Nagoya seminar
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Analysis of $\tau^- \to K_S \pi^- \nu_\tau$ decay at Belle

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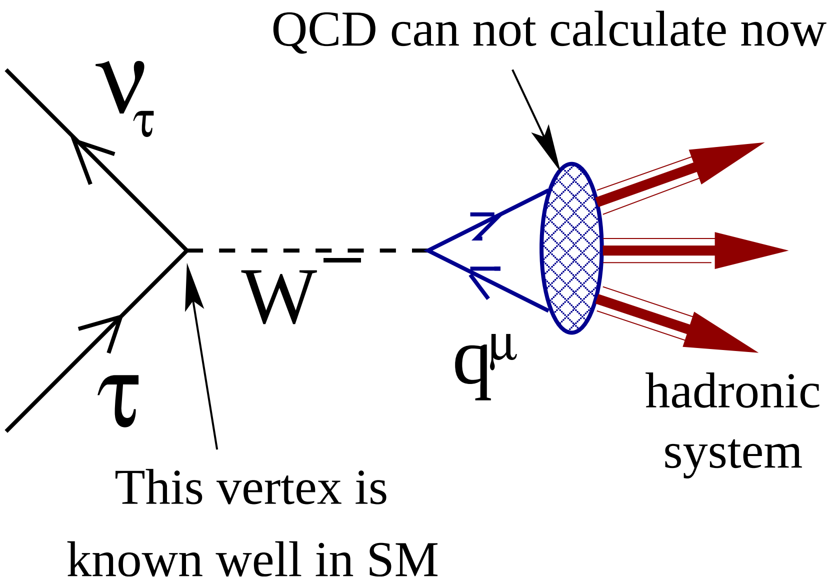
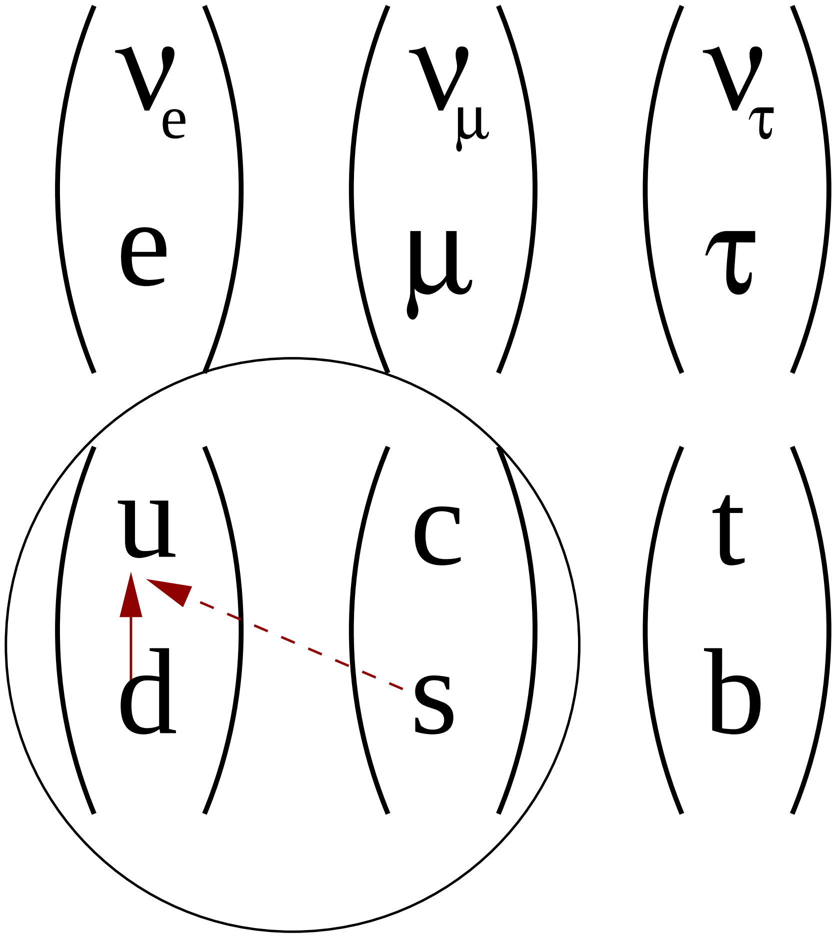
Outline:

- Motivation
- τ analysis at Belle
- Selection of τ events
- Background, detection efficiency, corrections
- Measurement of $\mathcal{B}(\tau \to K_S \pi \nu)$
- Study of the $K_S \pi$ mass spectrum
- Conclusion and Plans

Motivation

τ is the only lepton decaying to hadrons.

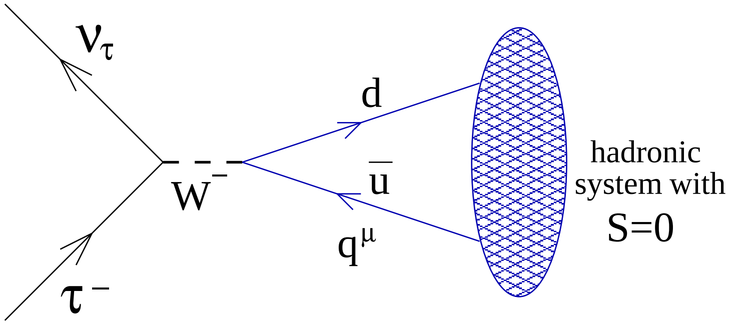




There is no strong interaction between initial and final particles.

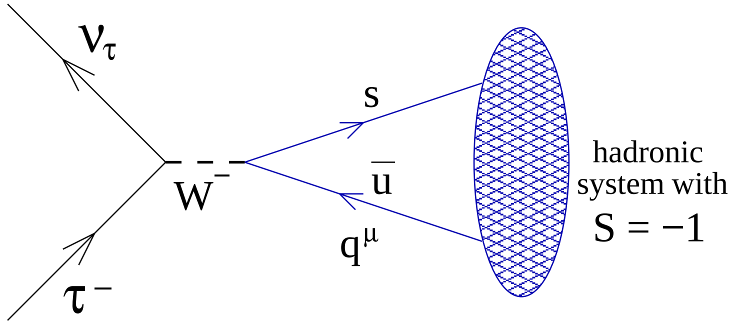
Cabibbo allowed decays ($\mathcal{B} \sim \cos^2\theta_c$)

$$\tau^- \to \text{hadrons}(S=0)^- \nu_\tau$$



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

$$\tau^- \to \text{hadrons}(S=-1)^- \nu_\tau$$



Mode	$\mathcal{B}$, %
$\pi^-\pi^0\nu_\tau$	25.50 ± 0.10
$\pi^-\nu_\tau$	10.90 ± 0.07
$\pi^-\pi^-\pi^+\nu_\tau$	9.33 ± 0.08
$\pi^-\pi^0\pi^0\nu_\tau$	9.25 ± 0.12
$\pi^-\pi^-\pi^+\pi^0\nu_\tau$	4.59 ± 0.07
$K^-K^0\nu_\tau$	0.153 ± 0.016
$K^0\bar{K}^0\pi^-\nu_\tau$	0.160 ± 0.031
$K^-K^0\pi^0\nu_\tau$	0.154 ± 0.020
$K^-K^+\pi^-\nu_\tau$	0.153 ± 0.010

Mode	$\mathcal{B}$, 10^{-3}
$\bar{K}^0\pi^-\nu_\tau$	9.0 ± 0.4
$K^-\nu_\tau$	6.91 ± 0.23
$K^-\pi^0\nu_\tau$	4.52 ± 0.27
$K^-\pi^+\pi^-\nu_\tau$	3.9 ± 0.4
$\bar{K}^0\pi^-\pi^0\nu_\tau$	3.8 ± 0.4
$K^-\pi^0\pi^0\nu_\tau$	0.58 ± 0.23
$K^-\pi^+\pi^-\pi^0$	0.79 ± 0.12
$K^-3\pi^0\nu_\tau$	0.42 ± 0.21
$\phi K^-\nu_\tau$	$(4.05 \pm 0.25 \pm 0.26) \times 10^{-5}$

Cabibbo suppression in $\mathcal{B}$: $\tan^2\theta_c \simeq 1/20$

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

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

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

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

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:

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

Study of hadronic τ decays with $S = -1$

- **Measurement of branching fractions with highest possible accuracy**

  S. Schael *et al.* [ALEPH Collaboration], "Branching ratios and spectral functions of tau decays: Final ALEPH measurements and physics implications," Phys. Rept. **421**, 191 (2005) [arXiv:hep-ex/0506072].

  M. Davier, A. Hocker and Z. Zhang, "The physics of hadronic tau decays," Rev. Mod. Phys. **78**, 1043 (2006) [arXiv:hep-ph/0507078].

- **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.**

  J. H. Kuhn and E. Mirkes, "Structure functions in tau decays", Z.Phys. C **56** (1992) 661, Erratum-ibid. C **67** (1995) 364.

  R. Decker, E. Mirkes, R. Sauer, Z. Was, "Tau decays into three pseudoscalar mesons", Z.Phys. C **58** (1993) 445.

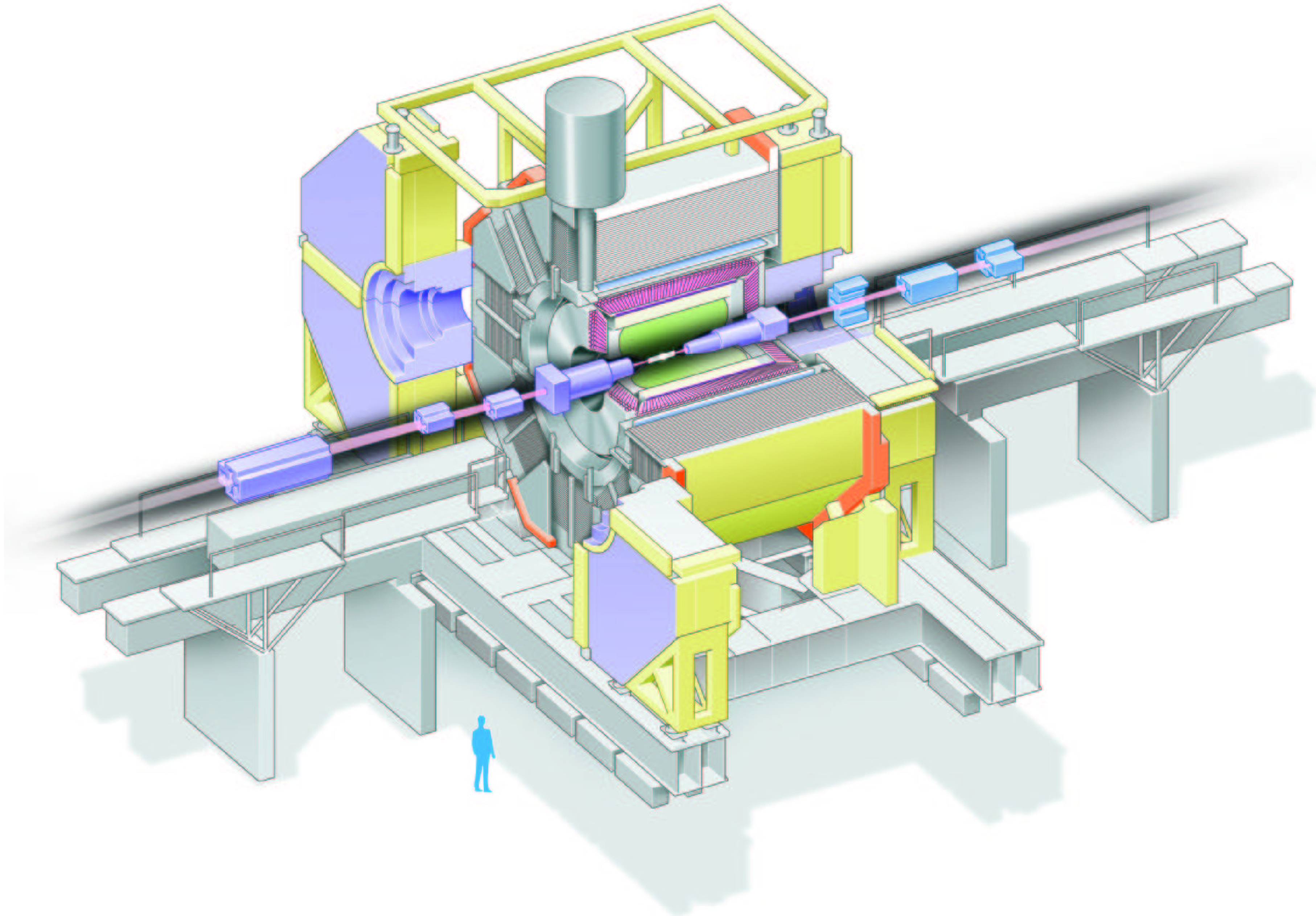
- **Measurement of $\Gamma_{\mathrm{inclusive}}(S = -1)$ to determine V_{us} and s-quark mass.**

  R. Barate *et al.* [ALEPH Collaboration], "Study of tau decays involving kaons, spectral functions and determination of the strange quark mass," Eur. Phys. J. C **11**, 599 (1999) [arXiv:hep-ex/9903015].

