Core-to-Core Program

Commissioning of Radiative Decay Counter for MEG II Experiment in 2017

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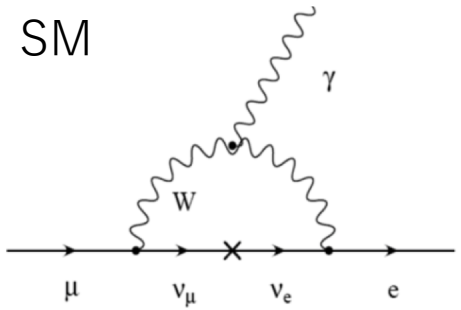
On behalf of MEG II collaboration

The University of Tokyo

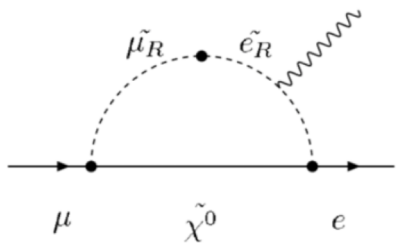
μ → e γ Search

- charged Lepton Flavor Violation (cLFV)
- Good prove for new physics
  - Standard Model : Br < 10^{-50}
  - New physics : Br ~ 10^{-12} - 10^{-14}

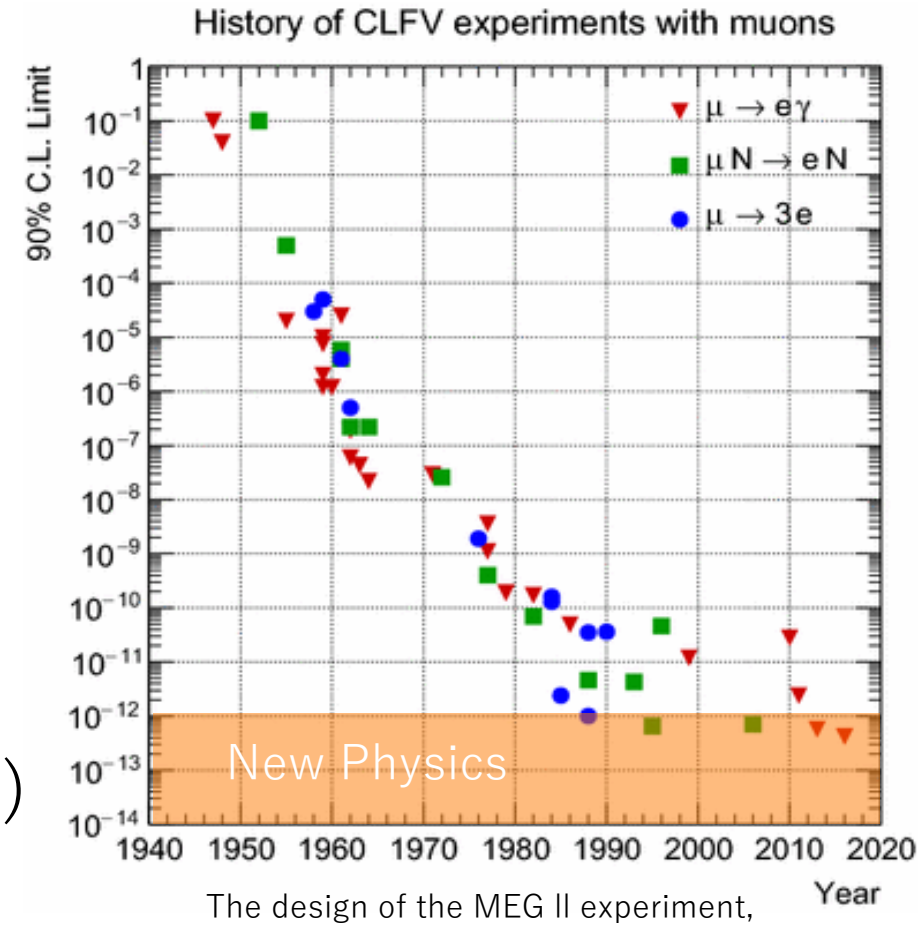
SM



New physics

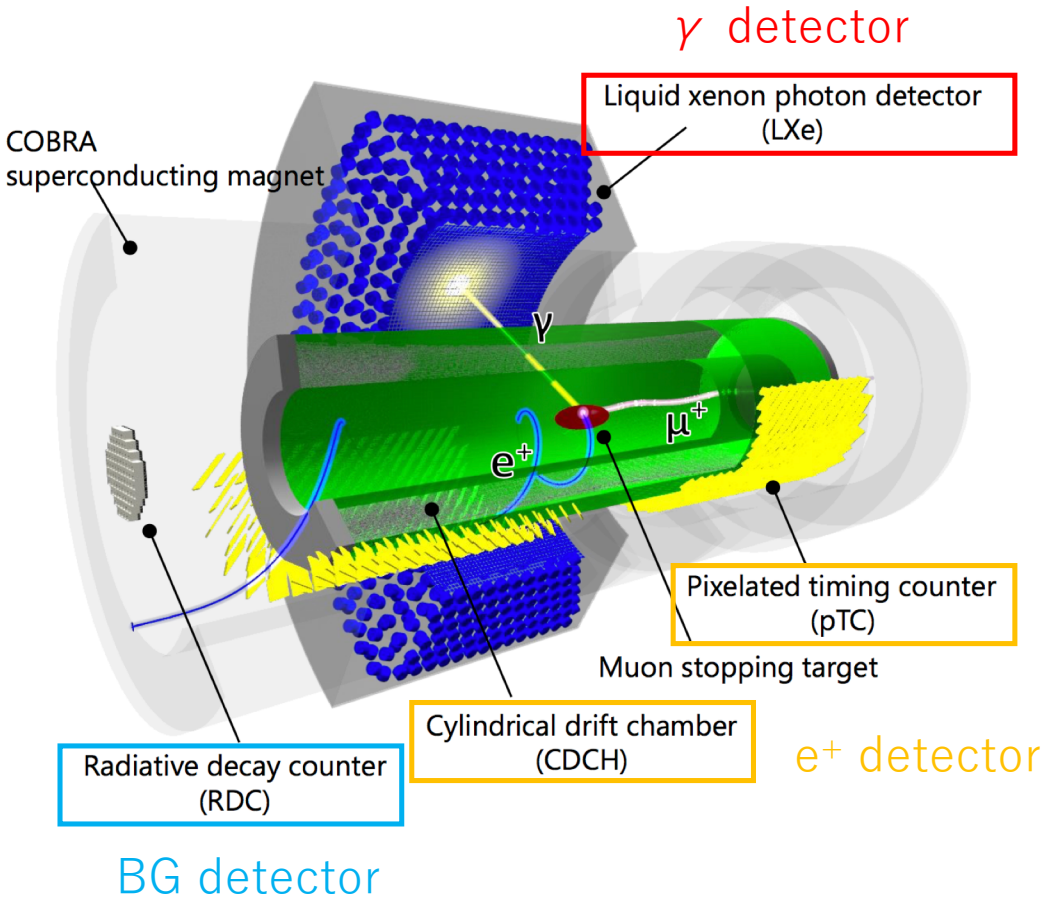


- The most stringent limit, 4.2 × 10^{-13} (90% C.L.) was given by MEG experiment



The design of the MEG II experiment, Eur. Phys. J. C (2018) 78: 380.

MEG II Experiment



Upgraded from MEG

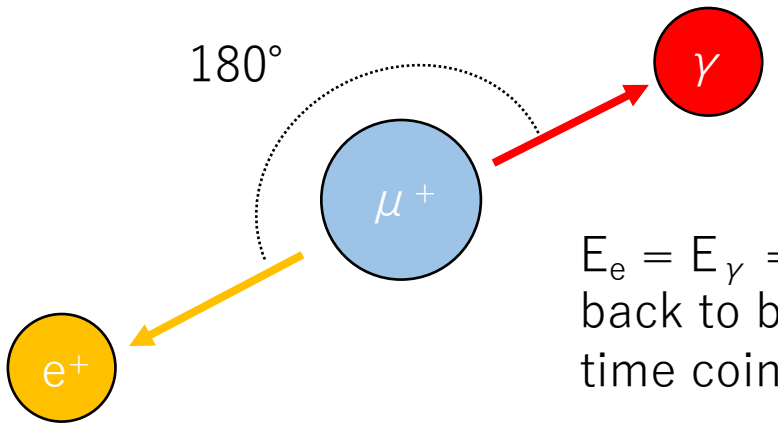
- μ^+ beam stopping rate
  3×10^7 /s → 7×10^7 /s
- Improved efficiency and resolution of each detector
- Installed a new detector for BG detection

Expected sensitivity :

5.3×10^{-13} → 6×10^{-14}

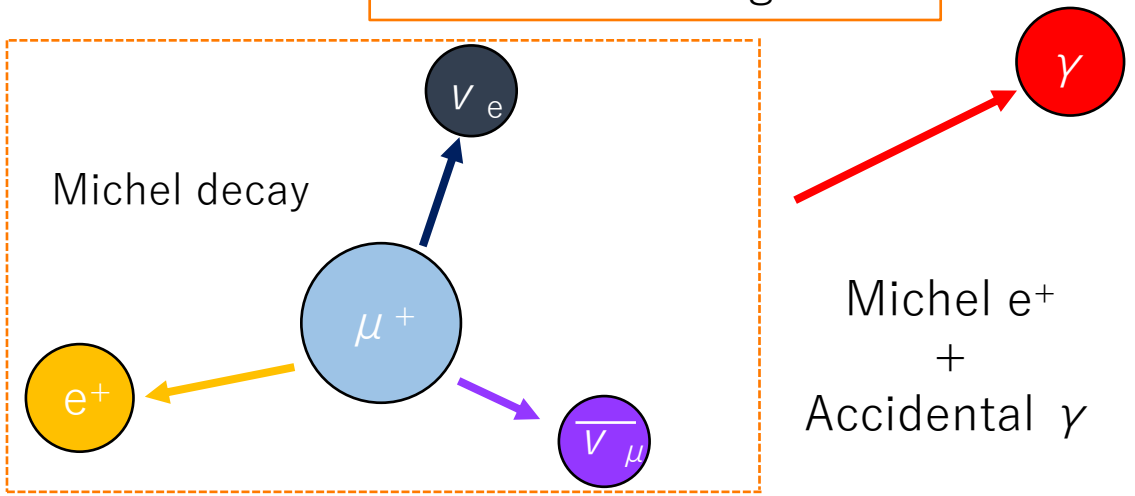
Signal & BG in MEG II

$\mu \rightarrow e\gamma$ signal



$E_e = E_\gamma = 52.8$ [MeV]
back to back
time coincidence

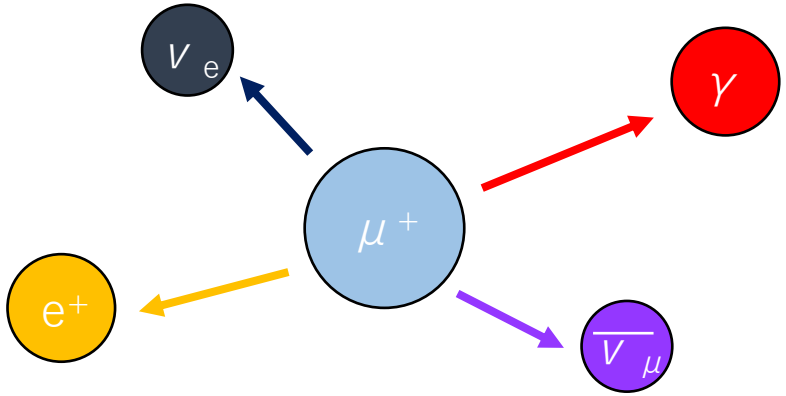
Dominant Background



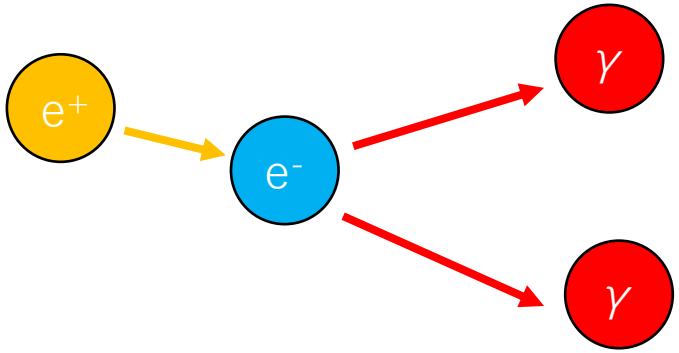
Michel e^+
+
Accidental γ

Sources of Accidental γ

Radiative Muon Decay(RMD)

