Searching for the decay $\mu \to e\gamma$ with the MEG experiment: status and perspectives

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on behalf of the MEG collaboration

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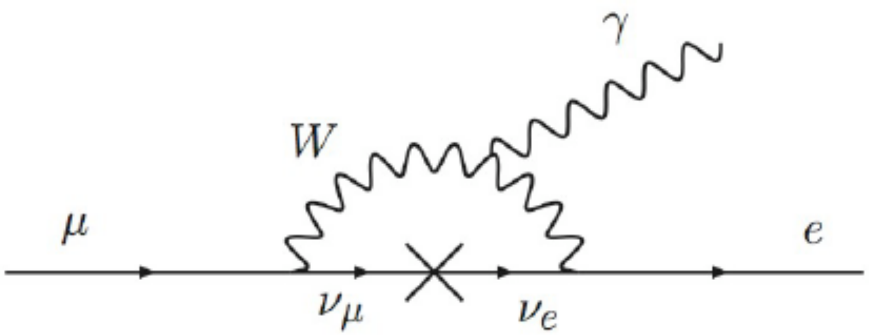
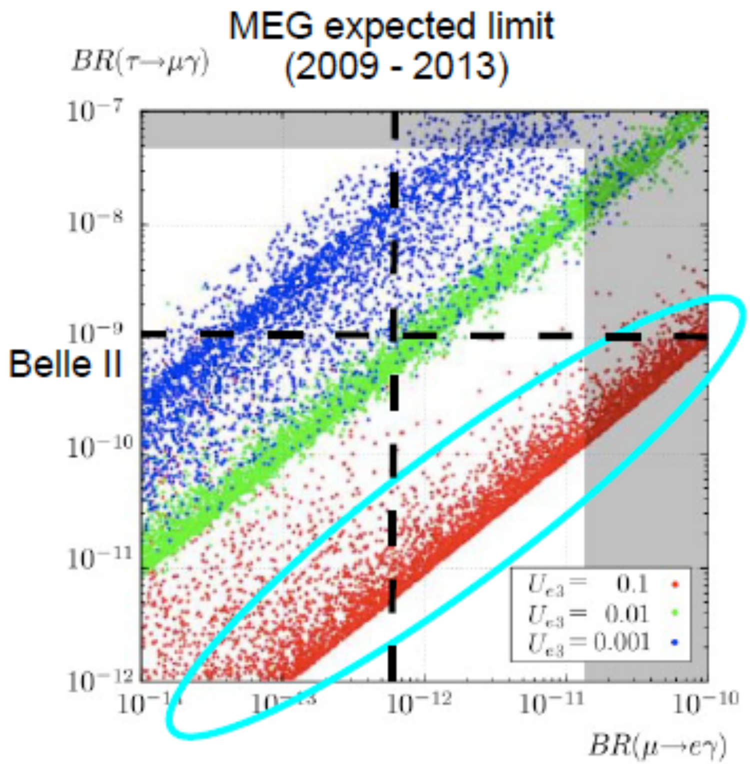
Why μ→eγ? - theory

- As for other charged lepton flavor violating decays: allowed but unobservable in the Standard Model (SM)



$$BR(\mu \to e\gamma)\big|_{SM} < 10^{-50}$$



Hisano, Nagai, Paradisi, Shimizu '09

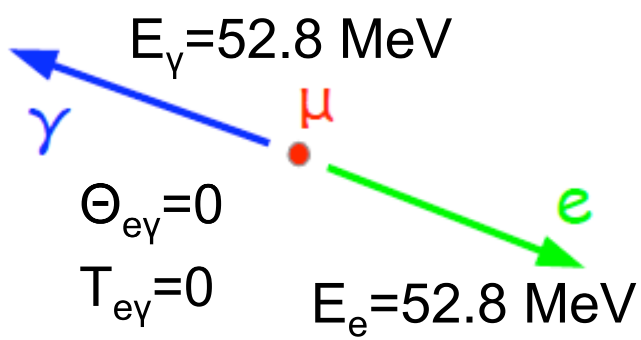
- Enanched (sometimes just below experimental limit) in many New Physics Model

Observation of μ→eγ is Physics beyond SM

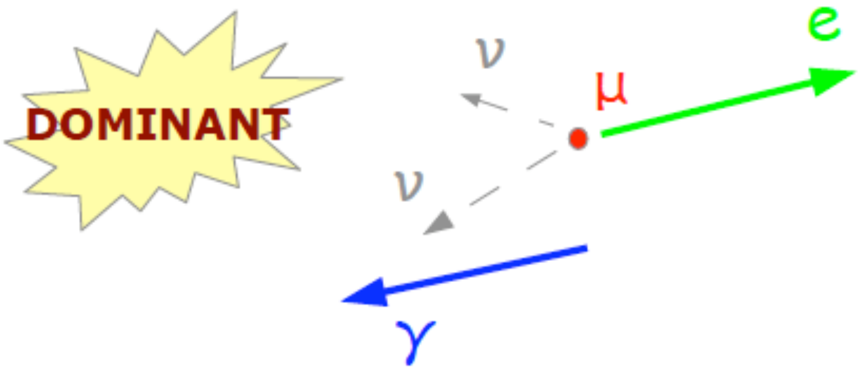
Why μ→eγ? - experiment

- Intense muon beams available
- Clear two-body signature (muon decays at rest)
- Very good experimental resolutions are needed to suppress backgrounds

SIGNAL

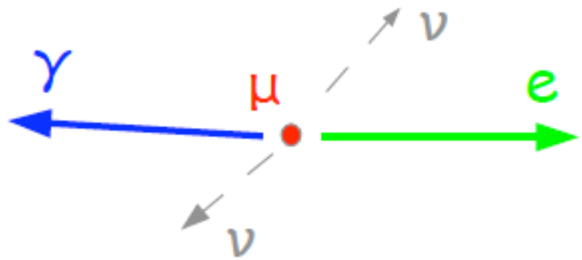


ACCIDENTAL BACKGROUND



Rate goes with square of beam intensity

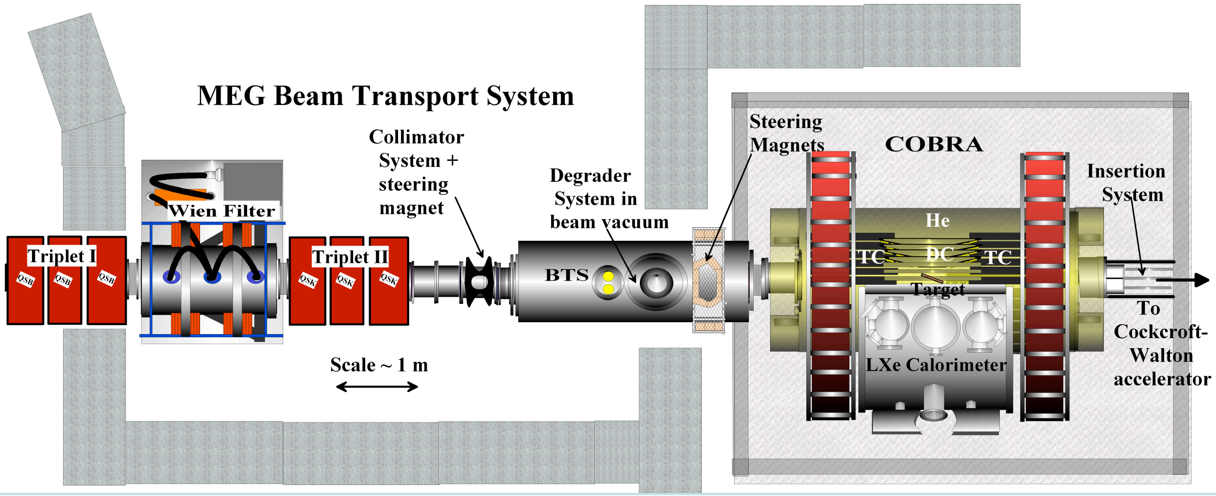
RADIATIVE MUON DECAY



The muon beam: why PSI?

