Tau Lepton Studies at the Belle

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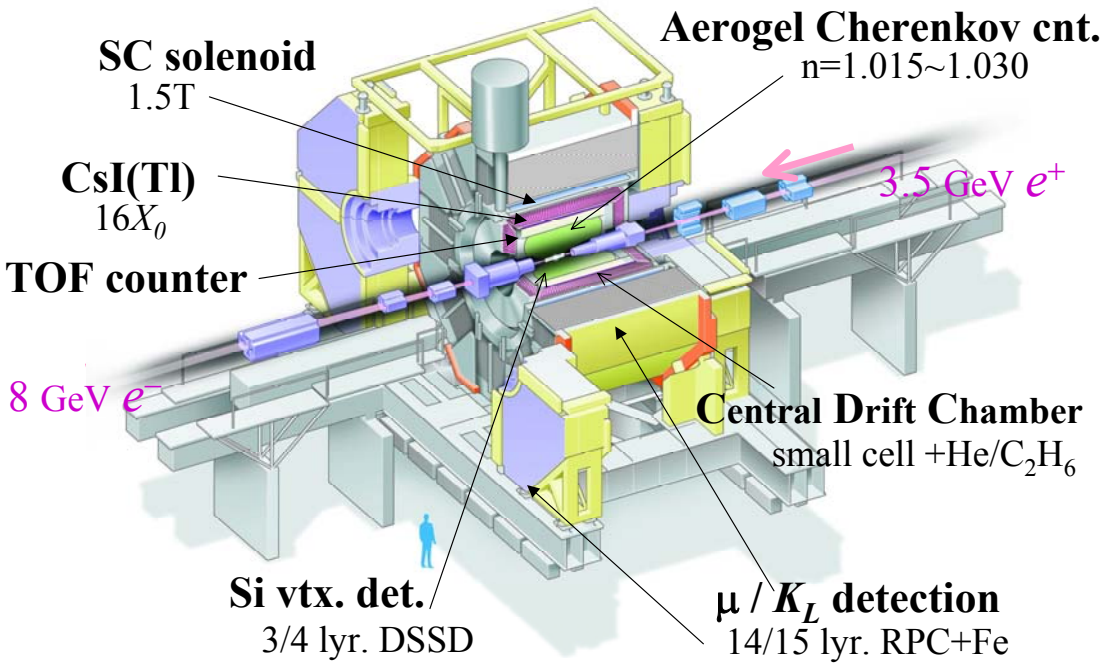
Belle Detector



The primary goal of the Belle and BaBar experiments was to discover the CP violation in B mesons and to measure the parameters of CPV. This was achieved by both experiments in 2001

However, wide research area became possible because of clean event environment and well defined initial state in the e+e– experiments as well as high luminosity and general-purpose detectors

