NOW 2012

μ→eγ search with MEG: results and perspectives

Luca Galli, INFN Pisa

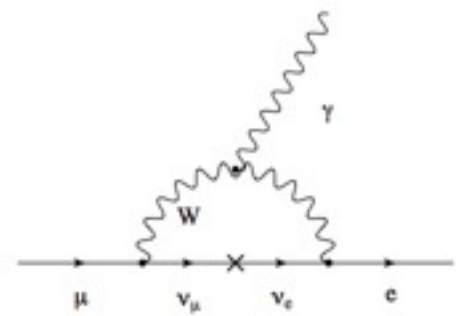
Conca Specchiulla, September 9-16, 2012

Outline

- Physics motivations
- The experiment
  - *detector and beam*
  - *signal and background*
  - *calibrations*
- Analysis scheme
- Run 2009+2010
  - *normalization and sensitivity*
  - *results*
- MEG upgrade

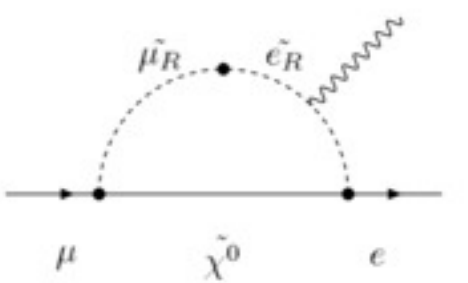
cLFV in the Standard Model and beyond

μ-cLFV undetectably small in the **Standard Model** with **ν-oscillations**



$$\frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\bar{\nu})} \approx \left(\frac{\alpha}{2\pi}\right) \sin^2(2\theta) \left(\frac{\Delta m^2}{M_W^2}\right)^2 \approx 10^{-54}$$

- *process* ***enhanced*** *in* ***SUSY theories and others***
  - **expected rate ≈ experimental sensitivities $10^{-12} \div 10^{-14}$**
- ***no SM contamination:*** **μ→eγ** ***New Physics*** *clean* ***probe***

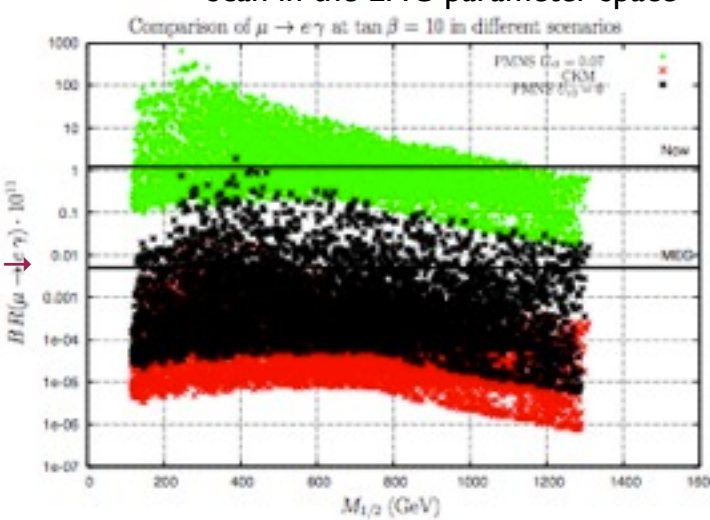


$$B(\ell_i \to \ell_j \gamma) \propto \frac{\alpha^3 \pi \theta^2_{\tilde{\ell}_i \tilde{\ell}_j}}{G_F^2 \tilde{m}^4} \tan^2(\beta)$$

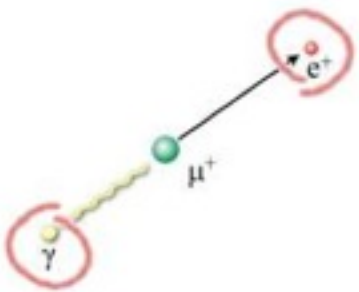
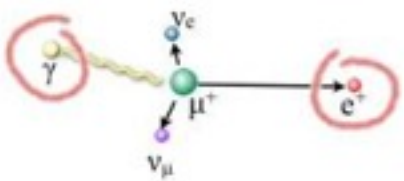
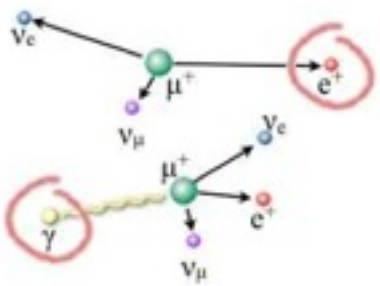
R. Barbieri et al., Nucl. Phys. B445(1995) 215
J. Hisano, N. Nomura, Phys. Rev. D59 (1999)
A.Masiero et al. Nucl. Phys. B649 (2003) 189
L.Calibbi et al. Phys. Rev. D74 (2006) 116002
G.Isidori, Phys Rev. D75 (2007) 115019

Scan in the LHC parameter space

MEG goal →



Signal and background

Signal	Radiative Muon Decay	Accidental
		
$E_\gamma = 52.8$ MeV $E_{e^+} = 52.8$ MeV $\Theta_{e\gamma} = 180°$ $T_{e\gamma} = 0$ s	$E_\gamma < 52.8$ MeV $E_{e^+} < 52.8$ MeV $\Theta_{e\gamma} < 180°$ $T_{e\gamma} = 0$ s	$E_\gamma < 52.8$ MeV $E_{e^+} < 52.8$ MeV $\Theta_{e\gamma} < 180°$ $T_{e\gamma} \Rightarrow$ flat

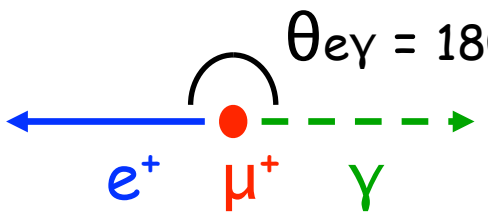
Accidental bkg is **dominant** and determined by **beam rate** and **resolutions**

$$B_{acc} \propto R_\mu \Delta E_e \Delta E_\gamma^2 \Delta \Theta_{e\gamma}^2 \Delta t_{e\gamma}$$

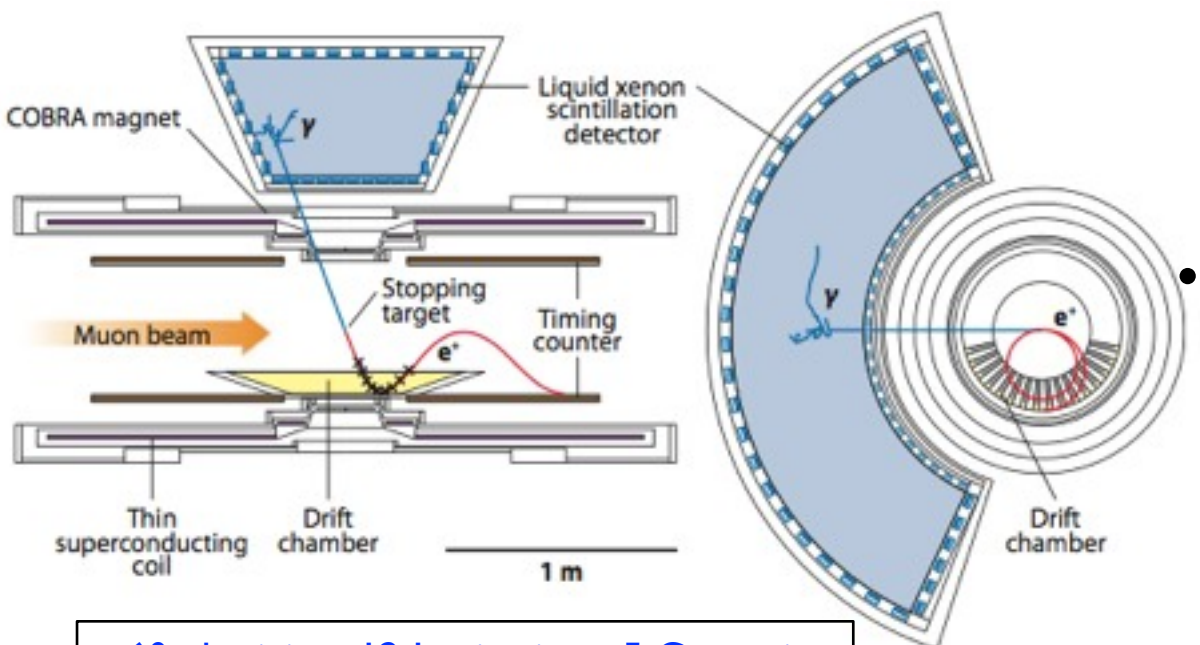
$$B_{RMD} \approx 0.1 \cdot B_{acc}$$

Exp./Lab	Year	ΔEe/Ee (%)	ΔEγ /Eγ (%)	Δteγ (ns)	Δθeγ (mrad)	Stop rate (s^{-1})	Duty cyc.(%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^5	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^5	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^5	6.4	1.7×10^{-10}
Crystal Box	1986	8	8	1.3	87	4×10^5	(6..9)	4.9×10^{-11}
MEGA	1999	1.2	4.5	1.6	17	2.5×10^8	(6..7)	1.2×10^{-11}
MEG	2008 - x	1	4.5	0.15	19	3×10^7	100	5×10^{-13}

