

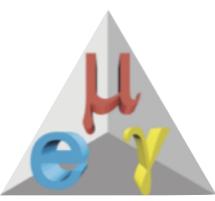
Elisabetta Baracchini  
University of California, Irvine  
on behalf of the MEG Collaboration



Rencontres de Moriond - EW Interaction and Unified Theories - 2010

# First results from the MEG experiment

- Lepton Flavour Violation and motivation
- Experimental challenge
- Experimental setup
- First physics run result in 2008
- 2009 run and prospectives



# Lepton Flavour Violation



Lepton Flavour Conservation is an accidental symmetry of SM:

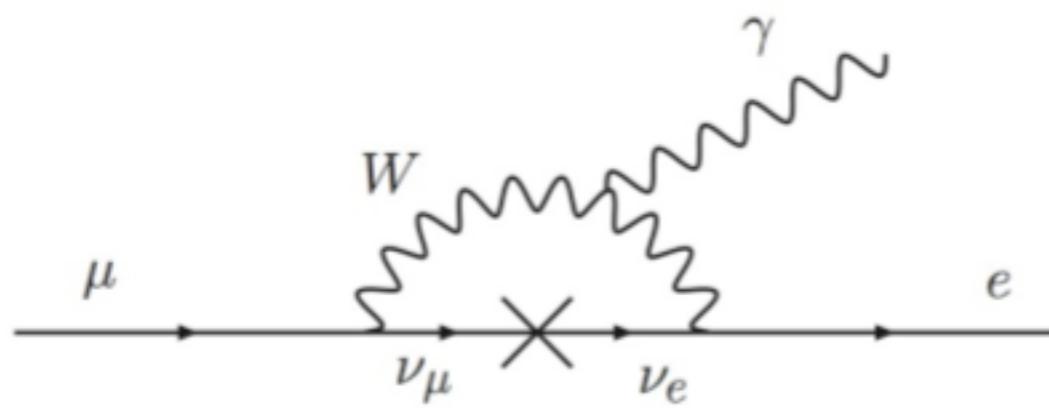
- Not related to the gauge structure of the theory
- Naturally violated in SM extensions

Observation of  $\mu \rightarrow e \gamma$  would be an unambiguous evidence of NP beyond SM

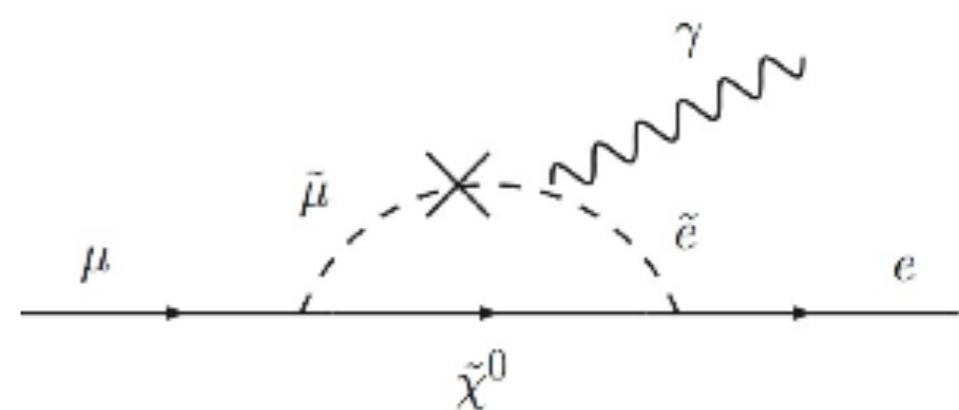
LFV already observed in the neutral sector: neutrino oscillations

LFV in charged sector could be mediated by

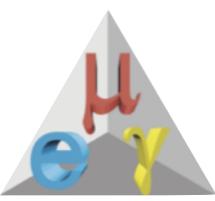
- neutrino oscillation in SM extensions with massive neutrinos
- off-diagonal terms in the slepton mass matrix (through RG evolution) in SUSY



$$BR \sim m_\nu^4/m_W^4 \sim 10^{-54}$$



$$BR(\ell_i \rightarrow \ell_j \gamma) \propto \delta_{ij}^2 \tan^2 \beta$$



# LFV in SUSY scenarios



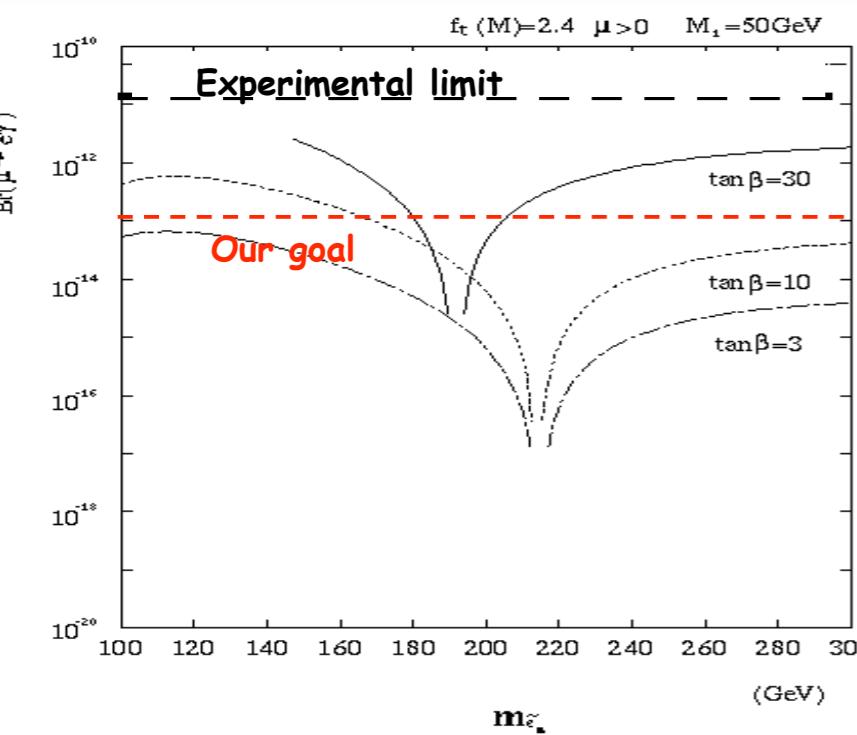
BR ( $\mu \rightarrow e \gamma$ ) is a function of  $\tan\beta$  and the selectron mass

In SUSY-GUT scenarios, LFV parameters can be related to the CKM matrix (minimal mixing) or PMNS matrix (maximal mixing)

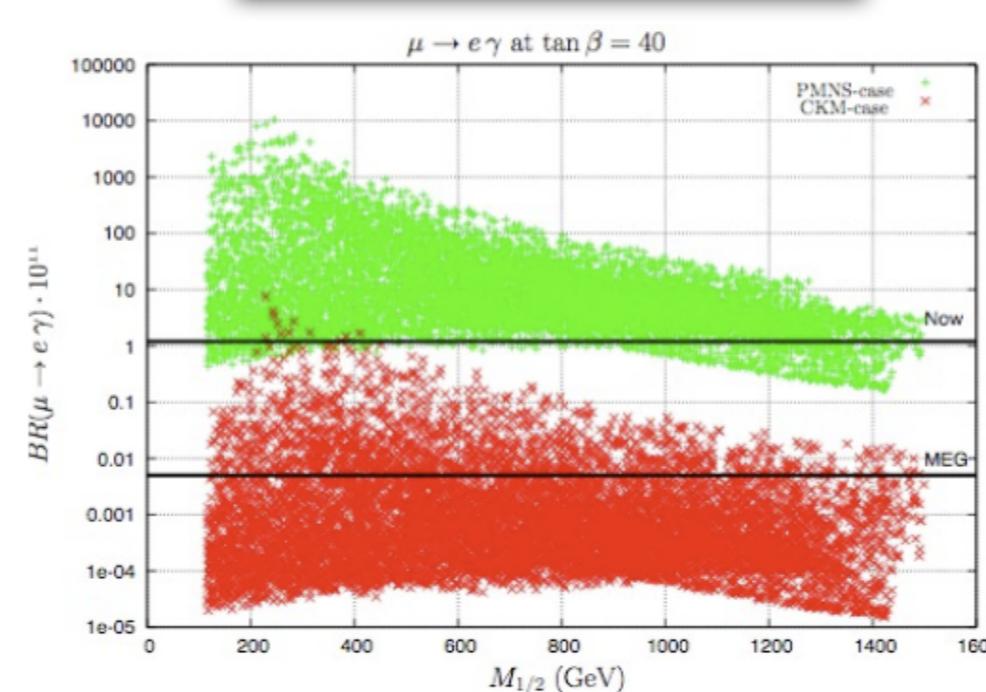
See Malaescu's talk for  $g_\mu - 2$  status

SUSY solution of  $g_\mu - 2$  anomaly predicts BR( $\mu \rightarrow e \gamma$ ) just around the corner

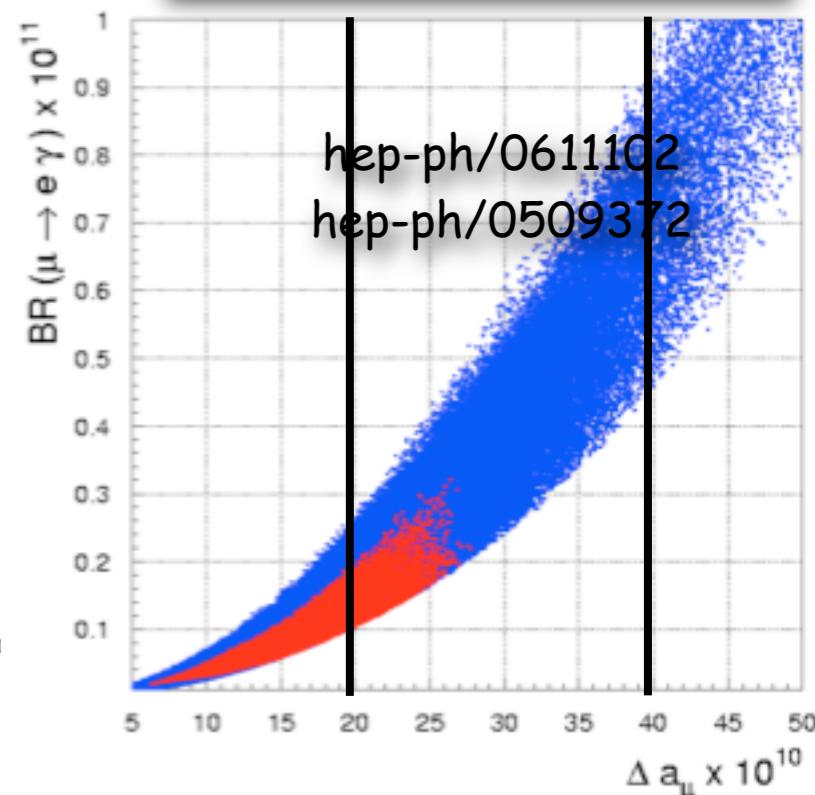
Barbieri et al, Phys. Lett B 338:212, 1994  
Barbieri et al, Nucl. Lett B 445:215, 1995

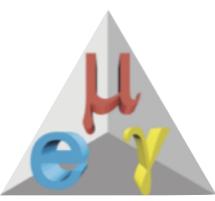


Masiero et al.  
Nucl.Phys. B 649:189, 2003



Isidori et al.  
Phys.Rev. D 75:115019, 2007



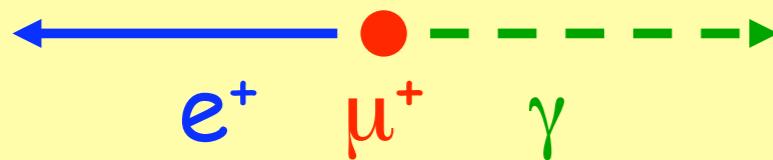


# Experimental signature



signal

$$\mu \rightarrow e \gamma$$



$$\theta_{e\gamma} = 180^\circ$$

$$E_e = E_\gamma = 52.8 \text{ MeV}$$

$$T_e = T_\gamma$$

$$\propto (\mu \text{ rate})$$

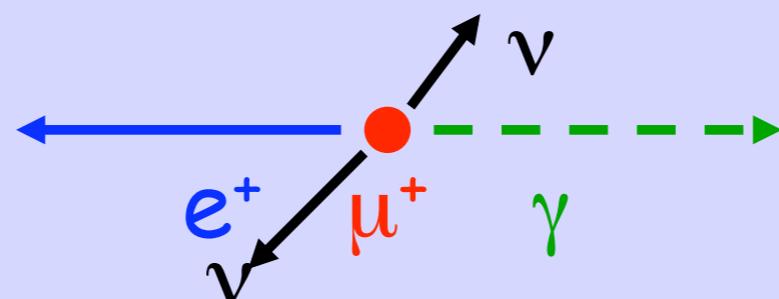
background

accidental

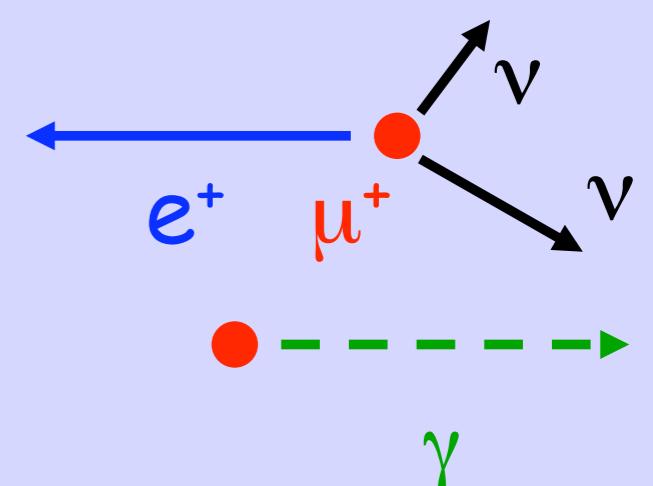
$$\mu \rightarrow e \nu \nu$$

physical

$$\mu \rightarrow e \gamma \nu \nu$$



$$\left\{ \begin{array}{l} \mu \rightarrow e \gamma \nu \nu \\ ee \rightarrow \gamma \gamma \\ eZ \rightarrow eZ \gamma \end{array} \right.$$

