Lepton Flavour Violation: an experimental review

Donato Nicolò

Università & INFN, Pisa

Neutrino 2010, Athens

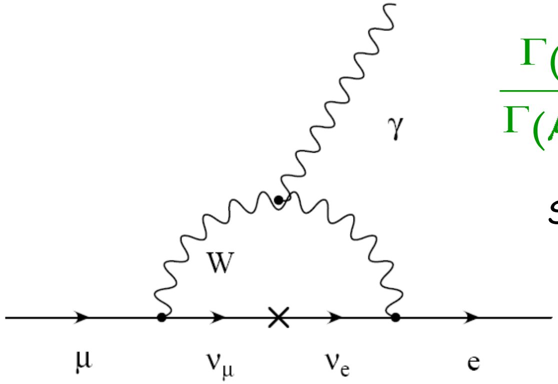
16 June 2010

Outline

- Theoretical hints
  - SUSY vs SM predictions for
    - LFV
    - EDM
    - MDM (g-2)
- Muon LFV: status and perspectives
  - $\mu \to e\,\gamma$ news
    - MEG
  - future plans in $\mu Z \to e Z$ conversion
    - Mu2e
    - COMET
    - PRISM I+PRIME
- EDM
  - current results and future reach on
    - neutron
    - deuteron
    - muon
- Conclusions

LFV in the SM and beyond

- SM: Dirac ν-oscillations ⇒ flavour mixing in lepton sector



$$\frac{\Gamma(\mu \to e\gamma)}{\Gamma(\mu \to e\nu\bar{\nu})} \approx \left(\frac{\alpha}{2\pi}\right)\sin^2 2\theta_{\oplus}\left(\frac{\Delta m^2}{M_W^2}\right)^2 \approx 10^{-55}$$

larger mass scale needed ➔ SUSY

S.M. Bilenky, S.T. Petcov, B.Pontecorvo
Phys. Lett. B67 (1977)309

too tiny to be ever observed!

- SUSY theories can give rise to LFV through radiative corrections induced by mixing in the high energy sector
  - mixing matrix may be proportional to
    - PMNS (enhanced due to solar νs)
    - CKM
  - constrained by MEG also if U_{e3} = 0

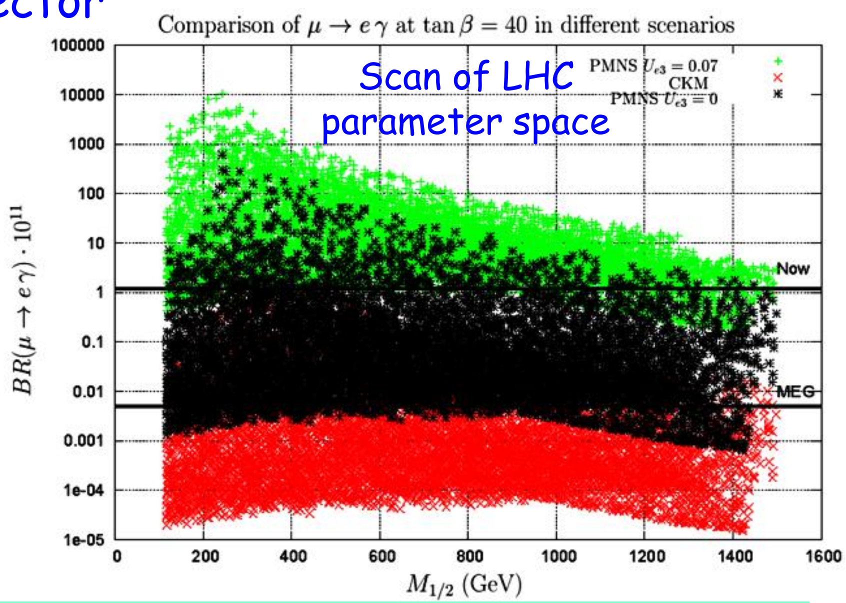
R. Barbieri *et al.*, Nucl. Phys. B445(1995) 215

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

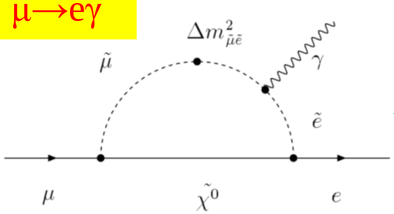
J. Valle, this conference



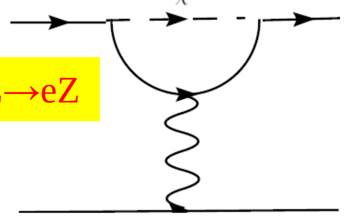
LFV relation to EDM, g-2

- Contribution to EDM, MDM of leptons (hadrons) from diagonal elements of the slepton (squark) mass matrix
- LFV processes induced by off-diagonal terms (depend on how SUSY breaking is generated and what kinds of LFV interactions exist at the GUT scale)

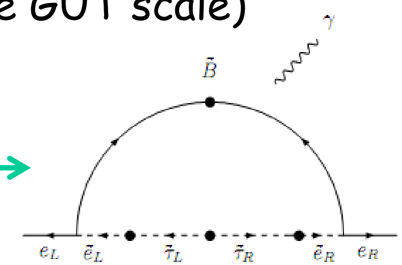
μ→eγ



μZ→eZ



$$M^2_{\tilde{l}\tilde{l}} = \begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$



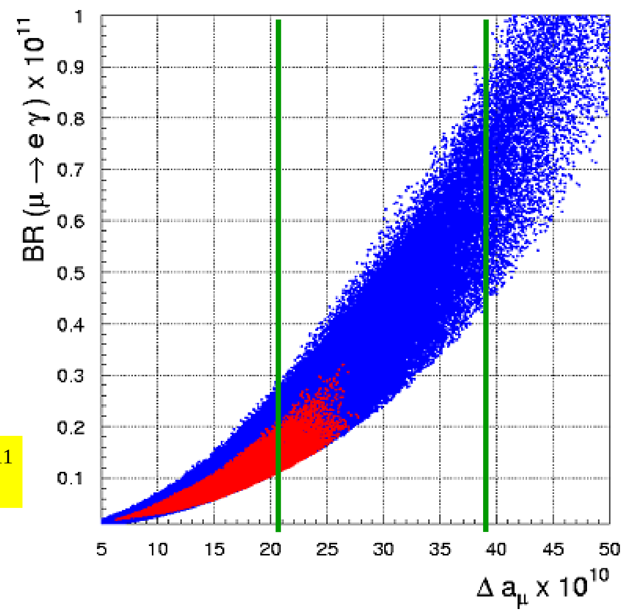
g-2 $\propto \Re(m^2_{\tilde{\mu}\tilde{\mu}})$

EDM $\propto \Im(m^2_{\tilde{\mu}\tilde{\mu}})$

- SUSY effect on g-2 ➔ deviations from SM predictions
- an experimental clue: E821 results

$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM} = (297 \pm 79) \times 10^{-11}$$

G.W.Bennett *et al.*
Phys.Rev.Lett. 92(2004) 1618102



$\Delta a_\mu \neq 0$ associated with SUSY

➔ $BR(\mu \to e\gamma) \geq 10^{-12}$

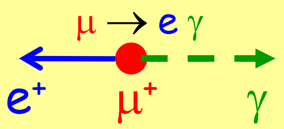
G.Isidori *et al.*

Phys. Rev. D75 (2007) 115019

➔ strong physics case

$\mu^+ \to e^+\gamma$: signal and background

signal



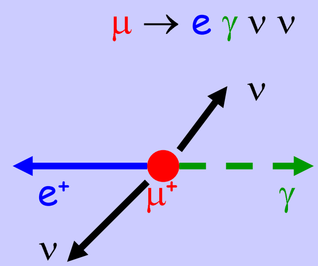
$\theta_{e\gamma} = 180°$

$E_e = E_\gamma = 52.8$ MeV

$t_e = t_\gamma$

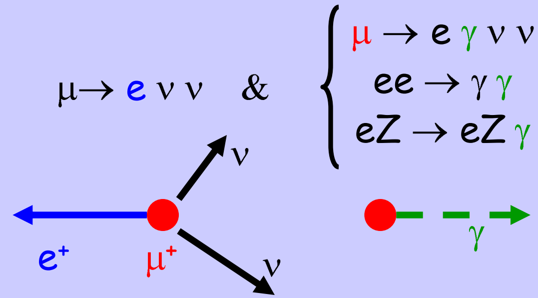
background

correlated



$B_{\text{prompt}} \approx 0.1 \times B_{\text{acc}}$

accidental



$B_{\text{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$

accidental background dominant at high rate

➔ need to improve detection techniques and use continuous beam

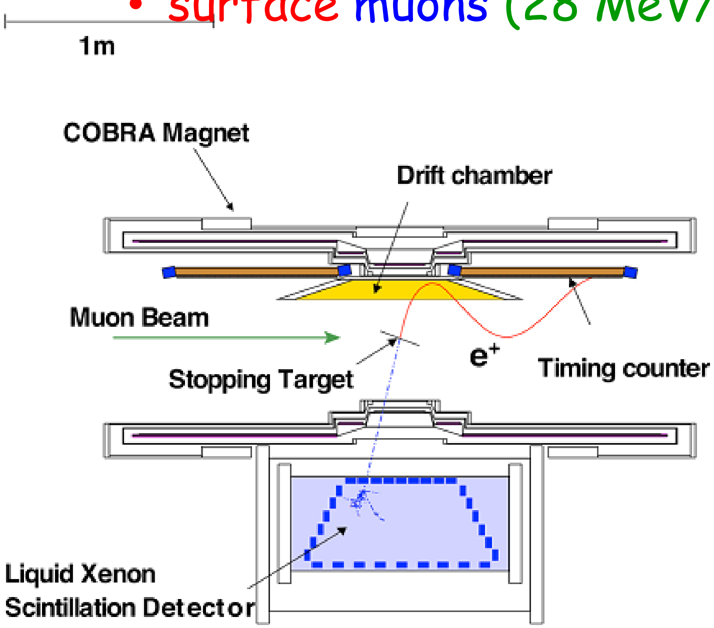
Exp./Lab	Year	$\Delta E_e/E_e$ (%)	$\Delta E_\gamma/E_\gamma$ (%)	$\Delta t_{e\gamma}$ (ns)	$\Delta\theta_{e\gamma}$ (mrad)	Stop rate (s^{-1})	Duty cycle(%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^5	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^5	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^5	6.4	1.7×10^{-10}
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	2010	0.8	4	0.15	19	3×10^7	100	1×10^{-13}

*quoted resolutions are FWHM

The layout

The beam

- located at Paul Scherrer Institut (CH)
- the most intense in the World ($>3\times10^8\mu$/s @ 2 mA)
- continuous (good for B_{acc} suppression)
- surface muons (28 MeV/c)



