Latest results and future upgrade of the MEG Experiment

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On behalf of the MEG Collaboration

Neutrino Telescopes 2017 **Venice, 13-17 March 2017**

Outline

- Generalities on **Lepton Flavour Violation** (**LFV**)
- The **MEG** experiment
- **Results of MEG full data sample**
- Impact of MEG results
- The **MEG Upgrade**
- Perspectives of MEG Upgrade

LFV 1)

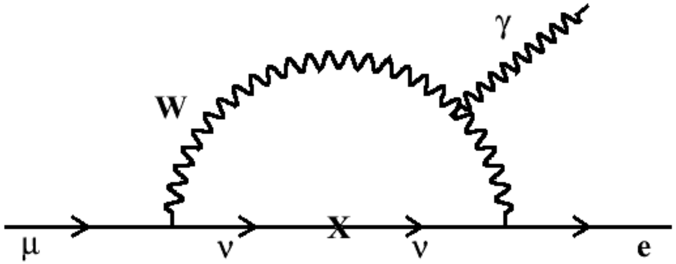
- In the **SM of electroweak interactions** leptons are grouped in doublets and there is **no space for transitions where the lepton flavour is not conserved**.
- However, **lepton flavour is experimentally violated** in neutral sector (**neutrino oscillations**) $\Rightarrow$ needed to **extend the standard model by including neutrino masses and coupling between flavours**.
- **cLFV** indicates **non conservation of lepton flavour** in processes involving **charged leptons**.

LFV 2)

Including neutrino masses and oscillations in SM:

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

$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3} \frac{3\alpha}{32\pi} \left(\frac{\Delta m_{23}^2 s_{13} c_{13} s_{23}}{M_W^2}\right)^2 \qquad \approx 10^{-54}$$



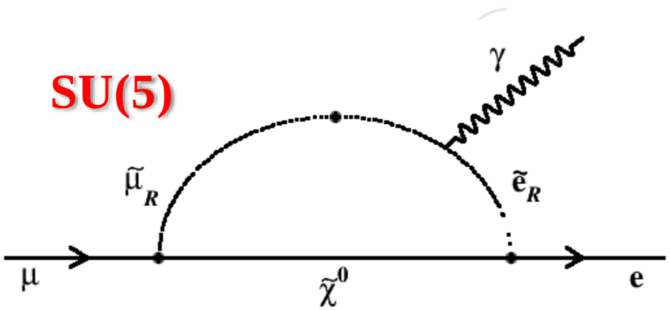
Experimentally not measurable !

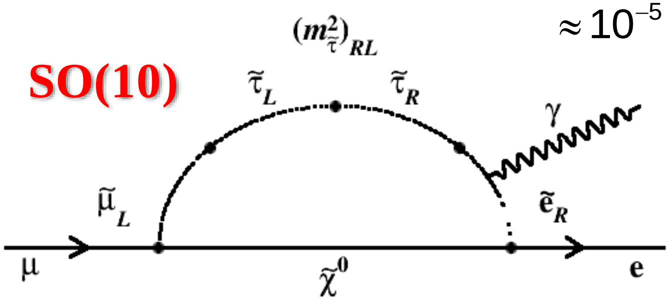
Huge rate enhancement in almost all SM extensions ⇒

predicted rates experimentally accessible ! (Barbieri, Masiero, Ellis, Hisano ..)

$$\approx 10^{-5} \frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\bar{m}^2_{\tilde{\ell}}} \left(\frac{100 \text{ GeV}}{m_{\text{SUSY}}}\right)^4 \tan^2\beta$$

$\approx 10^{-12}$

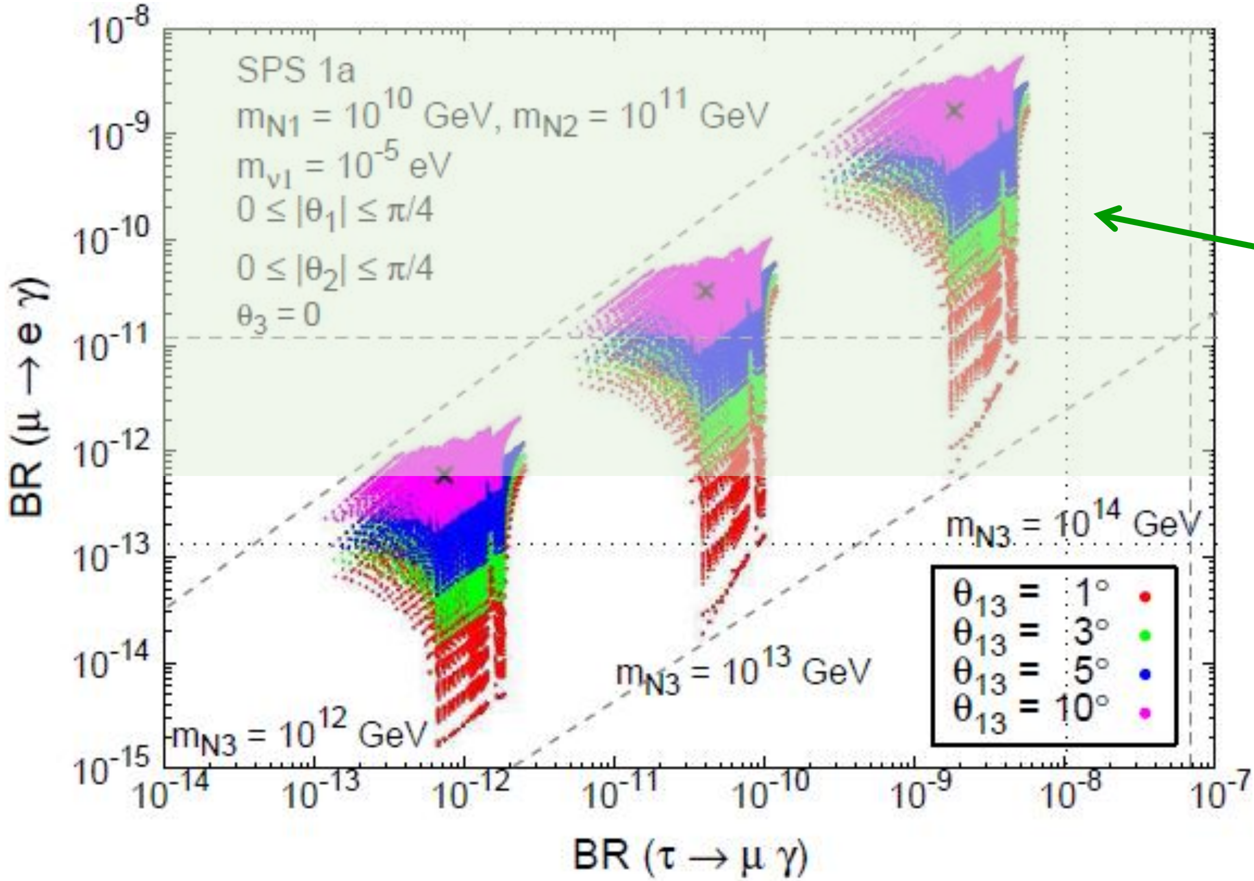




⇒ **Observation of cLFV clear evidence for physics beyond SM**

LFV 3)

LFV and neutrino oscillations



Excluded by 2013 MEG result
(now updated)

θ_{13} measured by Daya Bay, Reno, Double Chooz, T2K
$(8.9 \pm 0.3)^o$

Antusch et al. JHEP **0611** (2006) 090

Why muons ?

Muons are very sensitive probes to study Lepton Flavour Violation:

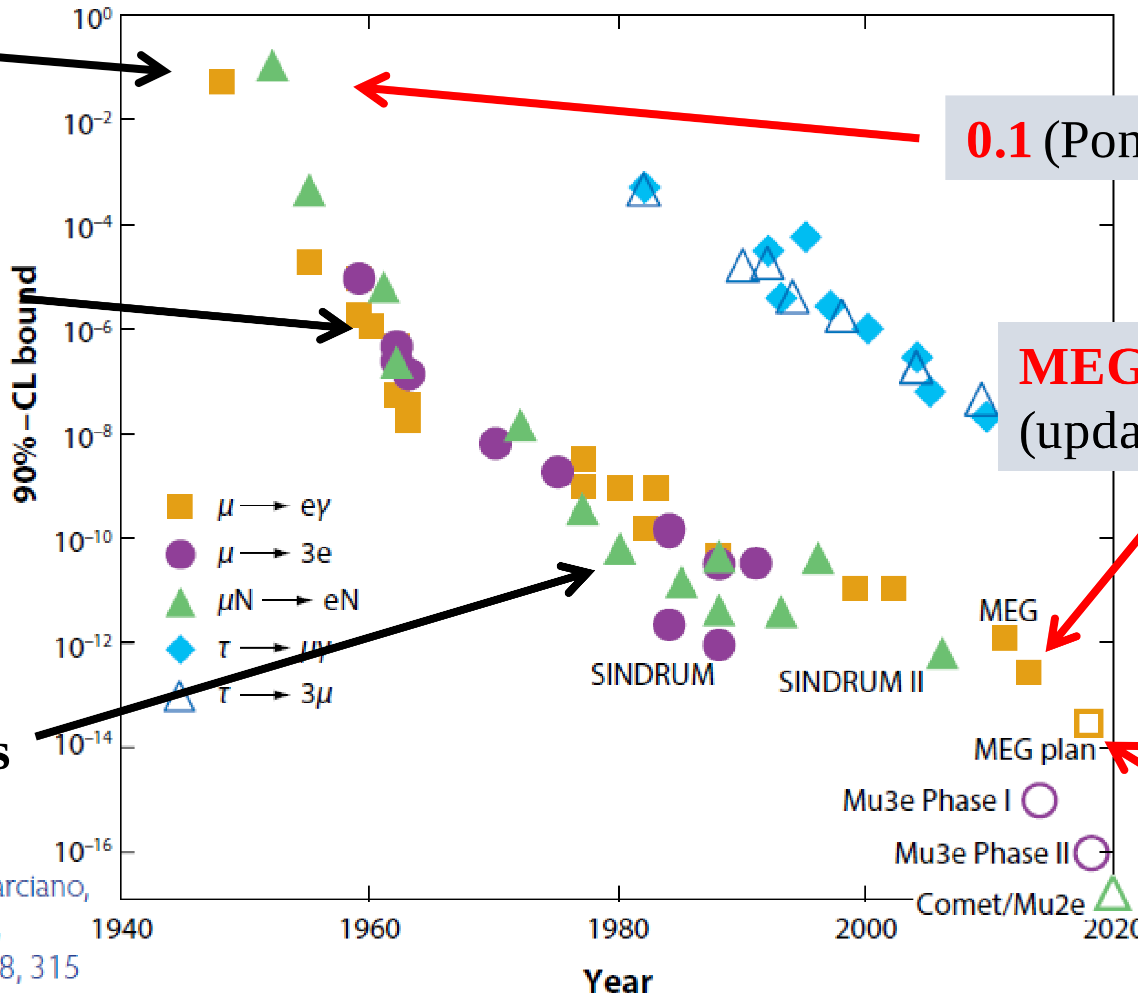
- **intense muon beams (≈ 10^{7-8} muons/sec)** can be obtained at **meson factories** and **proton accelerators** (**PSI, LAMPF, J-PARC, Fermilab ...**)**;**
- **muon lifetime** is rather long **(2.2 μs);**
- **final states** are **very simple** and can be **precisely measured.**

A 70 year history …

Cosmic μ’s

Stopped π’s

Muon beams



0.1 (Pontecorvo & Hincks)

MEG 2013: 5.7×10^{-13}
(updated in this talk)

Gained twelve orders of magnitude !

MEG upgrade

(Updated from W.J. Marciano, T. Mori and J.M. Roney, Ann.Rev.Nucl.Part.Sci. 58, 315 (2008))

Empty symbols: future experiments

The MEG Experiment

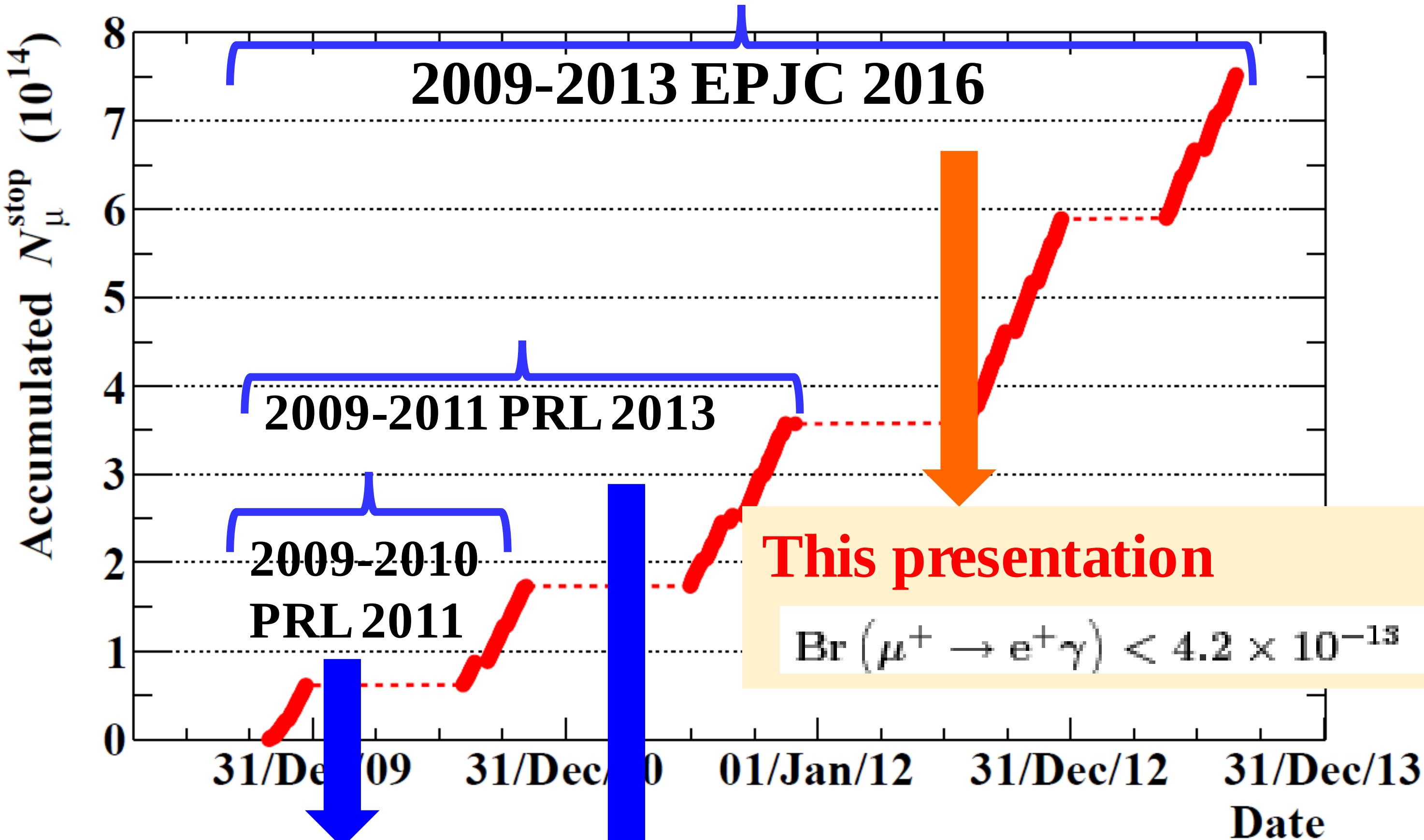
Goal: search for $\mu^+ \to e^+ \gamma$ decay with a sensitivity on BR $\leq 10^{-13}$

Part of the MEG Collaboration

～70 researchers from 5 countries

Data taking history

Stable data-taking runs from 2009 until 2013



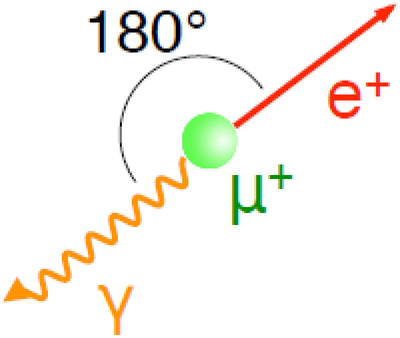
$$\mathrm{Br}\left(\mu^+ \rightarrow e^+\gamma\right) < 4.2 \times 10^{-13} \quad (90\,\%\,\mathrm{CL})$$

$$\mathrm{Br}\left(\mu^+ \rightarrow e^+\gamma\right) < 2.4 \times 10^{-12} \quad (90\,\%\,\mathrm{CL})$$

$$\mathrm{Br}\left(\mu^+ \rightarrow e^+\gamma\right) < 5.7 \times 10^{-13} \quad (90\,\%\,\mathrm{CL})$$

Signal and background

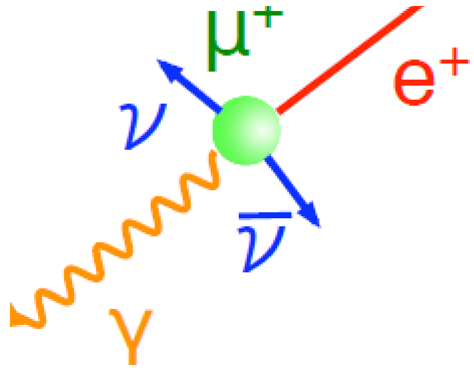
Signal



$E_e = E_\gamma = m_\mu/2$ **(52.8 MeV)**

$T_e = T_\gamma$

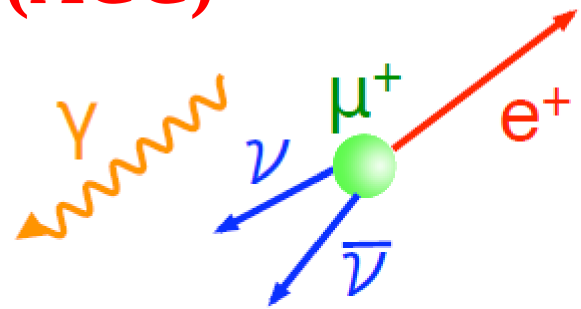
Radiative muon decay (RMD)



$E_e, E_\gamma < m_\mu/2$

$T_e = T_\gamma$

Accidental Background (ACC)

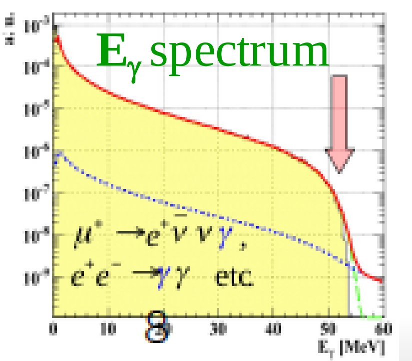


e^+ from Michel decay, γ from RMD, e^+e^- annihilation ..

