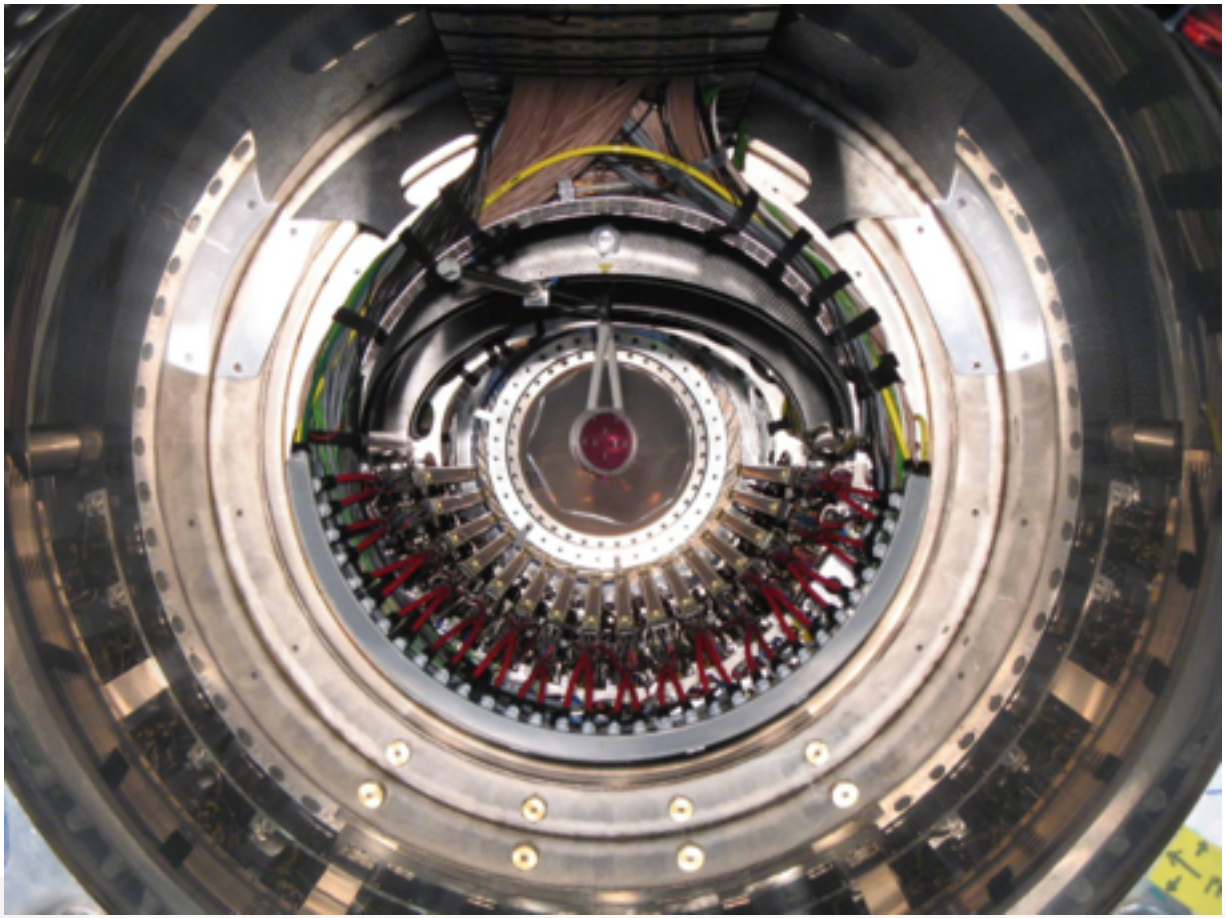
The MEG experiment result and the MEGII status



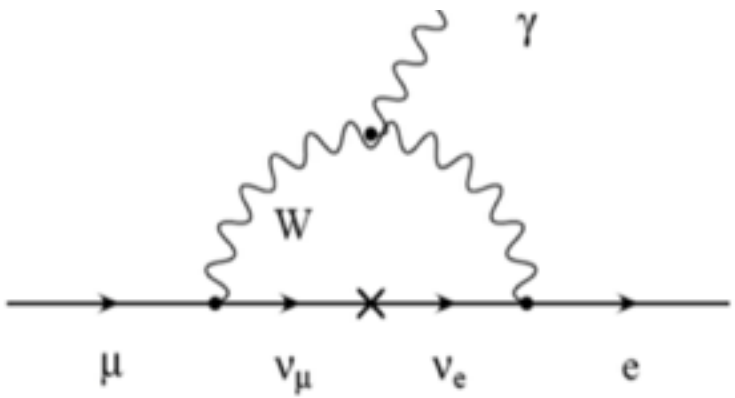
Luca Galli, INFN Sezione di Pisa

ICHEP 2016 - Chicago 05-08-2016

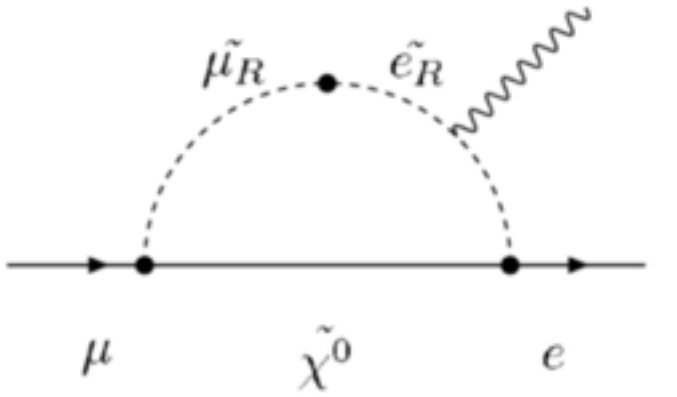
charged Lepton Flavour Violation (cLFV)

- **LFV observed** in the **neutral** sector but **not** in the **charged** one (yet)
  - ***"accidentally"*** *due to* ***tiny*** *neutrino* ***masses*** *compared to* ***electroweak energy scale***
    - **cLFV signal** would **definitely** be due to **BSM physics**

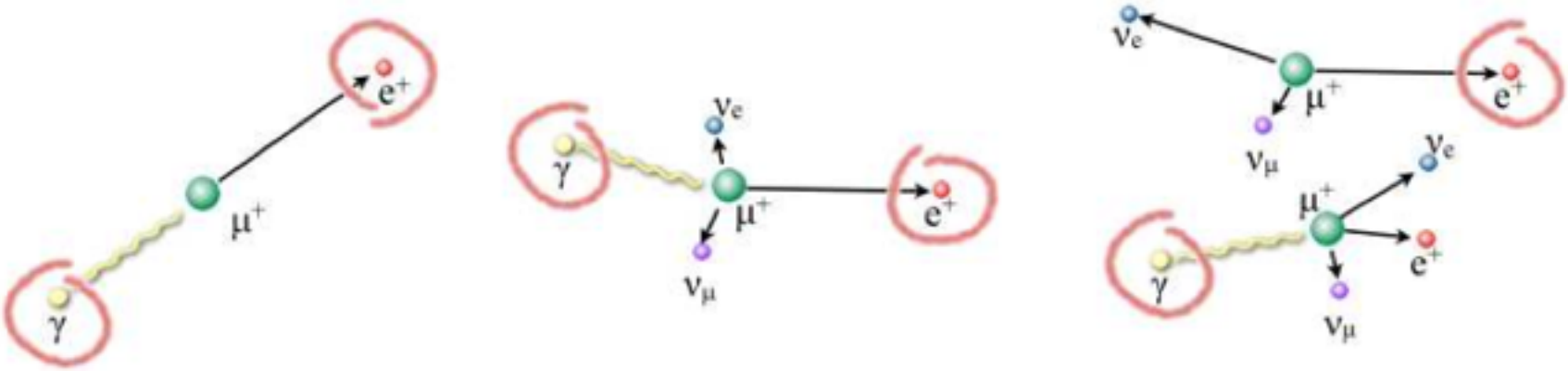
$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M_W^2}\right|^2 \simeq 10^{-54}$$



$$B(\mu \to e\gamma) = (1 \times 10^{-11}) \times \left(\frac{2\,\text{TeV}}{\Lambda_D}\right)^4 \left(\frac{\theta_{\mu e}}{10^{-2}}\right)^2$$



Signal and background



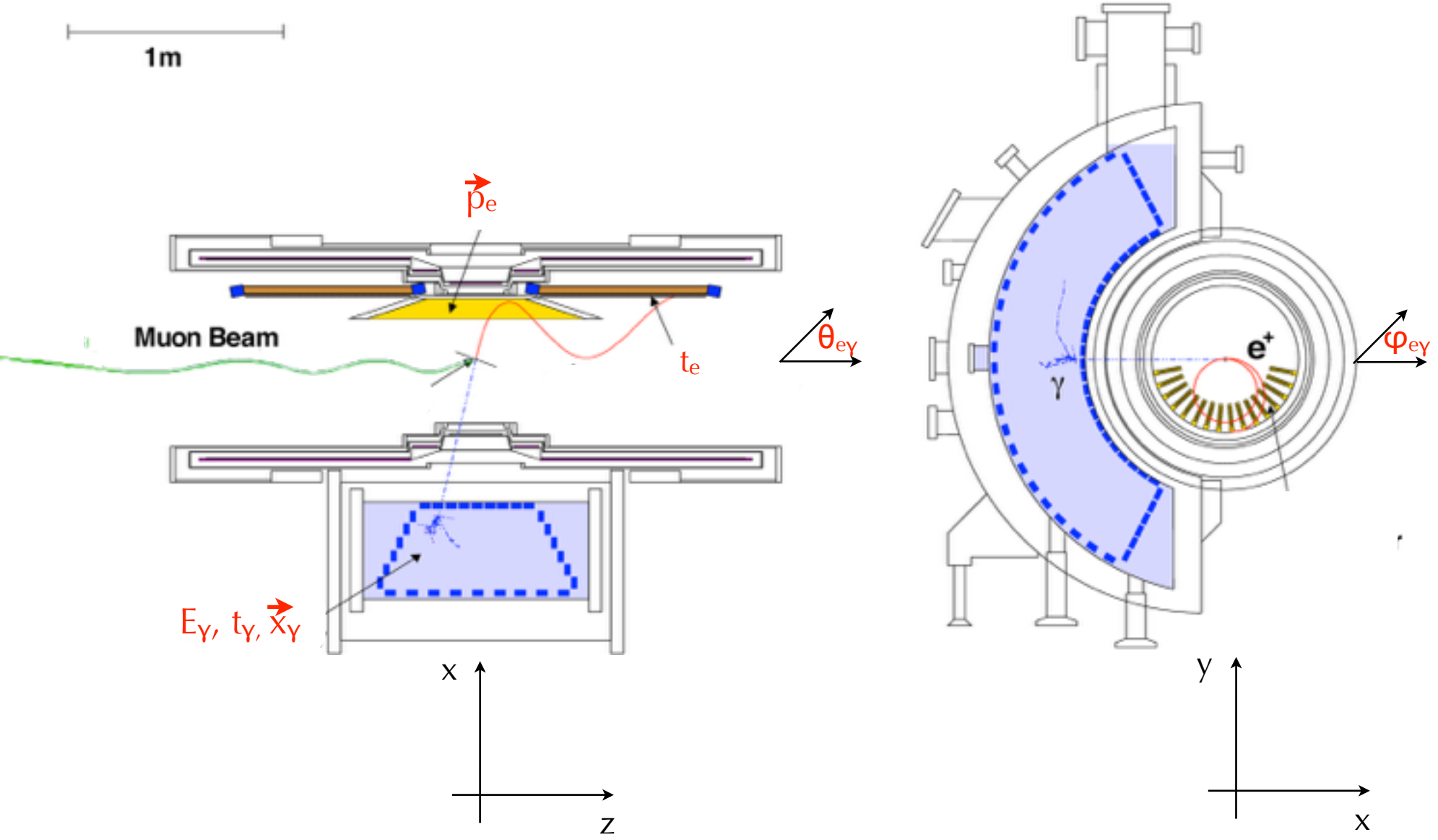
$E_\gamma = 52.8$ MeV	$E_\gamma < 52.8$ MeV	$E_\gamma < 52.8$ MeV
$E_{e^+} = 52.8$ MeV	$E_{e^+} < 52.8$ MeV	$E_{e^+} < 52.8$ MeV
$\Theta_{e\gamma} = 180°$	$\Theta_{e\gamma} < 180°$ [1]	$\Theta_{e\gamma} < 180°$
$T_{e\gamma} = 0$ s	$T_{e\gamma} = 0$ s	$T_{e\gamma} \Rightarrow$ flat

Accidental background is **dominant** and determined by **beam rate** and **resolutions**

$$B_{acc} \propto R_\mu \Delta E_e \Delta E_\gamma^2 \Delta \Theta_{e\gamma}^2 \Delta t_{e\gamma}$$

