Measurement of the Michel Parameters and the Chirality Parameter from τ Decays in $e^+e^- \to \tau^+\tau^-$

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Representing the
L3 collaboration

Outline

- Introduction
- Motivation and Method
- Detector Overview
- Analysis
- Results and Conclusion

Introduction

1991-93 integrated $\mathcal{L} = 69\ \mathrm{pb}^{-1}$

$\Downarrow$

selected 32 012 $Z \to \tau^+\tau^-(\gamma)$ events

with ≥ 1 τ decay identified as one of:

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

We measure:

- Michel parameters ρ, η, ξ, $\xi\delta$
- chirality parameter (ν_τ helicity) ξ_h
- average τ polarization $\mathcal{P}_\tau$

using:

- energy spectra in $\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau$ and $\tau^- \to \pi^-\nu_\tau$
- 'optimal' variable ω spectrum in $\tau^- \to \rho^-\nu_\tau$
- correlations when both τ decays identified

(N.B. The charge conjugate decays for the τ^+ are also used.)

(N.B. We do not distinguish between charged π and K in $\tau^- \to h^-\nu_\tau$ decays.)

- Studies of $\mu^- \to e^- \bar{\nu}_e \nu_\mu$ support the Standard Model (SM) V-A structure of the weak charged current:

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

	PDG 94	V−A prediction
ρ	0.7518 ± 0.0026	0.75
η	-0.007 ± 0.013	0.
ξ	1.0027 ± 0.0085	1.0
$\xi\delta$	0.751 ± 0.007	0.75

(Other Michel parameters not easily measured in $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$.)

$\Rightarrow$ Leptonic τ decays allow independent study of charged current

$\Rightarrow$ Large τ mass allows greater sensitivity to new physics whose couplings are proportional to mass

$\Rightarrow$ Non-zero $\mathcal{P}_\tau$ in $Z \to \tau^+\tau^-$ facilitates ξ, $\xi\delta$ and ξ_h measurement

$\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ Decays

General matrix element :

$$\mathcal{M} = \frac{4G_F}{\sqrt{2}} \sum_{\substack{\gamma=S,V,T \\ \lambda,\iota=R,L}} g^\gamma_{\lambda\iota} < \bar{l}_\lambda|\Gamma^\gamma|(\nu_l)_n >< (\bar{\nu}_\tau)_m|\Gamma_\gamma|\tau_\iota >$$

$\Rightarrow$ Michel parameters are combinations of coupling constants $g^\gamma_{\lambda\iota}$

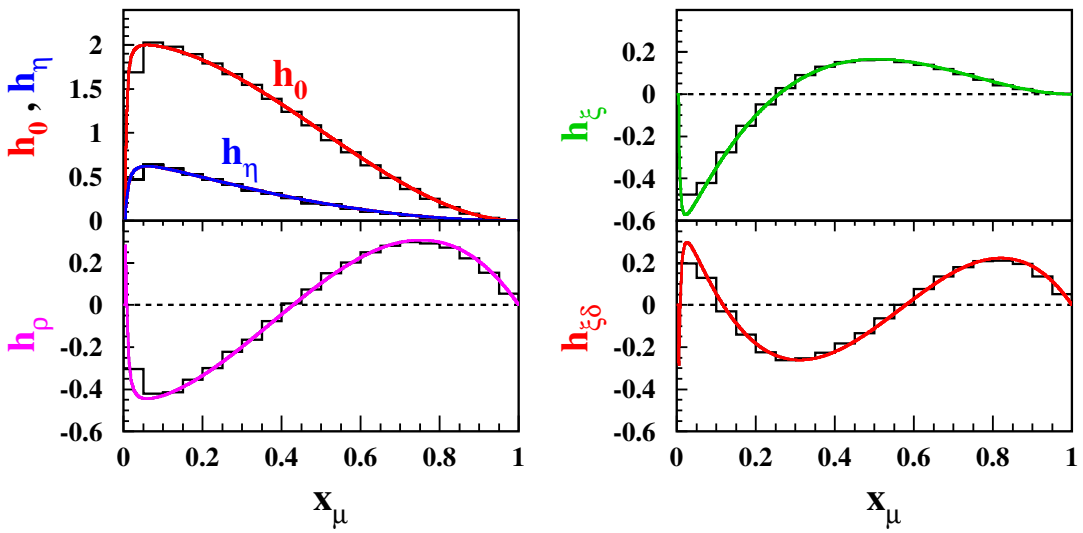
In SM, $g^V_{LL} = 1$ and other couplings $= 0$

$$\Rightarrow \rho = 3/4,\ \eta = 0,\ \xi = 1,\ \xi\delta = 3/4$$

ℓ^- energy spectrum ($x_\ell = E_\ell/E_\tau \approx E_\ell/E_{beam}$) :

$$\frac{1}{\Gamma}\frac{d\Gamma}{dx_\ell} = h^\ell_0(x_\ell) + \eta h^\ell_\eta(x_\ell) + \rho h^\ell_\rho(x_\ell) - \mathcal{P}_\tau\,[\xi h^\ell_\xi(x_\ell) + \xi\delta h^\ell_{\xi\delta}(x_\ell)]$$
$$= \mathrm{H}^\ell_0(x_\ell) - \mathcal{P}_\tau\,\mathrm{H}^\ell_1(x_\ell)$$

