Recent Tau Decay Results from OPAL

EPS 1997, Jerusalem

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- $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau$ and $\tau \rightarrow \mu\bar{\nu}_\mu\nu_\tau\gamma$
- Studies of the $a_1(1260)$
- Strangeness Content in multi-prong tau decays
- Limit on 7-prong decays of the tau

$\tau \rightarrow \mu \bar{\nu}_\mu \nu_\tau$

LEPTONINC COUPLINGS: FUNDAMENTAL TO S.M.

$\Rightarrow$ STRINGENT TEST

LEPTON UNIVERSALITY: $g_\tau = g_\mu = g_e$

$\Rightarrow$ BRs, Masses and Widths of e, μ, τ

OPAL 1991-94 data: B$_e$= $(17.78 \pm 0.10 \pm 0.09)$% (0.007)

τ_τ= $289.2 \pm 1.7 \pm 1.2$fs (0.007)

PRELIMINARY 1991-94 ANALYSIS OF B($\tau \rightarrow \mu \bar{\nu}_\mu \nu_\tau$)

GOAL : $< 1\%$ measurement

$\rightarrow$ ONLY VERY WELL MODELLED REGIONS OF DETECTOR USED

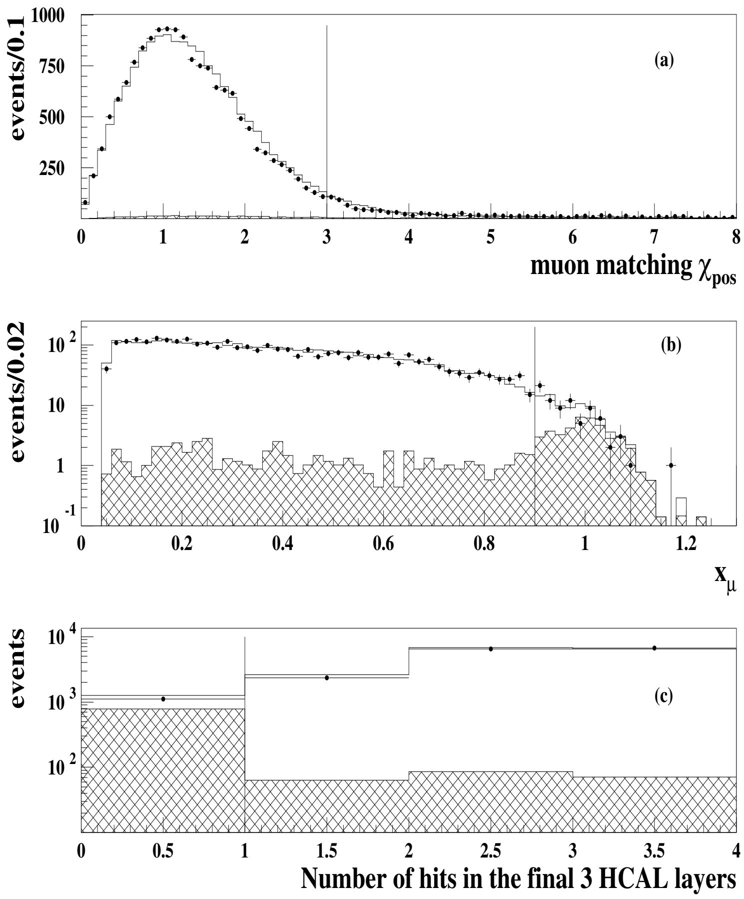
$\rightarrow$ DETERMINE EFFICIENCY AND PURITY WITH DATA

$\rightarrow$ KEEP PROBLEMATIC BACKGROUND LOW:
CUT VERY HIGH AND VERY LOW ENERGY MUONS

TWO SELECTIONS:

(M) MUON CHAMBERS + TRACKING ONLY

(C) ECAL + HCAL + TRACK-ECAL MASS



USE (C) TO CORRECT MC EFFICIENCIES OF (M)

$\Rightarrow$ CHECK TECHNIQUE WITH CONTROL SAMPLES

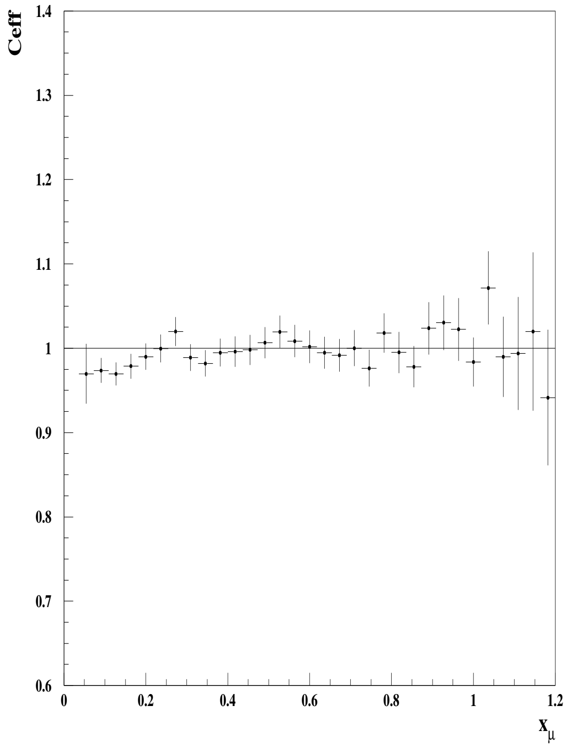
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-$ good to $< 1\%$

