MEG II実験：液体キセノン検出器の物理ラン開始に向けたコミッショニング(3)

家城 佳 for MEG II collaboration

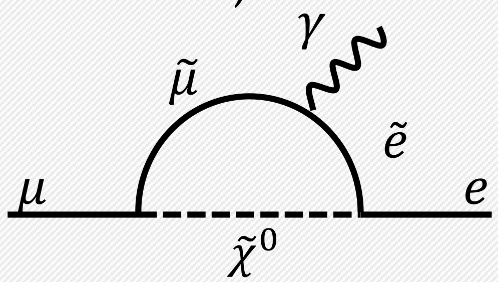
東大素セ

Core-to-Core Program

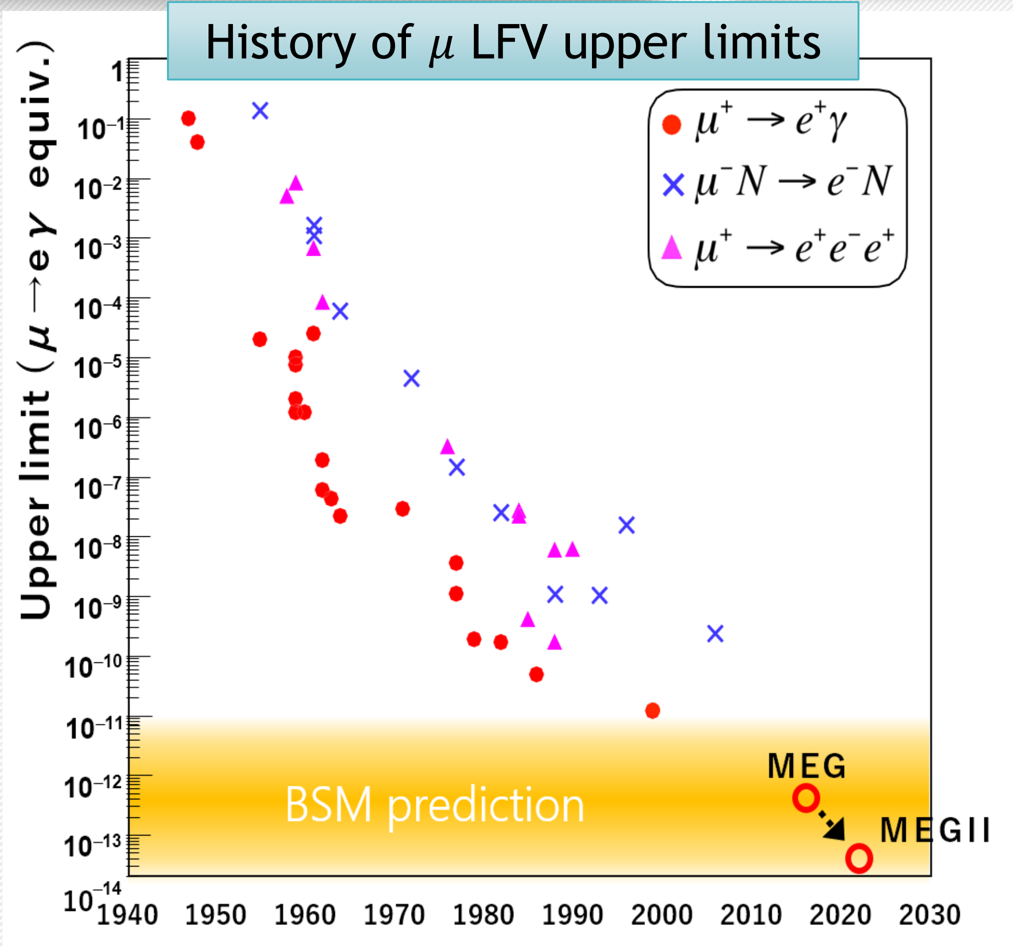
$\mu \to e\gamma$ decay

MEG II experiment searches for cLFV decay, $\mu \to e\gamma$.

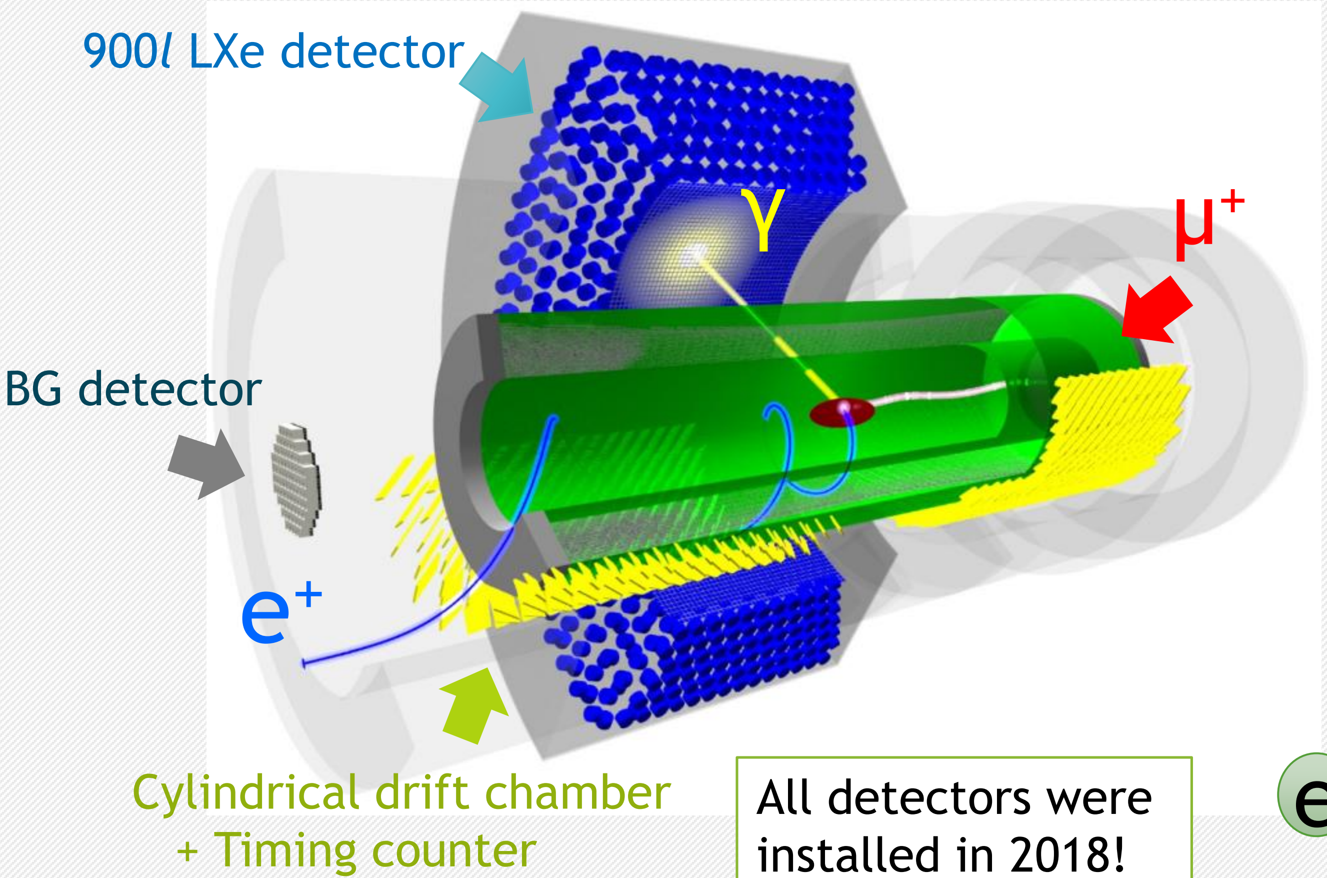
- Sensitivity goal: 6×10^{-14}
  (10 times better than MEG)
- BSM prediction : $O(10^{-14})$
  (e.g. SUSY-seesaw)



If $\mu \to e\gamma$ is found → Discovery new physics!



