Search for Lepton Flavor Violation in Tau Decays at BABAR

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- Introduction
- BABAR Detector
- Search for $\tau \rightarrow lll$
- Search for $\tau \rightarrow \mu\gamma$
Lepton Flavor Violating (LFV) tau decays are forbidden in the classical Standard Model; are allowed but very small in SM with neutrino mixing; are very sensitive to non-SM physics.

The limits on LFV before BABAR/Belle:
- $\mathcal{B}(\tau \to \mu \gamma) < 1.1 \times 10^{-6}$ at 90% CL [CLEO, 13.8 fb$^{-1}$]
- $\mathcal{B}(\tau \to \mu\mu\mu) < 1.9 \times 10^{-6}$ at 90% CL [CLEO, 4.8 fb$^{-1}$]
<table>
<thead>
<tr>
<th>Model</th>
<th>$\tau \rightarrow \ell\gamma$</th>
<th>$\tau \rightarrow \ell\ell\ell$</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM + lepton CKM</td>
<td>$10^{-40}$</td>
<td>$10^{-14}$</td>
<td>hep-ph/9810484</td>
</tr>
<tr>
<td>SM + left-h. heavy Dirac neutrino</td>
<td>$&lt; 10^{-18}$</td>
<td>$&lt; 10^{-18}$</td>
<td>SJNP25(1977)340</td>
</tr>
<tr>
<td>SM + right-h. heavy Majorana neutrino</td>
<td>$&lt; 10^{-9}$</td>
<td>$&lt; 10^{-10}$</td>
<td>PRD66(2002)034008</td>
</tr>
<tr>
<td>SM + left and right-h. neutral singlets</td>
<td>$10^{-8}$</td>
<td>$10^{-9}$</td>
<td>PRD66(2002)034008</td>
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<tr>
<td>MSSM + right-h. heavy Majorana neutrino</td>
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<td>$10^{-9}$</td>
<td>hep-ph/0306195</td>
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<tr>
<td>MSSM + seesaw</td>
<td>$10^{-7}$</td>
<td></td>
<td>hep-ph/0206110</td>
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<tr>
<td>left-right SUSY</td>
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<td>$10^{-10}$</td>
<td>hep-ph/0306195</td>
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<tr>
<td>SUSY SO(10)</td>
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<td>hep-ph/0209303</td>
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<td>SUSY-GUT</td>
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<td></td>
<td>hep-ph/0307393</td>
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<tr>
<td>SUSY + neutral Higgs</td>
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<td>$10^{-10} - 10^{-7}$</td>
<td>hep-ph/0304081</td>
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<td>SUSY + Higgs triplet</td>
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<td>hep-ph/0209170</td>
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<td>gauge mediated SUSY breaking</td>
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<td>hep-ph/0310148</td>
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<tr>
<td>MSSM+universal soft SUSY breaking</td>
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<td>$10^{-9}$</td>
<td>hep-ph/9911459</td>
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<tr>
<td>MSSM+nonuniversal soft SUSY breaking</td>
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<td>$10^{-6}$</td>
<td>hep-ph/0305290</td>
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<tr>
<td>Non universal $Z'$ (technicolor)</td>
<td>$10^{-9}$</td>
<td>$10^{-8}$</td>
<td>PLB547(2002)252</td>
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<tr>
<td>two Higgs doublet III</td>
<td>$10^{-15}$</td>
<td>$10^{-17}$</td>
<td>hep-ph/0208117</td>
</tr>
<tr>
<td>seesaw with extra dimensions</td>
<td>$10^{-11}$</td>
<td></td>
<td>hep-ph/0210021</td>
</tr>
</tbody>
</table>

See also E. Ma hep-ph/0209170 for a review

(Some of the numbers are guesses on base on given publication. For precise information, please, consult the reference)
244 fb\(^{-1}\) recorded, more data on its way
\[ \sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.89 \text{ nb} \]
Almost 220 millions \(\tau^+\tau^-\) events!
Results shown today use \(\sim 90 \text{ fb}^{-1}\)
Search for $\tau \to \ell\ell\ell$ decay

- One prong on the tag side ($\pi\nu_\tau$, $\rho\nu_\tau$, $e\nu_e\nu_\tau$, $\mu\nu_\mu\nu_\tau$, ..) $\sim 85\%$
- Three well identified leptons on the signal side
- No missing momentum on the signal side

**Neutrinoless Decay**

$\Delta M = M_{rec} - M_\tau \sim 0$

$\Delta E = E_{rec}^{CM} - E_{CM}/2 \sim 0$

Smeared by resolution and radiative effects

**MC:** $\tau^- \to \mu^- e^+ e^-$

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**LFV tau decays**

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DPF 2004
Require 1-3 topology, reject conversions; apply lepton identification and selection cuts. Selection cuts and signal box borders are optimized for each channel separately.
Different channels are contaminated with different backgrounds:

- $\tau^- \rightarrow e^- e^+ e^-$, $\tau^- \rightarrow e^- \mu^+ \mu^-$ - Bhabha, $q\bar{q}$, $\tau \tau$
- $\tau^- \rightarrow e^- \mu^+ \mu^-$, $\tau^- \rightarrow \mu^- \mu^+ \mu^-$ - Di-muon, $q\bar{q}$, $\tau \tau$
- $\tau^- \rightarrow \mu^+ e^- e^-$, $\tau^- \rightarrow e^+ \mu^- \mu^-$ - $q\bar{q}$, $\tau \tau$

Suppress Bhabha and di-muon events with $p_T^{cms} > 100$ MeV/$c$;
On 1-prong side - $p_1^{cms} < 4.8$ GeV/$c$ and lepton veto for Bhabha and di-muon contaminated channels;
On 3-prong side - kaon veto and no photon candidates with $E > 100$ MeV
Each background shape \( (P_i) \) is fitted on MC or data control sample. Data are fitted with sum of 3 PDFs. The contribution of backgrounds in signal box is estimated using sideband region.

\[
P_{\text{data}}^M = f_{QED} \cdot P_{QED} + f_{q\bar{q}} \cdot (1 - f_{QED}) \cdot P_{q\bar{q}} + (1 - f_{QED} - f_{q\bar{q}} \cdot (1 - f_{QED})) \cdot P_{\tau\tau}
\]

\[
N_{\text{bkgr}} = N_{GS} \int_{SB} P_{\text{data}} dM dE \frac{dM dE}{\int_{GS} P_{\text{data}} dM dE}
\]
No excess found in $\mathcal{L} = 91.6$ fb$^{-1}$; $\mathcal{B}(\tau \rightarrow \ell\ell\ell) < (1 - 3) \times 10^{-7}$ at 90% CL
Select 1-1 topology; $e$ or $\rho$ tag; only $\mu$ and $\gamma$ on signal side; cuts on missing momentum and net $p_T$ in the event. Significant background from $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau\gamma$

$$\mathcal{L} = 63 \text{ fb}^{-1}$$

$$\varepsilon = (5.2 \pm 0.5)\%$$

Expected $N_{bkgr} = 7.8 \pm 1.4$

Data observed: 13

$$\mathcal{B}(\tau \rightarrow \mu\gamma) < 2.0 \times 10^{-6} \text{ at 90\% CL}$$

Update with 220 fb$^{-1}$ is expected for Tau2004
Limits ($\times 10^{-7}$) at 90% CL based on $\sim 90$ fb$^{-1}$ per experiment

<table>
<thead>
<tr>
<th>Mode</th>
<th>BABAR</th>
<th>Belle</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{B} (\tau^- \to \mu^- \mu^+ \mu^-)$</td>
<td>1.9</td>
<td>2.0</td>
</tr>
<tr>
<td>$\mathcal{B} (\tau^- \to e^- \mu^+ \mu^-)$</td>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>$\mathcal{B} (\tau^- \to e^+ \mu^- \mu^-)$</td>
<td>1.3</td>
<td>2.0</td>
</tr>
<tr>
<td>$\mathcal{B} (\tau^- \to \mu^- e^+ e^-)$</td>
<td>2.7</td>
<td>1.9</td>
</tr>
<tr>
<td>$\mathcal{B} (\tau^- \to \mu^+ e^- e^-)$</td>
<td>1.1</td>
<td>2.0</td>
</tr>
<tr>
<td>$\mathcal{B} (\tau^- \to e^- e^+ e^-)$</td>
<td>2.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Also $\mathcal{B} (\tau \to \mu \gamma) < 3.1 \times 10^{-7}$ and $\mathcal{B} (\tau \to \mu \eta') < 3.4 \times 10^{-7}$ (Belle)

B Factories have lowered limits on LFV in tau decays to $10^{-7}$

Over 500 fb$^{-1}$ expected in next few years; $\tau \to \ell \ell \ell$ limits should approach $\mathcal{O}(10^{-8})$ soon: many predictions are above this level!

Many more channels to study $\tau \to \ell h h$, $\tau \to \mu \eta'$, $\tau \to p \gamma$, etc.
New **BABAR** results on search of $\tau \rightarrow \ell \ell \ell$ are presented for $\mathcal{L} = 91.6$ fb$^{-1}$. $\mathcal{B}(\tau \rightarrow \ell \ell \ell) < (1 - 3) \times 10^{-7}$ at 90% CL, where $\ell = e$ or $\mu$.

**BABAR** preliminary result for $\tau \rightarrow \mu \gamma$ on $\mathcal{L} = 63$ fb$^{-1}$ is $\mathcal{B}(\tau \rightarrow \mu \gamma) < 2.0 \times 10^{-6}$ at 90% CL - will be updated soon.

Current experimental sensitivity to LFV tau decays approaches theoretical predictions.

Run 4 was very successful for **BABAR**, the total integrated luminosity is over 220 fb$^{-1}$ ⇒

expect many more new results on tau physics and LFV processes soon!