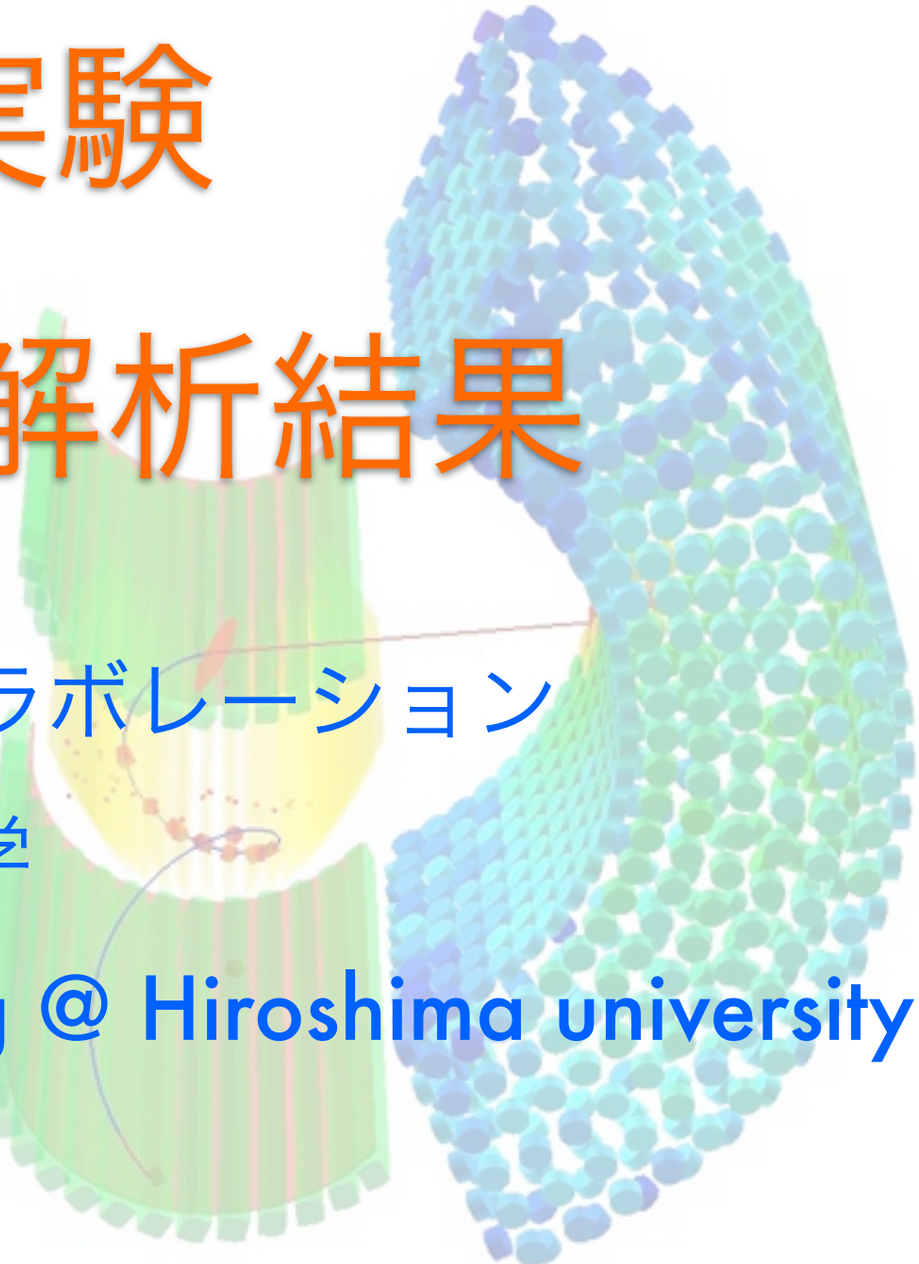
MEG実験

最新の物理解析結果



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東京大学

29th, March 2013 JPS meeting @ Hiroshima university

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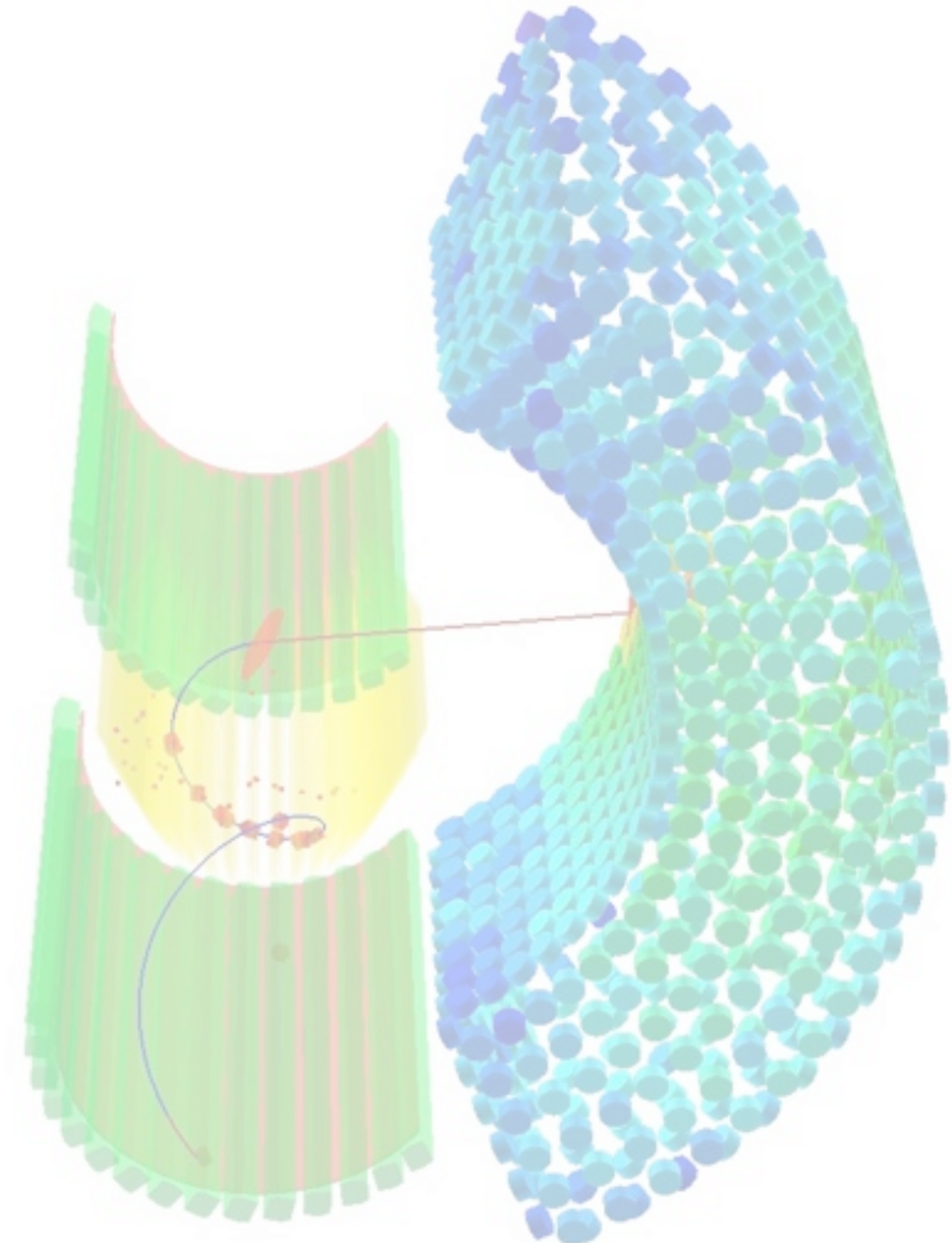
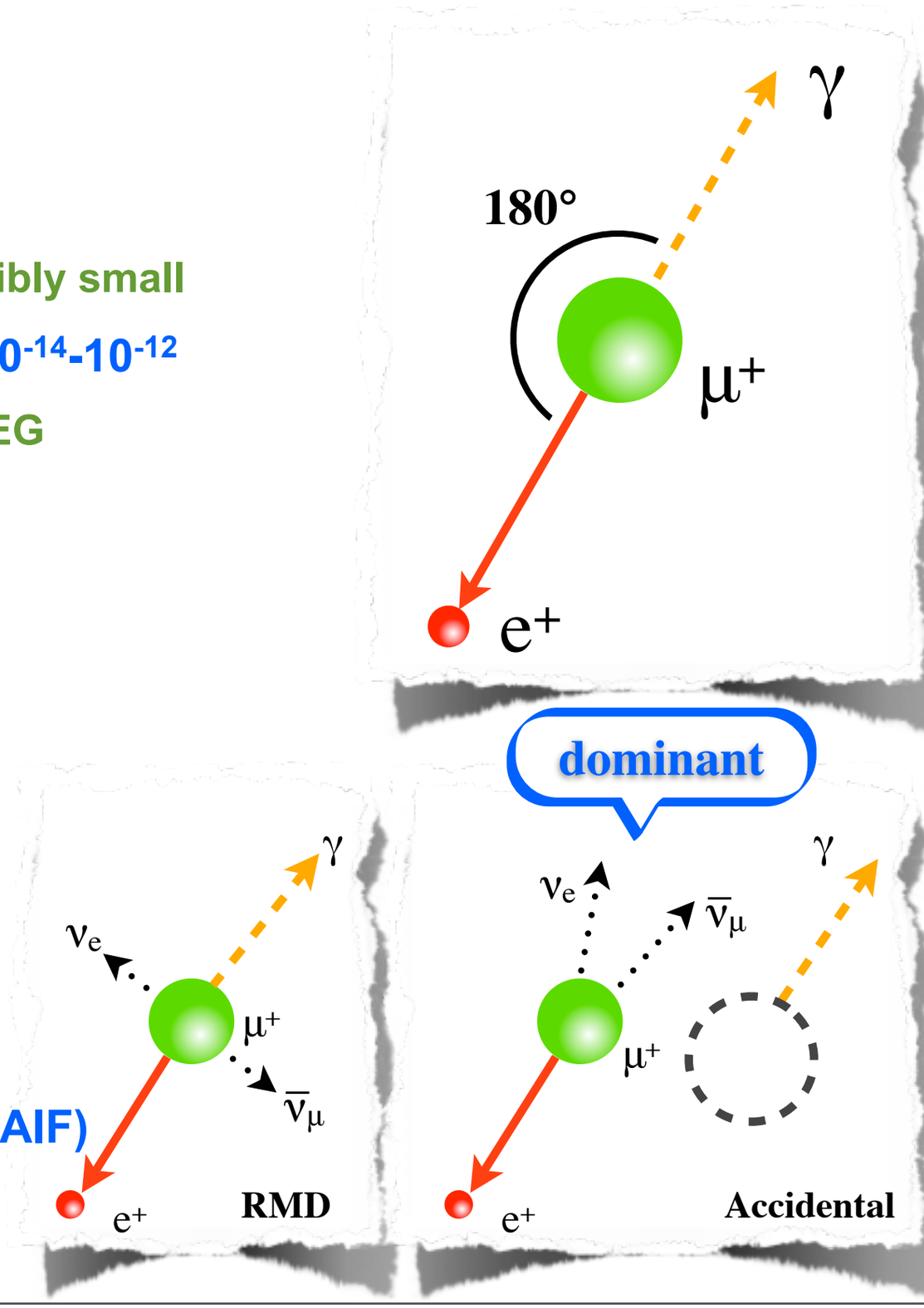


μ→eγ

- Why μ→eγ ?
  - strictly forbidden in SM
    - Contribution from neutrino oscillation is negligibly small
  - Many BSM predict the reachable BR(μ→eγ) : 10^{-14}-10^{-12}
    - Previous best limit : 2.4×10^{-12} @ 90% C.L. by MEG
    - Already in new physics region !
  - simple final state
    - Back-to-back
    - 52.8 MeV monochromatic e and γ
    - Time coincident
  - → Good probe to search for the new physics !
- Background
  - Prompt : Radiative Muon Decay (RMD)
  - Accidental : Michel e^+ + overlapped γ (RMD or AIF)



The MEG experiment

Mu-E-Gamma Collaboration

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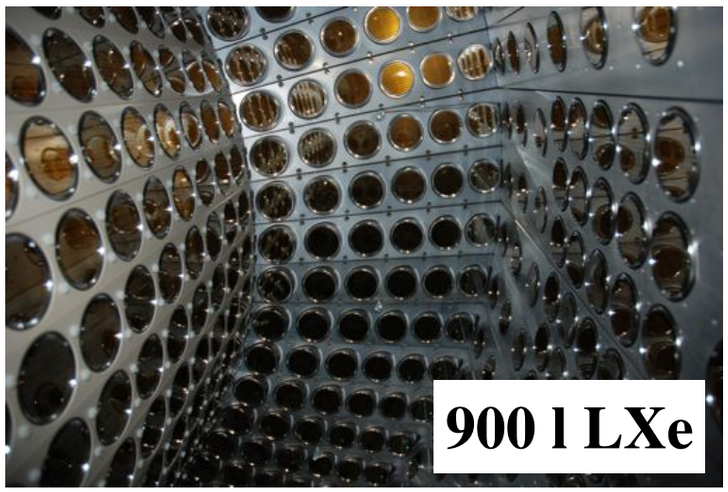
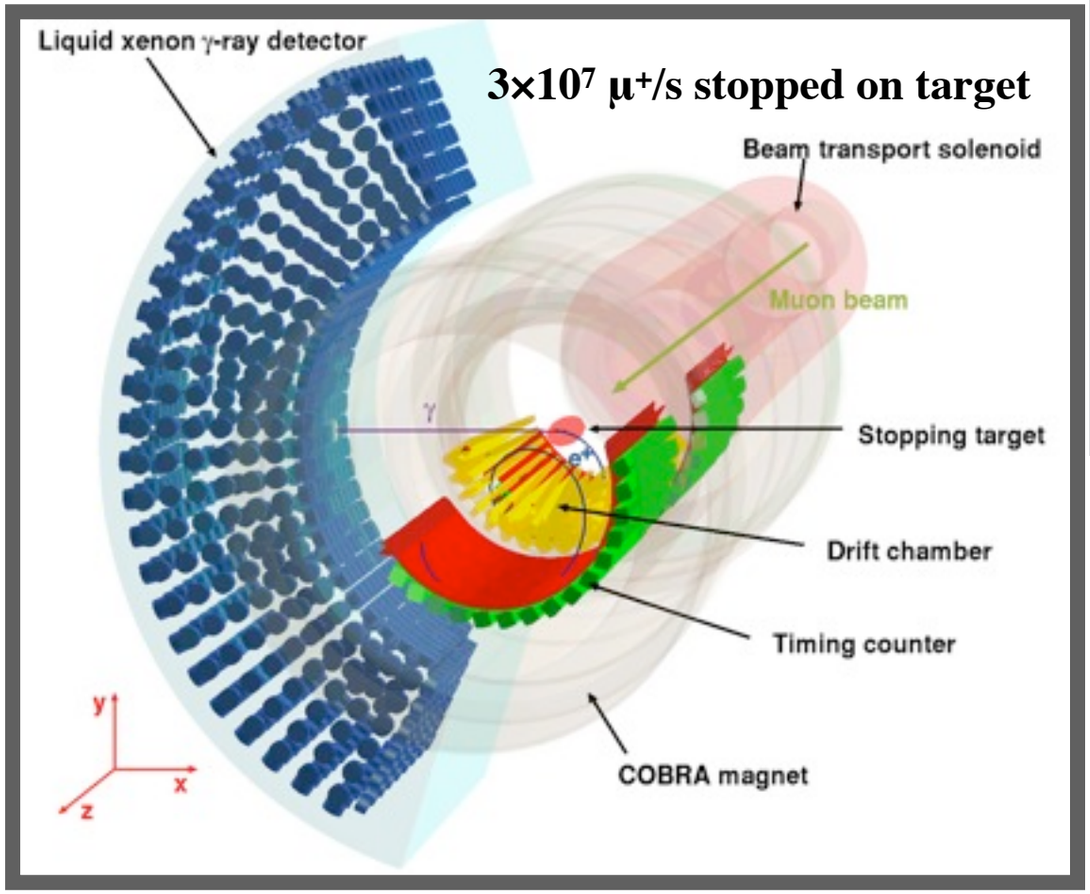
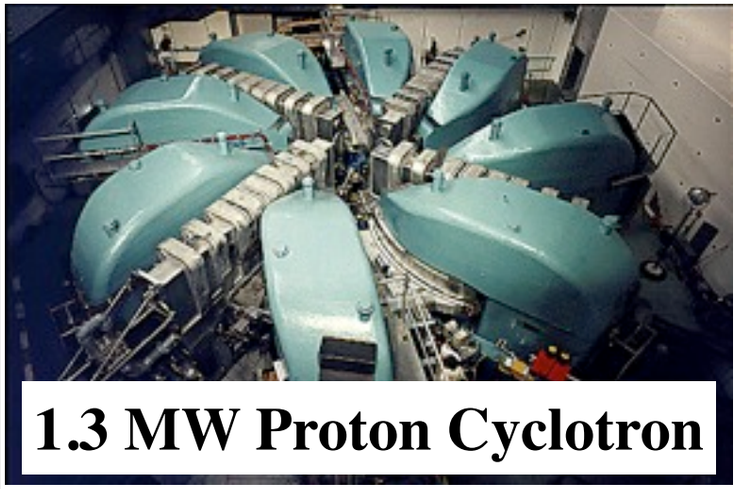
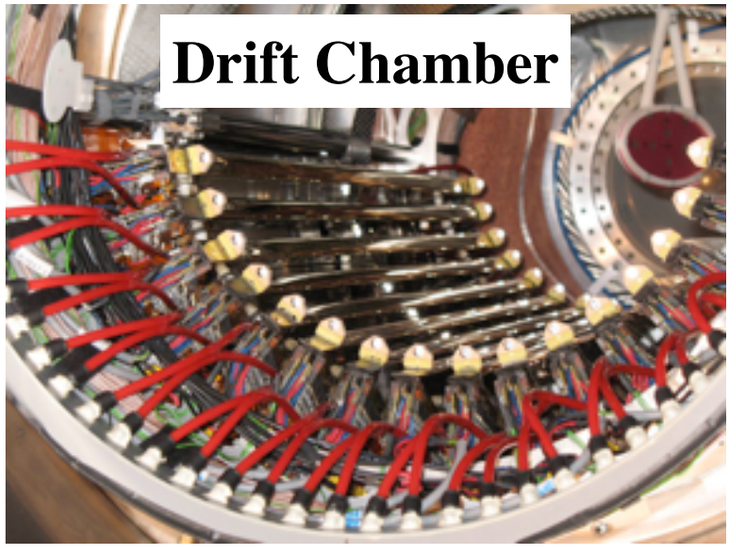
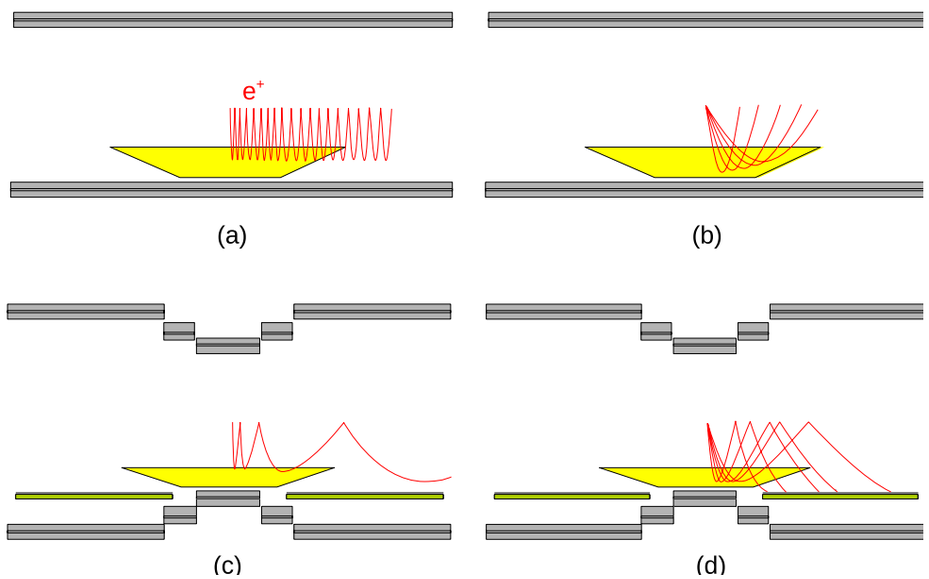


