

The final result of the MEG experiment and the status of the MEG II experiment

Toshiyuki Iwamoto on behalf of MEG and MEG II Collaboration

ICEPP, the University of Tokyo

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SUSY 2016 @ The University of Melbourne

$$\mu^+ \rightarrow e^+ \gamma$$

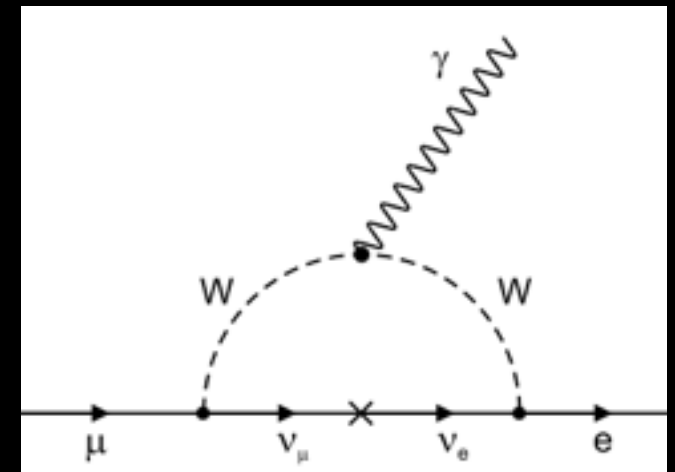
- Standard Model prediction for $\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 10^{-50}$

- Current Br upper limit (10^{-13}) close to many New Physics predictions

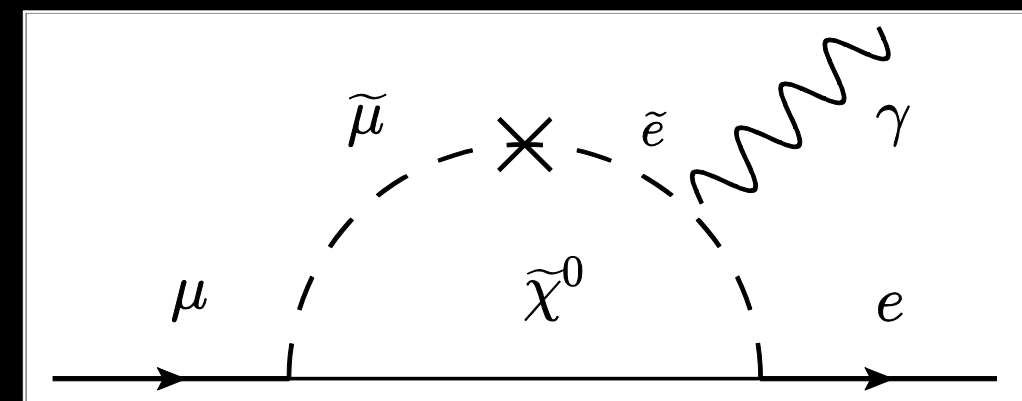
- Clear two body final state, background suppressed by better detector resolutions

- Real chance to discover new physics

$\mu^+ \rightarrow e^+ \gamma$ via SM+M ν

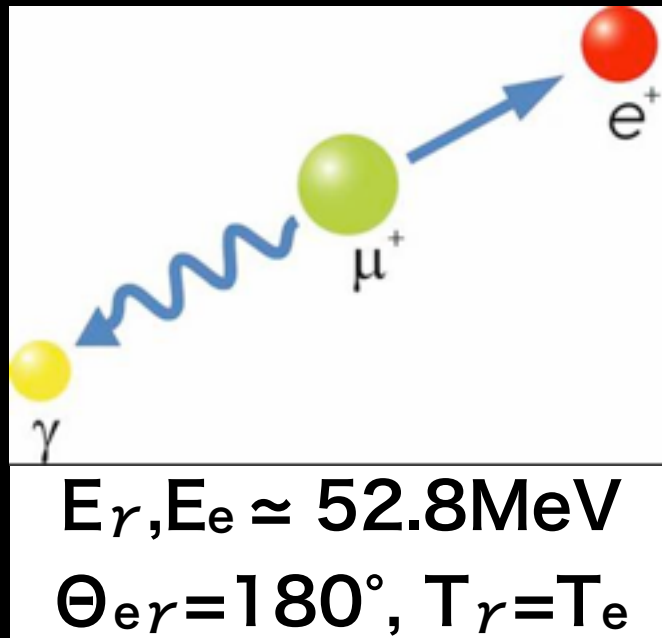


$\mu^+ \rightarrow e^+ \gamma$ via new physics

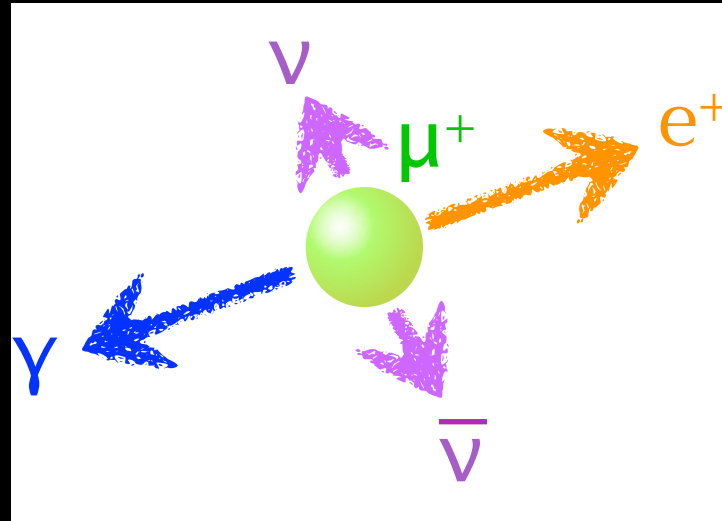


Signal and Background

Signal

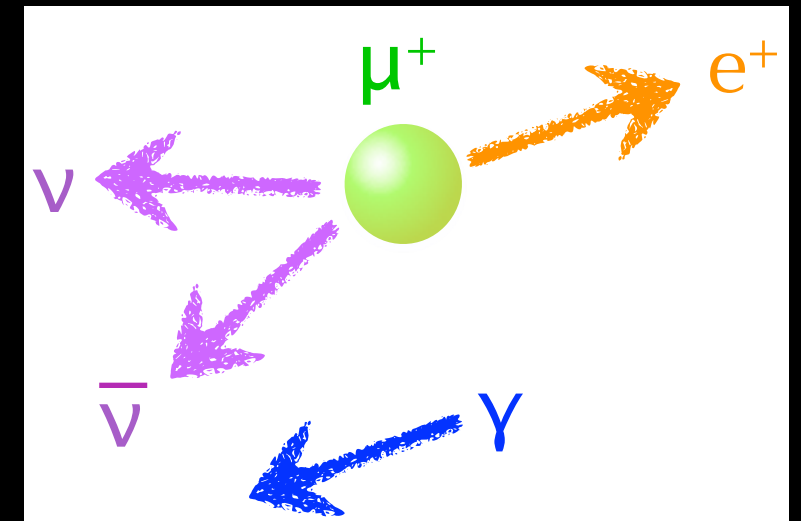


Radiative Muon Decay (RMD) background



- $e^+ - \gamma$ timing coincident
- Good for timing calib.

Accidental background



- Dominant BG
- Michel e^+ + random γ from RMD/Annihilation in flight (AIF)

The MEG experiment

PSI π E5 DC positive muon beam $R_\mu=3 \times 10^7$ stopped μ/s

900L liquid xenon γ detector

Low mass drift chambers with fast scintillators in a gradient B field

COBRA magnet

Drift chamber
(segmented)