- Most intense continuous muon beam in the world

- Up to ~10^8 μ^+/s: only 3×10^7 μ^+/s used for MEG to optimize the sensitivity

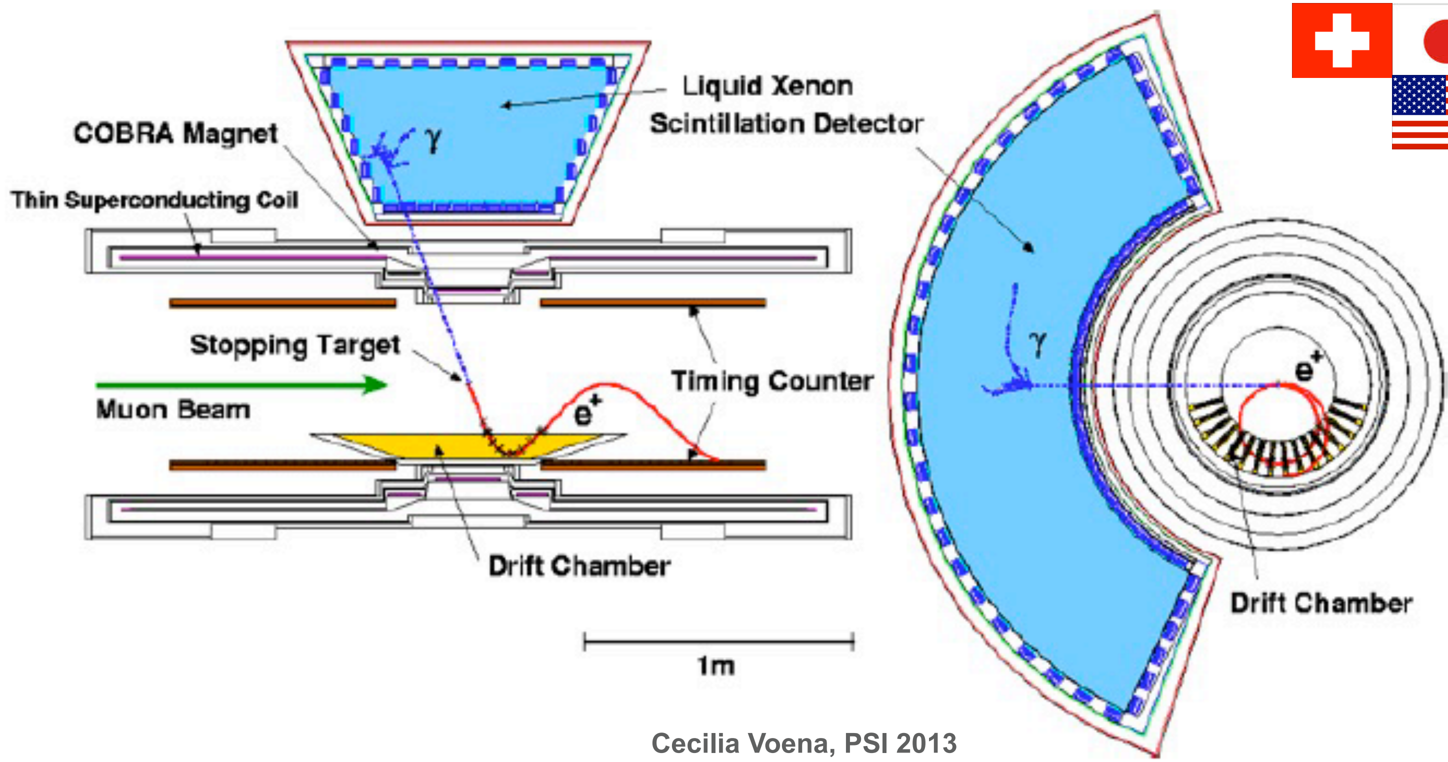


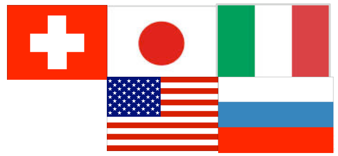
Proton beam current	: ~2.2mA
Muon production	: from π decaying on the production target surface
Muon central momentum	: 28 MeV/c
Δp/p	: 5% (full-width)

The MEG experiment

J.~Adam et al., Eur.Phys.J. C 73 (2013) 2365

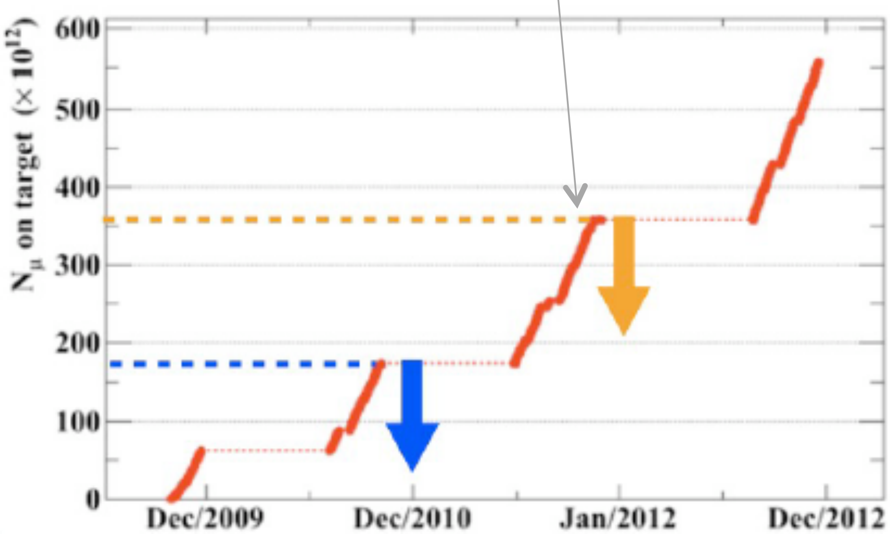
- Liquid xenon photon detector
- Gradient magnetic field
- Low mass drift chambers
- Fast timing detector
- Full digitization of all channels with a custom board (designed at PSI)





Data samples and results

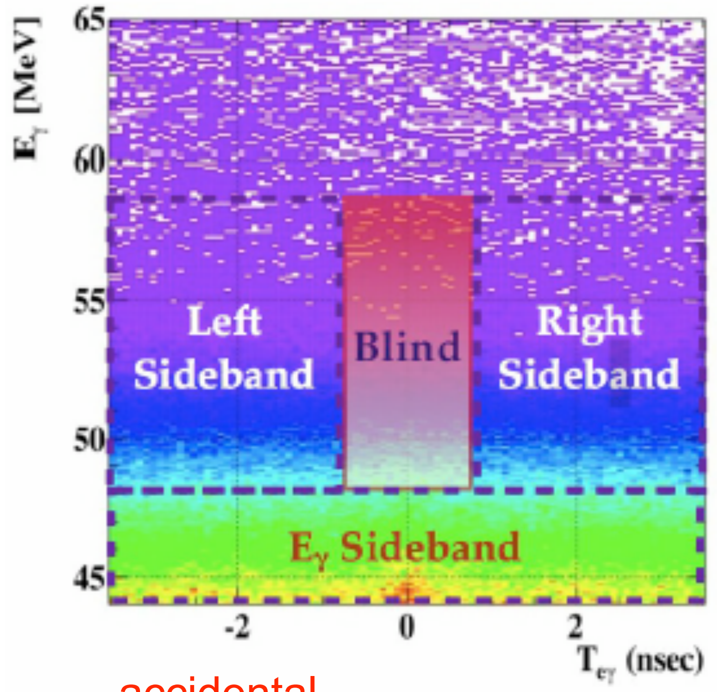
- 2008: first run with poor detector stability **Nucl.Phys.B834 1-12(2010)**
- Stable run in 2009-2010: $BR(\mu \to e\gamma) < 2.4 \times 10^{-12} @ 90\% C.L.$
  PRL 107,171801 (2011)
- 2009-2011 data: results on 2009-2010 with improved analysis* and 2011 data presented in this talk
  PRL 110,201801(2013)
- 2012 and 2013 data: ~double statistics



* Better filtering of DC noise, improved tracking and photon waveform analysis, more sensitive likelihood analysis (per event error on positron side)
=> 20%
improvement in sensitivity

Analysis strategy

- Blind-box likelihood analysis strategy



- Observables: $E_{e+}, E_\gamma, \theta_{e\gamma}, \varphi_{e\gamma}, T_{e\gamma}$
  (energies, relative angle and time)