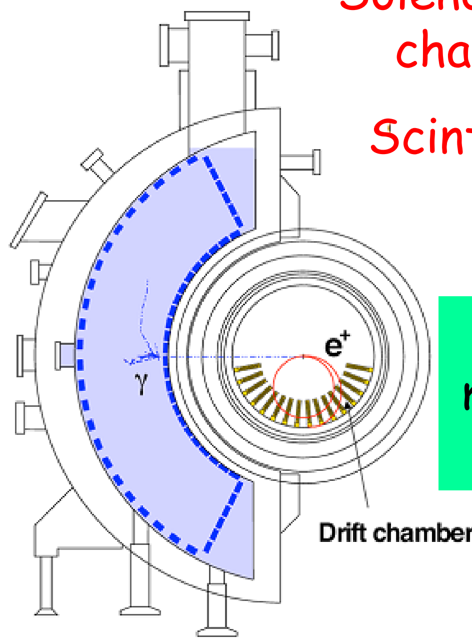
The detector

Beam of 3×10^7 μ /sec stopped in a 175 μm target

Liquid Xenon calorimeter for γ detection (scintillation)

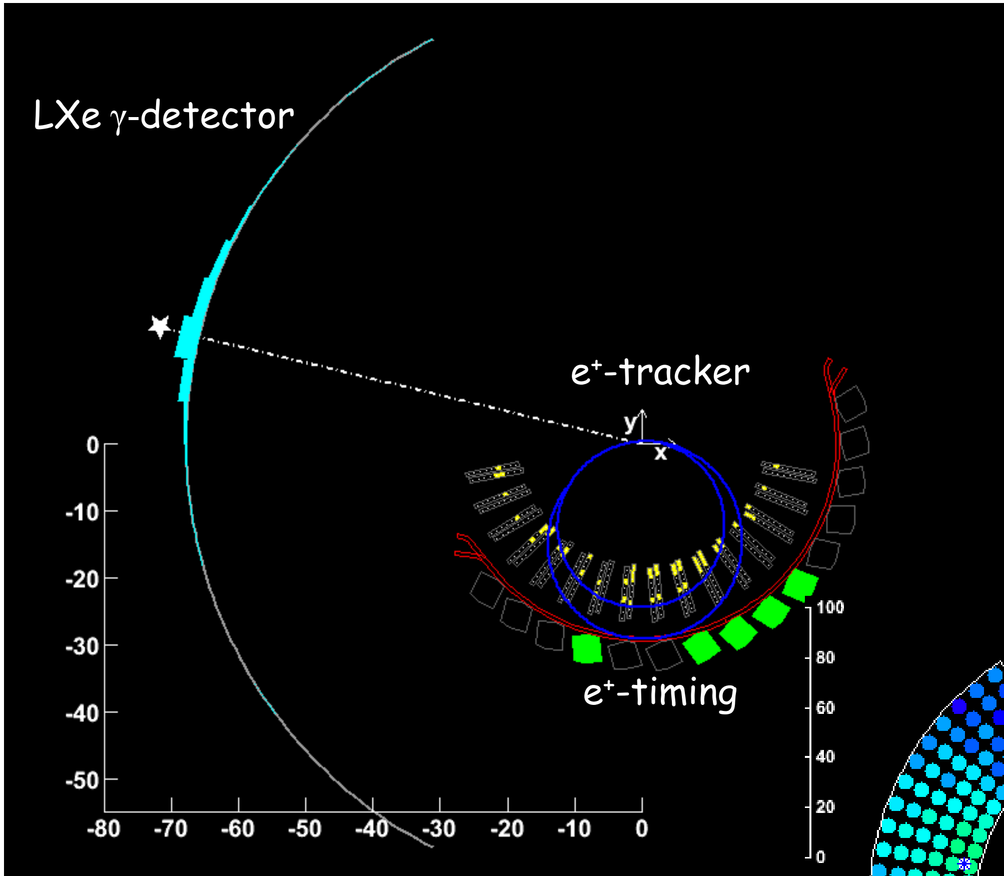
Solenoid spectrometer & drift chambers for e^+ momentum

Scintillation counters for e^+ timing



Matter effects must be minimized in order not to spoil the resolution

The run

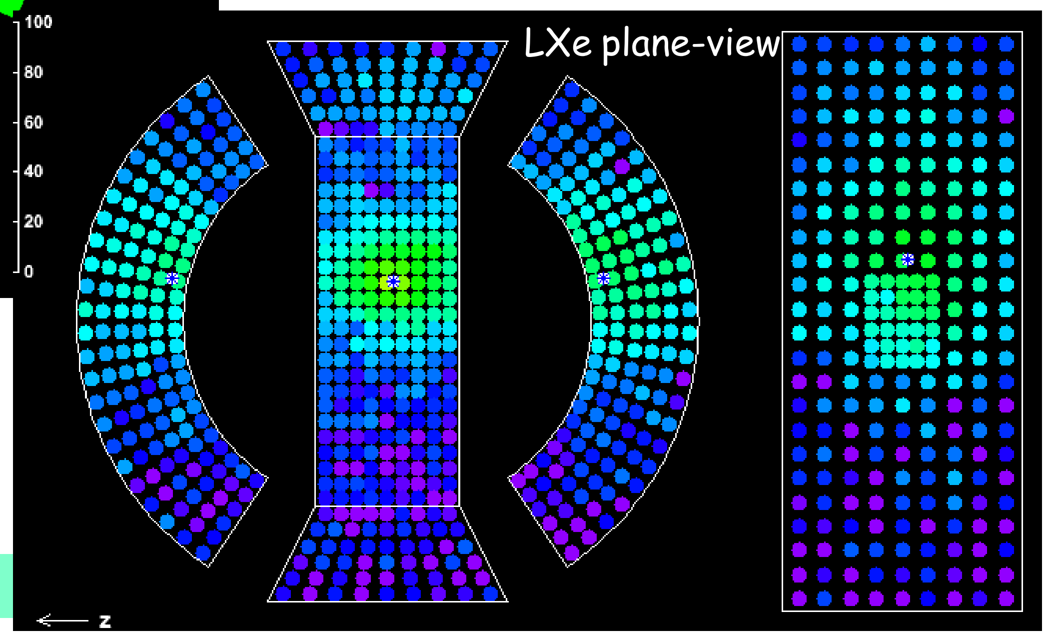


Run 2008

- from 12 September to 14 December (total time = $7 \cdot 10^6$ s)
- overall live-time = 49%

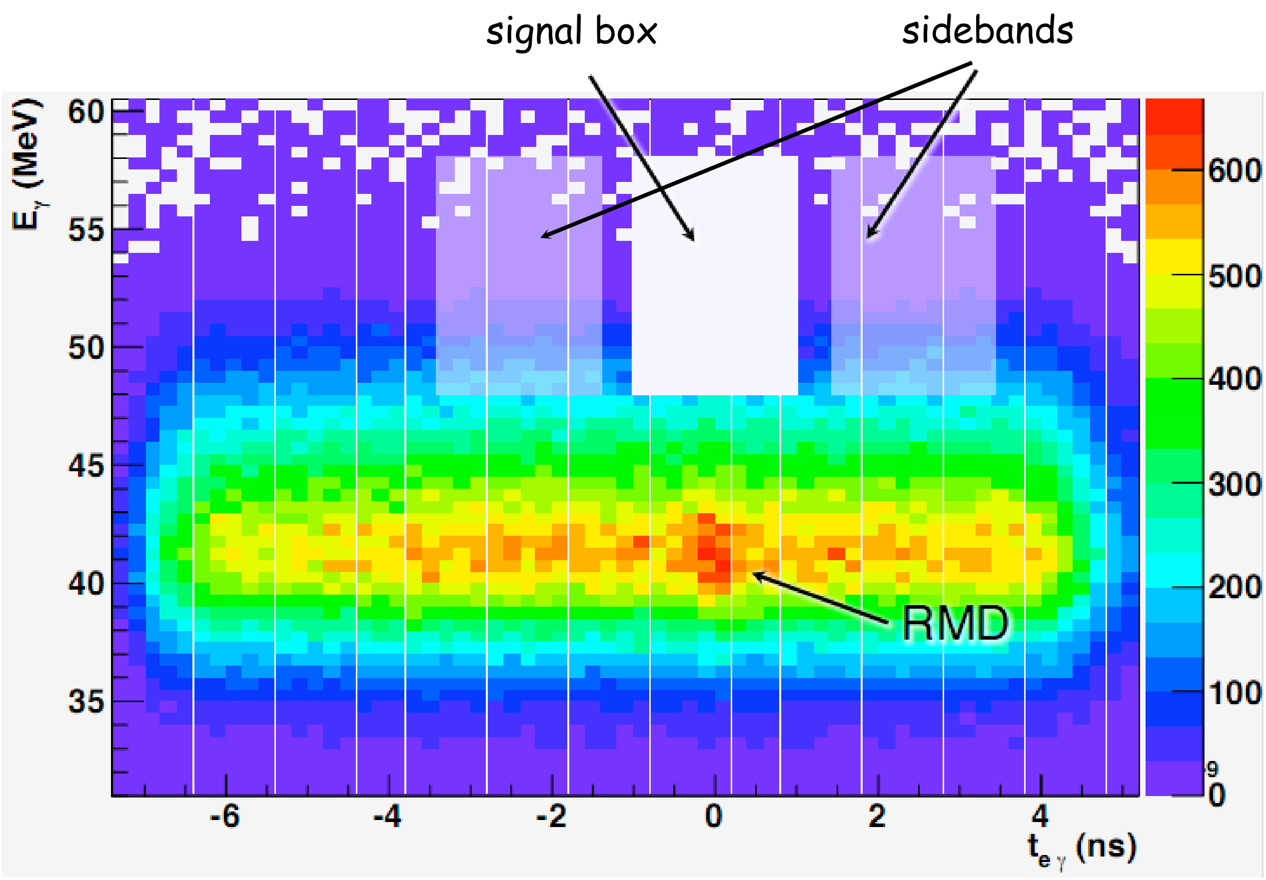
Run 2009

- from 5 November to 14 December (total time = $4 \cdot 10^6$ s)
- μ-stop rate on target = $3.0 \cdot 10^7\ s^{-1}$
- overall live-time = 65%



Analysis strategy

- Decided to adopt a blind-box likelihood analysis strategy
  - blinding observables are E_γ and $\Delta t_{e\gamma}$



pdfs:

- signal: from detector response function
- accidental: from event distribution in data sidebands
- RD: from RD data distribution and trigger simulation (angular cut)

MEG sensitivity prospect

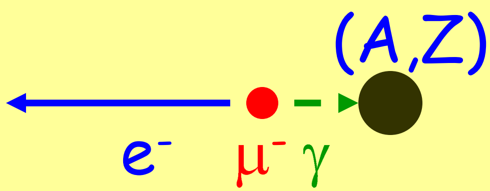
Limit published based on Run 2008 J.Adam *et al.*, Nucl.Phys.B834(2010)1
Analysis of Run 2009 data going to be finalized ➔ unblinding foreseen by next week
Computed sensitivity would significantly probe the "g-2" hint

	2008	2009	"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^+ Timing (psec)	<125	←	50
e^+ Momentum (%)	1.6	0.85	0.3-0.38(100%)
e^+ Angle (mrad)	10(ϕ)/18(θ)	8(ϕ)/11(θ)	3.8-5.1
e^+ Efficiency (%)	14	40	90
e^+-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^{-1})	3×10^7 (300μm)	2.9×10^7 (300μm)	3×10^7
DAQ time/Real time (days)	48/78	35/43	300/-
S.E.S @90% box	5×10^{-12}	2.3×10^{-12}	3.8×10^{-14}
Expected N_{BG}	0.5	0.7	0.5
Sensitivity	1.3×10^{-11}	4×10^{-12}	1.0×10^{-13}
BR upper limit (obtained)	2.8×10^{-11}	-	-