MEG II experiment

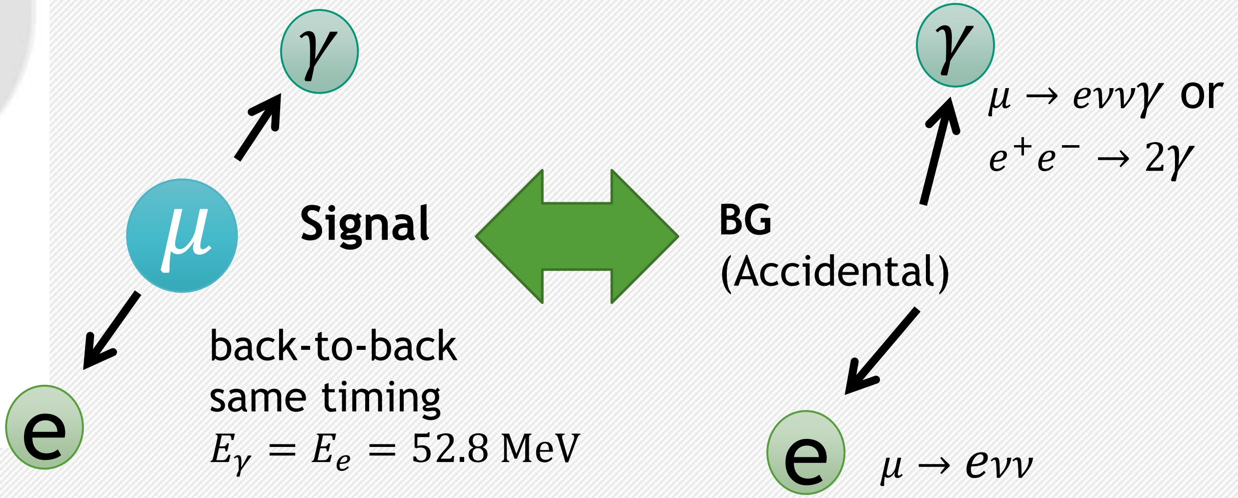


All detectors were installed in 2018!

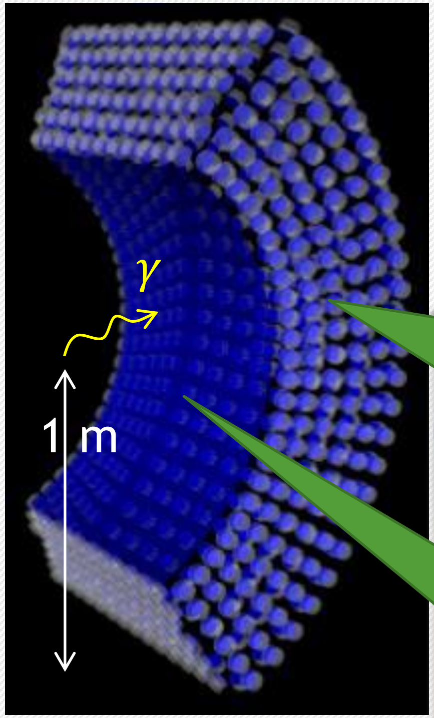
(w/ partial readout electronics)

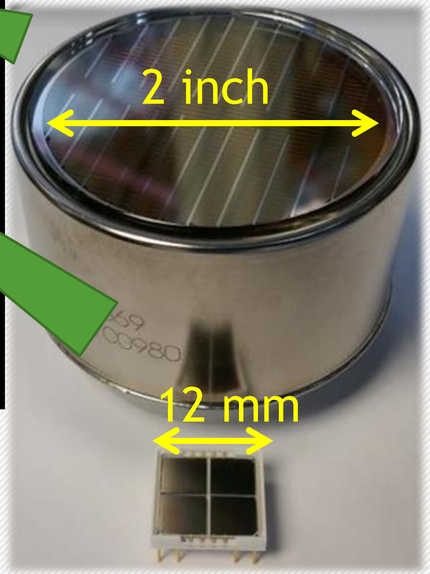
Key concepts:

- **High rate** continuous μ^+ beam at PSI $(7 \times 10^7 \mu/\mathrm{sec})$
- **High resolution** detectors to distinguish $\mu \to e\gamma$ from accidental BG



