$\mu \to e\gamma$ and $\mu \to eee$ status & perspectives

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INFN Genova/Roma
on behalf of the MEG collaboration

FPCP2011, May 23-27
Kibbutz Maale Hachamisha, Israel

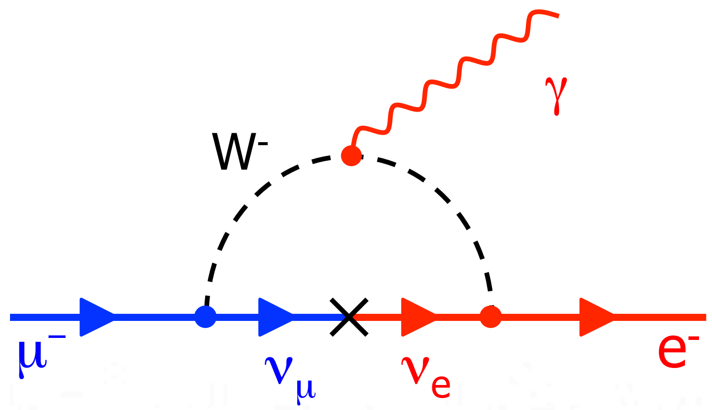
Outline

- (few) physics motivations for LFV searches in μ channel
- Current experimental status and perspectives
  - $\mu \to eee$
  - $\mu \to e\gamma$
- First results from MEG experiment
- Conclusions

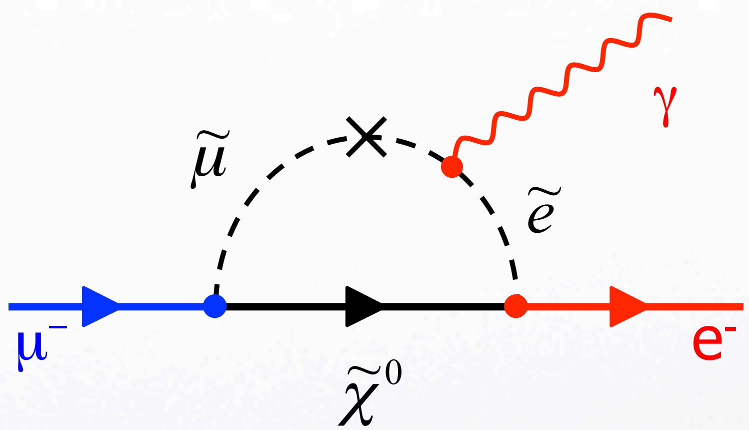
Physics motivation

Exploring (and understanding) a new world...

LFV in charged sector strongly suppressed in SM with neutrino oscillations: i.e. $BR(\mu \rightarrow e\gamma) < 10^{-52}$.



Same decay enhanced in new physics scenarios via new particles interactions: expected $BR(\mu \rightarrow e\gamma) \sim 10^{-12} \div 10^{-14}$ depending on NP parameters.



slepton mixing

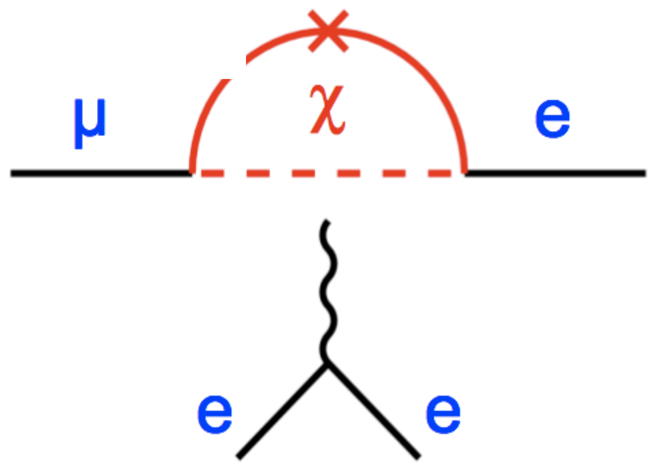
No contamination from Standard Model processes

A powerful probe for NP!

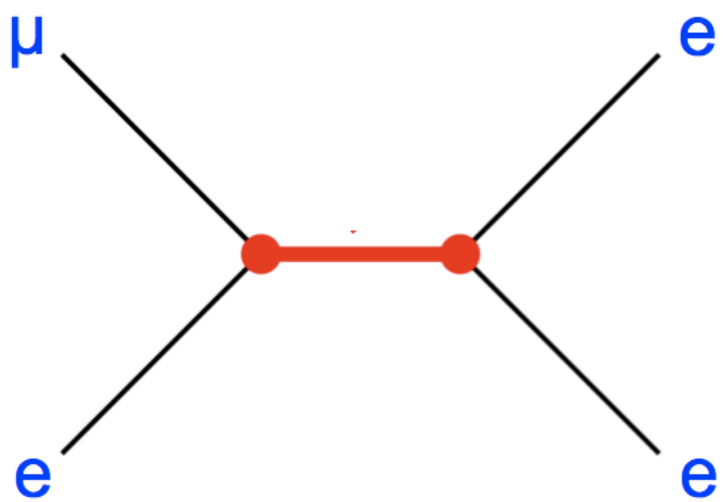
Physics motivation

Combined searches in different channels should be performed, in order to distinguish between possible new physics scenarios.

Penguin like



4 fermions interaction:



$\mu \to e\gamma > \mu \to eee$ (α suppressed)

$\mu \to eee > \mu \to e\gamma$

Comparison between BR would give us very useful informations..

(see, i.e., A. de Gouvea, Nucl. Phys. B188(2009))

Physics motivation

New limits are predicted close the current ones.

For example: BR(μ→eγ)~10^{-12} ÷10^{-14}

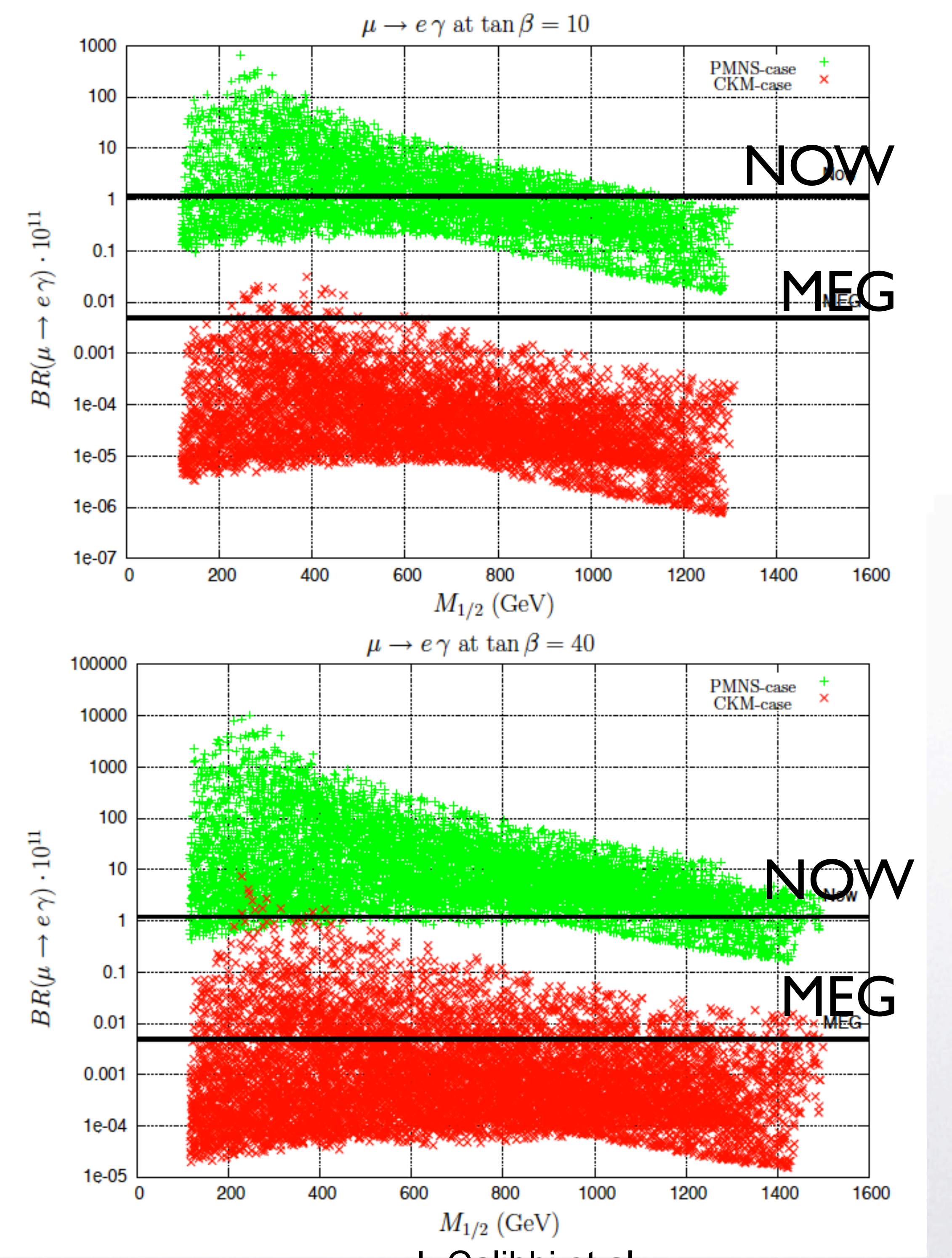
in SO(10)SUSY GUT with seesaw

CKM like matrix

PMNS like matrix

More detailed calculations and reviews:

R. Barbieri et al., Nucl. Phys. B445, 219(1995)
J. Hisano et al., Phys. Rev. D59 116005(1999)
A. Masiero et al., Nucl. Phys. B649, 189(2003)



