The MEG experiment at PSI: recent results and outlook

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on behalf of the MEG collaboration

Outline

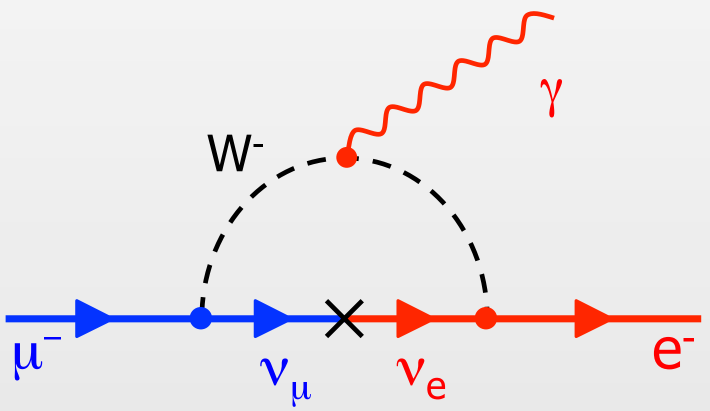
- Physical motivation: Lepton Flavor Violation (LFV)
- The MEG experiment: detector and analysis technique
- Analysis of 2009-2011 data and combined result
  - A new limit on BR($\mu \rightarrow e\gamma$)!
- 2013: the last MEG run in current configuration
- The MEG upgrade: how to improve $\mu \rightarrow e\gamma$ sensitivity down to 5×10^{-14}!

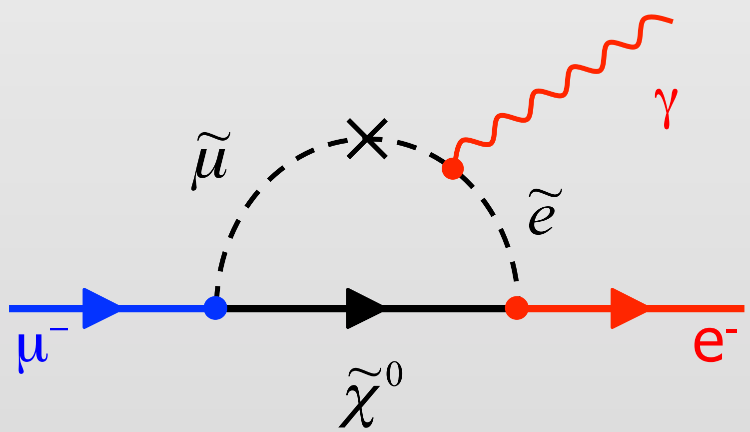
Physical motivations

Exploring (and understanding) a new world...

$\mu \to e\gamma$ strongly suppressed in SM with neutrino oscillations: $BR(\mu \to e\gamma) < 10^{-50}$.

Same decay enhanced in new physics scenarios by loop diagram with new particles exchange: $BR(\mu \to e\gamma) \sim 10^{-12} \div 10^{-14}$ strongly depending on parameters.





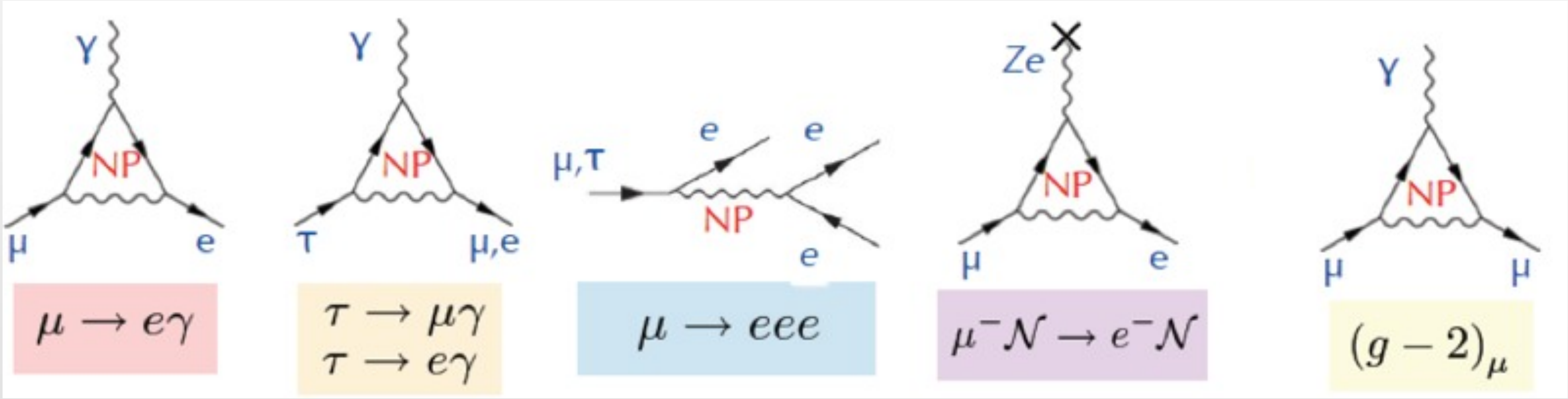
just an example: slepton mixing

No contamination from Standard Model processes

A powerful probe for NP!

Lepton Flavor Violation

A lot of cLFV processes sensitive to New Physics



μ,τ anomalous decay

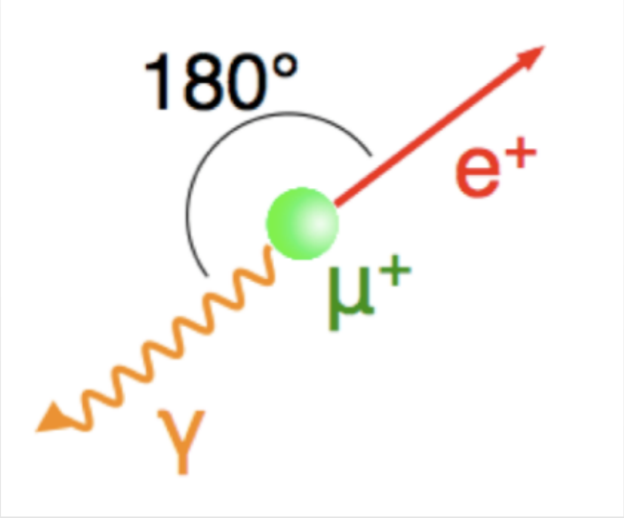
μ→e conversion

anomalous magnetic moment

- Complementary processes to define the nature of new physics
- Among them, MEG is a "golden channel"
  - small mass, long life
  - high intensity μ beam are easily produced
  - μ→eγ channel can put strong constraint on new theories parameters

MEG: signal and background

Signal

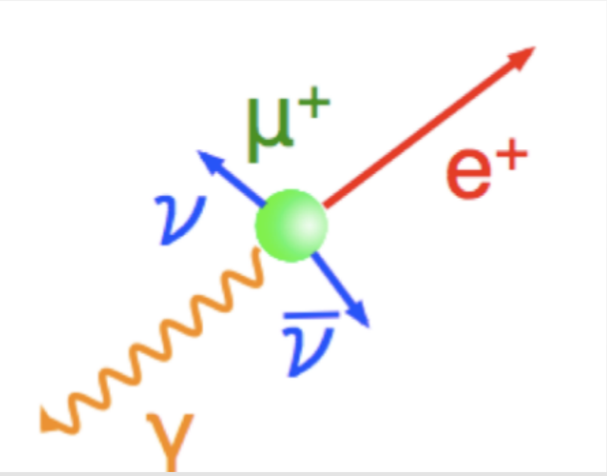


2 bodies final state

$$E_\gamma = E_e = \frac{m_\mu}{2} = 52.8MeV$$
$$\Delta t_{e\gamma} = 0$$
$$\theta_{e\gamma} = \phi_{e\gamma} = 180°$$

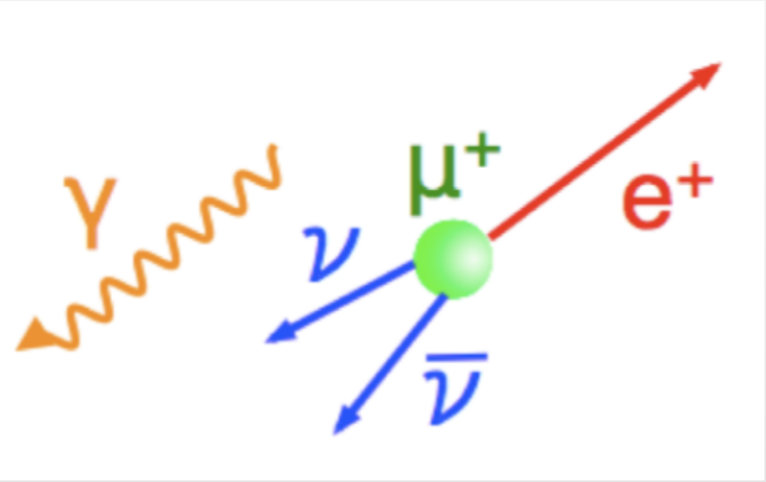
Background

Correlated



radiative μ decay

Accidental



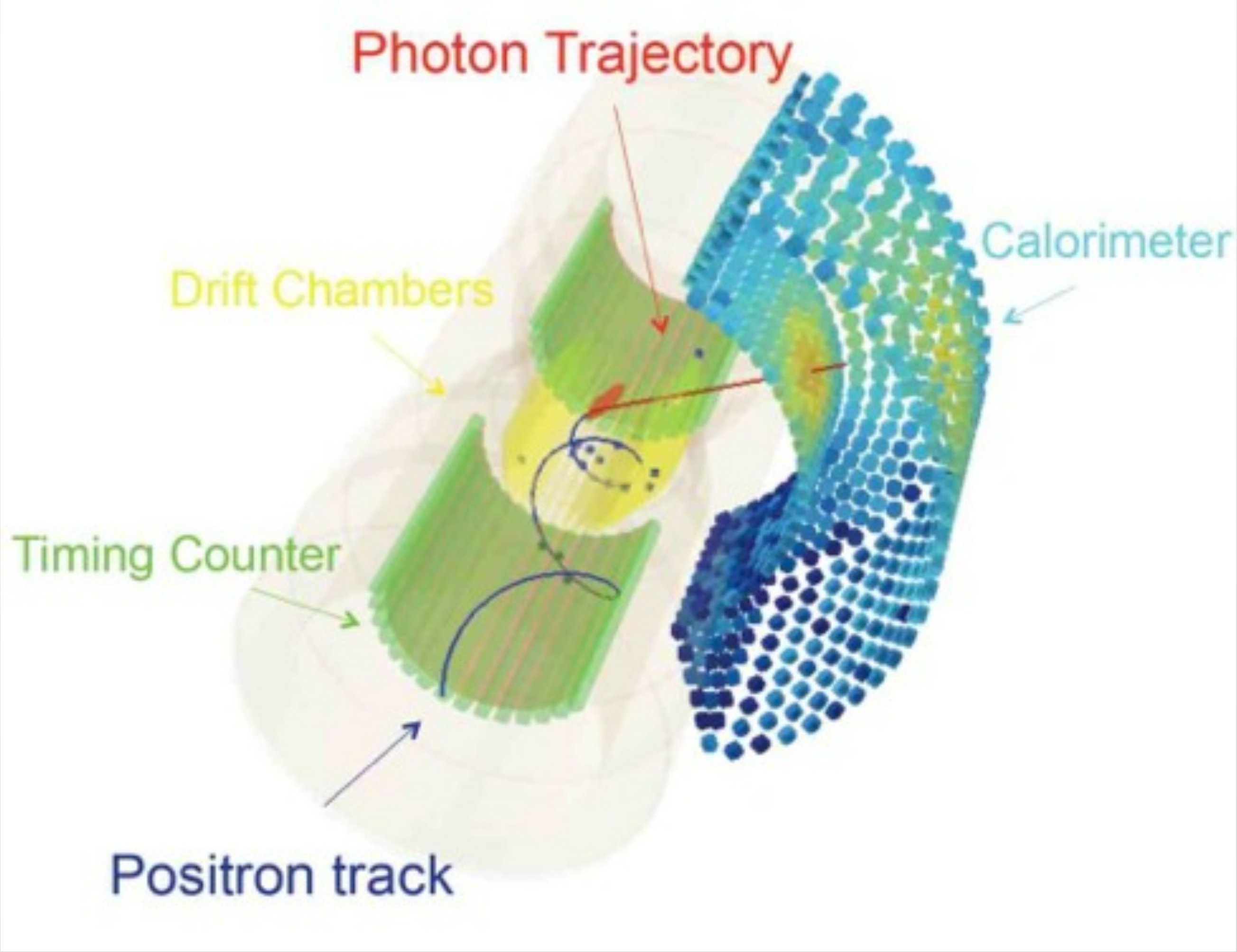
Michel decay +
γ from other processes

$$R_{rad} \simeq R_\mu \times BR(\mu \to e\nu\bar{\nu}\gamma)$$
$$R_{acc} \simeq R_\mu^2 \sigma^2(E_\gamma)\sigma^2(\Omega_{e\gamma})\sigma(t_{e\gamma})\sigma(E_e)$$

The accidental background is dominant and determined by detector resolutions.

