• The Reconstruction of $\tau$ Decays
• Lepton Universality from $\tau$ decays to $e\nu_e\nu_\tau$ and $\mu\nu_\mu\nu_\tau$
• $|v_{us}|$ from $\tau$ decays to $\pi\nu_\tau$ and $K\nu_\tau$
• Second Class Currents
• Lepton Flavor Violation
• Tau Mass

Recent results presented at Tau08 workshop, Sep. 2008
Typical BaBar Tau Event

- Taus decay into odd number of charged tracks (1,3,5) and any number of pi_zero (0,1,2,3)
- Taus produced back to back in CMS
- Makes for an easy topological identification of events and good background suppression
- Typically there are one or two neutrinos per side, but there would be zero in lepton flavor violating decays
- One side is used for tagging, the other is the decay of interest
- Luminosity used for tau analysis varies between 350/fb and 467/fb
Lepton Universality

Standard Model assumes that the weak couplings of all leptons are the same: \( g_e = g_\mu = g_\tau = g \)

\[
\frac{\Gamma_{\tau \rightarrow e}}{\Gamma_{\mu \rightarrow e}} \propto \left( \frac{g_\tau}{g_\mu} \right)^2 = \frac{\tau_\mu}{\tau_\tau} \text{BF}(\tau^- \rightarrow e^- \nu_e \bar{\nu}_\tau) \left( \frac{m_\mu}{m_\tau} \right)^5 \frac{f(m_e^2/m_\mu^2)}{f(m_e^2/m_\tau^2)} r_{EW}^\mu
\]

\[
\frac{\Gamma_{\tau \rightarrow \mu}}{\Gamma_{\mu \rightarrow e}} \propto \left( \frac{g_\tau}{g_\mu} \right)^2 = \frac{\tau_\mu}{\tau_\tau} \text{BF}(\tau^- \rightarrow \mu^- \nu_\mu \bar{\nu}_\tau) \left( \frac{m_\mu}{m_\tau} \right)^5 \frac{f(m_e^2/m_\mu^2)}{f(m_e^2/m_\tau^2)} r_{EW}^\tau
\]

\[
\frac{\Gamma_{\tau \rightarrow e}}{\Gamma_{\tau \rightarrow \mu}} \propto \left( \frac{g_e}{g_\mu} \right)^2 = \frac{\text{BF}(\tau^- \rightarrow e^- \nu_e \bar{\nu}_\tau)}{\text{BF}(\tau^- \rightarrow \mu^- \nu_\mu \bar{\nu}_\tau)} \frac{f(m_\mu^2/m_\tau^2)}{f(m_e^2/m_\tau^2)}
\]

\( f(x) = 1 - 8x + 8x^3 - x^4 - 12x \ln x \) (approximating all \( m_\nu = 0 \))

\( r_{EW}^\ell = 0.9960 \) (EW radiative corrections, Marciano-Sirlin)

Need to measure ratios of branching ratios:

\[ \text{BR}(\tau \rightarrow e \nu_e \bar{\nu}_\tau) / \text{BR}(\tau \rightarrow \mu \nu_\mu \bar{\nu}_\tau) \]
• 1 vs. 3 topology
• 3-prong is the tagging side
• very low backgrounds
• excellent electron and muon id. on the signal side
• no other neutral particles in the event
$|V_{us}|$ from $\tau$ Decays

\[
\frac{B(\tau^- \to K^{-}\nu_{\tau})}{B(\tau^- \to \pi^{-}\nu_{\tau})} = \frac{f_K^2}{f_{\pi}^2} \left| \frac{V_{us}}{V_{ud}} \right|^2 \left( 1 - \frac{m_K^2}{m_{\tau}^2} \right)^2 \left( 1 - \frac{m_{\pi}^2}{m_{\tau}^2} \right)^2
\]

Take $f_K/f_{\pi} = 1.189\pm0.007$ from Lattice QCD

\[|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1\]

$|V_{ud}| = 0.97408 \pm 0.00026$

$|V_{ub}| = (3.93 \pm 0.36) \times 10^{-3}$

$|V_{us}| = 0.2262 \pm 0.0011$

T. Eronen, et. al. PRL100, 132502 (2008)

from e.g. inclusive B to $X_u\nu$ decays
• 1 vs. 3 topology
• 3-prong is the tagging side
• low backgrounds no other neutral particles in the event
• higher systematics due to hadron ID on signal side
# Systematic Errors