L.Calibbi et al.,
Phys. Rev. D74(2006) 116002

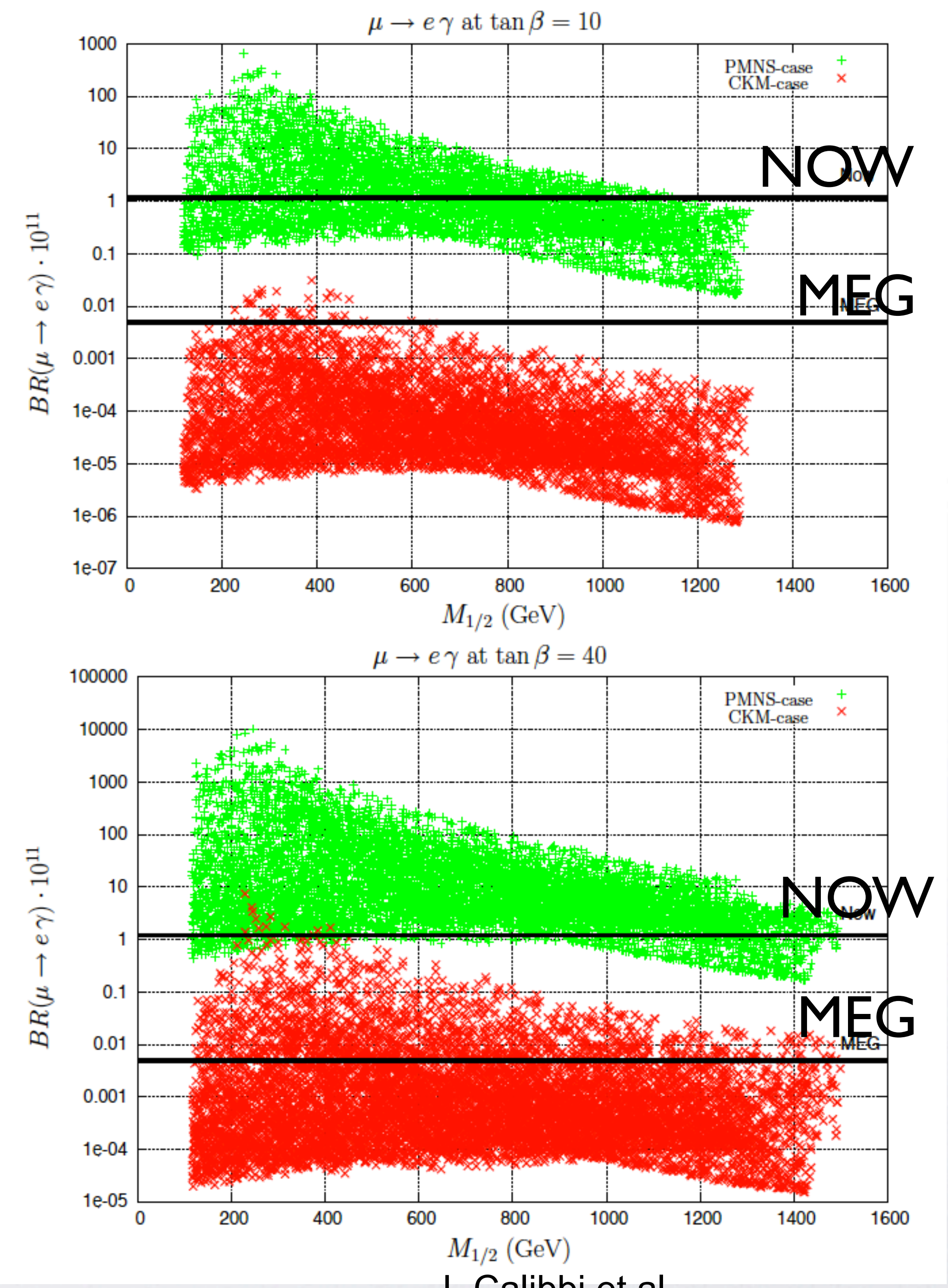
μ channel has also some practical implications:

- high μ beam intensity are available
- low energy decay products, implying "human size" detectors

3 fundamental channels:

- μ→eγ
- μ→eee
- μ→e conversion on nuclei

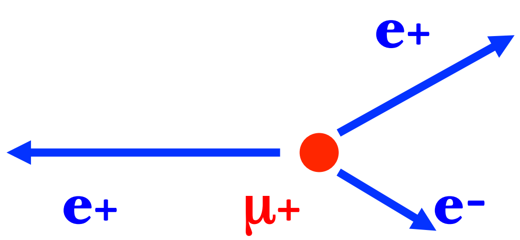
(see T. Nomura, JParc flavor program and B. Casey, Fermilab flavor program)



L.Calibbi et al., Phys. Rev. D74(2006) 116002

μ → eee

Signal

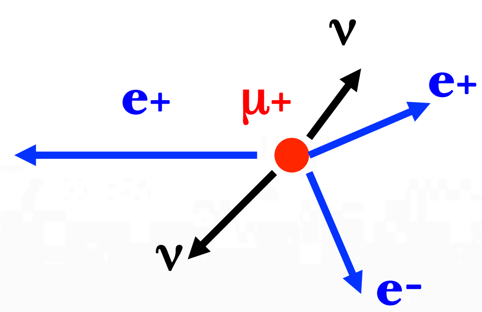


Event reconstruction:

- μ invariant mass
- $\sum p_i = 0$
- vertexing
- time coincidence

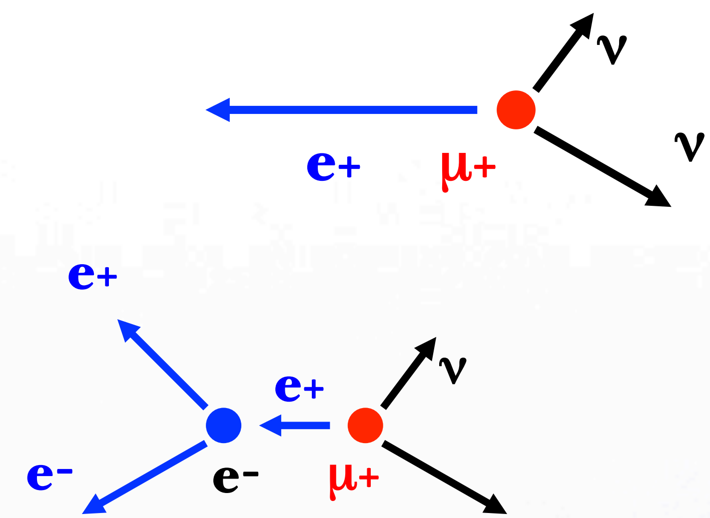
Background

Correlated



Radiative muon decay with photon internal conversion

Accidental



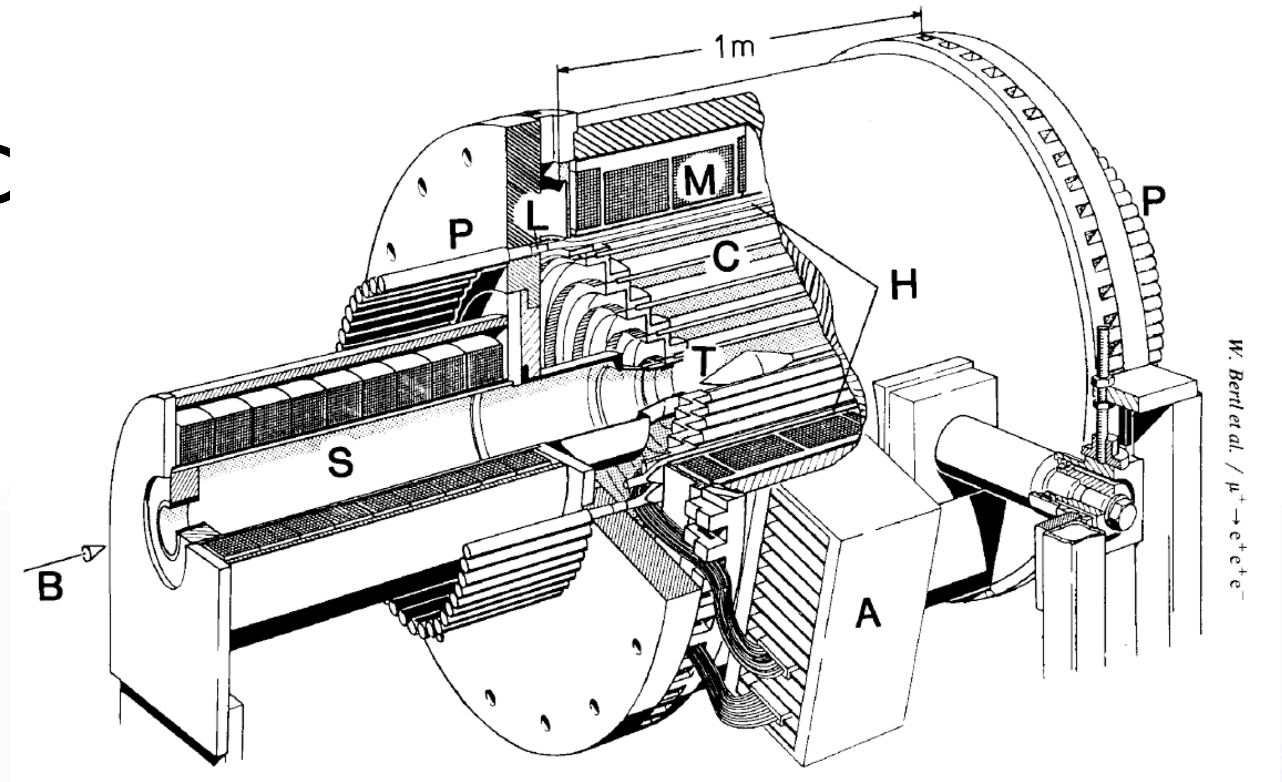
Standard Michel decay
+
e^+e^- pair from Bhabha scattering

Correlated background ~ (R_μ)
Accidental background ~ $(R_\mu)^2$

High intensity beam requires extreme high detector resolution for background rejection.

μ→eee status

SINDRUM (@PSI):
solenoidal spectrometer with MWPC concentrical with beam axis.



beam intensity: 6×10^6 μ/s
μ momentum: 25 MeV/c
momentum reso.: 10% (FWHM)
vertex reso.: 2mm^2 (FWHM)
timing reso.: 1ns
acceptance: 24%

BR(μ→eee) < 1×10^{-12}
U.Bellgardt et al., Nucl.Phys. B299(1988)1

A new experiment should have at least >10^8 μ/s beam and must face with a huge (mainly) uncorrelated background.
Means a factor 10 improvement in detector resolutions...

μ→eee perspectives

Detector should be a tracker system able to:

- cover the whole Michel spectrum, down to low energy;
- substain a huge particles crowding
- cover largest solid angle as possible

Recent interest from Heidelberg University in a μ→eee search down to 10^{-16} with 10^{9} μ/s beam.

Silicon pixel (tracking) and scintillating fiber (timing) based detector.

Potential resolutions:

$\sigma_t \sim 100$ps

$\sigma_p \sim 1\div2\%$

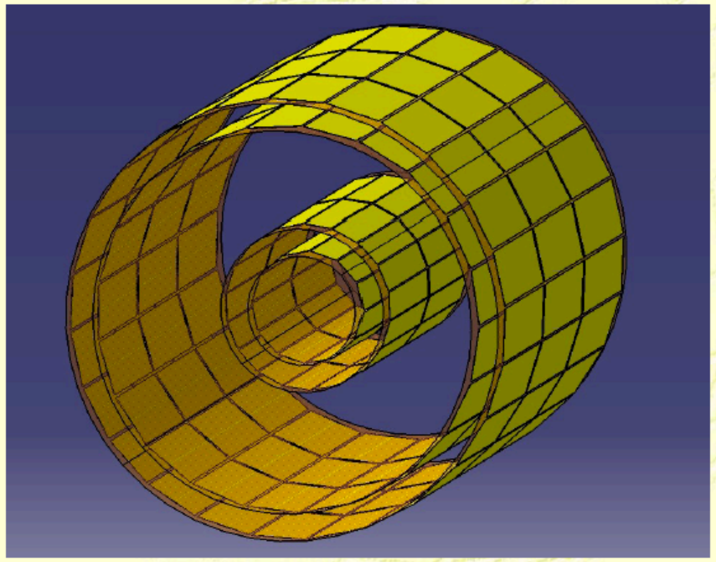
$\sigma_{vtx} \sim 200\mu$m

Summary

- Novel detector concept for μ → eee experiment
- Technologies: Silicon Pixel and Scintillating Fibers Trackers
- sensitivity BR(μ → eee) < 10^{-16} seems feasible but more detailed simulations are required
- first prototype for 2012?
- could replace completed MEG experiment (in 2-3 years)
- later go to ar

