Tau Physics at the B-Factories Babar & Belle

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Summary

Topics on τ Physics at B-Factories covered in this talk:

- Search for Lepton Flavor Violation $\Rightarrow$ Search for New Physics
  - *tau* $\rightarrow e\,\gamma$
  - *tau* $\rightarrow \ell\, K_S^0$
  - *tau* $\rightarrow \ell\, hh' (\ell\, \pi K, \ell\, \pi\pi \ldots)$
  - $e^+e^- \rightarrow \tau e$, $e^+e^- \rightarrow \tau\mu$
- A high statistics study of the decay $\tau \rightarrow \pi\pi^0\nu_\tau$
  - *Determination of ρ's parameters and $\mathcal{B.R.}$*
  - *Determination of the hadronic vacuum polarization contribution to $g_\mu - 2$*
- Search for rare τ decays
- τ mass measurement and CPT test

Tau decays with Lepton Flavour Violation (LFV)

Search for LFV tau decays $\Rightarrow$ probe new physics effects

- In the SM with massless neutrino Lepton Flavour Number is conserved [a]
- SM with right handed massive neutrinos cannot accomodate for sizable LFV in charged leptons (GIM)
- much larger $\mathcal{B}.\mathcal{R}.$ predicted by several SM extensions

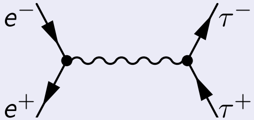
Model	$\tau \to \ell\gamma$	$\tau \to \ell\ell\ell$	**Reference**
SM + lepton mixing	10^{-40}	10^{-14}	hep-ph/9810484
SM + rh heavy Majorana neutrino	$<10^{-9}$	$<10^{-10}$	PRD66(2002)034008
mSUGRA + seesaw	$<10^{-7}$	$<10^{-9}$	hep-ph/0206110, hep-ph/9911459
SUSY $SU(5)$	$<10^{-4}$		hep-ph/0303071
SUSY $SO(10)$ + seesaw	$<10^{-5}$	$<10^{-10}$	hep-ph/0304190, hep-ph/0405017
SUSY anomalous $U(1)$	$<10^{-7}$		hep-ph/0308093
neutral SUSY Higgs	$<10^{-10}$	$<10^{-7}$	hep-ph/0304081)
MSSM+nonuniversal soft SUSY breaking	$<10^{-10}$	$<10^{-6}$	hep-ph/0305290
Non universal Z' (technicolor)	$<10^{-9}$	$<10^{-8}$	PLB547(2002)252
extra dimensions	$<10^{-11}$		hep-ph/0210021

(E. Ma hep-ph/0209170 for a review)

[a] at any level of the perturbative expansion (Kuzmin *et al.* Phys.Lett. B155:36 1985)

A B-factory is a τ factory too!

Production

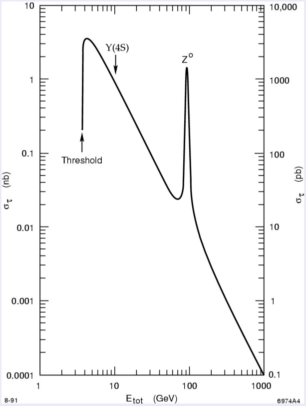


$$\sigma\left(e^+e^- \to \tau^+\tau^- \text{ @ } \Upsilon(4S)\right) \sim 1\,\text{nb}$$

$$\mathcal{L} \sim 10^{34}\,\text{cm}^{-2}\text{s}^{-1}$$

$$f_{\text{prod.}} \sim 10\,\text{Hz} \Rightarrow \frac{100\text{ millions } \tau^+\tau^-}{\text{SnowmassYear}}$$

