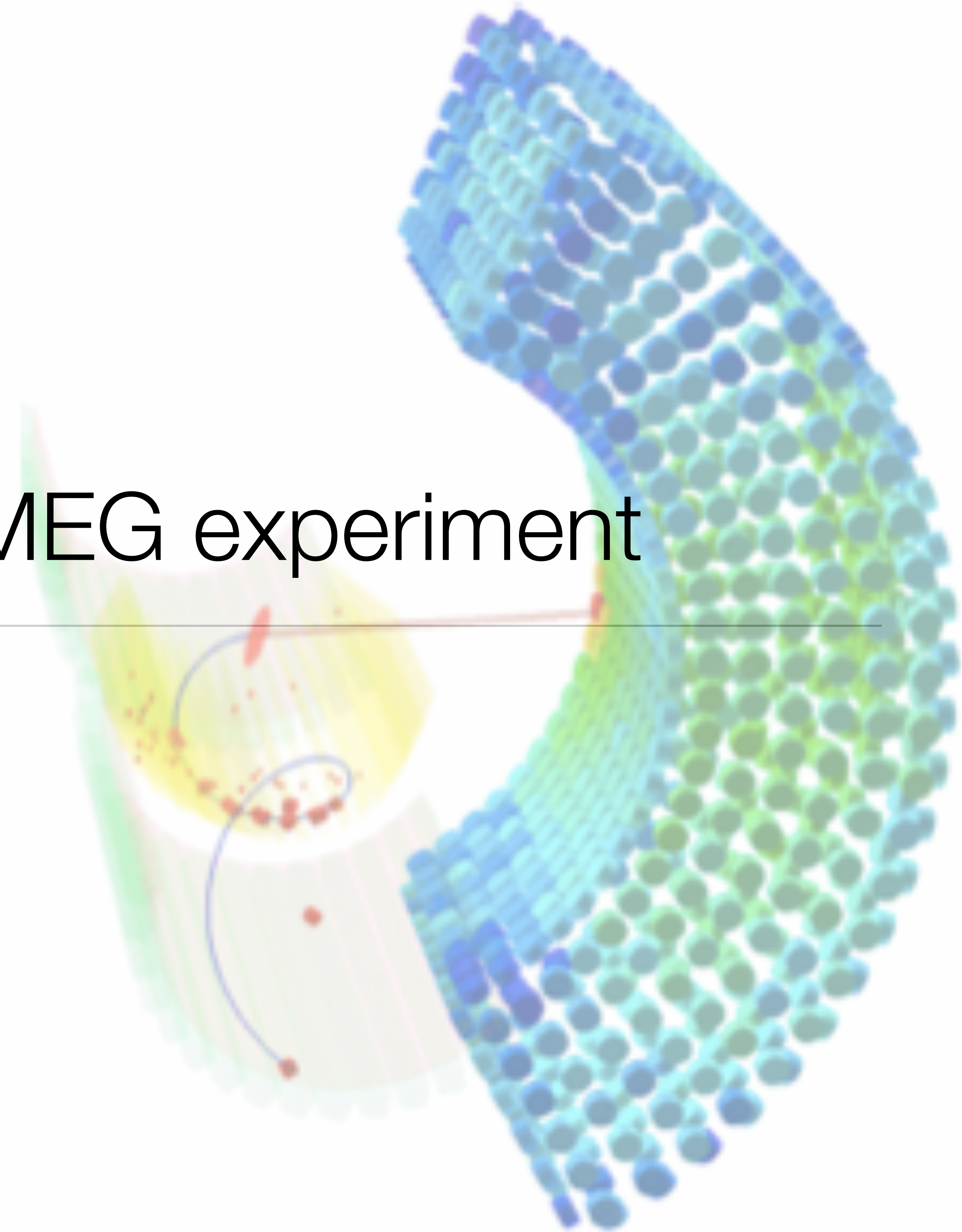
Latest News from the MEG experiment



Angela Papa
Paul Scherrer Institute
on behalf of MEG Collaboration

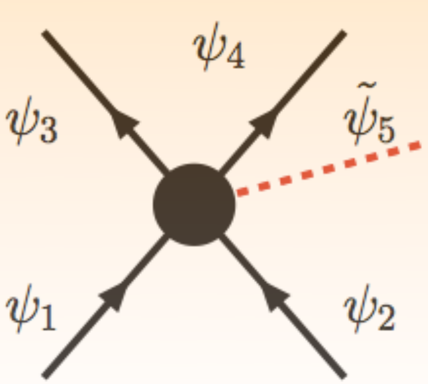
June 3-6 Latsis Symposium 2013
ETH Zurich, Switzerland

(*)BSM = Beyond Standard Model

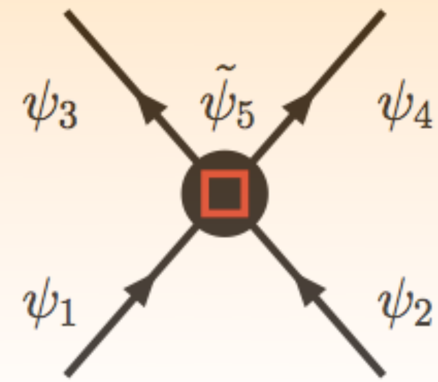
The role of low energy physics in the LHC era

How can low energy experiments be sensitive to high-energy physics (BSM*)?

- Direct/indirect production of BSM particles



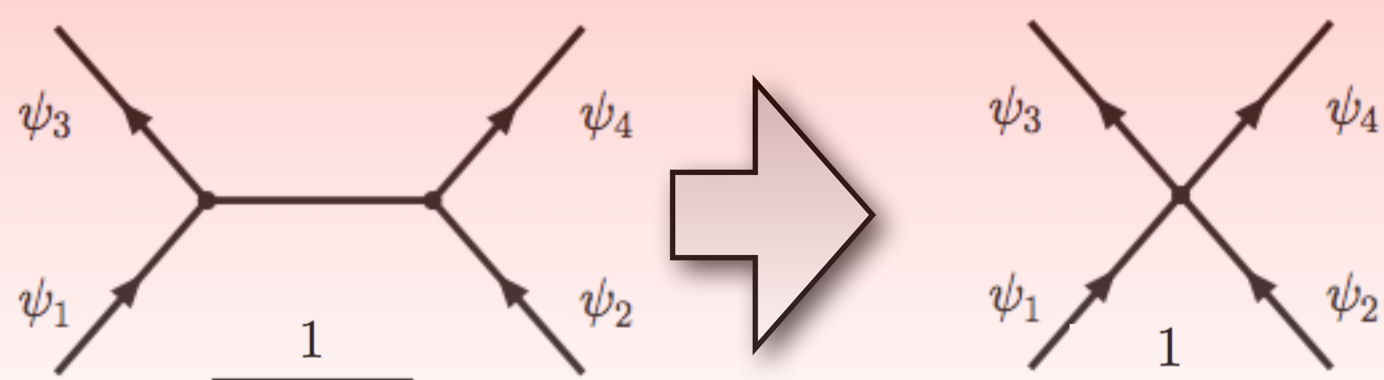
- Real BSM particles produced in the final state
- Energy frontier (LHC)



- Virtual BSM particles produced in loops
- Precision and intensity frontier

- Effective field theory approach

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$



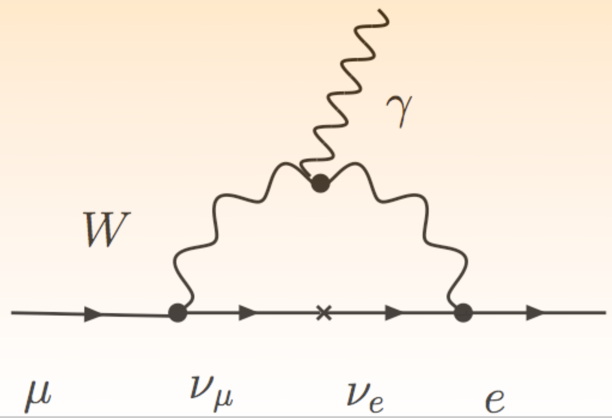
$$\frac{1}{p^2 - M^2} \qquad \frac{1}{\Lambda^2}$$

- L_{eff} is in terms of inverse powers of heavy scale

[1] R. Barbieri, L. Hall and A. Strumia, Nucl. Phys. B 455 (1995) 219
[2] J. Hisano, D. Nomura and T. Yanagida, Phys. Lett. B 437 (1998) 351
[3] M. Raidal et al., Eur. Phys. J. C 57 (2008) 13
[4] G. Blankenburg et al., Eur. Phys. J. C 72 (2012) 2126

The $\mu^+ \rightarrow e^+ \gamma$ decay

- Experimental evidence of neutrino oscillations



SM with massive neutrinos (Dirac)

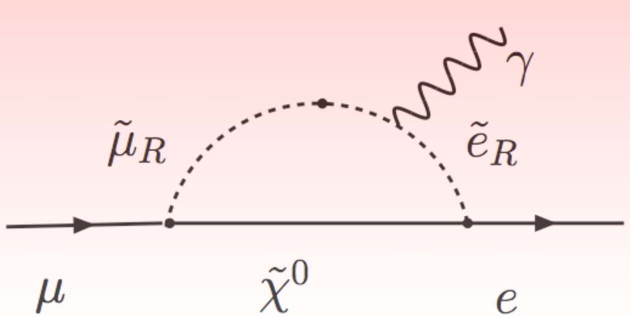
$$\Gamma(\mu \to e\gamma) = \approx \frac{G_F^2 m_\mu^5}{192\pi^3} \frac{\alpha}{2\pi} \sin^2 2\theta \, sin^2 \left(\frac{\Delta m^2 L}{4E}\right)$$

$$B(\mu^+ \to e^+\gamma) \approx 10^{-54}$$

- SU(5) SUSY-GUT and SO(10) SUSY-GUT models predict measureble LFV decay BR
- Null results
  - precise test of established model
  - rule out speculative models

$$\Gamma(l_1 \to l_2\gamma) = \frac{\alpha G_F^2 m_{l_1}^5}{2048\pi^4}(|D_R|^2 + |D_L|^2)$$

$$D_R = D_L \approx \frac{1}{G_F \Lambda^2}$$

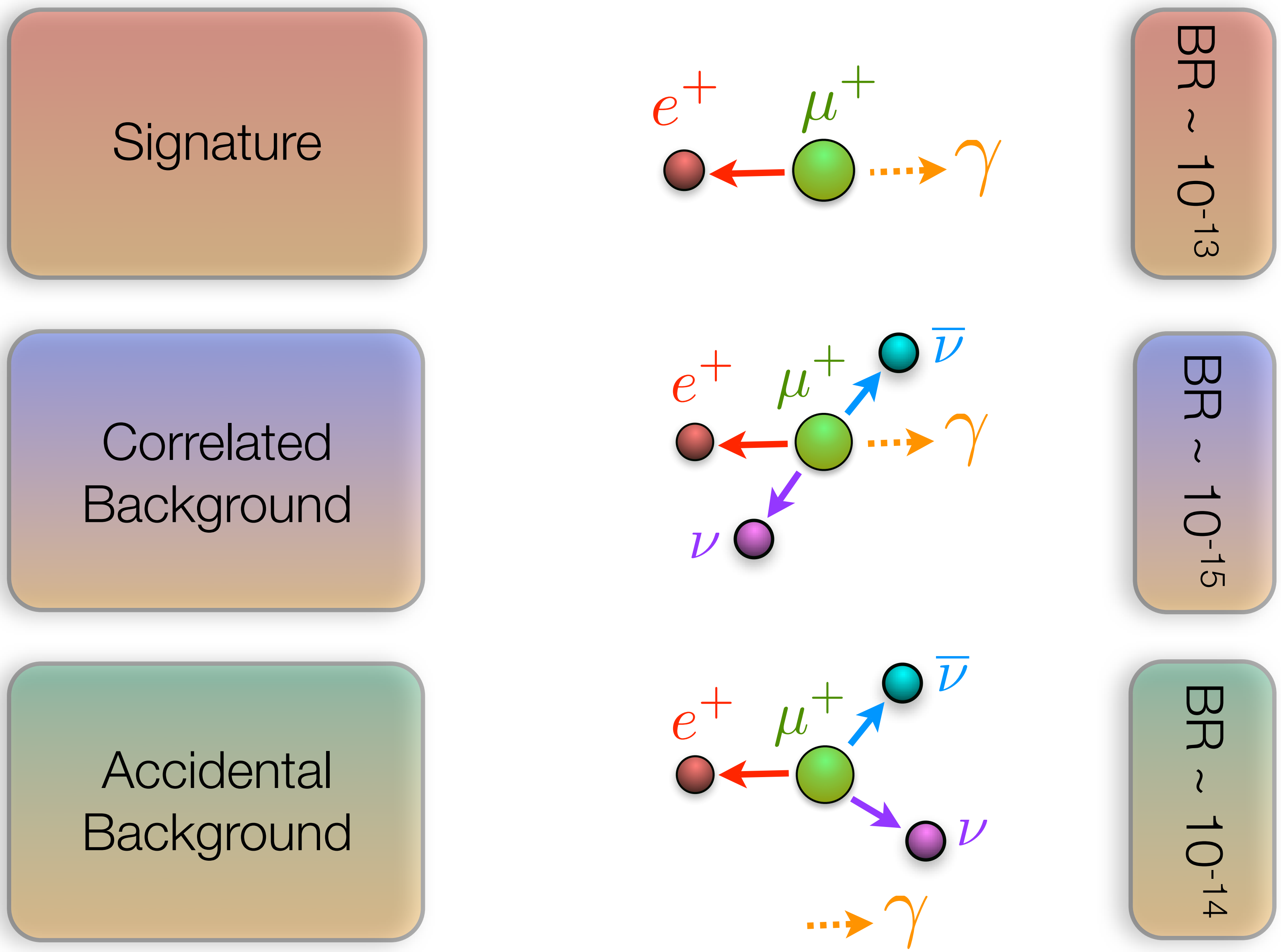


SU(5) SUSY-GUT o SO(10) SUSY-GUT

$$10^{-14} < B(\mu^+ \to e^+\gamma) < 10^{-11}$$

The MEG experiment

- The MEG experiment aims to search for $\mu^+ \rightarrow e^+ \gamma$ with a sensitivity of $\sim 10^{-13}$ (previous upper limit $BR(\mu^+ \rightarrow e^+ \gamma) \leq 1.2 \times 10^{-11}$ @90 C.L. by MEGA experiment)
- **Five observables** **(E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg})** **to characterize** $\mu \rightarrow e\gamma$ **events**