Andre Schöning, PI Heidell

Possible Tracker Layout



40 μm Silicon on 20 μm Kapton

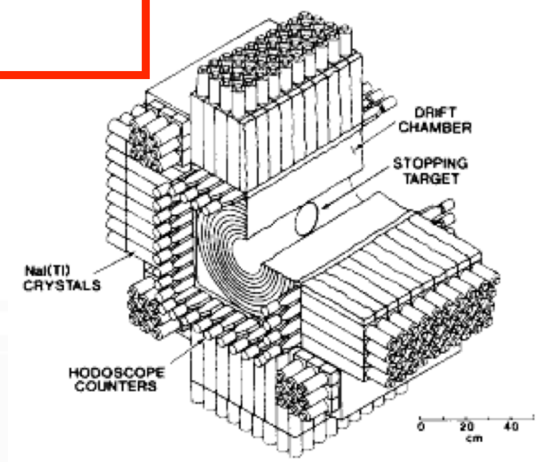
Andre Schöning, PI Heidelberg 36 Seminar, Rome, March 21st, 2011

Andre Schoning, presented in Rome, March 21st, 2011

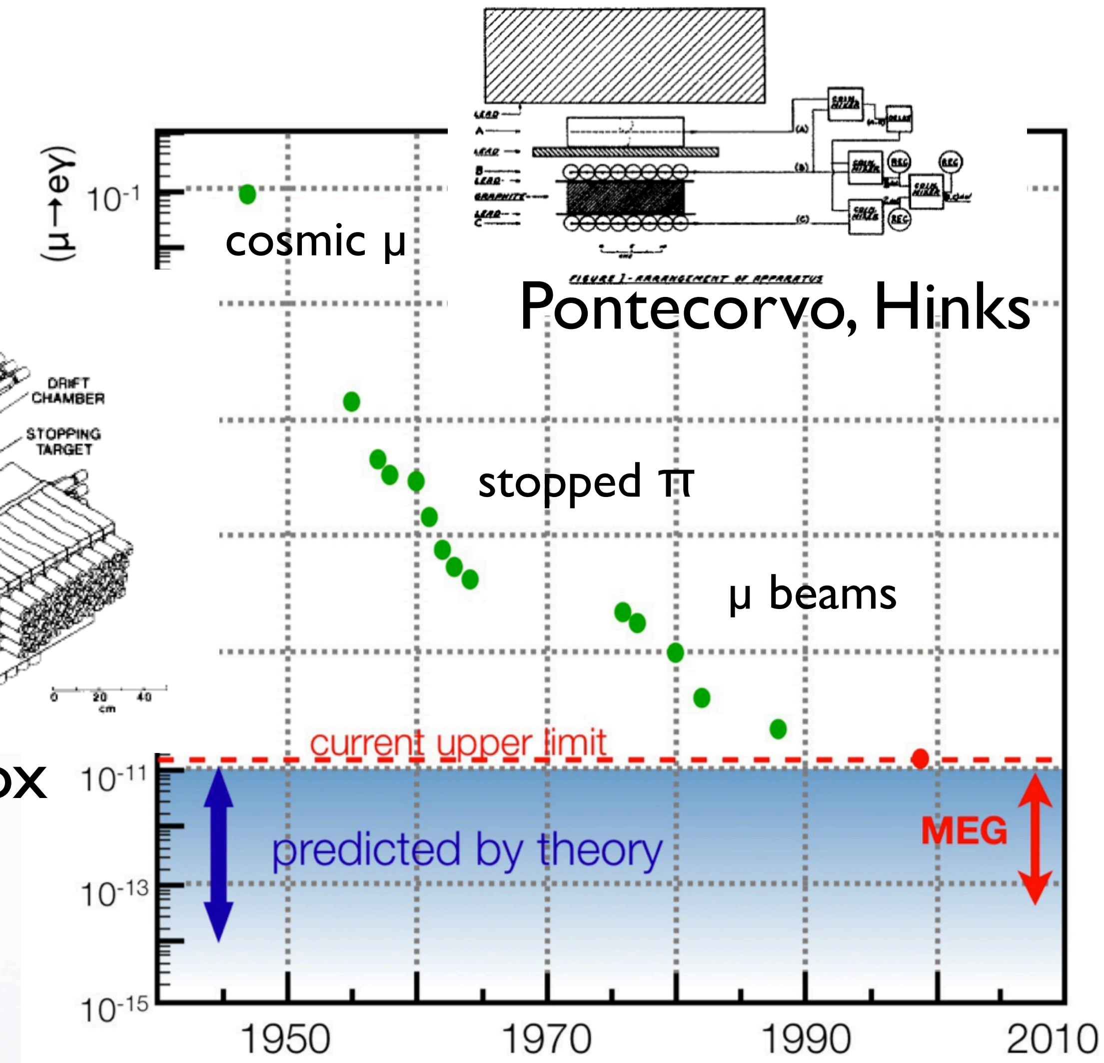
$\mu \rightarrow e\gamma$ status

Current limit by MEGA collaboration:
$BR(\mu \rightarrow e\gamma < 1.2 \times 10^{-11}$ @90%C.L.)

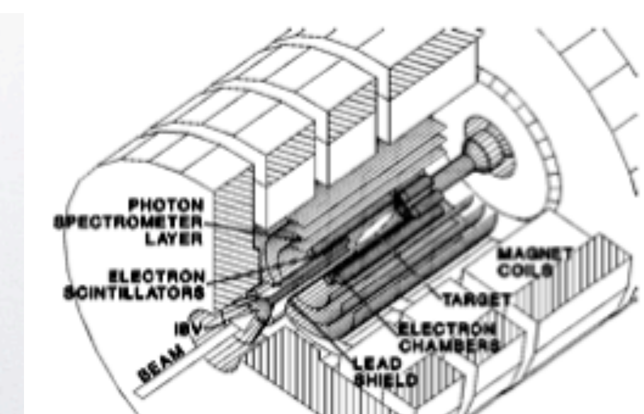
A sixty years old story: searches evolved with μ beam and detector technology.



Crystal Box



2 (different) particles in final state, positron and photon: needs both spectrometer and calorimeter for particles reconstruction.



MEGA

Maybe the most promising channel: predicted limits are close the current one and (very important) new results are coming from MEG collaboration!

The MEG collaboration

Aims to explore BR(μ→eγ) down to 10^{-13}.
2 orders of magnitude better than current limit.

Paul Scherrer Institute (CH)

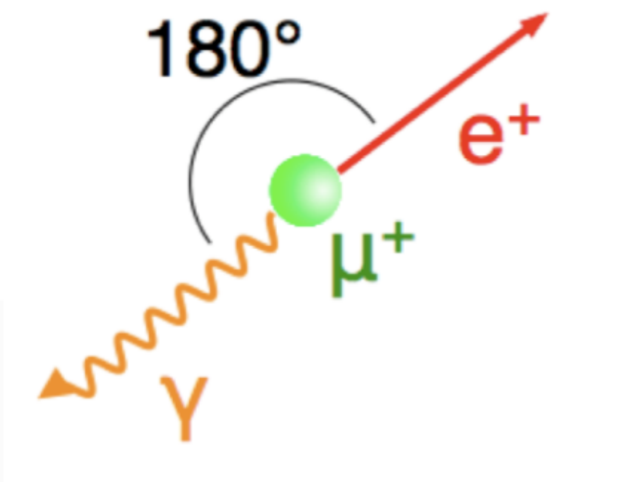
~60 physicist from 5 countries and 12 institutions.

Data taking started in 2008.

First published results: BR(μ→eγ)<2.8×10^{-11}

Nucl. Phys. B834 (2010)

Signal

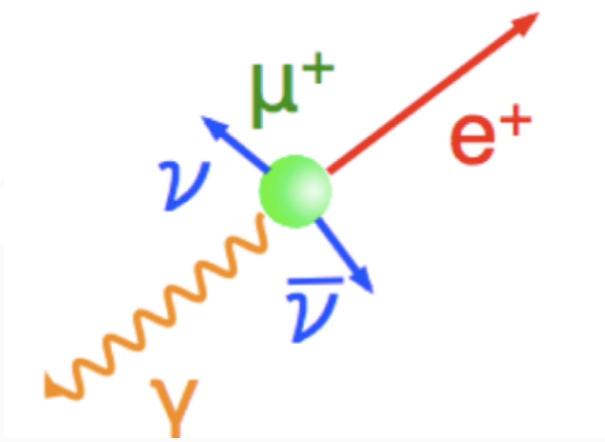


2 bodies final state

$$E_\gamma = E_e = \frac{m_\mu}{2} = 52.8MeV$$
$$\Delta t_{e\gamma} = 0$$
$$\theta_{e\gamma} = \phi_{e\gamma} = 180^\circ$$

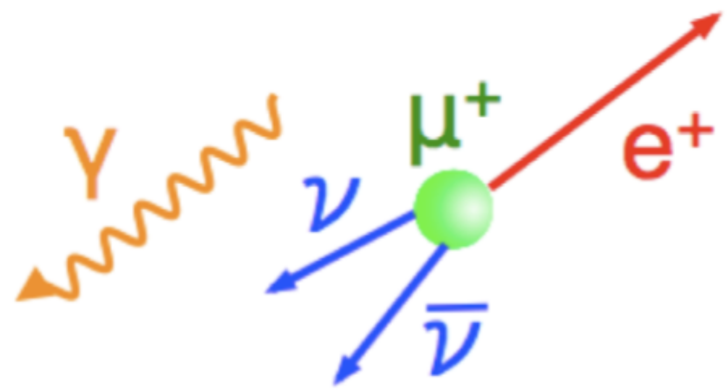
Background

Correlated



radiative μ decay

Accidental



Michel decay + γ from other processes

$$R_{acc} \simeq R_\mu^2 \sigma^2(E_\gamma)\sigma^2(\Omega_{e\gamma})\sigma(t_{e\gamma})\sigma(E_e)$$

