Risultati e prospettive di misura dell'esperimento MEG(II)

Marco Venturini

Scuola Normale Superiore,

INFN Sezione di Pisa

IFAE 2014, 9 Aprile – L' Aquila

Hunt for New Physics

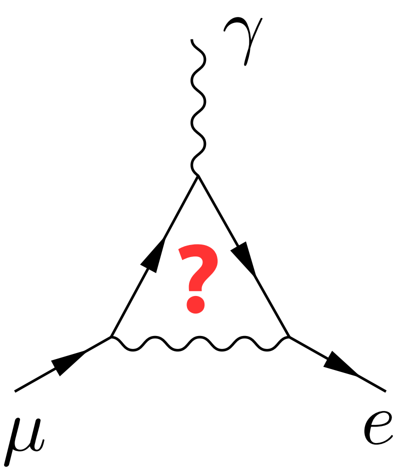
- Energy frontier
- Intensity frontier
- Cosmic frontier

→ **Search for deviations from Standard Model predictions**
in rare processes

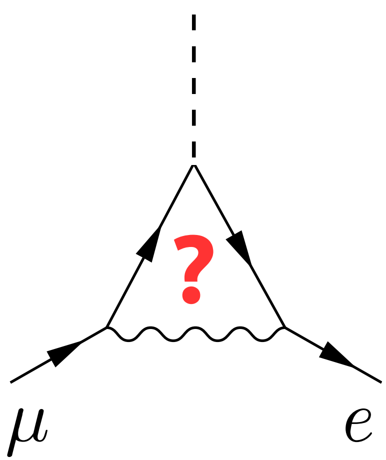
e.g.

Charged Lepton Flavour Violation

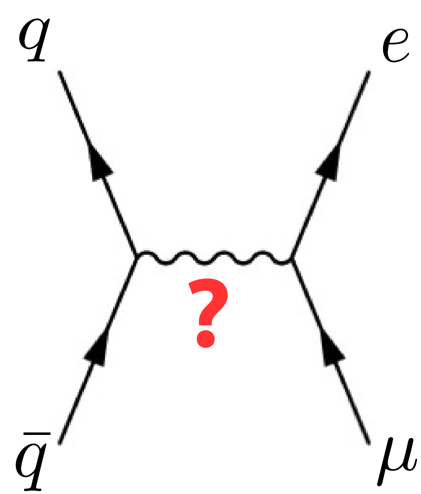
Lepton decays



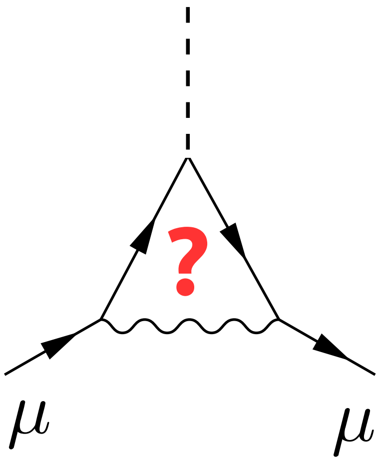
μ-e conversion



Meson decays

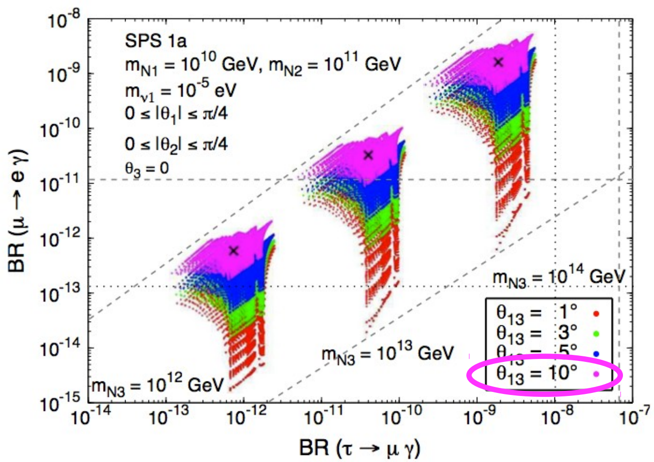


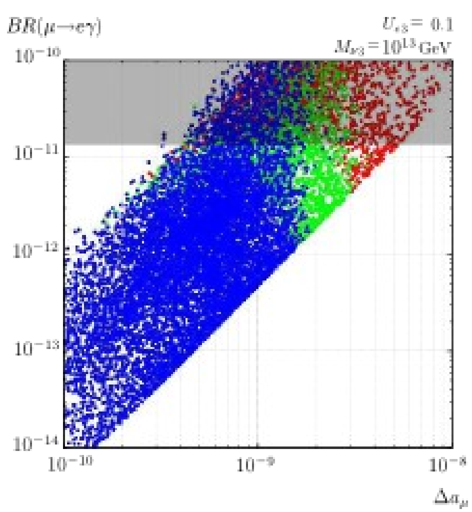
Anomalous Magnetic Moment



Probes to New Physics

Between the different processes **tight connections** are envisaged in several models

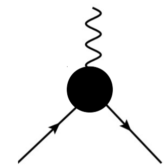




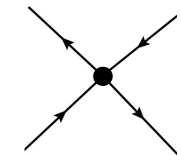
Antusch et al.,JHEP (2006),0611:090
Hisano et al., JHEP (2009),0912:030

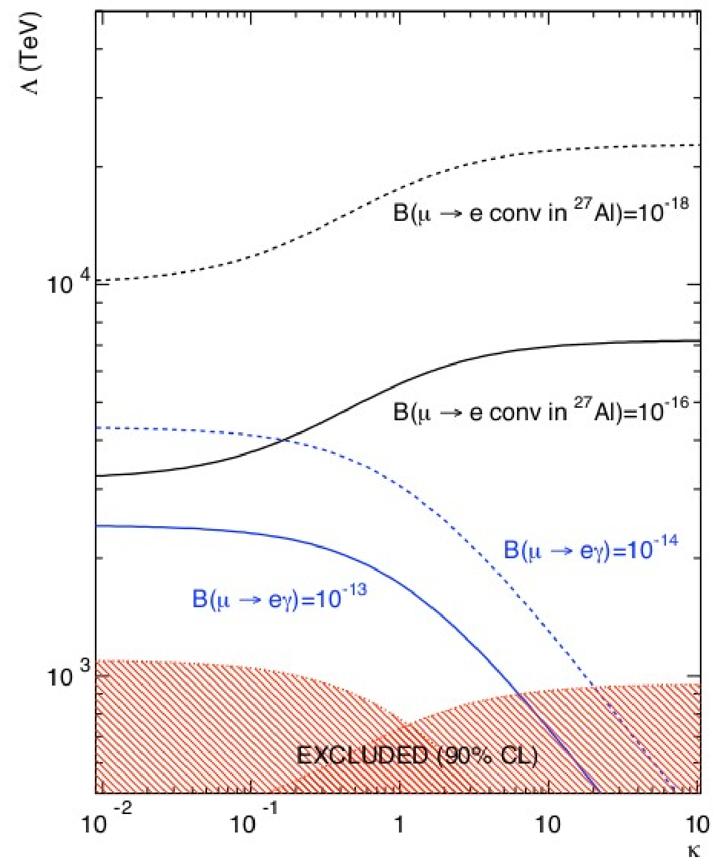
With a **general approach**, CLFV processes are sensitive to high-mass New Physics