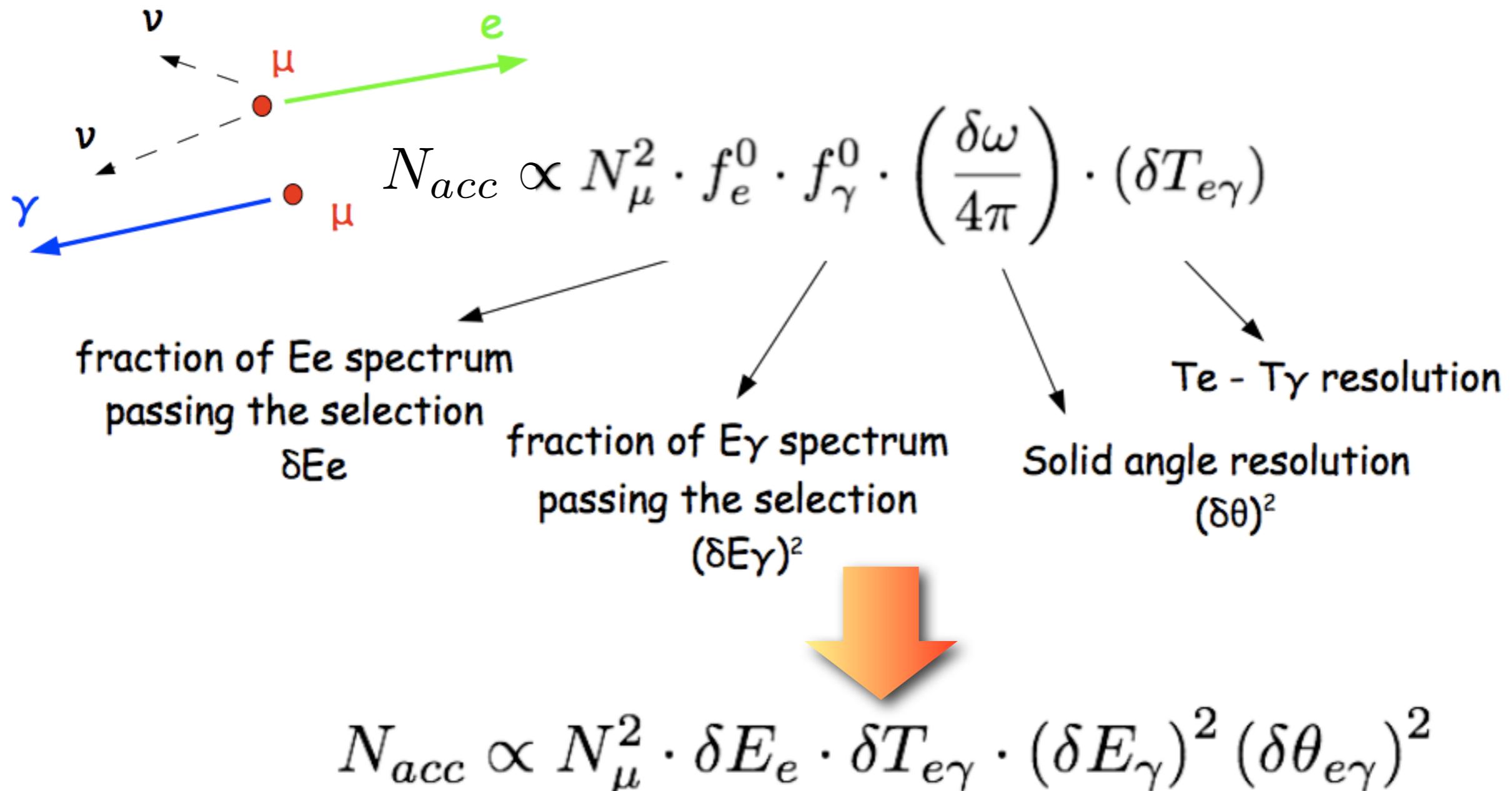


$$\propto (\mu \text{ rate})$$

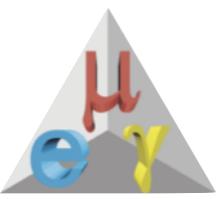
$$\propto (\mu \text{ rate})^2$$



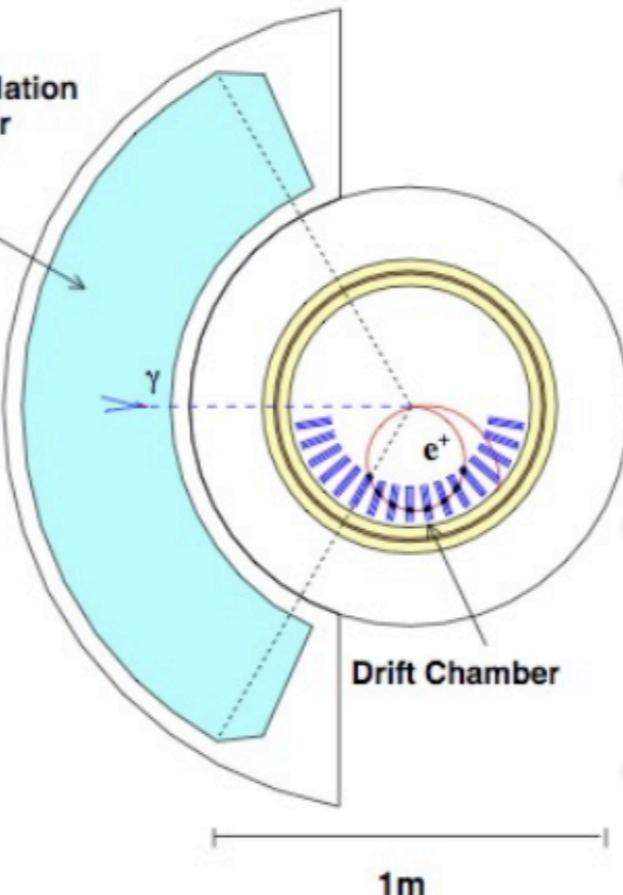
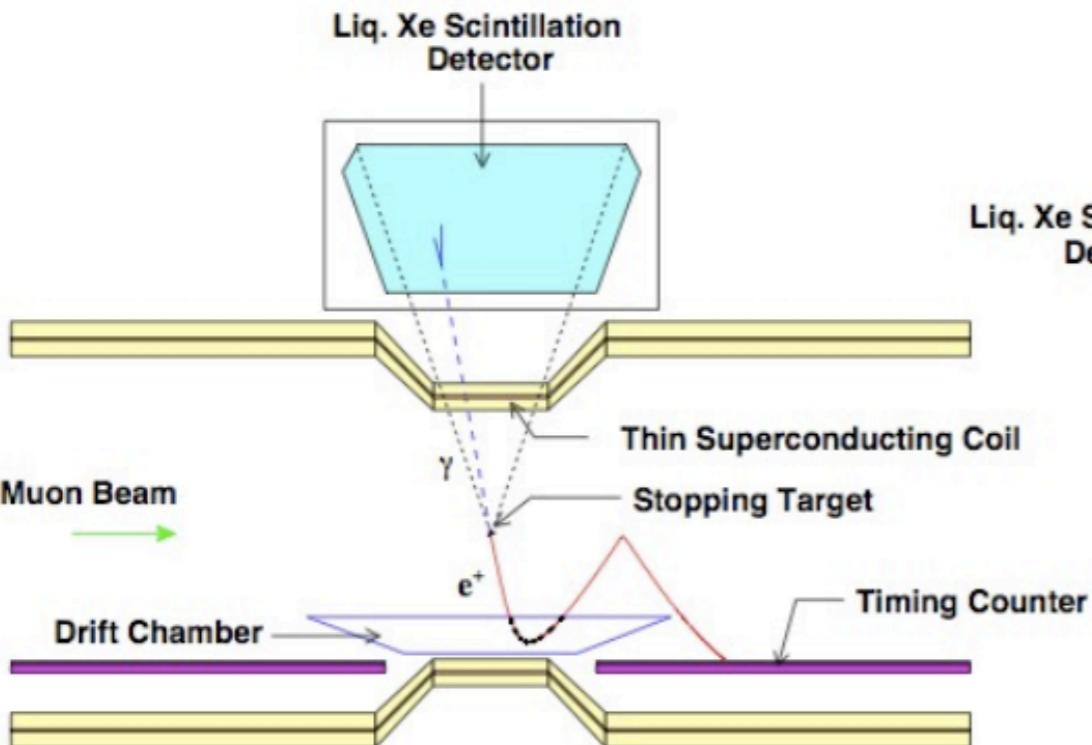
# Experimental challenge



In order to get  $O(10^{-13})$  sensitivity:  
High statistic - High resolutions



# MEG in a nutshell



- Very high rate DC muon beam of  $3 \times 10^7$  muon/s
- Solenoid spectrometer & drift chamber for  $e^+$  momentum
- Scintillator bars and fibers for  $e^+$  timing
- Liquid Xenon calorimeter for photon detection



KEK  
Tokyo Univ.  
Waseda Univ.



UC Irvine



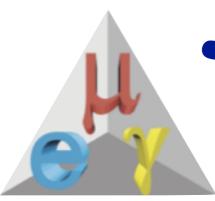
PSI



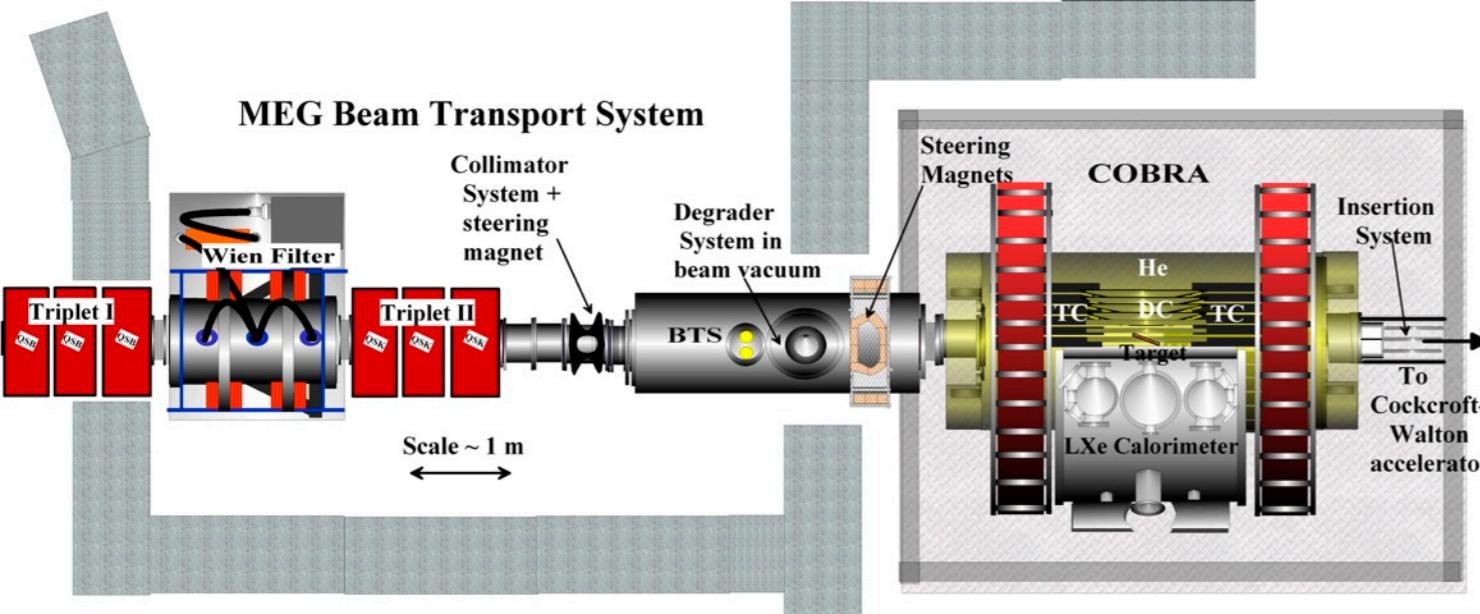
BINP - Novosibirsk  
JINR - Dubna



INFN - Genova  
INFN - Lecce  
INFN - Pavia  
INFN - Pisa  
INFN - Roma



# The PSI πE5 beam & target



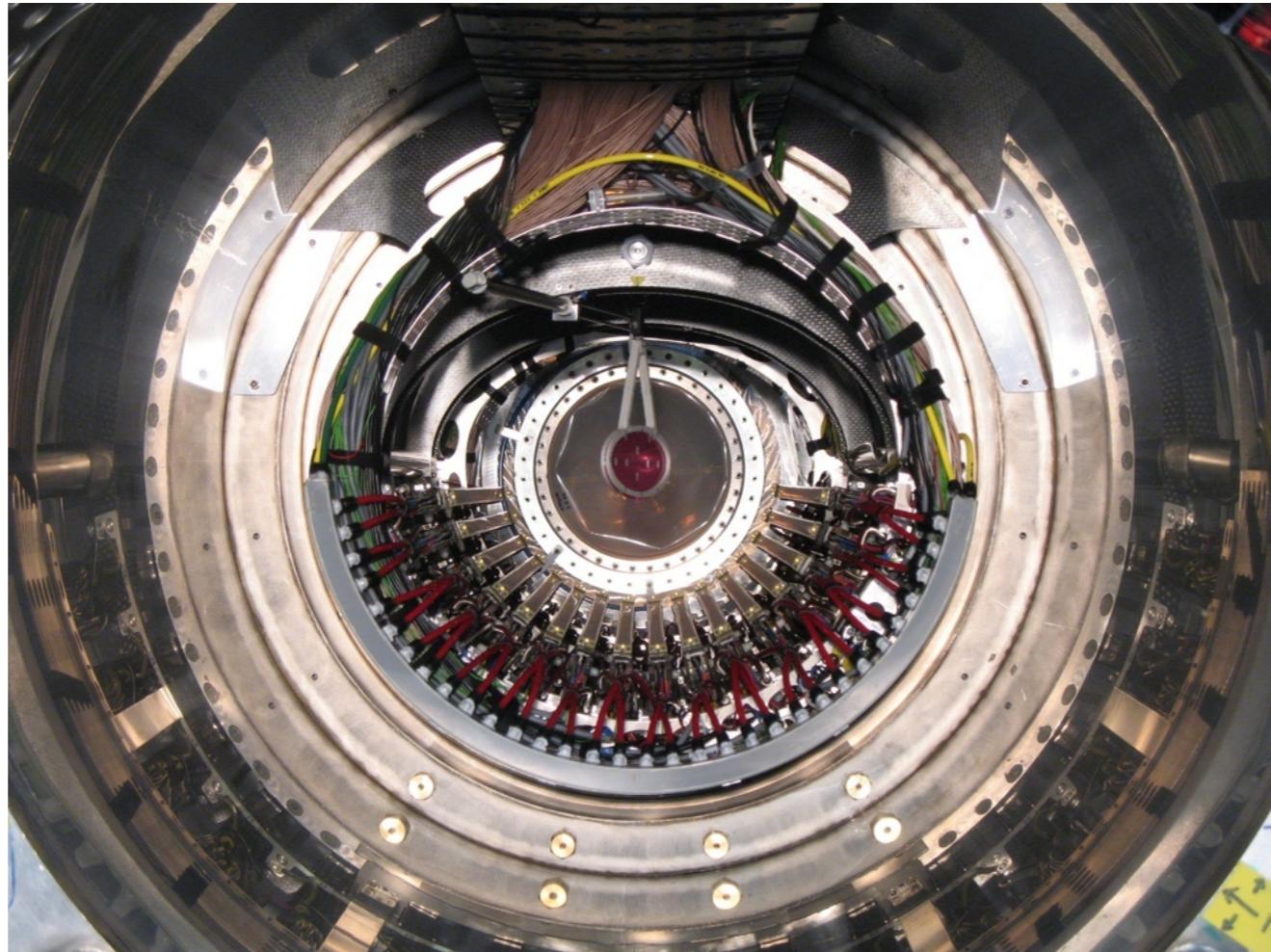
- Most intense proton DC beam in the world : 2 mA @ 1.3 MW
- 28 MeV/c "surface muons" from decay of  $\pi$  at rest
- Wien filter for e/ $\mu$  separation
- Solenoid to couple beam with the COBRA magnetic field

- Need enough material for stopping muons but low bremsstrahlung for signal positron:

- degrader 200/300  $\mu\text{m}$  + target 205  $\mu\text{m}$
- 20.5° angle between beam and target
- material with high radiation length  $X_0$  ( $\text{CH}_2$ )