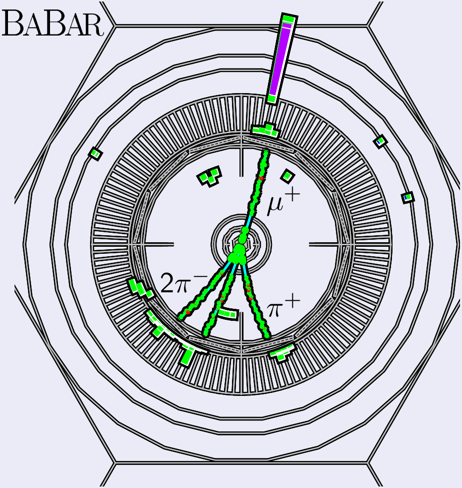
$\sigma(e^+e^- \to \tau^+\tau^-) \quad (\text{nb})$



Tau Pairs Event Selection: Topology and Event Shape

...undetectable ν's

$e^+e^- \to \tau^+ (\mu^+\nu_\mu\overline{\nu}_\tau)\tau^-(3\,\text{"prongs"}\,\nu_\tau)$



Selection Criteria

Topological:

- low multiplicity

  $\tau \to 1\,\text{"prong"} + \nu\ \text{(neutrals)}$

  $\tau \to 3\,\text{"prongs"} + \nu\ \text{(neutrals)}$

  $\Upsilon(4S) \to 11\,\text{"prongs"}$

- 2 jets well collimated and separated

Kinematical:

- missing energy
- missing momentum

Search for LFV: $\tau \to e\gamma$

hep-ex/0508012

Strategy

Tag: $\tau \to 1/3$ "prongs"

Veto: $\tau \to e\bar{\nu}_e\nu_\tau$

Identification of the

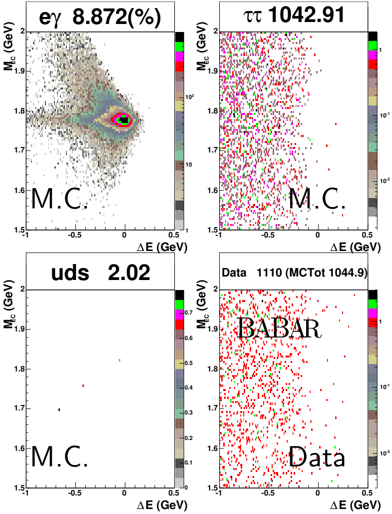
$$\tau \to e\gamma$$

candidate on the plane

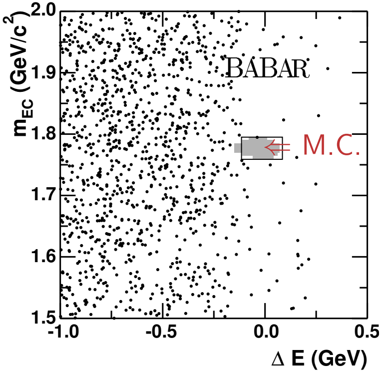
- $\Delta E = (E^\star_\gamma + E^\star_e) - \sqrt{s}/2$
- $M_{e\gamma} = \mathrm{En.Constr.}m(e\gamma)$

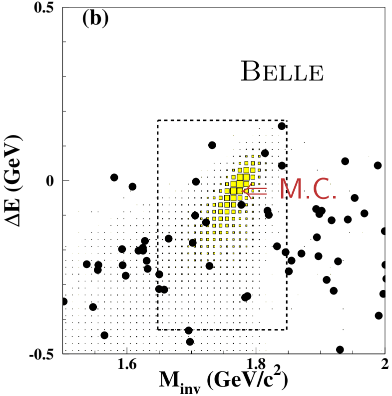
Backgrounds:

- $e^+e^- \to \tau^+\tau^-$ *x.feed*
- *other QED* $e^+e^- \to \ell^+\ell^-$
- $e^+e^- \to q\bar{q}$