$\tau \to \mu\bar{\nu}\nu$



Born level with radiative corrections

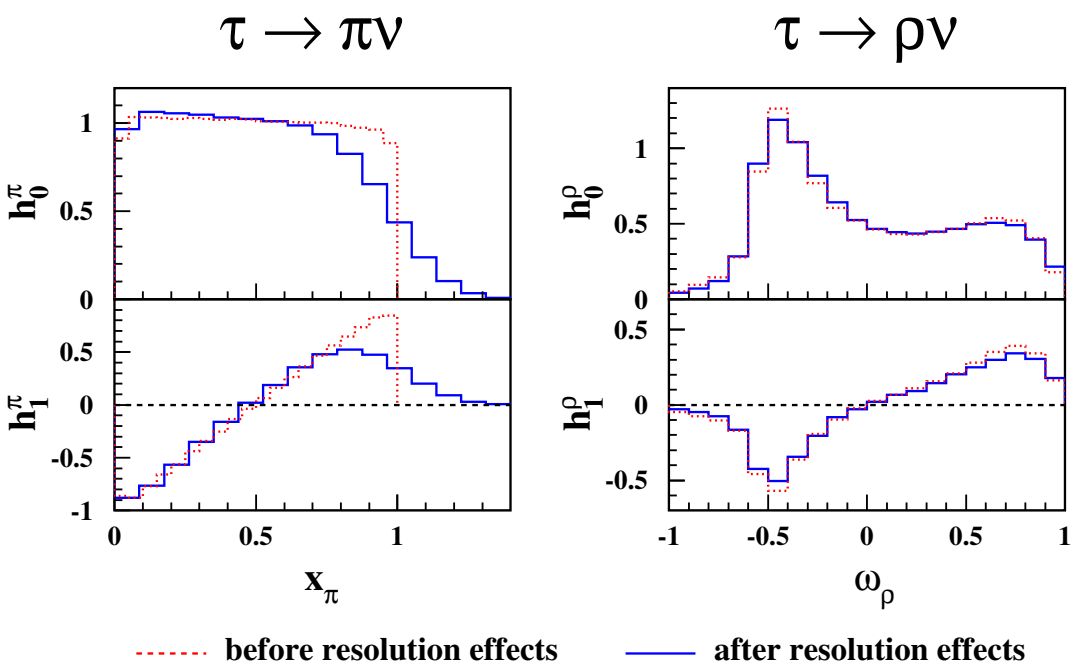
$\tau^- \to h^- \nu_\tau$ Decays

- Assume only V or A interactions in $\tau^- \to h^- \nu_\tau$ $(h = \pi^-, \rho^-)$
- Chirality parameter ξ_h = 2 * average ν_τ helicity
- In SM, neutrinos are left-handed $\Rightarrow$ $\xi_h = -1$

Decay spectra of h^- :

$$\frac{1}{\Gamma}\frac{d\Gamma(\tau^- \to h^- \nu_\tau)}{dx_h} = h_0^h(x_h) - \mathcal{P}_\tau \xi_h h_1^h(x_h)$$
$$= \mathrm{H}_0^h(x_h) - \mathcal{P}_\tau \mathrm{H}_1^h(x_h)$$

- $\tau^- \to \pi^- \nu_\tau$: $x_\pi = E_\pi / E_\tau \approx E_\pi / E_{beam}$
- $\tau^- \to \rho^- \nu_\tau$: $x_\rho \to \omega$ = function of π^- and π^o energies and decay angles in $\rho^- \to \pi^- \pi^o$



$\tau^+\tau^-$ Decay Correlations

- Disentangle ξ, $\xi\delta$ and ξ_h from $\mathcal{P}_\tau$ using correlations

- In $Z \to \tau^+\tau^-$, τ helicities opposite up to $\mathcal{O}\left(\frac{m_\tau^2}{M_Z^2}\right) \sim 10^{-4}$

