Les Rencontres de Physique de la Vallée d'Aoste

La Thuile, Aosta Valley, Italy

February 27 - March 5, 2011

$\mu \to e\gamma$ search with MEG: results and perspectives

Luca Galli, INFN Pisa

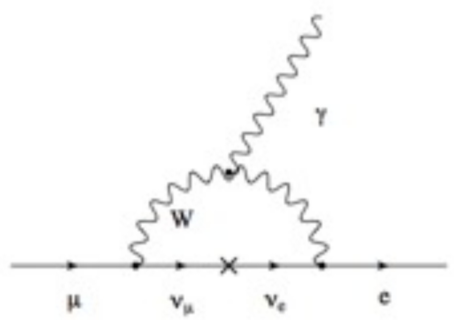
INFN

Outline

- Physics motivations
- The experiment
  - *detector and beam*
  - *signal and background*
- Analysis scheme
- Results from Run 2009
  - *normalization and sensitivity*
  - *results and upgrades*
- Perspectives
  - *Run 2010 data*
  - *2011 and future*

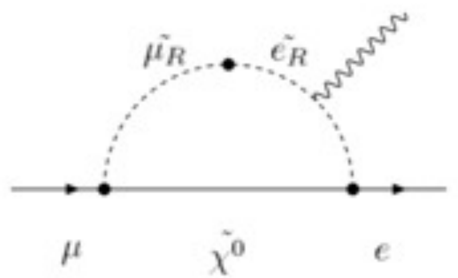
cLFV in the Standard Model and beyond

cLFV undetectably small in the **Standard Model** with **ν-oscillations**



$$\frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\overline{\nu})} \approx \left(\frac{\alpha}{2\pi}\right) \sin^2(2\theta) \left(\frac{\Delta m^2}{M_W^2}\right)^2 \approx 10^{-54}$$

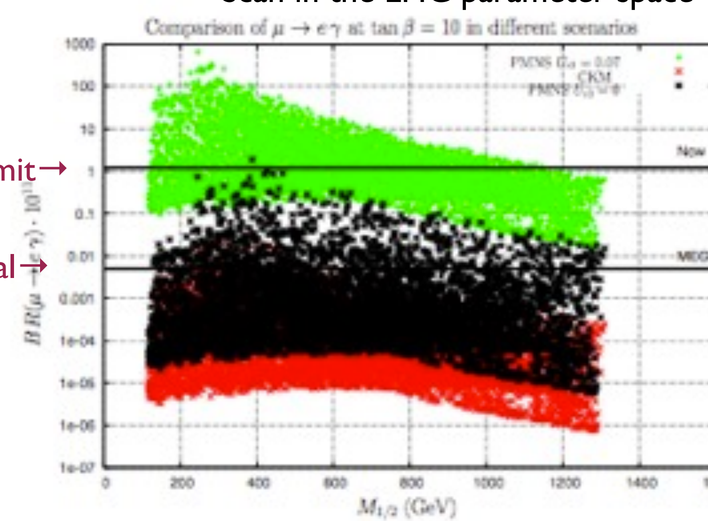
- *process **enhanced** in **SUSY theories and others***
  - **expected rate ≈ experimental sensitivities $10^{-12} \div 10^{-14}$**
- ***no SM contamination: μ→eγ New Physics clean probe***



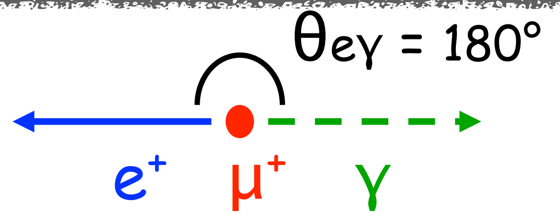
$$\mathrm{B}(\ell_i \to \ell_j\gamma) \propto \frac{\alpha^3 \pi \theta^2_{\tilde{\ell}_i \tilde{\ell}_j}}{G_F^2 \tilde{m}^4} \tan^2(\beta)$$

R. Barbieri et al., Nucl. Phys. B445(1995) 215
J. Hisano, N. Nomura, Phys. Rev. D59 (1999)
A.Masiero et al. Nucl. Phys. B649 (2003) 189
L.Calibbi et al. Phys. Rev. D74 (2006) 116002
G.Isidori, Phys Rev. D75 (2007) 115019
P. Paradisi, this conference

