τ Tau Physics

A. Pich

"Heavy Flavours II" (World Sci., 1998)
hep-ph/9704453

- Charged Current Universality
- Lorentz Structure
- Neutral Currents
- Searching for New Physics
- Hadronic Decays
- QCD Tests

Proc. TAU 98, Nucl. Phys. (Proc. Suppl.) (1999)

Flavour Structure of the Standard Model:

3 Families of fundamental fermions

$$\begin{pmatrix} u & \nu_e \\ d & e \end{pmatrix} \quad \begin{pmatrix} c & \nu_\mu \\ s & \mu \end{pmatrix} \quad \begin{pmatrix} t & \nu_\tau \\ b & \tau \end{pmatrix}$$

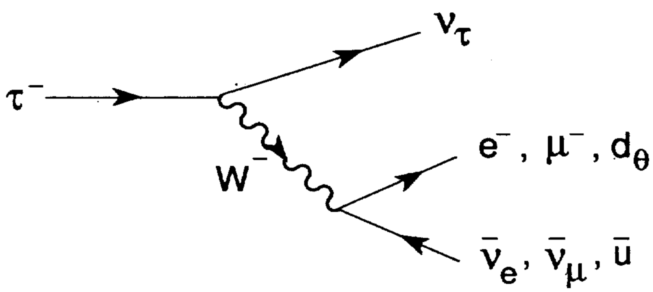
- Why 3 ?
- Pattern of masses
- Are the masses the only difference among the 3 generations ?
- Flavour mixing
- CP violation

- The *light* fermions are the best known
- The *heavy* fermions are expected to be more sensitive to any New Physics related to mass generation $[\sim (m_f / M_{New})^n]$

➡ 3rd Generation

τ , ν_τ

TAU DECAY



$d_\theta \equiv \cos\theta_C\, d + \sin\theta_C\, s$

$$B_l \equiv Br(\tau^- \to \nu_\tau l^- \bar{\nu}_l) \approx \frac{1}{5} = 20\%$$

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \text{hadrons})}{\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)} \approx N_C = 3$$

Experiment: (TAU 98)

$\tau_\tau = (290.5 \pm 1.0)$ fs

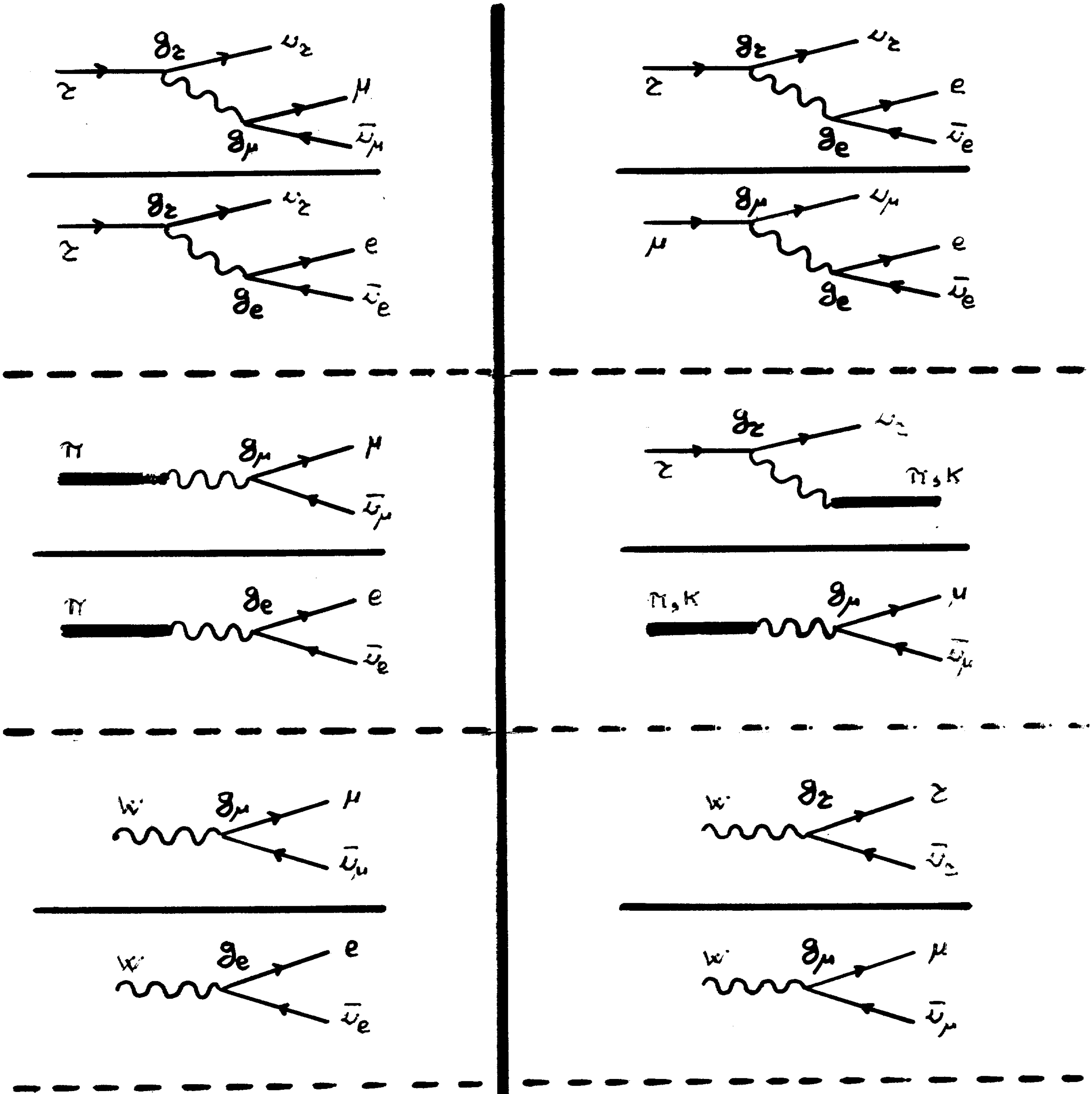
$B_e = (17.81 \pm 0.06)\%$, $\quad B_\mu = (17.36 \pm 0.06)\%$

$$R_\tau^B \equiv \frac{1 - B_e - B_\mu}{B_e} = 3.640 \pm 0.016$$

$$R_\tau^\Gamma \equiv \frac{\Gamma_\tau - \Gamma_{\tau\to e} - \Gamma_{\tau\to\mu}}{\Gamma_{\tau\to e}} = 3.646 \pm 0.020$$