Results of the Searches





BABAR: hep-ex/0508012

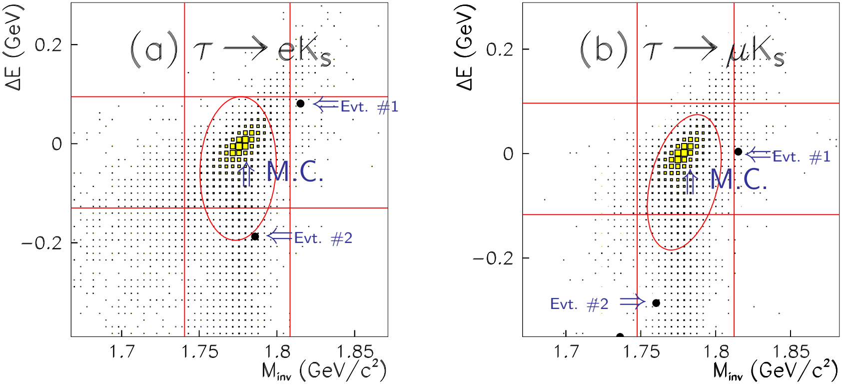
- $\mathcal{L} = 232\,\mathrm{fb}^{-1}$, $\epsilon = 4.7\%$
- Exp. bkg. (1.9 ± 0.4) evt.
- 1 evt. found in the signal box
- $\mathcal{B.R.} < 1.1 \times 10^{-7}$ (90% C.L)

BELLE: PLB 613 22-28 (2005)

- $\mathcal{L} = 87.1\,\mathrm{fb}^{-1}$, $\epsilon = 6.37\%$
- Exp. bkg. (25.7 ± 0.3) evt.
- 20 evt. found in the signal box
- $\mathcal{B.R.} < 3.8 \times 10^{-7}$ (90% C.L)

Search for $\tau \to \ell K_s^0$ (on $\mathcal{L} = 281\,\text{fb}^{-1}$)

Phys.Rev. **D67** 012002



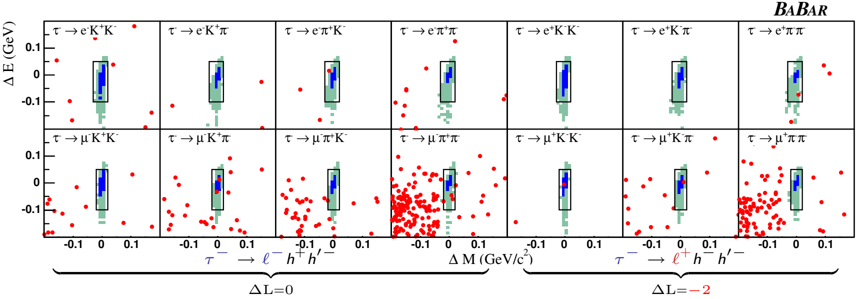
$\tau \to eK_s^0$ ($K_s^0 \to \pi^+\pi^-$)

- Exp. bkg. (0.2 ± 0.2) evt.
- 0 evt. found in the signal box
- $\mathcal{B}.\mathcal{R}. < 5.6 \times 10^{-7}$ (90% C.L)

$\tau \to \mu K_s^0$ ($K_s^0 \to \pi^+\pi^-$)

- Exp. bkg. (0.2 ± 0.2) evt.
- 0 evt. found in the signal box
- $\mathcal{B}.\mathcal{R}. < 4.9 \times 10^{-7}$ (90% C.L)

Search for $\tau \to \ell h h'$



BABAR: hep-ex/0506066

- $\mathcal{L} = 221\,\text{fb}^{-1}$, $\epsilon = 2 - 3\%$
- Exp. bkg. (0.1 – 3) evt.
- No signal found
- $\mathcal{B.R.} < (0.7 - 4.8) \times 10^{-7}$ (90% C.L)

Belle: Nucl.Phys.B144,173(2005)

- $\mathcal{L} = 158\,\text{fb}^{-1}$, $\epsilon = 4 - 7\%$
- Exp. bkg. (0.3 – 15.3) evt.
- No signal found
- $\mathcal{B.R.} < (2.1 - 15.5) \times 10^{-7}$ (90% C.L)

