New Physics with τ Lepton at Belle and BaBar

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Outline

1. General
2. Lepton Universality
3. Lepton Flavor Violation in τ lepton decay
4. Second class currents
5. Conclusions

General – I

Two trends in modern high energy collider physics:

- New energy frontiers, quest for very heavy particles
  LEP, Tevatron, RICH, LHC, ILC/CLIC
- New luminosity frontiers, quest for very rare phenomena
  DAFNE, BEPC-II, PEP-II, KEKB

General – II

Some milestones of the Standard Model:

- There are three generations (families) of quarks and leptons, each has a charged lepton (e^-, μ^-, τ^-) and its neutrino (ν_e, ν_μ, ν_τ)
- Each generation has its unique conserved flavor (family number), i.e., $\mu^- \to e^- \nu_\mu \bar{\nu}_e$ and there are no neutrinoless decays
- Coupling of W with leptons is family-independent: $G_e = G_\mu = G_\tau = G_F$ (lepton universality)

Discovery of neutrino oscillations $\Rightarrow$ reconsideraton of these concepts

General – III

- τ lepton is one of the six fundamental leptons
- As the heaviest lepton, it may decay into both leptons and hadrons: PDG lists more than 200 different τ decays
- We can study all interactions allowed in the Standard Model and search for effects of New Physics
- It is a very clean laboratory with no hadrons in the initial and only a few in the final state: 85.36% – 1-prong, 14.56% – 3-prong, 10^{-3} – 5-prong events

τ Lepton Factories

Group	$\int L\,dt$, fb^{-1}	$N_{\tau\tau}$, 10^6
LEP (Z-peak)	0.34	0.33
CLEO (10.6 GeV)	13.8	12.6
BaBar (10.6 GeV)	516	482
Belle (10.6 GeV)	782	719
τ-c (4.2 GeV)	10	32
SuperB	50k	45k

BaBar ($\sim$ 557 fb^{-1}) and Belle ($\sim$ 984 fb^{-1}) collected together about 1.5 ab^{-1}

B-factory is also a τ factory producing $0.9 \cdot 10^6$ $\tau^+\tau^-$ pairs per each fb^{-1}!!

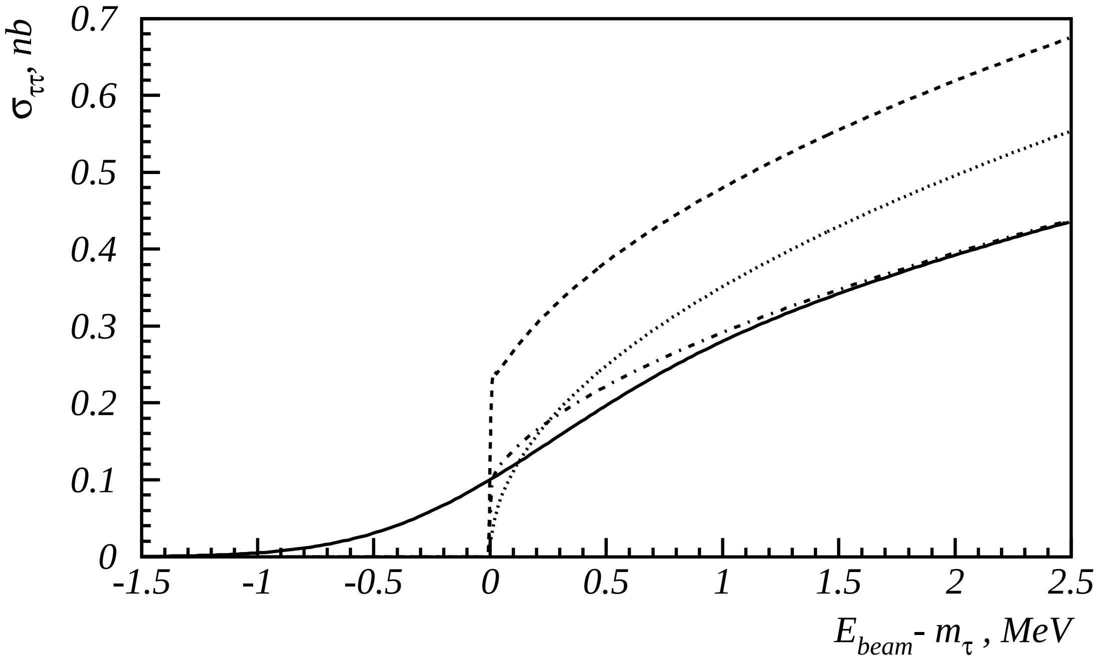
Super-c-τ-factory (10^{35} cm^{-2} s^{-1}) with $\int Ldt = 10$ ab^{-1} will yield $32 \cdot 10^9$ $\tau^+\tau^-$ pairs!!

Lepton universality and M_τ

$$r = \left(\frac{G_{\tau\to e\nu_\tau\bar{\nu}_e}}{G_{\mu\to e\nu_\mu\bar{\nu}_e}}\right)^2 = \left(\frac{M_\mu}{M_\tau}\right)^5 \left(\frac{t_\mu}{t_\tau}\right) \mathcal{B}(\tau \to e\nu_\tau\bar{\nu}_e) \frac{F_{\rm cor}(M_\mu, M_e)}{F_{\rm cor}(M_\tau, M_e)}$$

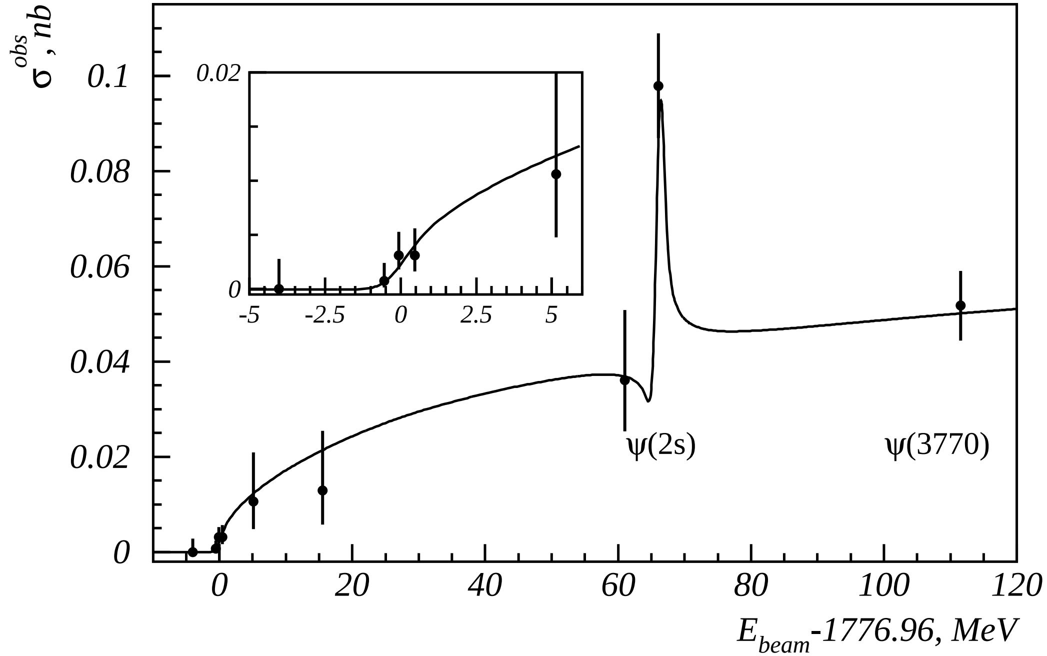
r	t_τ, fs	$\mathcal{B}(\tau \to e\nu_\tau\bar{\nu}_e)$, %	M_τ, MeV	Comments
0.9405 ± 0.0249	305.6 ± 6.0 ± 0.0185	17.93 ± 0.26 ± 0.0136	$1784.1^{+2.7}_{-3.6}$ $^{+0.0071}_{-0.0095}$	PDG, 1992 -2.4σ
0.9999 ± 0.0069	291.0 ± 1.5 ± 0.0052	17.83 ± 0.08 ± 0.0045	$1777.0^{+0.30}_{-0.27}$ ± 0.0008	PDG, 1996 -0.01σ
1.0020 ± 0.0051	290.6 ± 1.1 ± 0.0038	17.84 ± 0.06 ± 0.0034	$1776.99^{+0.29}_{-0.26}$ ± 0.0008	PDG, 2004 $+0.4\sigma$

$\sigma(e^+e^- \to \tau^+\tau^-)$ Near Threshold



Dotted – Born, dashed – Coulomb, FSR and VP,
dash-dotted – ISR, solid – beam energy spead

M_τ at KEDR: Observed $\sigma(e^+e^- \to \tau^+\tau^-)$



$\int Ldt = 6.7\ \text{pb}^{-1}$, 81 events selected

$M_\tau = (1776.81^{+0.25}_{-0.23} \pm 0.15)\ \text{MeV}/c^2$

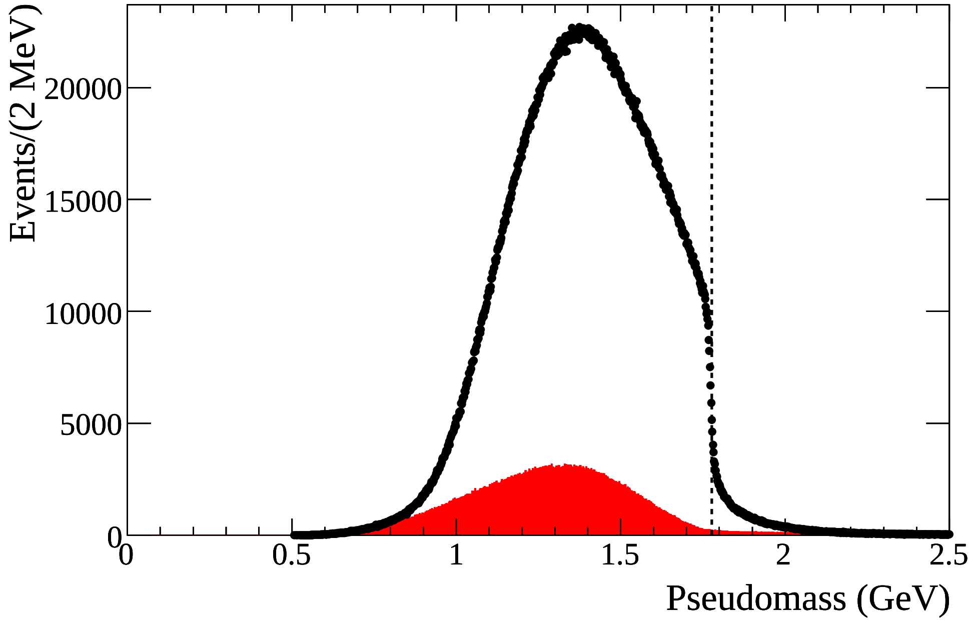
V.V. Anashin et al., JETP Lett. 85, 347 (2007)

