Liquid xenon gamma-ray calorimeter for the MEG experiment

- Outline
  - Introduction
  - MEG experiment
  - LXe Detector
    - Principle
    - Calibration
    - Purification
    - Performance
    - Background
  - Summary

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On behalf of MEG Collaboration

The University of Tokyo
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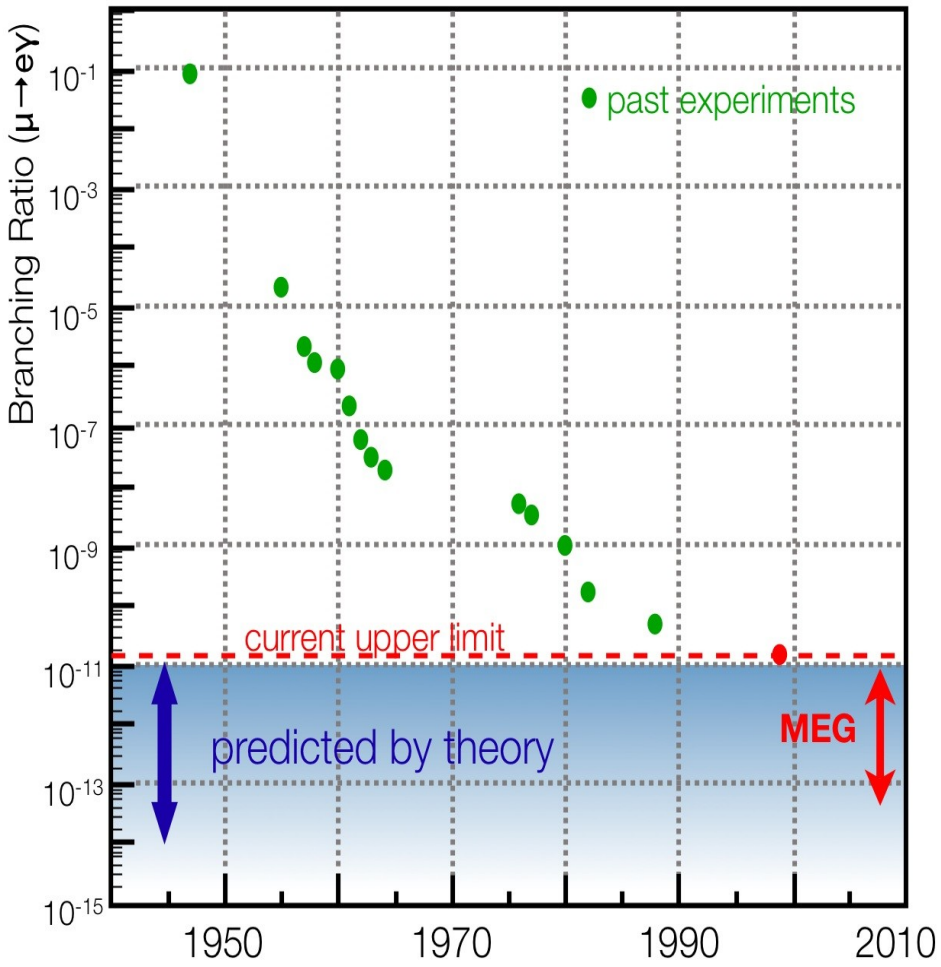
TIPP 2011, Chicago

Lepton Flavor Violation

- μ -> eγ decay
  - Lepton flavor violating decay
  - In the SM with neutrino oscillation, the branching ratio is tiny(~10^{-50})
  - Current experimental upper limit
    - 1.2x10^{-11} (MEGA)
  - Well motivated new physics (SUSY-GUT, SUSY seesaw,...) predict the branching ratio around 10^{-11} -10^{-13} region
- MEG experiment
  - Explore down to 10^{-13} level

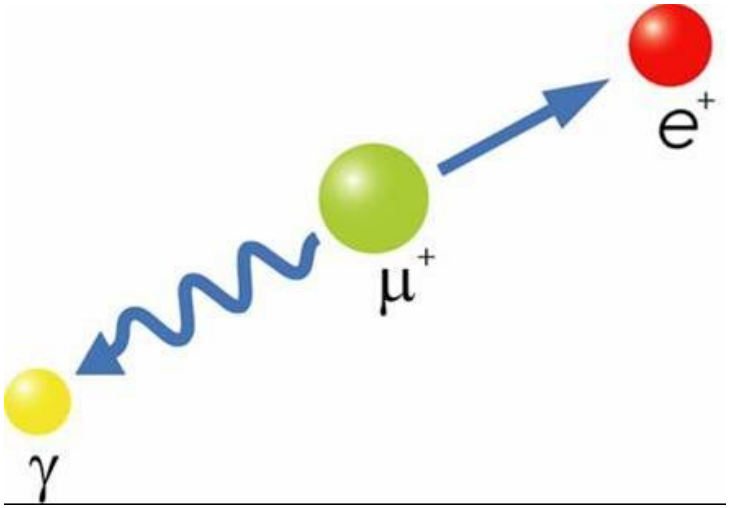


Current Status of MEG

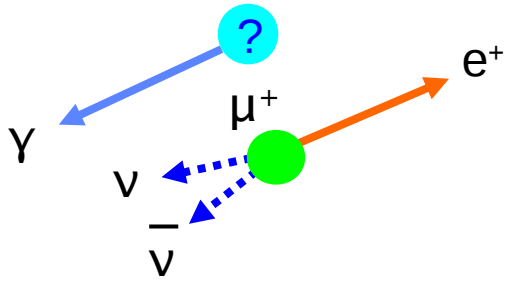
- Physics data taking started in 2008
  - 2008 data
    - Br(μ->eγ)<2.8x10^{-11} at 90%C.L., published in Nucl.Phys.B834:1-12,2010
    - Sensitivity: 1.3x10^{-11}
  - 2009 data
    - Br(μ->eγ)<1.5x10^{-11} at 90%C.L. (preliminary)
    - Sensitivity: 6.1x10^{-12} (preliminary)
  - 2010 data
    - 1.9x statistics of 2009
    - We are analyzing 2009-2010 data now, and combined result will be presented in summer conferences
- MEG Collaboration
  - ~60 Collaborators from Japan, Italy, Switzerland, Russia, and USA

Signal & background

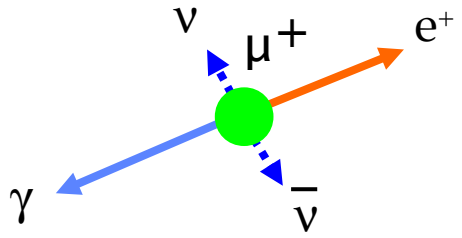
- Signal
  - 52.8MeV (half of muon mass)
  - Back-to-back
  - μ^+ decay at rest
  - Timing coincidence



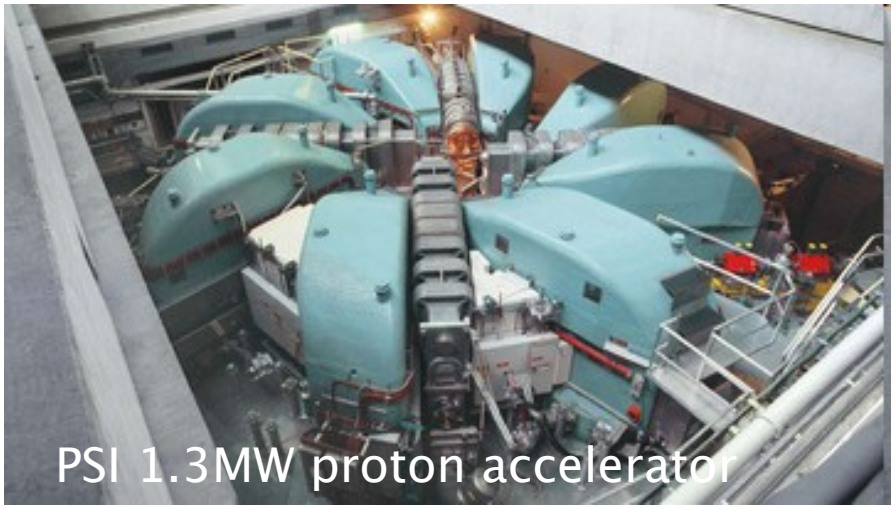
- Accidental background
  - Michel decay e^+ + random γ
  - Dominant background for us
  - Random timing, angle, <52.8MeV



- Radiative muon decay
  - $\mu \rightarrow e\nu\nu\gamma$
  - Timing coincident, not back-to back, <52.8MeV



