Search for Lepton Flavour Violation in the decay

$\tau \longrightarrow \mu\gamma$

@ BaBar

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Outline

- Theoretical Motivations
- The BaBar Detector
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- Cut-Based Event Selection
- Likelihood Approach and Neural Network Method
- Results and Statistical Interpretation
- Conclusions

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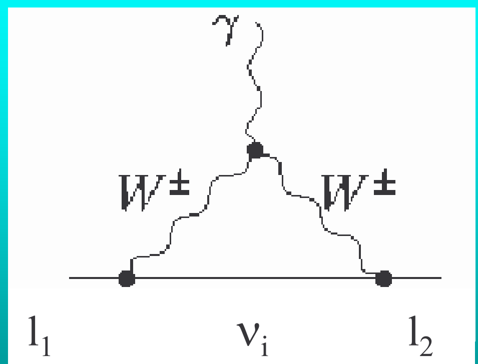
Theoretical Motivations (1)

- Lepton Flavour Violation observed in athmosferic and solar neutrino oscillations
- LFV processes in the charged lepton sector predicted within Standard Model scenario extended to include finite m_ν

lepton-neutrino couplings

$$BR(l_1 \to l_2\gamma) \propto \sum_i V^*_{l_1 i} V_{l_2 i} \left(\frac{m^2_{\nu_i}}{m^2_W}\right)^2$$



strongly suppressed because of $m_{\nu_i} \sim eV$

$$BR(\mu \to e\gamma) \approx O(10^{-50})$$

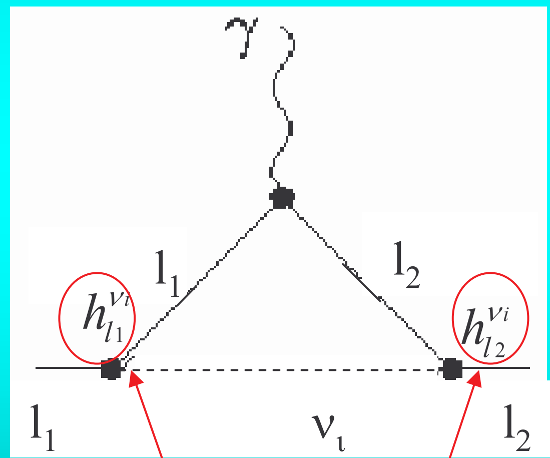
$$BR(\tau \to \mu\gamma) \approx O(10^{-39} \div 10^{-40})$$

Theoretical Motivations (2)

- LFV processes with higher $\mathcal{BR}$ evidence of physics beyond SM
- Prediction of $\mathcal{BR}(\tau \to \mu\gamma) \approx O(10^{-8} - 10^{-10})$ in many SUSY models
- Within SUSY SU(10) Right Handed ν model:

$$\mathcal{BR}(l_1 \to l_2\gamma) \propto \frac{([m^2_{\tilde{L}}]_{ij})^2}{m^8_{SUSY}} \cdot \tan^2\beta$$

(depending on model parameters)