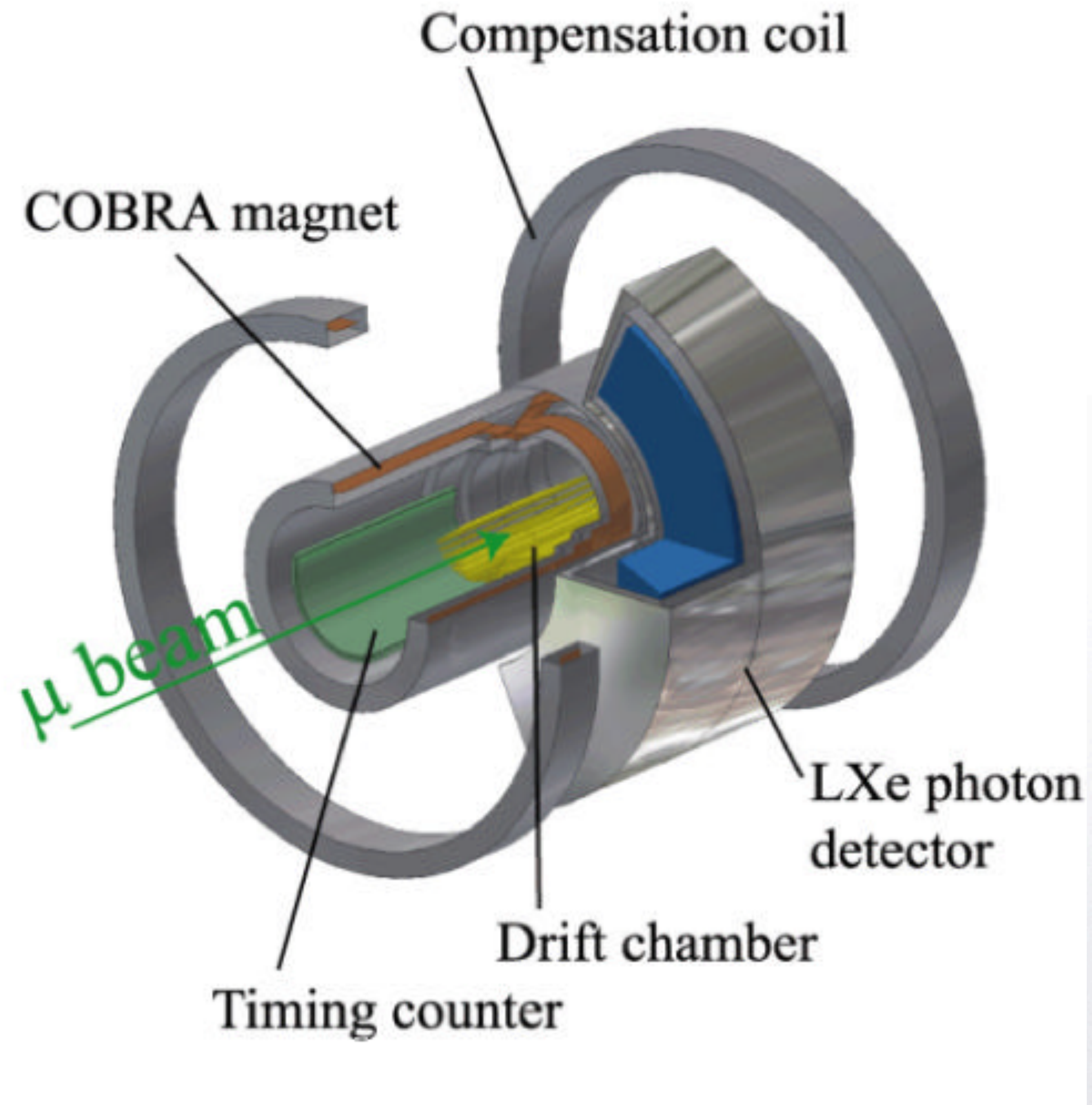
for more details: Kuno, Okada, arXiv:hep-ph/9909265v1

The accidental background is dominant: need of extreme high resolutions on kinematic variables

Experimental apparatus

- High rate continous beam ~ 3×10^7 μ/s focused on a thin plastic target inside a superconductive solenoid magnet.
- Positron momentum is measured by a Drift Chambers system positioned inside magnetic field, then time is reconstructed by Timing Counter.
- γ time and momentum reconstructed in a Liquid Xenon Calorimeter.

Trigger based on TC and LXe information.



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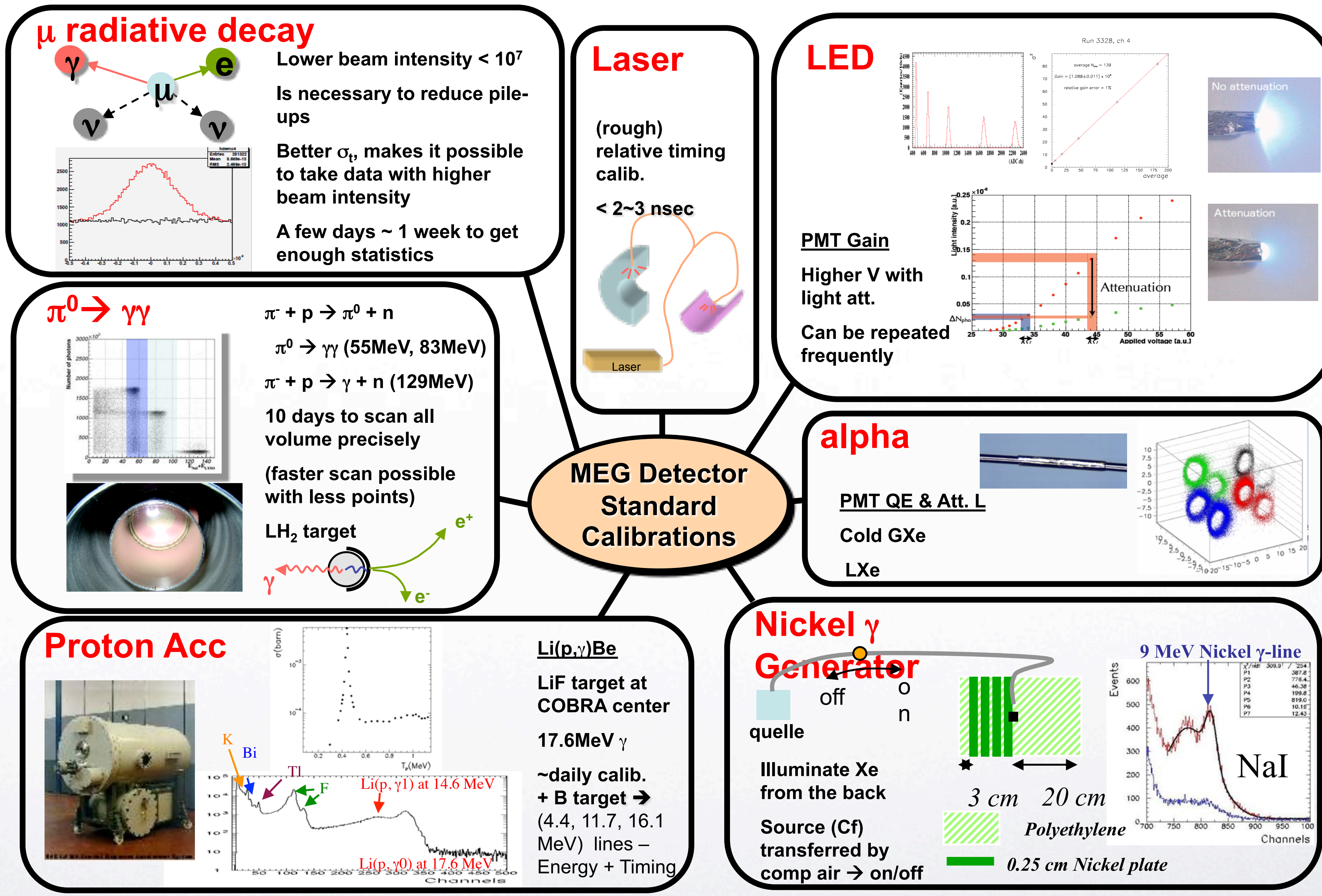
Trigger based on TC and LXe information.

Calibrations (a lot of...)

LXe calorimeter:
- π^0 dedicated run
- CW accelerator
- LED & α sources
- cosmic rays

Drift Chamber
- Michel data
- Mott data (new)
- cosmic rays

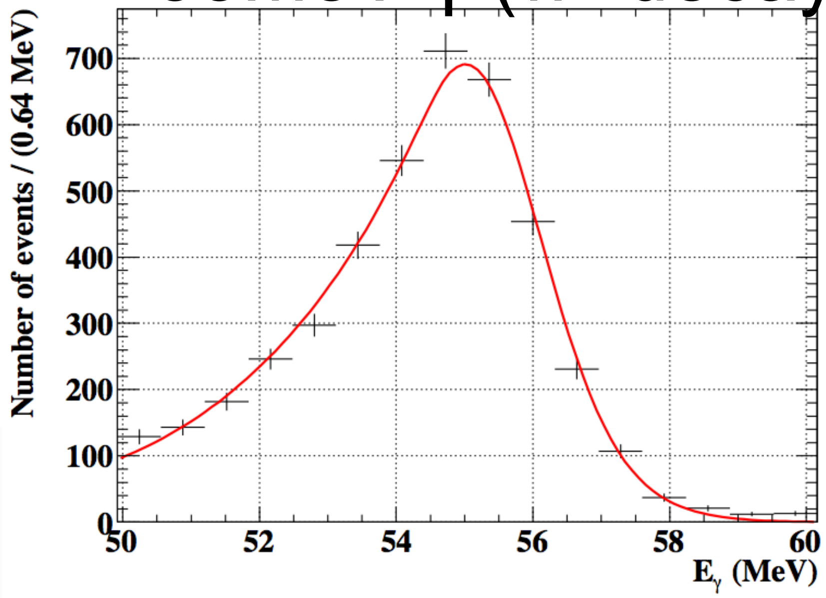
Timing Counter
- Michel data
- π^0 data
- cosmic rays



Full set of (periodic) calibrations for: energy scale resolution, detectors time and space alignment, calorimeter light yield and much more..

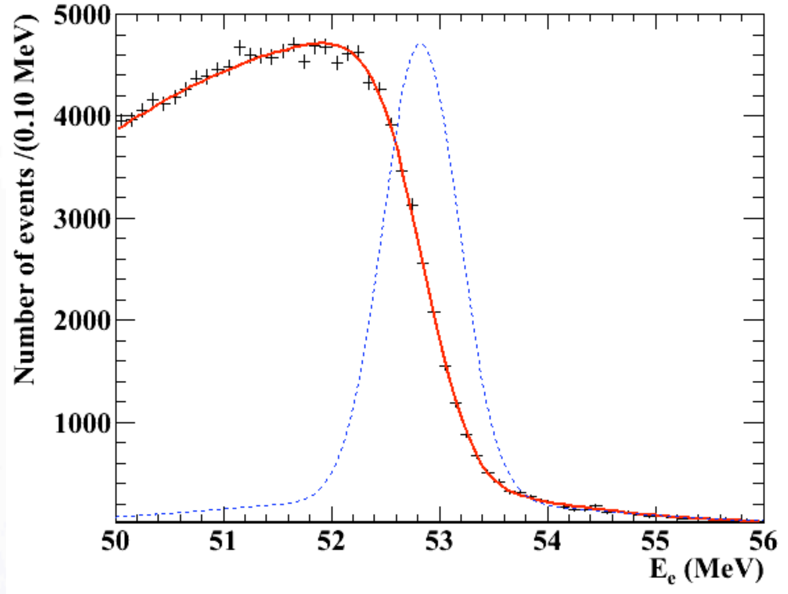
Resolutions

γ energy reso from 55MeV γ (π^0 decay)