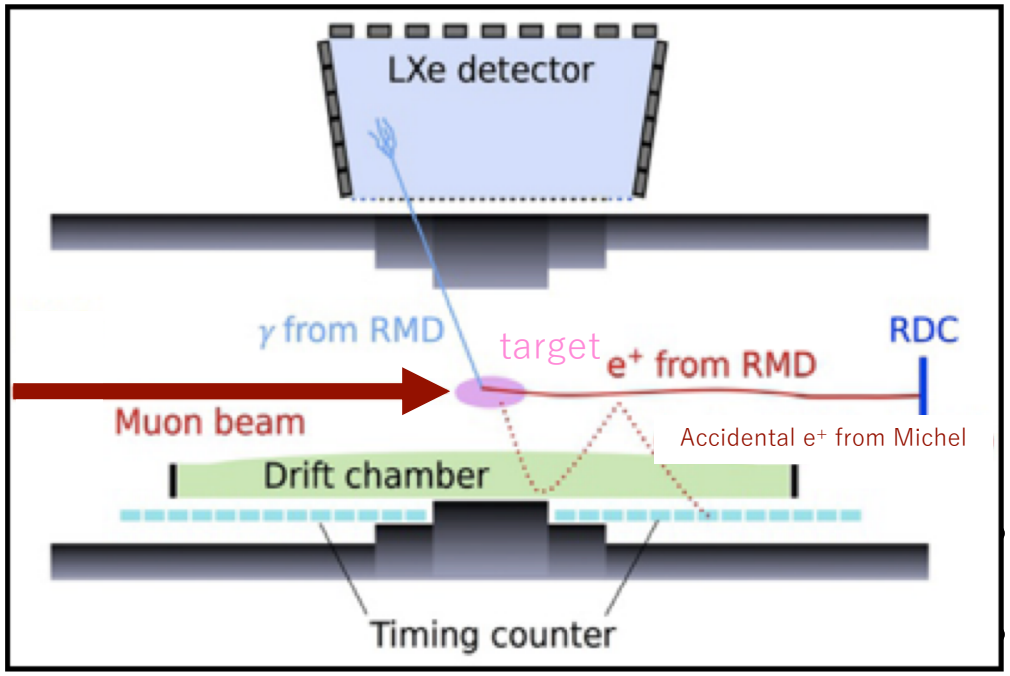


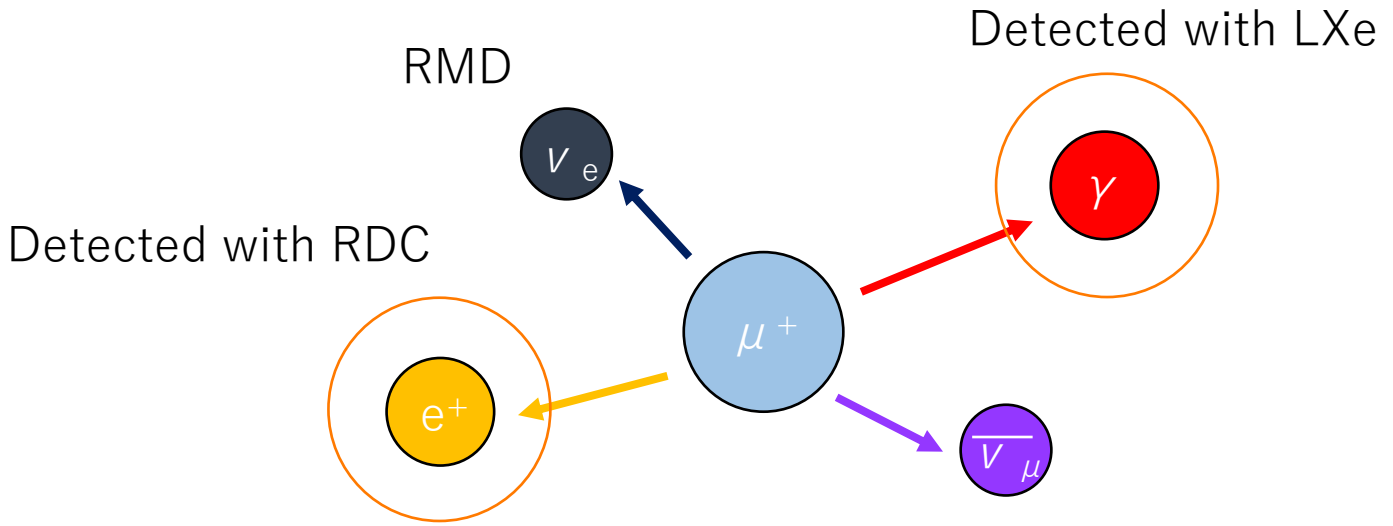
Annihilation In Flight(AIF)



2 : 1
($E_\gamma > 48$ MeV)

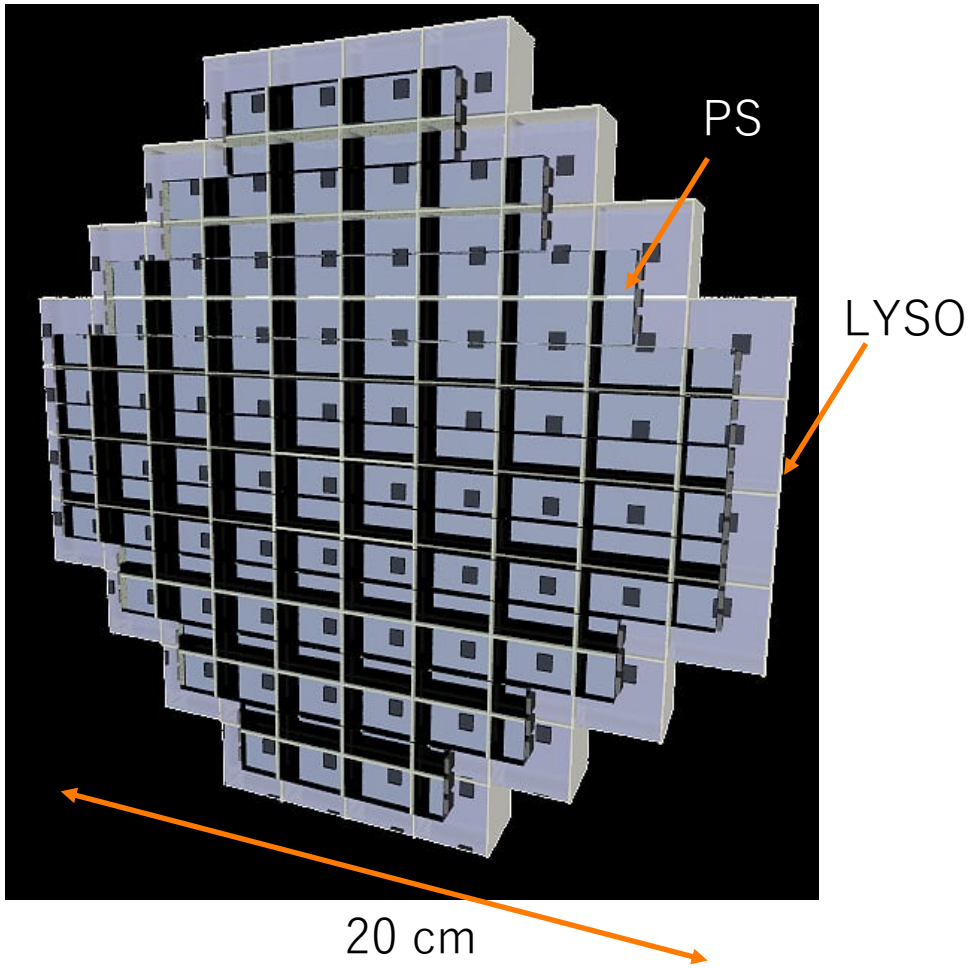
Radiative Decay Counter (RDC)



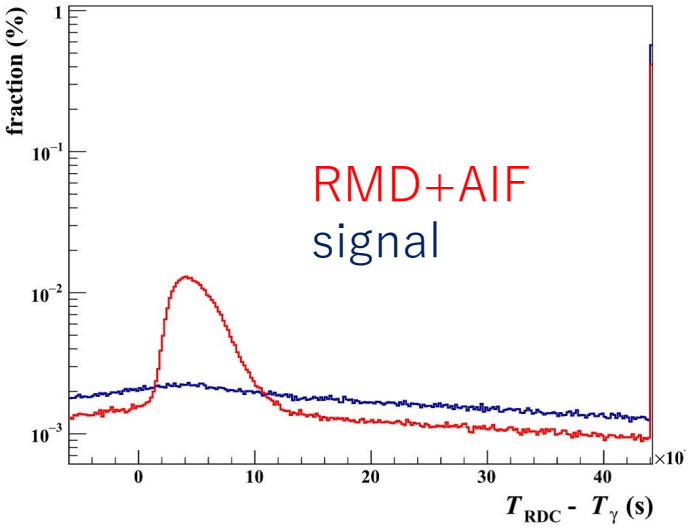


- Newly installed in MEG II
- Identify RMD events by detecting low energy e^+ deriving from RMD
  → time coincidence with γ detected by LXe

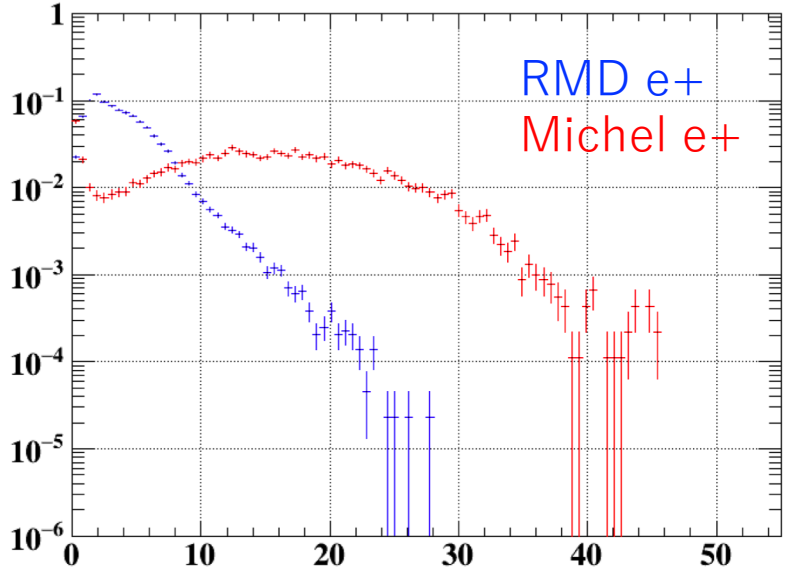
Downstream RDC



Timing difference of RDC e^+ and LXe γ

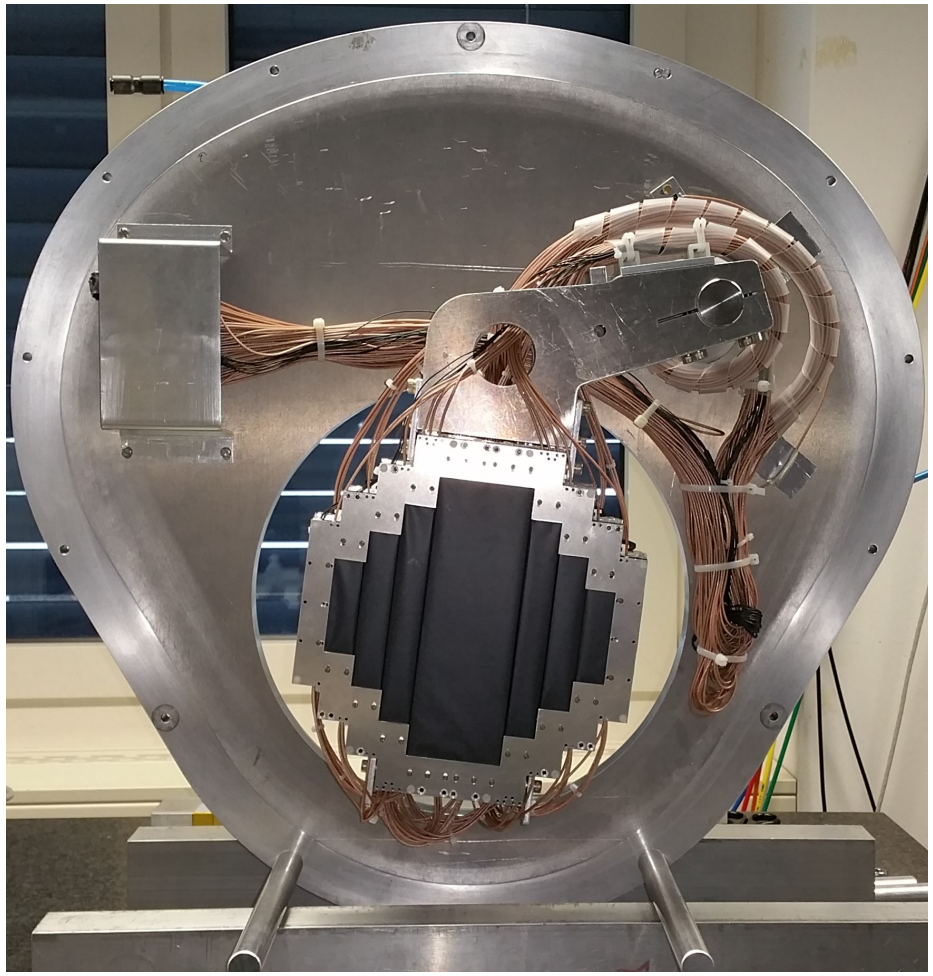


RDC e^+ Energy



- Timing measurement
  - 12 plastic scintillators (PS)
  - 2, 3 MPPCs on each side in series connection
- Energy measurement
  - 76 LYSO crystals
  - 1 MPPC on the back of one crystal

