MEG実験 背景ガンマ線の研究

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2010年9月11日

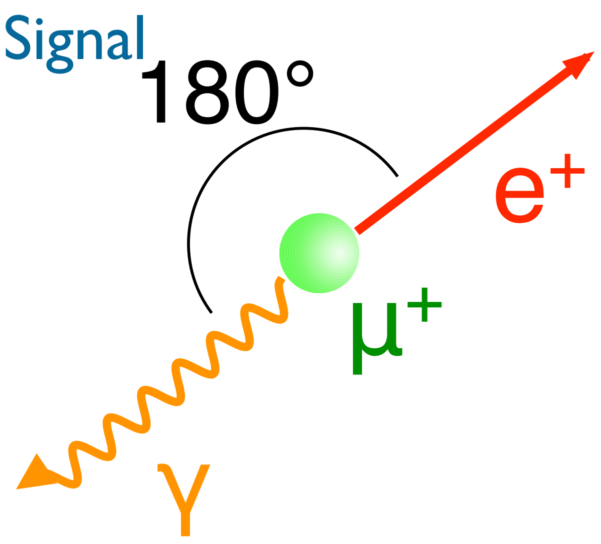
日本物理学会 2010年秋季大会
九州工業大学戸畑キャンパス

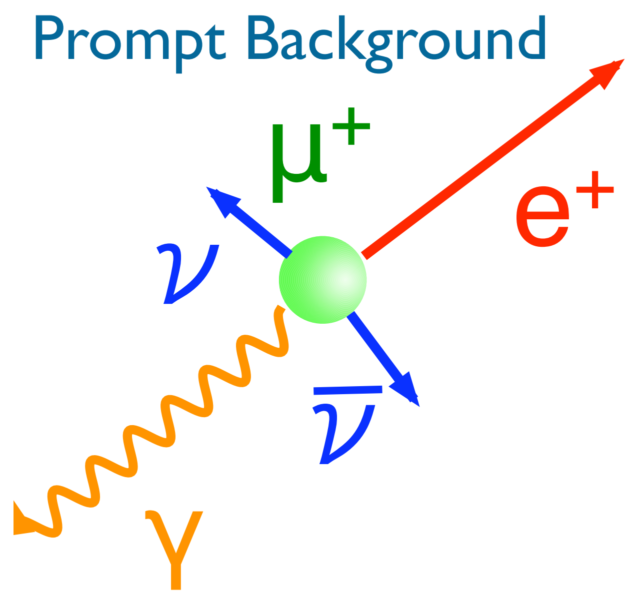
Outline

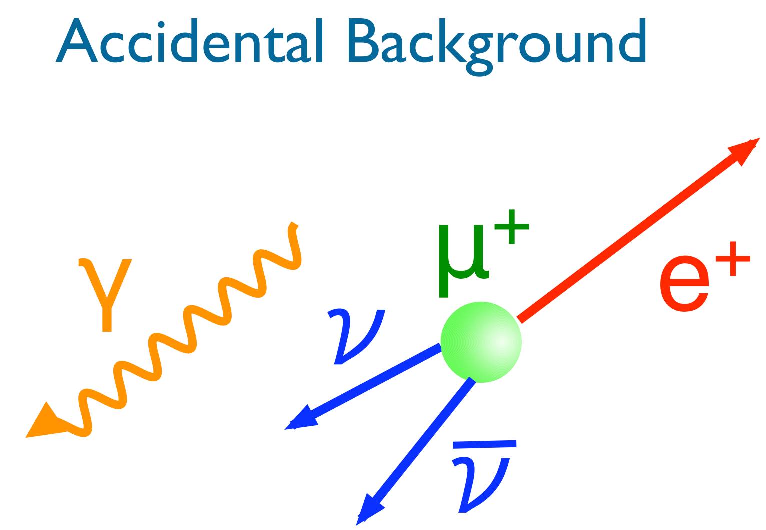
- Introduction
- Pileup
  - Pileup identification
  - Pileup elimination
- Cosmic ray
  - Cosmic ray rejection
- Background components
- Summary

Introduction

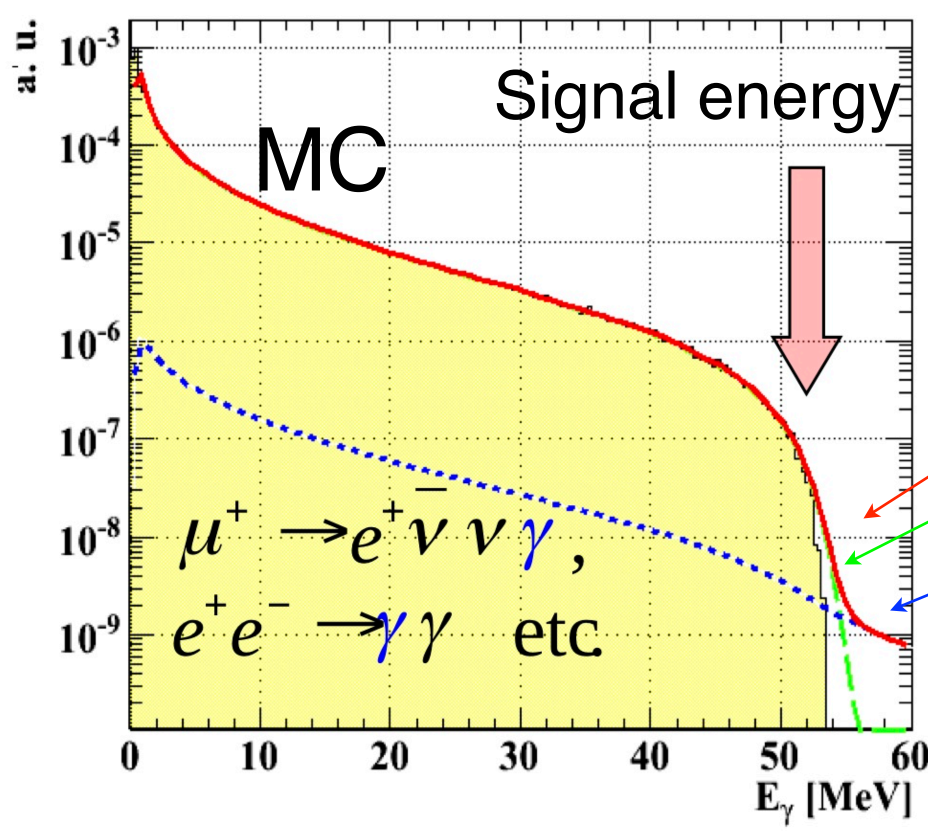
Background







γ BG



$$R_{acc} \propto (R_\mu)^2 * (\Delta\theta)^2 * (\Delta E_\gamma)^2 * \Delta T * \Delta E_e$$

Gamma background (total)

- Single gamma (AIF + RD)
- Pileup
- (Cosmic ray)

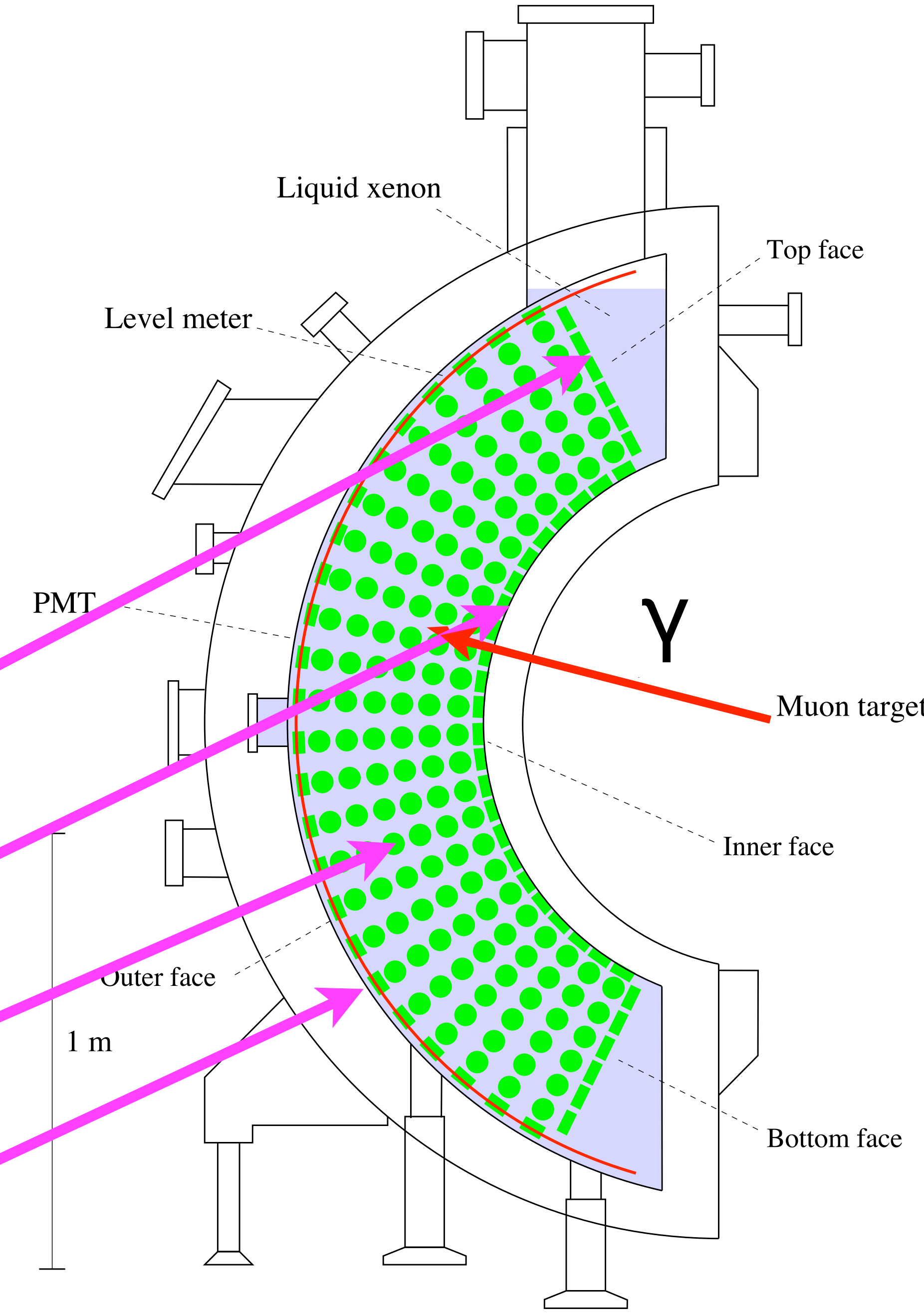
This talk

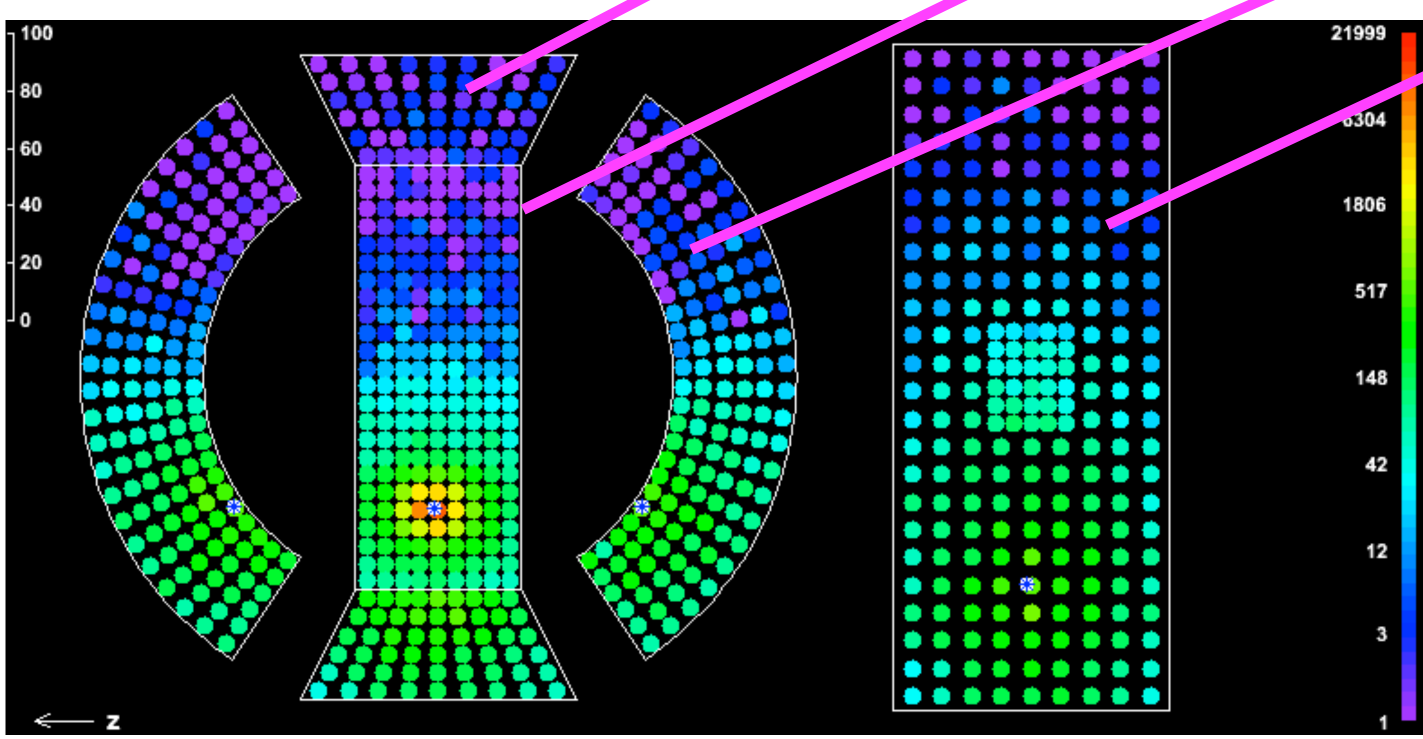
High energy BG events
→ Larger effect in likelihood analysis

AIF : positron annihilation in flight
RD : muon radiative decay

Liquid Xenon Calorimeter

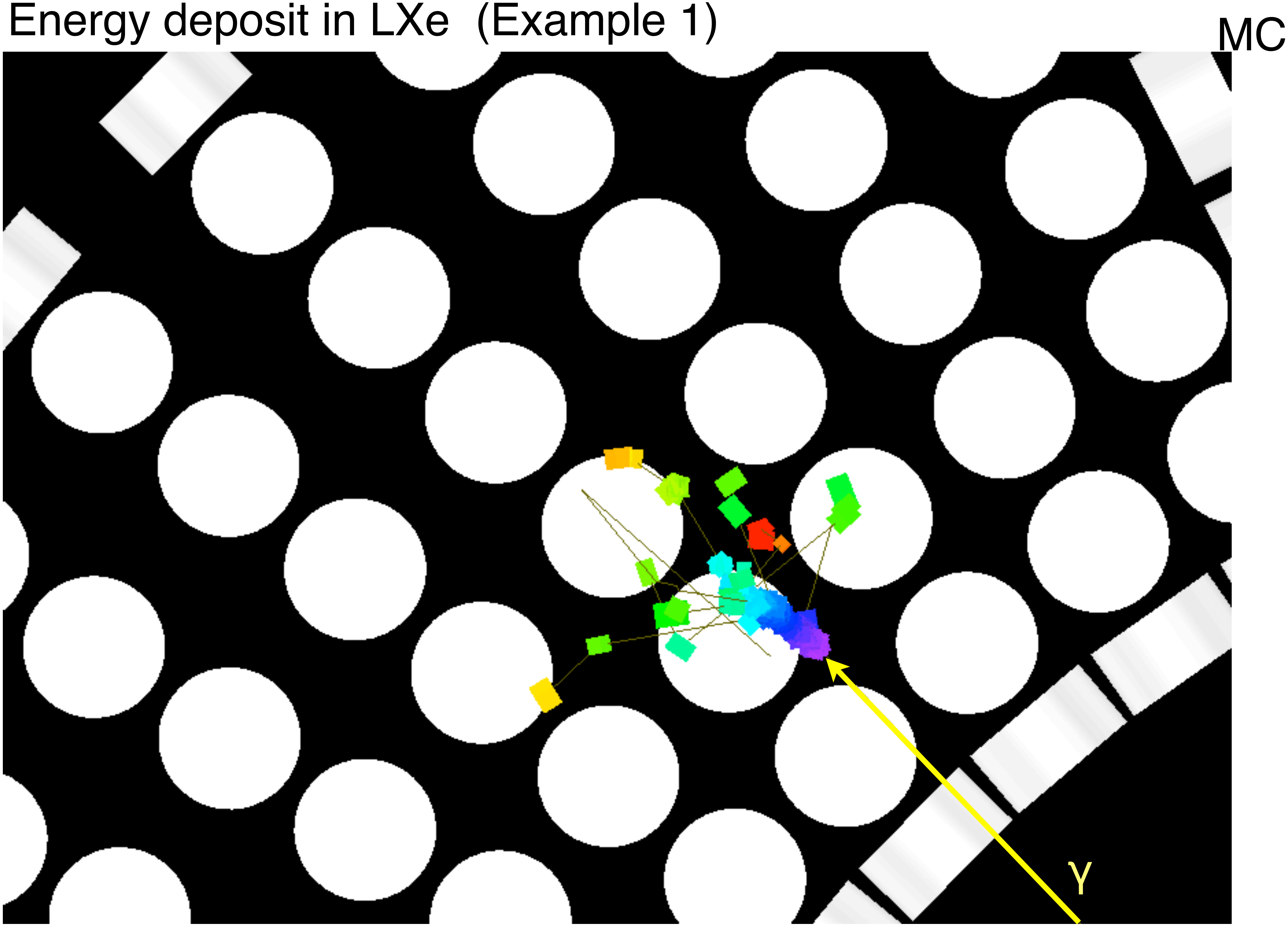
Non-segmented detector
➔ all PMTs are used to
reconstruct each single photon





Expanded view
(Color code = PMT charge)