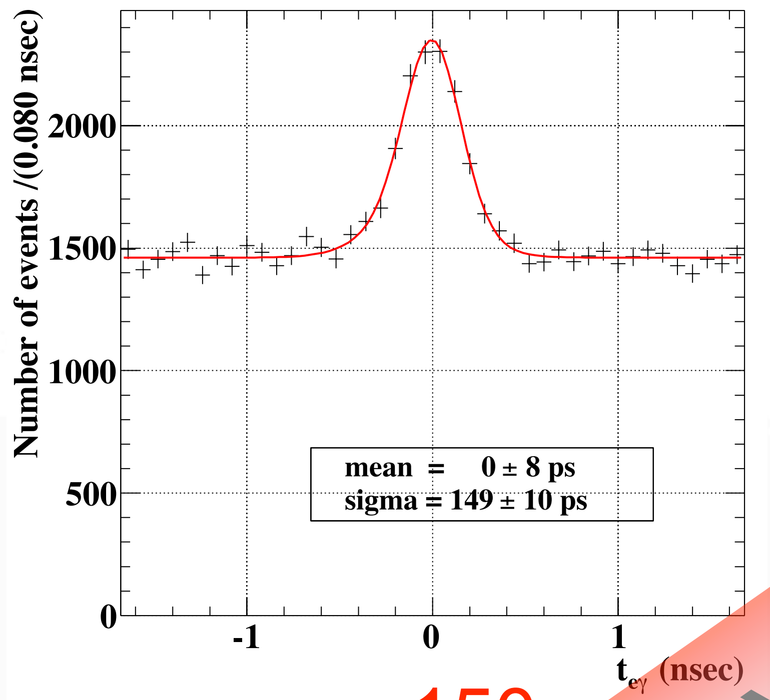
σ~2%
small position dep. taken into account

e^+ momentum from Michel edge



triple gaussian fit: 370KeV (core)

$T_{e\gamma}$ from RMD peak

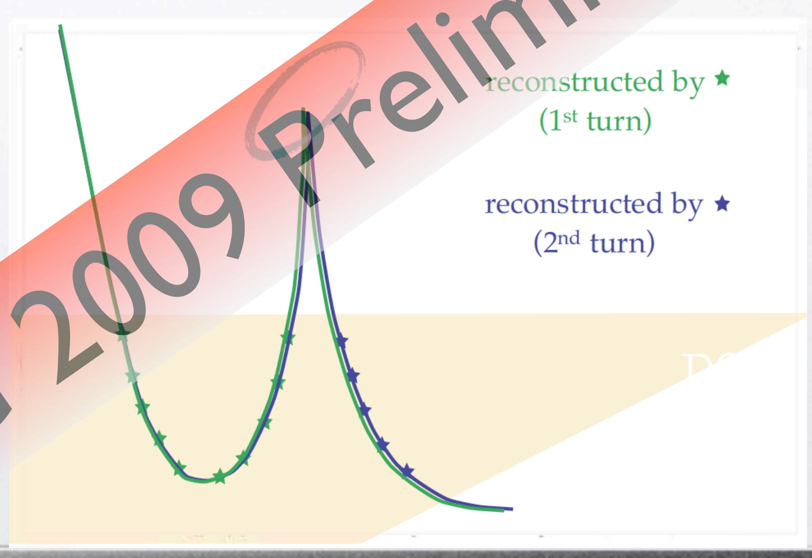


σ~150ps

Angular reso from double turn tracks method:

σ_θ~11mrad

σ_φ~7mrad



MEG 2009 Preliminary!

Performances

2009 run: ~2 months of stable data taking: 6.5×10^{13} μ stopped in target.

γ energy (%)	2.1 (w>2cm)
γ position (mm)	5(u,v) / 6(w)
e^+ momentum (%)	0.74 (core)
e^+ angle (mrad)	7.1 (Φ core)/11.2 (θ core)
vertex position (mm)	3.4 (Z) / 3.3 (Y)
γe timing (ps)	142 (core)
γ efficiency (%)	58
trigger efficiency (%)	83.5

values are given in σ

MEG 2009 Preliminary!

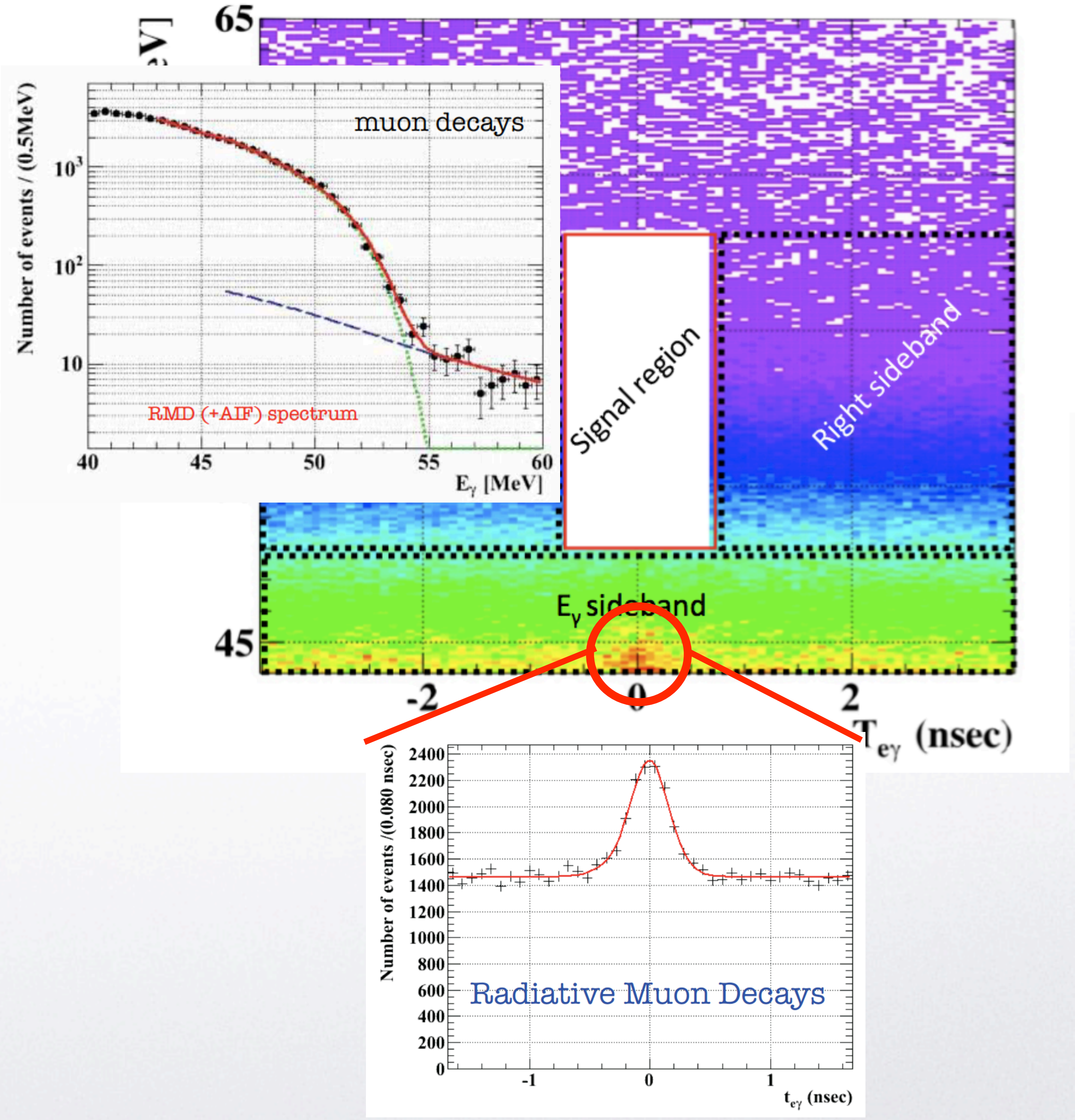
Data analysis

μ decays collected and blinded until analysis tools are developed on sideband data.

PDF for signal and background extrapolated from sideband data and calibration run.

Left/Right sideband: accidental
Energy sideband: RMD

Exstensive MC simulation for background study



Data analysis

Likelihood built as a function of signal, radiative decay and accidental events number and PDFs:

$$L(N_{SIG}, N_{RAD}, N_{BG}) = \frac{N^{N_{obs}} exp^{-N}}{N_{obs}!} \prod_{i}^{N_{obs}} \left[\frac{N_{SIG}}{N} S_i + \frac{N_{RMD}}{N} R_i + \frac{N_{ACC}}{N} B_i \right]$$

Number of signal, radiative decay and accidental events counted simultaneously with an unbinned fit over the analysis box.

3 independent approaches from 3 different groups:

- Frequentistic approach:
  - event by event PDF with separated θ, φ
  - stereo angle Θ
- Bayesian approach

Building PDFs

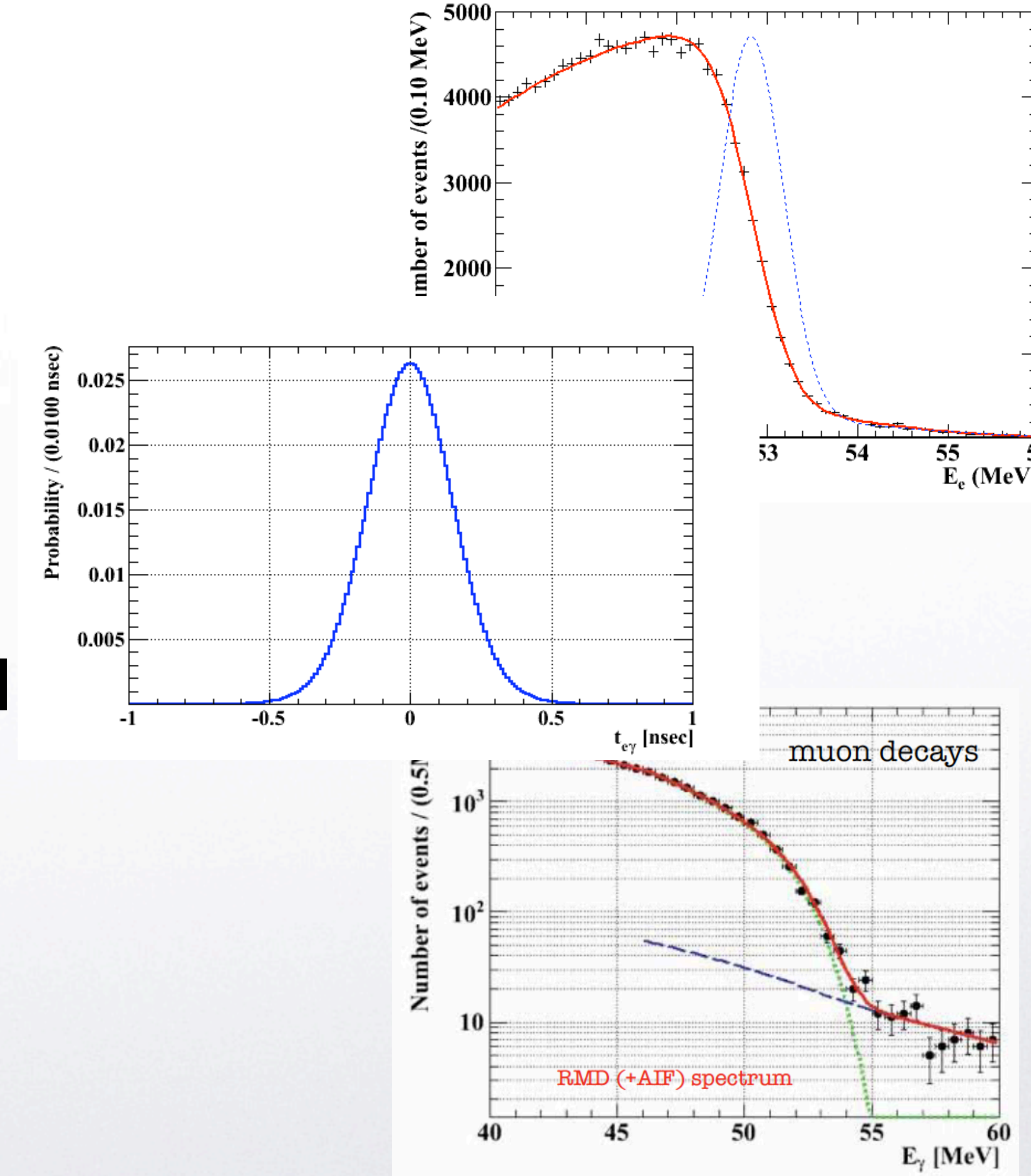
PDFs are mainly extracted from data: calibrations run and sideband data.

