Incontri di Fisica delle Alte Energie (IFAE 2010)
Roma, 8 Aprile 2010

Searches for Lepton Flavour Violation

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Outline

- Introduction to Lepton Flavour Violation (LFV);
- LFV in the muon sector: the MEG experiment;
- LFV at the B-Factories:
  - τ LFV;
  - LFV in Υ(nS) decays;
- Conclusions and perspectives.

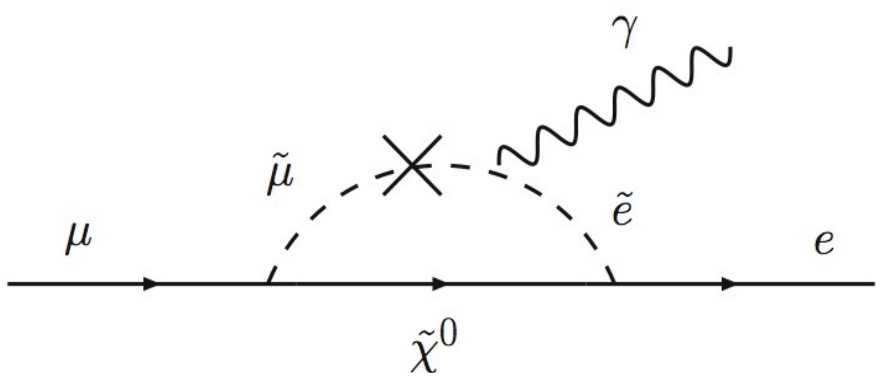
Lepton Flavour Violation

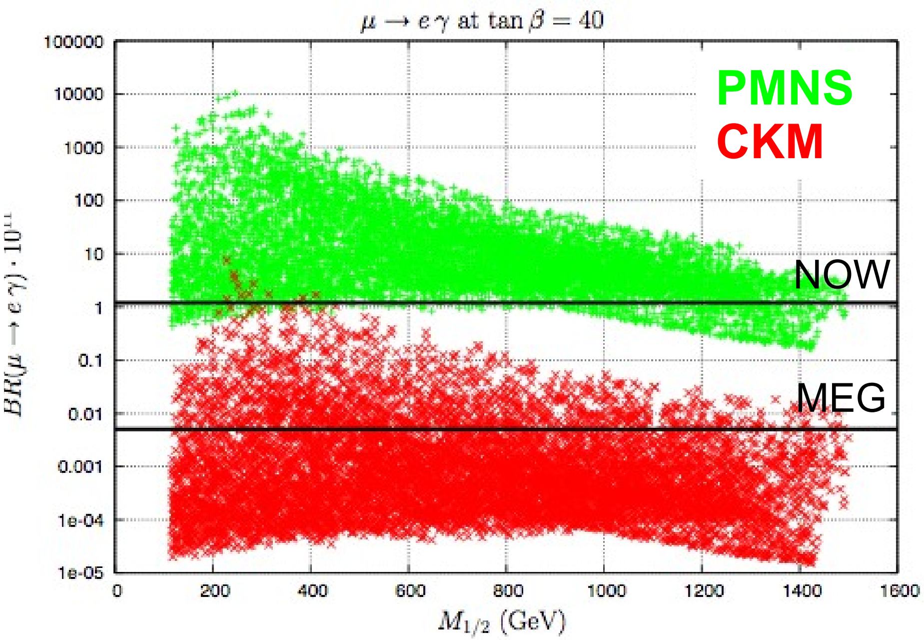
- Lepton Flavour conservation is an *accidental symmetry* in the Standard Model (SM):
  - Not related to gauge structure of the theory;
  - Naturally violated in SM extensions;
- Lepton Flavour Violation already observed in the neutrino sector (*neutrino oscillations*) :
  - Can be explained with a heavy right-handed neutrino;
  - Very small SM contribution in the charged lepton sector, e.g. BR($\mu \rightarrow e\,\gamma$) ~ 10^{-54};

Observation of LFV for charged lepton would be an unambiguous evidence of New Physics

LFV beyond the SM

- Many SM extensions predict LFV effects at a measurable level;
- SUSY:
  - Off-diagonal terms in the slepton mass matrix





- In SUSY-GUT, LFV parameters can be related to the CKM matrix (quark *mixing*) or the PMNS matrix (*neutrino mixing*);

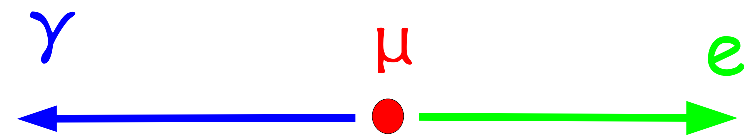
Calibbi *et al.*, Phys.Rev.D74: 116002,2006 (SO(10) SUSY-GUT)

The MEG Experiment

Experimental Signature

- To get 10^{-13} sensitivity:
  - high statistics;
  - high resolutions (energy, time, angle) for low background;

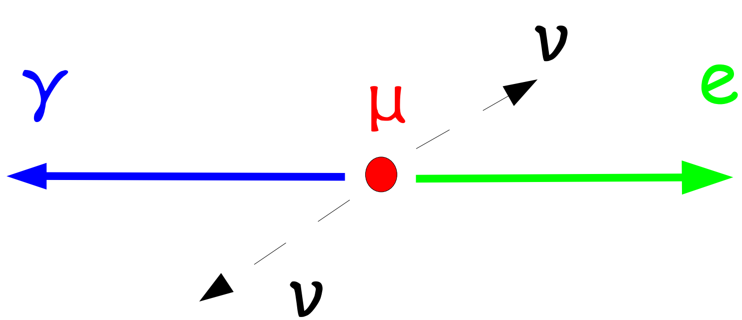
SIGNAL $\propto$ μ rate



$E_\gamma = E_e = 52.8$ MeV,

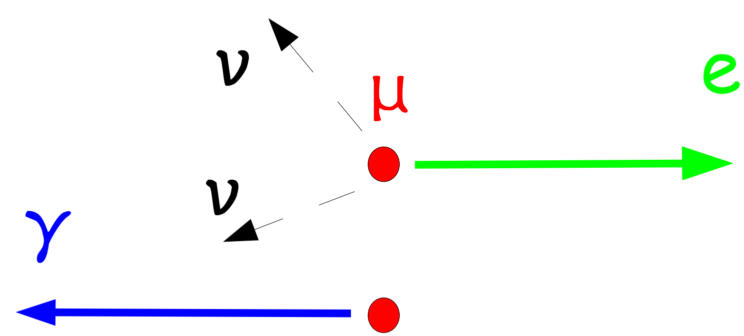
$\theta_{e\gamma} = 180°$, $T_e - T_\gamma = 0$

RADIATIVE DECAY $\propto$ μ rate



DOMINANT

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

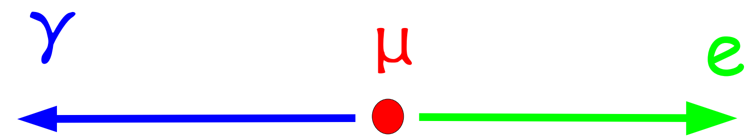


Experimental Signature

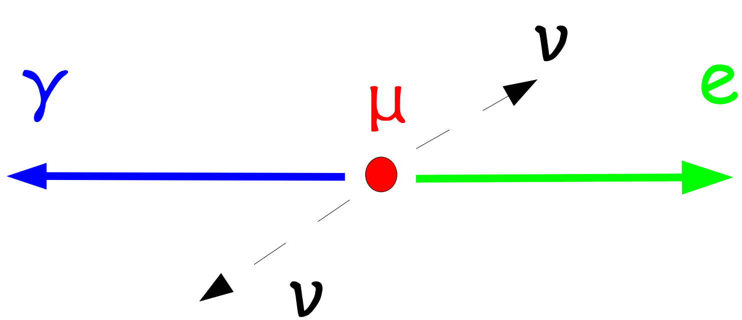
- To get 10^{-13} sensitivity:
  - high statistics;
  - high resolutions (energy, time

$$\Gamma_{acc} \propto \Gamma_\mu^2 \cdot \delta E_e \cdot \delta T_{e\gamma} \cdot (\delta E_\gamma)^2 \cdot (\delta \theta_{e\gamma})^2$$