$$\Longrightarrow \qquad R_\tau = 3.642 \pm 0.012$$

Lepton Universality



$$\frac{g_\mu}{g_e}$$

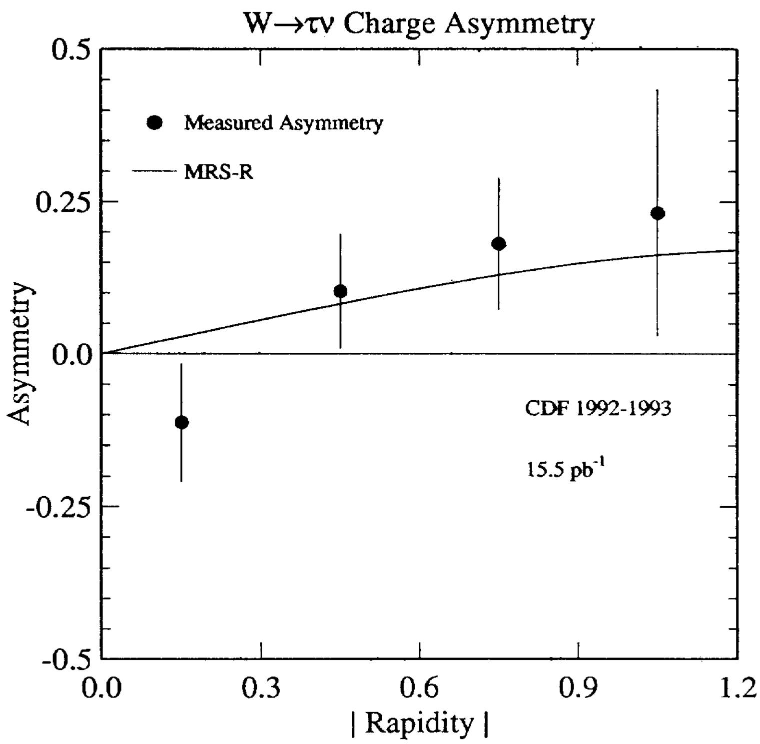
$$\frac{g_\tau}{g_\mu}$$

Charged–Current Universality Tests

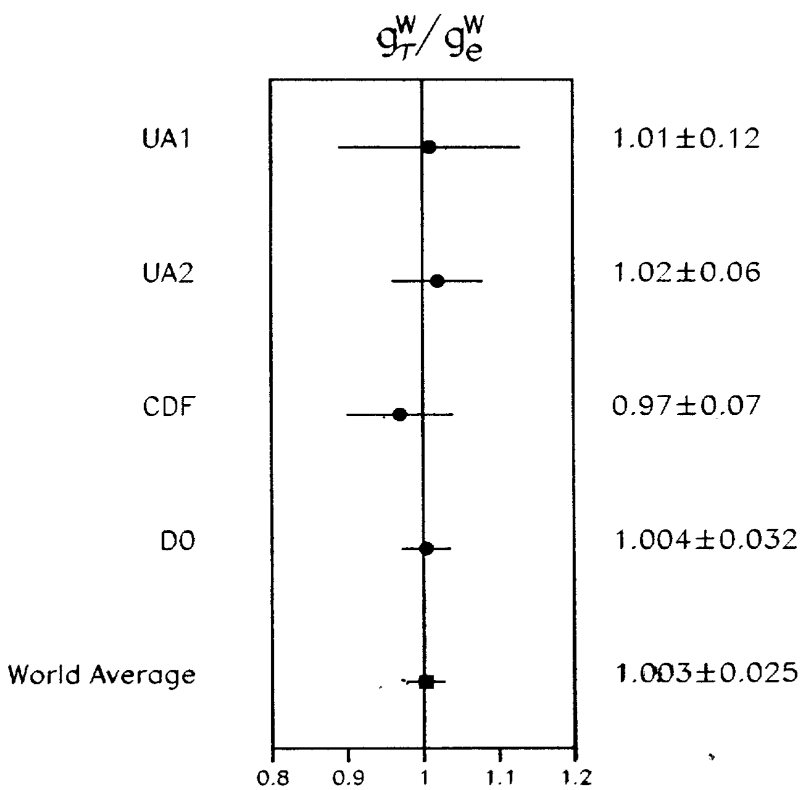
	$\lvert g_\mu / g_e \rvert$
$B_{\tau\to\mu}/B_{\tau\to e}$	1.0011 ± 0.0024
$R_{\pi\to e/\mu}$	1.0017 ± 0.0015
$\sigma \cdot B_{W\to\mu/e}$ $(p\bar{p})$	0.98 ± 0.03
$B_{W\to\mu/e}$ (LEP2)	0.971 ± 0.031

	$\lvert g_\tau / g_\mu \rvert$
$B_{\tau\to e}\, \tau_\mu/\tau_\tau$	1.0003 ± 0.0024
$R_{\tau/\pi}$	1.008 ± 0.008
$R_{\tau/K}$	0.997 ± 0.035
$B_{W\to\tau/\mu}$ (LEP2)	0.984 ± 0.037

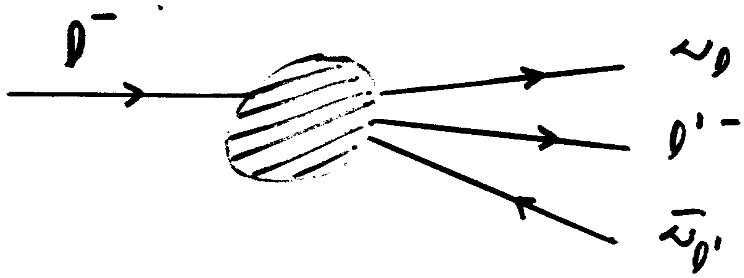
	$\lvert g_\tau / g_e \rvert$
$B_{\tau\to\mu}\, \tau_\mu/\tau_\tau$	1.0014 ± 0.0025
$\sigma \cdot B_{W\to\tau/e}$ $(p\bar{p})$	1.003 ± 0.025
$B_{W\to\tau/e}$ (LEP2)	0.955 ± 0.036


W→τν Charge Asymmetry
Measured Asymmetry
MRS-R
CDF 1992-1993
15.5 pb^{-1}
Asymmetry
| Rapidity |
0.5
0.25
0.0
-0.25
-0.5
0.0
0.3
0.6
0.9
1.2

$$\frac{N_+ - N_-}{N_+ + N_-}$$


g^W_τ / g^W_e
UA1
1.01±0.12
UA2
1.02±0.06
CDF
0.97±0.07
D0
1.004±0.032
World Average
1.003±0.025
0.8
0.9
1
1.1
1.2

Lorentz Structure of $l^- \to \nu_l \, l'^- \, \bar{\nu}_{l'}$



$\mu^- \to e^- \nu_\mu \bar{\nu}_e$; $\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$; $\tau^- \to e^- \nu_\tau \bar{\nu}_e$

$$\mathcal{H} = 4 \frac{G_{l'l}}{\sqrt{2}} \sum_{n,\epsilon,\omega} g^n_{l'_\epsilon l_\omega} \left[\overline{l'_\epsilon} \Gamma^n (\nu_{l'})_\sigma \right] \left[(\overline{\nu_l})_\lambda \Gamma_n \, l_\omega \right]$$

$$\Gamma^S = I \quad ; \quad \Gamma^V = \gamma^\mu \quad ; \quad \Gamma^T = \sigma^{\mu\nu}/\sqrt{2}$$

$\epsilon, \omega, \sigma, \lambda = L, R$

10 complex couplings $g^n_{\epsilon\omega}$ for each decay

➡ 3×19 Independent real parameters

(1 arbitrary phase)

<u>Standard Model:</u>

$G_{l'l} = G_F$; $g^V_{LL} = 1$;

All other couplings $g^n_{\epsilon\omega} = 0$

$\ell^- \to \ell'^- \nu_\ell \bar{\nu}_{\ell'}$ decay width :

Bouchiat – Michel
Kinoshita – Sirlin

$$\frac{d\Gamma}{dx\, d\cos\theta} \simeq \frac{m_\ell\, \omega^4}{2\pi^3} G^2 x \left\{ x(1-x) + \frac{2}{9}\rho\,(4x^2-3x) + \eta\, m_{\ell'} \frac{1-x}{\omega} - \frac{1}{3} \mathcal{P}_\ell\, \xi\, x \cos\theta \left[1-x+\frac{2}{3}\delta\,(4x-3) \right] \right\}$$

$\omega \equiv (m_\ell^2 + m_{\ell'}^2)/2m_\ell \quad ; \quad x \equiv E_{\ell'}/\omega$

$\mathcal{P}_\ell \equiv$ ℓ^- polarization

If ℓ'^- polarization is measured $\longrightarrow$ $\xi', \xi'', \eta'', \alpha', \beta'$

$$\Gamma = \frac{m_\ell^5\, G^2}{192\,\pi^3} \left\{ f(m_{\ell'}^2/m_\ell^2) + 4\,\eta\, \frac{m_{\ell'}}{m_\ell}\, g(m_{\ell'}^2/m_\ell^2) \right\} r_{RC}$$

$$f(z) = 1 - 8z - 12 z^2 \ln z + 8z^3 - z^4$$
$$g(z) = 1 + 9z - 9z^2 - z^3 + 6z(1+z)\ln z$$

$$r_{RC} = \left\{ 1 + \frac{\alpha}{2\pi}\left(\frac{25}{4} - \pi^2\right) \right\} \left\{ 1 + \frac{3}{5}\frac{m_\ell^2}{M_W^2} - 2\frac{m_{\ell'}^2}{M_W^2} \right\}$$

(Marciano – Sirlin)

Standard Model : $\rho = \delta = \frac{3}{4} \quad ; \quad \eta = 0 \quad ; \quad \xi = 1$

Fetscher et al.