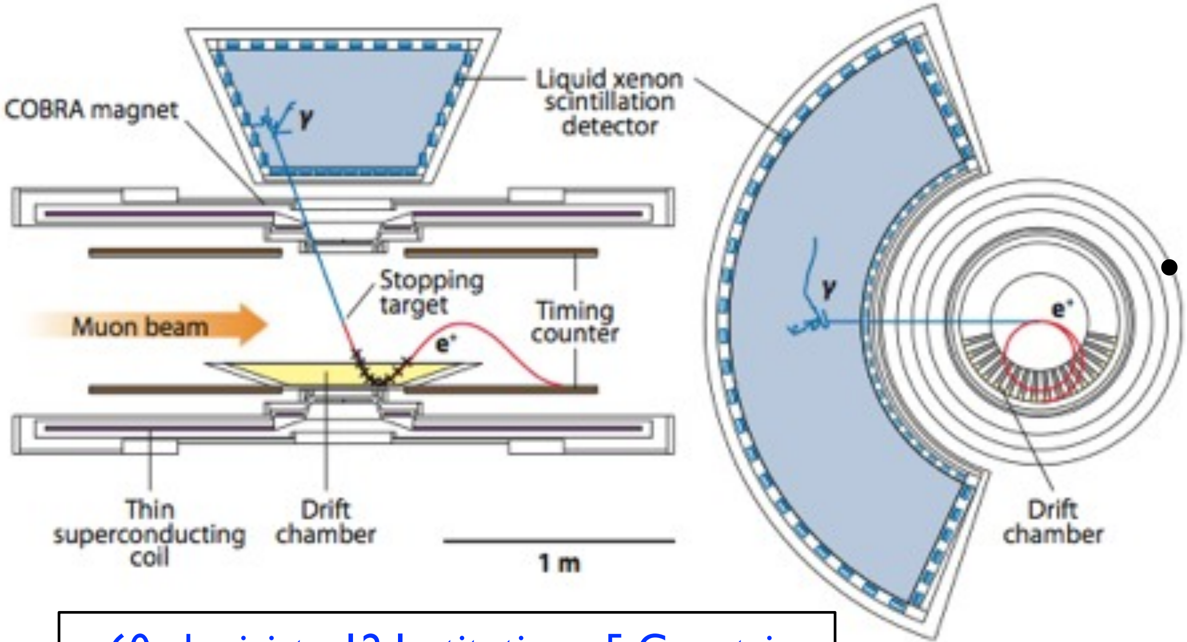
Scan in the LHC parameter space



Experimental method



$E_e = E_\gamma = 52.8$ MeV



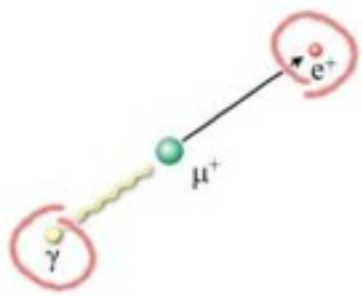
~60 physicists, 12 Institutions, 5 Countries
Italy, Japan, Russia, Switzerland, USA
Location: Paul Scherrer Institut (CH)

Detector OUTLINE

- **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
- e^+ 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**
    - **transverse scintillation fibers → hit position**

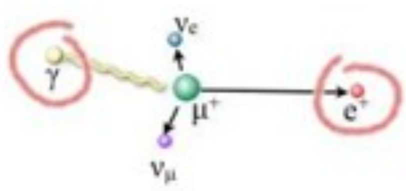
Signal and background

Signal



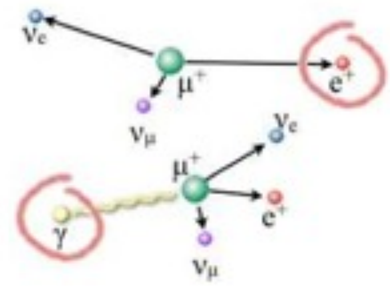
$E_\gamma = 52.8$ MeV
$E_{e^+} = 52.8$ MeV
$\Theta_{e\gamma} = 180°$
$T_{e\gamma} = 0$ s

Radiative Muon Decay



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

Accidental



$E_\gamma < 52.8$ MeV
$E_{e^+} < 52.8$ MeV
$\Theta_{e\gamma} < 180°$
$T_{e\gamma} \Rightarrow$ flat

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

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

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

Exp./Lab	Year	ΔEe/Ee (%)	ΔEγ /Eγ (%)	Δteγ (ns)	Δθeγ (mrad)	Stop rate (s^{-1})	Duty cyc.(%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^5	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^5	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^5	6.4	1.7×10^{-10}
Crystal Box	1986	8	8	1.3	87	4×10^5	(6..9)	4.9×10^{-11}
MEGA	1999	1.2	4.5	1.6	17	2.5×10^8	(6..7)	1.2×10^{-11}
MEG	2008 - x	1	4.5	0.15	19	3×10^7	100	$3\text{-}5 \times 10^{-13}$

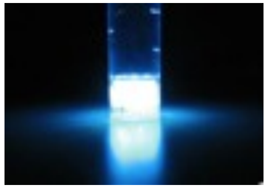
MEG key elements

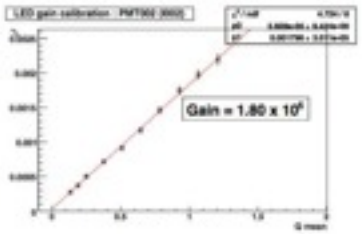
- **MEG** is a **precision experiment** which **demands** for
  - ***unprecedented detector resolution at these energies*** *for effective* ***background rejection***
  - *accurate* ***monitoring*** *of detector* ***performances with time***
- The detector is **operated in conjunction** with an **impressive set** of **calibration tools**

LXe calibrations (subset...)

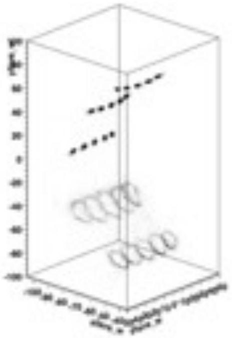
Artificial light source... ... events **inside** the **detector**... ... low energy γs **with beam**...

LED
PMT gain

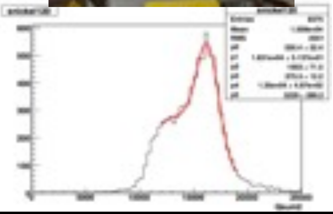




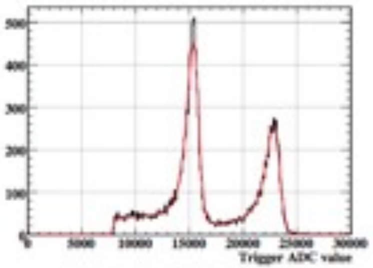
α source
PMT QE
Absorption length

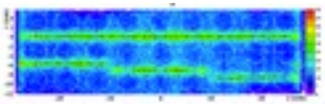


Ni γ generator
9 MeV γ-line
beam on/off calib.