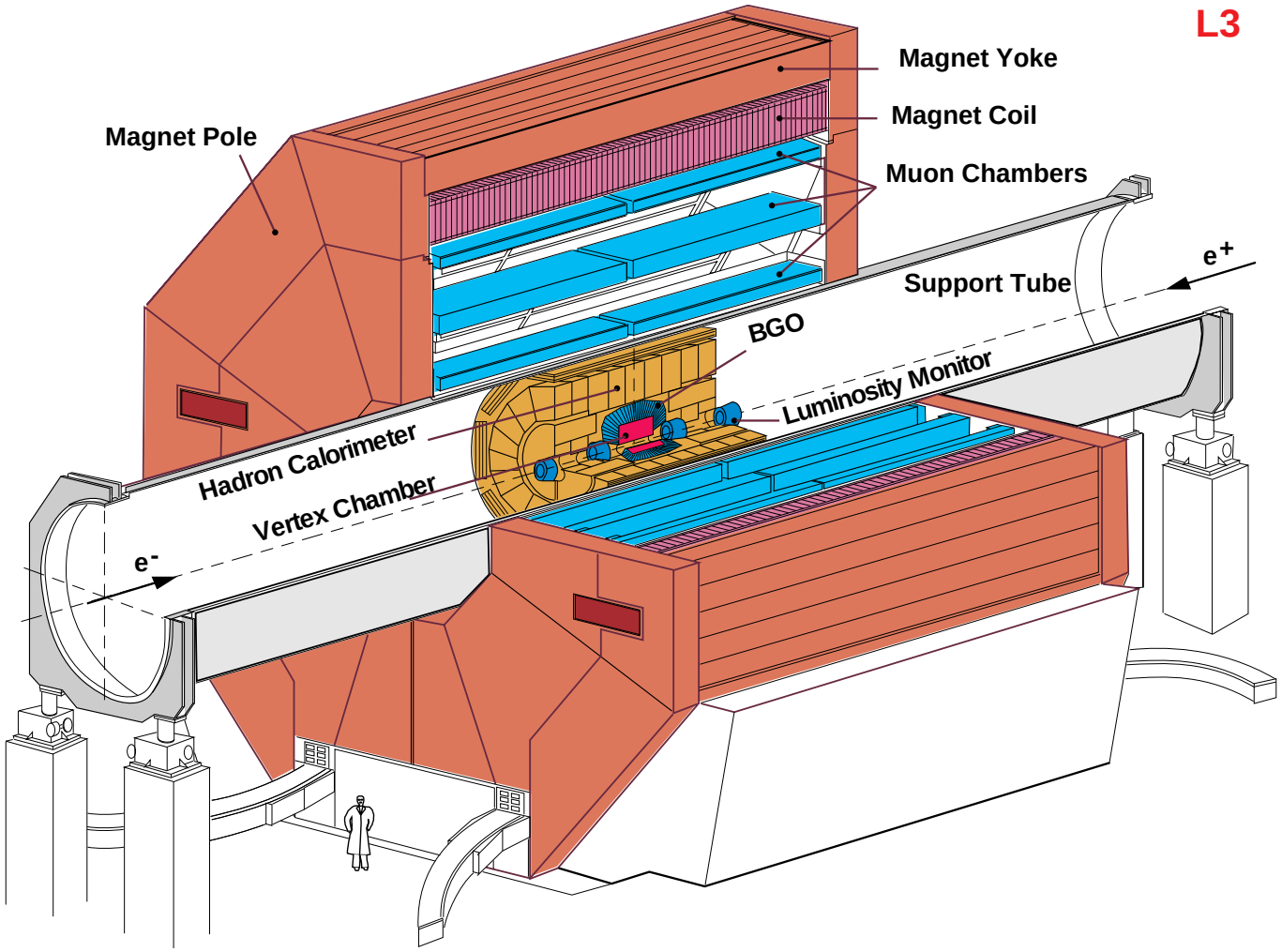
$$\Rightarrow \tau_L^+ \tau_R^- \quad \text{or} \quad \tau_R^+ \tau_L^-$$

- Joint decay distribution
  for $Z \to \tau^+\tau^- \to A^\pm B^\mp n\nu$ $(2 \le n \le 4)$:

$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dx_A dx_B} = \mathrm{H}_0^A(x_A)\mathrm{H}_0^B(x_B) + \mathrm{H}_1^A(x_A)\mathrm{H}_1^B(x_B) - \mathcal{P}_\tau\left[\mathrm{H}_1^A(x_A)\mathrm{H}_0^B(x_B) + \mathrm{H}_0^A(x_A)\mathrm{H}_1^B(x_B)\right]$$