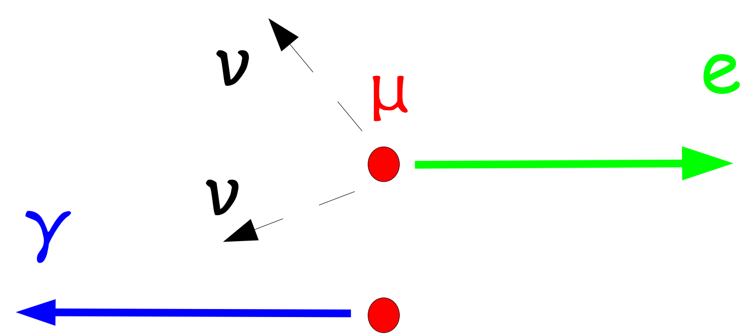
SIGNAL ∝ μ rate



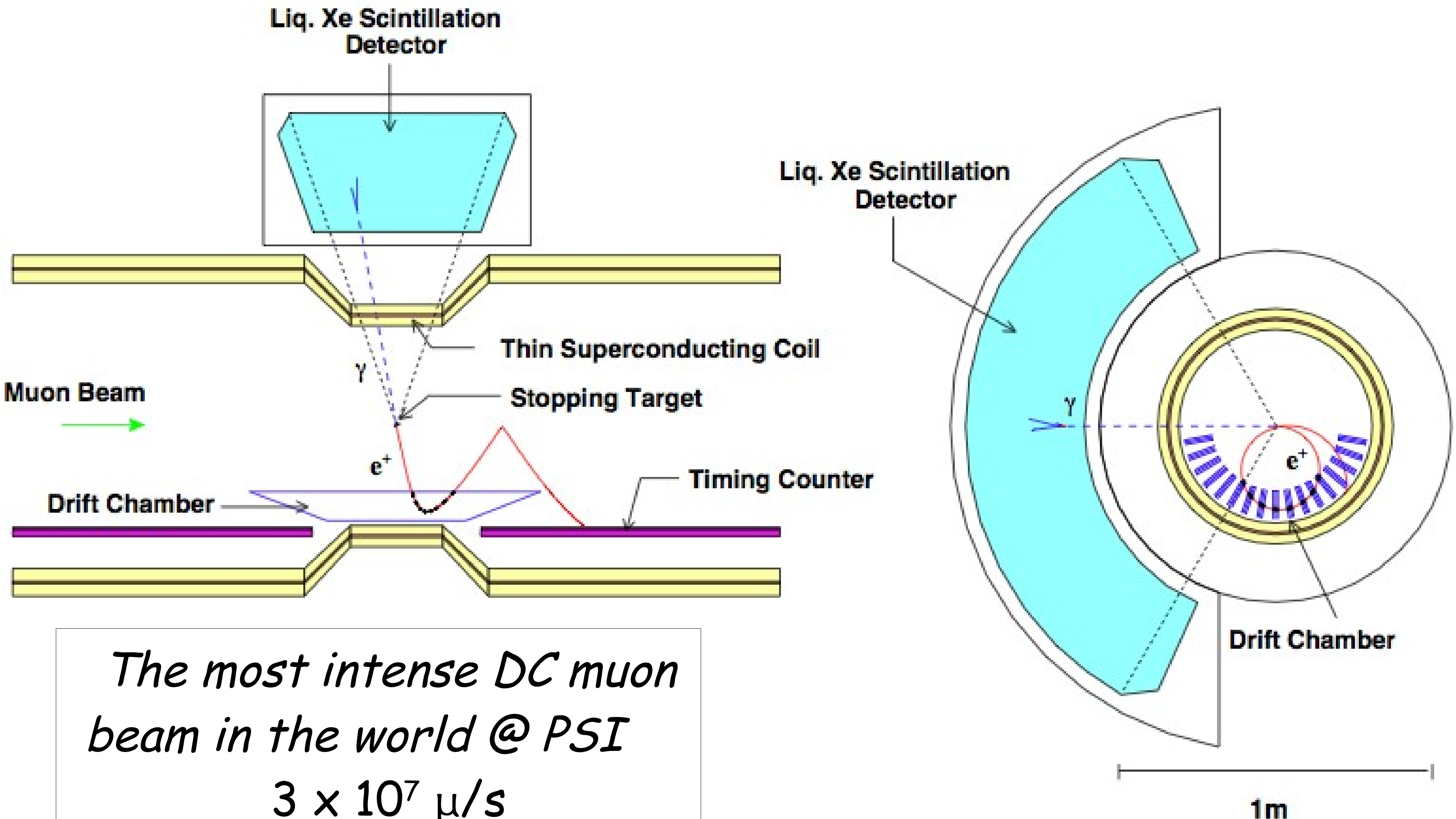
DECAY ∝ μ rate



∝ (μ rate)²



The MEG Experiment

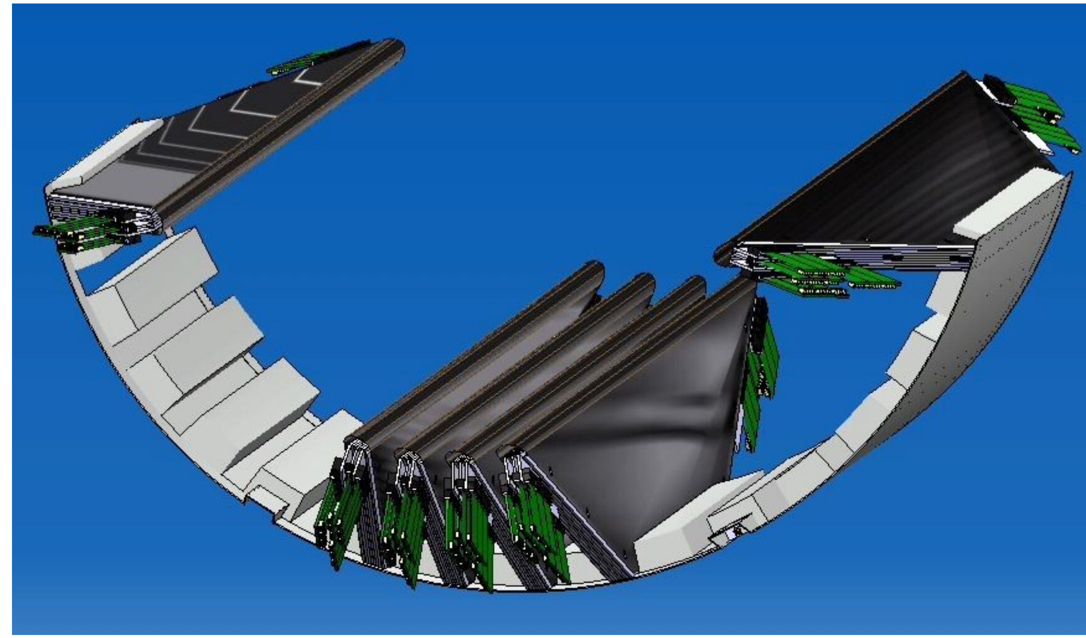


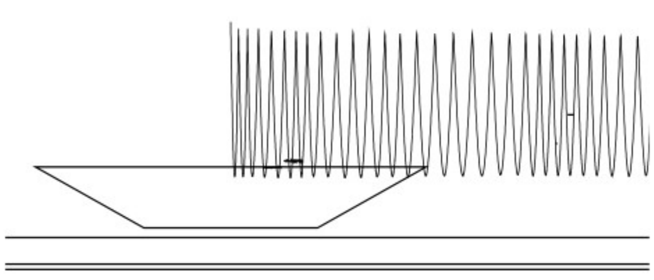
The most intense DC muon beam in the world @ PSI

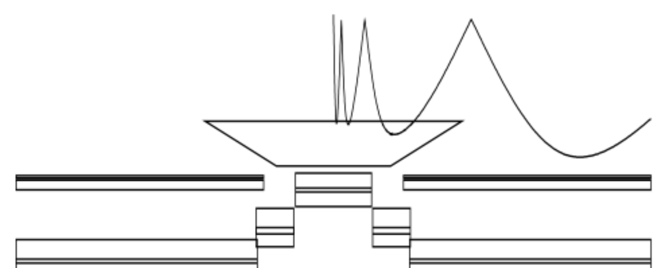
$3 \times 10^7\ \mu/s$

Positron Spectrometer

- 16 low mass drift chambers in a graded magnetic field;
- Goal $\sigma(p) \sim 200$ keV/c;