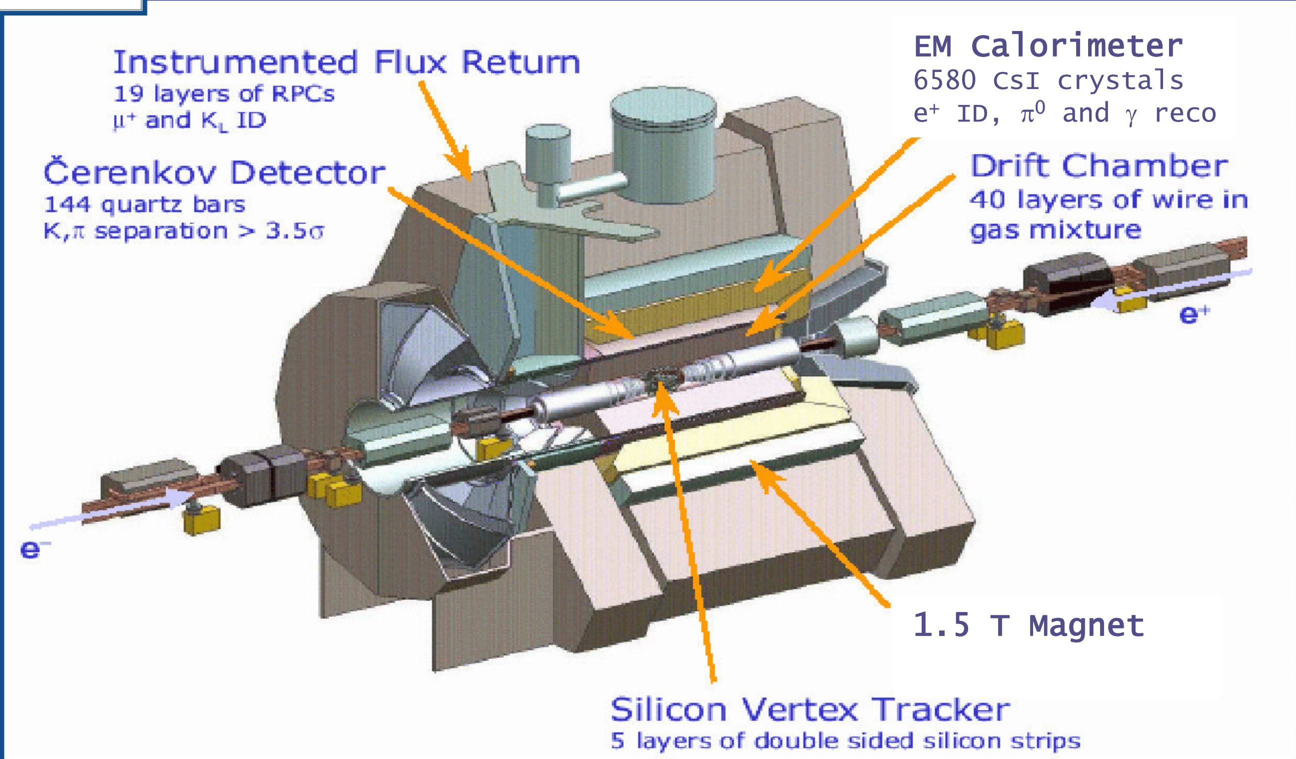
ν_Yukawa coupling of the order of top_Yukawa coupling

- Predictions with
  - $2 \le \tan\beta \le 4$
  - $90\ \text{GeV} \le m_0 \le 900\ \text{GeV}$
  - $90\ \text{GeV} \le M_{1/2} \le 700\ \text{GeV}$

$$\mathcal{BR}(\mu \to e\gamma) \approx O(10^{-14})$$
$$\mathcal{BR}(\tau \to \mu\gamma) \approx O(10^{-8})$$

BaBar Detector

- *B-factory*: pairs of mesons are produced almost at rest in the CM frame from: $\Upsilon(4S) \rightarrow B^+B^-, B^0\bar{B}^0$
- *Asymmetrical*: the CM is boosted forward by $\beta\gamma \sim 0.55$



Sample

- 229.4 fb^{-1} data collected by BaBar
- center of mass energy ≈ 10.5 GeV
- $\sigma(e^+e^- \to \tau^+\tau^-) \approx 0.89$ nb, similar to $\sigma(e^+e^- \to b\bar{b})$
- ~ 360M τ-pairs

Signal events:

$e^+e^- \to \tau^+\tau^-$ with $\tau \to \mu\gamma$

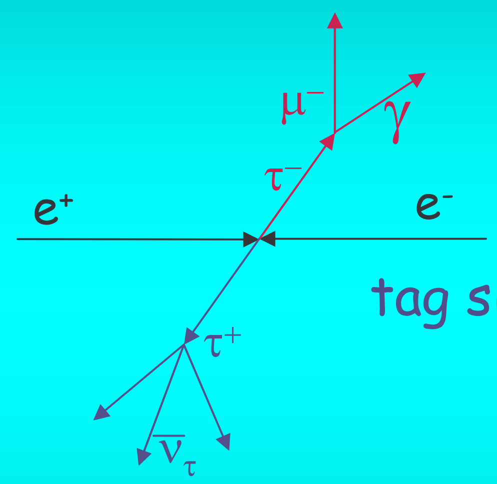
- IFR-identified μ
- EMC-reconstructed γ or reconstructed $\gamma \to e^+e^-$ (converted γ)

