Weak magnetic and electric dipole moments of the τ lepton from azimuthal asymmetries

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Outline

- Theoretical Introduction
- Definition of Measured Asymmetries
- Reconstruction of $\tau^+\tau^-$ kinematics
- Systematic Uncertainties
- Results

Theoretical Introduction

$$e^+e^- \rightarrow \tau^+\tau^- \rightarrow h^+\bar{\nu_\tau} h^-\nu_\tau$$

Consider the effective interaction Lagrangian:

$$L = -\frac{i}{2}\frac{eF_3^w}{2m_\tau}\bar{\psi}\sigma^{\mu\nu}\gamma_5\psi Z_{\mu\nu} + \frac{1}{2}\frac{eF_2^w}{2m_\tau}\bar{\psi}\sigma^{\mu\nu}\psi Z_{\mu\nu}$$

Where

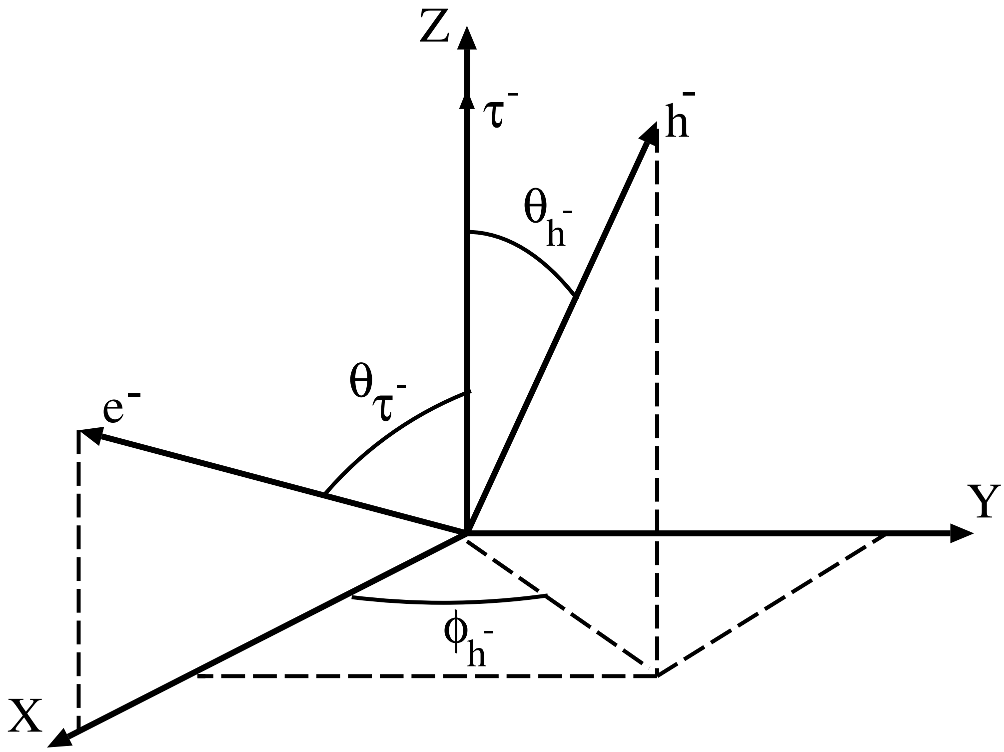
$$Z_{\mu\nu} = \partial_\mu Z_\nu - \partial_\nu Z_\mu$$

And

$$a_\tau^w \quad \equiv \quad F_2^w \quad \text{(Weak anomalous magnetic moment)}$$

$$d_\tau^w \quad \equiv \quad \frac{eF_3^w}{2\,m_\tau} \quad \text{(weak dipole moment, CP-violating)}$$

These parameters have a non-zero value in the Standard Model , but they are very small , clearly out of the present experimental sensitivity. Hence, a measured non-zero value for these numbers is a strong evidence for new physics.



