Performance of the MEG detector to search for $\mu^+ \rightarrow e^+\gamma$ decays at PSI

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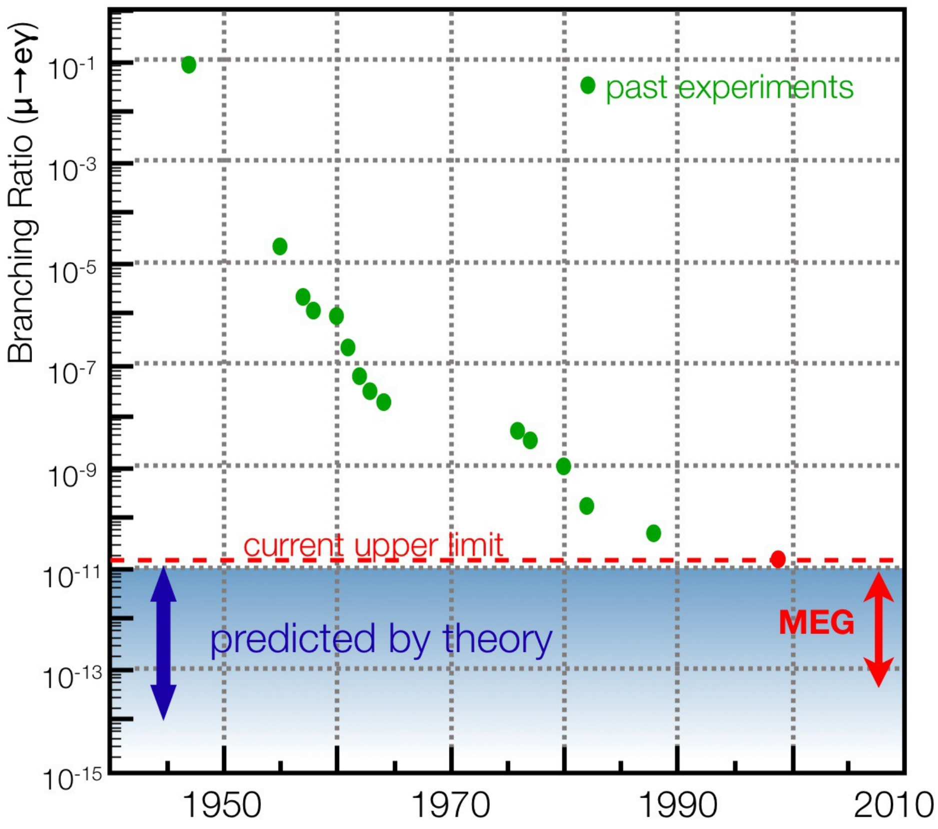
Outline

- Motivation
- Signal and Background
- MEG Experiment
- MEG Detectors
  - Liquid xenon photon detector
  - Positron spectrometer
- Calibration methods for physics analysis
- Performance in 2009
- Plan and prospects

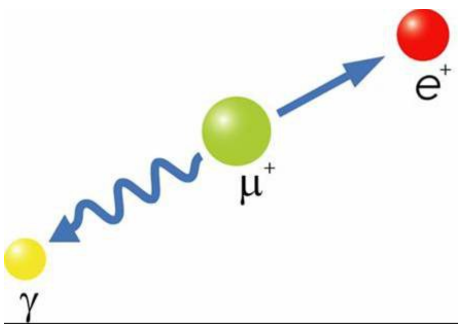
Motivation

- In the standard Model, even if taking into account the neutrino mass, the charged lepton flavor violation(LFV) is predicted to be tiny, $\sim 10^{-50}$, and the current experimental bound is set by MEGA
  - $Br(\mu \rightarrow e\gamma) < 1.2 \times 10^{-11}$
- New physics like SUSY-GUT, SUSY-seesaw predicts measurable LFV just below the current limit
- Discovery of charged LFV is a clear evidence of physics beyond the Standard Model
- MEG goal : $Br(\mu \rightarrow e\gamma) \sim$ a few $\times 10^{-13}$
- Real chance to discover new physics



Signal and Background

- Positive μ decay at rest
- Clear two body kinematics



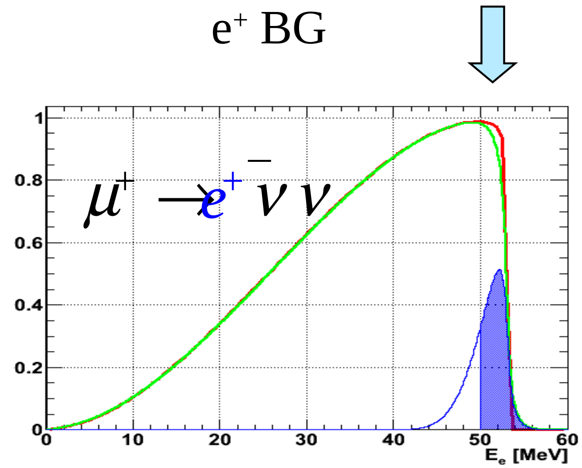
- Back to back ($\theta_{e\gamma}$=180°)
- $E_e \approx E_\gamma$=52.8MeV
- Coincident ($T_{e\gamma}$=0)