Experimental method



Ee = Eγ = 52.8 MeV



~60 physicists, 12 Institutions, 5 Countries
Italy, Japan, Russia, Switzerland, USA
Location: Paul Scherrer Institut (CH)

Detector OUTLINE

- **μ decay** at **rest**
  - *Beam rate:* ***3×10⁷ μ/s***
  - *μ stopped in* ***205 μm target***
- **γ** detection
  - ***Liquid Xenon*** *calorimetry with* ***scintillation light***
    - **fast**: 4/22/45 ns
    - **high LY**: ~0.8 NaI
    - **short X_0**: 2.77 cm
- **e^+** detection
  - ***magnetic spectrometer***
    - **non-uniform B field → constant bending radius** and **e^+ swept rapidly away**
    - **ultra-thin drift chambers** to **limit matter effects (X_0 ~ 0.0003 per module)**
  - ***TC detector***
    - **time of flight** with **plastic scintillator counters**
    - **transverse scintillation fibers → hit position**

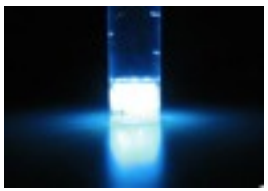
MEG key elements

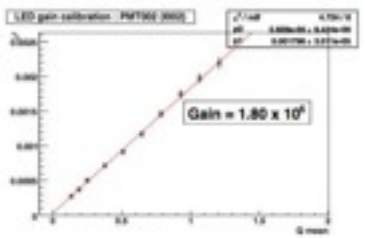
- **MEG** is a **precision experiment** which **demands** for
  - ***unprecedented detector resolution at these energies*** *for effective* ***background rejection***
  - *accurate* ***monitoring*** *of detector* ***performances with time***
- The detector is **operated in conjunction** with an **impressive set** of **calibration tools**

LXe calibrations (subset...)

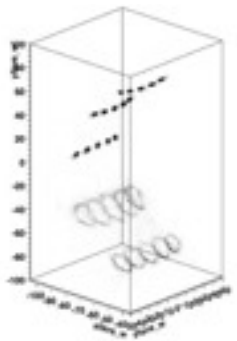
Artificial light source... ... events **inside** the **detector**... ... low energy γs **with beam**...

LED
PMT gain

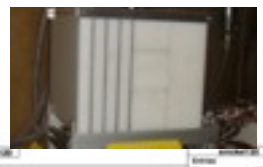


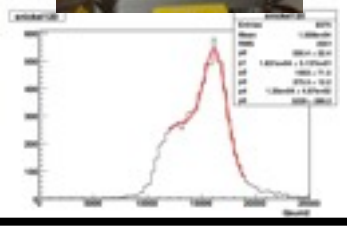


α source
PMT QE
Absorption length

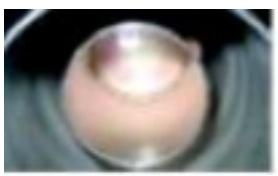


Ni γ generator
9 MeV γ-line
beam on/off calib.

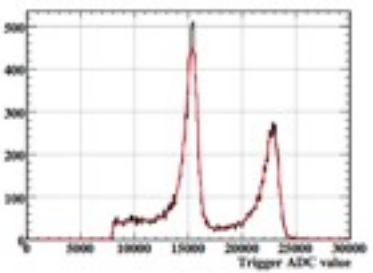


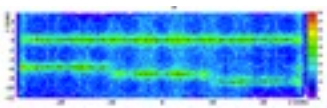


CEX
γ-resolutions:
- energy
- time
- impact point



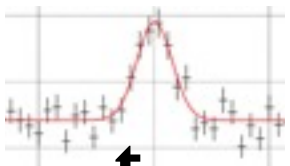
LH_2 target





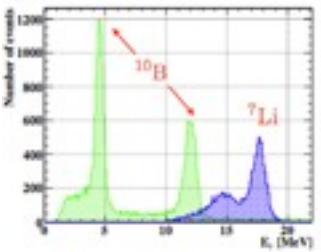
XENON CALIBRATION

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



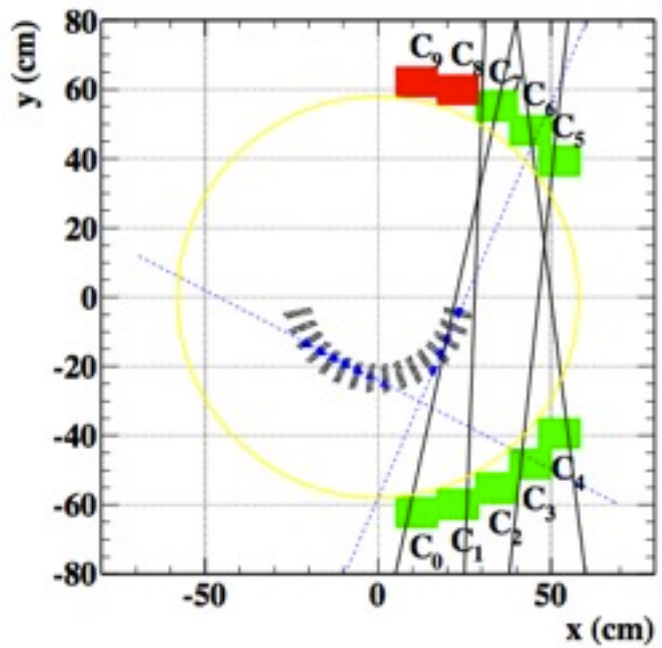
$t_{e\gamma}$

CW p-accel
Light Yield
LXe-TC t-calib



... **@signal energy**!! ... **during** DAQ... ... **frequent** and **fast** LY monitor...

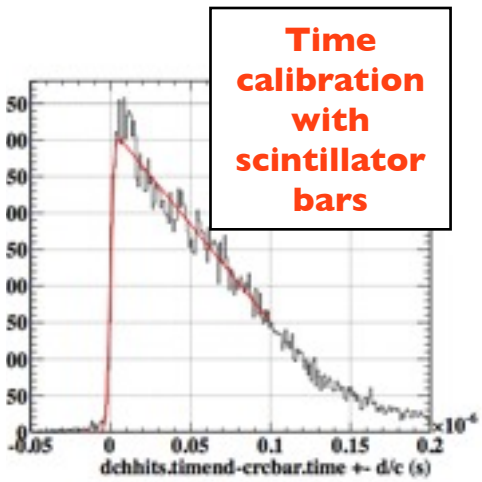
Spectrometer calibration (again subset!)