Adding this lagrangian to the Standard Model one, the cross section for $e^+e^- \rightarrow \tau^+\tau^- \rightarrow h^+\bar{\nu}_\tau h^-\nu_\tau$ can be written:

$$\frac{d\sigma}{d(\cos\theta_{\tau^\pm})d\phi_{h^\pm}} = (\frac{d\sigma}{d(\cos\theta_{\tau^\pm})d\phi_{h^\pm}})_{SM} + \alpha_{h^\pm}(X_\pm \cos\phi_{h^\pm} + Y_\pm \sin\phi_{h^\pm})$$

Where

$$X_\pm = X_\pm(\theta_{\tau^\pm}, F_2^w)$$

$$Y_\pm = Y_\pm(\theta_{\tau^\pm}, F_3^w)$$

And $\phi_{h^\pm}$ are defined in the corresponding τ rest frame !!

Theoretical Introduction

Then we need:

- The τ flight direction (To obtain the τ rest frame)
- Some observables (asymmetries in $\cos\phi_{h^\pm}$ and $\sin\phi_{h^\pm}$) which measure F_2^w and F_3^w.

Define:

$$\sigma_{cc}^{\pm}(+) = \left(\int_0^1 d(\cos\theta_{\tau^-}) \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} d\phi_{h^\pm} + \int_{-1}^{0} d(\cos\theta_{\tau^-}) \int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} d\phi_{h^\pm}\right)\frac{d\sigma}{d(\cos\theta_{\tau^-})d\phi_{h^\pm}}$$

$$\sigma_{cc}^{\pm}(-) = \left(\int_0^1 d(\cos\theta_{\tau^-}) \int_{\frac{\pi}{2}}^{\frac{3\pi}{2}} d\phi_{h^\pm} + \int_{-1}^{0} d(\cos\theta_{\tau^-}) \int_{\frac{-\pi}{2}}^{\frac{\pi}{2}} d\phi_{h^\pm}\right)\frac{d\sigma}{d(\cos\theta_{\tau^-})d\phi_{h^\pm}}$$

$$\sigma_{sc}^{\pm}(+) = \left(\int_0^1 d(\cos\theta_{\tau^-}) \int_{0}^{\pi} d\phi_{h^\pm} + \int_{-1}^{0} d(\cos\theta_{\tau^-}) \int_{\pi}^{2\pi} d\phi_{h^\pm}\right)\frac{d\sigma}{d(\cos\theta_{\tau^-})d\phi_{h^\pm}}$$

$$\sigma_{sc}^{\pm}(-) = \left(\int_0^1 d(\cos\theta_{\tau^-}) \int_{\pi}^{2\pi} d\phi_{h^\pm} + \int_{-1}^{0} d(\cos\theta_{\tau^-}) \int_{0}^{\pi} d\phi_{h^\pm}\right)\frac{d\sigma}{d(\cos\theta_{\tau^-})d\phi_{h^\pm}}$$

Definition of Measured Asymmetries

OBSERVABLES

Using $\sigma_{cc}^{\pm}(\pm)$ and $\sigma_{sc}^{\pm}(\pm)$, we define:

$$A_{cc}^{\pm} = \frac{\sigma_{cc}^{\pm}(+) - \sigma_{cc}^{\pm}(-)}{\sigma_{cc}^{\pm}(+) + \sigma_{cc}^{\pm}(-)}$$

$$A_{sc} = \frac{\sigma_{sc}^{\pm}(+) - \sigma_{sc}^{\pm}(-)}{\sigma_{sc}^{\pm}(+) + \sigma_{sc}^{\pm}(-)}$$

And :