$$\frac{m_\mu}{(\kappa+1)\Lambda^2} \times$$



$$+ \quad \frac{\kappa}{(\kappa+1)\Lambda^2} \times$$

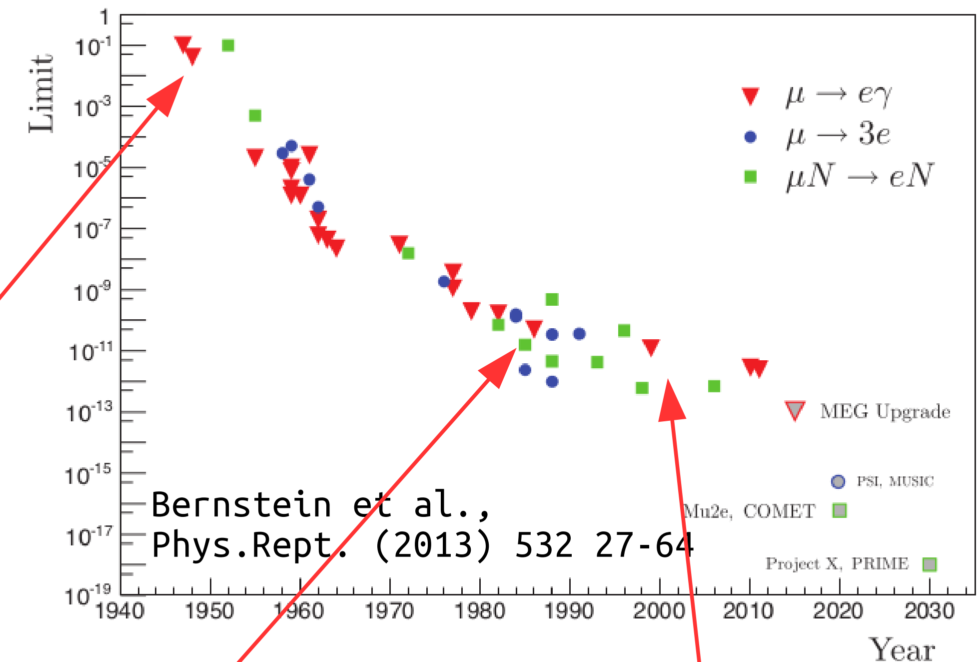




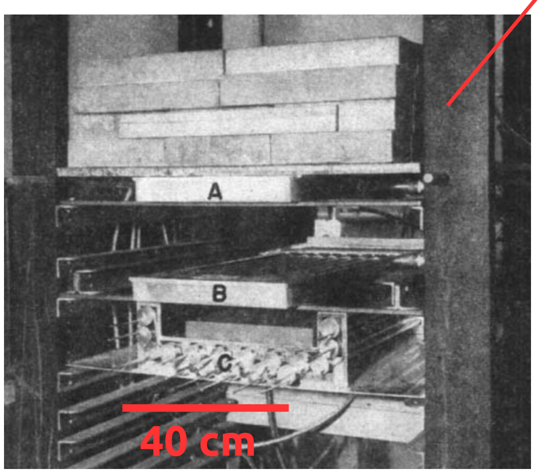
de Gouvea et Vogel, *ArXiv e-prints* (2013),1303.4097

“Table-top”experiments

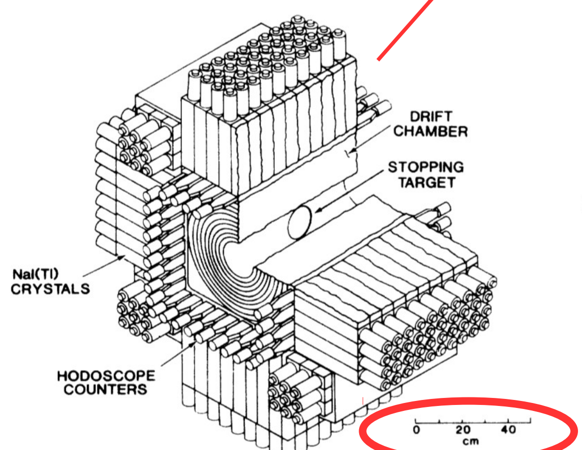
- Dedicated experiments
- A long road in beam and detector technology improvements



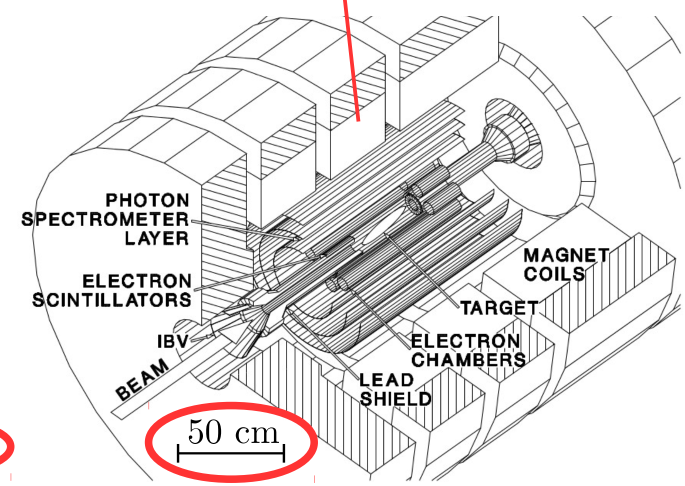
<u>Experiments looking for $\mu \to e\gamma$</u>



