New results from the MEG experiment at PSI

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on behalf of the MEG collaboration

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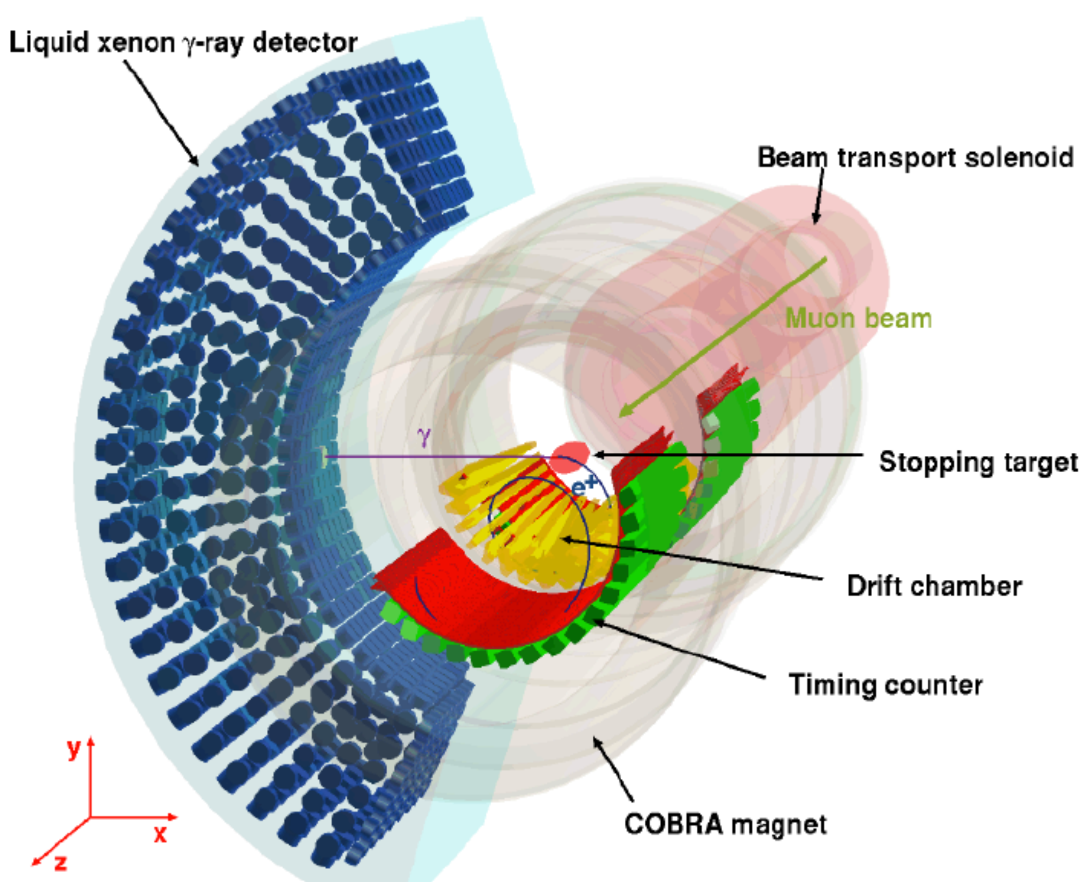
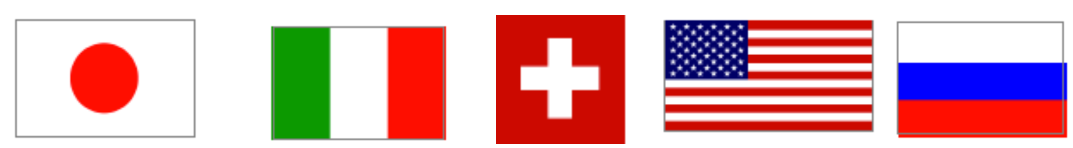
Introduction

The MEG experiment, located at the Paul Scherrer Institute (Villigen CH), searches for $\mu \longrightarrow e\gamma$ by **stopping the most intense muon beam available in the world on a thin target**.



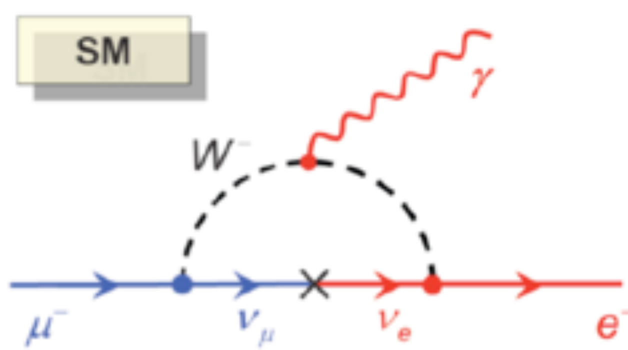
The MEG collaboration



Theoretical motivations

The μ⟶ eγ decay violates the lepton flavor conservation and it is then strongly suppressed in the Standard Model.

Standard Model with massive neutrinos

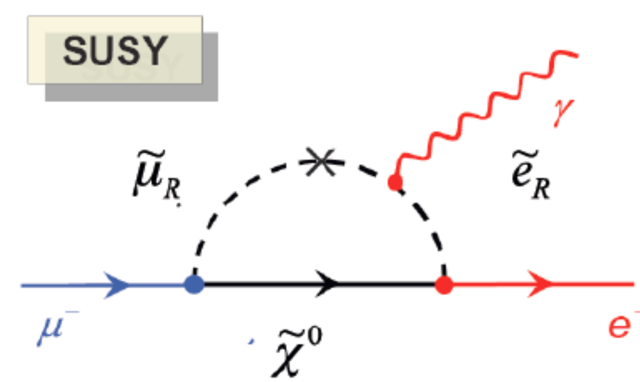


$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\text{muon decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\text{photon vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\text{neutrinos oscillation}}$$

$$BR(\mu \to e\gamma)\big|_{SM} \propto \frac{m_\nu^4}{m_W^4} \approx 10^{-54}$$

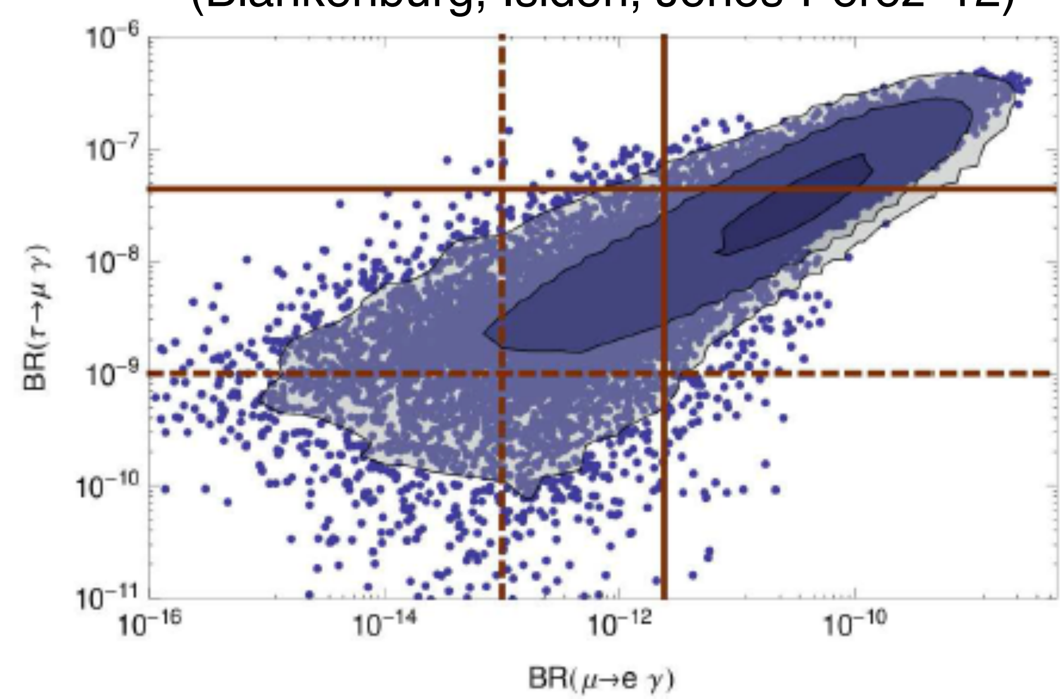
Example of μ ⟶ eγ branching ratio prediction in a supersymmetric extension of the Standard Model

Beyond the Standard Model



Most of the models beyond the Standard Model foresee the lepton flavor violation with experimentally measurable BR.

