Spin Analysis of the Process

$e^+e^- \to \tau^+\tau^-$ at LEP

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(L3 Collaboration)

“The Irresistible Rise of the Standard Model”

San Miniato, April 22nd, 1997

(WWW: *http://l3www.cern.ch/conferences/ps/PGA_sm97.ps.gz*)

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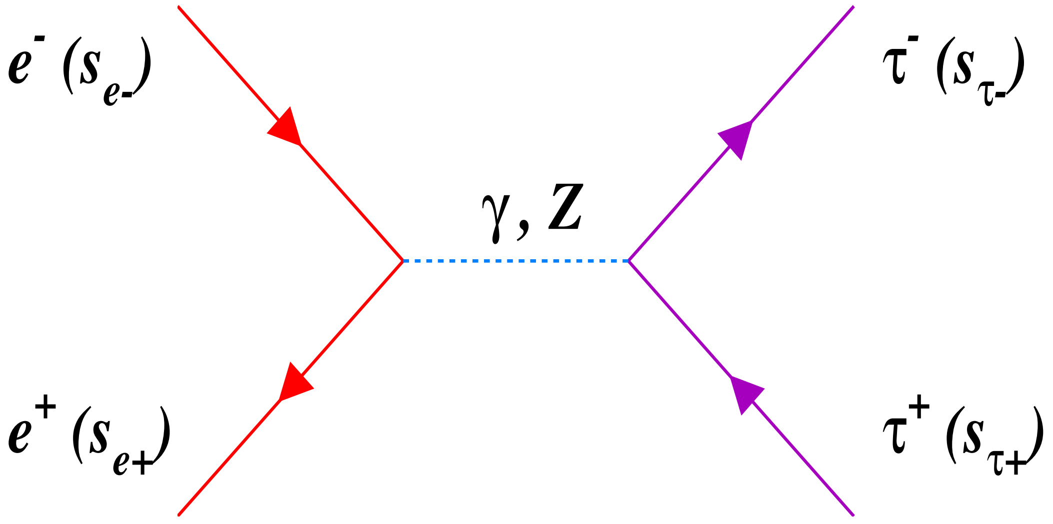
Motivation



$$\sqrt{s} \approx M_Z$$

$$\frac{d\sigma}{ds_i\, d\Omega} = f\,(a_e,\ v_e,\ a_\tau,\ v_\tau,\ \ldots)$$

OBSERVABLES

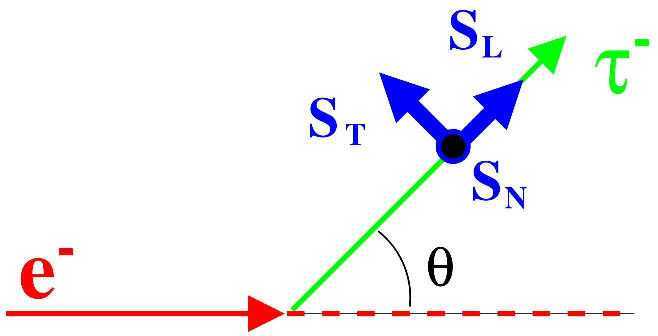
- Longitudinal Polarisation $\longrightarrow$ $P_\tau\,(\cos\theta)$
- Transverse and Normal Spin Correlations $\longrightarrow$ $C_{TT}\ ,\ C_{TN}$

High Precision Test of the Standard Model

$$P_\tau,\ C_{TT},\ C_{TN} \longrightarrow a_\tau\ ,\ v_\tau \longrightarrow \sin^2\theta_W$$
$$(\ a_e\ ,\ v_e\ )$$

Observables at LEP

<u>LEP</u>: no initial state polarisation



$$
\begin{aligned}
\frac{d^5\sigma}{ds_{\tau^-}ds_{\tau^+}d\Omega} = \ & \frac{1}{4} \ |P(q^2)|^2 \{ C_0\,(1+\cos^2\theta) \\
+ \ & C_1\,2\cos\theta \\
- \ & D_0\,(s^L_{\tau^-} - s^L_{\tau^+})\,(1+\cos^2\theta) \\
- \ & D_1\,(s^L_{\tau^-} - s^L_{\tau^+})\,2\cos\theta \\
- \ & C_0\,s^L_{\tau^-}s^L_{\tau^+}\,(1+\cos^2\theta) \\
- \ & C_1\,s^L_{\tau^-}s^L_{\tau^+}\,2\cos\theta \\
+ \ & C_2\,(s^N_{\tau^-}s^N_{\tau^+} - s^T_{\tau^-}s^T_{\tau^+})\,\sin^2\theta \\
+ \ & D_2\,(s^N_{\tau^-}s^T_{\tau^+} + s^N_{\tau^-}s^T_{\tau^+})\,\sin^2\theta \}
\end{aligned}
$$

$$
< P_L > \equiv P_\tau = -\frac{D_0}{C_0} = \frac{2\,a_\tau\,v_\tau}{|a_\tau|^2 + |v_\tau|^2}
$$

$$
< P_T\,P_T > \equiv C_{TT} = \frac{C_2}{C_0} = \frac{|a_\tau|^2 - |v_\tau|^2}{|a_\tau|^2 + |v_\tau|^2}
$$

$$
< P_T\,P_N > \equiv C_{TN} = \frac{D_2}{C_0} = -\frac{2\,\Im(v_\tau\,a_\tau^*)}{|a_\tau|^2 + |v_\tau|^2}
$$

τ Longitudinal Polarisation

– P_τ –

Definition: *Born approximation* at Z pole

$$P_\tau \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad ; \quad \sigma_{\substack{L \\ R}} = \sigma\,(e^- e^+ \to \tau^-_{\substack{L \\ R}} \tau^+_{\substack{R \\ L}})$$

Using the former definition of the cross section:

$$P_\tau\,(\cos\theta) = -\frac{\mathcal{A}_\tau\,(1+\cos^2\theta) + \mathcal{A}_e\,2\cos\theta}{(1+\cos^2\theta) + \mathcal{A}_\tau\mathcal{A}_e\,2\cos\theta}$$

where ($l = e,\ \tau$):

$$\mathcal{A}_l \equiv \frac{2\,a_l\,v_l}{|a_l|^2 + |v_l|^2} = \frac{2\,(1-4\sin^2\theta_W)}{1+(1-4\sin^2\theta_W)^2}$$

High precision:

$$\Delta\sin^2\theta_W \simeq \frac{1}{8}\Delta\mathcal{A}_l$$

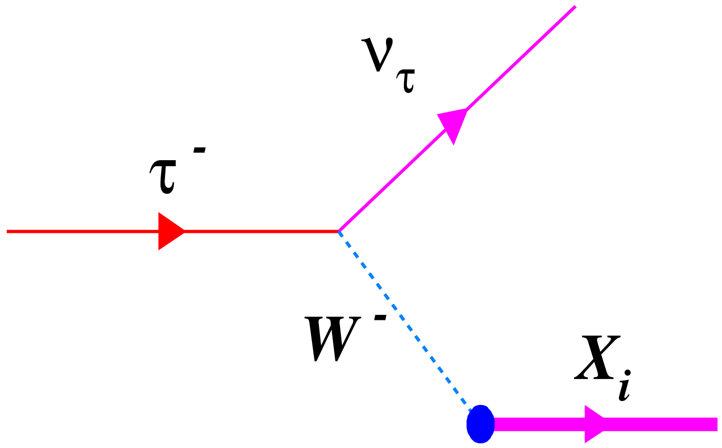
Analysis

τ Decay Products:

$\tau \rightarrow e\nu\bar{\nu}$ $\qquad$ $\tau \rightarrow \rho/K^*\nu$

$\tau \rightarrow \mu\nu\bar{\nu}$ $\qquad$ $\tau \rightarrow a_1\nu$

$\tau \rightarrow \pi/K\,\nu$ $\qquad$ $\tau \rightarrow \pi\ n\pi^0\nu$



$$x = \frac{E_i}{E_\tau}$$

Observed spectra:

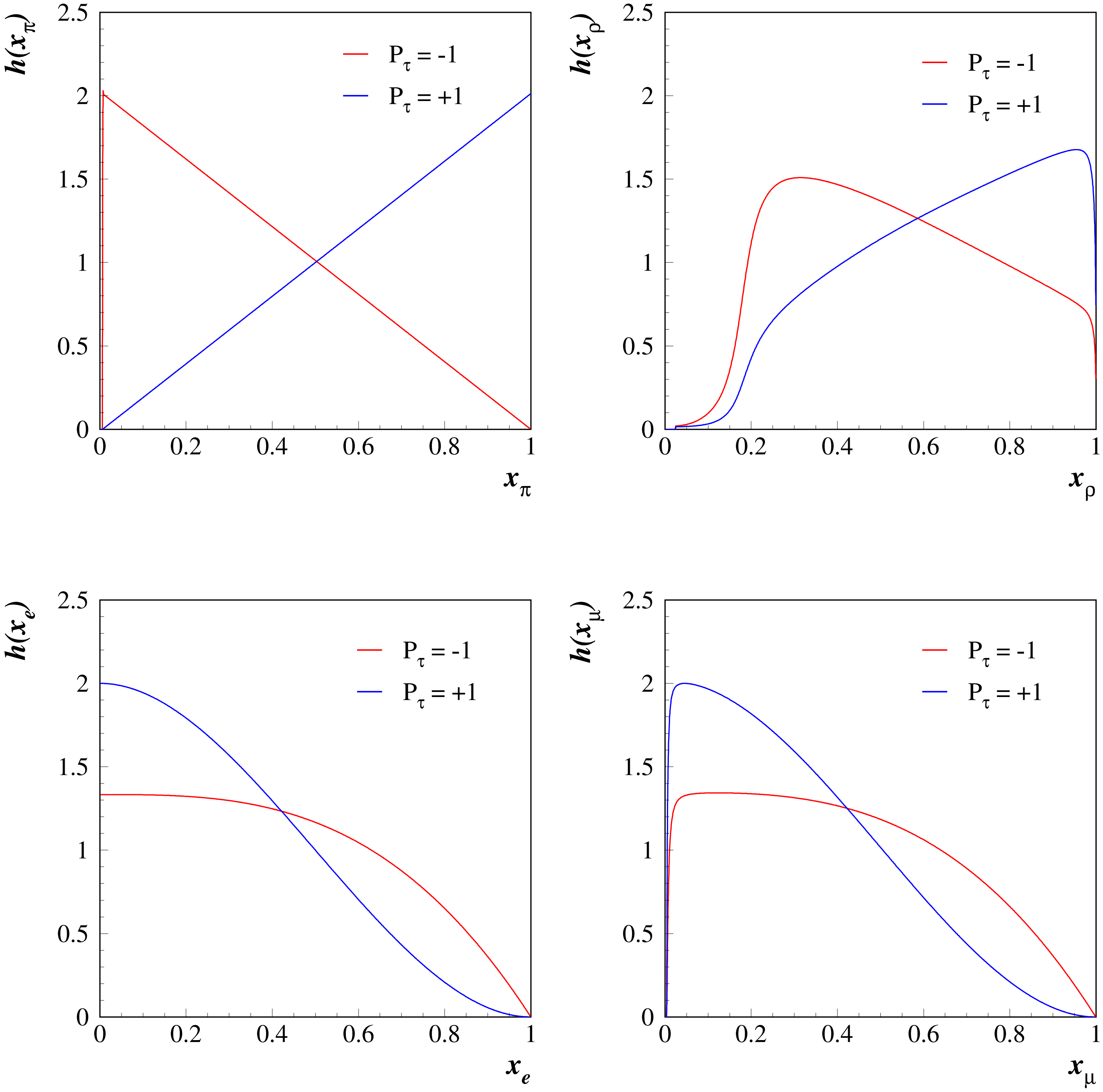
$$\frac{dN}{dx} = \sigma_L \cdot \frac{dN^L}{dx} + \sigma_R \cdot \frac{dN^R}{dx}$$

$$\frac{1}{N}\frac{dN}{dx} = h_0(x) - h_1(x) \cdot P_\tau$$

$h_0(x)$, $h_1(x)$ known: Monte Carlo and Analytical Expresions

Zero Order Energy Spectra

$\tau \to \pi\nu$ $\tau \to \rho\nu$



$\tau \to e\nu\overline{\nu}$ $\tau \to \mu\nu\overline{\nu}$

Detector effects will go in (MC simulation...)

Analysis: ρ and a_1

<u>Resonances:</u>

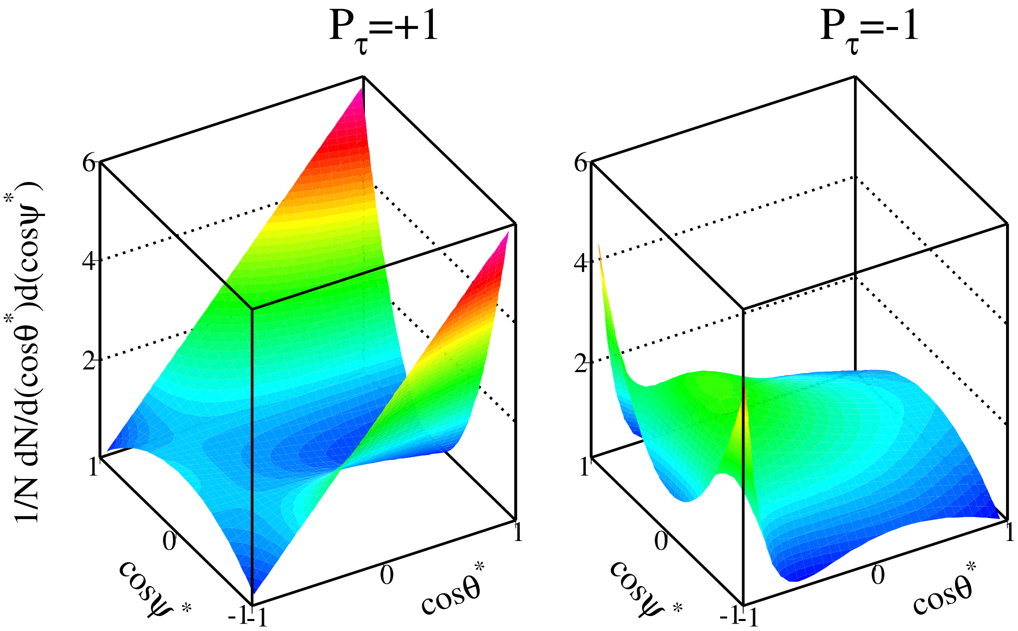
$$\tau \to \rho\nu \to \pi\pi^0\,\nu$$
$$\tau \to \mathrm{a}_1\nu \to \pi\pi\pi^0\,\nu$$