Background

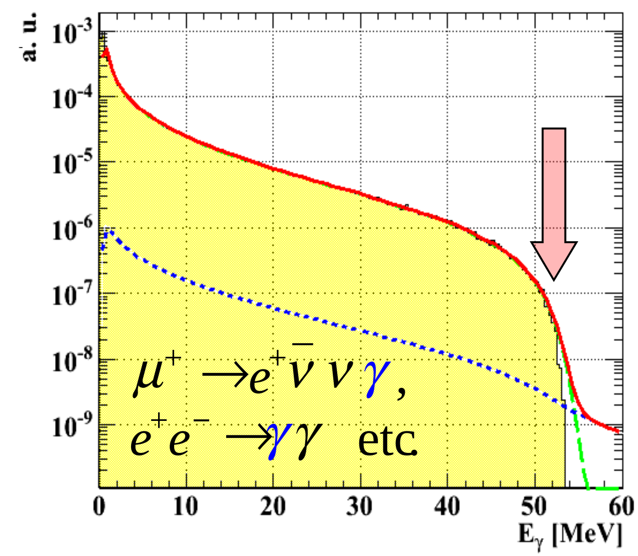
Accidental background is dominant

Michel e^+ + random γ

e^+ BG



γ BG



$$B_{acc} \propto \delta E_e \cdot (\delta E_\gamma)^2 \cdot (\delta \vartheta_{e\gamma})^2 \cdot \delta t_{e\gamma}$$

Good detector performance is essential (especially, Eγ)

High rate e^+ measurement with intense μ beam

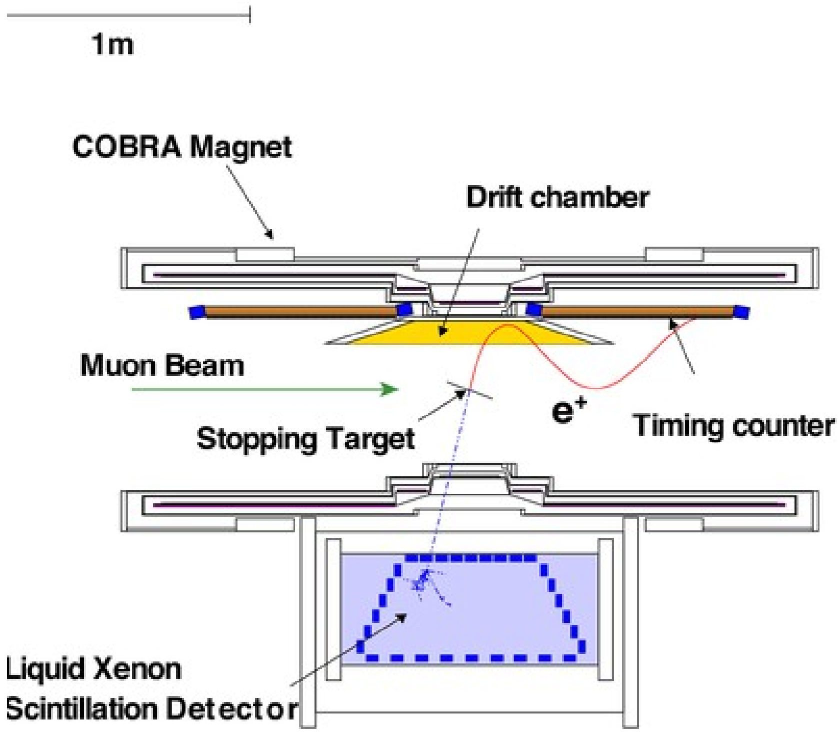
Pileup rejection is necessary

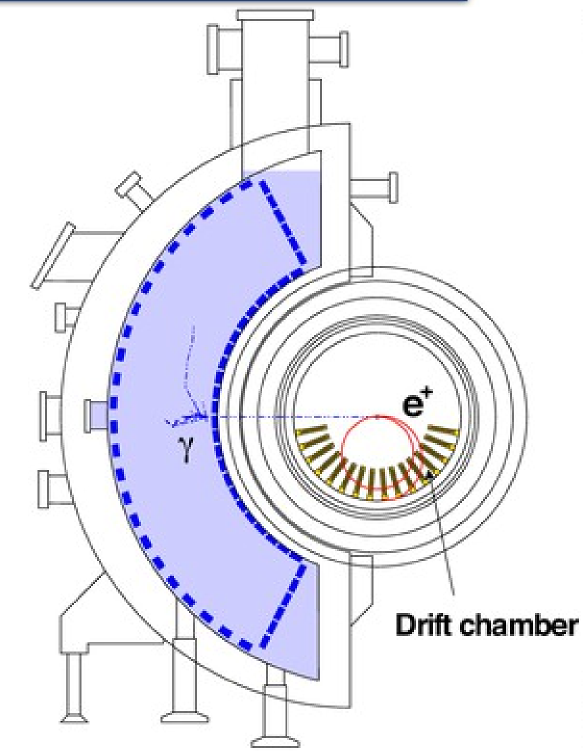
MEG Experiment

1.3MW most intense proton accelerator at PSI in Switzerland

DC muon beam 3×10^7 μ/s (possible up to ~1×10^8 μ/s)

