Report on MEG experiment

Search for Lepton Flavor Violation in $\mu \rightarrow e+\gamma$ decay

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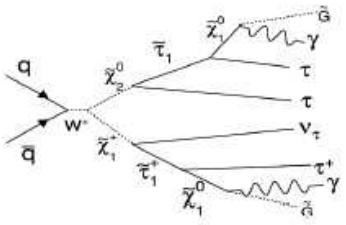
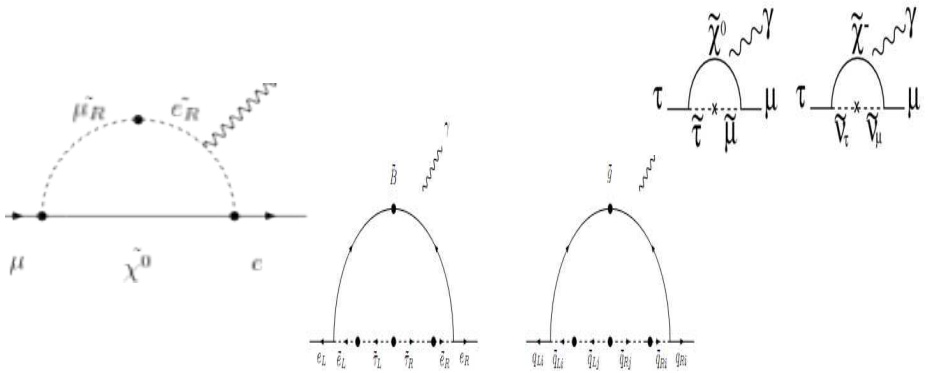
Physics motivations

The Standard Model (SM) is believed to be a low-energy approximation a of a more fundamental theory
DM, number of parameters, unexplained symmetries, flavor structure, …

All models beyond the SM contains new particles that could
either be directly discovered
(high energy frontier)



or seen through their contributions in loops
(high precision frontier)



Physics motivation

1) The cLFV decay is undetectably small in the extended SM, which takes into account the neutrino masses and mixings

Example $\mu \to e\,\gamma$ decay

$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3}\left(\frac{\alpha}{2\pi}\right)\sin^2 2\theta_\odot \left(\frac{\Delta m^2}{M_W^2}\right)^2, \quad \Rightarrow \mathbf{BP \sim 10\text{–}54}$$

2) New Physics scenarios usually enhance the rate of cLFV decay by many orders of magnitude, through loops of new particles

3) cLFV decays are clean, no SM contaminated, evidence of new physics

4)The expected rates are close to the experimental upper bound and within the capabilities of present and near future experiments

Signal and Background

Signal

e+ μ+ γ

Θeγ = 180°

Ee = Eγ = 52.8 MeV

Te = Tγ

Prompt

e+ ν

ν μ+ γ

$\mu \rightarrow e\bar{\nu}\nu\gamma$

Accidental

μ+ ν $e^+e^- \rightarrow \gamma\gamma$

e+ ν $\mu \rightarrow e\bar{\nu}\nu\gamma$

γ $e\mathcal{N} \rightarrow e\mathcal{N}\gamma$

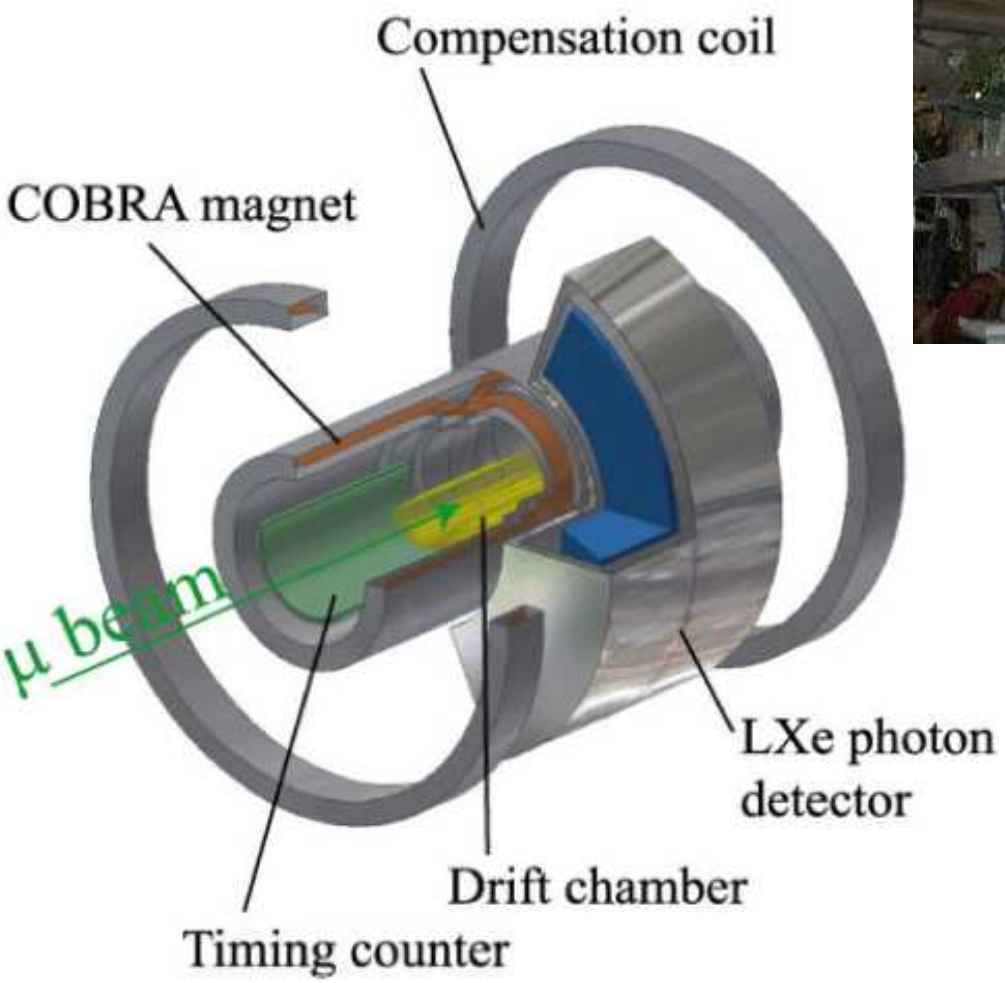
$\mu \rightarrow e\bar{\nu}\nu$

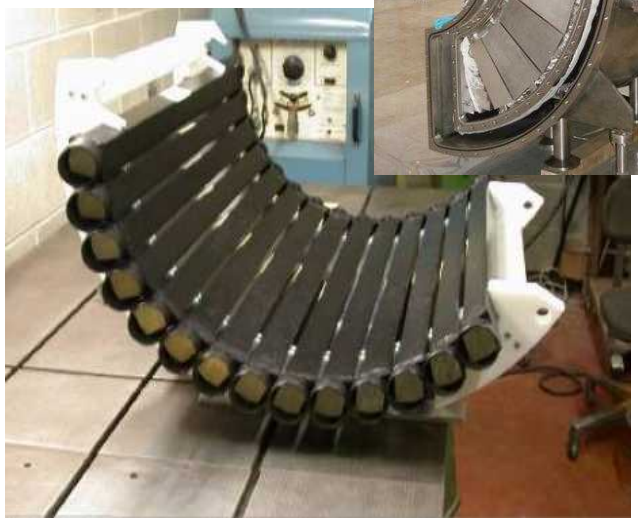
$B_{\text{prompt}} \approx 0.1 \times B_{\text{acc}}$ $B_{\text{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$

at 3x107 μ/s

The accidental background is dominant and it is determined by the experimental resolutions

