MEG II実験液体キセノンガンマ線検出器の全チャンネル読み出しでの性能評価

Performance evaluation of MEG II liquid xenon gamma-ray detector with full channel readout

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The University of Tokyo

日本物理学会
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(オンライン開催)
15pT3-6

MEG II
Mu - E - Gamma collaboration

THE UNIVERSITY OF TOKYO

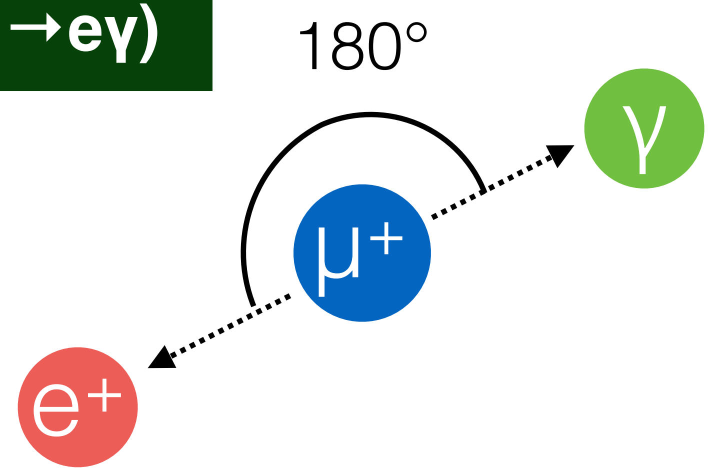
Core-to-Core Program

Outline

- Introduction
  - MEG II experiment
  - Liquid Xenon Gamma-ray Detector Upgrade
  - Previous commissioning runs
- 2021 Engineering run
  - Read out
  - Noise situation
  - Calibration, monitoring
- Summary & Prospects

μ→eγ search

Signal (μ→eγ)



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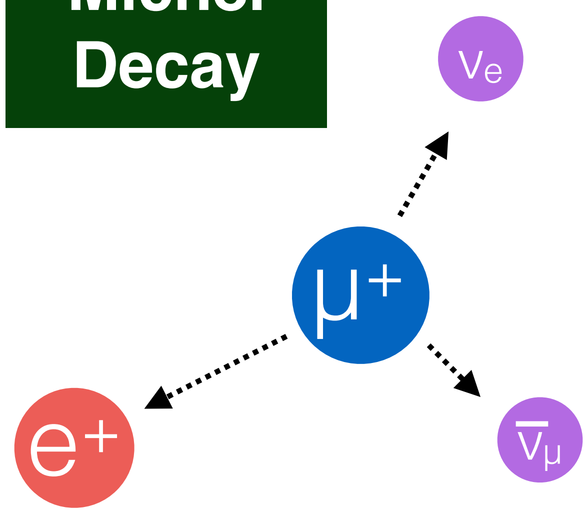
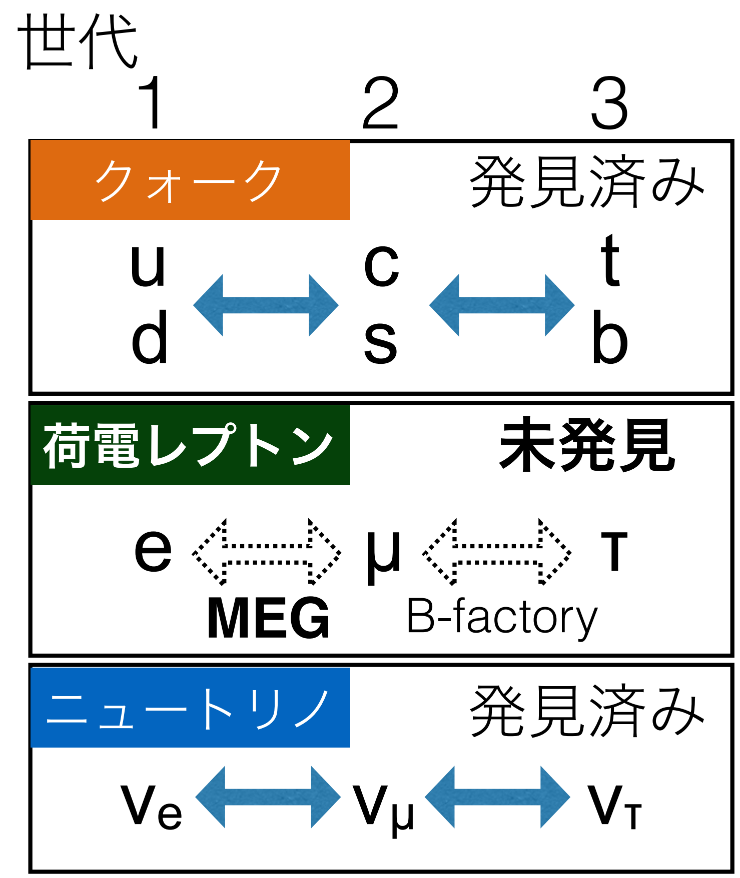
Michel Decay

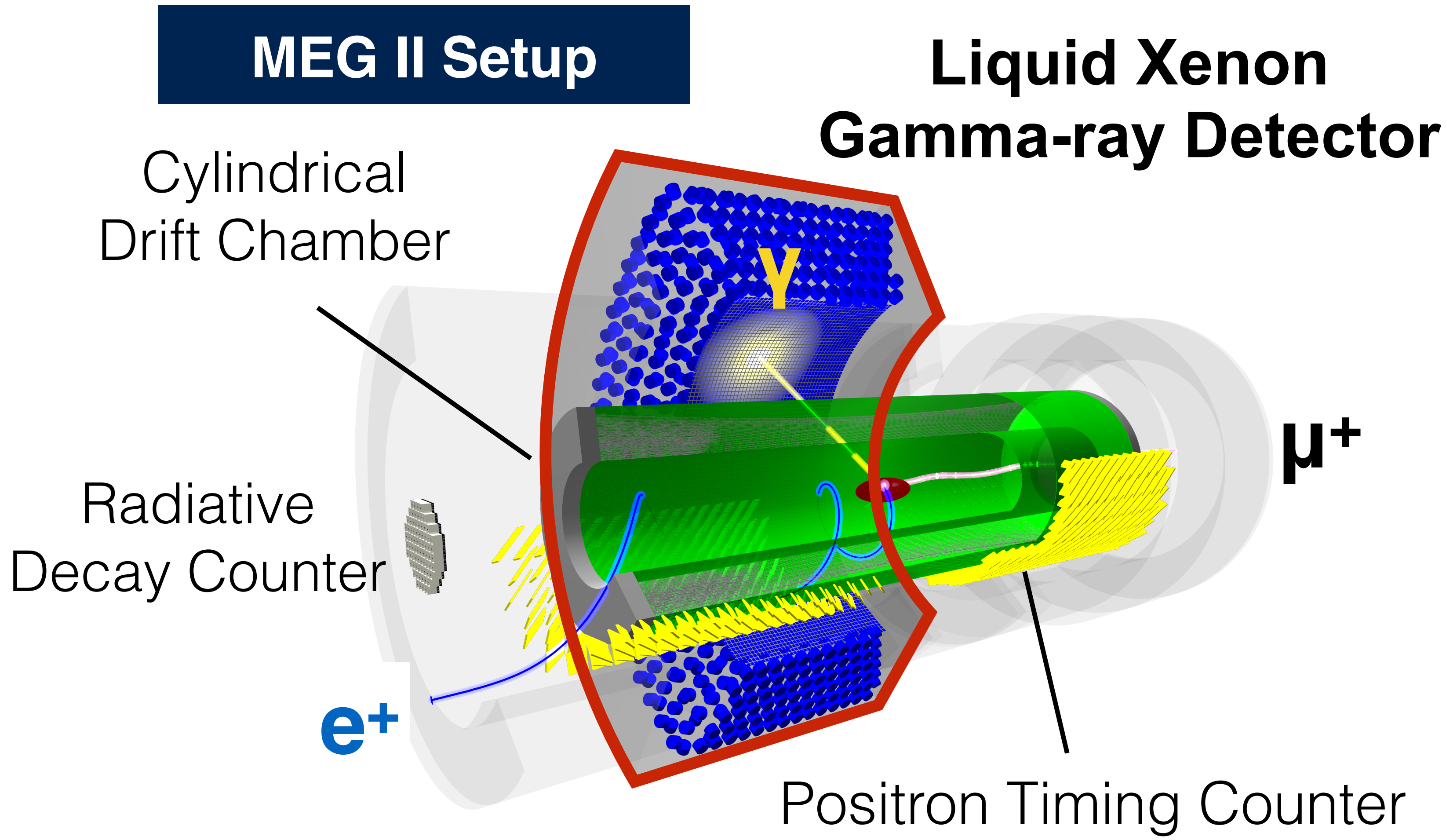




- Simultaneously emitted
- Back-to-back
- Same energy(52.8MeV)

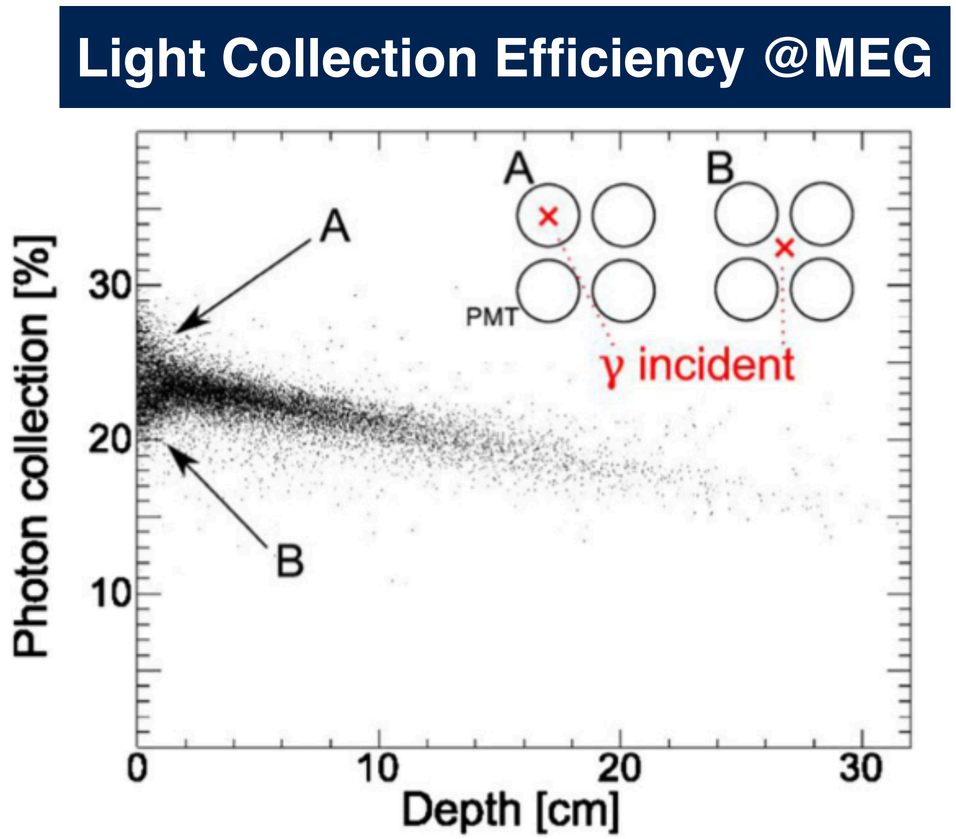
- μ→eγ decay is a charged lepton flavor violating(**cLFV**) decay.
  - **Almost forbidden** in SM+ν. oscillation (Br(μ→eγ)~10^{-54})
  - **Predicted** in some theories (Br(μ→eγ):10^{-11}~10^{-14})
- The MEG experiment gives the current upper limit of Br(μ→eγ).
  - Br($\mu^+ \to e^+\gamma$) < **4.2×10^{-13}** (90% C.L.)

