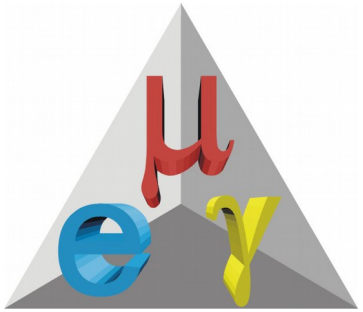
# Latest results from MEG and status of MEG-II

Francesco Renga
*INFN Roma*



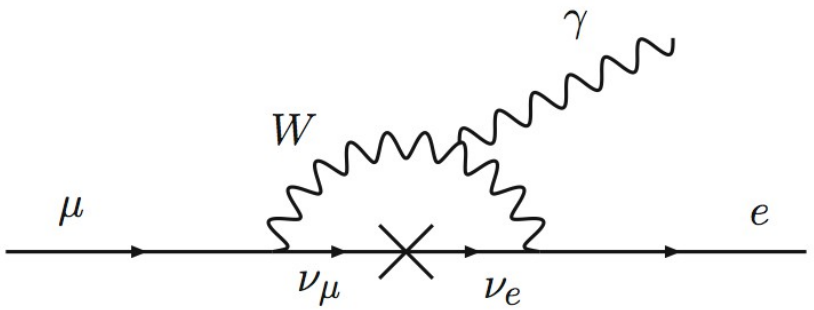


PANIC 2014 - Hamburg University, 24-29 August 2014

# The quest for $\mu \rightarrow e\,\gamma$

- A standard probe for New Physics (NP) beyond the Standard Model (SM):
  - unobservable rates in the SM;

SM (BR < $10^{-40}$)

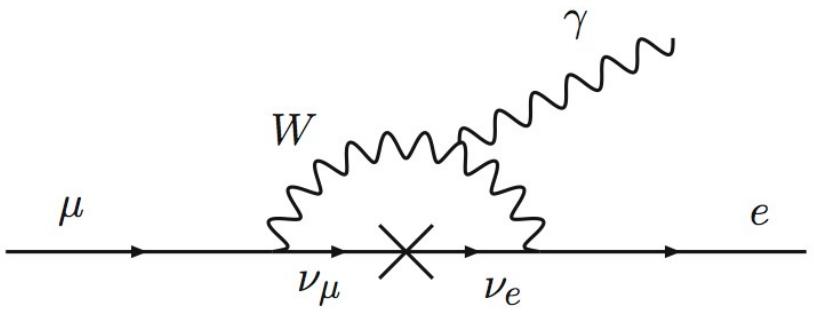



*Observation would be an* ***unambiguous evidence of NP***

# The quest for $\mu \rightarrow e\,\gamma$

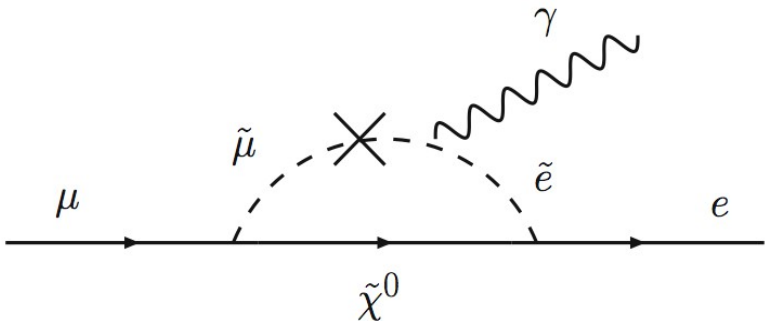
- A standard probe for New Physics (NP) beyond the Standard Model (SM):
  - unobservable rates in the SM;
  - naturally enhanced by NP (SUSY, Extra dimensions, unparticles, etc.);

SM (BR < $10^{-40}$)



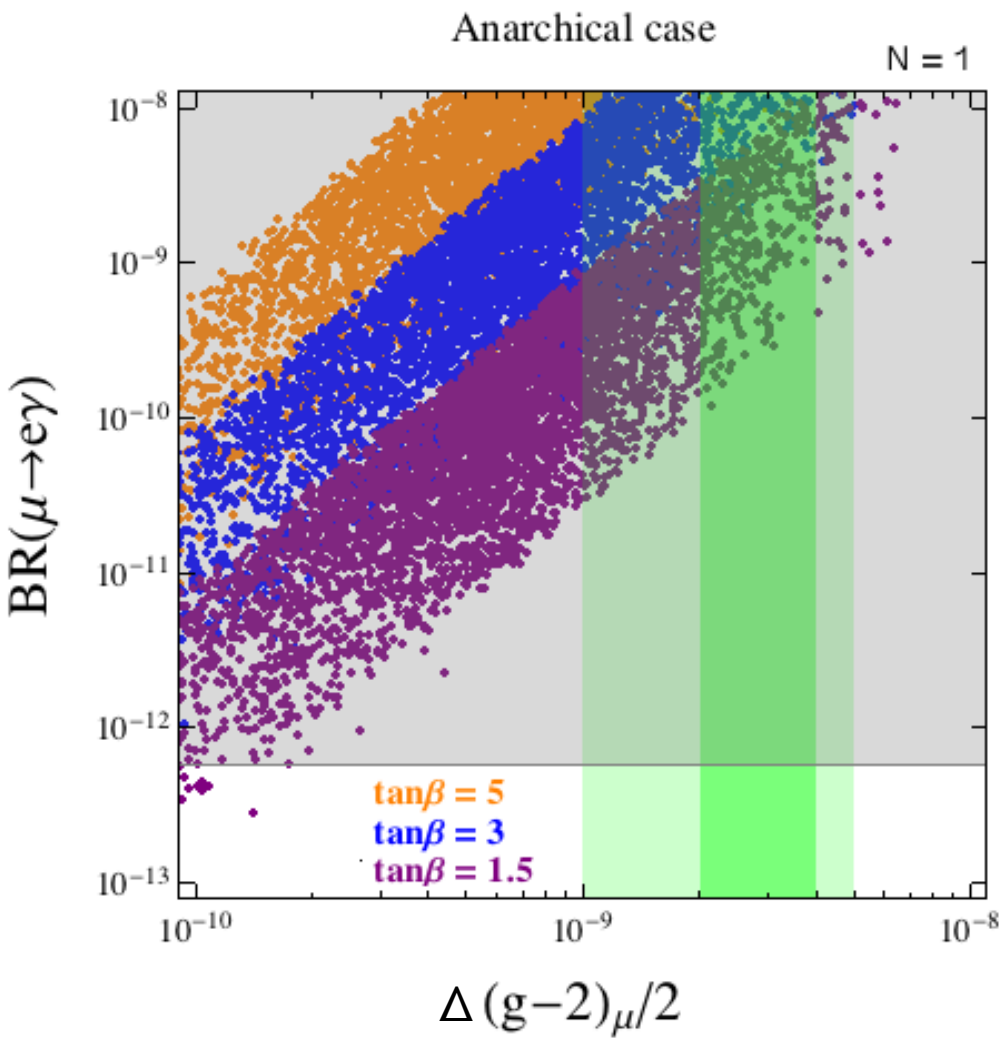

*Observation would be an* ***unambiguous evidence of NP***

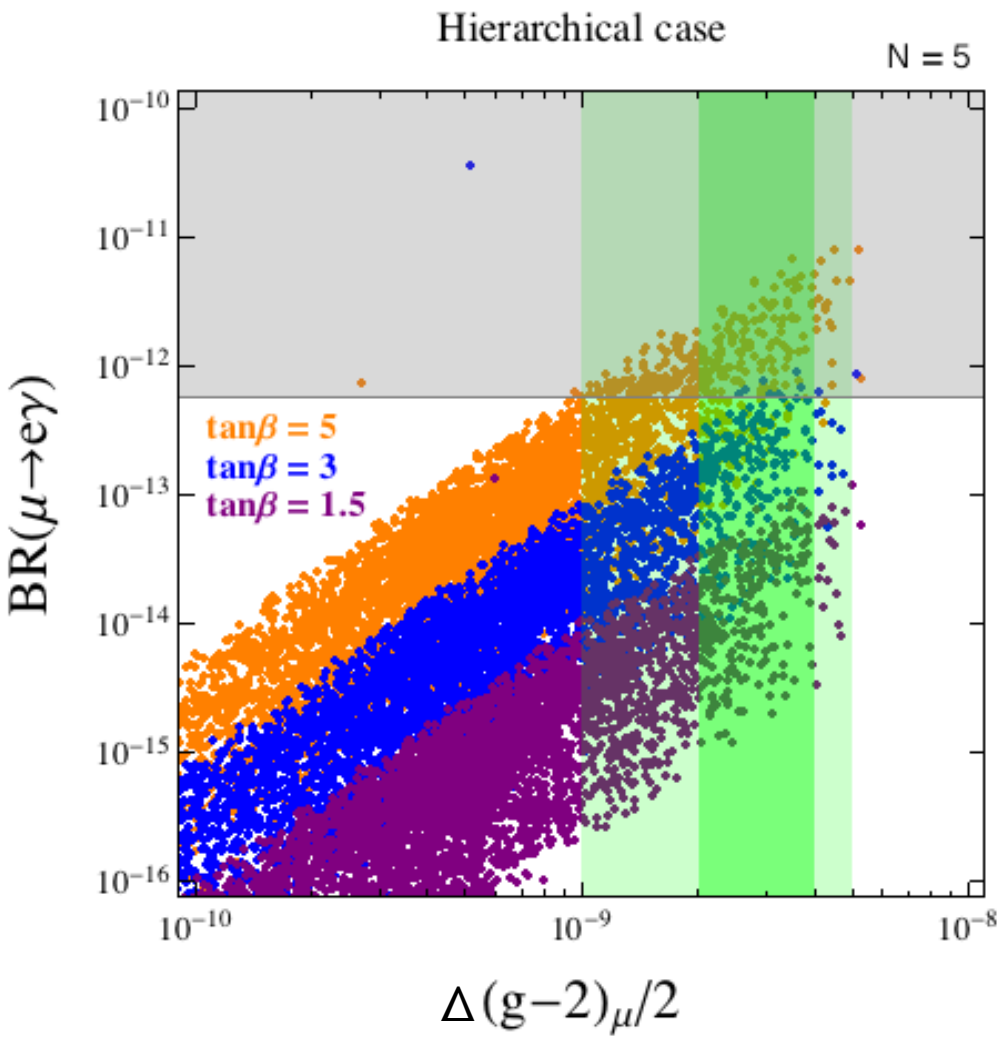
SUSY (BR ~ $10^{-11}$ - $10^{-15}$)




LFV through renormalization group running even if the theory is LF conserving at the high energy scale

