Performance of the Liquid Xenon Scintillation Detector for the MEG Experiment

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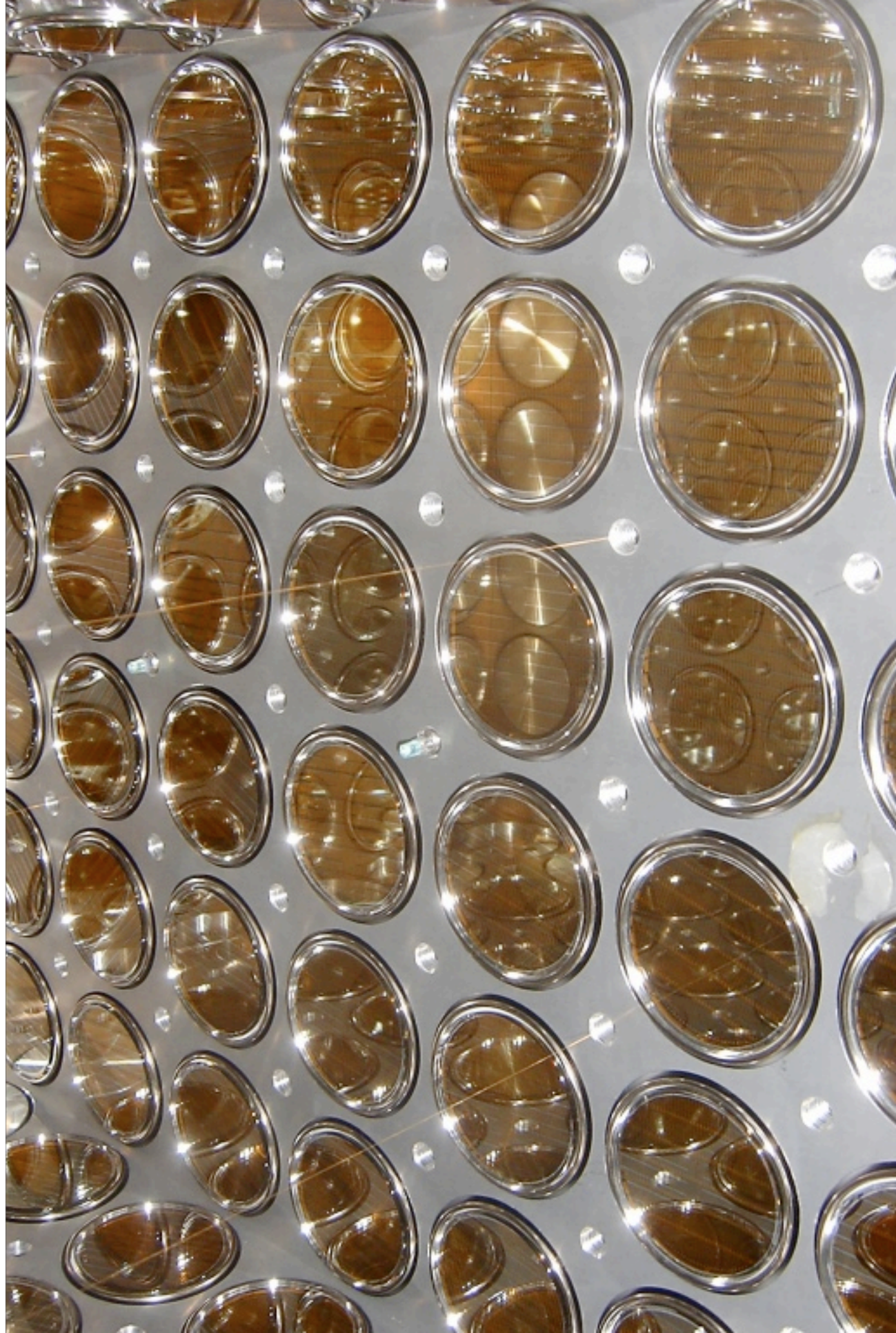
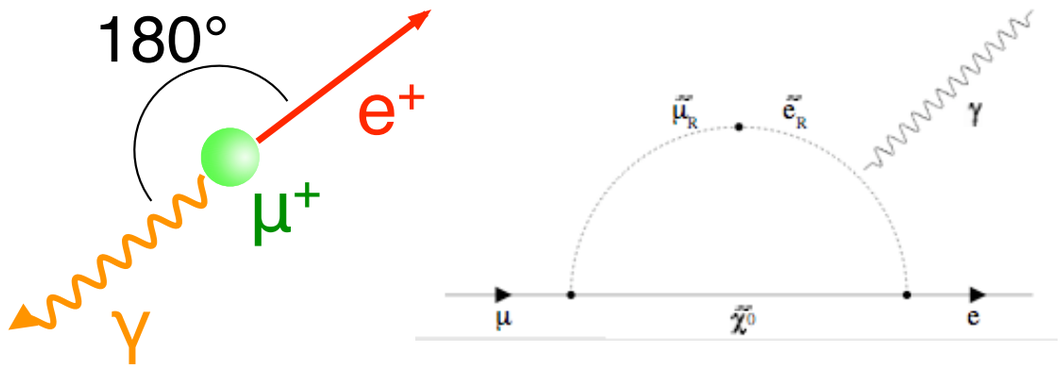
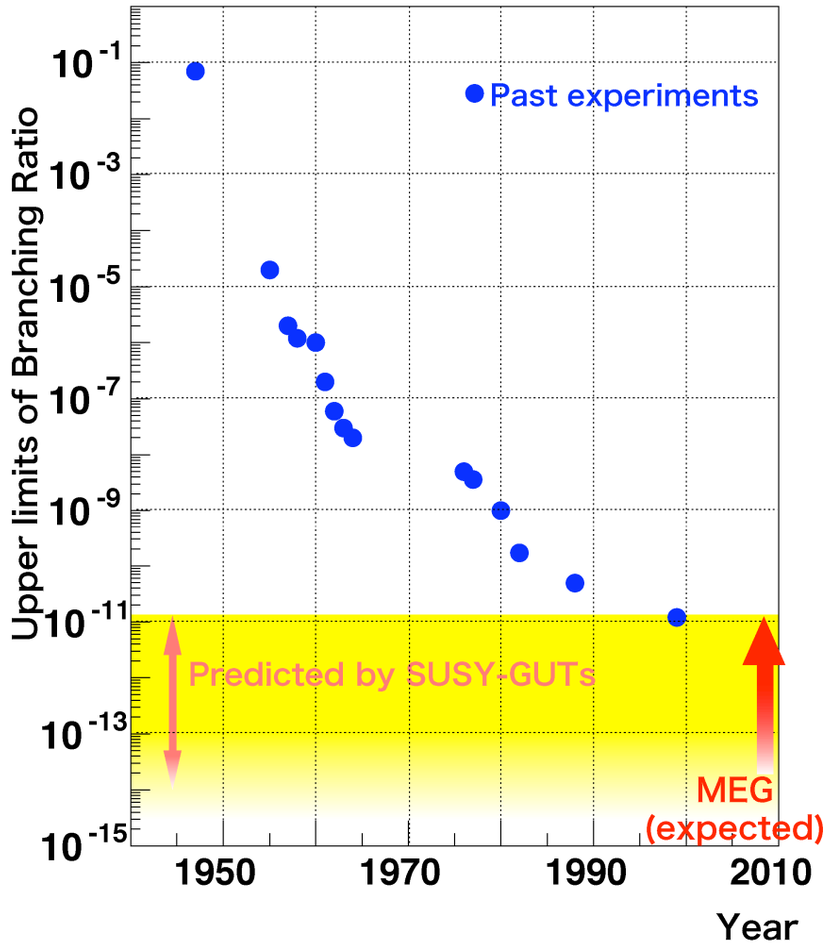


What Is MEG?