(Blankenburg, Isidori, Jones-Pérez '12)



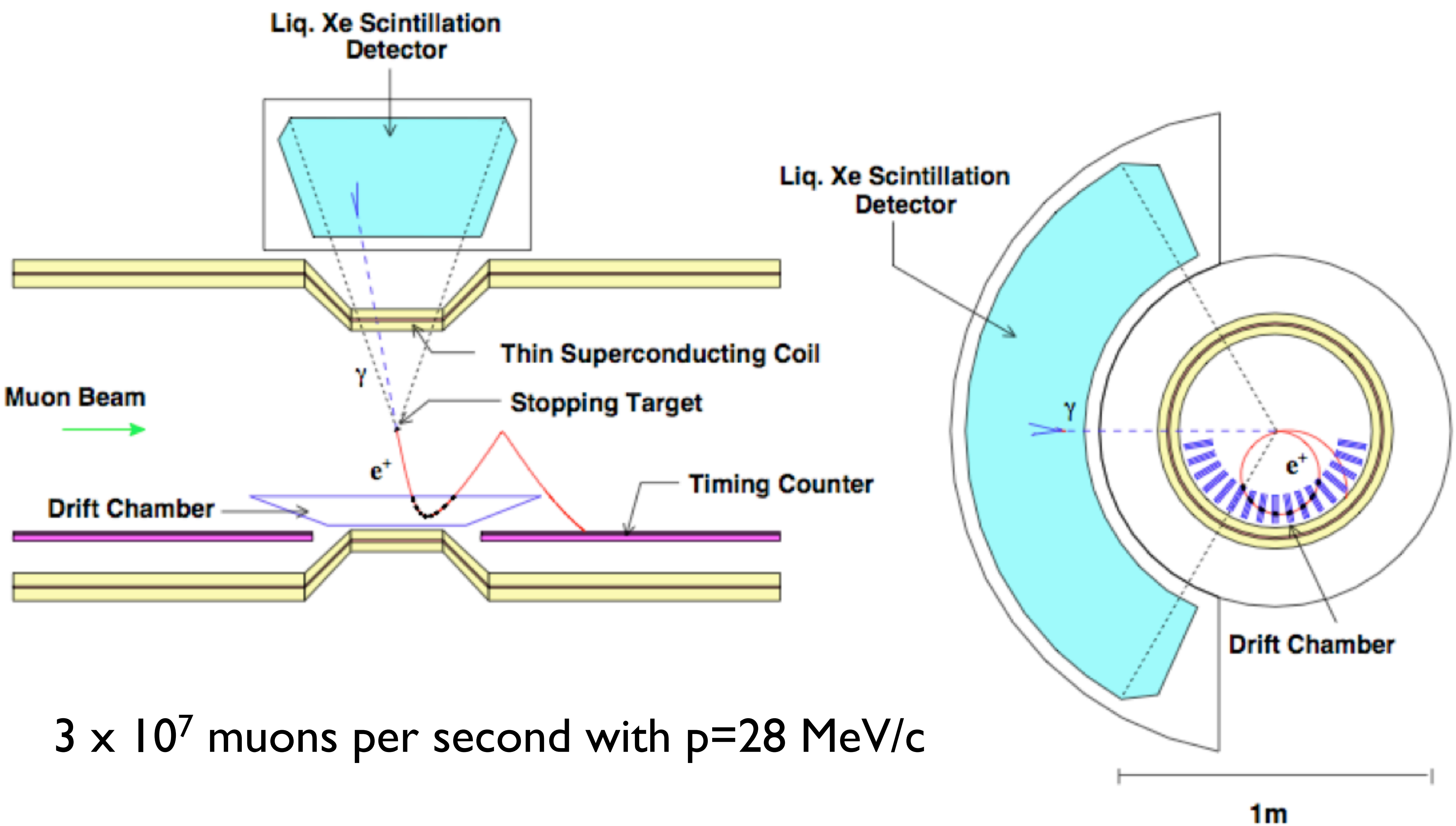
Current limits (MEG 2010/BaBar/Belle)

Expected limits (MEG 2012/SuperKEKB)

The MEG experiment

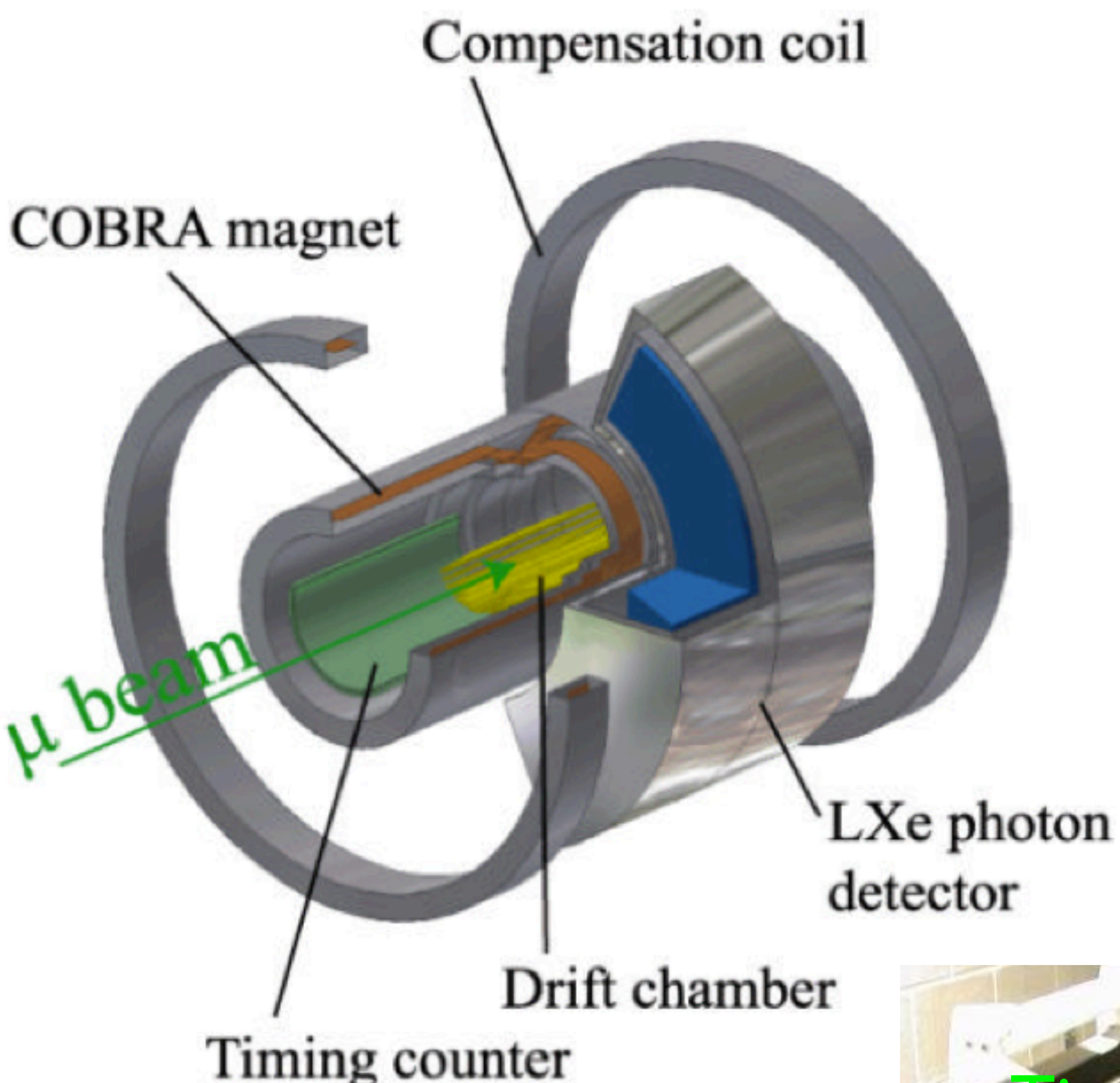
Apparatus devoted to the $\mu \longrightarrow e\gamma$ search