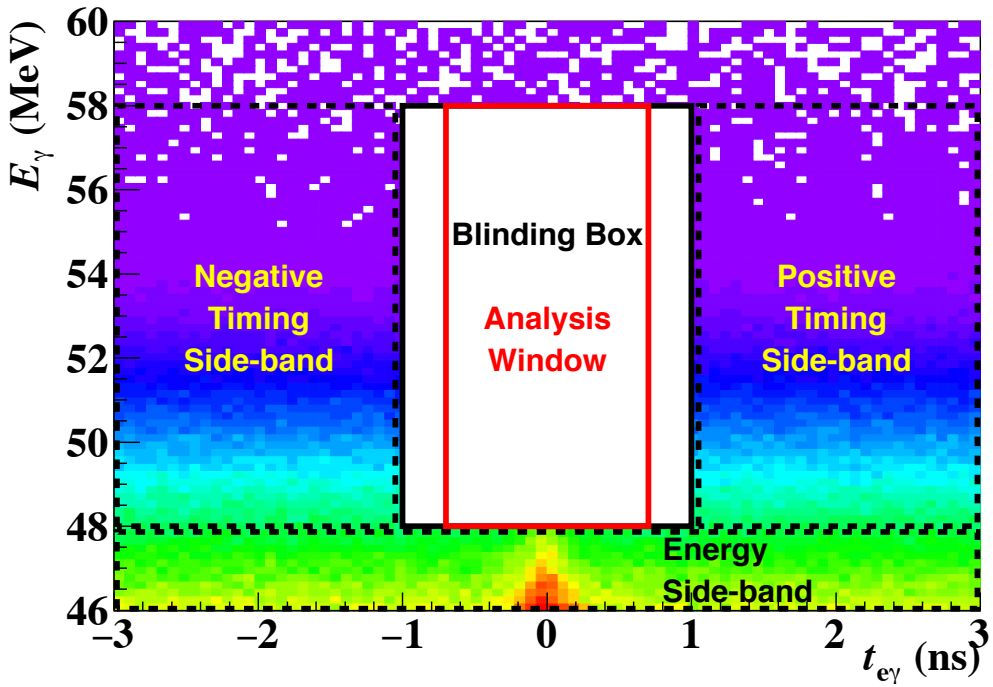
$$B_{RMD} \approx 0.1 \cdot B_{acc}$$

Detector overview



Analysis strategy

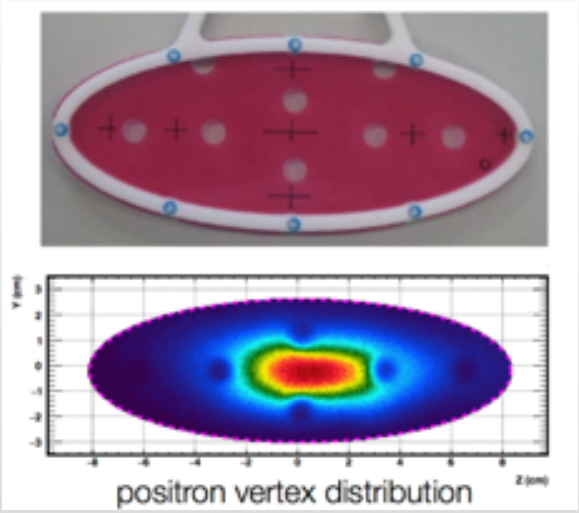
- Decided to extract **CL to B(μ→eγ)** from a **likelihood analysis** in a **wide signal box**
- Each **event** is described in terms of **5 kinematic variables**
  - $x_i = (E_\gamma, E_e, t_{e\gamma}, \varphi_{e\gamma}, \vartheta_{e\gamma})$
- **resolutions** and **PDFs** evaluated **on data outside the signal box**
  - *signal box **closed** until **analysis is fixed***
- Use of **sidebands**
  - ***accidental background** from **Left and Right sidebands***
  - ***Radiative Muon Decay** (RMD) studied in the E_γ sideband*

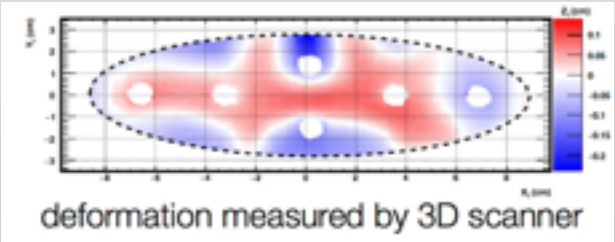


- ***BR(μ→eγ)<5.7 10^-13 @90% CL with half of the statistics***

  "New constraint on the existence of the μ → eγ decay" PRL110, 201801 (2013)

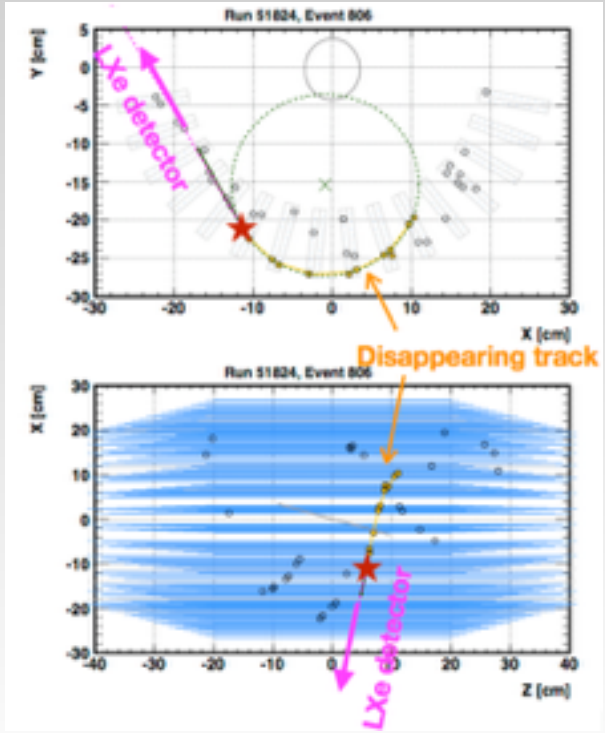
Analysis improvements

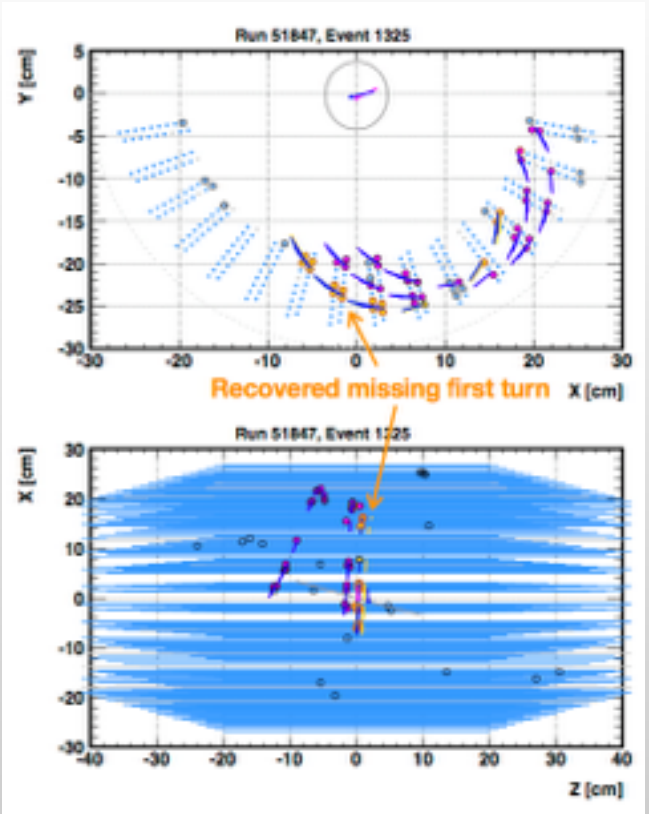




major systematic error
13% sensitivity worsening

positron AIF events
2% bkg suppression
1% sign inefficiency



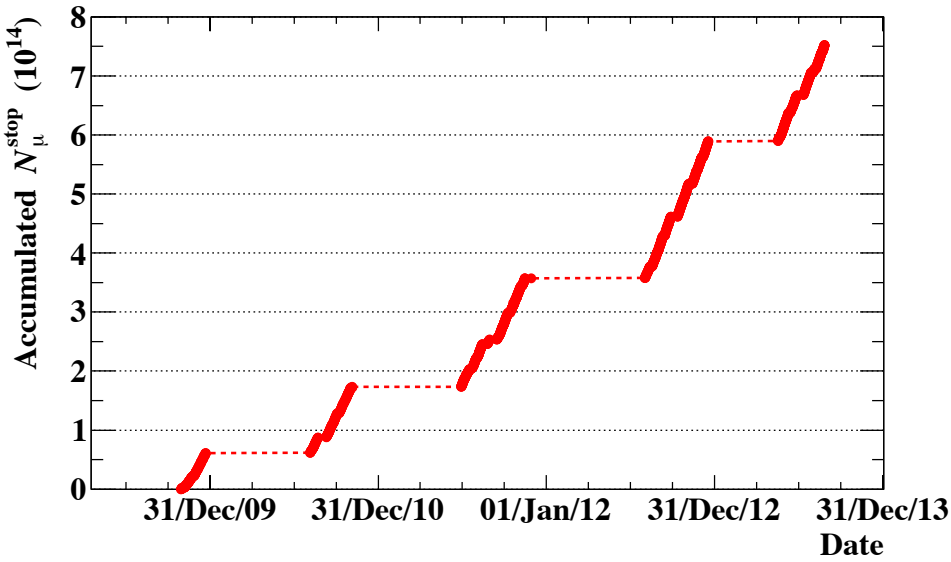


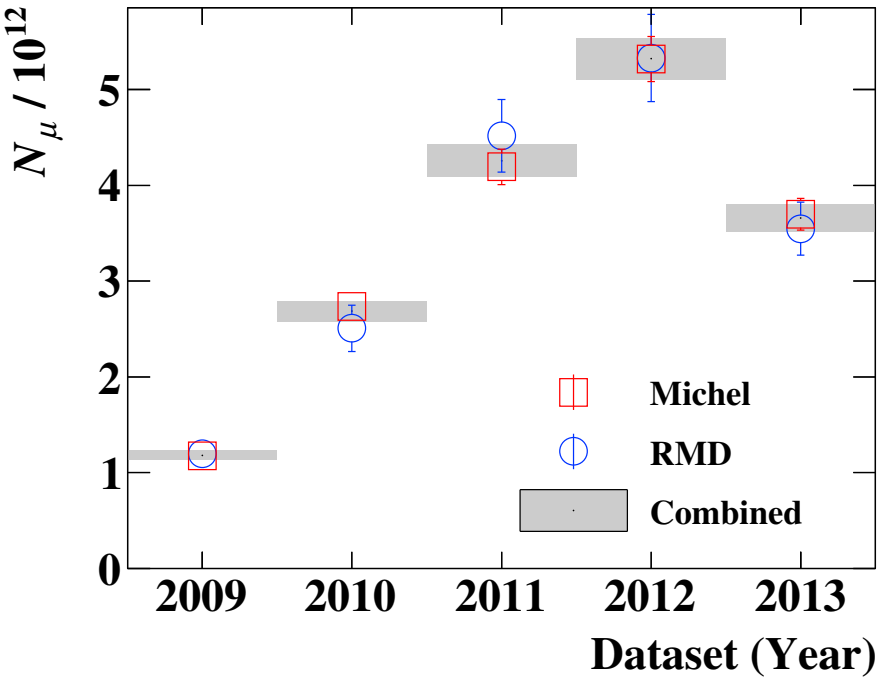
first missing turn recovery
+4% of tracking efficiency

Normalisation

$$\mathcal{B}(\mu^+ \to e^+\gamma) \equiv \frac{\Gamma(\mu^+ \to e^+\gamma)}{\Gamma_{\text{total}}} = \frac{N_{\text{sig}}}{N_\mu}$$

- **Two independent** normalisation **procedures**
  - ***count positrons*** *from μ→evν*
    - **dedicated pre-scaled trigger** in DAQ
  - ***radiative decay events***
    - in photon **energy side-band**
- **Integrated normalisation = 1.73 x 10^13**
  - ***4% uncertainty***

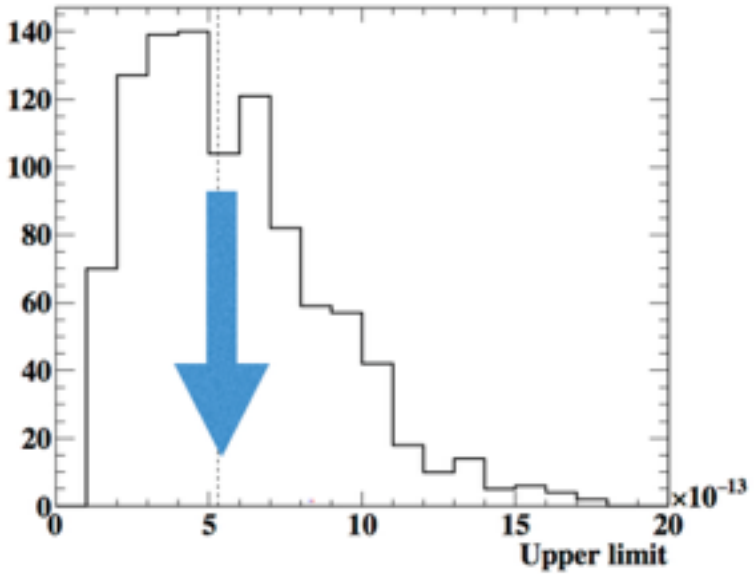


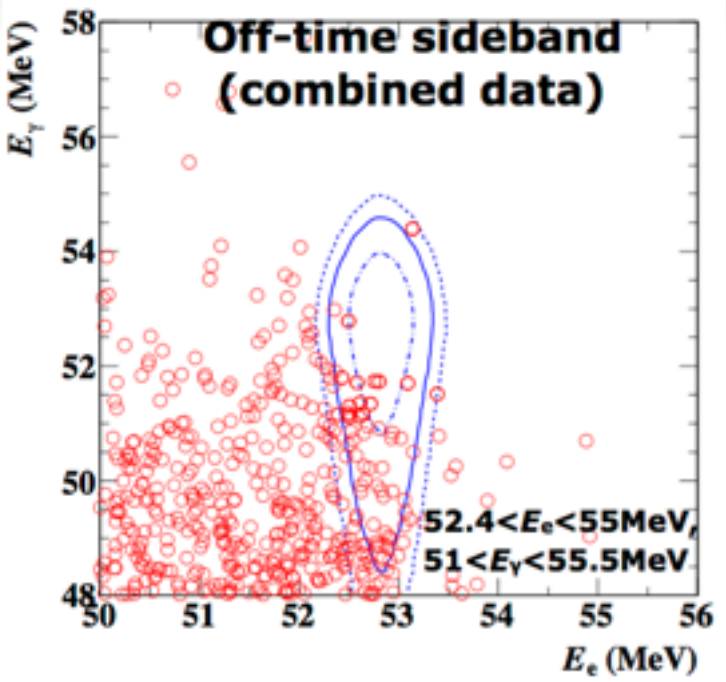


Sensitivity

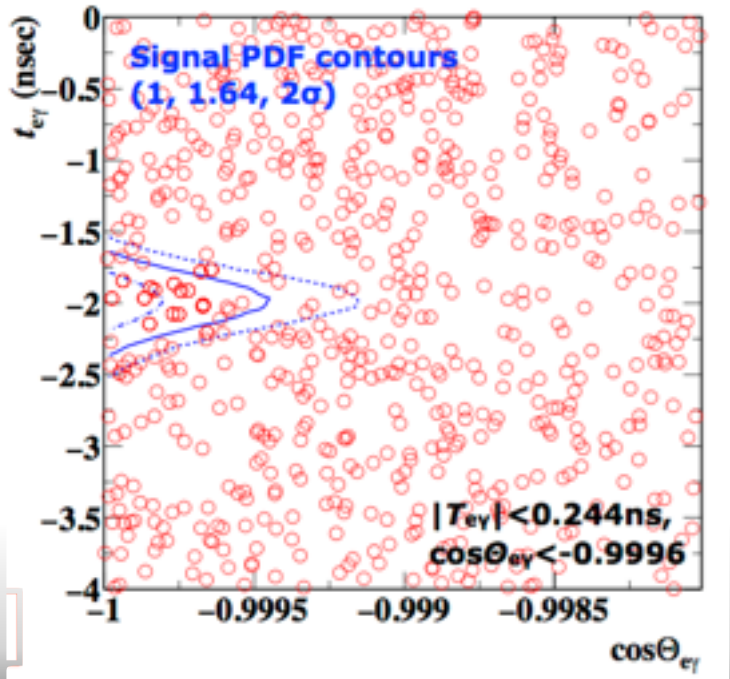
- **median 90% CL Upper Limit** on toy MC experiments with **null signal** hypothesis
- **Comparison** with **last publication** from 2009-2011 data
  - ***no significative difference***
- **Checked** by **timing side-band** data fits
- **5.3 10^-13 for all data**
  - ***8 10^-13 for 2009-2011 data***