- MEG is an experiment to seek evidence for lepton flavor violating muon decay, $\mu \rightarrow e\gamma$.
- Since $\mu \rightarrow e\gamma$ is forbidden in the Standard Model (SM), it can be a clear evidence for new physics beyond the SM such as SUSY-GUTs.
- Expected sensitivity ~ BR~10^{-13}-10^{-14} improving the present limit by two-three orders of magnitude.
- Essence of MEG
  - World's most intense DC muon beam up to 2×10^{8} μ^{+}/sec at Paul Scherrer Institute
  - MEG detector
    - Liquid Xe photon detector
    - COBRA positron spectrometer

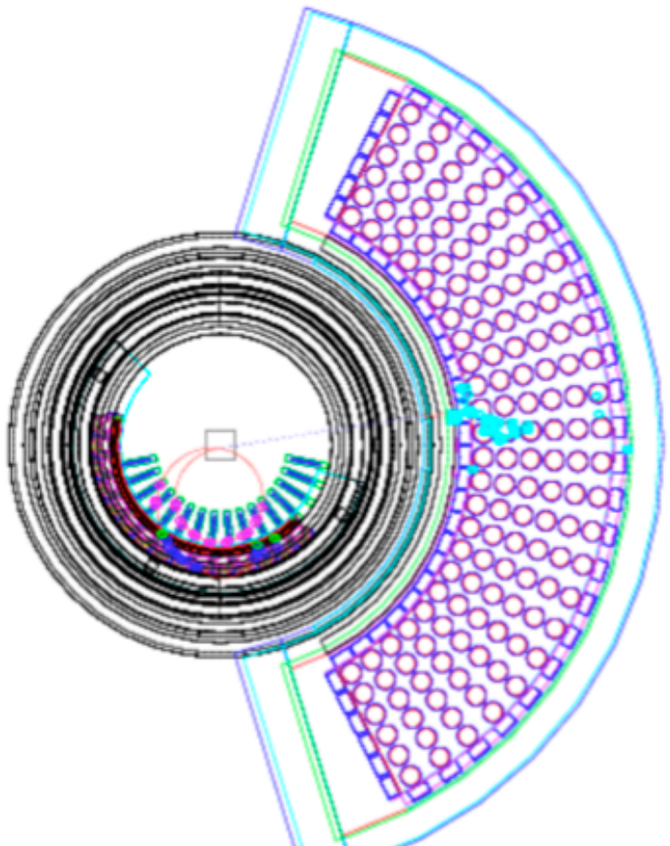


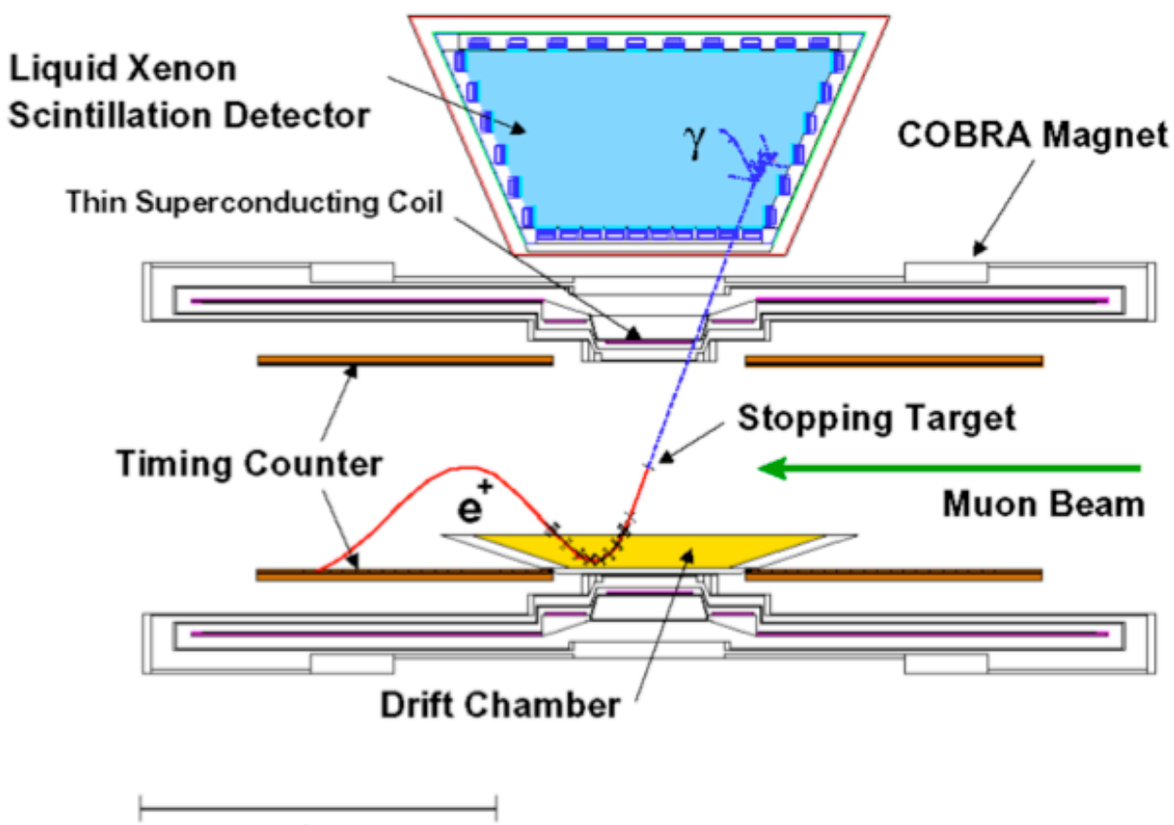
$\mu \rightarrow e\gamma$ search history



MEG Detector in a Nutshell

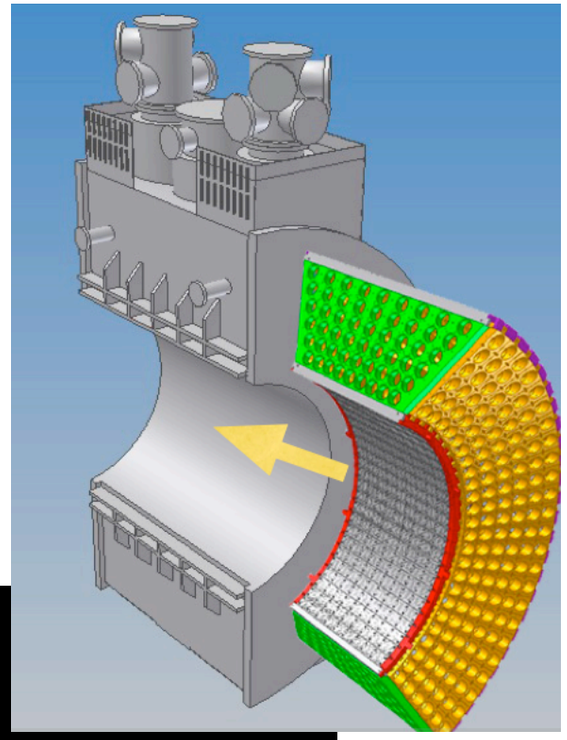
- Photon detection: LXe scintillation detector→this work
- Positron detection: COBRA positron spectrometer
  - Superconducting magnet with gradient field
  - Low-material drift chamber system to measure positron momentum
  - Fast timing counters to measure positron timing

