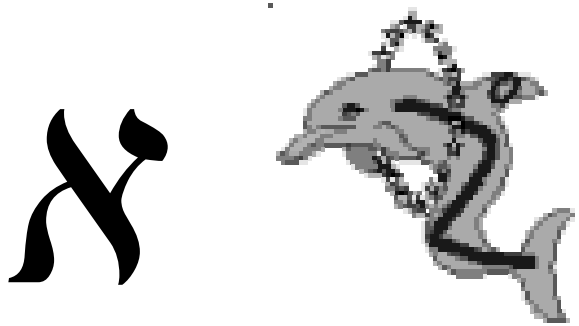


Properties of τ lepton

ON BEHALF OF LEP COLLABORATIONS

Vadym Zhuravlov

JINR Dubna

and

MPI für Physik Munich

New results from LEP

➢ τ decay

- ✓ $\tau \rightarrow$ *hadrons* DELPHI
- ✓ lifetime DELPHI
- ✓ ν_τ mass limit from $\tau \rightarrow 5\pi$ DELPHI

➢ τ production

- ✓ $\gamma\gamma \rightarrow \tau\tau$ DELPHI and L3
  - cross-section
  - electromagnetic moments
- ✓ $ee \rightarrow \tau\tau$
  - weak dipole moments

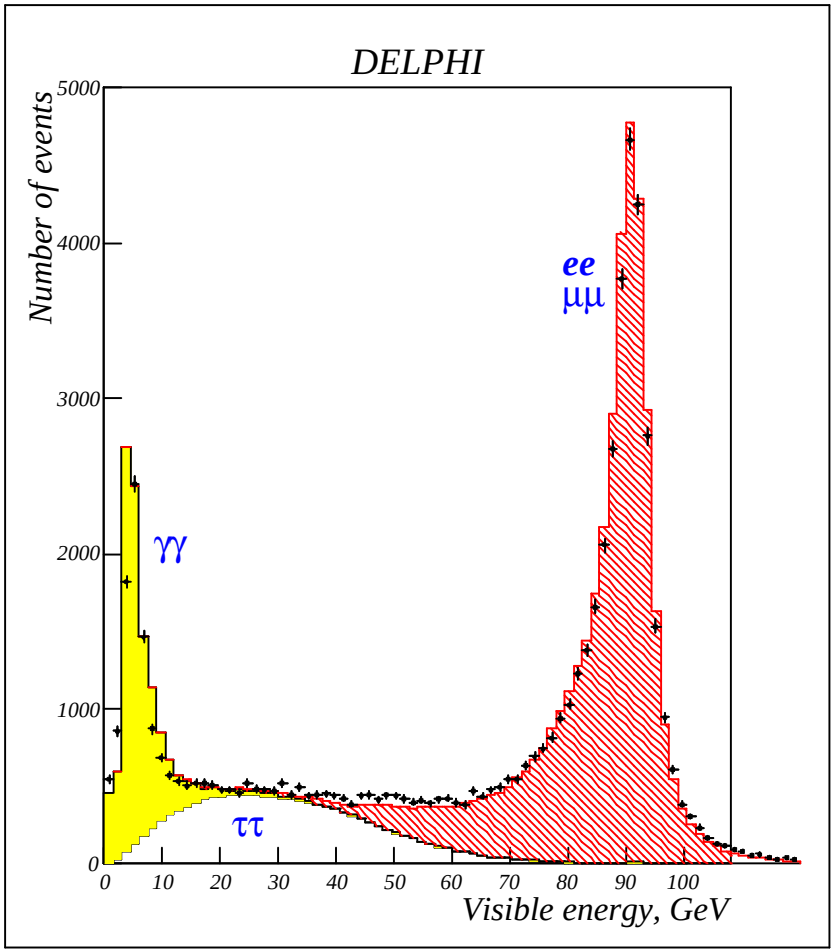
  ALEPH

Results are preliminary!

$ee \to \tau\tau$ selection at LEP

- Two low multiplicity "back-to-back" jets.
  Cut on charged multiplicity rejects $Z \to qq$ background
- $\gamma\gamma$ and $Z \to ee$, $Z \to \mu\mu$ backgrounds rejected by cuts on visible energy
- Tau selection based on event kinematic properties only.
  No particle identification

