Development of liquid xenon scintillation detector for new experiment to search for $\mu \rightarrow e\gamma$ decays

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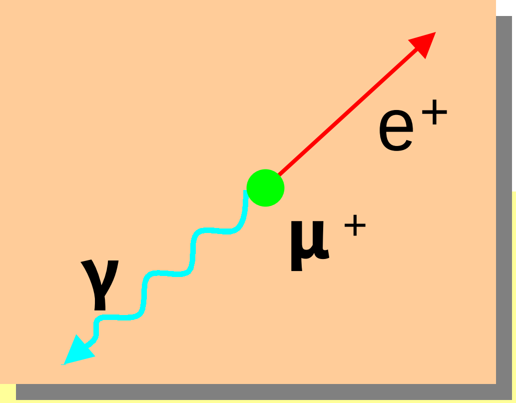
Physics motivations

$\mu \rightarrow e\gamma$ decay

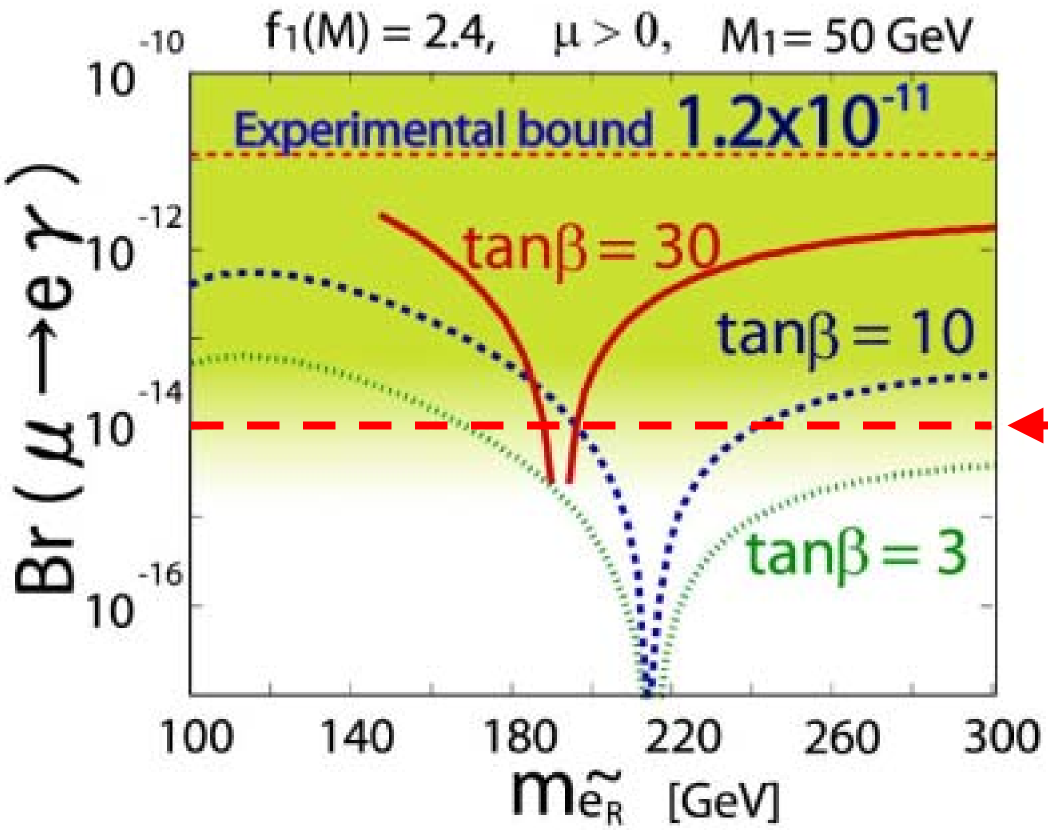


- Event signature
  - Back to back
  - Time coincident
  - $E_e = E_\gamma = 52.8$MeV
- Lepton-family-number nonconserving process
- Forbidden in the standard model
- Sensitive to physics beyond the standard model

  SUSY-GUT, SUSY+ν_R, …
- Present experimental bound

  $BR(\mu^+ \rightarrow e^+\gamma) < 1.2 \times 10^{-11}$ (MEGA experiment, 1999)
- New experiment with a sensitivity of BR~10^{-14} planned at PSI