- DC beam is suitable to reduce accidental background





- 1999 - a proposal to PSI
  - Detector R&D
- 2007 - all detectors ready
- 2008 - 3 month physics data
- 2009 - 2 month physics data

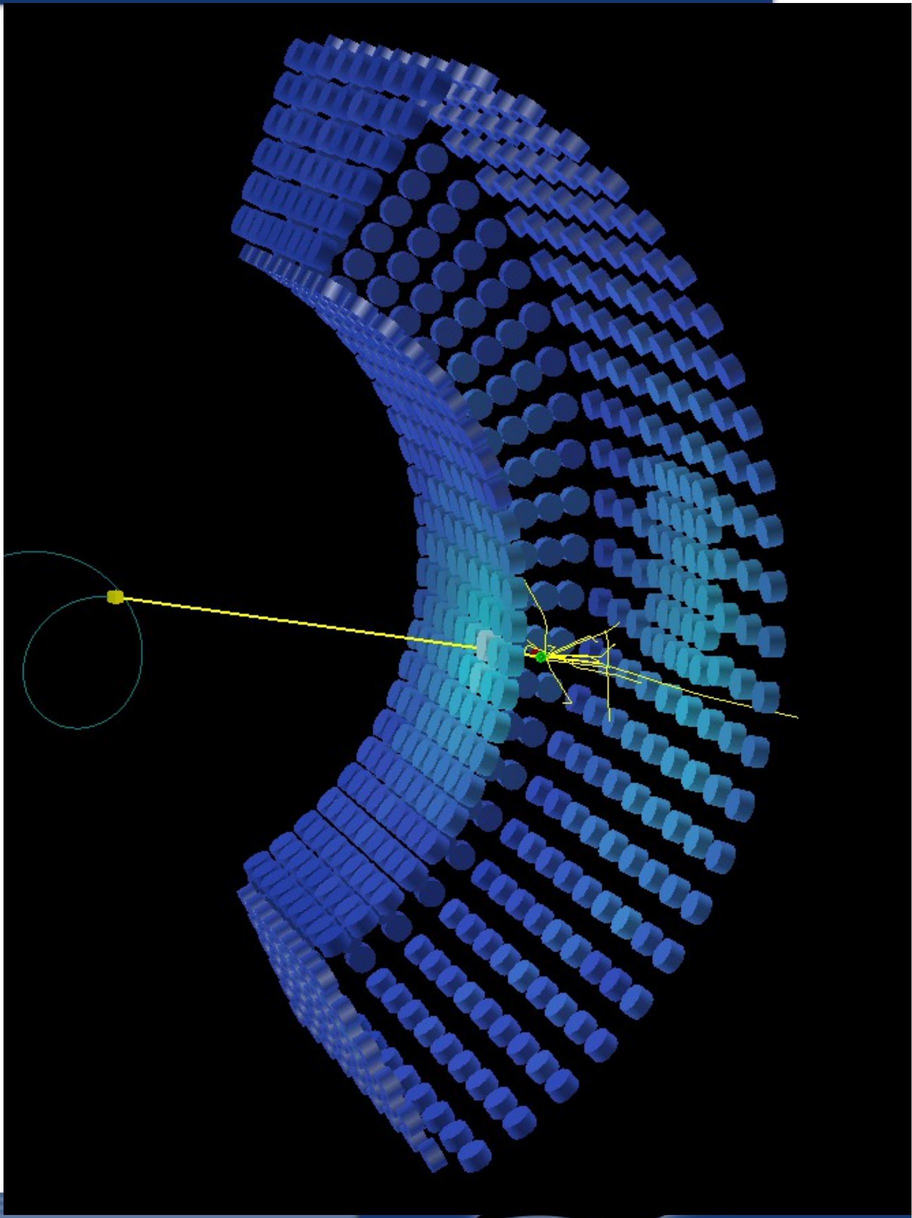
- High precision low mass positron spectrometer
  - SC magnet and low mass drift chamber, timing counter
- High performance photon detector
  - 900 liter liquid xenon + 846 PMTs
- Waveforms of all detectors are recorded by waveform digitizer

Liquid Xenon Detector

- 900 liter liquid xenon
- 846 2” PMTs (Hamamatsu R9869)
  - immersed in LXe directly

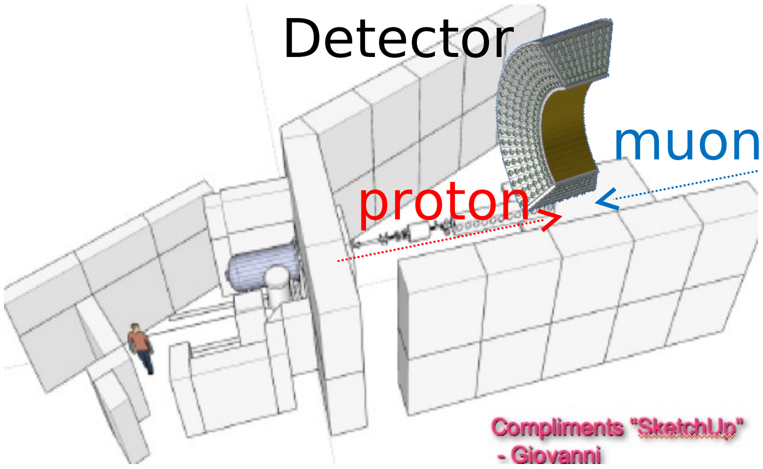
- Good uniformity (homogeneous, liquid)
- High light output (~75% of NaI)
- Short decay time (45ns)
- High density (3g/cm^3)