Timing counter
Scintillation bars

Stopping target

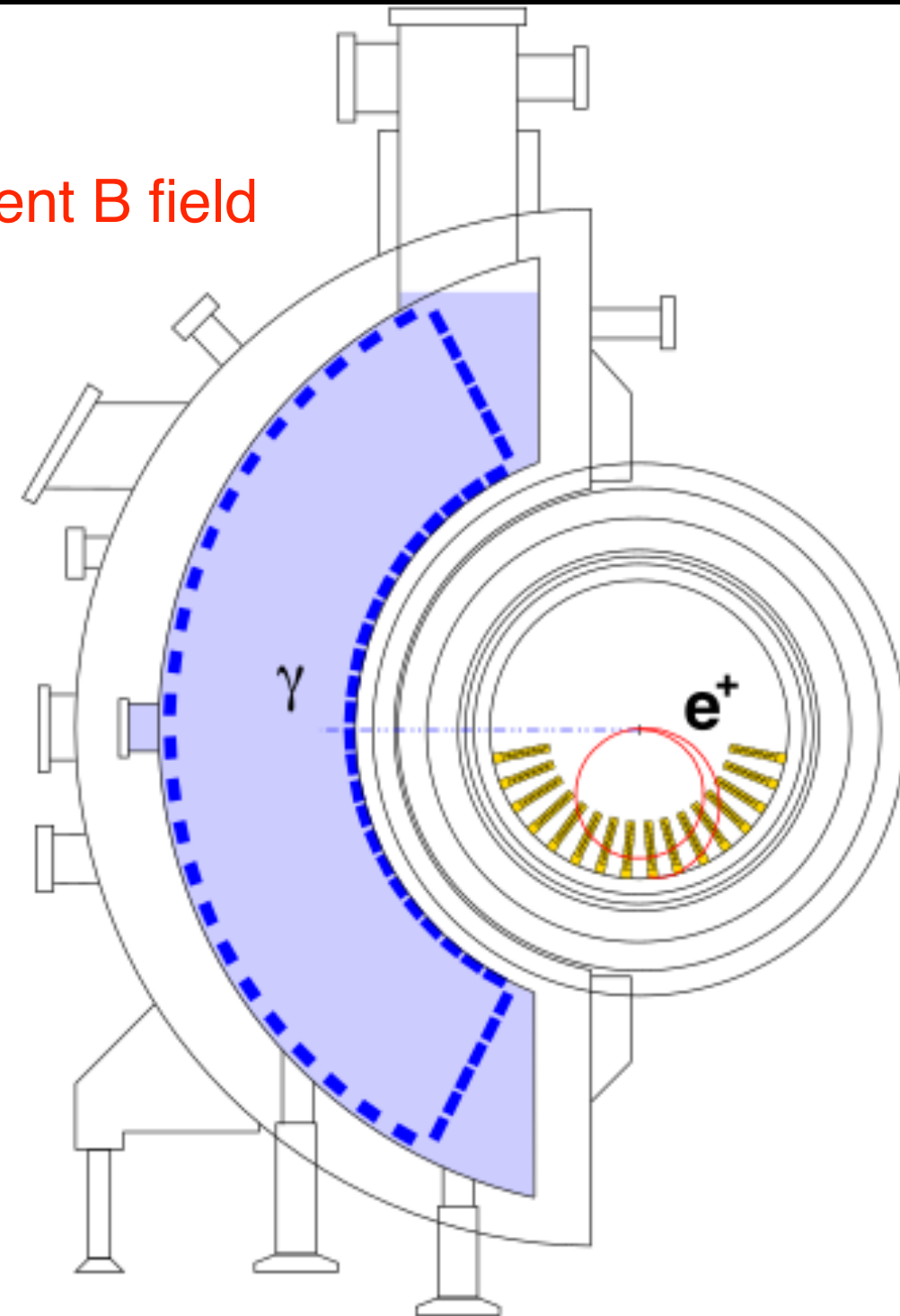
muon beam

e^+

γ

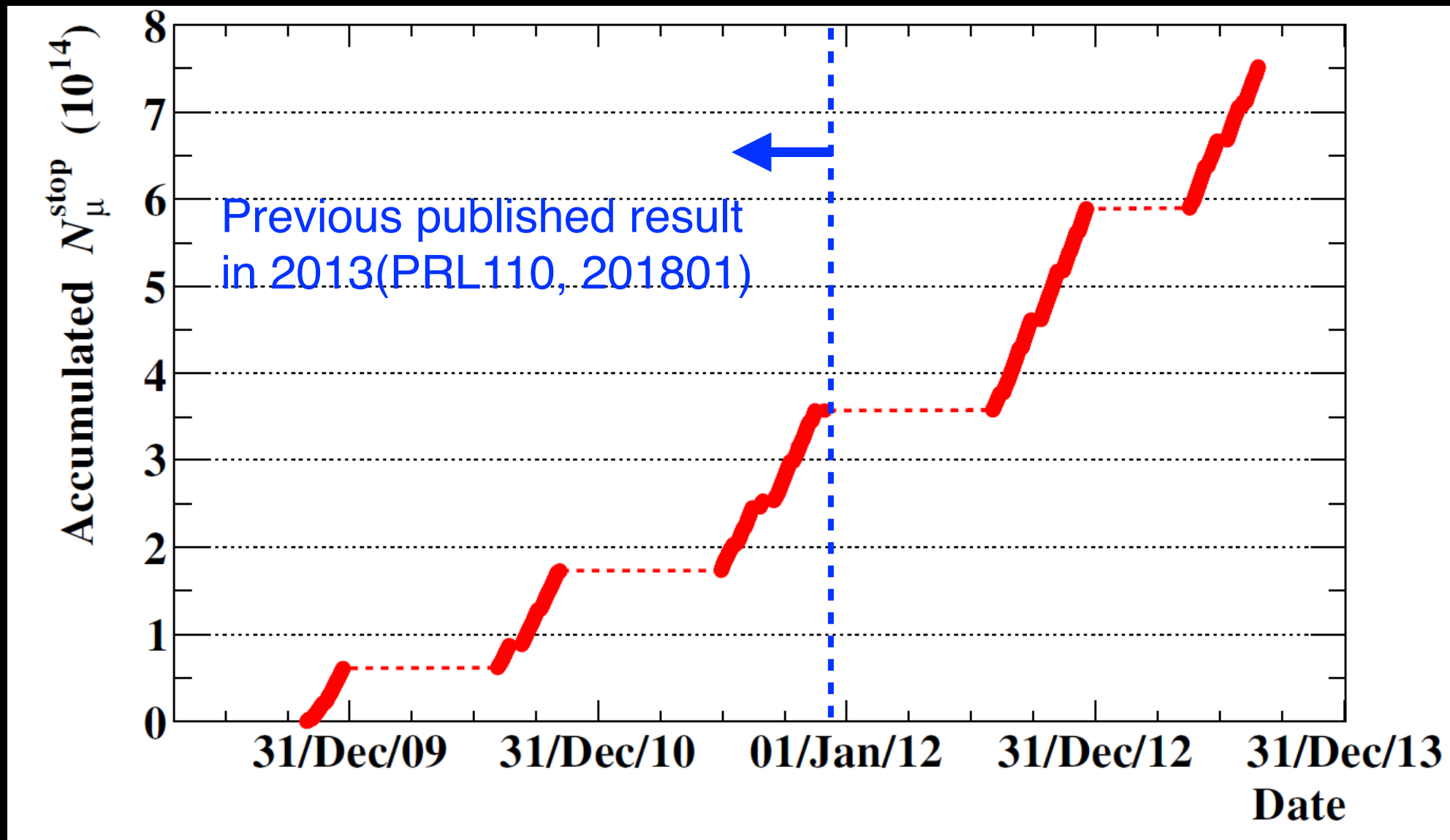
900L Liquid xenon
846 2" PMTs

1m



Final MEG dataset

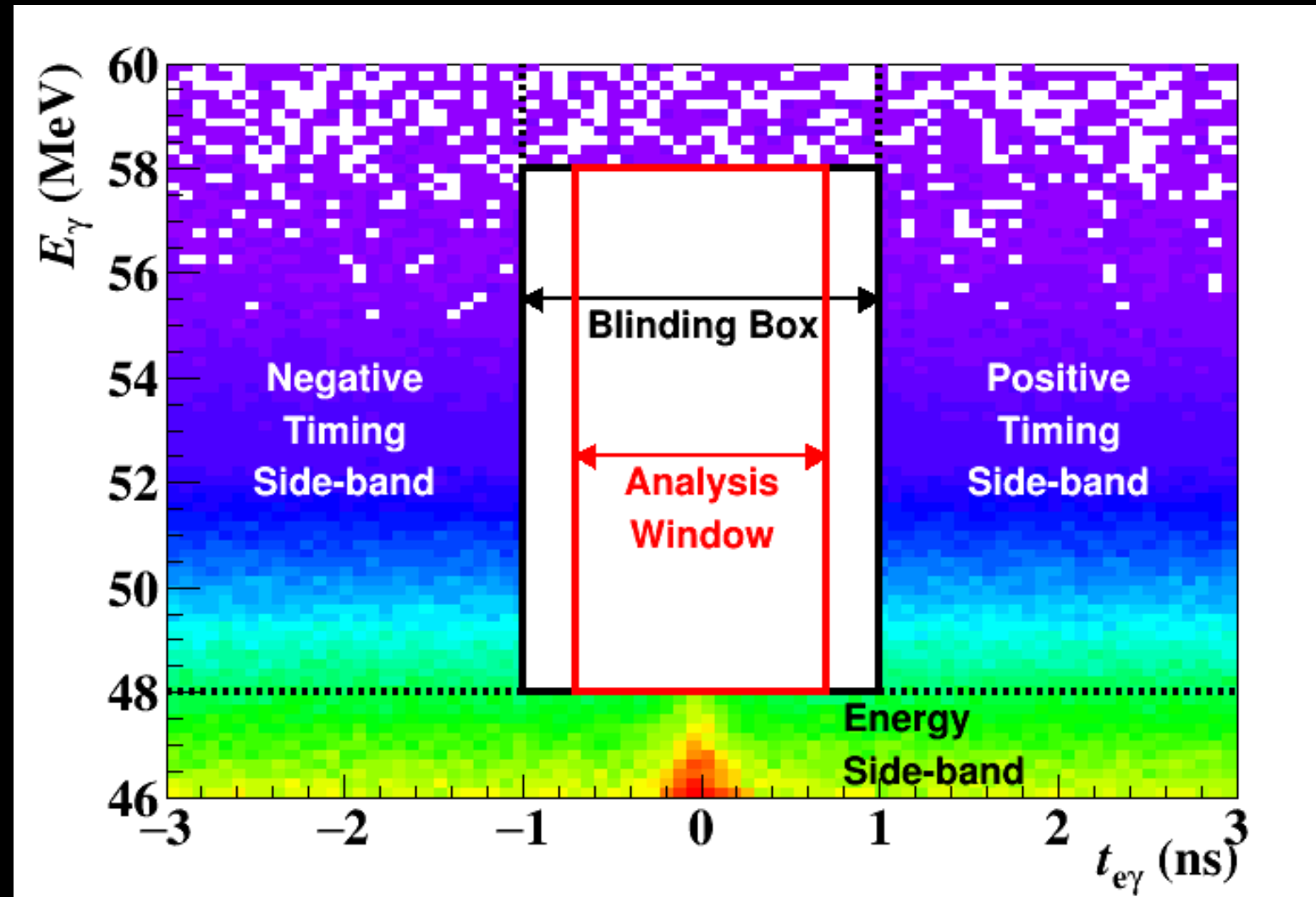
Number of muons stopped on the target



- Previous published result (2009-2011) : $\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 5.7 \times 10^{-13}$ at 90% C.L.
- Full dataset analysis results (7.5×10^{14} stopped muons on target) submitted to EPJC (arXiv: 1605.05081)

Analysis overview

- Blind analysis
- Five observables
 - E_γ , E_e , $t_{e\gamma}$, $\theta_{e\gamma}$, $\phi_{e\gamma}$
- Maximum likelihood analysis

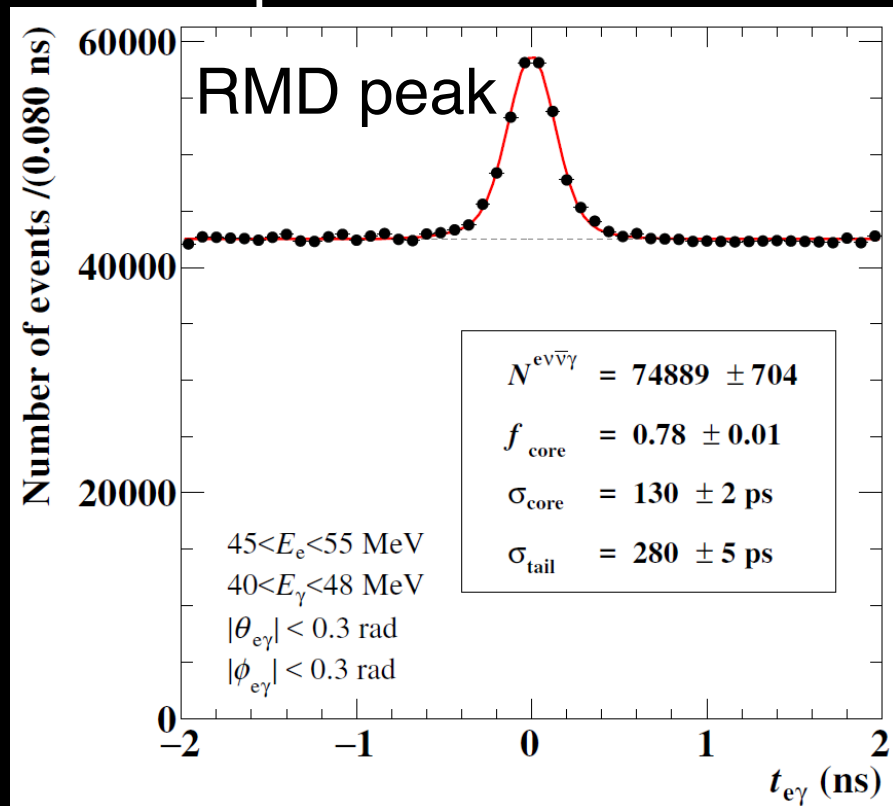


$$\mathcal{L}(N_{\text{sig}}, N_{\text{RMD}}, N_{\text{ACC}}, \mathbf{t}) = \frac{e^{-N}}{N_{\text{obs}}!} C(N_{\text{RMD}}, N_{\text{ACC}}, \mathbf{t}) \times \prod_{i=1}^{N_{\text{obs}}} (N_{\text{sig}} S(\mathbf{x}_i, \mathbf{t}) + N_{\text{RMD}} R(\mathbf{x}_i) + N_{\text{ACC}} A(\mathbf{x}_i))$$

PDFs (S, R, A) determined with detector responses, sideband data etc.

