Status and perspectives of the MEG Experiment

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On behalf of the MEG Collaboration

24th Rencontres de Blois

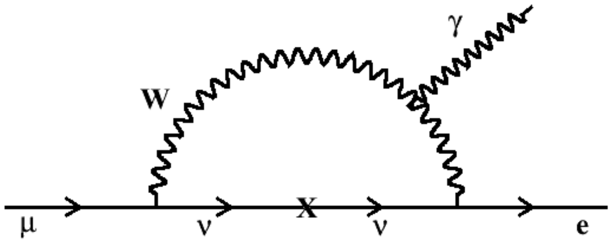
Blois (France), May30th 2012

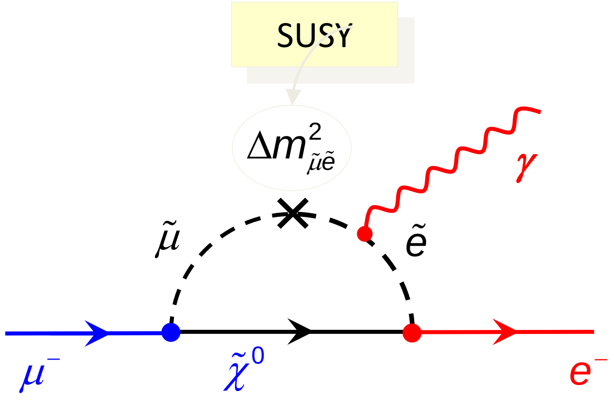
Outline

- Lepton Flavour Violation
- The MEG Experiment
- Results from 2009/2010 Data Analysis
- Present Status and Perspectives
- Conclusions

Lepton Flavour Violation 1)

- Lepton Flavour Violation (**LFV**) not allowed in the minimal SM and **predicted in the extended SM** (including neutrino mixing) **at a negligible level**, not experimentally detectable (**BR ~ 10^{-55}**).
- On the contrary, **LFV predicted in many SM extensions** (i.e. SUSY models) **at measurable levels** (**BR($\mu \rightarrow e\gamma$) ~ $10^{-(12\div14)}$**)



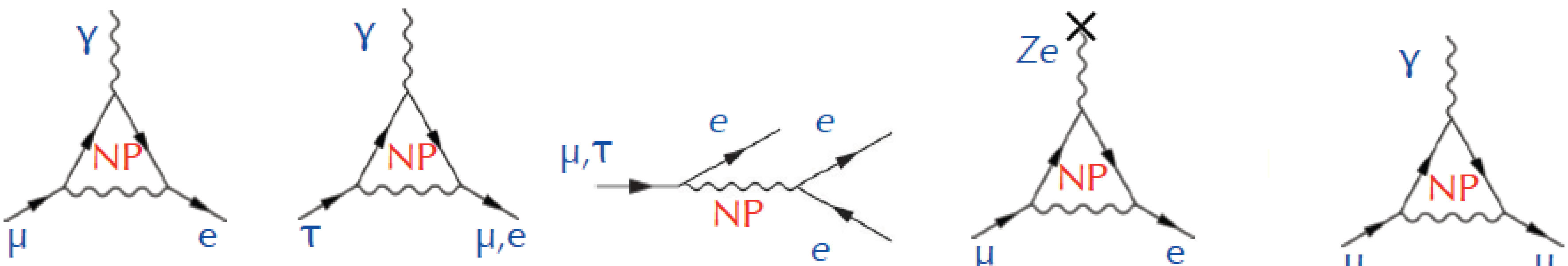


⇒ in case of discovery, **unambiguous evidence for Physics Beyond SM.**

Lepton Flavour Violation 2)

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

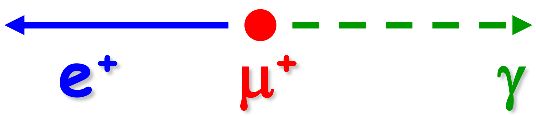
Anomalous magnetic moment

The MEG Experiment

Goal and signal

- Search for $\mu \to e\gamma$ **LFV decay**.
- **Target sensitivity** **BR ~ 10^{-13}** wrt normal muon decay.
- **Previous Upper Bound**: **BR $\leq$ 1.2 x 10^{-11}** (MEGA, 2001)
- **Signature**:

  - **back-to-back** topology;
  - **energy equally shared** between e^+ and γ;
  - **simultaneous emission**.



$\theta_{e\gamma}$ = 180°

$E_e = E_\gamma$ = 52.8 MeV

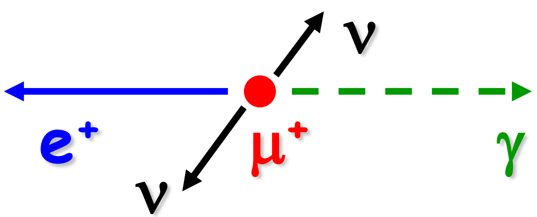
$T_e = T_\gamma$

Background

physical

$\mu \rightarrow e\,\gamma\,\nu\,\nu$

(radiative decay)

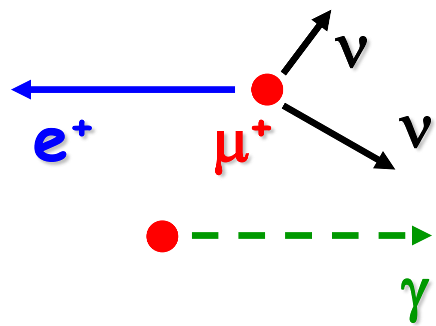


$R_{RD} = R_\mu * BR(\mu \rightarrow e\nu\nu\gamma)$
$\sim 0.1\ R_{acc}$

accidental

$\mu \rightarrow e\,\nu\,\nu$

$\left\{ \begin{array}{l} \mu \rightarrow e\,\gamma\,\nu\,\nu \\ ee \rightarrow \gamma\,\gamma \\ eZ \rightarrow eZ\,\gamma \end{array} \right.$



$R_{acc} \propto (R_\mu)^2 * (\Delta\Theta)^2 * (\Delta E_\gamma)^2 * \Delta T * \Delta E_e$

⇓

- **Muon rate** to be used is **a trade off between expected number of signal events** and **background level;**
- Used $3 \times 10^7\ \mu^+/s$;
- **Sensitivity** is limited by **accidental background;**
- **High resolution detectors** and a **continuous muon beam** are mandatory.


Part of
The MEG collaboration
Koshiba Hall
Total ≈ 60 physicists
KEK
Tokyo U.
Waseda U.
KEK
INFN & U Pisa
INFN & U Roma
INFN & U Genova
INFN & U Pavia
INFN & U Lecce
PSI
UCIrvine
JINR Dubna
BINP Novosibirsk
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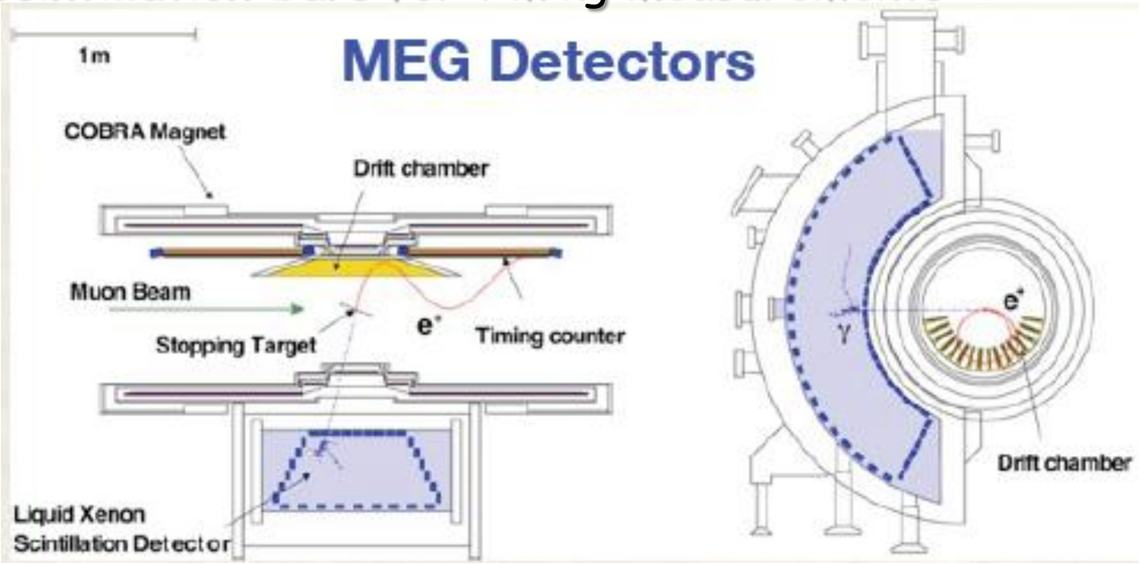
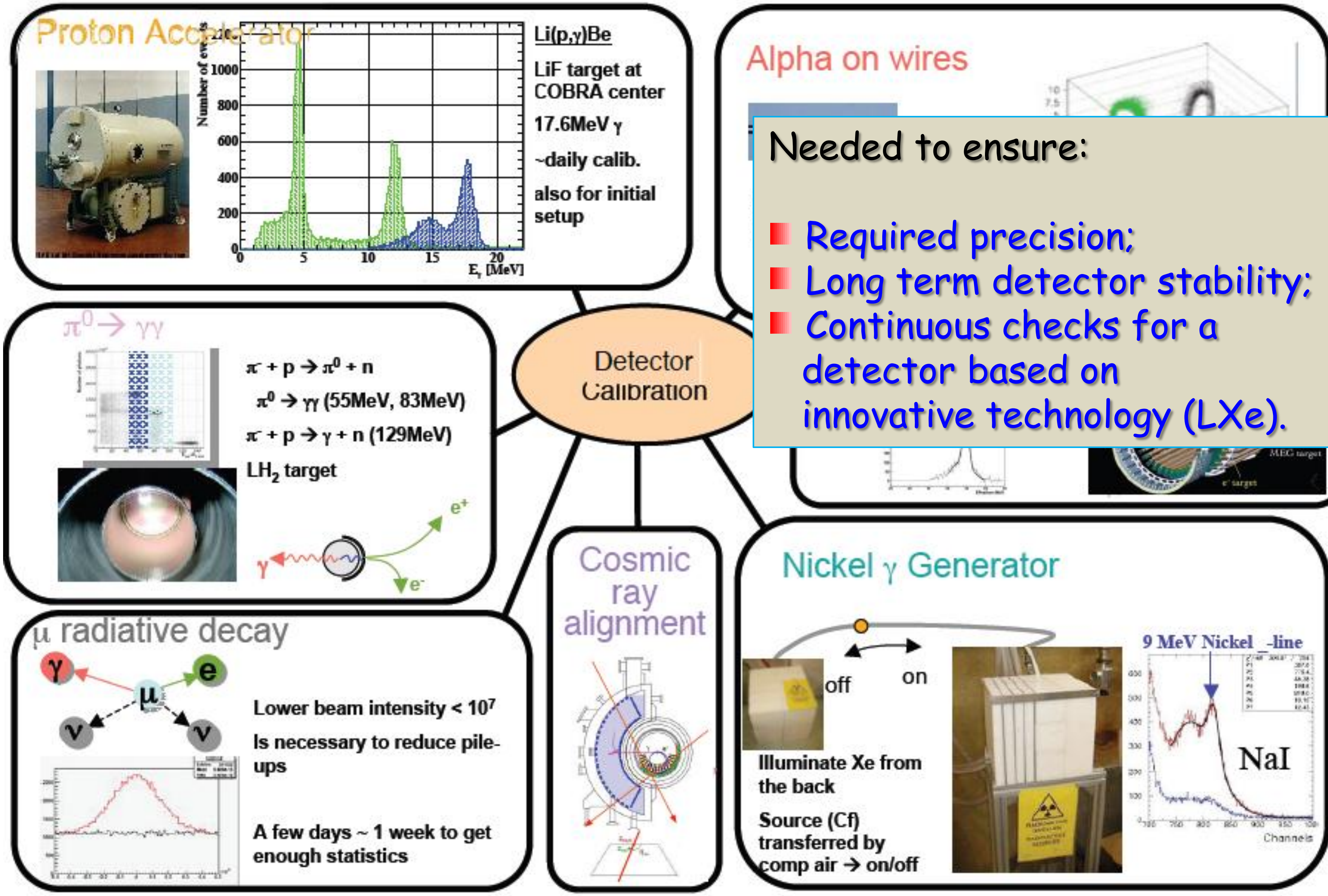
The Detector

- ✓ World's **most intense continuous muon beam** **πE5 line @PSI** (up to **10^8 stopped μ^+/s**);
- ✓ **Photon** detection by a **Liquid Xenon calorimeter**;
- ✓ **Positron** detection by a **Drift Chamber spectrometer** for momentum and by **scintillation bars** for timing measurements.