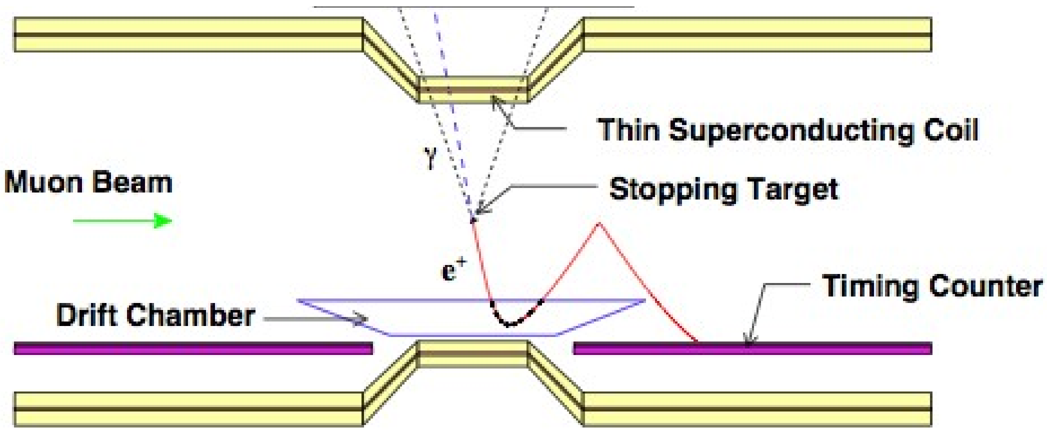


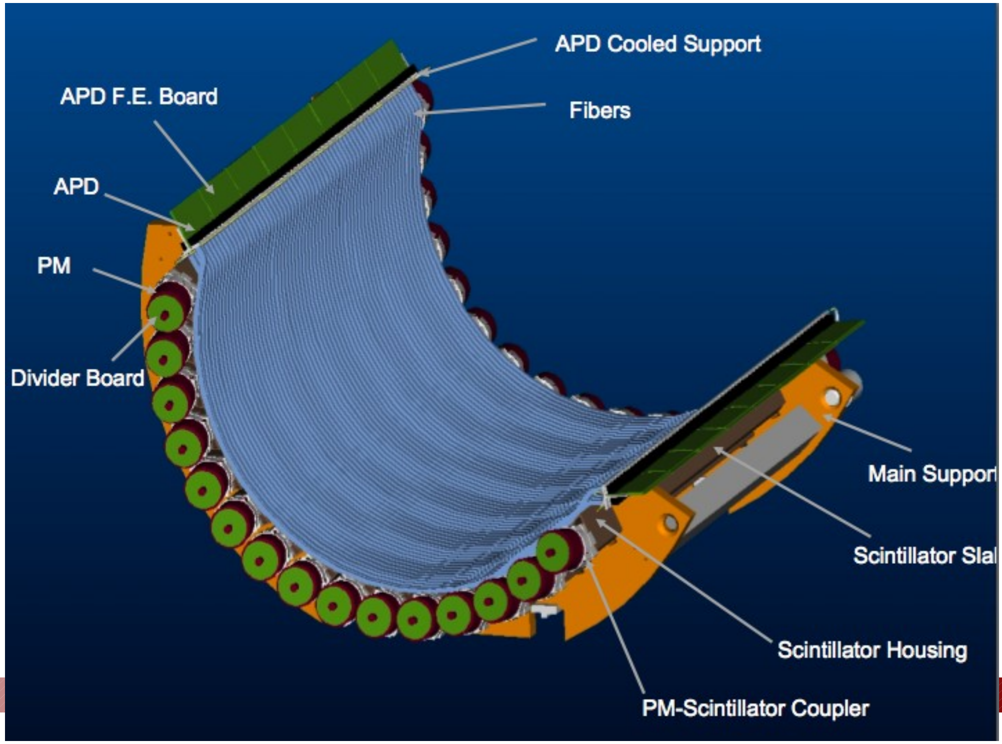




Timing Counter

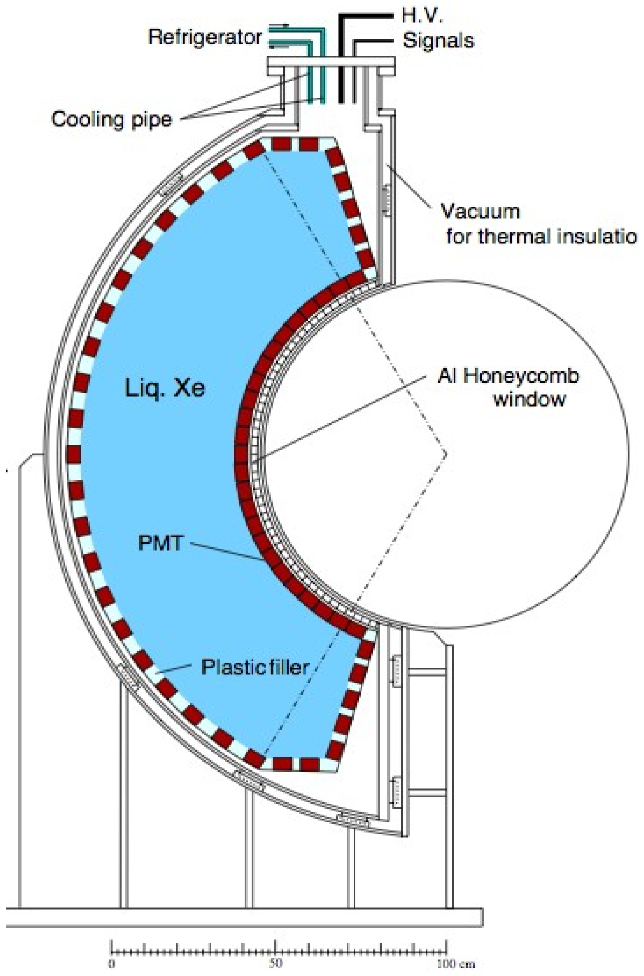
- 2 detectors (upstream & downstream) for precise positron timing and trigger;
- 15 plastic scintillating bars per detector read by PMTs:
  - timing, goal σ(t) ~ 45 ps
  - phi position
- 1 layer of scintillating fibers per detector, read by APDs:
  - z position
  - not yet fully operational





LXe Calorimeter

- The largest LXe calorimeter in the world (800 liters);
- Fast response: τ_{scint} = 45 ns for γ;
- Good light yield:
  - ~ 75% of NaI(Tl);
- Light collected by 846 PMTs;
- Not just a "calorimeter":
  - $\sigma(E)$ ~ 800 keV;
  - $\sigma(\gamma$ conv. point) ~ 2-4 mm;
  - $\sigma(t)$ ~ 65 ps



LXe Calibrations

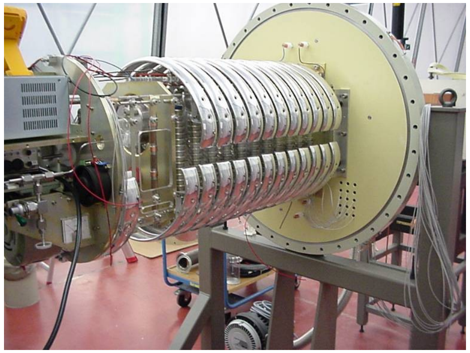
Charge Exchange (CEX)