Detector paper arXiv:1303.2348



3 x 10^7 muons per second with p=28 MeV/c

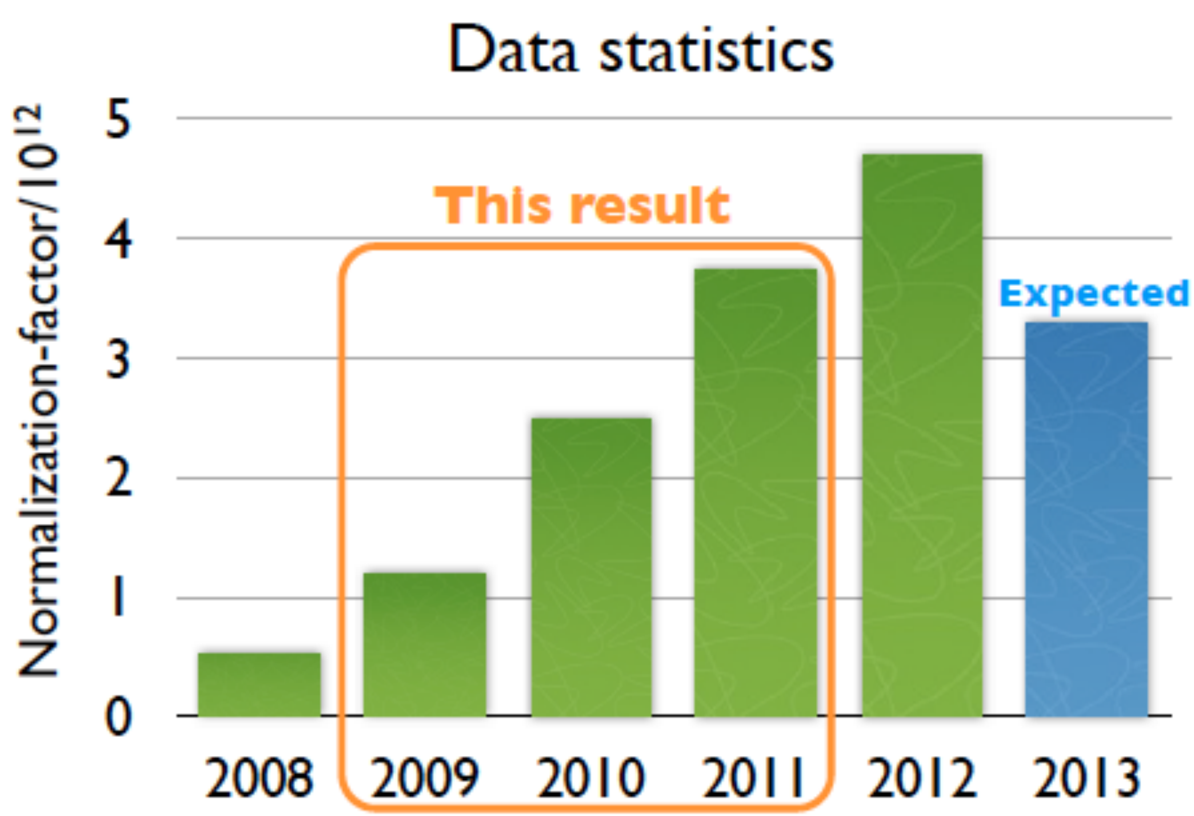
The MEG experiment



Data sets

Stable run 2009-2011

- First analysis of 2009-2010, $BR<2.4 \times 10^{-12}$ PRL108 171801
- A new analysis of 2009-2010 data, with improved analysis methods, and an analysis of 2011 data have been just performed



Physics Analysis overview

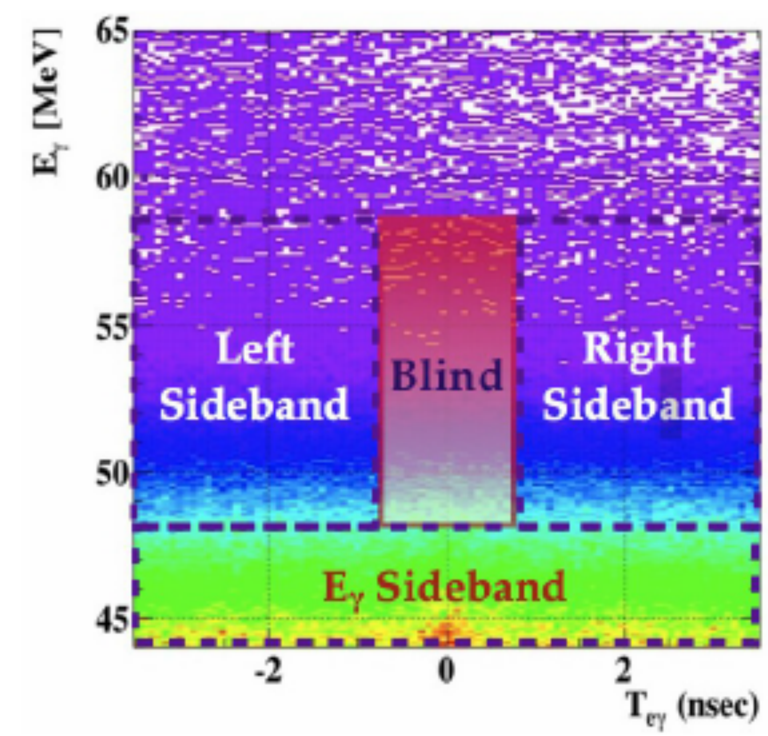
5 observables: $E_e, E_\gamma, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}$

- Signal
  - Monochromatic photon and positron $E_e = E_\gamma = m_\mu/2 = 52.8 MeV$
  - Back to back $\phi_{e\gamma} = \theta_{e\gamma} = 0$
  - Coincident $t_{e\gamma} = 0$

- Accidental background (predominant) $Rate \propto R_\mu^2$

accidental coincidence of Michel positron (μ⟶ e ν ν) and gamma (from radiative muon decay, Annihilation in flight, Bremsstrahlung)

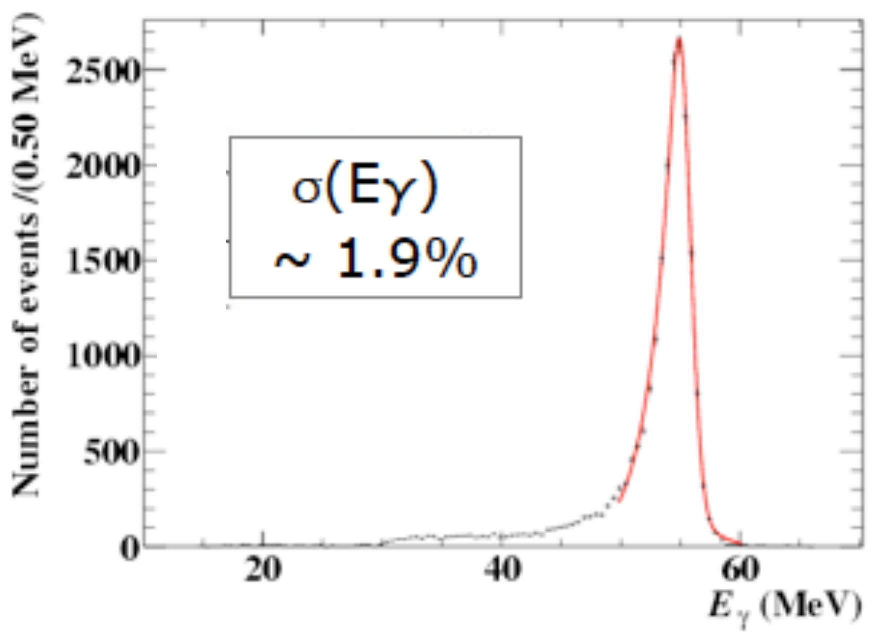
- Radiative Michel decay background $Rate \propto R_\mu$



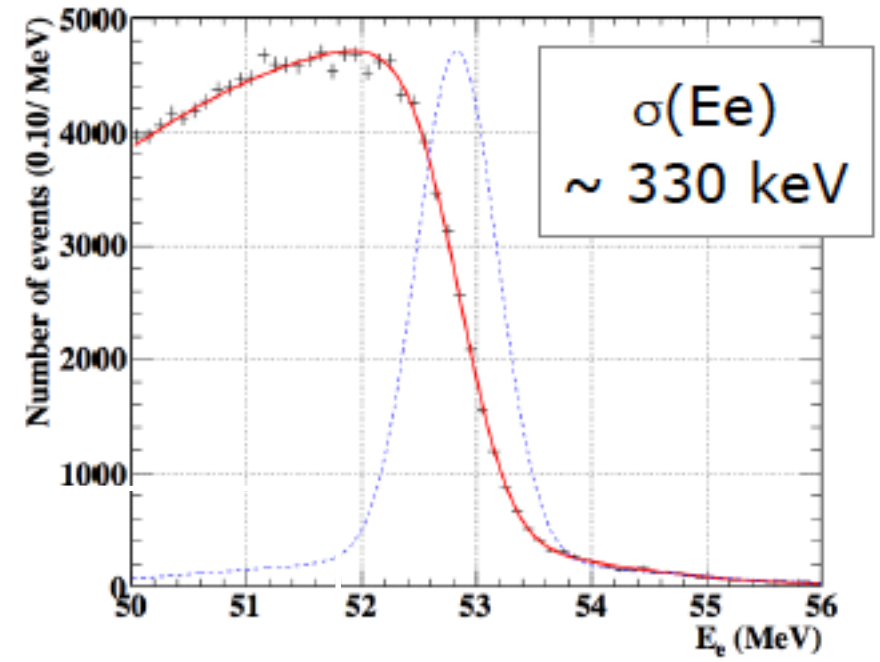
- Maximum likelihood analysis to extract Nsig
- Blind procedure