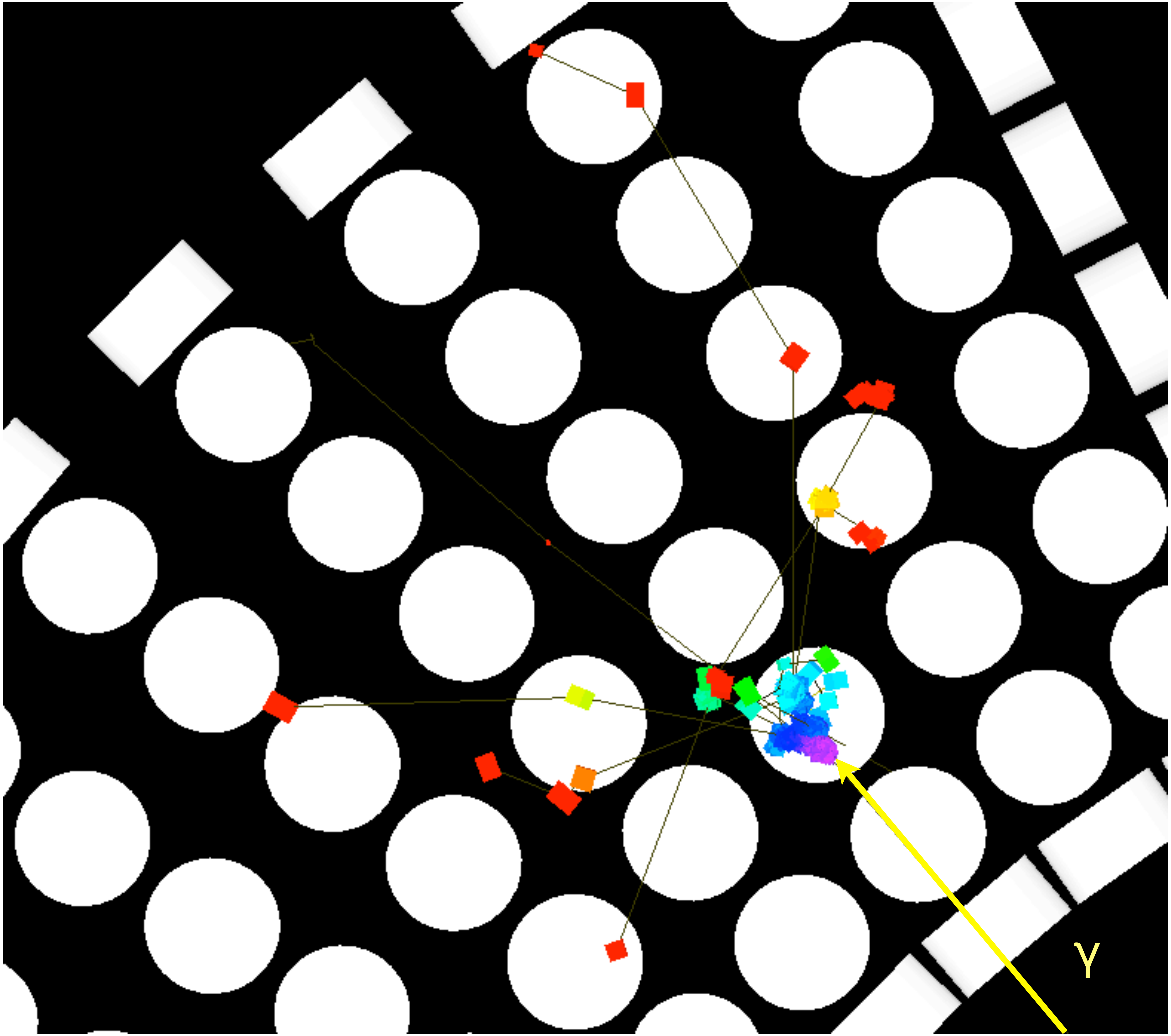
Energy deposit in LXe (Example 1)



Color represents time (blue -> red)

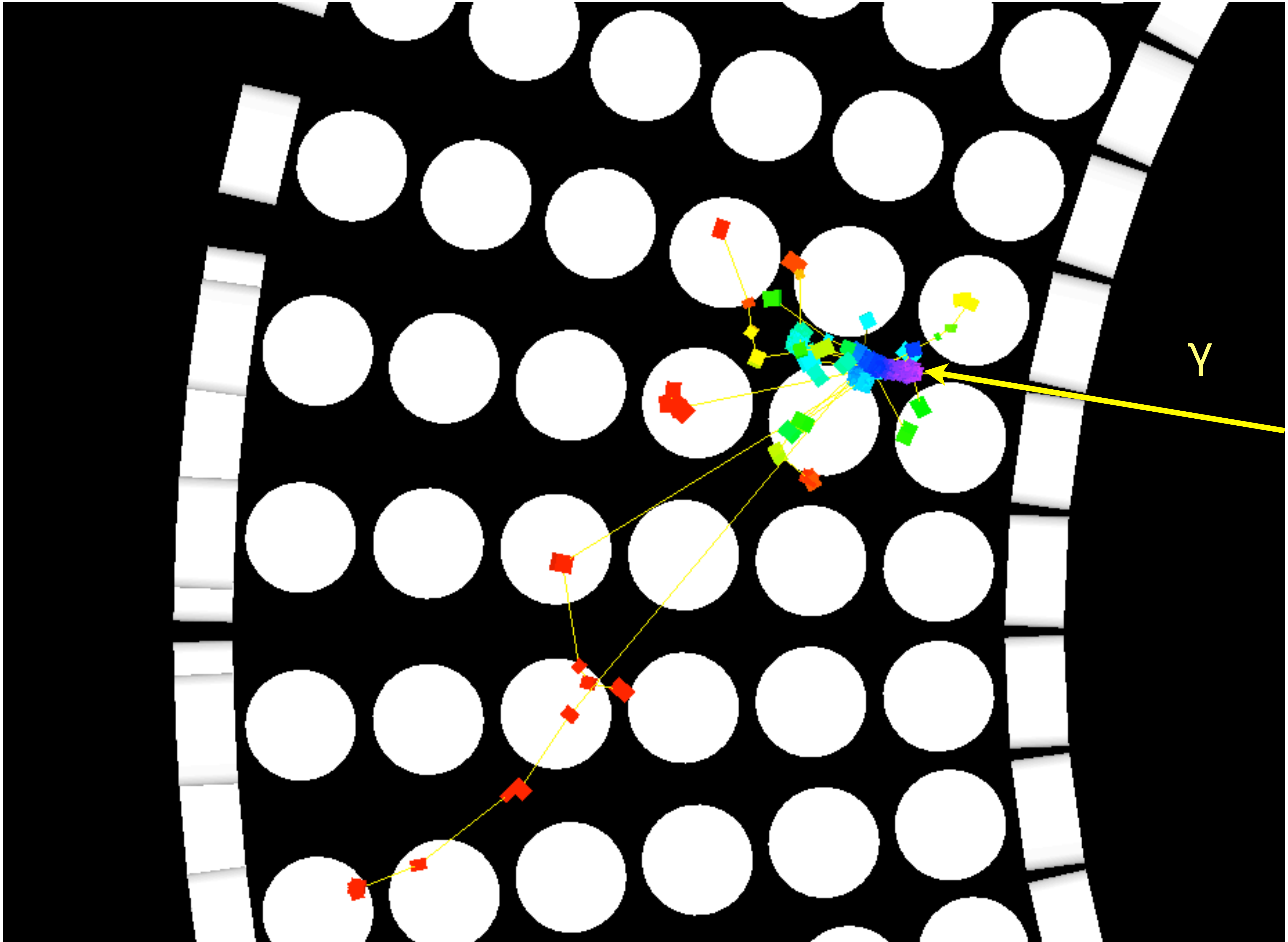
Energy deposit in LXe (Example 2)

MC

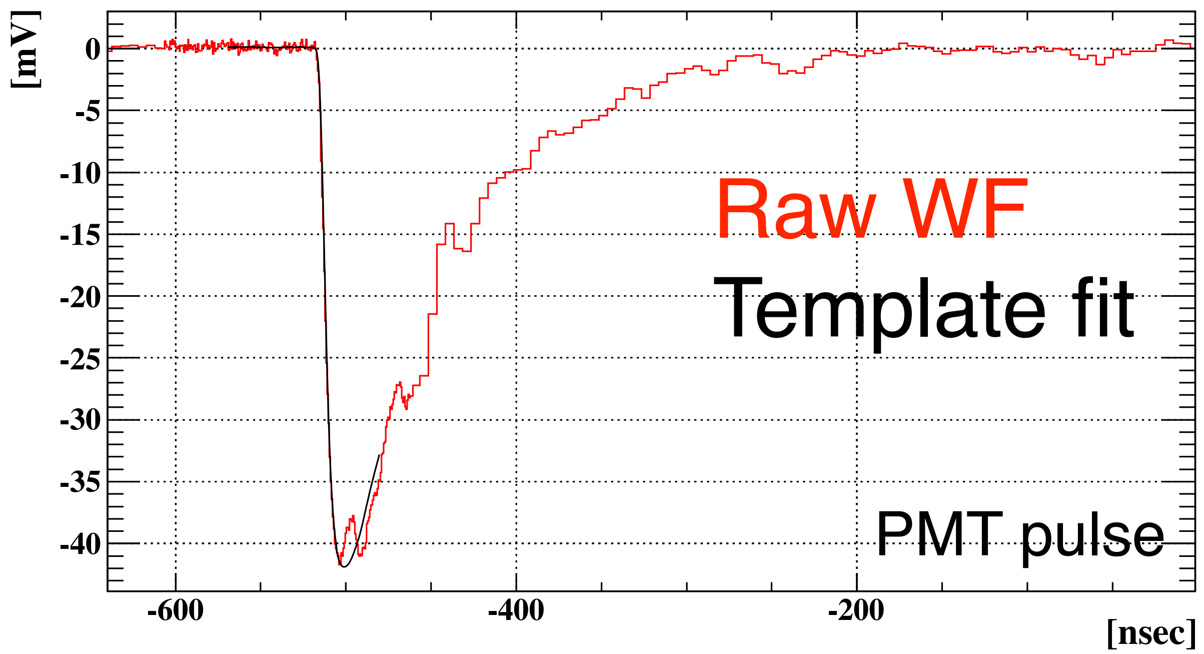


Energy deposit in LXe (Example 2)

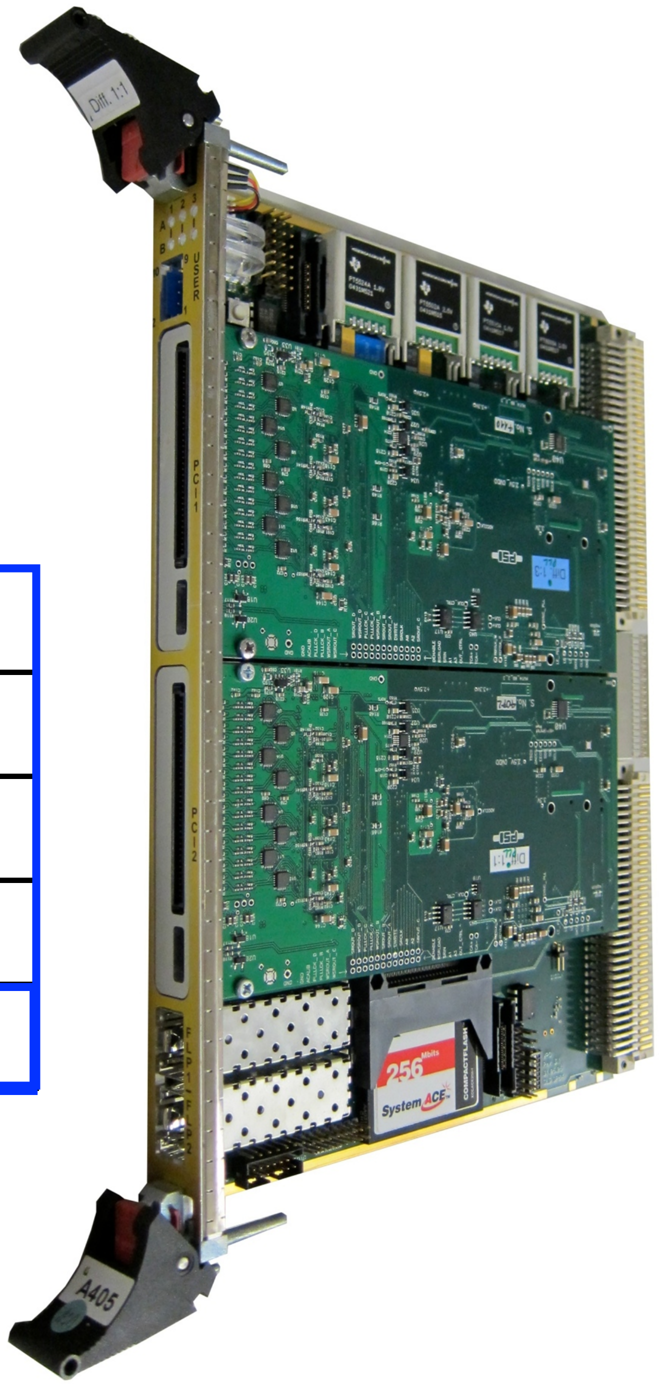
MC



LXe pulse



DRS4
MEG calorimeter WF
sampled at 1.6 GHz



	NaI	BGO	GSO	LSO	LXe
Effective atomic number	50	73	58	65	54
Density (g/cm^3)	3.7	7.1	6.7	7.4	3.0
Relative light output (%)	100	15	20-40	45-70	80
Decay time (nsec)	230	300	60	40	4.2, 22, 45

Fast decay ➔ Good to reduce pileup

All waveforms are recorded
➔ offline pileup identification

Energy reconstruction

1. Weighted photon sum

$$N = \sum Q_i / g_i / qe_i \times w_i$$

Q.E.

charge gain

correction for PMT coverage fraction (fixed)

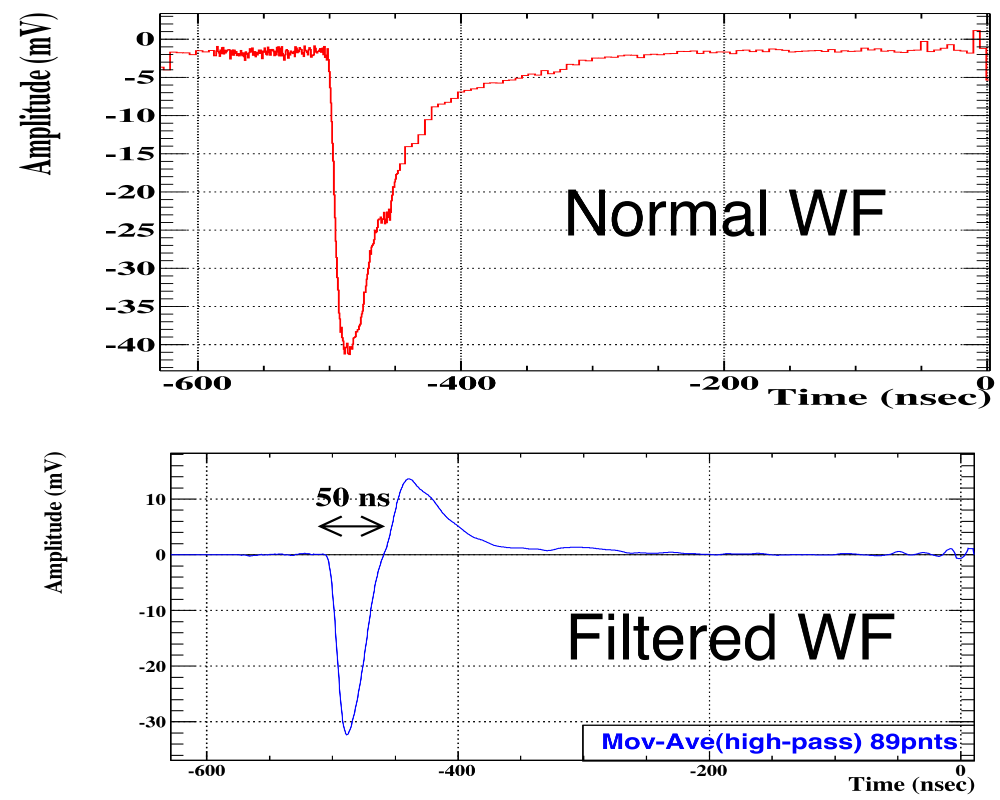
2. Correction of

- Non-uniform response in the detector
  - 5% difference depending on position and depth
- Variation of light yield

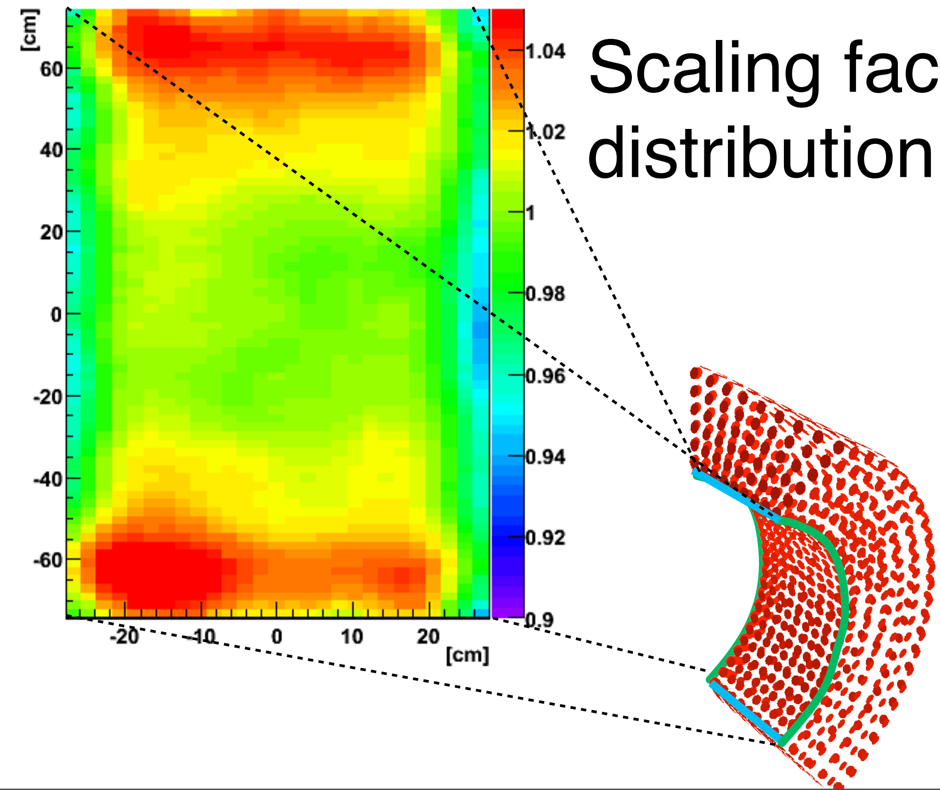
3. Scale to energy. (Single factor)

Required
- Charge of most of PMT
- Position and depth of conversion point

A PMT WF



Filtered WF is used for energy; Integration time is shorter.

