First results from the MEG experiment

Search for Lepton Flavor Violation in $\mu^+ \rightarrow e^+\gamma$ decay

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23rd Rencontres de Blois
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Outline

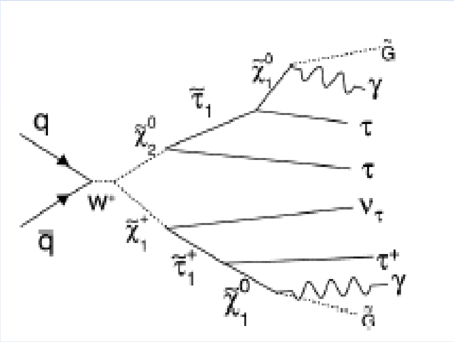
- Physics motivation for cLFV searches
- The muon channel
  - **μ -> eγ** (MEG)
  - **μ -> e e e** (SINDRUM)
  - **μA -> eA** (Mu2e, COMET)
- μ -> eγ status and perspectives
- First results from MEG experiment
- Conclusions

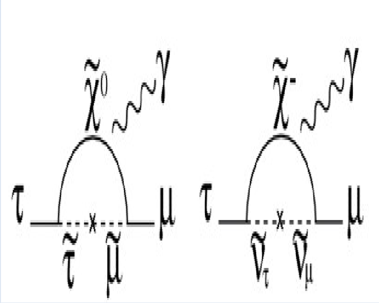
Physics motivations

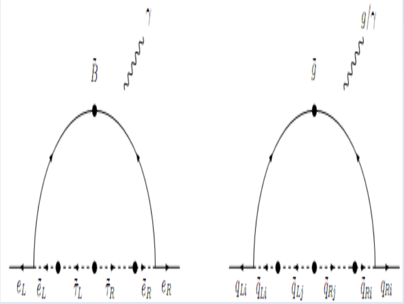
SM is believed to be a low-energy approximation a of a more fundamental theory

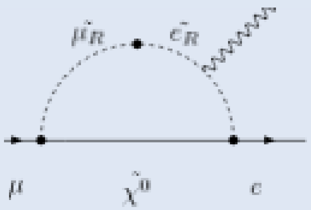
Models beyond SM contains new particles that could be directly discovered (high energy frontier) or

undirectly discovered through their contributions in loops (high precision frontier)









Physics motivations

cLFV decays is undetectably small in the extended Standard Model, whit ν masses and mixings

Example μ → e γ decay

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

$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3}\left(\frac{\alpha}{2\pi}\right)\sin^2 2\theta_\odot \left(\frac{\Delta m^2}{M_W^2}\right)^2, \Rightarrow \text{BP} \sim 10\text{–}50$$

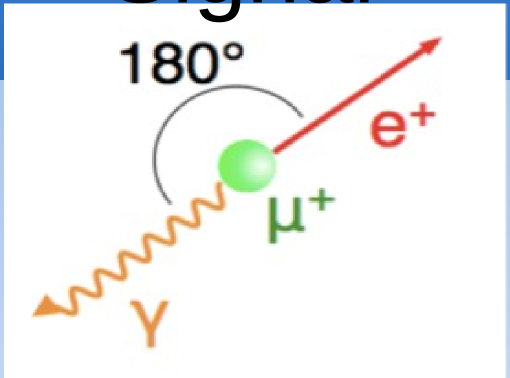
New Physics scenarios may enhance the rate of cLFV decay by over 30 orders of magnitude, through loops of new particles

cLFV decays are SM background free evidence of new physics

The expected rates are close to the experimental limits and within the capabilities of present and near future experiments

$\mu^+ \to e^+\gamma$ decay

Signal



- 2 body final state

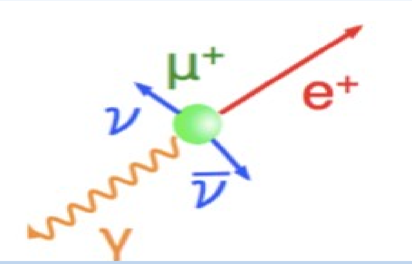
$E_\gamma = E_e = \frac{m_\mu}{2} = 52.8 MeV$

$\Delta t_{e\gamma} = 0$

$\theta_{e\gamma} = \phi_{e\gamma} = 180°$

Background

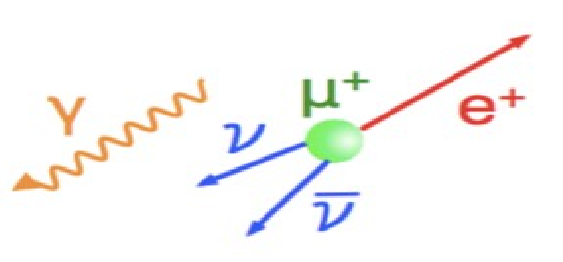
Correlated



radiative μ decay

$B_{\text{prompt}} \approx 0.1 \times B_{\text{acc}}$

Accidental

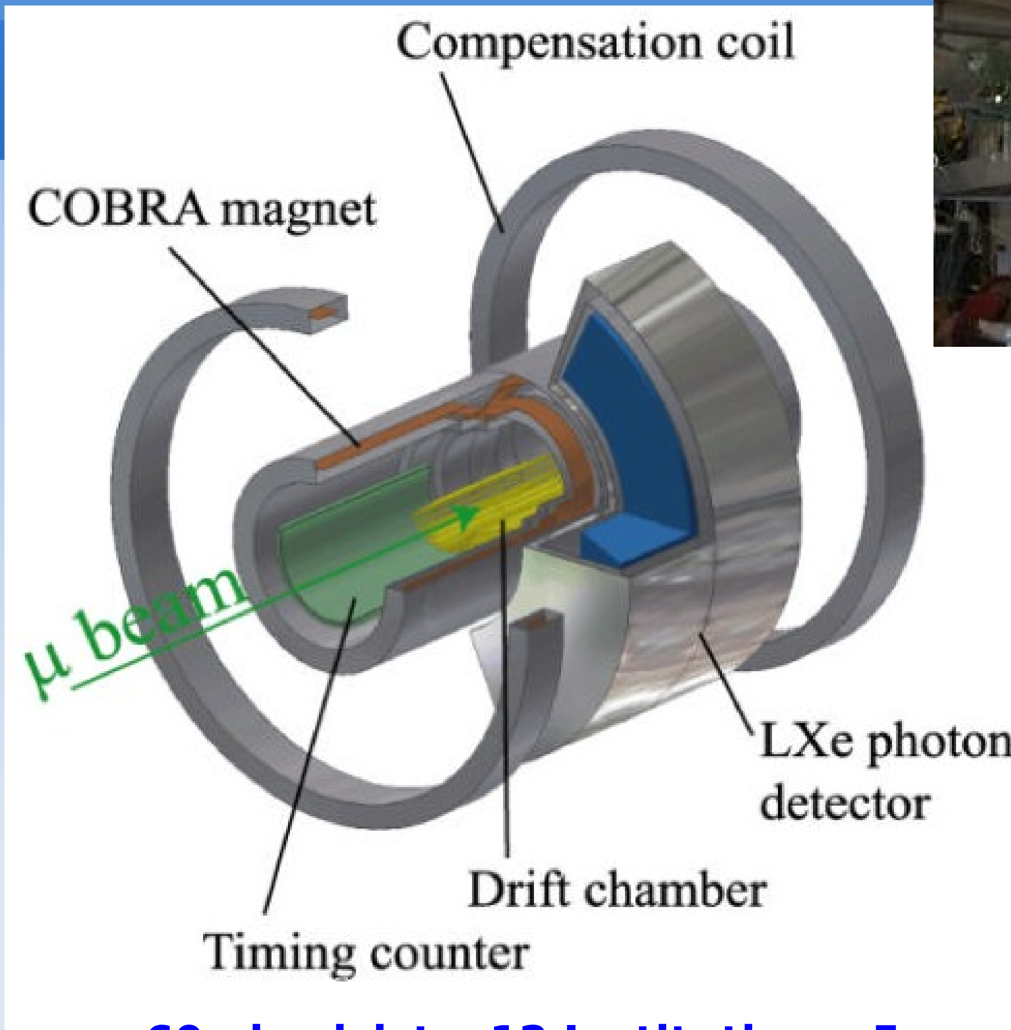


Michel decay + γ from other processes

$B_{\text{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$

- The accidental background is dominant: need of extreme high resolutions on kinematic variables

The MEG experiment



~60 physicists, 12 Institutions, 5 Countries
Italy, Japan, Russia, Switzerland, USA

