$\mu \rightarrow e\gamma$ decay search with a liquid Xe scintillation detector

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Contents

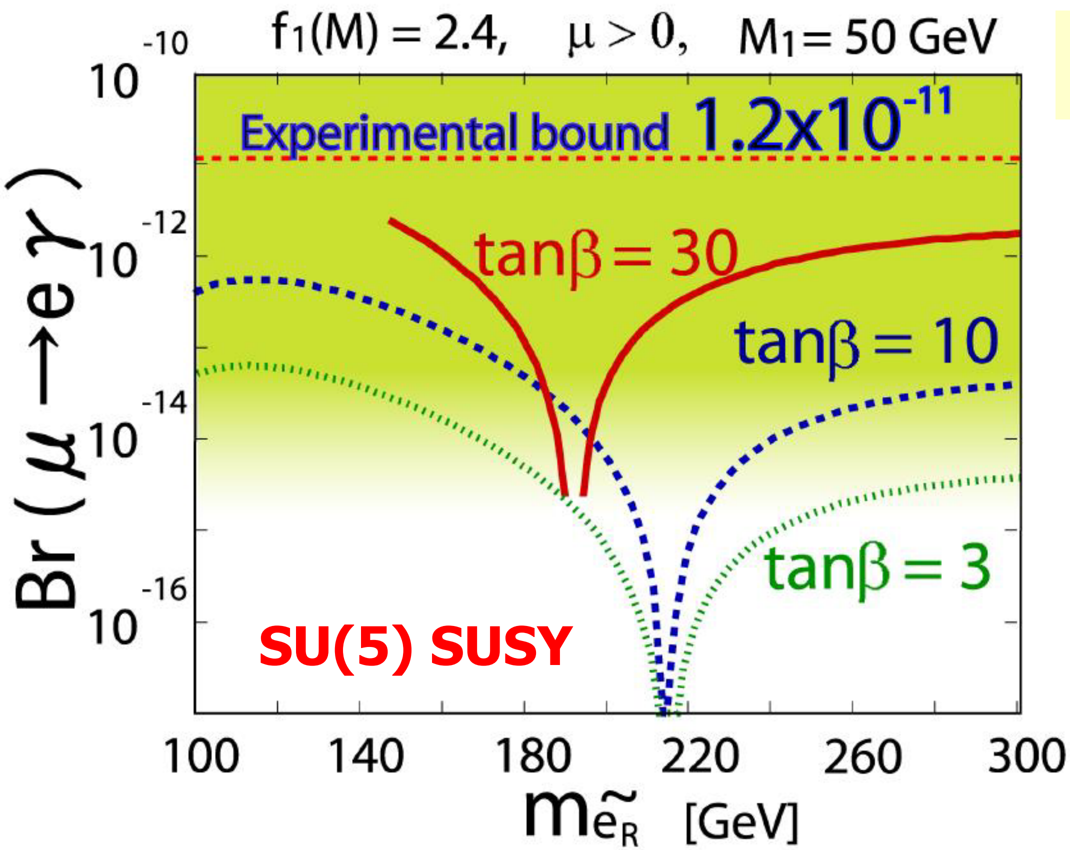
Collaboration for LXe detector in Japan

- ICEPP, Univ. of Tokyo
  小曽根健嗣、大谷航、澤田龍、西口創、真下哲郎、三橋利也、三原智、森俊則、山下了
- RISE, Waseda Univ.
  岡田宏之、菊池順、鈴木聡、寺沢和洋、道家忠義、山口敦史、山下雅樹、吉村剛史
- IPNS-KEK
  春山富義、真木晶弘、八島純

Thanks for beam tests to

- AIST
  豊川弘之,、大垣英明
- KSR, Kyoto Univ.
  野田章、白井敏之、頓宮拓

Physics Motivation



J. Hisano et al., Phys. Lett. B391 (1997) 341
MEGA, Phys. Rev. Lett. 83 (1999) 1521

- **MEGA** (～1999)
  Br < 1.2×10^{-11}
- **SINDRUM II**
  (μ e conversion search)
- SK (neutral LFV)
- Anomalous Muon (g-2)

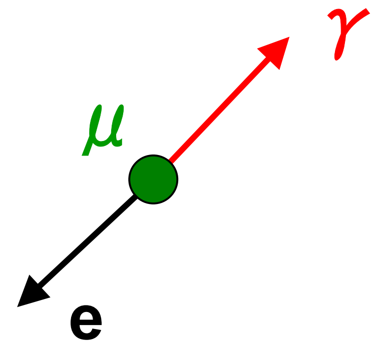
The MEG experiment is aiming to verify a new physics beyond the SM by searching the $\mu e \gamma$ decay.

Signal and Backgrounds

- $\mu \rightarrow e\gamma$ **decay**
  - $E_e = E_\gamma = 52.8$ MeV
  - Back to back, in time
  - ➢ **Sensitivity**

    Single Event: 0.94×10^{-14}

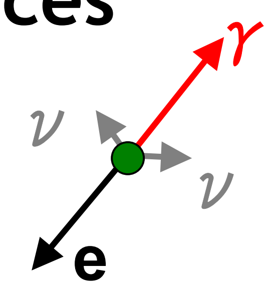
    $N_m = 1\times10^8$/sec, 2.2×10^7 sec running
    $\Omega/4\pi = 0.09$, $\varepsilon_e = 0.95$, $\varepsilon_\gamma = 0.7$, and $\varepsilon_{sel} = 0.8$

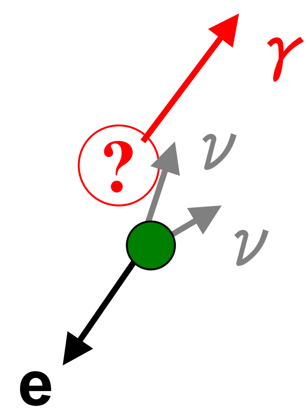


- **Two Major background sources**
  - Radiative μ^+ decay
  - Accidental overlap

  NOT back to back, NOT in time

  ⇨ Reduced down to 10^{-15} level



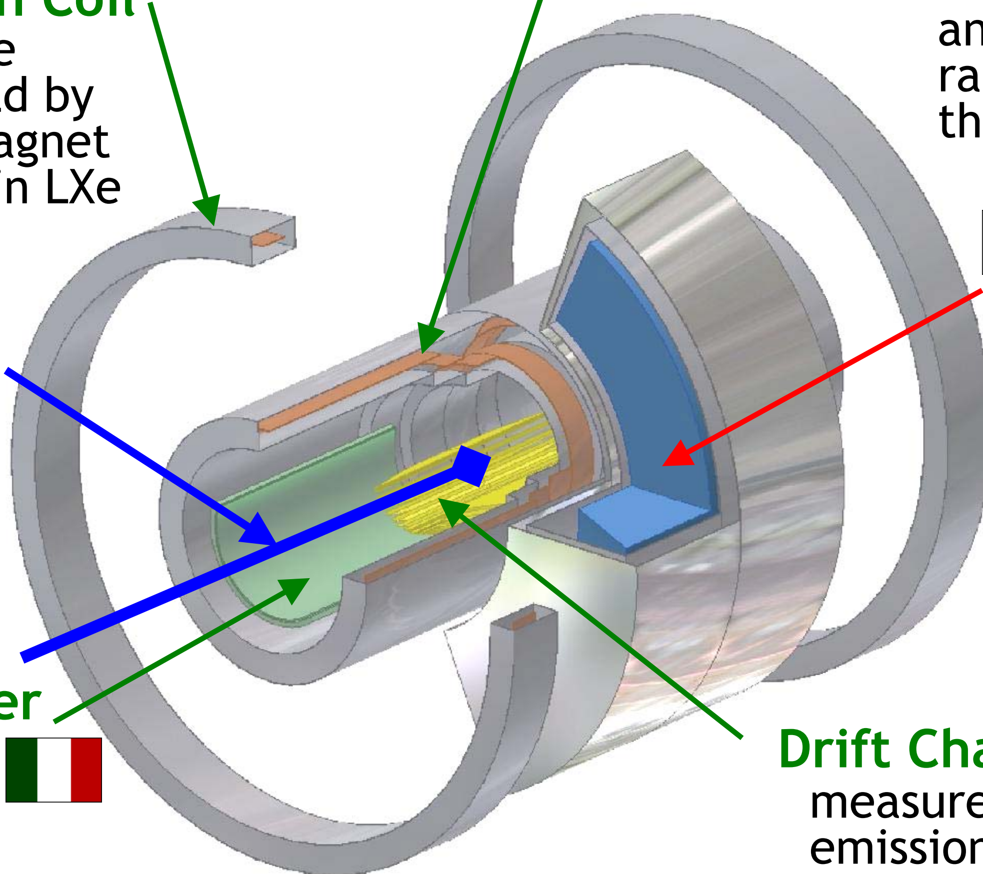


MEG Detector

Compensation Coil diminishes the residual B field by the COBRA magnet for the PMTs in LXe detector.

COBRA Magnet makes the positrons swept away quickly, and the bending radius is independent the emission angle.

Surface μ beam can be supplied at the rate of 10^8 sec^{-1}.



LXe scintillation detector measures time, energy, and position of γ rays with a great accuracy.

Timing Counter measures the arrival time of the positrons.

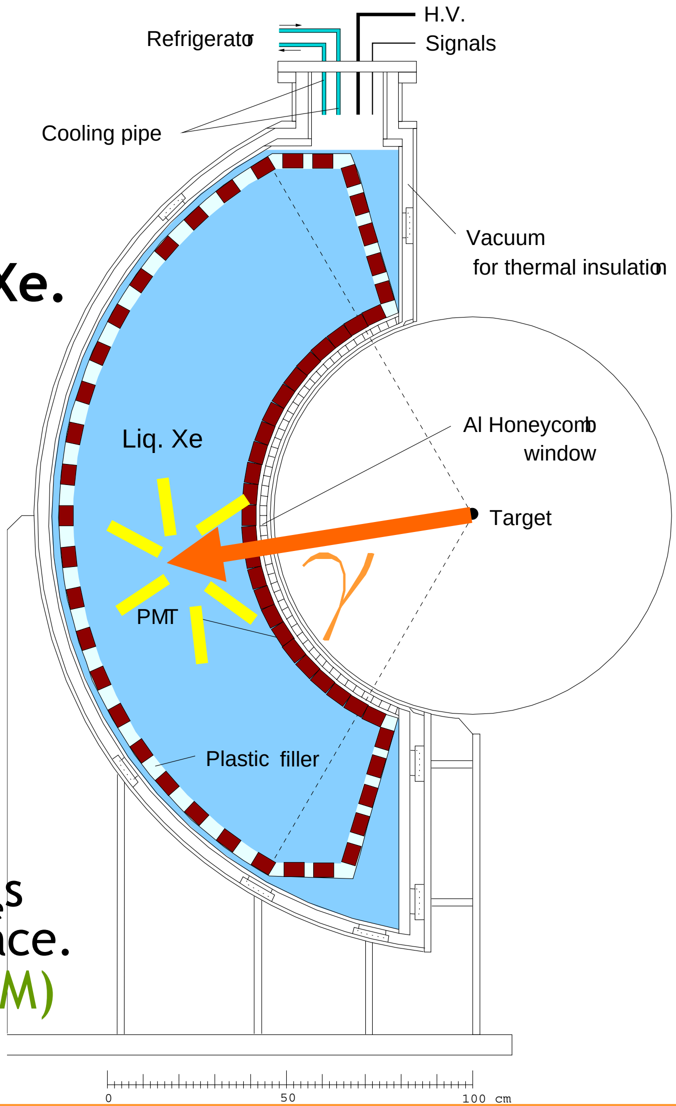
Drift Chamber measures the energy and emission angle of the positrons from the tracking points.