Signal:

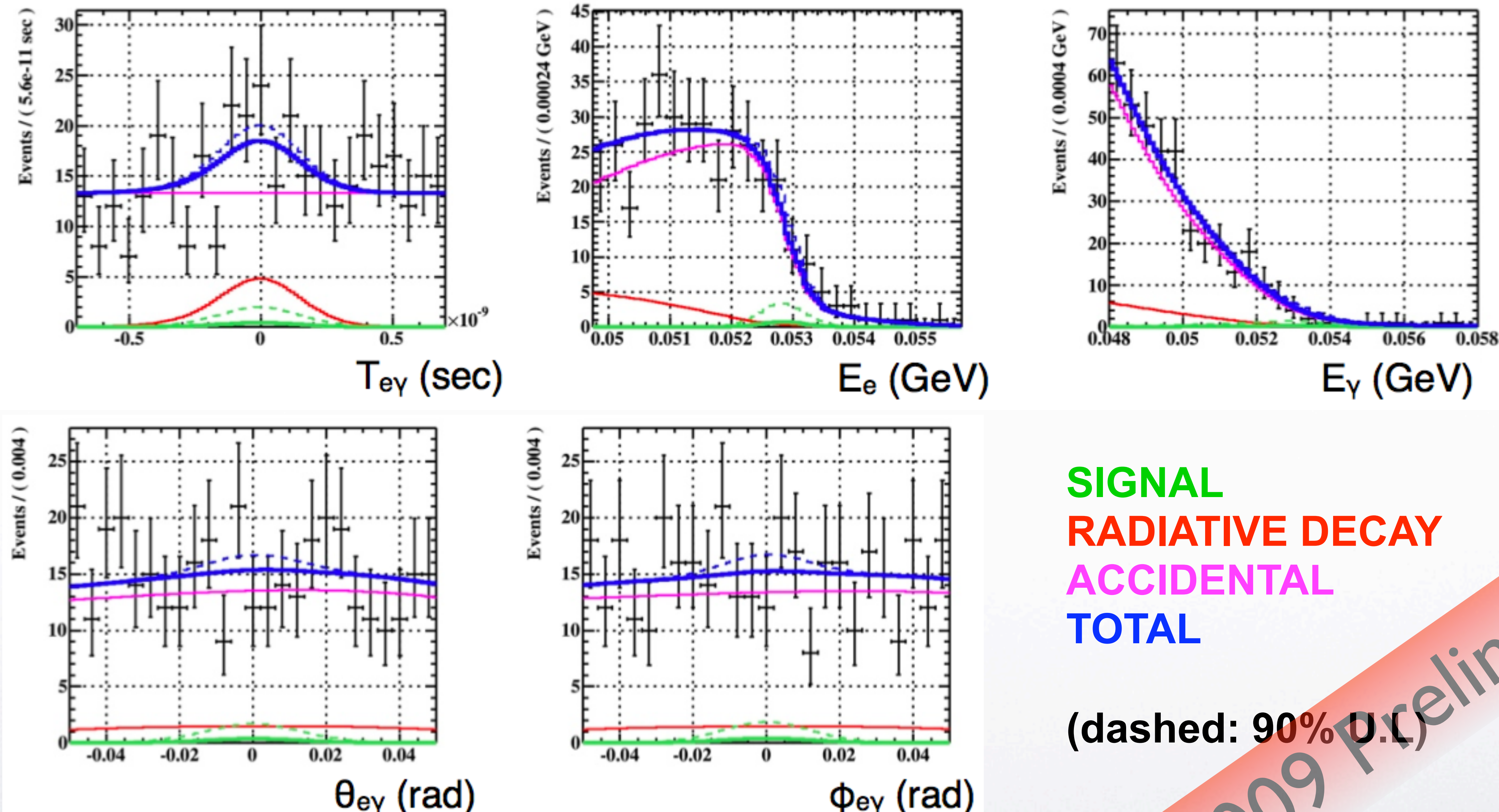
- calibration run: π^0 data, Cockcroft Walton run, Michel edge (γ/e energy and relative angles)
- sideband data: radiative muon decay (timing)

RMD: 3D theoretical distribution folded with measured detector response function. Same time PDF as for signal.

Accidental: sideband data



Likelihood analysis



SIGNAL
RADIATIVE DECAY
ACCIDENTAL
TOTAL

(dashed: 90% U.L)

MEG 2009 Preliminary!

Best fit:

N_{sig} = 3.0, N_{RMD} = 35^{+24}_{-22} (expected , N_{RMD} = 32 ± 2)

ICHEP2010

N_{sig} < 14.5 @ 90% C.L.

Normalization

The upper limit on BR(μ→eγ) is calculated by normalizing the upper limit on N_{SIG} obtained from Likelihood analysis to the number of Michel positrons counted simultaneously with signal, using the same analysis cuts.

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

Michel event counted ~ 18k   Prescaling TRG factor: 10^7 Efficiencies

(Almost) independent from DC inefficiencies and instability, and variations of beam intensity.

In 2009, $k=(1.0\pm0.1)\times10^{12}$ (was 1.3×10^{11} in 2008)

(preliminary) Results

From analysis of 2009 data:

$$BR(\mu \to e\gamma) < 1.5\times10^{-11}\ @90\%\ C.L.$$

Sensitivity: 6.1×10^{-12} average 90% C.L. upper limit obtained from null signal Toy MonteCarlo simulations.

Sensitivity extracted from sidebands is $(4\div6)\times10^{-12}$, consistent!

Why is preliminary? In the mean time, some improvements:

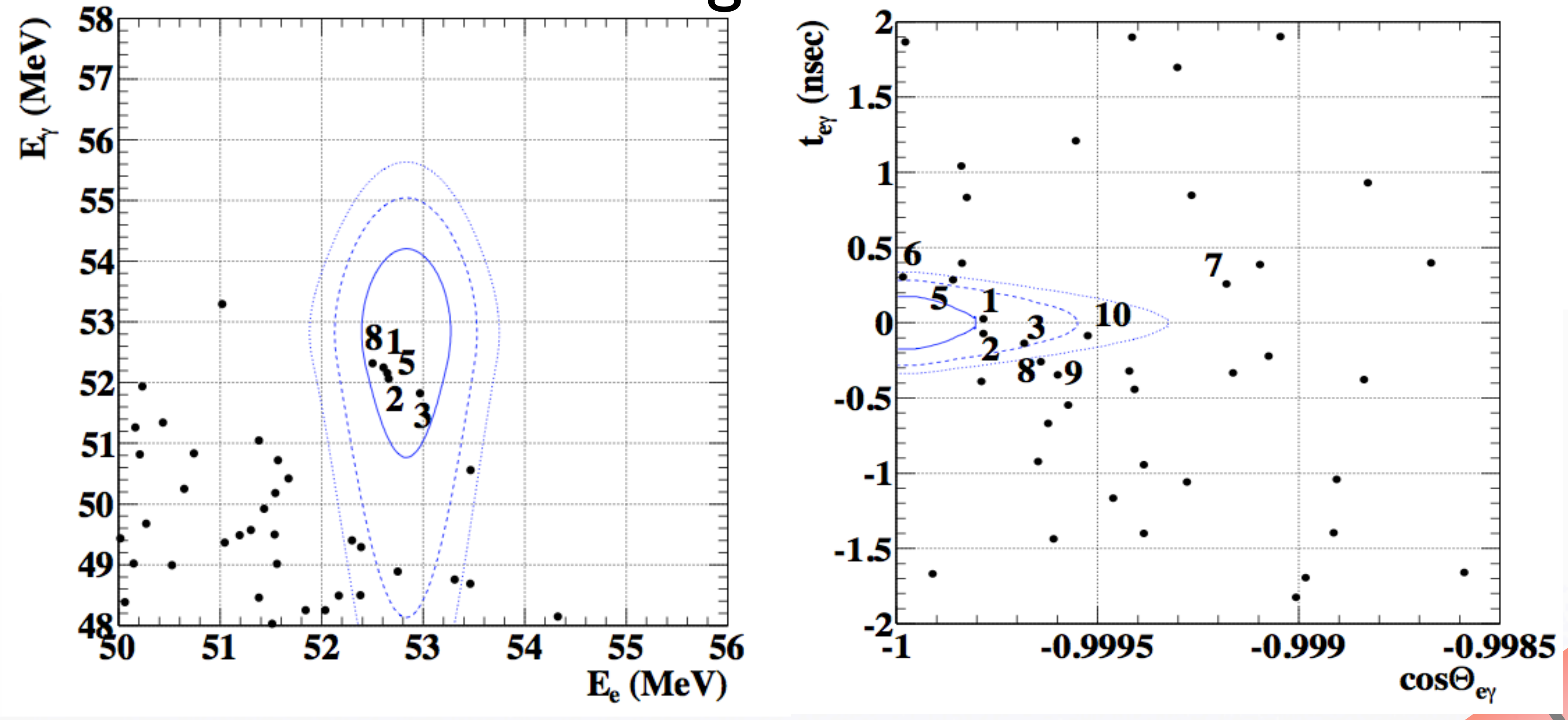
- better understanding of spectrometer and B field
  - positron resolution
- reduction of systematics in back-to-back alignment

We plan to present a combined 2009/2010 analysis as soon as possible...

Unblinding

Events distribution after unblinding

Signal box



Blue lines represent 1, 1.64 and 2 σ regions.

Same events in two plots are numbered correspondingly, by decreasing ranking in terms of relative signal likelihood

MEG 2010

Run shorter (~60days) than expectation: unfortunate problem on transport solenoid and little delay at the start-up...

The collected statistic is 2 times the 2009 one.

But with some detector improvements:

- better online efficiency and trigger direction match;
- new calibrations (Mott, 9MeV Ni line);
- less digitizer interboard jitter

2011 is starting now...

Summary

The μ channel is for sure a promising one in LFV searches:
all the current limits on the LFV decays may be really close the boundary of the new physics.

Experiments proposed and started looking for new limits: challenging $\mu \rightarrow e\gamma$ and $\mu \rightarrow eee$ searches (2 or more orders of magnitude improvement in BR limit).

MEG is running since 2008 looking for $\mu \rightarrow e\gamma$ decay at a level of 10^{-13}.

2008 and 2009 (preliminary) analysis show we currently are at MEGA level ($<1.5\times10^{-11}$).

Just wait for 2009/2010 combined analysis!