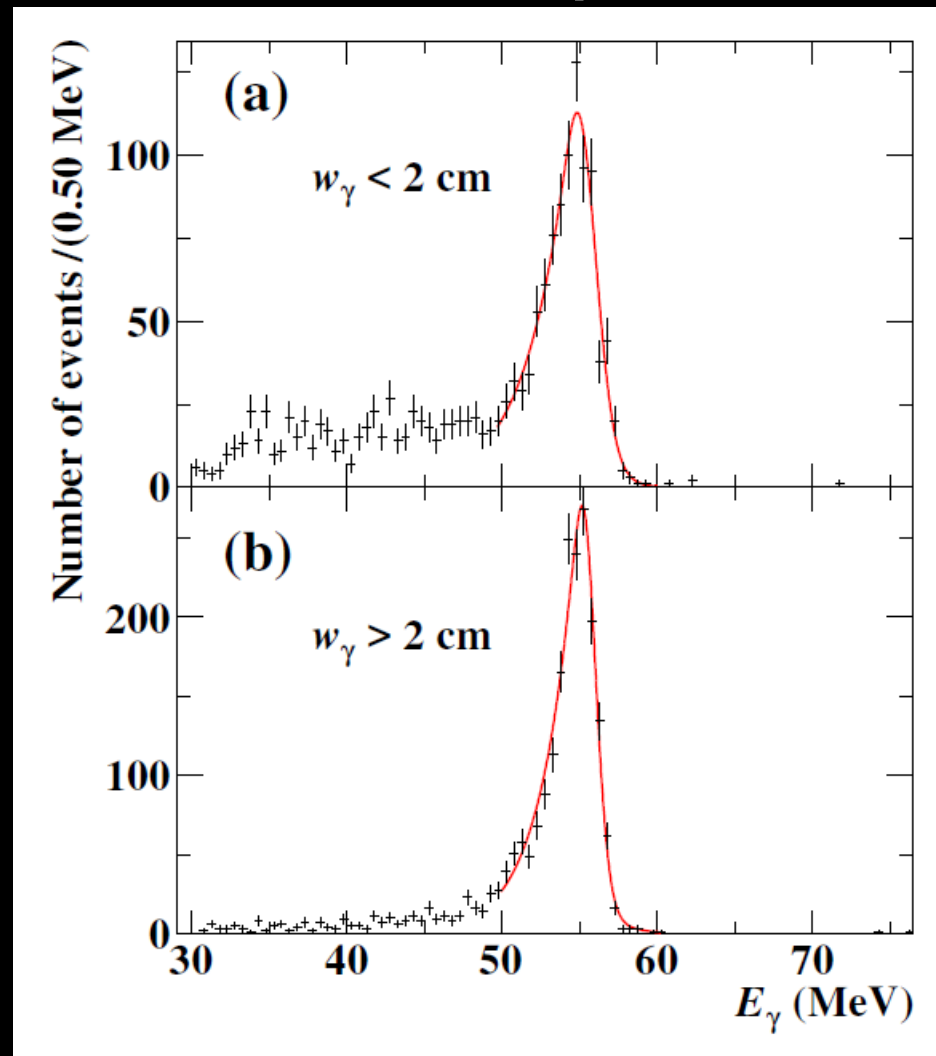
Detector resolutions

$T_{e\gamma}$ distribution



$$\sigma_{te+\gamma} = 122 \pm 4 \text{ ps}$$

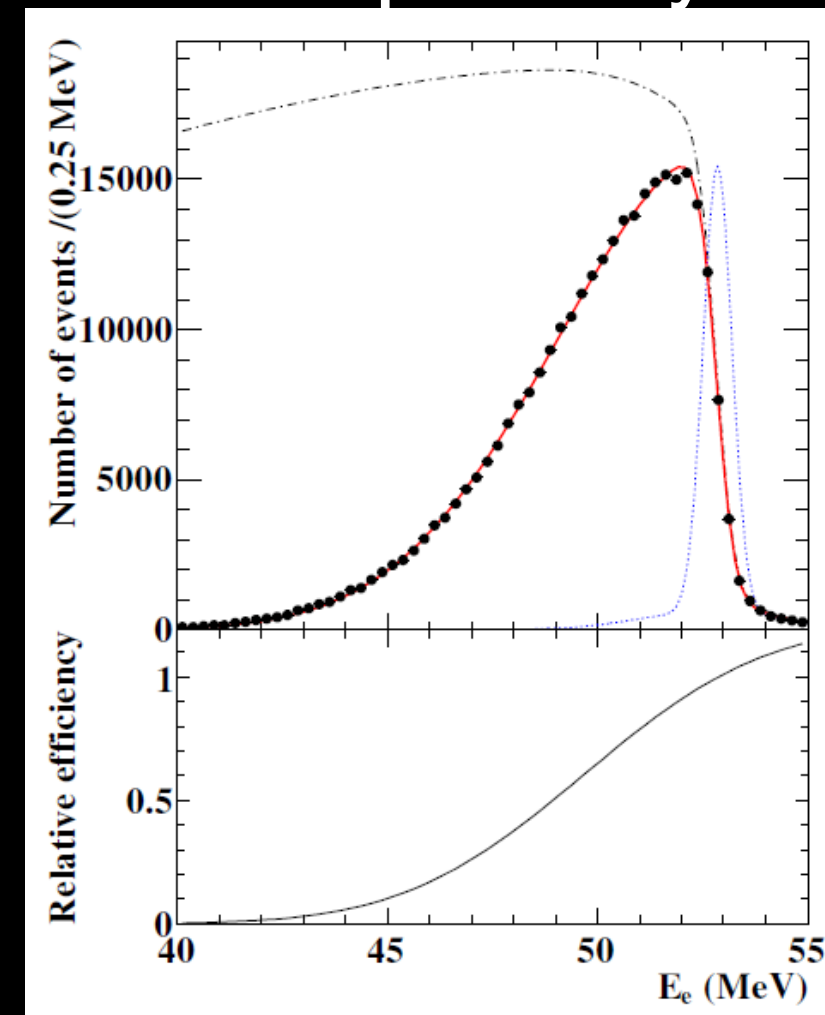
LXe E_γ response to 54.9 MeV photons



$$\sigma_{E_\gamma} = 2.3\% (w < 2 \text{ cm})$$

$$\sigma_{E_\gamma} = 1.6\% (w > 2 \text{ cm})$$

E_e response from μ decay



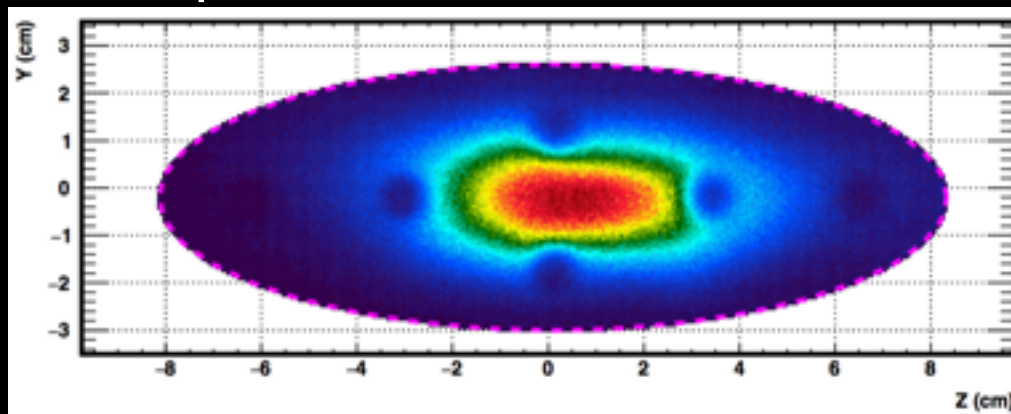
$$\sigma_{E_e} = 300 \text{ keV}$$

Analysis improvements

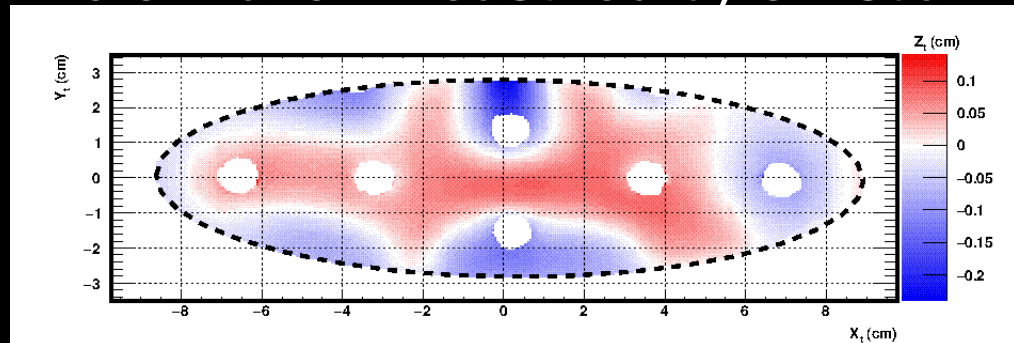
Target alignment and shape



positron vertex distribution

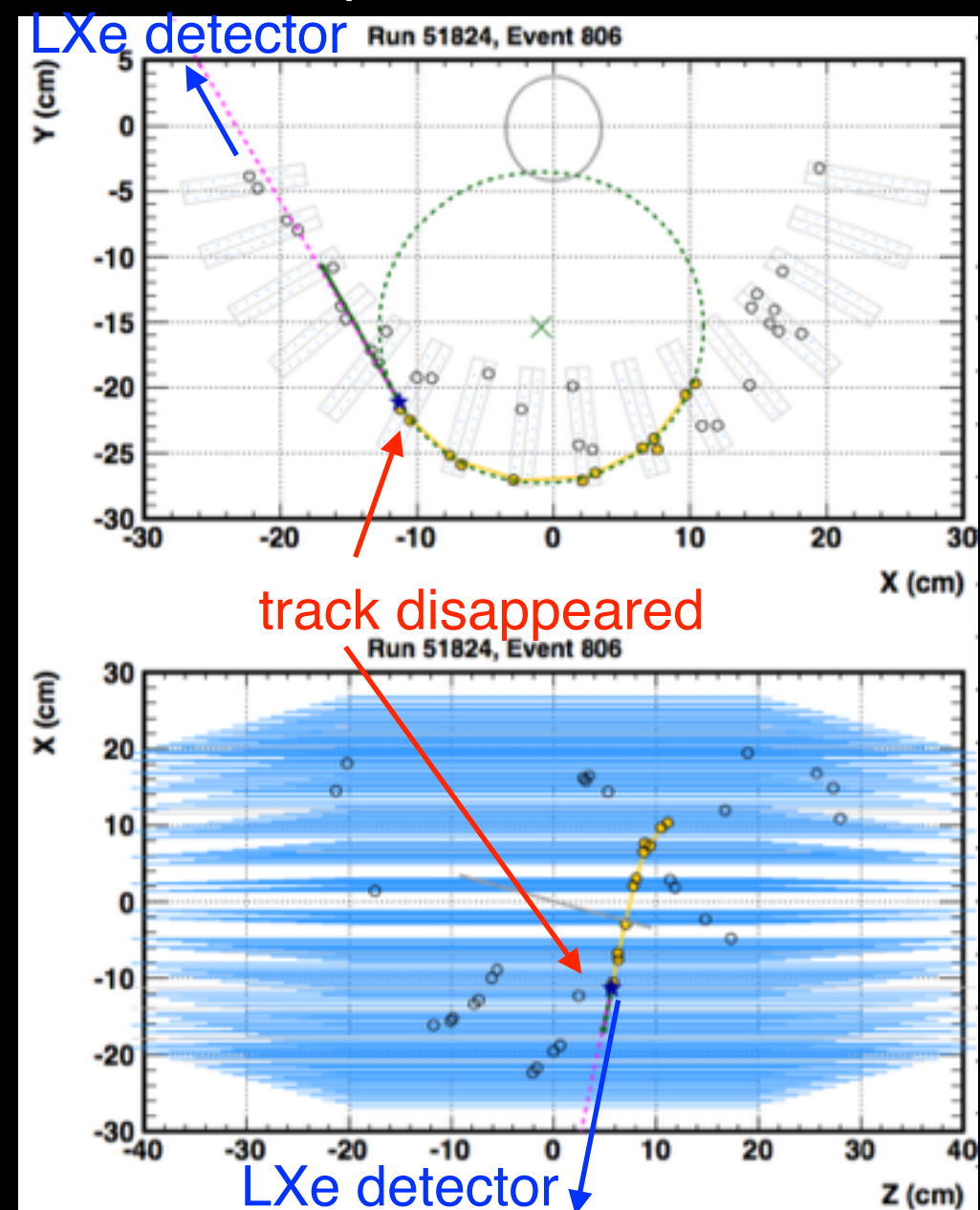


Deformation measured by 3D scanner



Significant contribution to
systematic uncertainty
(13% worse sensitivity)