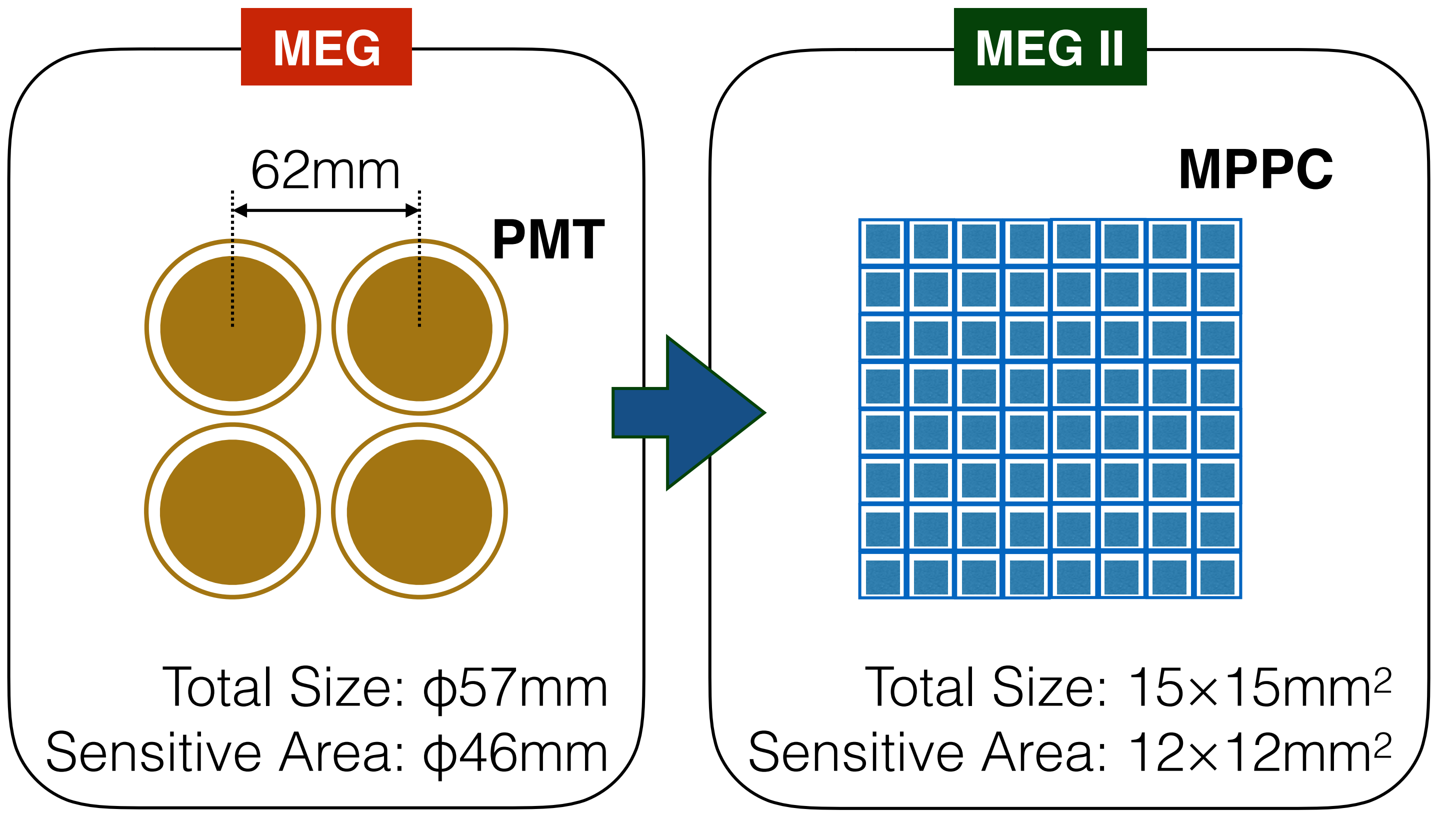
MEG II Experiment



- MEG II will search for the μ→eγ decay with unprecedented sensitivity.
  - Goal: **Br(μ→eγ)~6×10^{-14}** in 3 years of data acquisition.
  - Even **higher intensity muon beam** $(3 \times 10^7 \mu/s \rightarrow 7 \times 10^7 \mu/s)$
  - **Detector upgrade** ($\times 2$ resolution improvement for each detector)
- Liquid Xenon gamma-ray detector measures the position, energy, and timing of the incident gamma-ray.
  - 900 L liquid xenon + VUV-sensitive photosensor.

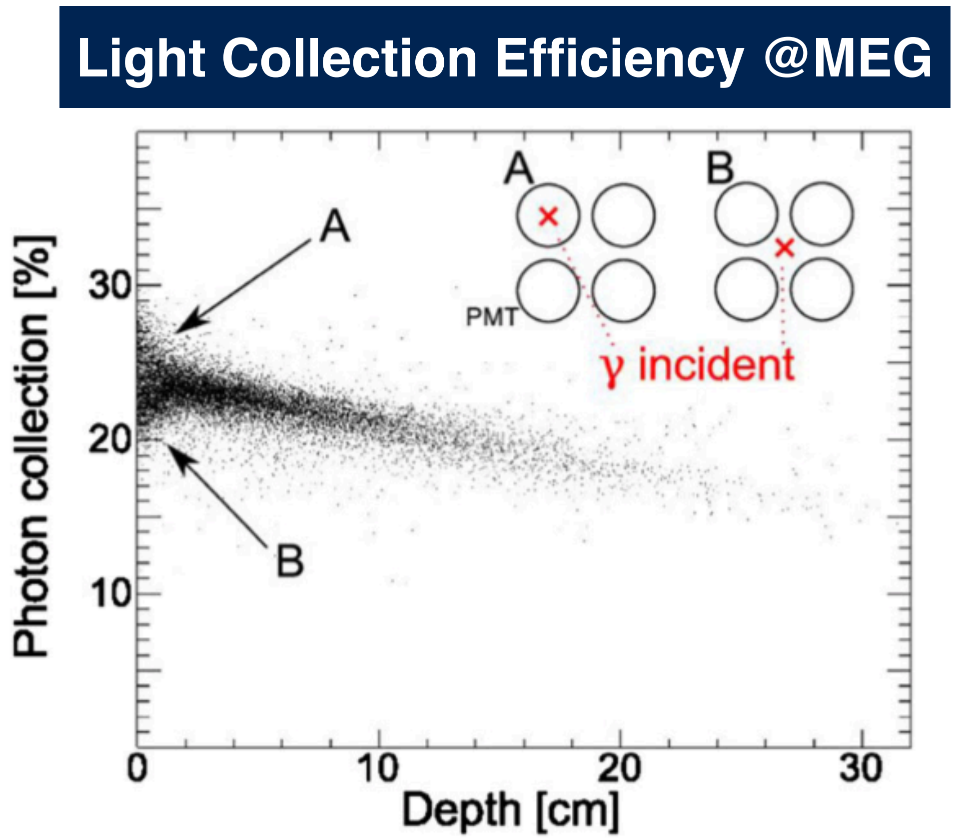
Liquid Xenon Detector Upgrade

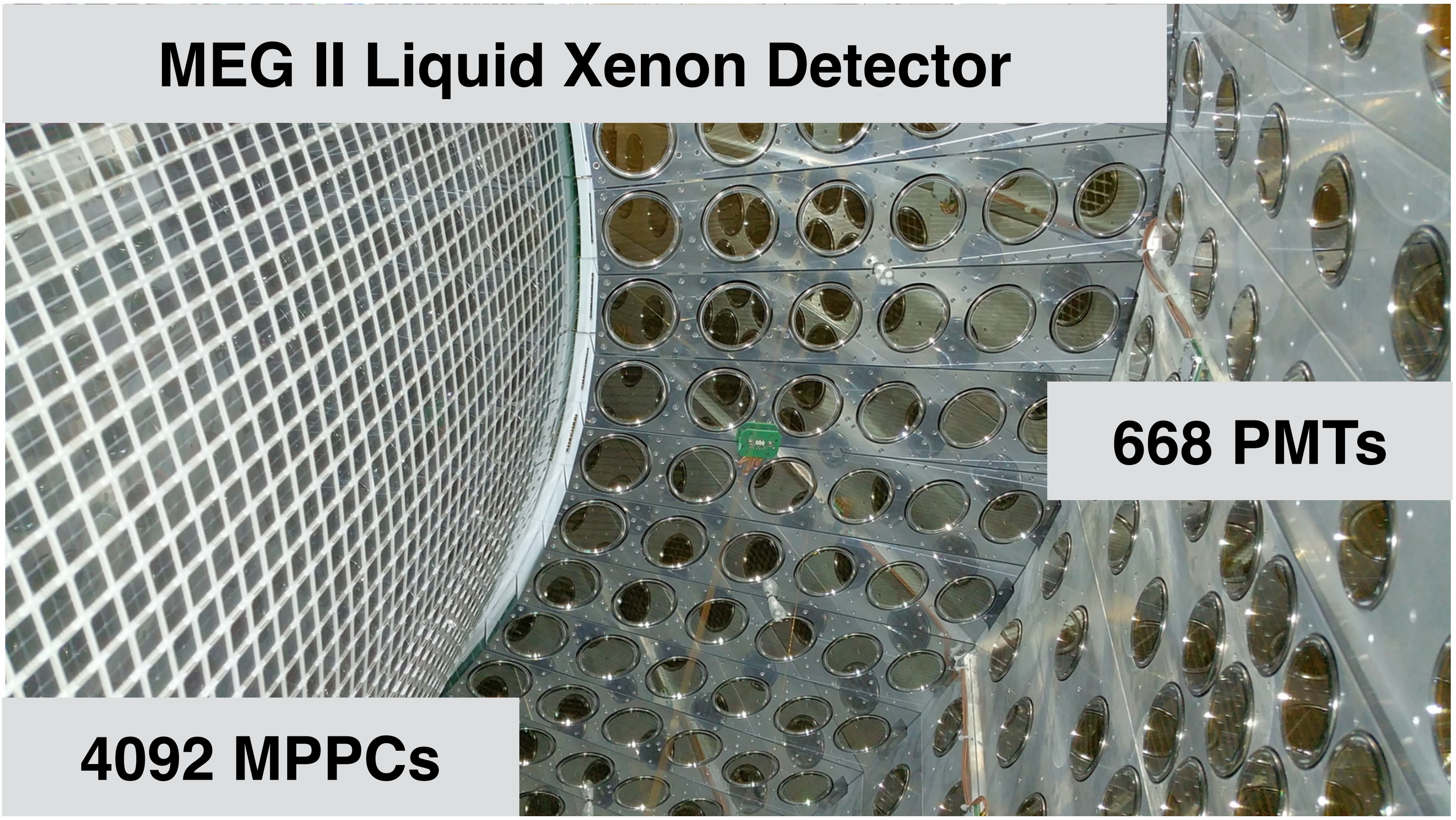




- MEG gamma-ray detector used 2-inch PMTs to detect scintillation light of liquid xenon in the VUV range ($\lambda \sim 175$ nm).
- Non-uniformity of light collection efficiency limited the resolution.
  - A small and square-shaped photosensor is desirable.
- We use **VUV-sensitive MPPCs** in MEG II.
  - Developed for MEG II in collaboration with Hamamatsu K.K.
  - Entrance face: 216 PMTs → **4092 MPPCs** (12×12 mm^2)