# The positron spectrometer



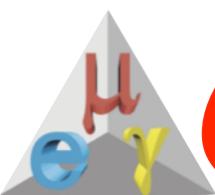
Experimental requirements:

Good momentum resolution ( $\sim 200$  KeV @ 52,8 MeV)

Low pile-up for background rejection



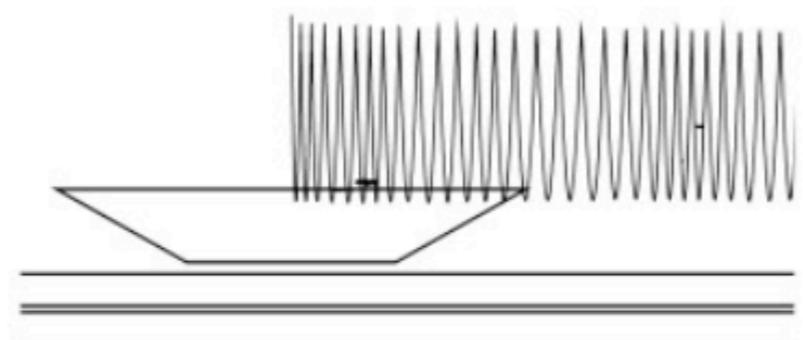
Drift Chamber in a Graded Magnetic Field (COBRA)



# Constant Bending RAdius



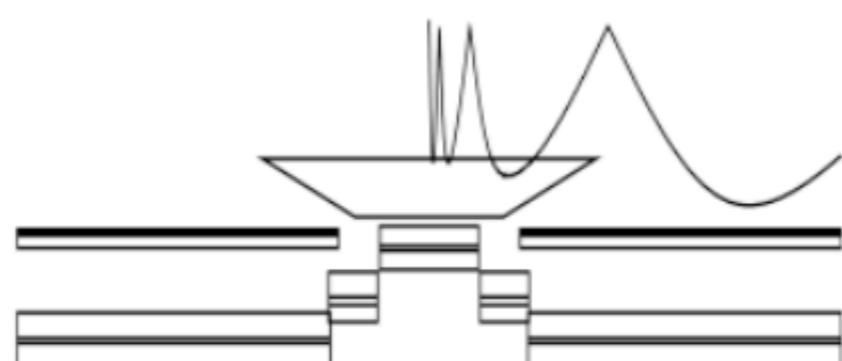
high  $\theta$



PILE UP

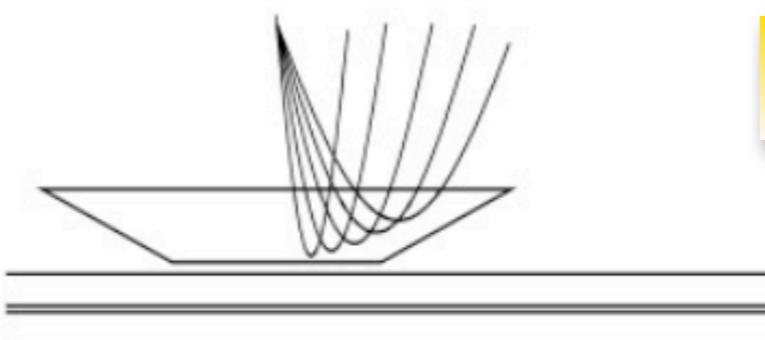


high  $\theta$



NO PILE UP!!

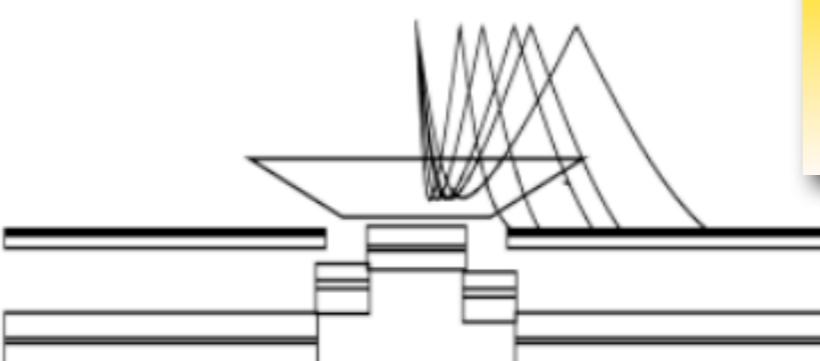
same momentum but  
different  $\theta$



WIDE RADIAL COVERAGE



same momentum but  
different  $\theta$



CONSTANT BENDING

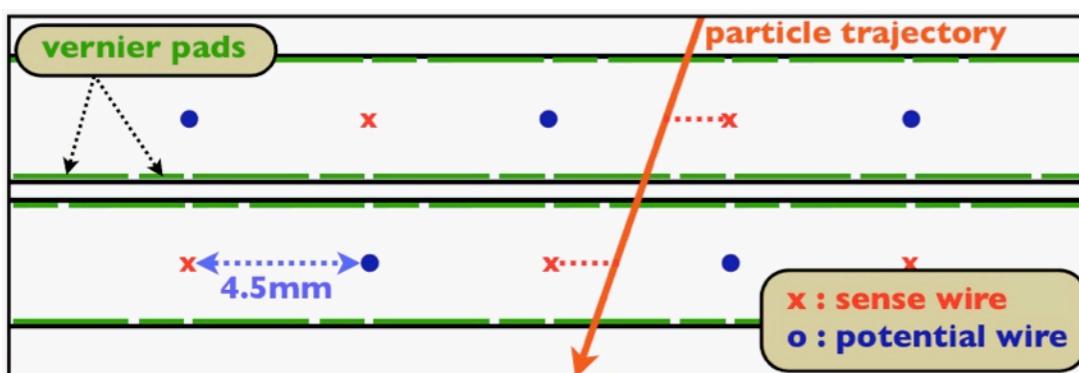
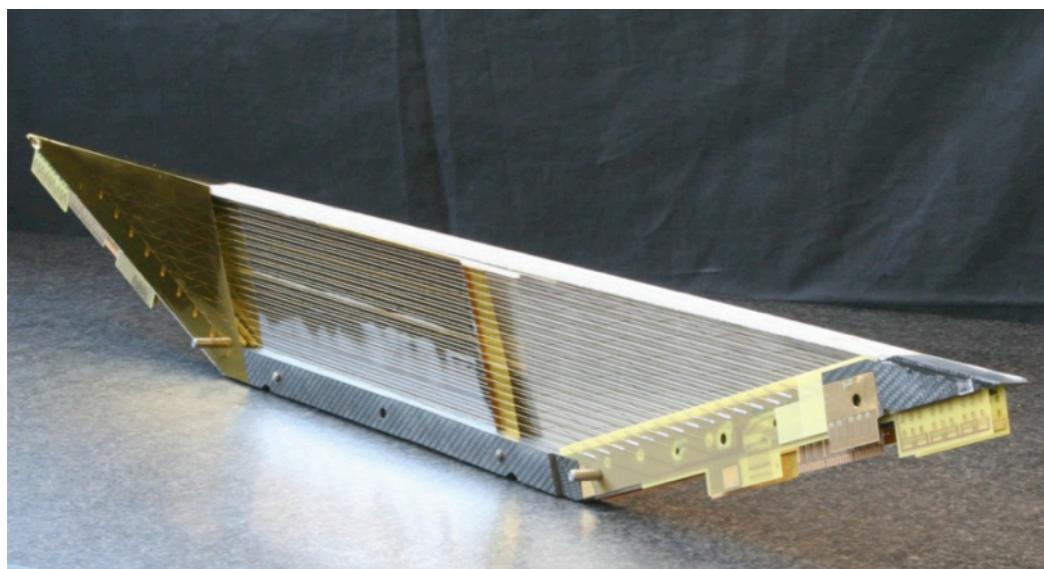
Uniform B field

Graded B field  
(max @ z=0)

# Drift Chambers



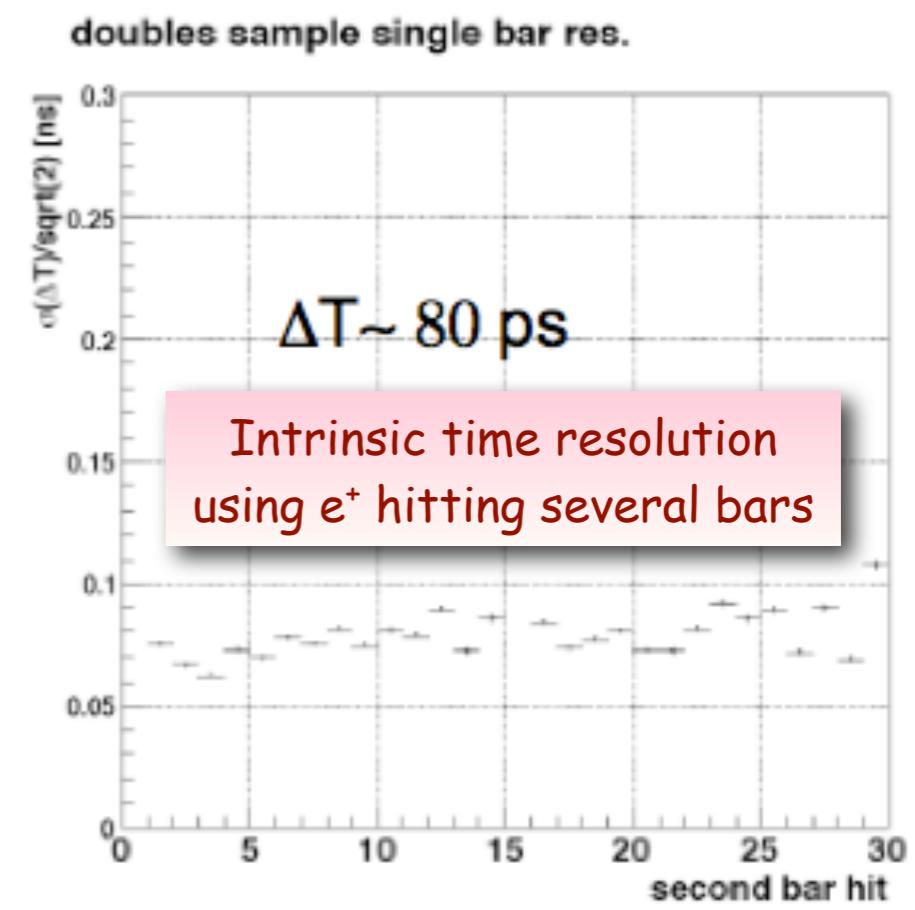
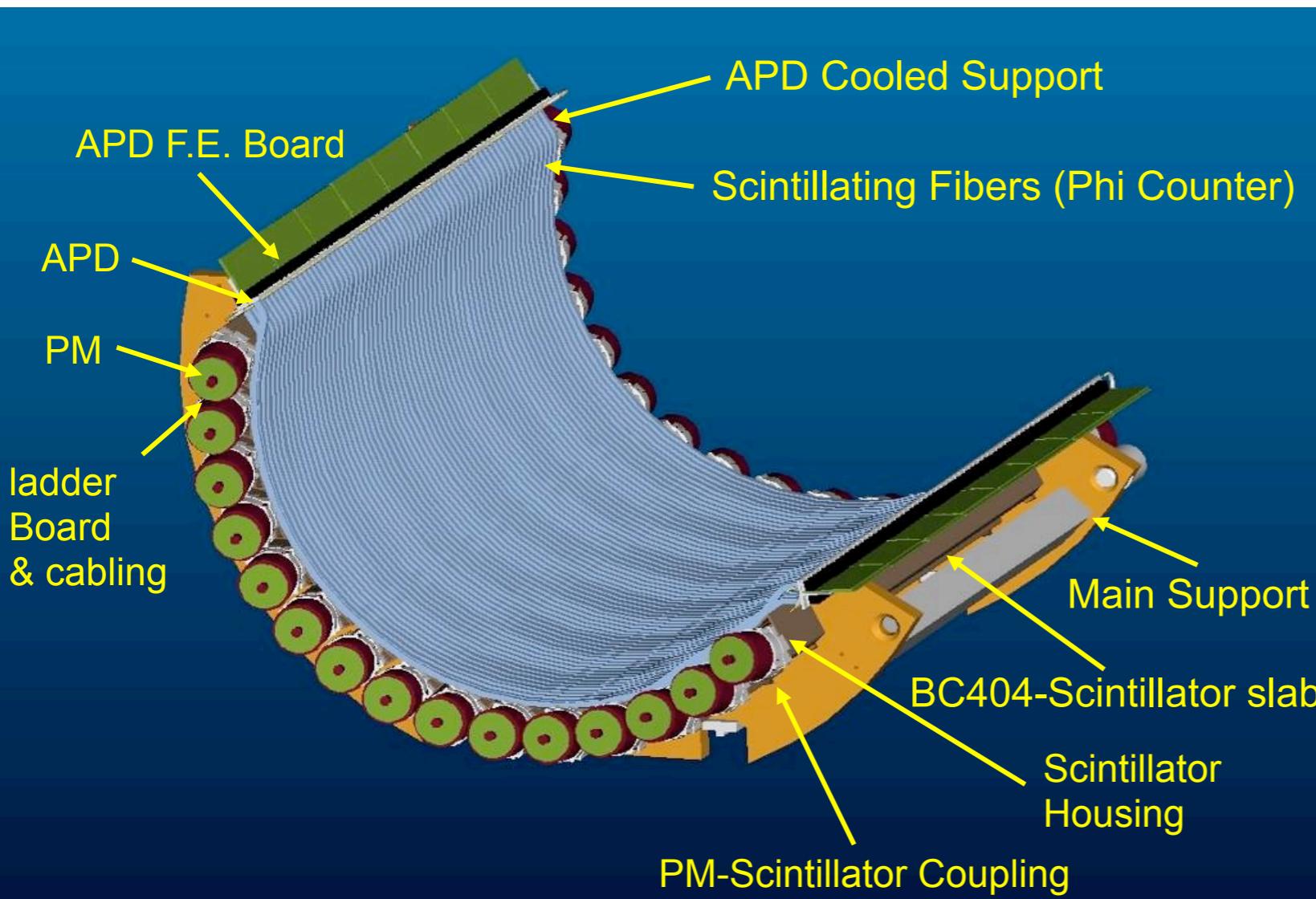
- 16 chamber sectors, 2 planes each
- Staggered array of drift cells
- Low mass:  $\sim 2.0 \times 10^{-3} X_0$  along positron trajectory
- Chamber gas: He-C<sub>2</sub>H<sub>6</sub> 50/50
- Vernier pattern on kapton foils to measure Z position
- Goals:

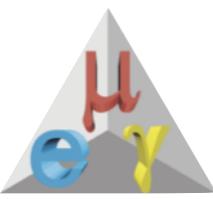


- $\sigma(X,Y) \sim 200\mu\text{m}$
- $\sigma(Z) \sim 400 \mu\text{m}$
- $\sigma(P) \sim 200 \text{ KeV}$

# Timing Counter

- Two section (upstream & downstream) of 15 bars each (BC 404 - Polyvinyltoluene)
- Time and z impact position from time average and difference in PMTs
- Scintillating fibers read by APDs for z impact position (not fully operational yet)
- Crucial for positron time measurement: goal  $\sigma(T) \sim 50$  ps
- Only positron measurement usable for trigger (DC is too "slow")