Hincks-Pontecorvo 1948



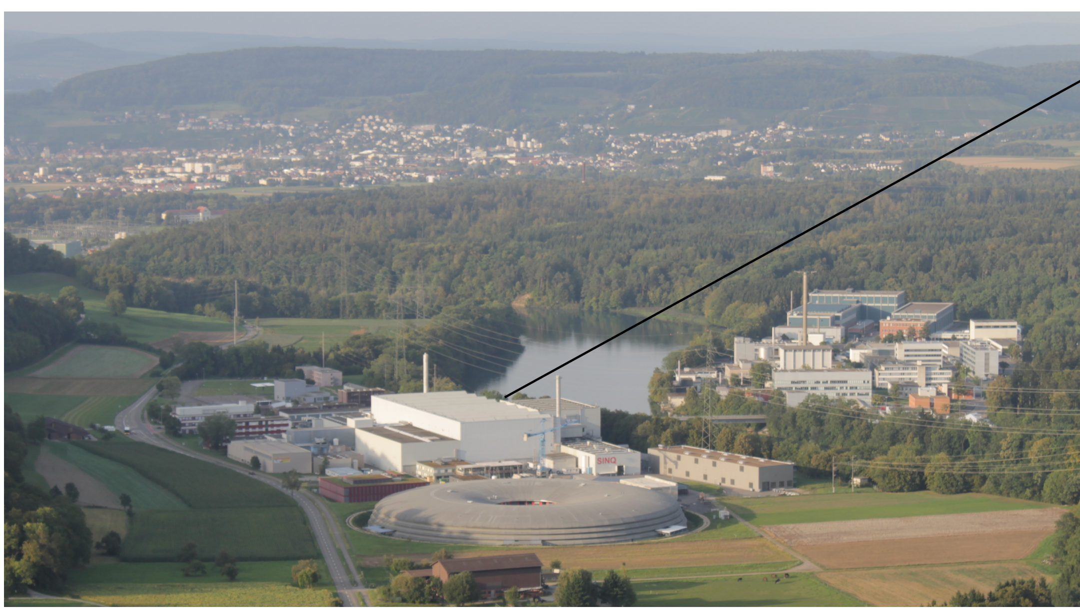
Crystal-Box 1988

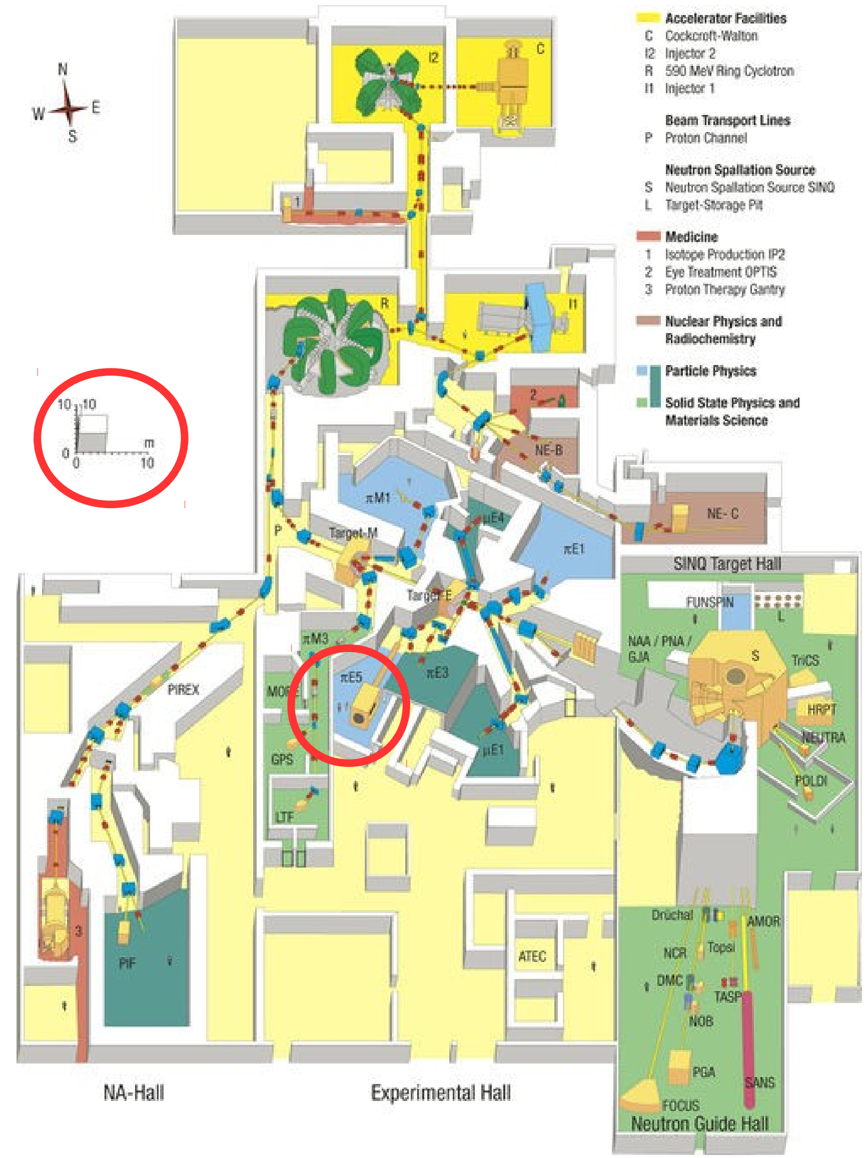


MEGA 1999

The MEG experiment

Search for the Lepton Flavour Violating process $\mu \to e\gamma$

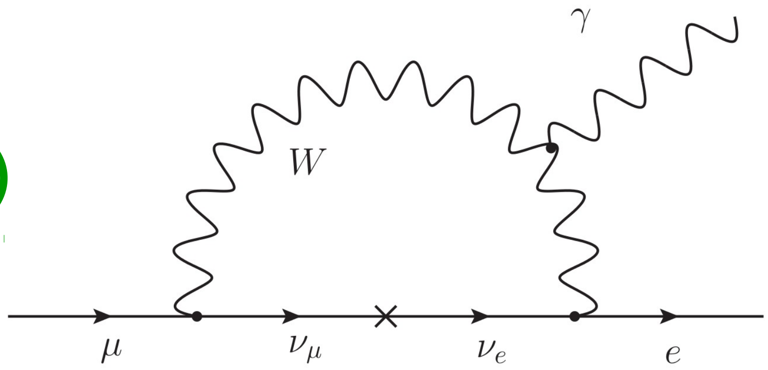




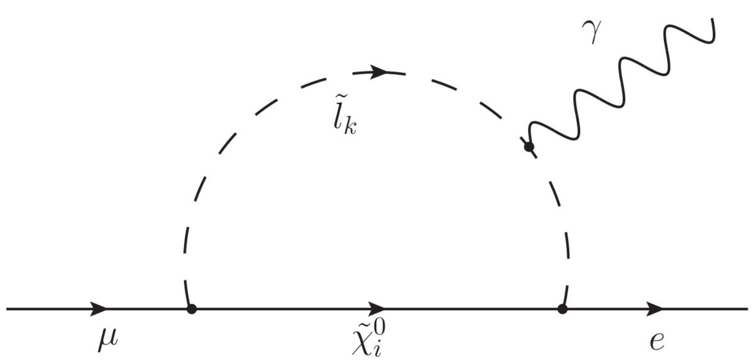
Physics motivations

Minimal Standard Model does not admit Lepton Flavour changing processes.
A non-null though **negligible** amplitude results from **neutrino oscillations**

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \sim \mathbf{10^{-54}}$$



Many new physics scenarios predict an **enhanced probability**, through **mixing** between new particles of the theory.

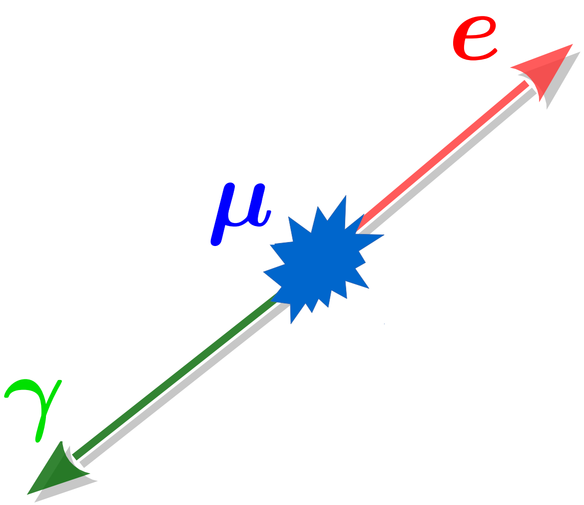


The existence of new physics at high energy scale may result in

$$\mathcal{B} \sim 10^{-12} \div 10^{-14}$$

free from SM background!

The $\mu \to e\gamma$ decay



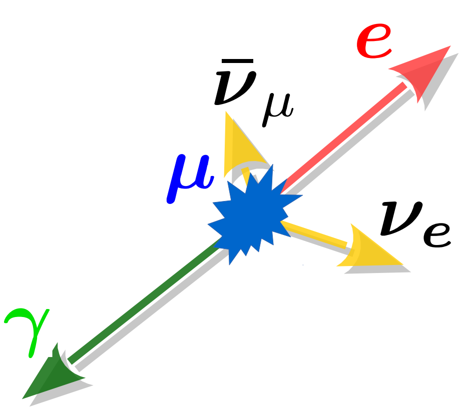
Clear kinematic signature (at rest):

1) $E_\gamma = m_\mu/2$
2) $E_e = m_\mu/2$
3) $\Theta_{e\gamma} = 180^\circ$
4) $t_{e\gamma} = 0$

$\propto R_\mu$

with two sources of background:

Radiative Muon Decay

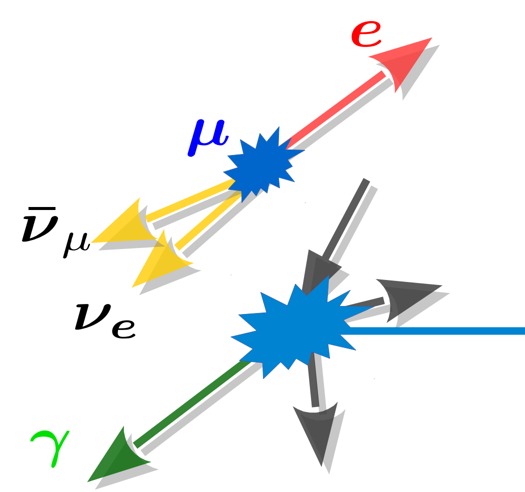


1) $E_\gamma \lesssim m_\mu/2$
2) $E_e \lesssim m_\mu/2$
3) $\Theta_{e\gamma} \lesssim 180^\circ$
4) $t_{e\gamma} = 0$

$\propto R_\mu$

Accidental Background

$\propto R_\mu^2$



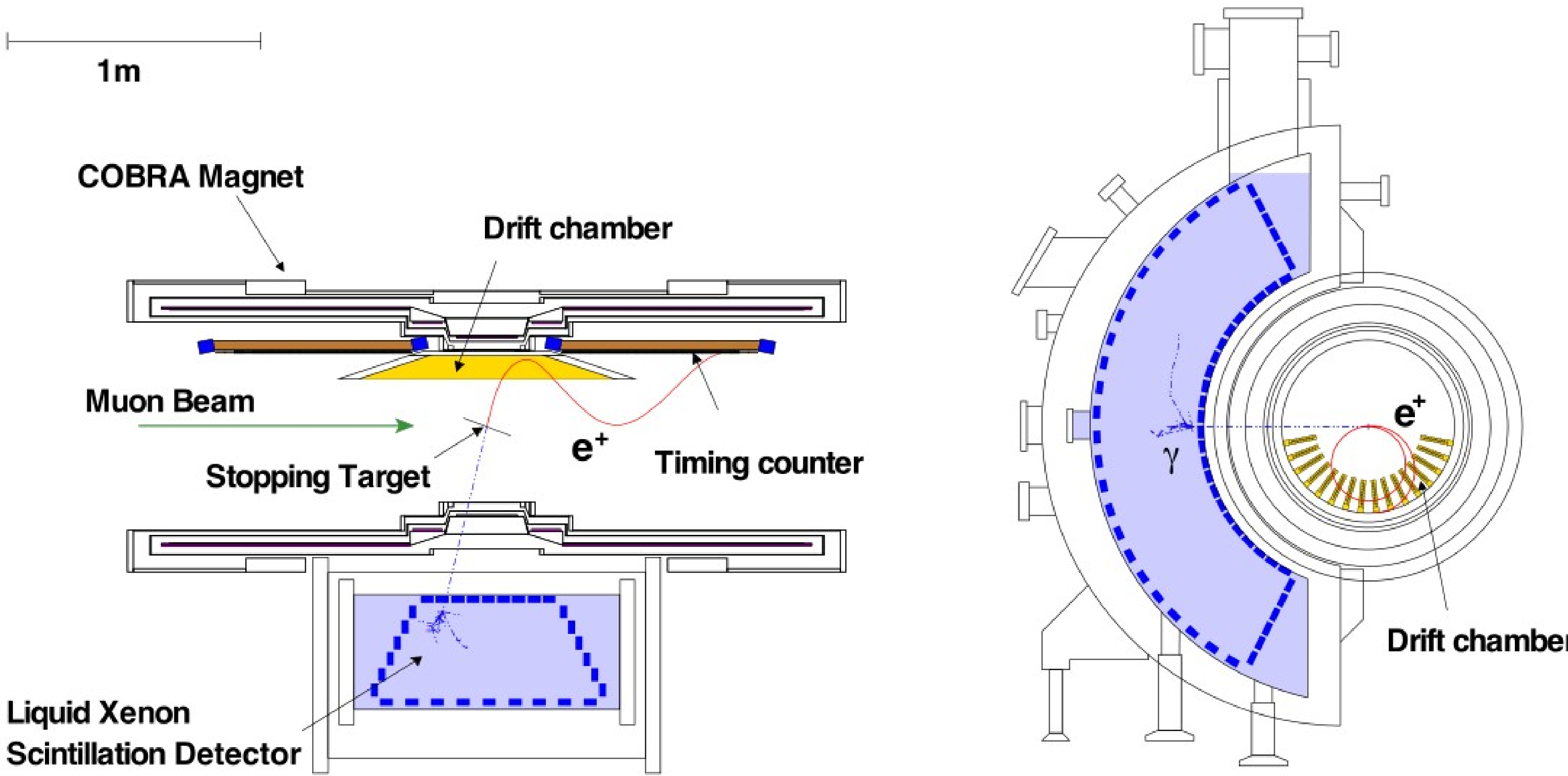
$\mu^+ \to e^+ \bar{\nu}_\mu \nu_e \gamma$

