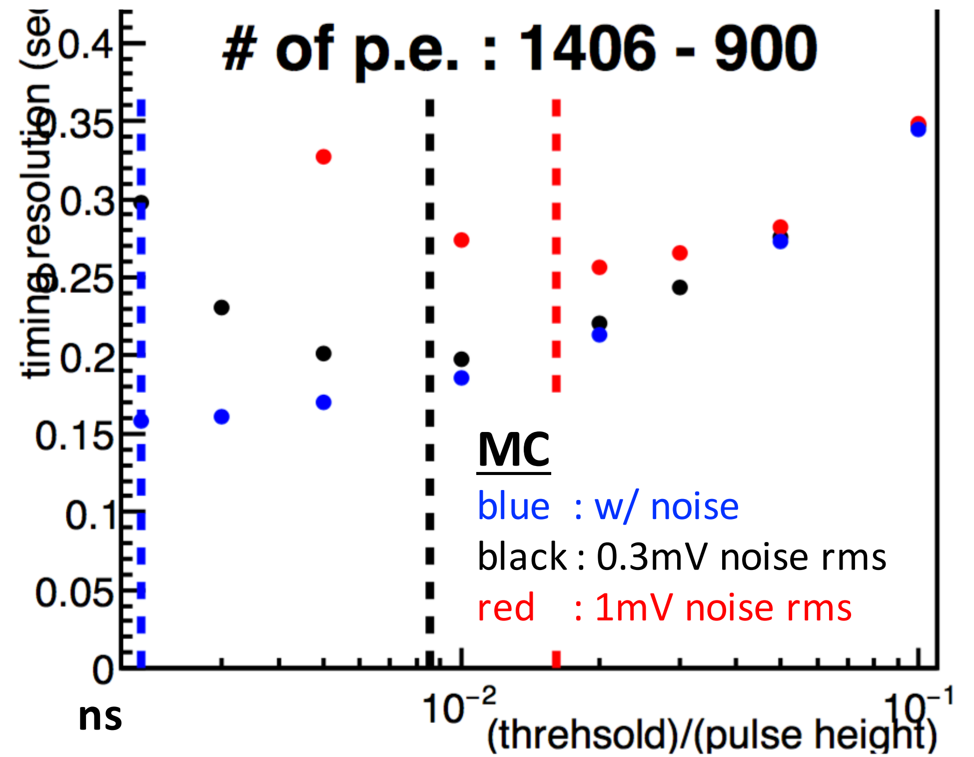


Motivation of Tγ study

- Our estimation of Tγ resolution was 40-70ps.
  - Tγ resolution is very sensitive to the noise level.
    - Reference: My report on 2015.Dec & 2016.Jul etc...

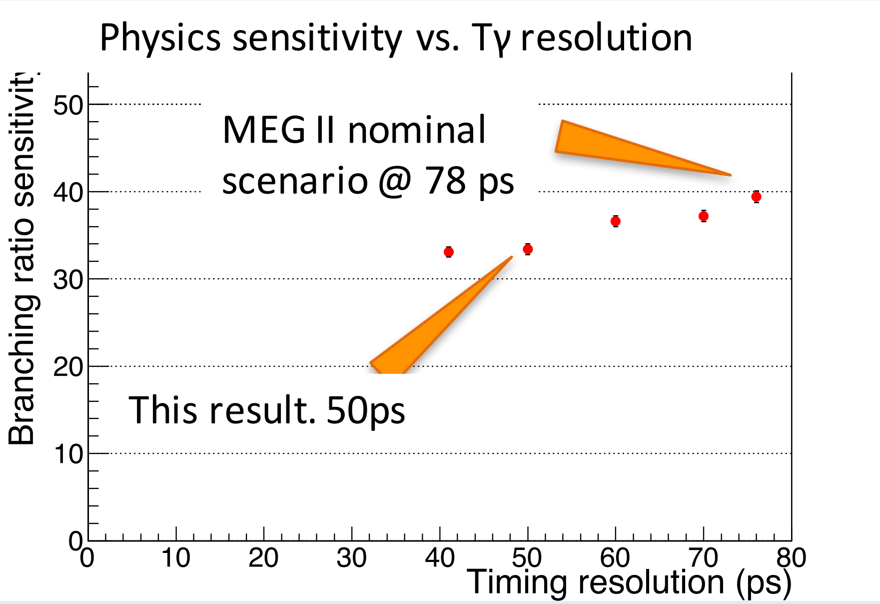
- If there is no noise, smaller threshold gives better timing resolution.
- Noise prevent us to use small threshold.