M_τ at Belle and BaBar – I

Pseudomass method (ARGUS – 1992) uses

M_p – maximum inv. mass of observed hadrons

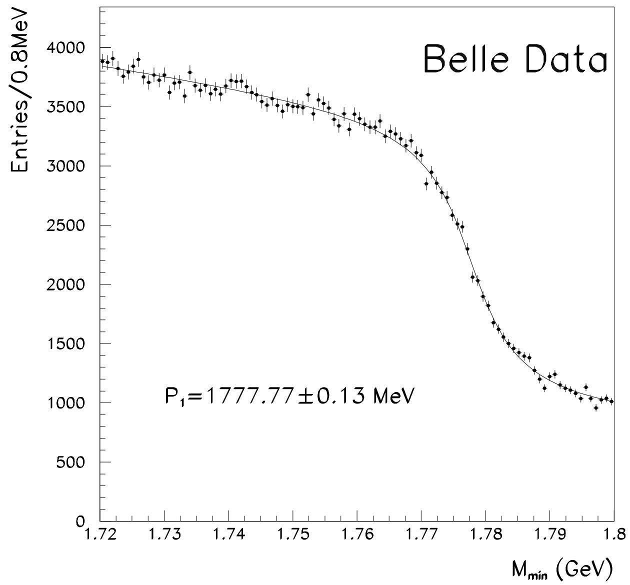
$$M_\tau^2 \geq M_p^2 = M_h^2 + 2(E_{\text{beam}} - E_h)(E_h - |\vec{p}_h|)$$



$$f(M_p) \sim (p_1 + p_2 M_p)\tan^{-1}(M_p - p_3)/p_4 + p_5 + p_6 M_p$$

The smearing of the endpoint and tail are caused by ISR/FSR and resolution

M_τ at Belle and BaBar – II



Both BaBar and Belle use $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ +c.c,
which has a large branching $\sim 9\%$
and large statistics in the endpoint region

M_τ at Belle and BaBar – III

Summary of Belle and BaBar measurements

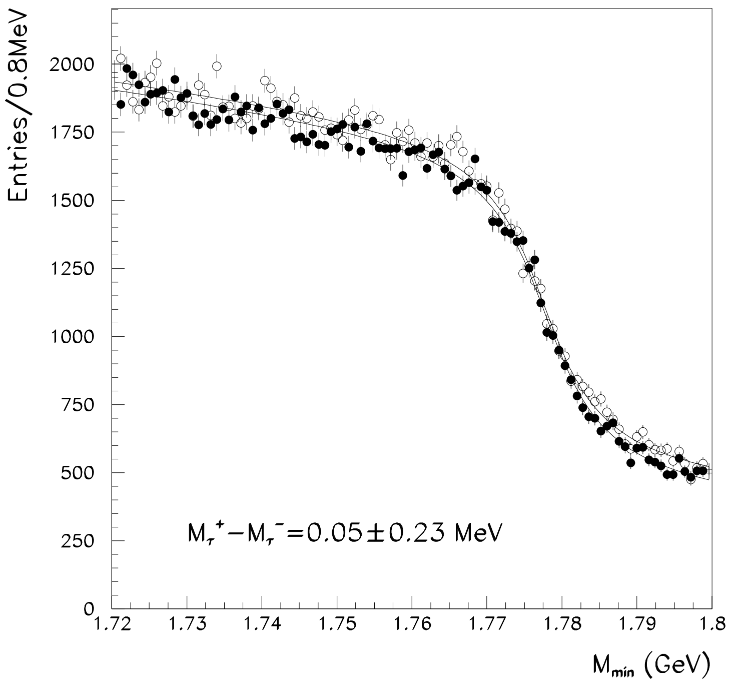
Group	BaBar	Belle
$\int L dt$, fb^{-1}	423	414
$N_{\tau\tau}$, 10^6	389	380
N_{ev}, 10^5	682	580
M_τ, MeV	$1776.68 \pm 0.12 \pm 0.41$	$1776.61 \pm 0.13 \pm 0.35$

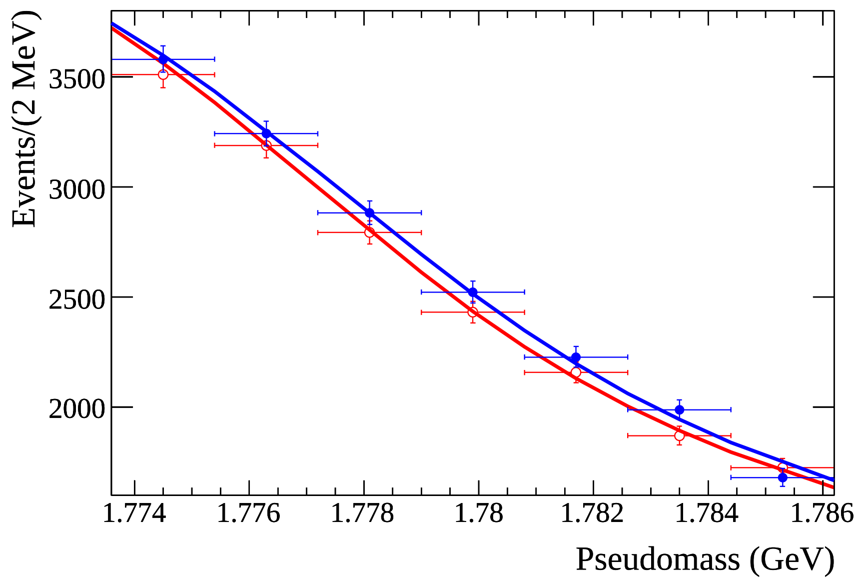
Belle: K. Belous et al., PRL 99, 011801 (2007)

BaBar: B. Aubert et al., PRD 80, 092005 (2009)

CPT Test by M_{τ^+} vs. M_{τ^-} – I

In the pseudomass method M_{τ^+} and M_{τ^-} are measured separately and $\Delta M = M_{\tau^+} - M_{\tau^-}$ can be determined





Belle: $\Delta M = 0.05 \pm 0.23 \pm 0.14$ MeV BaBar: $\Delta M = -0.61 \pm 0.23 \pm 0.06$ MeV

CPT Test by M_{τ^+} vs. M_{τ^-} – II

Group	OPAL, 2000	Belle, 2007	BaBar, 2009
$N_{\tau^+\tau^-}, 10^6$	0.16	380	388
ΔM, MeV	0.0 ± 3.2	0.05 ± 0.27	-0.61 ± 0.24
$\Delta M/M_\tau, 10^{-4}$	0.0 ± 18.0	0.3 ± 1.5	-3.4 ± 1.4
$\Delta M/M_\tau, 10^{-4}$ $90\% CL$	< 30.0	< 2.8	< 5.5

From MC studies BaBar finds, assuming no CPT violation, that there is a 1.2% chance of obtaining a result as different from zero as that of BaBar.

τ Lepton Mass Measurements

Group	M_τ, MeV
BES, 1996	$1776.96^{+0.18+0.25}_{-0.21-0.17}$
PDG, 2006	$1776.99^{+0.29}_{-0.26}$
KEDR, 2007	$1776.81^{+0.25}_{-0.23} \pm 0.15$
Belle, 2007	$1776.61 \pm 0.13 \pm 0.35$
PDG, 2008	1776.83 ± 0.18
KEDR, 2008	$1776.69^{+0.17}_{-0.19} \pm 0.15$
BaBar, 2008	$1776.68 \pm 0.12 \pm 0.41$

$r = 1.0039 \pm 0.0040$ $(0.99\sigma) \Rightarrow$ Leptonic universality is OK!

The r sensitivity is six times higher than in 1992 (0.004 vs. 0.025)

This test (G_τ/G_μ) is limited by the accuracy of τ_τ and $\mathcal{B}(\tau^- \to e^-\bar{\nu}_e\nu_\tau)$

BES-III can move much further

Charged Current Universality – I

$|G_\mu/G_e|$

$\mathcal{B}(\tau \to \mu)/\mathcal{B}(\tau \to e)$	1.0000 ± 0.0020
$\mathcal{B}(\pi \to \mu)/\mathcal{B}(\pi \to e)$	1.0021 ± 0.0016
$\mathcal{B}(K \to \mu)/\mathcal{B}(K \to e)$	1.004 ± 0.007
$\mathcal{B}(K \to \pi\mu)/\mathcal{B}(K \to \pi e)$	1.002 ± 0.002
$\mathcal{B}(W \to \mu)/\mathcal{B}(W \to e)$	0.997 ± 0.010

A. Pich: NPB (Proc. Suppl.) 181-182, 300 (2008)

Charged Current Universality – II

$|G_\tau/G_e|$

$\mathcal{B}(\tau \to \mu)\tau_\mu/\tau_\tau$	1.0005 ± 0.0023
$\mathcal{B}(W \to \tau)/\mathcal{B}(W \to e)$	1.036 ± 0.014

$|G_\tau/G_\mu|$

$\mathcal{B}(\tau \to e)\tau_\mu/\tau_\tau$	1.0006 ± 0.0022
$\Gamma(\tau \to \pi)/\Gamma(\pi \to \mu)$	0.996 ± 0.005
$\Gamma(\tau \to K)/\Gamma(K \to \mu)$	0.979 ± 0.017
$\mathcal{B}(W \to \tau)/\mathcal{B}(W \to \mu)$	1.039 ± 0.013

Lepton Universality and Branching Fractions – I

Three recent measurements at BaBar (467 fb^{-1} or 429.2M $\tau^+\tau^-$:)

Ratio	BaBar	PDG-08
$\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)/\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$	$0.9796 \pm 0.0016 \pm 0.0036$	0.9725 ± 0.0039
$\mathcal{B}(\tau^- \to \pi^- \nu_\tau)/\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$	$0.5945 \pm 0.0014 \pm 0.0061$	0.6076 ± 0.0061
$\mathcal{B}(\tau^- \to K^- \nu_\tau)/\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$	$0.03882 \pm 0.00032 \pm 0.00057$	0.0384 ± 0.0013

Mode	$e^-\bar{\nu}_e\nu_\tau$	$\mu^-\bar{\nu}_\mu\nu_\tau$	$\pi^-\nu_\tau$	$K^-\nu_\tau$
$N_{\rm ev}, 10^3$	884	731	369	25

$$\left(\frac{G_\mu}{G_e}\right)^2 = \frac{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}{\mathcal{B}(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} \frac{f(m_e^2/m_\tau^2)}{f(m_\mu^2/m_\tau^2)},$$

where $f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x,\ m_\nu = 0.$

$|G_\mu/G_e| = 1.0036 \pm 0.0020$, consistent with 1.000 ± 0.002 (A. Pich, 2008).