Liquid Xenon Detector Upgrade





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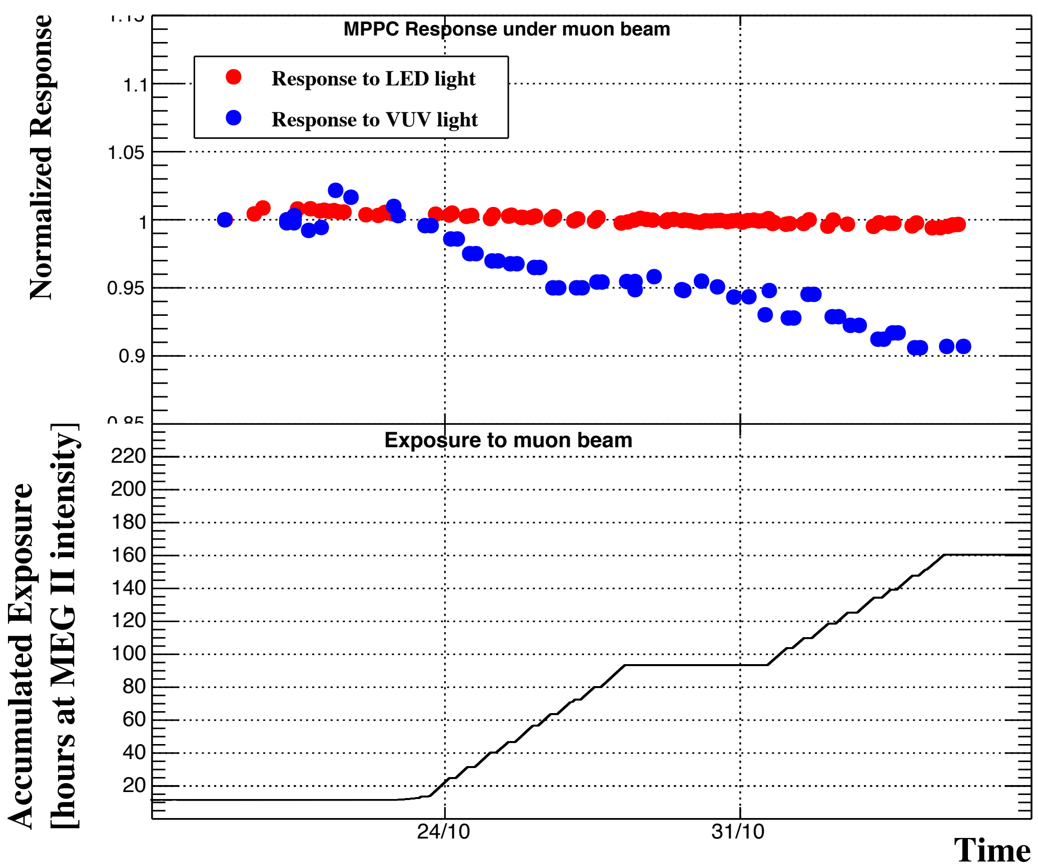
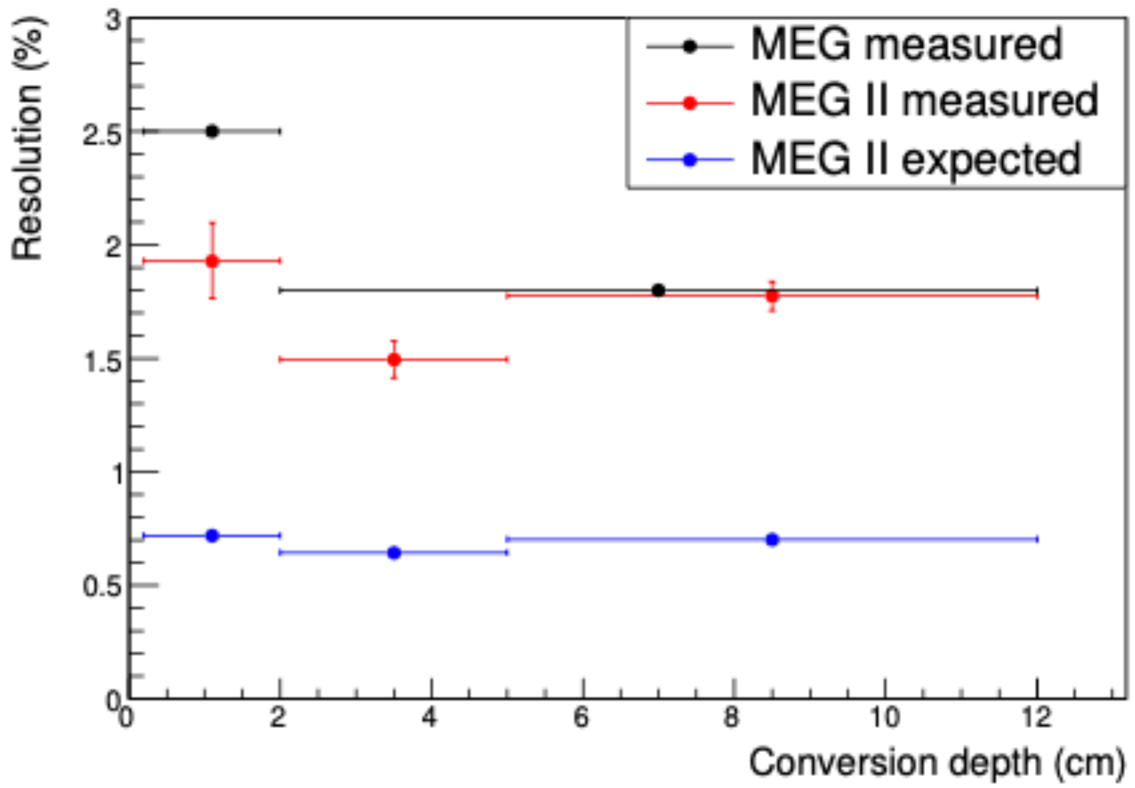
Highlight of pre-engineering runs 2017 - 2020

MPPC radiation damage under beam



2020年年次大会、小林

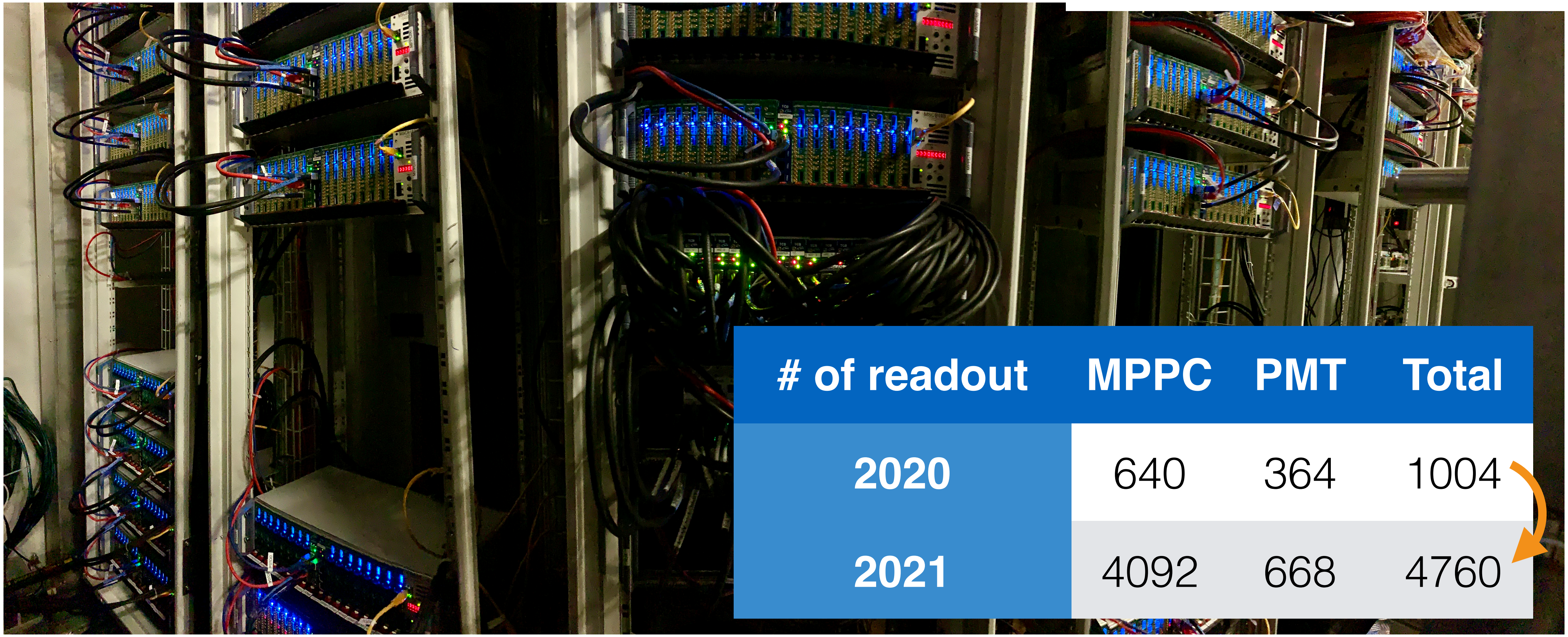
Improved energy resolution



2019年年次大会、小川(現九州大)

- Limited number of readout: 1004 / 4760 channels.
- Known issues: radiation damage
  - **MPPC PDE & PMT gain degradation under beam**.
  - Solution: thermal annealing recovers MPPC PDE.
- Detector performance:
  - **Acceptable energy & position resolution (1.7% / 2.5 mm)**
  - **Timing resolution & Detection efficiency: reliable measurement to be done.**

Engineering run 2021

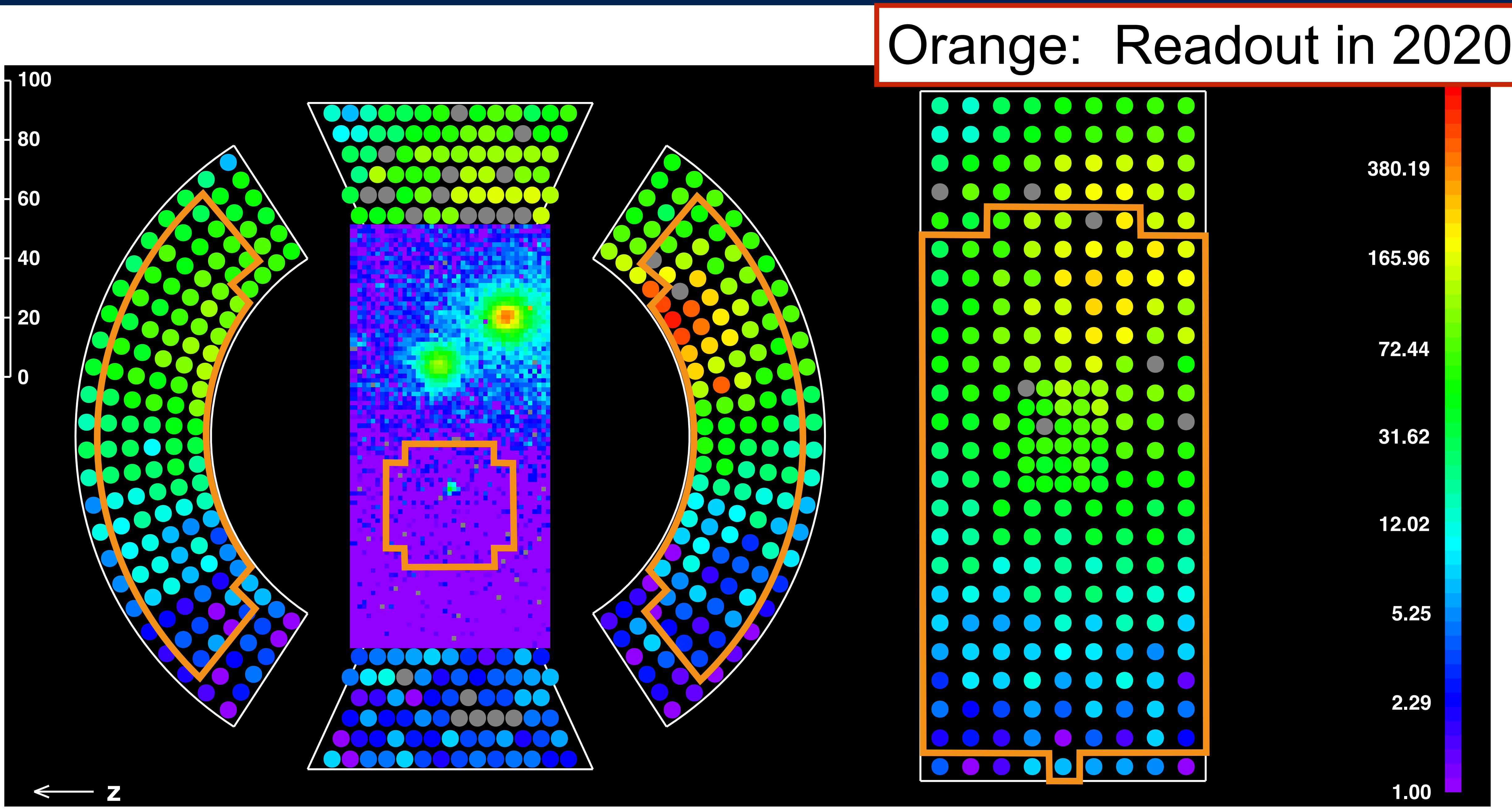


# of readout	MPPC	PMT	Total
2020	640	364	1004
2021	4092	668	4760

x4-5

- Finally, the whole detector : 4760 channels are read out.
- The beam time started on 13th Aug.
  - Reduced beam intensity to investigate radiation damage
  - Stopping rate $R_\mu = 3 \times 10^7 \mu/s$: ~40% of $7 \times 10^7 \mu/s$
- The first missions:
  - Performance evaluation of the readout electronics.
  - Monitor of the radiation damage.