Overview of calibration system



Needed to ensure:

- *Required precision;*
- *Long term detector stability;*
- *Continuous checks for a detector based on innovative technology (LXe).*

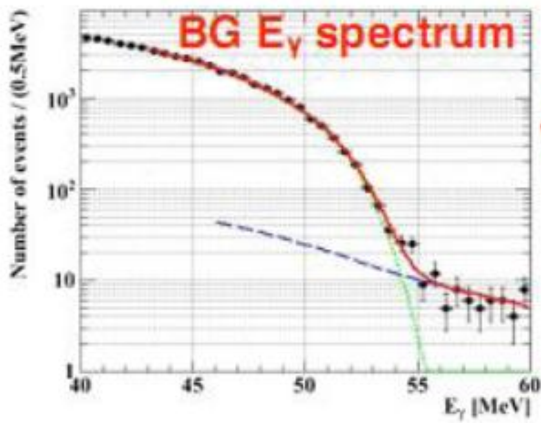
Summary of MEG performances

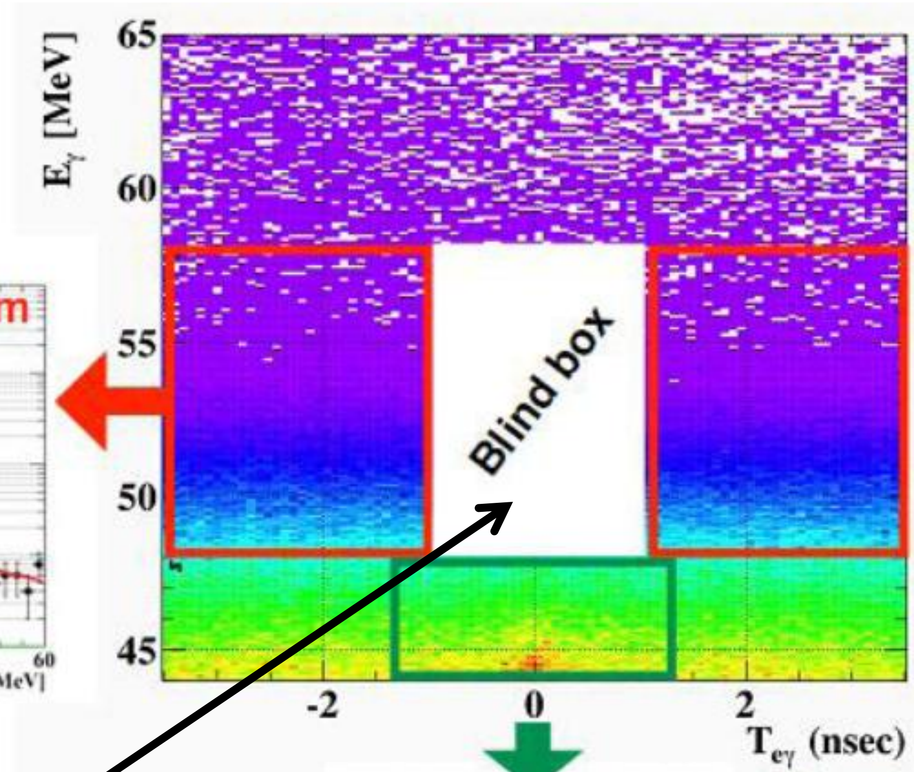
	2009	2010
Gamma E [σ_R, w>2cm – 63%]	1.9%	1.9%
Relative timing $T_{e\gamma}$ (RMD)	150ps	130ps
Positron E [Michel edge]	330 keV(82% core)	330 keV (79% core)
Positron θ	9.4 mrad	11.0 mrad
Positron ϕ [at zero]	6.7 mrad	7.2 mrad
Positron Z/Y	1.5/1.1(core) mm	2.0/1.1(core)mm
Gamma position	5(u,v)6(w) mm	5(u,v)6(w) mm
Trigger efficiency	91%	92%
Gamma efficiency	58%	59%
Positron efficiency	40%	34%
Muon stopping rate	$2.9\ 10^7$ s-1	$2.9\ 10^7$ s-1
DAQtime/real time	35/43 days	56/67 days
SES [analysis region]	$0.92\ 10^{-12}$	$0.44\ 10^{-12}$

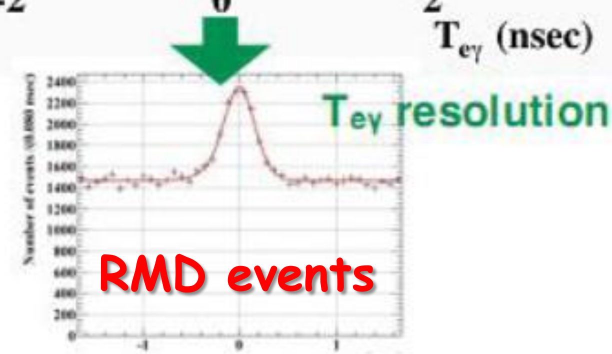
Results from 2009-2010 Data

Blind + likelihood analysis

Signal and bkg optimization done in sidebands







Timing sidebands

E_γ sideband

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

MEG likelihood analysis

- **Maximum likelihood analysis** to extract N_{signal}
  - Observables: E_γ, E_e, $T_{e\gamma}$, $\theta_{e\gamma}$, $\Phi_{e\gamma}$
  - **PDFs are formed mostly from data.**
    - **Signal**: Measured resolutions
    - **Accidental BG** : Measured spectrum in sidebands
    - **RMD**: Theoretical spectrum smeared by detector resolutions
- Different likelihood analyses performed to check systematics
  - **PDF**: Event-by-event PDF, different PDFs according to tracking quality, averaged PDF

The most dangerous bck is measured !

Likelihood function

PDFs

$$\mathcal{L}(\vec{x}_1,\ldots,\vec{x}_N,R_\diamond,A_\diamond|\hat{S},\hat{R},\hat{A}) = \frac{e^{-\hat{N}}}{N!} e^{-\frac{1}{2}\frac{(A_\diamond-\hat{A})^2}{\sigma_A^2}} e^{-\frac{1}{2}\frac{(R_\diamond-\hat{R})^2}{\sigma_R^2}} \prod_{i=1}^{N}\left(\hat{S}s(\vec{x}_i)+\hat{R}r(\vec{x}_i)+\hat{A}a(\vec{x}_i)\right)$$

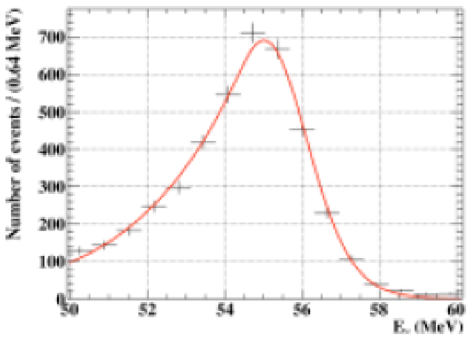
Background rate constraints

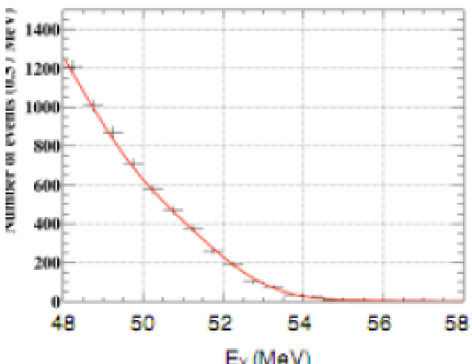
Signal
Radiative Bkg
Accidental Bkg

PDF= Probabilty Distribution Function

PDF's

55 MeV π^0 peak





Gamma

Signal PDF from 55MeV calibration gamma (π^0 decay)

BG measured in sideband

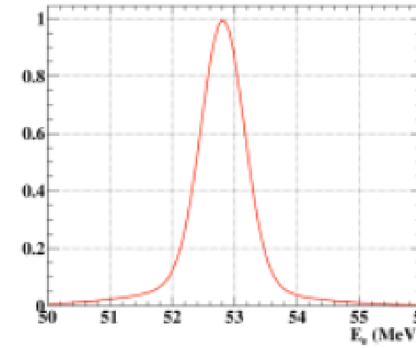
Positron

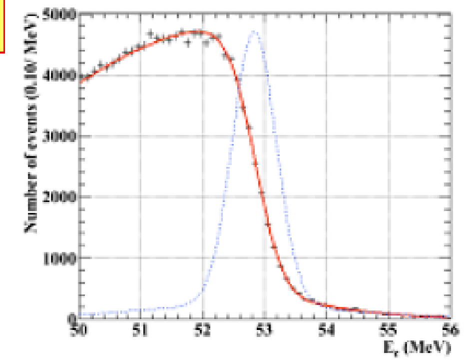
Signal PDF from measured resolution

Michel positrons

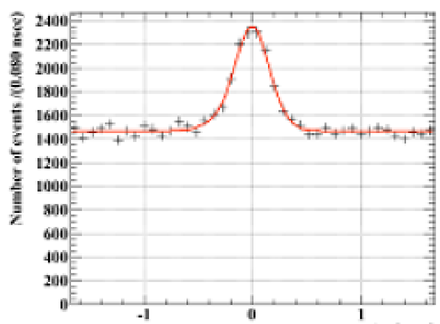
Mott scattering device

BG measured in sideband





RMD peak
mostly in low energy part



Relative time

Signal PDF from measured RMD peak

Relative angle

From measured double turn tracks

Normalization

$$N_{e\gamma} = BR(\mu^+ \to e^+\gamma) \cdot k$$

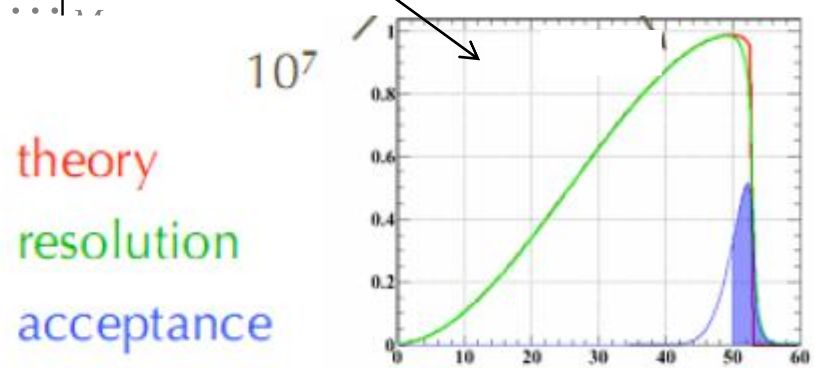
where:

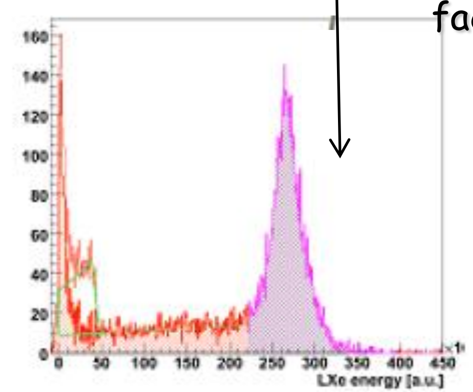
$$k \equiv N_{e\nu\nu} \times \left[\frac{f_S}{f_M}\right] \times \left[\frac{\varepsilon(TRG=0\,|\,e^+\gamma)}{\varepsilon(TRG=22\,|\,track \cap e^+_m \cap TC)}\right] \times A(\gamma\,|\,track) \cdot \varepsilon(\gamma) \cdot Psc(22)$$

$$f_S \equiv A(DC) \cdot \varepsilon(track, p_e > 50\mathrm{MeV}\,|\,DC) \cdot \varepsilon(TC\,|\,p_e > 50\mathrm{MeV})\big|_S$$

$$f_M \equiv \ldots\big|_M$$

10^7 pre-scaling factor



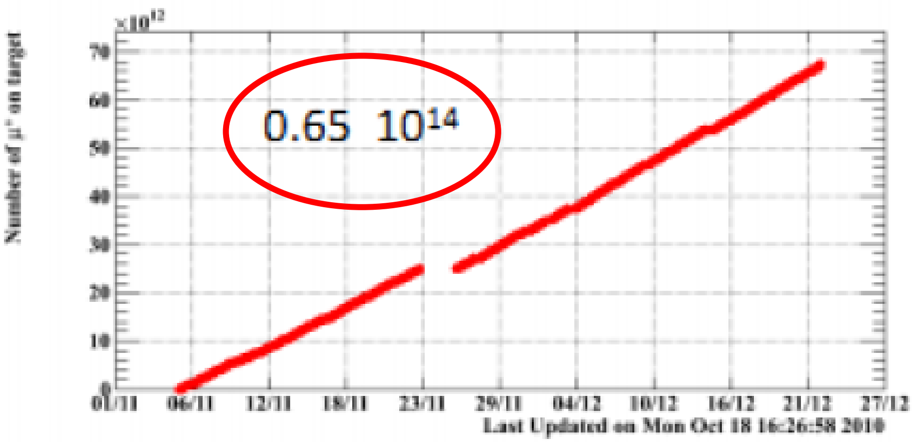


TRG = 22: Michel events trigger (only DCH track required)

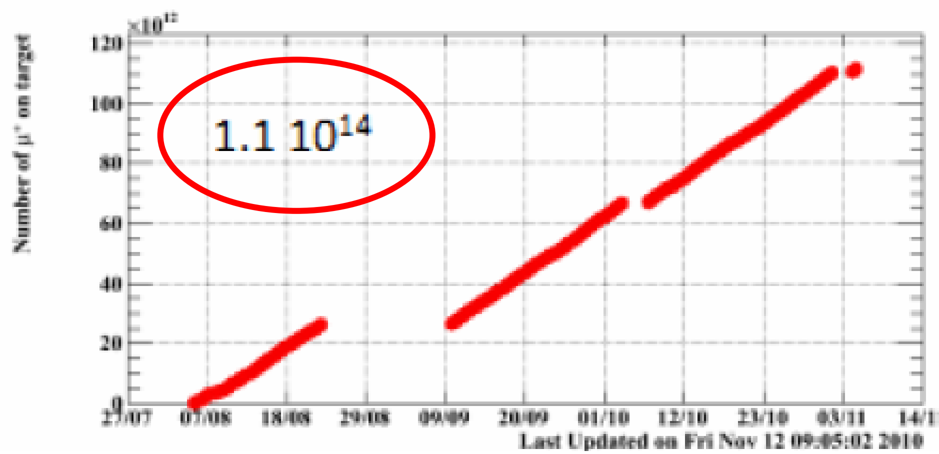
TRG = 0: MEG events trigger

Data sets for 2009 & 2010

Muons on target 2009



Muons on target 2010



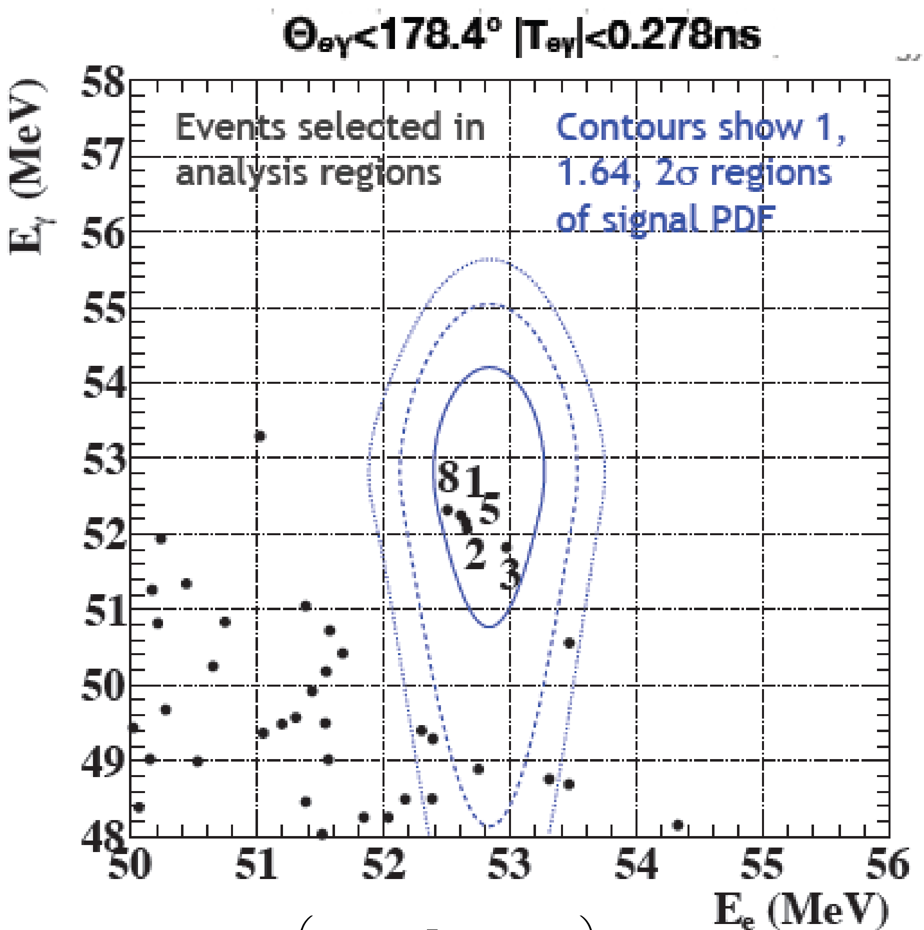
Statistics for 2010 about twice that for 2009