<table>
<thead>
<tr>
<th></th>
<th>$B(\tau\rightarrow \mu^+\nu_\mu\bar{\nu}_e)$</th>
<th>$B(\tau\rightarrow \pi^+\nu_\pi\bar{\nu}_\pi)$</th>
<th>$B(\tau\rightarrow K^+\nu_K)$</th>
<th>$B(\tau\rightarrow \pi^+\nu_\pi)$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Statistical Uncertainty</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>data statistical</td>
<td>0.16%</td>
<td>0.24%</td>
<td>0.84%</td>
<td>0.85%</td>
</tr>
<tr>
<td><strong>Systematic Uncertainty</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$L_\sigma$</td>
<td>0.02%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>$BF(\tau^-\rightarrow \pi^-\pi^-\pi^+\nu_\tau)$</td>
<td>0.01%</td>
<td>0.4%</td>
<td>0.4%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>$\epsilon$ and particle ID</td>
<td><strong>0.32%</strong></td>
<td><strong>0.5%</strong></td>
<td><strong>0.9%</strong></td>
<td><strong>0.9%</strong></td>
</tr>
<tr>
<td>$\tau^-\rightarrow \pi^-\pi^-\pi^+\nu_\tau$ modelling</td>
<td>0.01%</td>
<td>0.1%</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>EMC and DCH response</td>
<td>0.08%</td>
<td>0.6%</td>
<td>0.5%</td>
<td>0.2%</td>
</tr>
<tr>
<td>triggers</td>
<td>0.10%</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>backgrounds</td>
<td>0.08%</td>
<td><strong>0.4%</strong></td>
<td>0.9%</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>Systematic Total</strong></td>
<td><strong>0.35%</strong></td>
<td>1.0%</td>
<td>1.4%</td>
<td>1.4%</td>
</tr>
</tbody>
</table>
Results

Use electron branching ratio for normalization

$B(\tau^- \rightarrow e^+ \nu_\tau \nu_e) = (17.82\pm0.05\%)$

Results

Lepton Universality

World Average (PDG2008): \(|g_\mu/g_e|\) 1.0015 +/- 0.0011

BaBar preliminary: \(|g_\mu/g_e|\) 1.0036 +/- 0.0020

BaBar preliminary (\(\tau \rightarrow \pi\)): \(|g_\tau/g_\mu|\) 0.9859 +/- 0.0057

BaBar preliminary (\(\tau \rightarrow K\)): \(|g_\tau/g_\mu|\) 0.9836 +/- 0.0087

\[|V_{us}|\]

Unitarity (PDG2008): 0.2262 +/- 0.0011

BaBar preliminary: 0.2255 +/- 0.0023
Second Class Currents in $\tau^-$ → $\eta'$π$^-$ ν$_{\tau}$

In $\tau$ decays the $\eta'$($958$) $\pi^-$ has $J^{PG}$ of $0^{+-}$ or $1^{--}$ → 2$^{nd}$ Class Currents

$\eta'$ → $\eta$ $\pi^+$ $\pi^-$
$\eta$ → $\gamma$ $\gamma$
• 1 vs. 3 analysis
• Higher bg due to photons in event
• Tag 1-prong as electron or muon

BR($\tau^-$ → $\eta'$π$^-$ ν$_{\tau}$) < 7.2 x 10$^{-6}$ @ 90% CL
An order of magnitude better than previous limits

Published: hep-ex/0803.0772
Second Class Currents II

\[ \tau^- \rightarrow \omega \pi^- \nu_\tau \] with \[ \omega \rightarrow \pi^+\pi^-\pi^0 \]

- 1 vs. 3 topology
- reconstructed \( \pi^0 \) on 3-prong
- background from other channels decaying into \( \omega \)
- perform angular analysis of \( \omega \pi \) system (cos\( \theta_{\omega\pi} \)) and compare vector and non-vector contributions

\[
\frac{N(\omega\pi)_{\text{non-vector}}}{N(\omega\pi)_{\text{vector}}} < 0.69\% @ 90\% \text{ CL.}
\]

\[
\text{BR} \left( \tau^- \rightarrow \omega \pi^- \nu_\tau \right) \ 2^{\text{nd}} \text{ CC} < 1.3 \times 10^{-4} @ 90\% \text{ CL.}
\]

