Tau Physics Experimental Overview

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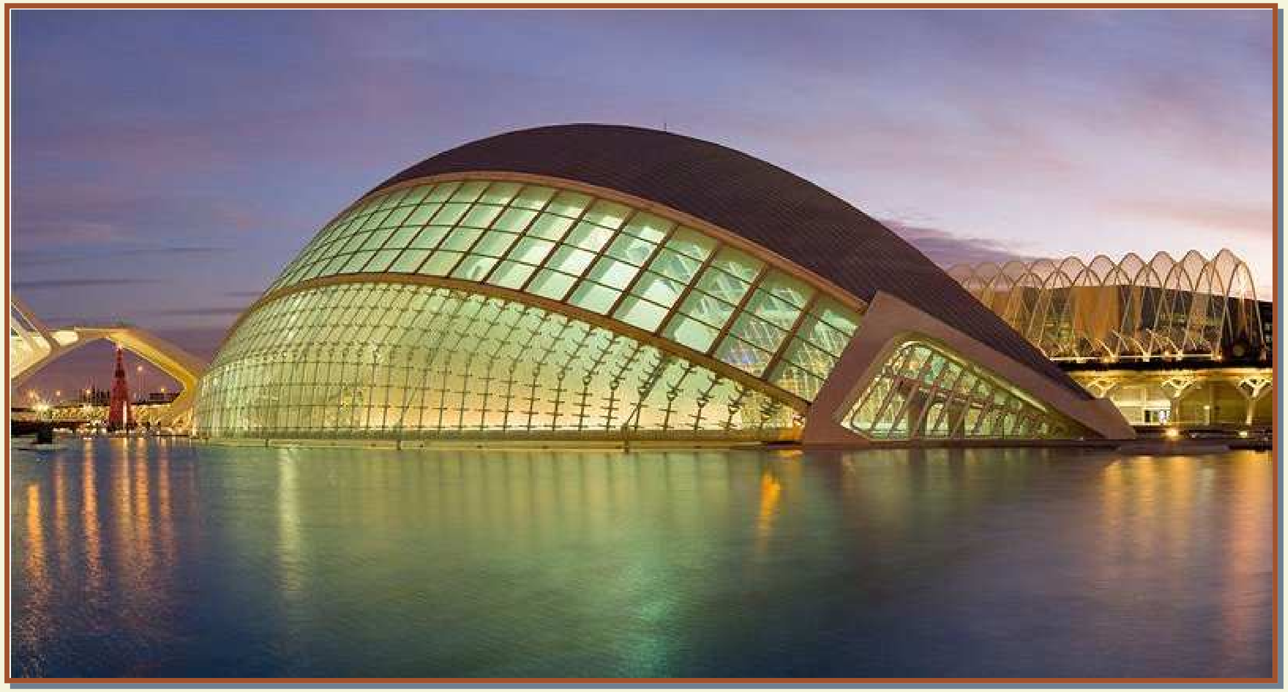
SuperB Workshop VI
New Physics at the Super Flavour Factory SuperB
January 7-15th, 2008 (IFIC-Valencia)



Outline

(note: this talk had to be prepared at very short notice, and will be very concise)

- summarize CDR information on exp. Tau Physics with 75 ab^{-1} Superb
  - topics, experimental reach estimates, and how estimates were obtained
- summarize activity and news news since CDR
  - CDR review, some anticipations about RC questions
  - work done to refine estimates of SuperB experimental reach
- plans
  - answer review committee questions: LFV and CPV in decay
  - improve understanding of SuperB tau physics reach
  - improve understanding of benefits from polarized beams (provide feedback for machine design)
  - verify simulation requirements, possibly implementation of required missing features

Tau physics topics in SuperB CDR

LFV Decays

- SuperB golden channels, esp. $\tau \to \mu\gamma$
- experimental physics reach from basic extrapolation of B-factories results

CPV in tau decay

- analysis methods described
  - also relying on polarized beams
- no estimate of experimental precision
- can test multi-Higgs doublets NP

Tau EDM

- exp. UL estimate from hep-ph/0610135
  - using polarized beams
- not accessible with “standard” NP
- however, can set model ind. limits