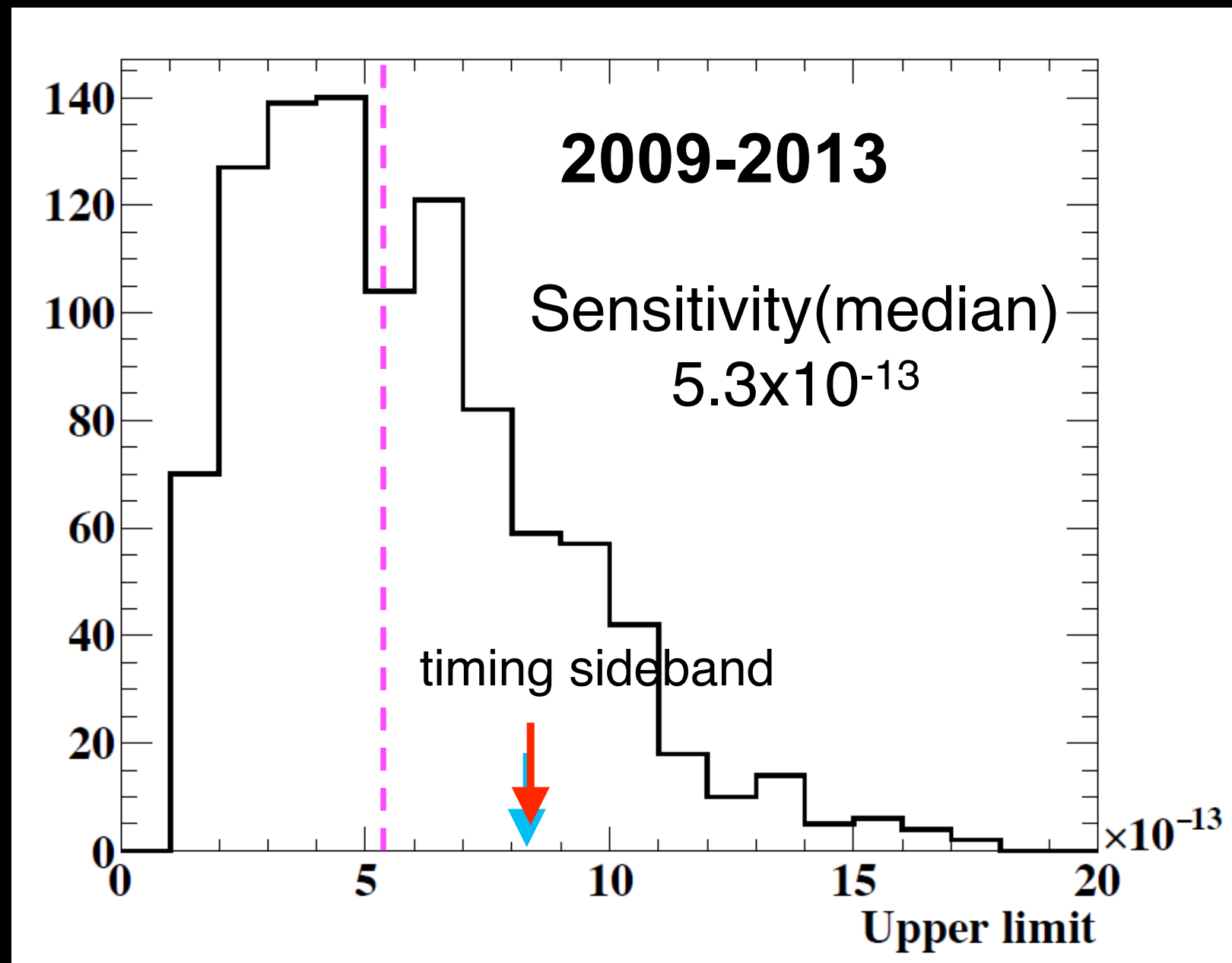
Identification of positron annihilation in flight



Matching γ s with a disappearing positron track
Rejected AIF background events : 1.9%
signal efficiency loss : 1.1%

Final MEG sensitivity

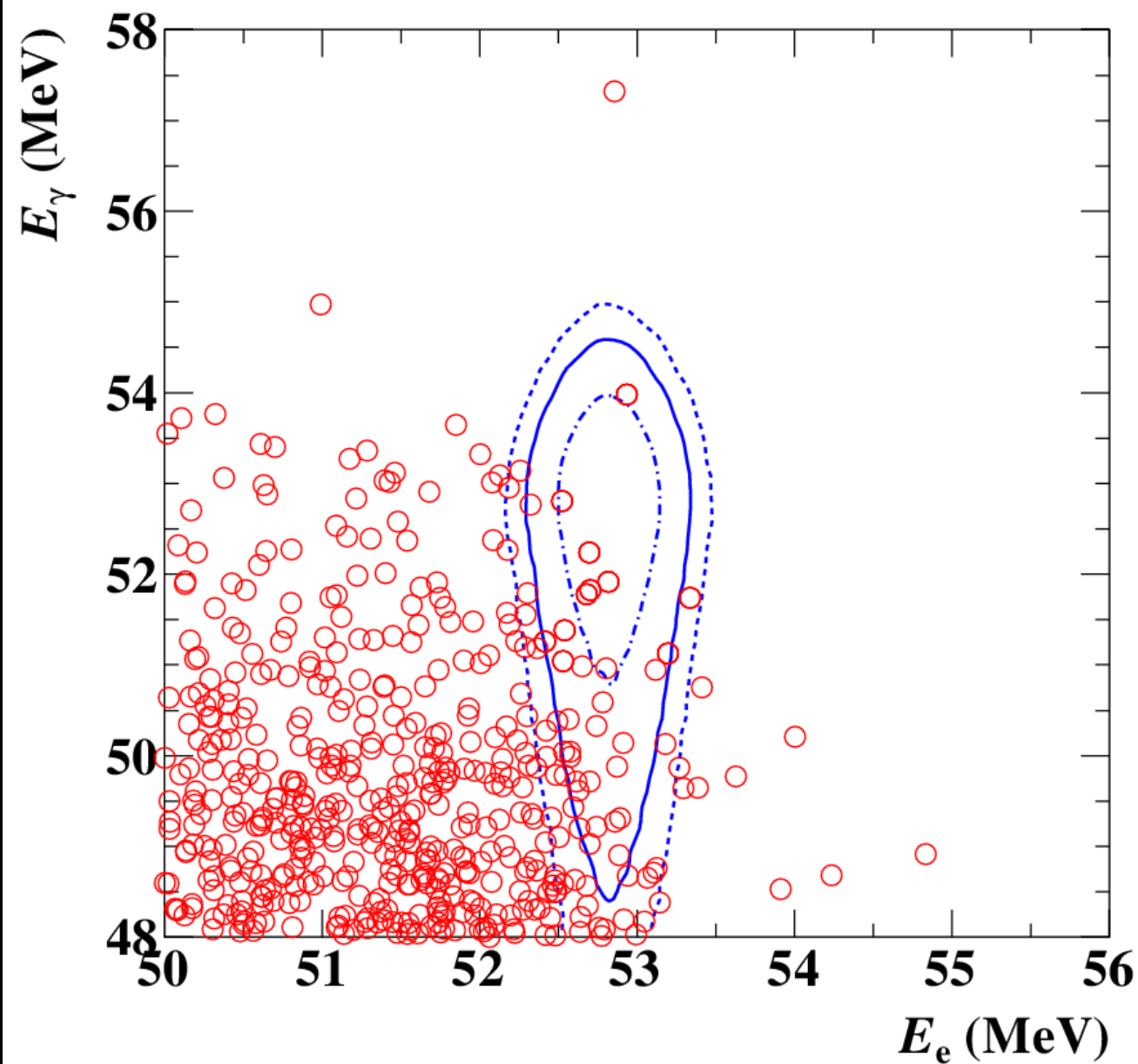
- Distribution of the branching ratio upper limits for MC experiments with null signal hypothesis



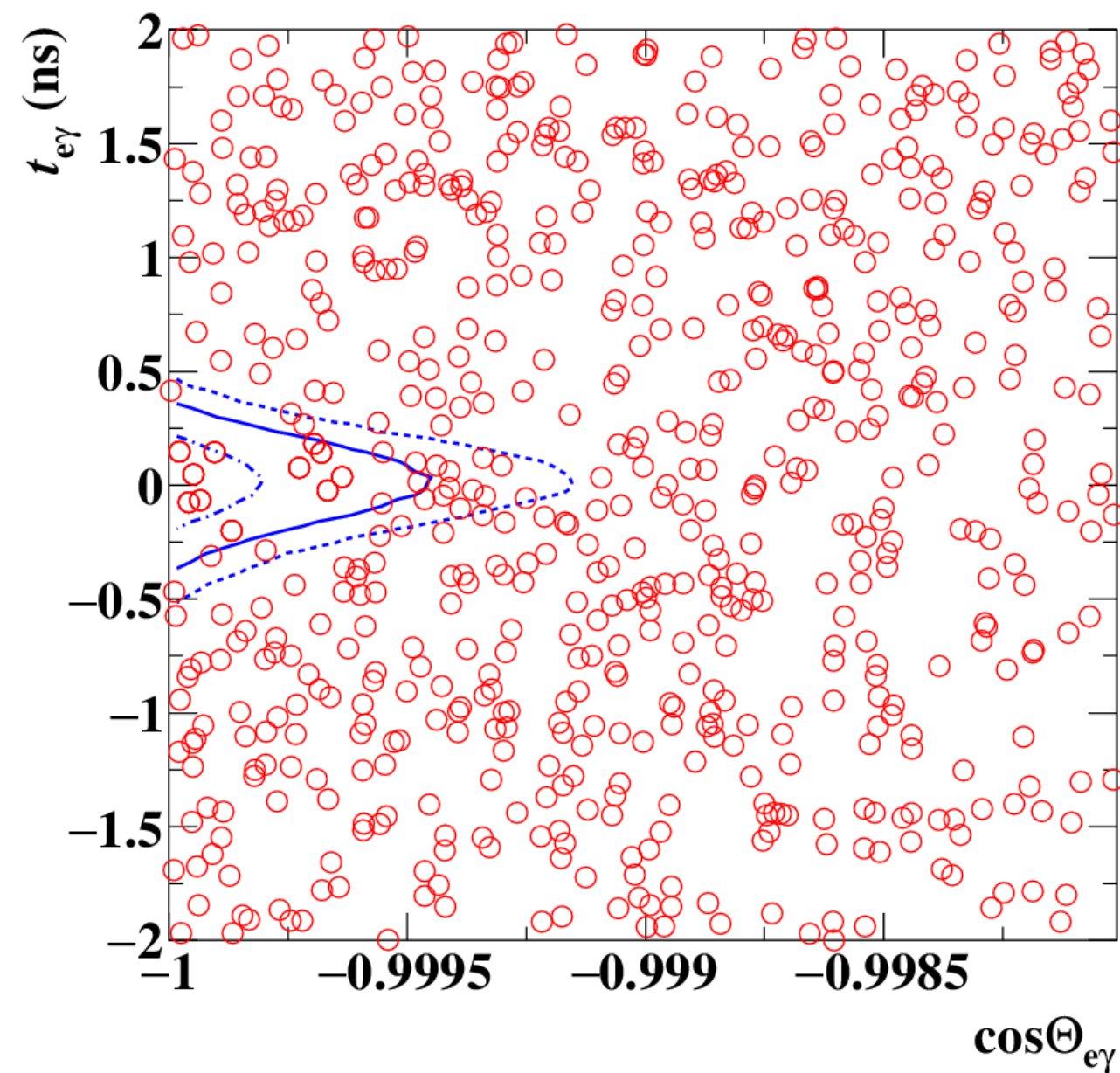
Event distribution

$\cos\Theta < -0.99963$ (90% ϵ_{signal})
 $|t_{\text{ey}}| < 0.2443\text{ns}$ (90% ϵ_{signal})