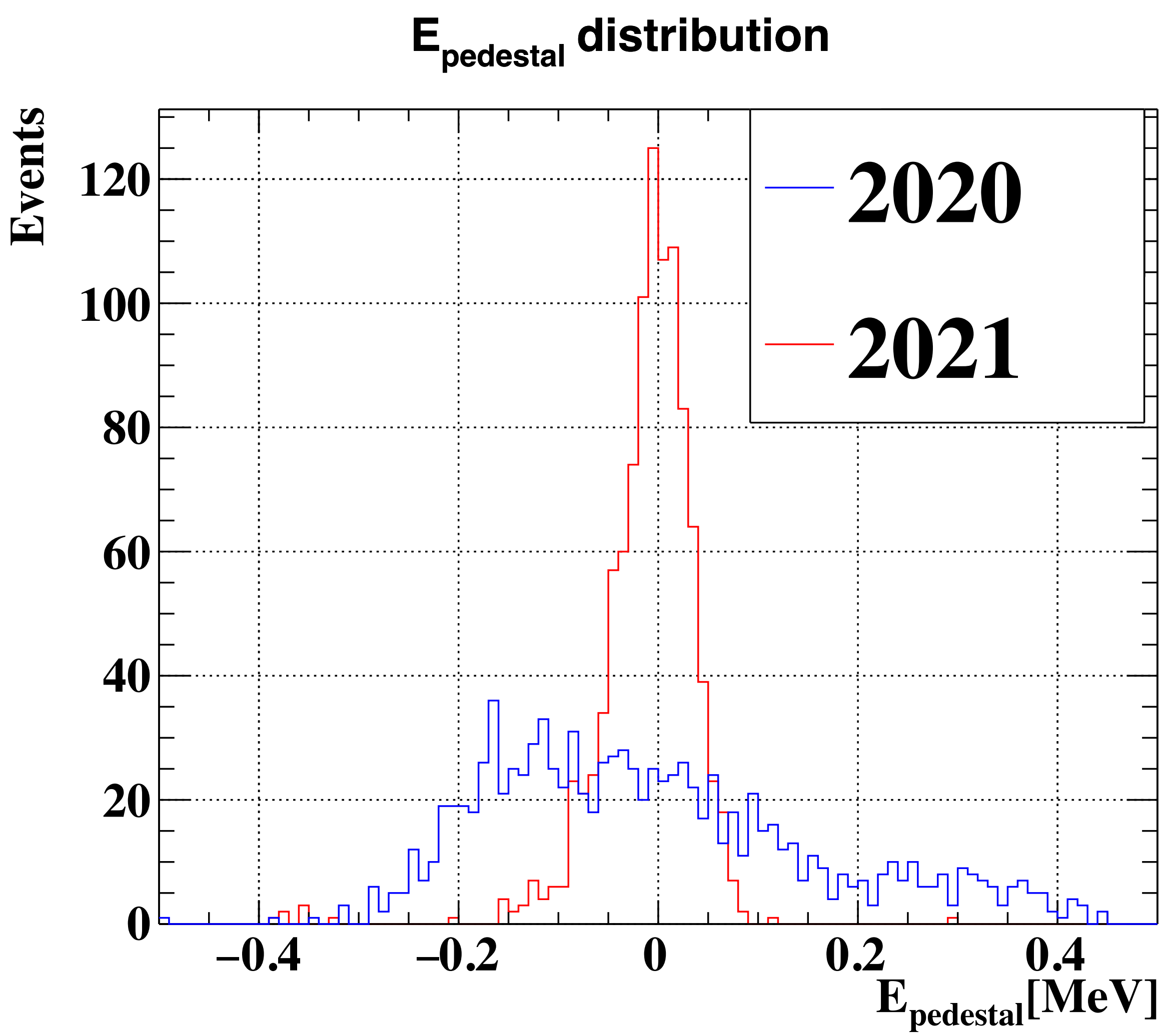
Engineering run 2021: Readout



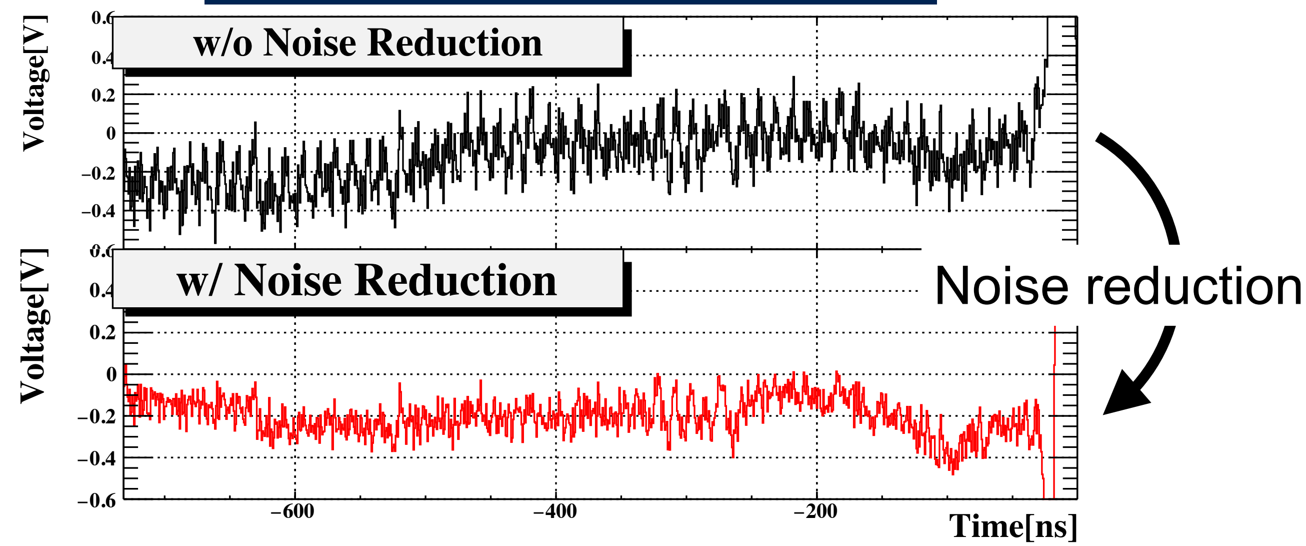
Gamma-ray pile up event (Data)

- Almost all photosensors are working well.
  - 28 MPPCs and 27 PMTs don't work due to short circuit / HV supply.
- Reasonable DAQ rate (~10 Hz, 100 MB/s).

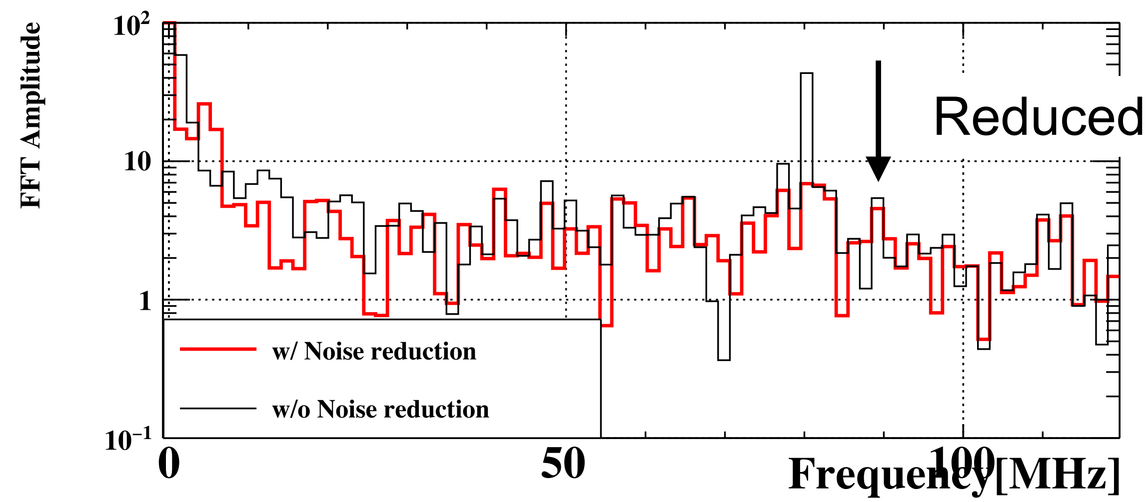
Engineering run 2021: Noise



Sum Waveform (same event)