Charged Current Universality Measurements

- now limited by leptonic BF and tau lifetime
- non trivial measurements at B-factories
- limited improvements expected
- in itself, not a physics case for SuperB

CPT test on tau lifetime

- *BABAR* prelim. result in 2004
- interesting precision if extrapolated to SuperB
- no evident serious systematic limitation needs studies on limiting systematics

CPT test on tau mass

- Belle 2006 result
- not promising because of syst. limitations

Anticipations on review committee questions on CDR

- compare physics reach LHCb vs. SuperKeKB with 15 ab^{-1} vs. SuperB with 75 ab^{-1} for a few tau golden channels:
  - LFV decays
  - CPV and T-odd observables in tau decay

Polarized beams, tau polarization

- tau spins and tau spins correlations
  - provide valuable physics information
  - may be exploited to improve selection of signal events (e.g. LFV events)
- polarized beams enhance spin effects and allow measurements otherwise unaccesible
- must assess physics gains from polarized beams to provide useful feedback for machine design

LFV decays in CDR

- assume same analysis as B-factories but:
  - for $\tau \to \ell\gamma$, assume all BKG but irreducible $\tau \to \ell\nu\nu\gamma$(ISR) can be suppressed
  - for $\tau \to 3\ell$, $\tau \to \ell h$ assume analysis can be BKG free up to SuperB

SuperB 75 ab^{-1} expected 90% CL ULs

Process	Sensitivity
$\text{BF}(\tau \to \ell\gamma)$	2×10^{-9}
$\text{BF}(\tau \to 3\ell)$	$1–3 \times 10^{-10}$
$\text{BF}(\tau \to \ell\eta)$	$4–6 \times 10^{-10}$
$\text{BF}(\tau \to \ell K_S^0)$	2×10^{-10}

LFV decays updates and plans

- Belle paper on 535 fb^{-1} $\boxed{\tau \to 3\ell}$ search
  → no BKG until 7-50 ab^{-1} for all channels but *eee* even without improving the analysis
- work done to improve *BABAR* $\boxed{\tau \to \mu\gamma}$ analysis with also SuperB in mind
  - see S.Banerjee talk in LFV parallel session
  - plans:
    - study use of tau polarization to improve $\tau \to \mu\gamma$ selection (sponsored by M.Giorgi)
    - also, study use of tau polarization to characterize LFV interaction
    - properly simulate tau polarization and spin correlations
      - KK & Tauola claim can simulate spin effects (practicalities being investigated)
- baseline: going from 15 to 75 ab^{-1} will at least improve LFV ULs by $\sqrt{75/15}$
  - if analysis BKG free, then improvement is $75/15$
  - if detector and/or analysis improve, UL improve even $> 100\times$ w.r.t. B-factories

T/CP-odd observables in tau decay in CDR

- CPV asymmetry in $\tau \to K\pi^0\nu$ via $H - W$ interference
- can be measured on two structure functions $W_{\mathrm{SF}}[\tau^\pm]$ and $W_{\mathrm{SG}}[\tau^\pm]$ [Kuehn Z. Phys. C **56**, 661 (1992)]
  - ΔW_{SF} is obtained from an analysis of the difference in the correlated energy distribution of the charged K and π^0 in τ^+ and τ^- decays in the LAB
  - ΔW_{SG} can be extracted from T-odd observable $P_Z^\tau \cdot (\vec{p}_{K^+} \times \vec{p}_{\pi^0})$ where P_Z^τ is the component of the τ polarization along the beam axis averaged over the production angle
- beam polarization crucial in other channels like $\tau^- \to a_1^- \pi^0 \nu_\tau$ (Datta 2006 arXiv:hep-ph/0610162)
- no estimate of experimental reach

Plans

- estimate experimental reach on simulated events or toy MC
  - one prerequisite is correct simulation of tau spin effects including $\tau^+\tau^-$ correlation

Tau EDM and (g-2) in CDR

- EDM: no measurable effect with "standard" NP models, given existing e, μ constraints
- $g-2$ not considered

