A Measurement of Tau Polarization Using L3 Detector at LEP

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Introduction

From Tau Polarization to $\sin^2\theta_w^{eff}$

At LEP I, τ's from the process $e^+e^- \rightarrow Z \rightarrow \tau^+\tau^-$ are polarized. In the Born approximation, $\mathcal{P}_\tau(\cos\theta)$ is a simple function of the vector and axial vector coupling constants.

$$\mathcal{P}_\tau \equiv \frac{\sigma(h_\tau = 1/2) - \sigma(h_\tau = -1/2)}{\sigma(h_\tau = 1/2) + \sigma(h_\tau = -1/2)}$$

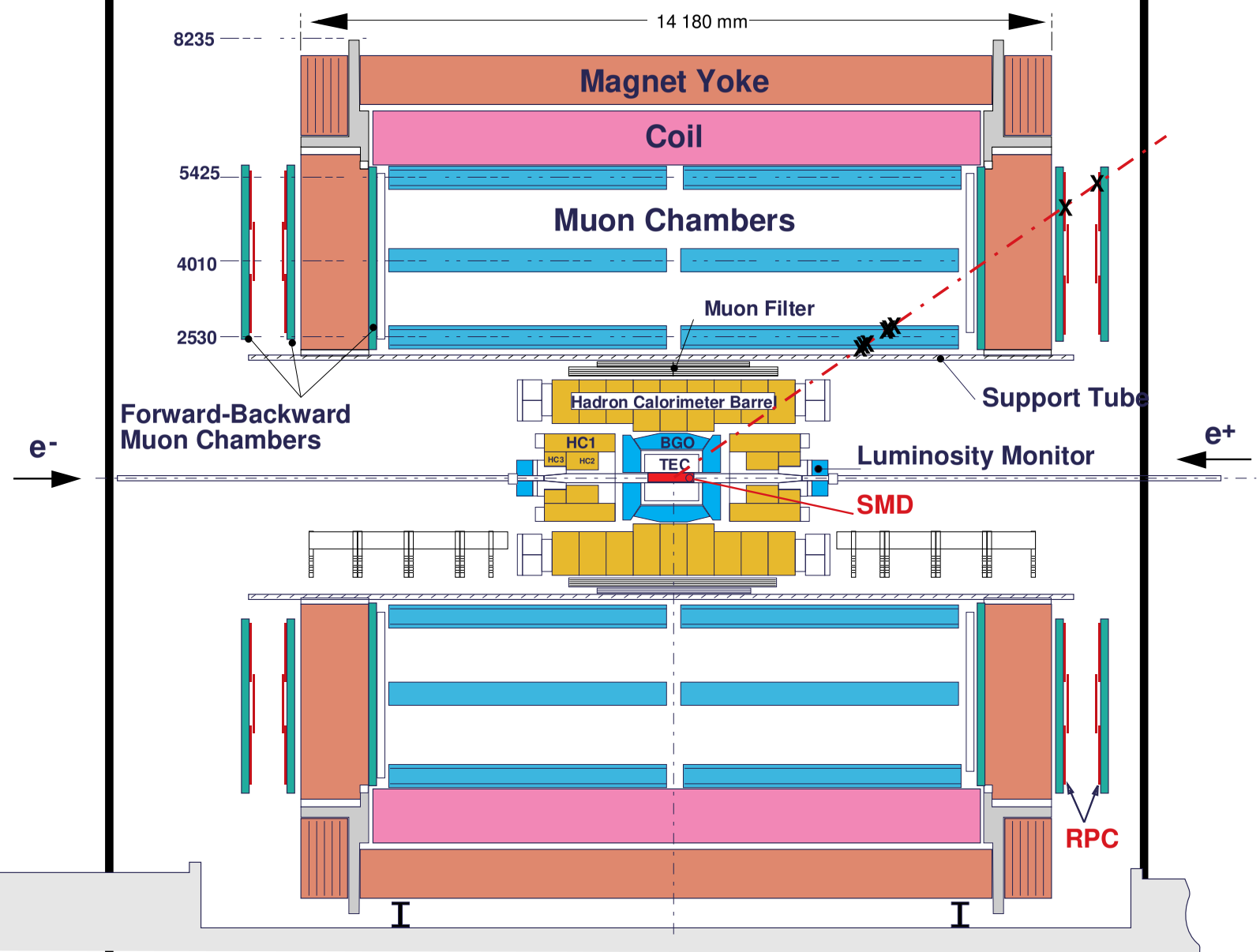
$$\mathcal{P}_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau + 2\mathcal{A}_e \cos\theta/(1+\cos^2\theta)}{1 + 2\mathcal{A}_\tau\mathcal{A}_e \cos\theta/(1+\cos^2\theta)}$$