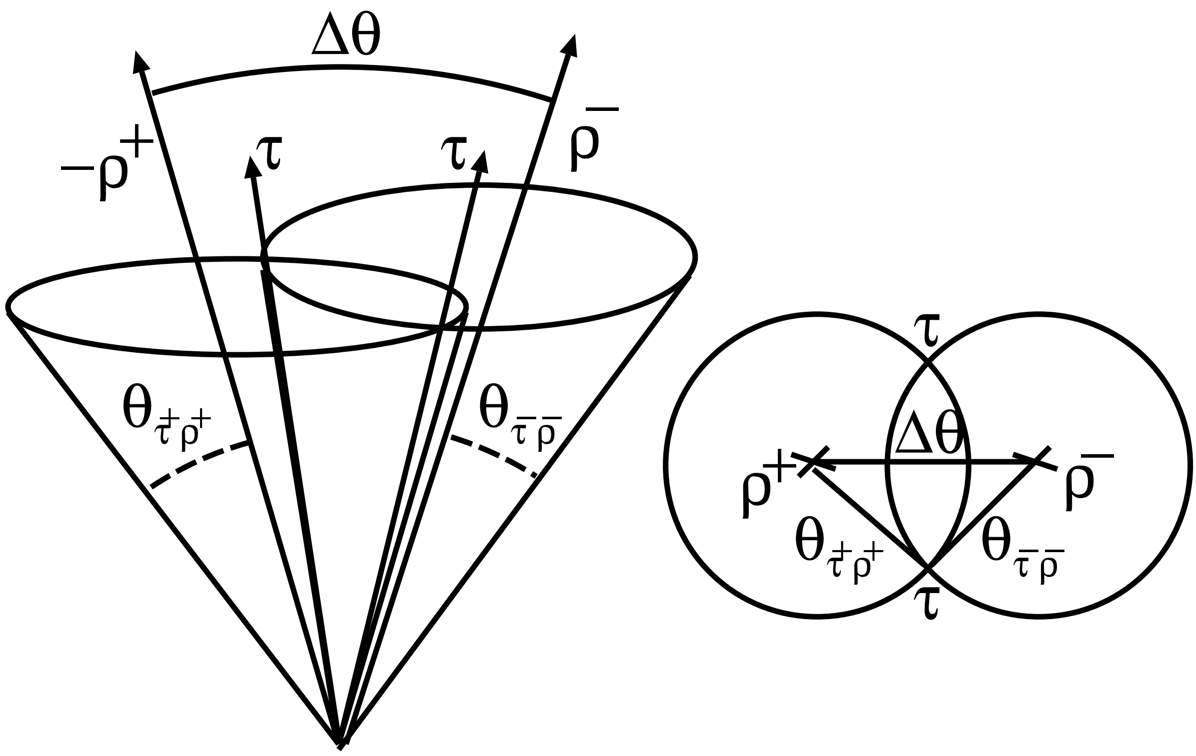
$$\begin{aligned} A_{sc}^{\rho^-} &= \quad A_{sc}^{\rho^+} &&= -3.8 F_3^w \\ A_{cc}^{\rho^-} &= -A_{cc}^{\rho^+} &&= 0.0003 + 5.0 F_2^w \end{aligned}$$

$$\begin{aligned} A_{sc}^{\pi^-} &= \quad A_{sc}^{\pi^+} &&= -10.6 F_3^w \\ A_{cc}^{\pi^-} &= -A_{cc}^{\pi^+} &&= 0.0007 + 10.6 F_2^w \end{aligned}$$

These are the ideal relations. Now we have to introduce the effects of the detector and of the analysis method.

Reconstruction of $\tau^+\tau^-$ kinematics

$$Z \to \tau^+\tau^- \to h^+h^-\nu_\tau\bar{\nu}_\tau$$



The reconstruction of the τ flight direction is possible up to a twofold ambiguity for the hadronic decay channels, with both τ's going to hadrons ($\tau \to \rho\nu$ and $\tau \to \pi\nu$) :

- Suppose that τ^+ and τ^- are back to back
- 3 unknowns from τ energy-momentum
- 3 contraints from energy momentum conservation and the hypothesis of back to back τ's.

3 unknowns + 3 constraints $\Longrightarrow$ Solutions

Reconstruction of $\tau^+\tau^-$ kinematics

The τ flight direction can be written as:

$$\hat{e}_\tau = a\hat{n}_1 + b\hat{n}_2 + c\hat{n}_3$$

where

$$\hat{n}_3 \parallel -\vec{p}_{\rho^+}$$

$$\hat{n}_2 \parallel \vec{p}_{\rho^-} \times \vec{p}_{\rho^+}$$

$$\hat{n}_1 = \hat{n}_2 \times \hat{n}_3$$

And applying energy-momentum conservation we can compute a, b, c to be

$$a = (\cos(\theta_{\rho^-\tau-}) + \cos(\theta_{\rho^+\tau+})\cos(\Delta\theta))/\sin(\Delta\theta))$$

$$c = \cos(\theta_{\rho^+\tau+})$$

$$b = \pm\sqrt{1 - a^2 - c^2}$$

To solve the ambiguity we have chosen the $+$ sign for b in this analysis.

Systematic Uncertainties

Consequences of the τ direction reconstruction

- $\phi_{rec.}$ is wrong in a 50% of the times.
- We have to take into account the bias introduced by this behaviour.
- There are contributions to both asymmetries coming from F_2^w and F_3^w.