Normalization :

$$1 = \frac{1}{4}\left(|g^S_{LL}|^2 + |g^S_{LR}|^2 + |g^S_{RL}|^2 + |g^S_{RR}|^2 \right)$$
$$+ |g^V_{LL}|^2 + |g^V_{LR}|^2 + |g^V_{RL}|^2 + |g^V_{RR}|^2$$
$$+ 3\left(|g^T_{LR}|^2 + |g^T_{RL}|^2 \right)$$

Decay Probabilities :

$$Q_{LL} = \frac{1}{4}|g^S_{LL}|^2 + |g^V_{LL}|^2 \qquad = \frac{1}{4}\{-3 + \frac{16}{3}\rho - \frac{1}{3}\xi + \frac{16}{9}\xi\delta + \xi' + \xi''$$

$$Q_{RR} = \frac{1}{4}|g^S_{RR}|^2 + |g^V_{RR}|^2 \qquad = \frac{1}{4}\{-3 + \frac{16}{3}\rho + \frac{1}{3}\xi - \frac{16}{9}\xi\delta - \xi' + \xi''$$

$$Q_{LR} = \frac{1}{4}|g^S_{LR}|^2 + |g^V_{LR}|^2 + 3|g^T_{LR}|^2 = \frac{1}{4}\{5 - \frac{16}{3}\rho + \frac{1}{3}\xi - \frac{16}{9}\xi\delta + \xi' - \xi''$$

$$Q_{RL} = \frac{1}{4}|g^S_{RL}|^2 + |g^V_{RL}|^2 + 3|g^T_{RL}|^2 = \frac{1}{4}\{5 - \frac{16}{3}\rho - \frac{1}{3}\xi + \frac{16}{9}\xi\delta - \xi' - \xi''$$

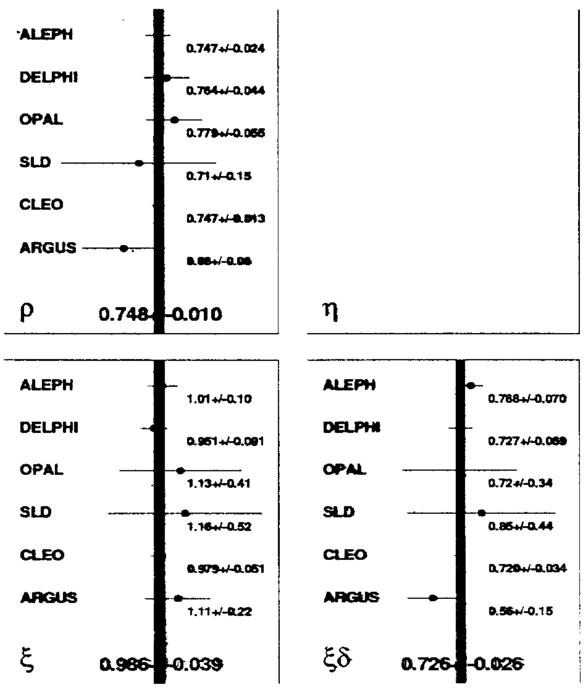
$$\boxed{Q_{\ell_R} \equiv Q_{RR} + Q_{LR} = \frac{1}{2}\left[1 + \frac{\xi}{3} - \frac{16}{9}\xi\delta\right]}$$

2 ℓ^--polarization parameters bound 5 couplings

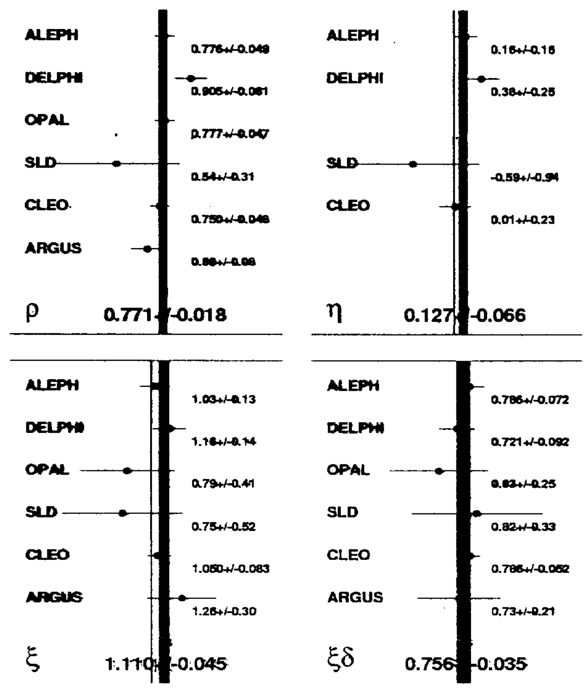
$$\boxed{Q_{\ell'_R} \equiv Q_{RR} + Q_{RL} = \frac{1}{2}\left[1 - \xi'\right]}$$

1 single measurement of the final-lepton polarization needed to bound the 5 RR and RL couplings

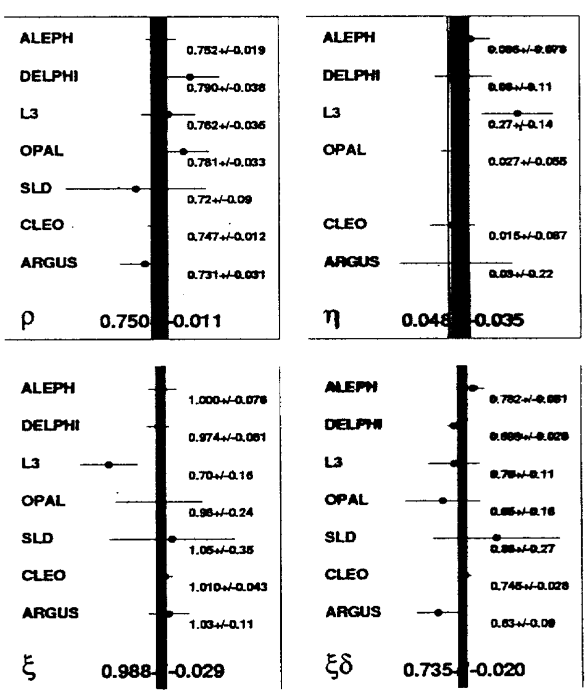
$\tau \to e \nu_e \nu_\tau$



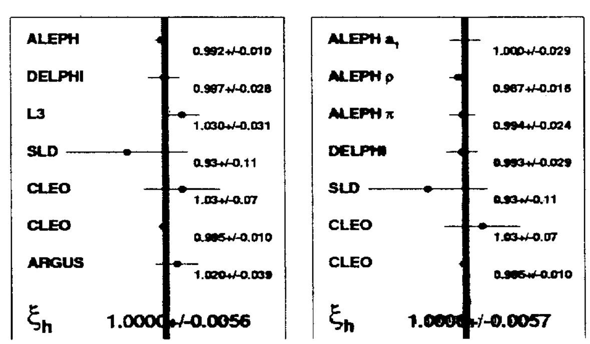
$\tau \to \mu \nu_\mu \nu_\tau$



$\tau \to l \nu_l \nu_\tau \quad (l = e, \mu)$



$\tau \to \nu_\tau h \quad (h = \pi, 2\pi, 3\pi)$



$\tau \to e \nu_e \nu_\tau$

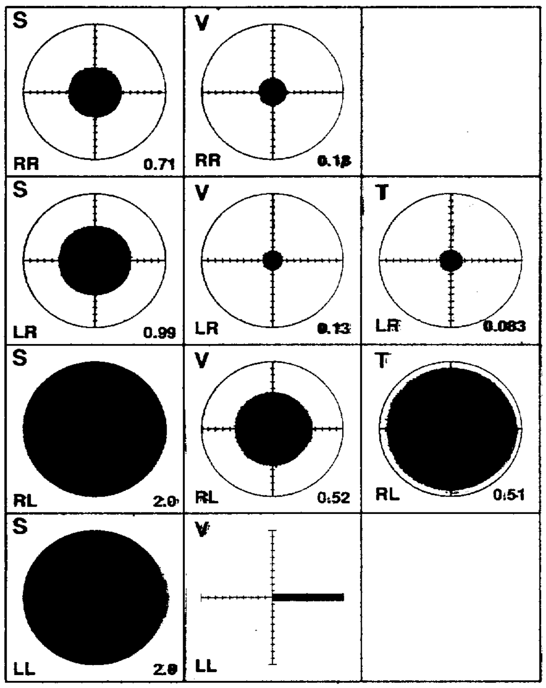


Figure 4. Limits on the coupling constants $g^\kappa_{\epsilon\rho}$ for $\tau \to e\,\nu_e\nu_\tau$ decays: The upper letter in each box indicates the type of coupling (Scalar/Vector/Tensor), the lower two letters the chirality of the τ (right letter) and the daughter lepton (left letter). The circle defines the allowed range of the couplings (assuming $A_\ell = 1$) and the shaded area is the region still consistent with the measurements of A_e and the Michel parameters (90 % confidence level). These limits on the couplings are also printed in the lower right corner of each box.