Experimental apparatus

- High rate continuous beam ~ 3×10^7 μ/s focused on a thin plastic target inside a superconductive solenoid magnet (COBRA).
- Positron momentum is measured by a Drift Chambers system positioned inside magnetic field, then time is reconstructed by Timing Counter.
- γ time and momentum reconstructed in a Liquid Xenon Calorimeter.
- Trigger based on TC and LXe information.
- Signals are sampled with a PSI custom digitizer board (DRS)



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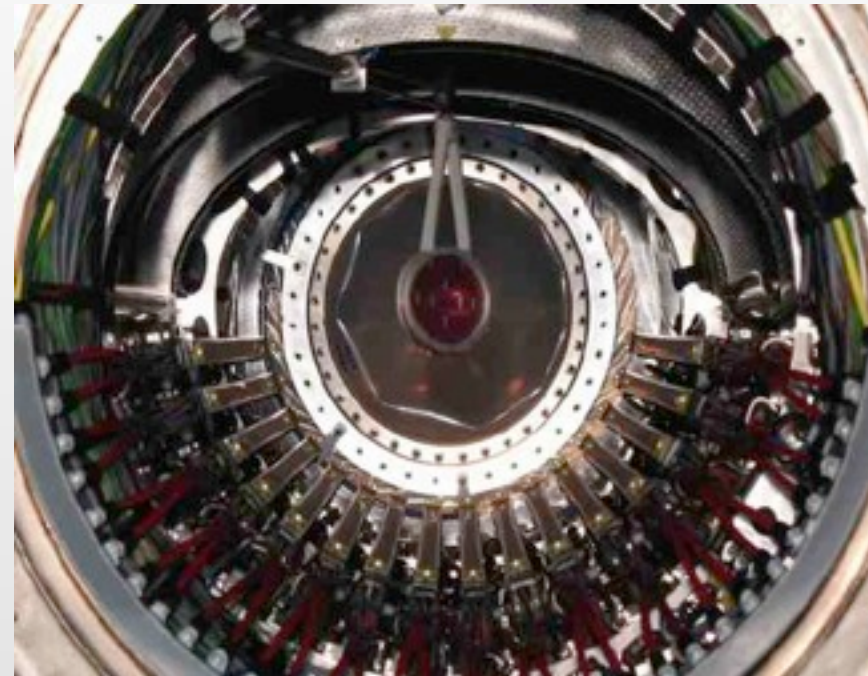
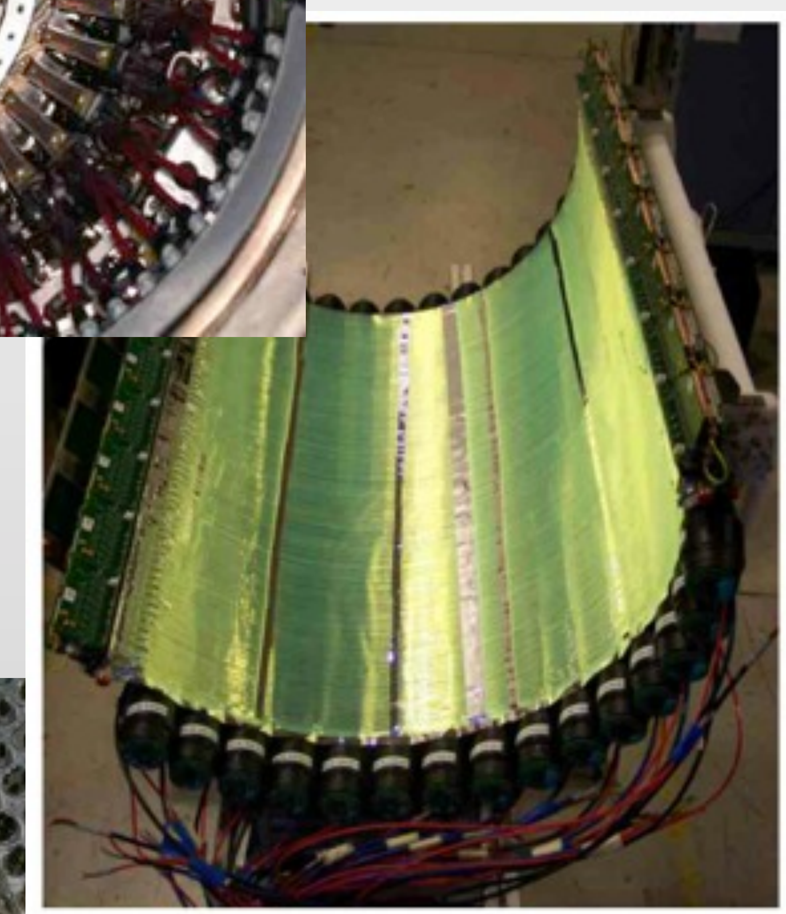
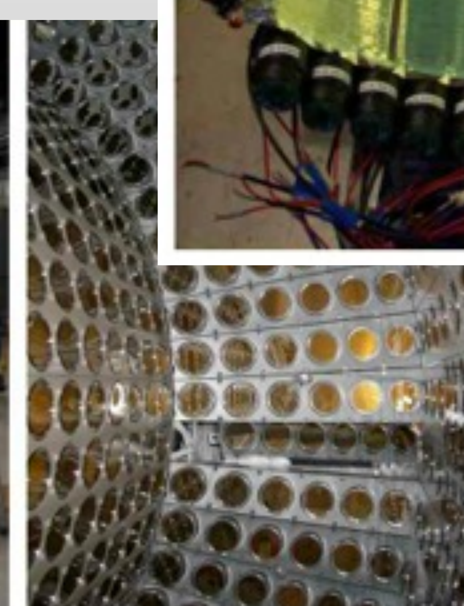





Calibrations (a lot of...)

LXe calorimeter:

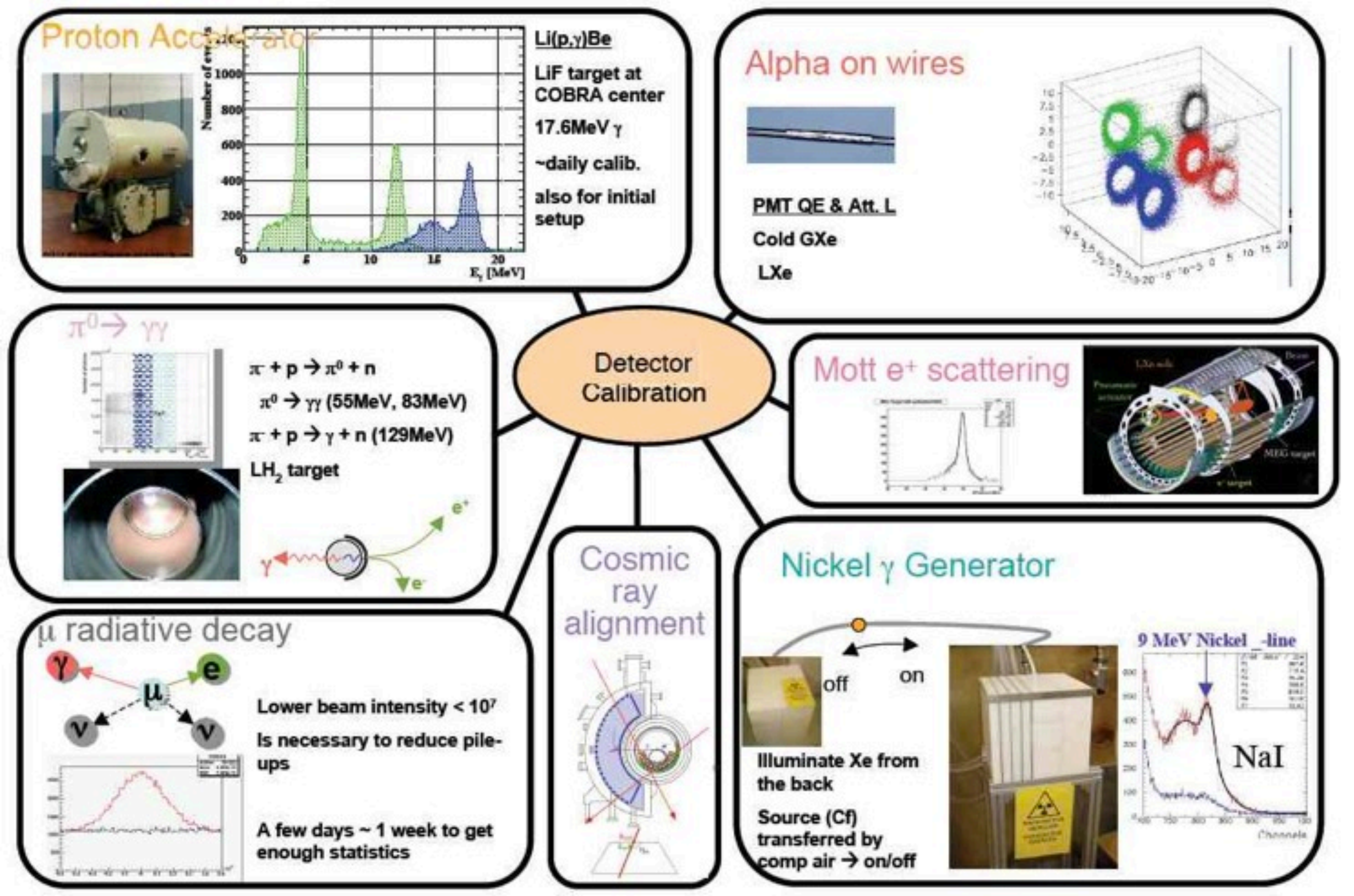
- π^0 dedicated run
- monochromatic γs from CW accelerator
- LED & α sources
- 9 MeV line from Ni neutron capture