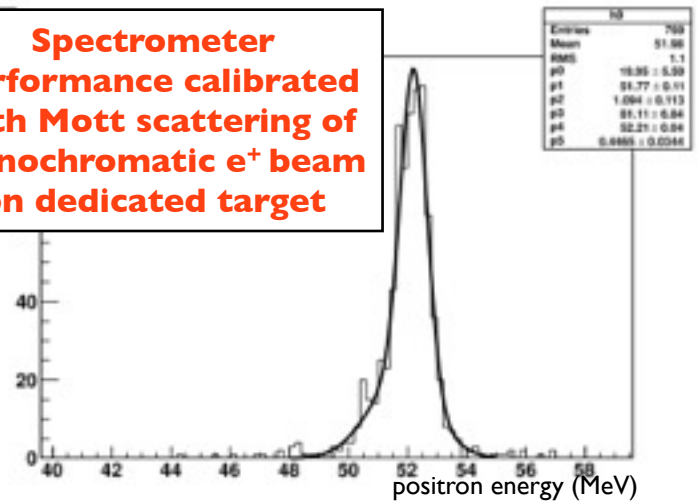
DC

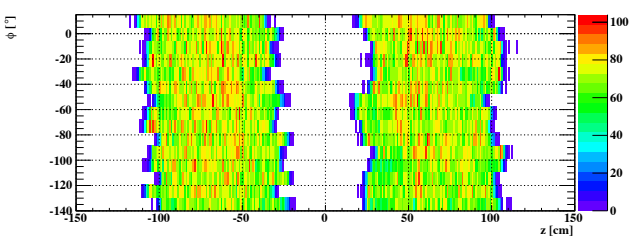
Internal spectrometer **alignment** with muon **straight tracks, global alignment** with **optical survey**

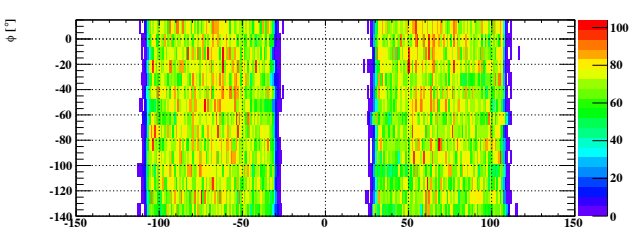
Time calibration with scintillator bars



Spectrometer performance calibrated with Mott scattering of monochromatic e^+ beam on dedicated target

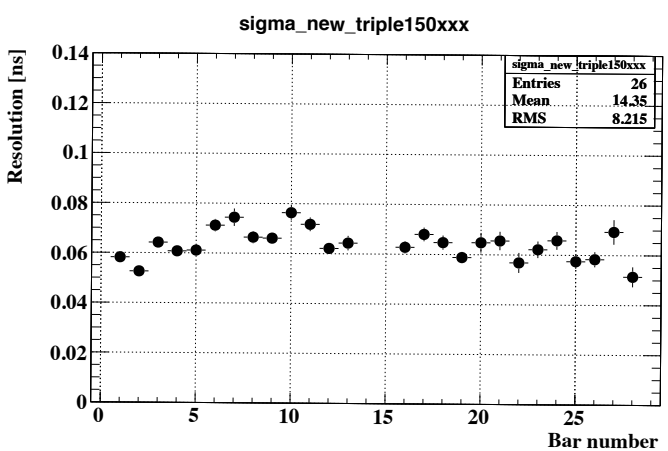






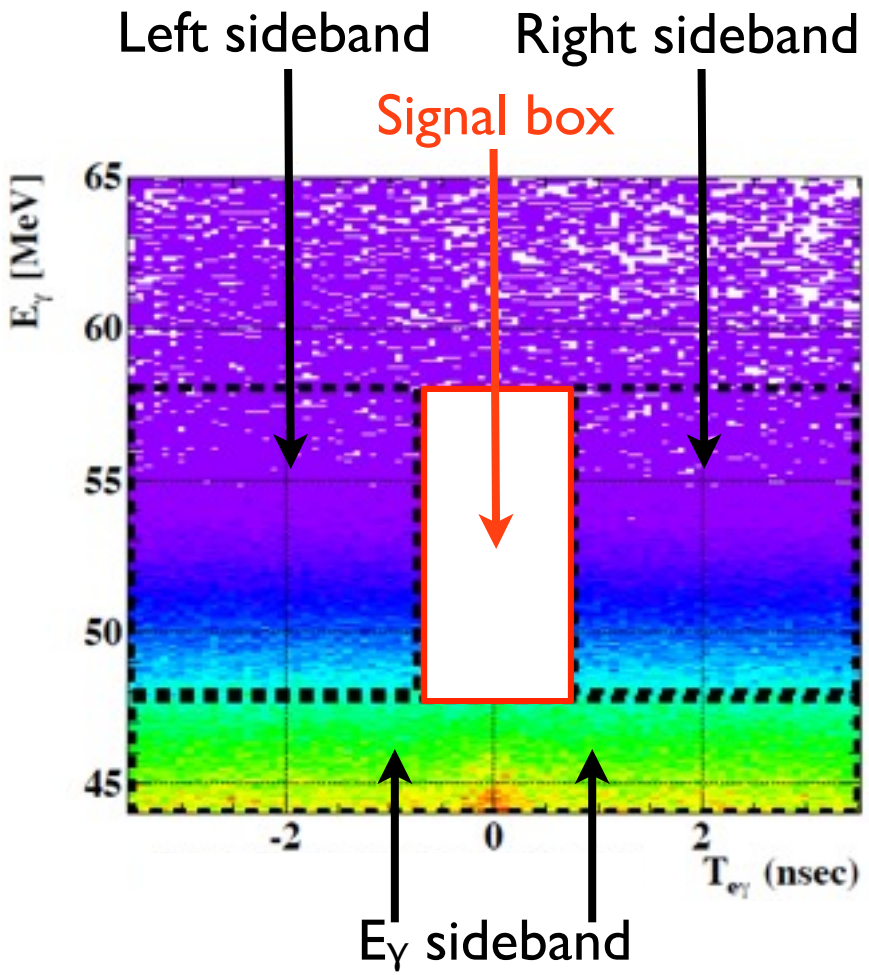
TC

PMT time offset with **cosmics** and **Michel** events, **inter bar time offset** w.r.t. **LXe detector** with **CW accelerator**



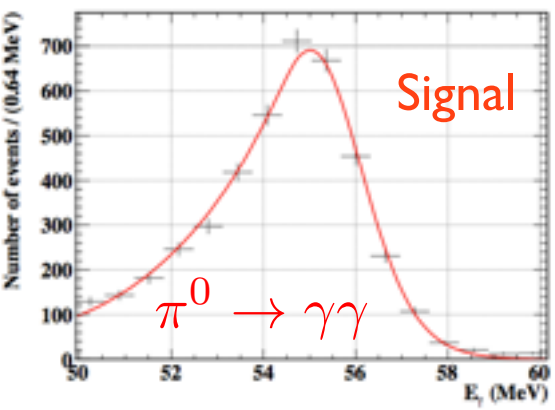
Analysis strategy

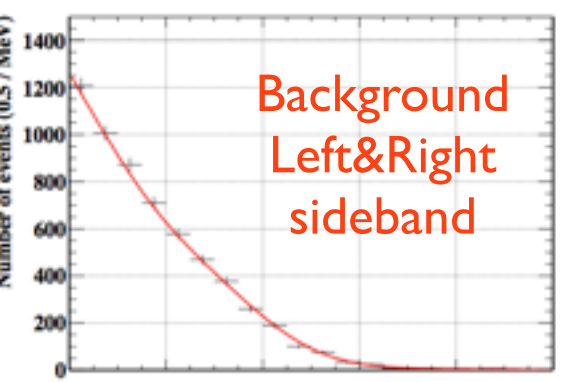
- Decided to extract **CL to B(μ→eγ)** from a **likelihood analysis** in a **wide signal box**
- Each **event** is described in terms of **5 kinematic variables**
  - $x_i = (E_\gamma, E_e, t_{e\gamma}, \varphi_{e\gamma}, \theta_{e\gamma})$
- **resolutions** and **PDFs** evaluated **on data outside the signal box**
  - *signal box* ***closed*** *until* ***analysis is fixed***
- Use of **sidebands**
  - ***accidental background*** *from* ***Left and Right sidebands***
  - ***RMD*** *studied in the* E_γ ***sideband***