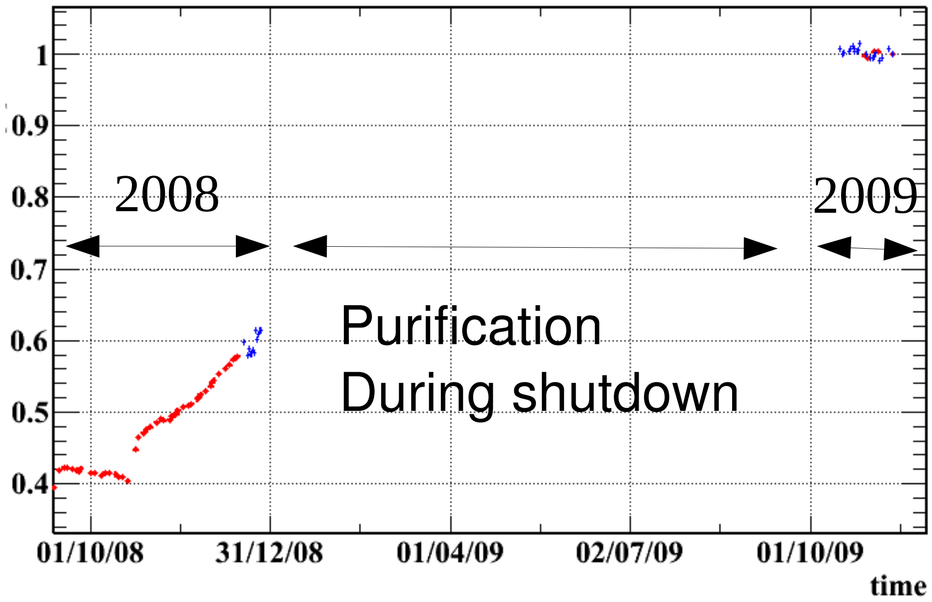
- Short scintillation wavelength ~ 175nm
  - Quartz window for PMT
- Low temperature 165K
  - pulse tube cryocooler developed by KEK
- Purification to remove H_2O, O_2, N_2 etc. < 10ppb



Calibration and Monitoring

- PMT gain monitored by LED, QE by α
- Light yield monitoring (CW, CR, AmBe etc.)
- Cockcroft-Walton proton accelerator
  - 17.6MeV γ by Li(p,γ)Be reaction
  - Light yield monitoring & σ_E at 17.6MeV





2008 physics run and shutdown:
gaseous purification to increase light yield

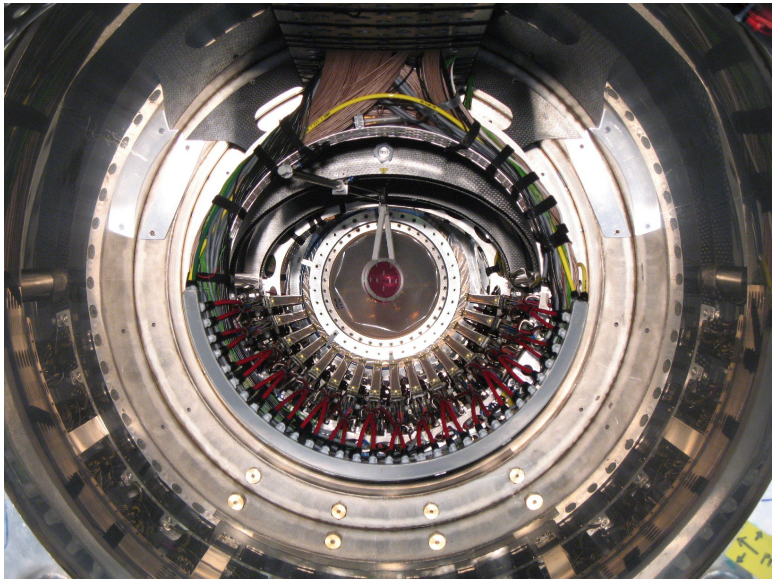
Light yield became as much as expected
And decay time of γ waveform changed