	ALEPH	DELPHI	L3	OPAL
efficiency	80 %	62 %	62 %	75%
background	2 %	3 %	2 %	3%

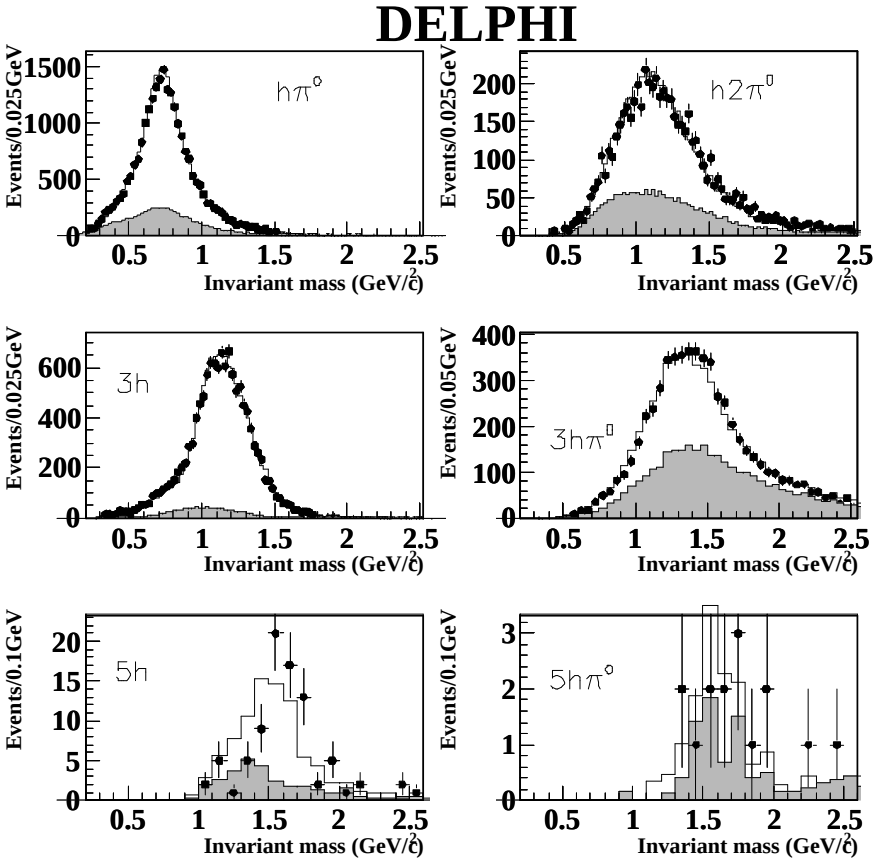


Hadronic Branching Ratios

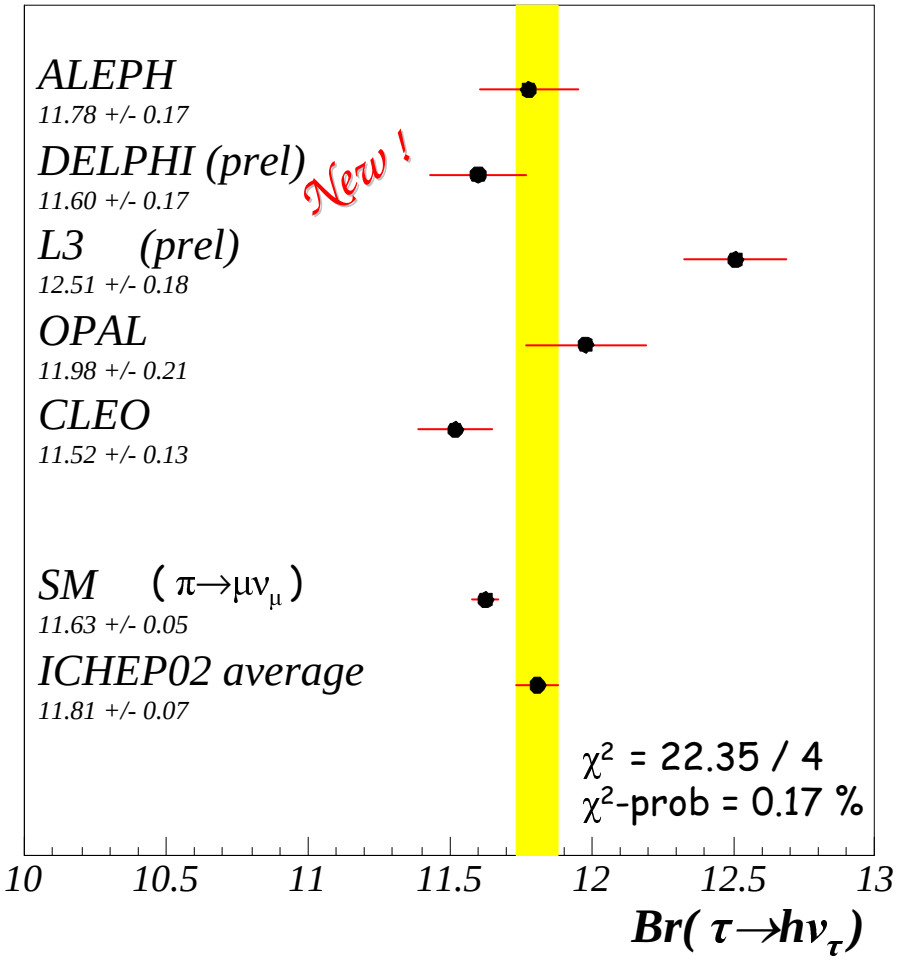
Delphi 92 – 95

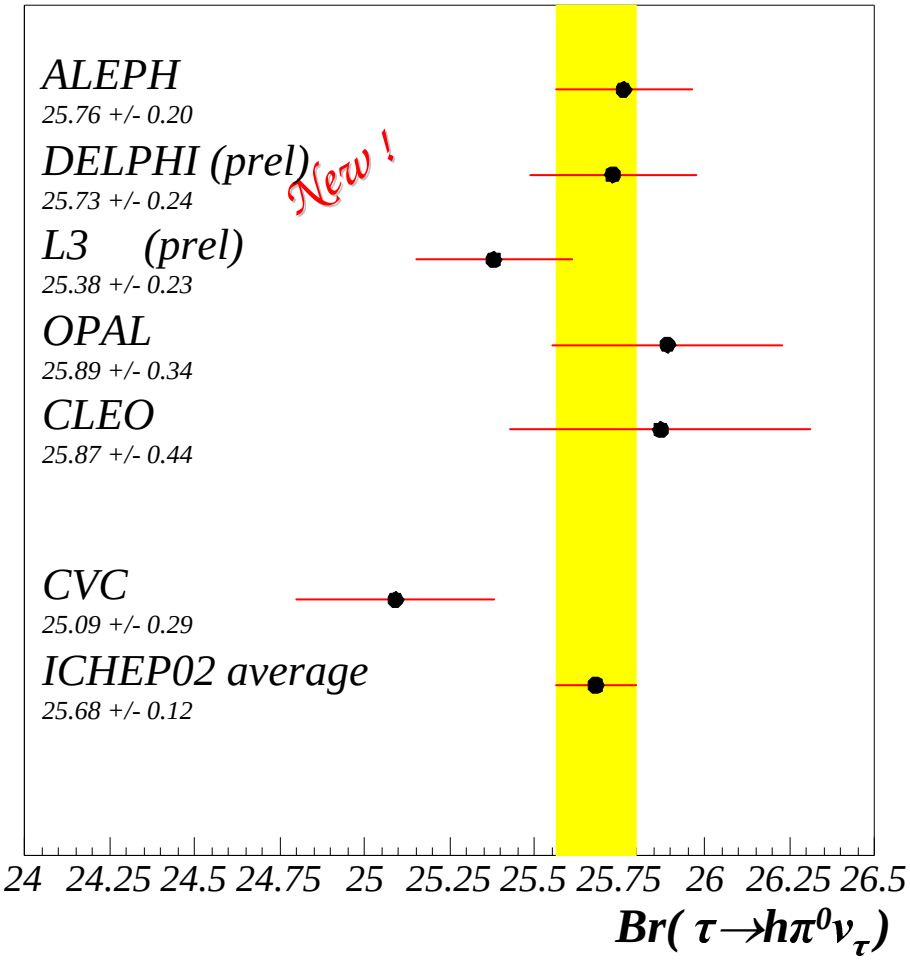
- Charged multiplicity:
  - *photon conversion: 7 % of γ's converted before TPC*
  - *Dalitz decays: 1 % of π^0 decay to $e^+ e^- \gamma$*
  - *nuclear reinteraction: 3 % of hadrons interact before TPC*
  - *δ-rays, two-track resolution, …*

- π^0 reconstruction:
  - *type I*
    single EM cluster:
    analysis of cluster structure
  - *type II*
    2 EM clusters
  - *type III*
    EM cluster + converted γ
  - *type IV*
    EM cluster + EM energy
    associated to track