CEX
γ-resolutions:
- energy
- time
- impact point

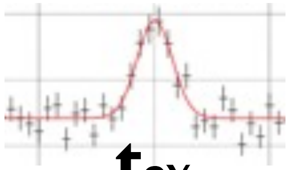




LH_2 target

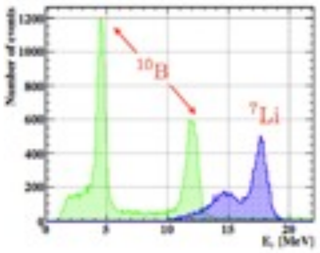
XENON CALIBRATION

$\mu \to e\nu\bar{\nu}\gamma$



$t_{e\gamma}$

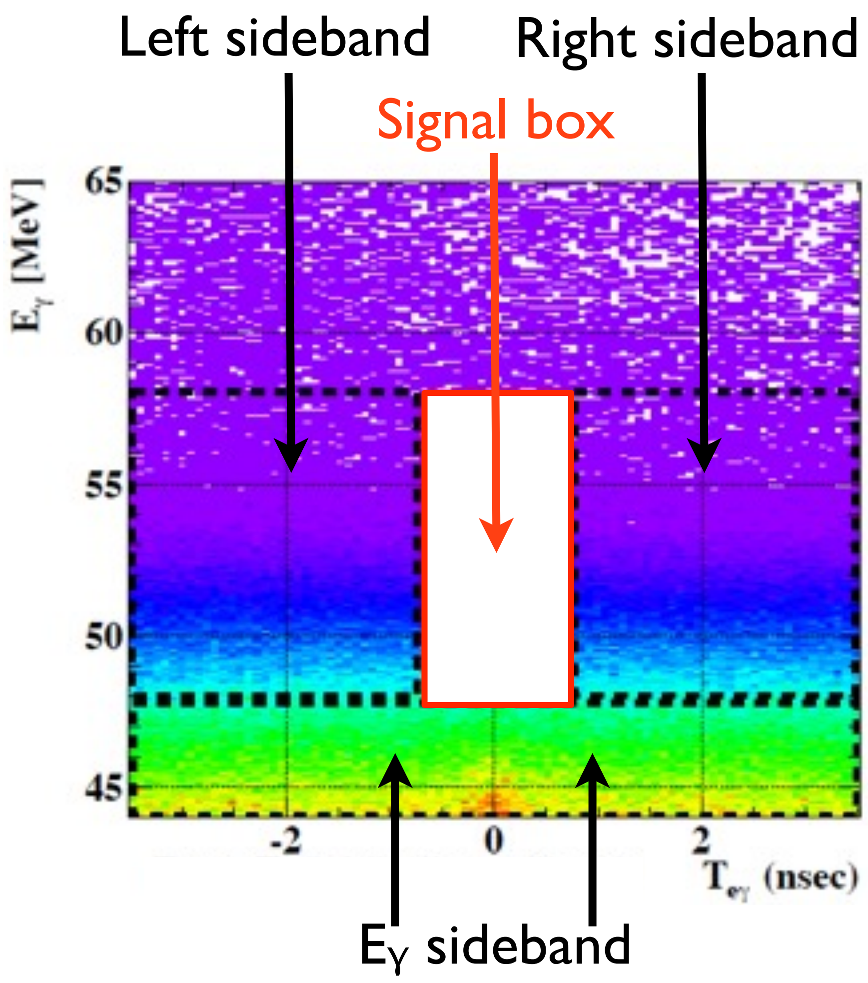
CW p-accel
Light Yield
LXe-TC t-calib



... **@signal energy**!! ... **during** DAQ... ... **frequent** and **fast** LY monitor...

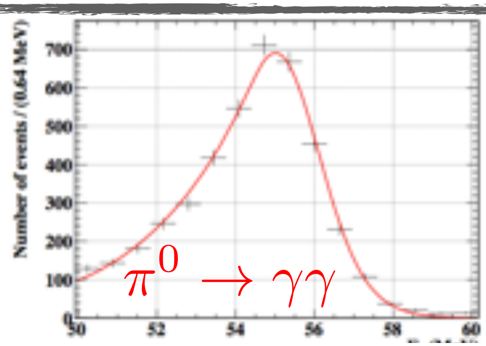
Analysis strategy

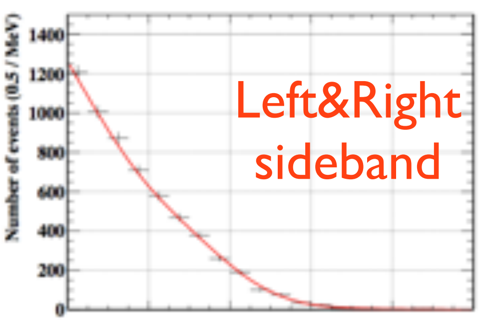
- Decided to extract **CL to B(μ→eγ)** from a **likelihood analysis** in a **wide signal box**
- Each **event** is described in terms of **5 kinematic variables**
  - *$x_i = (E_\gamma, E_e, t_{e\gamma}, \varphi_{e\gamma}, \theta_{e\gamma})$*
- **resolutions** and **PDFs** evaluated **on data outside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



Run 2009: PDFs

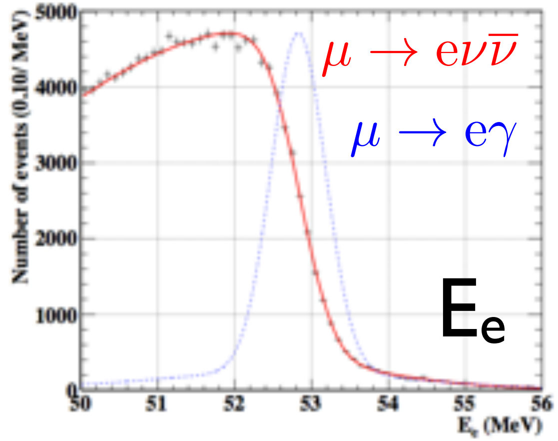
E_γ





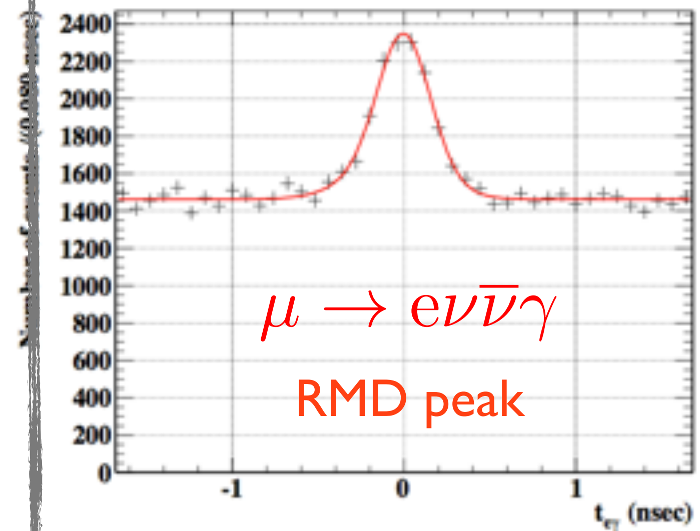
- **σ_R = 2.1± 0.15%** measured with CEX events
- **Sys** uncertainty in **energy scale 0.6%**