Lepton Flavor Violation in $e^+e^- \to \ell\ell'$
Preliminary

Some extensions of the Standard Model (e.g. the Dualized Standard Model[1]) predict:

- observable rates for the Lepton Flavour Violating processes

$$e^+e^- \to \tau\mu \quad e^+e^- \to \tau e \quad e^+e^- \to e\mu$$

- unobservable rates for the the LFV decays:

$$\tau \to e\gamma \quad \tau \to \mu\gamma \quad \mu \to e\gamma$$

- current PDG upper limits:
  - ▷ $\mathcal{B}.\mathcal{R}.(Z^0/\gamma^\star \to \mu^\pm\tau^\mp) < 1.2 \times 10^{-5}(90\% C.L.)$ *from DELPHI*
  - ▷ $\mathcal{B}.\mathcal{R}.(Z^0/\gamma^\star \to e^\pm\tau^\mp) < 9.8 \times 10^{-6}(90\% C.L.)$ *from OPAL*

[1] J. Bordes *et al.*,Phys.Rev.D65:093006,2002

$e^+e^- \to \tau\ell$: Kinematic

$\tau \to \pi\nu_\tau$ and $\tau \to 3\pi\nu_\tau$.

Measured quantities:

- $\mathbf{p}_\ell$: 3-momentum of the long lived lepton.
- p_π : 4-momentum of the hadrons

Kinematical costraints:

▷ *2-body process: $p^\star_\ell$ and $p^\star_\tau$ fixed*

$$E^\star_\ell = \frac{\sqrt{s}}{2} - \frac{m_\tau^2 - m_\ell^2}{2\sqrt{2}} \qquad |\mathbf{p}^\star_\ell| = \sqrt{E^{\star\,2}_\ell - m_\ell^2}$$

$$E^\star_\tau = \frac{\sqrt{s}}{2} + \frac{m_\tau^2 - m_\ell^2}{2\sqrt{2}} \qquad \mathbf{p}^\star_\tau = -\mathbf{p}^\star_\ell \frac{\sqrt{E^{\star\,2}_\tau - m_\tau^2}}{|\mathbf{p}^\star_\ell|}$$

▷ *3-momentum conservation in τ decay :*

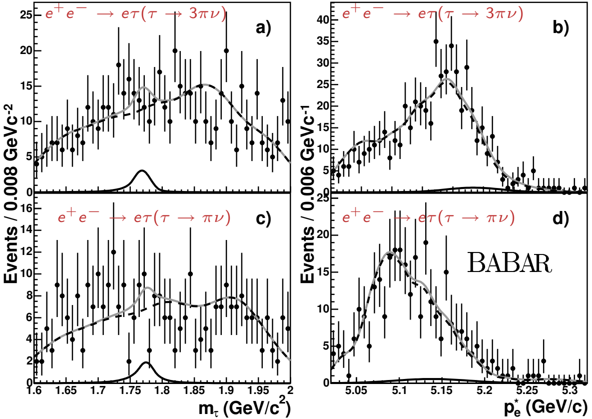
$$\mathbf{p}^\star_\tau = \mathbf{p}^\star_\pi + \mathbf{p}^\star_\nu \quad \Rightarrow \quad \mathbf{p}^\star_\nu = \mathbf{p}^\star_\tau - \mathbf{p}^\star_\pi \quad (m_\nu = 0 \quad \Rightarrow \quad E^\star_\nu = |\mathbf{p}^\star_\nu|)$$

▷ *Reconstructed τ mass:*

$$m = \sqrt{(E^\star_\pi + |\mathbf{p}^\star_\nu|)^2 - |\mathbf{p}^\star_\tau|^2}$$

$e^+e^- \to \tau\ell$: Fit Results

Preliminary on ($210.6\,\mathrm{fb}^{-1}$)



Maximum likelihood bi-dimensional fit to $|\mathbf{p}^\star_\ell|, m$.