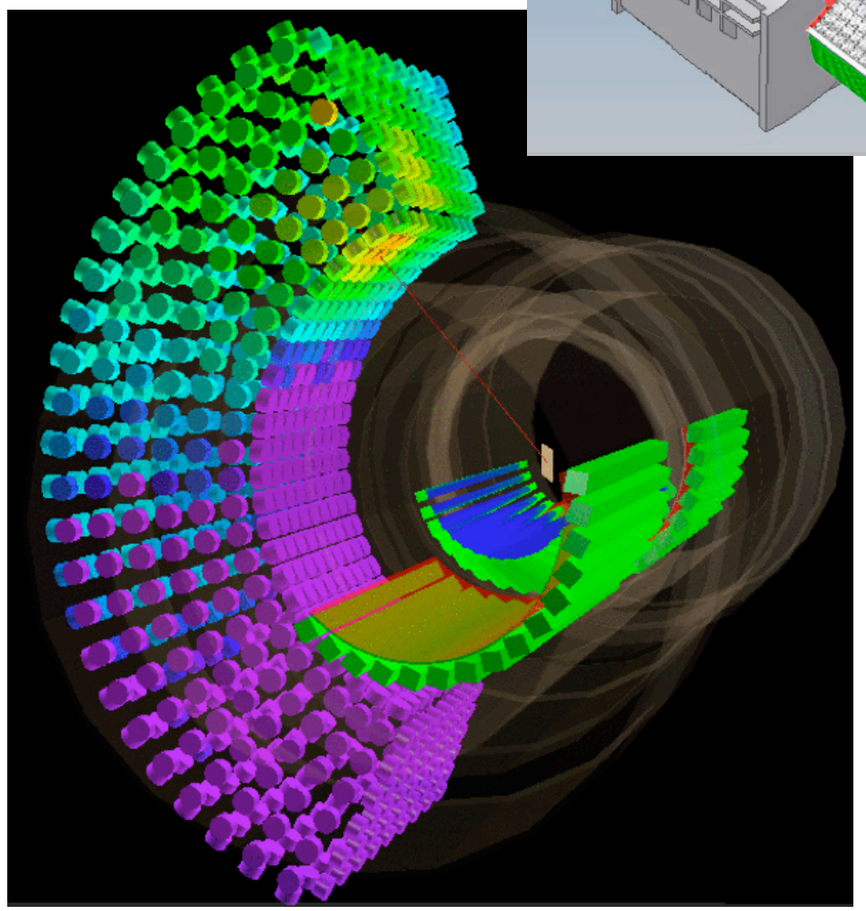




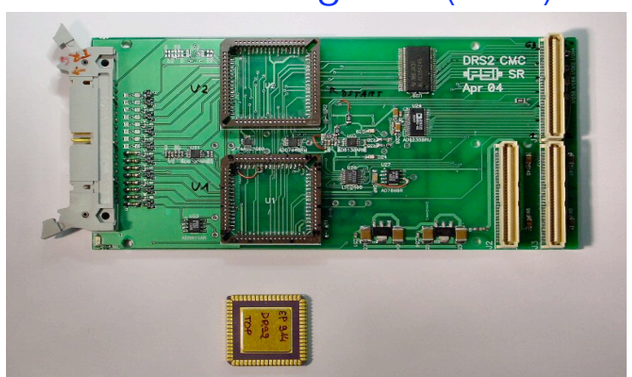
Liquid Xenon Photon Detector

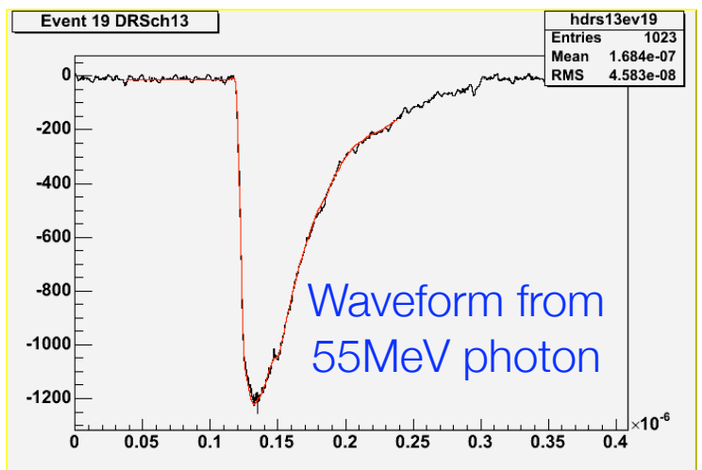
- Measure energy, position and time of 52.8MeV-photon from μ→eγ
- All sides of C-shape 800L LXe are surrounded by 848 photomulipliers(PMTs).
- All PMTs read out by waveform digitizer→pileup rejection, particle ID
- How to measure high energy gamma-ray?
  - Energy: collect scintillation light as much as possible
  - Position: PMT output distribution
  - Time: average photon arrival time





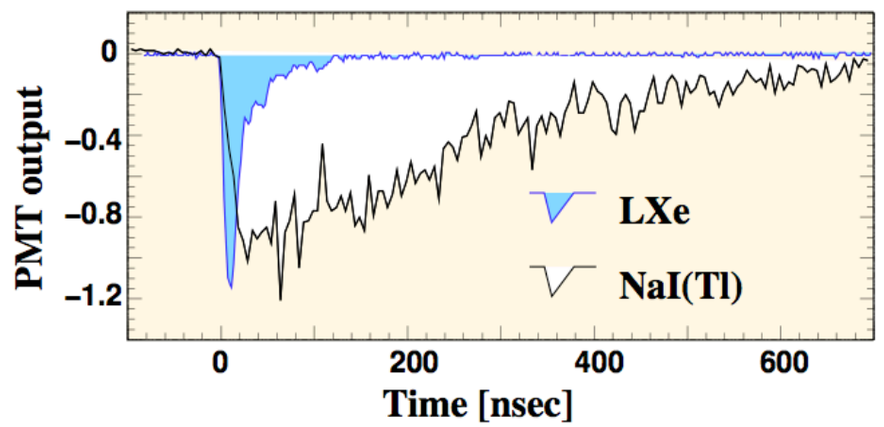
Waveform digitizer (DRS)

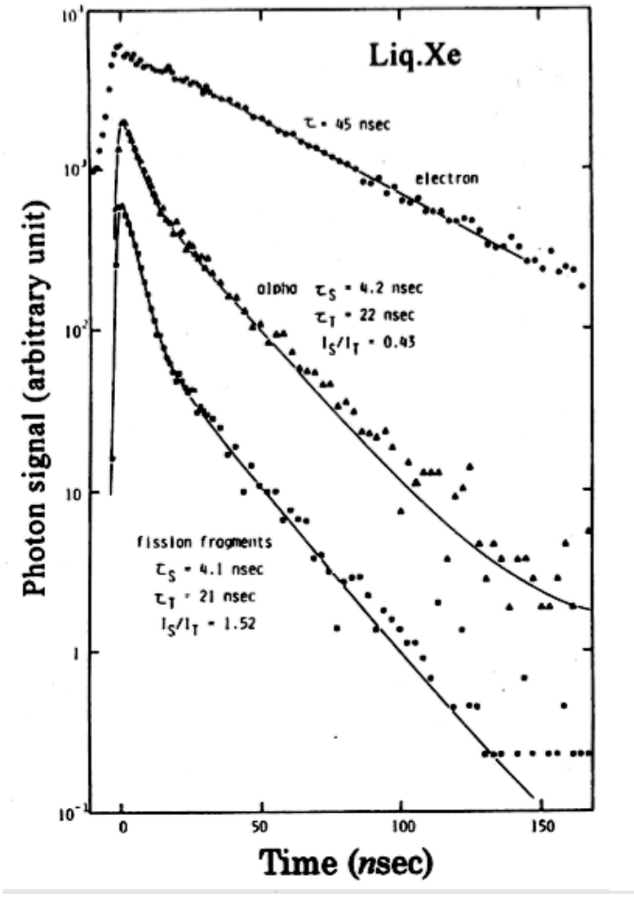




Liquid Xenon Photon Detector, cont'd

- Why LXe?
  - High light yield (75% of NaI(Tl))
  - Short radiation length (X_0=2.77cm)
  - Fast response
  - Homogeneous
  - Can be large and non-segmented
  - Purification even after the construction
  - No self-absorption of scintillation light