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

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

high energy photons for XeC energy & relative time calibrations

Cockcroft-Walton accelerator

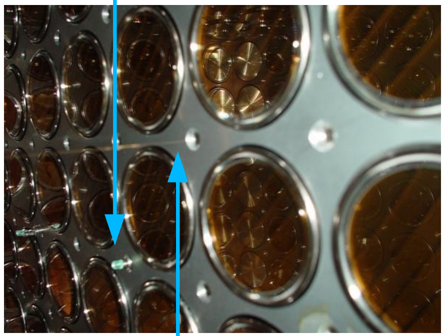


Protons on a Lithium Tetra-borate target

low-energy photons for XeC energy & relative time calibration

LED

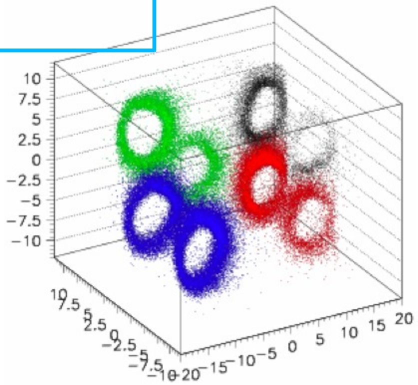
Installed inside the XeC



PMT gain calibration

α sources

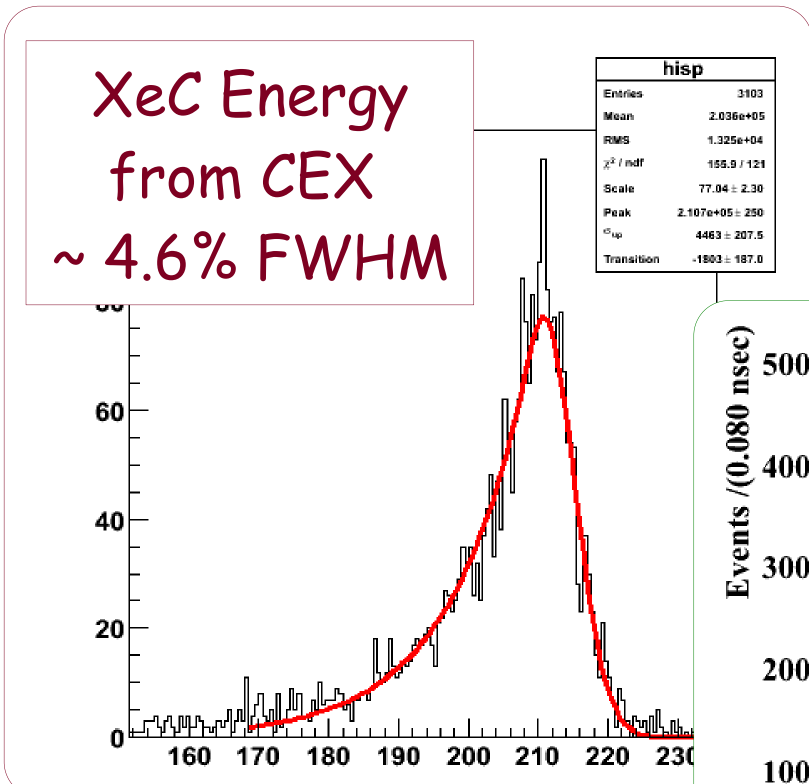
Installed in wires inside the XeC

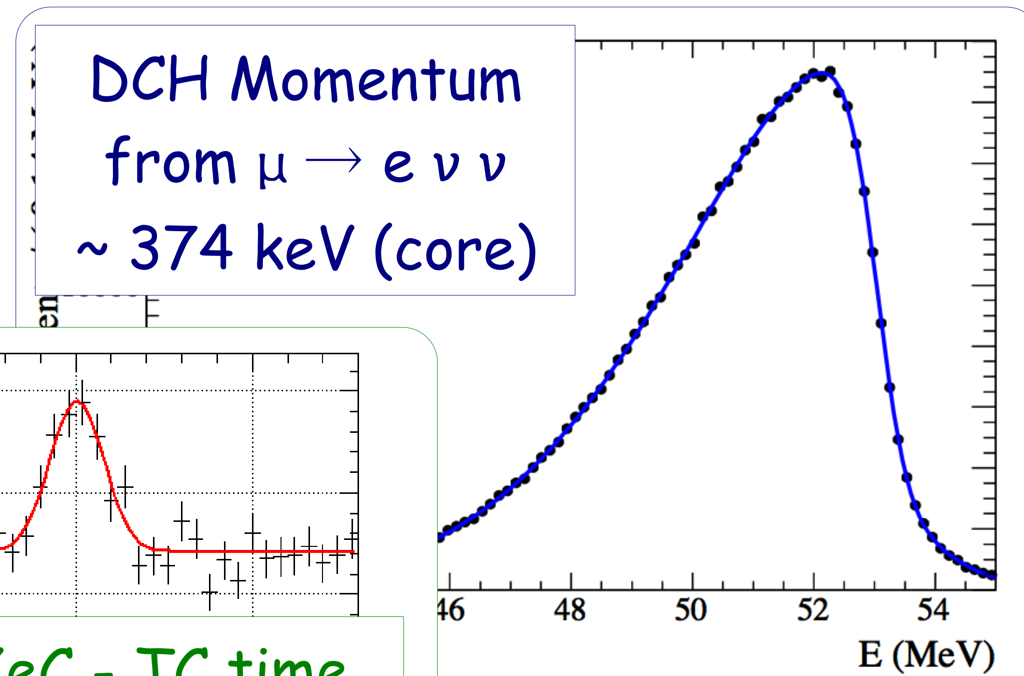


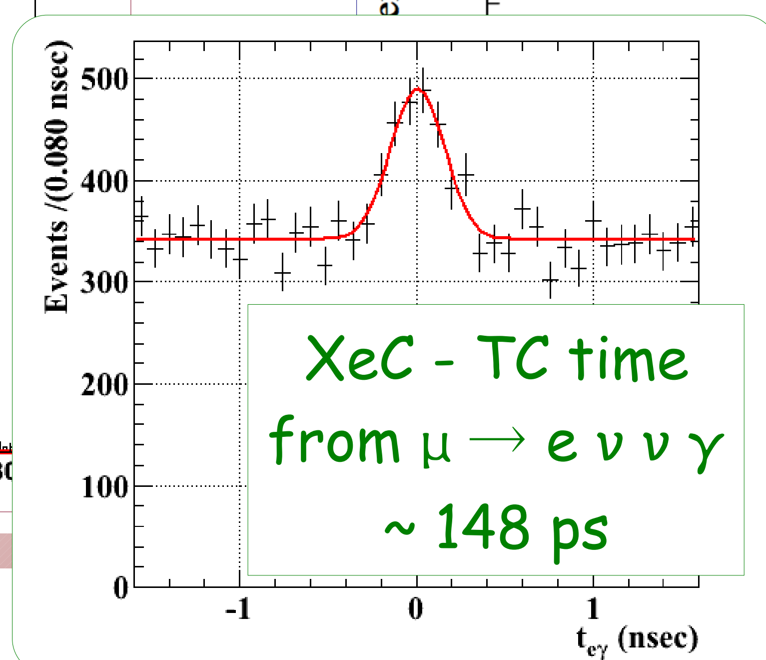
Calibration of Q.E., attenuation length, position

The 2008 Run

- The first physics run, affected by instabilities (frequent DCH trips, LXe purification on going) – solved now!
- Performances not yet at the goal level.



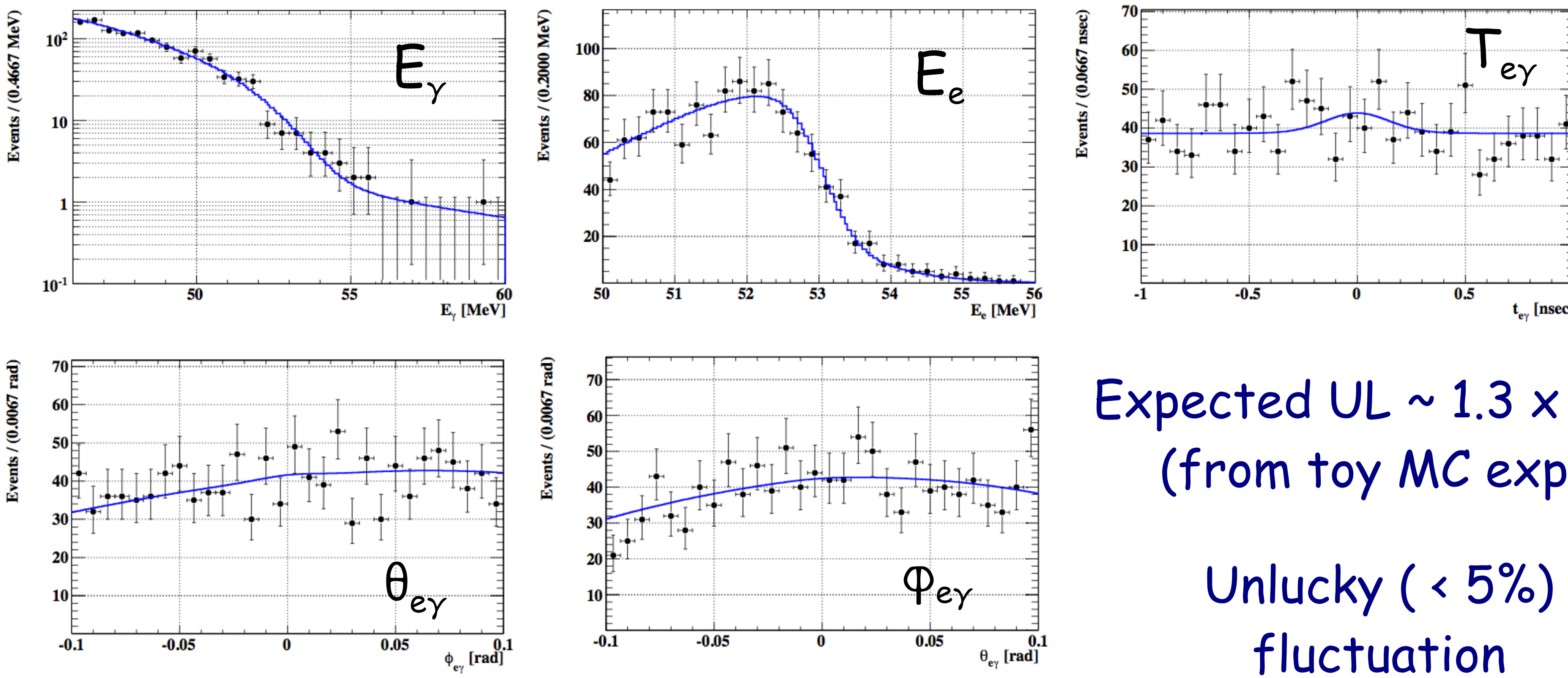




The First Limit

arXiv: 0908.2594

- Extended ML fit including SIGNAL, ACCIDENTAL and RADIATIVE DECAY.



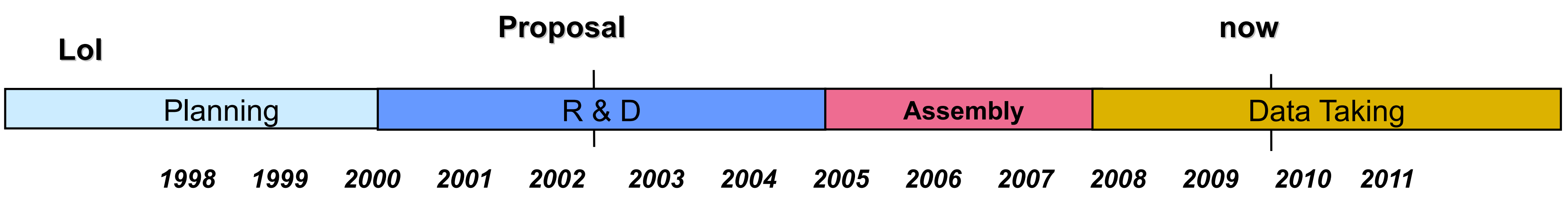
Expected UL ~ 1.3×10^{-11}
(from toy MC exp.)