Random ΔT, $\Delta\Theta$, E_e, $E_\gamma < m_\mu/2$

Signal, RMD $\propto R_\mu$; ACC $\propto R_\mu^2 \Rightarrow$

- **ACC is dominant** (> 10 RMD in signal region);
- needed continuous beam & accurate choice of R_μ;
- needed high precision experiments.

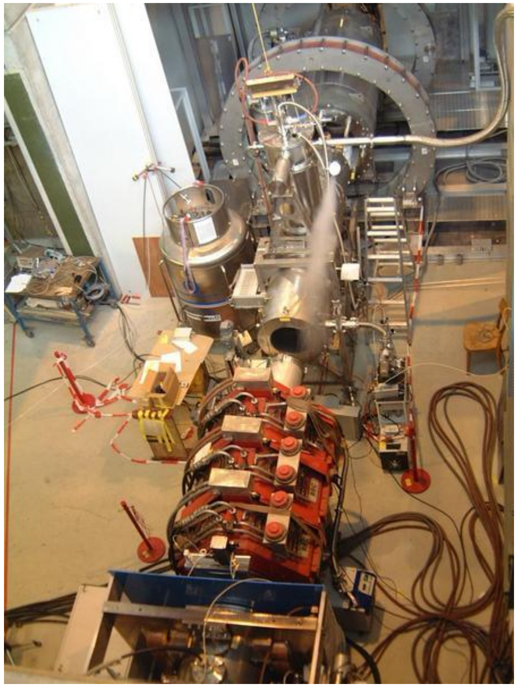


The Paul Scherrer Institute (PSI)

- The **most powerful continuous machine** (proton cyclotron) in the world;
- **Proton energy 590 MeV**;
- **Power 1.4 MW**;
- **Nominal operational current 2.2 mA**.

MEG beam line (πE5 secondary muon line):

- Wien filter
- Beam transport solenoid (BTS)
- Muon degrader
- 2-d beam spot on target: ~ (1×1) cm^2

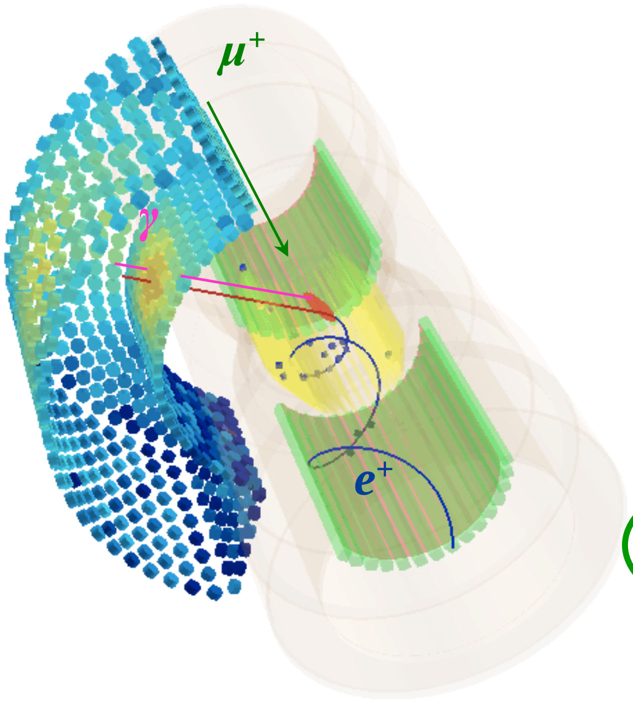


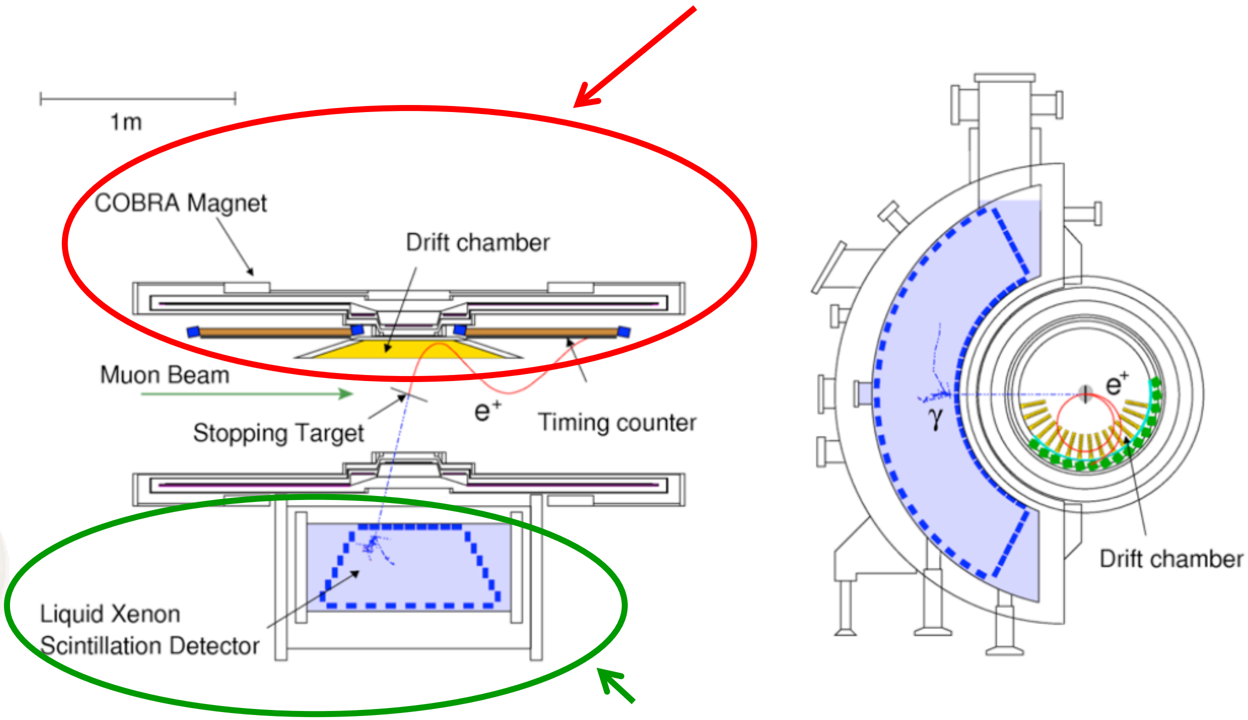
Detector layout

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

Muon beam intensity 3 × 10^{7} stopped μ^{+}/s

Positron spectrometer: measurement of positron momentum vector and timing





LXe photon detector: measurement of photon energy, impact point and timing

Trigger and electronics

- **Trigger**

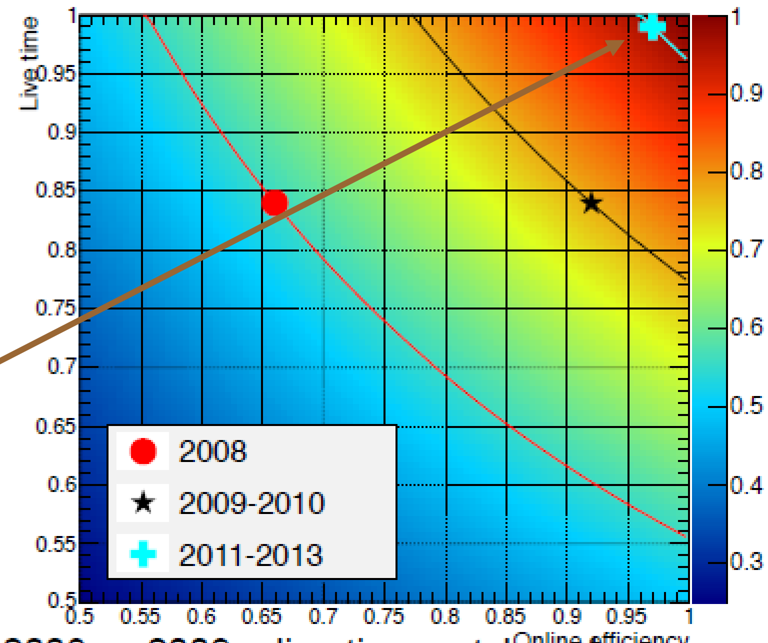
  FPGA based system
  designed to reduce the trigger rate by using fast estimates:

  γ-energy: → 2×10^3 Hz
  $e^+\gamma$ timing → 100 Hz
  $e^+\gamma$ direction → **10 Hz**

  Signal efficiency > 95%
  Live Time fraction 99%

  JINST **9** (2014) P04022

Live time - online efficiency plane



2008 → 2009 : direction-match and γ energy resolution improvement
2010 → 2011 : multiple-buffer readout

- **Readout**

  DRS custom-made digitizer chip.
  Maximum sampling speed 5 GHz, used in MEG **0.8 and 1.6 GHz**.
  12 bit voltage digitization.

Analysis improvements

Three important improvements with respect to analysis published in 2013 (PRL **110** (2013) 201801):

- Missing 1st-turn recovery algorithm (**MFT**);
- Identification of annihilation in flight (**AIF**) events;
- Year by year target alignment

⇓

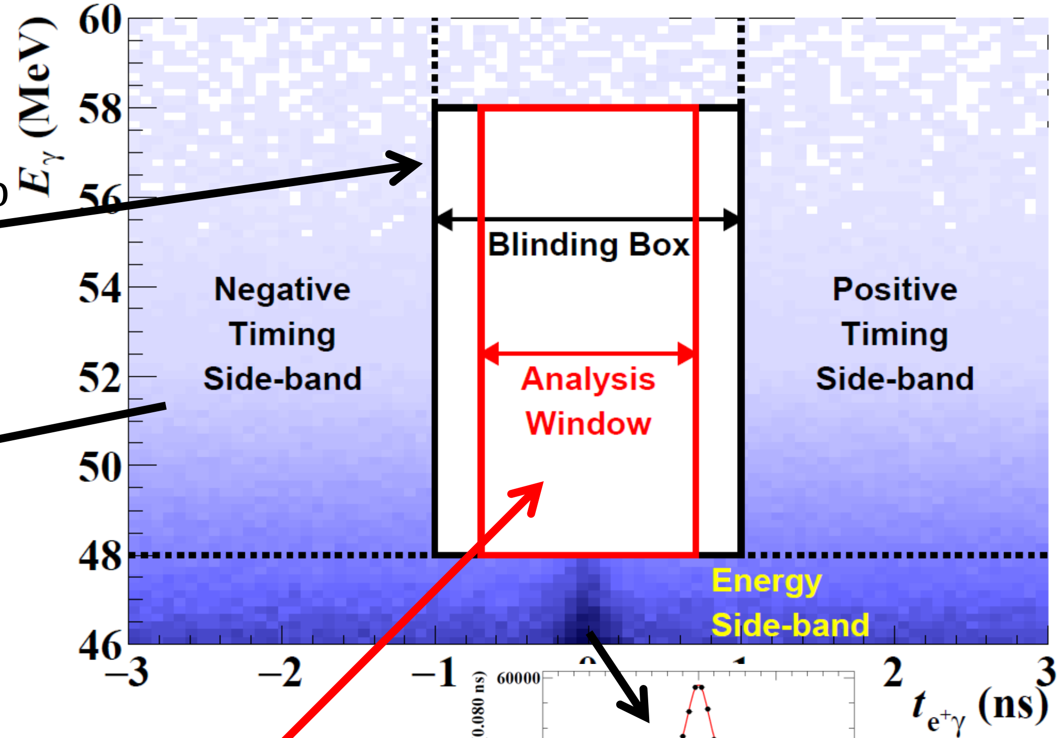
- significant software and likelihood function modifications;
- needed to re-process the full MEG sample from scratch.

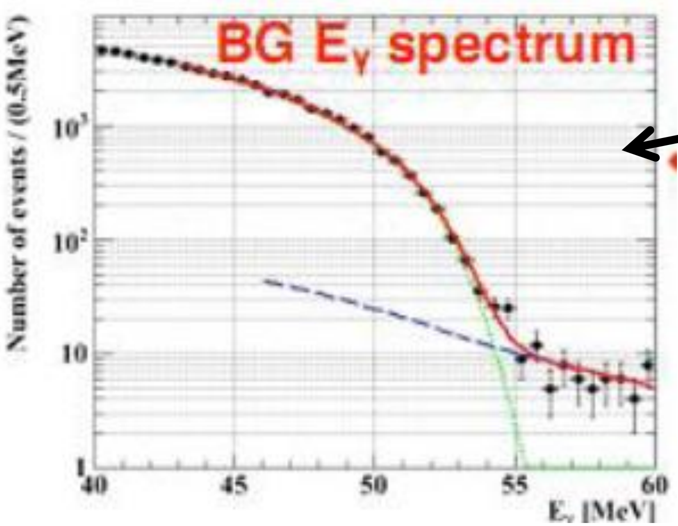
MEG analysis strategy

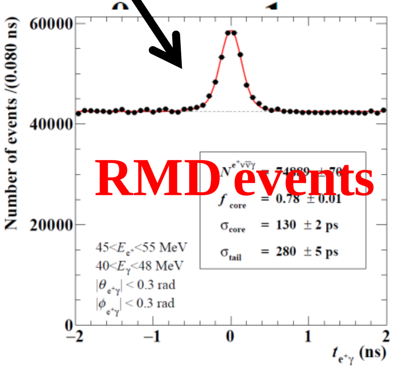
Combination of **Likelihood & Blind** analysis

Signal and background optimization done in sidebands

Events in the blind box (≈ 0.2 %) hidden up to the end of optimization procedure







Final analysis on events falling in **Analysis Window**

MEG analysis generalities

- **Maximum likelihood analysis** to extract N_{signal}.
- **Two independent analyses** with pretty **consistent results**:
  - **Event-by-event PDF**, **relative polar angles** used separately;
  - **Constant (year-by-year) PDF, relative stereo angle** used.
- Standard **frequentistic approach** (Feldman & Cousins); toy MCs for Upper Limit and sensitivity determinations.
- **Observables**: E_e, E_γ, $T_{e\gamma}$, $\theta_{e\gamma}$, $\phi_{e\gamma}$ (or $\Theta_{e\gamma}$).
- **PDF mostly formed from data**:
  - Signal from measured resolutions (calibration data);
  - Accidental background from sideband data (dominant background directly measured in spectral distributions and rate !);
  - RMD from theoretical distribution smeared with measured resolutions.

MEG likelihood function

Poissonian fluctuation of total number of events.

$$\mathcal{L}\left(N_{\text{sig}}, N_{\text{RMD}}, N_{\text{ACC}}, \boldsymbol{t}\right) = \frac{e^{-N}}{N_{\text{obs}}!} C(N_{\text{RMD}}, N_{\text{ACC}}, \boldsymbol{t}) \times \prod_{i=1}^{N_{\text{obs}}} \left(N_{\text{sig}} S(\boldsymbol{x}_i, \boldsymbol{t}) + N_{\text{RMD}} R(\boldsymbol{x}_i) + N_{\text{ACC}} A(\boldsymbol{x}_i)\right)$$

Where:

x_i is the vector of observables;

$S(x_i, t)$, $R(x_i)$, $A(x_i)$ are the PDFs calculated on the experimental points;

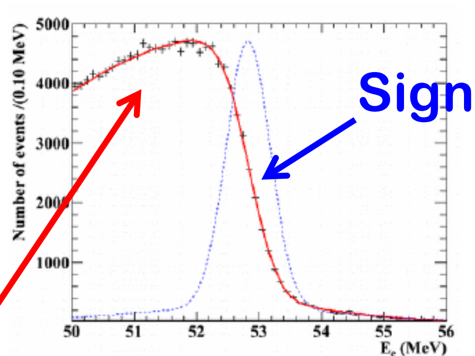
N_{sig}, N_{RMD}, N_{ACC} are the numbers of Signal, RMD and Acc events **to be fitted**;

t is a vector of parameters (two per year) which take into account the deformation and the position shift of target with time;

C incorporates sideband constraints on NRMD and NACC and target effects.

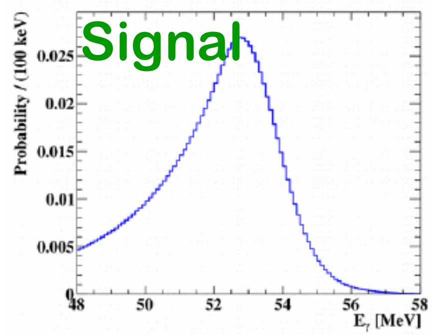
PDF's

Positron Energy

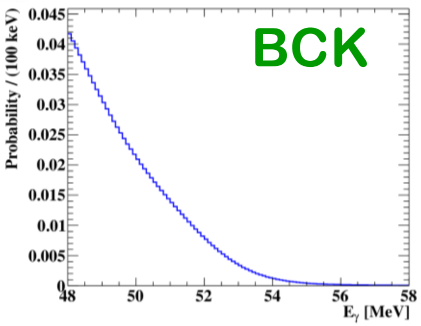


BCK fit from Michel endpoint left/right sidebands

Photon Energy

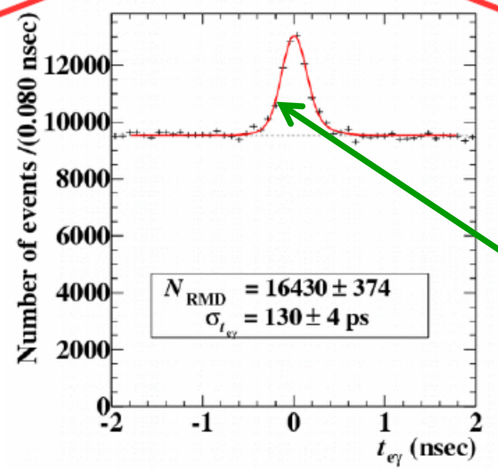


fit from 55 MeV calibration



fit from sidebands

Relative Time



from lower sideband

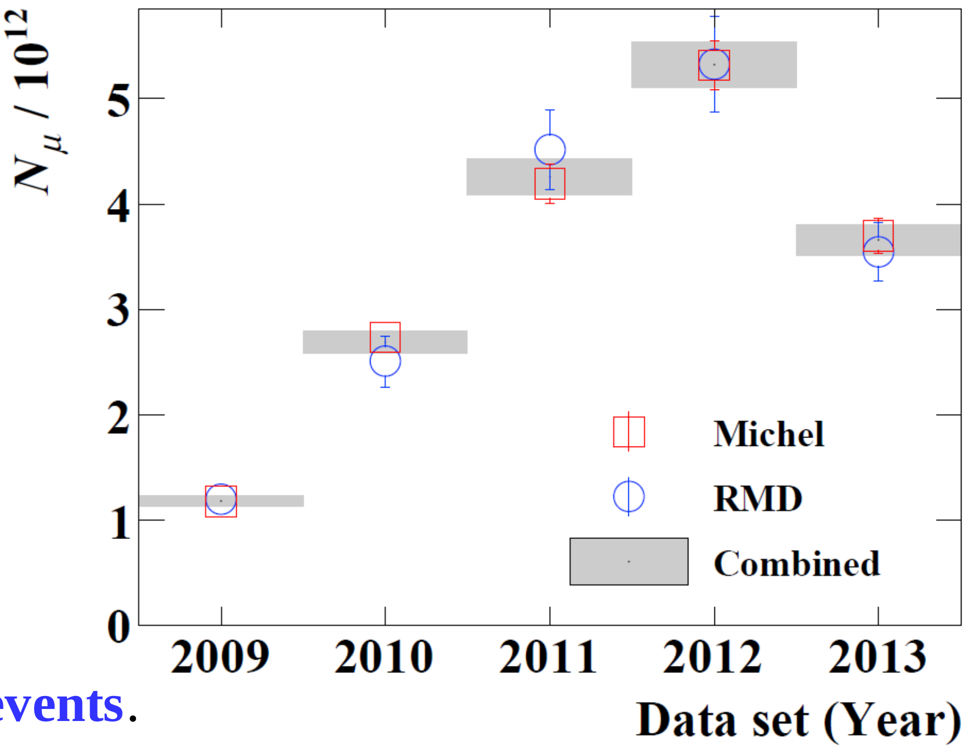
RMD peak

Normalization

Normalization based on **two independent determinations** both using **MEASURED data**:

1) Count **number of Michel positron events** (usual muon decay) collected by a dedicated pre-scaled trigger;
2) Fit **number of RMD events** in the MEG sample outside the hidden box.