$e^+e^- \rightarrow \mu^+\mu^-$ good to $< 0.3\%$

$\Rightarrow$ CHECK INDEPENDENCE OF SAMPLES:

$$\frac{\epsilon_{BOTH}}{\epsilon_{(C)}\epsilon_{(M)}} = 1.00 \qquad \text{Good to} \sim 1\%$$

$$C_{eff} = \left(\frac{(C)AND(M)}{(C)}\right)^{DATA} / \left(\frac{(C)AND(M)}{(C)}\right)^{MC}$$



Statistics from DATA $\rightarrow$ Final Data statistics

Background Systematics of Correction:

Loosen cuts $\rightarrow$ $\times$ 2 increase in background

$\Rightarrow$ NO SIGNIFICANT CHANGE

Background Systematics Error:

Enhance background in sample and correct MC by data

Error: MAX(statistics, 1/2 size of correction)

Largest systematic errors:

$\tau \rightarrow \pi$(K)ν_τ and $\tau \rightarrow \rho\nu_\tau$(statistical)

multihadron background in tau sample: modelling of B**.

	91-92	93	94
N^{τ}_{Cand} $N^{\tau\to\mu\nu\bar{\nu}}_{Cand}$	31201 4777	20759 3287	48782 7647
f^{τ}_{Bkgd}(%)	1.10 ± 0.16	1.21 ± 0.18	1.09 ± 0.29
$f^{\tau\to\mu\nu\bar{\nu}}_{Bkgd}$(%) $\epsilon^{\tau\to\mu\nu\bar{\nu}}$(%) $F^{\tau\to\mu\nu\bar{\nu}}_{Bias}$	2.65 ± 0.37 89.54 ± 1.28 0.9800 ± 0.0012	2.31 ± 0.45 90.78 ± 1.56 0.9806 ± 0.0012	2.49 ± 0.29 89.41 ± 1.01 0.9800 ± 0.0009
B($\tau \to \mu\nu\bar{\nu}$)	$17.18 \pm 0.22 \pm 0.07$	$17.59 \pm 0.27 \pm 0.09$	$17.64 \pm 0.18 \pm 0.08$

$$B(\tau \to \mu\nu\bar{\nu}) \equiv \frac{N^{\tau\to\mu\nu\bar{\nu}}_{Cand}}{N^{\tau}_{Cand}} \cdot \frac{(1 - f^{\tau\to\mu\nu\bar{\nu}}_{Bkgd})}{(1 - f^{\tau}_{Bkgd})} \cdot \frac{1}{\epsilon^{\tau\to\mu\nu\bar{\nu}}} \cdot \frac{1}{F^{\tau\to\mu\nu\bar{\nu}}_{Bias}}$$

B($\tau \to \mu\bar{\nu}_\mu\nu_\tau$) = ($17.48 \pm 0.12 \pm 0.08$)% (rel. error=0.8%)

GOOD AGREEMENT WITH W.A.

without OPAL: (17.31 ± 0.08)% (TAU96 Colorado)

GOOD AGREEMENT WITH ALEPH: $(17.31 \pm 0.11 \pm 0.05)$%

NEW WA: (17.354 ± 0.071)% (rel. error=0.4%)

e-μ UNIVERSALITY:

OPAL $\frac{g_\mu}{g_e} = 1.005 \pm 0.005$

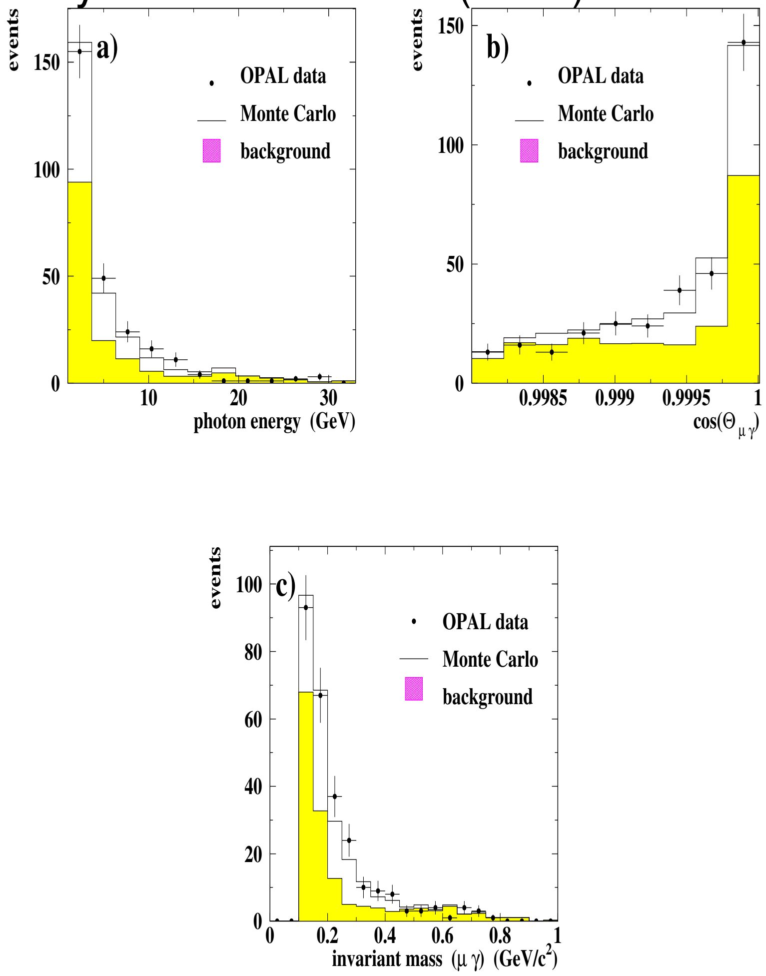
NEW τ W.A. $= 1.0016 \pm 0.0027$ (opal weight=30%)