Tracking



- **σ(p) = 390 keV** (core 0.74%, double gaussian)
- **$\sigma(\varphi_e)$ = 7.1 mrad** (core)
- **$\sigma(\theta_e)$ = 11.2 mrad**
- **$\sigma(Z)_{vertex}$ = 3.4 mm**
- **$\sigma(Y)_{vertex}$ = 3.3 mm**

$t_{e\gamma}$



- **$\sigma(t_{e\gamma})$ = 142 ps** (core)

Likelihood function

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

$$\mathcal{L}(N_S, N_R, N_B) = \frac{N^{obs} e^{-N}}{N_{obs}!} \prod_{i=1}^{N_{obs}} \left[\frac{N_S}{N} S + \frac{N_R}{N} R + \frac{N_B}{N} B \right]$$

- **N_S, N_R, N_B** measured **simultaneously** with an **un-binned** Likelihood fit in the **analysis box**
- **B(μ→eγ) C.L.** with **Feldman and Cousins**
- Cross-check:
  - ***two*** *independent* ***frequentistic analysis*** *with* ***different PDFs***
    - **Analysis A:** separated angles **(θeγ, φeγ)** and **event by event PDFs**
    - **Analysis B**: stereo angle **Θeγ**
  - ***third*** *analysis based on* ***Bayesian statistics***

Normalization and sensitivity

Normalization from $\mathbf{N_{\mu\rightarrow e\nu\nu}}$ **events** counted **simultaneously** with the signal with **pre-scaled trigger**

O(1)

$$\frac{\mathcal{B}(\mu^+ \to e^+\gamma)}{\mathcal{B}(\mu^+ \to e^+\nu\bar{\nu})} = \frac{N_{\rm sig}}{N_{e\nu\bar{\nu}}} \times \frac{f^{e}_{e\nu\bar{\nu}}}{P \cdot \epsilon_{\rm pu}} \times \frac{\epsilon^{\rm trig}_{e\nu\bar{\nu}}}{\epsilon^{\rm trig}_{e\gamma}} \times \frac{\epsilon^{\rm DC}_{e\nu\bar{\nu}}}{\epsilon^{\rm DC}_{e\gamma}} \times \frac{1}{A^{\rm geo}_{e\gamma}} \times \frac{1}{\epsilon_{e\gamma}} = \frac{N_{sig}}{k}$$

~18k

107

MEGPreliminary

k = 1.0 ± 0.1 × 10^{12}

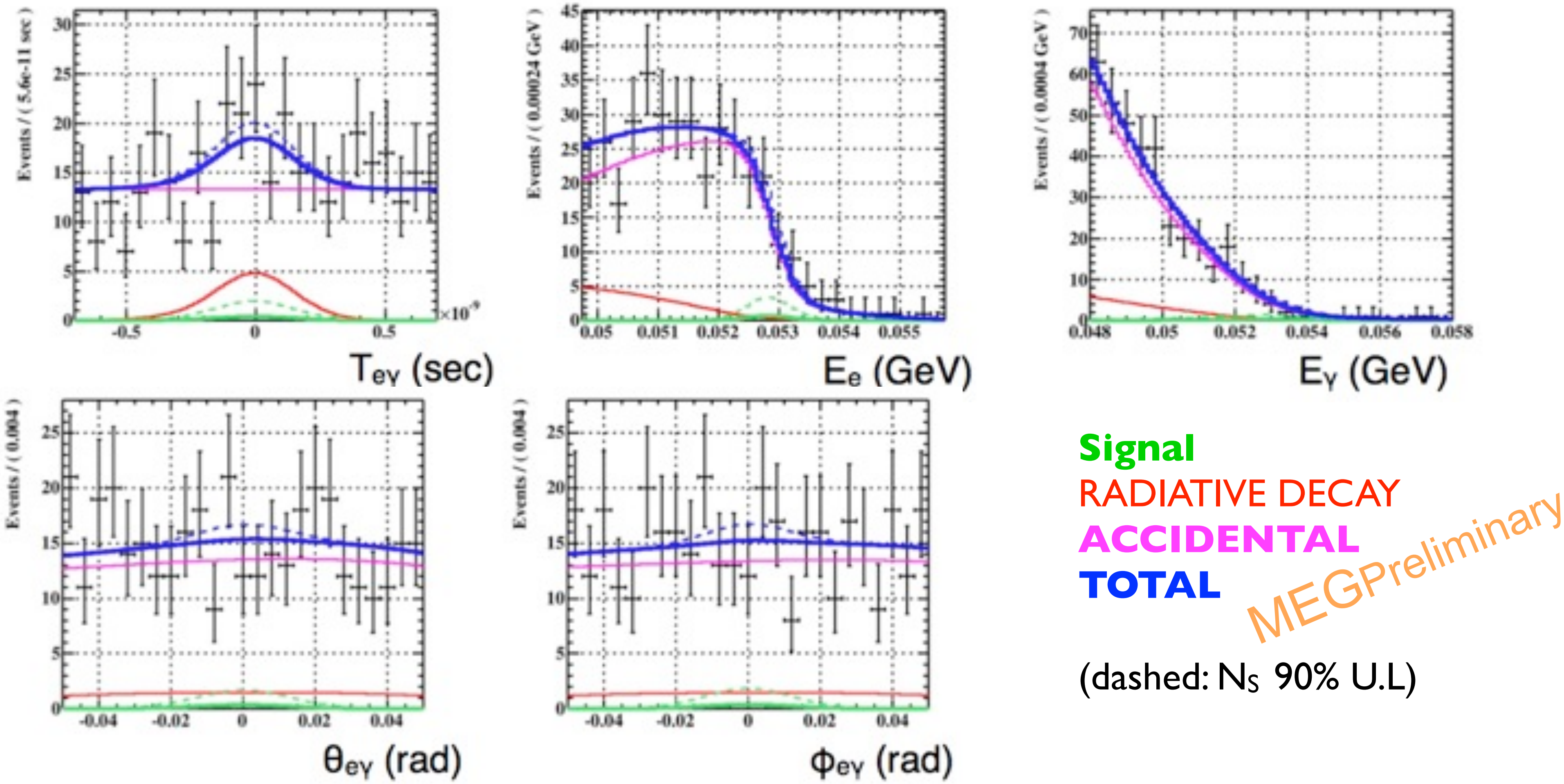
MEGPreliminary

Sensitivity = 6.1 × 10^{-12}

average 90% CL upper limit of toy MC with **0 signal**

consistent *with* ***sideband*** *results* ***4÷6 10^{-12}***

Fit result



Best Fit: $N_S = 3$, $N_R = 35^{+24}_{-22}$

N_S<14.5 @90%C.L. (Feldman-Cousins)