Timing resolution of a MPPC
vs. threshold (used for constant fraction method)

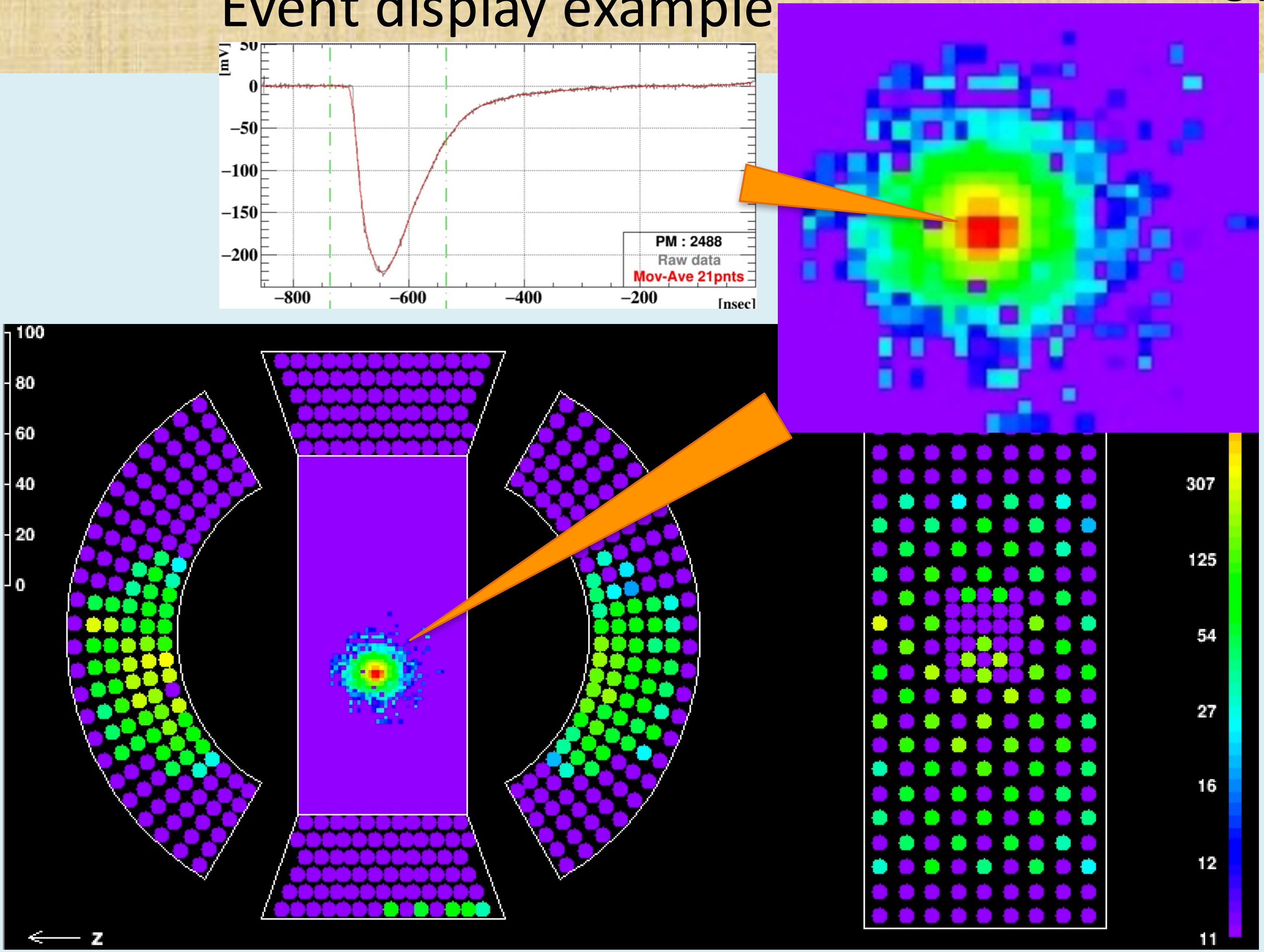


Motivation of Tγ study

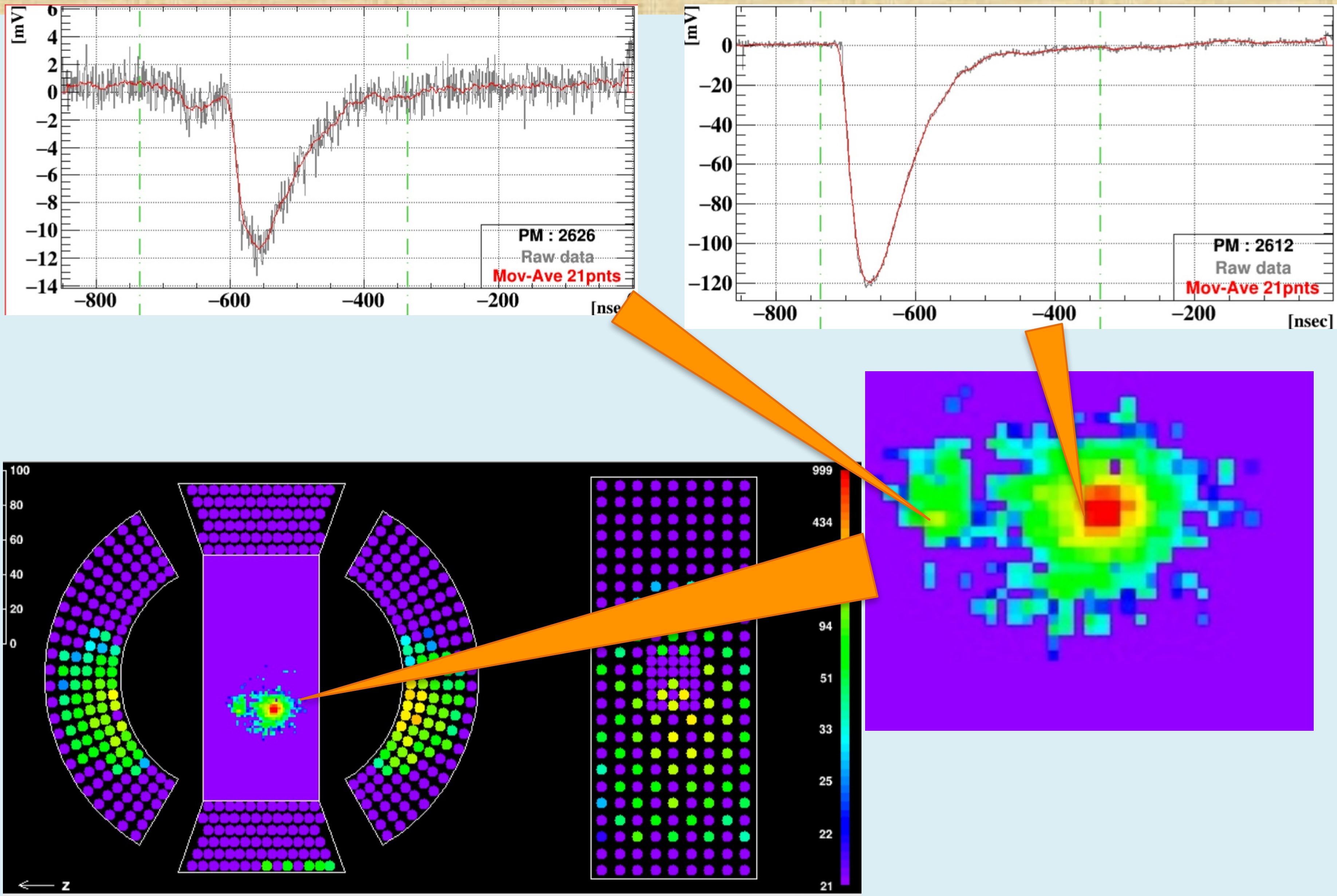
- aaa



Event display example