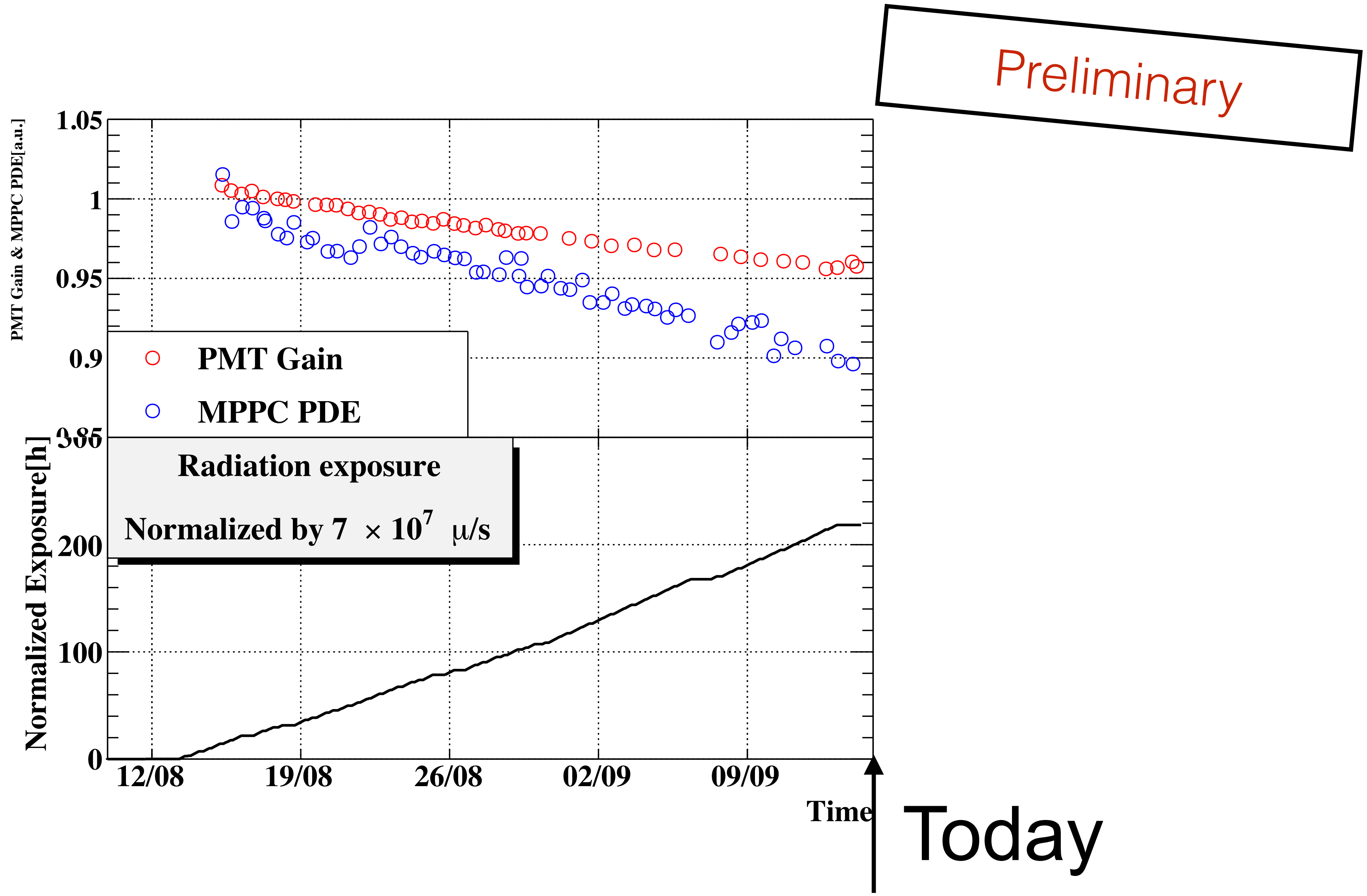


FFT Spectrum



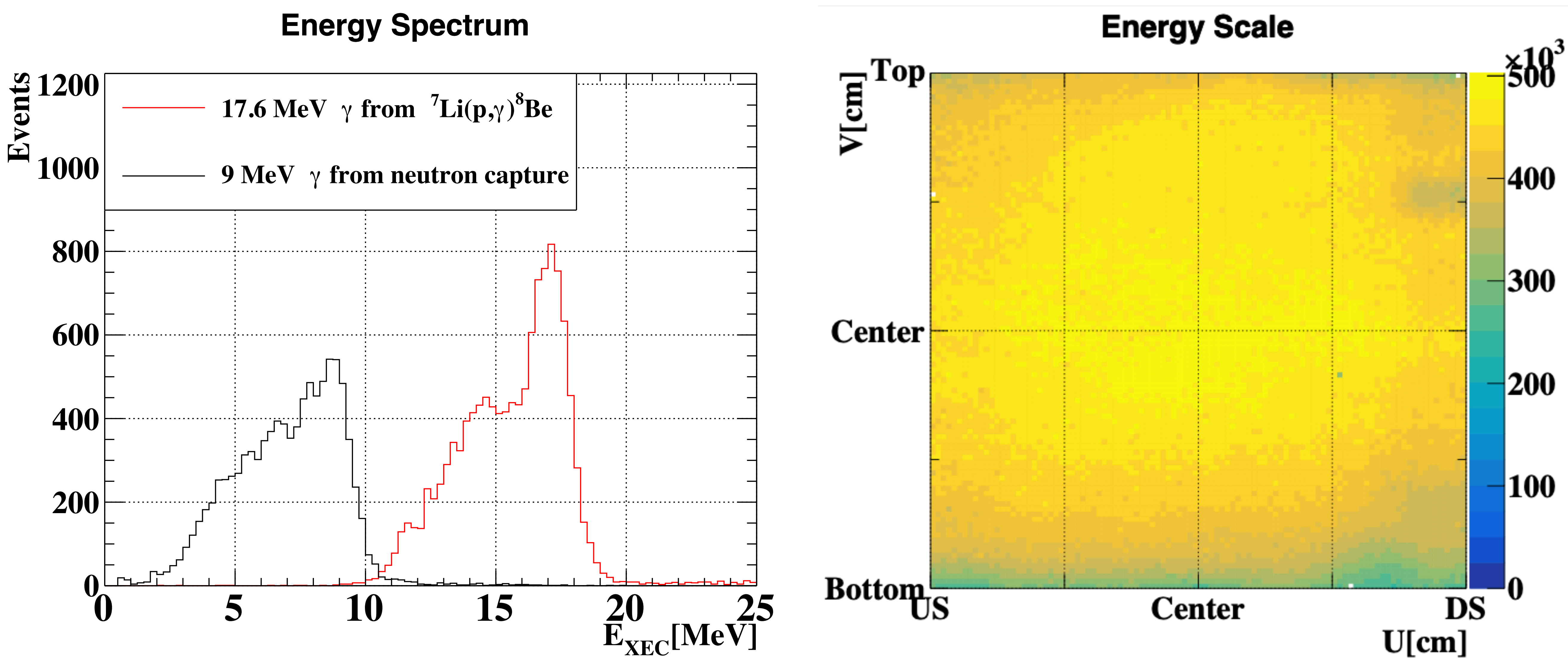
- $\sigma_{E,pedestal} = 3.7 \times 10^{-2}$ MeV: 0.08% of 52.8 MeV.
  - 2020: 1.3×10^{-1} MeV… Improved by a factor of 3.5.
  - Reduced coherent noise probably due to choke coil.
- **Negligible impact on the energy resolution (~1%).**
- High-frequency noise is suppressed with offline noise reduction.

Engineering run 2021: Calibration



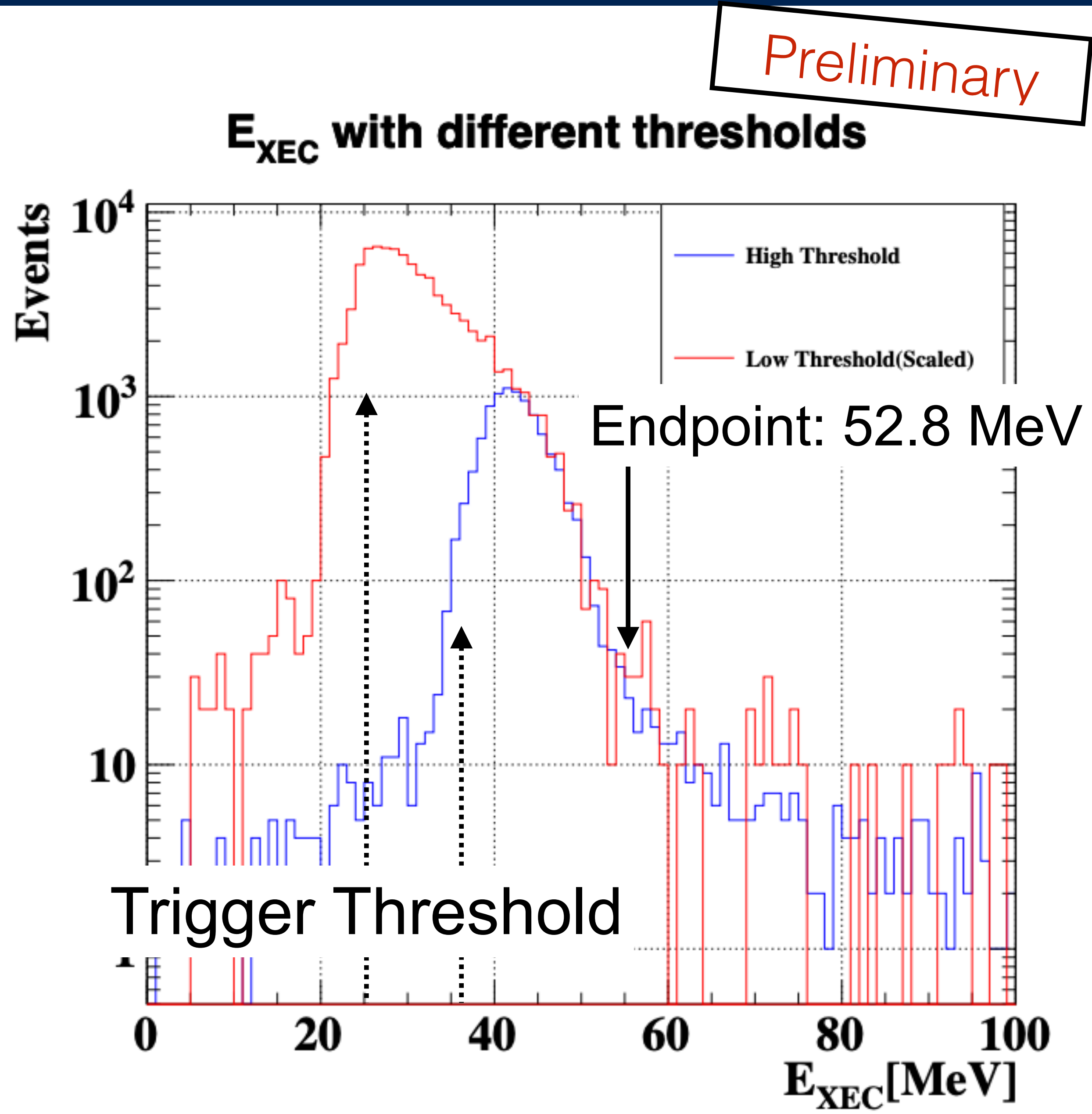
- Radiation damage of PMT gain and MPPC PDE are monitored with intrinsic sources (LED, $^{241}\mathrm{Am}$).
- The degradation rate is consistent with previous measurements.
  - MPPC PDE decrease: 0.05(1)% / hour at $7 \times 10^7 \mu/s$
  - PMT Gain decrease: ~0.02% / hour at $7 \times 10^7 \mu/s$