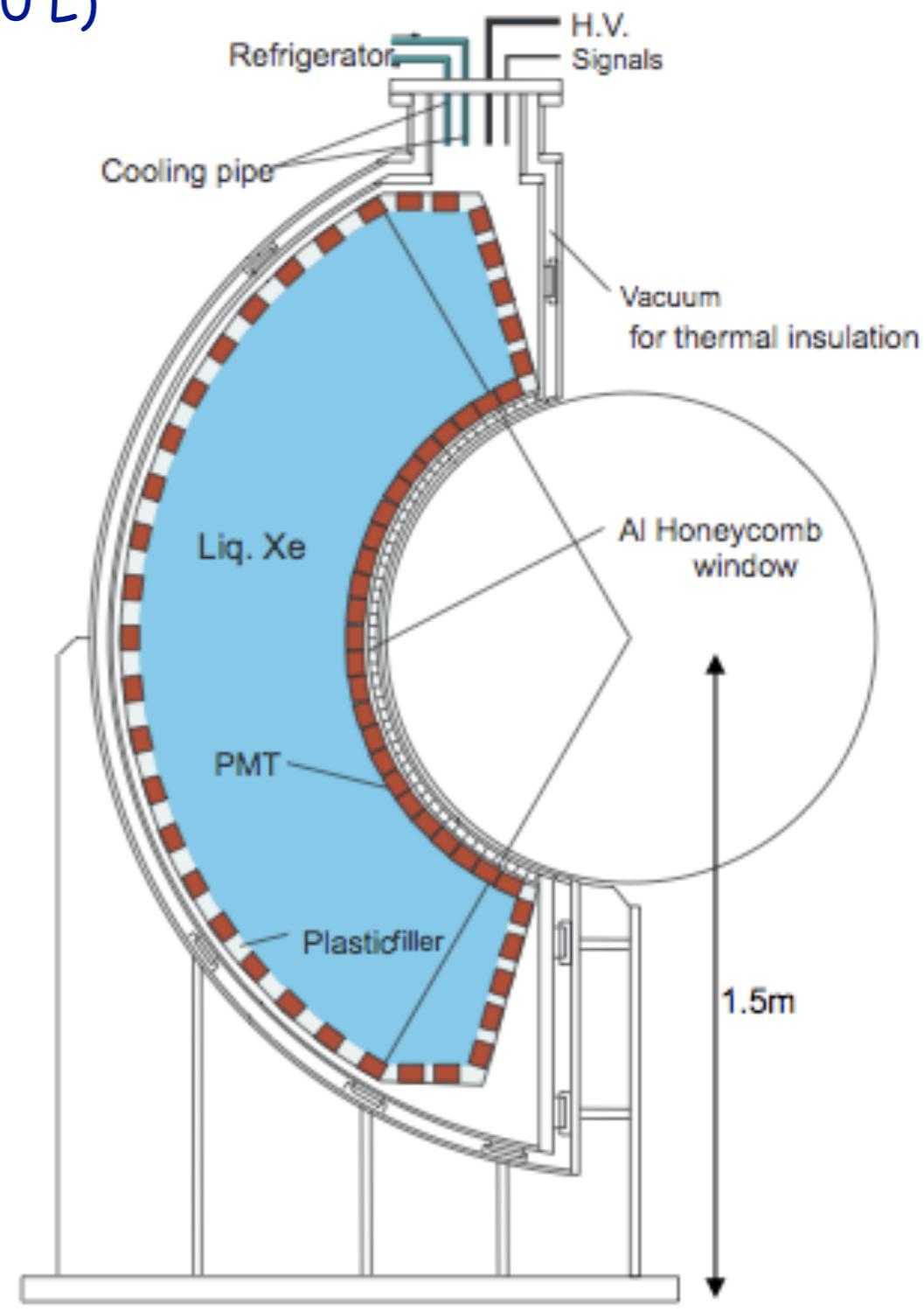
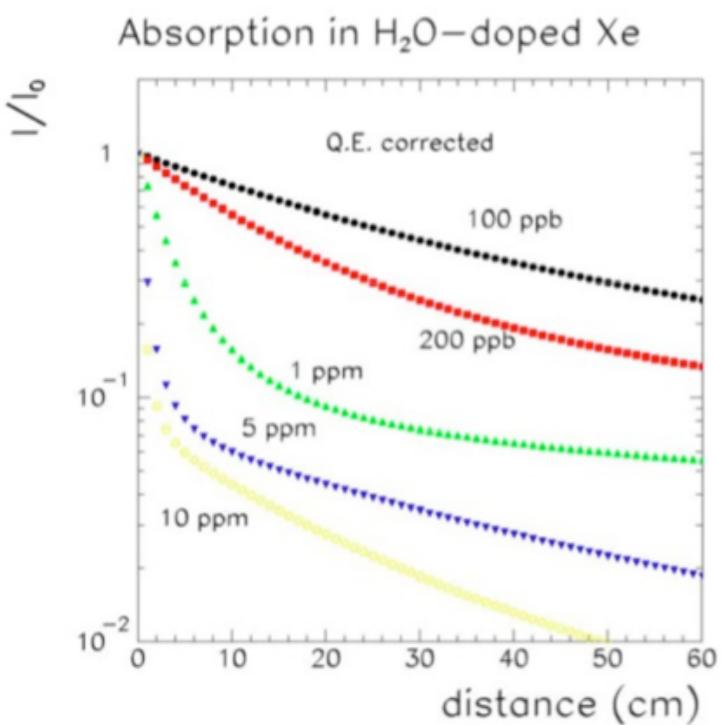


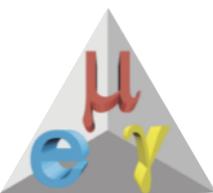
# LXe Calorimeter (XEC)



- Largest LXe calorimeter in the world (800 L)
- Fast response ( 4 ns/ 22 ns) and uniform
- High light yield ( ~75% NaI )
- Essential to maintain high purity in Xe
- Light collected by ~800 PMTs
- Goals:

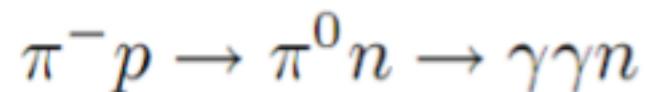
- $\sigma(E) \sim 800$  KeV
- $\sigma(T) \sim 65$  ps
- Conversion point  $\sim 2\text{-}4$  mm



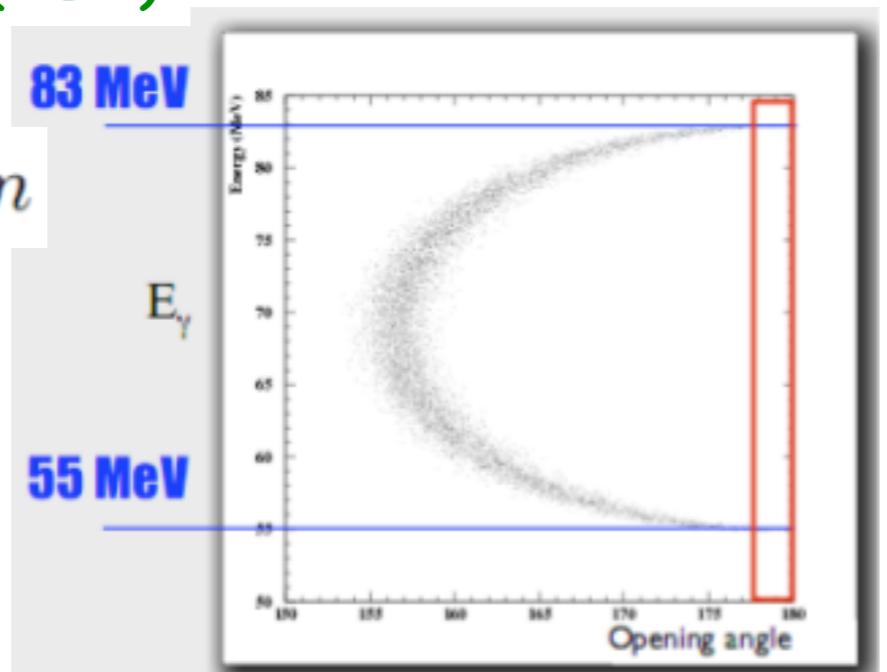


# XEC calibrations

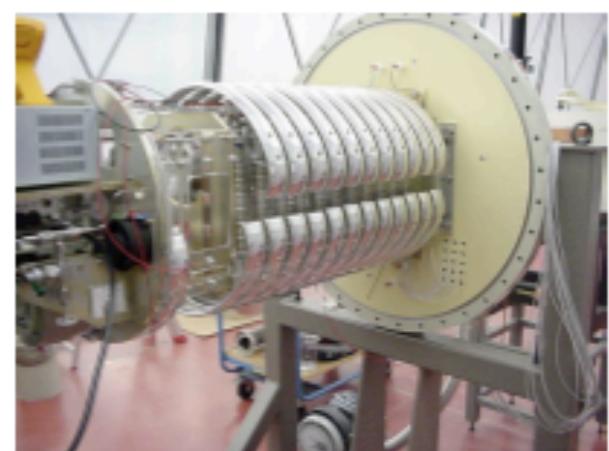
## Charge Exchange (CEX)



