Tau Physics at LEP: Status and Potential

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Tau Charm Workshop
SLAC
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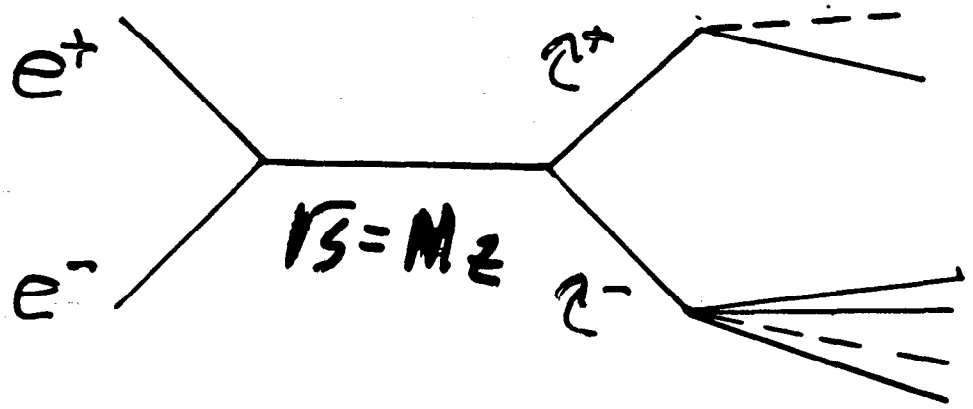
τ - PHYSICS AT LEP



τ PRODUCTION

$\sigma_{\tau\tau} \Rightarrow g_V^2 + g_A^2$

A_{FB}^{τ}

$\langle P_\tau \rangle$

$P_\tau(\cos\theta)$

$\Big\}$ g_V/g_A for e & τ

⋮

τ DECAY

LIFETIME

BR's: $\ell \nu \bar{\nu}$

$h \nu X$

KAONS

$\alpha_s(M_\tau) \rightarrow \alpha_s(M_Z)$

MICHEL PARAMETERS

M_{ν_τ} LIMIT

⋮

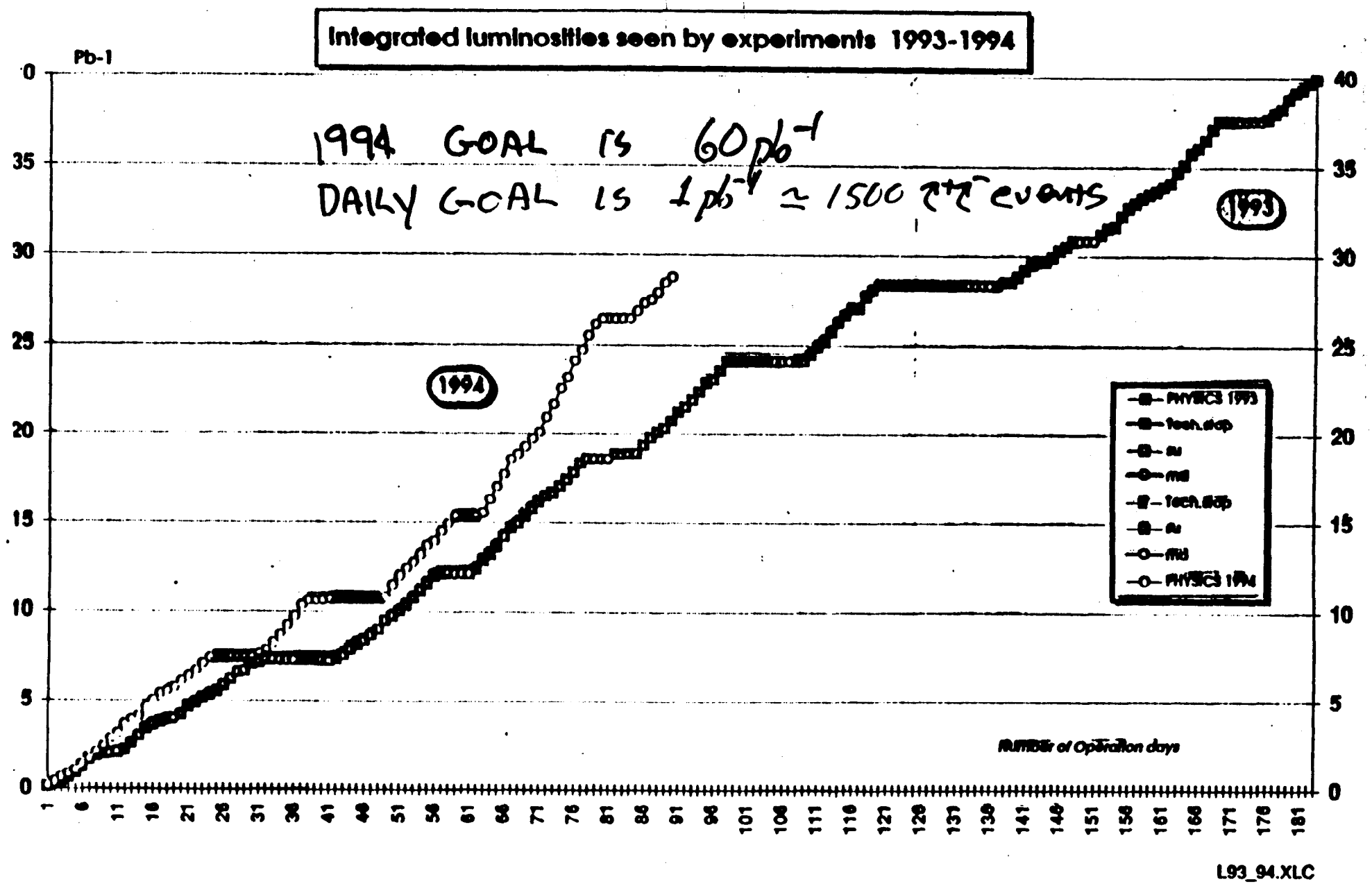
OUTLINE

- LEP PERFORMANCE IN 1994.
- EXTRAPOLATION TO END LEP-I.
- τ'S AT $\sqrt{s} = M_Z$
- NEUTRAL CURRENT MEASUREMENTS

- MICHEL PARAMETERS
- LIFETIME
- $BR(\ell \nu \bar{\nu})$

} UNIVERSALITY IN DECAY

- BR'S $(h \nu X)$
- BR'S $(K \nu X)$
- TOPOLOGICAL BR'S
- α_s
- M_{ν_τ}
- SUMMARY


Integrated luminosities seen by experiments 1993-1994
Pb-1
1994 GOAL IS 60 pb⁻¹
DAILY GOAL IS 1 pb⁻¹ ≃ 1500 τ⁺τ⁻ events
1994
1993
PHYSICS 1993
Tech.stop
PHYSICS 1994
Number of Operation days
L93_94.XLC

τ's AT LEP

'89-'91	~23,000	$\tau^+\tau^-$ PAIRS PRODUCED/EXPT.
'92	~35,000	
'93	~32,000	

SO FAR in '94 ~ 40,000 HOPE FOR 60-70,000

ESTIMATE '95, '96 ~40-80,000

TODAY'S RESULTS

'89-'93 DATA ← AT MOST. ~90,000 $\tau^+\tau^-$ PAIRS PRODUCED/EXPT.

EXTRAPOLATE TO END LEP-I

~190,000 - 240,000 / EXPT.

- $\mathcal{L}$ USED TO DATE
- LATEST SYSTEMATICS WITH
  - KNOWN IMPROVEMENTS
  - REASONABLE ESTIMATES

    eg: REDUCE MC STATS

τ SELECTION AT $\sqrt{s} = M_Z$

- τ's ARE HIGHLY BOOSTED
- BACKGROUNDS ARE LOW

FOR AN INCLUSIVE $\tau^+\tau^-$ EVENT SELECTION ($\sigma_{\tau\tau}$, A_{FB}):

$$\varepsilon_{\tau\tau}^{SEL} \simeq 70-80\% \quad (\text{in } 4\pi)$$

$$BCK \simeq 1/2 - 1\%$$

FOR PARTICULAR DECAY MODES:

$\ell\nu\bar{\nu}$: $\varepsilon^{SEL} \simeq 50-70\%$

$BCK-\cancel{\tau} \simeq 1-3\%$

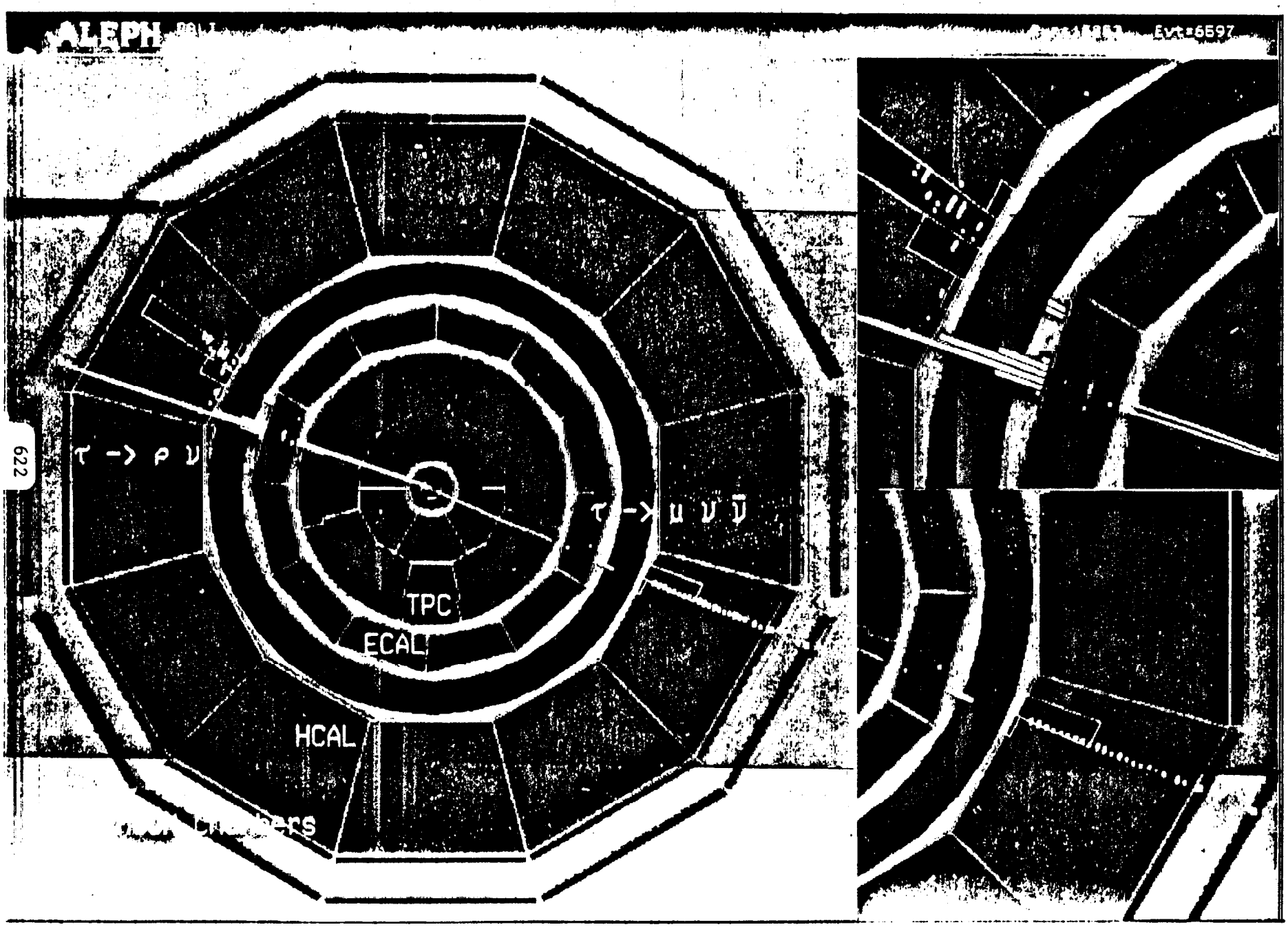
$BCK-\tau \simeq 1-5\%$

$h\nu X$: $\varepsilon^{SEL} \simeq 25-60\%$

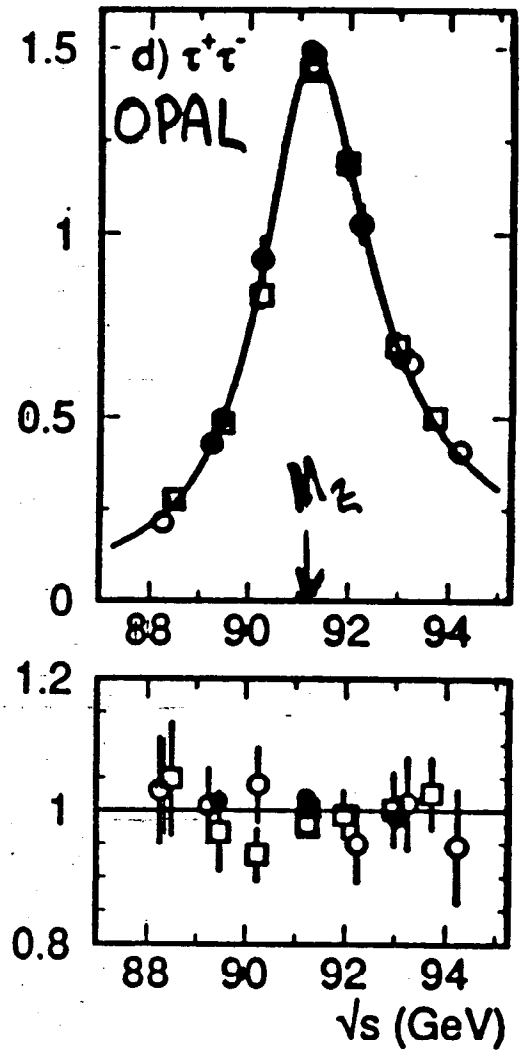
$BCK-\cancel{\tau} \simeq 0-2\%$

$BCK-\tau \simeq 6-15\%$

OR MUCH HIGHER FOR MULTI-π^0 DECAY MODES


ALEPH
Evt:6597
τ -> ρ ν
τ -> μ ν ν̄
TPC
ECAL
HCAL

CROSS-SECTION AND A^{τ}_{FB}

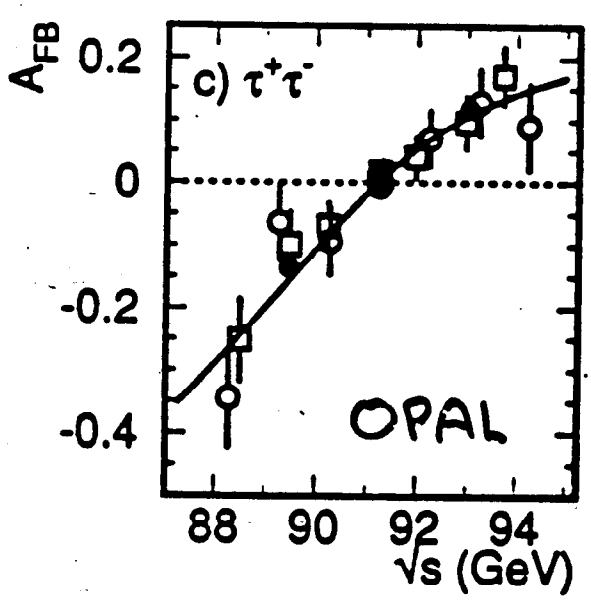


$e^+e^- \to \tau^+\tau^-, \ \sqrt{s} \simeq M_Z$

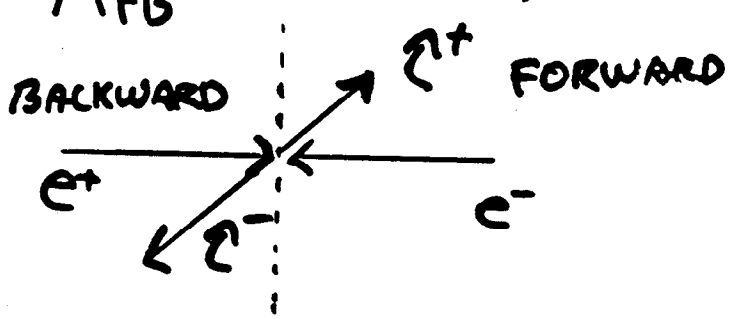
$$\Gamma_{Z\to\tau^+\tau^-} \sim \underbrace{g^2_{V,\tau} + g^2_{A,\tau}}_{\text{NEUTRAL CURRENT}}$$

USUALLY REPORT

$$R = \frac{\Gamma_{Z\to q\bar{q}}}{\Gamma_{Z\to\tau^+\tau^-}} \simeq 20.8$$

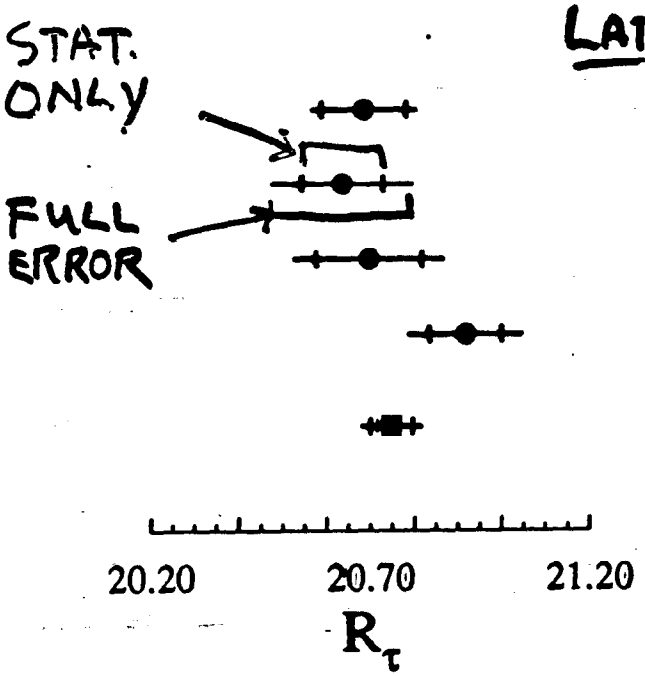


$$A^{\tau}_{FB} \simeq N_F - N_B / N_F + N_B$$



$$A_{FB} \sim \frac{g_{V,\tau}}{g_{A,\tau}} \cdot \frac{g_{V,e}}{g_{A,e}}$$

$$R_\tau = \Gamma_{had} / \Gamma_{\tau^+\tau^-}$$



LATEST YEAR OF DATA USED

ALEPH	93 prelim.
DELPHI	93 prelim.
L3	93 prelim.
OPAL	93 prelim.
LEP	average (χ^2=2.52)