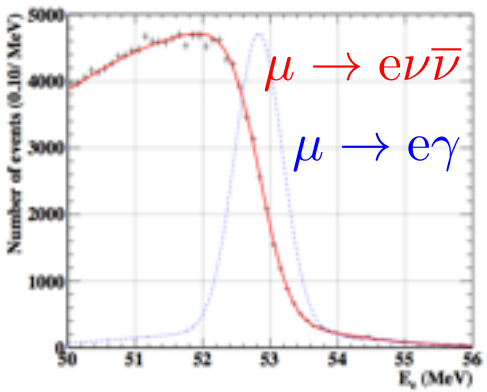
Probability density functions

Photon

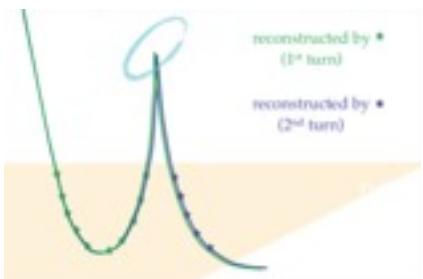




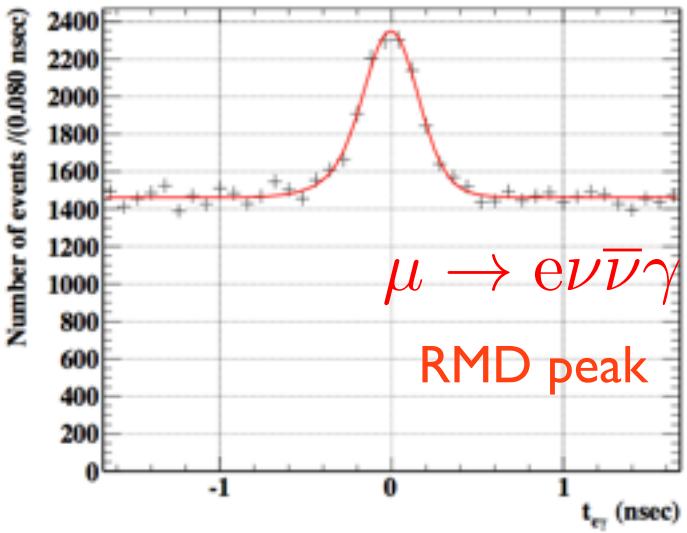
Positron



Resolutions from Michel edge and double turns method



Relative timing



	2009	2010	2011(preliminary)
γ energy (%)	1.9 (w>2cm)	1.9 (w>2cm)	1.7 (w>2cm)
γ position (mm)	5(u,v) / 6(w)	5(u,v) / 6(w)	5(u,v) / 6(w)
e^+ momentum (%)	0.59 (core 80%)	0.61 (core 79%)	0.61 (core 86%)
e^+ angle (mrad)	6.7 (Φ)/9.4 (θ)	7.2 (Φ)/11.0 (θ)	6.5 (Φ)/10.8 (θ)
vertex position (mm)	1.5 (Z) / 1.1 (Y)	2.0 (Z) / 1.1 (Y)	1.9 (Z) / 1.0 (Y)
γe timing (ps)	146	126	133
γ efficiency (%)	58	59	59
trigger efficiency (%)	91	92	95

Likelihood function

- **Likelihood** function in terms of **S**ignal, **R**adiative muon decay, and accidental **B**ackground **number of events** and **PDFs**

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

Number of background events constrained with side bands

- N_S, N_R, N_B measured **simultaneously** with an **un-binned** Likelihood fit in the **analysis box**
- **B(μ→eγ) C.L.** with **Feldman and Cousins**
- Cross-check:
  - ***two*** *independent* ***frequentistic analysis*** *with* ***different PDFs***
    - **Analysis A:** separated angles **(θeγ, φeγ)** and **event by event PDFs**
    - **Analysis B**: stereo angle **Θeγ**
  - ***third*** *analysis based on* ***Bayesian statistics***

Normalization and sensitivity

Normalization from $\mathbf{N_{\mu\to evv}}$ **events** counted **simultaneously** with the signal with **pre-scaled trigger**

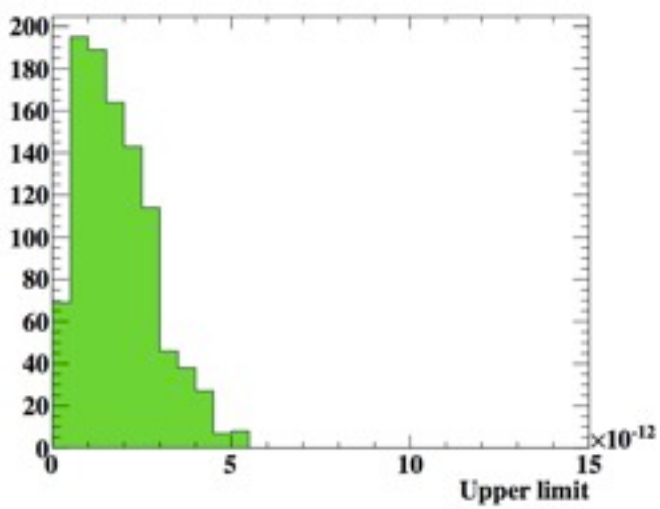
$$\frac{\mathcal{B}(\mu^+ \to e^+\gamma)}{\mathcal{B}(\mu^+ \to e^+\nu\bar{\nu})} = \frac{N_{\rm sig}}{N_{e\nu\bar{\nu}}} \times \frac{f^e_{e\nu\bar{\nu}}}{P \cdot \epsilon_{\rm pu}} \times \frac{\epsilon^{\rm trig}_{e\nu\bar{\nu}}}{\epsilon^{\rm trig}_{e\gamma}} \times \frac{\epsilon^{\rm DC}_{e\nu\bar{\nu}}}{\epsilon^{\rm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

O(1)

10^7

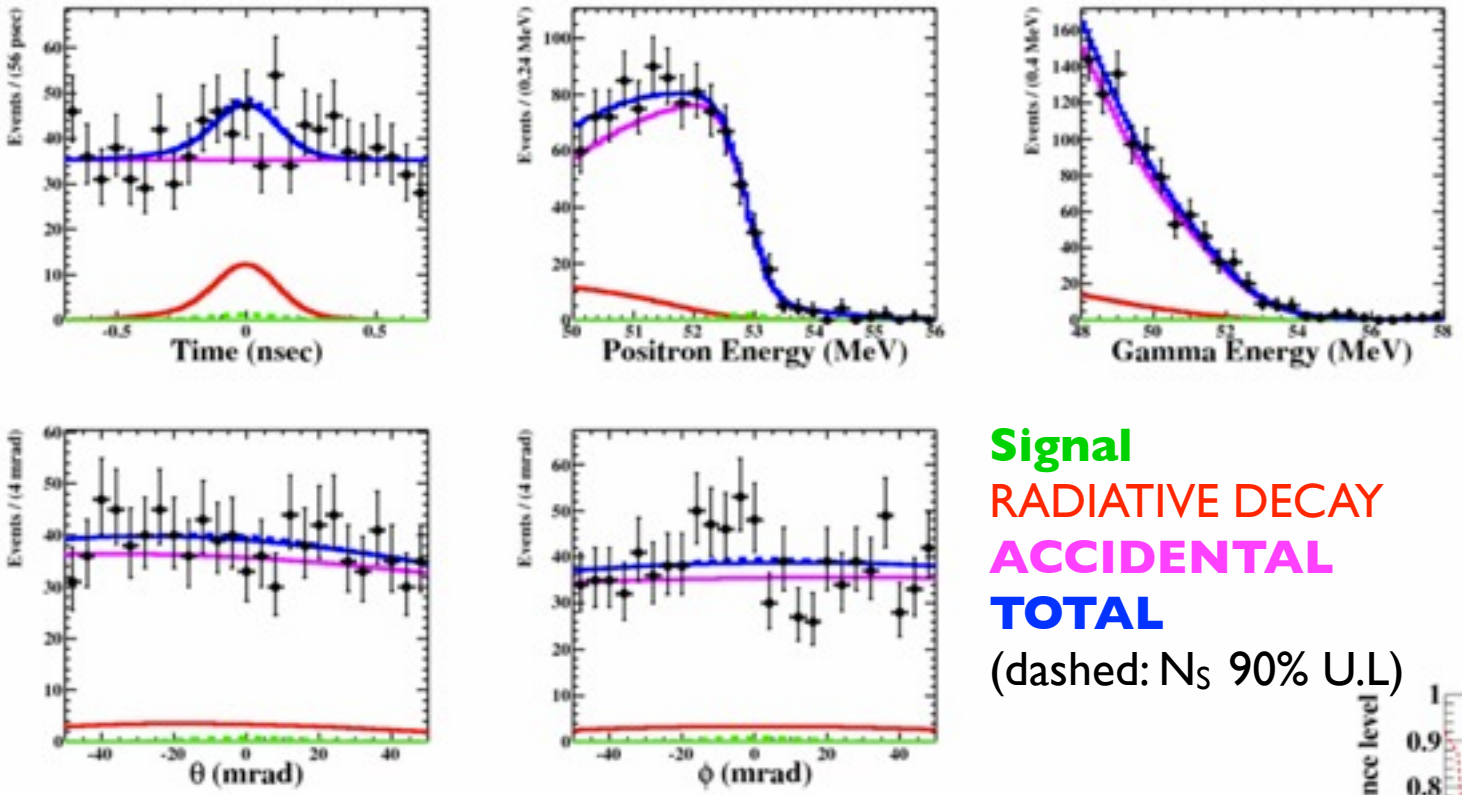
Independent estimation with **RMD, final result** by **combination**

k = 3.4 ± 0.2 × 10^{12}



Sensitivity = 1.6 × 10^{-12}
average 90% CL upper limit of toy MC with **0 signal, *consistent*** *with* ***sideband*** *results*