Tau EDM and (g-2) updates and plans

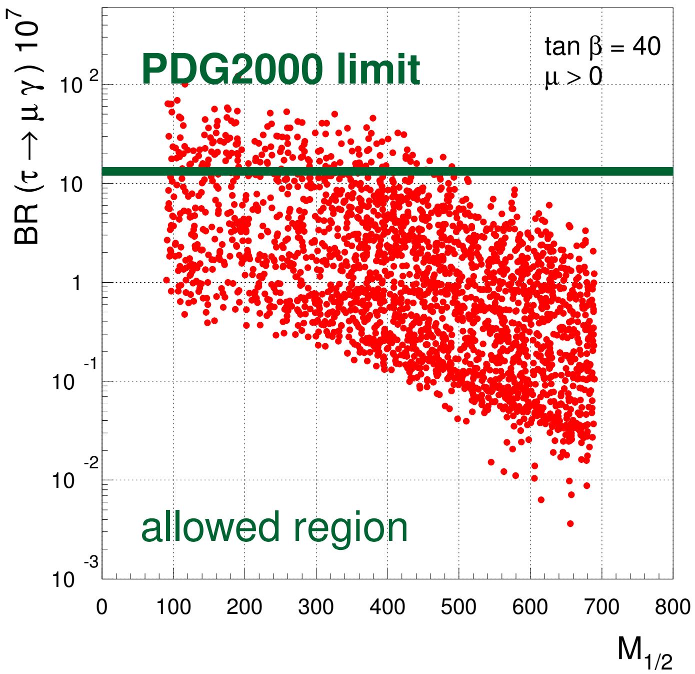
- J.Bernabeu et al. papers on tau EDM & $g-2$
  arXiv:0707.1658v1 [hep-ph] Tau electric dipole moment with polarized beams
  arXiv:0707.2496v1 [hep-ph] Tau anomalous magnetic moment form factor at Super B/Flavor factories
- can set limits on coefficients of model independent effective theory
- work done to refine exp. reach estimate on $(g-2)_\tau$ (A.Cervelli in parallel session)
- several measurements using polarized beams suggested
  - again, one prerequisite is correct simulation of tau spin effects including $\tau^+\tau^-$ correlation

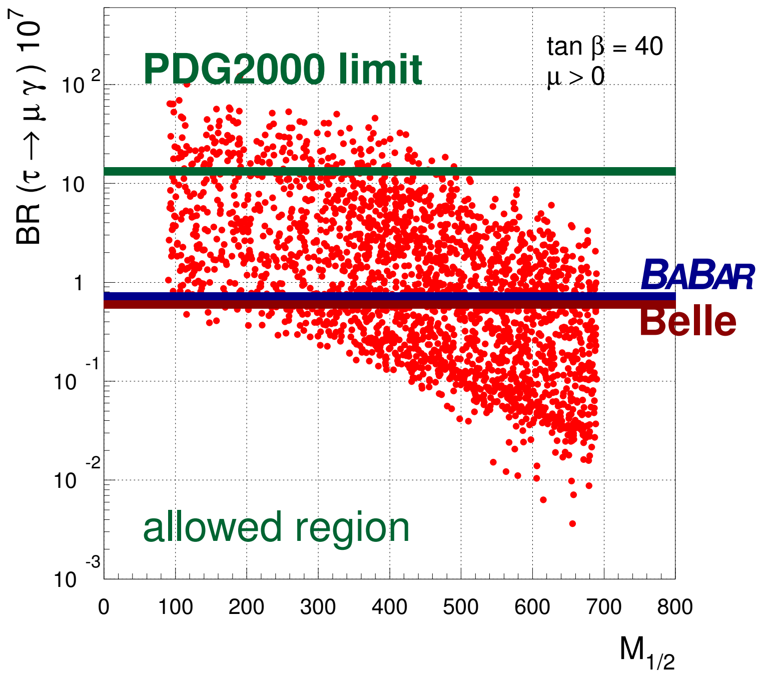
Conclusions

- will discuss with Charm WG about running around 4 GeV
  - expect no real interest for considered channels
- will discuss with Spectroscopy WG on $H \to \tau^+\tau^-$
  - tau spin correlations measurement can determine Higgs parity
- improve estimates of experimental reach on tau LFV
- produce estimates of experimental reach on CP-odd observables in tau decay
- refine estimates of experimental reach on tau EDM, g-2
- undertand better benefits of polarized beams