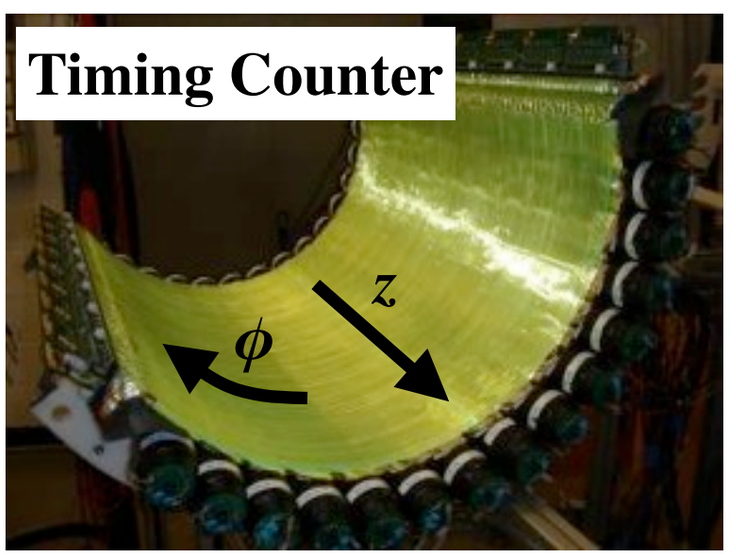






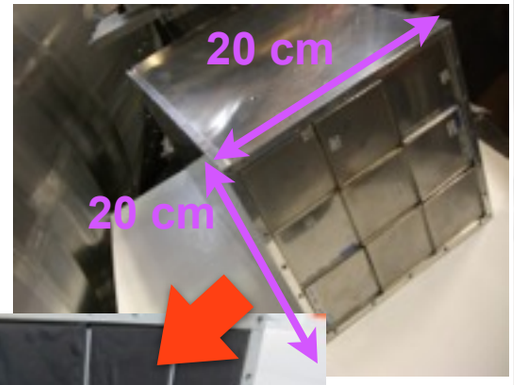
COnstant Bending RAdius



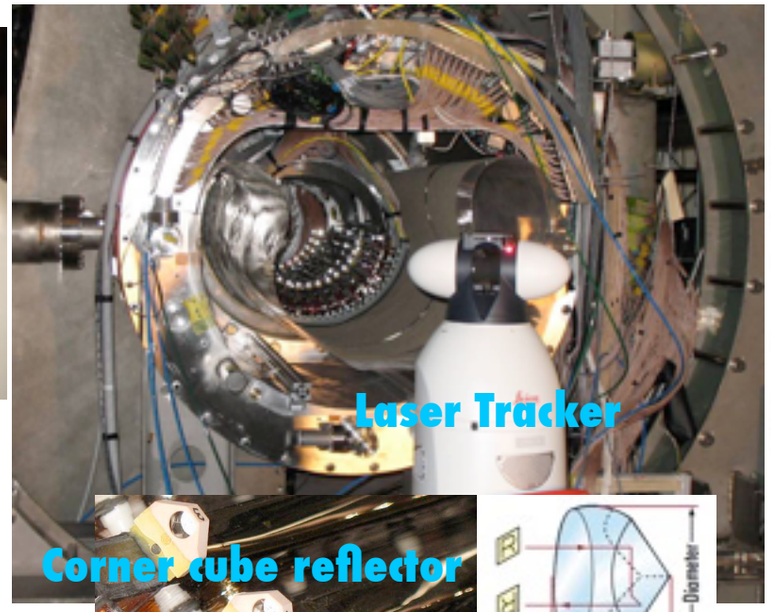


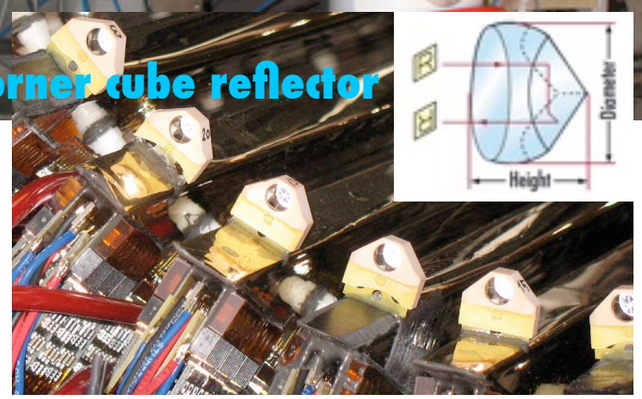
Run 2011

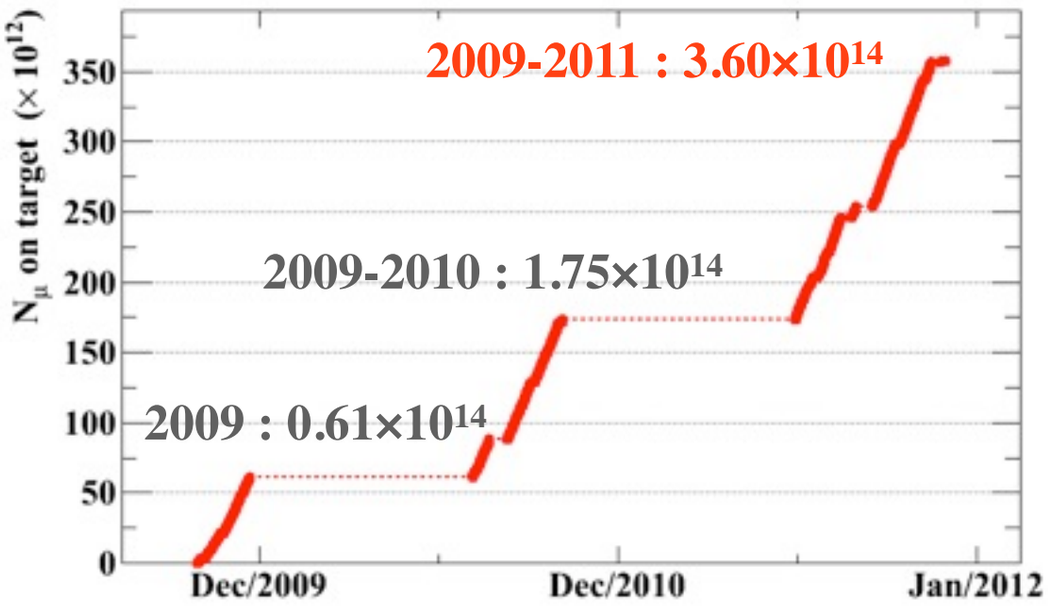
3×3 NaI



4×4 BGO
Better energy &
position resolutions







- NaI detector for calorimeter calibration was replaced by BGO
  - Better extraction of gamma energy response with more efficient calibration runs
- New laser tracker system for target and drift chamber alignment
  - Better measurement of initial alignment
- Total number of muons stopped on target reached 1.85×10^{14} @ 3×10^{7} μ^+/s
  - More than 2009+2010 statistics

MEG Analysis Improvements

Mu-E-Gamma Collaboration

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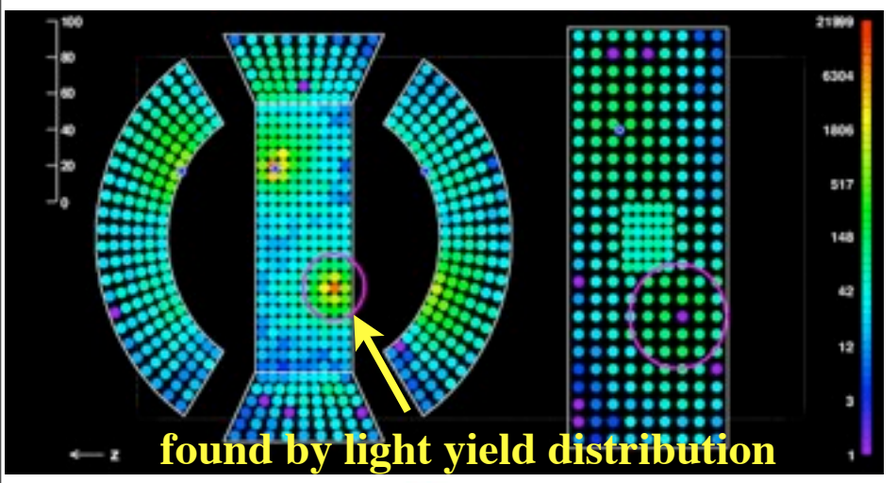
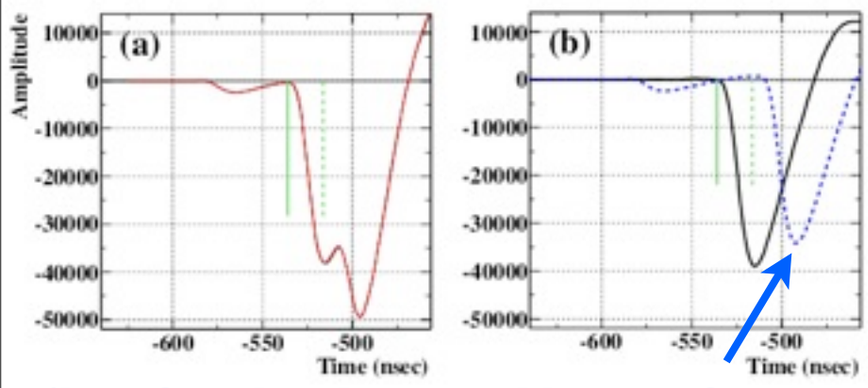
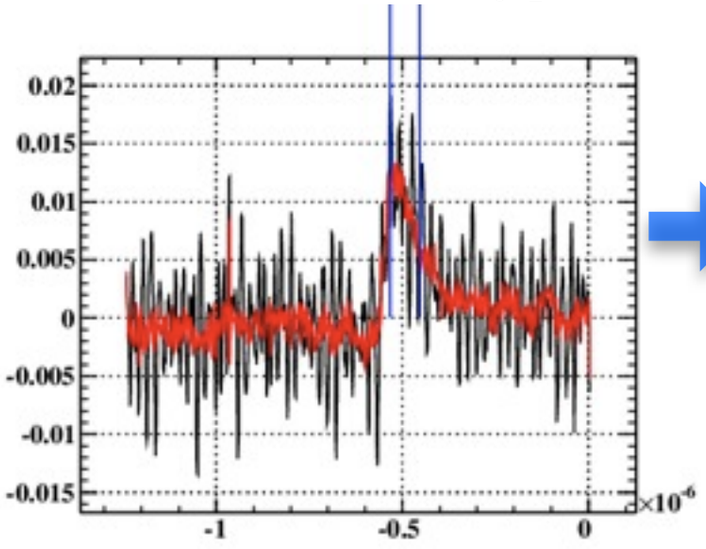


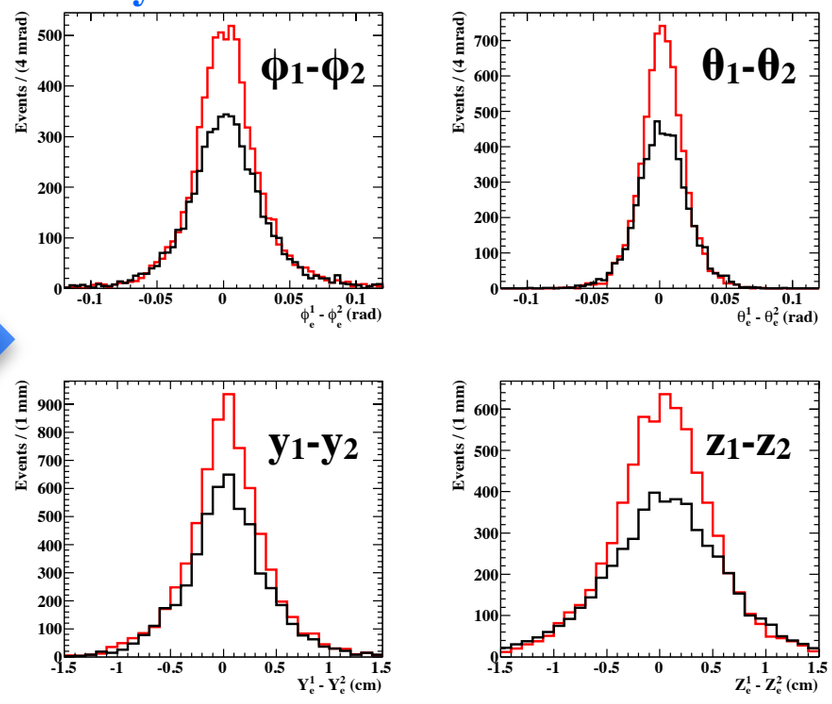


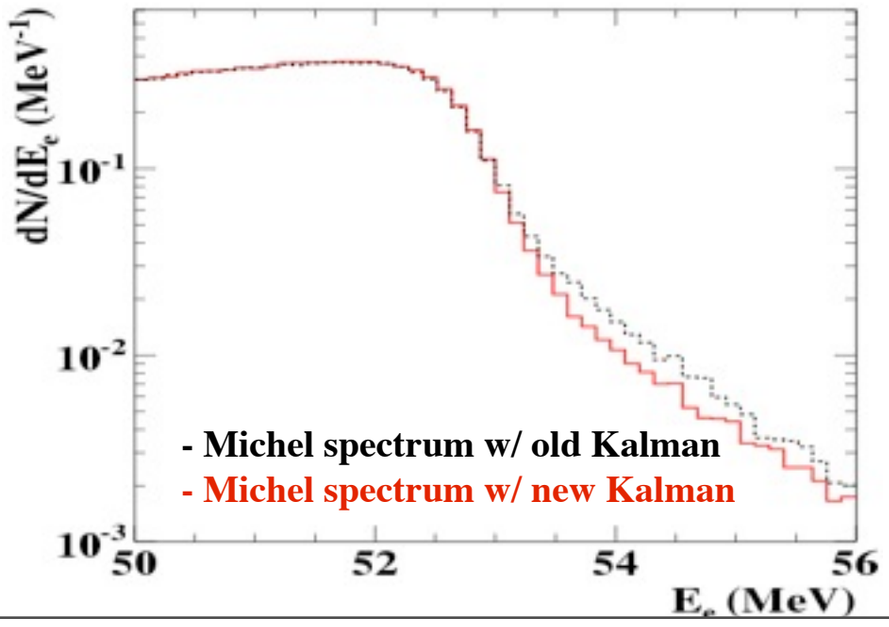
pileup found and removed by waveform analysis

- New pileup elimination algorithm for γ reconstruction
  - 7% more efficiency, smaller tail of Eγ spectrum
- FFT Noise filtering for drift chamber waveform
  - Improve resolutions
  - Recover the efficiency as well
- New Kalman filter based on GEANE
  - GEANT3 detector description
  - Better hit modeling
  - 7% more efficiency, enable to use per-errors for PDF
  - Reduced momentum tail on Michel spectrum

DCH waveform in noisy period





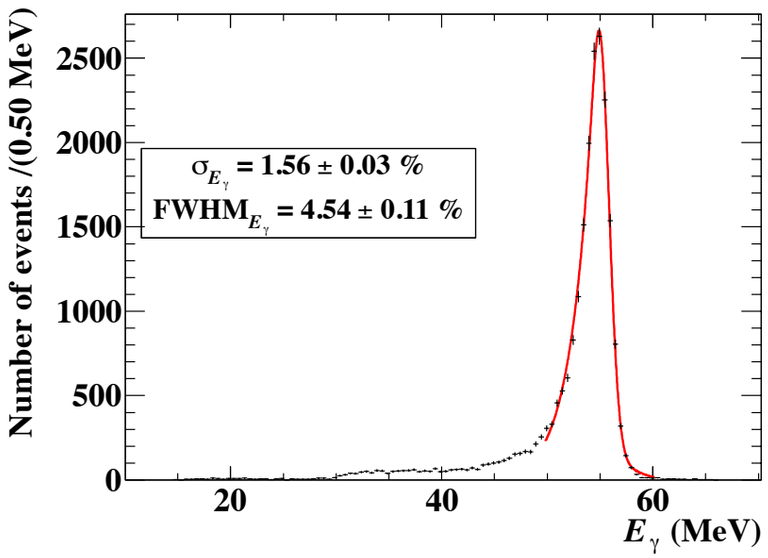


PDFs

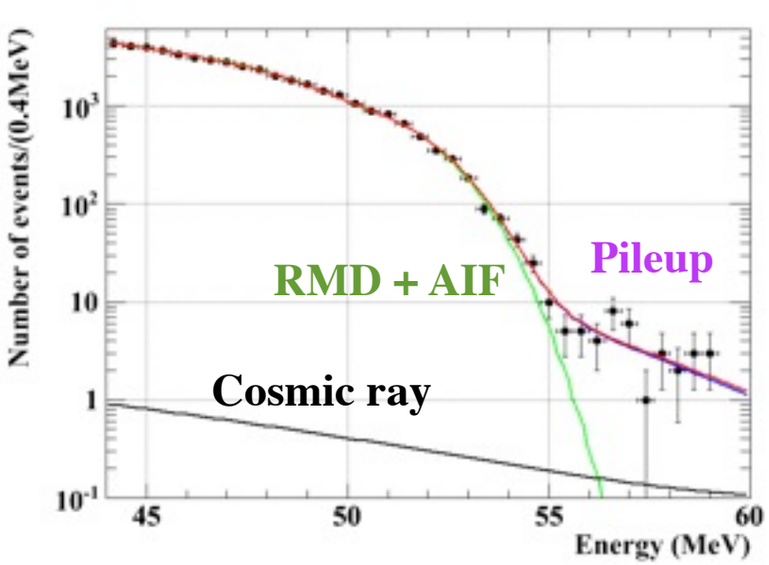
- PDFs for likelihood function
  - Blind analysis for 2011 dataset : PDFs extracted from calibration & sideband data
  - Gamma
    - Energy scale, response : 55 MeV gamma from π^0 decay
    - BG spectrum : sideband data
  - Timing : RMD from E_γ sideband
  - Positron → per-event PDF is newly implemented to get better sensitivity
    - 10% sensitivity improvement !