π-decay W.A. $= 1.0012 \pm 0.0015$

OVERALL W.A. $= 1.0013 \pm 0.0013$ (opal weight=7%)

$\tau \to \mu\bar{\nu}_\mu\nu_\tau\gamma$

Physics Letters B388 (1996) 437-449



B($\tau \to \mu\bar{\nu}_\mu\nu_\tau\gamma$) = $(3.0 \pm 0.4 \pm 0.5) \times 10^{-3}$ E$^*_\gamma > 20$MeV

GOOD AGREEMENT WITH QED MONTE CARLO:

2.82×10^{-3}

GOOD AGREEMENT WITH MARK II MEASUREMENT:

OPAL: B($\tau \to \mu\bar{\nu}_\mu\nu_\tau\gamma$) = $(2.7 \pm 0.6) \times 10^{-3}$ E$^*_\gamma > 37$MeV

MARK II: B($\tau \to \mu\bar{\nu}_\mu\nu_\tau\gamma$) = $(2.3 \pm 1.1) \times 10^{-3}$ E$^*_\gamma > 37$MeV

Hadronic Current and h_{ν_τ} in $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$

CERN-PPE/97-020, Zeit. fur Physik C (in press)

STRONG INTERACTION:

o G-parity ($\pi^-\pi^-\pi^+$) = -1 $\Rightarrow$ rules out vector current (G=+1)

o PCAC $\Rightarrow$ suppresses pseudo-scalar currents

AXIAL-VECTOR CURRENT:

$a_1(1260)$ $I^G(J^{PC}) = 1^-(1^{++})$

$a_1 \rightarrow \rho\pi$ dominant

$a_1 \rightarrow \pi\gamma$ seen

$a_1 \rightarrow \pi K\bar{K}^*(892)$ possibly seen

mass and width have historical 'difficulty'

USE OPAL'S 1992-94 DATA (10^5 tau pairs) $\Rightarrow$ SEE HOW WELL $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$ SYSTEM IS UNDERSTOOD

NOTE:

- a_1 is used in $\mathcal{A}_\tau$ and $\mathcal{A}_e$ measurements at LEP
- Low Q^2 properties predicted by CHPT
- models needed in resonance region

$$d\Gamma(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau) = \sum_{\mu\nu} \frac{G_F^2}{4m_\tau} \cos\theta_c L_{\mu\nu} H^{\mu\nu} \, dPS^{(4)}$$

$$= \sum_X \frac{G_F^2}{4m_\tau} \cos\theta_c L_X W_X dPS^{(4)}$$

$L_{\mu\nu}$ and $H^{\mu\nu}$ $\to$ symmetric and antisymmetric functions:

9 symmetric (X=A,B,...I)

7 antisymmetric (X=AS,AB,...AG)

LEPTONIC FUNCTIONS: L_X(P_τ, γ_{VA}, Q^2, 4 decay angles)

HADRONIC STRUCTURE FUNCTIONS: W_X(Q^2, s_1,s_2)

P_τ = -0.144 $\pm$ 0.003 from Standard Model fits (LEP/SLD/TEVETRON/νN)

γ_{VA} = $\frac{2g_V g_A}{g_V^2+g_A^2}$

= 1 for left handed neutrinos

$$Q^2 = (p_{\pi^-_1} + p_{\pi^-_2} + p_{\pi^+})^2$$
$$s_1^2 = (p_{\pi^-_1} + p_{\pi^-_2})^2 \qquad |p_{\pi^-_1}| > |p_{\pi^-_2}|$$
$$s_2^2 = (p_{\pi^-_1} + p_{\pi^+})^2$$

PURE AXIAL VECTOR CURRENT

$\Rightarrow$ 16 $\to$ 4 structure functions: W_A, W_C, W_D, W_E

NO PRECISE THEORY FOR $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$

MODELS WITH PARAMETERS TUNED USING DATA

GOALS:

- Compare Dalitz distributions of data and models
- Measure M_{a_1} and Γ_{a_1} (model dependent)
- Measure W_X Structure Functions: Check G-parity conservation and PCAC; how well models perform
- Measure ν_τ helicity via γ_{VA}

Consider TWO Models:

- KS (Kühn and Santamaria, Z.P. C48, 1990)
  - point-like strong form-factors
  - lowest dimensional Born term
  - include $\rho(1450)$
- IMR (Isgur, Morningside and Reader, P.R.D39, 1989)
  - strong form-factors with off-shell dependence (flux tube)
  - D/S: ratio of 2 angular momentum states of $\rho\pi$ system
  - $\mathrm{K\bar{K}}^*(892)$ contributes to total width
  - 3-parameter polynomial term: allow for non-resonant component and model deficiencies