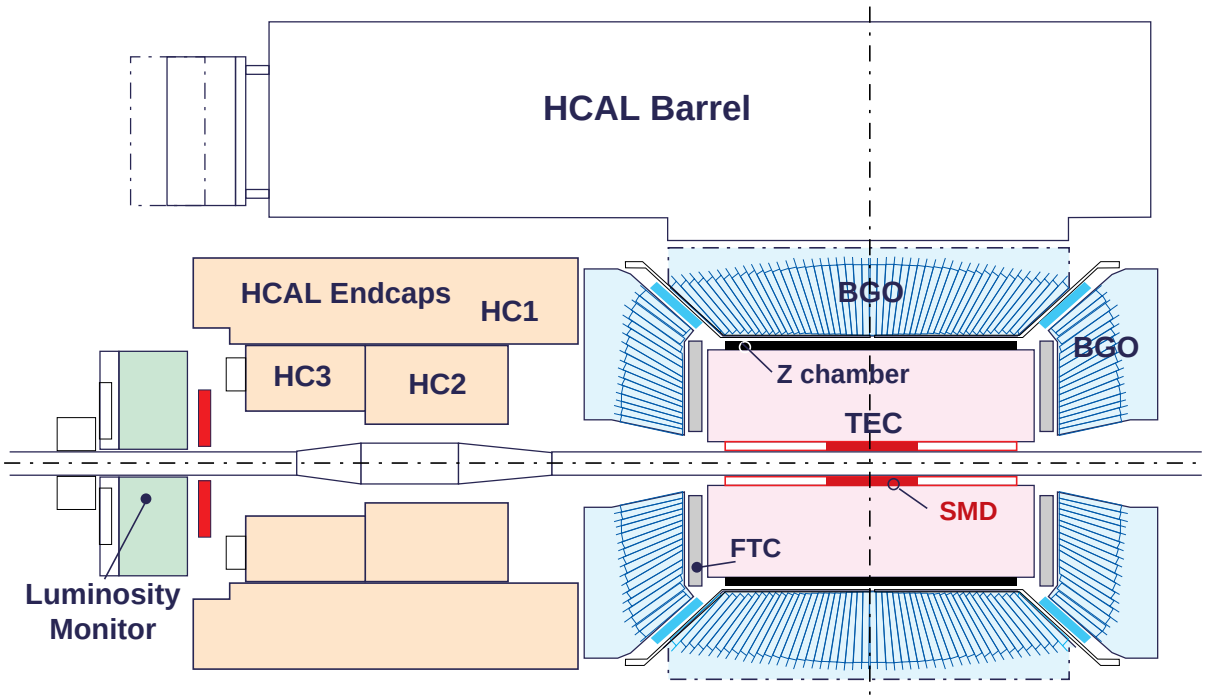
where A, B = e, μ, π or ρ

The L3 Detector

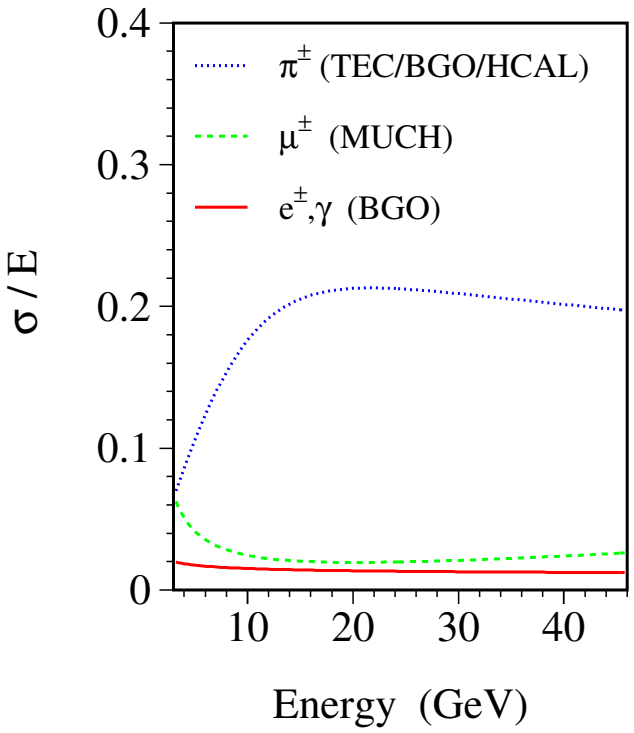


- 12 m diameter solenoid magnet = 0.5 T field $\parallel$ beam axis
- muon spectrometer (MUCH) = 3 layers of multiwire drift chambers
- hadronic calorimeter (HCAL) = U/wire chamber layers
- EM calorimeter = Bismuth Germanium Oxide (BGO) crystals
- Time Expansion Chamber (TEC) = tracking (r, ϕ) coordinates
- Z Chamber = tracking z coordinates

The L3 Detector



Energy Resolution



Event Selection

Data sample: 1991-93 integrated $\mathcal{L} = 69\ \mathrm{pb}^{-1}$

- **Obtain a clean sample of leptonic Z decays**
- **Select events with thrust axis in barrel $\Rightarrow |\cos\theta| < 0.7$**
- **Identify particles in each hemisphere independently**
- **Retain events with ≥ 1 identified τ decays and classify as:**
  - ▷ $\mathrm{e}X$, μX, πX, ρX (X = unidentified τ decay)
  - ▷ ee, eμ, eπ, eρ, $\mu\pi$, $\mu\rho$, $\pi\pi$, $\pi\rho$, $\rho\rho$
  - $\Rightarrow$ $\mu\mu$ final state not used due to high background from $\mathrm{Z} \to \mu^+\mu^-$
- **Apply additional cuts to reduce non-τ background**

$\Rightarrow$ **Selected 32012 events**

Particle Identification

Electron identification:

- BGO bump consistent in position and energy with TEC track
- HCAL energy < 3 GeV consistent with tail of EM shower

Muon identification:

- tracks in 3 planes of MUCH pointing to interaction point
- minimum ionizing particle signature in calorimeters

Neutral pion candidate criteria:

- 2 distinct neutral clusters with $|m_{\gamma\gamma} - m_{\pi^o}| < 40$ MeV
- single neutral cluster > 1 GeV with transverse profile:
  - ▷ single electromagnetic shower
  - ▷ 2 merged showers with $|m_{\gamma\gamma} - m_{\pi^o}| < 50$ MeV

Charged pion identification:

- no π^o candidates and no neutral cluster > 500 MeV
- energy of non-EM shower consistent with track momentum

Rho candidate criteria:

- exactly one π^o candidate in hemisphere
- 0.45 GeV $< (\pi^-\pi^o)$ invariant mass < 1.20 GeV
- $(\pi^-\pi^o)$ energy > 5 GeV

Efficiencies and Backgrounds

- selection efficiencies obtained from MC
- background from other τ decays estimated from MC
- spectral shapes from non-τ background from MC but normalized to data

Channel	Events	ε (%) in 4π	Bkgd. (%)	
			τ	non-τ
e X	5891	61.8	1.1	6.2
μ X	3870	42.5	0.6	5.6
π X	3733	57.0	10.3	2.3
ρ X	6830	52.5	13.0	0.4
e e	1005	34.4	2.0	3.1
e μ	1322	26.1	1.9	0.5
e π	1092	30.2	9.7	1.0
e ρ	2269	30.0	13.5	0.2
μ π	802	25.2	10.8	5.6
μ ρ	1743	24.5	13.3	3.2
π π	371	26.3	15.3	2.5
π ρ	1460	26.0	20.2	0.2
ρ ρ	1624	25.7	24.0	0.2
Total	32012			