Next slide for more details

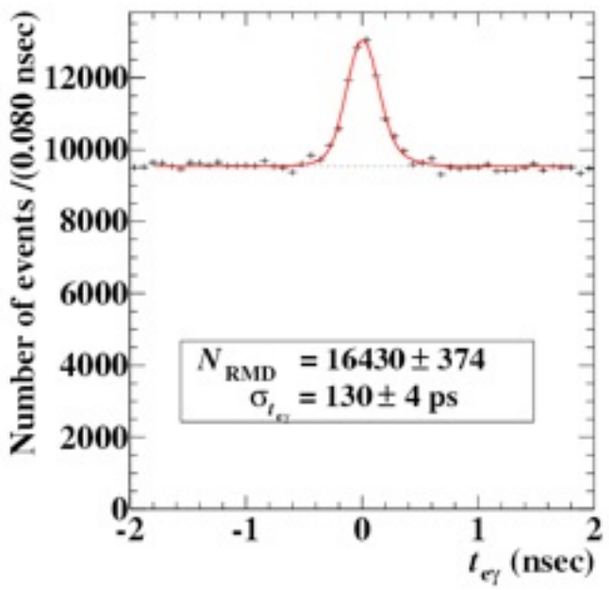
Signal Eγ



BG Eγ



Teγ



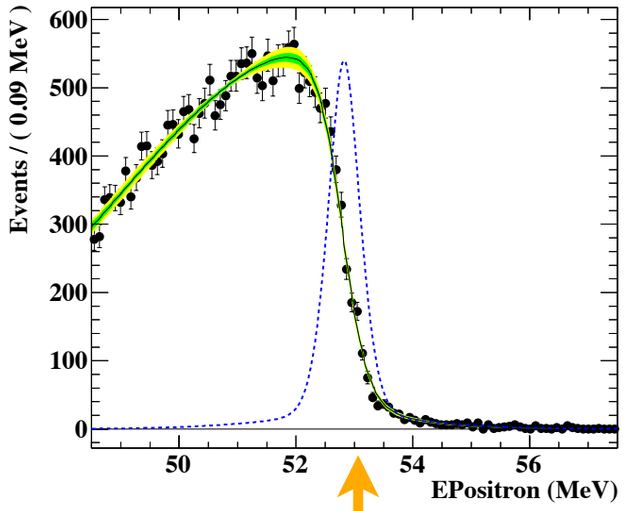
PDFs

- Event-by-event PDF for positron side (σ'_x : event-bv-event fit-error of "x")

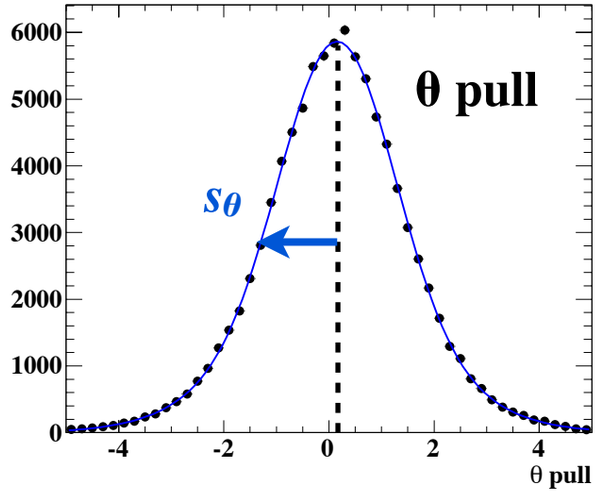
Resolutions :

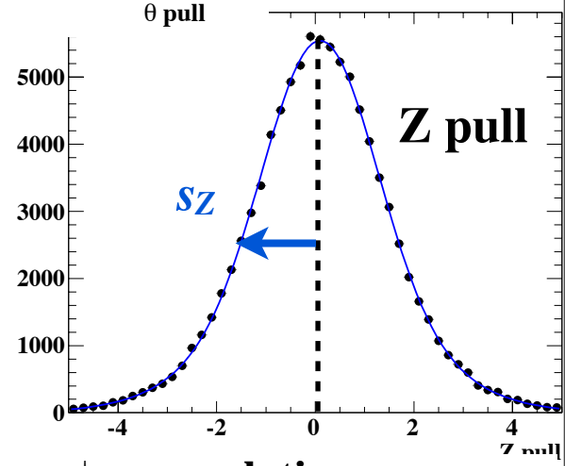
$$\sigma_x = s_x \times \sigma'_x$$

Scaling factors extracted from
1) Michel spectrum : Momentum
2) 2-turn method : Angular & Vertex



***'s'* calculated by fitting Michel edge**





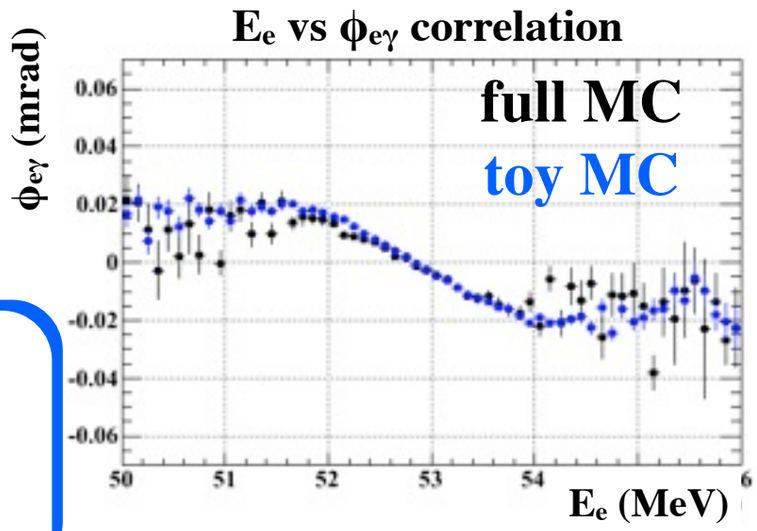
***'s'* calculated from σ of pull($\delta x/\sigma'_x$)**

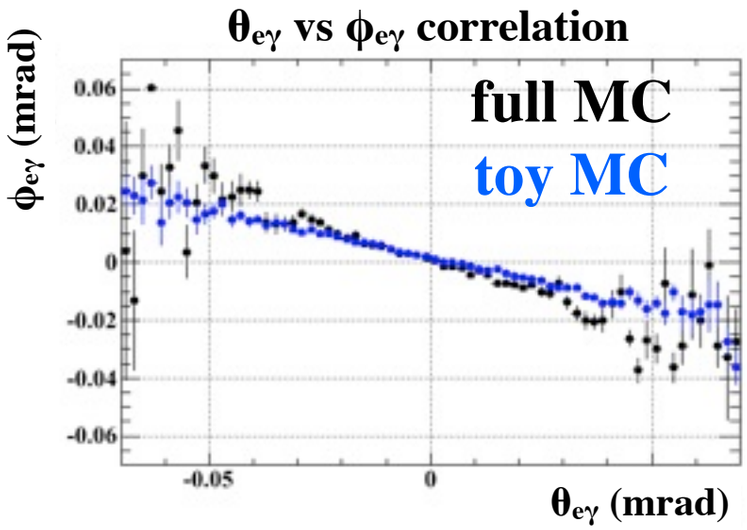
Correlations :

$$d\mu_y = p_{xy} \times dx$$

$$p_{xy} = p'_{xy} \times \frac{\sigma'_y}{\sigma'_x}$$

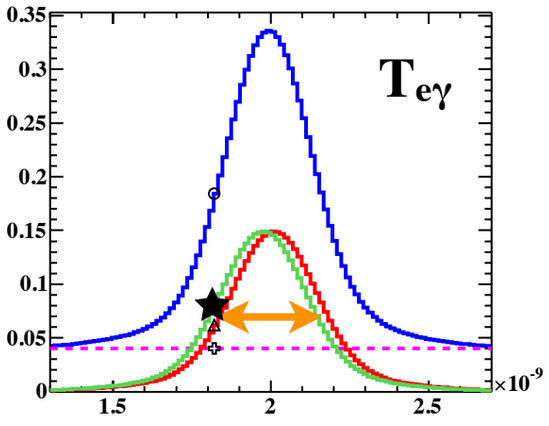
Correlation parameters extracted from data and MC

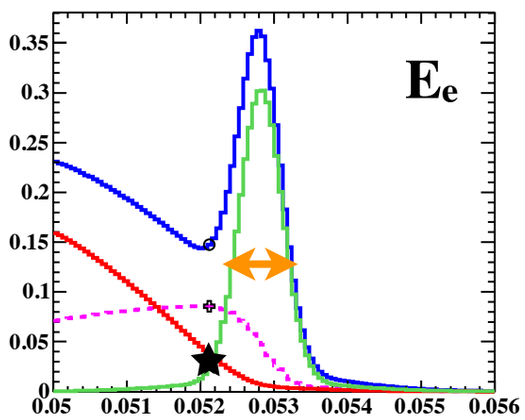


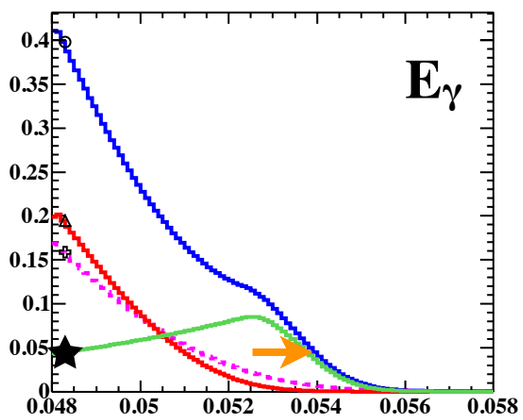


PDFs

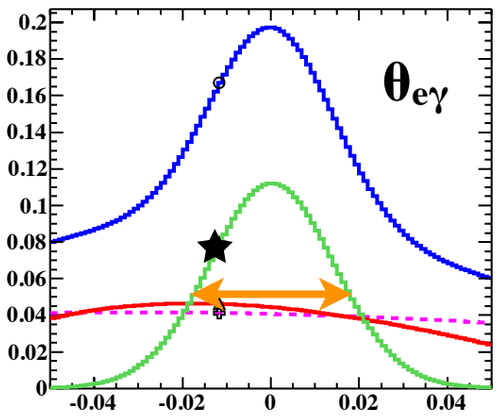
- **Event-by-event PDF @ positive time sideband (+2 nsec)**

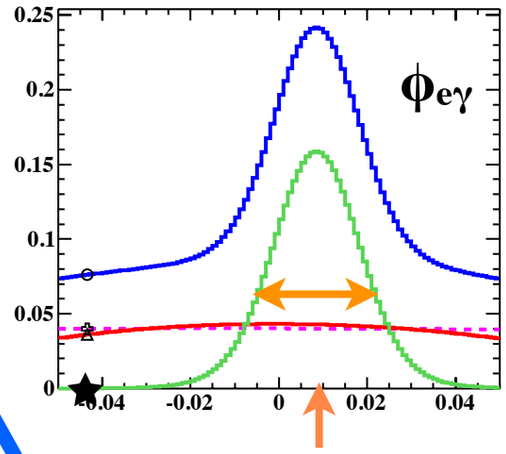






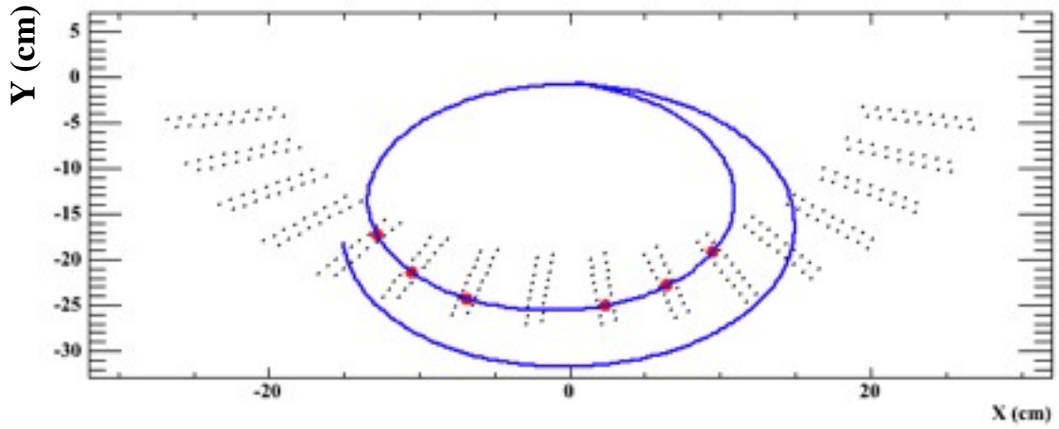
Signal PDF
BG PDF
RMD PDF
Total

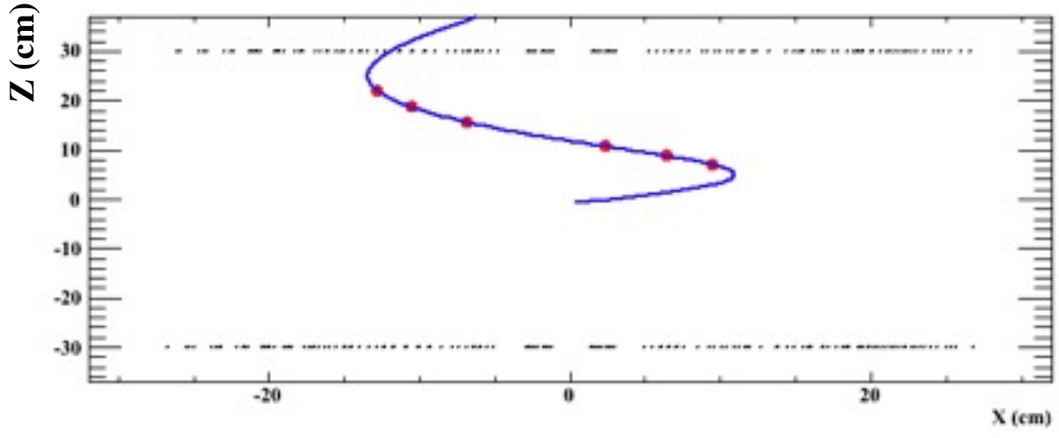




Resolutions & Correlations :

Teγ : DC-TC matching quality, correlation
Ee : Fitting quality
Eγ : γ-conversion point
θeγ : Fitting quality, γ-conversion point, correlation
ϕeγ : Fitting quality, γ-conversion point, correlation





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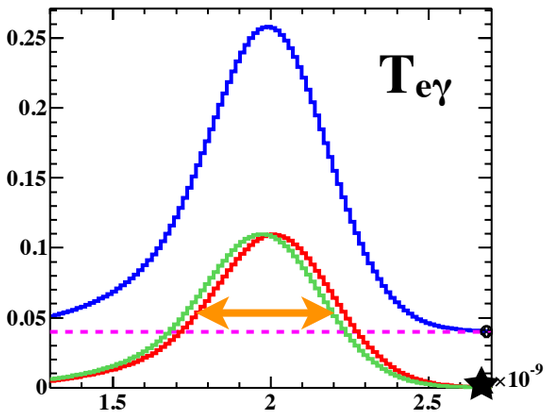

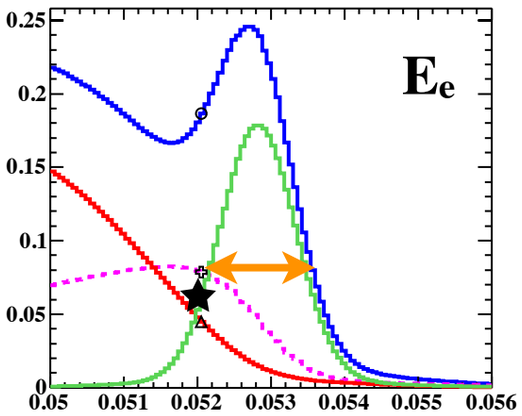

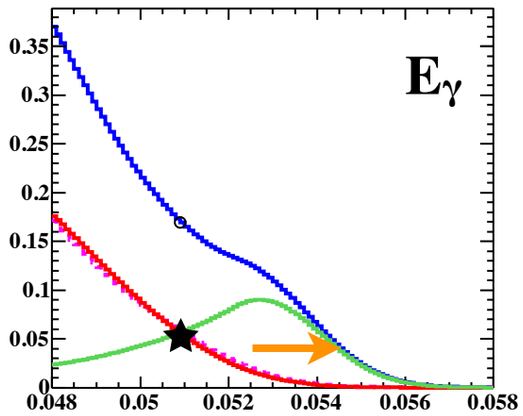

Signal PDF
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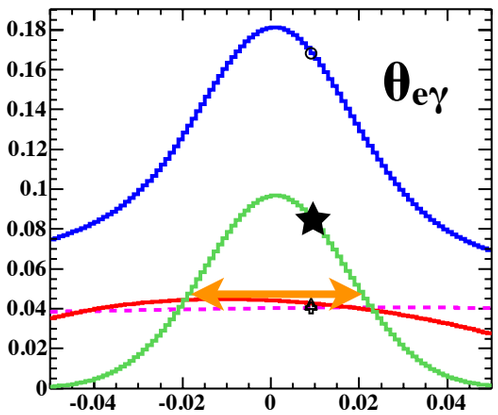
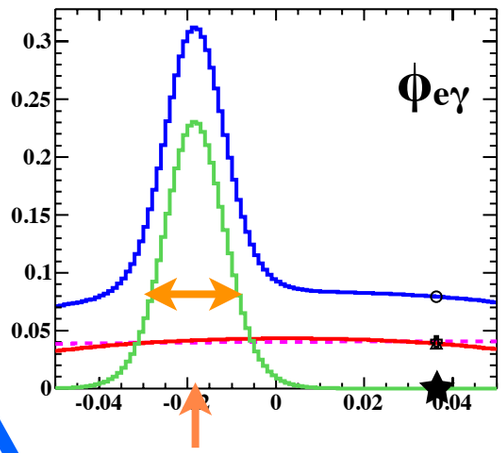
RMD PDF
Total





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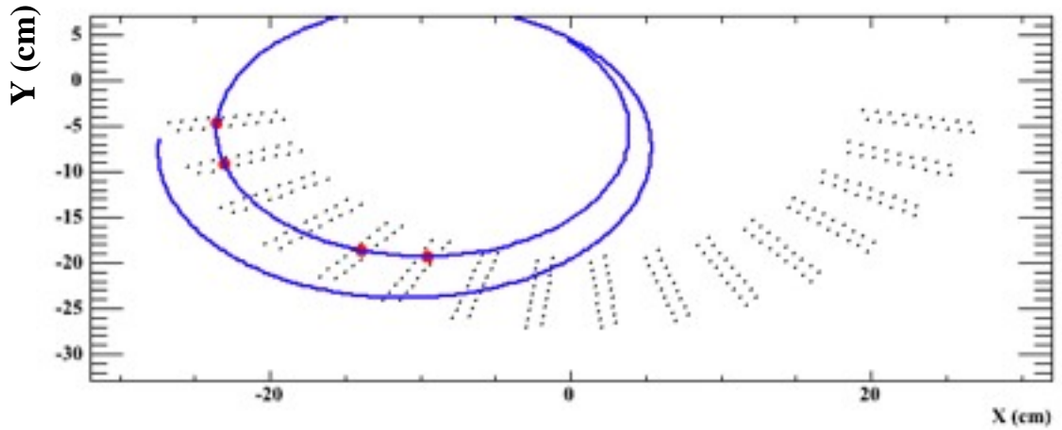

