Final result of the MEG experiment and prospects on μ→eγ searches

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on behalf of the MEG collaboration

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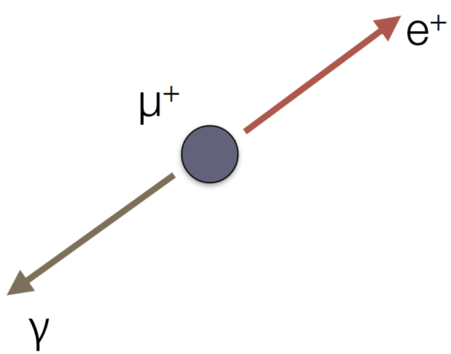
Outline

- Brief history of $\mu \to e\gamma$ searches
- The MEG experiment
- Analysis method
- Final MEG result
- The upgrade: MEG-II
- Prospects

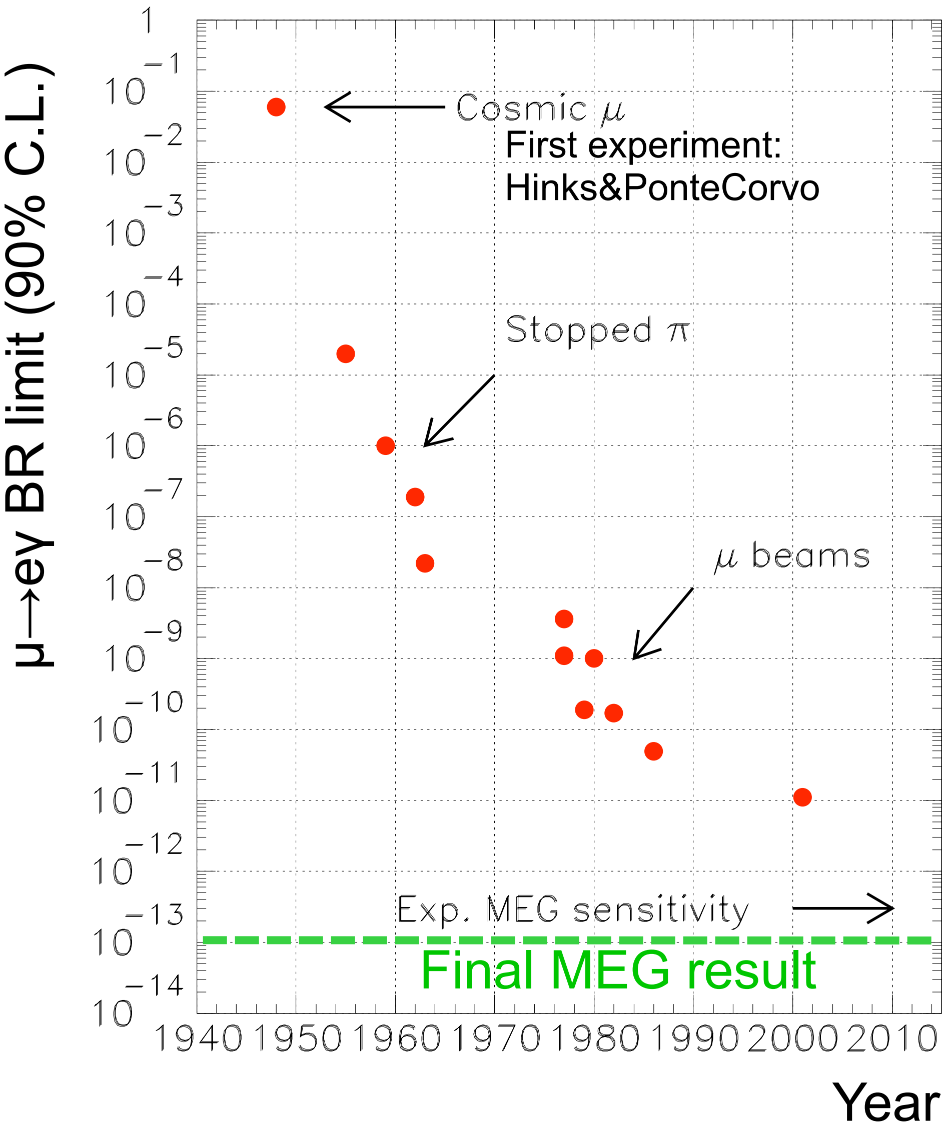
Why $\mu \rightarrow e\gamma$

- Standard Model prediction for BR: $\propto \left(\frac{m_\nu}{m_W}\right)^4 < 10^{-55}$
- Current experimental limit close to predictions in many New Physics models
- Would be clear sign of New Physics
- Intense muon beam available
- Clean experimental signature



Simultaneous back-to-back e^+ and γ with $E_\gamma = E_{e+} = 52.8$MeV

A long quest



The sensitivity greatly improved every time that a more intense muon “source” was available

=> more muons

With a given muon “source” improvements are obtained with detectors improvements

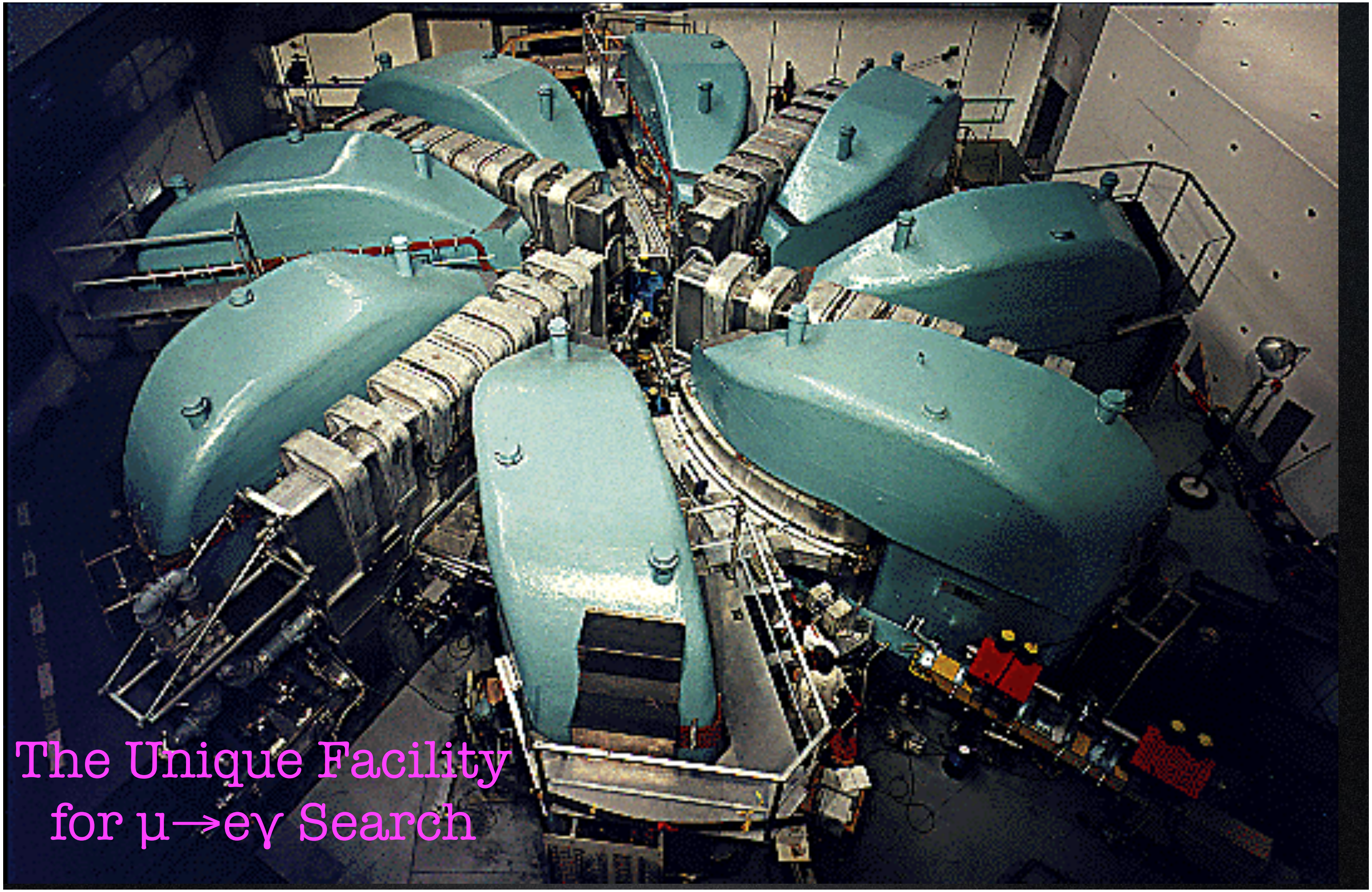
=> lower background

The location: PSI lab

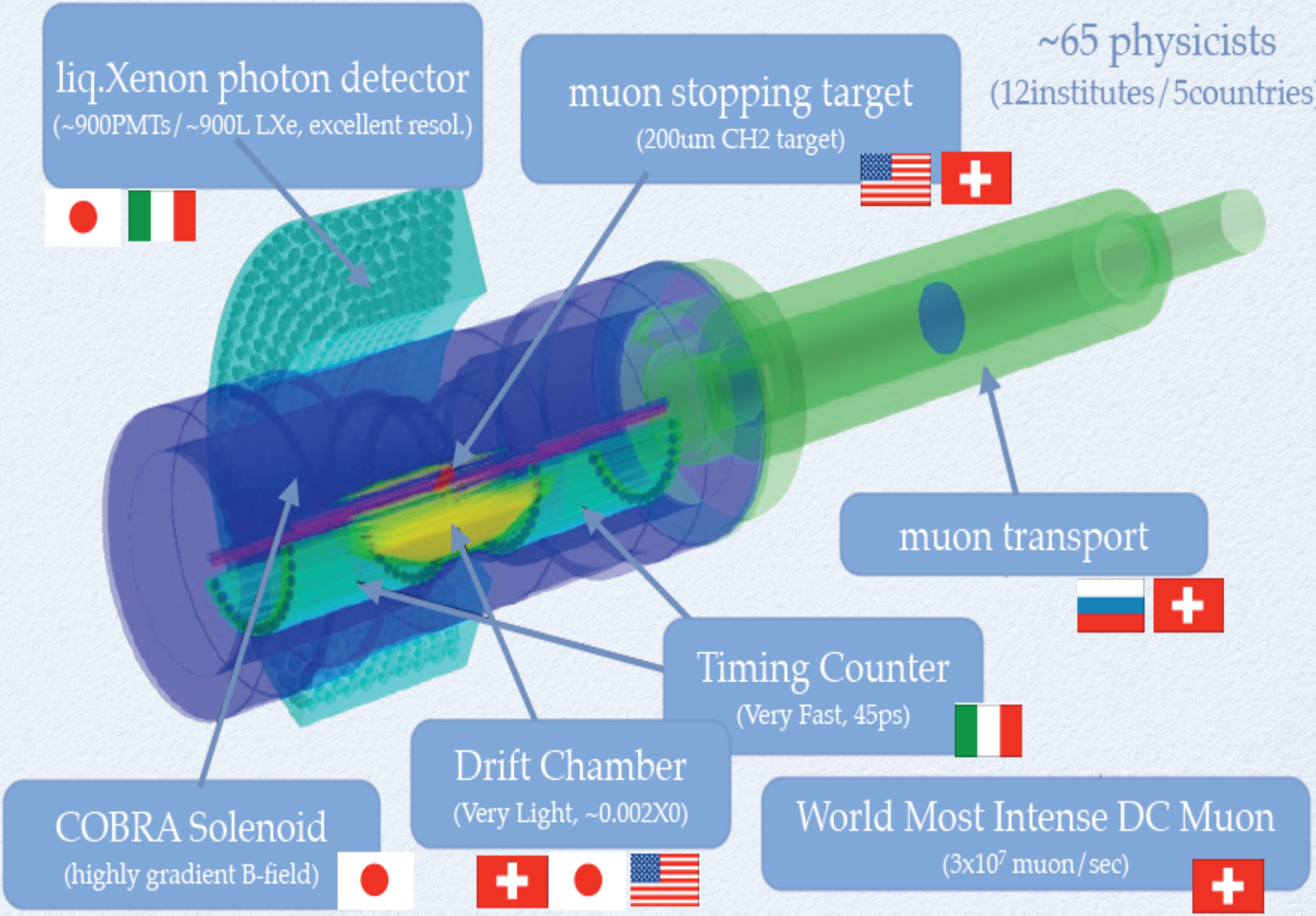
The Paul Scherrer Institute
Continuous muon beam up to 2×10^{8} μ^{+}/s