Final state ($\pi^\pm$,π^0) kinematics depends on ρ, a_1 spin:

$$E_{\pi^\pm}\ ;\ E_{\pi^0}\ ;\ \alpha\left(\pi^\pm,\pi^0\right)$$

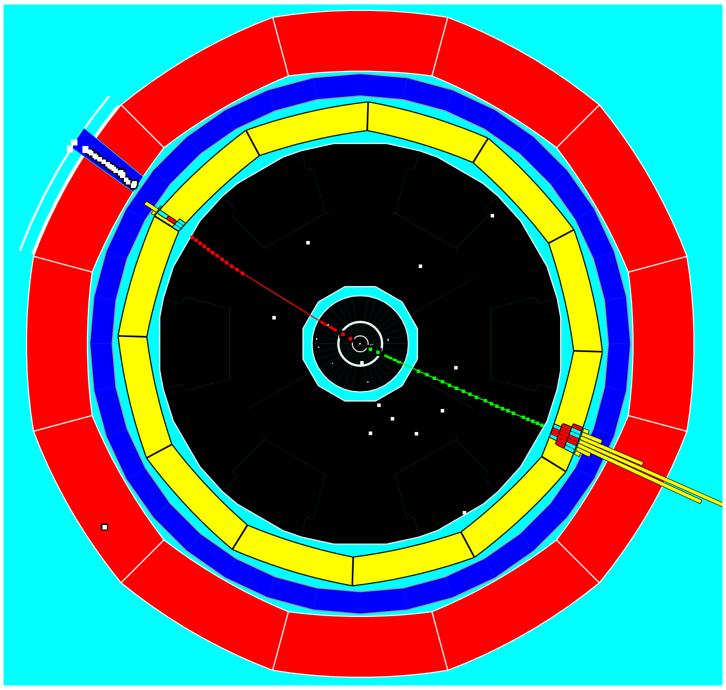
*** Higher sensitivity to P_τ than using E_ρ, E_{a_1} ***

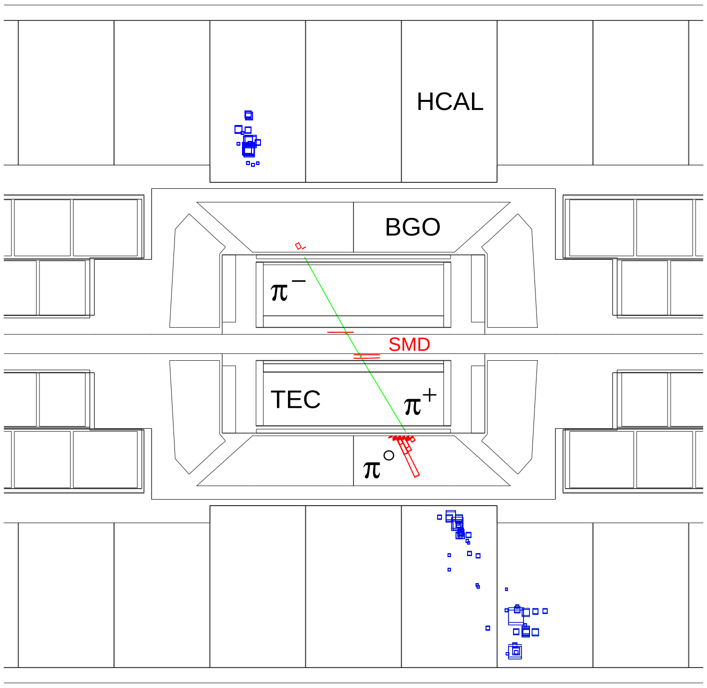
$$\left.\begin{array}{c}\cos\theta^*\ ,\ \cos\psi^* \\ \omega\end{array}\right\} = f\left(E_i,\alpha\right)$$



$\tau \to \rho\nu$

τ Decay Products: $\quad$ e, μ, π/K, ρ, a_1 $(\pi\ \mathrm{n}\pi^0)$





$\mathrm{e}^+\mathrm{e}^- \to \tau^+\tau^-$ easy to characterize (low non–τ background)

Identification based on *all subdetectors*

clean channels, especially: e, μ (π)

main difficulty: $\pi\ \mathrm{n}\pi^0$ (π)

Data Sample

Experiment	Years	e	μ	π/K	ρ	a_1	# decays
ALEPH	90–92	59	82	71	59	59	52 K
		2	4	7	9	9	
DELPHI	90–94	92	87	60	45	60	71 K
		5	3	10	15	15	(49 K)
OPAL	90–94	96	87	83	70	66	123 K
		3	2	19	27	25	
L3	90–94	76	70	72	70	33	111 K
		5	5	15	11	28	

(Efficiency / BG [%])