Detector Performances

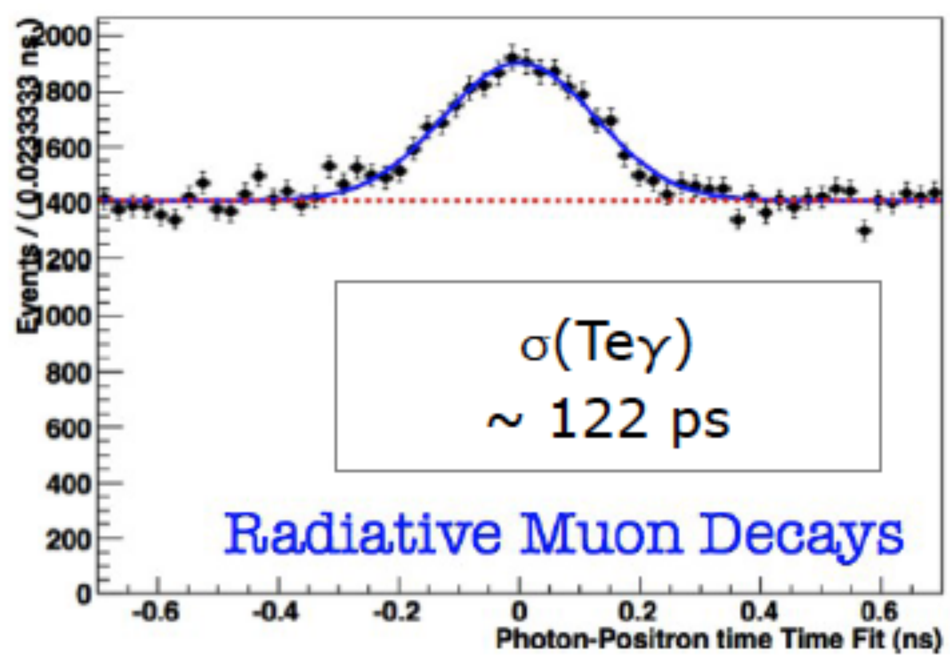
Photon Energy resolution



Positron Energy resolution

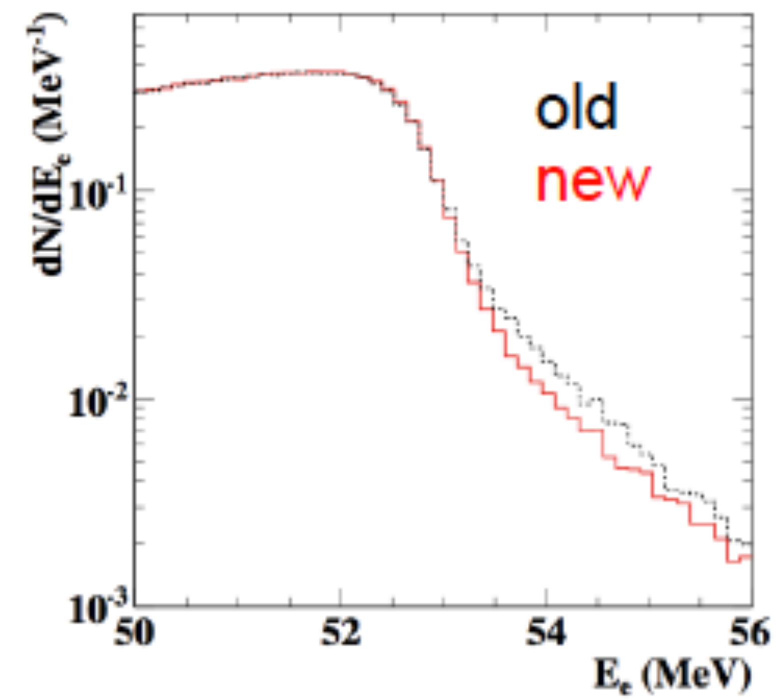


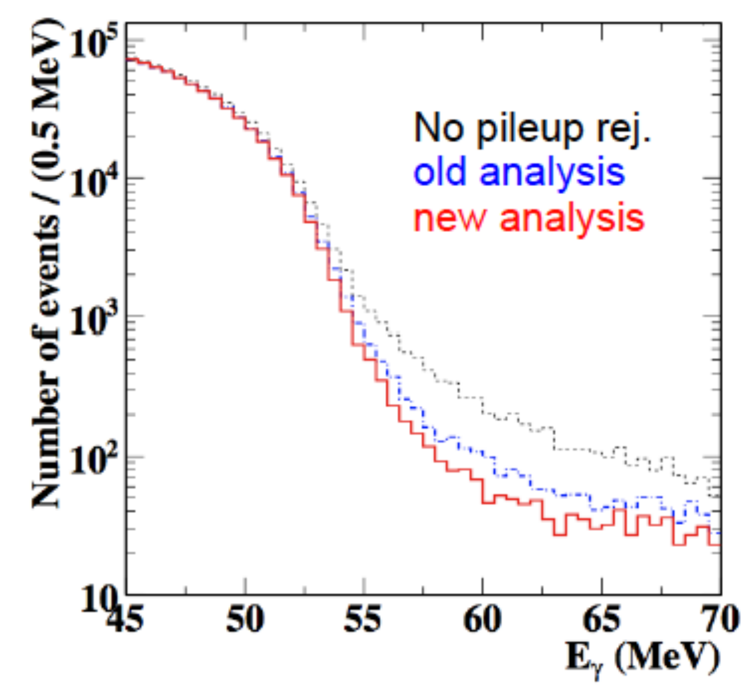
Relative time resolution



Recent Improvements

- New track fit algorithm based on Kalman Filter technique
  - 7 % more positron efficiency
  - Reduced tail in resolution function
  - per-event error matrix introduced in likelihood analysis
- Improved gamma pileup elimination algorithm
  - 7 % more photon efficiency
  - less pileup





Maximum likelihood analysis

- Analysis region

$48MeV < E_\gamma < 58MeV \quad 50MeV < E_e < 56MeV \quad |\theta_{e\gamma}| < 50mrad \quad |\phi_{e\gamma}| < 50mrad$
$|t_{e\gamma}| < 0.7ns$

- Event by event PDF

Signal PDF RMD* PDF BG** PDF

$$\mathcal{L}(N_{\rm sig}, N_{\rm RMD}, N_{\rm BG}) = \frac{e^{-N}}{N_{\rm obs}!} e^{-\frac{(N_{\rm RMD}-\langle N_{\rm RMD}\rangle)^2}{2\sigma_{\rm RMD}^2}} e^{-\frac{(N_{\rm BG}-\langle N_{\rm BG}\rangle)^2}{2\sigma_{\rm BG}^2}} \prod_{i=1}^{N_{\rm obs}} (N_{\rm sig} S(\vec{x}_i) + N_{\rm RMD} R(\vec{x}_i) + N_{\rm BG} B(\vec{x}_i))$$

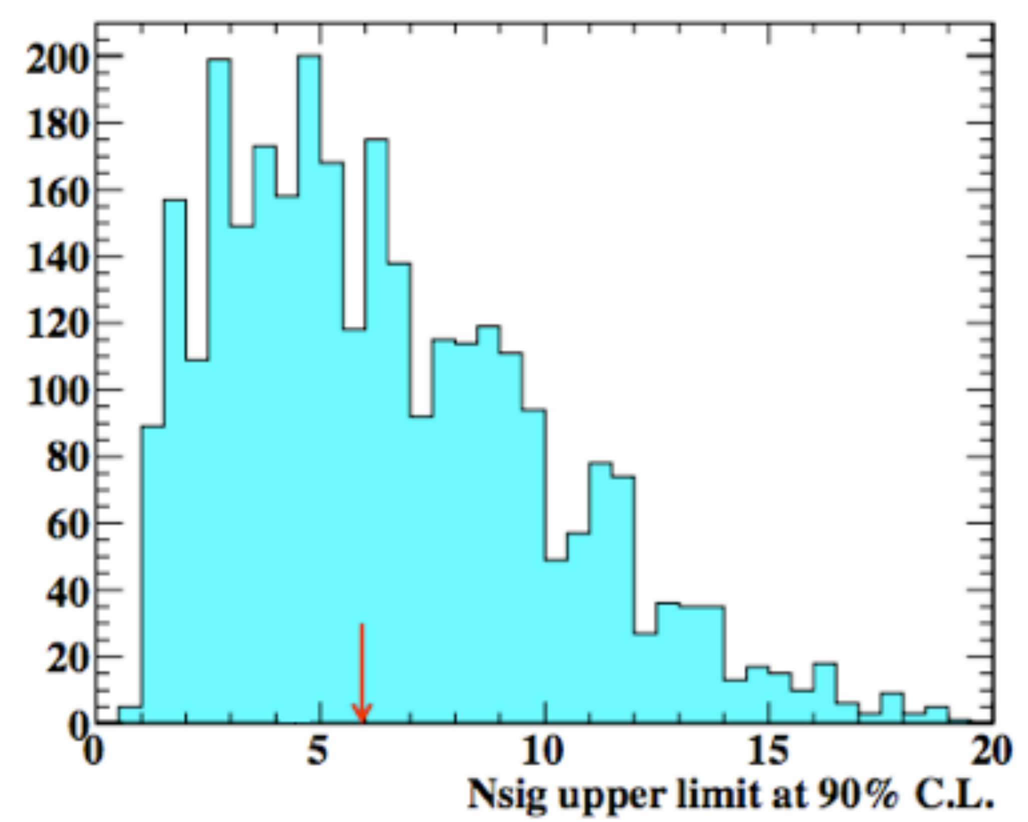
$$\vec{x}_i = (E_e, E_\gamma, \theta_{e\gamma}, \phi_{e\gamma}, T_{e\gamma})$$

