Recent CLEO Results on Tau Hadronic Decays

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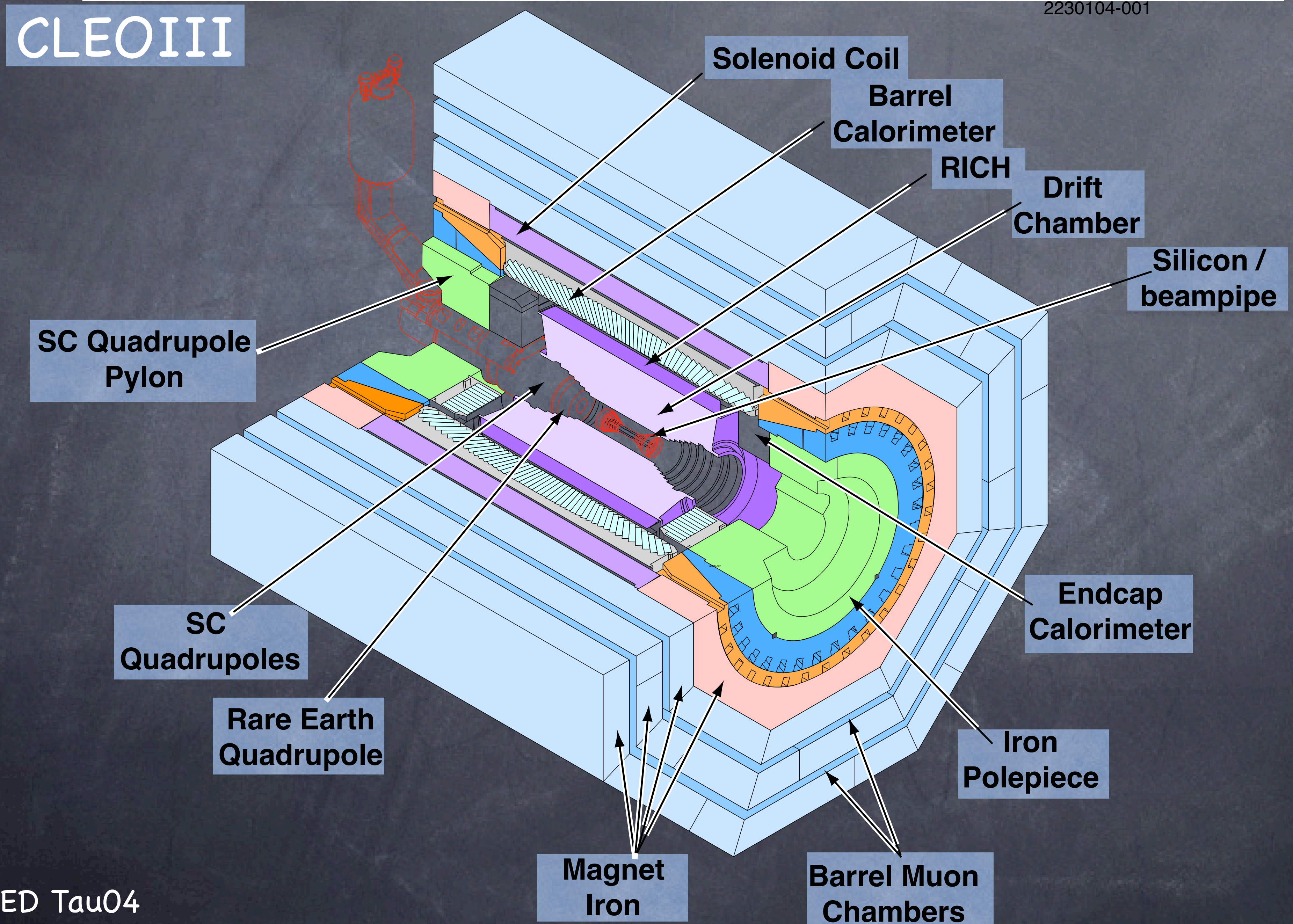
CLEO Hadronic Tau Results