$$with \;\; \mathcal{A}_l \equiv 2g_{Vl}g_{Al}/(g_{Vl}^2 + g_{Al}^2).$$

In the Standard Model,

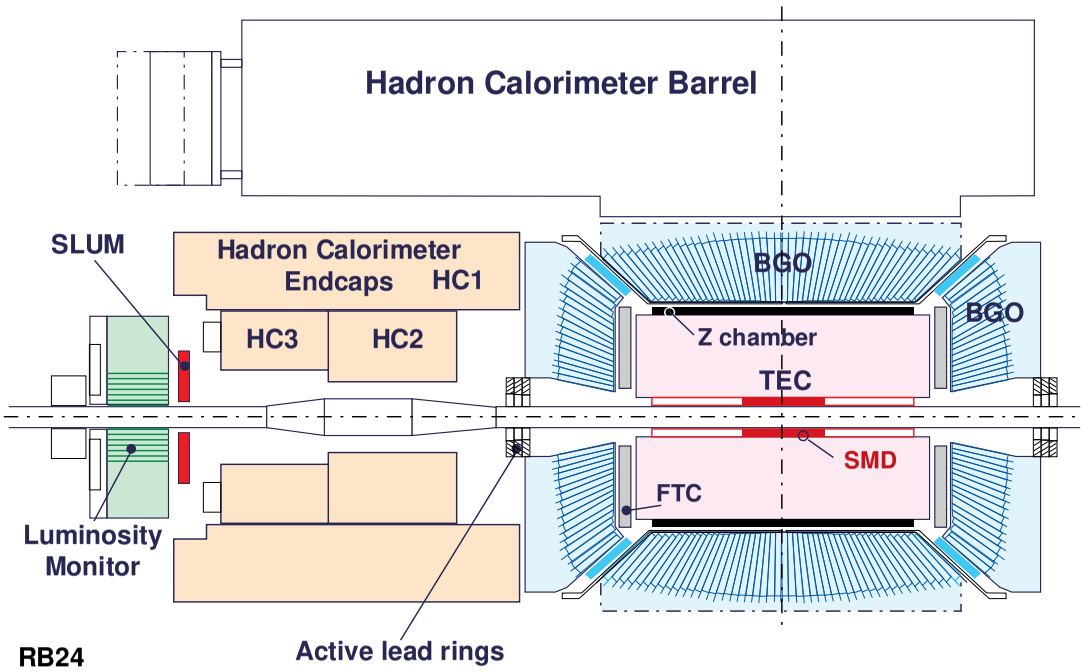
- $\mathcal{A}_\tau = \mathcal{A}_e$
- $g_{Vl}/g_{Al} = 1 - 4\sin^2\theta_w^{eff}$

L3 Detector


14 180 mm
8235
5425
4010
2530
Magnet Yoke
Coil
Muon Chambers
Muon Filter
Hadron Calorimeter Barrel
Forward-Backward
Muon Chambers
Support Tube
e-
e+
HC1
HC3
HC2
BGO
TEC
Luminosity Monitor
SMD
RPC

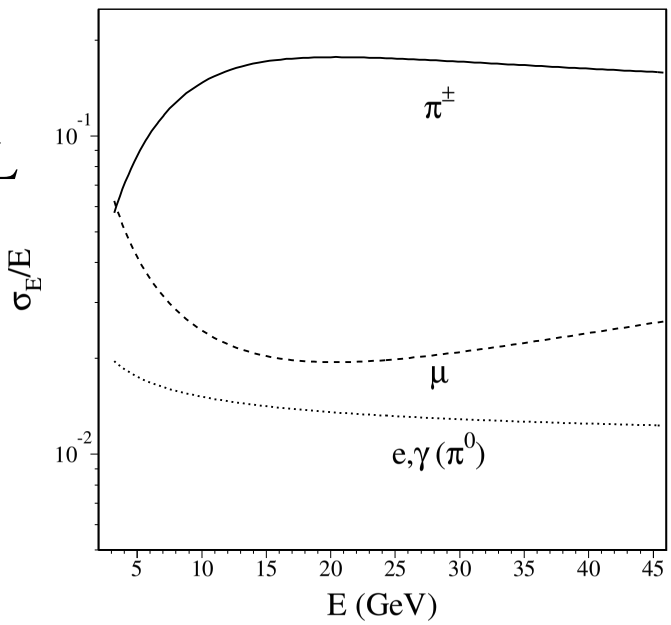
L3 Detector

Inner view of L3 Detector



Energy Resolution

- π^- determined by TEC, ECAL, HCAL
- μ by the muon spectrometer
- $e, \gamma(\pi^0)$ by ECAL



Selection of Tau Decays

Dilepton Preselection

- Selection cuts are imposed to reject $Z \longrightarrow hadrons$, cosmic muons, and $\mathrm{e}^+\mathrm{e}^- \longrightarrow f^+ f^- \mathrm{e}^+\mathrm{e}^-$
- 94 data in the barrel region of the L3 detector

Particle Identification

The following τ decay channels are used in the analysis.

- $\tau^- \longrightarrow e^- \nu_e \nu_\tau$
- $\tau^- \longrightarrow \mu^- \nu_\mu \nu_\tau$
- $\tau^- \longrightarrow \pi^- \nu_\tau$
- $\tau^- \longrightarrow \rho^- \nu_\tau$
  where $\rho^- \longrightarrow \pi^- \pi^0$
  and subsequently $\pi^0 \longrightarrow \gamma\gamma$

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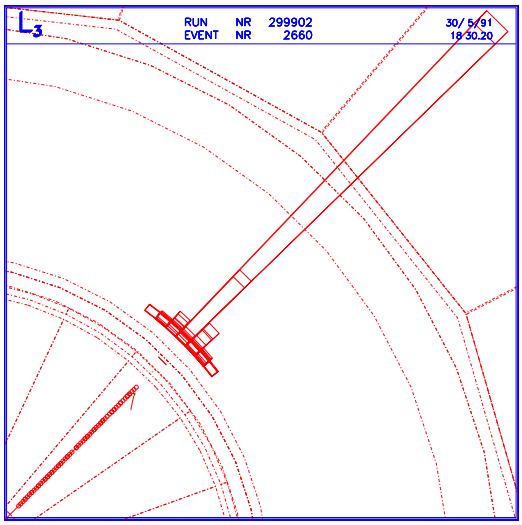
Selection of Tau Decays