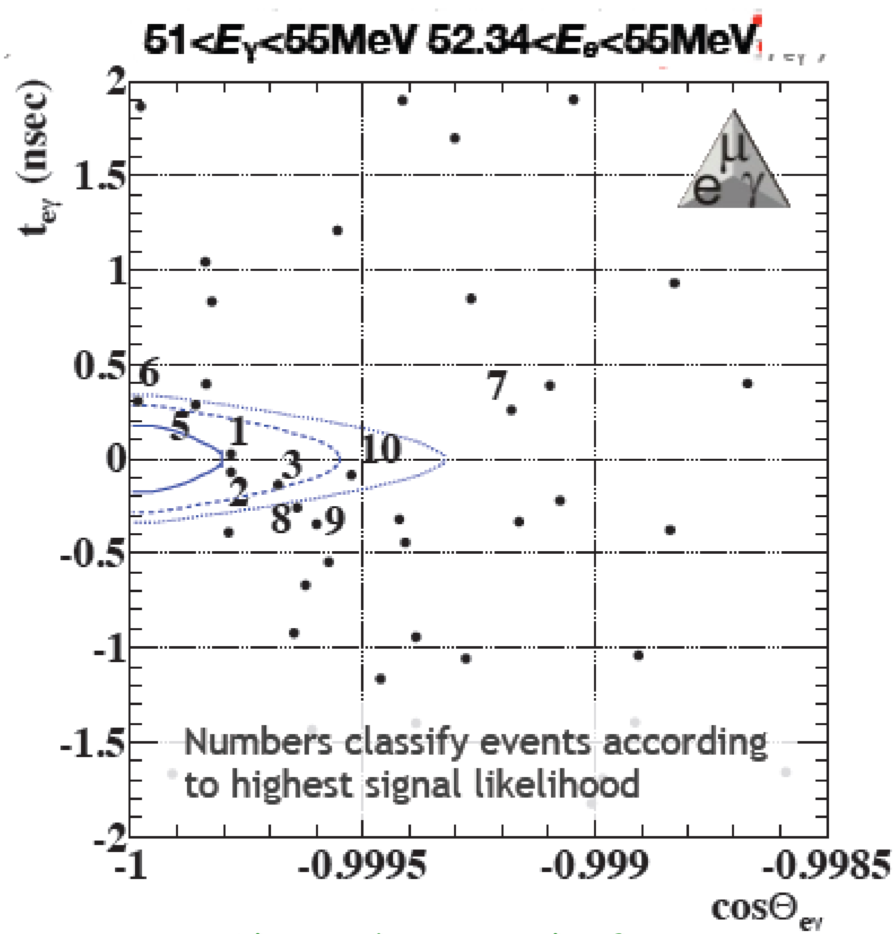
Stable detector conditions (LXe, DC, TC)

Optimized degrader
Improved electronics timing

Slightly lower DC efficiency because of higher noise.

Preliminary results @ICHEP 2010 (Data 2009)





$$R_{sig} = Log_{10}\left(\frac{L_{sig}}{0.1L_{RMD} + 0.9L_{BG}}\right)$$

Ranking variable

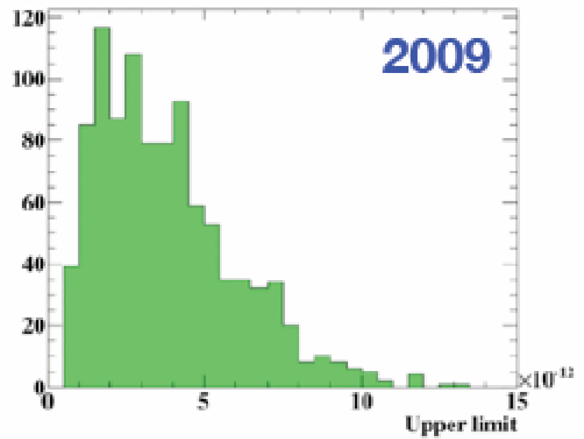
N.B. Plots shown only for reference; not used in analysis

Updates after ICHEP 2010

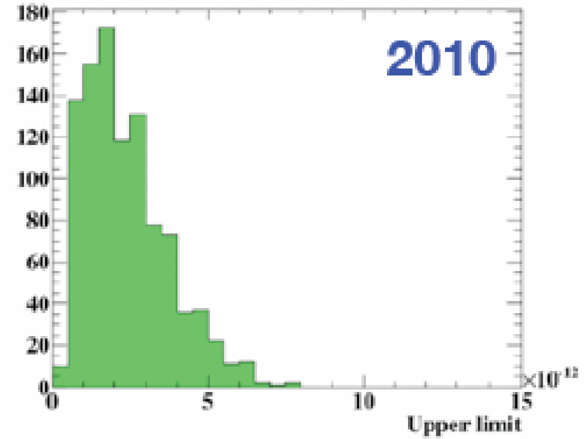
- Used **also 2010 data** (statistics twice that of 2009);
- Improved **detector alignment** (cosmic rays, MILLEPEDE algorithm);
- Implementation of **correlations between positron variables** (energy, angles ...);
- Improved knowledge of **magnetic field map**;
- Improved **likelihood analysis procedure**;
- **Combination of 2009 and 2010 data** $\Rightarrow$ published paper PRL **107**,171801,(2011) with **new upper bound on $\mu \to e\gamma$ BR**

Sensitivity evaluation

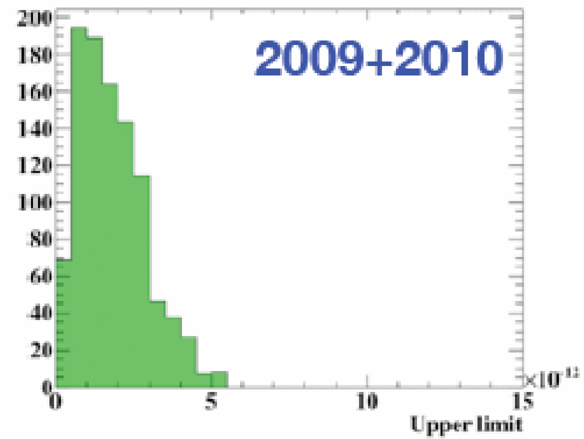
- Upper limit averaged over a sample of 1000 toy MCs, generated with **0 signal events** and using the **background rate measured in the sidebands**.



$\mathcal{B} = 3.3\times10^{-12}$ (median)



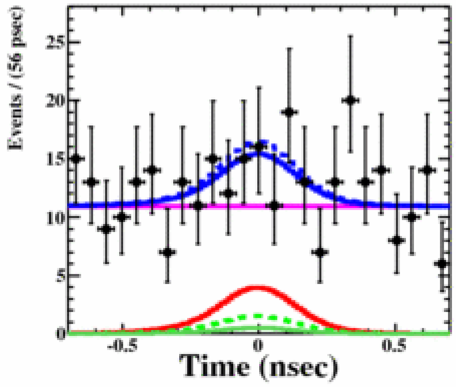
$\mathcal{B} = 2.2\times10^{-12}$ (median)

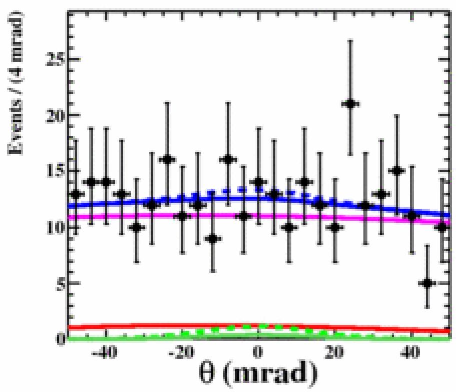


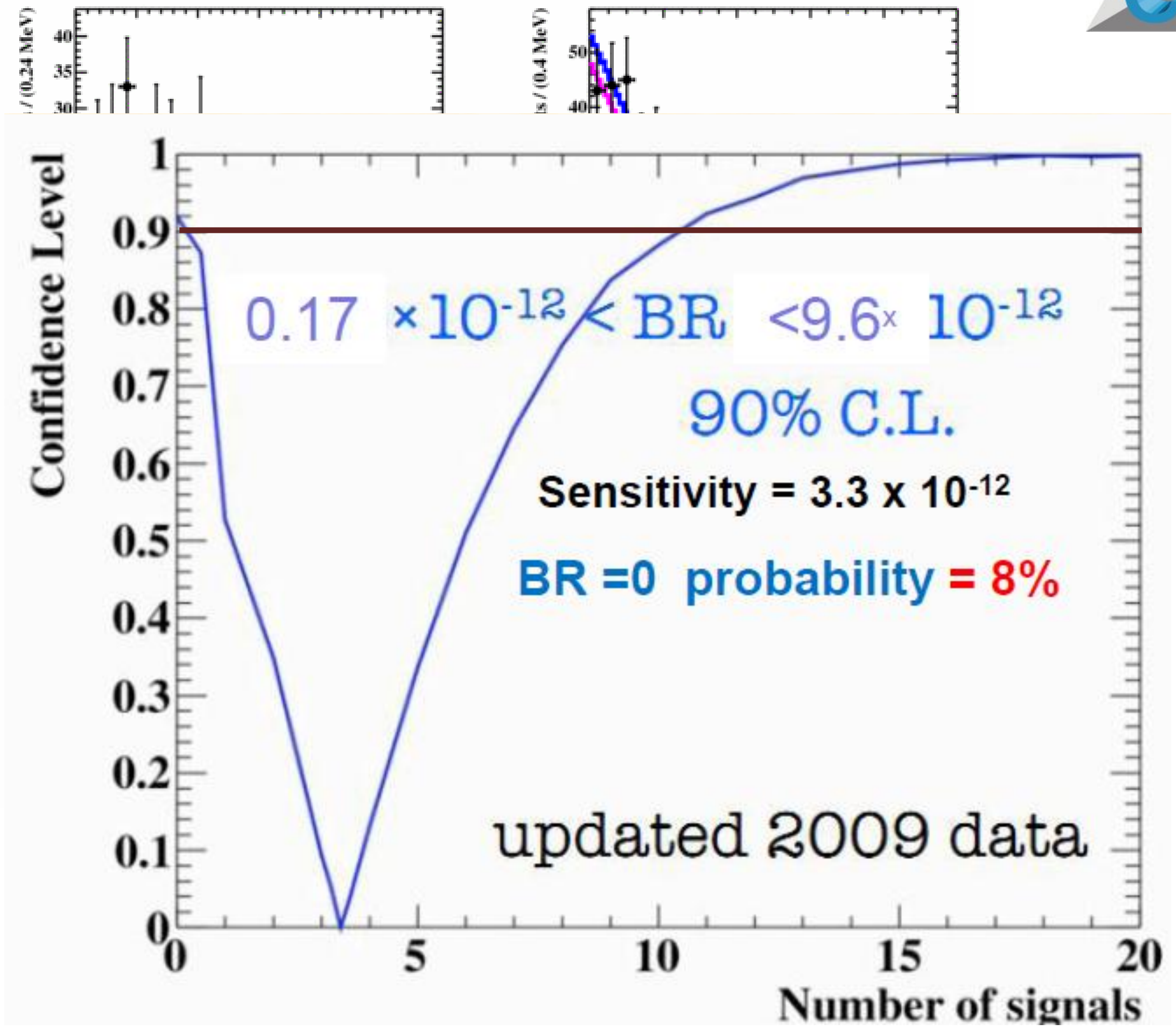
$\mathcal{B} = 1.6\times10^{-12}$ (median)

- Confirmed by **applying the analysis procedure** to events falling in **timing** and **angular sidebands**.