2009 physics run: no purification

Light yield monitoring: < 1% level

Positron spectrometer

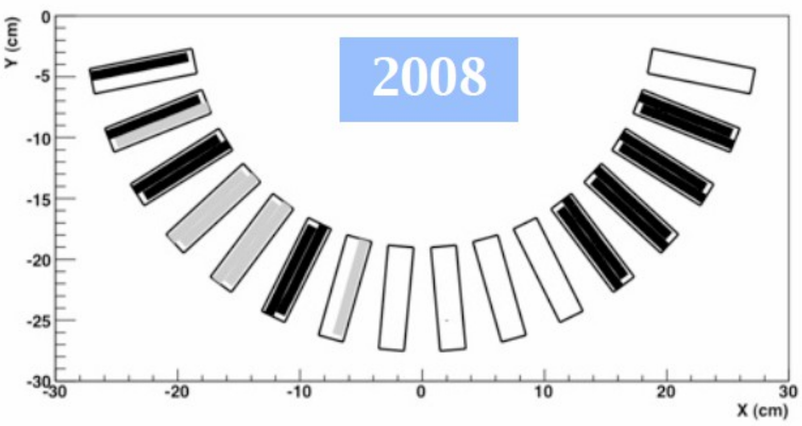
- SC magnet produces special gradient magnetic field, 1.27(at z=0) ~0.49Tesla
  - To sweep out low momentum e^+
- Timing counter (T_e, σ_{Te} <50ps)
  - Plastic scintillator + fine-mesh PMTs
  - Scintillating fiber + APD

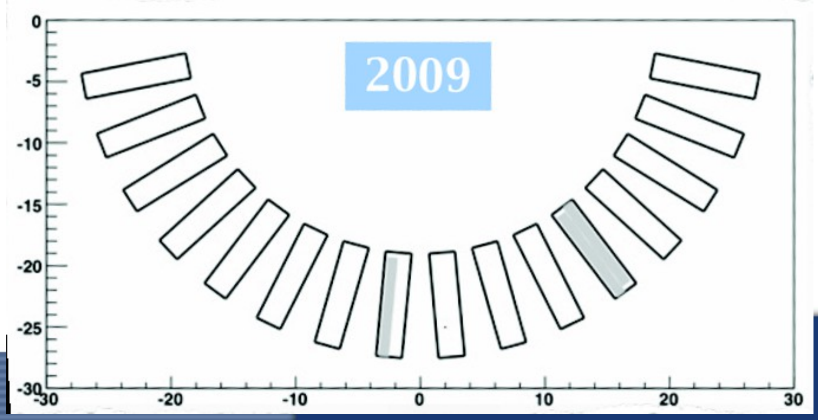


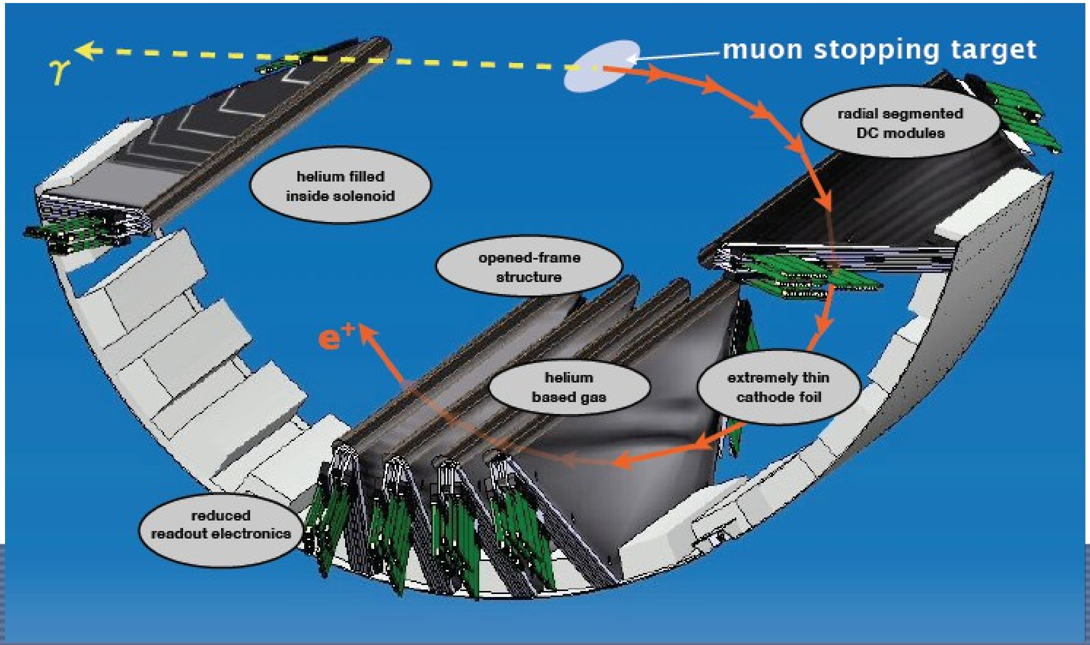
- Drift chamber (E_{e+} , θ_{e+} , ϕ_{e+})
  - 16 segmented chambers radially
  - Position resolution ~ 200μm(r), 500μm(z)
  - Momentum resolution ~ 1%
  - Low material budget (low multiple scattering, low γ background)

Drift chamber

- 2008
  - Discharge problem reduced e^+ detection efficiency and resolution for positron measurement
    - ε ~14%(~1/3), σ_E, $\sigma_{\theta\phi}$ were worse
  - The problem was long term exposure to helium, fixed before physics run in 2009
- 2009
  - e^+ detection efficiency(30~40%, including TC matching) and resolutions improved



