Tau Physics: Status and Prospects

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Content

- The tau in the Standard Model
- Production of taus
- Decays of taus in the Standard Model
- Static properties of the tau
  - Mass, Lifetime
- Tests of lepton universality, CPT and CP-violation
- (Semi) hadronic tau decays
  - QCD, α_s, $(g-2)_\mu$, CKM, second-class currents
- SM Higgs
- Tau decays beyond the Standard Model
  - Lepton flavour violation
  - SUSY
- Prospects for tau physics

The tau in the Standard Model

Leptons spin = 1/2			
Flavor		Mass GeV/c^2	Electric charge
ν_e	electron neutrino	$<1\times10^{-8}$	0
e	electron	0.000511	–1
ν_μ	muon neutrino	<0.0002	0
μ	muon	0.106	–1
ν_τ	tau neutrino	<0.02	0
τ	tau	1.7771	–1

Quarks spin = 1/2			
Flavor		Approx. Mass GeV/c^2	Electric charge
u	up	0.003	2/3
d	down	0.006	–1/3
c	charm	1.3	2/3
s	strange	0.1	–1/3
t	top	175	2/3
b	bottom	4.3	–1/3

The tau lepton

- A fundamental fermion in the Standard Model
- Well specified EW couplings $\gamma\tau^+\tau^-$, $Z\tau^+\tau^-$, $W\tau\nu$
- Massive enough to decay to hadrons, but light enough to decay to a tractable set of final states
- Allows many precise EW and QCD measurements
- Wide scope to search for New Physics (NP) beyond the Standard Model

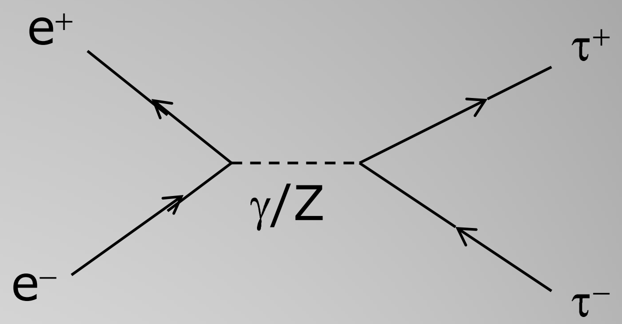
Tau production in SM

- Main source for tau physics is e^+e^- annihilation

- At B factories, σ_{BBbar} = 1.05 nb and $\sigma_{\tau^+\tau^-}$ = 0.91 nb $\Rightarrow$
  - ~1M tau pairs per fb^{-1}
  - Samples of ~500M (BaBar) and ~900M (Belle) tau pairs
  - c.f. ~100k pairs for each LEP experiment; ~14M at CLEO

- But cleaner LEP event environment $\Rightarrow$ lower systematic errors
  - LEP is better for measuring the large branching fractions
  - Lorentz boost at LEP give advantage for lifetime measurement
  - Boost also helps reduce backgrounds

- But huge statistics at B factories
  - Detailed study of the structure of the hadronic mass spectra
  - Measurements of smaller BFs and rare decay modes
  - Searches for forbidden decay modes and limits for New Physics