ALEPH	20.69 ± 0.12
DELPHI	20.64 ± 0.16
L3	20.70 ± 0.17
OPAL	20.92 ± 0.13
LEP	20.749 ± 0.070

STAT SYST

$\simeq \pm 0.048 \pm 0.050$

TODAY

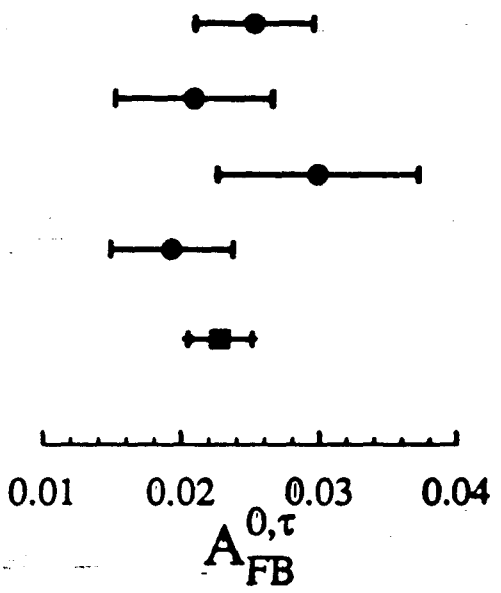
END LEP-I

MAIN SYST. IS $\tau^+\tau^-$ SELECTION

NO COMMON SYSTEMATICS

$\Delta R_\tau \simeq \pm .03 \pm .04 = \pm .05$

$A_{FB}^{\tau^+\tau^-}$



ALEPH	0.0253 ± 0.0043	(FULL UNCERTAINTIES)
DELPHI	0.0209 ± 0.0057	
L3	0.0299 ± 0.0073	
OPAL	0.0193 ± 0.0044	
LEP	$0.0228 \pm \underbrace{0.0026}_{\simeq \pm .0022 \pm .0013}$	

TODAY

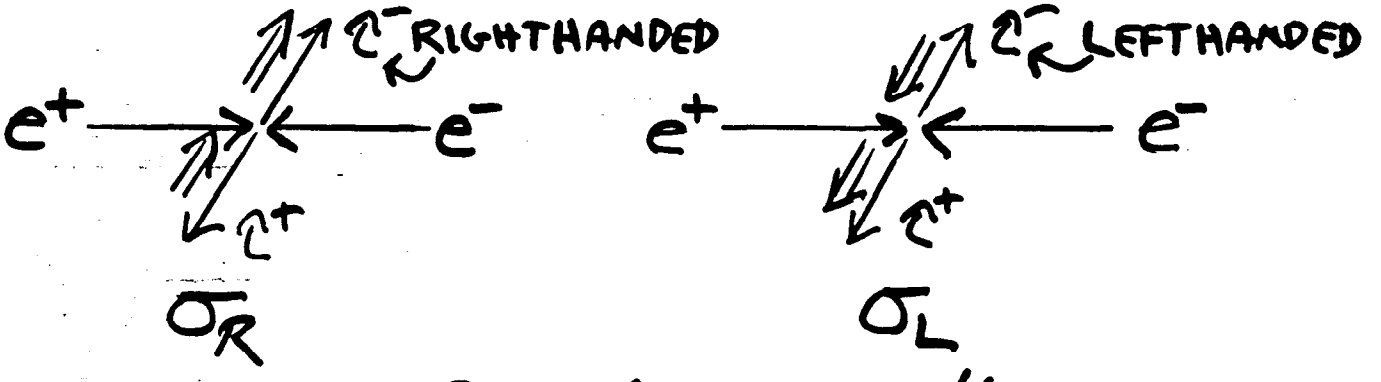
END LEP-I

MAIN SYST'S: SELECTION
e^+e^- BACKGROUND
$\pm .0008$ FROM ELEP COMMON

$$\Delta A_{FB}^{0,\tau} \simeq \pm .0016 \pm .0010 = \pm .0019$$

TAU POLARIZATION

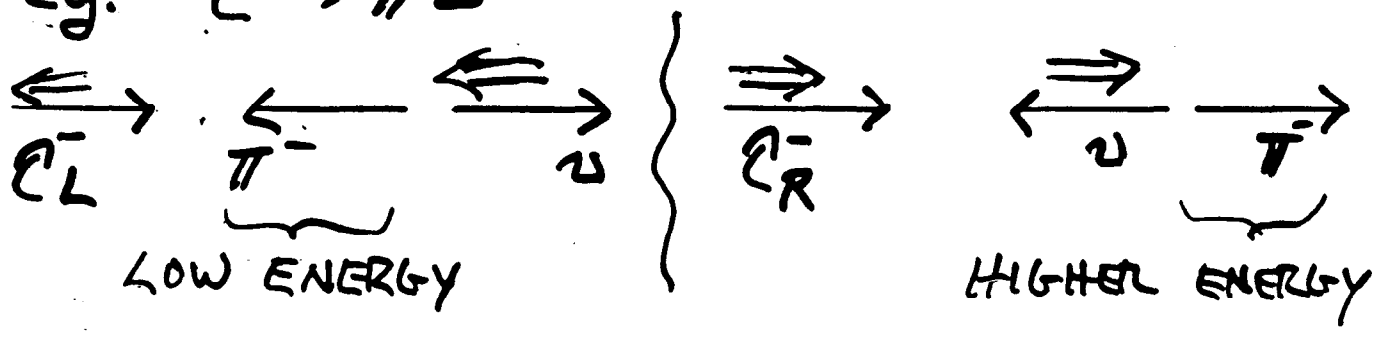
* IMPORTANT BECAUSE IT IS SOMEWHAT CORRELATED TO THE MICHEL PARAMETERS (ALSO MEASURES g_V/g_A, τ & e & $\sin^2\theta_W$)

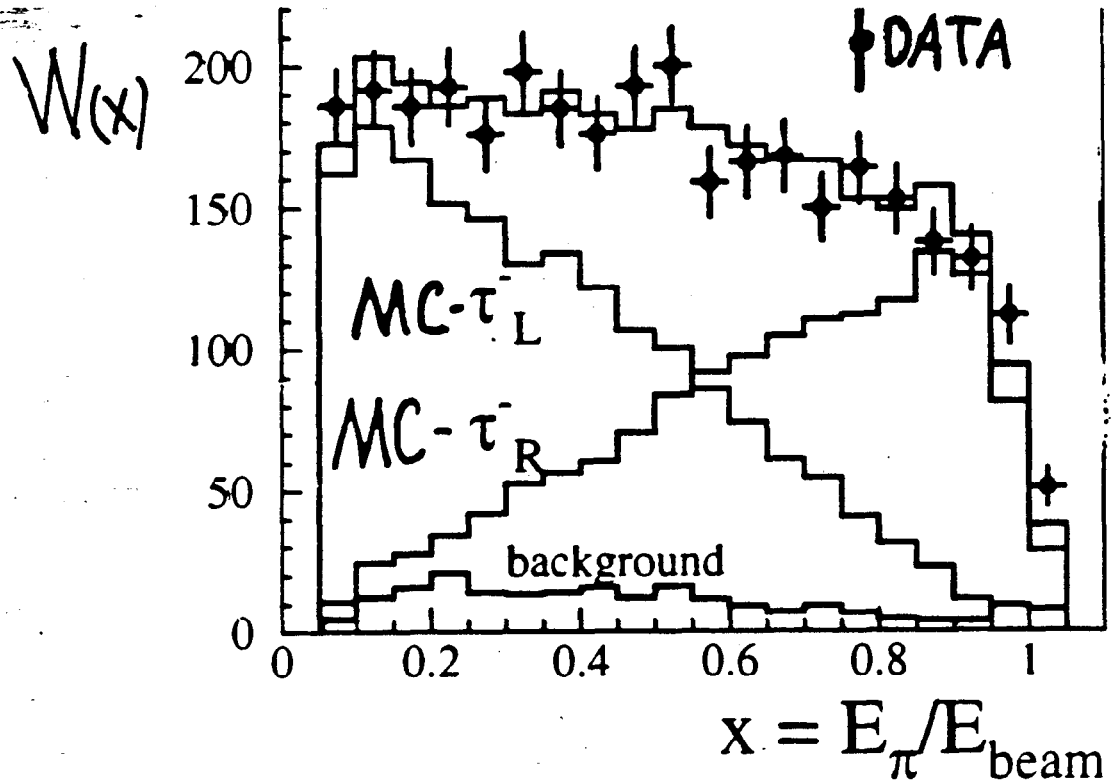


$$P_\tau = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L)$$

- ASSUME PURE V-A IN DECAY.
- DECAY PRODUCT KINEMATICS ARE DIFFERENT FOR RIGHT- & LEFT-HANDED.

eg: $\tau \to \pi\nu$





ANGULAR DEPENDENCE:

$$P_\tau(\cos\theta) \simeq 2\frac{g_V^\tau}{g_A^\tau} + \frac{2g_V^e}{g_A^e}\frac{2\cos\theta}{1+\cos^2\theta}$$

EXPERIMENTS USE

$\tau \to e\nu\bar{\nu}$, $\mu\nu\bar{\nu}$, $\pi\nu$ } TRACK ENERGY IS ONLY MEASURABLE

POLARIZATION INFO IS LOST TO HADRON SPIN

$\rho\nu$, $a_1\nu$ } RECOVER INFO BY MEASURING DECAY ANGLES, ETC.

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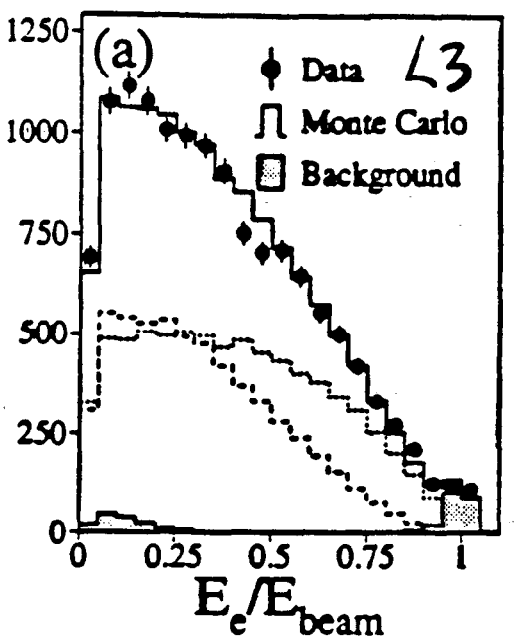
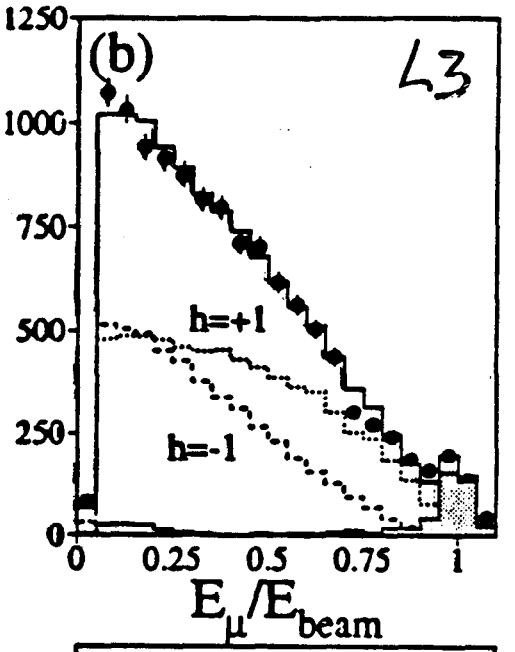


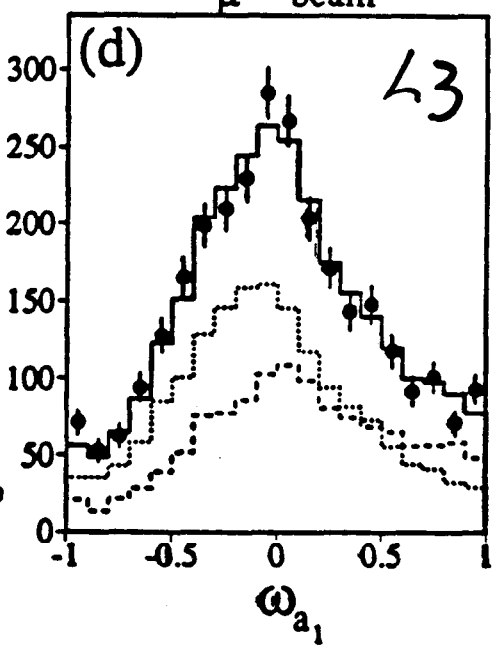


FOR $\tau \to a_1 \nu$ AND $\tau \to \rho \nu$ MORE INFORMATION AVAILABLE:

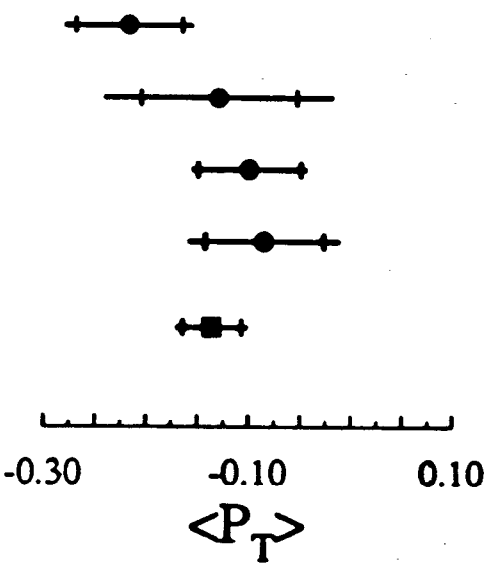
$\rho \to \pi \pi^0$

$a_1 \to$ 3-PR OR $\pi \pi^0 \pi^0$

$\Rightarrow$ ω VARIABLE



$\langle P_\tau \rangle$ $\tau \to e \nu \bar{\nu}$ CHANNEL



*ALEPH	$-0.218 \pm 0.052 \pm 0.034$
DELPHI	$-0.130 \pm 0.076 \pm 0.081$
L3	$-0.100 \pm 0.050 \pm 0.024$
OPAL	$-0.085 \pm 0.058 \pm 0.045$
LEP	$-0.136 \pm \underbrace{0.034}_{\simeq \pm .028 \pm .019}$

TODAY

MAIN SYST'S: MC STAT, $e^\pm$ ENERGY, $Z \to e^+e^-$ BCKGND.