Commissioning Run in 2017



- Purpose
  - The first operation test with LXe
  - Confirm the performance
- μ beam configuration
  - Rate ~ 5.6×10^7 μ^+ stops/s

    $\downarrow \times 0.57$

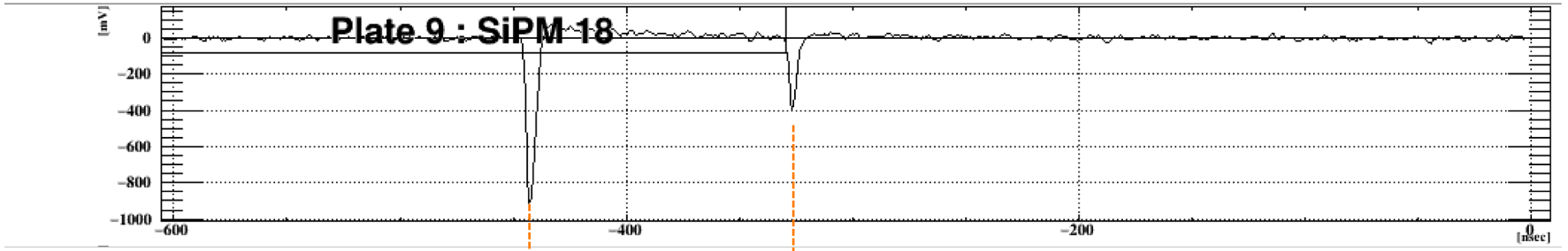
    3.2×10^7 μ^+ stops/s

    (adjusted beam slits because LYSO current exceeded its limit)
- MPPCs on LYSO were operated at lower voltage than 2016 because of current limit
- A mockup was installed instead of CDCH
- E_γ threshold ~ 43MeV

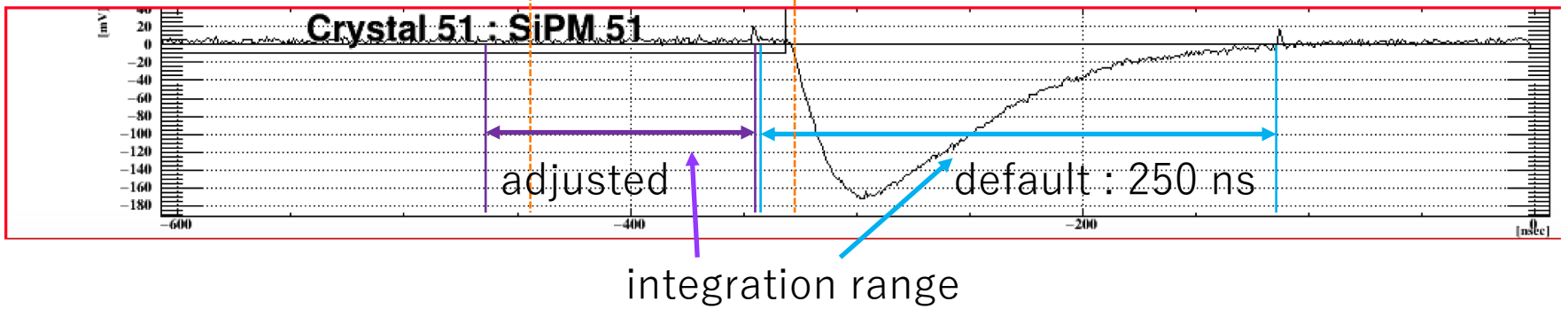
  → 48 MeV (after event selection)

Waveform Analysis

PS Waveform (gain 100, shaper)

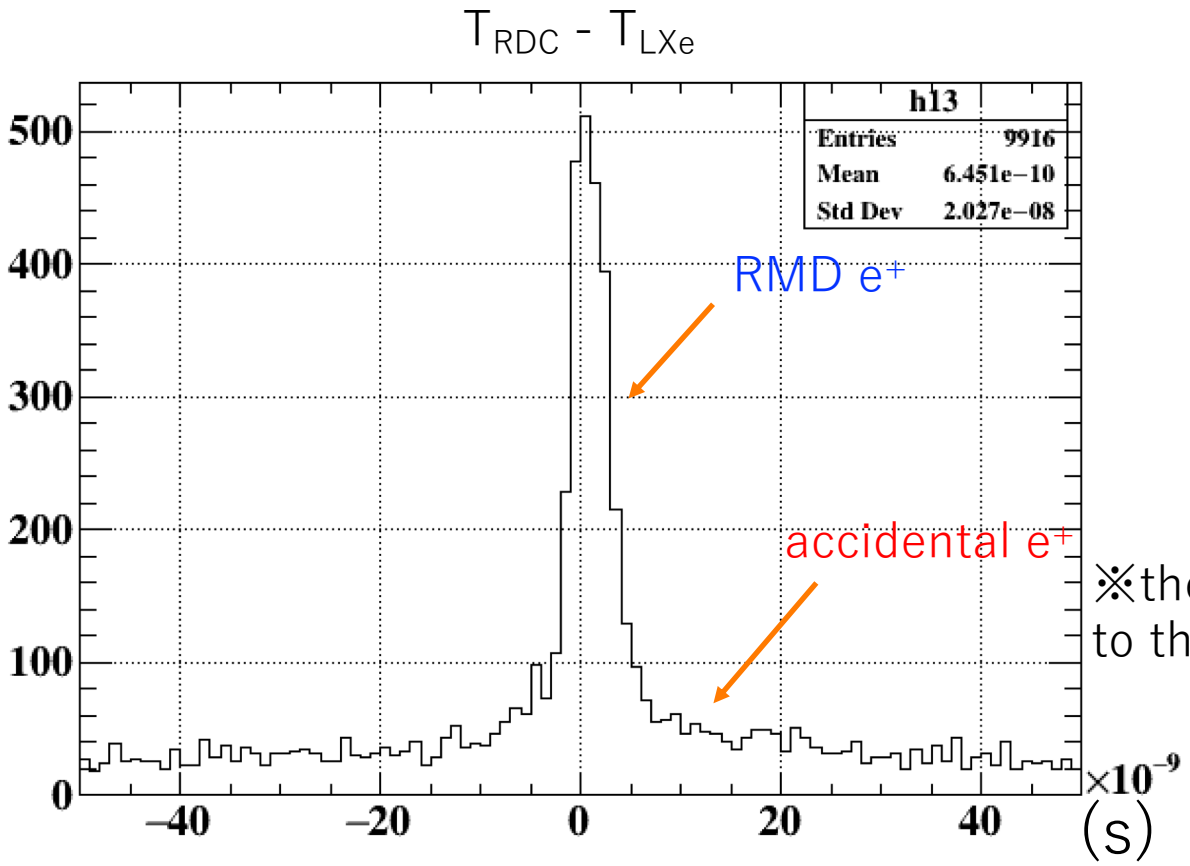


LYSO Waveform (gain 1)



- Hits were reconstructed requiring hits in PS
- Energy was calculated by integrating waveforms of all crystals based on PS hit timings
  ← can sum up hits with small energy deposits which are not found by peak search
- Integration range were adjusted to avoid pileups

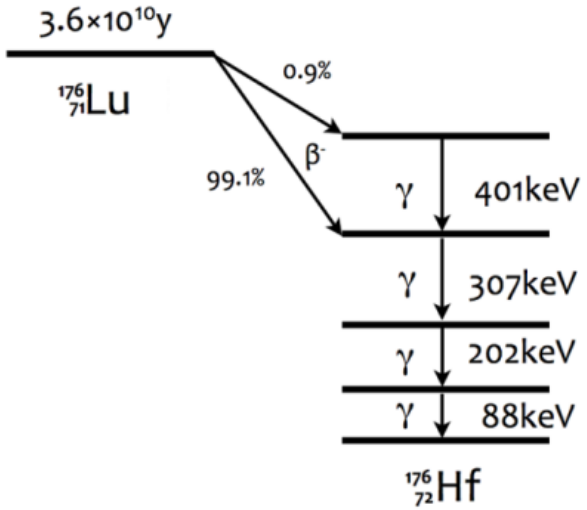
RDC and LXe Timing Coincidence



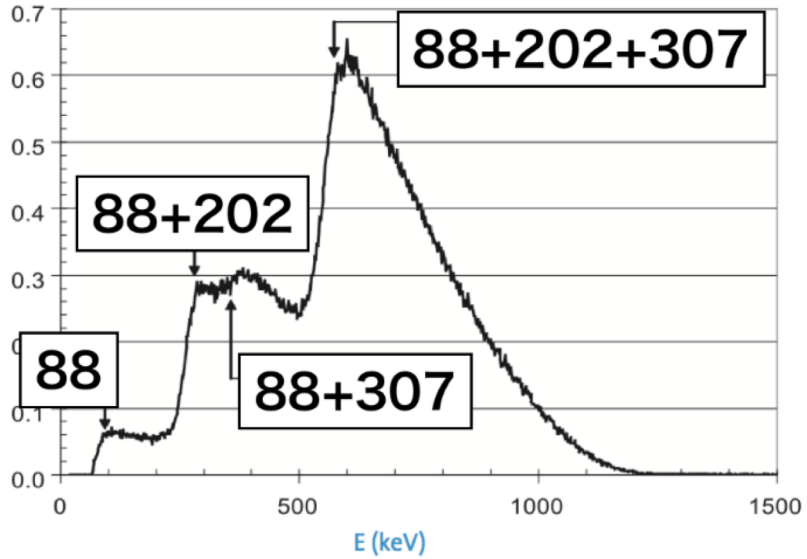
※the nearest timing hit of RDC to the LXe time was selected

A clear peak corresponding to RMD events was observed

LYSO Energy Calibration

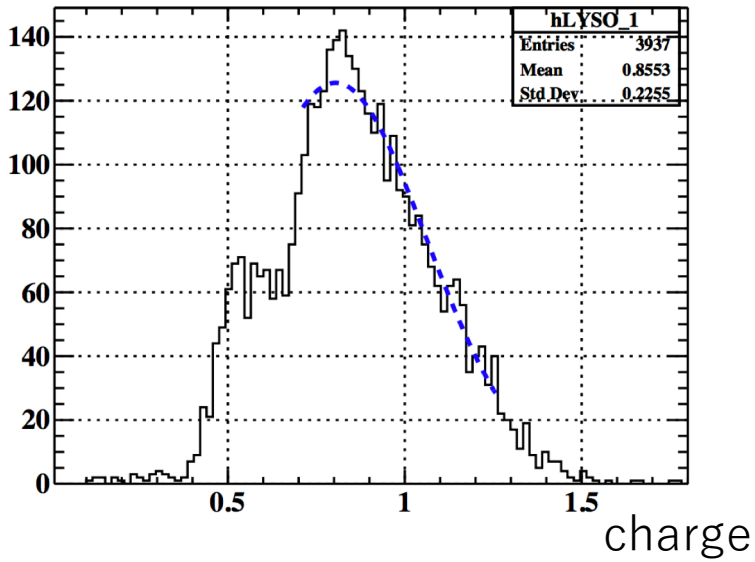


Energy Spectrum of LYSO self-radiation



Saint-Gobain, PreLudeTM 420 data sheet

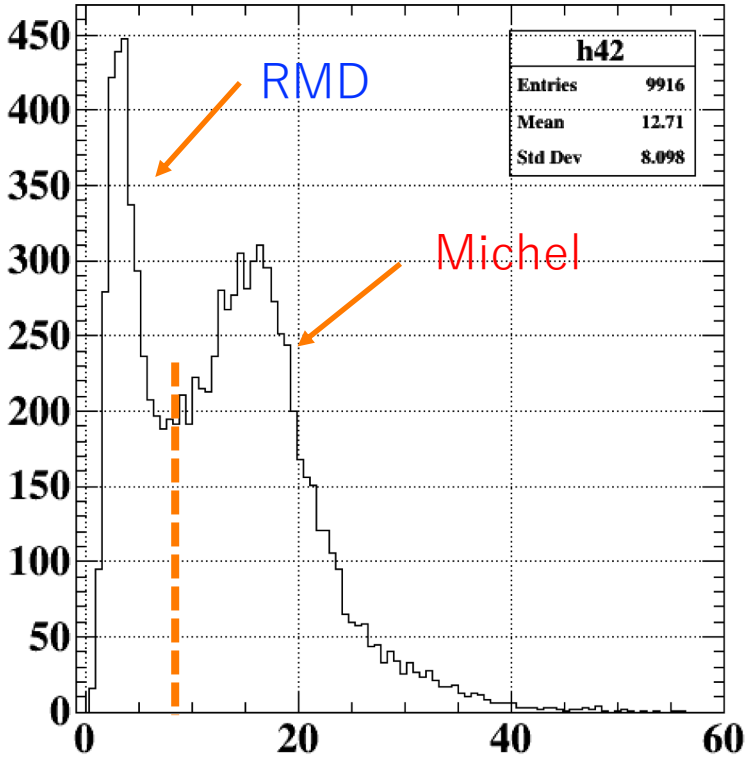
Example of Fitting



- ^{176}Lu in LYSO decays emitting γ and β
- LYSO was calibrated using the 597 keV peak in self-radiation spectrum
  Fit function : γ peaks + β decay spectrum