# Theory and Experiment



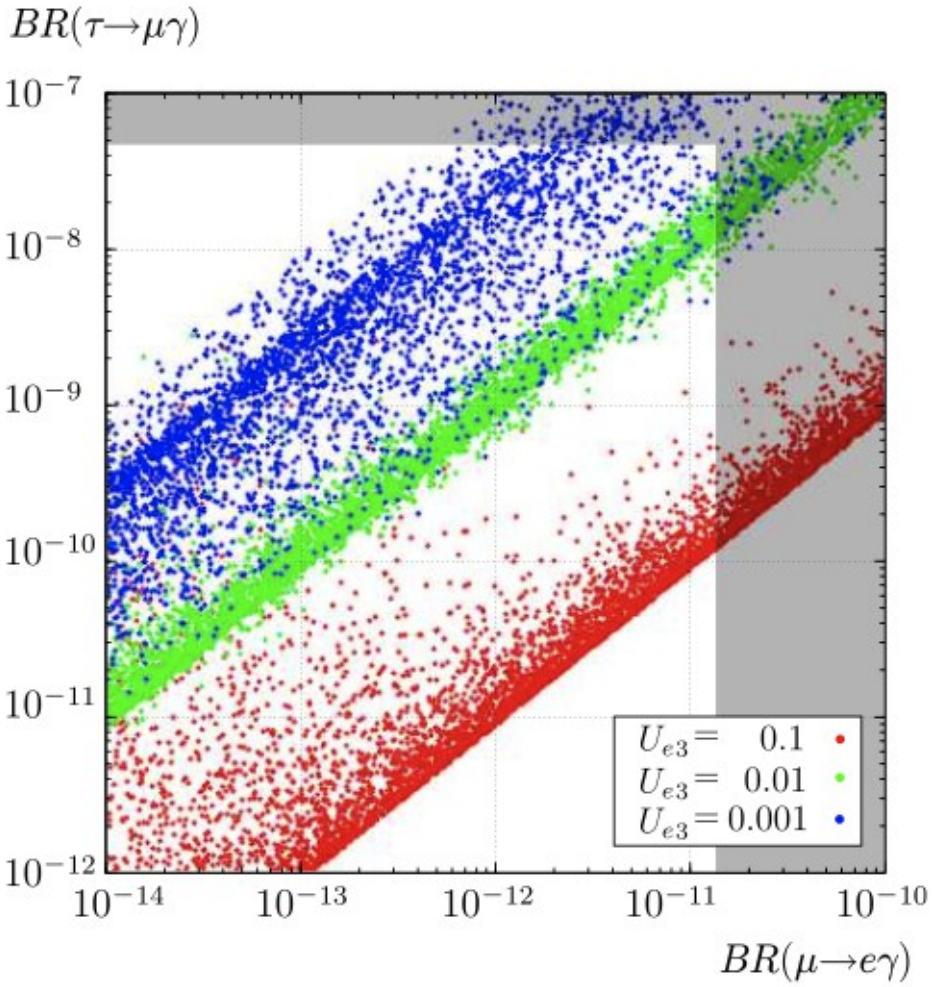




***Lepton Flavor Violation in Flavored Gauge Mediation***
**Calibbi, Paradisi, Ziegler (2014)**

# LFV and $\theta_{13}$

- In SUSY GUTs, LFV in $\mu$ decays is strongly related to the neutrino mixing angle $\theta_{13}$.

$\nu$ mixing parameter
$U_{e3} \sim \sin(\theta_{13})$




*SUSY SU(5) with right-handed neutrino (Hisano, Nagai, Paradisi, Shimizu '09)*

# LFV and $\theta_{13}$

- In SUSY GUTs, LFV in μ decays is strongly related to the neutrino mixing angle $\theta_{13}$.

$\nu$ mixing parameter

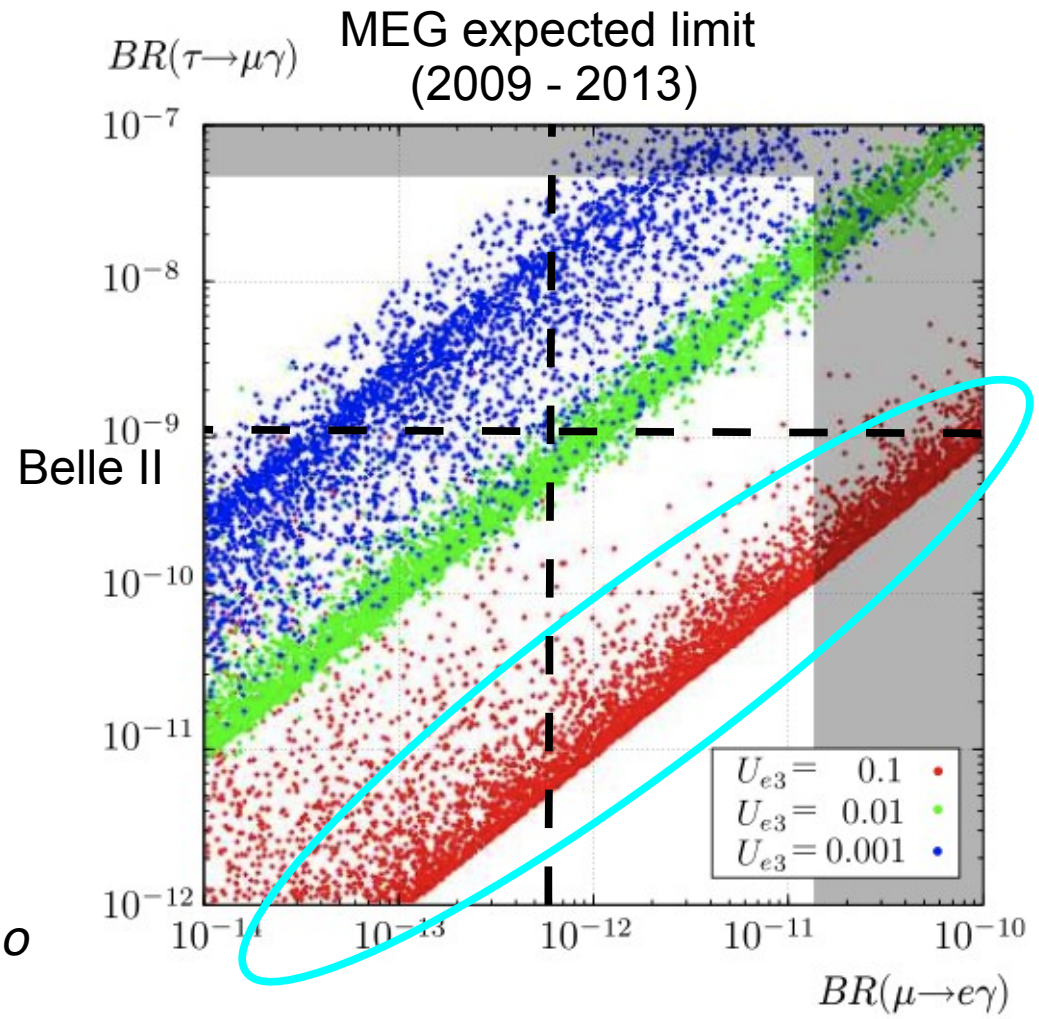
$U_{e3} \sim \sin(\theta_{13}) \sim 0.15$

$\sin^2(2\theta_{13}) = 0.084 \pm 0.005$

(Daya Bay)

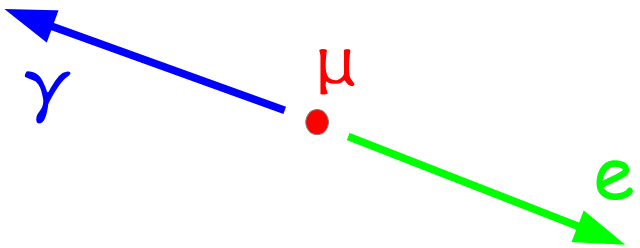
*μ LFV is favored!*

*SUSY SU(5) with right-handed neutrino*
*(Hisano, Nagai, Paradisi, Shimizu '09)*



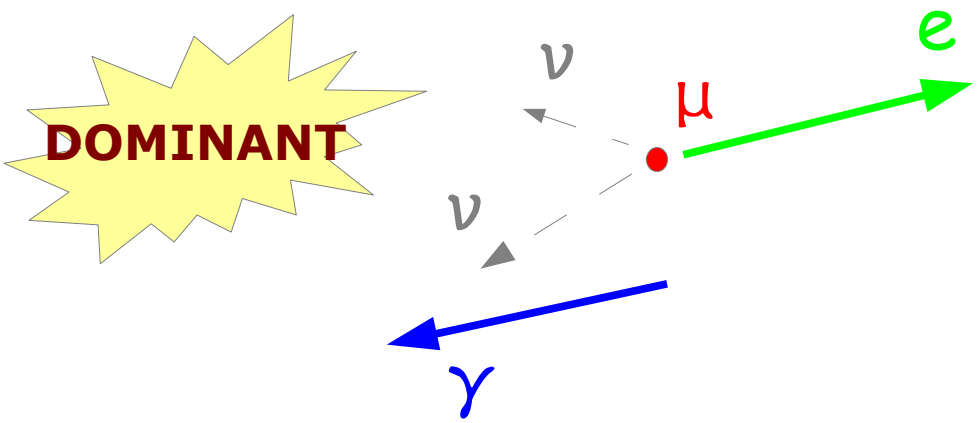
# Experimental Signature

**SIGNAL**

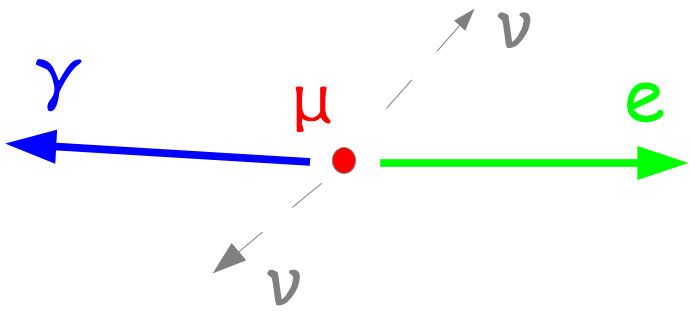



Monochromatic (52.8 MeV), back-to-back $e^+$ $\gamma$ produced at the same time;

**ACCIDENTAL BACKGROUND**



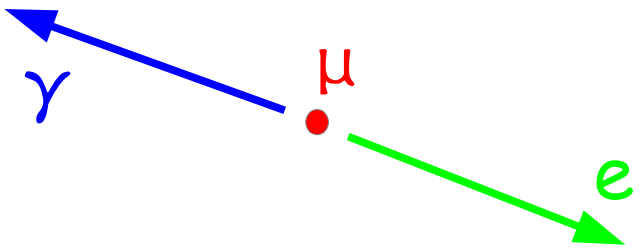

**RADIATIVE MUON DECAY (RMD)**




*Signal/Background discrimination from* ***photon and positron energies, relative angles and relative time***

# Experimental Signature

**SIGNAL**




Monochromatic (52.8 MeV), back-to-back $e^+$ $\gamma$ produced at the same time;