LXe scintillation detector for the MEG experiment

Detector concepts

Observing as many photoelectrons as possible with a great accuracy.

- **Many PMTs are directly immersed in LXe.**
  Kamiokande-like detector.
- **Thin material on the incident face.**
  Al honeycomb, compact PMT…



Incident γ-ray reconstruction

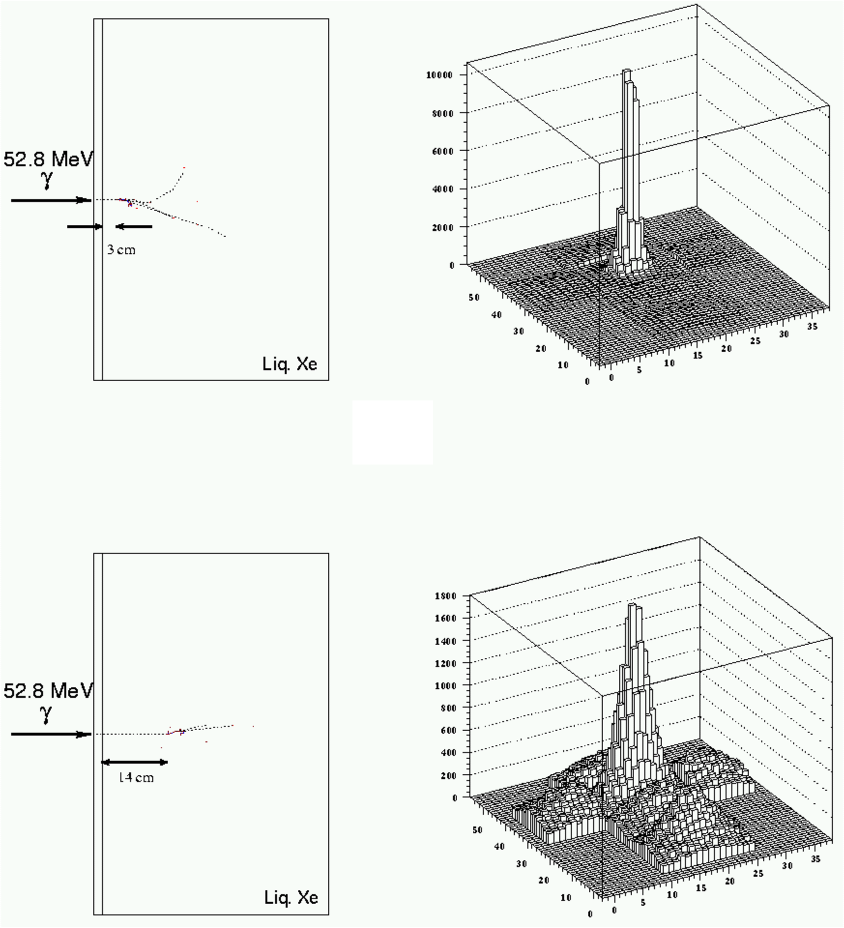
Energy: total number of photoelectrons(N_{pe})
1.4~2.0 % (FWHM)

Time: Average time in PMTs observing many photons.
~100 psec (FWHM)

Position: evaluated from the distribution of N_{pe}s observed by PMTs in front and back face.
4 mm in x and y, 16 mm in z (FWHM)

Position reconstruction

To estimate the 1st conversion points is the most important for reconstruction of the incident γ rays .

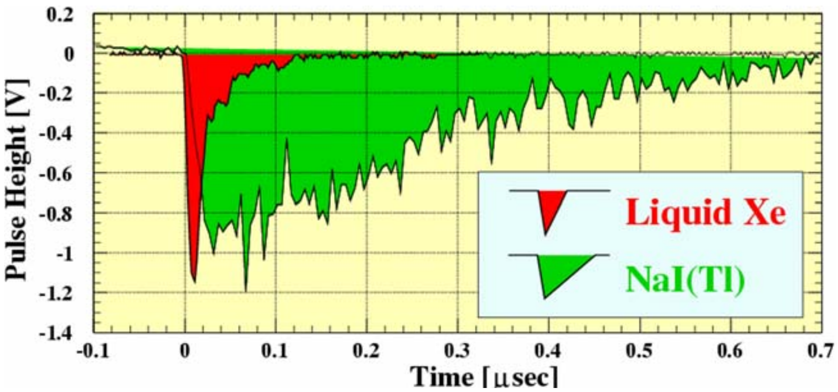


- Using the weighted mean of the distribution, the incident γ ray position is determined.

- Using the broadness of the distribution, the depth of the γ ray conversion point is determined.

Liquid Xe scintillator for the MEG experiment

- High density and High light yield
  - 1^{st} conversion depth: 2 cm ~ 10 cm
  - Wph: 21.7 eV (NaI: 17 eV)
  - T.Doke and K.Masuda, Nucl. Instr. And Meth.A420 (1999) 62.



- Fast Decay reduces pile-ups.
  - τ (recombi.) = 45 nsec

✓ Low temperature: 165 K
  requires refrigerator and special PMT.

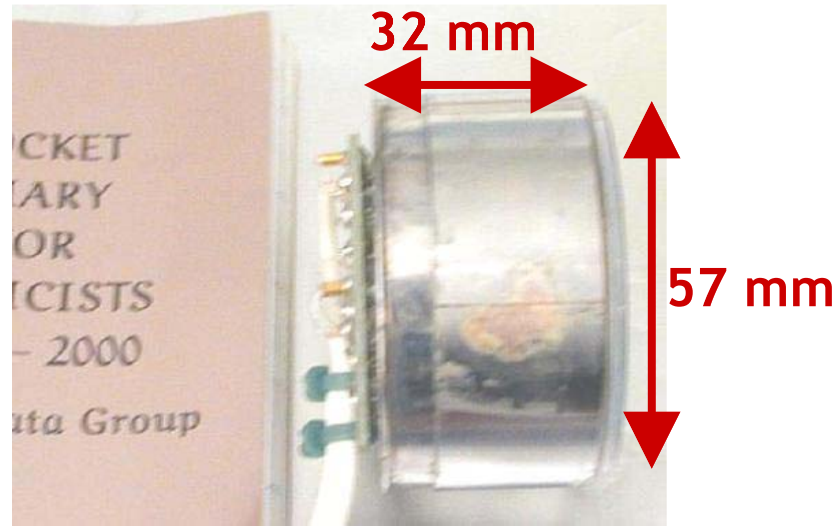
✓ Wavelength: ~175 nm
  requires special PMT.

PMT (HAMAMATSU R6041Q)

Features

- 2.5-mmt quartz window
- Q.E.: 6% in LXe (TYP)

  (includes collection eff.)
- Collection eff.: 79% (TYP)
- 3-atm pressure proof
- Gain: 10^6 (900V supplied TYP)
- Metal Channel Dynode → thin and compact
- TTS: 750 psec (TYP)
- Works stably within a fluctuation of 0.5 % at 165K

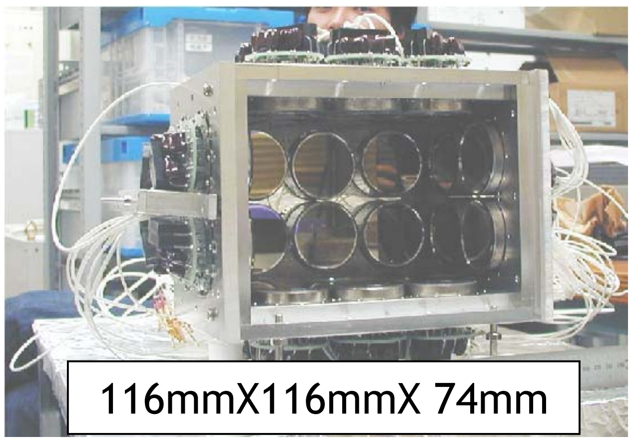


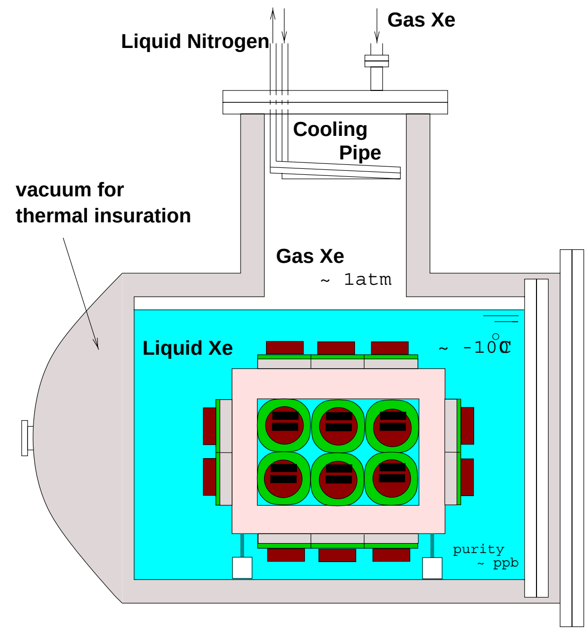
10-liter (small) prototype

Purpose

- First "Kamiokande"-like LXe detector
- Test for R6041Q in LXe and cryostat for LXe.
- Estimate of the performance for low energy γ rays

  Energy, time, and position resolutions with < 1.8-MeV γ sources.