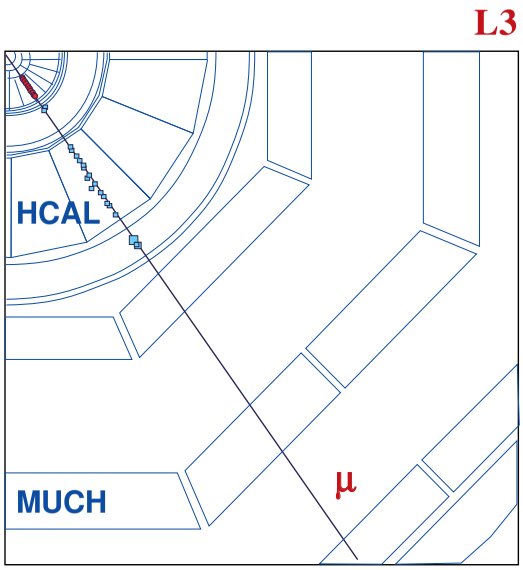
- The electron signature

  A sharp narrow shower in ECAL with a matching TEC track. Little HCAL deposit.



- The muon signature

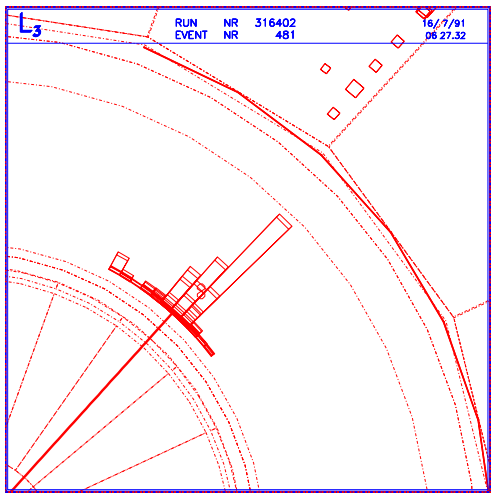
  A minimum ionizing track in HCAL with a matching TEC track or hits in the muon spectrometer.



Selection of Tau Decays

- The charged pion signature

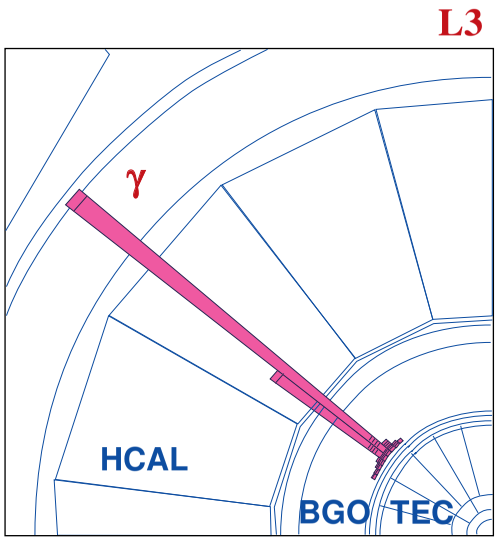
  A wide asymmetrical shower in ECAL with a matching TEC track. visible HCAL clusters.



- The photon signature

  A sharp narrow shower in ECAL only.

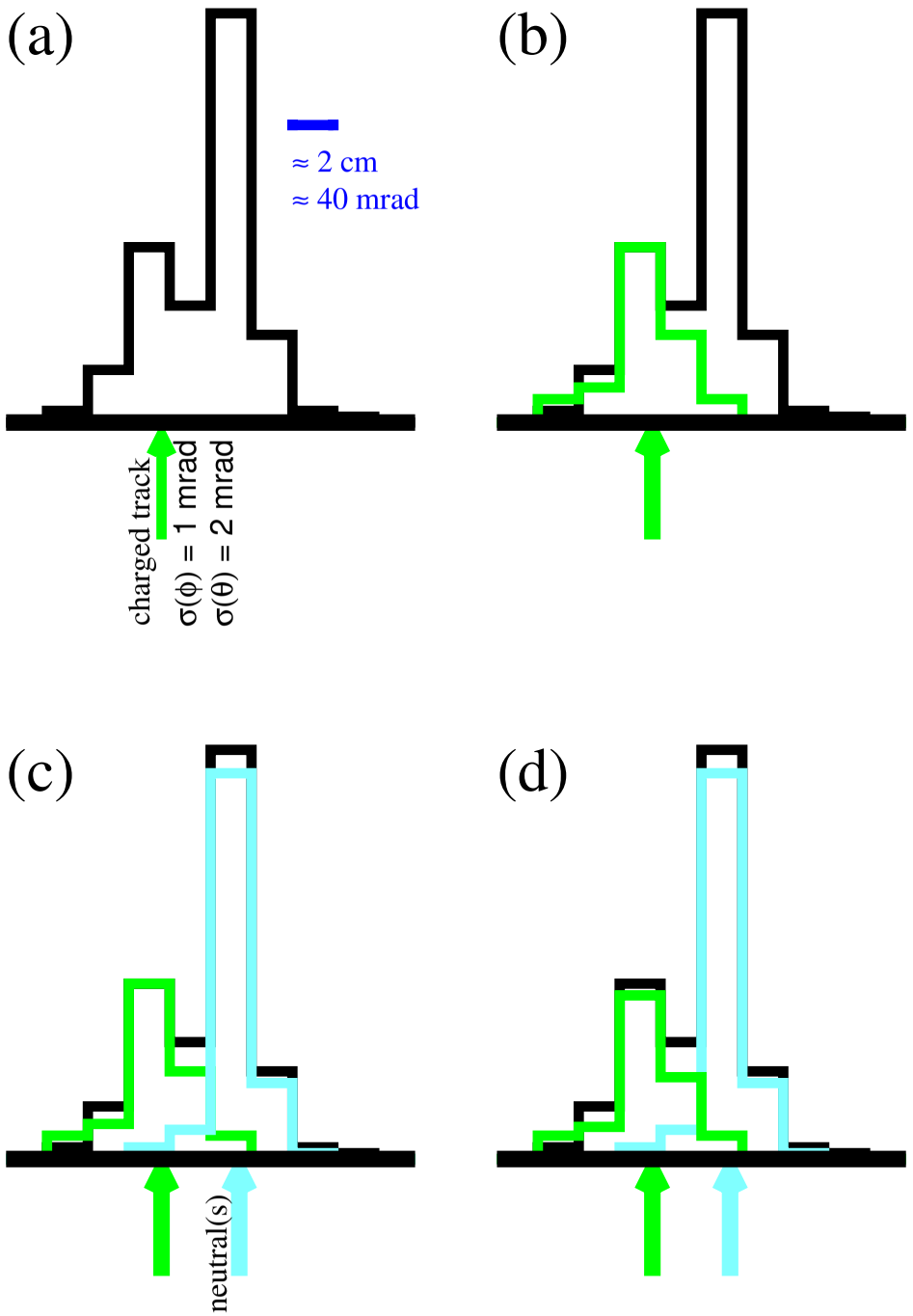
- π^0 is determined by the invariant mass of the two photon clusters in ECAL.