Systematics

The effect of **systematics** is taken into account in the calculation of the confidence region by **fluctuating the PDFs** according to uncertainty values

	Uncertainty	
Normalization	8%	P_{e+} ε_γ ε_{TRG}
E_γ scale	0.4%	Light yield stability, gain shift
E_γ resolution	7%	
E_e scale	50 keV	from Michel edge
E_e resolution	15%	
$t_{e\gamma}$ center	15 ps	
$t_{e\gamma}$ resolution	10%	RMD peak
Angle	7.5 mrad	Tracking + LXe position
Angular resolution	10%	
E_e–φ_e correlation	50%	MC evaluation

Greater systematics from positron reconstruction code

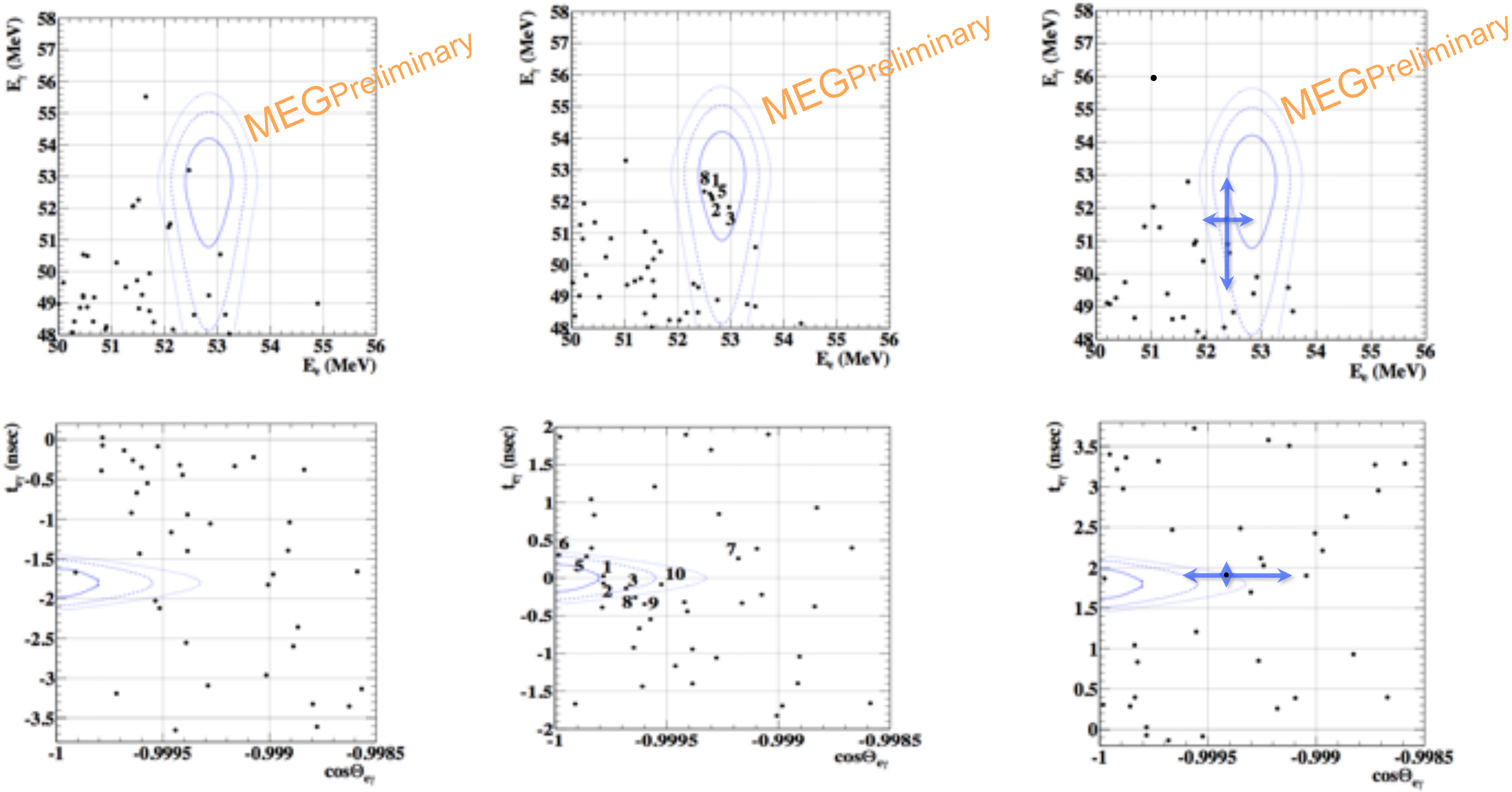
Overall effect **~10% on N_S C.L.**

Preliminary result

- A **preliminary result** of **2009 data** for the **MEG experiment**
  - ***$B(\mu \to e\gamma) < 1.5 \times 10^{-11}$ @90% C.L. (ICHEP 2010)***
- Notes:
  - *the **three analysis** are **consistent***
  - *the **null hypothesis** has a **probability of 20-60%***
- The MEG **published result** on **2008 data** was (Nucl.Phys B **834**(2010) 1)
  - ***$B(\mu \to e\gamma) < 2.8 \times 10^{-11}$ @90% C.L.***
- The **current best Upper Limit** from **MEGA (1999)** is (Phys.Rev.Lett. D **65** (2002) 112002)
  - ***$B(\mu \to e\gamma) < 1.2 \times 10^{-11}$ @90% C.L***

Event distribution

Left sideband | **Signal box** | **Right sideband**



Blue lines are 1(39.3% included inside the region w.r.t. analysis window), 1.64(74.2%) and 2(86.5%) sigma regions.
For each plot, cut on the other variables for roughly 90% window is applied.