Selection of the sample

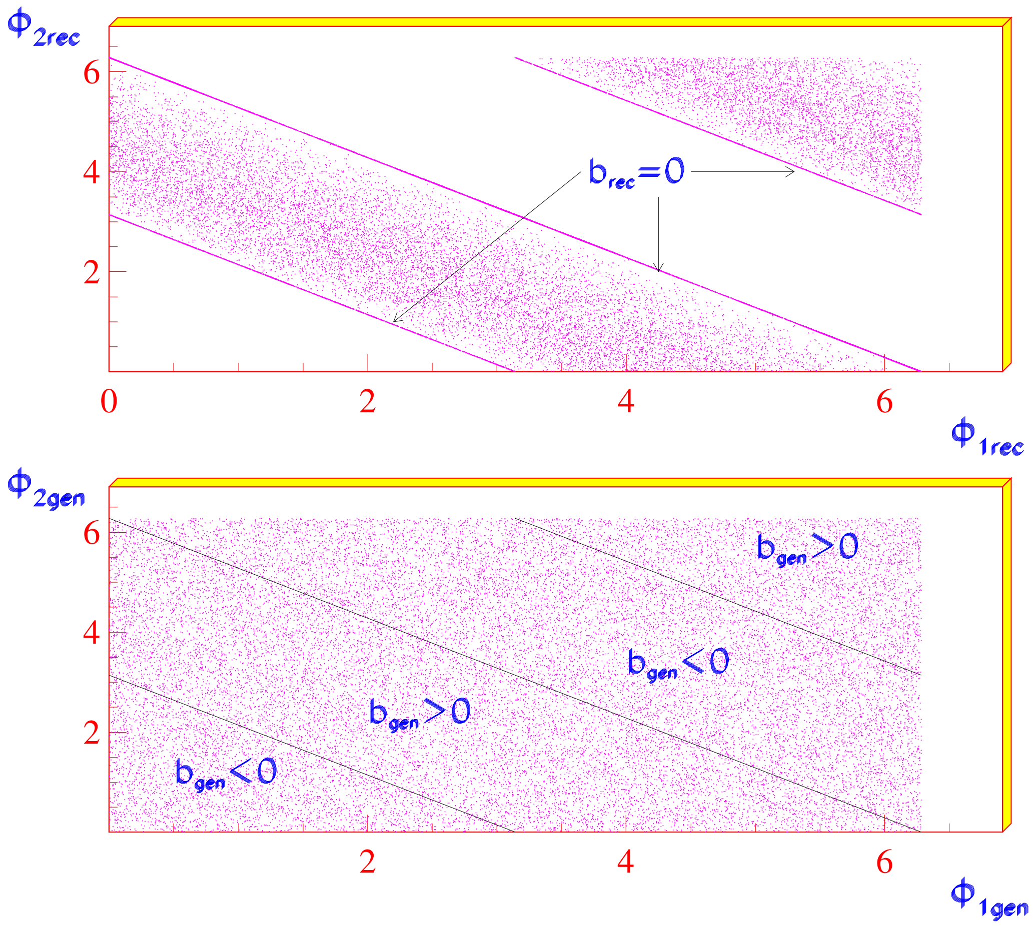
- Data collected at L3 from 1991 to 1994
- efficiencies:

channel	efficiency	purity	N. of selected events
$\rho^-\rho^+$	0.243	0.768	1814
$\pi^-\rho^+$	0.188	0.756	913
$\pi^+\rho^-$	0.183	0.750	822
$\pi^-\pi^+$	0.313	0.699	537

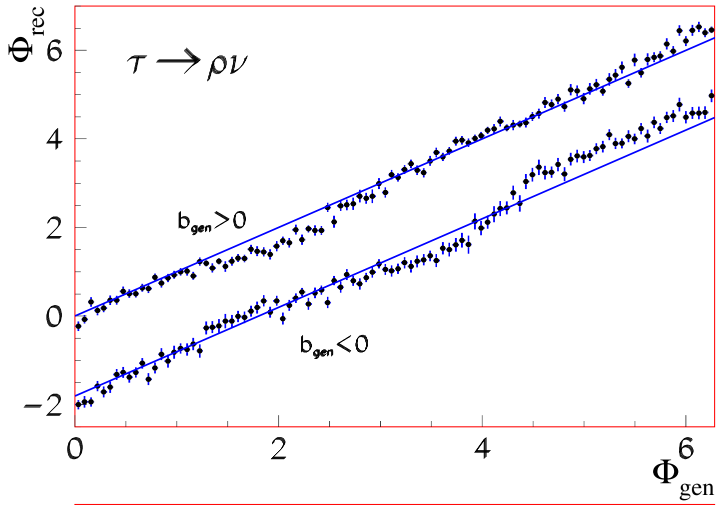
- All the backgrounds come from other tau decays.