Backup slides

MEG systematics

The effects of systematics is taken into account in the calculation of the confidence region by fluctuating the PDF according to the uncertainty values

	Uncertainty	
Normalization	8 %	e^+ mementum dep. ⊕ γ det. ε ⊕ trigger ε
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 %	RD peak
Angle	7.5 mrad	Tracking ⊕ LXe position
Angle resolution	10 %	
E_e-ϕ_e correlation	50%	MC evaluation

The overall effect is estimated to be $\Delta N_{SIG} \sim 1$

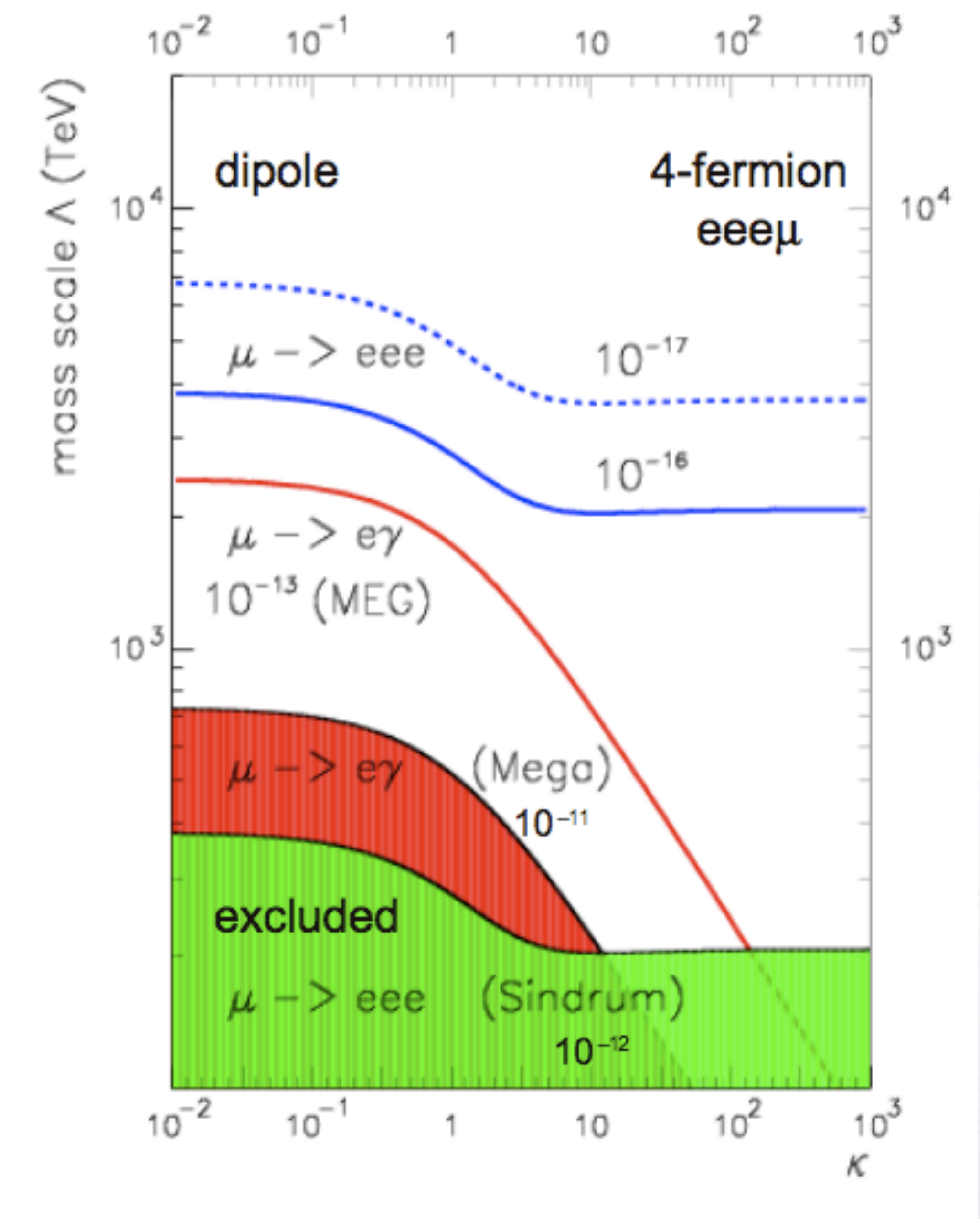
Physics motivation

Effective cLFV Lagrangian:

$$L = \frac{m_\mu}{\Lambda^2(1+\kappa)} H^{dipole} + \frac{\kappa}{\Lambda^2(1+\kappa)} J_\nu^{e\mu} J^{\nu,ee}$$

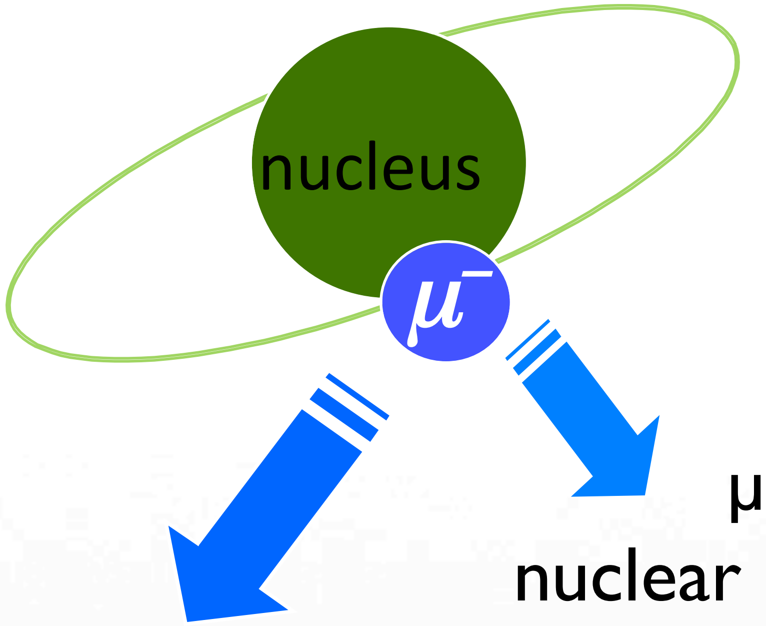
Λ=NP scale
k=relative amplitude between terms

If k<<1, dipole dominates
If k>>1, 4 fermions dominates



A. de Gouvea / Nucl. Phys. B188(2009)

$\mu Z \rightarrow eZ$



$\mu Z \rightarrow \nu Z$
nuclear muon capture

$\mu \rightarrow e\nu\nu$
muon decay in orbit

But also neutrinoless nuclear capture $\mu Z \rightarrow eZ$...

Only one particle in final state: no accidental background issue. Background scales only linearly with beam rate → very big chance to explore extremely low BR...

Looking for single monoenergetic electron: $E_e \sim E_\mu - B_\mu$ (recoil energy negligible)

Background coming from:
- μ decay in orbit
- radiative μ capture

Beam related background:
- π and e contaminations

improving detector resolutions

high purity environment:
curved solenoid with gradient field
pulsed beam with challenging extinction time

μZ→eZ status

Current limit by SINDRUM II:

BR(μTi→eTi)< 4.3×10^{-12}

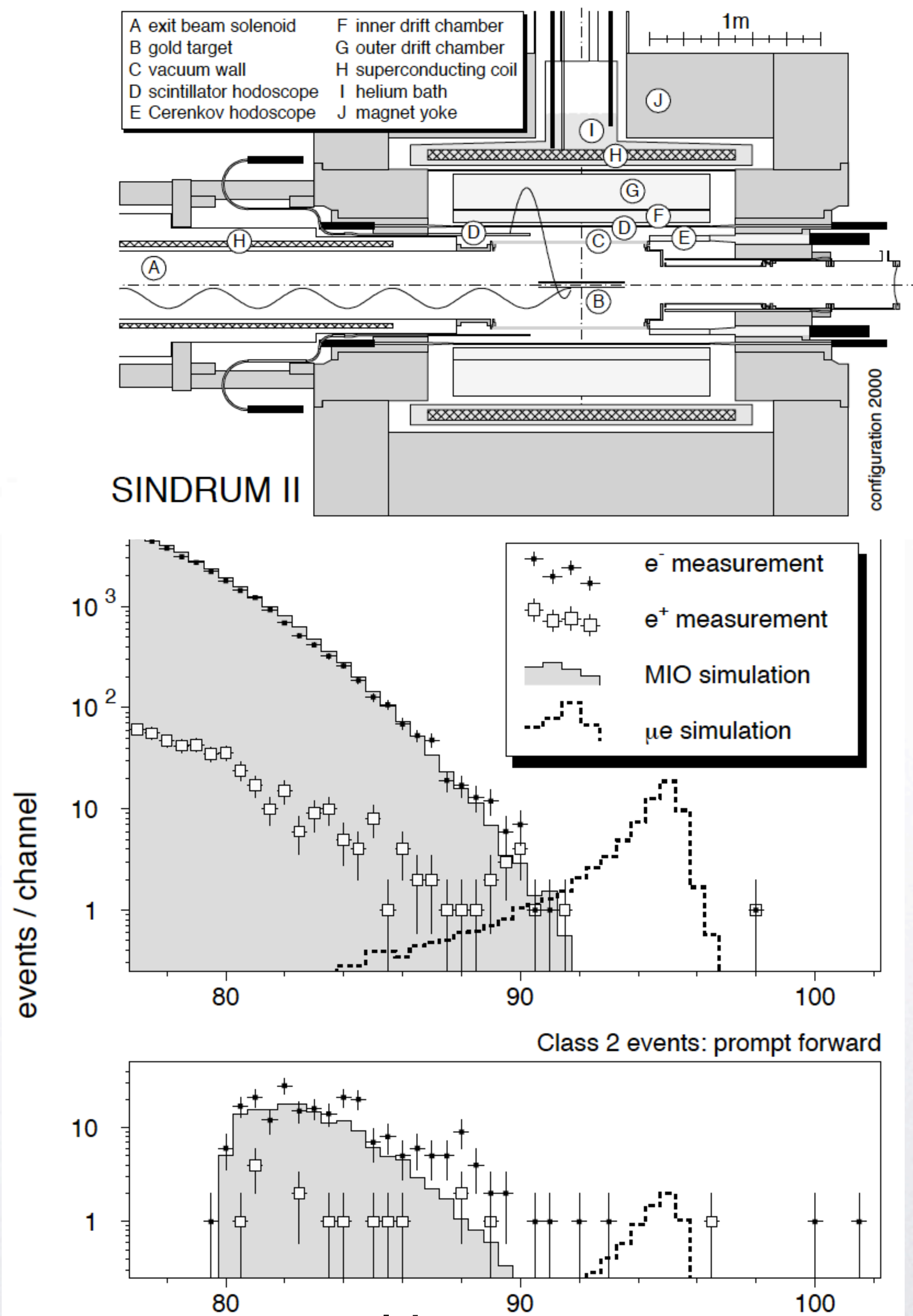
BR(μAu→eAu)< 7×10^{-13}

Beam intensity: 3×10^{7} μ/s (@PSI)

Energy of emitted electrons is measured with a cylindrical magnetic spectrometer: drift chamber and scintillators/Cerenkov hodoscope.

