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

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Representing the
L3 collaboration

Introduction

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

$$\Downarrow$$

selected 32 012 $\mathrm{Z} \to \tau^+\tau^-(\gamma)$ events
with ≥ 1 τ decay identified as one of:

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

We measure the Michel parameters ρ, η, ξ and $\xi\delta$, the chirality parameter ξ_h, and the τ polarization $\mathcal{P}_\tau$ using:

- energy spectra in $\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau$ and $\tau^- \to \pi^-\nu_\tau$
- energy spectrum and decay angle 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.)

- **High precision studies of muon decay 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 and $\xi\delta$ measurement**

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

$\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ decays described by general matrix element:

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

The Michel parameters depend on the complex coupling constants $g^\gamma_{\lambda\iota}$.

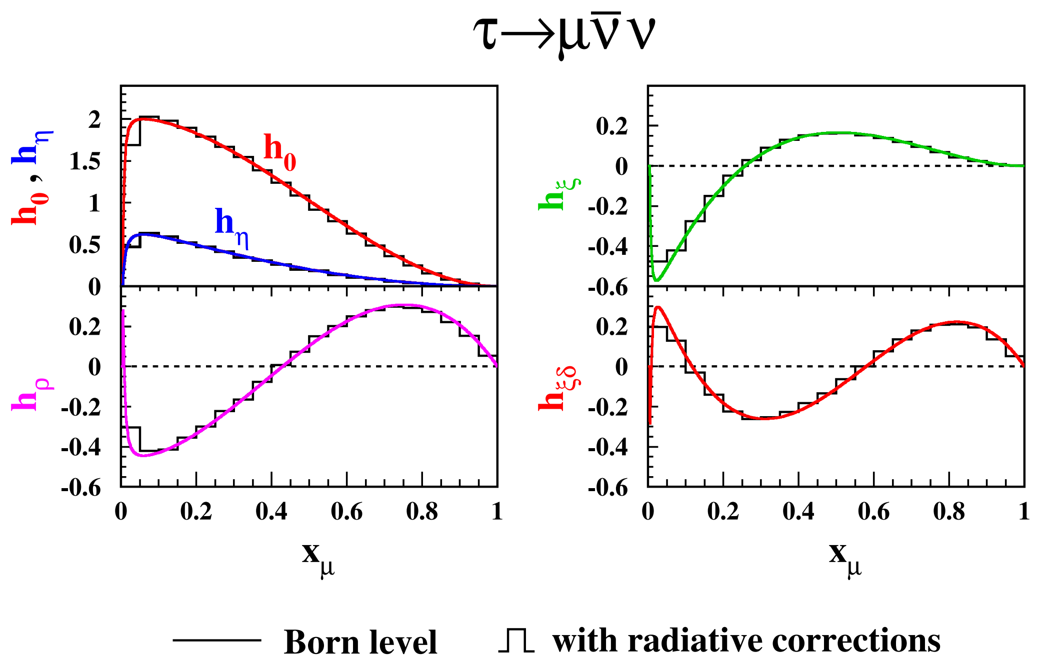
In SM, $g^V_{LL} = 1$ and other couplings $= 0$

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

Decay spectrum of charged lepton:

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

where $x_\ell = E_\ell / E_\tau \approx E_\ell / E_{beam}$. The kinematic h^ℓ_i functions look like:



The spectra for $\tau^- \to e^- \bar{\nu}_e \nu_\tau$ look similar except for h_η, which is suppressed by a factor of m_e/m_μ.