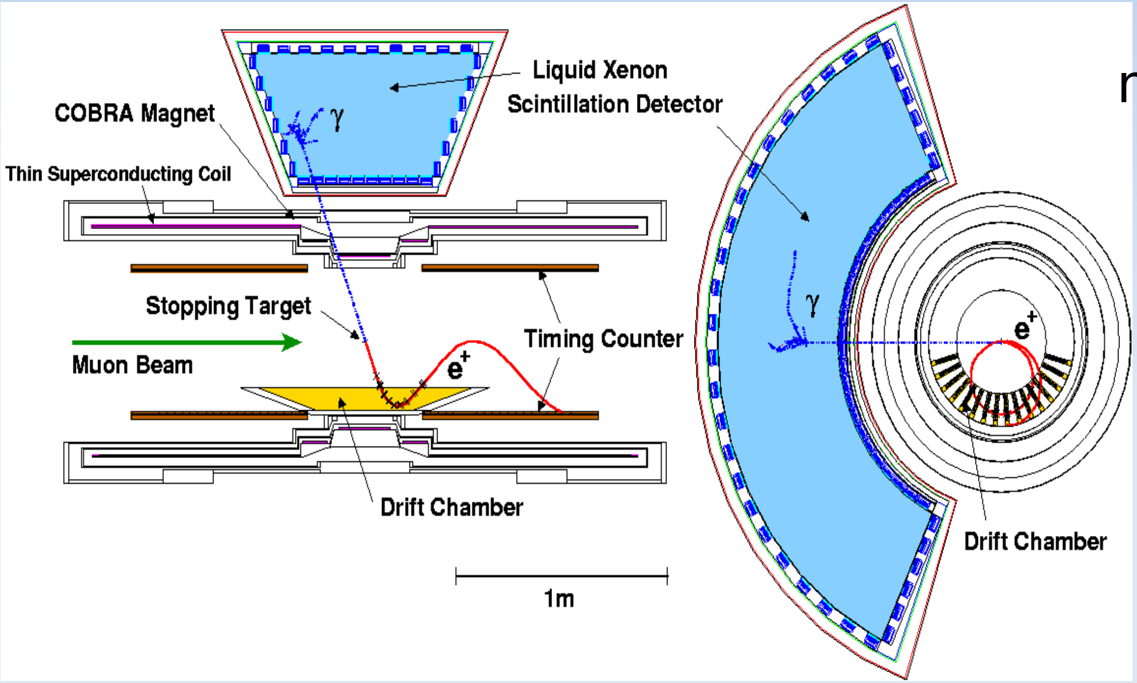
Experimental concept

Easy signal selection with μ^+ decay at rest

$$\theta_{e\gamma} = 180°$$

e^+ μ^+ γ

$$E_e = E_\gamma = 52.83 \text{ MeV}$$



Detector outline

Stopped beam of $\sim 3\times10^7$ μ /s in a 205 µm target

γ detection

Liquid Xenon calorimeter based on scintillation light

e^+ detection

magnetic spectrometer composed by solenoidal magnet with drift chambers for momentum and scintillation counters for timing

μ beam and target

Target

Intensity (μ-stop/s)

- Low 2.5×10^6
- Normal 3.0×10^7
- Max 2×10^8

Characteristics

- $P = 27.7$ MeV/c
- $\Delta P = 0.3$ MeV/c
- $\sigma_X = 9.5$ mm
- $\sigma_Y = 10.0$ mm

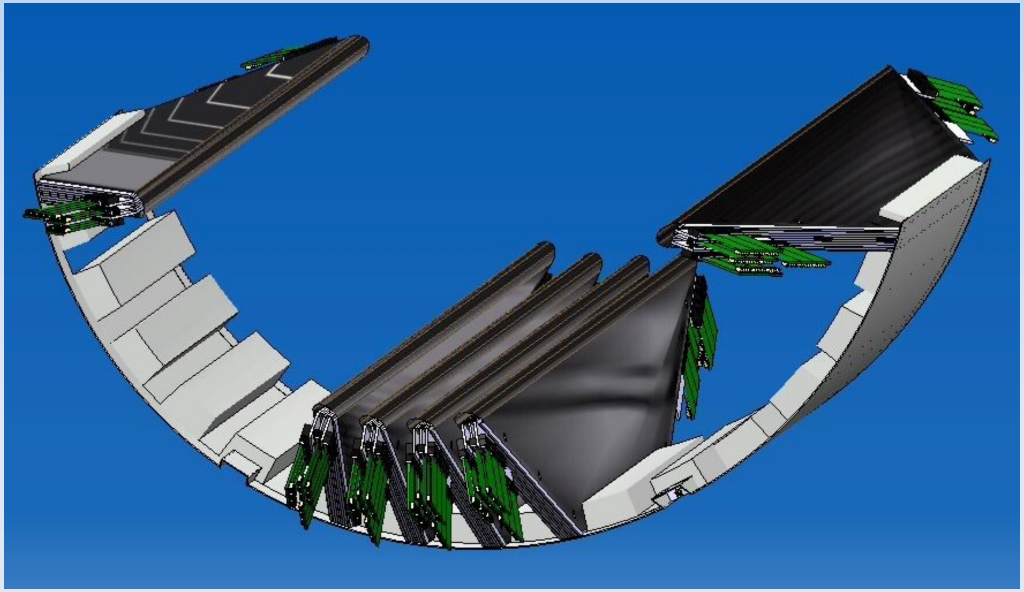
MEG target

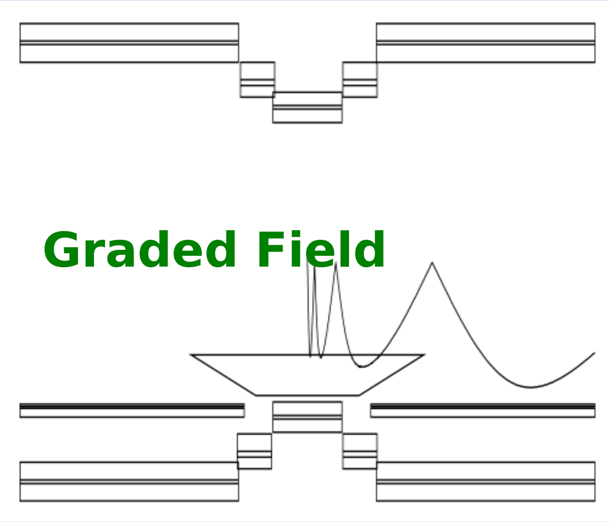
- Material CH_2
- $\theta = 22.5^o$
- Thickness = 205 μm
- Size = 15x25 cm^2

The positron spectrometer

16 low-mass *Drift Chambers* in a He atmosphere with a *graded magnetic field* :

- very low total material budget (< 5 x 10^{-3} X0);
- fast removal of tracks from the spectrometer at large polar angles.

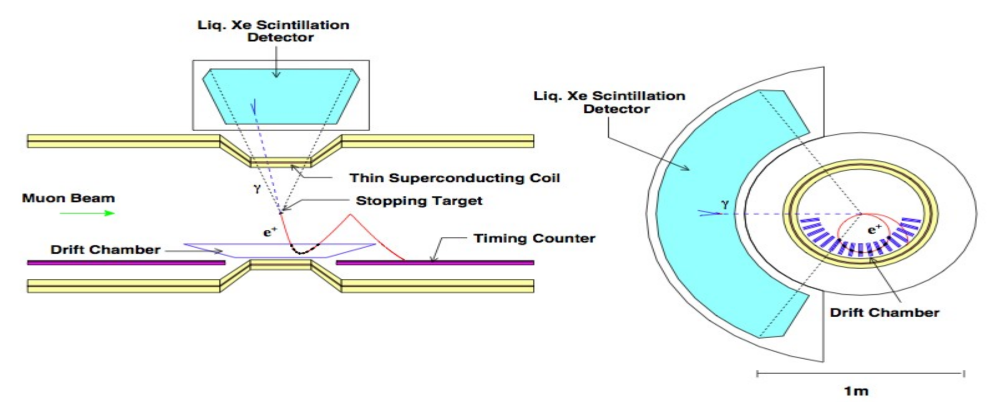


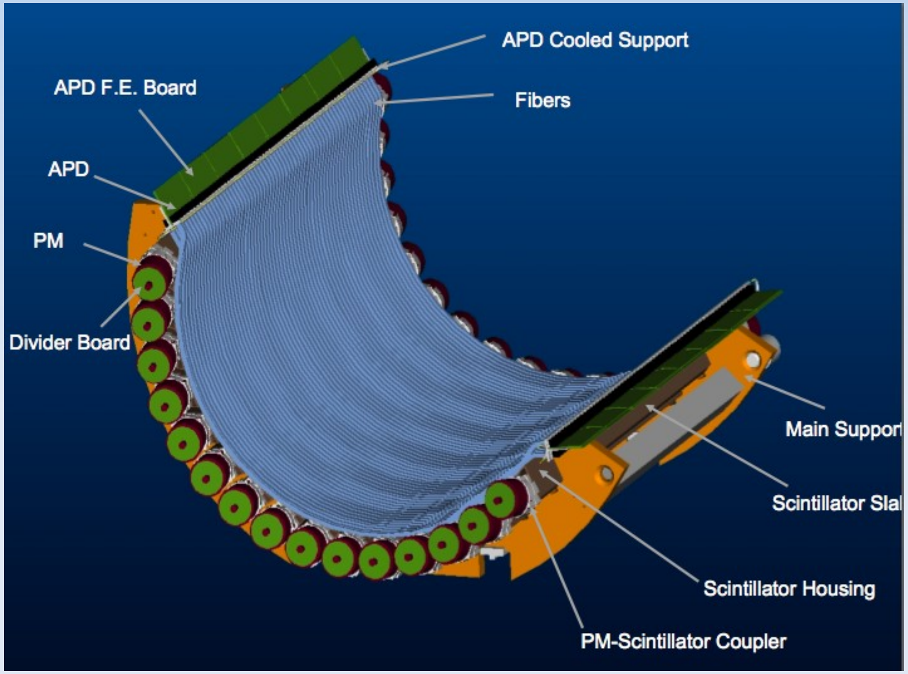


Design Resolutions
Momentum: 200 keV/c
Direction: 5.0 mrad

The timing counter

- 2 detectors (upstream & downstream) for precise positron timing and trigger;
- 15 plastic scintillating bars per detector read by PMTs:
  - timing
  - phi position
  - trigger
- 1 layer of scintillating fibers per detector, read by APDs:
  - zposition
  - trigger