SYSTEMATICS

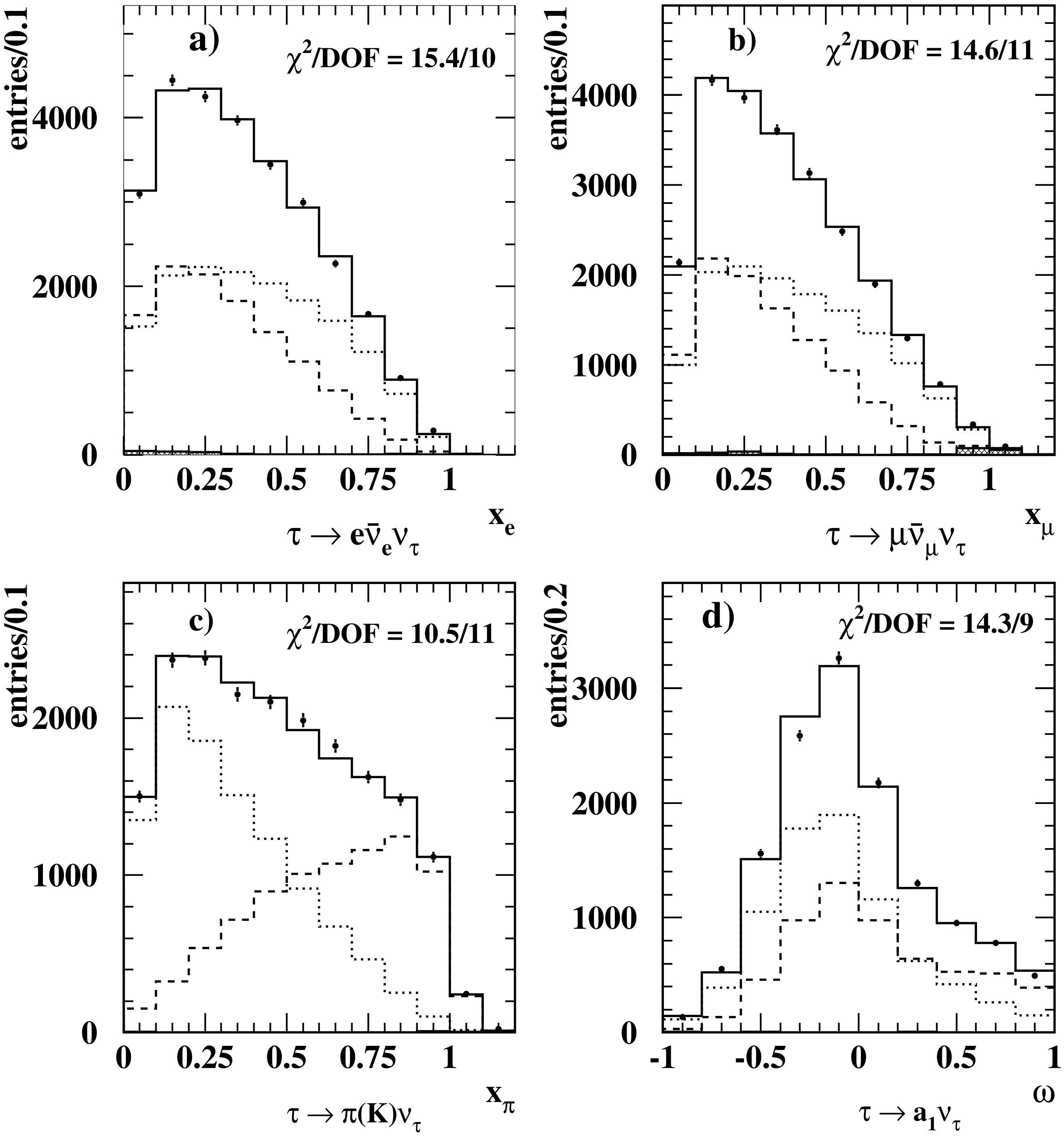
Calibration (energy scales): important to control

Extracted from data ($\mathrm{Z} \rightarrow \mathrm{e}^+\mathrm{e}^-$, $\mathrm{Z} \rightarrow \mu^+\mu^-$, two–photon)