- γ sources (^{137}Cs, ^{51}Cr, ^{54}Mn, ^{88}Y)

  Resolution evaluation
- α source (^{241}Am)

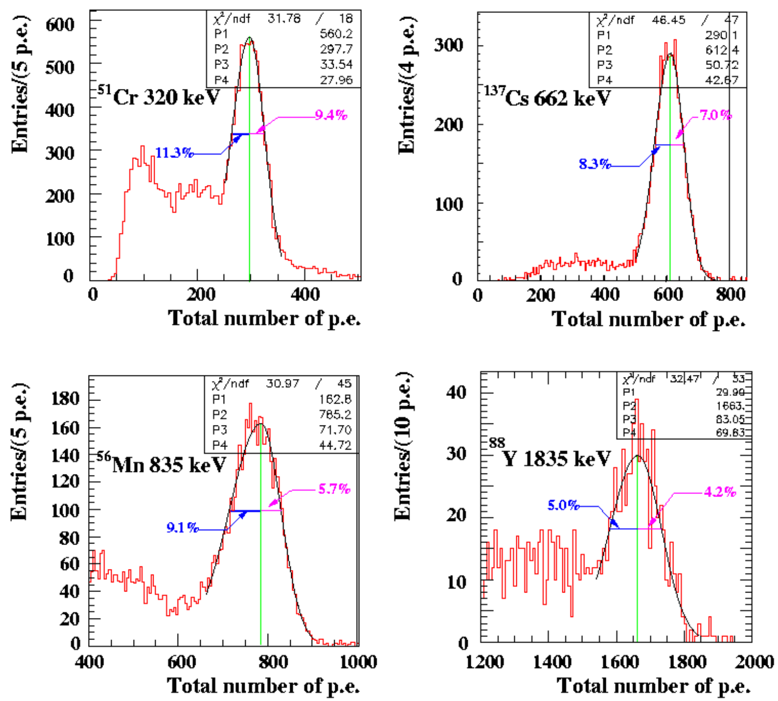
  PMT calibration, stability check
- LED

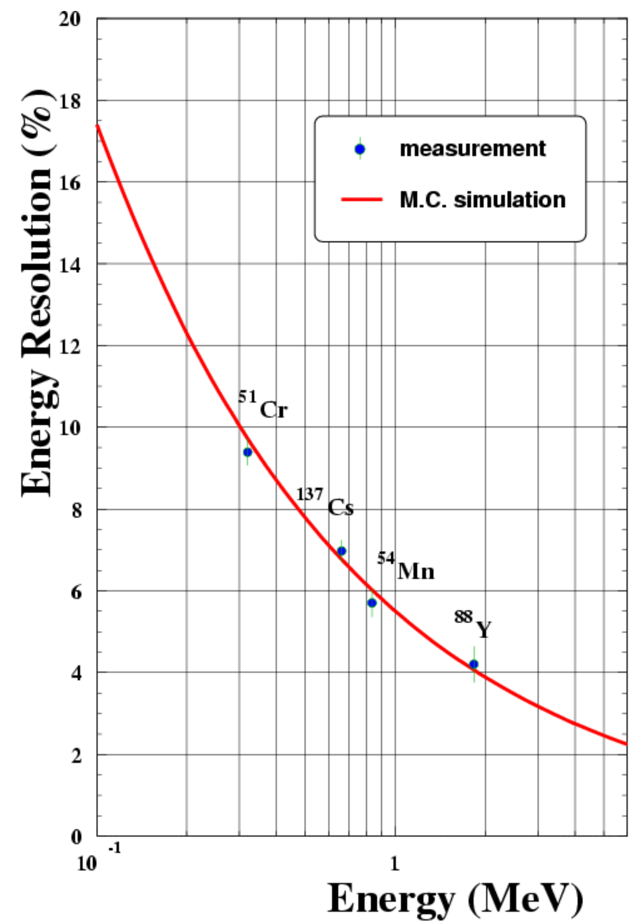
  PMT calibration

- 2.34-liter active volume
- 32 PMTs

Energy Resolution

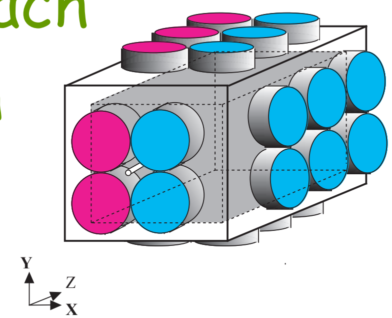
Fully-contained events in each energy distributions are fitted with an asymmetric Gaussian.



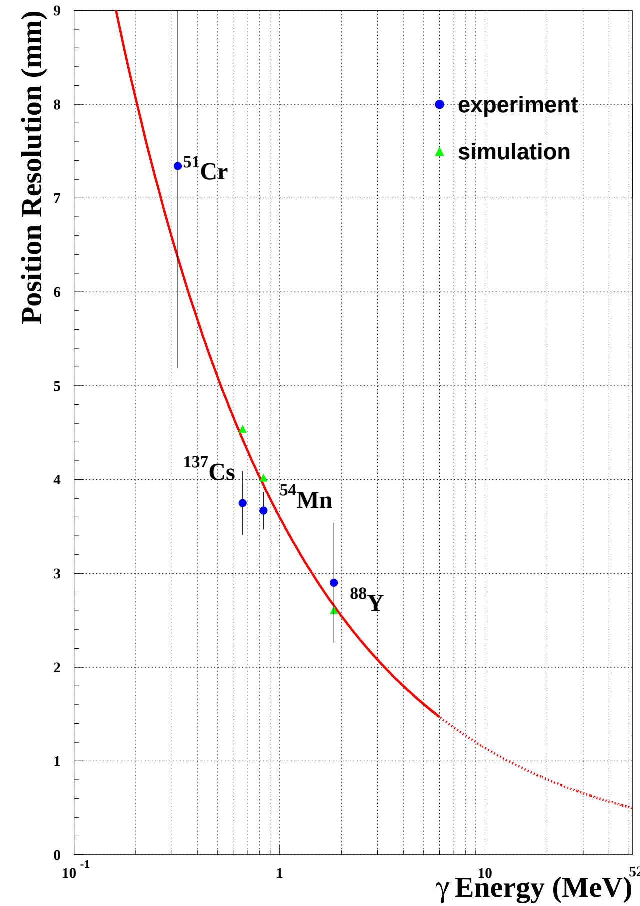


Position Resolution

- PMTs are divided into two groups.
- γ int. positions are calculated in each group and then compared with each other.

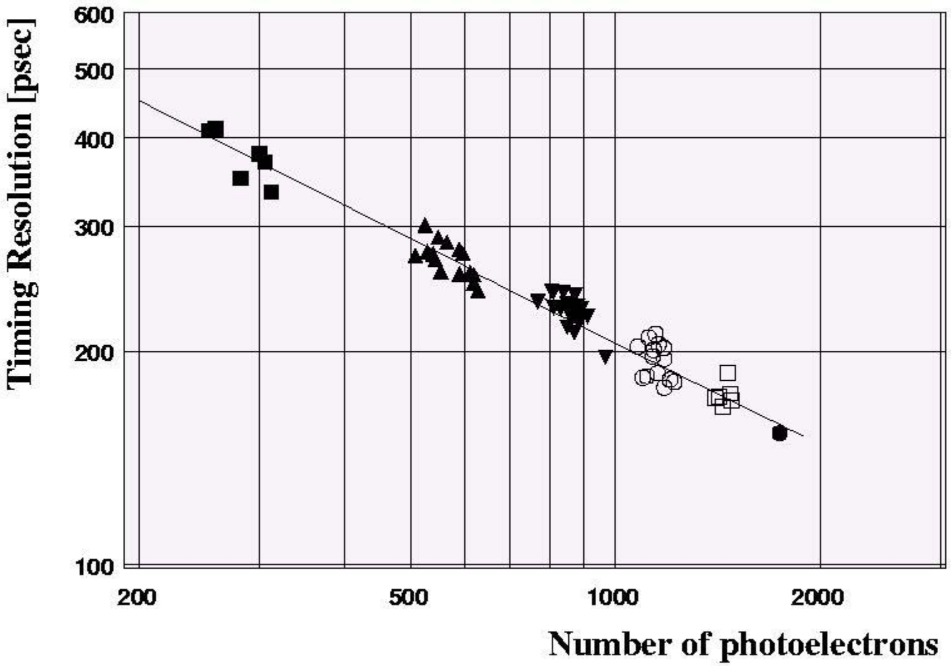


- Events in the central 2cmX2cm area are selected.
- Position resolution is estimated as $\sigma_{z1-z2}/\sqrt{2}$



Time Resolution

- PMTs are divided again into two groups.
- In each group the average of the time measured by TDC is calculated after slewing correction for each PMT.
- The time resolution is estimated by taking the difference between two groups.
- Resolution improves as $\sim 1/\sqrt{Npe}$
- **FWHM**<120 psec for 52.8 MeV γ.



Summary on Small Prototype

- Constructed the first LXe scintillation detector.
- The resolutions are evaluated for low energy γ.

  Energy: 4.2~9.4%, Position: 6.3 ~ 19 mm,

  Time: ~380 psec (FWHM)

  If extrapolated to 52.8-MeV, resolutions are be expected:
  energy; ~1%, position; a few mm, time;~100 psec (FWHM)

- Stable operation for the cryostat.

  PMT output fluctuation: ~ 0.5 %.

Purpose of 100-liter (large) prototype

- Construction of a larger prototype of LXe scintillation detector

  Never constructed such a large detector.

- Test for detector components

  PMTs, feed-through connectors, Cryostat, PMT holder,
  DAQ, Slow-control system, Purification system,...

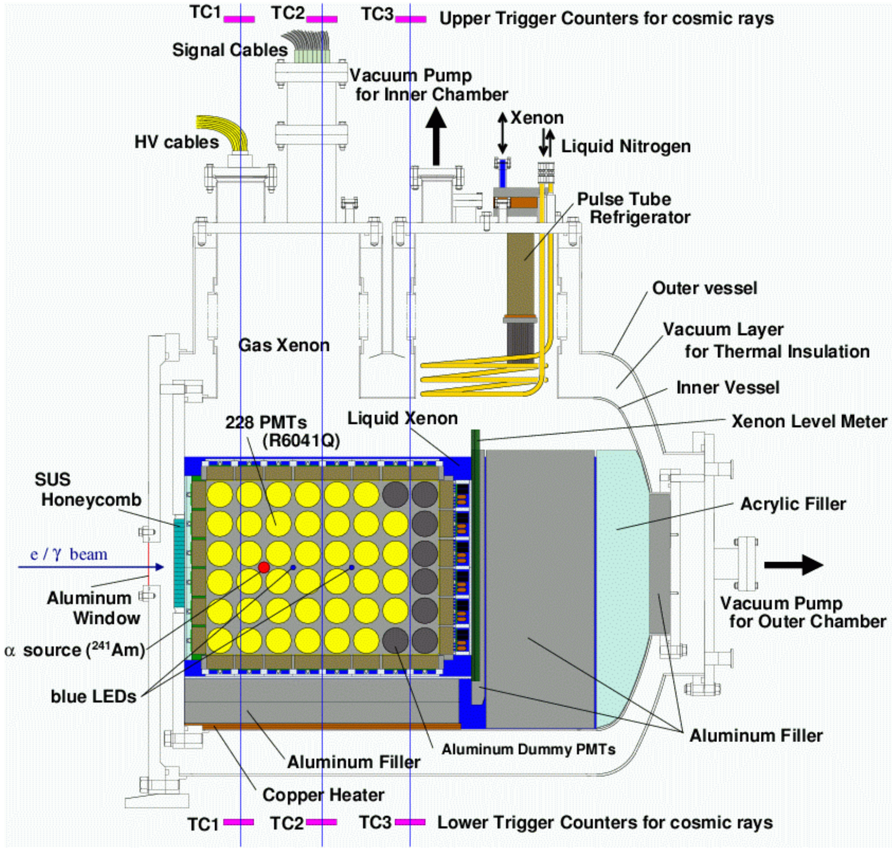
- long-term stable operation

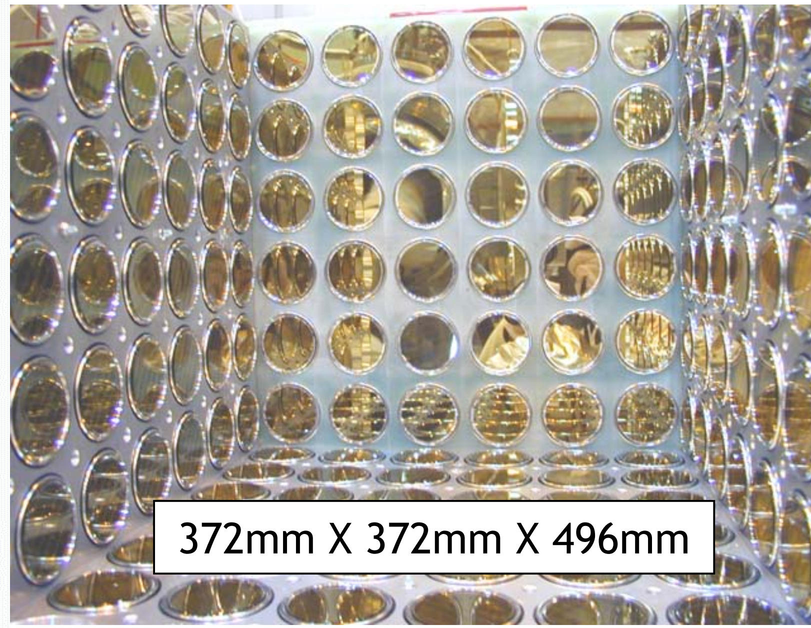
  GM pulse tube Refrigerator,
  monitoring of temperature and pressure

- Performance Test for higher energy gamma rays

  Resolutions of energy, time, and position
  Large proto: ~ 40 MeV γ
  As expected in simulation ?