B. Aubert et al., arXiv:0912.0242

Lepton Universality and Branching Fractions – II

$$\left(\frac{G_\tau}{G_\mu}\right)^2 = \frac{\mathcal{B}(\tau^- \to \pi^- \nu_\tau)}{\mathcal{B}(\pi^- \to \mu^- \bar{\nu}_\mu)} \frac{2 m_\pi m_\mu^2 \tau_\pi}{\delta_{\tau^- \to \pi^- \nu / \pi^- \to \mu^- \nu} m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_\pi^2}{1 - m_\pi^2/m_\tau^2}\right)^2,$$

$$\left(\frac{G_\tau}{G_\mu}\right)^2 = \frac{\mathcal{B}(\tau^- \to K^- \nu_\tau)}{\mathcal{B}(K^- \to \mu^- \bar{\nu}_\mu)} \frac{2 m_k m_\mu^2 \tau_K}{\delta_{\tau^- \to K^- \nu / K^- \to \mu^- \nu} m_\tau^3 \tau_\tau} \left(\frac{1 - m_\mu^2/m_K^2}{1 - m_K^2/m_\tau^2}\right)^2,$$

where the radiative corrections are

$\delta_{\tau^- \to \pi^- \nu / \pi^- \to \mu^- \nu} = 1.0016 \pm 0.0014$ and $\delta_{\tau^- \to K^- \nu / K^- \to \mu^- \nu} = 1.0090 \pm 0.0022$.

$|G_\tau/G_\mu| = 0.986 \pm 0.006 (0.983 \pm 0.009)$ with pions (kaons)

compared to $0.996 \pm 0.005 (0.979 \pm 0.017)$.

Their combination gives $|G_\tau/G_\mu| = 0.985 \pm 0.005$.

Search for New Physics in the Charged Lepton Sector

Searches for LFV decays with muons started long ago, in 70-ies, when even the concept of 3 families was not yet firmly established.

Discovery of neutrino oscillations, in particular $\nu_\mu \to \nu_\tau$ oscillations with a big mixing angle (S/K) $\Rightarrow$ searches for large $\mu - \tau$ LFV, e.g., $\tau^- \to \mu^- \gamma$

In schemes with inverted hierarchy $\tau - e$ is also possible, e.g., $\tau^- \to e^- \gamma$

Many models consider extensions of the Standard Model with enhanced LFV. Particularly popular are SUSY models, e.g. MSSM extension of SM, also discussed SUGRA, GUT, Higgs, little Higgs

The predicted $\mathcal{B}(\tau^- \to \mu^- \gamma)$ reaches $10^{-8} - 10^{-7}$

Search for $\mu^- \to e^-\gamma$

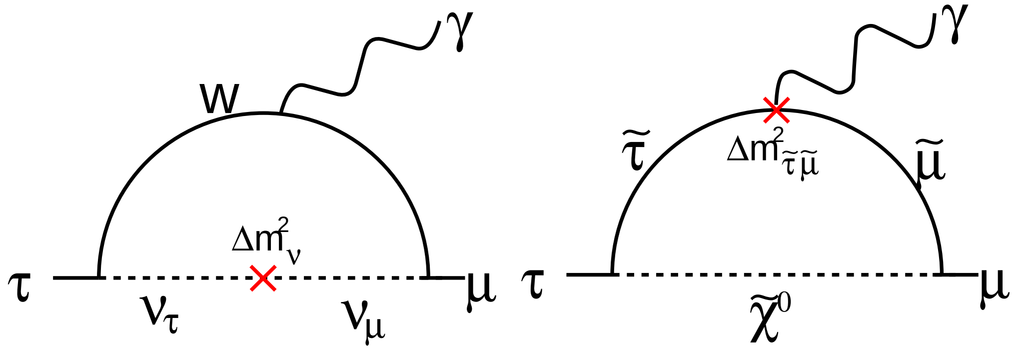
90% CL upper limits on the branching fraction $\mathcal{B}$

Group	Date	$\mathcal{B}, 10^{-11}$	$N_\mu, 10^{11}$
SIN	1980	100	–
NaI (LAMPF)	1982	17	27
NaI (TRIUMF)	1983	100	5.3
Cr. Box (LAMPF)	1988	4.9	14
MEGA (LAMPF)	1999	1.2	1200

Summary on LFV with Muons

Mode	$\mathcal{B}$ or $\mathcal{R}$ today	$\mathcal{B}$ or $\mathcal{R}$ expected
$\mu^- \to e^-\gamma$	$1.2 \cdot 10^{-11}$ (MEGA)	$\sim 10^{-13}(10^{-14})$ (MEG)
$\mu^- \to e^-e^+e^-$	$1.0 \cdot 10^{-12}$ (SINDRUM)	? (MEG)
$\mu^- \to e^-2\gamma$	$7.2 \cdot 10^{-11}$ (Cr.BOX)	? (MEG)
$\mu^-N \to e^-N$	$7 \cdot 10^{-13}$ (SINDRUM II)	$10^{-17} - 10^{-18}$ (PRISM)

LFV in τ decays (SM and SUSY)



In SM LFV is suppressed by $\Delta m^2_{ij}/m^2_W \sim 10^{-49} - 10^{-52}$

The effective Δm^2 in SUSY loops can be quite large,
there might also be enhancement due to large $\tan\beta$

E. Arganda, M. Herrero, J. Portoles, JHEP 0806:079 (2008)
consider various LFV decays in constrained MSSM-seesaw scenarios:

$$\mathcal{B}(\tau^- \to \mu^-\eta) = 1.2 \cdot 10^{-7}|\delta_{32}|^2\left(\frac{100}{m_{A^0}(GeV)}\right)^4\left(\frac{\tan\beta}{60}\right)^6$$

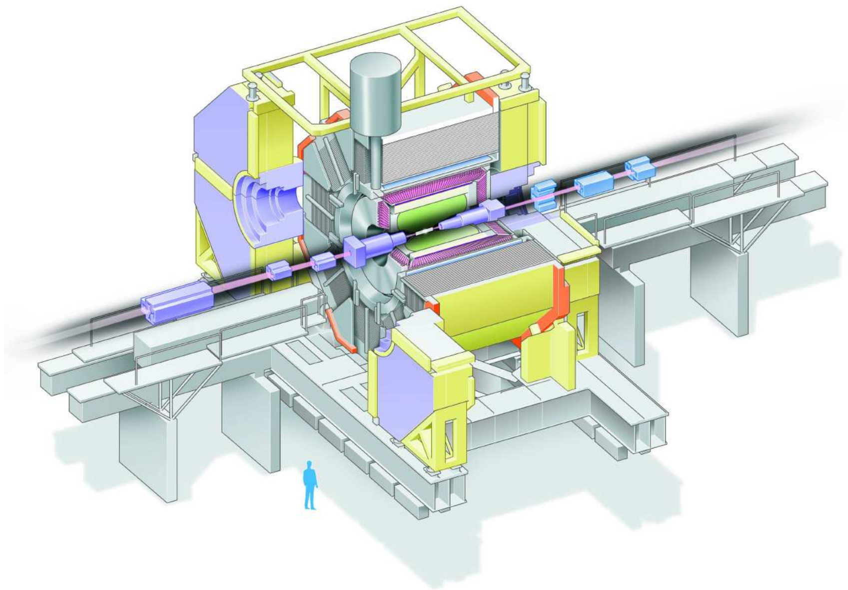
PEP-II and BaBar Detector

- PEP-II: 3.1 GeV $e^+ \times$ 9.0 GeV e^-
- $\mathcal{L}_{\rm max} = 1.21 \times 10^{34} {\rm cm}^{-2}{\rm s}^{-1}$
- Continuous injection $\rightarrow 0.91\,{\rm fb}^{-1}$/day
- $\int \mathcal{L}dt \approx 557\,{\rm fb}^{-1}$ Turned off in April 2008
- BaBar – 600 physicists from 75 Institutes in 10 countries

- Sil. vertex tracker
- Drift chamber
- DIRC
- CsI(Tl) calorimeter
- μK_L RPC

KEKB and Belle Detector

- KEKB: 3.5 GeV e^+ $\times$ 8.0 GeV e^-
- $\mathcal{L}_{\max} = 2.11 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Continuous injection $\rightarrow 1.52\,\mathrm{fb}^{-1}/\mathrm{day}$
- $\int \mathcal{L}dt \approx 984\,\mathrm{fb}^{-1}$ Operation continues
- Belle – 370 physicists from 60 Institutes in 15 countries

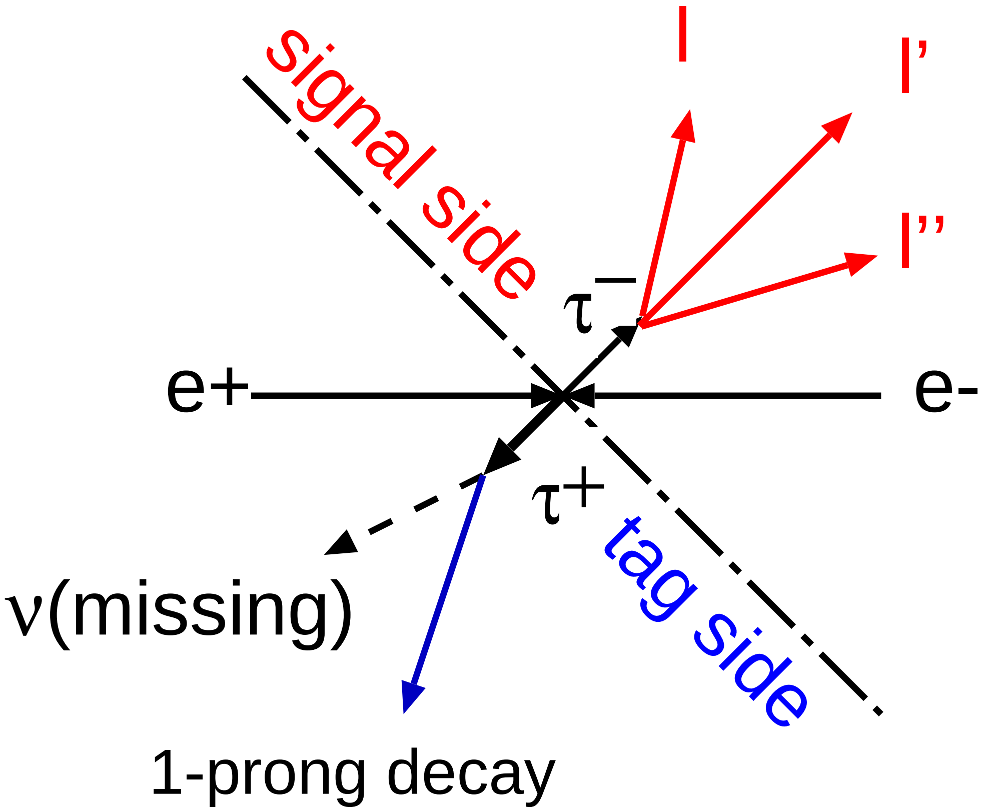


- Sil.VD: 3(4) layers DSSD
- CDC : small cells $He + C_2H_6$
- TOF counters
- Aerogel CC:$n = 1.015 \sim 1.030$
- CsI(Tl) 16 X_0
- SC solenoid 1.5 T
- μK_L detection 14-15 layers RPC+Fe

How Do We Search for LFV τ Decays – I

- We divide the event space by the plane perpendicular to the thrust axis into two hemispheres – "tag" side , in which some ordinary τ decay (usually 1-prong modes are selected) is observed and "signal" side , in which we try to completely reconstruct a neutrinoless LFV τ decay.
- Decays we are searching for are very rare ($\mathcal{P} < 10^{-7}$) $\Rightarrow$ mostly background (BG) is detected in the "signal" side. We apply various kinematical, topological and PID cuts to suppress BG.
- We compare various distributions in data with MC to be sure that we completely understand BG.