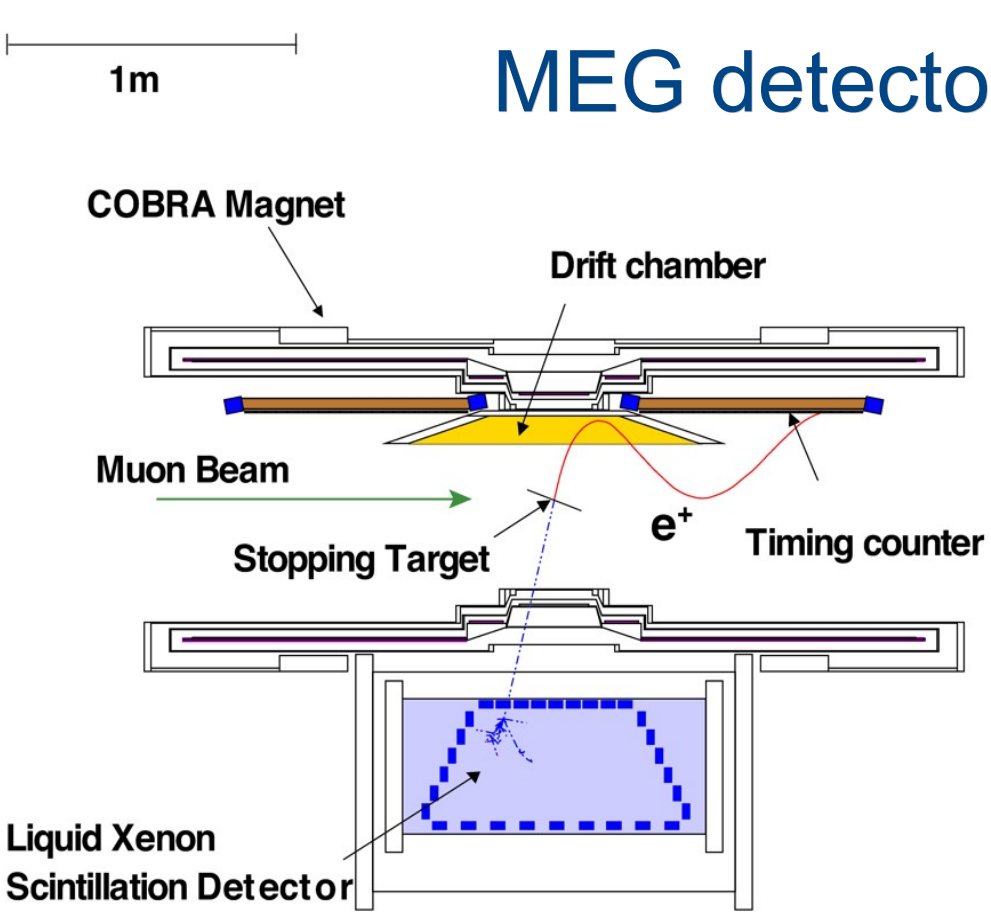
MEG experiment

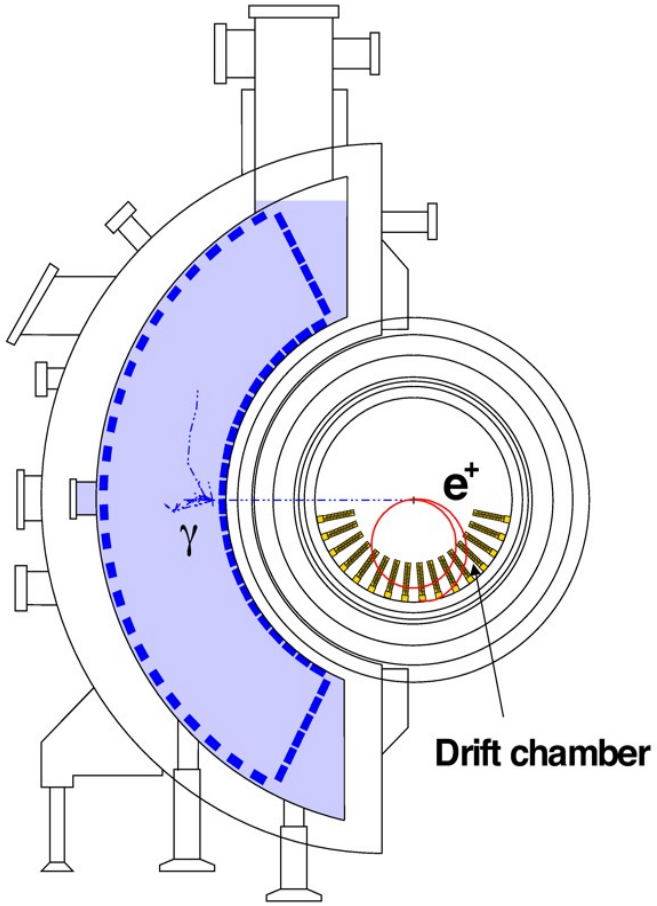


Most intense DC muon beam
($>1x10^8 \mu^+/s$) possible

- Requirement:
  - Need many muon decays
  - Detectors(e^+) should be working in high rate environment
  - Good energy, timing, and position resolutions

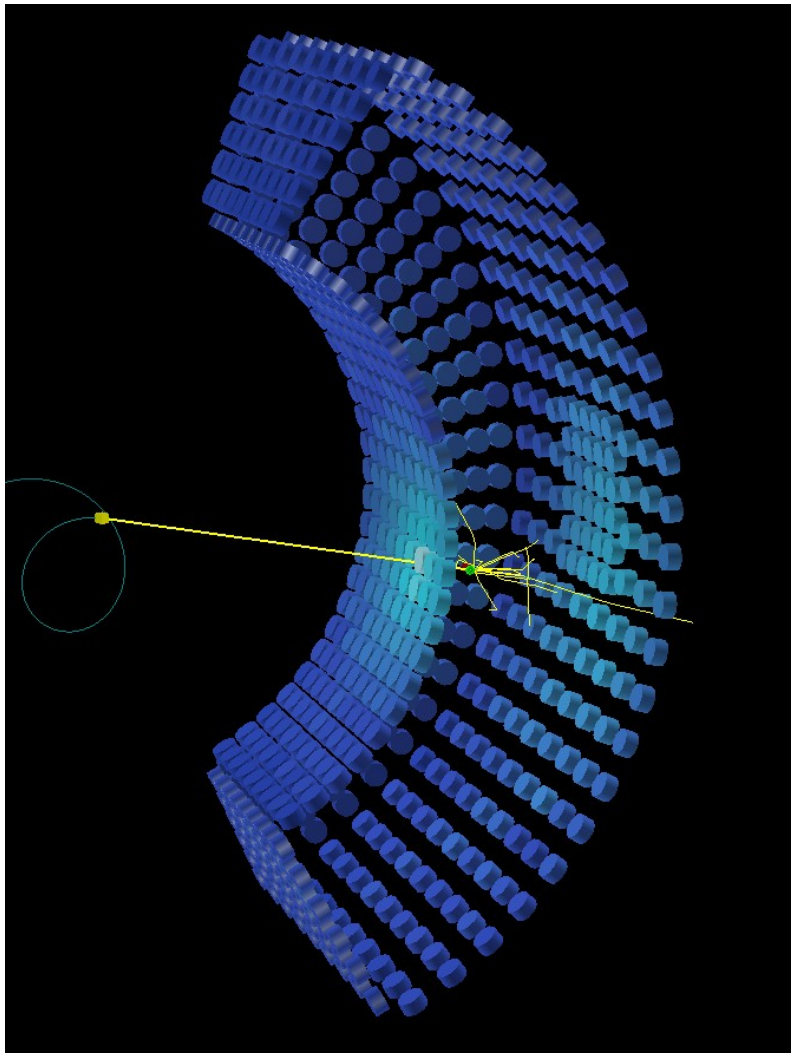
MEG detector





- Positron spectrometer
  - Special gradient magnetic field(COBRA)
    - Sweeps out high rate e+ quickly
    - Constant bending radius of e+
  - Drift chamber
    - Made of ultra thin material
    - Precise e+ tracking
  - Timing counter
    - Precise e+ timing
    - Plastic scintillator + PMTs
- LXe gamma detector
  - 2.7 ton of liquid xenon
  - Homogeneous detector
  - Good time, position, energy resolution
- Waveform digitizer for all detectors (pileup ID)

2.7t Liquid xenon gamma-ray detector

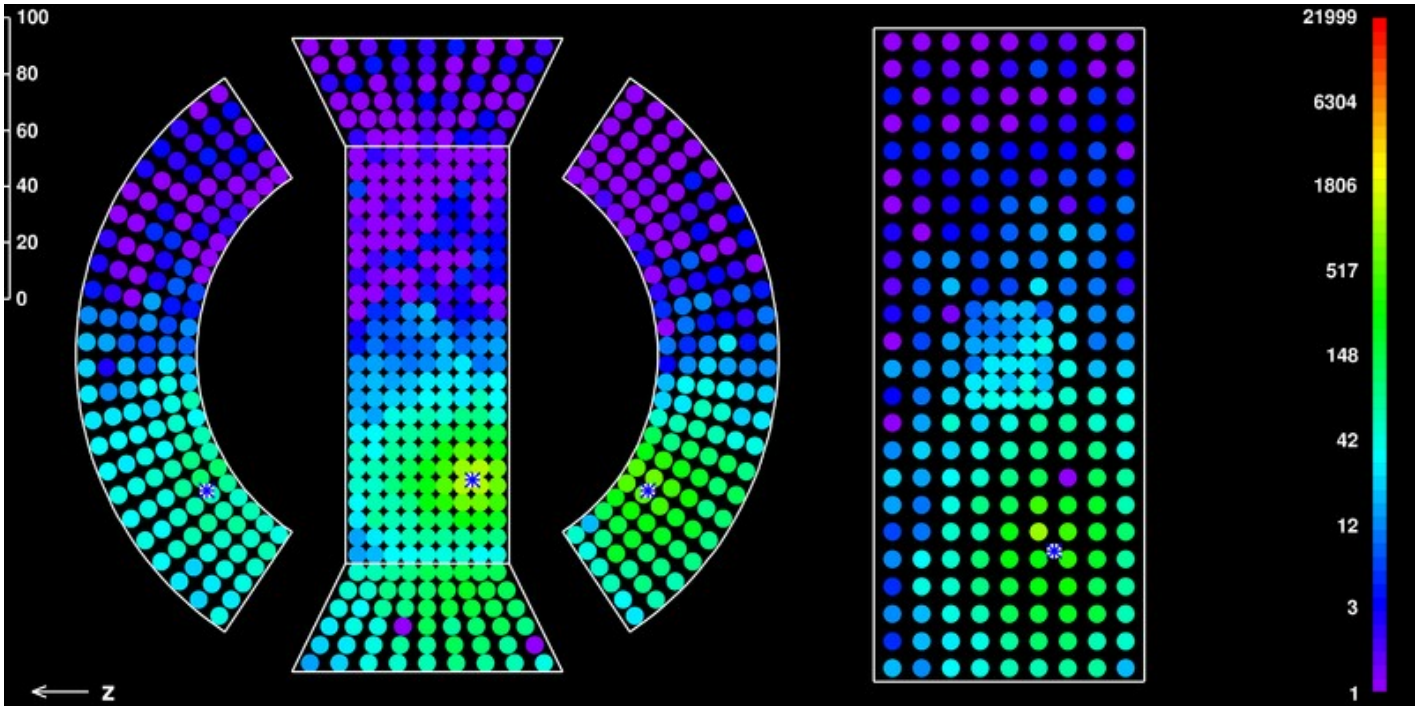


- 900L liquid xenon
- 846 2” PMTs (Hamamatsu)
  - Submerged in Liquid
- γ energy, position, and timing reconstruction
- Merits
  - High light output(80% of NaI)
  - Fast timing response(45ns)
  - Heavy(3g/cm^3)
- Challenges
  - Low temperature(160K)
    - 200W pulse tube cryocooler
  - Short scintillation wavelength (178nm)
  - Gas/liquid purification

Reconstruction & Goal of gamma ray detector

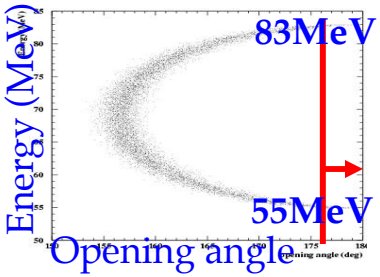
- Reconstruction
  - Energy: weighted sum of all PMTs
  - Position: peak of light distribution
  - Time: weighted average of time of PMTs
- Pileup detection
  - Waveform
  - Light distribution