Large prototype





- 68.6-liter active volume
- 228 PMTs

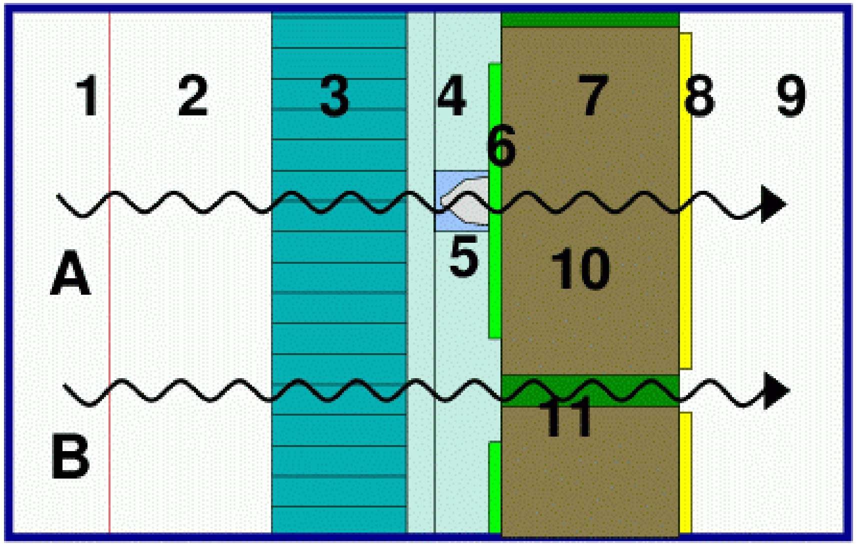
- α source (^{241}Am)

  PMT calibration (QE measurement)

  Stability monitor
- LED

  PMT calibration (gain adjustment)

Thickness of incidence face



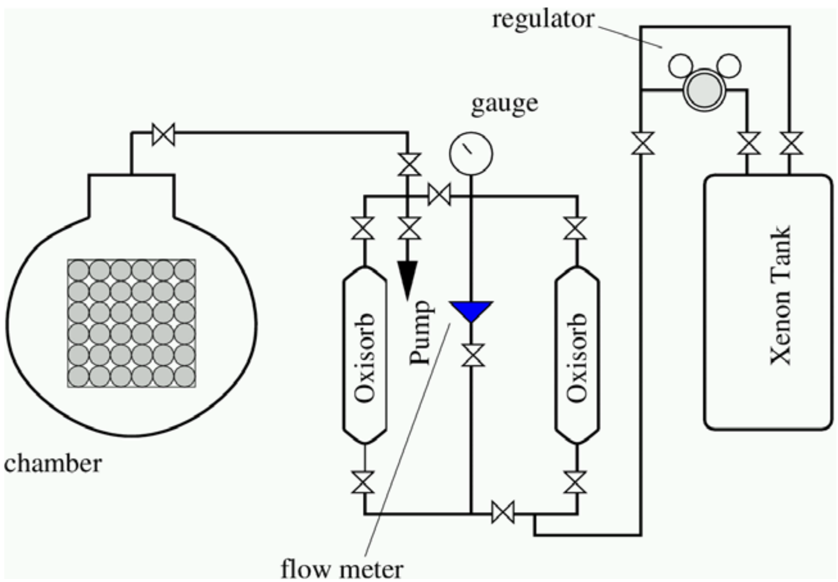
Materials	thickness	rad.–L	X_0
1. Aluminum Window	0.1 mm	8.9 cm	0.001
2. Vacuum	——	——	——
3. SUS Honeycomb	20 mm	——	0.039
4. Acrylic Cover	5+11 mm	34.7 cm	0.014+0.032
5. PMT Tip Tube(Pyrex glass)	0.916 mm	12.6 cm	0.074
6. G10–base PCB	2 mm	18.5 cm	0.011
7. SUS Tube	30 mm	1.75 cm	1.714
8. Quartz Window	3 mm	12.3 cm	0.024
9. Liquid Xenon	——	2.87 cm	——
10. Metal Channel Dynodes	12x 0.0126 mm	1.76 cm	0.086
11. G10 front face	29 mm	18.5 cm	0.157

PATH A: 0.24 X_0

PATH B: 0.24 X_0

The Most of γ-rays transmit to the LXe volume through the incident face.

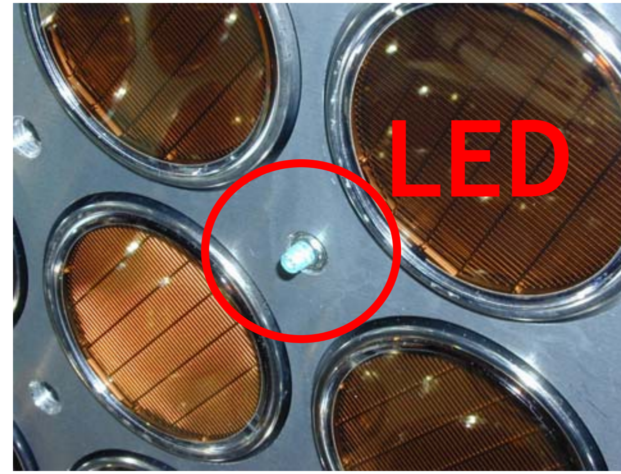
LXe liquefaction process

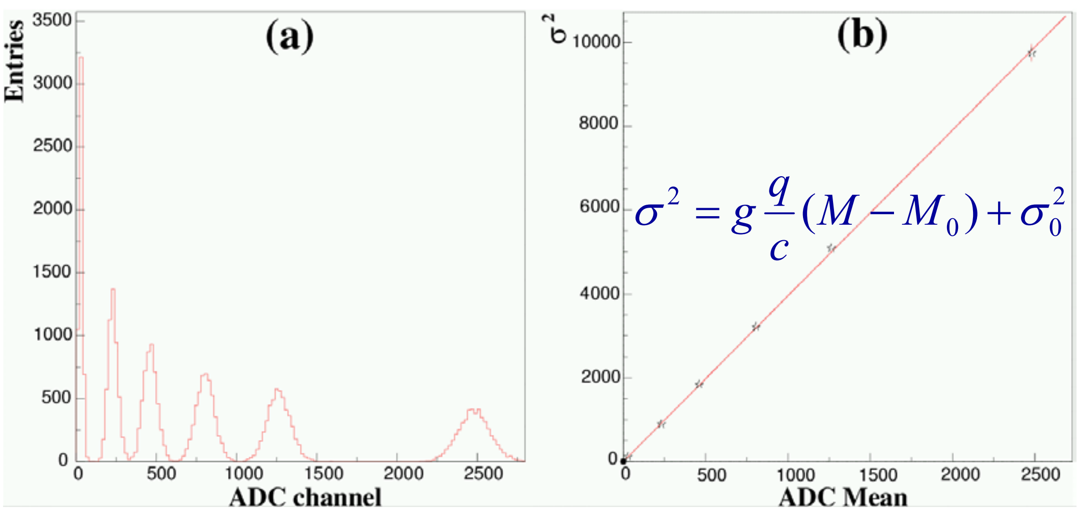


- **Evacuating: ~10 days**
  downs to an order of 10^{-3} Pa.
- **Pre-cooling: 1 day**
  The 0.2 MPa GXe in the inner vessel is cooled to 165 K in advance.
- **Liquefaction: 2 days**
  Liquefied with LN_2 cooling pipe.
  GXe is purified before entering the vessel.
  The pressure is kept <0.13 MPa.
- **LXe-keeping: 2000 hours max.**
  Mainly by refrigerator.
  By LN_2 if over 0.13 MPa.
- **Recovery: 2 days**
  Cool Xe tank storage with LN_2.
- **Warming-up: 3 days**

Gain adjustment with LEDs

- By changing the intensity of the LED, the PMT output varies as below figure.
- The gain can be adjusted to 1×10^6 at 165K and 1.3atm with an accuracy of ~3%.