Physics motivations, cont'd

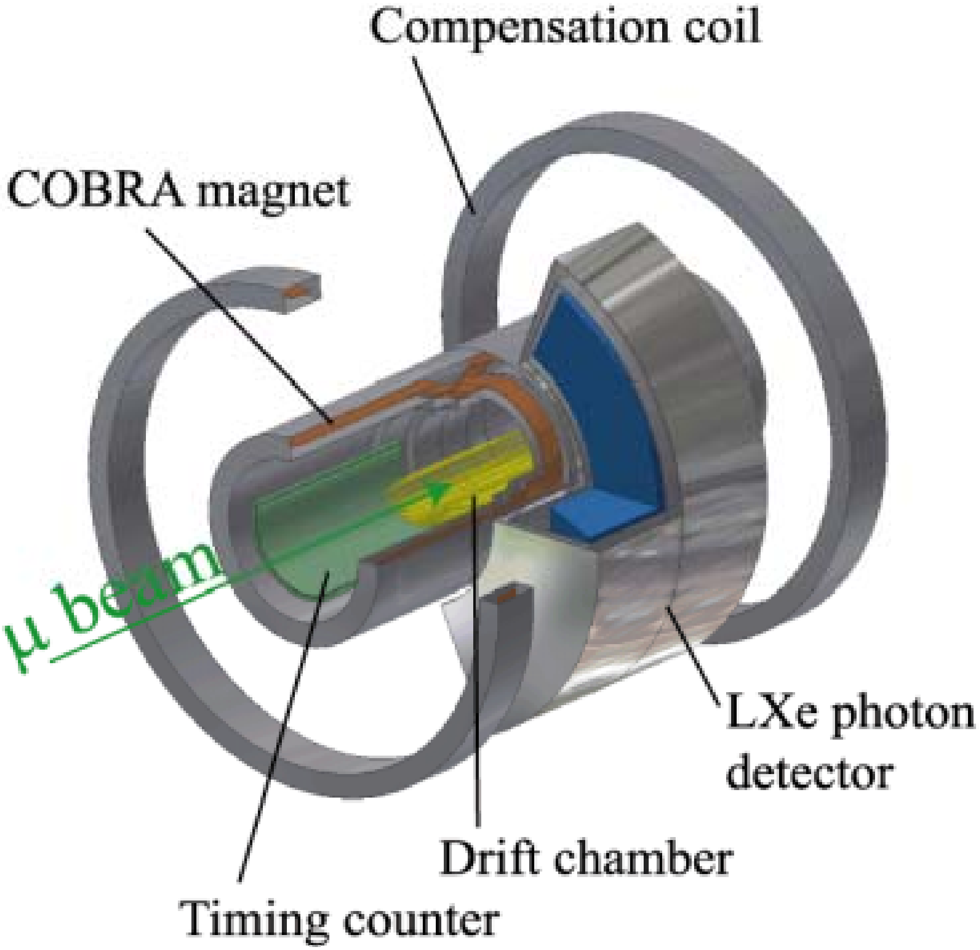


← Our goal

J. Hisano et al.,
Phys. Lett. B391 (1997) 341

SU(5) SUSY-GUT predicts BR $(\mu \rightarrow e\gamma)$ = 10^{-15} - 10^{-13}
(SO(10) SUSY-GUT: even larger value 10^{-13} - 10^{-11})

New μ→e γ experiment at PSI



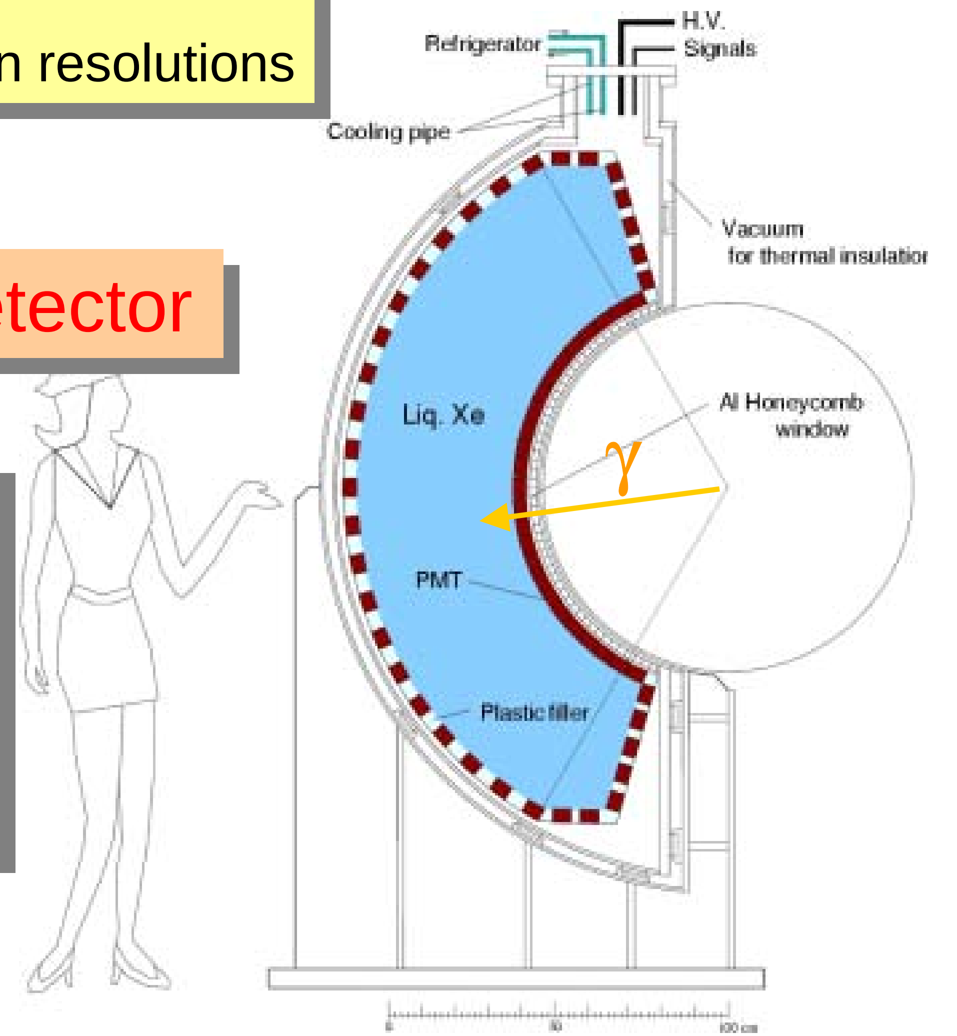
- Sensitivity down to BR~10^{-14}
- World's most intense DC beam at PSI
- Liquid xenon gamma detector
- Positron spectrometer with gradient magnetic field
- Thin superconducting magnet
- Engineering/physics run will in 2003