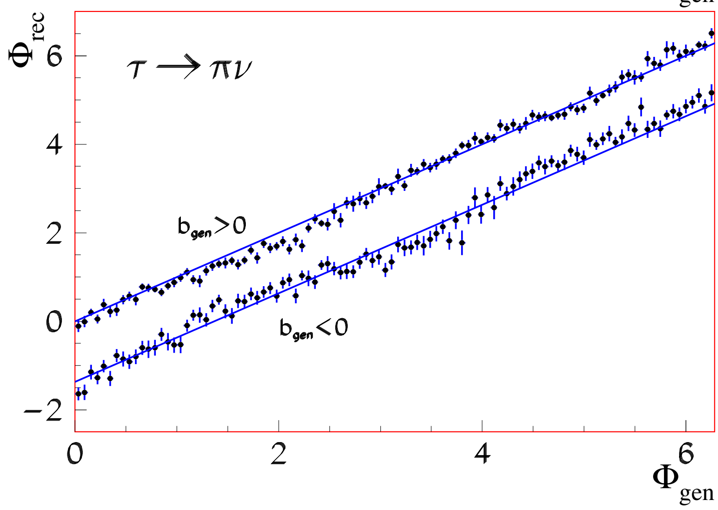
Imperfect Detector Resolution and Radiation

- Events with $b^2 < 0$ reconstructed are concentrated in the lines.

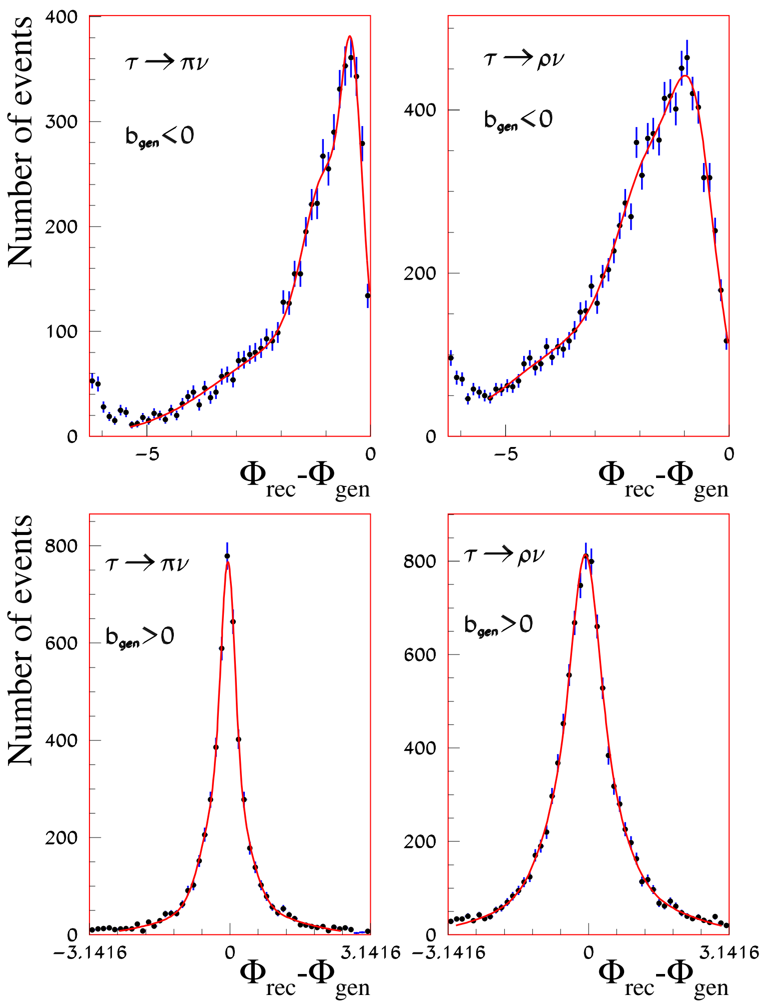


- The final consequence is that the $\vec{p}_\tau$ reconstruction efficiency is $\approx 50\%$





- Events with $b < 0$ at generator level have a bias in the reconstruction procedure.
- This is because there are contributions to the asymmetries coming from F_2^w and F_3^w.