σ : deviation of LED spectrum,

σ_0 : deviation of pedestal spectrum,

M : Mean of LED spectrum,

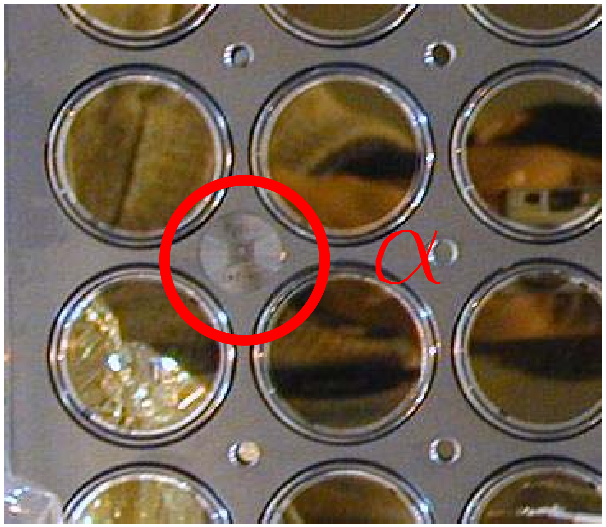
M_0 : Mean of LED spectrum,

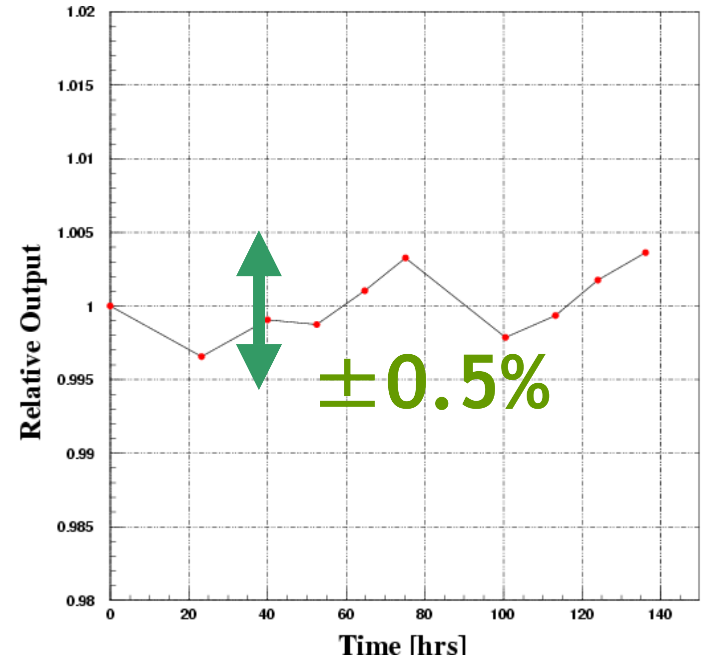
g : gain,

q : elementary electron charge,

$c := 200\text{fC/ch}$

Stability of PMT outputs



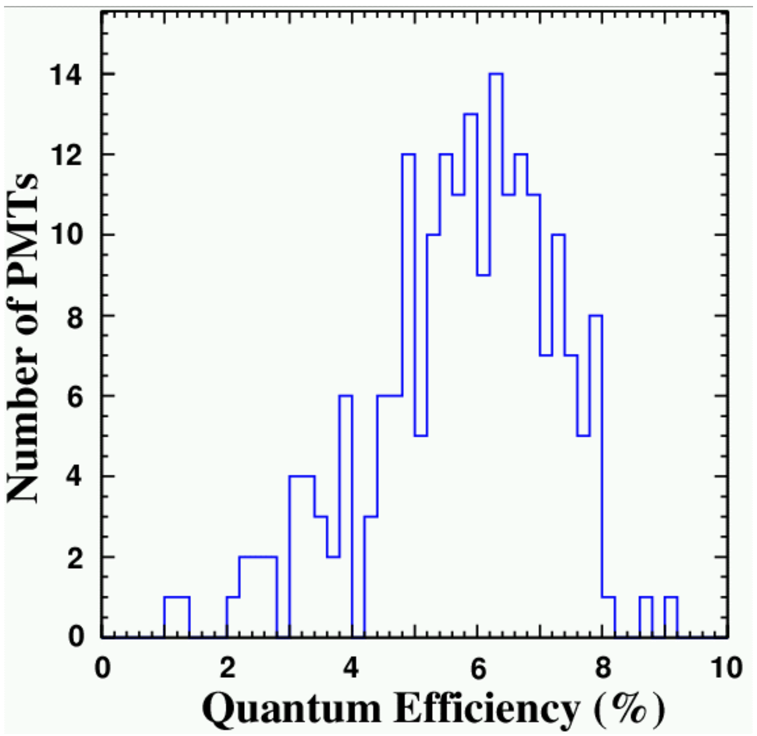


The data by α particle is useful for monitoring the stability of PMTs because it is regarded to be a point-like source.

After the completion of the liquefaction, the PMT output is stabilized within 0.5 % in 50 hours.

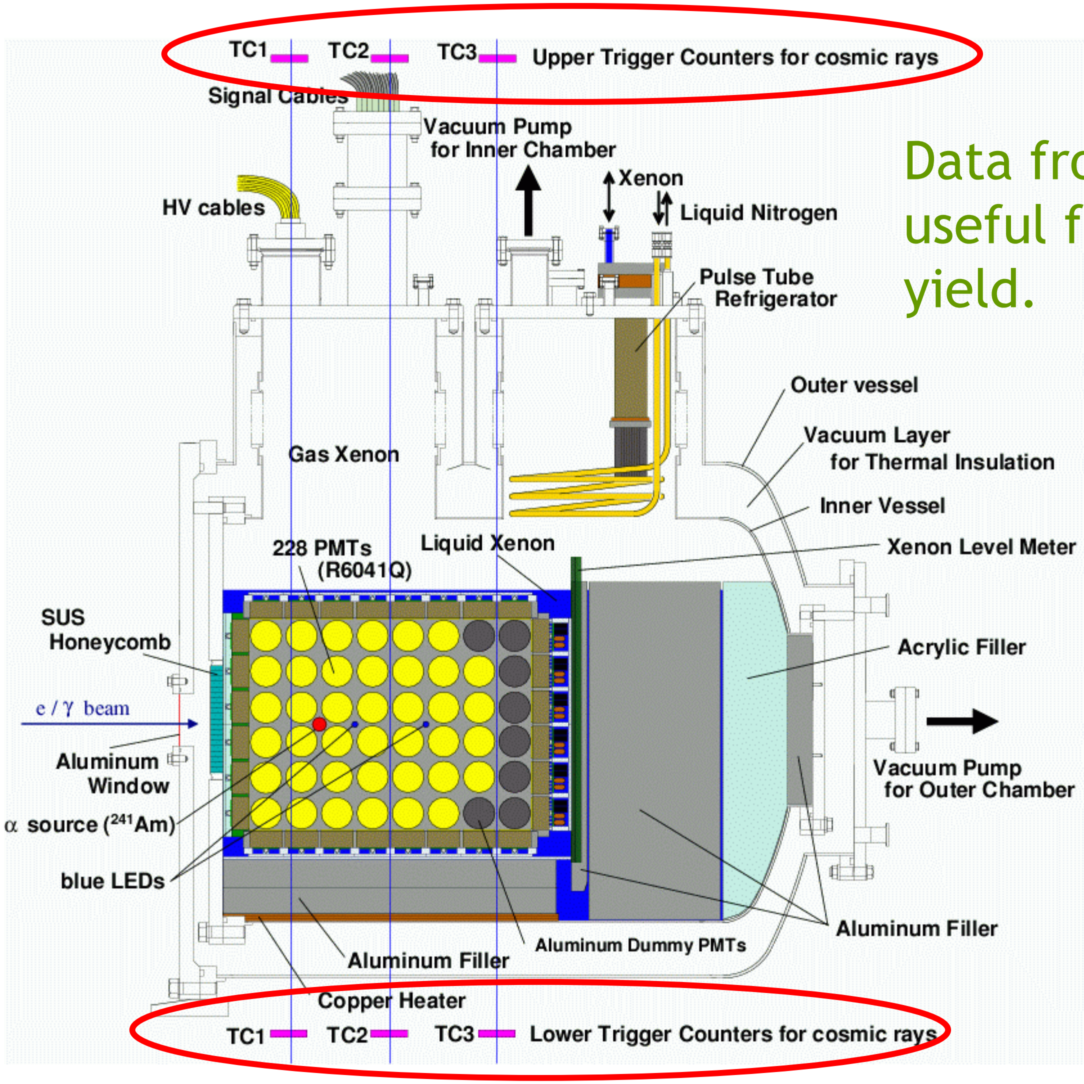
Q.E. estimation by α data in GXe

Compared with the simulated data, the α data in GXe can estimate Q.E.s, which include collection efficiencies, of the PMTs.



The α data in GXe can more easily compare with the simulated data than those in LXe because the effects of absorption and Rayleigh scattering in GXe is negligible and the simulation for the GXe has fewer parameters.

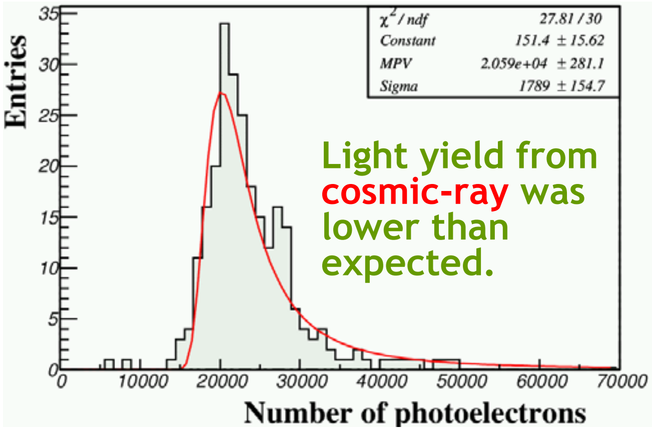
Light yield monitor by cosmic-ray muons

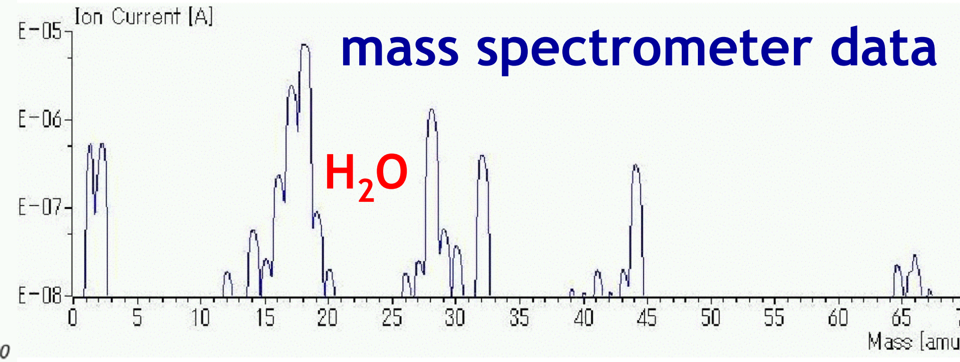


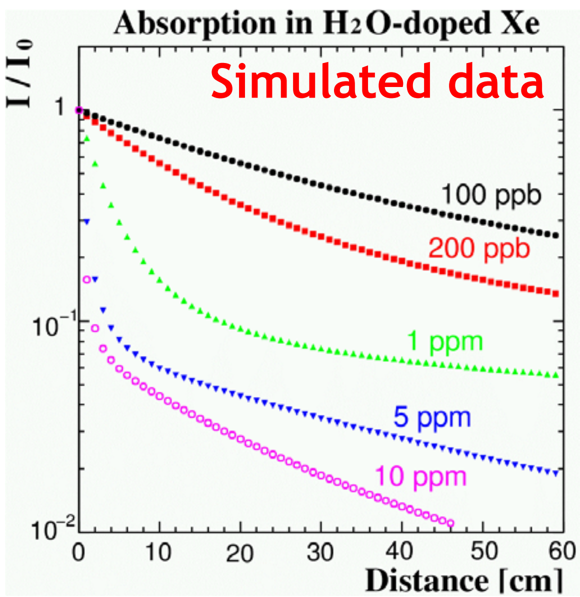
Data from cosmic-ray muons is useful for monitoring higher light yield.

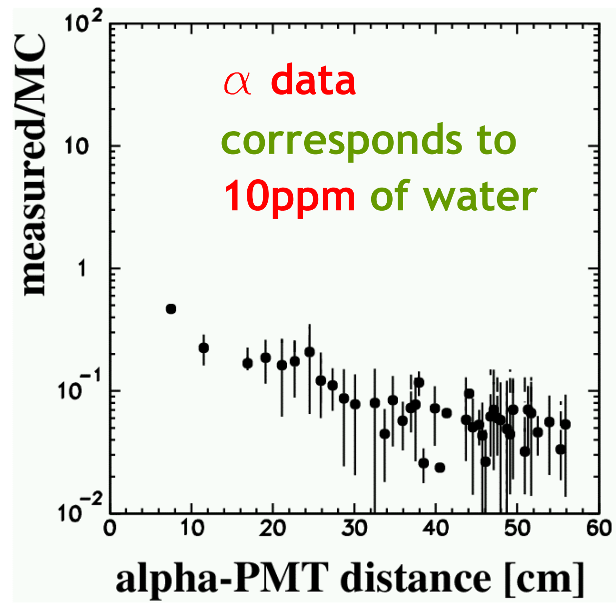
The cosmic-ray events are triggered with three pairs of counters (7cm x 7cm) above and below the vessel.