No evidence for a signal

$$\sigma_{\mu\tau} < 4.6\,\mathrm{fb}$$

$$\sigma_{e\tau} < 10.1\,\mathrm{fb}$$

$$\sigma_{\mu\tau}/\sigma_{\mu\mu} < 4.0 \times 10^{-6}$$

$$\sigma_{e\tau}/\sigma_{\mu\mu} < 8.9 \times 10^{-6}$$

.

A High Statistics Study of the Decay $\tau \to \pi^- \pi^0 \nu_\tau$

Why are we so interested in the SM decay $\tau \to \pi^- \pi^0 \nu_\tau$?

- The measurement of the differential partial decay width ($s = M^2_{\pi^- \pi^0}$):

$$\frac{1}{\Gamma}\frac{d\Gamma}{ds} = \frac{6\pi |V_{ud}|^2 S_{EW}}{m_\tau^2} \left(\frac{\mathcal{B}_e}{\mathcal{B}_{\pi\pi}}\right) \left(1 - \frac{s}{m_\tau^2}\right)^2 \left(1 + \frac{2s}{m_\tau^2}\right) v_-(s)$$

  can be used to reduce the uncertainty on the theoretical prediction of the muon magnetic anomaly
- Dominated by ρ, ρ', ρ'' intermerdiate resonances
  - ▷ *clean environment to study their parameters*
- Most frequent τ decay ($\mathcal{B}.\mathcal{R}. \sim 25\%$)
  - ▷ *background for other τ studies*

$\tau \to \pi^-\pi^0\nu_\tau$: Event Selection ($72.2\,\mathrm{fb}^{-1}$)

Analysis Strategy

Select an inclusive sample:

- 2/4 tracks and zero net charge
- requirements on:

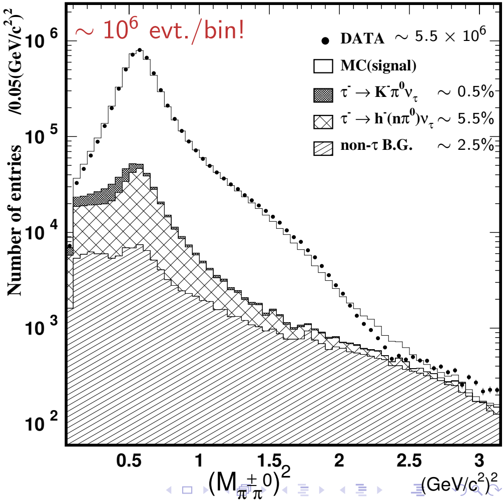
	$\tau^+\tau^-$	$\ell^+\ell^-$
total CM energy	small	$m(\Upsilon(4S))$
CM track momenta	soft	$m(\Upsilon(4S))/2$
missing mass (MM)	$\gg 0$	~ 0

$$(MM)^2 = (P_{\rm ini} - P_{\rm tracks} - P_{\gamma s})^2$$

22.7×10^6evt. $(\tau^+\tau^- > 90\%)$

Define two hemispheres w.r.t. the stiffest track. Require

- one hemisphere with just
  - ▷ *one track and one* $\pi^0 \to \gamma\gamma$



K. Abe *et al.*, hep-ex/0512071

First unambiguous demonstration of ρ'' in τ decay!