Unbinned maximum likelihood fit 2009

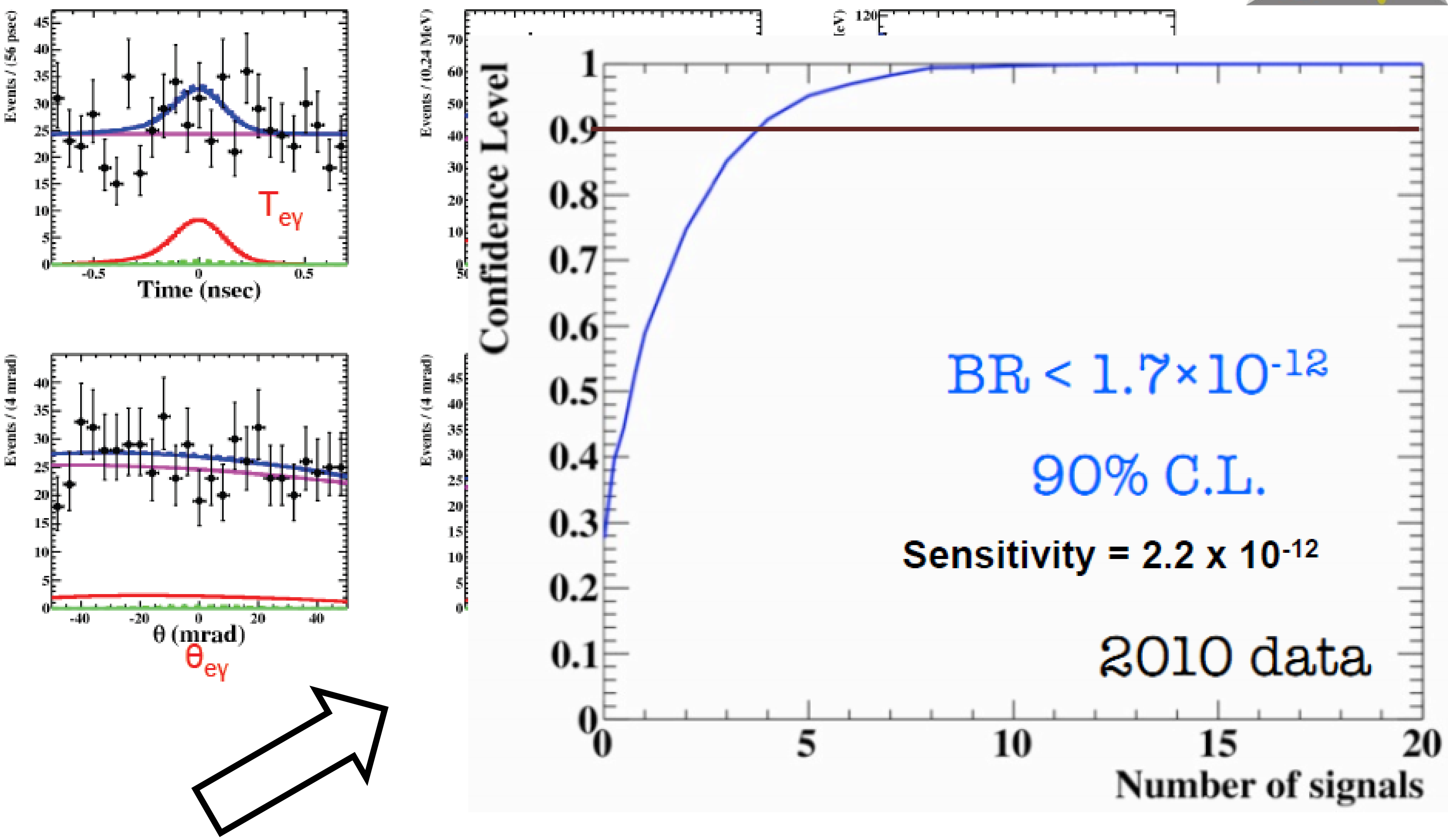




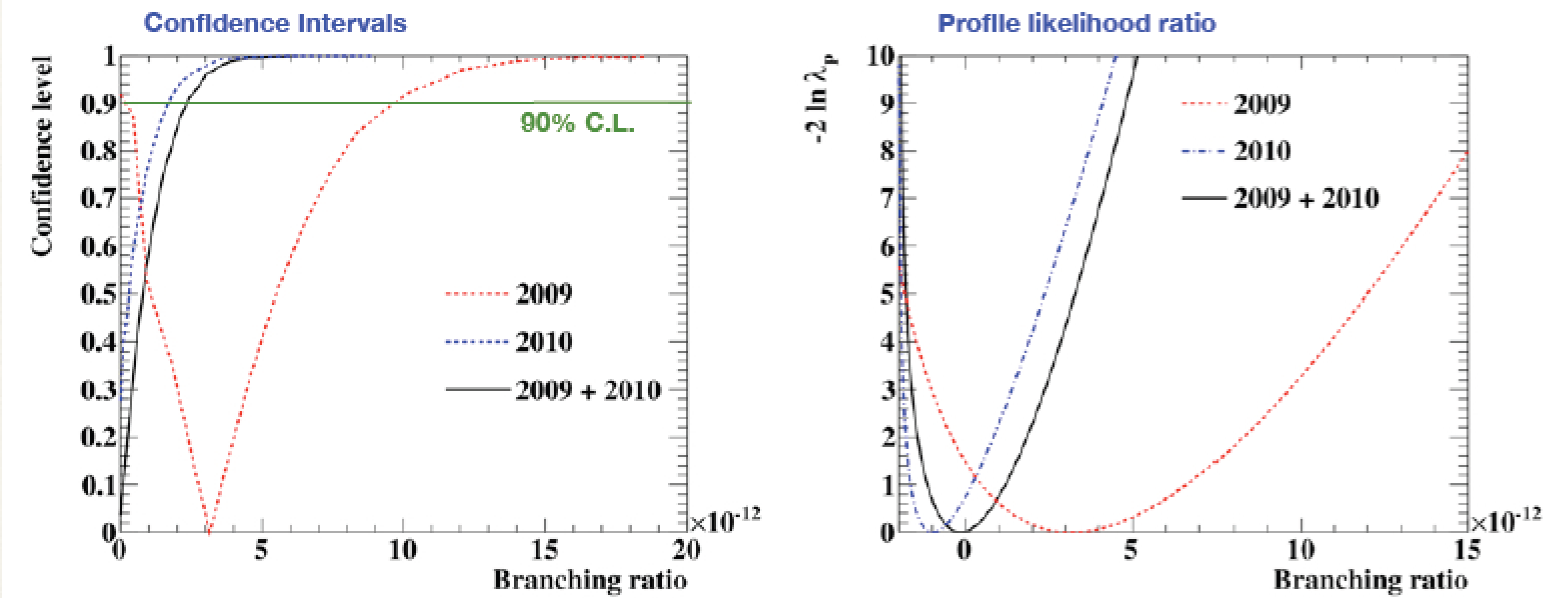


consistent results.

Unbinned maximum likelihood fit 2010

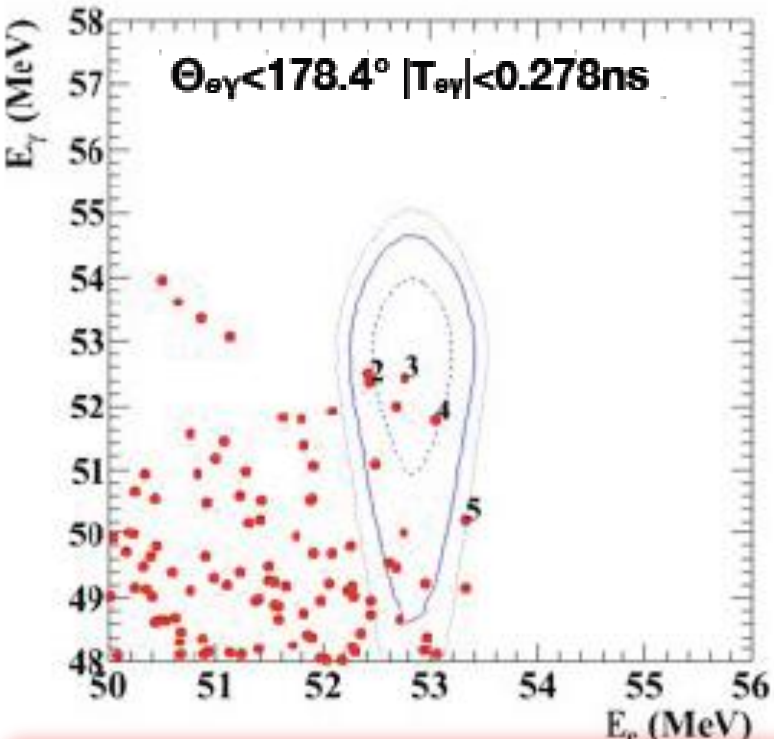


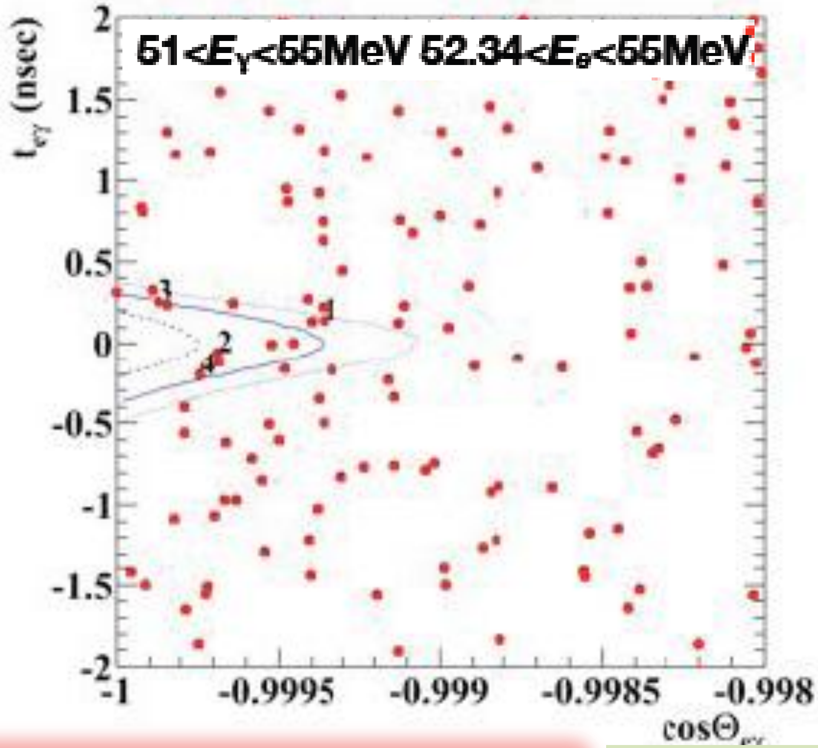
Combination of 2009 and 2010



- In 2009 a **fluctuation of 3 events above the background** was observed, **consistent with zero signal events at 8% probability.**
- **Such a fluctuation disappeared in 2010**. 2009-2010 compatibility at 15%.
- Because of higher statistics of 2010 sample, **the combined limit is dominated by 2010 results**. Then, **no lower bound at 90% C.L.**

Combined result and BR Upper Bound





2009 && 2010

90% C.L. Feldman-Cousins upper limit

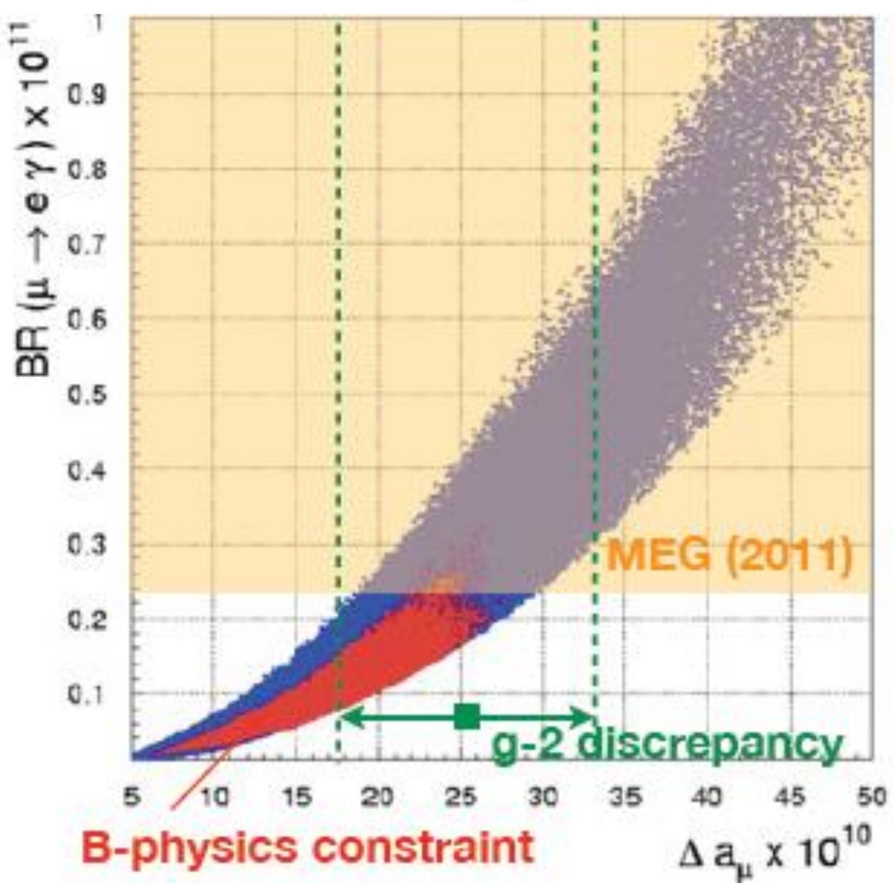
$$\frac{\Gamma(\mu^+ \rightarrow e^+\gamma)}{\Gamma(\mu^+ \rightarrow e^+\nu\bar{\nu})} \leq 2.4 \times 10^{-12}$$

Factor five improvement wrt previous limit !

Sensitivity 1.6 x 10^{-12}; difference due to 2009 fluctuation.