$51 < E_\gamma < 55.5\text{MeV}$ (74% ϵ_{signal})
 $52.385 < E_e < 55\text{MeV}$ (90% ϵ_{signal})

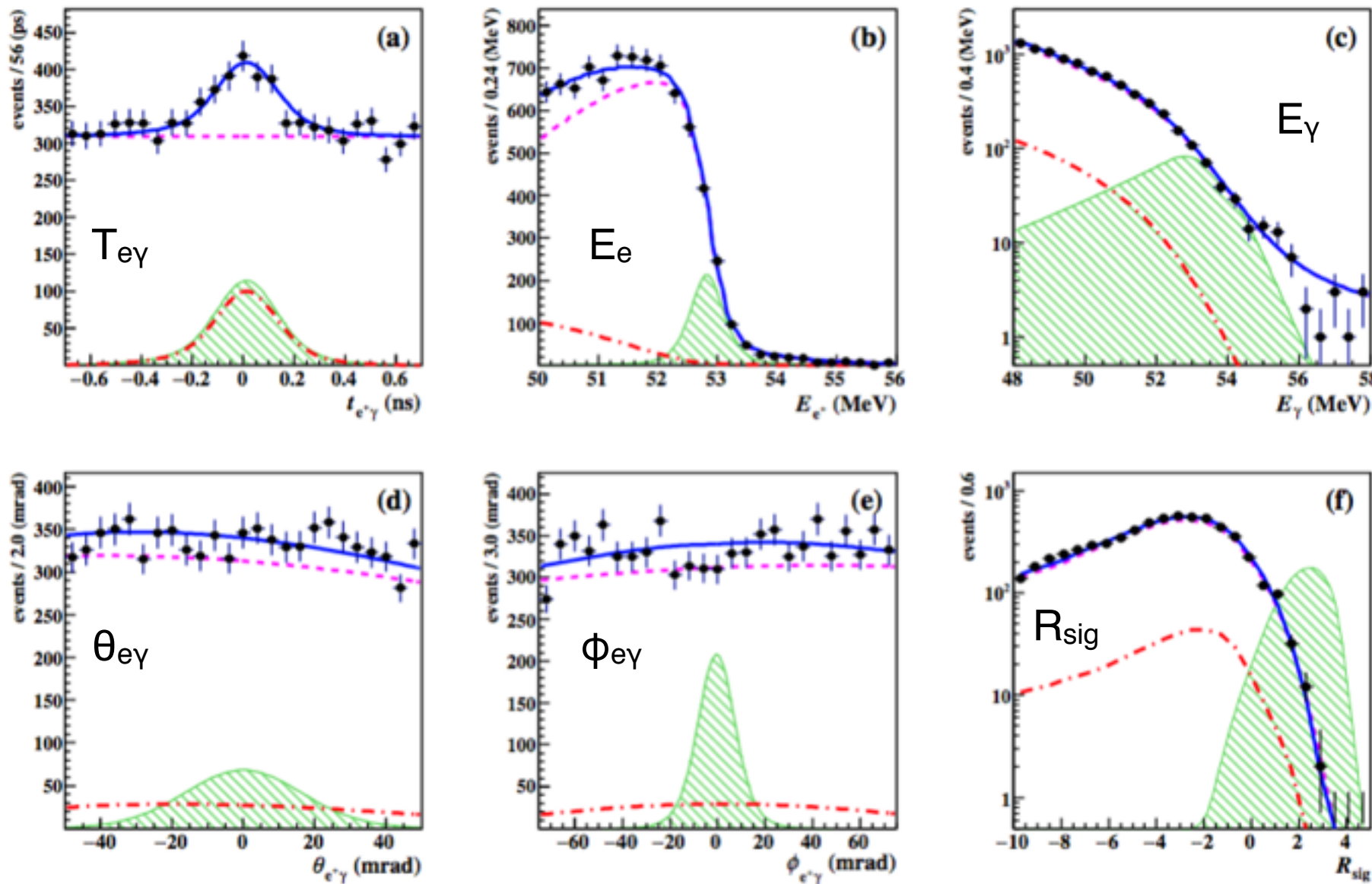


2009-2013 data



Signal PDF contour (1 σ , 1.64 σ , 2 σ)

Likelihood fit result



- $N_{RMD} = 663 \pm 59$
- $N_{ACC} = 7684 \pm 103$
- Consistent with no signal (Signal PDF enhanced)
- All PDFs well consistent with data

$\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 4.2 \times 10^{-13}$ @ 90% C.L.
submitted to EPJC (arXiv:1605.05081)

MEG II Experiment

- Higher muon stopping rate
 - is already available at PSI
- Need better resolutions
 - to reduce accidental background
- Improvement by factor 10 from the MEG results
 - target sensitivity : 4×10^{-14}
- Physics data taking from 2017

MEG II Experiment

Liquid Xenon Gamma-ray Detector
finer granularity at γ incident face

COBRA
Superconducting
Magnet

Gamma ray

PMT \rightarrow
MPPC

Drift Chamber
single volume, stereo wires
transparent for TC

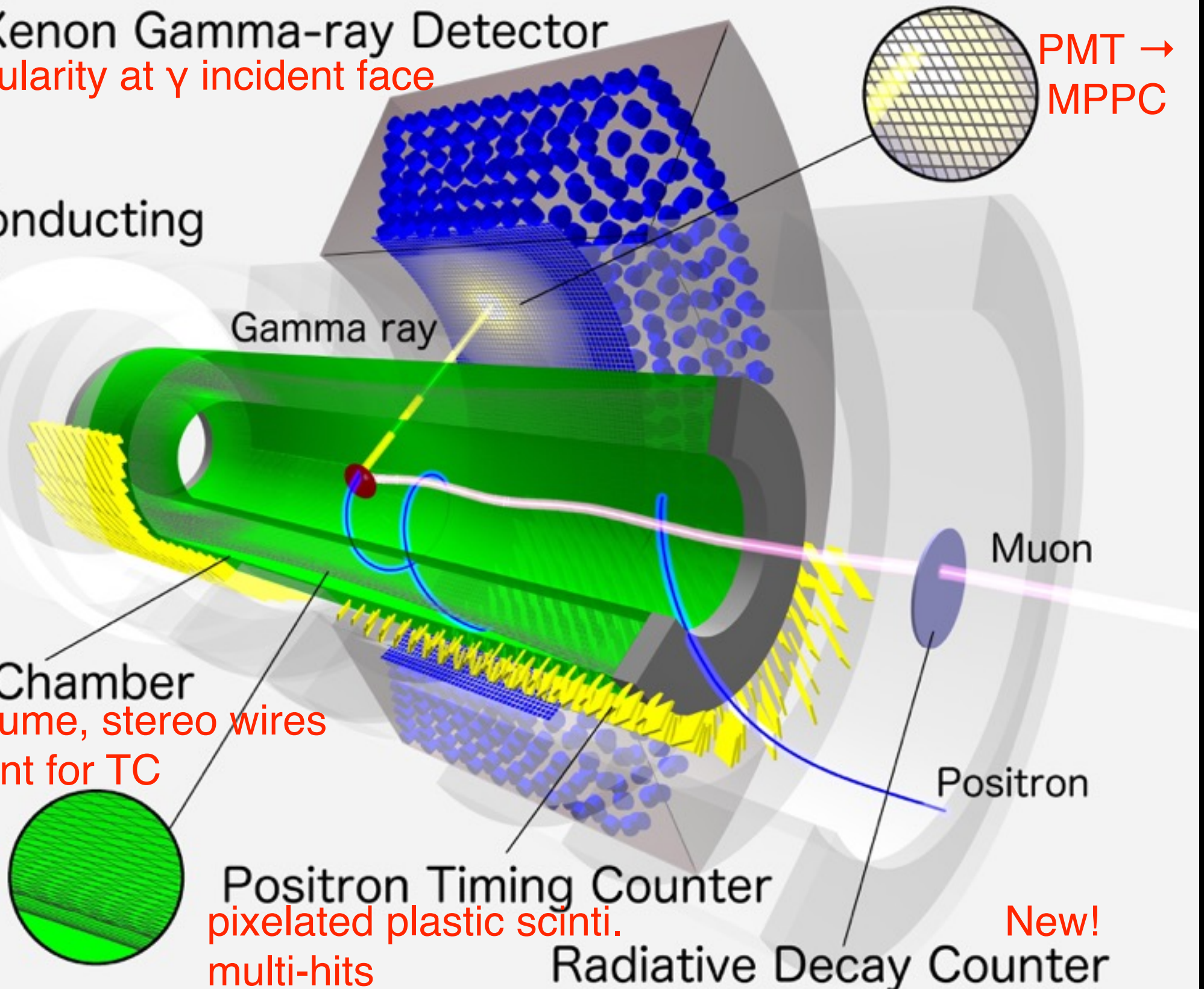
Positron Timing Counter
pixelated plastic scinti.
multi-hits