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

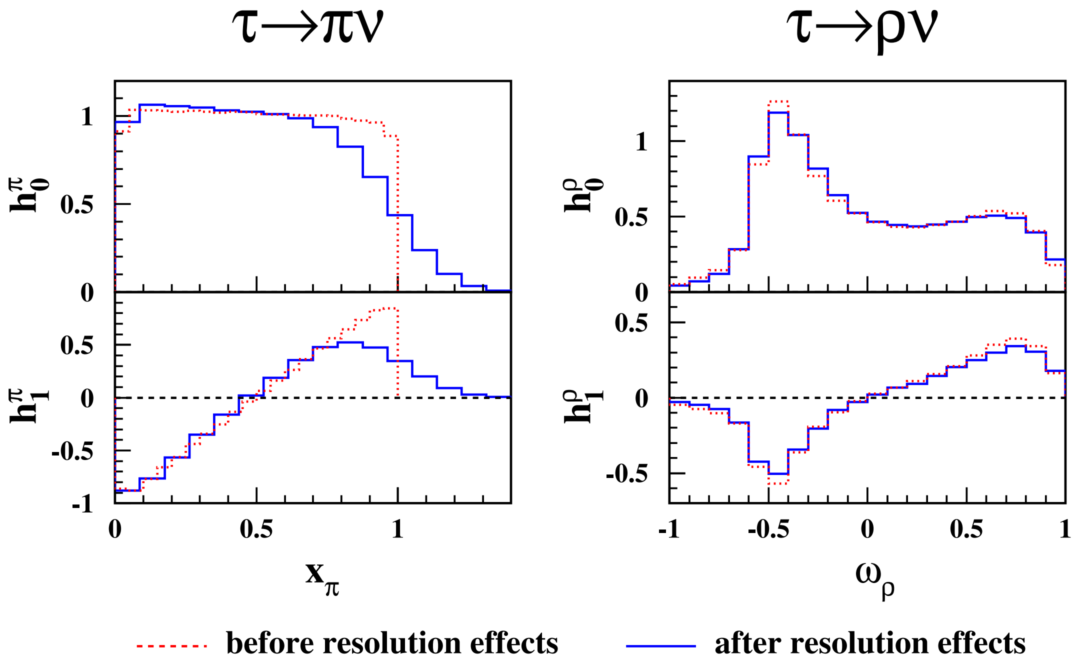
Decay spectra of h^- :

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

- For $\tau^- \to \pi^- \nu_\tau$: $x_\pi = E_\pi / E_\tau \approx E_\pi / E_{beam}$

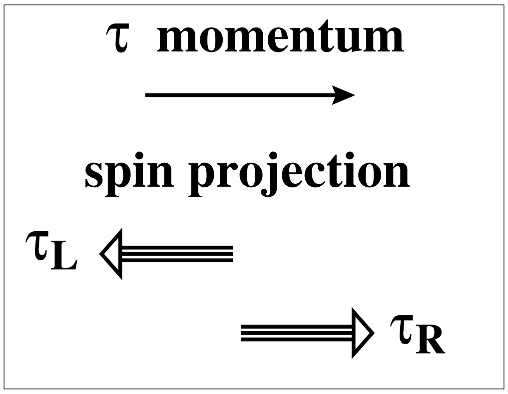
- For $\tau^- \to \rho^- \nu_\tau$: $x_\rho \to \omega =$ complicated function of π^- and π^o energies and decay angles in $\rho^- \to \pi^- \pi^o$

Kinematic h functions for $\tau^- \to h^- \nu_\tau$:



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

In $Z \rightarrow \tau^+\tau^-$, τ^+ and τ^- helicities are opposite up to $\mathcal{O}(m_\tau^2/m_Z^2)$. $\Rightarrow$ τ_L^-, τ_R^+ or τ_R^-, τ_L^+