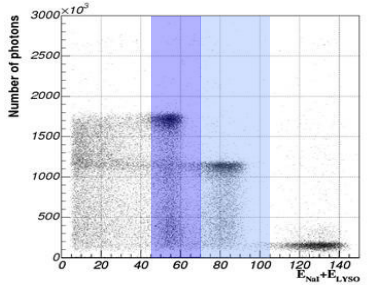
- Goal
  - Energy resolution: 1.2–1.5%
  - Opening angle: 2–4mm
  - Time resolution: 65ps

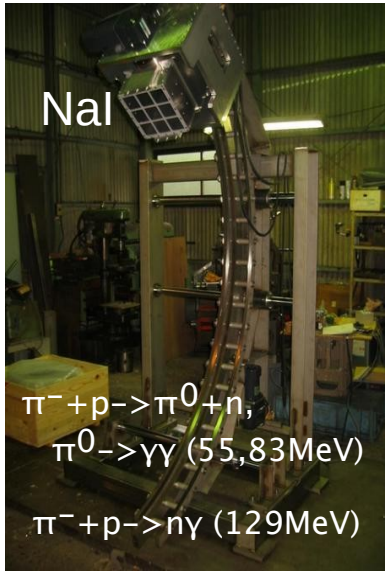


Calibration methods

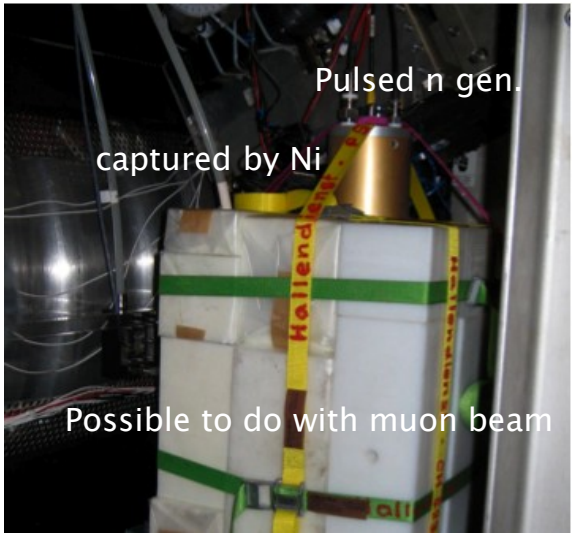
55MeV γ (CEX)



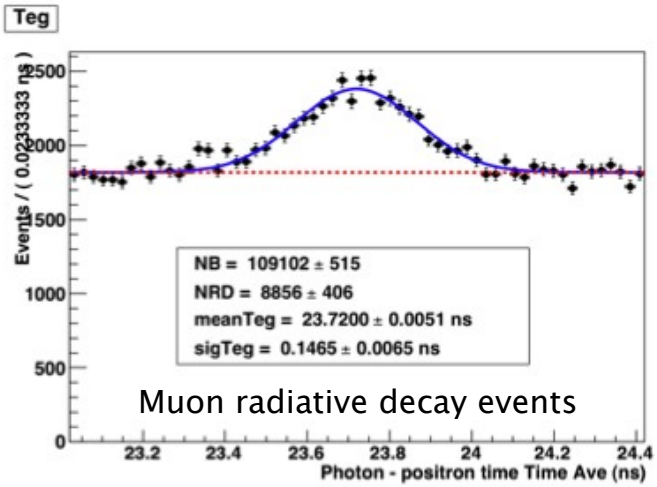




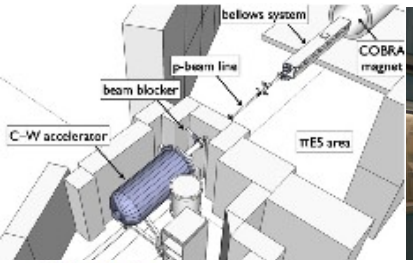
9MeV γ

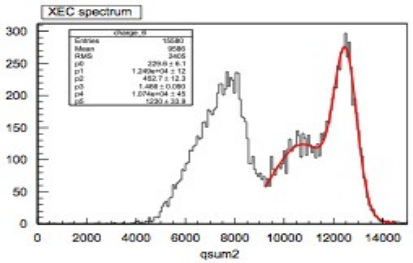


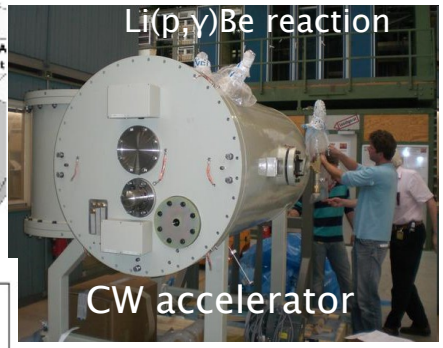
Timing resolution



17.6MeV γ







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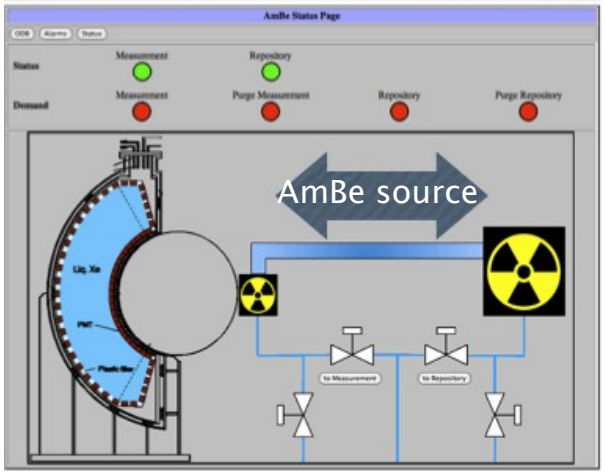
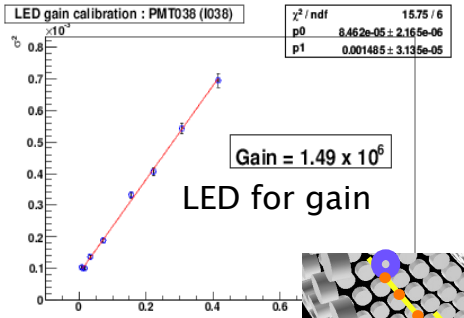
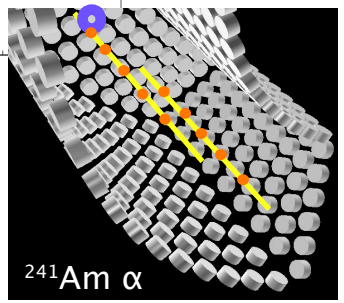
4.4MeV γ