Backup slides

Progress on $\tau \to \mu\gamma$ since pre-B-factory era





SUSY SO(10) + seesaw – Masiero et al., NJP 6 (2004) 202

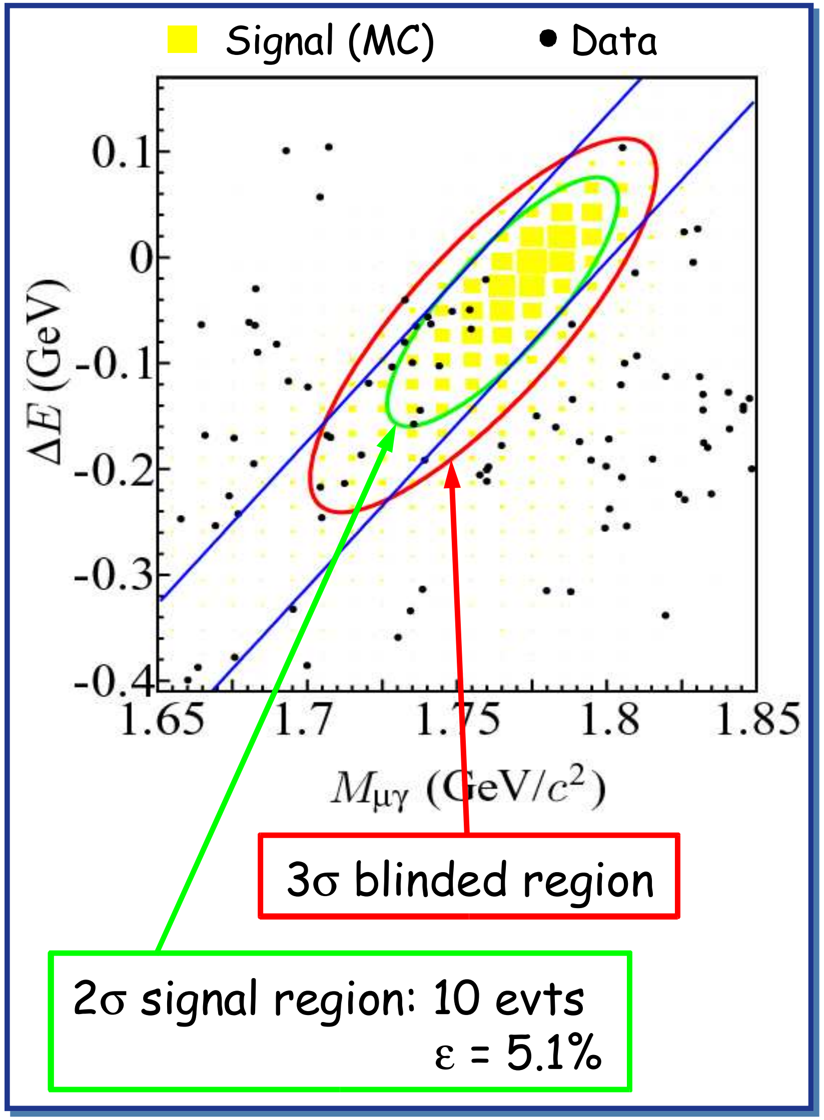
LFV search for $\tau \to \mu\gamma$

BELLE

preliminary

535 fb^{-1}

- 94 events in 5σ region (88.4 ± 7.4 MC predicted)
- 2D UEML fit in 2σ $\Delta M - \Delta E$ signal region
  - BKG shapes from MC
  - BKG normalizations from data 2D sideband
  - $s = -3.9^{+3.6}_{-3.2}$ $b = 13.9^{+6.0}_{-4.8}$
- toy MC simulation with input signal increased until 90% fits otbain $s > -3.9$ (more than observed signal)
  → $s < 2$ (90% CL)
- P($s < -3.9$) = 25% for zero signal simulation
- **BF($\tau \to \mu\gamma$) < $0.45 \cdot 10^{-7}$ (90% CL)**
- BKG: $\tau\tau\gamma$ (79%), $\mu\mu\gamma$ (16%), $ee\gamma \to ee\mu\mu$ (5%)
- arXiv:0705.0650[hep-ex], submitted to PLB