Multi-disciplinary lab:
- fundamental research, cancer therapy, muon and neutron sources
- protons from cyclotron ($D=15$m, $E_{proton}=590$MeV $I=2.2$mA)

1.4MW Proton Cyclotron at PSI

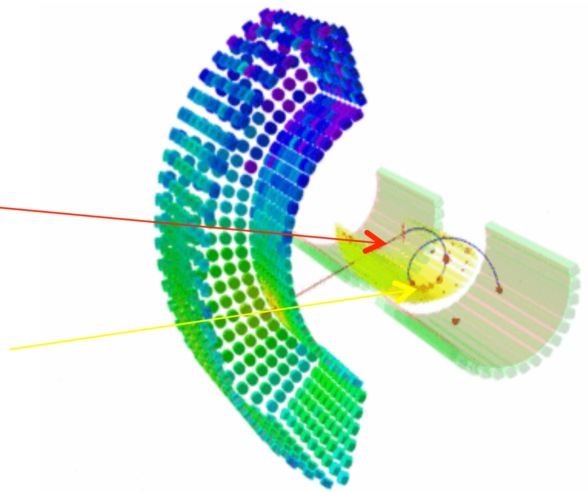


The MEG experiment for μ→eγ search

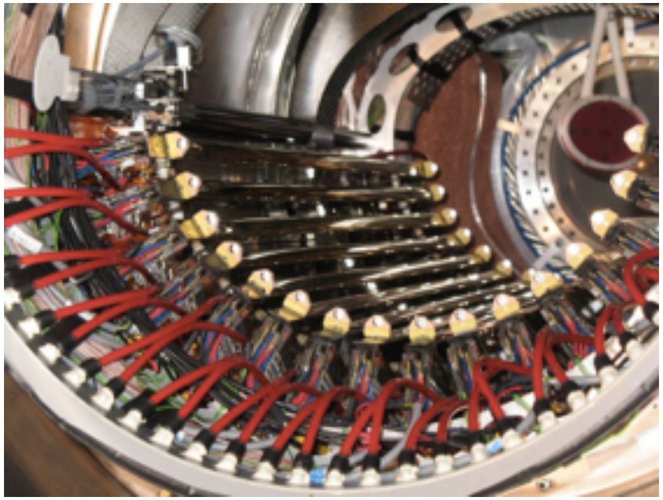


Detector concept: search for μ→eγ

- $I_{\mu} \approx 3 \cdot 10^{7}$ μ/s stopped in a thin plastic target

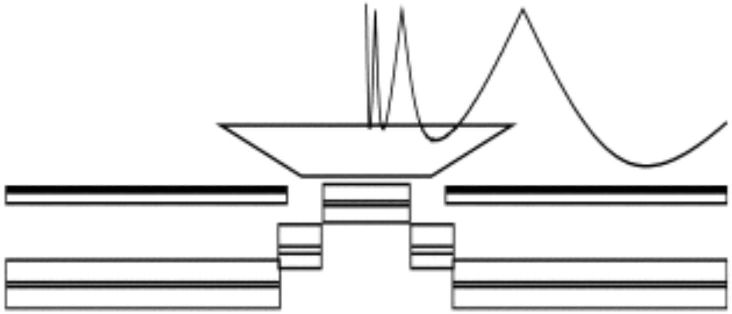


- Drift Chambers in highly-gradient B-field:
  - 16 drift chamber modules
  - very light
  - gradient magnetic field to sweep out Michel positrons



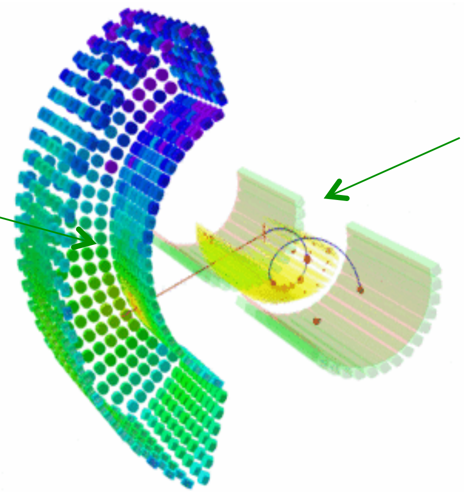
Measure:
- Positron energy E_{e+}
- Positron vertex
- Positron track

Gradient Magnetic Field



Detector concept: search for μ→eγ

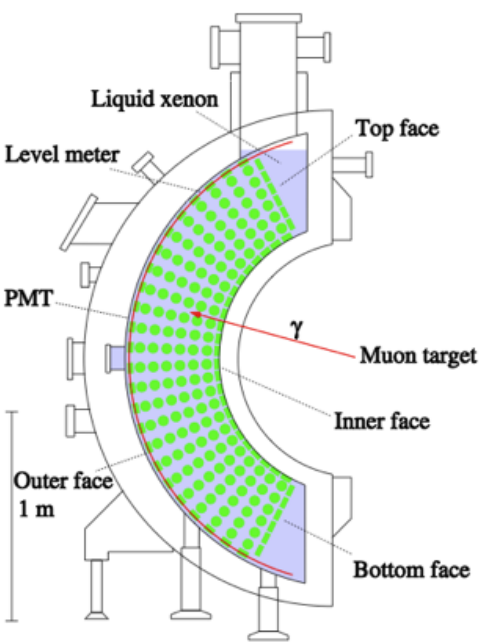
- Liquid Xe Calorimeter
  - 900l liquid Xe
  - read out by PMTs

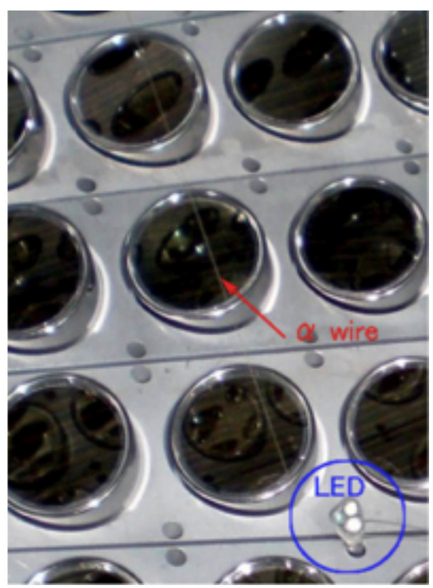


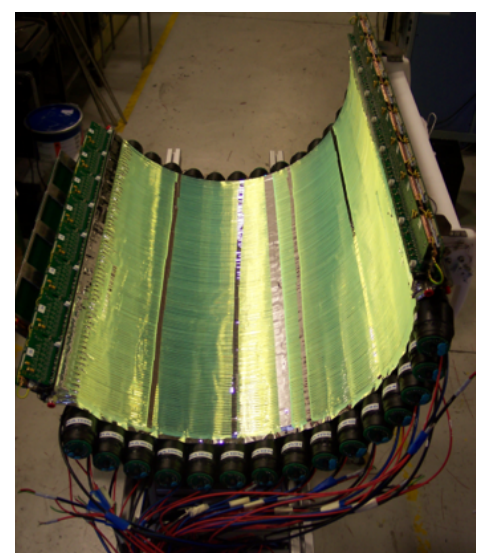
- Timing Counter
  - 15 scintillating bars for two sectors
  - read out by PMTs

Measures:
- Photon energy E_γ
- Photon time and vertex at conversion point

Measures:
- Positron time at impact on TC

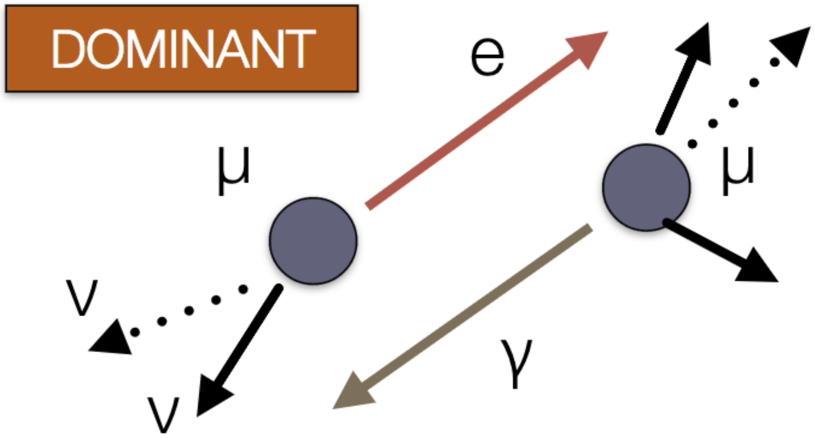




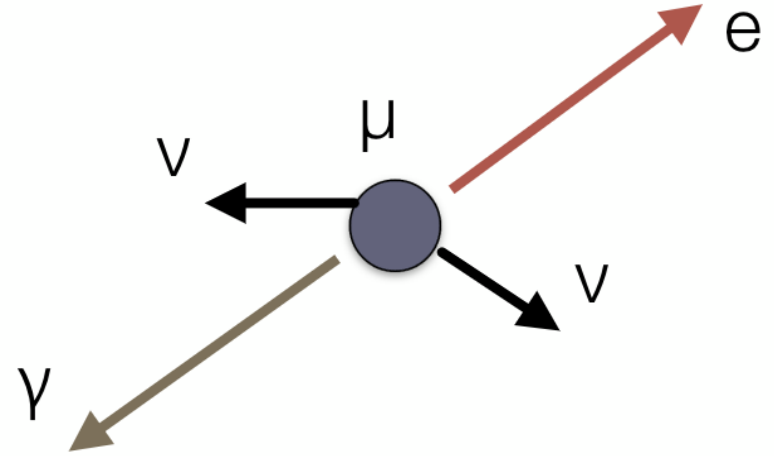


Backgrounds

- Accidental background
  - Accidental coincidence of e^+ and γ:
  - Proportional to I^2_μ while signal proportional to I_μ
  - Compromise between high intensity and low background