The MEG experiment

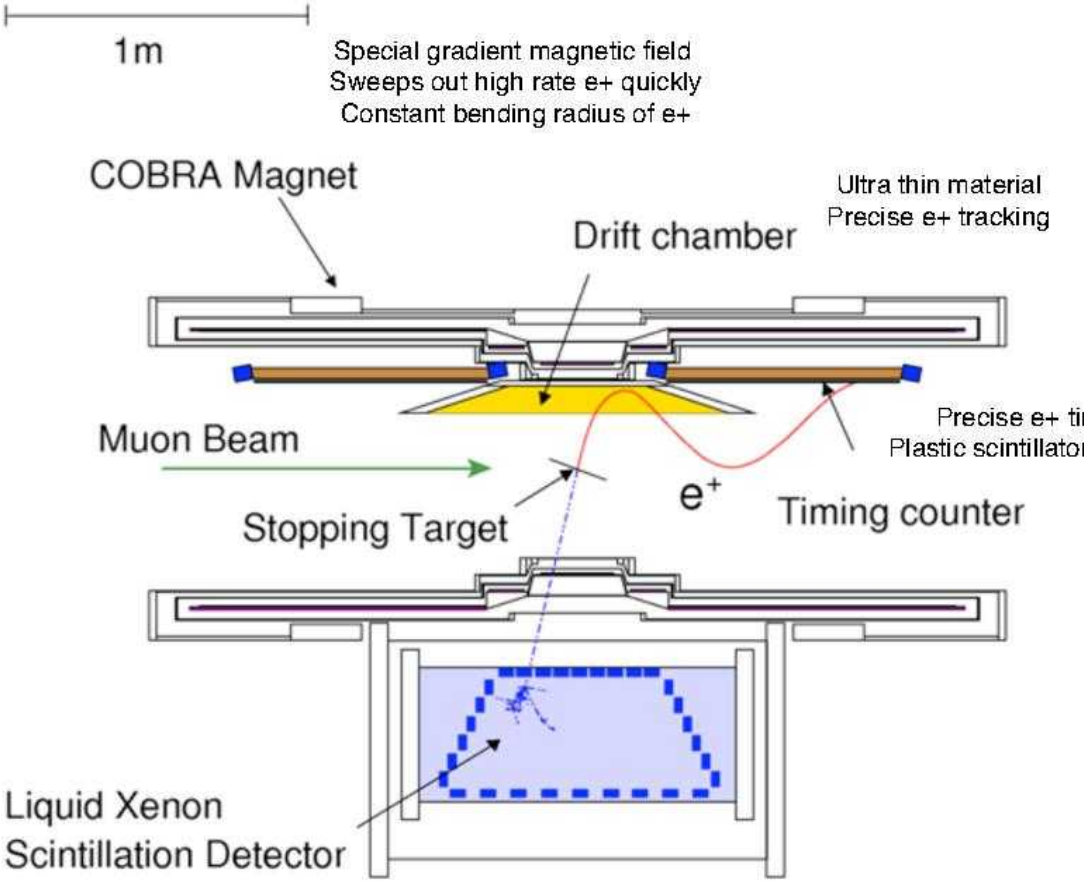


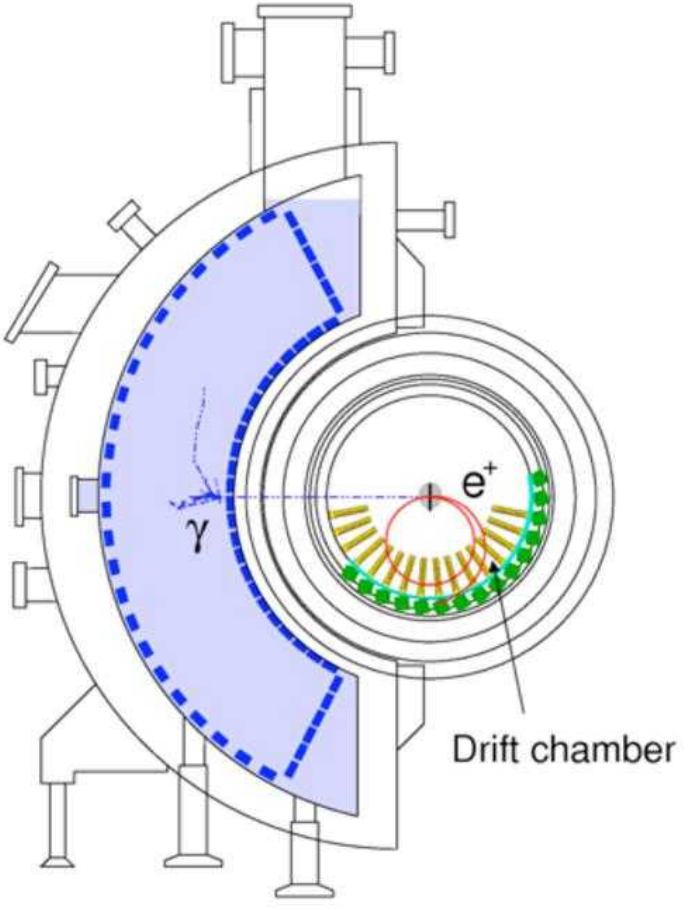


~60 physicists, 12 Institutions, 5 Countries
Italy, Japan, Russia, Switzerland, USA

MEG Experiment

The most intense DC muon beam, 3×10^7 μ/s @ PSI, Switzerland





Waveform digitizer for all detectors

Time Line

	Jan-Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008		Detector preparation				Calibration →		Physics run →		Calibration →
2009		Other experiment(Lamb shift) →				Detector installation & preparation →		Calibration →	Physics run →	
2010			Cosmic alignment →		e⁺ Mott → Beam study →		Calibration →	Physics run →	Physics run →	
2011							Calibration →	Physics run →	Physics run →	

PSI accelerator Shutdown period

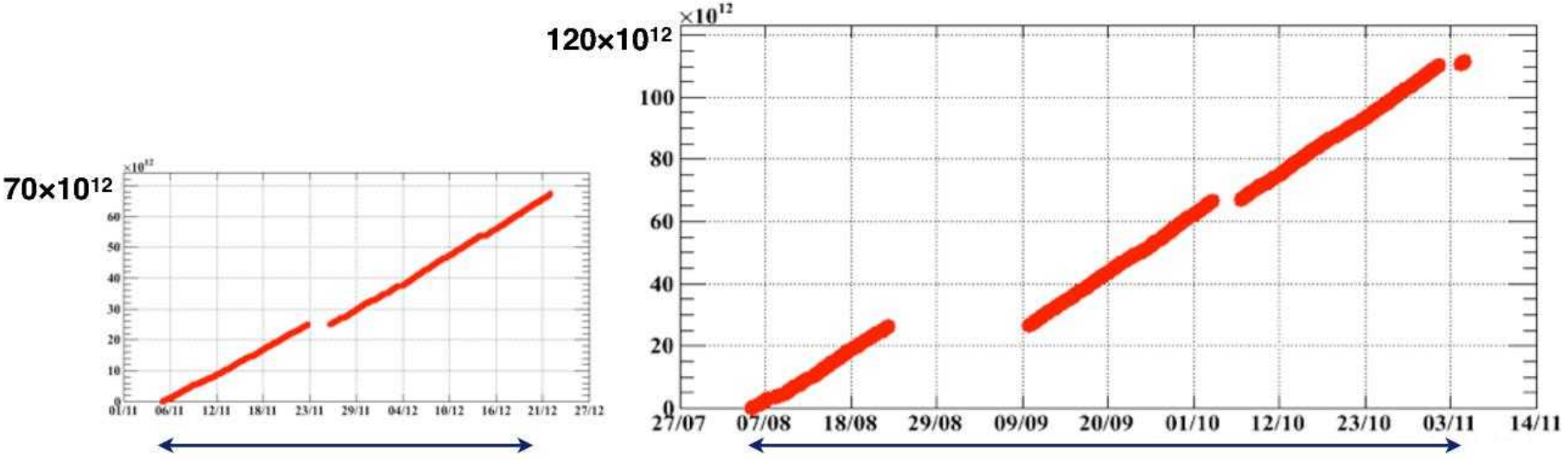
Results using data up to 2010 were published
Data 2011 is not unblinded yet

Data Statistics and sensitivity

of muons stopped on the target

2009

2010



~1.5 months

~3 month

Sensitivity (Expected UL@90%C.L.)