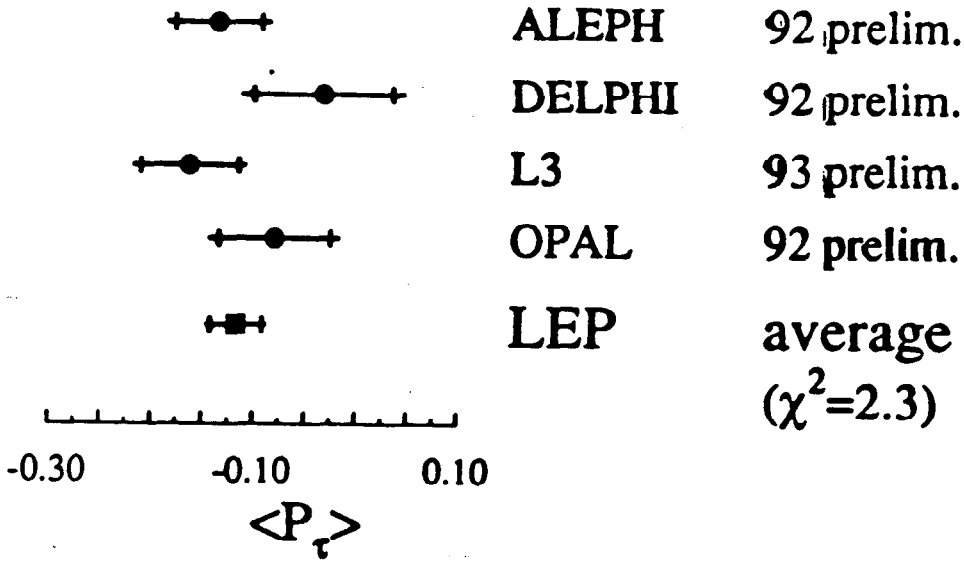
END LEP-I

$\Delta P_\tau(\tau \to e\nu\bar{\nu}) \simeq \pm .016 \pm .013 = \pm .021$

MC STATS $\to 0$ & $\times$ ENERGY SCALE $\sim \frac{1}{\sqrt{N}}$

* My Average of '90, '91 & '92

$\langle P_\tau \rangle$ $\tau \to \mu \nu \bar{\nu}$ CHANNEL



*ALEPH	$-0.136 \pm 0.042 \pm 0.027$
DELPHI	$-0.033 \pm 0.068 \pm 0.041$
L3	$-0.163 \pm 0.048 \pm 0.027$
OPAL	$-0.080 \pm 0.054 \pm 0.033$
LEP	$-0.117 \pm \underbrace{0.030}_{\simeq \pm .025 \pm .015}$

TODAY

MAIN SYST'S: MC STATS., PART. I.D., MOMENTUM SCALE

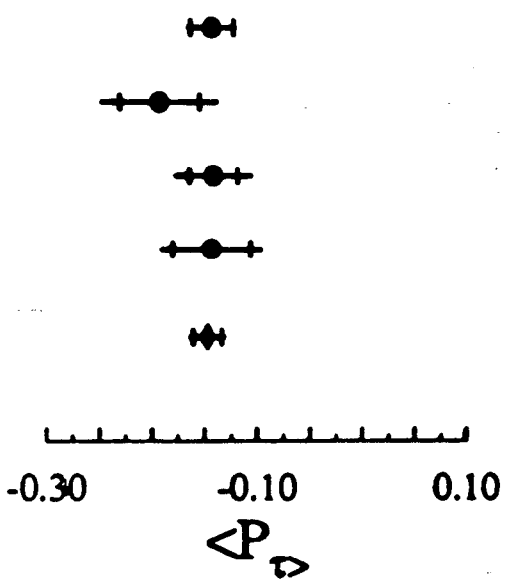
END LEP-I

$\Delta P_\tau(\mu\nu\bar{\nu}) \simeq \pm .015 \pm .011 = \pm .019$

REMOVED MC STATS. ONLY

* My average of '90, '91 + '92

$\langle P_\tau \rangle$ $\tau \to \pi \nu$ CHANNEL



ALEPH	92 prelim.
DELPHI	92 prelim.
L3	93 prelim.
OPAL	92 prelim.
LEP	average (χ^2=0.75)

ALEPH	$-0.142 \pm 0.020 \pm 0.011$
DELPHI	$-0.192 \pm 0.038 \pm 0.040$
L3	$-0.141 \pm 0.023 \pm 0.028$
OPAL	$-0.143 \pm 0.037 \pm 0.030$
LEP	$-0.147 \pm \underbrace{0.017}_{= \pm .013 \pm .011}$

TODAY

MAIN SYST'S: P.I.D, MC STATS
ENERGY CALIBRATION
(DIFFERENT FOR EACH EXPT)

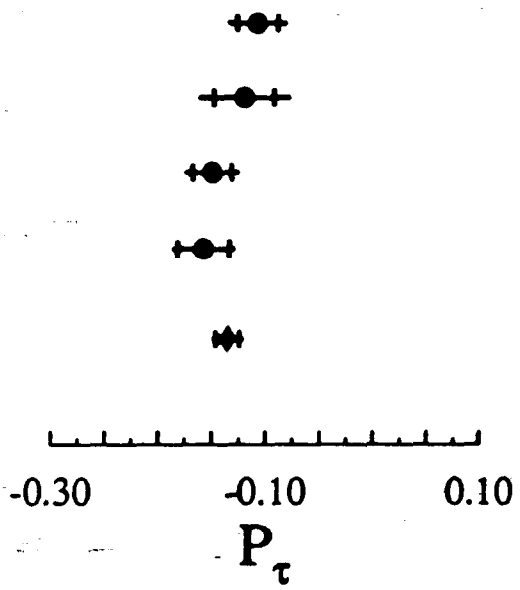
NO COMMON SYST'S.

END LEP-I

$\Delta P_{\tau_{\pi 0}} \simeq \pm .007 \pm .008 = \pm .011$

MAYBE LOWER

P_τ $\tau \to \rho\,\nu$ CHANNEL



ALEPH	$-0.106 \pm 0.019 \pm 0.019$
DELPHI	$-0.119 \pm 0.028 \pm 0.031$
L3	$-0.149 \pm 0.018 \pm 0.017$
OPAL	$-0.157 \pm 0.024 \pm 0.015$
LEP	$-0.135 \pm \underbrace{0.014}_{\simeq \pm .011 \pm .010}$

TODAY

MAIN SYST: • γ/π^0 RECON. ← NO KINEMATIC π^0 SAMPLE!

• E-CALIB/CORRECTIONS

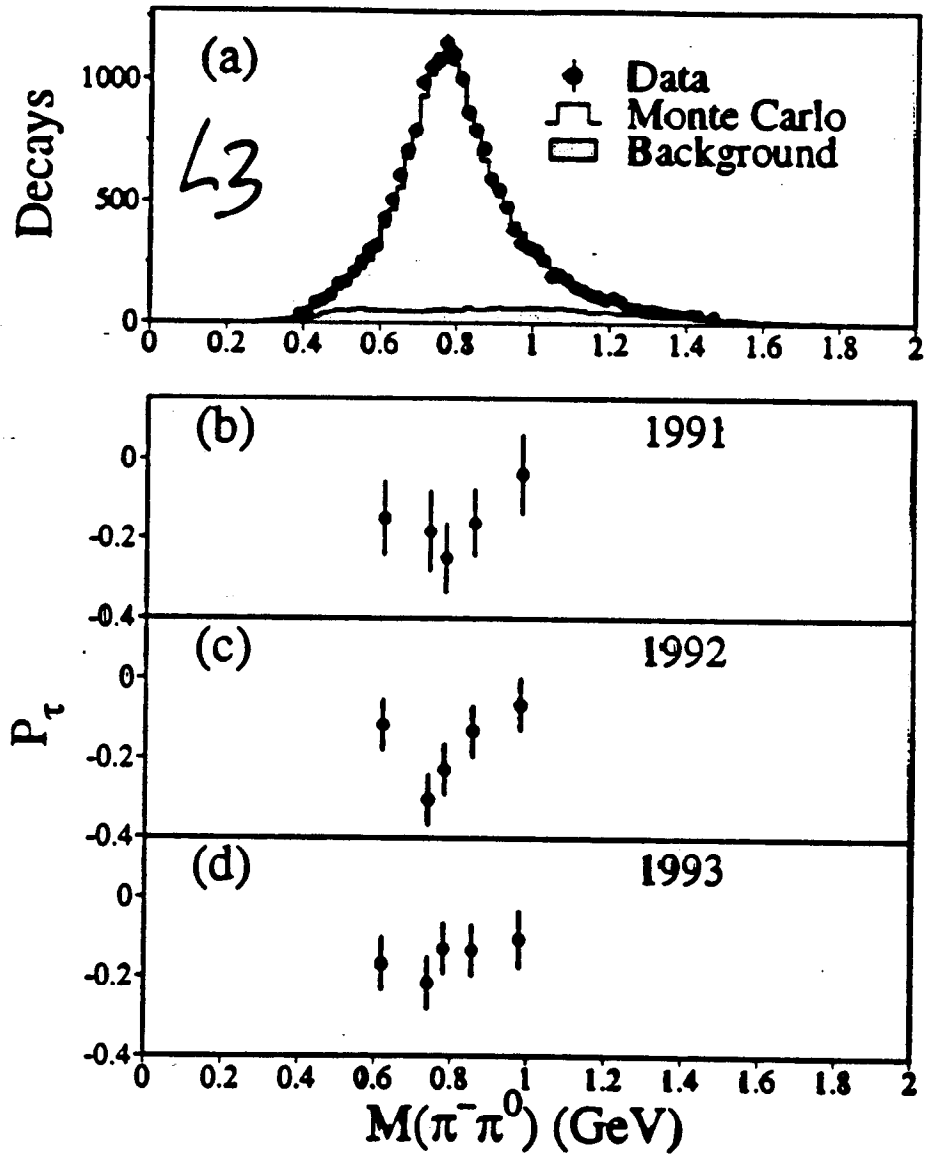
• MC STATISTICS

END LEP-I

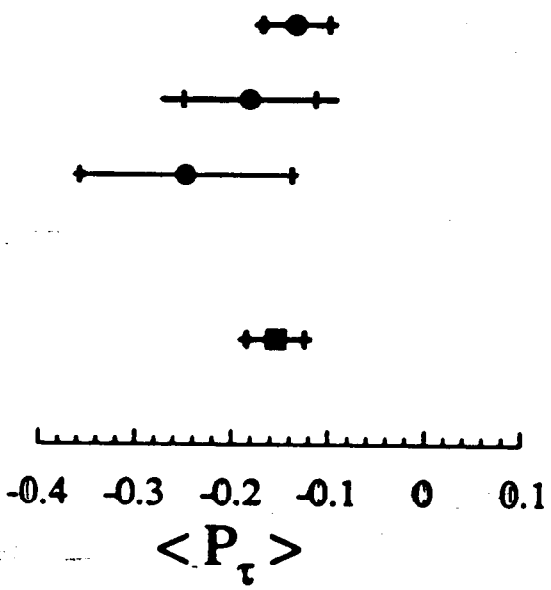
$\Delta P_{\tau\,\rho\nu} \simeq \pm .006 \pm .008 = \pm 0.010$

BY THE WAY ...

EFFECT IN $\tau \to \rho\nu$ REPORTED BY L3 IS GOING AWAY.



P_τ $\tau \to a_1 \nu$ CHANNEL



ALEPH	$-0.136 \pm 0.035 \pm 0.023$ } 3-PR
DELPHI	$-0.184 \pm 0.069 \pm 0.059$ } 3-PR
L3	$-0.250 \pm 0.110 \pm 0.034$ } $\pi\, 2\pi^0$
LEP	$-0.155 \pm \underbrace{0.037}_{\simeq \pm .030 \pm .022}$

TODAY

MAIN SYST'S: MC STAT, CALIB

END OF LEP-I

COMMON SYST: $\pm .012$ a_1 DECAY MODEL

$\Delta P_{\tau\, a_1 \nu} \simeq \pm .015 \pm .015 = \pm .021$

LEP τ-POLARIZATION

INDIVIDUAL CHANNELS

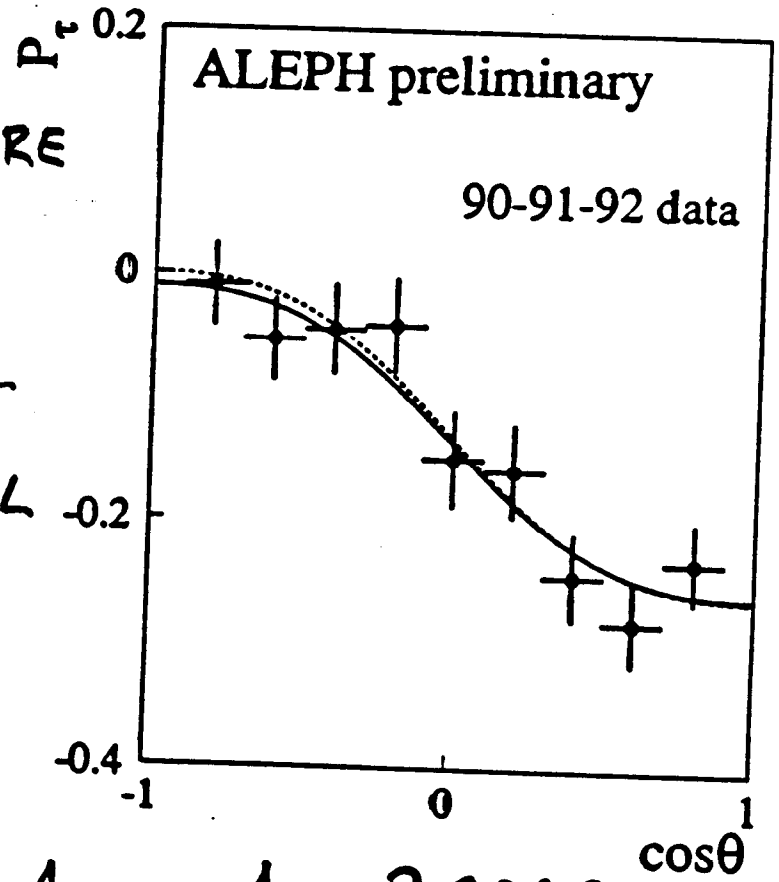
	$\langle P_\tau \rangle$	WEIGHT IN AVERAGE
$e\nu\bar{\nu}$	$-.136 \pm .034$	.077
$\mu\nu\bar{\nu}$	$-.117 \pm .030$	.098
$\pi\nu$	$-.147 \pm .017$	.31
$\rho\nu$	$-.135 \pm .014$	.45
$a_1\nu$	$-.155 \pm .036$	.068

$\tau \to \pi\nu$ & $\tau \to \rho\nu$ CARRY 3/4 OF WEIGHT IN LEP AVERAGE

WEIGHTS WILL STAY ABOUT THE SAME WITH MORE DATA ($\rho\nu \to \sim .40$ AT END LEP-I IS BIGGEST PROJECTED CHANGE).

IN ADDITION TO $\langle P_\tau \rangle$ FOR EACH CHANNEL, THE EXPT'S COMBINE 4 (OR 5) CHANNELS TO EXTRACT A_e & A_τ, $A_\ell = \dfrac{2 g_V g_A}{g_V^2 + g_A^2}$

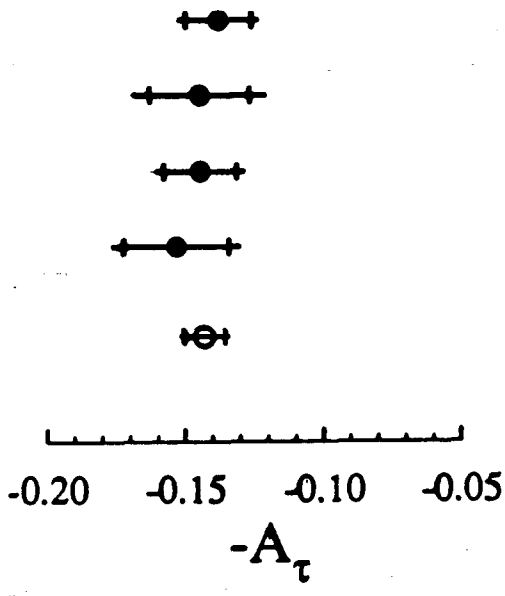
- A_e & A_τ ARE UNCORRELATED.
- MANY SYSTEMATICS CANCEL FOR A_e



$$-P_\tau(\cos\theta) \simeq A_\tau + A_e \frac{2\cos\theta}{1+\cos^2\theta}$$

$$\sin^2\theta_W^{eff} \equiv \frac{1}{4}\left(1 - \frac{g_V}{g_A}\right)$$

$\langle P_\tau \rangle$



ALEPH	$-0.137 \pm 0.012 \pm 0.008$
DELPHI	$-0.144 \pm 0.018 \pm 0.016$
L3	$-0.144 \pm 0.013 \pm 0.009$
OPAL	$-0.153 \pm 0.019 \pm 0.013$
LEP	$-0.143 \pm \underbrace{0.009}_{\simeq \pm .007 \pm .005}$

TODAY

MAIN SYST: MC STAT, PID, γ/π^0, ENERGY CALIBRATION.

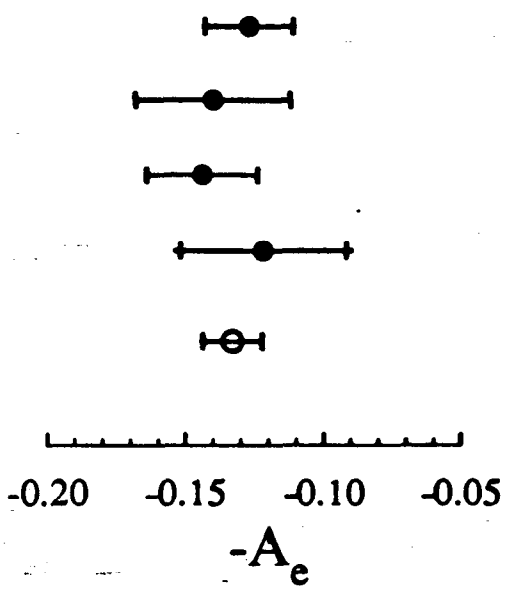
END LEP I

COMMON SYST'S: VERY SMALL

$\Delta A_\tau \simeq \pm .004 \pm .004 = \pm .006$

OR BETTER

$P_\tau(\cos\theta)$



ALEPH	$-0.127 \pm 0.016 \pm 0.005$
DELPHI	$-0.140 \pm 0.028 \pm 0.003$
L3	$-0.144 \pm 0.020 \pm 0.005$
OPAL	$-0.122 \pm 0.030 \pm 0.012$
LEP	$-0.133 \pm \underbrace{0.011}_{\simeq \pm .010 \pm .003}$

TODAY

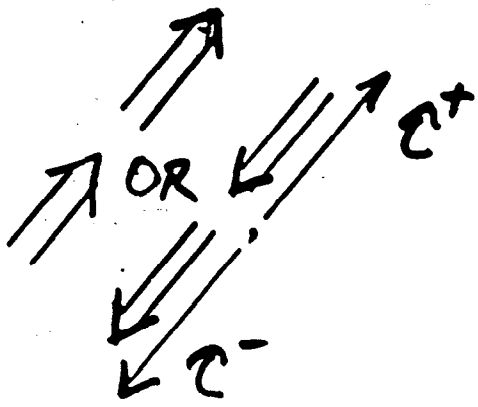
MAIN SYSTS: MC STATS, $\cancel{2}$-BCK.

END LEP I

NO COMMON SYST'S.