LXe γ detector

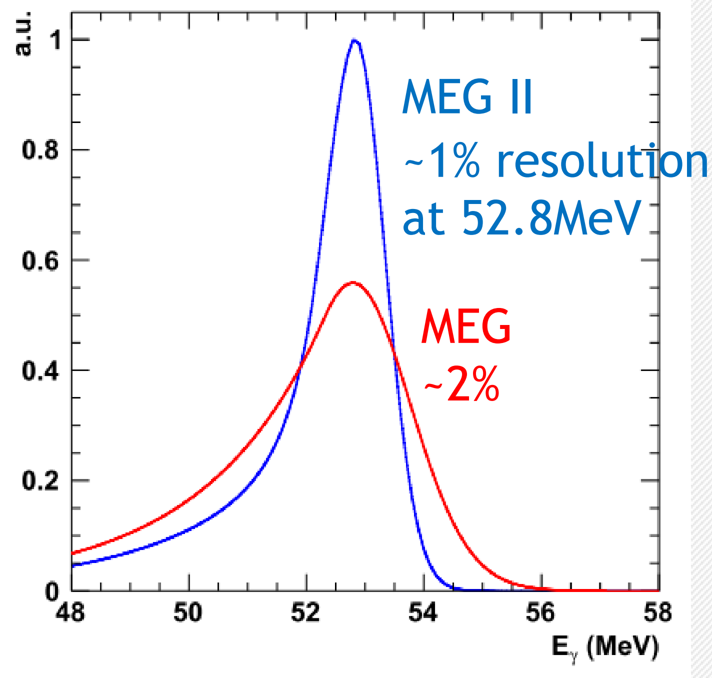




900L liquid Xe (LXe) scintillator
to detect energy, position and timing of γ

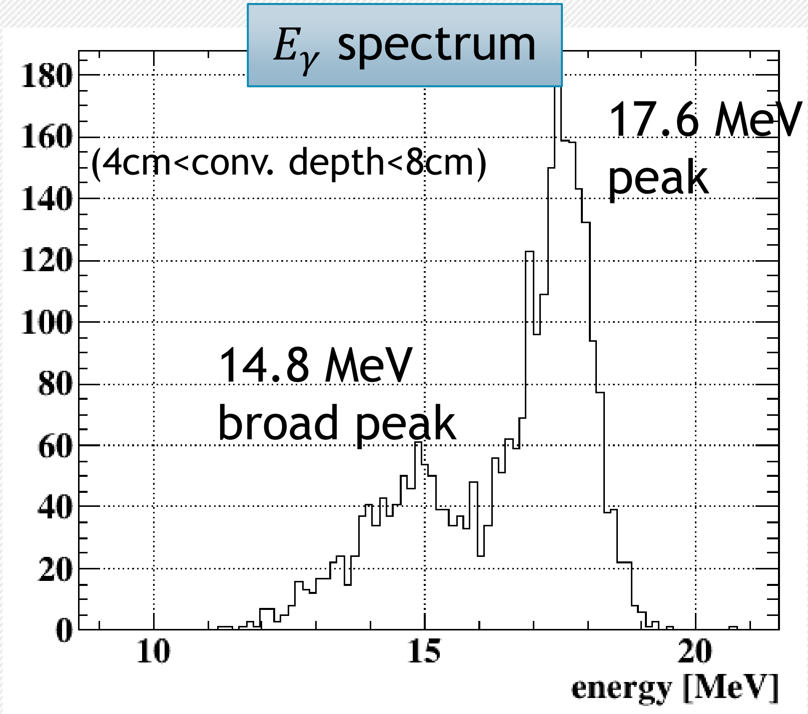
In MEG II, γ entrance face is replaced from
- 216 PMTs (2 inches)
- to 4092 MPPCs (12x12 mm^2)

Light collection uniformity and granularity improved!
→ x2 energy and position resolution improvement expected



Commissioning with 17.6 MeV γ

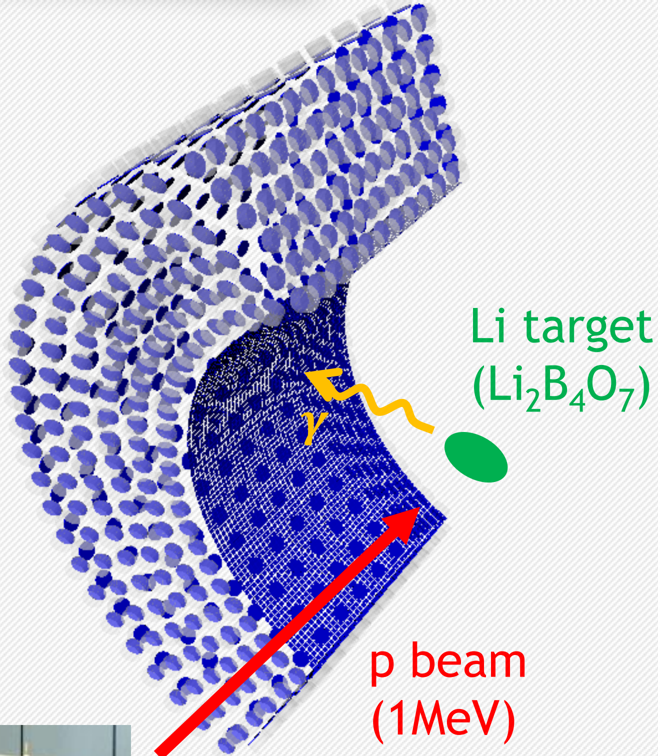
Monochromatic 17.6 MeV γ from ${}^{7}_{3}\mathrm{Li}(p,\gamma){}^{8}_{4}\mathrm{Be}$ is used for commissioning.

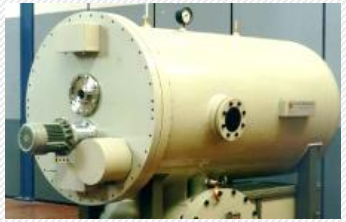


Energy resolution at 17.6 MeV:
$\sim 3\%$ (Data) $\Leftrightarrow$ $\sim 1\%$ (MC)

Resolution depends on statistical fluctuation of N_{pho}, EM shower shape etc.
Why Data disagree with MC?

→
- Problem in Data?
- MC is too good?





CW accelerator

Problem in Data?
MC is too good?