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

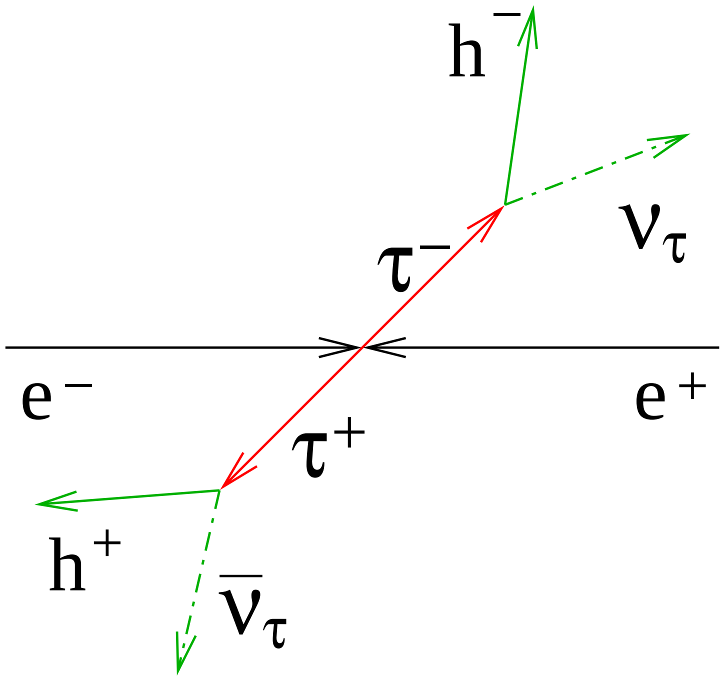
- **Measurement of $\tau \to K_S\pi\nu_\tau$ branching ratio** $\tau \to \bar{K}^0\pi\nu_\tau$ has the largest $\mathcal{B}$ among decays with one kaon, so provides the dominant contribution to the s-quark mass sensitive total strange hadronic spectral function.
- **$K_S\pi$ mass spectrum (F_V: $K^*(892)$, $K^*(1410)$, $K^*(1680)$; 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.

The Belle detector



τ analysis at Belle

We consider τ-pair production in the Belle CMS



Process	σ, nb
$e^+e^- \to e^+e^-(\gamma)$ (radiative Bhabha) $15^o \leq \theta \leq 165^o$	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

$$\frac{d\sigma_{\tau\tau}}{d\Omega} = \frac{\alpha^2}{4s}\beta((2-\beta^2)+\beta^2 cos^2\theta)$$

$$\sigma_{\tau\tau} = \frac{4\pi\alpha^2}{3s}\left(\beta\frac{3-\beta^2}{2}\right)$$

σ(Born Level)$=0.77$ nb

$2E = 10.58$ GeV

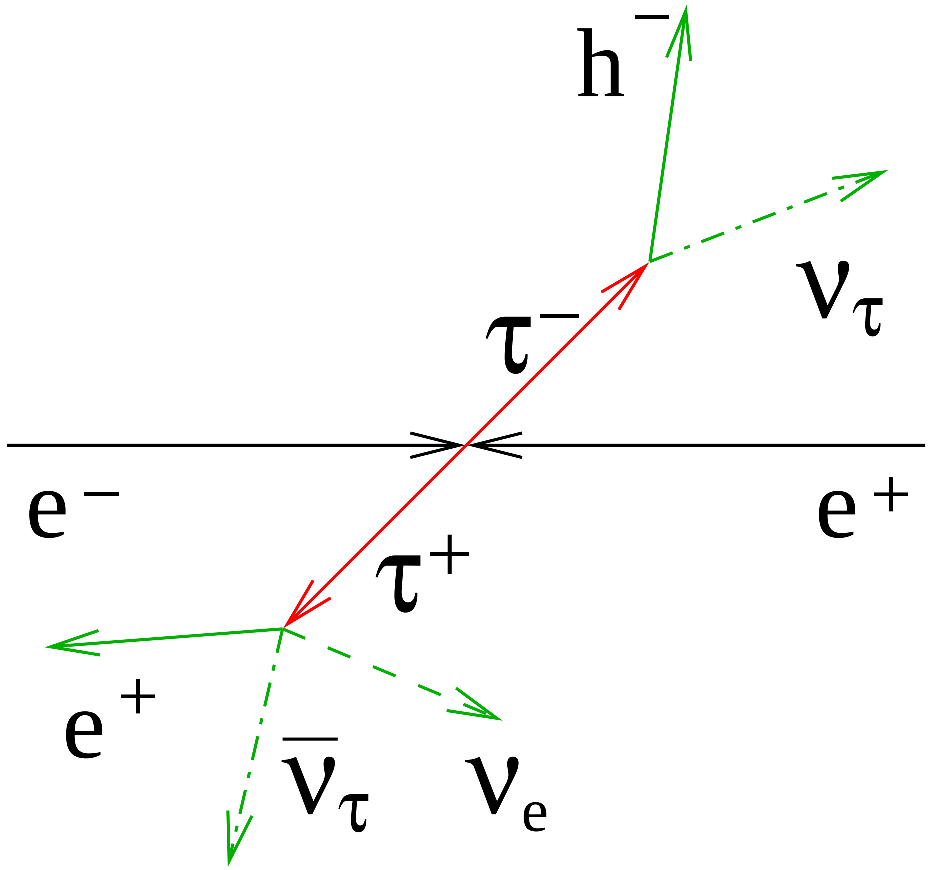
$E_\tau = E = 5.29$ GeV

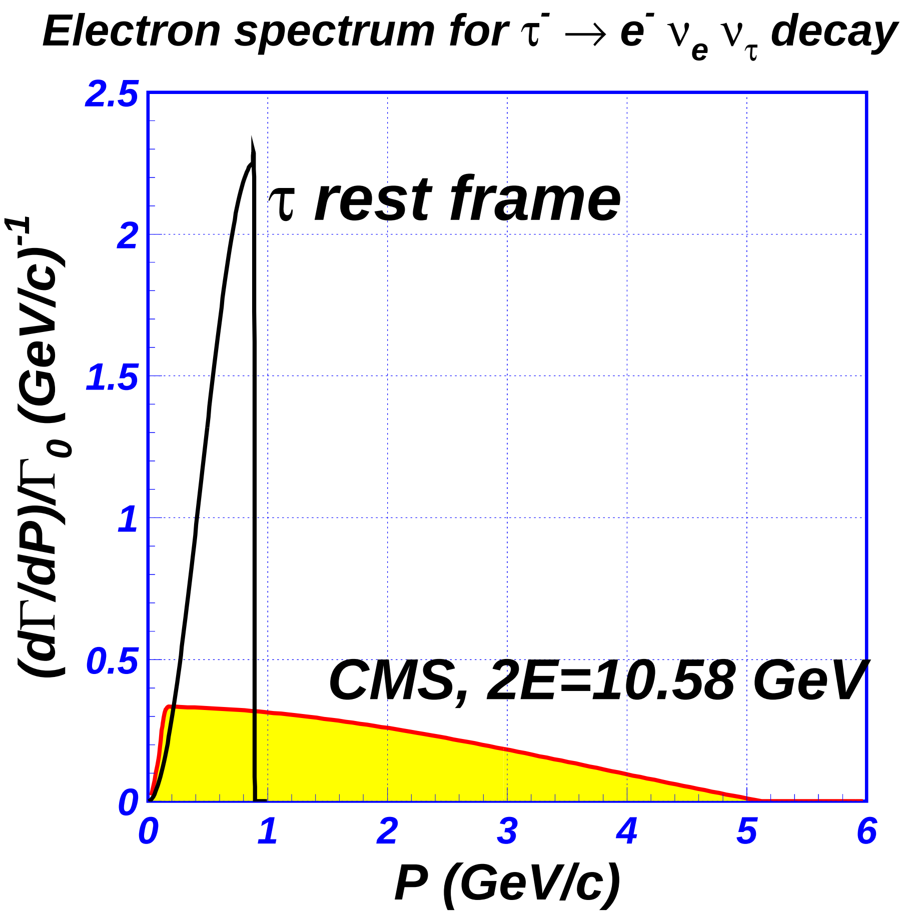
$\beta_\tau = 0.94$

$\lambda_\tau = 0.26$ mm

σ(Born Level + rad. cor.)$=0.89$ nb

The idea is to select $\tau\tau$ events tagging one τ by it's leptonic decay





$$\frac{\mathcal{B}(\text{hadrons})}{\mathcal{B}(\text{lepton})} = \left(\frac{\text{N(hadrons;lepton)}}{\text{N(lepton;lepton)}}\right)^{\text{EXP}} \cdot \left(\frac{\varepsilon(\text{lepton;lepton})}{\varepsilon(\text{hadrons;lepton})}\right)^{\text{MC}}$$

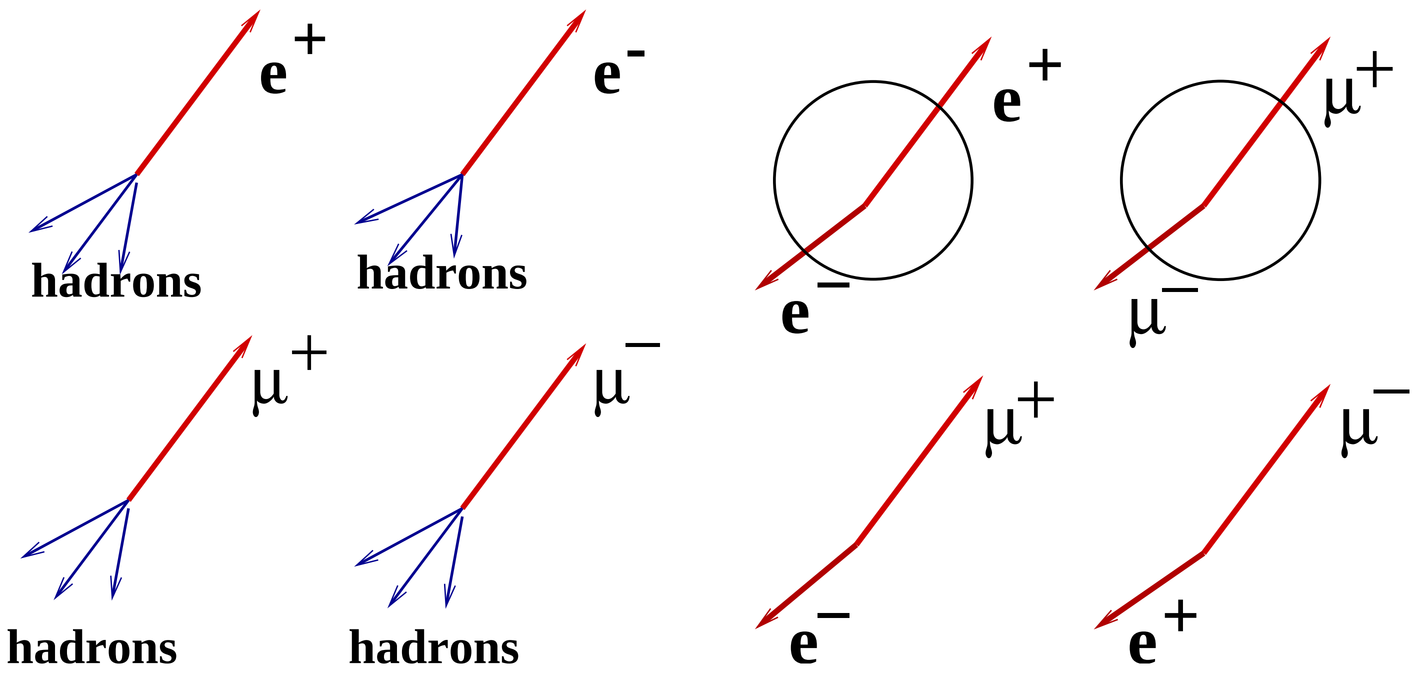
Selection of τ events

There are three stages of $\tau\tau$ events selection

I. **Preselection.** We select sample keeping $\simeq 70\%$ efficiency for $\tau\tau$ events, while having essential supression of background (K.Inami, Belle note 629).

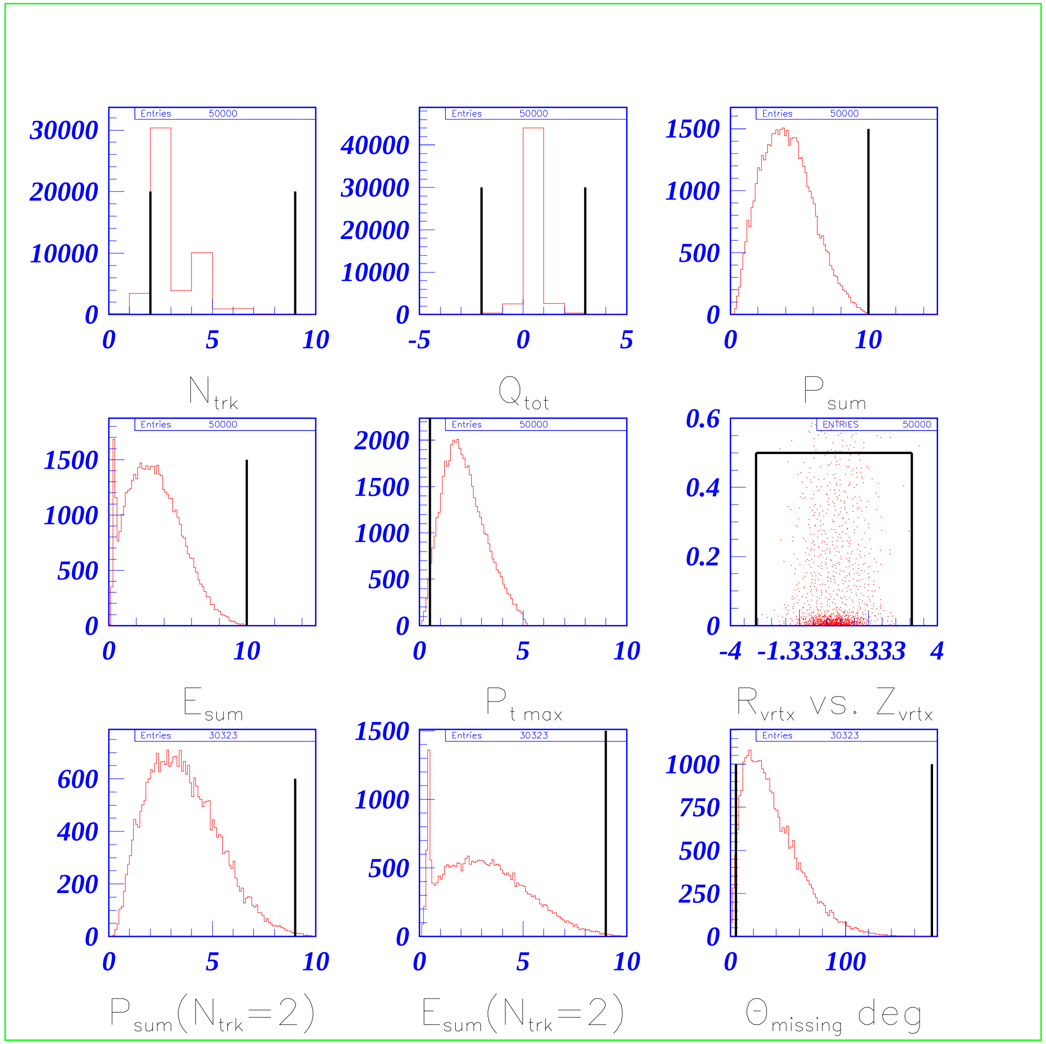
II. **Additional selection criteria** provide further background supression. The efficiency for $\tau\tau$ events is 46%. Selected sample contains 80% of $\tau\tau$ events and 20% of background events.