Drift Chamber

- Michel data
- Mott data
- cosmic rays

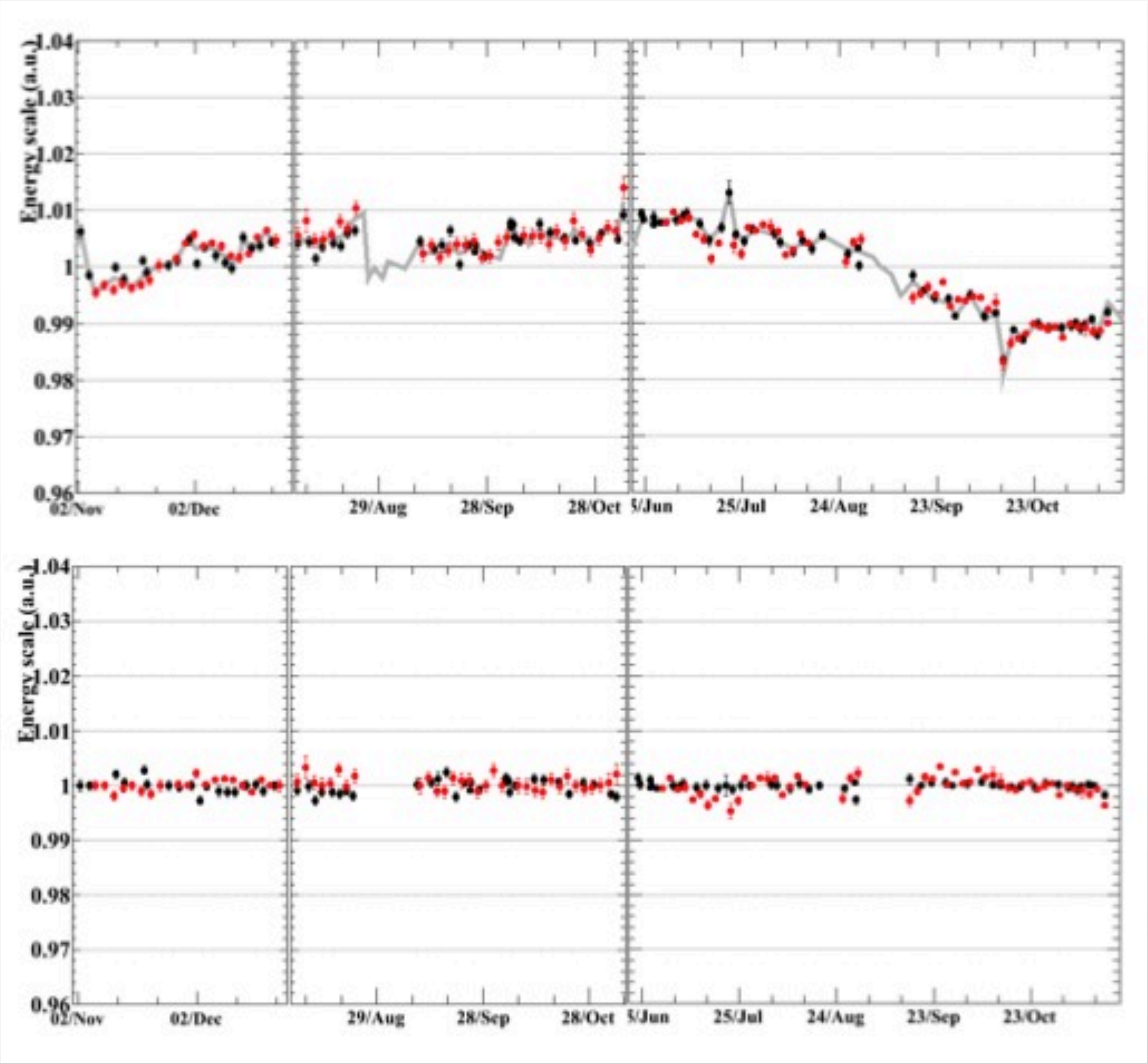
Timing Counter

- Michel data
- π^0 data
- cosmic rays



Full set of (periodic) calibrations for: energy scale resolution, detectors time and space alignment, calorimeter light yield and much more..

Example: XEC energy scale

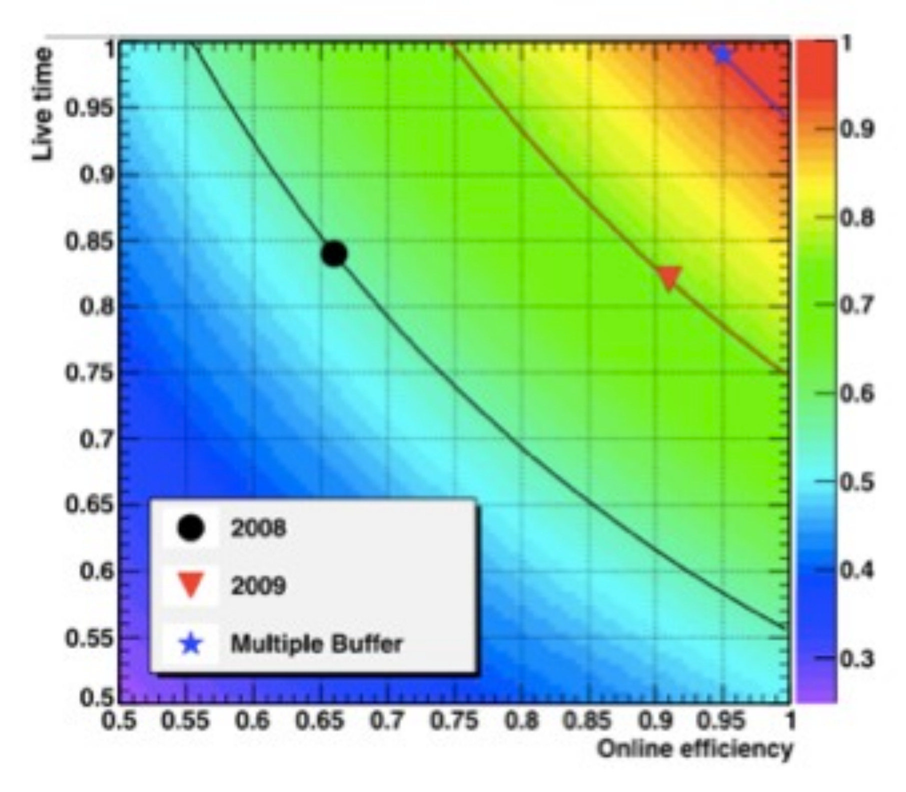


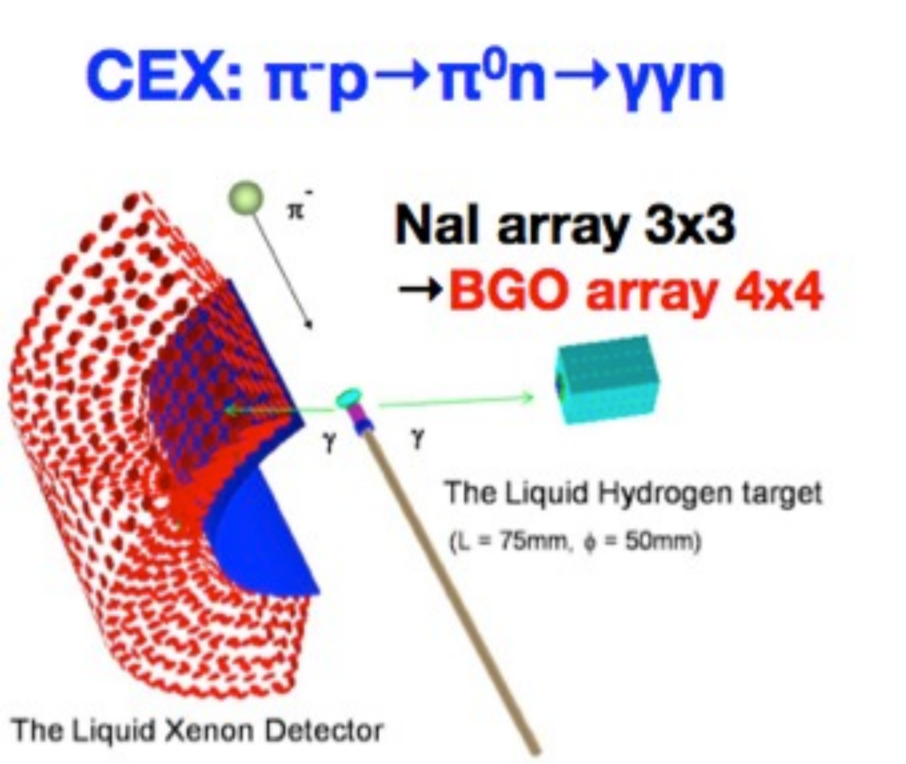
γ energy scale before and after calibration over a 3 years run 2009-2011(scale)

RMS < 0.2%

What's new in 2011

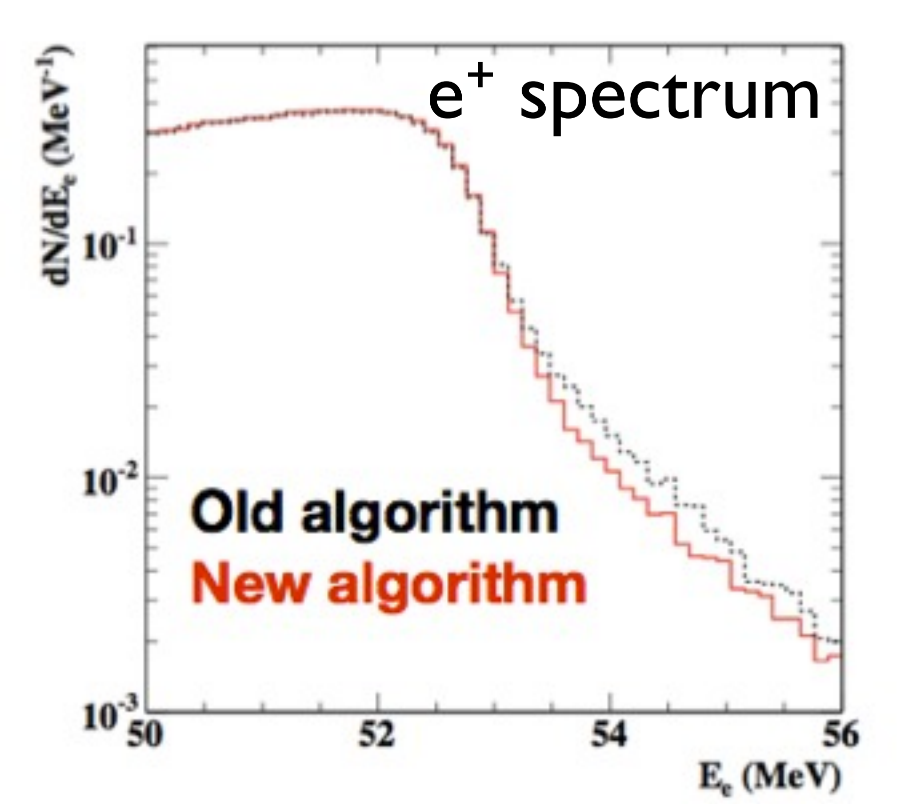
- HW improvements:
  - Higher trigger and DAQ efficiency (multiple buffer readout)
  - Better LXE calibration with CEX thanks to a new higher resolution BGO array auxiliary detector
  - New DCH optical survey technique with laser tracker

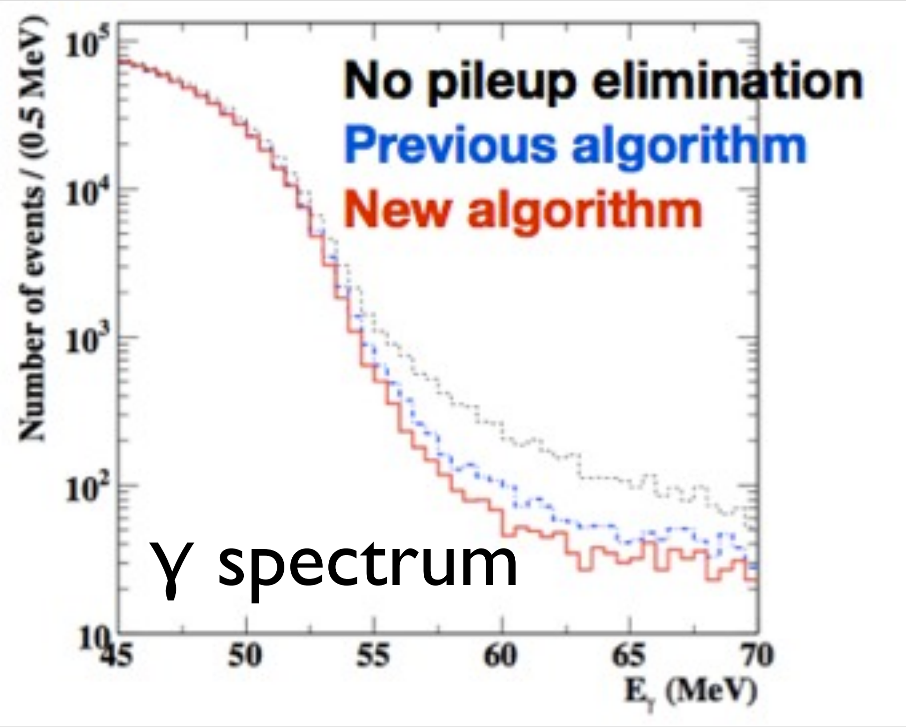




What's new in 2011

- SW improvements:
  - e-side: new Kalman filter; DCH noise reduction with FFT offline analysis
  - γ-side: improved pile-up rejection method
  - Improvements applied on 2011 data and 2009-2010 re-analysis





