47th Course – ERICE-SICILY

29 August – 7 September, 2009

Study of $\tau^- \to K_S \pi^- \nu_\tau$ decay at Belle

Denis Epifanov

(Budker Institute of Nuclear Physics, Novosibirsk, Russia)

Outline:

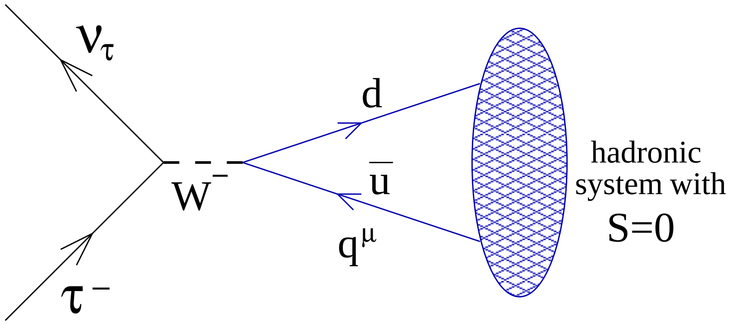
- Motivation
- Belle at KEKB
- Measurement of $\mathcal{B}(\tau \to K_S \pi \nu)$
- Study of the $K_S \pi$ mass spectrum
- Prospects to search for CP violation
- Conclusion

Hadronic τ decays

τ is the only lepton decaying to hadrons

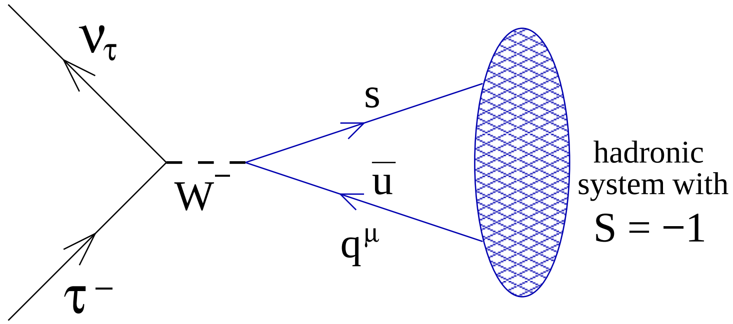
Cabibbo-allowed decays ($\mathcal{B} \sim \cos^2\theta_c$)

$$\mathcal{B}(S=0) = (61.85 \pm 0.10)\%$$



Cabibbo-suppressed decays ($\mathcal{B} \sim \sin^2\theta_c$)

$$\mathcal{B}(S=-1) = (2.95 \pm 0.07)\%$$



- **Measurement of branching fractions with highest possible accuracy**
- **Measurement of low-energy hadronic spectral functions**
  - **Determination of the decay mechanism (what are intermediate mesons and their contributions)**
  - **Precise measurement of masses and widths of the intermediate mesons**
- **Comparison with hadronic formfactors from e^+e^- experiments to check CVC theorem**
- **Measurement of $\Gamma_{\text{inclusive}}(S=-1)$ to determine V_{us} and s-quark mass**
- **Search for CP violation in particular decay modes**

Study of the $\tau^- \to K_S \pi^- \nu_\tau$ decay

- **Measurement of $\tau \to K_S \pi \nu_\tau$ branching ratio** $\tau \to \bar{K}^0 \pi \nu_\tau$ has the largest $\mathcal{B}$ among decays with one kaon, so provides the dominant contribution to the s-quark mass sensitive total strange hadronic spectral function.
- **$K_S\pi$ mass spectrum (F_V: $K^*(892)$, $K^*(1410)$, $K^*(1680)$; F_S: $K_0^*(800)(\kappa)$, $K_0^*(1430)$)**
  - M. Battle *et al.* [CLEO Collaboration], "Measurement of Cabibbo suppressed decays of the tau lepton," Phys. Rev. Lett. **73**, 1079 (1994) [arXiv:hep-ph/9403329].
  - P. Lichard, Phys.Rev.D **60**, 093012 (1999) (nonzero value of the slope parameter λ_0 of the $K^{\pm}_{\mu 3}$ and $K^0_{\mu 3}$ formfactors implies the existence of the $\tau \to K_0^\star(1430)\nu_\tau$ decay)
  - M. Finkemeier and E. Mirkes, "The scalar contribution to $\tau \to K\pi\nu_\tau$", Z. Phys. C **72**, 619 (1996) [arXiv:hep-ph/9601275].
- **CP violation in $\tau \to K_S \pi \nu_\tau$**
  - J.Kuhn, E.Mirkes,Phys. Lett. **B398**, 407 (1997)
  - G.Bonvicini *et al* (CLEO), Phys.Rev.Lett.**88**, 111803 (2002)
  - I.I.Bigi, A.I.Sanda, Phys. Let. B **625**, 47 (2005)
  - G. Calderon, D. Delepine and G. L. Castro, "Is there a paradox in CP asymmetries of $\tau^\pm \to (K_L, K_S)\pi^\pm\nu_\tau$ decays?" arXiv:hep-ph/0702282.

Theoretical framework

$$iM_{\rm fi}({\rm S}=0) = \frac{\rm ig}{2\sqrt{2}}\overline{u}_{\nu_\tau}\gamma^\mu(1-\gamma^5)u_\tau \cdot \frac{i(-g_{\mu\nu}+q_\mu q_\nu/M_W^2)}{q^2-M_W^2+iM_W\Gamma_W}\cdot\langle{\rm hadrons}(q^\mu)|\frac{\rm ig}{2\sqrt{2}}\cos\theta_{\rm c}\overline{u}_d\gamma_\nu(1-\gamma^5)v_u|0\rangle$$

$$iM_{\rm fi}({\rm S}=-1) = \frac{\rm ig}{2\sqrt{2}}\overline{u}_{\nu_\tau}\gamma^\mu(1-\gamma^5)u_\tau \cdot \frac{i(-g_{\mu\nu}+q_\mu q_\nu/M_W^2)}{q^2-M_W^2+iM_W\Gamma_W}\cdot\langle{\rm hadrons}(q^\mu)|\frac{\rm ig}{2\sqrt{2}}\sin\theta_{\rm c}\overline{u}_s\gamma_\nu(1-\gamma^5)v_u|0\rangle$$

$q^2 \ll M_W^2$, $M_{\rm fi}$ can be written in terms of four-fermion interaction with ${\rm G_F}/\sqrt{2} = {\rm g}^2/8M_W^2$:

$$iM_{\rm fi}\left\{\begin{array}{c} S=0 \\ S=-1\end{array}\right\} = \frac{\rm G_F}{\sqrt{2}}\overline{u}_{\nu_\tau}\gamma^\mu(1-\gamma_5)u_\tau\cdot\left\{\begin{array}{l}\cos\theta_{\rm c}\cdot\langle{\rm hadrons}(q^\mu)|\hat{J}_\mu^{S=\,0}(q^2)|0\rangle \\ \sin\theta_{\rm c}\cdot\langle{\rm hadrons}(q^\mu)|\hat{J}_\mu^{S=-1}(q^2)|0\rangle\end{array}\right\},\ q^2\le M_\tau^2$$

Isotopic structure of the hadronic currents (T-isospin):

$$\hat{J}_\mu^{S=\,0}(q^2) = \overline{d}\gamma_\mu(1-\gamma_5)u, \quad \hat{J}_\mu^{S=\,0}(q^2)|0\rangle \sim |T=1;T_z=+1\rangle$$

$$\hat{J}_\mu^{S=-1}(q^2) = \overline{s}\gamma_\mu(1-\gamma_5)u, \quad \hat{J}_\mu^{S=-1}(q^2)|0\rangle \sim |T=1/2;T_z=+1/2\rangle$$

