BELLE

東京大学 THE UNIVERSITY OF TOKYO

Study of Michel parameters in leptonic τ decays at Belle

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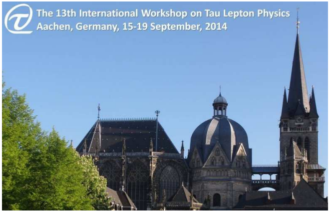
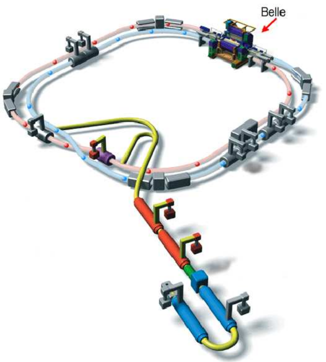
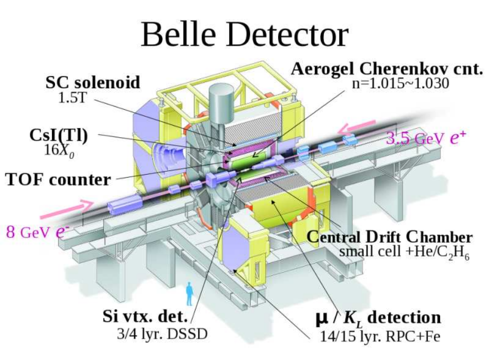


Introduction: Belle experiment





Process	σ, nb
$e^+e^- \to e^+e^-(\gamma)$ $15^o \leq \theta \leq 165^o$	123.5
$e^+e^- \to \mu^+\mu^-(\gamma)$	1.005
$e^+e^- \to q\bar{q}$ $(q = u, d, s, c)$	3.39
$e^+e^- \to b\bar{b}$	1.05
$e^+e^- \to e^+e^- f\bar{f}$ $(f = u, d, s, c, e, \mu, \tau)$	72.6
$e^+e^- \to \tau^+\tau^-(\gamma)$	0.919

- $E_{e^-} = 8$ **GeV,** $E_{e^+} = 3.5$ **GeV**
- **Peak luminosity:** $L = 2.11 \times 10^{34}$ **cm**$^{-2}$**s**$^{-1}$
- **Integrated luminosity:** $\int Ldt \simeq 1$ **ab**$^{-1}$**,** $N_{\tau\tau} \simeq 10^9$
- B-factory is also τ-factory

This analysis is based on a $485\ \mathrm{fb}^{-1}$ data sample (446 $\times 10^6$ $\tau^+\tau^-$)

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:

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

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

Ten couplings g_{ij}^N, in the SM the only non-zero constant is $g_{LL}^V = 1$

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

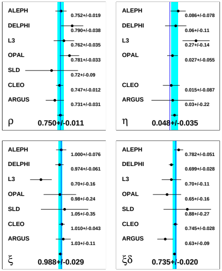
$$\frac{d\Gamma(\tau^\mp)}{d\Omega dx} = \frac{4G_F^2 M_\tau E_{\max}^4}{(2\pi)^4} \sqrt{x^2 - x_0^2} \left(x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x) \right.$$

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

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
$\xi_{\rm h}$ (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

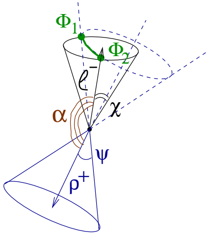
In BSM models the couplings to τ are expected to be enhanced in comparison with μ.

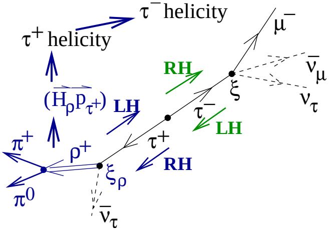
Also contribution from New Physics in τ decays can be amplified by $(\frac{m_\tau}{m_\mu})^n$.

- In the 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
- Dark Sector (arXiv:1311.0029 [hep-ph])

Method, study of $\ell - \rho$ and $\rho - \rho$ events

Effect of τ spin-spin correlation is used to measure ξ and δ MP.
Events of ($\tau^{\mp} \to \ell^{\mp}\nu\nu$; $\tau^{\pm} \to \rho^{\pm}\nu$) 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.