Data analysis

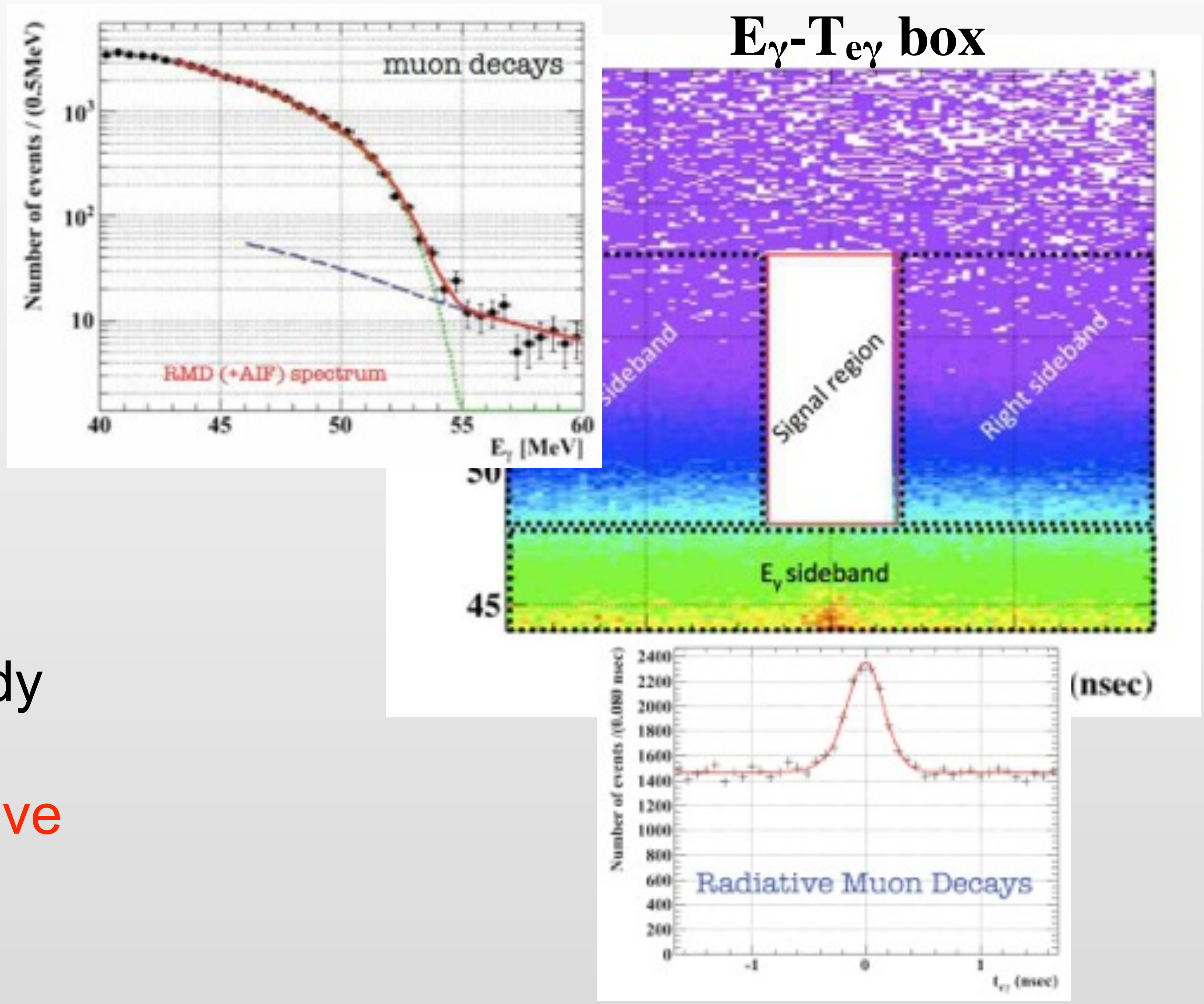
Blind analysis

PDF for signal and background extrapolated from sideband data and calibration run.

Left/Right sideband: accidental
Energy sideband: RMD

Extensive MC simulation for background study

Likelihood built as a function of signal, radiative decay and accidental events number and PDFs:



$$\mathcal{L}(N_{\mathrm{sig}}, N_{\mathrm{RMD}}, N_{\mathrm{BG}}) = \frac{e^{-N}}{N_{\mathrm{obs}}!} e^{-\frac{(N_{\mathrm{RMD}}-\langle N_{\mathrm{RMD}}\rangle)^2}{2\sigma^2_{\mathrm{RMD}}}} e^{-\frac{(N_{\mathrm{BG}}-\langle N_{\mathrm{BG}}\rangle)^2}{2\sigma^2_{\mathrm{BG}}}} \times \prod_{i=1}^{N_{\mathrm{obs}}} \left(N_{\mathrm{sig}} S(\vec{x}_i) + N_{\mathrm{RMD}} R(\vec{x}_i) + N_{\mathrm{BG}} B(\vec{x}_i)\right)$$

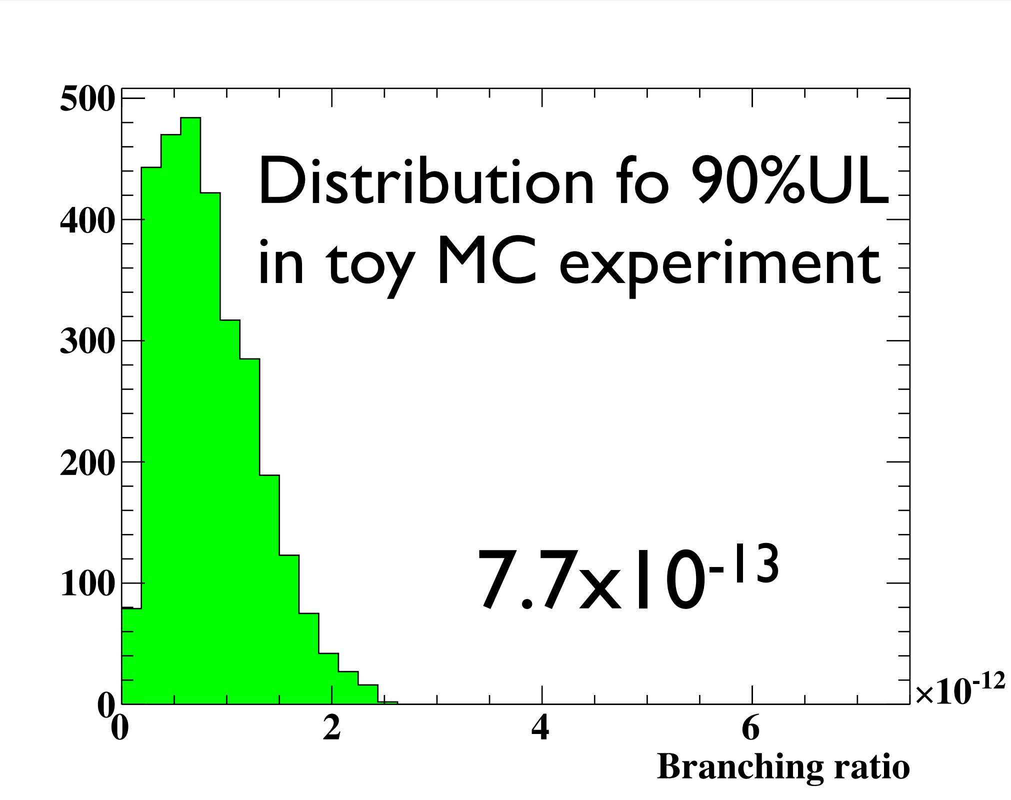
gaussian constraints from sideband analysis

N_{SIG}, N_{RMD} and N_{BG} are counted simultaneously with an unbinned fit over the analysis region.

Sensitivity

- Sensitivity is defined as the upper limit calculated over a set of toy MC experiments with background only hypothesis, using background expectations from sideband analysis.
- We have a 20% improvements in same sample 2009-2010 with new algorithms

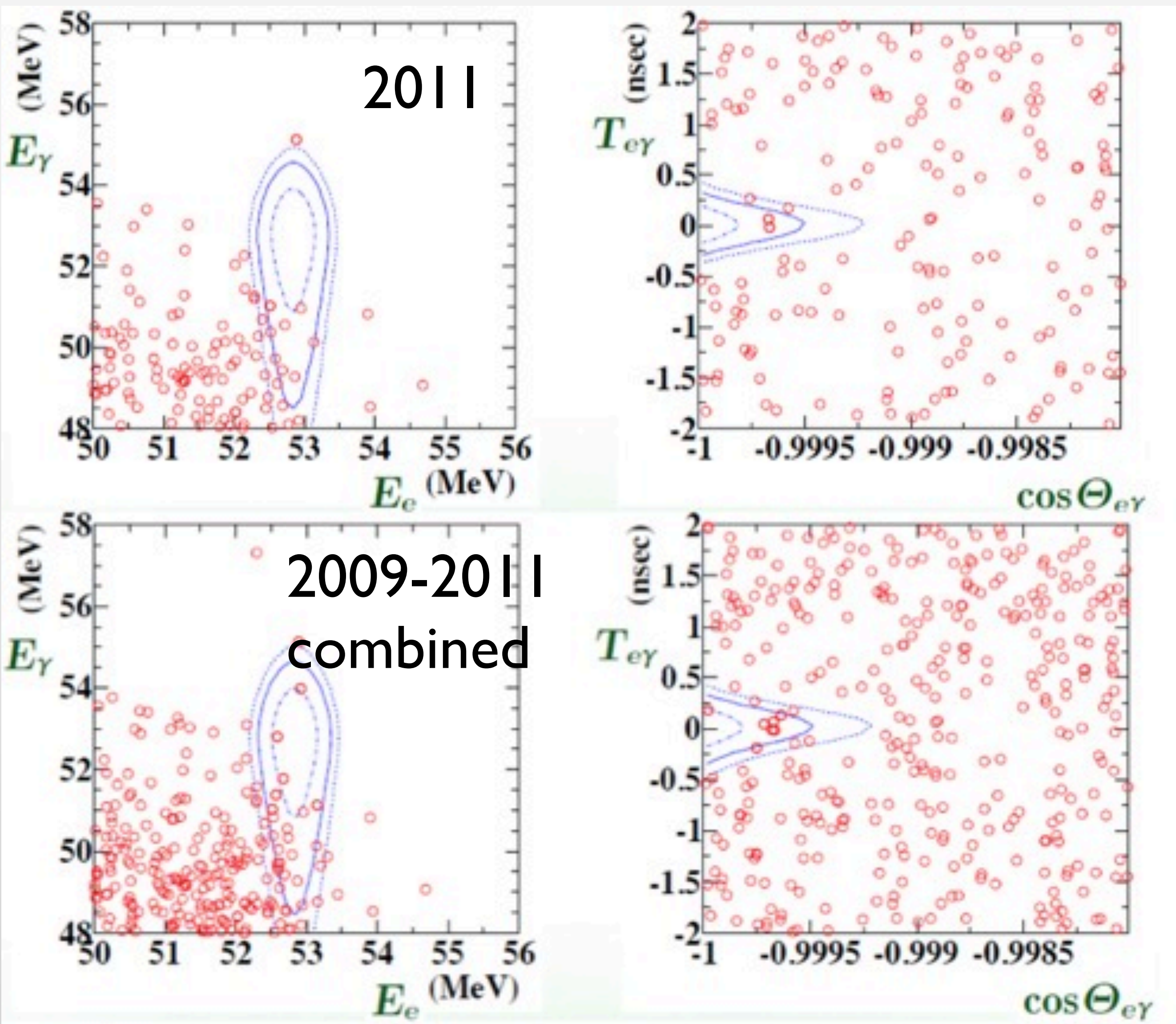
data set	μ+ stopped	sensitivity
2009-2010	1.75×10^{14}	1.3×10^{-12}
2011	1.85×10^{14}	1.1×10^{-12}
combined	3.60×10^{14}	7.7×10^{-13}