Unlucky (< 5%) fluctuation

$BR(\mu^+ \to e^+ \gamma) < 2.8 \times 10^{-11}$ @ 90% C.L.
(Feldman-Cousins)

MEG Perspectives

- New data from 2009 run currently analyzed:
  - improved efficiency (factor 3), improved spectrometer resolutions, higher and stable LXe light yield;
  - expected UL ~ 5×10^{-12};
- Continue running in 2010-2011 for the final 10^{-13} goal.



τ LFV at the *B*-Factories

....which are also τ factories

$\sigma(\tau\tau) \sim \sigma(bb) \sim 1$ nb...

τ vs. μ LFV

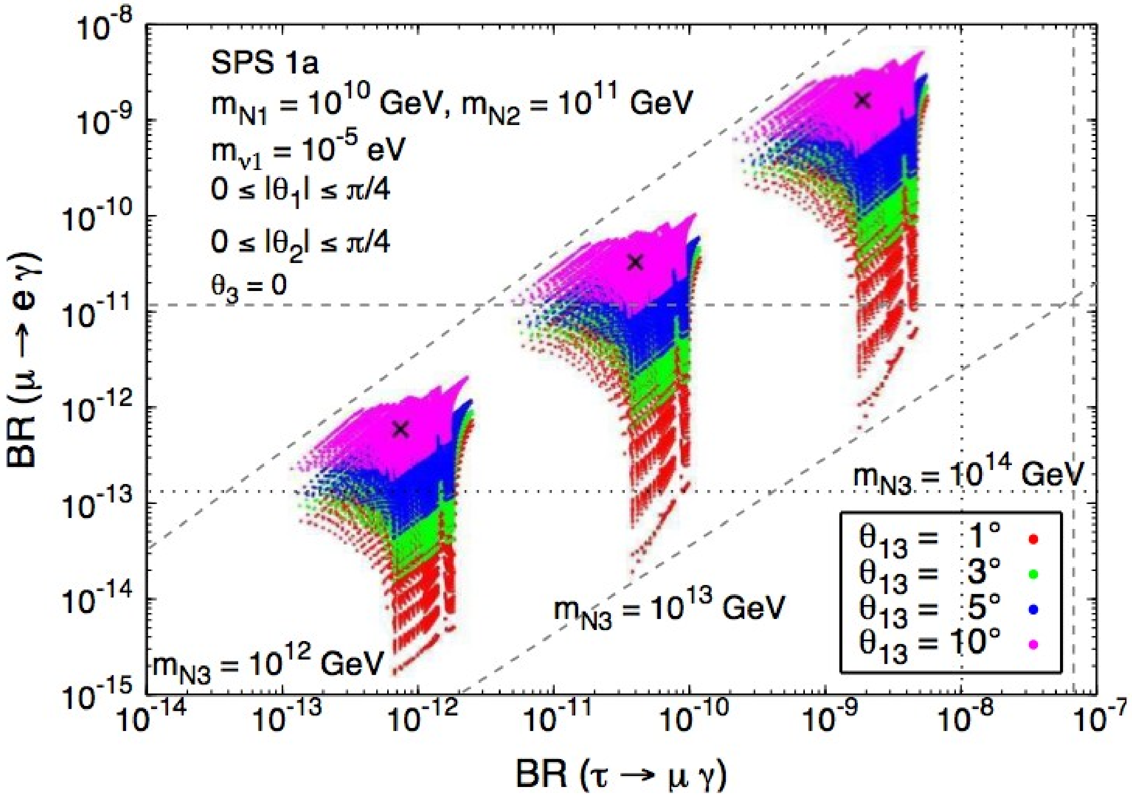
- Different sectors of the NP mixing matrices are investigated → *complementarity*
- Larger BR expected for τ LFV → *needed sensitivity ~ 10^{-8} - 10^{-9}*
- Several possible channels:

τ → l γ

τ → l l l

τ → l h (h = π^0, ω, ρ, ...)

...



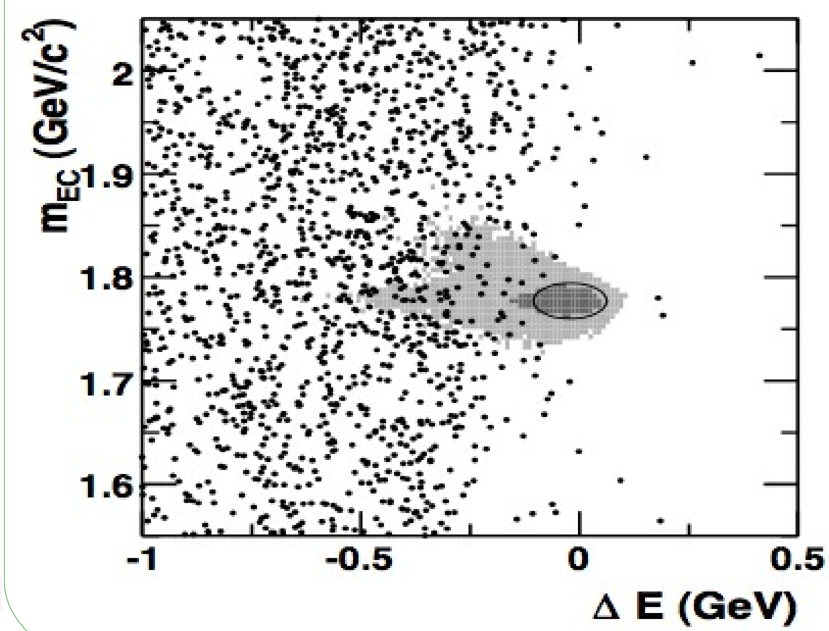
$\tau \to l\,\gamma$

- Require a lepton (muon or electron PID) and a photon;
- Consistency with a τ produced in $e^+e^- \to \tau^+\tau^-$, in terms of:

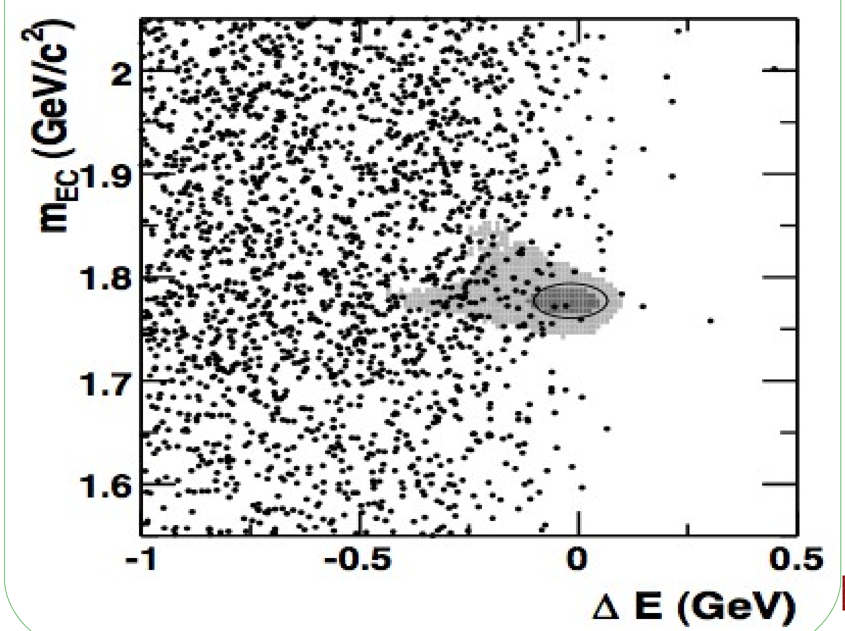
$$M_{EC} = \sqrt{E^{*2}_{beam} - |\mathbf{p}^*_\tau|^2}$$

