Study of Michel parameters in τ decays at Belle

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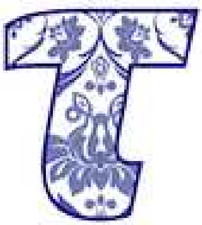
Outline:



Introduction

In the SM charged weak interaction is described by the exchange of $W^{\pm}$ with a pure vector coupling to only left-handed fermions ("V-A" Lorentz structure). Deviations from "V-A" indicate New Physics. $\tau^- \to \ell^- \bar{\nu}_\ell \nu_\tau$ $(\ell = e, \mu)$ decays provide clean laboratory to probe electroweak couplings.

The most general, Lorentz invariant four-lepton interaction matrix element:

$$\mathcal{M} = \frac{4G}{\sqrt{2}} \sum_{\substack{N=S,V,T \\ i,j=L,R}} g^N_{ij} \left[\bar{u}_i(l^-) \Gamma^N v_n(\bar{\nu}_l) \right] \left[\bar{u}_m(\nu_\tau) \Gamma_N u_j(\tau^-) \right],$$

$$\Gamma^S = 1,\ \Gamma^V = \gamma^\mu,\ \Gamma^T = \frac{i}{2\sqrt{2}}(\gamma^\mu \gamma^\nu - \gamma^\nu \gamma^\mu)$$

Ten couplings g^N_{ij}, in the SM the only non-zero constant is $g^V_{LL} = 1$

Four bilinear combinations of g^N_{ij}, which are called as Michel parameters (MP): ρ, η, ξ and δ appear in the energy spectrum of the outgoing lepton:

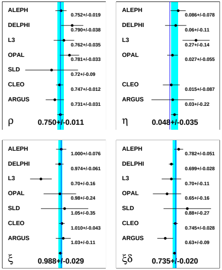
$$\frac{d\Gamma(\tau^\mp)}{d\Omega dx} = \frac{4G_F^2 M_\tau E^4_{\max}}{(2\pi)^4} \sqrt{x^2 - x_0^2} \left(x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x) \right.$$

$$\left. \mp \frac{1}{3} P_\tau cos\theta_\ell \xi \sqrt{x^2 - x_0^2} \left[1 - x + \frac{2}{3}\delta \left(4x - 4 + \sqrt{1 - x_0^2}\right) \right] \right),\ x = \frac{E_\ell}{E_{\max}},\ x_0 = \frac{m_\ell}{E_{\max}}$$

In the SM: $\rho = \frac{3}{4}$, $\eta = 0$, $\xi = 1$, $\delta = \frac{3}{4}$

Status of Michel parameters in τ decays

Michel par.	Measured value	Experiment	SM value
ρ (e or μ)	$0.747 \pm 0.010 \pm 0.006$ 1.2%	CLEO-97	3/4
η (e or μ)	$0.012 \pm 0.026 \pm 0.004$ 2.6%	ALEPH-01	0
ξ (e or μ)	$1.007 \pm 0.040 \pm 0.015$ 4.3%	CLEO-97	1
$\xi\delta$ (e or μ)	$0.745 \pm 0.026 \pm 0.009$ 2.8%	CLEO-97	3/4
ξ_h (all hadr.)	$0.992 \pm 0.007 \pm 0.008$ 1.1%	ALEPH-01	1



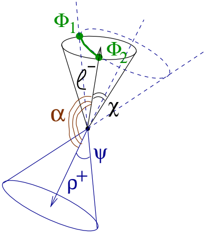
With $\times$300 Belle statistics we can improve MP uncertainties by one order of magnitude

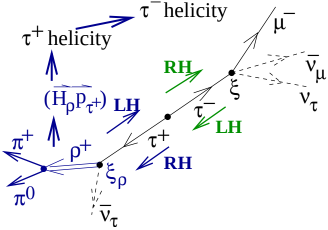
In BSM models the couplings to τ are expected to be enhanced in comparison with μ.