III. **Selection of pure τ^- decay mode tagging the τ^+ and vice versa.**

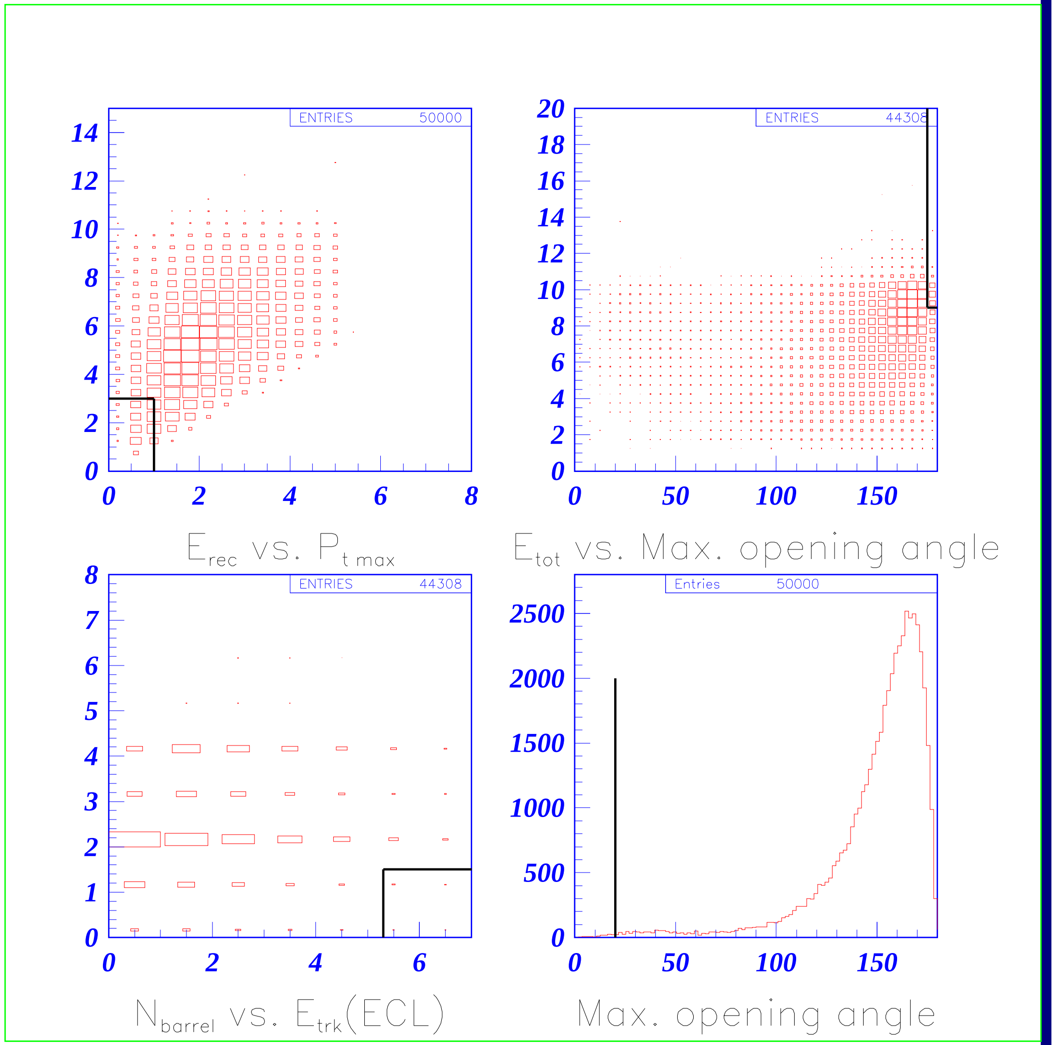


I. Preselection criteria

- $2 \leq N_{tracks} \leq 8$
- $|Q_{total}| \leq 2$
- $\sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} < 10$ GeV/c
- $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 10$ GeV
- $P_{\perp\ max}^{LAB} > 0,5$ GeV/c
- Event vertex $|R| < 0,5$ cm, $|Z| < 3$ cm
- For $N_{trk} = 2$:
  - $\sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} < 9$ GeV/c
  - $\sum_{i=1}^{N_{clusters}} E_i^{LAB}(ECL) < 9$ GeV
  - $5^o < \theta_{missing}^{LAB} < 175^o$
- $E_{rec} = \sum_{i=1}^{N_{trk}} |\vec{P_i}|^{CMS} + \sum_{j=1}^{N_\gamma} |\vec{K_j}|^{CMS} > 3$ GeV/c **OR** $P_{\perp\ max}^{LAB} > 1,0$ GeV/c
- If $2 \leq N_{trk} \leq 4$:
  - $E_{tot} = E_{rec} + |\sum_{i=1}^{N_{trk}} \vec{P_i}^{CMS} + \sum_{j=1}^{N_\gamma} \vec{K_j}^{CMS}| < 9$ GeV/c **OR** Maximum opening angle$< 175^o$
  - $N_{barrel} \geq 2$ **OR** $\sum_{All\ clusters} E^{CMS} - \sum_{photons} E_\gamma^{CMS} < 5,3$ GeV
- Maximum opening angle $> 20^o$



N_trk
Q_tot
P_sum
E_sum
P_t max
R_vrtx vs. Z_vrtx
P_sum(N_trk=2)
E_sum(N_trk=2)
Θ_missing deg



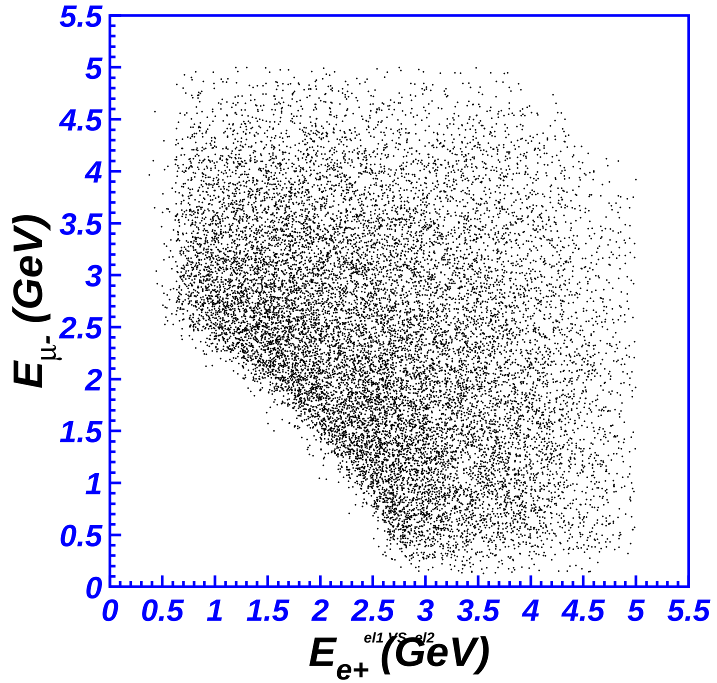
E_rec vs. P_t max
E_tot vs. Max. opening angle
N_barrel vs. E_trk(ECL)
Max. opening angle

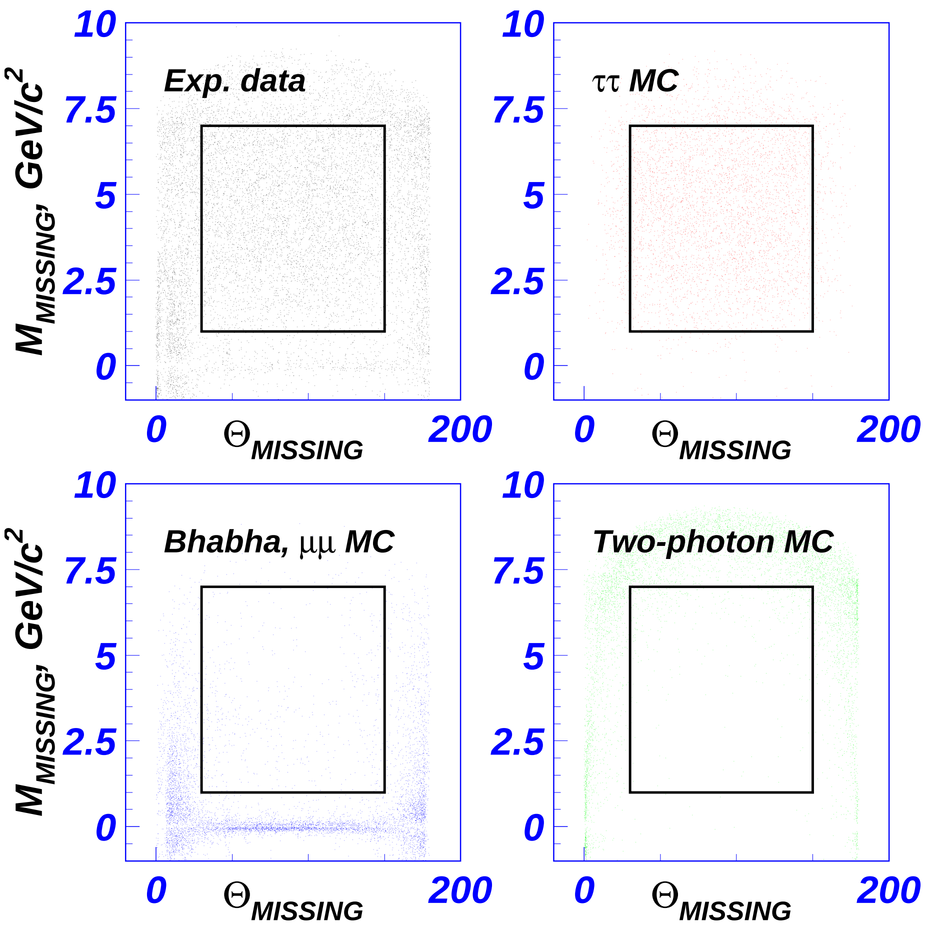
II. Additional selection criteria

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

$$1\ \mathrm{GeV/c^2} \leq M_{\mathrm{missing}} \leq 7\ \mathrm{GeV/c^2}$$
$$30^{\mathrm{o}} \leq \theta_{\mathrm{missing}}^{\mathrm{CMS}} \leq 150^{\mathrm{o}}$$

Two-lepton (e^+,μ^-) events



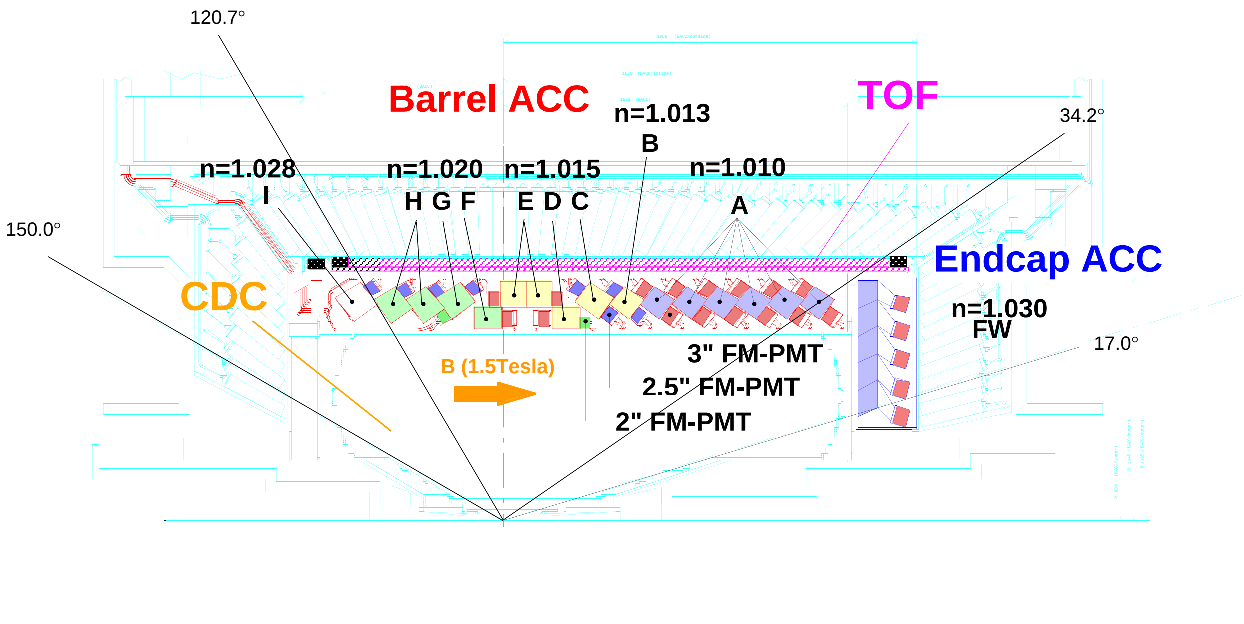


III. Selection of two-lepton and lepton-hadrons events

For $e^{\pm}$ a likelihood ratio requirement $\mathcal{P}_e = \mathcal{L}_e/(\mathcal{L}_e + \mathcal{L}_x) > 0.8$ is applied. $\mathcal{L}_e$ and $\mathcal{L}_x$ include information on the specific ionization (dE/dx) measurement by the CDC, the ratio of the cluster energy in the ECL to the track momentum, the transverse ECL shower shape and the light yield in the ACC. eID efficiency is 93%.