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

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

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

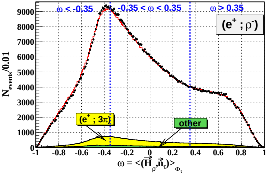
MP are extracted in the unbinned maximum likelihood fit of (ℓ, ρ) events in the 9D phase space $\vec{z} = (p_\ell,\ \cos\theta_\ell,\ \phi_\ell,\ p_\rho,\ \cos\theta_\rho,\ \phi_\rho,\ m^2_{\pi\pi},\ \cos\tilde{\theta}_\pi,\ \tilde{\phi}_\pi)$ in CMS.

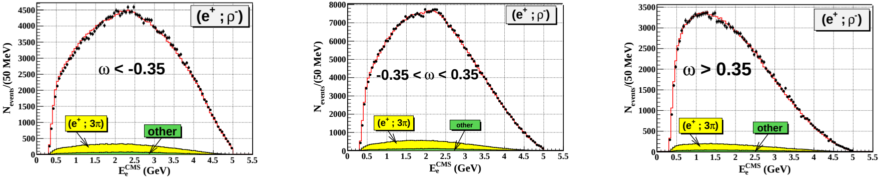
Method, helicity sensitive variable ω

M. Davier *et. al* Phys. Lett. B **306** (1993) 411.

Helicity sensitive variable ω is introduced as:

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





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

Corrections, detector effects, background

Physical corrections:

- All $\mathcal{O}(\alpha^3)$ QED and electroweak higher order corrections to $e^+e^- \to \tau^+\tau^-$ are included
- Radiative leptonic decays $\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau\gamma$
- Radiative decay $\tau^- \to \pi^-\pi^0\nu_\tau\gamma$

Detector effects:

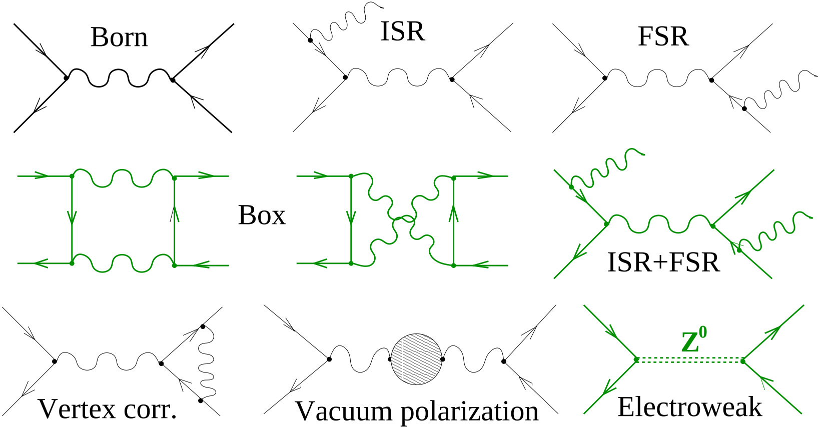
- Track momentum resolution
- γ energy and angular resolution
- Effect of external bremsstrahlung for $e - \rho$ events
- Beam energy spread
- EXP/MC efficiency corrections (trigger, track rec., π^0 rec., ℓID, πID)

Background:

The main background comes from $\ell - \pi\pi^0\pi^0$(∼10%) and $\pi - \pi\pi^0(\pi \to \mu)$(∼1.5%) events, it is included in PDF analytically. The remaining background(∼2.0%) is taken into account using MC-based approach. Background from the non-$\tau\tau$ events is $\lesssim$ 0.1%.

$$\mathcal{P}_{TOT} = (1 - \lambda_{3\pi} - \lambda_\pi - \lambda_{other})\mathcal{P}^{signal} + \lambda_{3\pi}\mathcal{P}^{BG}_{3\pi} + \lambda_\pi\mathcal{P}^{BG}_{\pi} + \lambda_{other}\mathcal{P}^{BG}_{other}(MC)$$

α^3 corrections to $e^+e^- \to \tau^+\tau^-$



S. Jadach and Z. Was, Acta Phys. Polon. B **15** (1984) 1151 [Erratum-ibid. B **16** (1985) 483].
A. B. Arbuzov *et al* JHEP **9710** (1997) 001.