- The CLEO3 Detector
- Tau Decays to 3 Charged Hadrons + ν

  PRL90:181802,2003
- Structure of KKpi and Wess-Zumino

  PRL92:232001,2004

The CLEO3 Detector



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}

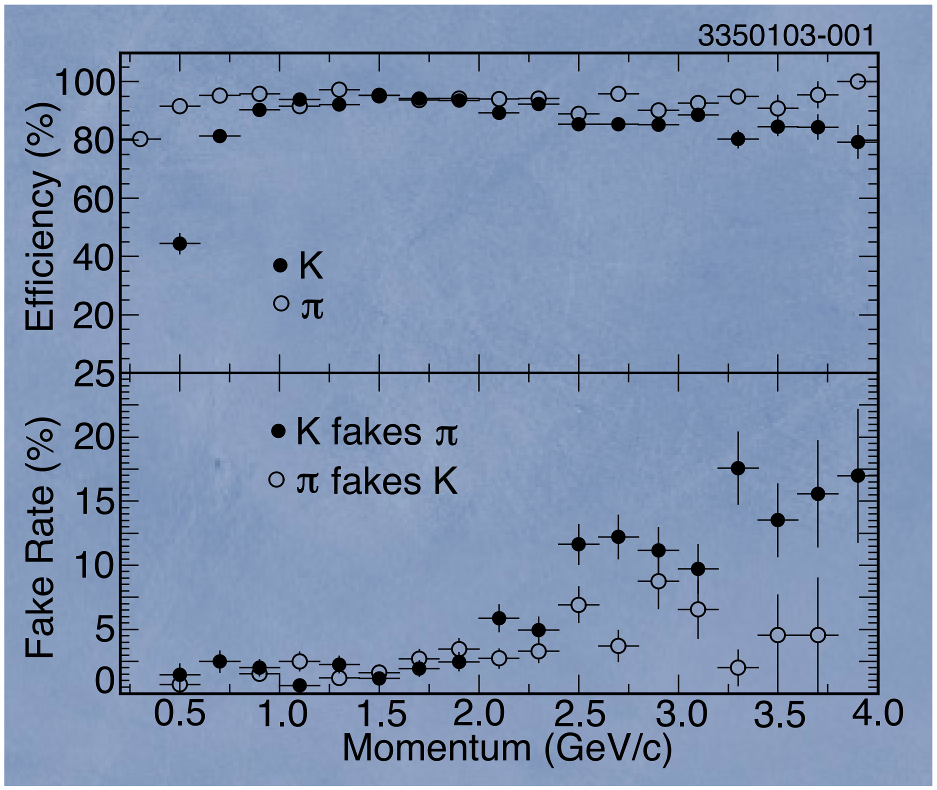
- $K^-K^+\pi^-$ state probes Wess-Zumino term