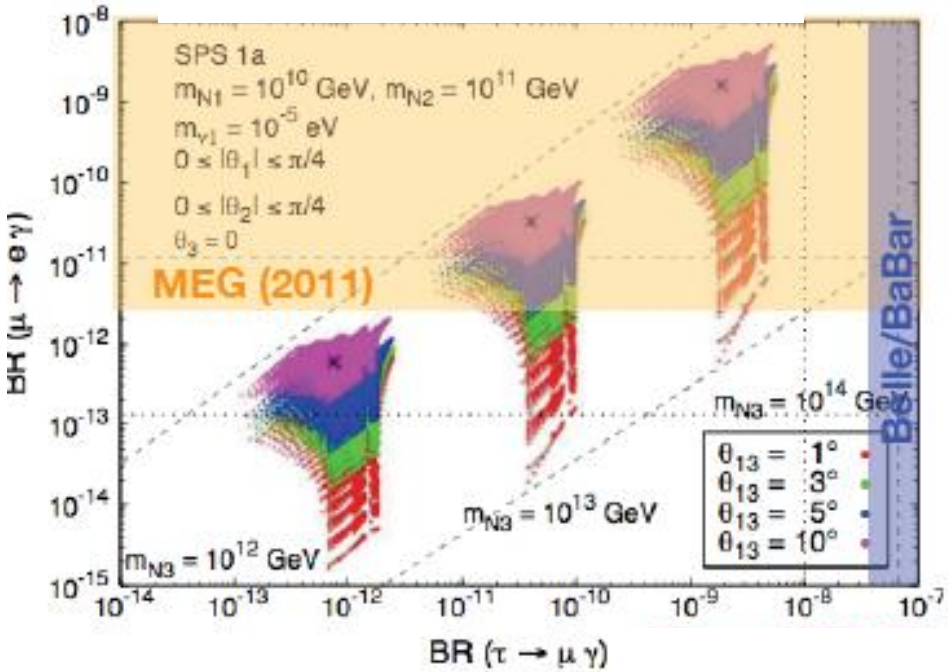
MEG Constraints on New Physics

MSSM with large tan β



G. Isidori et al., PRD **75** (2007) 115019

SUSY-Seesaw

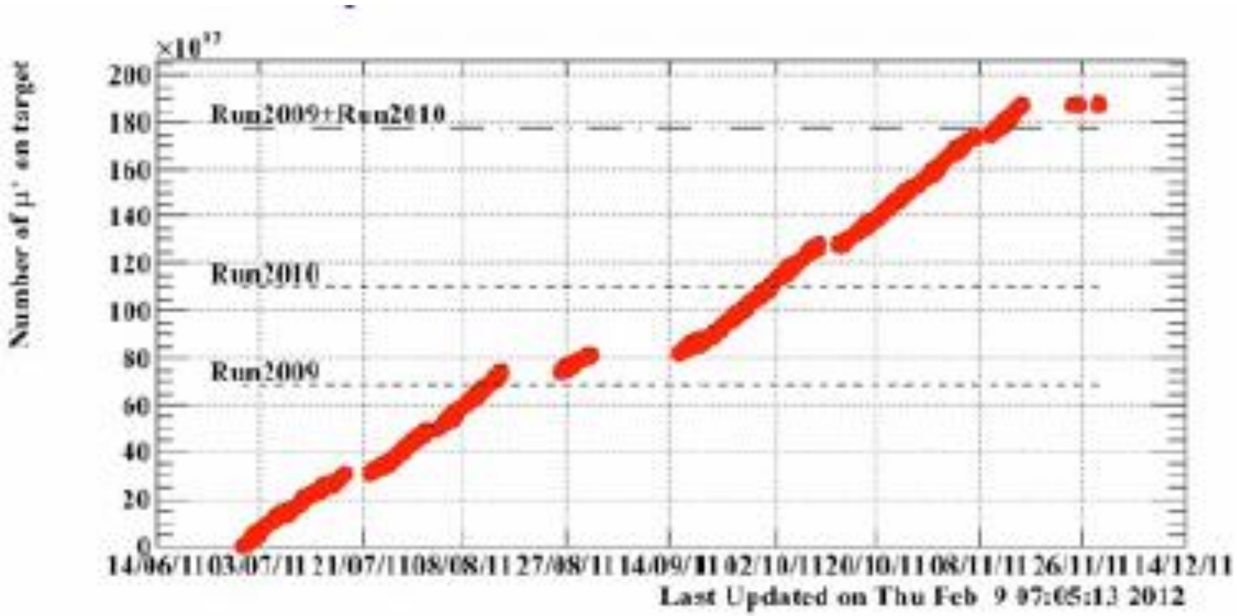


Recent results from **ν-oscillation exps** (Daya Bay, Reno, T2K, Minos, Double Chooz) favour **"large" θ_{13} (~ (7 ÷ 10) degrees)**.

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

Future perspectives

Data 2011



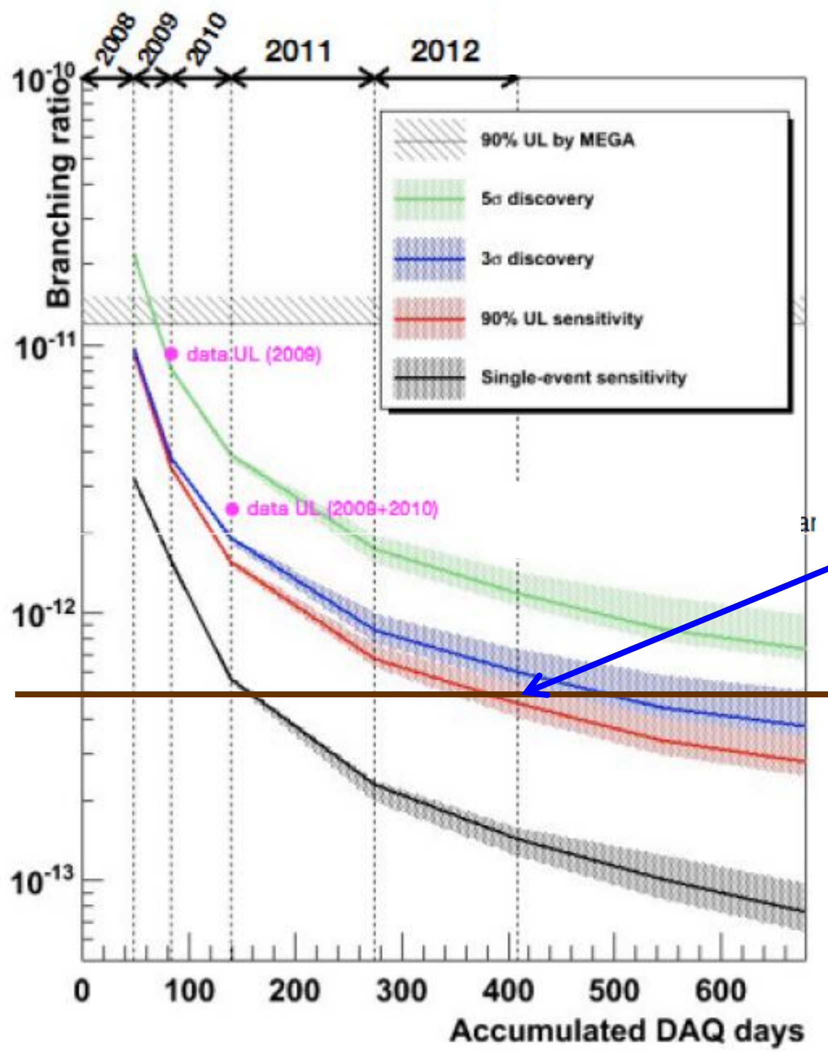
Number of stopping muons in 2011.

Data statistics more than doubled:

2011 > (2009 + 2010)

- Smooth running conditions (except for a cryo-plant damage in November);
- Improved LXe calibration (NaI replaced by BGO);
- Higher DAQ Efficiency and live time (> 95 %);
- Preliminary measurements of resolutions/efficiencies gave results comparable with that of previous years;
- Analysis under way.

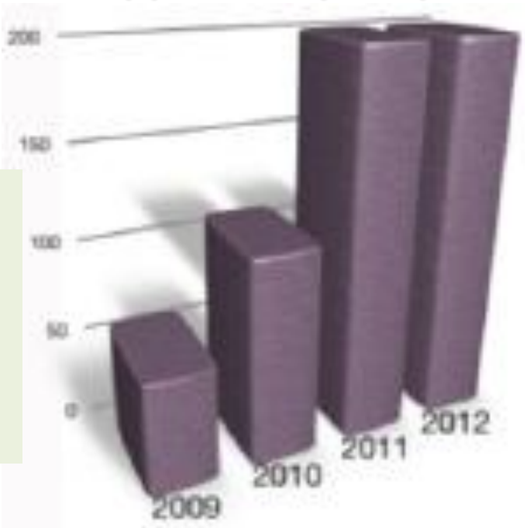
Projected sensitivity



Evaluated by toy MC and likelihood analysis

Expected final sensitivity:
$\approx 5 \times 10^{-13}$

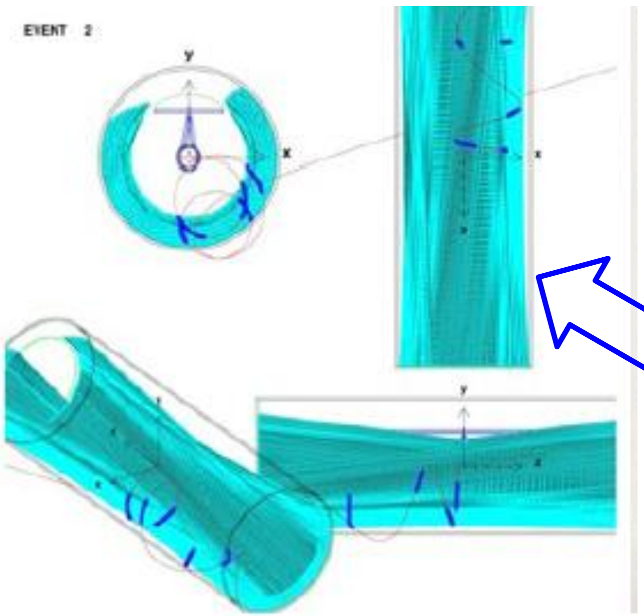
Stopped μ^+ per year



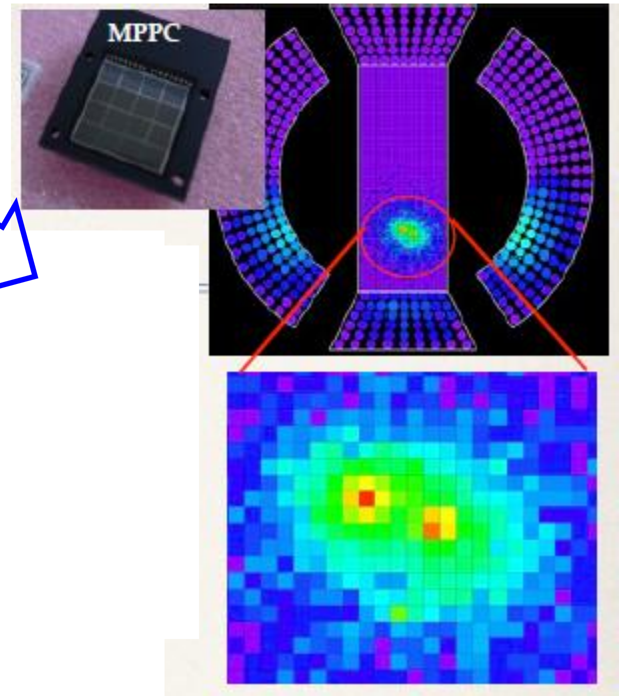
Sensitivity increases slowly with DAQ time because of background/detector performances $\Rightarrow$ **to hope to gain a further order of magnitude, we need to upgrade our detector !**

Studies for a MEG upgrade

Several studies under way to improve detector performances:



- Calorimeter readout by fine grain MPPC instead of PMTs
- Unique volume gas chamber
- Active target
- Timing Counter improvements



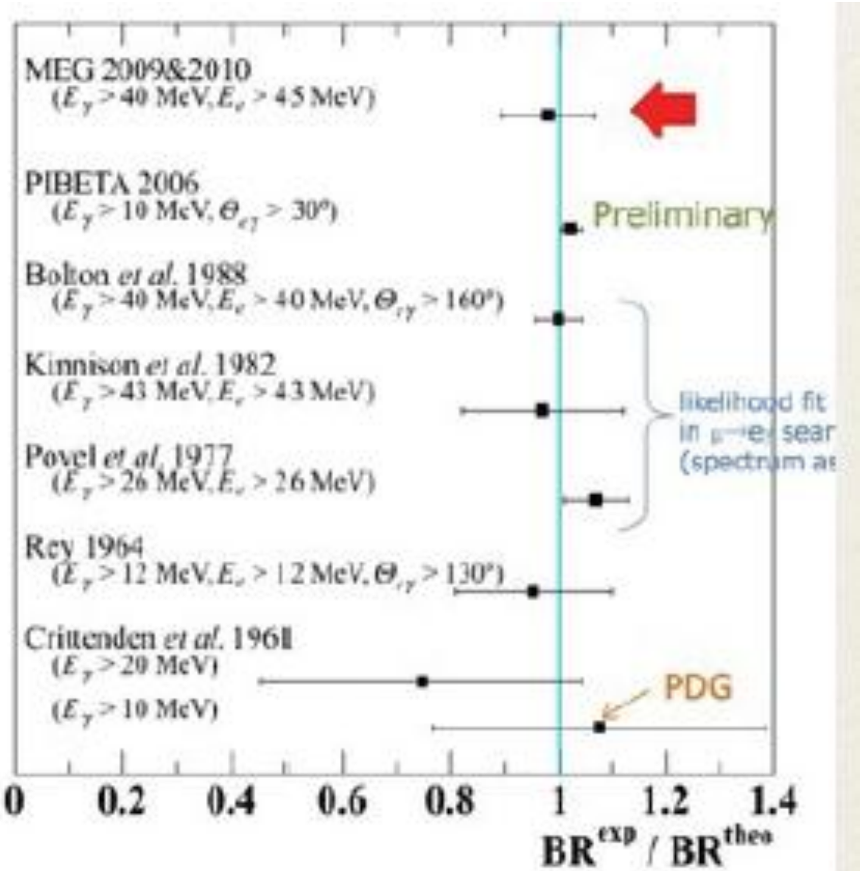
Final goal: reach a **sensitivity ~ 5 x 10^{-14}**

Other searches

- Study of **RMD events** and measurement of **RMD branching ratio** and **Michel parameters** (included measurement of **muon beam polarization**).

  Paper in preparation.

- Search for **exotic muon decays** (mediated by pseudo-scalar particles or with massless Majorons).