The **normalization factor N_μ** is extracted by **correcting for relative efficiencies** of these two samples **with respect to $\mu \to e\gamma$ events**.



Combined result: $\mathbf{SES = 1/N_\mu = (5.84 \pm 0.21) \times 10^{-14}}$

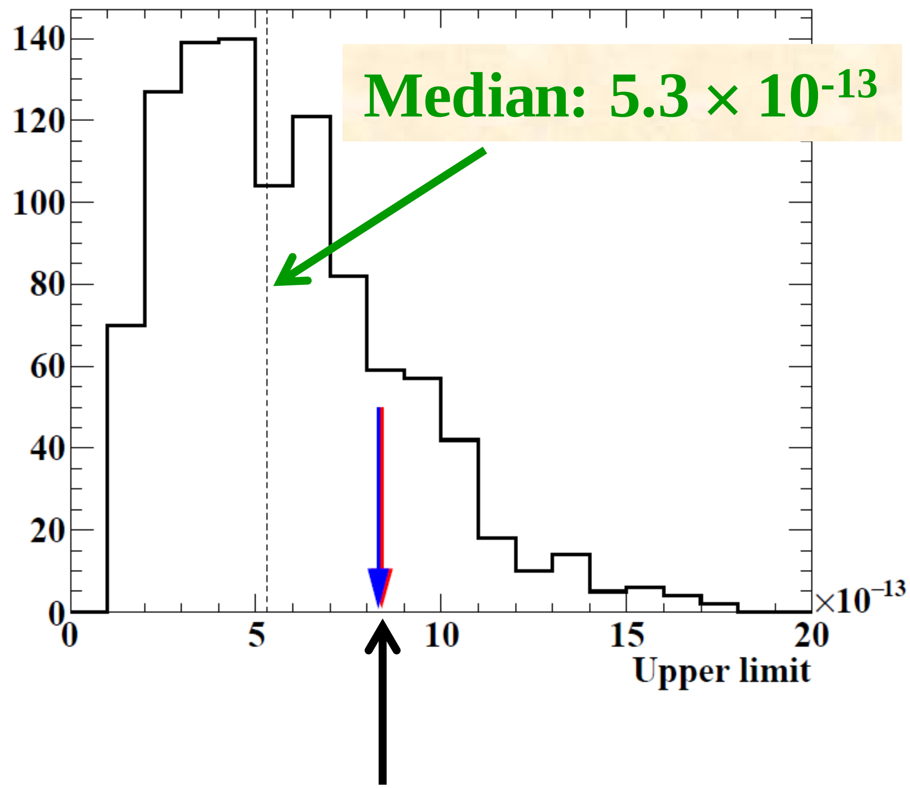
(3.5% uncertainty)

Sensitivity

Sensitivity evaluated by **using toy MCs with zero signal events**.
Systematic effects included (energy scale, angular misalignment, target effects ...).

Median:
4.6×10^{-13} (no systematics)
5.3×10^{-13} (including systematics)

Target deformation dominates; it produces 13% sensitivity degradation; other effects < 1%.

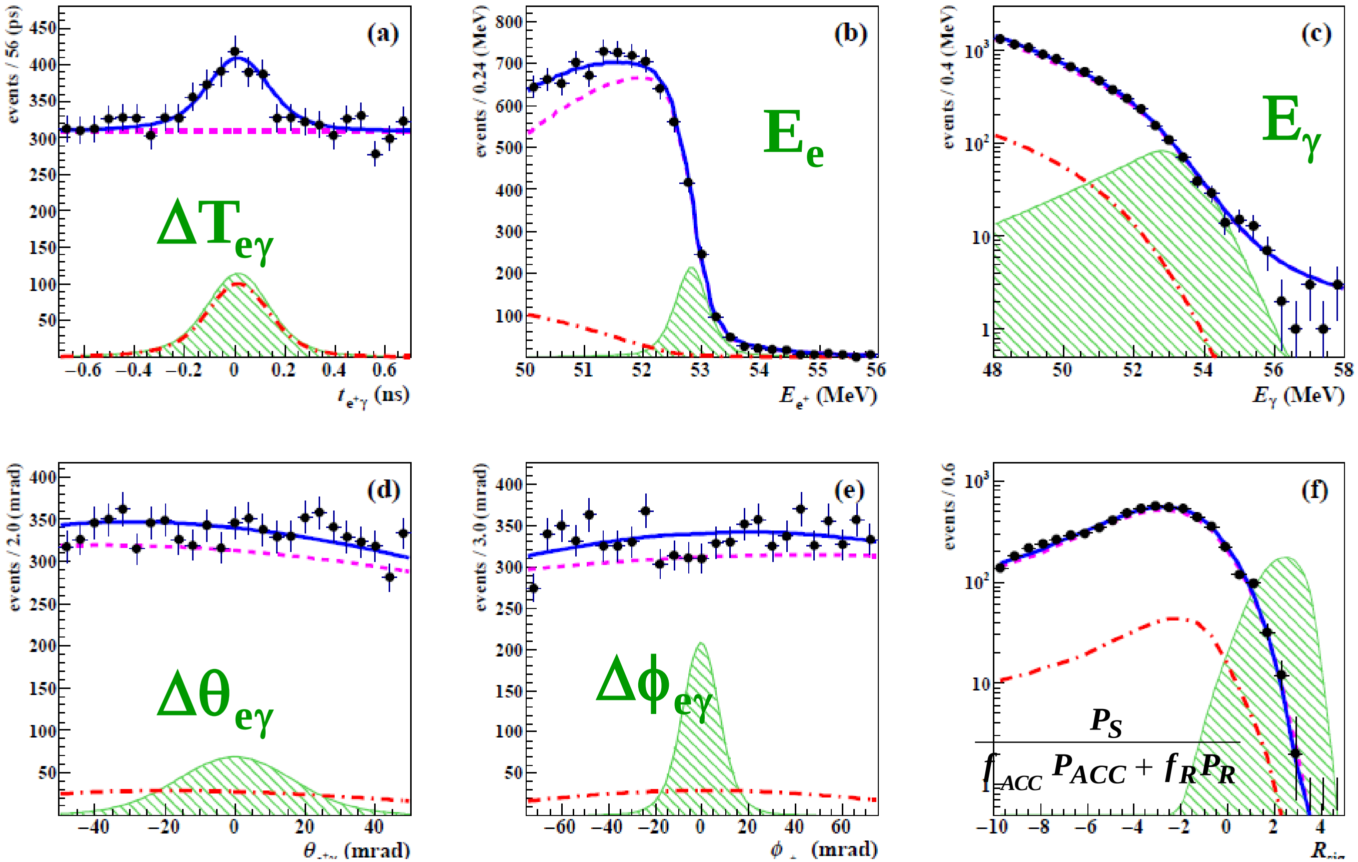


Fit on **"Timing Sidebands": $(8.1\text{-}8.2) \times 10^{-13}$**

Results 1)

Likelihood fit on events falling in Analysis Window within Blinding Box

Event-by-event PDF



MAGENTA: ACC
RED: RMD
BLU: total
GREEN: Signal UL × 100

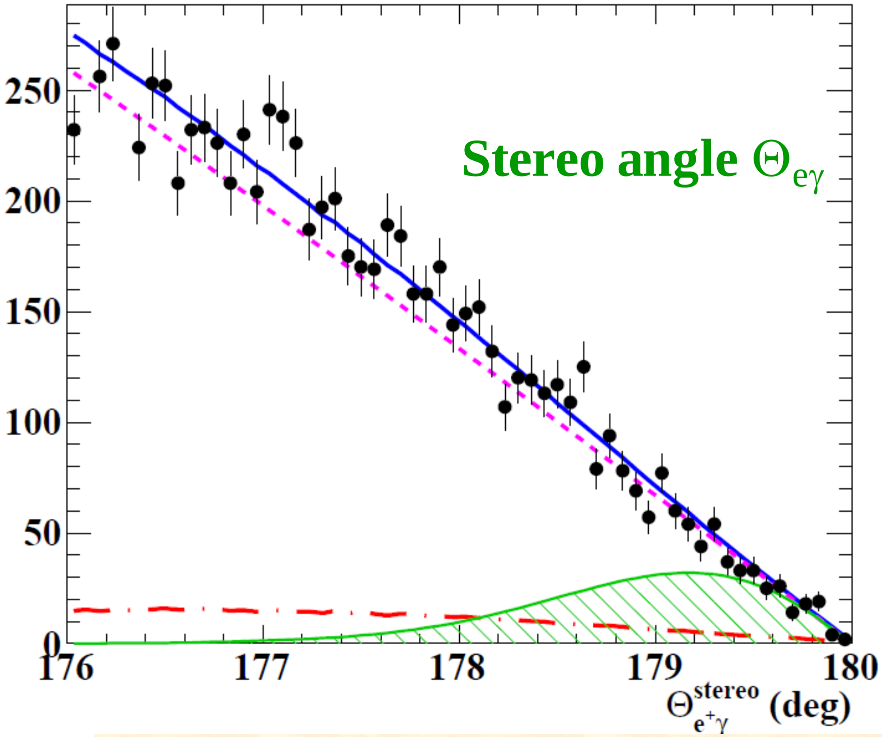
Best fit:
BR (μ → eγ)
= - 2.2 × 10^{-13}
(negative) ⇒

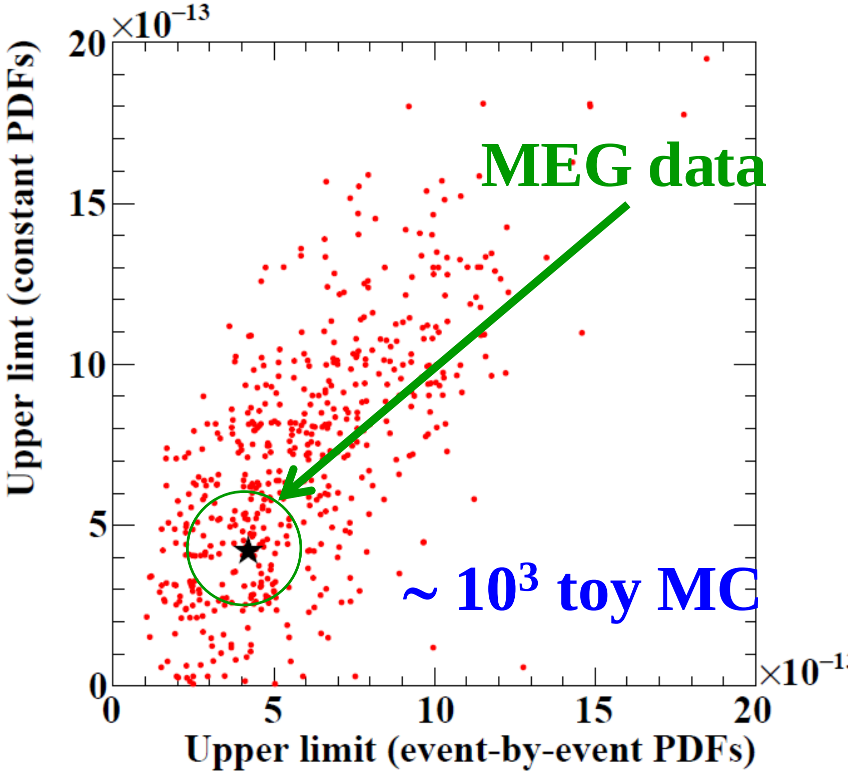
UL
BR (μ → eγ)
≤ 4.2 × 10^{-13}
@90% CL

Results 2)

Alternative analysis:
"constant PDF"

Good consistency between analyses

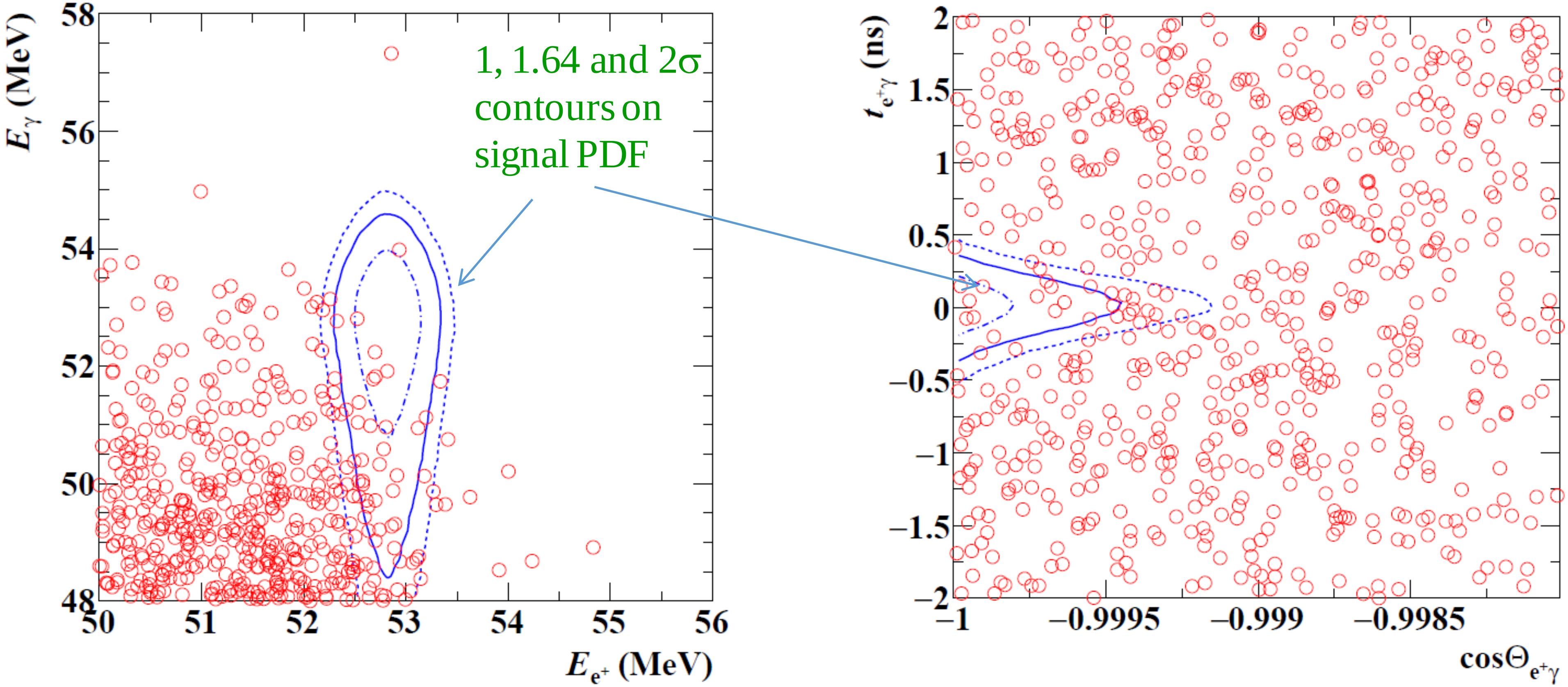




Agreement within 10 % for Best Fit & UL

Results 3)

90% signal efficiency cut (74% for E_γ) for not displayed variables.

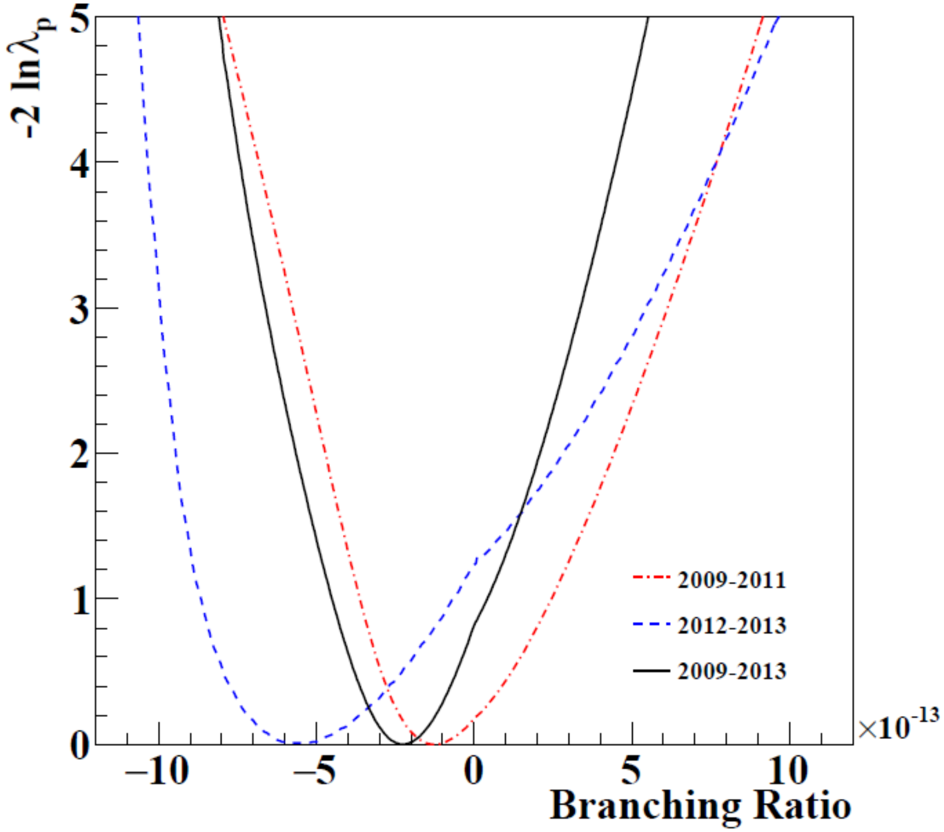


No indications of signal excesses.