Future (and) improvements

1. **Increase statistics!!**
   - *Run **2010** with **double statistics** w.r.t. 2009 **k~2×10¹²***
     - **analysis on going**
     - **2009 & 2010** data **together**
   - *In **2011** and **2012** dedicated to **intensive DAQ**, integrated **k~3×10¹³***
2. **Improve detector** (and) **resolutions:**

SOFTWARE

- ***better understanding** of **spectrometer** and **B-field** related **systematics***
  - **improved e^+ resolutions**, from **2009 data**
- ***LXe simulation***
  - better **PMT QE evaluation** to improve γ **reconstruction,** from **2009 data**

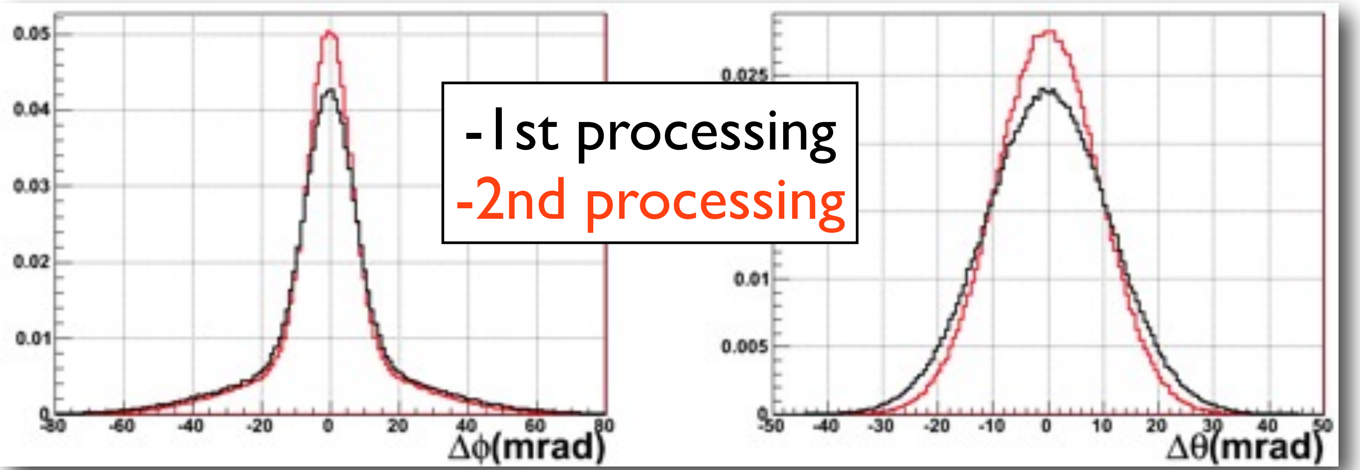
HARDWARE

- ***New calibration technique***
  - **Mott scattering** with **monochromatic e^+ beam,** from **2010 data**
- *new **HV distributor** for **DC***
  - **20-30% lower noise → better angular resolution**, from **2011 data**
- *new **DAQ read out** scheme*
  - **~99% Live Time** with **trigger efficiency >95%**, from **2011 data**

New result with 2009 data

- What's new?
  - ***systematic** in the COBRA **B-field measurement***
    - **φ component** in the **measured B-field** not taken into account in reconstruction **$B_\varphi/B_Z \sim 2\text{-}3\times10^{-3}$**
  - *use of **calculated B-field***
    - **better resolution** and **lower systematics**

e^+ resolutions	1st processing	2nd processing
σ(p) (%)	0.74 (core)	0.61 (core)
σ(φ) (mrad)	7.4 (core)	6.2 (core)
σ(θ) (mrad)	11.2	9.4