Charge-odd part of the cross section comes from the interference of the ISR+FSR and Born diagrams, box and Born diagrams and Z^0-exchange and Born diagrams.

Description of background

Likelihood per event

$$\mathcal{P}(x) = \frac{\overline{\varepsilon(x)}}{\bar{\varepsilon}}\Bigg((1-\sum_i \lambda_i)\frac{S(x)}{\int \frac{\overline{\varepsilon(x)}}{\bar{\varepsilon}} S(x)dx} + \lambda_{3\pi}\frac{\tilde{B}_{3\pi}(x)}{\int \frac{\overline{\varepsilon(x)}}{\bar{\varepsilon}} \tilde{B}_{3\pi}(x)dx} + \lambda_{\pi}\frac{\tilde{B}_{\pi}(x)}{\int \frac{\overline{\varepsilon(x)}}{\bar{\varepsilon}} \tilde{B}_{\pi}(x)dx} + \lambda_{other}\frac{B^{MC}_{other}(x)}{\int \frac{\overline{\varepsilon(x)}}{\bar{\varepsilon}} B^{MC}_{other}(x)dx}\Bigg)$$

$$\tilde{B}_{3\pi}(x) = \int (1-\varepsilon_{\pi^0}(y))\varepsilon_{add}(y)B_{3\pi}(x,y)dy,\ \tilde{B}_{\pi}(x) = \frac{\varepsilon_\pi(x)}{\varepsilon(x)}B_\pi(x),\ \frac{\varepsilon_\pi(x)}{\varepsilon(x)} = \frac{\varepsilon^{\mu ID}_{\pi\to\mu}(x)}{\varepsilon^{\mu ID}_{\mu\to\mu}(x)}$$

$$\overline{\varepsilon(x)} = \epsilon^{trg}_{corr}(x)\epsilon^{\ell ID}_{corr}(x)\varepsilon(x)$$

- $x = (p_\ell,\ \Omega_\ell,\ p_\rho,\ \Omega_\rho,\ m^2_{\pi\pi},\ \tilde{\Omega}_\pi);\ y = (p_{\pi^0},\ \Omega_{\pi^0})$;
- $S(x)$ - density of signal ($\ell^\mp,\ \pi^\pm\pi^0$) events;
- $B_{3\pi}(x,y)$ - density of background ($\ell^\mp,\ \pi^\pm 2\pi^0$) events;
- $B_\pi(x)$ - density of background ($\pi^\mp,\ \pi^\pm\pi^0$) events;
- $B^{MC}_{other}(x)$ - MC density of the remaining background;
- $\varepsilon(x)$ - detection efficiency for signal events;
- $\varepsilon_{\pi^0}(y)$ - π^0 detection efficiency;
- $\varepsilon_{add}(y)$ - additional efficiency for ($\ell^\mp,\ \pi^\pm 2\pi^0$) events;
- $\varepsilon_\pi(x)$ - detection efficiency for ($\pi^\mp,\ \pi^\pm\pi^0$) events;

Validation of the fitter with MC

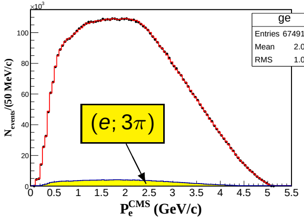
For each configuration 5M MC sample is fitted. The other, statistically independent, 5M MC sample was used to calculate normalization.

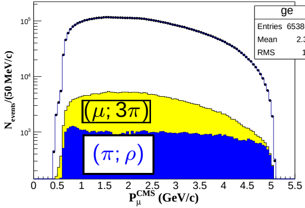
$(e^+; \pi^-\pi^0)$

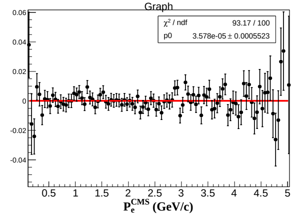
ρ	=	0.7517	$\pm$	0.0010
η	=	0	–	fixed
ξ	=	1.0092	$\pm$	0.0043
$\xi\delta$	=	0.7538	$\pm$	0.0027