Engineering run 2021: Gamma-ray calibration

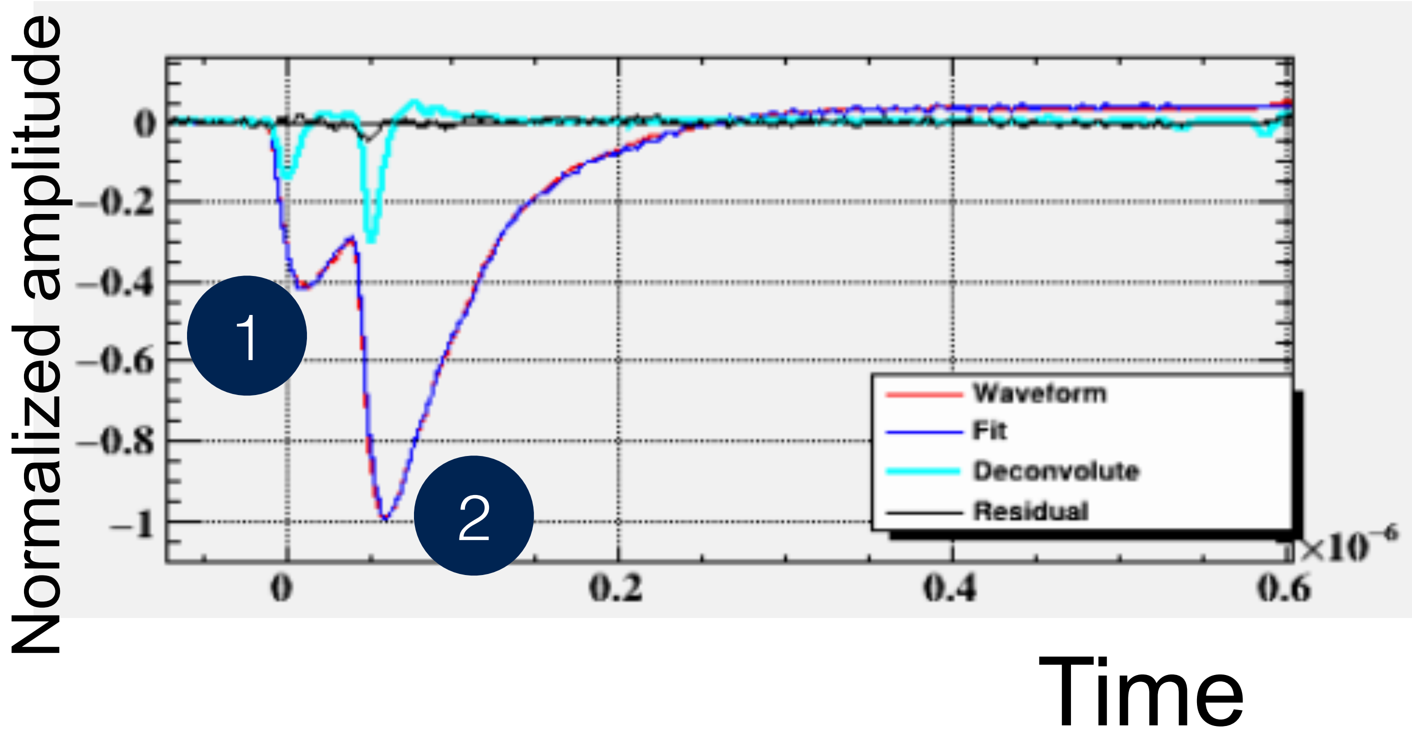


- We have two external gamma-ray sources:
  - 17.6 MeV gamma-ray from $^{7}\mathrm{Li}(p, \gamma)^{8}\mathrm{Be}$ reaction.
  - 9 MeV gamma-ray from neutron capture.
- This data will be used to monitor the total detector response.

Engineering run 2021: Gamma-ray from muon decay



Pileup identification & deconvolution



- Energy spectrum of background gamma-ray from muon decay.
- Development of pileup analysis for the data is in progress.
  - Next talk: Development of algorithm with simulation
- The uniformity of the energy resolution will be studied with this data.

Summary

- The commissioning of the liquid xenon gamma-ray detector for the MEG II experiment is in progress.
- Finally the readout of all 4760 channels is available.
  - **99% of photosensors are working**.
- The noise situation has been greatly improved.
  - The noise from readout electronics is negligible.
- Calibration apparatus and analysis to monitor the radiation damage are ready.
  - MPPC PDE and PMT gain decreases over beam time, but are monitored frequently.

Prospects

- 2021 beam time: ~ the end of 2021
  - Set up ‘MEG trigger’
    - Online selection based on timing, direction, and energy of both gamma-rays and positrons.
  - Reliable time resolution & efficiency measurement
  - Investigate the uniformity of detector resolution
  - **First physics data acquisition**
- Next year: Start a long physics data acquisition.

Finally we are about to start physics data acquisition.

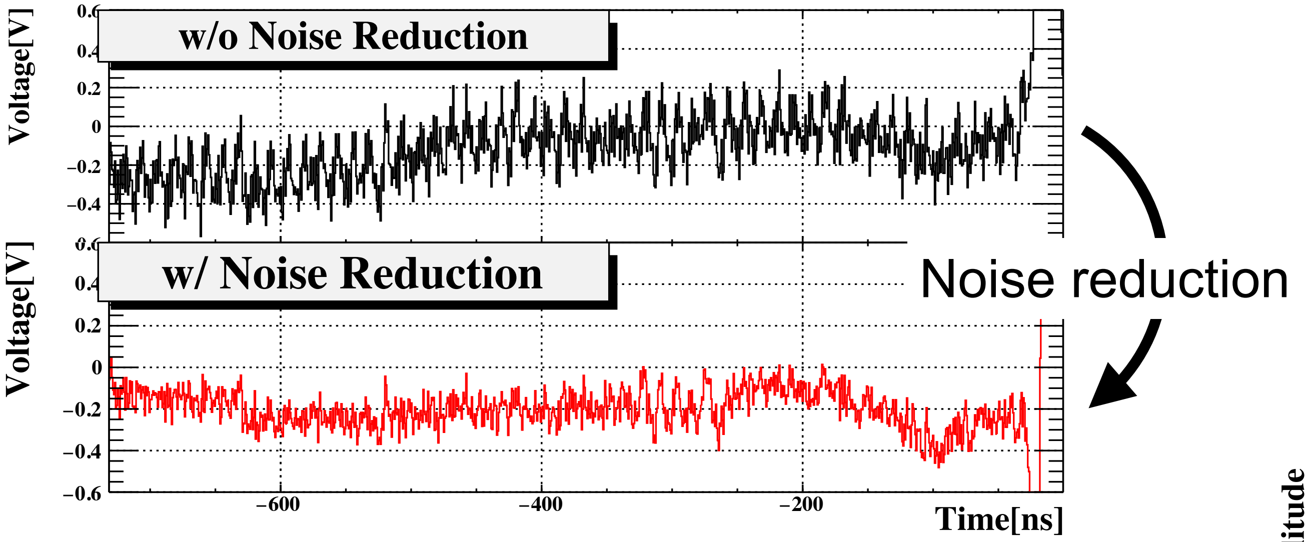
Stay tuned!

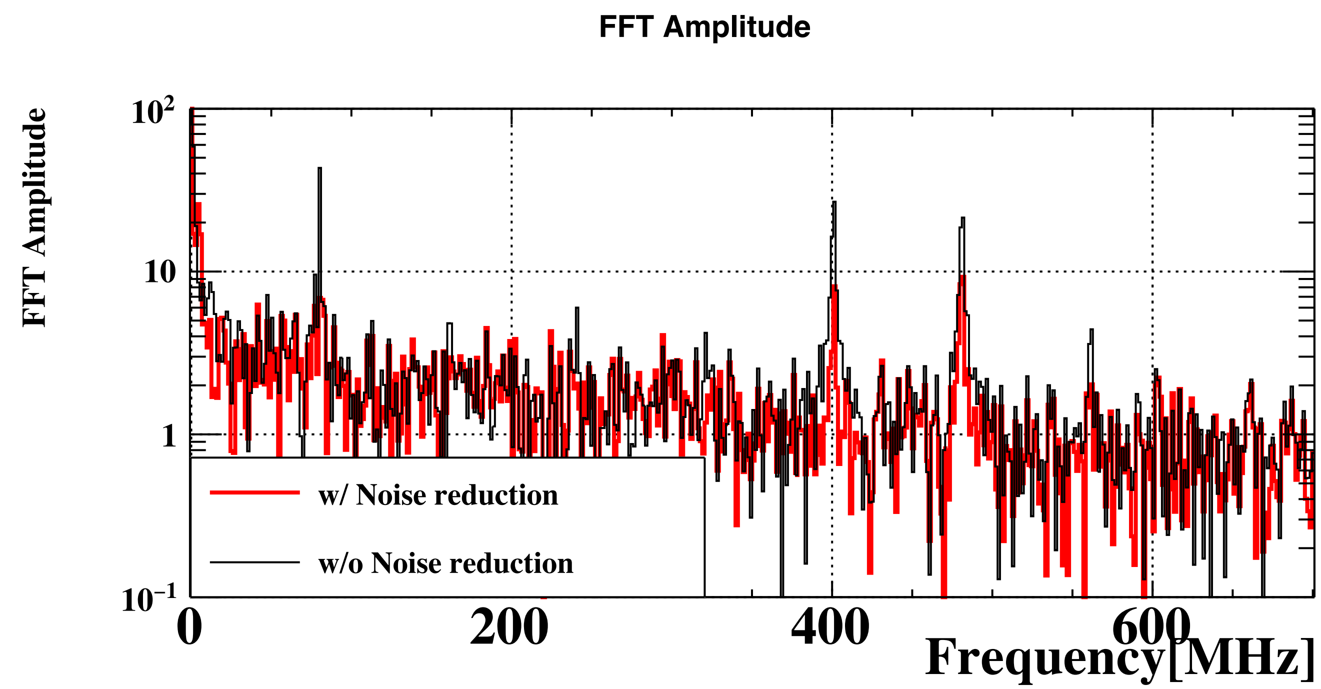
Back up

- Offline noise reduction
- Data reduction
- MPPC PDE decrease in 2019
- PMT Gain decrease
- Energy resolution measurement
- Position resolution measurement
- Study on the possible causes of worse resolution

Offline Noise Reduction

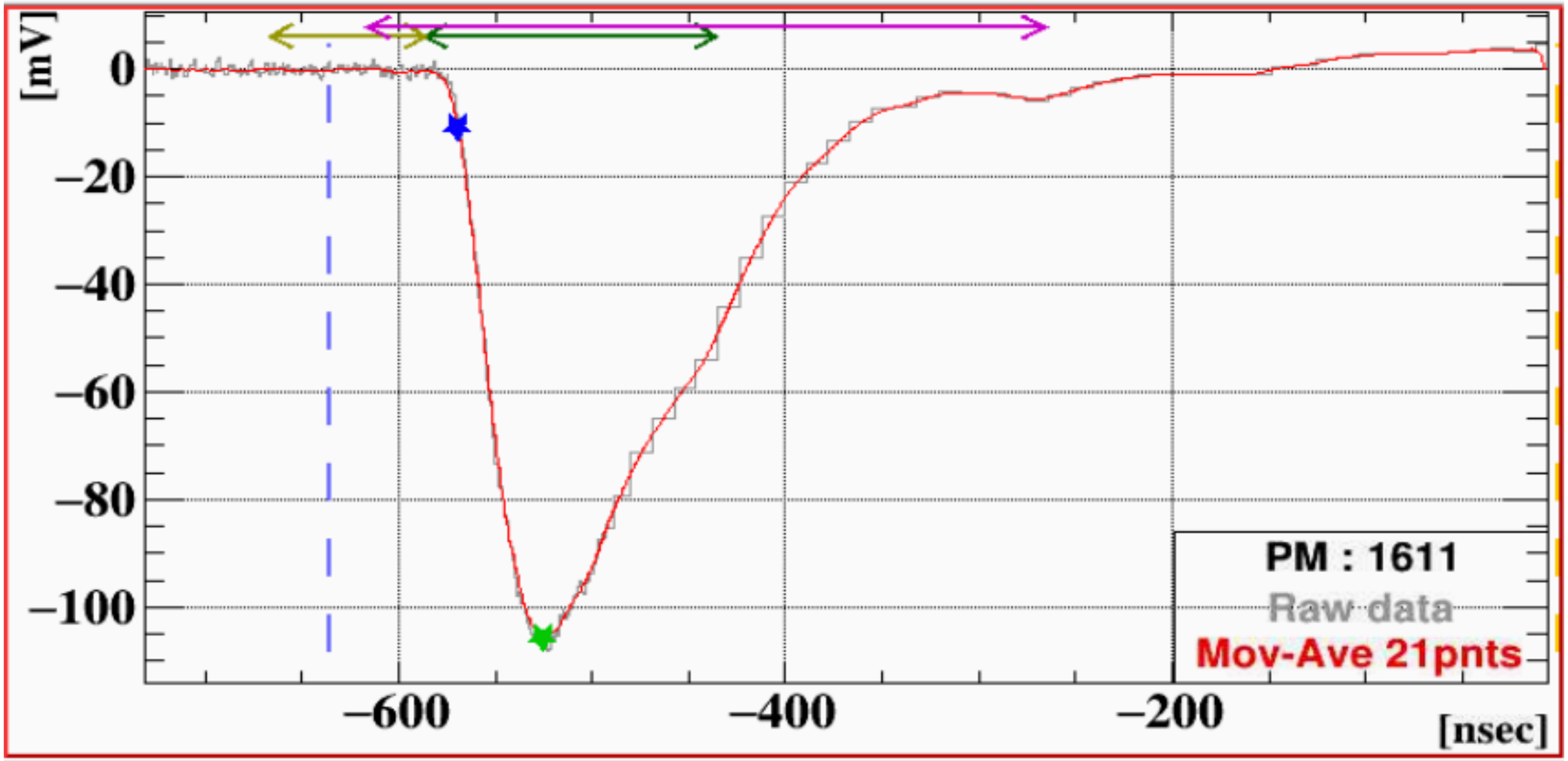
Sum Waveform (same event)