2009 : 3.3×10^{-12}

2010 : 2.2×10^{-12}

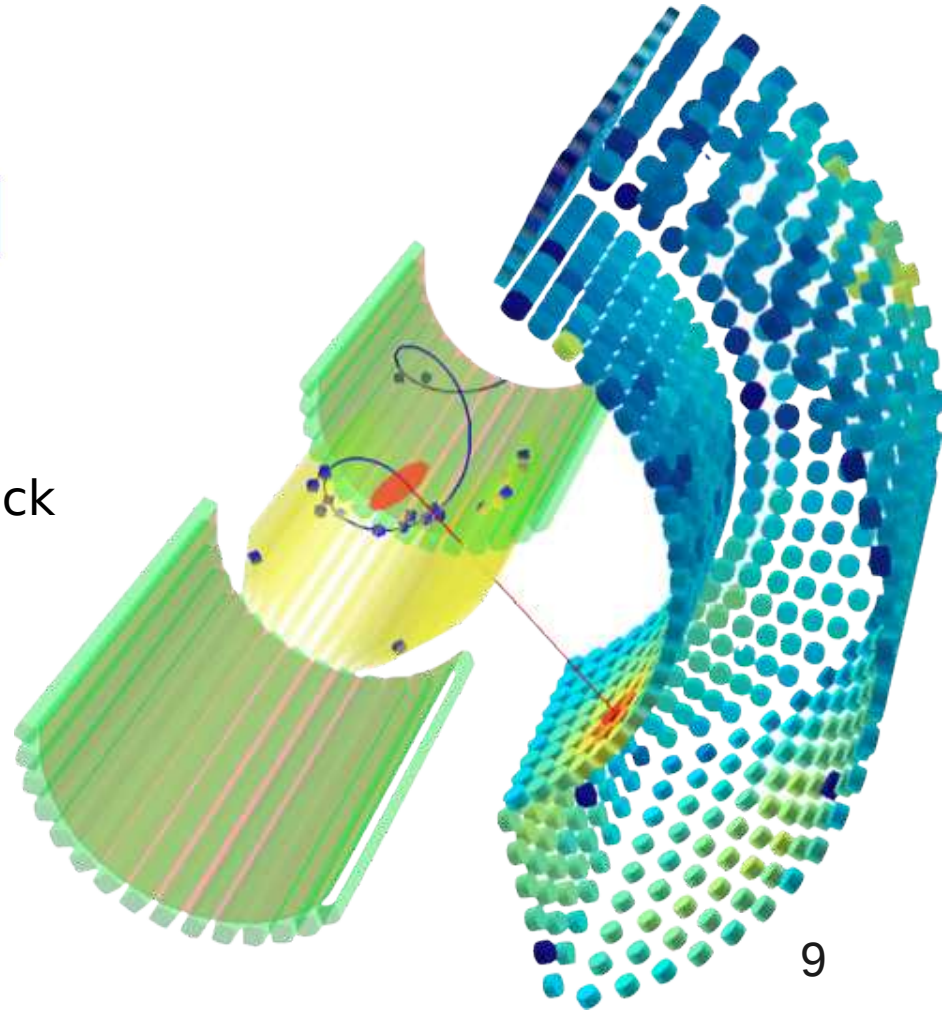
2009+2010 : 1.6×10^{-12}

Analysis principle

Likelihood function is built in terms of Signal, radiative Michel decay RMD and accidental background BG number of events and their probability density function PDFs

$$
\begin{aligned}
&-\ln \mathcal{L}\left(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}\right) \\
&= N_{\mathrm{exp}} - N_{\mathrm{obs}} \ln\left(N_{\mathrm{exp}}\right) \\
&\quad - \sum_{i=1}^{N_{\mathrm{obs}}} \ln\left[\frac{N_{\mathrm{sig}}}{N_{\mathrm{exp}}} S(\vec{x_i}) + \frac{N_{\mathrm{RMD}}}{N_{\mathrm{exp}}} R(\vec{x_i}) + \frac{N_{\mathrm{BG}}}{N_{\mathrm{exp}}} B(\vec{x_i})\right]
\end{aligned}
$$

- Un-binned likelihood fit of over the entire blind box
- Three different analysis for cross check
  - PDF
  - Approach (freq. or Bayes)

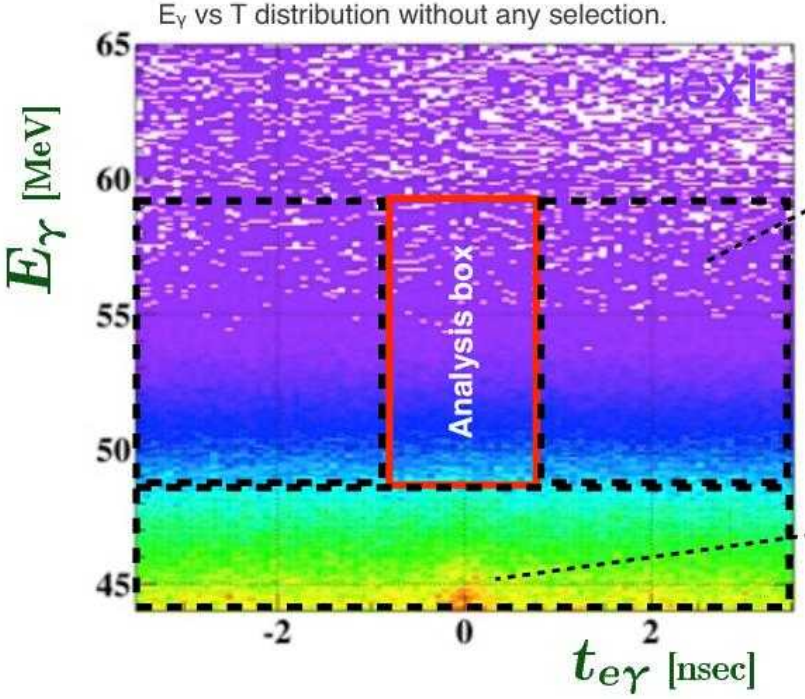


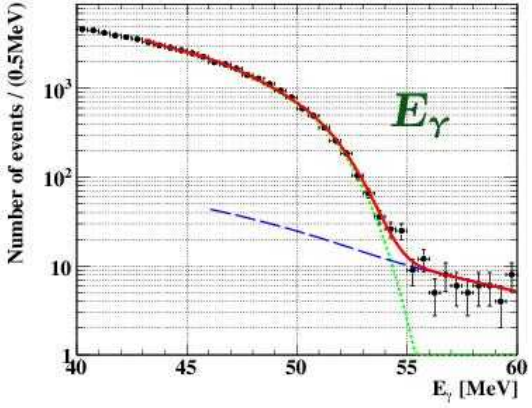
Analysis

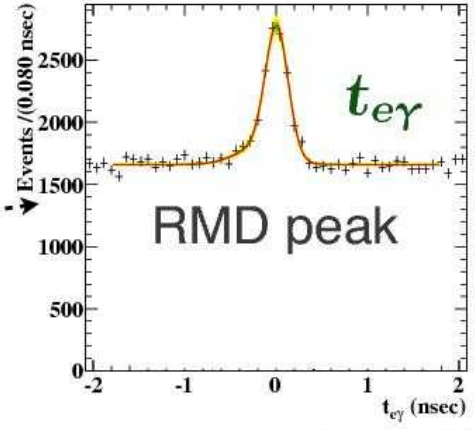
Likelihood fitting with 5 observables

$$\vec{x} = \begin{pmatrix} E_\gamma & : \text{Gamma energy} \\ E_e & : \text{Positron energy} \\ t_{e\gamma} & : \text{Time difference} \\ \vartheta_{e\gamma} & : \vartheta \text{ angle difference} \\ \varphi_{e\gamma} & : \varphi \text{ angle difference} \end{pmatrix}$$

- Analysis box is hidden until calibration and optimization are finalized
- BG shape and number of muons are known from sidebands