- The **Blinded Box** was **opened** in **December 2015**

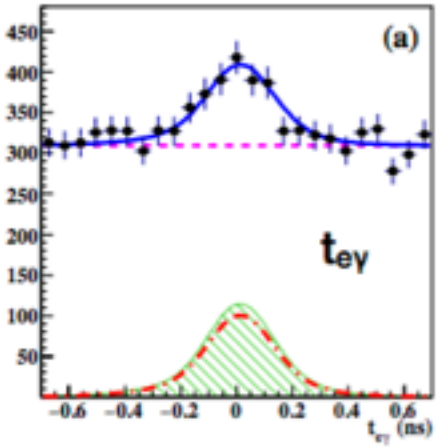


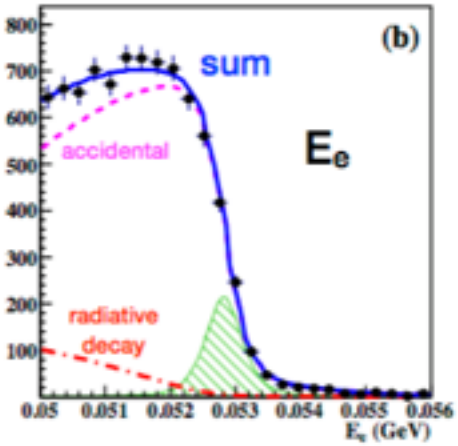


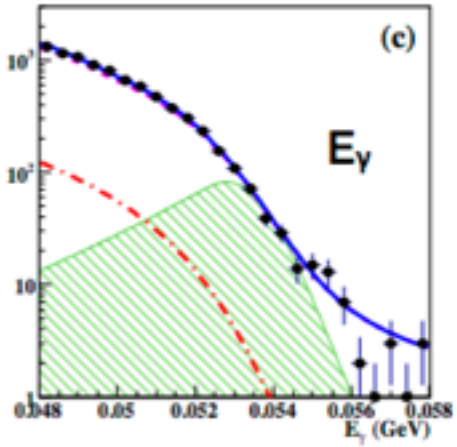
signal contours of 1, 1.64, 2σ are shown



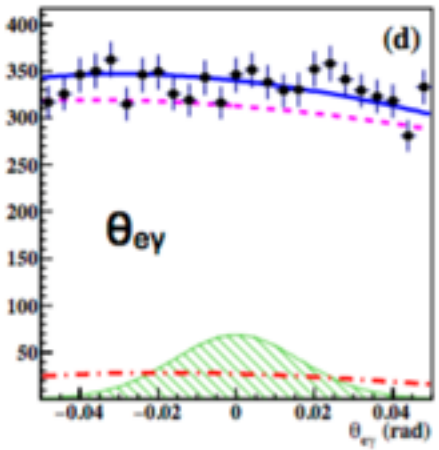
The 5(+1) observables & Rsig

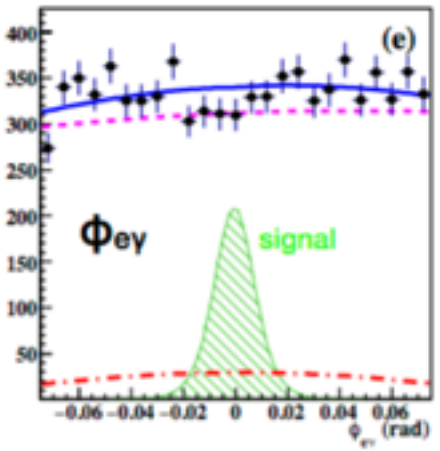


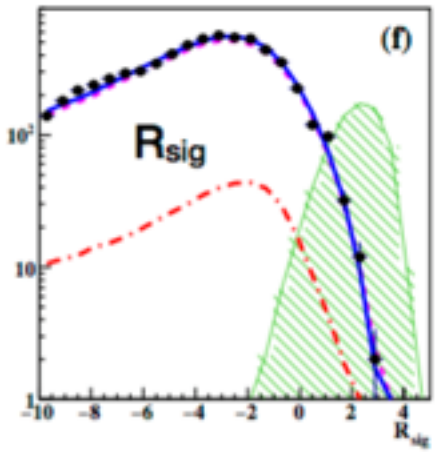




signal enhanced by a factor100



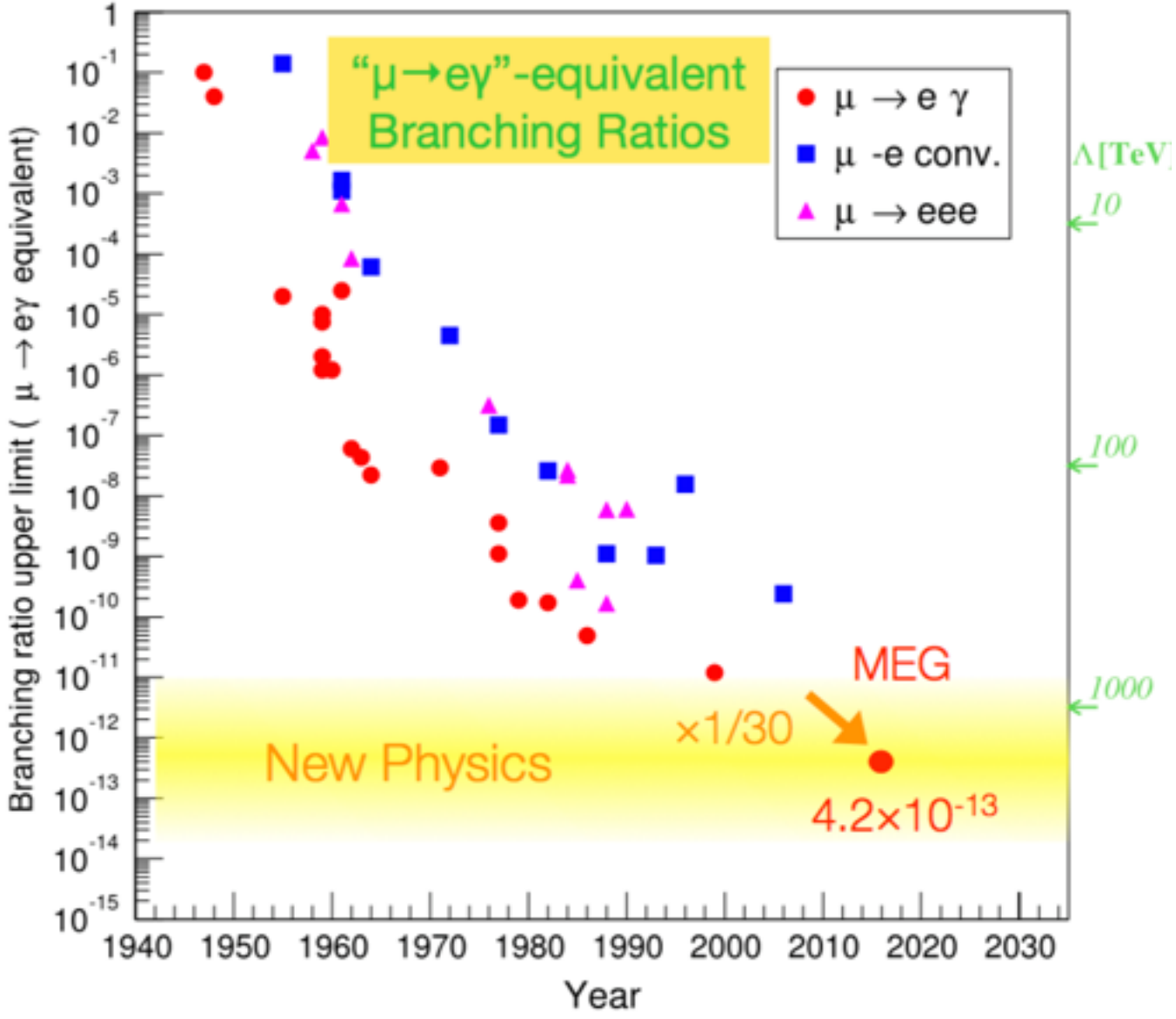


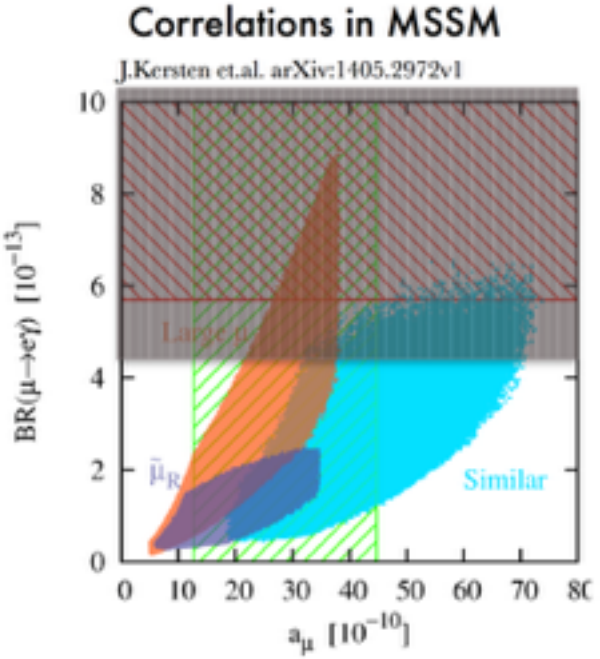


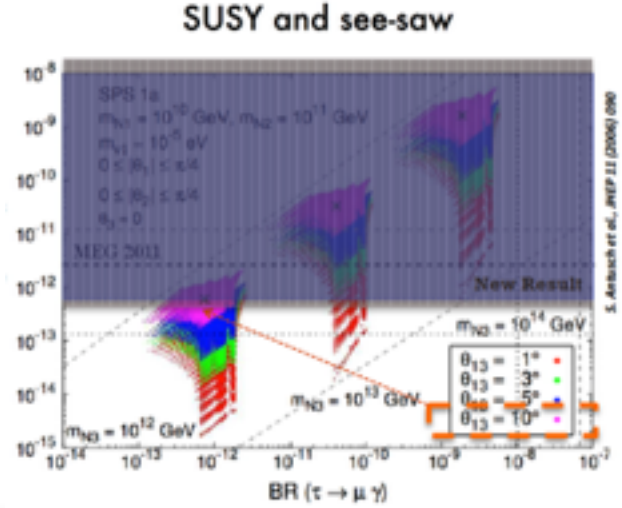
$$R_{Sig} = Log_{10}(\frac{S}{0.1R + 0.9B})$$