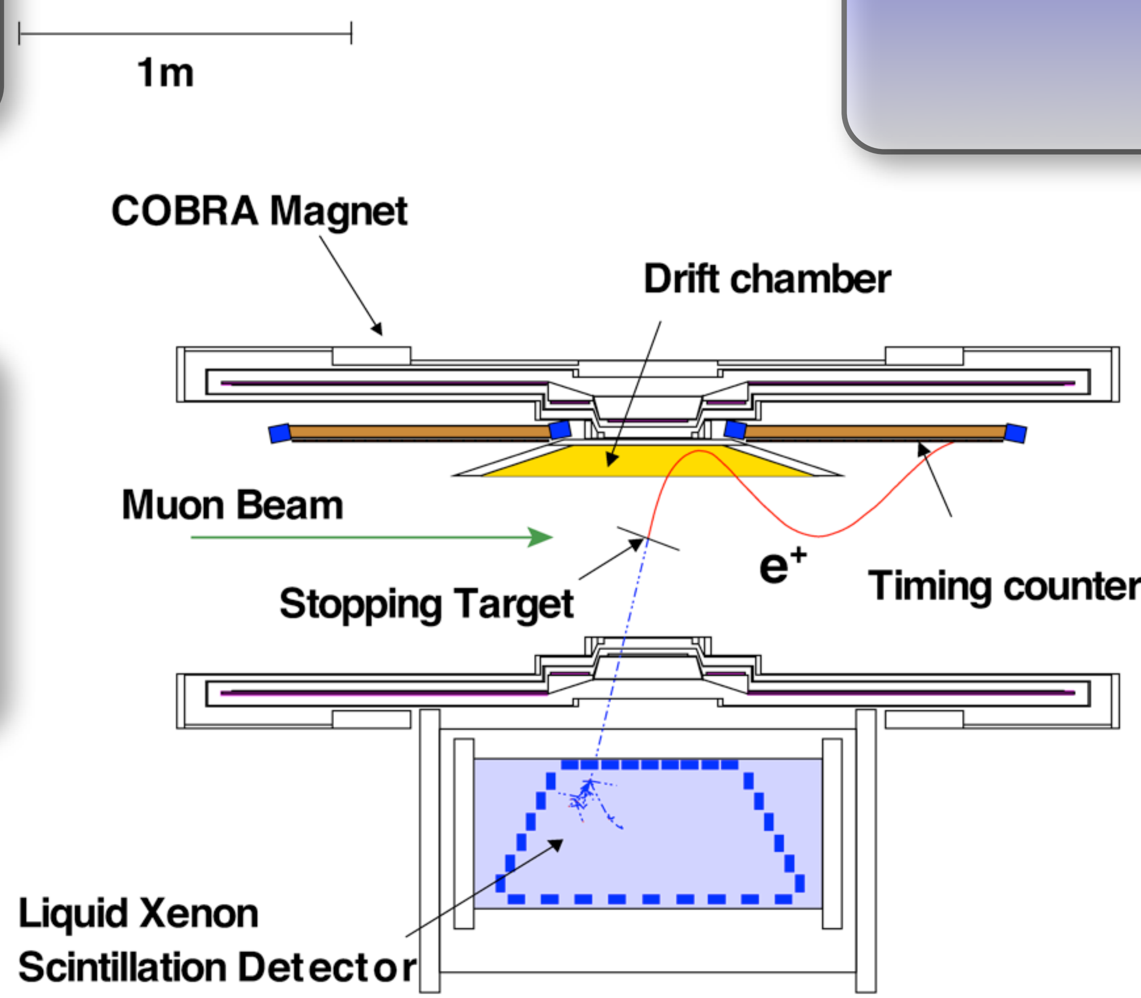
(*) Eur. Phys. J. C (2013) 73:2365

Experimental set-up

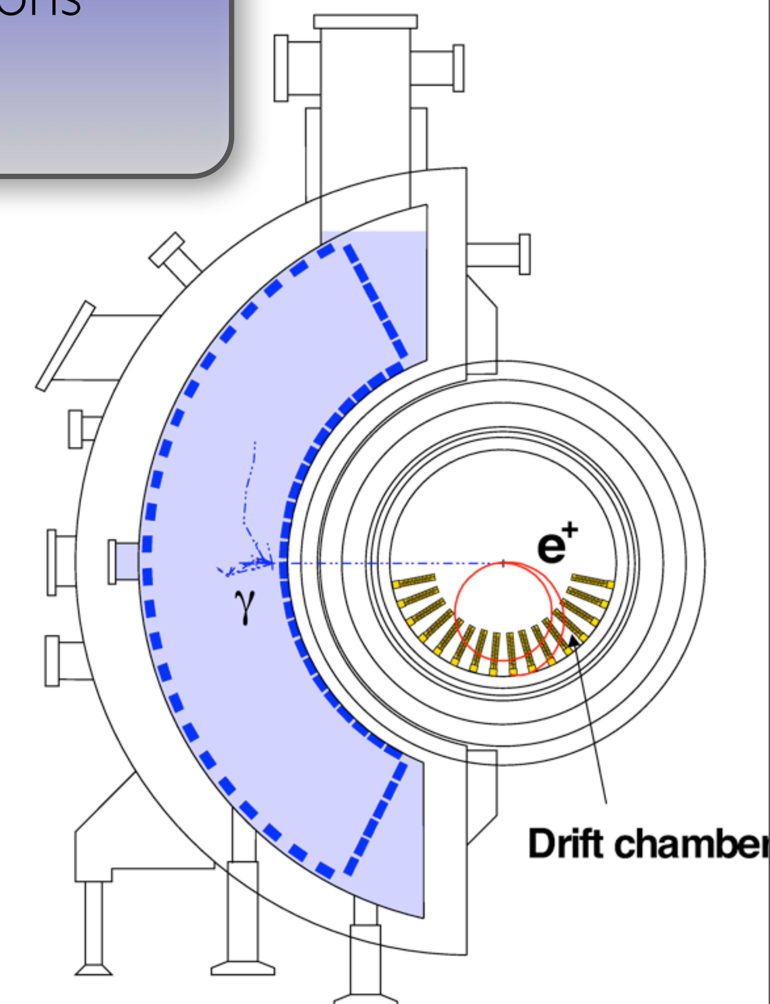
The world most intense dc muon beam at PSI

I = 3x 10^7 muon/s

Very precise positron momentum and time resolutions



High gamma energy and time resolutions

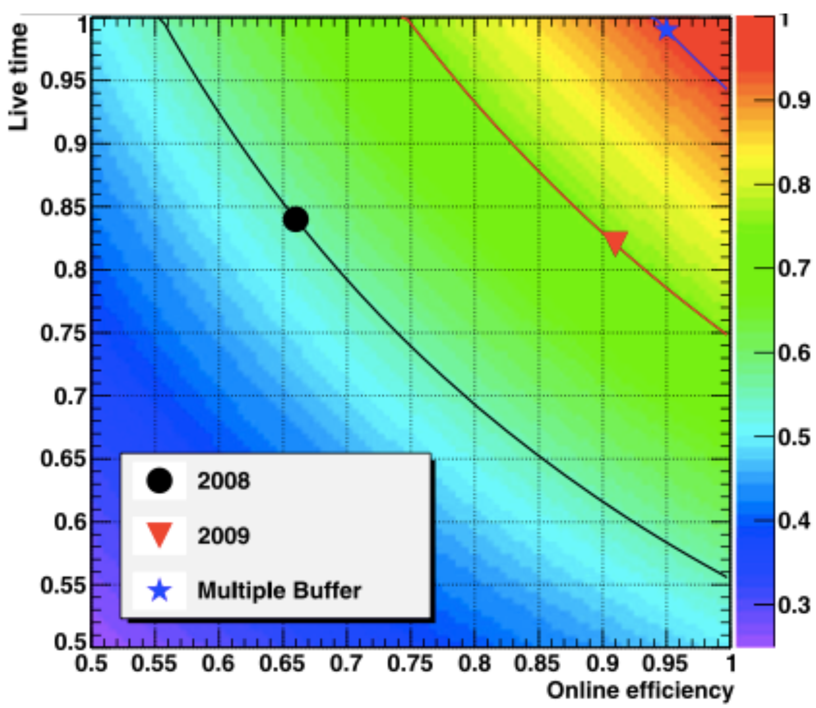


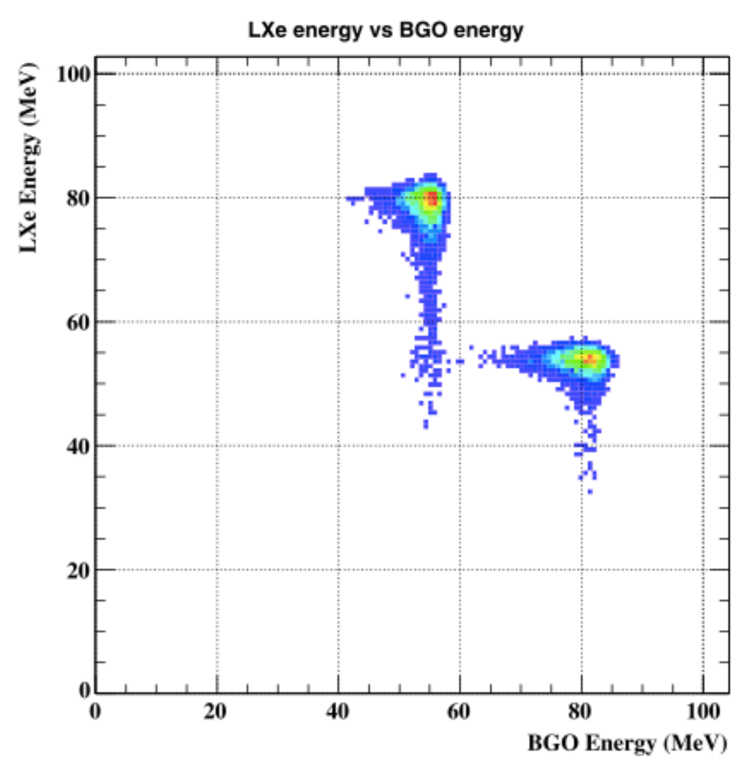
High efficiency event selection and frequency signal digitization

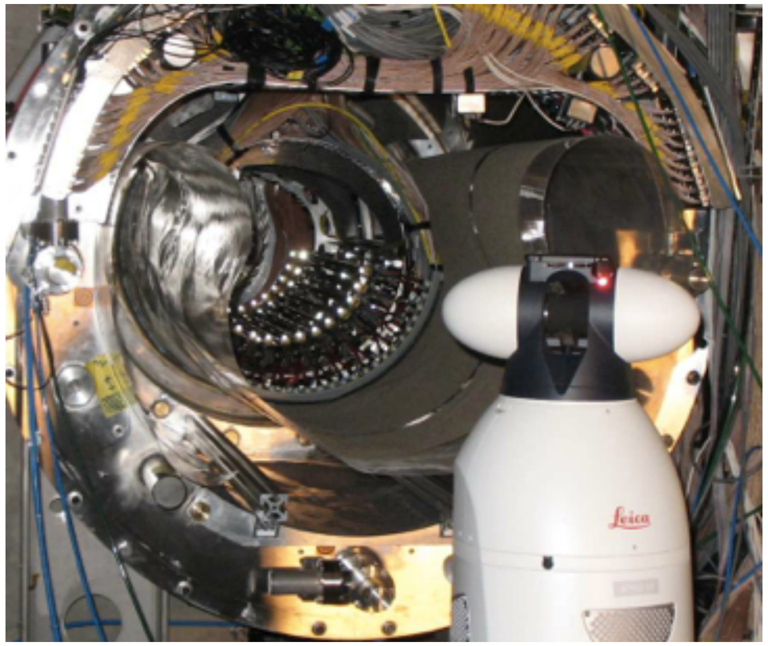
Complementary calibration and monitoring methods