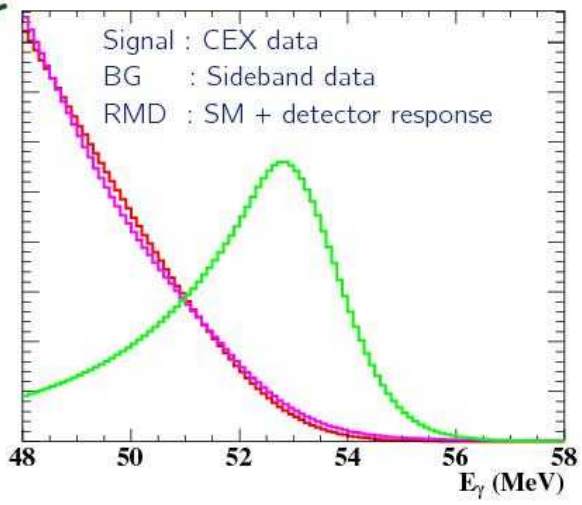




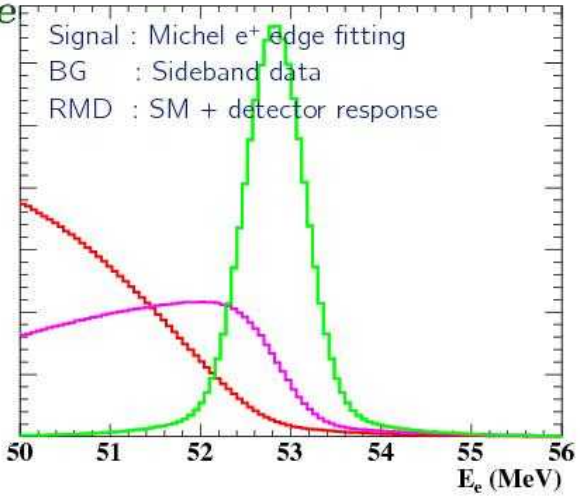
Signal RMD BG

PDF

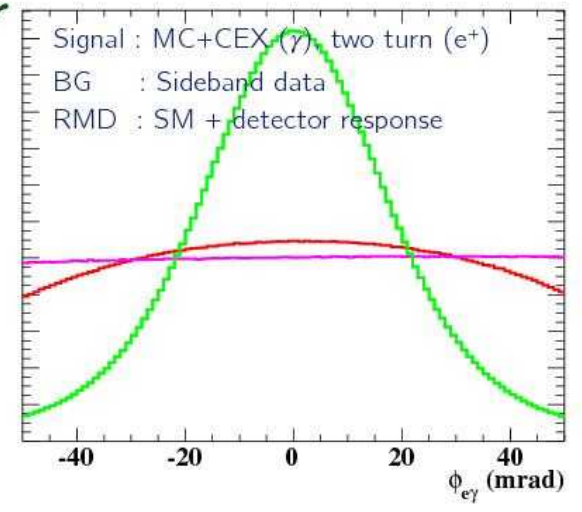
E_γ



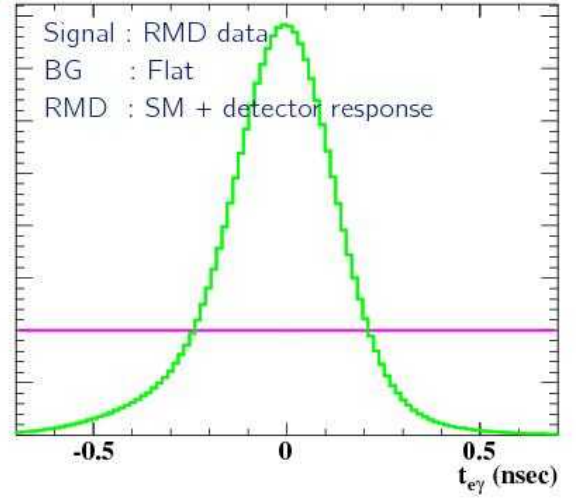
E_e



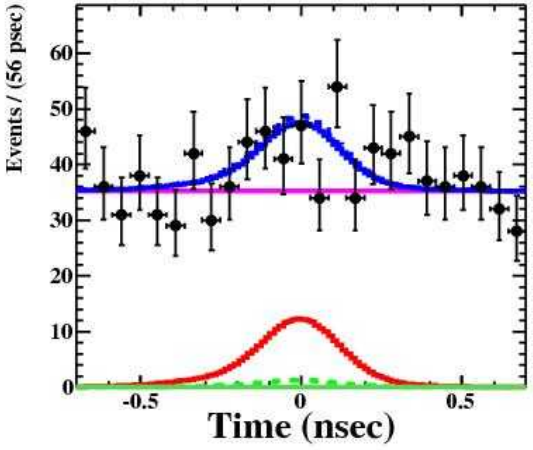
$\vartheta_{e\gamma}$

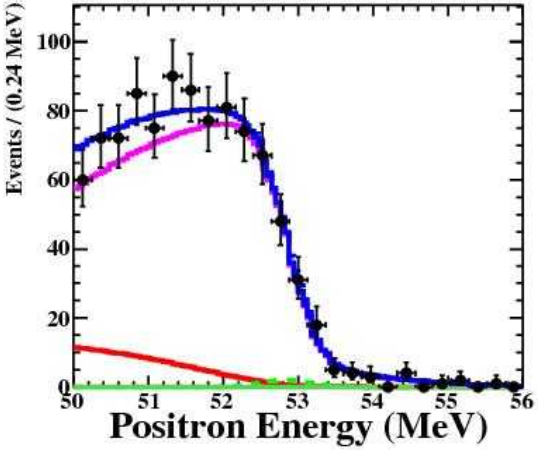


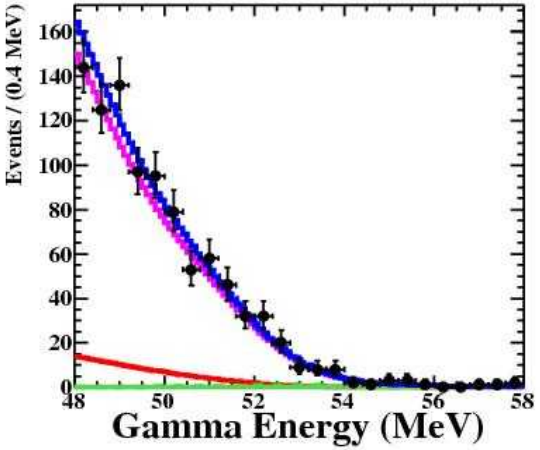
$t_{e\gamma}$

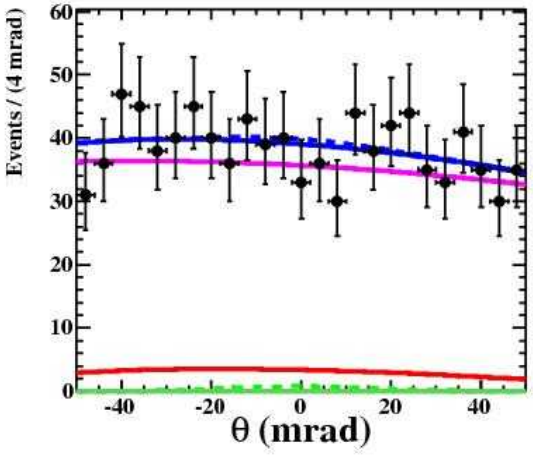


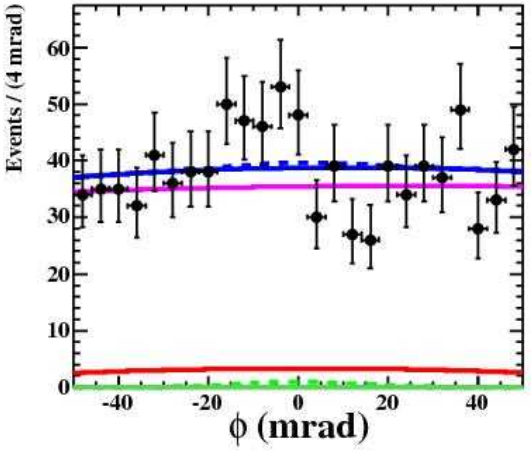
2009+2010 fit result











$N_{sig} = -0.5^{+7.9}_{-4.7}$

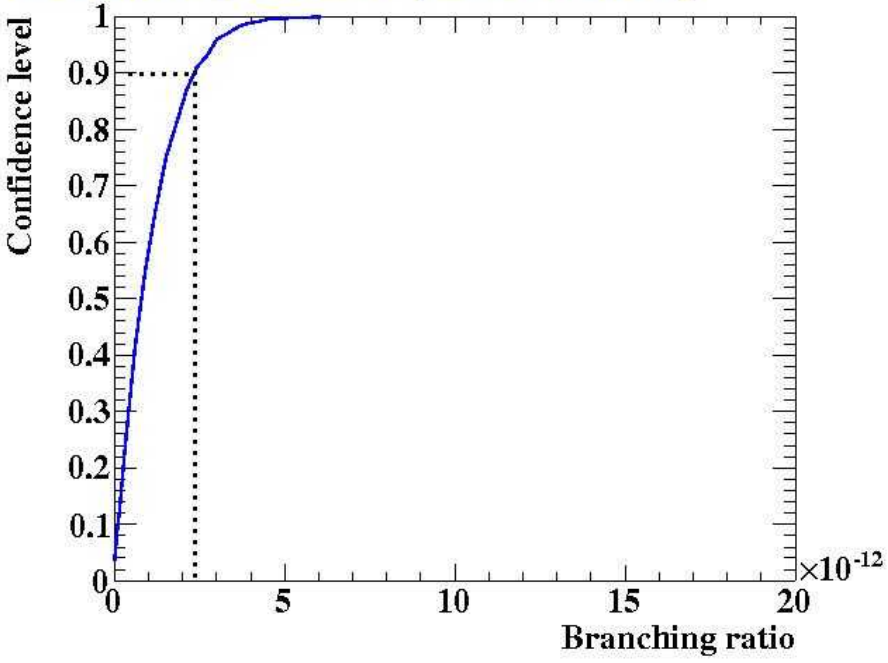
$N_{acc} = 882 \pm 22$

$N_{RMD} = 76.5 \pm 12$

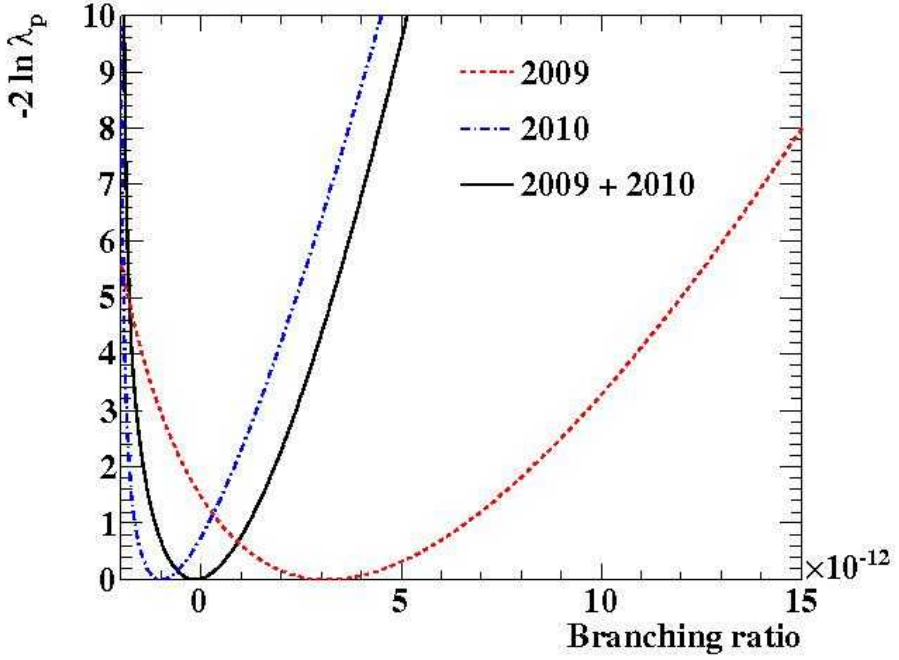
arXiv:1107.5547 [hep-ex]
Phys. Rev. Lett. 107, 171801 (2011)

2009+2010 result