In the case of two pseudoscalar hadrons ($J^{\rm PC}=0^{-+}$) with momenta q_1^μ and q_2^μ:

$$J^\mu = F_V(q^2)\left(g^{\mu\nu}-\frac{q^\mu q^\nu}{q^2}\right)(q_1-q_2)_\nu + F_S(q^2)q^\mu,\ q^\mu = q_1^\mu+q_2^\mu$$

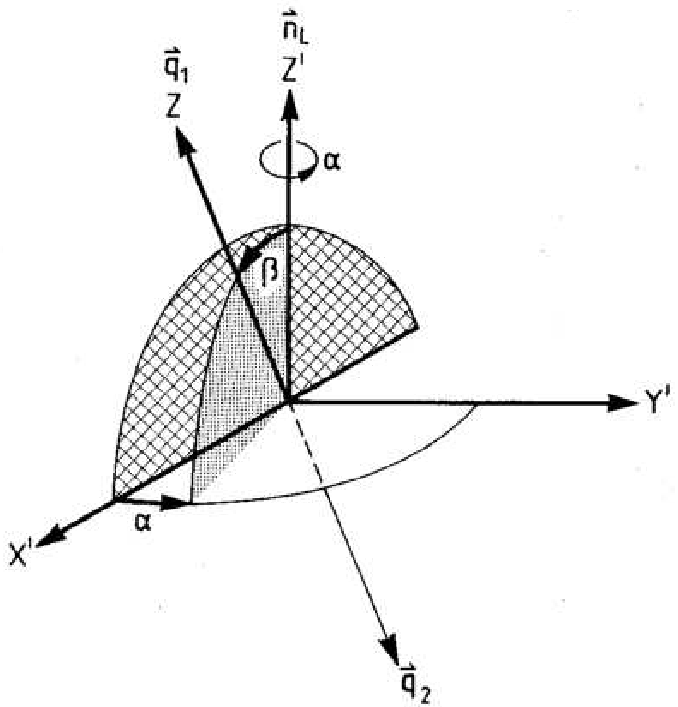
$\tau \to K\pi\nu_\tau$ decay

$$d\Gamma = \frac{G_F^2}{256\pi^3 m_\tau} \sin^2\theta_c \{L_{\mu\nu} H^{\mu\nu}\} \left(1 - \frac{s}{m_\tau^2}\right) |\vec{P}| \frac{ds}{\sqrt{s}} \frac{d\alpha}{2\pi} \frac{d\cos\beta}{2} \frac{d\cos\theta}{2}$$

$$L_{\mu\nu} H^{\mu\nu} = 2m_\tau^2 \left(1 - \frac{s}{m_\tau^2}\right) (\overline{L}_B W_B + \overline{L}_{SA} W_{SA} + \overline{L}_{SF} W_{SF})$$

$$W_B = 4\vec{P}^2 |F_V|^2, \; W_{SA} = s|F_S|^2, \; W_{SF} = 4s|\vec{P}|\mathrm{Re}[F_V F_S^*]$$

$$\overline{L}_B = \frac{1}{3}\left(2 + \frac{m_\tau^2}{s}\right) - \frac{1}{6}\left(1 - \frac{m_\tau^2}{s}\right)(3\cos^2\psi - 1)(3\cos^2\beta - 1), \; \overline{L}_{SA} = \frac{m_\tau^2}{s}, \; \overline{L}_{SF} = -\frac{m_\tau^2}{s}\cos\psi\cos\beta$$

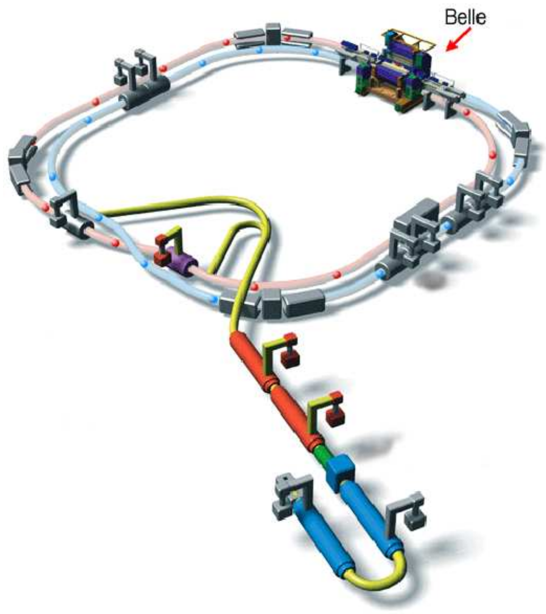


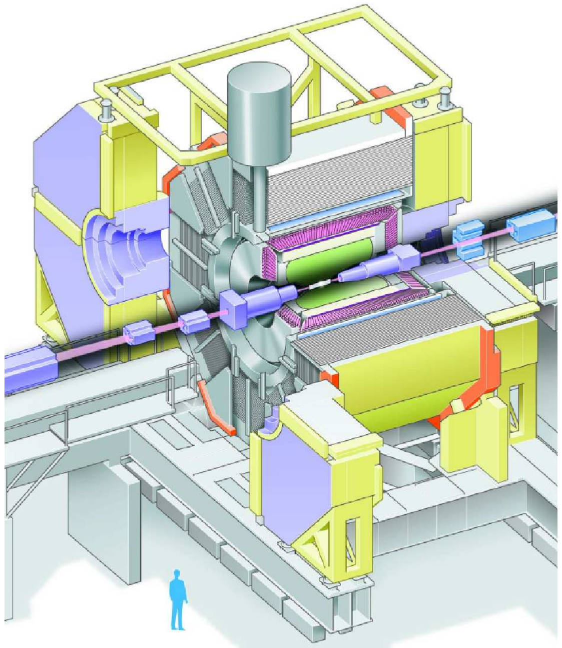
$$\cos\beta = \vec{n_L} \cdot \frac{\vec{P}}{|\vec{P}|}$$

$$\cos\theta = \frac{(2\frac{E_h}{E_\tau} - 1 - \frac{s}{m_\tau^2})}{(1 - \frac{s}{m_\tau^2})\sqrt{1 - m_\tau^2/E_\tau^2}}$$

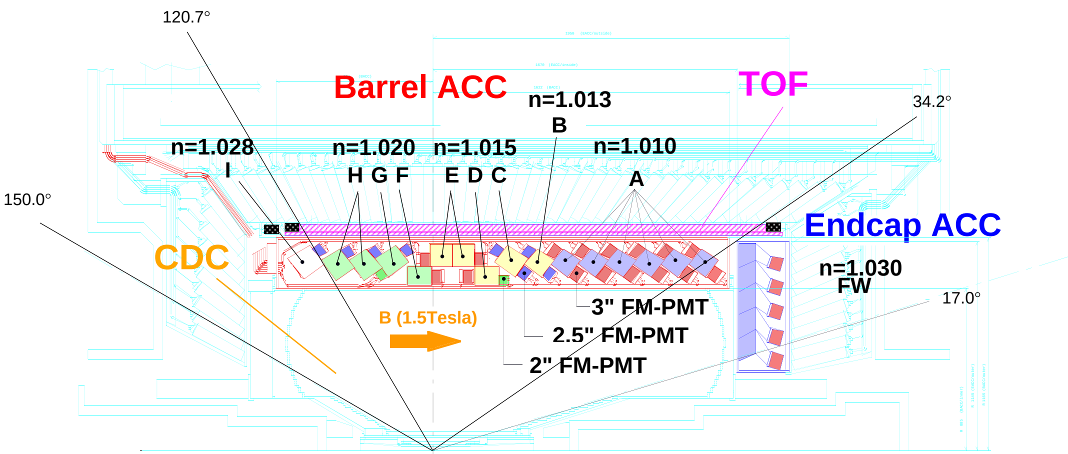
$$\cos\psi = \frac{\frac{E_h}{E_\tau}(m_\tau^2 + s) - 2s}{(m_\tau^2 - s)\sqrt{(E_h^2 - s)/E_\tau^2}}$$