Conclusions

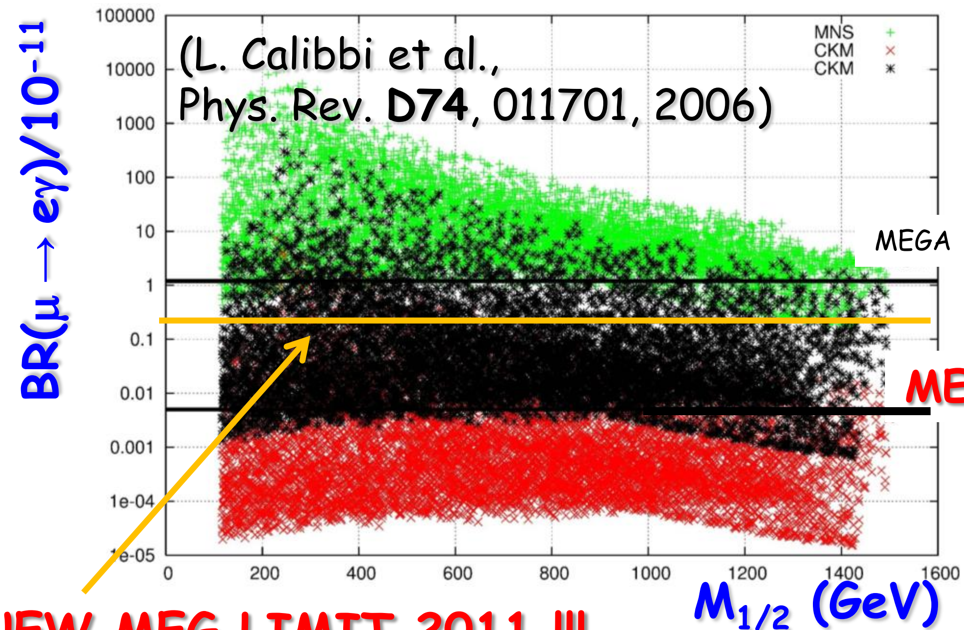
- The MEG Experiment is **running since 2008** in the **search for $\mu \to e\gamma$ decay**.
- Analysis of data collected in 2009 & 2010 established an **Upper Bound** on $\mu \to e\gamma$ branching ratio of **2.4×10^{-12} @ 90% CL.,** a **factor 5 improvement** with respect to the previous limit.
- The result is already significant.
- At the **end of data taking**, MEG will reach a **sensitivity $\approx 5 \times 10^{-13}$**
- A **null result** with this final sensitivity will be a **strong constraint for SUSY/BSM parameter space.**
- Studies are under way for **possible upgrades of the experiment** in order to **improve sensitivity by better detector resolutions.**

Backup slides

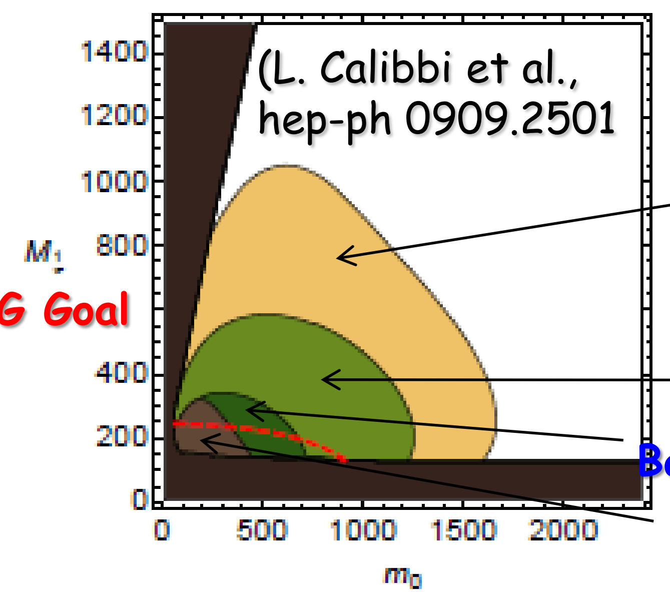
Lepton Flavour Violation 3)

Strong impact of LFV searches in particle physics development:

- beginning of **lepton physics** (Pontecorvo & Hincks, 1947);
- **universality** of Fermi interaction ⇒ **standard model** (1955);
- **flavour physics** (> 1960);
- possibility to explore **high mass SUSY scale (> 1000 TeV)** and give insights about **large mass range, parity violation, number of generations** ... (now)



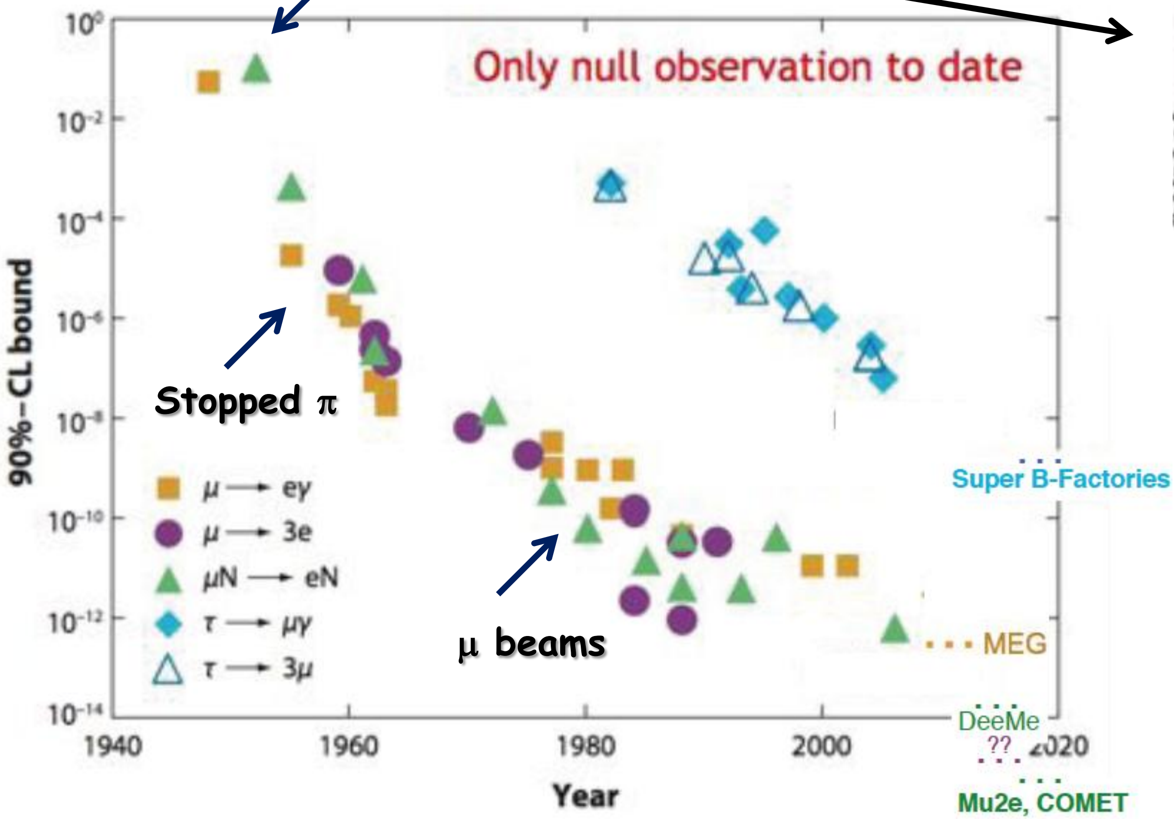
Examples of recent predictions



70 years of physics history linked with improving technologies

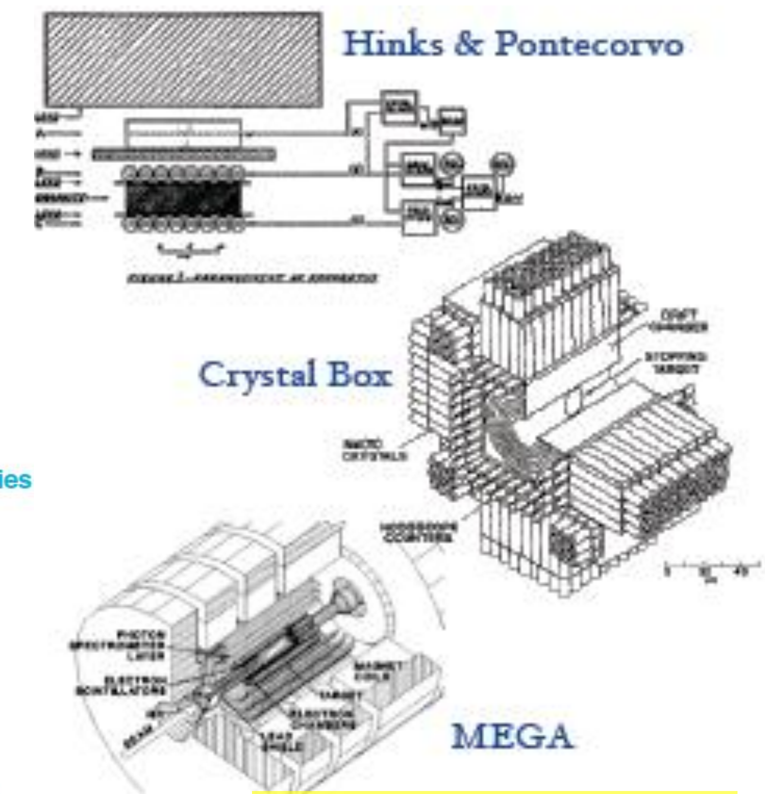
Cosmic μ

BR < 0.1



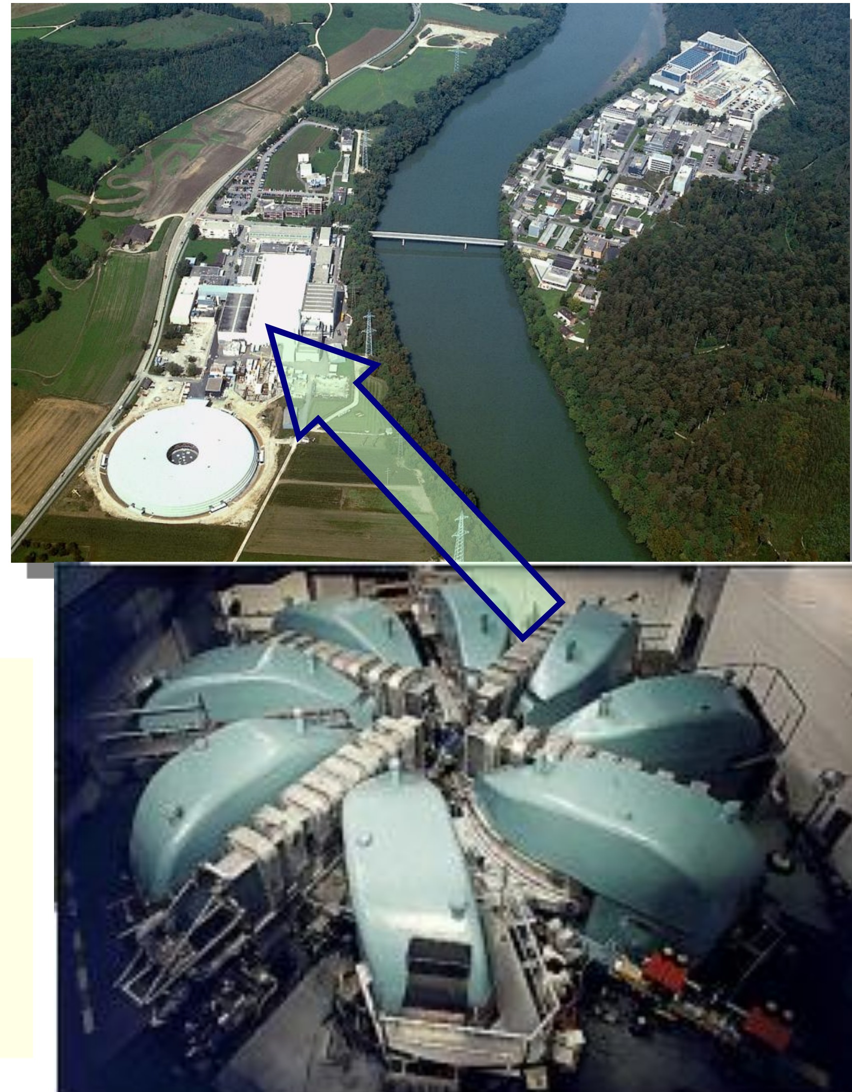
Stopped π

μ beams



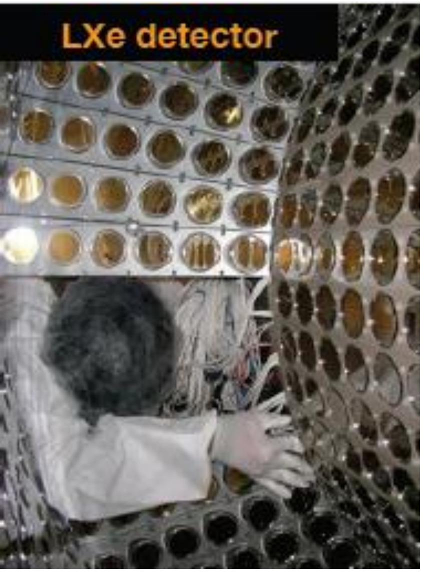
BR < 1.2 × 10^{-11}

The Paul Scherrer Institute (PSI)



- The **most powerful continuous machine** in the world;
- **Proton energy 590 MeV**;
- **Power 1.2 MW**;
- **Nominal operational current 2.2 mA** (to be further increased).

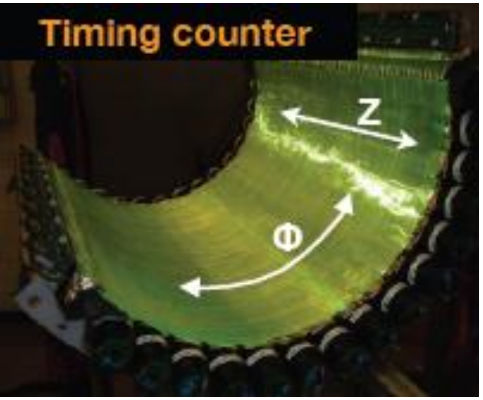
The Sub-Detectors



The world's largest **Liquid Xenon calorimeter**:

- **900 l**
- **846 PMT's**
- Thin entrance window
- $\Delta E(FWHM)/E \approx 5\%$
- $\sigma_T \approx 70$ ps
- $\sigma_\theta \approx 8$ mrad

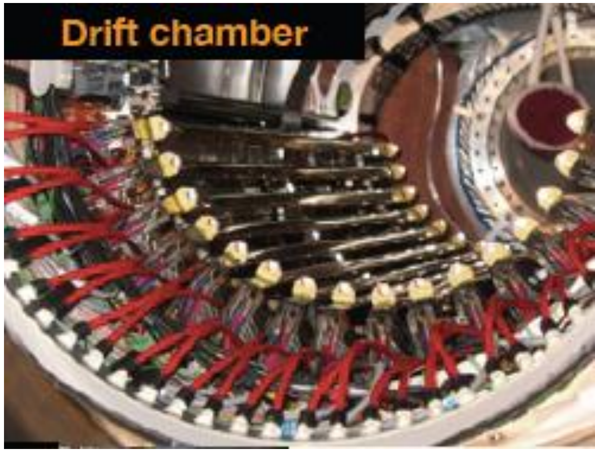
All resolutions @52.8 MeV



2 x 15 scintillator bars for positron timing (and position) and trigger purposes.

- $\sigma_T \approx 70$ ps

Sixteen modules, each one formed by **two staggered layers of plane wires plus cathode foils** for longitudinal information.