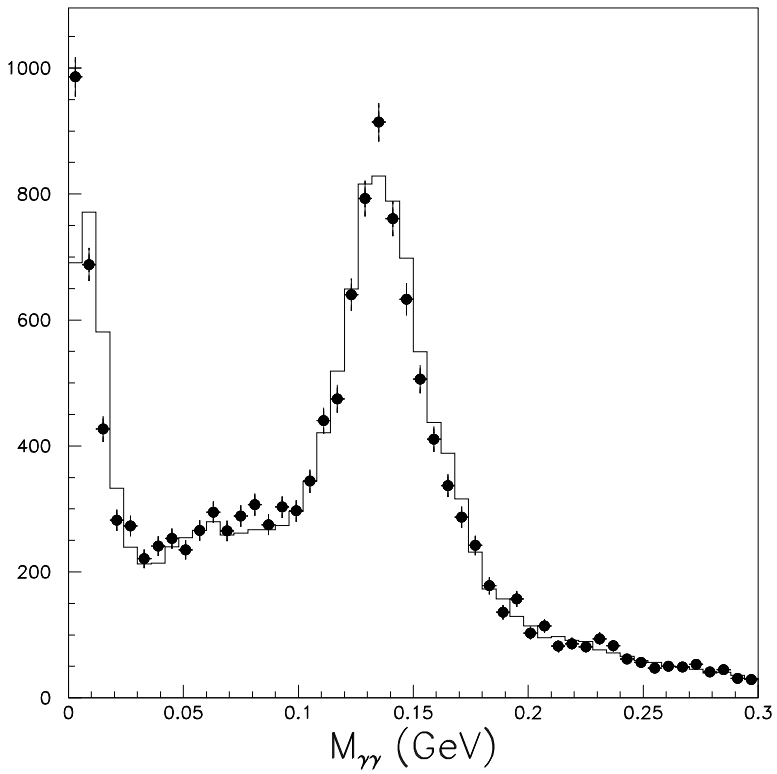
Background Rejection

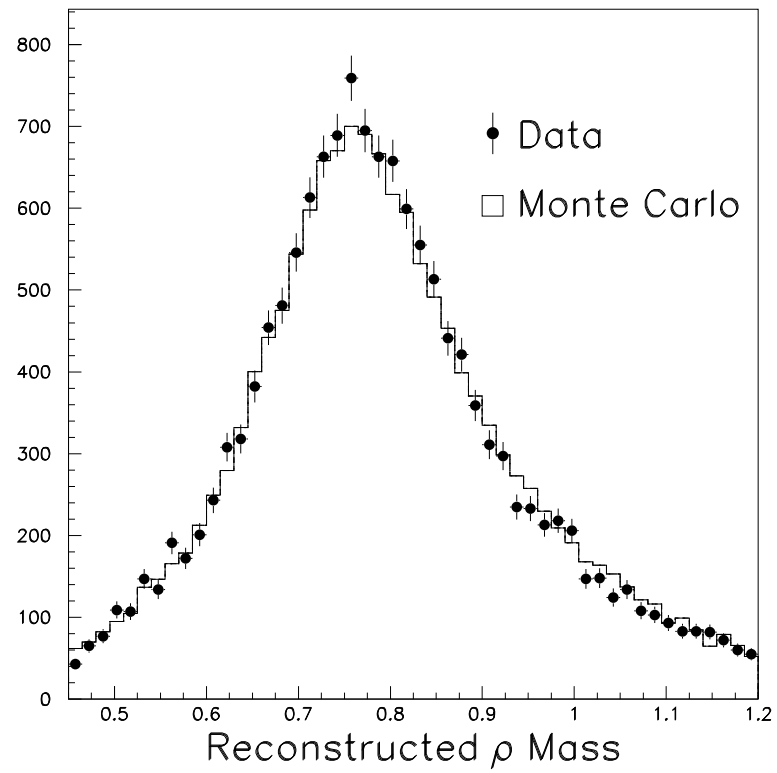
- After the particle identification, the opposite hemisphere is checked to reject bhabha and dimuon events.