$E^- = 8$ GeV, $E^+ = 3.5$ GeV, $\sqrt{s}=10.58$ GeV, $\beta\gamma=0.42$

Peak lumi record at KEKB: L=2.1 x 10^{34}/cm2/sec with crab cavities

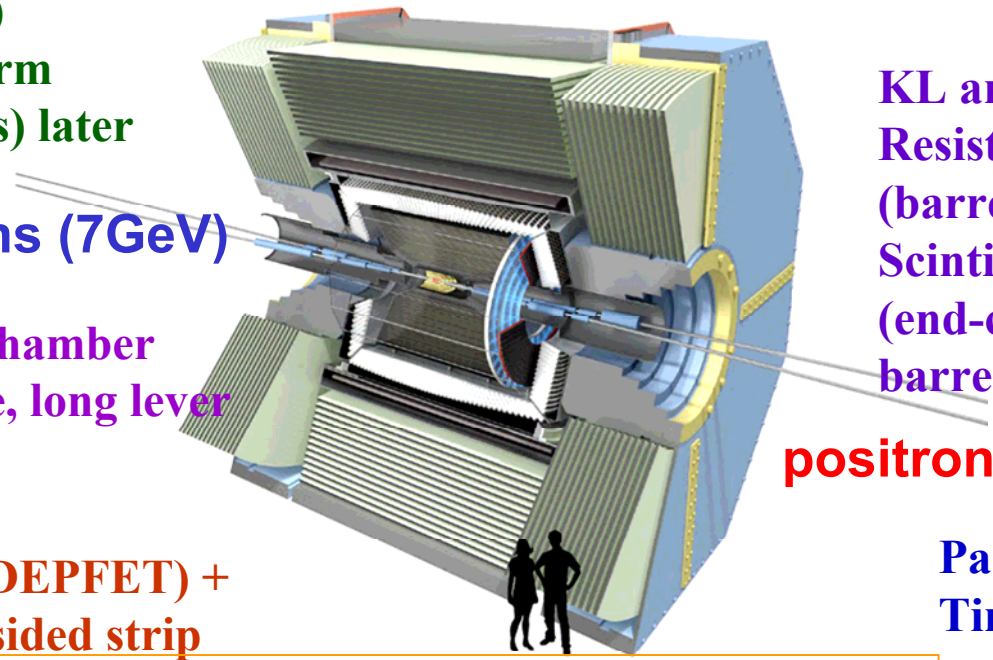
$$\int_{1999}^{2010} Ldt = 1\ ab^{-1}$$

F/B asymmetric detector: High vertex resolution, magnetic spectrometry, excellent calorimetry and sophisticated particle ID ability

Belle II Detector

All details are in the Changzheng YUAN talk

EM Calorimeter:
CsI(Tl), waveform sampling electronics (barrel)
Pure CsI + waveform sampling (end-caps) later



electrons (7GeV)

KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

Central Drift Chamber
Smaller cell size, long lever arm

positrons (4GeV)

Vertex Detector
2 layers Si Pixels (DEPFET) +
4 layers Si double sided strip DSSD

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (forward)

+ New software, improved tracking, ...
+ Optimization for low multiplicity trigger