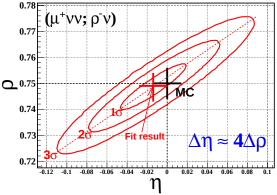
- **Type II 2HDM:** $\eta_\mu(\tau) = \frac{m_\mu M_\tau}{2}\left(\frac{\tan^2\beta}{M^2_{H^\pm}}\right)^2$; $\frac{\eta_\mu(\tau)}{\eta_e(\mu)} = \frac{M_\tau}{m_e} \approx 3500$
- **Tensor interaction:** $\mathcal{L} = \frac{g}{2\sqrt{2}} W^\mu \left\{ \bar{\nu}\gamma_\mu(1-\gamma^5)\tau + \frac{\kappa^W_\tau}{2m_\tau}\partial^\nu\left(\bar{\nu}\sigma_{\mu\ nu}(1-\gamma^5)\tau\right)\right\}$, $-0.096 < \kappa^W_\tau < 0.037$: DELPHI Abreu EPJ C16 (2000) 229.
- **Unparticles:** Moyotl PRD 84 (2011) 073010, Choudhury PLB 658 (2008) 148.
- **Lorentz and CPTV:** Hollenberg PLB **701** (2011) 89
- **Heavy Majorana neutrino:** M. Doi *et al.*, Prog. Theor. Phys. **118** (2007) 1069.

Method, study of $(\ell\nu\nu;\ \rho\nu)$ and $(\rho\nu;\ \rho\nu)$ events

Effect of τ spin-spin correlation is used to measure ξ and δ MP.
Events of the $(\tau^{\mp} \to \ell^{\mp}\nu\nu;\, \tau^{\pm} \to \rho^{\pm}\nu)$ topology are used to measure: ρ, η, $\xi_\rho\xi$ and $\xi_\rho\xi\delta$, while $(\tau^{\mp} \to \rho^{\mp}\nu;\, \tau^{\pm} \to \rho^{\pm}\nu)$ events are used to extract ξ_ρ^2.







$$\frac{d\sigma(\ell^{\mp}\nu\nu,\rho^{\pm}\nu)}{dE^*_\ell\, d\Omega^*_\ell\, d\Omega^*_\rho\, dm^2_{\pi\pi}\, d\tilde{\Omega}_\pi\, d\Omega_\tau} = A_0 + \rho A_1 + \eta A_2 + \xi_\rho\xi A_3 + \xi_\rho\xi\delta A_4 = \sum_{i=0}^{4} A_i\Theta_i$$

$$\mathcal{F}(\vec{z}) = \frac{d\sigma(\ell^{\mp}\nu\nu,\rho^{\pm}\nu)}{dp_\ell\, d\Omega_\ell\, dp_\rho\, d\Omega_\rho\, dm^2_{\pi\pi}\, d\tilde{\Omega}_\pi} = \int_{\Phi_1}^{\Phi_2} \frac{d\sigma(\ell^{\mp}\nu\nu,\rho^{\pm}\nu)}{dE^*_\ell\, d\Omega^*_\ell\, d\Omega^*_\rho\, dm^2_{\pi\pi}\, d\tilde{\Omega}_\pi\, d\Omega_\tau} \left| \frac{\partial(E^*_\ell, \Omega^*_\ell, \Omega^*_\rho, \Omega_\tau)}{\partial(p_\ell, \Omega_\ell, p_\rho, \Omega_\rho, \Phi_\tau)} \right| d\Phi_\tau$$

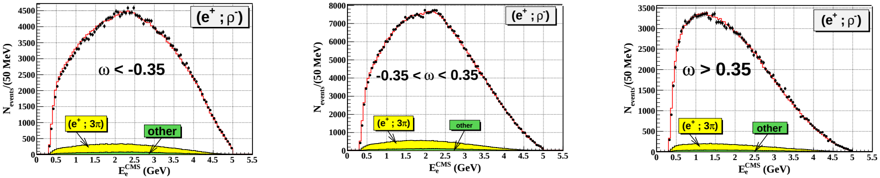
$$L = \prod_{k=1}^{N} \mathcal{P}^{(k)},\ \mathcal{P}^{(k)} = \mathcal{F}(\vec{z}^{(k)})/\mathcal{N}(\vec{\Theta}),\ \mathcal{N}(\vec{\Theta}) = \int \mathcal{F}(\vec{z})d\vec{z},\ \vec{\Theta} = (1, \rho, \eta, \xi_\rho\xi_\ell, \xi_\rho\xi_\ell\delta_\ell)$$

$$\boldsymbol{\mathcal{P}}_{\textbf{total}} = (1 - \sum_{i=1}^{4}\lambda_i)\boldsymbol{\mathcal{P}}^{\ell-\rho}_{signal} + \lambda_1\mathcal{P}^{\ell-3\pi}_{bg} + \lambda_2\mathcal{P}^{\pi-\rho}_{bg} + \lambda_3\mathcal{P}^{\rho-\rho}_{bg} + \lambda_4\boldsymbol{\mathcal{P}}^{other}_{bg}\ \textbf{(MC)}$$

MP are extracted in the unbinned maximum likelihood fit of $(\ell\nu\nu;\ \rho\nu)$ events in the 9D phase space $\vec{z} = (p_\ell,\ \cos\theta_\ell,\ \phi_\ell,\ p_\rho,\ \cos\theta_\rho,\ \phi_\rho,\ m^2_{\pi\pi},\ \cos\tilde{\theta}_\pi,\ \tilde{\phi}_\pi)$ in CMS.