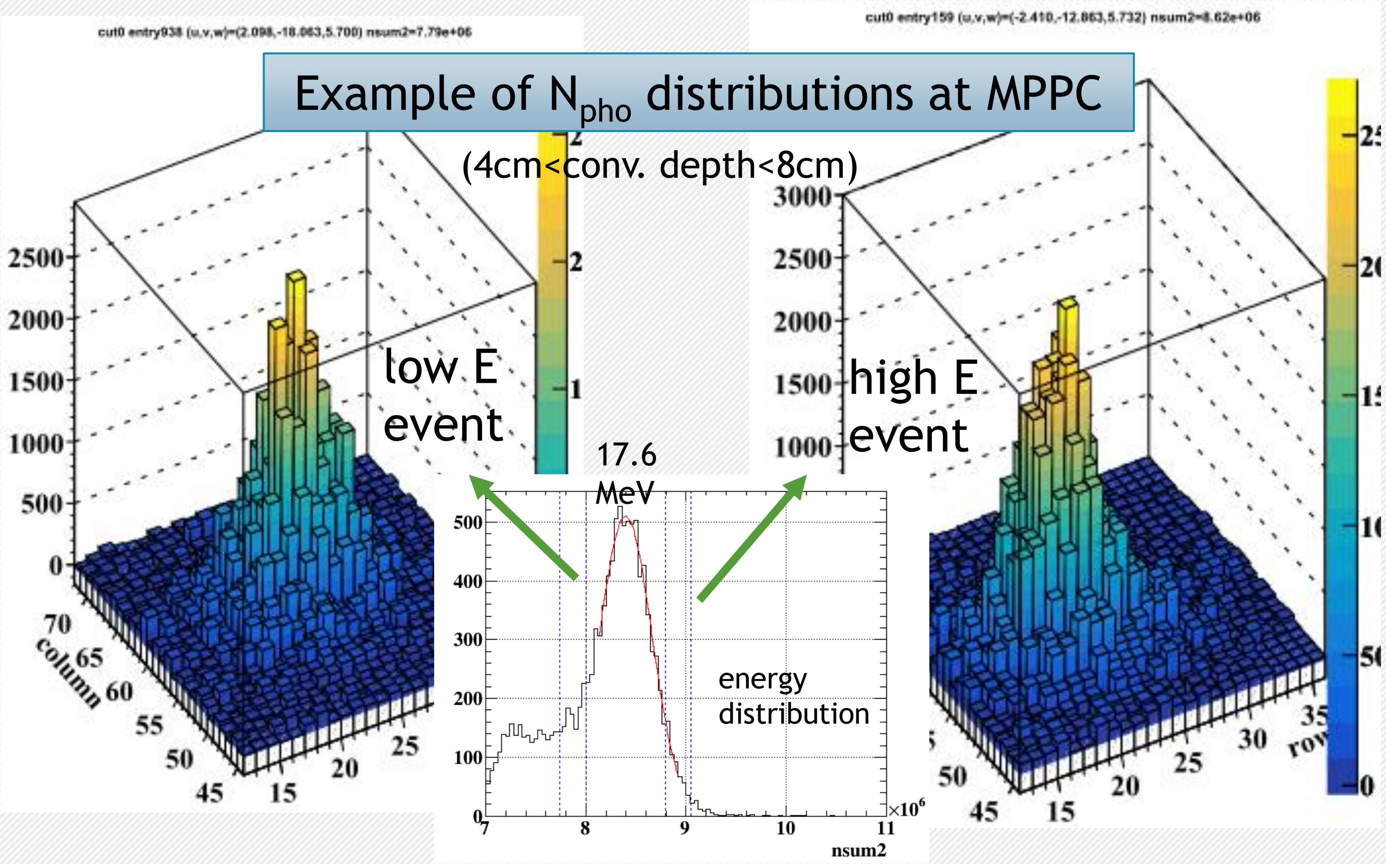
6

Example of events

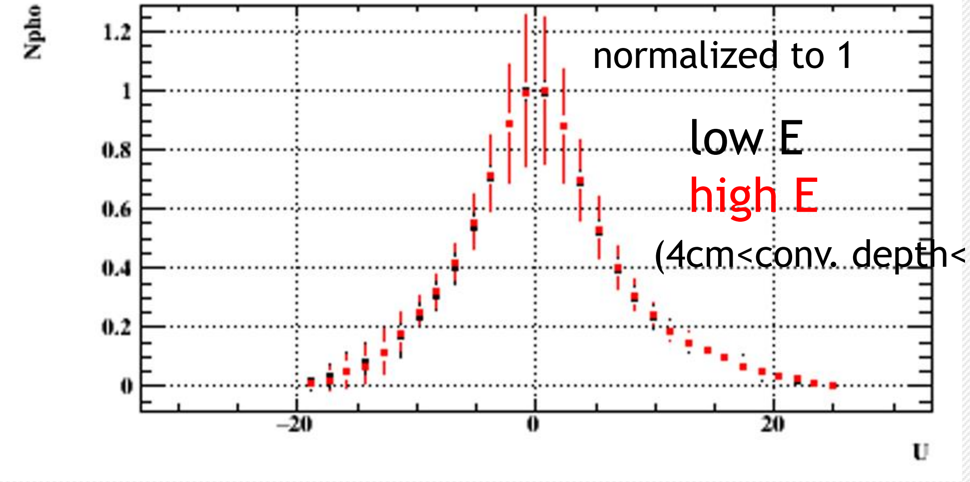
Distribution of N_{pho} is compared between high energy event and low energy events.

Example of N_{pho} distributions at MPPC

(4cm<conv. depth<8cm)



Averaged distribution of N_{pho} (MPPC, projected to 1D)



No specific difference can be seen.

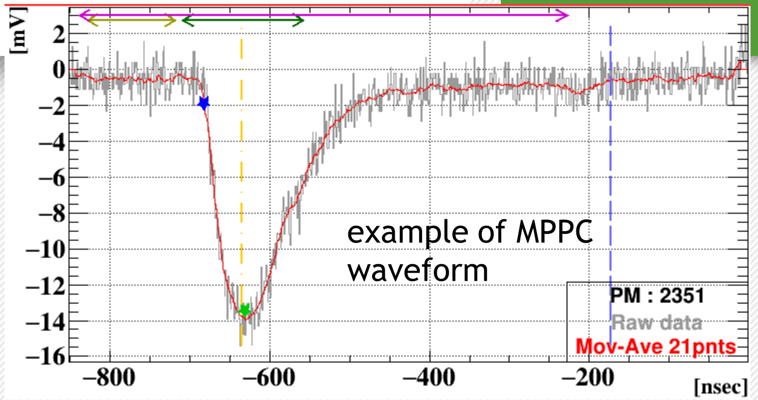
Energy reconstruction procedure

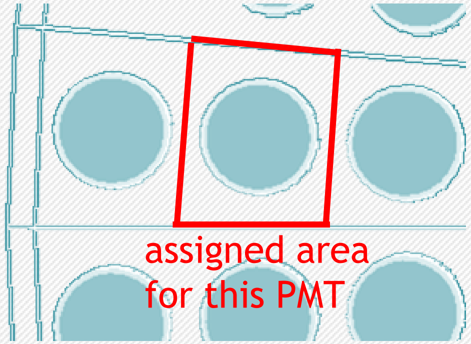
1. Charge integration of each channel
2. Charge → N_{photon} conversion with calibration constants
3. Calculate sum of N_{photon}

$$N_{\mathrm{sum}} = \sum N^{i}_{photon} \cdot C_i$$

4. Convert to energy

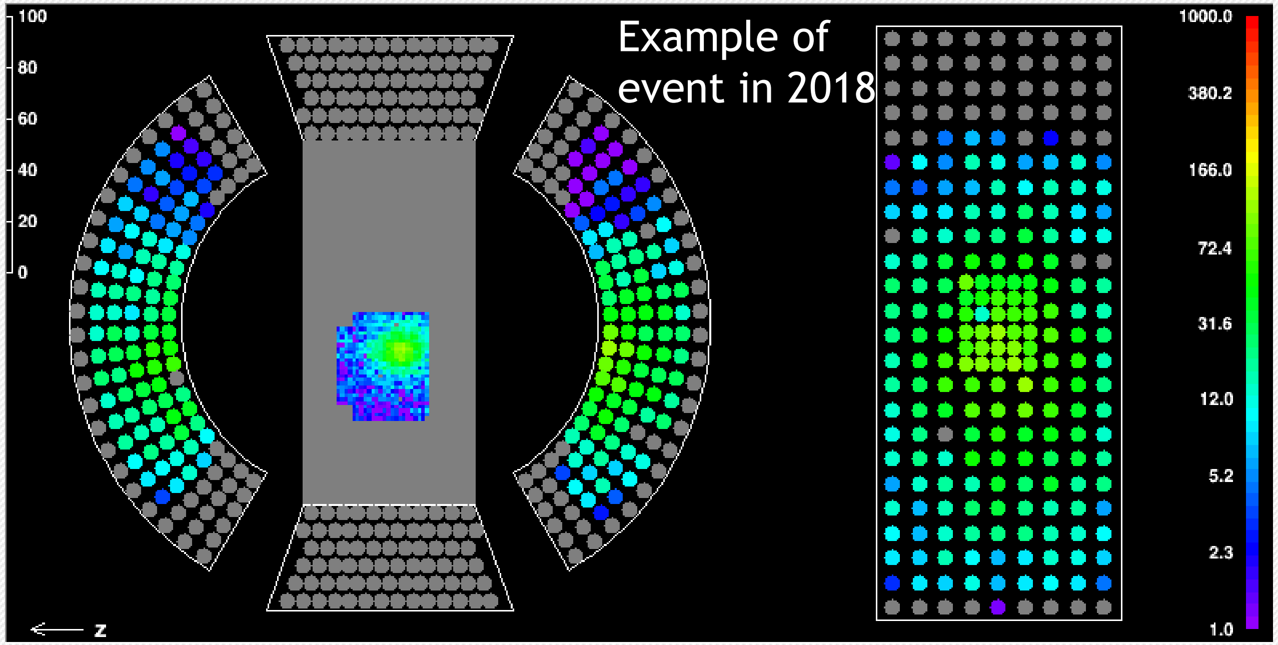
$$E = C \times N_{sum} \text{ (× position dependent correction)}$$