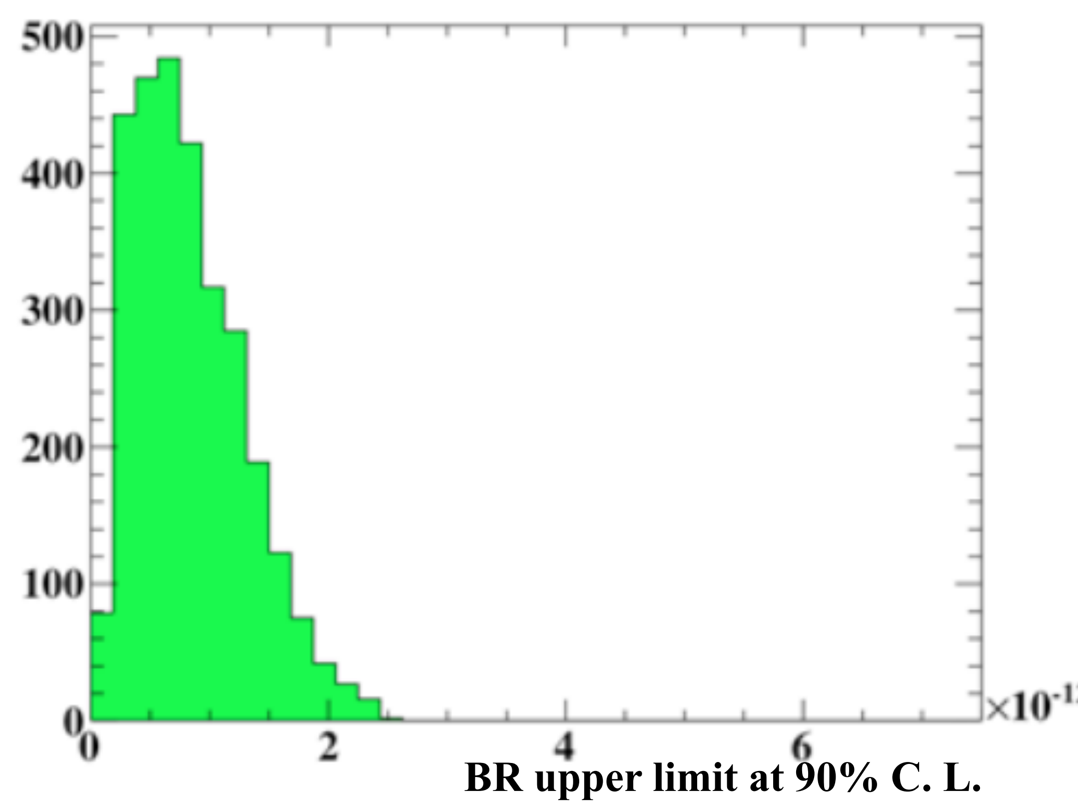
- Confidence interval for Nsig
    - Frequentist approach with likelihood profile ratio

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

Sensitivity

Estimated from pseudo experiments generated according to PDFs (Toy MC) and including systematics