Excitation

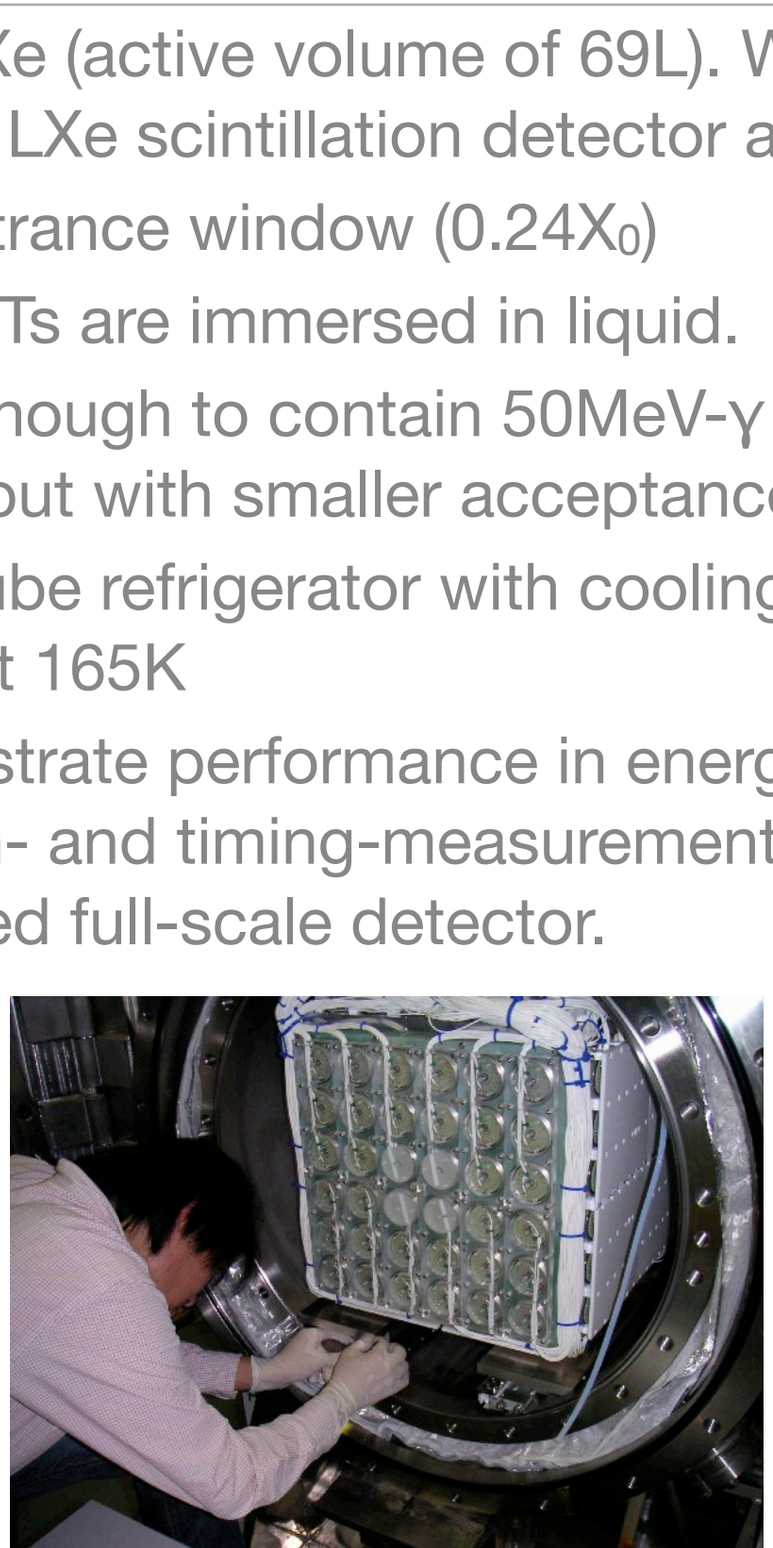
$$\begin{aligned} \mathrm{Xe} + \mathrm{Xe}^* &\rightarrow \mathrm{Xe}_2^*, \\ &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

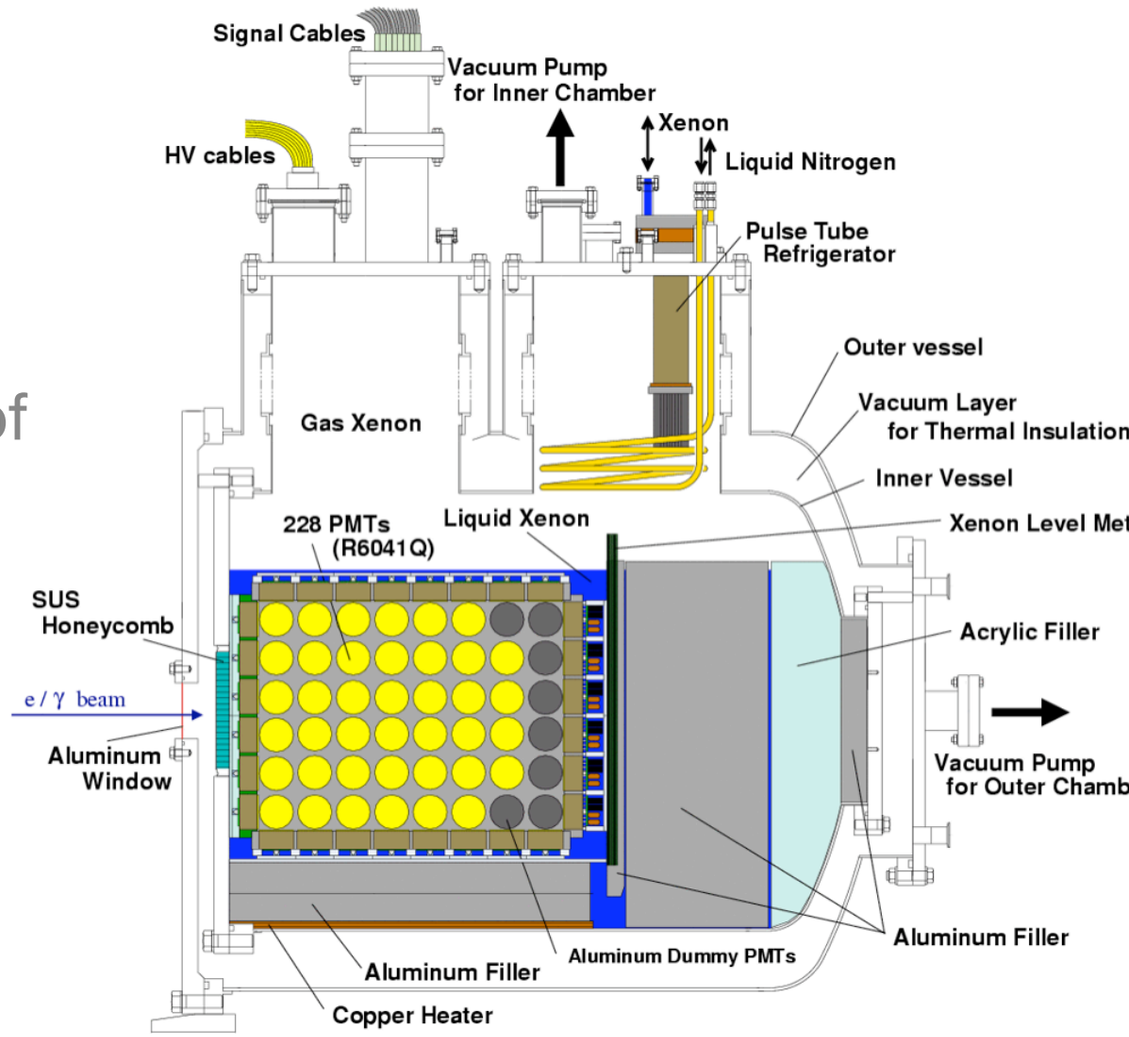
Ionization and recombination

$$\begin{aligned} \mathrm{Xe}^+ + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^+, \\ \mathrm{Xe}_2^+ + e &\rightarrow \mathrm{Xe}^{**} + \mathrm{Xe}, \\ \mathrm{Xe}^{**} &\rightarrow \mathrm{Xe}^* + \text{heat}, \\ \mathrm{Xe} + \mathrm{Xe}^* &\rightarrow \mathrm{Xe}_2^*, \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu, \end{aligned}$$

100L Prototype

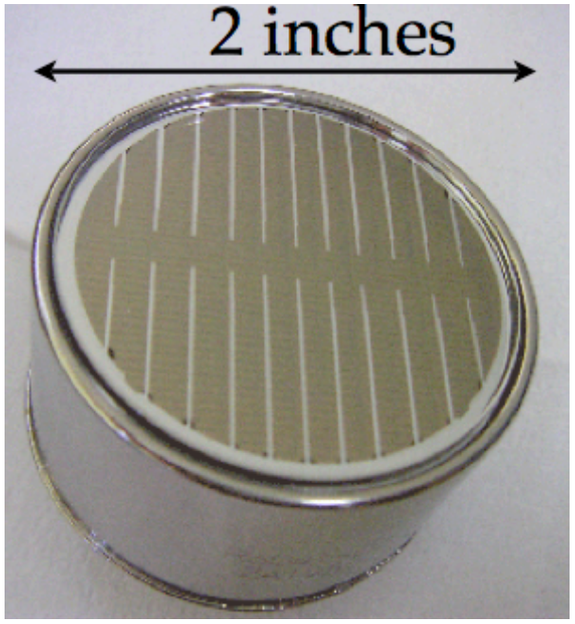
- 100L LXe (active volume of 69L). World's biggest LXe scintillation detector already.
- Thin entrance window ($0.24X_0$)
- 238 PMTs are immersed in liquid.
- Large enough to contain 50MeV-γ event ($17X_0$), but with smaller acceptance.
- Pulse tube refrigerator with cooling power of 190W at 165K
- Demonstrate performance in energy-, position- and timing-measurements of the proposed full-scale detector.