**ACC** **(RMD)**

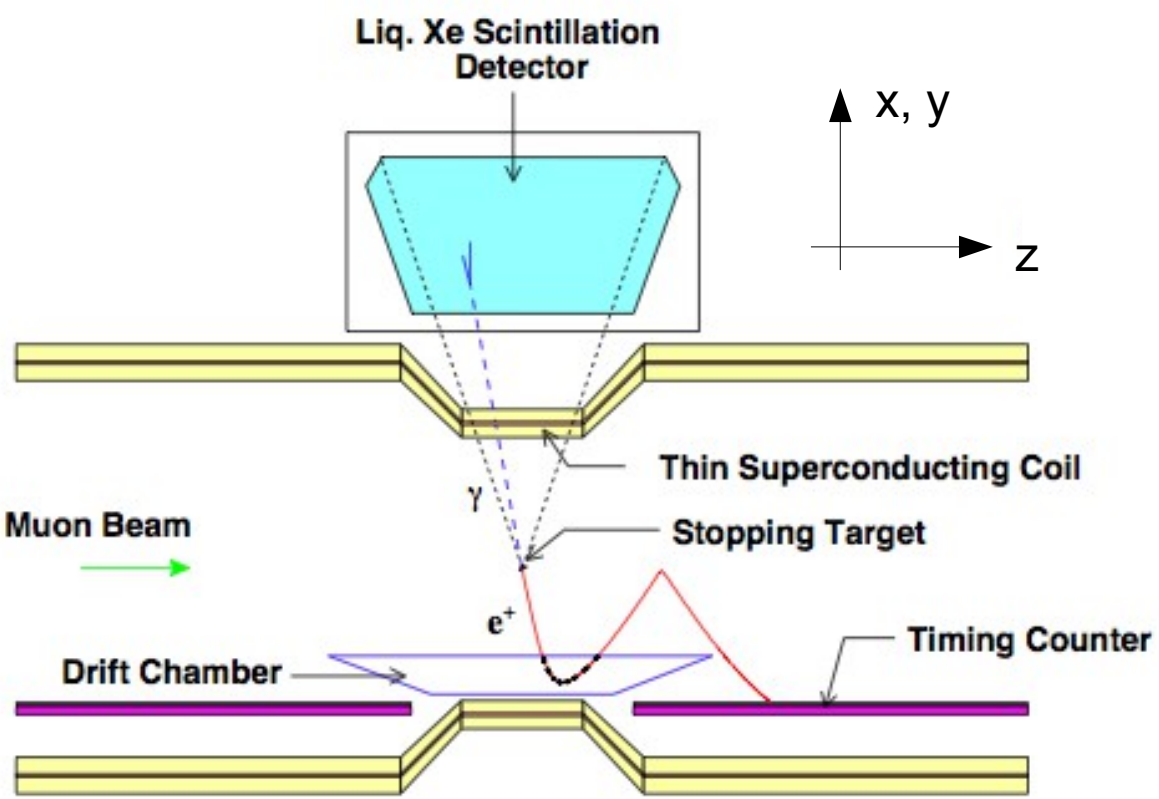
$$\Gamma_{acc} \propto \Gamma_\mu^2 \cdot \delta E \cdot \delta T_{e\gamma} \cdot (\delta E_\gamma)^2 \cdot (\delta \Theta_{e\gamma})^2$$

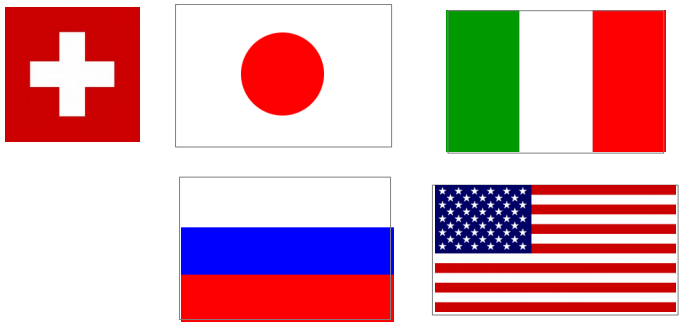
**DOMINA**

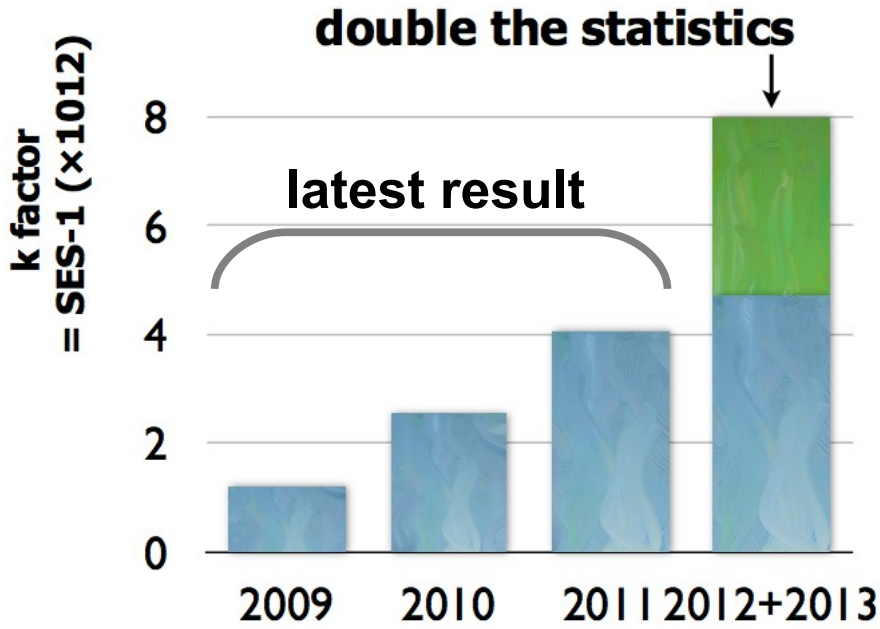

*Signal/Background discrimination from* ***photon and positron energies, relative angles and relative time***

# The MEG Experiment

- A search for $\mu \rightarrow e\,\gamma$ with **the most intense DC muon beam of the world** ($3 \times 10^7$ $\mu$/s @ PSI, Switzerland);

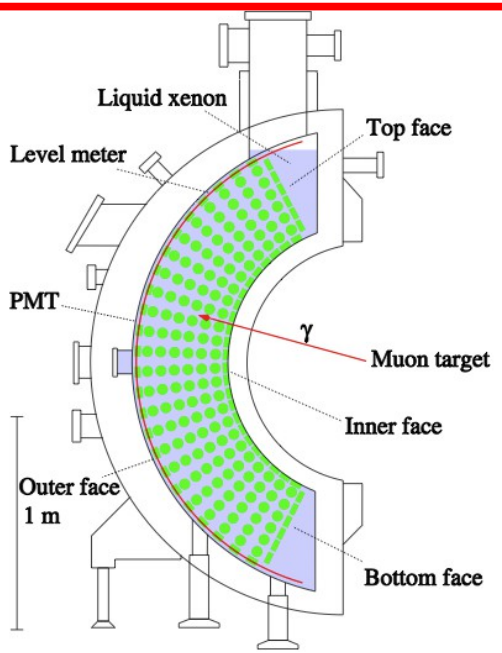


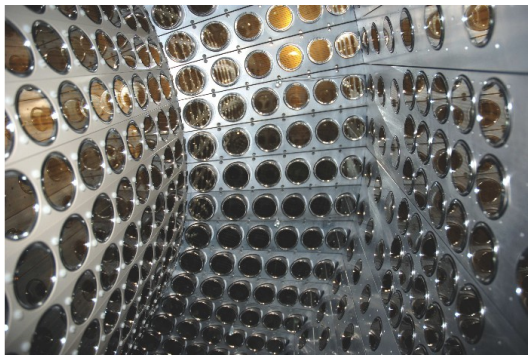






**Eur. Phys. J. C (2013) 73:2365**

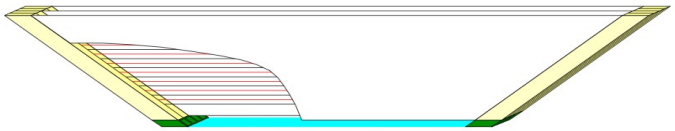
# The MEG Experiment



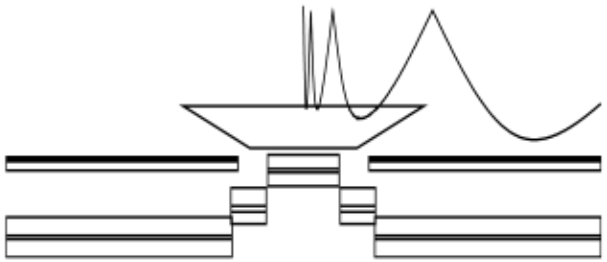



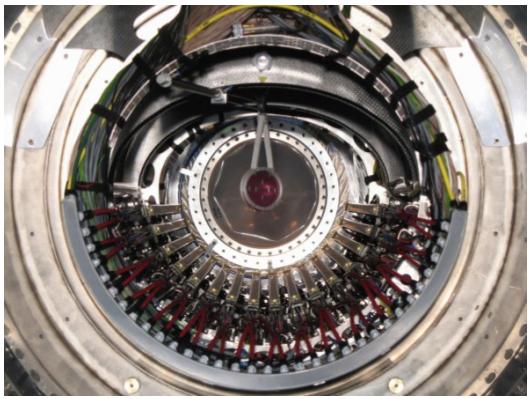
800 liter LXe detector
read by 856 PMTs

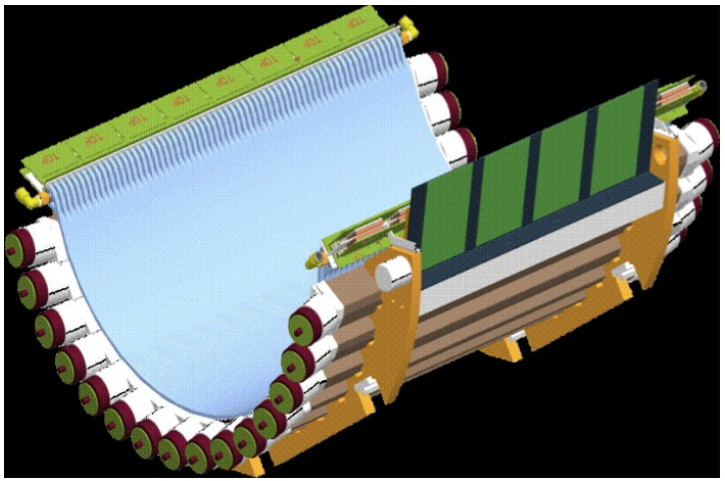
16 drift chambers
$\sigma_R \sim 300\ \mu m$, $\sigma_Z \sim 1$ mm



Gradient
magnetic field







Timing counter
2 x 15 scintillating bars
2 x 256 fibers (z measurement)

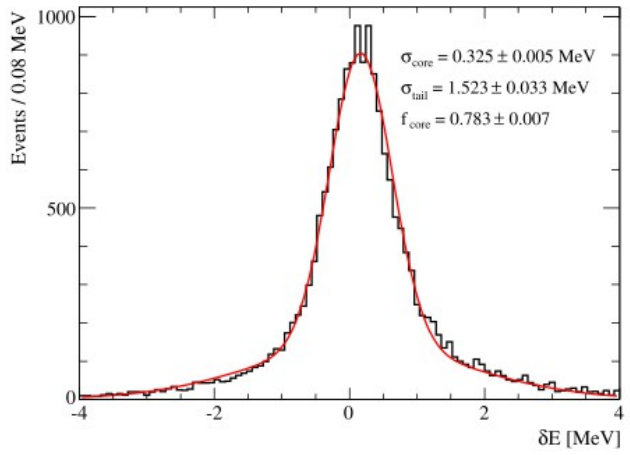
# Ultimate Performances

## $e^+$ Spectrometer

$\sigma(E) \sim 330$ keV (core)