KEKB B-factory, detector Belle





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
$e^+e^- \to q\overline{q}\ (q = u, d, s, c)$	3.39
$e^+e^- \to b\overline{b}$	1.05
$e^+e^- \to e^+e^- f\overline{f}$ $(f = u, d, s, c, e, \mu, \tau)$	72.6
$e^+e^- \to \tau^+\tau^-(\gamma)$	0.919

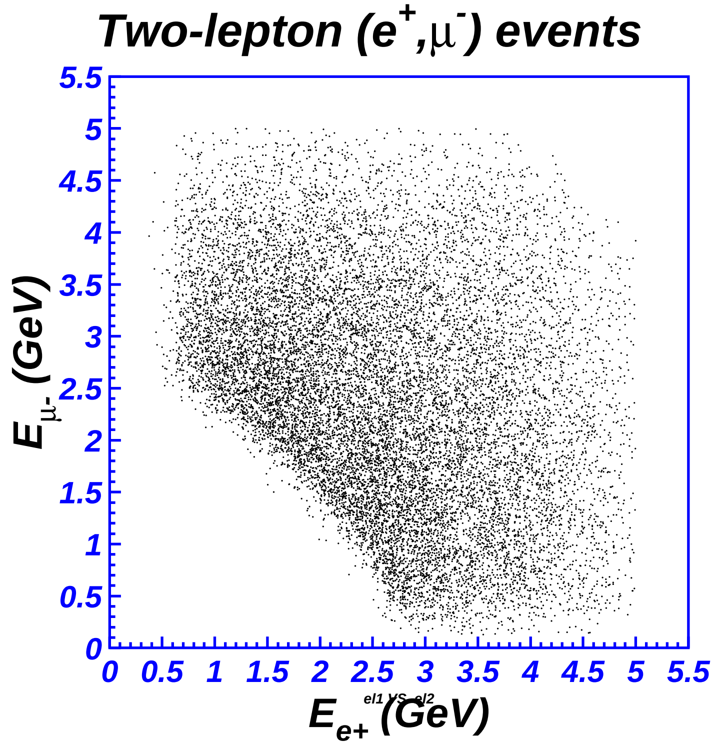


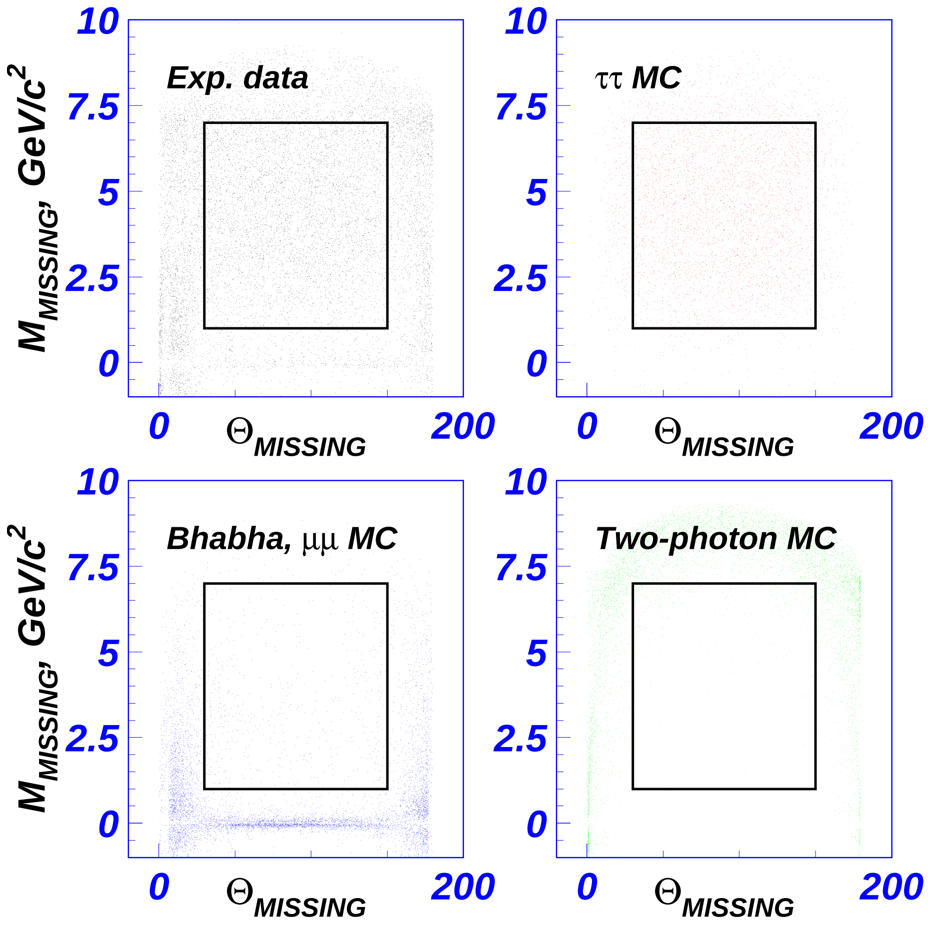
- **Peak luminosity**
  $L = 2.11 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$
- **Integrated luminosity**
  $\int L dt = 946\ \mathrm{fb}^{-1}$
- **B-factory is also τ-factory**

Main preselection criteria

- $2 \leq N_{\rm tracks} \leq 4$ $(P_{\perp}^{\rm CMS} > 0.1$ MeV/c, $|\triangle r| < 0,5$ cm, $|\triangle z| < 2.5$ cm $)$
- $|Q_{total}| \leq 1$
- $N_{\gamma} \leq 5$ $(E_{\gamma}^{CMS} > 0.08$ MeV $)$
- $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 9$ MeV

$$1 \text{ MeV}/c^2 \leq M_{\rm missing} \leq 7 \text{ MeV}/c^2$$
$$30^{\rm o} \leq \theta_{\rm missing}^{\rm CMS} \leq 150^{\rm o}$$