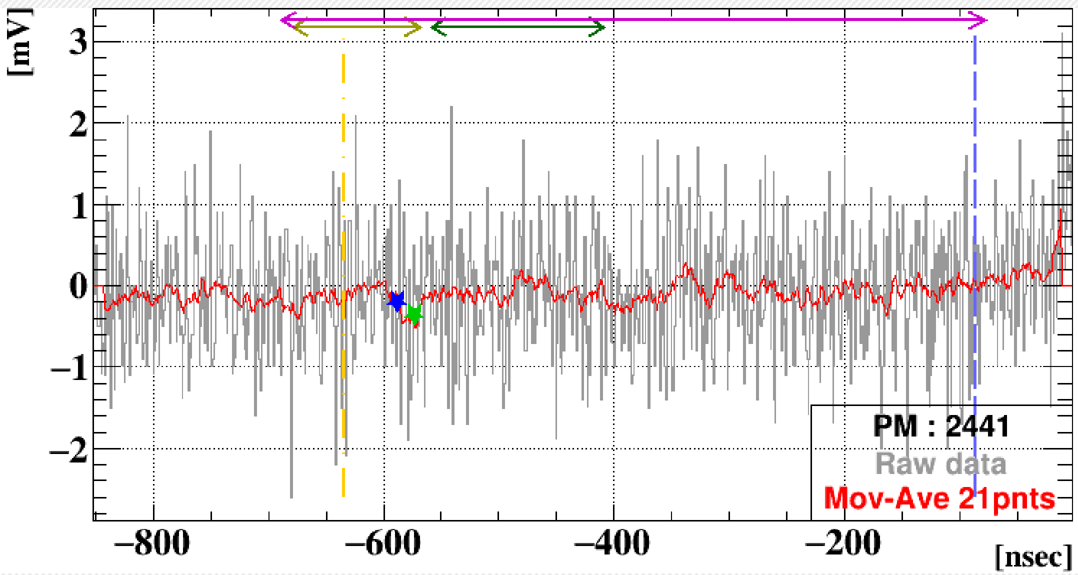
C_i is a coverage factor

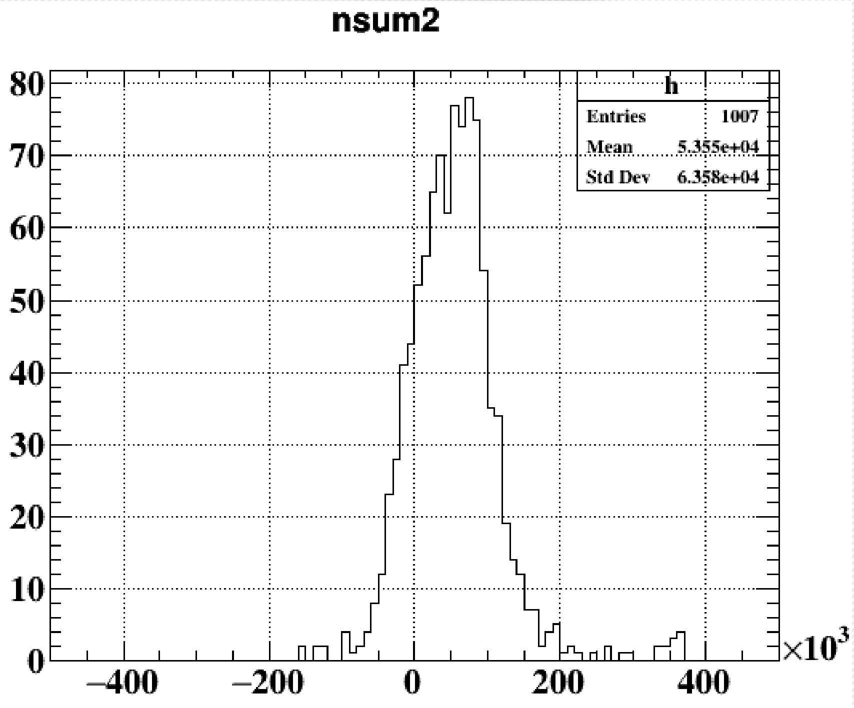
$$C_i = \frac{assigned\ area}{sensor\ area}$$



Possible reasons of bad E resolution:
noise, calibration …

Noise?





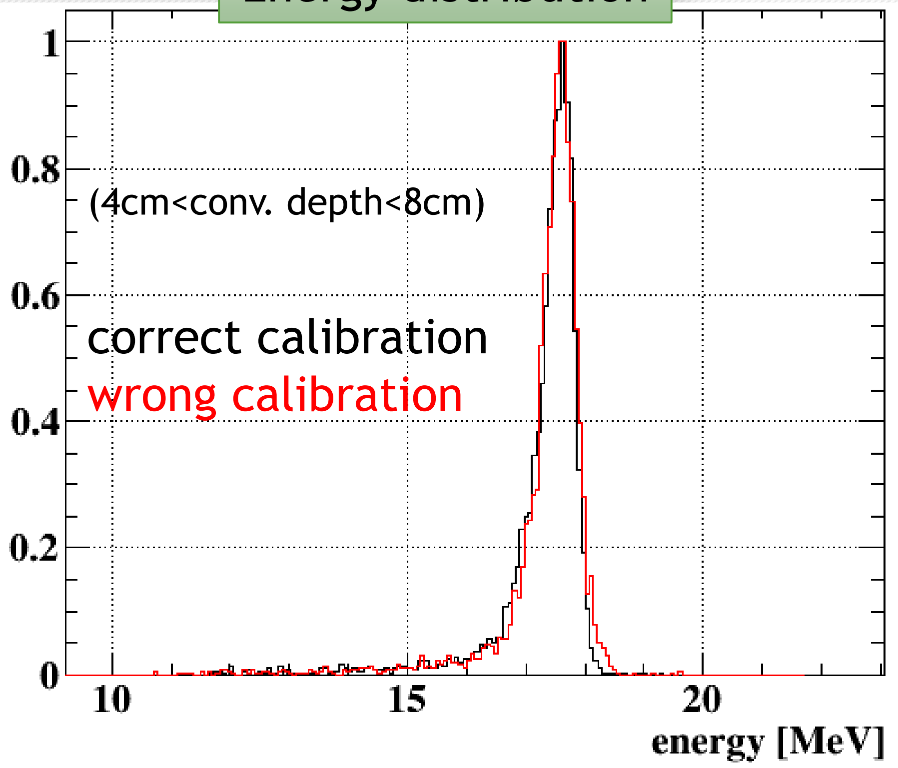
Effect of coherent noise can be measured in random trigger data.
→ Fluctuation is 0.6% of 17.6 MeV. Much smaller than 3%.

Calibration?

- How much does resolution change if we make mistake in calibration?

We compared two cases in MC
Correct calibration:
  Use same calibration constants for all channels
Wrong calibration:
  Apply calibration constants obtained in Data