What's new in 2011

- Hardware improvements
  - **Improved** trigger and DAQ efficiency (Double buffer) (**ε ~95% ; livetime ~99%**)
  - **Improved** LXe calibration with CEX reaction ($\pi^- p \rightarrow \pi^0 n$, $\pi^0 \rightarrow 2\gamma$) thanks to the higher BGO array (auxiliary) detector resolutions
  - **New** optical survey technique **with laser tracker**

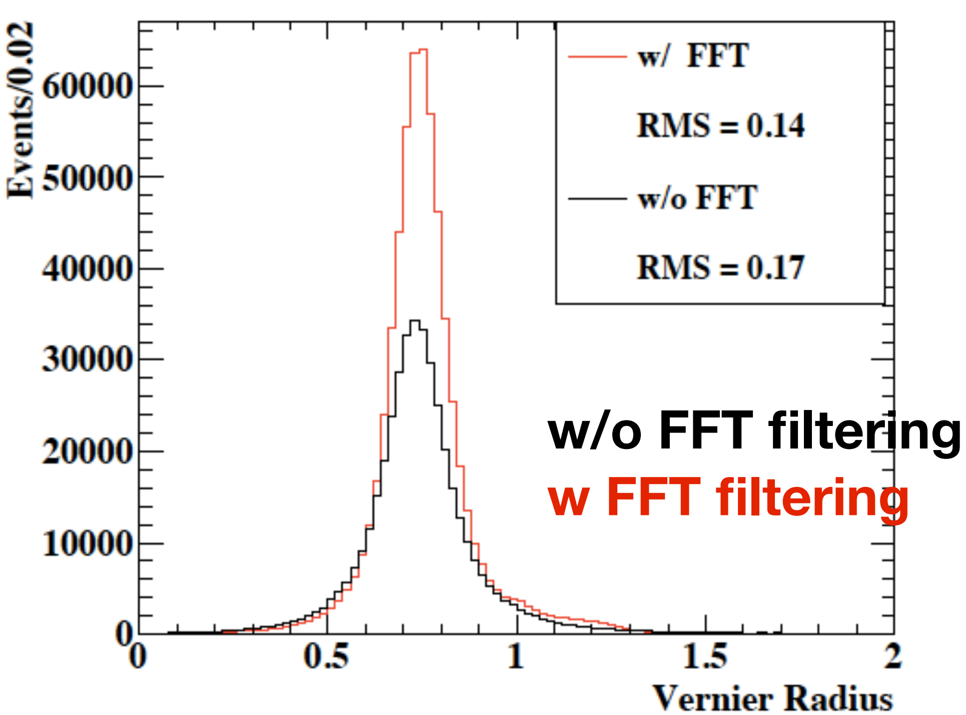


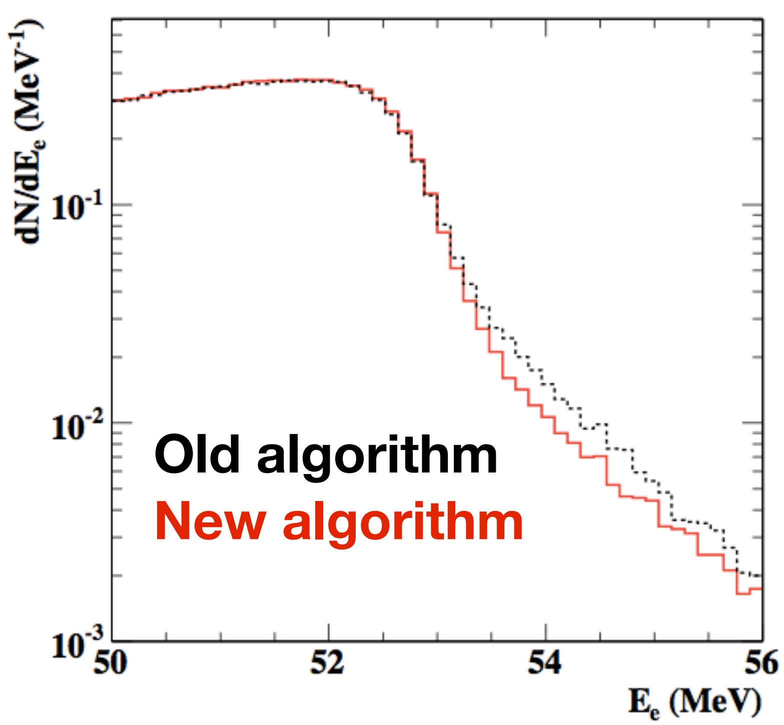


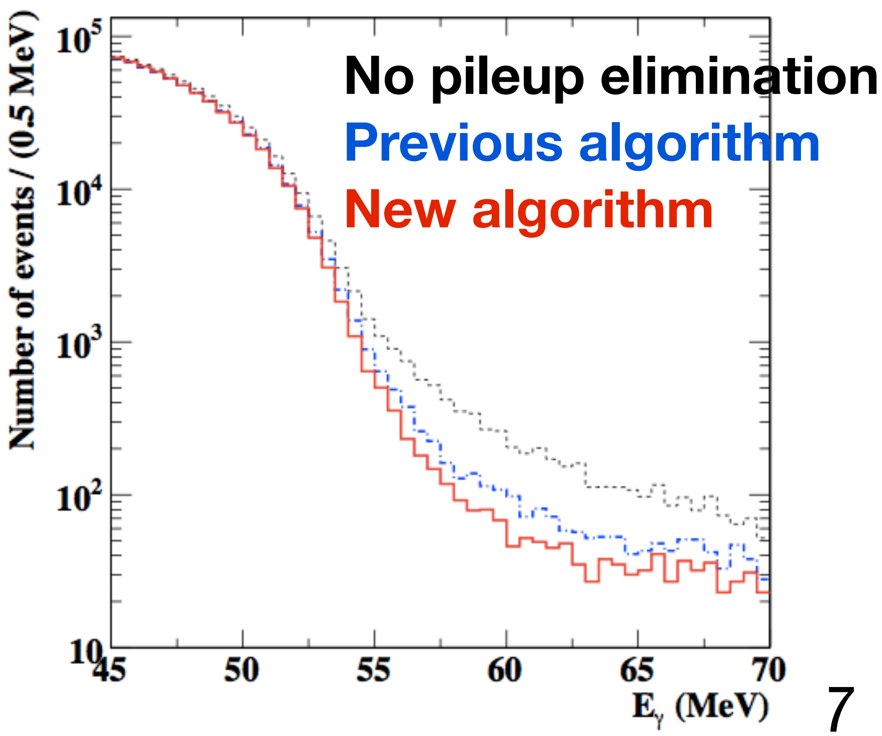


What's new in 2011

- Software improvements
  - **Reduced** drift chamber noise **with FFT filtering** (**$\sigma(\Theta)$ < 10%**)
  - **New track fit** algorithm based on Kalman filter technique (**ε > 7%**)
  - **Improved** pileup elimination algorithm in LXe detector (**ε > 7%**)



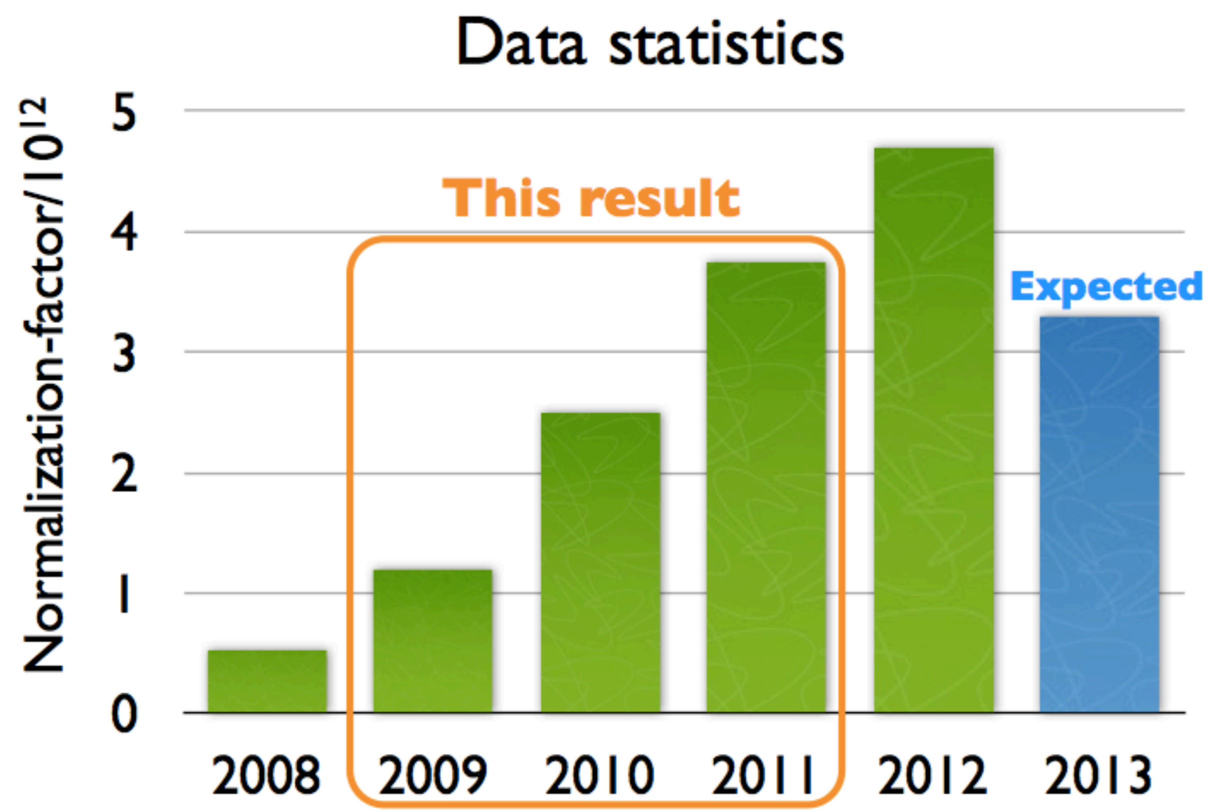




Detector performance and Data sample

New 2011

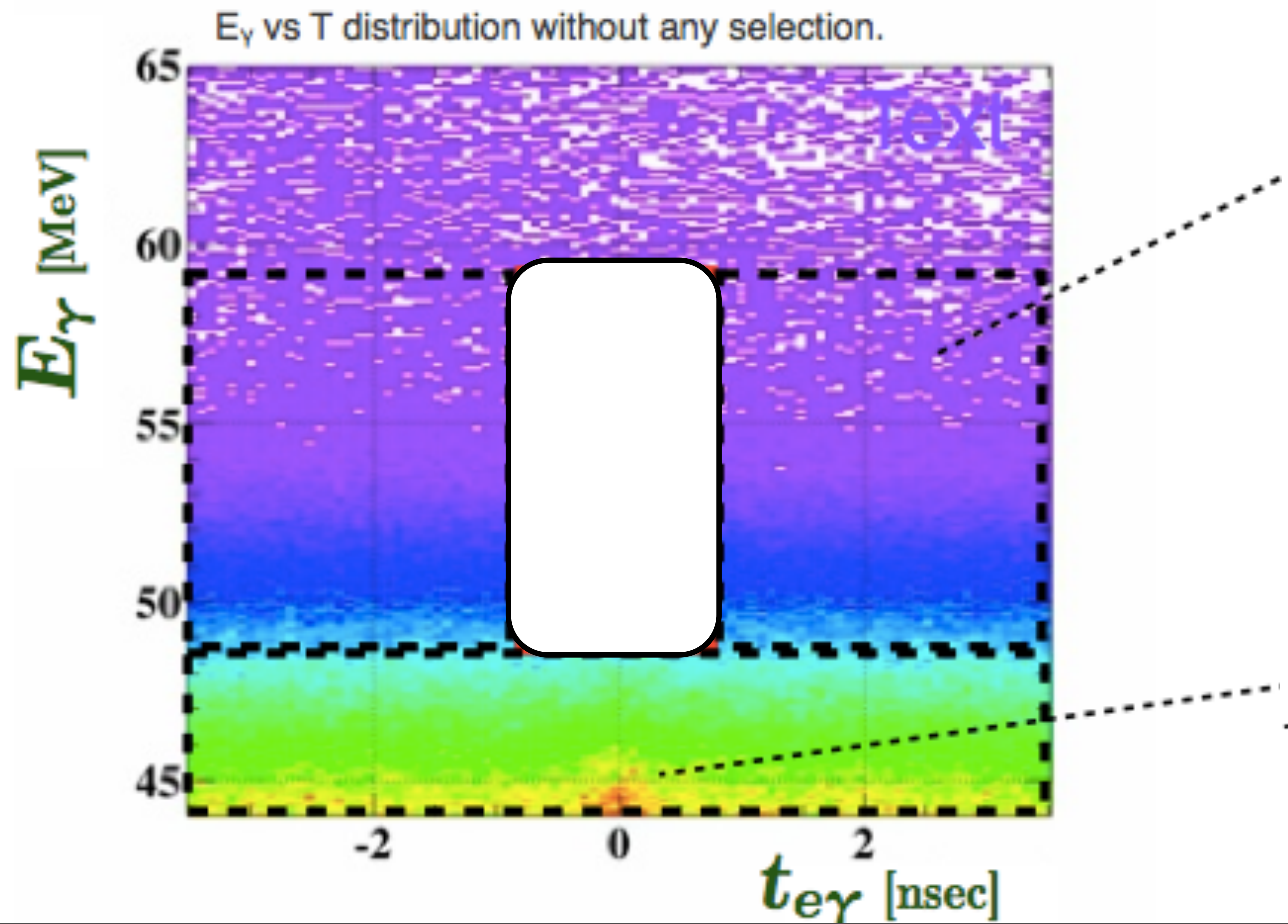
	Resolutions (σ)
Gamma Energy (%)	1.7(depth>2cm), 2.4
Gamma Timing (psec)	67
Gamma Position (mm)	5(u,v), 6(w)
Gamma Efficiency (%)	63
Positron Momentum (KeV)	305 (core = 85%)
Positron Timing (psec)	108
Positron Angles (mrad)	7.5 (Φ), 10.6 (θ)
Positron Efficiency (%)	40
Gamma-Positron Timing (psec)	127
Muon decay point (mm)	1.9 (z), 1.3 (y)