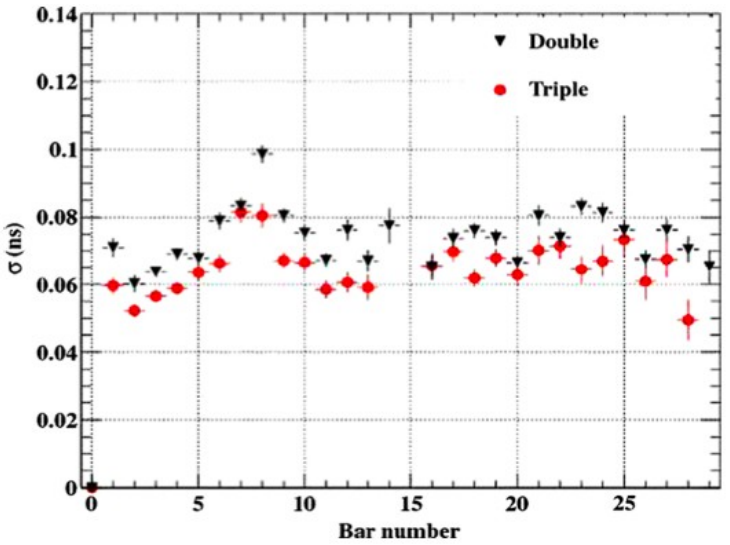
$\sigma(\theta,\varphi) \sim 10$ mrad

positron eff. $\sim 30\%$




## Timing Counter

$\sigma(T) \sim 70$ ps



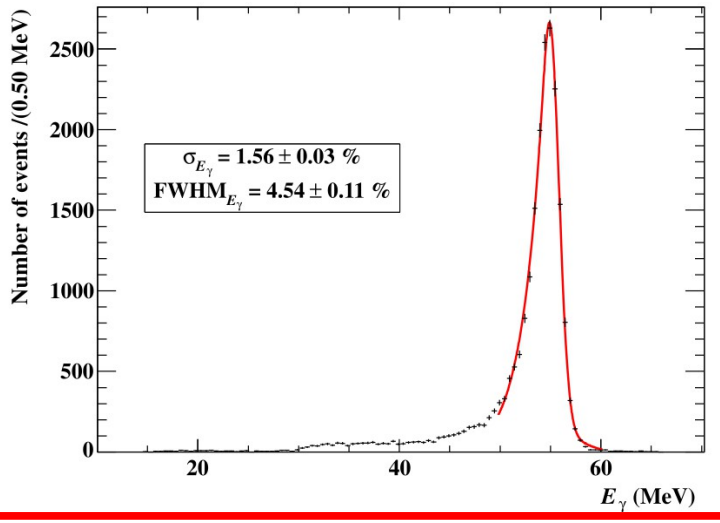

## LXe Detector

$\sigma(E) \sim 900$ keV (bulk region)

$\sigma_{pos} \sim 5$-6 mm

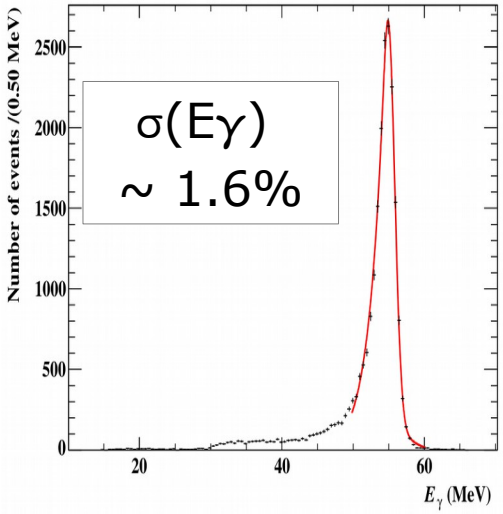
$\sigma(T) \sim 70$ ps

photon efficiency $\sim 63\%$



# Calibrations & Monitoring (I)

## Charge Exchange (CEX)



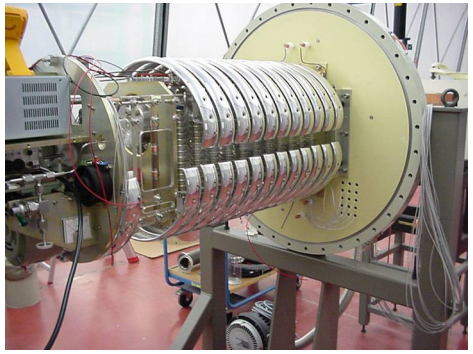

~ monochromatic $\gamma$ @ 55 MeV from...

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

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

...by selecting back-to-back $\gamma$'s

## Cockcroft-Walton accelerator

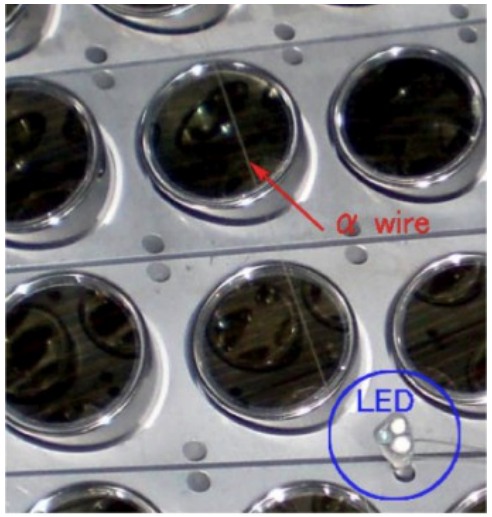


Protons on a Lithium Tetra-borate target

*bi-weekly monitoring of calorimeter's energy scale*

## LEDs

Installed inside the XeC



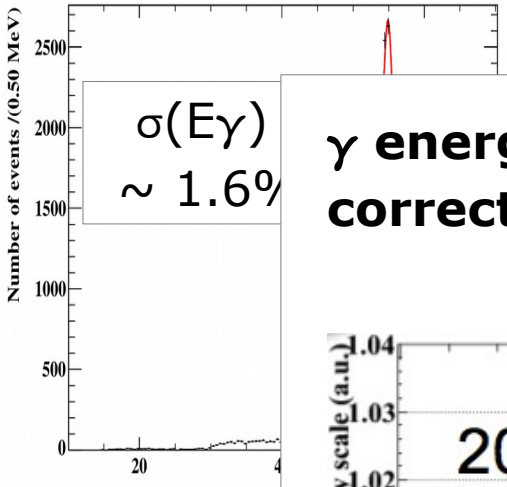

## α sources

Installed in wires inside the XeC

*bi-weekly calibration of PMT quantum efficiencies and gains*

# Calibrations & Monitoring (I)

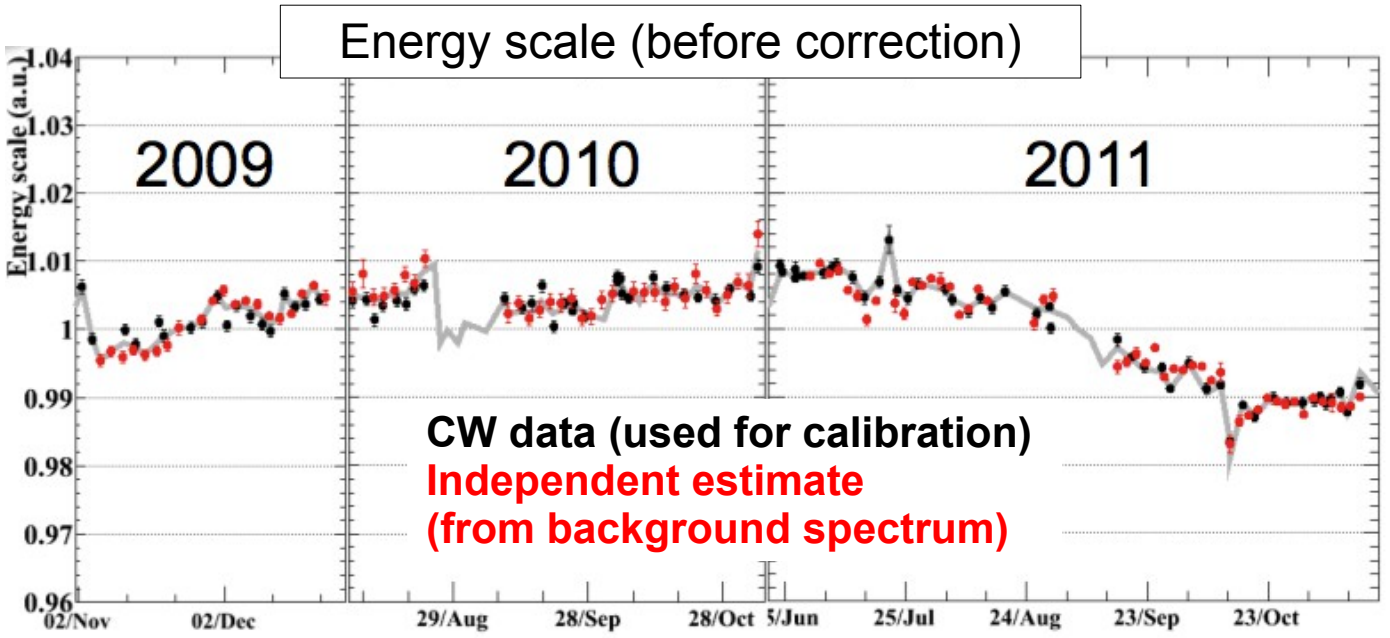
## Charge Exchange (CEX)