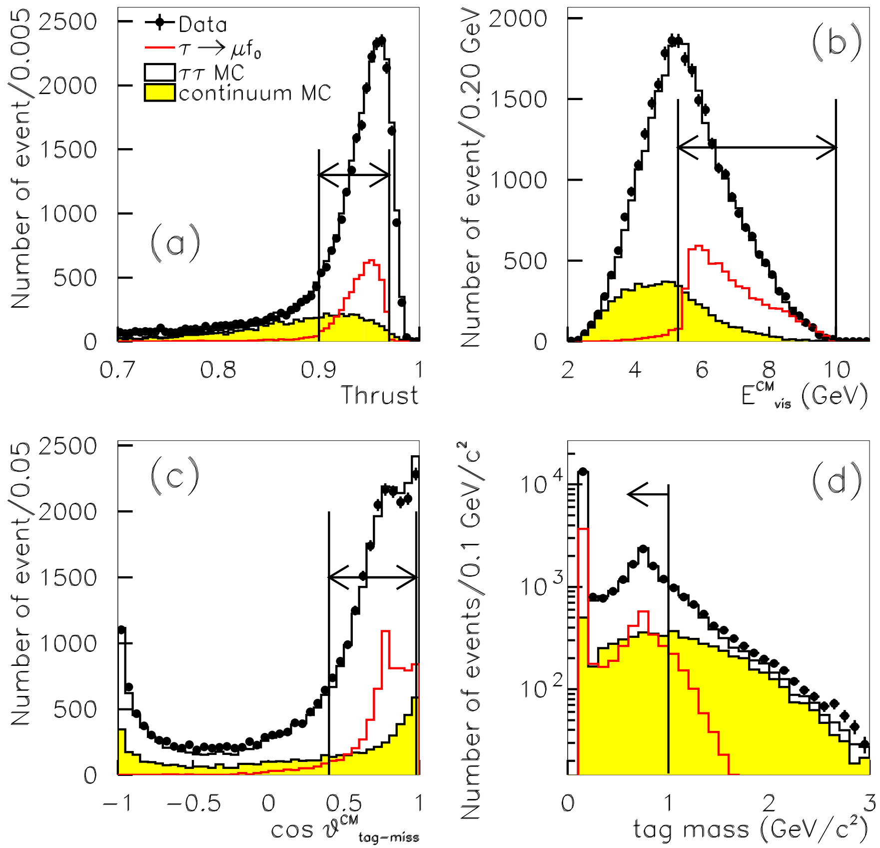
Signal and Tag Sides



How Do We Search for LFV τ Decays – II

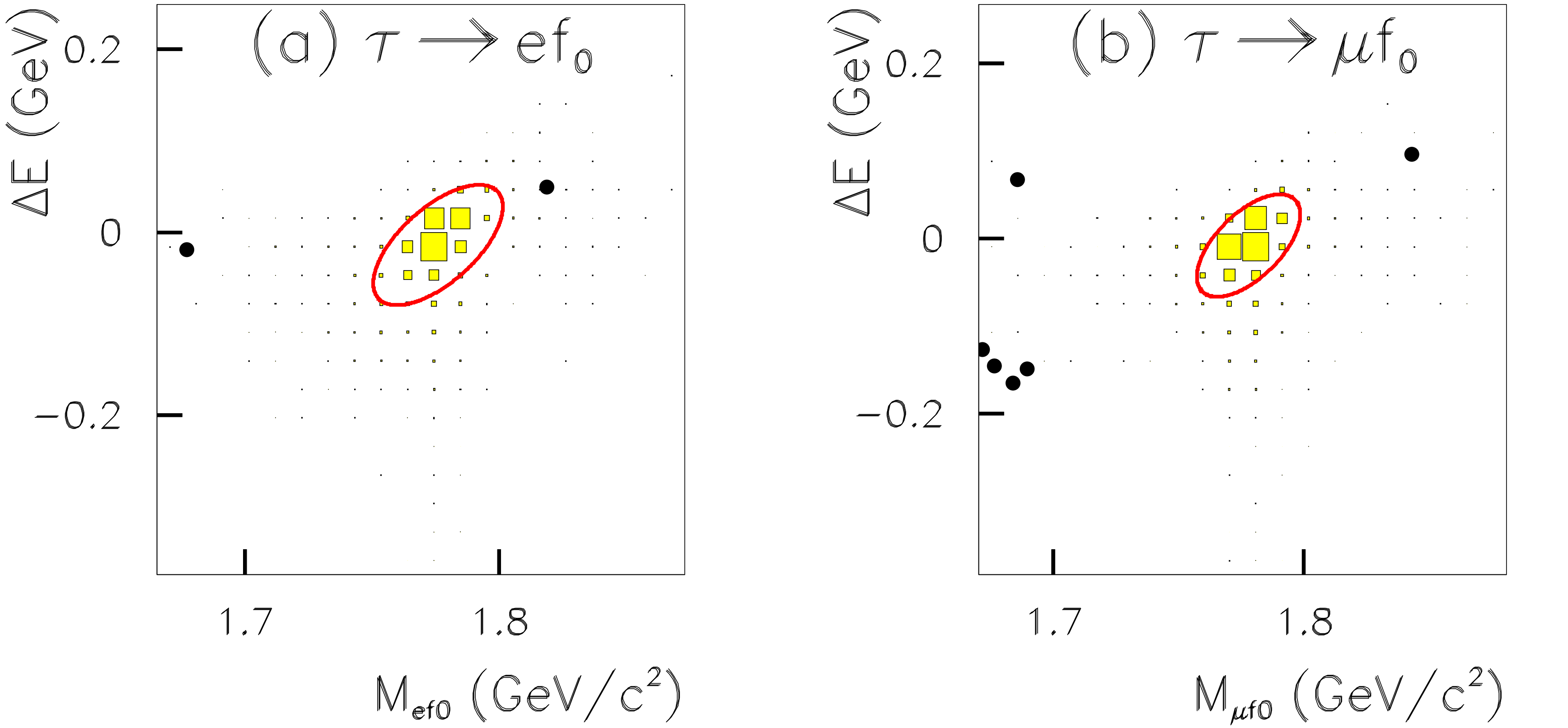
- We calculate an invariant mass of a signal candidate $M_{\rm inv}$ (for BaBar it's $M_{\rm EC}$ using $E_{\rm meas} = E_{\rm beam}$) and $\Delta E = E_{\rm meas} - E_{\rm beam}$. Signal events should have $M_{\rm inv(EC)} \approx M_\tau$, $\Delta E \approx 0$
- We blind the signal region (box or ellipse) within $\pm 3\sigma$ and optimize all selection criteria based on MC and sideband data
- We calculate the expected background in signal region
- We open the signal region and determine the signal yield s_0 from $N_{\rm obs}$ and $N_{\rm exp}$ taking into account systematic errors
- We calculate the branching ratio or place an upper limit: $\mathcal{B} = s_0/2N_{\tau\tau}\epsilon$, $N_{\tau\tau}$ – the number of $\tau^+\tau^-$ pairs, ϵ – acceptance

Search for $\tau^- \to \mu^- f_0(980)$ – I



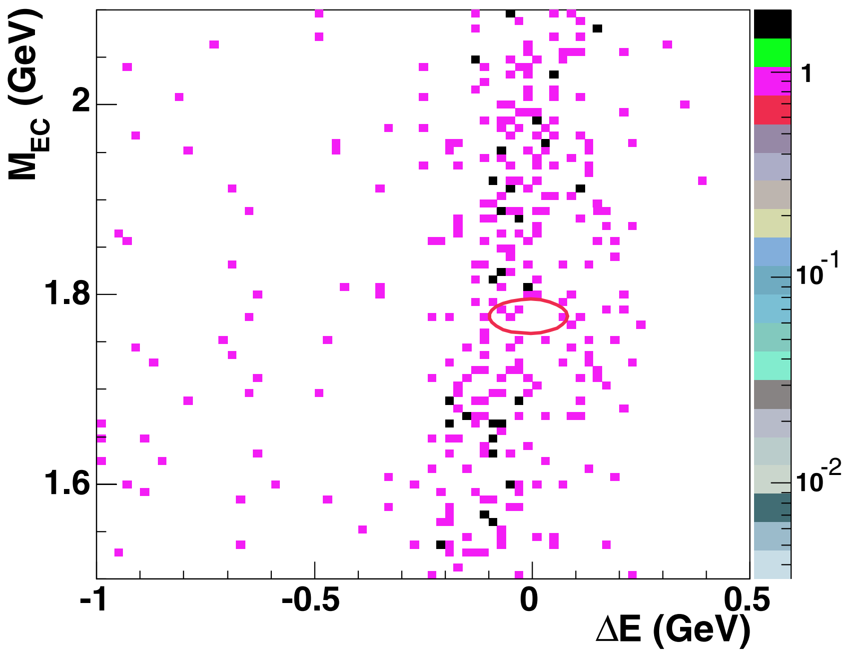
Background is well understood!