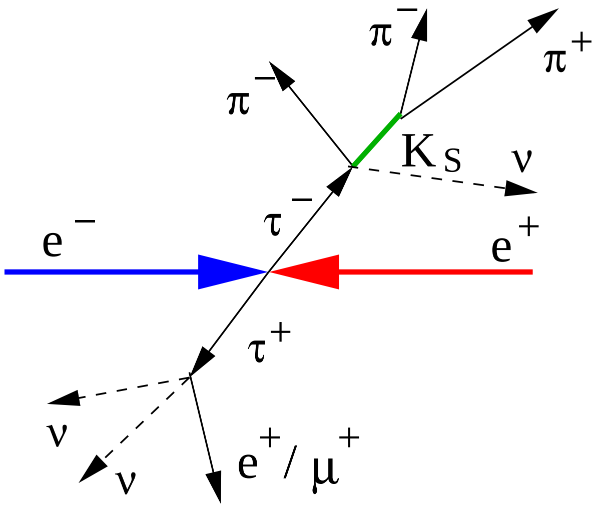


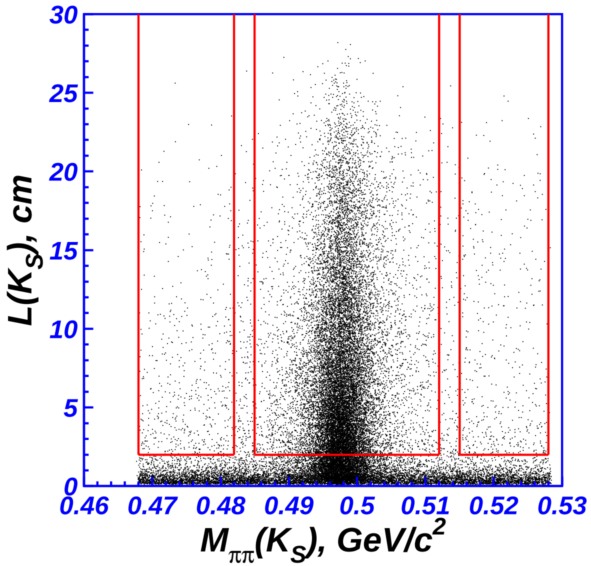


The efficiency for $\tau\tau$ events is 46%. Selected sample contains 80% of $\tau\tau$ events and 20% of background events.

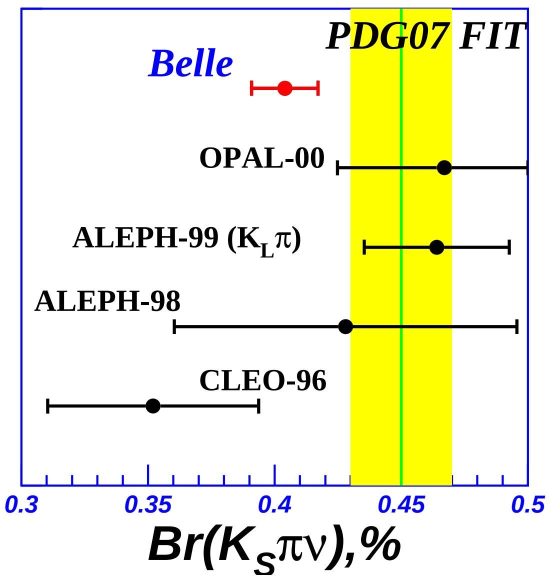
Measurement of $\mathcal{B}(\tau^- \to K_S \pi^- \nu_\tau)$

Statistics: $\int L dt = 351\ \mathrm{fb}^{-1} \to 323 \times 10^6\ \tau\tau$ events





Mode	Contents, %
$K_S \pi \nu$	79
$K_S \pi K_L \nu$	9
$K_S \pi \pi^0 \nu$	4
$K_S K \nu$	2
$3\pi\nu$	5
non-$\tau\tau$	1



53110 signal events with efficiency $\varepsilon_{\mathrm{det}} \simeq 6\%$

Two-lepton (e, μ) events are used for normalization

$$\mathcal{B}(K_S \pi^\mp \nu_\tau) = \frac{N(l_1^\pm, K_S \pi^\mp)}{N(l_1^\pm, l_2^\mp)} \cdot \frac{\varepsilon(l_1^\pm, l_2^\mp)}{\varepsilon(l_1^\pm, K_S \pi^\mp)} \cdot \mathcal{B}(l_2^\mp \nu_l \nu_\tau), \quad l_{1,2} = e, \mu$$

$\mathcal{B}(\tau^- \to K_S \pi^- \nu_\tau) = (0.404 \pm 0.002(\mathrm{stat.}) \pm 0.013(\mathrm{syst.}))\%$

Is in agreement with

$\mathcal{B}(\tau^- \to K^- \pi^0 \nu_\tau) = (0.416 \pm 0.003(\mathrm{stat.}) \pm 0.018(\mathrm{syst.}))\%$

measured by BaBar.

Study of the $K_S\pi$ mass ($\sqrt{s}$) spectrum

$$\frac{d\Gamma}{d\sqrt{s}} \sim \frac{1}{s}\left(1-\frac{s}{M_\tau^2}\right)^2\left(1+2\frac{s}{M_\tau^2}\right)P\left\{P^2|F_V|^2+\frac{3(M_K^2-M_\pi^2)^2}{4s(1+2\frac{s}{M_\tau^2})}|F_S|^2\right\}$$

$$F_V = \frac{BW_{K^*(892)} + a(K^*(1410)) \cdot BW_{K^*(1410)} + a(K^*(1680)) \cdot BW_{K^*(1680)}}{1 + a(K^*(1410)) + a(K^*(1680))}$$

$$F_S = a(K_0^*(800)) \cdot BW_{K_0^*(800)} + a(K_0^*(1430)) \cdot BW_{K_0^*(1430)}$$

$$BW_X = \frac{M_X^2}{M_X^2 - s - i\sqrt{s}\Gamma_X(s)}$$

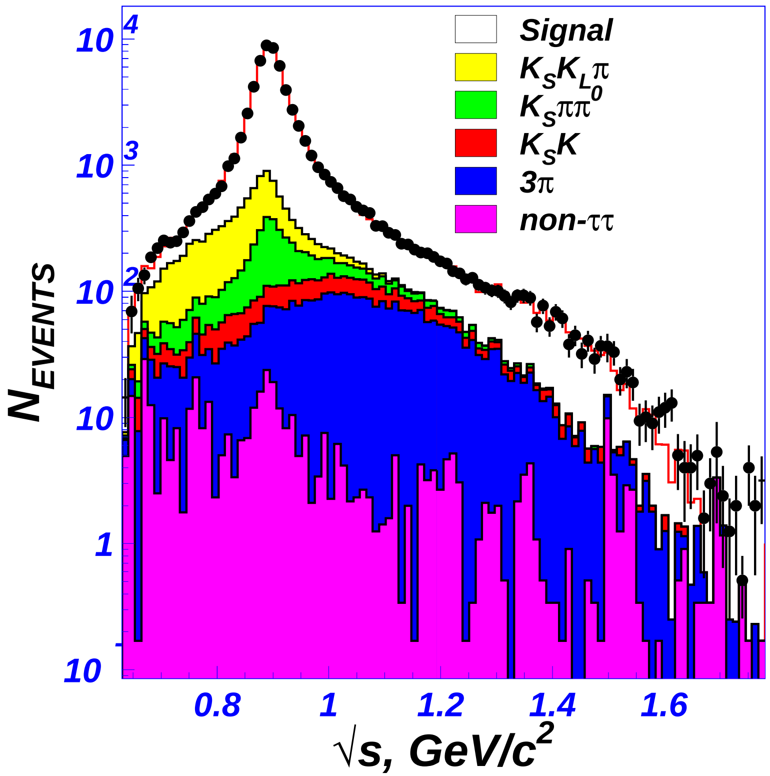
$$\Gamma_X(s) = \Gamma_X \frac{M_X^2}{s}\left(\frac{P(s)}{P(M_X^2)}\right)^{2\ell+1} \cdot F_R^{\ell 2}$$

$$P(s) = \frac{\sqrt{(s-(M_K+M_\pi)^2)(s-(M_K-M_\pi)^2)}}{2\sqrt{s}}$$

Spin ℓ	Blatt-Weisskopf factor F_R^ℓ
0	1
1	$\sqrt{\frac{1+R^2P^2(M_X^2)}{1+R^2P^2(s)}}$
2	$\sqrt{\frac{9+3R^2P^2(M_X^2)+R^4P^4(M_X^2)}{9+3R^2P^2(s)+R^4P^4(s)}}$

$K_0^*(800) + K^*(892) + K^*(1410)$

The $K^*(892)$ alone is not sufficient to describe the $K_S\pi$ spectrum



$$M_{K^*(892)} = 895.47 \pm 0.20 \text{ MeV/c}^2$$
$$\Gamma_{K^*(892)} = 46.19 \pm 0.57 \text{ MeV}$$
$$|a(K^*(1410))| = (75 \pm 6) \times 10^{-3}$$
$$\arg(a(K^*(1410))) = 1.44 \pm 0.15$$
$$|a(K_0^*(800))| = 1.57 \pm 0.23$$
$$\chi^2/\text{Ndf} = 90.2/84, \; P(\chi^2) = 30\%$$

We take $K_0^*(800)$ parameters:
$M_{K_0^*(800)} = 878 \pm 23 \pm 60$ MeV/c^2, $\Gamma_{K_0^*(800)} = 499 \pm 52 \pm 71$ MeV/c^2 from:
M. Ablikim *et al.*, (BES Collaboration), Phys. Lett. B **633** (2006) 681.