LXe gamma-ray detector

Detector requirements:

Excellent energy-, timing-, and position resolutions

Liquid xenon scintillation detector



Detector design

- Active volume of LXe: 800 liter
- Scintillation light is collected by ~800 PMTs immersed in LXe
- Effective coverage: ~ 35%

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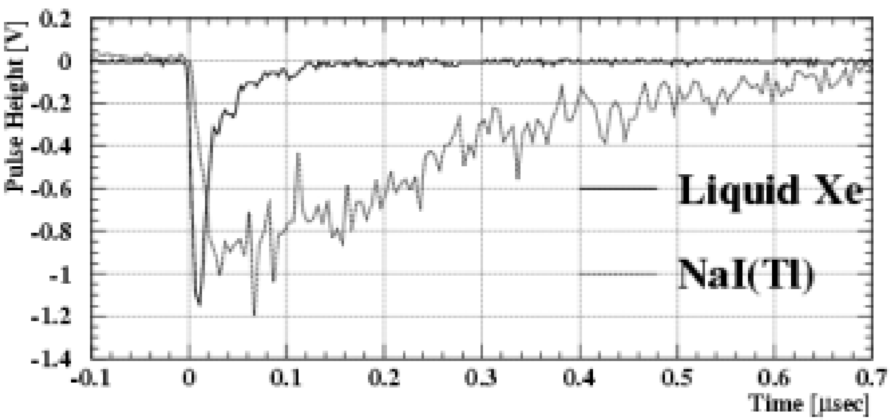
Liquid xenon scintillator

- High light yield (75% of NaI(Tl))
- Fast signals
  →avoid accidental pileups
- Spatially uniform response
  →no need for segmentation



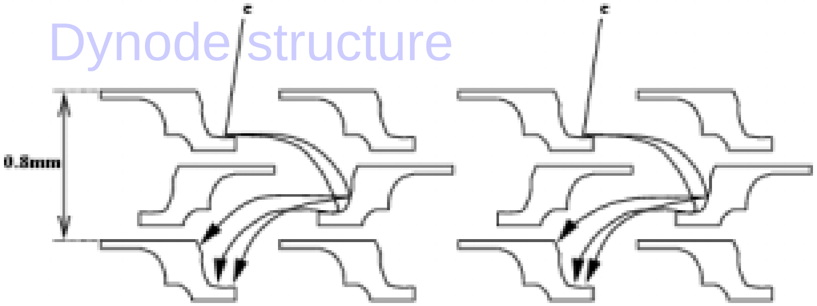
LXe properties

Mass number	131.29
Density	3.0 g/cm^3
Boiling and melting points	165 K, 161 K
Energy per scintillation photon	21.7 eV for β 18.1 eV for α
Radiation length	2.77 cm
Decay time	4.2 nsec (fast) 22 nsec (slow) 45 nsec (recombi.)
Scintillation light wave length	175 nm
Refractive index	1.57

Photomultiplier

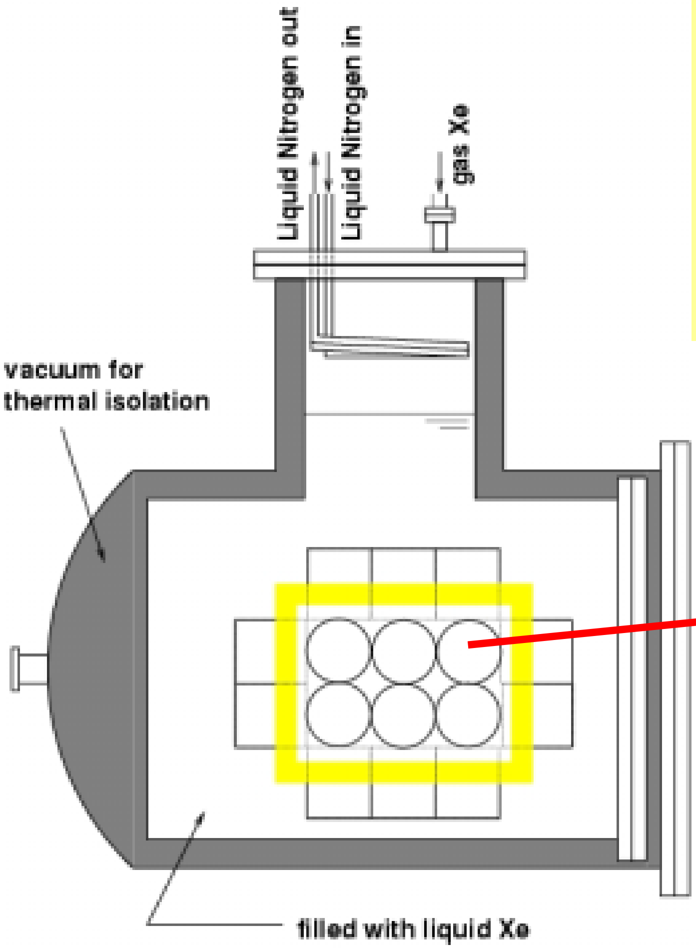
Hamamatsu R6041Q

Dynode structure	Metal channel
Photo cathode	Rb-Cs-Sb
Window	Quartz
Quantum efficiency	~10 %
PMT size	57 mm ϕ
Effective area	46 mm ϕ
PMT Length	32 mm
Typical H.V.	1000 V
Current amplification	10^6 - 10^7
TTS	0.3 ns typ.