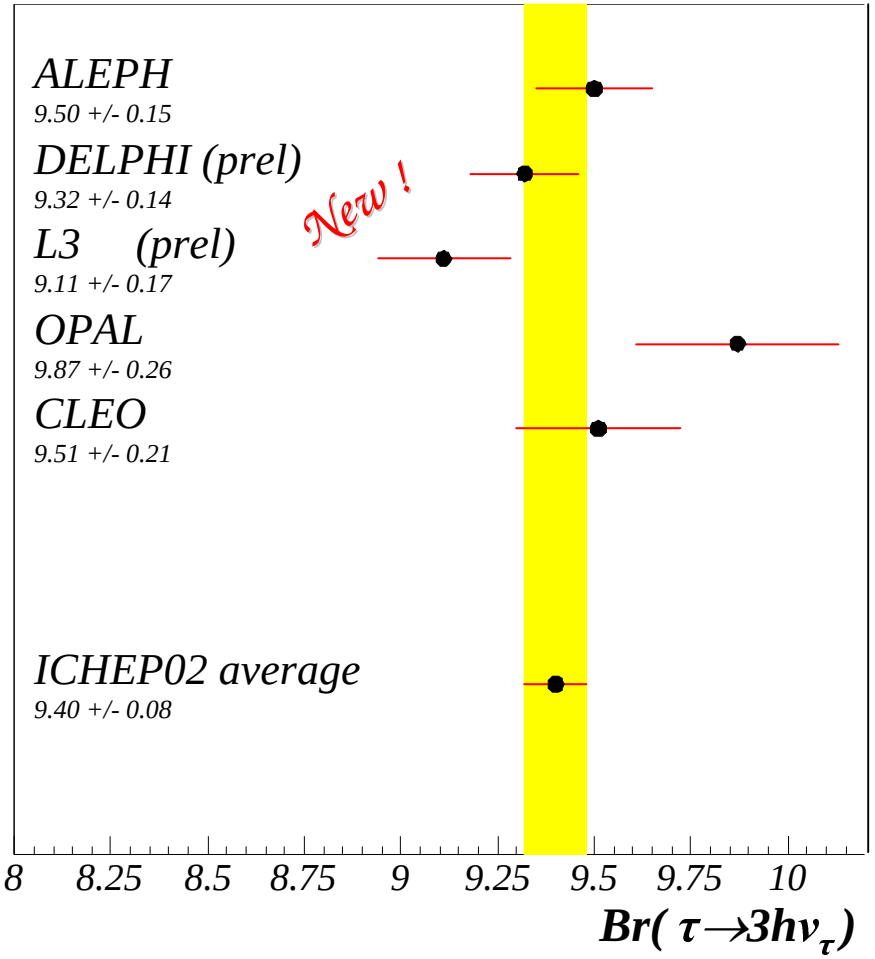


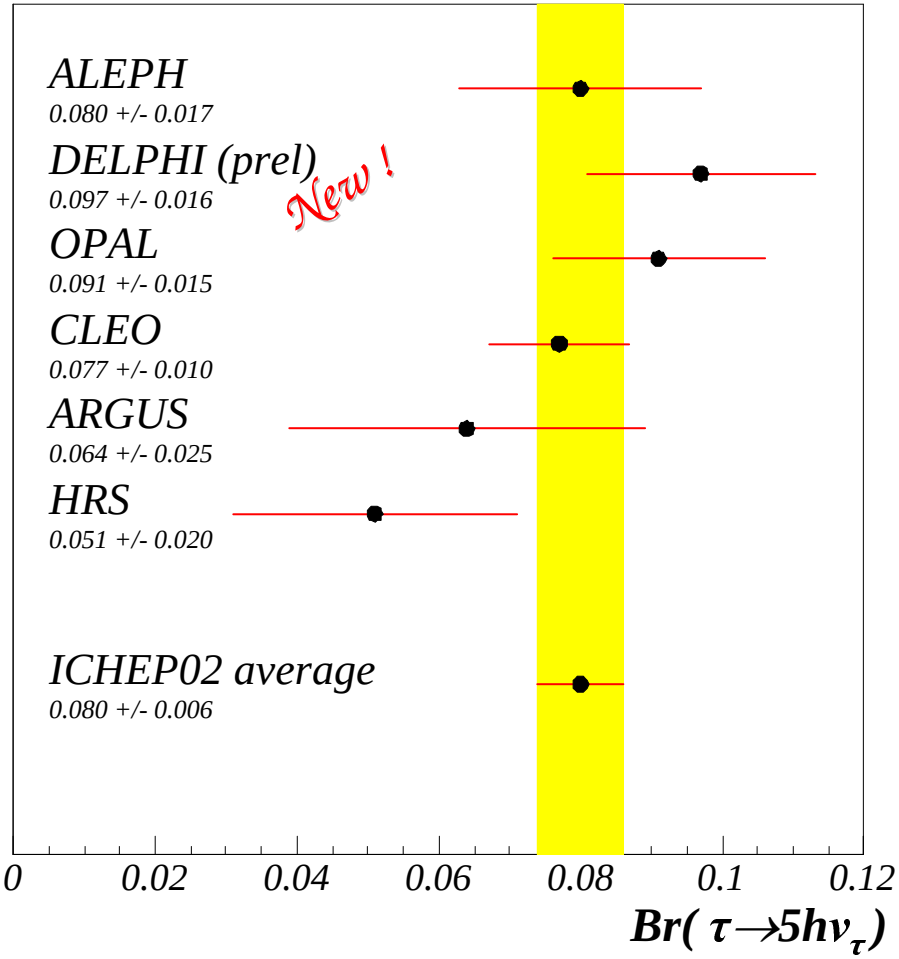
Hadronic branching ratios: 1-prong



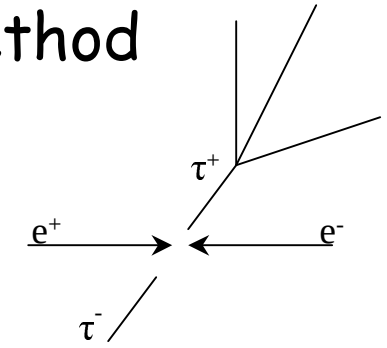


Hadronic branching ratios: 3- and 5- prongs





τ lifetime: decay vertex reconstruction method



1. **Decay length determination:**
   distance between center of beam crossing region and decay vertex. $\sigma = \sigma_{prod} \oplus \sigma_{decay}$
2. **Conversion to decay time:**
   dividing by $\gamma\beta c \sin\theta_\tau$
3. **Fit of τ lifetime to the data:**