Latest result: 2009+2010 combined analysis



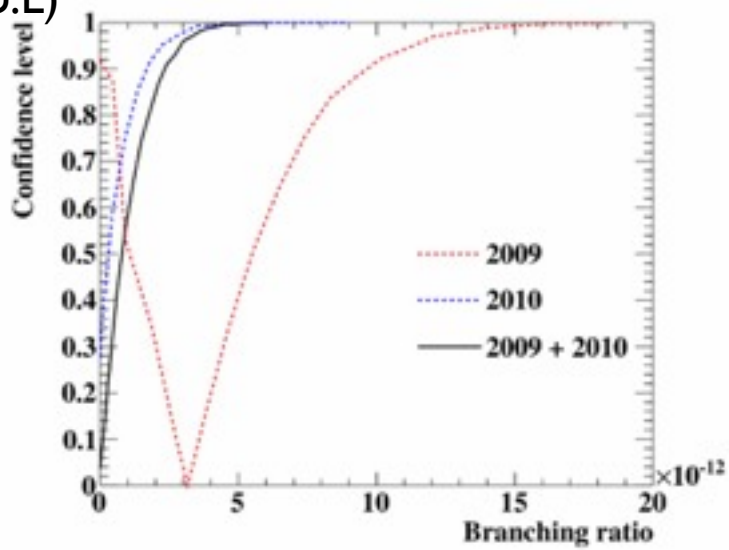
Signal
RADIATIVE DECAY
ACCIDENTAL
TOTAL
(dashed: N_S 90% U.L)

Normalization factor

$k = 3*10^{12}$

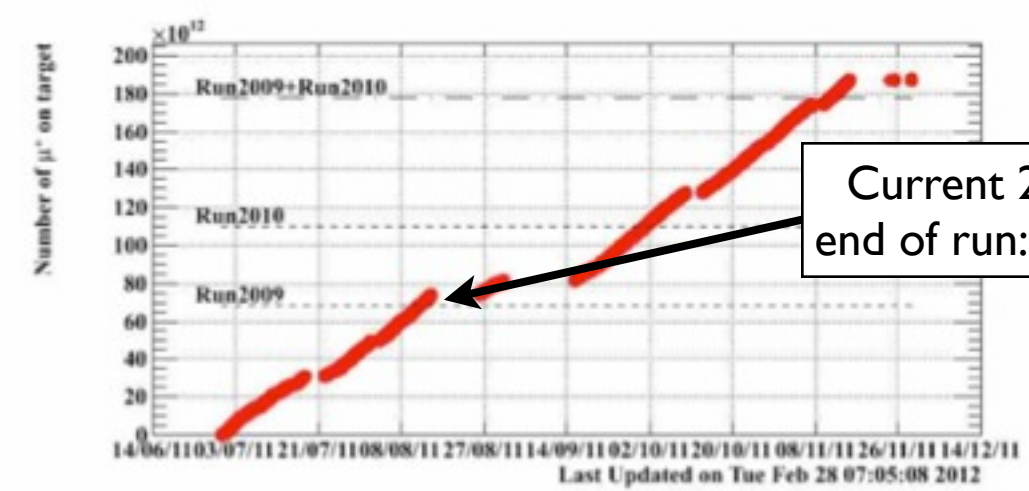
$$BR(\mu \to e\gamma) < 2.4 * 10^{-12} @ 90\% \text{C.L.}$$

Phys. Rev. Lett. 107, 171801(2011)

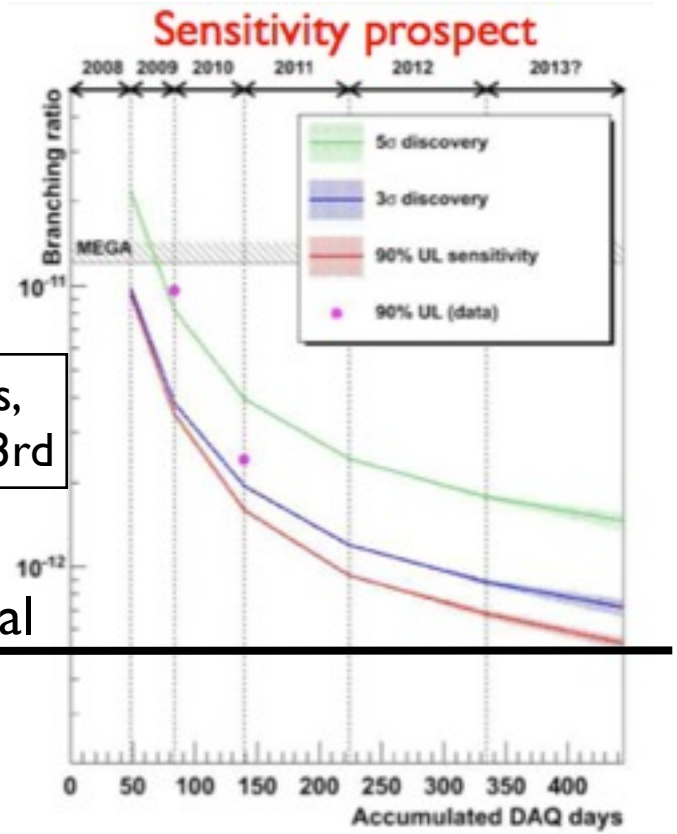


MEG future and prospects

Run2011 statistics to double
2009+2010
analysis on going (unblinding before end of this year)



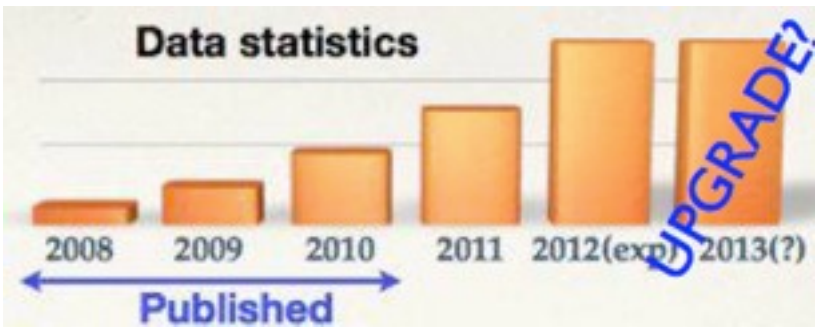
Current 2012 statistics,
end of run: december 23rd