+ Improved simulation, generators and GRID

	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

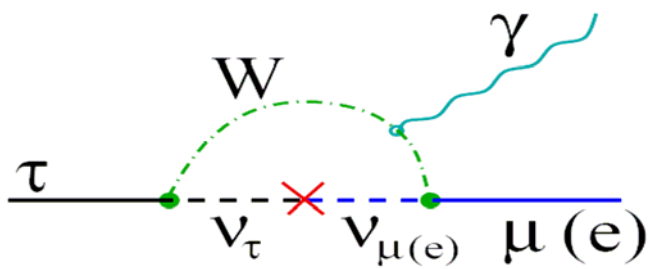
Tau studies at Belle

- **28 journal papers in total**
- **18 papers on LVF**
- **6 branching fractions and spectral functions**

and

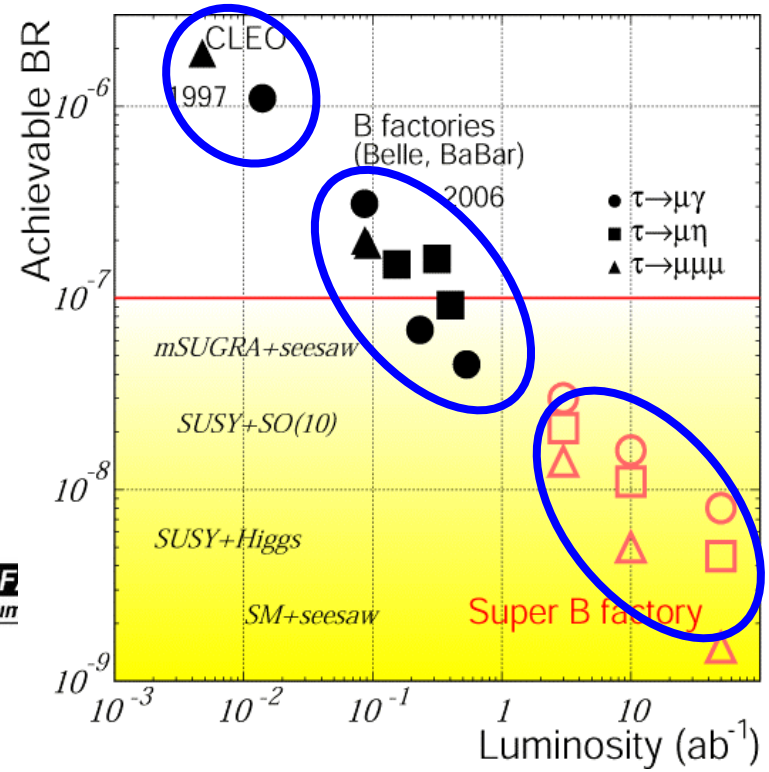
- **Search for the Electric Dipole Moment of the tau lepton** K.Inami, et al.(Belle Collaboration), PLB 551, 16 (2003)
- **Measurement of the τ Lepton Mass and an Upper Limit on the Mass Difference between τ^+ and τ^-**, M. Shapkin, K. Belous, A. Sokolov et al. (The Belle Collaboration), PRL 99, 011801 (2007)
- **Measurement of the τ-lepton Lifetime at Belle,** K.Belous, M.Shapkin, A.Sokolov, et al. (Belle Collaboration), PRL 112, 031801 (2014)
- **Search for CP Violation in $\tau^\pm \to K_S^0\pi^\pm\nu_\tau$ Decays at Belle,** M.Bischofberger, H.Hayashii, et al. (The Belle Collaboration), PRL 107, 131801 (2011)