Resolution functions obtained for the $\vec{p}_\tau$ reconstruction.

- We have to convolute the theoretical expressions for the asymmetries with these functions to obtain the measured asymmetries.
- These functions are parametrized as a sum of 3 gaussians.

EXPRESSIONS FOR THE MEASURED ASYMMETRIES

$\tau \rightarrow \rho\nu$

$$
\begin{aligned}
A_{sc}^{\rho^-} &= A_{sc}^{\rho^+} = 0.0001 - 2.53F_3^w + 1.59F_2^w \\
A_{cc}^{\rho^-} &= -A_{cc}^{\rho^+} = 0.0002 + 1.59F_3^w + 2.54F_2^w
\end{aligned}
$$

$\tau \rightarrow \pi\nu$

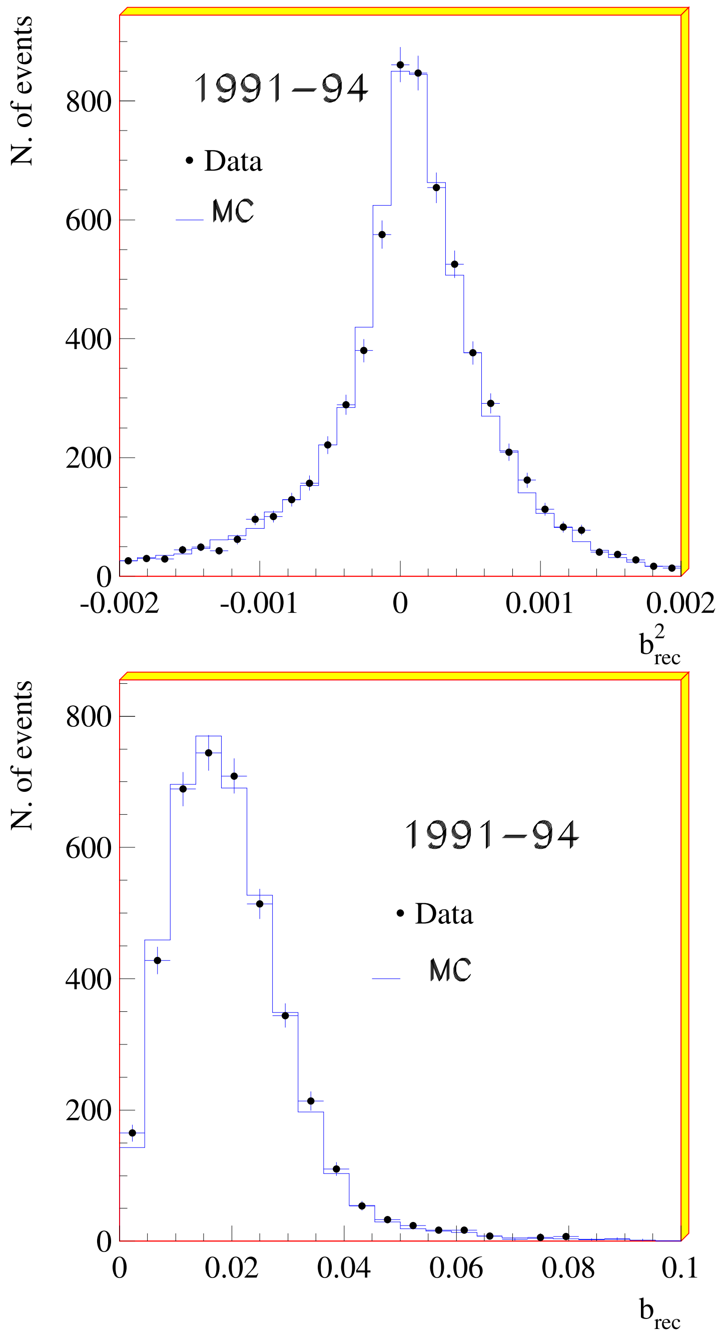
$$
\begin{aligned}
A_{sc}^{\pi^-} &= A_{sc}^{\pi^+} = 0.0002 - 7.41F_3^w + 2.59F_2^w \\
A_{cc}^{\pi^-} &= -A_{cc}^{\pi^+} = 0.0005 + 2.59F_3^w + 7.41F_2^w
\end{aligned}
$$