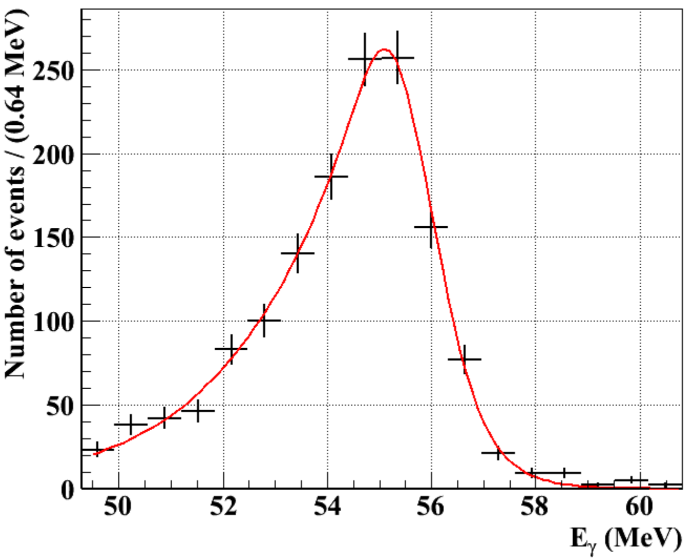


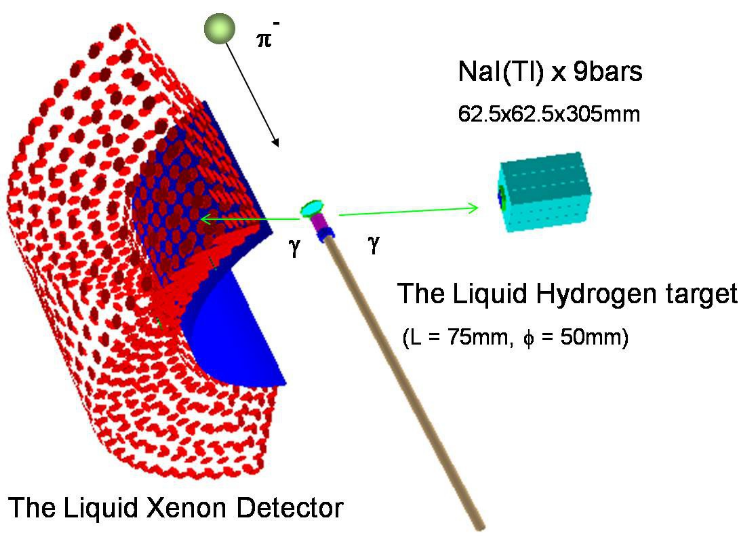


Calibrations for physics analysis

CEX calibration (E_γ, T_γ, XY_γ)

- $\pi^- p \rightarrow \pi^0 n \rightarrow \gamma\gamma n$ (CEX reaction)
  - 55, 83MeV γs are available once back-to-back photons are selected
  - Energy close to our signal (52.8MeV)
- Tagging detector
  - NaI + APD array
- LH2 target