Confidence level (2009+2010)



Likelihood



$$\mathcal{B}(\mu \to e\gamma) < 2.4 \times 10^{-12} \text{ @ 90\% C.L.}$$

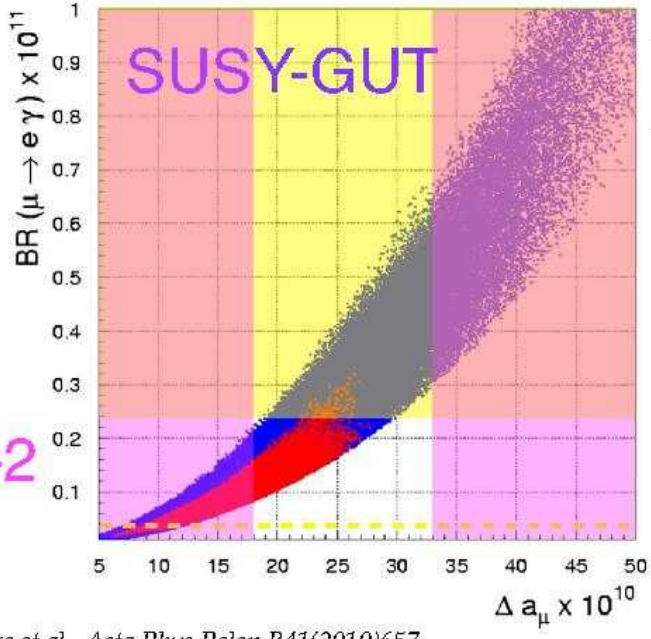
Data set	$\mathcal{B}_{\rm fit}$	LL	UL
2009	3.2×10^{-12}	1.7×10^{-13}	9.6×10^{-12}
2010	-9.9×10^{-13}	–	1.7×10^{-12}
2009 + 2010	-1.5×10^{-13}	–	2.4×10^{-12}

Systematic uncertainties (in total 2% in UL)

- relative angle offsets
- correlations in e^+ observables
- normalization

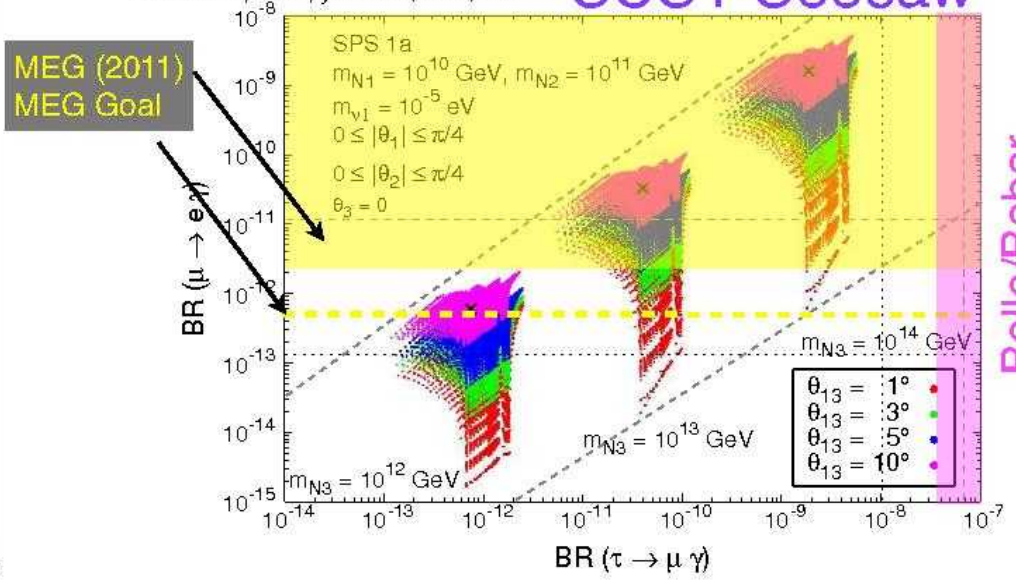
New physics models

G.Isidori, et al., PRD75(2007)115019



S. Antusch, et al., JHEP11(2006)090

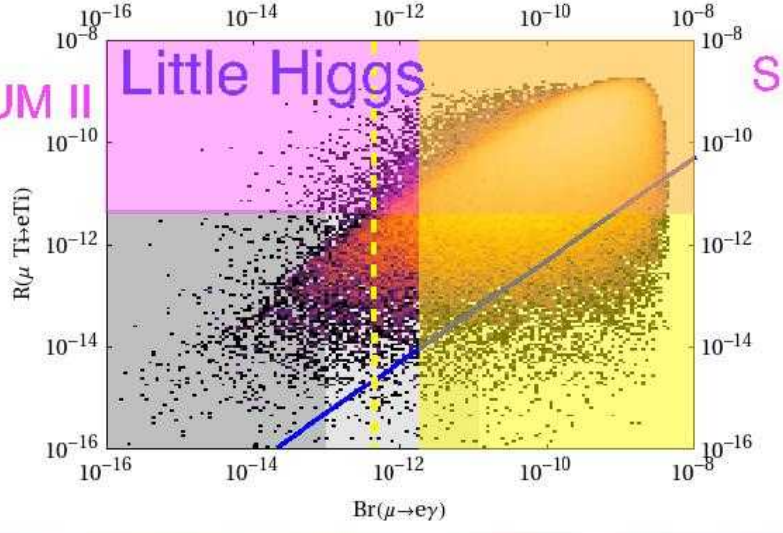
SUSY-Seesaw



Belle/Babar

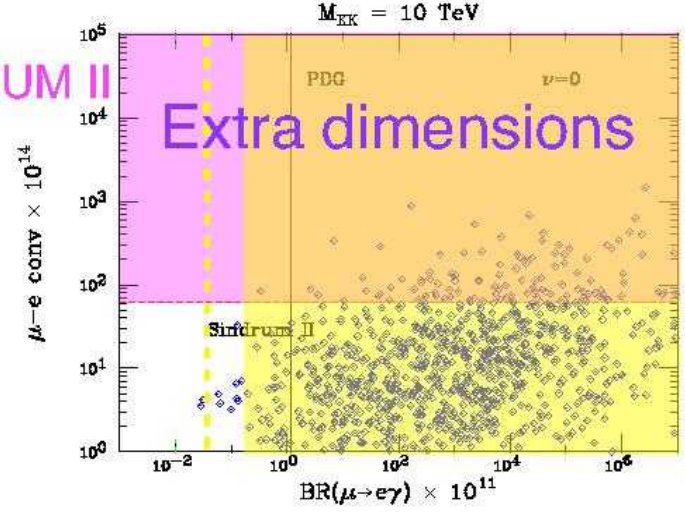
M.Blanke et al., Acta Phys.Polon.B41(2010)657