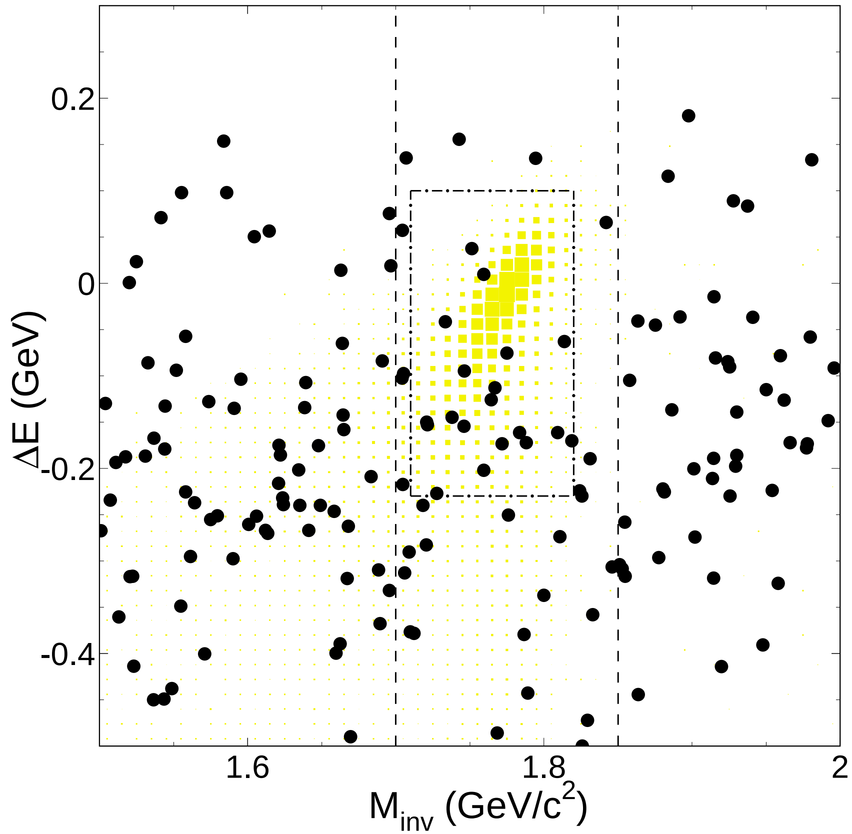
Search for $\tau^- \to \mu^- f_0(980)$ – II



BG is suppressed ⇒ no events in the signal ellipse

Search for $\tau \to \mu\gamma$





$\tau^- \to l^- \gamma$

90% upper limits on the branching fraction $\mathcal{B}$

τ^-	Belle		BaBar		CLEO	
mode	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$\mu^-\gamma$	4.5	491.7	4.4	429.2	110	12.7
$e^-\gamma$	12	491.7	3.3	429.2	270	4.3

Belle: K. Hayasaka et al., PLB 666, 16 (2008)

BaBar: B. Aubert et al., arXiv:0908.2381

$\tau^- \to l_1^- l_2^- l_3^+$

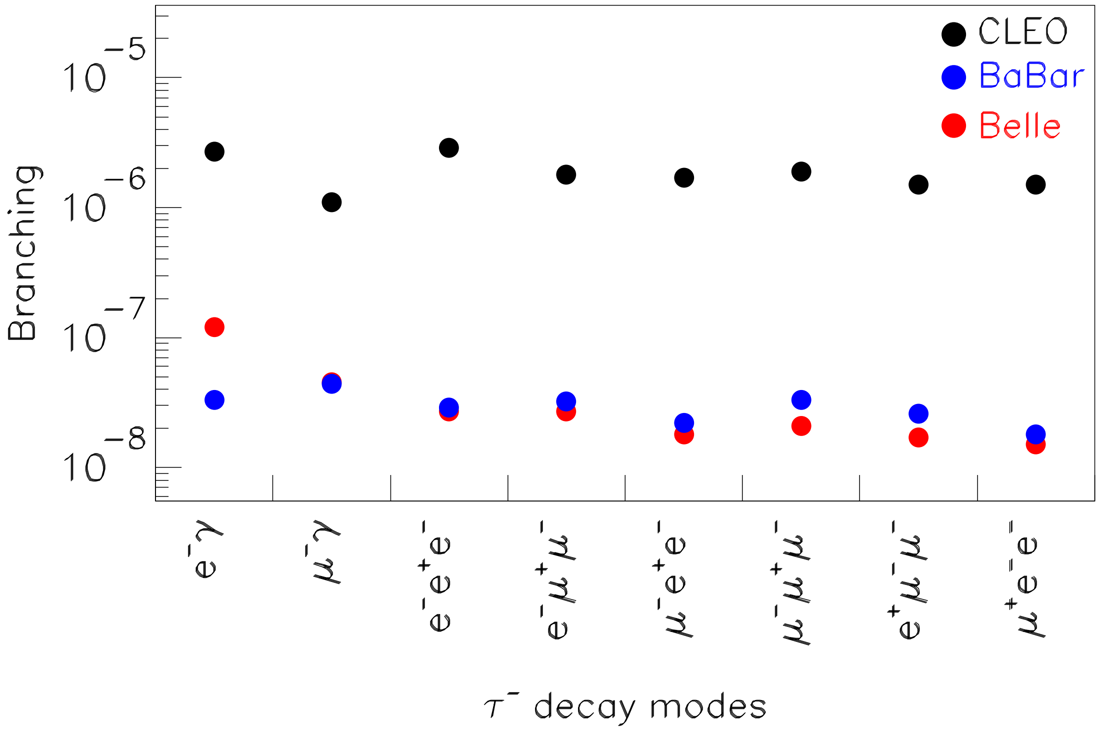
90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^-e^-e^+$	2.7	718.7	2.9	438.4	290	4.4
$e^-\mu^-\mu^+$	2.7	718.7	3.2	438.4	180	4.4
$e^+\mu^-\mu^-$	1.7	718.7	2.6	438.4	150	4.4
$\mu^-e^-e^+$	1.8	718.7	2.2	438.4	170	4.4
$\mu^-\mu^-\mu^+$	2.1	718.7	3.3	438.4	190	4.4
$\mu^+e^-e^-$	1.5	718.7	1.8	438.4	150	4.4

BaBar: B. Aubert et al., PRL 99, 251803 (2008)

Belle: Y. Miyazaki, EPS-09

Summary on Leptonic LFV Decays



UL's reach $(3-4)\cdot 10^{-8}$ for $l^-\gamma$ and $(1.5-3.3)\cdot 10^{-8}$ for $l_1^- l_2^- l_3^+$

$\tau^- \to l^- P^0$

90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^-\pi^0$	8.0	368.5	13	311.5	370	4.3
$e^-\eta$	9.2	368.5	16	311.5	820	4.3
$e^-\eta'$	16	368.5	24	311.5	–	–
$\mu^-\pi^0$	12	368.5	11	311.5	400	4.3
$\mu^-\eta$	6.5	368.5	15	311.5	960	4.3
$\mu^-\eta'$	13	368.5	14	311.5	–	–

BaBar: B. Aubert et al., PRL 98, 061803 (2007)
Belle: Y. Miyazaki et al., PLB 648, 341 (2007)

$\tau^- \to l^- K^0_S,\ l^- K^0_S K^0_S$

90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^- K^0_S$	2.6	616.6	3.3	431	91	12.8
$\mu^- K^0_S$	2.3	616.6	4.0	431	95	12.8
$e^- K^0_S K^0_S$	7.1	616.6	–	–	220	12.8
$\mu^- K^0_S K^0_S$	8.0	616.6	–	–	340	12.8

BaBar: B. Aubert et al., PRD 79, 012004 (2009)

Belle: Y. Miyazaki, EPS-09

$\tau^- \to l^- f_0(980),\ l^-\omega$

90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^- f_0(980)$	3.4	616.6	–	–
$\mu^- f_0(980)$	3.2	616.6	–	–
$e^-\omega$	18	499	11	352.9
$\mu^-\omega$	8.9	499	10	352.9

BaBar: B. Aubert et al., PRL 100, 071802 (2008)

Belle ($l\omega$): Y. Nishio, PLB 664, 35 (2008)

Belle ($l f_0$): Y. Miyazaki, PLB 672, 317 (2009)

$\tau^- \to l^- V^0$

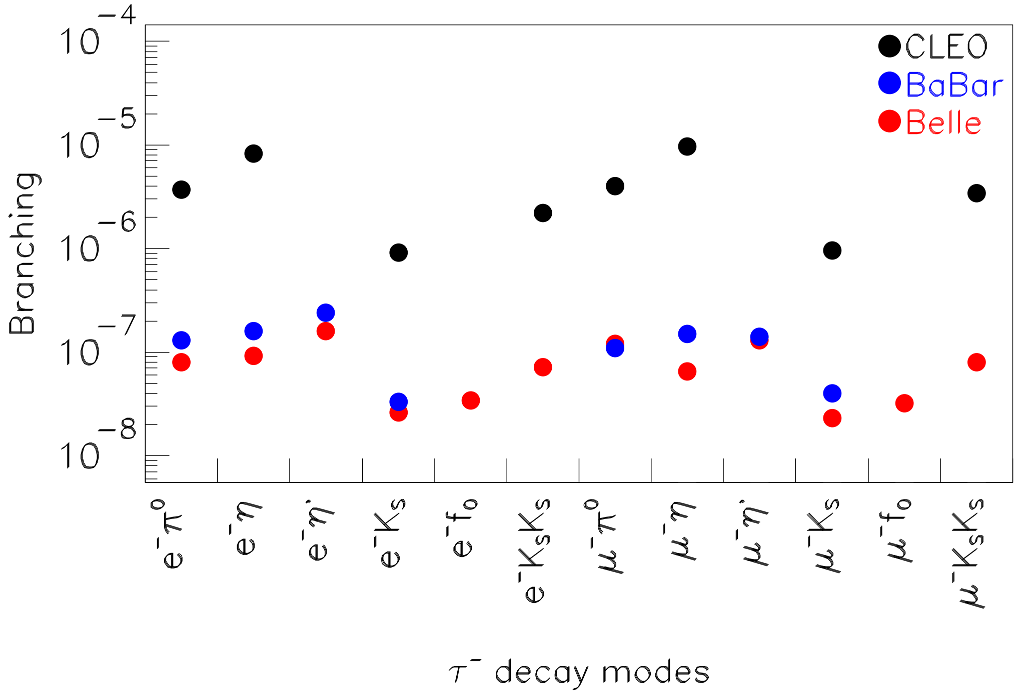
90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^-\rho^0$	6.3	499	4.6	414.5	200	4.4
$e^-K^*(892)^0$	7.8	499	5.9	414.5	510	4.4
$e^-\bar{K}^*(892)^0$	7.7	499	4.6	414.5	740	4.4
$e^-\phi$	7.3	499	3.1	414.5	690	4.4
$\mu^-\rho^0$	6.8	499	2.6	414.5	630	4.4
$\mu^-K^*(892)^0$	5.9	499	17	414.5	750	4.4
$\mu^-\bar{K}^*(892)^0$	10	499	7.3	414.5	750	4.4
$\mu^-\phi$	13	499	19	414.5	700	4.4

BaBar: B. Aubert et al., PRL 103, 021801 (2009)