$$\Delta E = E^*_\tau - E^*_{beam}$$

BR($\tau \to e\,\gamma$) < 3.3×10^{-8}



BR($\tau \to \mu\,\gamma$) < 4.4×10^{-8}

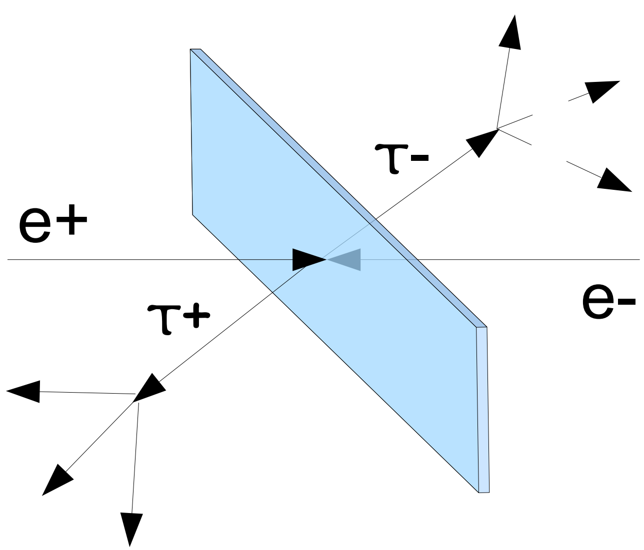


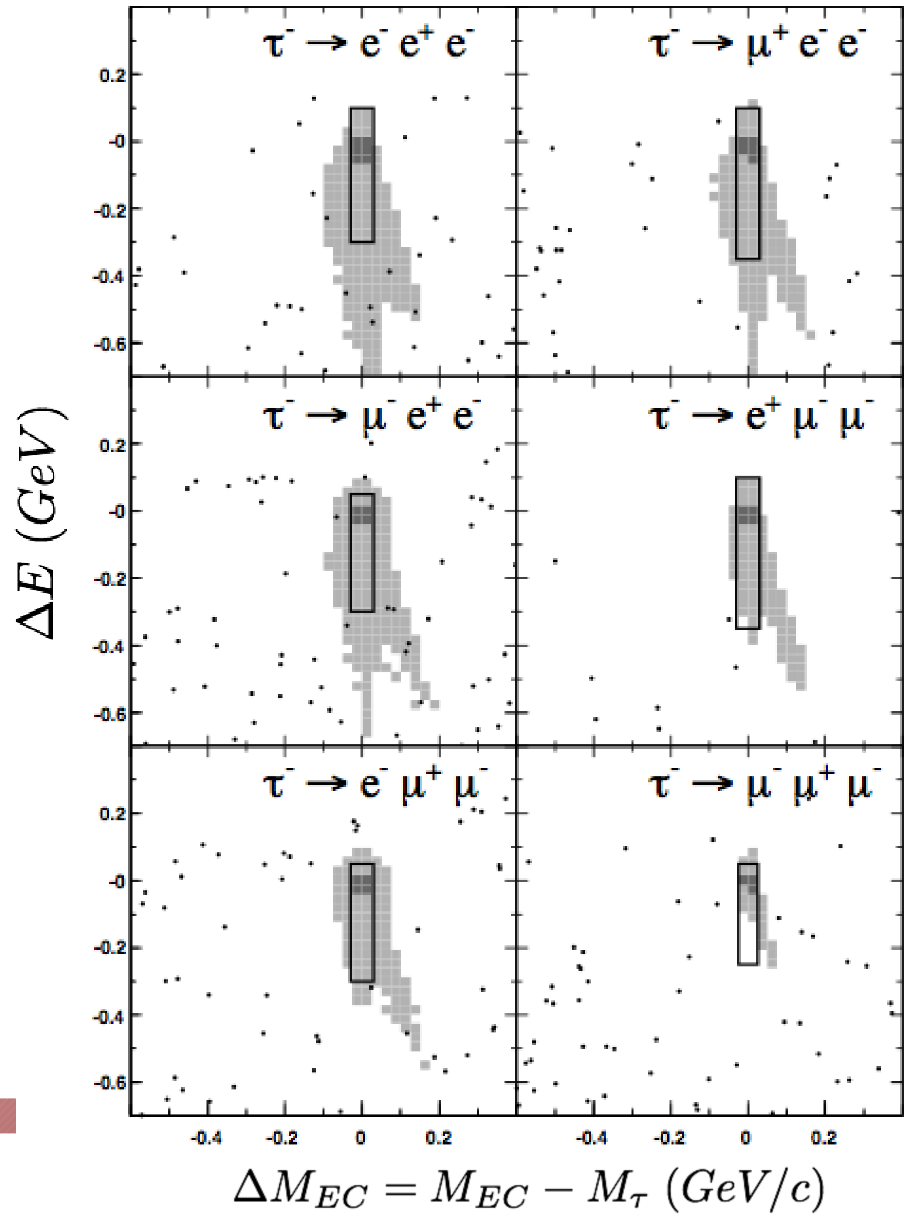
BaBar Collaboration, Phys. Rev. Lett. 104, 021802 (2010)

$\tau^+ \to l^+ l^- l^+$

BaBar Collaboration, arxiv:1002.4550 submitted to PRD-RC

- "1 – 3" topology:
  - 2 hemispheres;
  - 1 track in the tag side;
  - 3 tracks on the signal side;





BaBar vs. Belle

BR($\tau \to \mu\gamma$) < 4.4 x 10^{-8}

BR($\tau \to e\gamma$) < 3.3 x 10^{-8}

BaBar, Phys. Rev. Lett. 104, 021802 (2010)

BaBar, arxiv:1002.4550, UL in 10^{-8}

Mode	Eff. [%]	N_{bgd}	UL_{90}^{exp}	N_{obs}	UL_{90}^{obs}
$e^-e^+e^-$	8.6 ± 0.2	0.12 ± 0.02	3.4	0	2.9
$\mu^-e^+e^-$	8.8 ± 0.5	0.64 ± 0.19	3.7	0	2.2
$\mu^+e^-e^-$	12.7 ± 0.7	0.34 ± 0.12	2.2	0	1.8
$e^+\mu^-\mu^-$	10.2 ± 0.6	0.03 ± 0.02	2.8	0	2.6
$e^-\mu^+\mu^-$	6.4 ± 0.4	0.54 ± 0.14	4.6	0	3.2
$\mu^-\mu^+\mu^-$	6.6 ± 0.6	0.44 ± 0.17	4.0	0	3.3

BR($\tau \to \mu\gamma$) < 4.5 x 10^{-8}

BR($\tau \to e\gamma$) < 12.0 x 10^{-8}

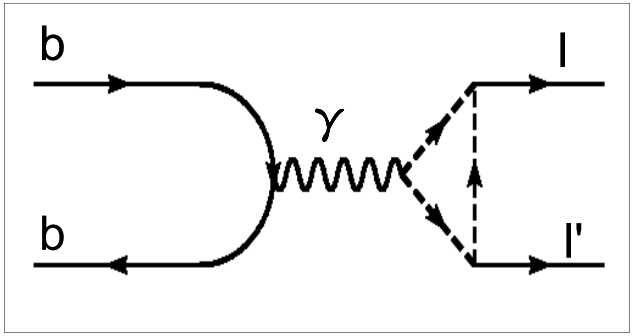
Belle, Phys.Lett.B 666:16-22,2008

Belle, Phys.Lett.B660:154-160,2008

Mode	ε (%)	N_{BG}	σ_{syst} (%)	N_{obs}	s_{90}	$\mathcal{B}(\times 10^{-8})$
$\tau^- \to e^-e^+e^-$	6.00	0.40 ± 0.30	9.8	0	2.10	3.6
$\tau^- \to \mu^-\mu^+\mu^-$	7.64	0.07 ± 0.05	7.4	0	2.41	3.2
$\tau^- \to e^-\mu^+\mu^-$	6.08	0.05 ± 0.03	9.5	0	2.44	4.1
$\tau^- \to \mu^-e^+e^-$	9.29	0.04 ± 0.04	7.8	0	2.43	2.7
$\tau^- \to e^+\mu^-\mu^-$	10.8	0.02 ± 0.02	7.6	0	2.44	2.3
$\tau^- \to \mu^+e^-e^-$	12.5	0.01 ± 0.01	7.7	0	2.46	2.0

LFV in Υ(nS) decays

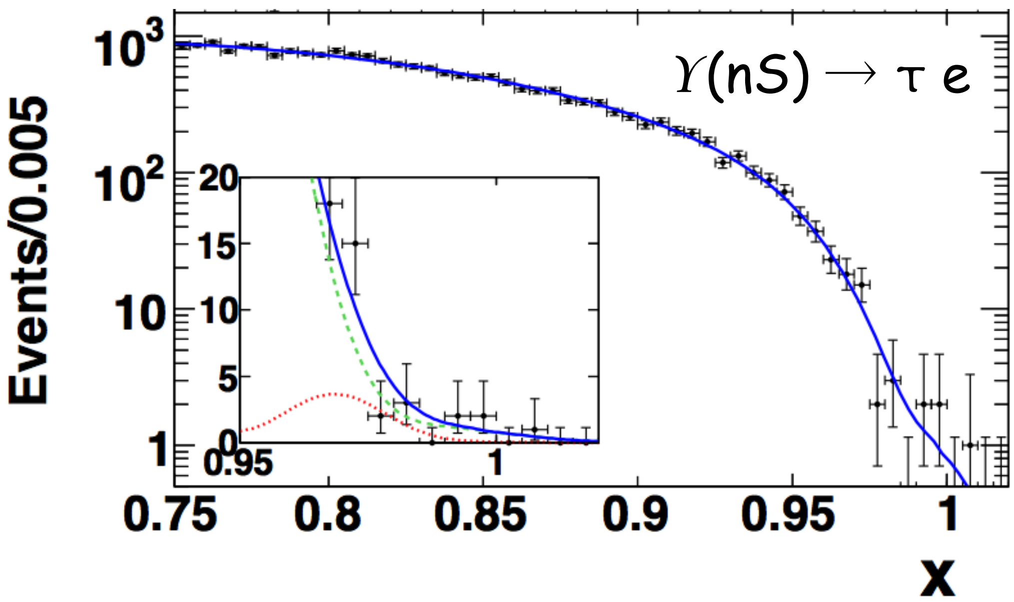
- BaBar collected a large statistics at the $\Upsilon(2S)$ and $\Upsilon(3S)$:
  - Sensitivity to LFV in $\Upsilon(nS) \to l\, l'$:



- Search for $\Upsilon(nS) \to \tau\, e$ and $\Upsilon(nS) \to \tau\, \mu$:
  - 1 high energy primary lepton + 1 track from τ decay;
  - Fit to $x = p^*_l / E^*_{beam}$.