Water contamination

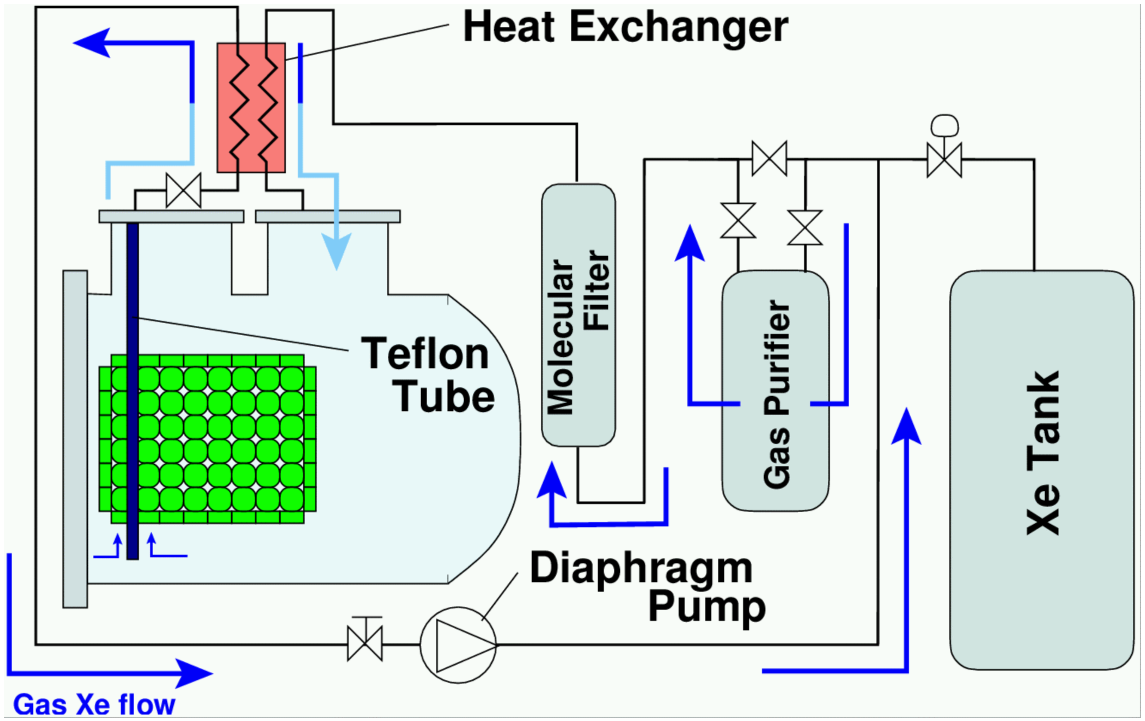








Purification system

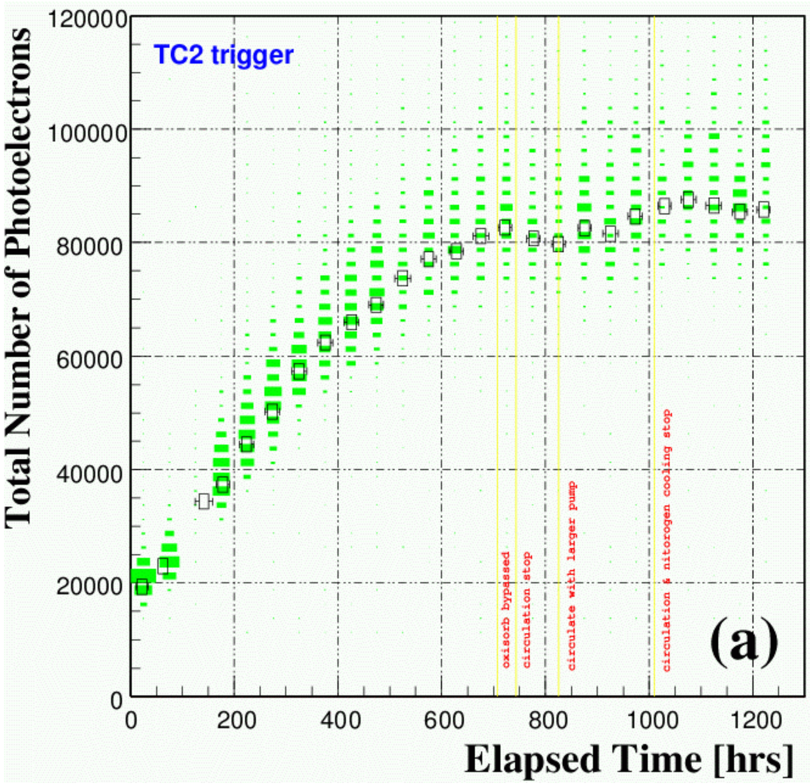


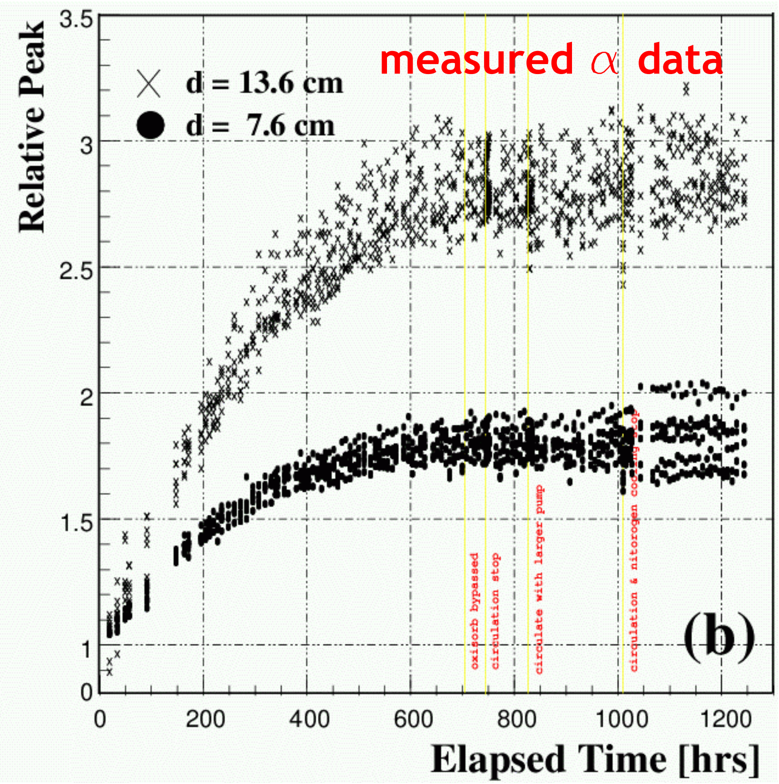
Purification

- ~1200 hours
- 10cc/min (LXe)

After gas xenon evaporated in the inner vessel is sent to a circulating pump, it is purified by gas purifier and filter to return to the inner vessel.

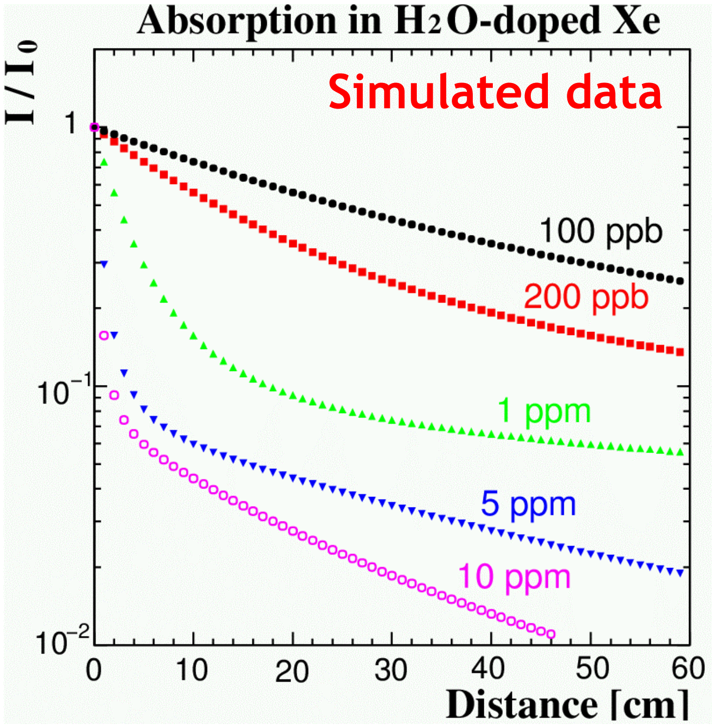
Growth of scintillation photons

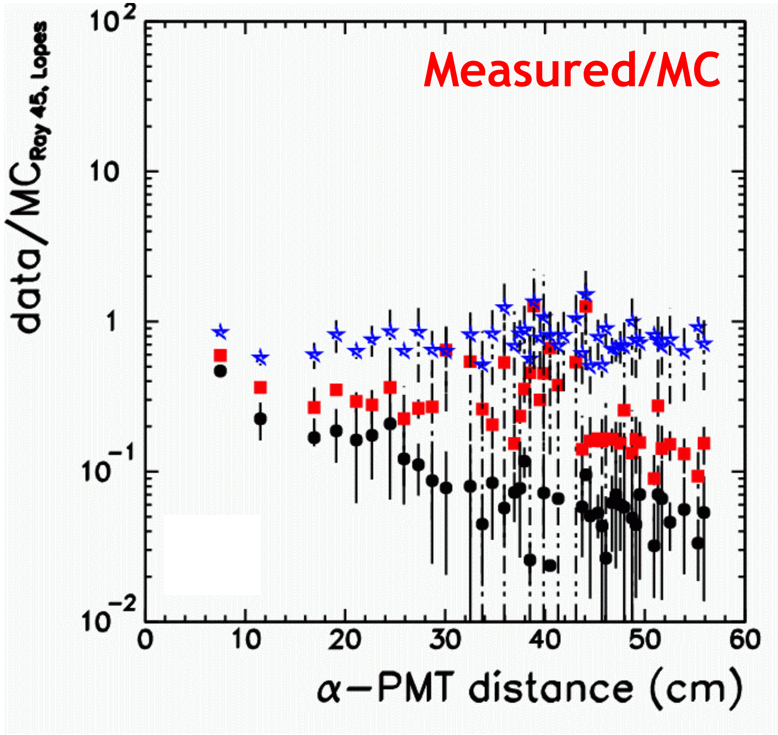




After 600-hour purification, the light yield was settled down to a constant level.In particular it is found that the rates of the light yield growth are different in the two cases: the far PMTs and the near PMTs from the light source. It follows that low light yield was caused by contaminations in LXe.

How much water contamination?