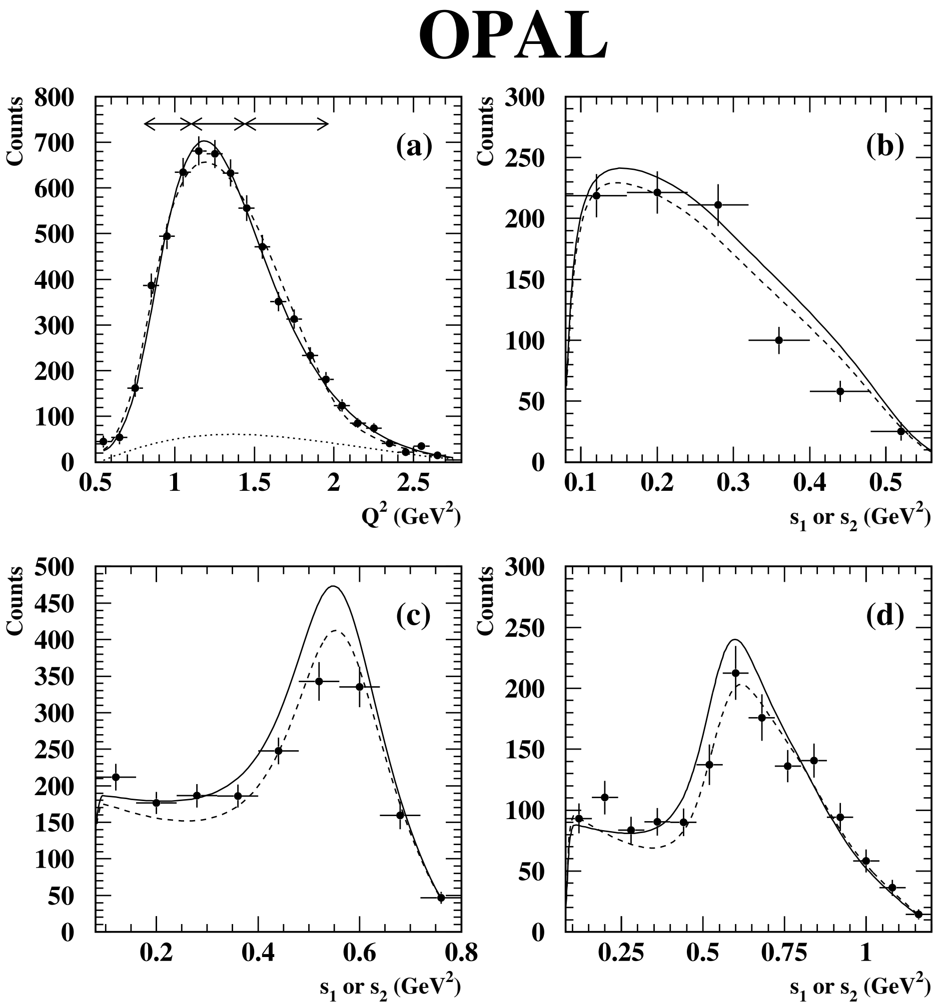
SELECT $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$ SAMPLE

$\sim$ 40% efficiency within $|\cos\theta_\tau| < 0.95$

7443 decays selected, 85% Pure

DATA corrected for efficiency and background;

detector resolution folded into Models



KS fit (solid) to Q^2 distribution only: 10% normalisation ‘problem’

IMR fit (dashed) to all: polynomial background term in Q^2

compensates the normalization ‘problem’

	KS	IMR
M_{a_1} (GeV)	$1.262 \pm 0.009 \pm 0.007$	$1.210 \pm 0.007 \pm 0.017$
Γ_{a_1} (GeV)	$0.621 \pm 0.032 \pm 0.058$	$0.457 \pm 0.015 \pm 0.017$
D/S amplitude ratio	—	$-0.10 \pm 0.02 \pm 0.02$
$\chi^2/d.o.f.$	$25.2/20$ (3π) $111/49$ (global)	— $91.9/45$ (global)
polyn, bkgrnd frac	—	$(13.8 \pm 2.4)\%$

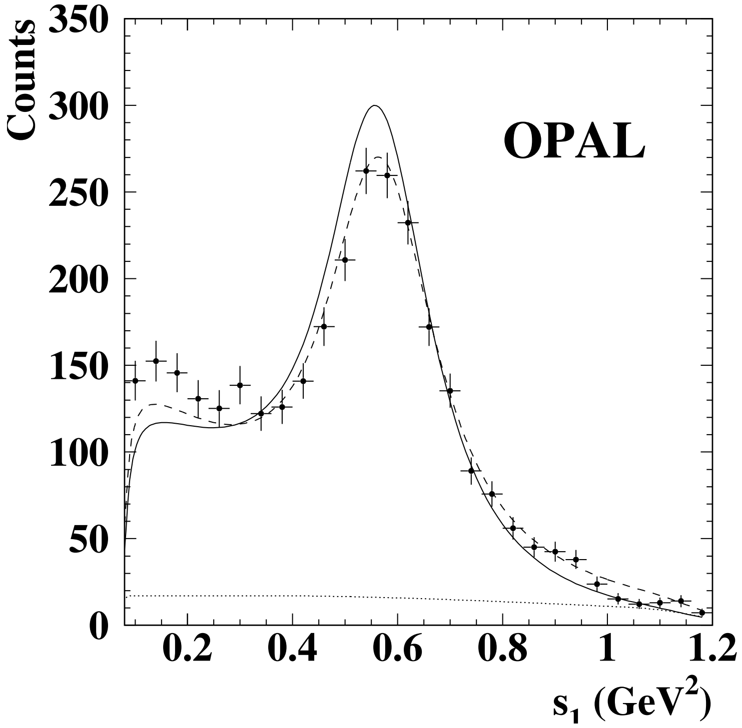
Γ_{a_1} and the D/S amplitude ratio for the IMR model are calculated quantities, not parameters of the fit.

Major background is $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu_\tau$

systematics from modelling of this checked with high purity sample.