We extract the fraction of the $K^*(892)\nu$ mechanism:

$$\mathcal{B}(\tau \to K^*(892)\nu_\tau) \cdot \mathcal{B}(K^*(892) \to K_S\pi)/\mathcal{B}(\tau \to K_S\pi\nu_\tau) = 0.933 \pm 0.027$$

$K_0^*(800) + K^*(892) + K_0^*(1430)$

	solution 1	solution 2
$M_{K^*(892)}$, MeV/c^2	895.42 ± 0.19	895.50 ± 0.22
$\Gamma_{K^*(892)}$, MeV	46.14 ± 0.55	46.20 ± 0.69
$\lvert\gamma\rvert$	0.954 ± 0.081	1.92 ± 0.20
$arg(\gamma)$	0.62 ± 0.34	4.03 ± 0.09
$\varkappa$	1.27 ± 0.22	2.28 ± 0.47
χ^2/ndf	$86.5/84$	$95.1/84$
$P(\chi^2), \%$	41	19
$\mathcal{B}(K_0^*(1430) \to K_S \pi)$	1/3	1/3
$\mathcal{B}(\tau \to K_0^*(1430)\nu_\tau)$	$(13 \pm {}^{3}_{2}) \times 10^{-5}$	$(54 \pm {}^{18}_{9}) \times 10^{-5}$

M. Z. Yang, "Testing the structure of the scalar meson $K_0^*(1430)$ in $\tau \to K_0^*(1430)\nu_\tau$ decay", Mod. Phys. Lett. A **21**, 1625 (2006) [arXiv:hep-ph/0509102]:

$$\mathcal{B}(\tau \to K_0^*(1430)\nu_\tau) = (7.9 \pm 3.1) \times 10^{-5}$$

LASS parametrization of the scalar formfactor F_S

P.Estabrooks, Phys.Rev. **D19**, 2678 (1979)

D.Aston et al. (LASS), Nucl. Phys. **B296**, 493 (1988)

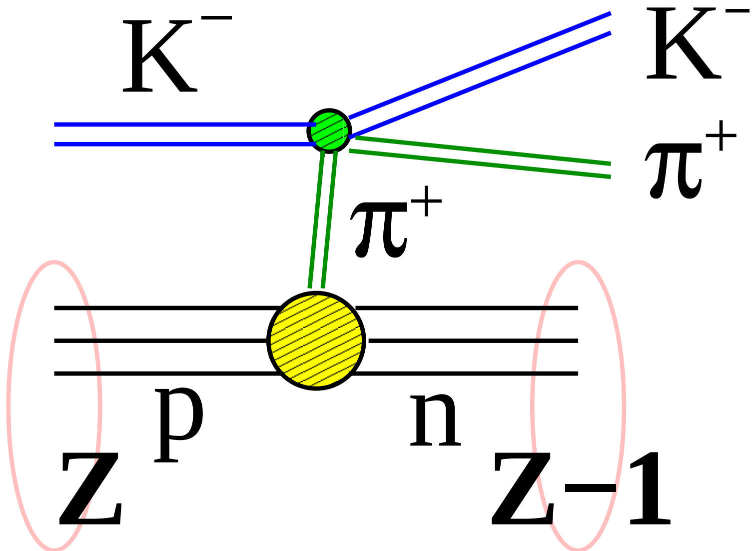
$$F_S = \frac{M_{K\pi}}{P}(\sin\delta_B e^{i\delta_B} + e^{2i\delta_B} BW_{K_0^*(1430)}(M_{K\pi}))$$

$$\cot\delta_B = \frac{1}{aP} + \frac{bP}{2}$$

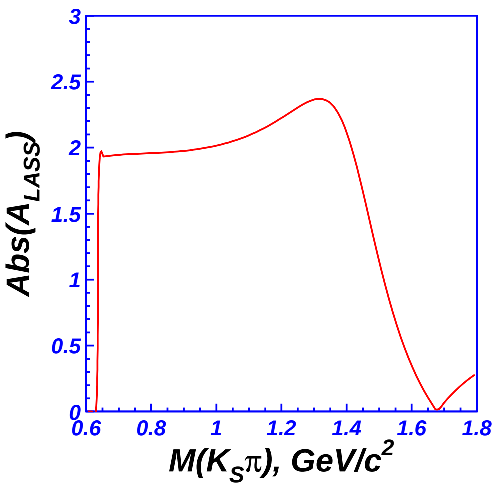
$$a = (2.07 \pm 0.10)\ (\mathrm{GeV/c})^{-1}$$

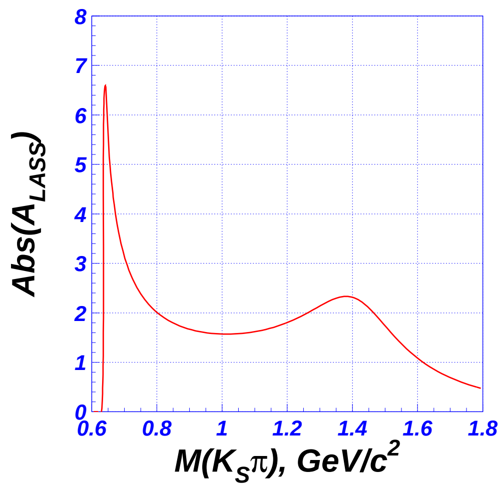
$$b = (3.32 \pm 0.34)\ (\mathrm{GeV/c})^{-1}$$

$$P = \frac{\sqrt{(M^2_{K\pi} - (M_K + M_\pi)^2)(M^2_{K\pi} - (M_K - M_\pi)^2)}}{2M_{K\pi}}$$



	$K^*(892)$+LASS a, b-fixed	$K^*(892)$+LASS a, b-free
M_{K^*}, MeV/c^2	895.42 ± 0.19	895.38 ± 0.23
Γ_{K^*}, MeV	46.46 ± 0.47	46.53 ± 0.50
λ	0.282 ± 0.011	0.298 ± 0.012
a, (GeV/c)$^{-1}$	2.13 ± 0.10	$10.9 + 7.4 - 3.0$
b, (GeV/c)$^{-1}$	3.96 ± 0.31	$19.0 + 4.5 - 3.6$
χ^2/n.d.f.	196.9/86	97.3/83
$P(\chi^2)$, %	10^{-8}	13





$K^{*-}(892)$ mass and width

Model uncertainties in $K^*(892)$ mass and width are evaluated from approximations with the following models: $K_0^*(800) + K^*(892) + K_0^*(1430)$, $K_0^*(800) + K^*(892) + K^*(1680)$, $K^*(892)$+LASS.