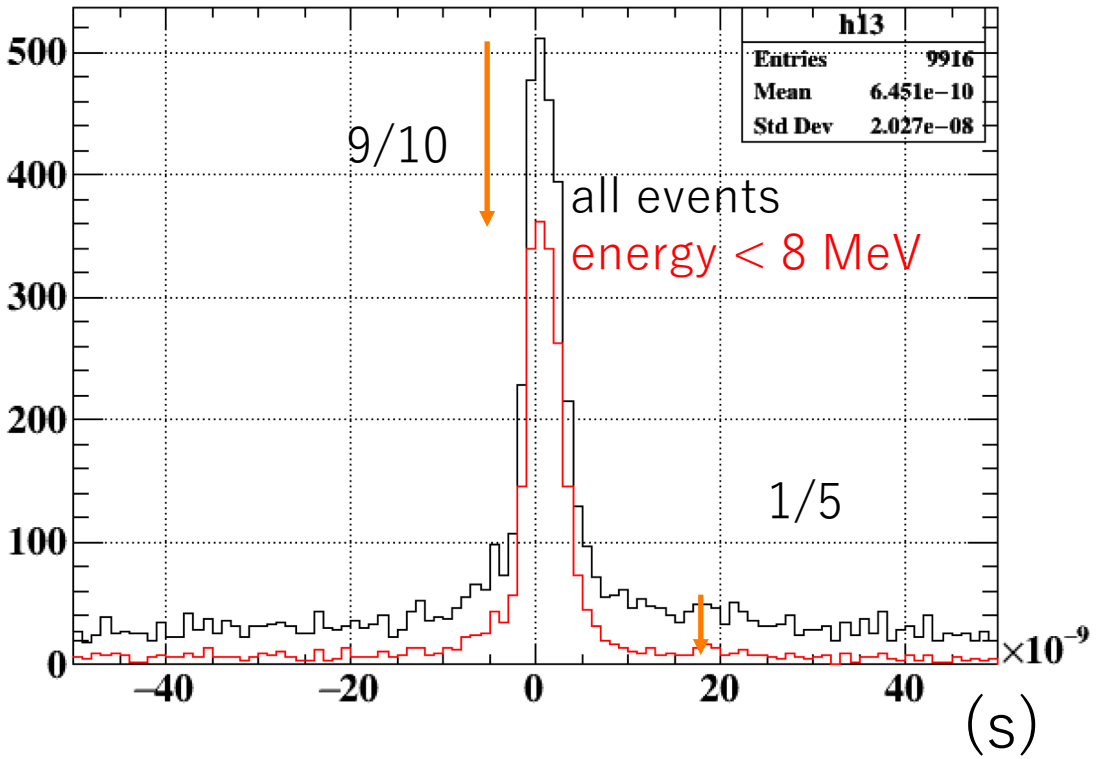
LYSO Energy

Reconstructed Energy



(MeV)

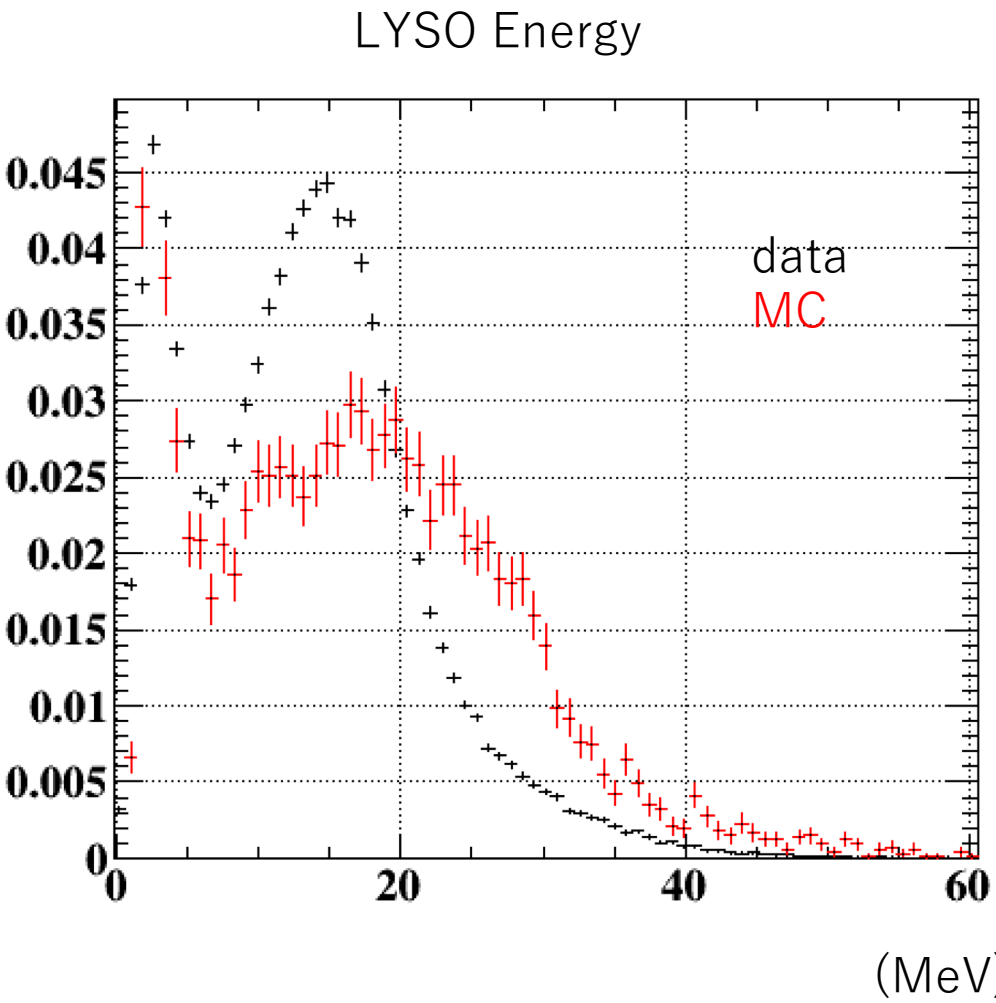
$T_{RDC} - T_{LXe}$

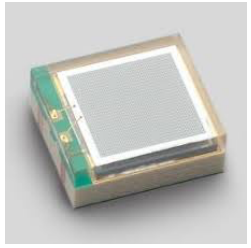


(s)

- A separation b/w RMD and Michel events can be seen in the energy distribution (~8 MeV)
- Energy cut reduces background to 1/5, but the RMD events to 9/10
  → Energy can be used for RMD identification
- The decrease of RMD events is supposed to be less if E_γ is higher

MPPC Saturation

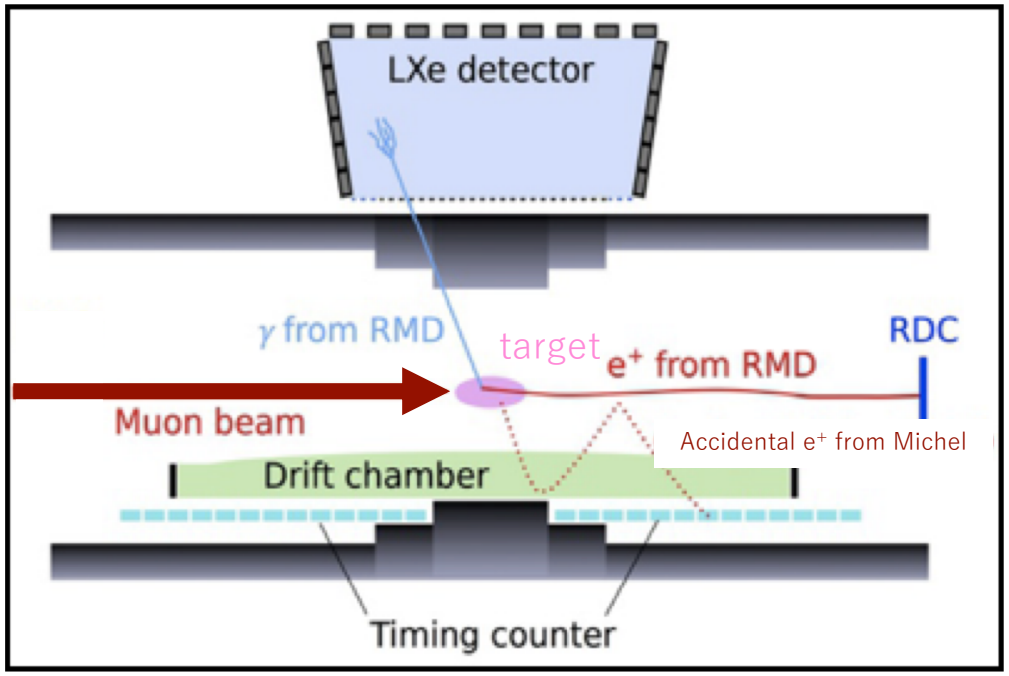




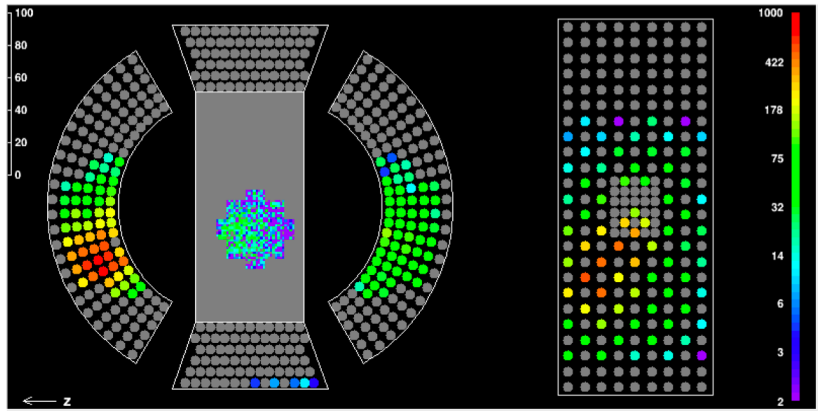
MPPC : S12572-025P
pitch size = 25 μm
N_{pixel} = 14400
V_{over} ~ 1.5 – 2.0 V

- The amount of high energy events of data is less than MC
  → saturation of MPPC
- $N_{p.e.} \sim N_{pixel}$
  if an energy deposit of 1 MPPC is about 12MeV
- Low energy events including most RMD events, are not affected
  → not crucial