$\Delta A_e \simeq \pm .006 \pm .002 = \pm .006$

MICHEL PARAMETERS and τ-NEUTRINO HELICITY AT LEP



IN THE STANDARD MODEL:

- τ^+ & τ^- SPINS ARE ~100% ANTI-CORRELATED
- DECAY SPECTRA ARE PREDICTED (V-A)

DEVIATIONS FROM SM WOULD:

- REDUCE PERFECT ANTI-CORRELATION N.C.
- CHANGE DECAY SPECTRA C.C

STANDARD MODEL PARAMETERS:

$\tau \to \ell \nu \bar{\nu}$: $\rho = \delta = \frac{3}{4}$ $\eta = 0$ $\xi_\ell = 1$

ν_τ-helicity: $\xi_T = \xi_P = -1$

DIRECT ξ_ℓ & δ MEASUREMENT NEEDS $P_\tau \neq$

L3 MEASURES δ_ℓ & ξ_ℓ (& P_τ)

- USE $\tau \to e \nu \bar{\nu}$ and $\mu \nu \bar{\nu}$, X CORRELATED SPECTRA & single τ's
- ASSUME UNIVERSALITY
- SET $\rho = 3/4$, $\eta = 0$

ALEPH MEASURES δ_e, ξ_e, ρ_e
$\delta_\mu, \xi_\mu, \rho_\mu$
ξ_π, ξ_ρ (& P_τ)

- USE $\tau \to e \nu \bar{\nu}, \mu \nu \bar{\nu}$
$\pi \nu$ $\rho \nu$, X
CORRELATED SPECTRA & single τ's
- SET $\eta = 0$

(ALL RESULTS CONFORM TO SM.)

ALEPH MICHEL PARAMETERS, h_{ν_τ}

SM	e	μ	UNIV.
3/4 ρ	.838 ± .058	.767 ± .049	.798 ± .041
3/4 δ	.92 ± .29	.66 ± .25	.79 ± .18
1 ξ_ℓ	1.05 ± 0.29	1.21 ± .25	1.13 ± 0.18

(ALL PRELIMINARY)

$$\xi_\pi = -0.990 \pm 0.062$$

$$\xi_\rho = -0.893 \pm 0.087$$

$$\langle h_{\nu_\tau} \rangle = \xi_h = -0.951 \pm 0.051 \pm 0.028$$

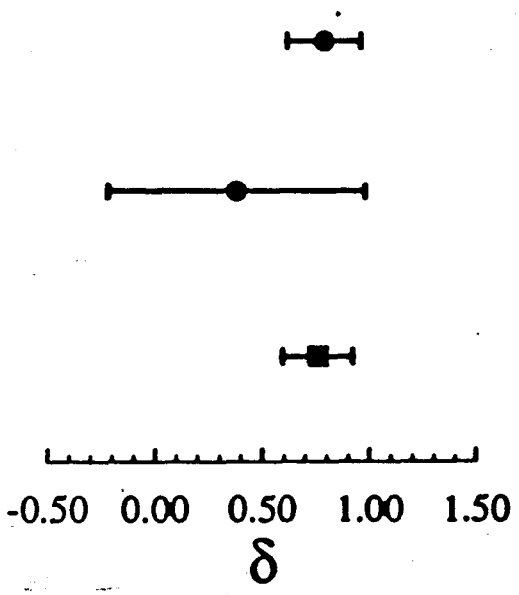
EXTRAPOL. END LEP-I

$$\Delta\rho \simeq \pm .015 \pm .020 = \pm .025$$

better? ± .015?

$$\Delta\langle h_{\nu_\tau} \rangle \simeq \pm .025 \pm .020 = \pm .032$$

Leptonic Michel Parameter δ



ALEPH	$0.79 \pm 0.17 \pm 0.06$
L3	0.38 ± 0.60
LEP	$0.76 \pm \underbrace{0.17}_{\text{MOSTLY STAT.}}$

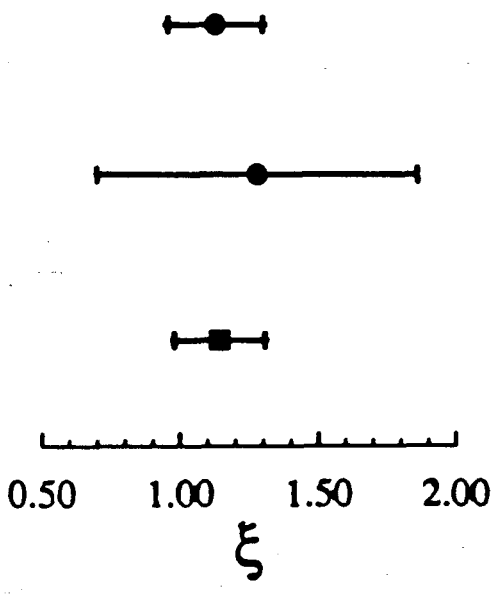
TODAY

MAIN SYST'S. MC STAT, SELECTION EFF.

END LEP-I

$\Delta_\delta \simeq 1.10$ OR BETTER

Leptonic Michel Parameter ξ



ALEPH	$1.13 \pm 0.17 \pm 0.07$
L3	1.28 ± 0.58
LEP	$1.14 \pm \underbrace{0.18}_{\text{MOSTLY STAT.}}$

TODAY

MAIN SYST'S: MC STAT., BCK.

END-I. LEP

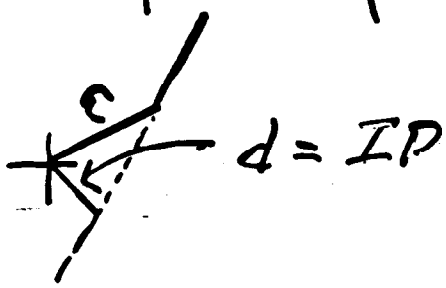
$\Delta_\xi \simeq \pm .10$ OR BETTER

τ LIFETIME

$\sqrt{s} = M_Z \Rightarrow \sim 2$ mm DECAY LENGTH.

TWO VARIABLES ARE USED:

① IMPACT PARAMETER



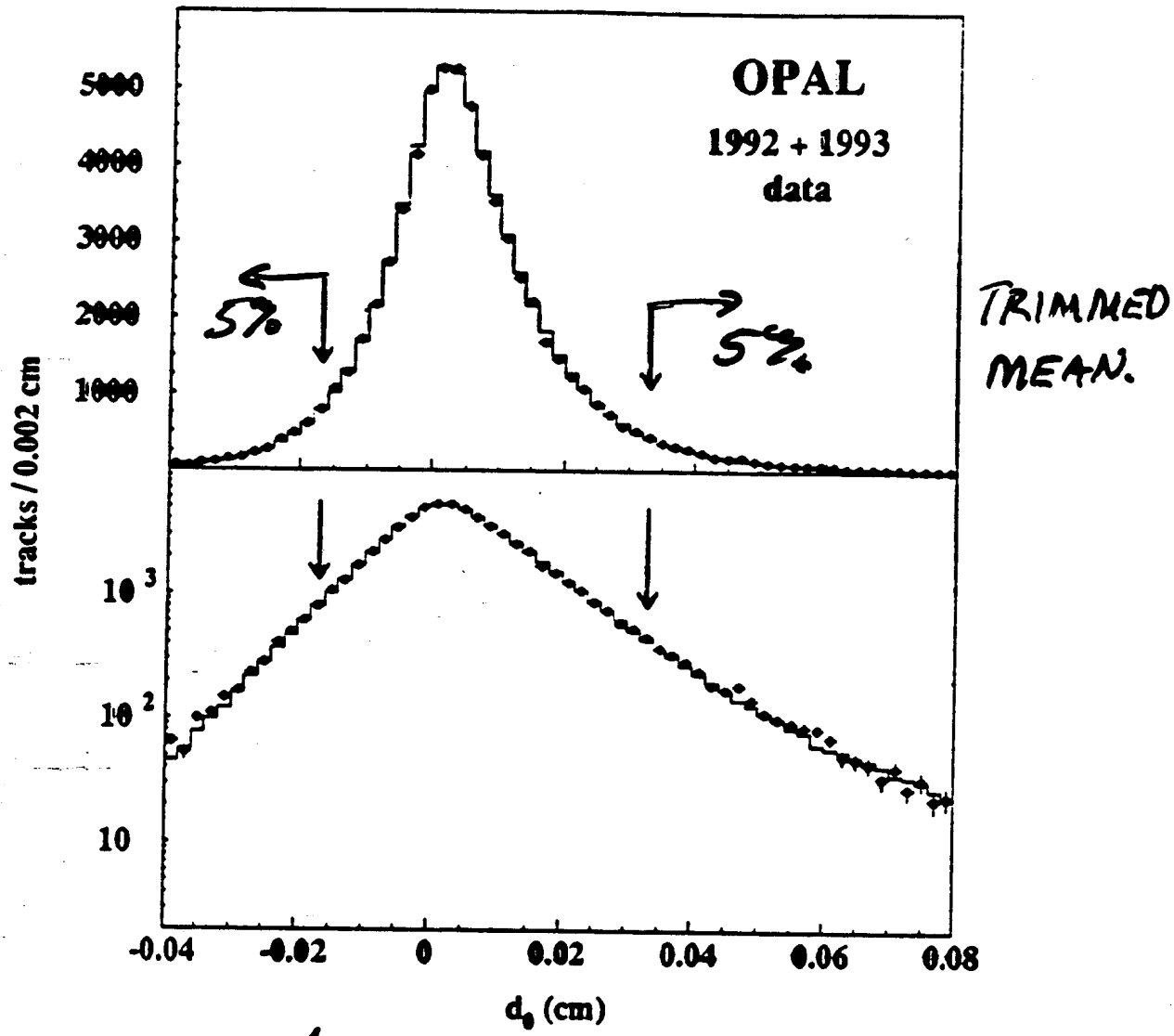
USED FOR 1-PRONG DECAYS.

② DECAY LENGTH

MEASURED IN 3-PRONG DECAYS.

VARIANTS:
- I.P. SUM
- MOMENTUM-DEPENDENT IP SUM
- IP DIFFERENCE

IMPACT PARAMETER



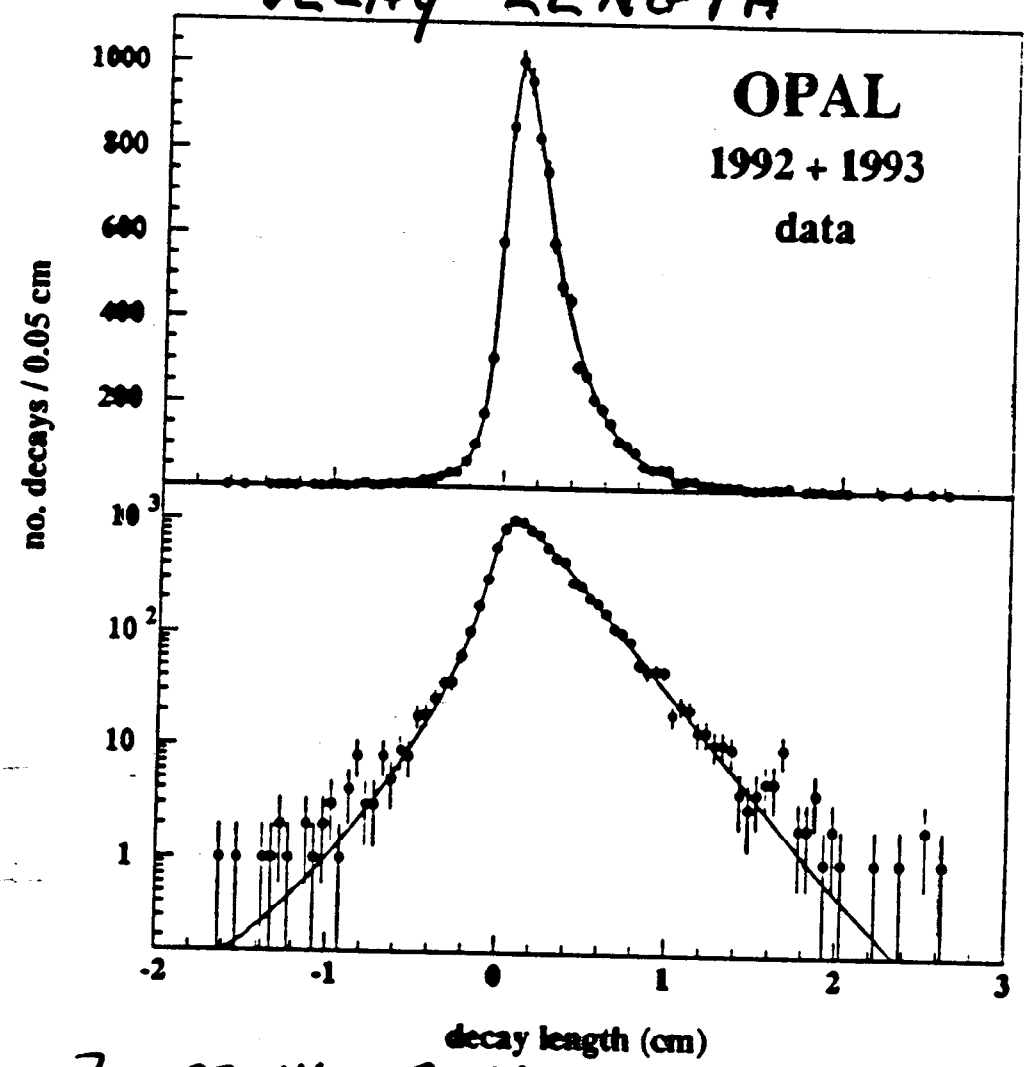
1-PRONG DECAYS (HEMISPHERES)

$\overline{d_0} \sim \ell_\tau$

MAIN PROBLEM:
- RESOLUTION MATCHING DATA – MC.
- BEAM SIZE UNCERT.

(· MC STATS)

DECAY LENGTH



3-PRONG DECAYS

MEASURE D.L.

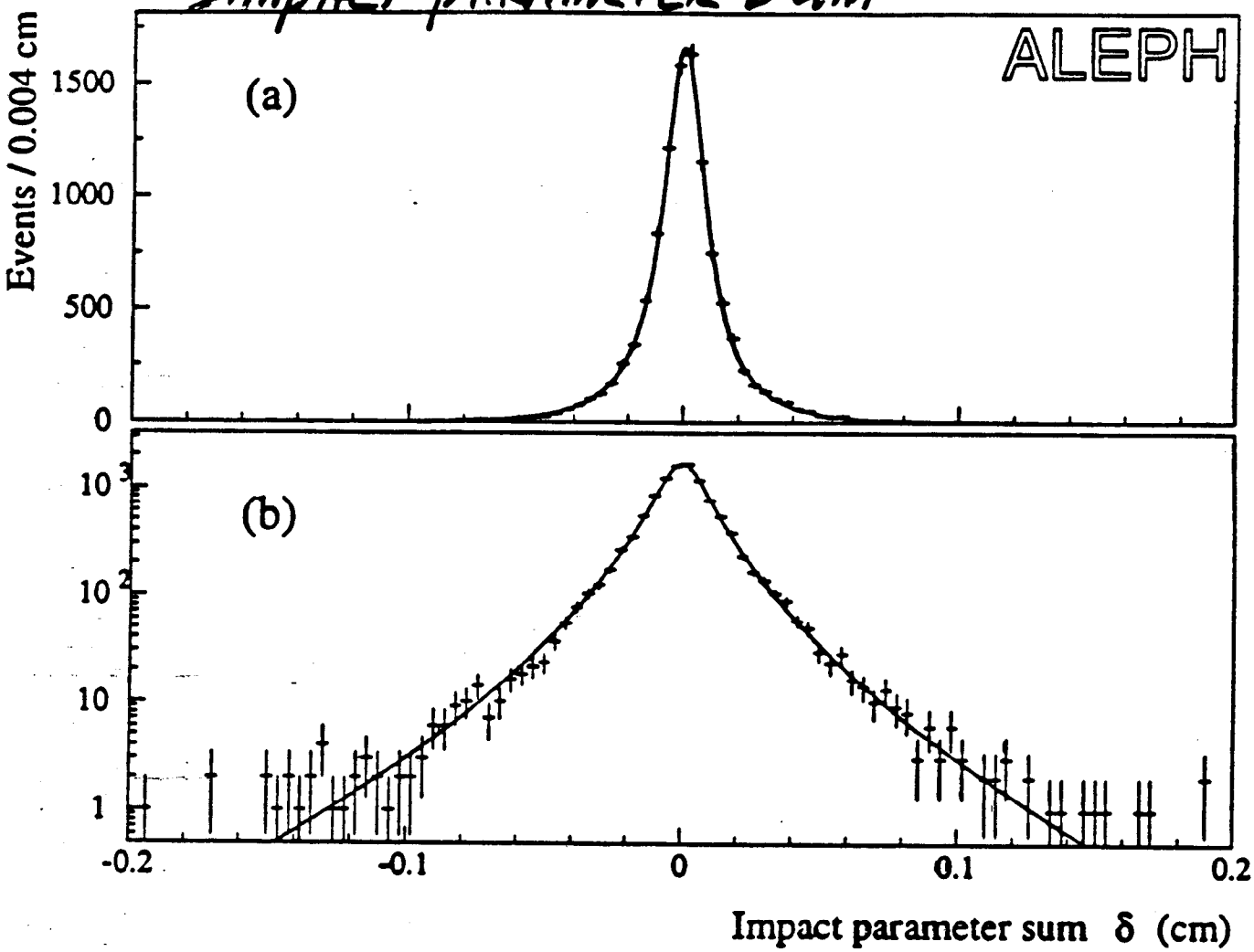
MASS KNOWN
BOOST KNOWN } $\Rightarrow \tau_\tau$