PMT calibration

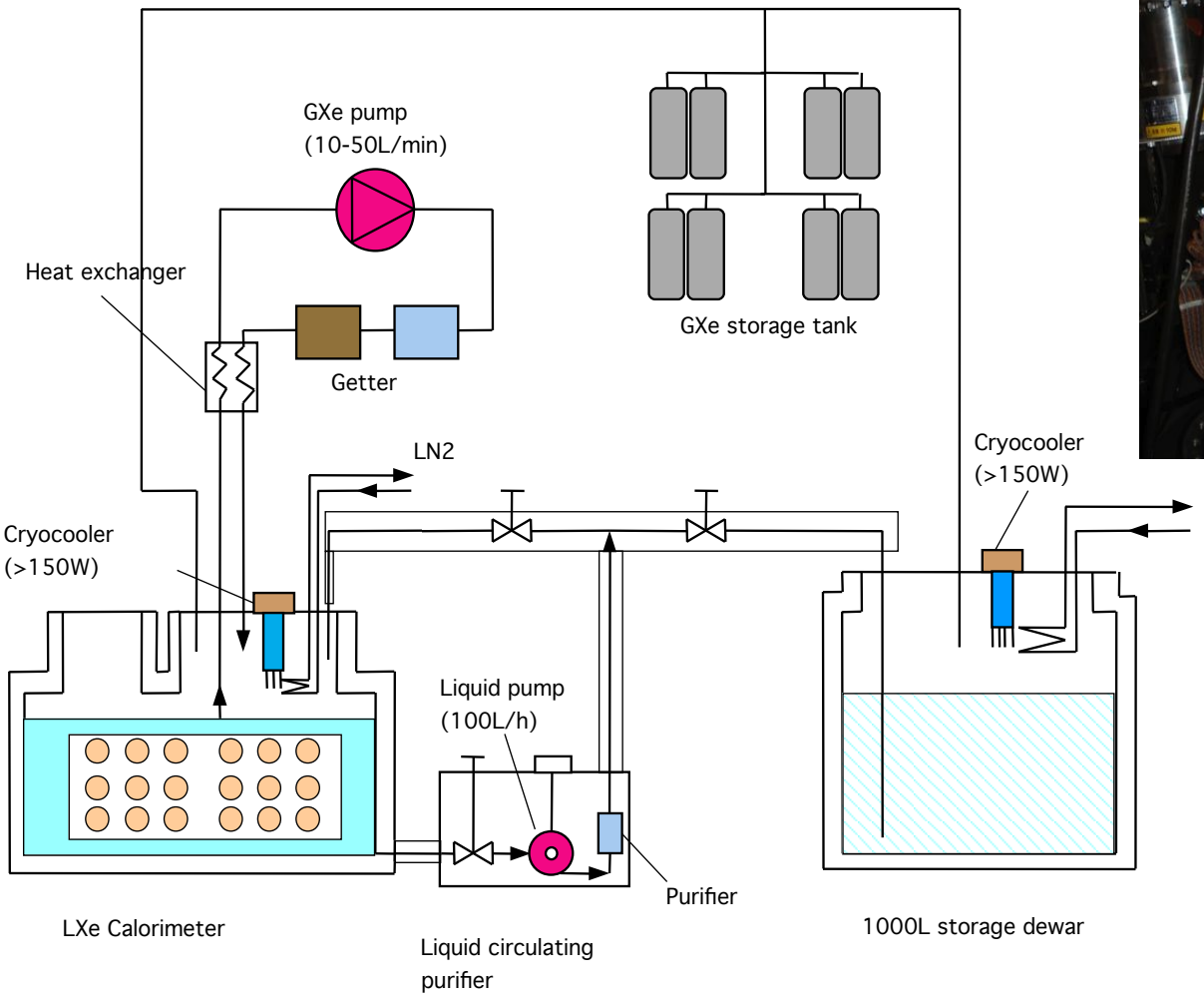


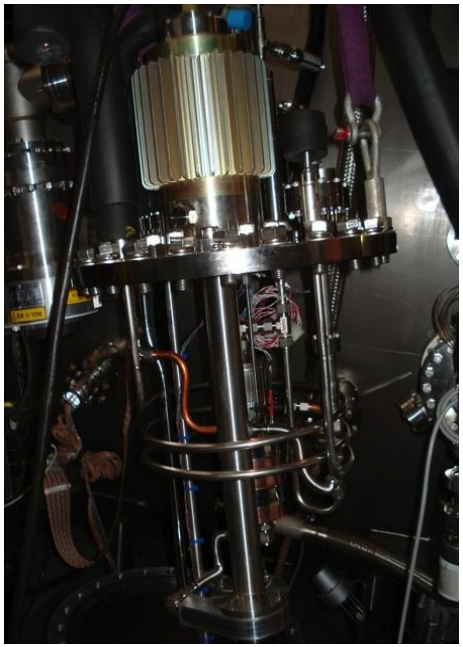


Purification system

- Gaseous purification
- Liquid purification

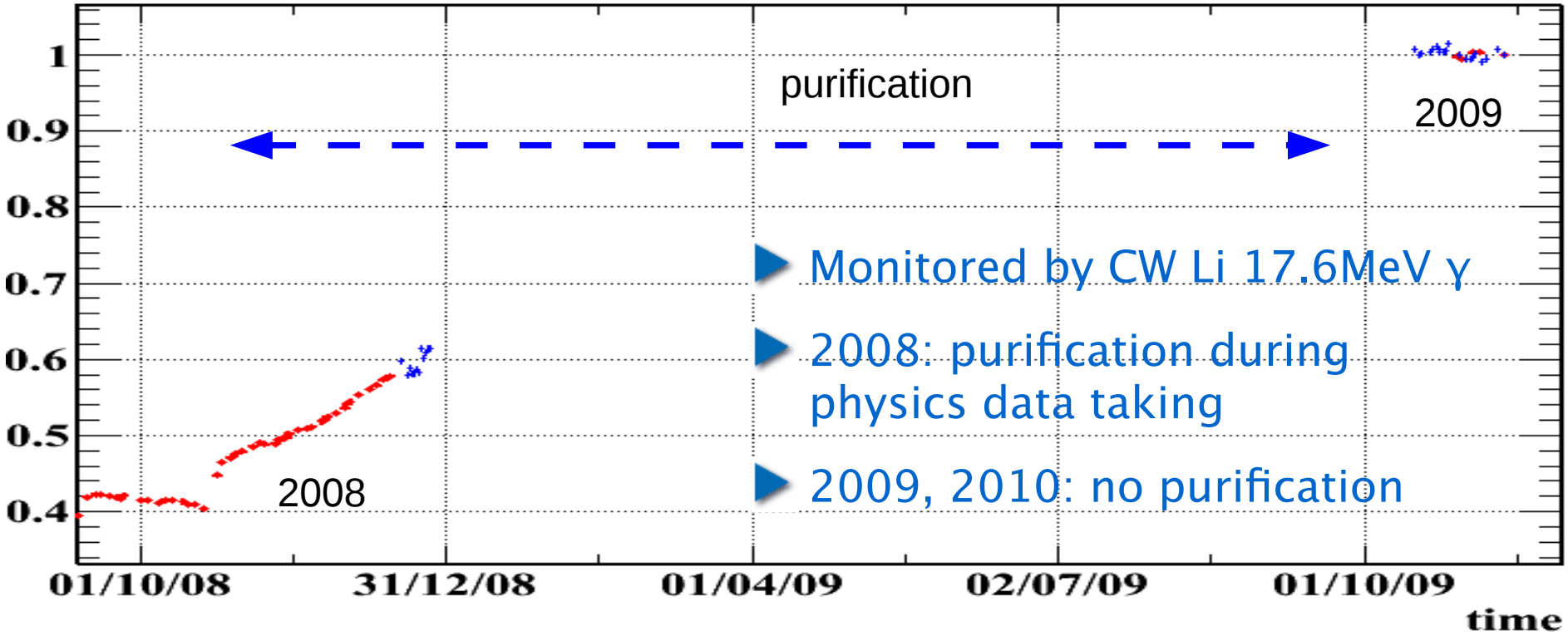
Metal heated getter
H_2O, O_2, N_2,...
Diaphragm pump
~1L/h

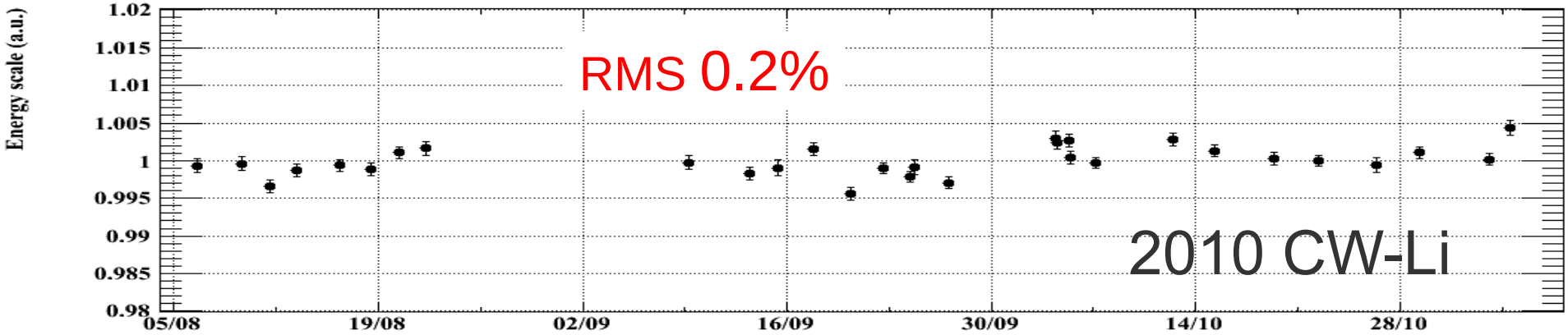




Molecular sieves
Mainly H_2O rejection
Cryogenic centrifugal pump
~100L/h

Light yield

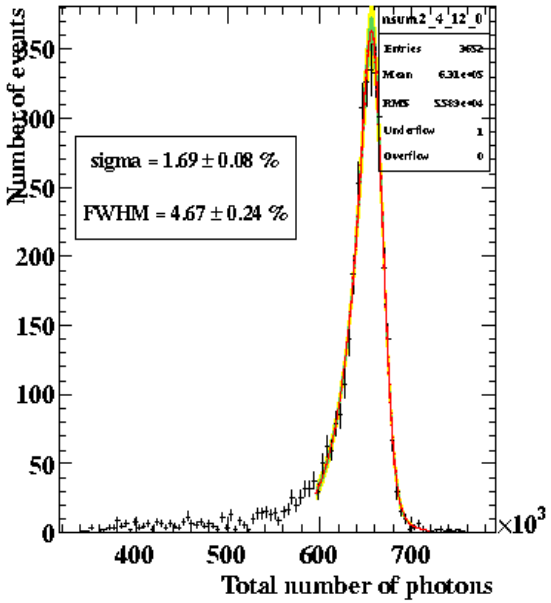

purification
2009
2008
Monitored by CW Li 17.6MeV γ
2008: purification during physics data taking
2009, 2010: no purification
1
0.9
0.8
0.7
0.6
0.5
0.4
01/10/08
31/12/08
01/04/09
02/07/09
01/10/09
time

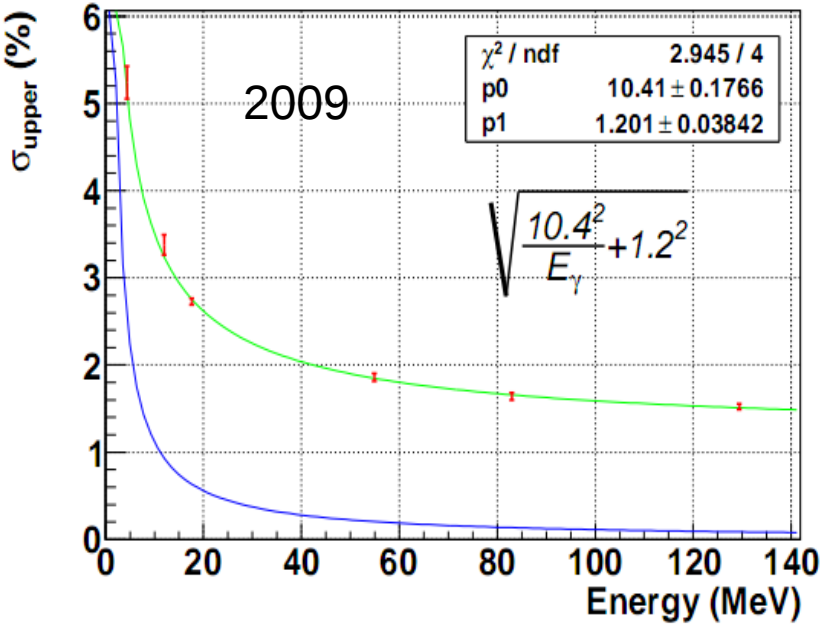

Energy scale (a.u.)
RMS 0.2%
2010 CW-Li
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
05/08
19/08
02/09
16/09
30/09
14/10
28/10