- $K^-K^+K^-$ state as yet unobserved

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

Hadronic Particle ID

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



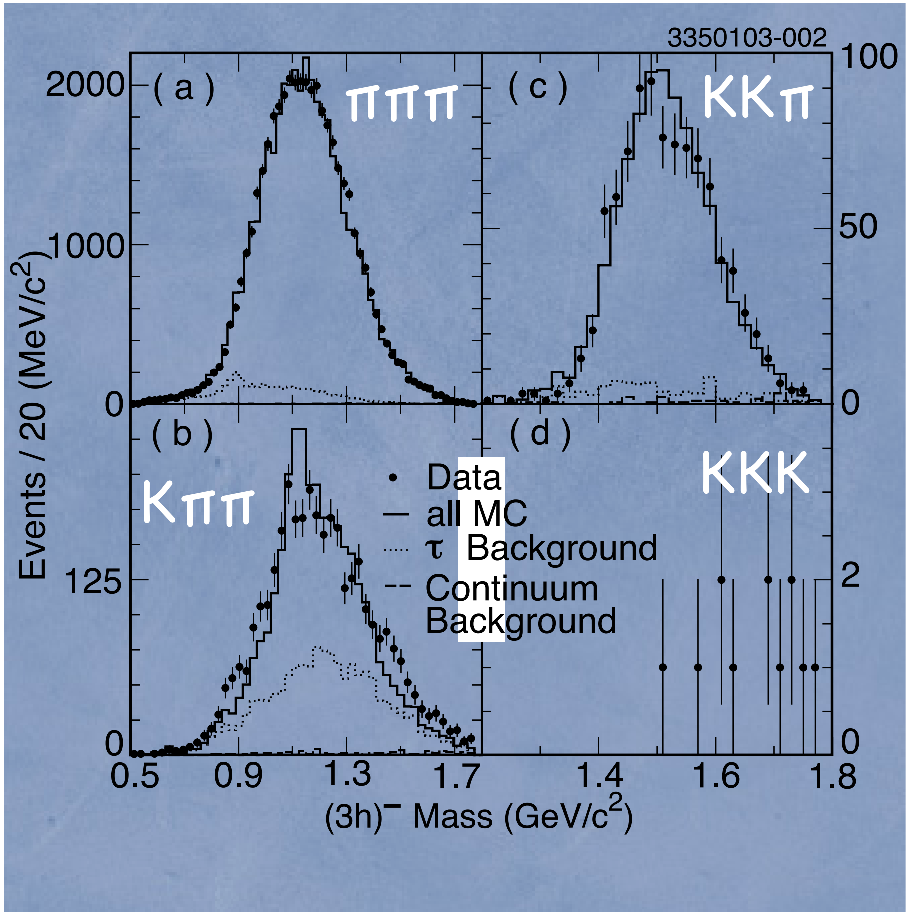
Event Selection

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

3h Results

Mode	Data	τ bgd	qq bgd	ϵ(%)
πππ	43543	3207±57	152±12	10.27±0.08
Kππ	3454	1475±38	57±8	11.63±0.12
KKπ	932	86±9	19±4	12.48±0.11
KKK	12	4±2	0.4±0.6	9.43±0.10

- Largest τ bgd from other $\tau \to 3h\nu$ modes
- Use MC to get feed-across
- For KKK use data to get feed-across
- KKπ Substructure tuned to fit data

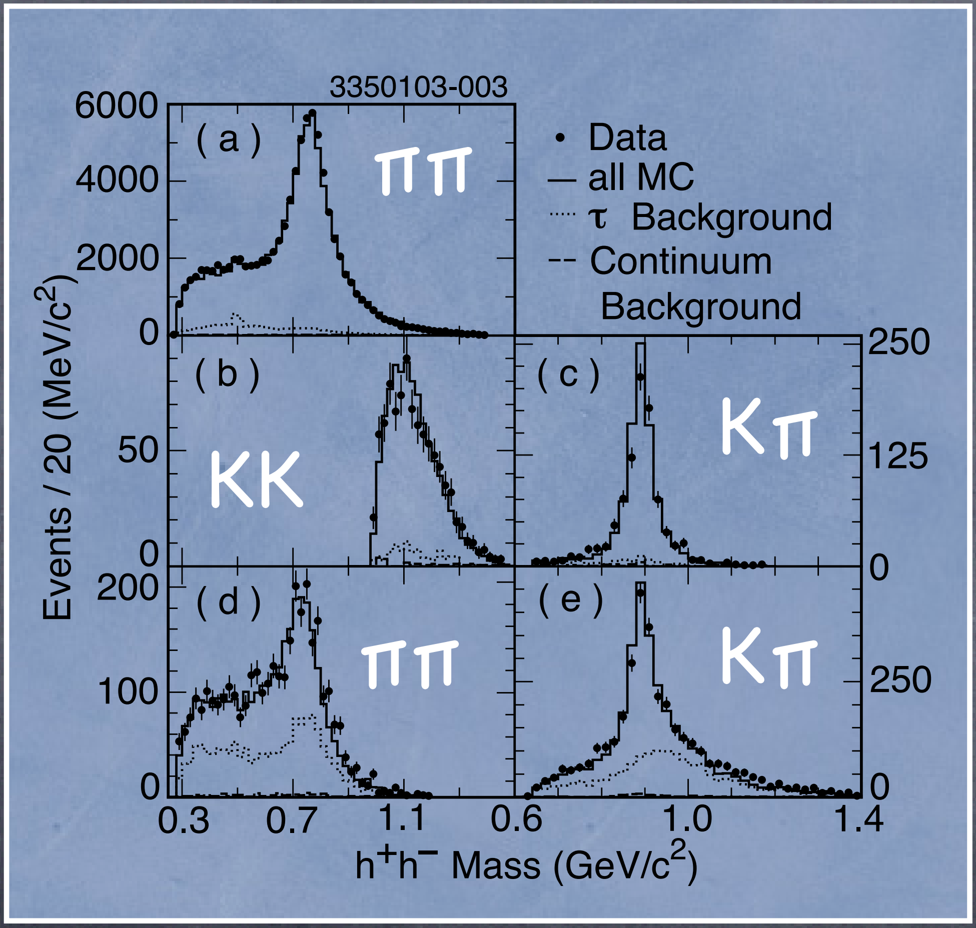


3h Substructure Plots

πππ

KKπ

Kππ



- Very Good Data MC agreement
- Used 3π, Kππ tuning from TAU02
- Tuned KKπ substructure: Less K*, more ρ', no ρ''