SYSTEMATICS: MC STATS

SILICON SURVEY

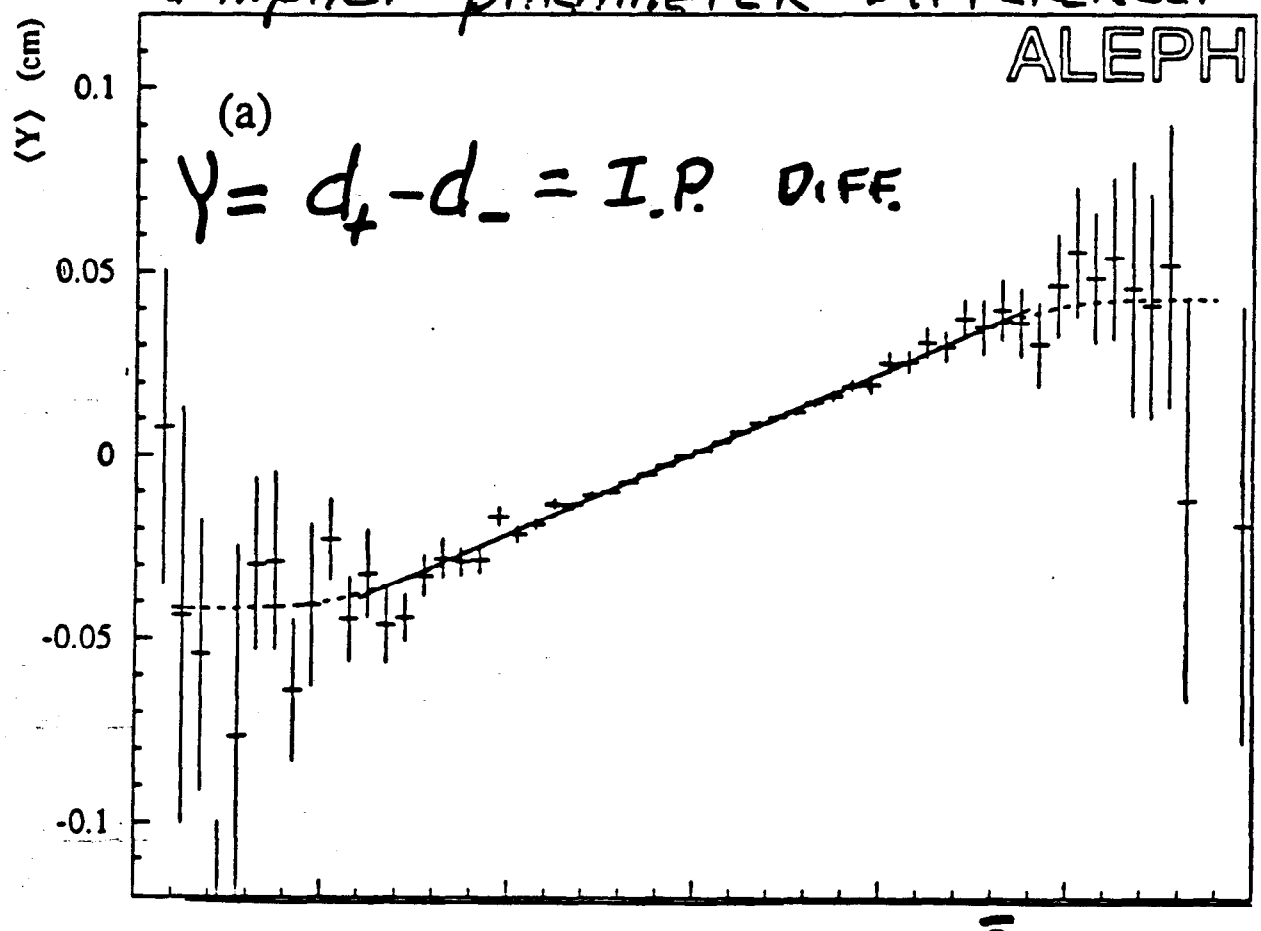
$q\bar{q}$ BCKGND

IMPACT PARAMETER SUM



- 1-ON-1 PRONG EVENTS
- BEAM SIZE NOT A PROBLEM.
- I.P. RESOLUTION IS VERY DOMINANT SYSTEMATIC

IMPACT PARAMETER DIFFERENCE.



$Y = d_+ - d_- =$ I.P. DIFF.

$$X = \frac{\bar{P}_\tau}{\bar{P}_\tau^0} \Delta\phi \sin\theta$$

$$\langle Y \rangle = \bar{P}_\tau^0 \frac{c_\tau}{m_\tau} X$$

- τ - DIRECTION NOT NEEDED
- DETECTOR RESOLUTION NOT IMPORTANT.

MAIN SYSTS: TRACKING ERRORS
TRIMMING
SELECTION PROCEDURE.

ALEPH & OPAL
TAU LIFETIME MEASUREMENTS.

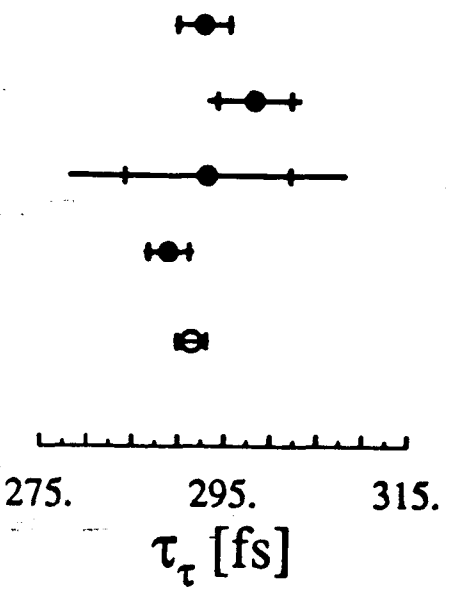
OPAL (→1993)

I.P.	287.2 ± 3.4 ± 2.0 fs
D.L.	288.9 ± 3.6 ± 1.7

ALEPH (→1992)

(m) I.P.S.	298.2 ± 3.4 ± 4.6
I.P.D.	288.1 ± 5.4 ± 1.2
D.L.	290.0 ± 5.8 ± 2.1

τ Lifetime



ALEPH	92 prelim.	
DELPHI	92 prelim.	
L3	91 final	
OPAL	93 prelim.	
LEP	average (χ^2=2.9)	

		WEIGHT
ALEPH	$292.5 \pm 2.8 \pm 1.5$	.34
DELPHI	$298. \pm 4. \pm 3.$	.14
L3	$293. \pm 9. \pm 12.$	.02
OPAL	$288.8 \pm 2.2 \pm 1.4$	.51
LEP	$291.4 \pm \underbrace{1.9}_{\simeq \pm 1.6 \pm 1.0}$ [fs]	

END LEP-I

$$\Delta\tau_\tau \simeq \pm 0.9 \pm 0.7 = \pm 1.1 \text{ [fs]}$$

LEPTONIC Br's $\tau \to e\nu\bar{\nu}$ / $\mu\nu\bar{\nu}$

USED WITH τ-LIFETIME TO TEST LEPTON UNIVERSALITY

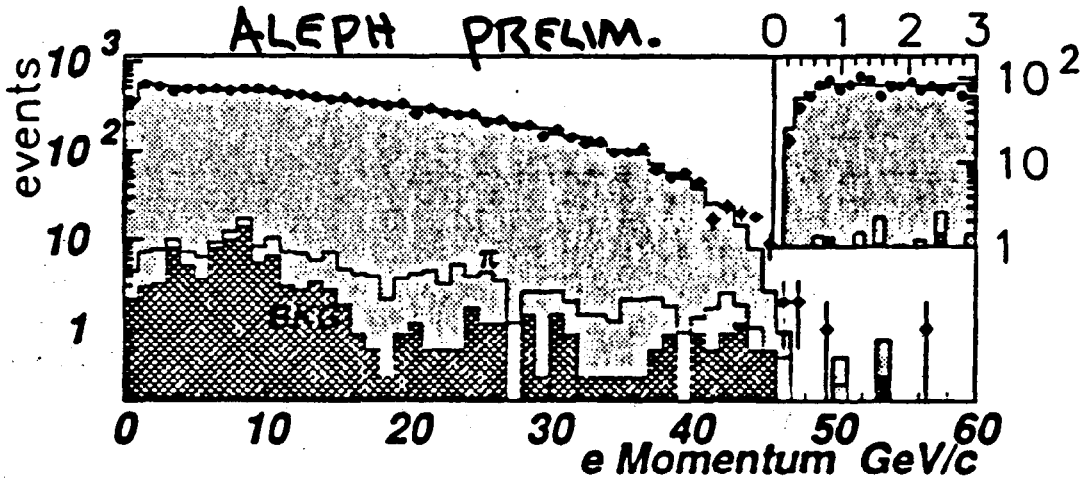
$$1^* \stackrel{?}{=} (g_\tau/g_\mu)^2 = \frac{\tau_\mu}{\tau_\tau} \cdot \frac{m_\mu^5}{m_\tau^5} \cdot Br(\tau \to e\nu\bar{\nu})$$

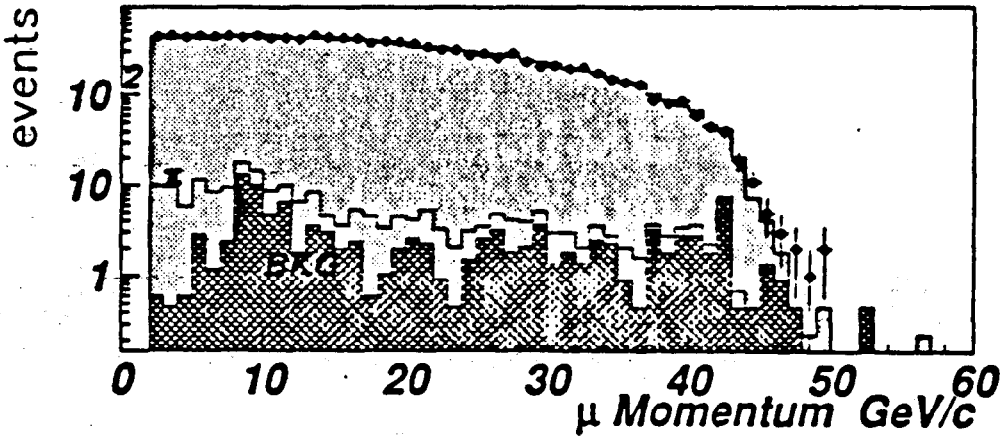
NEW SINCE MORIOND (MARCH '94):

→ ALEPH RESULTS WITH REDUCED SYSTEMATICS.

→ DELPHI B_μ

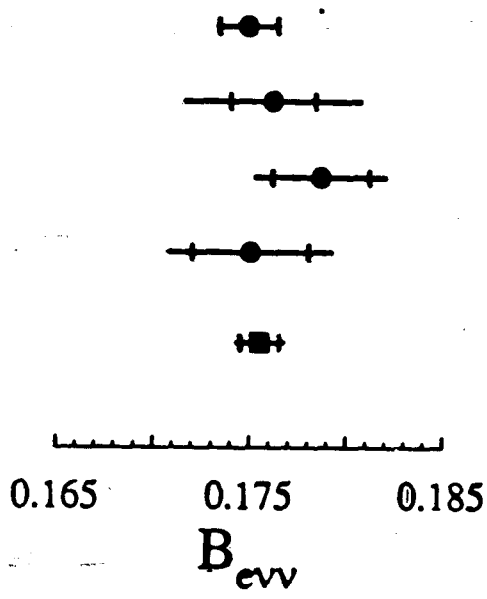
* SMALL CORRECTIONS $\approx -2 \cdot 10^{-4}$





SELECTION TESTED ON DATA WITH KINEMATICALLY ID'ed PARTICLES.

Branching Ratio $\tau \to e\,\nu\bar{\nu}$



		WEIGHT
ALEPH	$0.1748 \pm 0.0015 \pm 0.0006$	.65
DELPHI	$0.1761 \pm 0.0022 \pm 0.0040$	.08
L3	$0.1786 \pm 0.0025 \pm 0.0023$	.16
OPAL	$0.175 \pm 0.003 \pm 0.003$	.10
LEP	$0.1755 \pm \underbrace{0.0013}_{\simeq \pm .0010 \pm .0008}$	

TODAY

MAIN SYST'S: ALEPH - $\tau^+\tau^-$ SELECTION

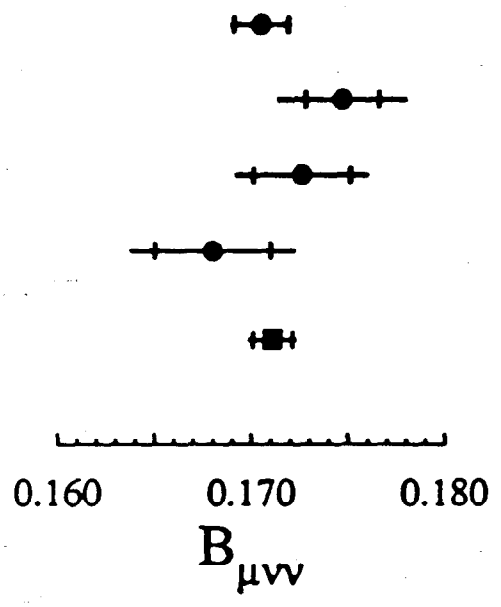
OTHERS - lepton SEL. & BACKGND.

END LEP-I

$\Delta B_e^{LEP} \simeq \pm .0005 \pm .0006 = \pm .0008$

$(\Delta B_e^{ALEPH} \simeq \pm .0008 \pm .0006 = \pm .0010)$?

Branching Ratio $\tau \to \mu \nu \bar{\nu}$



		WEIGHT
ALEPH	$0.1705 \pm 0.0014 \pm 0.0006$	.65
DELPHI	$0.1747 \pm 0.0019 \pm 0.0027$	.14
L3	$0.1726 \pm 0.0025 \pm 0.0023$	.13
OPAL	$0.168 \pm 0.003 \pm 0.003$	.08
LEP	$0.1711 \pm \underbrace{0.0012}_{\simeq \pm .0010 \pm .0007}$	

TODAY

SYSTEMATICS ~ SAME AS $e\nu\bar{\nu}$

ALEPH - $\tau^+\tau^-$ SELECTION

OTHERS - 6prong SELECTION & BCKGND.

END LEP I

$\Delta B_\mu^{LEP} \simeq \pm .0005 \pm .0005 = \pm .0007$

$(\Delta_\mu^{ALEPH} \simeq \pm .0008 \pm .0006 = \pm .0010)$

$B(\ell\nu\bar{\nu})$:

$$B^{LEP}(e\nu\bar{\nu}) = 0.1755 \pm 0.0013$$

$$\frac{B^{LEP}(\mu\nu\bar{\nu})}{0.9726} = 0.1759 \pm 0.0012$$

COMBINED VALUE $\quad B^{LEP}(\ell\nu\bar{\nu}) = 0.1757 \pm 0.0009$

USE THIS IN UNIV. TEST

$$(g_\tau/g_\mu)^2 = 0.9921 \pm \underbrace{0.0041}_{\pm .0004 \;\; \pm .0032 \;\; \pm .0027}$$

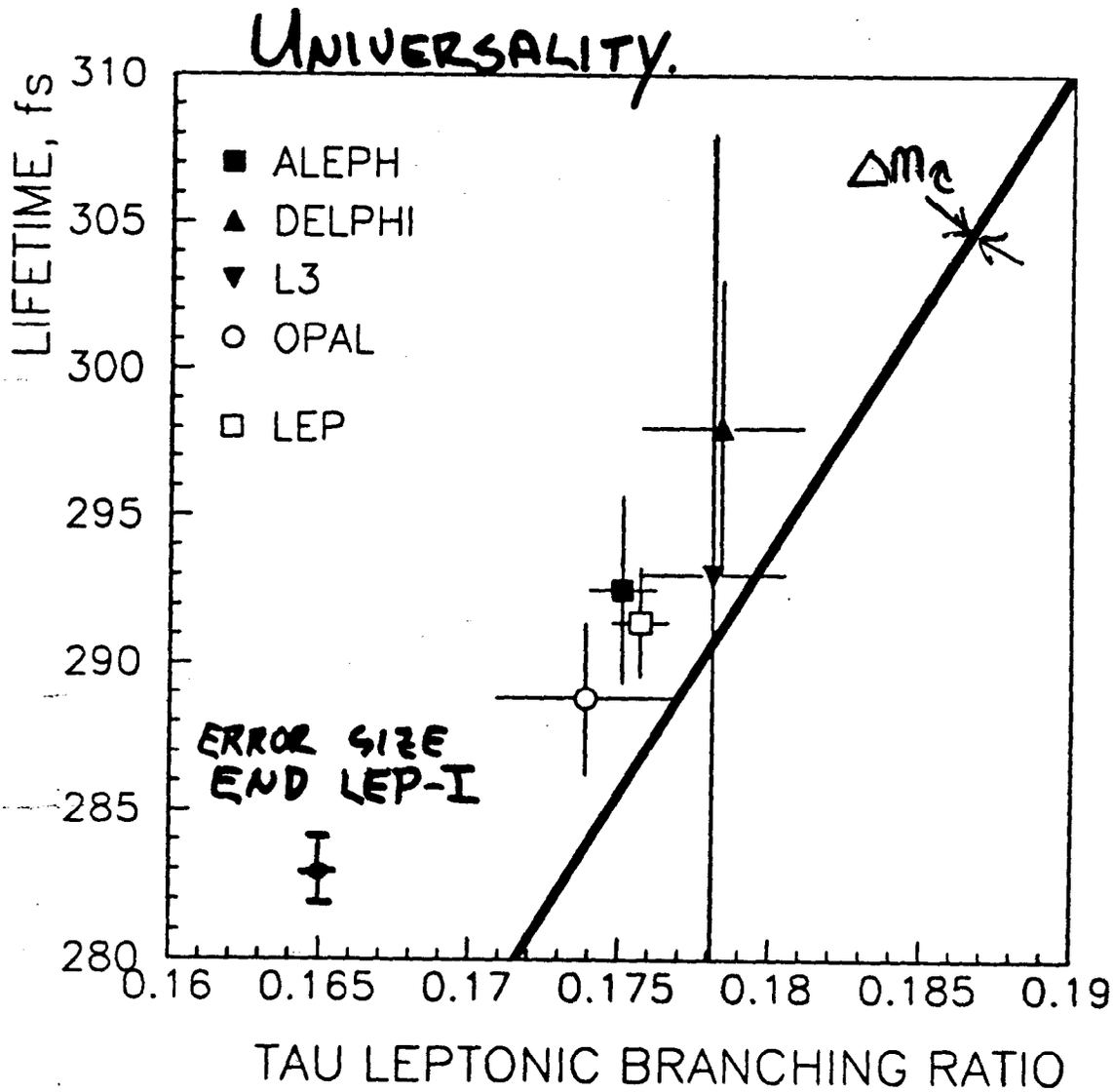
$m_\tau \qquad \tau_\tau \qquad B_e$

BY THE END OF LEP I

$$\Delta\tau_\tau \simeq 1.1\,[fs] \qquad \Delta B_\ell \simeq .0006$$

$$\Rightarrow \Delta(g_\tau/g_\mu)^2 \simeq \underbrace{\pm 0.0025}_{\pm .0004 \;\; \pm .0018 \;\; \pm .0017}$$