Charged/Neutral Cluster Reconstruction (BGO Calorimeter, TEC, Z-Chamber)

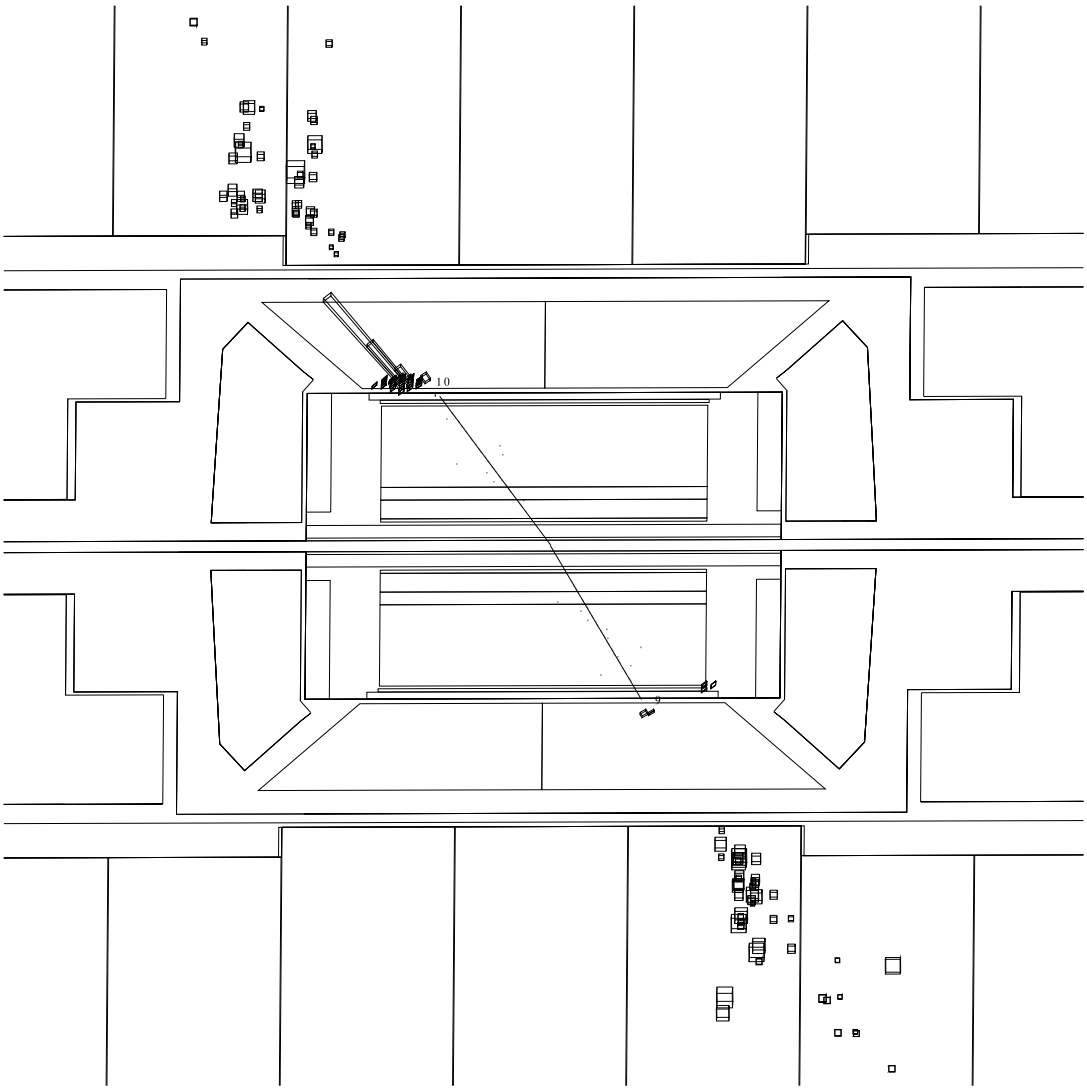


Selection of Tau Decays





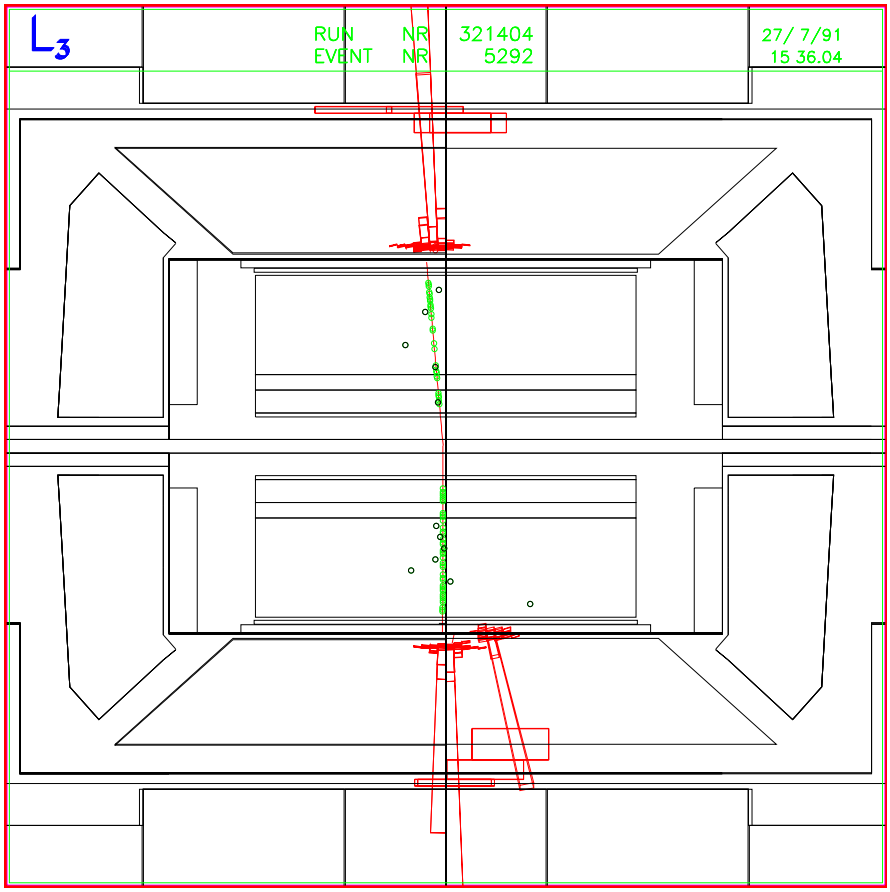
Selection of Tau Decays



$\tau^+\tau^- \longrightarrow \rho^+\pi^-\nu_\tau\nu_\tau$ candidate

$\hookrightarrow \pi^+\pi^0$

Selection of Tau Decays

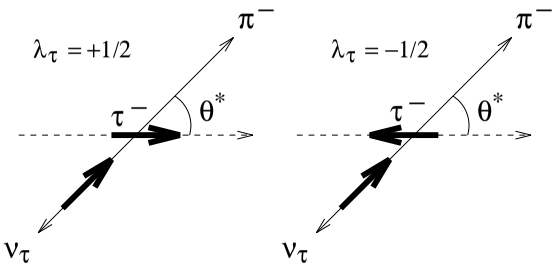


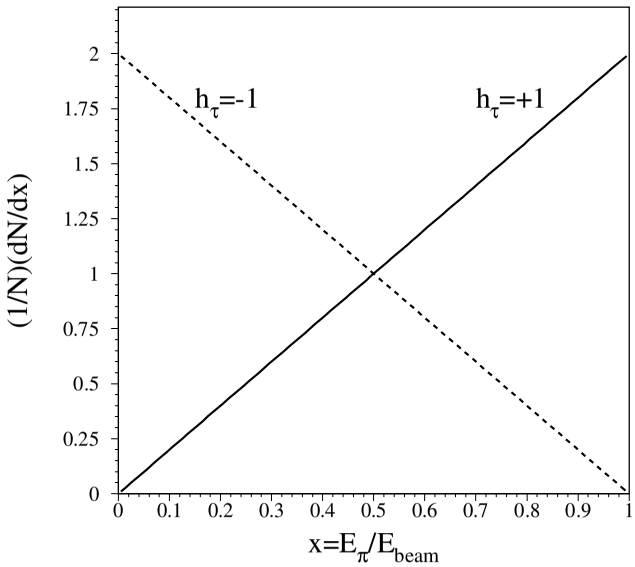
non-τ event $e^+e^-\gamma$

$\mathcal{P}_\tau$ Fitting

Fitting Method The kinematical distribution of the decay particles from τ depends on $\mathcal{P}_\tau$. In each τ decay channel, the combination of the positive and negative helicity MC histograms is fitted with the data histogram with the variables sensitive to τ polarization.

Example: τ to $\pi\nu$





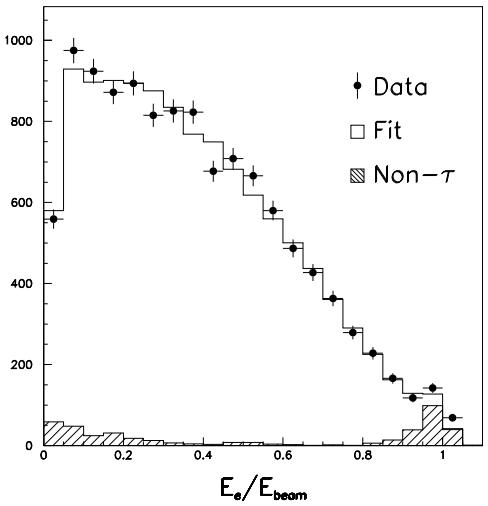
Sensitivity

Decay Channel	Variables	Sensitivity
$e\nu\nu, \mu\nu\nu$	E_l/E_{beam}	0.22
$\pi\nu$	E_π/E_{beam}	0.58
$\rho(\pi^-\pi^0)\nu$	$\cos\theta^*, \cos\psi^*$	0.49

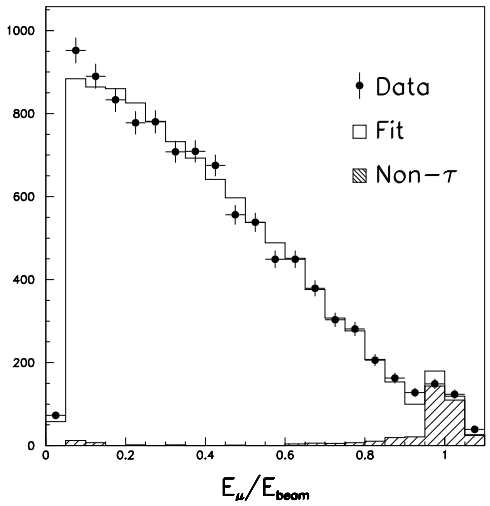
$\mathcal{P}_\tau$ Fitting

Fitted Result

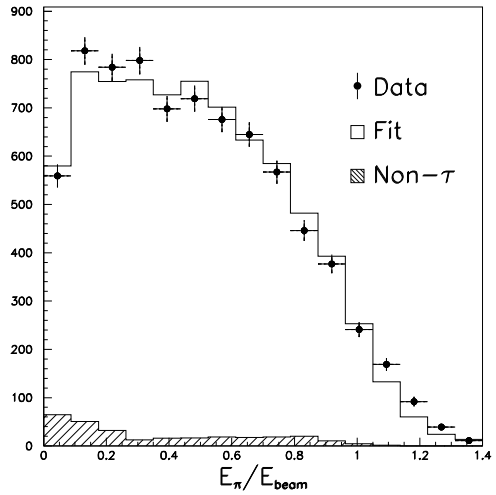
(a)