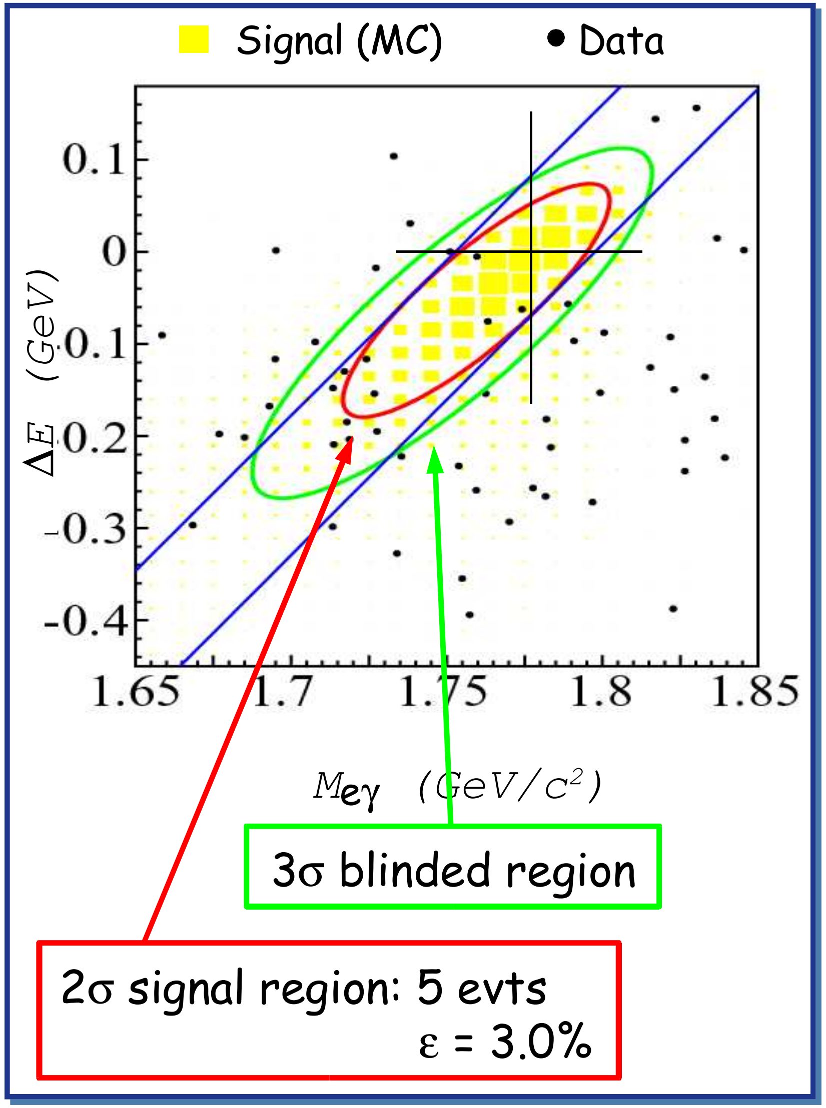
LFV search for $\tau \to e\gamma$

preliminary

$535\ \text{fb}^{-1}$

- 55 events in 5σ region (42.8 ± 3.7 MC predicted)
- 2D UEML fit in 2σ ΔM–ΔE signal region
  - BKG shapes from MC
  - BKG normalizations from data 2D sideband
  - $s = -0.14^{+2.18}_{-2.45}$ $b = 5.14^{+3.86}_{-2.81}$
- toy MC simulation with input signal increased until 90% fits otbain $s > -0.14$ (more than observed signal)