BaBar Collaboration, arXiv:1001.1883

	$\mathcal{B}\ (10^{-6})$	UL (10^{-6})
$\mathcal{B}(\Upsilon(2S) \to e^\pm \tau^\mp)$	$0.6^{+1.5+0.5}_{-1.4-0.6}$	< 3.2
$\mathcal{B}(\Upsilon(2S) \to \mu^\pm \tau^\mp)$	$0.2^{+1.5+1.0}_{-1.3-1.2}$	< 3.3
$\mathcal{B}(\Upsilon(3S) \to e^\pm \tau^\mp)$	$1.8^{+1.7+0.8}_{-1.4-0.7}$	< 4.2
$\mathcal{B}(\Upsilon(3S) \to \mu^\pm \tau^\mp)$	$-0.8^{+1.5+1.4}_{-1.5-1.3}$	< 3.1



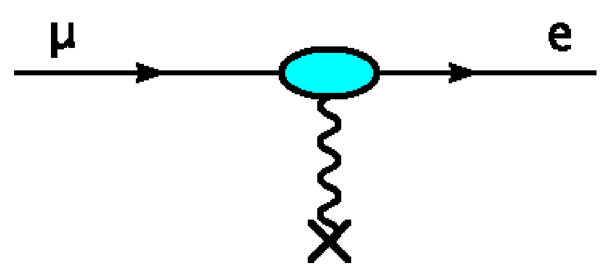
Perspectives at SuperB

- Integrated luminosity (L) of 75 ab^{-1} ~ 150 x BaBar;
- Background-dominated channels ($\tau \to \mu\, \gamma$):
  - the limit scale with 1/sqrt(L);
- If the background can be kept below ~ 1 event ($\tau \to l\, l\, l$):
  - the limit scale with 1/L;
- Moreover:
  - smaller beam size (stronger topological constraints);
  - lower boost (larger acceptance);
  - possible beam polarization;

Process	Expected 90% CL upper limit
$\mathcal{B}(\tau \to \mu\,\gamma)$	2.1×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2.7×10^{-9}
$\mathcal{B}(\tau \to \ell\ell\ell)$	$2.3–8.3 \times 10^{-10}$

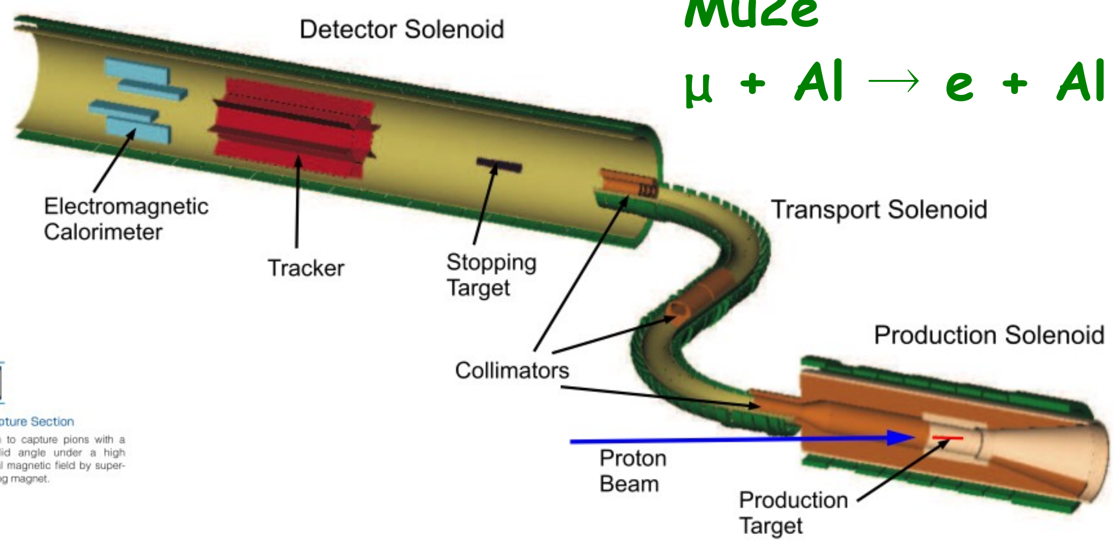
Other Perspectives

- Best sensitivity to NP scenarios could be reached in the searches for $\mu \to e$ *conversion in nuclei*



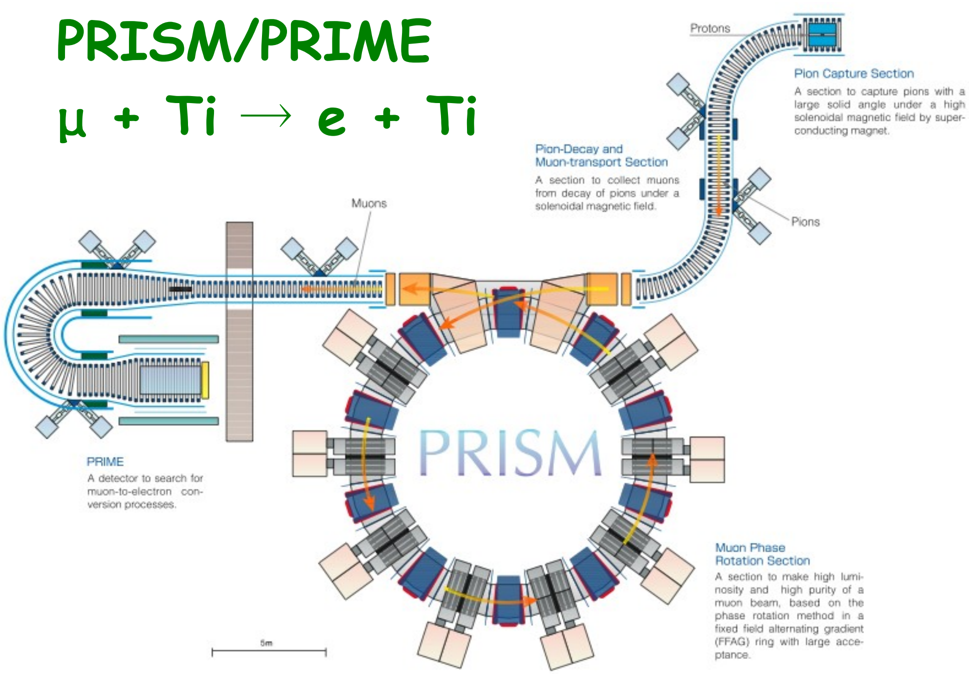
Mu2e

$\mu + Al \to e + Al$



PRISM/PRIME

$\mu + Ti \to e + Ti$



$$BR(\mu^- N \to e^- N) = \frac{\Gamma(\mu^- N \to e^- N)}{\Gamma(\mu^- N \to \nu N')}$$

SENSITIVITY ~ 10^{-17} - 10^{-19}

Conclusions

- The search for LFV is one of the main challenges of particle physics;
- An observation of LFV for charged leptons would be an unambiguous evidence of New Physics;
- μ and τ sectors provide complementary information;
- LFV searches complementary to direct NP searches at LHC;
- Main programs:
  - $\mu \rightarrow e \gamma$ at MEG;
  - τ LFV at the (Super)B-Factories;
  - $\mu \rightarrow e$ conversion in nuclei;

} *Indirect sensitivity to the TeV scale*

Backup

LFV in Υ(nS) decays

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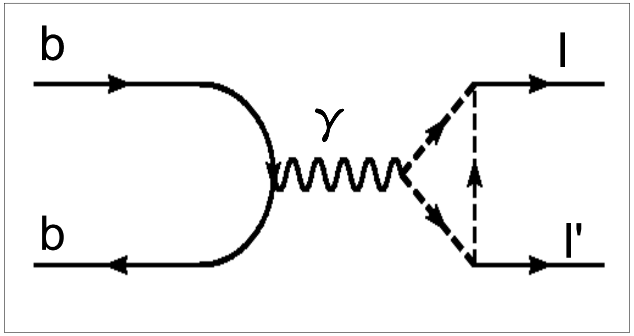