BR(μ→eγ)<4.2 10^-13 @90% CL

Final MEG result and constraints

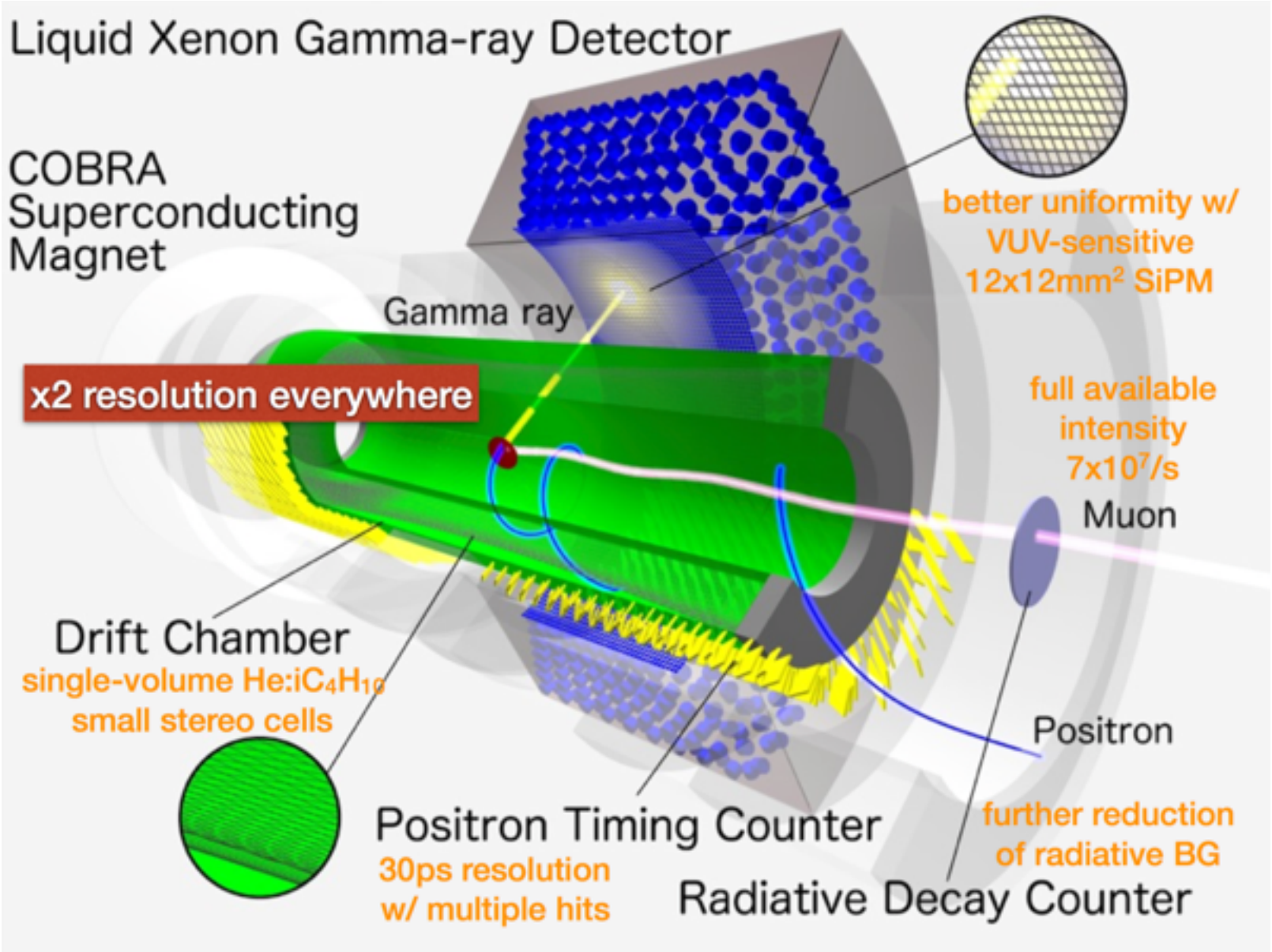




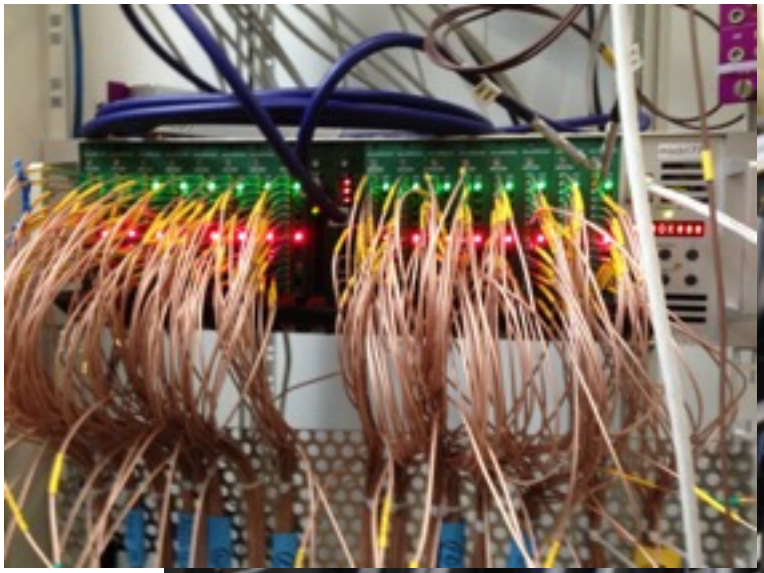


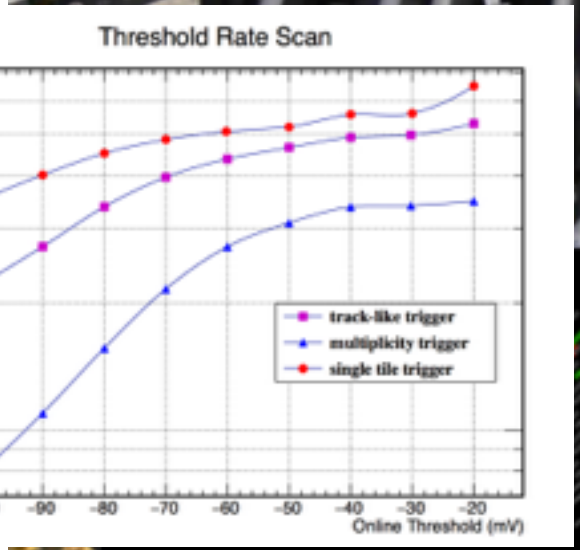
accepted by EPJ C, arXiv:1605.05081v3

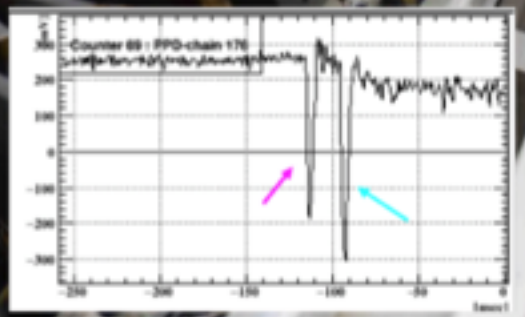
MEG II at a glance

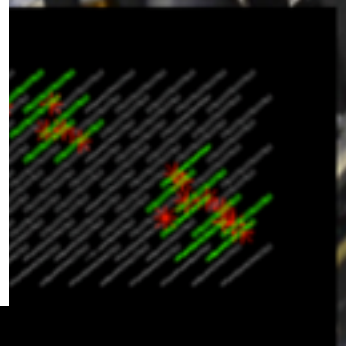


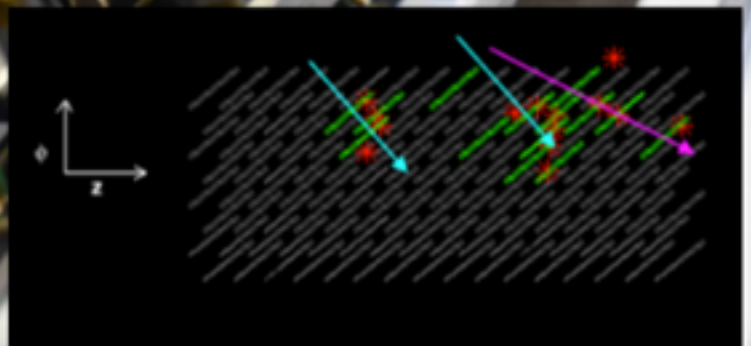
The first MEG II data…

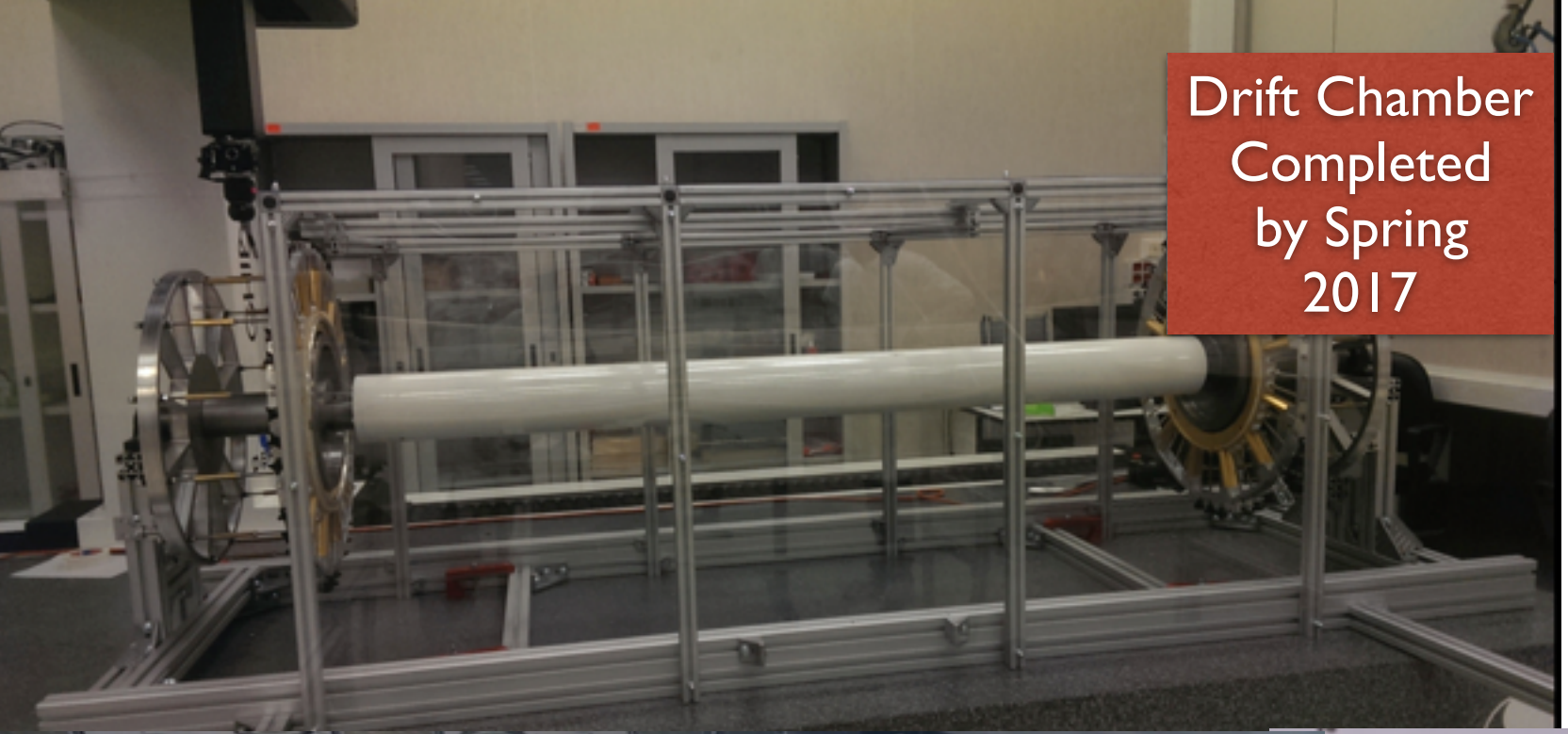






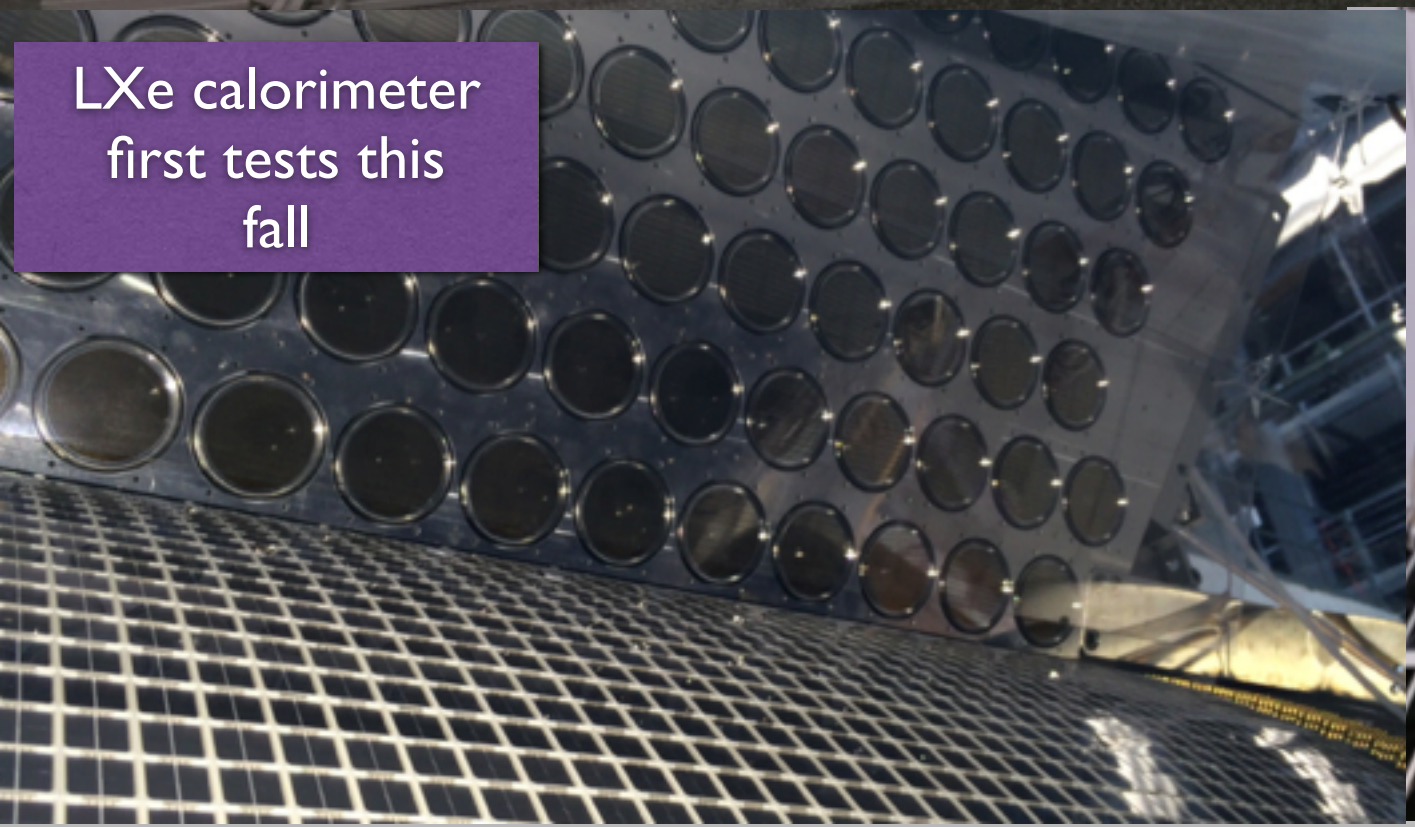




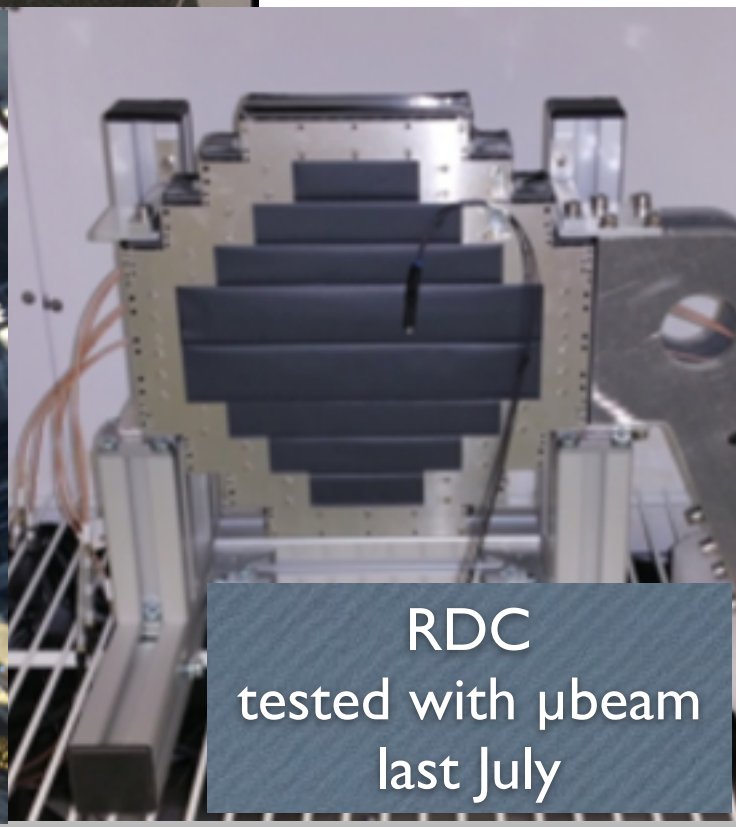


Drift Chamber Completed by Spring 2017

Work in progress

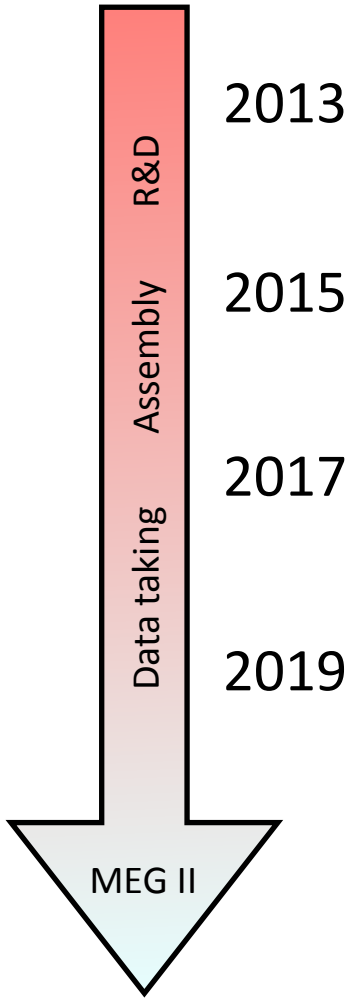