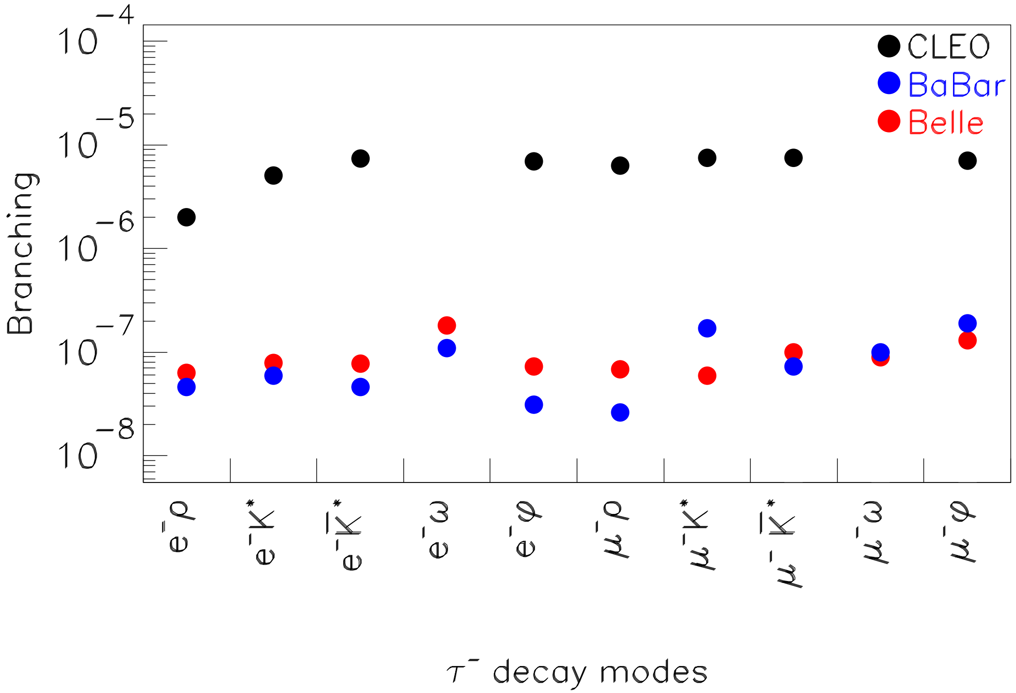
Belle: Y. Nishio, PLB 664, 35 (2008)

Summary on $\tau^- \to e^- P^0$



Belle reached UL's of $(2.3 - 2.6) \cdot 10^{-8}$

Summary on $\tau^- \to e^- V^0$



BaBar reached UL's of $(2.6 - 7.3) \cdot 10^{-8}$

$\tau^- \to (eh_1h_2)^-$

90% upper limits on the branching fraction $\mathcal{B}$

τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$e^-\pi^+\pi^-$	4.4	616.6	12	203.5	220	4.4
$e^+\pi^-\pi^-$	8.8	616.6	27	203.5	190	4.4
$e^-\pi^+K^-$	5.8	616.6	32	203.5	640	4.4
$e^-\pi^-K^+$	5.2	616.6	17	203.5	380	4.4
$e^+\pi^-K^-$	6.7	616.6	18	203.5	210	4.4
$e^-K^+K^-$	5.4	616.6	14	203.5	600	4.4
$e^+K^-K^-$	6.0	616.6	15	203.5	380	4.4

BaBar: B. Aubert et al., PRL 95, 191801 (2005)

Belle: Y. Miyazaki et al., PLB 682, 355 (2010)

$\tau^- \to (\mu h_1 h_2)^-$

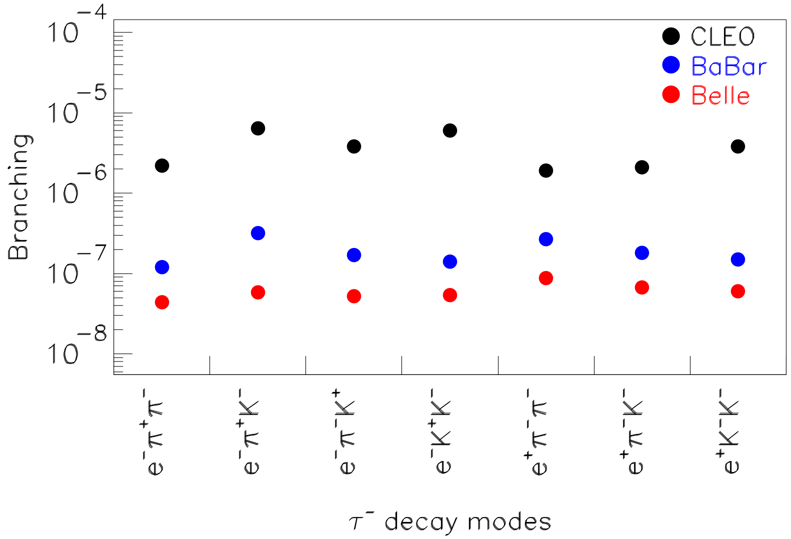
90% upper limits on the branching fraction $\mathcal{B}$

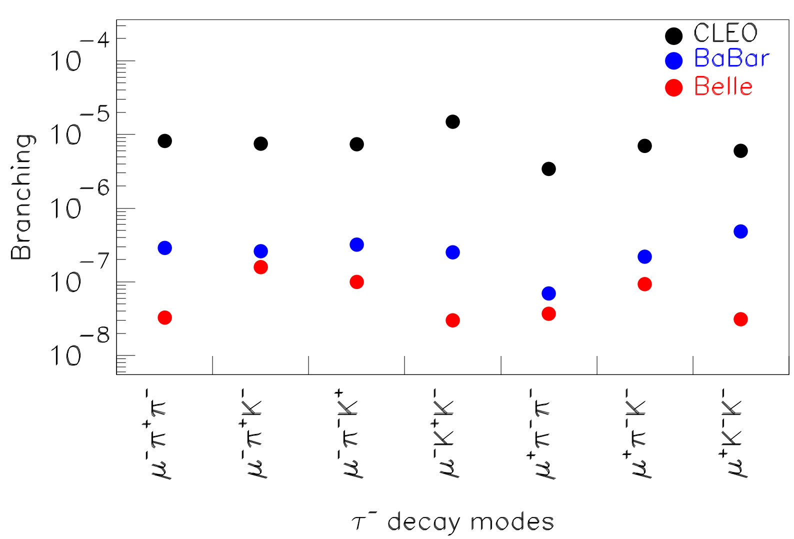
τ^-	Belle		BaBar		CLEO	
mode	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$\mu^-\pi^+\pi^-$	3.3	616.6	29	203.5	820	4.4
$\mu^+\pi^-\pi^-$	3.7	616.6	7	203.5	340	4.4
$\mu^-\pi^+K^-$	16	616.6	26	203.5	750	4.4
$\mu^-\pi^-K^+$	10	616.6	32	203.5	740	4.4
$\mu^+\pi^-K^-$	9.4	616.6	22	203.5	700	4.4
$\mu^-K^+K^-$	3.0	616.6	25	203.5	1500	4.4
$\mu^+K^-K^-$	3.1	616.6	48	203.5	600	4.4

BaBar: B. Aubert et al., PRL 95, 191801 (2005)

Belle: Y. Miyazaki, PLB 682, 355 (2010)

Summary on lh_1h_2 Decays





Belle obtained UL's of $(4.4 - 8.8) \cdot 10^{-8}$ for eh_1h_2 and $(3 - 16) \cdot 10^{-8}$ for μh_1h_2

$\tau \to l$ + Baryon

90% upper limits on the branching fraction $\mathcal{B}$

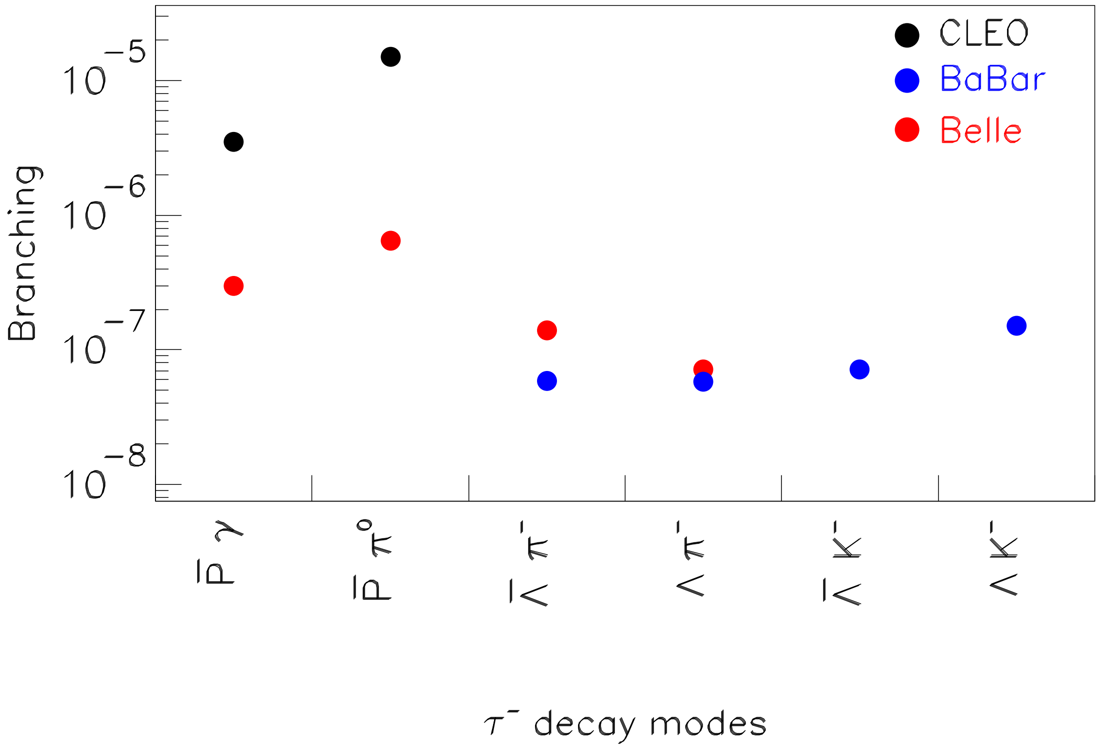
τ^- mode	Belle		BaBar		CLEO	
	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$	$\mathcal{B}, 10^{-8}$	$N_{\tau\tau}, 10^6$
$\bar{p}\gamma$	30	80	–	–	350	4.3
$\bar{p}\pi^0$	65	141.5	–	–	1500	4.3
$\bar{\Lambda}\pi^-$	14	141.5	5.9	217.8	–	–
$\Lambda\pi^-$	7.2	141.5	5.8	217.8	–	–
$\bar{\Lambda}K^-$	–	–	7.2	217.8	–	–
ΛK^-	–	–	15	217.8	–	–

Belle ($\bar{p}\gamma(\pi^0)$): N. Sato, NPB(PS) 144, 179 (2004)

Belle ($\bar{\Lambda}(\Lambda)\pi^-$): Y.Miyazaki et al., PLB 632, 51 (2006)

BaBar: G. Lafferty, NPB(PS) 169, 186(2007)