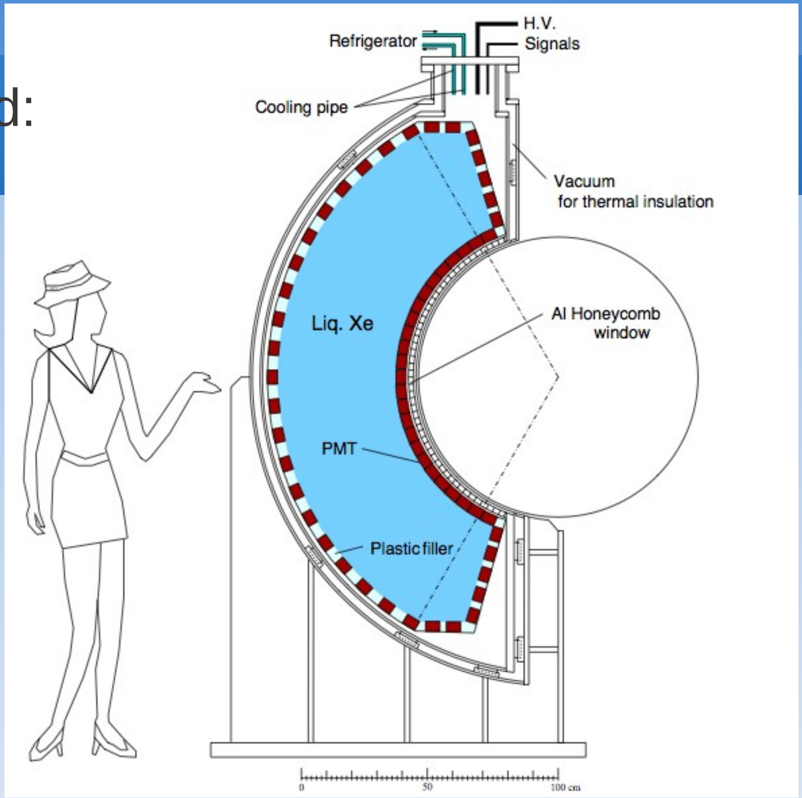




Design Resolution
Timing : 45 ps

The LXe calorimeter

- The largest LXe calorimeter in the world:
  - 800 liters;
- Fast response:
  - t = 4ns / 22ns / 45ns;
- Good light yield:
  - ~ 75% ofNaI(Tl);
- Light collected by 846 PMTs.

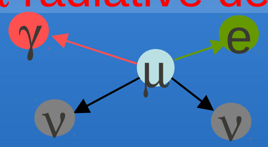


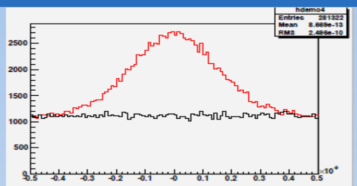
Hamamatsu R9288

Design Resolutions
Energy: 2.4MeV(FWHM)
Conversion Point: 4 mm
Time: 65 ps

Calibration tools

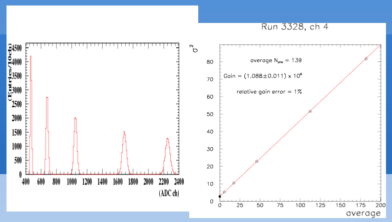
μ radiative decay

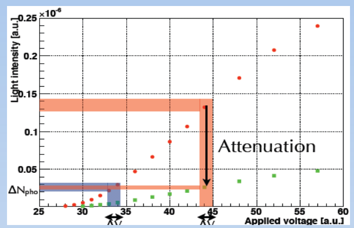




Lower beam intensity < 107
Is necessary to reduce pile-ups
Better σt, makes it possible to take data with higher beam intensity
A few days ~ 1 week to get enough statistics

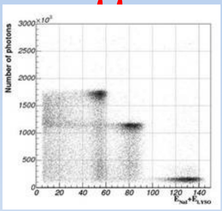
LED

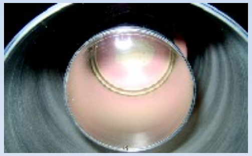




PMT Gain
Higher V with light att.
Can be repeated frequently

π0-> γγ



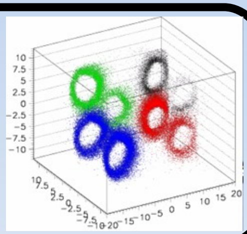


π- + p -> π0 + n
Π0 → γγ (55MeV, 83MeV)
π- + p -> γ + n (129MeV)
10 days to scan all volume precisely
(faster scan possible with less points)
LH2 target

e+
γ
e-

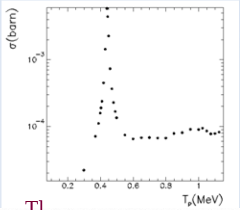
MEG Detector Standard Calibrations

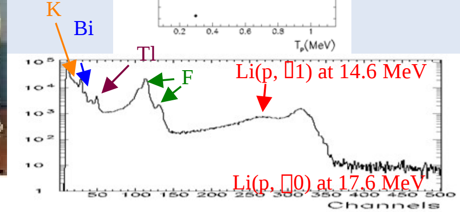
alpha



PMT QE & Att. L
Cold GXe
LXe

Proton Acc



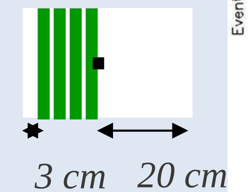


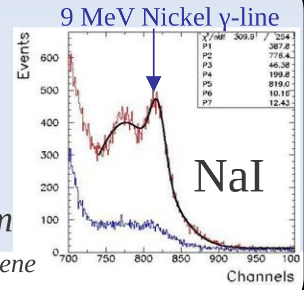
Li(p,γ)Be
LiF target at COBRA center
17.6MeV γ
~daily calib.
+ B target γ (4.4, 11.7, 16.1 MeV)
lines – Energy + Timing

Nickel γ Generator

off
on
quelle

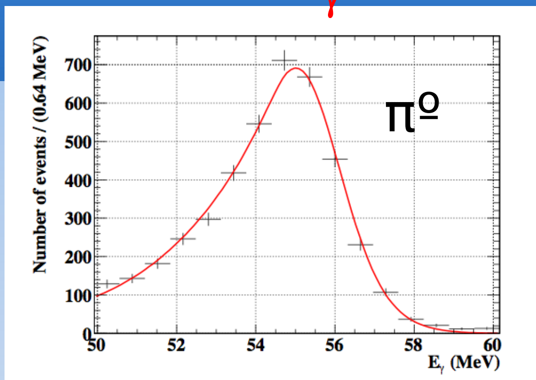
Illuminate Xe from the back
Source (Cf) transferred by compr @ on/off

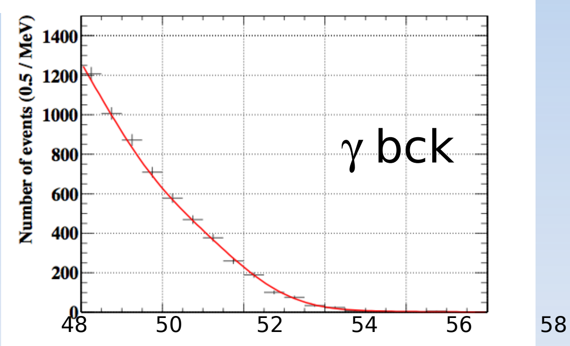




Resolutions

E_γ





Average upper tail for deep conversions

- $\sigma(E\gamma)$ = **(2.1 +-0.15) %**

Systematic uncertainty on energy scale **<0.6%**

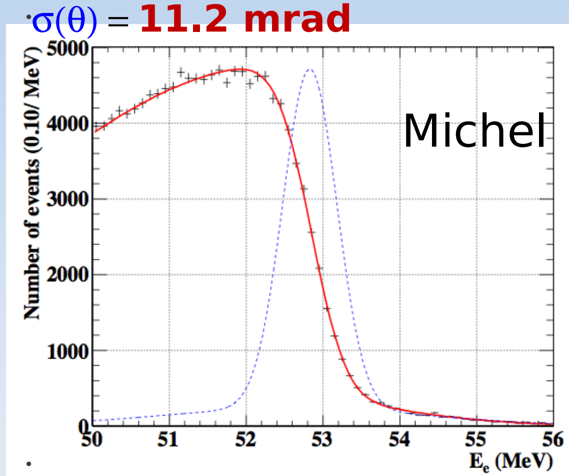
E_{e+}

Double gaussian momentum resolution

- $\sigma(p)$ = **390 KeV (0.74%)** (core)

Positron angle resolution measures using multi-loop tracks

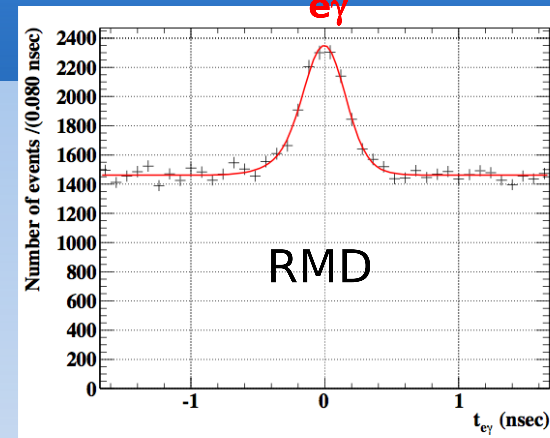
- $\sigma(\phi)$ = **7.1 mrad** (core)
- $\sigma(\theta)$ = **11.2 mrad**