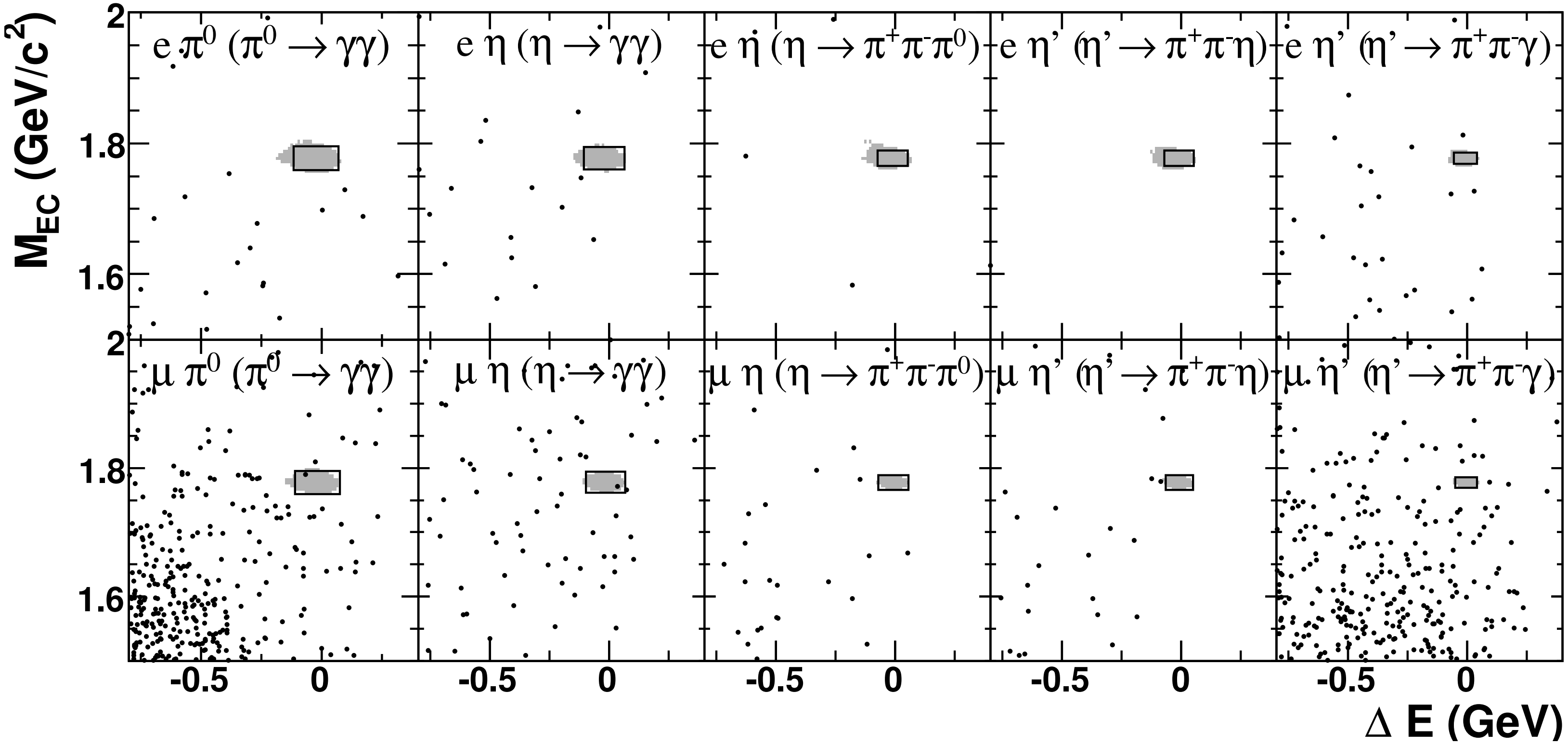
  $\Longrightarrow$ $s < 2$ (90% CL)
- P($s < -0.14$) = 48% for zero signal simulation
- **BF($\tau \to e\gamma$) < $1.2 \cdot 10^{-7}$ (90% CL)**
- BKG: $\tau\tau\gamma$ (82%), $ee\gamma$ (18%)
- arXiv:0705.0650[hep-ex], submitted to PLB



$\tau \to \ell\pi^0, \ell\eta, \ell\eta'$ LFV search

BABAR

339 fb^{-1}



- expected BKG/channel: 0.1–1.3 events
- total expected BKG: 3.1 events, candidates: 2

BF($\tau \to \ell\pi^0, \ell\eta, \ell\eta'$) < 1.1–2.4 · 10^{-7} (90% CL

PRL 98.061803 (2007)