- $\sigma_E \approx 330$ keV
- $\sigma_\theta \approx 10$ mrad

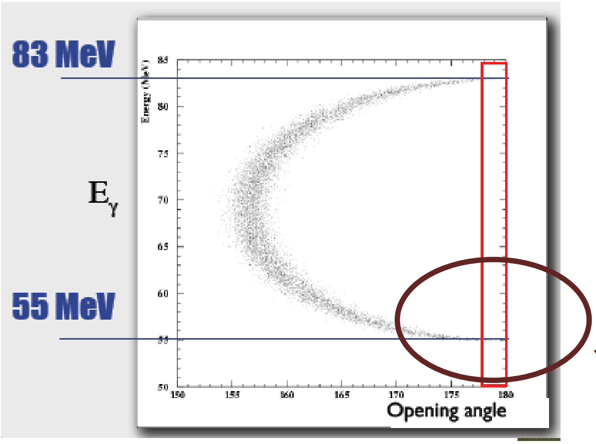
} at 52.8 MeV

Thin wall superconducting magnet (COBRA) generating a graded magnetic field to sweep out high P_T positrons.

$B_{max} \approx 1.26$ T

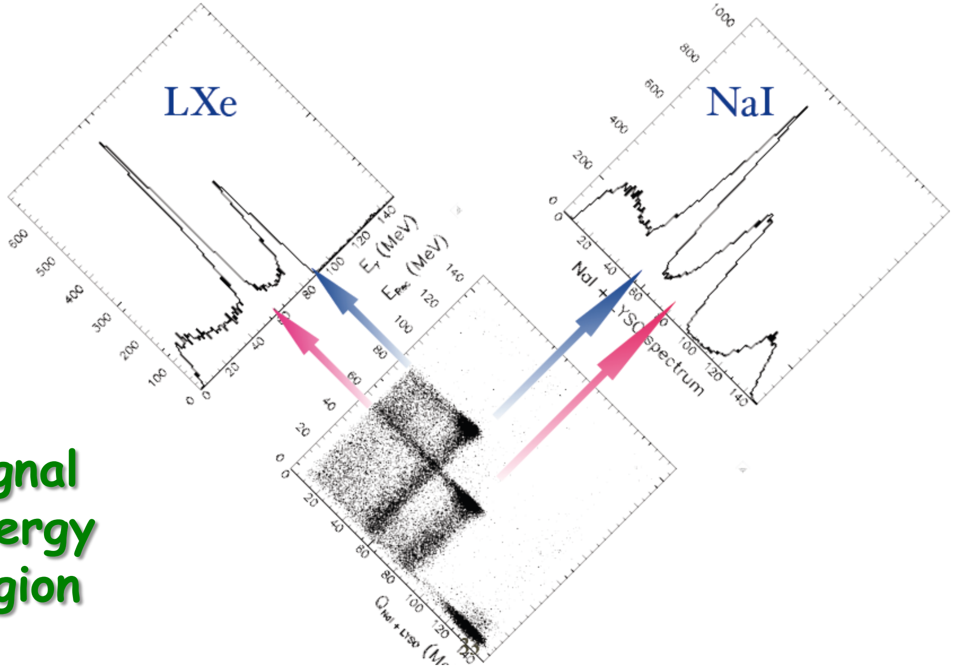
CEX calibration

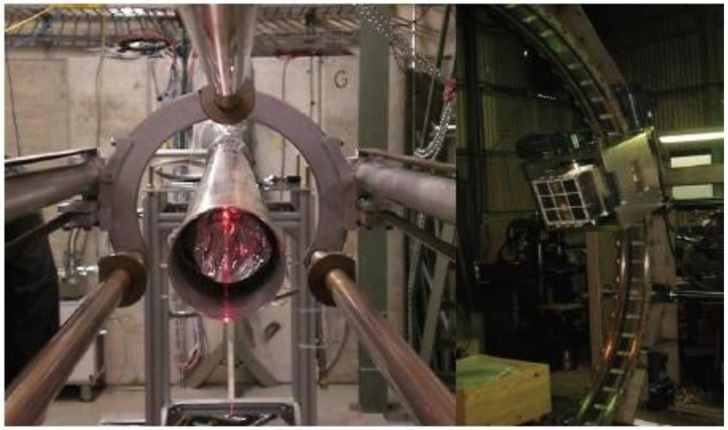
$$\pi^- p \rightarrow \pi^0 n \rightarrow \gamma\gamma n$$



Signal energy region

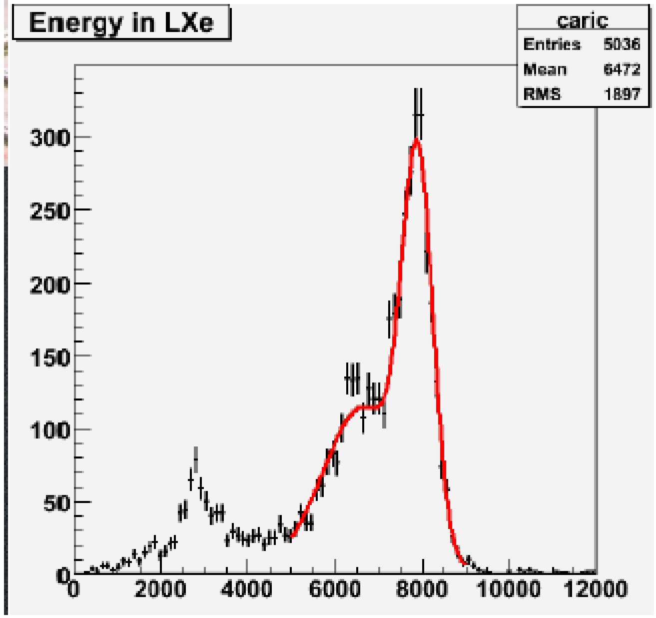
Photons detected at opposite boundaries of energy spectrum. Back-to-back condition ensured by an **auxiliary NaI** (or **BGO**) **detector**.



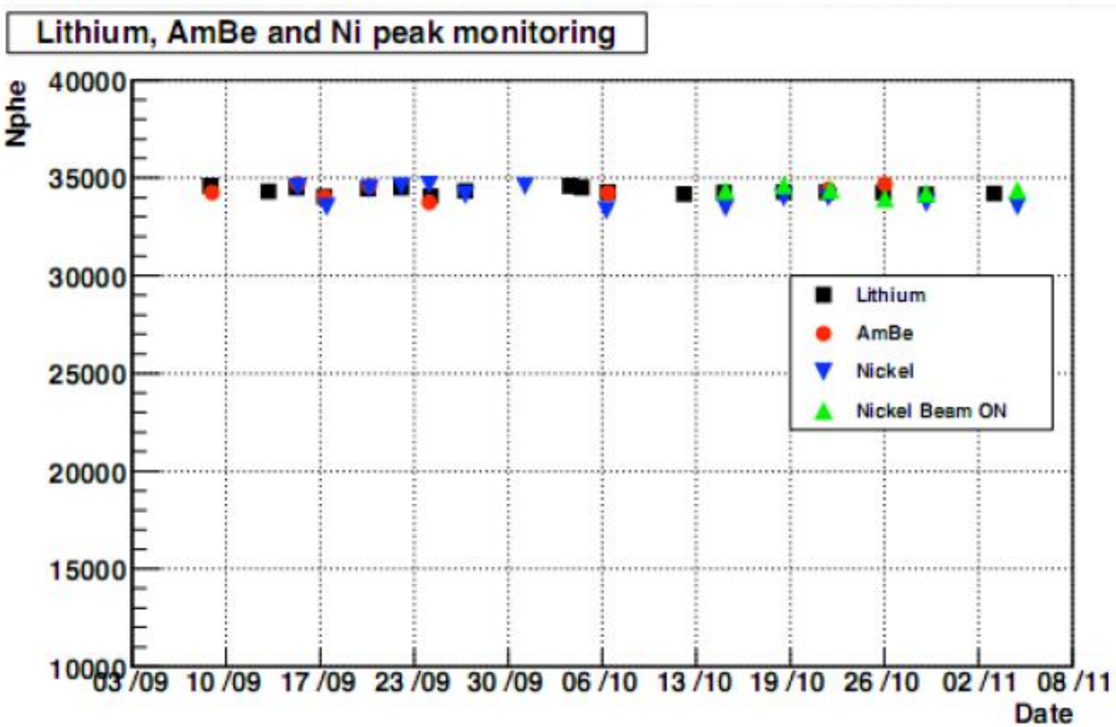


Dedicated run periods with **the normal MEG target replaced by a Liquid Hydrogen target.**

γ-energy scale monitoring

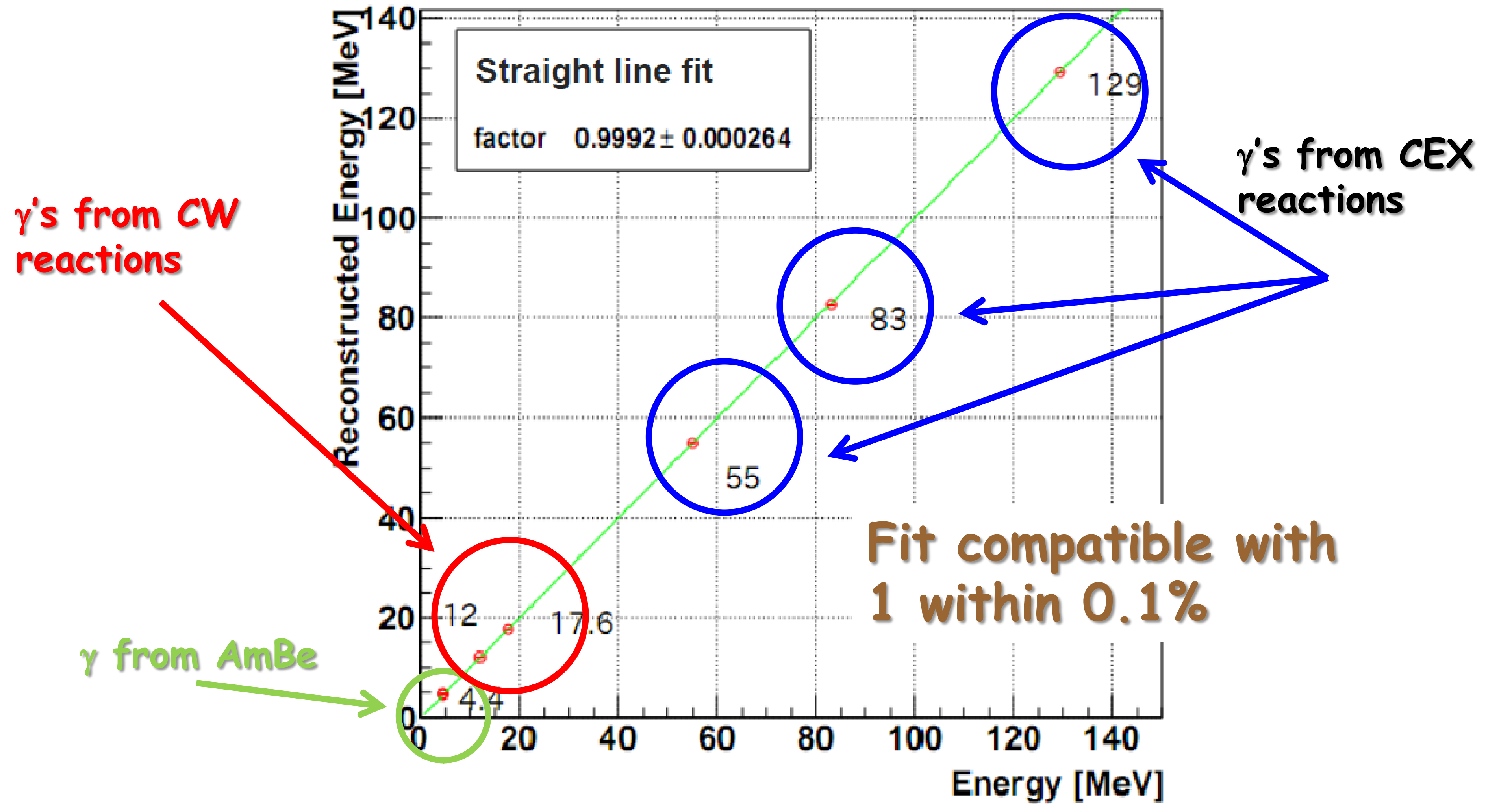


17.6 MeV γ-line from
p-induced reactions on Li



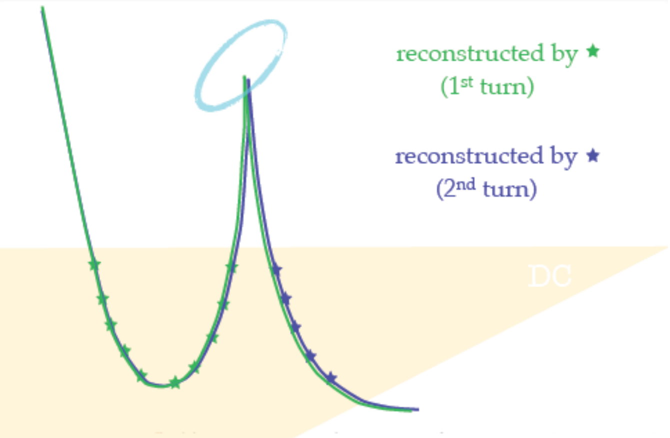
All systems working during 2010 run.
Energy scale known with 0.3% precision.
Full set of calibrations every three days;
~ 3 hours/set.

Energy scale linearity



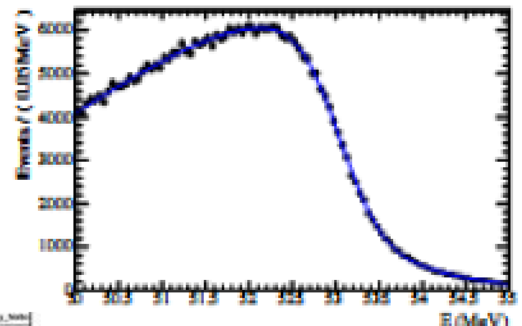
Fit compatible with 1 within 0.1%

Spectrometer resolution measurement

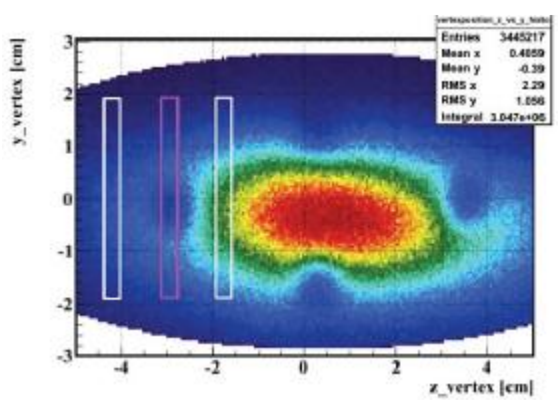


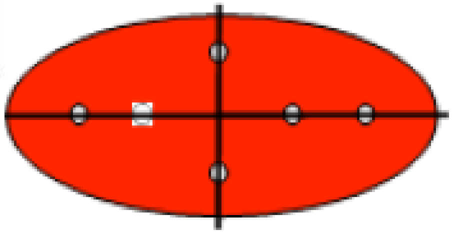
Angular resolution evaluated by **tracks with two turns in the DC system**, treated as independent.