Overall angular resolution combining XEC+DCH+target

- $\sigma(\phi)$ = **12.7 mrad** (core)
- $\sigma(\theta)$ = **14.7 mrad**

$T_{e\gamma}$



40 MeV < Eg < 48 MeV

Resolution corrected for a small energy-dependence

- $\sigma(t)$ = **(142 +- 15) ps**

Stability along the run

- **< 15 ps**

Analysis principle

A μ→eγ event is described by

5 kinematical variables

We decided to adopt a likelihood analysis strategy

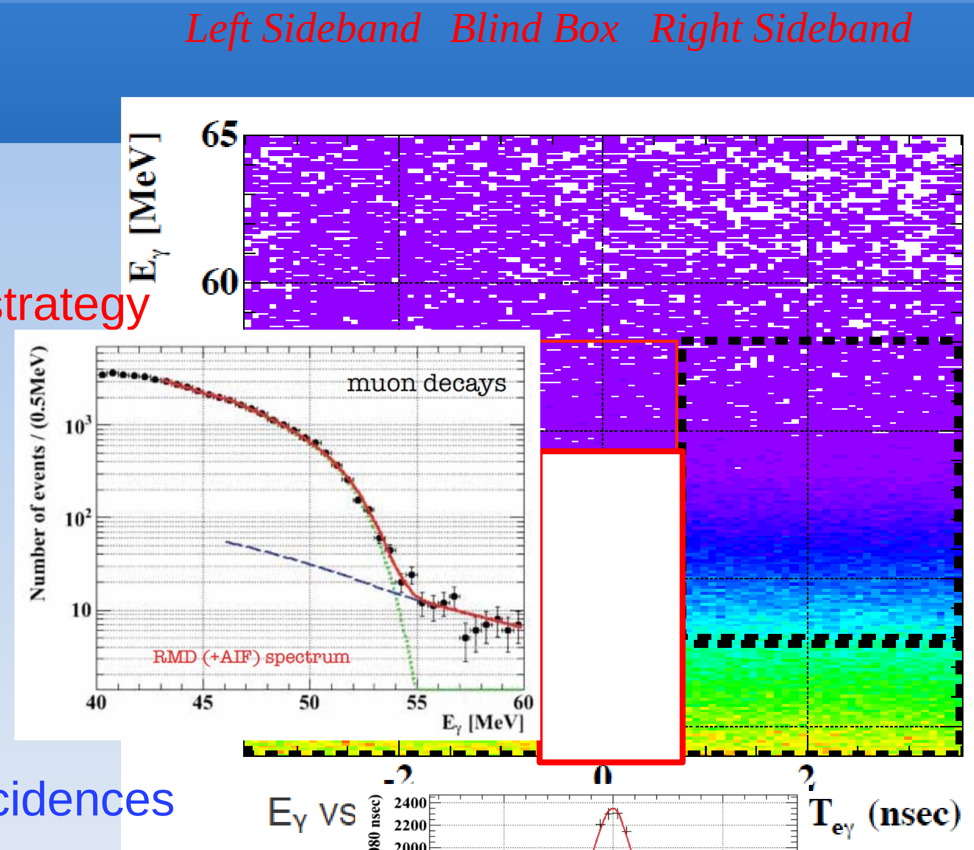
on a wide blind box

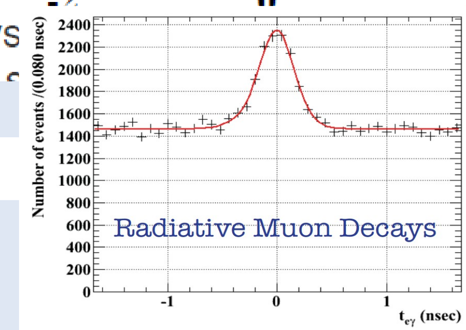
The blinding variables are

hidden until analysis is fixed

using sideband data

- main background from accidental coincidences
- RMD can be studied in the low Eγ sideband





Analysis principle

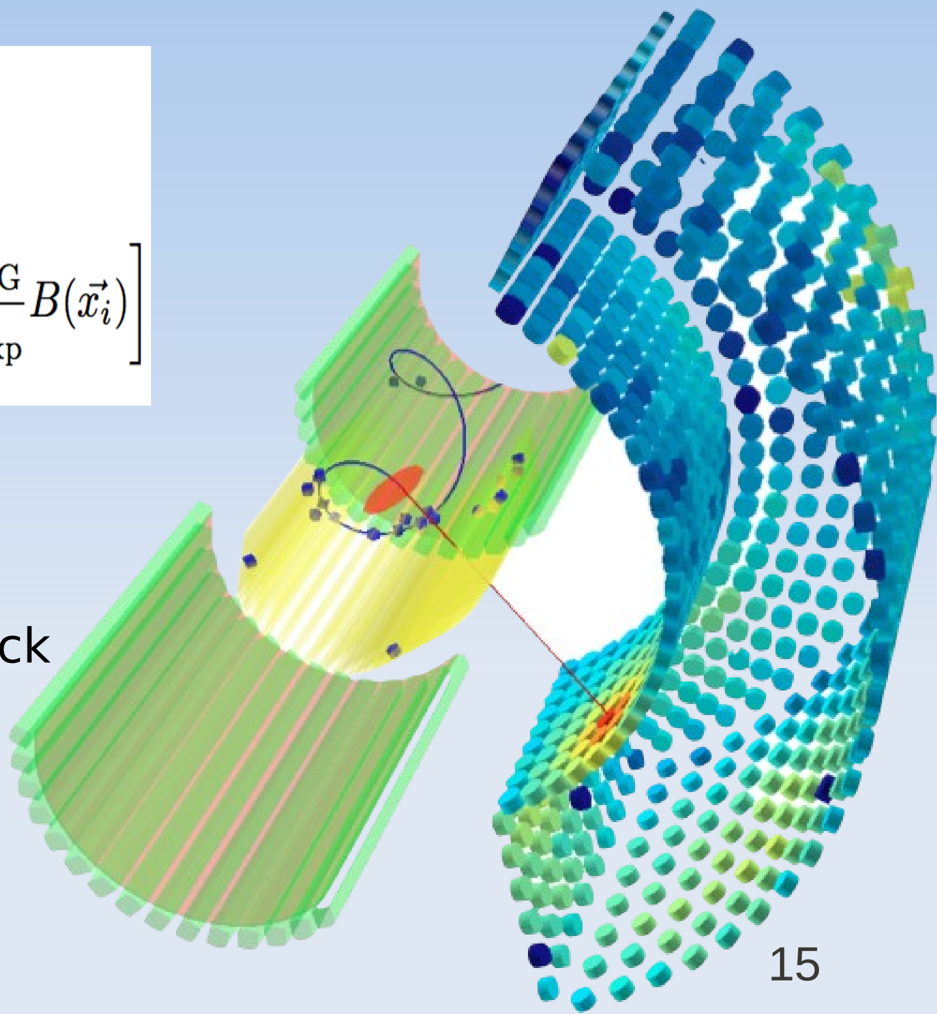
Likelihood function is built in terms of Signal, radiative Michel decay RMD and accidental background BG number of events and their probability density function PDFs

$$
\begin{aligned}
-\ln\mathcal{L}\left(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}\right) \\
&= N_{\mathrm{exp}} - N_{\mathrm{obs}}\ln\left(N_{\mathrm{exp}}\right) \\
&\quad - \sum_{i=1}^{N_{\mathrm{obs}}} \ln\left[\frac{N_{\mathrm{sig}}}{N_{\mathrm{exp}}}S(\vec{x_i}) + \frac{N_{\mathrm{RMD}}}{N_{\mathrm{exp}}}R(\vec{x_i}) + \frac{N_{\mathrm{BG}}}{N_{\mathrm{exp}}}B(\vec{x_i})\right]
\end{aligned}
$$

Un-binned likelihood fit of
over the entire blind box

Three different analysis for cross check

- PDF
- Approach (freq. or Bayes)



Probability Density Functions

Signal

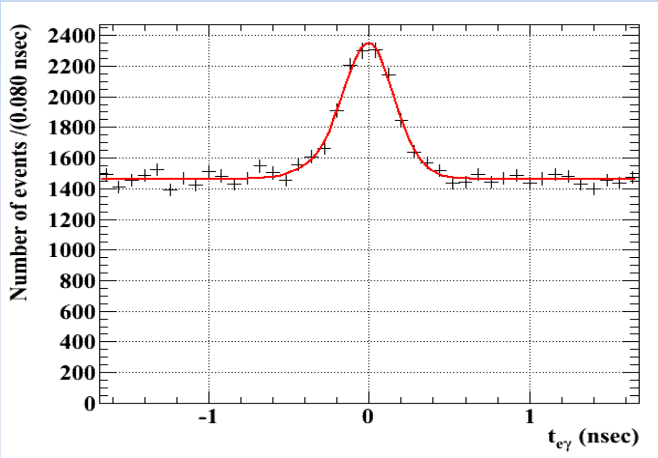
- calibration data (p0, Michel edge, CW, XEC single events ...) for photon/positron energy and relative angle
- RD data on sideband for timing (corrected for energy dependence)

RMD

- 3-D theoretical distribution folded with detector response to take into account kinematical constraints
- direct measurement for timing

BG

- Everything measured on sidebands



Important: PDF for BG are measured !

Normalization 2009

Data taking 2009 ~60 days for a total of 6.5 x 10^{13} μ

The normalization factor is obtained from the number of positrons from μ decay taken simultaneously (prescaled) with the $\mu \rightarrow e\gamma$ trigger

Cancel at first order

- Absolute e+ efficiency
- Instantaneous beam rate variations

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

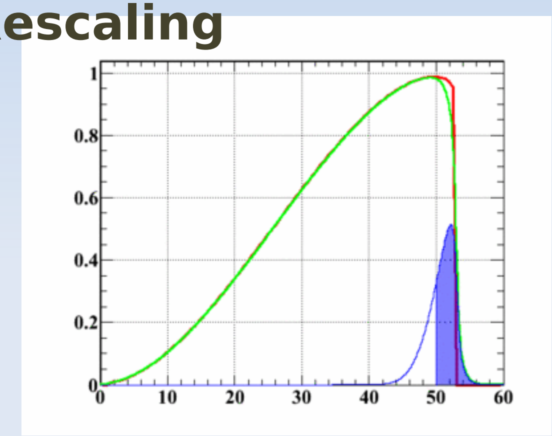
O(1)