$\tau \to \mu \nu_\mu \nu_\tau$

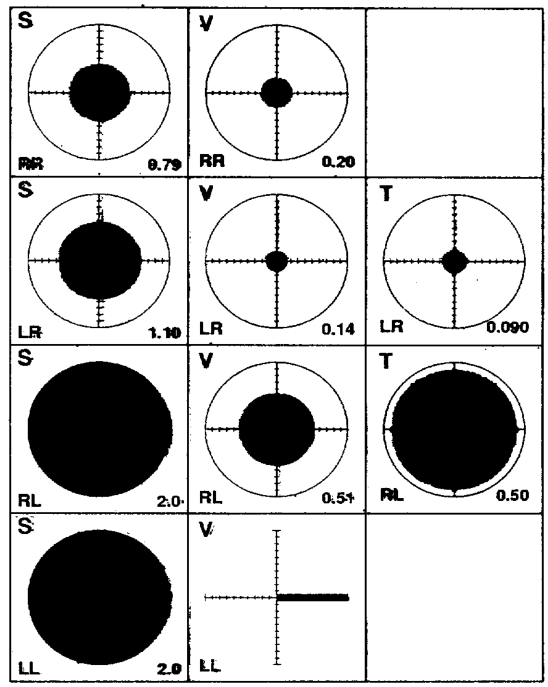


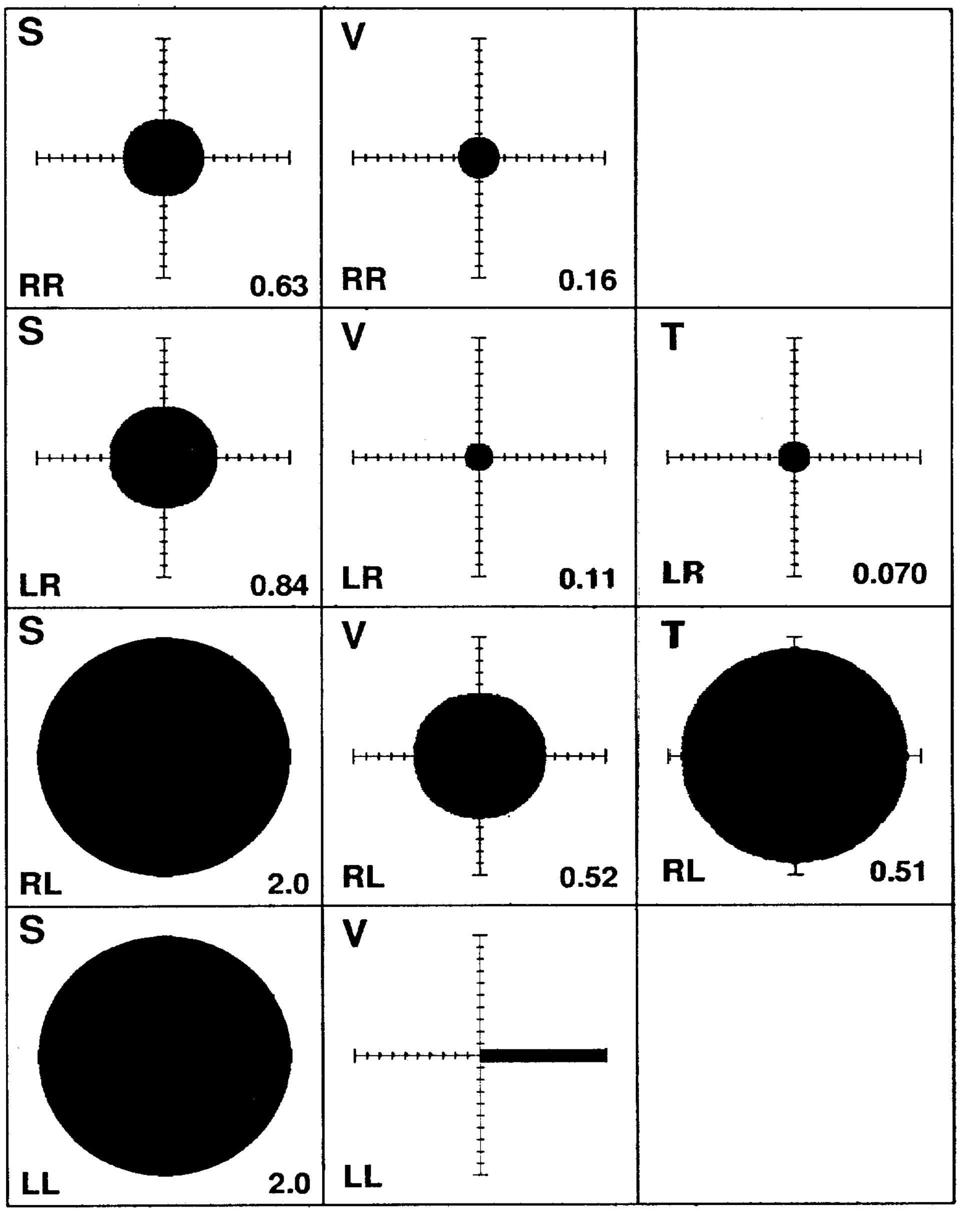
Figure 5. Limits on the coupling constants $g^\kappa_{\epsilon\rho}$ for $\tau \to \mu\,\nu_\mu\nu_\tau$ decays: The upper letter in each box indicates the type of coupling (Scalar/Vector/Tensor), the lower two letters the chirality of the τ (right letter) and the daughter lepton (left letter). The circle defines the allowed range of the couplings (assuming $A_\ell = 1$) and the shaded area is the region still consistent with the measurements of A_μ and the Michel parameters (90 % confidence level). These limits on the couplings are also printed in the lower right corner of each bo

$Q_{\tau_R \to e} < 0.058$ $\quad$ $Q_{\tau_R \to \mu} < 0.065$

$g^n_{\varepsilon\omega} / N^n$, $N^n \equiv \max(|g^n_{\varepsilon\omega}|)$

$N^S = 2$, $N^V = 1$, $N^T = 1/\sqrt{3}$

$\tau \to l \nu_l \nu_\tau \qquad (l = e, \mu)$



Black circles = μ decay limits

$Q_{\tau_R \to \ell} < 0.041$

Z peak : $(s = M_Z^2)$

$$\sigma_{peak} = \frac{12\pi}{M_Z^2} \frac{\Gamma_e \Gamma_f}{\Gamma_Z^{2}} \quad ; \quad \Gamma_f \equiv \Gamma(Z \to f\bar{f})$$

