Recent CLEO Results on Tau Hadronic Decays

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CLEO Hadronic Tau Results

- The CLEO3 Detector
- Tau Decays to 3 Charged Hadrons + $\nu$
- Structure of KK$\pi$ and Wess-Zumino

PRL90:181802,2003
PRL92:232001,2004
The CLEO3 Detector

CLEOIII

Solenoid Coil
Barrel Calorimeter
RICH
Drift Chamber
Silicon / beampipe
Endcap Calorimeter
Iron Polepiece
Magnet Iron
Barrel Muon Chambers
SC Quadrupoles
Pylon
SC Quadrupole
Rare Earth Quadrupole
Tau to $3h^\pm + \nu$

- $\tau^- \rightarrow h^-h^+h^-\nu$ decays predominantly to pions
- $K^-\pi^+\pi^-$ final state important to strange spectral function, $m_s$, $V_{us}$
- $K^-K^+\pi^-$ state probes Wess-Zumino term
- $K^-K^+K^-$ state as yet unobserved

The Data Sample: $3 \times 10^6$ tau pairs at $\Upsilon(4s)$ produced at CESR
Hadronic Particle ID

- Combine RICH and dE/dx
- Use DATA $D^* \rightarrow D\pi$, $D \rightarrow K\pi$ to obtain PID $\epsilon$ and fake rates
- Cross check with wrong sign $K$ in $\tau^- \rightarrow K^+\pi^-\pi^+\nu$ search
- (Use only loose dE/dx for $\pi$ in $KK\pi$ – $KKK$ not a background!)

$\tau^- \rightarrow h^-h^+h^-\nu$
Event Selection

- Select 1 vs 3 tracks (using Thrust)
- Require e/ /ρ/π tag
- Reject events w/ extra showers (3hπ⁰ rejection)
- Missing momentum, $E_{\text{vis}}$ cuts reject 2γ background
- $K_s^0$ rejection for $K\pi\pi$ mode
- Use KORALB, JETSET, GEANT for efficiency (use data for PID)

$\tau^- \rightarrow h^-h^+h^-\nu$
3h Results

<table>
<thead>
<tr>
<th>Mode</th>
<th>Data</th>
<th>$\tau$ bgd</th>
<th>qq bgd</th>
<th>$\epsilon$(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi\pi\pi$</td>
<td>43543</td>
<td>3207±57</td>
<td>152±12</td>
<td>10.27±0.08</td>
</tr>
<tr>
<td>$K\pi\pi$</td>
<td>3454</td>
<td>1475±38</td>
<td>57±8</td>
<td>11.63±0.12</td>
</tr>
<tr>
<td>$KK\pi$</td>
<td>932</td>
<td>86±9</td>
<td>19±4</td>
<td>12.48±0.11</td>
</tr>
<tr>
<td>$KKK$</td>
<td>12</td>
<td>4±2</td>
<td>0.4±0.6</td>
<td>9.43±0.10</td>
</tr>
</tbody>
</table>

- Largest $\tau$ bgd from other $\tau \rightarrow 3h(\pi^0)\nu$ modes
- Use MC to get feed-across
- For KKK use data to get feed-across
- $KK\pi$ Substructure tuned to fit data
3h Substructure Plots

- Very Good Data MC agreement
- Used $3\pi$, $K\pi\pi$ tuning from TAU02
- Tuned $KK\pi$ substructure: Less $K^*$, more $\rho'$, no $\rho''$
3h Systematics

- 3% PID systematic
- 2% each systematic for Lumi, $\sigma(\tau\tau)$, track finding
- 1% each syst for $\tau$ backgrounds, CC cuts

PID Fake rate syst 0.1%/9%/2%/12%
MC/Data studies, $\tau^-\rightarrow K^+\pi^-\pi^+\nu$ search

qq background - MC vs data above tau mass syst = 0.2%/2%/1%/3%

KK$\pi$ substructure 2%

$\tau^-\rightarrow h^-h^+h^-\nu$
Final 3h Results

\[ B(\tau^− \rightarrow )^- + ) −ν_{\tau} ) = 9.13±0.05±0.46\% \]
\[ B(\tau^− \rightarrow K^- ) + ) −ν_{\tau} ) = 0.384±0.014±0.038\% \]
\[ B(\tau^− \rightarrow K^-K^+ ) −ν_{\tau} ) = 0.155±0.006±0.009\% \]
\[ B(\tau^− \rightarrow K^-K^+K^-ν_{\tau} ) < 3.7×10^{-5} @90\% \text{ CL} \]

First direct 3π result

Kππ consistent w/OPAL (0.360±0.082±0.048%) &
CLEO2 (0.346±0.023±0.056%), higher than ALEPH (0.214±0.037±0.029%)

Best precision on KKπ

Most stringent limit on KKK

\[ \tau^− \rightarrow h^-h^+h^-ν \]
**KKπ Structure - Wess Zumino Anomaly**

- Simplest $\tau$ decay picture: Vector (axial) current produces even (odd) numbers of pseudoscalars

- WZ Anomaly allows parity flip and allows a violation of this rule

- Golden mode $\tau \rightarrow \eta \gamma \nu$ previously observed by CLEO (no axial component)