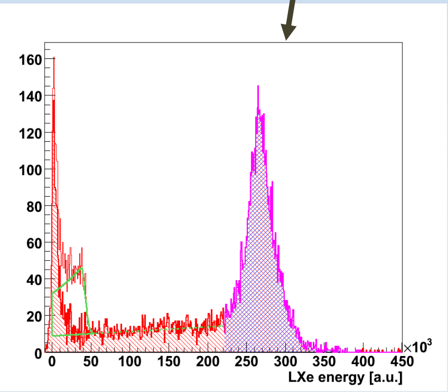
~18k **10^7 Rescaling**

theory

resolution

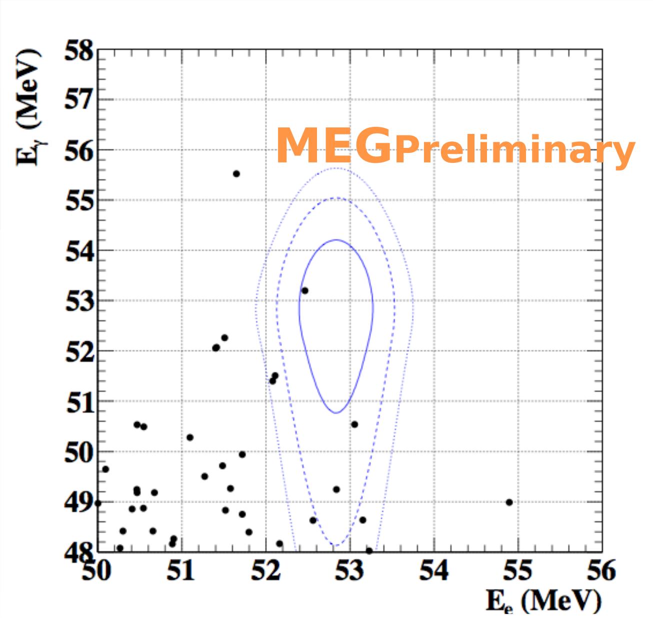
acceptance

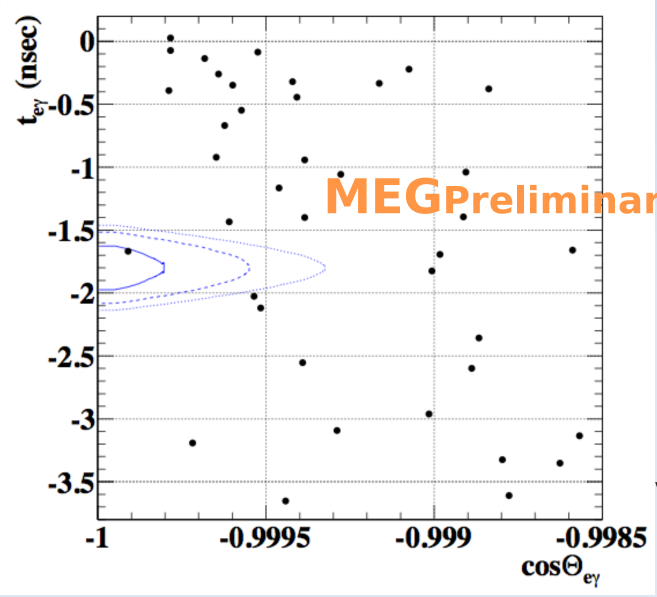




B.R. = Nsig x (1.01 ± 0.08) × 10^{-12}

Control samples





Likelihood analysis performed on the Left and Right tey sidebands gives

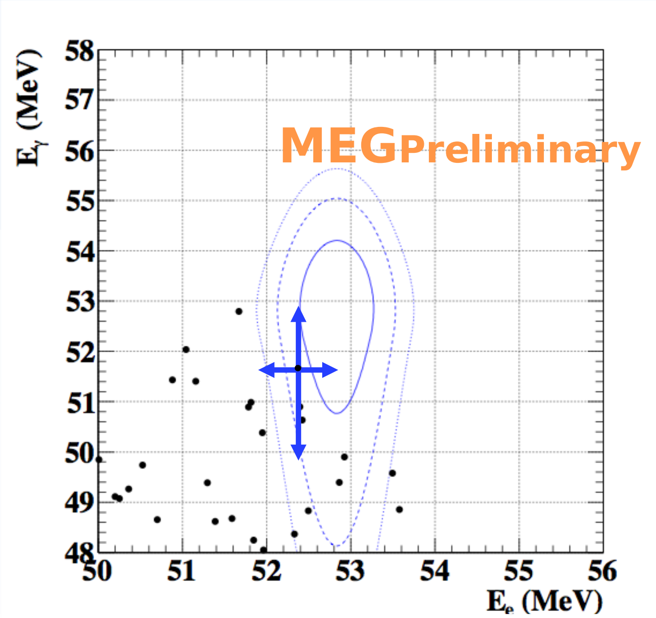
- Nsig and NRMD = 0
- BR < (4 ÷ 6) x 10^{-12}

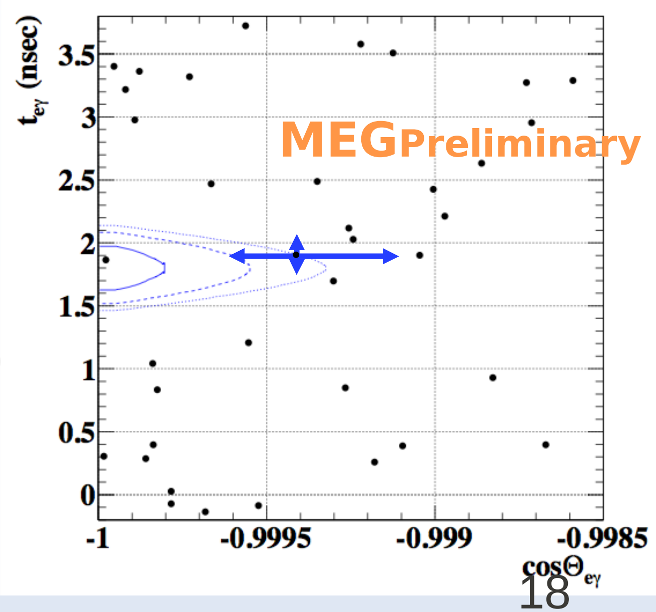
Experiment sensitivity is computed as the average 90% upper limit on toy experiments

- no signal in MC generation
- 6.1 x 10^{-12}

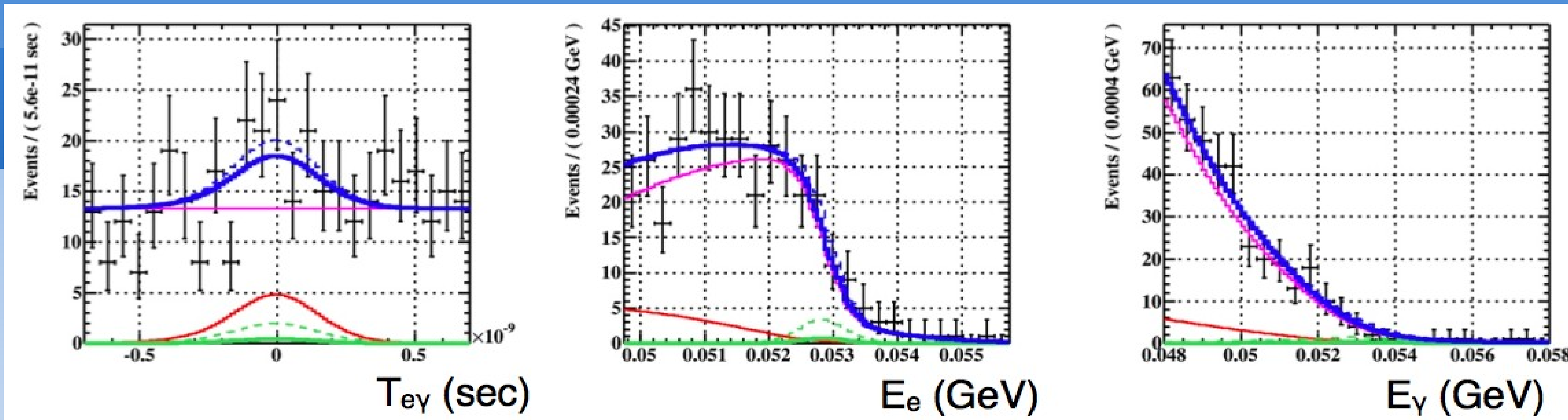
Blue lines are 1(39.3 % included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5% sigma regions.

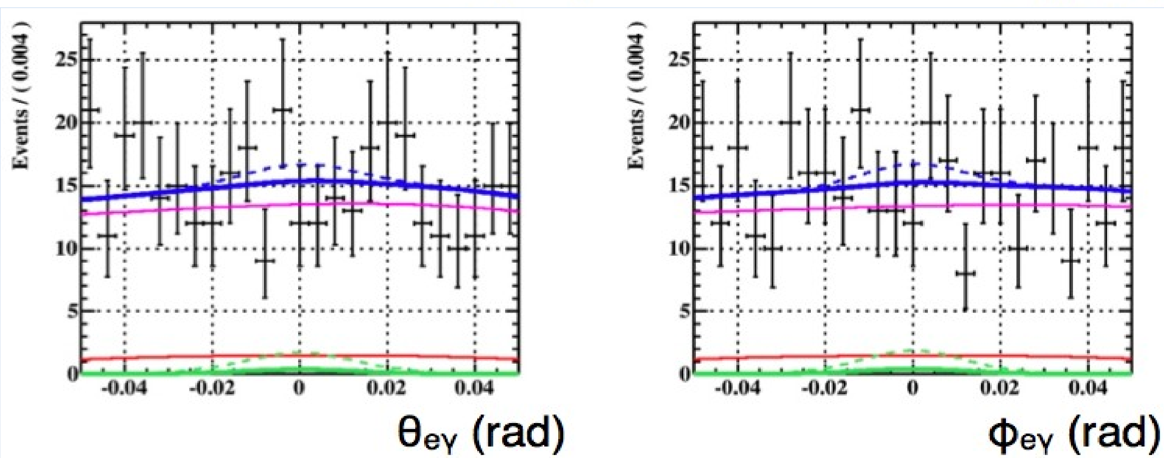
For each plot, cut on other variables for roughly 90% window is applied.