High energy photons for XEC energy and relative time calibration



## Cockcroft-Walton accelerator



Protons on a Lithium Tetra-borate target

low-energy photons for XEC energy & relative time calibration

## LED

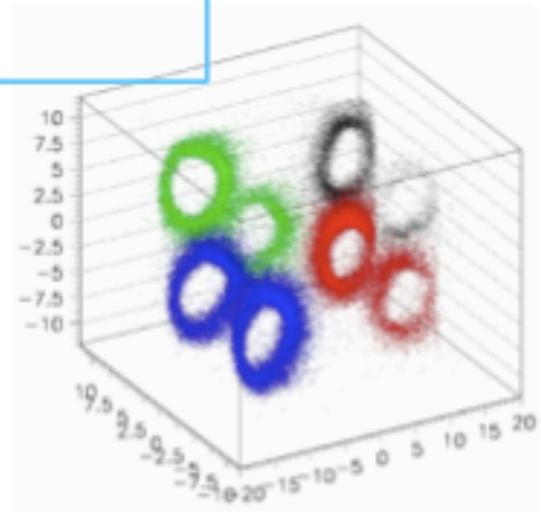
Installed inside the XeC



PMT gain calibration

## $\alpha$ sources

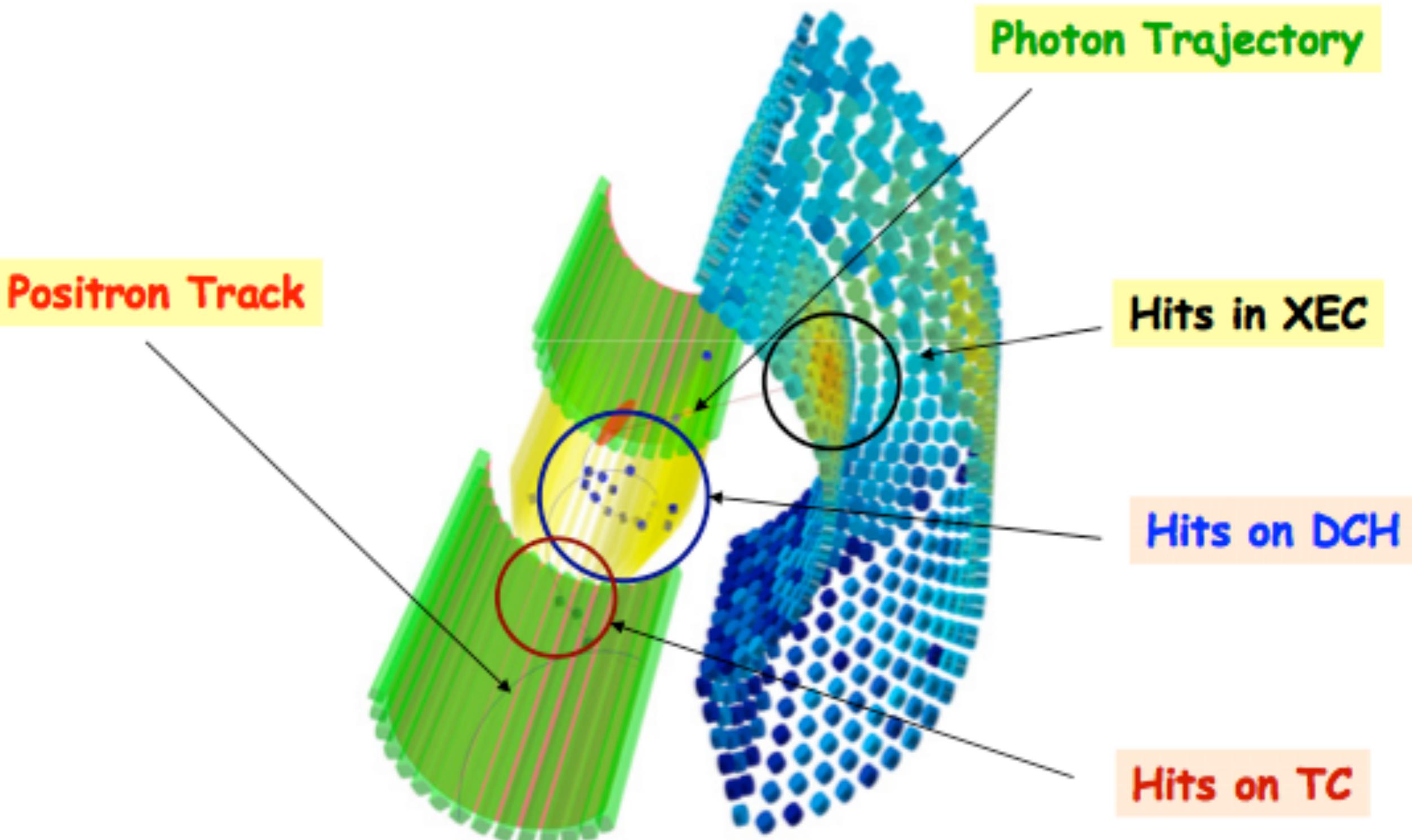
Installed in wires inside the XeC

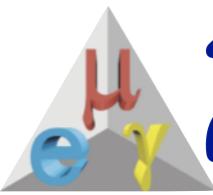


Calibration of Q.E., attenuation length, position



# A MEG event





# 2008: the first physics run



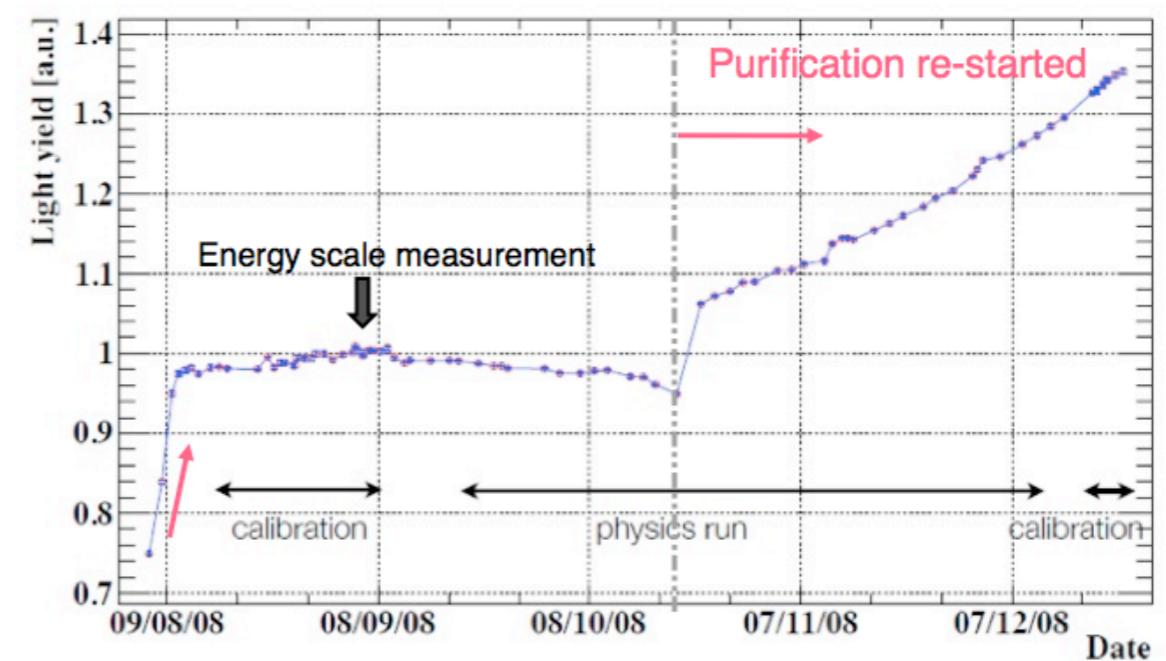
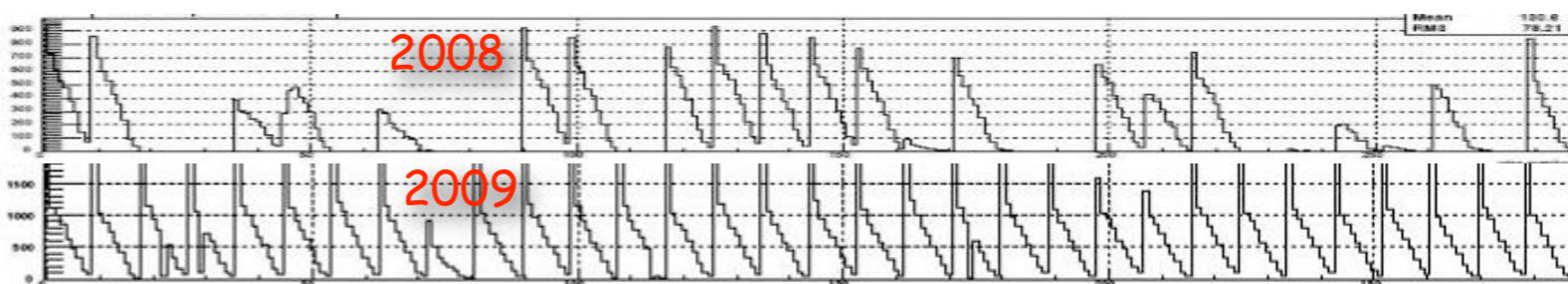
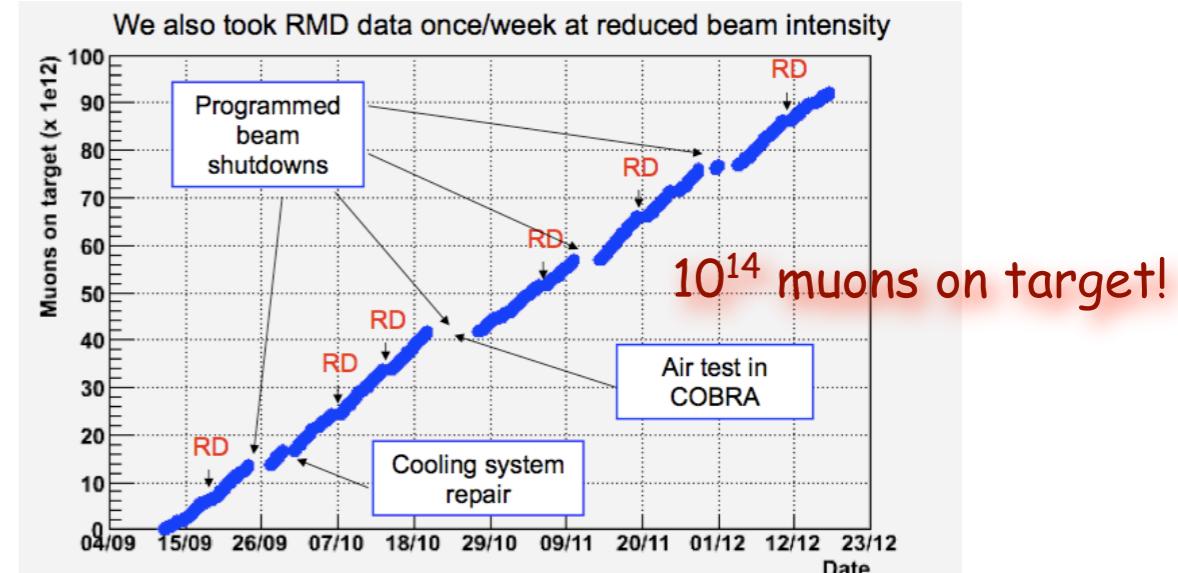
- # First 3 months of physics data taking ( 09/08 - 12/08)

## DCH trips and instabilities:

- reduction of efficiency to 30% (from 90% in MC)