Energy distribution

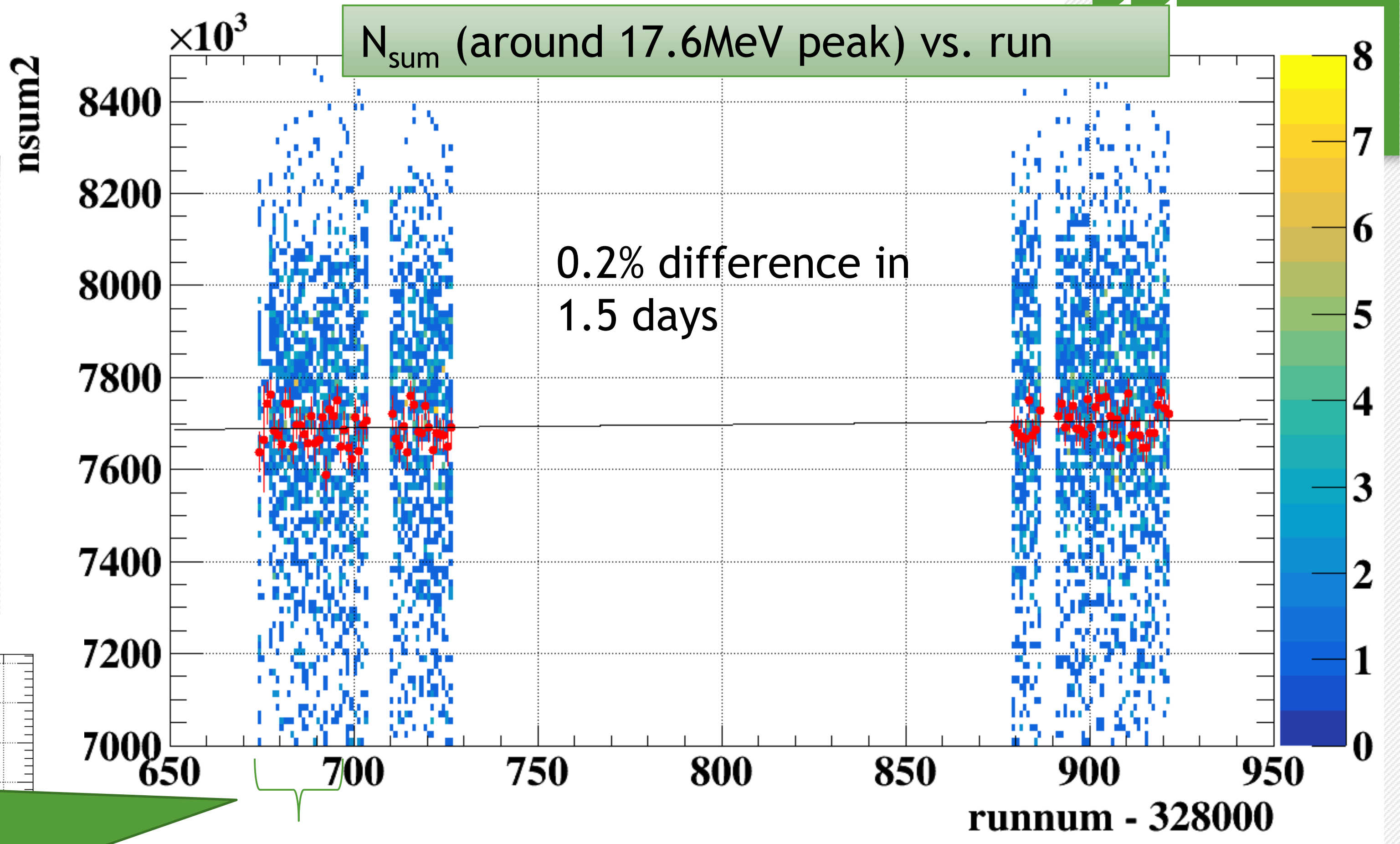


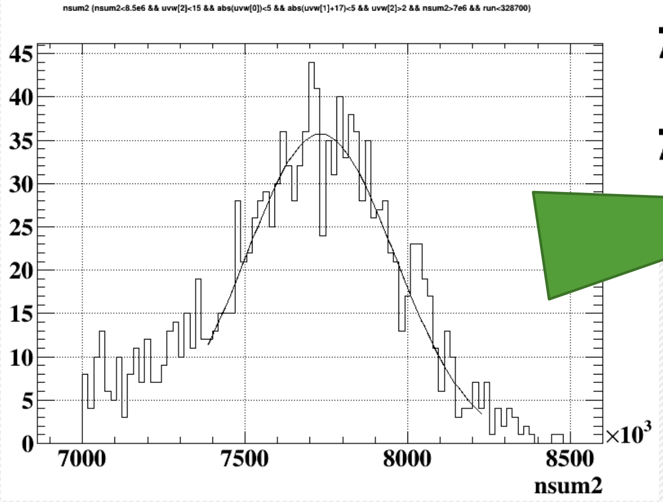
Resolution become worse (1.2→1.3%) with (completely) wrong calibration, but it is not big enough to explain data (3%).

Stability?

Instability of gain, PDE might explain bad resolution.

Time dependence is found to be too small to explain bad resolution.





3% resolution
2.5 hrs data

Fluctuation of sensor response?

There might be a event-by-event fluctuation in response of MPPC or PMTs (crosstalk + afterpulsing probability etc.)

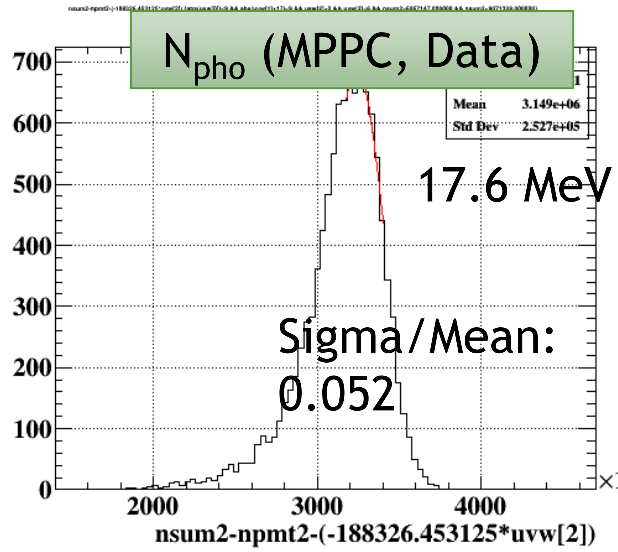
To distinguish such effect from fluctuation of sum of N_{pho}, even-odd resolution is calculated like this:

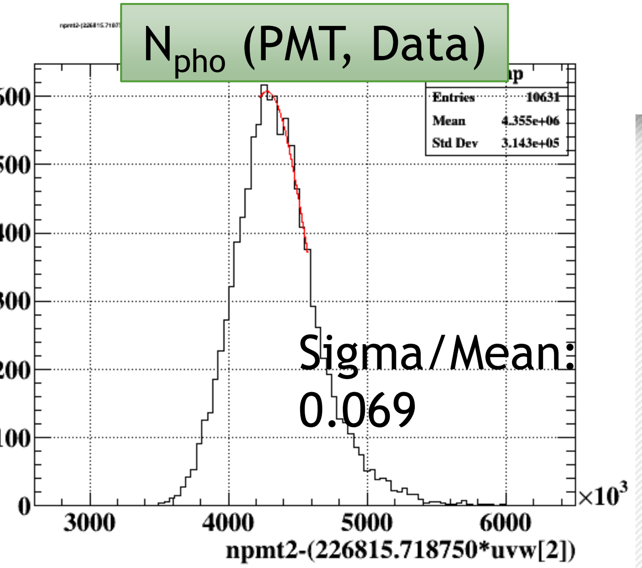
$$\Delta E_{even\_odd} = \Delta\left(\frac{E_\gamma(\mathrm{even}) - E_\gamma(\mathrm{odd})}{E_\gamma(\mathrm{even}) + E_\gamma(\mathrm{odd})}\right)$$