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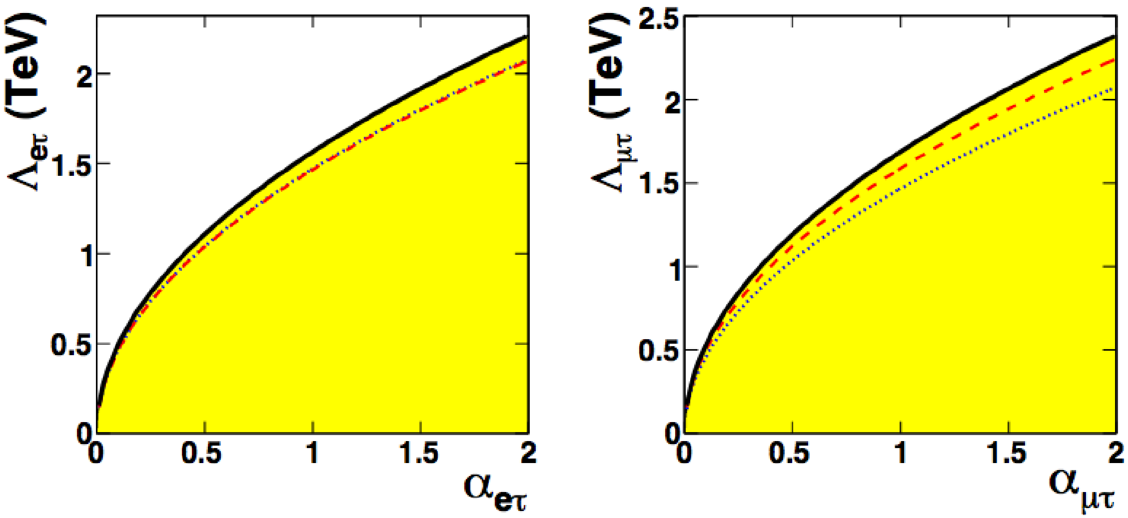
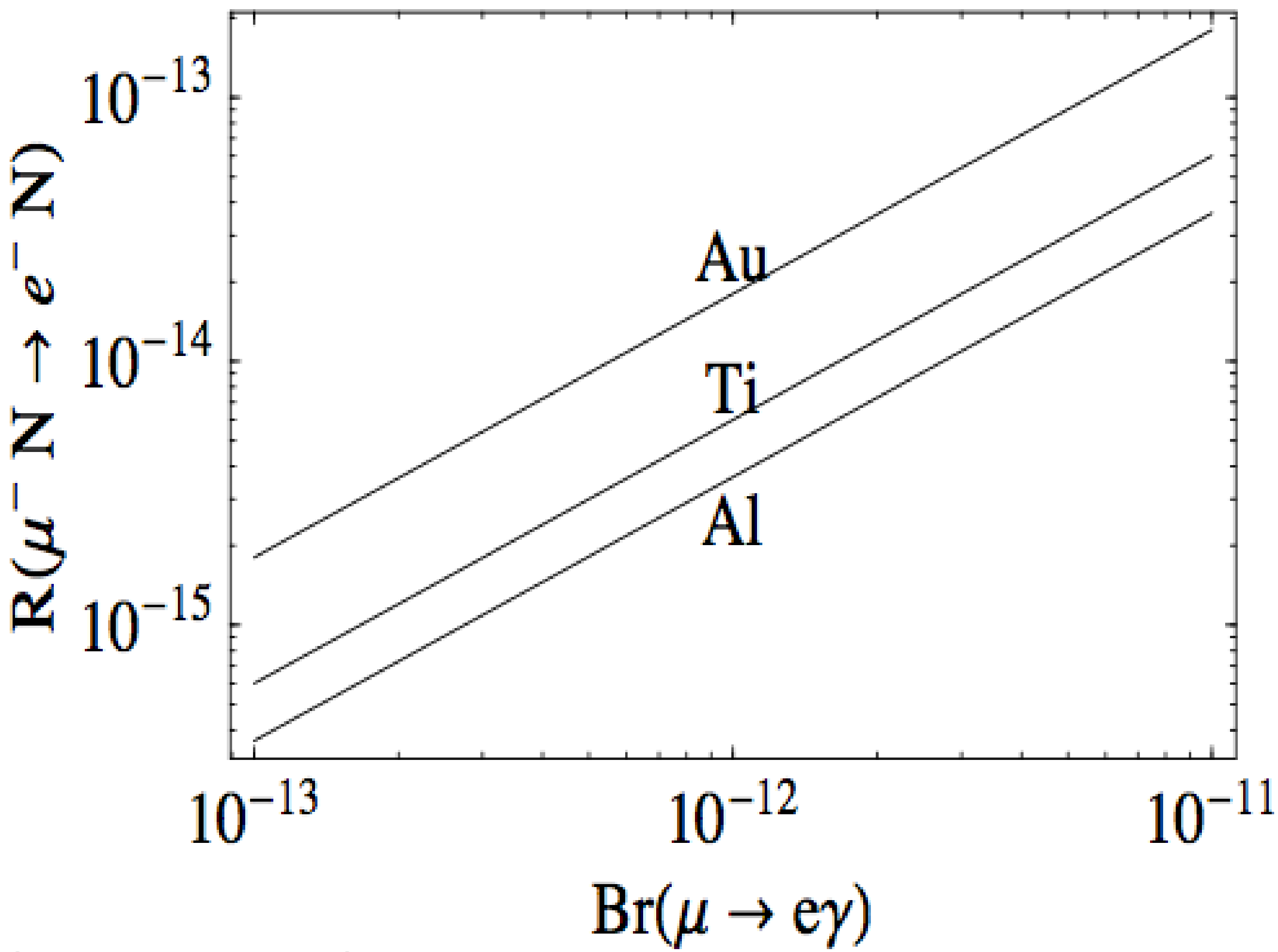


$\mu \to$ e conversion vs. $\mu \to e\gamma$

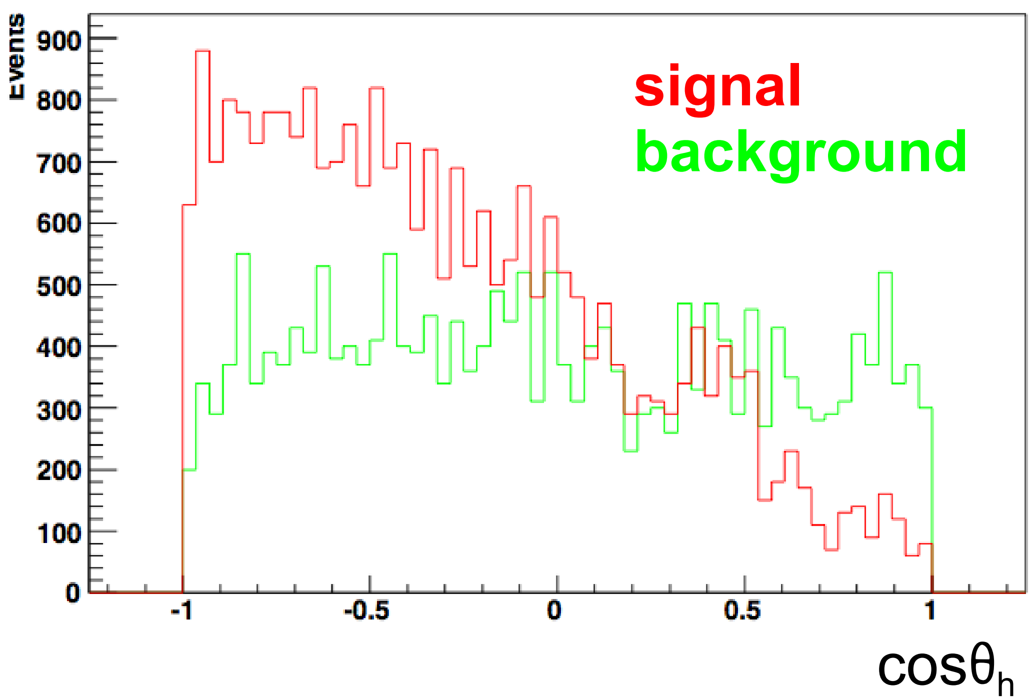


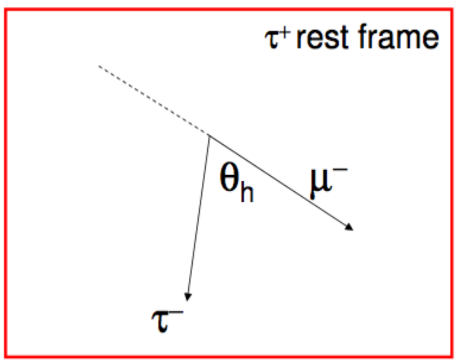
INVERSE SEESAW MODEL

Deppisch et al., Nucl.Phys.B752:80-92,2006

Beam Polarization

- Beam polarization modifies the angular distributions of signal and background in τ decays;
- Angular distributions can become discriminating $\rightarrow$ bkg. suppression.





helicity angle for muons emitted in the forward region