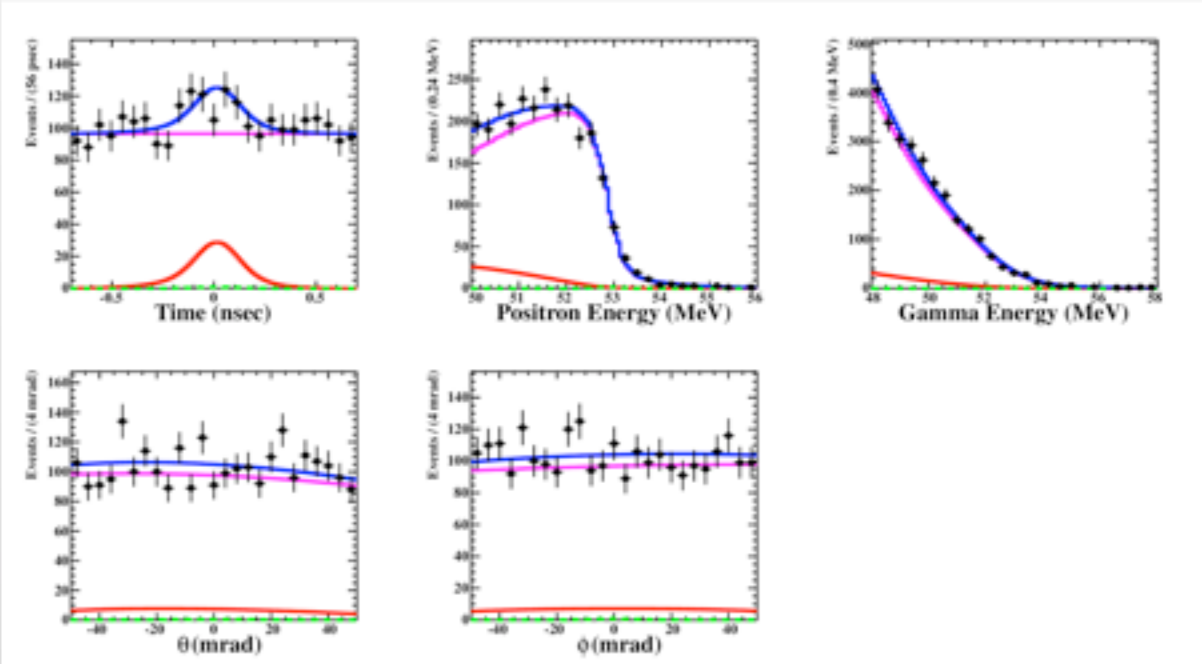
Finally MEG reached $O(10^{-13})$ sensitivity!

Open the box...

Events distribution: cuts on not shown variables



Likelihood fit 2009-2011 combined



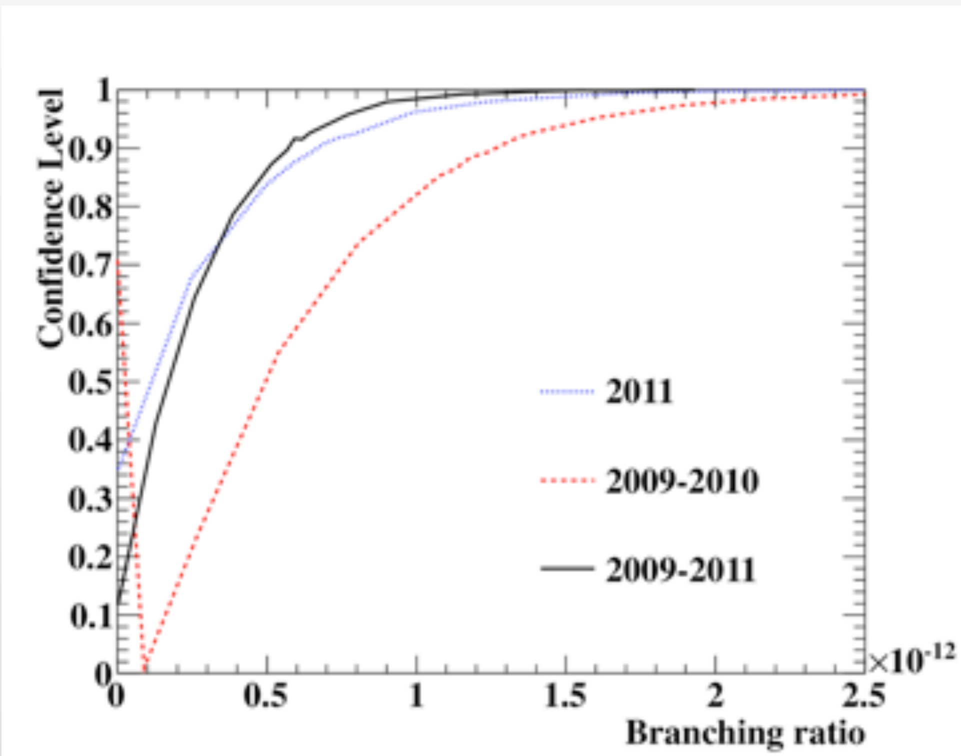
2009-2011

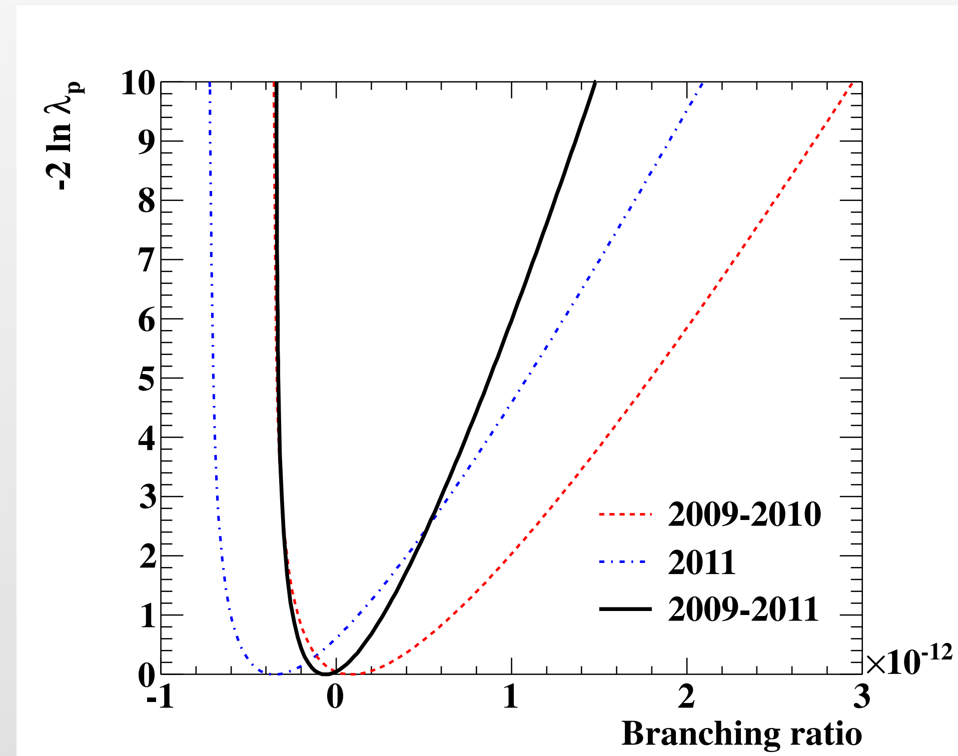
Nsig best fit: $-0.4^{+4.8}_{-1.9}$

No excess is observed in all samples.

Confidence interval

Frequentistic analysis, Feldmann-Counsin method





Branching ratio $\mu \to e\gamma < 5.7 \times 10^{-13}$ @90 C.L.

summary of all data sample

Data set	$\mathcal{B}_{fit} \times 10^{12}$	$\mathcal{B}_{90} \times 10^{12}$	$\mathcal{S}_{90} \times 10^{12}$
2009–2010	0.09	1.3	1.3
2011	−0.35	0.67	1.1
2009–2011	−0.06	0.57	0.77

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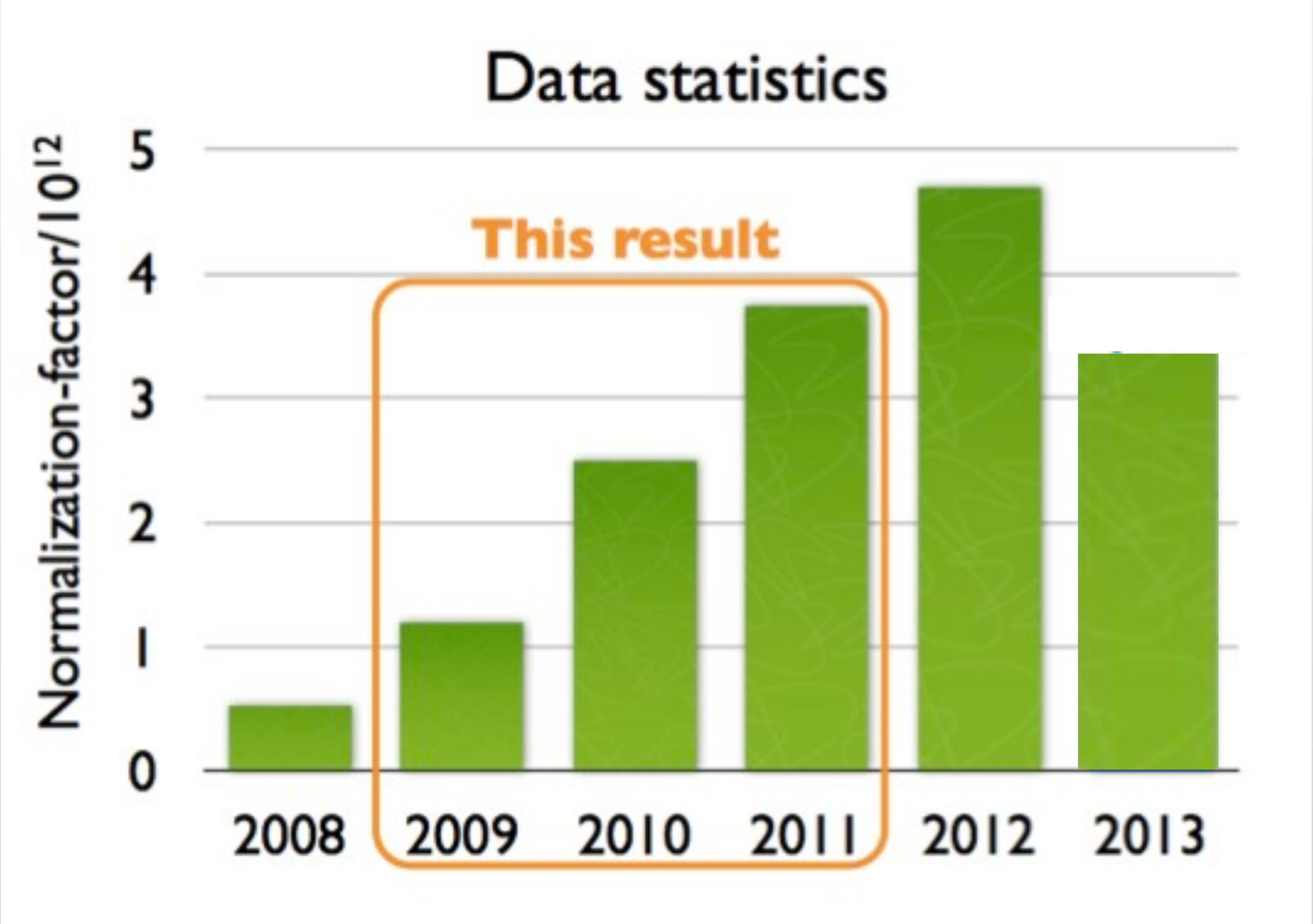
x4 more stringent than the previous upper limit
BR($\mu \to e\gamma$) < 2.4×10^{-12} (MEG2009-2010)

x20 more stringent than the MEGA limit
BR($\mu \to e\gamma$) < 1.2×10^{-11} (MEGA)

Run 2012, 2013 and more

- The analysis showed in this talk refers to 2009-2011
- MEG has taken data also in 2012 and 2013, increasing its statistics by a factor 2. Analysis is ongoing. Expected sensitivity is $5x10^{-13}$