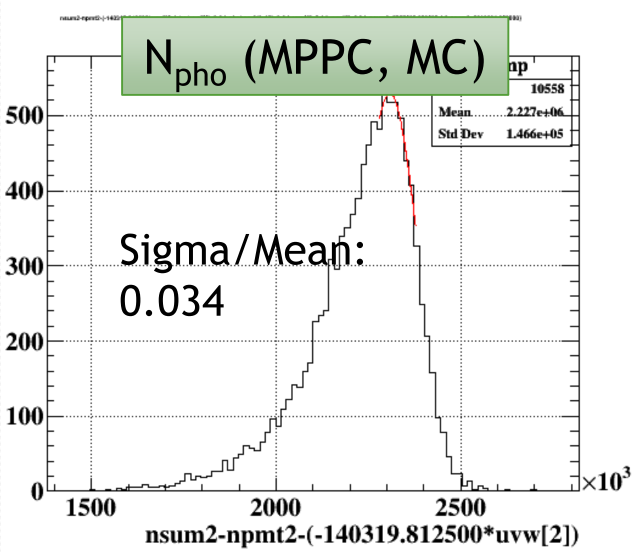
	Even-odd resolution
MPPC Data	1.36%
MPPC MC	1.08%
PMT Data	1.00%
PMT MC	0.92%

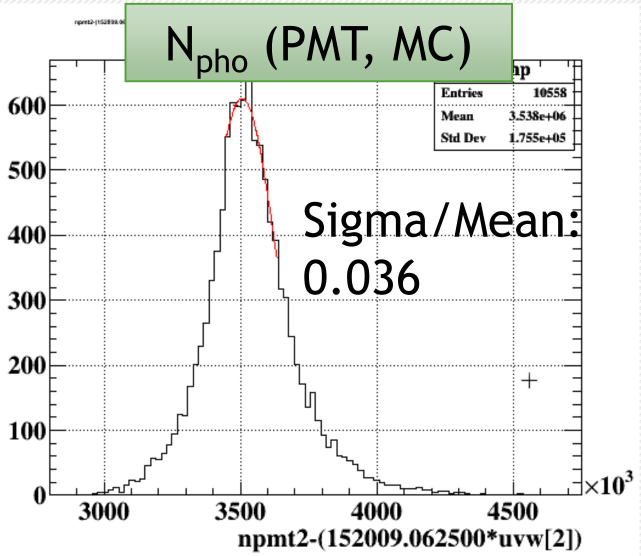
Such fluctuation does not seem to be big enough compared to MC to explain bad resolution in Data.

PMT or MPPC?









We checked N_{pho} sum distribution for both MPPC and PMT.

Resolution looks bad for both MPPC and PMT. (Especially for PMT.)

	$\Delta E_{data}/\Delta E_{MC}$
MPPC	1.55
PMT	1.93

Problem in Data?
MC is too good?

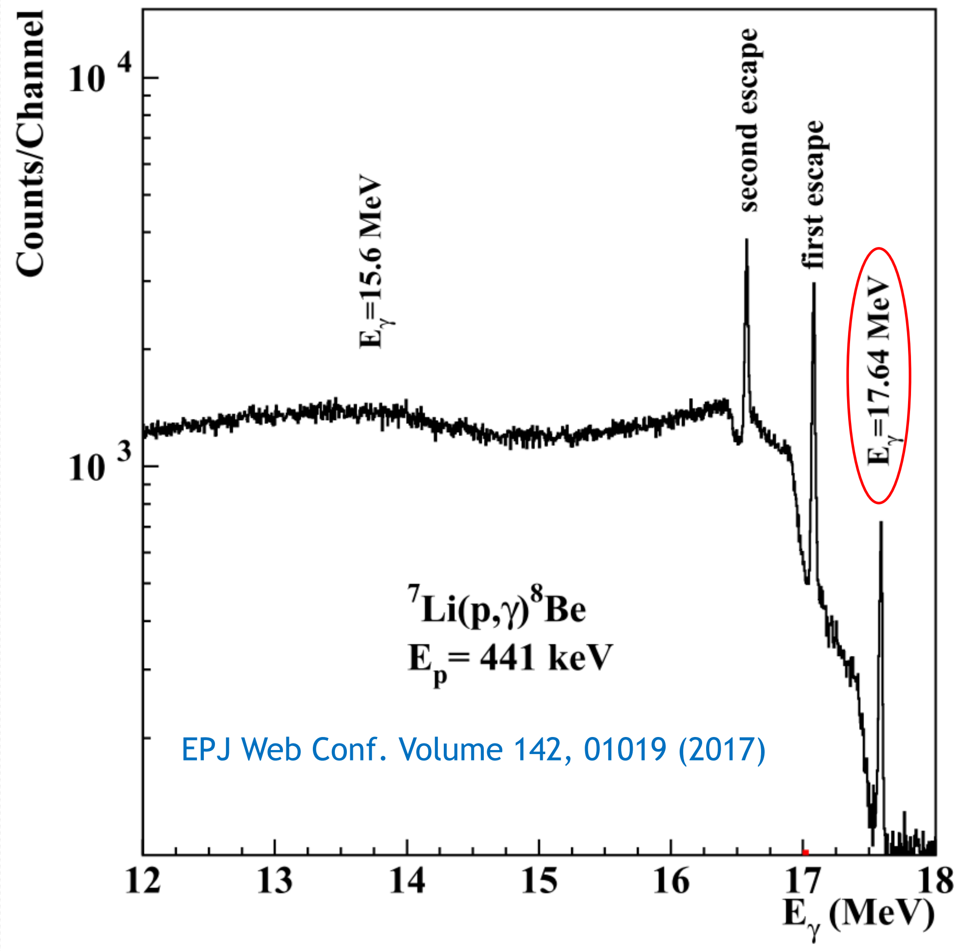
14

CW γ energy?

Is CW peak really monochromatic?

→ width is only ~12 keV.

If the target is thin enough and the energy deposit of proton on target is negligibly small, γ energy fluctuation is negligible.



EPJ Web Conf. Volume 142, 01019 (2017)

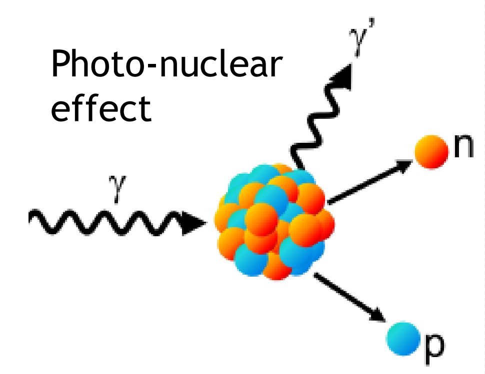
Physics parameters in MC?

Is there any parameters in MC which affect the resolution?