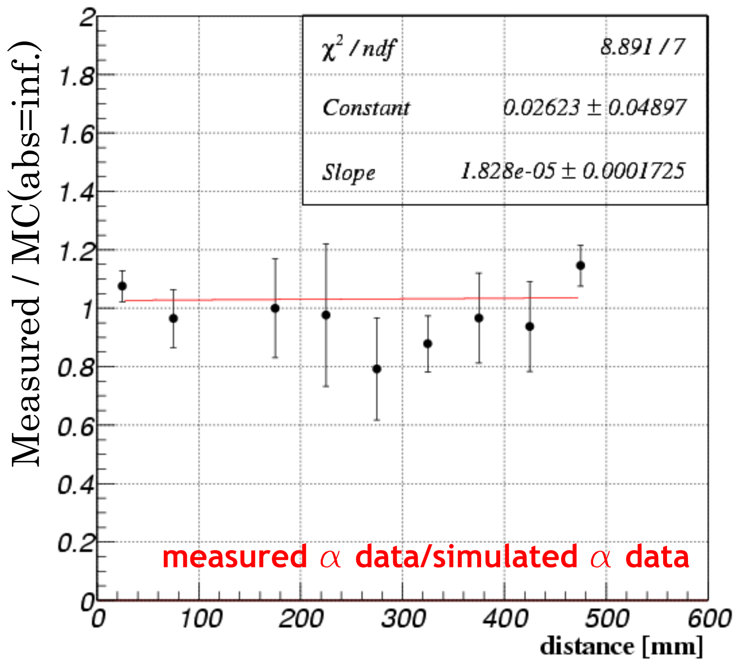


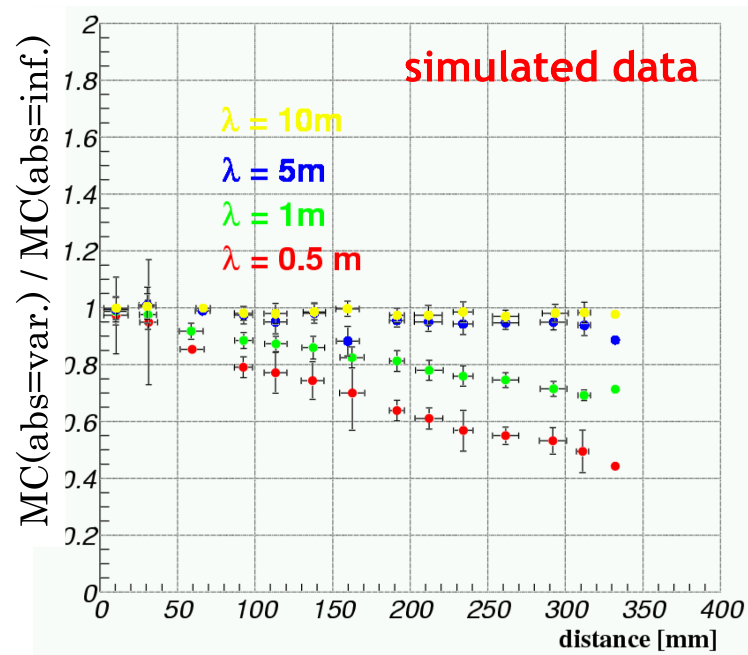


Before purification: ~10 ppm

After purification: ~10 ppb

Absorption length estimation





Comparing the two results,

the absorption length is estimated to be

<u>over 3m (97.8% C.L.)</u>.

Other efforts for pure LXe

- Replacement

  PMT cover: acrylic to Teflon

  Filler in incident face:

  Silicon rubber to stycast with glass

  Filler at the side of PMT holder:

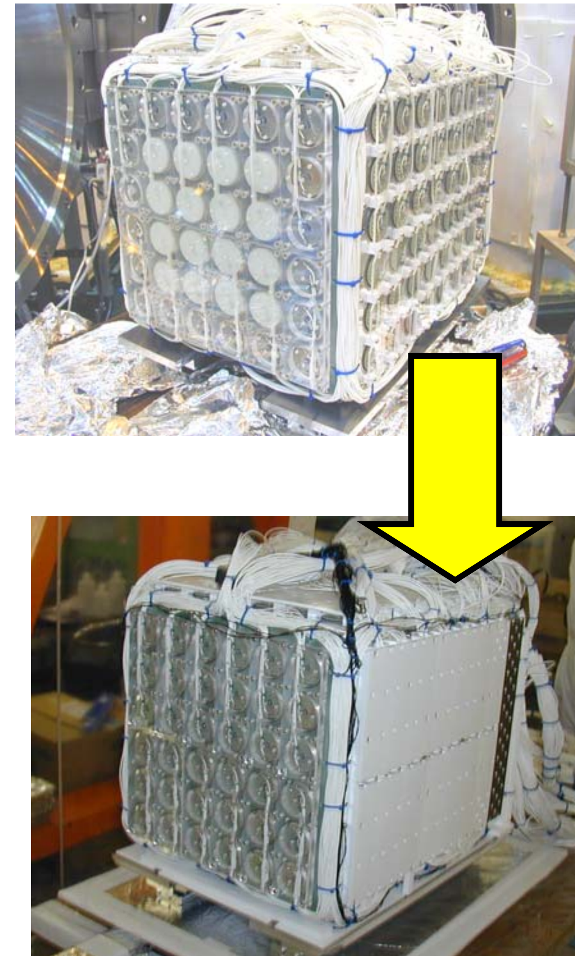
  acrylic plate to SUS hollow box

- Working environment

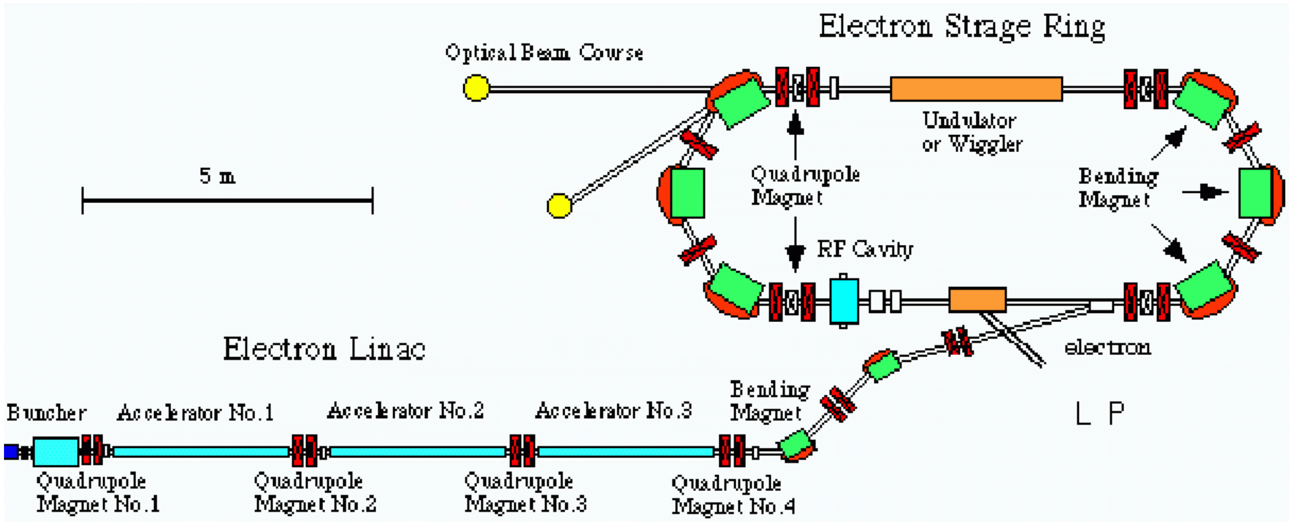
  open-air to clean-room

- Circulating pump (is planned to be)

  gaseous pump to fluid pump



beam test with e^- @ Kyoto Univ.



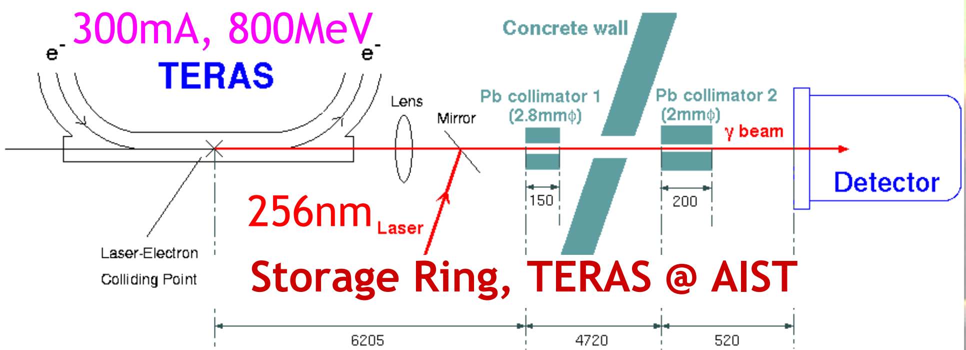
This test was performed in 12, 2002.

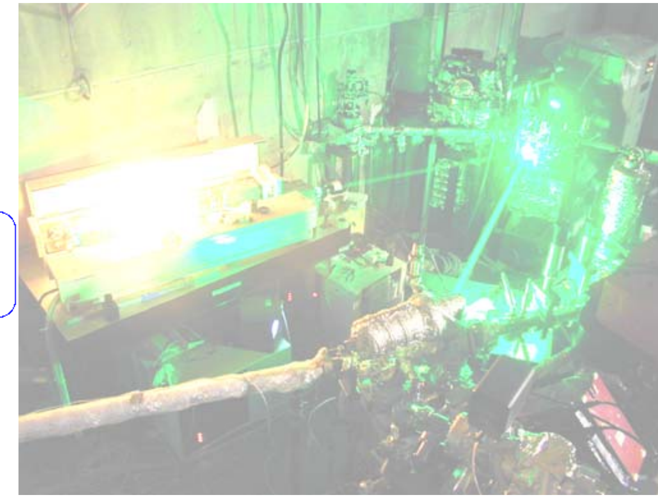
- Purpose
  - Time resolution estimation
  - Verification of the MC simulation.

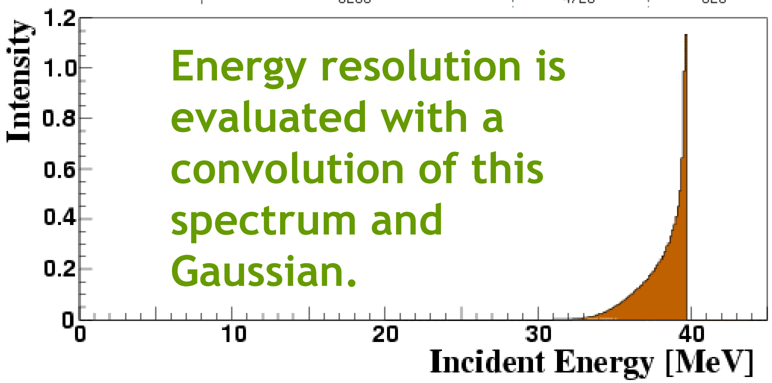
Detailed results are talked by R. Sawada: 31aSP-6

TERAS Beam Test @ AIST

Purpose: Estimation of the detector performance such as energy, position, time resolutions.