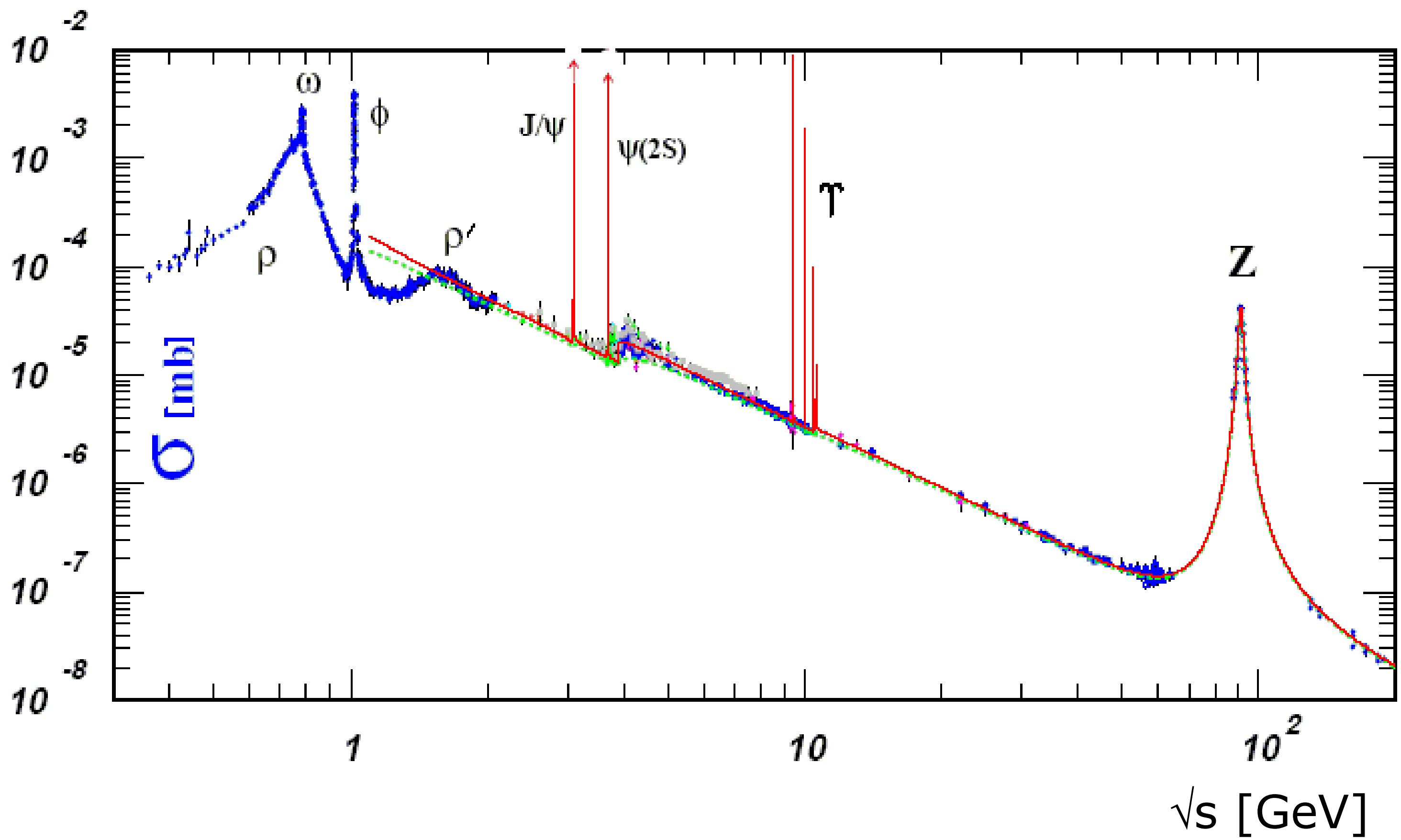


Virtual photon couples to electric charge so, at B Factory energy, all fermion pair cross sections are of the same order

In s-channel, to first order:

$$\sigma = 4\pi\alpha^2 / 3s$$

Total cross section in e⁺e⁻ collisions



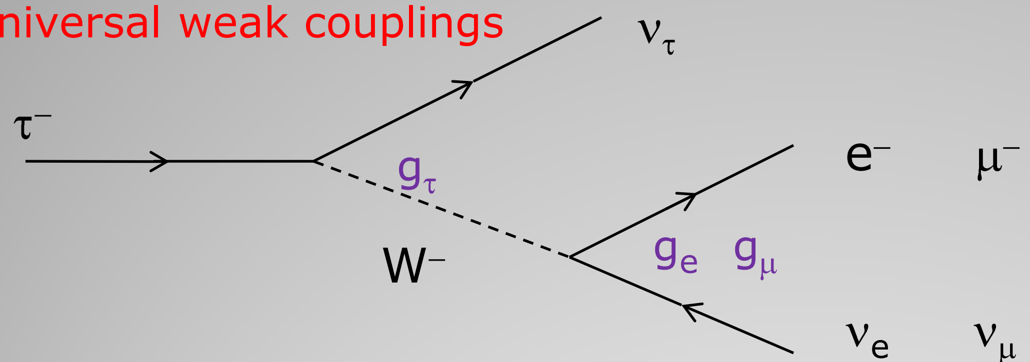
Tau production in SM (continued)

- Important SM sources at LHC:
  - $pp \to X + (Z \to \tau^+\tau^-)$
  - $pp \to X + (W^+ \to \tau^+\nu)$
  - $pp \to X + (H \to \tau^+\tau^-)$

- At LHCb:
  - Designed for CP-violation studies in B decays
  - But copious tau production from D (esp. D_s) and B decays:
    - e.g. $BF(D_s^+ \to \tau^+\nu) = 7\%$)
  - Cross section:
    - $\sigma\ (pp \to B/D_{(s)} + X \to \tau + X') \approx 120\ \mu b$

Tau decays in the Standard Model

Universal weak couplings



$d' = d \cos\theta_c + s \sin\theta_c$

Cabbibo angle

Without QCD, and up to phase space factors:

$$BF(\tau^- \to e^- \nu) = BF(\tau^- \to \mu^- \nu) = 1/3\ BF(\tau^- \to d' \bar{u}) = 20\%$$

In fact:

$$BF(\tau^- \to e^- \nu) = 17.82 \quad 0.05\ \%$$
$$BF(\tau^- \to \mu^- \nu) = 17.33 \quad 0.05\ \%$$

Lepton universality

QCD enhances hadronic BFs, giving α_s at tau mass scale

Ratios of strange to non-strange hadronic decays give strange quark mass and $\cos\theta_c$ i.e. |Vus| (CKM sector)

Semihadronic tau decays

Helicity suppression: Partially conserved axial current

Isospin invariance: Conserved vector currents

G-parity: Suppression of second-class currents

Cabibbo suppression of strange decays

Nonstrange decays

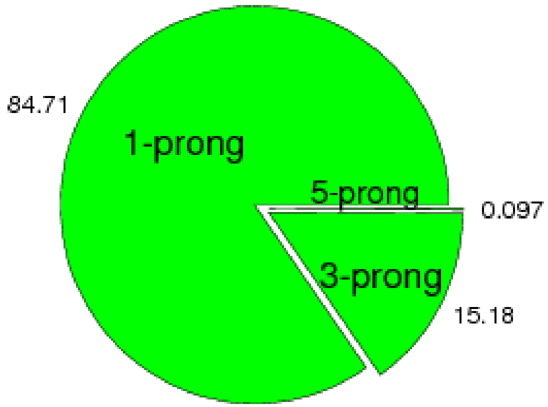
J^{PG}	Helicity PCAC	Isospin CVC	Second class	Exotic	
0^{++}		x		x	
0^{+-}		x	x		$a_0(980)$
0^{-+}	x		x	x	
0^{--}	x				π
	x				$\pi(1300)$
1^{++}			x		$b_1(1235)$
1^{+-}					$a_1(1260)$
1^{-+}					$\rho(770)$
					$\rho(1450)$
					$\rho(1700)$
1^{--}			x	x	