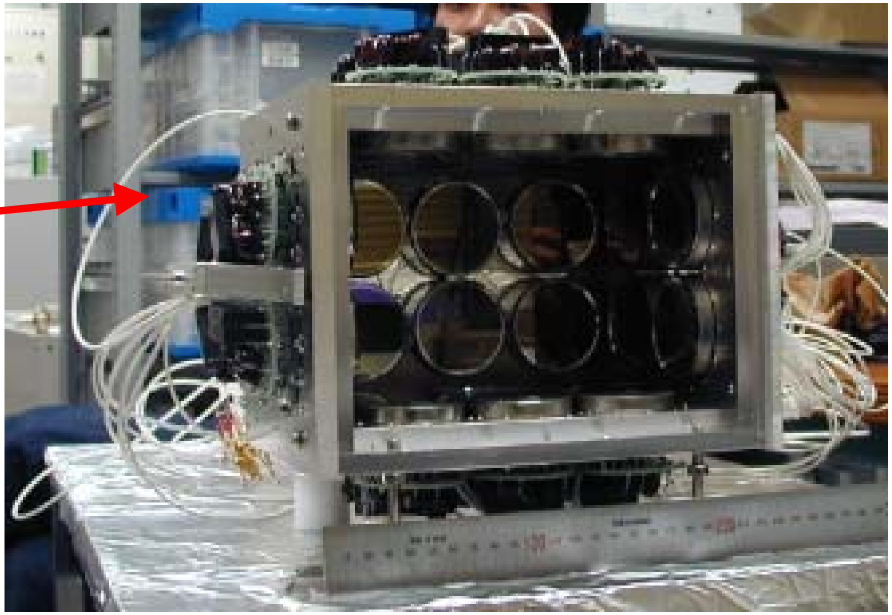
Successfully operated in liquid xenon

First prototype of LXe detector



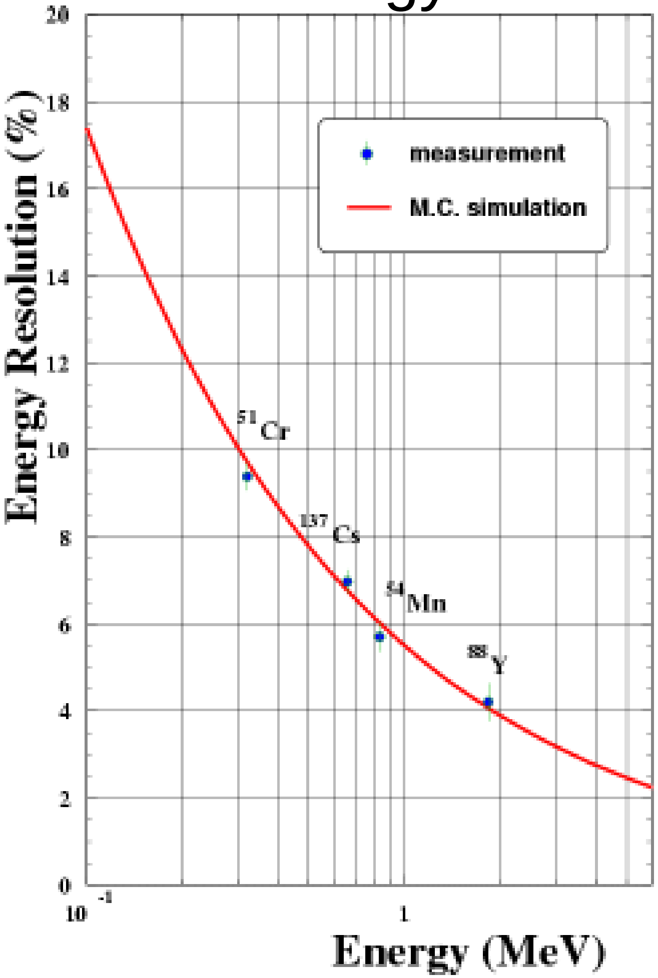
- 32 x PMTs
- Active LXe volume

  116 x 116 x 174 mm^3 (2.3liter)
- Energy-, Position-, and Timing resolutions for gamma up to 2MeV