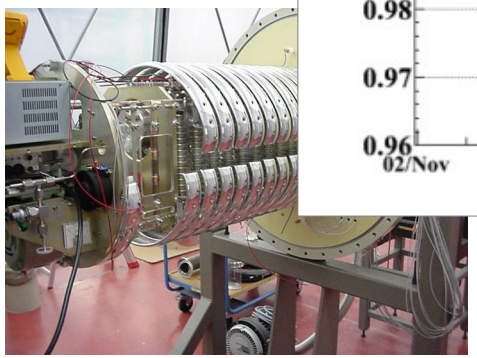

σ(Eγ) ~ 1.6%

~ monochromatic γ

**γ energy scale variations can be caught and corrected with a 0.2% precision**



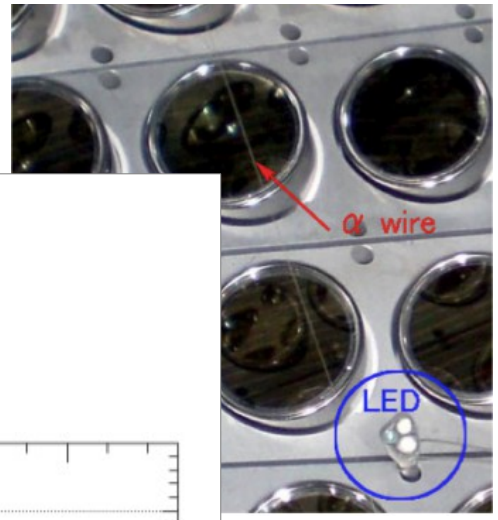

## Cockcroft-



*calorimeter's energy scale*

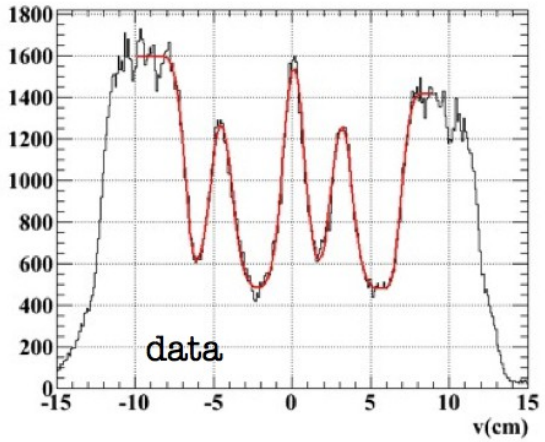
## LEDs

Installed inside

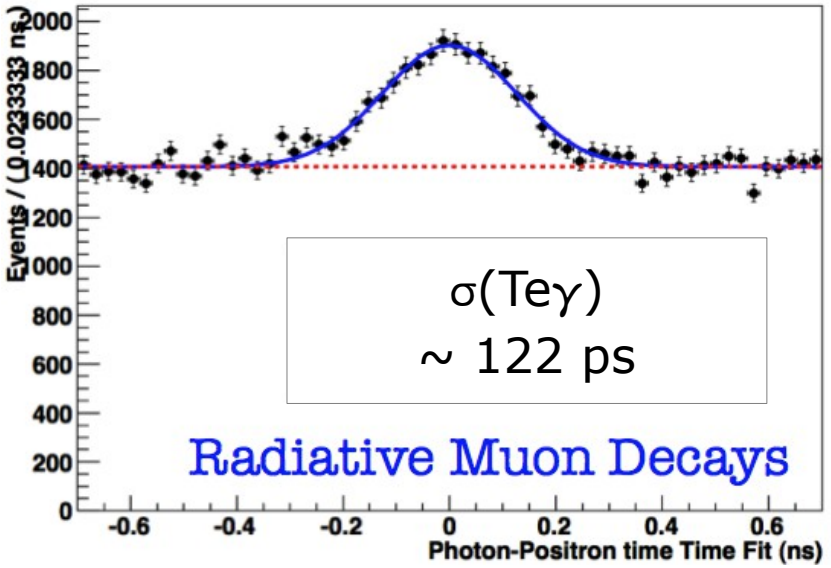



*bi-weekly calibration of PMT quantum efficiencies and gains*

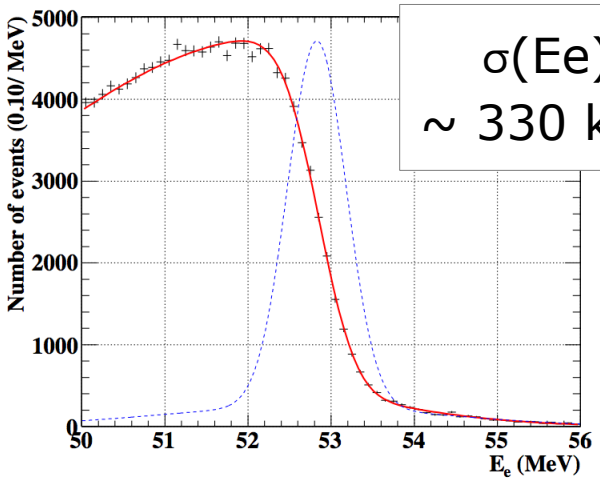
# Calibrations & Monitoring (II)




γ position resolution from special data taking w/ collimators

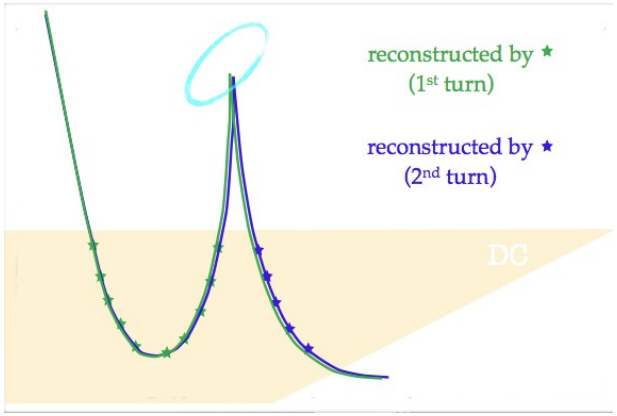



Tracks from μ → e ν ν and cosmics to calibrate the positron spectrometer



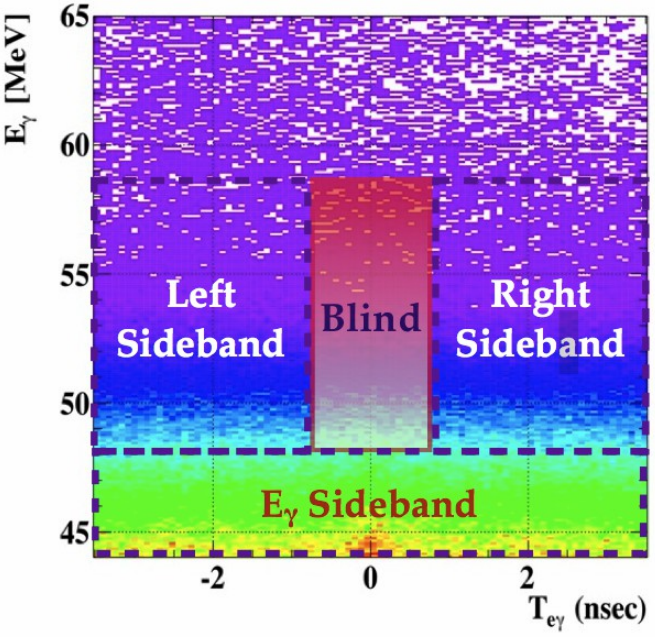

angle & vertex resolution from multi-turn tracks

momentum resolution and scale from the μ → e ν ν kin. edge



# Analysis Strategy

- Likelihood analysis of 5 discriminating variables ($E_e$,$E_\gamma$,$\theta_{e\gamma}$,$\varphi_{e\gamma}$,$T_{e\gamma}$):
  - year-by-year and event-by-event PDFs;
  - careful treatment of **correlations** (from well understood geometrical effects)

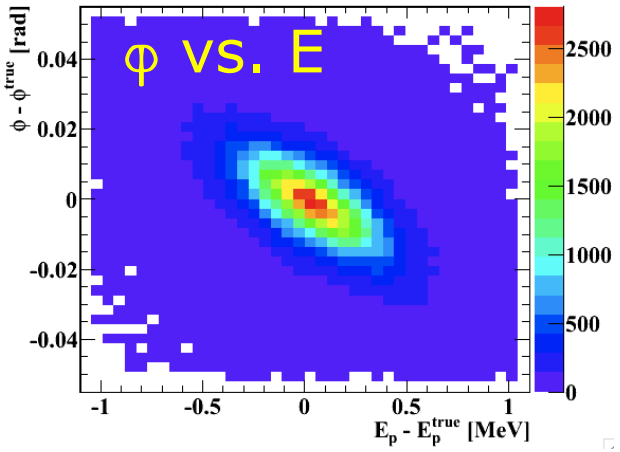


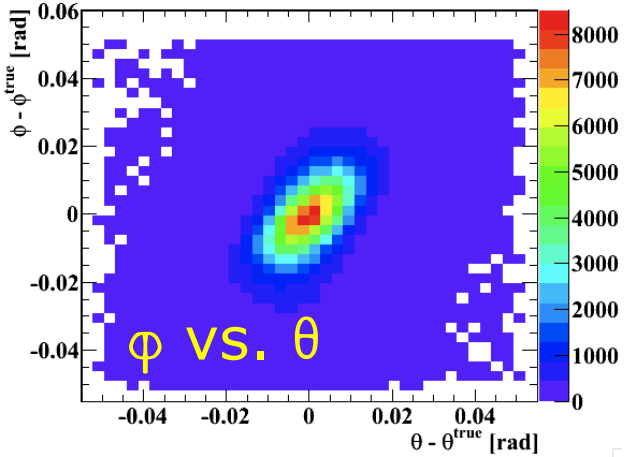

- Accidental **background PDFs** are fully defined **from data** sidebands:
  - very solid determination of the (largely) dominant background;
- Signal and radiative decay PDFs by combining the results of the **calibration procedures**;

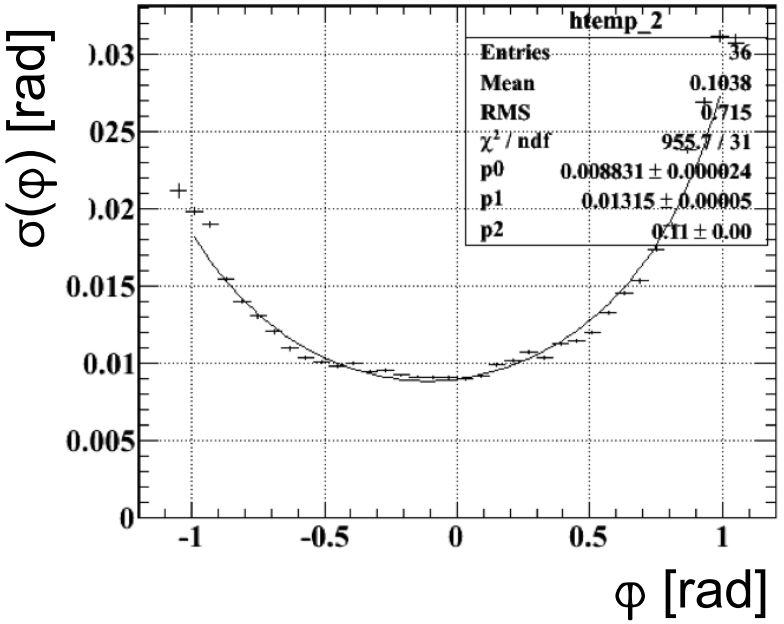
# Correlations

- We account for *correlations* among positron variables and *direction-dependent positron resolutions*:
  - expected and well understood geometrical effects;
  - mostly <u>measured on data</u> from two turn tracks.