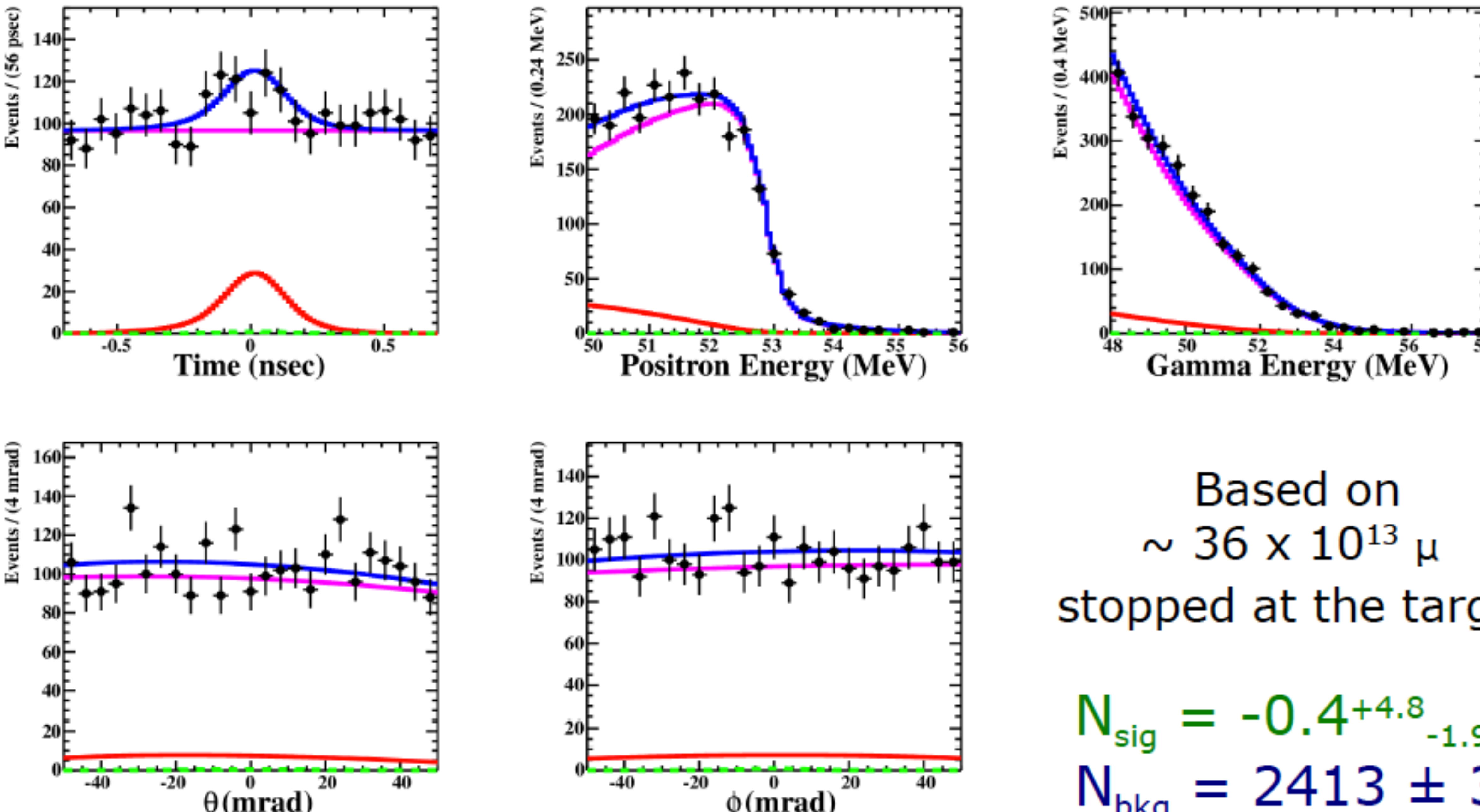


UL Nsig (median) ~ 6

UL BR (median) 7.7×10^{-13}

Likelihood fit

2009-2011 all combined



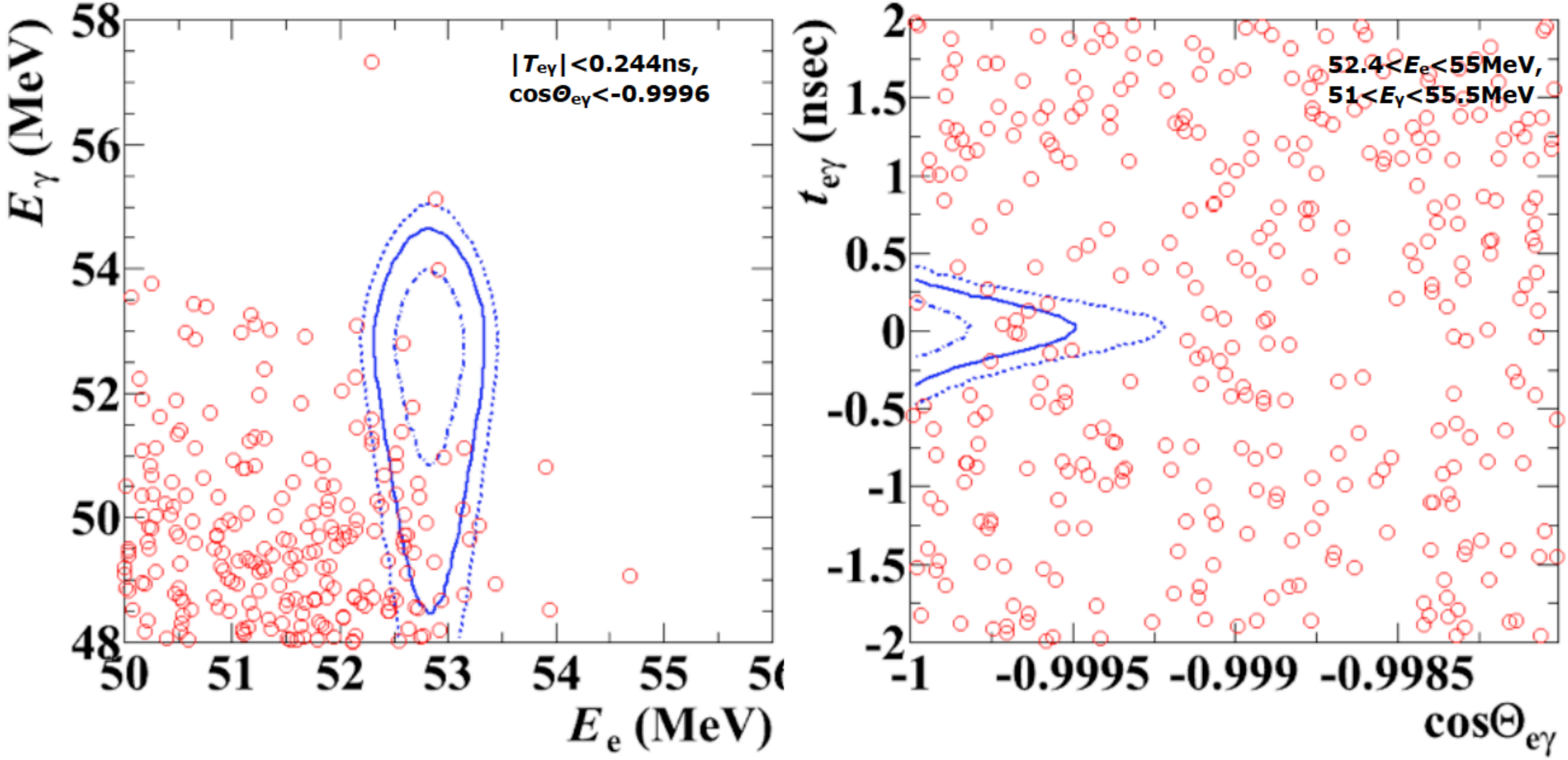
Based on
~ 36 x 10^{13} μ
stopped at the target