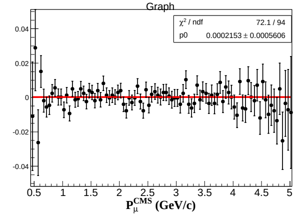
$(\mu^+; \pi^-\pi^0)$

ρ	=	0.7494	$\pm$	0.0027
η	=	0.0052	$\pm$	0.0101
ξ	=	0.9995	$\pm$	0.0050
$\xi\delta$	=	0.7519	$\pm$	0.0033



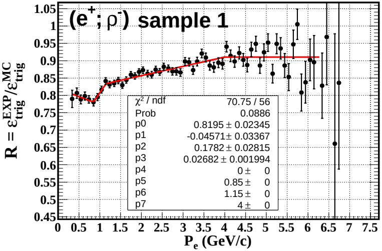


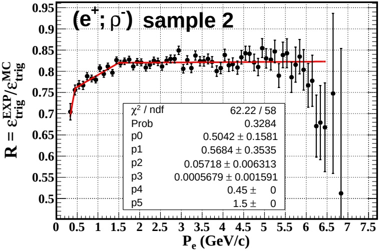




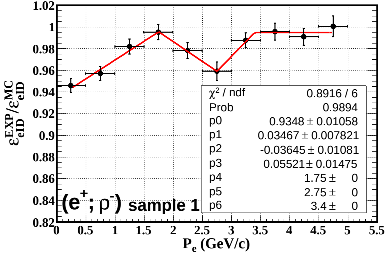
EXP/MC efficiency corrections ($(e^+; \rho^-)$ events)

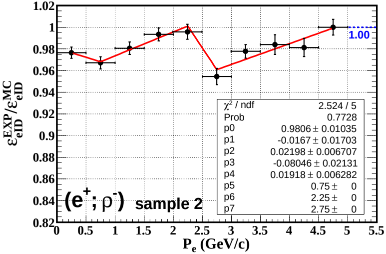
Two independent subtriggers (neutral (ECL) and charged (CDC⊕TOF⊕KLM)) are used to evaluate EXP/MC trigger efficiency correction.





The lepton detection efficiency is corrected using the $e^+e^- \to e^+e^-\ell^+\ell^-,\ \ell = e, \mu$ two-photon data sample.

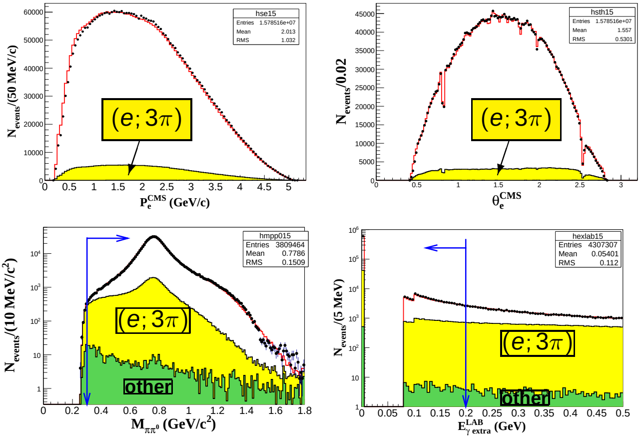




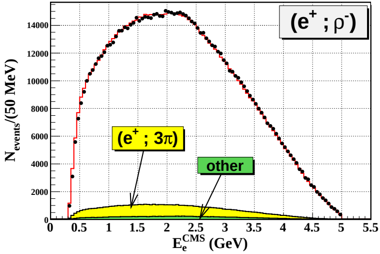
Selections

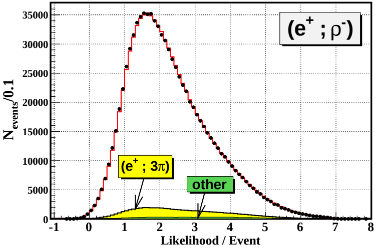
- After the standard preselections we take events with two oppositely charged tracks, one of them is identified as lepton (eID, $\mu ID > 0.9$) and the other one as pion ($PID(\pi/K) > 0.4$).
- π^0 candidate is reconstructed from the pair of gammas ($E_\gamma^{\rm LAB} > 80$ MeV) satisfying 115 MeV/$c^2 < M_{\gamma\gamma} <$ 150 MeV/c^2, $P_{\pi^0}^{\rm CMS} > 0.3$ GeV/c.
- $\cos(\vec{P}_{\rm lep}, \vec{P}_\pi) < 0$, $\cos(\vec{P}_{\rm lep}, \vec{P}_{\pi^0}) < 0$, 0.3 GeV/$c^2 < M_{\pi\pi^0} <$ 1.8 GeV/c^2.
- $E_{{\rm rest}\gamma}^{\rm LAB} < 0.2$ GeV