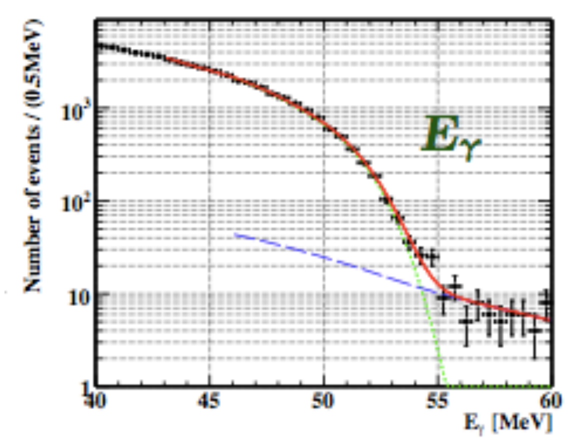


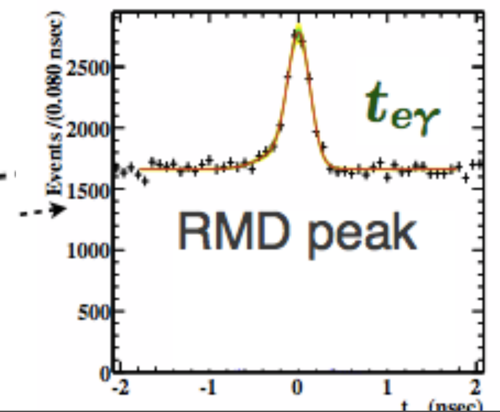
	μ stopped	sensitivity
2009+10	1.75×10^{14}	1.3×10^{-12}
2011	1.85×10^{14}	1.1×10^{-12}
2009+10+11	3.60×10^{14}	7.7×10^{-13}

Physics Analysis Overview and Event Selection

- Five observables **(E_g, E_e, t_{eg}, ϑ_{eg}, ϕ_{eg})** to characterize $\mu \to e\gamma$ events
- Event selection: Trigger selection ($E_g > 45$ MeV , $|\Delta t_{eg}| < 10$ ns, $|\Delta\phi| < 7.5^0$) + at least 1 reconstructed track
- Blind Analysis (Sideband, Blind box)
- Maximum likelihood to extract N_{sig}
- CL frequentistic approch







Maximum Likelihood Analysis

- Analysis region: $48<E_\gamma<58$MeV, $50<E_e<56$MeV, $|\theta_{e\gamma}|<50$mrad, $|\Phi_{e\gamma}|<50$mrad, $|T_{e\gamma}|<0.7$ns
- Maximum likelihood analysis to estimate # of signal
  - Event-by-event PDF
    - gamma: position dependent resolutions
    - positron: per-event error matrix from Kalman filter

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

- Confidence interval of N_{sig} (or B)
  - Frequentist approach with profile likelihood ratio ordering

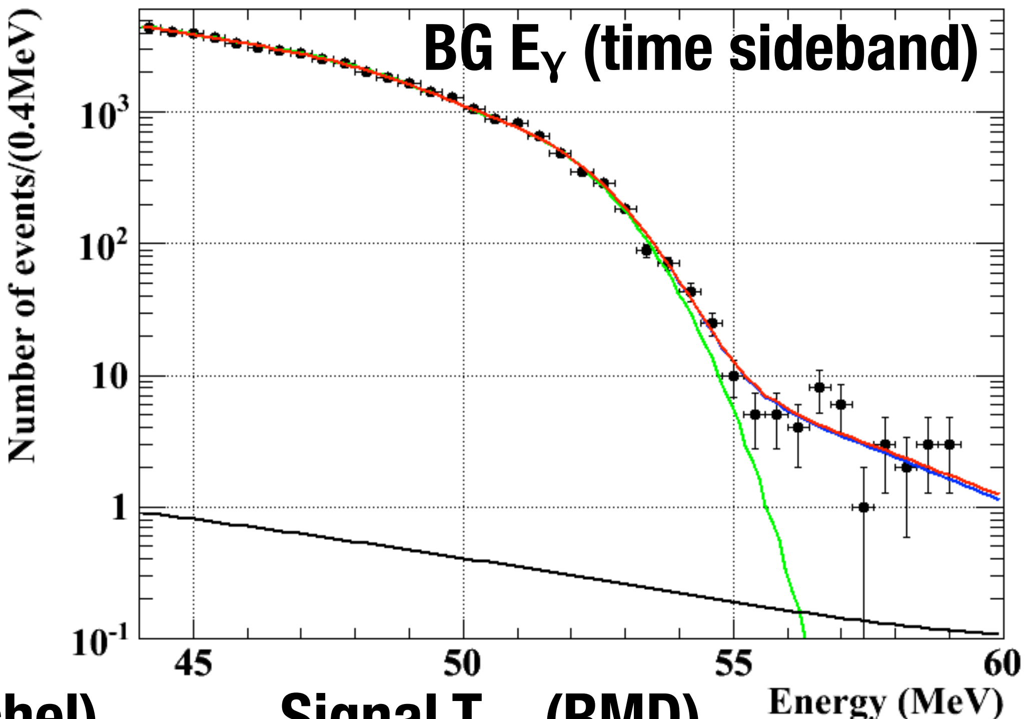
Probability Density Functions

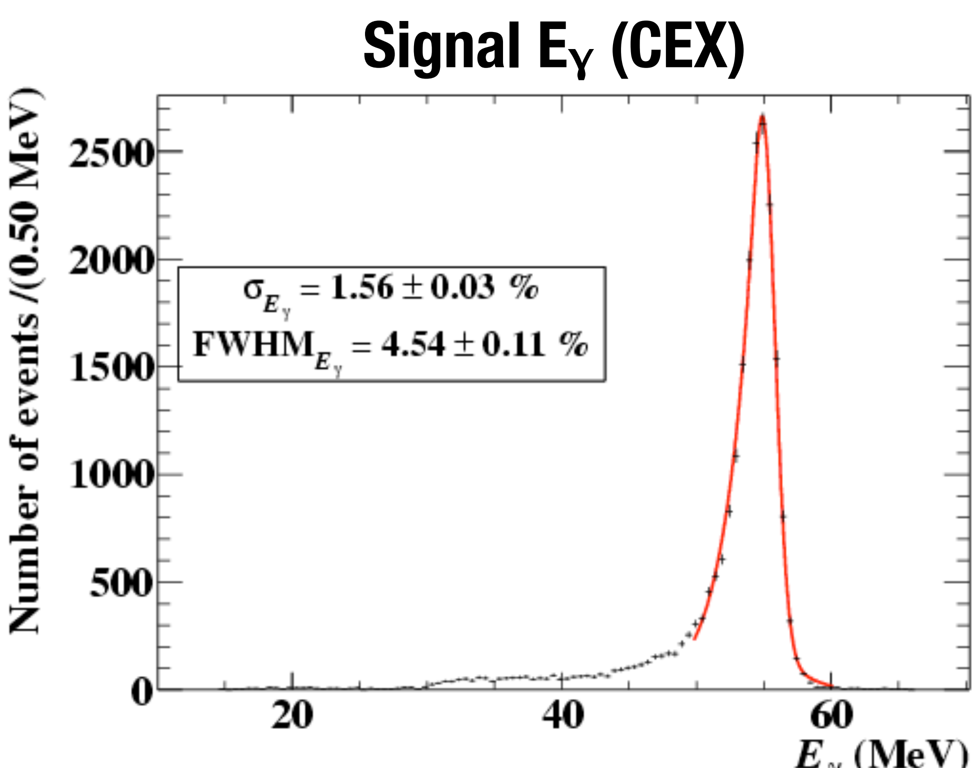
- **Probability density functions (PDF)** for likelihood function are mostly extracted from **data**

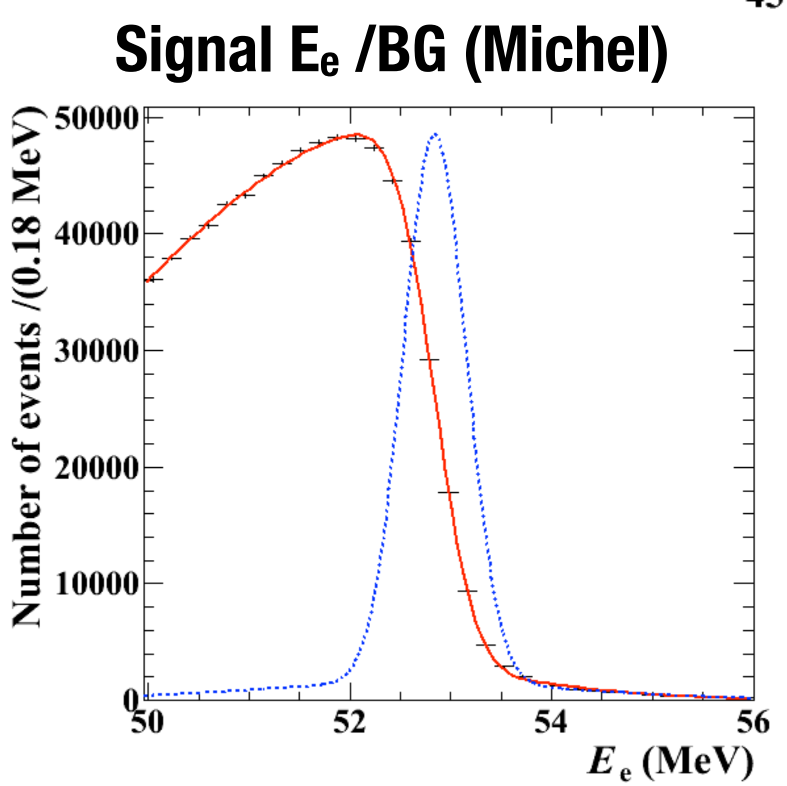
The signal PDF *S* is the product of the PDFs for Ee, θeγ, Φeγ,Teγ which are correlated variables, and the Eγ PDF

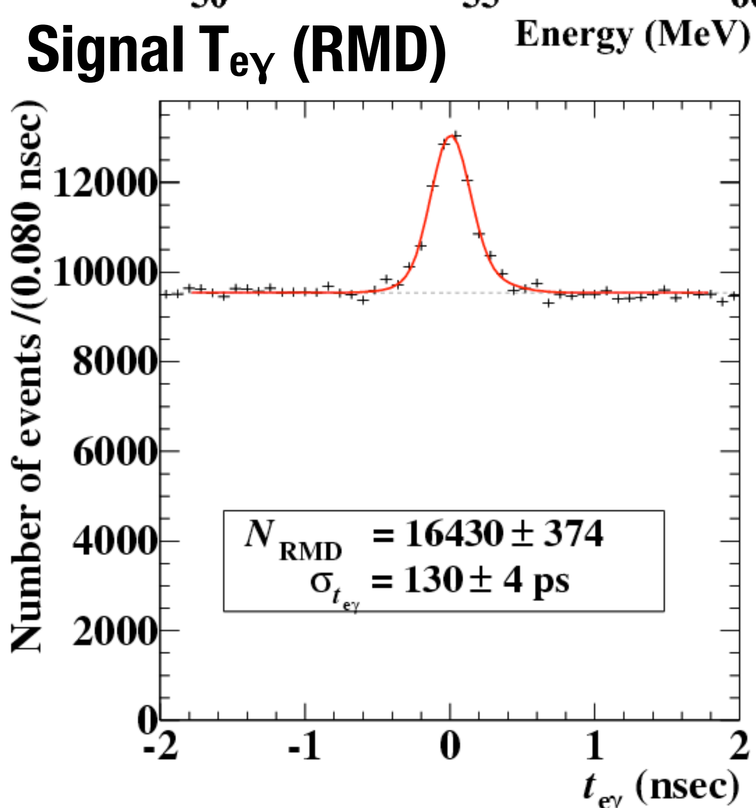
The RMD PDF *R* is the product of the same Teγ PDF as that of the signal and the PDF of the other four correlated observables, which is formed by folding the theoretical spectrum with the detector response functions