SINDRUM II



K.Agashe, et al., PRD74(2006)053011

SINDRUM II



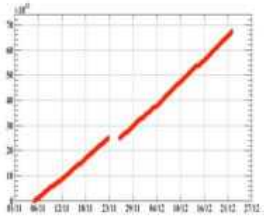
Data statistics : present and future

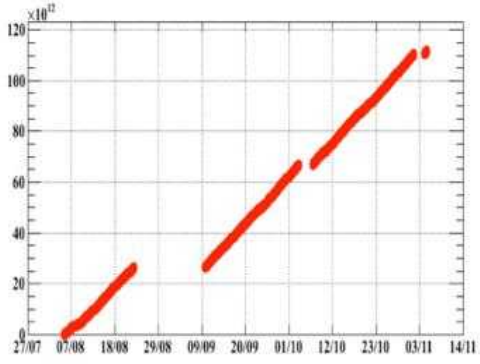
2009 2010 2011 2012

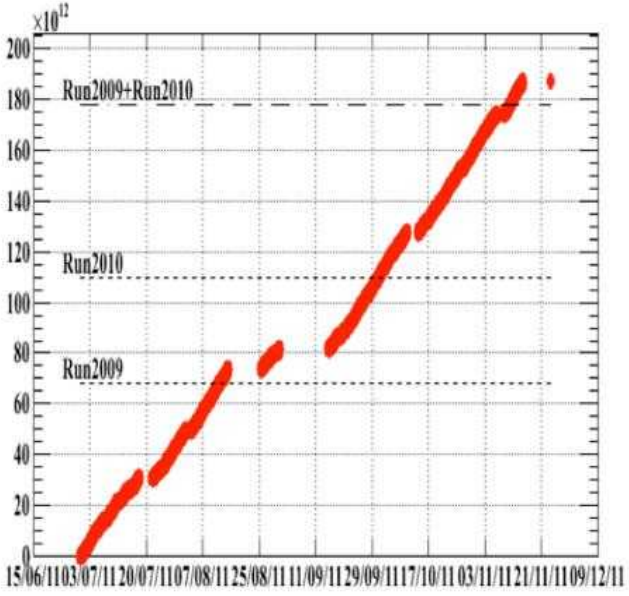
Published

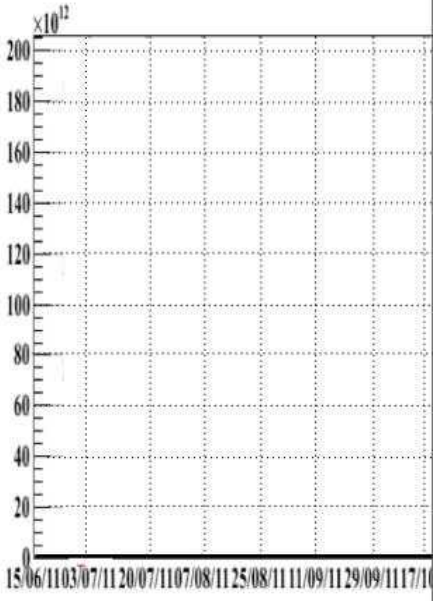
Almost same as 2011

# of muons stopped on the target









~1.5 months ~3 month ~6 month

Prospect

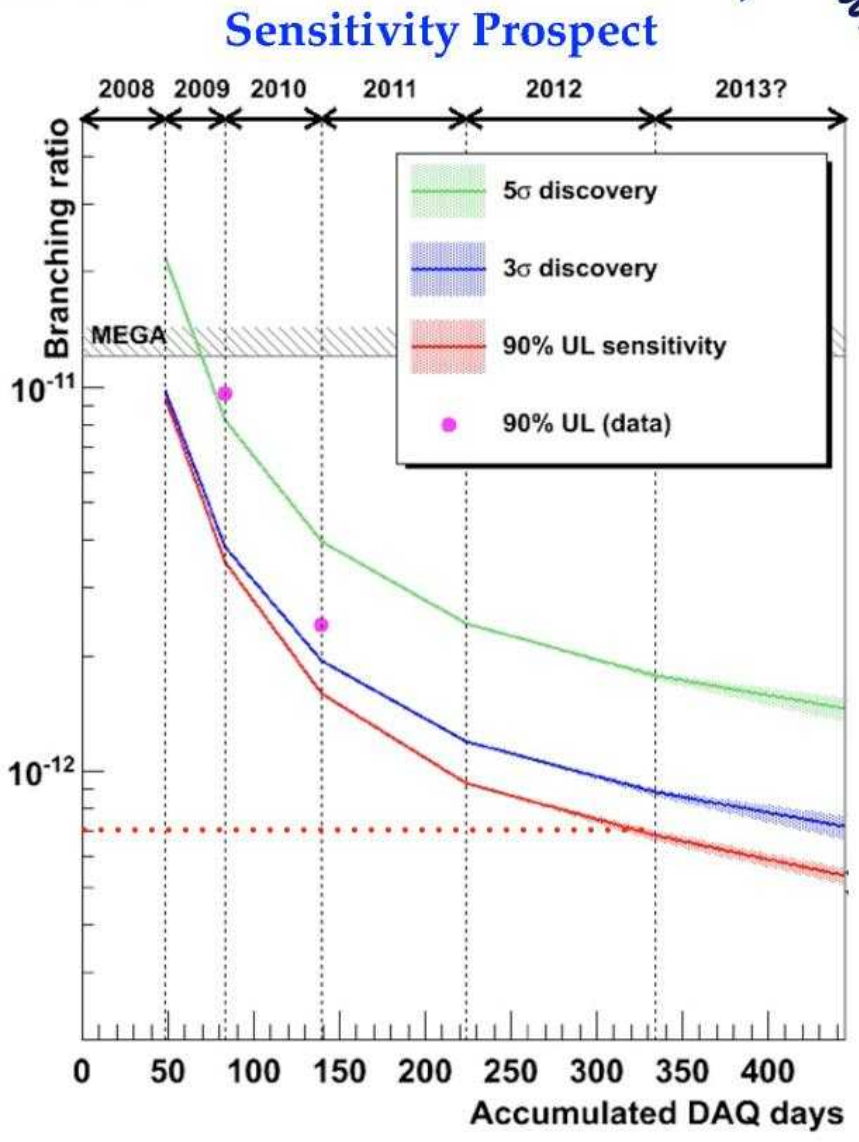
2011 data

1.1× (2009 + 2010 data) statistics
Analysis on going

2012 data taking will start soon

Almost the same statistics with 2011 data is expected

A major upgrade (design, R&D, simulation) understudy



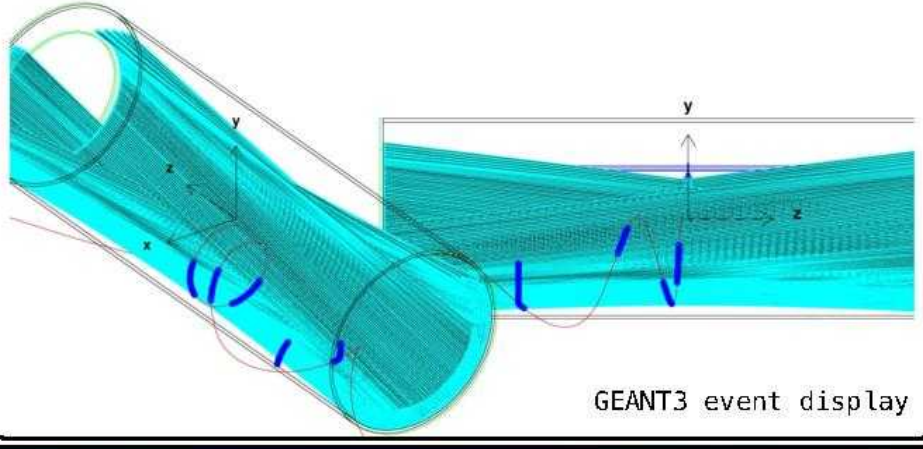
Upgrade

Several studies are ongoing for the upgrade of MEG to improve the sensitivity by one order of magnitude.