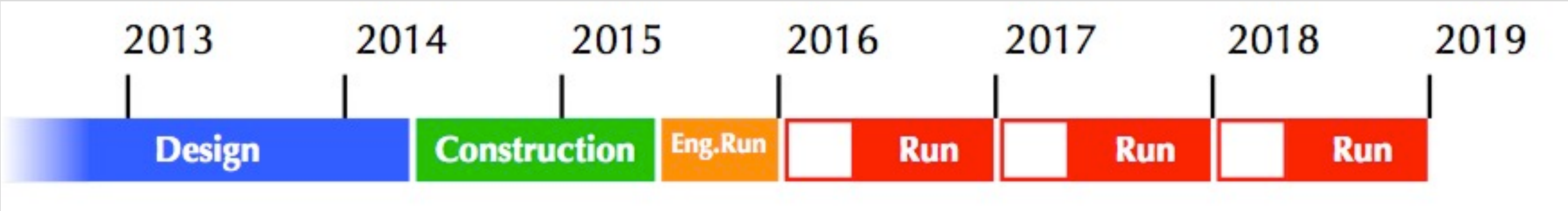


- MEG has saturated its sensitivity with 2013 data
- 2013 was last year for MEG DAQ with current configuration

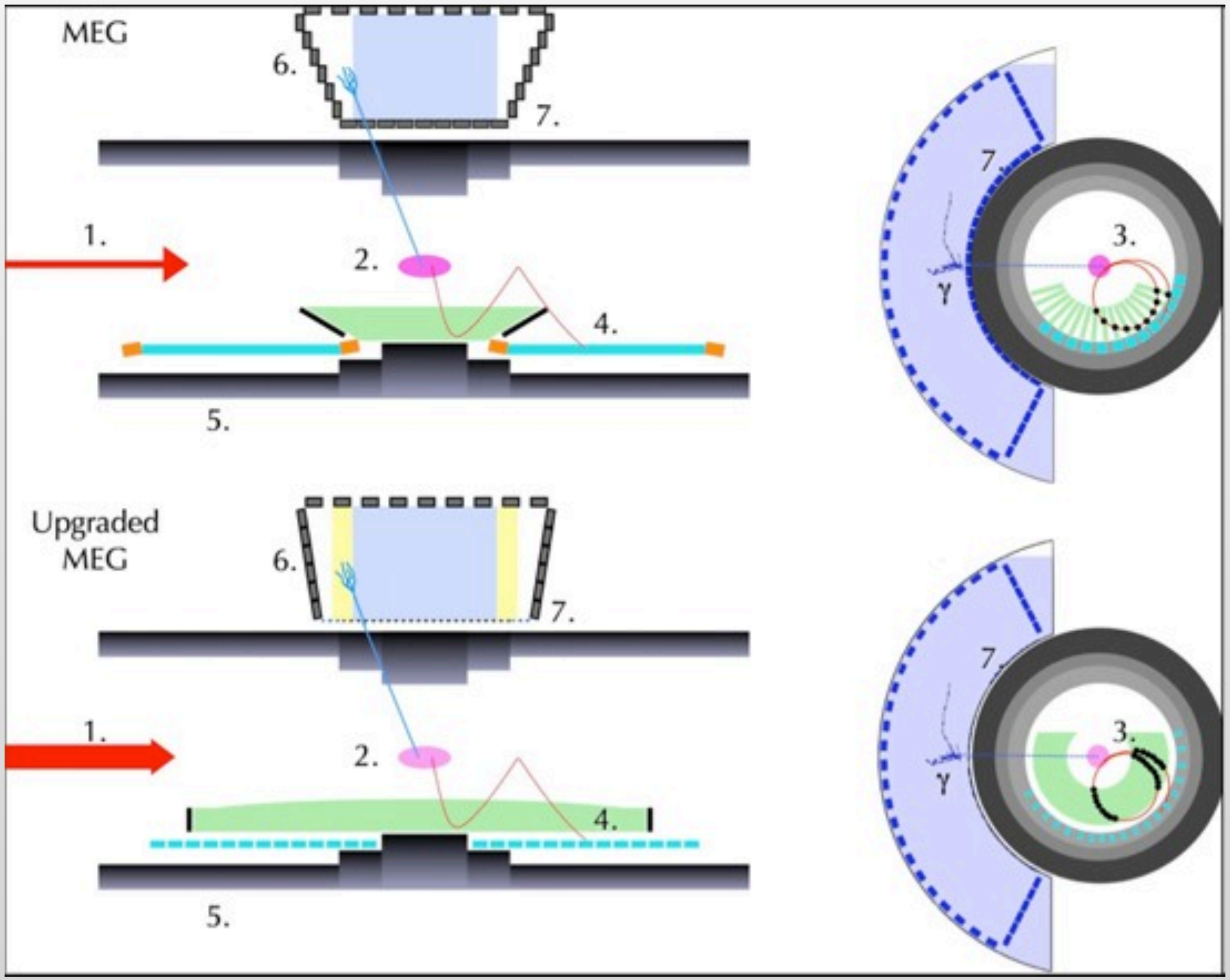
And now? ...MEG II

- It is possible to improve MEG sensitivity by 1 order of magnitude down to 5×10^{-14} with a re-design of some parts of the detector.
- It can be done in a reasonable time schedule (physics data expected from 2016), making the best usage of existing:
  - infrastructure: beam line, magnet, cryostat, calibration (CW)
  - knowledge accumulated in these 12 years of MEG
  - expertise inside the collaboration

- MEG II is already approved and funded by Italian, Swiss and Japanese funding agencies



Upgrade concept



1. Higher beam rate (statistic)

2. Thinner target (less background)

3. Higher DC granularity to have more point for a better track reconstruction (positron resolution)

4. Shorter path from last DC point to Timing Counter (time resolution)

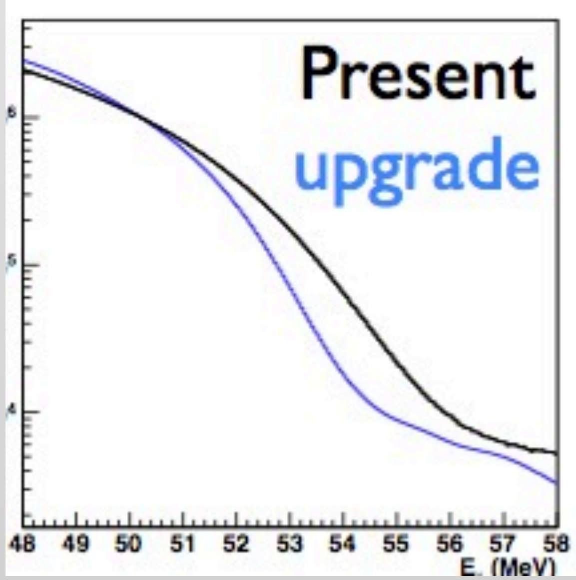
5. Segmented Timing Counter for better matching with DC volume and multiple hit timing method (time resolution)

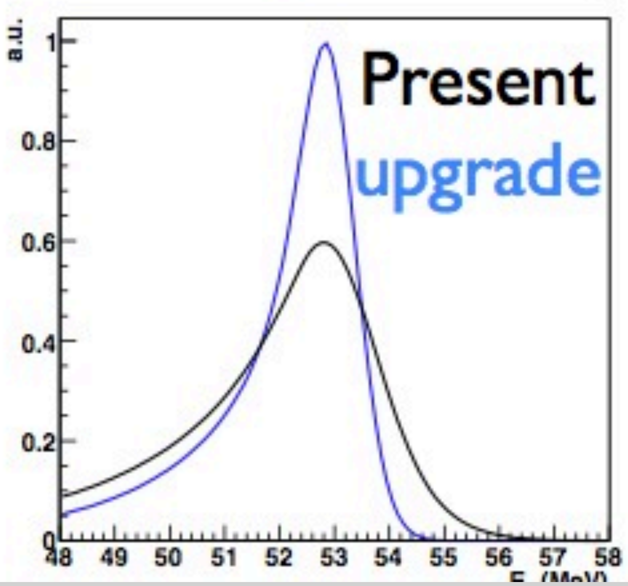
6. Different Calorimeter shape inside existing cryostat

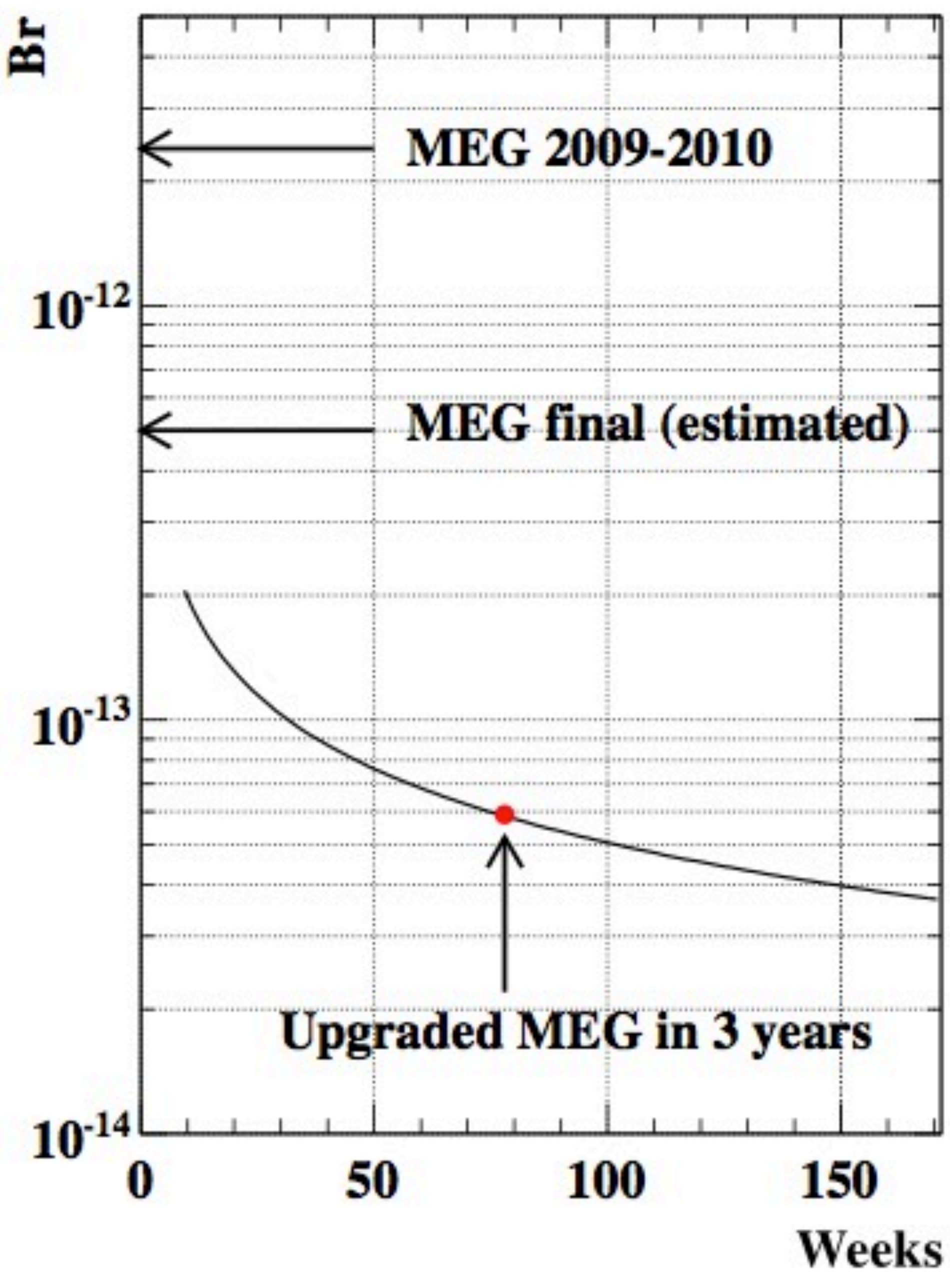
7. Higher inner face granularity with new read-out devices (SiPMs) for better energy reconstruction and pile-up rejection

Expected sensitivity

PDF parameters	Present MEG	Upgrade scenario
$\sigma_{E_{e^+}}$ (keV)	380	110
e^+ σ_θ (mrad)	9	5
e^+ σ_ϕ (mrad)	11	5
e^+ σ_Z / σ_Y(core) (mm)	2.0/1.0	1.2/0.7
$\frac{\sigma_{E_\gamma}}{E_\gamma}$ (%) w>2 cm	1.6	1.0
γ position at LXe $\sigma_{(u,v)}$-σ_w (mm)	4	2
γ-e^+ timing (ps)	120	80
Efficiency (%)		
trigger	≈ 99	≈ 99
γ reconstruction	60	60
e^+ reconstruction	40	95
event selection	80	85







Conclusion

- The MEG experiment analyzed data taken in 2009-2011 with a sensitivity of 7.7×10^{-13}

- No excess was , a new limit on BR($\mu \rightarrow e\gamma$) was set: BR($\mu \rightarrow e\gamma$)$<5.7 \times 10^{-13}$ @90% C.L.