SINDRUM II parameters:

- beam intensity: 3×10^{7} μ/s
- μ momentum: 53 MeV/c
- magnetic field: 0.33T
- acceptance: 7%
- momentum res.: 2% FWHM
- S.E.S 3.3×10^{-13}



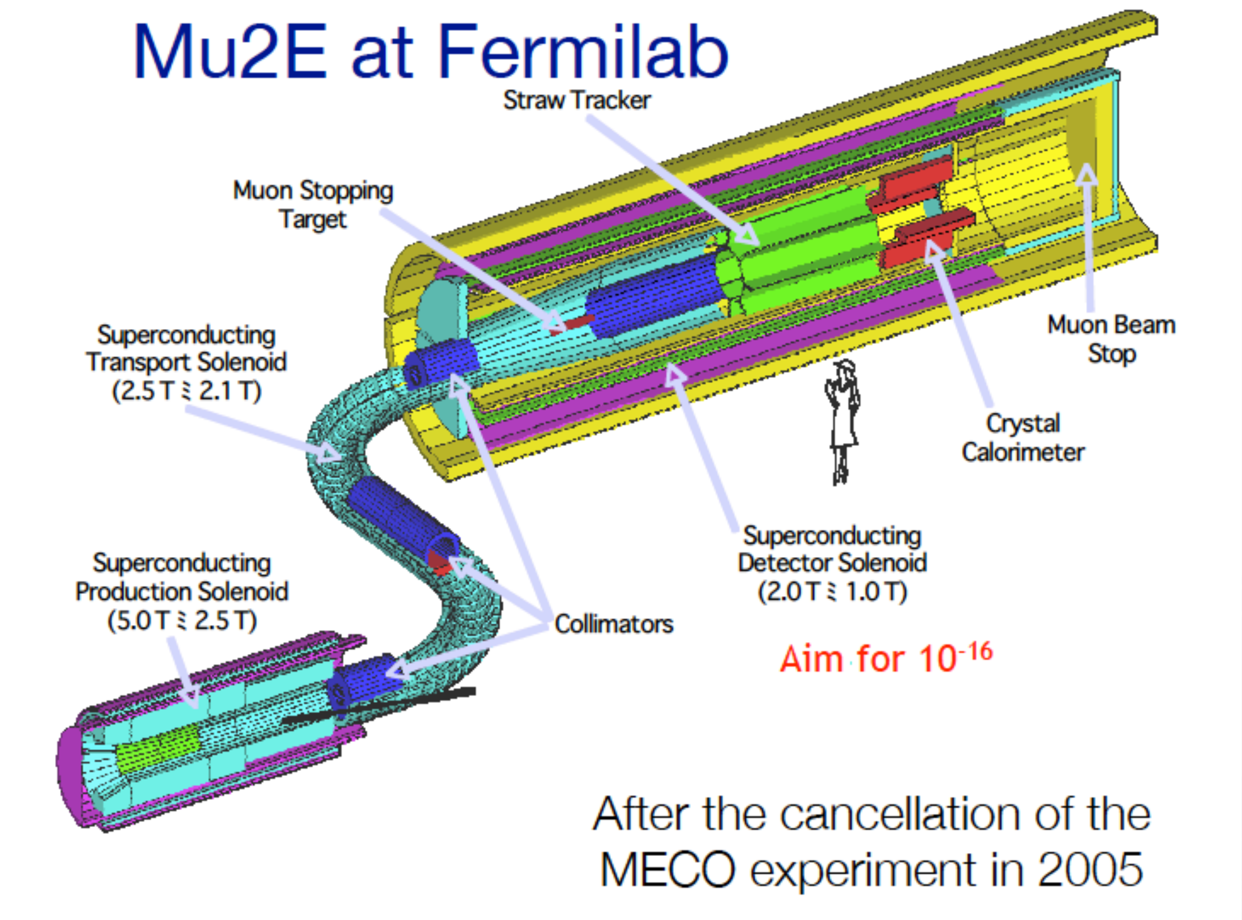
μ→e conv. in gold

μZ→eZ perspective

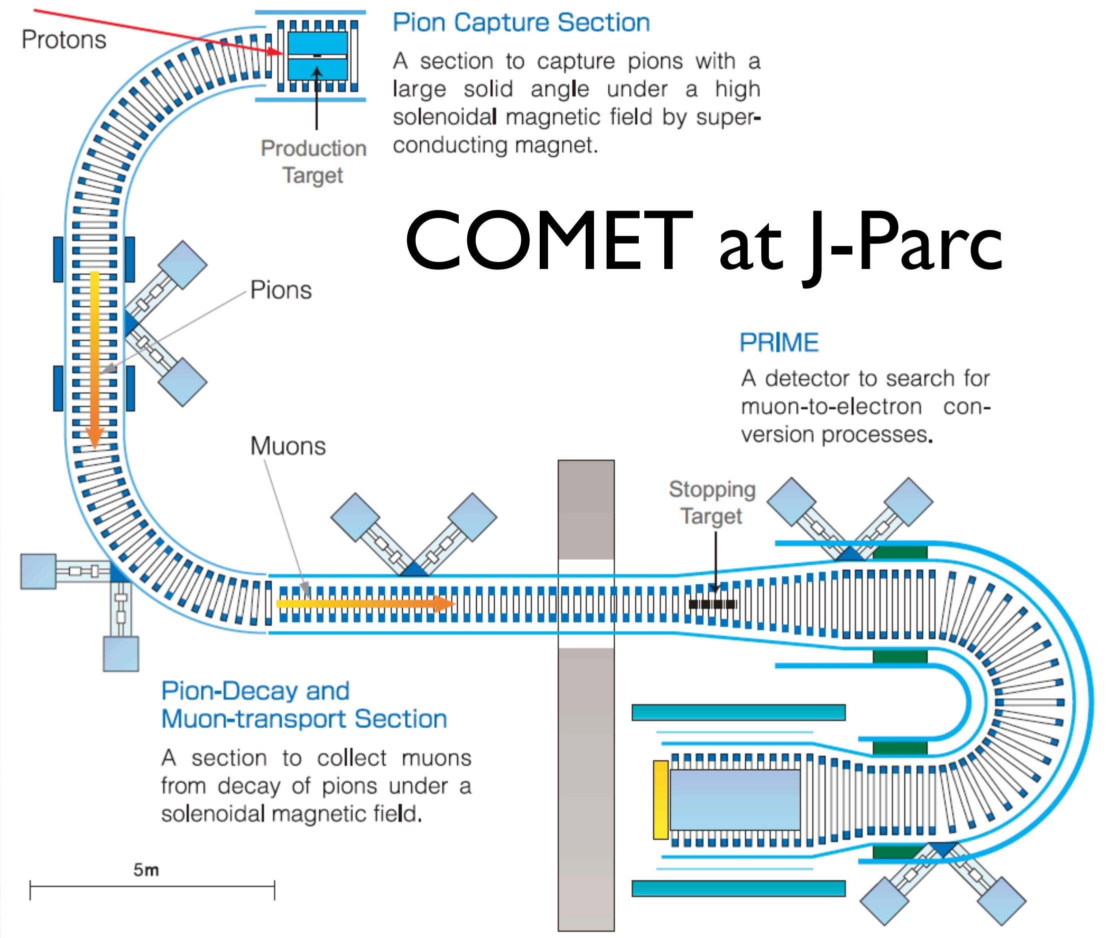
2 experiments proposed aiming to reach 10^{-16} sensitivity.

"S" shaped μ beam line
straight spectrometer

"C" shaped μ beam line
curved spectrometer



see B. Casey, FermiLab flavor program, this conf.



see T. Nomura, JParc flavor program, this conf.

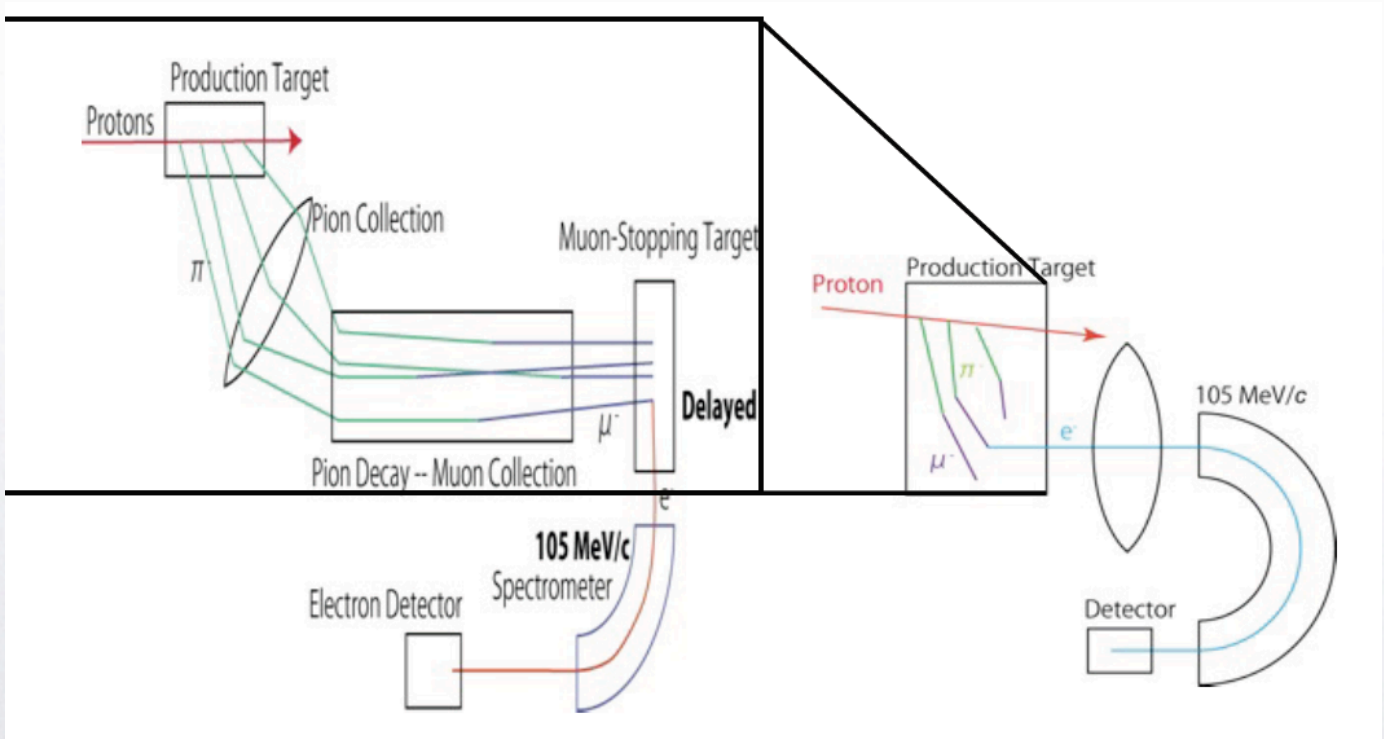
Both proposals were approved!

μZ→eZ perspective

Another proposal for searching for μ-e conversion at sensitivity of 10^{-14} with a pulsed proton beam: DeeMe @J-Parc

Aims to obtain result in a short time schedule (~5 years).

μ-e electrons directly come from a production target: experiment could be simple, quick and low cost.



Simplified beam line layout: π production target coincides with - μ-e conversion site.

see T. Nomura, JParc flavor program, this conf.

PRISM at J-Parc

Aiming for a 10^{-18} search with an extreme high intensity ($10^{11} \div 10^{12}$ μ/s) beam with μ storage ring.

Fixed-field alternating gradient synchrotron perform conversion from original short-pulse beam with high momentum spread (30%) into a long pulse beam with narrow momentum spread (3%).

PRISM at J-Parc
(R&D phase)