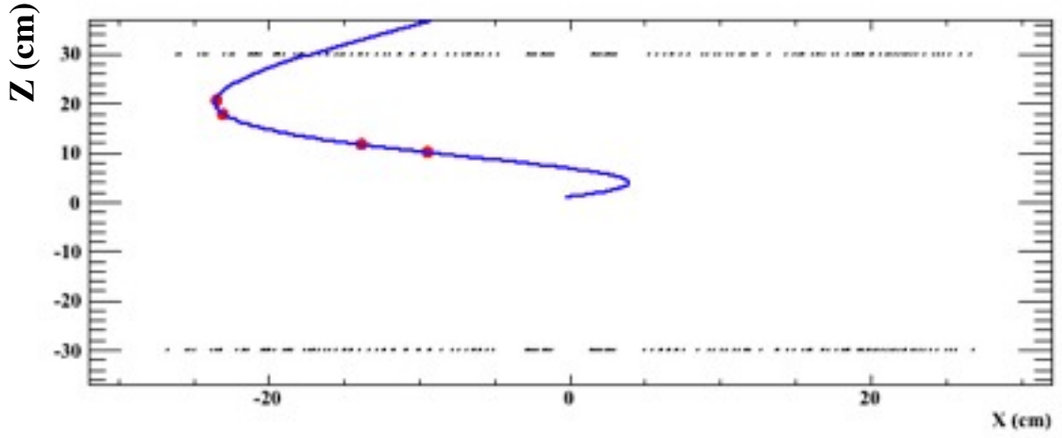

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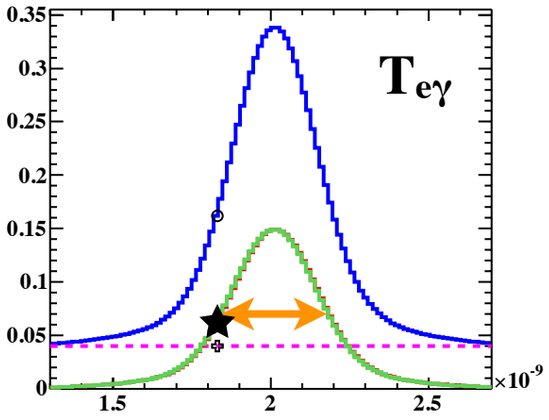

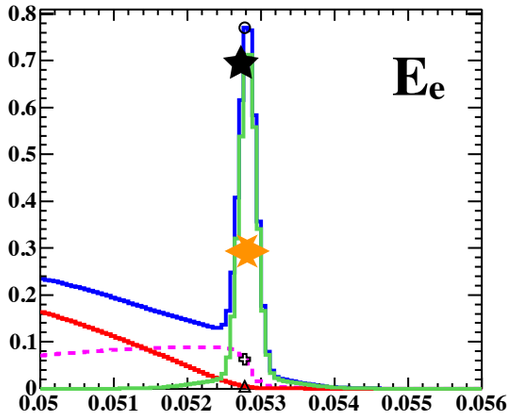

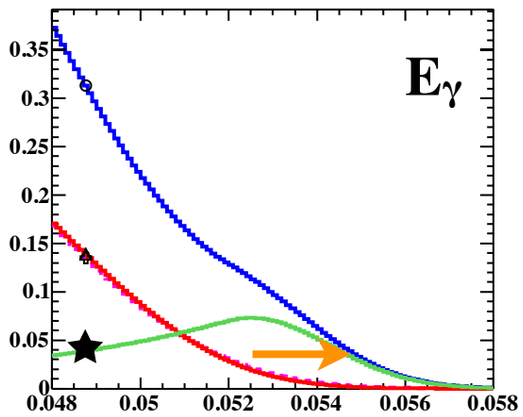

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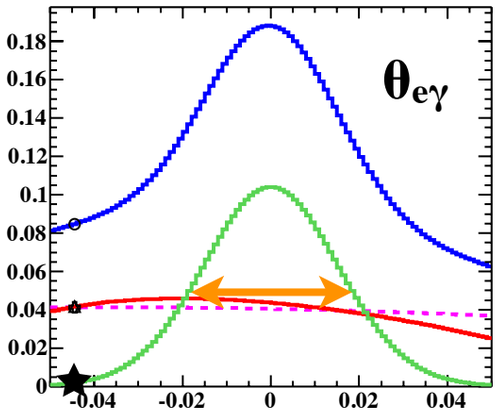

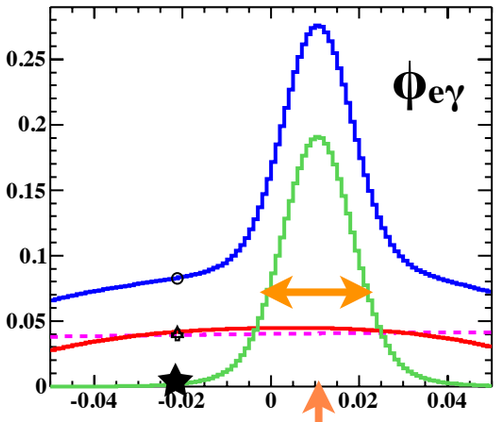

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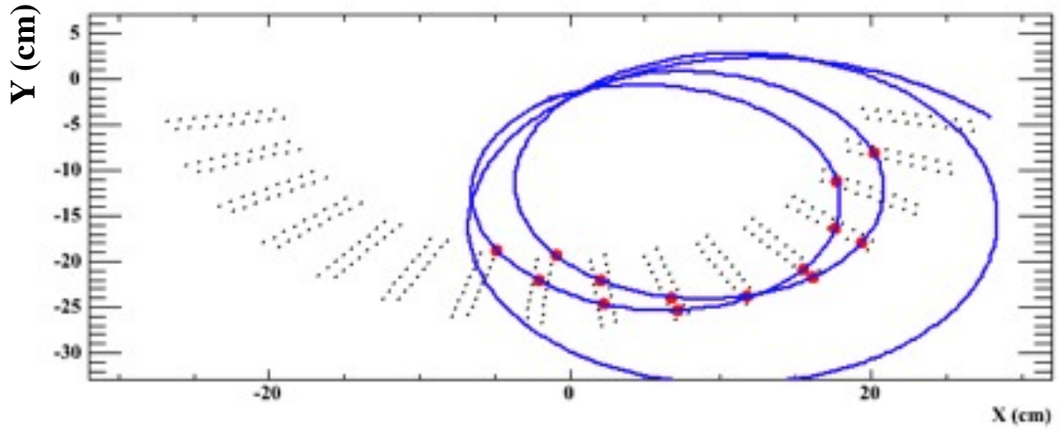

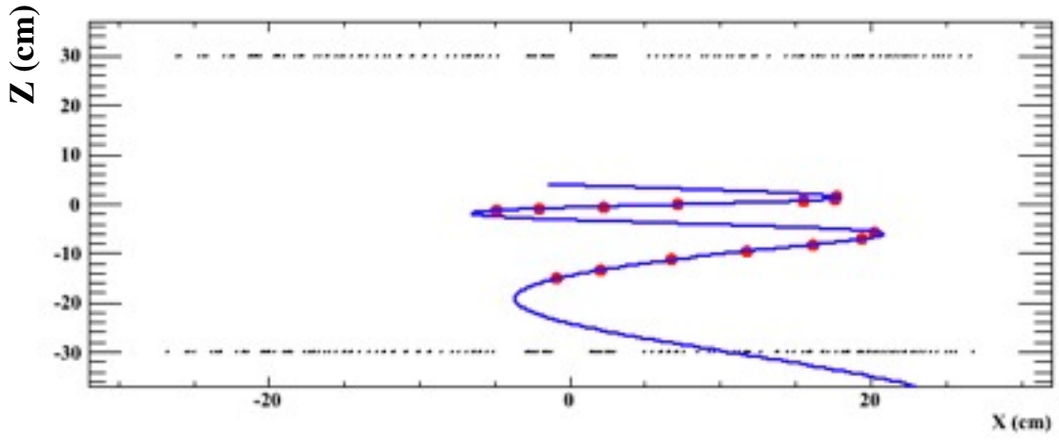

MEG Sensitivity & Sidebands

Mu-E-Gamma Collaboration

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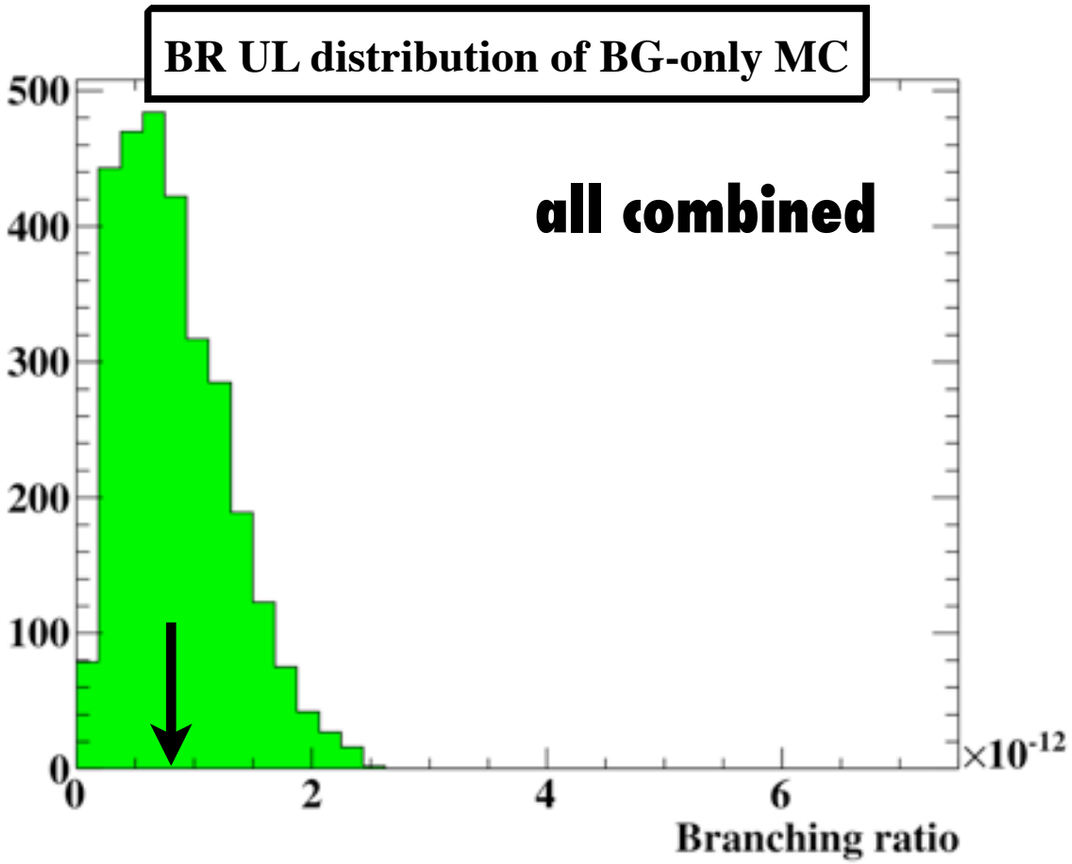
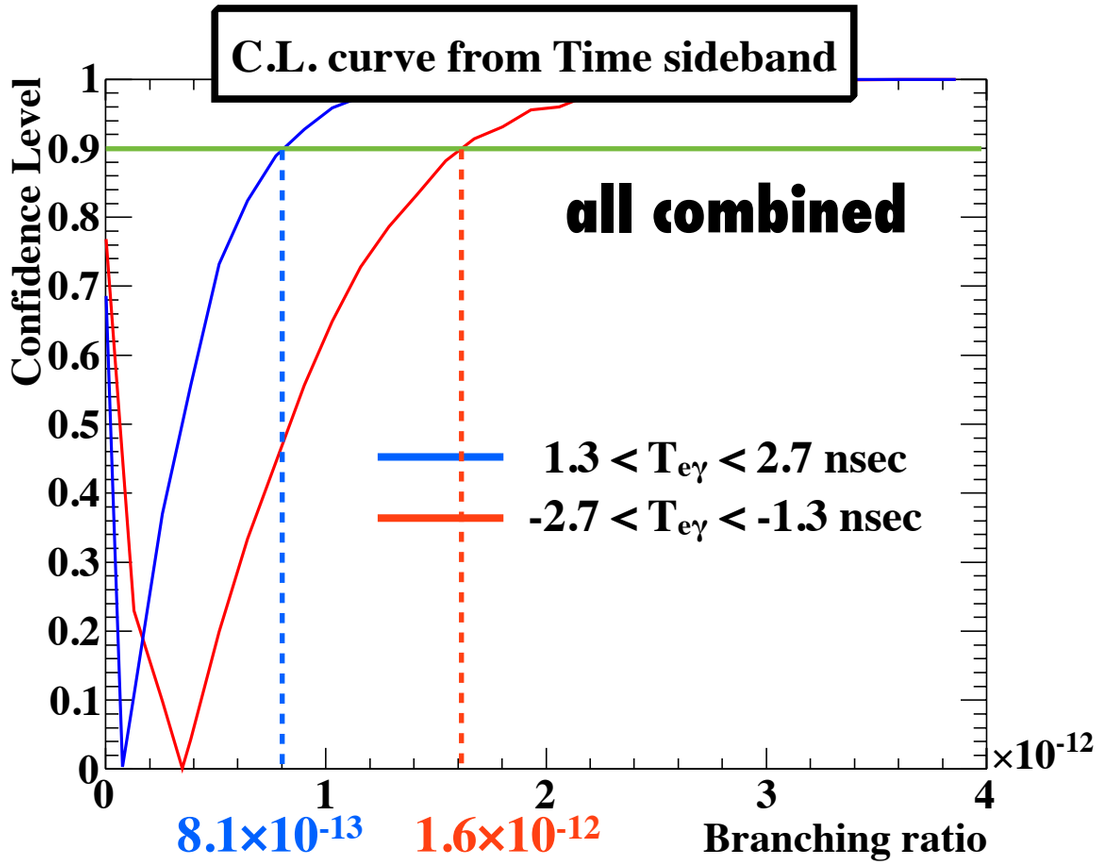
- **Normalization** $BR(\mu^+ \to e^+\gamma) = \frac{N_{\rm signal}}{k}$
  - Counting Michel positron
  - Counting radiative muon decay

Combined → $k = (7.77 \pm 0.31)\times10^{12}$ (all combined)

- Expected median upper limit (sensitivity) from BG-only MC
  - 2009-2010 combined : 1.6×10^{-12} (in 2011 published) → 1.3×10^{-12} (~20% improvement !)
  - 2009-2011 combined : 7.7×10^{-13}
- Upper limits from time sidebands are calculated → consistent w/ sensitivity

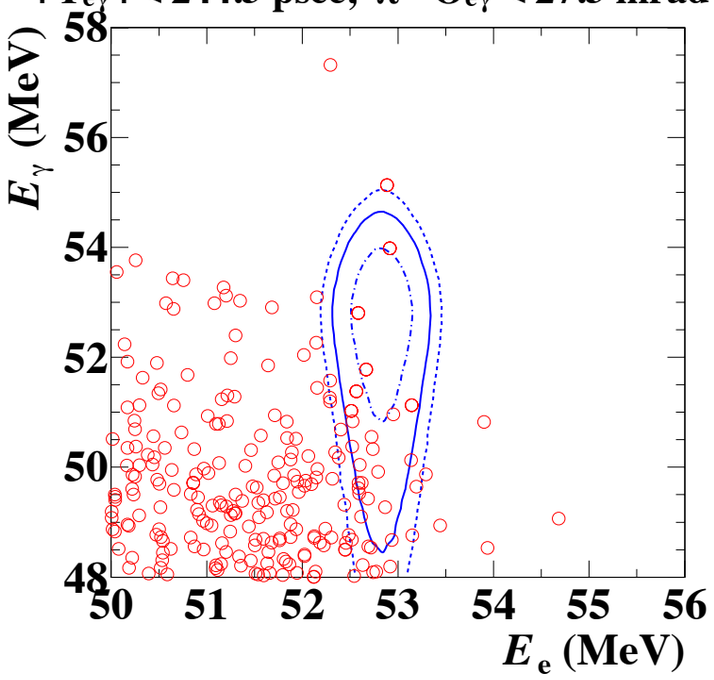




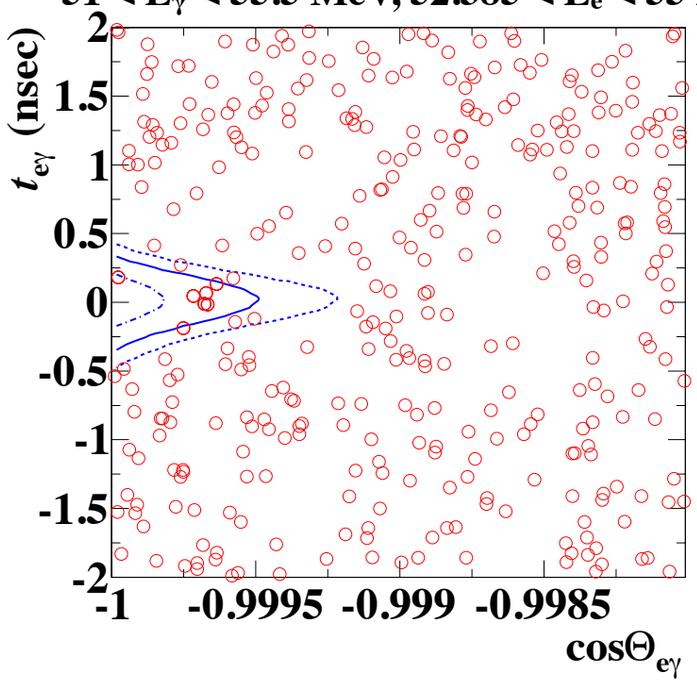
→ Unblind the analysis region ! (24th/Jan)

Result

$|T_{e\gamma}| < 244.3$ psec, $\pi - \Theta_{e\gamma} < 27.3$ mrad



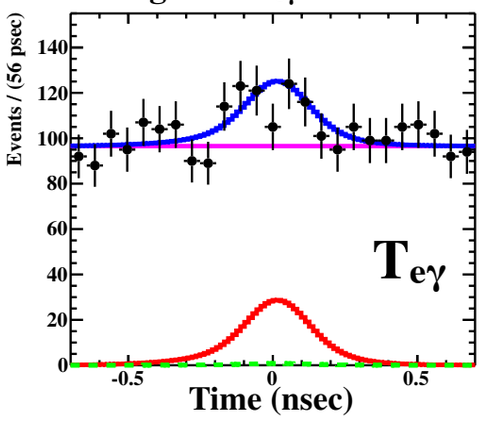
$51 < E_\gamma < 55.5$ MeV, $52.385 < E_e < 55$ MeV

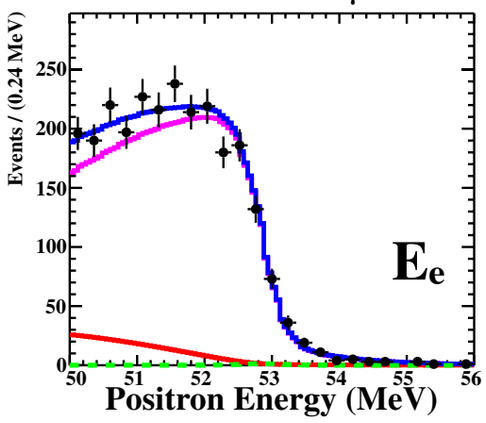


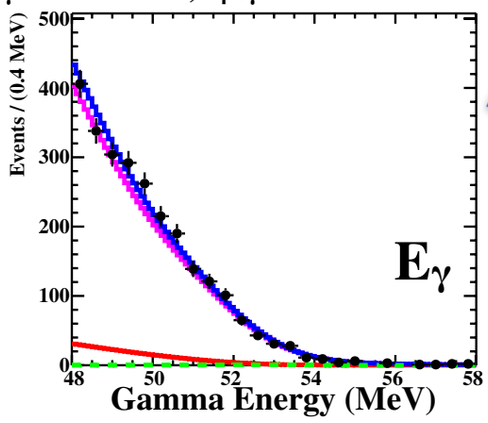
Event distributions
→ 2009-2011 combined
- ○ data
- \- signal PDF