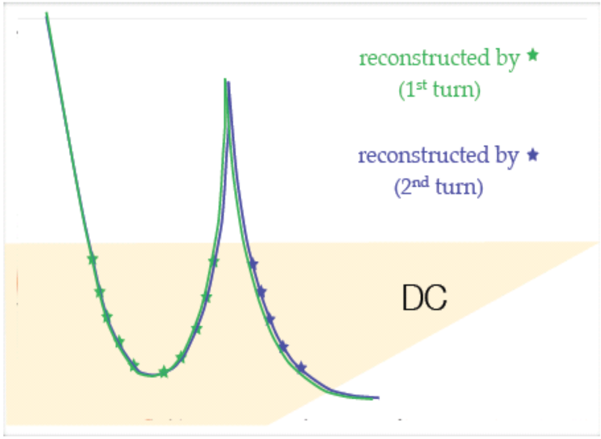


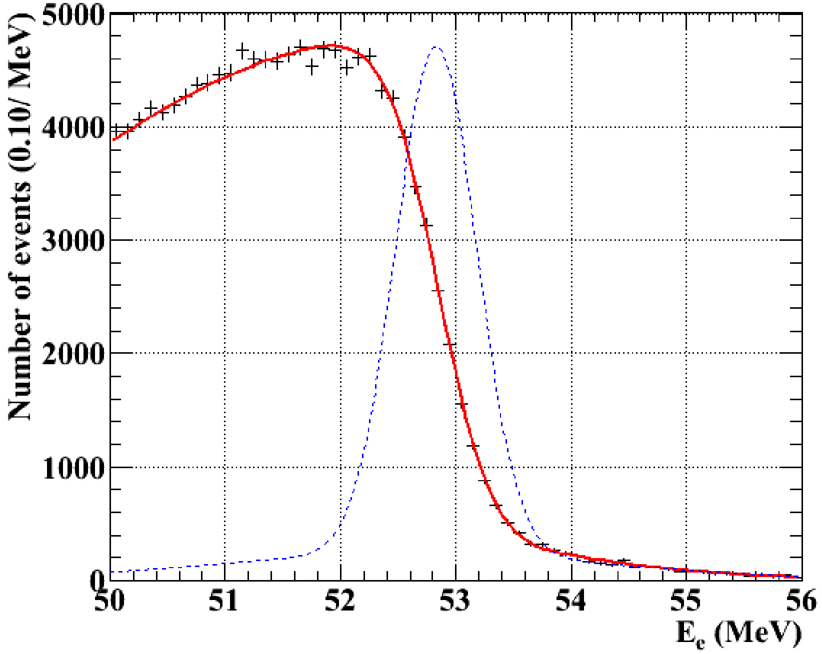


- Energy, timing, and position resolution
  - 2.1%(depth>2cm), >68ps, 5mm(XY), 6mm(depth)
- Position dependence by moving NaI
- Signal response function
- γ efficiency: 58%

Positron resolution

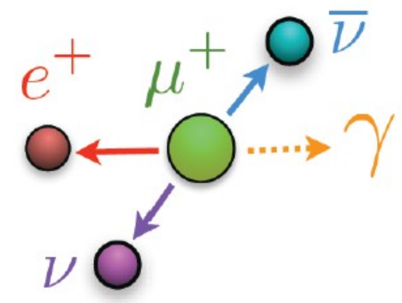
- Resolution and signal response can be extracted from residuals of two turn tracks
  - Momentum resolution
    - σ_E ~ 0.74% core
  - Angle resolution
    - σ_ϕ ~ 7.1mrad (core)
    - σ_θ ~ 11.2mrad
- Background spectrum
  - Michel spectrum fit smeared by detector resolution
  - Double Gaussian plus acceptance

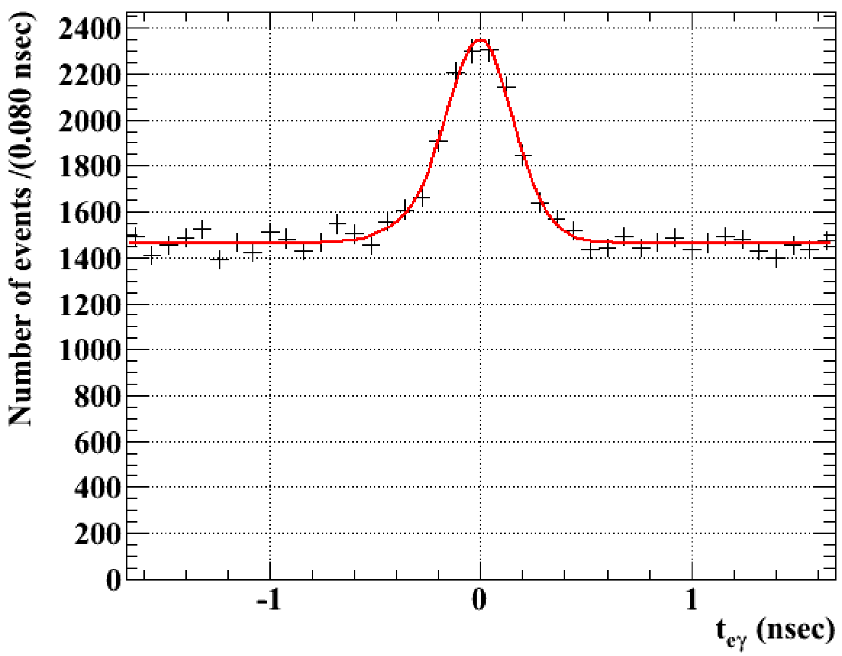




Radiative muon decay ($T_{e\gamma}$)

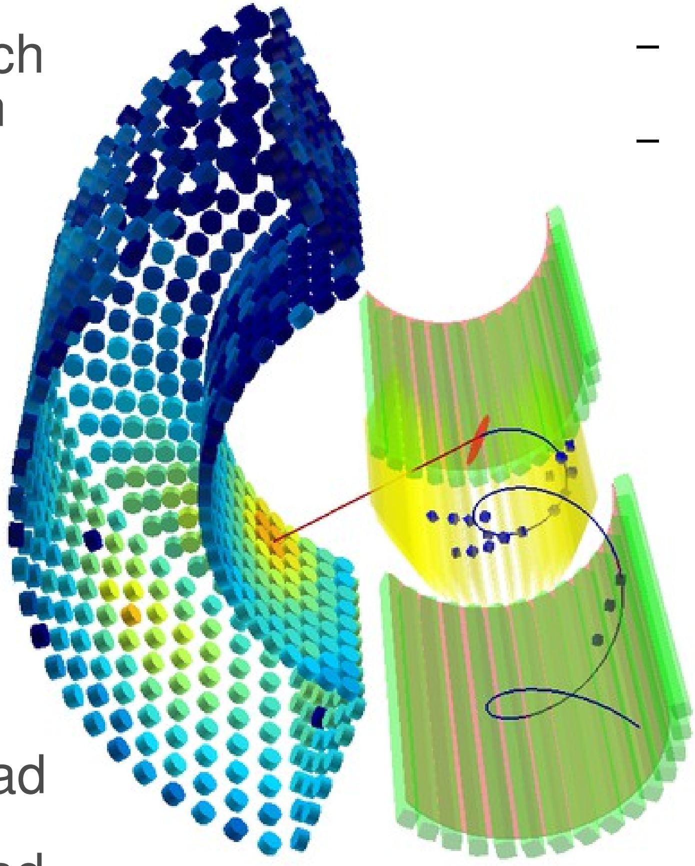
- Relative timing resolution can be estimated directly by physics data (RMD)
  - Coincident, not back-to-back, γ low energy
  - $\sigma_{Te\gamma}$ consists of each detector resolution, tracking ambiguity etc.
  - Good test to detect $\mu \to e\gamma$ events, and possible to measure $\sigma_{Te\gamma}$ directly
  - Can be also used to check overall detection efficiency
  - $\sigma_{Te\gamma}$ ~ 142ps (core)