KS AND IMR: REASONABLE MODELLING OF Q^2 DISTRIBUTION

BUT IMPRECISE MODELLING OF S$_1$,S$_2$ DISTRIBUTION DETAILS



MODEL INDEPENDENT MEASUREMENTS OF STRUCTURE FUNCTIONS

(follow formalism of Kühn and Mirkes Z.P. C48, 1990)

Bin data in Q^2, s_1 and s_2 then calculate for each decay i in bin j:

$$\frac{d\Gamma}{dz}(z_i, W_X^j)$$

$dz = dQ^2\ ds_1\ ds_2\ d\vec{\alpha}_{decay}$

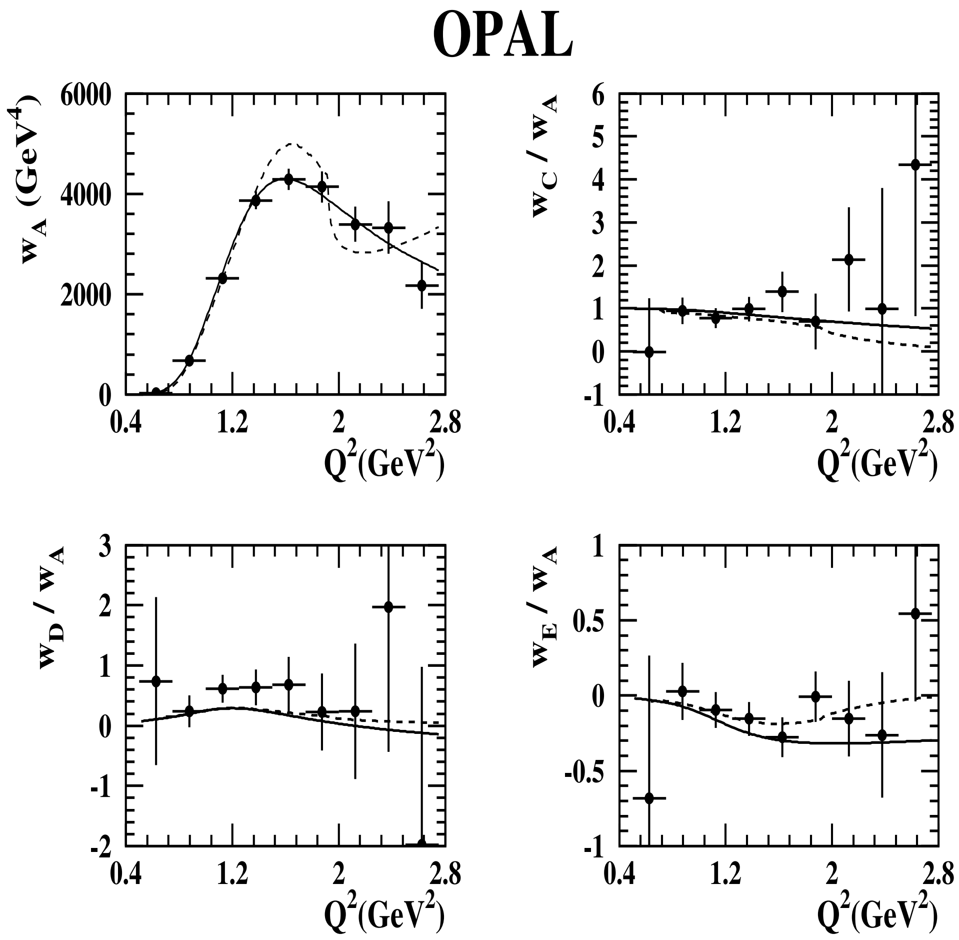
W_X^j: average values of W_X within bin j, obtained from extended maximum likelihood fit to data in each bin.

Detector efficiencies and resolution, bin migrations and background all taken into account.

NO MODELS USED BUT ASSUME PURE AXIAL VECTOR CURRENT

Present: $w_X(Q^2) = \int W_X(s_1, s_2, Q^2)\, ds_1\, ds_2$

Most significant systematic errors: migration and background from $\tau \to$ K$\bar{\text{K}}^* \nu_\tau$and $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu_\tau$.



OVERLAY the KS (solid) and IMR (dashed) model predictions

GOOD AGREEMENT for w_X/w_A, X=B,C,D for both models

KS describes w_A well (χ^2/bin=6.2/9)

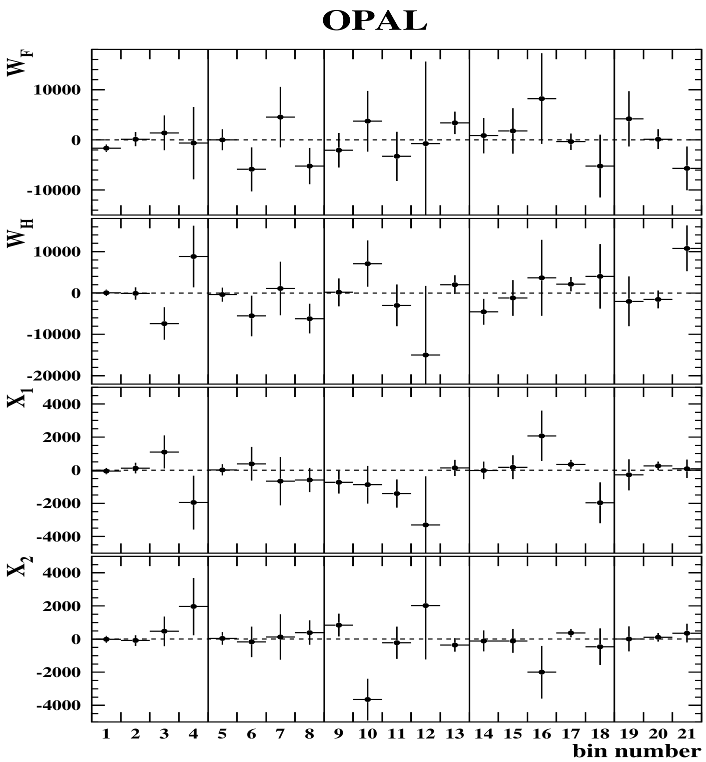
IMR disprepancy in w_A (χ^2/bin=16.9/9)

Failure of a$_1 \to$ K$\bar{\text{K}}^*$modelling in IMR model?