$N_{sig} = -0.4^{+4.8}_{-1.9}$

$N_{bkg} = 2413 \pm 37$

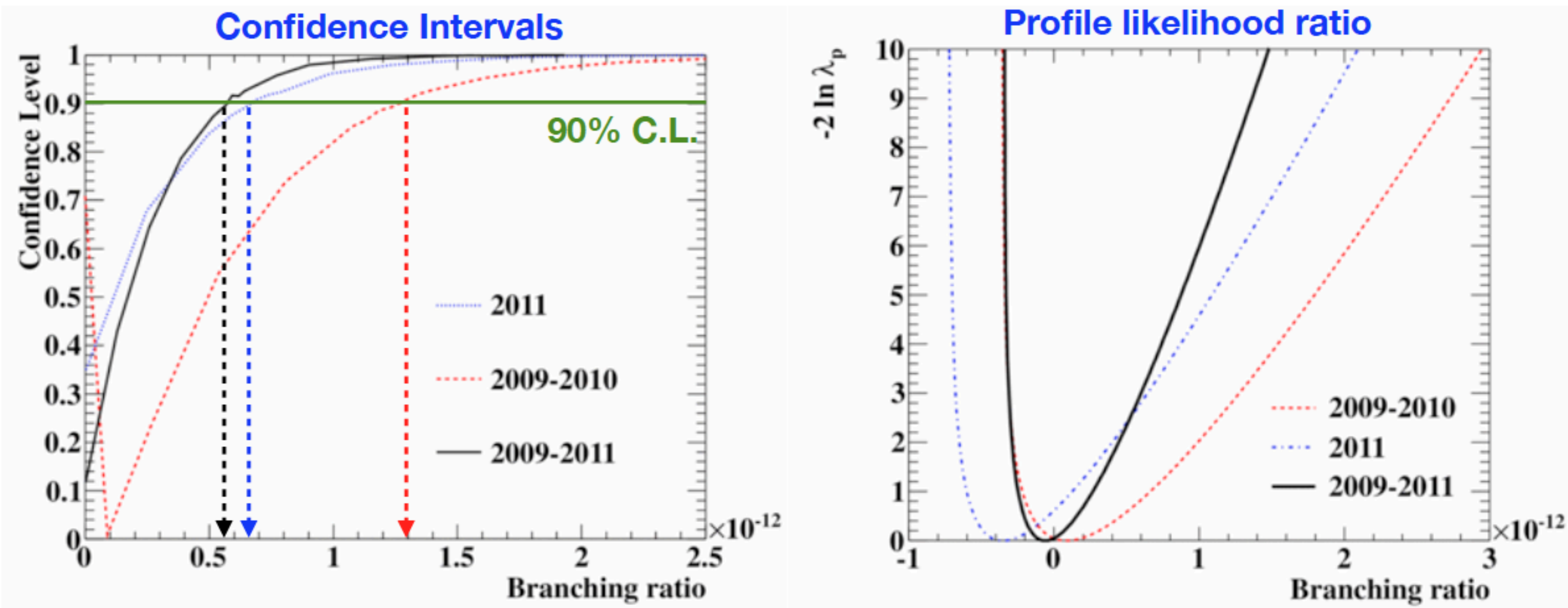
$N_{RD} = 167 \pm 24$

Event distribution



Confidence interval

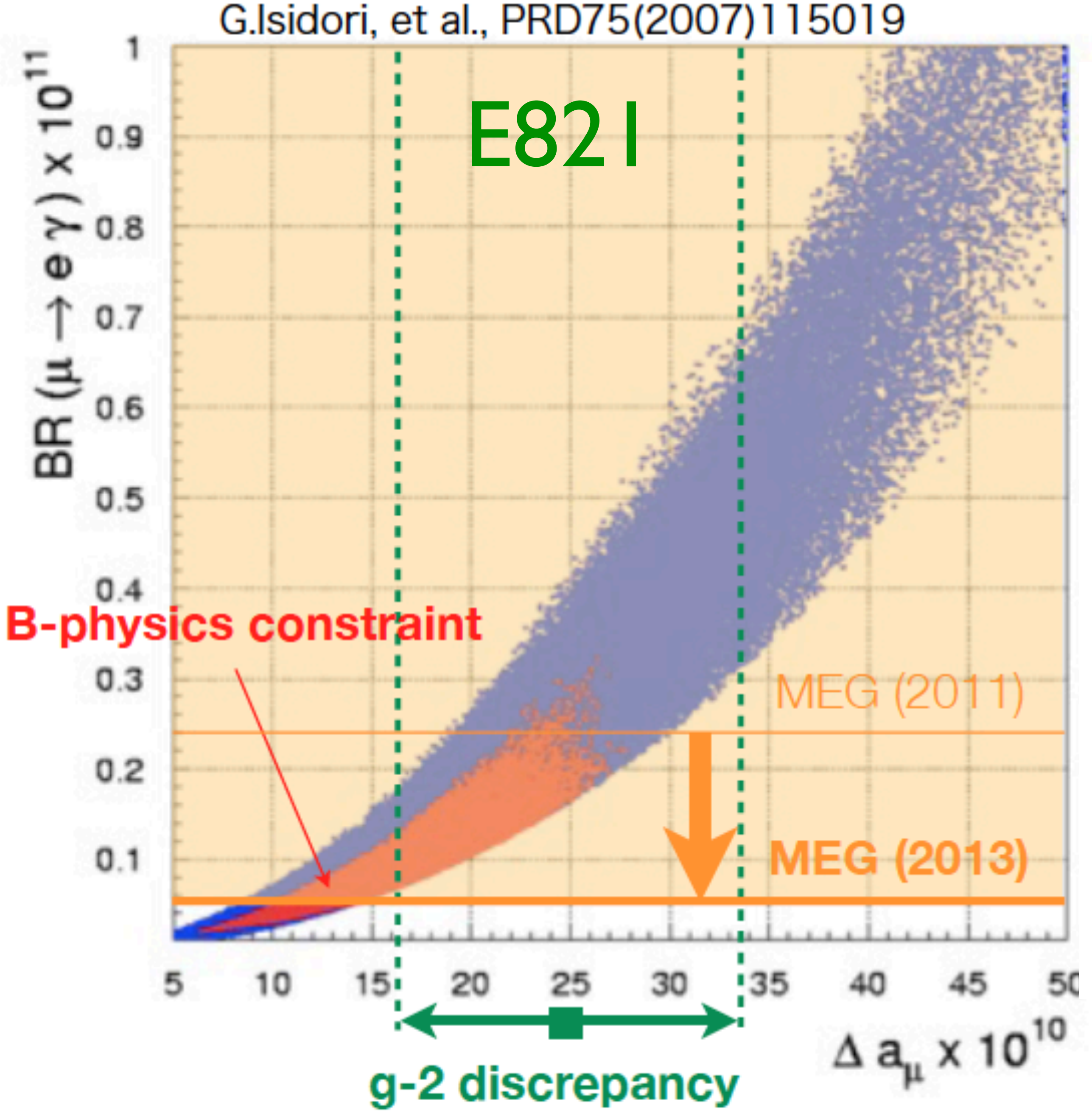
Consistent with null hypothesis



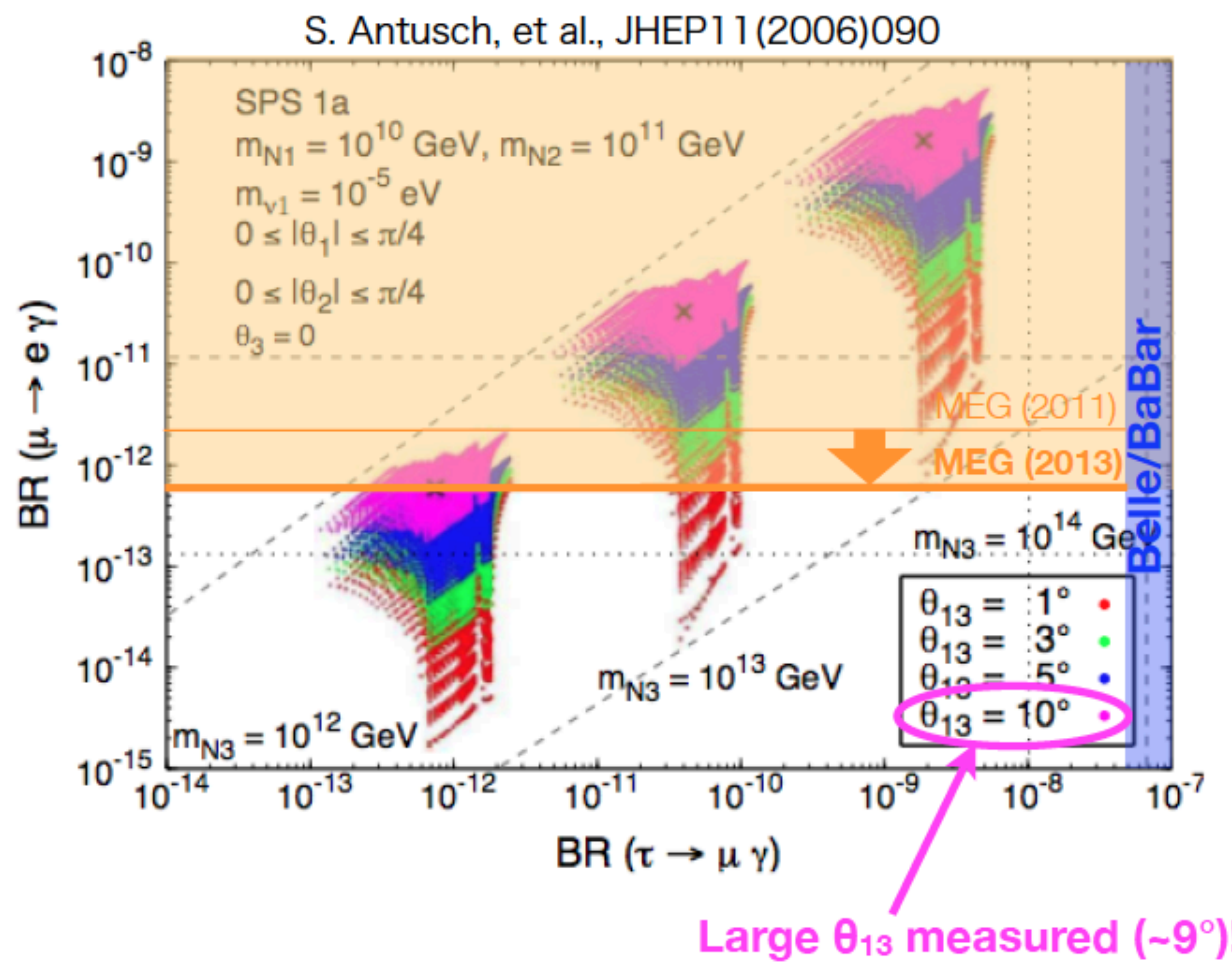
BR<5.7 x 10^{-13} @ 90 % CL

arXiv:1303.0754 (submitted to Phys. Rev. Lett.)

Theoretical constraints



$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM}$$



MEG upgrade

Now | Upgraded

Approved at PSI in January 2013

A higher beam intensity

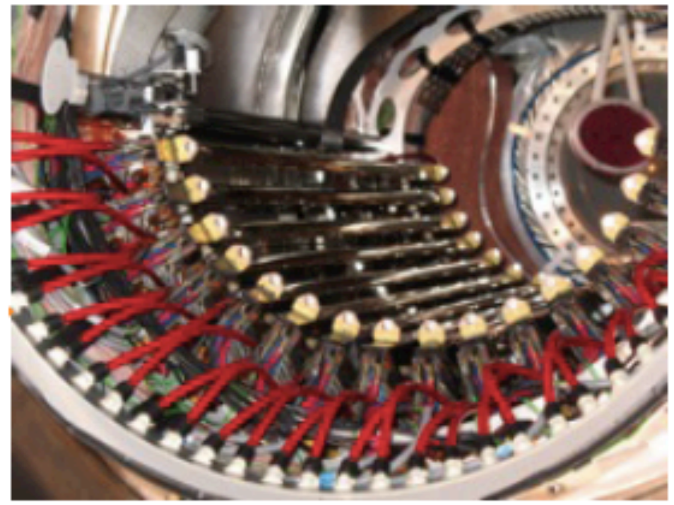
Single volume drift chamber with stereo angle wires configuration

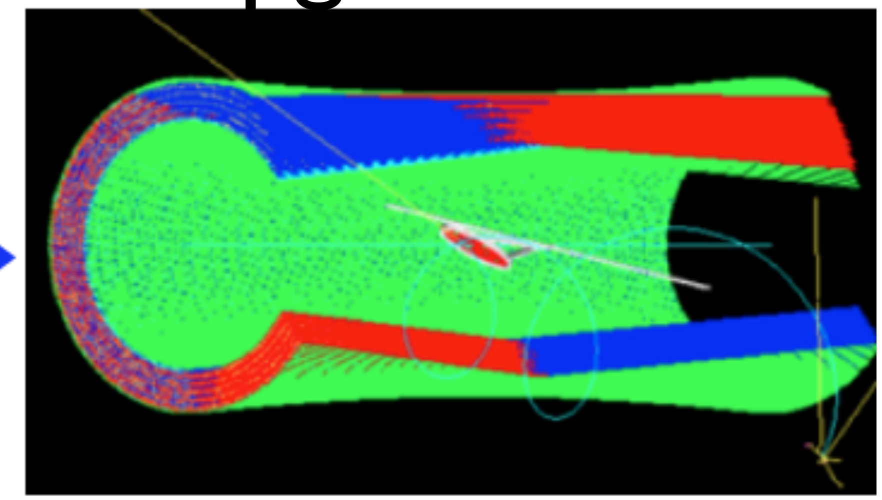
Scintillator tile timing counter (pixelated TC) with SiPM readout