Summary on LFV Decays with Baryons



UL's reach $\mathcal{O}(10^{-7})$ for decays with baryons

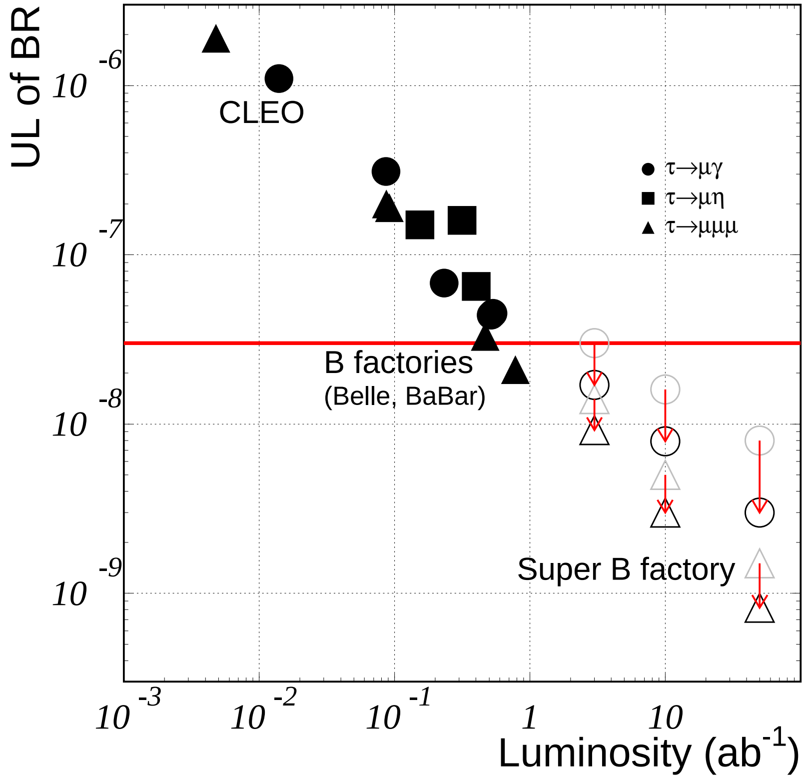
W. Marciano (2004): from $\tau_p > 10^{33}$ years $\mathcal{B}(\tau \to p + X) < 10^{-42}$

Progress of LFV Studies – $\tau^- \to \mu^-\gamma$

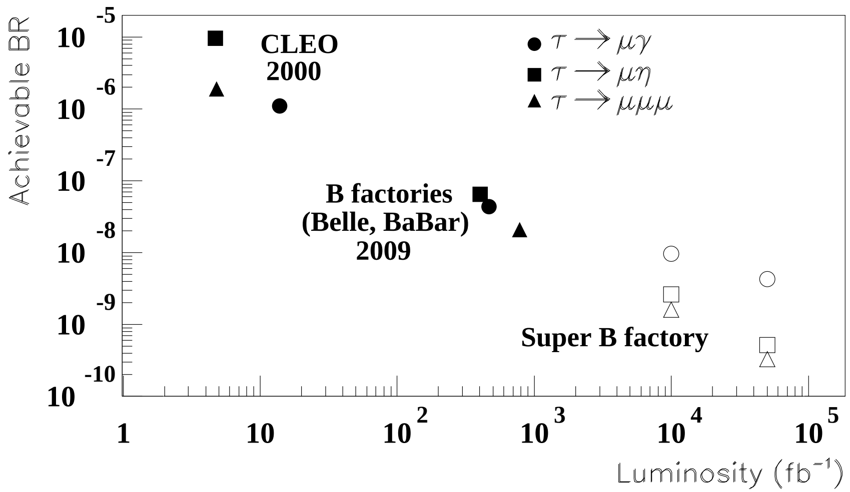
Group	Date	$\mathcal{L}$, pb^{-1}	$N_{\tau\tau}$, 10^6	$B^{90}_{\rm UL}$
MARK II	1982	17	0.048	5.5×10^{-4}
ARGUS	1992	387	0.374	3.4×10^{-5}
DELPHI	1995	70	0.081	6.2×10^{-5}
CLEO	2000	13.8	12.6	1.1×10^{-6}
Belle	2008	535	491.7	4.5×10^{-8}
BaBar	2009	515.5	473.7	4.4×10^{-8}
BaBar & Belle	2006	767.2	684	1.6×10^{-8}

Prospects for LFV Studies (Realist)

- With 10^{10} $\tau^+\tau^-$ and $\epsilon \sim 3\%$: $\mathcal{B} < 3 \times 10^{-9}$ for $N_{\rm ev} = 0$
- Background suppression needed (PID, higher ϵ)
- $\tau \to l\gamma, \mu\eta(\gamma\gamma), l\rho:$ BG $\neq 0$, $\mathcal{B} \propto 1/\sqrt{N}$
- $\tau \to lll, \mu\eta(\pi^+\pi^-\pi^0), \Lambda\pi:$ BG $= 0$, $\mathcal{B} \propto 1/N$



Prospects for LFV Studies (Optimist)



2nd Class Currents in $\tau^- \to \eta\pi^-\nu_\tau$ – I

- 2nd class currents suppressed in SM: $\propto m_{\rm u} - m_{\rm d}$
- $\tau^- \to \eta\pi^-\nu_\tau$ has $J^{PG} = 0^{+-}$
- Theory prediction: $\mathcal{B}(\tau^- \to \eta\pi^-\nu_\tau) \sim 10^{-6} - 10^{-5}$.
- Large BG from $\tau^- \to \eta\pi^-\pi^0\nu_\tau$ with $\mathcal{B} = (1.77 \pm 0.24) \cdot 10^{-3}$
- CLEO and ALEPH observed $\tau^- \to \eta K^-\nu_\tau$: $\mathcal{B}_{\rm exp} = (2.7 \pm 0.6) \cdot 10^{-4}$ vs. $\mathcal{B}_{\rm th} \sim 1.2 \cdot 10^{-4}$

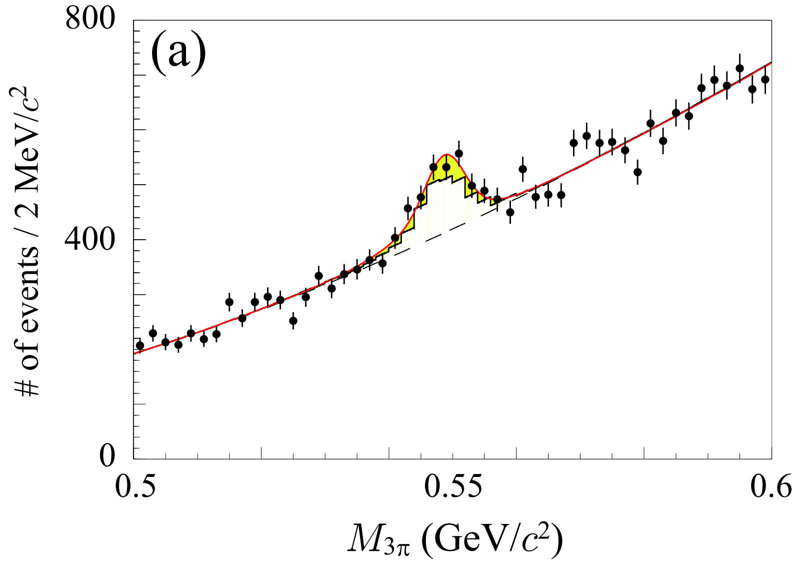
Source	$\mathcal{B}_{95}(\tau^- \to \eta\pi^-\nu_\tau),\ 10^{-4}$
HRS, 1987	$510 \pm 100 \pm 120$
CLEO, 1987	< 100
ARGUS, 1988	< 90
CLEO, 1992	< 3.4
CLEO, 1996	< 1.4
ALEPH, 1997	< 6.2

Decays with η Mesons at Belle

Mode	Group	N_{ev}	$\mathcal{B}_{\text{exp}}$
$\pi^-\pi^0\eta\nu_\tau$	Belle, 2008	5675 ± 111	$(1.35 \pm 0.03 \pm 0.08) \cdot 10^{-3}$
	CLEO, 1992	125 ± 16	$(1.7 \pm 0.2 \pm 0.2) \cdot 10^{-3}$
$K^-\eta\nu_\tau$	Belle, 2008	1545 ± 51	$(1.58 \pm 0.05 \pm 0.09) \cdot 10^{-4}$
	CLEO, 1996	61 ± 14	$(2.6 \pm 0.5 \pm 0.4) \cdot 10^{-4}$
$K^-\pi^0\eta\nu_\tau$	Belle, 2008	241 ± 34	$(4.6 \pm 1.1 \pm 0.4) \cdot 10^{-5}$
	CLEO, 1999	47 ± 12	$(17.7 \pm 5.6 \pm 7.1) \cdot 10^{-5}$
$K^{*-}\eta\nu_\tau$	Belle, 2008	119 ± 19	$(1.30 \pm 0.13 \pm 0.11) \cdot 10^{-4}$
	CLEO, 1999	27 ± 6	$(2.90 \pm 0.80 \pm 0.42) \cdot 10^{-4}$
$K_S\pi^-\eta\nu_\tau$	Belle, 2008	45 ± 8	$(4.4 \pm 0.7 \pm 0.2) \cdot 10^{-4}$
	CLEO, 1999	15	$(1.00 \pm 0.35 \pm 0.11) \cdot 10^{-3}$

Belle (490 fb^{-1}): K. Inami et al., Phys. Lett. B 672, 209 (2009)

2nd Class Currents in $\tau^- \to \eta\pi^-\nu_\tau$ – II



$\mathcal{B}(\tau^- \to \eta\pi^-\nu_\tau) = (4.4 \pm 1.6 \pm 0.8) \cdot 10^{-5}$ or 2.4σ signal,

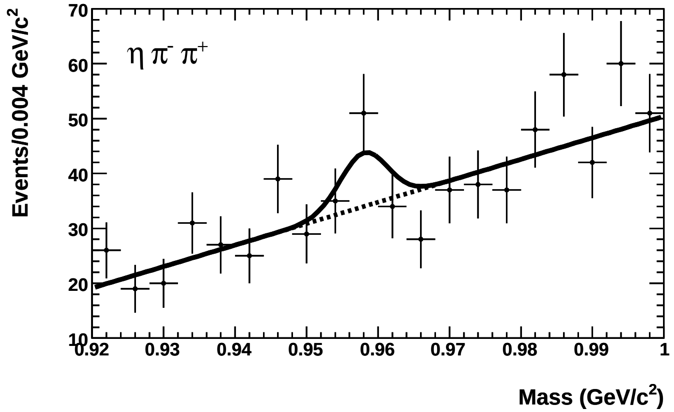
the corresponding upper limit is $\mathcal{B} < 7.9 \cdot 10^{-5}$ at 95% CL

compared to $< 1.4 \cdot 10^{-4}$ at CLEO

Belle (675 fb^{-1}) K.Hayasaka, EPS-2009

2nd Class Currents in $\tau^- \to \eta'\pi^-\nu_\tau$

BaBar



Group	$\int Ldt$, fb^{-1}	$\mathcal{B}_{95}(\tau^- \to \eta'\pi^-\nu_\tau)$, 10^{-6}
CLEO, 1997	4.7	< 74
BaBar, 2008	384	< 7.2
Belle, 2009	675	< 7.0

