Results on Tau Physics from BaBar

Eric Torrence
University of Oregon

• Search for Lepton Flavor Violation
• Study of $\tau^- \rightarrow 3h^-2h^+\nu_\tau$ (5 prong)
• Tau Lifetime
The BaBar Experiment

244 fb\(^{-1}\) recorded, more data on its way

\[ \sigma(e^+e^- \rightarrow B\bar{B}) = 1.05 \text{ nb} \]

\[ \sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.89 \text{ nb} \]

Almost 220 million \(\tau^+\tau^-\) events!

Results shown today use \(~100\) fb\(^{-1}\)
Lepton Flavor Violation

Limits on Lepton Flavor Changing Decays before BaBar/Belle

- $B(\mu \rightarrow e\gamma) < 1.2 \times 10^{-11}$ at 90% CL \[MEGA/LAMPF]\]
- $B(\mu \rightarrow eee) < 1.0 \times 10^{-12}$ at 90% CL \[SINDRUM]\]
- $B(\tau \rightarrow \mu\gamma) < 1.1 \times 10^{-6}$ at 90% CL \[CLEO]\]
- $B(\tau \rightarrow \mu\mu\mu) < 1.9 \times 10^{-6}$ at 90% CL \[CLEO]\]

Forbidden in SM, but no good theoretical motivation

Neutrino Oscillations

$\tau^- \quad \nu_\tau \quad \nu_\mu \quad \mu^- \quad W \quad \gamma$

LFV allowed in principle, but rate is very, very small. $O(10^{-40})$?

Signature of new physics! Search for $\tau \rightarrow \mu\gamma, \tau \rightarrow lll,...$
Natural part of many models of new physics, particularly those trying to explain neutrino data.

String inspired, heavy $\nu_R$ SUSY [King and Oliveira, 1999]

See E. Ma Tau02 proceedings for concise review
One prong on “tag” side \((\pi \nu, \rho \nu, e\nu\nu, \mu\nu\nu,...) \sim 85\%\)

- Strict lepton identification
- No missing momentum on signal side

**Neutrinoless** Decay

\[ \Delta m = m_{rec} - m_{\tau} \]

\[ \Delta E = E_{rec} - E_{beam} \]

Smeared by resolution and radiative effects

Count events in signal box

**LFV Signature**

\[ \tau \rightarrow \mu \gamma \]

\[ \tau \rightarrow lll \]
Require 1-3 topology, reject $\gamma$ conversions, Particle ID, plus specific cuts per channel against major backgrounds

3 background PDFs, shape from MC/control, rate from data
No excess found! Limits $(1 - 3) \times 10^{-7}$ @ 90% CL

$L = 91.6 \text{ fb}^{-1}$, $\sigma_\tau = 0.89 \text{ nb}$  

PRL 92, 121801 (2004)
Significant background from $e^+e^- \rightarrow \mu^+\mu^-\gamma$ and $\tau \rightarrow \mu \bar{\nu}_\mu \nu_\tau \gamma$

Require electron or rho tag
(no muon or pion tags allowed)

$L = 63 \text{ fb}^{-1}, \sigma_\tau = 0.89 \text{ nb}$

Bgd expected: $7.8 \pm 1.4$
Data observed: 13

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

Limit $2.0 \times 10^{-6}$ @ 90% CL

Not competitive due to fluctuation
Update with 220 fb$^{-1}$ expected for Tau04...
Published Belle $\tau \rightarrow \mu \gamma$ Limits

$L = 86.3 \text{ fb}^{-1}$, $\varepsilon = (11.0 \pm 0.5)\%$

Expected: $20.2 \pm 2.1$ Observed: 19

BF Limit $3.1 \times 10^{-7}$ @ 90% CL

PRL 92, 171802 (2004)

Also $B(\tau \rightarrow \mu \eta) < 3.4 \times 10^{-7}$

Submitted to PRL

Updates expected this week, see BSM-5 2:30 Tuesday
### Published Lepton Flavor Violation Limits