Radiative Decay Counter

Muon

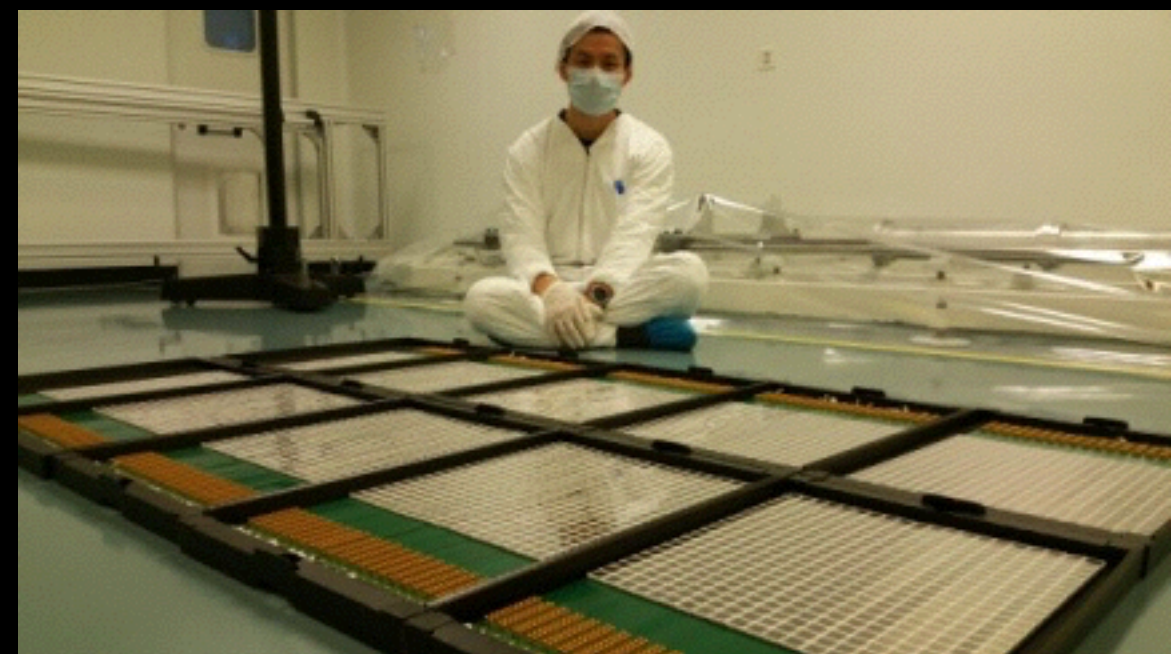
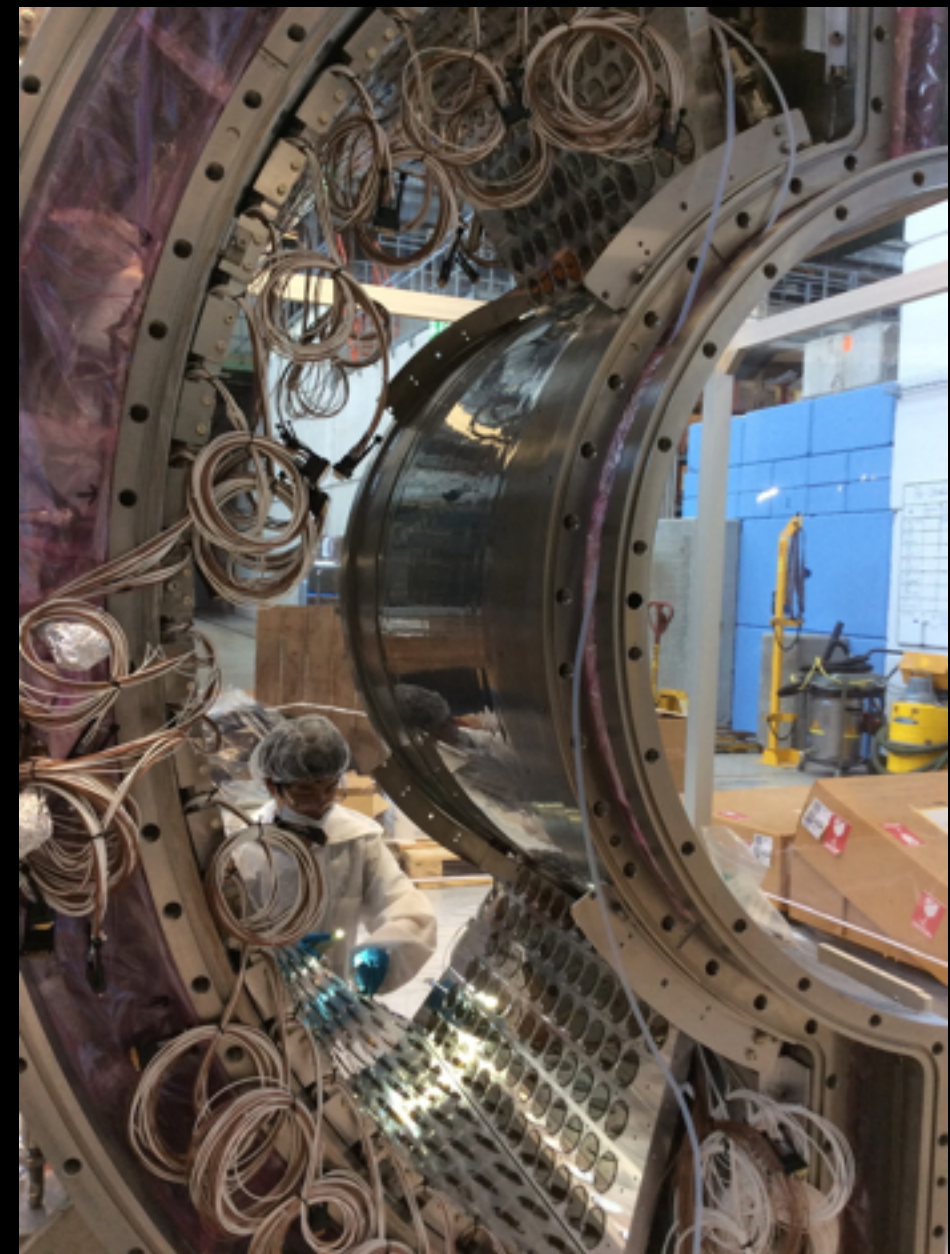
Positron

New!



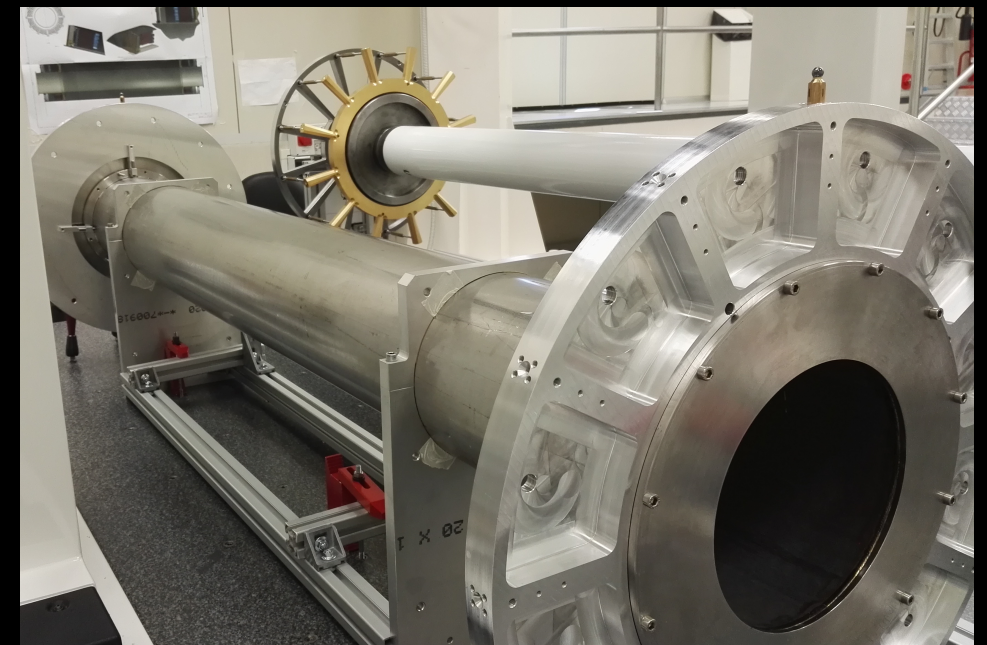
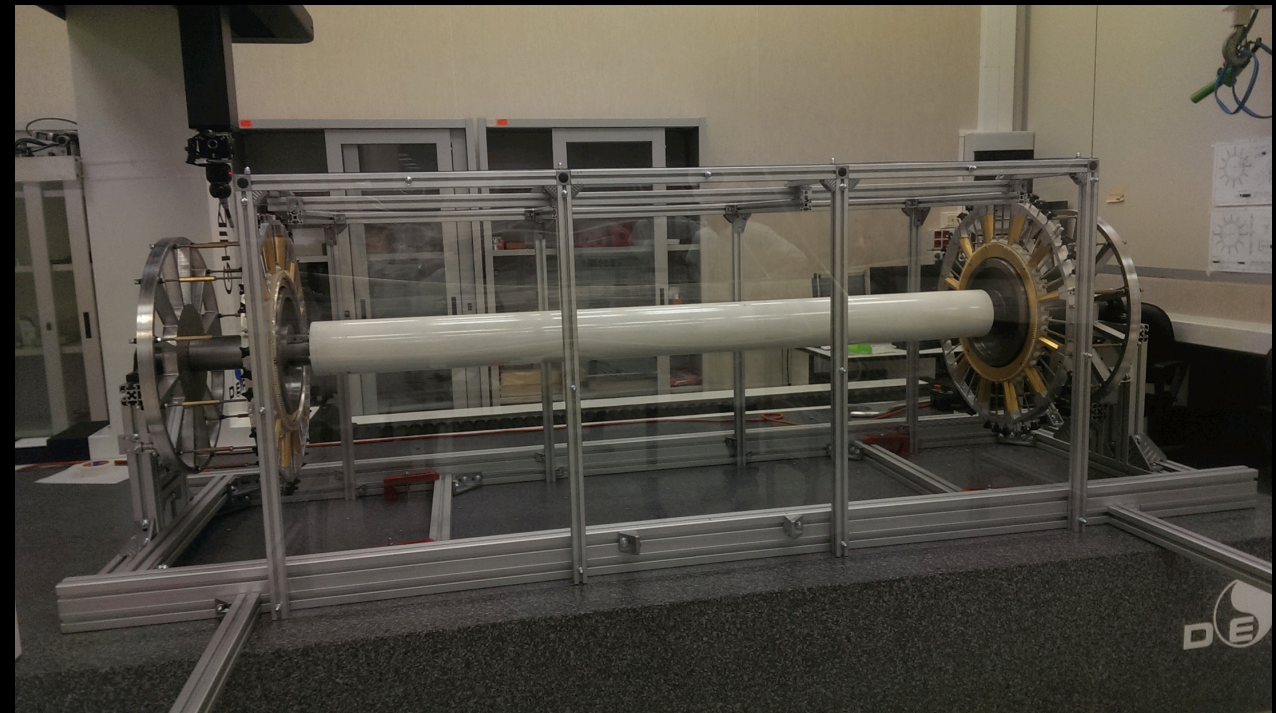
Liquid xenon detector upgrade

- New SiPM developed with HPK (MPPC)
 - can be used in LXe
- 216 2" PMT on γ incident face replaced with 4092 12x12mm² SiPMs
 - finer granularity
 - better position, energy resolutions especially for shallow events
 - $\sigma_{E\gamma} \sim 1\%$, $\sigma_{xy/z} = 2/5\text{mm}$
- Detector construction in progress
 - MPPCs will be mounted soon on the γ incident face
 - LXe into the detector this autumn