$\tau^- \to h^- h^+ h^- \nu$

3h Systematics

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

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

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

KKπ substructure 2%

Final 3h Results

$B(\tau^- \rightarrow \pi^-\pi^+\pi^-\nu_\tau) = 9.13 \pm 0.05 \pm 0.46\%$

$B(\tau^- \rightarrow K^-\pi^+\pi^-\nu_\tau) = 0.384 \pm 0.014 \pm 0.038\%$

$B(\tau^- \rightarrow K^-K^+\pi^-\nu_\tau) = 0.155 \pm 0.006 \pm 0.009\%$

$B(\tau^- \rightarrow K^-K^+K^-\nu_\tau) < 3.7\times10^{-5}$ @90% CL

First explicit 3π result

$K\pi\pi$ consistent w/OPAL and CLEO, higher than ALEPH

Best precision on $KK\pi$

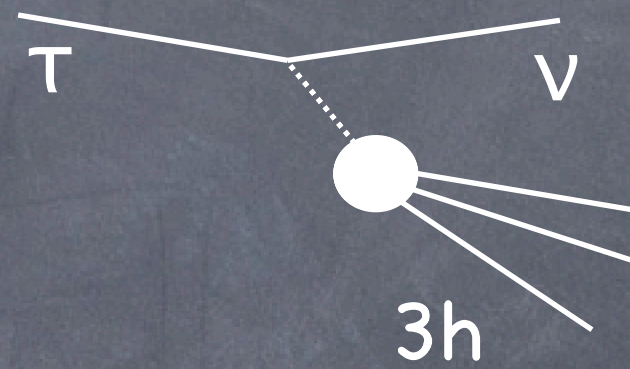
Most stringent limit on KKK

KKπ Structure - Wess Zumino Anomaly

- Simplest τ 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 $\tau \to \eta\pi\pi^0\nu$ previously observed by CLEO (no axial component)
- $\tau \to KK\pi\nu$ has both axial and vector (WZ) contribution
- WZ effects rate and substructure of KKπ

Structure of tau to 3hν Decays

- SM matrix element $M \propto L\,J$



- 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 $J^P=1^-$ axial terms

F_3 is the WZ vector $J^P=1^+$ term $f3=i\epsilon^{\alpha\beta\gamma}q_{1\alpha}q_{2\beta}q_{3\gamma}$

F_4 is the scalar current $J^P=0^+$ (negligible)

Kuhn, Mirkes, Z.PhysC56, 661(1992)

Structure of tau to 3hν Decays

- Integrate over ν direction
- Two remaining Euler angles are kinematically determined
- $d\Gamma(\tau \to KK\pi)/dQ^2 ds_1 ds_2 \propto W_A(F_1,F_2)+W_B(F_3)$
- No interference between Axial and WZ term
- Measurement possible entirely by using Dalitz plot and Q^2

The Physics We Fit

Decker etal, ZPhysC.58,445(1993)

Finkemeir & Mirkes, ZPhysC69, 243(1996)

$a_1 \rightarrow \rho^{(\prime)}\pi$, $\rho^{(\prime)} \rightarrow KK$

$$F_1 \propto BW_{a1}(Q^2) \times \left(BW_{\rho}(s_2) + \beta_{\rho} BW_{\rho'}(s_2) \right)$$

$a_1 \rightarrow K^*K$, $K^* \rightarrow K\pi$

$$F_2 \propto \boxed{R_F}\, BW_{a1}(Q^2) \times BW_{K^*}(s_1)$$

$\rho^{(\prime,\prime\prime)} \rightarrow K^*K$, $K^* \rightarrow K\pi$ $\qquad$ $\rho^{(\prime,\prime\prime)} \rightarrow \omega\pi$, $\omega \rightarrow KK$

$$F_3 \propto \boxed{R_B^{1/2}}\,(BW_{\rho}(Q^2) + \boxed{\lambda}\, BW_{\rho'}(Q^2) + \boxed{\delta}\, BW_{\rho''}(Q^2)) \times$$
$$(BW_{\omega}(s_2) + \boxed{\alpha}\, BW_{K^*}(s_1))$$

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 $\tau \to 3h\nu$ analysis
- 2255 signal events, $256 \pm 16 \pm 46$ 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
- ≈1/2 is from WZ