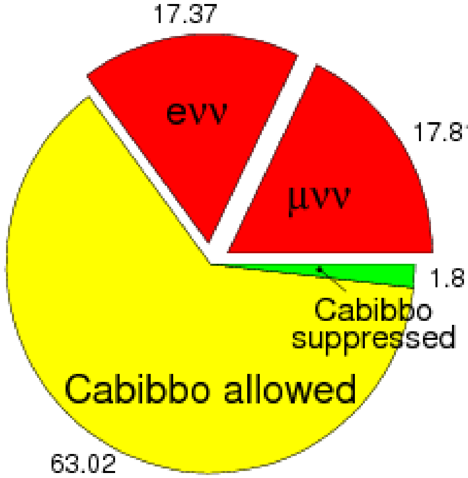
Strange decays

J^P	Cabibbo	Helicity	
0^+	x	x	$K_0^*(1430)$
0^-	x	x	K
1^+	x		$K_1(1270)$
	x		$K_1(1400)$
1^-	x		$K^*(892)$
	x		$K^*(1410)$
	x		$K^*(1680)$

Tau Decays (with thanks to Achim Stahl)

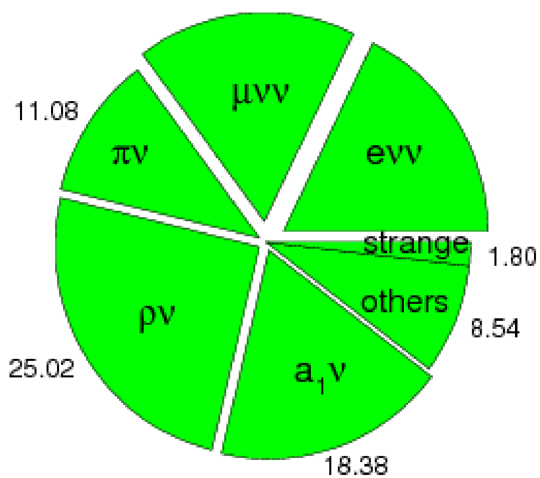
Topology

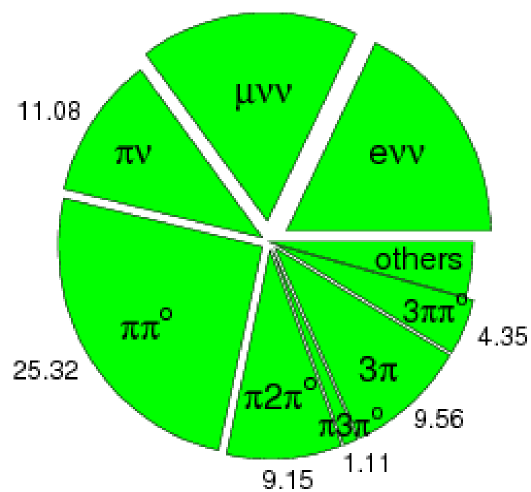




Leptonic/ Hadronic

Major resonances



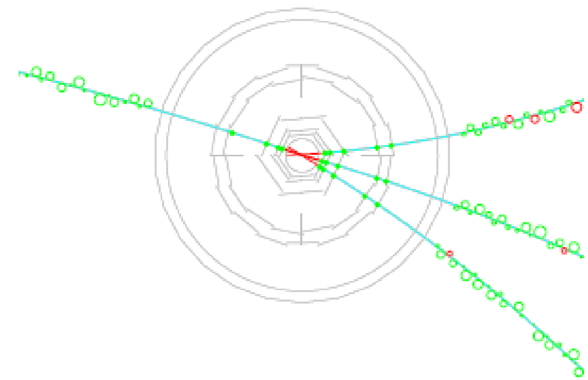


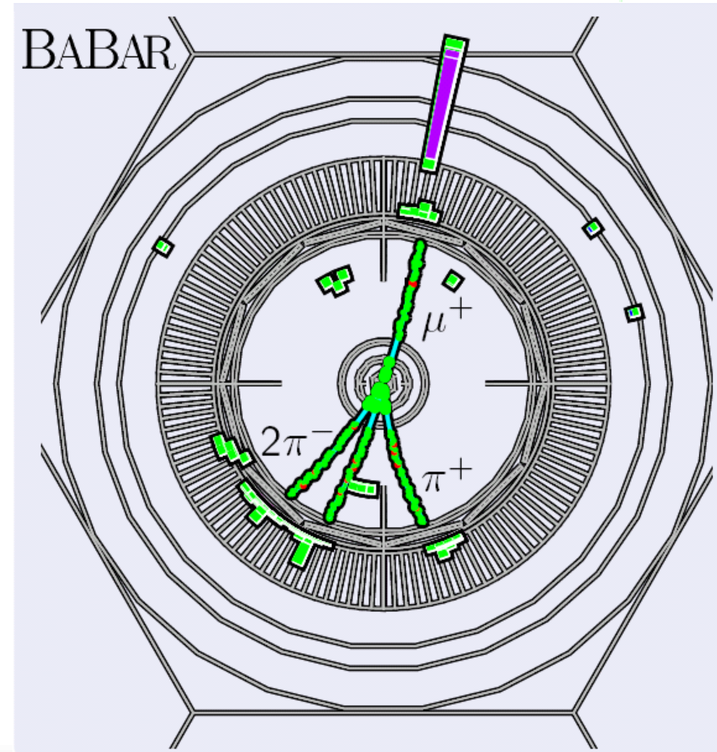
Largest exclusive

Identifying tau-pair events in e^+e^- annihilation

- Decay products of 2 taus are well separated in space and easily reconstructed (except ν).