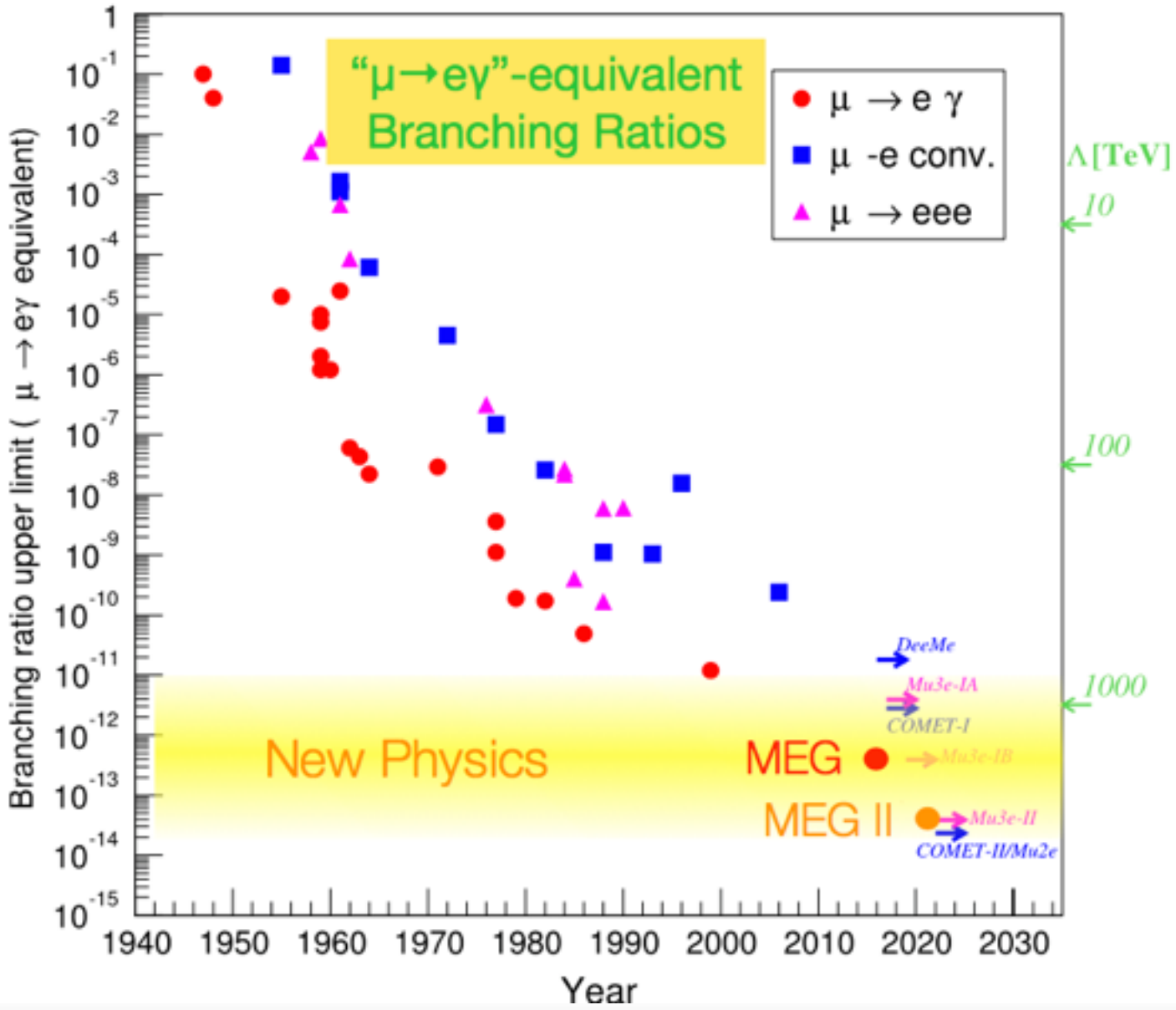
LXe calorimeter first tests this fall



RDC tested with μbeam last July

Perspectives





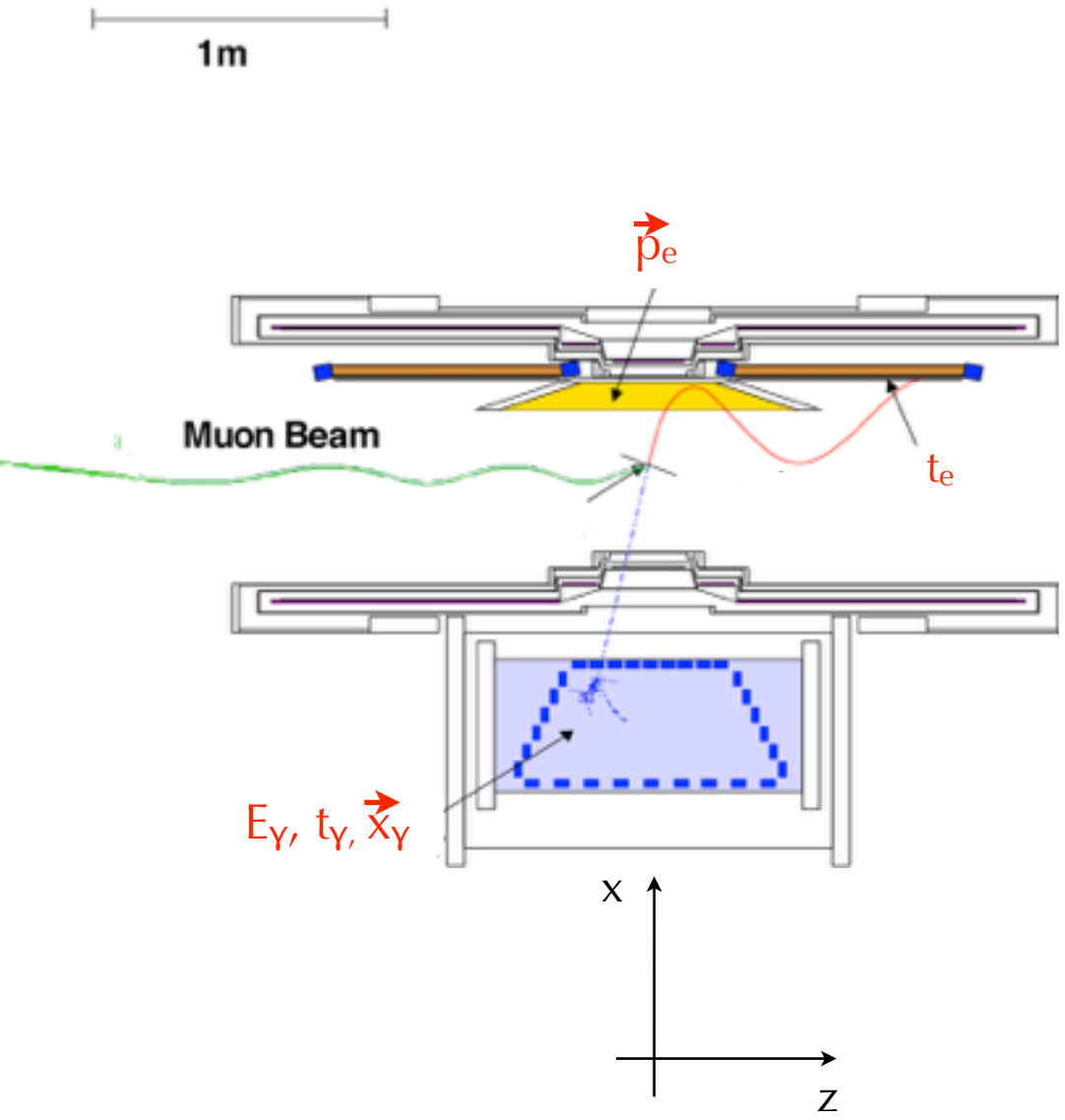
Conclusions

- The final result of the MEG experiment is
  - *BR(μ→eγ) < 4.2 10^-13 @90% CL*
    - many improvements in reconstruction and systematics treatments developed
- The MEG II is going to improve MEG sensitivity by one order of magnitude
- construction on going
  - *first data taken last year with a part of the TC detector and the RDC counter with the first TDAQ system*
  - *in 2016 is going to be crucial for the realisation of the new devices*

Thank you…
and stay tuned!