  - total positron eff ~ 14%
  - Hardware problem due to long exposure to helium:  
all chambers rebuild and running nicely in 2009

## Xe light yield increased:

-  now in 2009 at the  
nominal value



# Analysis Technique



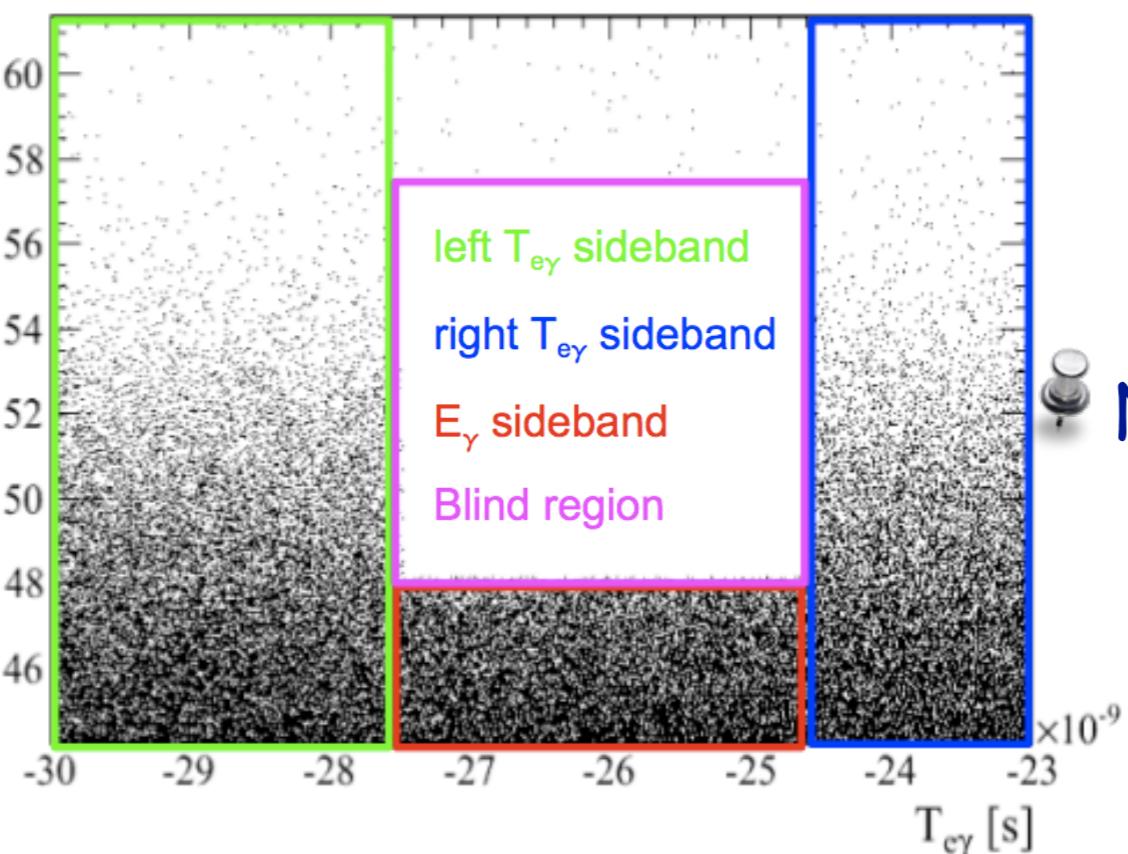
Blind analysis technique adopted:

-  Events inside a signal region of  $E_\gamma$  and  $T_{e\gamma}$  not used for analysis development
-  Background characterization from sidebands



Normalization to Michel BR (~100%)

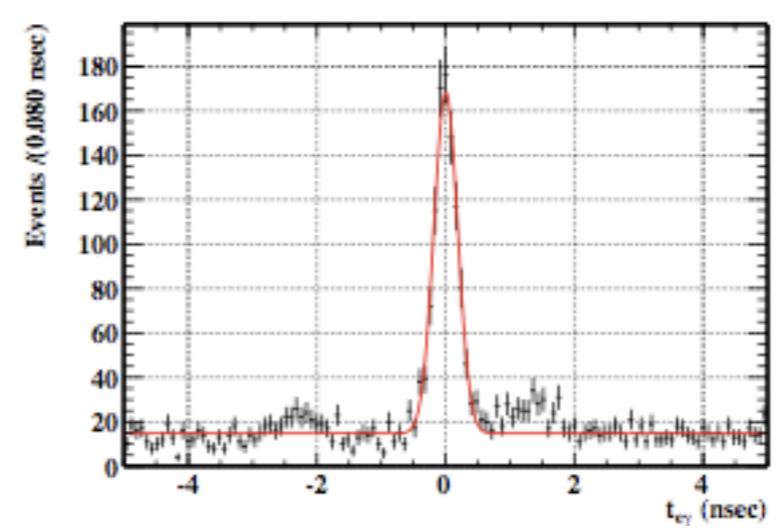
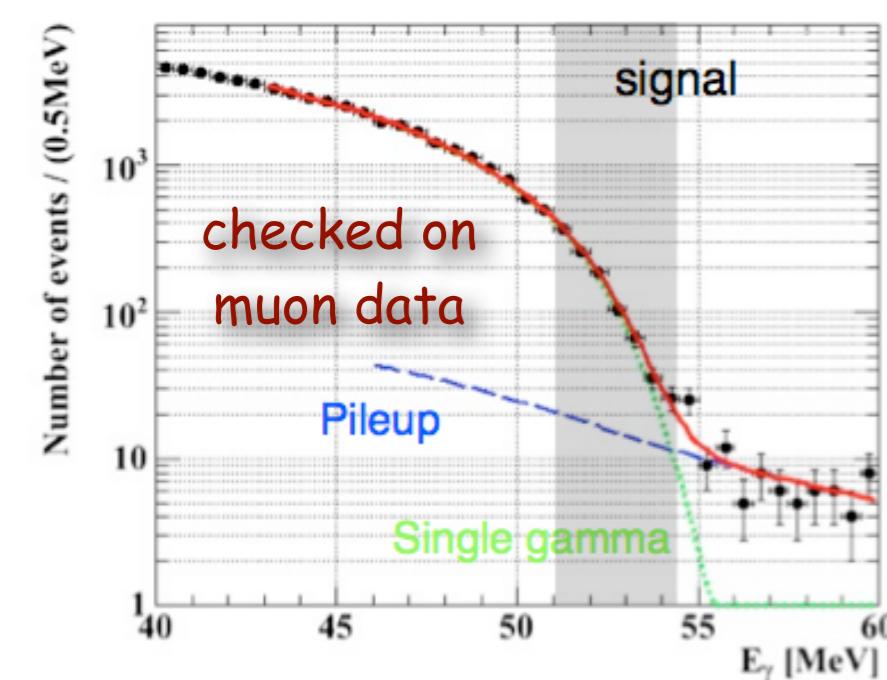
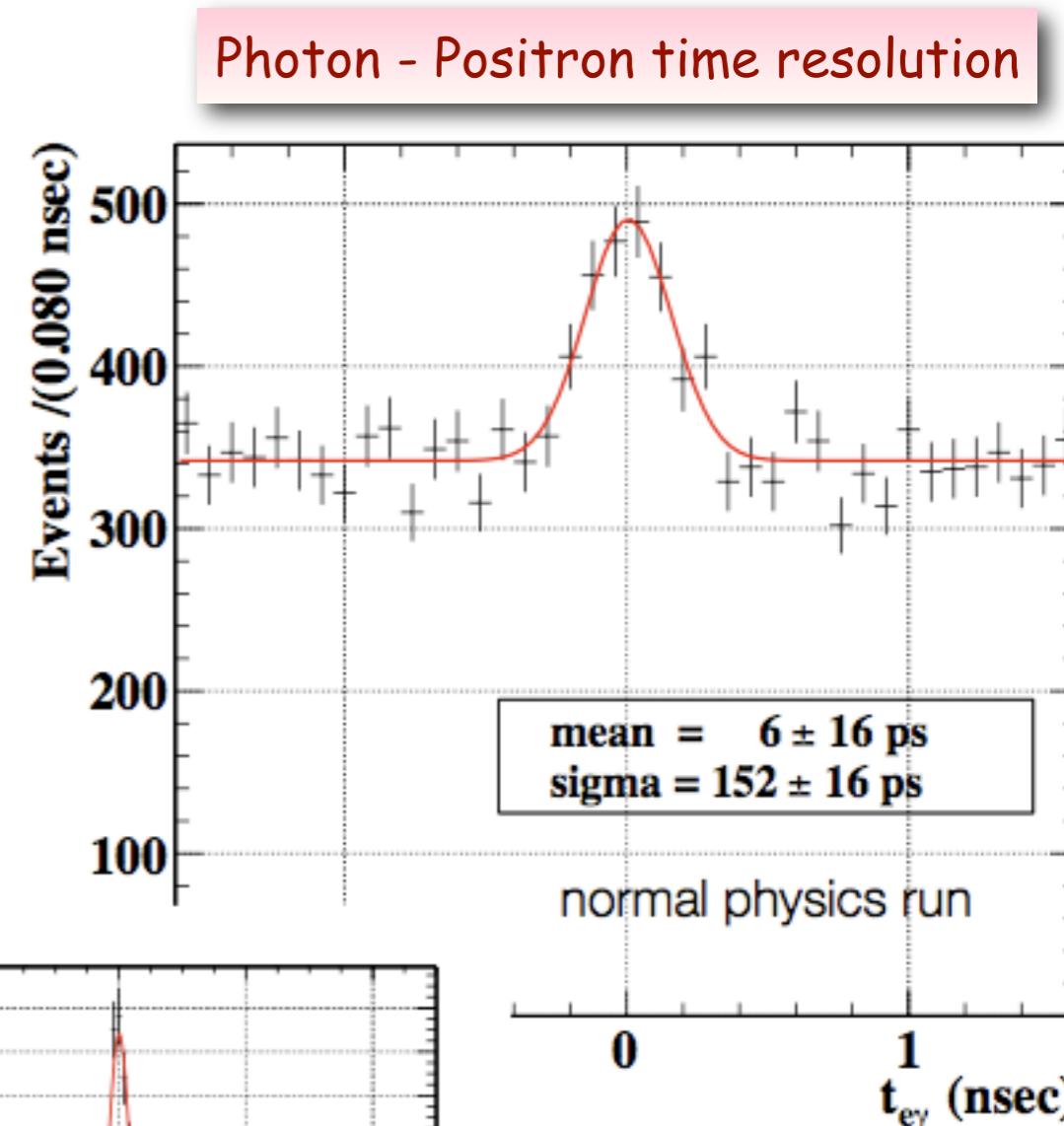
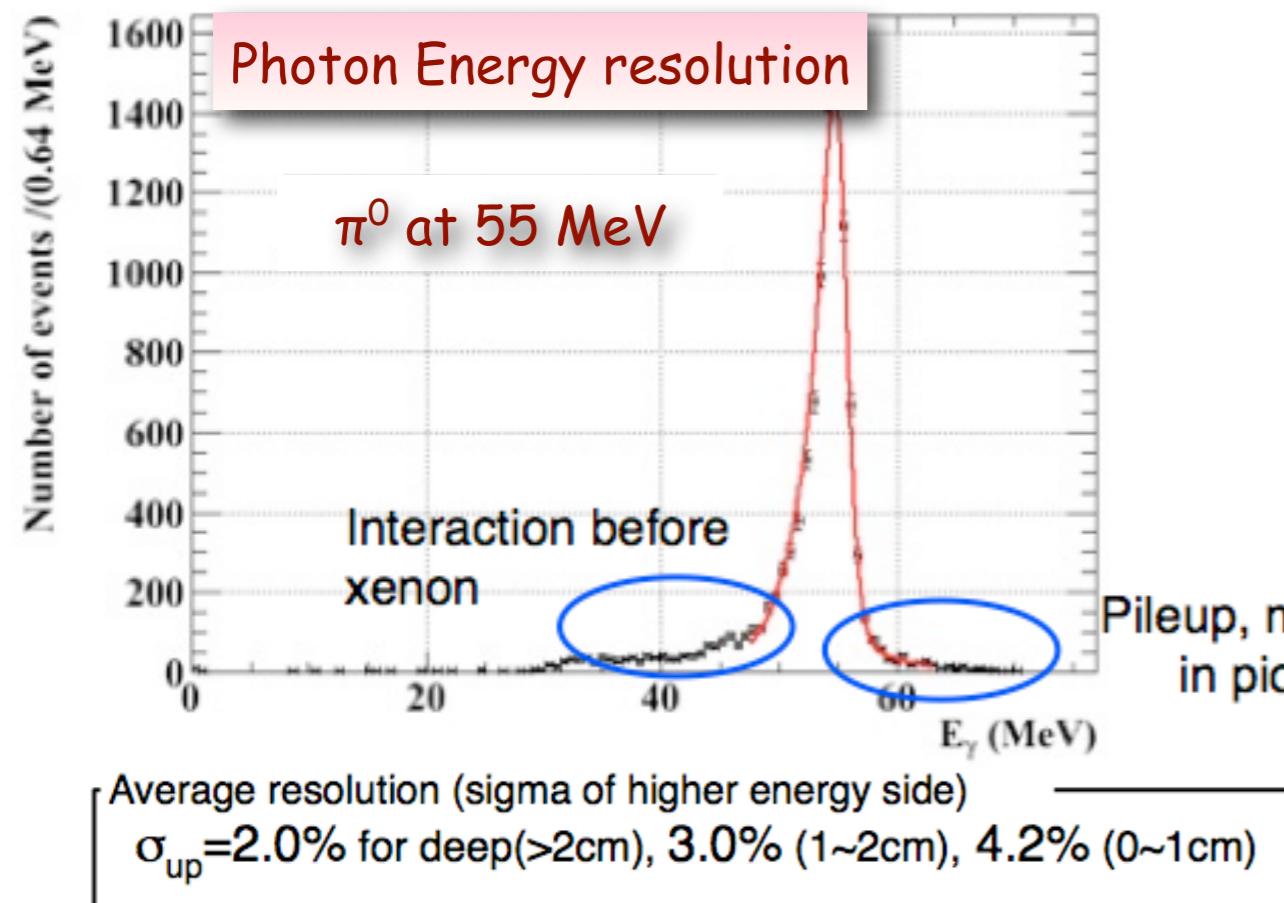
-  Michel positrons counted simultaneously with the signal
-  Independent of instantaneous beam rate and insensitive to acceptance and efficiency