IS IT ALL AXIAL VECTOR?

$W_F, W_H, X_1(W_G, W_{SD}), X_2(W_I, W_{SB})$ non-zero if pseudo-scalar and vector components present.

INCLUDE THEM IN THE FIT:



PURE Axial Vector Hypothesis: $\chi^2/dof = 81.2/84$

FIRST MODEL INDEP. LIMIT ON NON-AV COMPONENT:

IF PURE Axial Vector THEN: $W_A^2 = W_C^2 + W_D^2 + W_E^2$

$$\frac{\Gamma^{non-AV}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)}{\Gamma^{total}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)} < 26.1\%$$

MODEL DEPEND. LIMIT ON SCALAR COMPONENT

USING KS AND IMR DESCRIPTION OF $\tau^- \to \pi(1300)\nu_\tau$;

$\pi(1300) \to \rho^0\pi^-\nu_\tau$:

$$\frac{\Gamma^{PScaler}(\tau^- \to \pi(1300)\nu}{\Gamma^{total}(\tau^- \to \pi^-\pi^-\pi^+\nu_\tau)} < 0.84\%$$

NEUTRINO HELICITY:

$\gamma_{VA} \rightarrow$ free parameter in structure function fits

1) MODEL INDEPENDENT (pure Axial Vector current constraint):

$$\gamma_{VA} = 1.29 \pm 0.26 \pm 0.11$$

(systematics: resolution and background with kaons)

2) KS MODEL constrained W_X

$$\gamma_{VA} = 0.87 \pm 0.16 \pm 0.04$$

3) IMR MODEL constrained W_X

$$\gamma_{VA} = 1.20 \pm 0.21 \pm 0.14$$

$\Rightarrow$ unambiguous determination of the Sign of the neutrino helicity.

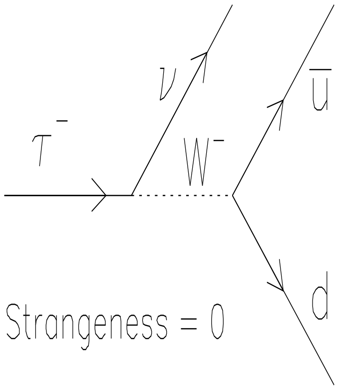
WARNING:

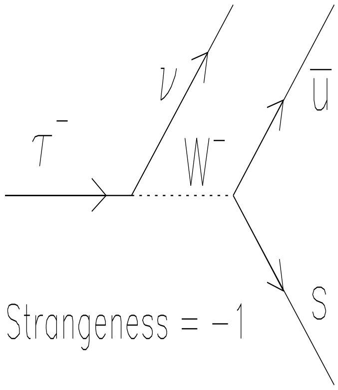
MODEL DEPENDENCE IS EVIDENT HERE. POSSIBLE PROBLEM FOR PRECISION MEASUREMENTS RELYING ON MODELLING OF $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$

Strangeness Content in Multi-prong Tau Decays

- CHPT and effective Lagrangians
- SU(3)$_F$ and isospin symmetries
- R$_{\tau,S}$ + QCD $\longrightarrow$ s-quark mass
- structure of the hadronic current
- dynamics and rates $\longrightarrow$ engineering for other measurements

MODE	DOMINANT MEASUREMENT (%)	CALCULATIONS
$\tau^- \to \nu_\tau K^- \pi^+ \pi^- \geq 0\pi^0$	0.275 ± 0.064 (ALEPH)	0.18 (Li) 0.35-0.45(Mirkes) 0.77 (Finkemeir/Mirkes)
$\tau^- \to \nu_\tau K^- K^+ \pi^- \geq 0\pi^0$	0.238 ± 0.042 (ALEPH)	0.20/0.08 (Finkemeir et al)
$\tau^- \to \nu_\tau K^0_S K^0_S \pi^- \geq 0\pi^0$	0.092 ± 0.023 (CLEO)	0.20/0.08 (Finkemeir et al)





$\tau^- \to \nu_\tau K^+ \pi^- \pi^- \geq 0\pi^0$ highly suppressed

PRELIMINARY OPAL RESULTS 90-95 DATA (200k τ-pairs)

$\tau^- \to \nu_\tau K^- \pi^+ \pi^-$ $\qquad$ $\tau^- \to \nu_\tau K^+ K^- \pi^-$

STANDARD OPAL τ-pair barrel selection

3-track sample: remove K^0_S and conversions

ID charged kaons with dE/dx:

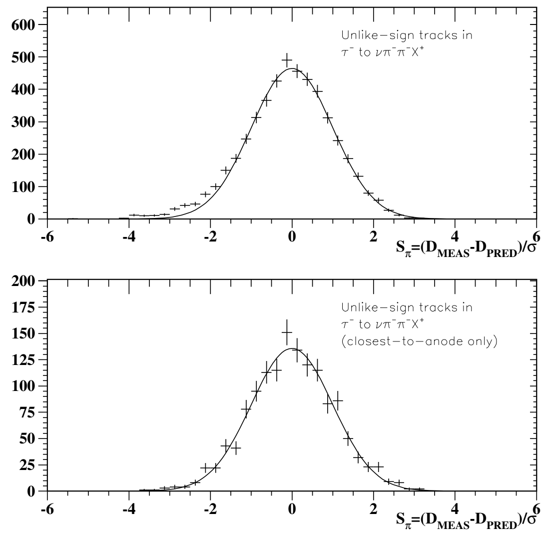
VERY HIGH QUALITY TRACKS FOR MEASUREMENT

- barrel region
- CLOSEST-TO-ANODE PLANE TRACKS ONLY
- high resolution z
- momentum $>$3 GeV