$\alpha=0.471\pm0.060\pm0.034$

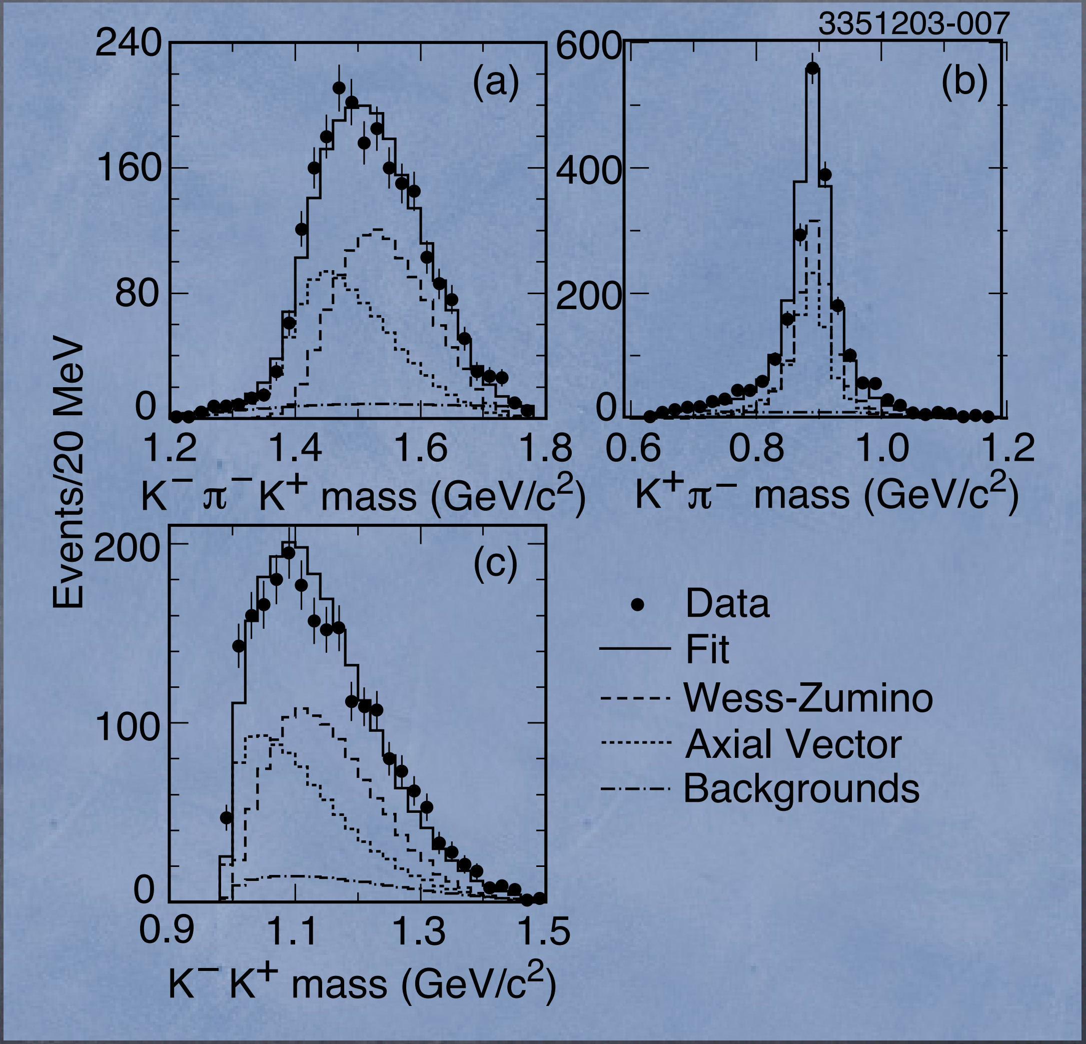
$\lambda=-0.314\pm0.073\pm0.080$

$\delta=0.101\pm0.020\pm0.156$

$R_B=3.23\pm0.26\pm1.90$

$R_F=0.98\pm0.15\pm0.36$

$$\frac{\Gamma_{WZ}}{\Gamma_{Tot}}=55.7\pm8.4\pm4.9\%$$



Substructure Result

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

$R^{\omega\pi}_{WZ} = 3.4 \pm 0.9 \pm 1.0\%$ $R^{\rho^{(,)}\pi}_{Axial} = 2.50.8 \pm 0.4\%$

$R^{K^*K}_{WZ} = 60.8 \pm 8.5 \pm 6.0\%$ $R^{K^*K}_{Axial} = 46.8 \pm 8.4 \pm 5.2\%$