- $\tau \rightarrow KK\pi\nu$ has both axial and vector (WZ) contribution

- WZ effects rate and substructure of $KK\pi$
Structure of tau to 3hv Decays

- SM matrix element $M_{\alpha L} J$
- Define: $Q = (q_1 + q_2 + q_3)$, $s_i = (q_j + q_k)$
- $J$ is a sum over 4 form factors:
  $$J = \sum f_i(q_1, q_2, q_3, Q)F_i(s_1, s_2, Q)$$

$f_i$ are kinematics - $F_i$ are Form Factors (physics)

$F_1, F_2$ are axial terms
$F_3$ is the WZ vector term
$F_4$ is the scalar current (negligible)

Kuhn, Mirkes, Z.PhysC56, 661(1992)
Structure of tau to 3hv Decays

- Integrate over $\nu$ direction
- Two remaining Euler angles are kinematically determined
- $d\Gamma(\tau \rightarrow K\kappa\pi)/dQ^2ds_1ds_2 \propto W_A(F_1,F_2)+W_B(F_3)$
- No interference between Axial and WZ term
- Measurement possible entirely by using Dalitz plot and $Q^2$
The Physics We Fit

\[ a_1 \rightarrow \rho' \pi, \quad \rho' \rightarrow KK \]

\[ F_1 \propto BW_{a_1}(Q^2) \times (BW_{\rho}(s_2) + \beta_{\rho} BW_{\rho'}(s_2)) \]

\[ a_1 \rightarrow KK^*, \quad K^* \rightarrow K\pi \]

\[ F_2 \propto BW_{a_1}(Q^2) \times BW_{K^*}(s_1) \]

\[ \rho^{(','')} \rightarrow KK^*, \quad K^* \rightarrow K \]

\[ \rho^{(','')} \rightarrow \omega, \quad \omega \rightarrow KK \]

\[ F_3 \propto R_{B}^{1/2} (BW_{\rho}(Q^2) + \lambda BW_{\rho'}(Q^2) + \delta BW_{\rho''}(Q^2)) \times \]
\[ (BW_{\omega}(s_2) + \alpha BW_{K^*}(s_1)) \]

Five real fit parameters to KK\pi, K\pi, KK masses
The Data and Fit Procedure

- Use 7.09×10^6 τ pairs from CLEO3
- Use same cuts as τ→3ν analysis
- 2255 signal events, 256±16±46 background
- Obtain consistent overall Branching Fraction
- Use unbinned extended Maximum Likelihood fit including background term
- PDF = PDF(KKπ) x PDF(KK) x PDF(Kπ)
- Use best known params for BW’s
Fit Results

- Shown is total fit and contributions from Axial and WZ components
- $\approx 1/2$ is from WZ

$\alpha = 0.471 \pm 0.060 \pm 0.034$
$\lambda = -0.314 \pm 0.073 \pm 0.080$
$\delta = 0.101 \pm 0.020 \pm 0.156$
$R_B = 3.23 \pm 0.26 \pm 1.90$
$R_F = 0.98 \pm 0.15 \pm 0.36$

$\frac{\Gamma_{WZ}}{\Gamma_{Tot}} = 55.7 \pm 8.4 \pm 4.9\%$
Substructure Result

- Relative rates in Kuhn & Mirkes model
  - Axial current: $\tau \to a_1 (\to \rho^{(')}) \ , K^*K) \nu$
  - Vector current (WZ): $\tau \to \rho^{('','')} (\to K^*K , \omega) \) \nu$

\[
R_{WZ}^{\omega)} = 3.4^{+0.9}_{-1.0}\% \\
R_{WZ}^{K^*K} = 60.8^{+8.5}_{-6.0}\% \\
R_{Axial}^{\rho^{(')}} = 2.50.8^{+0.4}_{-0.4}\% \\
R_{Axial}^{K^*K} = 46.8^{+8.4}_{-5.2}\%
\]

Decay dominated by $K^*K$, 50/50 WZ and Axial

$B(a1 \text{ to } K^*K) = 2.2^{+0.5}_{-0.5}\%$ consistent w/ previous CLEO $\pi\pi^0\pi^0$ result

Axial component much smaller than ALEPH CVC estimate from DM1, DM2 data $94^{+6}_{-8}\%$ CERN EP99-026
Angular Distributions

\( \beta: \angle P(KK\pi) \) in lab frame,
\( p_K \times p_{\pi} \)

\( \theta: \angle P(\tau) \) in lab, \( P(KK\pi) \) in \( \tau \) frame

\( \psi: \angle P(\tau), P(\text{lab}) \) in \( KK\pi \) frame

Angles are all expressible in terms of observables

Angles alone are not enough to extract WZ/Axial contributions
Summary

Using CLEO3, we have presented:

- First direct $B(\tau \to 3\pi \nu)$ result

- $B(\tau \to K\pi\pi\nu)$ consistent w/OPAL and CLEO, higher than ALEPH

- Most stringent limit on $\tau \to KKK\nu$

- Best precision on $B(\tau \to KK\pi\nu)$

- First Study of WZ and Axial parts of $\tau \to KK\pi\nu$

- Breakdown of $KK\pi$ in Kuhn+Mirkes model