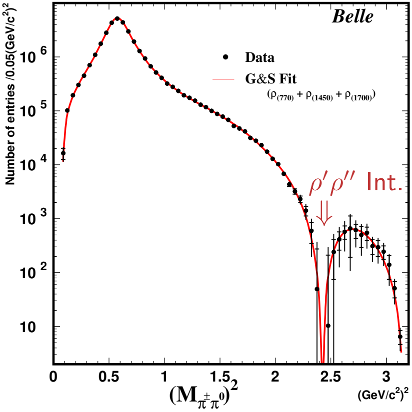
K. Abe *et al.*,hep-ex/0512071

Fit Results

Parameter	Belle[a] (fixed ϕ_γ)	ALEPH(τ)[b] ($M_{\rho''}, \Gamma_{\rho''}, \phi_\gamma$)
M_{ρ^-} (MeV/c^2)	774.3 ± 0.2	775.5 ± 0.7
Γ_{ρ^-} (MeV)	150.0 ± 0.3	149.0 ± 1.2
$M_{\rho'}$ (MeV/c^2)	1436 ± 15	1328 ± 15
$\Gamma_{\rho'}$ (MeV)	553 ± 31	468 ± 41
$\|\beta\|$	0.161 ± 0.020	0.120 ± 0.008
ϕ_β (degree)	149.1 ± 2.4	153 ± 7
$M_{\rho''}$ (MeV/c^2)	1804 ± 16	[1713]
$\Gamma_{\rho''}$ (MeV)	567 ± 81	[235]
$\|\gamma\|$	0.136 ± 0.024	0.023 ± 0.008
ϕ_γ (degree)	[0]	[0]
χ^2/(d.o.f)	94 / 52	119 / 110

[a] K. Abe *et al.*, hep-ex/0512071

[b] S. Schael *et al.*, Phys. Rep. **421**, 191 (2005).



Fit of the Gounaris-Sakurai model to the $M^2_{\pi^\pm\pi^0}$ distribution after:

- background subtraction
- finite resolution effects unfolding
- acceptance correction

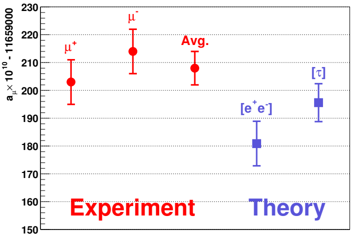
Prediction of the Muon Magnetic Anomaly

$a_{\mu^-}(\mathrm{exp}) = 11\,659\,214(8)(3) \times 10^{-10}$ $(0.7ppm)$

- The muon magnetic anomaly is $a_\mu = \left(\frac{g_\mu - 2}{2}\right)$
- Its prediction receives the contributions:

$$a_\mu = a_\mu^{Q.E.D.} + a_\mu^{had.} + a_\mu^{weak}$$

- Main theoretical uncertainty: the leading term of the hadronic vacuum polarization.
  Can be determined from
  - ▷ $\sigma(e^+e^- \rightarrow had.)$ *(dispersion relation)*
  - ▷ $\tau \rightarrow \pi\pi^0\nu_\tau$ *assuming CVC and correcting for isospin breaking*



$[\tau]$ from ALEPH and CLEO results only
G.W. Bennett *et al.* Phys.Rev.Lett 92; 1618102 (2004)

- ▷ *the two determinations* $[e^+e^-]$ *and* $[\tau]$ *slightly agree*

Belle determination of a_μ^{had}:

$$a_\mu^{\pi\pi}[0.50, 1.80] = (462.6 \pm 0.6\,(\mathrm{stat.}) \pm 3.2\,(\mathrm{sys.}) \pm 2.3\,(\mathrm{isospin})) \times 10^{-10} \quad (\tau : \mathrm{Belle})$$

$$a_\mu^{\pi\pi}[0.50, 1.80] = (464.0 \pm 3.0\,(\mathrm{exp.}) \pm 2.3\,(\mathrm{isospin})) \times 10^{-10} \quad (\tau : \mathrm{ALEPH, CLEO})$$

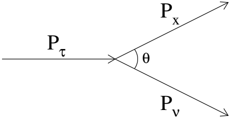
$$a_\mu^{\pi\pi}[0.50, 1.80] = (448.3 \pm 4.1\,(\mathrm{exp.}) \pm 1.6\,(\mathrm{rad.})) \times 10^{-10} \quad (e^+e^- : \mathrm{CMD2, KLOE})\,.$$

(K. Abe *et al.*,hep-ex/0512071)