Highest probability events different in left and right plots.

Comments

- Final **MEG phase I Upper Limit** is:
  - ✓ a factor **1.4 better than 2013 UL**
  - ✓ **30 times better than MEGA UL** (pre-MEG epoch);
- Analysis of 2009-2011 data (PRL 2013) repeated for check (different analysis algorithms); **~ 5% worse result, but statistically compatible**;
- **Upper limit checked with log-likelihood analysis**; **results in agreement** with full frequentistic analysis.

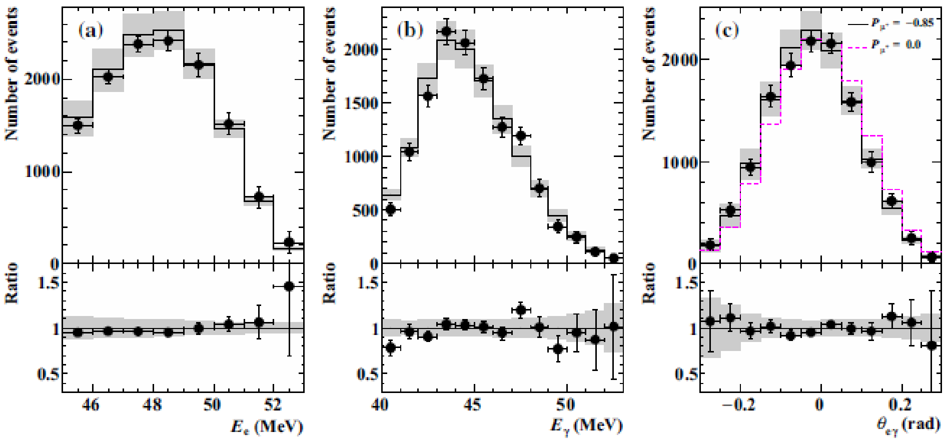


Other MEG results

"Measurement of the radiative decay of polarized muons in the MEG experiment"

EPJC **76**(3) (2016) 108

First **radiative decay measurement at high statistics** (~ 10^4 RMD events) on polarized muons in the high energy region and large e^+-γ stereo angle regions.

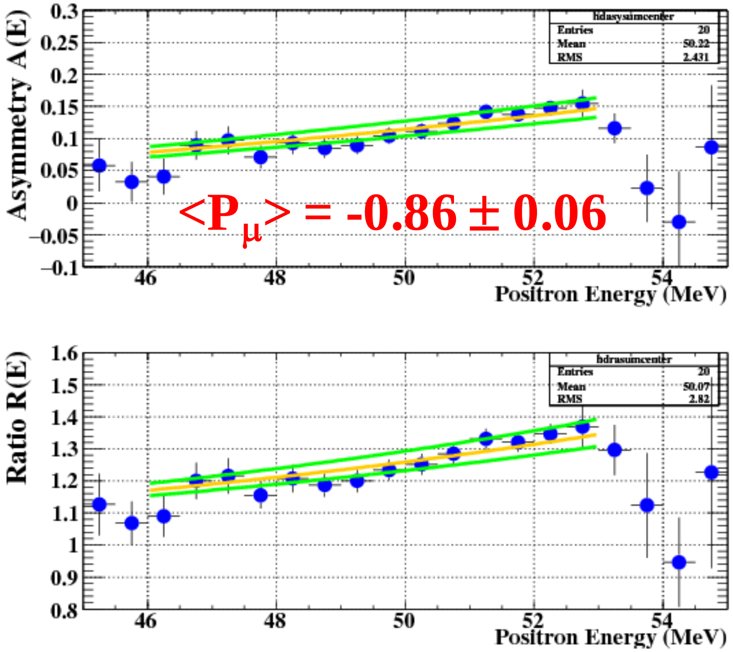


"Muon polarization in the MEG experiment: prediction and measurements"

EPJC **76**(4) (2016) 223

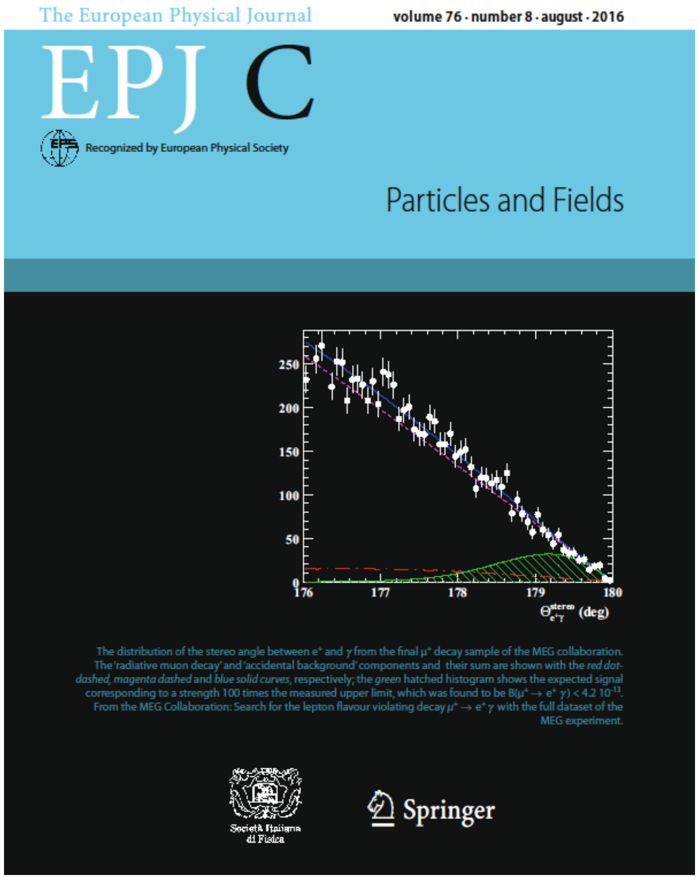
Measurement of **residual polarization of muon beams**:

- ❖ Check of simulation and data analysis;
- ❖ Ingredient in $\mu \to e\gamma$ and RMD search.

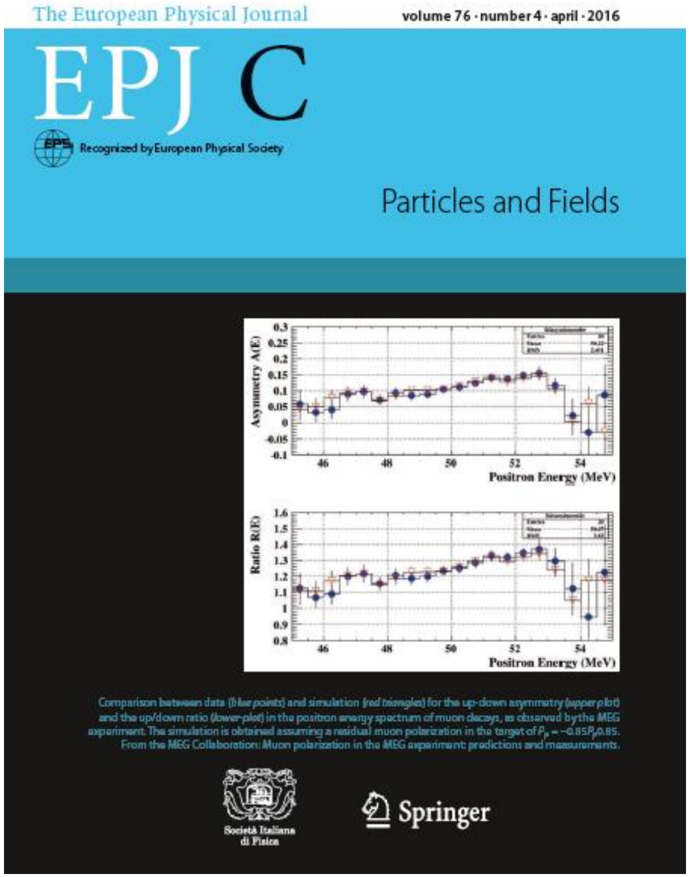


MEG: a "cover-experiment"

Final MEG paper

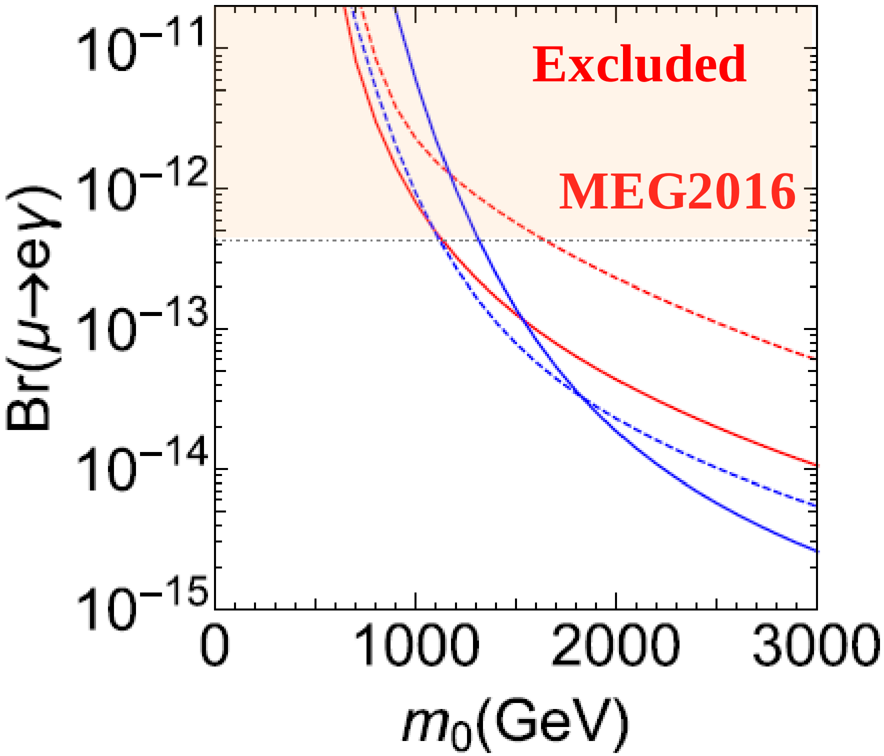


Polarization paper



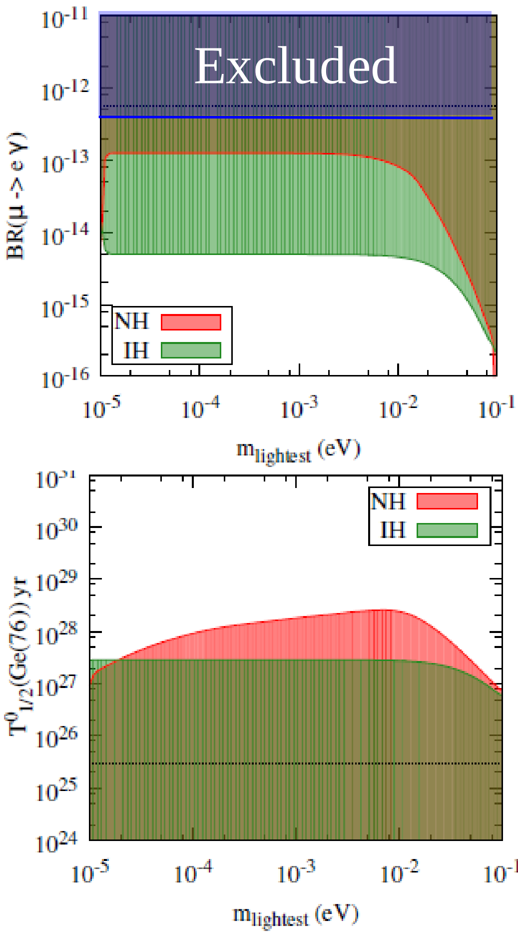
Impact of MEG results 1)

SO(10) SUSY-GUT models with different vacuum expectation values



T. Fukuyama et al.
Phys.Rev. D **94** (2016) no.7, 075018

Correlation with neutrinoless double deta decay in see-saw models

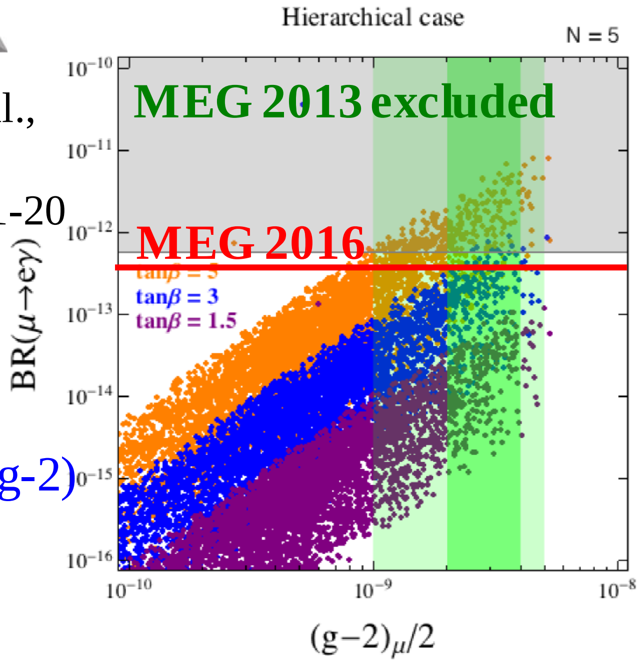


MEG 2016

D. Borah & A. Dasgupta JHEP **1607** (2016) 022

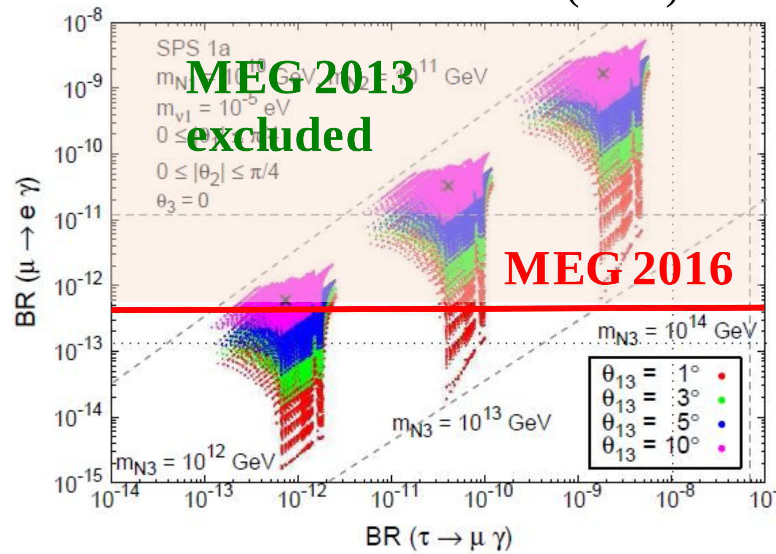
Impact of MEG results 2)

L. Calibbi et al., Eur. Phys. J. **C74**, (2014), 1-20



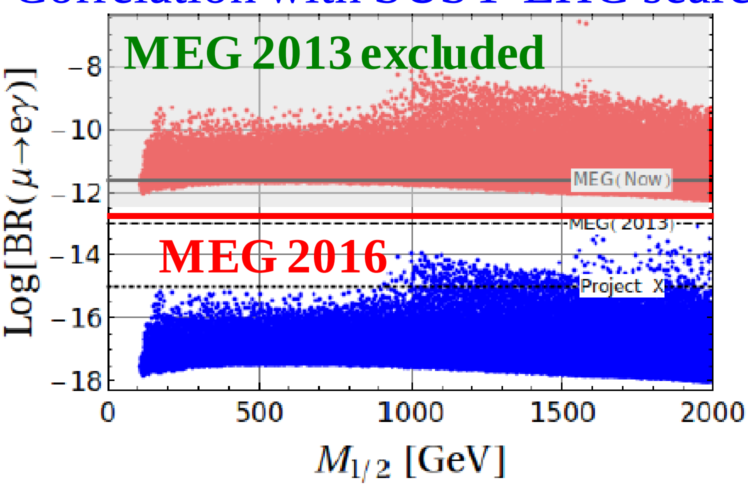
$\mu \to e\gamma$ vs (g-2)