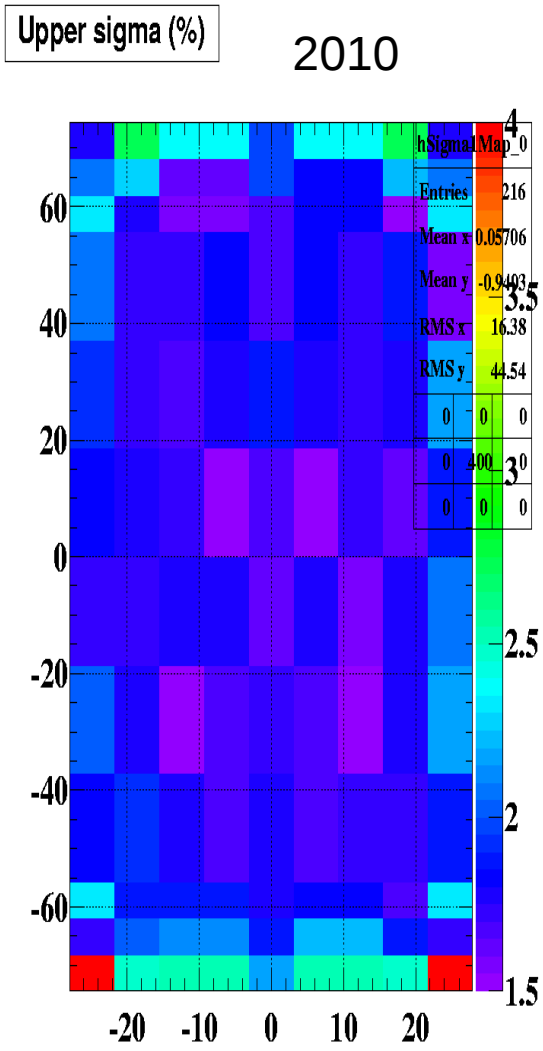
Performance

Energy resolution

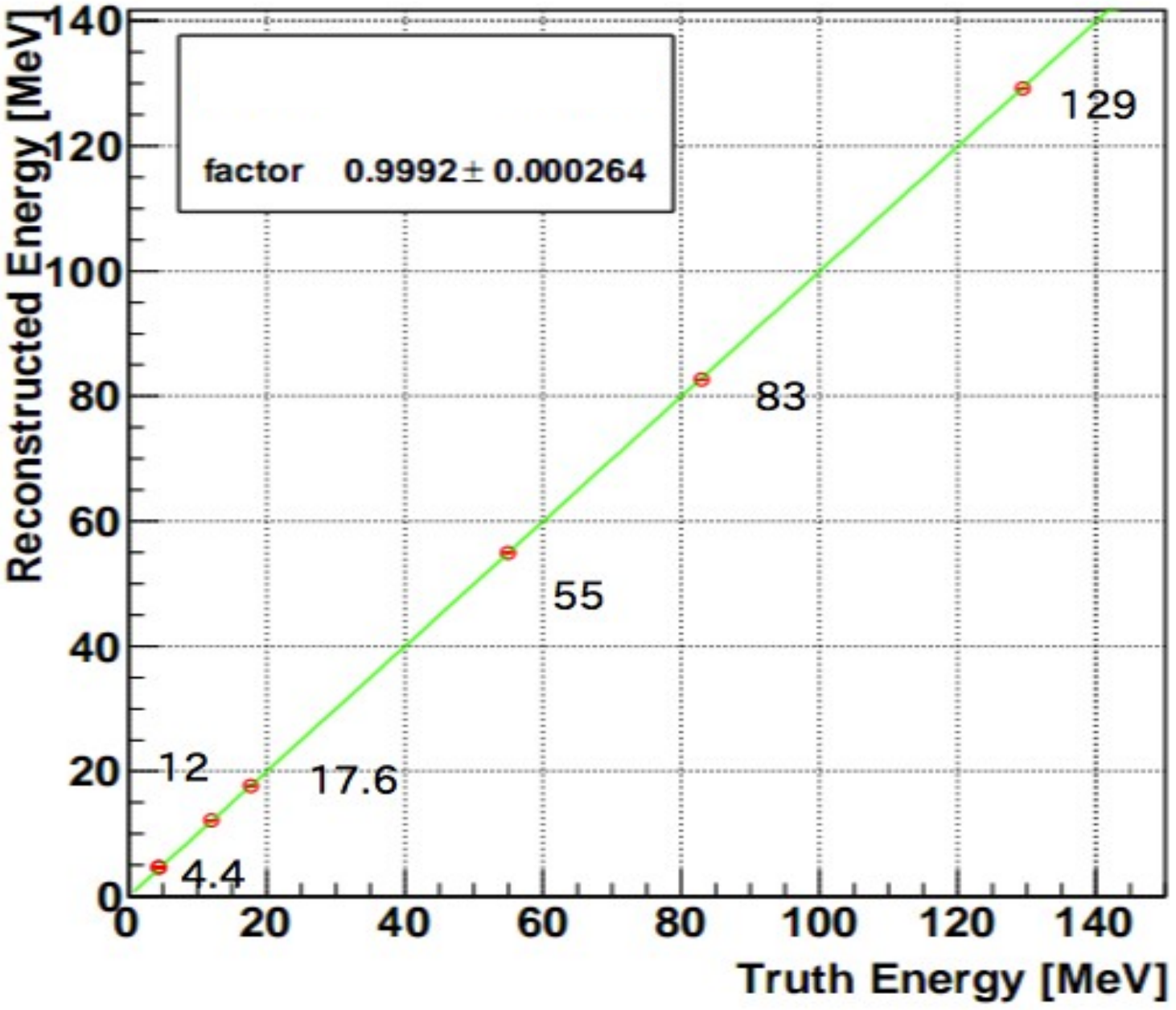
- Energy resolution is evaluated with 55MeV γ in CEX
- Resolution map on incident position is measured by moving NaI detector
- Typical resolution in 2009 (preliminary)
  - 2.1% (depth>2cm), 2.8% (1–2cm), 3.3%(0–1cm)
  - 2010 data show similar results





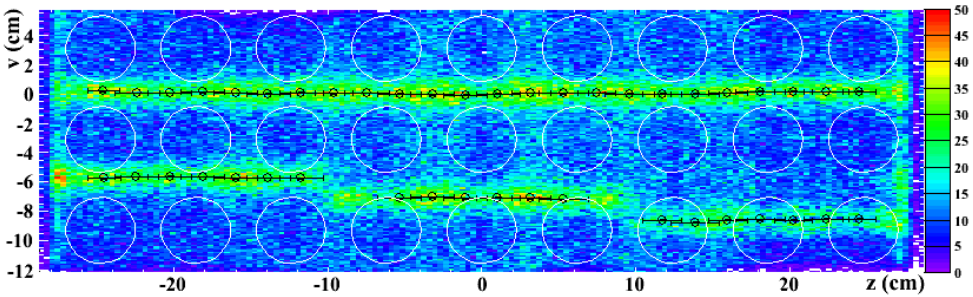


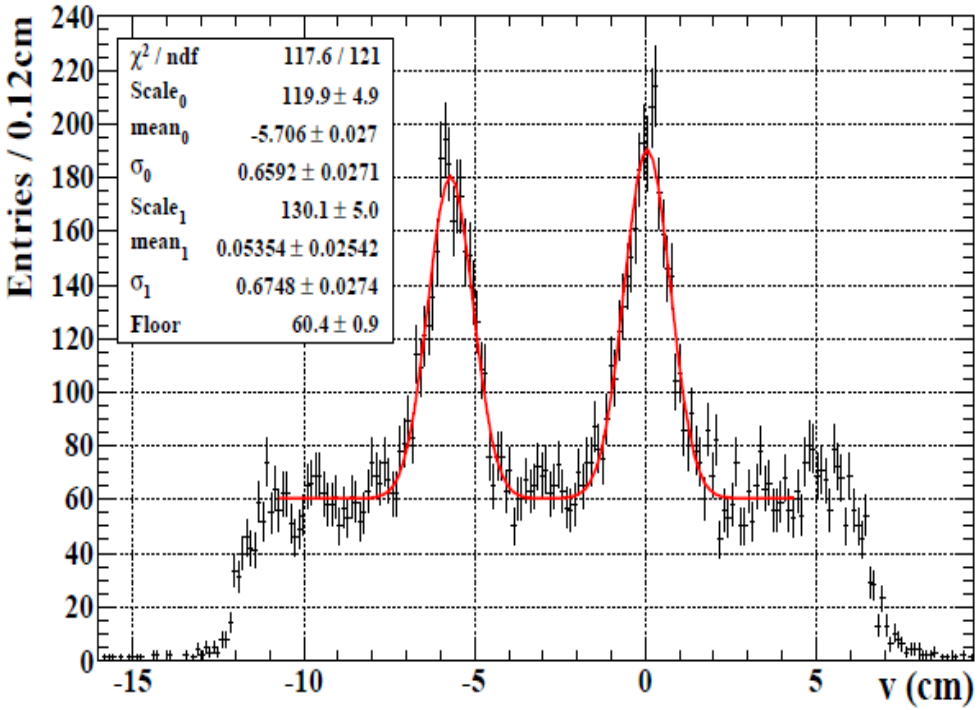
Linearity

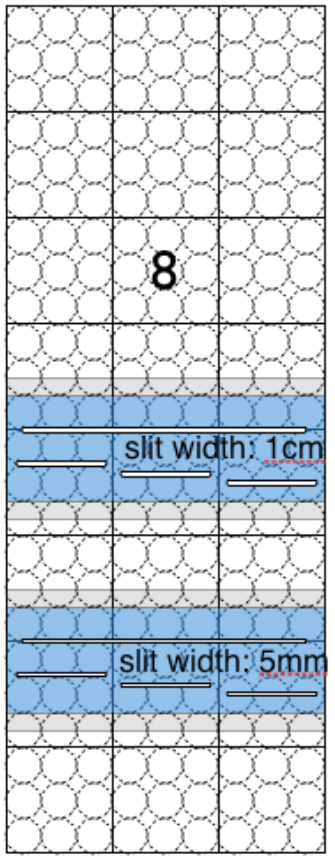

factor 0.9992 ± 0.000264
Reconstructed Energy [MeV]
Truth Energy [MeV]
0
20
40
60
80
100
120
140
4.4
12
17.6
55
83
129

Position resolution

- Position resolution is evaluated CEX data with lead collimator
- Resolution in 2009
  - XY direction: 5mm
  - Depth: 6mm
  - Similar result with 2008