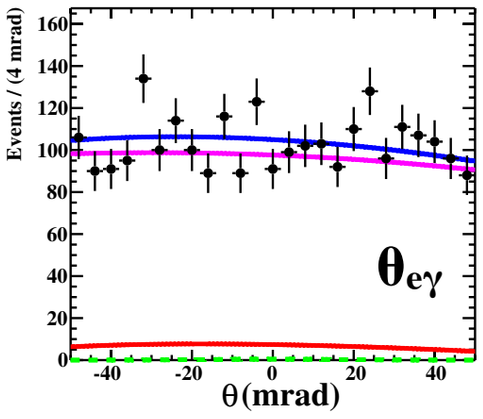
Projection of fitted PDF

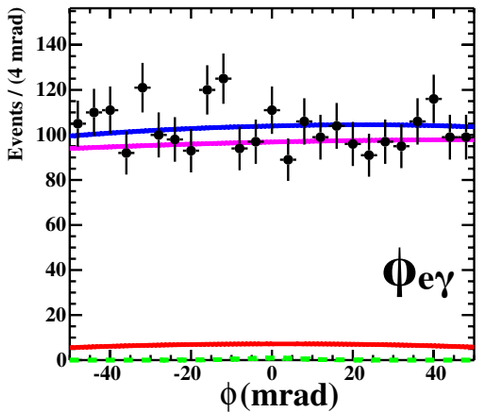
fit region : $|T_{e\gamma}| < 0.7$ nsec & $50 < E_e < 56$ MeV & $48 < E_\gamma < 58$ MeV, $|\theta_{e\gamma}| < 50$ mrad, $|\phi_{e\gamma}| < 50$ mrad











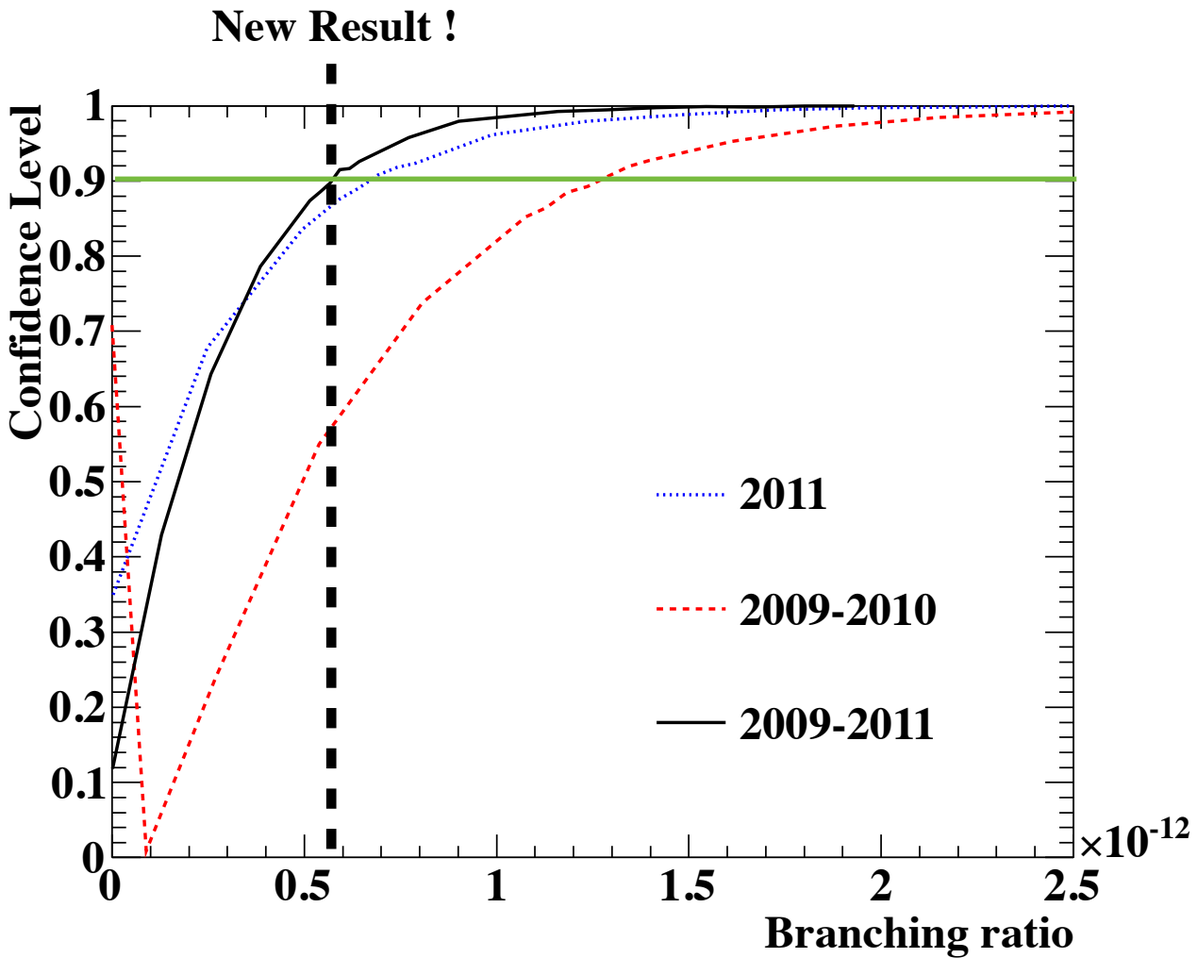
Data is in good agreement with BG+RMD PDF
→ 2009-2011 combined
- • data
- \- RMD
- \- BG
- \- Signal
- \- Total

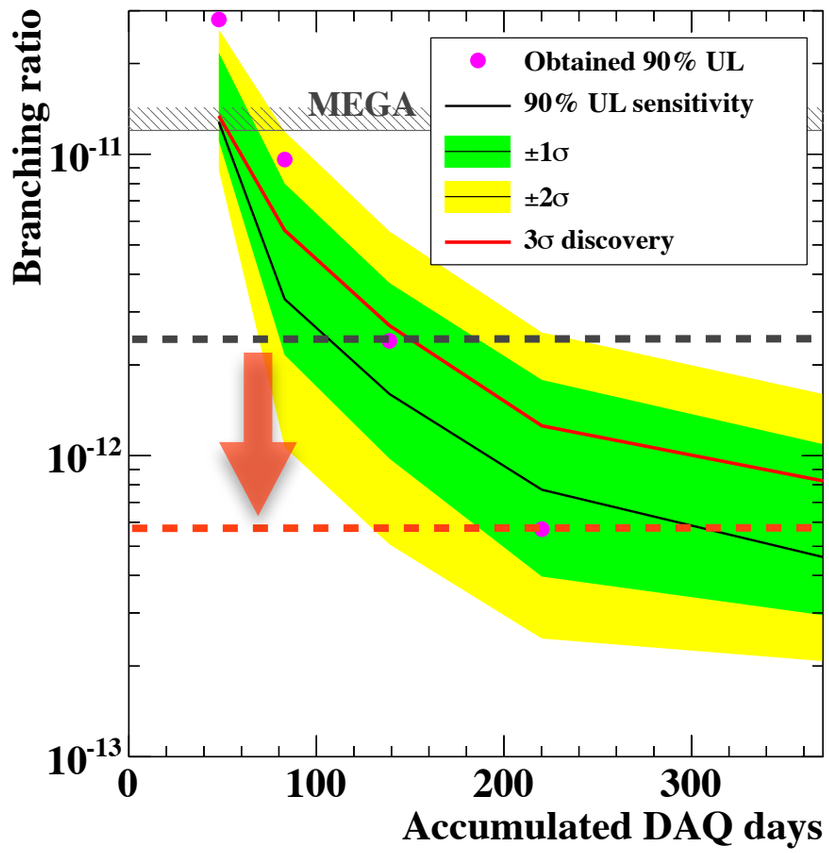
Consistent with BG-only hypothesis

	Expected	Fit
N_{BG}	2415.0±25.0	$2413.6^{+37.1}_{-37.0}$
N_{RMD}	169.3±17.0	$167.5^{+24.2}_{-24.0}$
N_{signal}	-	$-0.4^{+4.8}_{-1.9}$

Result

- Full frequentist approach with Feldmann & Cousins method





Previous Result

New Result

	Best fit in B.R.	90% Upper Limit
2009-2010 combined	8.9×10^{-14}	1.3×10^{-12}
2011	-3.5×10^{-13}	6.7×10^{-13}
2009-2011 combined	-5.8×10^{-14}	5.7×10^{-13}

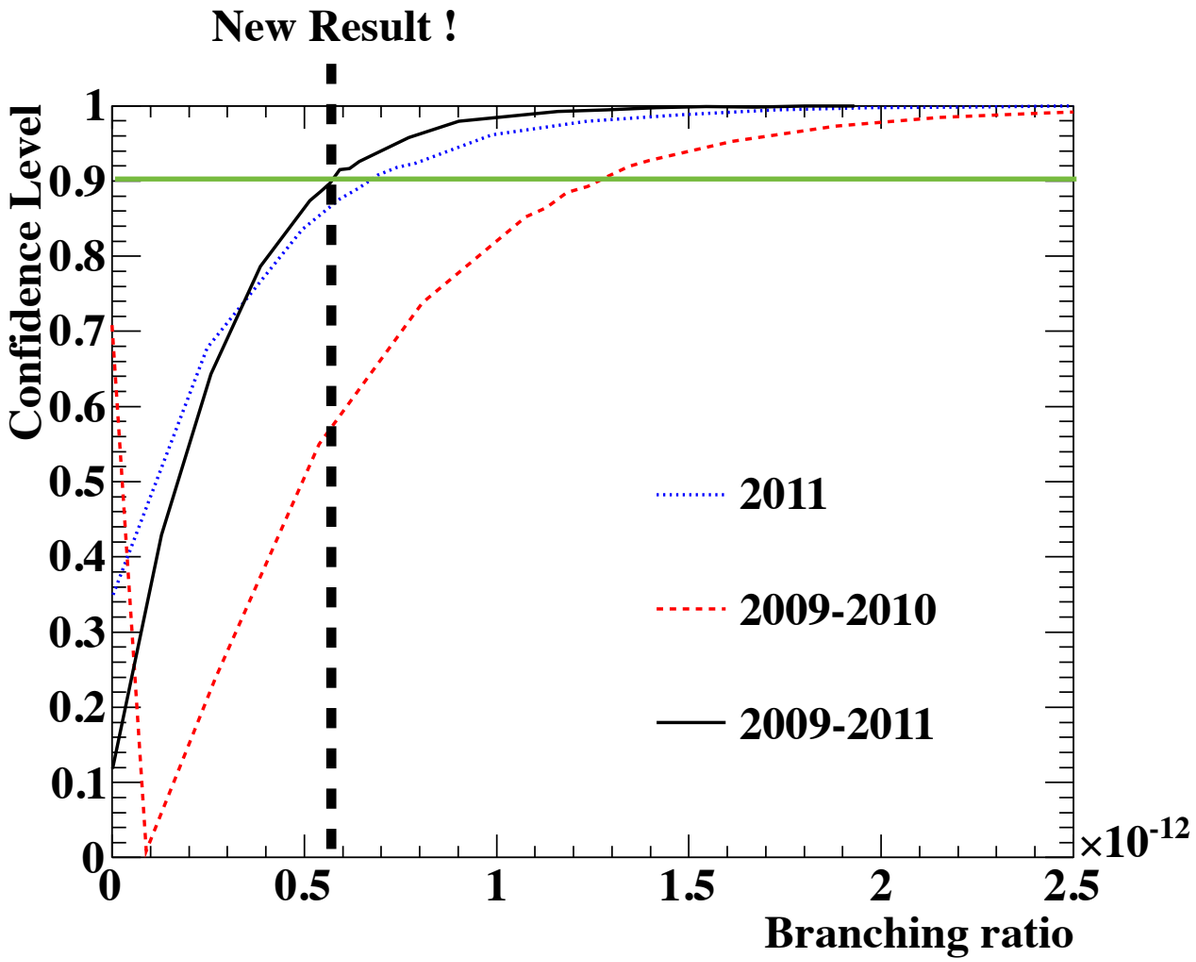
← 2.4×10^{-12} in the previous analysis

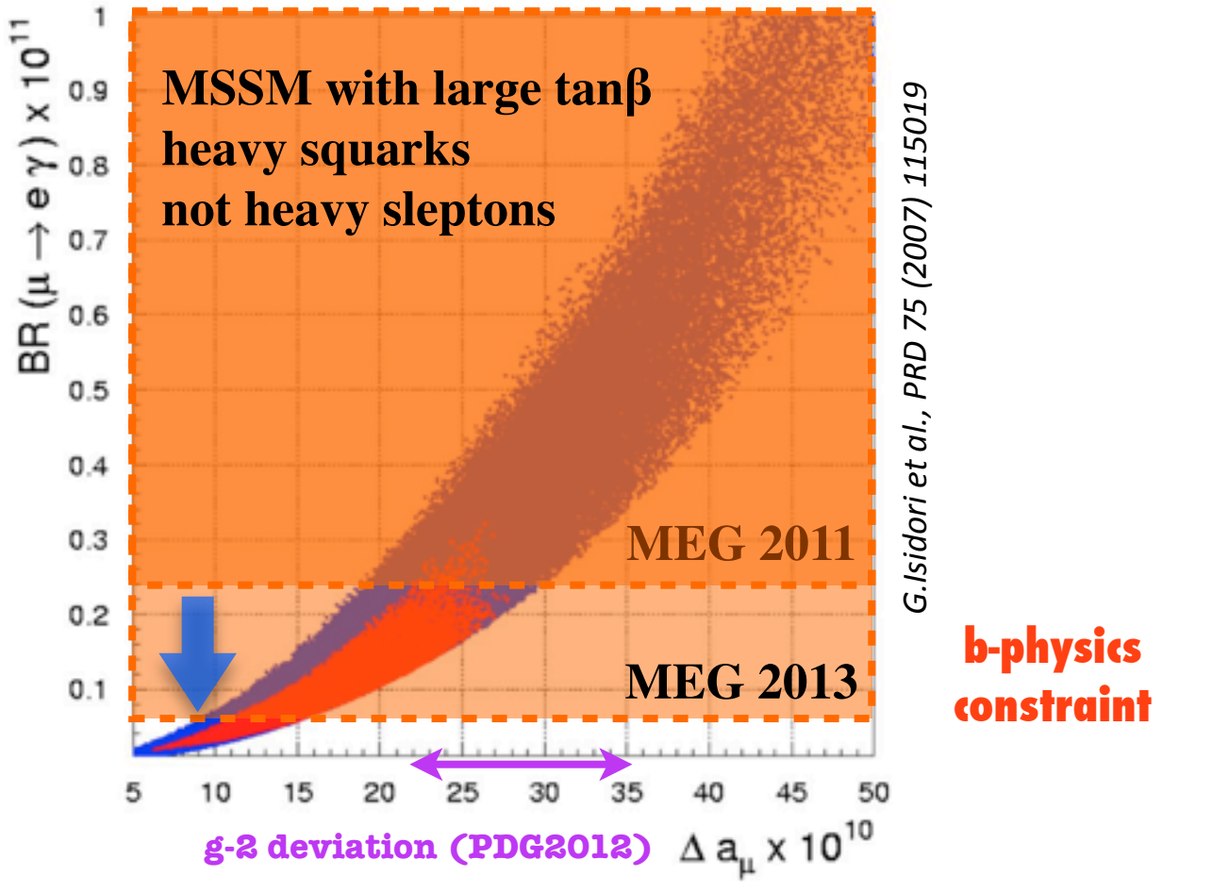
4 times more stringent

http://arxiv.org/pdf/1303.0754v1.pdf ← published in March 2013 !

Result

- Full frequentist approach with Feldmann & Cousins method





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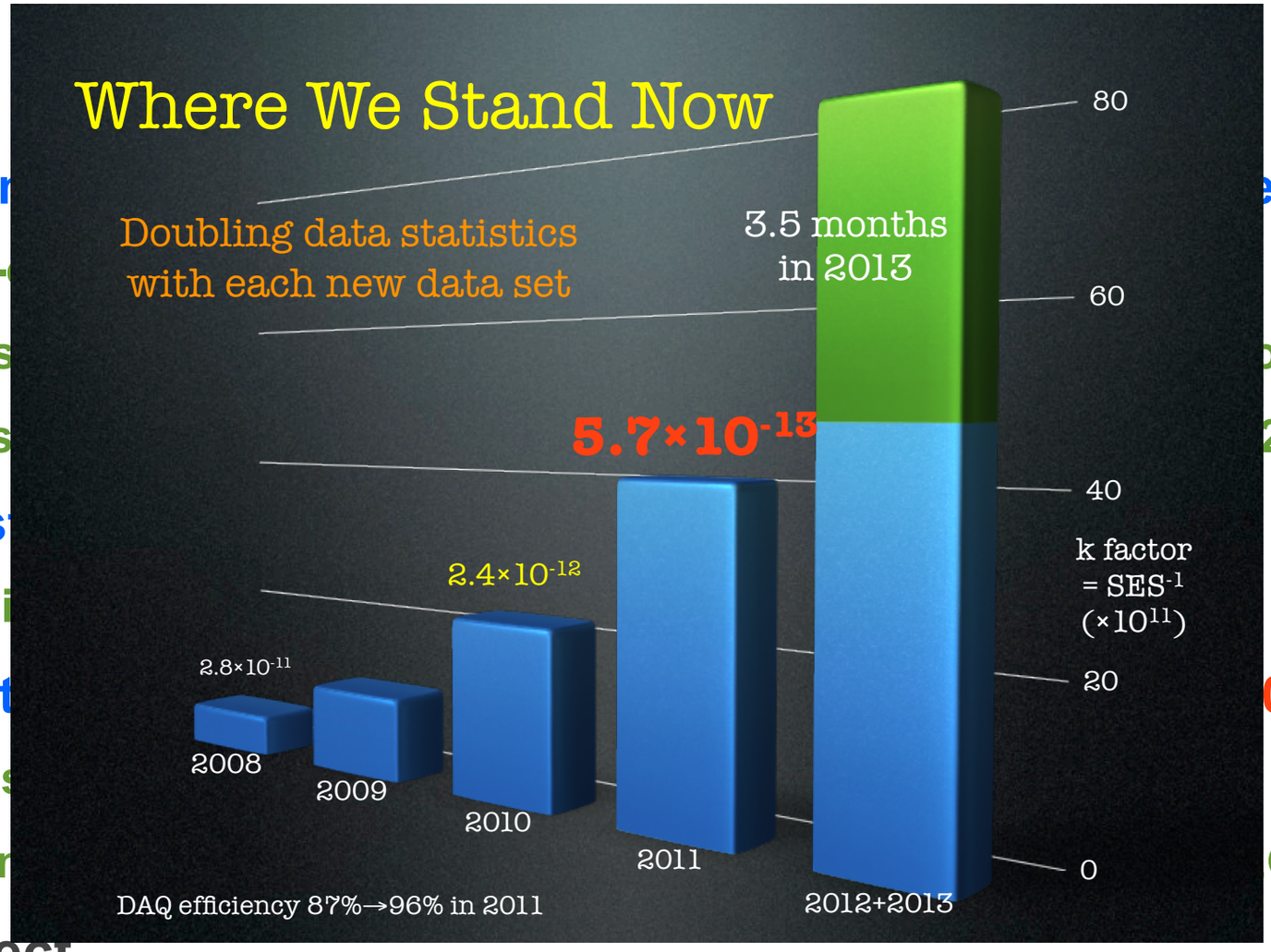
4 times more stringent

http://arxiv.org/pdf/1303.0754v1.pdf ← published in March 2013 !