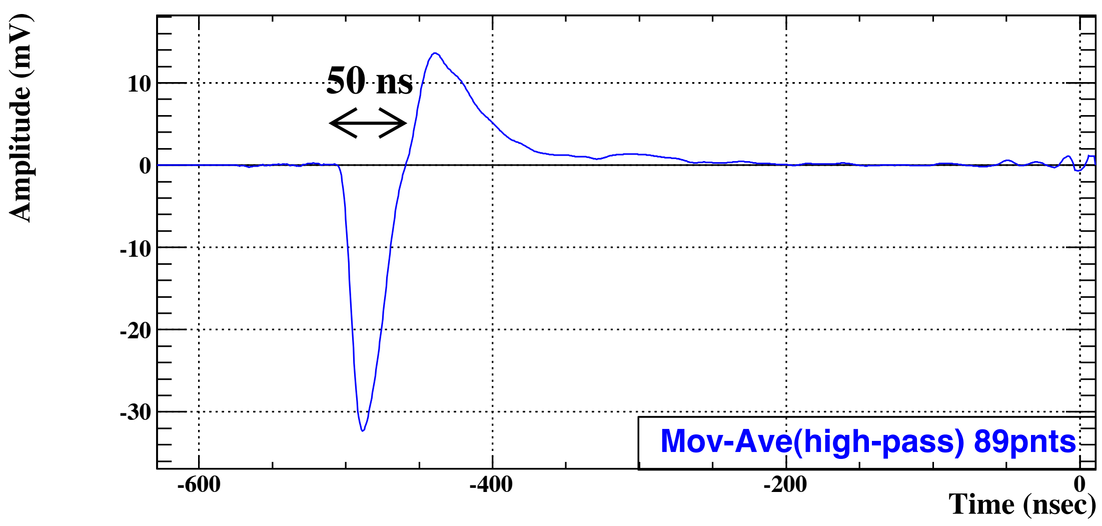


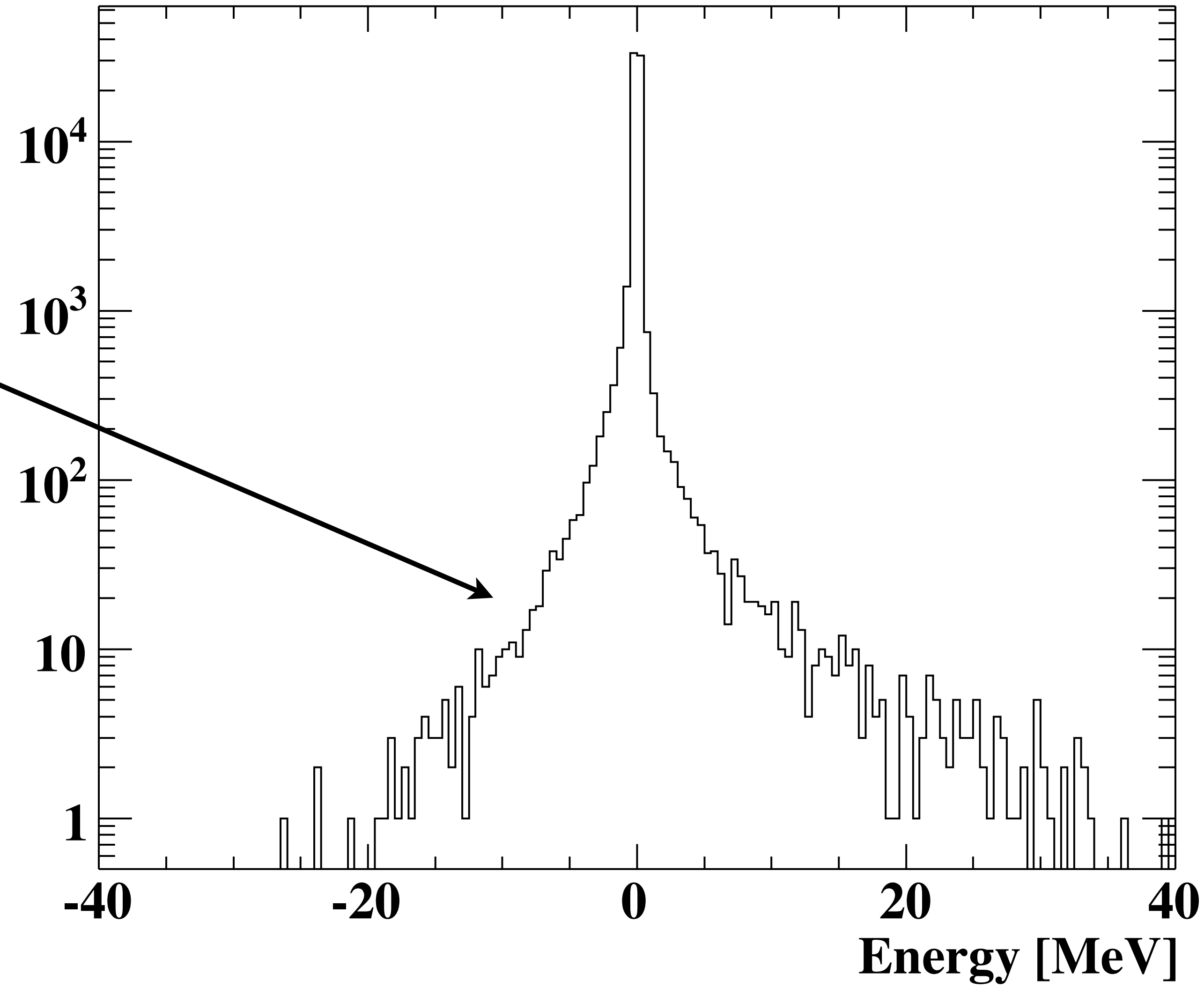
Pileup

How pileup gamma look

Random trigger data

Negative energy is due to overshoot of shaped WF



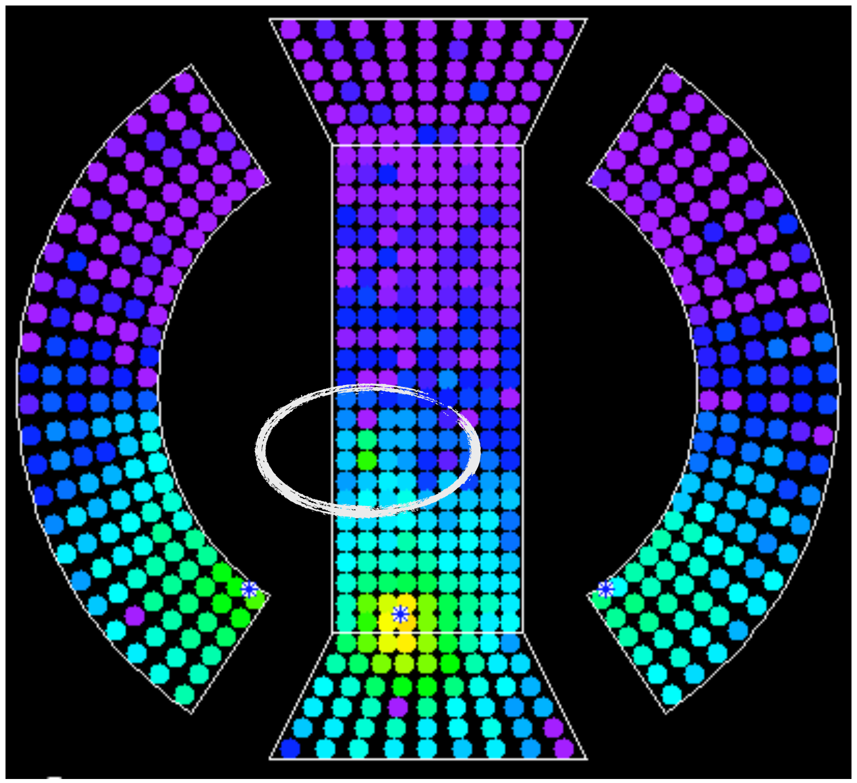


Most of pile up is low energy

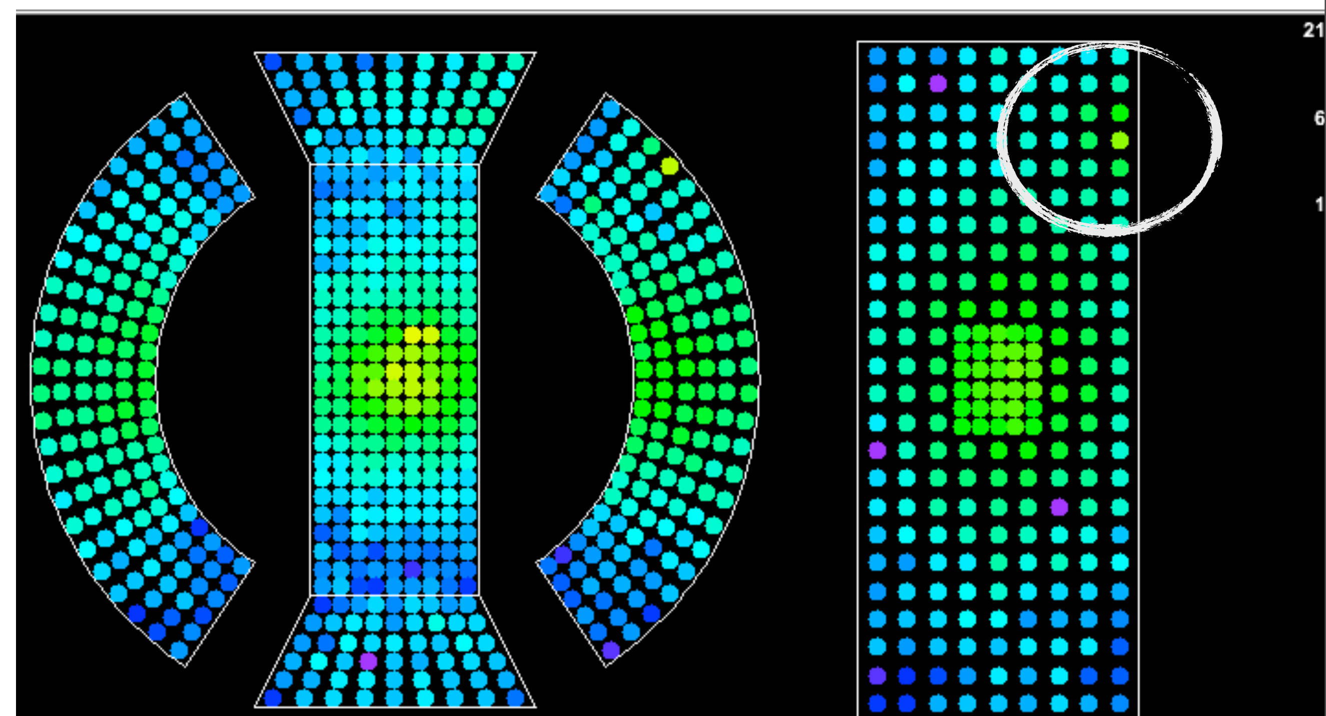
*shaping is done to reduce slow component noise

ID by charge distribution

Example 1



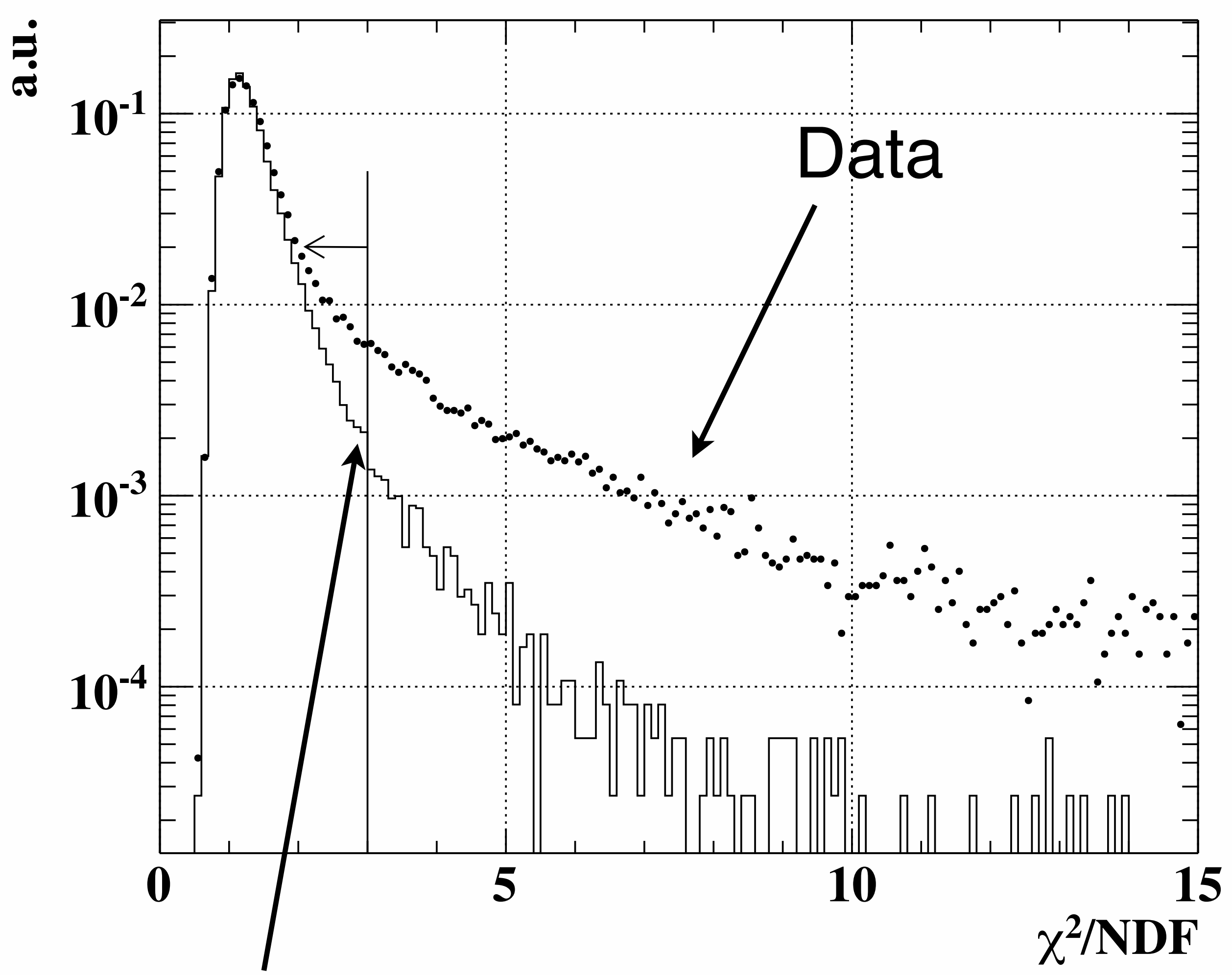
Example 2

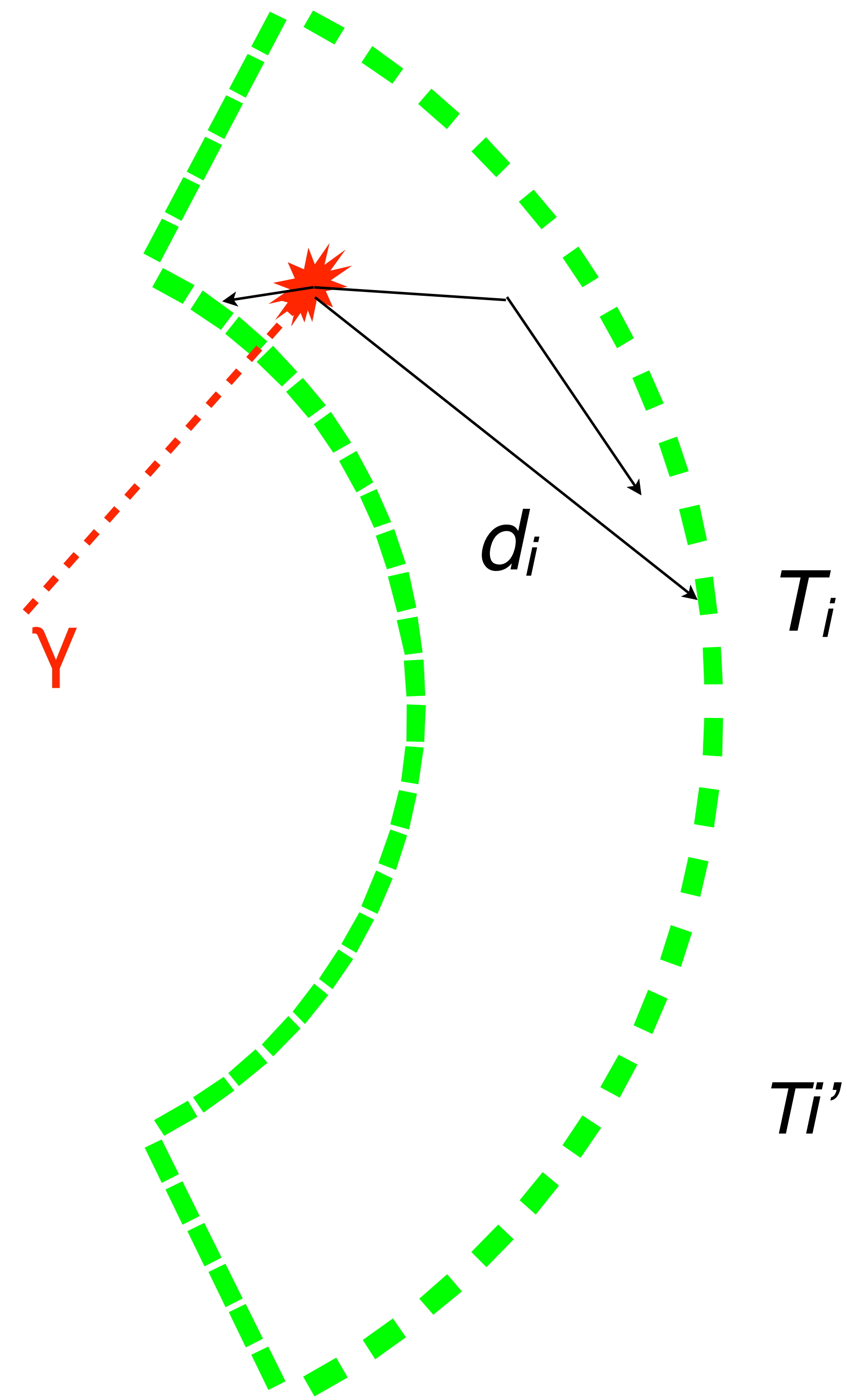


Peak search in the largest faces (inner and outer)

Time fitting χ^2

Reconstruction : Fitting Ti' distribution





$Ti' = Ti - di / c'$

c' : speed of scintillation light in LXe

Thought

Easiest way is rejecting all the pileup events

Real signal can be pileup !