The BG PDF *B* is the product of the five PDFs, each of which is defined by the single background spectrum, precisely measured in the sidebands

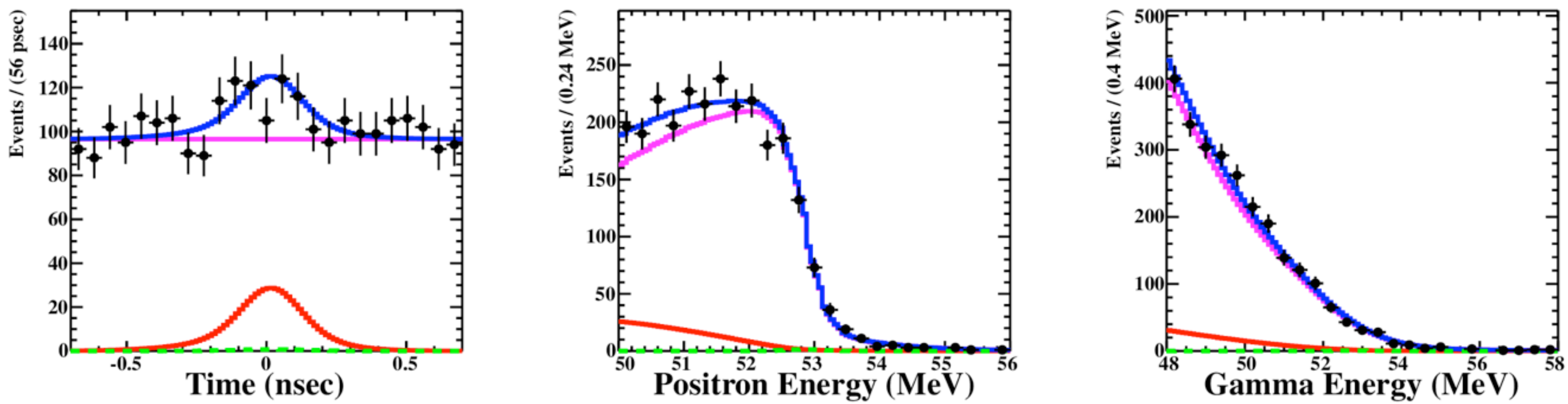


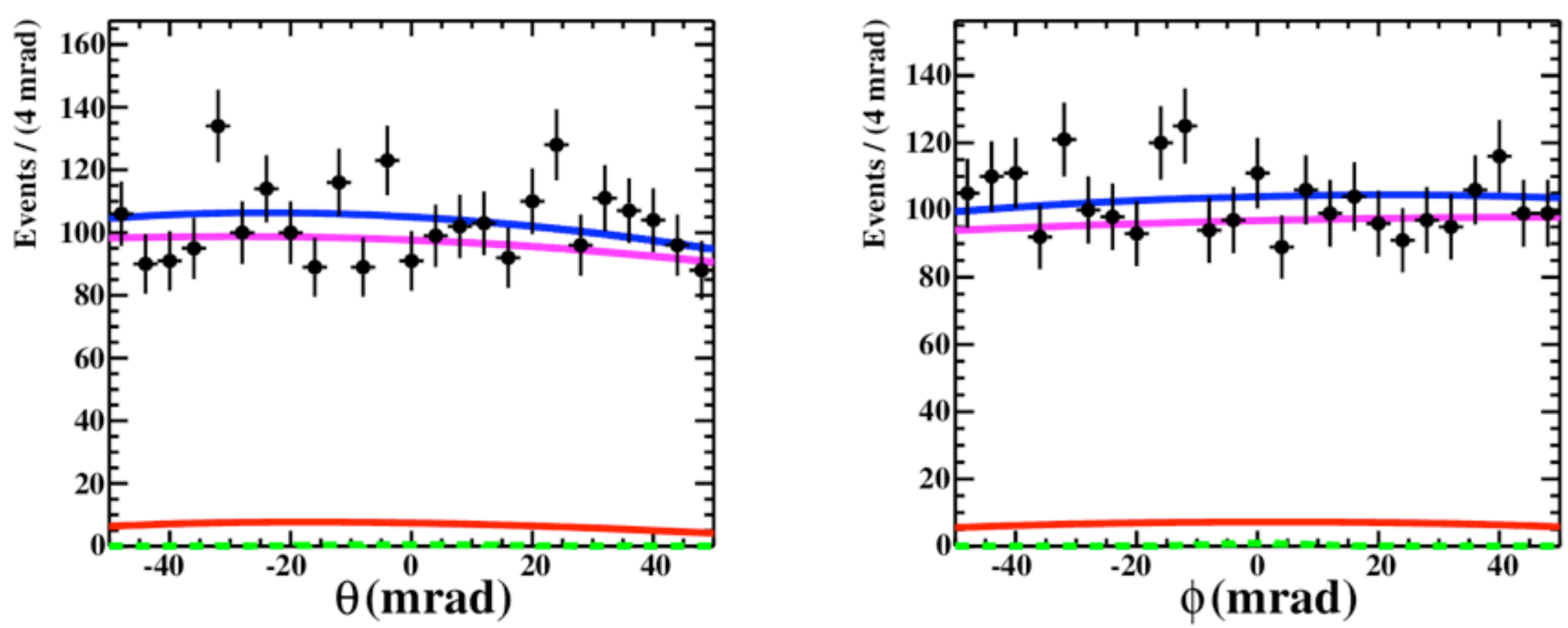






Likelihood Fit (2009-2011)



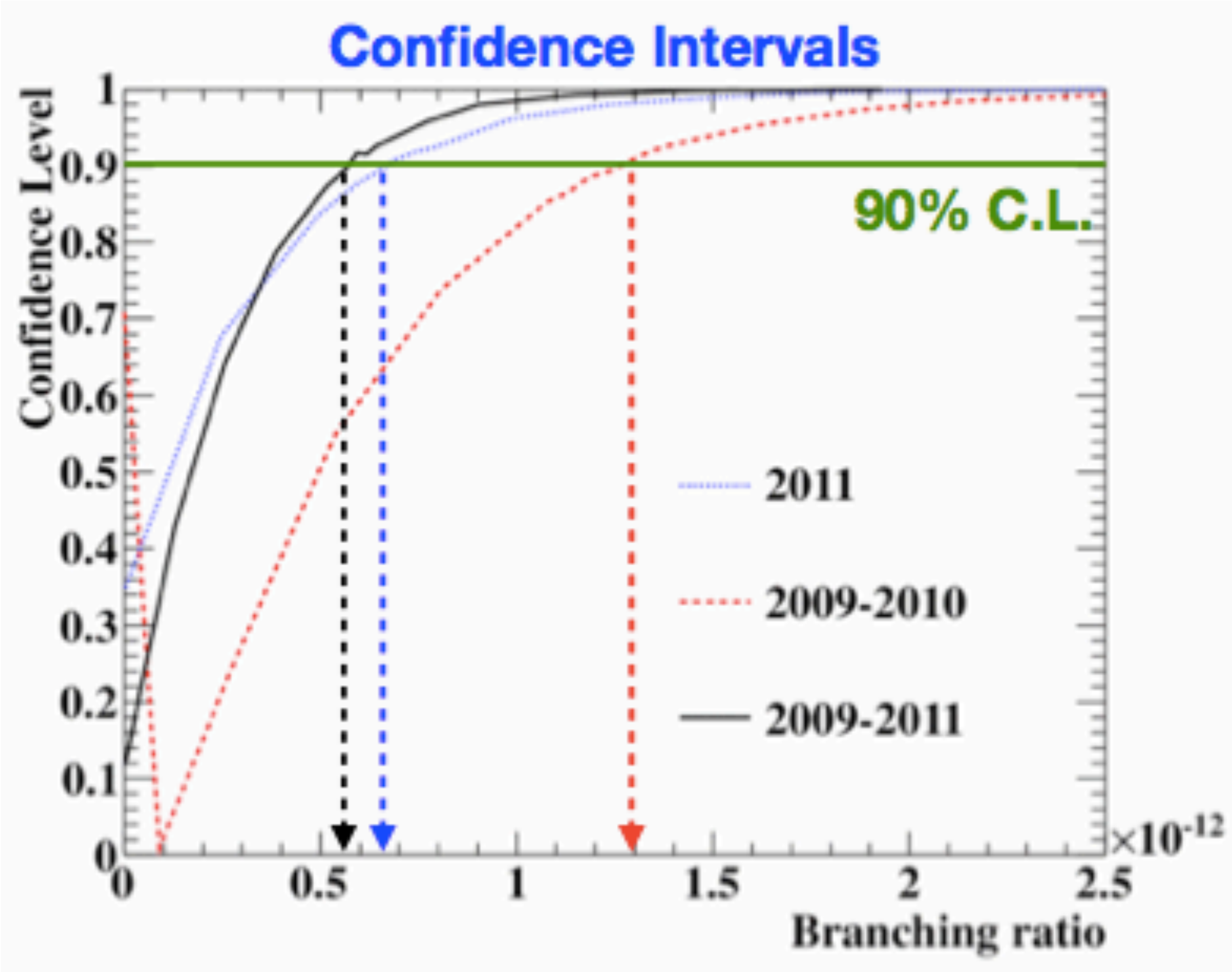


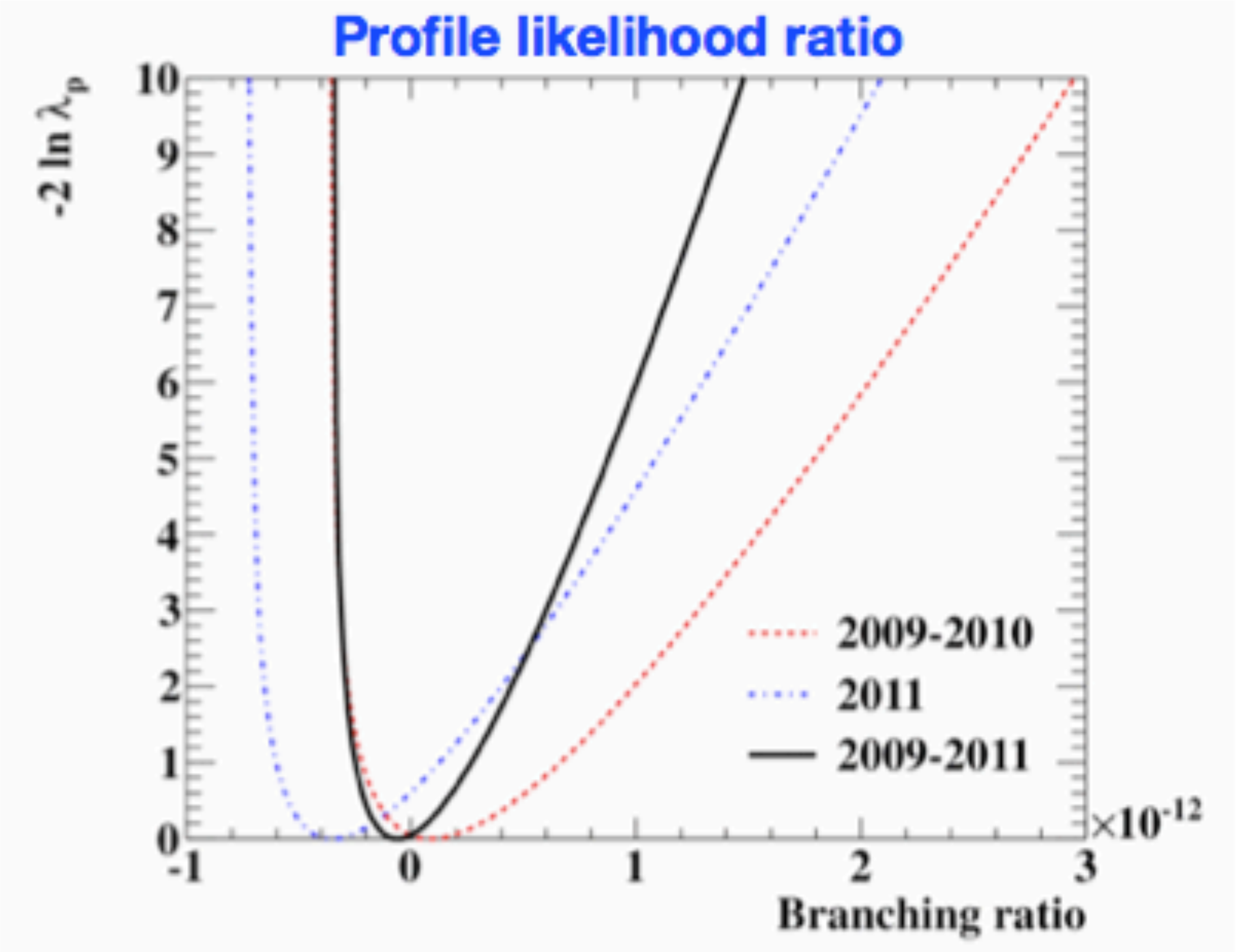
Green: Signal
Red: RMD
Purple: BCK
Blue: Total
Black: Data