Fit Procedure

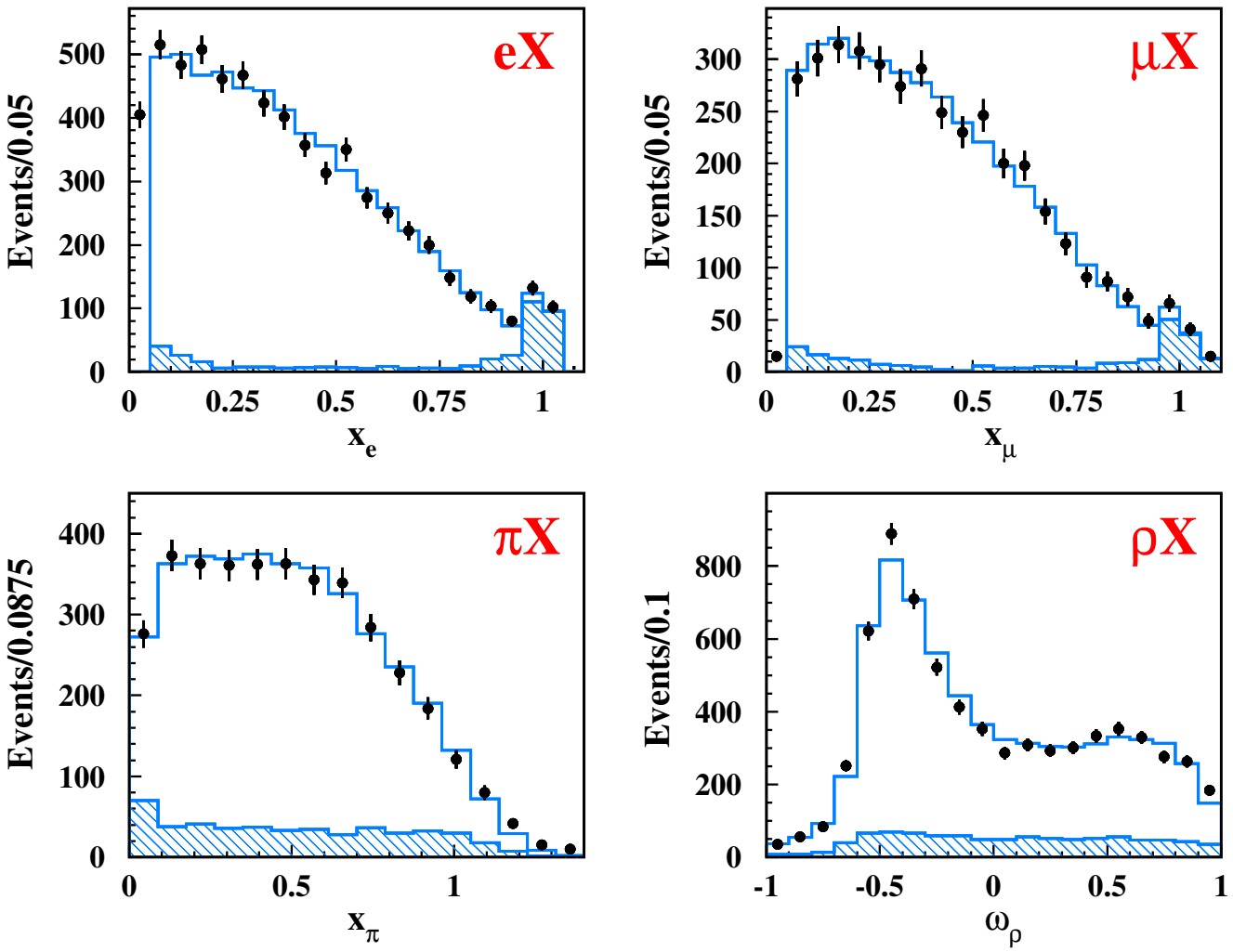
Construct kinematic h functions from Monte Carlo