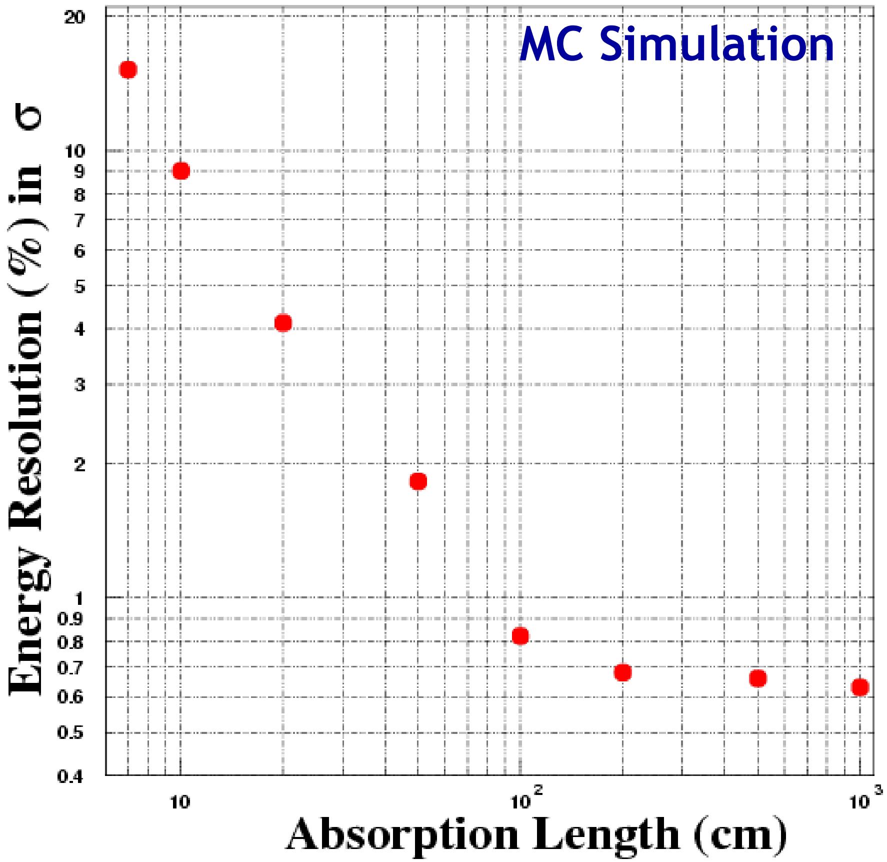


Incident γ-rays

- 10-MeV, 20-MeV, and 40-MeV Compton edge.
- Focused with a 2 mm φ collimator.

The topics about γ-ray beam tests are talked by H. Nishiguchi: 31aSp-7 (TERAS, $\pi^- p \rightarrow \pi^0 n \rightarrow 2\gamma$ @ PSI,…)

Energy resolution and absorption length



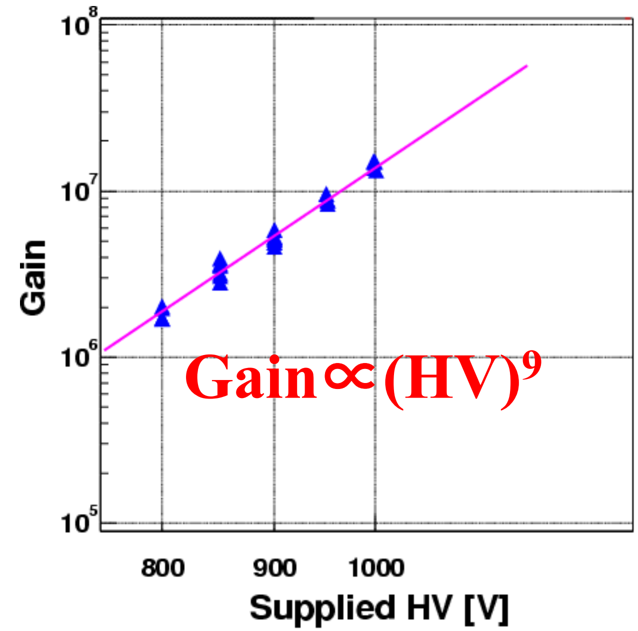
Abs. Length	Energy resolution
7 cm	34 % (FWHM)
1 m	1.9 % (FWHM)
3 m	1.6 % (FWHM)
5 m	1.5 % (FWHM)

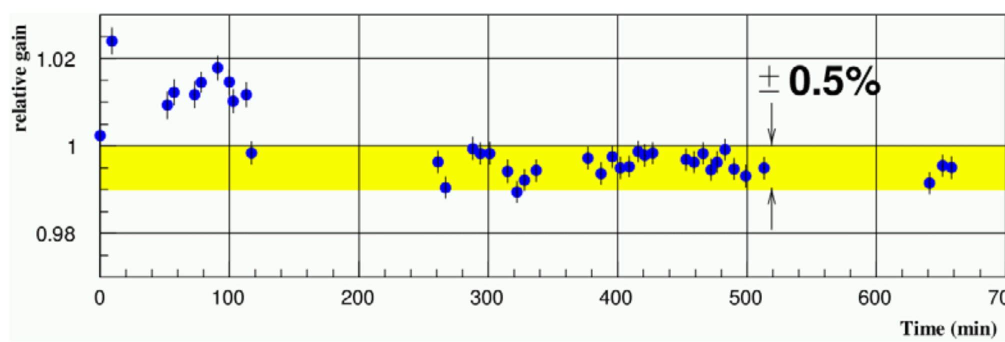
Summary

- We proposed a novel LXe scintillation detector for the MEG experiment.
- A 100-liter detector was constructed to design the final detector.
- The components such as monitoring system, PMTs, and, especially the cryostat, worked as expected.
- We developed a purification technique and absorption length reached ~3m corresponding to energy resolution of ~2% for 40 MeV.
- We have a plan to perform beam tests at TERAS and PSI this year to evaluate the detector performance.
- Also the final detector was already designed, and is ready for construction.

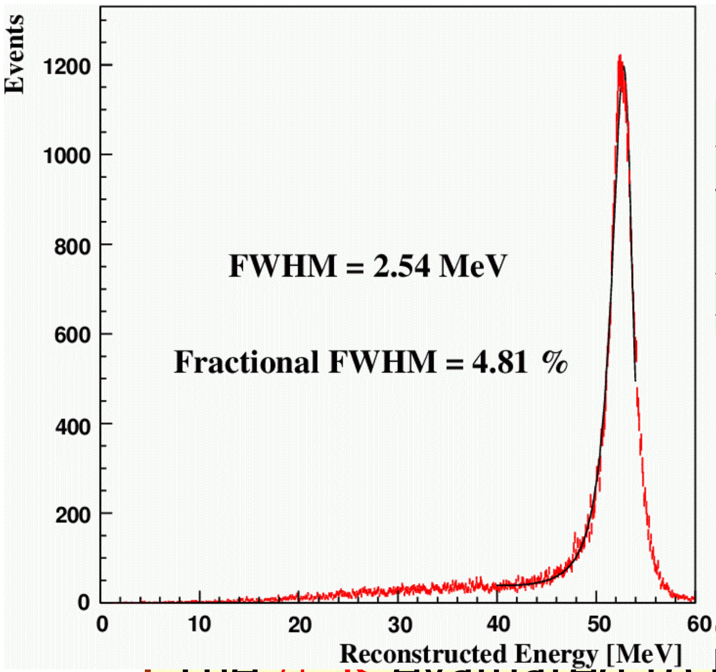
PMT calibration

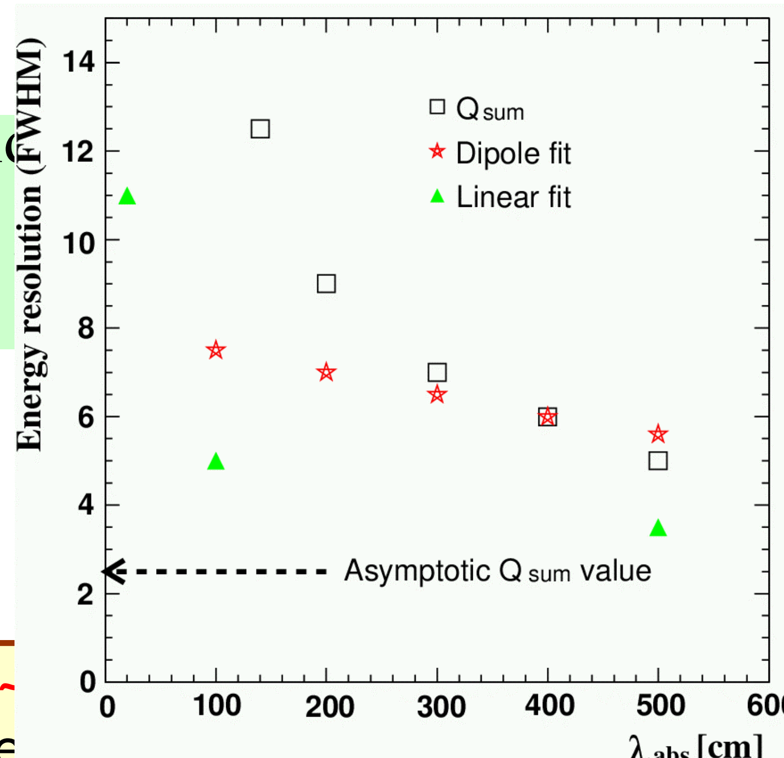
$$g = \frac{c\sigma^2}{qM}$$





dustbox

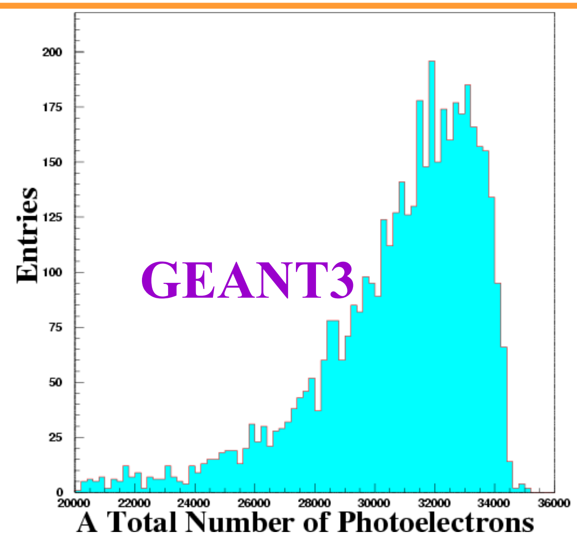


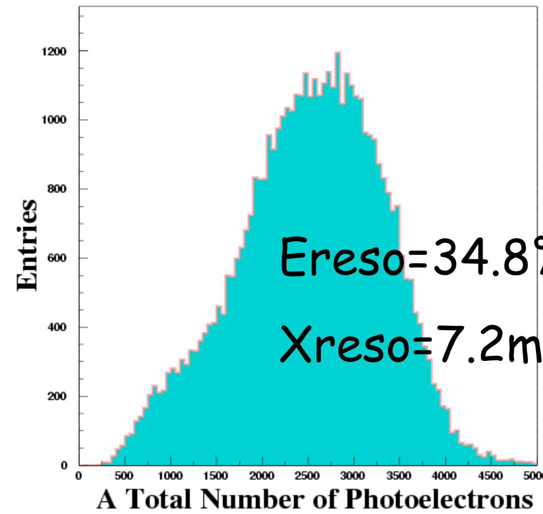


The σ_t is evaluated to be ~ ... ns
estimated from the re...

The σ_E is evaluated to be ~1% from the extrapolation to 52.8 MeV.

beam tests @ AIST





Ereso=34.8%x2.35

Xreso=7.2mm~11.8mm

このテストで光量がシミュレーションより圧倒的に少ないことが判明した。

とりあえずこの状況での分解能を示す。位置とエネルギーの絵。

How about crystals?

- Disadvantage
  NaI: long decay time
  CsI, BGO: low light yield
- Inhomogeneous to cover large area.