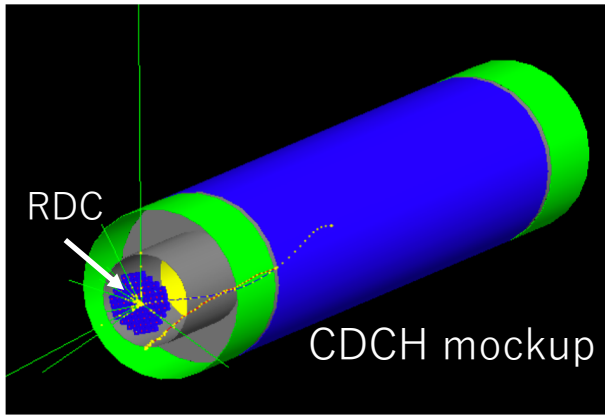
MC Simulation Configuration



LXe Event Display

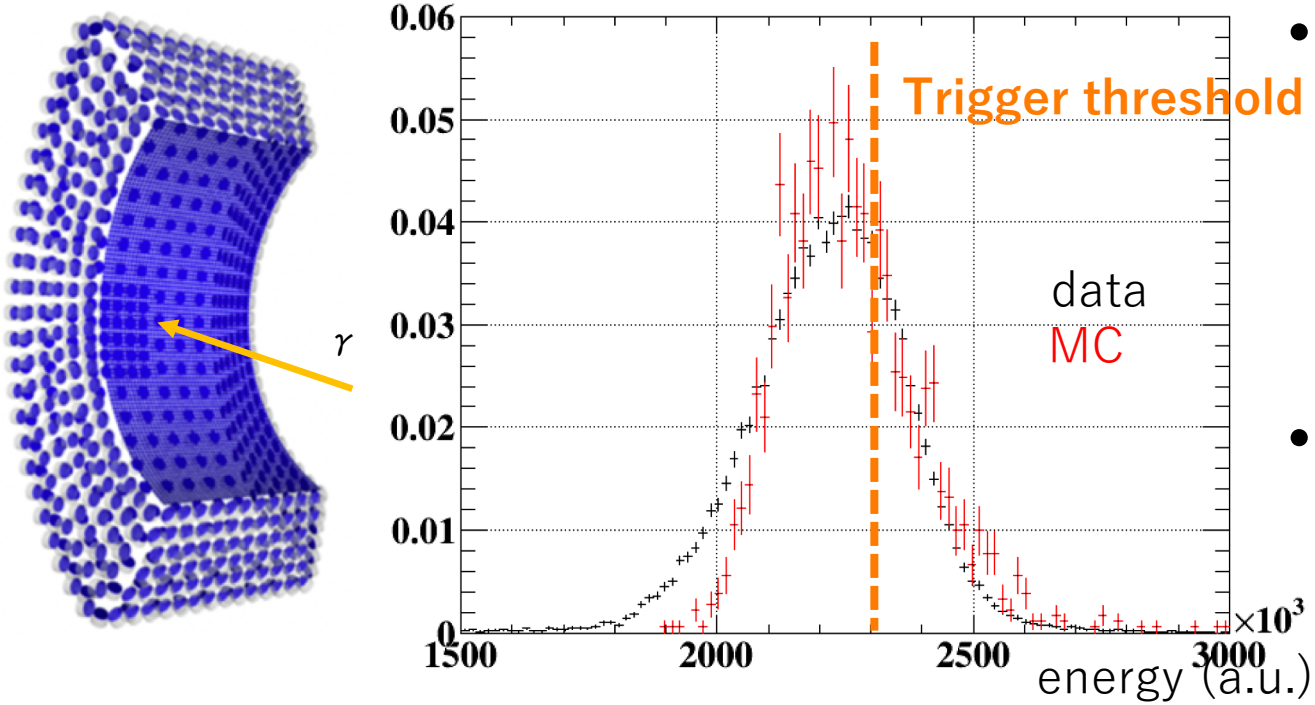


CDCH mockup



- Generated μ beam
- Total 2.4×10^9 events
- Trigger : LXe hits
  (limited readout channels due to electronics)
- Materials around RDC affect RDC BG hit rate
  →implemented CDCH mockup (may not be perfect)

Trigger Simulation



※MC energy was scaled so that the trigger rate became the same as data

- In the beam time, a trigger was generated by high energy deposits in LXe

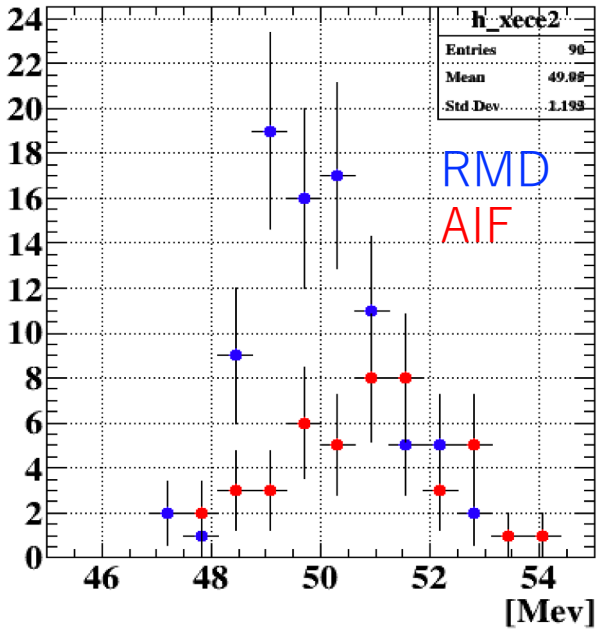
  Threshold : E_γ ~ 43 MeV

- Higher energy events were selected to be consistent with MC in terms of energy distribution

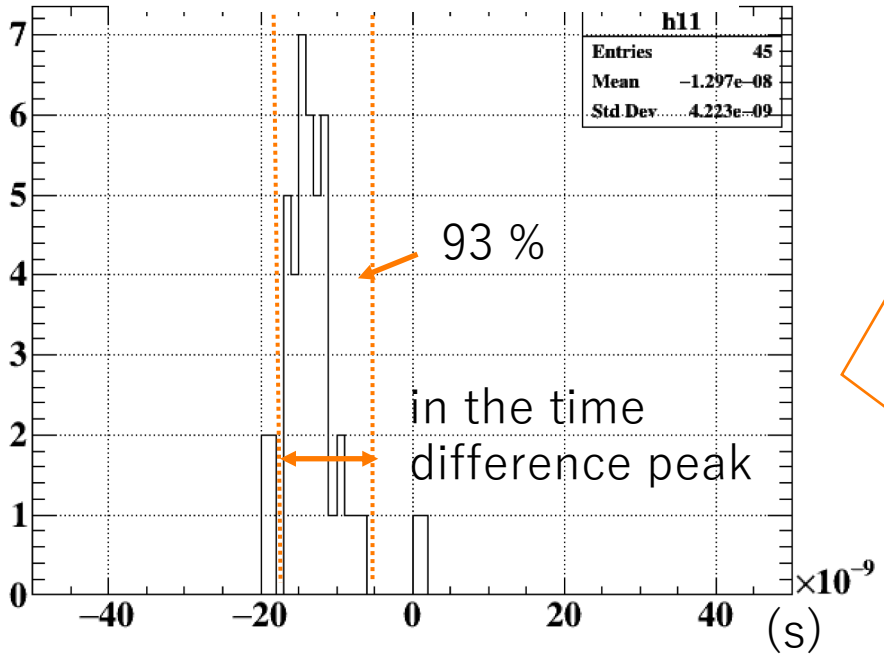
  Threshold : E_γ ~ 48 MeV

Results of MC Simulation

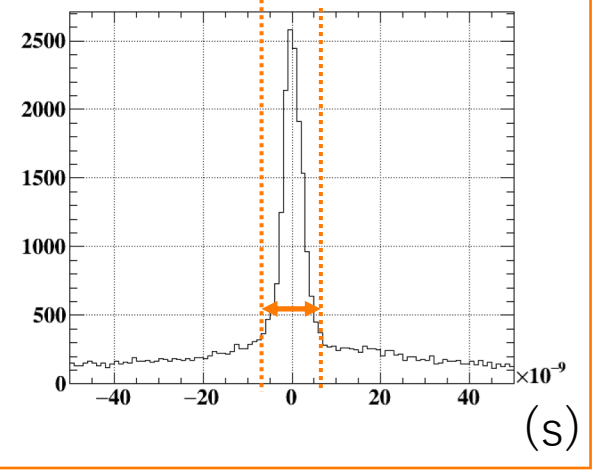
LXe Energy of Triggered Events



RDC hit time of RMD events



$T_{RDC} - T_{LXe}$ (data)



the number of events

	LXe Trigger	RDC hit
RMD	90 (73%) →	45
AIF	47 (27%) →	1
Total	137 →	46

- RMD event fraction : 66 %
  (RMD event) / (RMD + AIF event)
- RDC hit in time window : 93%
  (in the timing peak) / (RMD hit to RDC)
- RMD hit probability to RDC : 50%
  (RMD hit to RDC) / (RMD event)
- hit probability to RDC : 14%
  (hit to RDC) / (μ beam event)

Comparison with MC

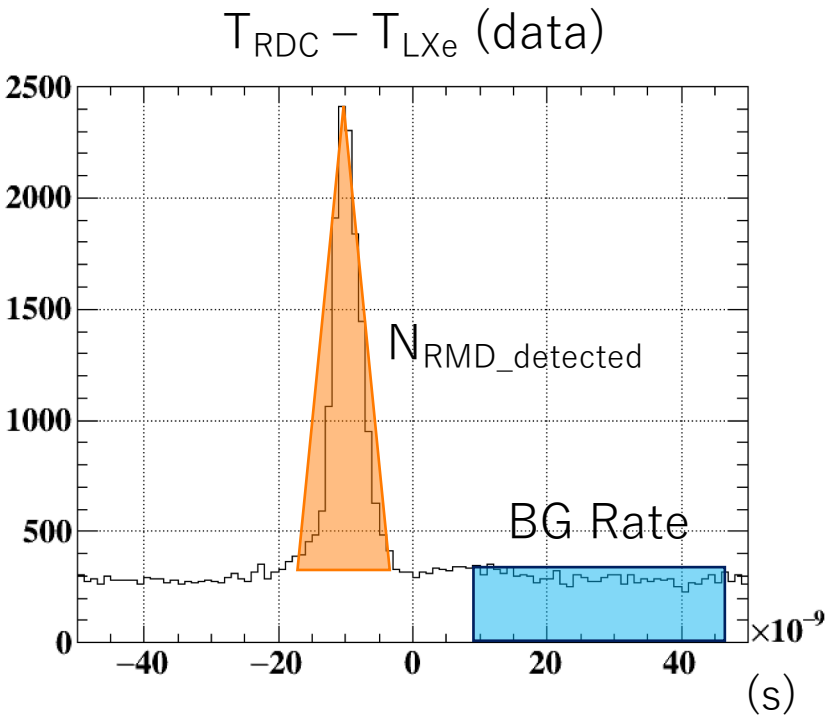
- $N_{RMD\_detected}$ = 2478 ± 196 events
- $N_{RMD\_expected}$
  = N_{events} * (RMD hit probability to RDC) * (RMD trigger fraction)
  * (RDC hit in time window)
  = 9916 (events) * 0.50 * 0.66 * 0.93
  = 3043 ± 391 events

  ➡ Detected RMD events were 80% of the expectation (1.3 σ)
  - statistic error is too large
  - LXe data (uniformity, resolution, energy scale) was difficult to understand due to limited read-out channels

- (RDC BG Rate) = 5.75 ± 0.05MHz
- (Expected RDC BG Rate)
  = (Beam stopping rate) * (hit probability to RDC)
  = 32 MHz * 0.14
  = 4.48 ± 0.07MHz

  ➡ RDC BG events exceeded the expectation

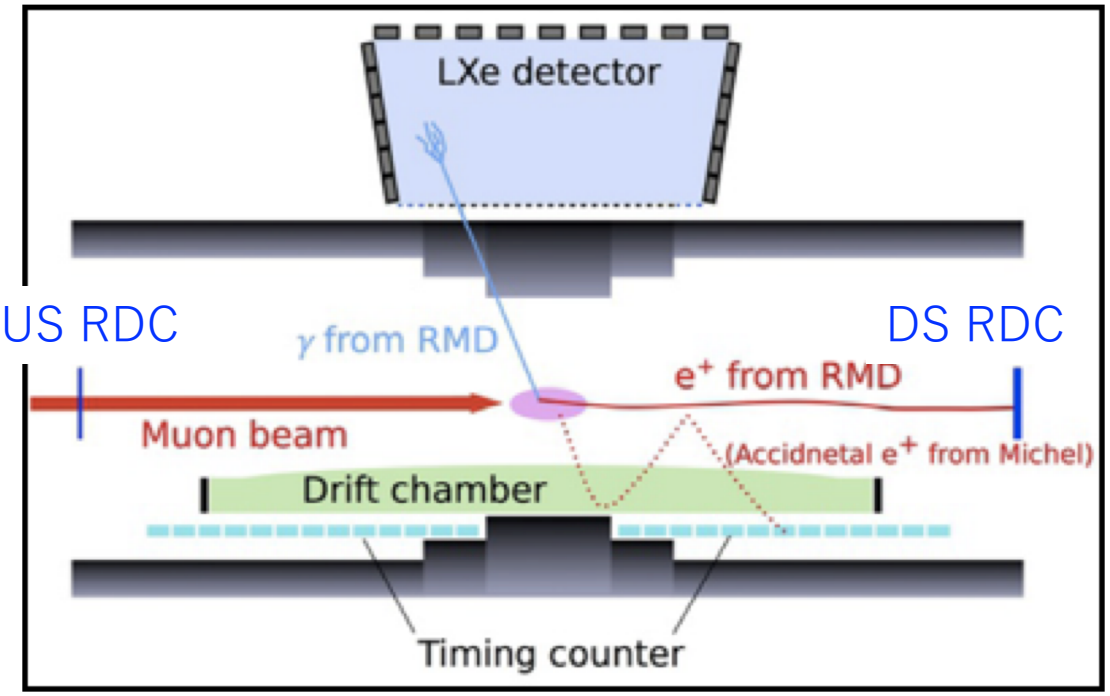
  CDCH mockup may not be simulated well
  → can be checked in beam time 2018