B-Factories LFV limits

	Belle		BABAR	
	UL90 (10^{-7})	Lumi (fb^{-1})	**UL90 (10^{-7})**	**Lumi (fb^{-1})**
$\mu\gamma$	0.5*	535	**0.7**	**232**
$e\gamma$	1.2*	535	**1.1**	**232**
$\mu\eta$	0.65	401	**1.5**	**339**
$\mu\eta'$	1.3	401	**1.3**	**339**
$e\eta$	0.92	401	**1.6**	**339**
$e\eta'$	1.6	401	**2.4**	**339**
$\mu\pi^0$	1.2	401	**1.5**	**339**
$e\pi^0$	0.8	401	**1.3**	**339**
$\ell\ell\ell$	0.2–0.4	535	**0.4–0.8**	**376**
$\ell hh'$	2–16	158	**1–5**	**221**
μV^0	1.0–1.5	543	**1.1***	**384**
eV^0	0.8–1.9	543	**1.0***	**384**

	Belle		BABAR	
	UL90 (10^{-7})	Lumi (fb^{-1})	**UL90 (10^{-7})**	**Lumi (fb^{-1})**
μK_S	0.49	281	**in progress**	
eK_S	0.56	281	**in progress**	
$\Lambda\pi, \overline{\Lambda}\pi$	0.72–1.4	154	**0.58–0.59***	**237**
$\Lambda K, \overline{\Lambda}K$			**0.72–1.5***	**237**
$\sigma_{\ell\tau}/\sigma_{\mu\mu}$			**40–89**	**211**

(* preliminary)

$V^0 = \omega$ for BABAR, $V^0 = \rho, \phi, \overset{(-)}{K}{}^{*0}$ for Belle

LFV Searches Prospects

- B-factories improved LFV tau BF limits by factor 10–100
  - whenever BKG $\mathcal{O}(1)$ at constant efficiency, upper limits improve $\propto \mathcal{L}$
    (channels with only charged tracks tend to be in this regime right now)
  - otherwise (BKG limited) upper limits improve $\propto \sqrt{\mathcal{L}}$
    (channels with photons, e.g. $\tau \to \mu\gamma$, appear to be entering this regime now)
- limits can improve by factor 2–4 analyzing all planned B-Factories yield ($2\,\mathrm{ab}^{-1}$)
- Super B-Factories expected to improve LFV limits again by factor 10–100
  must care about:
  - detector hermeticity
  - resolution on neutral energy / angle

Lepton Universality Tests

- Standard Model (SM) predicts that leptons have same weak charged current couplings
- B-Factories can measure **several relatively less known ingredients** for LU tests below

$$\frac{\Gamma_{\tau\to e}}{\Gamma_{\mu\to e}} \propto \left(\frac{g_\tau}{g_\mu}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\mathrm{BF}(\tau^- \to e^-\bar{\nu}_e\nu_\tau)\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{f(m_e^2/m_\mu^2)r_{EW}^\mu}{f(m_e^2/m_\tau^2)r_{EW}^\tau}$$

$$\frac{\Gamma_{\tau\to \mu}}{\Gamma_{\mu\to e}} \propto \left(\frac{g_\tau}{g_e}\right)^2 = \frac{\tau_\mu}{\tau_\tau}\mathrm{BF}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau)\left(\frac{m_\mu}{m_\tau}\right)^5 \frac{f(m_e^2/m_\mu^2)r_{EW}^\mu}{f(m_\mu^2/m_\tau^2)r_{EW}^\tau}$$

$$\frac{\Gamma_{\tau\to e}}{\Gamma_{\tau\to \mu}} \propto \left(\frac{g_e}{g_\mu}\right)^2 = \frac{\mathrm{BF}(\tau^- \to e^-\bar{\nu}_\mu\nu_\tau)}{\mathrm{BF}(\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau)}\frac{f(m_\mu^2/m_\tau^2)}{f(m_e^2/m_\tau^2)}$$

$f(x) = 1 - 8x + 8x^3 - x^4 - 12x \ln x$ (approximating all $m_\nu = 0$)

$r_{EW}^\ell = 0.9960$ (EW radiative corrections, Marciano-Sirlin)

Lepton Universality Tests (A.Pich, SuperB Workshop, Paris, May 2007)

- Δm_μ = 56 ppb, τ_μ = 2.197019(21)μs (9.6 ppm) 2007 WA using MuLan 2007 result
- PDG2006: Δm_τ = 0.015%, ΔBF($\tau \to e/\mu$) = 0.28–0.29%, $\Delta\tau_\tau$ = 0.34%