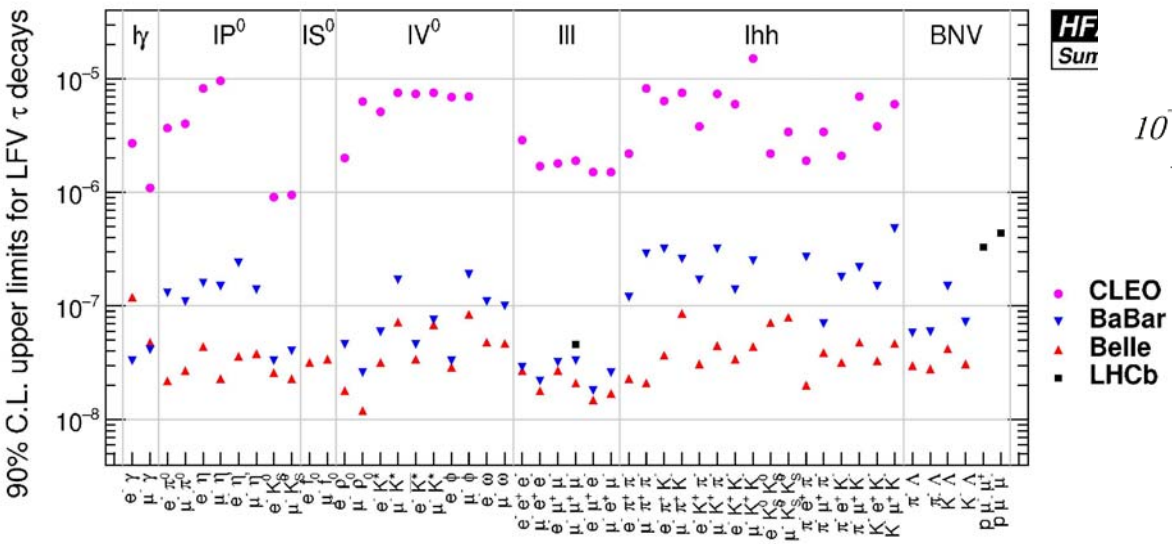
Searches for lepton flavour violation in tau decays



In the SM the lepton flavour violation decays are extremely small:

$Br(\tau \to l\gamma) \sim 10^{-54}$





Expected sensitivity

$\tau \to \ell\gamma$ Br~O($10^{-8\sim9}$)

$\tau \to \ell\ell\ell$, l+meson Br~O($10^{-9\sim10}$)

Lepton universality in the SM

$$\Gamma(L^- \to l^- \bar{\nu}_l \nu_L) = \frac{B(L^- \to l^- \bar{\nu}_l \nu_L)}{\tau_\tau} = \frac{G_L G_l m_L^5}{192\pi^3} f(m_l^2 / m_L^2) R_W R_\gamma,$$

$$G_l = \frac{g_l^2}{4\sqrt{2} M_W^2}, \quad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x,$$

$$R_W = 1 + \frac{3}{5}\frac{m_L^2}{M_W^2} + \frac{9}{5}\frac{m_l^2}{M_W^2}, \quad R_\gamma = 1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)$$