- Radiative muon decay background
  - Proportional to I_μ
  - Note: e^+ and γ simultaneous as for signal



Final dataset

- Published results

  - 2008 dataset:

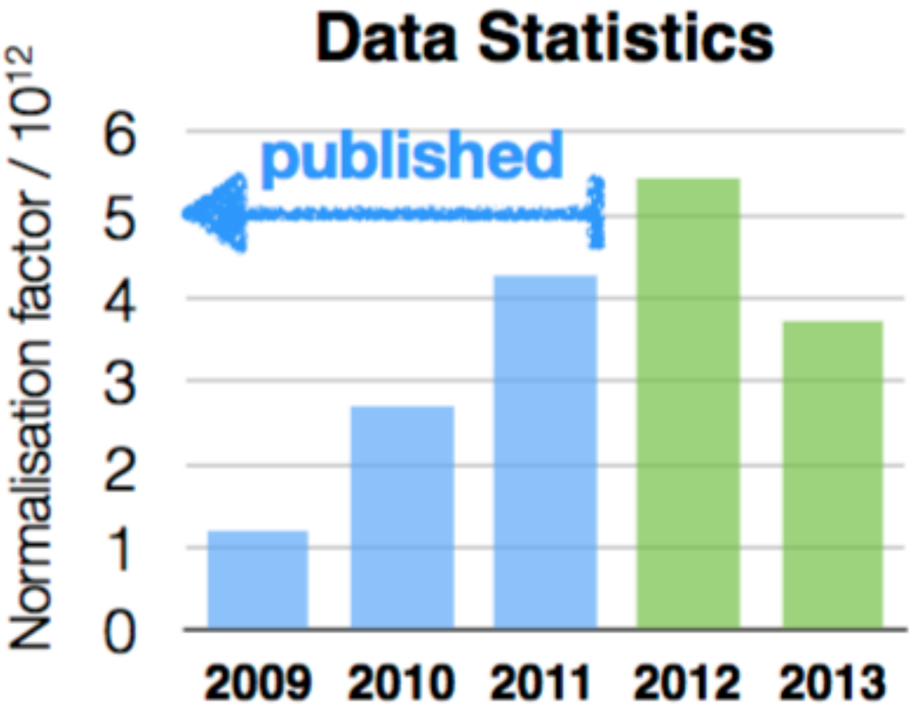
    BR<2.8x10^{-11} @90% CL NPB 834 (2010),1

  - 2009-2010 dataset:

    BR<2.4x10^{-12} @90% CL **PRL,107 171801 (2011)**

  - 2009-2011 dataset:

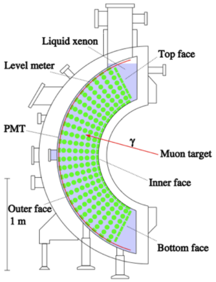
    BR<5.7x10^{-13} @90% CL **PRL 110, 201801 (2013)**



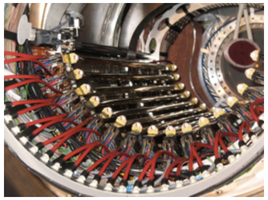
- 2009-2013 data set: **this result**

7.5x10^{14} stopped μ^+

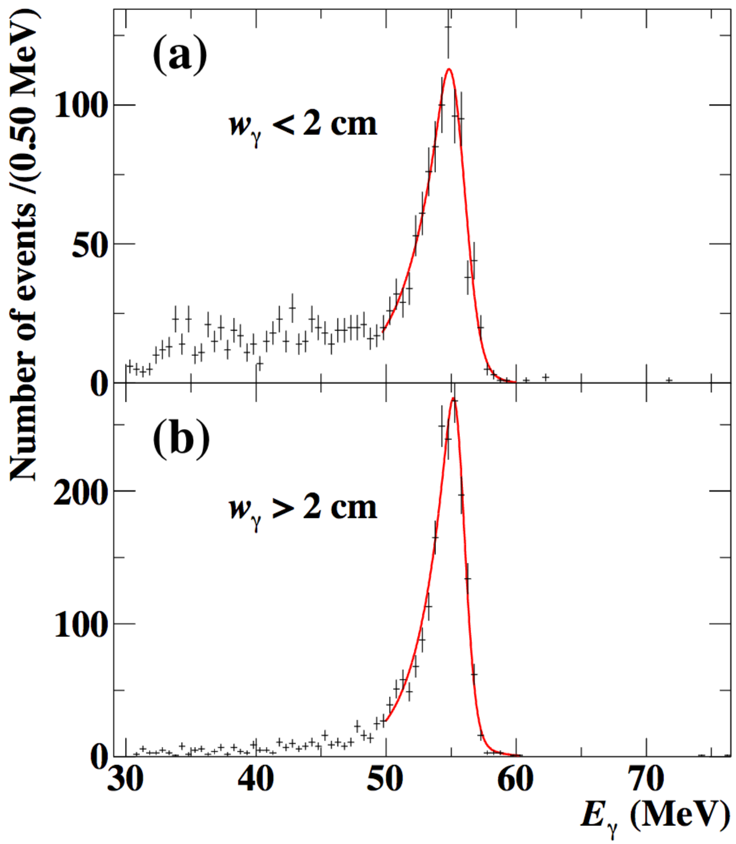
Detector resolutions

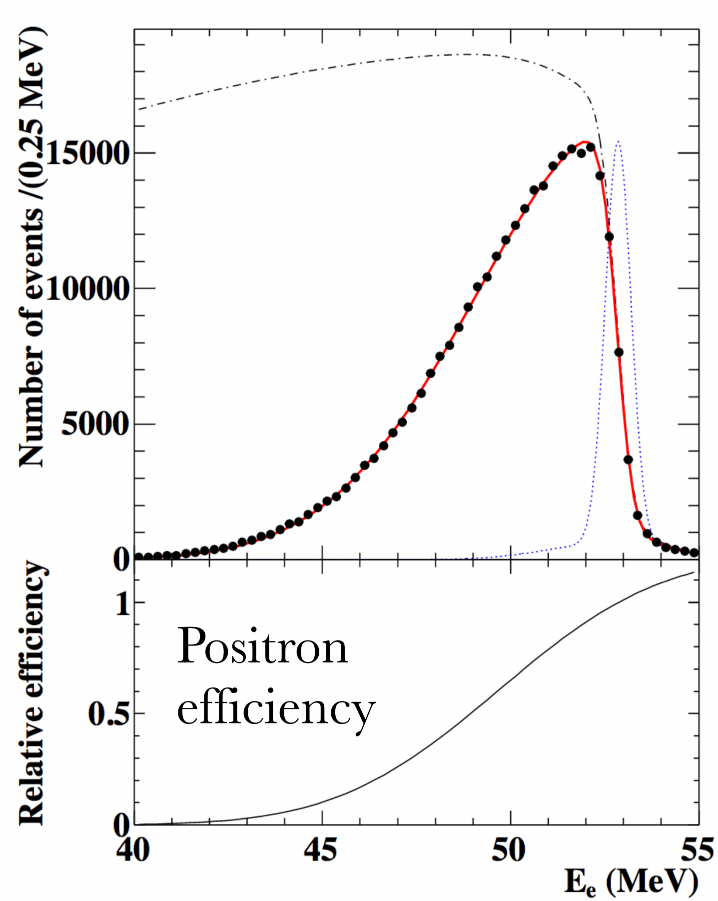


- **Photon energy**
  $\sigma_{E\gamma}$~1.9%
- **Positron energy**
  σ_{Ee+}~300 keV



Shallow and deep events

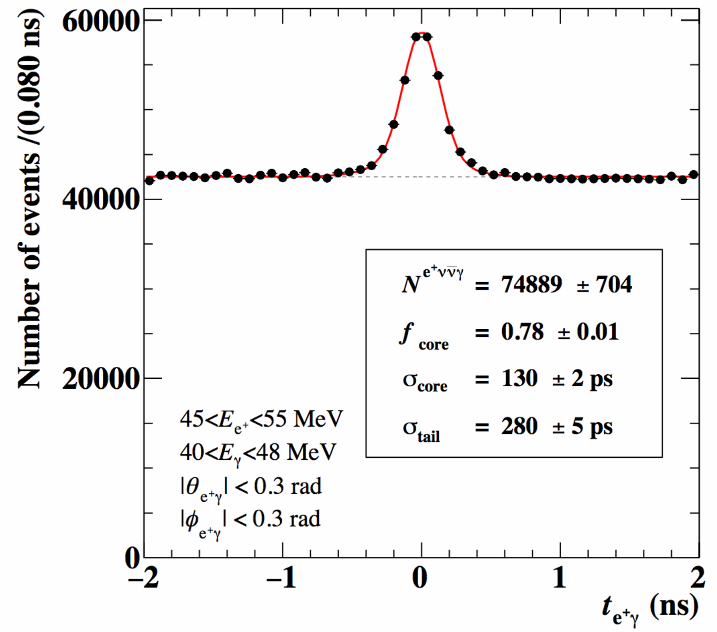




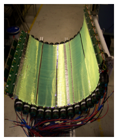
Detector resolutions

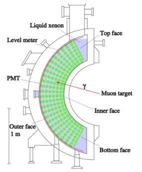
- Relative time $\sigma_{T_{e\gamma}}$~130ps

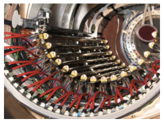
$$T_{e\gamma} = T_{XEC} - \frac{L_\gamma}{c} - \left[T_{TC} - \frac{L_{e+}}{c} \right]$$



- Relative angle
  $\sigma_{\theta e\gamma}$~15mrad,$\sigma_{\varphi\gamma}$~ 9mrad