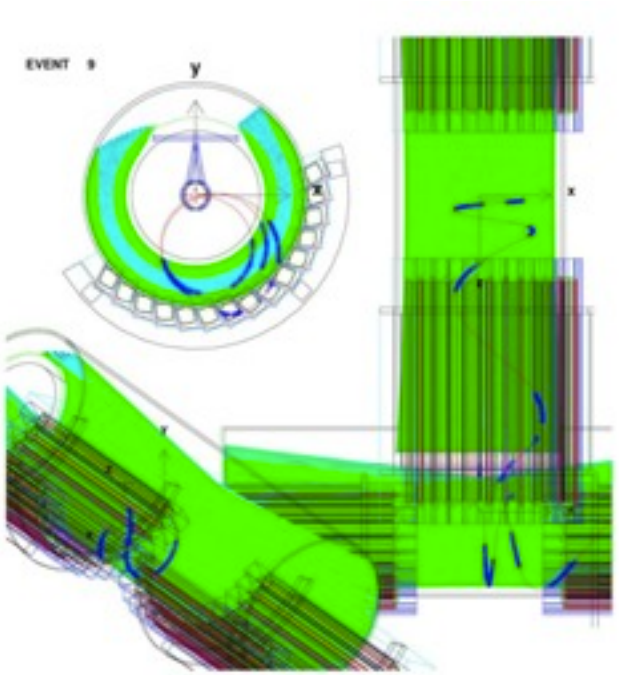
MEG goal

Goal of first part of MEG
Sensitivity = $5*10^{-13}$

Idea for a MEG upgrade
to reach $5*10^{-14}$
in 6 years from now

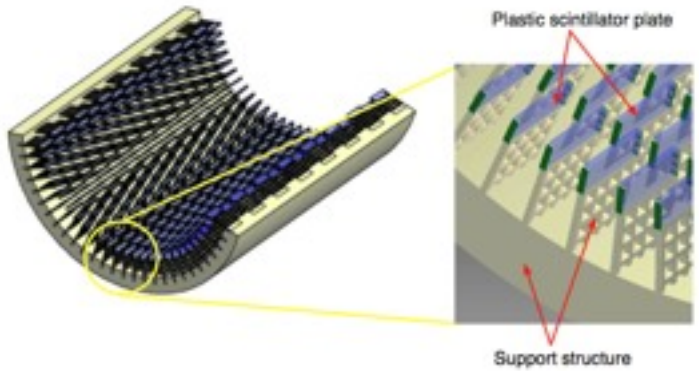


MEG baseline upgrade

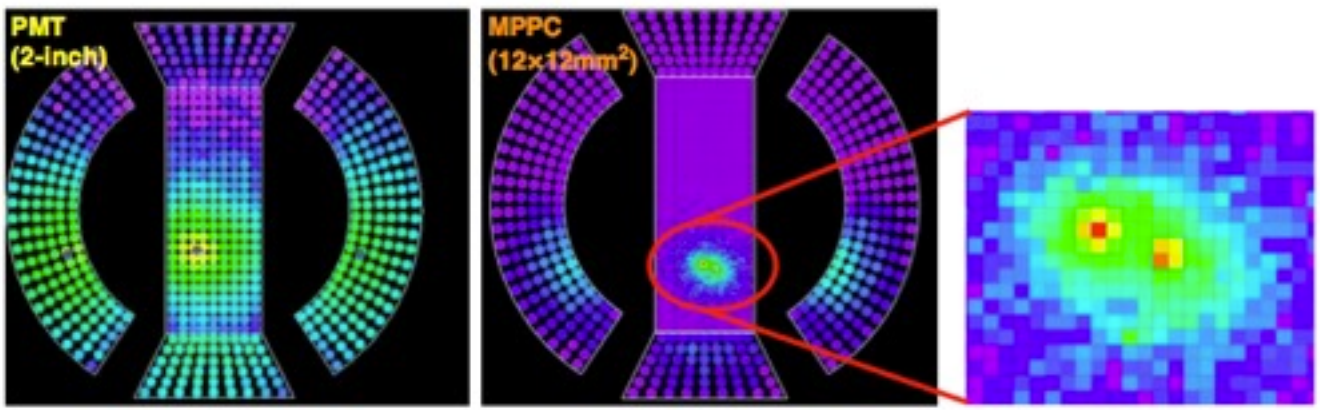


Unique volume
DC

pro: 3 times more hit, tracking up to TC and lower MS



Segmented TC with scintillator bricks and MPPC
pro: reduce pile up and multiple hit information



MPPC instead of PMT in inner face
pro: increase sensitive area close to photon conversion

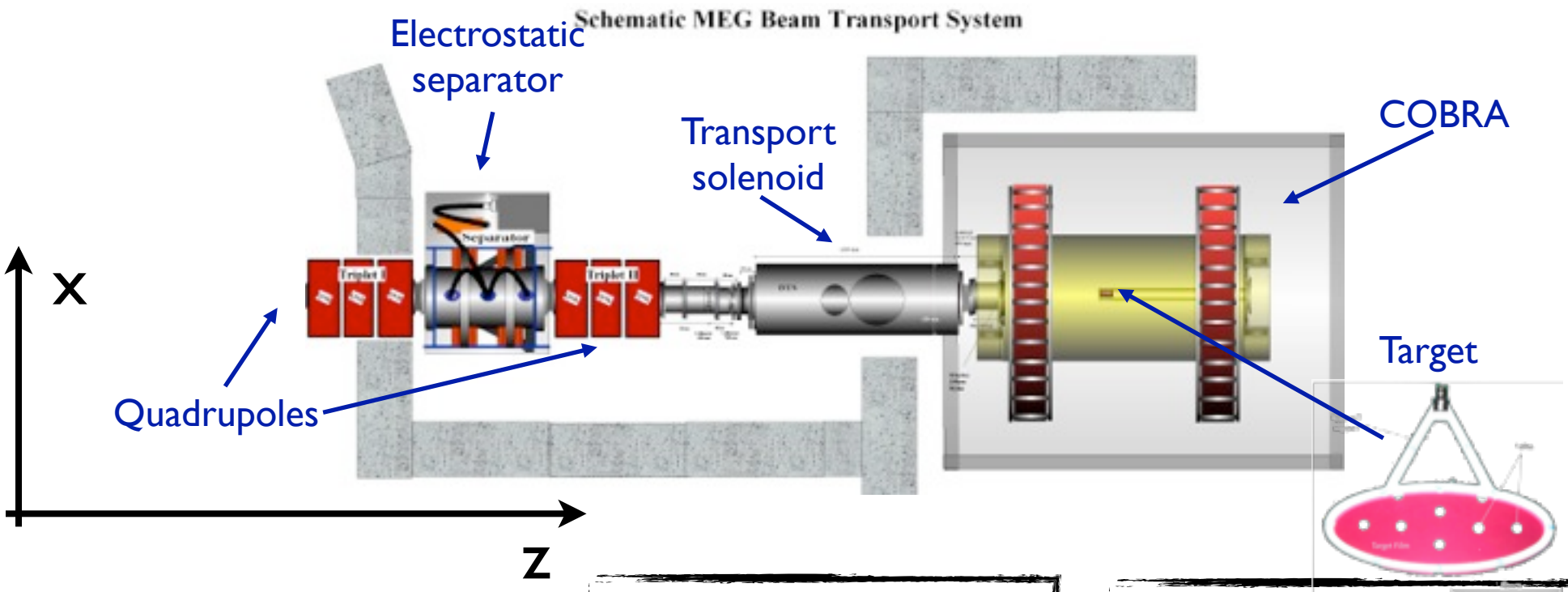
Conclusions

- In **2009 + 2010** MEG took data in a **stable detector condition** collecting **~1/3** of the **expected final statistics**
- **Result**
  - ***Sensitivity: 1.6×10^{-12}***
  - ***90% C.L. upper limit: 2.4×10^{-11}***
    - With **2011** and **2012** the **statistics** will be **tripled**
    - **2009+2010+2011** combined analysis **on going** and will be **published soon!**
- **MEG upgrade** under study
  - ***R&D*** *on going*
  - *In* ***2013 proposal to PSI*** *for* ***2 years of R&D*** *and* ***3 years*** *of* ***DAQ***
    - **MEG upgrade** goal **sensitivity = 5*10^{-14}**

Thanks for you attention!

Backup slides

μ-beam



Intensity (μ-stop/s)