$$\text{Log } L = \Sigma \log (f_{vtx} \otimes f_{res})$$

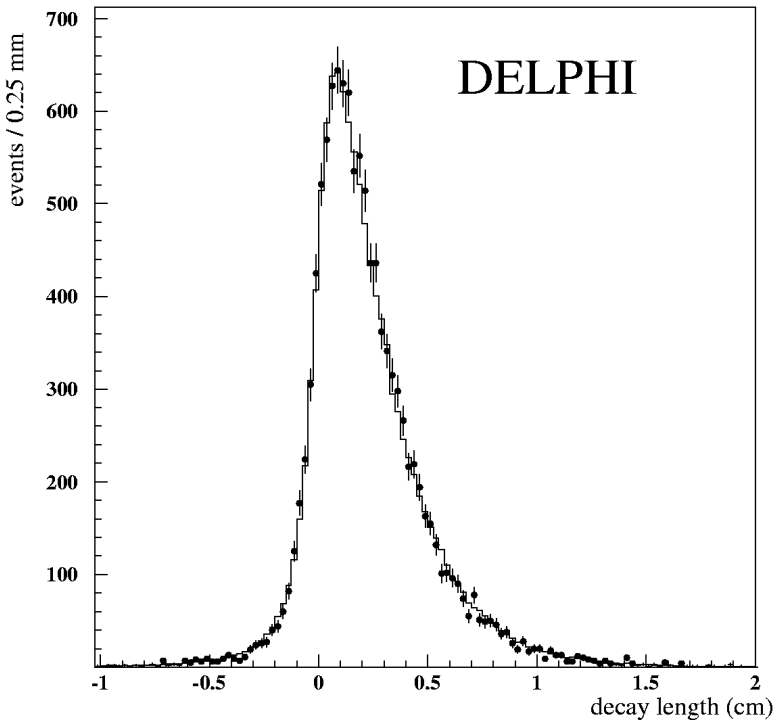
$$f_{vtx} = (1 - b_f - b_h)\, E(t \mid \tau) + b_f\, E(t \mid 0.75\,\tau) + b_h \delta(t)$$

$$f_{res} = (1 - f_2 - f_3)\, G(t \mid k_1\sigma) + f_2\, G(t \mid k_2\sigma) + f_3\, G(t \mid k_3\sigma)$$

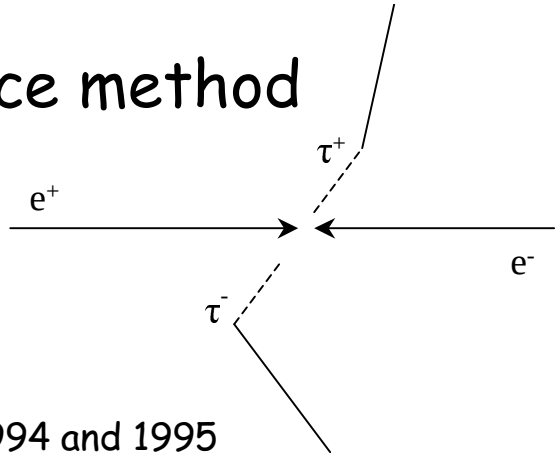
$$1 : k_2 : k_3 = 1.0 : 1.6 : 5.1$$
$$1 : f_2 : f_3 = 1 : 0.25 : 0.007$$

$$\tau_{3\text{-prong}} = 288.6 \pm 2.4_{(stat)} \pm 1.4_{(syst)}\ fs$$

DELPHI 1991 – 1995 data sample
15427 3v1 and 2101 3v3
(total 19629 vertices)



τ lifetime: impact parameter difference method



Impact parameter in transverse plane:

$$d = L \sin\theta_\tau \sin(\varphi - \varphi_\tau)$$

Impact parameter difference:

$$d_+ - d_- = L_+ \sin\theta_{\tau+} \sin(\varphi_+ - \varphi_{\tau+}) - L_- \sin\theta_{\tau-} \sin(\varphi_- - \varphi_{\tau-})$$

Averaging over decay lengths

$$\langle d_+ - d_- \rangle = \langle L \rangle (\varphi_+ - \varphi_- + \pi) \sin\theta_\tau = \langle L \rangle \Delta\varphi \sin\theta_\tau$$

$$\langle L \rangle = \gamma\beta c\, \tau_\tau$$

Impact parameter difference is proportional to projected acoplanarity with a proportionality constant ~ lifetime

Lifetime is extracted by straight line fit to

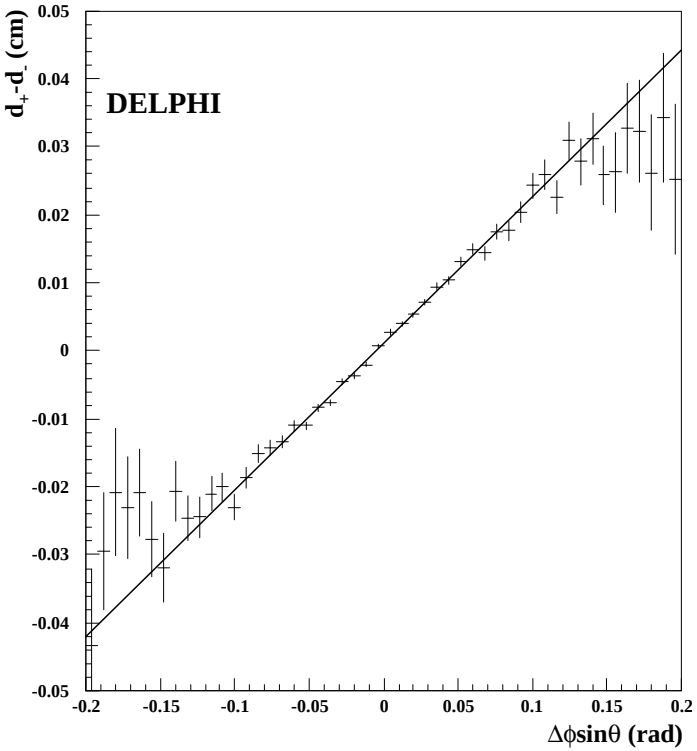
$$Y = d_+ - d_-$$

as a function of

$$X = \Delta\varphi \sin\theta_\tau$$

$$\tau_{ipd} = 291.4 \pm 3.6_{(stat)} \pm 1.5_{(syst)}\ fs$$

1994 and 1995
26036 events



τ lifetime: miss distance method

Miss distance

$$d_{miss} = d_+ + d_$$

Lifetime is determined by fit to the observed d_{miss} distribution with probability density function

$$f = f_{phys} \otimes f_{res}$$

Physics function:

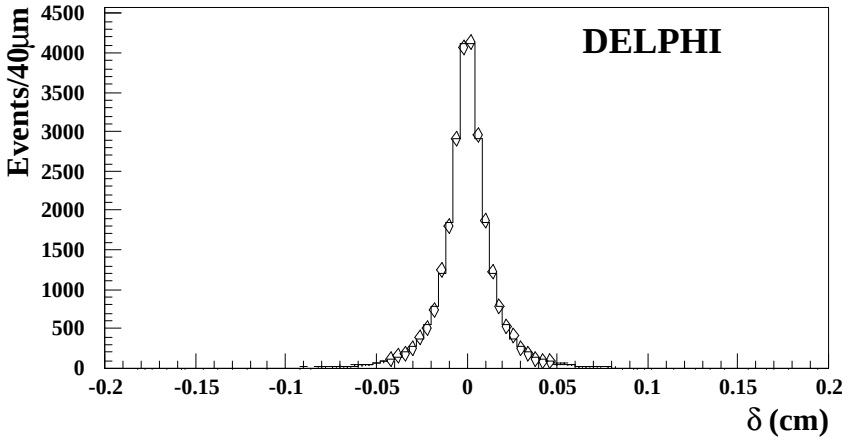
$$f_{phys} = f_+(d_+) \otimes f_-(d_-)$$

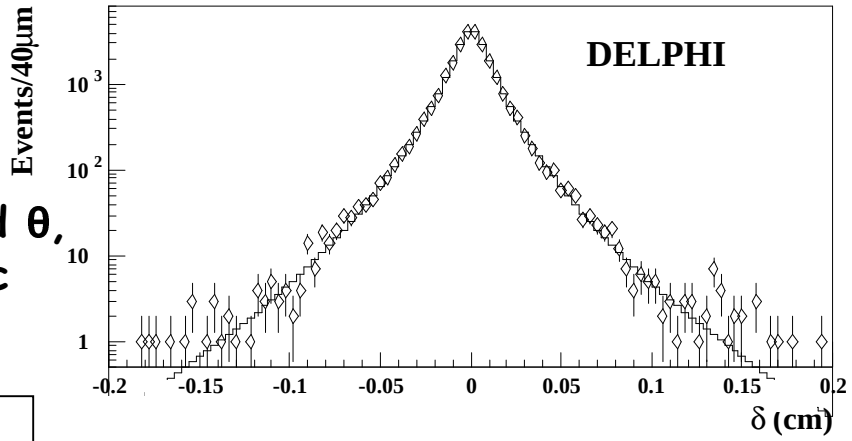
Resolution function:

$$f_{res} = f_1 G(\sigma_1) + f_2 G(\sigma_2) + f_3 G(\sigma_3)$$

f_1 f_2 f_3 **and** σ_1 σ_2 σ_3 **are functions of p and θ, calibrated separately for hadronic and leptonic decays**

$$\tau_{miss} = 292.0 \pm 2.3_{(stat)} \pm 2.1_{(stat)}\ fs$$





τ lifetime

Average:

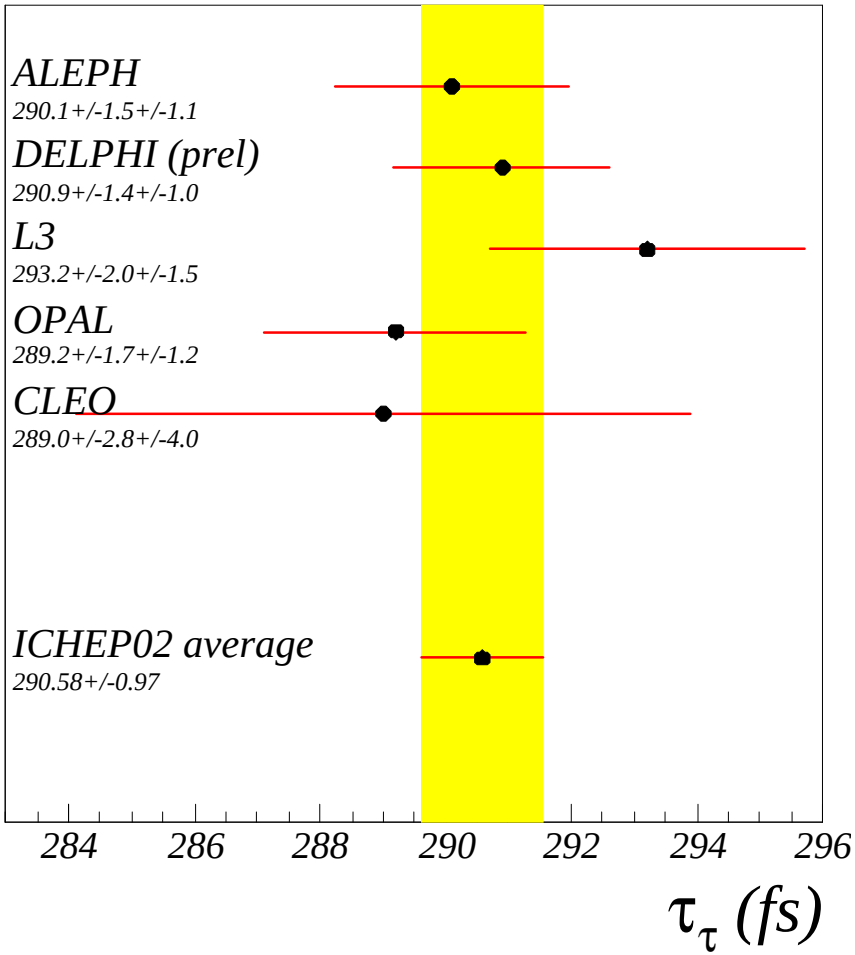
IPD and MD (1991 -1995) *36% correlation*

$\tau_{1\text{-prong}} = 292.3 \pm 1.8_{(stat)} \pm 1.2_{(syst)}$ fs

1-prong and 3-prong *5% correlation*

$\tau_\tau = 290.9 \pm 1.4_{(stat)} \pm 1.0_{(stat)}$ fs

Most precise measurement to date!