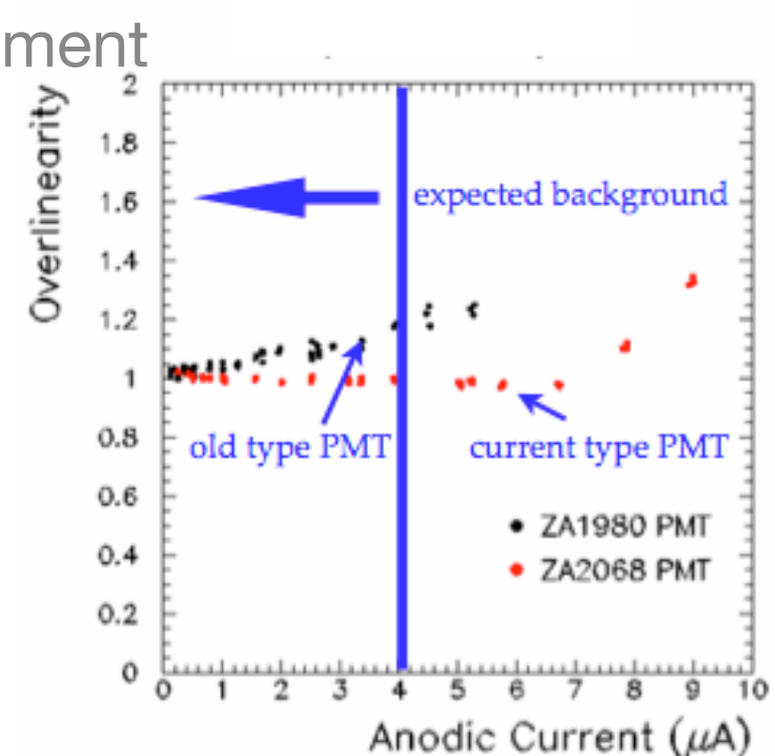


PMT

- Developed in collaboration with Hamamatsu
- Operational in LXe (T=165K, pressure<3atm)
- Synthetic quartz window (λx_e=175nm)
- Photocathode: K-Cs-Sb
  - QE=15% at 165K
  - Al strips to supply electrons at low temperature
- Metal channel dynode (tube length = 33mm)
- Low anode current to minimize heat dissipation in LXe.
- Zenner diode in breeder circuit for high rate environment

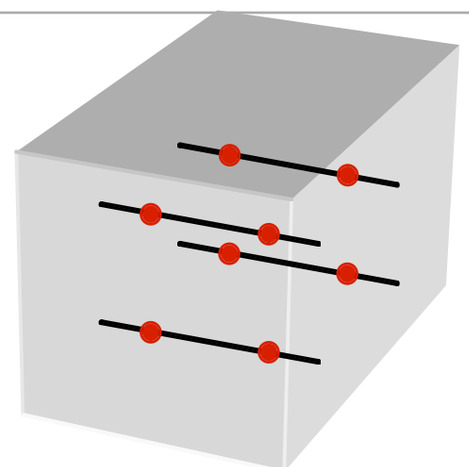


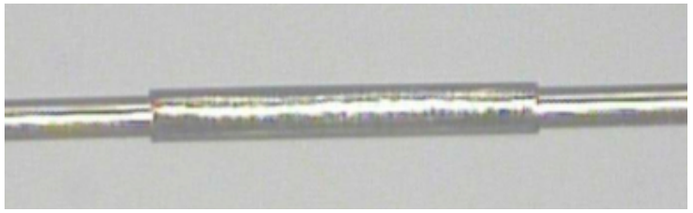
Size	57mm ϕ
Active area size	45mm ϕ
PMT length	32mm
Photocathode material	K-Cs-Sb
Dynode type	Metal channel
Number of dynode	12
Typical HV	900V
Typical gain	1×10^6
Typical Q.E.	15%
Rise time	2nsec
Transit time	12.5nsec Typ.
TTS	0.75nsec Typ.



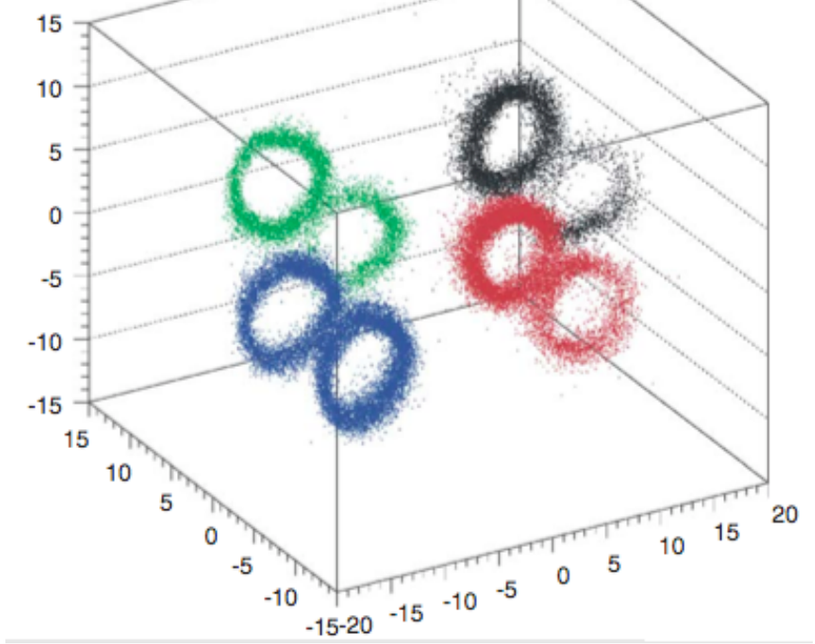
Alpha Spot Source on Wire

- Alpha spot sources on wire for calibration and stability monitor.
- ^{210}Po (30-100Bq) electrodeposited on a gold-plated tungsten wire (50μmϕ)
- Each PMT can see the light from alpha sources at different distances.
- ^{241}Am will be used for the full-scale detector.