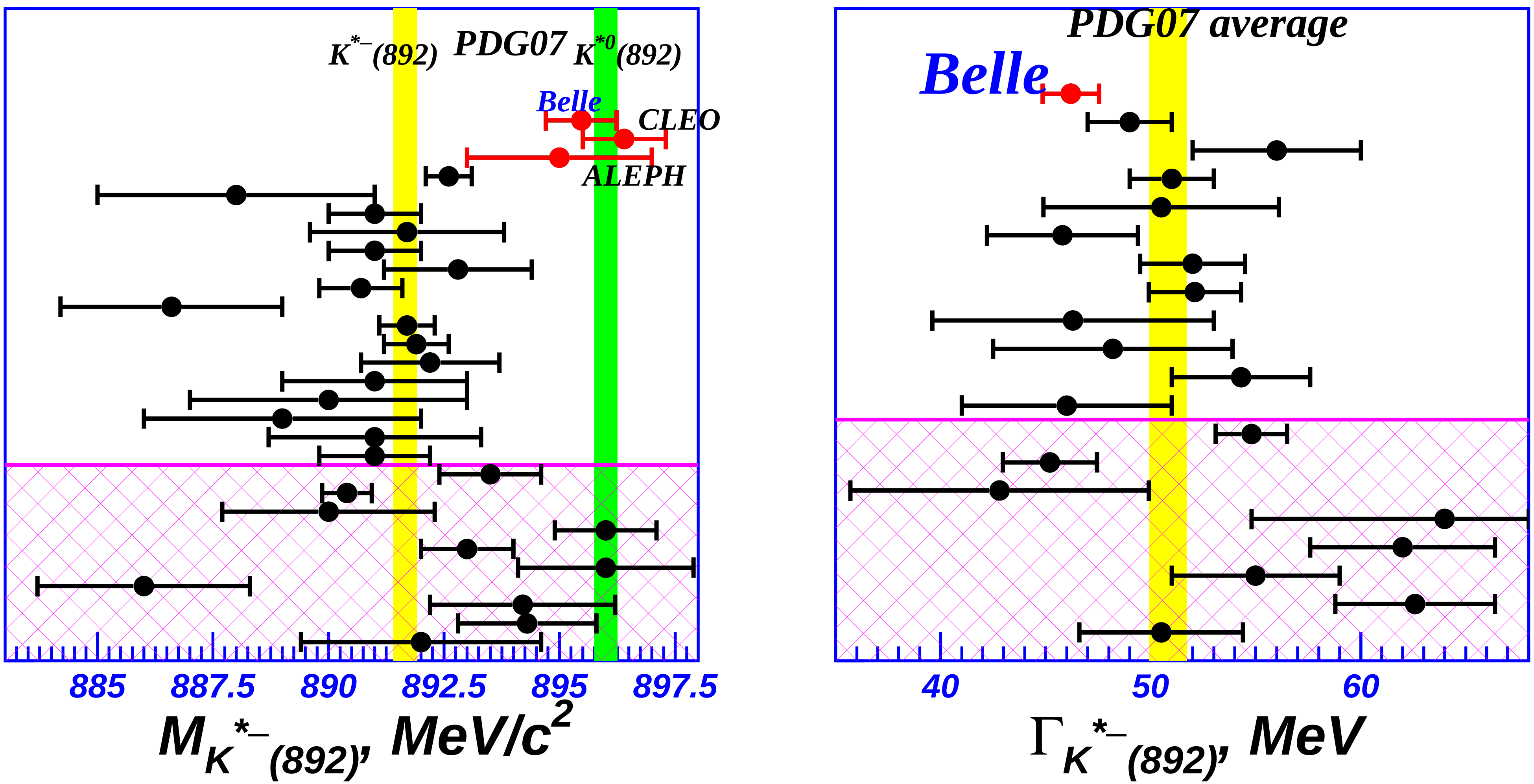
	$\mathrm{M(K^*(892)),\ MeV/c^2}$	$\Gamma(\mathrm{K^*(892)}),\ \mathrm{MeV}$
This work	$895.47 \pm 0.20_{stat} \pm 0.44_{syst} \pm 0.59_{mod}$	$46.2 \pm 0.6_{stat} \pm 1.0_{syst} \pm 0.7_{mod}$
PDG-2008	891.66 ± 0.26	50.8 ± 0.9
Difference	3.81 ± 0.80	-4.6 ± 1.7

PDG average is based on the results from the fixed target experiments

894.3 ±1.5	1150	[2,3] CLARK	73	HBC	–	3.3 $K^- p \to \overline{K}^0 \pi^- p$
892.0 ±2.6	341	[2] SCHWEING...	68	HBC	–	5.5 $K^- p \to \overline{K}^0 \pi^- p$

CHARGED ONLY, PRODUCED IN τ LEPTON DECAYS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
895.47±0.20±0.74	53k	[6] EPIFANOV	07	BELL	$\tau^- \to K_S^0 \pi^- \nu_\tau$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
895.3 ±0.2		[7,8] JAMIN	08	RVUE	$\tau^- \to K_S^0 \pi^- \nu_\tau$
896.4 ±0.9	11970	[9] BONVICINI	02	CLEO	$\tau^- \to K^- \pi^0 \nu_\tau$
895 ±2		[10] BARATE	99R	ALEP	$\tau^- \to K^- \pi^0 \nu_\tau$

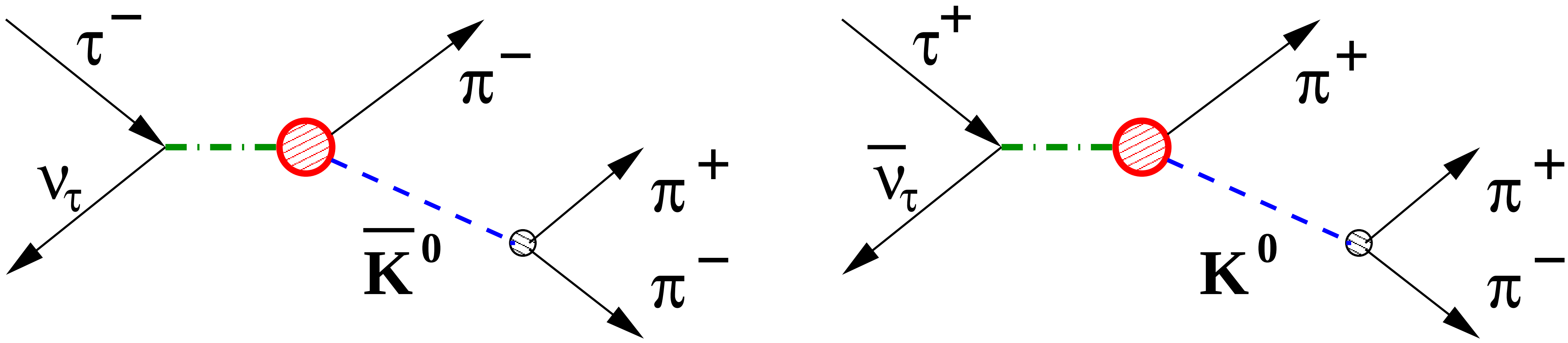


D. Epifanov *et al.* [Belle Collaboration], "Study of $\tau^- \to K_S \pi^- \nu_\tau$ decay at Belle," Phys. Lett. B **654** (2007) 65

CP violation in $\tau \to K_S \pi \nu$

A known CP violation in neutral kaon decays induces asymmetry in τ decays with K_S