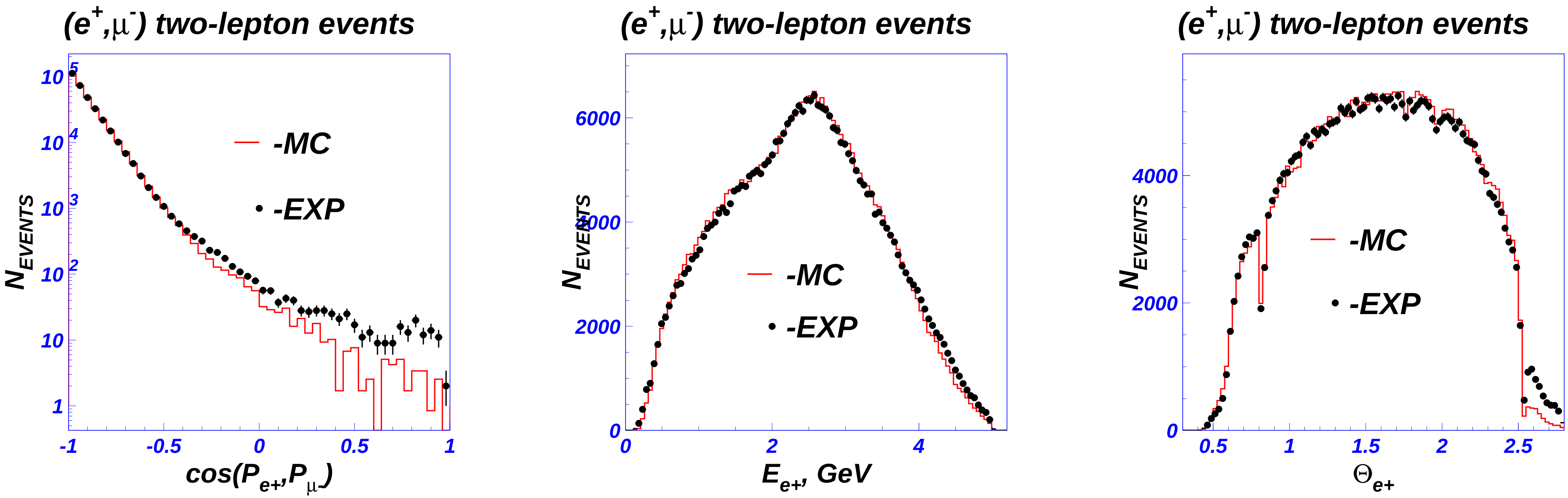
For $\mu^{\pm}$ a likelihood ratio requirement $\mathcal{P}_\mu = \mathcal{L}_\mu/(\mathcal{L}_\mu + \mathcal{L}_\pi + \mathcal{L}_K) > 0.8$ is applied. $\mathcal{L}_\mu$), $\mathcal{L}_\pi$ and $\mathcal{L}_K$) are evaluated from the information on the difference between the range calculated from the momentum of the particle and the range measured by KLM, and the χ^2 of the KLM hits with respect to the extrapolated track. μID efficiency is 88%.

To separate pions from kaons we determine the pion $\mathcal{L'}_\pi$ and kaon $\mathcal{L'}_K$ likelihoods from ACC response, the specific ionization (dE/dx) measurement in the CDC and the TOF flight-time measurement for each track, and form a likelihood ratio $\mathcal{P}_{K/\pi} = \mathcal{L'}_K/(\mathcal{L'}_\pi + \mathcal{L'}_K)$



Two-lepton (e^+, μ^-) and (e^-, μ^+) events

We select events with two leptons having $cos(\vec{P_e}, \vec{P_\mu}) < 0$



4046048 selected events, detection efficiency $\varepsilon_{\rm det}(e,\mu) = (19.26 \pm 0.01)\%$

The main source of non-$\tau\tau$ background, $e^+e^- \to e^+e^-\mu^+\mu^-$ process, gives about 2% contaminaton. The contribution of the other non-$\tau\tau$ processes is found to be less than 0.1%.

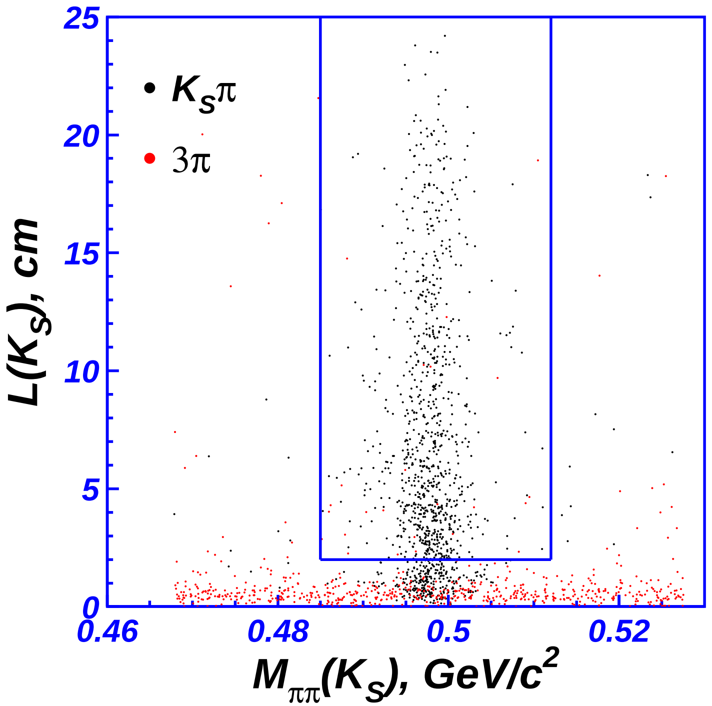
	Selected $(e^+;\mu^-)$	Selected $(e^-;\mu^+)$
$(e^\pm,\pi^\mp)$	$(1.81 \pm 0.01)\%$	$(1.84 \pm 0.01)\%$
$(e^\pm,\pi^\mp\pi^0)$	$(0.412 \pm 0.005)\%$	$(0.411 \pm 0.005)\%$
$(\pi^\pm,\mu^\mp)$	$(0.216 \pm 0.004)\%$	$(0.168 \pm 0.003)\%$
$(e^\pm,K^\mp)$	$(0.141 \pm 0.003)\%$	$(0.199 \pm 0.004)\%$
other	$(0.238 \pm 0.004)\%$	$(0.246 \pm 0.004)\%$
Total admixture	$(2.82 \pm 0.01)\%$	$(2.86 \pm 0.01)\%$
$(e^+\nu_e\bar{\nu}_\tau;\mu^-\bar{\nu}_\mu\nu_\tau)$	$(97.18 \pm 0.01)\%$	0%
$(e^-\bar{\nu}_e\nu_\tau;\mu^+\nu_\mu\bar{\nu}_\tau)$	0%	$(97.14 \pm 0.01)\%$

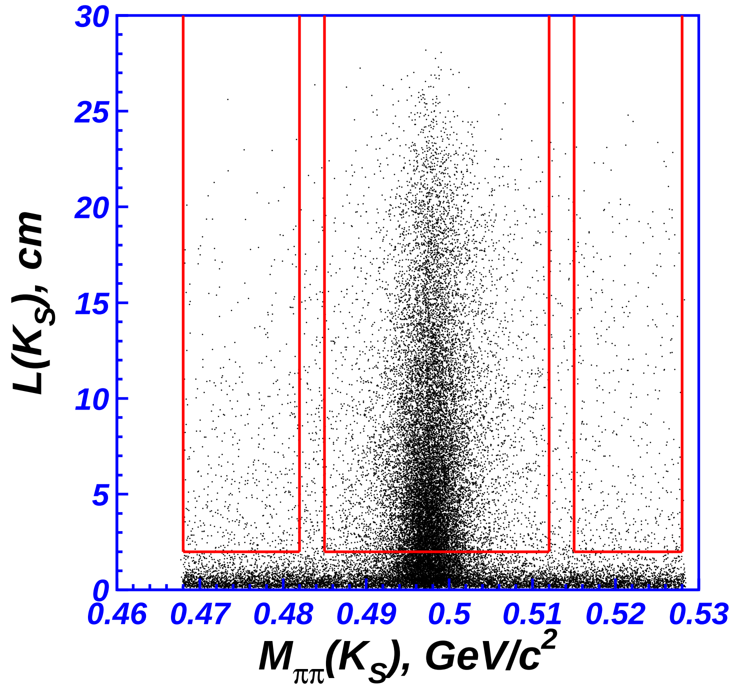
$$N(e^+,\mu^-) = (2017905 - 32502) \times 0.9718 = 1929323 \pm 1406$$

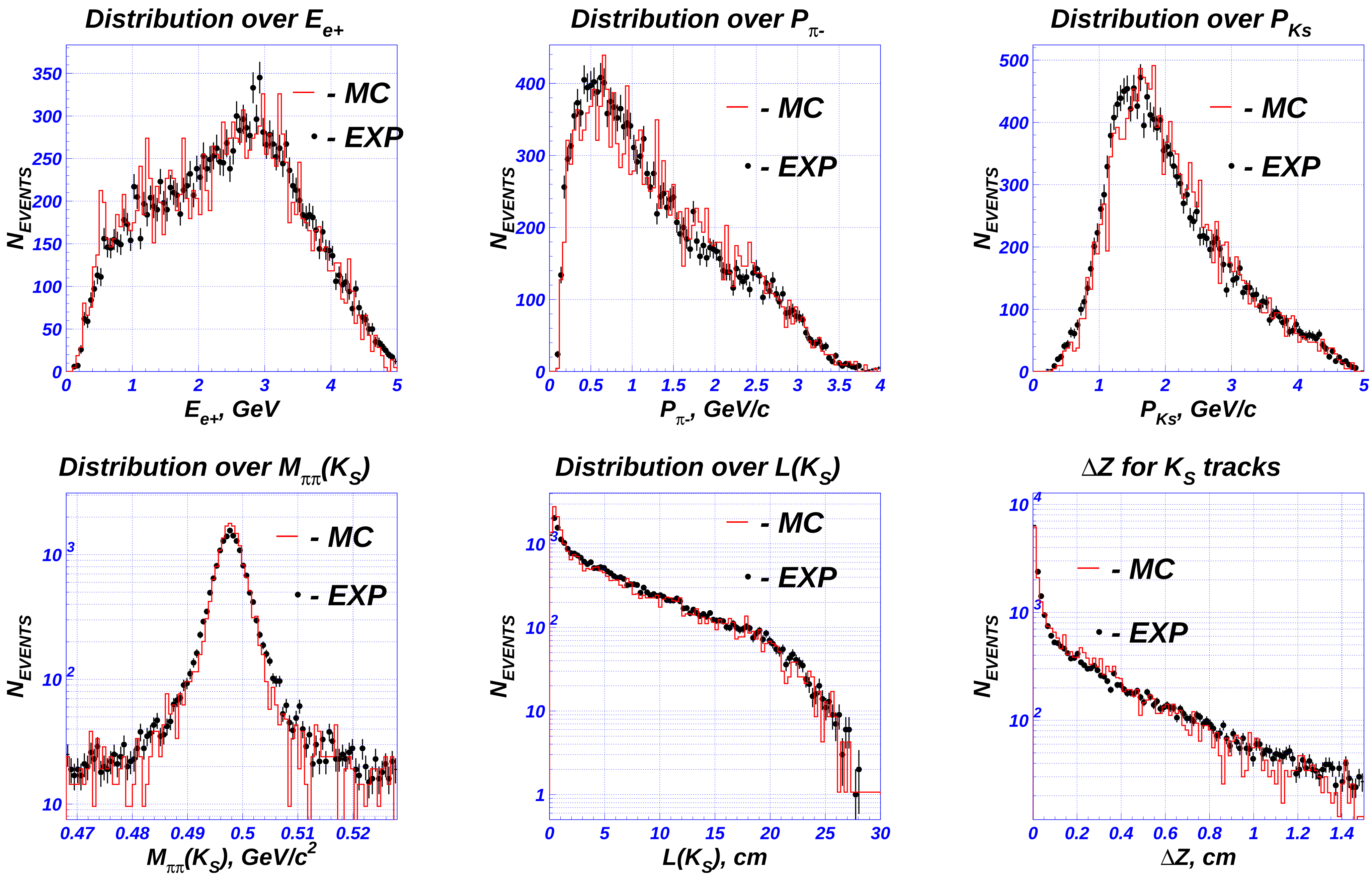
$$N(e^-,\mu^+) = (2028143 - 45865) \times 0.9714 = 1925553 \pm 1413$$

Selection of signal events

- **1 lepton** (e/μ) **with** $\mathcal{P}_e, \mathcal{P}_\mu > 0.8$
- **1 charged pion** π **with** $\mathcal{P}_{K/\pi} < 0.3$
- **1** K_S **candidate reconstructed from** $K_S \to \pi^+\pi^-$
  - $\Delta Z_{1,2} < 1.5cm$
  - $0.1 < l_{\rho-\phi}(K_S) < 20cm$
  - $cos(\vec{P}_\perp, \vec{r}_\perp) \geq 0.95$
  - $L_{K_S} > 2\ cm$, $485 < M_{\pi\pi}(K_S) < 512\ MeV/c^2$ $(\pm 5\sigma)$







68107 selected events, detection efficiency $\varepsilon_{\rm det} \simeq 6\%$

Non-$\tau\tau$ background in signal sample

The contribution of non-$\tau\tau$ processes was calculated from the luminosity($L = 351.4$ fb^{-1}), cross sections and MC efficiencies.