➔ **Simple rejection make inefficiency**

15% of events of MEG data sample have pileup.

Better way is unfolding pileup gamma, but not trivial.

Case of MEG

- MEG calorimeter is non-segmented.
- Light distribution is not constant
  - Low energy → point-like
  - High energy → shower shape is approximately constant.
  - Middle energy → Light distribution much different event-by-event.
- Position and depth of low energy photon is difficult

Subtract pileup energy from total energy

Pileup elimination

Finding pileup gamma positions

⇩

Estimating energy without using PMTs around the pileup

⇩

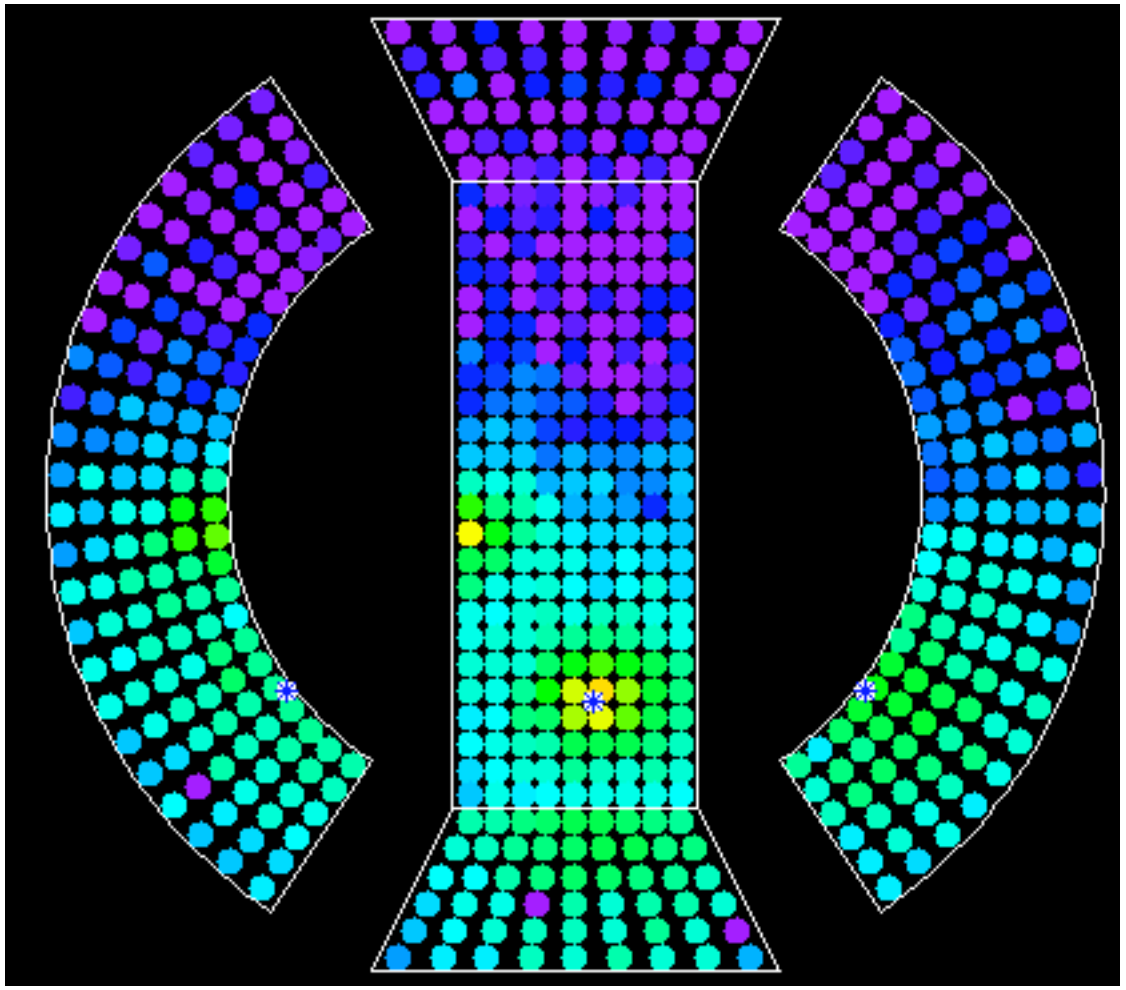
Expecting #photons of PMTs in case of no pileup

⇩

Replace #photons around the pileup

⇩

Doing the usual reconstruction



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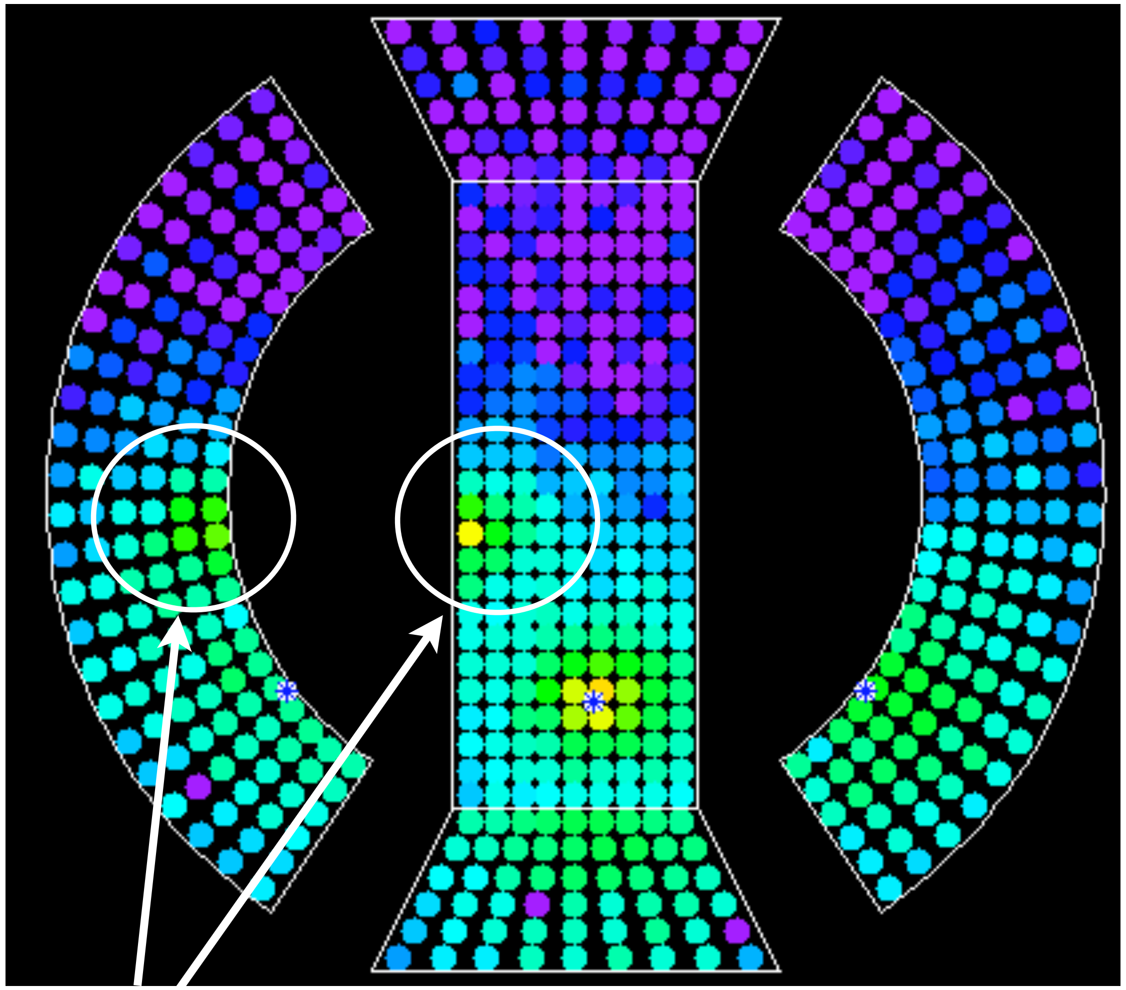


Not used

Energy is estimated by fitting main gamma PMTs, without using PMTs around pileup

Fitting function is made from calibration 17MeV gamma data

Pileup elimination

Finding pileup gamma positions

⇩

Estimating energy without using PMTs around the pileup

⇩

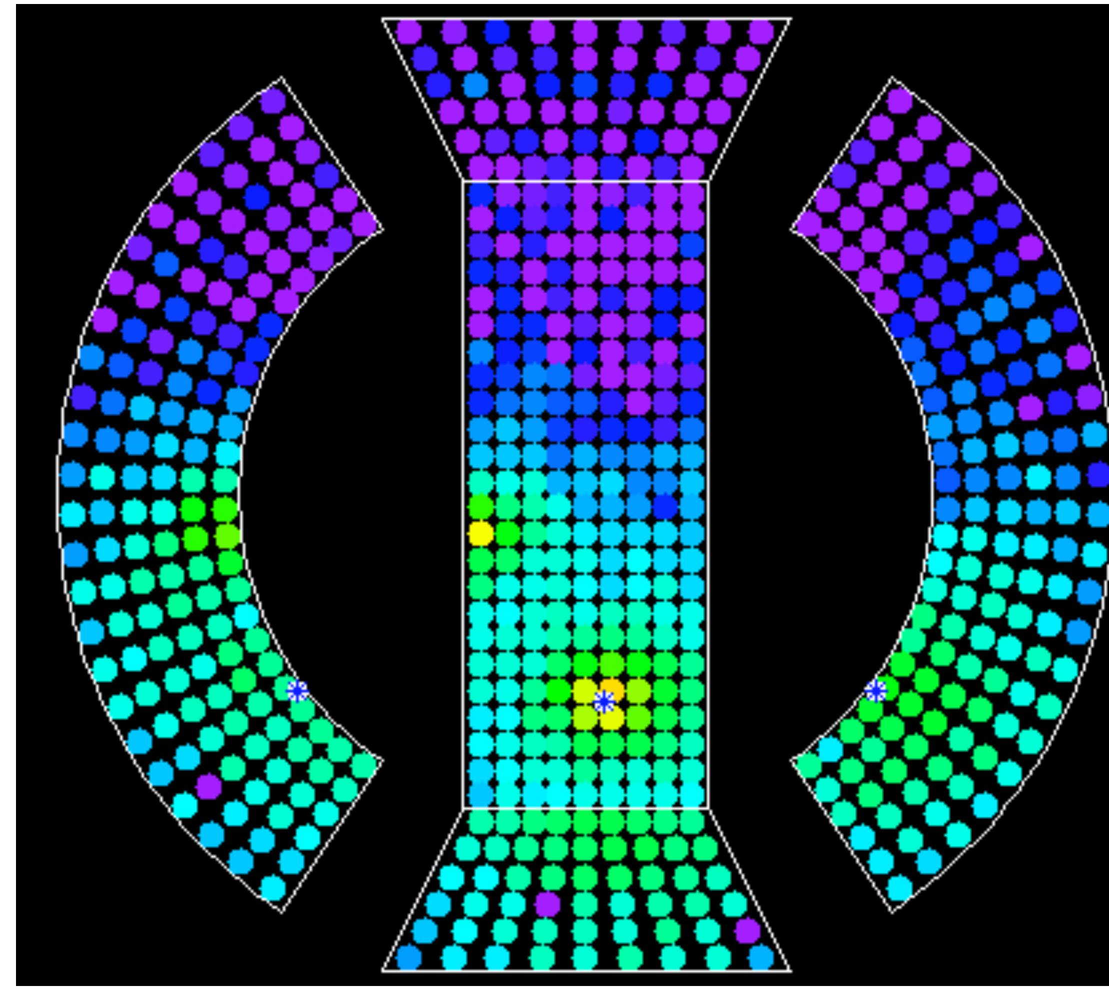
Expecting #photons of PMTs in case of no pileup

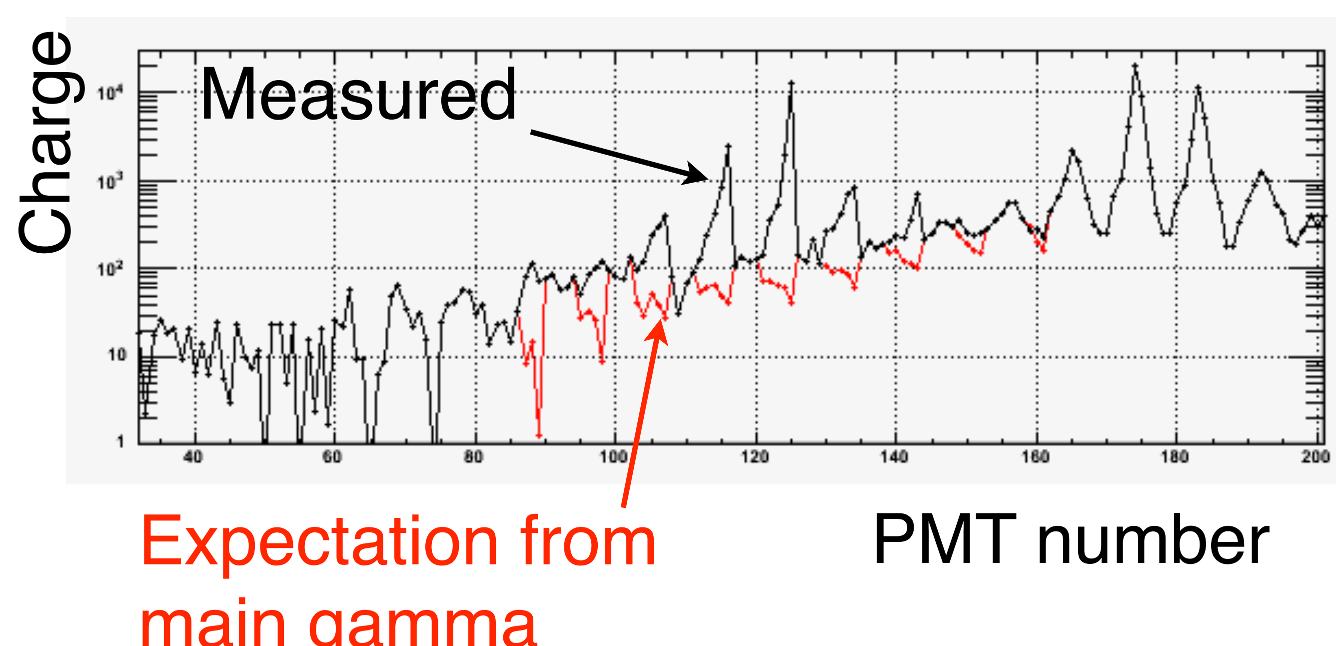
⇩

Replace #photons around the pileup

⇩

Doing the usual reconstruction





Pileup elimination

Finding pileup gamma positions

⇩

Estimating energy without using PMTs around the pileup

⇩

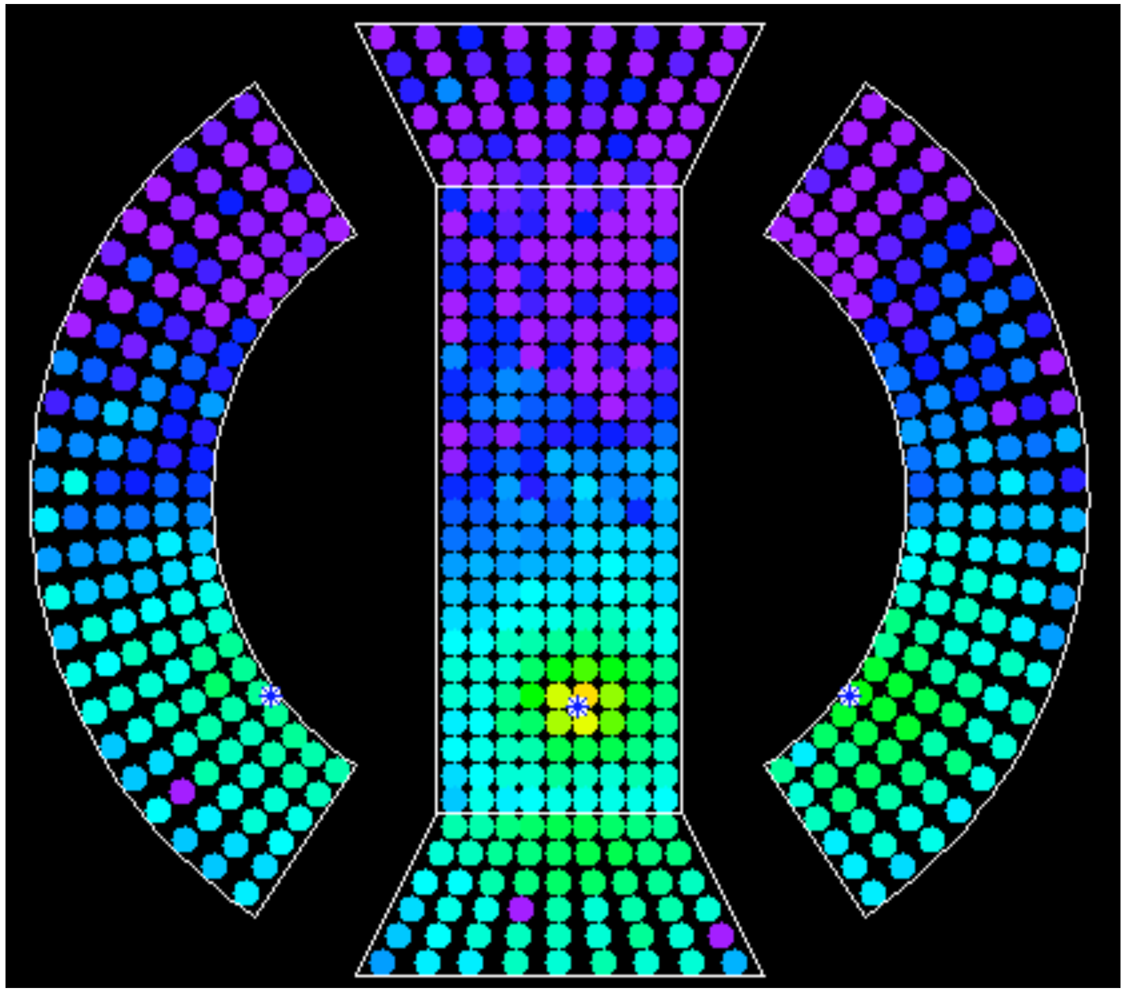
Expecting #photons of PMTs in case of no pileup