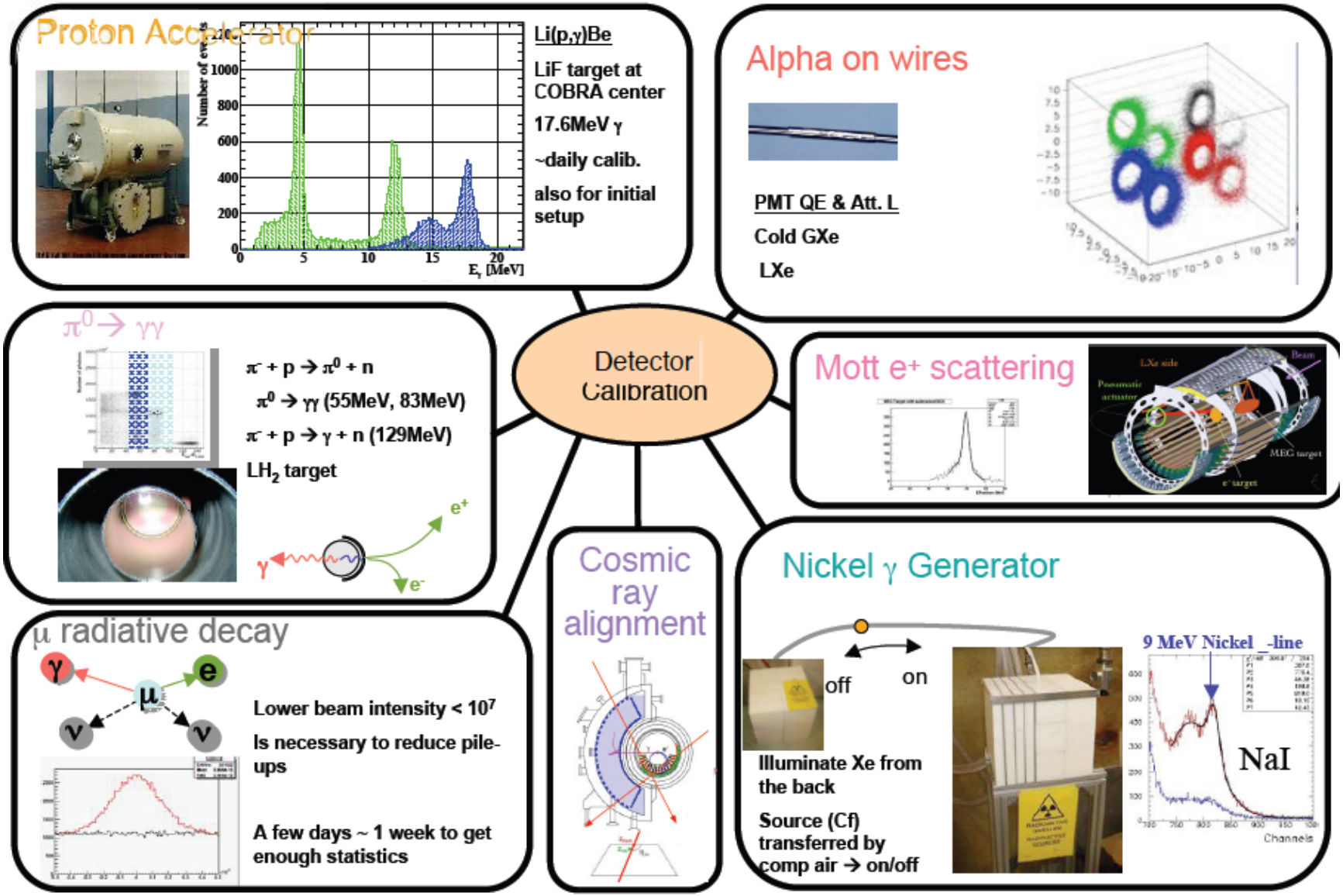
Backup

Detector overview

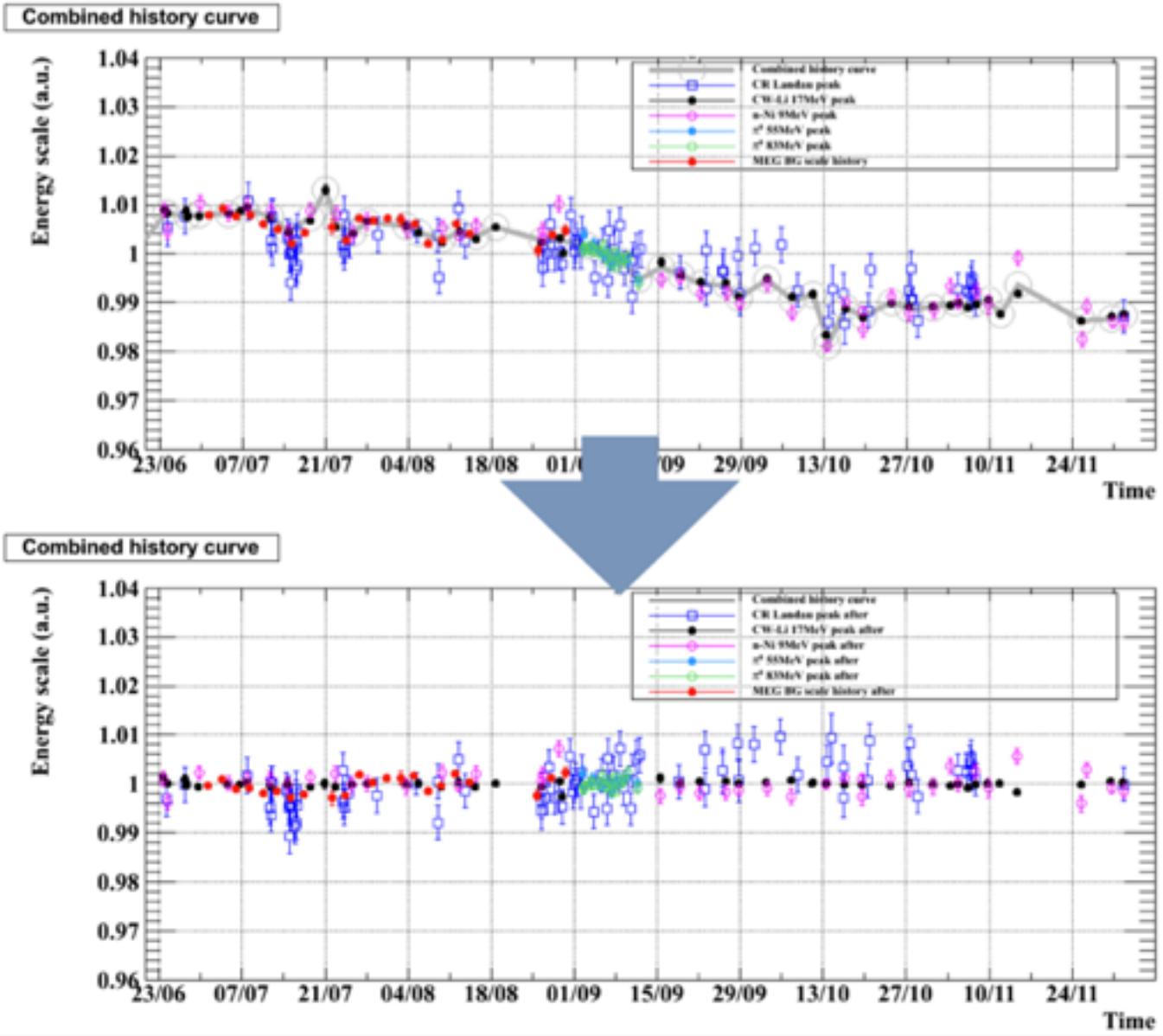


- **μ decay** at **rest**
  - *Beam rate:* ***3×10^7 μ/s***
  - *μ stopped in* ***205 μm target***
- **γ** detection
  - ***Liquid Xenon*** *calorimetry with* ***scintillation light***
    - **fast**: 4/22/45 ns
    - **high LY**: ~0.8 NaI
    - **short X_0**: 2.77 cm
- **positron** detection
  - ***magnetic spectrometer***
    - **non-uniform B field → constant bending radius** and **e swept rapidly away**
    - **ultra-thin drift chambers** to **limit matter effects (X_0 ~ 0.0003 per module)**
  - ***TC detector***
    - **time of flight** with **plastic scintillator counters**

Calibration system (a subset!)



Relevant example

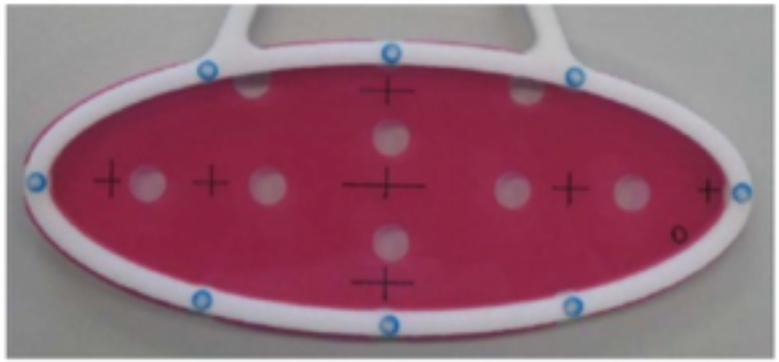


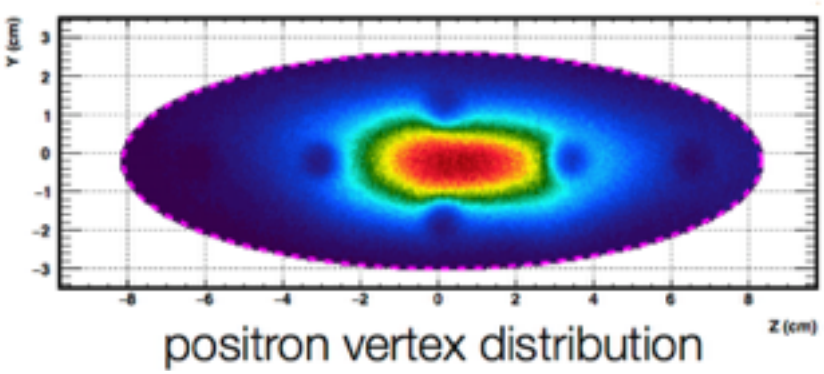
γ energy scale **before** and **after** calibration

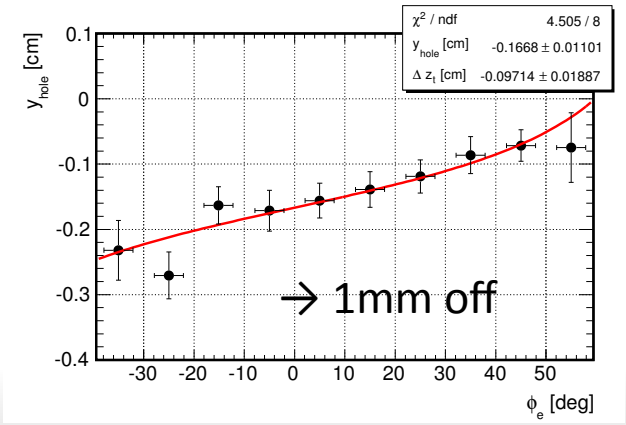
uncertainty less than 0.5%

Target Alignment

- **Position** and **target** shape are surveyed by
  - ***hole reconstructions*** *from data*
  - ***optical survey*** *between runs*
- **worked well** for the **first part** of the experiment
  - ***problems arising*** *in 2012 2013 data*

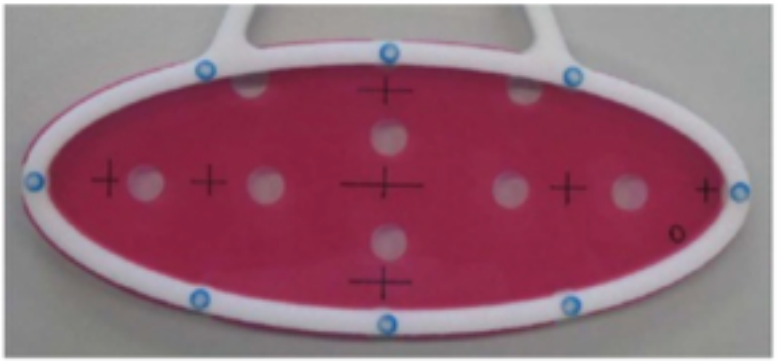


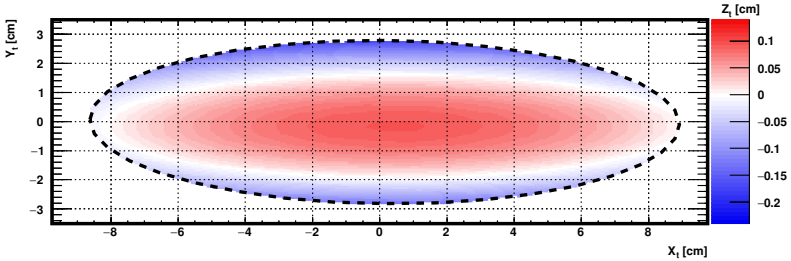




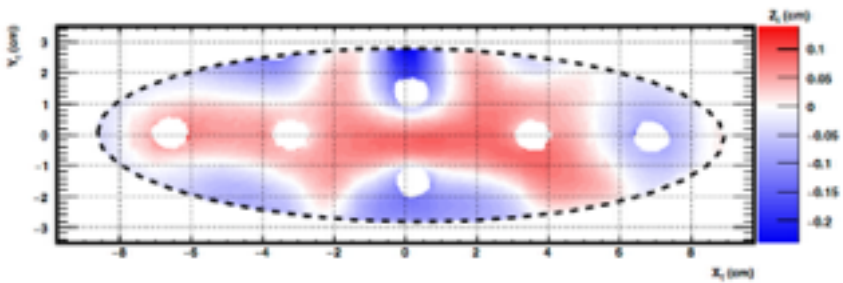
Target Alignment (2)

- **Significant** target **planarity deformation** for **2012-2013** runs
  - *led to **~0.5 mm uncertainty** on the target **position** perpendicular to its plane*
    - a **factor 2 larger** than other years
  - *treated with **nuisance parameters** in **likelihood** analysis*
- **~13%** on **average degradation** in sensitivity
  - ***largest systematic** effect*
- A **few different** target **materials** being studied for **MEG II**