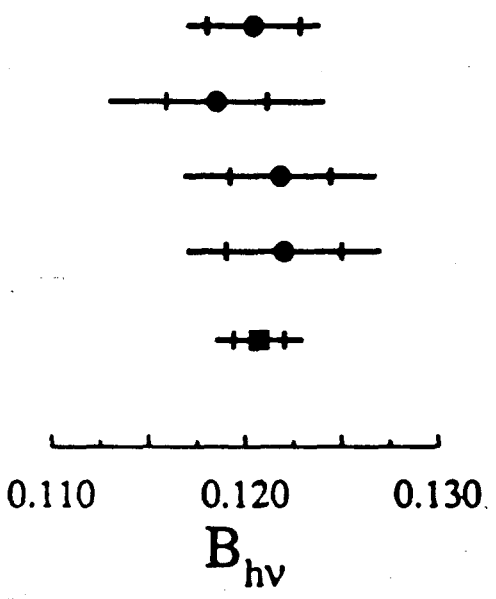
$m_\tau \qquad \tau_\tau \qquad B_\ell$



$$\left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\left(\frac{m_\mu}{m_\tau}\right)^5 B_{\tau\to l\nu\bar{\nu}}$$

$$= 0.9921 \pm 0.0041$$

Branching Ratio $\tau \to h\,\nu$



ALEPH	$0.1204 \pm 0.0024 \pm 0.0024$
DELPHI	$0.1185 \pm 0.0026 \pm 0.0049$
L3	$0.1218 \pm 0.0026 \pm 0.0042$
OPAL	$0.122 \pm 0.003 \pm 0.004$
LEP	$0.1207 \pm \underbrace{0.0022}_{\simeq \pm 0.0013 \pm 0.0018}$

TODAY

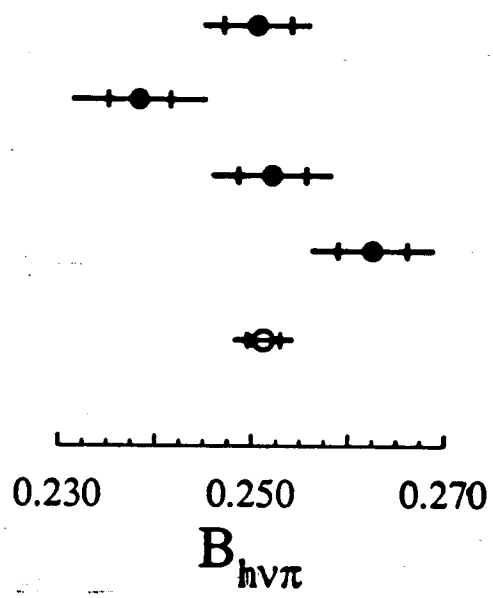
MAIN SYST'S: γ's & P.I.D.

END LEP-I

$\Delta B(h\nu) \simeq \pm .0005 \pm .0010 = \pm .0011$

NICE IMPROVEMENTS EXPECTED SOON TO ALLOW THIS SIZE SYST.

Branching Ratio $\tau^- \to h^- \nu \pi^0$



ALEPH	$0.2504 \pm 0.0035 \pm 0.0042$
DELPHI	$0.2382 \pm 0.0032 \pm 0.0061$
L3	$0.2520 \pm 0.0035 \pm 0.0050$
OPAL	$0.2625 \pm 0.0036 \pm 0.0052$
LEP	$0.2512 \pm \underbrace{0.0030}_{\simeq \pm .0017 \pm .0025}$

TODAY

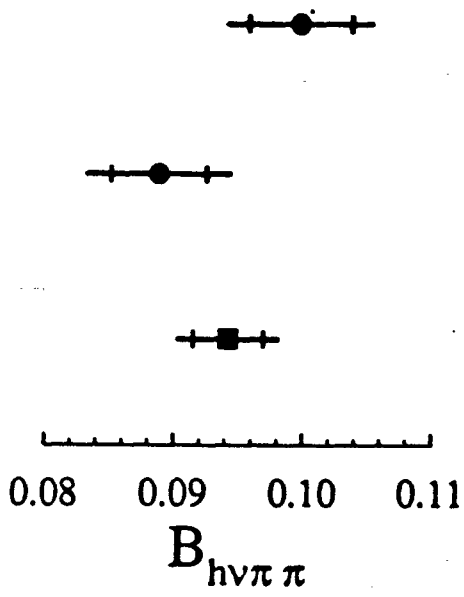
MAIN SYST'S: γ's, P.I.D., BCKG-ND

END LEP-I

$\Delta B(h\pi^0\nu) \simeq \pm .0007 \pm .0013 = \pm .0015$

IMPROVED γ UNDERSTANDING COMING SOON...

Branching Ratio $\tau^- \to h^- \nu \pi^0 \pi^0$



OPAL MEASURES
$h \geq 2\pi^0$
$B = .0989 \pm .0034 \pm .0055$

ALEPH	$0.0998 \pm 0.0040 \pm 0.0040$
L3	$0.0888 \pm 0.0037 \pm 0.0042$
LEP	$0.0942 \pm \underbrace{0.0040}_{\simeq \pm .0027 \pm .0029}$

TODAY

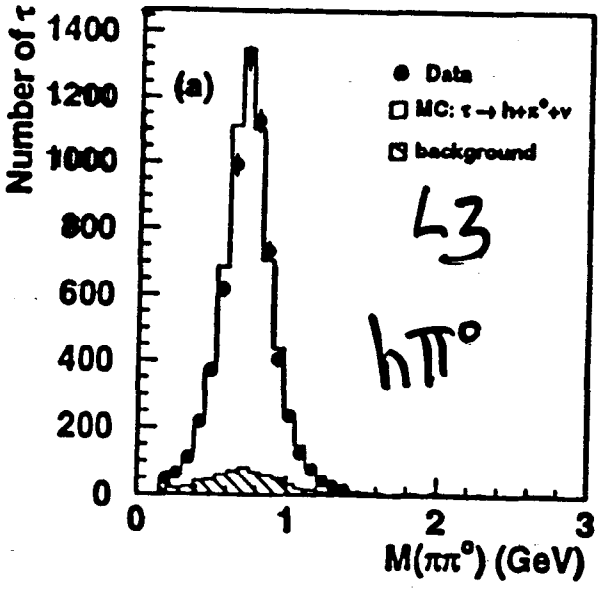
γ's, PID, MC STATS ARE MAIN SYSTEMATICS.

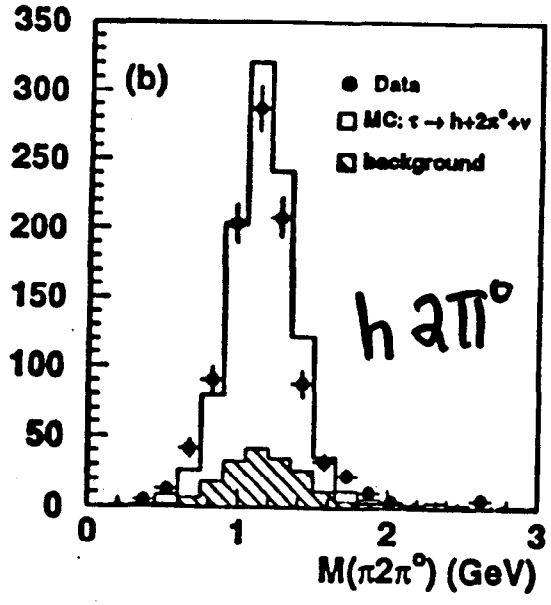
END LEP-I

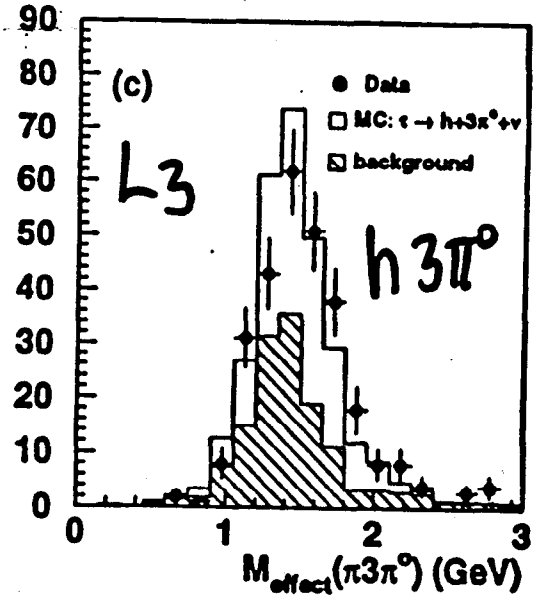
$\Delta B(h\pi^0\pi^0) \simeq \pm .0010 \pm .0013 = \pm .0016$

LOOKING FOR NICE IMPROVEMENTS.

L3 RESULTS WITH π^0's.



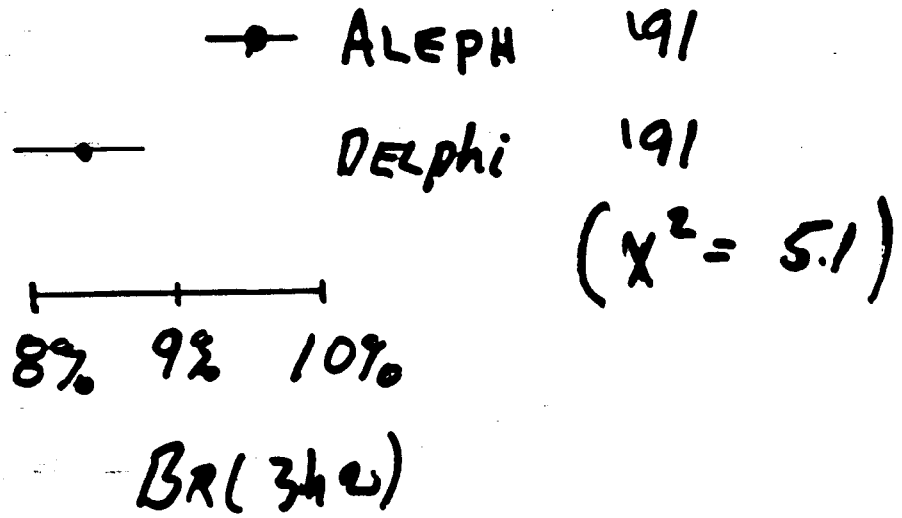




$B(\tau \to h\nu 3\pi^0)$

$= 1.70 \pm 0.24 \pm 0.40\%$

$BR(\tau \to 3h\nu)$



ALEPH	$0.0956 \pm 0.0024 \pm 0.0022$
DELPHI	$0.0835 \pm 0.0035 \pm 0.0024$
LEP	$0.0911 \pm \underbrace{0.0026}_{\simeq \pm 0.0020 \pm 0.0017}$

TODAY

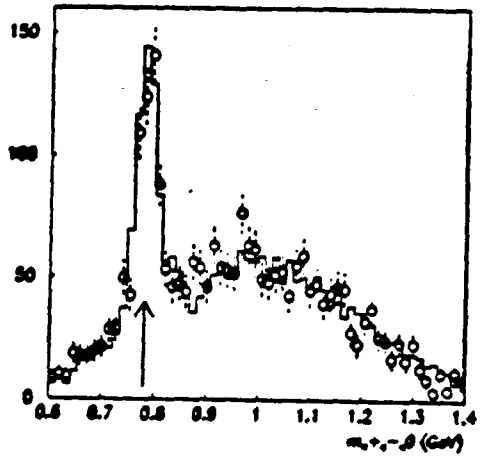
MAIN PROBS: γ/π^0, P.I.D.
MC STAT'S.

END LEP I

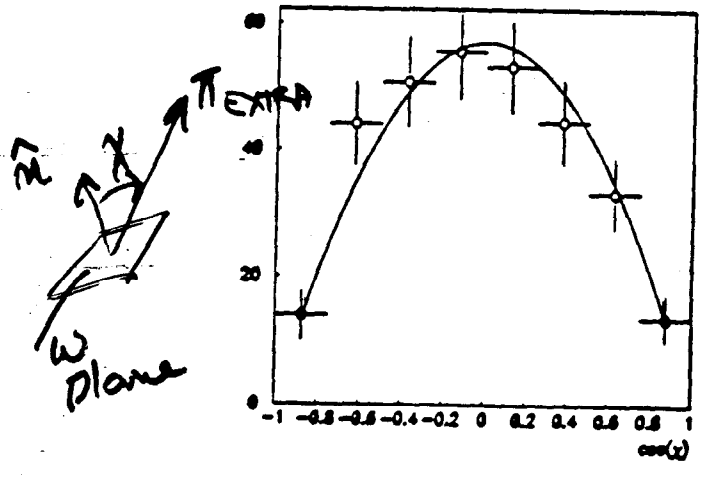
$$\Delta B(3h\nu) \simeq \pm 0.0006 \pm 0.0010^{?}_{?} = \pm .0012$$

BIG IMPROVEMENTS EXPECTED

ALEPH $\tau \to 3\pi\pi^0\nu$ BR.



$\tau^- \to \omega\pi^-\nu$
$\hookrightarrow \pi^+\pi^-\pi^0$



Pure $J^{PG} = 1^{-+}$
As EXPECTED.

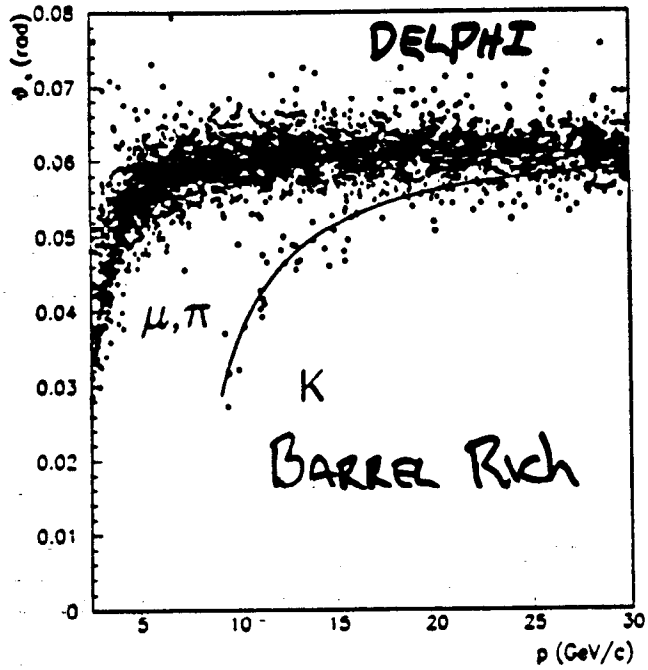
$$BR(\tau \to 3\pi\pi^0\nu) = 4.25 \pm 0.13 \pm 0.13\ \%$$

and

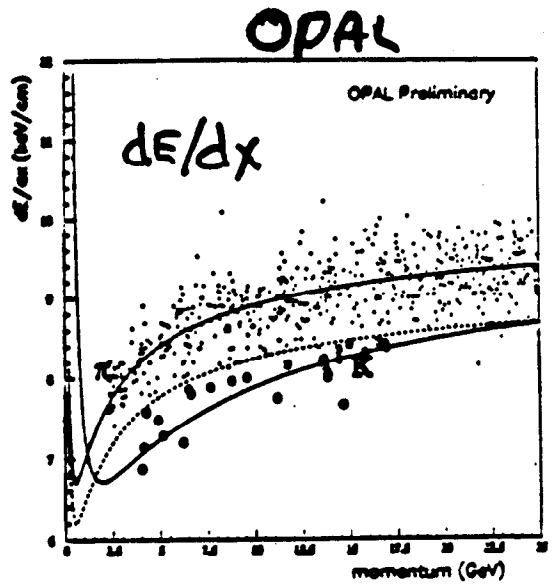
$$\frac{\Gamma(\tau \to \omega\pi) \times BR(\omega \to \pi^+\pi^-\pi^0)}{\Gamma(\tau \to 3\pi\pi^0)}$$

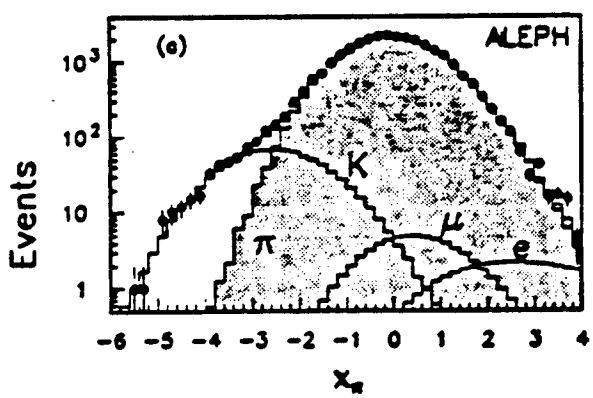
$$= 43.8 \pm 1.9 \pm^{2.5}_{2.6}\ \%$$

KAONS IN τ DECAYS AT LEP.