$\mu^- \rightarrow e^-$ conversion

signal

$\mu\ (A,Z) \rightarrow e\ (A,Z)$



$$E_e = m_\mu - E_B$$

E_e = 105.4 MeV for Al

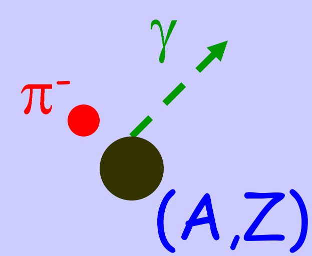
E_e = 104.3 MeV for Ti

E_e = 94.9 MeV for Pb

Background (beam related)

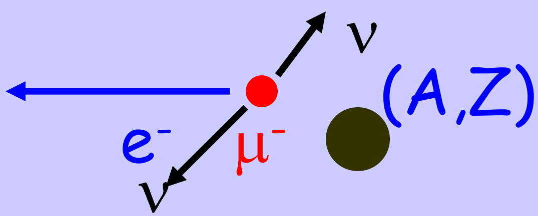
Radiative Pion Capture

$\pi\ (A,Z) \rightarrow \gamma\ (A,Z\text{-}1)$



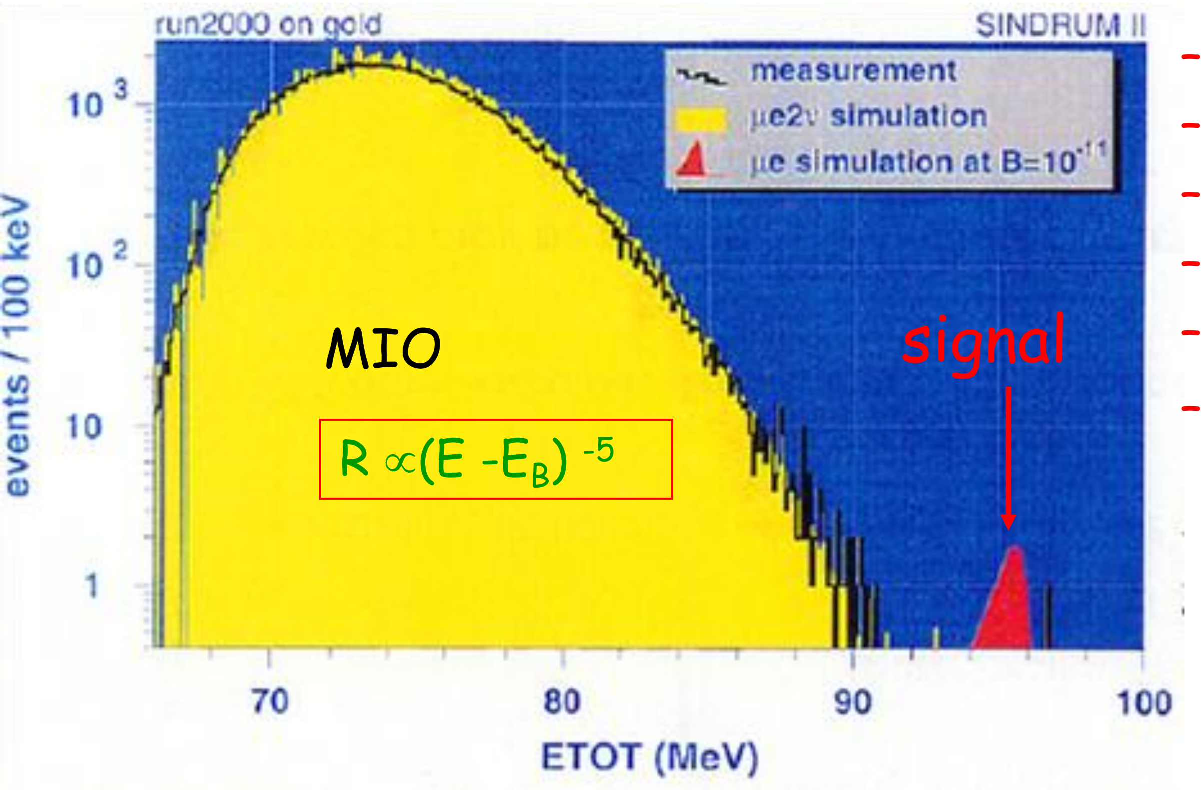
Muon-decay In Orbit

$\mu\ (A,Z) \rightarrow e\ \nu\ \nu\ (A,Z)$



Not limited by accidentals!

$\mu^- \to e^-$: SINDRUM II result



SINDRUM II parameters

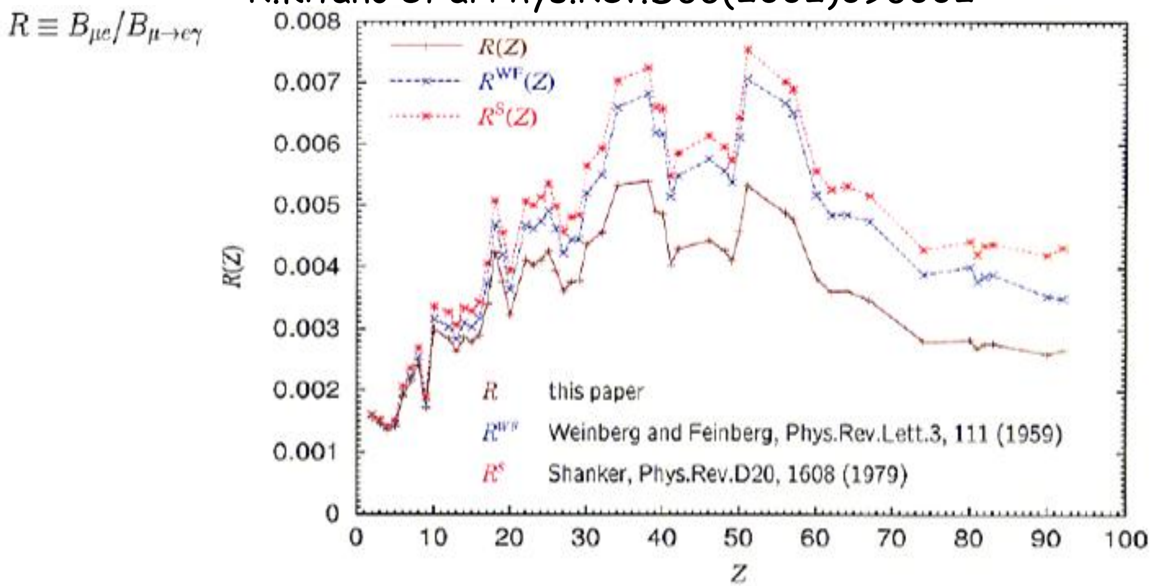
- beam intensity $3\times10^7\ \mu^-/s$
- μ^- momentum 53 MeV/c
- magnetic field 0.33T
- acceptance 7%
- momentum res. 2% FWHM
- S.E.S 3.3×10^{-13}
- $B(\mu\to e:Au)$ 8×10^{-13}

A. Van der Schaaf, NOON03

New proposals

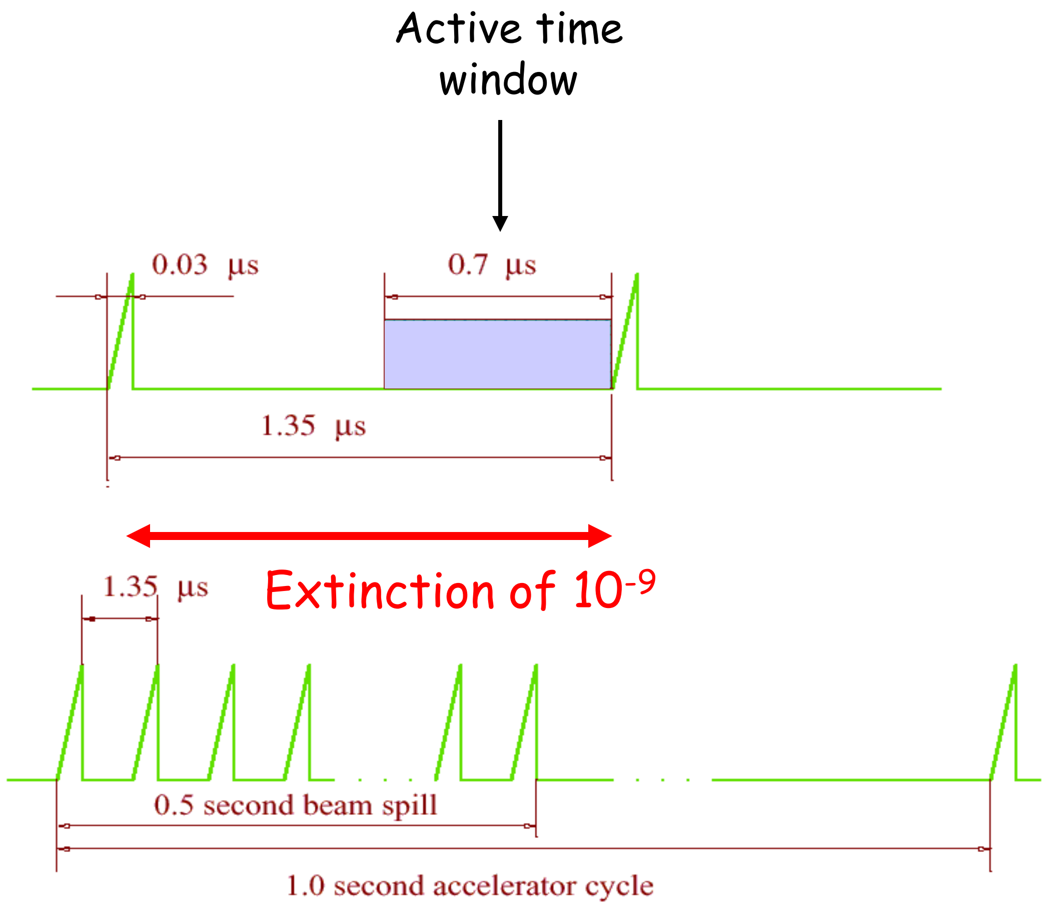
- *Mu2e* at Fermilab
  based on MECO / MELC proposals
  Goal: $B(\mu + Al \rightarrow e + Al) < 6\times10^{-17}$ @90% CL
- COMET at J-PARC
  - aims at $B(\mu \rightarrow e) < 10^{-16}$ @90% CL
  - to be upgraded to PRISM/PRIME