Convolute spectra with L3 resolution functions

Add backgrounds

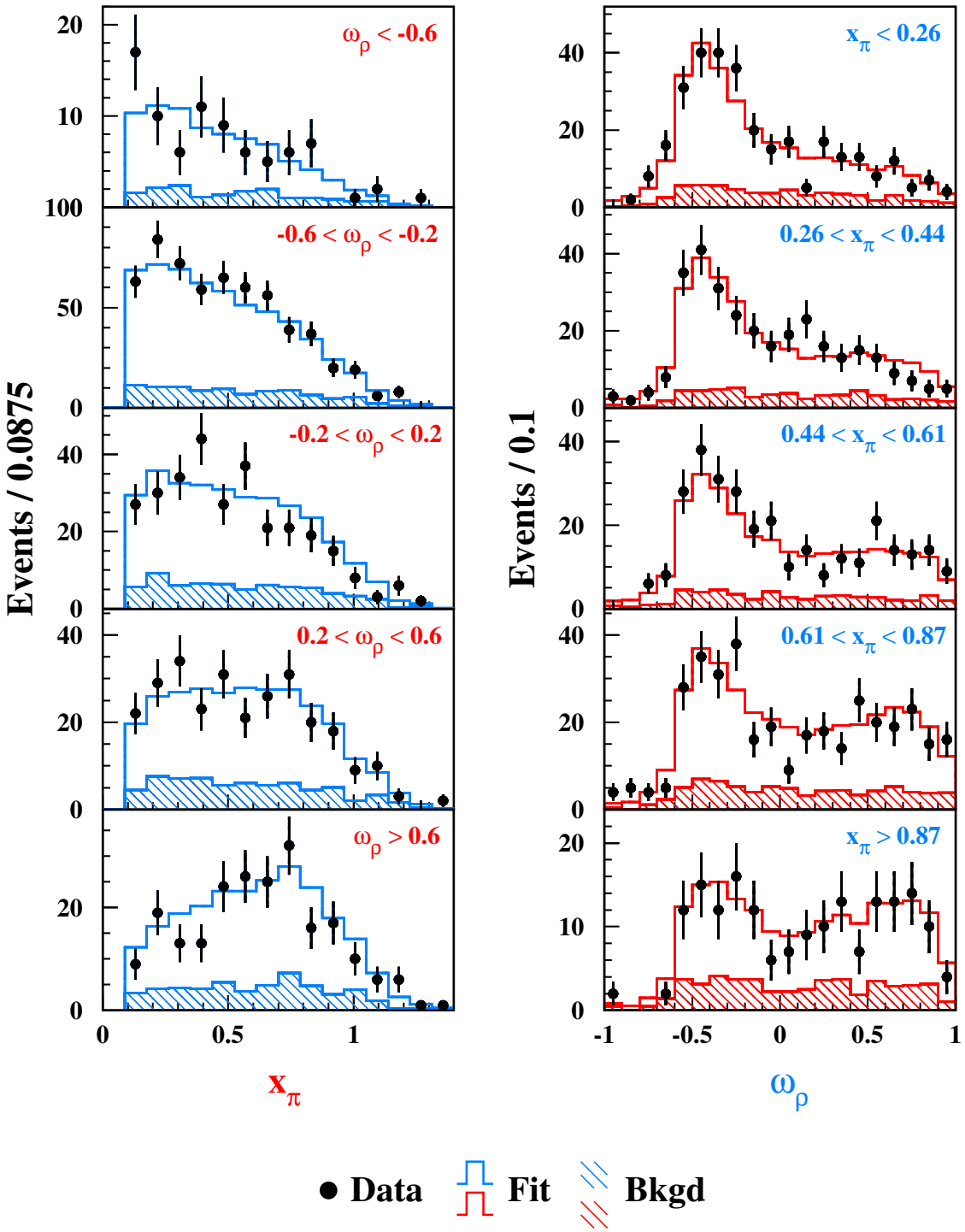
Use binned maximum likelihood method to simultaneously fit one dimensional spectra and joint decay distributions