$$A_{FB} = \frac{3}{4} \mathcal{P}_e \mathcal{P}_f$$

$$A^{Pol} = \mathcal{P}_f$$

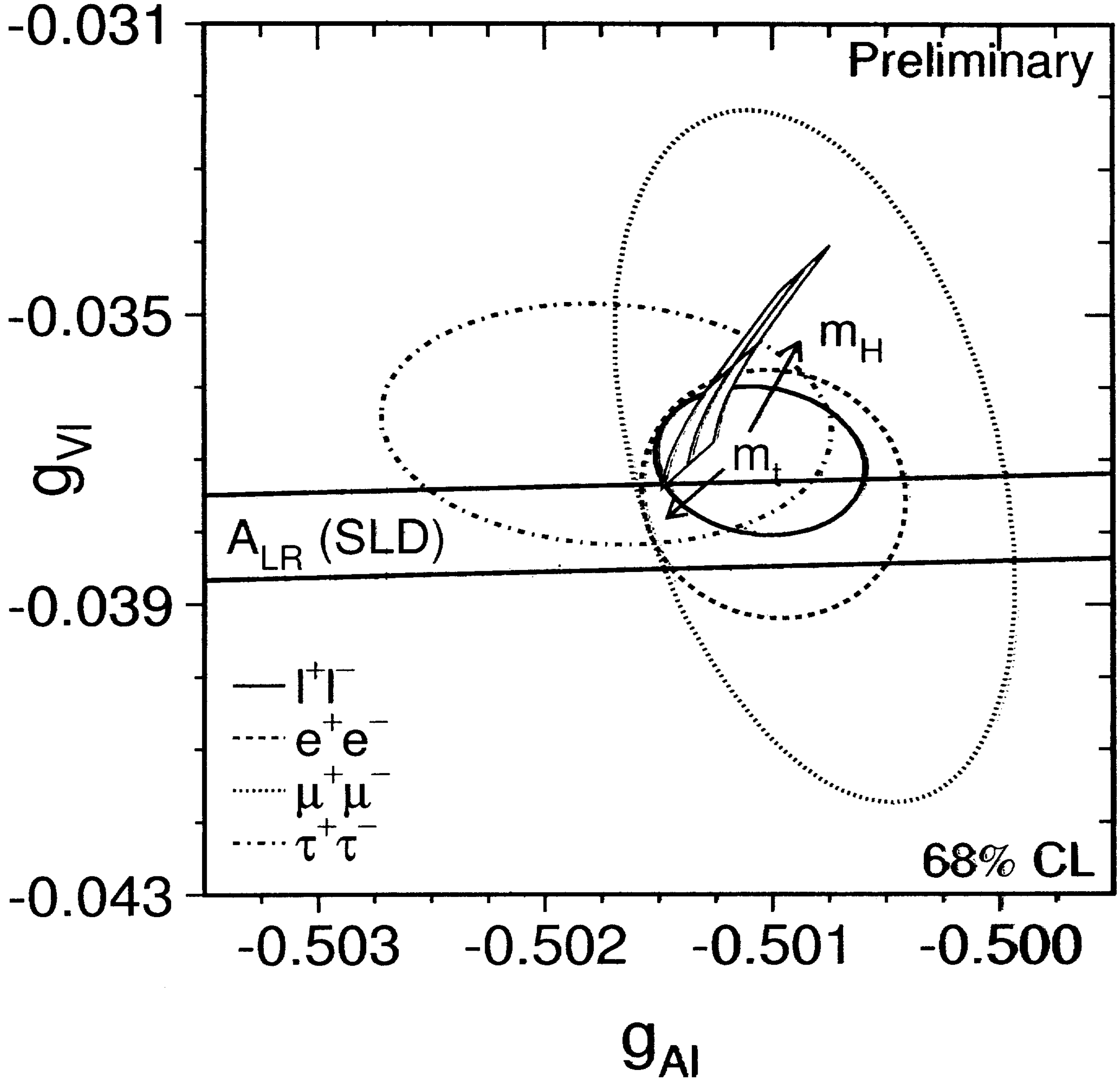
$$A_{FB}^{Pol} = \frac{3}{4} \mathcal{P}_e$$

$$A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = - \mathcal{P}_e$$

$$\mathcal{P}_f \equiv - A_f = \frac{-2 v_f a_f}{v_f^{2} + a_f^2}$$

Measuremts of A^{Pol} and A^{Pol}_{FB} are only available for $f = \tau$

LEP / SLD , CERN-EP/99-15



$m_t = 173.8 \pm 5.0$ GeV ; $m_H = 300\ ^{+700}_{-210}$ GeV

	Without Lepton Universality: LEP	LEP+SLD
g_{Ve}	-0.0375 ± 0.0011	-0.03781 ± 0.00052
$g_{V\mu}$	-0.0369 ± 0.0031	-0.0366 ± 0.0030
$g_{V\tau}$	-0.0365 ± 0.0011	-0.0365 ± 0.0011
g_{Ae}	-0.50099 ± 0.00038	-0.50098 ± 0.00038
$g_{A\mu}$	-0.50081 ± 0.00058	-0.50082 ± 0.00058
$g_{A\tau}$	-0.50173 ± 0.00065	-0.50171 ± 0.00065
	Ratios of couplings: LEP	LEP+SLD
$g_{V\mu}/g_{Ve}$	0.984 ± 0.098	0.967 ± 0.082
$g_{V\tau}/g_{Ve}$	0.974 ± 0.043	0.965 ± 0.032
$g_{A\mu}/g_{Ae}$	0.9996 ± 0.0014	0.9997 ± 0.0014
$g_{A\tau}/g_{Ae}$	1.0015 ± 0.0015	1.0015 ± 0.0015
	With Lepton Universality: LEP	LEP+SLD
$g_{V\ell}$	-0.03703 ± 0.00068	-0.03753 ± 0.00044
$g_{A\ell}$	-0.50105 ± 0.00030	-0.50102 ± 0.00030
g_{ν}	$+0.50123 \pm 0.00095$	$+0.50123 \pm 0.00095$

Searching for New Physics

*) **$\not{L}_i$, $\not{L}$** CLEO, ARGUS, ...

$B(\tau^- \to \mu^- \gamma) < 3.0 \times 10^{-6}$, $B(\tau^- \to e^- \rho^0) < 2.0 \times 10^{-6}$

$B(\tau^- \to e^- e^+ e^-) < 2.9 \times 10^{-6}$, $B(\tau^- \to \mu^- \mu^+ \mu^-) < 1.9 \times 10^{-6}$

(90% CL)

$B(Z \to e\tau) < 9.8 \times 10^{-6}$, $B(Z \to \mu\tau) < 1.2 \times 10^{-5}$ (95% CL)

OPAL, DELPHI

*) **$m_\nu \neq 0$**

$m_{\nu_\tau} < 24$ MeV (95% CL) ALEPH

18.2

⇒ $"m_{\nu_e}" \sim \left(\frac{m_e}{m_\tau}\right)^2 m_{\nu_\tau} \sim 2$ eV !

1.5

Neutrino Oscillations E 531

$\nu_\mu \to \nu_\tau$: $\sin^2(2\theta_{\mu\tau}) < 0.004$ (large $\delta m^2_{\mu\tau}$)

$\delta m^2_{\mu\tau} < 0.9$ eV^2 ($\sin^2(2\theta_{\mu\tau}) = 1$)

$\nu_e \to \nu_\tau$: $\sin^2(2\theta_{e\tau}) < 0.12$ (large $\delta m^2_{e\tau}$)

$\delta m^2_{e\tau} < 9$ eV^2 ($\sin^2(2\theta_{e\tau}) = 1$)

⇔ $|g_{\tau\nu_\mu}| < 0.002$, $|g_{\tau\nu_e}| < 0.073$

(90% CL)

R. Stroynowski , TAU 98

Table 1
Upper limits for neutrinoless τ decays (90% CL)

Channel	UL, 10^{-6}	Channel	UL, 10^{-6}
$e^-\gamma$	2.7	$\mu^-\gamma$	3.0
$e^-e^+e^-$	2.9	$\mu^-\mu^+\mu^-$	1.9
$e^-e^+\mu^-$	1.7	$\mu^-\mu^+e^-$	1.8
$e^-\mu^-e^-$	1.5	$\mu^-e^+\mu^-$	1.5
$e^-\pi^0$	3.7	$\mu^-\pi^0$	4.0
$e^-\eta$	8.2	$\mu^-\eta$	9.6
$e^-\rho^0$	2.0	$\mu^-\rho^0$	6.3
e^-K^{*0}	5.1	μ^-K^{*0}	7.5
$e^-\bar{K}^{*0}$	7.4	$\mu^-\bar{K}^{*0}$	7.5
$e^-\phi$	6.9	$\mu^-\phi$	7.0
$e^-\pi^+\pi^-$	2.2	$\mu^-\pi^+\pi^-$	8.2
$e^-\pi^+K^-$	6.4	$\mu^-\pi^+K^-$	7.5
$e^-K^+\pi^-$	3.8	$\mu^-K^+\pi^-$	7.4
$e^-K^+K^-$	6.0	$\mu^-K^+K^-$	15
$e^+\pi^-\pi^-$	1.9	$\mu^+\pi^-\pi^-$	3.4
$e^+\pi^-K^-$	2.1	$\mu^+\pi^-K^-$	7.0
$e^+K^-K^-$	3.8	$\mu^+K^-K^-$	6.0
$e^-\pi^0\pi^0$	6.5	$\mu^-\pi^0\pi^0$	14
$e^-\pi^0\eta$	24	$\mu^-\pi^0\eta$	22
$e^-\eta\eta$	35	$\mu^-\eta\eta$	60
e^-K^0	1300	μ^-K^0	1000
$\bar{p}\gamma$	290		
$\bar{p}\pi$	660		
$\bar{p}\eta$	1300		
$\pi\pi^0$	370		