R.Kitano et al Phys.Rev.D66(2002)096002

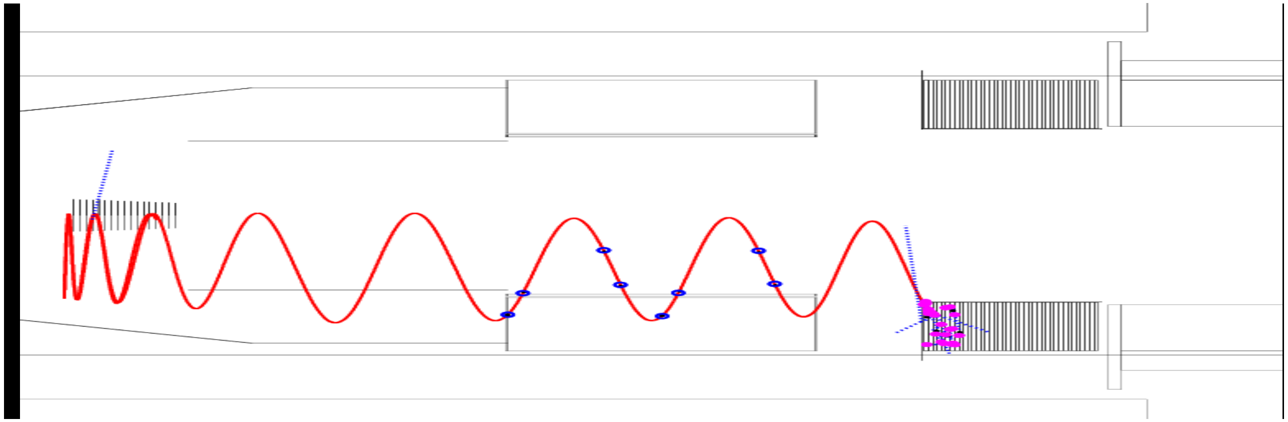


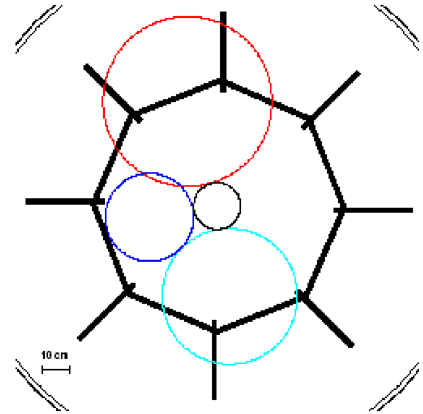
$\mu^- \to e^-$: strategy

Pulsed beam to eliminate prompt backgrounds

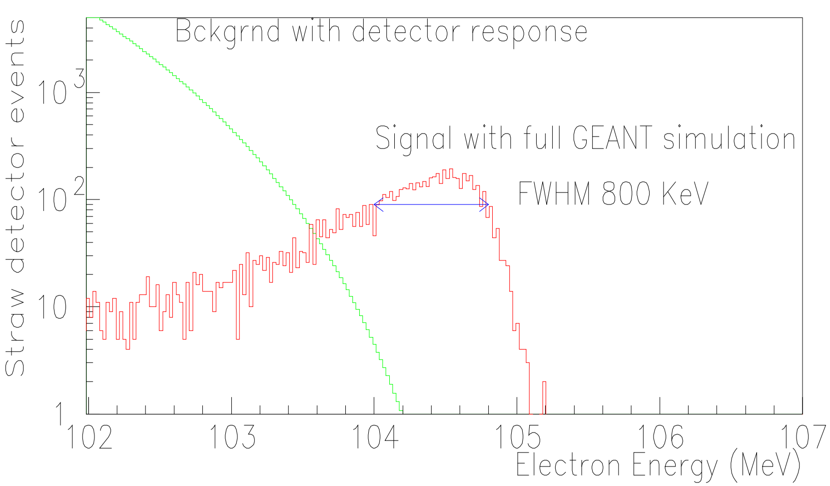


Spectrometer Performance





55, 91, & 105 MeV e^- from target



- Performance calculated using Monte Carlo simulation of all physical effects
- Resolution dominated by multiple scattering in tracker ($\Delta p/p = 0.8\%$)
- Resolution function of spectrometer convolved with theoretical calculation of muon decay in orbit to get expected background.

$\mu^- \rightarrow e^-$: PRISM beam

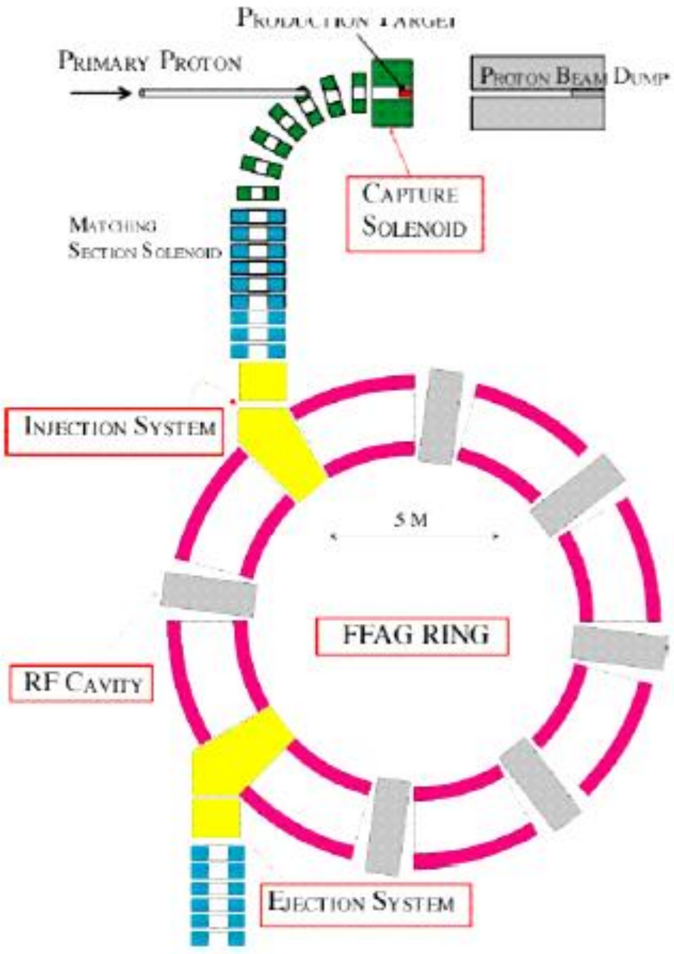


Fig.2 Schematic PRISM Layout

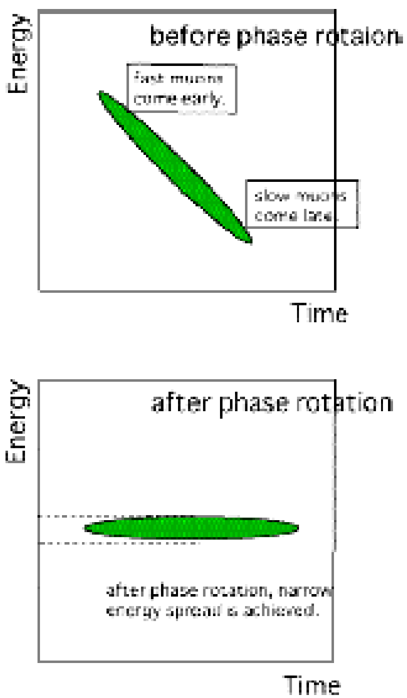


Fig.1 Phase Rotation

- High intensity pulsed proton beam
- Pion capture solenoid
- Pion decay section
- Phase rotation (muon energy spread reduction) with a FFAG ring ➔ smaller μ-target

➔better momentum resolution ($\Delta p/p$ = 0.3%)

➔suppression of MIO background ($\propto \Delta E^{-5}$)

FFAG approved and financed

EDM potential reach

- As in the case of LFV, EDM predicted values are greatly enhanced in SUSY with respect to SM ➔ any detection of an EDM≠0 is a signal for New Physics

particle	current limit (e cm)	future goal (e cm)	SM predicted (e cm)
n	2.9×10^{-26}	5×10^{-28}	$< 10^{-32}$
μ	2.0×10^{-19}	10^{-24}	$< 10^{-38}$
d		10^{-29}	
p	7.9×10^{-25}	10^{-29}	
e	1.6×10^{-27}		$< 10^{-41}$
^{199}Hg	3.1×10^{-29}	10^{-29}	

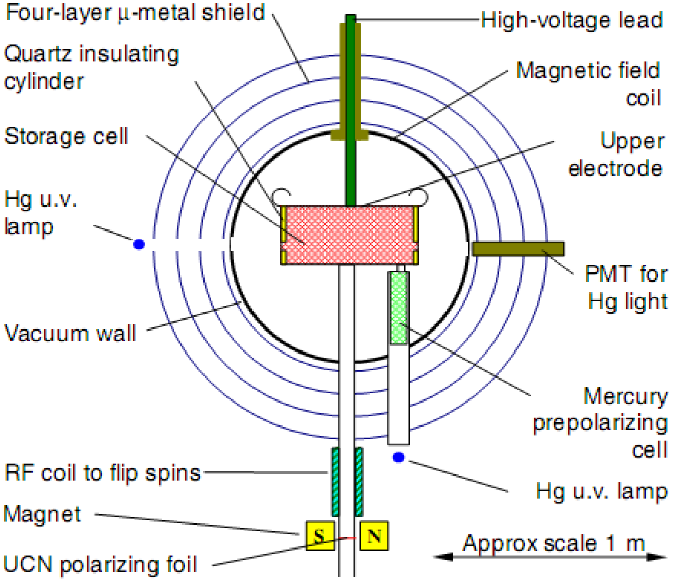
- correlation to muon g-2

$$d_\mu^{\mathrm{NP}} \simeq 3\times10^{-22}\left(\frac{a_\mu^{\mathrm{NP}}}{3\times10^{-9}}\right)\tan\phi_{CP} \quad \mathrm{e\cdot cm}$$

➔ either $d_\mu \approx 10^{-22}$ e cm or the CP-phase is strongly suppressed ($< 10^{-3}$)

Neutron EDM

- Measured at ILL (RAL/Sussex experiment) with
  - ultra-cold neutrons (UCN) trapped in vacuum with uniform, parallel (anti-) E and B fields
  - measurement of the spin Larmor frequency according to the Ramsey technique
    $h\nu = |2\mu_n B \pm 2d_n E|$
  - $d_n \neq 0$ ➔ precession frequency shifted as E-direction flips w.r.t. B
  - found $d_n < 2.9 \times 10^{-26}$ e cm (90% CL) C.A.Baker et al. Phys.Rev.Lett. 97 (2006)131801
- Towards a new measurement at PSI
  - Phase I
    - operation of old ILL set-up in situ (completed 2008)
    - shipping to PSI (02/2009)
  - Phase II
    - installation+commissioning (completed 2009)
    - operation at PSI UCN source (2009-2011)
    - sensitivity goal: 5×10^{-27} e cm
  - Phase III
    - commissioning of new apparatus "n2EDM" with
    - larger volume ($\times\sqrt{5}$)
    - longer running time (4y since 2011)
    - increased E-field strength (x2)
    - sensitivity goal: 5×10^{-28} e cm