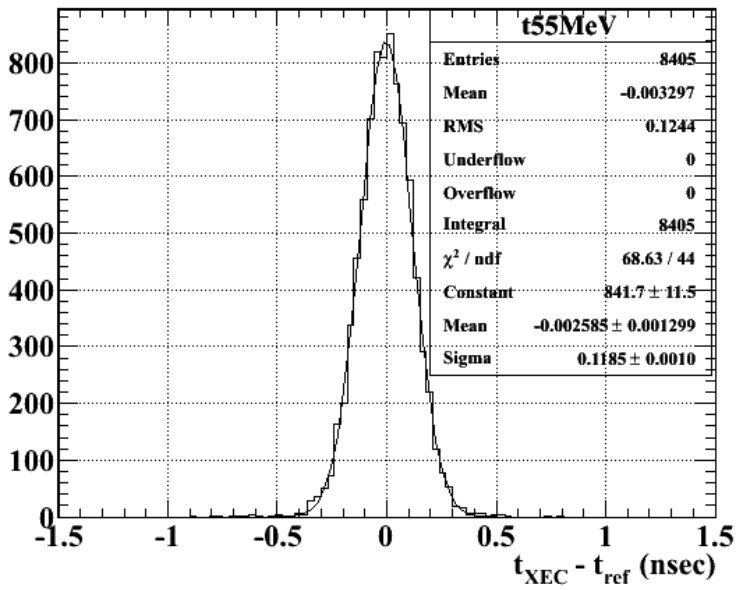


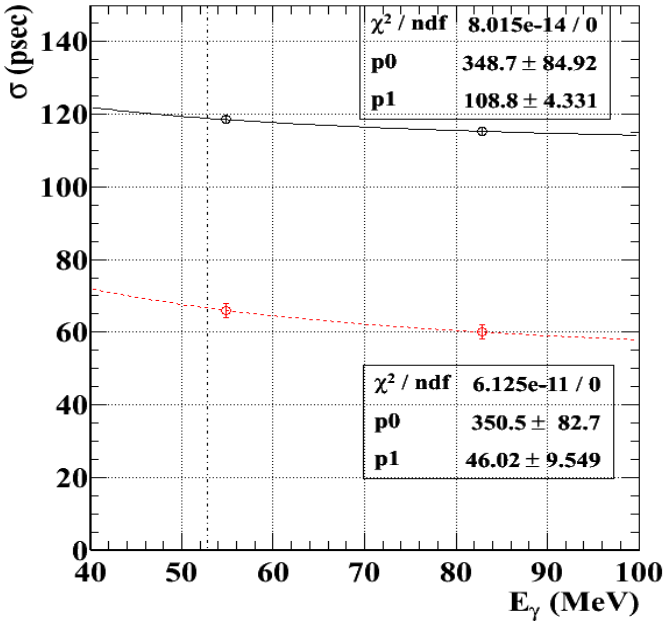




Timing resolution

- Time difference between XEC and reference counter in CEX
- Result
  - 119ps at 55MeV
  - XEC resolution : ~67ps
    - 119ps – beam spread(58ps) – resolution of reference counter(81ps)
    - Goal resolution is almost achieved





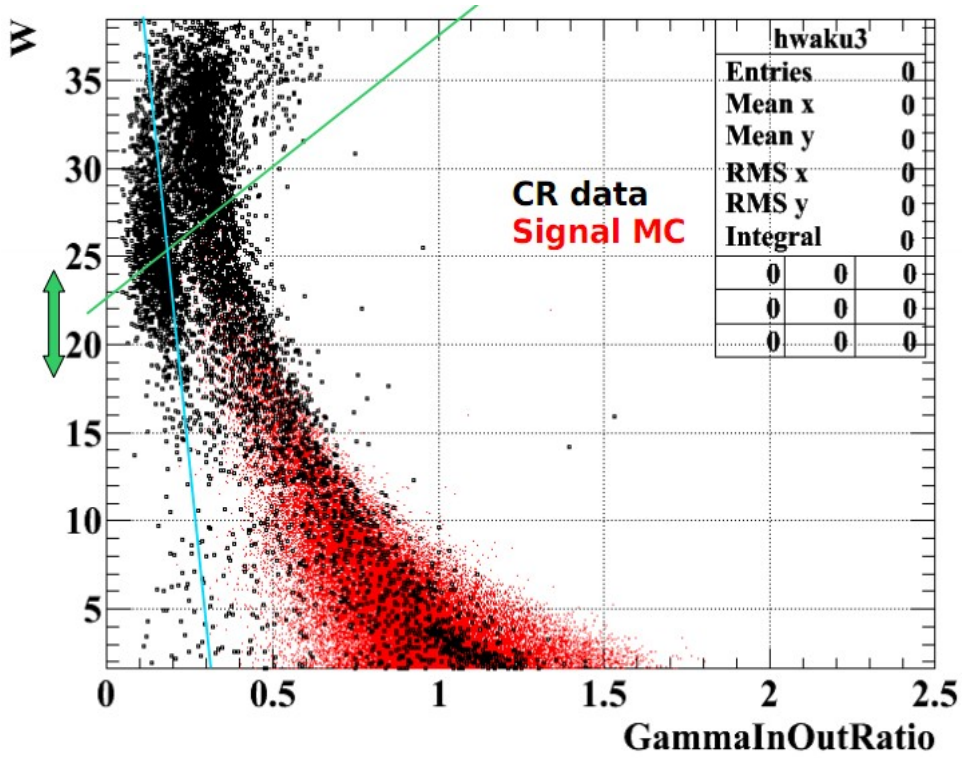
Resolution summary

	2009(preliminary)	goal
Gamma energy(%,w>2cm)	2.1	1.2-1.5
Gamma timing(ps)	67	65
Gamma position(mm)	5(xy)/6(depth)	4/6
Gamma efficiency(%)	60	60