$e^+ e^- \to \gamma\gamma$

$e^+ N \to e^+ N \gamma$

The MEG apparatus

Tailored to take advantage of the well-defined kinematics

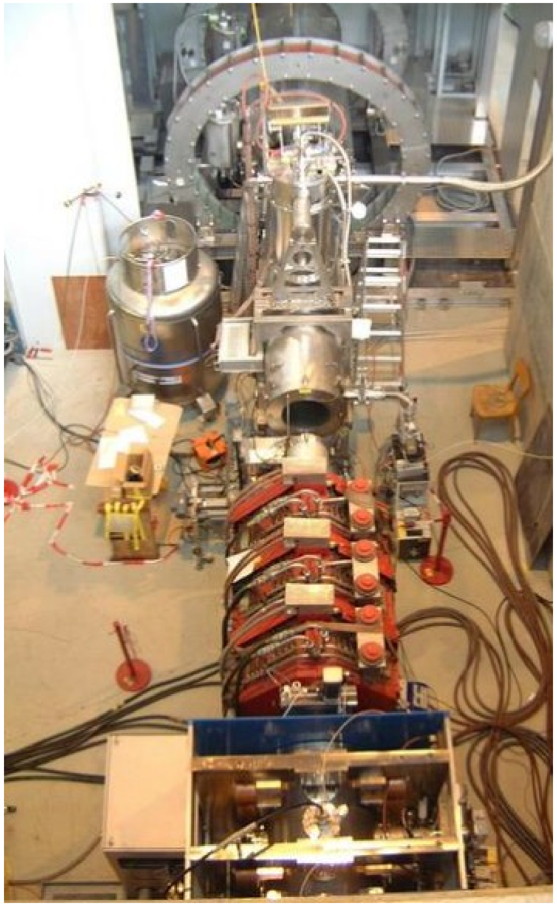


Adam et al., Eur.Phys.J.,2013, C73:2365

- Positive muons stopped in a thin polyethylene target
- Positrons are detected by a spectrometer immersed in a non-uniform magnetic field
- Photons are detected by a liquid Xenon calorimeter

The MEG apparatus

μ

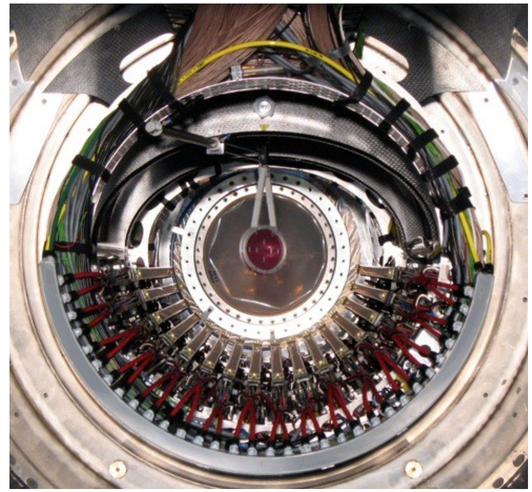


from PSI πE5 beam line

$$3 \times 10^7 \mu^+/s$$

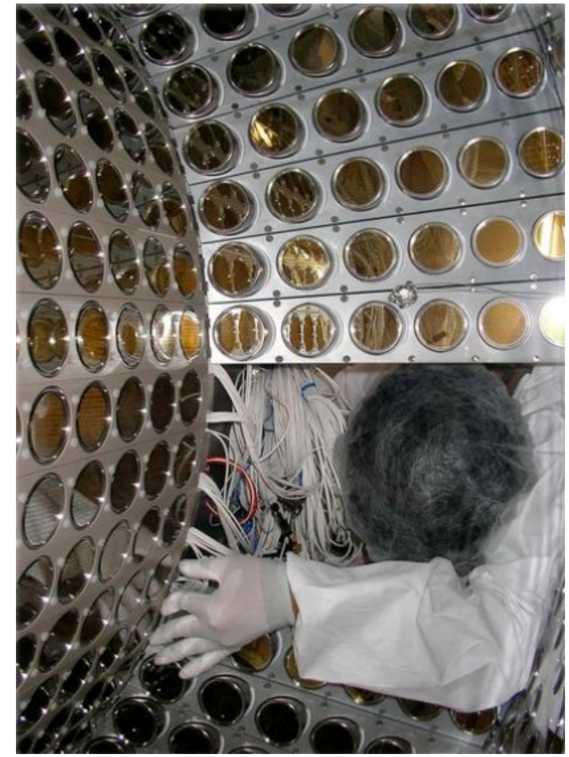
$$p = 29\,\mathrm{MeV}/c$$

e



- 16 drift chamber modules
- 15 plastic bars + scintillating fibres for timing

γ



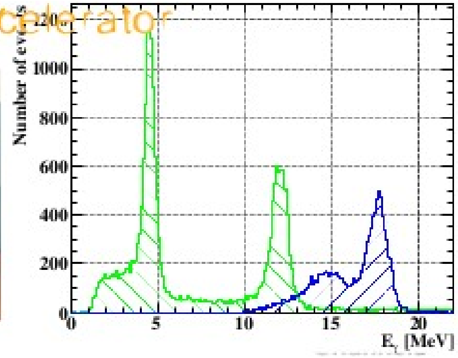
- fast: $\tau\text{'s} = 4/22/45$ ns
- high Light Yield $LY \sim 0.8\, LY_{\mathrm{NaI}}$
- Short Radiation Length

$$X_0 = 2.77 \text{ cm}$$

Detector calibrations

Detector Calibration

Proton Accelerator



Li(p,γ)Be

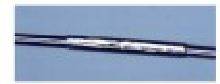
LiF target at COBRA center

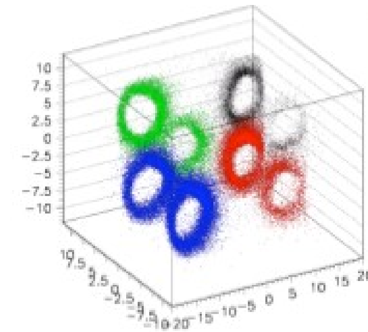
17.6MeV γ

~daily calib.

also for initial setup

Alpha on wires



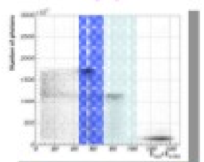


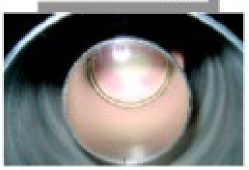
PMT QE & Att. L

Cold GXe

LXe

$\pi^0 \rightarrow \gamma\gamma$



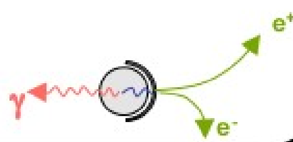


$\pi^- + p \rightarrow \pi^0 + n$

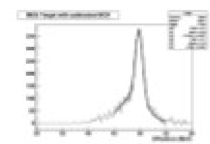
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

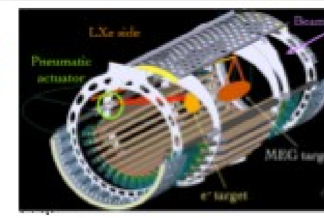
$\pi^- + p \rightarrow \gamma + n$ (129MeV)