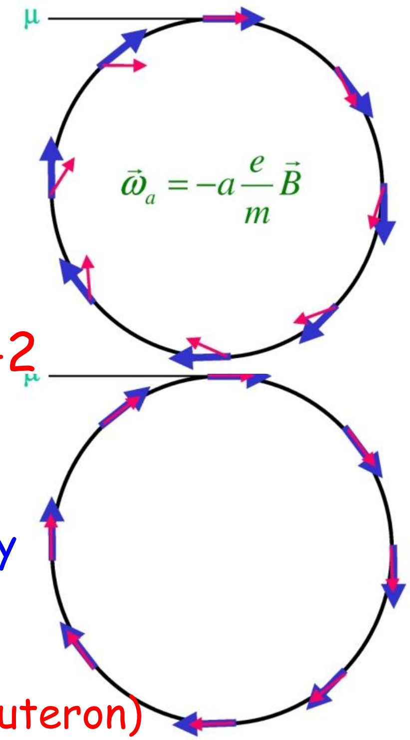


Muon EDM

- Makes use of spin precession in storage rings

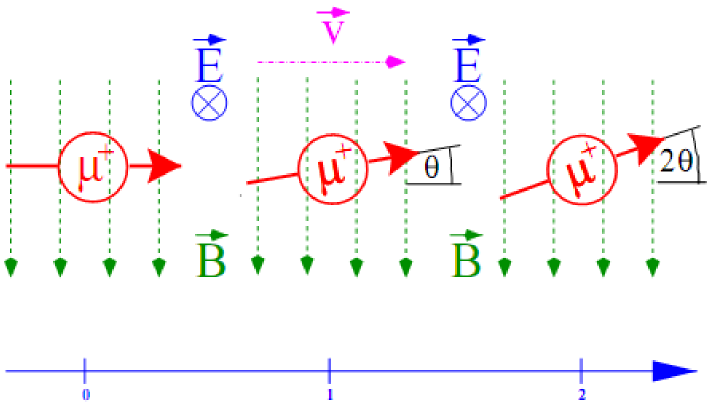
$$\vec{\omega} = -\frac{e}{m}\left\{\underbrace{a\vec{B} + \left(\frac{1}{\gamma^2-1} - a\right)\frac{\vec{\beta}\times\vec{E}}{c}}_{\text{MDM}} + \underbrace{\frac{\eta}{2}\left(\frac{\vec{E}}{c} + \vec{\beta}\times\vec{B}\right)}_{\text{EDM}}\right\}$$

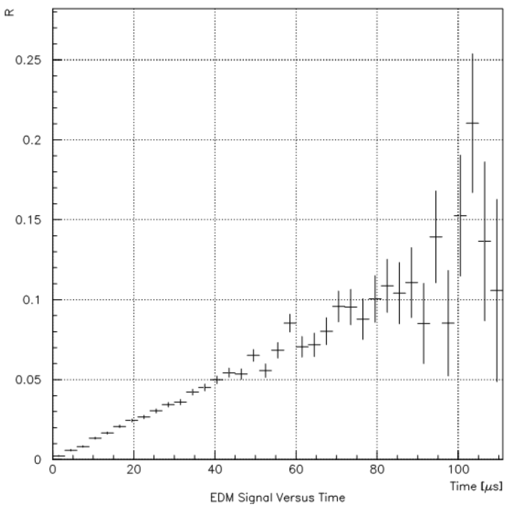
- Previous measurement at magic momentum (➔ γ = 29.3)
  - EDM effects
    - tilt of the precession plane by an angle $\delta = \tan^{-1}\left(\frac{\eta\beta}{2a_\mu}\right)$ w.r.t. the ring
      ➔ up/down asymmetry
      $N^{\pm}(t) \propto [1 \mp A_{EDM}\sin(\omega t+\phi) + A_\mu \cos(\omega t+\phi)]$
    - increase by $\omega = \omega_a / \cos\delta$ of the precession frequency
  - both effects are overwhelmed by precession due to g-2
- New idea: make the precession independent of g-2
  - use radial electric field to counteract a_μ ("frozen" spin)
    $E \simeq aBc\beta\gamma^2$
  - due to limited field strength (E < 2 MV/m), it is necessary to use low momentum muons (average p ≈ 500 MeV/c)
  G.W.Bennett et al., J-PARC-LOI-030109
  - method applicable to other charged particles (such as deuteron)
  D. Anastassopoulos et al., AGS proposal, March 2008



Sensitivity to μEDM

- EDM-precession decoupled from MDM
  - spin rotates around a radial axis
  - ➔ up/down asymmetry linearly increasing as a function of time





- Feasibility
  - uncertainty given by $\sigma_\eta = \frac{\sqrt{2}}{\gamma\tau(e/m)\beta BAP\sqrt{N}}$
  - need to maximize NP^2 (should be 10^{16} in order to achieve 10^{-24} e cm sensitivity)
    - very intense muon beam from pion decays
    - phase space rotation to reduce momentum spread 30% → 2%
      (so as to fit the momentum acceptance window of the storage ring) ➔ PRISM II
  - no proposal submitted yet

Conclusions

- LFV and EDM are sensitive probes of New Physics beyond the Standard Model
- If associated with SUSY-induced corrections, the observed discrepancy of muon anomaly w.r.t. the SM indicates relevant effects on both LFV decays and EDM
  - to be covered soon by MEG and nEDM at PSI
- An intensive programme of measurements has been proposed for the future
  - LFV
    - COMET, PRISM/PRIME
    - τ-decays at Super-B factories
  - EDM
    - Neutron
    - Deuteron
    - (muon)
- Strong case for experimental searches in all channels

$\mu^- \to e^-$: comparison

Background	SINDRUM	Mu2E	PRISM/PRIME
μ decay in orbit MIO	Resolution 2%	Resolution .8%	Resolution .3%
Radiative μ decay	Resolution 2%		
Beam e^-	Low momentum	Pulsed beam + 10^{-9} extinction	FFAG
μ decay in flight	Low momentum	Pulsed beam + 10^{-9} extinction	FFAG
π decay in flight	Low momentum	Pulsed beam + 10^{-9} extinction	FFAG
Radiative π capture RPC	PMC magnet	Pulsed beam + 10^{-9} extinction	FFAG
Anti-proton induced	-	Pulsed beam + 10^{-9} extinction	FFAG
Cosmic ray induced	Cosmic veto	Cosmic veto	n/a

$(E - E_B)^{-5}$

$\mu^- \rightarrow e^-$: Mu2e background

~ 0.45 background events

- for 10^7 s running time with 4×10^{13} proton/s
- sensitivity of ~ 5 signal events for $R_{\mu e} = 10^{-16}$

Source	Events	Comments
μ decay in orbit	0.25	S/N = 20 for $R_{\mu e} = 10^{-16}$
Tracking errors	< 0.006	
Radiative μ decay	< 0.005	
Beam e^-	< 0.04	
μ decay in flight	< 0.03	Without scattering in stopping target
μ decay in flight	0.04	With scattering in stopping target
π decay in flight	< 0.001	
Radiative π capture	0.07	From out of time protons
Radiative π capture	0.001	From late arriving pions
Anti-proton induced	0.007	Mostly from π^-
Cosmic ray induced	0.004	Assuming 10^{-4} CR veto inefficiency
Total Background	0.45	Assuming 10^{-9} inter-bunch extinction

The MEG collaboration

Univ. of Tokyo
X. Bai, T. Iwamoto, T. Mashimo, **T. Mori**, Y. Morita, H. Natori, Y. Nishimura, W. Ootani, K. Ozone, R. Sawada, Y. Uchiyama

KEK
T. Haruyama, K. Kasami, A. Maki, Y. Makida, S. Mihara, H. Nishiguchi, A. Yamamoto, K. Yoshimura

Waseda Univ.
K. Deguchi, T. Doke, J. Kikuchi, S. Suzuki, K. Terasawa

INFN Pisa
A. Baldini, C. Bemporad, F. Cei, C. Cerri, L. Galli, G. Gallucci, M. Grassi, F. Morsani, D. Nicolò, A. Papa, R. Pazzi, F. Sergiampietri, G. Signorelli

INFN and Univ. of Genova
M. De Gerone, S. Dussoni, K. Fratini, F. Gatti, R. Valle

INFN and Univ. of Pavia
G. Boca, P. W. Cattaneo, G. Cecchet, A. De Bari, P. Liguori

INFN and Univ. of Roma I
G. Cavoto, G. Piredda, F. Renga, C. Voena, D. Zanello

INFN and Univ. of Lecce
M. Panareo

Paul Scherrer Institute
J. Egger, M. Hildebrandt, P.-R. Kettle, S. Ritt, M. Schneebeli

BINP Novosibirsk
L. M. Barkov, A. A. Grebenuk, D. N. Grigoriev, B. I. Khazin, N. M. Ryskulov

JINR Dubna
A. Korenchenko, N. Kravchuk, A. Moiseenko, D. Mzavia

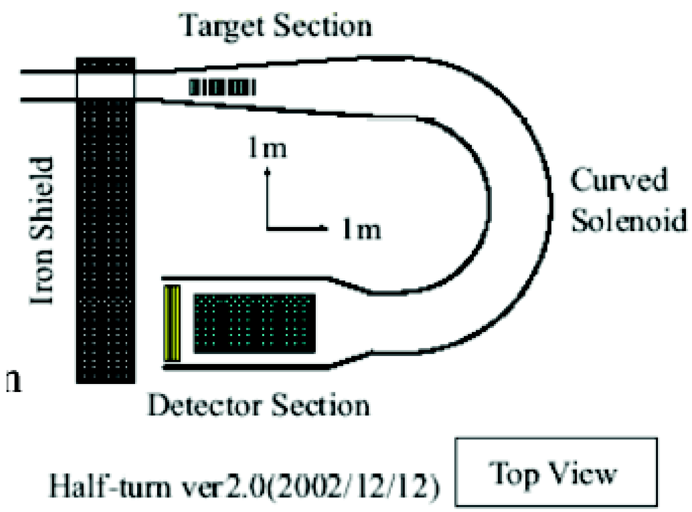
Univ. of California, Irvine
E. Baracchini, W. Molzon, C. Topchyan, V. Tumakov, F. Xiao

Σ ~40 FTEs

$\mu^- \to e^-$: PRIME detector

PRISM/PRIME parameters

- beam intensity 3×10^{11} μ^-/s
- μ^- momentum 68 MeV/c
- momentum res. 350 keV FWHM
- S.E.S 6×10^{-19}
- $B(\mu \to e)$ 10^{-18}



Preliminary, rough, estimates for a possible SPL pulsed muon beam

(J. Aysto et al., CERN-TH/2001-231,

A.Baldini, MultiMW may04)

- Macro duty cycle: 1.2 ms every 20 ms (6% duty cycle)
- By the help of a chopper 40 mA of protons in bursts of 200 ns can be provided every 2 μs (good microstructure for mu-e conv)
- This corresponds to $1.5*10^{15}$ p/s @2.2 GeV (0.5 MW)

R.Garoby

- An extinction factor of 10^8 might be within reach (difficult to be measured): confirmation in 2007
- An additional 10^3 might be added to the extinction factor by using a veto counter active only between the p bursts
- By using GHEISHA to scale #π/p from 8 to 2.2 GeV (HARP results needed) → 10^{12} μ/s (tungsten target) Sensitivity down to $B=10^{-18}$
- Need of precise design/estimates