Summary & Prospects

- **Summary**
  - **By many analysis improvements, we succeeded to improve the sensitivity**
    - The per-event PDF gives 10% higher sensitivity
    - Remains are come from improvements on the reconstruction algorithms
    - → 20% sensitivity improvement is confirmed by comparing 2009-2010 combined dataset
  - **Total statistics is doubled by adding 2011 data**
    - Sensitivity reaches 7.7×10^{-13} with 2009-2011 combined dataset
  - **We obtain the most stringent U.L. of Br($\mu^+\to e^+\gamma$) : 5.7×10^{-13} @ 90% C.L.**
    - No excess is observed in the signal region
    - 4 times more stringent than the previous result, 20 times than MEGA
- **MEG-I prospect**
  - **DAQ will continued until summer 2013**
    - The final statistics will be twice higher than the 2009-2011 combined dataset
    - → final sensitivity will be 5×10^{-13}, O(-13) search !
- **MEG upgrade (arXiv:1301.7225)**
  - **MEG upgrade proposal is approved at PSI and many R&Ds are ongoing**
    - Goal sensitivity of upgraded MEG is an order of magnitude higher than the present MEG

Summary & Prospects



- Summary
  - By many ar… e sensitivity
    - The per-…
    - Remains… orithms
    - → 20% s… 2010 combined dataset
  - Total statis…
    - Sensitivi…
  - We obtain t… 0% C.L.
    - No exces…
    - 4 times r… GA
- MEG-I prospect
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Summary & Prospects

- Summary
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- MEG upgrade (arXiv:1301.7225)
  - MEG upgrade proposal is approved at PSI and many R&Ds are ongoing
    - Goal sensitivity of upgraded MEG is an order of magnitude higher than the present MEG

Can be realized in short time

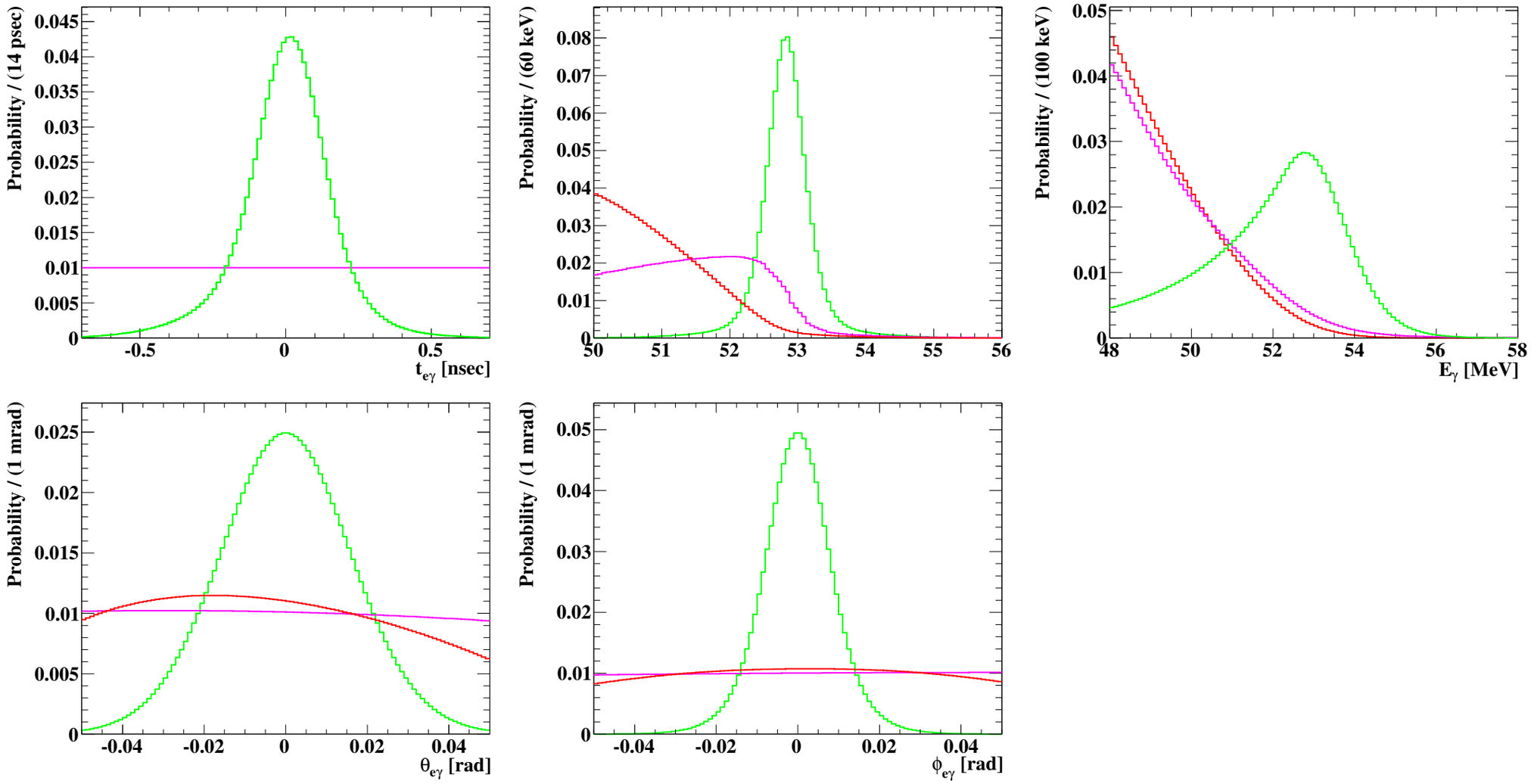
Backup

Likelihood Analysis

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

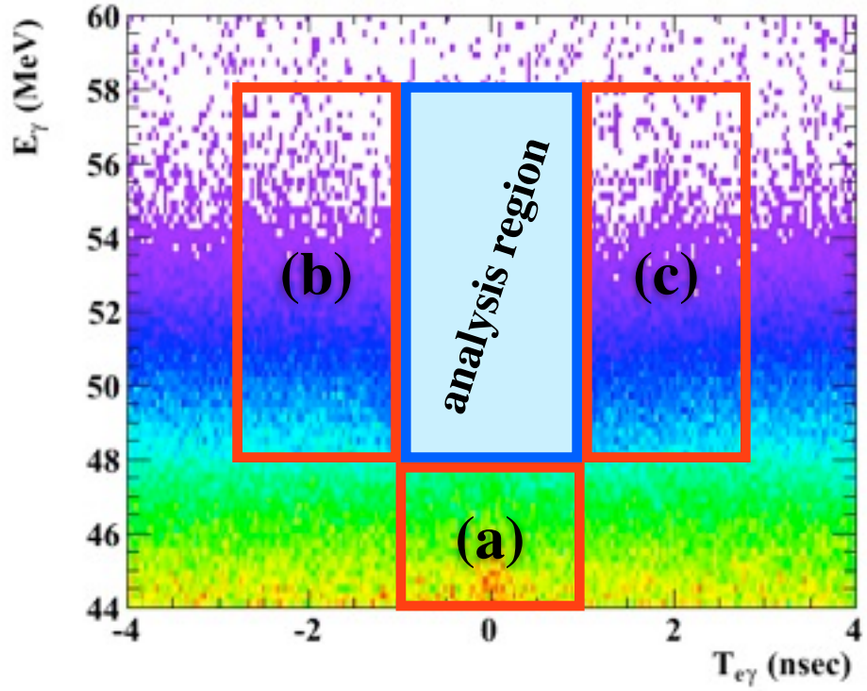
Signal PDF　RMD PDF　BG(Accidental) PDF

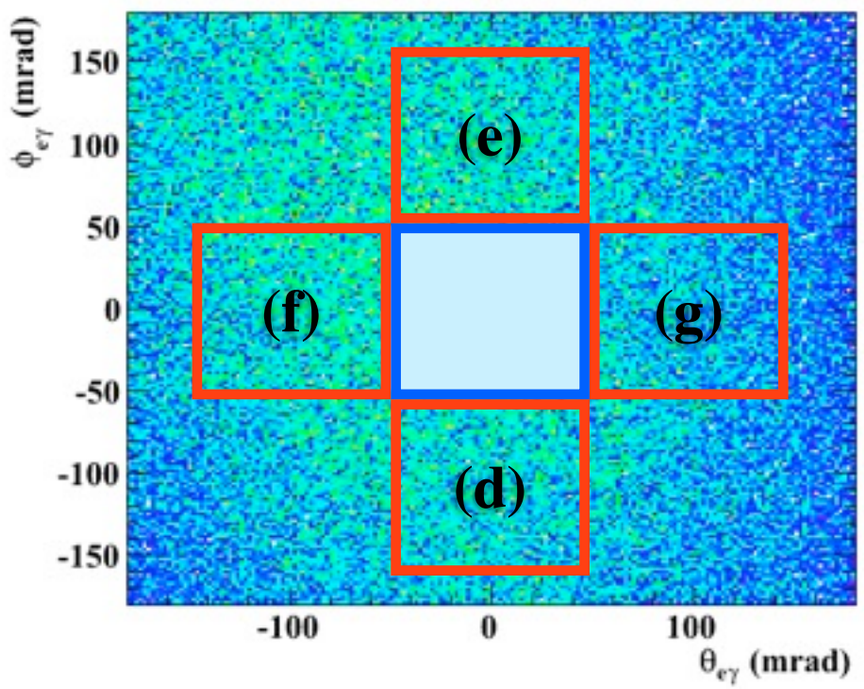
*** Integrated PDFs for 2009-2011 combined dataset are shown here**



Physics Analysis

- Sideband data
  - analyzed before unblind the analysis region
  - Eγ sideband
    - used to estimate k_{RMD} & N_{RMD} in signal region (a)
  - time sidebands (off-time)
    - negative : $-2.7 < T_{e\gamma} < -1.3$ nsec (b)
    - positive : $1.3 < T_{e\gamma} < 2.7$ nsec (c)
  - angle sidebands (off-axis)
    - φ negative : $-150 < \varphi_{e\gamma} < -50$ mrad (d)
    - φ positive : $50 < \varphi_{e\gamma} < 150$ mrad (e)
    - θ negative : $-150 < \theta_{e\gamma} < -50$ mrad (f)
    - θ positive : $50 < \theta_{e\gamma} < 150$ mrad (g)





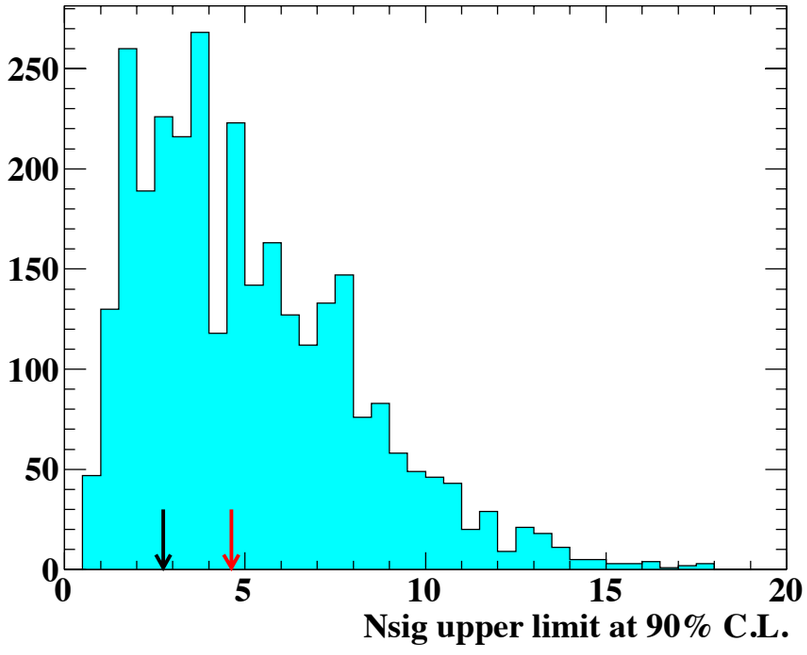
Dataset comparison

$$k_{\mathrm{Michel}} = \frac{N^{\mathrm{Obs}}_{\mathrm{Michel}}}{f_{\mathrm{Michel}}} \times s_{\mathrm{trig.}} \times p_{\mathrm{DM}} \times \frac{\epsilon_{\mathrm{signal}}}{\epsilon_{\mathrm{Michel}}} \times \epsilon_{\gamma} \times \epsilon_{\mathrm{analysis}}$$

$$k_{\mathrm{RMD}} = \frac{N^{\mathrm{Obs}}_{\mathrm{RMD}}}{\mathcal{B}_{\mathrm{RMD}}} \times \frac{\epsilon_{\mathrm{signal}}}{\epsilon_{\mathrm{RMD}}} \times \epsilon_{\mathrm{analysis}}$$

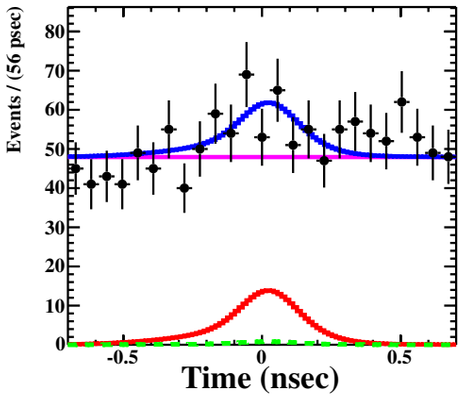
	k-factor	Sensitivity	90% upper limit
2009-2010 combined	$(3.52\pm0.14)\times10^{12}$	1.3×10^{-12}	1.3×10^{-12}
2011	$(4.05\pm0.16)\times10^{12}$	1.1×10^{-12}	6.7×10^{-13}
2009-2011 combined	$(7.77\pm0.31)\times10^{12}$	7.7×10^{-13}	5.7×10^{-13}

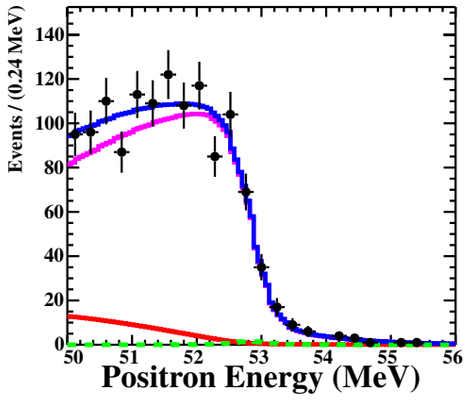
90% N_{sig} upper limit of 2011 dataset from toy MC

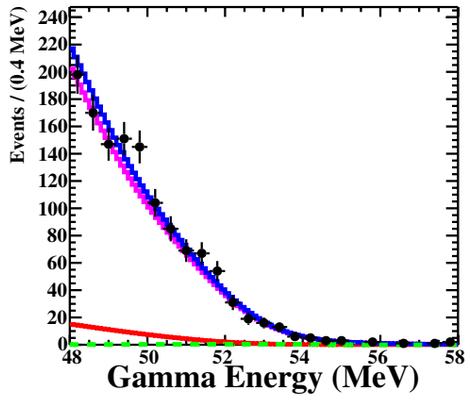


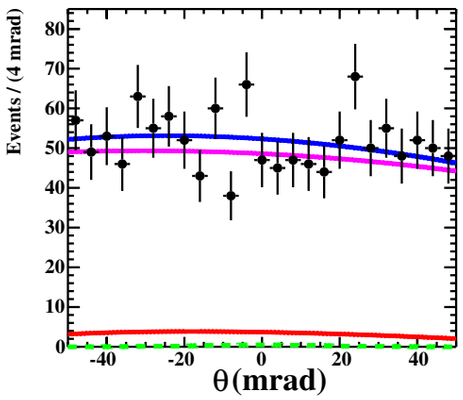
Black arrow : observed upper limit
Red arrow : median upper limit
→ The observed can happen in 24% probability