NEW RESULT
ready **SOON**

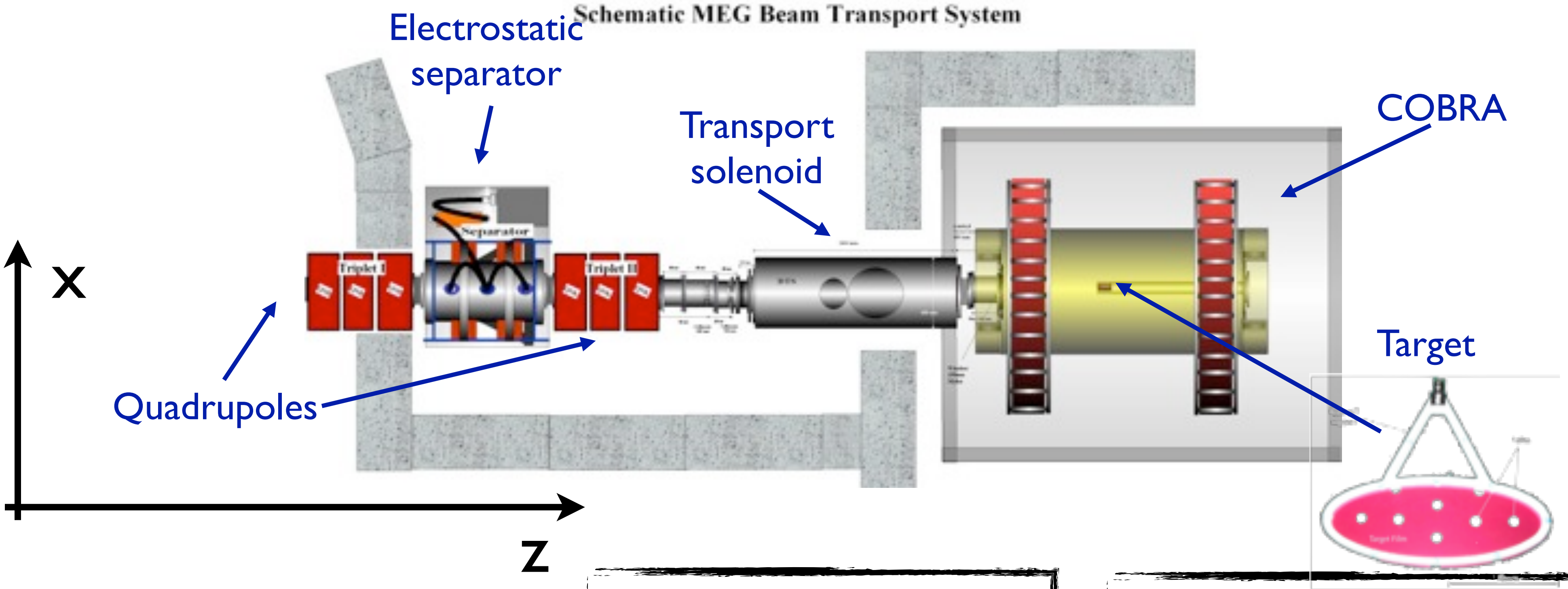
Conclusions

- In **2009** MEG took data for **2 months** in a **stable detector condition**
- **Preliminary result**
  - ***Sensitivity: 6.1×10^{-12}***
  - ***90% C.L. upper limit: 1.5×10^{-11}***
- **Update about 2009 data**
  - ***calculated B-field in tracking***
  - ***e^+ resolutions improved***
    - **result** ready **soon**
- **2010: 2x statistics** w.r.t. 2009
  - ***$k\sim2\times10^{12}$ (+ 2009 data...)***
- **2011-2012: ~5x statistics** w.r.t $2009\oplus2010$

Thanks for you attention!

Backup slides

μ-beam



Intensity (μ-stop/s)

- Low 2.5 x 10^6
- Normal 3.2 x 10^7
- Max 2 x 10^8

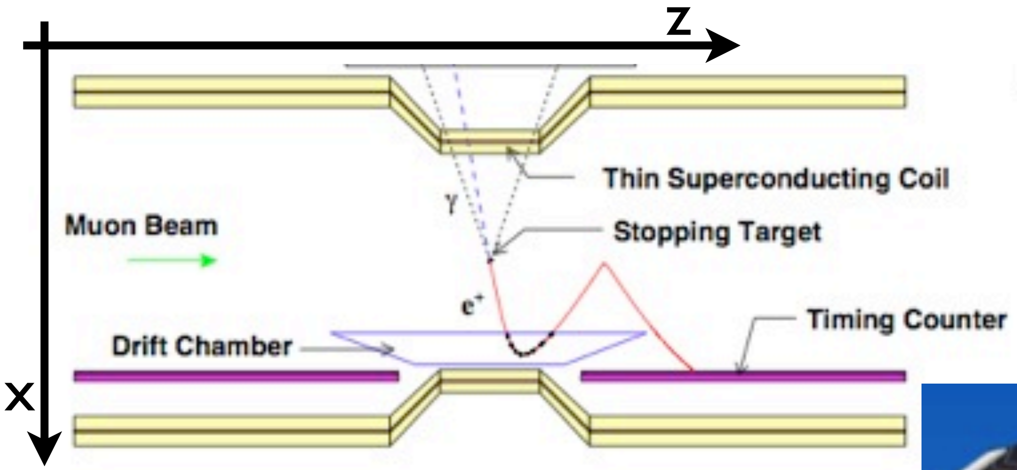
characteristics

- P = 27.7 MeV/c
- ΔP = 0.3 MeV/c
- σ_X = 9.5 mm
- σ_Y = 10. mm

MEG target

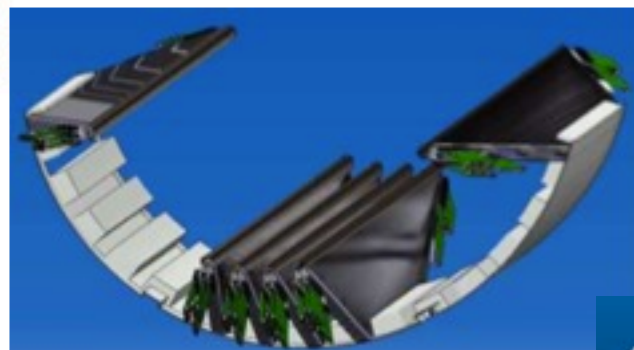
- Material CH_2
- θ = 22.5°
- thick = 205 μm
- Size = 15x25 cmxcm

Positron spectrometer



Gradient magnetic field:

- e^+ *rapidly swept away from detector*
- *bending radius* $\propto |p|$



DC system

e^+ momentum

- *16 staggered ultra-thin DC (~0.0003 X_0)*

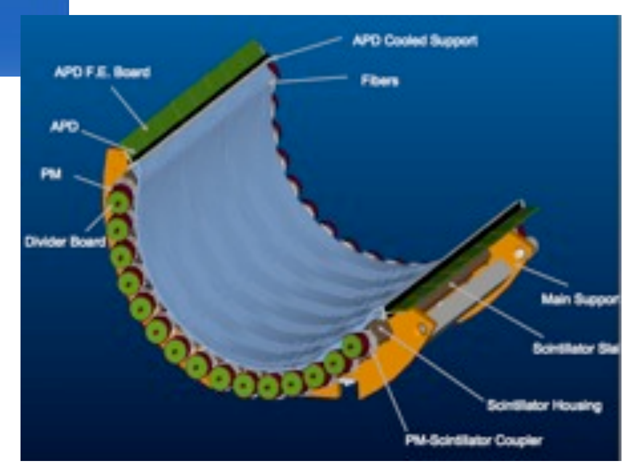
$\sigma(p)$ = 200 keV/c (design)
direction = 5 mrad (design)