Data fits and systematic uncertainties

Helicity sensitive variable $\omega = \frac{1}{\Phi_2-\Phi_1}\int_{\Phi_1}^{\Phi_2}(\vec{H}_{\rho^\pm},\vec{n}_{\tau^\pm})d\Phi = <(\vec{H}_{\rho^\pm},\vec{n}_{\tau^\pm})>_{\Phi_\tau}$



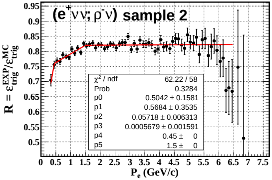
Spin-spin correlation manifests itself through momentum-momentum correlations of final lepton and pions.

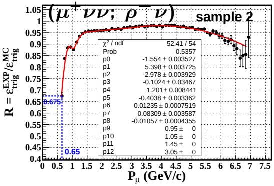
Source	$\Delta(\rho)$, %	$\Delta(\eta)$, %	$\Delta(\xi_\rho\xi)$, %	$\Delta(\xi_\rho\xi\delta)$, %
Physical corrections				
ISR+$\mathcal{O}(\alpha^3)$	0.10	0.30	0.20	0.15
$\tau \to \ell\nu\nu\gamma$	0.03	0.10	0.09	0.08
$\tau \to \rho\nu\gamma$	0.06	0.16	0.11	0.02
Background	0.20	0.60	0.20	0.20
Apparatus corrections				
Resolution $\oplus$ brems.	0.10	0.33	0.11	0.19
$\sigma(E_{\rm beam})$	0.07	0.25	0.03	0.15
Normalization				
$\Delta\mathcal{N}$	0.11	0.50	0.17	0.13
without Data/MC corr.	**0.29**	**0.95**	**0.38**	**0.38**
trigger eff. corr.	**$\sim$ 1**	**$\sim$ 2**	**$\sim$ 3**	**$\sim$ 3**

We are working on the Data/MC efficiency corrections (trigger, ℓID, track rec., π^0 rec.).

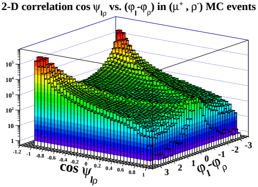
Data/MC efficiency corrections

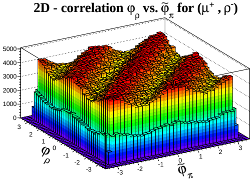
We found that the **Data/MC trigger efficiency correction, $\mathcal{R}_{\rm trg}$, is the** dominant one. Two independent subtriggers (energy trigger and track trigger) are used to evaluate it.





$\mathcal{R}_{\rm trg}$ varies in 9D phase space, a set of 2D-maps is used to approximate it.





The track reconstruction efficiencies are different for the energy and track triggers, the combined procedure is under development.

Summary

- The procedure to measure 4 Michel parameters (MP) (ρ, η, ξ, $\xi\delta$) in leptonic τ decays at B factory has been developed and tested. It is based on the analysis of the $(\ell^{\mp}\nu\nu;\ \rho^{\pm}\nu)$, $\ell = e,\ \mu$ events and utilizes spin-spin correlation of tau leptons.
- We confirmed that with the whole Belle data sample the statistical accuracy of MP is by one order of magnitude better than in the previous best measurements (CLEO, ALEPH).
- The main background components $((\ell\nu\nu;\ \pi 2\pi^0\nu), (\pi\nu;\ \rho\nu), (\rho\nu;\ \rho\nu))$ are described analytically in the fitter, the remaining background (with the fraction of about 2.0%) is described with help of the MC-based method. We reached acceptable description of the backgrounds in the PDF.
- Various Data/MC efficiency corrections provide the dominant contribution to the systemtic uncertainties of MP. **The largest contribution comes from the trigger efficiency correction (1–3)%**. We are working to improve this uncertainty.