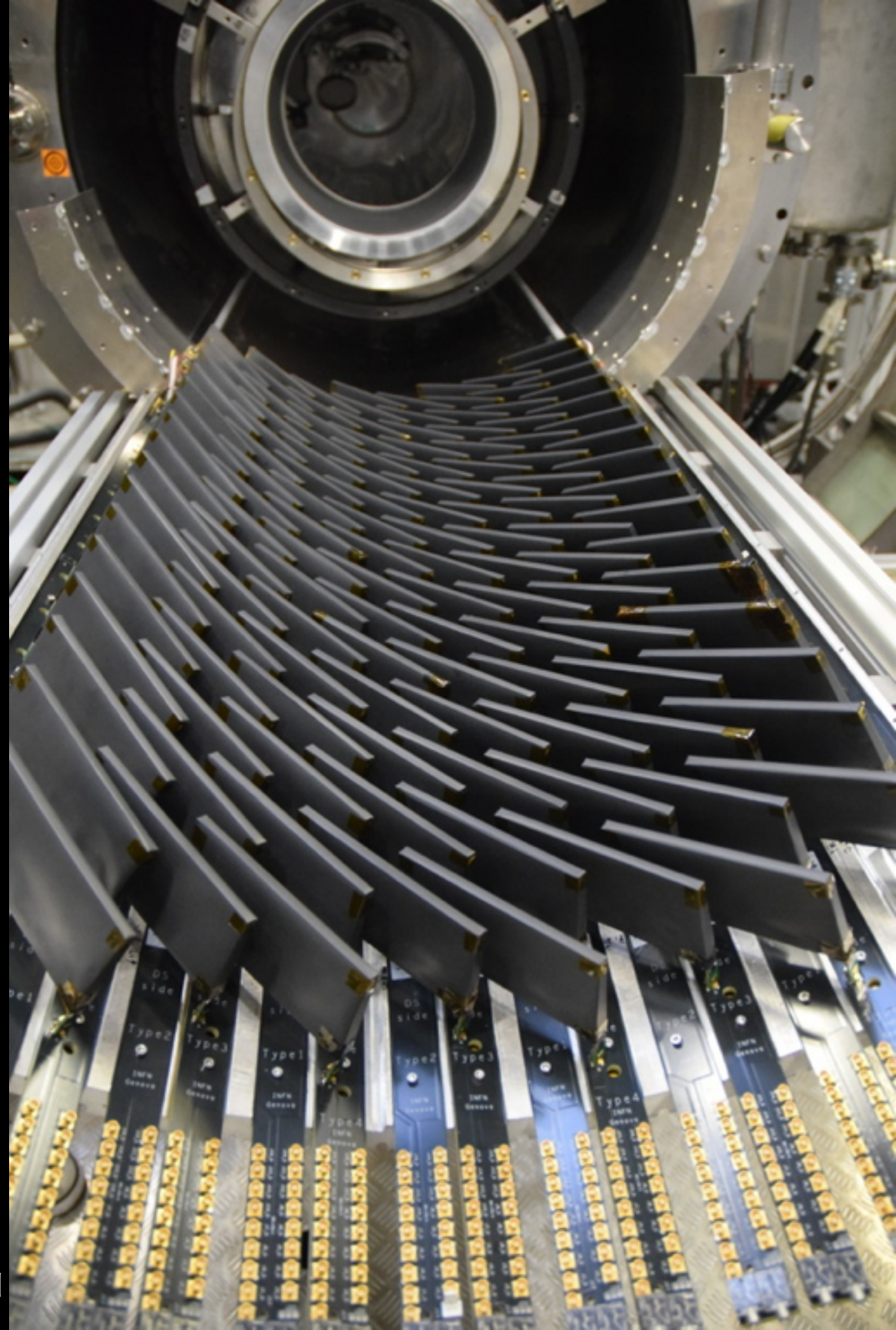
Drift chamber upgrade

- Cylindrical drift chamber
 - Single volume
 - 2m long stereo wires
 - Low mass
 - More hits, better resolution
 - $\sigma_{Ee} \sim 130 \text{ keV}$,
 $\sigma_{\text{angles}} \sim 5 \text{ mrad}$
 - Higher transparency to TC
 - double the detection efficiency
- Drift chamber wiring started
- Chamber completed spring 2017



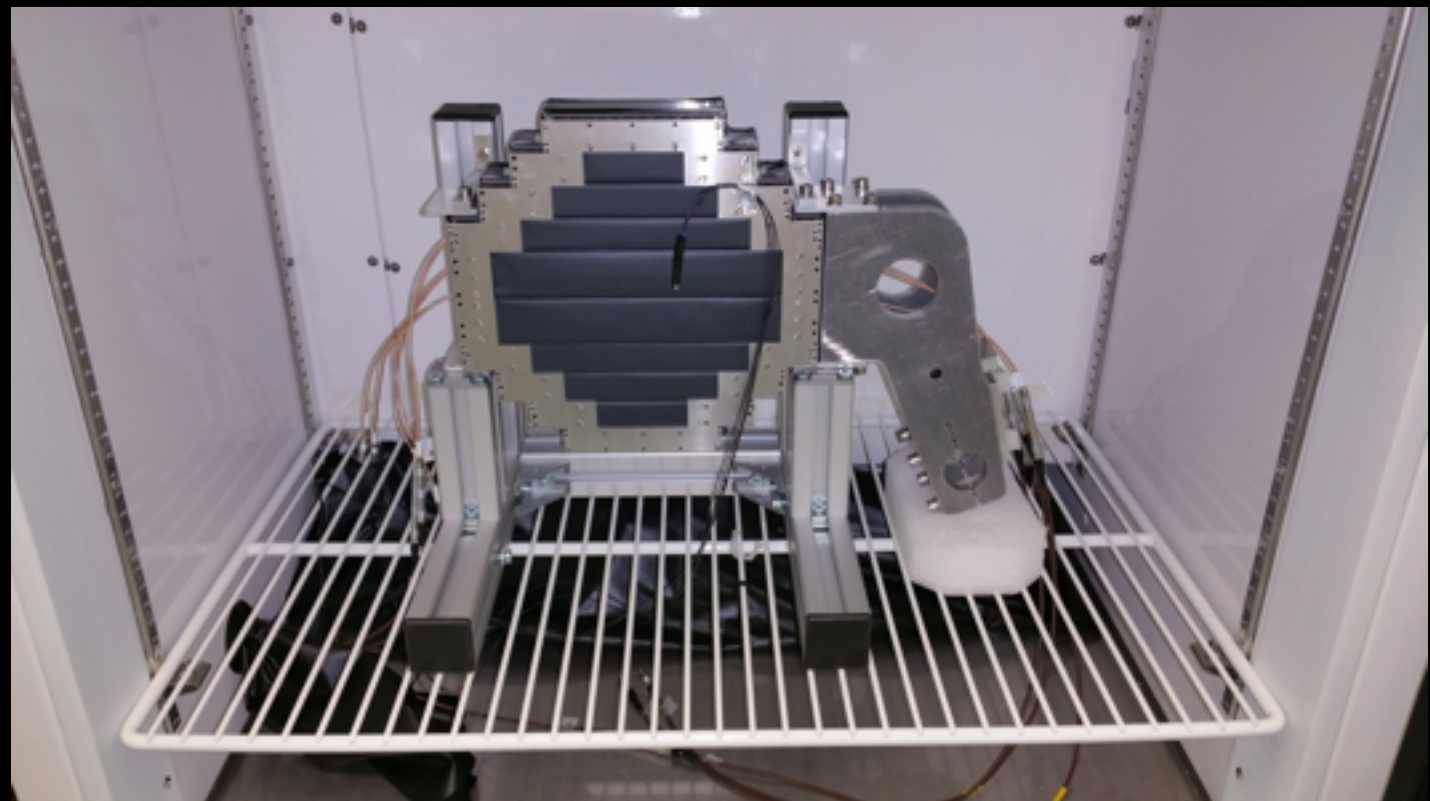
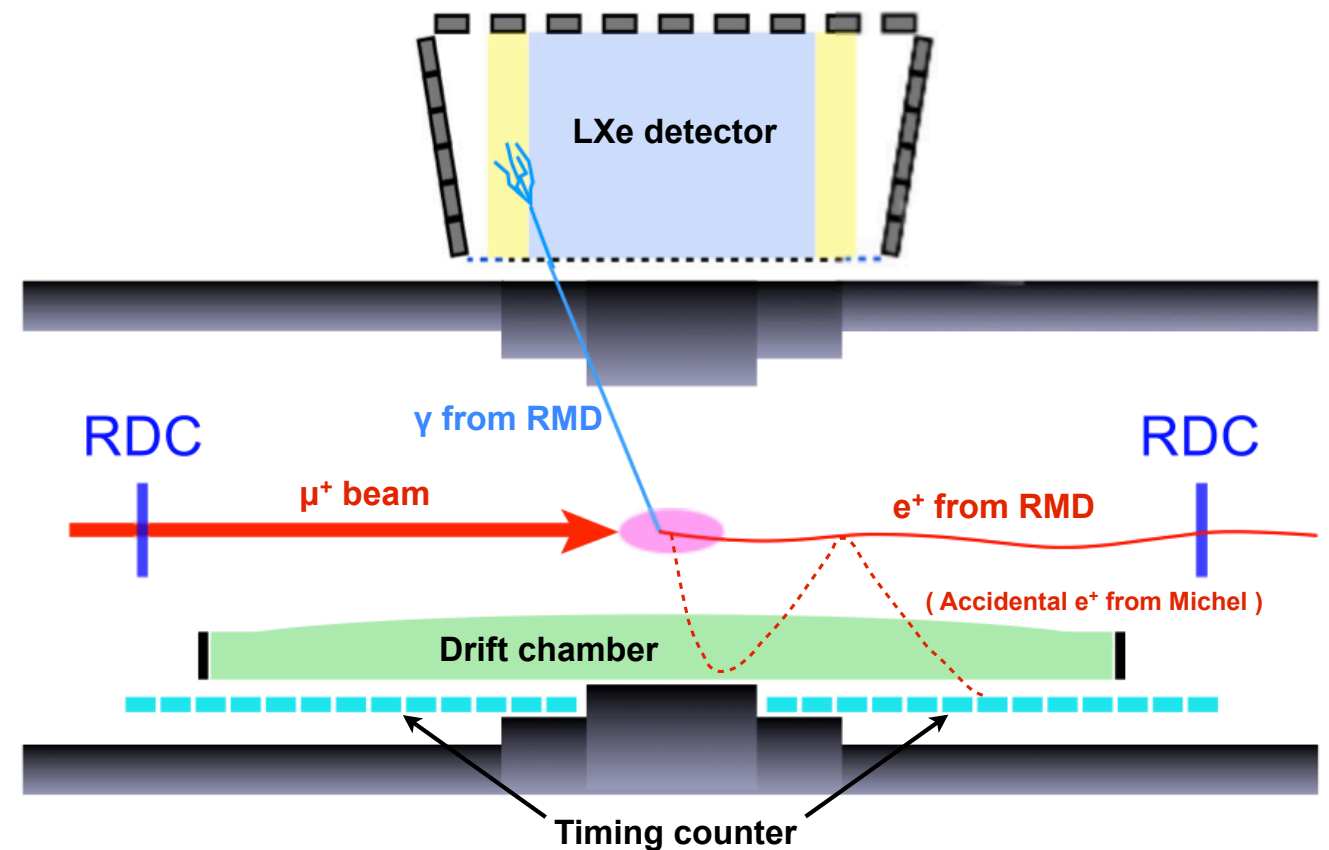
New positron timing counter

- Pixelated scintillator counters read out by SiPM
 - Multi counter hits for e^+ :
 $\sigma \sim 30\text{ps}$
- 1/4 of the new TC assembled, took data twice at PSI last December, this June
- The full TC will be ready this autumn