Typical 1-3 $\tau\tau$ event



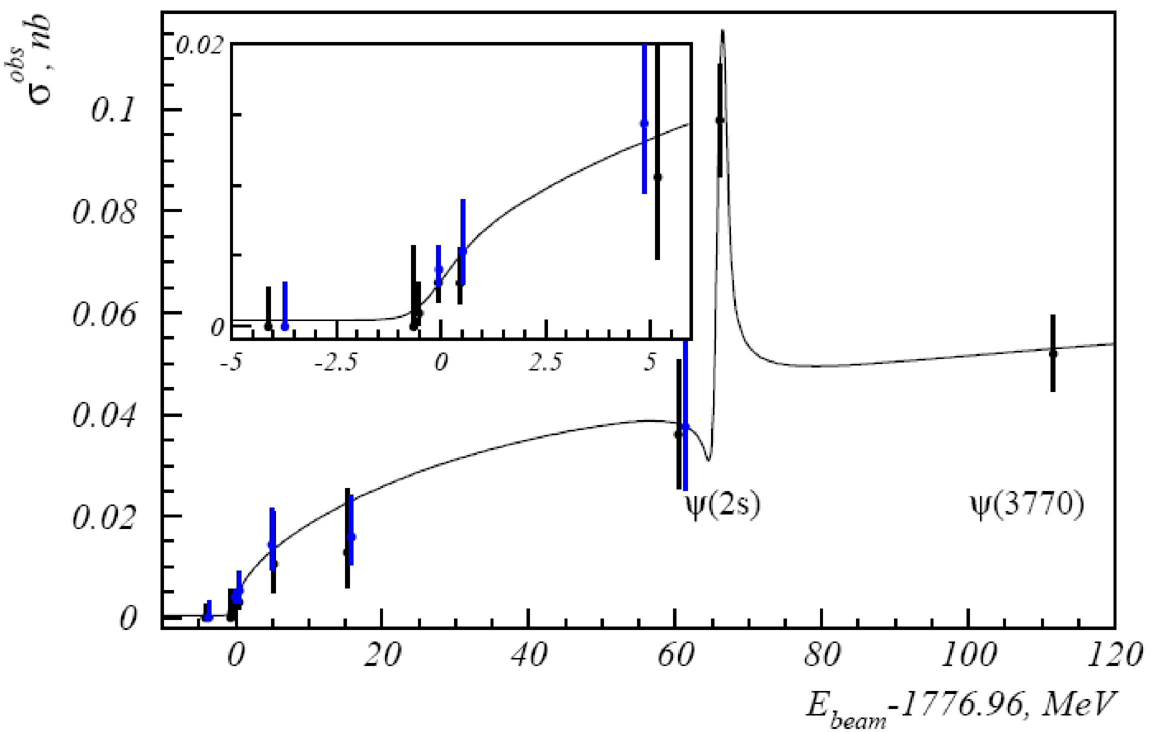


One tau decay, usually an e or μ with missing energy, provides a clean “tag” of a tau in the opposite hemisphere

Tau mass

KEDR at VEPP-4M (Novosibirsk)

- Beam energy by resonant depolarisation
- 15.2 pb^{-1} : 26 events at threshold



$$M_\tau^{KEDR} = 1776.69^{+0.17}_{-0.19} \pm 0.15 \text{ MeV}$$

Tau Mass

- KEDR preliminary result on τ–mass
$$M_\tau = 1776.69^{-0.19}_{+0.17} \pm 0.15 \text{ MeV}$$
agrees with PDG-2006 value
$$M_\tau = 1776.99^{+0.29}_{-0.26} \text{ MeV}$$
- Plan is to achieve error of ~0.15–0.18 MeV on completion of analysis