Likelihood analysis



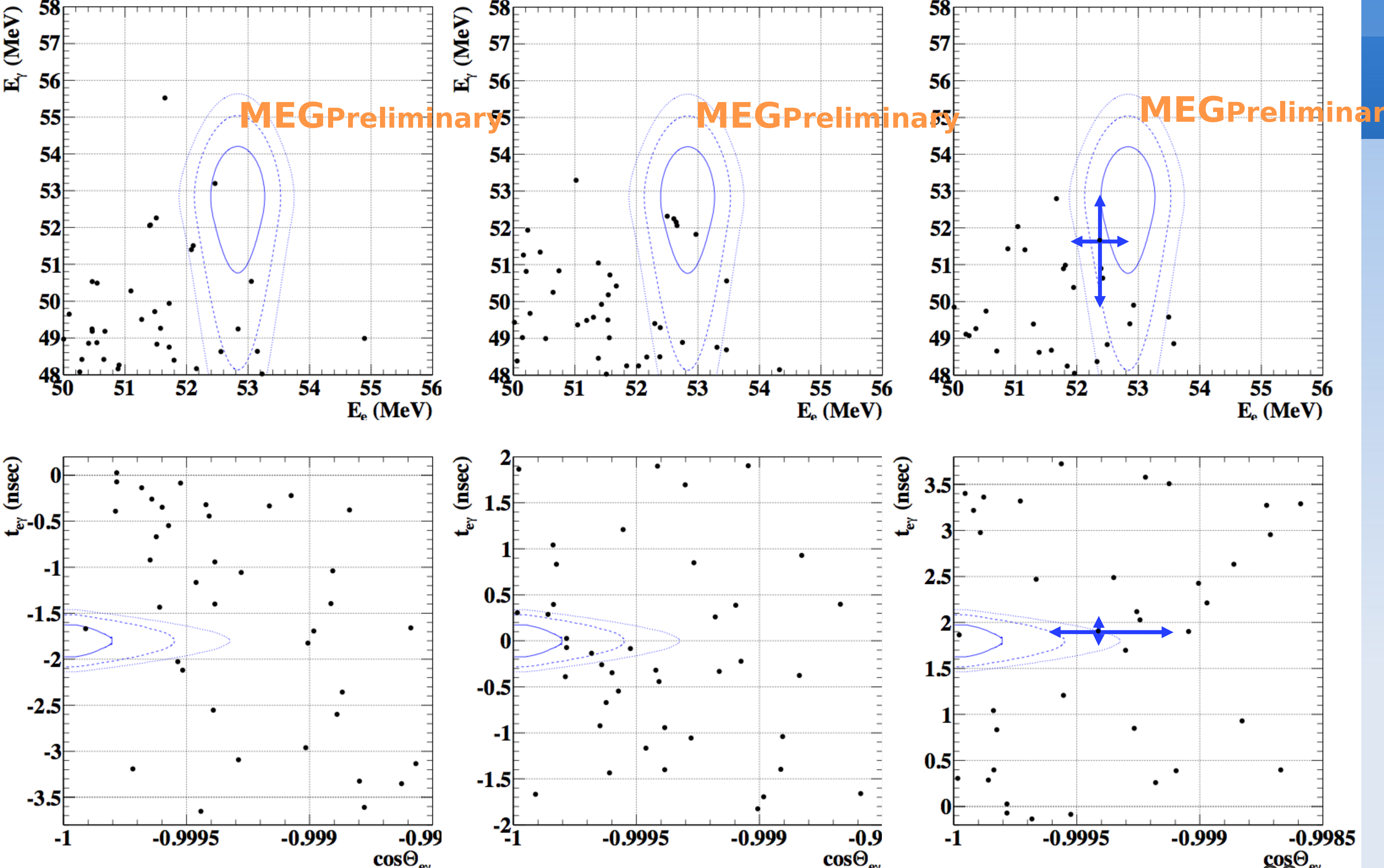


SIGNAL
RAD. DECAYS
ACCIDENTAL
TOTAL

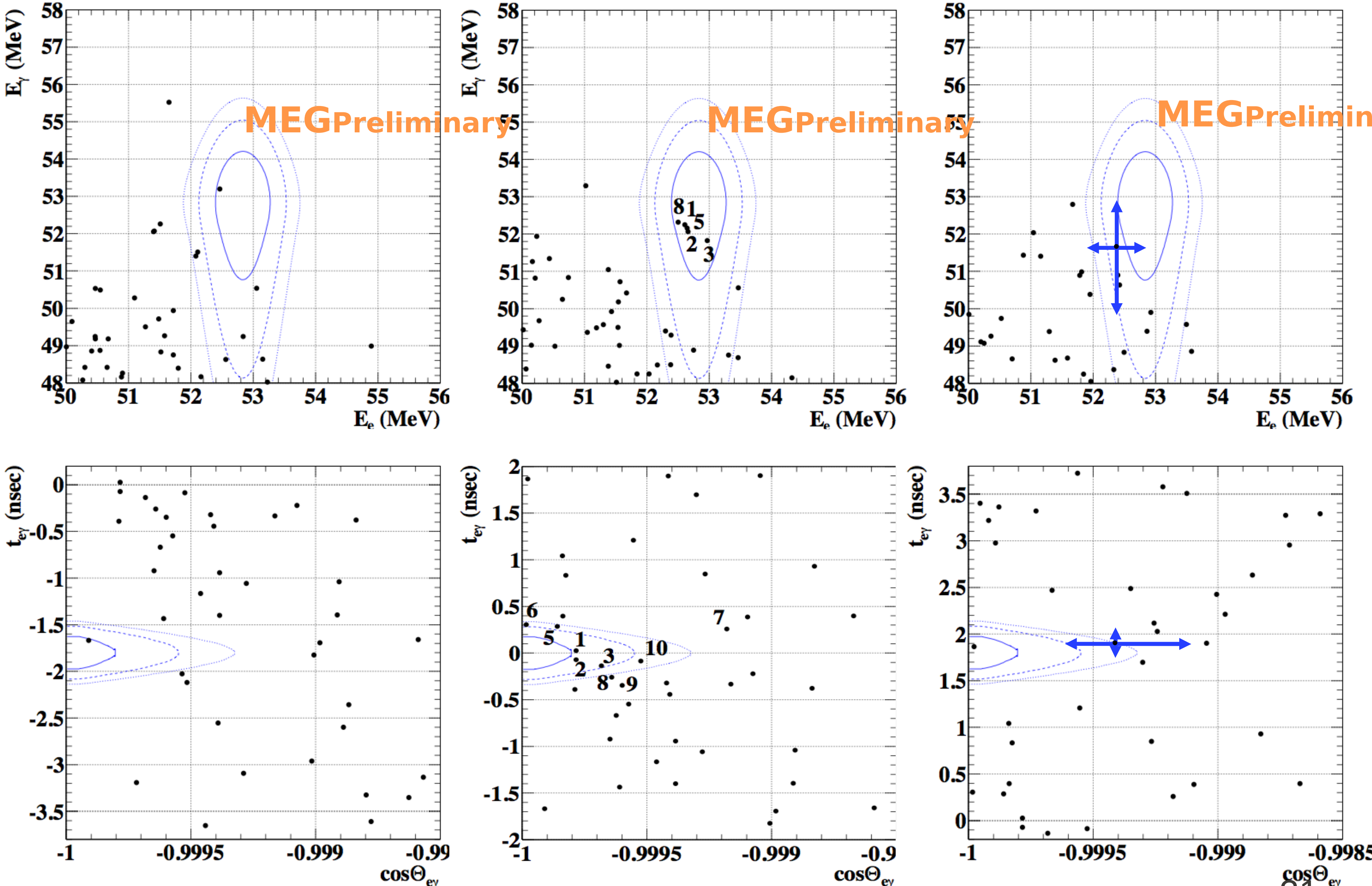
(dashed: 90% U.L)

Best fit:
Nsig = 3.0, NRMD = 35+24-22
(expected , NRMD = 32 ± 2)
Nsig < 14.5 @ 90% C.L. (Feldman-Cousins)

Blind box content



Blind box content



Result

From the preliminary analysis of 2009 data the MEG Upper Limit is

BR($\mu \rightarrow e\gamma$) @90% CL < 1.5 x 10^{-11}

The Nsig = 0 hypothesis is included in the 90% interval

The published result on 2008 data was (Nucl.Phys. B834(2010)1-12)

BR(μ->$e\gamma$) @90% CL < 2.3 x 10^{-11}

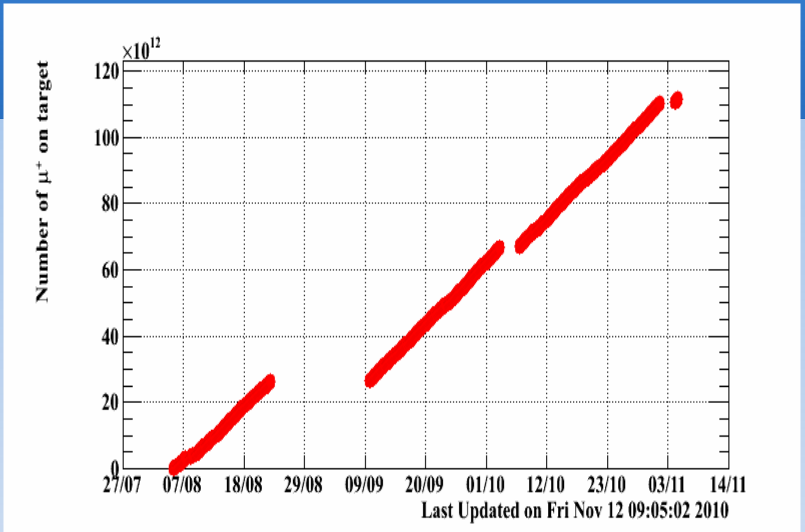
The best Upper Limit from MEGA is (Phys.Rev. D65 (2002) 112002)

BR($\mu \rightarrow e\gamma$) @90% CL < 1.2 x 10^{-11}

MEG 2010 and later

2010 run prematurely ended by a quench in the Beam Transport Solenoid

2009 statistics only doubled



The collaboration is considering the publication of combined 2009-2010 data in summer.