Momentum resolution measured by fitting the **edge of Michel spectrum** and using the **Mott calibration**.

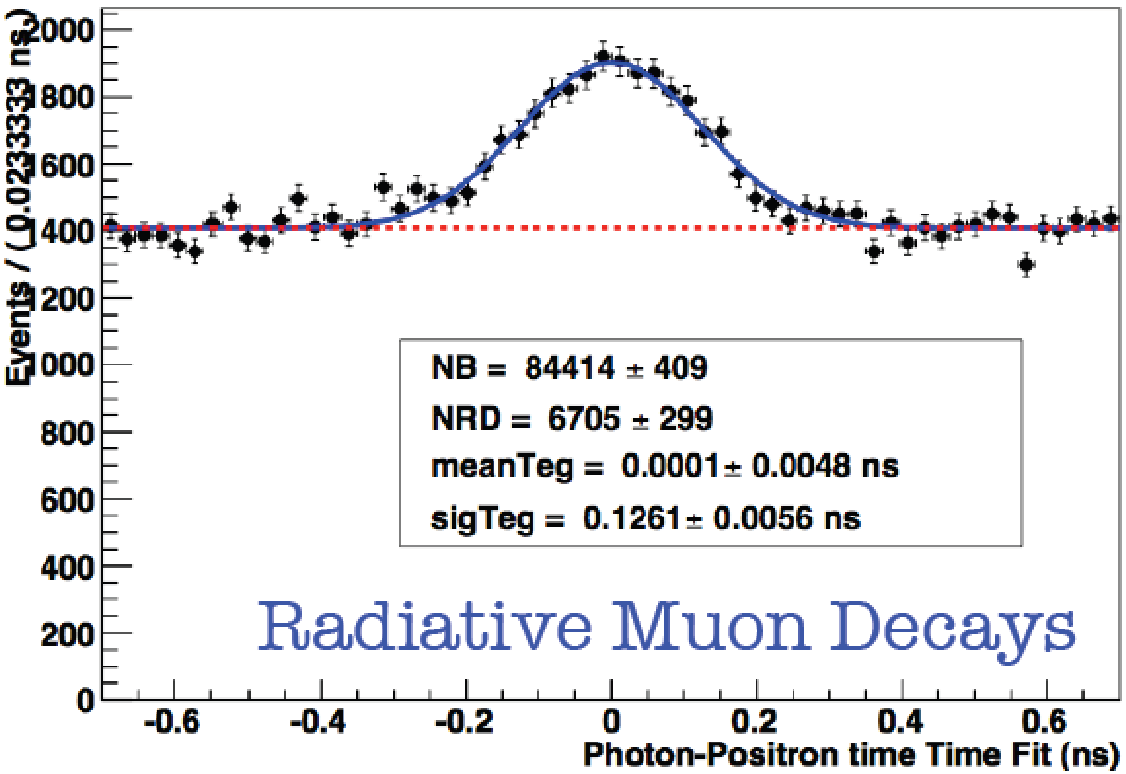


Muon decay vertex resolution measured by identifying the **target holes** in the **positron position distribution** on target.





Positron-photon relative timing



Peak position stable within 20 ps

Relative bar-bar and bar-LXe sinchronization perfomed py using **p-induced reactions on Boron** (two photons emitted). Monitored **1÷2/month**.

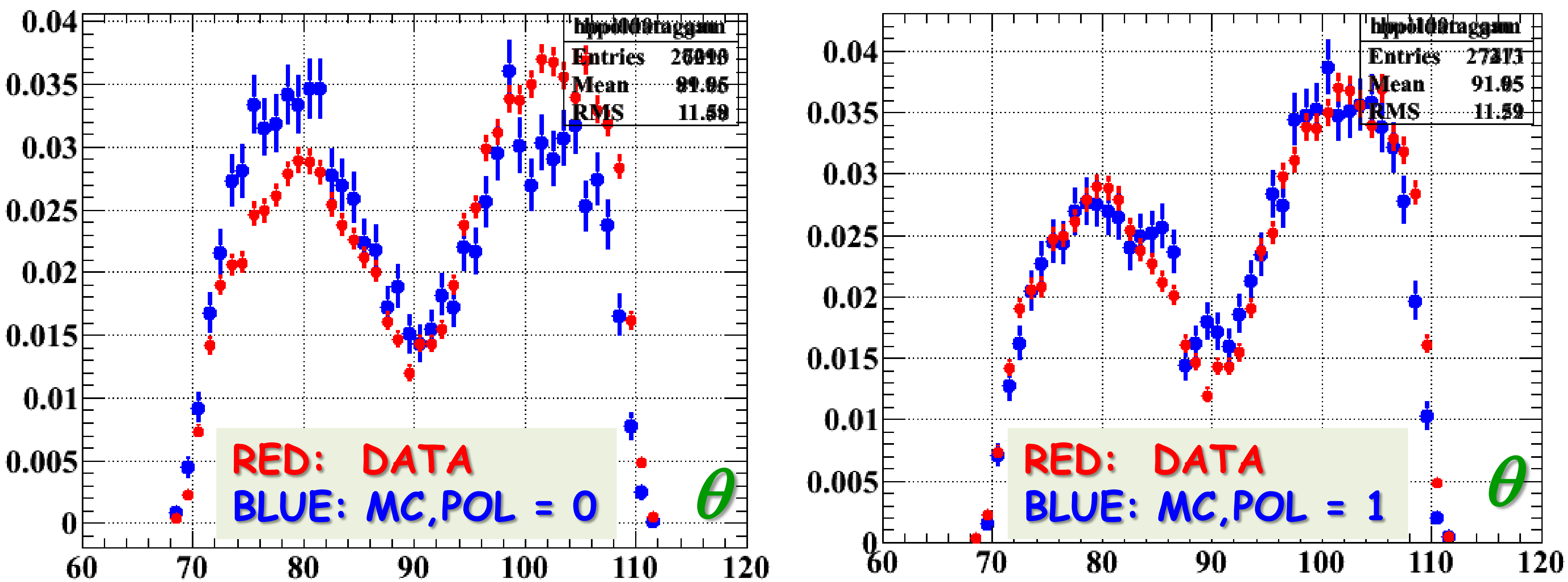
Positron time measured by **TC and corrected for ToF** using DC track information.

Photon time measured in **LXe and corrected for ToF** from target to calorimeter

RMD peak seen in normal runs and corrected by small energy dependence.

Measurement of muon polarization

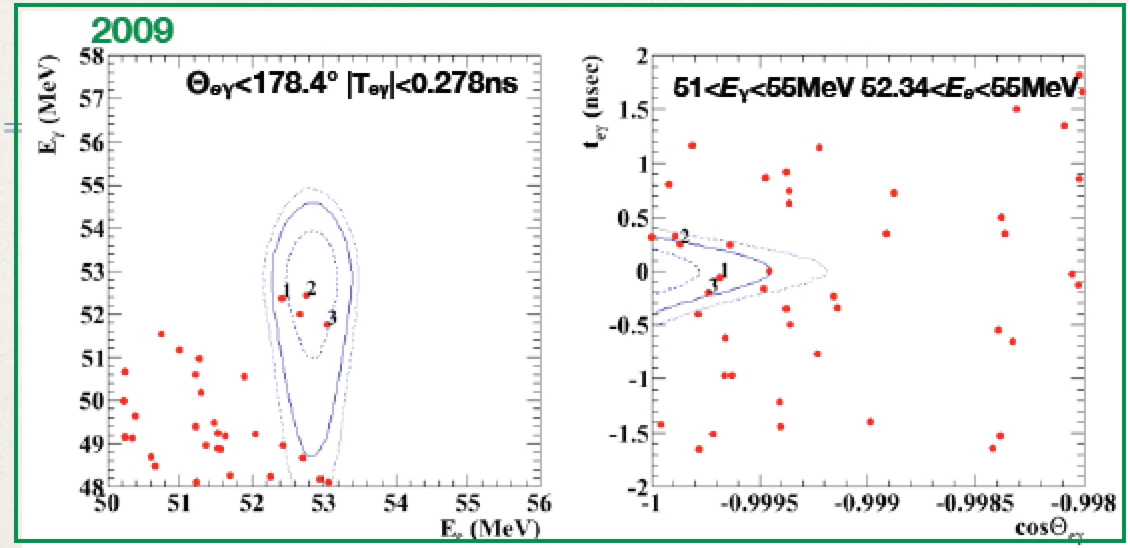
Surface muons are **fully polarized** $\Rightarrow$ **energy/angle distributions of Michel e^+ and γ's** from RD decay are modified. Depolarizing effects estimated < 10%.



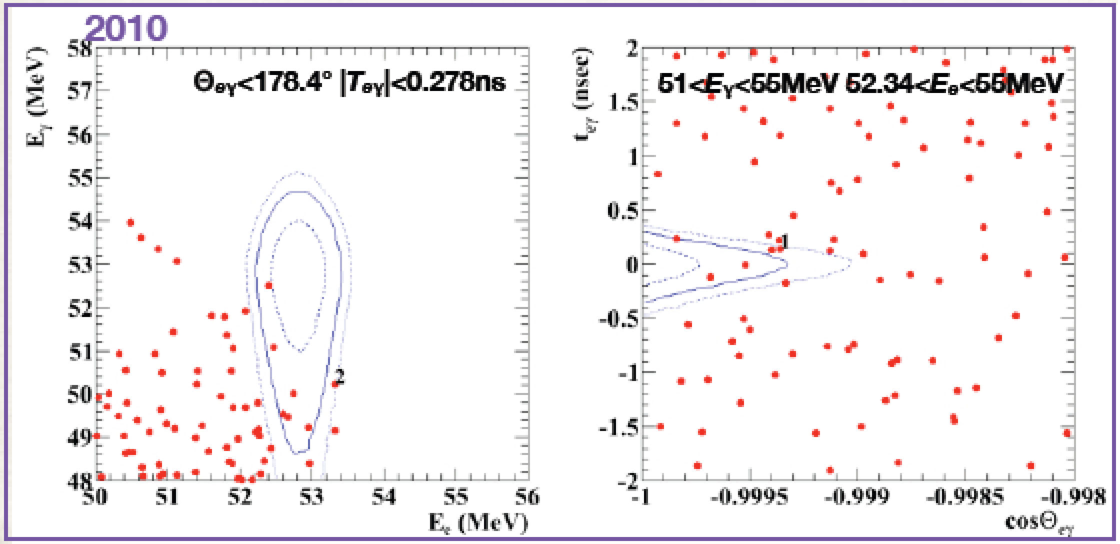
By fitting **positron energy distributions in angular slices** we obtained:

$$\langle P \rangle = 0.89 \pm 0.04$$

Event distribution 2009 & 2010

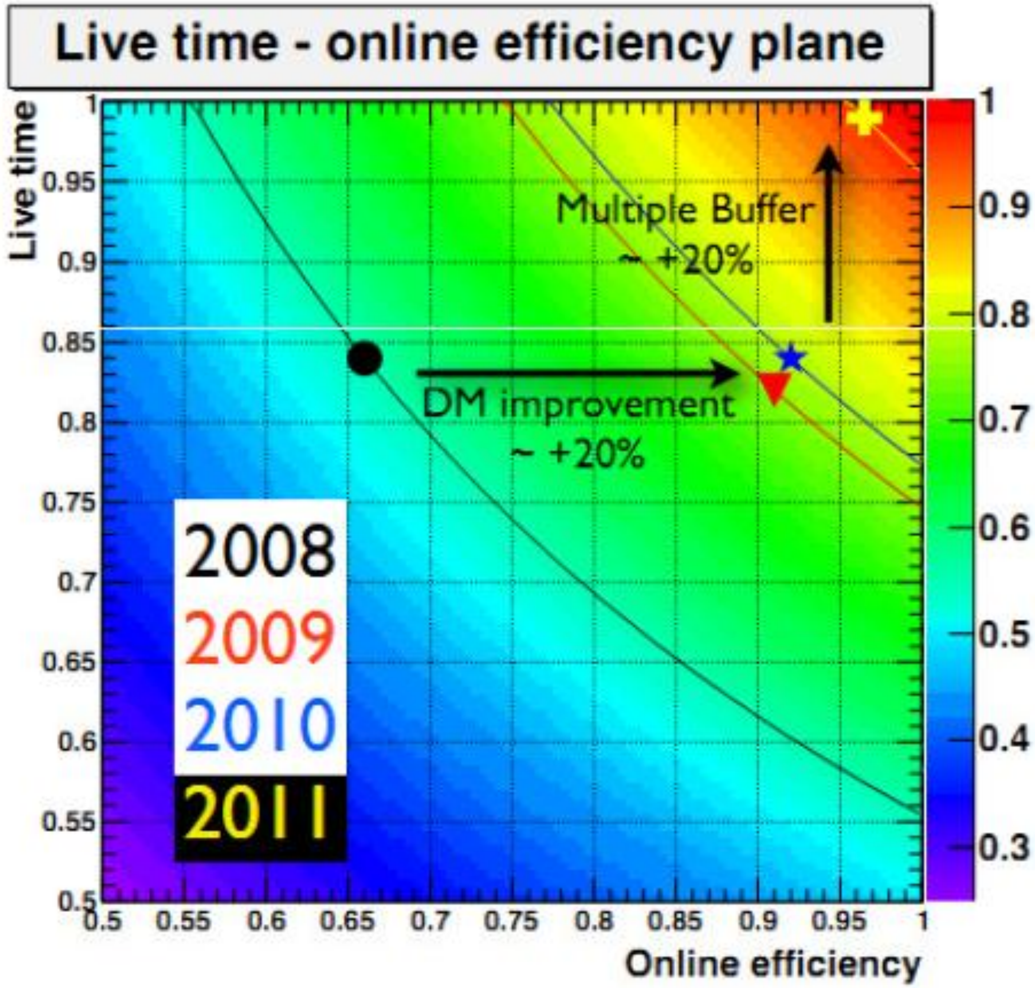


2009: small differences with respect to ICHEP 2010 presentations.



2010: no evidence for excesses in both plots.

Trigger/DAQ upgrades 2008-2011



20% absolute improvement with respect to 2010 run

Fully efficient DAQ system