Summary

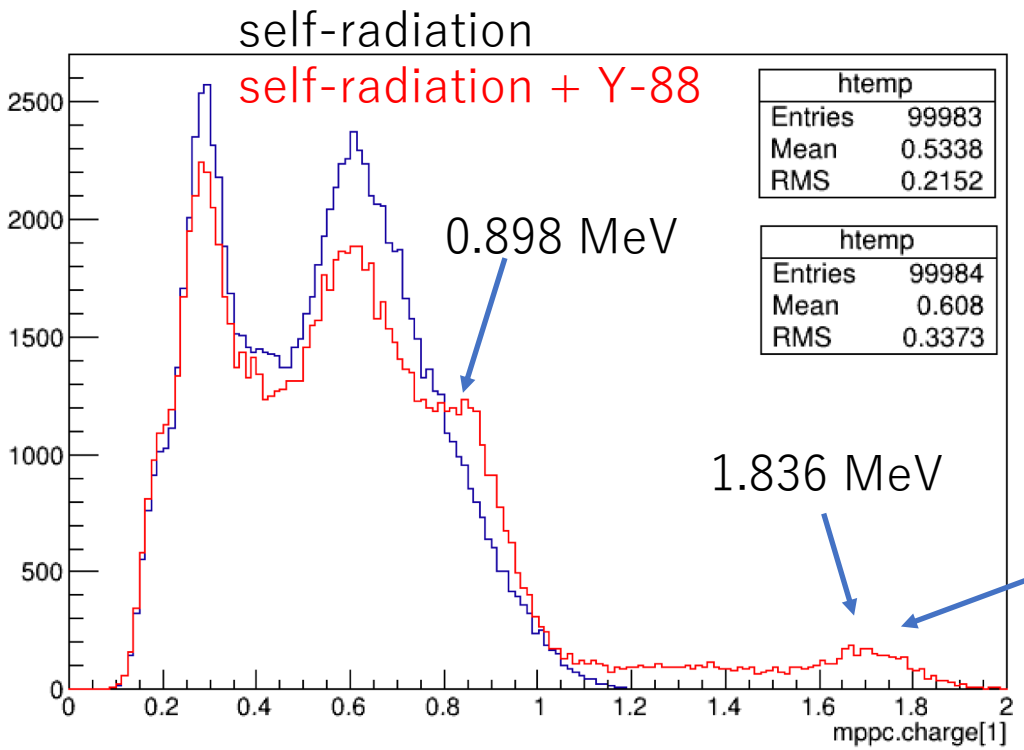
- Commissioning run for RDC with LXe was performed.
- RMD events can be seen clearly in the plot of RDC and LXe time difference.
- Energy was reconstructed properly and energy information was effective for RMD identification.
- RMD detection efficiency was 80% of MC.
  → need to understand LXe data.
- Check RDC BG rate with CDCH in beam time 2018.

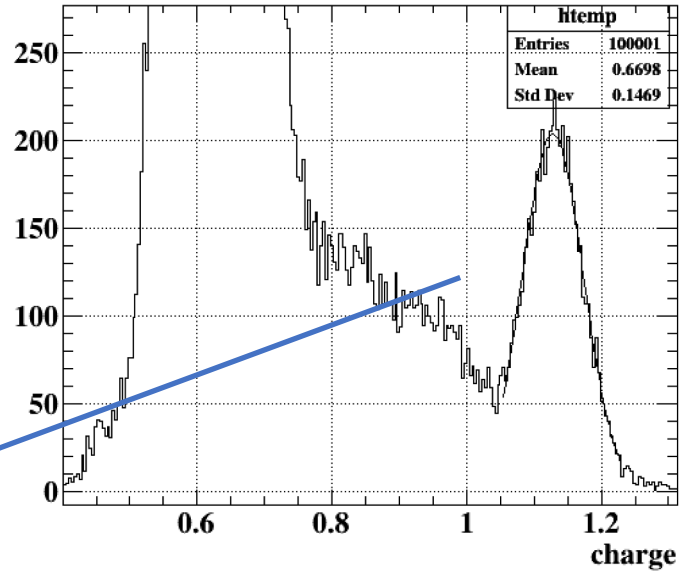
US RDC



- RDC placed on the upstream side is planned
  → further BG reduction
  10% improvement of sensitivity
- Severe requirements because it is placed on the path of μ beam
  - low material to avoid effects on beam
  - fast response and finely segmented structure to distinguish beam and RMD e^+
  - radiation hardness

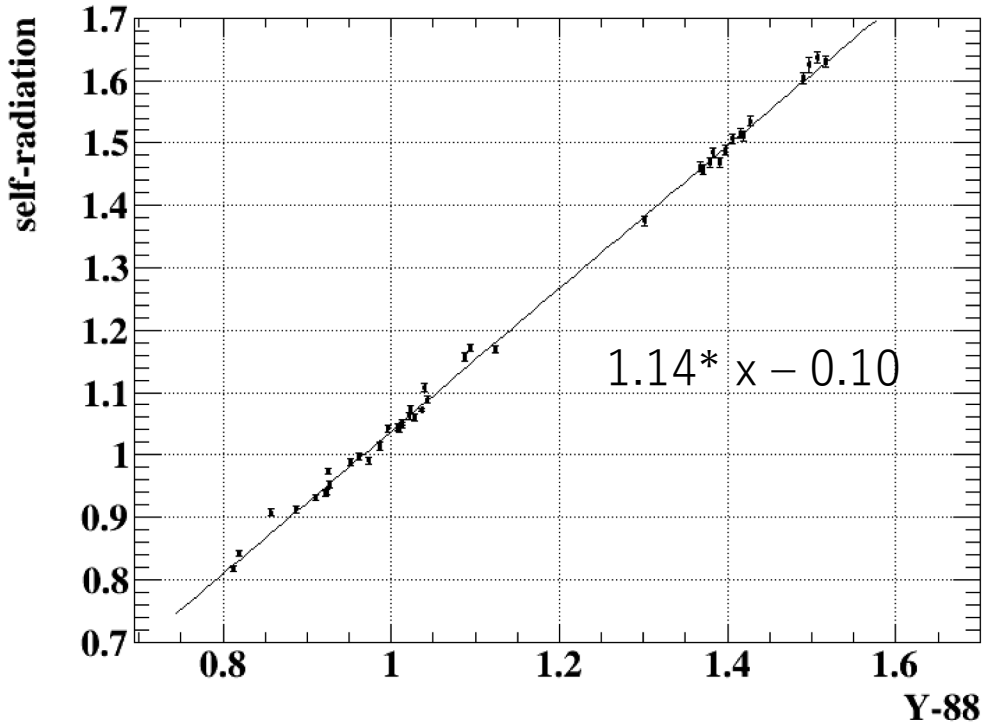
Energy Calibration Check

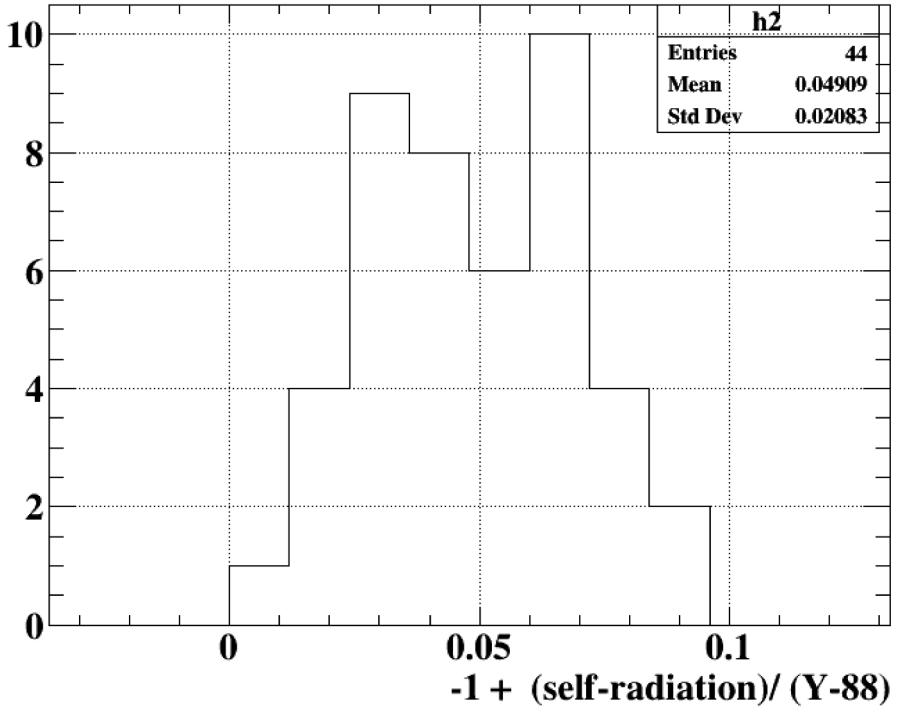




- Self-radiation: fit to 0.596 MeV peak with the fitting function
  γ peaks + β decay spectrum
- Y-88 : fit to 1.836 MeV peak with Gaus