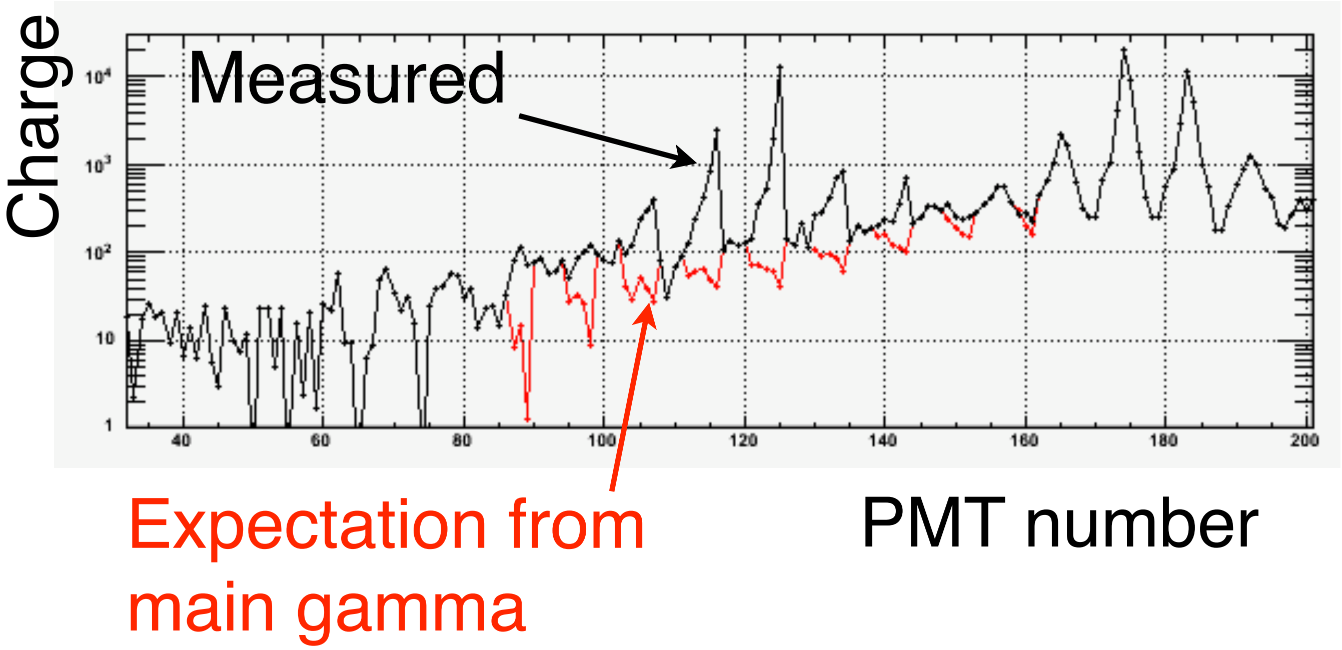
⇩

Replace #photons around the pileup

⇩

Doing the usual reconstruction





Pileup elimination

Finding pileup gamma positions

⇩

Estimating energy without using PMTs around the pileup

⇩

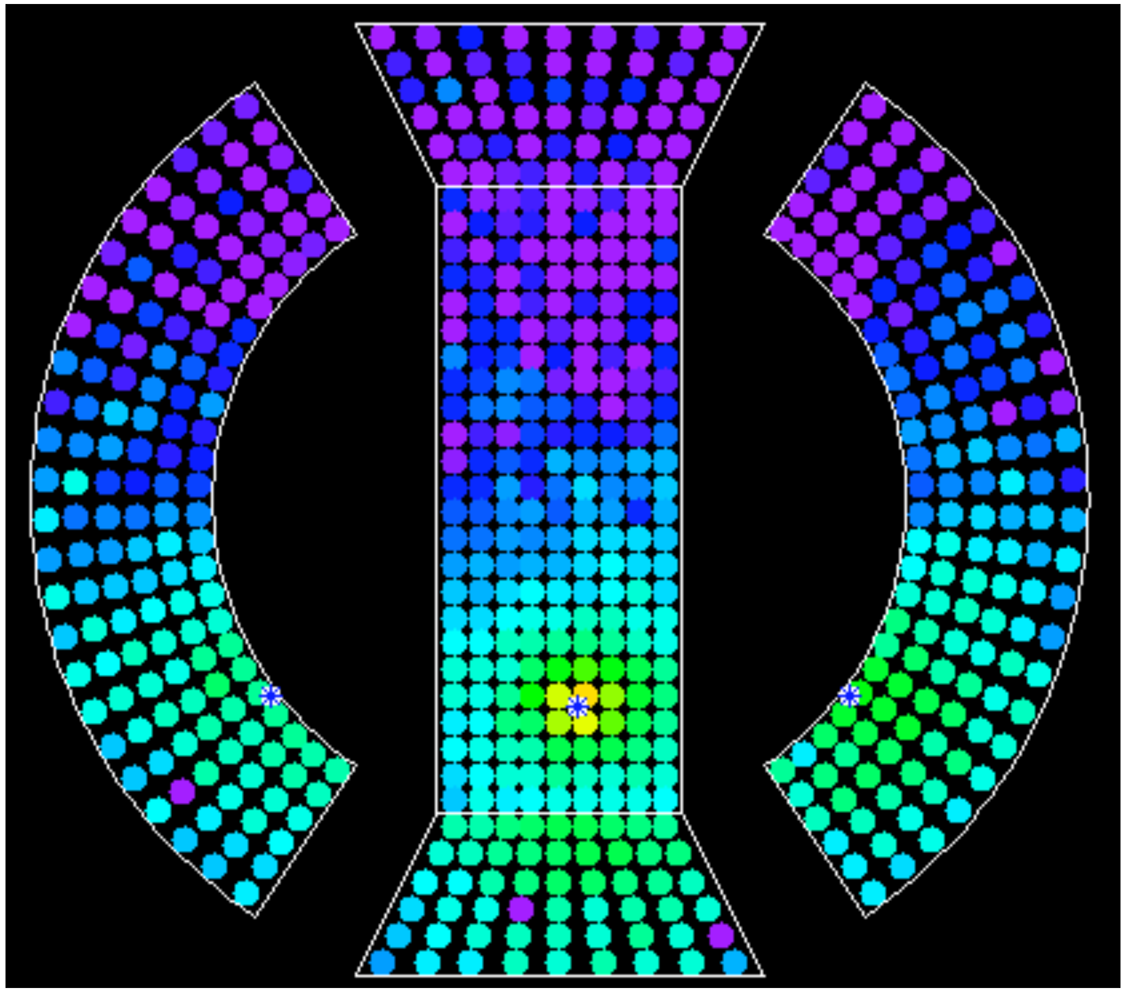
Expecting #photons of PMTs in case of no pileup

⇩

Replace #photons around the pileup

⇩

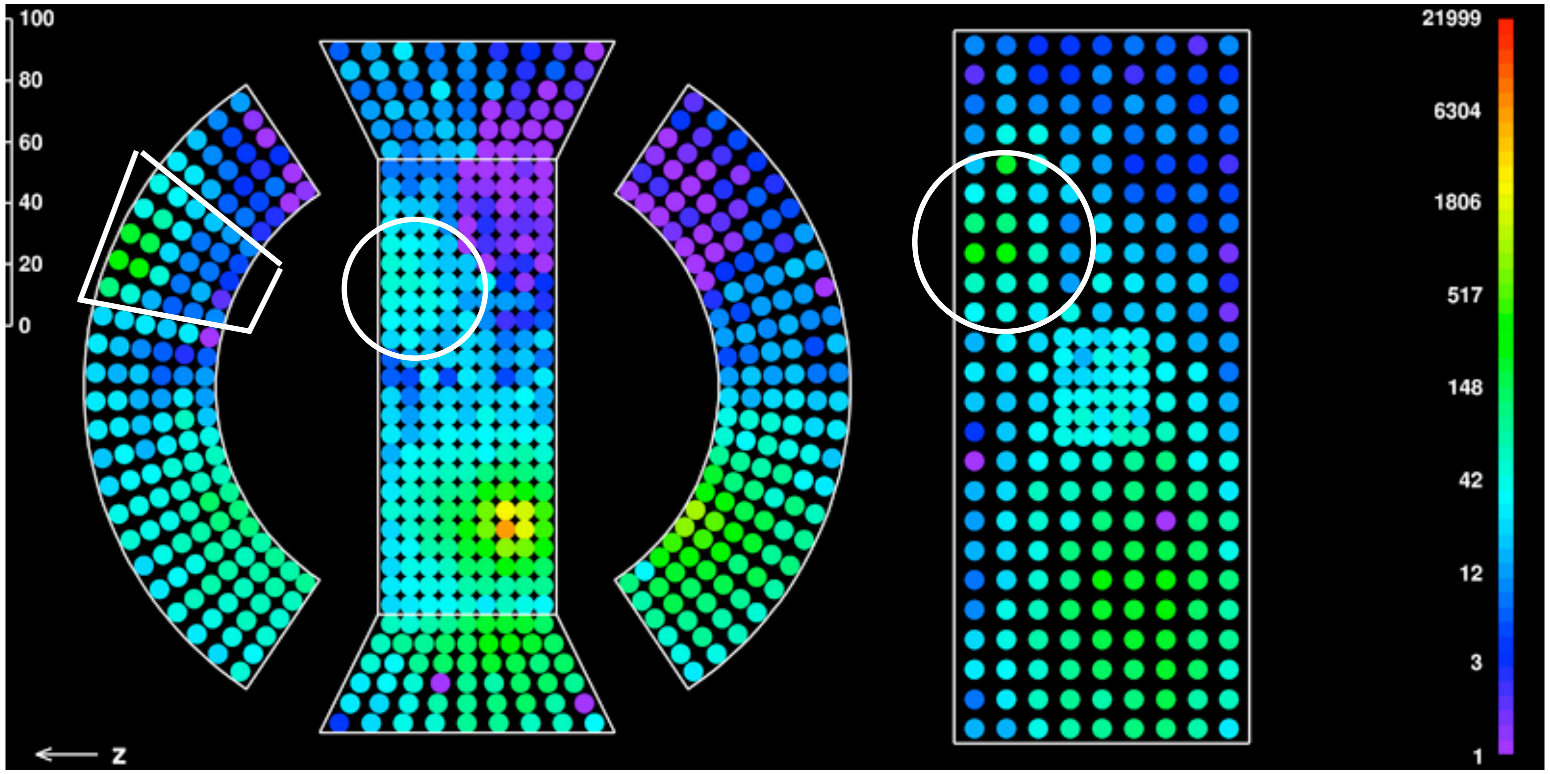
Doing the usual reconstruction



Energy of pileup gamma is estimated from information of main gamma.
Only a part of PMTs are replaced, and most of original information is used for reconstruction

Enhanced pileup elimination

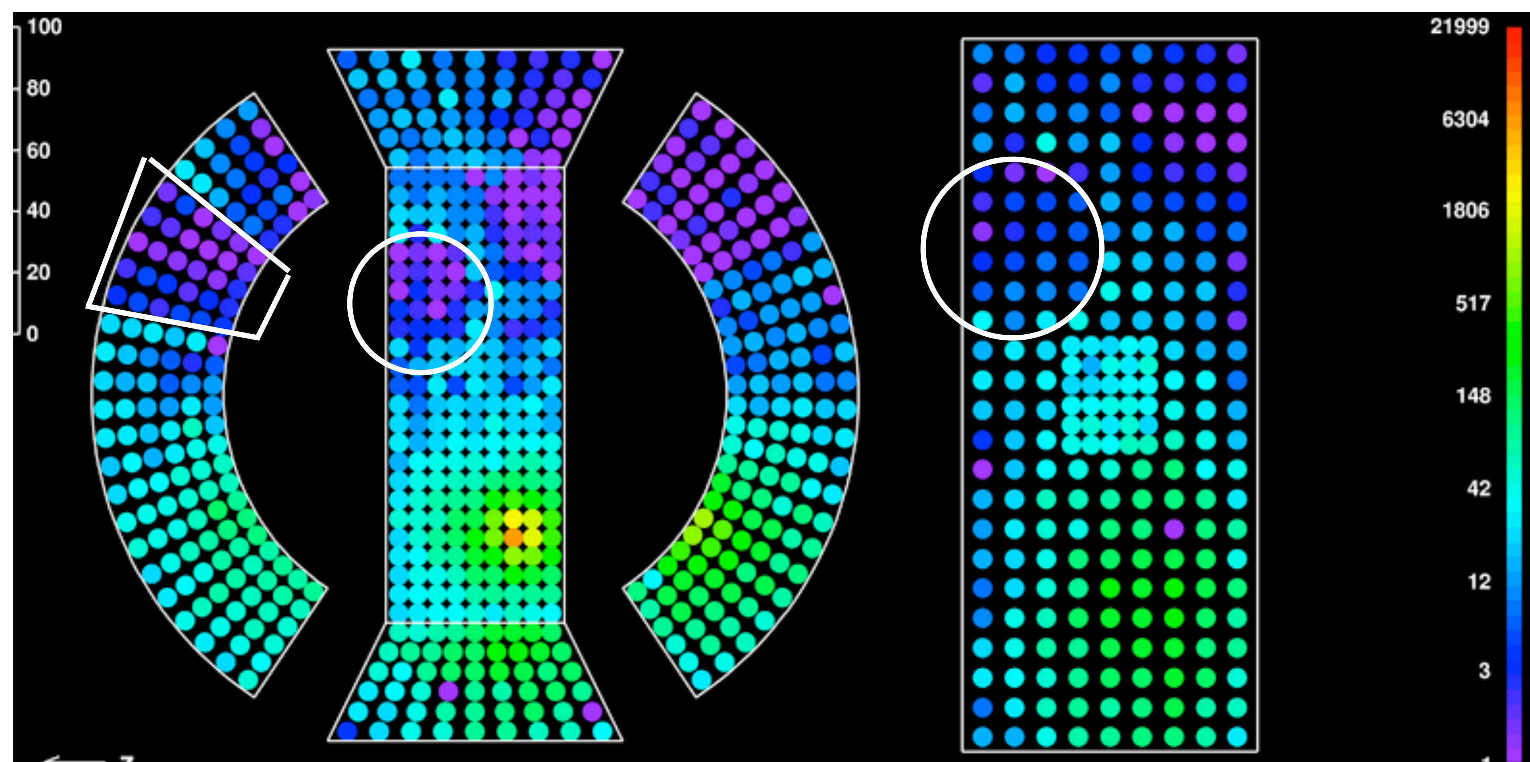
Original



Pileup-elimination algorithm can subtract a part of energy (i.e. not all)from pileup

PMTs in white circles and a trapezoid are replaced.