Single Sided Spectra



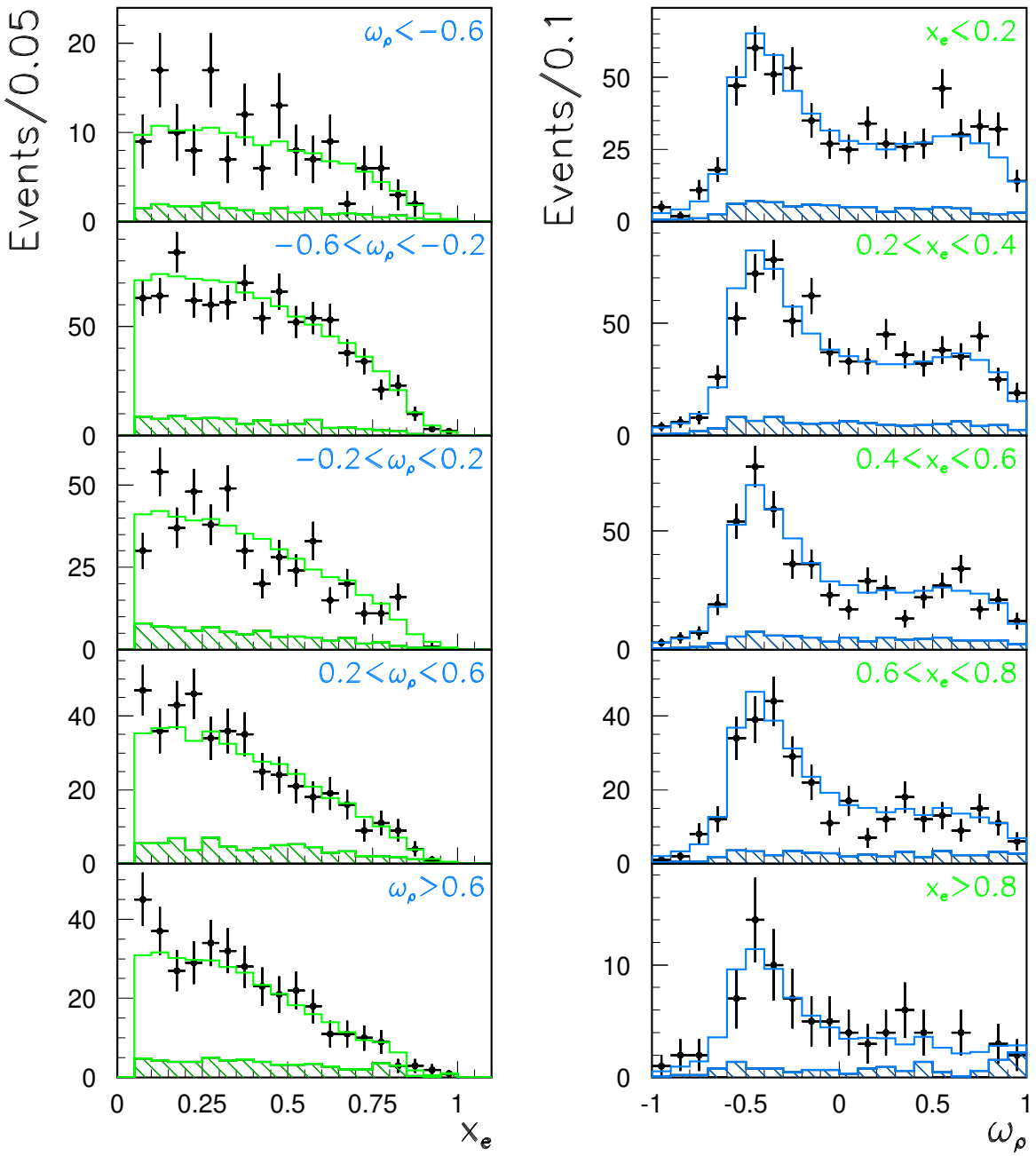
$\rho\pi$ Decay Distribution

$$Z \rightarrow \tau^+\tau^- \rightarrow (\pi\nu)(\rho\nu)$$



eρ Decay Distribution

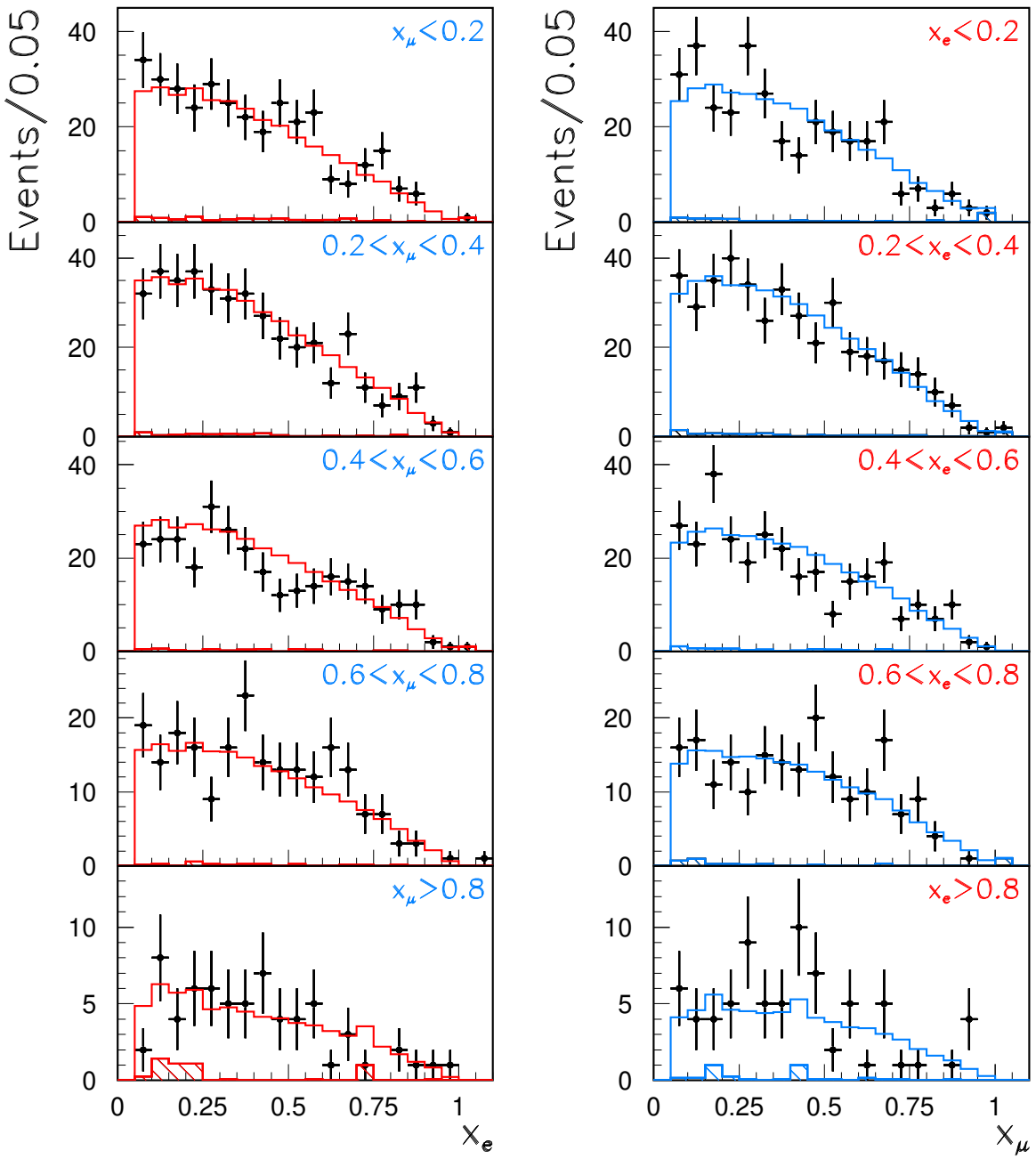
$$Z^0 \rightarrow \tau^+\tau^- \rightarrow (e\nu\nu)(\rho\nu)$$



● **Data** **Fit** **Bkgd**

$e\mu$ Decay Distribution

$$Z^0 \rightarrow \tau^+\tau^- \rightarrow (e\nu\nu)(\mu\nu\nu)$$



● **Data** **Fit** **Bkgd**

Systematic Uncertainties

Main sources of systematic uncertainties:

- event selection
- uncertainties in backgrounds
- calibration of subdetectors
- Monte Carlo statistics

These sources are considered to be independent.