Identification in multi–pion final states

Identification efficiency *energy*–independent

OPAL

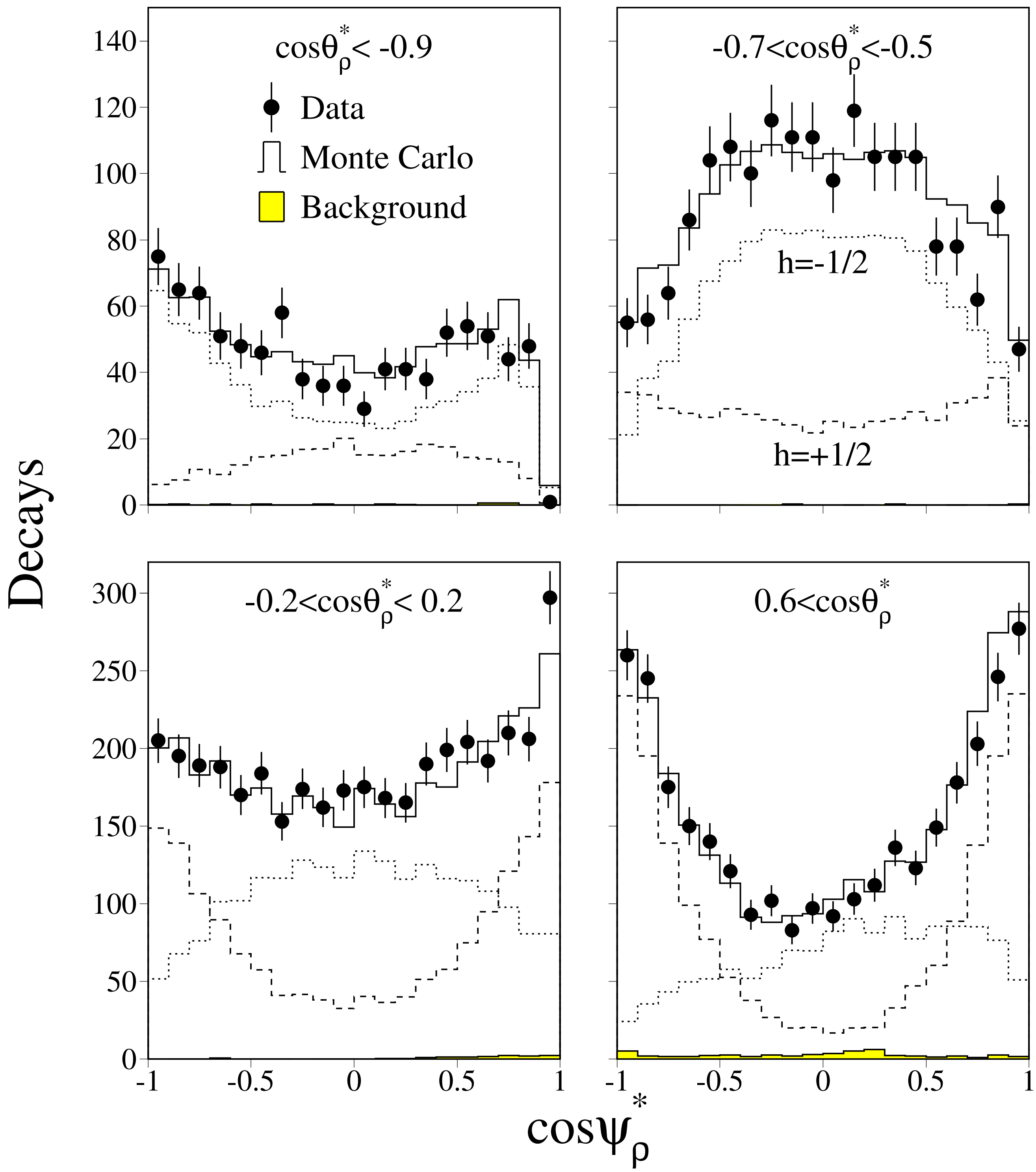


$\cdots\cdots$ $P_\tau = -1$

$- - -$ $P_\tau = +1$

Data Spectra: ρ

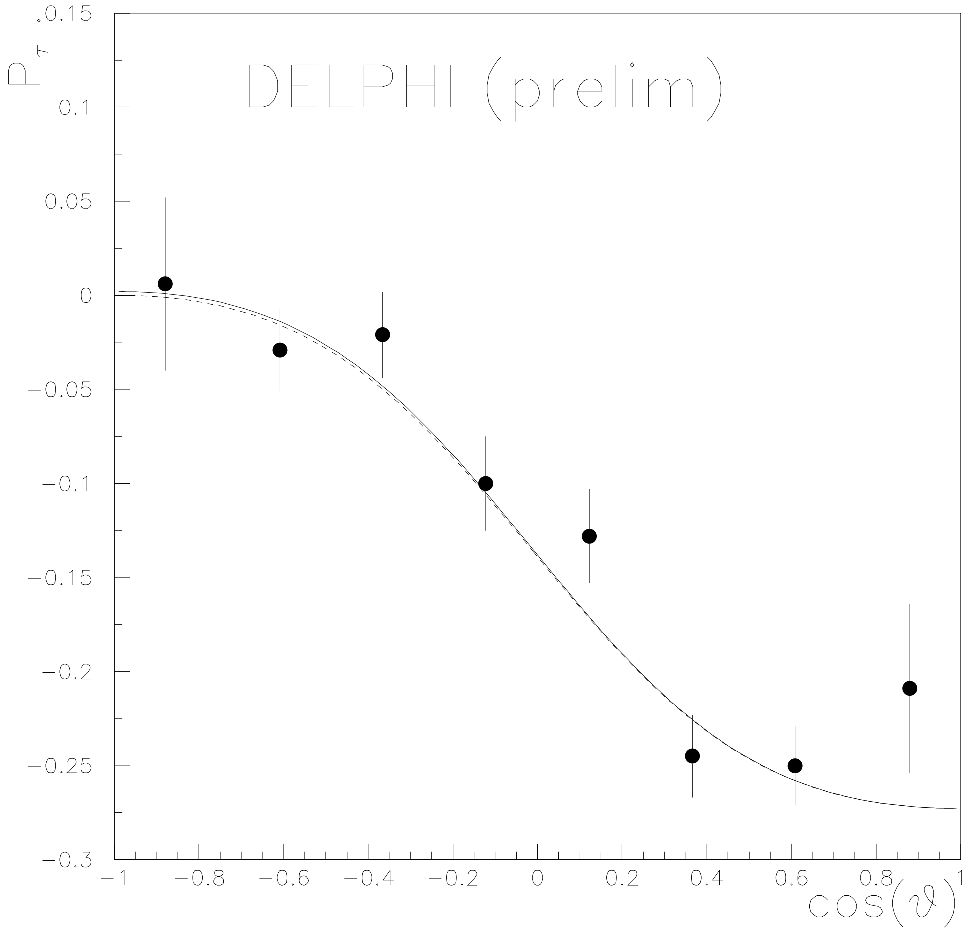
L3



$\mathcal{A}_\tau$, $\mathcal{A}_e$ are calculated from:

A. P_τ measured in $\cos\theta$ bins

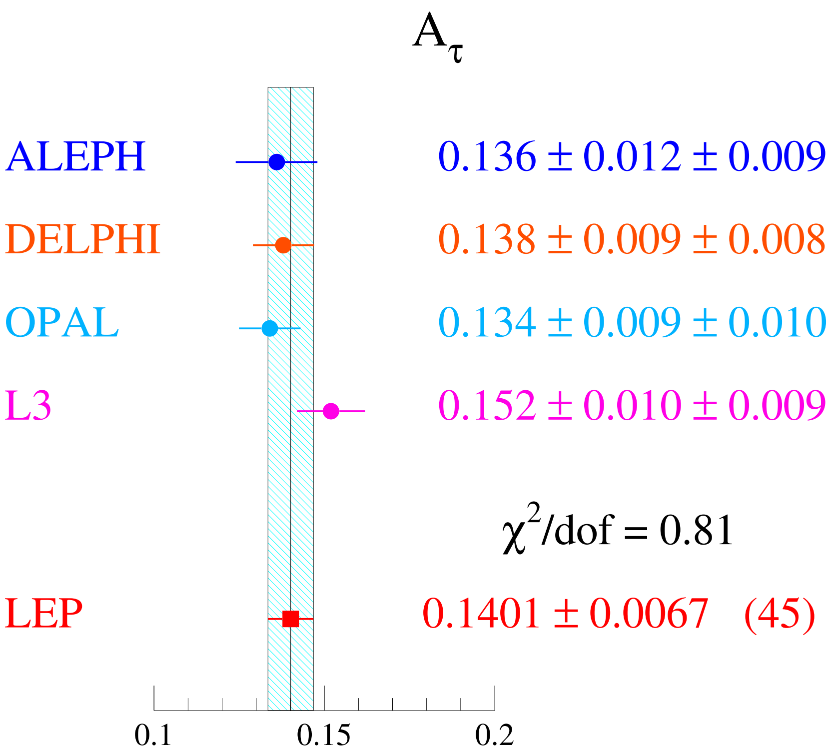
B. the joint distribution $P_\tau\,(\cos\theta, x_i)$

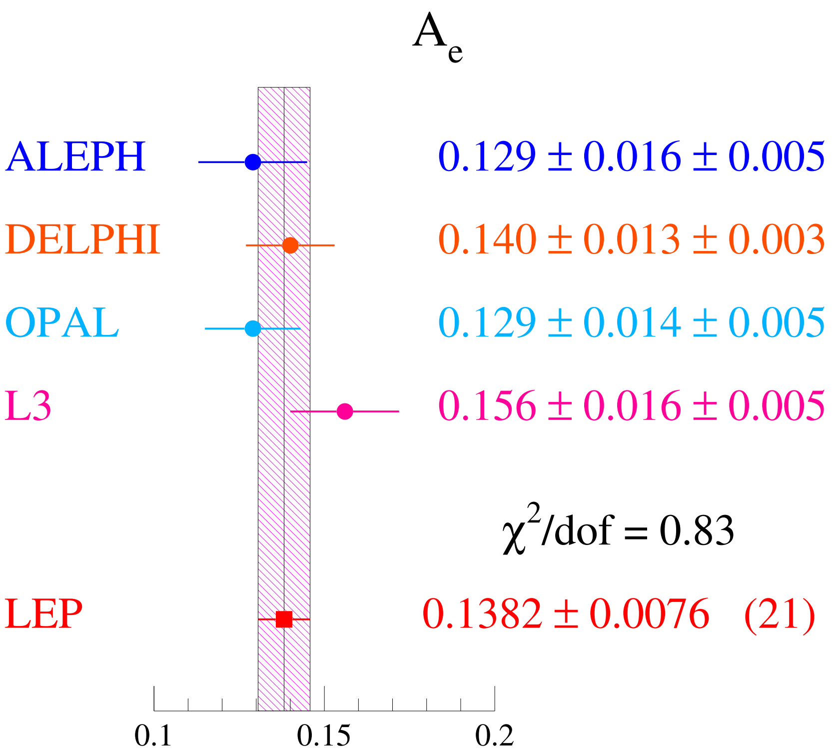


Reminder:

$$P_\tau\,(\cos\theta) \;=\; -\,\frac{\mathcal{A}_\tau\,(1+\cos^2\theta)\;+\;\mathcal{A}_e\,2\cos\theta}{(1+\cos^2\theta)\;+\;\mathcal{A}_\tau\mathcal{A}_e\,2\cos\theta}$$