After replacement

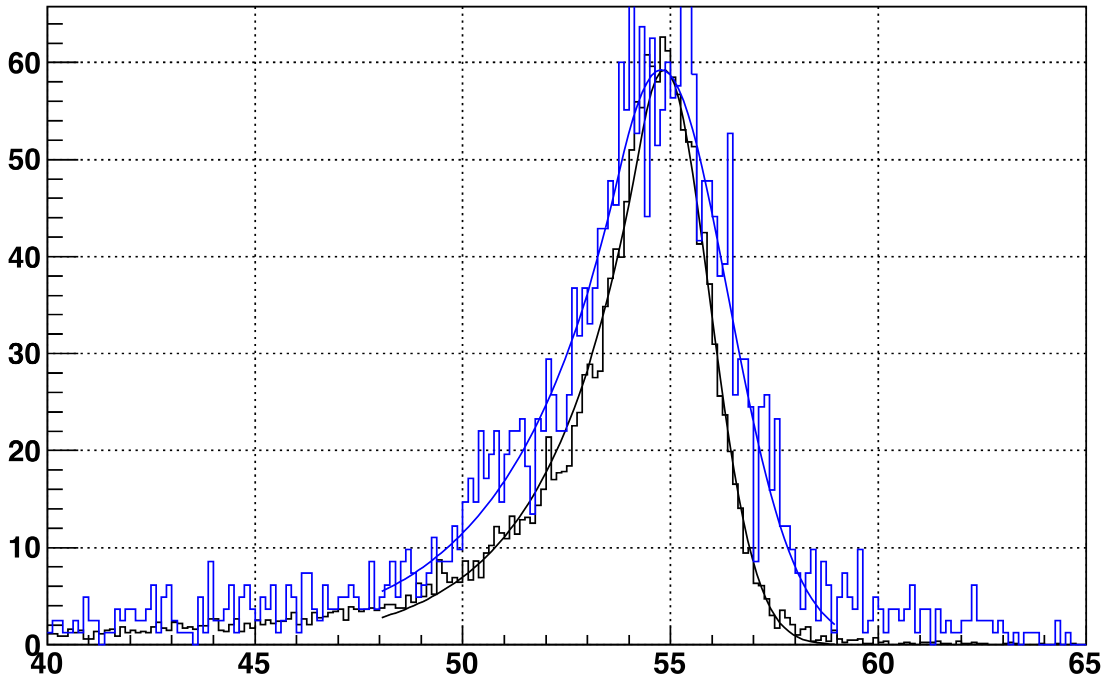


A correction of subtraction is needed

correction factor=2.5 is reasonable from calibration data

A check by using 55MeV calibration gamma

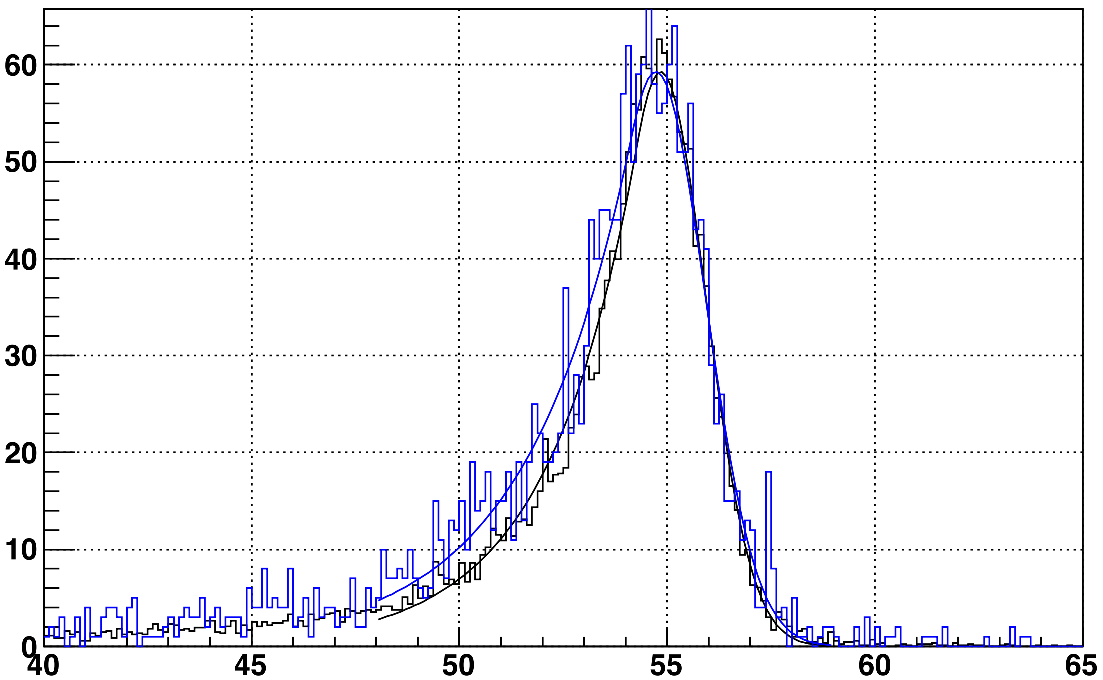
Before elimination



[MeV]

Black : Pileup all rejected
Blue : Only pileup events

After elimination



[MeV]

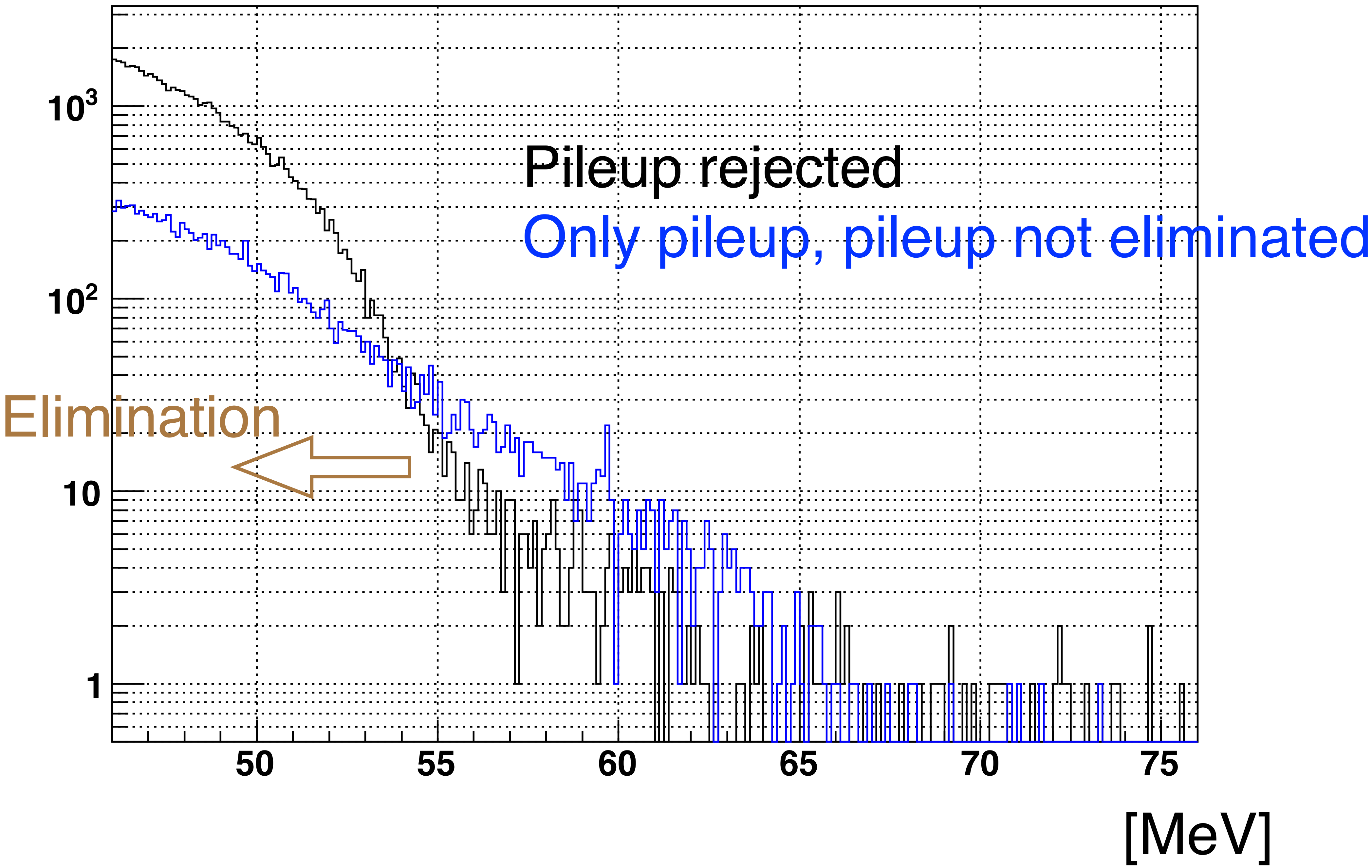
Black : Pileup all rejected
Blue : Only pileup events,
with enhanced pileup elimination

Resolution becomes almost same

Vertical scale is arbitrary. Background condition during calibration run is much different from physics runs.

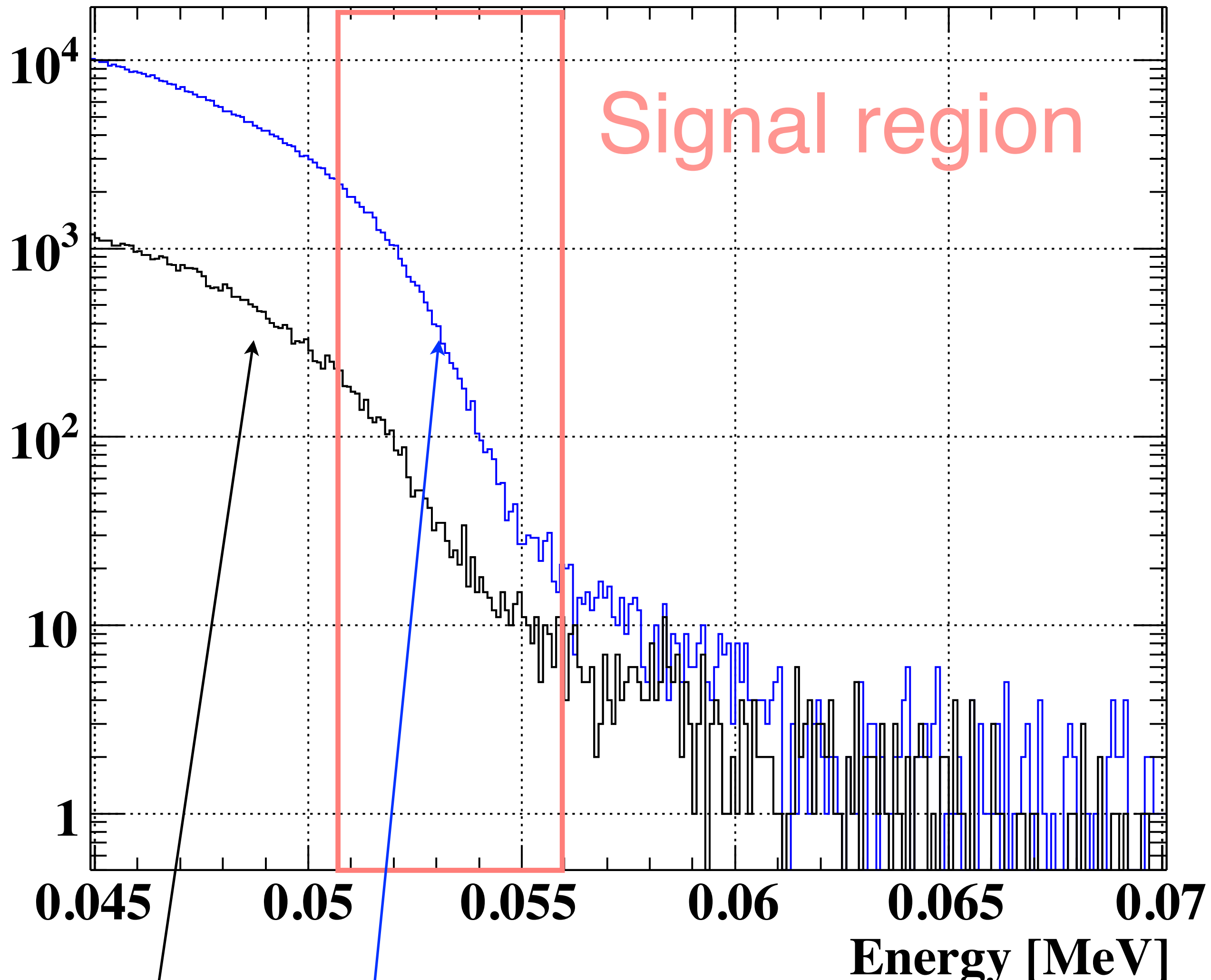
Gamma spectrum in physics runs

Before elimination



Check of the Gamma spectrum in physics runs

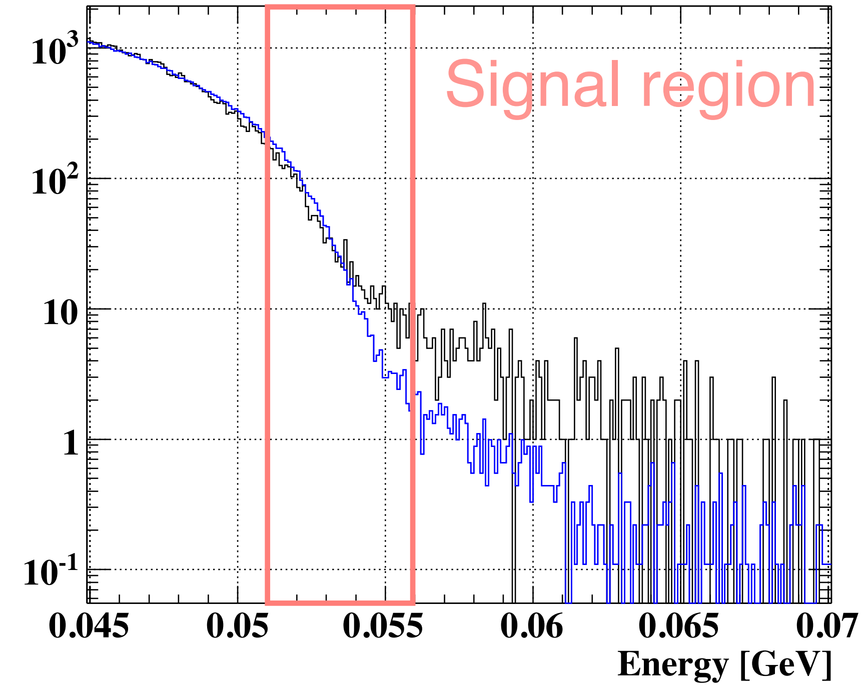
After elimination



All pileup rejected.

Only pileup events after elimination

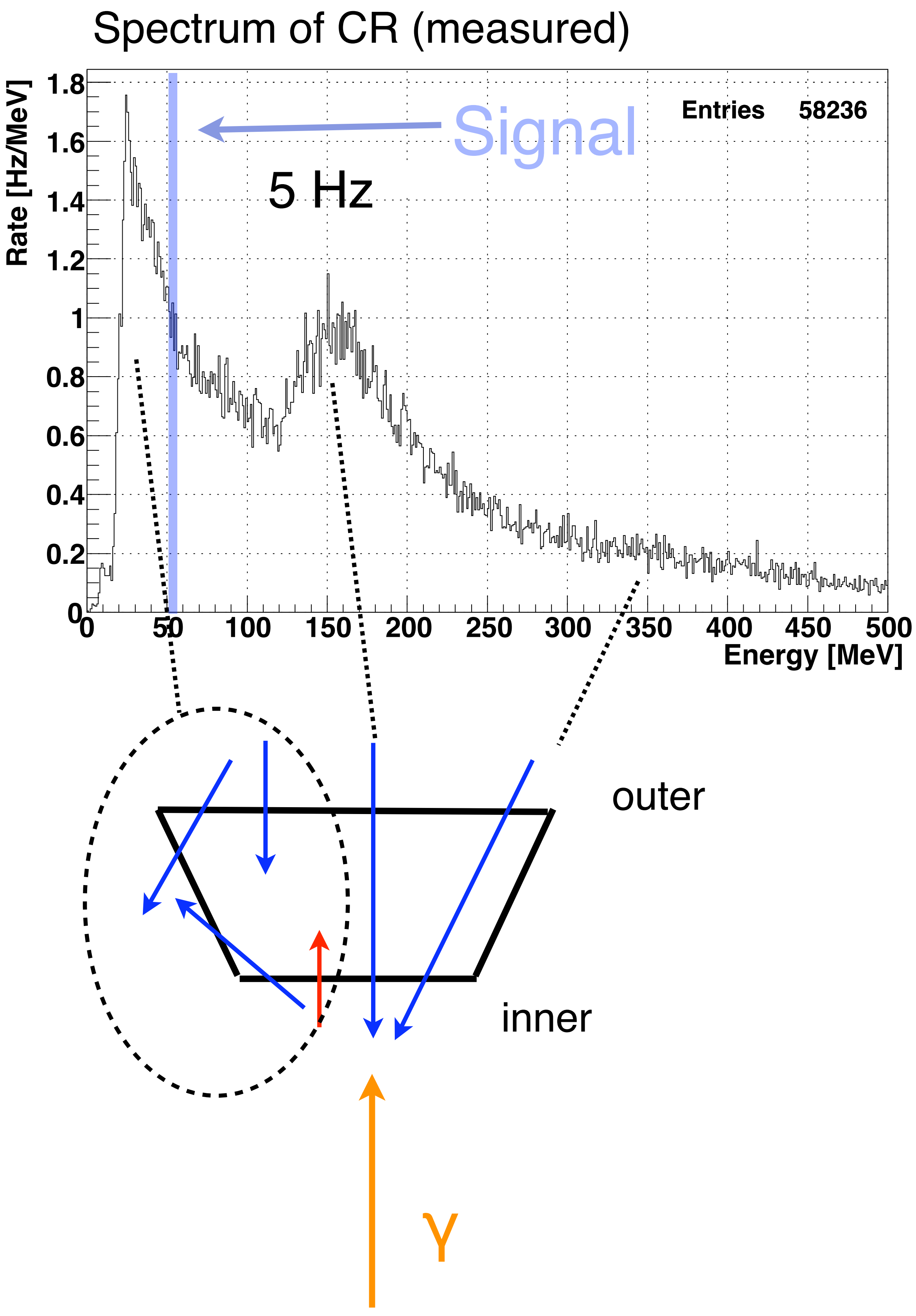
Blue one is scaled for comparison



Almost same shape in pileup and non-pileup events.
Still investigations are needed for higher tail.