Mode	$(e^+; K_S\pi^-)$	$(e^-; K_S\pi^+)$	$(\mu^+; K_S\pi^-)$	$(\mu^-; K_S\pi^+)$
Bhabha	23.9 ± 10.7	62.0 ± 17.2	< 11	< 11
$\mu\mu$	< 1.8	< 1.8	< 1.8	2.4 ± 1.4
eeee	2.5 ± 2.5	5.0 ± 3.5	< 5.8	< 5.8
ee$\mu\mu$	< 2.3	< 2.3	3.0 ± 1.7	1.0 ± 1.0
eeuu	84.7 ± 8.8	62.9 ± 7.6	2.7 ± 1.6	< 2.1
eess	36.4 ± 2.5	28.0 ± 2.2	0.5 ± 0.3	0.3 ± 0.2
eecc	3.5 ± 1.1	3.8 ± 1.1	< 0.8	< 0.8
$B^0\bar{B}^0$	2.7 ± 2.7	< 6.3	< 6.3	< 6.3
B^+B^-	< 6.4	< 6.4	< 6.4	< 6.4
charm	14.5 ± 8.4	4.9 ± 4.9	9.7 ± 6.9	14.5 ± 8.4
uds	16.7 ± 7.5	< 7.7	13.4 ± 6.7	13.4 ± 6.7
Total	185 ± 18	167 ± 20	29 ± 10	32 ± 11
$\tau\tau$ selected	16987	16883	17104	17133

Background in signal sample from the other τ decays

I. Decays with K_S in the final state:

- $\tau^- \to K_S K_L \pi^- \nu_\tau$ (K_L is not reconstructed in our analysis)
- $\tau^- \to K_S \pi^0 \pi^- \nu_\tau$ (one or two photons from π^0 are missed in the insensitive part of the detector)
- $\tau^- \to K_S K^- \nu_\tau$ (K^- is misidentified as π^-)

II. Decays without K_S in the final state:

- $\tau^- \to \pi^+ \pi^- \pi^- \nu_\tau$

The contribution from τ decay modes with K_S in the final state was calculated from the luminosity($L = 351.4$ fb^{-1}), cross sections ($\sigma_{\rm i} = \sigma_{\tau\tau}\mathcal{B}_\ell \mathcal{B}_{\rm i}$) and MC efficiencies. Contamination from $\tau^- \to \pi^+\pi^-\pi^-\nu_\tau$ is evaluated with sideband data:

Configuration	e^+ tag	e^- tag	μ^+ tag	μ^- tag
Number of events	1015	944	913	940

	$(e^+; K_S K_L \pi^- \nu_\tau)$	$(e^+; K_S \pi^0 \pi^- \nu_\tau)$	$(e^+; K_S K^- \nu_\tau)$
$N_{\tau\tau}^{\text{EXP}}$	313.5×10^6		
$N_{\tau\tau}^{\text{EXP}} Br(\tau \to e\nu_e\nu_\tau)$	55.93×10^6		
Branching ratio, %	0.078 ± 0.006	0.147 ± 0.041	0.079 ± 0.023
ε_{MC}, %	3.24 ± 0.04	0.83 ± 0.01	0.68 ± 0.02
N_{events}	1417 ± 18	685 ± 11	301 ± 8

$$\mathcal{B}(\tau^- \to K_S K_L \pi^- \nu_\tau) = 1/2\mathcal{B}(\tau^- \to K^+ K^- \pi^- \nu_\tau) = (0.078 \pm 0.006)\%$$

R.A. Briere *et al.*,(CLEO) Phys. Rev. Lett. **90** (2003) 181802.

	ϵ_{tag}, %
$(e^+; K_S\pi^-)$	99.63 ± 0.02
$(e^-; K_S\pi^+)$	99.70 ± 0.02
$(\mu^+; K_S\pi^-)$	97.59 ± 0.06
$(\mu^-; K_S\pi^+)$	97.66 ± 0.06

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

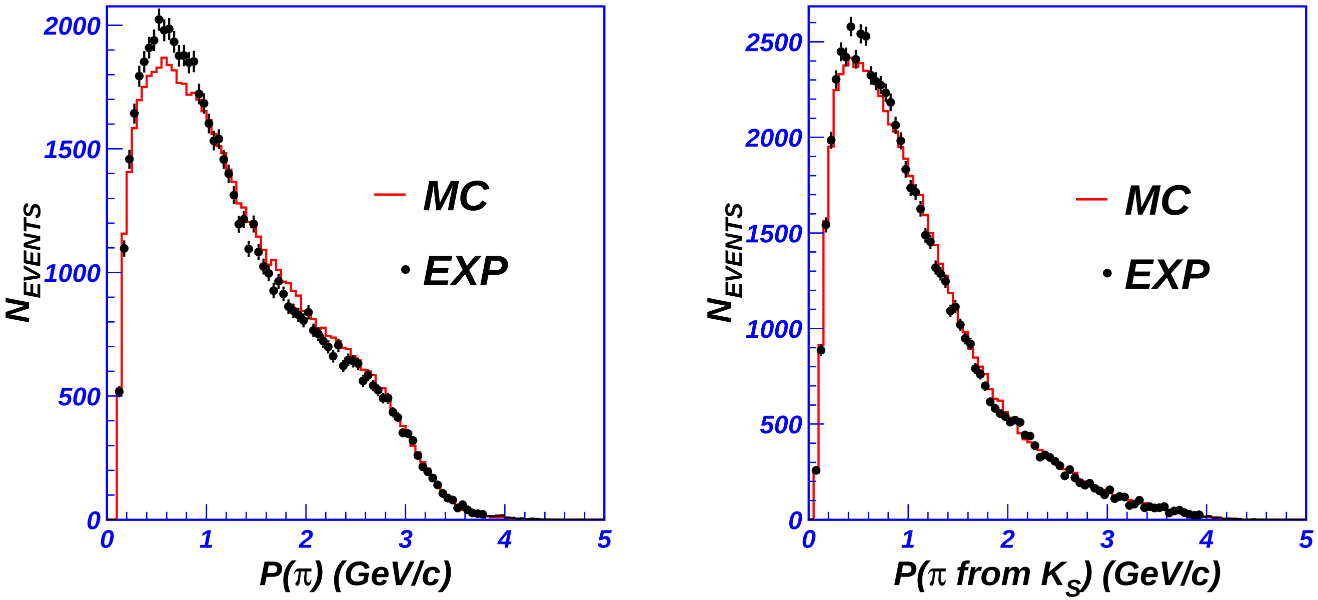
$$N_{\text{exp}}(\ell, K_S\pi) = \epsilon_{\text{tag}}(\ell, K_S\pi)\cdot(N_{\text{sel}}(\ell, K_S\pi) - N_{\text{bg}}(\text{non}-\tau\tau) - N_{\text{bg}}(\ell, \text{with } K_S) - N_{3\pi})$$

EXP/MC corrections

The lepton detection efficiency is corrected using events of the experimental two-photon sample $e^+e^- \to e^+e^-\ell^+\ell^-$, $\ell = e, \mu$. The efficiency correction table is calculated in 70 bins on the plane of momentum vs. polar angle in the laboratory frame and then applied to the Monte Carlo efficiencies $\varepsilon(\ell, K_S\pi)$ and $\varepsilon(e,\mu)$. Hence, the uncertainty on the leptonic efficiency is determined by the statistics of the $e^+e^- \to e^+e^-\ell^+\ell^-$ sample and long-term stability of the correction.

$$\epsilon_{\text{corr}}(e\text{ID}) = 0.981 \pm 0.008 \qquad \epsilon_{\text{corr}}(\mu\text{ID}) = 0.973 \pm 0.005$$

KID efficiency correction should be applied. The idea is to use K_S as a source of pions with low momenta (it has not been done yet):



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

$$\frac{\mathcal{B}(\text{hadrons})}{\mathcal{B}(\text{lepton})} = \left(\frac{\text{N(hadrons,lepton)}}{\text{N(lepton,lepton)}} \right)^{\text{EXP}} \cdot \left(\frac{\varepsilon(\text{lepton,lepton})}{\varepsilon(\text{hadrons,lepton})} \right)^{\text{MC}}$$

	e-tag	μ-tag
ℓ^+	$(0.396 \pm 0.005)\%$	$(0.387 \pm 0.004)\%$
ℓ^-	$(0.404 \pm 0.005)\%$	$(0.391 \pm 0.004)\%$
avg($\ell^+ \& \ell^-$)	$(0.400 \pm 0.003)\%$	$(0.389 \pm 0.003)\%$
avg(all tag)	$(0.395 \pm 0.002)\%$	

$$\mathcal{B}(\tau \to K_S \pi \nu_\tau) = (0.395 \pm 0.002_{\text{stat}} \pm 0.014_{\text{syst}})\%$$

The second way to calculate $\mathcal{B}(\tau^- \to K_S \pi^- \nu_\tau)$

$$Br(K_S\pi^-) = \frac{N(\ell^+, K_S\pi^-)}{N_{\tau\tau} Br_{\ell+} \varepsilon(\ell^+, K_S\pi^-)}$$

This technique suffers from additional sources of systematic uncertainties: number of $\tau\tau$ events ($2.2\% \bigoplus 1.4\%$), systematic uncertainty in the reconstruction efficiency of ℓ^+ and π^- tracks (2.2%).

$$\sigma_{\tau\tau}(\text{KKMC}) = 0.892 \text{ nb} \qquad \sigma_{\tau\tau}(\text{KORALB}) = 0.912 \text{ nb}$$

$$N_{\tau\tau} = L\sigma_{\tau\tau} = (351.4 \times 10^6) \text{ nb}^{-1} \cdot 0.892 \text{ nb} = 313.5 \times 10^6$$

	$(e^+; K_S\pi^-)$	$(e^-; K_S\pi^+)$	$(\mu^+; K_S\pi^-)$	$(\mu^-; K_S\pi^+)$
N_{exp}	13336 ± 137	13308 ± 137	13230 ± 134	13236 ± 134
$\varepsilon, \%$	5.84 ± 0.02	5.71 ± 0.02	6.09 ± 0.02	6.03 ± 0.02
$Br(K_S\pi), \%$	0.408 ± 0.005	0.417 ± 0.005	0.399 ± 0.005	0.403 ± 0.005
$< Br >, \%$	0.412 ± 0.003		0.401 ± 0.003	
$< Br >_{all}, \%$	0.407 ± 0.002			