Results from first prototype

Energy



Simple extrapolations from the results and simulation studies imply,

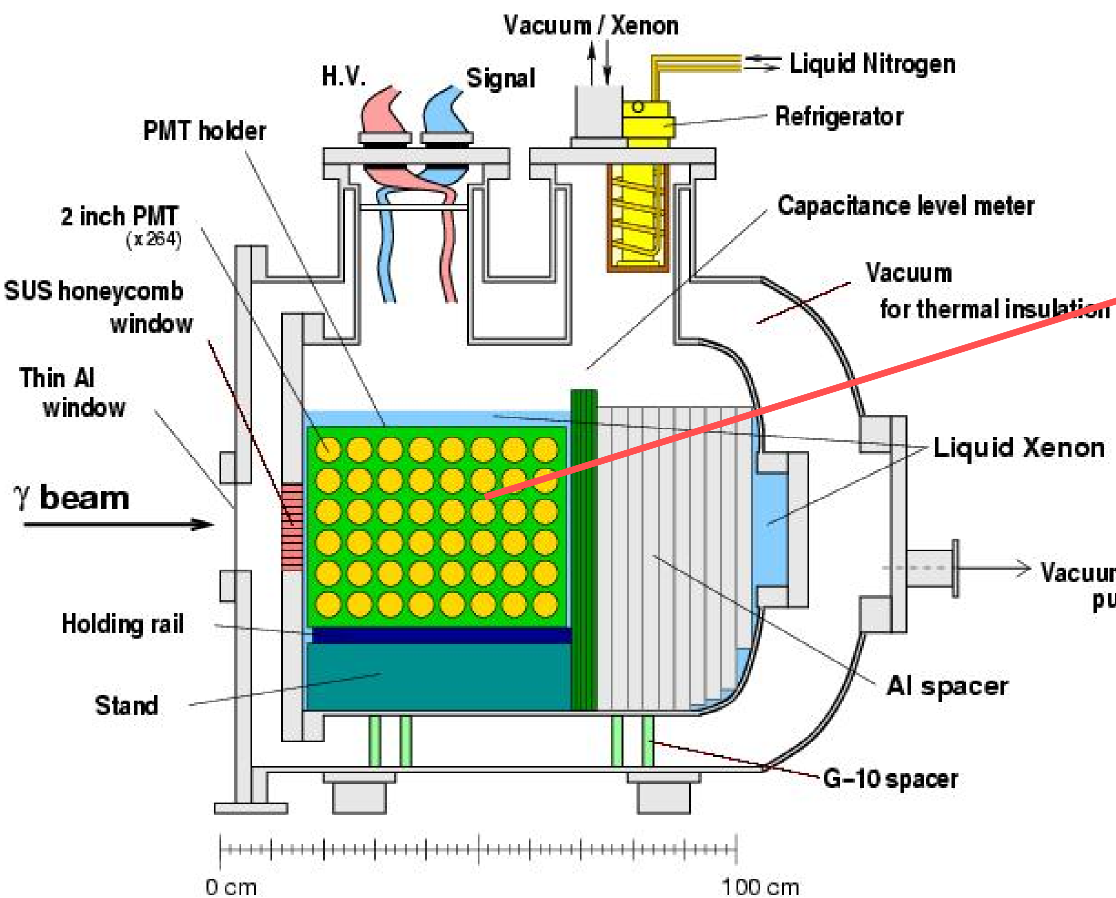
σ_{energy} ~ 1%,
$\sigma_{position}$ ~ a few mm,
σ_{time} ~ 50psec

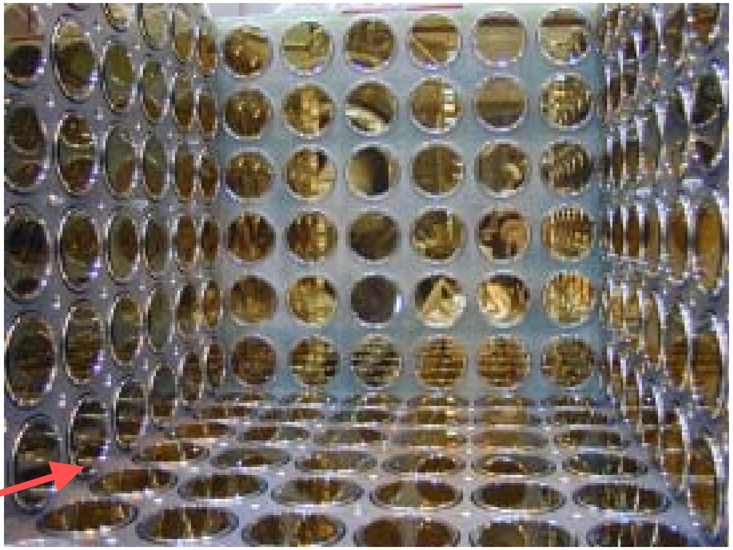
for 52.8MeV gamma from $\mu \rightarrow e\ \gamma$

Should be verified with larger detector for higher energy(~50MeV) gamma rays

Second prototype

Second prototype successfully constructed
Second prototype successfully constructed





Second prototype, cont'd

Second prototype (large prototype)

- Part of full-scale detector
- World's largest LXe scintillation detector!
- A total of 120 liter liquid xenon (active volume of 69 liter)
- Viewed by 228 PMTs
- Large enough to test with ~50MeV γ
- LEDs and α sources (^{241}Am) implemented for calibration

Purposes of second prototype

- Demonstrate performance of planned full-scale detector by using energy γ (Energy-, position-, time- resolutions)
- Check of cryogenics and other detector components
- Measurement of absorption length of scintillation light in LXe