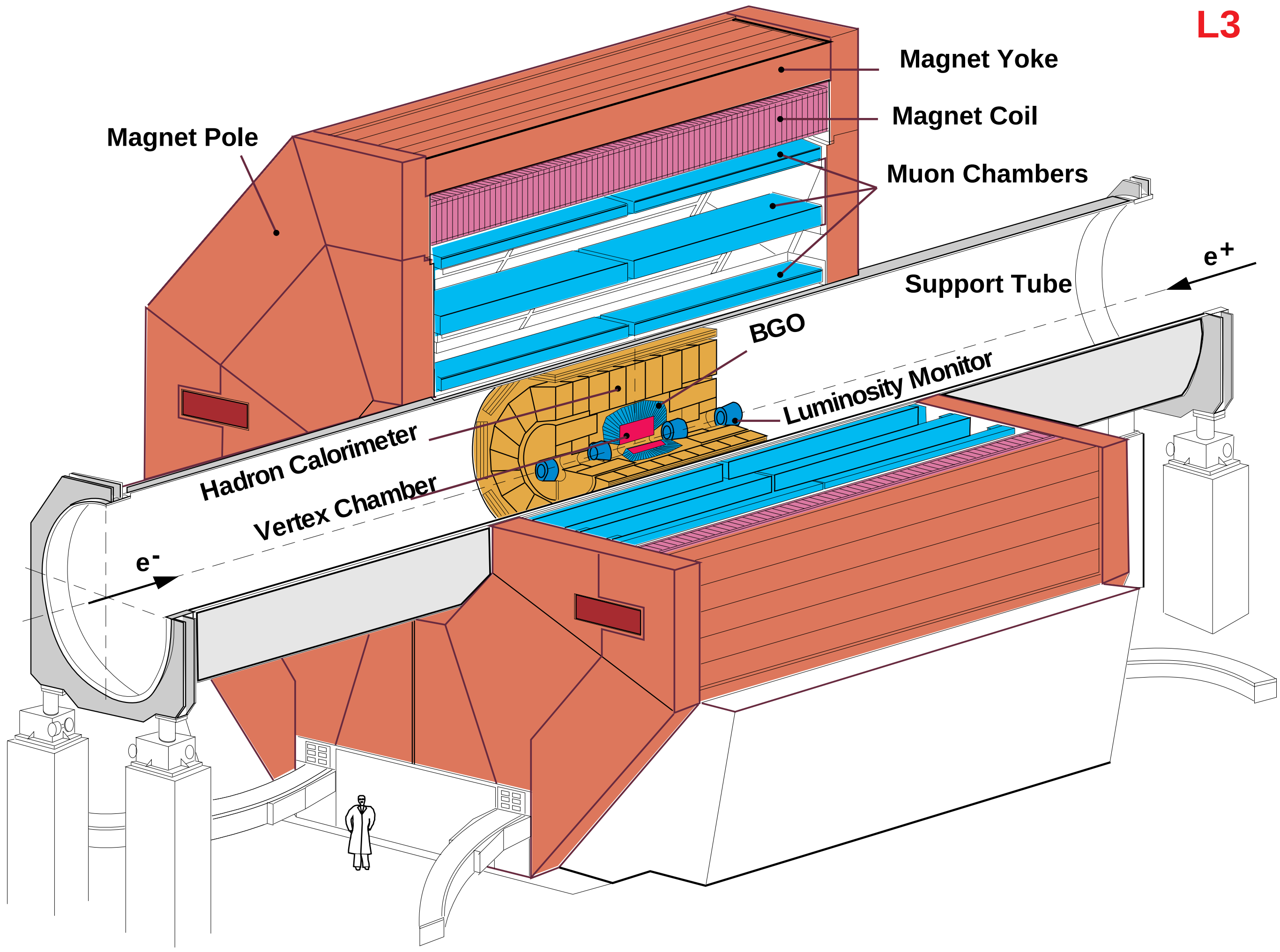
$$\mathcal{P}_{\tau^-} = -\mathcal{P}_{\tau^+} \equiv \mathcal{P}_\tau = \frac{N_R - N_L}{N_R + N_L}$$

When both τ decays identified, the joint decay distribution for $e^+e^- \rightarrow \tau^+\tau^- \rightarrow A^\pm B^\mp n\nu$ $(n = 2, 3, 4)$:

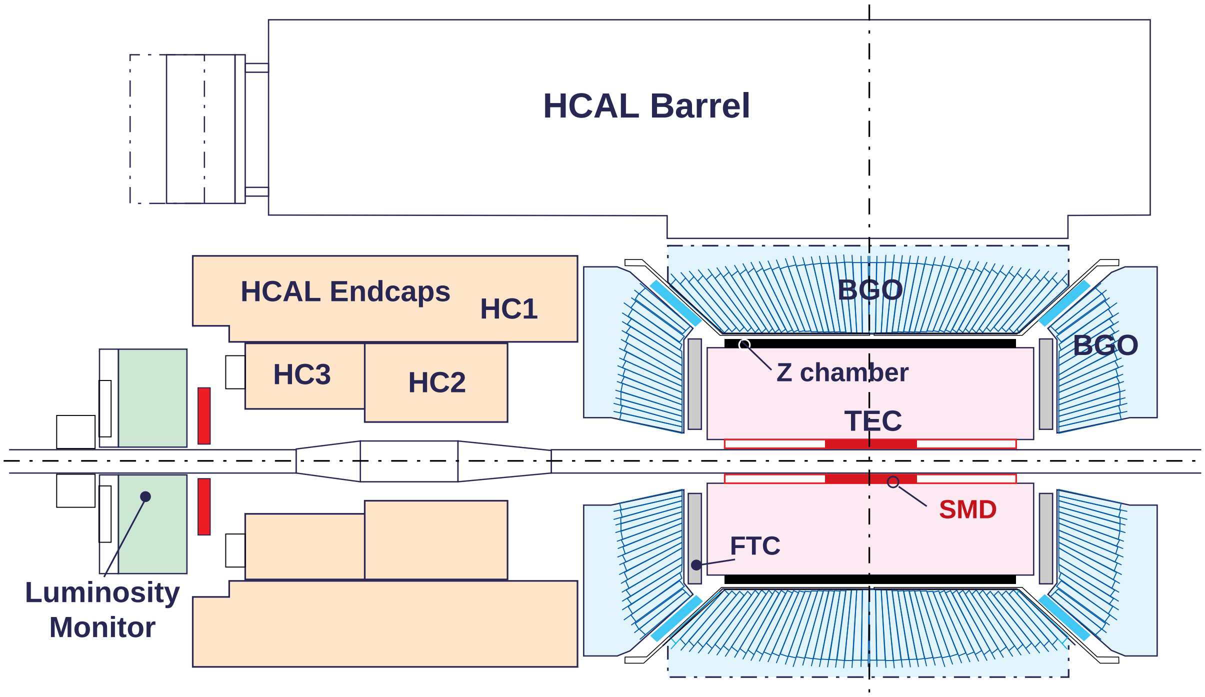
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{dx_A dx_B} = \mathrm{H}_0^{(A)}(x_A)\mathrm{H}_0^{(B)}(x_B) + \mathrm{H}_1^{(A)}(x_A)\mathrm{H}_1^{(B)}(x_B)$$
$$- \mathcal{P}_\tau \left[\mathrm{H}_1^{(A)}(x_A)\mathrm{H}_0^{(B)}(x_B) + \mathrm{H}_0^{(A)}(x_A)\mathrm{H}_1^{(B)}(x_B)\right]$$