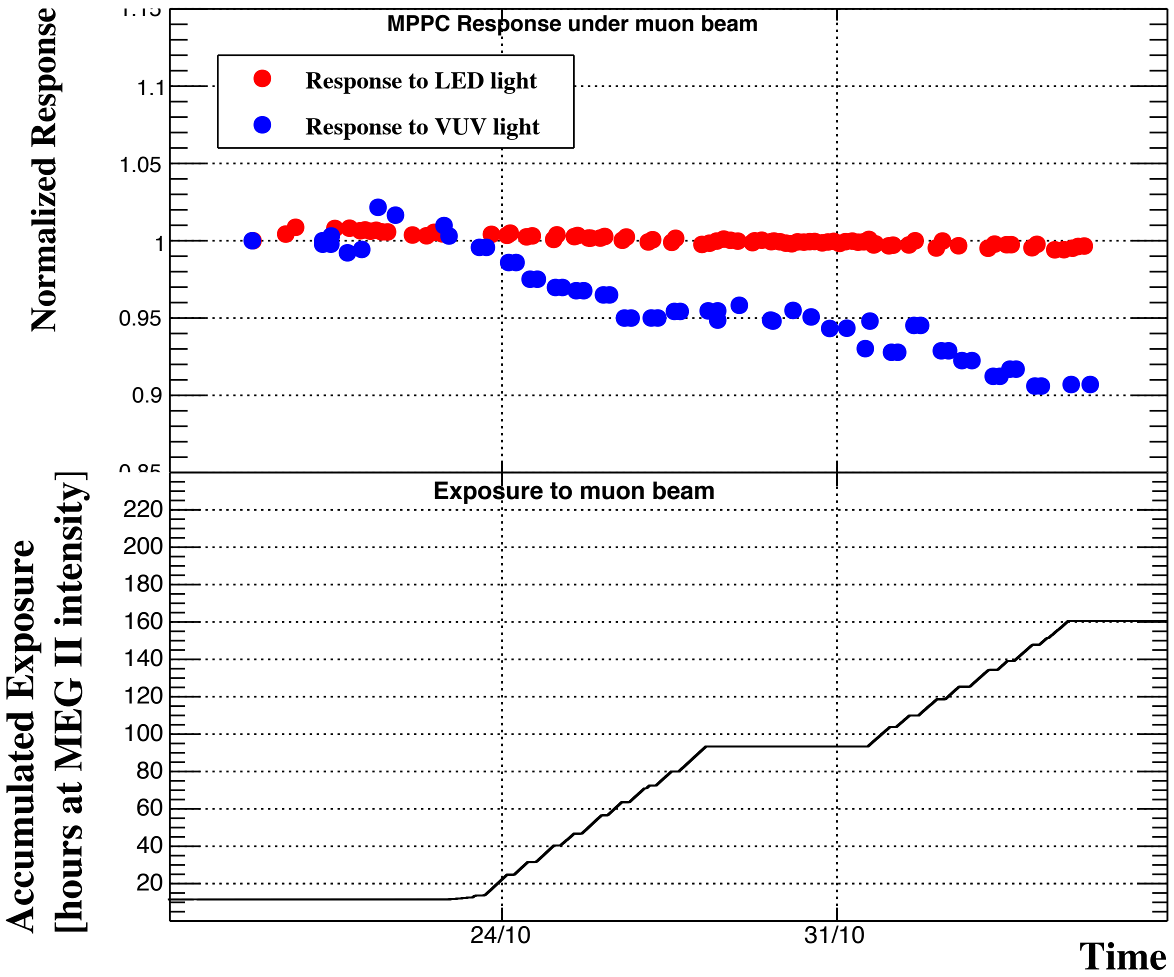
- So far, we have noise reduction for three-types of noises.
  - High-frequency noise synchronized with clock (n*80 MHz)
  - Cell pedestal fluctuation derived from incomplete DRS calibration.
  - Low- frequency noise depending on temperature.
- DRSNoiseReduction + DRSTMPCalibration tasks.

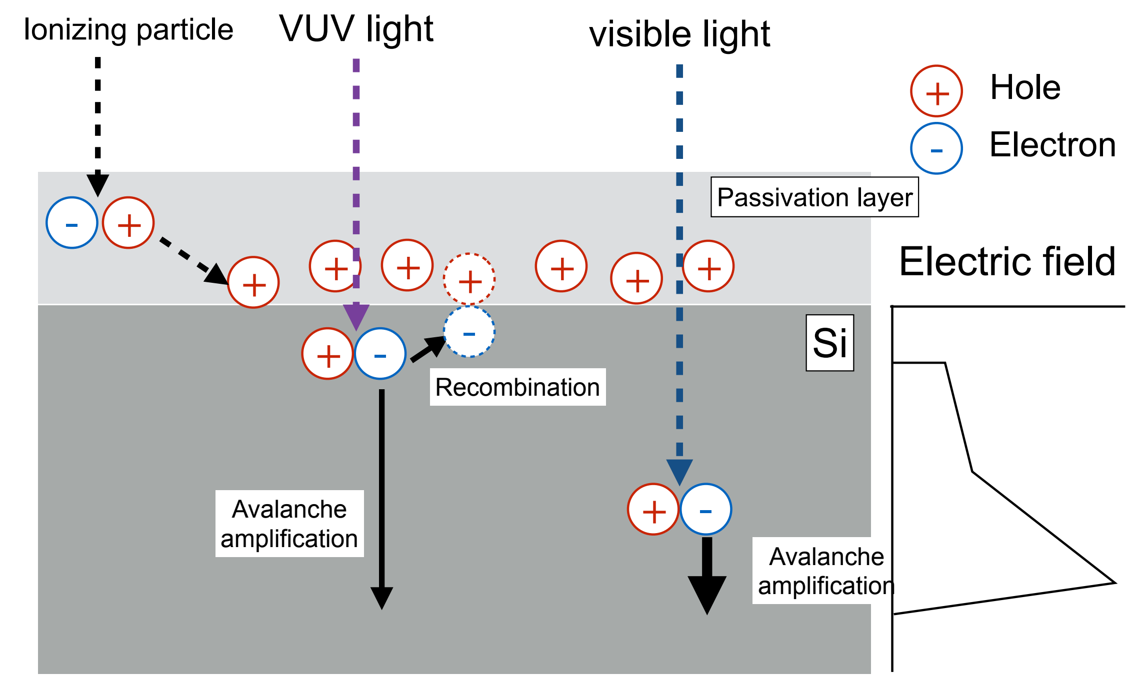
Data reduction



- Data reduction is required not to use up the storage.
- Implementation of rebin to DAQ frontend is foreseen.
- Offline rebin is already used to reduce computation time.
- Goal: 80% reduction with rebin.

MPPC PDE decrease

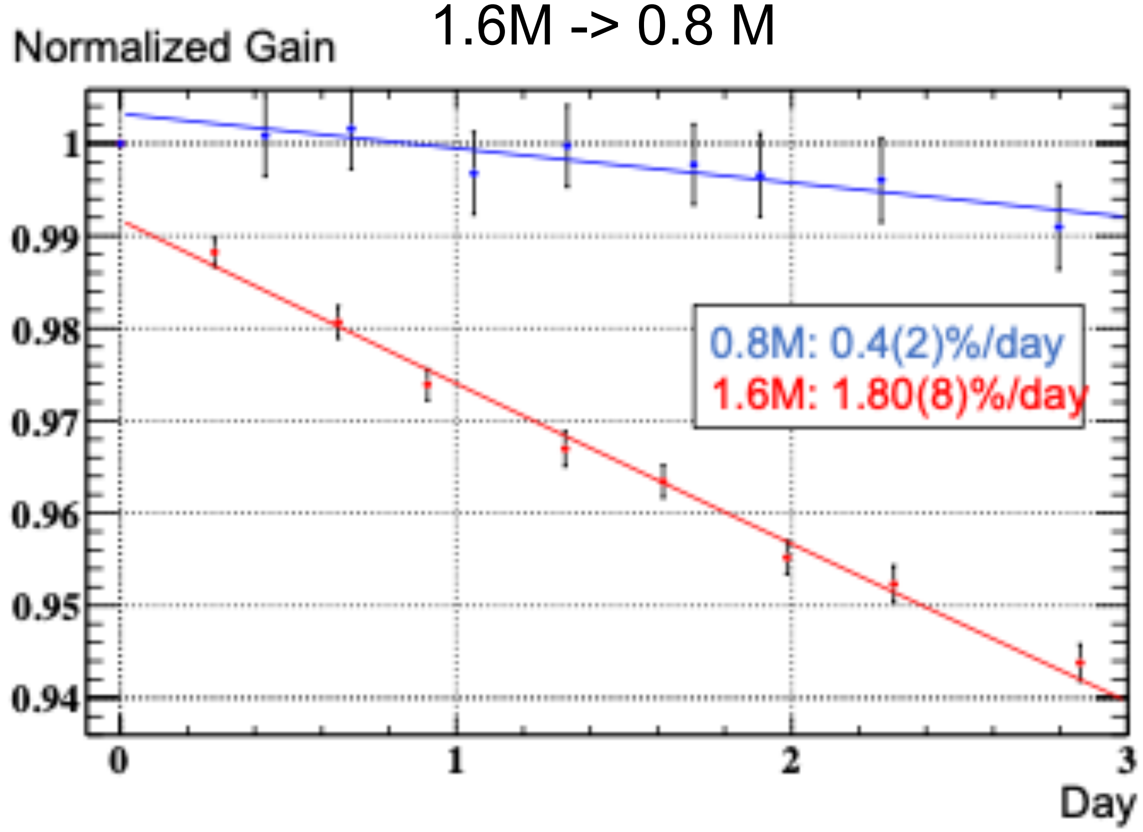




- PDE decrease rate:
  - 0.06(1)% / MEG II hour(2019)
- Wavelength dependence: deterioration of PDE for visible light is ~1/10.
- VUV light interact in the shallow region of MPPC.
  - The observed damage is likely to be surface damage.