Special re-calibration of dE/dx (μ controls)

1400 π^+ tracks in $\tau^- \to \pi^- \pi^- X^+$ event sample: $X^+ = \pi^+$

pure π sample $\to$ same tracking environment



TAILS IN ALL-TRACK SAMPLE REDUCED IN FIRST-TRACK SAMPLE

SEPARATE SAMPLE INTO:

LIKE-SIGN FIRST TRACKS $\Rightarrow \tau^- \to \nu_\tau K^- \pi^+ \pi^-$

UNLIKE-SIGN FIRST TRACKS $\Rightarrow \tau^- \to \nu_\tau K^- K^+ \pi^-$

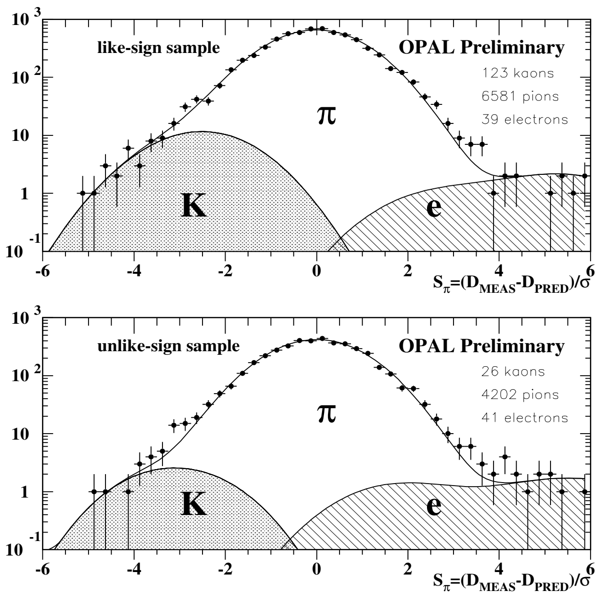
ANALYSIS ASSUMES BR($\tau^- \to \nu_\tau K^+ \pi^- \pi^-$) = 0

dE/dx event-by-event Maximum Likelihood fit

$\to$ fractions of e, π, K in 2 samples in momentum bins

GAUSSIAN IS INSUFFICIENT TO DESCRIBE DATA:

TAILS ARE EVIDENT IN REGION OF KAON PEAK



INSTEAD USE PROBABILITY DISTRIBUTION FROM 1400

π^+ tracks in $\tau^- \to \pi^- \pi^- \pi^+$ DATA sample IN LIKELIHOOD FIT

STUDY SELECTION SENSITIVITY TO RESONANCE

STRUCTURE IN $\tau^- \to \nu_\tau K^- \pi^+ \pi^-$:

$\tau^- \to \nu_\tau K_1(1400) \to \nu_\tau K^*(892)\pi^-$; $\nu_\tau \rho\, K^-$

$\tau^- \to \nu_\tau K_1(1270) \to \nu_\tau K^*(892)\pi^-$; $\nu_\tau K^*(1430)\pi^-$; $\nu_\tau \rho\, K^-$

Allow for systematic errors on states with π^0.

EXTRACT BRANCHING RATIOS FROM:

$$\frac{(N_{\mathrm{K}}^{j} - N_{\mathrm{bkgnd}}^{j})}{N_{\tau}^{\mathrm{pre-sel}}(1 - f^{\mathrm{non-}\tau})} = \epsilon_j^{\mathrm{K}\pi\pi}\mathrm{B}_{\mathrm{K}\pi\pi} + \epsilon_j^{\mathrm{K}\pi\mathrm{K}}\mathrm{B}_{\mathrm{K}\pi\mathrm{K}}$$

	like-sign	unlike-sign	$\mathrm{K}^-\pi^-\mathrm{K}^+$ enhanced	$\mathrm{K}^-\pi^-\mathrm{K}^+$ depleted
N_{K}	$96.2^{+19.0+7.6}_{-17.4-8.8}$	$13.4^{+14.0+6.8}_{-12.5-6.1}$	$23.4^{+13.2+4.7}_{-11.8-4.3}$	$-13.8^{+11.0+4.4}_{-9.6\ -4.1}$
N_{bkgnd}	7.1 ± 2.5	2.2 ± 2.1	2.1 ± 2.1	0.2 ± 0.2
$\epsilon^{\mathrm{K}\pi\pi}$	0.106 ± 0.003	0.001 ± 0.000	0.000 ± 0.000	0.000 ± 0.000
$\epsilon^{\mathrm{K}\pi\mathrm{K}}$	0.085 ± 0.005	0.138 ± 0.006	0.130 ± 0.006	0.009 ± 0.002
$\epsilon^{\pi\pi\mathrm{K}}$	0.001 ± 0.000	0.138 ± 0.006	0.057 ± 0.005	0.081 ± 0.004
$\sigma(\epsilon^{\mathrm{K}\pi\pi})$ sys	$^{+0.016}_{-0.006}$			

LARGEST SYSTEMATIC ERRORS FROM EFFICIENCY AND dE/dX PARAMETERISATION

RESULTS:

B($\tau^- \to \nu_\tau$K$^-\pi^+\pi^- \geq 0\pi^0$) = $(0.358 \pm^{0.089}_{0.084} \pm^{0.046}_{0.065})$%

GOOD AGREEMENT WITH W.A.: (0.314 ± 0.054)%

B($\tau^- \to \nu_\tau$K$^-$K$^+\pi^- \geq 0\pi^0$) = $(0.036 \pm^{0.047}_{0.042} \pm^{0.024}_{0.022})$%