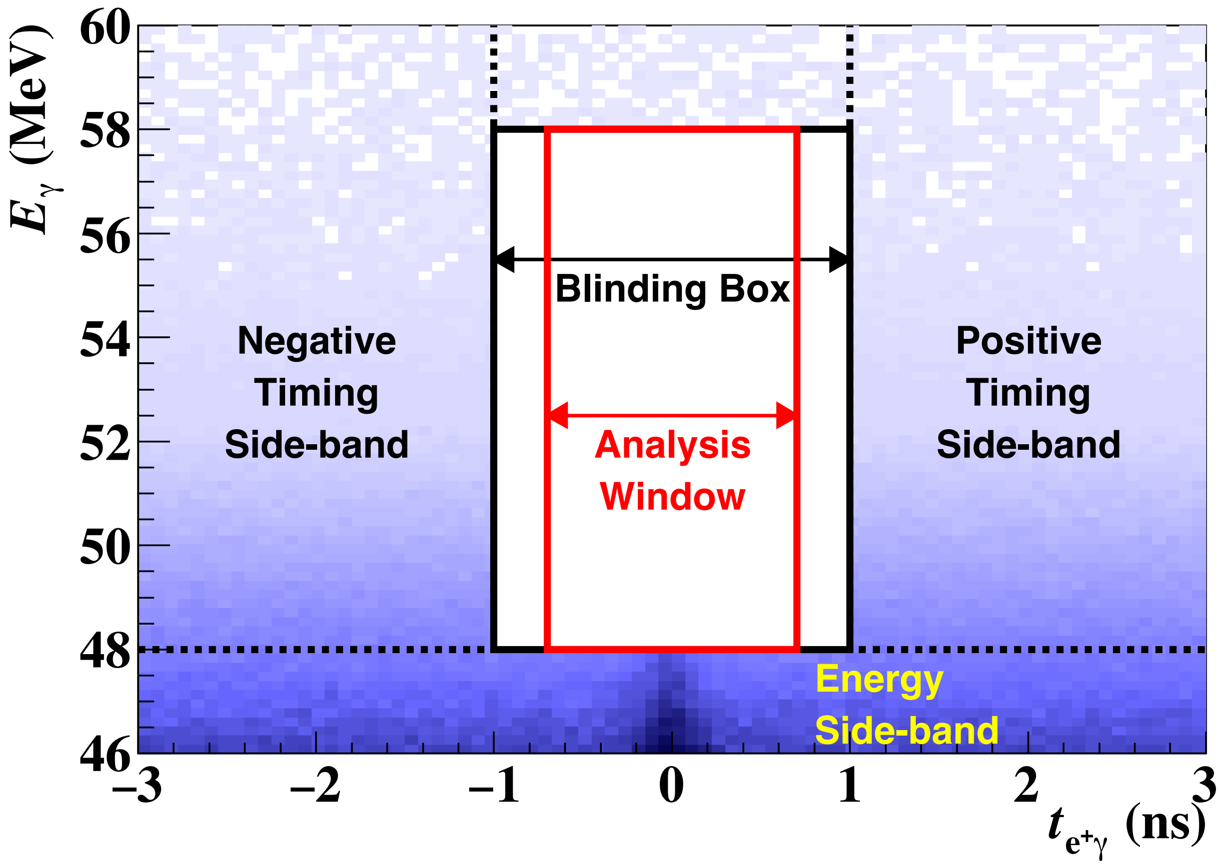


- Decay point of the muon from the intersection of the DC track with the target plane
- Relative angle from the combination of track direction+ decay point + photon conversion point
- No physical process to accurately calibrate the angle
- We have to rely on careful geometrical alignment and separate calorimeter and drift chamber resolutions

Analysis strategy

- Blind-box likelihood analysis strategy
- Observables: $E_{e+}, E_\gamma, \theta_{e\gamma}, \varphi_{e\gamma}, T_{e\gamma}$

$\vec{x} = \begin{pmatrix} E_\gamma \text{ : Gamma energy} \\ E_e \text{ : Positron energy} \\ t_{e\gamma} \text{ : Time difference} \\ \vartheta_{e\gamma} \text{ : } \vartheta \text{ angle difference} \\ \varphi_{e\gamma} \text{ : } \varphi \text{ angle difference} \end{pmatrix}$



Analysis strategy

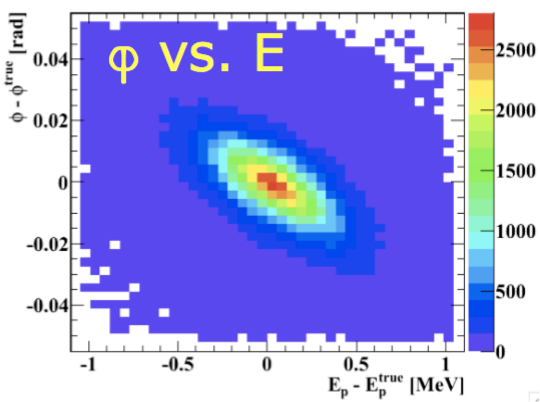
- Likelihood function

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

- Accidental pdfs fully defined from data sidebands:
  - very solid determination of the dominant background

- Signal and radiative decay pdfs by combining results of calibration

- Correlations between kinematic variables taken into account

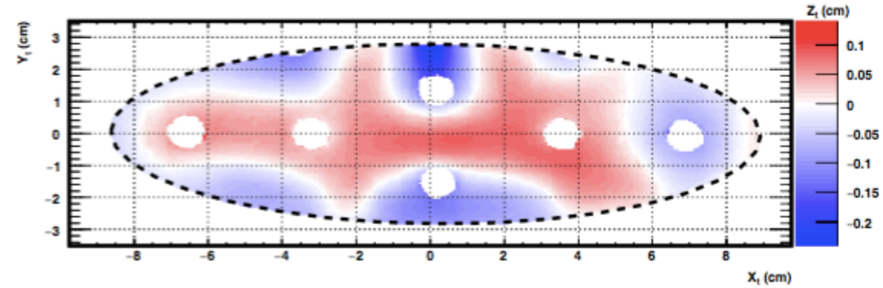


- Normalization from Michel & RD decays

Improvements in the analysis vs last publication

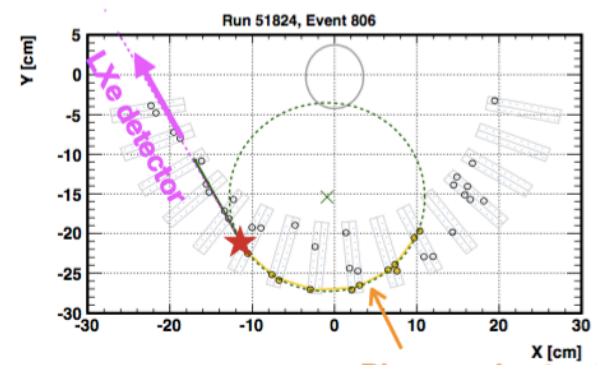
- Non planar, non negligible target deformation observed
  - taken into account in the likelihhod analysis
  - 13% worse sensitivity

Comparison 2009-2011 vs last publication ok

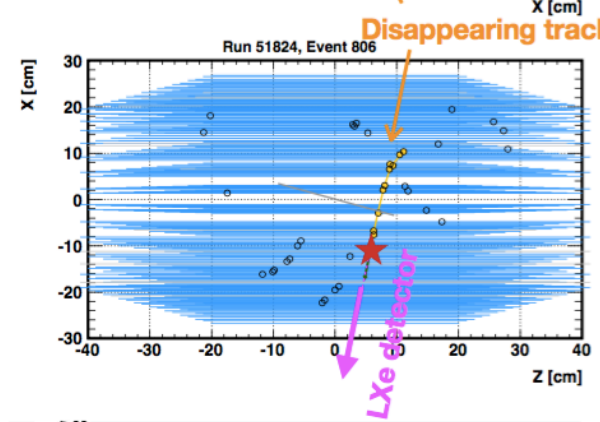


deformation measured by 3D scanner

- Photons from e+ annihilations inside DC were identified & removed
  - background rejection~2%
  - signal inefficiency~1%

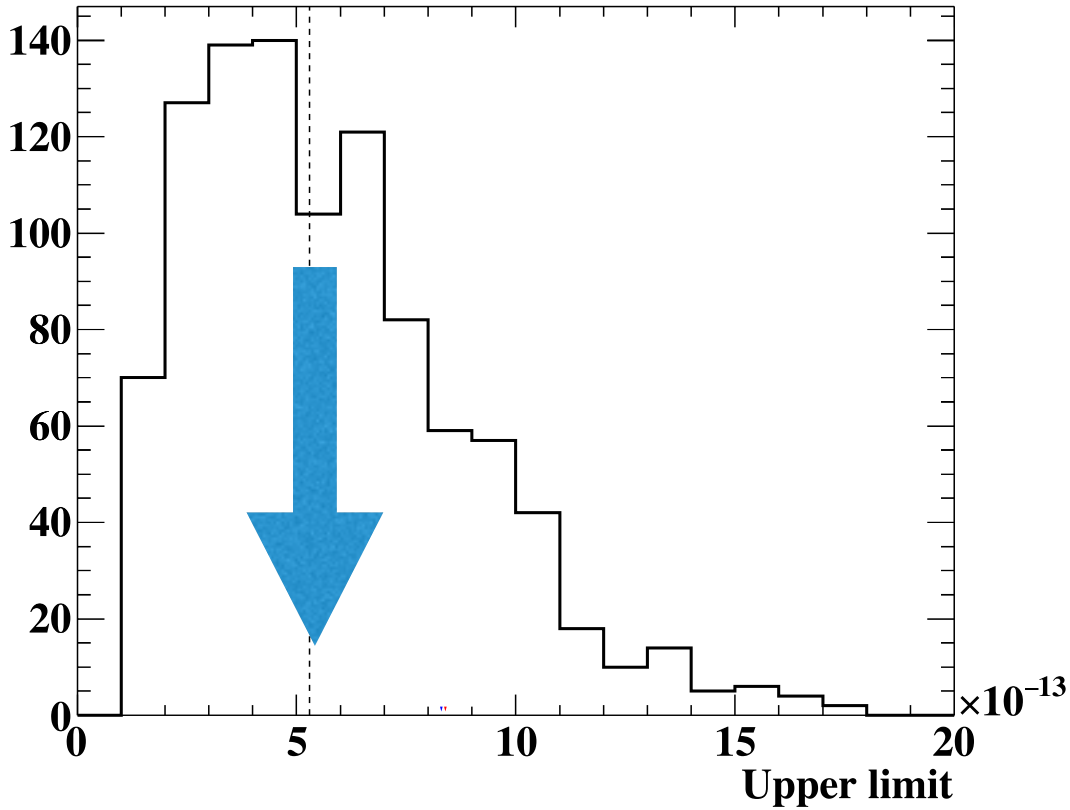


- Revised the algorithm to recover missing first turn of positron in the DC
  - Signal efficiency improved by 4%