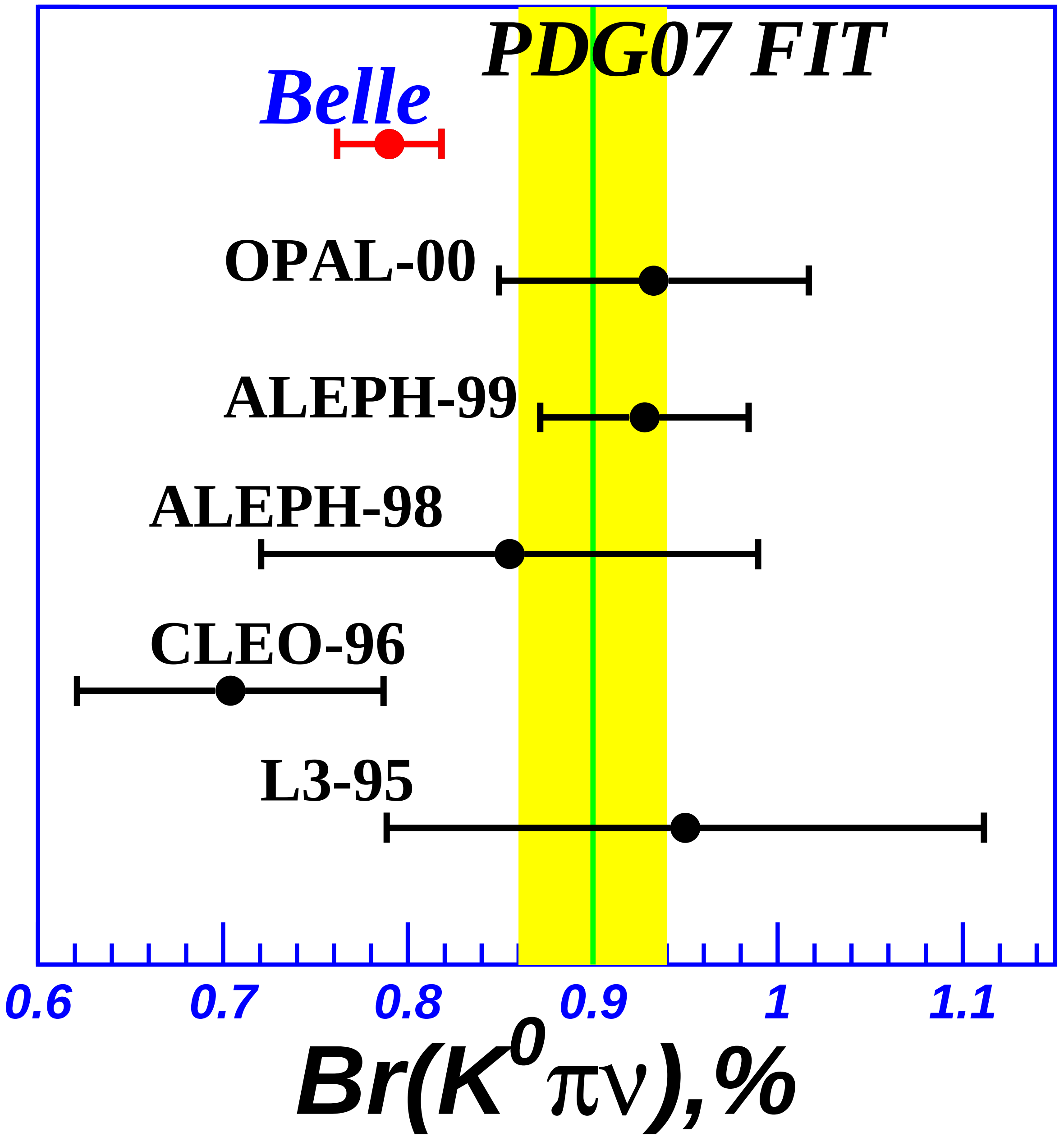
To calculate branching fraction we choose the first technique

Systematic uncertainties

Source	Contribution,%
K_S detection efficiency	$2.3\%\text{trk}\bigoplus 0.6\% M_{\pi\pi} \bigoplus 0.9\% \Delta Z_{1,2}=\mathbf{2.5}$
$\tau\tau$ background subtraction	$0.8\% KK\pi \bigoplus 1.1\% K\pi\pi^0 \bigoplus 0.6\% K_S K \bigoplus 0.5\% 3\pi=\mathbf{1.5}$
Pion identification efficiency	**1.0**
$\sum E_\gamma^{\mathrm{LAB}}$	**1.0**
Lepton identification efficiency	**0.8**
Pion momentum	**0.5**
Non-$\tau\tau$ background subtraction	**0.3**
$\mathcal{B}(l\nu_l\nu_\tau)$	**0.3**
$\frac{\varepsilon(l_1,l_2)}{\varepsilon(l_1,K_S\pi)}$	**0.2**
K_S momentum	**0.2**
Total	**3.5**

$$\mathcal{B}(\tau \to K_S\pi\nu_\tau) = (0.395 \pm 0.002_{\mathrm{stat}} \pm 0.014_{\mathrm{syst}})\%$$

$$\mathcal{B}(\tau \to \bar{K}^0 \pi^- \nu_\tau) = 2\mathcal{B}(\tau \to K_S \pi \nu_\tau) = (0.790 \pm 0.004_{\rm stat} \pm 0.028_{\rm syst})\%$$



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

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

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

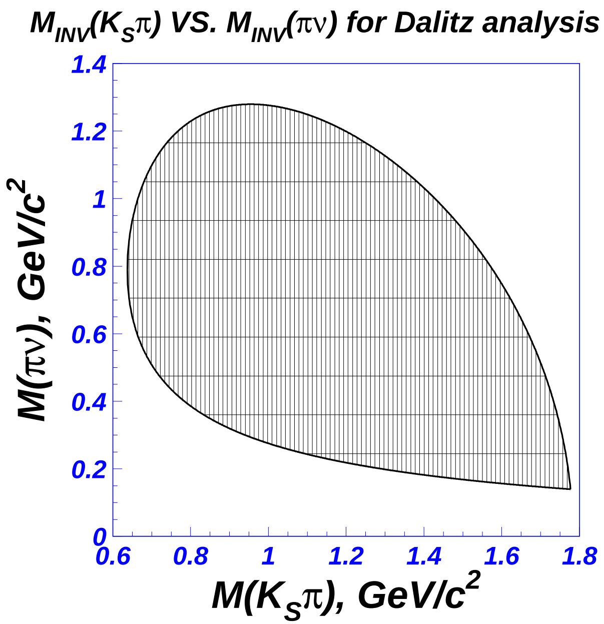
$$F_S = a(K_0^*(800))\cdot BW_{K_0^*(800)}+a(K_0^*(1430))\cdot BW_{K_0^*(1430)}$$

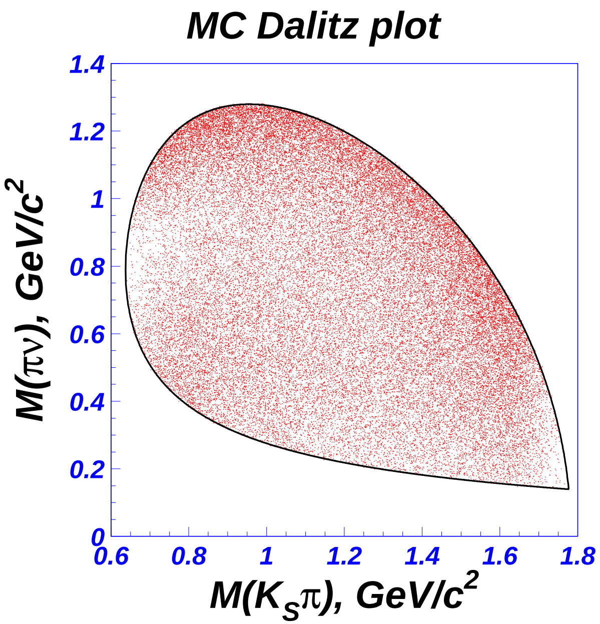
$$BW_X = \frac{M_X^2}{M_X^2-s-i\sqrt{s}\Gamma_X(s)}$$

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

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

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	$\sqrt{\frac{9+3R^2P^2(M_X^2)+R^4P^4(M_X^2)}{9+3R^2P^2(s)+R^4P^4(s)}}$





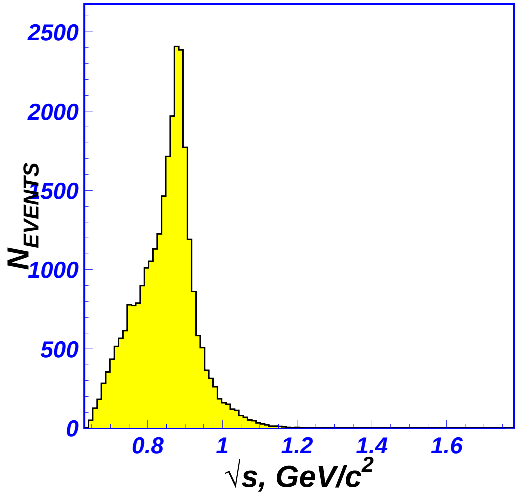
To take into account the detector apparatus function we introduce 100×1000 efficiency matrix:

$$\varepsilon_{\mathrm{ij}}(\mathrm{MC}) = \frac{\mathrm{N_i(reconstructed)}}{\mathrm{N_j(generated)}}, \ \ \mathrm{i} = 1 \div 100, \ \ \mathrm{j} = 1 \div 1000$$

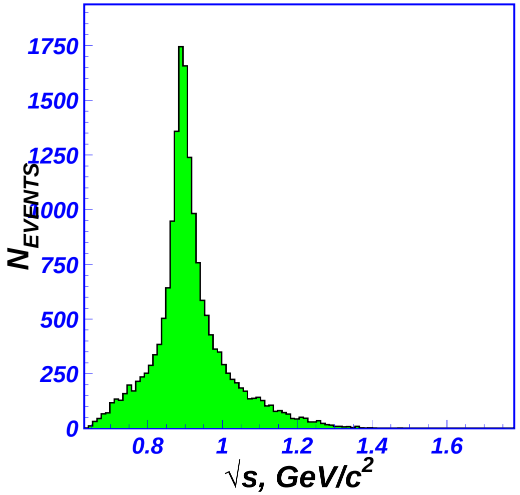
$$\chi^2 = \sum_{\mathrm{bins}} \frac{(\mathrm{N_i} - \varepsilon_{\mathrm{ij}}(\mathrm{MC})\mathrm{N_j(model)})^2}{\mathrm{N_i} + \sigma^2}$$

$$\mathrm{N_j(model)} = \int_{\mathrm{j}} \frac{\mathrm{d}\Gamma}{\mathrm{dm_{12}dm_{23}}} \mathrm{dm_{12}dm_{23}}$$

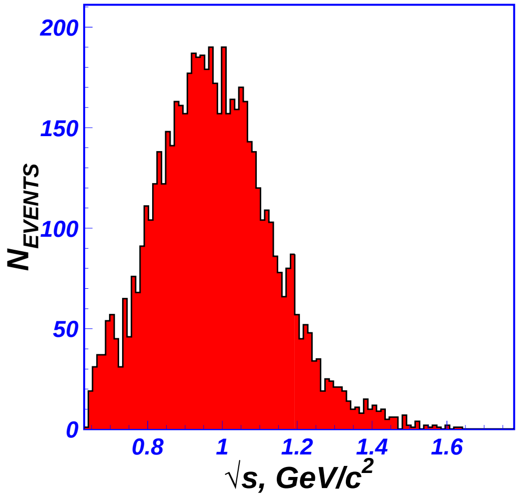
$K_S\pi$ mass spectra of background τ decays



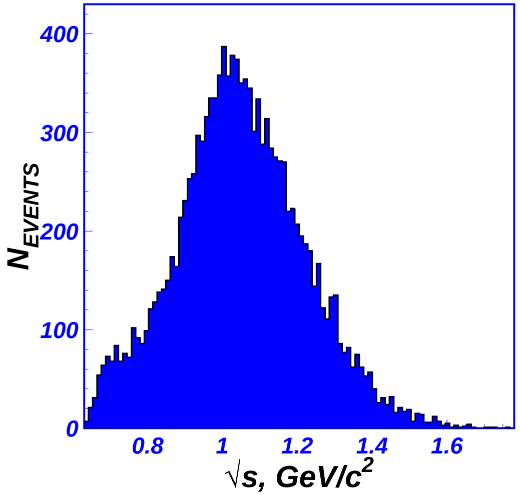
$\tau \longrightarrow K_S K_L \pi \nu$



$\tau \longrightarrow K_S \pi^0 \pi \nu$



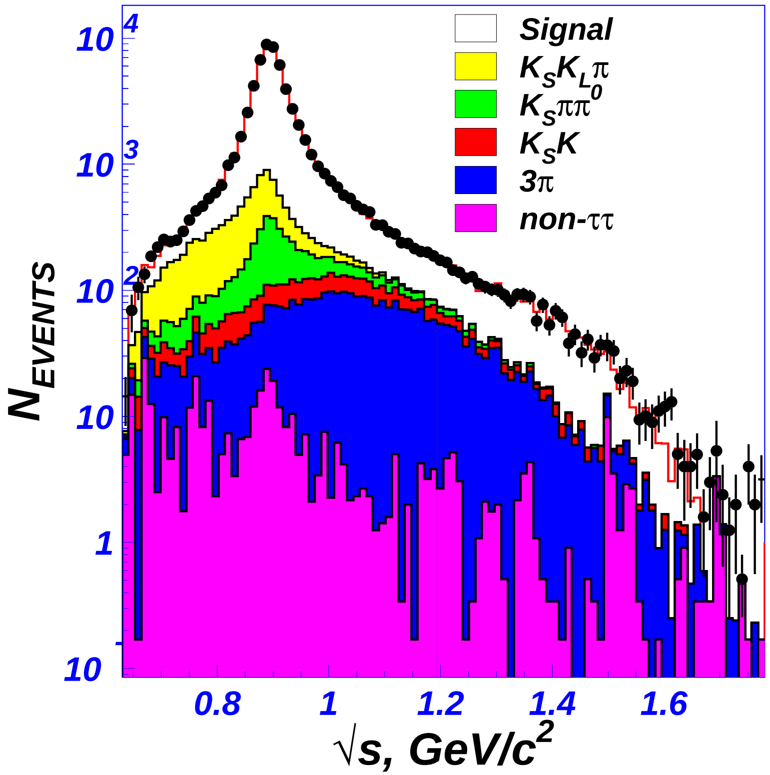
$\tau \longrightarrow K_S K \nu$



$\tau \longrightarrow \pi^+ \pi^- \pi \nu$

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

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



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

We take $K_0^*(800)$ parameters:
$M_{K_0^*(800)} = 878 \pm 23 \pm 60\ \mathrm{MeV/c^2}$, $\Gamma_{K_0^*(800)} = 499 \pm 52 \pm 71\ \mathrm{MeV/c^2}$ 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]:

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

Multiple solutions(two BW functions case)

$$|A|^2(s|a_1,a_2,\varphi) = \left| a_1 \frac{m_1^2}{s - m_1^2 + i m_1 \Gamma_1} + a_2 e^{i\varphi} \frac{m_2^2}{s - m_2^2 + i m_2 \Gamma_2} \right|^2$$