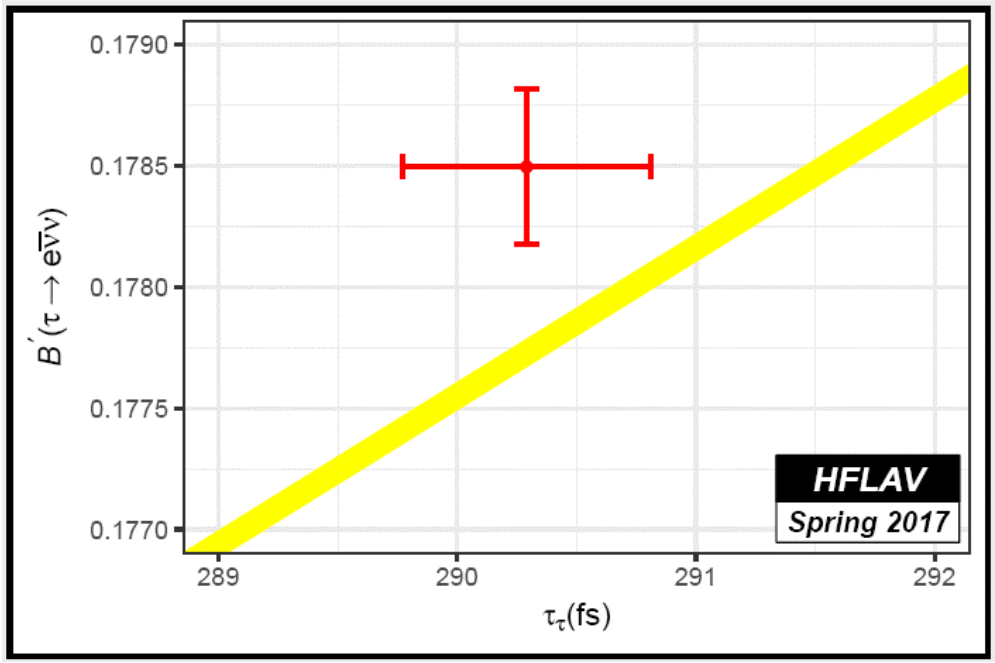
g_τ/g_μ = 1.0010 ± 0.0015

g_τ/g_μ = 1.0029 ± 0.0015

g_μ/g_e = 1.0019 ± 0.0014

HFLAV spring 2017
A.Lusiani, PhiPsi 2017

precision: 0.20-0.23% pre-B-Factories ⇒ 0.14- 0.15% today thanks essentially to the Belle tau lifetime measurement, PRL 112 (2014) 031801



Universality test uncertainty now limited by leptonic BRs and tau lifetime

parameter	Δ(value)	Δ(ratio)
τ_τ	0.090%	0.18%
$B_{\tau\to\mu e}$	0.115%	0.23%
m_τ	0.022%	0.009%

A.Lusiani, PhiPsi 2017

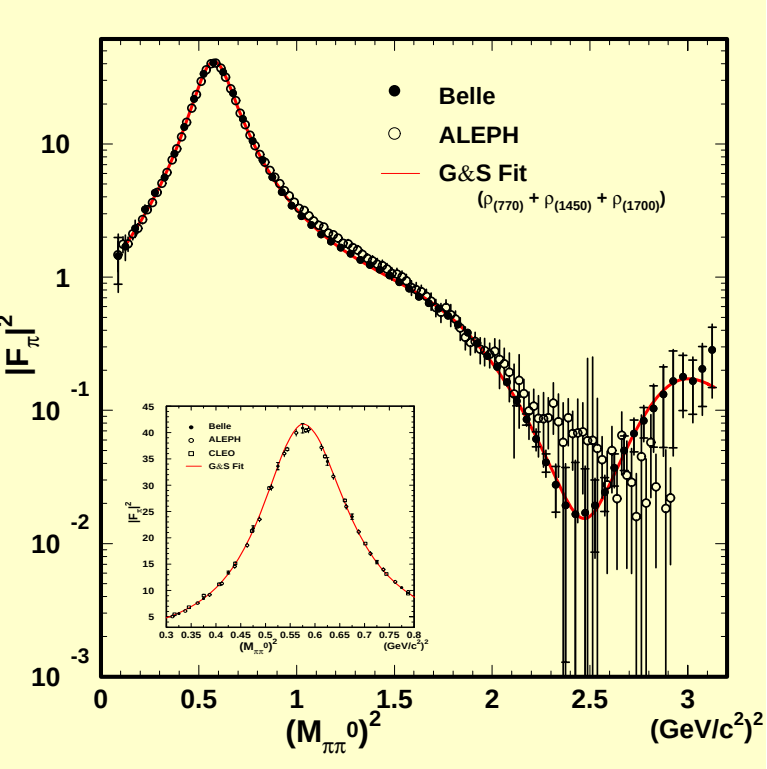
$B(\tau\to\mu\nu\nu)$= 17.392 ± 0.040 (HFLAV2017 fit) (17.319±0.070±0.032) (ALEPH)
$B(\tau\to e\nu\nu)$= 17.816 ± 0.041 (HFLAV 2017 fit) (17.837±0.072±0.036) (ALEPH)
$R(\mu/e)$= 0.9762 ± 0.0028 (HFLAV 2017 fit) (0.9796 ± 0.0016 ± 0.0036) BaBar