- The parameters F_2^w and F_3^w can be found using these equations.
- The resolution and reconstruction effects are taken into account in the coefficients.
- These expressions have been checked introducing large values of F_2^w and F_3^w reweighting the events according to the cross section dependence.

SYSTEMATIC ERRORS IN THE ASYMMETRIES

Source	ρ channel	π channel
Finite MC statistics	0.006	0.008
Selection	0.004	0.004
Recontruction method	0.034	0.062

- Reconstruction errors dominate the systematics.



- Good agreement between data and MC for the reconstruction.

Results

Raw Event Counts:

	Angular Region	τ^-	τ^+
A^{ρ}_{sc}	$\cos\theta_\tau > 0\ \phi_h < \pi$	696	654
	$\cos\theta_\tau < 0\ \phi_h > \pi$	664	677
	$\cos\theta_\tau > 0\ \phi_h > \pi$	653	711
	$\cos\theta_\tau < 0\ \phi_h < \pi$	623	685
A^{ρ}_{cc}	$\cos\theta_\tau > 0\ \phi_h \in (-\pi/2, \pi/2)$	672	701
	$\cos\theta_\tau < 0\ \phi_h \in (\pi/2, 3\pi/2)$	640	714
	$\cos\theta_\tau > 0\ \phi_h \in (\pi/2, 3\pi/2)$	677	664
	$\cos\theta_\tau < 0\ \phi_h \in (-\pi/2, \pi/2)$	647	648
A^{π}_{sc}	$\cos\theta_\tau > 0\ \phi_h < \pi$	362	333
	$\cos\theta_\tau < 0\ \phi_h > \pi$	374	363
	$\cos\theta_\tau > 0\ \phi_h > \pi$	378	299
	$\cos\theta_\tau < 0\ \phi_h < \pi$	336	364
A^{π}_{cc}	$\cos\theta_\tau > 0\ \phi_h \in (-\pi/2, \pi/2)$	370	332
	$\cos\theta_\tau < 0\ \phi_h \in (\pi/2, 3\pi/2)$	350	370
	$\cos\theta_\tau > 0\ \phi_h \in (\pi/2, 3\pi/2)$	370	300
	$\cos\theta_\tau < 0\ \phi_h \in (-\pi/2, \pi/2)$	360	357

Results

Background corrected asymmetries

$\tau \to \rho\nu$

$$
\begin{aligned}
A_{cc}^{\rho^-} &= -0.001 \pm 0.021 \pm 0.035 \\
A_{cc}^{\rho^+} &= 0.033 \pm 0.020 \pm 0.035 \\
A_{sc}^{\rho^-} &= 0.035 \pm 0.021 \pm 0.035 \\
A_{sc}^{\rho^+} &= -0.023 \pm 0.020 \pm 0.035
\end{aligned}
$$

$\tau \to \pi\nu$

$$
\begin{aligned}
A_{cc}^{\pi^-} &= -0.015 \pm 0.029 \pm 0.063 \\
A_{cc}^{\pi^+} &= 0.037 \pm 0.029 \pm 0.063 \\
A_{sc}^{\pi^-} &= 0.017 \pm 0.029 \pm 0.063 \\
A_{sc}^{\pi^+} &= 0.029 \pm 0.029 \pm 0.063
\end{aligned}
$$

PRELIMINARY L3 RESULTS:

$$d_\tau^w = (-2.2 \pm 3.9) \times 10^{-17}\, e \cdot cm$$

$$a_\tau^w = -0.0025 \pm 0.0070$$

Limits (95% C.L.)

$$-9.8 \times 10^{-17}\, e \cdot cm < d_\tau^w < 5.4 \times 10^{-17}\, e \cdot cm$$

$$-0.016 < a_\tau^w < 0.011$$

Remarks:

- Limit on d_τ^w not competitive with CP-odd tensor method.
- First DIRECT limit on a_τ^w.