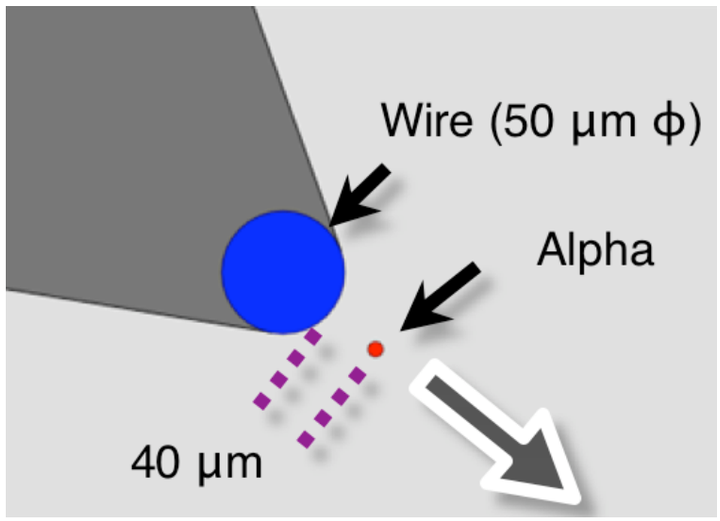




Reconstructed alpha-source positions

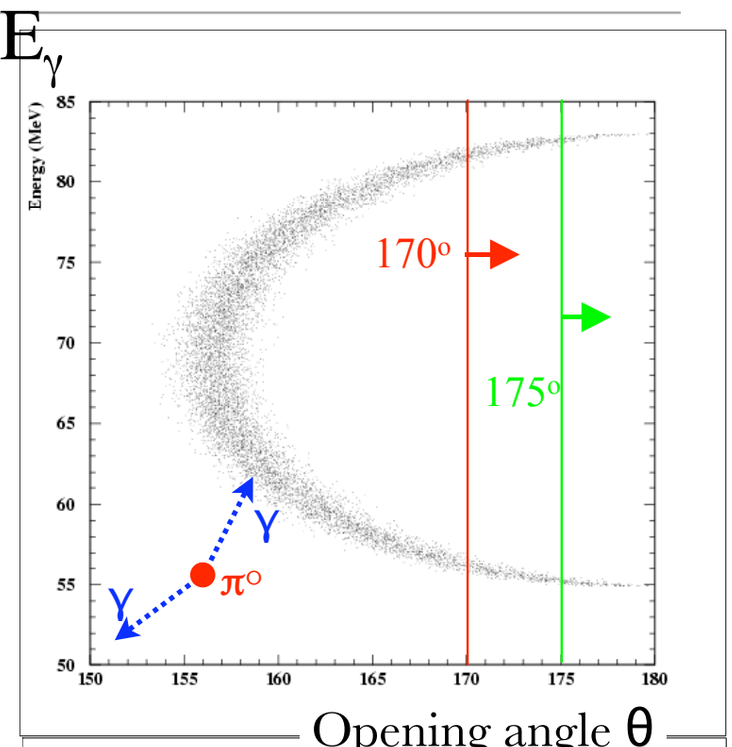


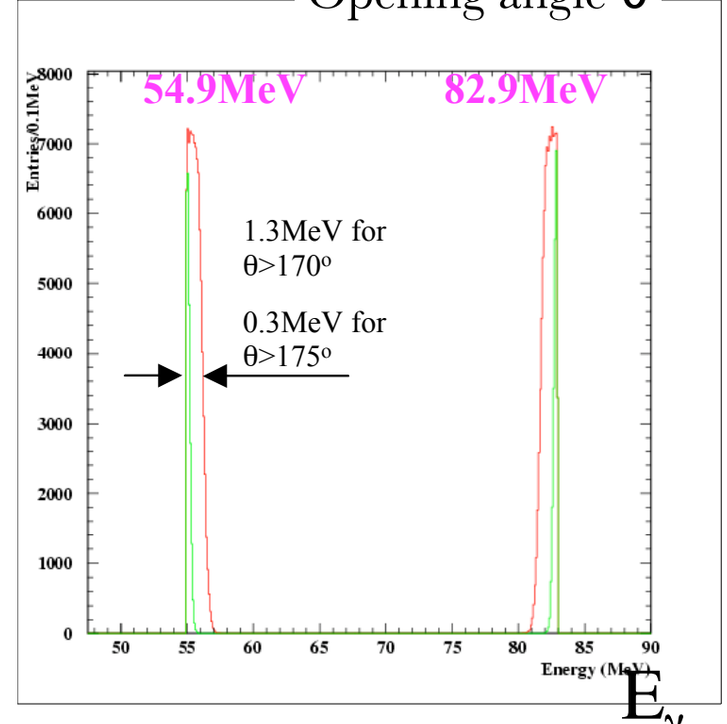
Shadow effect



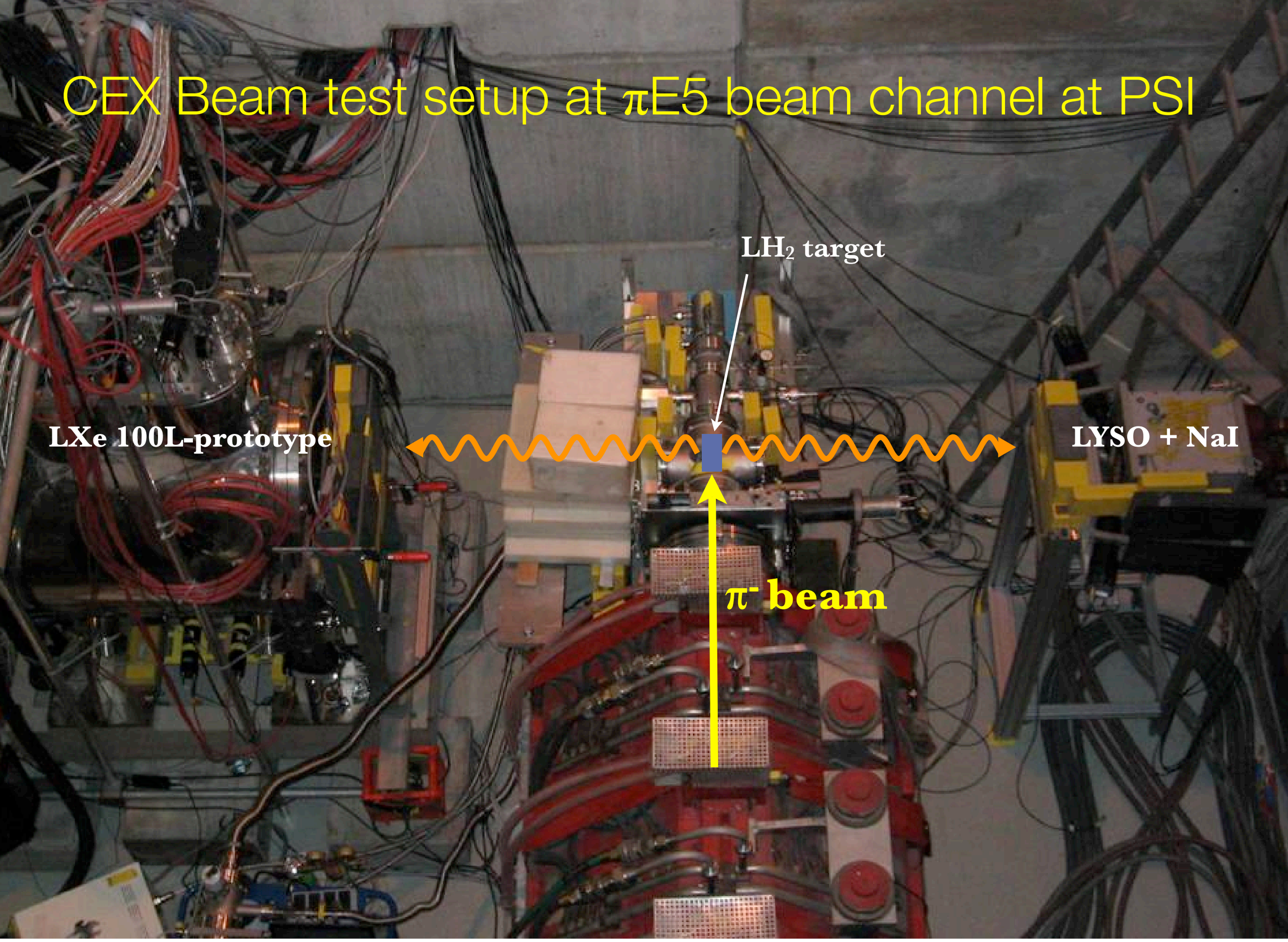
Beam Test with CEX Process

- Two photons from π^0 produced in charge exchange (CEX) process, $\pi^-+p \rightarrow \pi^0+n$.
  - Almost monochromatic 55MeV and 83MeV photons by selecting two photons with an opening angle θ~180°
  - Energy spread: 0.5%(2.3%) requiring θ>170°(175°) at 55MeV
- 129MeV photon from radiative capture process, $\pi^-+p \rightarrow \gamma+n$.
- Monochromatic photon (55, 83, and 129MeV) available.
- Improvements compared with the previous work
  - Front half of the PMTs were replaced with new PMTs with higher QE by a factor of three.
  - Energy and timing resolutions were measured with better photoelectron statistics.
  - Absolute timing resolution was measured for the first time.