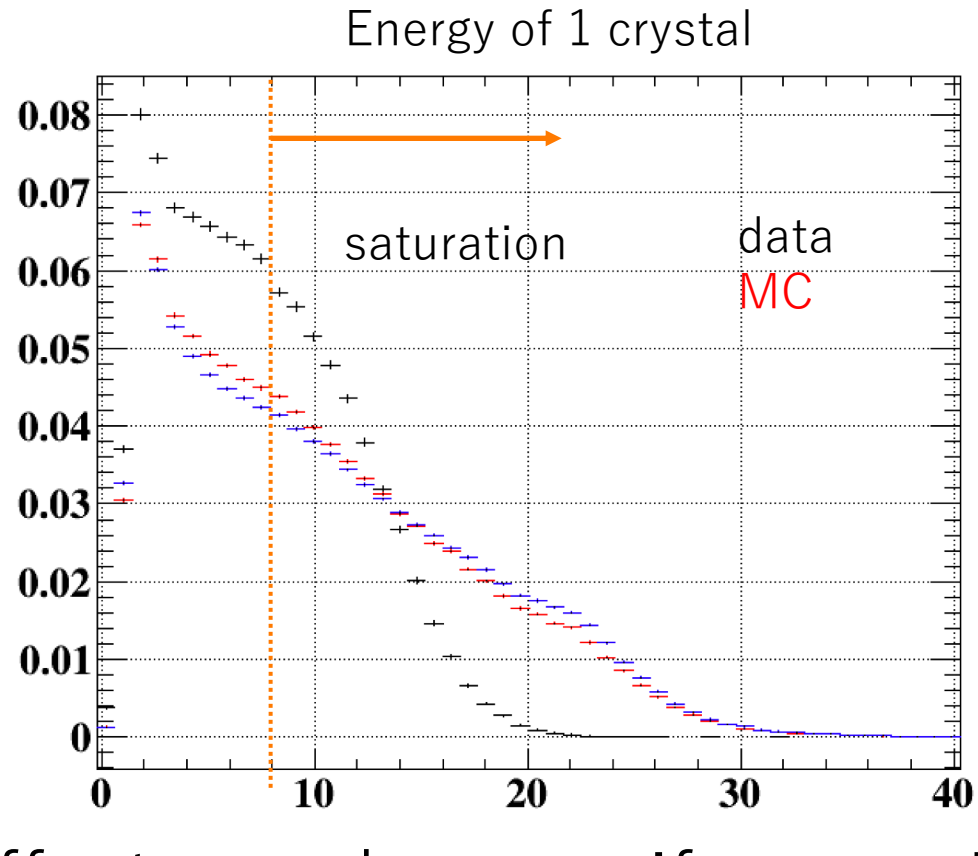
Comparison of Energy Scales





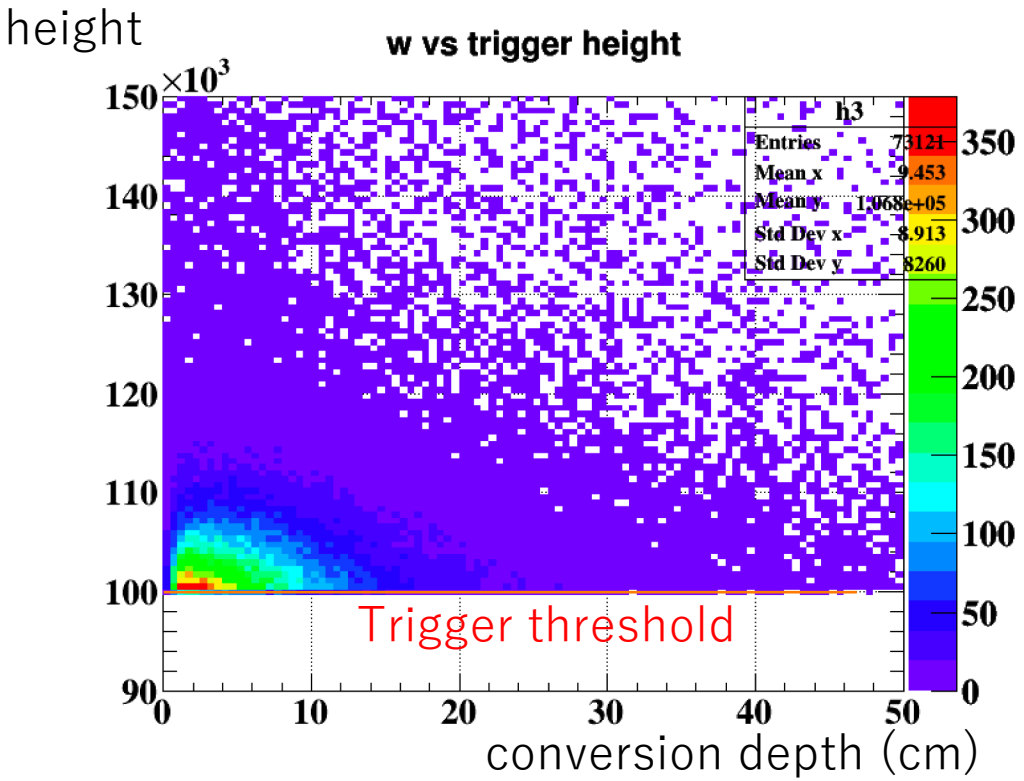
- Scale factors calculated with self-radiation are tend to be larger than Y-88 (~5%)
- Investigation is ongoing
  - systematic error in the fitting function?
  - non-linearity?

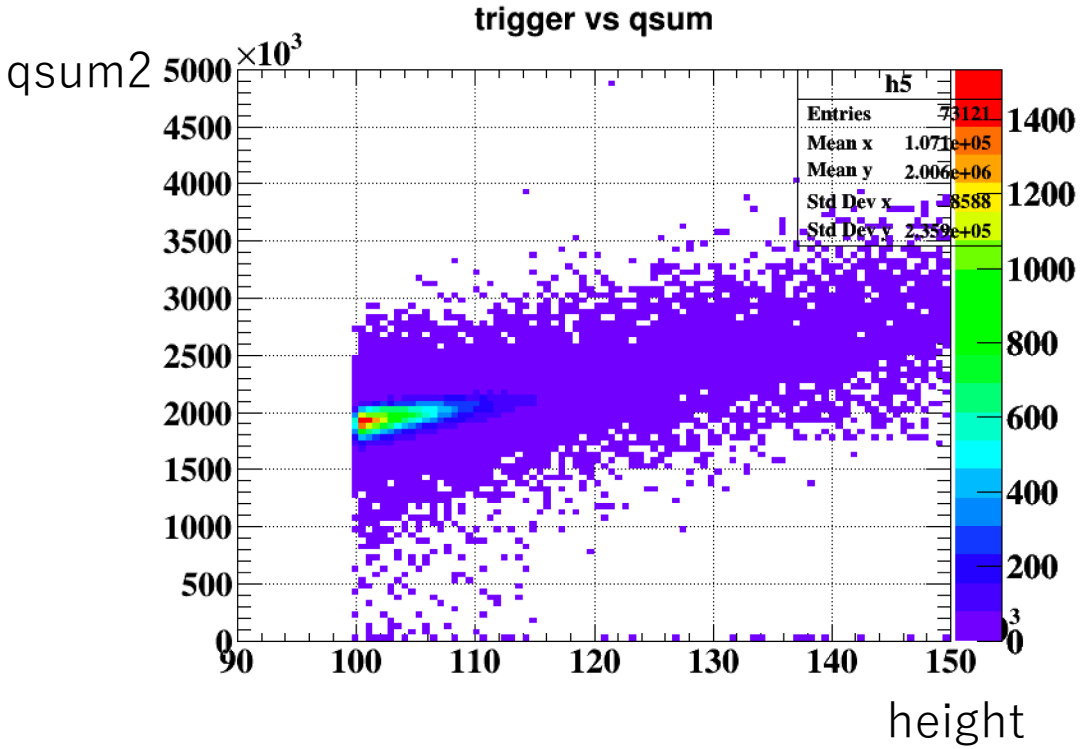
MPPC Saturation



- Saturation effects can be seen if energy is higher than 8MeV

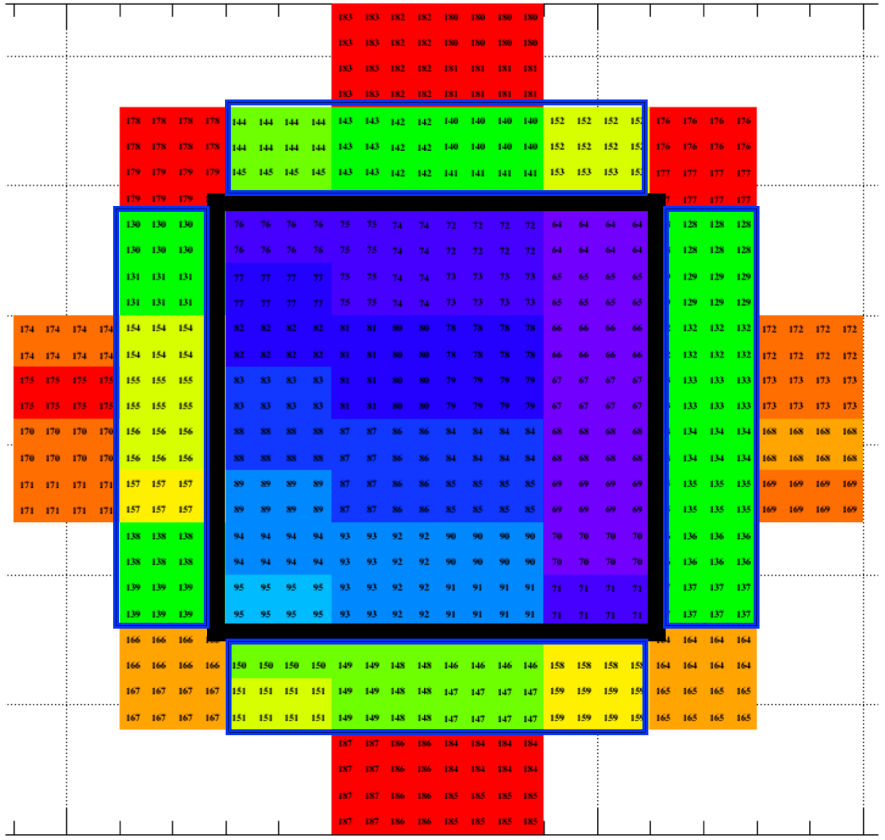
XEC Trigger Simulation





- For RDC simulation, XEC trigger condition is necessary
- In the real situation, DAQ was triggered by height of the sum of MPPC&PMT waveforms
- In simulation, trigger using qsum2 is desirable to make it easy
- Qsum2 has a correlation with the height of a trigger waveform.

XEC Trigger Simulation

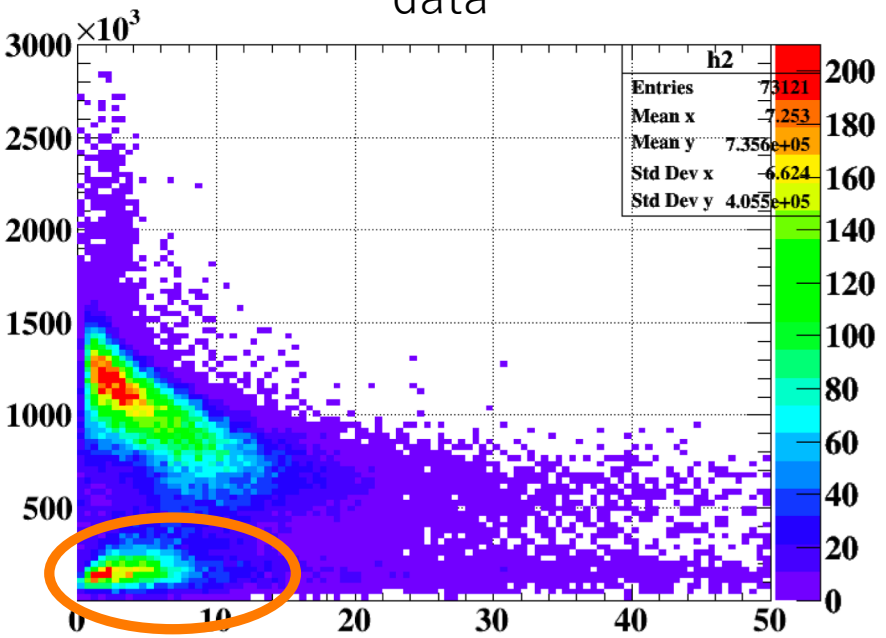


- Triggered if one of 4×4 boards in the center has the max sum of the number of photo-electrons among the DAQ boards in the blue rectangles
→”patch 1”