NSIG = -0.4(+4.8 -1.9)
NRMD = 167.5 ± 24
NBCK = 2414 ± 37

Confidence Interval

- Confidence interval calculated with Feldman-Cousins method + profile likelihood ratio ordering





Consistent with null-signal hypotesis

(*) Phy. Rev. Lett. 110, 201801 (2013)

Summary of Results

(**) 90% C.L. upper limit averaged over pseudo-experiments based on null-signal hypothesis with expected rates of RMD and BG

	Best fit	Upper Limit (90% C.L.)	Sensitivity **
2009+10	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+10+11	-0.06×10^{-12}	5.7×10^{-13}	7.7×10^{-13}

$B(\mu^+ \rightarrow e^+ \gamma) < 5.7\times10^{-13}$ (all combined data) *

x4 more stringent than the previous upper limit

($B(\mu^+ \rightarrow e^+ \gamma) < 2.4\times10^{-12}$ -MEG 2009-10)

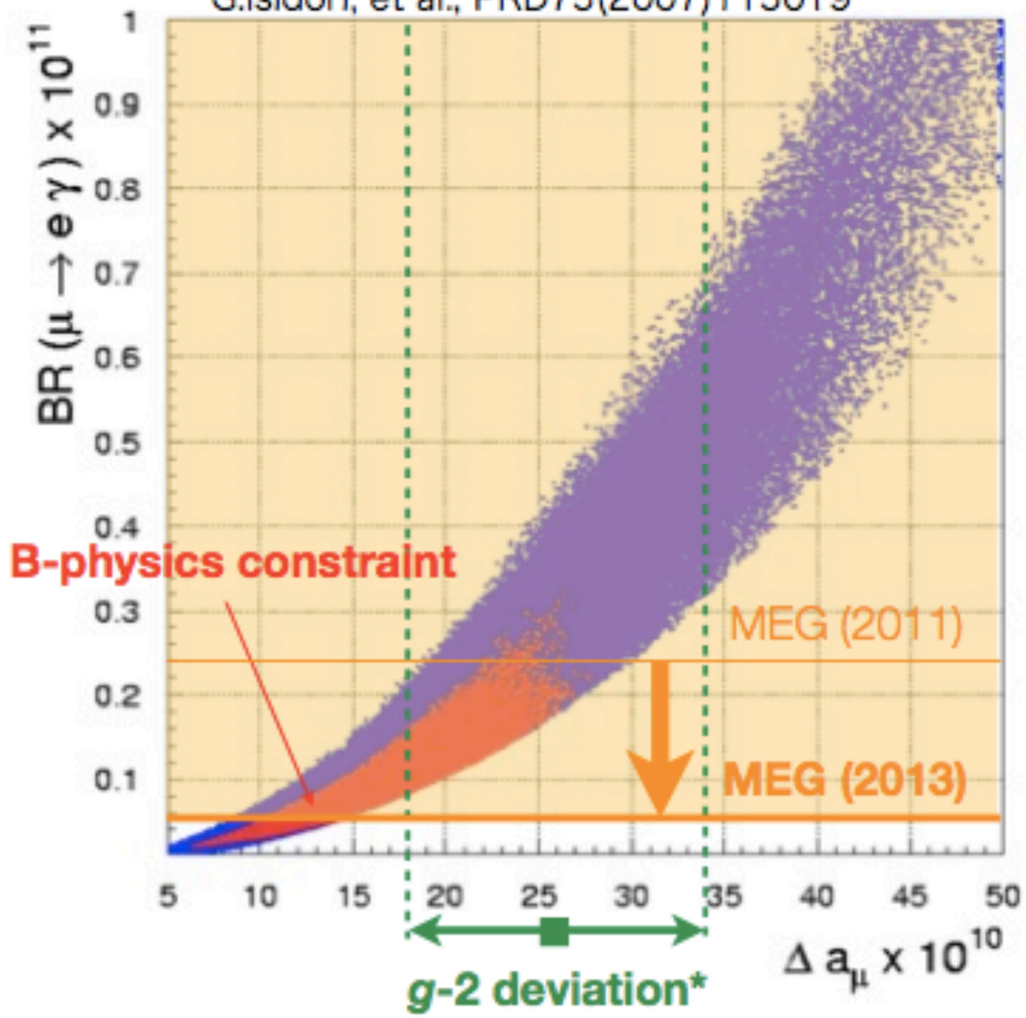
x20 more stringent than the MEGA experiment result

($B(\mu^+ \rightarrow e^+ \gamma) < 1.2\times10^{-11}$ -MEGA 2001)