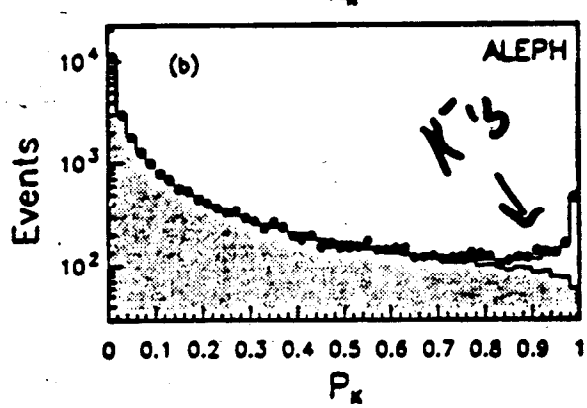


τ → 1 prong
[+ NEUTRALS]



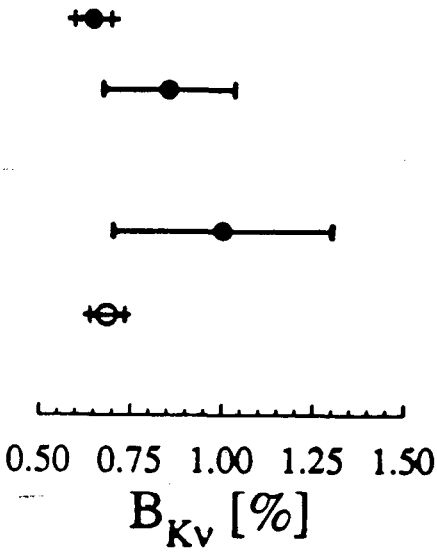


dE/dx



$$\frac{P_K}{P_\pi + P_K}$$

Branching Ratio $\tau^- \to K^-\nu$



ALEPH	$0.64 \pm 0.05 \pm 0.05$
DELPHI	0.85 ± 0.18 (FULL)
OPAL	1.00 ± 0.30 (FULL)
LEP	$0.685 \pm \underbrace{0.064}_{\simeq \pm .05 \pm .04\ \%}$ [%]

TODAY

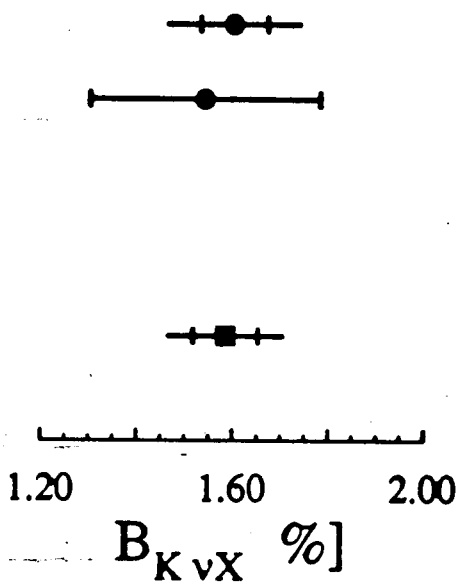
SYST'S: · π dE/dx shape (ALEPH)
· GEOMETRY ⇒ BCKGND γ's (DELPHI)
· dE/dx scaling parameter (OPAL)

END LEP-I

$\Delta B(K\bar{\nu}) \simeq \pm .025 \pm .03 = \pm .04\ \%$

HAS SOME STAT. COMPONENT

Branching Ratio $\tau^- \to K^- \nu X^0$



ALEPH	$1.60 \pm 0.07 \pm 0.12$
DELPHI	1.54 ± 0.24 (FULL)

LEP 1.58 ± 0.12 [%]

$\simeq \pm .07 \pm .10$ %

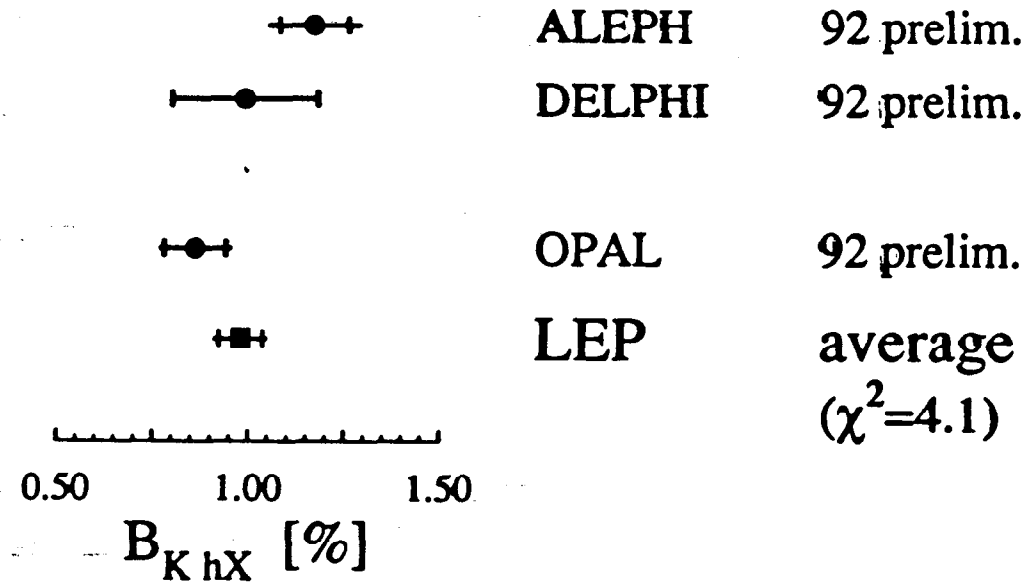
TODAY

SAME DOMINANT SYST'S AS $K^-\nu$

END LEP-I

$\Delta B(K\nu X^0) \simeq \pm .03 \pm .08 = \pm .09$%

Branching Ratio $\tau^- \to K^0_S h^- X^0 \nu$



ALEPH	$1.17 \pm 0.09 \pm 0.08$
DELPHI	0.99 ± 0.19 (FULL)
OPAL	$0.86 \pm 0.08 \pm 0.05$
LEP	0.980 ± 0.069 [%]

$\simeq \pm .06 \pm .04$ %

TODAY

MAIN SYST'S
- MC STATS
- TRACKING SIMULATION

END LEP-I

$\Delta B(K^0_S h^- X^0) \simeq \pm .03 \pm .03$ %

$= \pm .04$ %

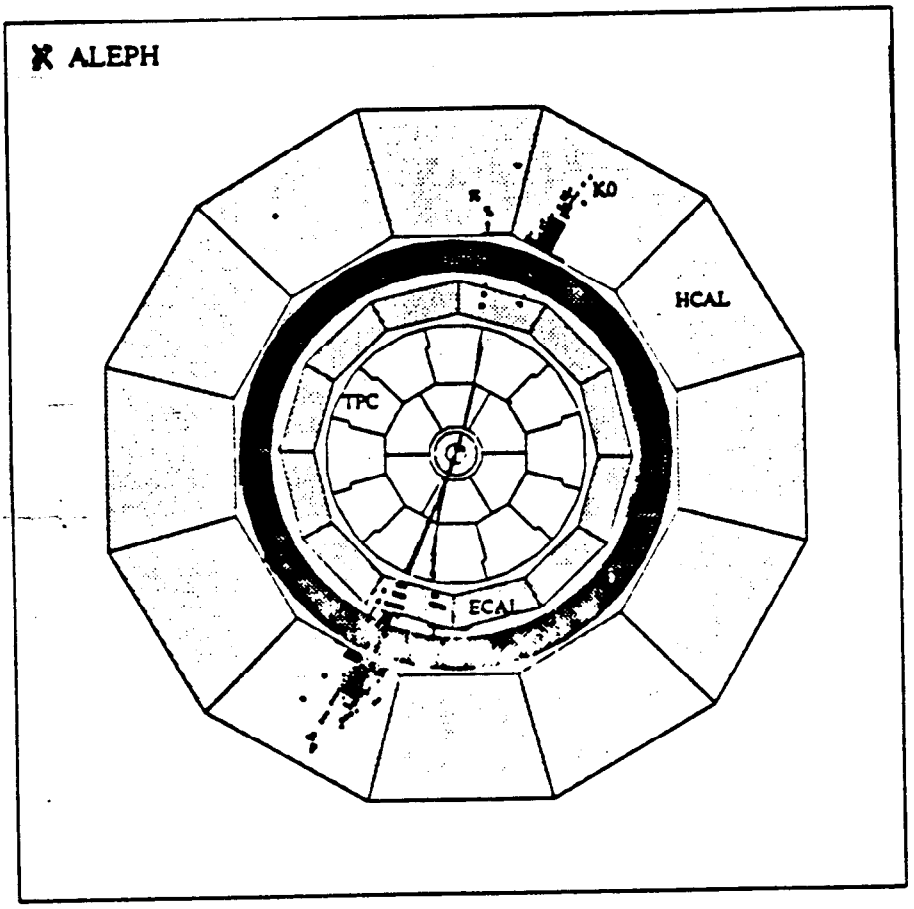
ALSO BY ALEPH:

$BR(K^- \pi^0 \pi^0 \nu)$

$= .04 \pm .03 \pm .02\ \%$

EXPECT STAT. $\rightarrow \sim \frac{\text{STAT}}{2}$ by END of LEP-I RUNNING.

ALEPH HAS MEASURED K^0_{LONG}'S IN τ-DECAY USING THE HADRONIC CALORIMETER.



$B(\nu\pi^-K^0) = .88 \pm .14 \pm .09$ %

$\nu K^- K^0 = .29 \pm .12 \pm .03$ (1ST MEAS'NT)

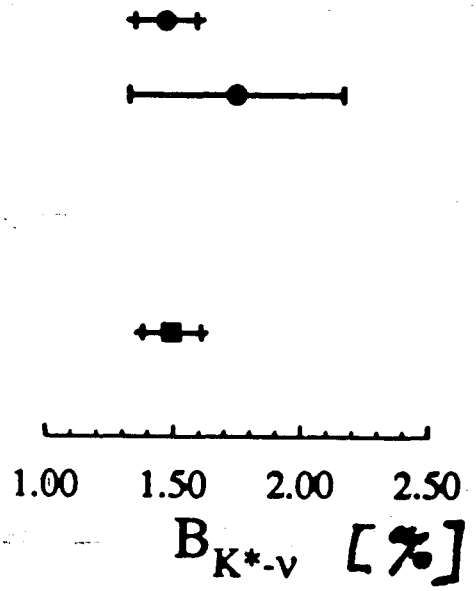
$\nu\pi^-\pi^0K^0 = .33 \pm .14 \pm .07$ (1ST MEAS'NT)

$\nu K\pi^0K^0 = .05 \pm .05 \pm .01$ (1ST MEAS'NT)

END LEP I.

EXPECT $\Delta_{STAT} \rightarrow \sim \frac{\Delta_{STAT}}{2}$ by

Branching Ratio $\tau^- \to K^{*-}\nu$



ALEPH	92 prelim.	$K^-\pi^0$, $K_L^0\pi^-$, $K_S^0\pi^-$
DELPHI	92 final	use K_S^0
LEP	average (χ^2=0.39)	

CPAL MEASURES
$K^*\nu \geq 0h^0 = 1.73 \pm 0.27\%$

ALEPH	$1.46 \pm 0.12 \pm 0.09$
DELPHI	1.74 ± 0.42 (FULL)

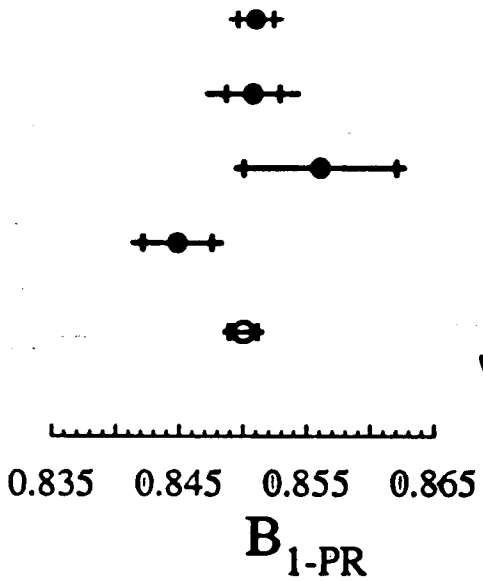
LEP	$1.49 \pm \underbrace{0.14}_{\simeq \pm .12 \pm .08\ \%}$ [%]

END LEP-I

$$\Delta B(K^*\nu) \simeq \pm .06 \pm \overset{?}{.07} = \pm .09\%$$

?!

1-Prong Branching ratio



ALEPH	92 prelim.	$B_{UNDET.} < .11\%$
DELPHI	92 prelim.	$\sum_1^5 B_i = 1$
L3	90 final	$\sum_1^5 B_i = 1$
OPAL	91 final	$\sum_1^5 B_i = 1$
LEP	average (χ^2=3.2)	

MIXING METHODS: $\sum_1^5 B_i = 1$ & $\cancel{\sum_1^5 B_i = 1}$

ALEPH	$0.8509 \pm 0.0014 \pm 0.0015$
DELPHI	$0.8507 \pm 0.0021 \pm 0.0030$
L3	$0.856 \pm 0.006 \pm 0.003$
OPAL	$0.8448 \pm 0.0027 \pm 0.0023$
LEP	$0.8500 \pm \underbrace{0.0016}_{\simeq \pm .011 \pm .011}$

TODAY

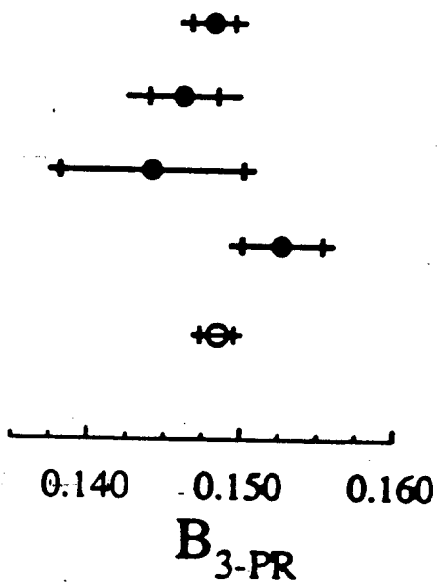
MAIN SYST'S: TRACKING, B_i's.

END LEP-I

$\Delta B_1 \simeq \pm .0004 \pm .0009 = .0010$

(BETTER IF TRACKING IMPROVEMENTS)

3-Prong Branching ratio



ALEPH	92 prelim.
DELPHI	92 prelim.
L3	90 final
OPAL	91 final
LEP	average (χ^2=2.4)

MIXING METHODS

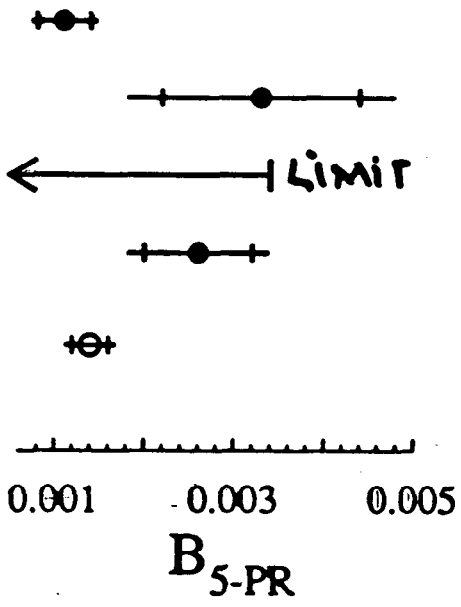
ALEPH	$0.1479 \pm 0.0014 \pm 0.0016$
DELPHI	$0.1460 \pm 0.0022 \pm 0.0030$
L3	$0.144 \pm 0.006 \pm 0.003$
OPAL	$0.1526 \pm 0.0026 \pm 0.0022$
LEP	$0.1484 \pm \underbrace{0.0016}_{\simeq \pm .0011 \pm .0012}$

END LEP-I

$$\Delta B_3 \simeq .0004 \pm .0010 \simeq .0011$$

?

5-Prong Branching ratio



ALEPH	92 prelim.
DELPHI	92 prelim.
L3	90 final
OPAL	91 final
LEP	average (χ^2=4.9)

ALEPH	$0.0011 \pm 0.0003 \pm 0.0002$
DELPHI	$0.0033 \pm 0.0011 \pm 0.0010$
(L3	< 0.0034 at 95% C.L.)
OPAL	$0.0026 \pm 0.0006 \pm 0.0005$
LEP	$0.0014 \pm \underbrace{0.0003}$

$\simeq .0002 \pm .0003$

TODAY

MAIN SYST'S: Br's, CONVERSIONS

END LEP-I

$$\Delta B_5 \simeq .0001 \pm .0002 \overset{?}{\underset{?}{}} = .00022$$

1-PRONG PROBLEM

DECLARED "DEAD" BY CLEO-II.