(b)



(c)



(a) $\tau \rightarrow e\nu\nu$ (b) $\tau \rightarrow \mu\nu\nu$

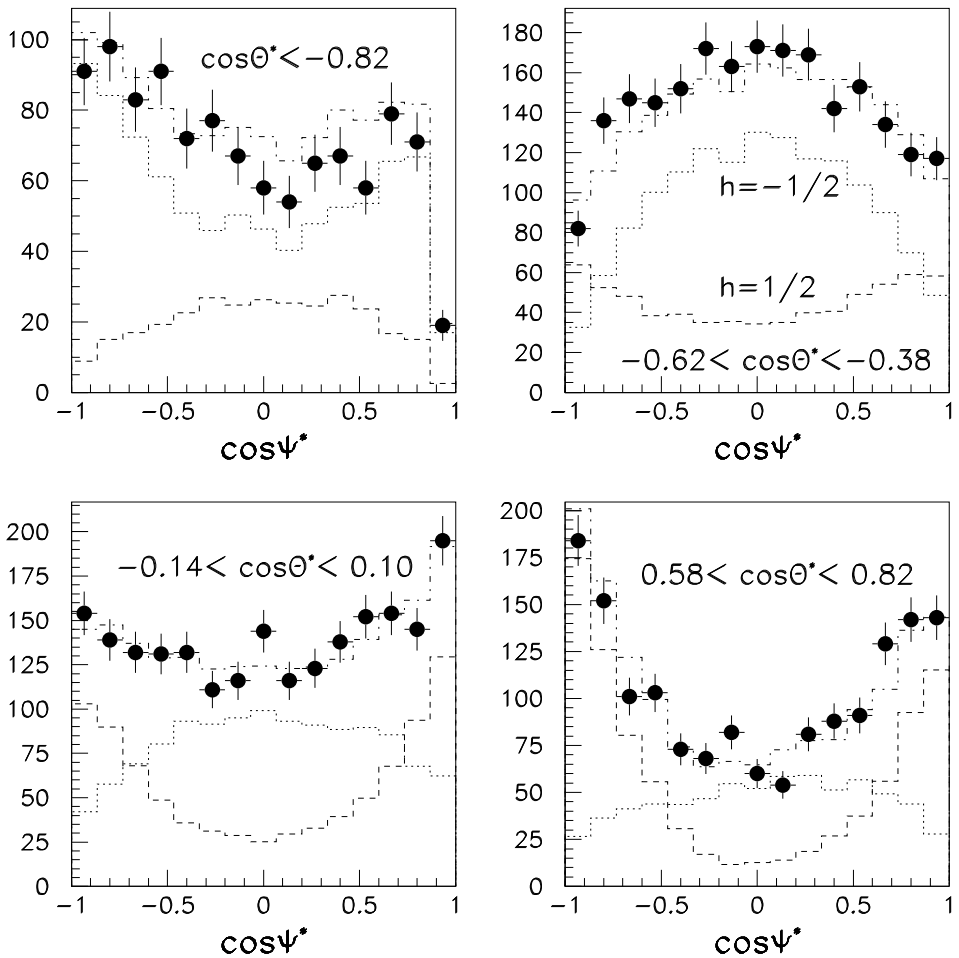
(c) $\tau \rightarrow \pi\nu$

$\mathcal{P}_\tau$ Fitting

Result for $\tau \to \rho\nu$ The ρ channel decay is described by two angles, the ρ direction at the τ rest frame and the π^- direction angle at the ρ rest frame.

$$\cos\theta^* = \frac{4m_\tau^2}{m_\tau^2 - m_\rho^2}\frac{E_{\pi 0} + E_{\pi -}}{E_{beam}} - \frac{m_\tau^2 + m_\rho^2}{m_\tau^2 - m_\rho^2} \sim \frac{E_\rho}{E_{beam}}$$

$$\cos\psi^* = \frac{m_\rho}{\sqrt{m_\rho^2 - 4m_\pi^2}}\frac{E_{\pi -} - E_{\pi 0}}{\left|\vec{P}_{\pi -} + \vec{P}_{\pi 0}\right|} \sim \frac{E_{\pi -} - E_{\pi 0}}{E_\rho}$$



$\mathcal{P}_\tau$ Fitting

L3 Result: 94 Preliminary From 58 000 τ pairs collected in 1994 at Z^0 peak, we get a preliminary measurement of the τ polarization in the barrel region of the L3 detector,

- $\mathcal{A}_\tau = 0.156 \pm 0.017 \pm 0.009$
- $\mathcal{A}_e = 0.155 \pm 0.025 \pm 0.005$

Systematic errors in $\mathcal{P}_\tau$ are coming from the selection procedure, background estimation, calibration, charge confusion and theoretical uncertainties.