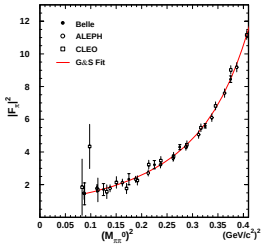
MASS =1776.86±0.12 (PDG) 1776.91±0.12+0.10−0.13 BES-III

MEAN LIFE 290.3±0.5 10^{-15}s (290.17±0.53±0.33 Belle)

High-statistics study of the $\tau^- \to \pi^- \pi^0 \nu_\tau$ decay

Phys. Rev. D 78, 072006





5.6x 10^6 $\tau^- \to \pi^- \pi^0 \nu_\tau$ decays (72.2/fb).

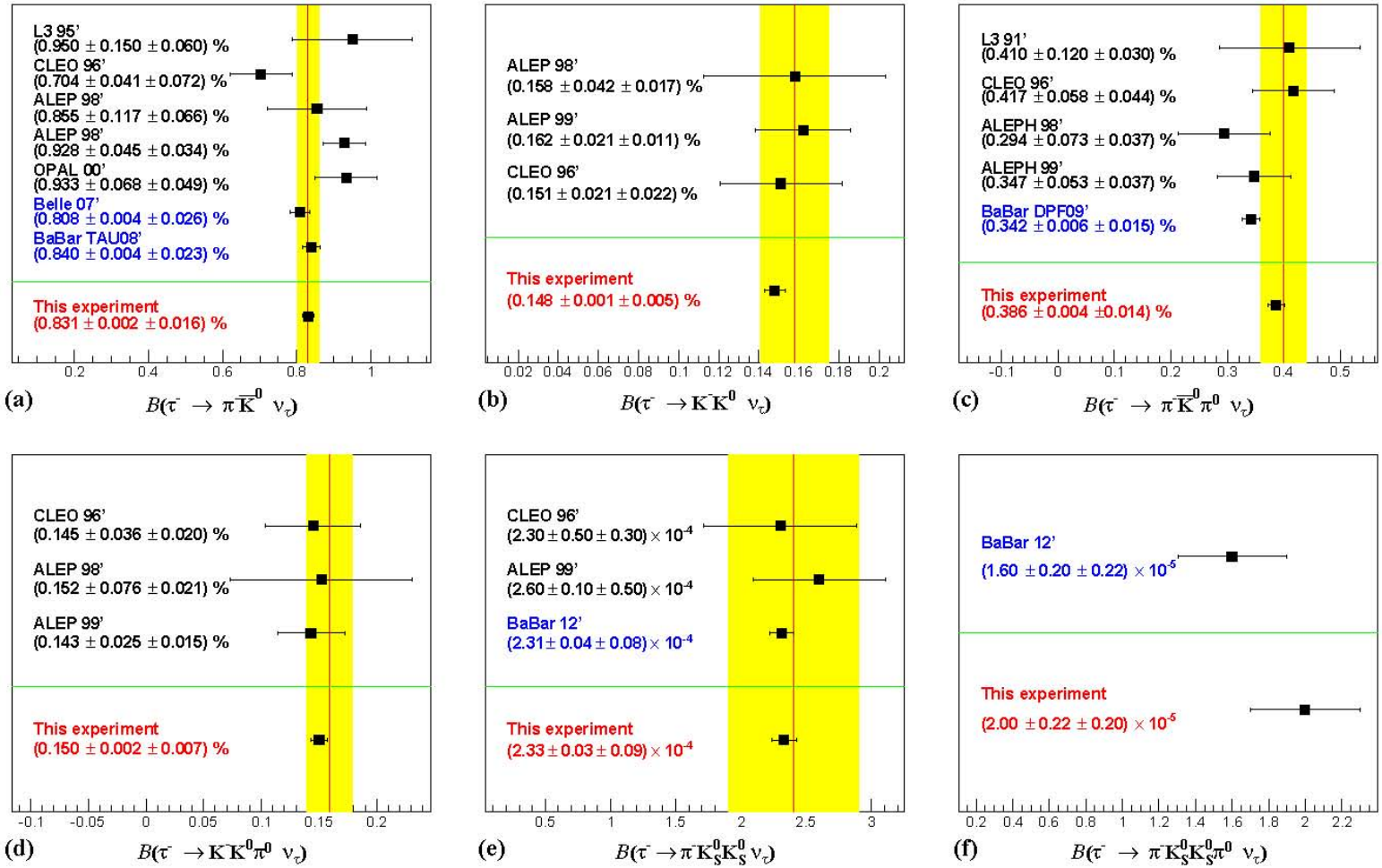
$$\mathrm{Br}(\tau^- \to \pi^- \pi^0 \nu_\tau) = (25.17 \pm 0.04 \pm 0.40)\%$$