On demand

The likelihood function

- Likelihood function built in terms of the number of
  - signal,
  - radiative decay
  - uncorrelated background

  events and their pdfs
- Each pdf is a function of 5 kinematical variables

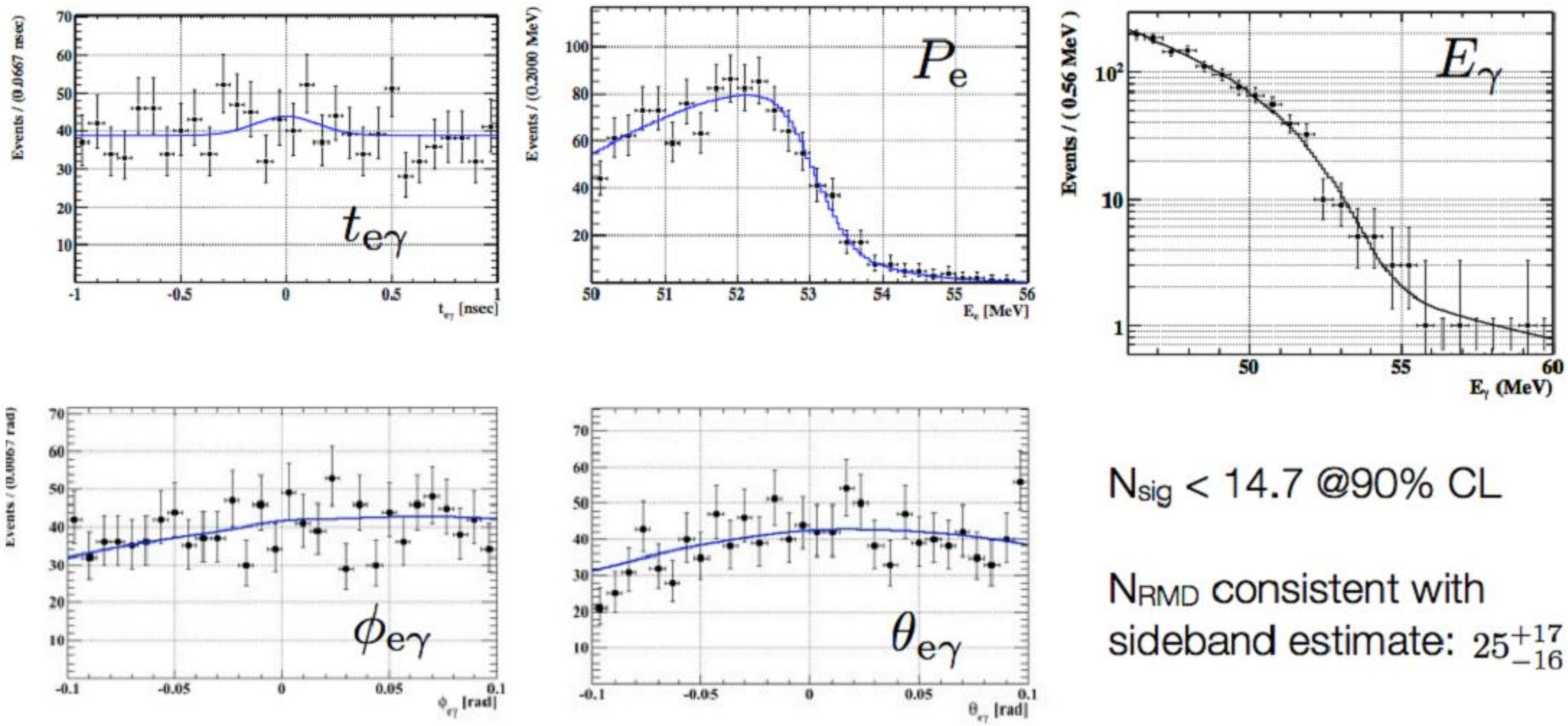
  E_e, E_γ, $\delta\theta$, $\delta\varphi$, $t_{e\gamma}$

$$\mathcal{L}(N_{\rm sig}, N_{\rm RMD}, N_{\rm BG}) = \frac{N^{N_{\rm obs}} \exp^{-N}}{N_{\rm obs}!} \prod_{i=1}^{N_{\rm obs}} \left[\frac{N_{\rm sig}}{N} S + \frac{N_{\rm RMD}}{N} R + \frac{N_{\rm BG}}{N} B \right]$$

- pdfs extracted from
  - data
  - MC tuned on the data

Likelihood test

- A "Feldman-Cousins" approach was adopted for the likelihood analysis
- Sensitivity (i.e. average expected 90% CL upper limit on assuming no signal) turns out to be
  - B < 1.3 x 10-11
- 90% CL upper limit from the sidebands
  - B < (0.9: 2.1) x 10^{-11}



Physics motivation

- Charged-Lepton Flavour Violation (cLFV) processes, like $\mu \to e\gamma$, $\mu \to eee$, $\mu \to e$ conversion, and also $\tau \to e\gamma$, are negligibly small in the extended Standard Model (SM) with massive Dirac neutrinos (BR $\approx 10^{-50}$)

- Super-Symmetric extensions of the SM (SUSY-GUTs) with right handed neutrinos and see-saw mechanism may produce LFV processes at significant rates

- cLFV decays are therefore a clean (no SM contaminated) indication of Super Symmetry

and

- the expected BR are close to the experimental limits

The Run 2008 limit

From the 90 % C.L. upper bound on number of signal events:

$$N_{Sig} \leq 14.7$$

we obtained the corresponding 90 % C.L. upper limit:

$$BR(\mu^+ \rightarrow e^+\gamma) \leq 3.0 \times 10^{-11}$$

$\approx$ 2 times worse than the expected sensitivity.

The probability of getting this result by a statistical fluctuation of the observed distributions is $(3 \div 5)$ %

(bad luck !)

J.Adam *et al.*, Nucl.Phys.B834(2010)1

MEG sensitivity summary

Detector parameters $T = 2.6 \cdot 10^7\, s$ $R_\mu = 0.3 \cdot 10^8\, \mu/s$ $\frac{\Omega}{4\pi} = 0.09$

$\varepsilon_e \approx 0.9$ $\varepsilon_{sel} \approx (0.9)^3 = 0.7$ $\varepsilon_\gamma \approx 0.6$

Cuts at 1,4×FWHM

Signal $N_{sig} = BR \cdot T \cdot R_\mu \cdot \frac{\Omega}{4\pi} \cdot \varepsilon_e \cdot \varepsilon_\gamma \cdot \varepsilon_{sel}$

Single Event Sensitivity $SES = 1 \Big/ T \cdot R_\mu \cdot \frac{\Omega}{4\pi} \cdot \varepsilon_e \cdot \varepsilon_\gamma \cdot \varepsilon_{sel}$ $\approx 4 \times 10^{-14}$

Backgrounds $BR_{acc} \propto R_\mu^2 \times \Delta E_e \times \Delta E_\gamma^2 \times \Delta\theta_{e\gamma}^2 \times \Delta t_{e\gamma} \approx 3 \times 10^{-14}$

$BR_{corr} \approx 3 \times 10^{-15}$

Upper Limit at 90% CL $BR(\mu \to e\gamma) \approx 1 \times 10^{-13}$

Discovery 4 events ($P = 2 \times 10^{-3}$) correspond $BR = 2 \times 10^{-13}$

Beam requirements

Experiment	q_μ	N_μ	T_μ	$\Delta P_\mu / P_\mu$	I_{off}/I_{on}	δt	Δt	BR
$\mu^+ \to e^+ e^+ e^-$	+	10^{17}	< 4 (MeV)	< 10 %	DC	n/a	n/a	10^{-15}
$\mu^+ \to e^+ \gamma$	+	10^{17}	< 4 (MeV)	< 10 %	DC	n/a	n/a	10^{-15}
$\mu^- \to e^-$ conv.	-	10^{21}	< 80 (MeV)	< 5 %	< 10^{-10}	< 100 ns	> 1 μs	10^{-19}
$\mu^- \to e^-$ conv.	-	10^{20}	< 80 (MeV)	< 5 %	DC	n/a	n/a	10^{-19}

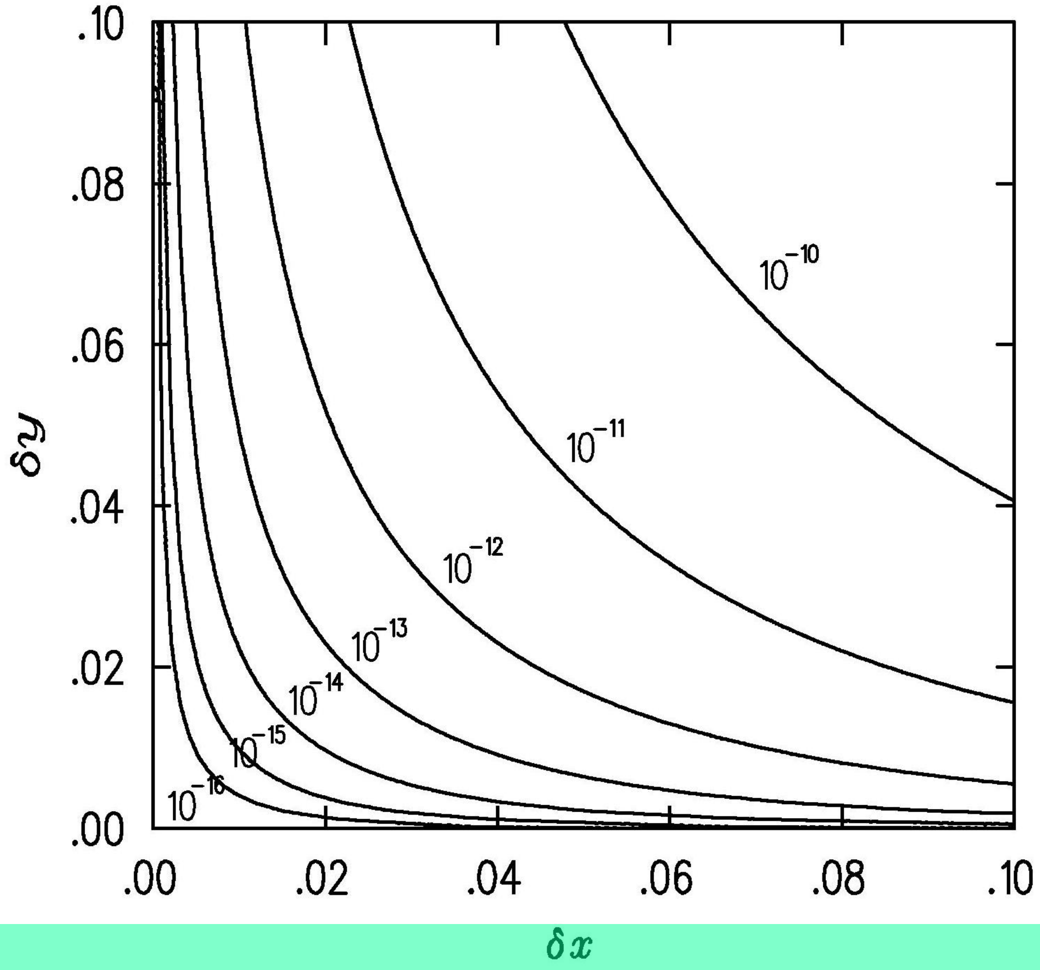
Supplementary information

$\mu^+ \to e^+\gamma$: correlated background

The correlated background is smaller than the accidental one

The correlated background

- has a complicate dependence on the photon (y) and positron (x) energy resolutions.
- depends linearly on the R_μ
- is 3×10^{-15}