where A, B $=$ e, μ, π or ρ

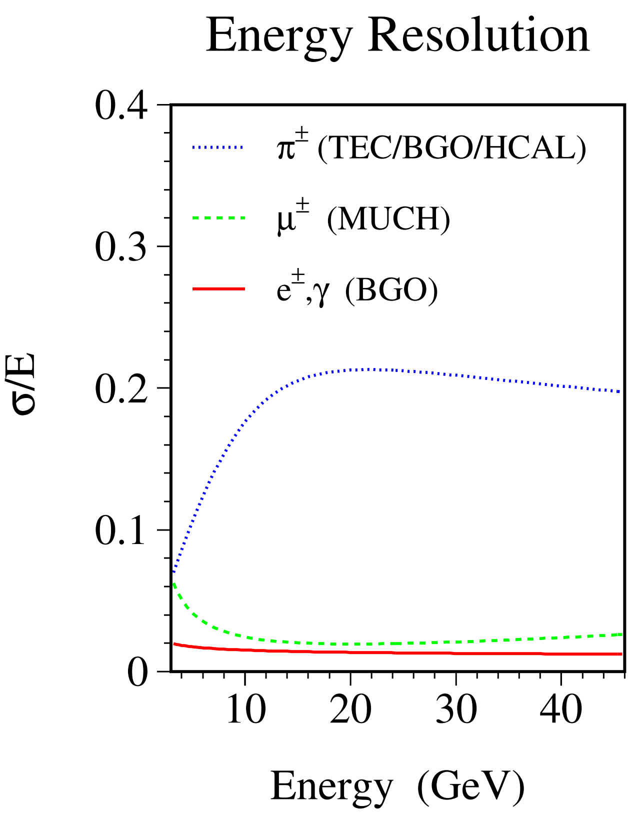
The L3 Detector



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



HCAL Barrel
HCAL Endcaps
HC1
HC3
HC2
BGO
BGO
Z chamber
TEC
SMD
FTC
Luminosity Monitor



Energy Resolution
0.4
0.3
0.2
0.1
0
σ/E
π± (TEC/BGO/HCAL)
μ± (MUCH)
e±,γ (BGO)
10
20
30
40
Energy (GeV)

Event Selection

- **Obtain a clean sample of leptonic Z decays**

$\Rightarrow$ **Restrict selection to events within barrel, $|\cos\theta| < 0.7$**

- **Identify particles in each hemisphere (separated by plane $\perp$ to thrust axis) independently**

- **Retain events with ≥ 1 identified τ decays and classify as:**

  ▷ **eX, 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 Z$\rightarrow \mu^+\mu^-$

- **Apply additional cuts to further reduce non-τ background**

Particle Identification

Electron identification:

- energy deposit in BGO consistent in position and energy with TEC track
- any energy deposit in HCAL must be consistent with tail of electromagnetic shower and less than 3 GeV