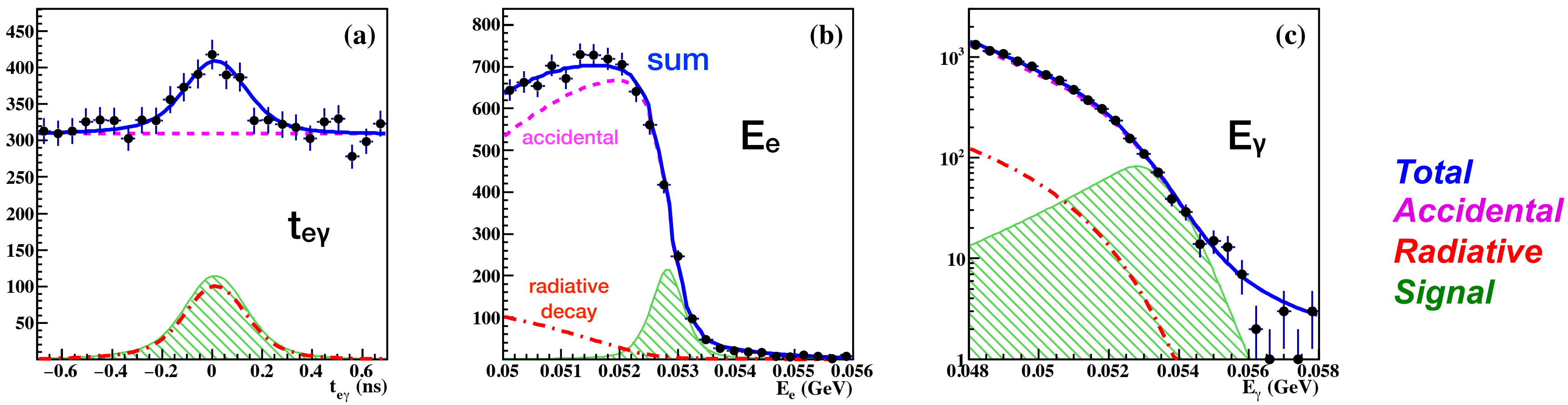
Sensitivity from toy Monte Carlo

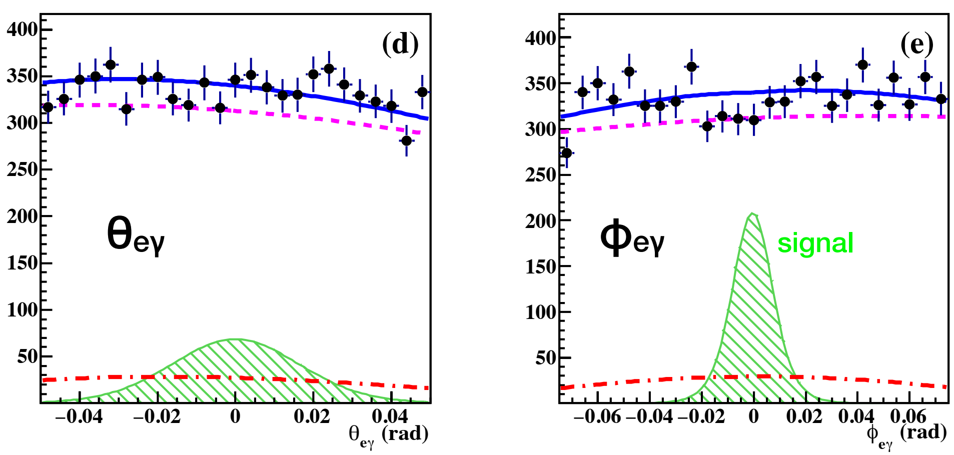
- Average 90% CL upper limit on branching ratio with null-signal hypotesis
- Checked with data sideband-fit
- Sensitivity = 5.3×10^{-13}



Unblinding the full data set: likelihood fit

The best fitted likelihood function (projection) is shown
"Signal" is magnified for illustrative purposes



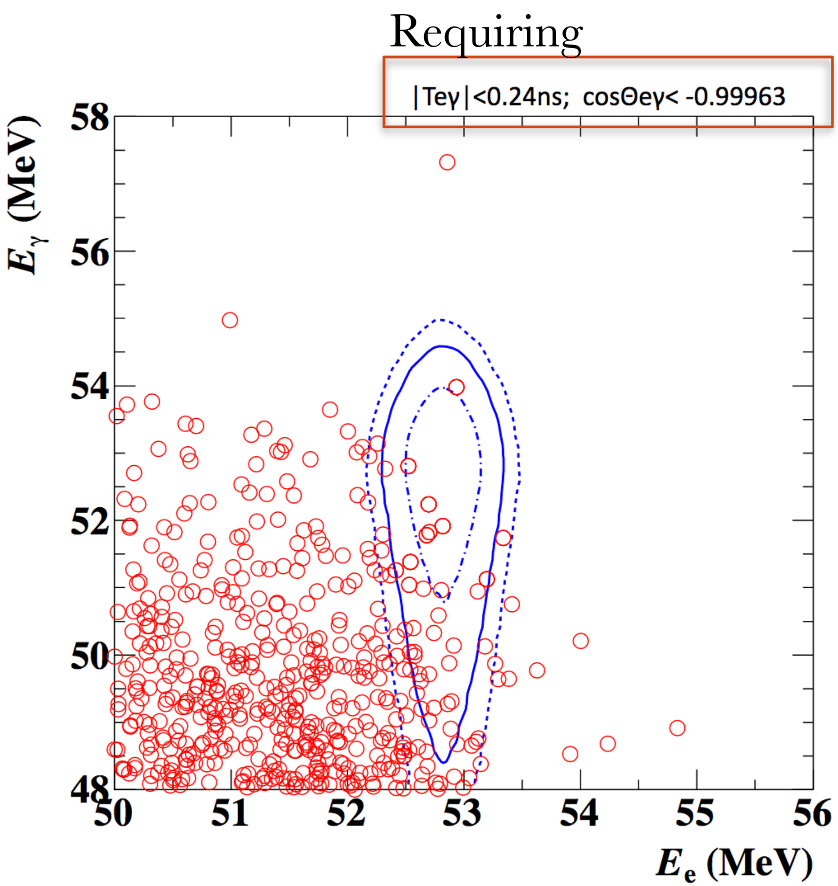


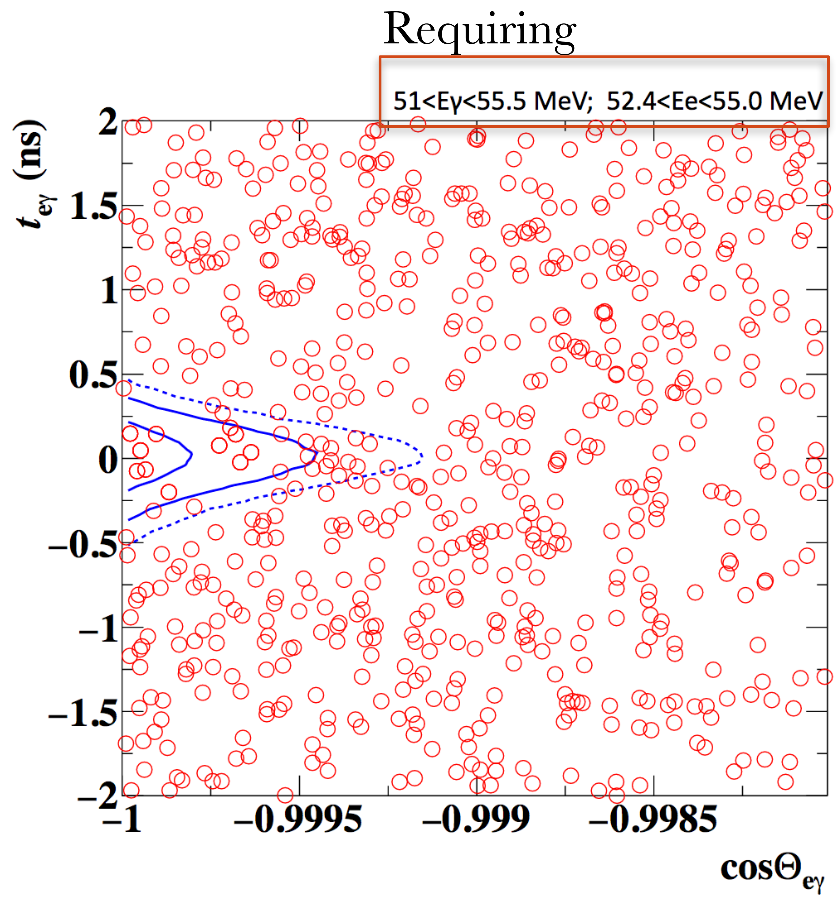
NO SIGNAL

N_{acc}= 7684 ± 103

N_{RD}= 663± 59

2D likelihood projection and event distribution



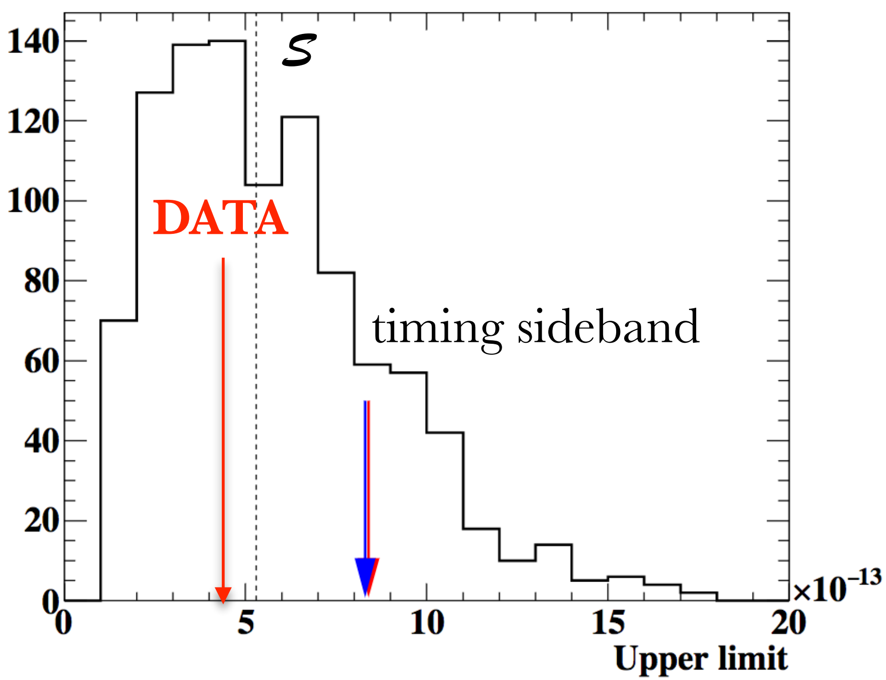


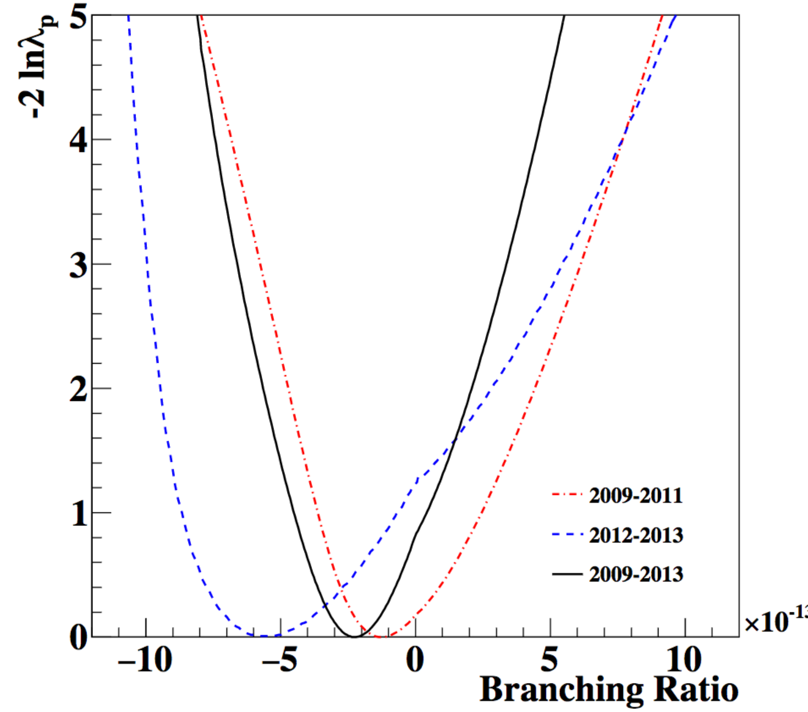
1σ, 1.64σ, 2σ contours are shown

BR(μ→eγ) limit result

BR (μ→eγ) < 4.2x 10^{-13} at 90% C.L.