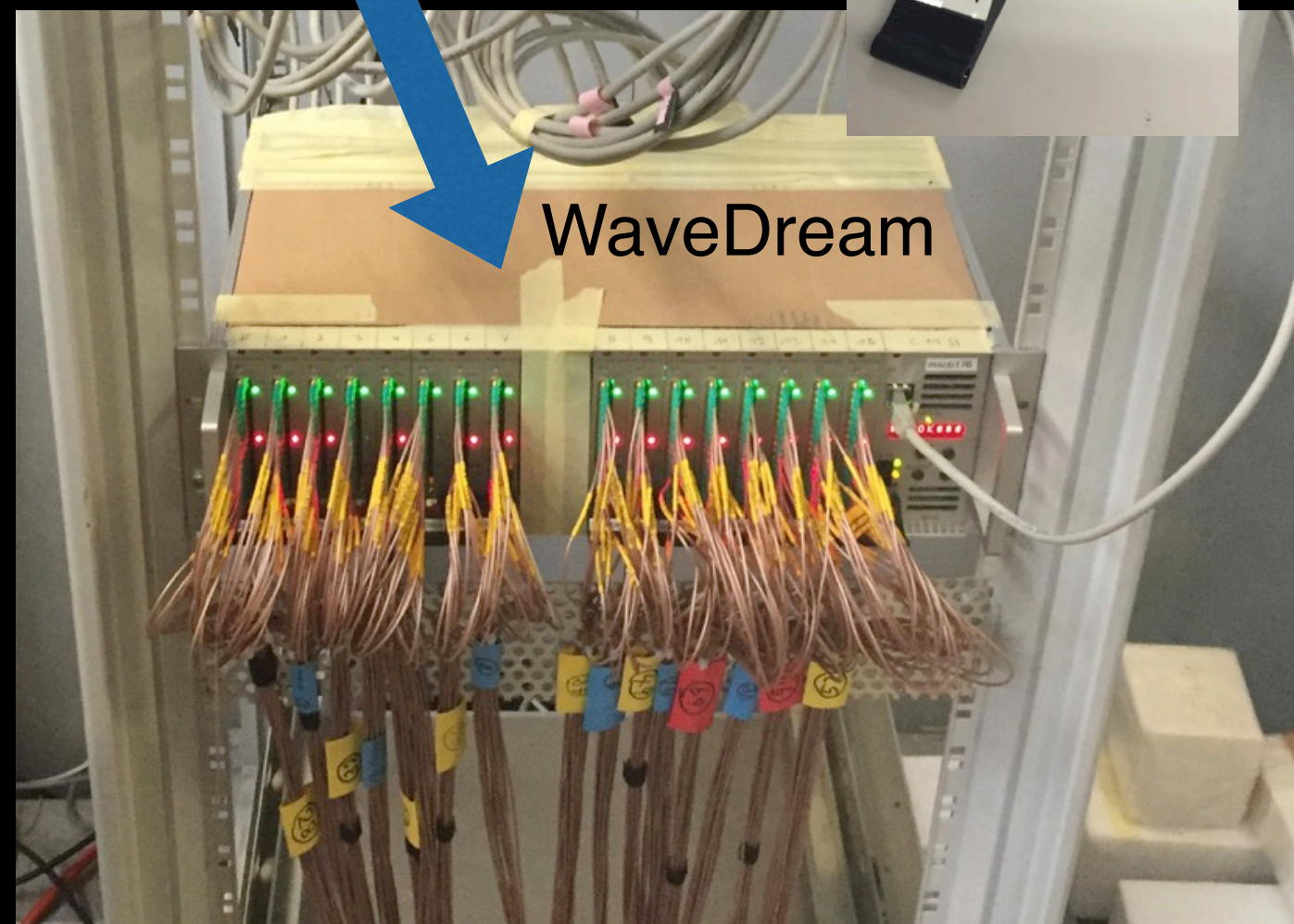
Radiative decay counter

- Many high energy γ s come from RMD in accidental background
- Can be tagged if a positron is found along the beam line in coincidence with γ
- 20-30% improvement of the MEG II sensitivity
- A new detector completed
 - Plastic scintillator + LYSO crystal with MPPC readout
- Beam test this week at PSI



Electronics

- Higher granular detectors
 - More readout ch. (3k \rightarrow 9k)
 - waveform must be recorded
- Waveform digitizer
 - DRS4 VME \rightarrow WaveDREAM
 - higher density
 - bias voltage supply, amplifier for SiPM, and simple trigger are integrated
- The first crate (256ch) is tested by the new TC, RDC system
- Three more crates in autumn 2016, full system in 2017

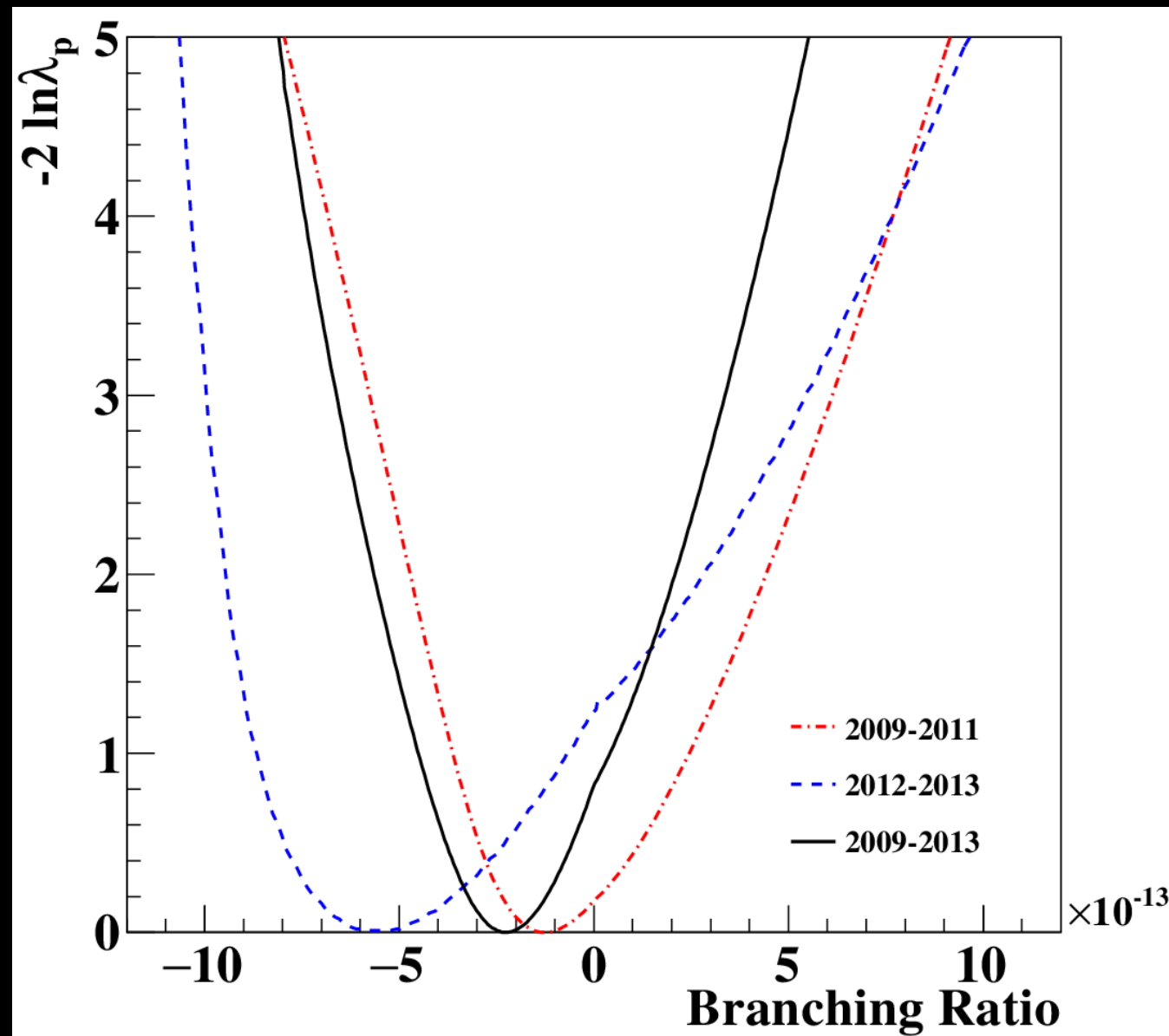


Conclusion

- MEG experiment completed the analysis of the full dataset (7.5×10^{14} μ on target), and established a new constraint on the existence of the LFV $\mu^+ \rightarrow e^+ \gamma$ decay
 - $\text{Br}(\mu^+ \rightarrow e^+ \gamma) < 4.2 \times 10^{-13}$ at 90% C.L.
- MEG II detector is in a construction phase
 - New timing counter, upgraded liquid xenon detector available in 2016, new DCH in early 2017
 - Engineering run and physics run in 2017
 - Target sensitivity : 4×10^{-14} in three years

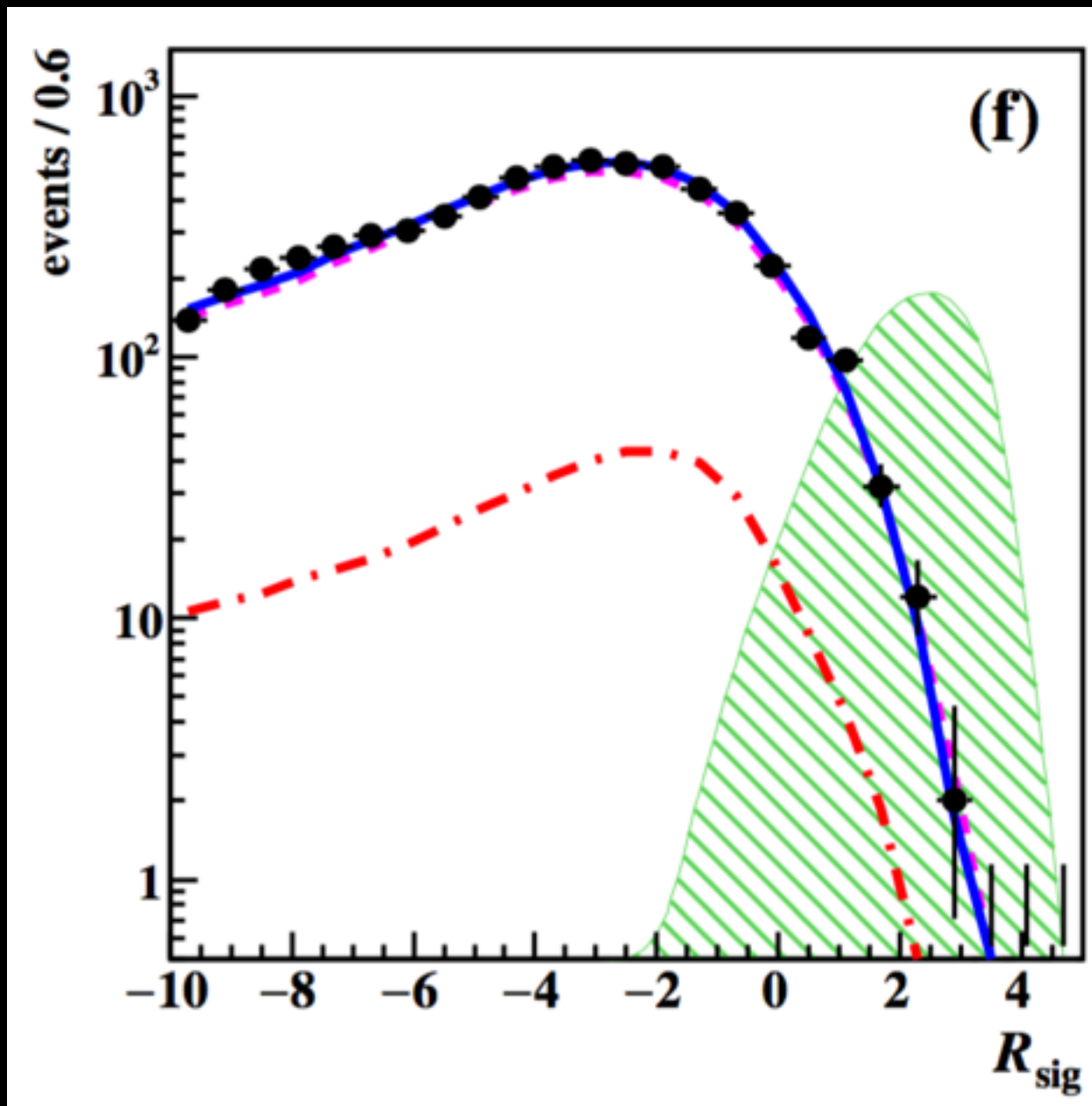
Profile-likelihood ratios as a function of the Br

Negative log-likelihood ratio (λ_p)



Consistent with a null-signal hypothesis

Relative signal likelihood R_{sig}



$$R_{\text{sig}} = \log_{10} \left(\frac{S(x_i)}{f_R R(x_i) + f_A A(x_i)} \right)$$

f_R : fraction of RMD = 0.07

f_A : fraction of ACC = 0.93

from the side-bands