- Analysis of last MEG data (2012-2013) is ongoing; we expect to improve our sensitivity down to $\sim 5 \times 10^{-13}$

- An upgrade of the experiment is already started since 2011 aiming to reach 5×10^{-14} sensitivity in a short time schedule: first physics data expected in 3 years from now

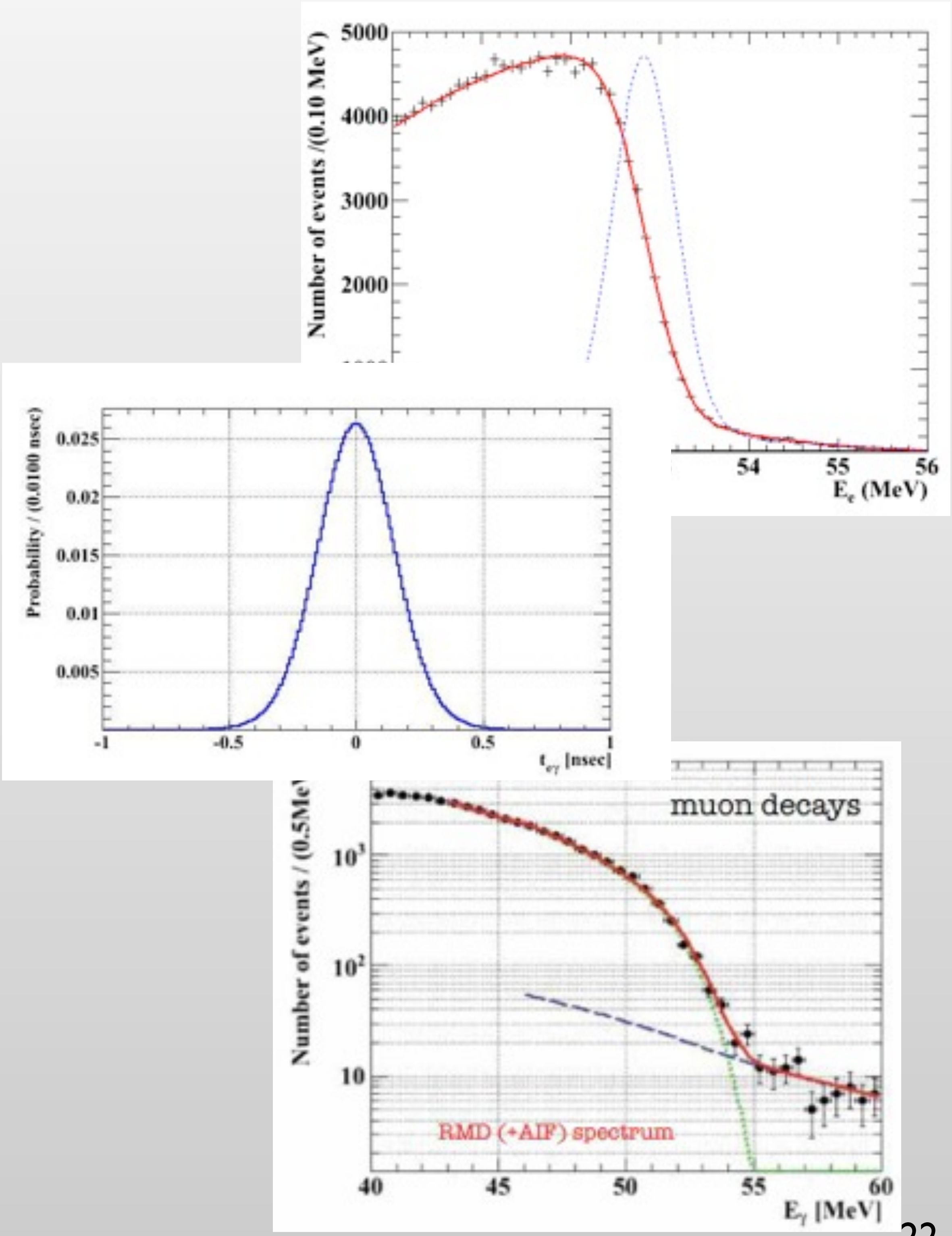
Back up slides

Building PDFs

PDFs are mainly extracted from data: calibrations runs and sideband data.

Signal:

- calibration run: π^0 data, Cockcroft Walton run, Michel edge (γ/e energy and relative angles)
- sideband data: radiative muon decay (timing)



RMD: 3D theoretical distribution folded with measured detector response function. Same time PDF as for signal.

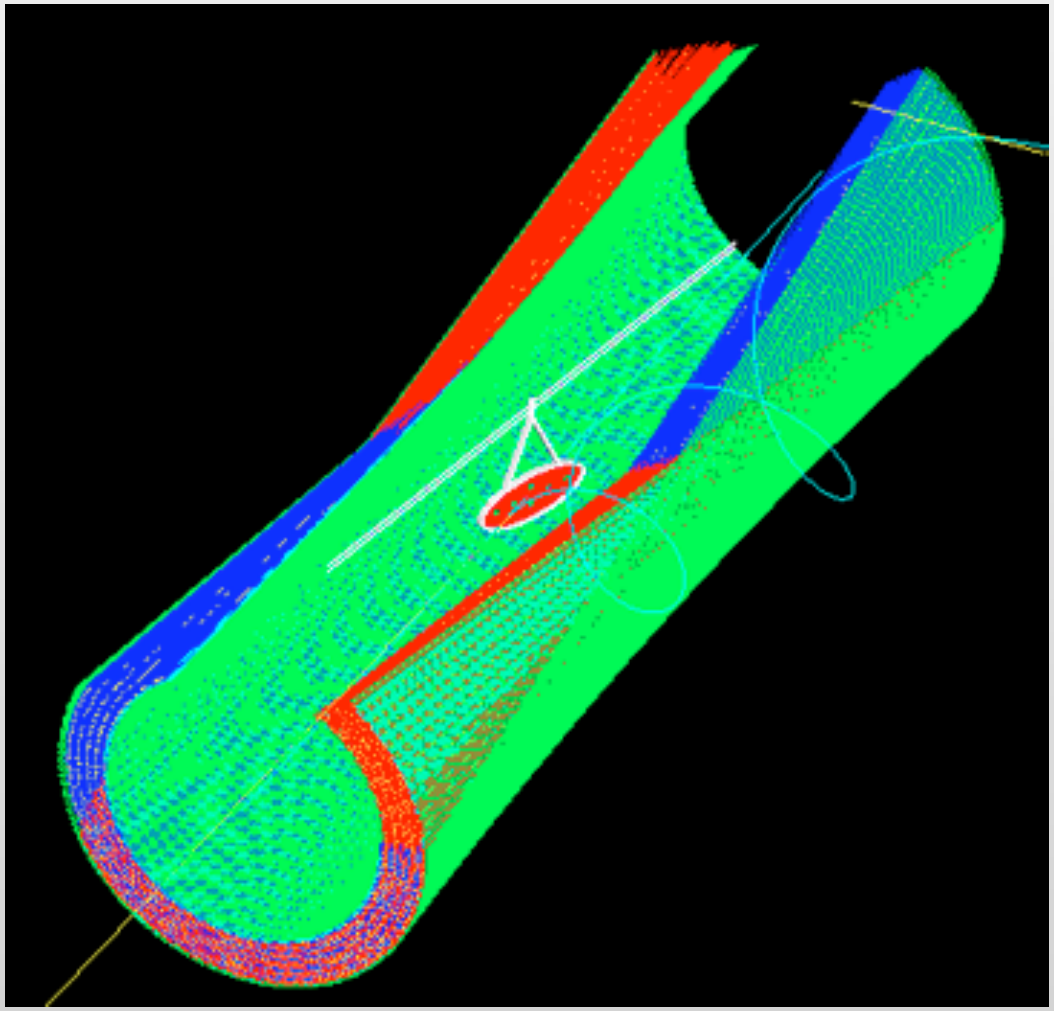
Accidental: sideband data

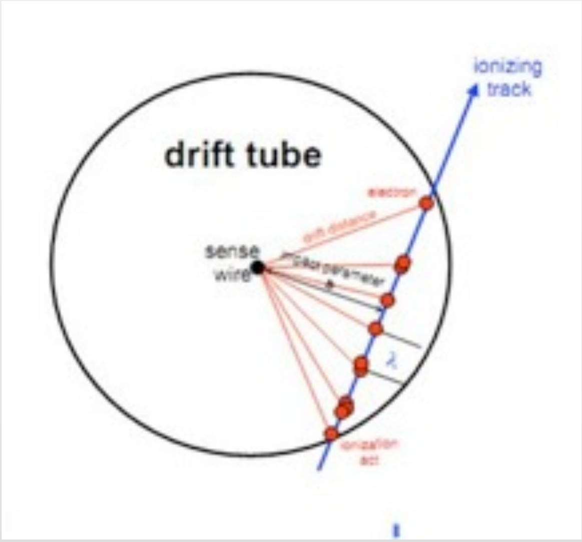
Systematics

	ΔΔNLL	Reference
Center of angles	0.18	γ position : 2.4 mrad for θ and φ
Positron correlations	0.11	The largest contribution is the θ-φ slope uncertainty of 25%; the slope is estimated from the MC.
E_γ scale	0.07	2009:0.33%, 2010:0.31%, 2011:0.32%
E_e bias	0.06	25 keV
$t_{e\gamma}$ signal shape	0.06	Fitting-errors on the RD peak
$t_{e\gamma}$ center	0.05	15 psec
Normalization	0.04	4% (relative)
E_γ signal shape	0.03	Fitting-errors on CEX 55 MeV peak
E_γ BG shape	0.03	Fitting-errors on sideband data
Positron angle and position resolutions	0.03	
γ angle resolutions	0.03	0.3 mm in (u, v) and 0.7 mm in w
E_e BG shape	0.01	Fitting-errors on Michel spectrum
E_e signal shape	0.01	Fitting-errors on Michel spectrum
Angle BG shape	0.00	Fitting-errors on sideband data
Total	0.25	

MEG Upgrade: Drift Chamber

- Unique volume, low mass gas detector.
- Cell size 7x7 mm^2, with stereo angle (~7°) between wires.
- Fast electronic allowing cluster timing tecnique for improved hit resolution.
- Less material: multiple scattering for e^+ and background γs reduced





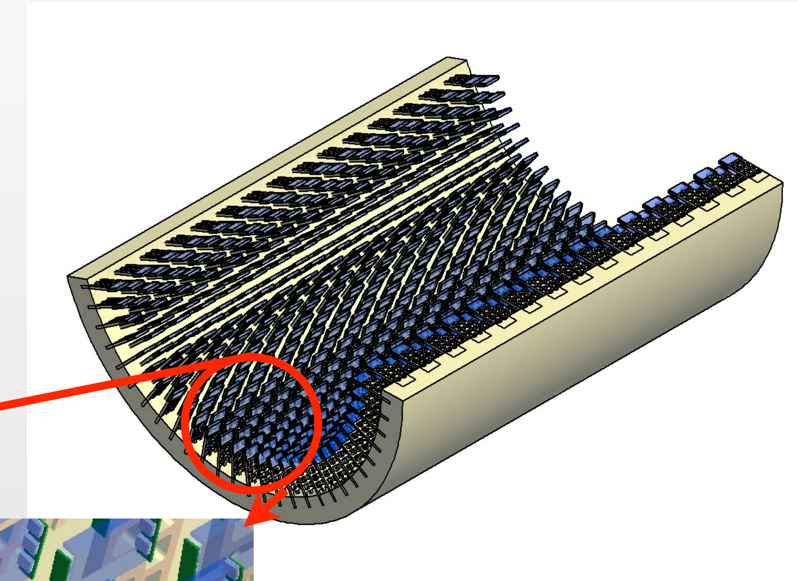
cluster timing: reduce bias in impact parameter estimation by using infos from all ionization clusters

R&D status:

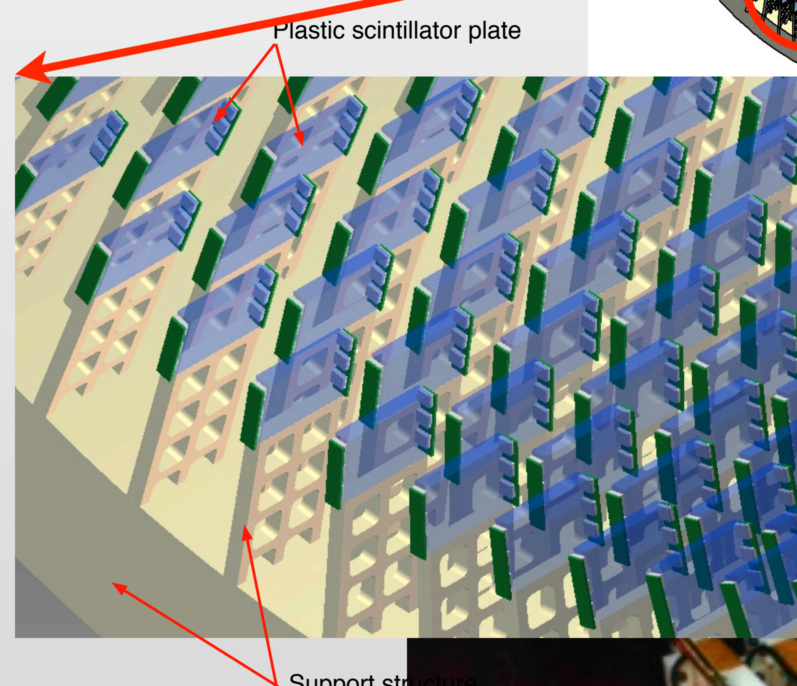
- Some prototype for ageing and time resolution measurement already built, under test
- Front-end electronic prototype successfully tested

MEG Upgrade: Timing Counter

- Small (90x40x4 mm³) scintillating pixels read out by SiPM from both ends.
- Reduced path length inside scintillator - better single hit resolution
- Lower hit rate and pile-up



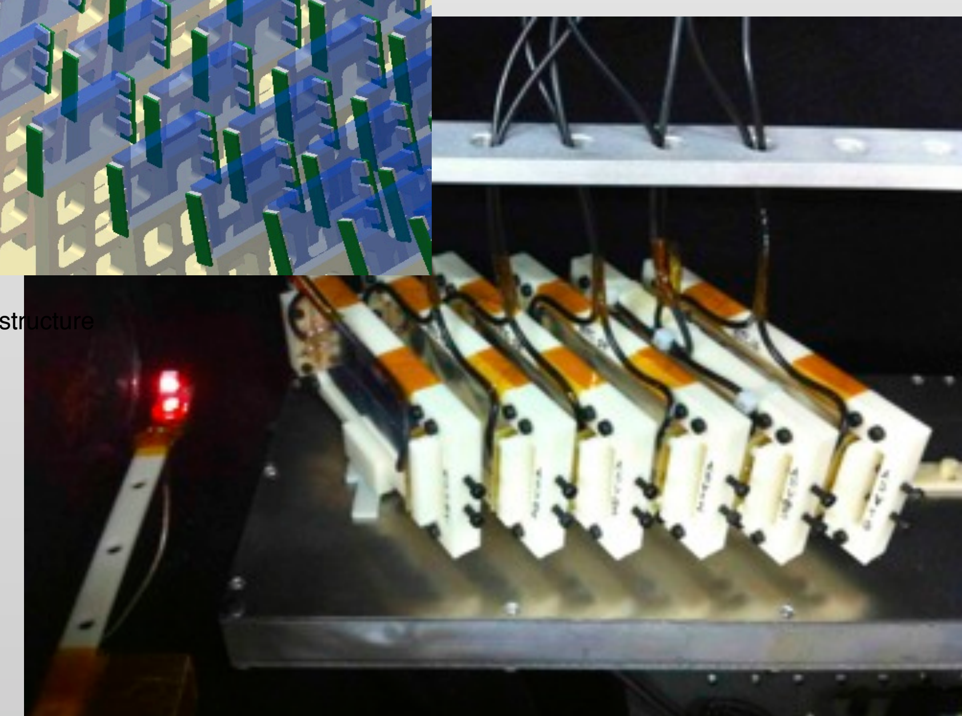
Expected improvement with multiple hit



$$\sigma_T^2 = \frac{\sigma^2_{single}}{N_{hit}} + \frac{\sigma^2_{interpixel}}{N_{hit}} + \sigma^2_{MS}(N_{hit})$$

R&D status:

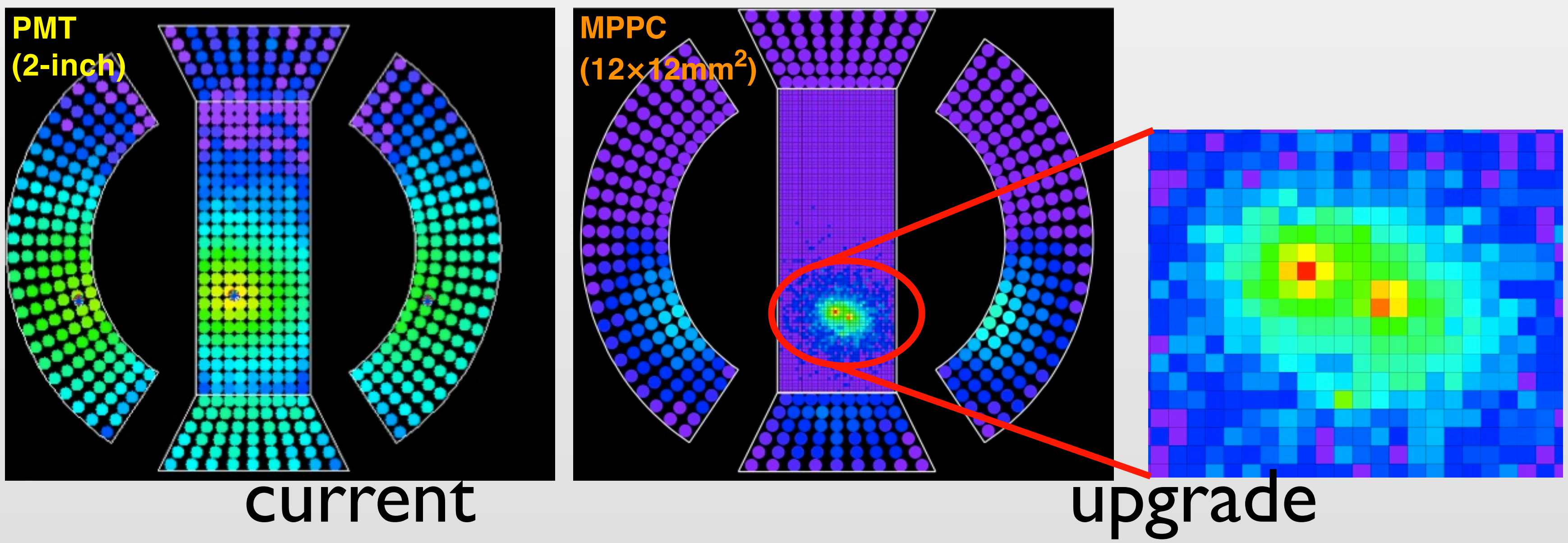
- Choice of best scintillator, SiPMs, geometry
- Small prototype (8 pixels) built and tested at BTF @Frascati (Rome) with 50MeV e-: we obtained a time resolution of ~40ps with 4 hits

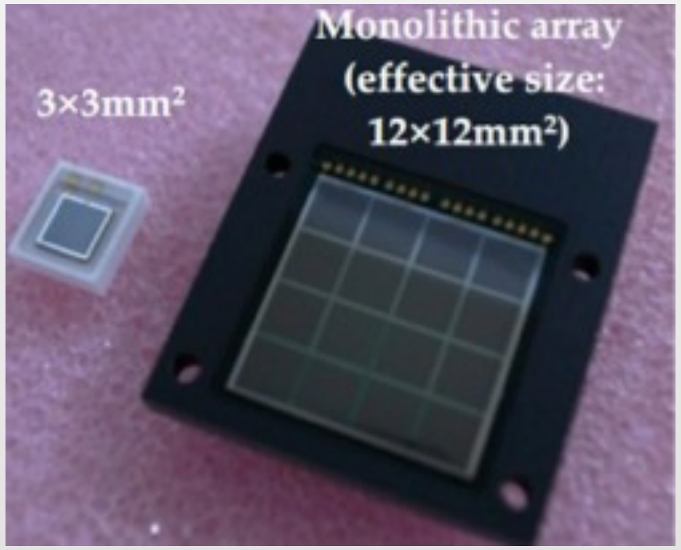


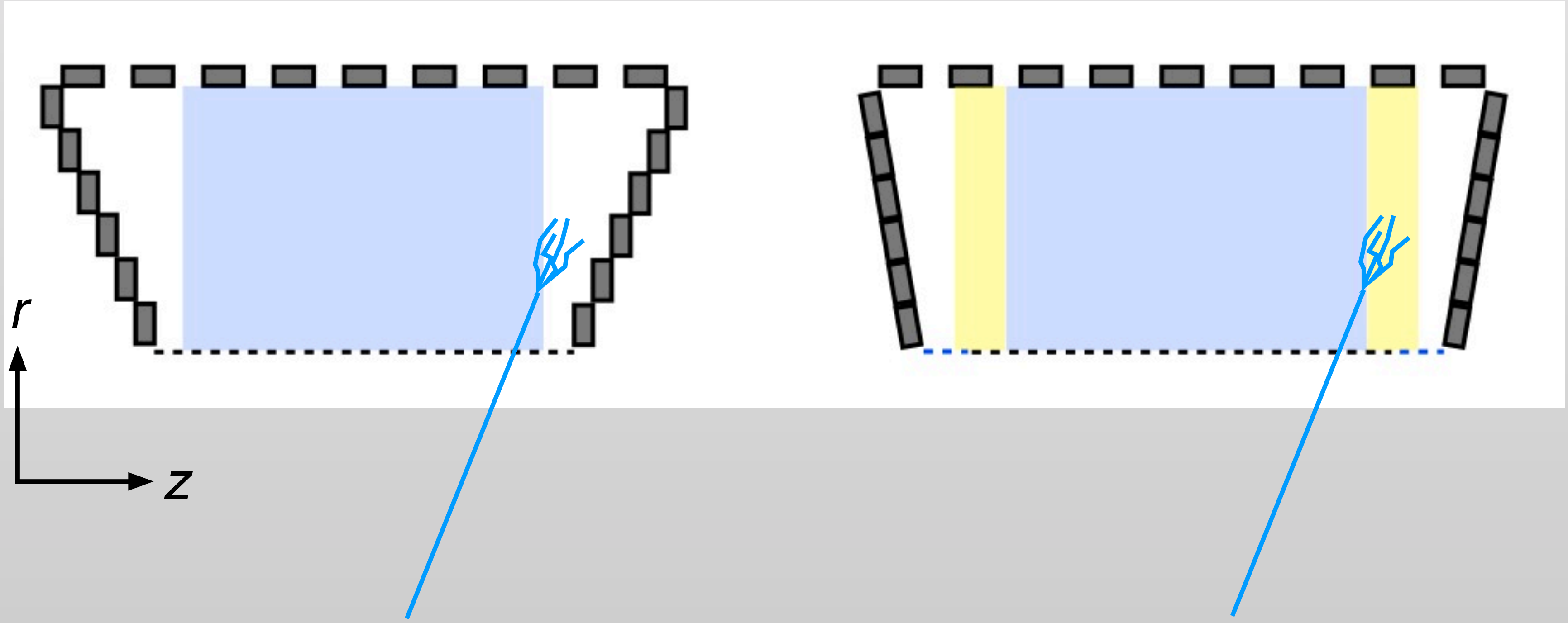
prototype under test

MEG Upgrade: LXe Calorimeter

- Replace current inner face PMTs with smaller sensors (SiPMs)
- Possible re-arrangement of lateral PMTs
- More uniform coverage - better position and energy resolutions







R&D status:

- Monolithic array $12x12mm^2$ successfully developed w/ Hamamatsu
- Test facility and protoype for further studies: readout of multiple channels in “experimental like” conditions