submitted to EPJC

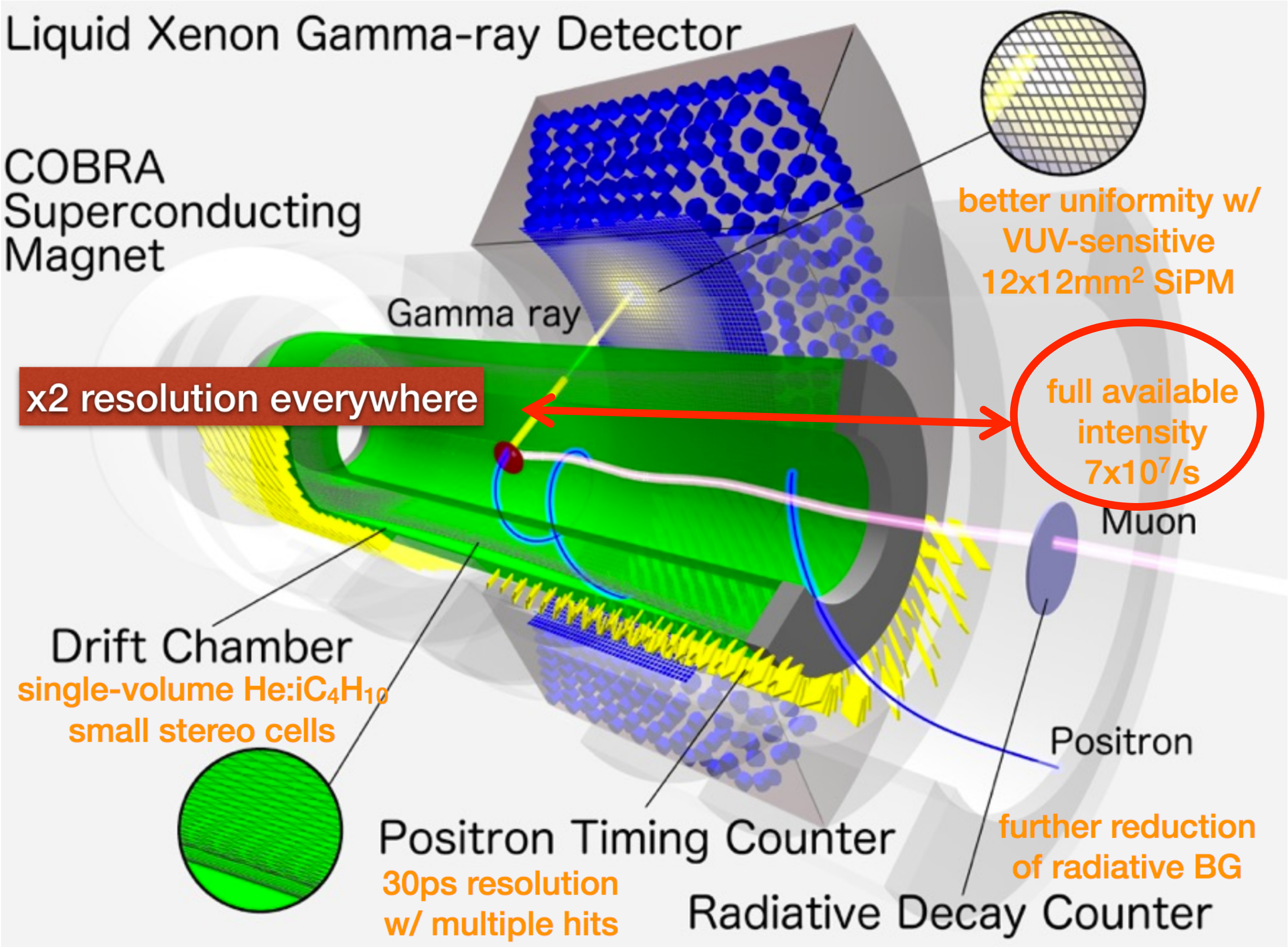




Note: Upper limit from frequentistic procedure a la Feldman-Cousins

Next: MEG upgrade: MEG-II

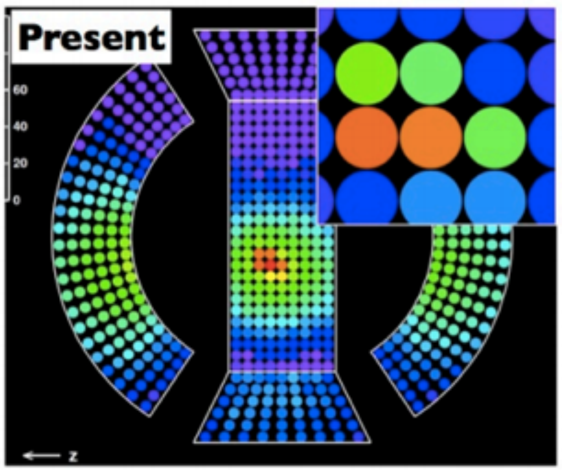
- Extending the search of $\mu \to e\gamma$ is complementary to New Physics searches at the high energy frontier

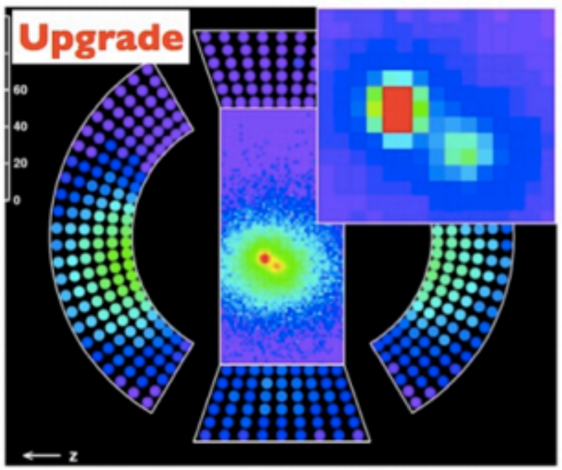


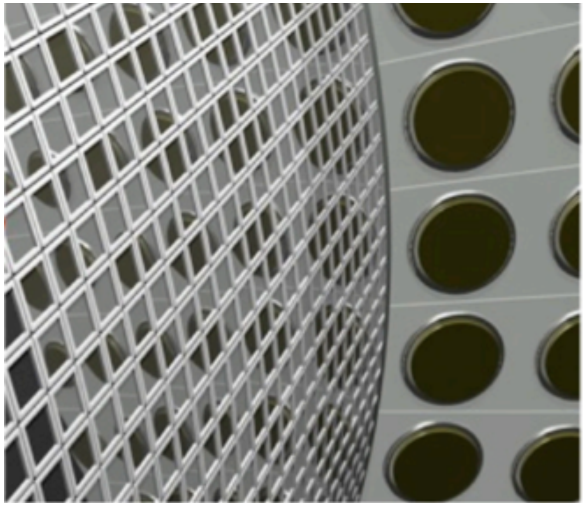
optimized to enhance sensitivity (accidental background prop. to I^2_{μ})

MEG-II detector highlights: Liquid Xenon

Liquid Xenon Calorimeter with higher granularity in inner face:
=> better resolution, better pile-up rejection



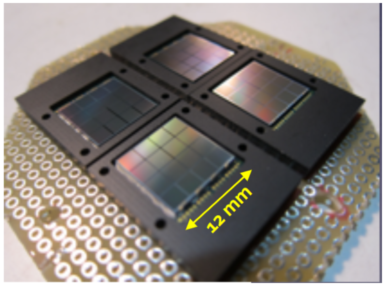




- Developed UV sensitive MPPC (vacuum UV 12x12mm^2 SiPM)

- Detector under commissioning (calibrations by end of 2016)

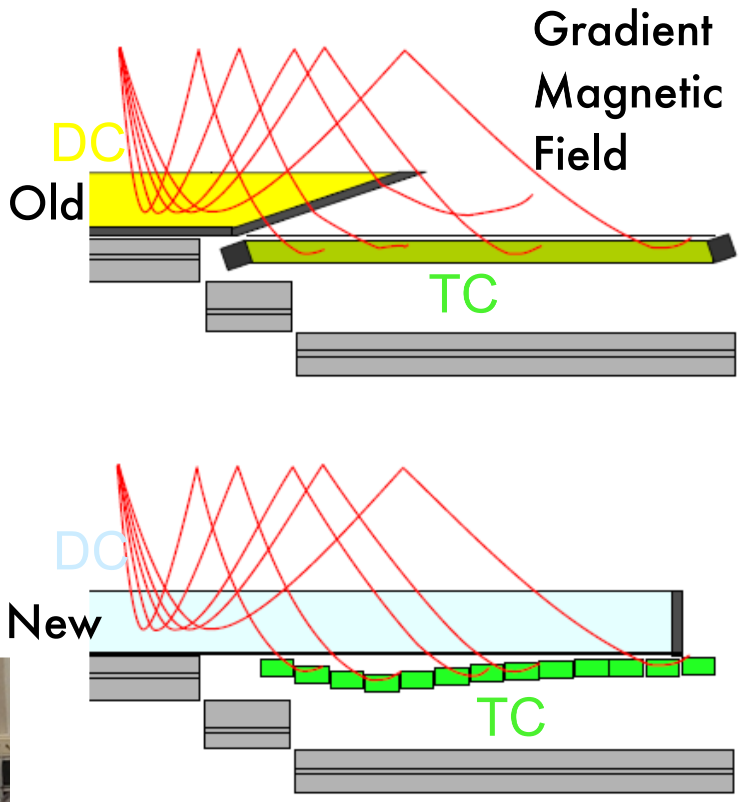
Large UV-ext SiPM



MEG-II detector highlights: Drift Chamber

- Single volume drift chamber with 2π coverage
  - 2m long
  - 1200 sense wires
  - stereo angle (8°)
  - low mass
  - high trasparency to TC
    (double signal efficiency)