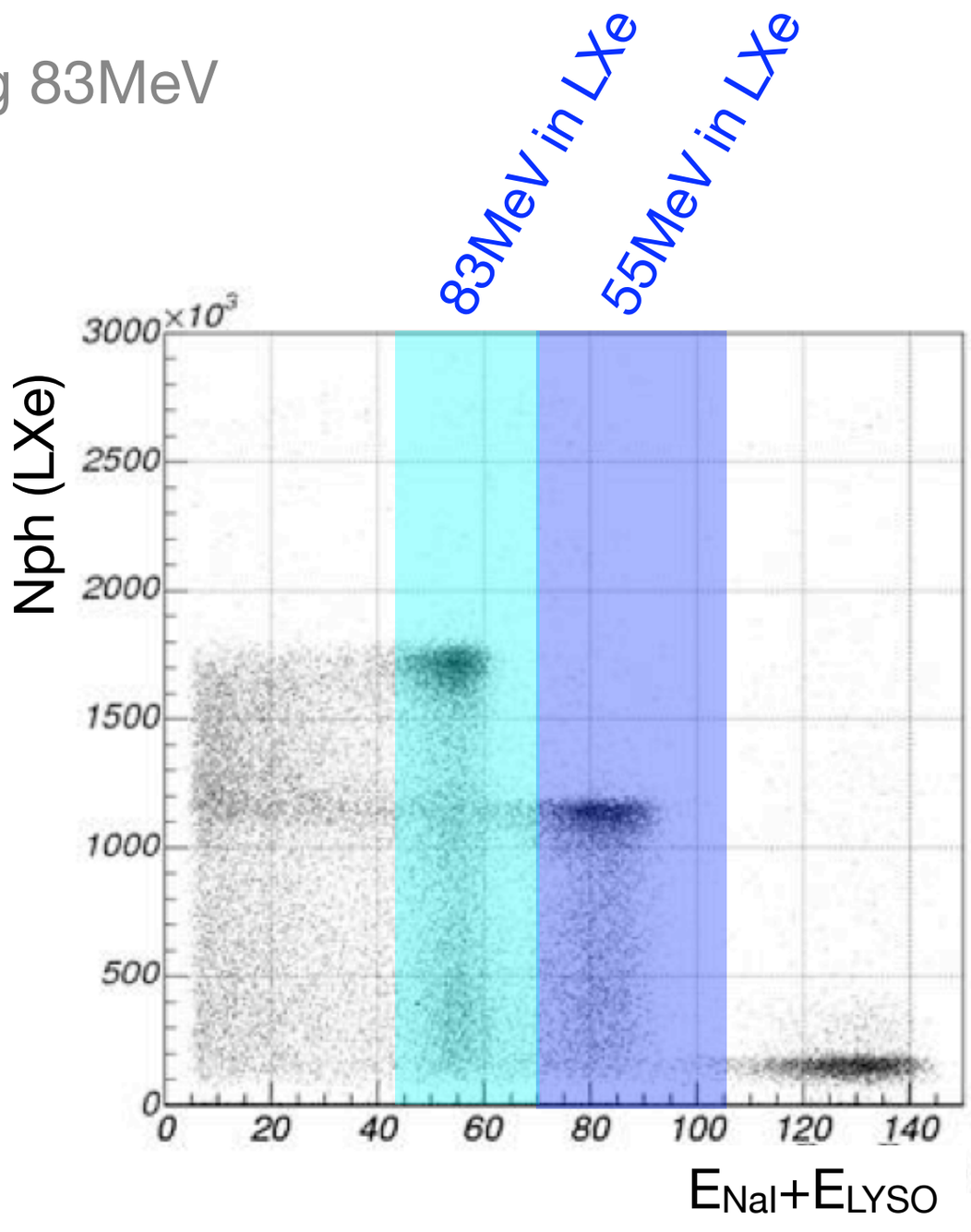


CEX Beam test setup at πE5 beam channel at PSI



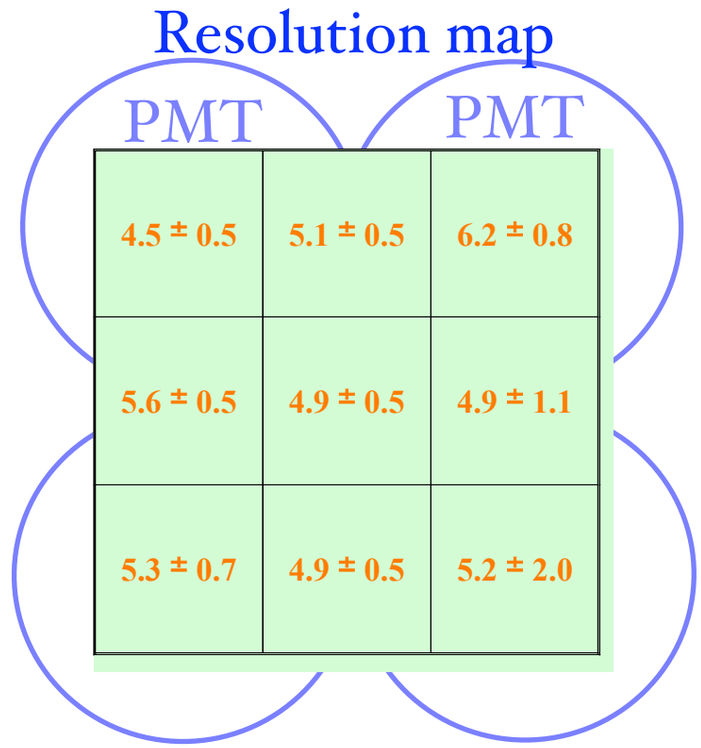
Energy Measurement

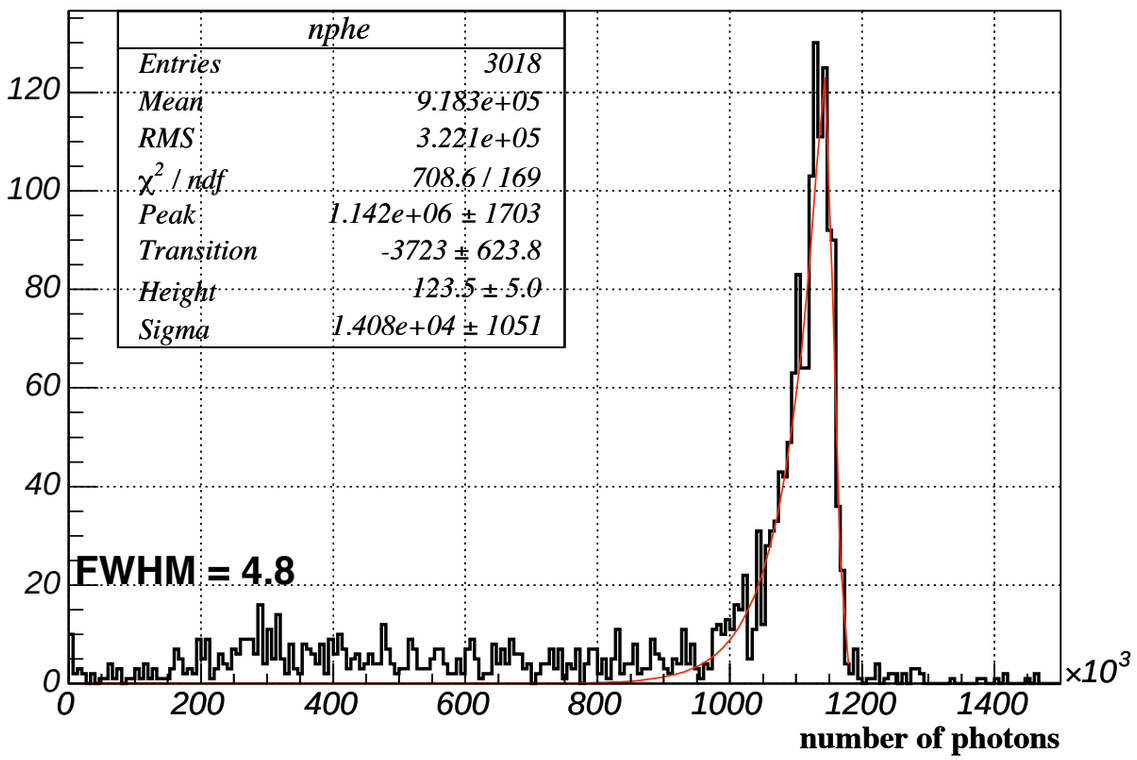
- 55MeV (83MeV) event in LXe by selecting 83MeV (55MeV) event in NaI
- |x|, |y| < 2cm
- 83MeV event in LXe
  - 45MeV < $E_{NaI}+E_{LYSO}$ < 70MeV
- 55MeV event in LXe
  - 70MeV < $E_{NaI}+E_{LYSO}$ < 105MeV
- Cut and correction with depth parameter