The Analytical Way

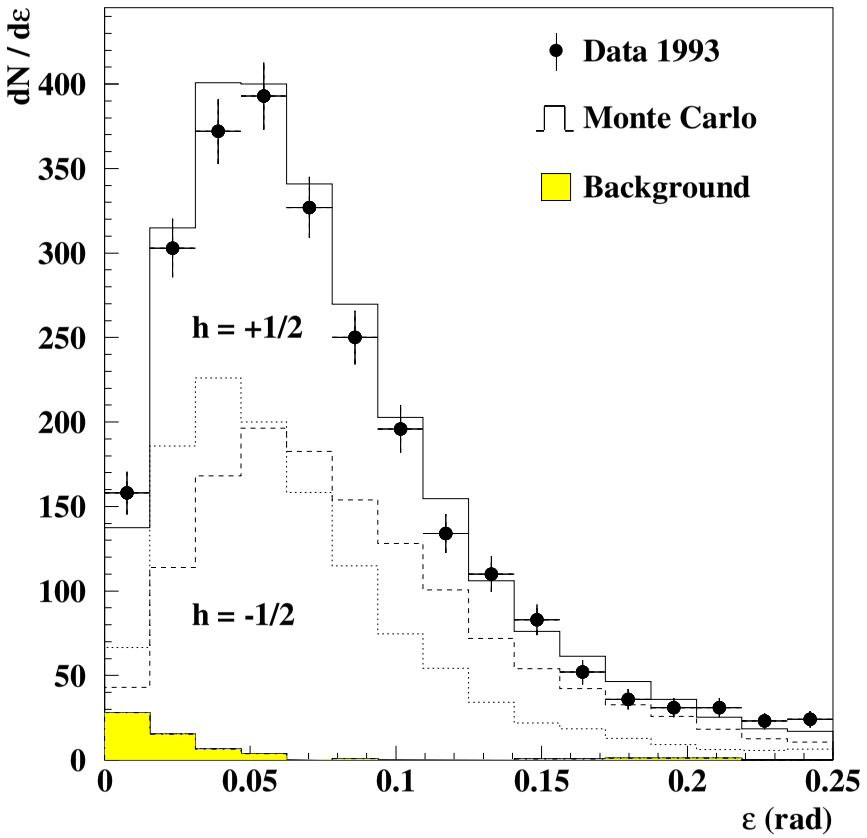
We have measured the polarization asymmetry ($\mathcal{A}_\tau$) using an independent method, based in the comparison of the energy spectra of τ decay products with analytical functions describing these spectra. While the standard one is based on the fit to Monte Carlo distributions. The result of the analytical method on the 91-94 data is comparable with the standard one.

$\mathcal{P}_\tau$ Fitting

The Acollinearity Method

From 38,000 Z $\longrightarrow \tau^+\tau^-(\gamma)$ events collected in 1993, the acollinearity between the τ decay products is used for an polarization measurement.

channel.. $\tau^+\tau^- \longrightarrow \pi^-\nu X$, $X = 1 - prong$

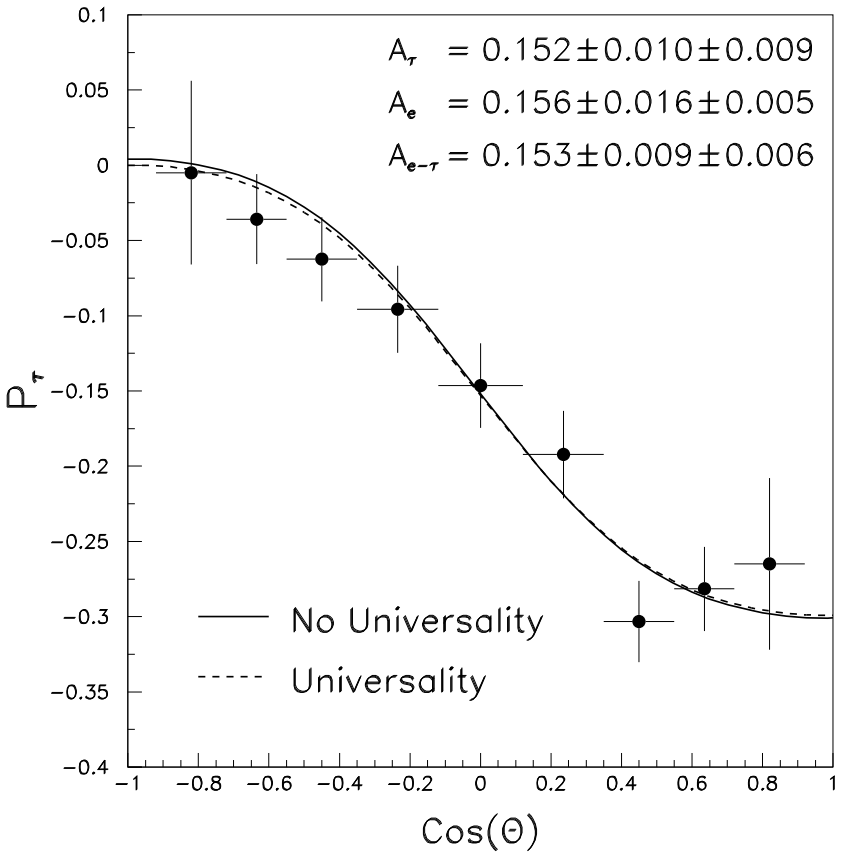


Conclusion

L3 Result: 1990-1994 Combined Preliminary

Combined with the measurement done on 1990-1993 data, we get

- $\mathcal{A}_\tau = 0.152 \pm 0.010 \pm 0.009$
- $\mathcal{A}_e = 0.156 \pm 0.016 \pm 0.005$

Assuming the lepton universality

- $\sin^2 \theta_w^{eff} = 0.2308 \pm 0.0013.$