Antusch et al. JHEP **0611** (2006) 090

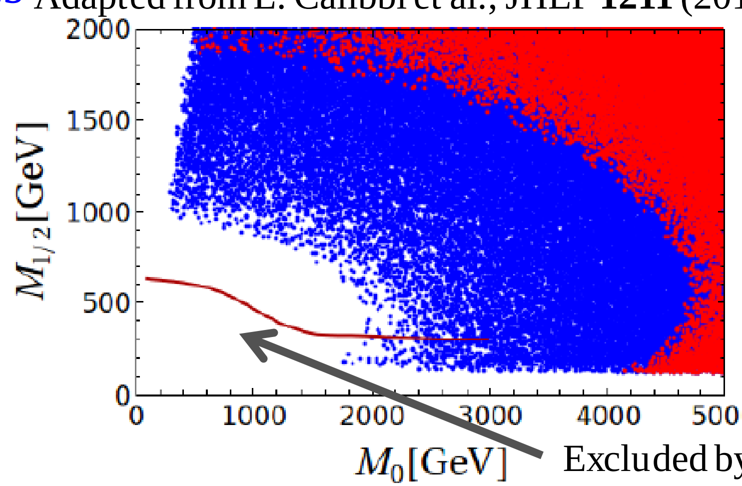


θ_{13} measured by Daya Bay, Reno, Double Chooz, T2K $(8.9 \pm 0.3)^o$

Correlation with SUSY LHC searches



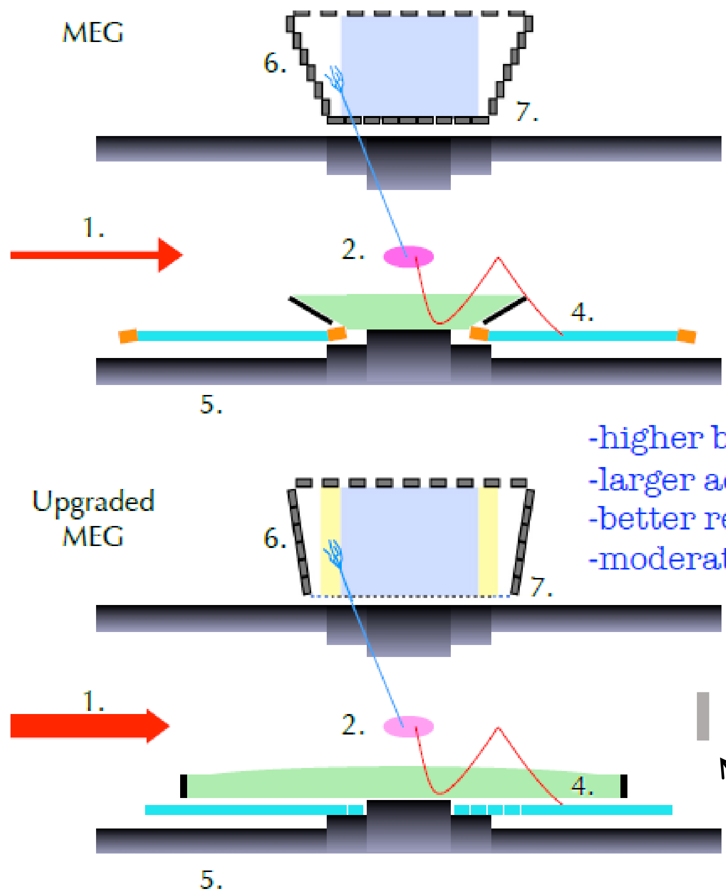
Adapted from L. Calibbi et al., JHEP **1211** (2012) 040



Excluded by direct LHC searches

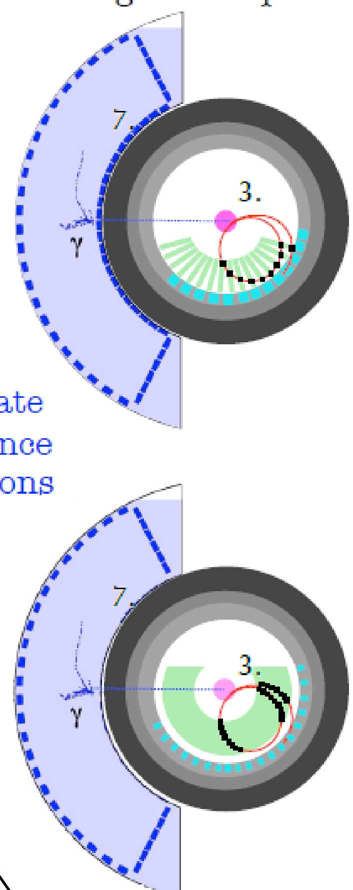
mSUGRA,
tan β = 10, U_{e3} = 0.11
Red points: **PMNS** based mixing
Blue points: **CKM** based mixing

MEG Upgrade: introduction



-higher beam rate
-larger acceptance
-better resolutions
-moderate cost

upgrade design based on our long time experience



Radiative Decay Counter

Upgrade proposal:

arXiv:1301.7225 [physics.ins-det]

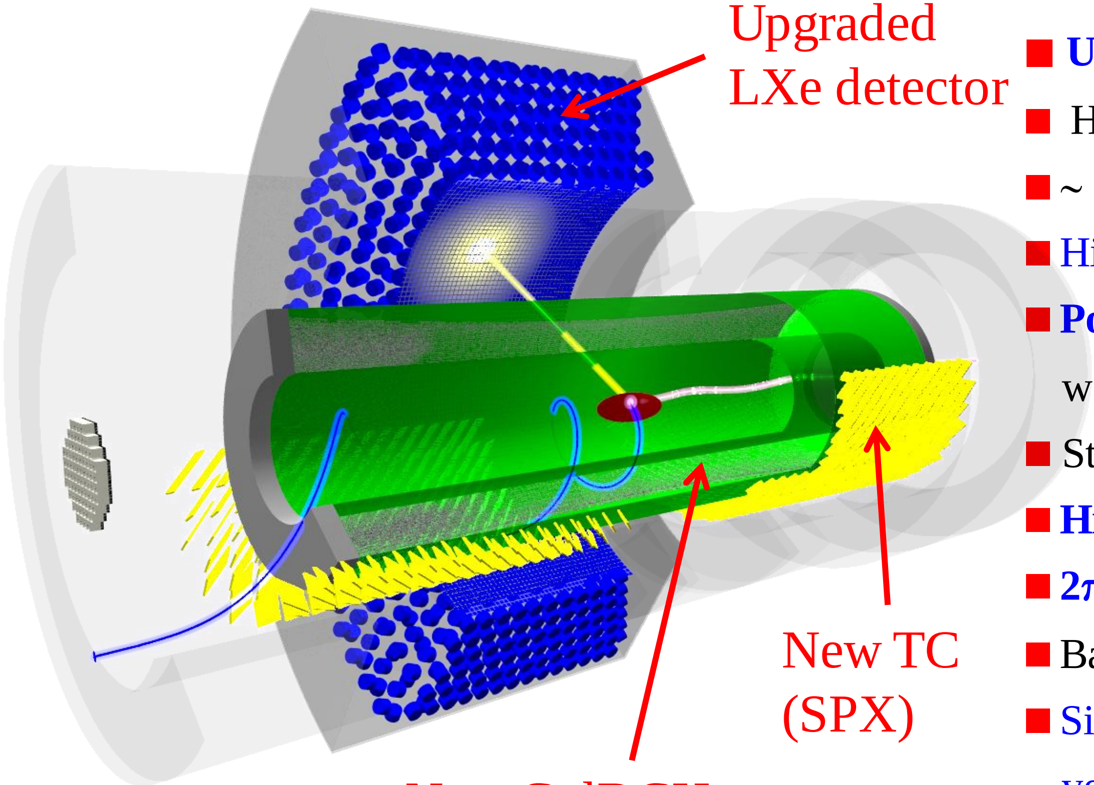
TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88

MEG Upgrade: overview 1)

Increased beam intensity 3×10^7 μ/s → 7×10^7 μ/s.

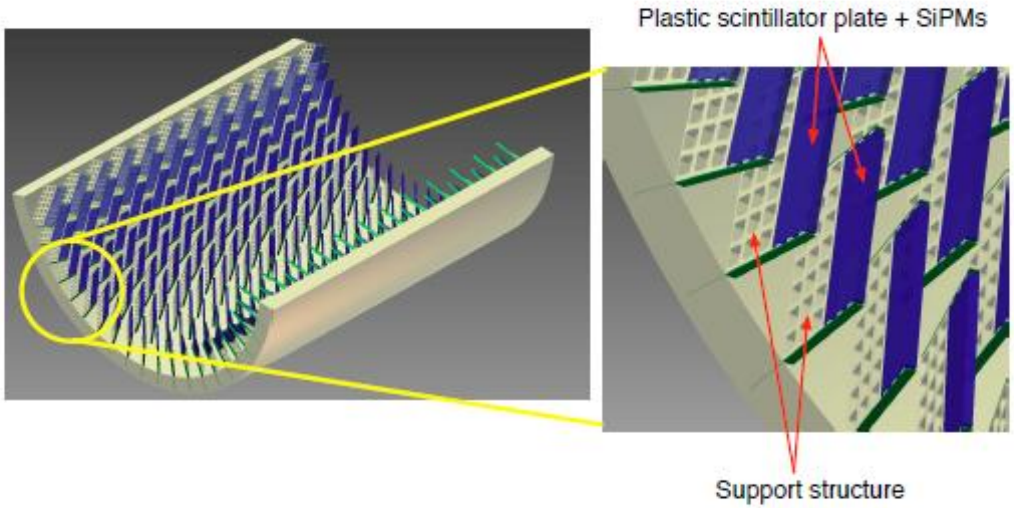
Optimized target thickness and slant angle: 140 μm thickness, 15° slant angle

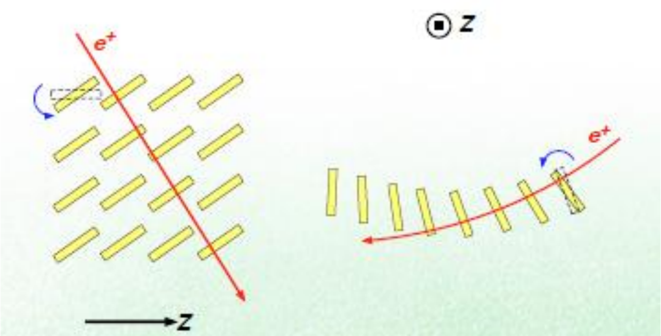


- **Unique volume cylindrical drift chamber;**
- He/Isobutane 85:15;
- ~ 1300 sense wires, ~ 8000 field + guard wires;
- High transparency ($< 2 \times 10^{-3}$ X_0);
- **Positron efficiency > 85%** (better coupling with TC, no extrapolation needed);
- Stereo view, $(7 \div 8)^o$ angle;
- **Hit resolution 120 μm;**
- **2π coverage** over about 2 meters;
- Based on KLOE experience;
- Single hit resolution and gas aging effects verified on prototypes and test stations.

MEG Upgrade: overview 2)

Pixelated Timing Counter equipped with SiPM



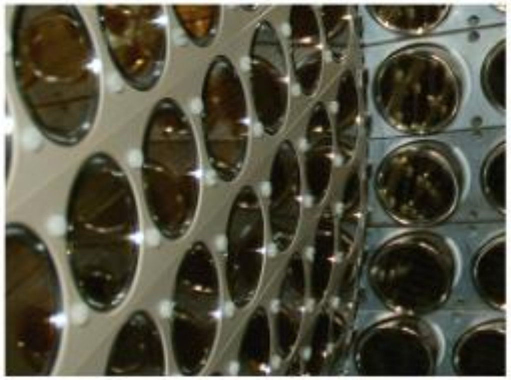


Improved resolution by multiple hits

Expected σ = 35 ps

(factor 2 better than present)

LXe detector: modifications in lateral faces & finer photon sensors at entrance face



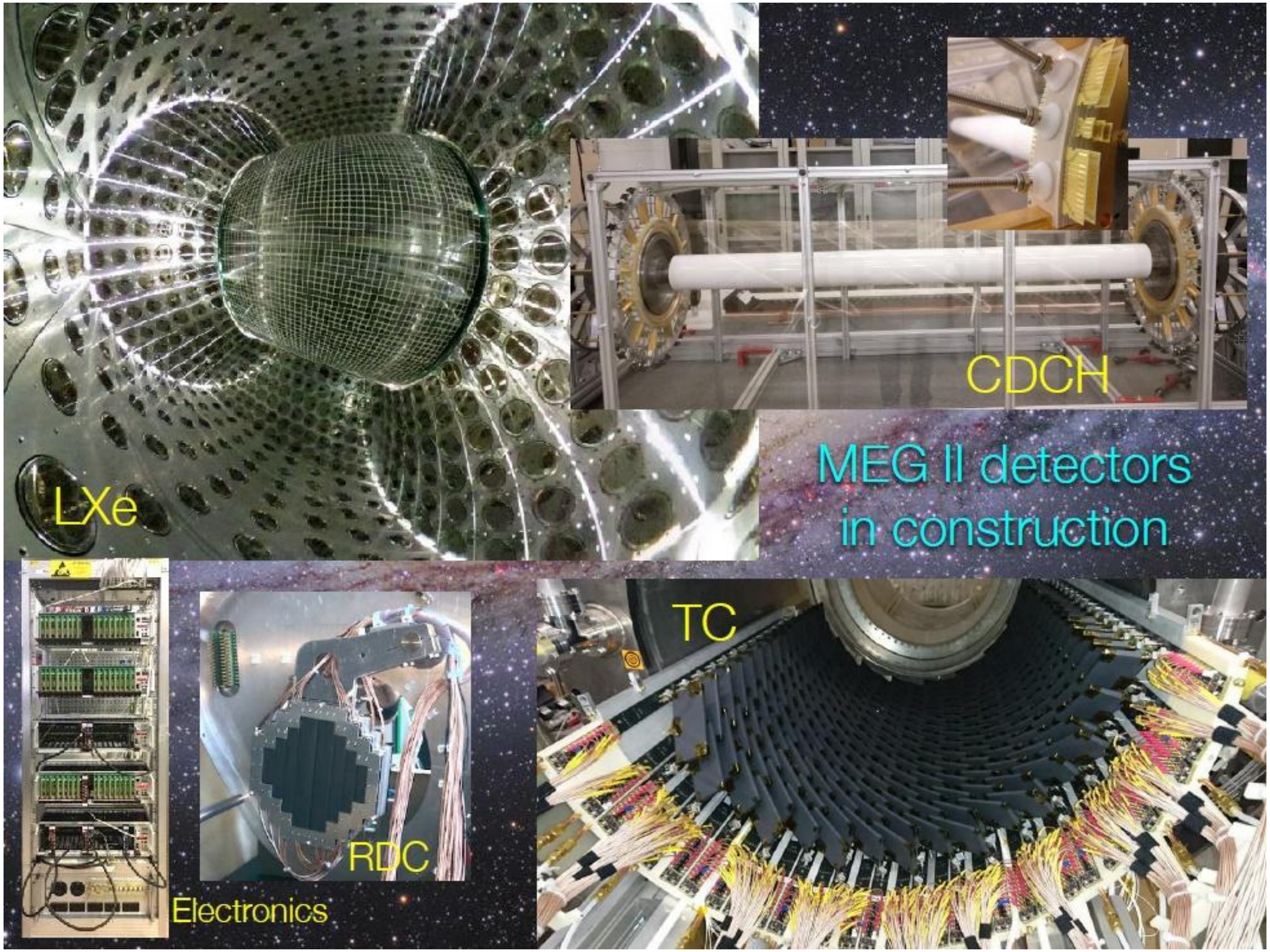
(a) Present detector

(b) Upgraded detector (CG)

12×12 mm^2 SiPM sensitive to LXe UV scintillation light.

Expected a factor 2 better resolution in position and almost a factor 2 in energy.

MEG Upgrade: construction

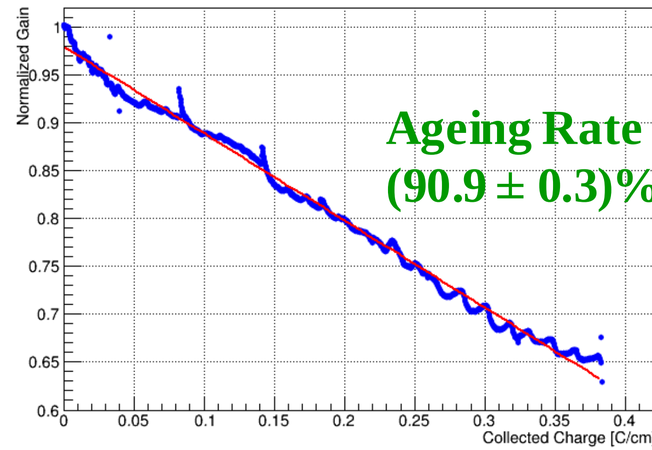


Drift chamber R&D

Ageing prototype

- Ageing effects obtained by high irradiation rate, corresponding to 0.32 C/cm for 3 years of DAQ;
- Tested up to 0.5 C/cm using powerful x-ray source;
- No severe problem (increase HV to compensate 40% gain drop).