Bibliography

J.Aysto et al. CERN-TH/2001-231

NuFact03 proceedings

NuFact02 proceedings

MultiMW Workshop, May 2004

SINDRUM coll., W Bertl et al. Nucl.Phys. B260(1988)1

SINDRUM2 coll., W Honecker et al. Phys.Rev.Lett. 76(1996)200

MECO coll., BNL proposal AGS P940 (1997)

MEG coll., "The MEG proposal" (2002)

LFV in the Standard Model

Neutrino oscillations $\Rightarrow$ flavour mixing in lepton sector

•Extensions of SM with massive Dirac neutrinos allow Lepton Flavour Violation (LFV) processes, like $\mu \rightarrow e\gamma$, $\tau \rightarrow e\gamma$, $\mu \rightarrow eee$, $\mu \rightarrow e$ conversion with $B \approx 10^{-50}$

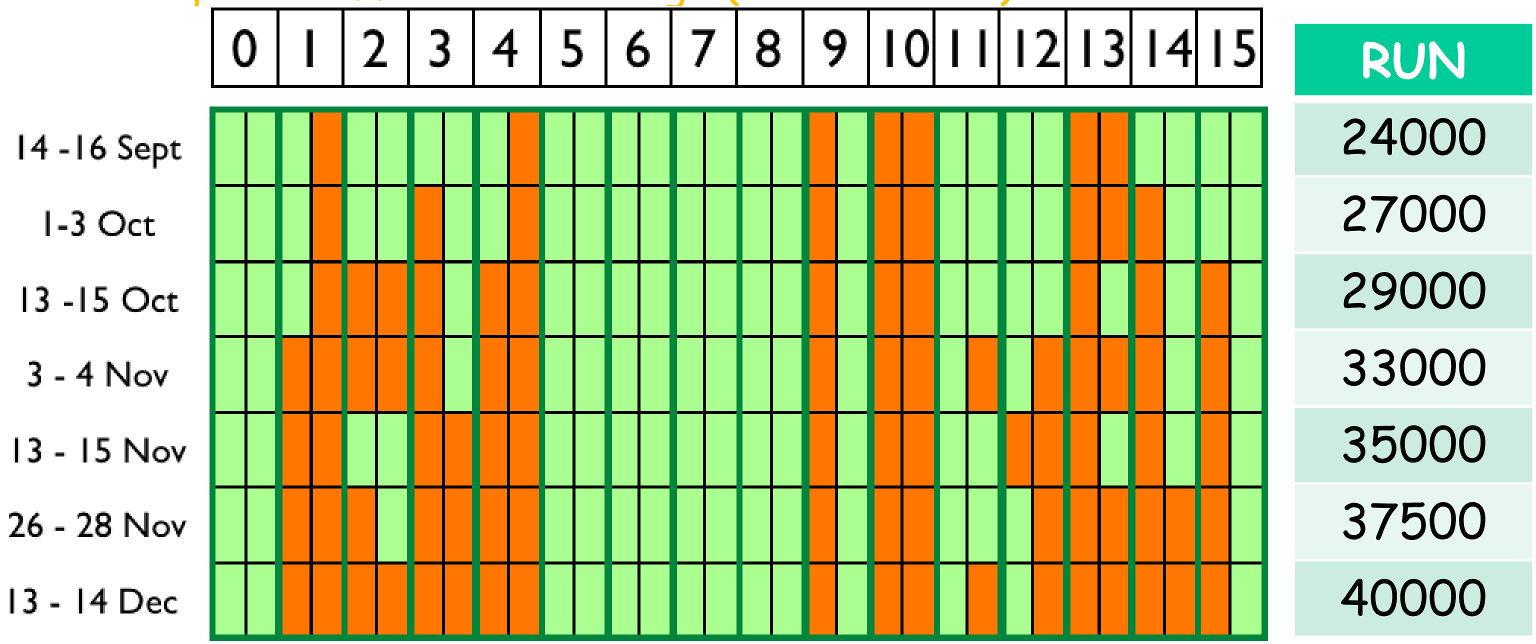
•Super-Symmetric extensions of the SM (SUSY-GUTs) with right handed neutrinos and see-saw mechanism may produce LFV processes at significant rates

A $\mu \rightarrow e \gamma$ decay is therefore a clean (no SM contaminated) indication of Super Symmetry but…

Are these rates accessible experimentally?

DC operation in Run 2008

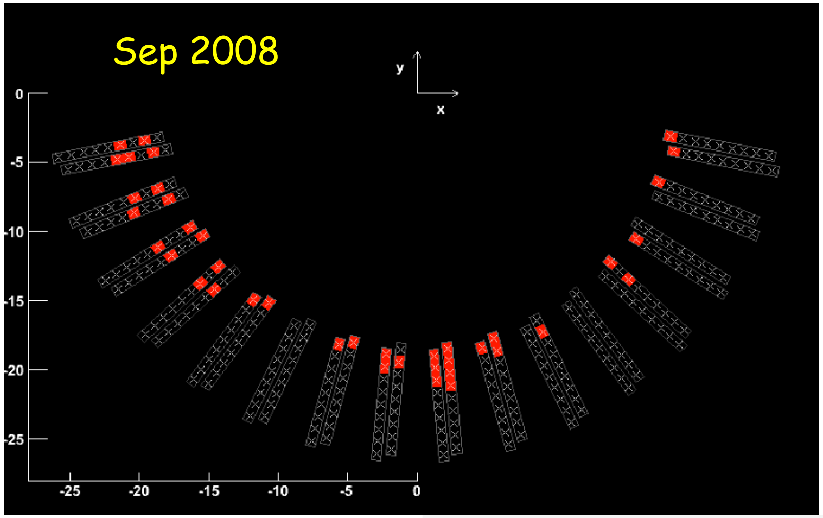
- at turn-on (July 08) the system was fine 30/32 planes OK (@1850 V)
- HV deterioration observed during the Run; at the end
  - 11/32 planes OK (@1850 V)
  - 7/32 planes off-nominal voltage (1700 1800 V)

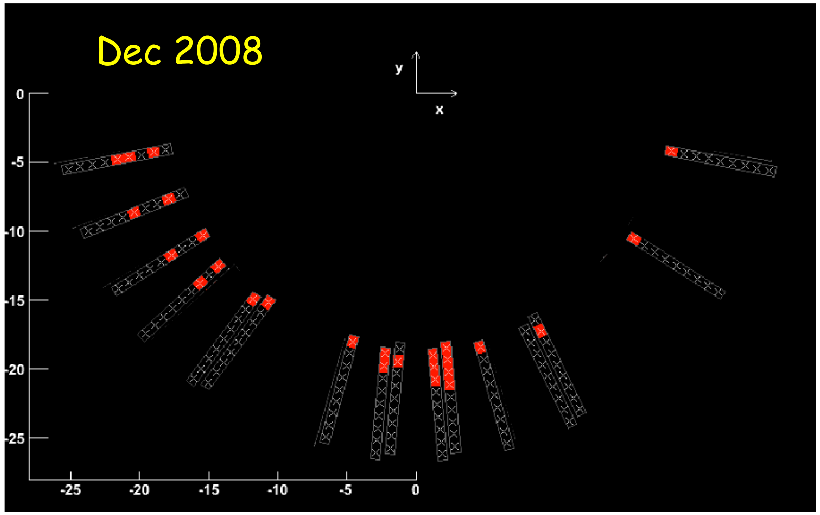


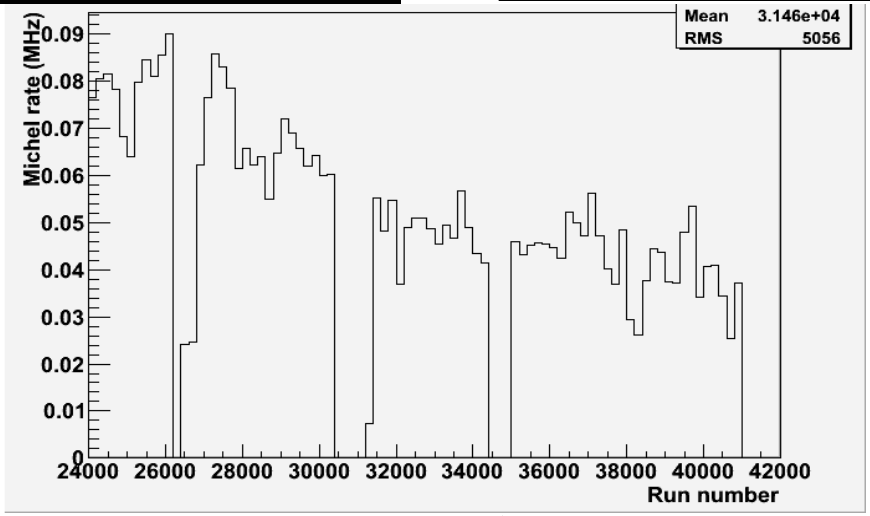
- body of evidence for He-diffusion inside the HV distribution

DC performance

The rate of events with a reconstructed track decreases with the Run going on ➔ absolute e^+-efficiency getting lower and lower (up to 25%)

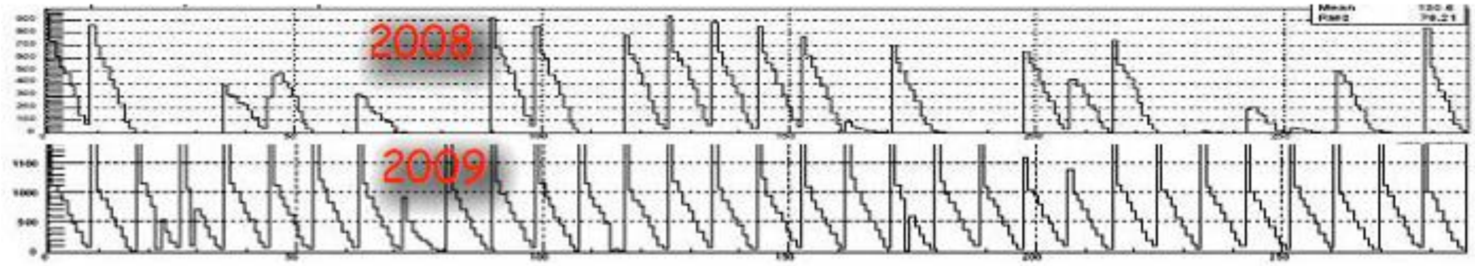






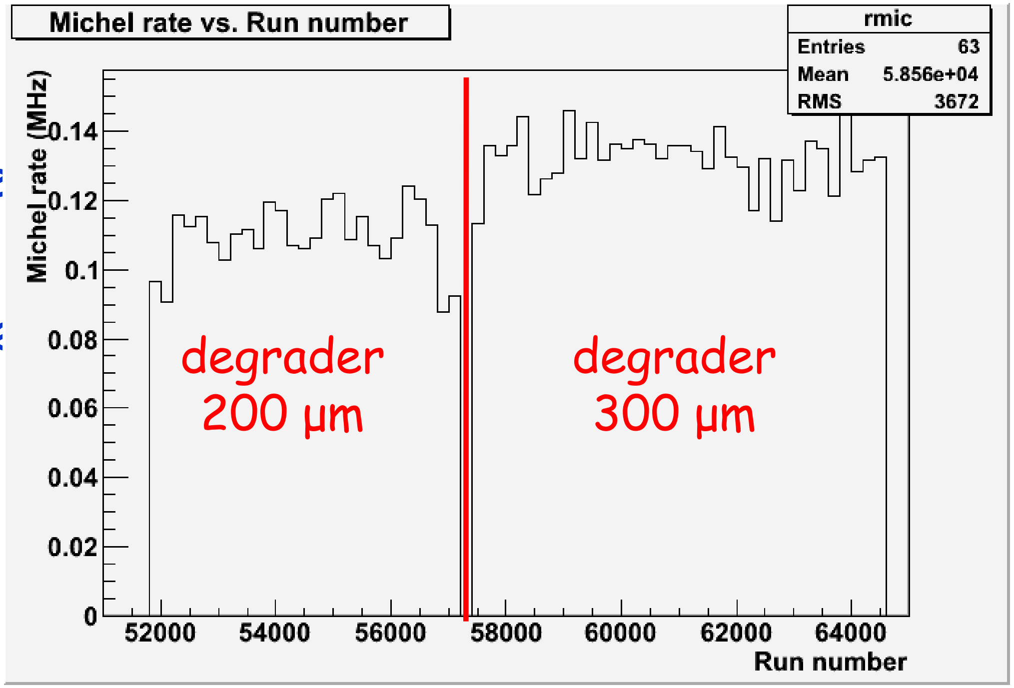
Run 2009 stability

- All planes working, 30/32 at nominal voltage (> 1800 V)