Background

Background rejection

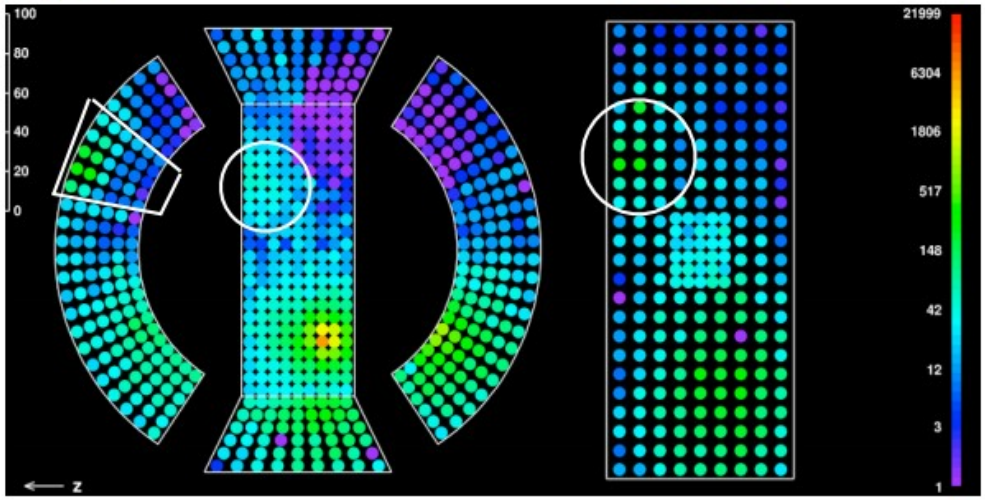
Cosmic ray rejection



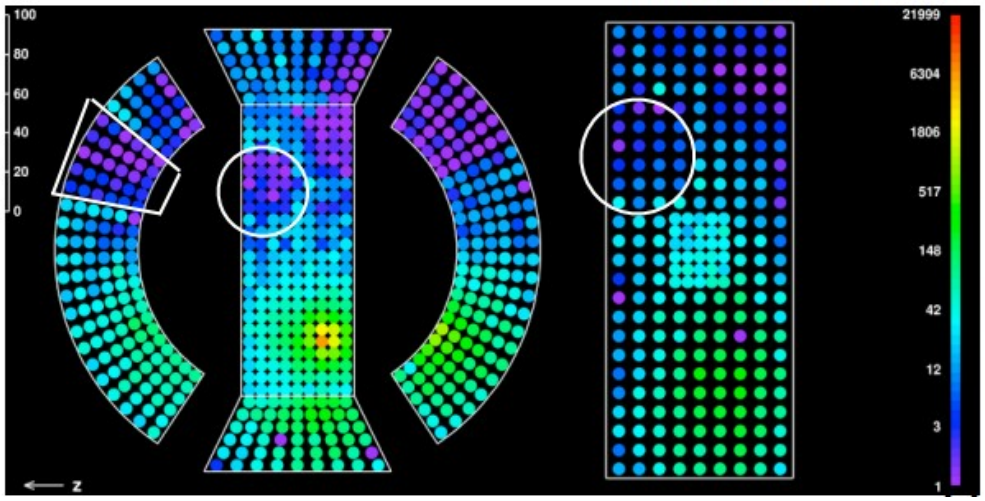
Inner/Outer charge Ratio

Pileup elimination

Original

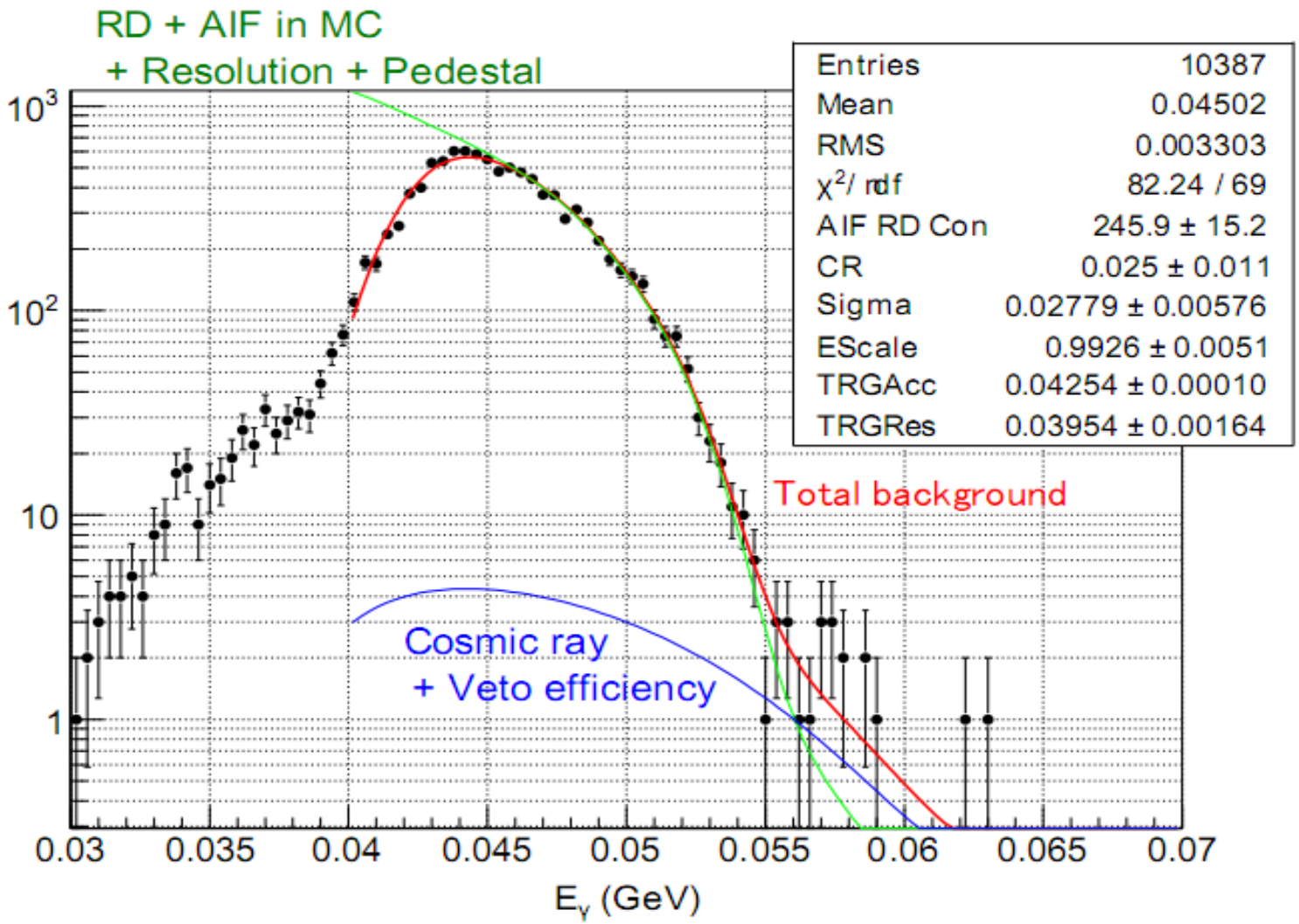


After replacement



1.Find pileup
2.Reconstruct energy w/o pileup region, calculate expected charge
3.Replace these charge

Background spectrum



Position dependent γ background spectra --> PDF for likelihood analysis
These can be extracted directly by data

Current Status

- Liquid xenon detector is almost ready for 2011, and full detector calibration will be started soon.
- Physics data taking will start at the end of June.
- Long term physic data taking in 2011–2012 to reach 10^{-13} level sensitivity

- Possible improvement
  - Analysis
    - Improve Q.E. estimation
    - New reconstruction algorithm
  - Calibration
    - Stable and better quality data of CEX with BGO

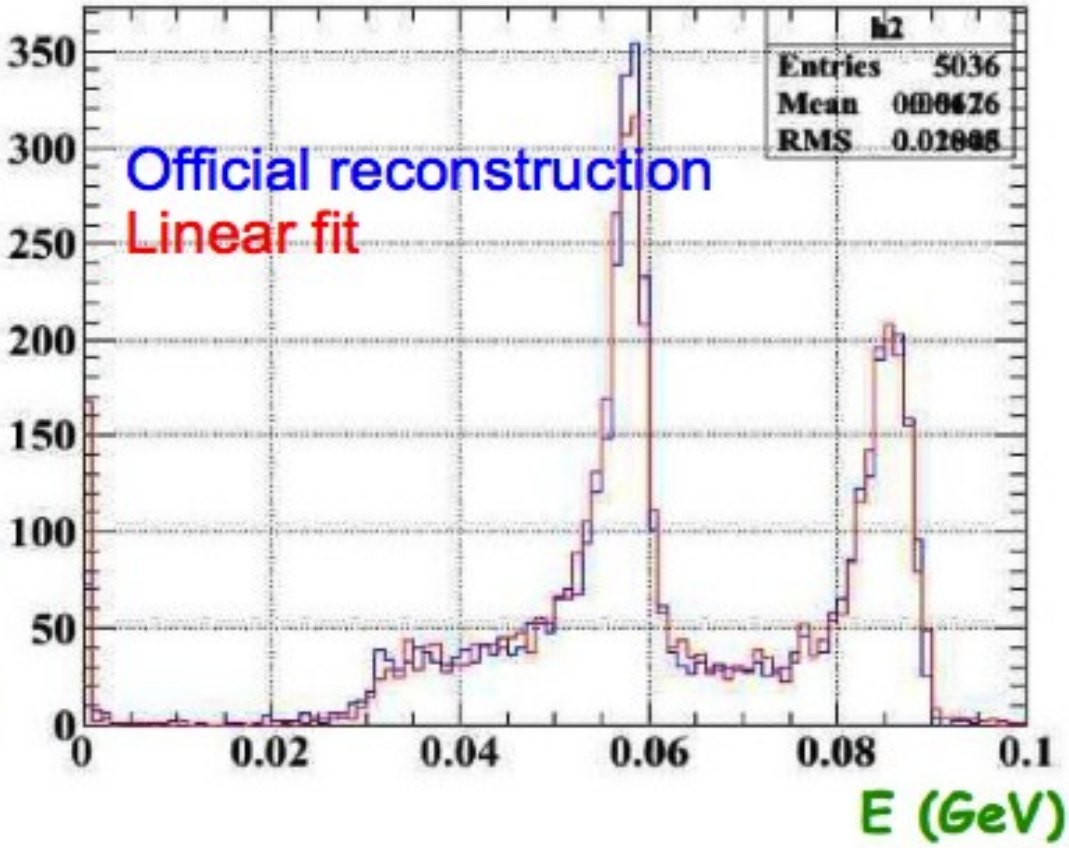
Summary

- Liquid xenon gamma-ray calorimeter has been operated stably and precise calibration methods have been established.
- High performance has been confirmed, and especially resolutions of timing, and position are close to design values.
- Important inputs for physics analysis can be extracted by calibration and sideband of physics data.
- We still believe there is room to improve energy resolution further.

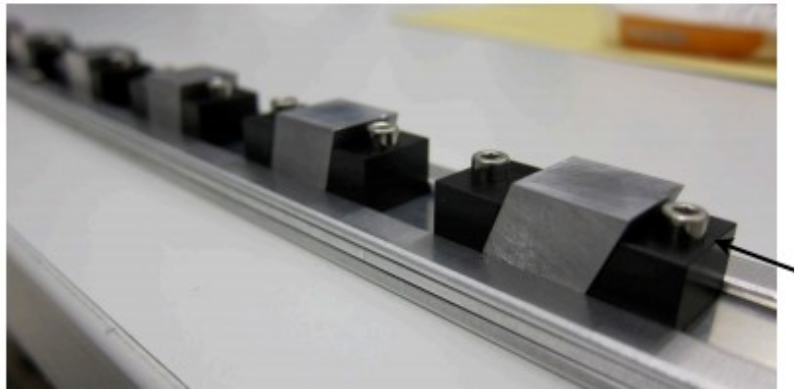
Linear-Fit

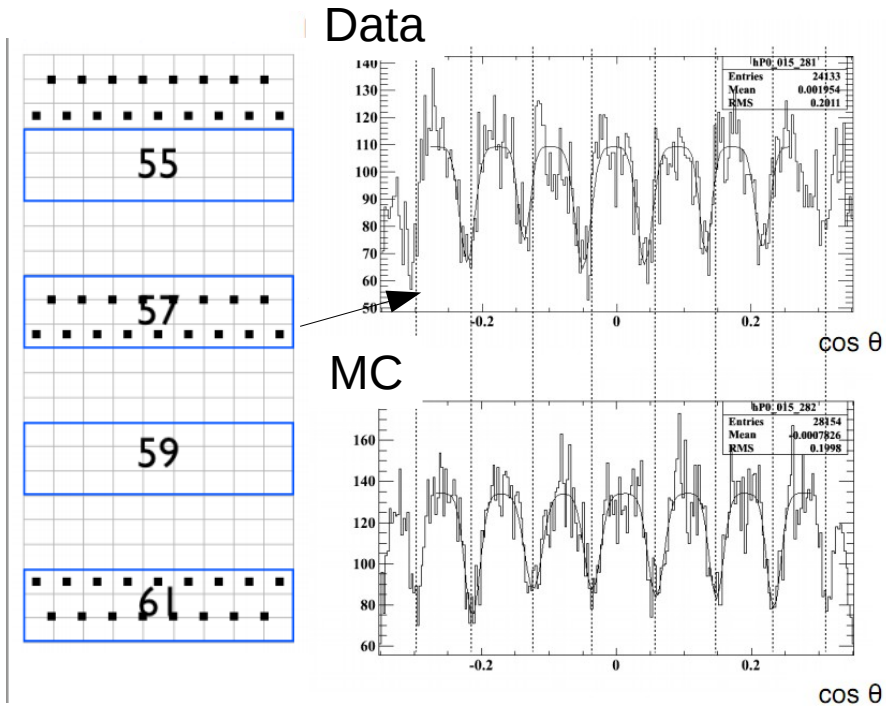
- Linear fit algorithm
  - $E = c + \Sigma c_i Q_i$
  - The weights are computed with MC
    - $\chi 2$ = distance from MC
    - Analytical minimization
- Worked well for prototype

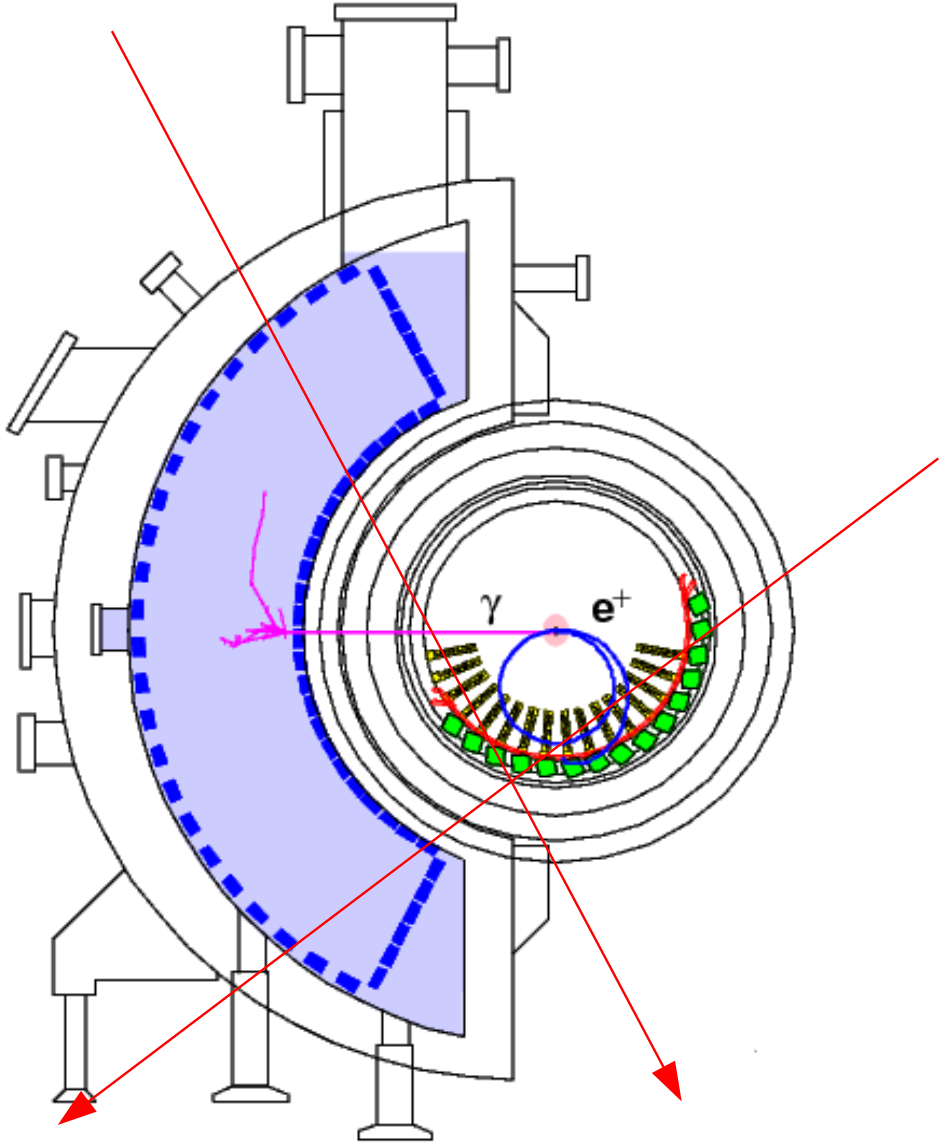
- With refinement of MC,
  - Progressing
  - Currently getting comparative to existing algorithm (still slightly worse)
  - Working further improvement of MC