- Low 2.5 x 10^6
- Normal 3.2 x 10^7
- Max 2 x 10^8

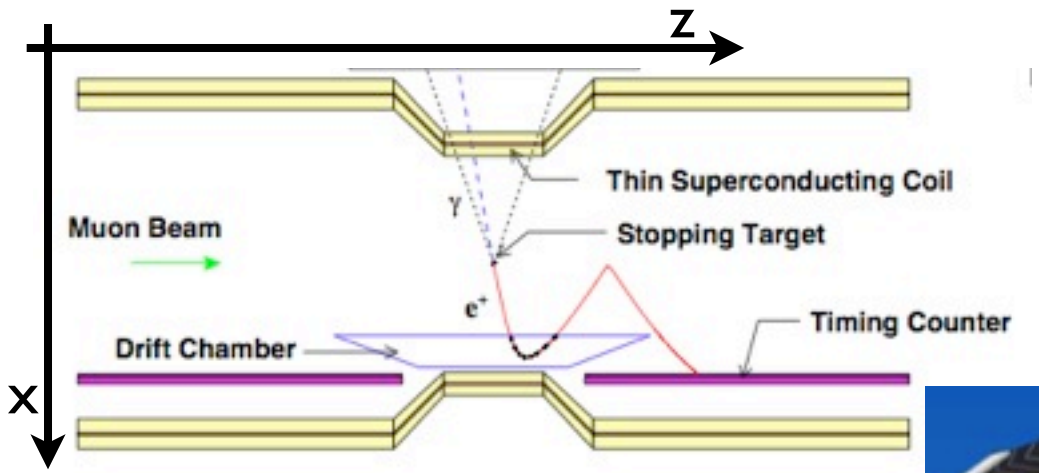
characteristics

- P = 27.7 MeV/c
- ΔP = 0.3 MeV/c
- σ_X = 9.5 mm
- σ_Y = 10. mm

MEG target

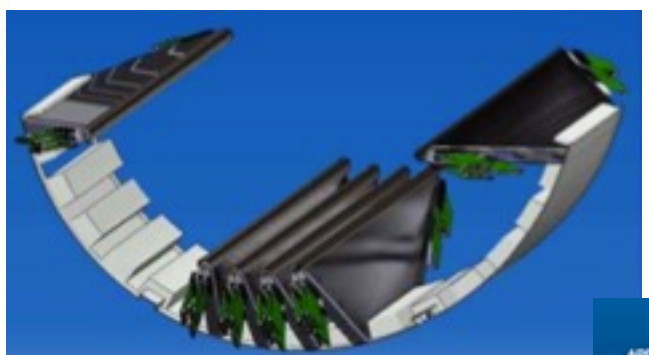
- Material CH_2
- θ = 22.5°
- thick = 205 μm
- Size = 15x25 cmxcm

Positron spectrometer



Gradient magnetic field:

- *e^+ rapidly swept away from detector*
- *bending radius ∝ |p|*



DC system

e^+ momentum

- *16 staggered ultra-thin DC (~0.0003 X_0)*

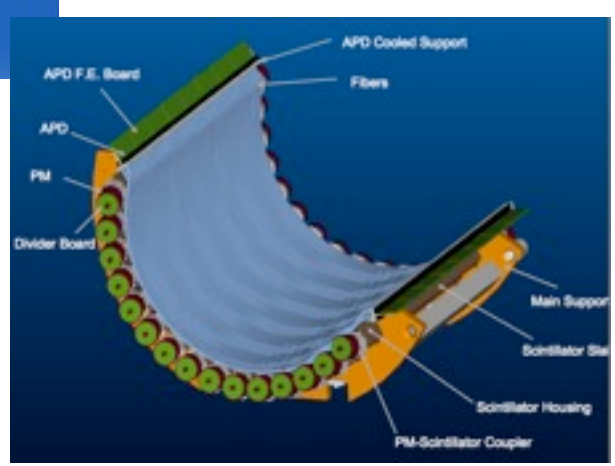
σ(p) = 200 keV/c (design)
direction = 5 mrad (design)

e^+ timing

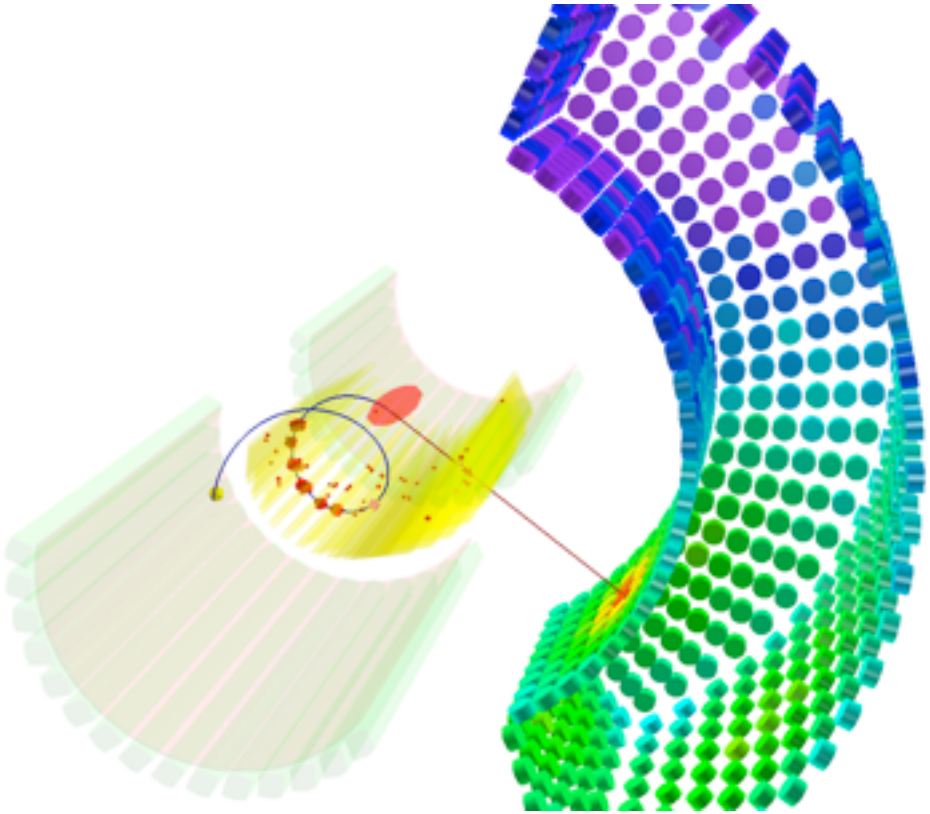
- *plastic scintillator counters*

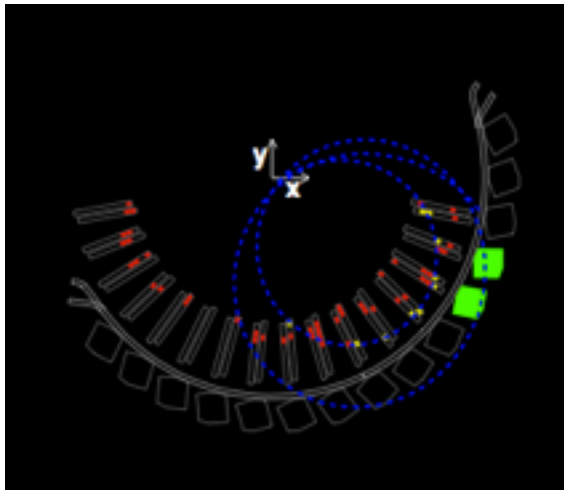
σ(t) = 45 ps (design)