- Careful treatment of correlations

constrained from sideband

accidental

$$\mathcal{L}(\vec{x}_1,\ldots,\vec{x}_N,R_\diamond,A_\diamond|\hat{S},\hat{R},\hat{A}) = \frac{e^{-\hat{N}}}{N!} e^{-\frac{1}{2}\frac{(A_\diamond-\hat{A})^2}{\sigma_A^2}} e^{-\frac{1}{2}\frac{(R_\diamond-\hat{R})^2}{\sigma_R^2}} \prod_{i=1}^{N}\left(\hat{S}s(\vec{x}_i)+\hat{R}r(\vec{x}_i)+\hat{A}a(\vec{x}_i)\right)$$

signal

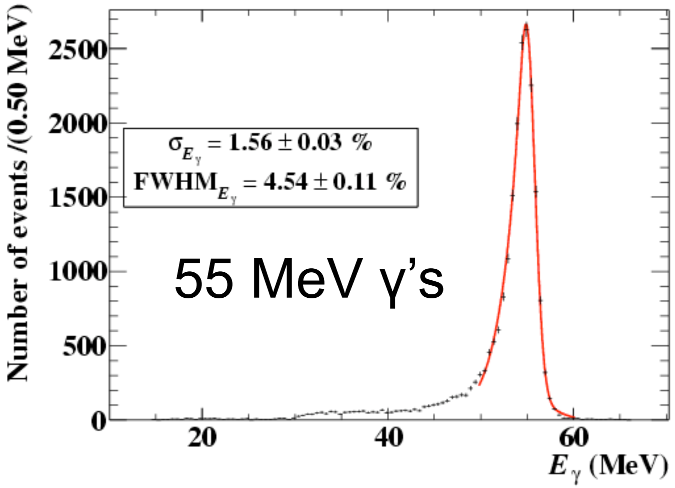
radiative

- Signal and radiative decay PDF by combining the results of the calibration procedures

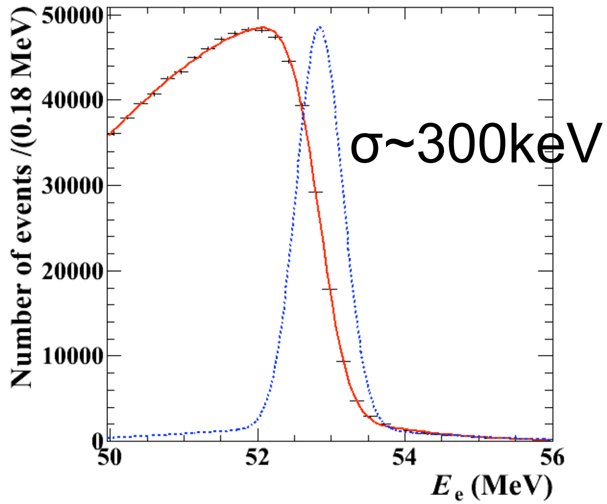
- Accidental background PDF from data sidebands

PDF definitions

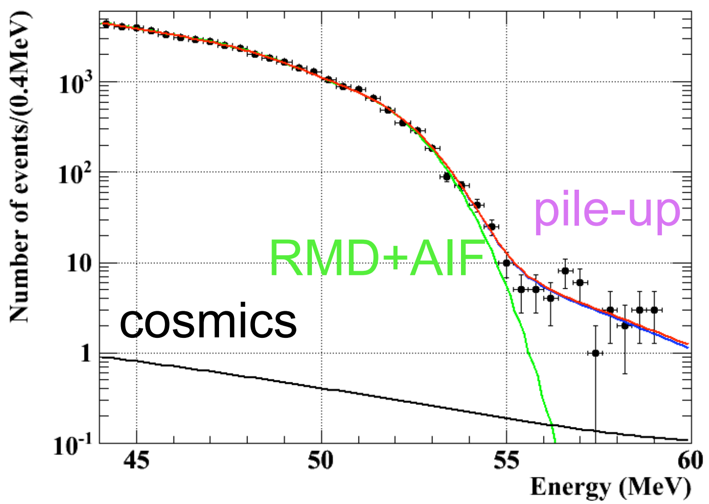
E_γ signal from CEX calibration ($\pi^- p \rightarrow \pi^0 n$)



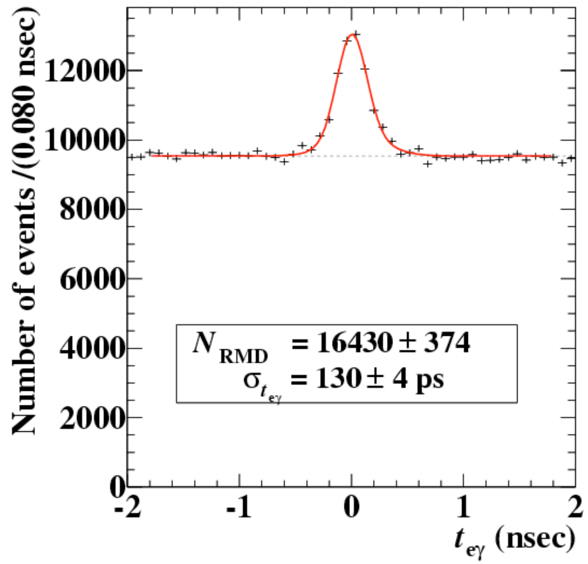
E_e signal (fit to the edge) and accidental background from Michel spectrum



E_γ accidental background from data sidebands



$T_{e\gamma}$ from radiative decays in sidebands



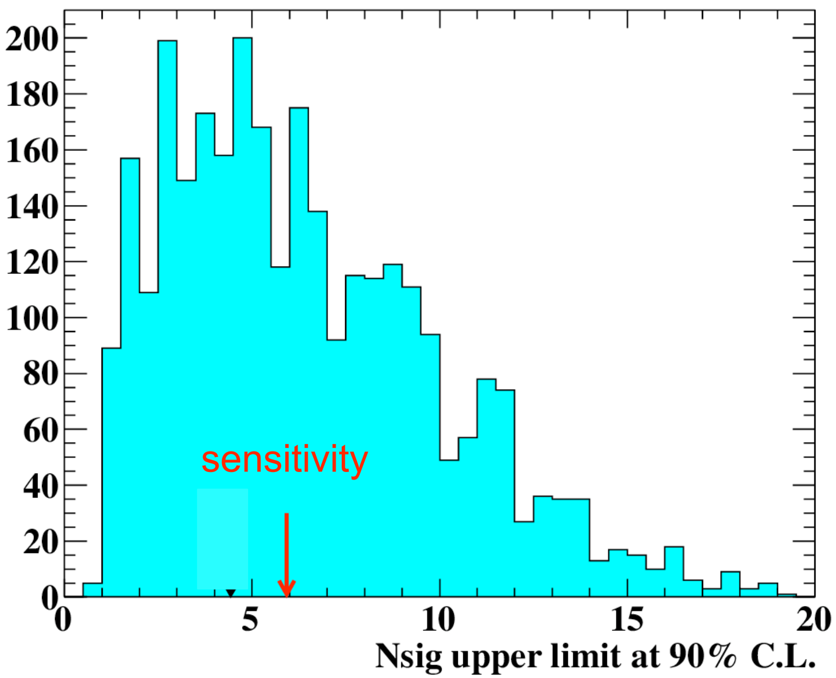
Positron angular and position resolution from double turn tracks

Statistical approach and sensitivity

Confidence intervals from a frequentistic procedure based on the profile likelihood ratio

$$\lambda_p(N_{SIG}) = \frac{\max_{N_{RMD},N_{ACC}} \mathcal{L}(N_{SIG}, N_{RMD}, N_{ACC})}{\max_{N_{SIG},N_{RMD},N_{ACC}} \mathcal{L}(N_{SIG}, N_{RMD}, N_{ACC})}$$