Ageing test

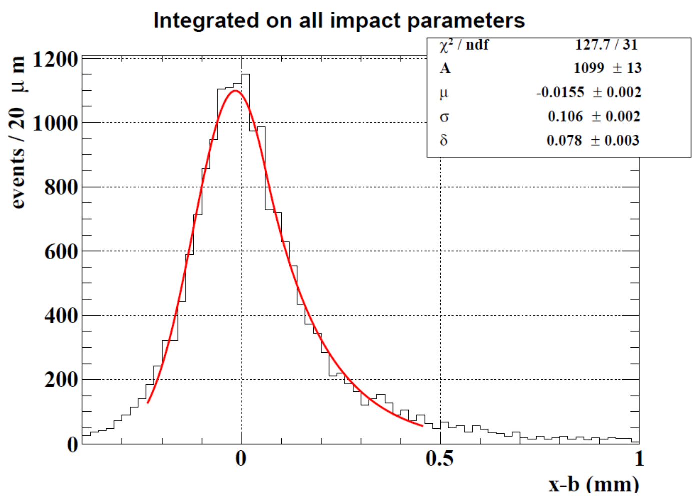


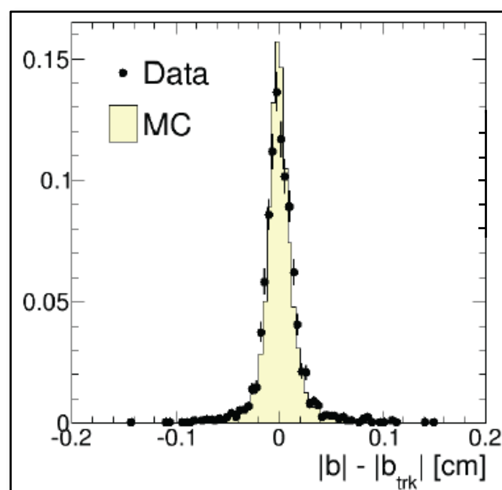
Ageing Rate (slope): (90.9 ± 0.3)% /(C/cm)

Single hit resolution measurements

σ = 105 μm better than requirements

Cosmic ray test facility in Pisa

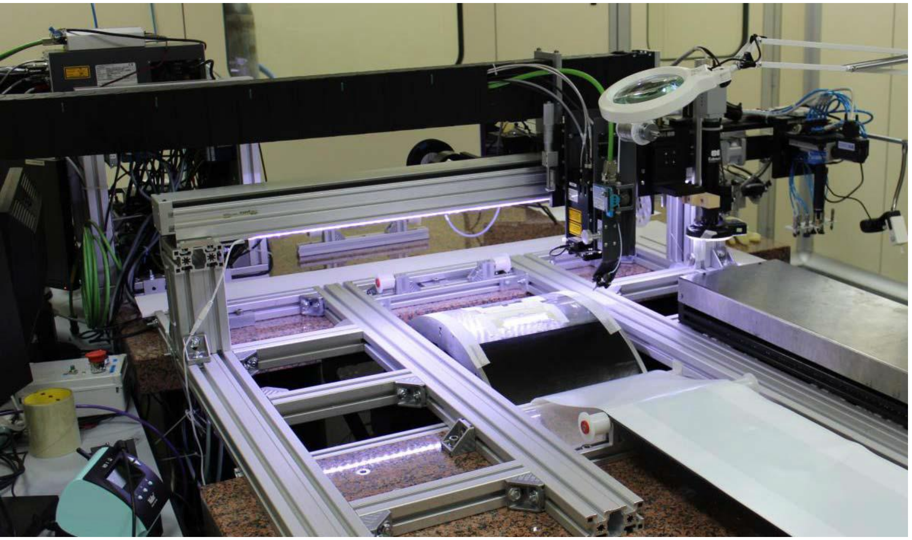




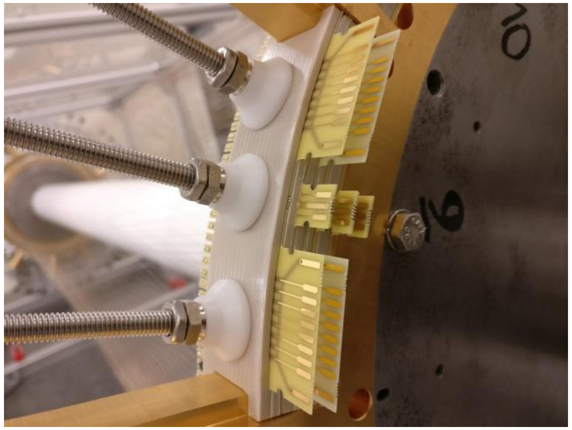
σ = 125 μm

Beam tests @LNF & PSI

Drift Chamber assembly



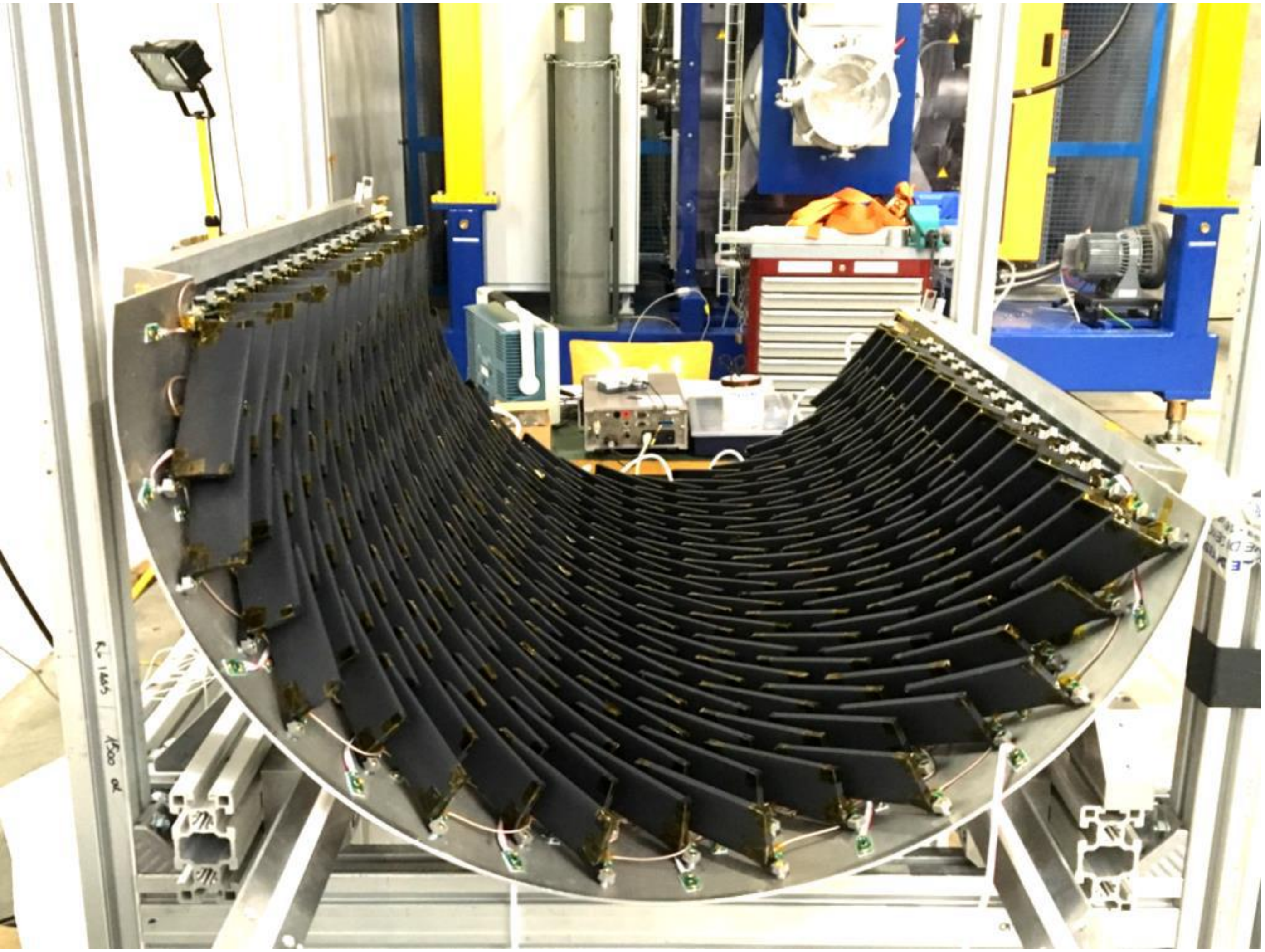
Automated wiring machine in Lecce. Wires mounted on frames and connected to Printed Circuit Boards (PCB) and sent to Pisa for elongation tests and final mounting on chamber structure.



Mounting in a clean room with controlled humidity and temperature.

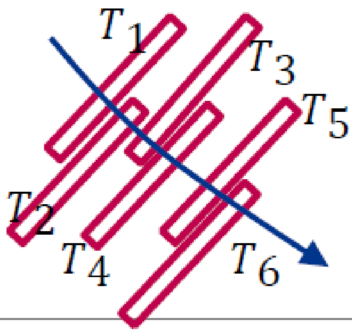
Chamber delivery at PSI expected for the end of this year.

Timing Counter assembly



A complete module successfully assembled in November 2016.

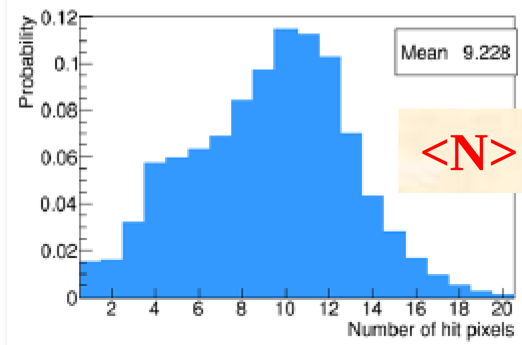
Timing Counter Engineering Run 2016



eg.
at N=6: $\{\frac{(T_1+T_3+T_5)}{3} - \frac{(T_2+T_4+T_6)}{3}\}/2$

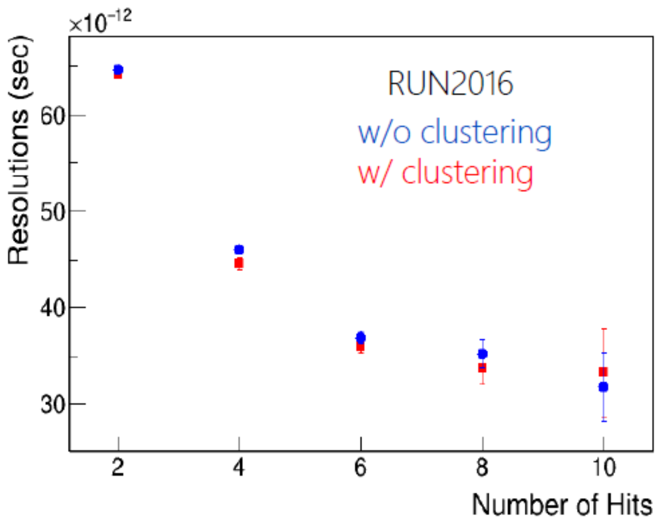
Evaluation of timing resolution by "Even-Odd" analysis

σ (N = 8) = 34 ps

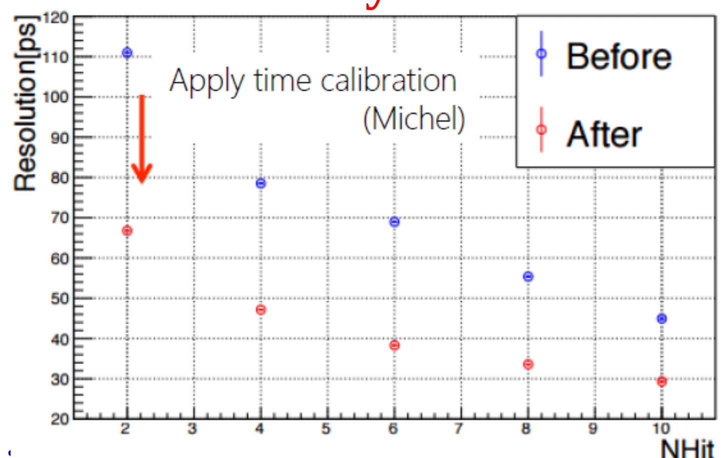


<N> = 9.2

Number of hits per e^+ track from μ→eγ (MC)



Timing calibration with laser-based and Michel track method. **Consistency between methods**.

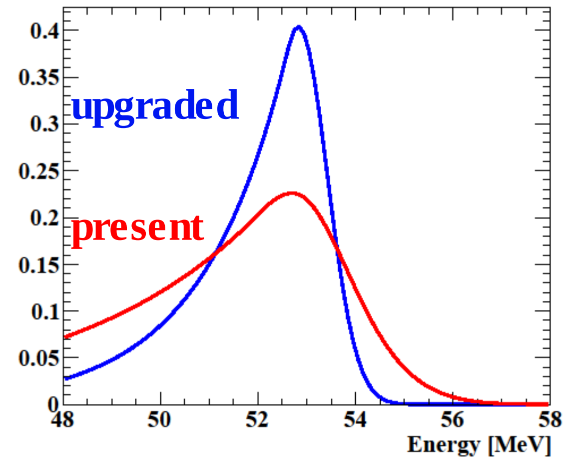


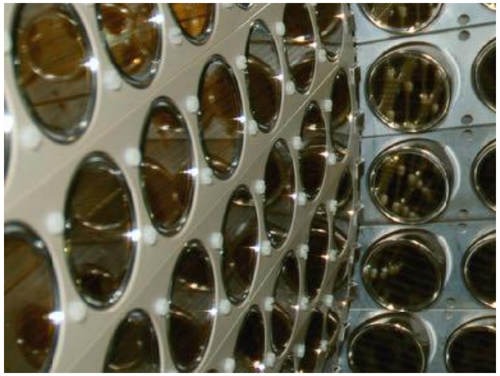
New LXe photon detector

Goals:

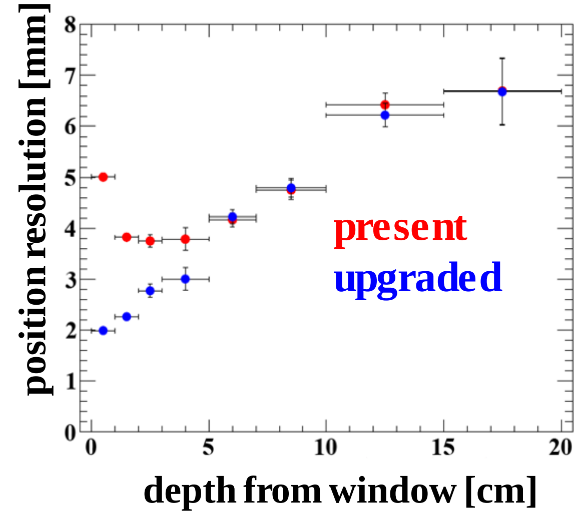
- Improve light collection efficiency and uniformity; (higher granularity and active coverage);
- Increase pile-up rejection efficiency;
- Increase γ detection efficiency (lower mass)
  $\Rightarrow$ **improve energy and position resolution**.

Depth < 2cm
2.4% → 1.1%

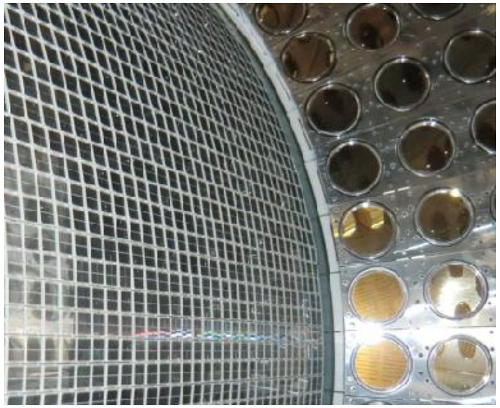




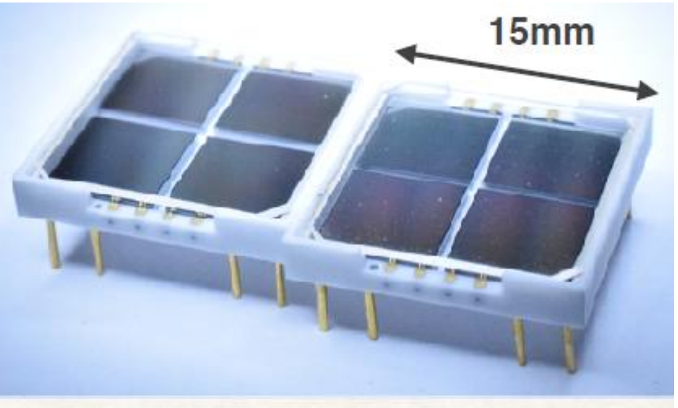
MEG I detector:
2-inch PMTS

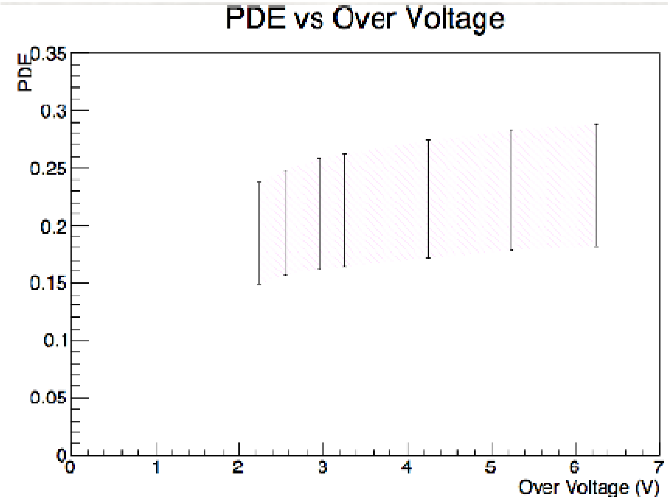


Upgraded detector:
12×12 mm^2 SiPM



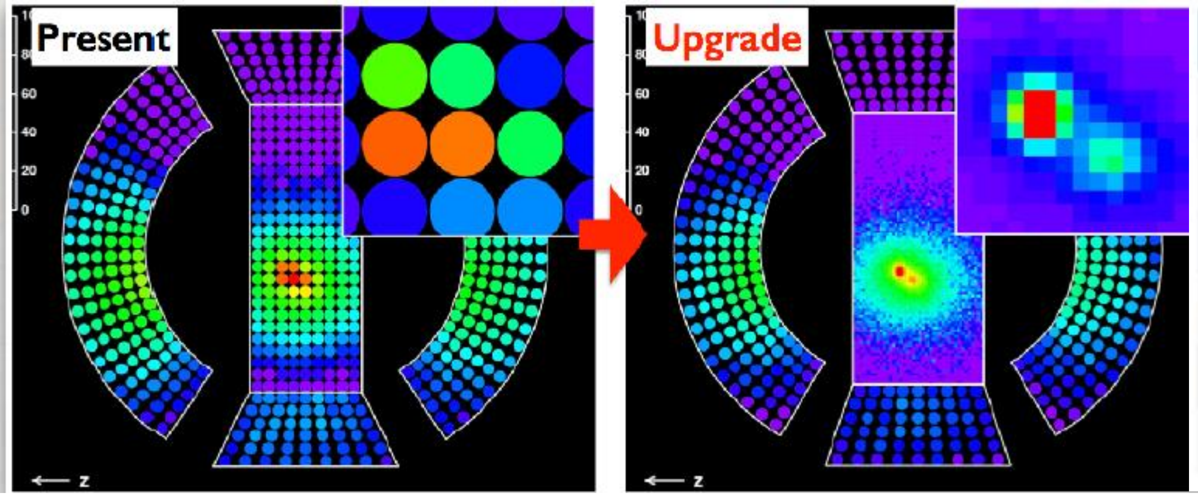
LXe detector assembly 1)





UV Sensitive MPPC

- **140 mm²** active area
- **PDE > 15%** for LXe scintillation light (λ = 175 nm)