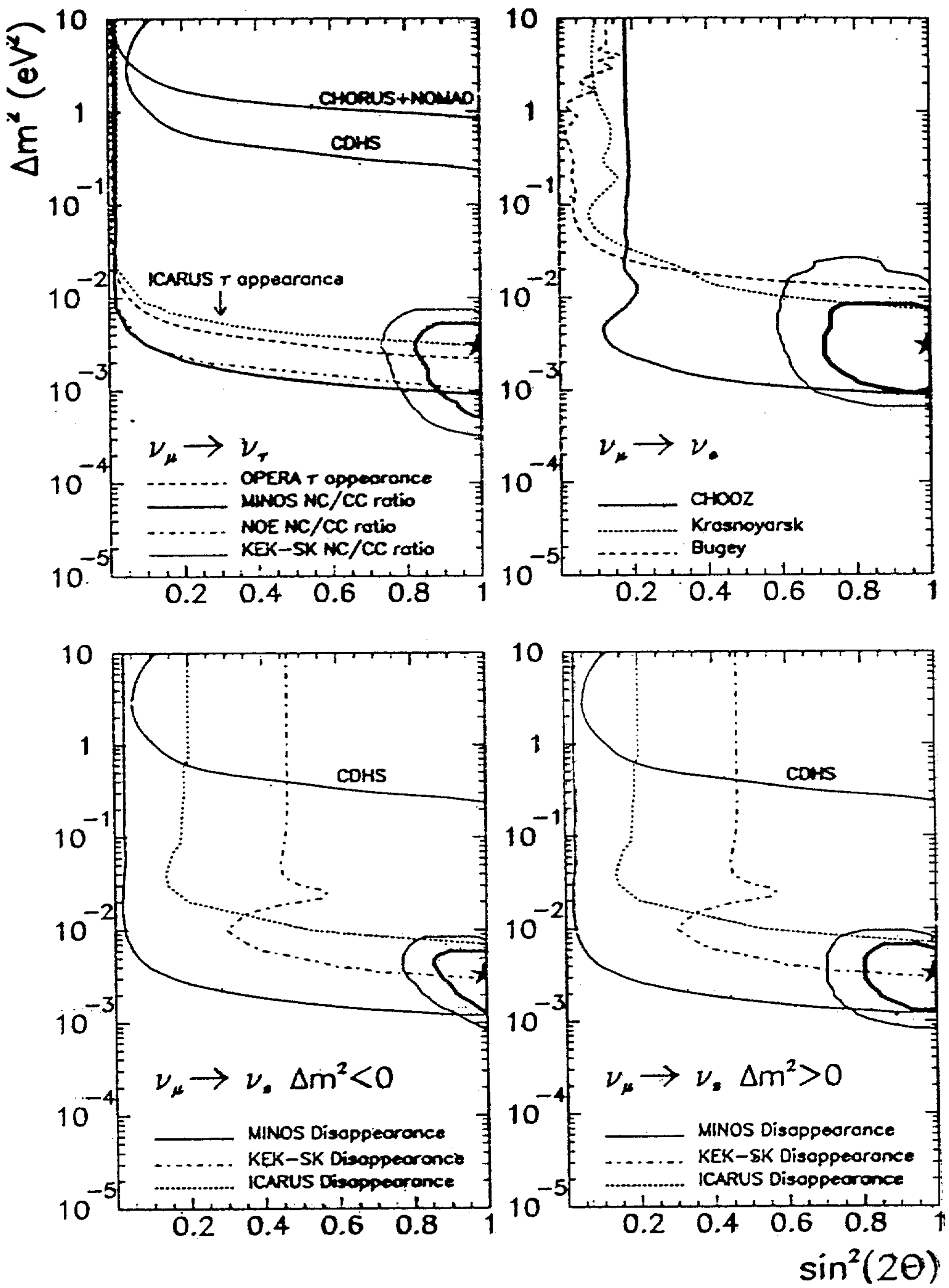
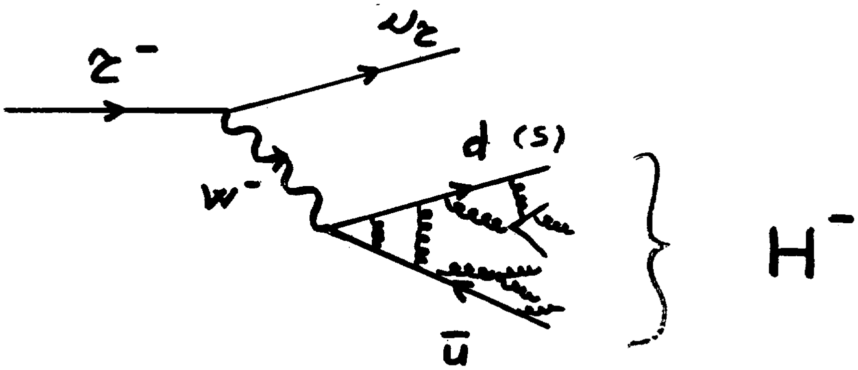
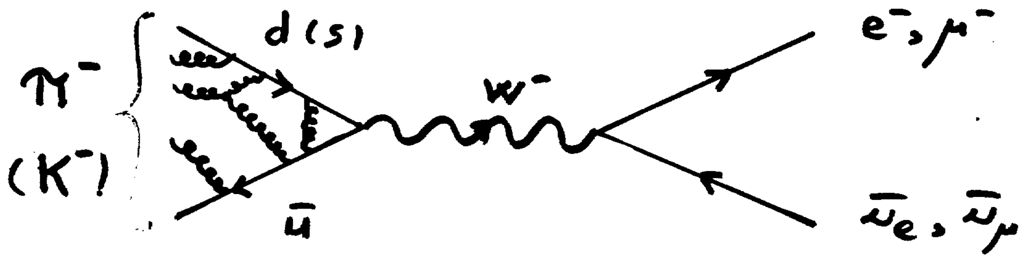


Figure 4. Allowed atmospheric oscillation parameters for all experiments including the SK data reported at Neutrino 98, combined at 90 (thick solid line) and 99 % CL (thin solid line) for all possible oscillation channels, from Ref. [26]. The sensitivity of the present accelerator and reactor experiments as well as the expectations of upcoming long-baseline experiments is also displayed.

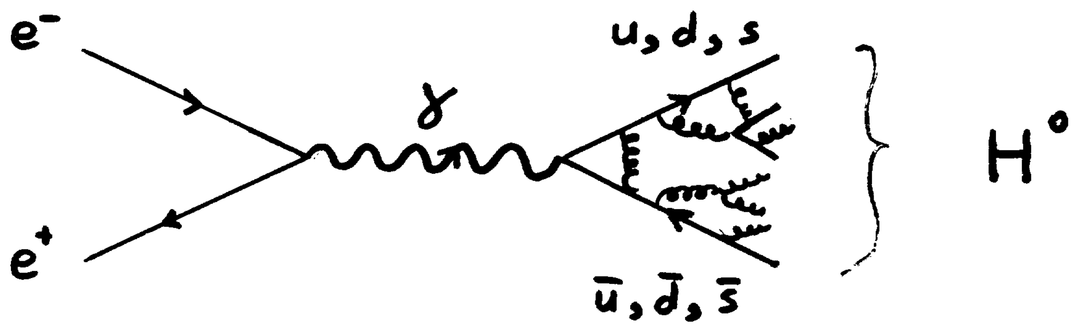


$$\Rightarrow \quad \langle H^- | V^\mu - A^\mu | 0 \rangle$$

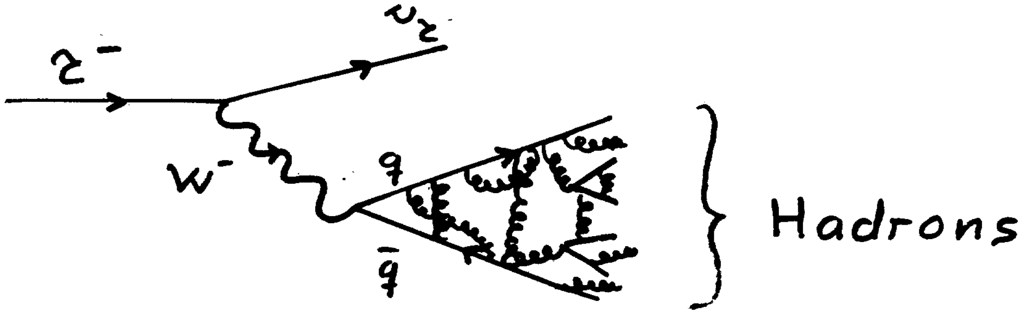


$$\Rightarrow \quad \langle \pi^- | A^\mu | 0 \rangle \equiv i \sqrt{2} \, f_\pi \, q^\mu$$