τ Mass & CPT Test Using $\tau \to 3\pi^{\pm}(\pi^0)\nu_\tau$

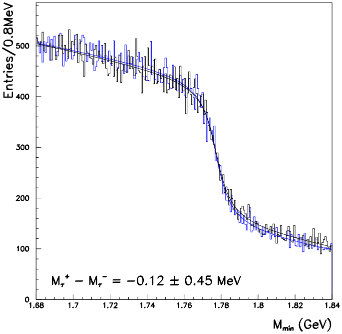
hep-ex/0511038

- Tag: $\tau \to \ell\overline{\nu}_\ell\nu_\tau$
- Analysis on the recoil: $\tau \to 3\pi^{\pm}(\pi^0)\nu_\tau$
- 4-momentum conservation:



$$m_\tau^2 = m_X^2 + m_\nu^2 + 2E_X E_\nu - 2\,|\mathbf{P}_X||\mathbf{P}_\nu|\cos\vartheta$$

$$m_\tau > M_{\mathrm{min}} = \sqrt{m_X^2 + 2\,(E_{\mathrm{beam}} - E_X)(E_X - |\mathbf{P}_X|)}$$



- Fit m_τ to the M_{min} distribution (preliminary)

$$m_\tau = 1776.71 \pm 0.25(\mathrm{stat}) \pm 0.62(\mathrm{syst})\ \mathrm{MeV}$$

$$m_\tau = 1776.99^{+0.29}_{-0.26}\ \mathrm{MeV(PDG2004)}$$

- CPT $\Rightarrow m_\tau^+ = m_\tau^-$:

$$|(m_{\tau^+} - m_{\tau^-})|/M_{\mathrm{average}} < 5.0 \times 10^{-4}$$

at 90% CL.

Search for $\tau^- \to 4\pi^- 3\pi^+ (\pi^0) \nu_\tau$ (on 232.2 fb^{-1})

hep-ex/0506007

Clean tagging τ decay:

- ▷ $\tau \to \ell \overline{\nu}_\ell \nu_\tau$
- ▷ $\tau \to \pi^- \nu_\tau$
- ▷ $\tau \to \rho^- \nu_\tau$ $(\rho^- \to \pi^- \pi^0)$

7 "prongs" in the opposite hemisphere.
In the center-of-mass frame:

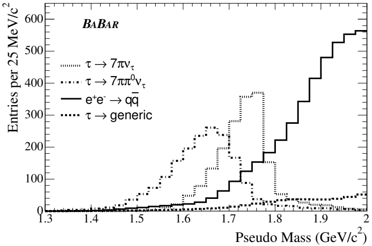
$$m_\tau^2 = E_\tau^2 - |\mathbf{p}_{7\pi} + \mathbf{p}_\nu|^2$$

$$E_\tau = E_{\text{beam}}/2$$

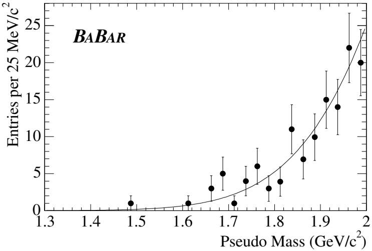
Pseudo mass (approx. $\mathbf{p}_\nu \parallel \mathbf{p}_{7\pi}$):

$$m^2 = 2\,(E_{\text{beam}} - E_{7\pi})(E_{7\pi} - |\mathbf{p}_{7\pi}|) + m_{7\pi}^2$$

Monte Carlo:



Data :



$$\mathcal{B}.\mathcal{R}(\tau \to 7\pi(\pi^0)\nu_\tau) < 3.0 \times 10^{-7} (90\% C.L.)$$

Conclusions

Babar & Belle are excellent Tau-Factories

- Top notch results on the search for lepton flavor violation and for rare Tau-decays
- Competitive results in the realm of the high precision measurements
- ... we are still waiting for any significant departure from the Standard Model, but new data (with effort and fantasy to analyze them) can still bring surprises!