Results from P_τ





Transverse and Normal Spin Correlations

$$- \; C_{TT} \; , \; C_{TN} \; -$$

Reminder:

$$C_{TT} \equiv \frac{C_2}{C_0} = \frac{|a_\tau|^2 - |v_\tau|^2}{|a_\tau|^2 + |v_\tau|^2}$$

$$C_{TN} \equiv \frac{D_2}{C_0} = -\frac{2\,\Im(v_\tau\, a_\tau^*)}{|a_\tau|^2 + |v_\tau|^2}$$

- C_{TT} is *NOT Symmetric* in a_τ and v_τ
- C_{TN} is *CP–odd* $\longrightarrow$ CP violation:

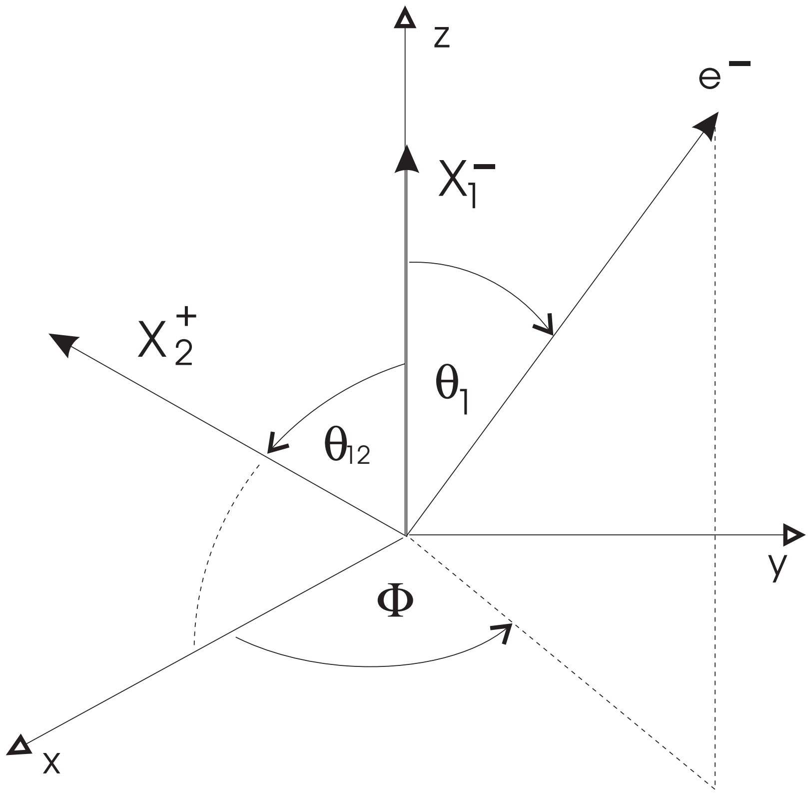
$$\Phi_{v_\tau} - \Phi_{a_\tau} = \arctan\left(\frac{C_{TN}}{P_\tau}\right)$$

In the Standard Model:

$$C_{TT} \approx 0.99$$

$$C_{TN} \approx 0.01$$

Processes: $e^+e^- \rightarrow \tau^+\tau^- \rightarrow X_1^-X_2^+ + n\nu$

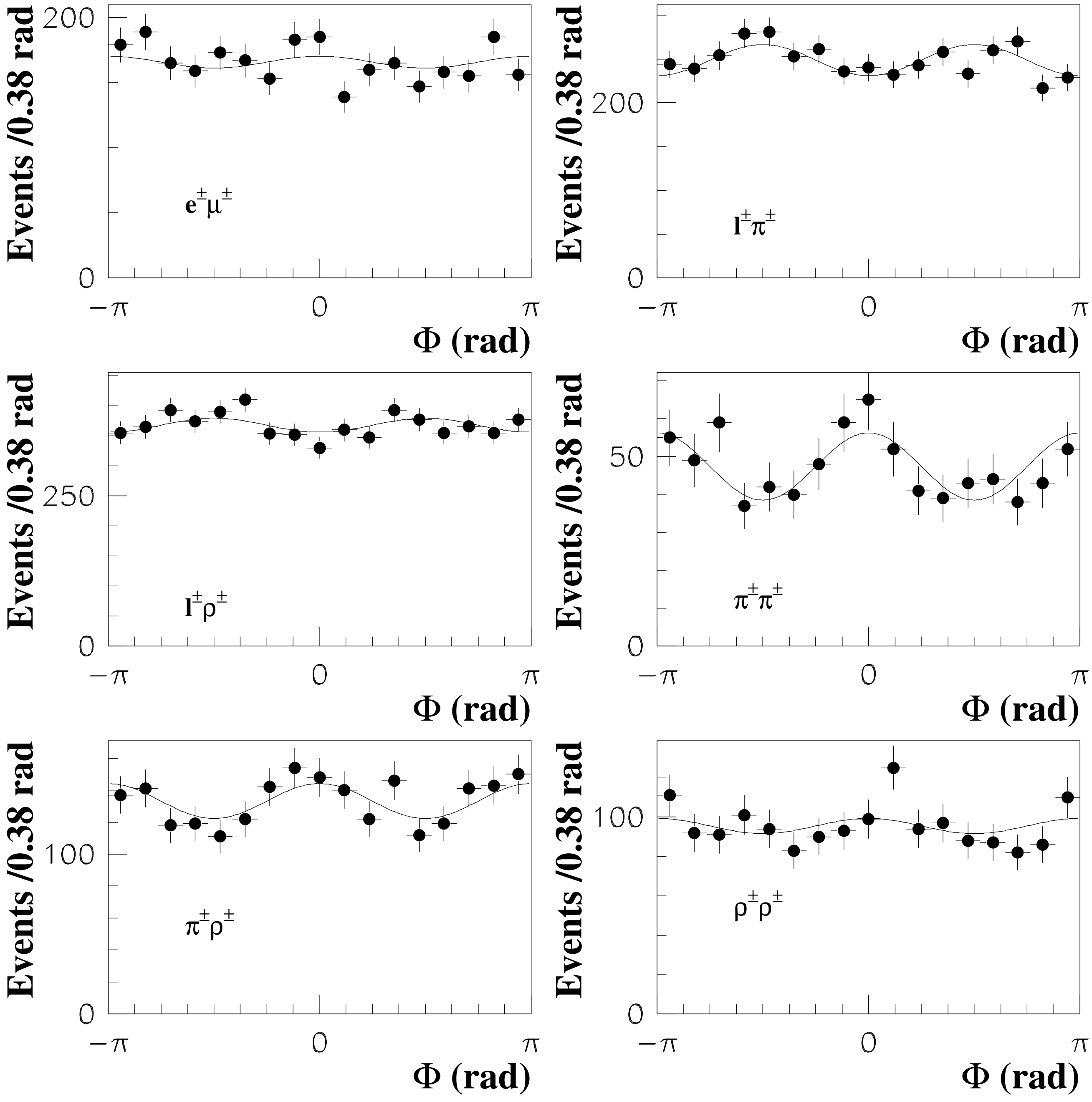


$$\frac{d^3\sigma^{ij}}{d\epsilon\, d\cos\theta_1\, d\Phi} \longrightarrow \frac{d\sigma^{ij}}{d\Phi} \propto C_{TT}\cos(2\Phi) + C_{TN}\sin(2\Phi)$$