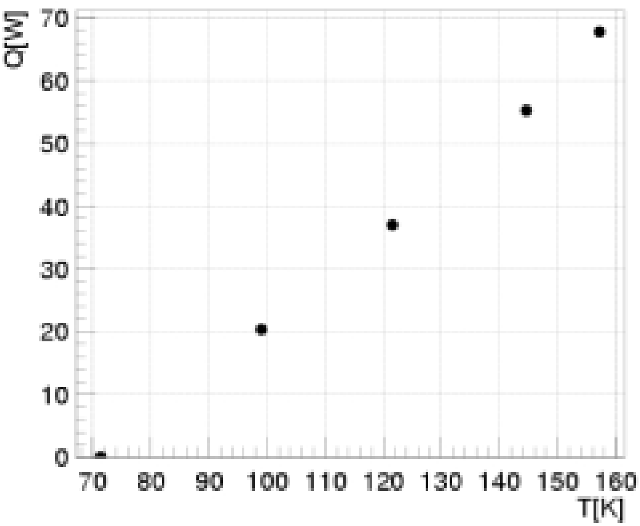
Cryogenic system

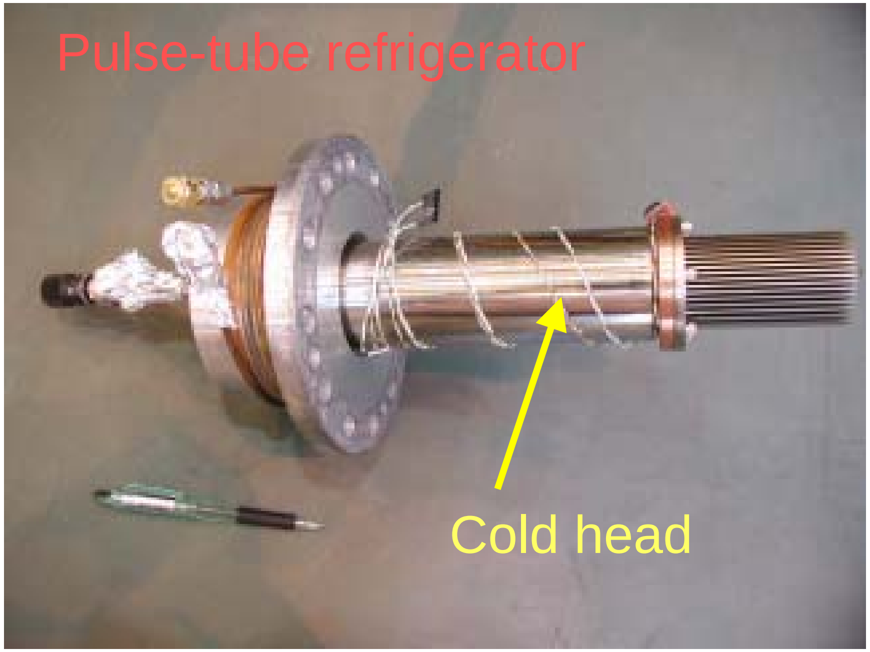
- Xenon is liquefied by heat exchange with LN_2.
- Liquid is kept stably with pulse-tube refrigerator after liquefaction.

  Measured cooling power at 165K ~ 70W

  (↔ total heat load of the prototype detector ~ 52W)
- No serious problem during over 50days detector operation!

Cooling power of pulse-tube refrigerator



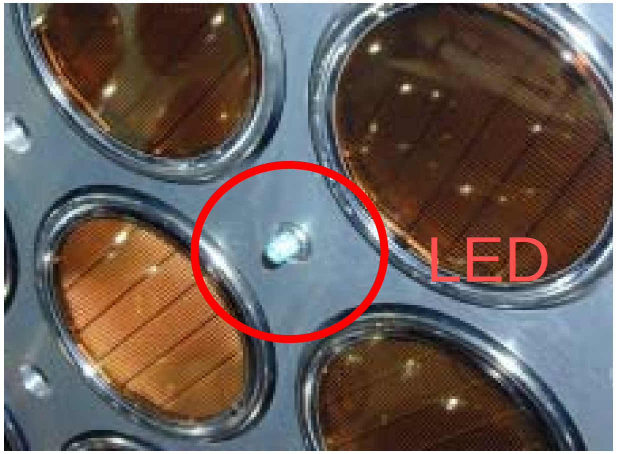


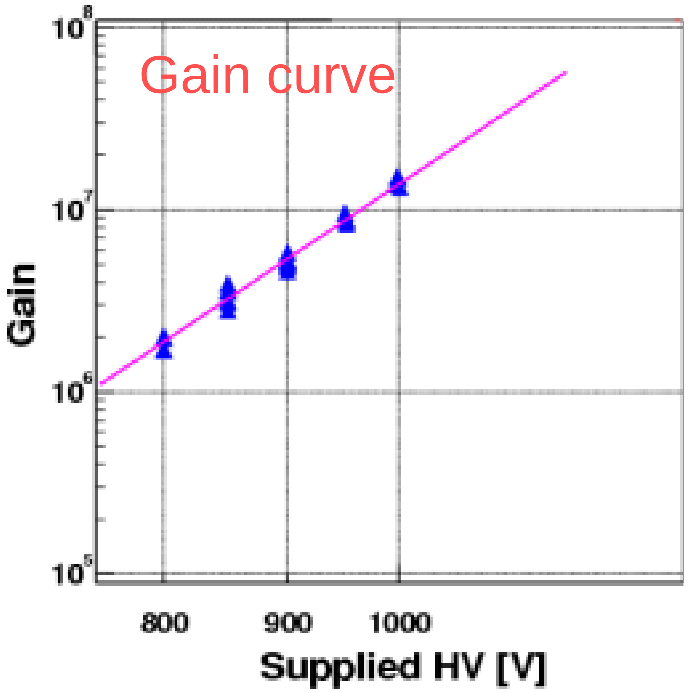
Purification system

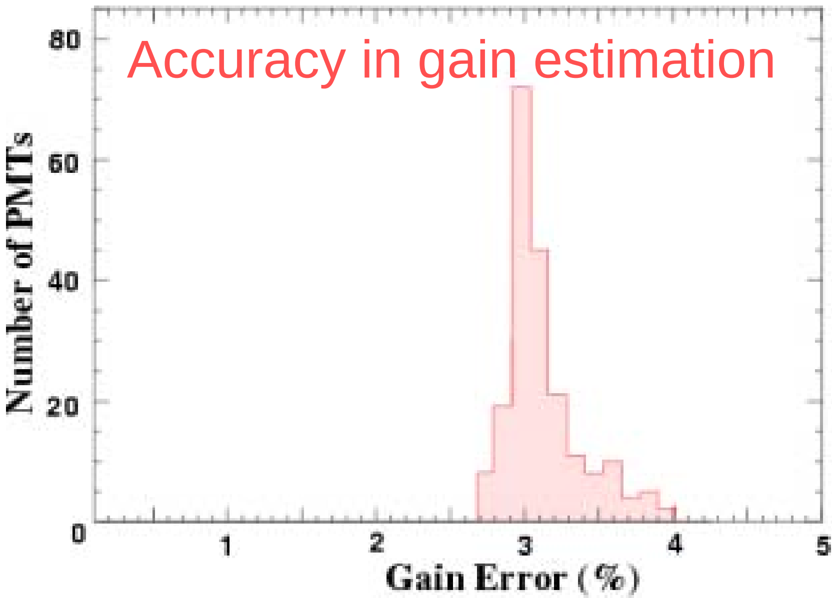
- Impurity in LXe such as H_2O, O_2 is critical.
  → absorption of scintillation light
- Two Purification filters employed
  - Oxisorb filter (Messer Griesheim)
  - Zr-V-Fe getter (SAES geeters, MonoTorr)
- Flushing chamber by hot xenon gas circulation prior to liquefaction
- Xenon vapor gas circulated during detector operation
- Monitoring impurity concentration using mass spectrometer