Main **background sources**:

- $e^+e^- \to \tau^+\tau^-$ with $\tau \to$ anything else
- $e^+e^- \to \mu^+\mu^-\gamma$
- $e^+e^- \to q\bar{q}$
- $e^+e^- \to e^+e^-$
- $e^+e^- \to B^+\underline{B}^-$
- $e^+e^- \to B^0\bar{B}^0$

Cut-Based Events Selection

signal side

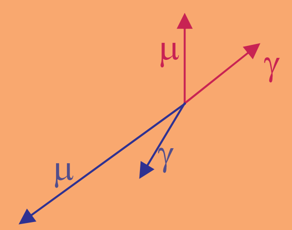


tag side

- Charged track:
  - none of the BaBar e-Id selectors allowed
- Neutral cluster:
  - Photon-quality cuts and π^0 veto for EMC reconstructed γ
  - Photon invariant mass and opening angle cuts for converted γ

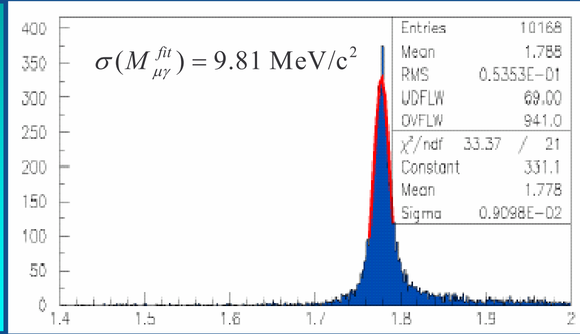
- 1-1 topology:
  - 1 charged track not identified as μ
- 3-1 topology:
  - 3 charged tracks
- $M_{recoil} < 2$ GeV/c^2, $|\cos\theta^{CM}_{miss}| < 0.95$, $p_T{}^{CM}_{miss} > 300$MeV/c

- Preliminary cuts on $|M^{inv}_{\mu\gamma} - m_\tau|$, $\Delta E \equiv \sqrt{s}/2 - E^{cm}_{\mu\gamma}$, $\cos\theta^{cm}_{\mu\gamma}$
- Rejection of "fake missing momentum event" ($e^+e^- \to \mu^+\mu^-(n)\gamma$):
  - $E_{EMC\ cluster} > 1$ GeV
  - $\#_{IFR\ hit\ layers} > 5$



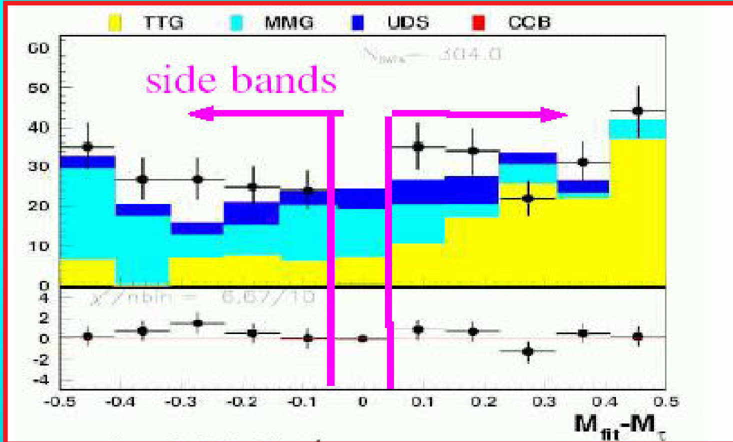
Kinematic Fit and Final Selection

- Kinematic Fit in order to remove background and improve mass resolution
- two constraints:
  - $\mu\gamma$ vertex
  - beam energy
- cut on distribution of χ^2 variable



- Final Selection: cuts optimization to improve the ratio $\frac{\text{Signal efficiency}}{\sqrt{\text{SideBandBackground}}}$