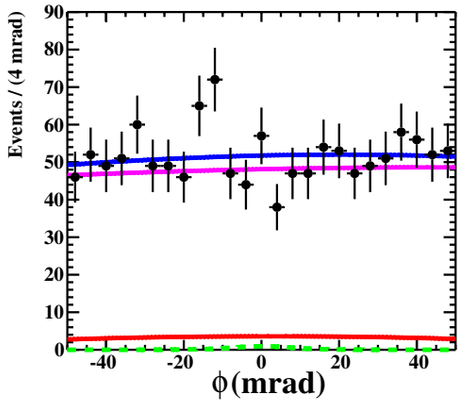
2009-2010 combined

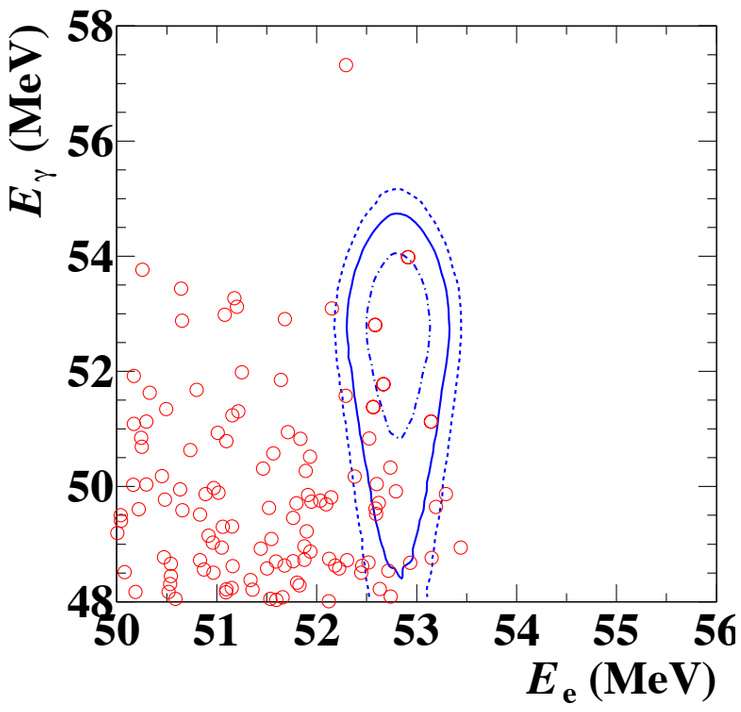


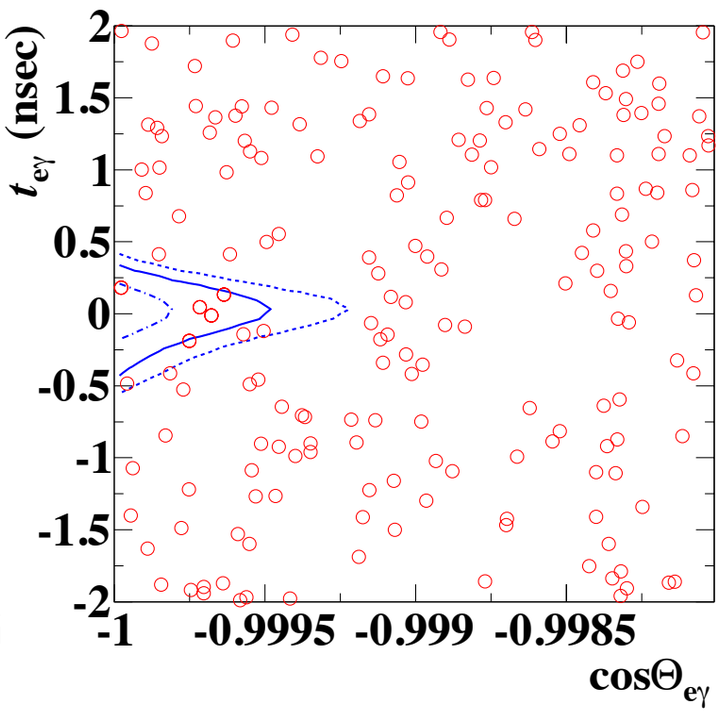




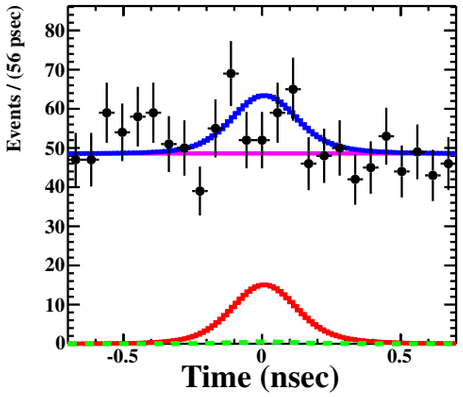


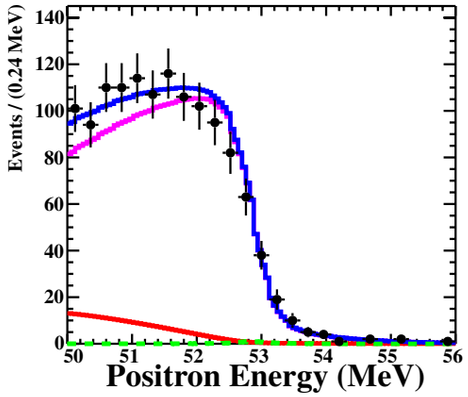


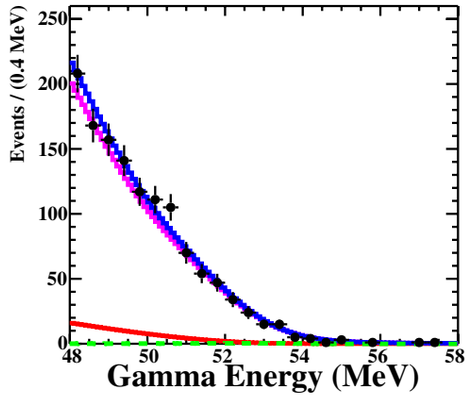


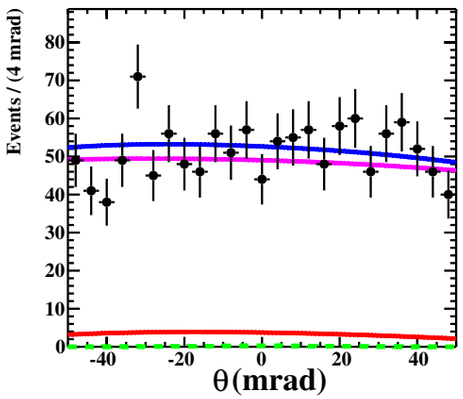


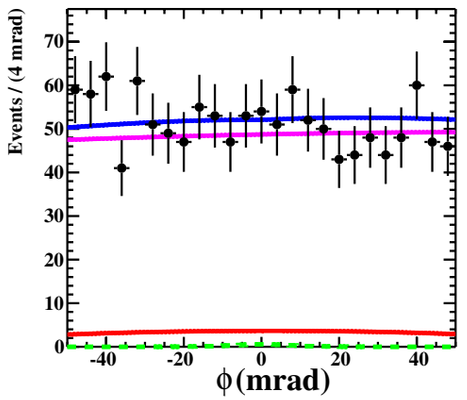
2011 only

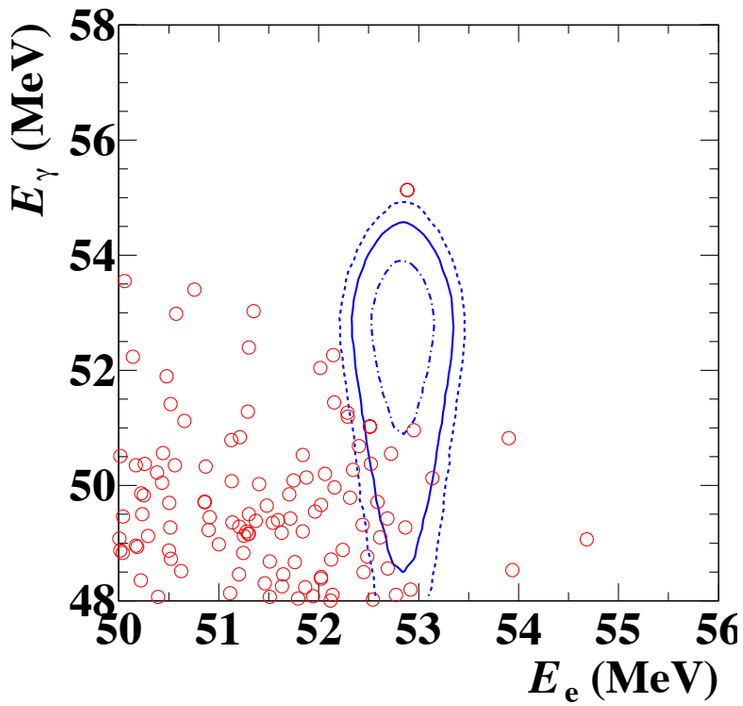

Events / (56 psec)
Time (nsec)

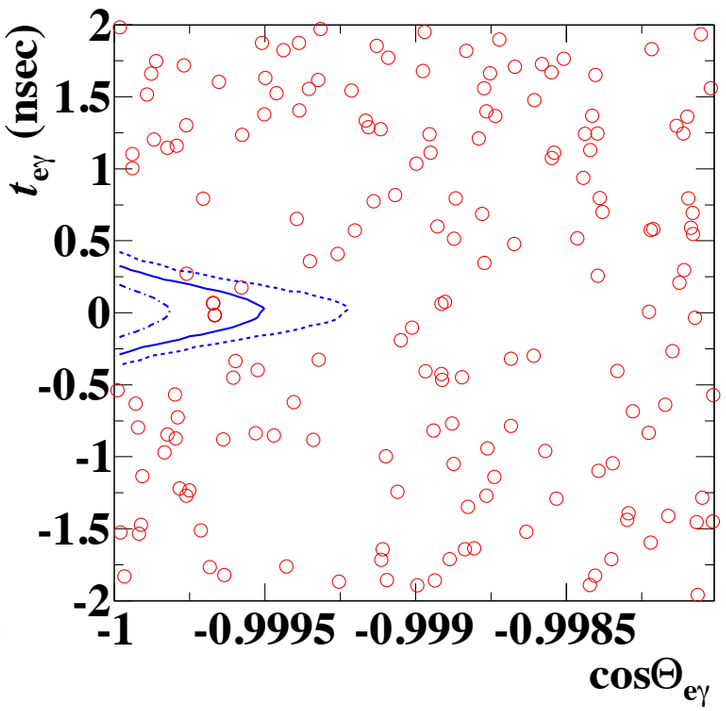

Events / (0.24 MeV)
Positron Energy (MeV)


Events / (0.4 MeV)
Gamma Energy (MeV)

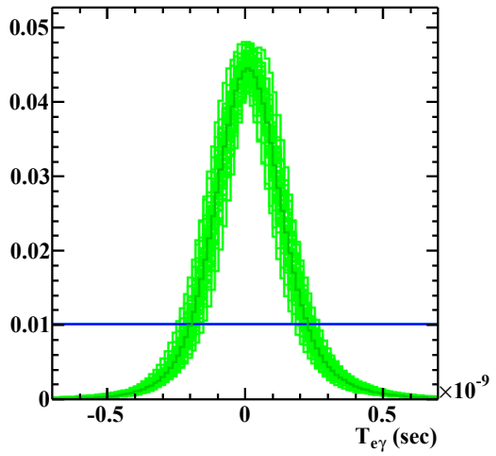

Events / (4 mrad)
θ(mrad)

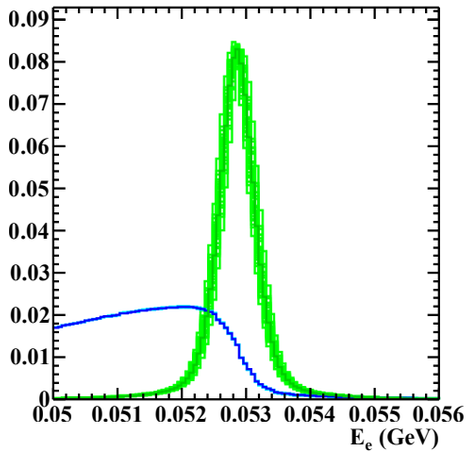

Events / (4 mrad)
ϕ(mrad)

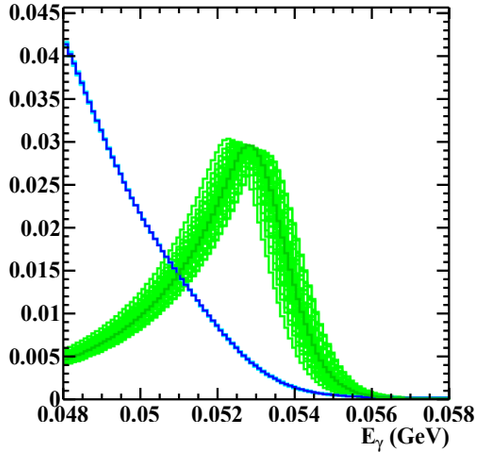

E_γ (MeV)
E_e (MeV)

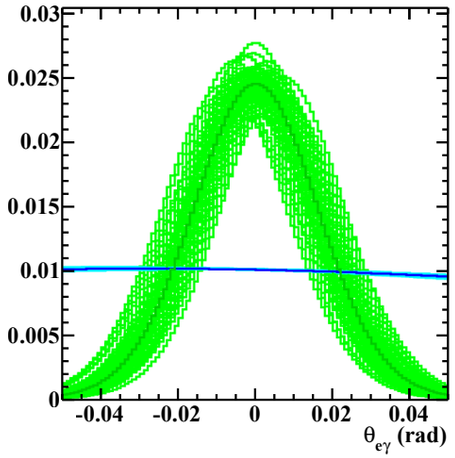

$t_{e\gamma}$ (nsec)
cosΘ$_{e\gamma}$

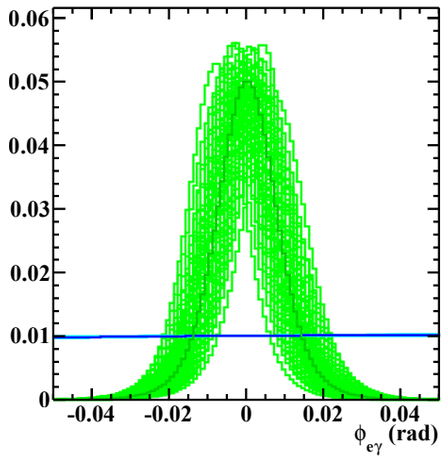
Systematics











1% effect on the BR upper limit

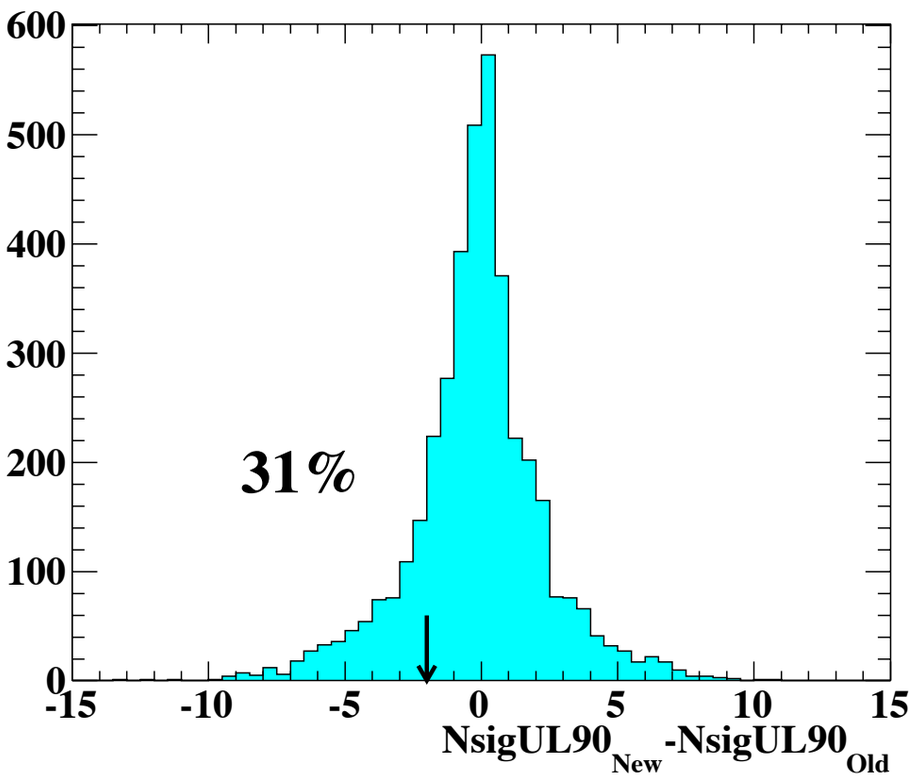
Table 16: Relative contributions of uncertainties to upper limit of $\mathcal{B}$.

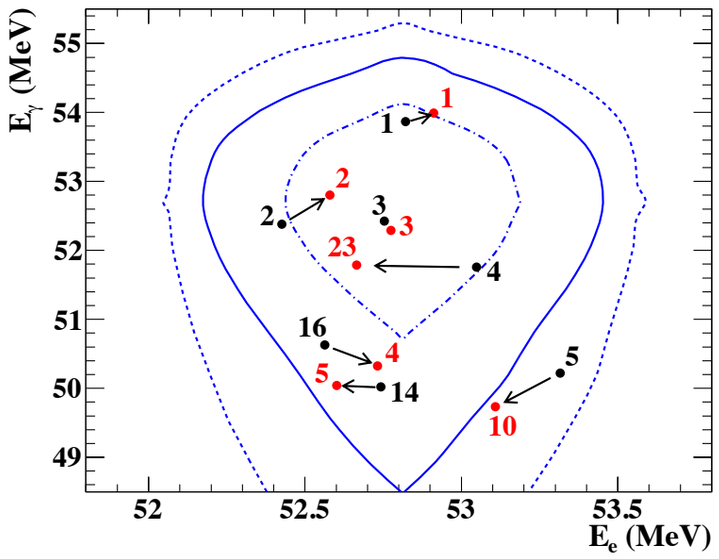
Center of $\theta_{e\gamma}$ and $\phi_{e\gamma}$	0.18
Positron correlations	0.11
E_γ scale	0.07
E_e bias	0.06
$t_{e\gamma}$ signal shape	0.06
$t_{e\gamma}$ center	0.05
Normalization	0.04
E_γ signal shape	0.03
E_γ BG shape	0.03
Positron angle resolutions (θ_e, ϕ_e, z_e, y_e)	0.03
γ angle resolution (u_γ, 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

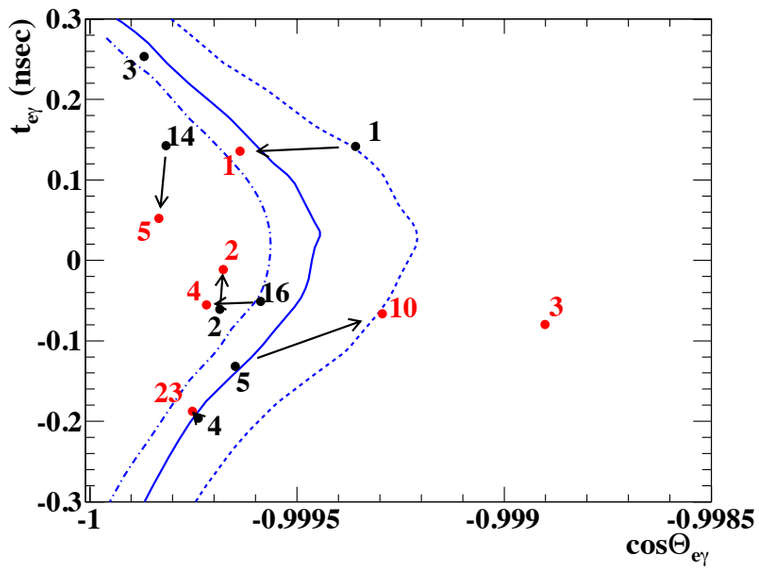
RMS of ΔNLL

Compatibility Test

- Compatibility check between previous/new results is done by using toy MC
  - Observed difference of N_{sig} upper limit in can happen in 31% probability in 2009-2010 dataset
- Event-by-event difference is checked for 5 highest ranked events in R_{sig}* ordering
  - Observed difference is smaller than the level of resolutions
  - 1 event is appeared/disappeared because of the difference of reconstructions
  - New analysis should be more precisely because of less tail components in the resolutions