LH_2 target

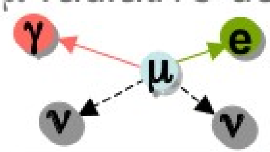


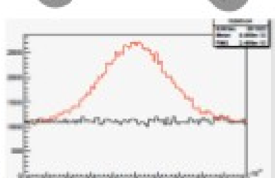
Mott e+ scattering





μ radiative decay



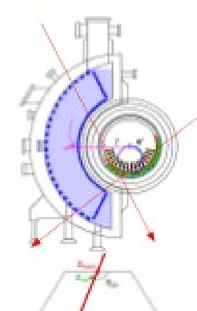


Lower beam intensity < 10^7

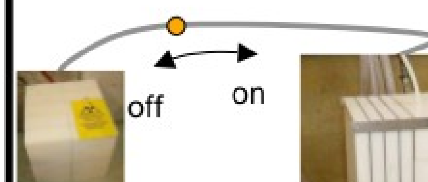
Is necessary to reduce pile-ups

A few days ~ 1 week to get enough statistics

Cosmic ray alignment

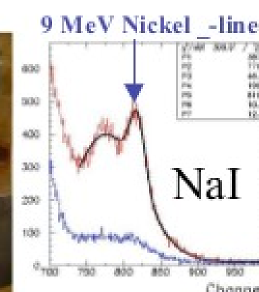


Nickel γ Generator



Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off



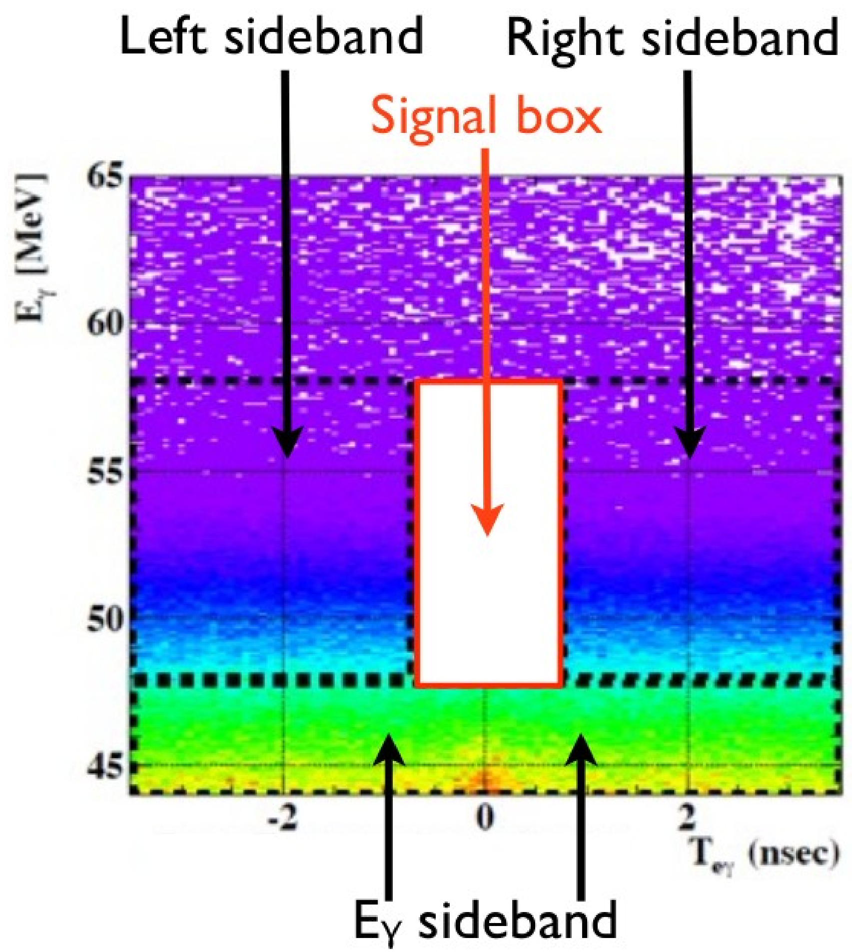
Analysis Strategy

- Events described by 5 variables:

$$\vec{x} = (E_\gamma,\, E_e,\, t_{e\gamma},\, \vartheta_{e\gamma},\, \varphi_{e\gamma})$$

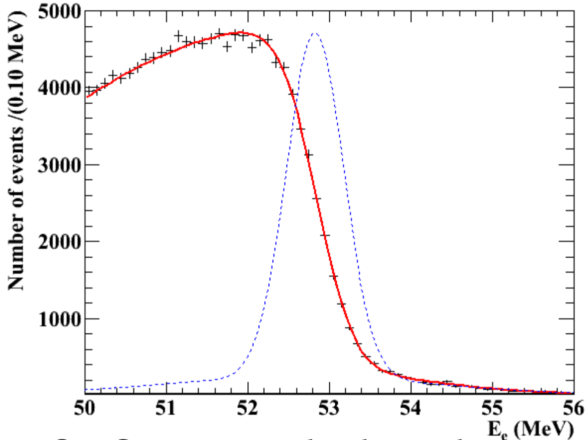
- Probability Density Functions (PDFs) for signal and backgrounds are determined starting from data **outside the signal box**.

- Two-fold use of sidebands
  - Evaluation of PDFs.
  - Estimate of the background events entering the signal box.



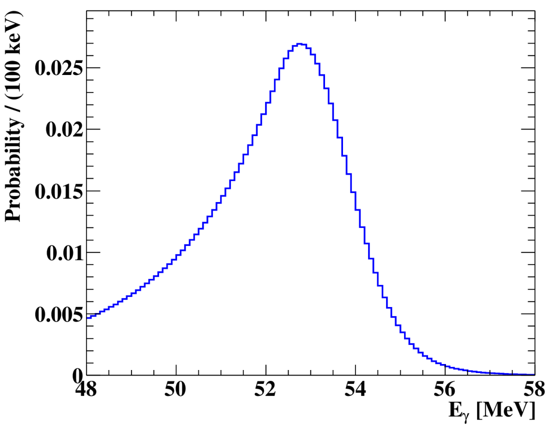
Probability Density Functions

Positron Energy



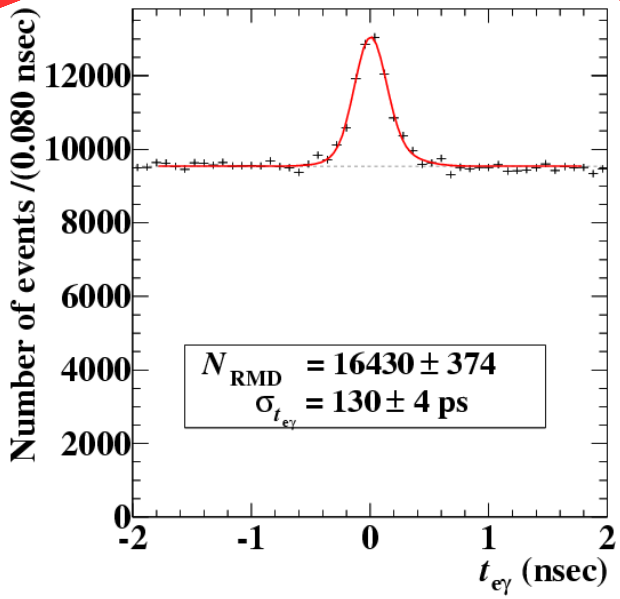
fit from Michel endpoint left/right sidebands