ν_τ mass limit from $\tau \to 5\pi$

Likelihood function:

$\mathcal{L} = \Pi_i f(m\ E) \otimes R(m\ E) \otimes \varepsilon(m\ E)$

$m = m_{5\pi}\ \ E = E_{5\pi}$

Fit region:

$m > 1.6\ GeV/c^2$

$0.85 < E / E_{beam} < 1.10$

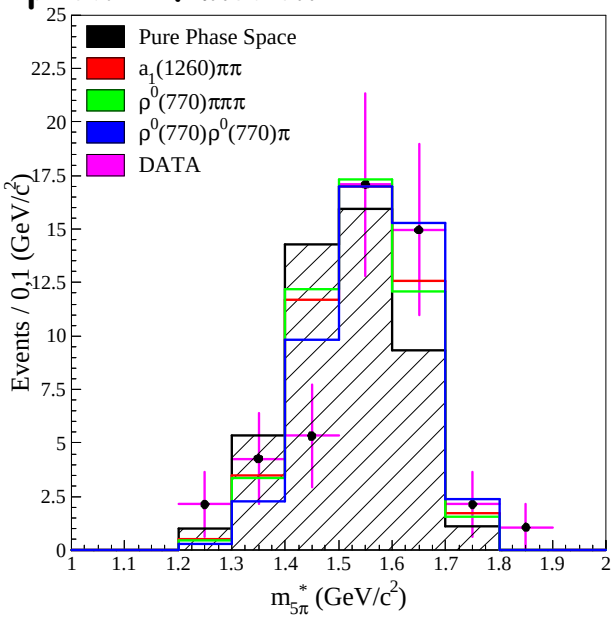
Typical resolution:

m: 16 MeV /c^2

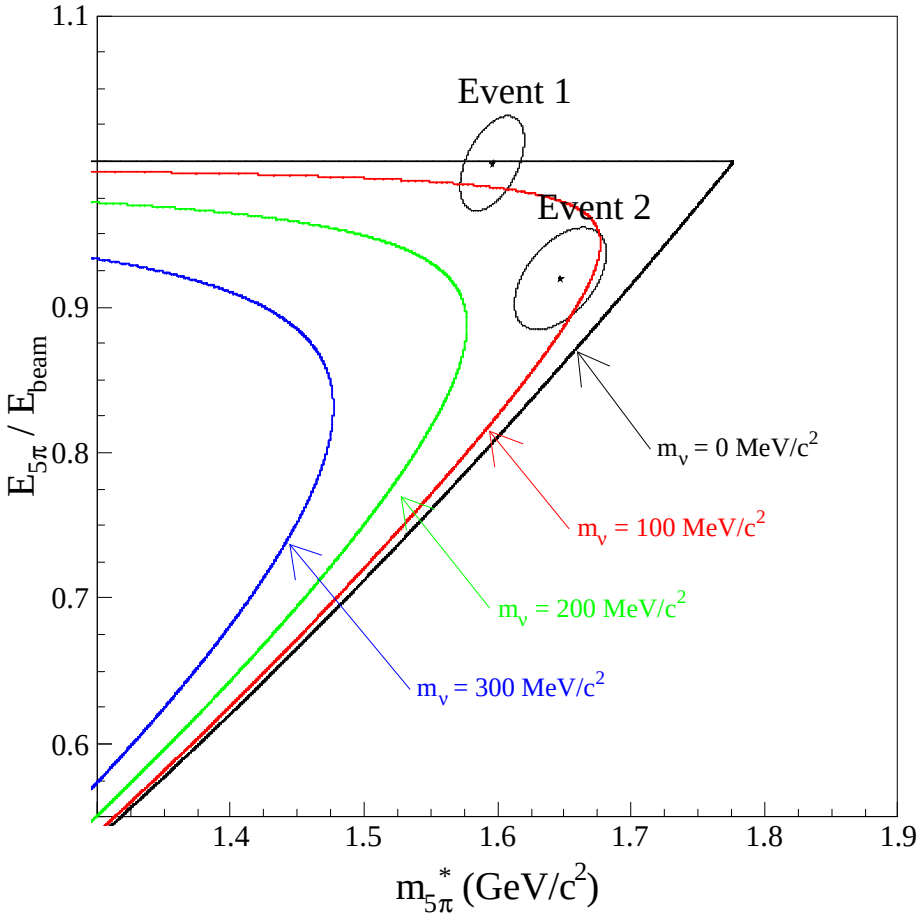
E: 500 MeV

Events in fit region: 15 (6 % bkg)

Spectral function:



DELPHI 1992 - 1995
47 5π vertices
background - 24 %
(mainly qq and 5ππ⁰)

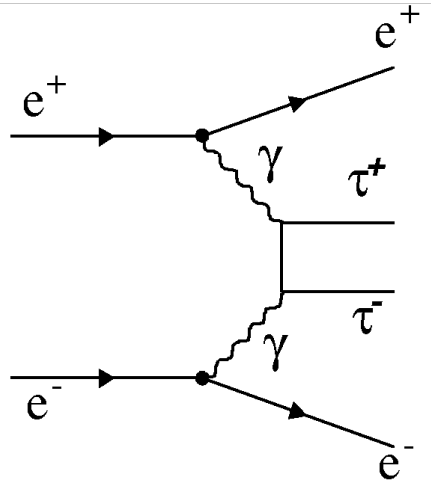


Summary of ν mass limits

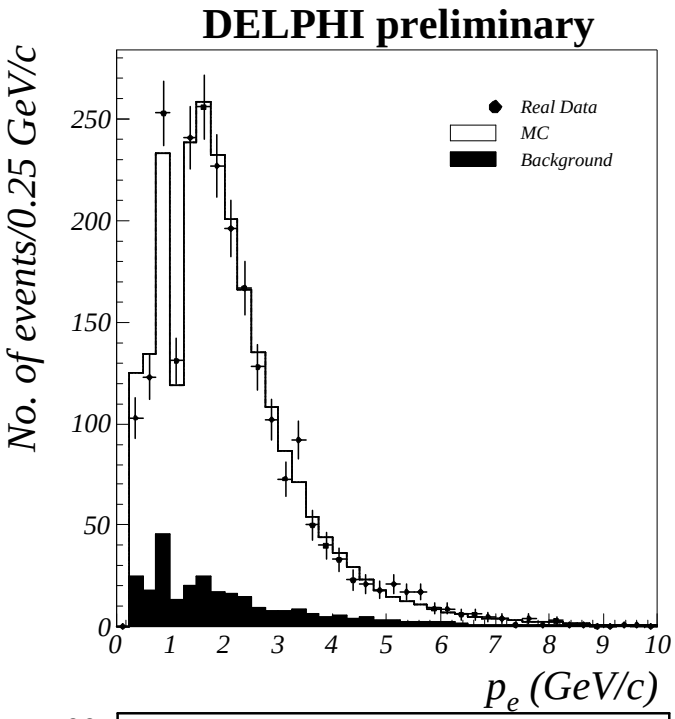
	3π		5π		Combined
	Events	$Limit_{95}$	Events	$Limit_{95}$	
ALEPH	2939	22.3 MeV	55	21.5 MeV	18.2 MeV
DELPHI	12 K	28 MeV	15	48.0 MeV	
OPAL	2514	35.3 MeV	22	43.2 MeV	27.6 MeV
ARGUS			19	31 MeV	
CLEO	17 K ($3\pi\pi^0$)	28 MeV ($3\pi\pi^0$)	55	30 MeV	