2009-2011 sensitivity



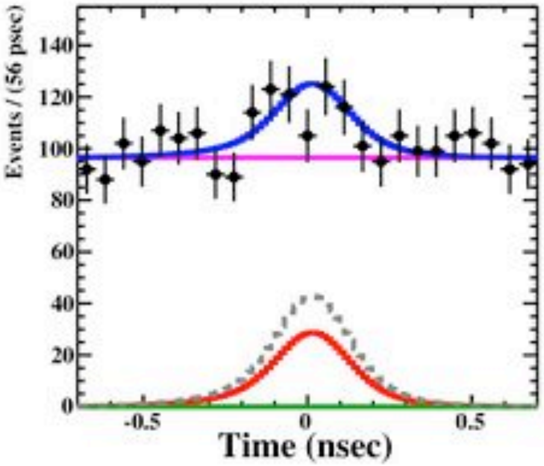
Sensitivity: median of upper limits from an ensamble of toy MC experiments (checked on data-sidebands)

sensitivity on branching ratio

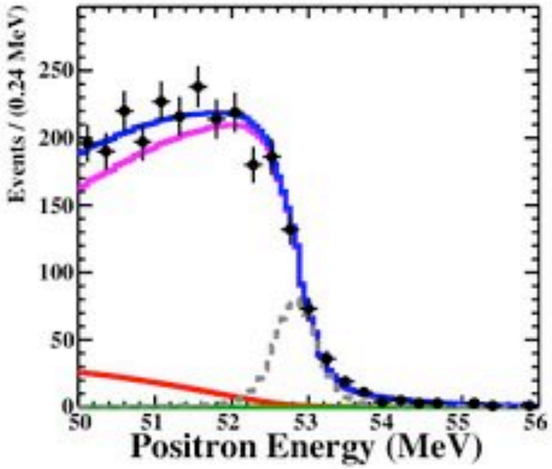
	Stopped μ [10^{13}]	s [10^{-12}]
2009&2010	17.5	1.3 (was 1.6)
2011	18.5	1.1
2009-2011	36	0.77

2009-2011 likelihood fit result

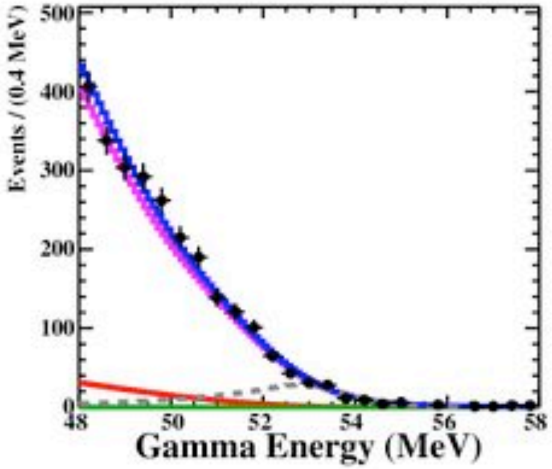
$T_{e\gamma}$

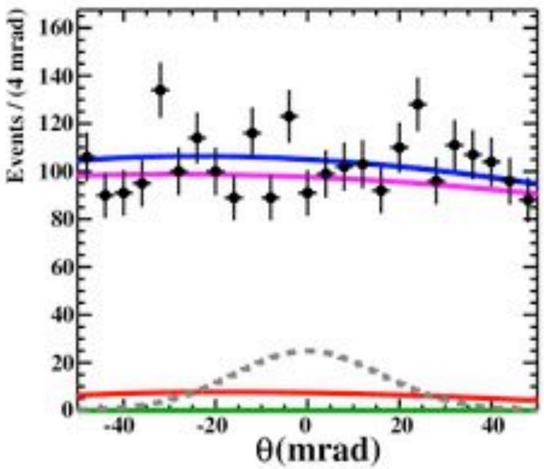


E_e

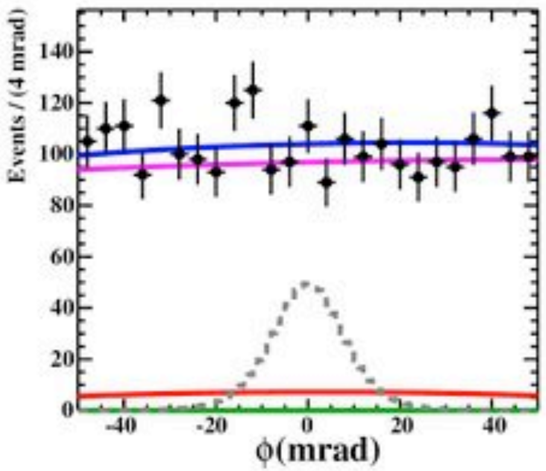


E_γ





$\theta_{e\gamma}$



$\varphi_{e\gamma}$

Signal=$-0.4^{+4.8}_{-1.9}$

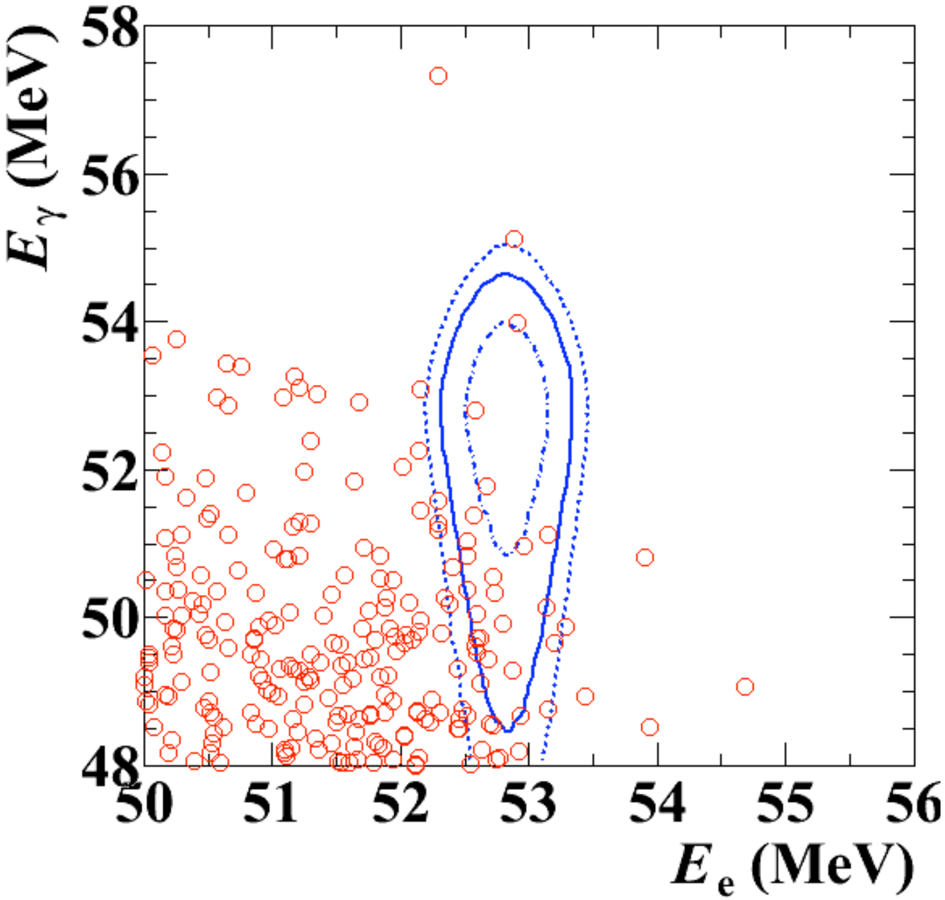
Accidental=2414±37

Radiative=168±24

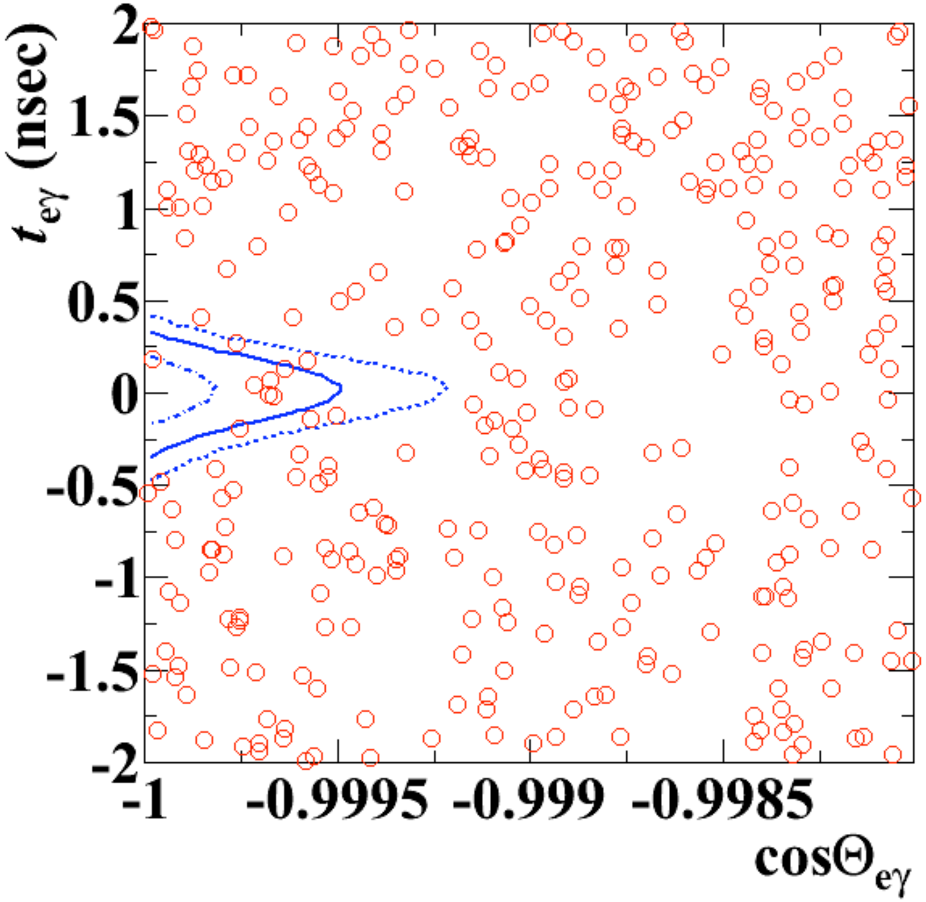
dotted line =pdfs for 250 signal events (for explicative purposes)