Systematic uncertainties for brancung fraction

Source of uncertainty	$\Delta\mathcal{B}_{h\pi^0}$ (%)	$(\Delta\mathcal{B}/\mathcal{B})$ (%)
Tracking efficiency	0.12	0.47
π^0 efficiency	0.36	1.4
Background for $\tau^+\tau^-$	0.09	0.36
Feed-down background for $\tau^- \to h^- \pi^0 \nu_\tau$	0.04	0.16
Non-τ background for $\tau^- \to h^- \pi^0 \nu_\tau$	0.05	0.20
γ veto	0.05	0.20
Trigger	0.08	0.32
MC statistics	0.02	0.08
Total	0.40	1.6

Measurements of branching fractions of τ lepton decays with one or more K_S^0

PRD 89, 072009 (2014)

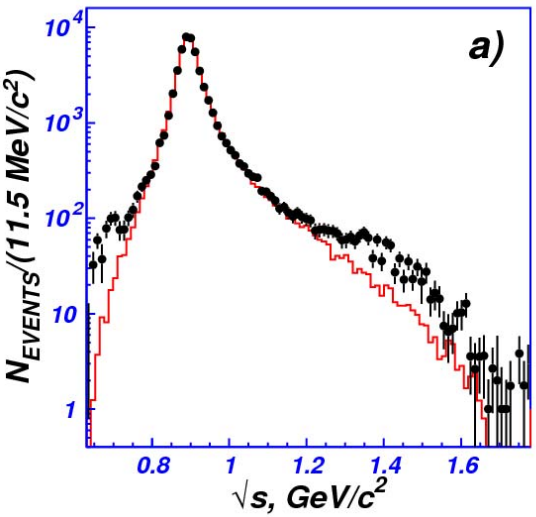


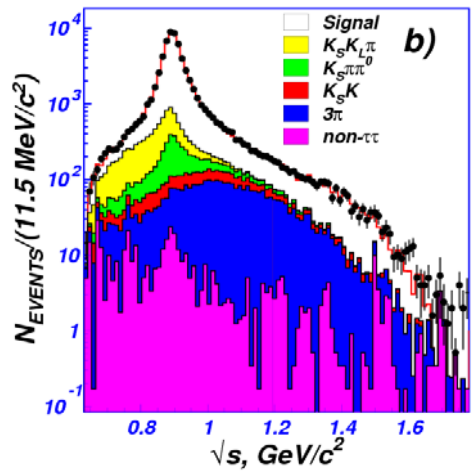
Spectral functions

PLB 654, 65 (2007) **351 fb^{-1}**

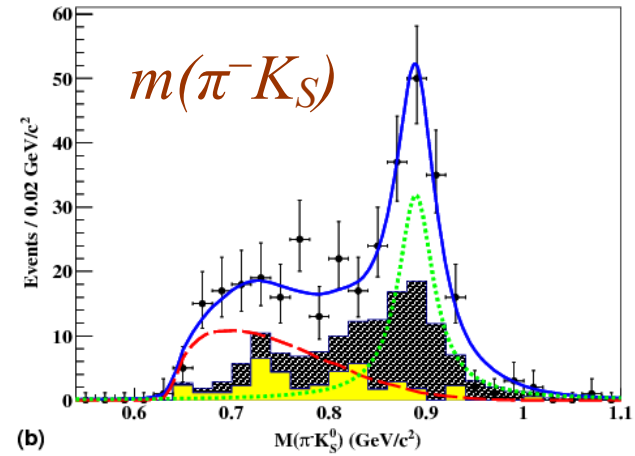
PRD 89, 072009 (2014) **669 fb^{-1}**

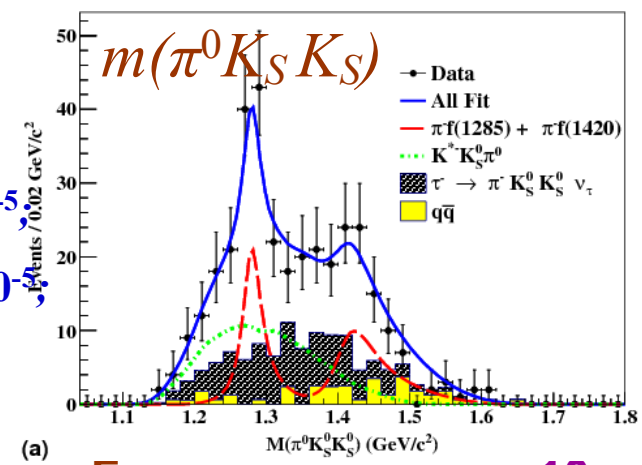
$$\tau^- \to K_S\, \pi^- \nu_\tau$$





$$\tau^- \to \pi^- K_S K_S \pi^0 \nu_\tau$$





$B(f_1(1285)\pi^-\nu) \cdot B(f_1(1285) \to K^0_S K^0_S \pi^0) = (0.74 \pm 0.12 \pm 0{:}08) \cdot 10^{-5}$,

$B(f_1(1420)\pi^-\nu) \cdot B(f_1(1420) \to K^0_S K^0_S \pi^0) = (0\ 20 \pm 0{:}09 \pm 0{:}02) \cdot 10^{-5}$,

$B(K^{*-} K^0_S \pi^0) \cdot B(K^{*-} \to K^0_S \pi^-) = (1.06 \pm 0.15 \pm 0.11) \cdot 10\text{-}5$:

Michel parameters

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

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

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

Michel par.	Measured value	Experiment	SM value
ρ=	0.747 ± 0.010 ± 0.006	CLEO-97	3/4
η	0.012 ± 0.026 ± 0.004	ALEPH-01	0
ξ	1.007 ± 0.040 ± 0.015	CLEO-97	1
$\xi\delta$	0.745 ± 0.026 ± 0.009	CLEO-97	3/4
ξh	0.992 ± 0.007 ± 0.008	ALEPH-01	1