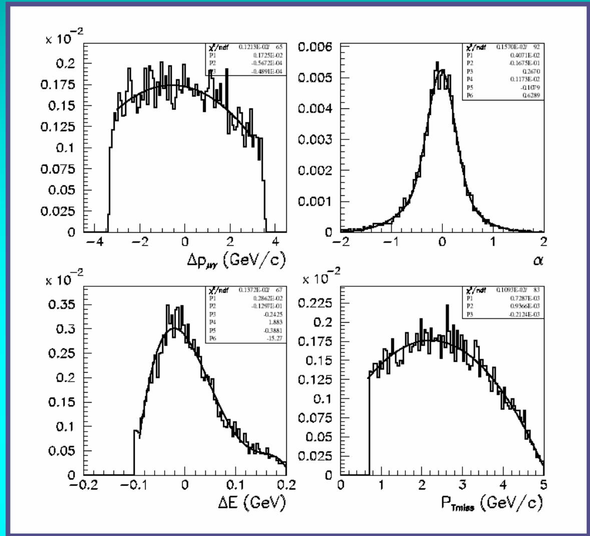
	1-1 topology	3-1 topology
CM μ momentunm	0.9 - 4.5 GeV/c	1.1-4.5 GeV/c
Minimum CM γ energy	0.9 GeV	0.9 GeV
minimum $p_{T\,CM}^{miss}$	1.2 GeV/c	0.6 GeV/c
$\cos\theta_{CM}^{miss}$	-0.85 - 0.75	-0.90 - 0.80
maximum M_{recoil}	1.65 GeV/c^2	1.75 GeV/c^2
ΔE	-0.06 - 0.10 GeV	-0.09 - 0.08 GeV
$M_{\mu\gamma}^{fit}$ window	$\pm 2.0\,\sigma(M_{\mu\gamma}^{fit})$	$\pm 2.0\,\sigma(M_{\mu\gamma}^{fit})$



- Efficiency = $(8.46 \pm 0.85)\%$
- Background events:
  - expected 11.10 ± 1.15
  - observed 12 ($11_{1-1}, 1_{3-1}$)

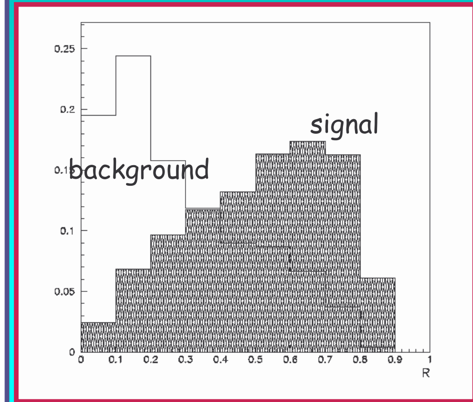
Likelihood method

- Four variables chosen:
  - ΔE
  - $p_{T\,miss}^{CM}$
  - $\alpha \equiv \phi_{\mu\gamma} - \phi_{tag} - \pi$
  - $\Delta p_{\mu\gamma}^{CM} \equiv |p_{\mu}^{CM}| - |p_{\gamma}^{CM}|$



to set up a likelihood ratio variable ($\mathcal{R}$) defined as :

$$\mathcal{R} = \frac{\prod_i P_i^{sig}(x_i)}{\prod_i P_i^{sig}(x_i) + \prod_i P_i^{bkgd}(x_i)}$$