Proposal in the next year.

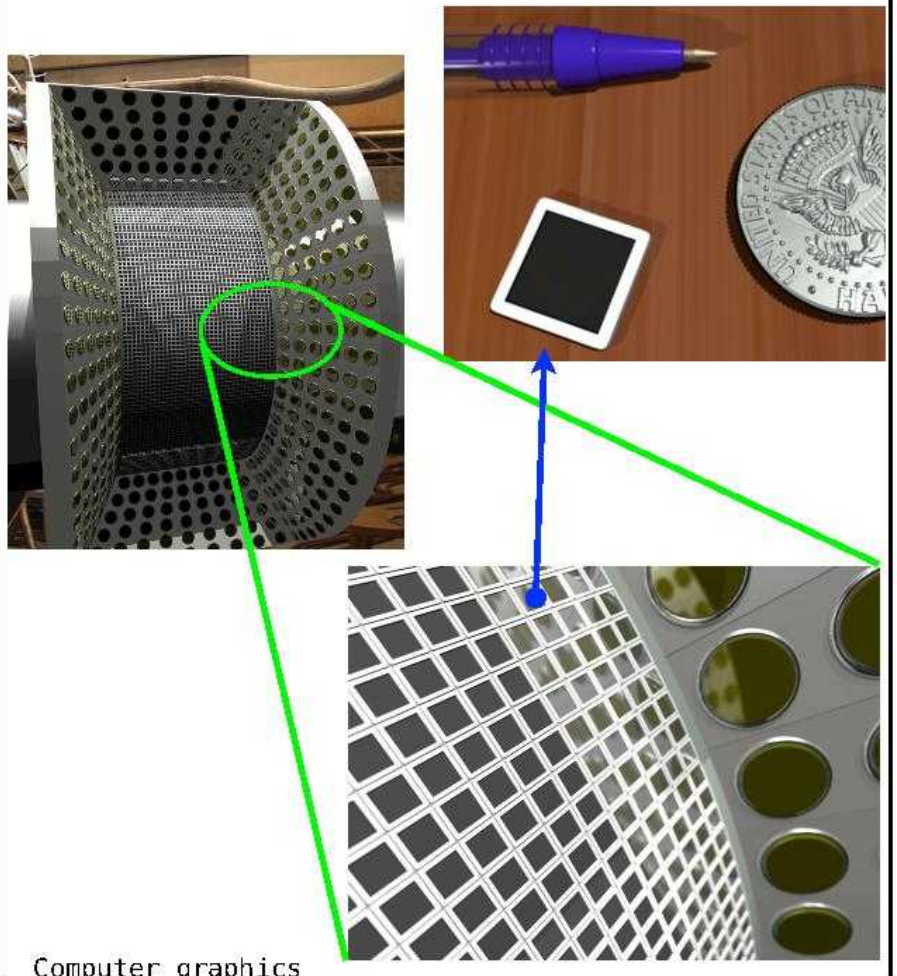
- 3 times higher beam intensity
- LXe γ detector upgrade with MPPC
- Unique volume gas chamber
- Active target / SVT / Thin e^+ timing counter...

Cylindrical drift chamber
Stereo wires



GEANT3 event display

~4000 MPPCs (15 x 15 mm) on the γ ray entrance face
New development of large MPPC for LXe



Computer graphics

Upgrade Pavia

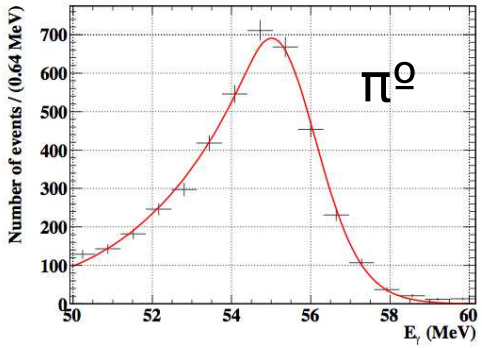
Pavia started an R&D to upgrade the TC for MEG2 (2015-2017)

Use of SiPM reading scintillator bars with simpler mechanics and better timing (to be proved)

Just started more in request for funding 2013

Resolutions

Eγ

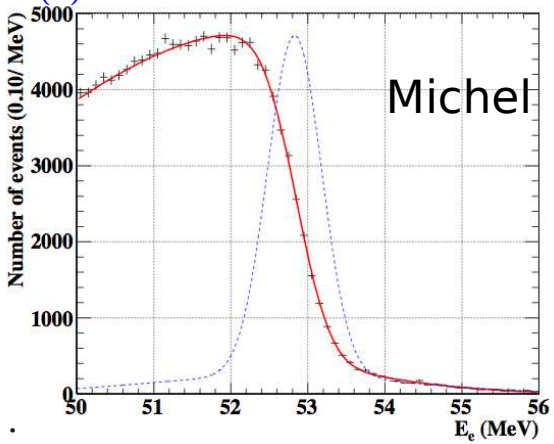


Average upper tail for deep conversions
·σR = **(2.1 ▯0.15) %**

Systematic uncertainty on energy scale **<0.6%**

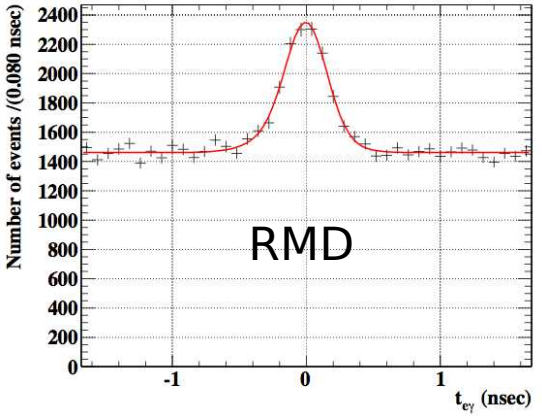
Ee+

Double gaussian momentum resolution
·σ(p) = **390 KeV (0.74%)** (core)
Positron angle resolution measures using multi-loop tracks
·σ(ϕ) = **7.1 mrad** (core)
·σ(θ) = **11.2 mrad**



Overall angular resolution combining XEC+DCH+target
·σ(ϕ) = **12.7 mrad** (core)
·σ(θ) = **14.7 mrad**

Teγ



40 MeV < Eg < 48 MeV

Resolution corrected for a small energy-dependence
·σ(t) = **(142 ▯ 15) ps**

Stability along the run
· **< 15 ps**

Normalization

The normalization factor is obtained from the number of observed μ decay positrons taken simultaneously (prescaled) with the m→eg trigger

Cancel at first order

- Absolute e+ efficiency and DCH instability
- Instantaneous beam rate variations

O(1)

$$\frac{\mathcal{B}(\mu^+ \to e^+\gamma)}{\mathcal{B}(\mu^+ \to e^+\nu\bar{\nu})} = \frac{N_{\rm sig}}{N_{e\nu\bar{\nu}}} \times \frac{f^{e}_{e\nu\bar{\nu}}}{P \cdot \epsilon_{\rm pu}} \times \frac{\epsilon^{\rm trig}_{e\nu\bar{\nu}}}{\epsilon^{\rm trig}_{e\gamma}} \times \frac{\epsilon^{\rm DC}_{e\nu\bar{\nu}}}{\epsilon^{\rm DC}_{e\gamma}} \times \frac{1}{A^{\rm geo}_{e\gamma}} \times \frac{1}{\epsilon_{e\gamma}}$$