PMT Gain decrease

Kazuki's master thesis
MEG II intensity,
1.6M -> 0.8 M



- The reason of the damage is not clear, but likely to be deterioration of dynodes.
- 0.4(2)%/MEG II day = 0.02%/MEG II hour

Possible Causes of Resolution Degradation

Summary

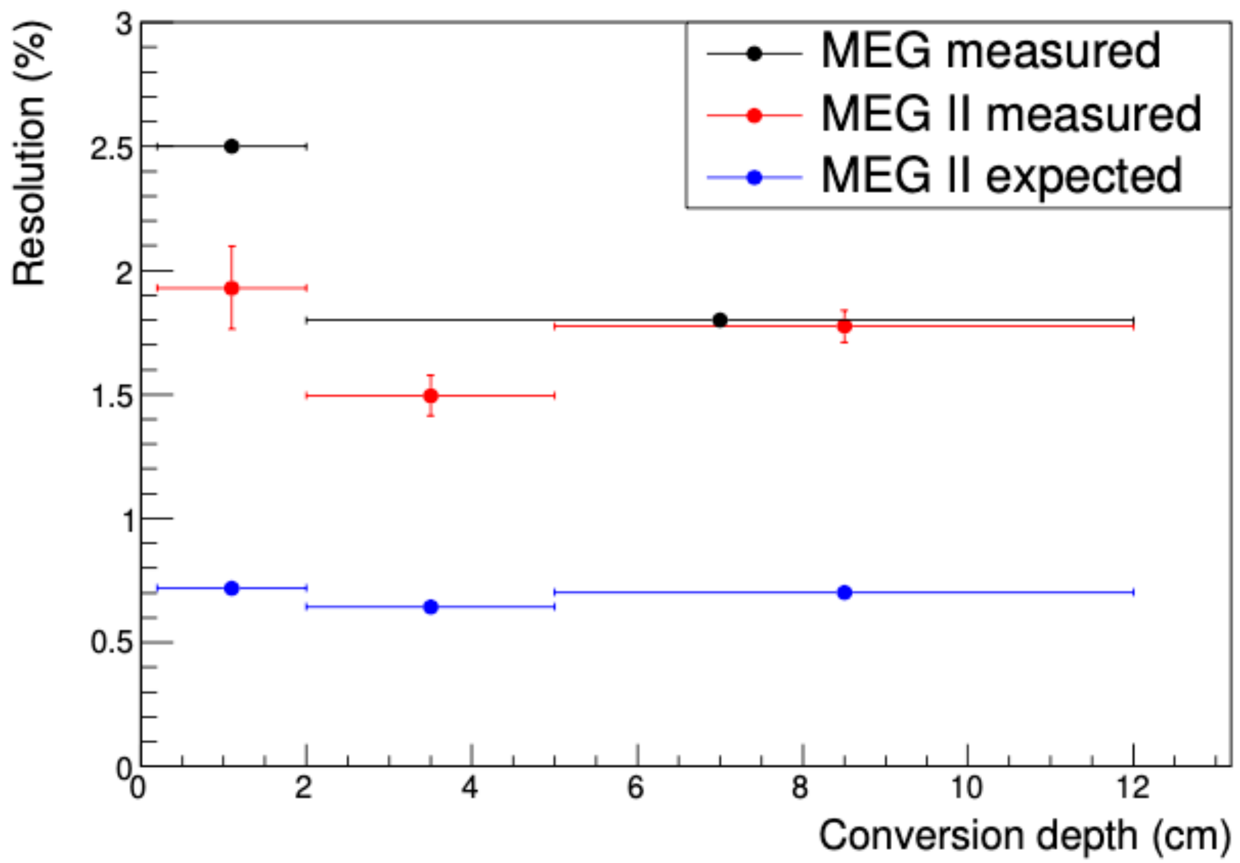
19

- Commissioning of MEG II LXe detector was done with 17.6 MeV monochromatic γ-source.
- Energy resolution was measured to be larger than what we expect from simulation.
  - Noise and calibration problem does not seem to explain the difference.
  - Both MPPC and PMT shows larger fluctuation
  - Changing parameter settings in simulation does not help
- Unknown component which affect resolution exists since MEG.
  - Resolution at ~52.8MeV needs to be checked this year with ~55 MeV calibration γ source.

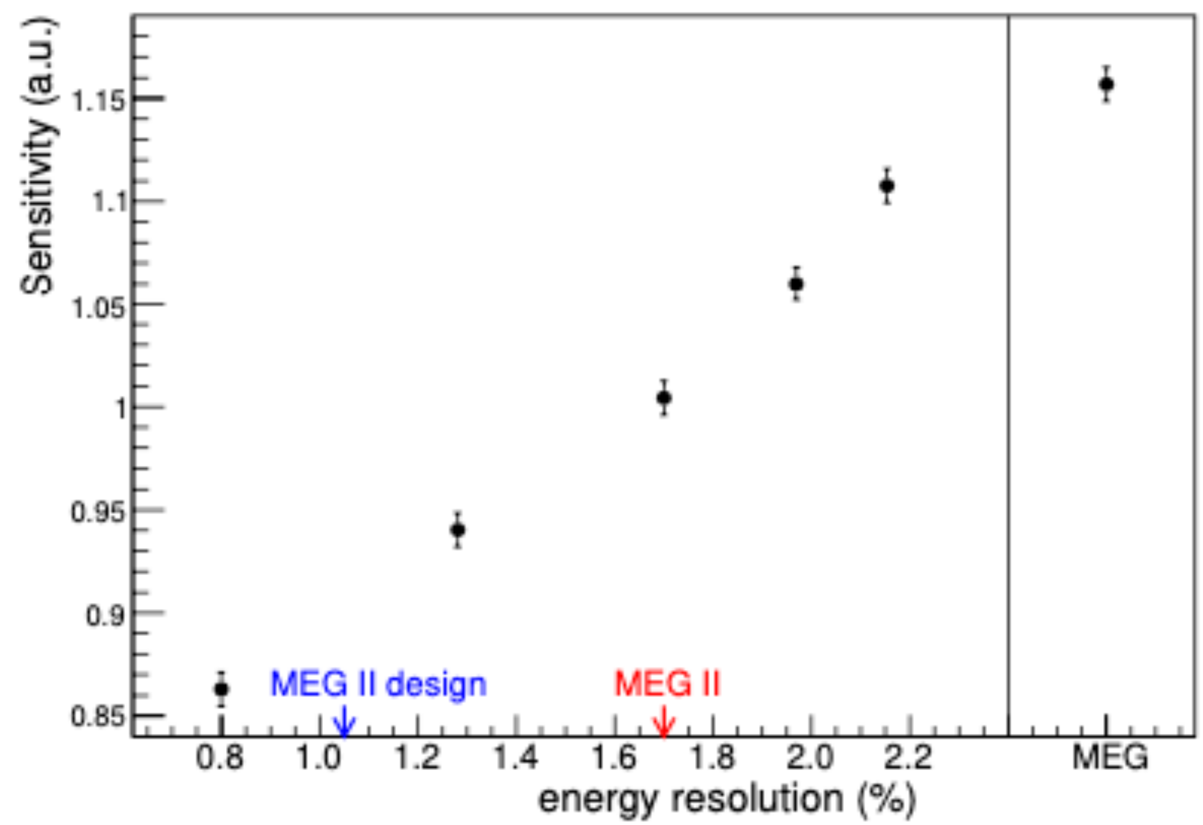
- 2019 Autumn JPS (家城)

Previous measurement of energy resolution

Energy resolution with muon BG gamma-ray spectrum



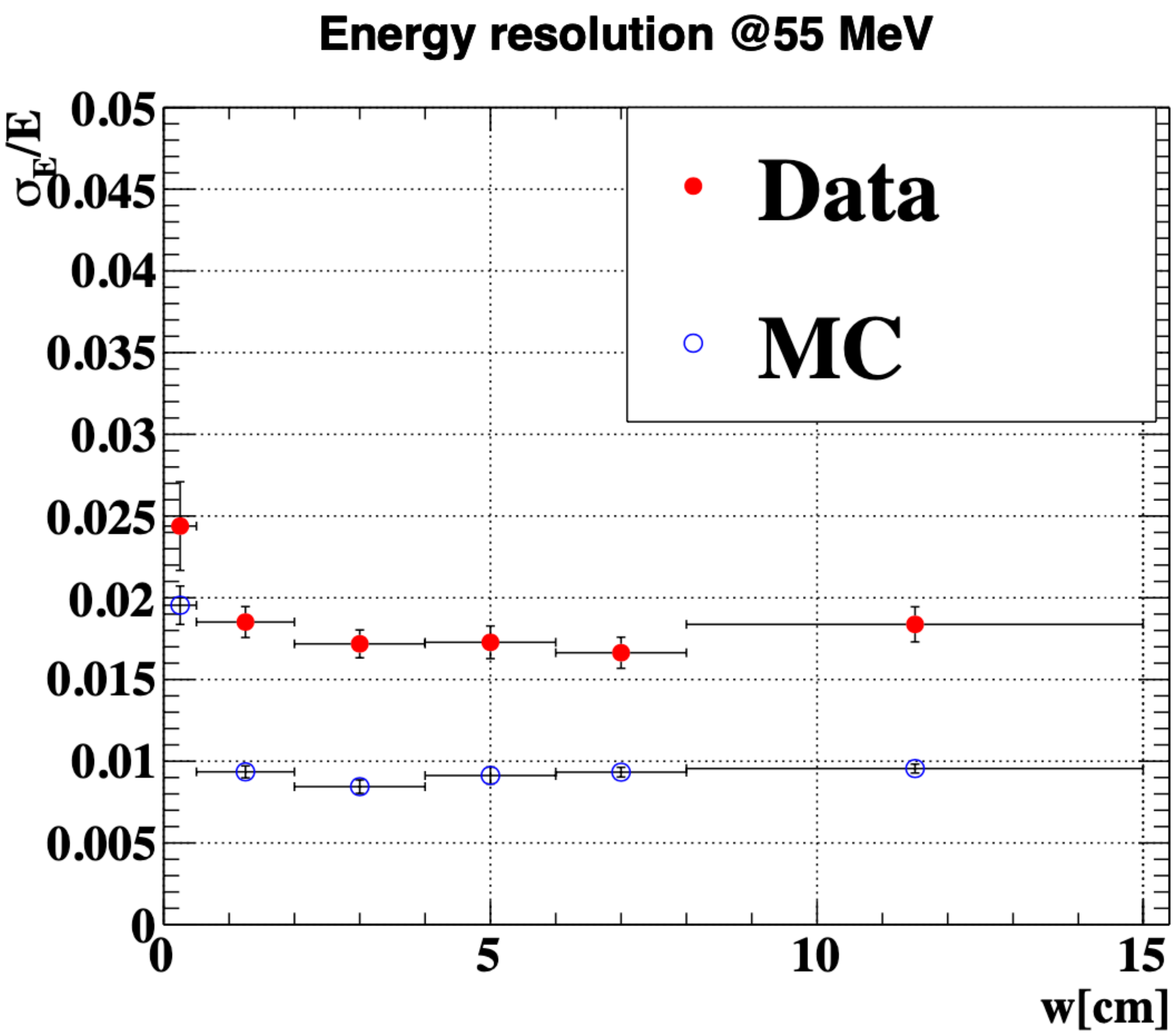
Sensitivity vs Energy resolution



from Shinji Ogawa's Ph.D. thesis

- Energy resolution @$E_\gamma \sim 52.8\ \mathrm{MeV}$ was measured with the BG gamma-ray energy spectrum from muon decay.
  - $\sigma_E = 1.7 \pm 0.1\ \%$: limited by an unknown term.
- Sensitivity improves by ~15% from MEG with energy resolution 1.7%, but ~10% worse than the design.

Energy resolution at 55 MeV



Energy resolution

$$\sigma_E^2 = \sigma_{fit}^2 - \sigma_{truth}^2$$

Sigma of fit function

Spread of hit energy

- Energy resolution σ_E was estimated from σ_{fit}.
  - Subtracted the hit energy spread σ_{truth} using MC.
- Measured energy resolution: 1.8 ± 0.1 % (0.5 cm < depth < 10 cm).
- Unknown term(Deviation from MC) is dominant.
  - MC: identical readout configuration to data.
  - Noise term: ~0.25% / Statistical term: ~0.4%: relatively small.

Liquid Xenon Detector Upgrade

Detector Resolution	MEG (measured)	MEG II (design)	MEG II (measured)	
Position(mm)	5 - 6	2.5	✓ 2.5	2020 Autumn JPS / 15aSE-9
Energy(%)	1.7 - 2.4	1.0 - 1.1	1.7	2019 Autum JPS(小川) / **2021 spring(小林)**
Timing(ps)	62	50 - 70	(40: intrinsic)	2018 Spring JPS(小川) / **2021 spring JPS**(恩田)
Efficiency(%)	63	69	-	

Design values : “The design of the MEG II experiment”,

- We need to measure energy and time resolution whereas **improvement of position resolution was already confirmed**.
- The number of readout electronics is limited(~1000/4760) in 2020.
  - Installation and commissioning of full system is now in progress.
- Today’s theme:
  - **Energy resolution measurement using pion decay** $\pi^0 \rightarrow \gamma\gamma$