2009-2011 event distribution

$|T_{e\gamma}|<0.244$ns; $\cos\Theta_{e\gamma}<-0.9996$



51 < E_γ <55 MeV; 52.4 E_e<55 MeV



contours: 1σ,1.64σ,2σ

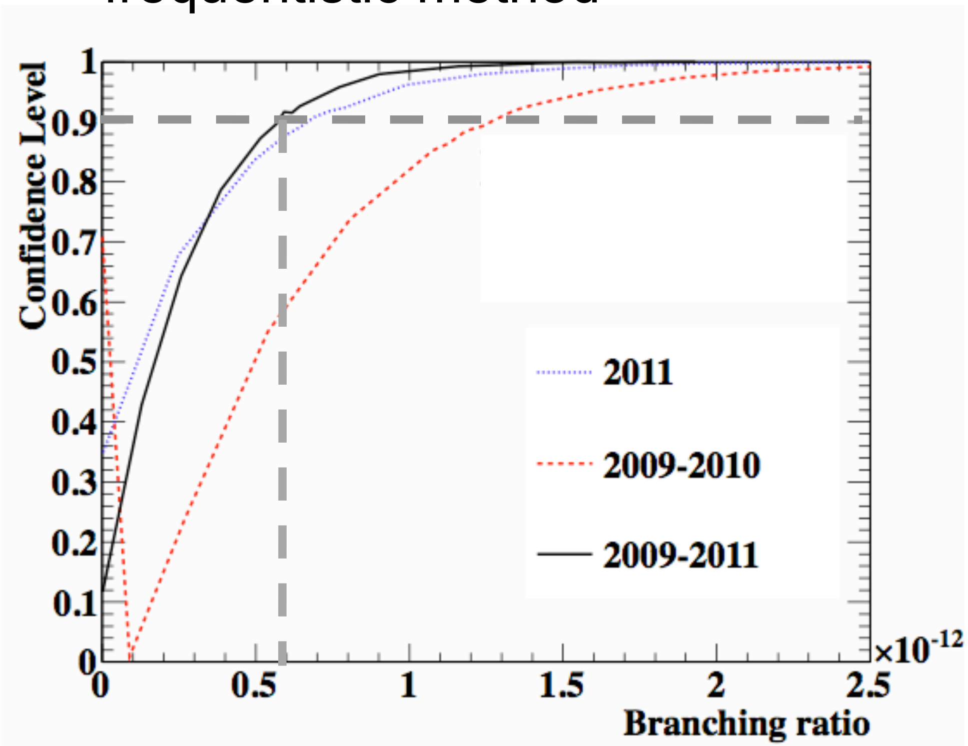
Physics results

$$BR(\mu \to e\gamma) < 5.7 \times 10^{-13} \; @90\%C.L.$$

including systematics

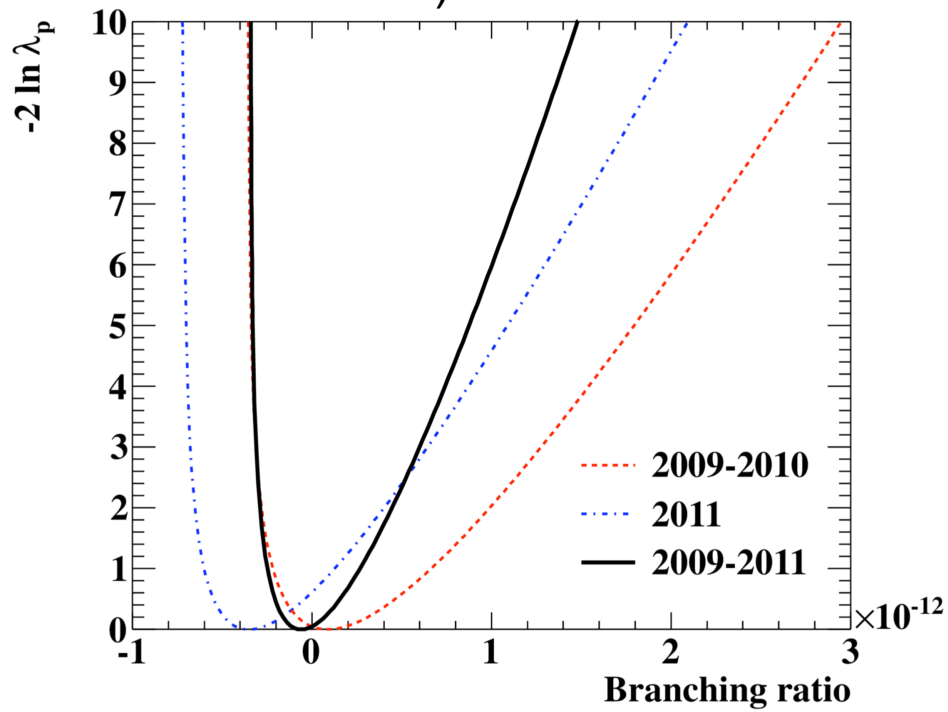
PRL 110,201801(2013)

Confidence levels from the frequentistic method



Profile likelihood curves

(note that these curves are not used to derive the U.L.)



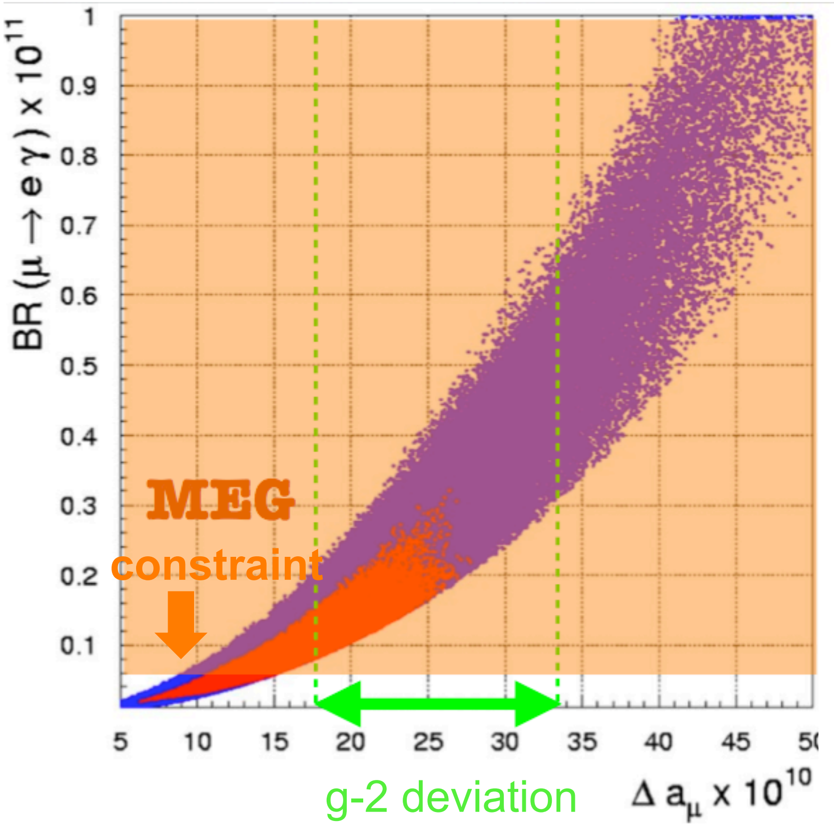
Normalization from the number of Michel decays and radiative decays