Theory predicts $\leq 1.4 \cdot 10^{-6}$

BaBar: B. Aubert et al., Phys. Rev. D77, 112002 (2008)

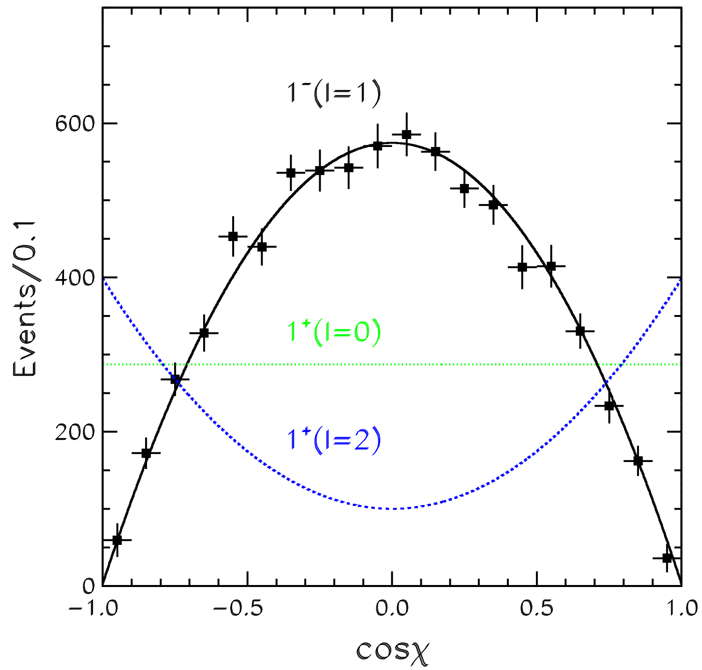
2nd Class Currents in $\tau^- \to \omega\pi^-\nu_\tau$

Both currents possible:

1st class current $J^{PG} = 1^{-+}, l = 1, \mathcal{B} \sim 1.9\%$.

2nd class current $J^{PG} = 1^{++}, l = 0, 2$.

Group	$\mathcal{B}_{\not{V}}/\mathcal{B}_V$ 95% CL
ARGUS, 1987	< 0.5
ALEPH, 1997	< 0.086
CLEO, 2000	< 0.064
BaBar, 2009	< 0.0069



$$F(\cos\chi) \;=\; = N \times \left[\tfrac{1}{2}\epsilon + \tfrac{3}{4}(1-\epsilon)\left(1-\cos^2\chi\right)\right]$$

BaBar (347 fb^{-1}) B. Aubert et al., Phys. Rev. Lett. 103, 041802 (2009)

Conclusions

- We know a lot about τ after CLEO and LEP, Belle and Babar gaining speed
- Huge advantage in statistics is very favorable
  in searches for suppressed and forbidden modes.
- Lepton universality holds, more precise τ_τ and $\mathcal{B}_e$ needed
- Why most $\mathcal{B}_{\rm new} < \mathcal{B}_{\rm old}$?
- Observation of second-class currents feasible
- Sensitivity of LFV searches approaches 10^{-8}
- B factories with ~ 1.5 ab^{-1} are also unique τ factories with high potential for New Physics and precision studies in SM, even more expected from SuperB

Backup Slides

Search for $\mu^- \to e^-e^+e^-$

90% CL upper limits on the branching fraction $\mathcal{B}$

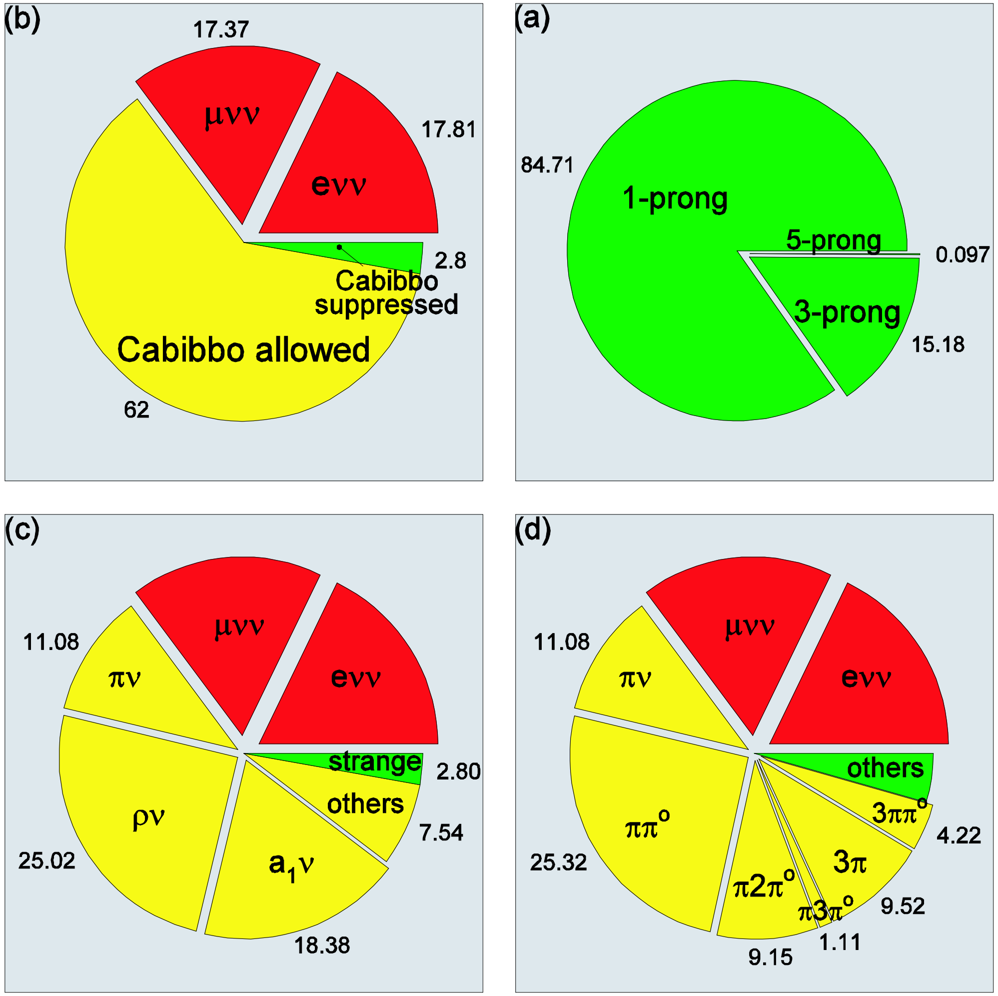
Group	Date	$\mathcal{B}, 10^{-12}$	$N_\mu, 10^{11}$
Cr. Box (LAMPF)	1984	130	2.2
SINDRUM (PSI)	1985	2.4	7.3
Cr. Box (LAMPF)	1988	35	14
ARES (JINR)	1991	36	11.5
SINDRUM (PSI)	1988	1.0	16

Search for $\mu^- \to e^- 2\gamma$

90% CL upper limits on the branching fraction $\mathcal{B}$

Group	Date	$\mathcal{B}, 10^{-11}$	$N_\mu, 10^{11}$
Review	1978	5000	–
NaI (TRIUMF)	1983	840	5.3
Cr. Box (LAMPF)	1988	7.2	14

A Zoo of τ decays

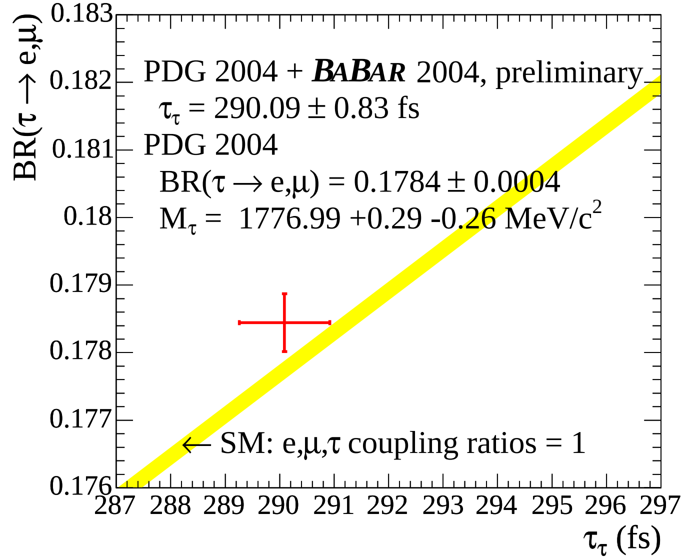


τ Lifetime

Measurements of τ_τ, fs

Source	$N_{\tau\tau}, 10^3$	τ_τ, fs	$\delta\tau_{\tau\,\mathrm{sys}}$, %
DELPHI, 2004	150	$290.9 \pm 1.4 \pm 1.0$	0.34
PDG, 2006	–	290.6 ± 1.0	0.28
BaBar, 2004	79000	$289.40 \pm 0.91 \pm 0.90$	0.31

- Measurement bias – 0.220%
- Background – 0.142%
- Alignment – 0.111%
- τ momentum – 0.100%
- Total – 0.310%



τ Leptonic Branching

Measurements of B_e, %

Source	$N_{\tau\tau}, 10^3$	$B, \%$	$\delta B_{sys}, \%$
ALEPH, 2005	56	$17.837 \pm 0.072 \pm 0.036$	0.2
CLEO, 1997	3250	$17.76 \pm 0.06 \pm 0.17$	1.0
PDG, 2006	–	17.84 ± 0.05	0.28

Systematic uncertainties in CLEO, %

N_{ev}	$N_{\tau\tau}$	ϵ	Trig.	PID	BG	Total
0.36	0.71	0.48	0.28	0.19	0.16	1.00

Alternatives for the pseudomass fit parameterization

Two other functions were considered:

$$F_1(M_p) = (p_3 + p_4 M_p)\frac{M_p - p_1}{\sqrt{p_2 + (M_p - p_1)^2}} + p_5 + p_6 M_p$$

and

$$F_2(M_p) = (p_3 + p_4 M_p)\frac{-1}{1 + \exp\frac{M_p - p_1}{p_2}} + p_5 + p_6 M_p.$$

Systematic uncertainties in M_τ

Source	BaBar	Belle
CM energy and $\|p\|$ reconstruction	0.40	0.26
MC Modeling ($\tau \to 3\pi\nu_\tau$)	0.05	0.02
MC Statistics	0.05	0.14
Fit Range	0.05	0.04
Parameterization	0.03	0.18
Momentum resolution	Negl.	0.02
Background	Negl.	0.01
Total	0.41	0.35

Both groups assume M_{ν_τ}=0

Belle: 10 MeV $\Rightarrow \Delta M_\tau$=-0.1 MeV

BaBar: 1 MeV $\Rightarrow \Delta M_\tau$=-0.02 MeV

Charge asymmetry from ΔM in $D^\pm$, $D_s^\pm$, $\Lambda_c^\pm$: Belle - 0.14 MeV, BaBar - 0.06 MeV