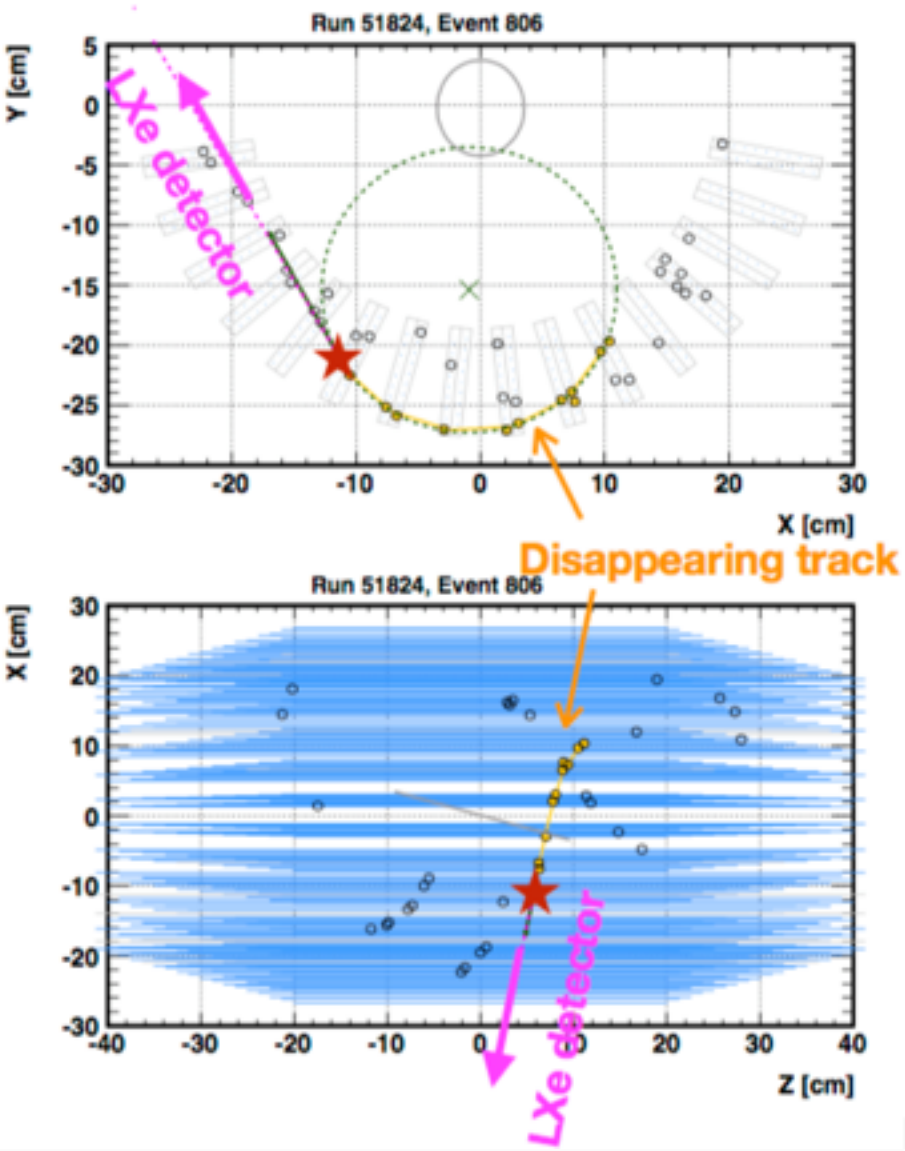


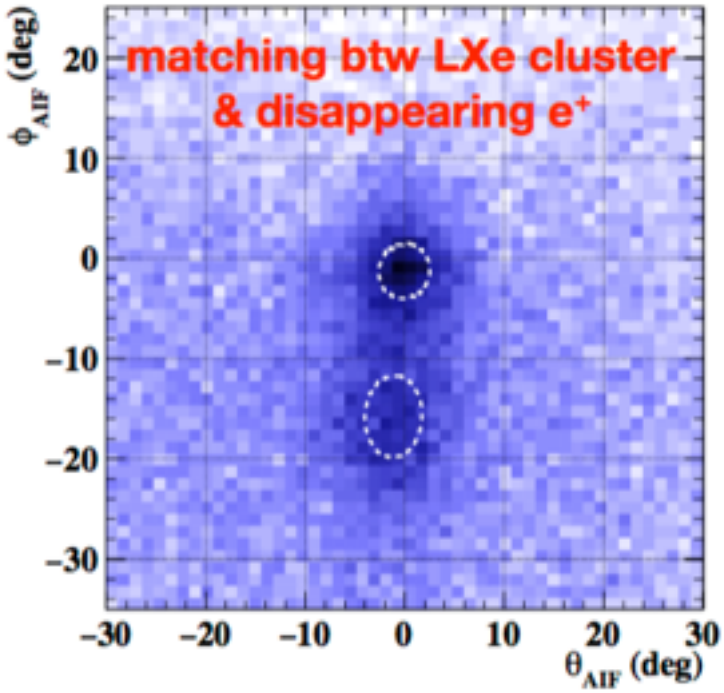
paraboloid shape from cross markers fit



deformation measured by 3D scanner

AIF Gamma-rays

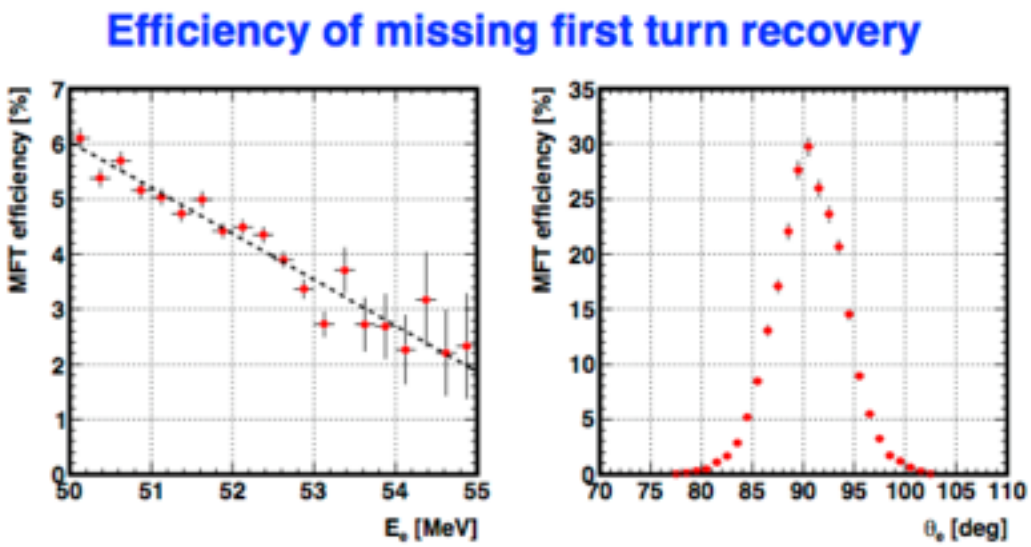


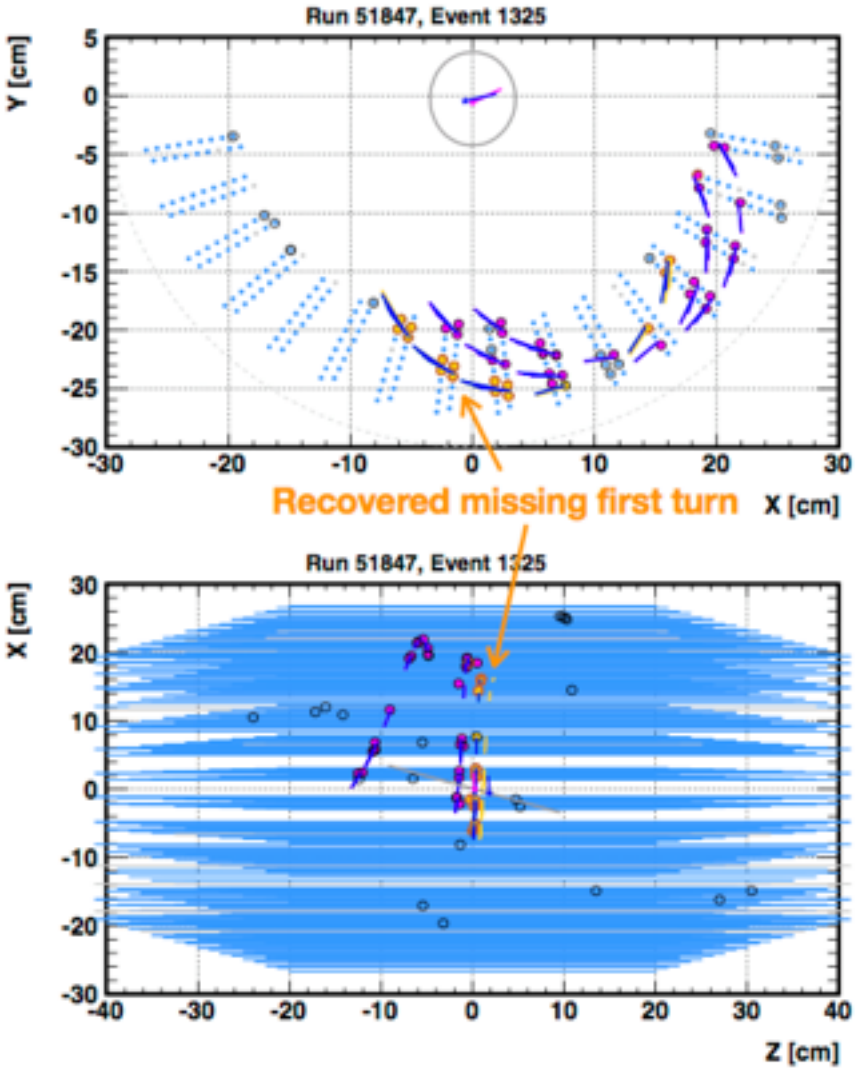


- **γ-rays** from **e+ annihilation** inside **DC** were **identified** and **rejected**
  - *overall **BG rejection 1.9%***
  - *signal **inefficiency 1.1%***
    - **protection** from **high γ-rays** outliers events
- **Double check** of **DC-Target-LXe alignment**

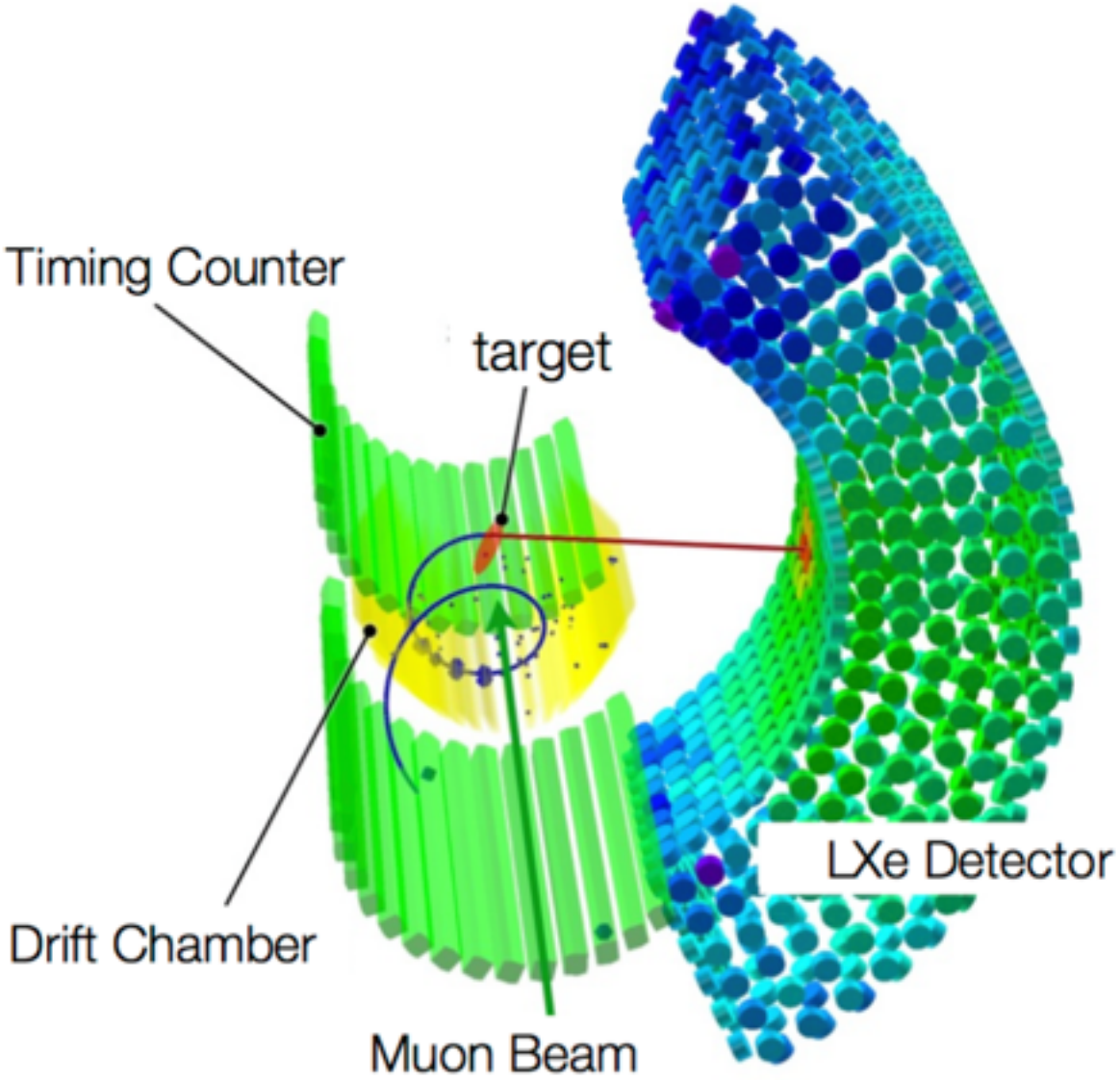
Missing 1st turn

- Possibility to **miss the first turn** in a **multiple hit event**
- **Algorithm revised** to **recover missing first turn**
  - *signal **efficiency improved** by **~4%***



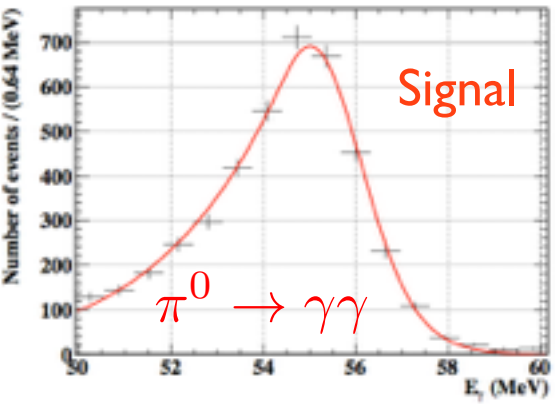


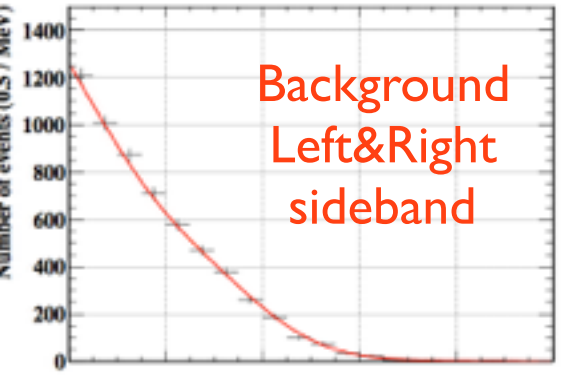
One event in the box



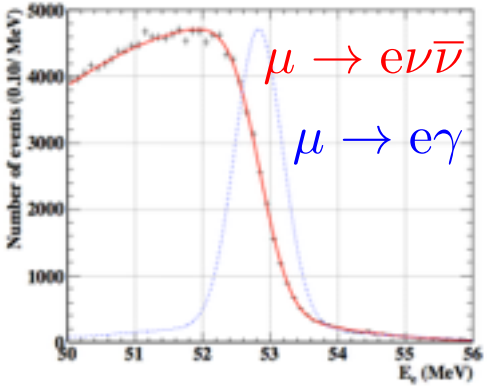
Probability density functions

Photon

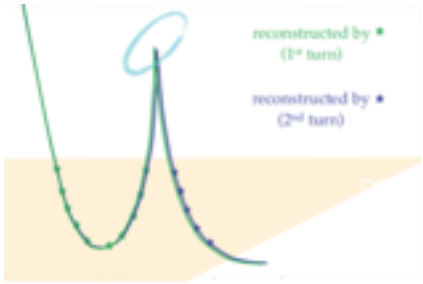




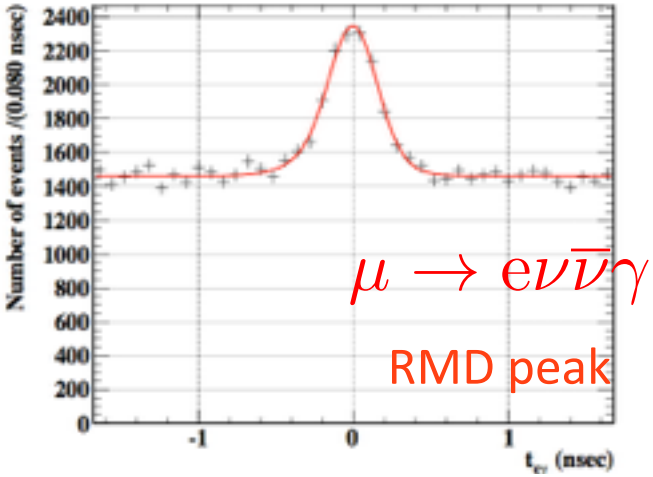
Positron



Resolutions from Michel edge and double turns method



Relative timing



Variable	Obtained
ΔE_γ (%)	1.7
Δt_γ (psec)	67
γ position (mm)	5(u,v),6(w)
γ efficiency (%)	63
ΔP_e (KeV)	306
e^+ angle (mrad)	8.7(ϕ_e),9.4(θ_e)
Δt_{e^+} (psec)	107
e^+ efficiency (%)	40
$\Delta t_{e\gamma}$ (ps)	122