Relative alignment

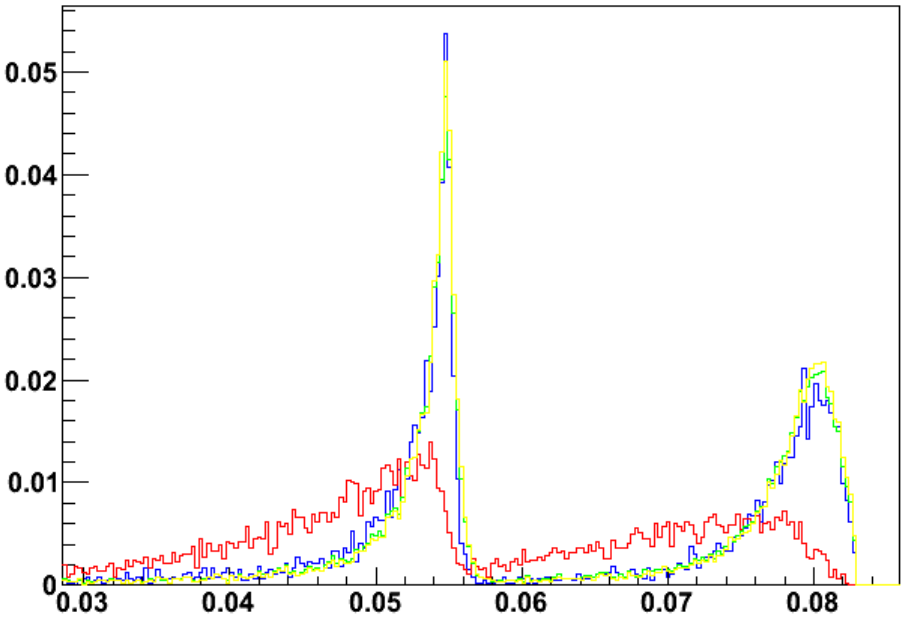


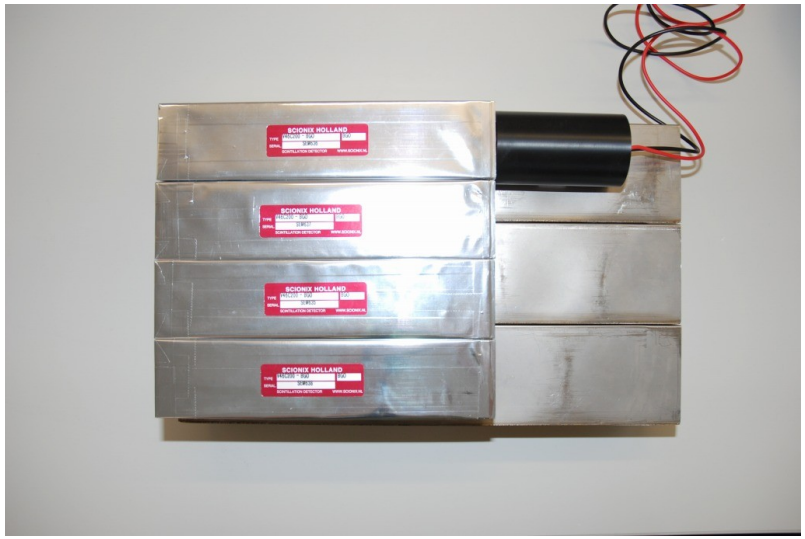




BGO

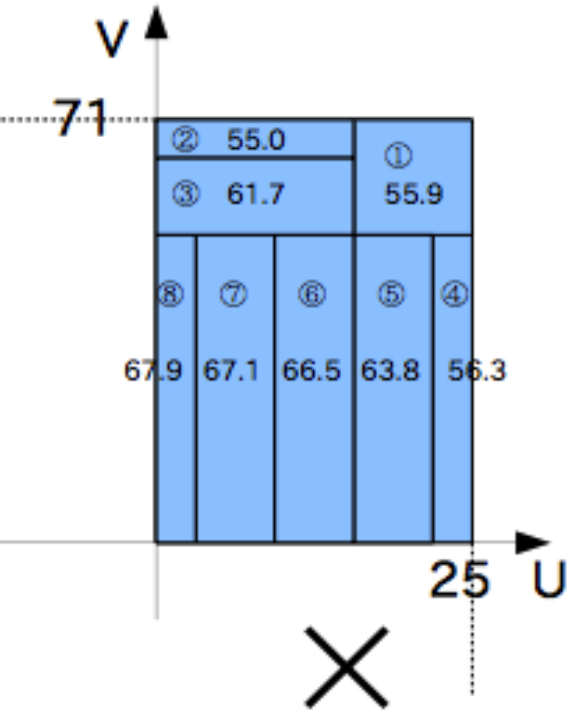
- NaI : 3x3 (6.5x6.5x33 cm^3 , 3.67g/cm^3)
- BGO : 4x4 (4.6x4.6x20 cm^3 , 7.13g/cm^3)
- Efficiency
  - 17% NaI center, 35% center 2x2 BGO
- Position reconstruction
  - NaI : 1.5cm, BGO : 1.1cm



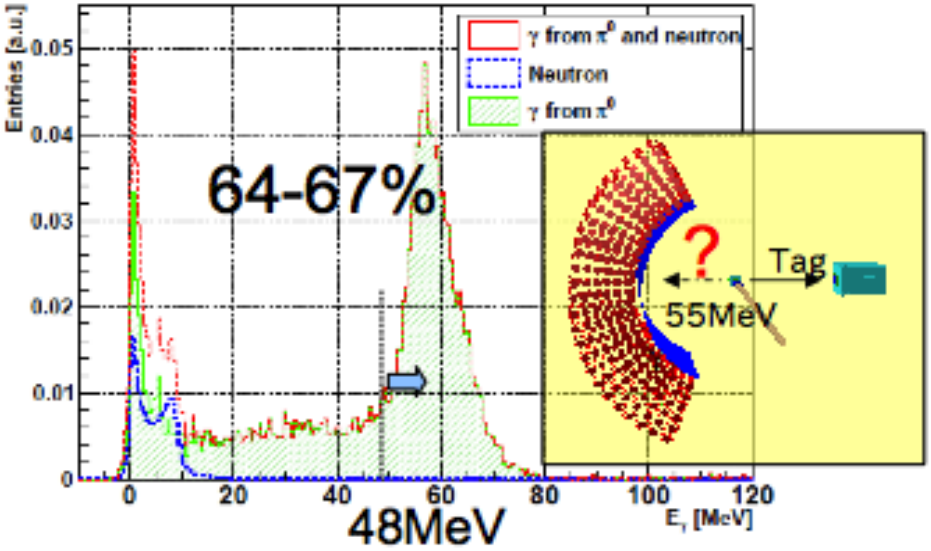


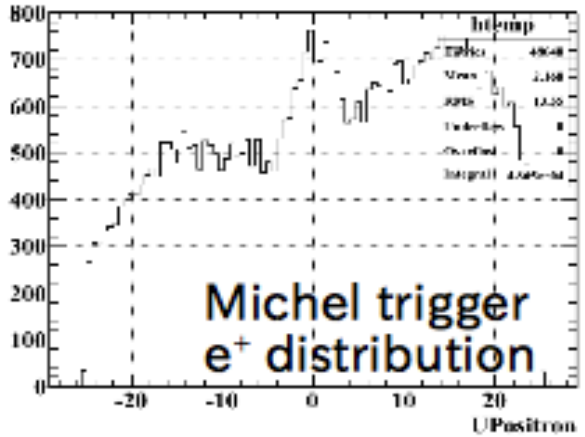
Efficiency

- For normalization, need eff conditional on the e^+ detection
  - Position-dependent efficiency from MC
  - Weighted by the e^+ distribution
- Confirmed with pi0 data (NaI-self)



ε_γ (>48MeV)= ε_{det} x ε_{ana}
= 0.647 x 0.893
= 0.58 ± 0.03





9% decrease from 2008

- Change of analysis window (46→48MeV) : 5%
- Higher pileup level & higher pileup cut threshold

→ rejected events have less significance, almost no effect on sensitivity.

In 2010, pileup reduced by beam optimization

→ ε_γ (>48MeV) = 60% (expected)

Systematic errors

	Uncertainty	
Normalization	8 %	e^+ mementum dep. ⊕ γ det. ε ⊕ trigger ε
E_γ scale	0.4 %	Light yield stability, gain shift
E_γ resolution	7 %	
E_e scale	50 keV	From Michel edge
E_e resolution	15 %	
$t_{e\gamma}$ center	15 ps	
$t_{e\gamma}$ resolution	10 %	RD peak
Angle	7.5 mrad	Tracking ⊕ LXe position
Angle resolution	10 %	
E_e-ϕ_e correlation	50%	MC evaluation