In the case of constant widths for each set of parameters (a_1, a_2, φ) there exists the other set (a_1', a_2', φ') $(a_1' \neq a_1,\ a_2' \neq a_2,\ \varphi' \neq \varphi)$, such as:

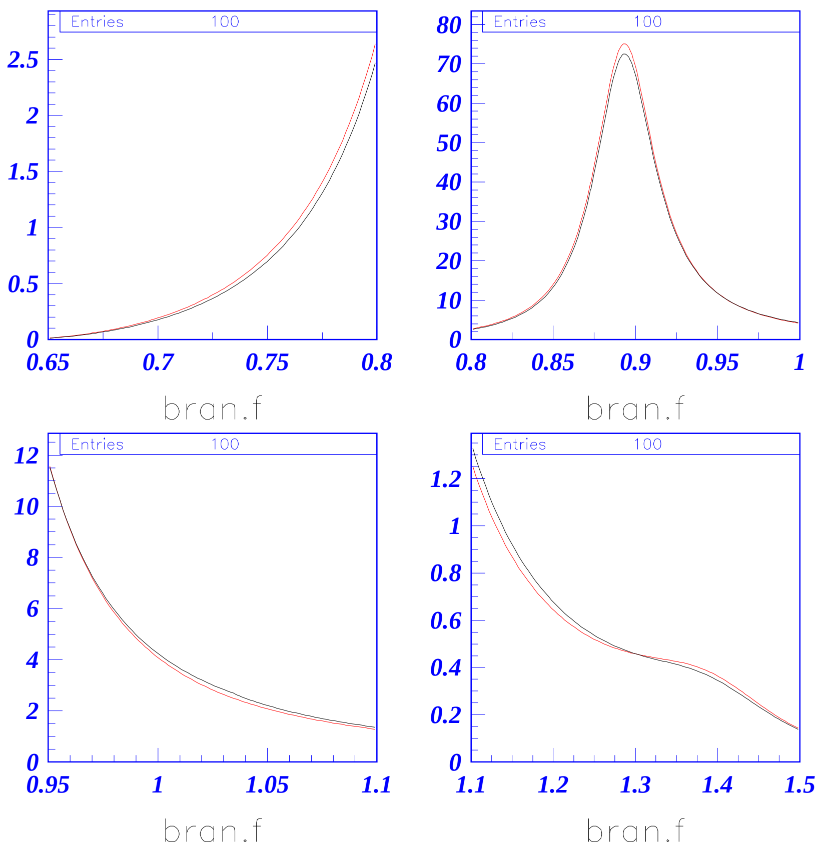
$$|A|^2(s|a_1', a_2', \varphi') = |A|^2(s|a_1, a_2, \varphi) \text{ for all values of } s$$

$$a_1' = f(a_1, a_2, \varphi),\ a_2' = g(a_1, a_2, \varphi),\ \varphi' = h(a_1, a_2, \varphi)$$

For example, for Breit-Wigner functions with following parameters:
$m_1 = 0.878$ GeV/c^2, $\Gamma_1 = 0.499$ GeV, $m_2 = 1.412$ GeV/c^2, $\Gamma_2 = 0.294$ GeV
$a_1 = 1.27,\ a_2 = 0.954,\ \varphi = 0.62;$

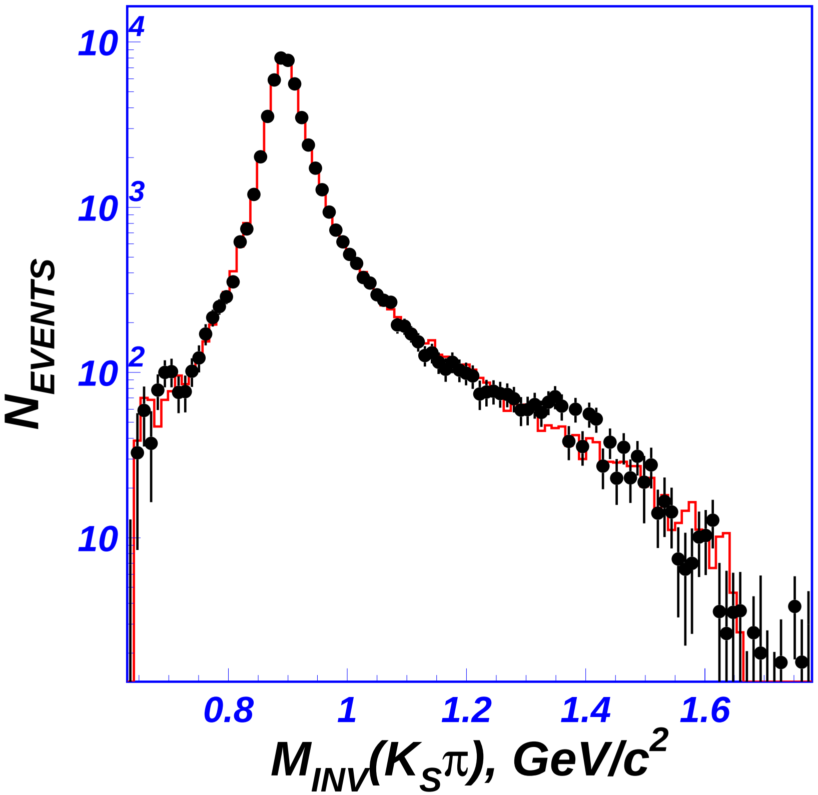
the second solution is: $a_1' = 3.26796,\ a_2' = 1.48136,\ \varphi' = 4.18711.$

In the case of s dependent widths $\Gamma_{1,2}(s)$ spectrum degeneration disappears and spectra for (a_1, a_2, φ) and (a'_1, a'_2, φ') sets become different:



But if the experimental errors are large enough, the χ^2 for both solutions will be almost the same, so we have to take into account both solutions. In general if the total amplitude is parametrized by sum of N BW functions (determined by $2N-1$ parameter set $(a_1, ..., a_N, \varphi_1, ..., \varphi_{N-1})$), there are 2^{N-1} solutions to check.

$K_0^*(800) + K^*(892) + K^*(1680)$



$$M_{K^*(892)} = 894.88 \pm 0.20 \text{ MeV/c}^2$$

$$\Gamma_{K^*(892)} = 45.52 \pm 0.51 \text{ MeV}$$

$$|a(K^*(1680))| = -0.117 \pm \begin{matrix} 0.017 \\ 0.033 \end{matrix}$$

$$\arg(a(K^*(1680))) = 0.03 \pm 0.47$$

$$|a(K_0^*(800))| = 1.53 \pm 0.24$$

$$\chi^2/\text{Ndf} = 106.8/84, \; P(\chi^2) = 4.7\%$$

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)

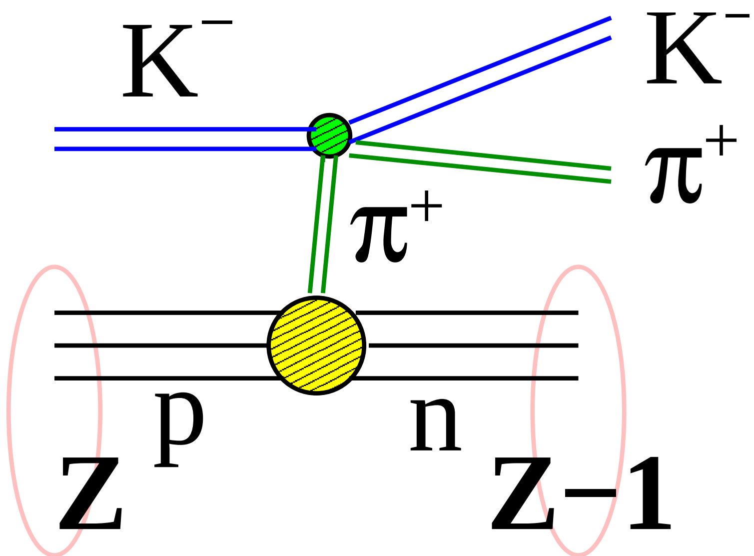
$$F_S = \frac{M_{K\pi}}{P}(\sin\delta_B e^{i\delta_B} + e^{2i\delta_B} BW_{K_0^*(1430)}(M_{K\pi}))$$

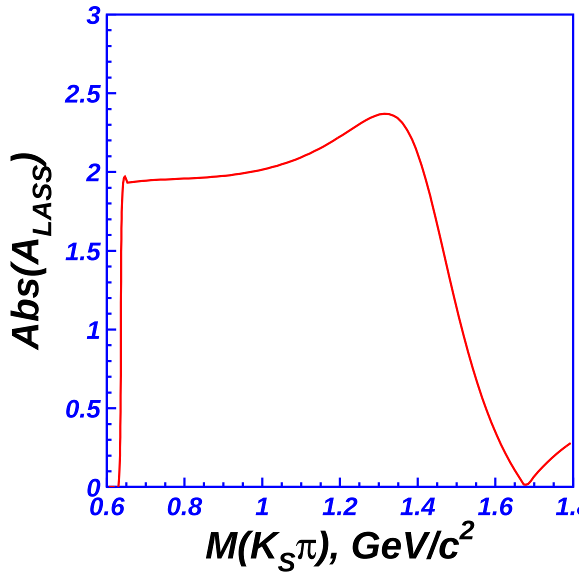
$$\cot\delta_B = \frac{1}{aP} + \frac{bP}{2}$$

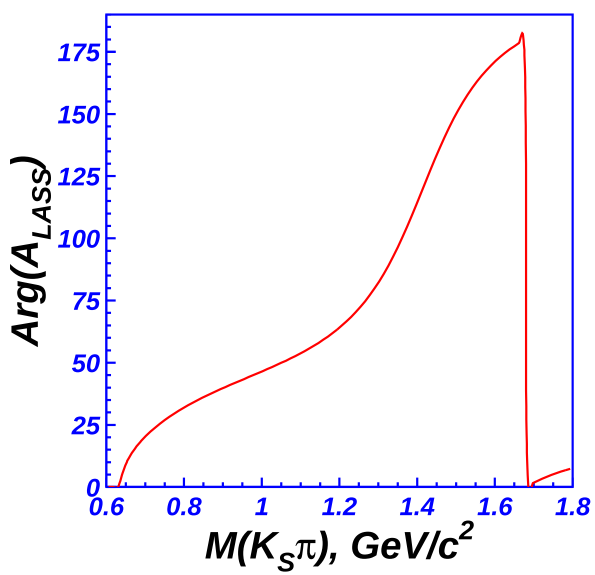
$$a = (2.07 \pm 0.10)\ (\mathrm{GeV/c})^{-1}$$

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

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

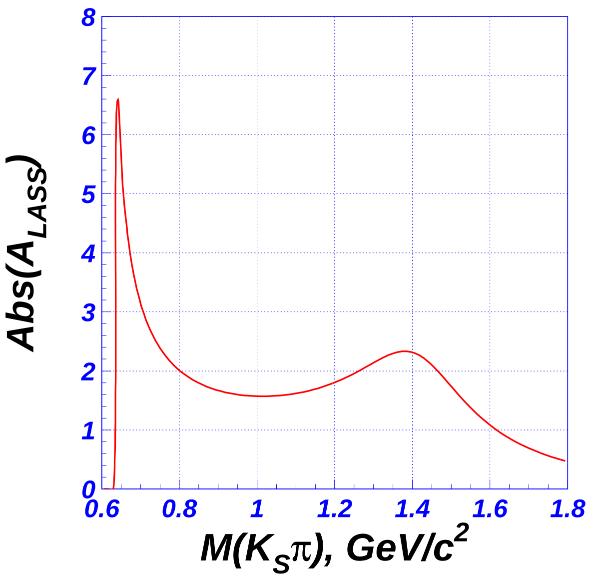


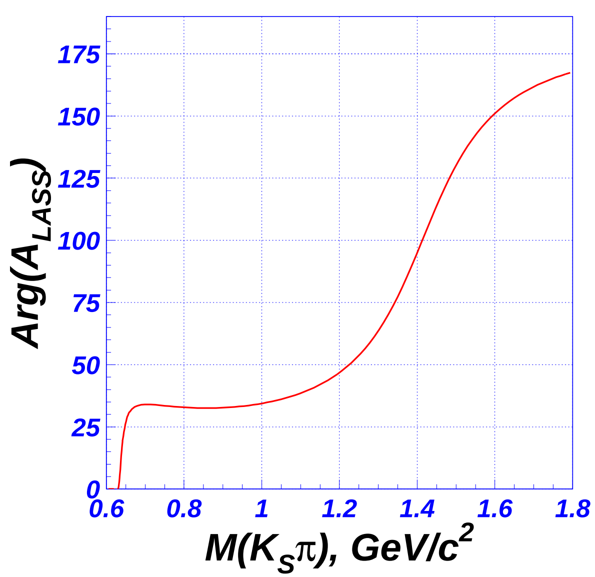




	$K^*(892)$+LASS a, b-fixed	$K^*(892)$+LASS a, b-free
$M_{K^*(892)}$, MeV/c^2	895.42 ± 0.19	895.38 ± 0.23
$\Gamma_{K^*(892)}$, MeV	46.46 ± 0.47	46.53 ± 0.50
λ	0.282 ± 0.011	0.298 ± 0.012
a, (GeV/c)$^{-1}$	2.13 ± 0.10	$10.9 \pm^{7.4}_{3.0}$
b, (GeV/c)$^{-1}$	3.96 ± 0.31	$19.0 \pm^{4.5}_{3.6}$
χ^2/n.d.f.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

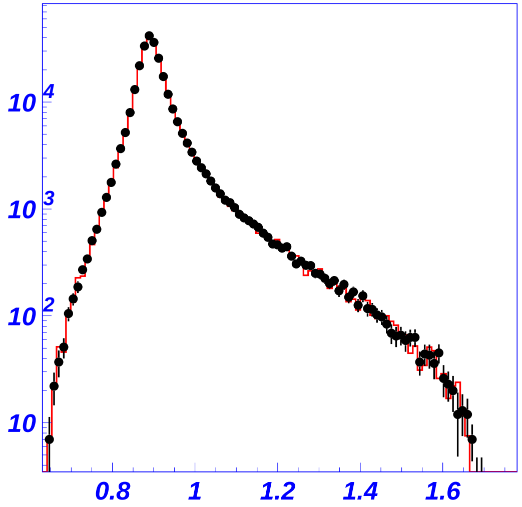
Our scalar amplitude



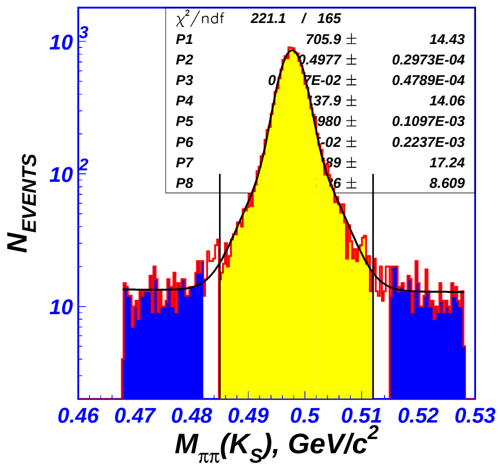


$K^{*-}(892)$ mass and width

We take a fit with $K_0^*(800) + K^*(892) + K^*(1410)$ model as a reference to extract $K^{*-}(892)$ mass and width.