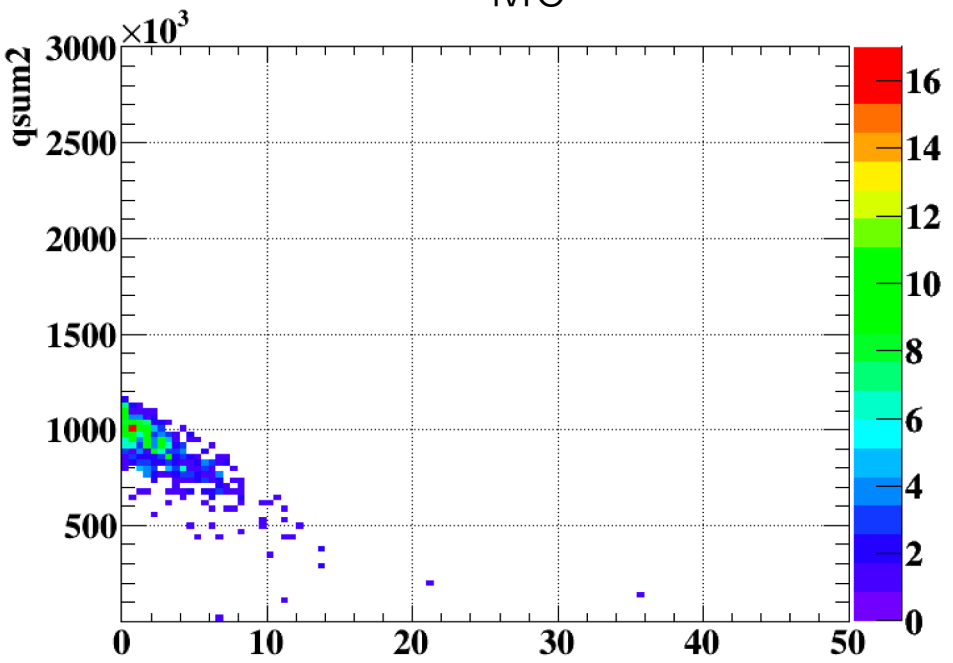
※ 4×4 MPPCs were in the same board

Energy of Trigger MPPCs

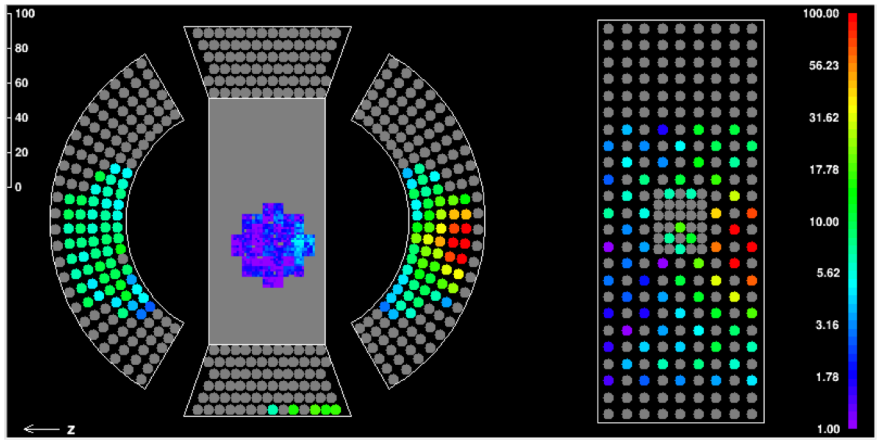
data



MC



w = 3.2 cm

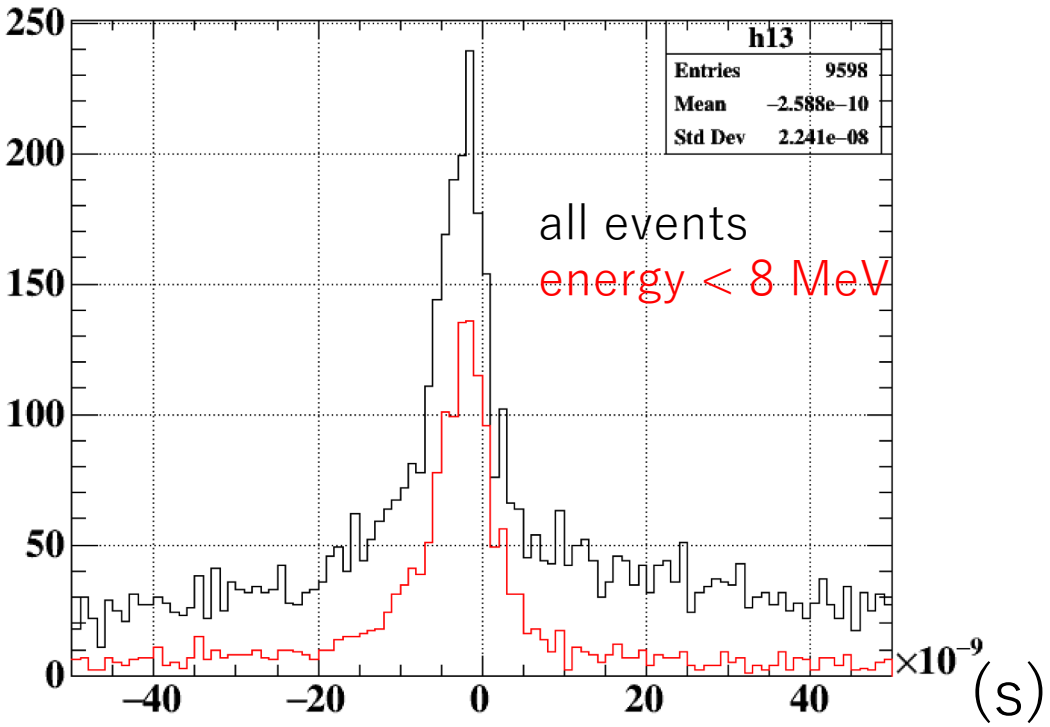


- Some energy values of MPPCs are in the small region, which are not included in MC

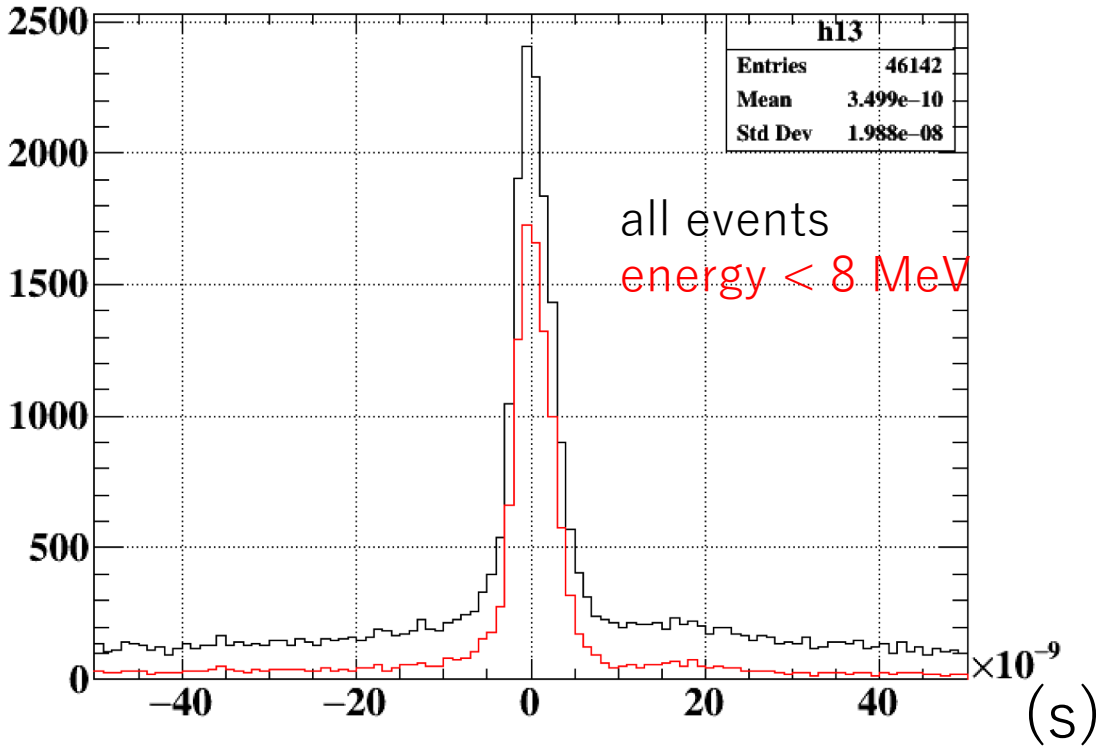
← should be cut by “patch1”

RMD Timing (Offline Patch1)

MPPC qum2 < 5e5



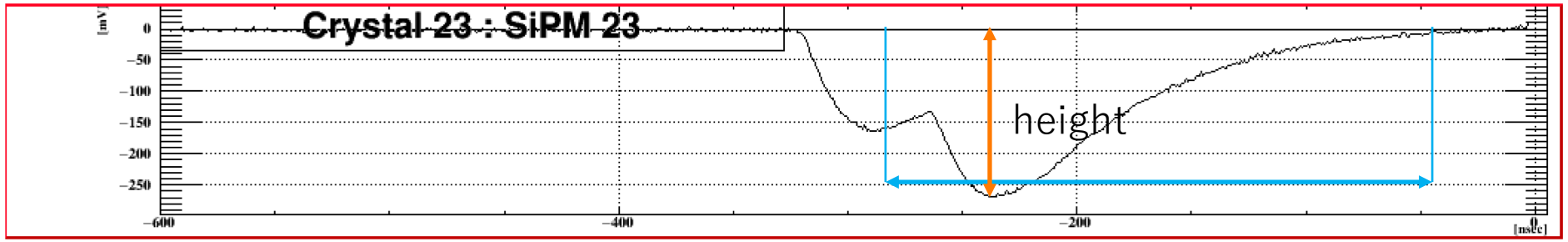
MPPC qum2 > 5e5



- After offline selection, many Michel events are still included in the events of MPPC qsum2 < 5e5
  ← hardly included in MC trigger events

Charge Estimation

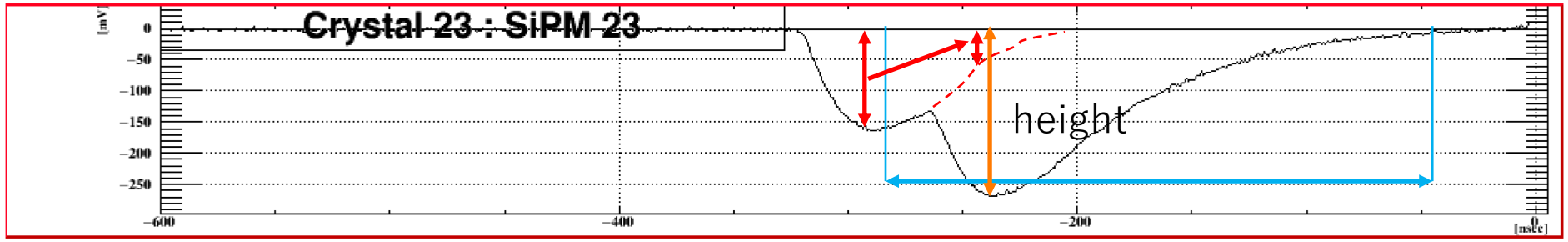
- Pulse search found a pulse around PS pulse timing.
- Estimate charge by height using a factor calculated by a template waveform
  charge = height * HeightToCharge



Integration area

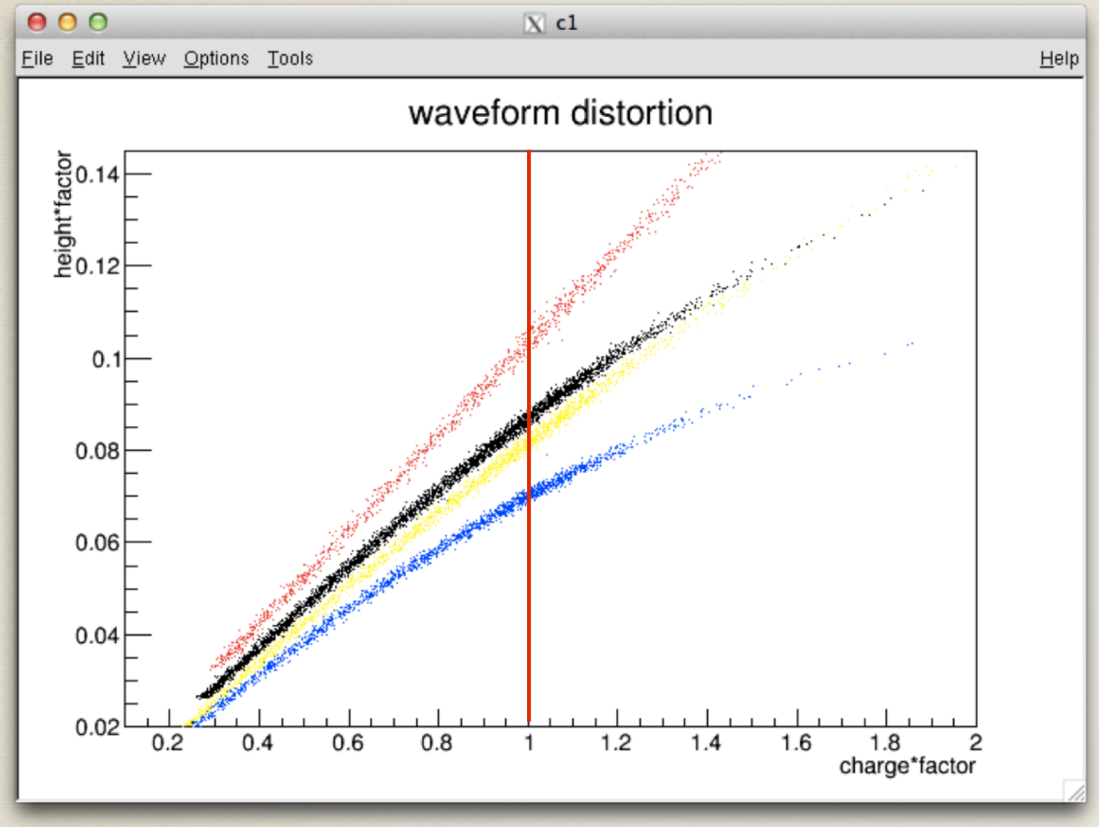
Charge Estimation

- Pulse search found a pulse around PS pulse timing.
- Sometimes adjust pulse is so close that pulse height is enhanced.
- Estimate the amplitude of the adjust pulse at peak time of the focused pulse using the template waveform.
- Subtract the effect from calculated height



Integration area

waveform distortion



red: 15um
(4.6V)
black: CT suppress
(3.1V)
yellow: 25um
(4.2V)
blue: 50um
(2.1V)

- CT suppress model shows smaller waveform distortion than normal one.
- the four types of distribution are not on the same line?
  →I cannot judge what MPPC is the best from this graph.
  (maybe 15 or 25 is the best)
  →another comparison method is needed?