Muon identification:

- tracks in 3 planes of muon spectrometer pointing to the 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
- consistent track momentum and energy deposit in the calorimeters

Rho candidate criteria:

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

Efficiencies and Backgrounds

- selection efficiencies and backgrounds from other τ decays are estimated from Monte Carlo

- spectral shapes from non-τ background are estimated from MC and normalized according to data

Channel	Events	ε (%) in 4π	Bkg. (%) τ	Bkg. (%) 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			

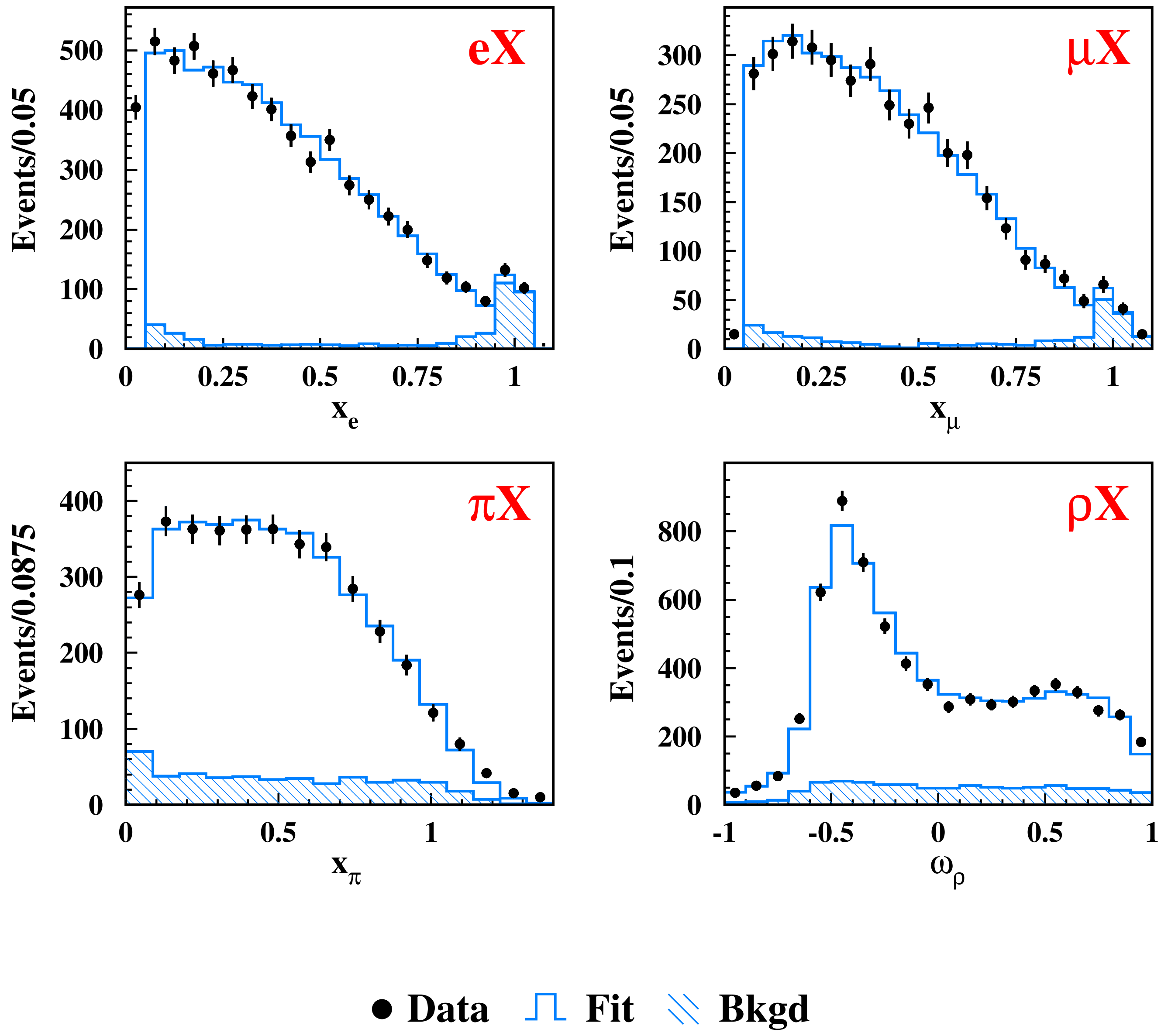
Fit Procedure