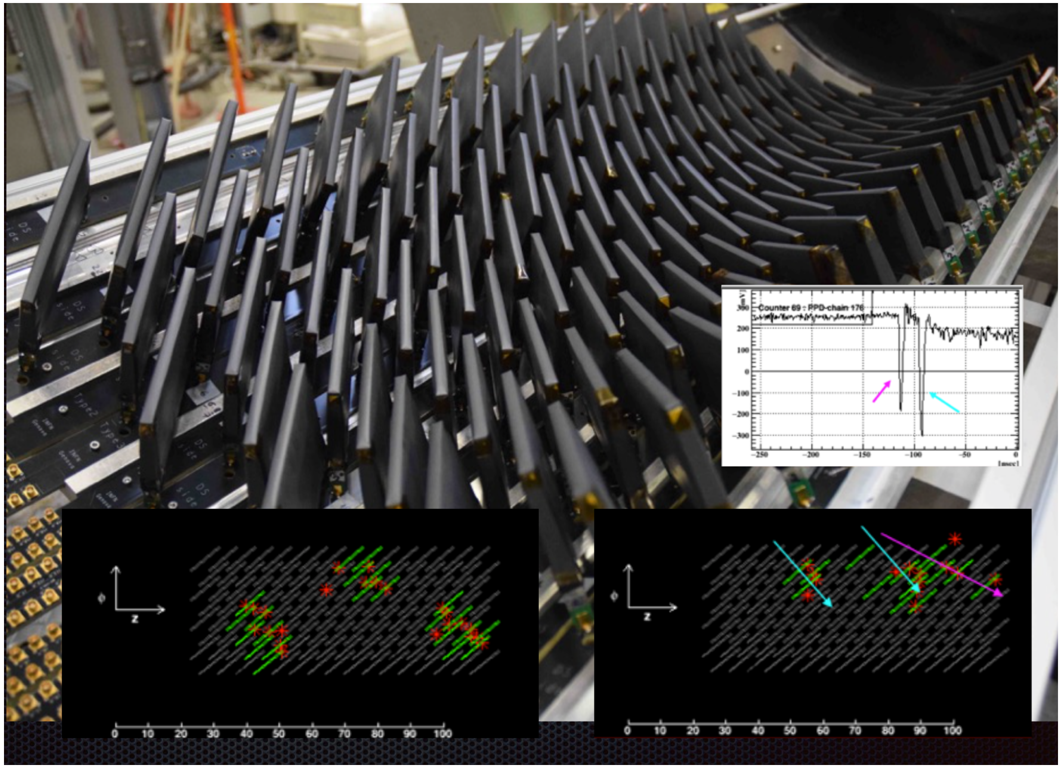
- Wiring in progress, to be completed by end of 2016)



MEG-II detector highlights: Timing Counter

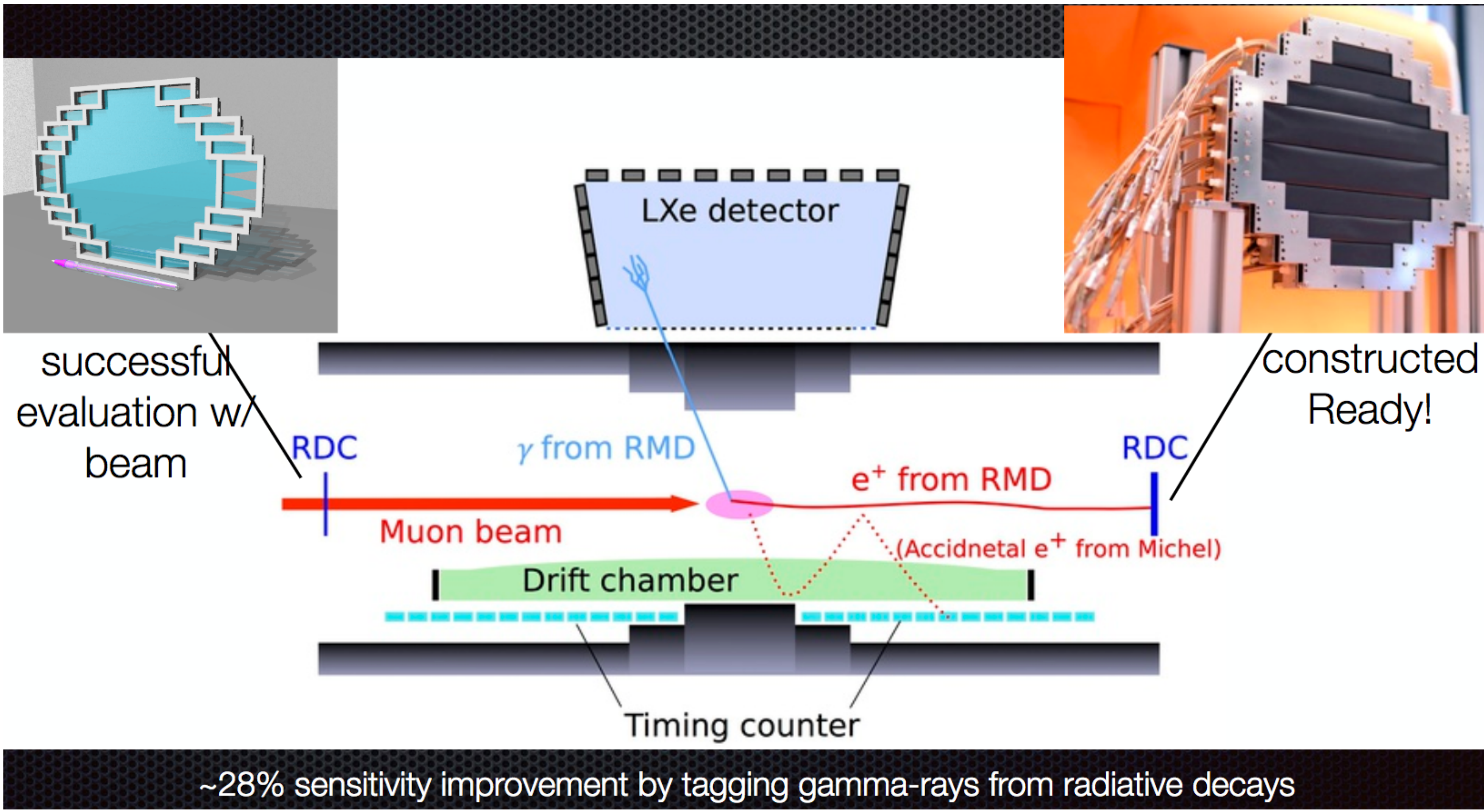
- Scintillator tiles read by SiPM
  - 1/4 of the detector installed and tested on beam with Michel decays last December

- To be completed and tested by the end of 2016



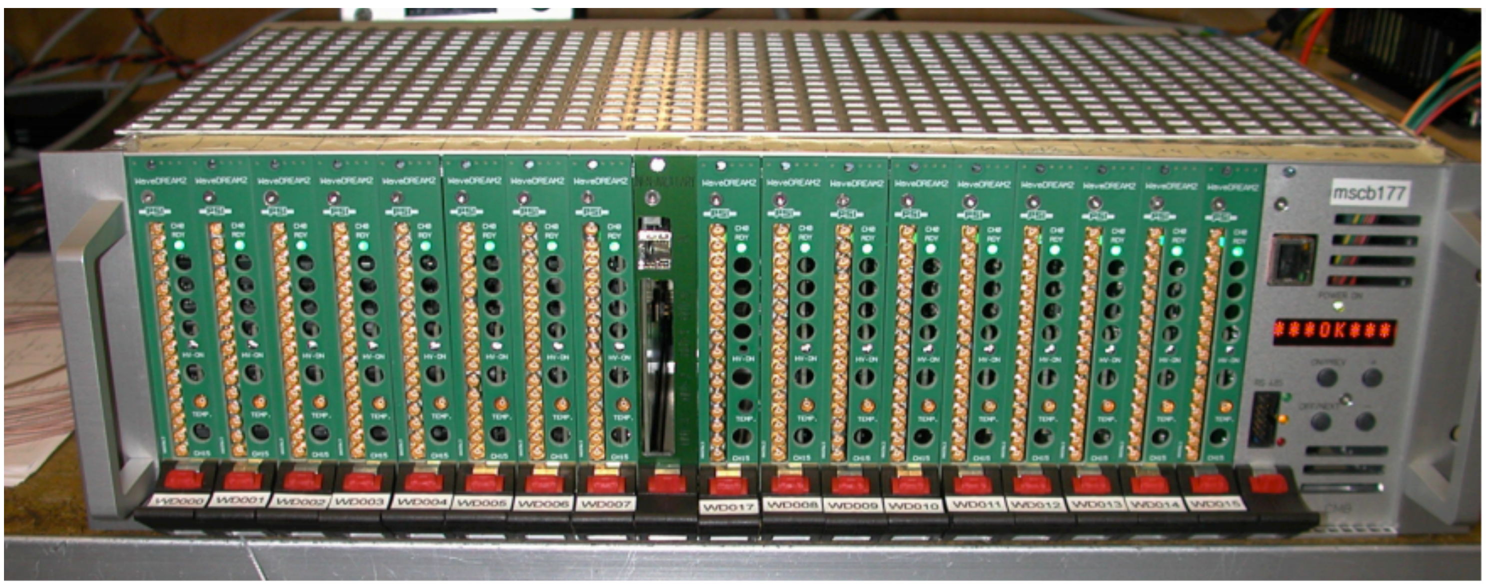
MEG-II detector highlights: Radiative Decay Counter

- 50% of the background photons comes from radiative muon decay with positron along the beam line
- Can be vetoed by detecting the positron in coincidence with the γ