Likelihood function

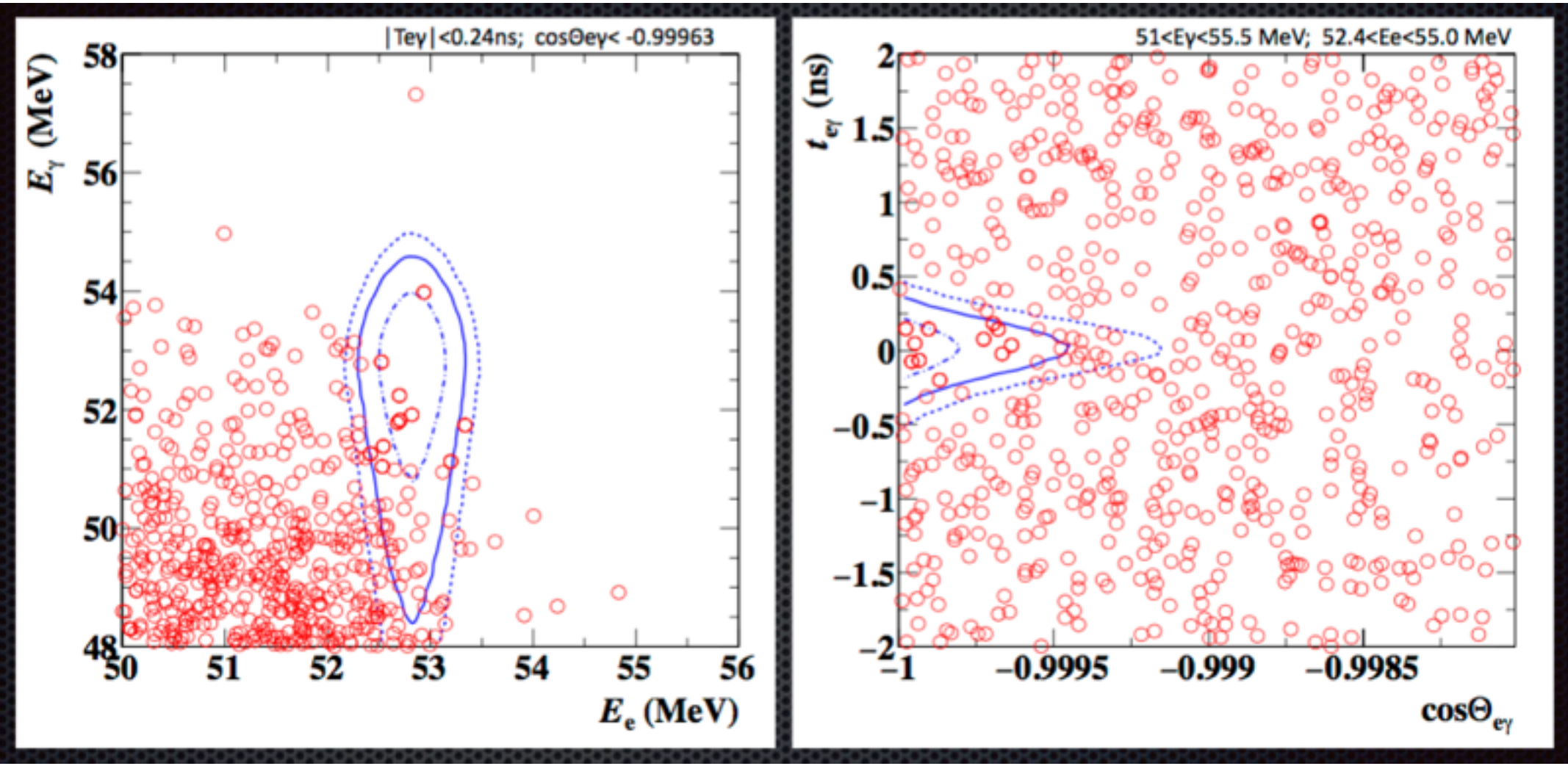
- **Likelihood** function in terms of **S**ignal, **R**adiative muon decay, and accidental **B**ackground **number of events** and **PDFs**

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

Number of background events constrained with side bands

- N_S, N_R, N_B measured **simultaneously** with an **un-binned** Likelihood fit in the **analysis box**
- **B(μ→eγ) C.L.** with **profiled-likelihood ratio ordering**
- Cross-check:
  - ***two*** *independent* ***analysis*** *with* ***different PDFs***
    - **Analysis A:** separated angles **(θeγ, ϕeγ)** and **event by event PDFs**
    - **Analysis B**: stereo angle **Θeγ**, **constant PDF (Pisa)**

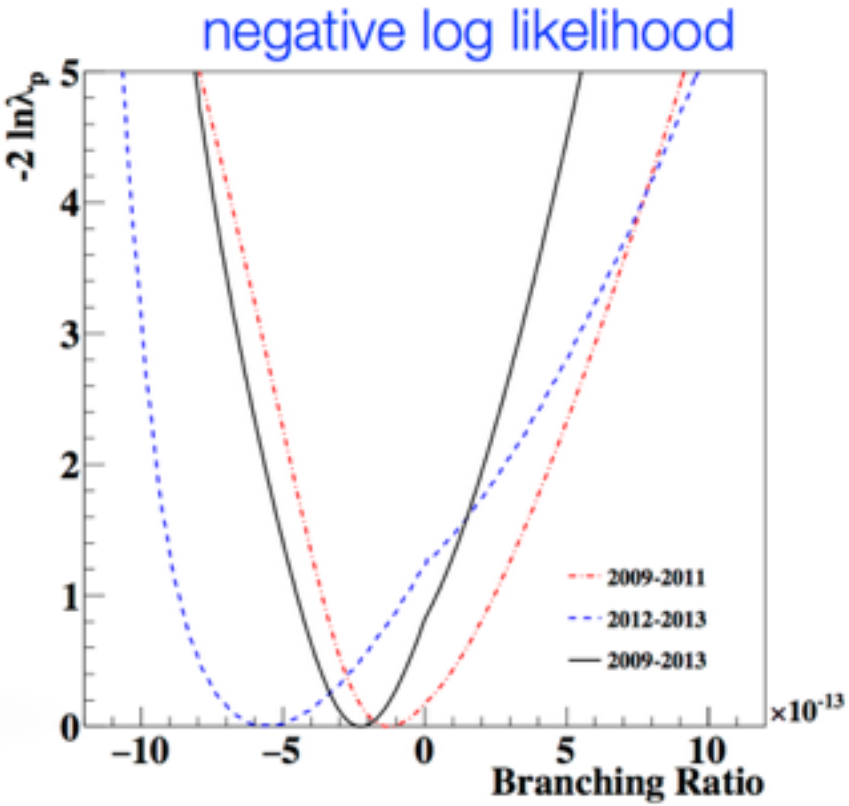
4D Event distribution



signal contours of 1, 1.64, 2σ are shown

Final MEG result

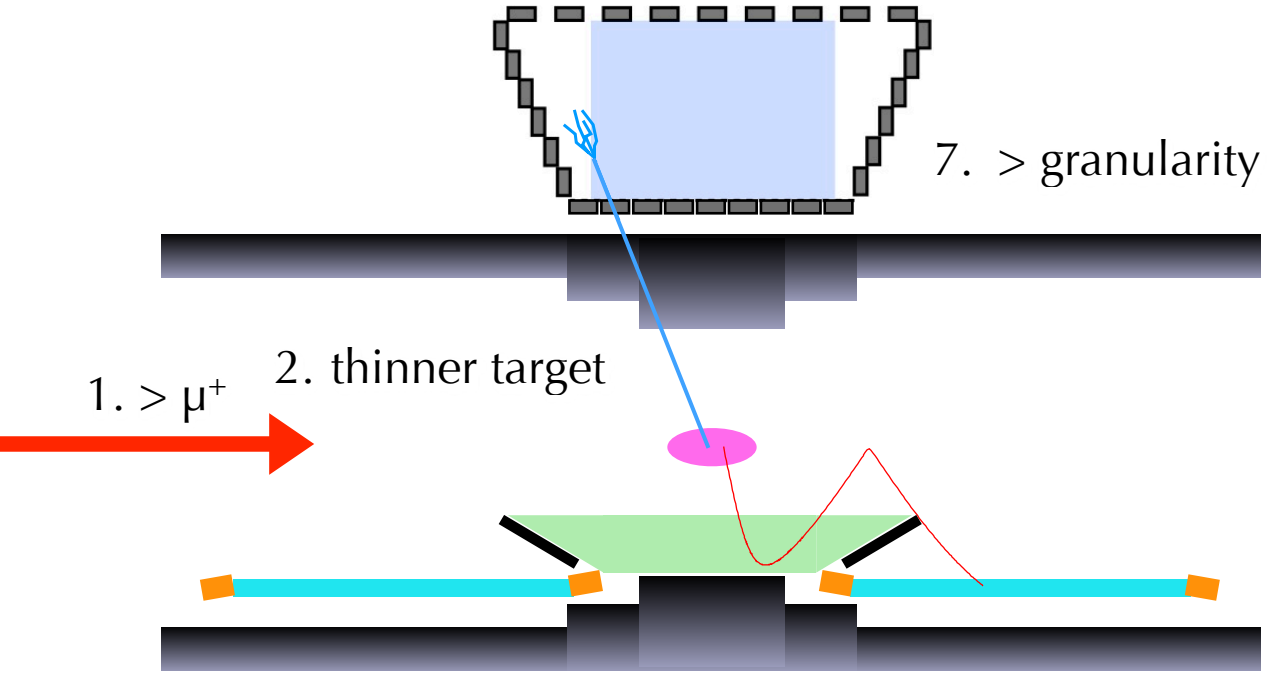
Dataset	2009-2011	2012-2013	All
Best Fit	-1.3	-5.5	-2.2
90% CL Upper Limit	6.1 10^-13	7.9 10^-13	**4.2 10^-13**
Sensitivity	8.0 10^-13	8.2 10^-13	5.3 10^-13



BR(μ→eγ)<4.2 10^-13 @90% CL

MEG II at a glance

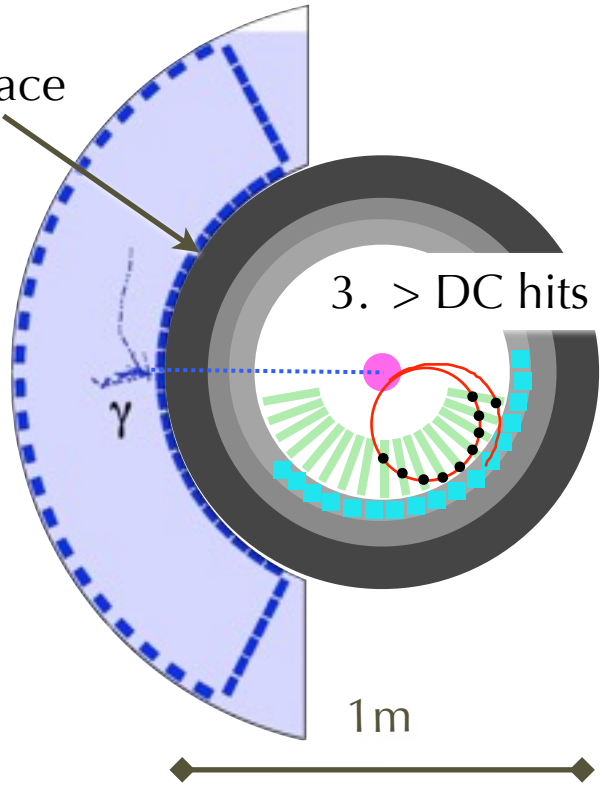
6. > LXe acceptance



7. > granularity on front face

1. > μ^+

2. thinner target



3. > DC hits

5. > TC granularity

4. e+ tracking up to TC

3. < Multiple scattering

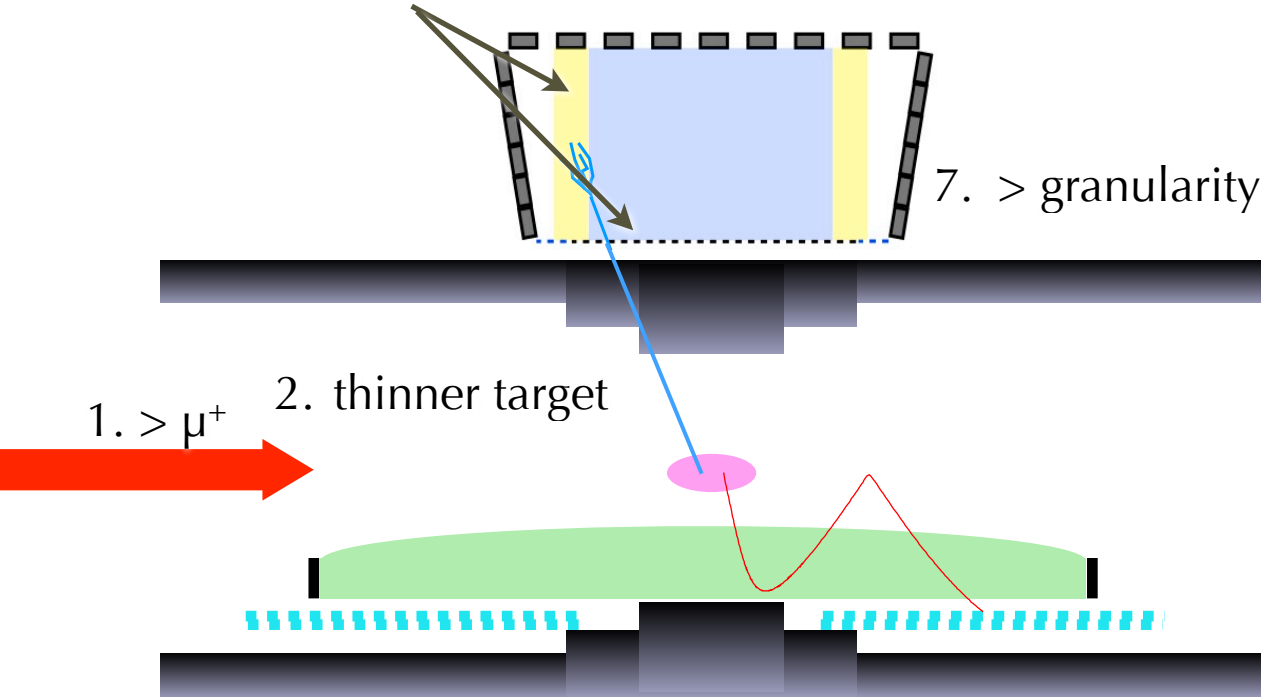
MEG II at a glance

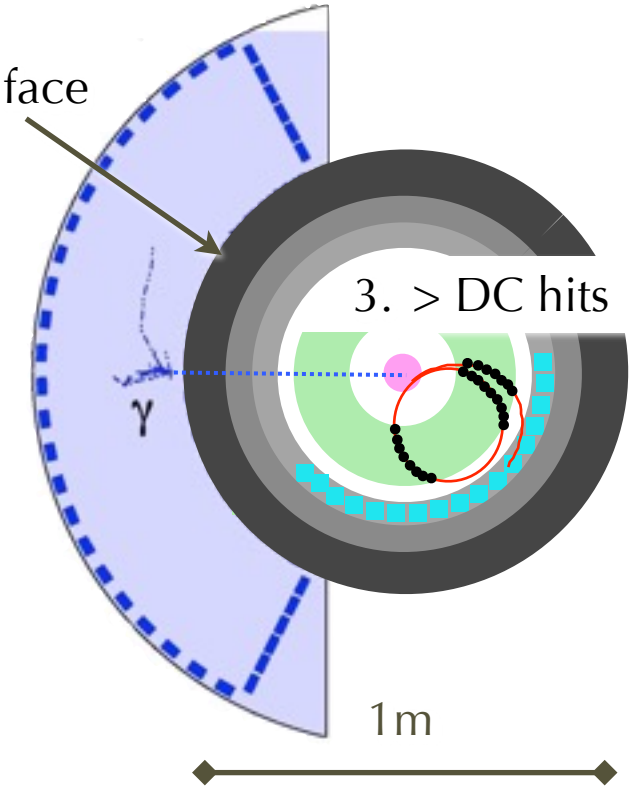
6. > LXe acceptance

7. > granularity on front face

1. > μ^+

2. thinner target





5. > TC granularity

4. e+ tracking up to TC

PMTs → SiPM / MPPC

3. < Multiple scattering

MEG II 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