Cosmic ray

Cosmic ray



Most of CR peak at 160 MeV and higher tail (Landau)
→ Not background

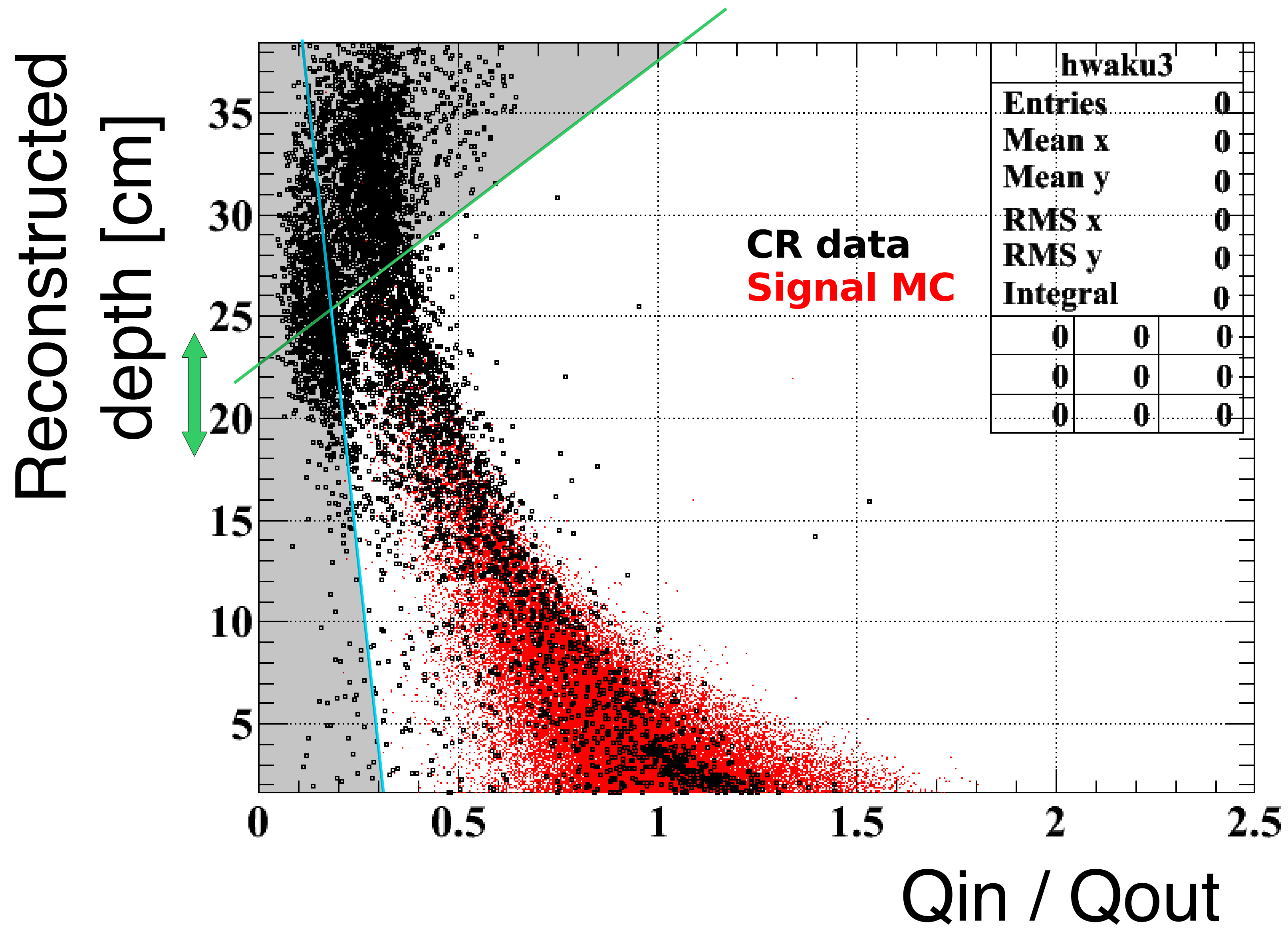
Low energy part around signal
- Mostly reconstructed around edge.
  →Outside of acceptance
  Automatically rejected.

- CR enter from outer face and stop in LXe volume can be identified by unusual light distribution.
  Identification needed.

- CR (or secondary particle) enter from inner face and stop in LXe can be accidental background

Cosmic ray rejection

Rejection of particles enter from outer face



99% efficiency for signal

56 % rejection in the signal energy range

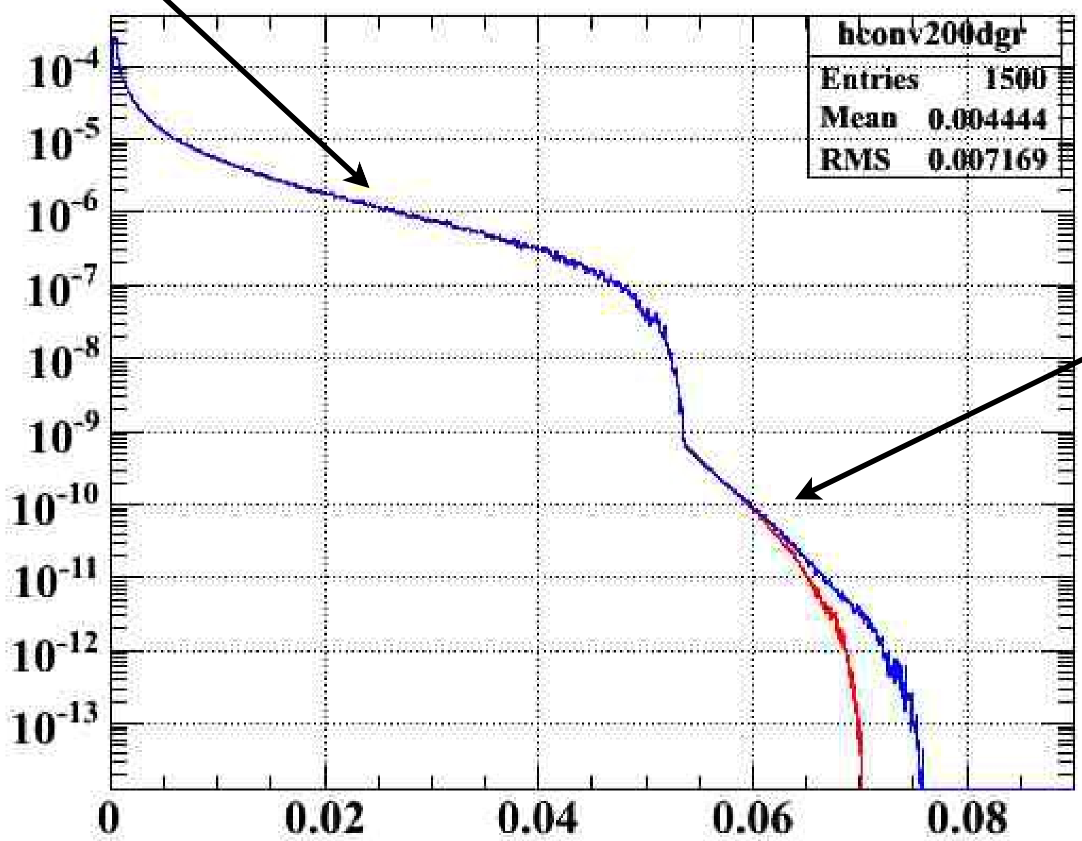
Background components

Fitting gamma data with
background components models

Model of background gamma components

1. Single gamma (AIF+RD)

MC x detector response



AIF : positron annihilation in flight

RD : muon radiative decay

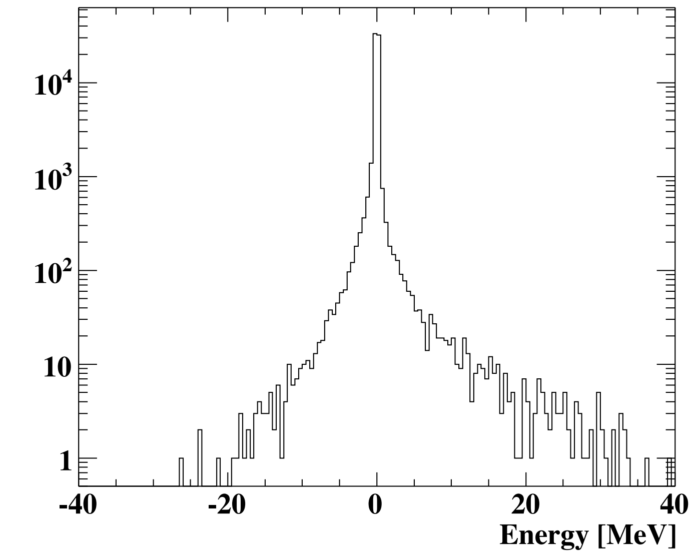
Different pileup due to beam tuning (red and blue)

Figure is before convoluting detector response

2. Pileup

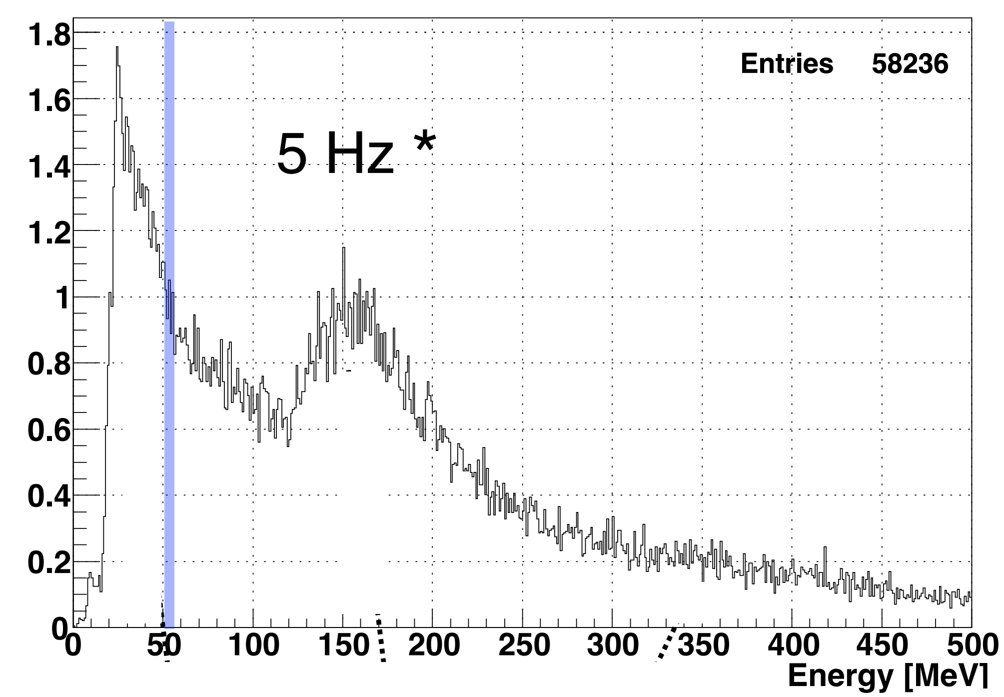
Random trigger data

energy is scaled to represent pileup elimination



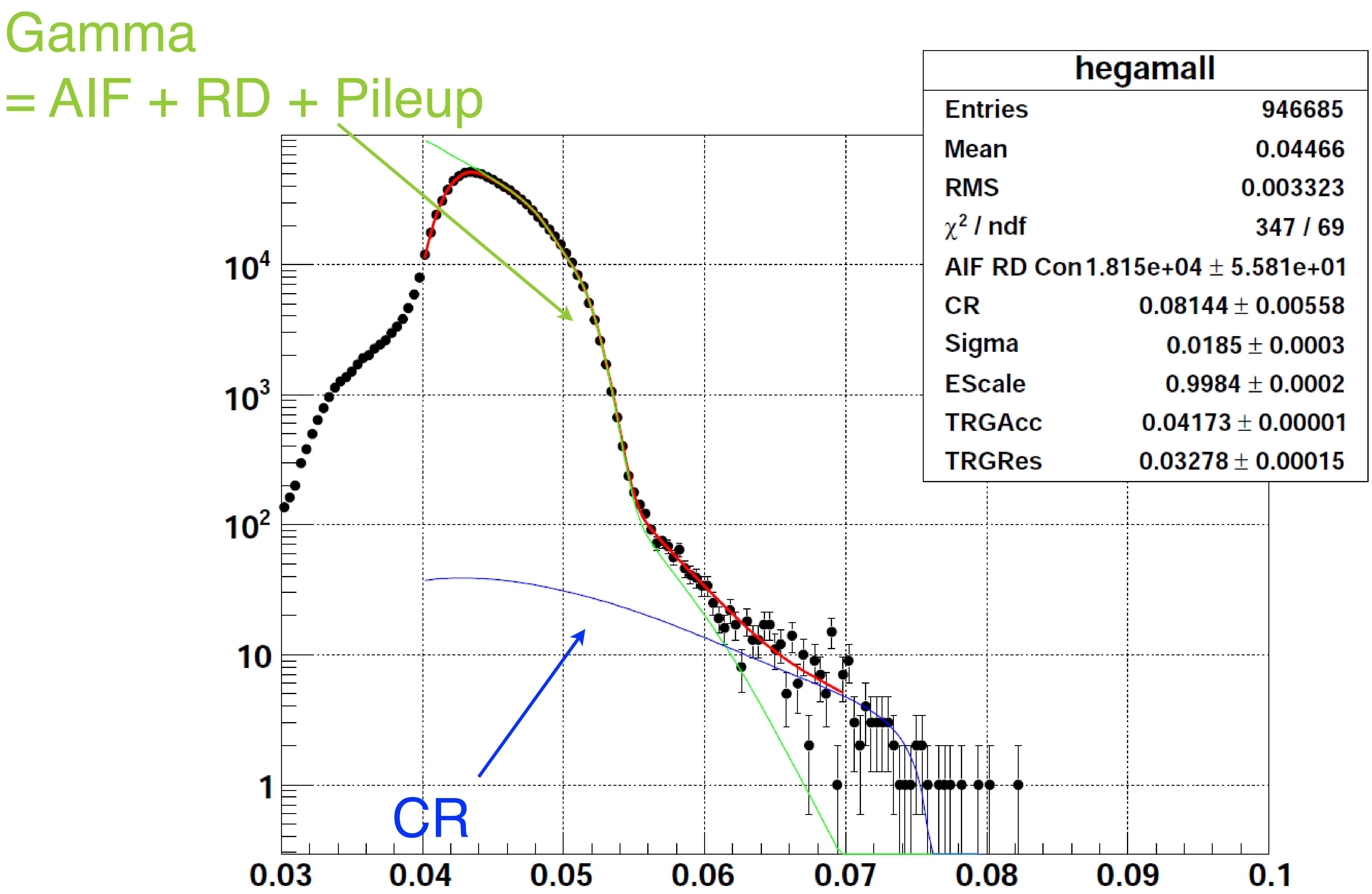
3. Cosmic ray

Spectrum of CR (measured)



Trigger veto for high energy is taken into account.

Fit to data

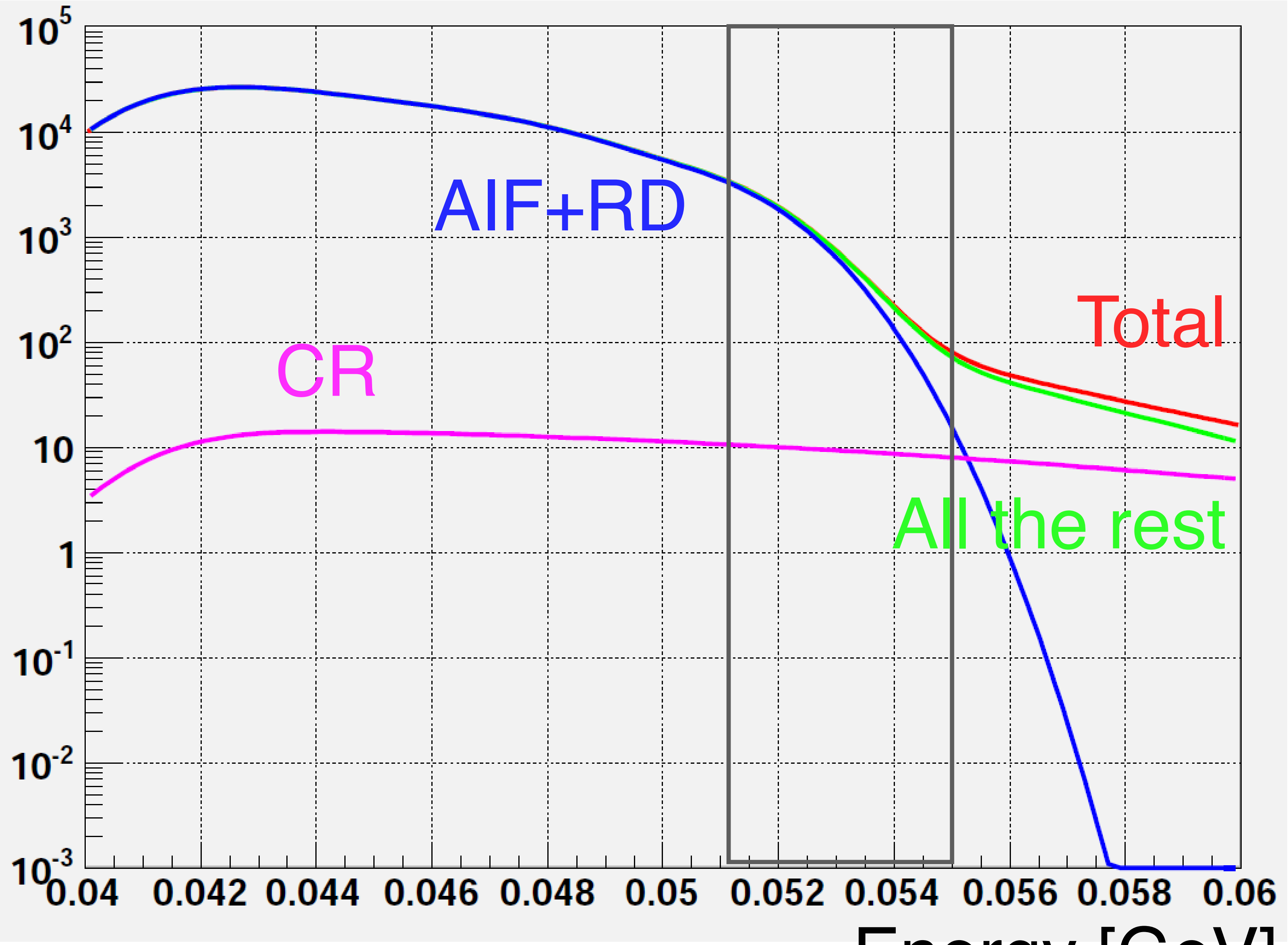


(This fitting is done for much wider region than physics analysis)

Background components

RD+AIF (Single gamma)	93%
Cosmic ray	1%
All the rest	6%

Signal region



Energy [GeV]

All the rest : pileup or reconstruction tail

Summary

- Gamma background of MEG
  - Main background source is single gamma from RD or AIF
    - Improvement of resolution must decrease background
      - 13pSM (白雪) : 液体キセノン検出器の性能
  - Cosmic ray
    - Negligible after a simple geometrical rejection
  - Pileup
    - Identification by space, and time methods
    - Analysis to eliminate pileup gamma energy was developed
      - We can use also pileup events for physics analysis *
    - Fraction would become larger when we increase beam rate.