- **Construct kinematic h functions from Monte Carlo**

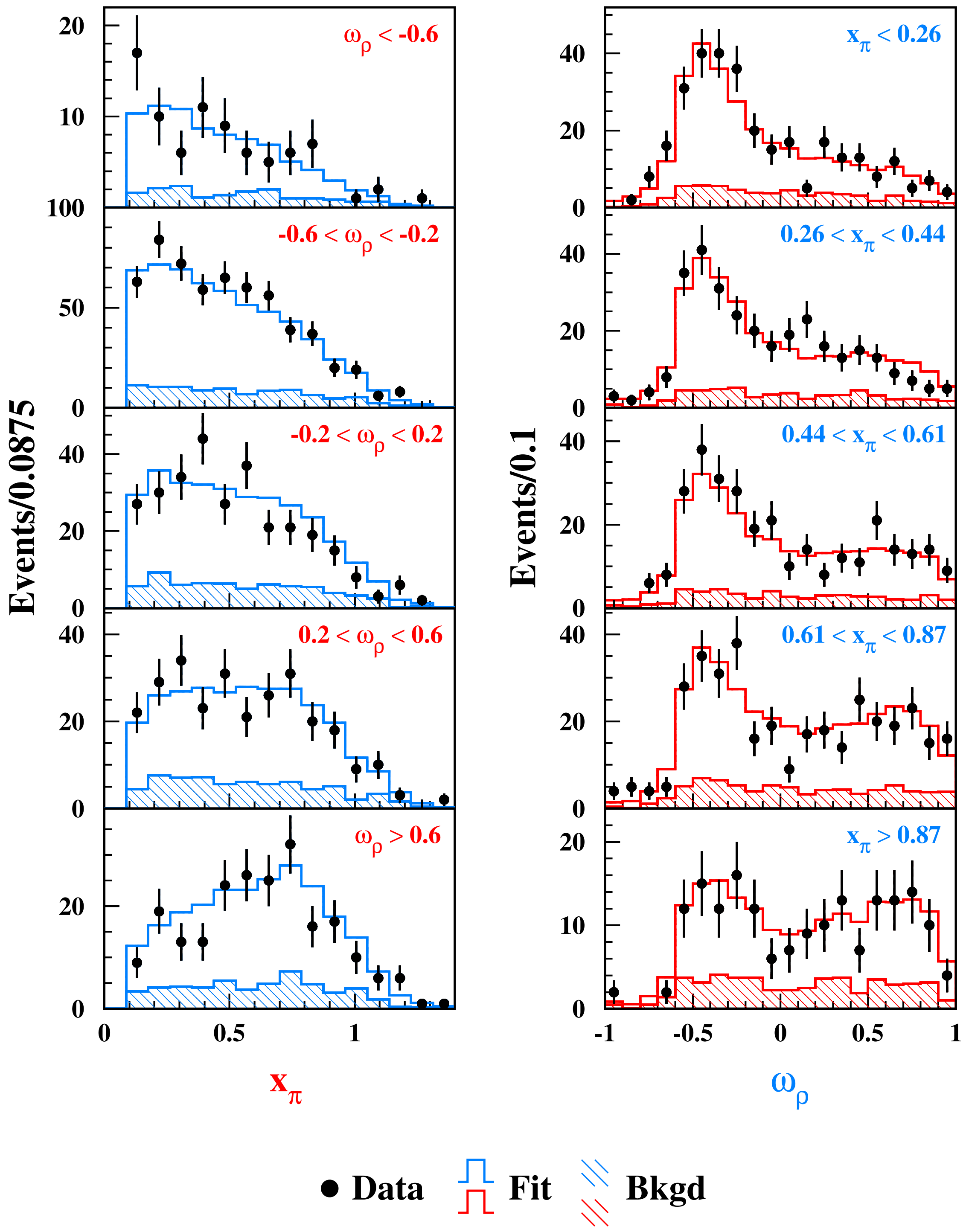
- **Convolute spectra with L3 resolution functions**

- **Assume universality in τ decays**

- **Use binned maximum likelihood fit to one dimensional spectra and joint decay distributions to simultaneously measure ρ, η, ξ, $\xi\delta$, ξ_h and $\mathcal{P}_\tau$**


Events/0.05
eX
x_e
Events/0.05
μX
x_μ
Events/0.0875
πX
x_π
Events/0.1
ρX
ω_ρ
● Data
Fit
Bkgd

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



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

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

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