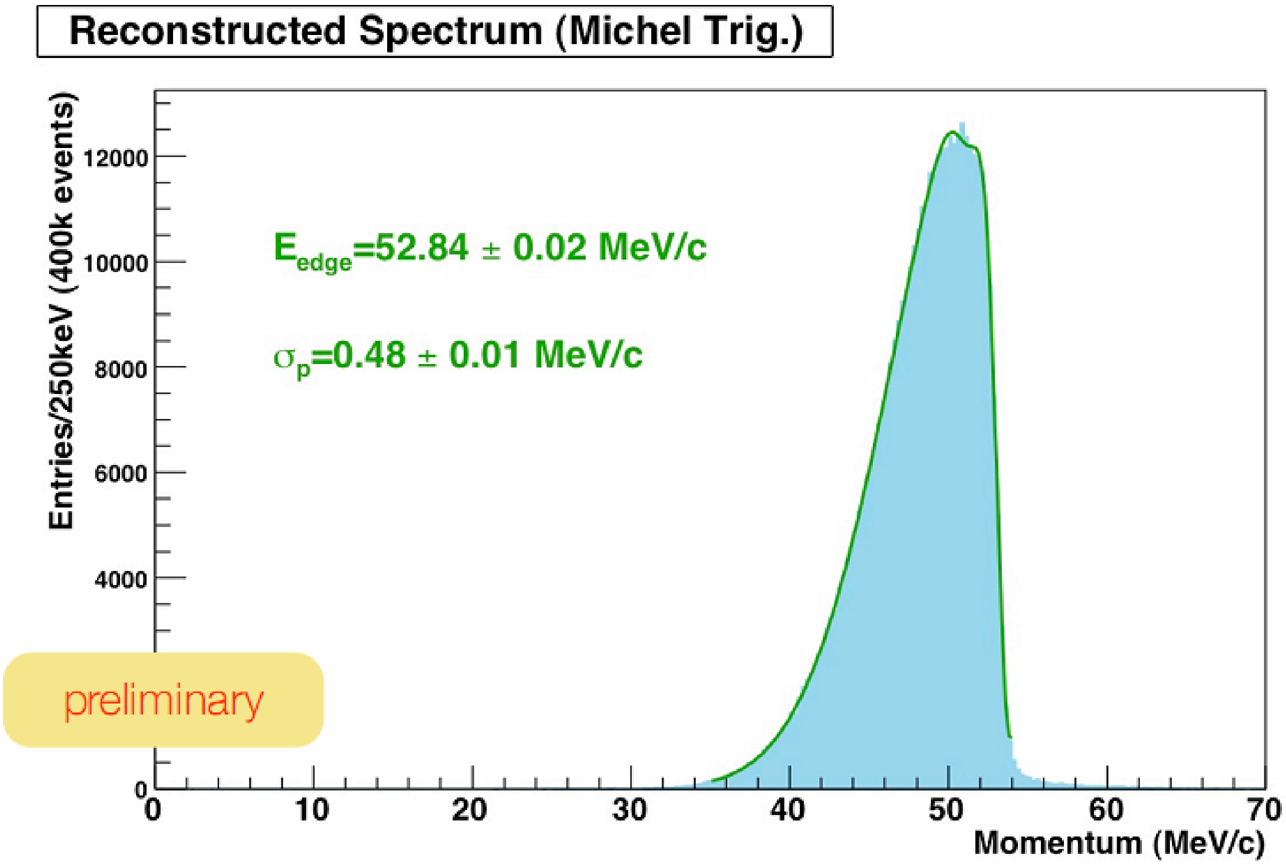


-

- no deterioration of DC stability during the Run (Sep-Dec 2009)
- measured rate compatible with full tracking efficiency



Positron momentum reconstruction



From 2007 engineering run

Michel edge smeared by

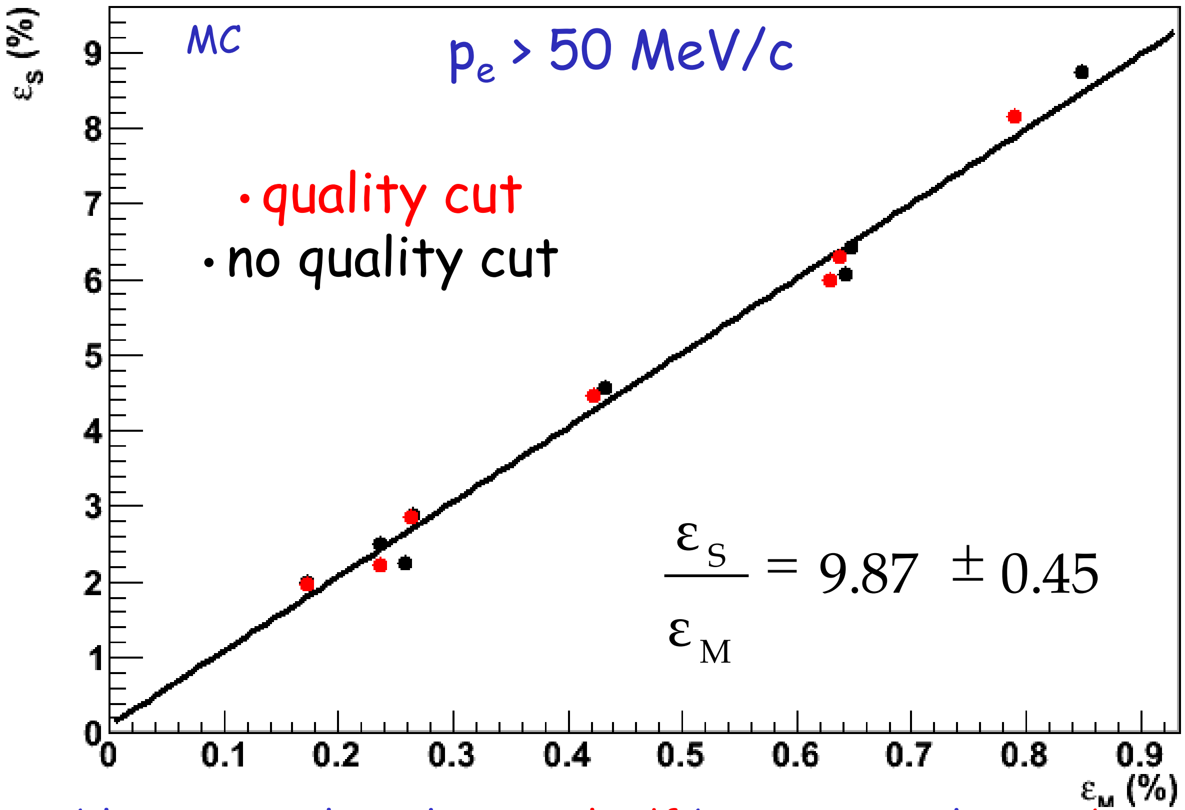
- radiative corrections
- resolution

pdfs

- Signal
  - E_γ from full signal simulation (response function tuned on the data)
  - E_e from 3-gaussian fit on data
  - $\theta_{e\gamma}$ from combined positron and gamma angular resolution (data fit)
  - $t_{e\gamma}$ gaussian fit to RD data spectrum
- RD
  - E_e, E_γ, $\theta_{e\gamma}$ 3d-histo pdf from toy MC (including resolution and acceptance smearing)
  - $t_{e\gamma}$ gaussian fit to RD data spectrum (as in the case of signal)
- accidentals
  - E_{γ}, $\theta_{e\gamma}$ from fit to the sidebands
  - E_e from the data
  - $t_{e\gamma}$ flat distribution

DC efficiency and normalization

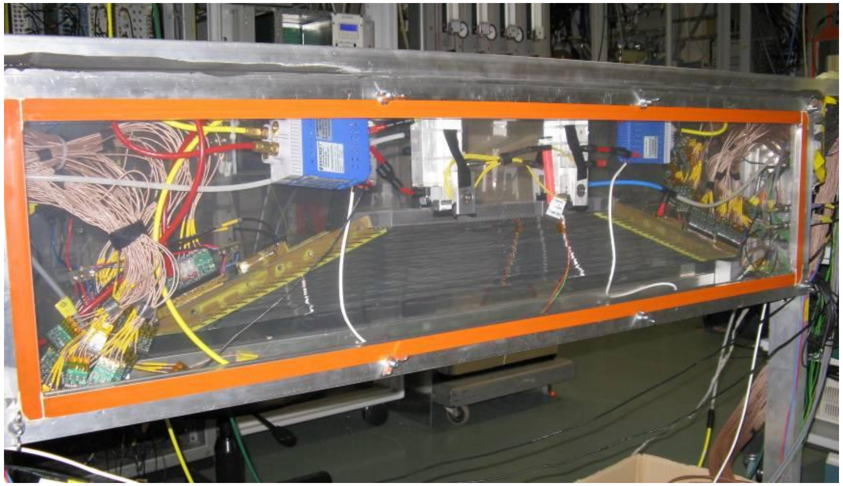
- Relative efficiency (i.e. fraction of signal/Michel events) is almost constant during the run (in spite of DC deterioration)
- average ratio agrees with the expected fraction of e^+ with p>50 MeV



➔ it is possible to normalize the signal pdf by counting the number of Michel in the analysis window (events recorded during the normal Run with a pre-scaled trigger)

Improvements in Run 2009

- Sparks observed in the "aquarium" test station
- Solution:
  - New PCB layout and production
  - Better insulation of HV and GND layers
  - HV net on an internal layer with blind vias
  - 16 newly assembled modules
  - Individual test in He-atmosphere
  - Long-term (6,5 m) test on 2 modules → OK



LXe up-to-date

- LXe tank re-filled after several cycles of gas-phase purification
- at detector turn-on we found:
  - LY(γ) improved by 30% w.r.t. end of Run2008 and in agreement with expectations
  - same LY(α) as Run2008