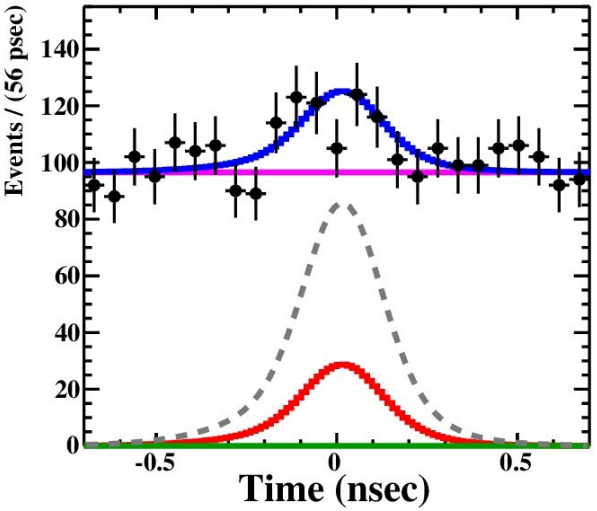
*just a few examples...*

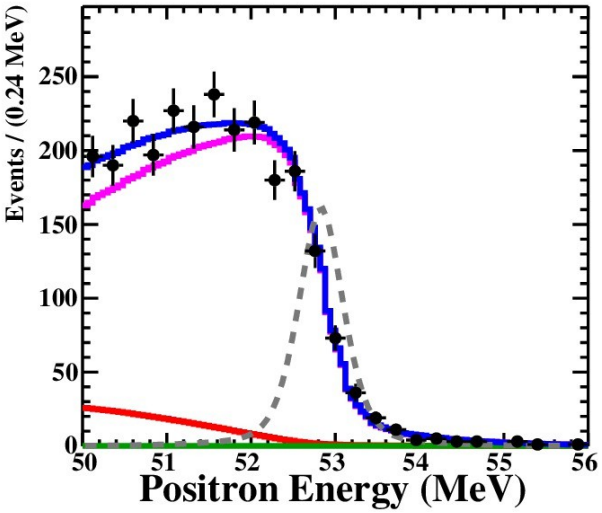


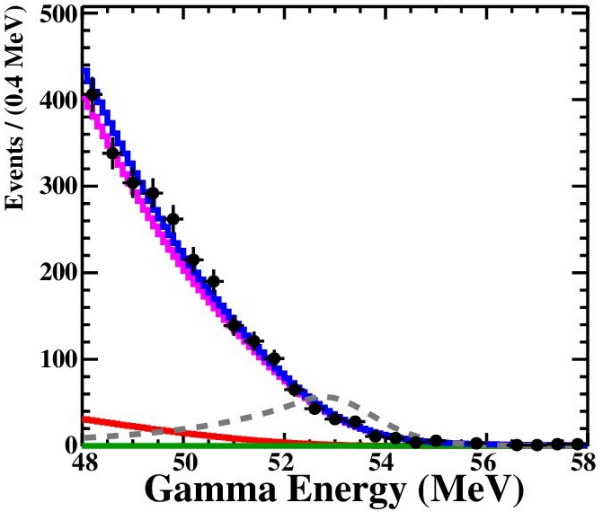



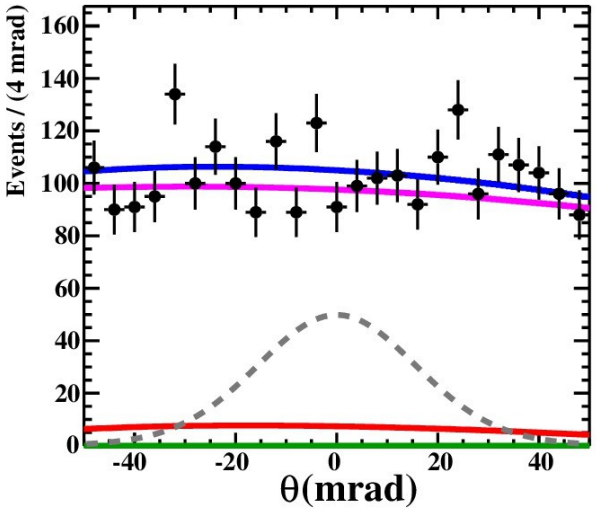



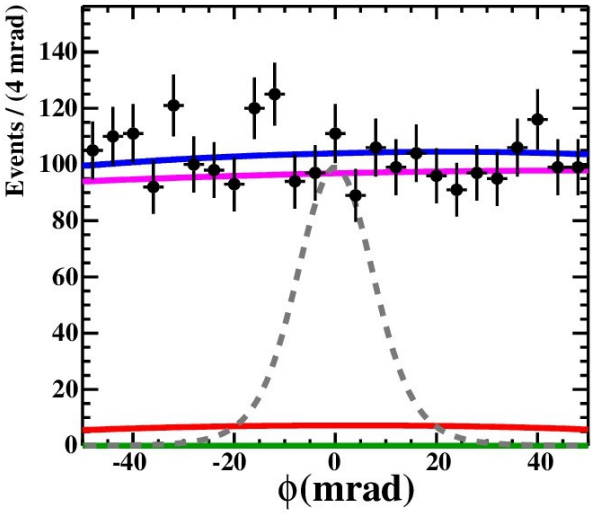
# Current Result (2009-2011)




Based on
~ 36 x $10^{13}$ μ
stopped at the target

$N_{sig} = -0.4^{+4.8}_{-1.9}$

$N_{bkg} = 2413 \pm 37$

$N_{RD} = 167 \pm 24$

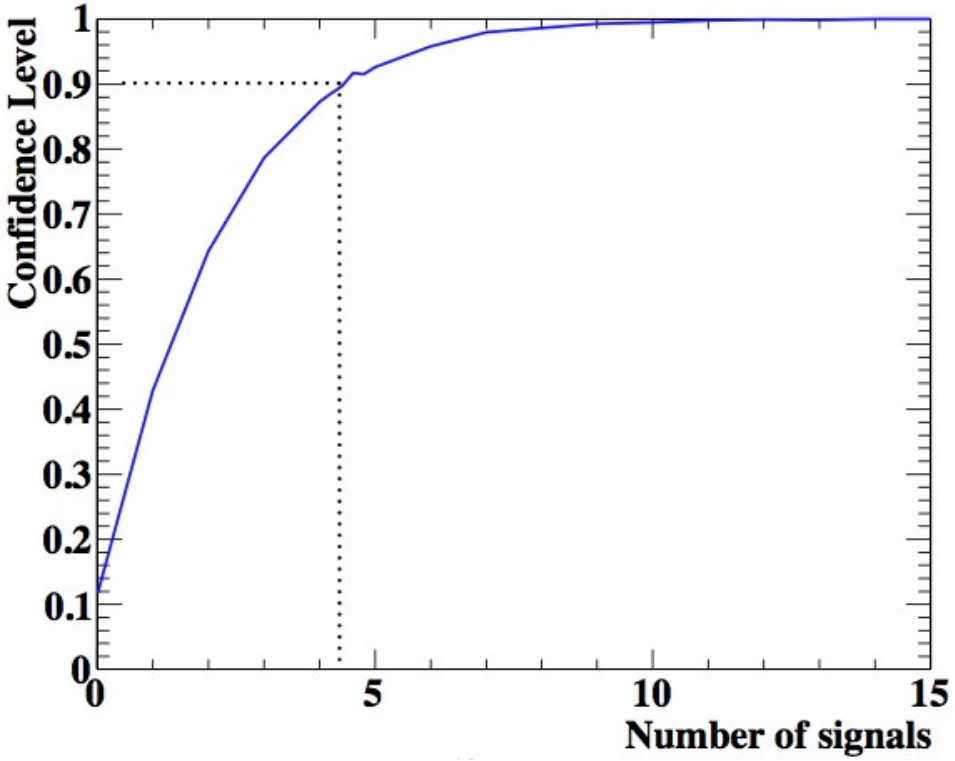
- - - - - SIGNAL WITH BR ~ 3 x $10^{-11}$

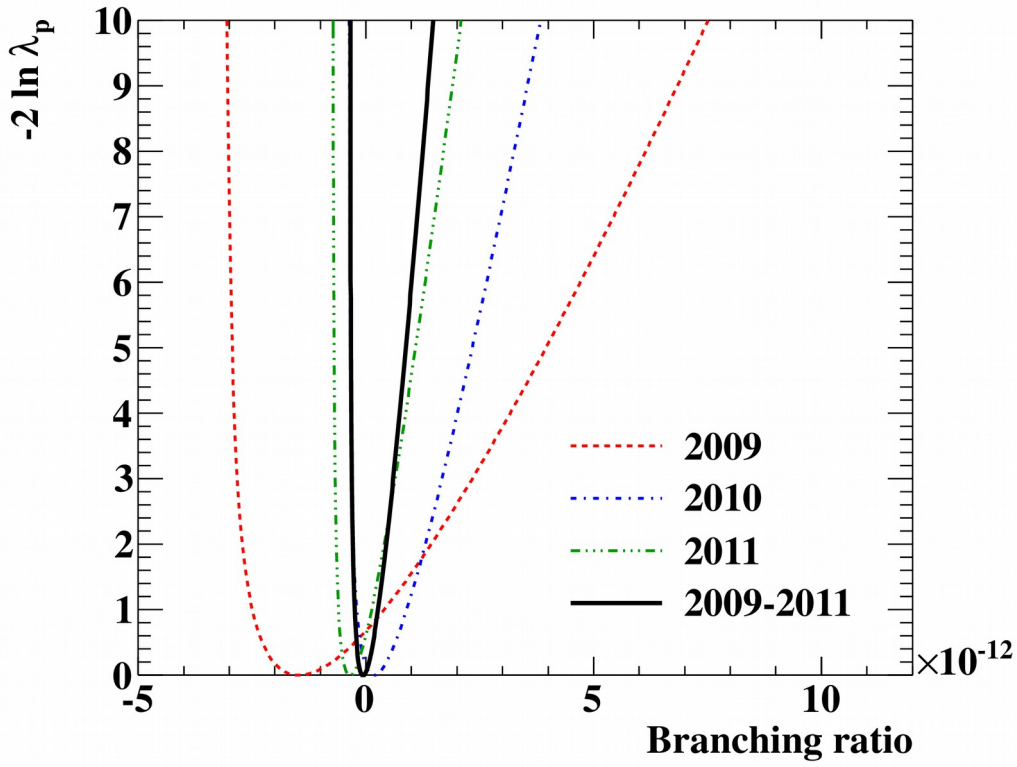
# Current Result (2009-2011)

**BR(μ → e γ) < 5.7 x $10^{-13}$**

**incl. systematics**

(expected limit: 7.7 x $10^{-13}$)

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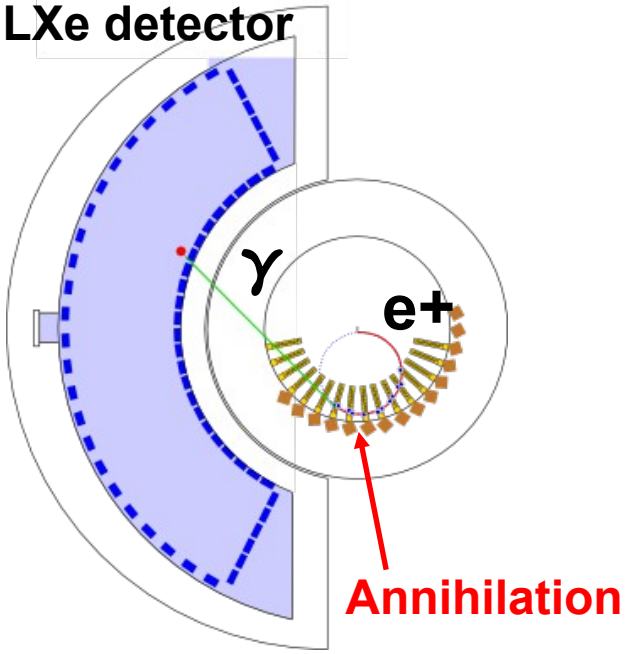
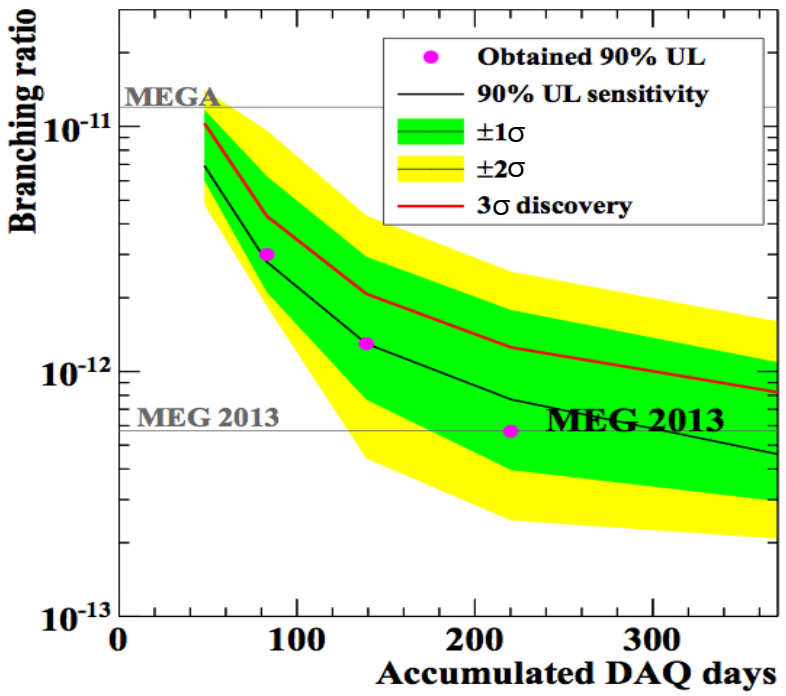
# Perspectives

- Several improvements in analysis and calibrations are ongoing:
  - recognition of background photon from positron annihilating in the spectrometer (~ 20% sens. improvment)
  - increased efficiency for tracks with multiple turns within the spectrometer
  - more accurate measurement of the magnetic field
- The assessment of the final sensitivity is on going