Impact on NP Models

SUSY-GUT

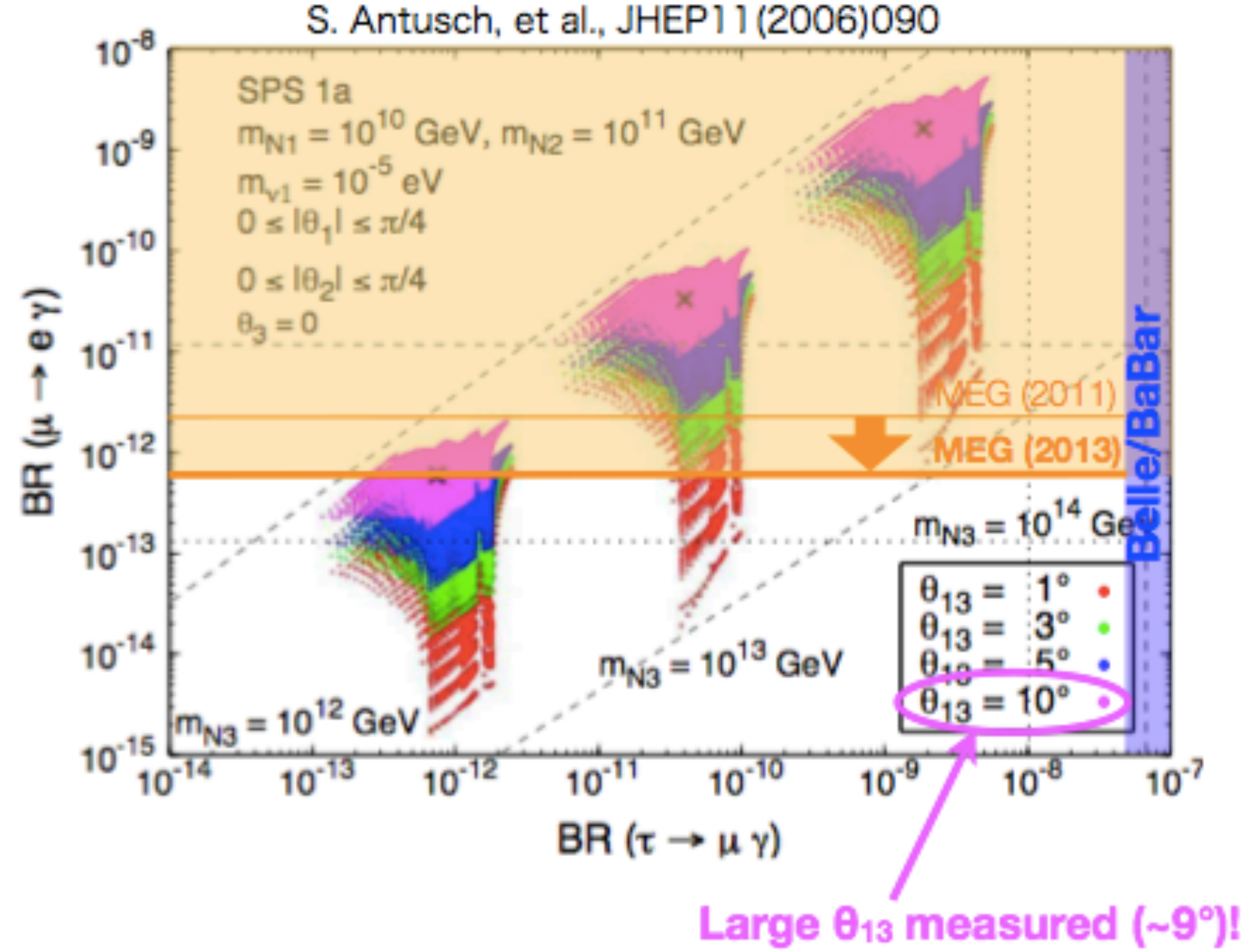
G.Isidori, et al., PRD75(2007)115019



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

SUSY-Seesaw

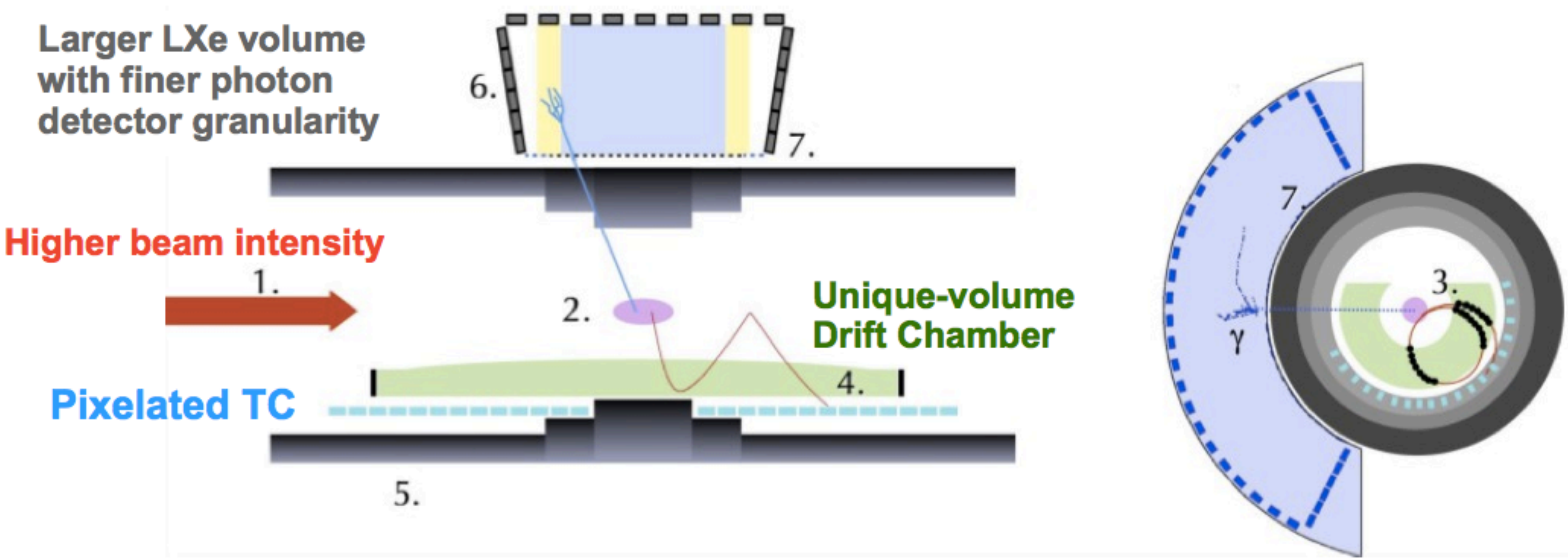
S. Antusch, et al., JHEP11(2006)090



(*) ArXiv:1301.7225.v2

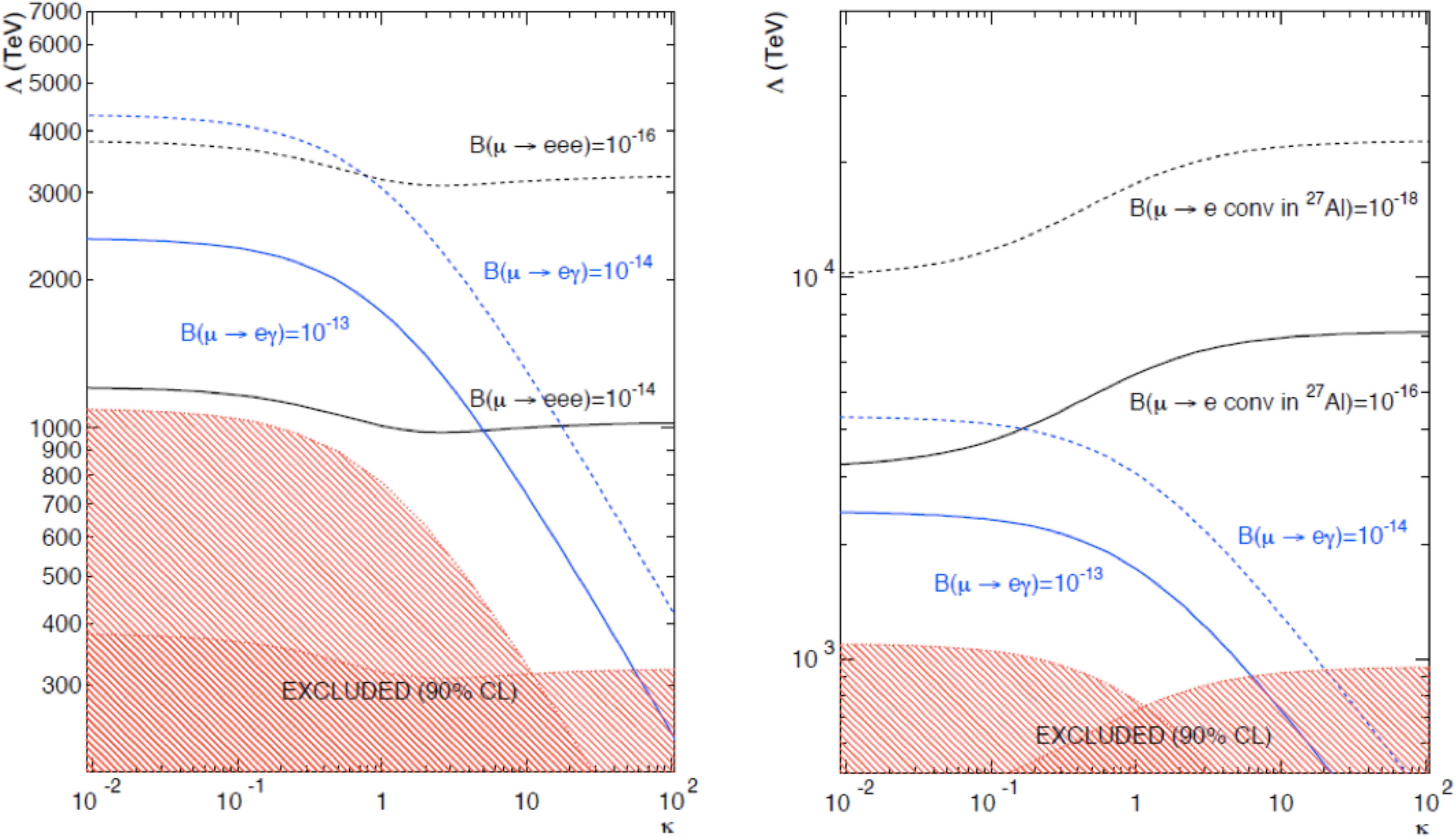
Future Prospects

- An upgrade of MEG, aiming at a sensitivity improvement of one order of magnitude (**down to 5 x 10^{-14}**) approved by PSI and funding agencies



(*) hep-ph:1303.4097

$\mu^+ \to e^+ \gamma$ vs $\mu^+ \to e^+ e^+ e^-$, N $\mu^- \to$ N e^-



Summary

- MEG is searching for lepton flavor violating decay, $\mu^+ \to e^+ \gamma$, aiming at a sensitivity of **few x10^{-13}**
- Based on 2009-11 data set, the new upper limit on the branching ratio is

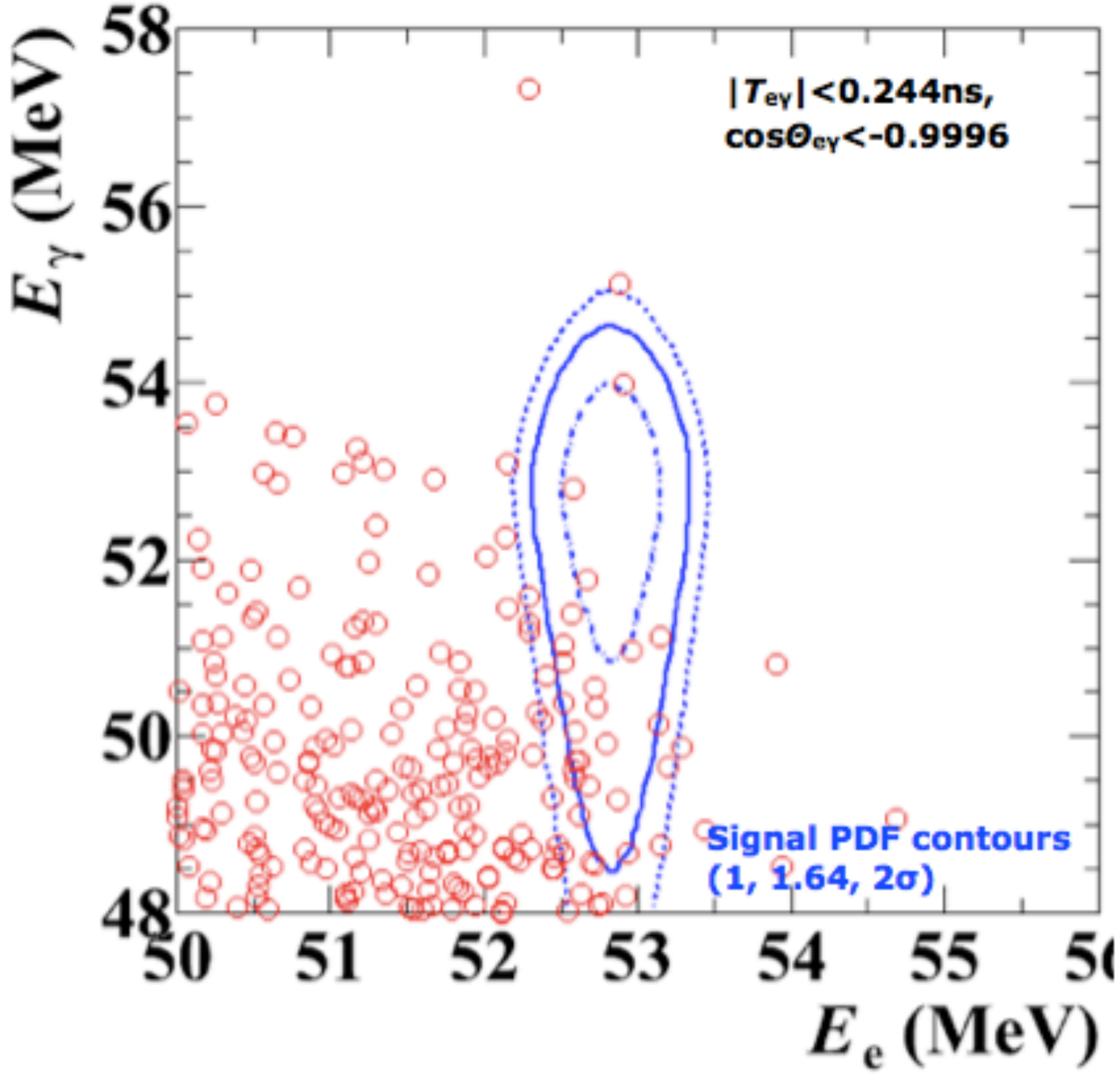
$$\mathbf{B}(\mu^+ \to e^+ \gamma) < \mathbf{5.7 \times 10^{-13}}$$

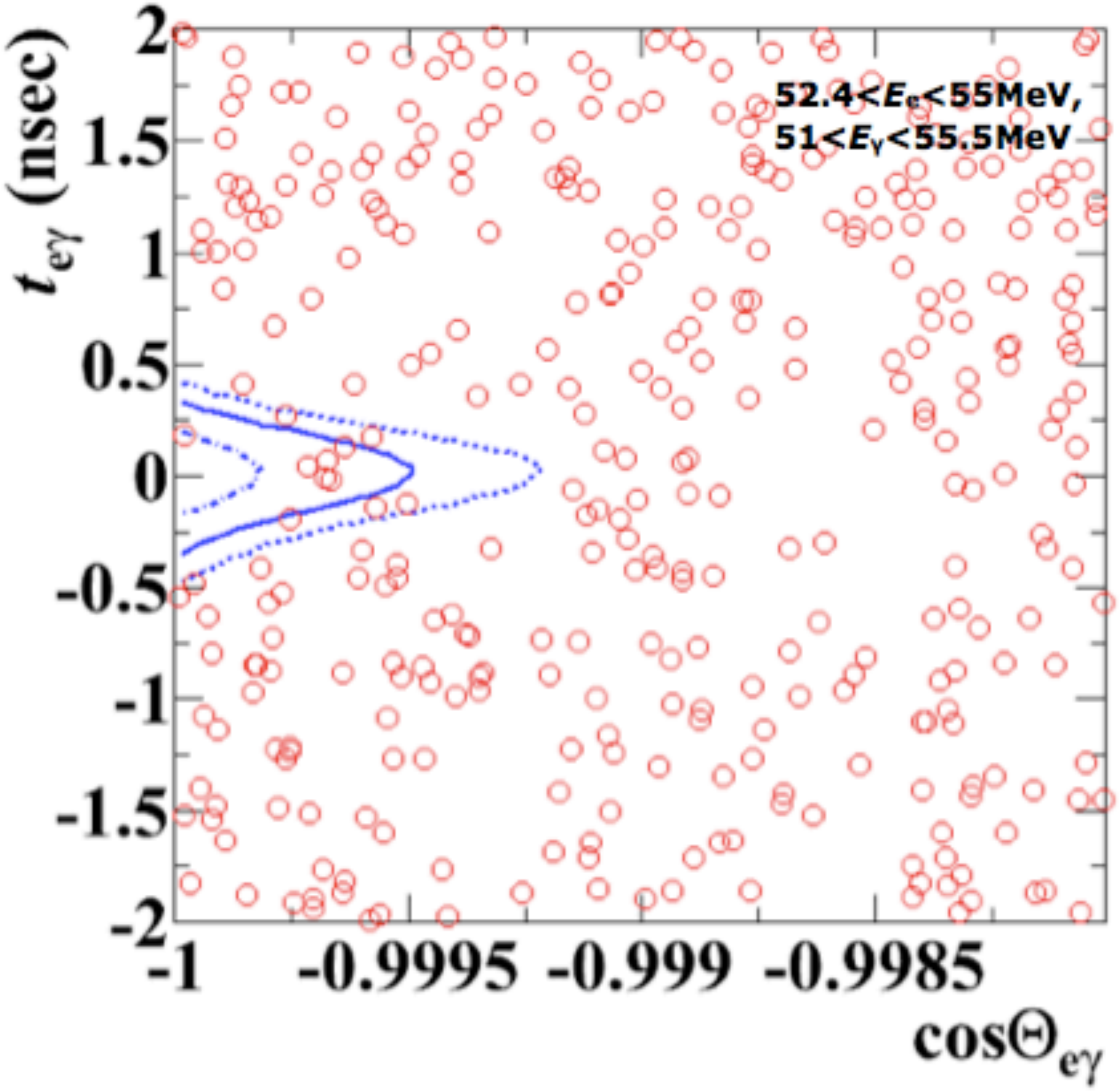
- The data statistics is expected **to be doubled with** (2012-13) sample
- The MEG upgrade has been approved by the PSI committee in Jan. 2013 and is in progress
- Upgraded MEG with an ultimate sensitivity (**x10 higher than the current MEG**) is planned to start in 2016