OPAL

B	e	$17.5 \pm .42\%$	$82.64 \pm 1.0\%$
	μ	$16.8 \pm .42\%$	
	h	$12.2 \pm .5\%$	
	$h\pi^0$	$36.14 \pm .67\%$	
	$h \geq 2\pi^0$		

$\sim 1.7\sigma$

$B_1 = 84.48 \pm .35\%$

Aleph

OLD B_e & B_μ (OHIO WKSHP)
$B_h, \ldots$

$$\Rightarrow \sum_{\text{EXCLUSIVE}} B_i = 99.93 \pm 1.1\%$$

NEW B_e & B_μ REDUCE Σ by 1.4%

(LET'S WAIT FOR NEW RESULTS FROM ALEPH ON $h\omega, h\pi^0, \ldots$)

$\alpha(s)$ in τ decays

$$R_\tau = \frac{\Gamma_{\tau\to hX}}{\Gamma_{\tau\to \ell\nu\bar{\nu}}} = \frac{1-B_e-B_\mu}{B_\ell}.$$

$$= \frac{1}{B_\ell} - \underbrace{\underset{\uparrow 1}{f_e} - \underset{\uparrow .9726}{f_\mu}}_{\text{phase space factors}}$$

MEASURE B_ℓ FROM THREE SOURCES:

(1) $\tau \to e\nu\bar{\nu}$

(2) $\tau \to \mu\nu\bar{\nu}$

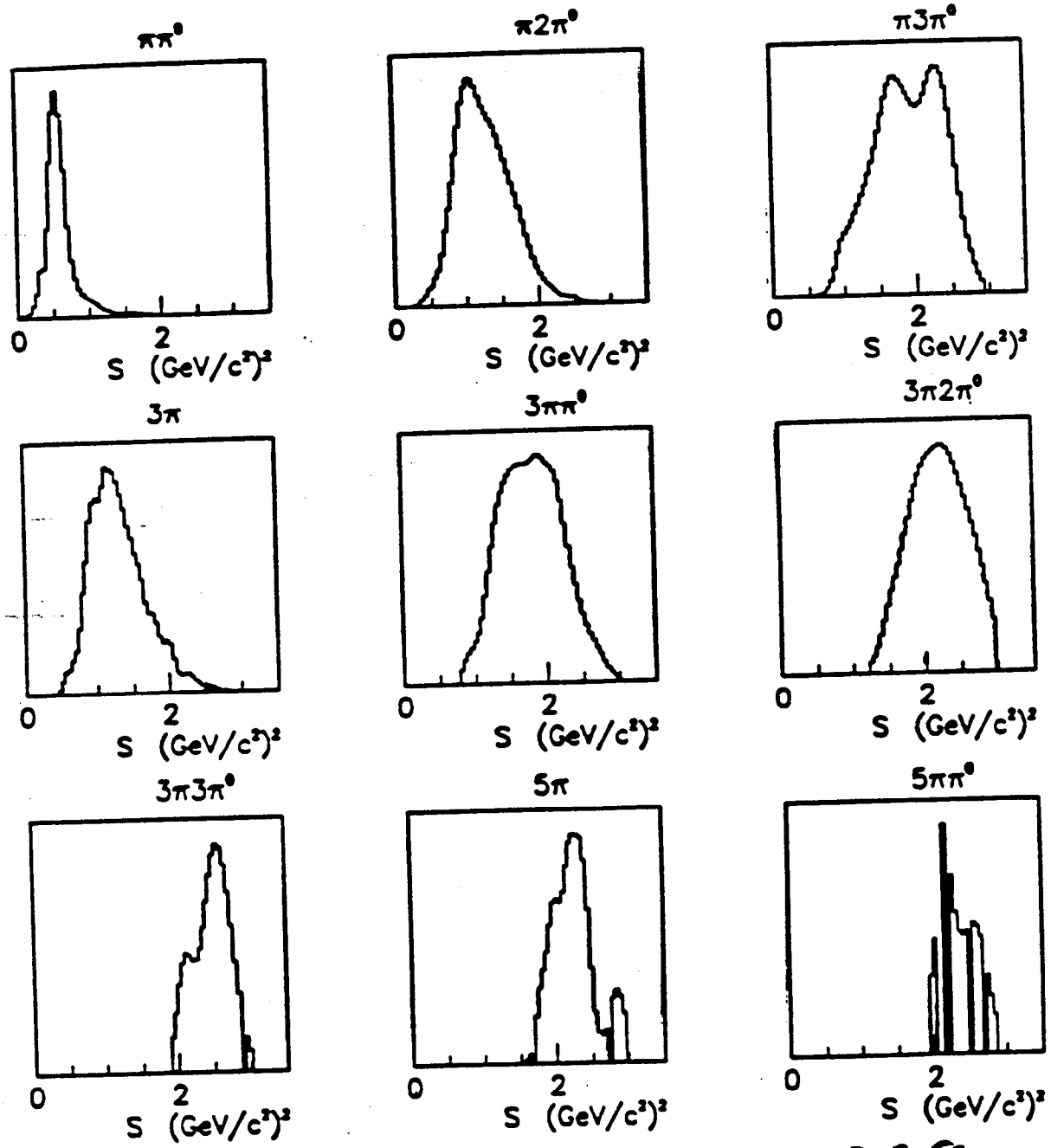
(3) τ LIFETIME & $B_\ell = \frac{\tau_\tau}{\tau_\mu}\left(\frac{M_\tau}{M_\mu}\right)^5$

QCD PREDICTS $R_\tau(\alpha_s(M_\tau))$ ...

(1) BUT THERE ARE NON-PERTURBATIVE PARTS TO CALCULATION. (SMALL)

(2) MOMENTS OF $M_{HADRONIC}$ MASS DISTRIBUTION GIVE INFORMATION ON NON-PERT PARTS.

ALEPH PRELIMINARY!



NON-PERT. PARTS = −0.1 ± 0.5 %

$R_\tau = 3 * (1 + \text{pert} + \text{non-pert})$

IN "SUZ" CONTEXT.

ALEPH RESULT!

$$R_\tau = 3.709 \pm 0.032$$

$$\alpha_s(M_\tau) = 0.387 \pm 0.025$$

$$\alpha_s(M_Z) = 0.1245 \pm \underbrace{0.0025}_{\pm 0.0016 \text{ EXP'T} \quad \pm 0.0016 \text{ THEORY} \quad \pm 0.0010 \; M_\tau \to M_Z}$$

2x BIGGER?

(PRELIM.)

SO ±.019 OUT OF .025 IS UNCERTAINTY FROM THEORY SIDE.

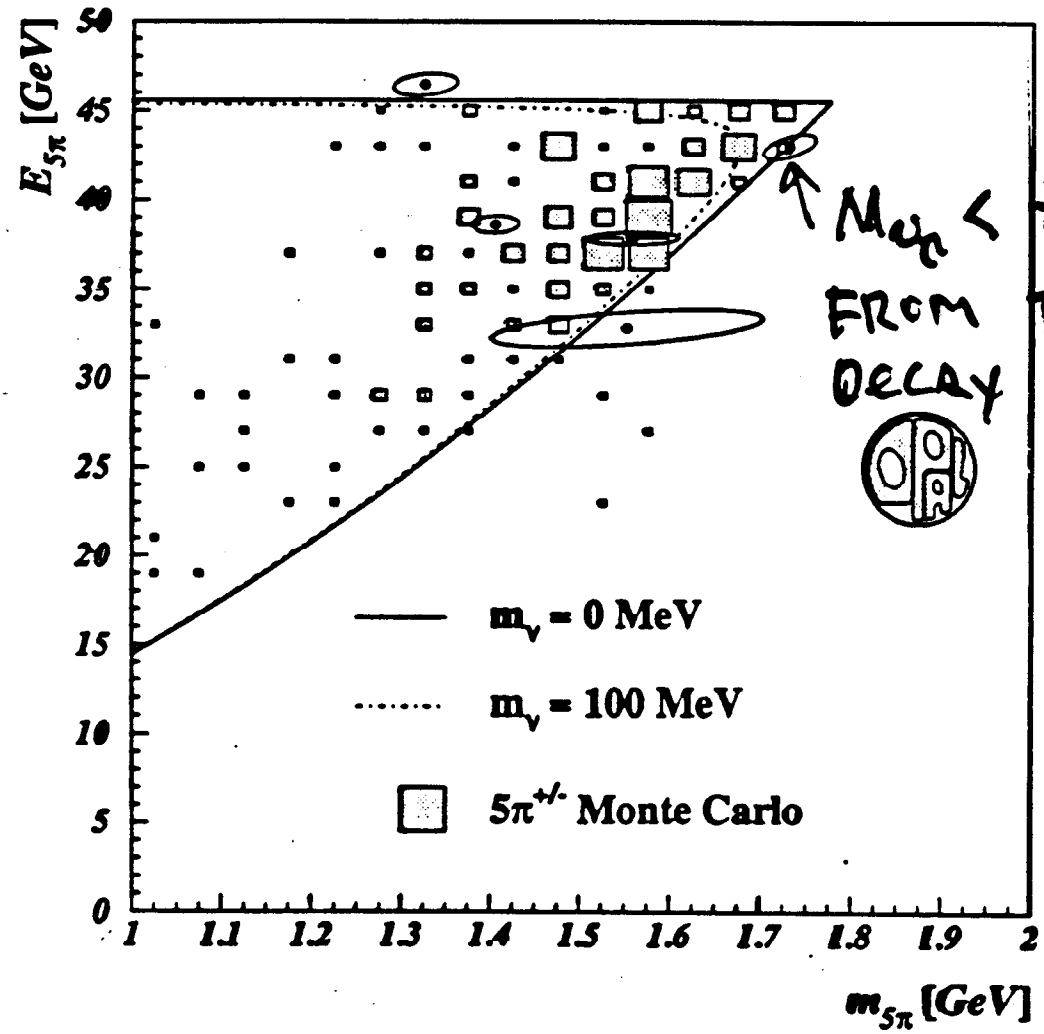
THERE IS NOT AGREEMENT ON THE SIZE OF $M_\tau \to M_Z$ UNCERTAINTY.

IMPROVEMENT MUST COME FROM THEORY.

OPAL M_{ν_τ} limit

$\tau \to 5\pi\nu_\tau\nu_\tau$

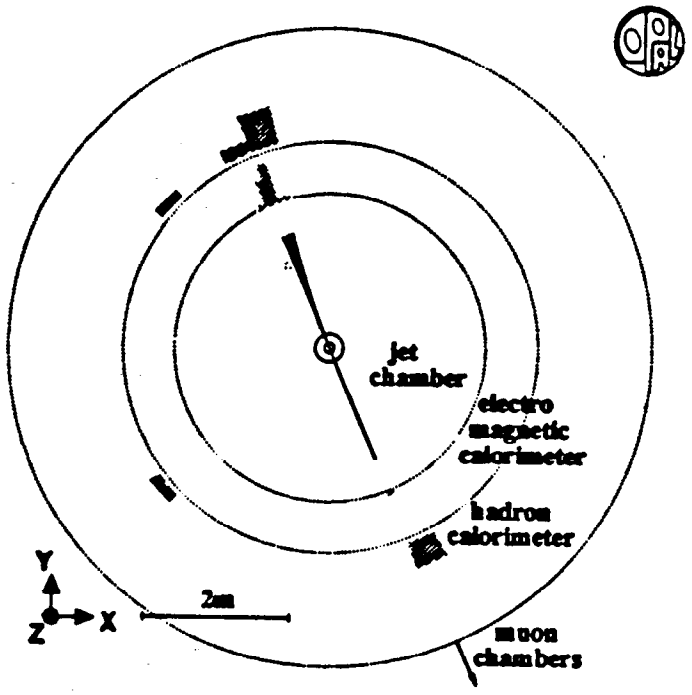
$M_{\nu_\tau} < 74$ MeV at 95% CL

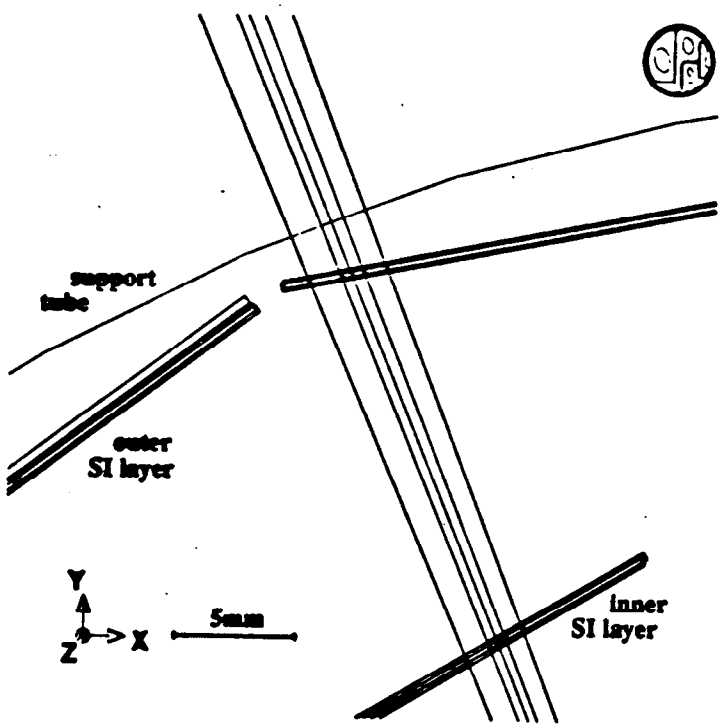


$M_{\nu_\tau} < 77$ MeV FROM THIS DECAY alone.

FUTURE

RESULTS COMPETETIVE WITH ARGUS 31 MeV RESULT ARE POSSIBLE.


jet
chamber
electro
magnetic
calorimeter
hadron
calorimeter
Y
Z
X
2m
muon
chambers


support
tube
outer
SI layer
Y
Z
X
5mm
inner
SI layer

SUMMARY OF LEP RESULTS

NEUTRAL CURRENT

TODAY	END LEP-I	OTHER EXP'T.
$R_\tau = 20.749 \pm 0.070$	$\pm .050$	—
$A_{FB}^{\tau,\tau} = 0.0228 \pm 0.0026$	$\pm .0019$	—
TAU POL.		
$A_\tau = 0.143 \pm 0.009$	± 0.006	—
$A_e = 0.133 \pm 0.011$	± 0.006	SLD $\pm .008$

τ DECAYS

$h_{\nu_\tau} = -0.951 \pm 0.058$	± 0.032 OR BETTER?	ARGUS $\pm .041$
MICHEL PARAM'S		
$\rho = 0.798 \pm 0.041$	$\pm .025$ BETTER?	ARGUS CLEO $\sim \pm .041$ ↑ ALEPH

TODAY	END LEP-I	OTHER EXP'T.
$\delta = 0.76 \pm 0.17$	± 0.10 Better?	—
$\xi = 1.14 \pm 0.18$	± 0.10 Better?	ARGUS $\pm .18$
$(\eta: \ \Delta\eta \simeq \pm .11$	$\simeq \pm .07)$	ARGUS $\pm .22$
LIFETIME		
$\tau_\tau = 291.4 \pm 1.9$	± 1.1	—
BRANCHING FRACTIONS		
$B_e = 0.1755 \pm 0.0013$	± 0.0008	CLEO-I $\pm .0027$
$B_\mu = 0.1711 \pm 0.0012$	± 0.0007	(CLEO-II)
$B_\ell = 0.1757 \pm 0.0009$	± 0.0006	CLEO-II
UNIVERSALITY		
$(g_e/g_\mu)^2 = 0.9923 \pm 0.0041$	± 0.0025	

TODAY	END LEP-I	OTHER EXPT'S.
$B(h\nu) = .1207 \pm .0022$	$\pm .0011$	—
$B(h\pi^0\nu) = .2512 \pm .0030$	$\pm .0015$	CLEO-II ARGUS
$B(h2\pi^0\nu) = .0942 \pm .0040$	$\pm .0014$	CLEO-II ARGUS
$B(h3\pi^0\nu) = 1.70 \pm 0.47\,\%$	$\pm .14\,\%$	CLEO-II ARGUS
$B(3h\nu) = 0.0911 \pm .0026$	$\pm .0012$	CLEO-II ARGUS
$B(3h\pi^0\nu) = 4.25 \pm 0.18\%$	$\pm .12\,\%$	* CLEO-II
$B(K^-\nu) = 0.685 \pm 0.064\,\%$	$\pm .04\,\%$	CLEO-II
$B(K^-\nu X^0) = 1.58 \pm 0.12\,\%$	$\pm .09\,\%$	
$B(K^0_S h^- X^0\nu) = 0.980 \pm .069\,\%$	$\pm .04\,\%$	
⋮		
$B(K^{*-}\nu) = 1.49 \pm 0.14\,\%$	$\pm 0.09\,\%$	CLEO-II
$B_1 = .8500 \pm .0016$	$\pm .0011$	HRS CELLO
$B_3 = .1484 \pm .0016$	$\pm .0011$	HRS CELLO
$B_5 = .0014 \pm .0003$	$\pm .0002$	* CLEO-II HRS

* ⇒ DOMINATES ALL MEAS'NTS.

CONCLUSION/OUTLOOK

- LEP PRODUCES LOTS OF <u>physics</u> WITH τ's (N.C.) AND <u>OF τ's (DECAY)</u>.
- LIFETIME UNCERTAINTY $\rightarrow \sim 1$ fs BY END LEP-I
- $\Delta B_\ell \rightarrow \pm .0006$ FOR e & μ (.4%)
- $\Delta(g_e/g_\mu)^2 \rightarrow \pm .0025$
- $\Delta B(h\nu) \rightarrow \pm .001$ (1%)

BES $\rightarrow$ .1% ? HARD EVEN WITH WITH SINGLE-hemisphere tag.

- $\Delta B(h\pi\pi^0)$ GOOD COMPETITION FOR CLEO-II, FOR NOW.
- $\Delta B(K\ldots) \rightarrow \sim 5\%$ FOR MANY MODES. K^0_{LONG} DETECTED
- $\Delta\alpha_s = \pm .0025$ THEORY WORK NEEDED
- M_{ν_τ} LIMIT: GOOD NUMBERS POSSIBLE
- LESS THAN 1/2 FULL LEP-I DATA HAVE BEEN ANALYZED.