Photon Energy



fit from 55 MeV calibration

Relative Time

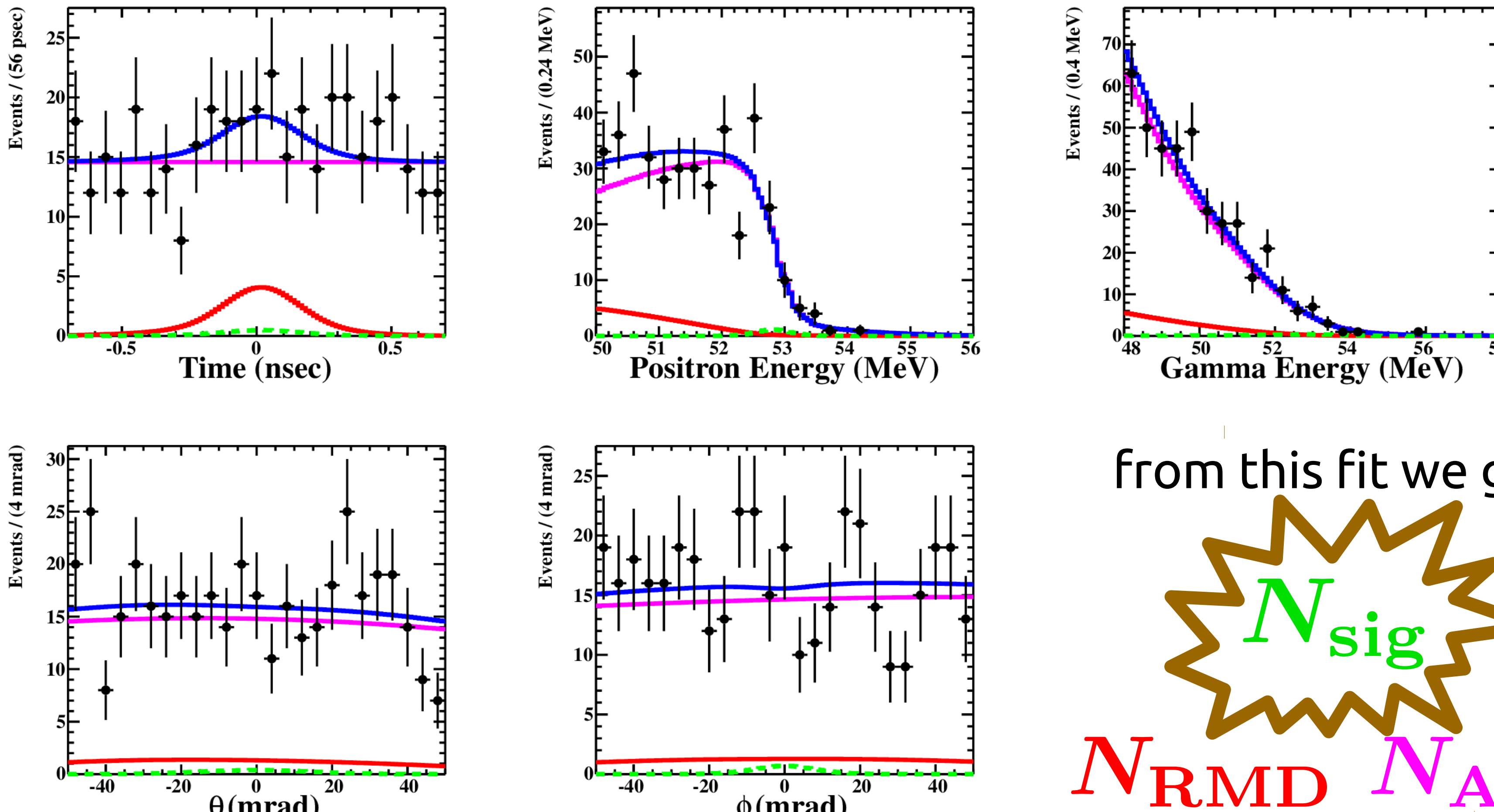


from lower sideband

Likelihood Fit

$$\mathcal{L}(N_{\rm sig}, N_{\rm RMD}, N_{\rm ACC}) = \frac{e^{-N}}{N_{\rm obs}!} \prod_{i=1}^{N_{\rm obs}} \left[N_{\rm sig}\, S(\vec{x}_i) + N_{\rm RMD}\, R(\vec{x}_i) + N_{\rm ACC}\, B(\vec{x}_i) \right]$$

$$\exp\left[-\frac{(N_{\rm RMD} - \langle N_{\rm RMD} \rangle)^2}{2\sigma_{\rm RMD}^2} \right] \exp\left[-\frac{(N_{\rm ACC} - \langle N_{\rm ACC} \rangle)^2}{2\sigma_{\rm ACC}^2} \right]$$



from this fit we get

$N_{\rm sig}$

$N_{\rm RMD}$ $N_{\rm ACC}$

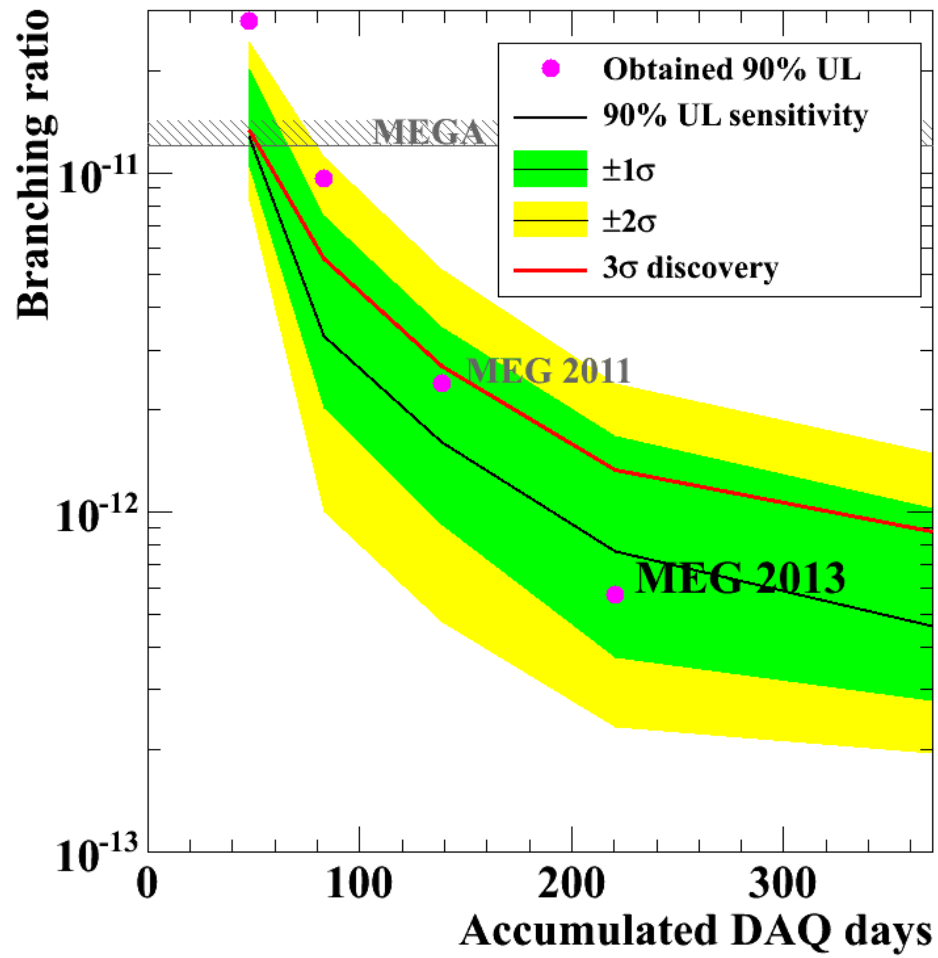
Branching Ratio

1) Normalization: obtained from Michel and radiative decays.
2) Confidence interval calculated with Feldman & Cousins approach with profile likelihood ratio ordering.

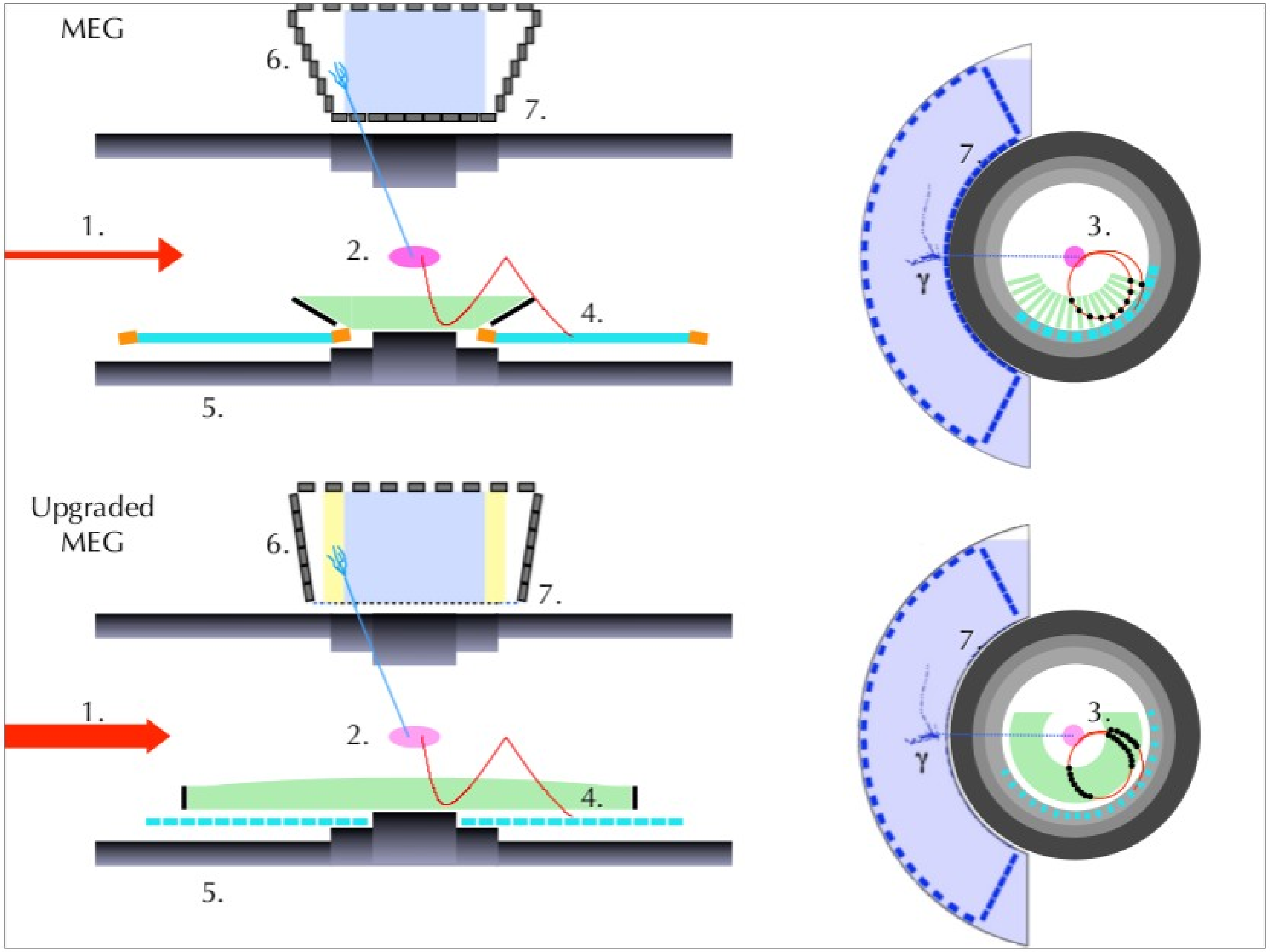
$$\mathcal{B}(\mu \to e\gamma) < 5.7 \times 10^{-13}$$
$$@\,90\%\ \text{C.L.}$$

Adam et al., Phys. Rev. Lett., (2013) 110:201801

Analysis is in progress on half statistics, but we are close to the final sensitivity dictated by the backgrounds



MEG upgrade



Baldini et al., ArXiv e-prints (2013), 1301.7225.