G. Calderon, D. Delepine and G. L. Castro, Phys. Rev. D **75** (2007) 076001



$$\eta_{+-} = \frac{\epsilon + \chi_{+-}}{1 + \chi_{+-}\epsilon} = |\eta_{+-}| e^{i\phi_{+-}}, \quad \chi_{+-} = \frac{\mathcal{M}(K_2 \to \pi^+\pi^-)}{\mathcal{M}(K_1 \to \pi^+\pi^-)}$$

$$\chi_{+-} = 0 \Longrightarrow \eta_{+-} = \epsilon = |\epsilon| e^{i\phi_{+-}}$$

$$|\mathcal{T}_-|^2(t) \equiv \frac{d\Gamma_-}{dt} \simeq \frac{B(1+2Re[\epsilon])}{4M^2}\left[e^{-\Gamma_S t} + |\epsilon|^2 e^{-\Gamma_L t} - 2|\epsilon| e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)t}\cos(\Delta m t - \phi_{+-})\right]$$

$$|\mathcal{T}_+|^2(t) \equiv \frac{d\Gamma_+}{dt} \simeq \frac{B(1-2Re[\epsilon])}{4M^2}\left[e^{-\Gamma_S t} + |\epsilon|^2 e^{-\Gamma_L t} + 2|\epsilon| e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)t}\cos(\Delta m t - \phi_{+-})\right]$$

$$A(t) = \frac{|\mathcal{T}_+|^2 - |\mathcal{T}_-|^2}{|\mathcal{T}_+|^2 + |\mathcal{T}_-|^2} \simeq 2Re[\epsilon]\left(\frac{\frac{1}{\cos\phi_{+-}} e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)t} \cos(\Delta m t - \phi_{+-}) - e^{-\Gamma_S t} - |\epsilon|^2 e^{-\Gamma_L t}}{e^{-\Gamma_S t} + |\epsilon|^2 e^{-\Gamma_L t} - 4|\epsilon|^2 e^{-\frac{1}{2}(\Gamma_S+\Gamma_L)t} \cos(\Delta m t - \phi_{+-}) \cos\phi_{+-}} \right)$$

$$\tau_S << T << \tau_L$$

$$A_{CP}^S = \frac{\int_0^T |\mathcal{T}_+(t)|^2 dt - \int_0^T |\mathcal{T}_-(t)|^2 dt}{\int_0^T |\mathcal{T}_+(t)|^2 dt + \int_0^T |\mathcal{T}_-(t)|^2 dt} \approx 2Re[\epsilon] = (3.32 \pm 0.06) \times 10^{-3}$$

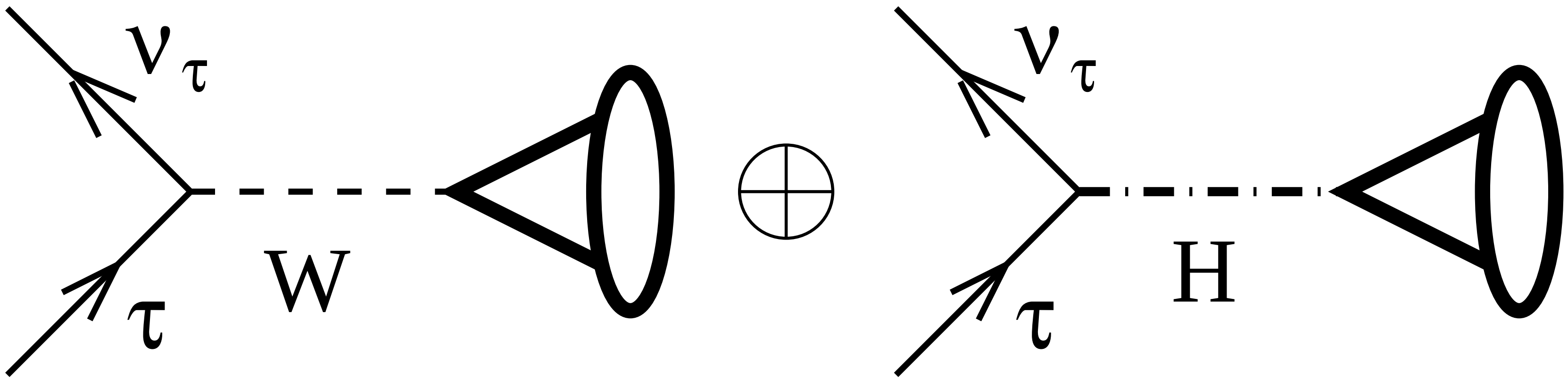
To extract A_{CP}^S from the experiment we have to take into account charge asymmetry of the detector response:

$$A_{CP}^S \approx A_{\text{visible}} - A_{\text{detector}}$$

The A_{CP}^S uncertainty of the order of 10^{-3} can be achieved with Belle data

J. H. Kuhn and E. Mirkes, "CP violation in semileptonic tau decays with unpolarized beams," Phys. Lett. B **398**, 407 (1997) [arXiv:hep-ph/9609502].

Possible CP violating signals from multi Higgs boson models can be observed



$$H_{CP}^{(0)} = \sin\theta_c \frac{G_F}{\sqrt{2}} \overline{u}_{\nu_\tau} \gamma_\mu (1-\gamma_5) u_\tau \left\{ \eta_S \frac{q^\mu}{m_\tau} \overline{u}_s v_u + \eta_P \frac{q^\mu}{m_\tau} \overline{u}_s \gamma_5 v_u \right\}$$

$$F_S(s) \rightarrow \tilde{F_S}(s) = F_S(s) + \frac{\eta_S}{m_\tau} F_H(s)$$

$$CP : d\Gamma_{\tau^-}(\vec{p_i}, \eta_S) \rightarrow d\Gamma_{\tau^+}(-\vec{p_i}, \eta_S^*)$$

$$\Delta_X = \frac{1}{2}[\overline{L}_X(\vec{p_i})W_X(\eta_S) - \overline{L}_X(-\vec{p_i})W_X(\eta_S^*)] = \frac{1}{2}\overline{L}_X(\vec{p_i})[W_X(\eta_S) - W_X(\eta_S^*)] \equiv \overline{L}_X \Delta W_X$$

$$\Delta W_B = 0,\ \Delta W_{SA} = \frac{2s}{m_\tau}\mathrm{Im}(F_S F_H^*)\mathrm{Im}(\eta_S),\ \Delta W_{SF} = \frac{4}{m_\tau}\sqrt{s}|\vec{P}|\mathrm{Im}(F_\mathrm{V} F_\mathrm{H}^*)\mathrm{Im}(\eta_\mathrm{S})$$

Due to the missing ν_τ we can not fully reconstruct the kinematics of τ decay. As a result we are not able to perform CP violation study in the same manner as in the B decays. The most general way is to define a CP-odd optimal observable and then to determine its average value.

$$\Delta(\vec{p_i}) = \frac{d\Gamma^{\tau^-}}{d\Phi}(\vec{p_i}) - \frac{d\Gamma^{\tau^+}}{d\Phi}(-\vec{p_i}),\ \Sigma(\vec{p_i}) = \frac{d\Gamma^{\tau^-}}{d\Phi}(\vec{p_i}, \eta_S = 0) + \frac{d\Gamma^{\tau^+}}{d\Phi}(-\vec{p_i}, \eta_S^* = 0)$$

$$\xi^-(\vec{p_i}) = \frac{\Delta(\vec{p_i})}{\Sigma(\vec{p_i})} = \frac{\overline{L}_{SF}(\vec{p_i})\Delta W_{SF}(\eta_S = i)}{\sum_X \overline{L}_X(\vec{p_i})W_X(\eta_S = 0)},\quad \xi^+(\vec{p_i}) = \xi^-(-\vec{p_i})$$