# The MEG Upgrade (MEG-II)

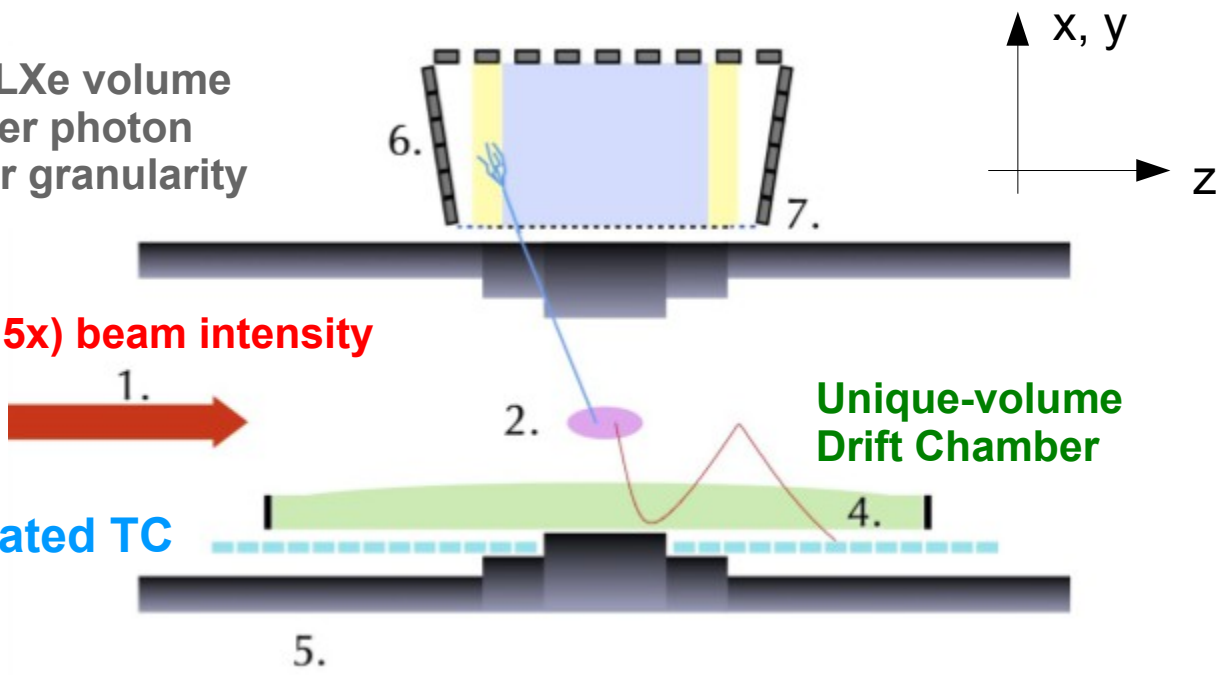
- An upgrade of MEG, aiming at a sensitivity improvement of **one order of magnitude** (down to 5 x $10^{-14}$) is under construction;

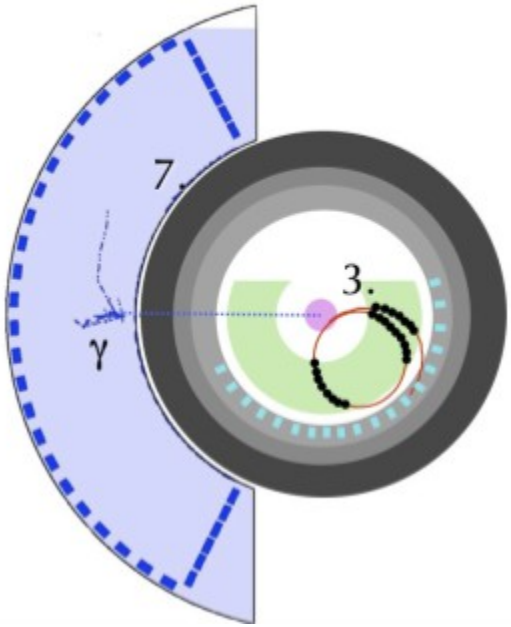

Larger LXe volume with finer photon detector granularity

Higher (2.5x) beam intensity

Pixelated TC

Unique-volume Drift Chamber




**arXiv:1301:7225**

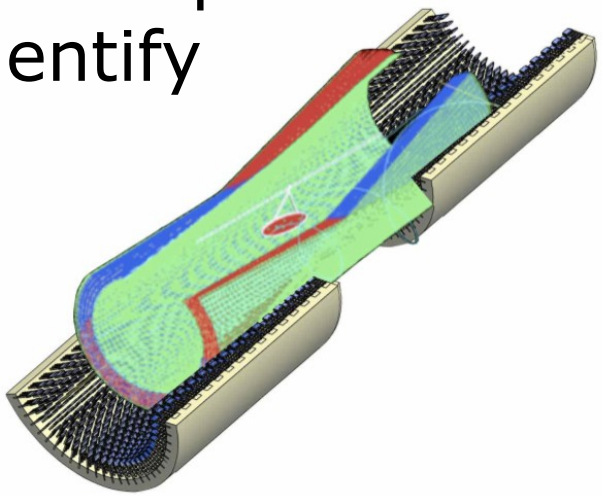
# Drift Chamber

- Unique-volume drift chamber with **stereo wires** and helium-isobutane gas admixture, to replace the current system of 16 independent chambers;

**MAIN IMPROVEMENTS**

- Longer tracking region with finer granularity;
- Lower material budget (30% less $X_0$);
- Faster readout electronics (~ GHz BW) to improve the drift time resolution and possibly identify single ionization cluster;

$\sigma(XY) \sim 120\ \mu m$
$\sigma(Z) \sim 900\ \mu m$
$\Rightarrow$
$\sigma(p) \sim 130$ keV
$\sigma(\theta,\varphi) \sim 5$ mrad

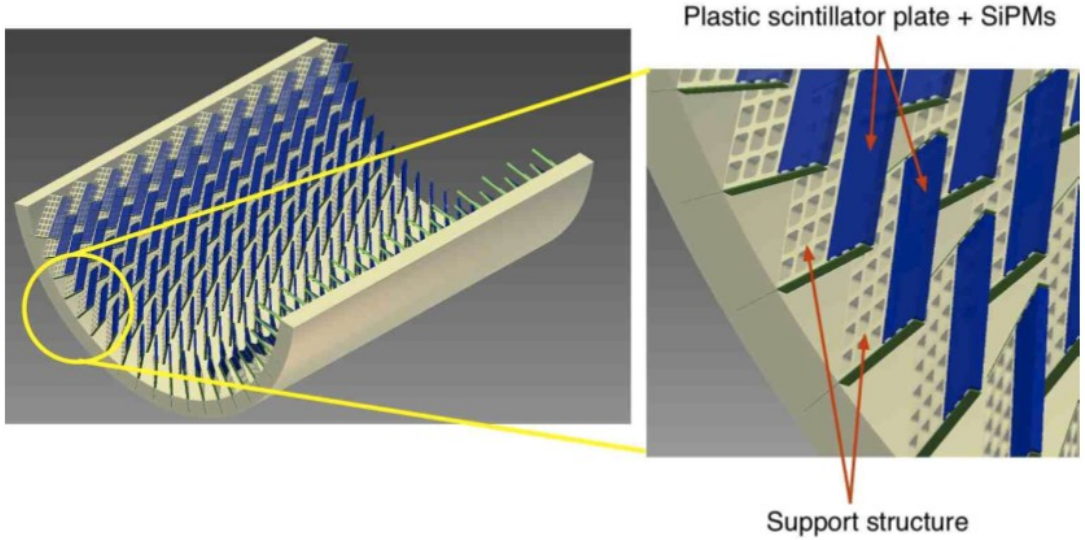


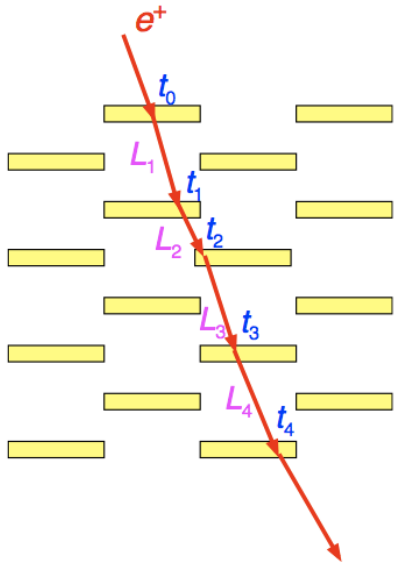
# Pixelated Timing Counter

- *Pixelated TC*: ~ 500 – 800 scintillating tiles, read out by SiPM, to replace the 30 bars of the present TC;

**MAIN IMPROVEMENTS**

- Better time resolution and multiple time measurements for the same positron;
- Higher rate tolerance.

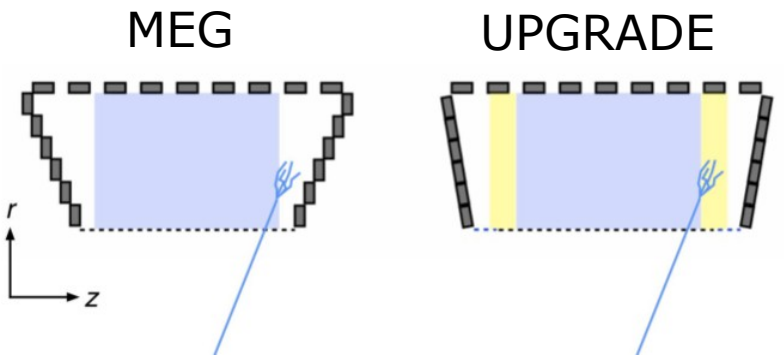



$$\sigma^2_{\text{overall}} = \frac{\sigma^2_{\text{single}}}{N_{\text{hit}}} + \frac{\sigma^2_{\text{inter-pixel}}}{N_{\text{hit}}} + \sigma^2_{\text{MS}}(N_{\text{hit}})$$

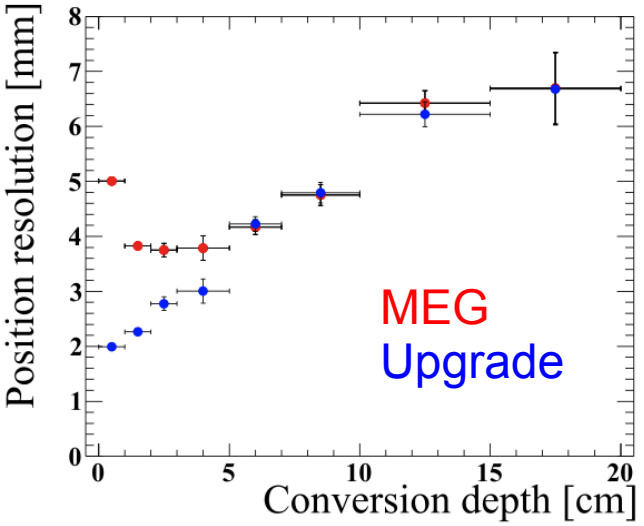
# LXe Calorimeter

- Silicon Photomultipliers (SiPM) to replace the PMTs in the inner face;
- New geometry of lateral faces.