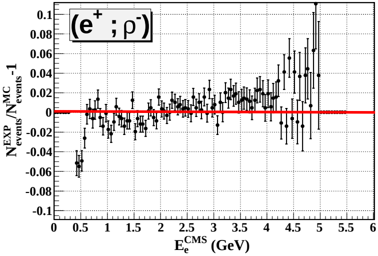
Detection efficiency $\varepsilon_{\rm det} \simeq 12\%$

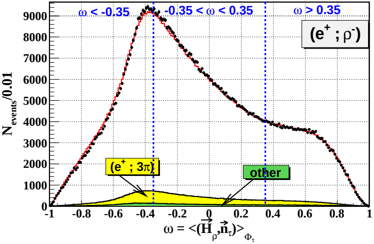


Fit of the experimental data, $(e^+; \rho^-)$

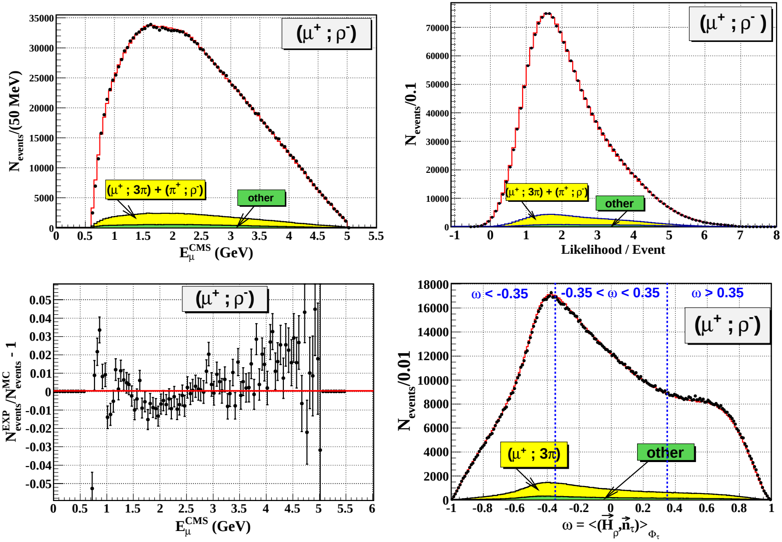








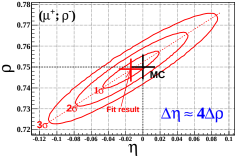
Fit of the experimental data, $(\mu^+; \rho^-)$



Systematic uncertainties

Source	$\sigma(\rho)$, %	$\sigma(\eta)$, %	$\sigma(\xi_\rho\xi)$, %	$\sigma(\xi_\rho\xi\delta)$, %
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
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
Normalisation				
$\Delta\mathcal{N}$	0.21	0.60	0.38	0.26
Total	0.27	0.81	0.47	0.40

We observe a systematic bias of the order of a few percent, especially in the $\xi_\rho\xi$ and $\xi_\rho\xi\delta$, which originates from the remaining inaccuracies in the description of the $\ell - 3\pi$ background.



The dominant systematic uncertainties coming from the various EXP/MC efficiency corrections are under investigation.

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 $(\ell^{\mp},\ \rho^{\pm})$, $\ell = e,\ \mu$ and $(\rho^{\mp},\ \rho^{\pm})$ events and utilizes spin-spin correlation of tau leptons.
- We confirmed that with Belle data the statistical accuracy of MP is by one order of magnitude better than in the previous best measurements (CLEO, ALEPH).
- Various EXP/MC efficiency corrections provide the dominant contribution to the systemtic uncertainties of MP. The trigger and lepton identification EXP/MC efficiency corrections have been already taken into account.
- Currently we have a few percent systematic bias in $\xi_\rho\xi$ and $\xi_\rho\xi\delta$ MP from the remaining inaccuracies in the description of the $\ell - 3\pi$ background. The analysis is going on.