Relative angle ($\theta_{e\gamma}$, $\phi_{e\gamma}$)

- Relative angle resolution is combination of each detector resolution
- Xenon detector position resolution
  - x,y : 5mm
  - Depth: 6mm
- In total,
  - $\theta_{e\gamma}$ ~ 14.7mrad
  - $\Phi_{e\gamma}$ ~ 12.7mrad



- Positron angle resolution
  - θ: 11.2mrad
  - ϕ: 7.1mrad (core)
  - Vertex resolution on the target
    - Extrapolation from the track
    - Resolution by target hole
    - R: 3.3mm
    - Z: 3.4mm

Performance

	2008	2009 (preliminary)
Gamma Energy (%)	2.0 (w>2cm)	2.1 (w>2cm)
Gamma Timing (psec)	80	>67
Gamma Position (mm)	5(u,v)/6(w)	←
Gamma Efficiency (%)	63	58
e^+ Timing (psec)	<125	←
e^+ Momentum (%)	1.6	0.74(core)
e^+ efficiency (%)	14	30~40%
e^+ angle (mrad)	10(ϕ)/18(θ)	7.1(ϕ core)/11.2(θ)
e^+ - gamma timing (psec)	148	142(core)
Muon Decay Point (mm)	3.2(R)/4.5(Z)	3.3(R)/3.4(Z)
Trigger efficiency (%)	66	83.5
Stopping Muon Rate (sec^{-1})	$3x10^7$	$2.9x10^7$(300μm)
DAQ time / Real time (days)	48/78	35/43
Sensitivity	$1.3x10^{-11}$	$6.1x10^{-12}$
BR upper limit (obtained)	$2.8x10^{-11}$	$1.5x10^{-11}$

- In 2008, sensitivity was $1.3x10^{-11}$, and our result was the BR UL $2.8x10^{-11}$ (90%C.L.)
- In 2009, our sensitivity reached $6.1x10^{-12}$, and the BR UL was $1.5x10^{-11}$ (90%C.L., these numbers are preliminary).

R. Sawada: 23rd 9:30 physics result

A. Baldini: 27th 15:30 plenary talk
“Rare lepton and K-meson decays “

Prospects

- Possible improvements
  - Improvement of synchronization of waveform digitizer (DRS4) improves σ_T
  - Possible better calibration with monochromatic positron beam and improve positron tracking
  - Noise reduction and electronics modification for DC
  - Refinement in calorimeter analysis
- 3 years physics data (2010-2012)
  - Sensitivity will reach our goal, a few x 10^{-13}
  - Each detector performance could be improved further!

	2010 (preliminary)
Gamma Energy (%)	1.5 (w>2cm)
Gamma Timing (psec)	67
Gamma Position (mm)	5(u,v)/6(w)
e^+ Timing (psec)	90
e^+ Momentum (%)	0.7
e^+ angle (mrad)	8(ϕ)/8(θ)
e^+ - gamma timing (psec)	120
Muon Decay Point (mm)	1.4(R)/2.5(Z)
Stopping Muon Rate (sec^{-1})	$3x10^7$
DAQ time / Real time (days)	95/117
Sensitivity	$2.0x10^{-12}$
BR upper limit	-

Summary

- MEG detector has started operation since 2007, and physics data have been taken in 2008 and 2009.
- Many calibration & monitoring methods have been established to check our detector performance.
- Our result to search for lepton flavor violating $\mu \rightarrow e\gamma$ decay is the branching ratio upper limit 1.5×10^{-11} (90%C.L., preliminary) based on 2009 data.
- We will have three years data taking(2010-2012) to reach our sensitivity, a few x 10^{-13} . Improvement of our detector performance is the most important for us.

DAQ and trigger

- All waveforms are taken for all detectors
  - Essential for us to remove pileup events
  - 1.6GHz waveform digitizer for LXe, TC
  - 0.8GHz waveform digitizer for DC
- MEG trigger
  - LXe total charge & TC total charge
  - Direction match & timing coincidence
  - 6Hz during physics run

Improve Resolutions, contd.

- New Calibration Source will be implemented.
- Using Mott-Scatt. (coherent elastic) on light nuclei.
- " **Variable / Monochromatic** " e^+ is available.
- Momentum Calibration and Resolution Understanding will be improved.