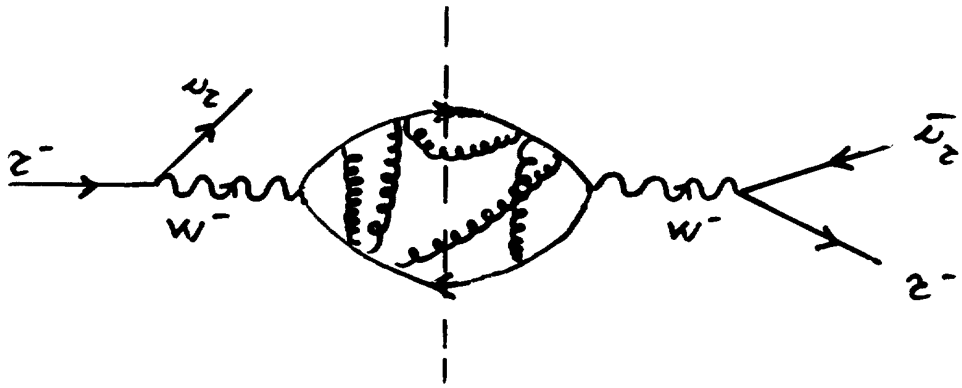
(K⁻) $\qquad\qquad$ (f_K)



$$\Rightarrow \quad \langle H^0 | V^\mu_{em} | 0 \rangle$$



$\Gamma_{\tau \to \text{Hadrons}} \propto$



$$\Pi^{\mu\nu}_{ij,J}(q^2) \equiv i \int d^4x \; e^{iqx} \langle 0 | T\left(J^\mu_{ij}(x) \, J^\nu_{ij}(0)^\dagger \right) | 0 \rangle$$

$$= (-g^{\mu\nu} q^2 + q^\mu q^\nu) \, \Pi^{(1)}_{ij,J}(q^2) \; + \; q^\mu q^\nu \, \Pi^{(0)}_{ij,J}(q$$

$i, j = u, d, s$

$J^\mu = V^\mu , \; A^\mu , \; L^\mu \equiv V^\mu - A^\mu$

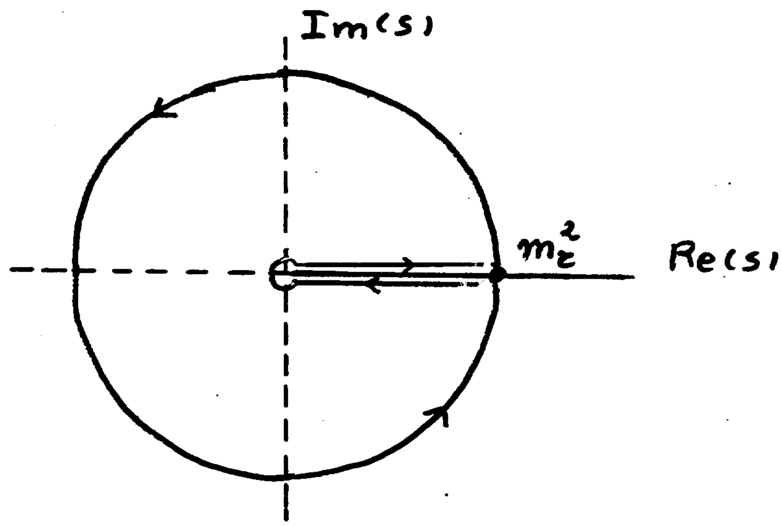
$V^\mu_{ij} = \bar{\psi}_j \gamma^\mu \psi_i \quad ; \quad A^\mu_{ij} = \bar{\psi}_j \gamma^\mu \gamma_5 \psi_i$

$$\Pi^{\mu\nu}_{ij,L} = \Pi^{\mu\nu}_{ij,V} + \Pi^{\mu\nu}_{ij,A}$$

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \text{Hadrons})}{\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)}$$

$$= 12\pi \int_0^{m_\tau^2} \frac{ds}{m_\tau^2} \left(1-\frac{s}{m_\tau^2}\right)^2 \left\{ \left(1+2\frac{s}{m_\tau^2}\right) \mathrm{Im}\,\Pi^{(1)}(s) + \mathrm{Im}\,\Pi^{(0)}(s) \right\}$$

$$\Pi^{(J)} \equiv \cos^2\theta_c \, \Pi^{(J)}_{ud,L} + \sin^2\theta_c \, \Pi^{(J)}_{us,L}$$



$$R_\tau = 6\pi i \oint \frac{ds}{m_\tau^2} \left(1-\frac{s}{m_\tau^2}\right)^2 \left\{ \left(1+2\frac{s}{m_\tau^2}\right) \Pi^{(1)}(s) + \Pi^{(0)}(s) \right\}$$

$$= 6\pi i \oint \frac{ds}{m_\tau^2} \left(1-\frac{s}{m_\tau^2}\right)^2 \left\{ \left(1+2\frac{s}{m_\tau^2}\right) \Pi^{(0+1)}(s) - 2\frac{s}{m_\tau^2} \Pi^{(0)}(s) \right\}$$

Braaten - Narison - Pich

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \text{hadrons})}{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

$$= N_c \, S_{EW} \left\{ 1 + \delta'_{EW} + \delta_P + \delta_{NP} \right\}$$

$S_{EW} = 1.0194$ (Marciano - Sirlin)

$\delta'_{EW} = 0.0010$ (Braaten - Li)

, $|\delta_{NP}| < 1\%$

$$\delta_P = \frac{\alpha_s(m_\tau)}{\pi} + 5.2023 \left(\frac{\alpha_s(m_\tau)}{\pi}\right)^2 + 26.366 \left(\frac{\alpha_s(m_\tau)}{\pi}\right)^3 + \ldots \simeq 20\%$$

	ALEPH	OPAL
δ_P	0.202 ± 0.013	
δ_{NP}	-0.003 ± 0.005	0.002 ± 0.005
$\alpha_s(m_\tau)$	0.334 ± 0.022	0.348 ± 0.021
$\alpha_s(M_Z)$	0.1202 ± 0.0027	0.1219 ± 0.0020
$R_{\tau,V}$	1.775 ± 0.017	1.764 ± 0.016
$R_{\tau,A}$	1.717 ± 0.018	1.720 ± 0.017
$R_{\tau,S}$	0.1610 ± 0.0066	

0.119 ± 0.002 (PDG 98)

↓

$m_s(m_\tau) = 149 \pm 44$ MeV

$m_s(1\,\text{GeV}) = 193 \pm 59$ MeV

Pich - Prades

$$v(s) \equiv 2\pi \; \mathrm{Im}\, \Pi_V(s) \quad , \quad a(s) \equiv 2\pi \; \mathrm{Im}\, \Pi_A(s)$$

$$R_{\tau, V/A} = 6\, S_{EW}\, |V_{ud}|^2 \int_0^{m_\tau^2} \frac{ds}{m_\tau^2} \left(1 - \frac{s}{m_\tau^2}\right)^2 \left(1 + 2\frac{s}{m_\tau^2}\right) \begin{pmatrix} v(s) \\ a(s) \end{pmatrix}$$