* Large (>13MeV) and negative pileup events are discarded

Back up

Estimation of energy

Excellent resolution is not required, since replaced PMTs are not so many(<100) typically.

Fitting PMTs except around pileup,

$$
\begin{aligned}
E_i &= C(u, v, w, i) \times N_i \times l_i^2 \\
\sigma_i &= E_i/\sqrt{n_i}
\end{aligned}
$$

C : Conversion factor

N : Number of photons

l : distance from conversion point to PMT center

n : number of electrons

C is extracted from CW data for 36×96×24×846, stored in a BIG table file.

u v w PMT 300 MB

In principle, everything (except time dependence) must be included. (i.e. depth or position dependence, scatter, error of PMT calibration...)

Expecting and replacing PMT output

Expectation can be done opposite way of energy fitting

$$N_i = E/C(u,v,w,i)/l_i^2$$

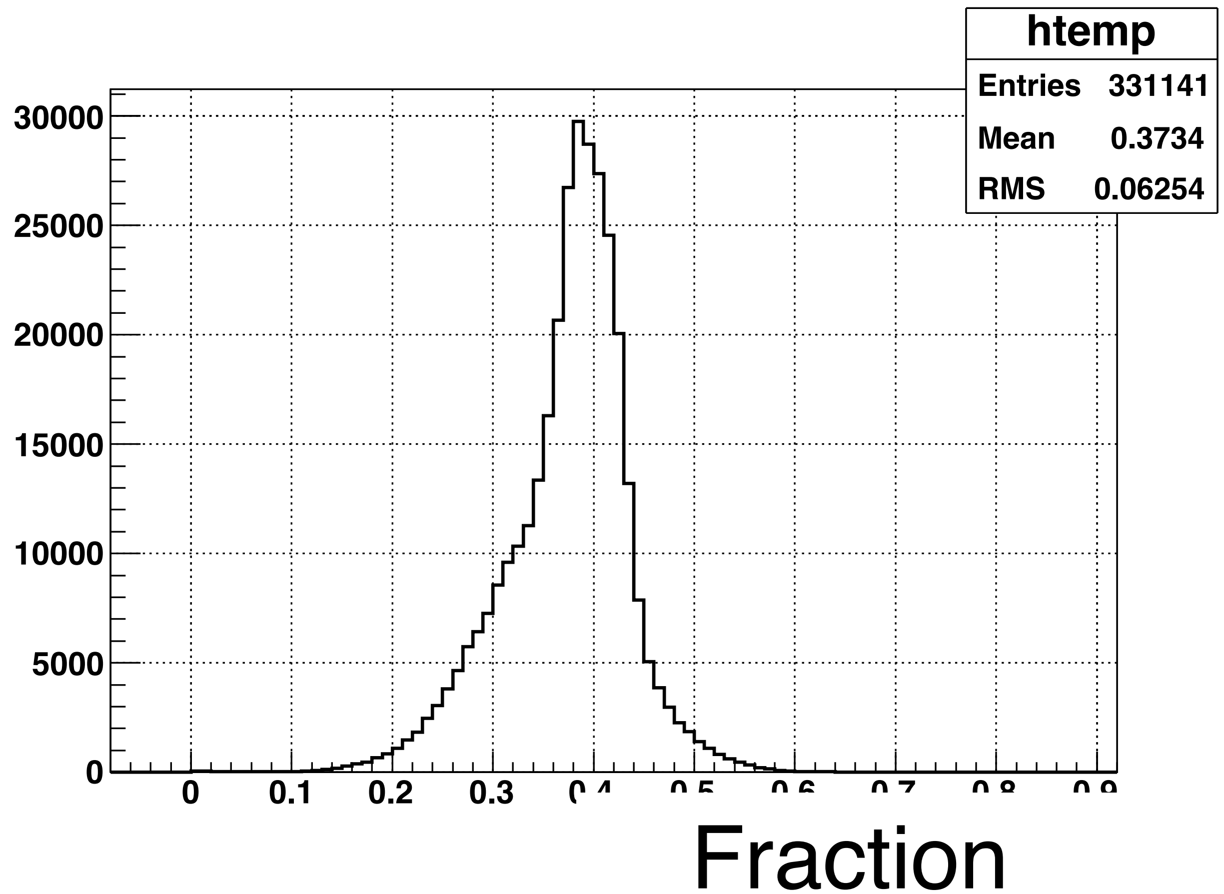
Currently, PMTs in a fixed distance(30 cm) from the pileup are replaced.
We could do some study to change it event-by-event.

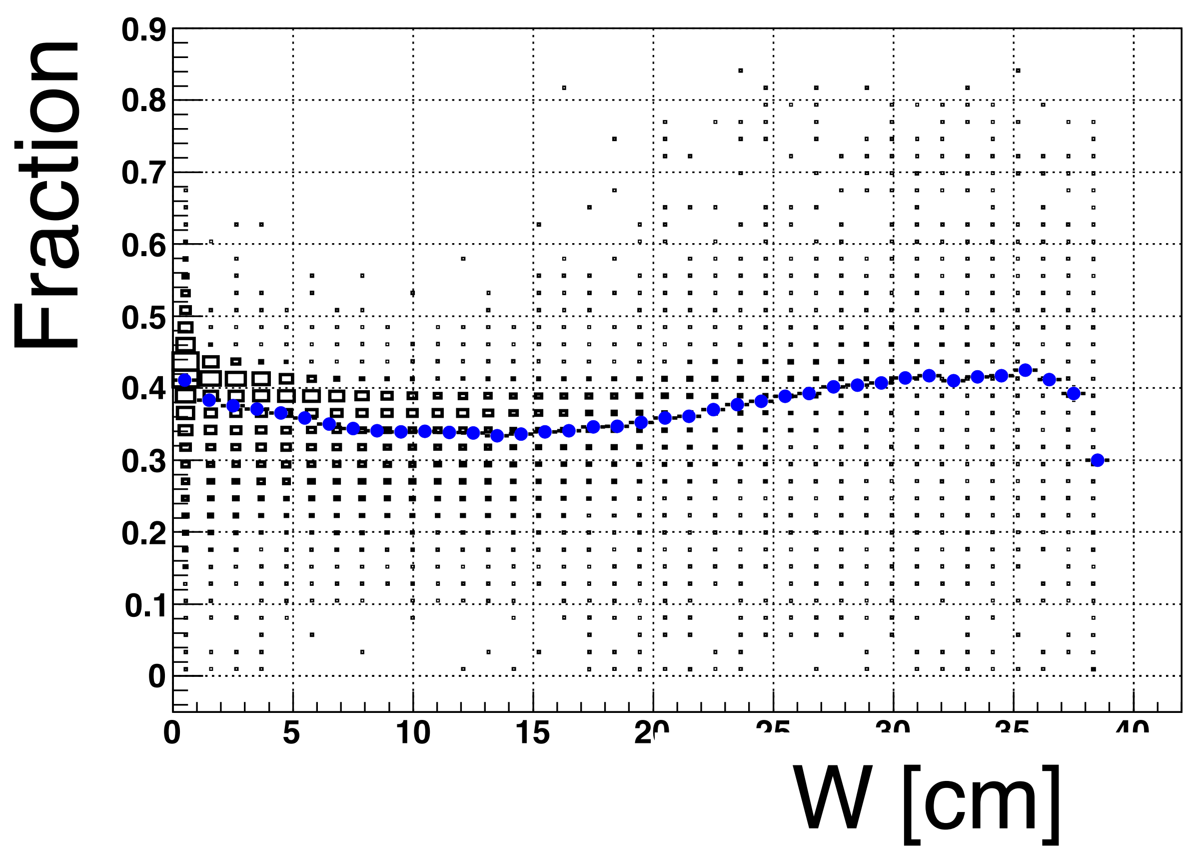
Including time information to eliminate pileup

- Up to now pileup-ID by time is used only to reject events
- In case of double-pileup, and if one of them is not identified by space, one of pileups is not eliminated but the event is used in analysis. => can make background
  - Probability is very small. $(P_{pileup} \times P_{not\_IDed})$^2
- Indices of rejected PMTs in time fitting, PMT time is far from gamma time than certain threshold, is written in result folder.
  - Modifications
    - These PMTs are not used in energy-fitting.
    - #photon of these PMTs are replaced by expectation from main gamma.

Fraction of eliminated energy

We can know the fraction from CW data.

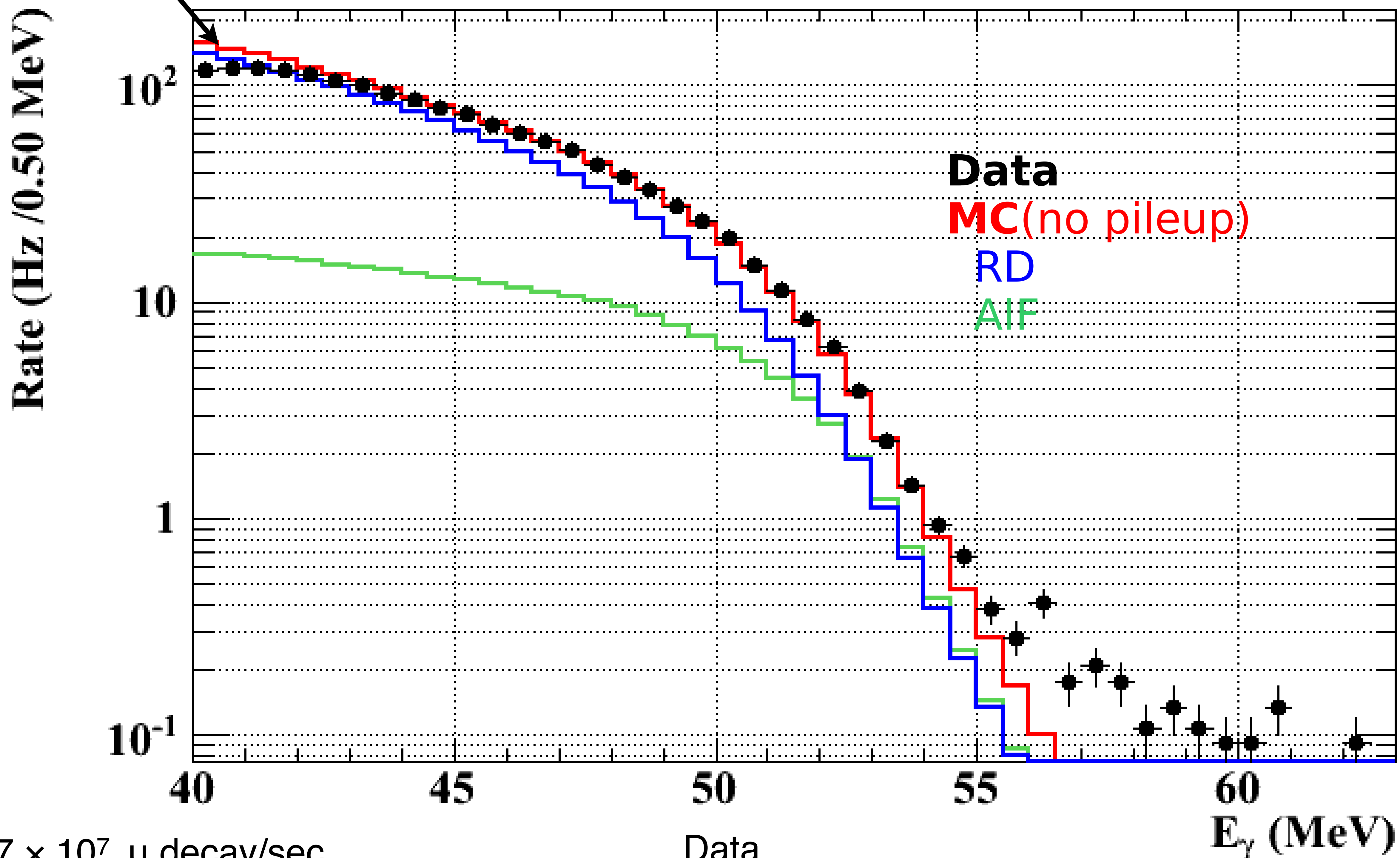




→ Enhancement by 2.5 is reasonable

Absolute background rate

Trigger threshold



MC

3.7×10^7 μ decay/sec

Detector response taken into account

No pileup

Uncertainty ~ 7%

Data

Self trigger data in 2008

Event selection and efficiency

- Event-selection
  - No selection on conversion depth
  - CR is rejected
  - Large (>13 MeV) and negative pileups events are rejected for safety.
  - Pileup event identified by time method, not by charge-distribution method are rejected. (Pileup elimination is not possible)
- Analysis efficiency is calculated from event-count “before” and “after” the cuts and corrected to signal efficiency known from MC

In 2009 run

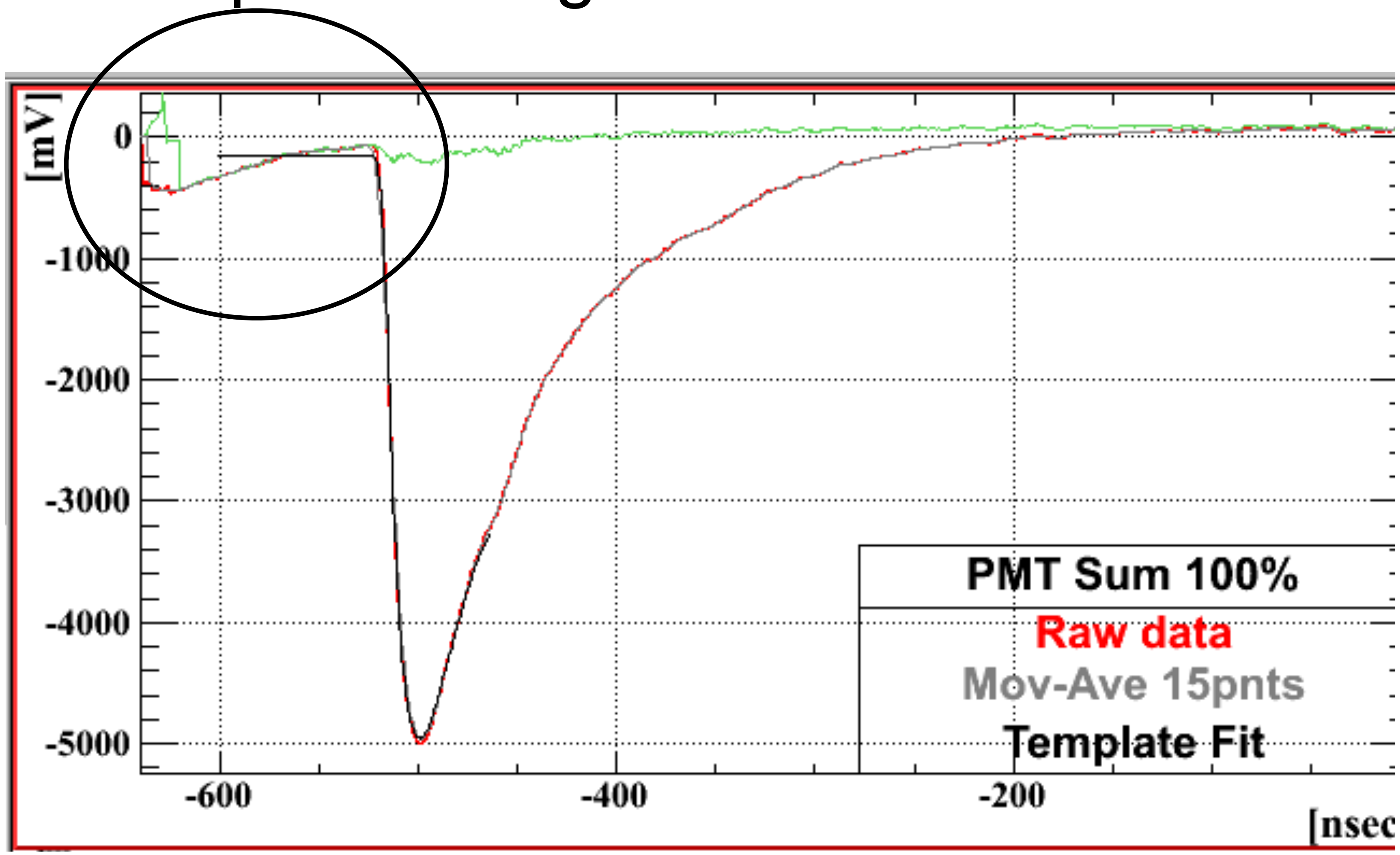
$$\boxed{0.58 = \underbrace{0.65}_{\text{detection}} * \underbrace{0.89}_{\text{analysis}}}$$

PRELIMINARY

Experiment requirement is 0.6 %

ID by sum waveform shape

Chi-square of template-fitting to sum-waveform



BG rejection ~ 1-2 % after applying other methods
Signal inefficiency < 1%

Because other methods, shown previous slides, work enough, this method is not used so far.