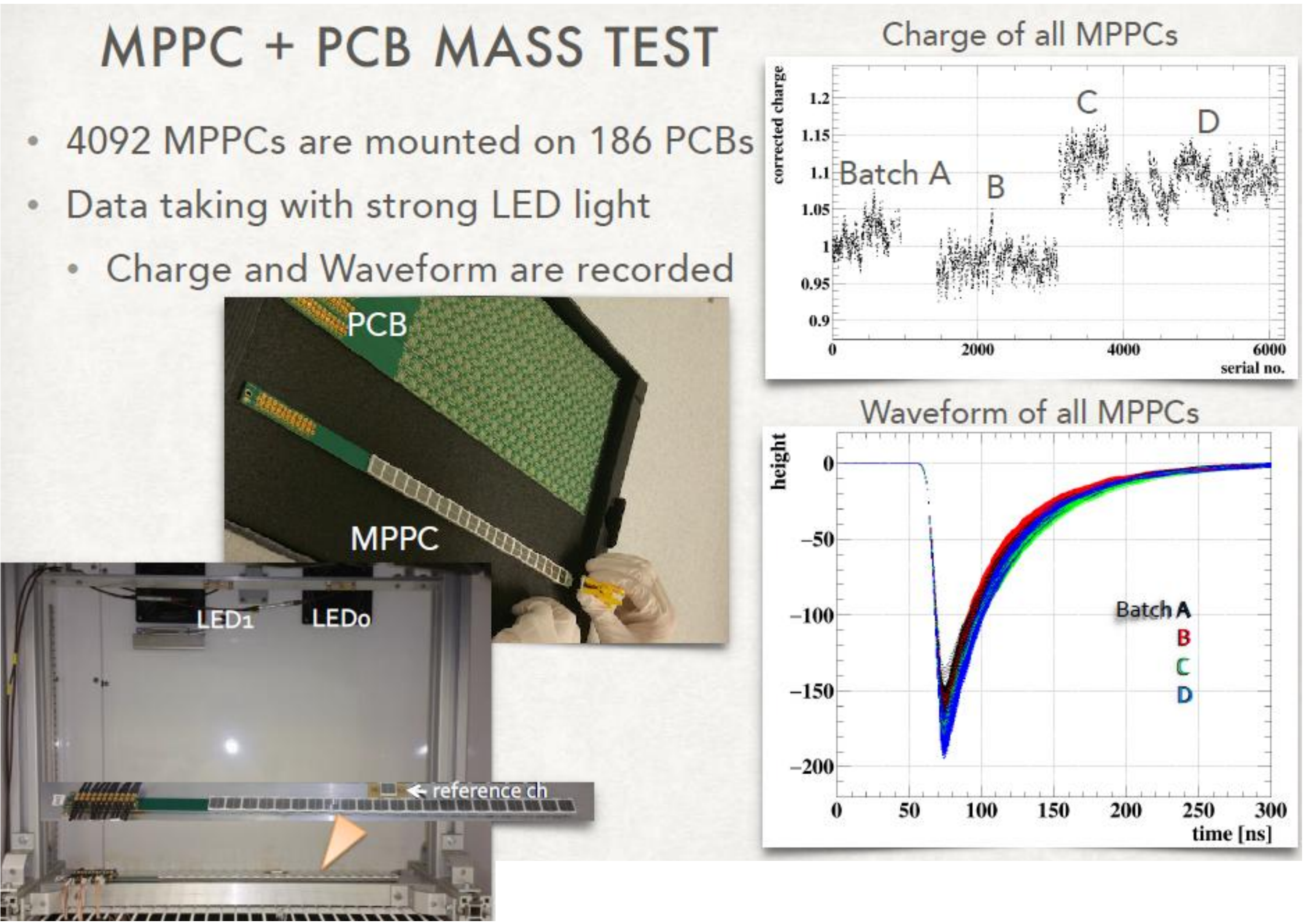
Resolution	MEGI	MEGII
u (mm)	5	2.4
v (mm)	5	2.2
w (mm)	6	3.1
E_γ (w<2cm)	2.4%	1.1%
E_γ (w>2cm)	1.7%	1.0%
t_γ (ps)	67	60

Position

Energy

Timing

LXe detector assembly 2)



Some cable bad connections and bad channels detected and fixed;

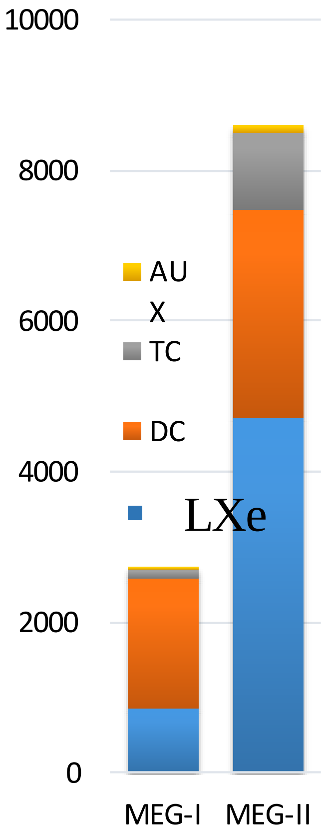
now 4092 MPPCs ok

Current LXe detector:

- All lateral PMTs installed;
- Calibration tools (LEDs, α sources ..) almost installed.

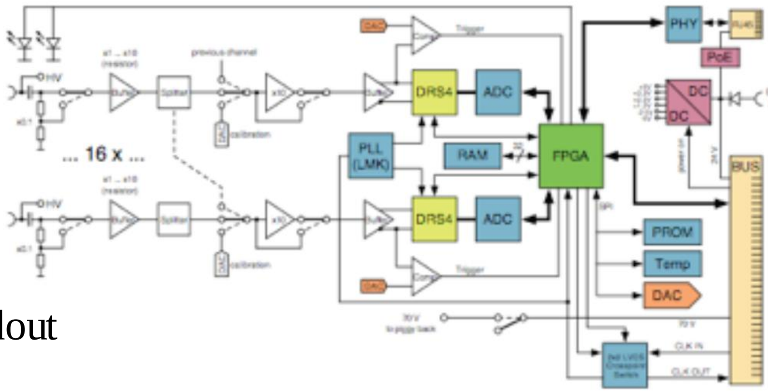
Trigger & DAQ Electronics

of readout channels:



Motivation:

- Increased # of readout channels
- Higher bandwidth to preserve full waveform digitization
- Higher event rate → faster readout



WaveDREAM board:

Multi-functional purpose board that integrates analog frontend, trigger, digitization (DRS4 chips, 2 GHz sampling) and HV supply on a single board.

Trigger:

Trigger principle unchanged; new system with higher performances (online reconstruction quality) in more severe working conditions.

Status:

R&D almost completed

Full production expected within this year

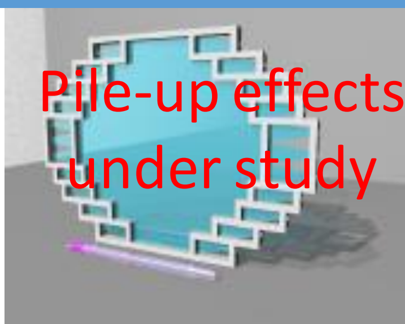
Radiative Decay Counter (RDC)

Motivation:

Identify photons from muon radiative decay by tagging low energy positrons emitted in the same decay: $\mu^+ \to e^+ \nu_e \overline{\nu_\mu} \gamma$ in coincidence with a γ in LXe detector.

Radiative Decay Counter

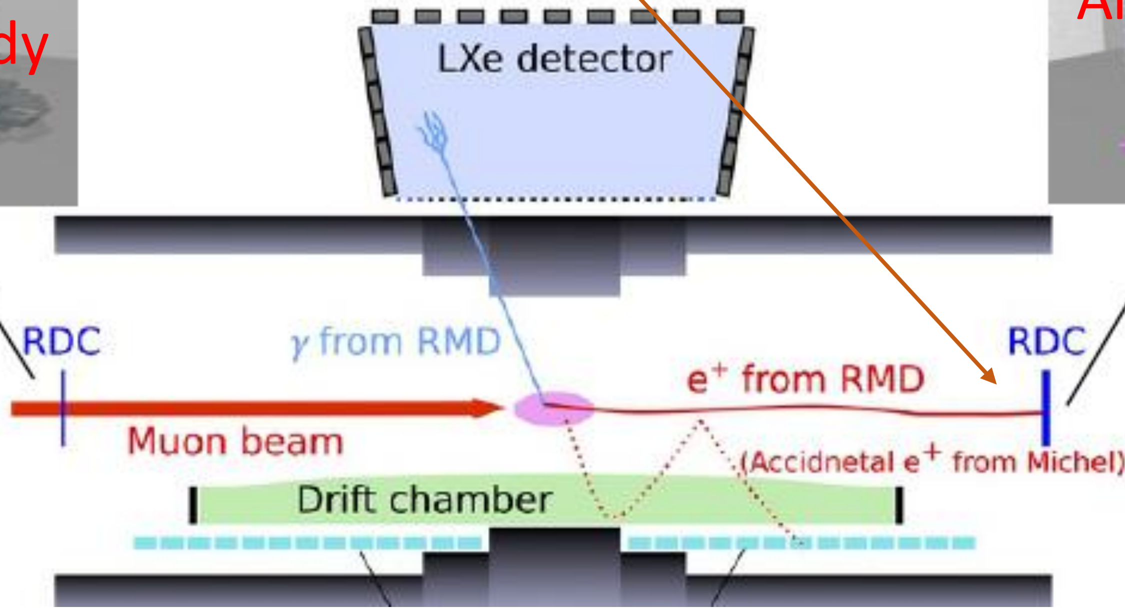
Up-stream RDC scintillation fiber



Pile-up effects under study

Down-stream RDC plastic scintillator + LYSO

Almost ready

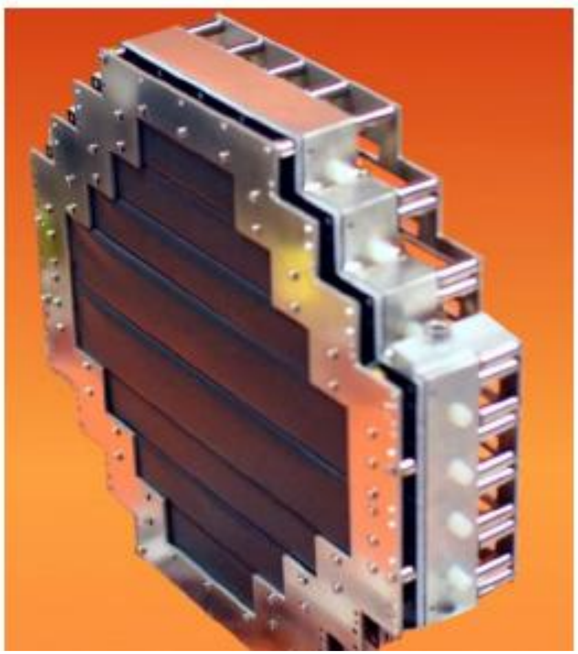


Expected efficiency: 40-48%

RDC assembly

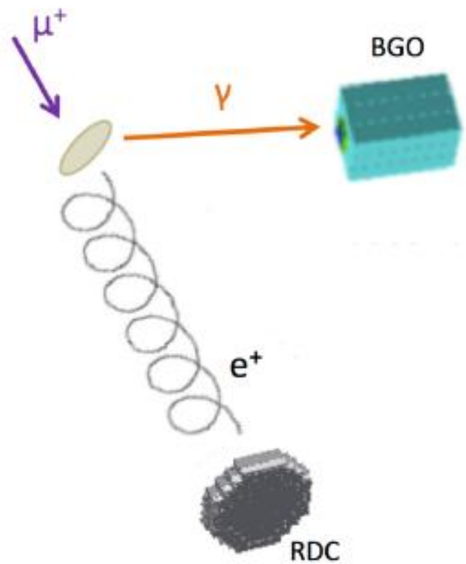
Downstream Side RDC

- ❑ Approved by collaboration
- ❑ All components tested
  - Timing resolution < 80 ps (Plastic Scintillator)
  - Energy resolution ~ 6% (LYSO)
- ❑ Construction completed



RDC beam test @πE5 beam line

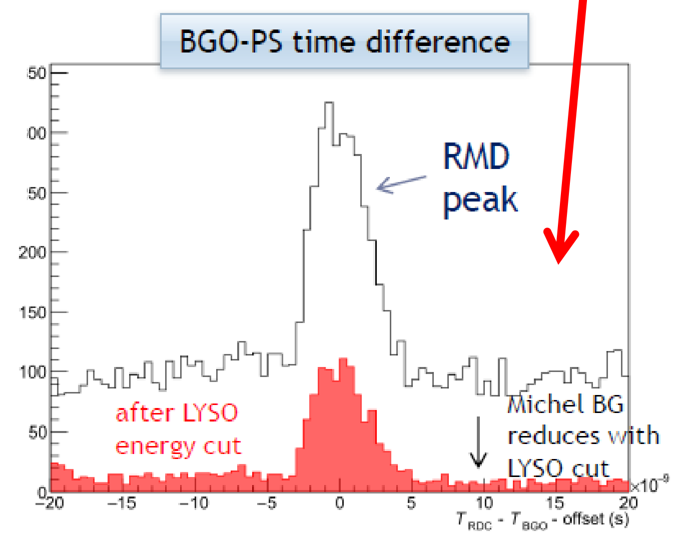
Beam intensity: ~ 10^8 μ^+/sec



BGO detector used to replace LXe detector

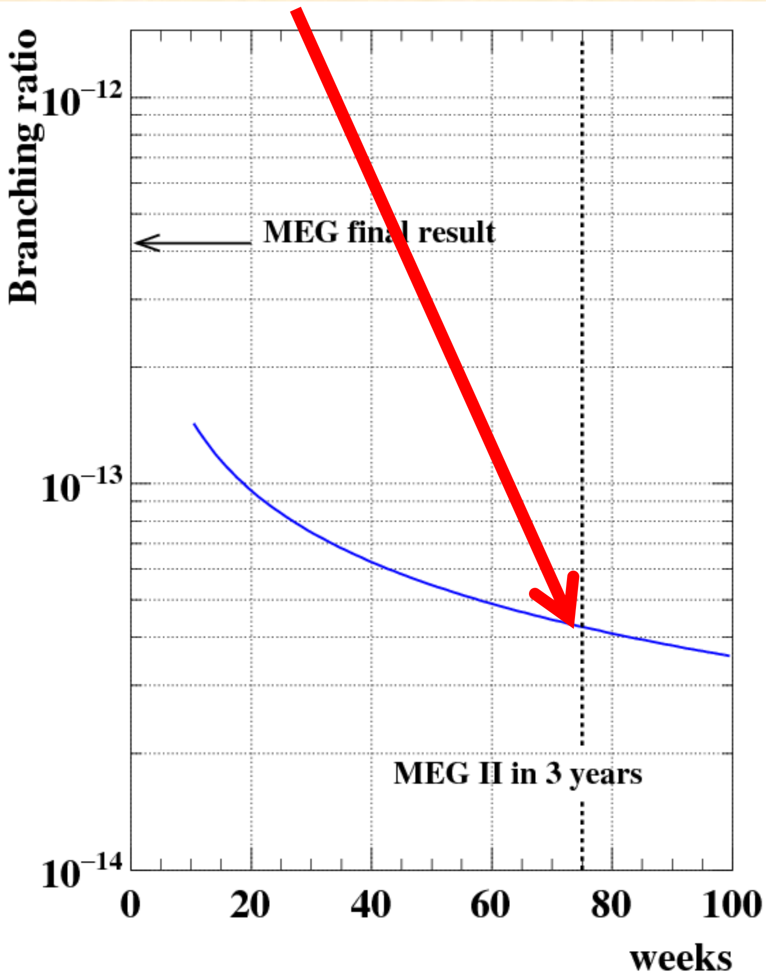
Goals:

- Observation of **RMD peak**
- DAQ and calibration test



MEG Upgrade: statistics & sensitivity

Expected sensitivity ~ (4÷5) × 10^{-14}



~10 times larger statistics with respect to MEGI

Sub-detector completion expected in 2017; final installation in 2018. Integration of sub-detectors & DAQ plus data taking envisaged in 2018.

Summary and Perspectives

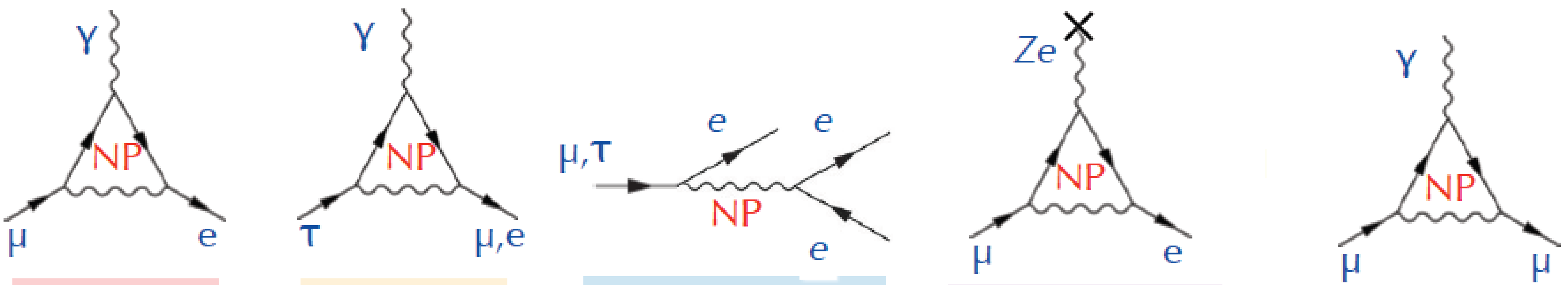
- The MEG experiment collected data in the years 2009-2013, corresponding to a total sample of $> 7 \times 10^{14}$ μ^+ stopped on target.
- Using the full data sample, MEG established **a new upper limit** on **$BR(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$** (90% C.L.), with **sensitivity = 5.3×10^{-13}**.
- **Detector upgrade** under way to improve the sensitivity by a further order of magnitude.
- Tests on upgrade prototypes and final detectors indicate resolutions in agreement with design requests.
- Construction under way for all detector and trigger/DAQ elements; **completion scheduled within this year and data taking expected to start in 2018**.