Constraints on new Physics

4 times more stringent constraint than previous result

muon (g-2) anomaly

MSSM with large tanβ
Isidori et al., PRD75, 115019

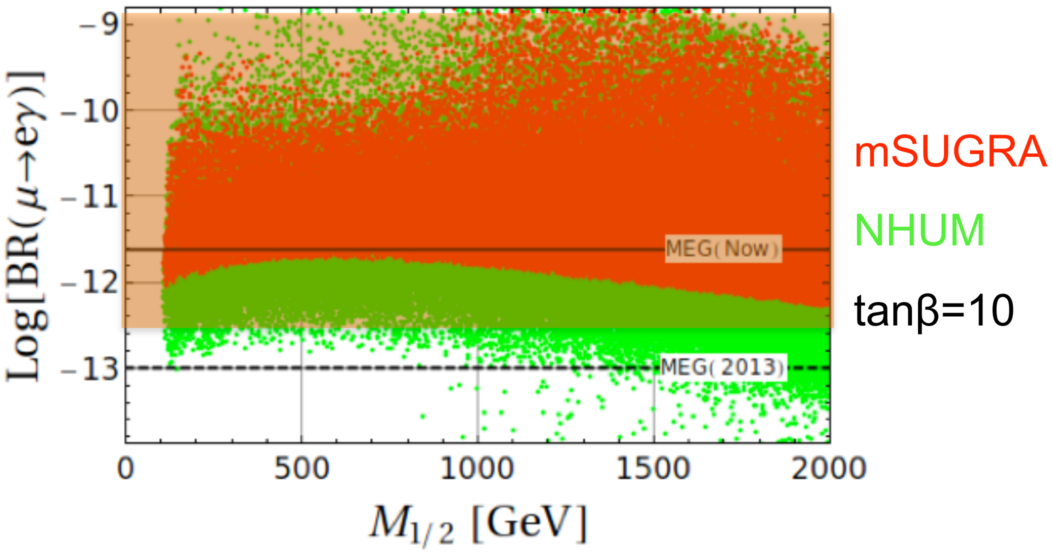


* a_μ(EXP):PRD73(2006)072,
a_μ(SM):Hagiwara et al., JPG38(2011)085003

Interplay with LHC

LFV rates depend on details of flavor structure of NP models, can be stronger or weaker than LHC constraints

SUSY GUT SO(10) with see-saw
Calibbi et al, JHEP 1211(2012) 040



Outlook

- Currently best limit in the world

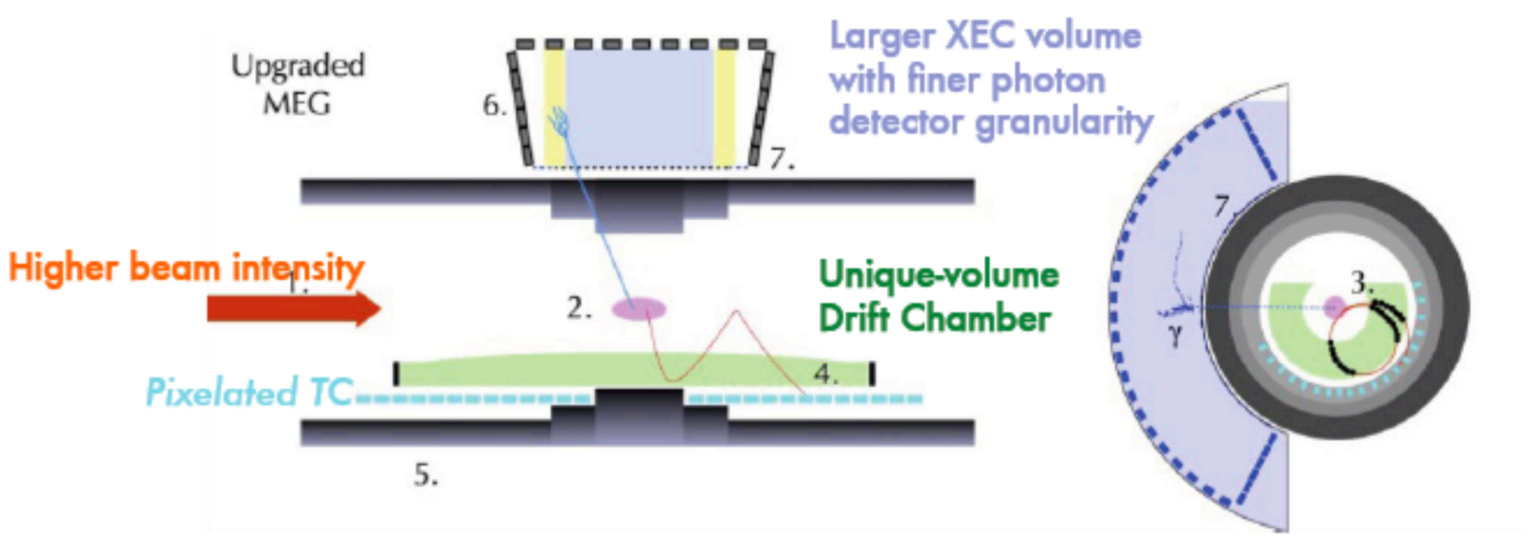
	BR(fit)	90%UL	sensitivity
2009+2010	0.09×10^{-12}	1.3×10^{-12}	1.3×10^{-12}
2011	-0.35×10^{-12}	0.67×10^{-12}	1.1×10^{-12}
2009-2011	-0.06×10^{-12}	0.57×10^{-12}	0.77×10^{-12}

- Analysis of 2012 data ongoing
- 2013 run just finished (2012+2013 will double statistics)

Final MEG sensitivity: 5×10^{-13}

Next step: the MEG upgrade

- Proposal for upgrade of the MEG experiment was submitted in December 2012 aiming at sensitivity of $5x10^{-14}$ (x10 improvement)
- Approved by PSI committee in January 2013



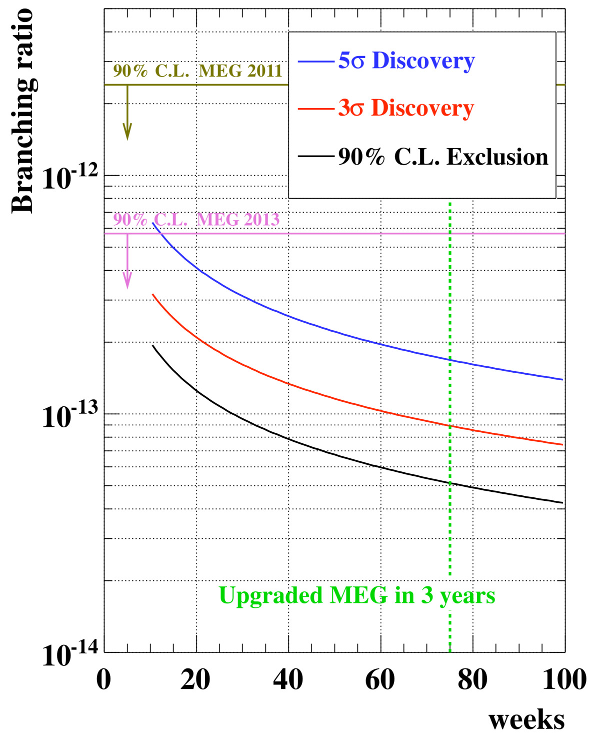
Conclusions

- The MEG experiment at PSI has established a new limit on the lepton flavor violating decay $\mu \to e\gamma$:

$$BR(\mu \to e\gamma) < 5.7 \times 10^{-13} \ @ 90\% C.L.$$

- The final sensitivity including all datasets (last run just ended) will be 5×10^{-13}

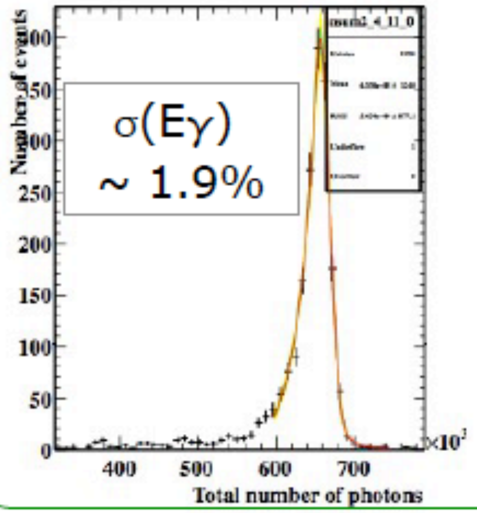
- An upgrade of the experiment is underway to push the sensitivity to 5×10^{-14} (time scale: 2016 start of data-taking)



Backup

Calibrations

Charge Exchange (CEX)



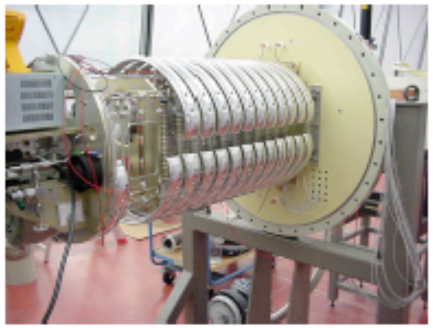
~ monochromatic γ @ 55 MeV from...