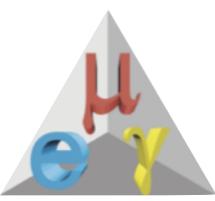
$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) = \frac{N_{\text{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^E}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{trig}}}{\epsilon_{e\gamma}^{\text{trig}}} \times \frac{A_{e\nu\bar{\nu}}^{\text{TC}}}{A_{e\gamma}^{\text{TC}}} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{DCH}}}{\epsilon_{e\gamma}^{\text{DCH}}} \times \frac{1}{A_{e\gamma}^g} \times \frac{1}{\epsilon_{e\gamma}},$$



# 2008 Performances



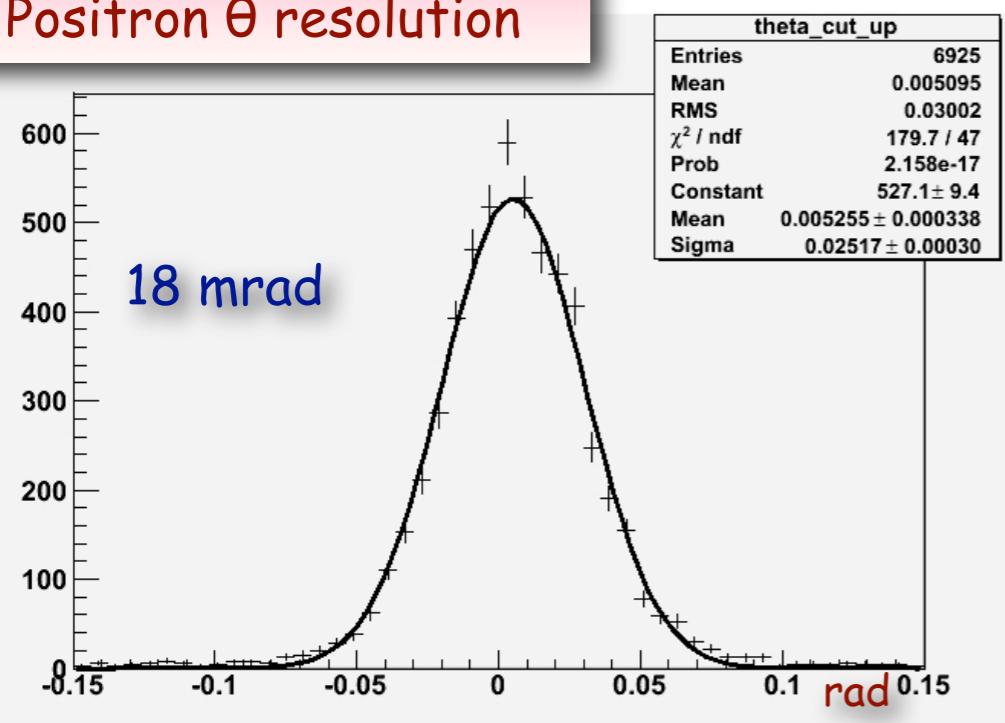
peak in the RMD run



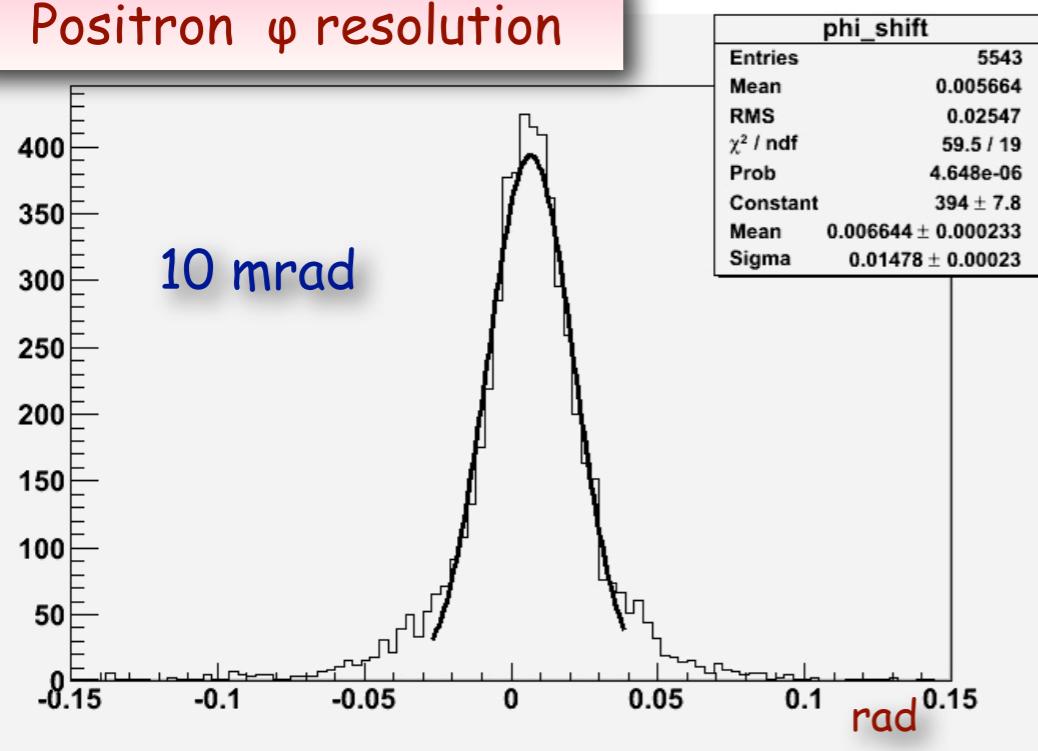
# 2008 Performances



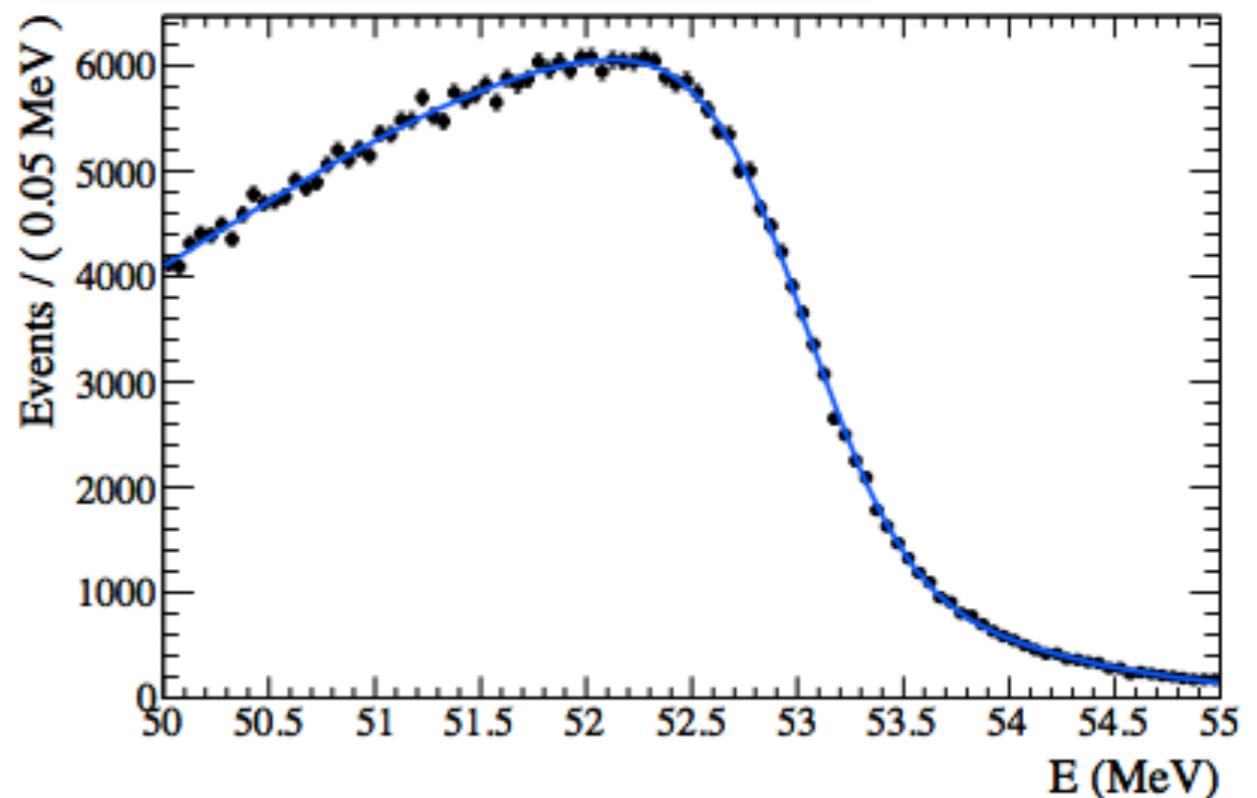
Positron  $\theta$  resolution



Positron  $\varphi$  resolution



Positron momentum resolution



• Positron momentum resolution: core and tails components

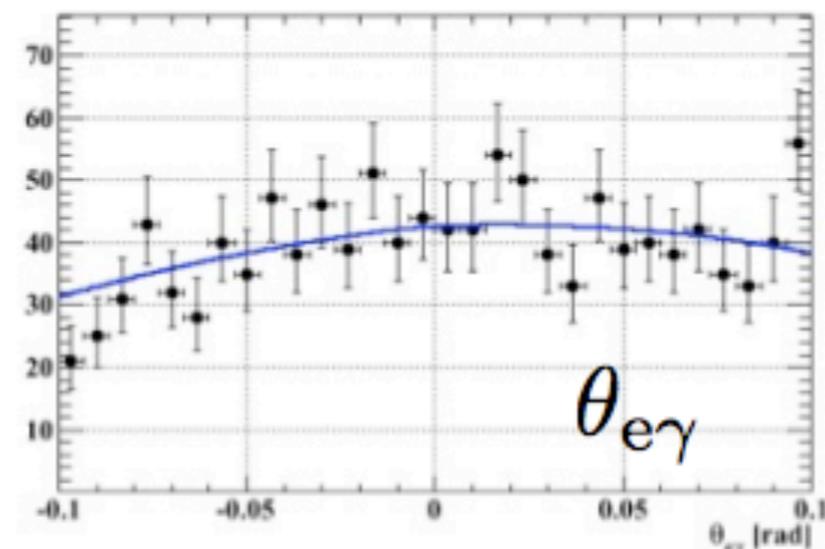
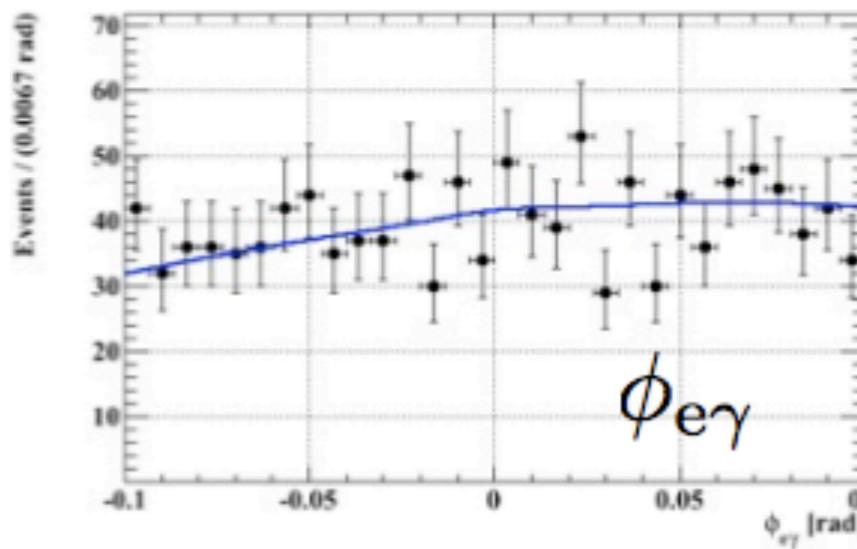
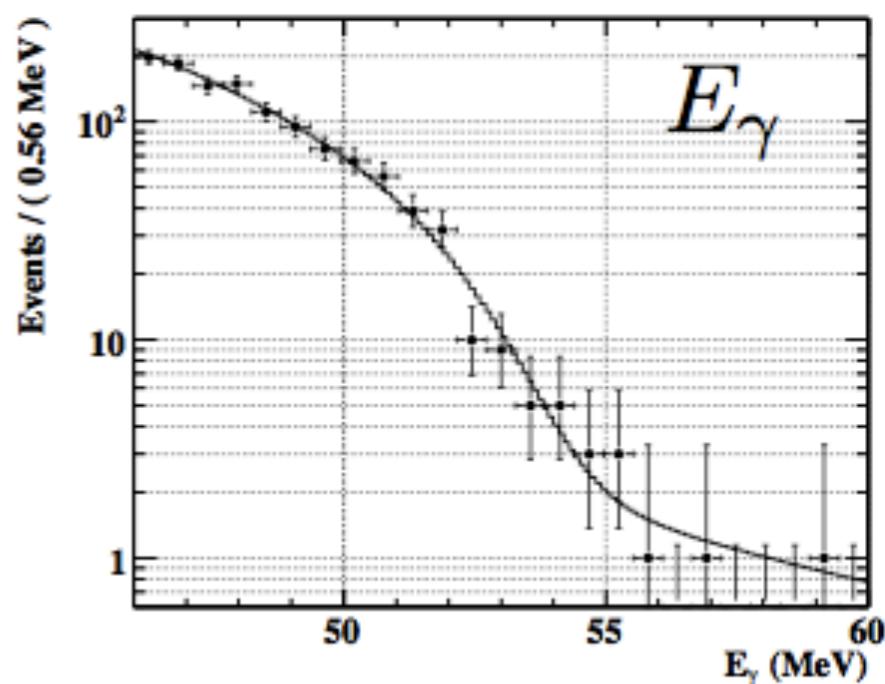
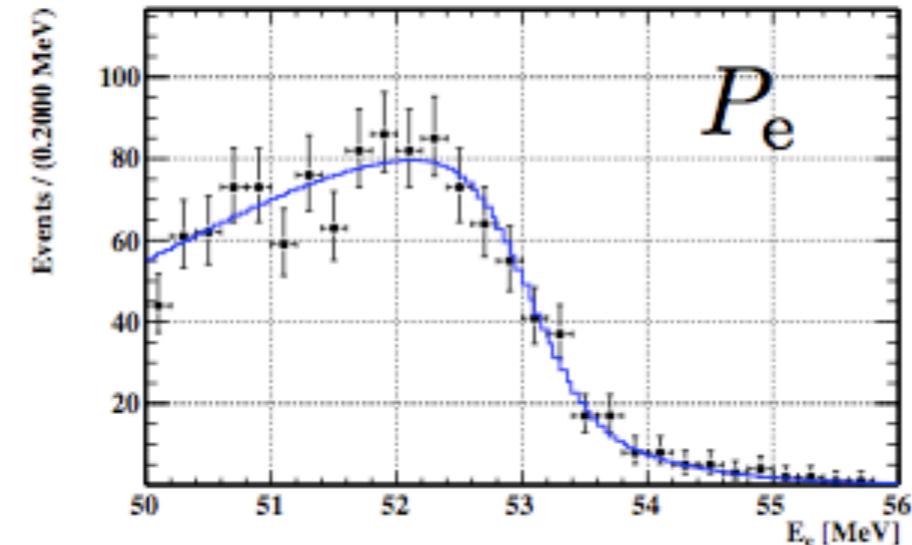
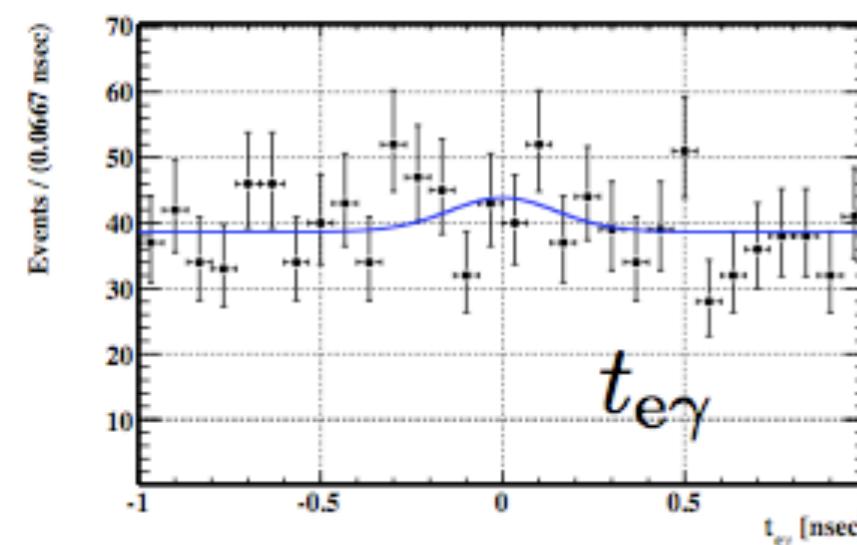
- core = 374 KeV (60%)
- tails = 1.06 MeV(33%) / 2.00 MeV (7%)



# Maximum Likelihood Fit



Extended ML fit including signal, accidental and radiative decays



$N_{\text{sig}} < 14.7 @ 90\% \text{ CL}$

$N_{\text{RMD}}$  consistent with sideband estimate:  $25^{+17}_{-16}$



# 2008 result

arXiv: 0908.2594

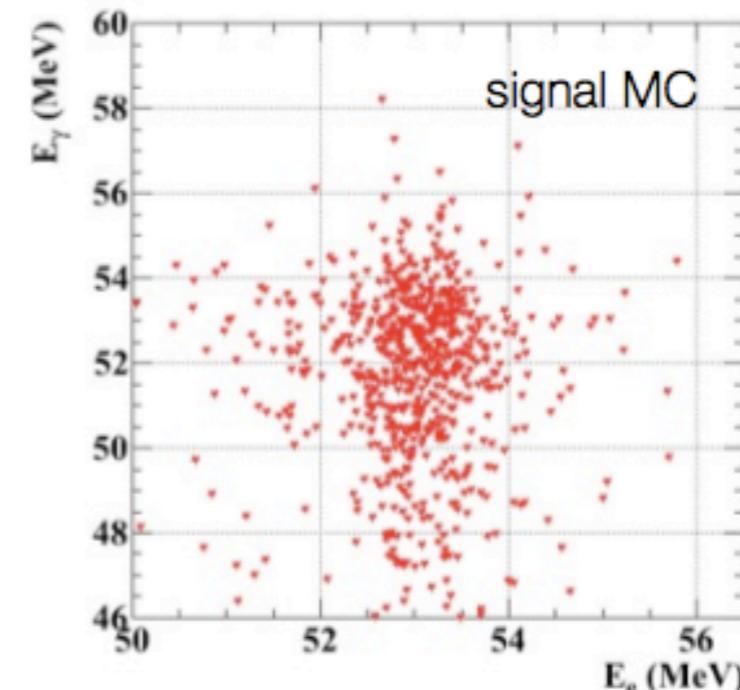
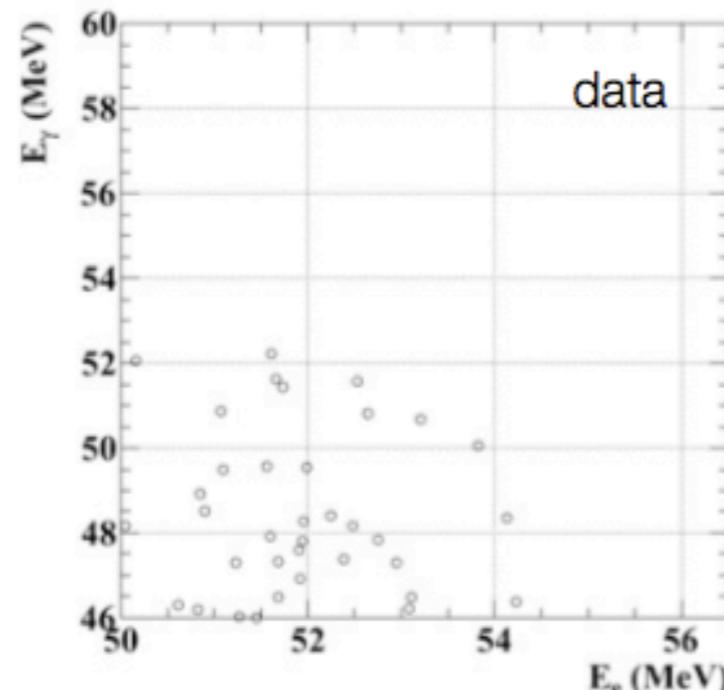
Sub to Nucl. Phys. B



Feldman-Cousins approach  
(compatible results within 3%-5% with Bayesian approach and box analysis)

$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) < 2.8 \times 10^{-11} \text{ @ 90% CL}$$

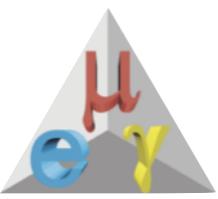
Present best UL from MEGA  $< 1.2 \times 10^{-11}$  @ 90% CL



Note: all the other parameters are cut to select ~90% of signal events in these plots

- expected 90% CL UL on BR (no signal)  $\sim 1.3 \times 10^{-11}$  (from toy MC)
- 90% CL UL from sideband data (no signal) :  $(0.9 - 2.1) \times 10^{-11}$

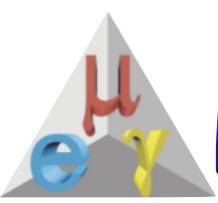
Statistical fluctuation 5% : BAD LUCK :(



# 2009 Run

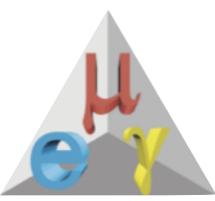


- 2009 run from October to December
- Electronic improvement: DRS2 → DRS4
  - better timing and less noise
- Factor 3-4 efficiency improvement
  - All DCH operational now
  - Improved trigger efficiency
- Several resolutions and efficiencies improved
- Corresponding expected 2009 sensitivity  $O(10^{-12})$
- Detector ready for a long and prosperous 2010 run



# Performances: past, present and future

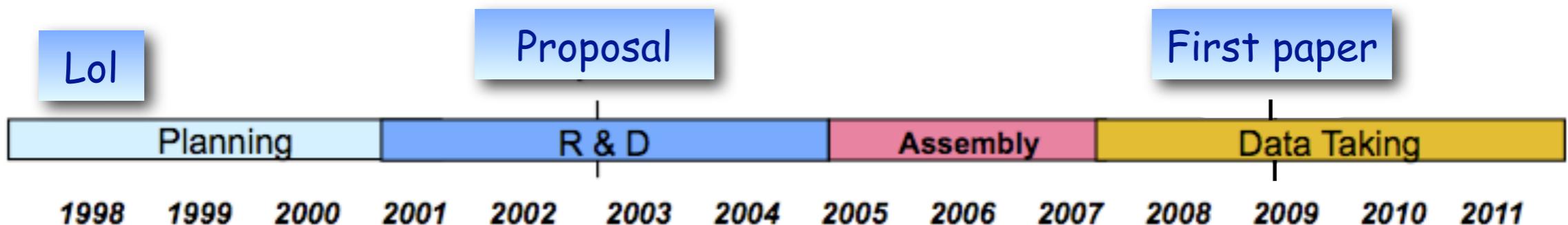
	2008	2009 (preliminary)	"Goal"
Gamma Energy (%)	2.0(w>2cm)	←	1.2
Gamma Timing (psec)	80	>67	43
Gamma Position (mm)	5(u,v)/6(w)	←	3.8(u,v)/5.9(w)
Gamma Efficiency (%)	63	←	60
e <sup>+</sup> Timing (psec)	<125	←	50
e <sup>+</sup> Momentum (%)	1.6	0.85	0.3-0.38(100%)
e <sup>+</sup> Angle (mrad)	10(ϕ)/18(θ)	8(ϕ)/11(θ)	3.8-5.1
e <sup>+</sup> Efficiency (%)	14	40	90
e <sup>+</sup> -gamma timing (psec)	148	<180	64
Muon Decay Point (mm)	3.2(R)/4.5(Z)	2.2(R)/3.1(Z)	0.9-1.1
Trigger efficiency (%)	66	88	100
Stopping Muon Rate (sec <sup>-1</sup> )	$3 \times 10^7$ (300 μm)	$2.9 \times 10^7$ (300 μm)	$3 \times 10^7$
DAQ time/Real time (days)	48/78	35/43	300/-



# Conclusions and Outlook

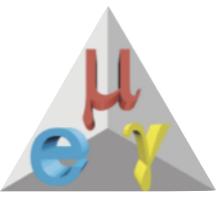


- First physics data taken in 2008 and paper on arXiv on August 2009
  - Detector not yet at design level
  - Reduced efficiencies and resolutions
  - Yet, result at same level of world best UL
- Successful run in 2009
  - Smooth operation without instabilities
  - Improved performances
  - Expected sensitivity  $O(10^{-12})$
- New data taking to start in May with a stable and improved detector (TIC fibers)
- Continue running in 2010-2011 for final ( $10^{-13}$ ) goal