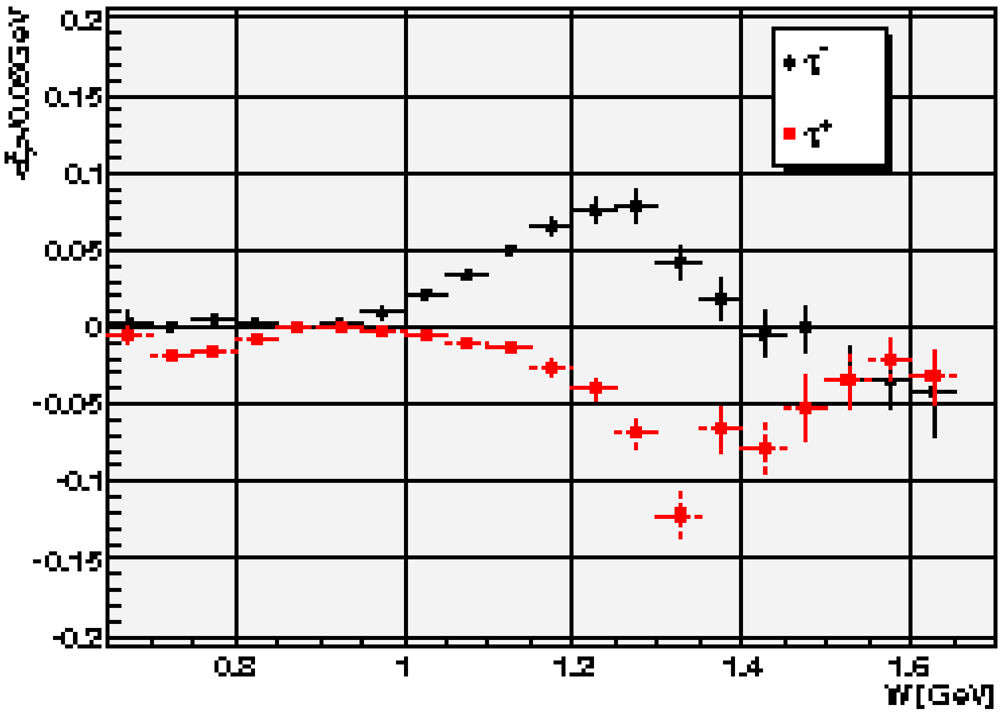
$\overline{L}_X(\vec{p_i})$, W_X depend on the four-momenta of K_S, π and on the F_V, F_S parametrizations

$$\int\limits_{\Delta\Phi}\left(\xi^-(\vec{p_i})\frac{d\Gamma^{\tau^-}}{d\Phi}(\vec{p_i}) - \xi^+(-\vec{p_i})\frac{d\Gamma^{\tau^+}}{d\Phi}(-\vec{p_i})\right)d\Phi = \mathrm{Im}(\eta_S)\int\limits_{\Delta\Phi}\frac{\Delta^2(\vec{p_i})}{\Sigma(\vec{p_i})}d\Phi$$

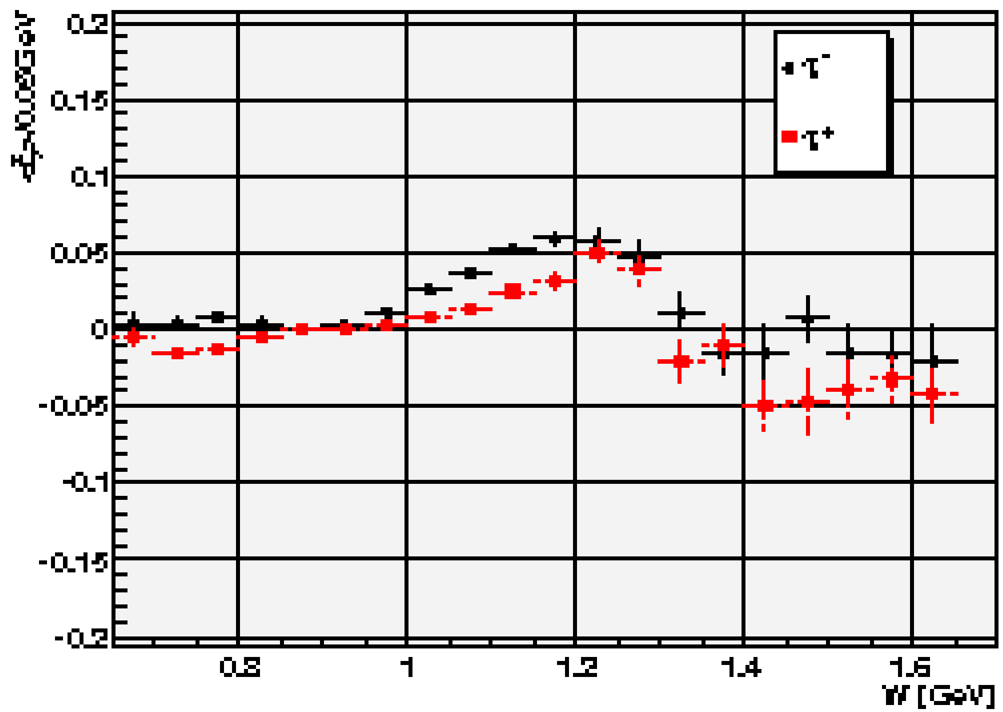
Integrating over all angles and finite Δs region:

$$\Delta < \xi > = < \xi^- > - < \xi^+ >,\quad < \xi^\mp > = \int\limits_{\Delta s}\xi^\mp\frac{d\Gamma^{\tau^\mp}}{ds d\Omega}d\Omega ds$$

$<\xi>$ as a function of the $K_S\pi$ invariant mass in the case of the maximal CP violation ($\eta_S = i$)



$K_0^*(800) + K^*(892) + K_0^*(1430)$



$K_0^*(800) + K^*(892) + K^*(1410)$

$$\tilde{F}_S(s) = \left(1 + \frac{s}{m_\tau(m_u - m_s)}\eta_S\right) F_S(s)$$

Conclusion

- **Huge statistics recorded by Belle allows us to study hadronic τ decays with high accuracy.** The measured branching fraction of $\tau^- \to K_S\pi^-\nu_\tau$ decay mode is consistent with the world average value and has better accuracy.

- We studied the $K_S\pi$ mass spectrum in the $\tau \to K_S\pi\nu$ sample. The $K^*(892)$ alone is not sufficient to describe the $K_S\pi$ invariant mass spectrum. The best description is achieved in the $K_0^*(800) + K^*(892) + K_0^*(1410)$ and $K_0^*(800) + K^*(892) + K_0^*(1430)$ models.

  The study of the full phase-space distribution will allow us to investigate the structure of the scalar formfactor, needed also in the search of the CP violation in $\tau^- \to K_S\pi^-\nu_\tau$ decay.

- For the first time the the $K^*(892)^-$ mass and width have been measured in τ decay. The $K^*(892)^-$ mass is significantly different from the current world average value. Future dedicated measurements of the $K^*(892)^-$ parameters with high precision are necessary to clarify this discrepancy.

- There are several possibilities to search for CP violation in $\tau^- \to K_S\pi^-\nu_\tau$ decay. Besides the known CP asymmetry induced by CP violation in neutral kaon decays tau decays themselves can be a source of CP violation effects coming from **New Physics**.