1. Higher Muon Rate
$\Leftarrow$ better detector resolutions

2. Less energetic muons
$\Rightarrow$ thinner target

3. New tracker with higher resolution

4. Improved matching between drift chamber and timing counter

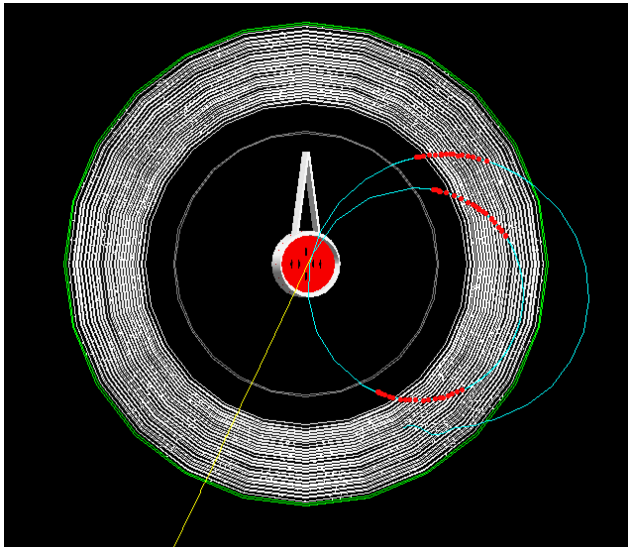
5. New timing counter.

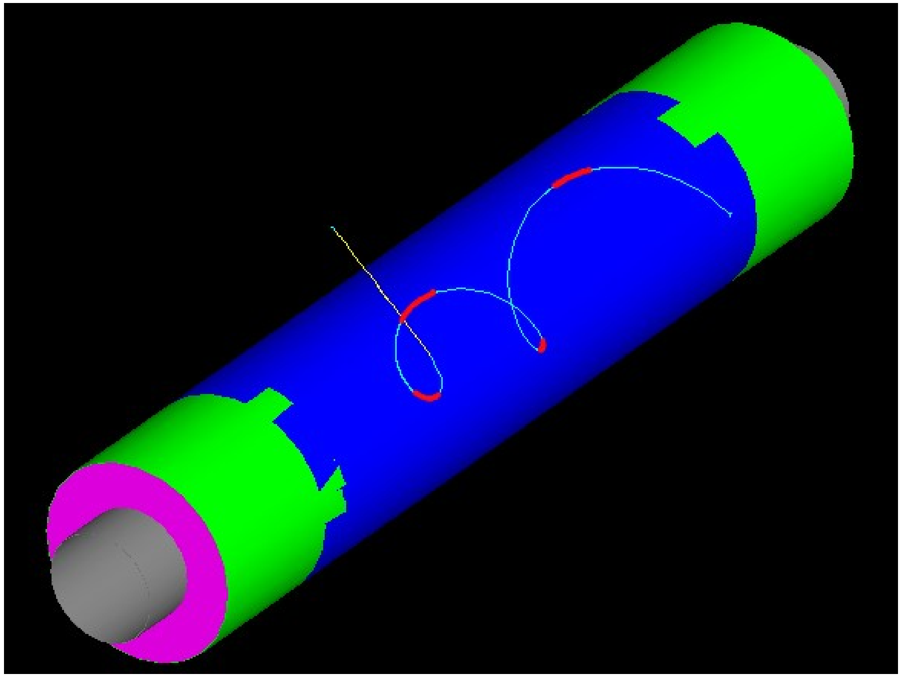
6. Larger XEC acceptance

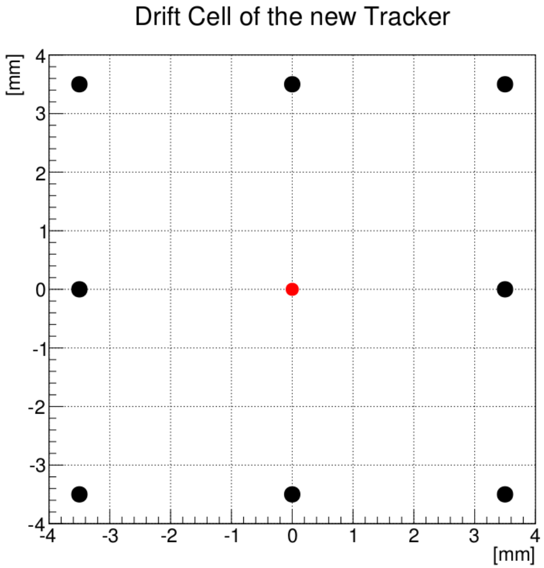
7. Better XEC scintillation light collection

A new Drift Chamber

- Hyperbolic Drift chamber with stereo angles ±7°÷8°.
- 10 layers with alternating stereo angles.
- Drift cells with approximately squared shape 7x7 mm^2.
- Low mass gas mixture with helium and isobutane 85:15.