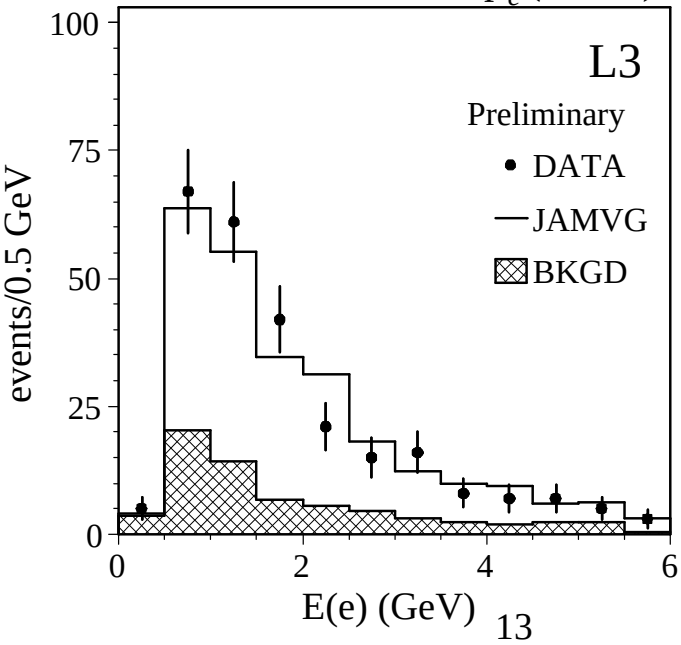
DELPHI epxected limit $\approx$ 30 MeV

$\gamma\gamma \rightarrow \tau\tau$

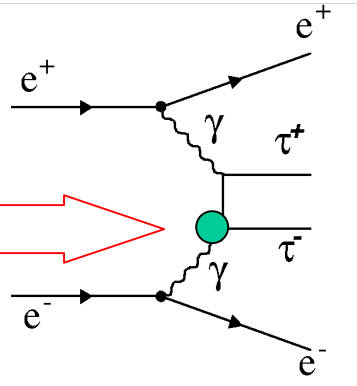


	DELPHI	L3
Data set	183 – 208 **GeV**	189 – 208 **GeV**
Mode	$\tau^+ \rightarrow e^+ \nu \nu$ $\tau^- \rightarrow$ *non* e^-	$\tau^+ \rightarrow e^+ \nu \nu$ $\tau^- \rightarrow \pi \pi^0 \nu$
e ID	dE/dx	BGO shower
non-e ID	dE/dx	charged track + 2 γ m ($\gamma\gamma$) = m (π^0) m ($\pi^0 \pi^\pm$) = m (ρ)
Sel.eff	0.8 %	0.1 %
Selected events	2154	266
background:	10 %	4 %





$\gamma\gamma \rightarrow \tau\tau$: electromagnetic moments



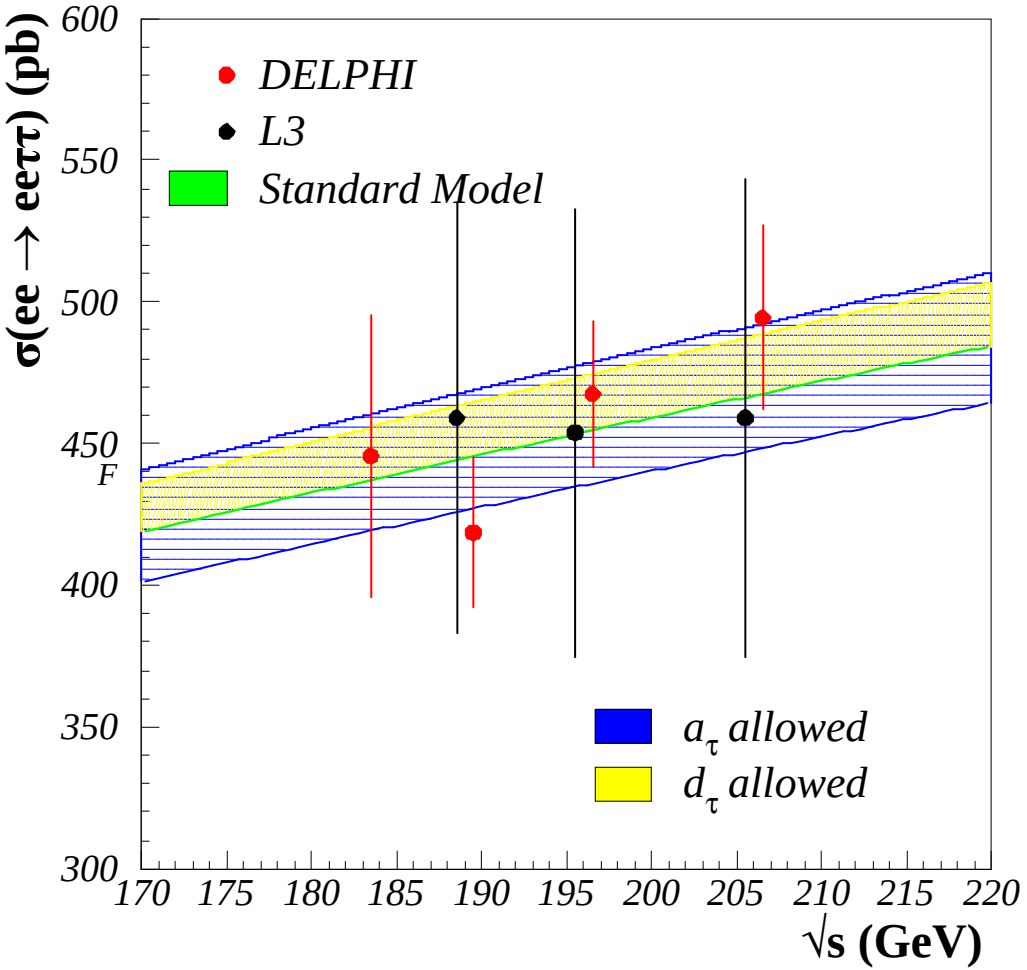
$$F_1(q^2)\gamma_\mu + iF_2(q^2)\sigma_{\mu\nu}\frac{q_\nu}{2m_\tau} + F_3(q^2)\gamma^5\sigma^{\mu\nu}\frac{q_\nu}{2m_\tau}$$