Backup slides

LFV 4)

Several LFV processes, sensitive to **New Physics (NP)** through

"new" lepton-lepton coupling $y_{ij}\bar{\ell}_i F^{\mu\nu} \ell_j \sigma_{\mu\nu}$



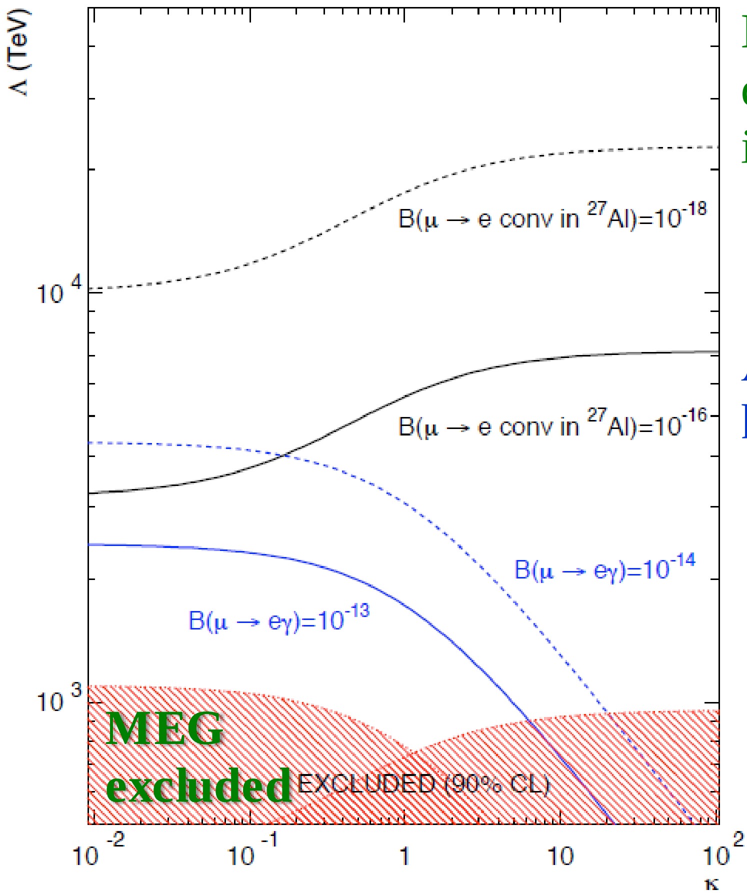
$\mu \to e\gamma$ | $\tau \to \mu\gamma$, $\tau \to e\gamma$ | $\mu \to eee$ | $\mu^- \mathcal{N} \to e^- \mathcal{N}$ | $(g-2)_\mu$

μ, τ anomalous decays | **μ → e conversion** | **Anomalous magnetic moment**

Sensitivity of different experiments 1)

$\mu \to e\gamma$ vs $\mu \to e$ conversion

Effective lagrangian



Magnetic dipole interaction

$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + h.c.$$
$$+ \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L\right) + h.c.\,.$$

Four quark interaction

Λ = New Physics scale
k = Relative weight of two terms

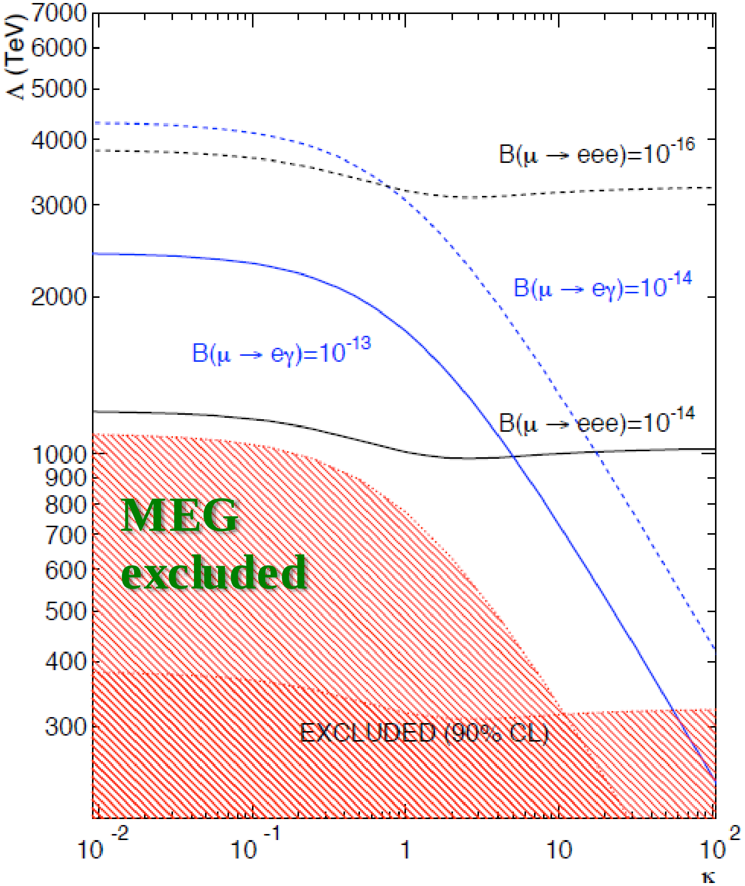
A $\mu \to e\gamma$ experiment with sensitivity of $\sim 10^{-14}$ is competitive with a $\mu \to e$ experiment with sensitivity $\sim 10^{-16}$ for **k < 1**; $\mu \to e\gamma$ sensitivity drops for **k >> 1**.

A. de Gouvea & P. Vogel, hep-ph 1303.4097

Sensitivity of different experiments 2)

$\mu \to e\gamma$ vs $\mu \to eee$

Effective lagrangian



A. de Gouvea & P. Vogel, hep-ph 1303.4097

$$\mathcal{L}_{\rm CLFV} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + h.c. + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{e}\gamma^\mu e\right) + h.c.\,.$$

Magnetic dipole interaction

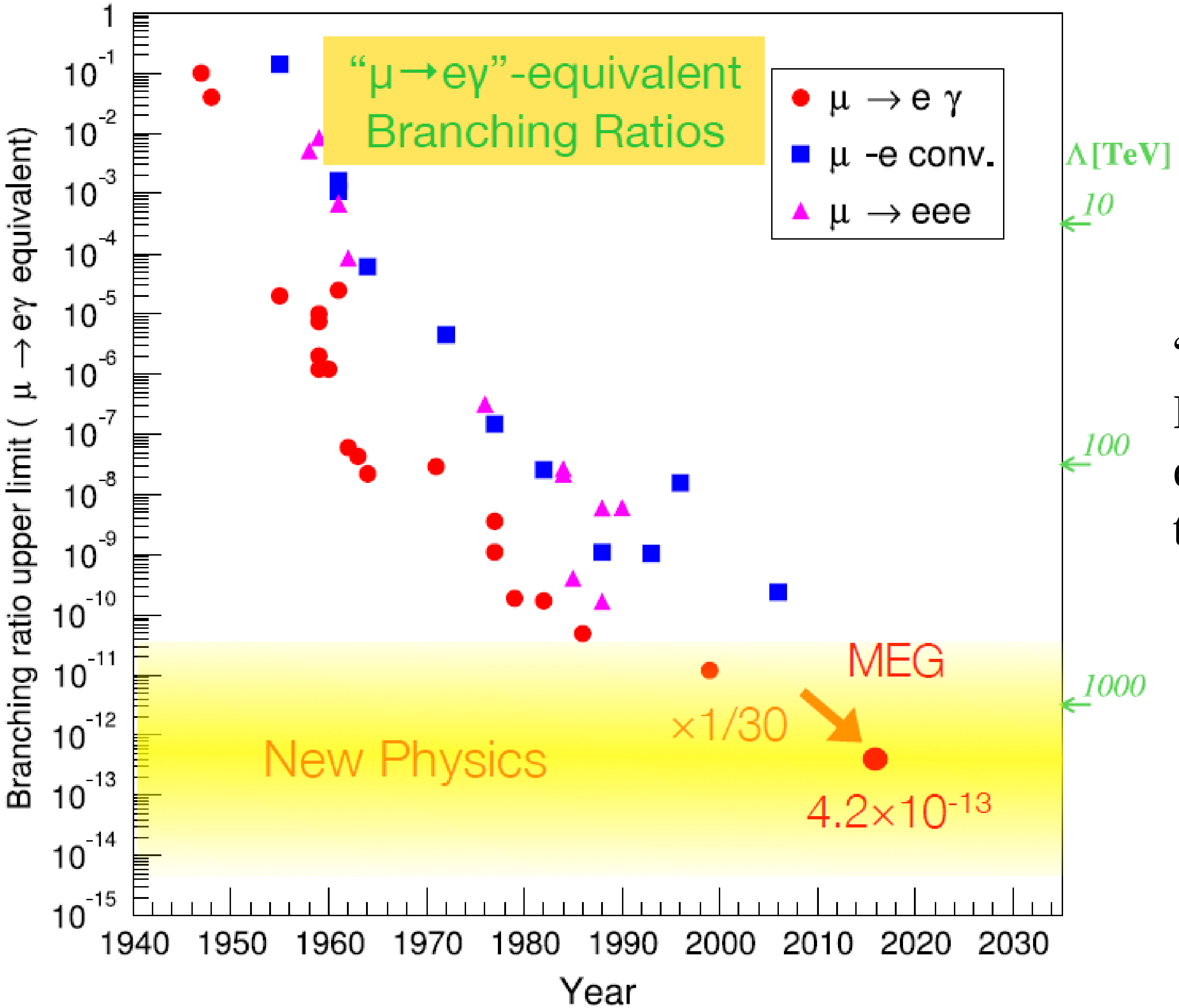
Four lepton interaction

Λ = New Physics scale
k = Relative weight of two terms

A $\mu \to e\gamma$ experiment with sensitivity of ~ 10^{-14} is competitive with a $\mu \to eee$ experiment with sensitivity ~ 10^{-16} for $k \leq 1$; for $k >> 1$, only $\mu \to eee$ survives.

Needed all types of experiments

Impact of MEG results 3)



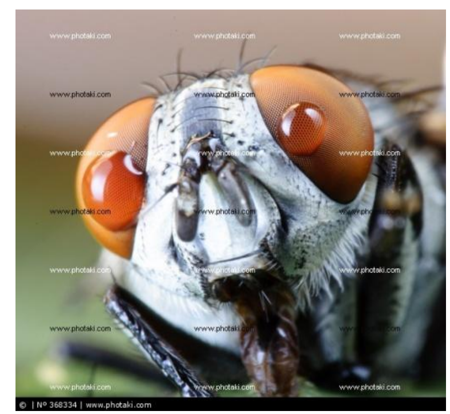
"equivalent" means: if LFV mechanism is dominated by dipole transition.

Multiple point of views …

Muon beam experiments are **very sensitive tools to look for New Physics**.

A "network" of **complementary searches**; **profound exploration of New Physics parameter space**.

New Physics

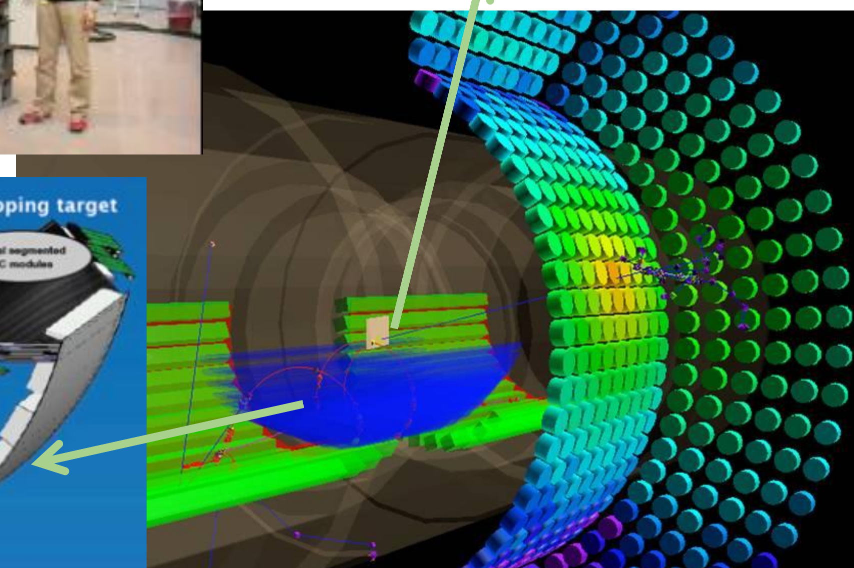


MEG detector components 1)

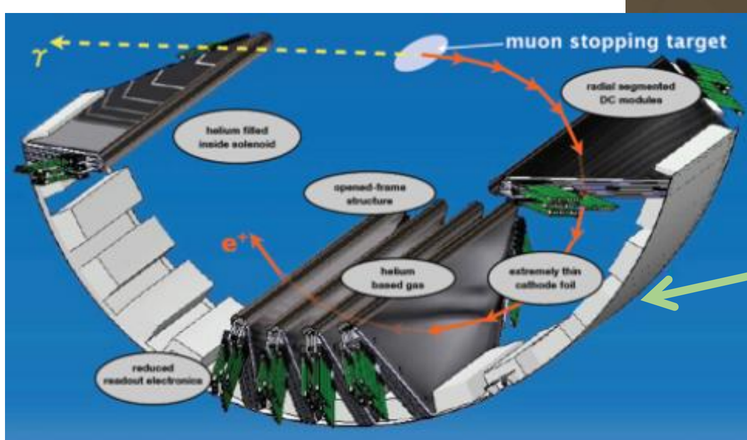
Superconducting solenoid with gradient field (**COBRA**)

Sweeps out low P_z positrons.
Bending radius nearly independent of θ emission angle.

205 μm polyethylene target, 20.5° slanted angle, stopping efficiency 82%

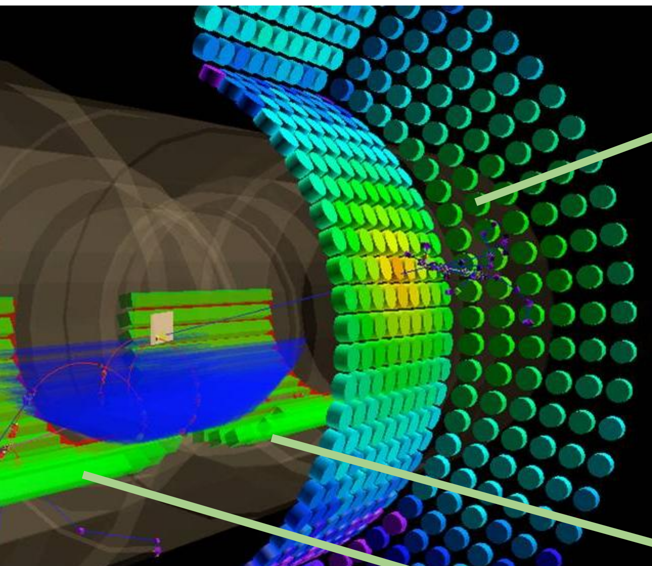


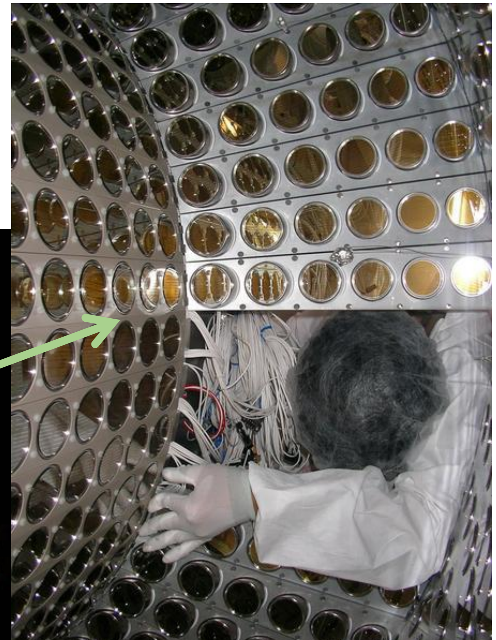
16 DCH with staggered anodic wires and cathodic strips in Vernier pattern. Gas mixture **He:C_2H_6 =50:50**



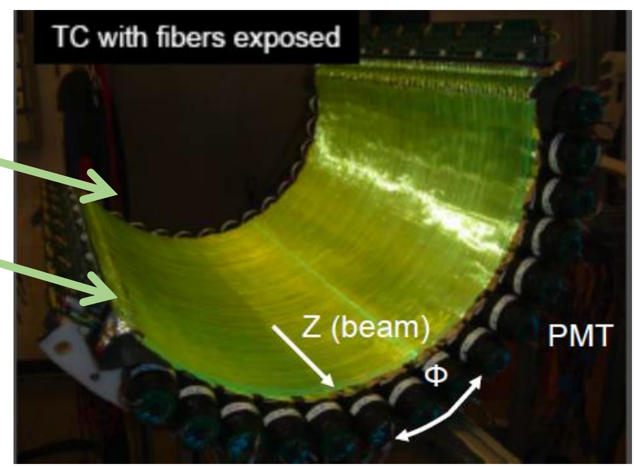
Positron momentum vector measurement.

MEG detector components 2)





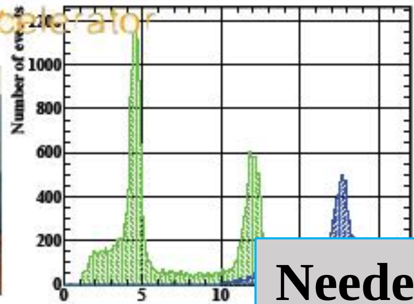
900 l Liquid Xenon photon detector.
846 UV sensitive PMTs.
Light yield **≈ 0.8 NaI**.
Fast timing response (**45 ns**)
$\Delta\Omega/4\pi \approx 0.12$
Photon energy, timing and interaction point measurement.



15 x 2 scintillator bars with fine mesh PMTs at both ends.
Positron timing measurement.

Overview of calibration system

Proton Accelerator

Li(p,γ)Be

LiF target at COBRA center

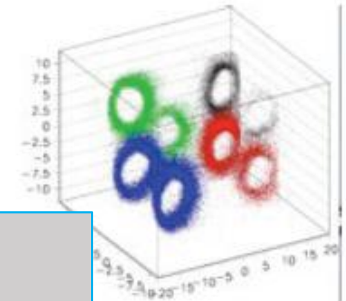
17.6MeV γ

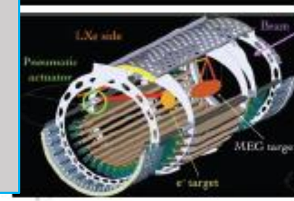
~daily calib.

also for initial

Alpha on wires

PMT QE & Att. L

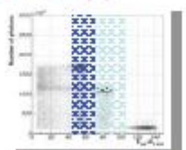




Needed to ensure:

- Required precision;
- Long term detector stability;
- Continuous checks.

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



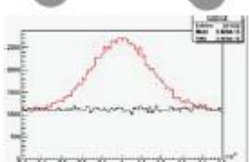

$\pi^- + p \rightarrow \pi^0 + n$

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

$\pi^- + p \rightarrow \gamma + n$ (12

LH_2 target

μ radiative decay

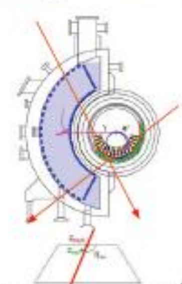


Lower beam intensity < 10^7

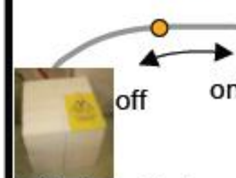
Is necessary to reduce pile-ups

A few days ~ 1 week to get enough statistics

Cosmic ray alignment

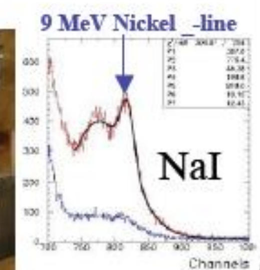


Nickel γ Generator



Illuminate Xe from the back

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



Summary of performances

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

MEG2 discovery potentiality