$M_{K^*(892)} =$	892.10 ± 0.11 MeV/c^2(891.66)
$\Gamma_{K^*(892)} =$	51.81 ± 0.25 MeV(50.8)
χ^2/n.d.f. = 90.8/87	$P(\chi^2) = 37\%$
ΔM(K*(892)), MeV/c^2	$\Delta\Gamma$(K*(892)), MeV
0.44 ± 0.11	1.01 ± 0.25



Configuration	$M(K_S)$, MeV/c^2
$(e^+; K_S\pi^-)$	497.721 ± 0.030
$(e^-; K_S\pi^+)$	497.708 ± 0.030
$(\mu^+; K_S\pi^-)$	497.738 ± 0.030
$(\mu^-; K_S\pi^+)$	497.750 ± 0.029
Average	497.729 ± 0.015

From MC: $M_{\text{visible}} - M_{\text{true}} = 0.126 \pm 0.005$ MeV/c^2

$\Delta M = M_{K_S}(\text{Our}) - M_{K_S}(\text{PDG}) = -0.045 \pm 0.027$ MeV/c^2

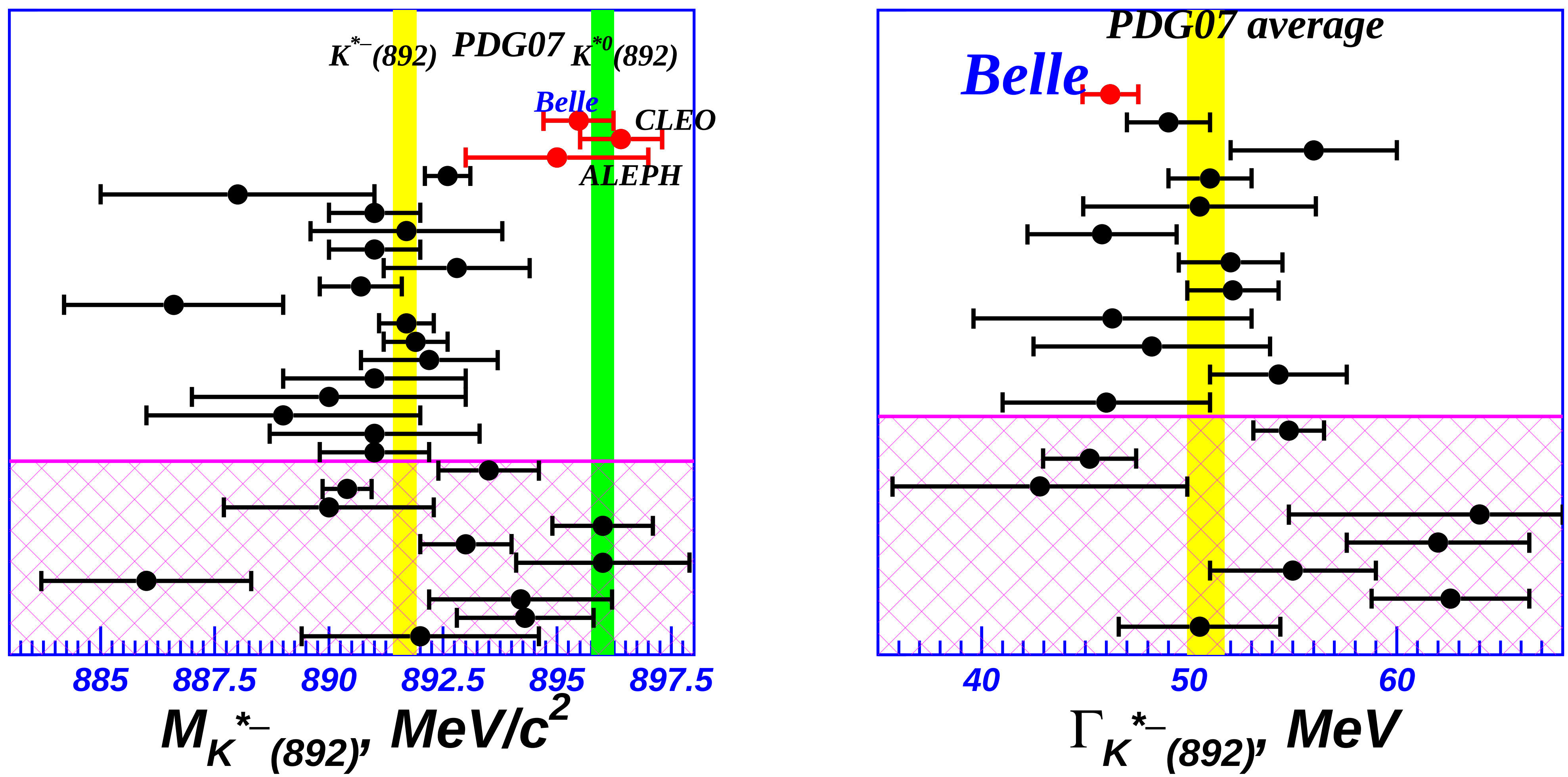
Model uncertainties in $K^*(892)$ mass and width are evaluated from approximations with the following models: $K_0^*(800) + K^*(892) + K_0^*(1430)$, $K_0^*(800) + K^*(892) + K^*(1680)$, $K^*(892)$+LASS.

	$\mathrm{M(K^*(892)),\ MeV/c^2}$	$\Gamma\mathrm{(K^*(892)),\ MeV}$
This work	$895.47 \pm 0.20_{\mathrm{stat}} \pm 0.44_{\mathrm{syst}} \pm 0.59_{\mathrm{mod}}$	$46.2 \pm 0.6_{\mathrm{stat}} \pm 1.0_{\mathrm{syst}} \pm 0.7_{\mathrm{mod}}$
PDG-2007	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

Already this summer PDG update will have a new section with $K^{*-}(892)$ parameters from τ decays. It will contain as NOT USED two results:

	$\mathrm{M(K^*(892)),\ MeV/c^2}$	$\Gamma\mathrm{(K^*(892)),\ MeV}$	
ALEPH	895 ± 2	55 ± 8	$K^-\pi^0$, syst. errors not est.
CLEO	896.4 ± 0.9		$K_S\pi^-$, syst. errors not est.



$K^{*-}(892)$
PDG07
$K^{*0}(892)$
Belle
CLEO
ALEPH
885
887.5
890
892.5
895
897.5
$M_{K^{*-}(892)}$, MeV/c^2
PDG07 average
Belle
40
50
60
$\Gamma_{K^{*-}(892)}$, MeV

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:

$$\mathcal{A}_{\mathcal{CP}} = \frac{\Gamma(\tau^+ \to K_S \pi^+ \bar{\nu}) - \Gamma(\tau^- \to K_S \pi^- \nu)}{\Gamma(\tau^+ \to K_S \pi^+ \bar{\nu}) + \Gamma(\tau^- \to K_S \pi^- \nu)}$$

I.I.Bigi, A.I.Sanda, Phys. Let. B **625**, 47 (2005): $\mathcal{A}_{\mathcal{CP}} = (3.27 \pm 0.12) \times 10^{-3}$

The main idea is to calculate asymmetry $\mathcal{A}_{\mathcal{CP}}$ from the numbers of signal events $\mathrm{A}_{\mathrm{visible}}$ and the asymmetry due to the detector apparatus function $\mathrm{A}_{\mathrm{detector}}$. $\mathrm{A}_{\mathrm{detector}}$ is evaluated from the experimental data using events of $\tau^\pm \to \pi^\pm \pi^+ \pi^- \nu$ decay having signature similar to the signal one.

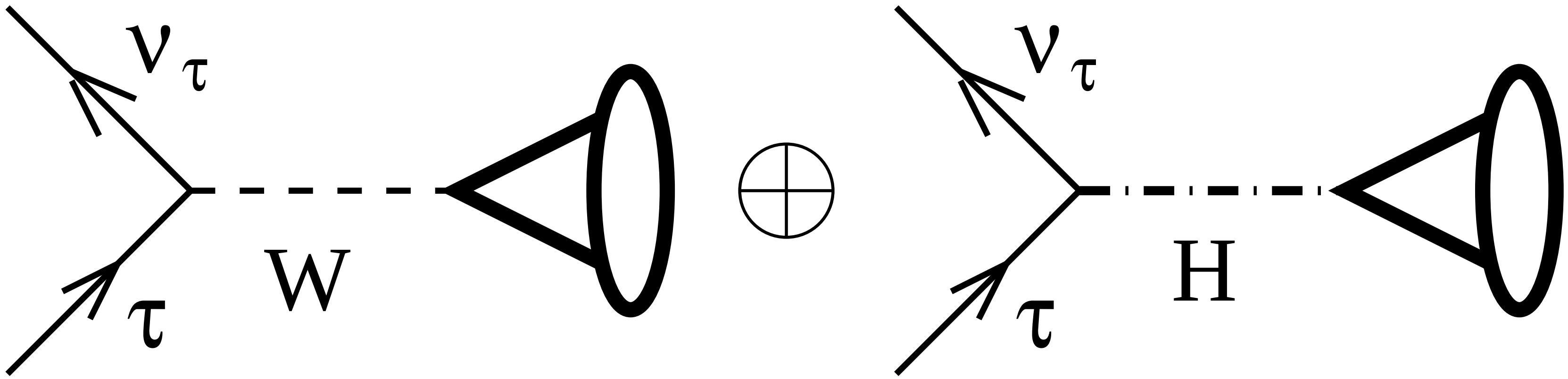
$$\mathcal{A}_{\mathcal{CP}} = \mathrm{A}_{\mathrm{visible}} - \mathrm{A}_{\mathrm{detector}}, \quad \mathrm{A}_{\mathrm{detector}} = (-7.7 \pm 1.3) \times 10^{-3}$$

$$-5.4 \times 10^{-3} < \mathcal{A}_{\mathcal{CP}} < 18.0 \times 10^{-3} \text{ (90\% CL)}$$

The origin of the detector charge asymmetry $\mathrm{A}_{\mathrm{detector}}$ is under investigation.

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 through:



$$F_{\rm S} = \bar{F}_{\rm S} + \frac{\eta_{\rm S}}{M_\tau} F_{\rm H}$$

$$\Delta W_{\rm SF} = 4\sqrt{s} P \frac{1}{M_\tau} {\rm Im}(F_{\rm V} F_{\rm H}^*) {\rm Im}(\eta_{\rm S})$$

G. Bonvicini *et al.* [CLEO Collaboration], "Search for CP violation in $\tau \to K\pi\nu_\tau$ decays," Phys. Rev. Lett. **88**, 111803 (2002) [arXiv:hep-ex/0111095].

Optimal variable technique: $\xi = \frac{\rm A(CP-odd)}{\rm A(CP-even)}$

Conclusions and Plans

The branching fraction of the $\tau^\pm \to K_S \pi^\pm \nu_\tau$ decay has been measured using a data sample of 351.4 fb^{-1} collected at the Belle detector. Our result is:

$$\mathcal{B}(\tau \to K_S \pi \nu_\tau) = (0.395 \pm 0.002_{\rm stat} \pm 0.014_{\rm syst})\%$$

Result of this work does not contradict to the previous measurements and has better accuracy.

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 values of the $K^*(892)$ mass and width we obtained are:

$$M(K^*(892)) = (895.47 \pm 0.20_{\rm stat} \pm 0.44_{\rm syst} \pm 0.59_{\rm mod})\ \mathrm{MeV/c^2}$$

$$\Gamma(K^*(892)) = (46.2 \pm 0.6_{\rm stat} \pm 1.0_{\rm syst} \pm 0.7_{\rm mod})\ \mathrm{MeV}$$

While our value of the width is compatible with most of the previous measurements within experimental errors, the mass value is systematically higher than those before and is in fact consistent with the world average value of the neutral $K^{*0}(892)$ mass, which is (896.00 ± 0.25) MeV

Plans

- Paper draft refereeing is in progress.
- We plan to measure CP violating asymmetry.
- We'll try to do full phase space analysis.