Limits ($\times 10^{-7}$) at 90% CL based on ~ 90 fb$^{-1}$ per experiment

<table>
<thead>
<tr>
<th>Mode</th>
<th>BaBar</th>
<th>Belle</th>
<th>My Combination</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B(\tau^- \rightarrow \mu^-\mu^+\mu^-)$</td>
<td>1.9</td>
<td>2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow \mu^-\mu^+e^-)$</td>
<td>3.3</td>
<td>2.0</td>
<td>1.4</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow \mu^-e^+\mu^-)$</td>
<td>1.3</td>
<td>2.0</td>
<td>0.7</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow \mu^-e^+e^-)$</td>
<td>2.7</td>
<td>1.9</td>
<td>1.2</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow e^-\mu^+\mu^-)$</td>
<td>1.1</td>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>$B(\tau^- \rightarrow e^-\mu^+e^-)$</td>
<td>2.0</td>
<td>3.5</td>
<td>1.5</td>
</tr>
</tbody>
</table>

BaBar: **PRL 92, 121801 (2004)**  
Belle: **PLB 589, 103 (2004)**

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

B-factories have lowered these limits $10^{-6} \rightarrow 10^{-7}$

Over 500 fb$^{-1}$ (0.5 ab$^{-1}$) expected in next few years

50 distinct modes listed in PDG with LF, L, or B violation

Many interesting channels: $\tau \rightarrow llh$, $\tau \rightarrow \mu \eta'$, $\tau \rightarrow p\gamma$, ...

$\tau \rightarrow lll$ limits should approach $O(10^{-8})$ soon

Many models predictions are above this level!
Five Prong Tau Decays

\[ \tau^- \rightarrow \pi^- \pi^0 \nu_\tau \] and \( \tau^- \rightarrow \pi^- \pi^+ \pi^- \nu_\tau \) extensively studied worldwide.

5-prong modes suffer from lack of statistics...

CLEO saw 295 events (1.7 fb\(^{-1}\))

PRL 73, 934 (1994)
$3h^-2h^+$ mass compared to TAUOLA (phase space)

1-5 topology, lepton tag, thrust, $P_t/E_{\text{miss}}$, no kaon id (yet)

veto $e^-$, $\pi^0$, and conversions from signal side

Efficiency: 7.5%, Purity: 79%, Events: 15,869, Lumi: 110.7 fb$^{-1}$

Backgrounds mostly from other tau decays with $\pi^0$ or $K_s$
### Preliminary 5-prong Results

<table>
<thead>
<tr>
<th>Tag</th>
<th>Efficiency [%]</th>
<th>Purity [%]</th>
<th>Events</th>
<th>(B(\tau^- \rightarrow 3h^- 2h^+ \nu_\tau))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>4.6</td>
<td>79</td>
<td>9668</td>
<td>((8.52 \pm 0.09 \pm 0.40) \times 10^{-4})</td>
</tr>
<tr>
<td>Muon</td>
<td>2.9</td>
<td>79</td>
<td>6201</td>
<td>((8.54 \pm 0.11 \pm 0.45) \times 10^{-4})</td>
</tr>
</tbody>
</table>

**Branching Fraction**

- **BaBar**: \(8.5 \pm 0.4\) Preliminary
- **Opal**: \(9.1 \pm 1.5\)
- **Aleph**: \(8.0 \pm 1.7\)
- **Cleo**: \(7.7 \pm 1.0\)
- **PDG**: \(8.2 \pm 0.6\)

**Future Plans:**
- Measure 5h \(\pi^0\), 5h \(2\pi^0\) modes
- Separate kaons from pions
- Study hadronic structure in detail

**Hadronic Structure in \(h^+h^-\) pairs**

- **\(B(\tau \rightarrow 3h^- 2h^+ \nu_\tau)\)**
  - **Data**
  - **3\(\pi^- 2\pi^+\) MC
  - **Background**

6 pairs/ev.
• Very clean 1-3 sample
• Reconstruct $r$-$\phi$ decay length from primary IP to 3-track vertex
• Use simple mean $\langle \lambda \rangle$ to reduce syst.

Lifetime with 30 fb$^{-1}$
$290.8 \pm 1.5^{(stat)} \pm 1.6^{(syst)}$ fs (prelim.)

Uncertainties will be significantly reduced for publication (80 fb$^{-1}$)
Summary

Lepton Flavor Violation

- $B(\tau \rightarrow lll) < (1 - 3) \times 10^{-7}$ published
- Prelim. result on $B(\tau \rightarrow \mu \gamma)$ to be updated shortly

Hadronic Structure

- Prelim. results with 16k $\tau^- \rightarrow 3h^-2h^+\nu_\tau$ events
- Much more to come here

Tau Lifetime

- Prelim. lifetime measurement among world’s best
- Improvements and publication expected soon

First results on tau physics from BaBar are just now being published

There is a lot of physics to be extracted from this huge data sample

See Tau04 (Nara, Japan, September 14-17) for more