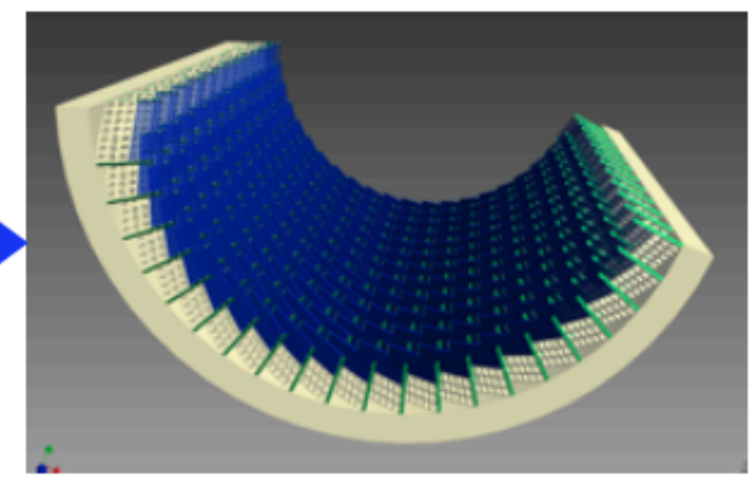
SiPM readout in LXe calorimeter with a larger fiducial volume

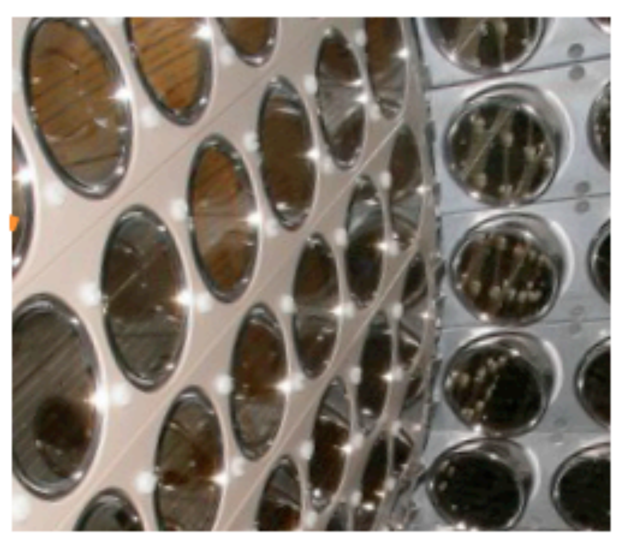
Thinner target or active target

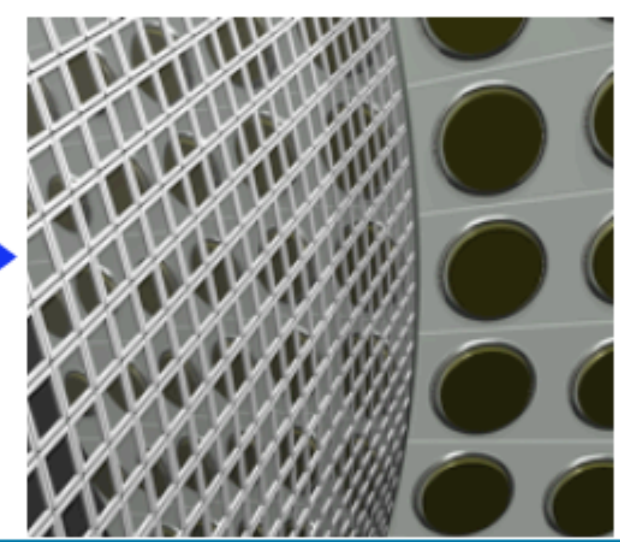
Re-designed trigger & DAQ







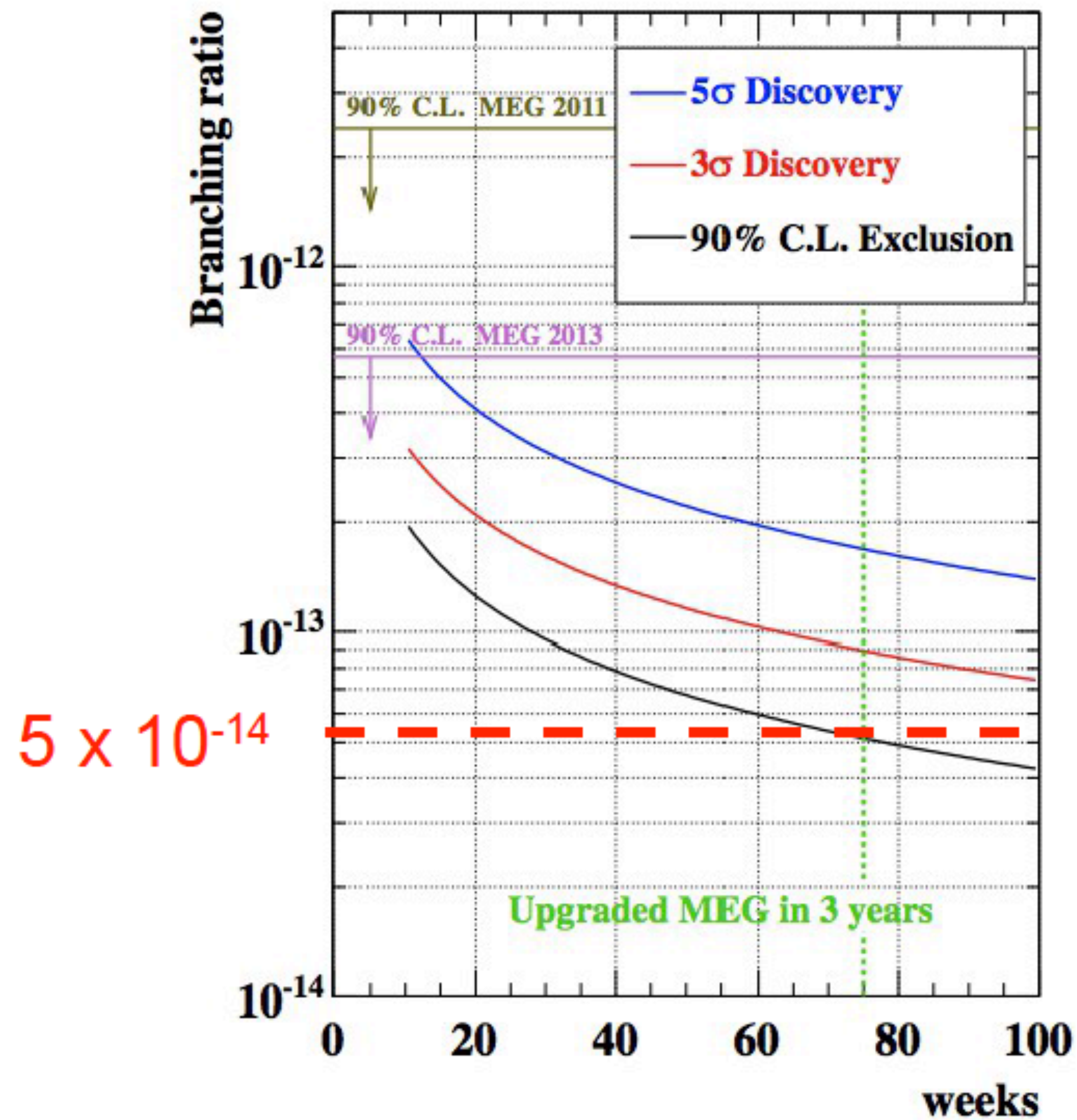




MEG upgrade

An improvement of an order of magnitude is expected on the sensitivity

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



Conclusions

With the 2009-2011 statistics MEG established the most stringet upper limit so far on **BR(μ⟶eγ)**

5.7×10^{-13} @ 90% CL

The statistics is expected to be doubled by the end of summer 2013 (expected sensitivity 5×10^{-13} @ 90% CL)

An upgrade of the experiment is expected to improve of an order of magnitude the sensitivity and it is planned to start in 2016

Backup

What's new

- Hardware improvements in 2011 run
  - Improved LXe calorimeter energy calibration
  - Better measurement of detector position
- Improved analysis algorithms
  - Reduced drift chamber noise with FFT filtering (better angular resolution)
  - New track fit algorithm based on Kalman Filter technique
    - 7 % more efficiency
    - Reduced tail in resolution function
    - per-event error matrix introduced in likelihood analysis
  - Improved pileup elimination algorithm
    - 7 % more efficiency
    - less pileup

Analysis summary

	Best fit	Upper limit (90% C.L.)	Sensitivity
2009-2010	0.09×10^{-12}	1.3×10^{-12}	1.3×10^{-12}
2011	-0.35×10^{-12}	6.7×10^{-13}	1.1×10^{-12}
2009-2011	-0.06×10^{-12}	5.7×10^{-13}	7.7×10^{-13}