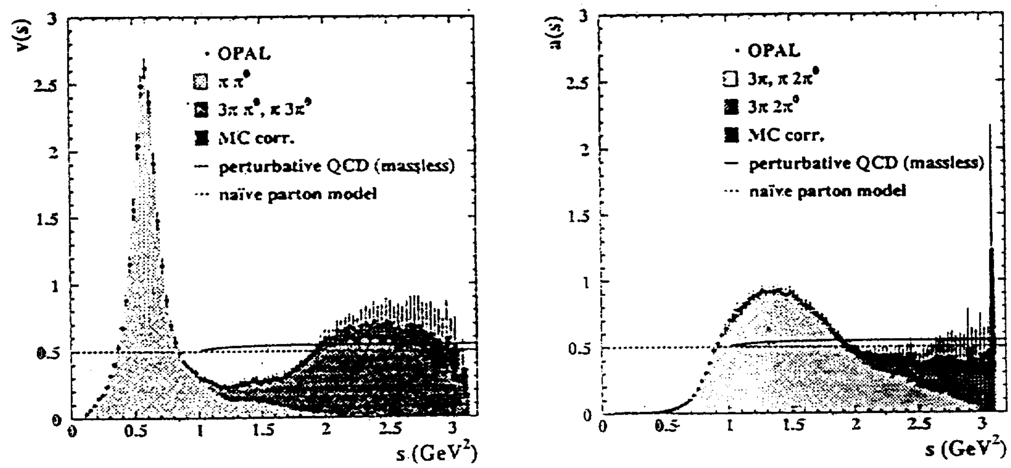


Figure 2. The vector and axial-vector spectral functions. Shown are the sums of all contributing channels as data points. Some exclusive contributions are shown as shaded areas. The naïve parton model prediction is shown as dashed line, while the solid line depicts the perturbative, massless QCD prediction for $\alpha_s(m_Z^2) = 0.122$. The error bars include statistical and systematic uncertainties.

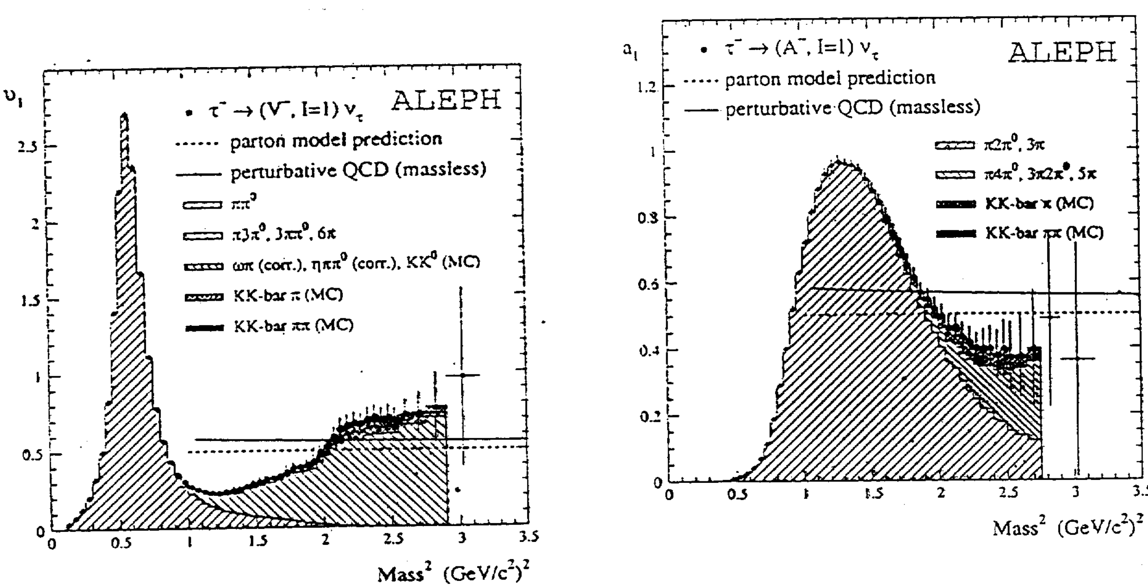


Figure 2. Total vector and axial-vector (without pion-pole) spectral functions. The contributions from the exclusive τ channels are indicated by the shaded areas. The shapes of the contributions labeled "MC" are taken from the Monte Carlo simulation. The lines show the predictions from the naive parton model and from massless perturbative QCD.

(Semi-) Inclusive q^2- Distributions

➡ $\frac{1}{\pi} \, \mathrm{Im}\, \Pi^{(s)}_{V,A,S}$

Very Important Information:

- $R_\tau(s_0) \equiv \int_0^{s_0} ds \, \frac{dR_\tau}{ds}$ — Le Diberder – A.P., Narison – A.P., Girone – Neubert

  ↓

  α_s

- $R_\tau^{k\ell}(s_0) \equiv \int_0^{s_0} ds \, \left(1-\frac{s}{s_0}\right)^k \left(\frac{s}{M_\tau^2}\right)^\ell \frac{dR_\tau}{ds}$ — Le Diberder – A.P., ALEPH – CLEO, OPAL

  ↓

  α_s, Non-Perturbative contributions $\left(\langle \frac{\alpha_s}{\pi} G^2 \rangle, \ldots\right)$

- $\frac{1}{\pi} \, \mathrm{Im}\, \Pi_V(s)$ — R. Alemany et al

  ↓

  $\alpha(M_Z)$, $(g-2)_\mu$, CVC $(e^+e^- \to \text{hadrons})$

  $\alpha^{-1}(M_Z) = 128.933 \pm 0.021$; $a_\mu^{had} = (692.4 \pm 6.2) \times 10^{-10}$ — Davier, TAU 98

- $R_{\tau,S}$ — Prades – A.P., Chetyrkin et al, ALEPH

  ↓

  m_s

- $\frac{1}{\pi} \, \mathrm{Im}\, \Pi_V(s) - \frac{1}{\pi} \, \mathrm{Im}\, \Pi_A(s)$ — ALEPH - OPAL

  ↓

  Chiral Sum Rules

- $R_{\tau,V} - R_{\tau,A}$ — Pure Non-Perturbative

τ Physics at Hadron Colliders

*) Difficult environment (backgrounds)
High statistics at LHC

*) C.C. Universality :

$W \to \tau \bar{\nu}_\tau \to$ hadrons $\nu_\tau \bar{\nu}_\tau$ — monojet + $\not{E}_T$ (1/3 prongs)

*) $\not{L}$: $\tau^- \to \mu^+ \mu^- \mu^-$

*) Searches : (M. Gallimaro, TAU 98)

- $p\bar{p} \to t\bar{t} \to (W^+ b)(W^- \bar{b}) \to (\ell^+ \nu_\ell\, b)\ (\tau^- \bar{\nu}_\tau \bar{b})$
  4 events at CDF (expected $\sim$ 1 + 2 backg.)

- $t \to H^+ b \to (\tau^+ \nu_\tau)\, b$ — CDF

  If $\tan(\beta) \geq 50$ $[Br(H^+ \to \tau^+ \nu_\tau) \sim 100\%] \longrightarrow M_{H^\pm} > 158$ GeV (95% CL)

- $Br(H^0_{SM} \to \tau^+ \tau^-) \simeq 8\%$ for $80\text{ GeV} \leq M_{H^0} \leq 130\text{ GeV}$

  Enhancement in 2-Higgs-Doublets models for large $\tan(\beta)$

- 3rd Generation Leptoquarks $[(LQ_3)(\overline{LQ_3}) \to \tau^+ \tau^- j j]$

  $M_{LQ_3}(J=0) > 99$ GeV — CDF

- SUSY $\tilde{\chi}^\pm_1 \chi^0_2 \to (\chi^0_1 \ell \nu)\ (\ell^+ \ell^- \tilde{\chi}^0_1)$

*) Higgs Couplings :

$g_{H^0 \ell^+ \ell^-} \sim m_\ell$?

SUMMARY

*) Lepton Universality tested to rather good accuracy both for charged and neutral currents

*) V-A Structure verified in $\mu \to e \bar{\nu}_e \nu_\mu$

But not in $\tau \to l \bar{\nu}_l \nu_\tau$

*) τ decays are a wonderful QCD Laboratory to study the hadronic V, A currents

- Exclusive: Chiral Dynamics
  Resonance Structure

- Inclusive: α_s, m_s, $\langle \frac{\alpha_s}{\pi} G^2 \rangle$, ...

*) New Physics could also show up

$\not{L}_i$, $\not{L}$, $m_{\nu_\tau} \neq 0$, a_τ, d_τ^γ, d_τ^Z, $\not{CP}$, ...