PMT calibration

- PMT calibration by using LEDs.
- Gain estimation with ~3% accuracy.

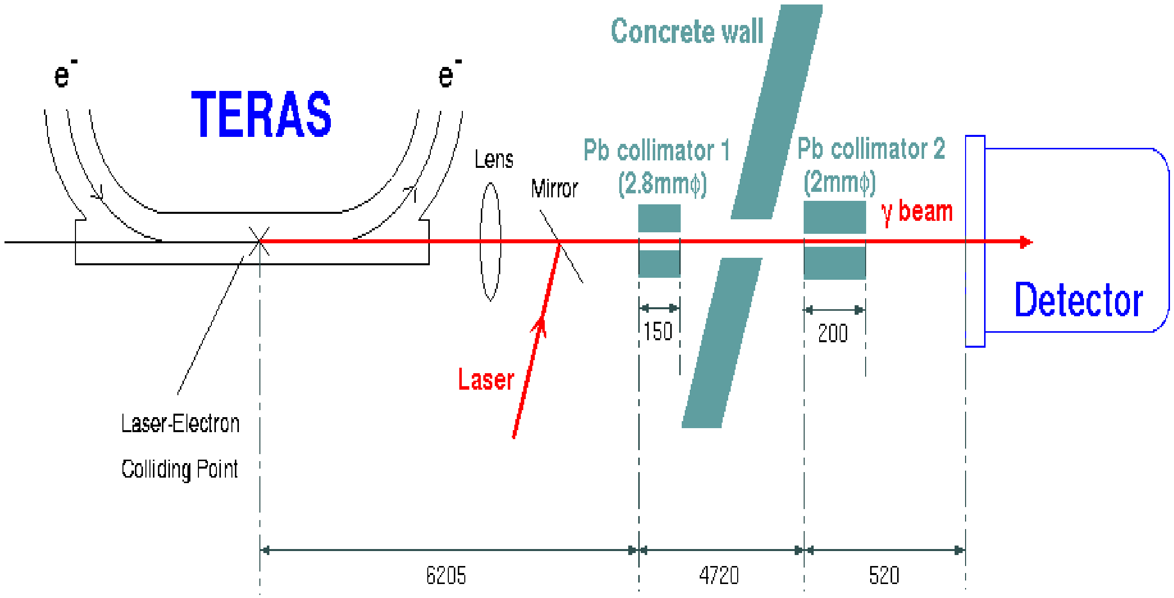






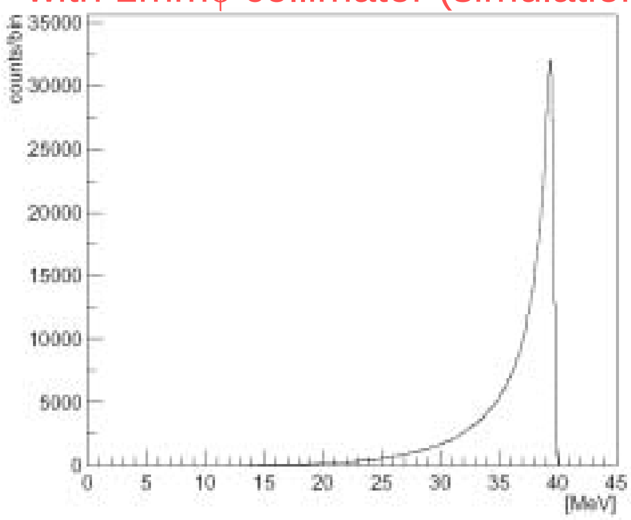
Gamma beam test

- Performance test of large prototype using high-energy gamma rays
- Laser Compton backscattering facility at TERAS electron storage ring of AIST, Tsukuba, Japan
- Gamma-ray beam with energy up to 40MeV
- Energy resolution evaluated by spread of Compton edge
- Position reconstructed by PMT output distribution with proper collimator
- Timing reconstructed by averaging arrival time