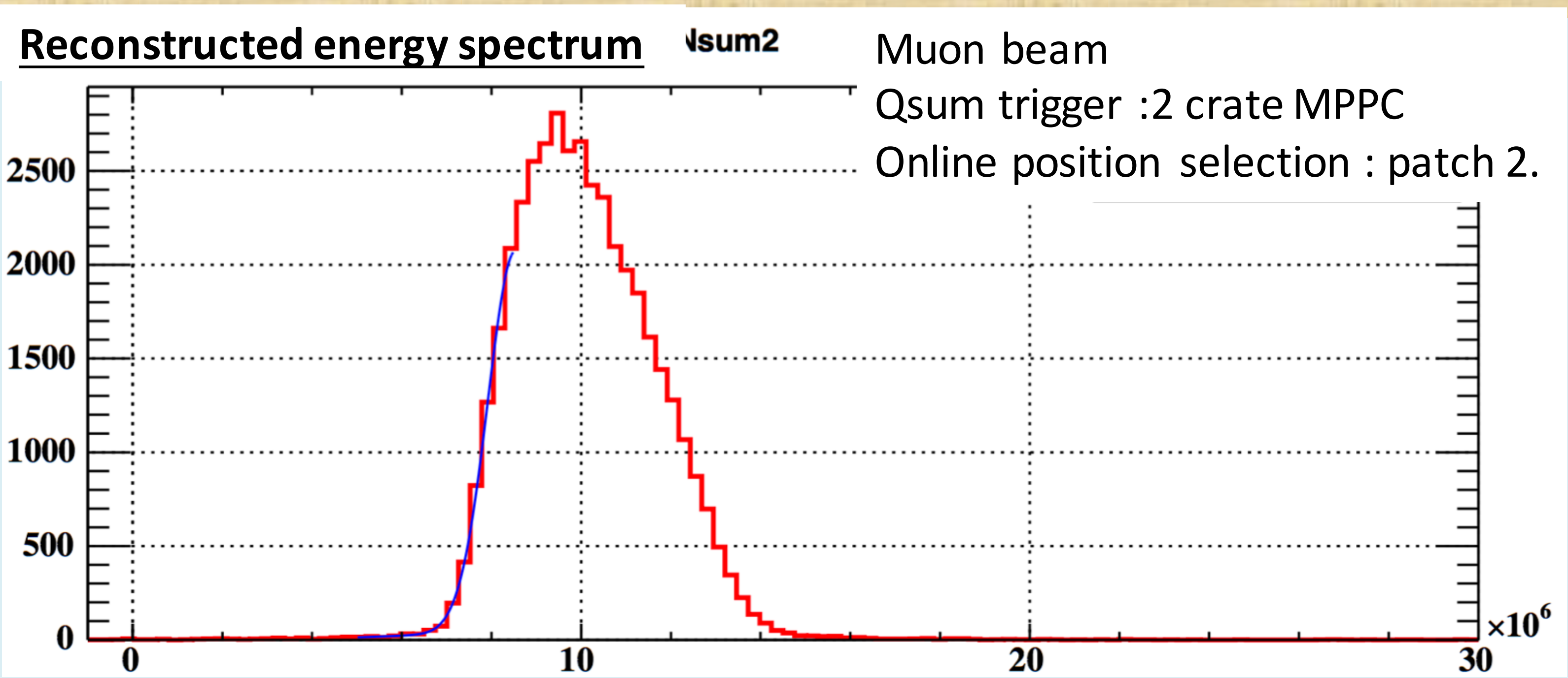


Event display example –pileup event-



Energy spectrum -muon beam-

Very Preliminary

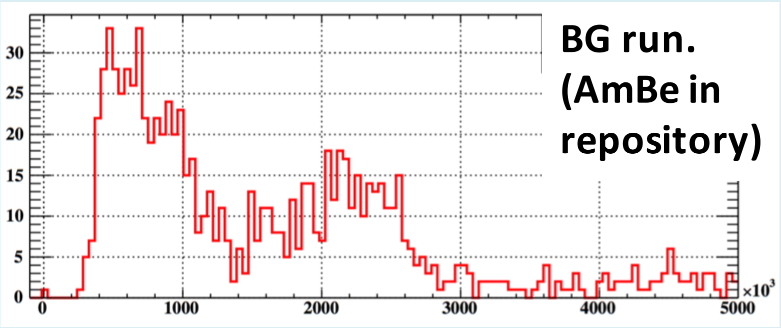


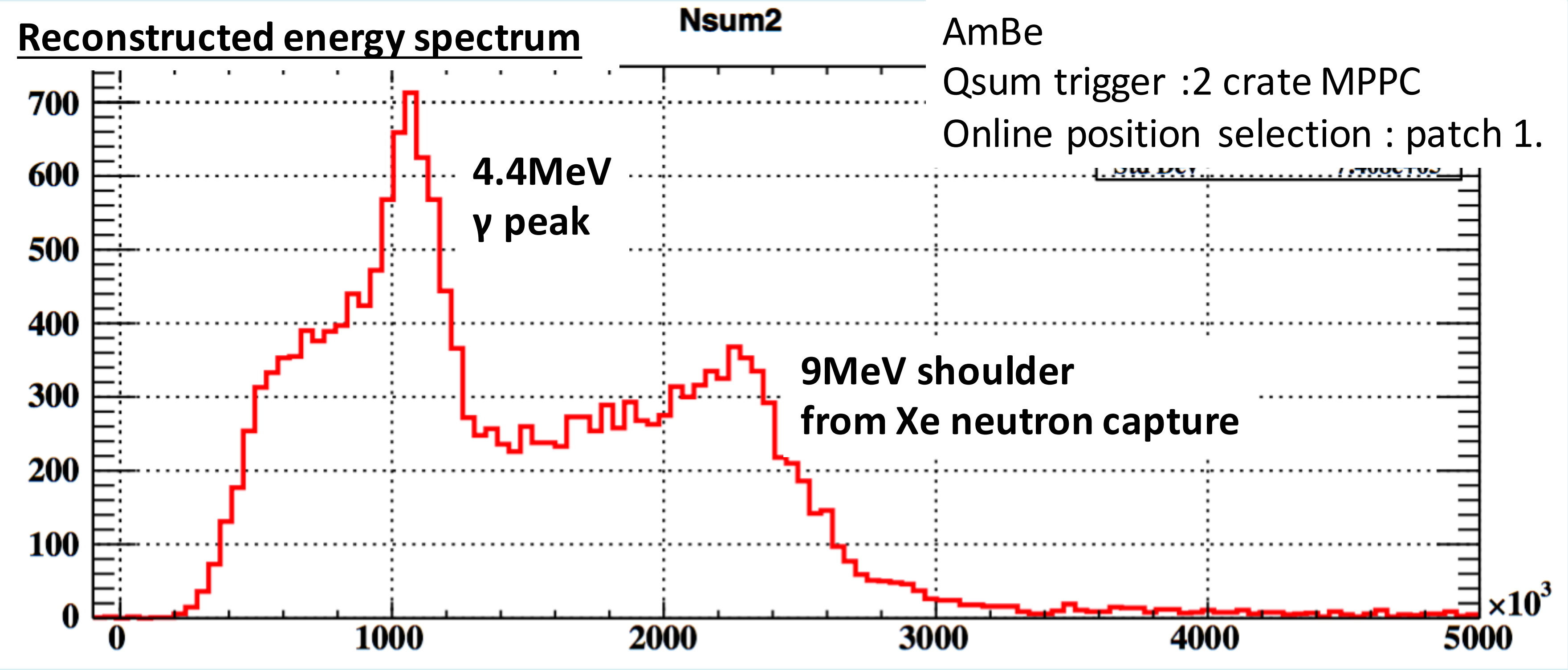
- Example of γ energy spectrum.
- In order to finalize the spectrum, we need to
  - calibrate sensor gain, crosstalk, afterpulse, PDE.
  - correct hit position dependence of energy.
  - correct WDB noise, non-linearity, real amp gain.
  - etc...

Energy spectrum -AmBe-

Very Preliminary

- We took 4.4MeV γ from AmBe.
- DAQ by self-trigger. Use WDB gain 5.
  - At WDB gain 1 (same config w/ signal), S/N ratio was too bad to trigger 4.4MeV.
- Offline event selection by Q/A of waveform to reject alpha event.