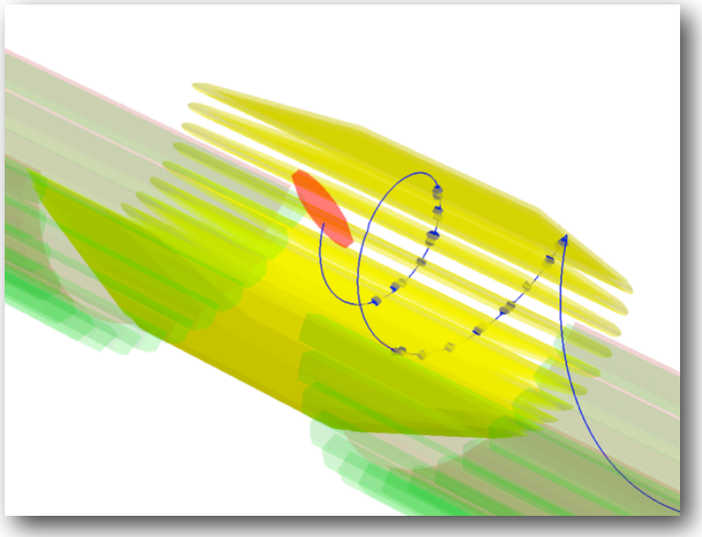


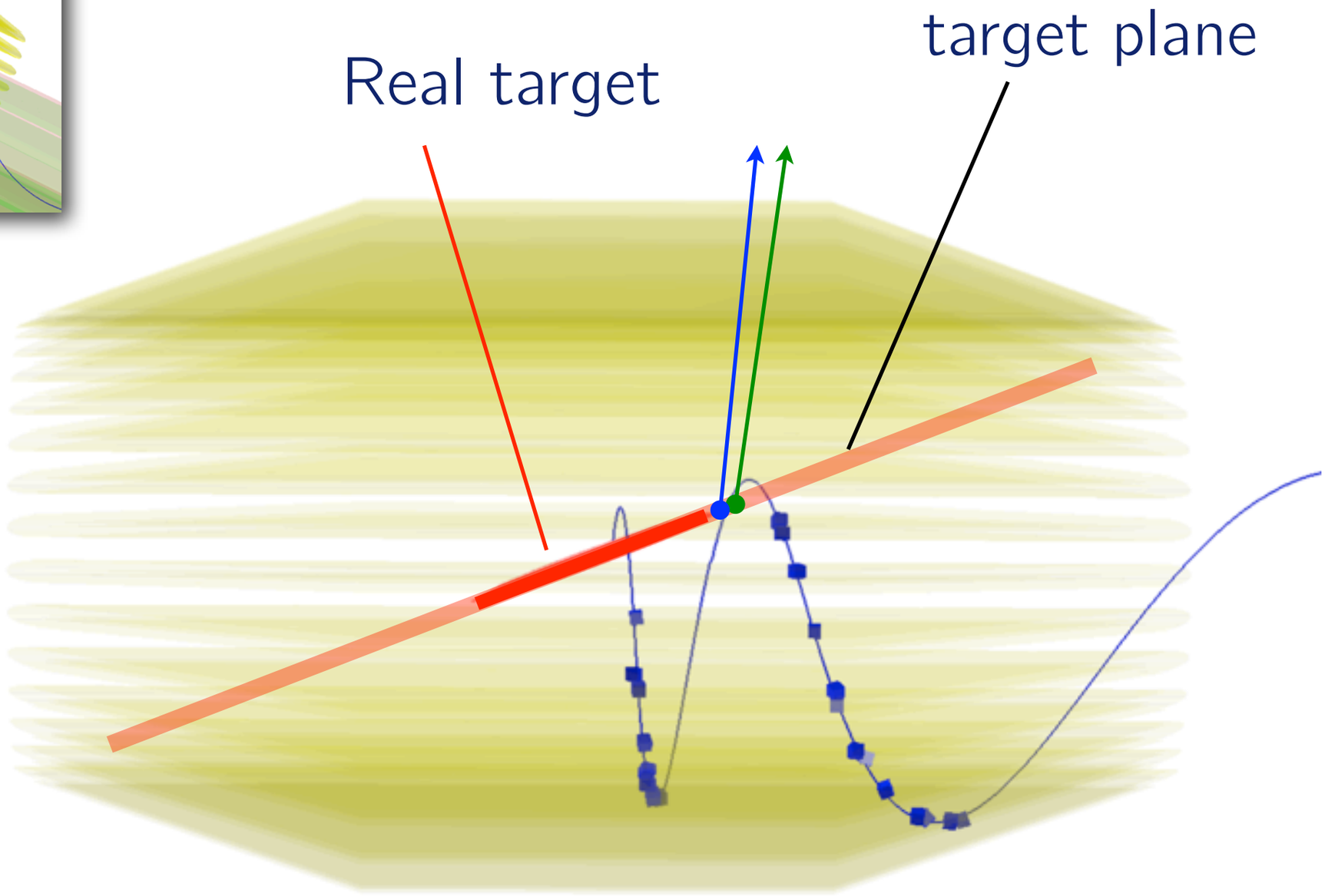
Red : New

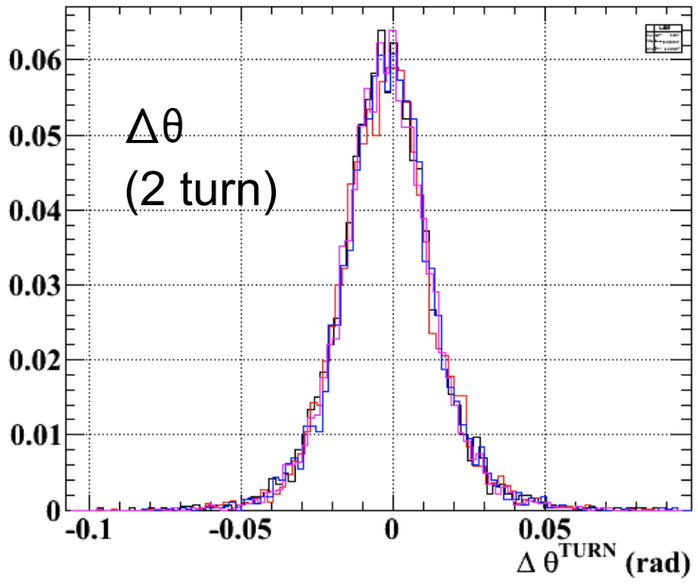
Black : Old

*** R_{sig} = L(signal)/(0.9L(BG)+0.1L(RMD))**

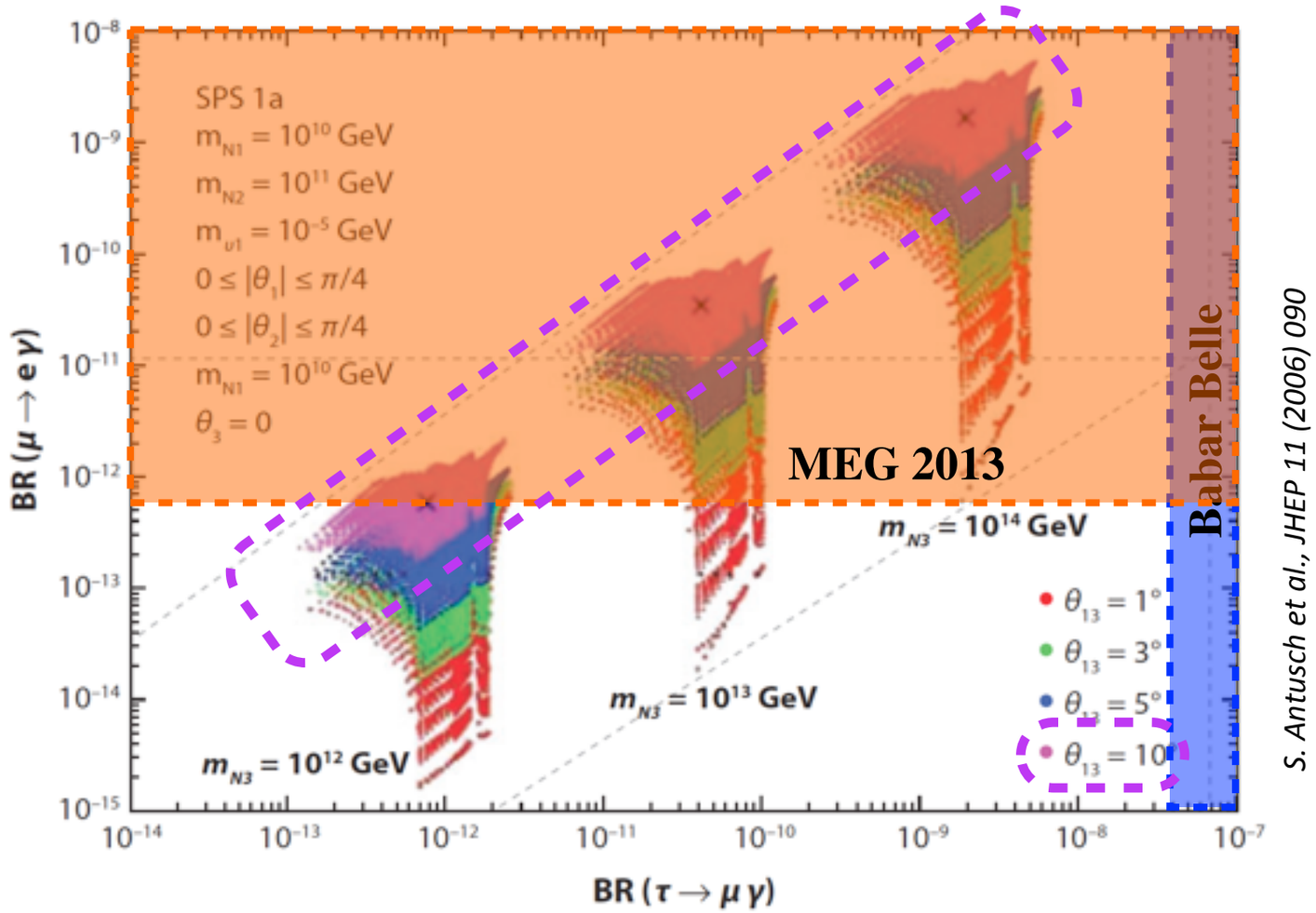
two turn method







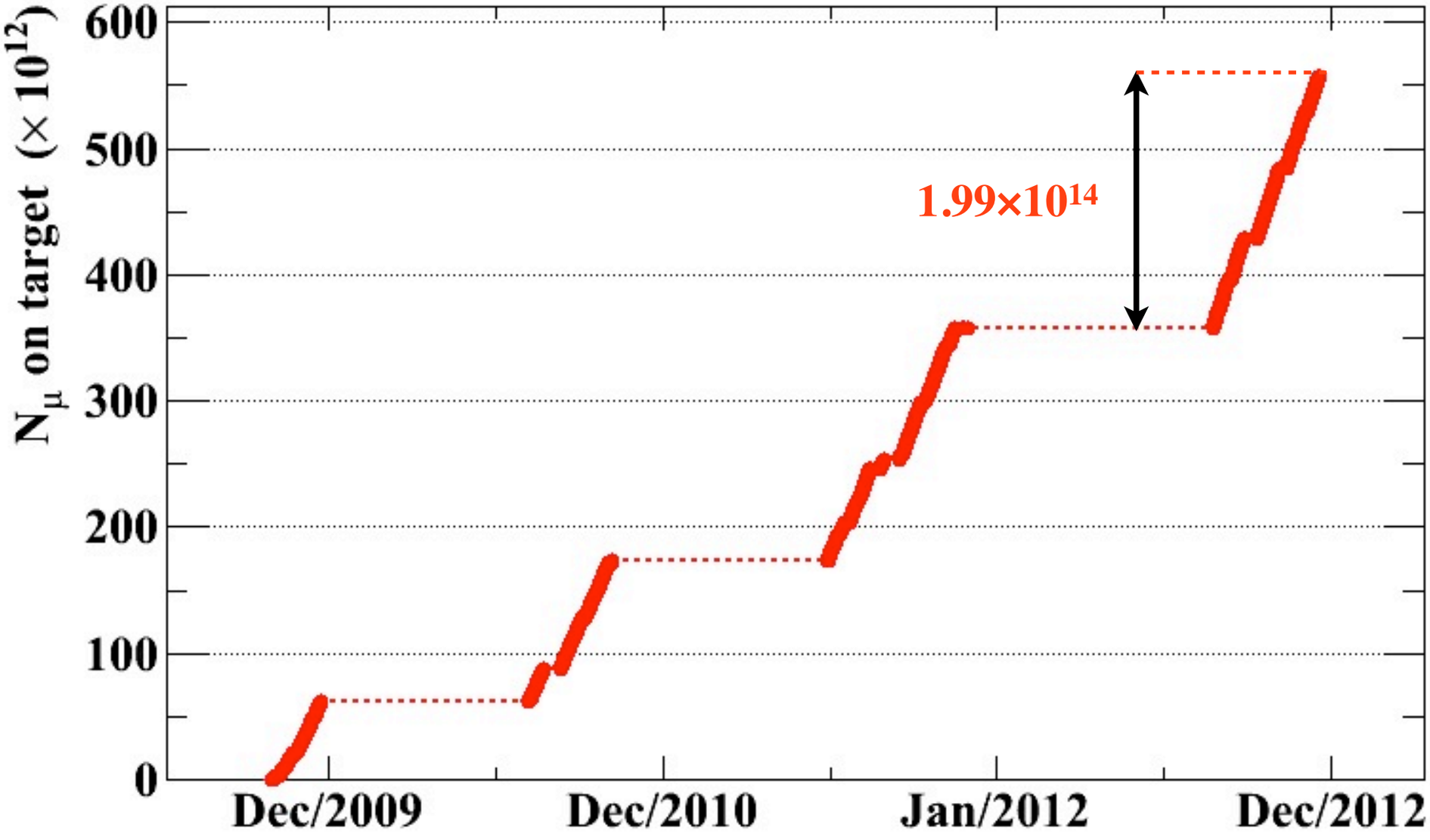
- **SUSY-Seesaw**



S. Antusch et al., JHEP 11 (2006) 090

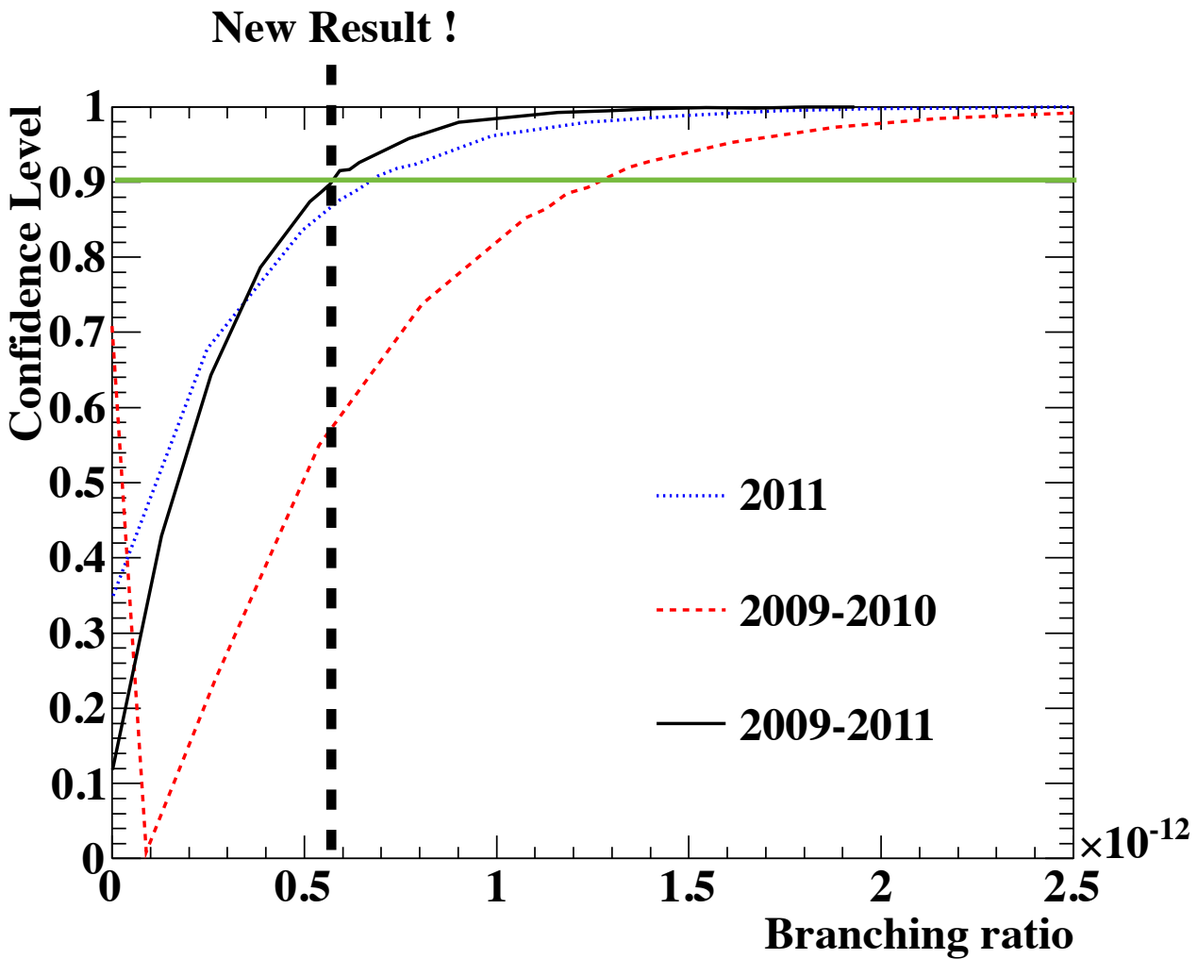
Run 2012

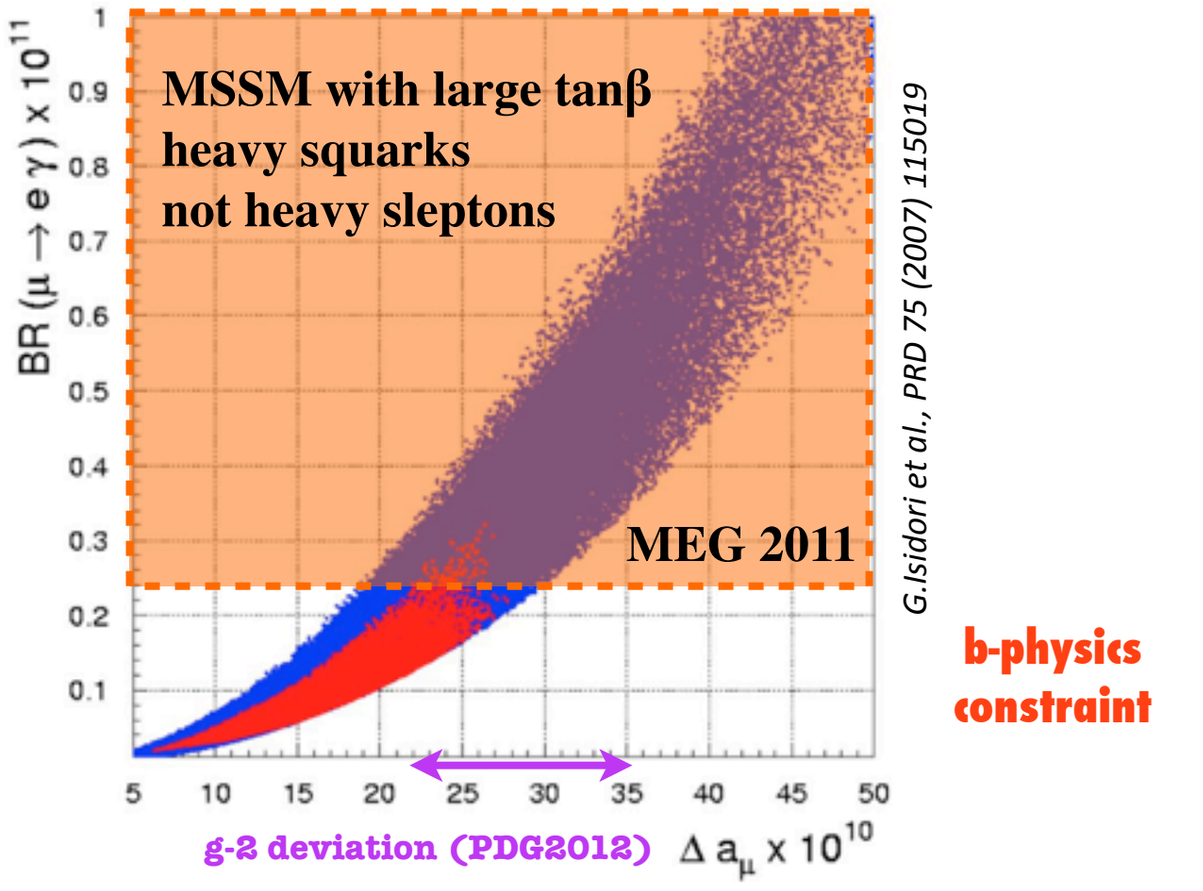
- Successfully finished
- 15% higher beam rate



Result

- Full frequentist approach with Feldmann & Cousins method





	Best fit in B.R.	90% Upper Limit
2009-2010 combined	8.9×10^{-14}	1.3×10^{-12}
2011	-3.5×10^{-13}	6.7×10^{-13}
2009-2011 combined	-5.8×10^{-14}	5.7×10^{-13}

← 2.4×10^{-12} in the previous analysis

4 times more stringent

http://arxiv.org/pdf/1303.0754v1.pdf ← published in March 2013 !