$|g_\tau / g_\mu|$

$B_{\tau\to e}\ \tau_\mu/\tau_\tau$	1.0004 ± 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
$B_{W\to\tau}/B_{W\to\mu}$	1.039 ± 0.013

$|g_\tau / g_e|$

$B_{\tau\to\mu}\ \tau_\mu/\tau_\tau$	1.0004 ± 0.0023
$B_{W\to\tau}/B_{W\to e}$	1.036 ± 0.014

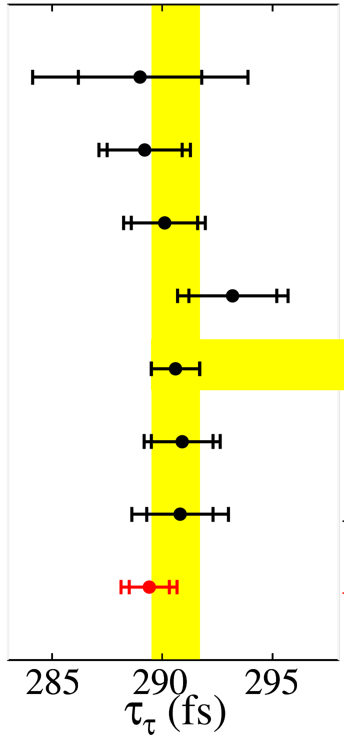
$|g_\mu / g_e|$

$B_{\tau\to\mu}/B_{\tau\to e}$	1.0000 ± 0.0020
$B_{\pi\to\mu}/B_{\pi\to e}$	1.0017 ± 0.0015
$B_{K\to\mu}/B_{K\to e}$	1.012 ± 0.009
$B_{K\to\pi\mu}/B_{K\to\pi e}$	1.0002 ± 0.0026
$B_{W\to\mu}/B_{W\to e}$	0.997 ± 0.010

Tau mass experimental results

$m_\tau = (1776.96^{+0.18}_{-0.21}{}^{+25}_{-17})$ MeV	BES 1996
$m_\tau = (1776.61 \pm 0.13 \pm 0.35)$ MeV	Belle 2006, 414 fb^{-1}
$m_\tau = (1776.80^{+0.25}_{-0.22} \pm 0.15)$ MeV	KEDR 2006

Tau lifetime experimental results



CLEO 1996	289.0 ± 2.8 ± 4.0 fs
OPAL 1996	289.2 ± 1.7 ± 1.2 fs
ALEPH 1997	290.1 ± 1.5 ± 1.1 fs
L3 2000	293.2 ± 2.0 ± 1.5 fs
PDG 2004	290.6 ± 1.1 fs
DELPHI 2004	290.9 ± 1.4 ± 1.0 fs
BABAR 2003, prelim.	290.8 ± 1.5 ± 1.6 fs
BABAR 2004, prelim.	289.40 ± 0.91 ± 0.90 fs

CPT test on tau lifetime from *BABAR*

$$\Delta_{\text{STAT}}\left(\frac{\tau_{\tau-}-\tau_{\tau+}}{\tau_{\tau-}+\tau_{\tau+}}\right) = 0.32\%$$

Prospects on Lepton Universality Tests at B-Factories

- modest progress, systematics typically larger that at LEP, pure selection difficult

	LEP	B-Factories
Δ tau cross-section	≈ 0.1–0.2%	2.2% ⟶ 0.31% recently, arXiv:0706.3235 [hep-ph]
Δ luminosity	≈ 0.1%	≈ 1%
Δ efficiency	≈ 0.2%	≈ 1–4% ($\tau \to 5\pi\nu$ vs. $\tau \to K\pi^0\nu$)

[see for ALEPH: Physics Reports 421 (2005) 191-284]

- tau mass measurement useful check of threshold measurements
  - CPT test cannot be done at threshold
- tau lifetime: should aim at 0.1% precision, least precise ingredient in several tests
- leptonic BFs measurements also useful for μ/e universality
  - dedicated systematics studies can help

    dedicated study for BABAR ISR events ⟶ **Δ muon-efficiency = 0.34%** (M.Davier, priv.comm.)