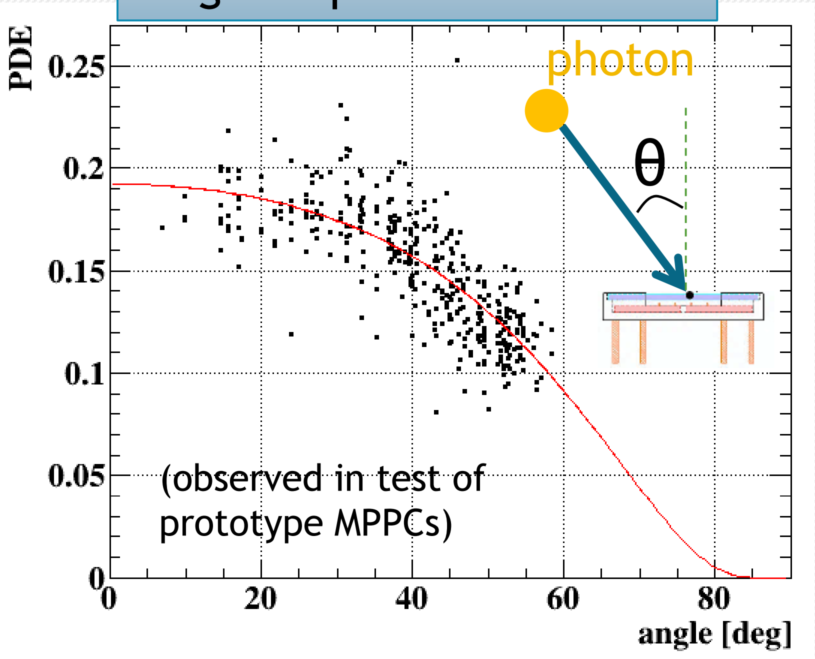
We tried changing settings as follows:

- Optical photon simulation
  - Reflection at PMT holders → off/on
  - LXe Absorption length 400cm → 100cm
  - LXe Rayleigh scattering length 45cm → 20cm
  - Cherenkov light
- Angular dependence of MPPC PDE → off/on
- Physics model
  - EM model → precise model option
  - Photo-nuclear effect → off/on

➡ None of these settings helped reproducing resolution of Data.



Angle dependence of PDE



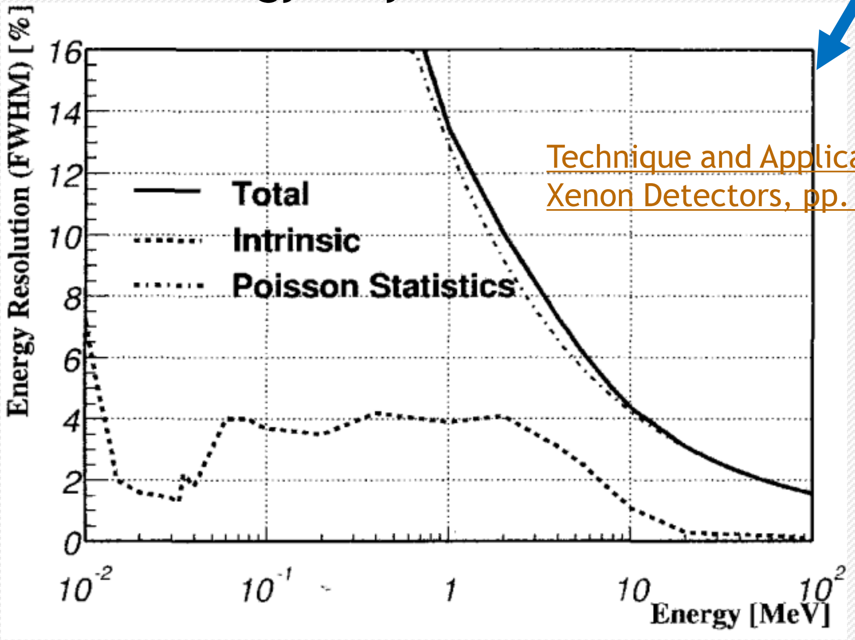
Intrinsic resolution of LXe?

Resolution depends on (at least) four parameters:

(K Ni *et al* 2006 *JINST* **1** P09004)

$$Resolution^2 = R_{stat}^2 + R_{shower}^2 + R_{non-prop}^2 + R_{escape}^2$$

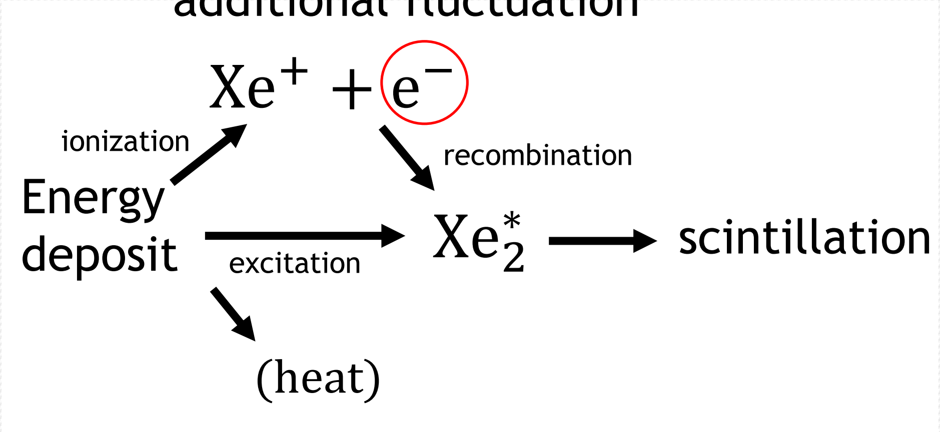
Non-proportional scintillation response to electron energy may worsen resolution



[Technique and Application of Xenon Detectors, pp. 17-27 (2003)]

Effect is expected to be ~0.5% @ 17.6 MeV

Number of escape electron may cause additional fluctuation

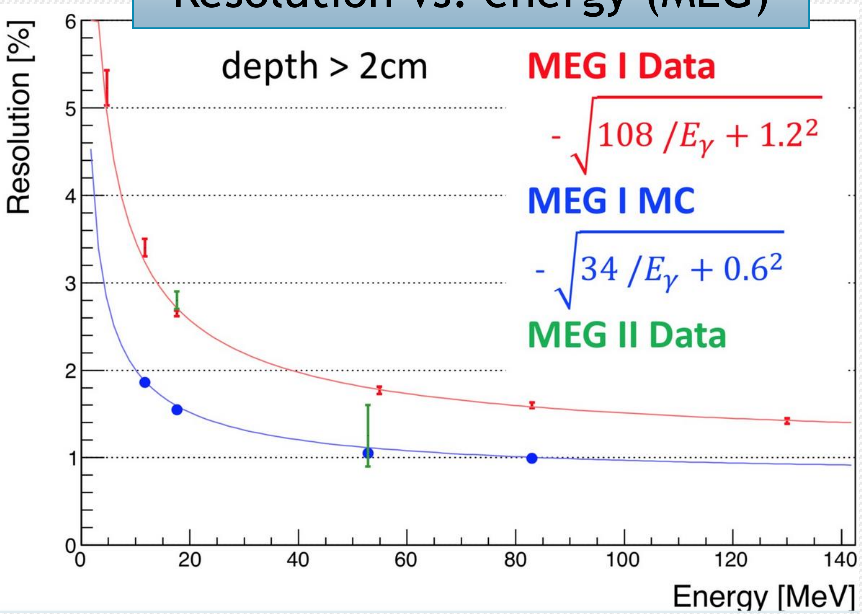


Effect on resolution is not known above ~10 MeV.

What do we expect at signal energy (52.8MeV)?

Energy dependence of resolution is not fully understood.
In MC, resolution simply depends on statistical fluctuation and EM shower shape fluctuation.
However, an unknown component which we observed in MEG might still exist.

Resolution vs. energy (MEG)



Resolution was ~1.2% with MEG prototype LXe detector, so the intrinsic resolution is expected to be ~1% level or less.

Energy resolution estimated from radiative muon decay spectrum was not bad (~1%), but we it needs to be confirmed with 55 MeV γ ($\pi^- p \rightarrow \pi^0 n, \pi^0 \rightarrow 2\gamma$) this year.

Summary

- 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.