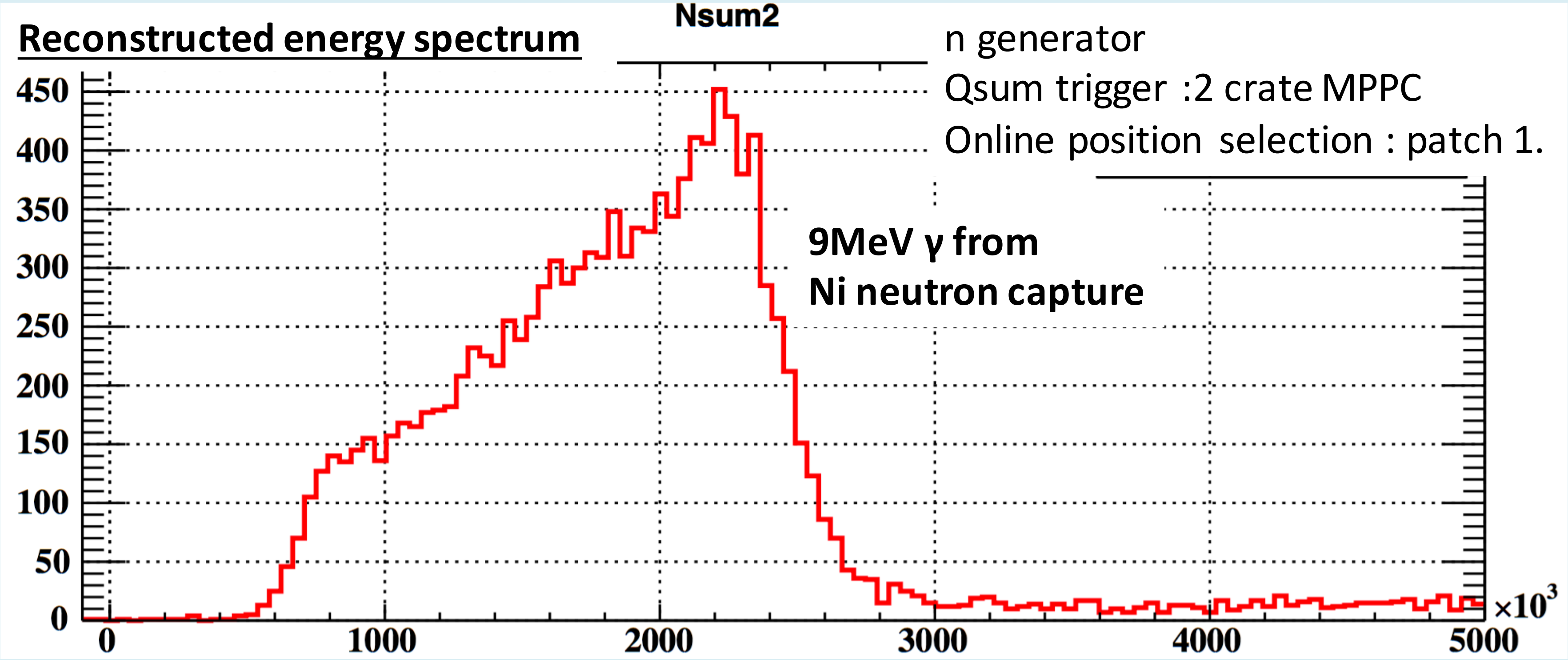




Energy spectrum -n generator-

Very Preliminary

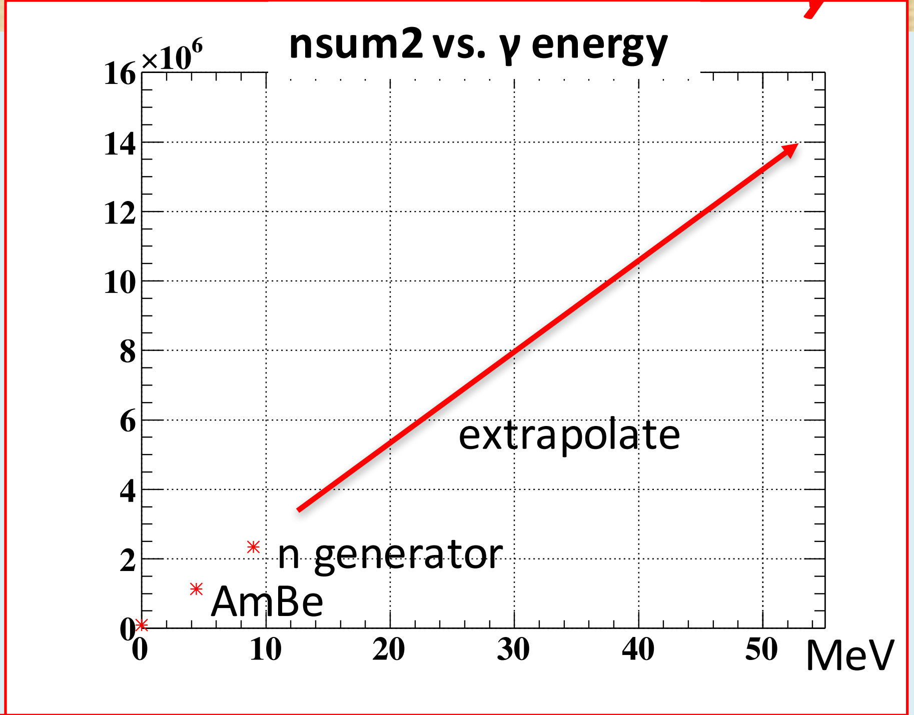
- We took 9MeV γ from neutron generator.
- DAQ by self-trigger. Use WDB gain 5.