AGREES WITH DELCO & TPC/2γ: (0.165 ± 0.080)%

POOR AGREEMENT WITH ALEPH: (0.238 ± 0.042)%

BELOW FINKEMEIR et al CALCULATION (0.20%) BY 3σ

$\tau^- \to \nu_\tau K^0_S 2h^- h^+$

STANDARD OPAL τ-pair barrel selection

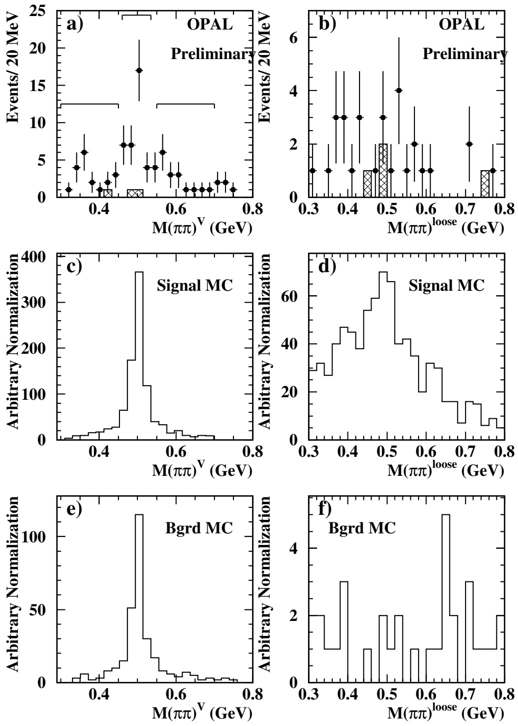
o Remove $q\bar{q}$: require N_1=1-track

o N_2=5-track sample: remove conversions

o Select decays with one clean K^0_S

BR($\tau^- \to \nu_\tau K^0_S 2h^- h^+$) = $(0.054 \pm 0.030 \pm 0.015)\%$

M($\pi^-\pi^+$) of remaining data consistent with K^0_S hypothesis



Consistent with CLEO result that $\tau^- \to \nu_\tau K^0_S 2h^+ \pi^-$ is predominantly $\tau^- \to \nu_\tau K^0_S K^0_S \pi^-$.

If interpret as $\tau^- \to \nu_\tau K^0_S K^0_S \pi^- \Rightarrow$ consistent with CLEO:

BR($\tau^- \to \nu_\tau K^0_S K^0_S \pi^-$) = $(0.023 \pm 0.005 \pm 0.003)\%$

Consistent with Finkemeir and Mirkes calculation: 0.048%

Limit on 7-Prong decays of the τ

CERN-PPE/97-049, Phys. Lett. B (in press)

NO PRECISE PREDICTIONS AVAILABLE

1990-1995 OPAL DATA: 210k τ-pairs

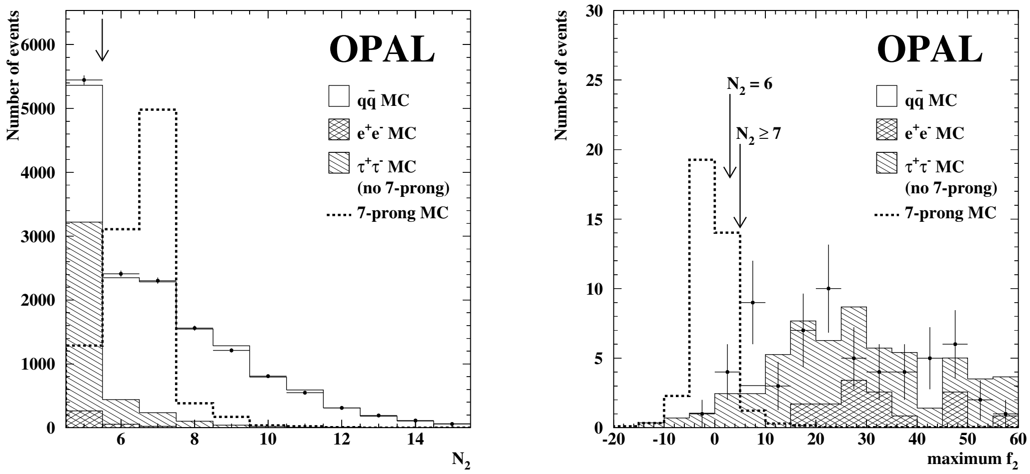
Select: N_1=1,3 AND $N_2 \geq 6$

Suppress:

multihadrons: mass cut, maximum opening angle cuts

τ and e^+e^- backgrounds: dE/dx using $f_2 = \log(P(e)/P(\pi))$

$$\sum ECAL/\sum P$$



Efficiency=41.0$\pm$1.8%

Expected Background=$0.5^{+1.0}_{-0.3}$ events

No. of events in sample= 0.

BR($\tau^- \to 4\pi^- 3\pi^+ \nu_\tau$(n$\geq$ 0))$<$ 1.4$\times 10^{-5}$ @ 90%CL

HRS Previous limit: 1.9$\times 10^{-4}$ @ 90%CL

Summary

- BR($\tau \to \mu\bar{\nu}_\mu\nu_\tau$) precision well below 1%. e-μ Universality tests @ 0.13% level. decay radiation well understood

- Studies of the a_1(1260): evidence for failure in details of popular models... caveat emptor
  First model independent limit on non-AV current;
  left-handedness of tau neutrino clearly evident.

- Strangeness Content in multi-prong tau decays:
  Measurements consistent in $K^-\pi^+\pi^-$ and $K^0_S K^0_S \pi^-$.
  But OPAL measures lower $K^-K^+\pi^-$ rate than ALEPH.

- 10$\times$ improvement on limit of 7-prong decays of the tau: 1.4×10^{-5}@90%CL