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

B(a1 to K*K)=2.2±0.5% consistent w/ previous CLEO $\pi\pi^0\pi^0$ result

Axial component much smaller than ALEPH CVC estimate

Angular Distributions

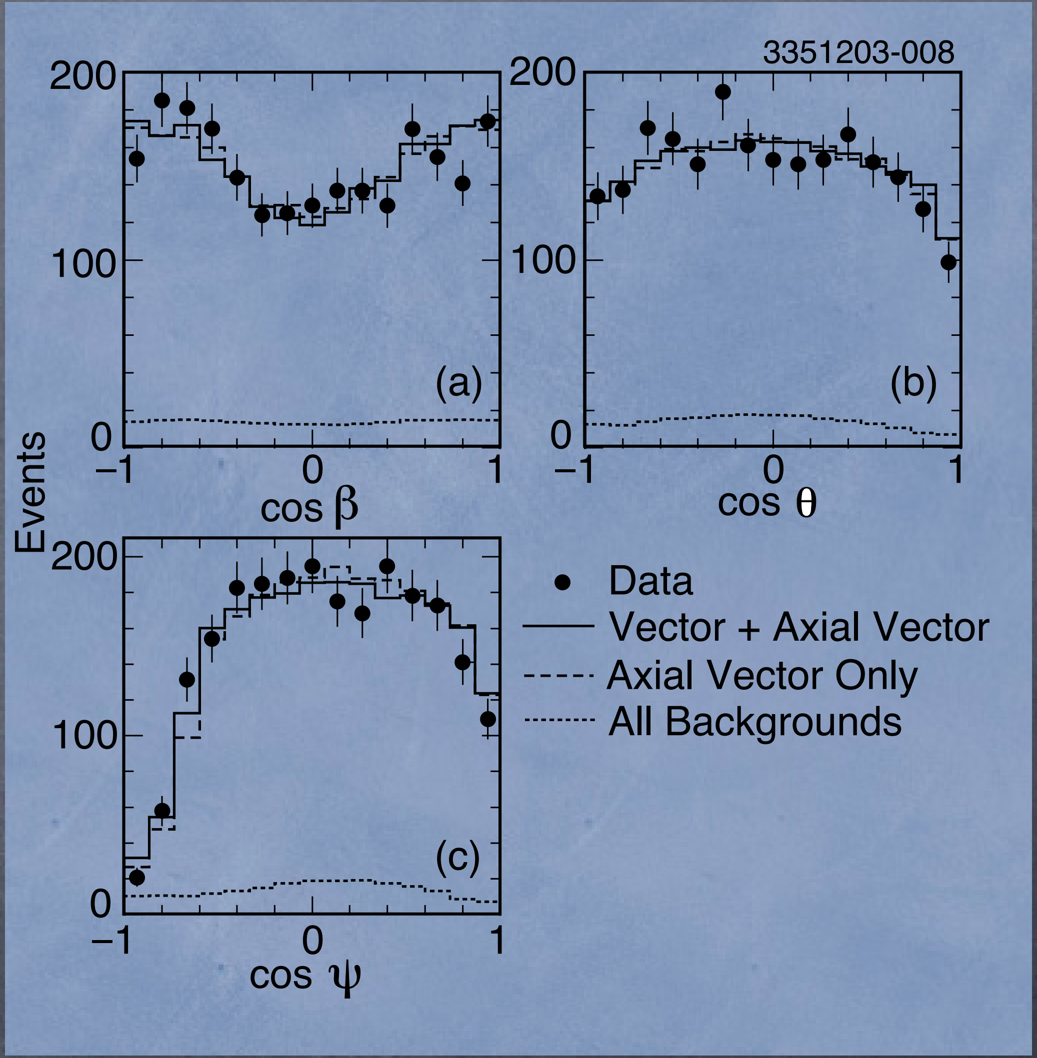
β: ∠ P(KKpi) in lab frame, $p_K \times p_\pi$

θ: ∠ P(τ) in lab, P(KKπ) in τ frame

ψ: ∠ P(τ), P(lab) in KKπ 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 explicit $B(\tau\rightarrow 3\pi\nu)$ result
- ✓ $B(\tau\rightarrow K\pi\pi\nu)$ consistent w/OPAL and CLEO, higher than ALEPH
- ✓ Most stringent limit on $\tau\rightarrow KKK\nu$
- ✓ Best precision on $B(\tau\rightarrow KK\pi\nu)$

- ✓ First Study of WZ and Axial parts of $\tau\rightarrow KK\pi\nu$
- ✓ Breakdown of $KK\pi$ in Kuhn+Mirkes model