At $q^2=0$
F2 – anomalous magnetic moment a_τ
F3 – dipole moment d_τ

SM values: $a_\tau = 1.1773(3) \cdot 10^{-3}$
$d_\tau \cong 0$

Limits from $\gamma\gamma \rightarrow \tau\tau$ cross-sections:

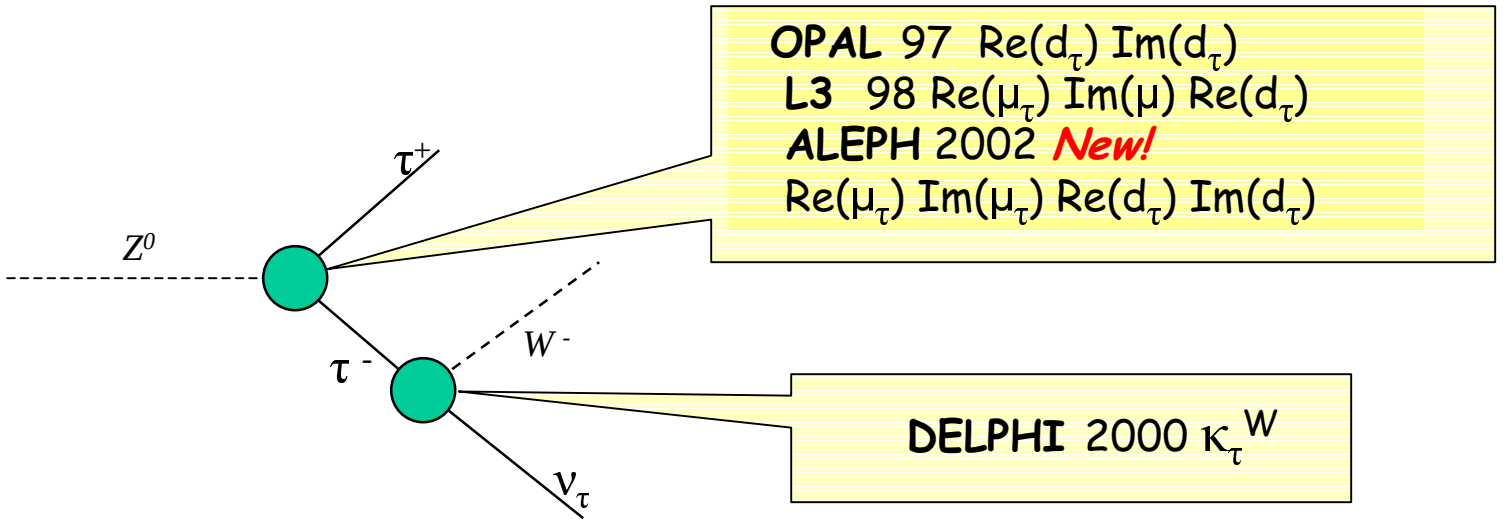
DELPHI (95% C.L.)
$-0.017 < a_\tau < 0.019$
$|d_\tau| < 3.8 \cdot 10^{-16}$ e · cm
L3 (68% C.L.)
$-0.062 < a_\tau < 0.044$
$|d_\tau| < 6.7 \cdot 10^{-16}$ e · cm



Weak dipole moments

Neutral current: $\bar{\tau}\left[v_\tau\gamma^\mu - a_\tau\gamma^\mu\gamma^5 + i\frac{\mu_\tau^Z}{2m_\tau}\sigma^{\mu\nu}q_\nu + \frac{d_\tau^Z}{2m_\tau}\gamma^5\sigma^{\mu\nu}q_\nu\right]\tau$

Charged current: $\bar{\nu}\left[\gamma_\mu\frac{1-\gamma^5}{2} - i\frac{\kappa_\tau^W}{2m_\tau}\sigma^{\mu\nu}q_\nu\frac{1+\gamma^5}{2} - \frac{d_\tau^W}{2m_\tau}\gamma^5\sigma^{\mu\nu}q_\nu\frac{1+\gamma^5}{2}\right]\tau$



Weak dipole moments

ALEPH measurement:
- **1990 – 1995**
- **$\tau \to \pi,\ \rho,\ a_1$ decays**
- **fit to spin-dependent differential cross-section**

$\mathrm{Re}(\mu_\tau)$ $(-0.33 \pm 0.42 \pm 0.26) \cdot 10^{-3}$

$\mathrm{Im}(\mu_\tau)$ $(-0.99 \pm 0.80 \pm 0.61) \cdot 10^{-3}$

$\mathrm{Re}(d_\tau)$ $(-0.59 \pm 2.14 \pm 1.26) \cdot 10^{-18}\ e \cdot cm$

$\mathrm{Im}(d_\tau)$ $(-0.45 \pm 4.00 \pm 4.01) \cdot 10^{-18}\ e \cdot cm$

Most precise measurement to date!

- d_τ^W not measured yet …
- Simultaneous fit to all moments μ_τ^Z , d_τ^Z, κ_τ^W, d_τ^W can be done
- Experimental bounds on charged current moments κ_τ^W and d_τ^W are not listed in PDG

Conclusion

- τ lepton electromagnetic moments measured from $\gamma\gamma \to \tau\tau$ DELPHI and L3
- τ lepton weak moments measured ALEPH
- hadronic branching ratios DELPHI

$\tau \to h^- \nu_\tau$ $\tau \to h^- \pi^0 \nu_\tau$ $\tau \to h^- \pi^0\pi^0 \nu_\tau$ $\tau \to h^- \geq 2\pi^0 \nu_\tau$ $\tau \to h^- \geq 3\pi^0 \nu_\tau$
$\tau \to 2h^- h^+ \nu_\tau$ $\tau \to 2h^- h^+ \pi^0 \nu_\tau$ $\tau \to 2h^- h^+ \geq 2\pi^0 \nu_\tau$
$\tau \to 3h^- 2h^+ \nu_\tau$ $\tau \to 3h^- 2h^+ \geq 1\pi^0 \nu_\tau$

- limit on ν_τ estimated DELPHI
- τ lepton lifetime DELPHI

All LEP experimental data are analysed,

almost all results are published,

preliminary results are close to completion