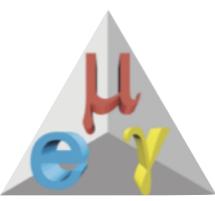




The MEG Collaboration



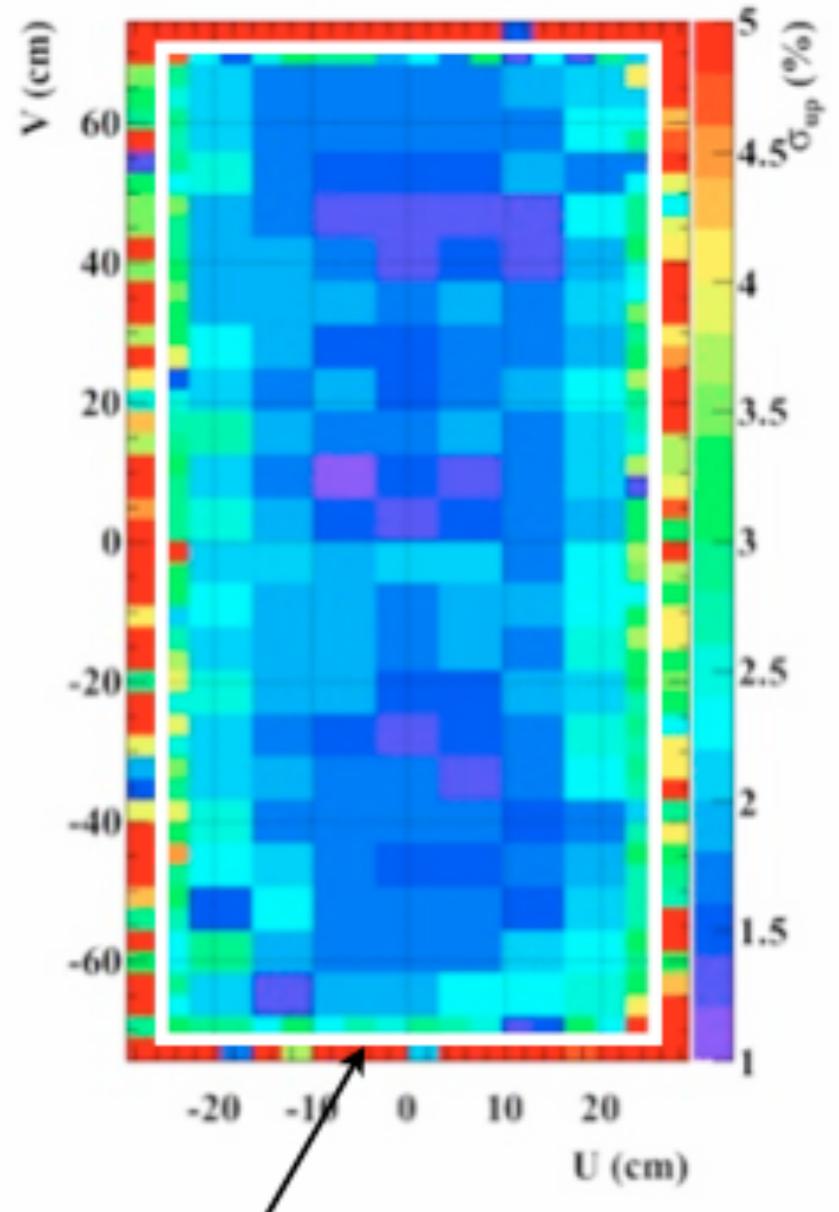
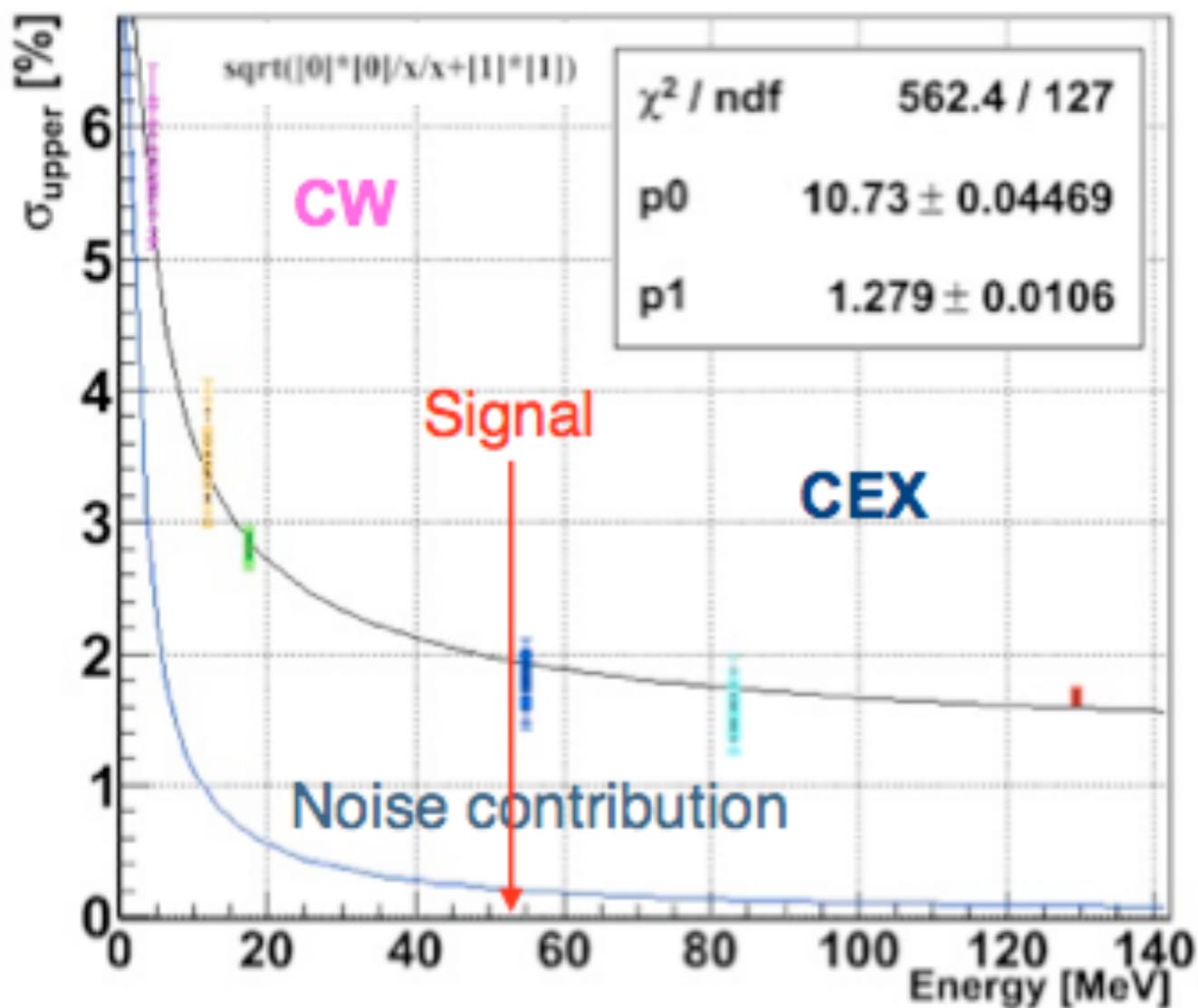
# Backup slides



# Photon energy resolution



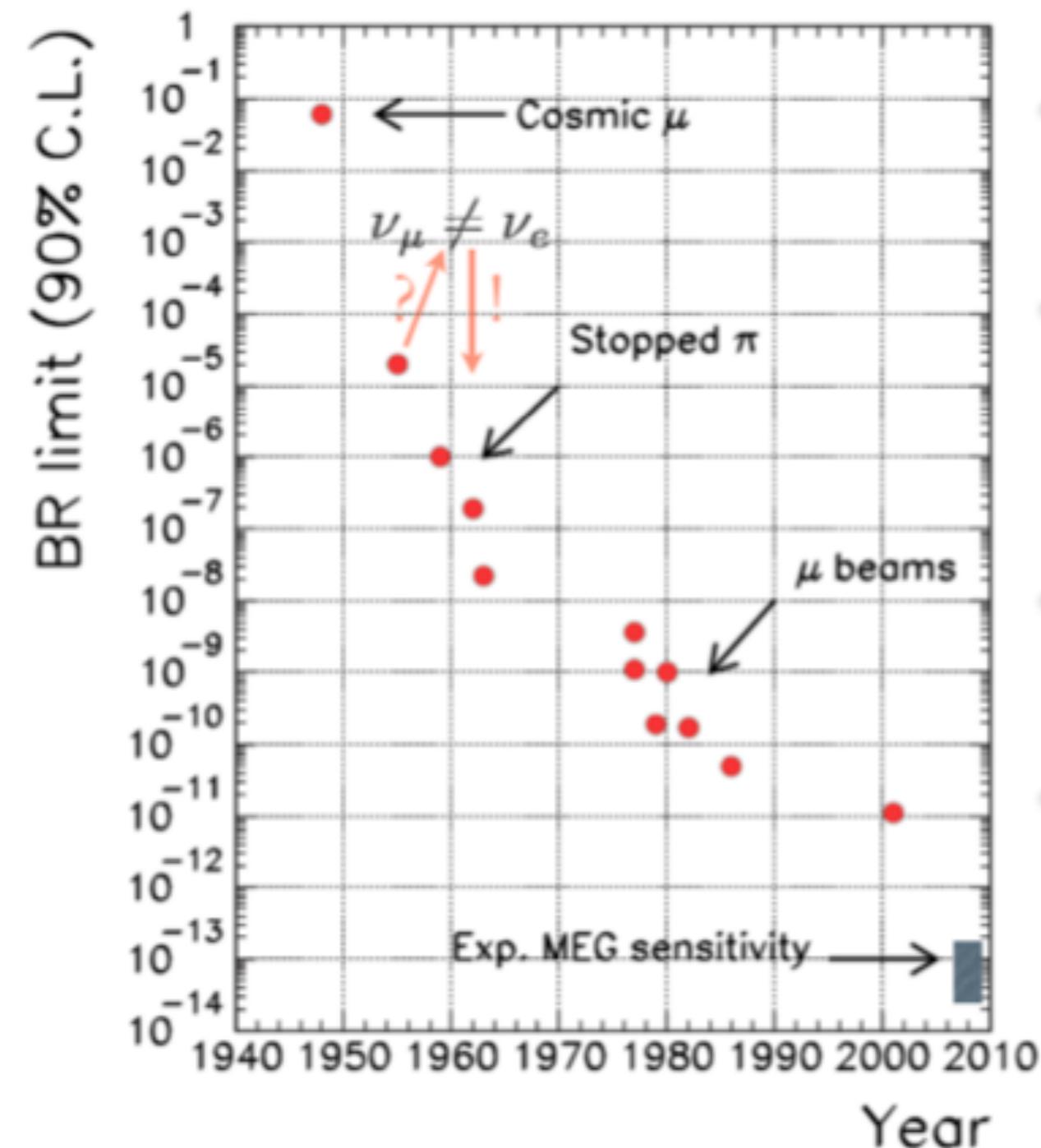
2009 Energy resolution as a function of energy



Energy resolution as a function of position



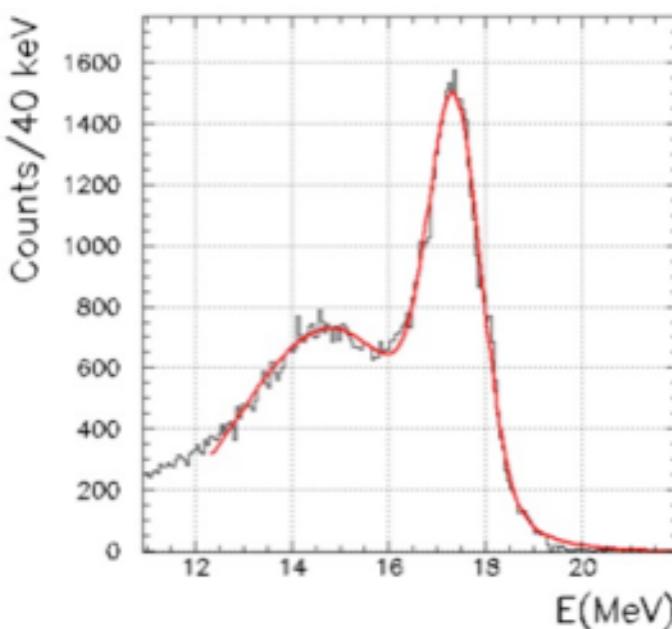
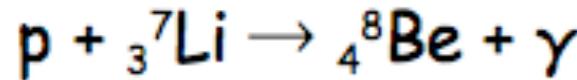
# A Long Quest



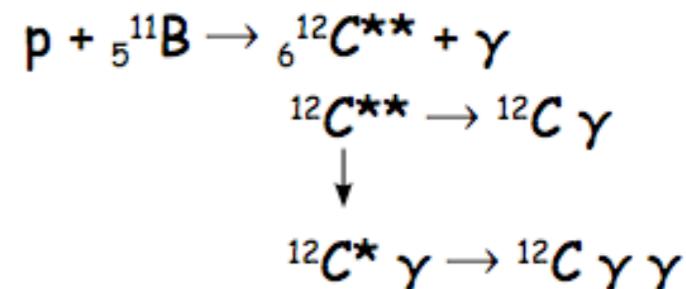
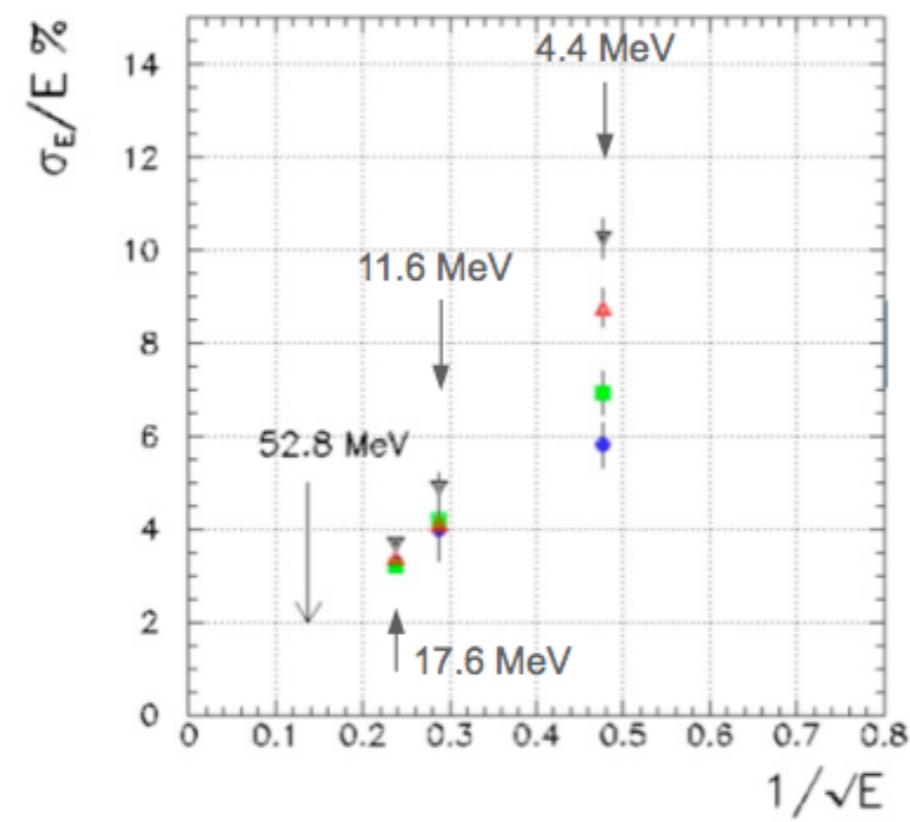
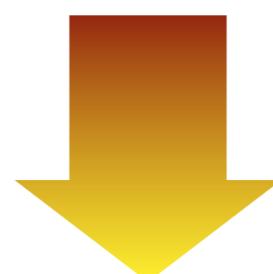
- > 60 years of quest
- Step forward in sensitivity due to technology upgrades
- Current best UL from MEGA  $< 1.2 \times 10^{-11}$
- MEG plans to improve sensitivity of  $\sim 2$  order of magnitude



# CW calibrations



Target of  $Li_2B_4O_7$   
allows both calibrations  
at same time



2 or 3 photons  
of 4.4 and 11.7 MeV  
*at the same time*