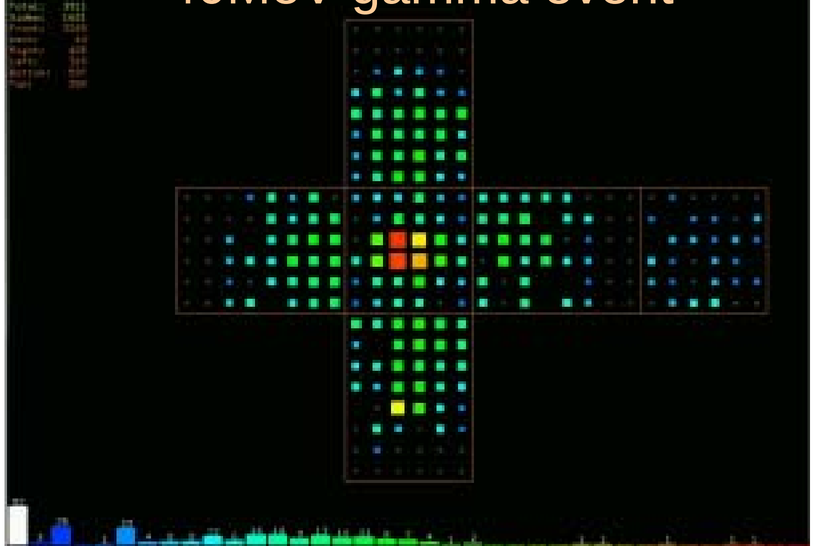
Gamma beam test, cont'd

Energy spectrum of gamma beam with 1mmϕ collimator (simulation)



Gamma beam test, cont'd

- Studies with high-energy gamma beam started
- Various detector components worked well
  (refrigerator, feedthrough, PMT holder, etc.)
- 40MeV gamma successfully observed
- Data analysis to evaluate detector resolutions(energy, spatial, timing) in progress
- Essential parameters such as QE of PMTs, absorption length of scintillation light in LXe, etc are needed
  - ← separate experiments to measure such parameters going on



~40MeV gamma event

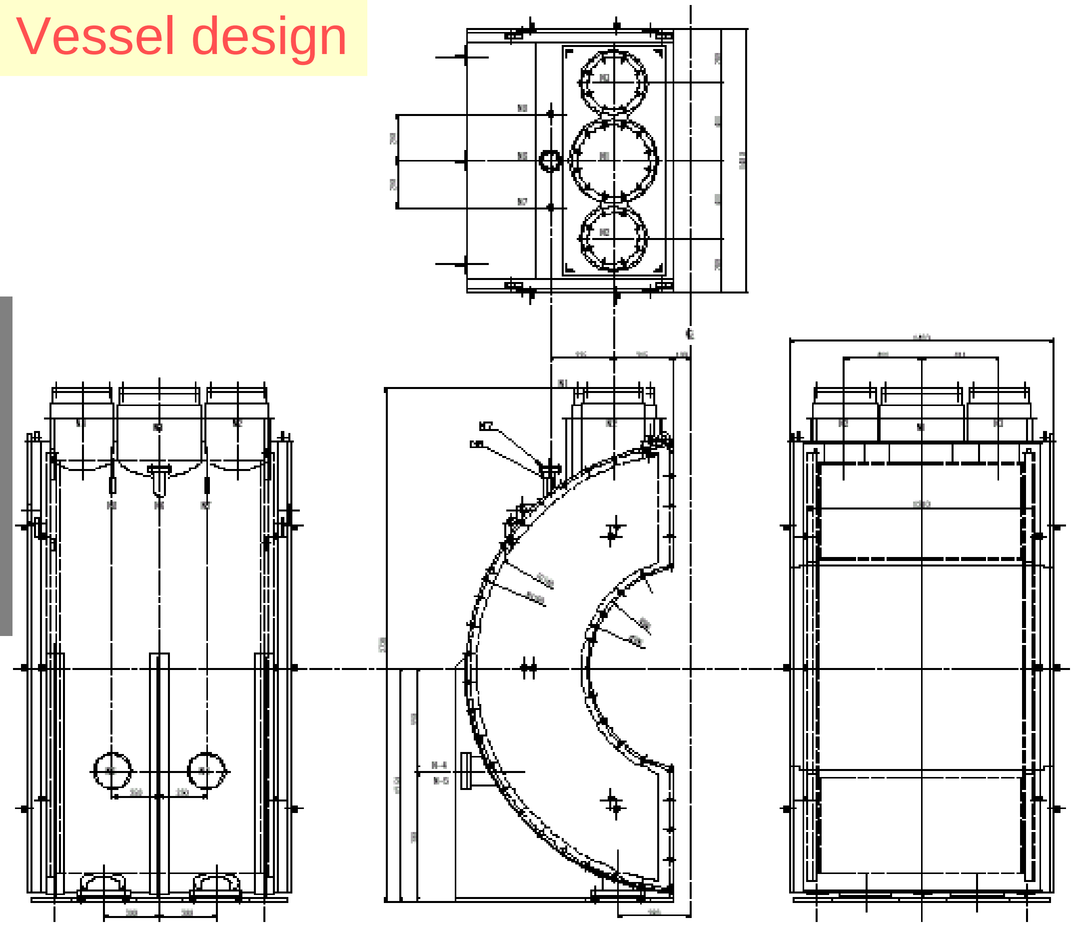
Design work on full-scale detector

Full-scale detector

- Active volume of 800 liter
- Viewed by ~800 PMTs

- Vessel design almost finalized
  (Heat load calculation,
  mechanical analysis)
- PMT frame design
- Refrigerator design

Vessel design



Summary

- New experiment to search for $\mu \rightarrow e\,\gamma$ with a sensitivity of BR~10^{-14} planned at PSI.
- Novel liquid xenon scintillation detector for the experiment under
- Large prototype with an active volume of 69 liter constructed.
- The prototype operated successfully over 50days.
- Studies with gamma beam up to 40MeV at laser Compton started.
- 40MeV gamma event successfully observed.
- Data analysis in progress to reliably evaluate energy-, position-, and resolutions.
- Separate experiments to measure essential parameters such as QE of absorption length, etc. are going on.
- Design work on full-scale detector going on.

For more info, see *http://meg.icepp.s.u-tokyo.ac.jp/*