Factor 10 better than previous limits
Lepton Flavour Violation

\[ \tau \rightarrow lK_S^0 \text{ and } \tau \rightarrow l(\rho^0, K^{*0}, \overline{K}^{*0}, \phi) \]

- 1 vs. 3 analysis
- Tag 1-prong as electron or muon
- No neutrino on signal side \( \implies \) fully reconstructed \( \tau \)
- Kinematic fit over full decay chain
- Signal box blinded

\[ \Delta M = m_{\text{Reco}} - m_{\text{Tau}} \]
\[ \Delta E = E_{\text{Reco}} - E_{\text{CM}} \]
## LFV Results

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\epsilon(%)$</th>
<th>$n_{bkg}$</th>
<th>$N_{obs}$</th>
<th>$UL_{90}(10^{-8})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$e\rho^0$</td>
<td>$7.31 \pm 0.18$</td>
<td>$1.32 \pm 0.19$</td>
<td>1</td>
<td>4.3</td>
</tr>
<tr>
<td>$\mu\rho^0$</td>
<td>$4.52 \pm 0.41$</td>
<td>$2.04 \pm 0.21$</td>
<td>0</td>
<td>0.8</td>
</tr>
<tr>
<td>$eK^*0$</td>
<td>$8.00 \pm 0.18$</td>
<td>$1.64 \pm 0.29$</td>
<td>2</td>
<td>5.6</td>
</tr>
<tr>
<td>$\mu K^*0$</td>
<td>$4.57 \pm 0.36$</td>
<td>$1.79 \pm 0.25$</td>
<td>4</td>
<td>16.7</td>
</tr>
<tr>
<td>$e\bar{K}^*0$</td>
<td>$7.76 \pm 0.17$</td>
<td>$2.76 \pm 0.30$</td>
<td>2</td>
<td>4.0</td>
</tr>
<tr>
<td>$\mu\bar{K}^*0$</td>
<td>$4.11 \pm 0.31$</td>
<td>$1.72 \pm 0.18$</td>
<td>1</td>
<td>6.4</td>
</tr>
<tr>
<td>$e\phi$</td>
<td>$6.43 \pm 0.18$</td>
<td>$0.68 \pm 0.14$</td>
<td>0</td>
<td>3.1</td>
</tr>
<tr>
<td>$\mu\phi$</td>
<td>$5.18 \pm 0.26$</td>
<td>$2.76 \pm 0.21$</td>
<td>6</td>
<td>18.2</td>
</tr>
<tr>
<td>$eK_S$</td>
<td>$9.28 \pm 0.19$</td>
<td>$1.03 \pm 0.36$</td>
<td>1</td>
<td>3.3</td>
</tr>
<tr>
<td>$\mu K_S$</td>
<td>$7.03 \pm 0.39$</td>
<td>$5.34 \pm 2.21$</td>
<td>2</td>
<td>4.0</td>
</tr>
</tbody>
</table>

\[ \mathcal{B}(\tau^{\pm} \rightarrow e^{\pm}\omega) < 1.1 \times 10^{-7} \]
\[ \mathcal{B}(\tau^{\pm} \rightarrow \mu^{\pm}\omega) < 1.0 \times 10^{-7} \]

Tau Mass and CPT Test

\[ M_\tau = 1776.68 \pm 0.12 \text{ (stat)} \pm 0.41 \text{ (syst)} \text{ MeV} \]

Test of CPT Symmetry:

\[ \frac{M(\tau^+) - M(\tau^-)}{M_{\text{Average}}} = (-3.5 \pm 1.3) \times 10^{-4} \]
Summary

• Lepton Universality holds as measured by BaBar
• BaBar’s $|V_{us}|$ agrees with the world average
• 2nd Class Currents are not seen on the $10^{-4}$ to $10^{-6}$ level
  $\Rightarrow$ improvement of the previous limits by a factor of 10
• New results for Lepton Flavor Violation
  $\Rightarrow$ limits are in the $10^{-7}$ to $10^{-8}$ (scratching $10^{-9}$) range
• Difference between $\tau^+$ and $\tau^-$ mass measurement
  provides new limits on CPT invariance

Was a productive year for BaBar’s Tau Folks