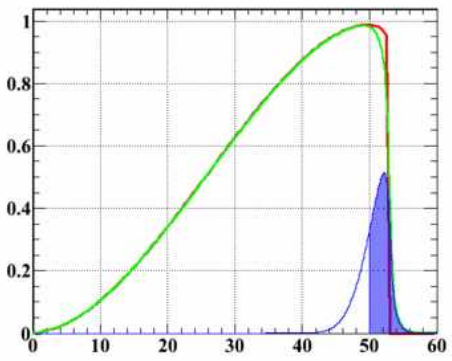
~18k

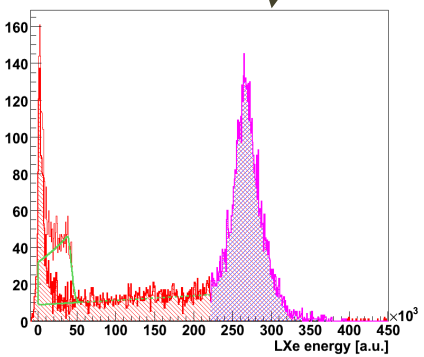
107

theory

resolution

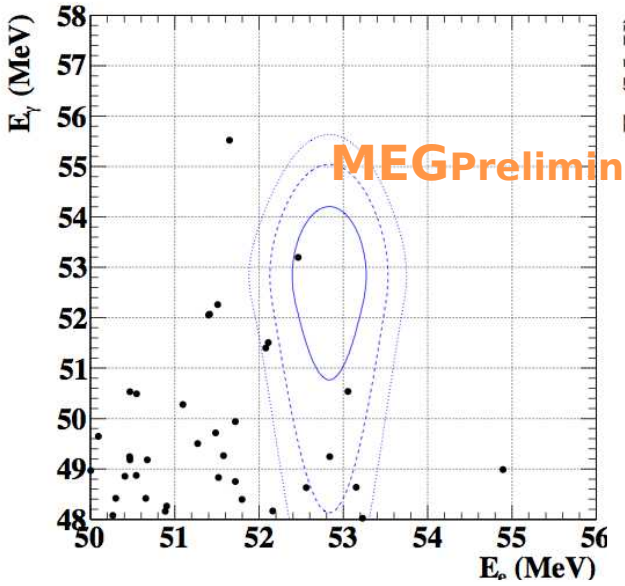
acceptance

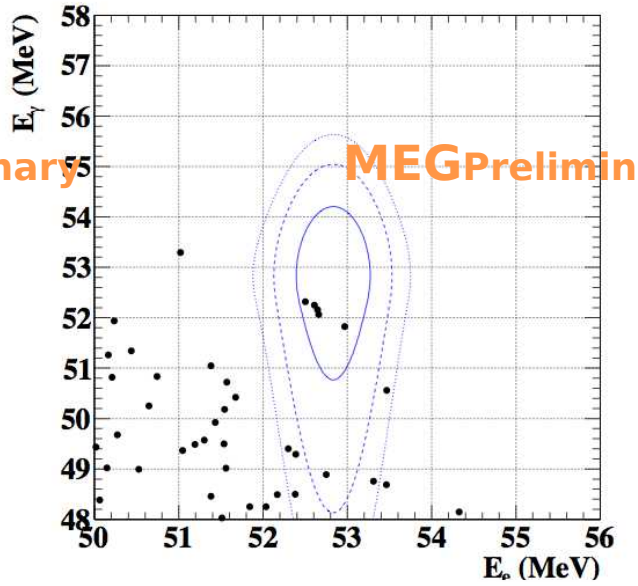


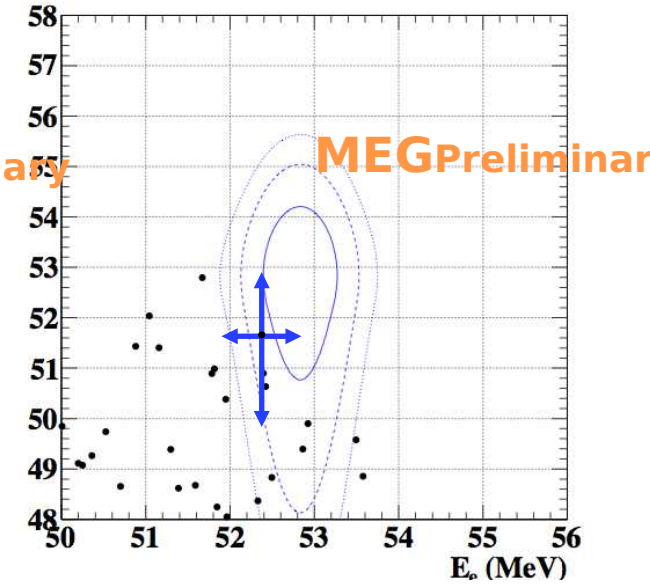


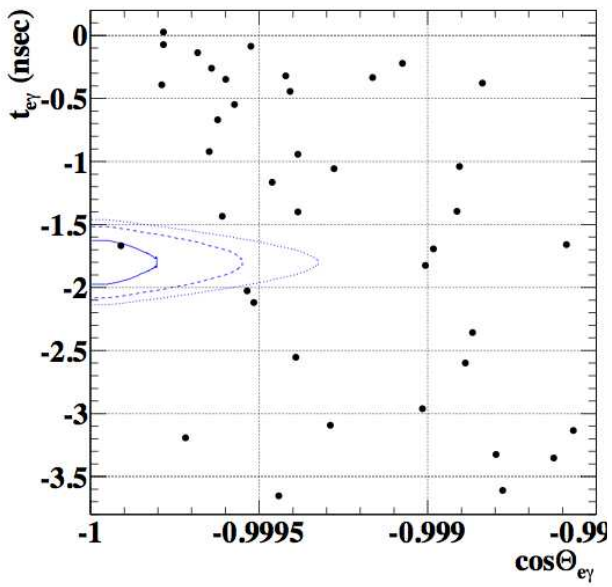
B.R. = Nsig x (1.01 ± 0.08) × 10-12

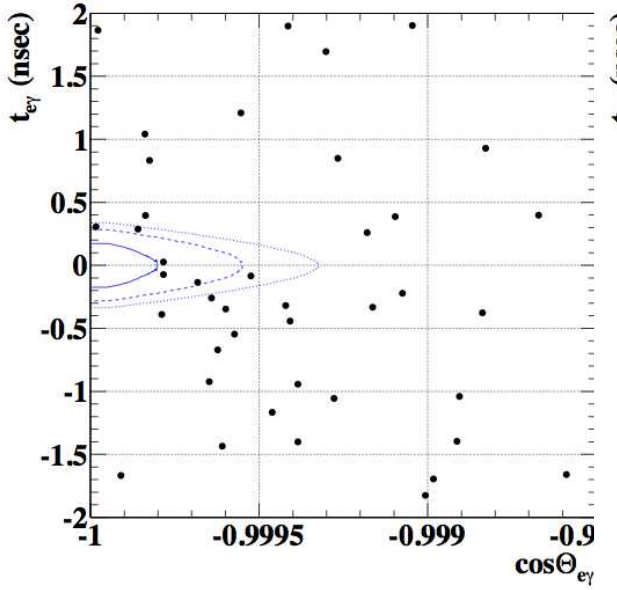
Blind box content

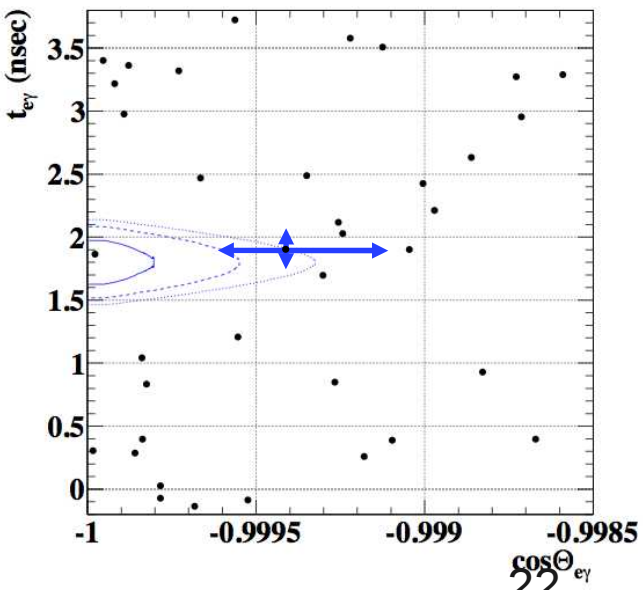












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