- 2011 run will start in July

- Two full year run 2011 / 2012

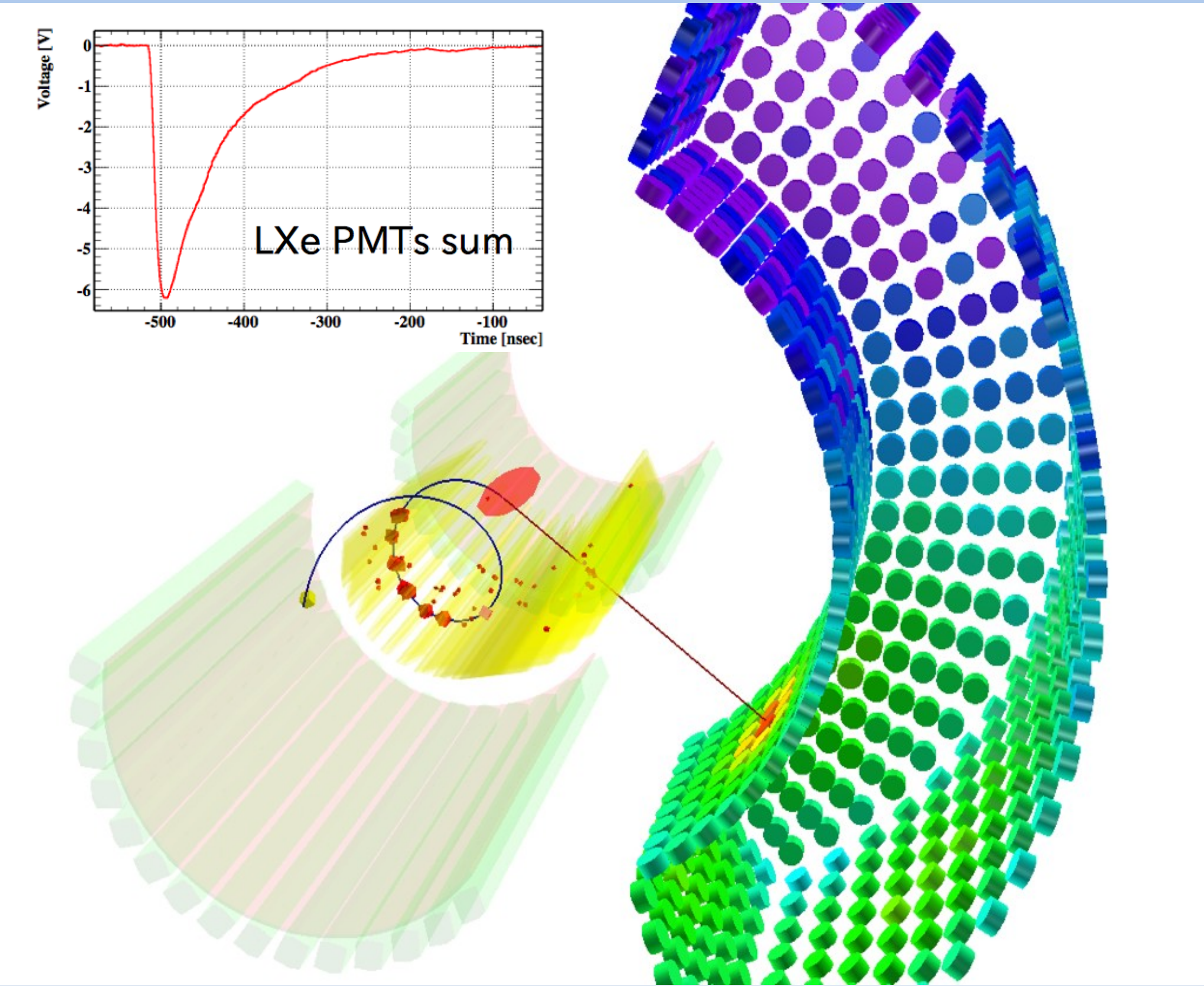
- Pushing sensitivity down to a few x 10^{-13} !

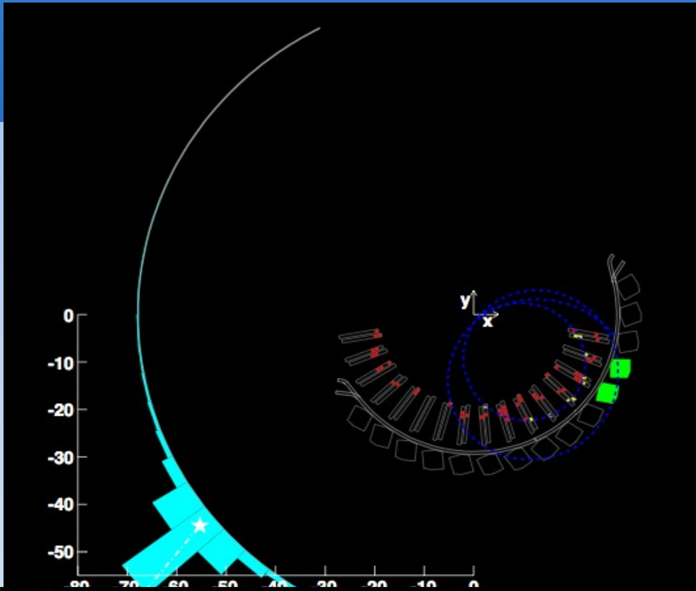
- **Backup slides**

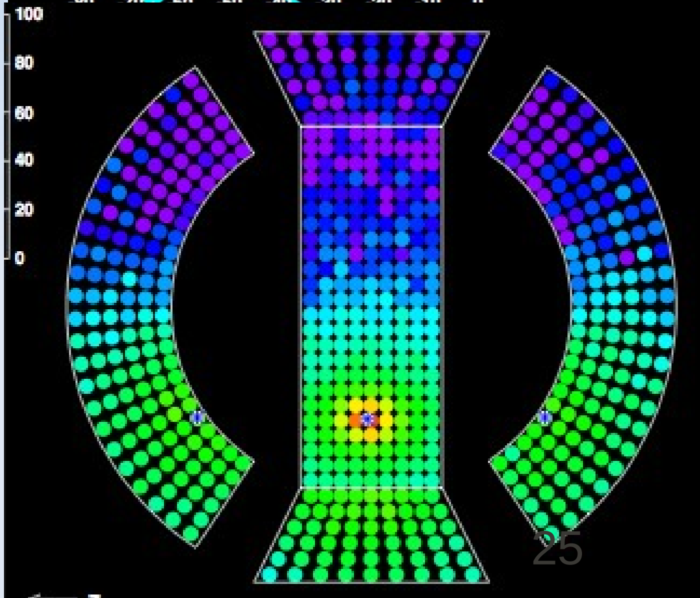
MEG Event display

Events in the signal region were checked carefully

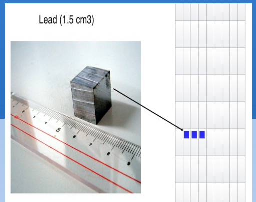
An event in the signal region

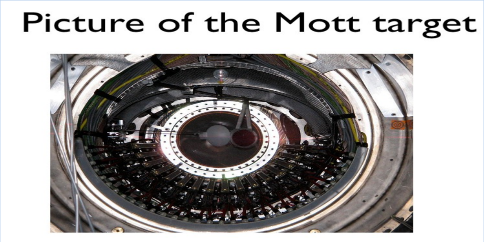






MEG perspectives





Not only statistics

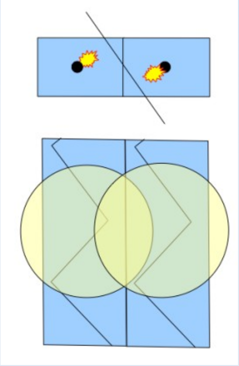
MC description of the LXe to implement different alignment

- more dedicated XEC–DCH coincidence
- Matrix of lead dices to improve Lxe position reconstruction

Mott scattering target to calibrate the tracker with monochromatic variable energy positron

tracking improvement

- better treatment of rapidly varying magnetic field
- cross talk between adjacent Vernier pads
- shadow effect from the anode wires on the Vernier pads



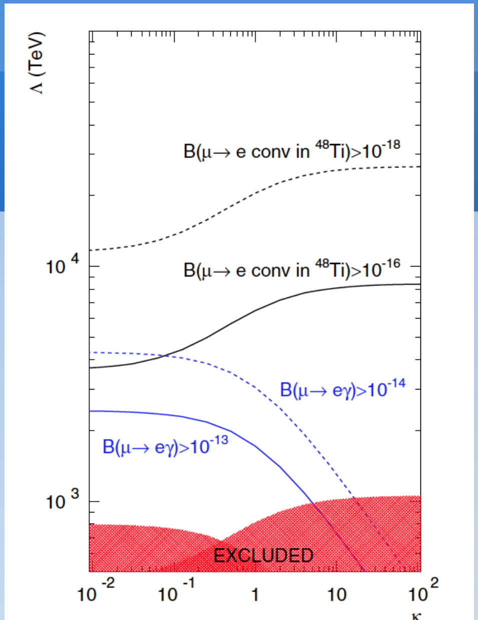
Analysis

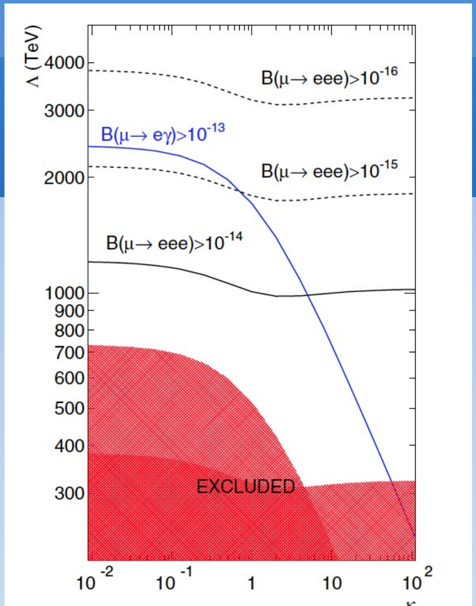
- Inclusion of information from the sidebands in the likelihood
- variations of proton current

Physics motivation

Will test a huge Λ energy range (until 10^4 TeV in some optimistic scenario)

Ratios between different channels BR will constrain new theories.