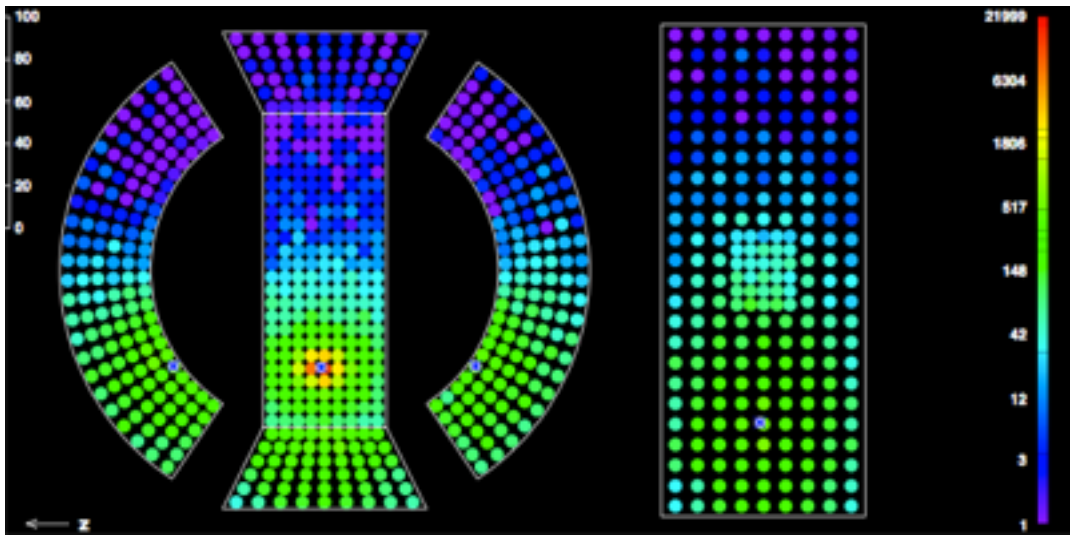
Timing Counter



MEG event display

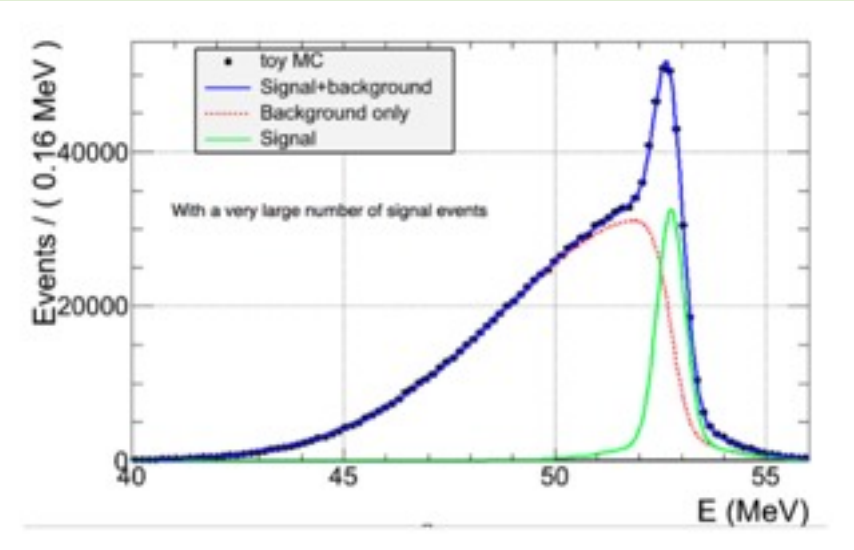




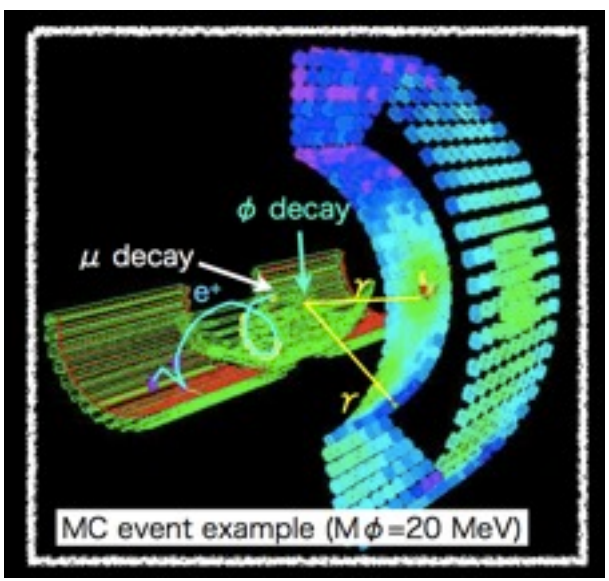


Other physics with MEG

Majoron search $\mu \to \mathrm{eJ}$
Goldstone boson from
R-parity breaking



precise measurement
of RMD a Michel
parameters

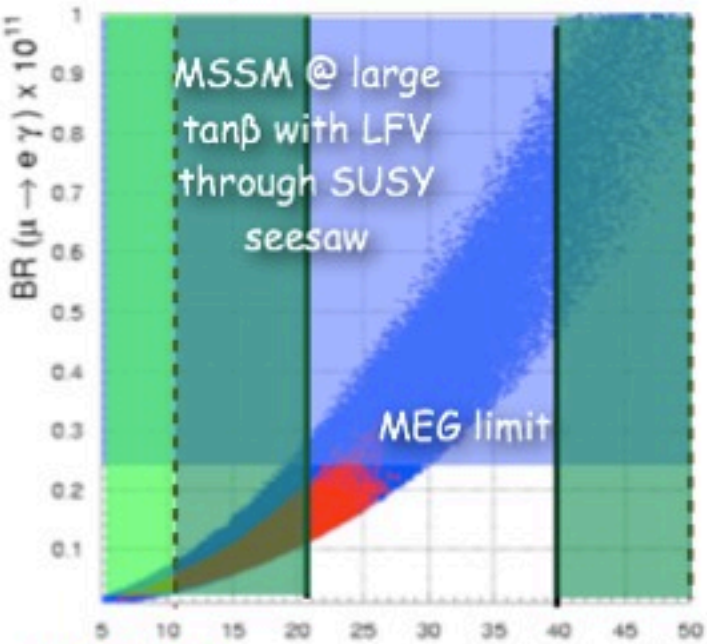


Exotic decay

$\mu \to \mathrm{e}\Phi \to \mathrm{e}\gamma\gamma$

Implications

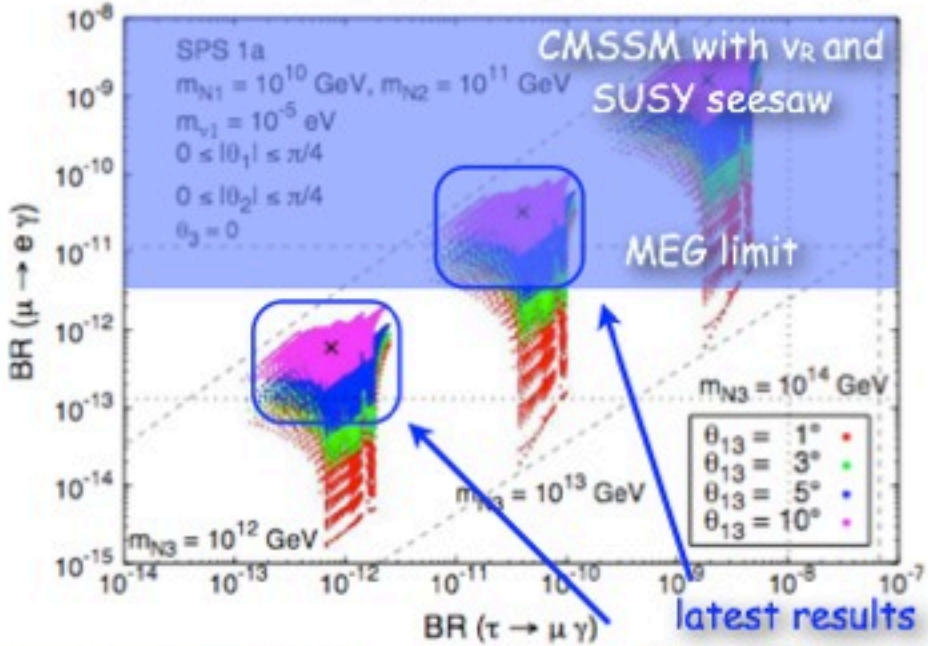
G. Isidori et al. Phys.Rev. D 75:115019, 2007



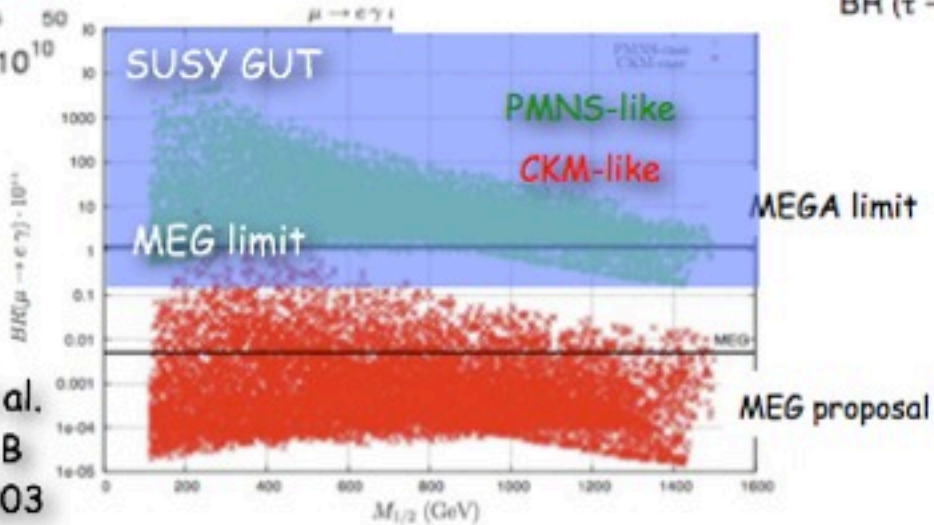
additional constraints from B physics

$\Delta a_\mu \pm 1\ (2)\ \sigma$ constraint

S. Antusch et al, JHEP 0611:090 (2006)



latest results from T2K/Double Chooz suggests theta$_{13}$ ~ 8°



Masiero et al. Nucl.Phys. B 649:189, 2003