e^+ timing

- *plastic scintillator counters*

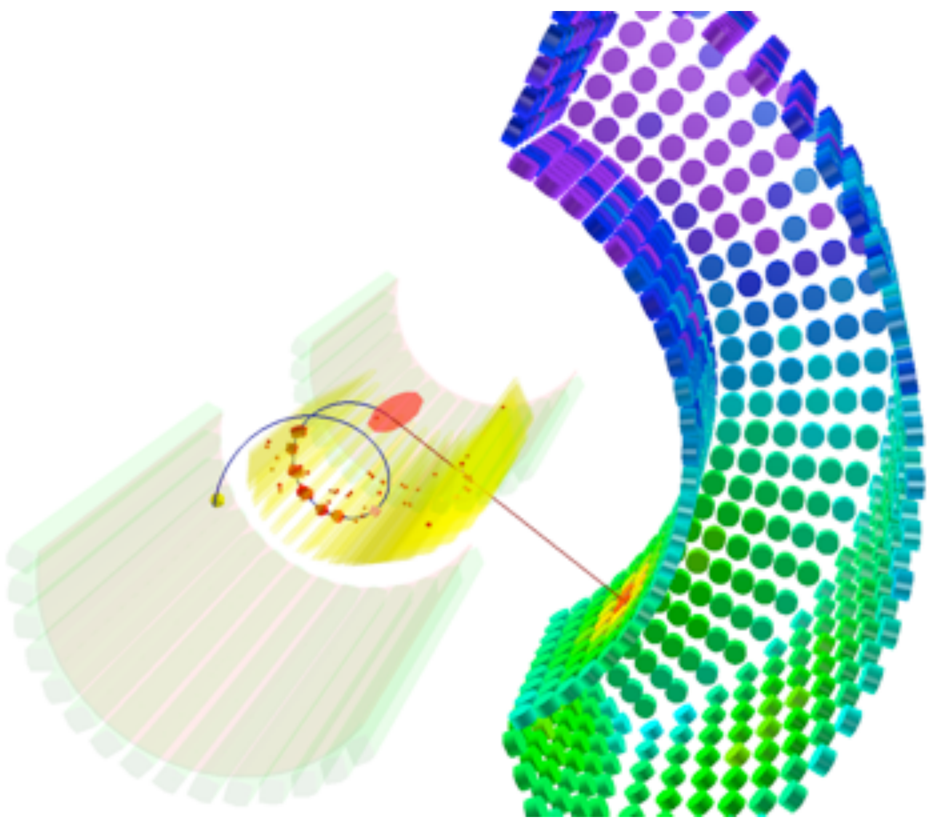
$\sigma(t)$ = 45 ps (design)

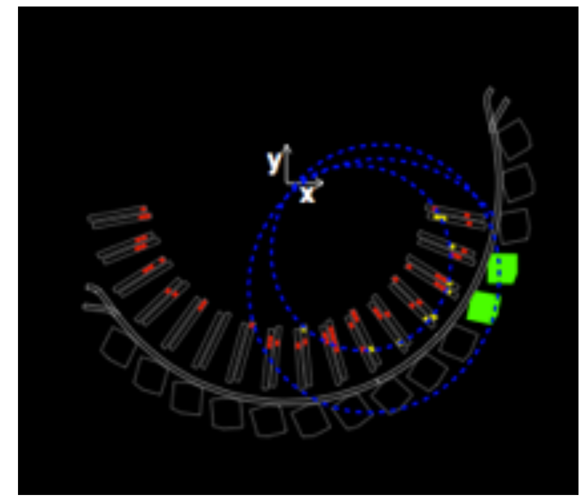
Timing Counter

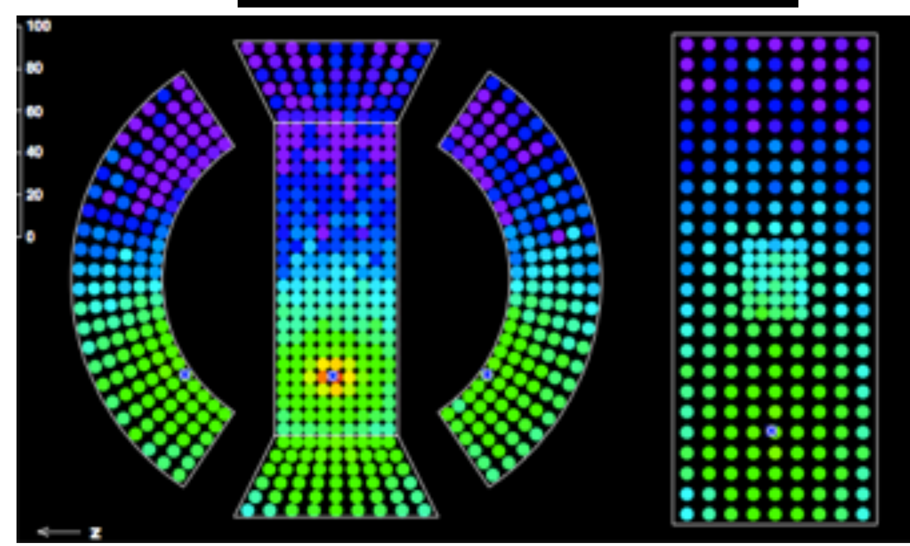


MEG event display

- Events in the signal region were checked carefully
- An event in the signal region



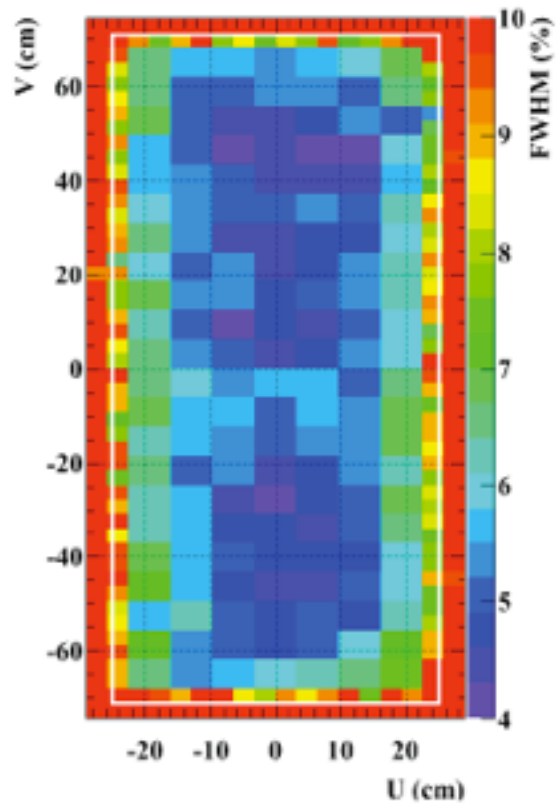




Uniformity

Calorimeter uniformity

- 55 MeV γ (from π^0 decay)
- Eγ resolution vs conversion point
- Close to design value



Timing uniformity and stability

- Events from raditive μ decay (RD)
- Requires LXe+TC+track
- Close to design value

  (if rescaled for the different Eg energy)