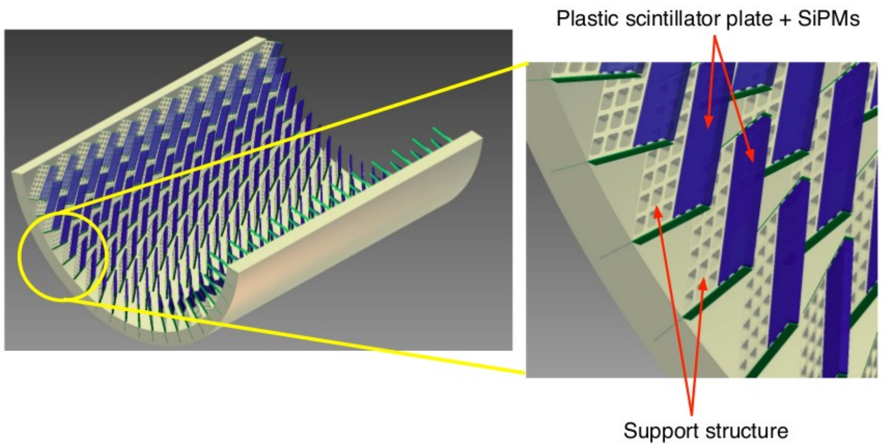




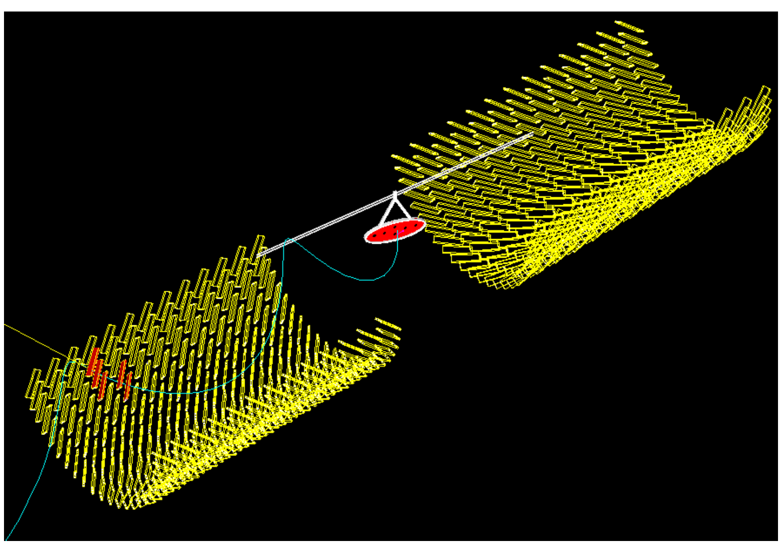


New detectors

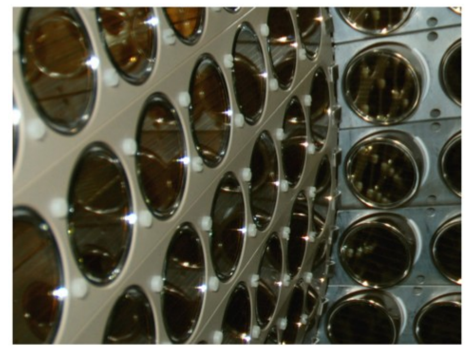
Timing Counters

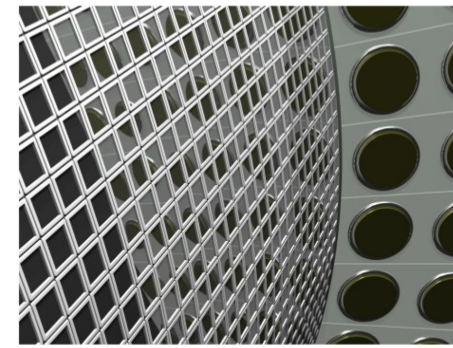


Pixelated TC

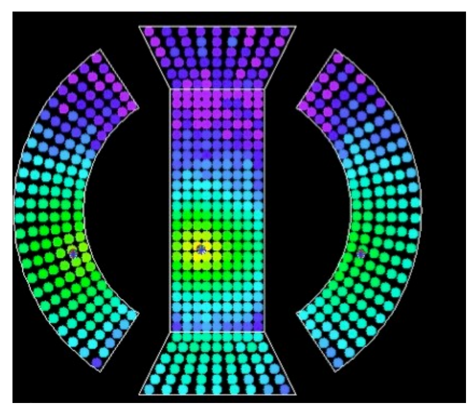


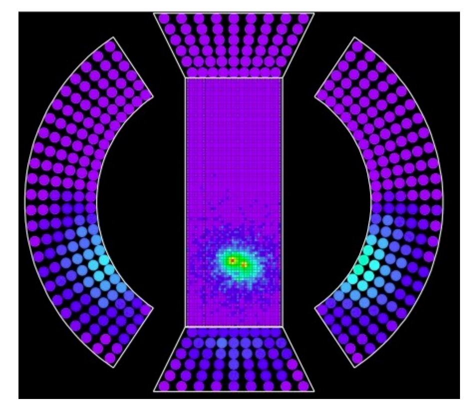
Xenon Detector





Better light collection





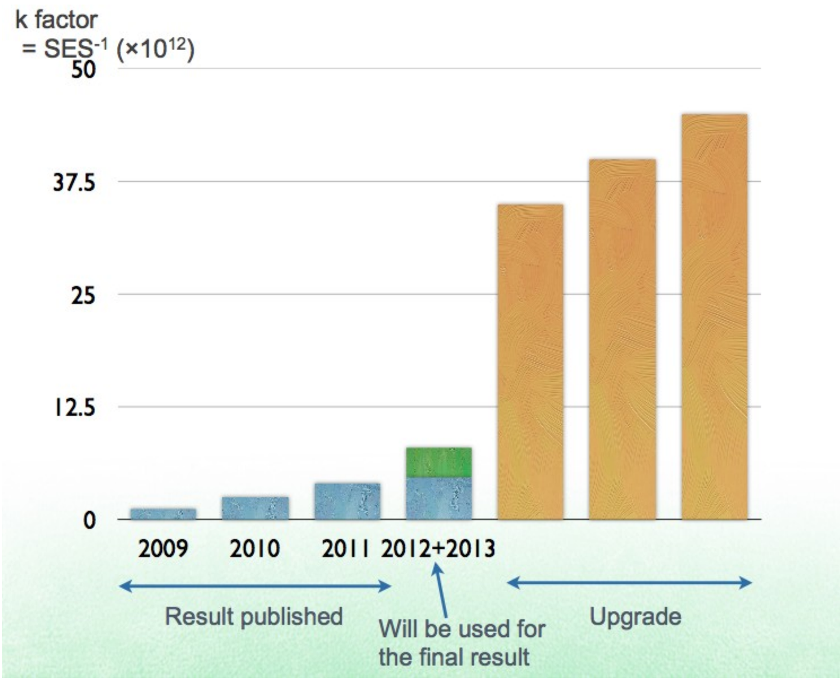
Resolution Improvements

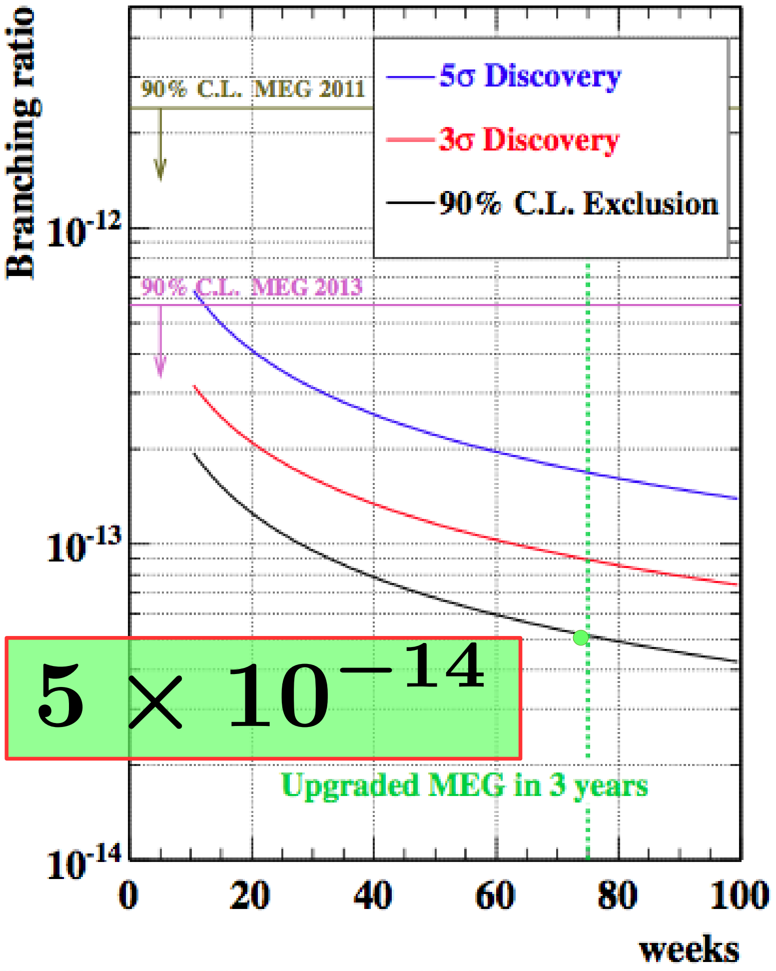
- The major improvements of the upgrade concern the positron spectrometer efficiency and resolution.

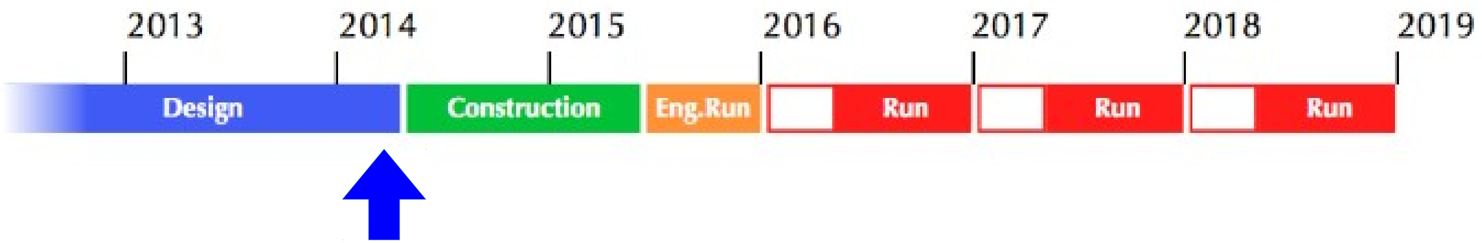
Variable	MEG	MEG2
$\Delta E_\gamma (\%)$	1.7	1.0
γ position (mm)	$5(u,v)$, $6(w)$	$2.6(u)$, $2.2(v)$, $5(w)$
ΔP_e (keV)	306	130
e^+ angle (mrad)	$7(\varphi_e)$, $9.4(\vartheta_e\ )$	$5.3(\varphi_e)$, $3.7(\vartheta_e\ )$
$\Delta t_{e\gamma}$ (ps)	122	84
e^+ efficiency (%)	40	88
γ efficiency (%)	63	69
trigger efficient(%)	~ 99	~ 99

MEG2 Expected Sensitivity

- 3 DAQ years estimated
- ~10x in stopped muons
- Schedule ongoing







Conclusions

- **Charged Lepton Flavour Violation** (CLFV) experiments represent a powerful tool to investigate new physics scenarios **with no SM background**.
- Combined measurements on CLFV processes can significantly **constrain** new physics at **high energy scales**.
- The MEG experiment has recently set **the most stringent limit** on CLFV physics scenarios.
- In a few years **MEG2** will improve MEG results by an order of magnitude.

In the next decade...