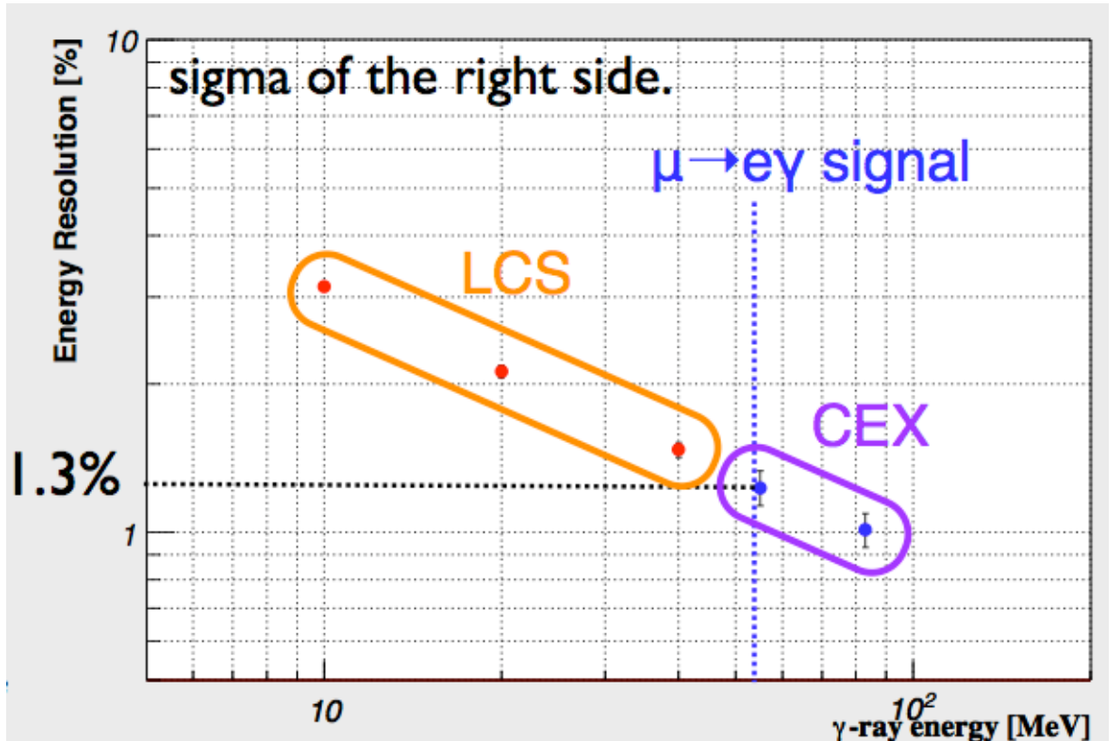


Energy Measurement, Result

- Energy resolution obtained in CEX test at detector center
  - 4.8%(FWHM)
  - 1.23%(σ on the right side)



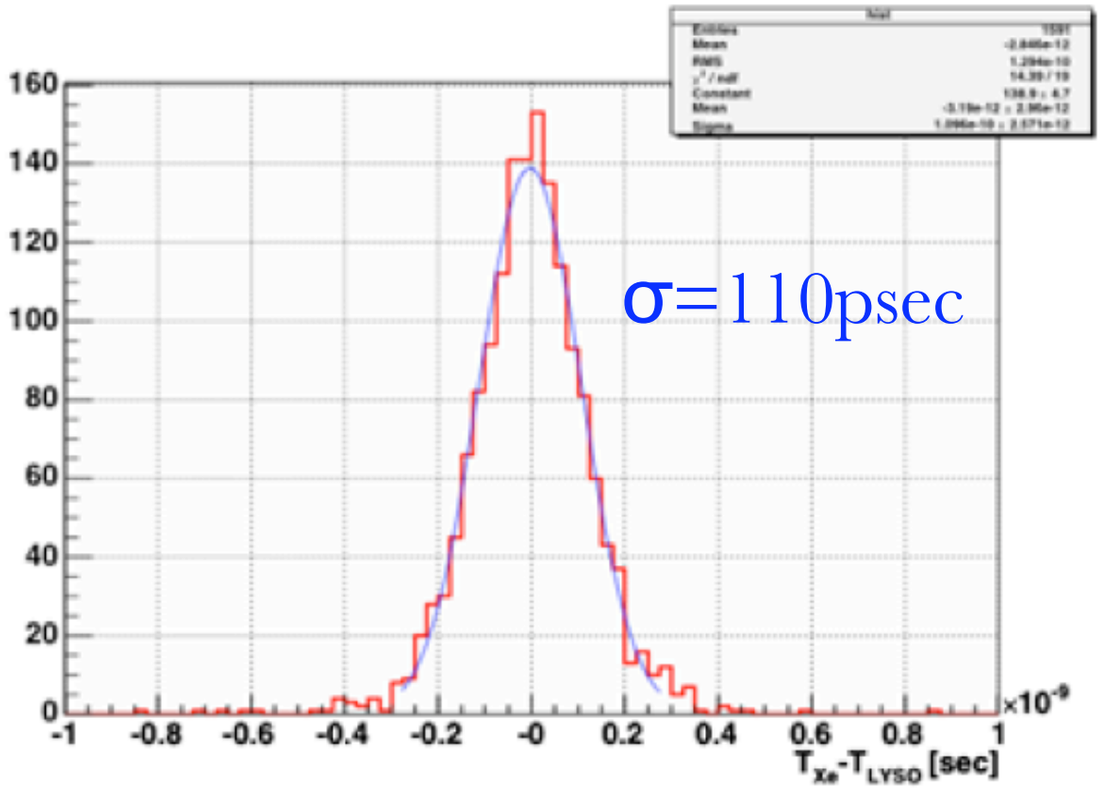




Time Measurement

- Timing of the event was measured with a time reference counter (LYSO).
- Timing at LXe calorimeter is calculated by averaging photon arrival time over the PMTs with a weight of number of photoelectrons.
- After correction of time-walk and reconstructed position, we obtained at 55MeV
  - σ=110psec
- This includes timing resolution of reference counter (64psec) and target size effect (61psec).
  - $\sigma_{absolute}$=110psec ⊖ 64psec ⊖ 61psec
    = 65psec

Reconstructed time spectrum for 55MeV



Summary

- High-performance LXe scintillation detector was developed for the MEG experiment.
- 100L prototype detector with higher-QE PMTs was tested out using high-energy photon beam.
- Energy resolution of 1.23%(in sigma on the right side) and timing resolution of 65psec in sigma were obtained for 55MeV photon.
- The results from the beam tests confirm that the full-scale detector under construction would fulfill the requirement for the MEG experiment to search for $\mu \rightarrow e\gamma$ with a sensitivity of BR $< 10^{-13}$.
- MEG experiment is starting next year together with...

800L Full-Scale Detector Is Showing Up...

PMT support structure

Low material front PMT structure

Cryostat

LXe purifier (gas phase)

Xe storage tanks