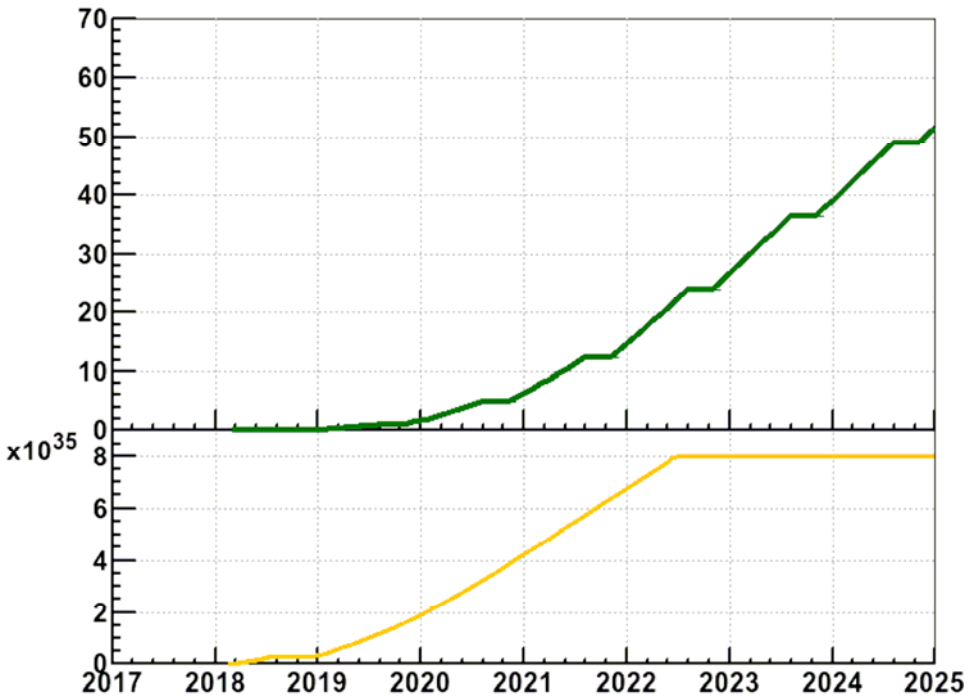
Effect of τ spin-spin correlation is used to measure ξ and δ . Topology of Events ($\tau^- \to l^- \nu\nu$; $\tau^+ \to \rho^+\nu$) are used to measure: ρ, η, $\xi_\rho\xi$, $\xi_\rho\xi\delta$, while ($\tau^- \to \rho^-\nu$; $\tau^+ \to \rho^+\nu$) events are used to extract ξ_ρ^2 (arXiv:1409.4969)

Conclusion

- At present SuperKEKB/Belle II project is in commissioning. Very high expected luminosity of this experiment provides a possibility of the precise study of the τ lepton physics.

- We hope that high statistics and improved detector will help to reduce considerably systematic uncertainties.

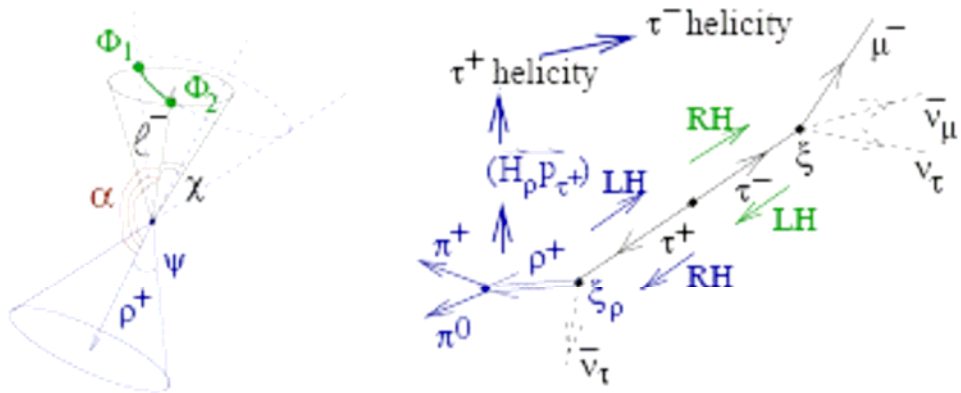
Expected Luminosity

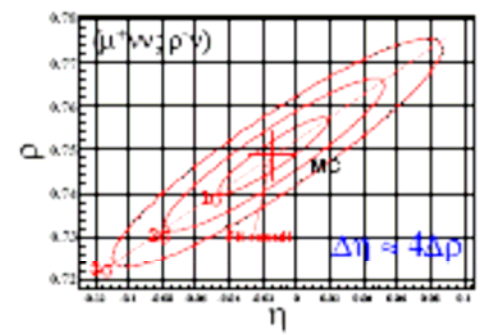


Back up

From D.Epifanov

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.





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

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

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

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

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.