To estimate systematic errors, vary:

- cuts for event selection
- fractions of τ and non-τ background
- energy calibrations of subdetectors
- acceptance values for each channel

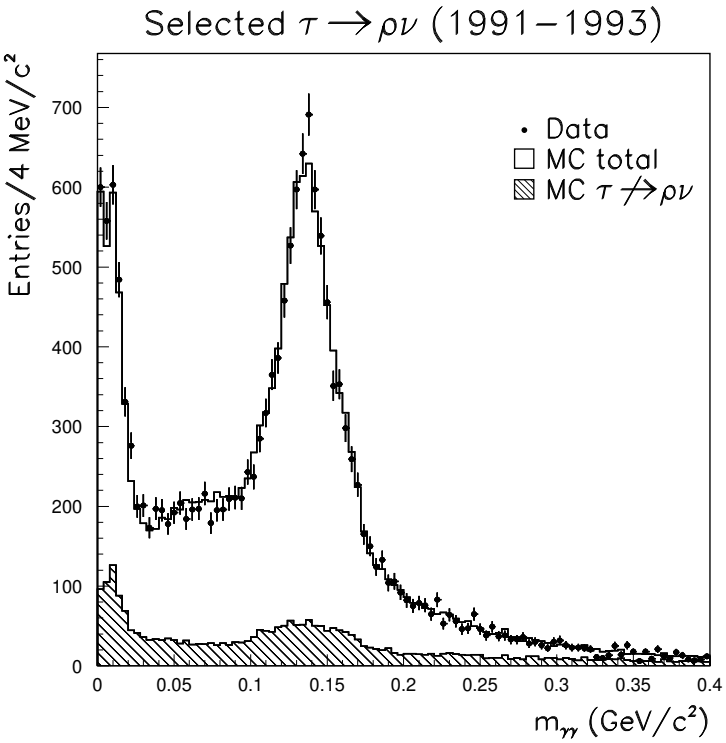
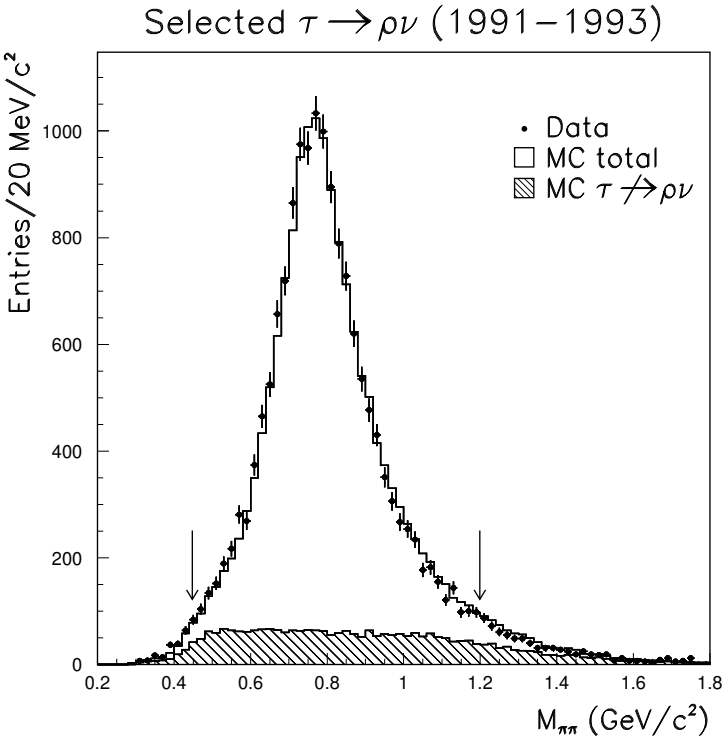
Source	$\Delta\rho$	$\Delta\eta$	$\Delta\xi$	$\Delta\xi\delta$	$\Delta\xi_h$	$\Delta\mathcal{P}_\tau$
selection	0.007	0.01	0.02	0.01	0.007	0.006
background	0.011	0.03	0.05	0.04	0.004	0.003
calibration	0.026	0.08	0.04	0.03	0.006	0.009
MC statistics	0.012	0.06	0.02	0.04	0.003	0.005
Total	0.031	0.11	0.07	0.06	0.011	0.012

Results

	this L3 measurement	V−A
ρ	$0.794 \pm 0.039 \pm 0.034$	0.75
η	$0.25 \pm 0.17 \pm 0.11$	0.
ξ	$0.94 \pm 0.21 \pm 0.07$	1.0
$\xi\delta$	$0.81 \pm 0.14 \pm 0.06$	0.75
ξ_h	$-0.970 \pm 0.053 \pm 0.011$	−1.0
$\mathcal{P}_\tau$	$-0.154 \pm 0.018 \pm 0.014$	

$\Rightarrow$ supports V-A structure of charged current in $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$

$\Rightarrow$ consistent with only left-handed neutrinos in $\tau^- \to h^- \nu_\tau$

No evidence for new physics

π^o and ρ Mass Distributions