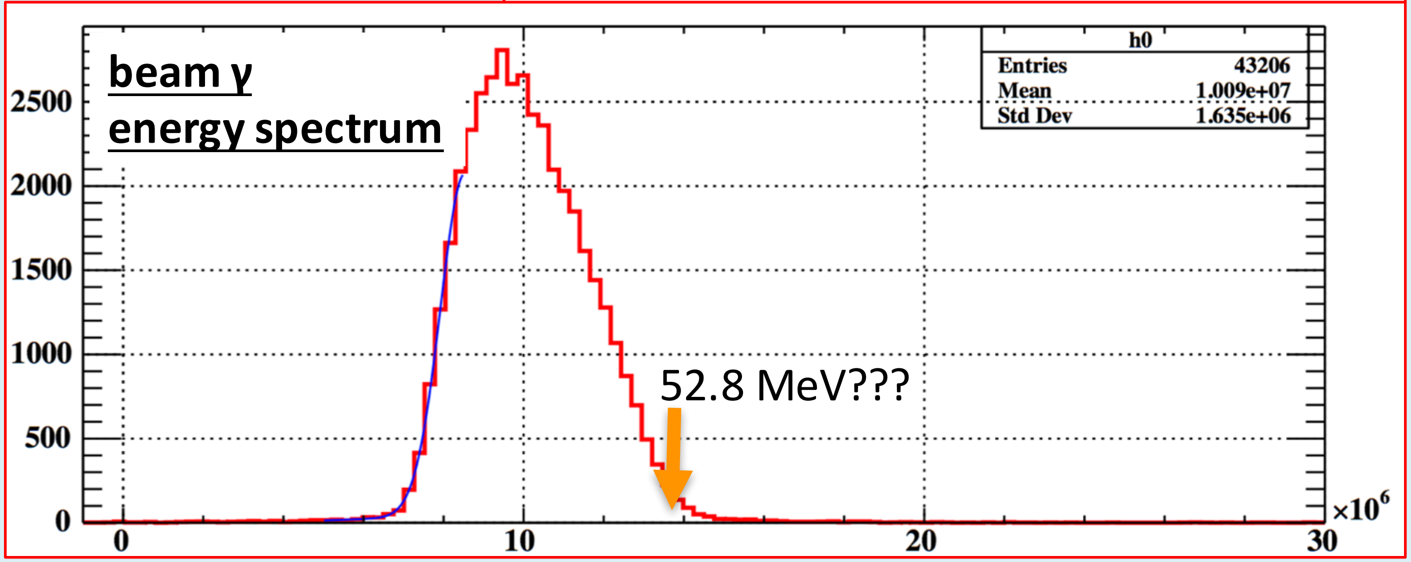


Rough estimate of energy scale

Preliminary

- AmBe & n generator is consistent w/ 1% precision.
- From AmBe and n generator, 52.8MeV is estimated to be corresponding to "nsum2 = 13.7x10^6"
- This is roughly consistent w/ beam γ spectrum.





Energy spectrum -n generator-

- We took 9MeV γ from neutron generator.
- DAQ by self-trigger. Use WDB gain 5.
- Some non-uniformity is observed. (as is sexpected)

n generator
Qsum trigger :2 crate MPPC
Online position selection : patch 1.

reco. energy vs. reco. position