- not necessary to reconstruct the τ direction !
- τ decay channels:

$\pi^\pm\pi^\mp$	(1.0)	$\rho^\pm\rho^\mp$	(0.2)
$\pi^\pm\rho^\mp$	(0.5)	$\rho^\pm l^\mp$	(0.15)
$\pi^\pm l^\mp$	(0.3)	$l^\pm l^\mp$	(0.1)

ALEPH

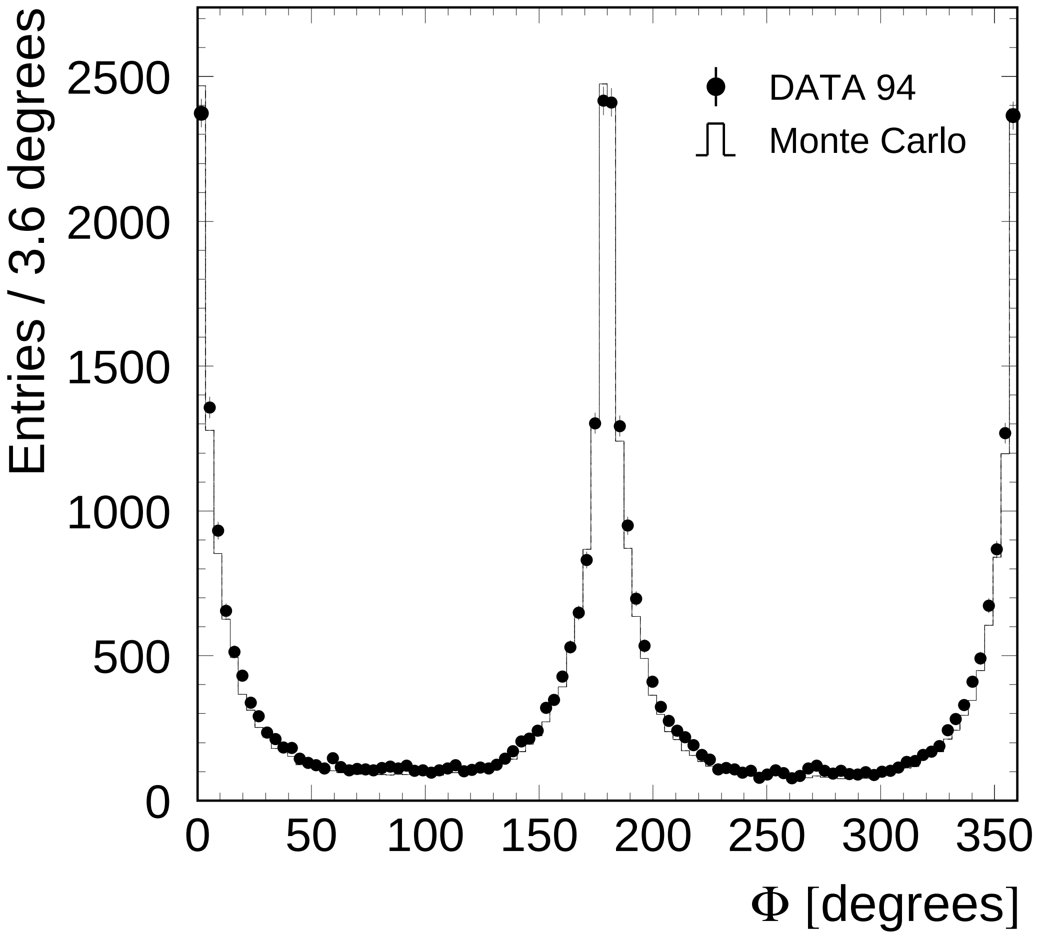


Events /0.38 rad
200
0
$e^{\pm}\mu^{\pm}$
$-\pi$
0
π
Φ (rad)
Events /0.38 rad
200
0
$l^{\pm}\pi^{\pm}$
Φ (rad)
Events /0.38 rad
250
0
$l^{\pm}\rho^{\pm}$
Φ (rad)
Events /0.38 rad
50
0
$\pi^{\pm}\pi^{\pm}$
Φ (rad)
Events /0.38 rad
100
0
$\pi^{\pm}\rho^{\pm}$
Φ (rad)
Events /0.38 rad
100
0
$\rho^{\pm}\rho^{\pm}$
Φ (rad)

Main sources:

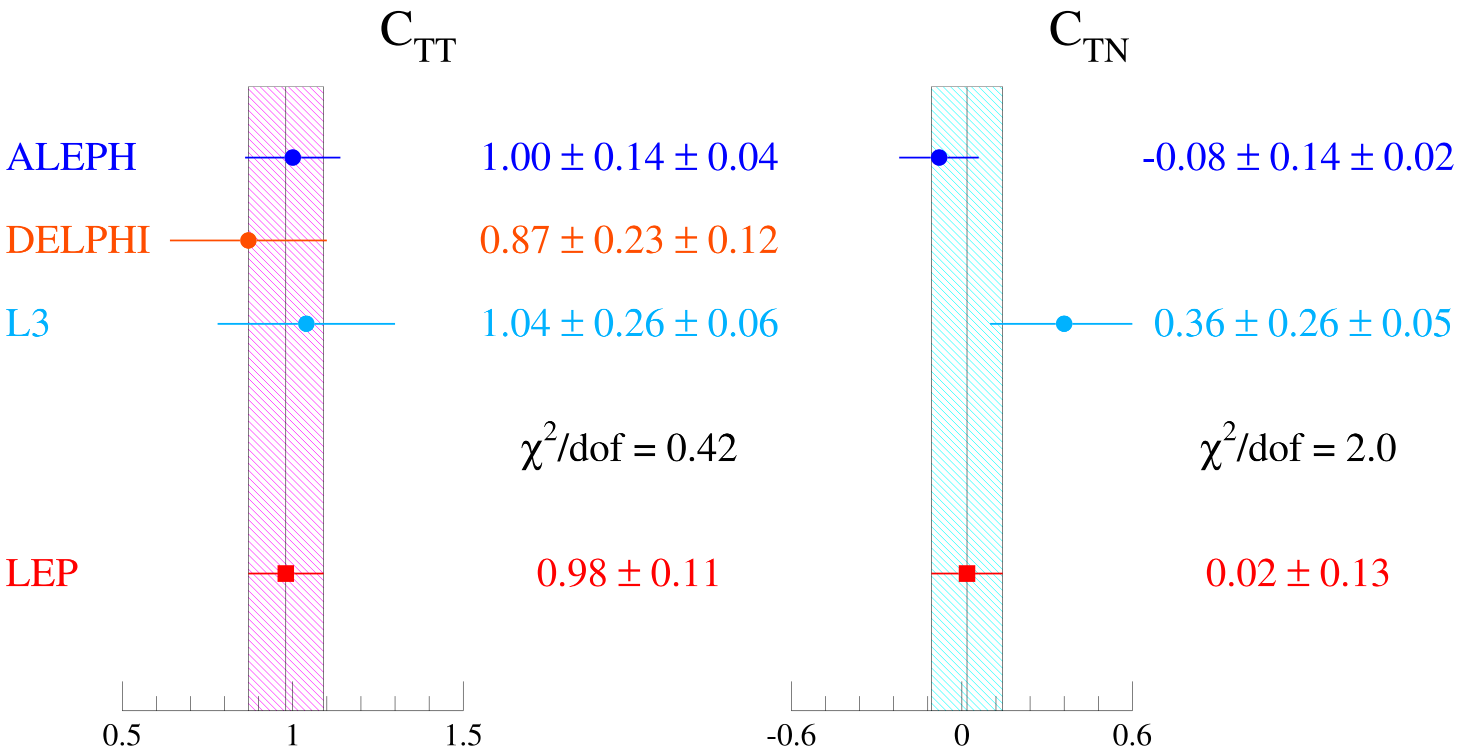
- Alignment
- Selection and Identification: background

Detector alignment and resolution is checked with $Z \to e^+e^-$ and $Z \to \mu^+\mu^-$ events



C_{TT} and C_{TN} Results

Experiment	years	$\mathcal{L}(pb^{-1})$	$N_{\tau\tau}$
ALEPH	92–94	80	20K
DELPHI	92–94	80	10K
L3	94	50	7K



$\tan(\Phi_{v_\tau} - \Phi_{a_\tau})$	
0.56 ± 0.98	ALEPH
-2.6 ± 1.7	L3
-0.23 ± 0.85	LEP

⋆ From P_τ analysis:

$$\begin{aligned}\mathcal{A}_\tau &= 0.1401 \pm 0.0067\\ \mathcal{A}_e &= 0.1382 \pm 0.0076\end{aligned}$$

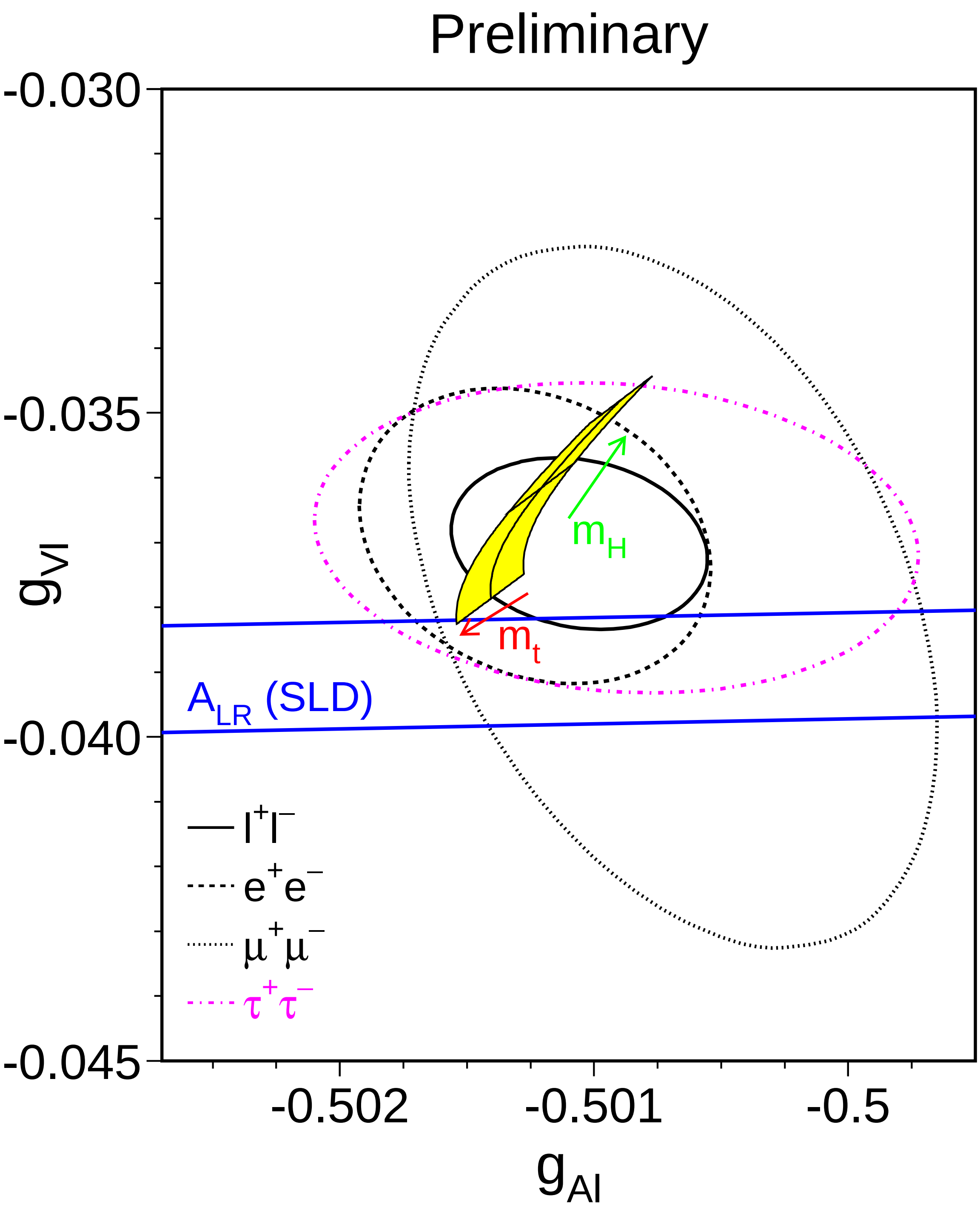
$$\mathcal{A}_{e-\tau} = 0.1393 \pm 0.0050$$

Results consistent with Lepton Universality:

$$\boxed{g_V/g_A = 0.0700 \pm 0.0026}$$

$$\boxed{\sin^2\theta_W = 0.2325 \pm 0.0006}$$

⋆ C_{TT}, C_{TN} measurements are consistent with Standard Model predictions



$$m_t = 175.6 \pm 5.5 \text{ GeV}$$

$$m_H = 300^{+700}_{-240} \text{ GeV}$$