$\pi^- + p \rightarrow \pi^0 + n$

$\pi^0 \rightarrow \gamma\ \gamma$

...by selecting back-to-back γ's

Cockcroft-Walton accelerator

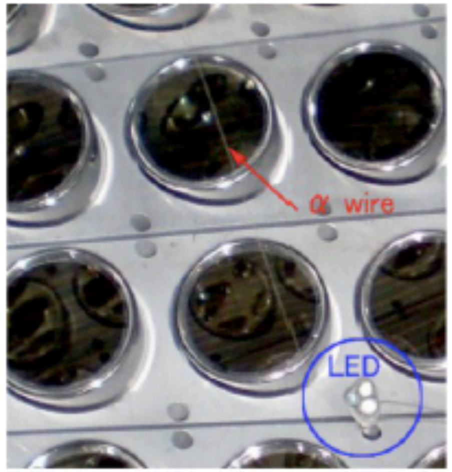


Protons on a Lithium Tetra-borate target

bi-weekly monitoring of calorimeter's energy scale

LEDs

Installed inside the XeC



α sources

Installed in wires inside the XeC

bi-weekly calibration of PMT quantum efficiencies and gains

New: pulsed neutron generator: 9 MeV photons

Performances

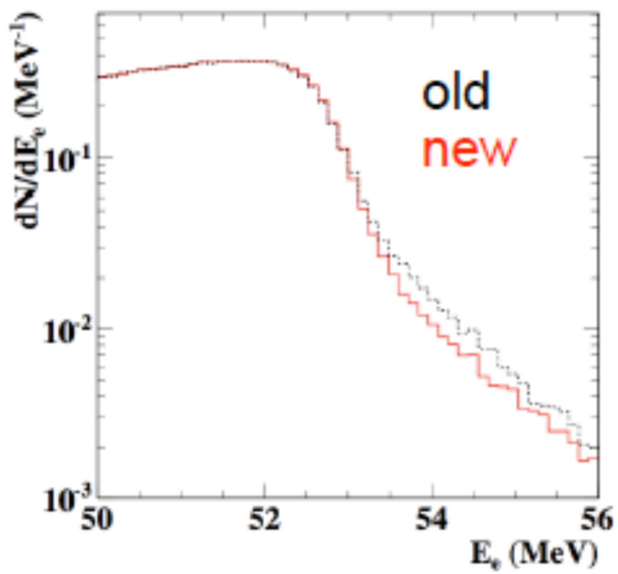
TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88
muon rate	3.3×10^7/sec	7×10^7/sec

New Kalman filter

- New Kalman filter procedure:

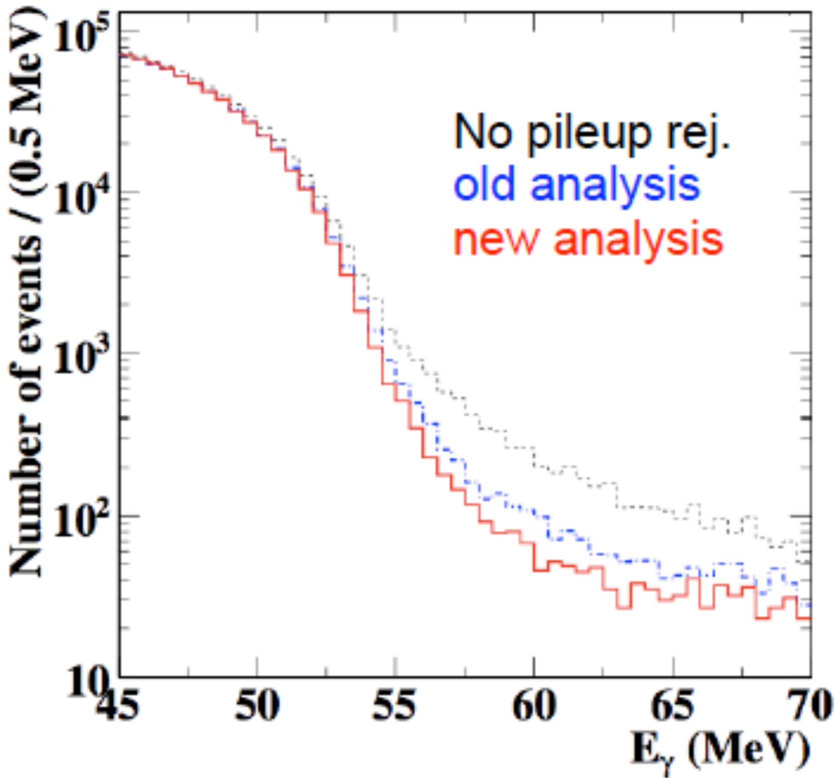
  - 7% increase in tracking efficiency
  - smaller resolution tails
  - per event estimate of track uncertainties parameters used in the likelihood analysis (10% increase of sensitivity)



New photon pile-up rejection

- New analysis of the Liquid Xenon waveforms to reject pile-up of photons

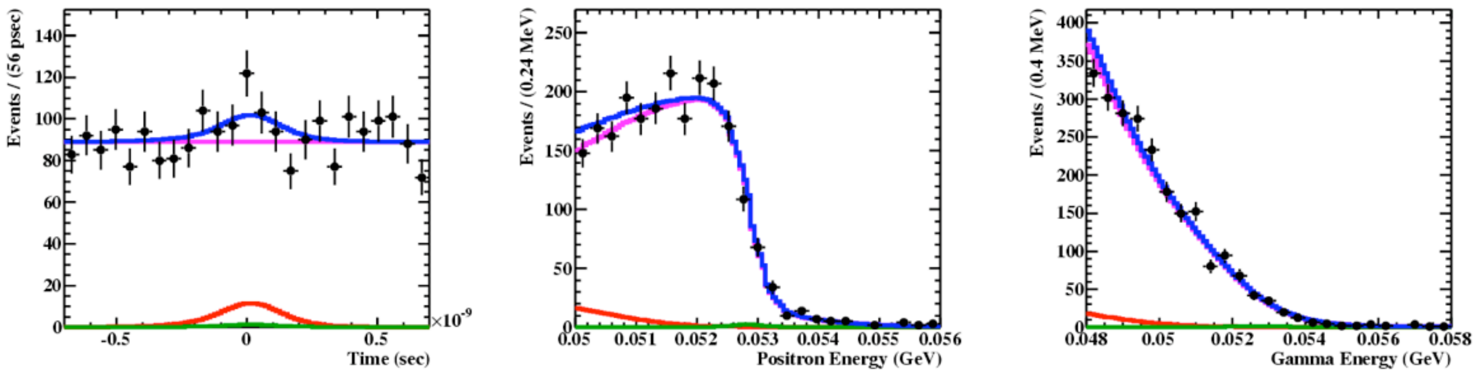
  - 7% increase in photon detection efficiency
  - suppressed rate of unrecognized pile-up events