New Electronics

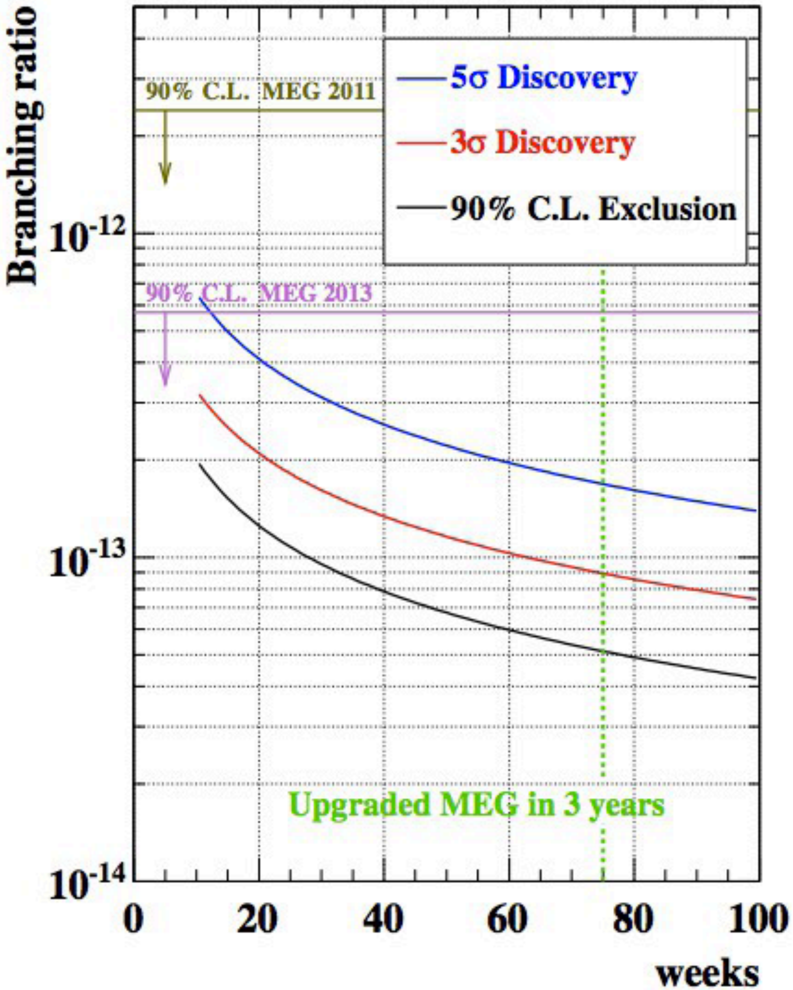
- New version of DRS custom digitization board integrating both digitization, triggering and some HV (four times more channels than before)
- About 1000 channels ready to be tested for the end of the year
- Final production expected in spring 2017



MEG-II goals

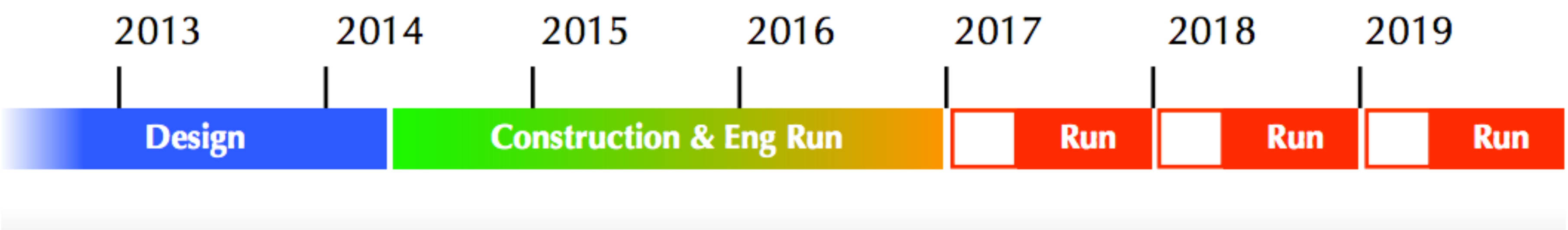
- **Beam rate ~7×10^7 μ/s**
- **Final sensitivity: 4×10^{-14}**

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88



MEG-II schedule

- Successfull pre-engineering run in late 2015
- Engineering run foreseen at end of 2016 with several parts of the MEG-II detector
- Expect full detector ready and run in 2017



Note: this schedule assume exclusive use of PiE5 beam line by MEG-II

Conclusion

- New constraint on the $\mu \rightarrow e\gamma$ decay set by the MEG experiment with its final dataset: 7.5×10^{14} stopped μ^+

BR ($\mu \rightarrow e\gamma$) < 4.2×10^{-13} at 90% C.L.

submitted to EPJC

- MEG-II detector is in the construction phase
  - same design of MEG but better resolution

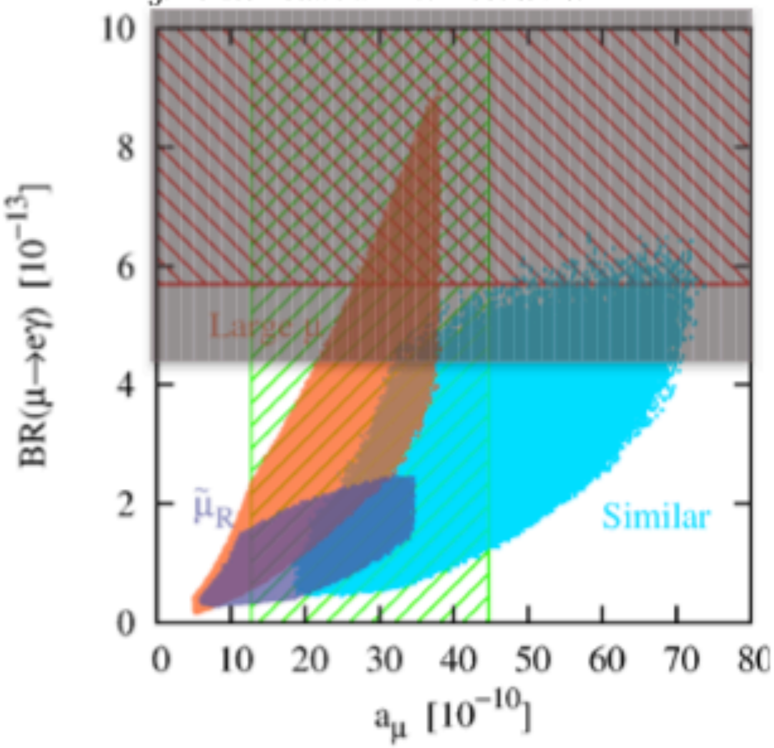
- By the end of a decade sensitivity pushed to $\sim 4 \times 10^{-14}$

- Ultimate $\mu^+ \rightarrow e^+\gamma$?
  - PSI HiMB Project: $\sim 1.3 \times 10^{10}$ μ/s seems possible..
  - Need to fight accidental background (photon conversion?)

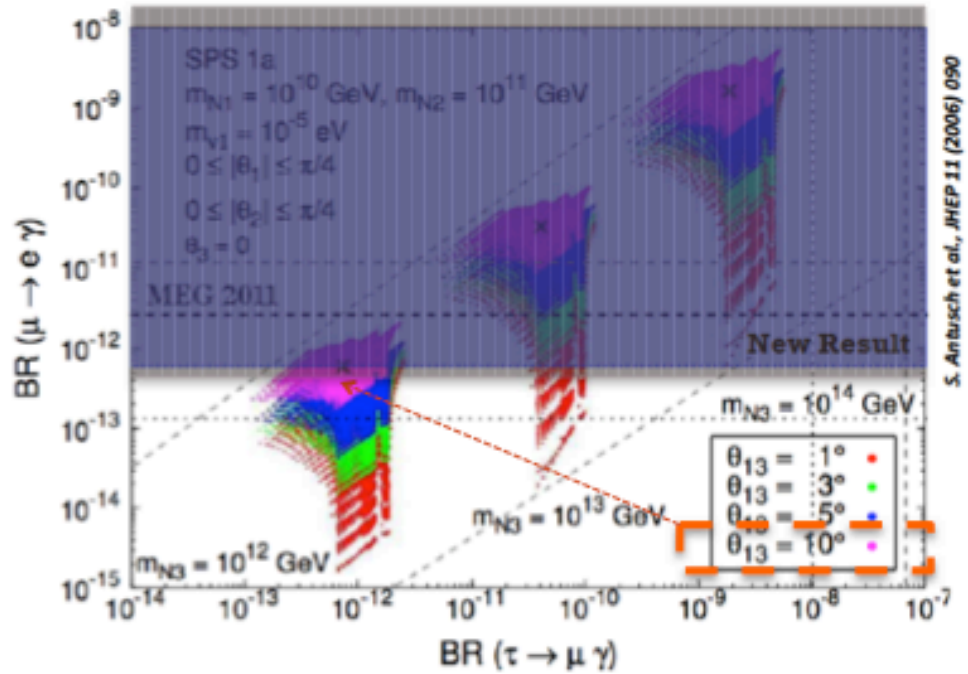
Backup

Correlations in MSSM

J.Kersten et.al. arXiv:1405.2972v1

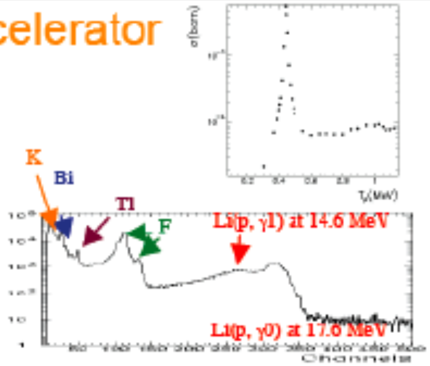


SUSY and see-saw



Calibrations

Proton Accelerator



Li(p,γ)Be

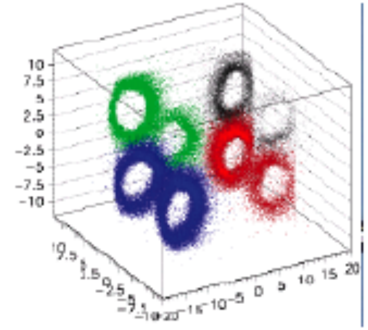
LiF target at COBRA center

17.6MeV γ

~daily calib.

also for initial setup

Alpha on wires

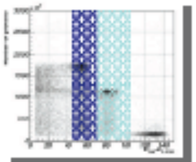


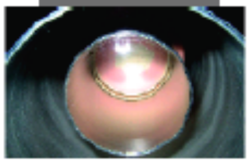
PMT QE & Att. L

Cold GXe

LXe

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



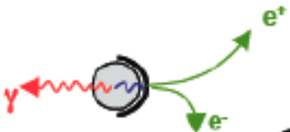


$\pi^- + p \rightarrow \pi^0 + n$

$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

$\pi^- + p \rightarrow \gamma + n$ (129MeV)

LH_2 target

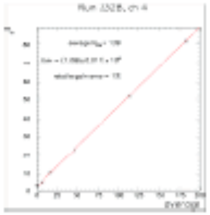


Xenon Calibration

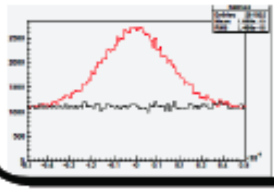
LED

PMT Gain

Higher V with light att.



μ radiative decay



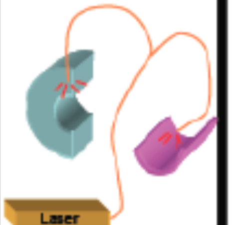
Lower beam intensity < 10^7

Is necessary to reduce pile-ups

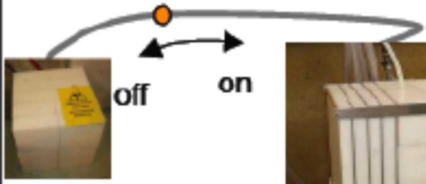
A few days ~ 1 week to get enough statistics

Laser

relative timing calib.



Nickel γ Generator



Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off