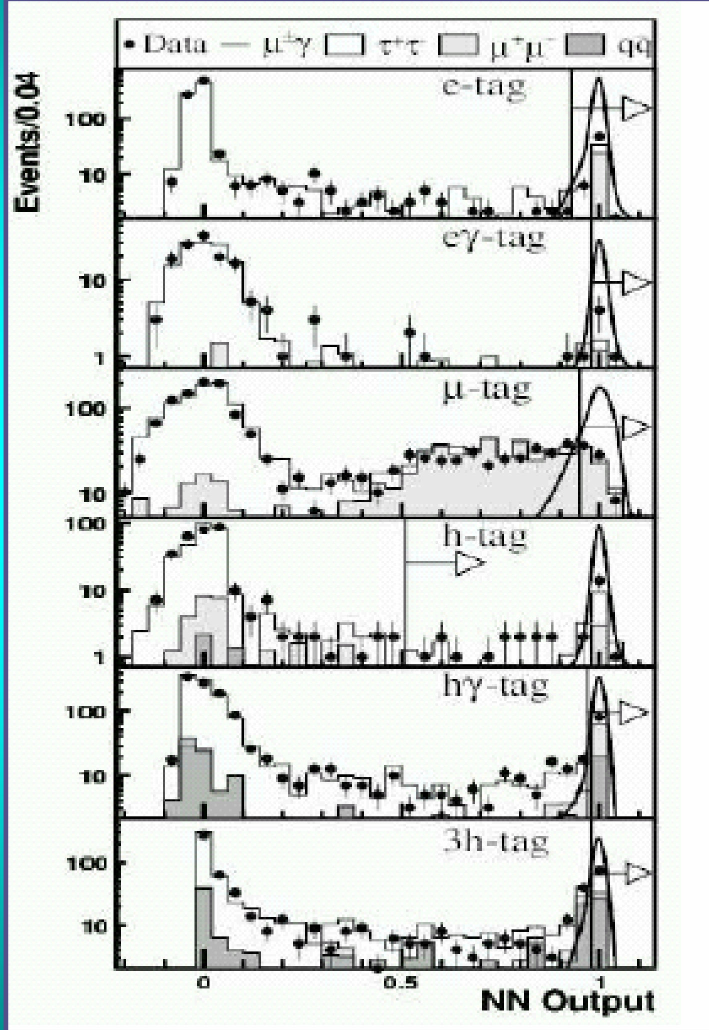
- Number of events determined from an Unbinned Maximum Likelihood fit to the variables:
  - $M_{\mu\gamma}^{fit}$, $\mathcal{R}$ for topology 1-1
  - $M_{\mu\gamma}^{fit}$ for topology 3-1

$\Rightarrow$

- Efficiency = 10.71%
- Background events:
  - expected 28.5 ± 2.3
  - observed 27 (26_{1-1},1_{3-1})

Neural Network approach

- 5 discriminant variables as inputs for NN:
  - M_{miss}
  - p_{CM}^{tag}
  - $\cos\theta_{H_T}$
  - p_{miss}
  - m_ν^2
- Different selection criteria for different tag modes:
  - $\tau_{tag} \to e\nu\nu$
  - $\tau_{tag} \to e\gamma\nu\nu$
  - $\tau_{tag} \to \mu\gamma\gamma$
  - $\tau_{tag} \to h\nu$
  - $\tau_{tag} \to h{\geq}1\pi^0\nu$
  - $\tau_{tag} \to 3h{\geq}\pi^0\nu$
- Unbinned Maximum Likelihood Fit to $M_{\mu\gamma}^{fit}$



- Efficiency = (7.42±0.65)%
- Background events:
  - expected 6.2 ± 0.5
  - observed 4

Results and Statistical Interpretation

Likelihood Method

- Definition of a test-statistic variable:

$$Q = \frac{\mathcal{L}(S+B)}{\mathcal{L}(B)}$$

- Evaluation of Q in binned 2-dimension $M_{\mu\gamma}^{fit}$ vs $\mathcal{R}$ plane
- Measurement of Q_{obs} on the data sample
- Generation of toy *MC* experiments with an arbitrary value, N'_{signal}, of signal events
- Evaluation of:
  - $CL_{S+B}=P_{S+B}(Q<Q_{obs})$ **(pure frequentist method)**
  - $CL_B=P_B(Q<Q_{obs})$
  - $CL_S=CL_{S+B}/CL_B$ **(modified frequentist method)**
- Iterating by varying N'_{signal} till $1-CL_S$ is 90%

	Sensitivity	Upper Limit
CL_{S+B}	11.9×10^{-8}	9.4×10^{-8}
CL_S	16.1×10^{-8}	14.6×10^{-8}

Neural Network Method

- Generation of 10k toy *MC* with Poisson-distributed number of background (fixed) and segnal events (s,floating)
- Iterating by varying s till fitted number of signal events greater than that observed

# of signal events	Sensitivity	Upper Limit
$-2.2^{+3.2}_{-2.4}$	13×10^{-8}	6.8×10^{-8}

Conclusions

- 229.4 fb^{-1} data analyzed
- Cut Based Selection +
  - Neural Network approach
  - Likelihood method
- Upper Limit @ 90% CL:

$$\mathcal{BR}(\tau \rightarrow \mu\gamma) < 6.8 \times 10^{-8}$$

- Improvement with respect to previous measurements
- Some SUSY scenarios excluded by this measurement