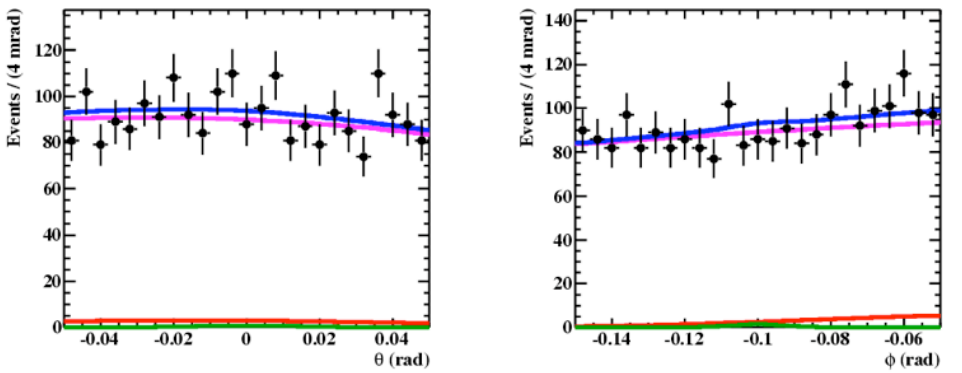


Control samples

- Fictitious analysis regions
  in the sidebands of E_γ, $T_{e\gamma}$ and angular

Example: phi negative sideband -150mrad<$\varphi_{e\gamma}$<50mrad





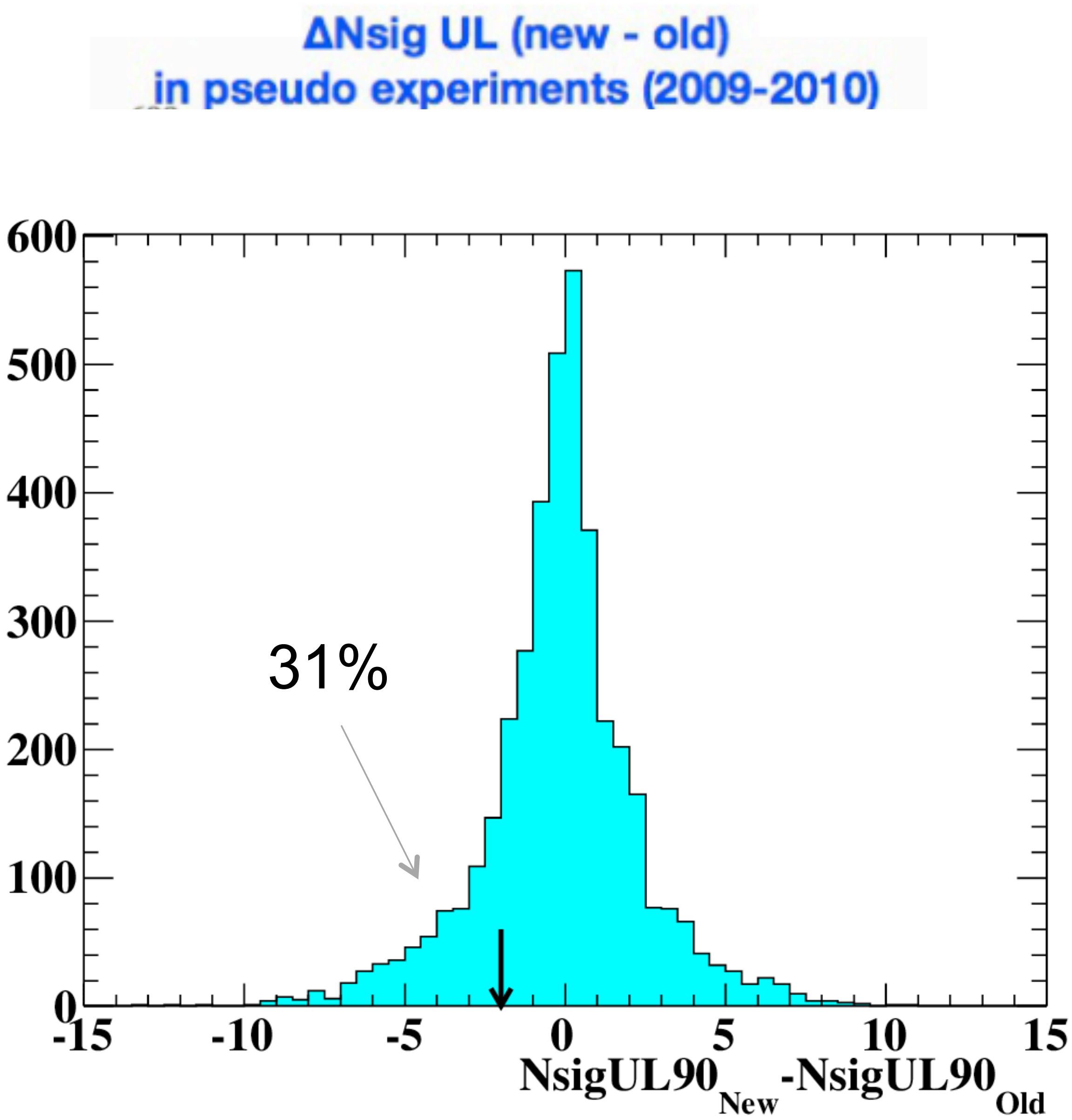
	Best fit	Error (MINOS 1.645σ)
N_{sig}	+2.8	+5.7−3.0
N_{RMD}	+34.0	+5.4−5.4
N_{BG}	+1098.1	+24.9−24.9

Systematic errors

Table 16: Relative contributions of uncertainties to upper limit of $\mathcal{B}$.

Center of $\theta_{e\gamma}$ and $\phi_{e\gamma}$	0.18
Positron correlations	0.11
E_{γ} scale	0.07
E_{e} bias	0.06
$t_{e\gamma}$ signal shape	0.06
$t_{e\gamma}$ center	0.05
Normalization	0.04
E_{γ} signal shape	0.03
E_{γ} BG shape	0.03
Positron angle resolutions (θ_e, ϕ_e, z_e, y_e)	0.03
γ angle resolution (u_{γ}, v_{γ}, w_{γ})	0.03
E_{e} BG shape	0.01
E_{e} signal shape	0.01
Angle BG shape	0.00
Total	0.25

Consistency check



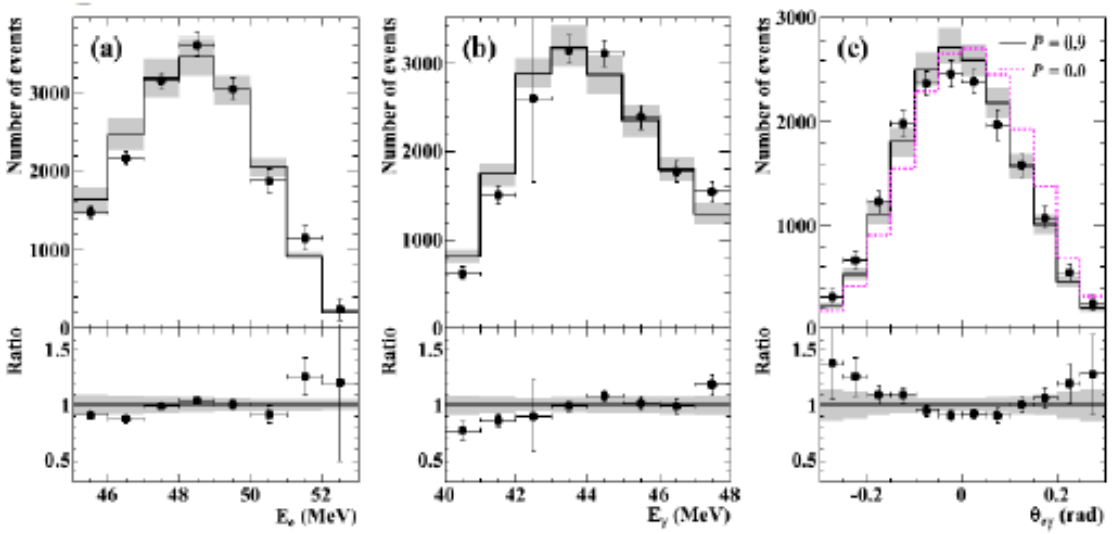
Normalization

Two methods:

- Count (prescaled) Michel positron (correcting for small differences with signal)

- Count radiative decays

Projected RMD distributions (2011 data)



	k (Michel) [10^{12}]
2009	1.21± 0.07
2010	2.66 ± 0.13
2011	4.10 ± 0.20

In 2011 data k(RMD) = 3.96 ± 0.24 10^{12}