Back-up

Event Distribution

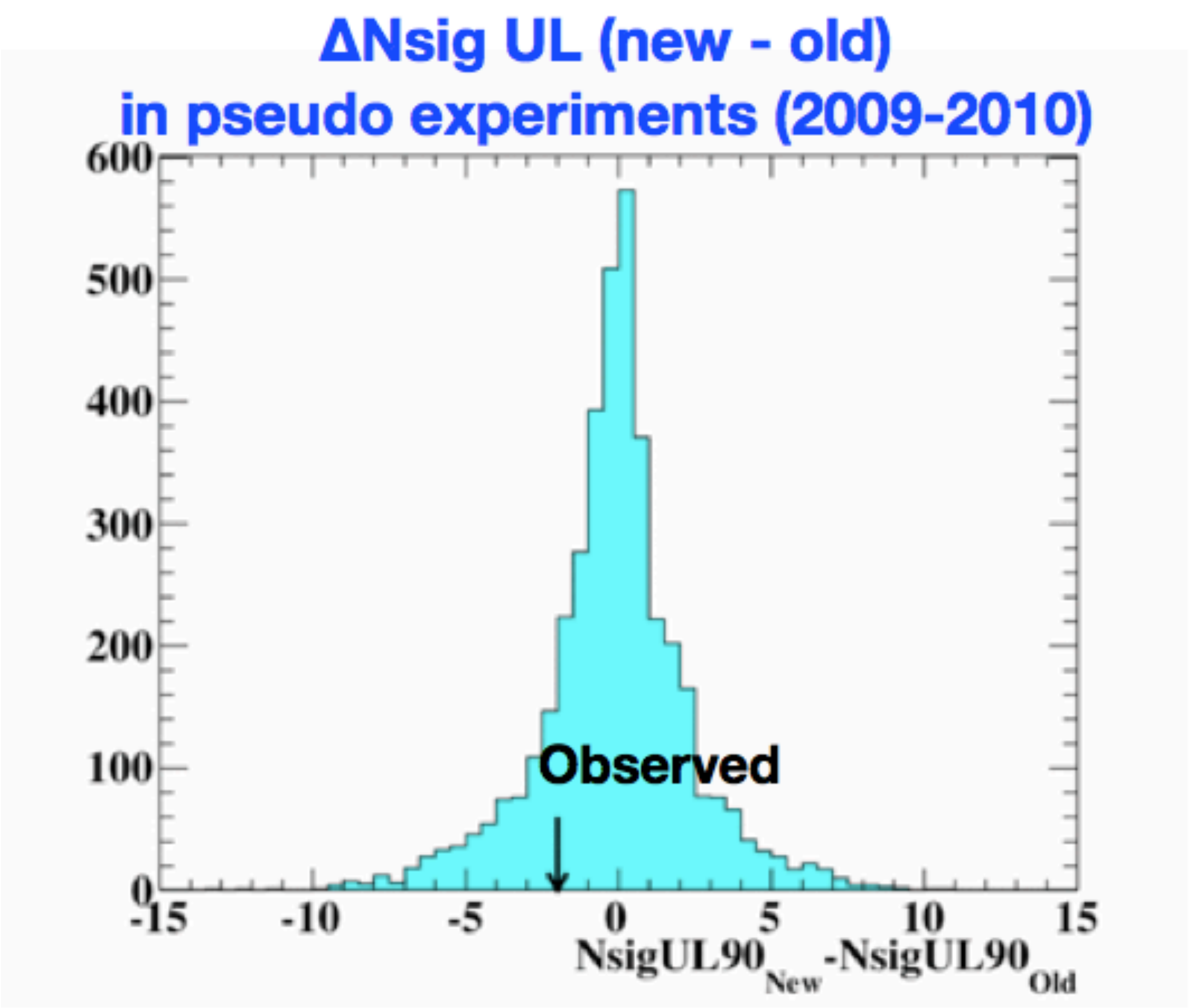
- All combined data (2009+10+11)

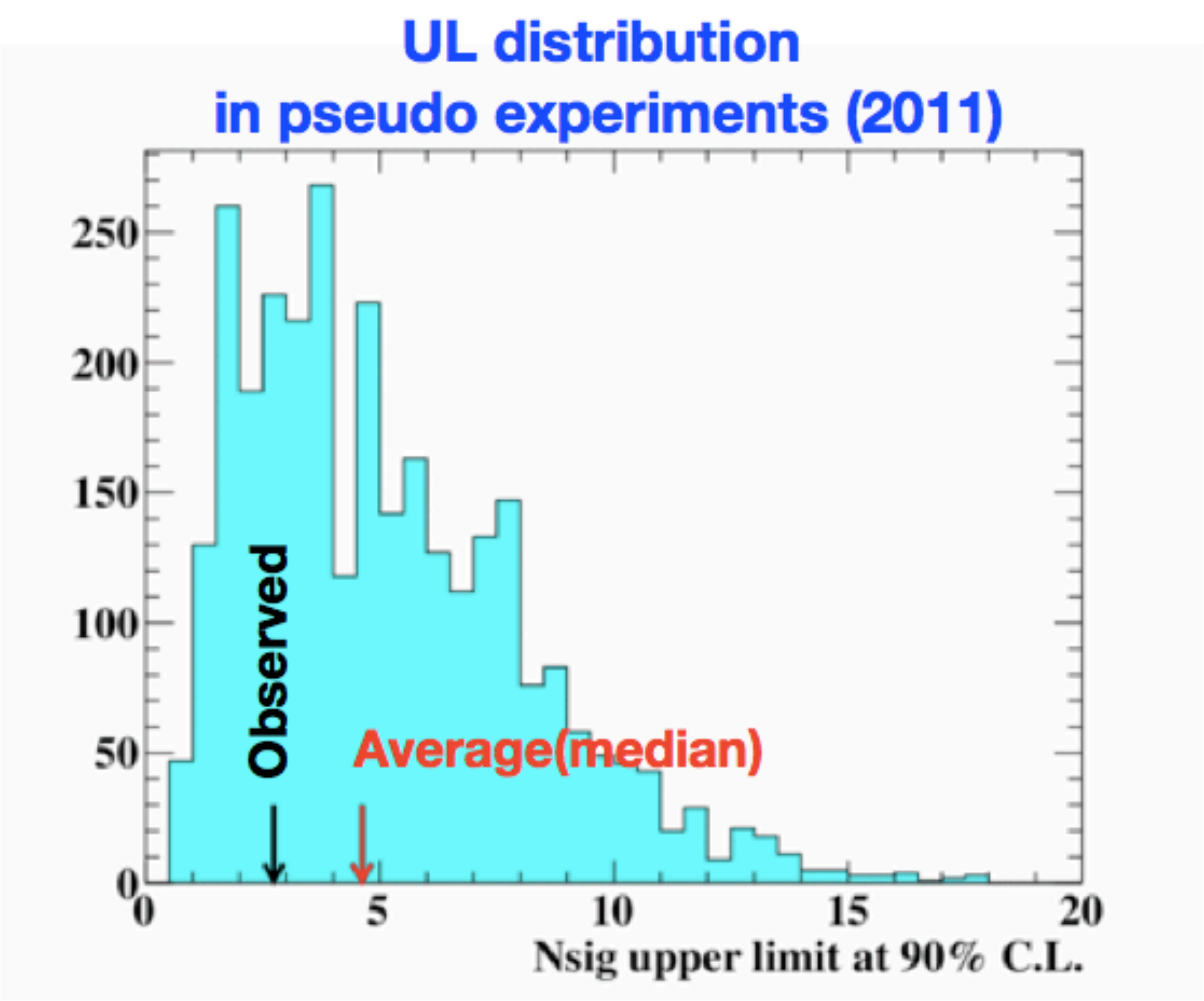




Consistency Check

- Compatibility bw new/old analisys
- UL distribution

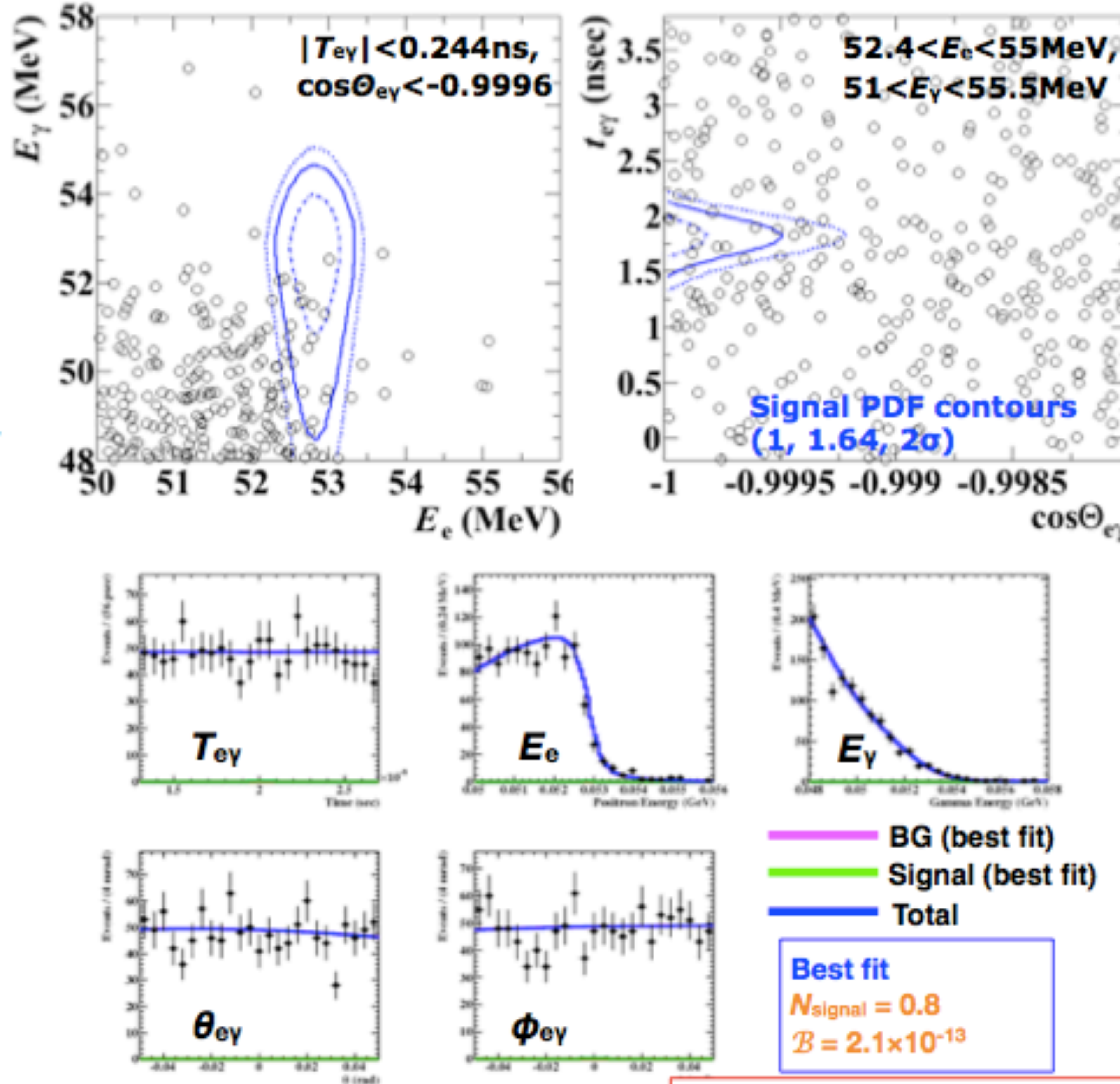




Sideband Fit

- Likelihood analyses in fictitious analysis regions in sidebands.
  - Off-time sideband
    $1.3<|T_{e\gamma}|<2.7$ns
  - Off-angle sideband
    $50<|\theta_{e\gamma}|(|\phi_{e\gamma}|)<150$mrad, $|T_{e\gamma}|<0.7$ns
- Observed upper limits are consistent with sensitivity.

Off-time sideband (2011 alone)



$\mathcal{B}<1.4\times10^{-12}$ (90%C.L.)

Normalization

- **Normalization to translate N_{sig} into $\mathcal{B}$**
  - **Two independent methods**
    - **Michel positrons counted with dedicated trigger**
    - **RMD rate observed at E_γ-sideband**
- **Combined estimate results in 4% uncertainty**

$$
\begin{aligned}
N_{sig} &= N_\mu \times \boxed{Br_{e\gamma}} \times \tau_{e\gamma} \times \epsilon^{trig}_{e\gamma} \times G^{DC}_{e\gamma} \times A^{TC}_{e\gamma} \times \epsilon^{DC}_{e\gamma} \times A^{LXe}_{e\gamma} \times \epsilon^{LXe}_{e\gamma} \\
N_{e\nu\bar{\nu}} &= N_\mu \times Br_{e\nu\bar{\nu}} \times \tau_{e\nu\bar{\nu}} \times \epsilon^{trig}_{e\nu\bar{\nu}} \times G^{DC}_{e\nu\bar{\nu}} \times A^{TC}_{e\nu\bar{\nu}} \times \epsilon^{DC}_{e\nu\bar{\nu}} \times f^{E}_{e\nu\bar{\nu}} \times P
\end{aligned}
$$

$$
\mathrm{BR}(\mu^+ \to e^+\gamma) = \frac{N_{\mathrm{signal}}}{N_{e\nu\bar{\nu}}} \times \frac{f^{E}_{e\nu\bar{\nu}}}{P} \times \frac{\epsilon^{\mathrm{trig}}_{e\nu\bar{\nu}}}{\epsilon^{\mathrm{trig}}_{e\gamma}} \times \frac{A^{\mathrm{TC}}_{e\nu\bar{\nu}}}{A^{\mathrm{TC}}_{e\gamma}} \times \frac{\epsilon^{\mathrm{DCH}}_{e\nu\bar{\nu}}}{\epsilon^{\mathrm{DCH}}_{e\gamma}} \times \frac{1}{A^{\mathrm{g}}_{e\gamma}} \times \frac{1}{\epsilon_{e\gamma}}
$$