- A. de Gouvea / Nucl. Phys. B188(

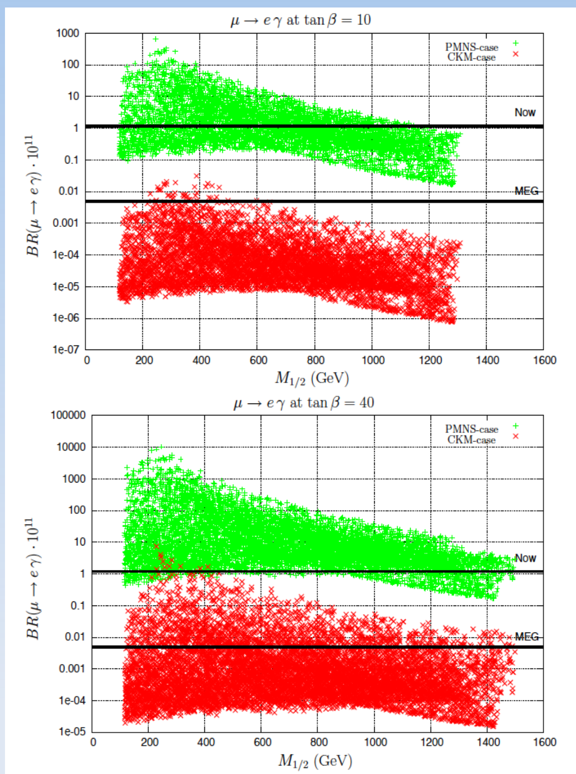
Existence of a decay does not imply the others.
For example: if μ→eγ exists, μ→e conversion must be.
Also if μ→eγ won't be observed, μ→e conversion may be.

- Combined searches in different channels can provide informations about new physics scenario and parameters constraints

Physics motivation

New limits are predicted near the current ones.
For example:

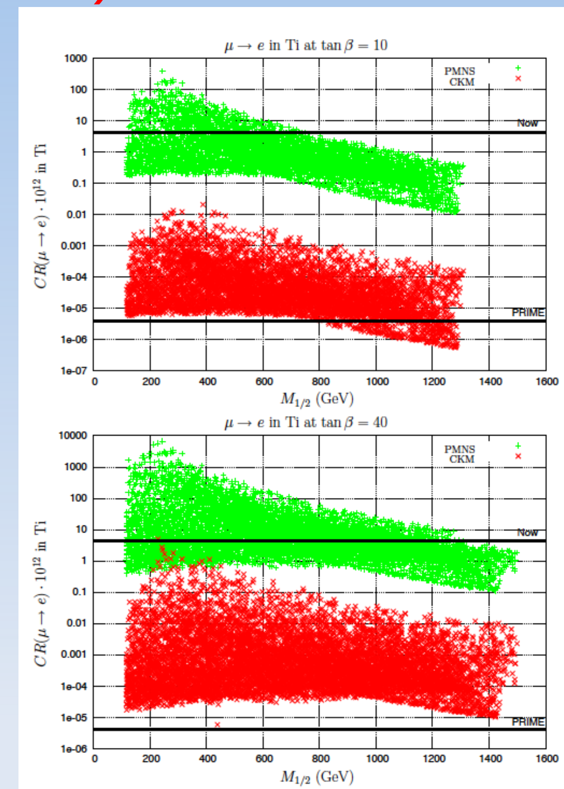
- $BR(\mu \rightarrow e\gamma) \sim 10^{-12} \div 10^{-14}$
- $BR(\mu Z \rightarrow eZ) \sim 10^{-16}$



- L.Calibbi et al.,
- Phys. Rev. D74(2006) 116002

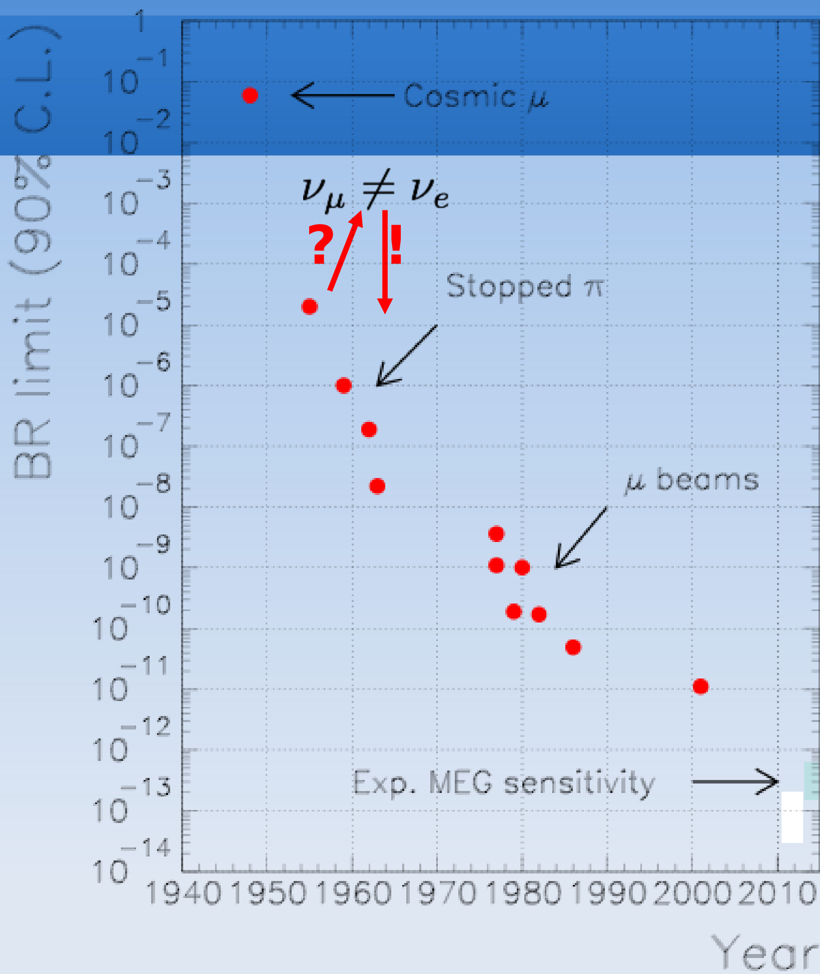
More detailed calculation and reviews:

- R. Barbieri et al., Nucl. Phys. B445, 219(1995)
- J. Hisano et al., Phys. Rev. D59 116005(1999)
- A.Masiero et al., Nucl. Phys. B649, 189(2003)

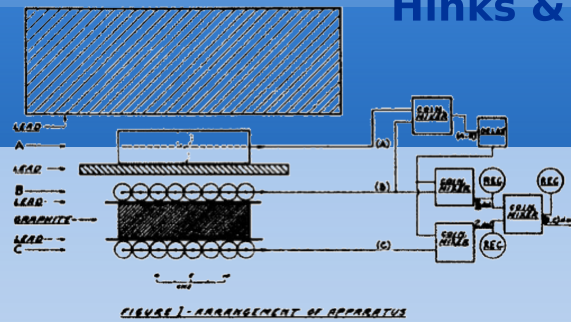


- L.Calibbi et al.,
- Phys. Rev. D74(2006) 116002

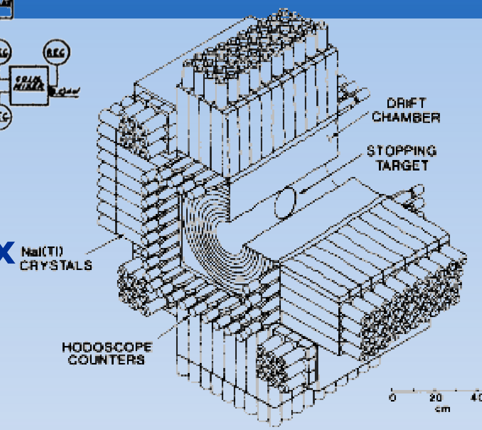
Historical perspective

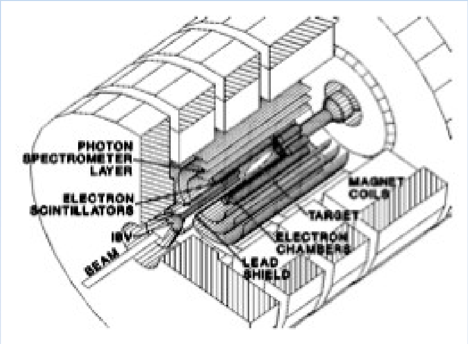


Hinks & Pontecorvo

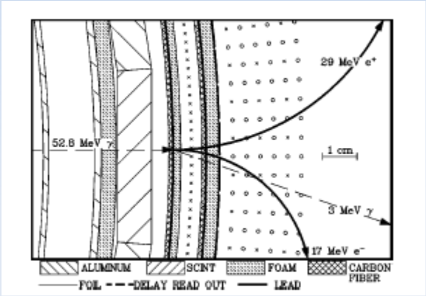


Crystal Box





MEGA



Each improvement linked to the technology either in the beam or in the detector

Always a trade-off between various sub-detectors to achieve the best "sensitivity"

The MEG collaboration

- Aims to explore BR($\mu \to e\gamma$) down to 10^{-13}
- 2 orders of magnitude better than current limit.

- Paul Scherrer Institute (CH)
- ~60 physicist from 5 countries and 12 institutions.
- Data taking started in 2008.
- First published results:
- BR($\mu \to e\gamma$)<2.8×10^{-11}

- Nucl. Phys. B834 (2010)