**MAIN IMPROVEMENTS**

- Larger fiducial volume;
- Better control of reflexions in the lateral faces.
- Finer granularity in the inner face:
  - better resolution for shallow $\gamma$;
  - better pileup recognition capabilities;




$\sigma$(E) ~ 1%  $\sigma$(position) ~ 2 (5) mm in u,v (depth)

# LXe Calorimeter

- Silicon Photomultipliers (SiPM) to replace the PMTs in the inner face;
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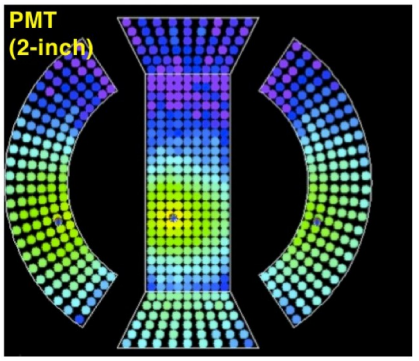
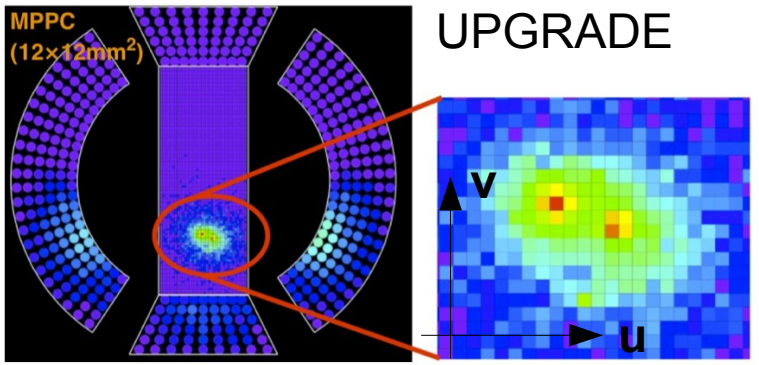



MEG

**MAIN IMPROVEMENTS**

- Larger fiducial volume;
- Better control of reflexions in the lateral faces.
- Finer granularity in the inner face:
  - better resolution for shallow $\gamma$;
  - better pileup recognition capabilities;

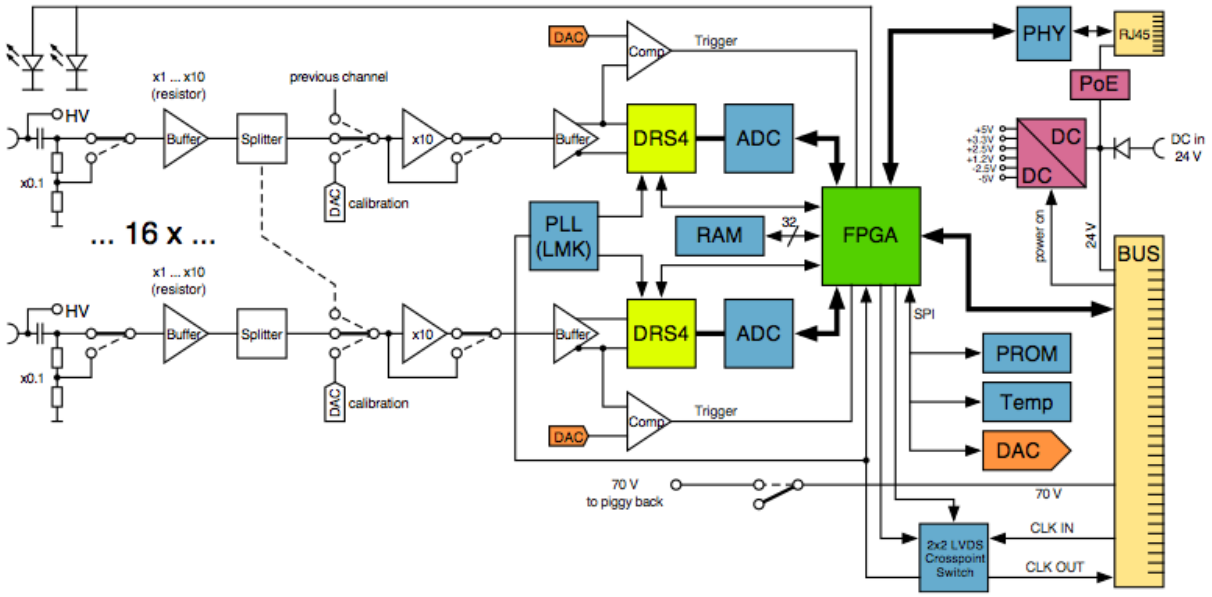


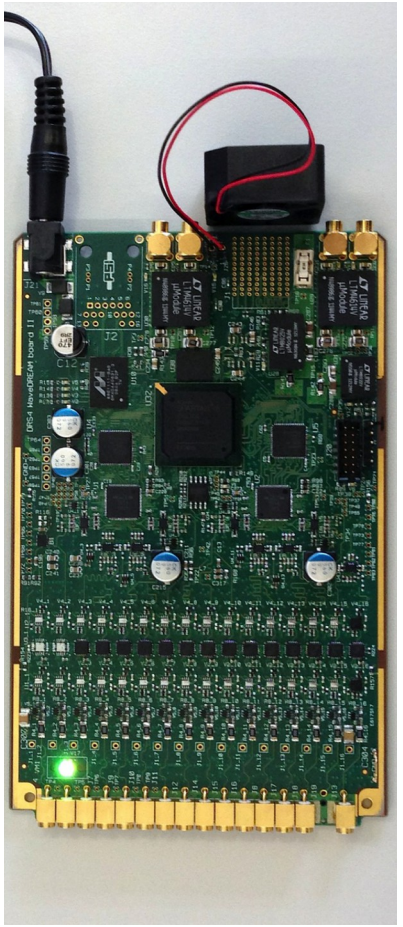

UPGRADE

$\sigma$(E) ~ 1%  $\sigma$(position) ~ 2 (5) mm in u,v (depth)

# DAQ Electronics & Trigger

- WaveDREAM electronic board:
  - HV and amplifiers for SiPM
  - digitization (DRS4 chip by PSI)
  - large bandwidth & fast data transmission
  - communication with trigger board (in the same crate) through custom back-plane

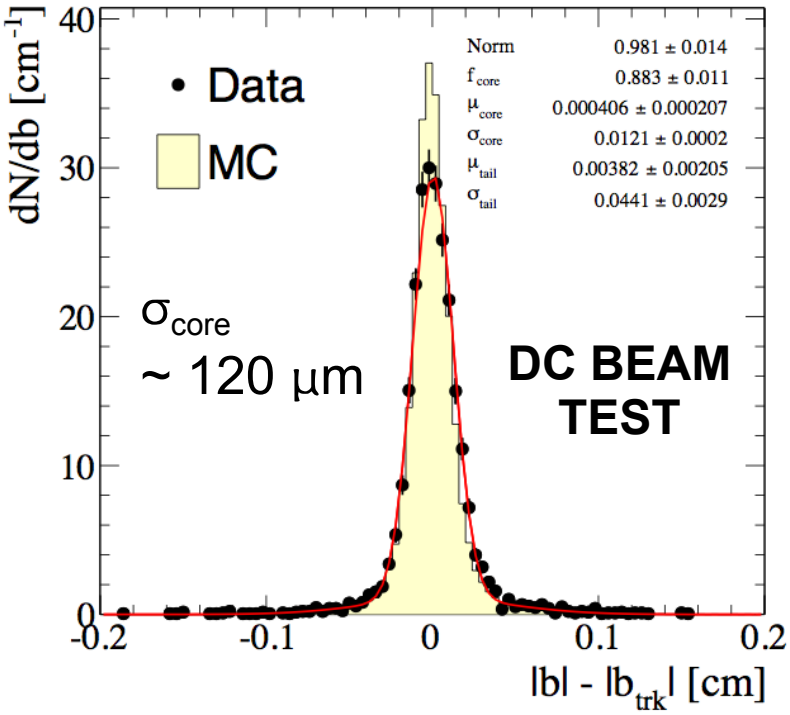


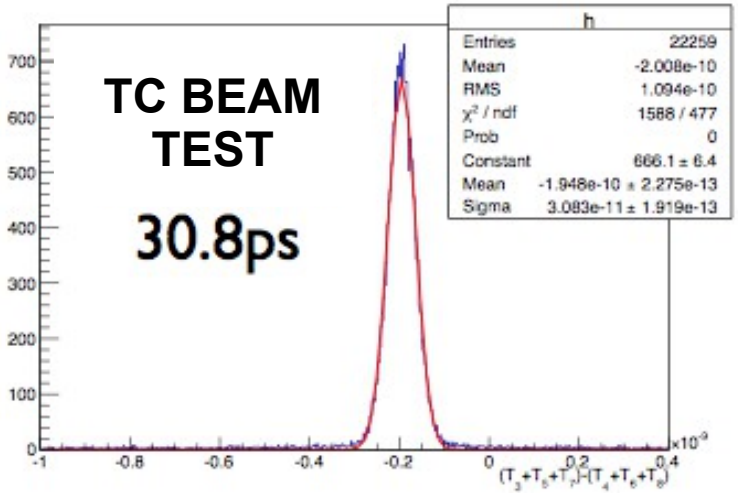



*A compact system to handle the increased number of channels*

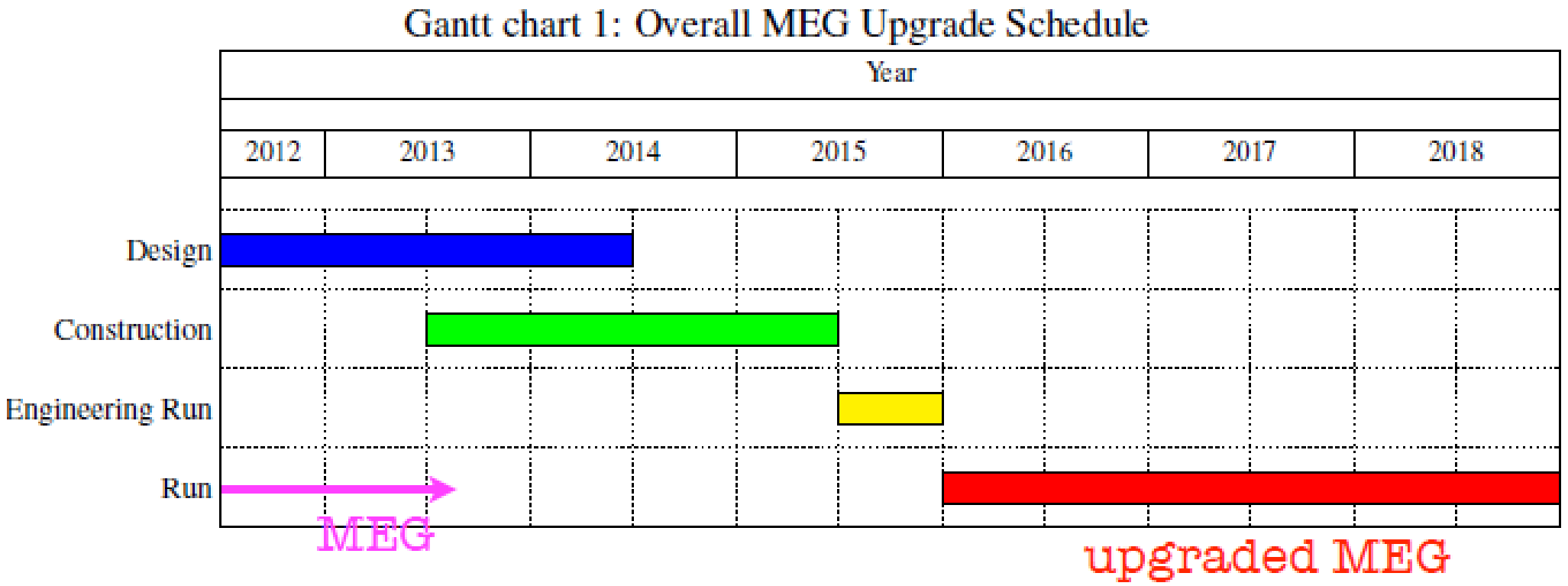
# R&D Highlights

- Drift chamber:
  - measured **single-hit resolution** (100-120 μm) in agreement with expectations in a few different prototypes
  - successful **aging tests**
- Timing Counter:
  - 30 ps **time resolution** measured with 50 MeV $e^-$
- LXe Calorimeter:
  - **successful tests** of specifically developed VUV-sensitive SiPM



# Upgrade Schedule



# Conclusions

- MEG has been a successful experiment with some well identified week points
- The on-going short-term upgrade is specifically tailored to address these issues:
  - expect to improve the MEG limit by a factor 10 within the end of this decade