- Then BES-BINP collaboration to reach ~0.09 MeV (50 ppm) at BESIII by ~2011
- Will need only a few days of data-taking

CPT tests

- Pseudomass technique to measure relative mass difference with low systematics

$$(m_{\tau-} - m_{\tau+}) / (m_{\tau-} + m_{\tau+}) \longrightarrow$$

- Prospects for improvement at B factories
- Should reach precision of 10^{-4} at SBF
- Should also measure relative lifetime difference

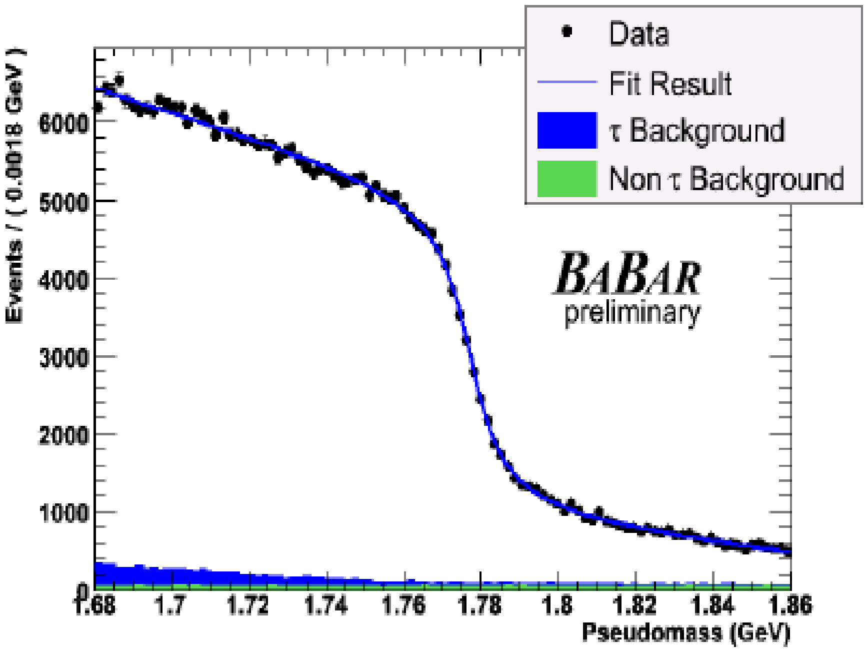
$$(\tau_{\tau-} - \tau_{\tau+}) / (\tau_{\tau-} + \tau_{\tau+})$$

- But we don't really learn anything from these measurements
  … unless they turn out to be non-zero

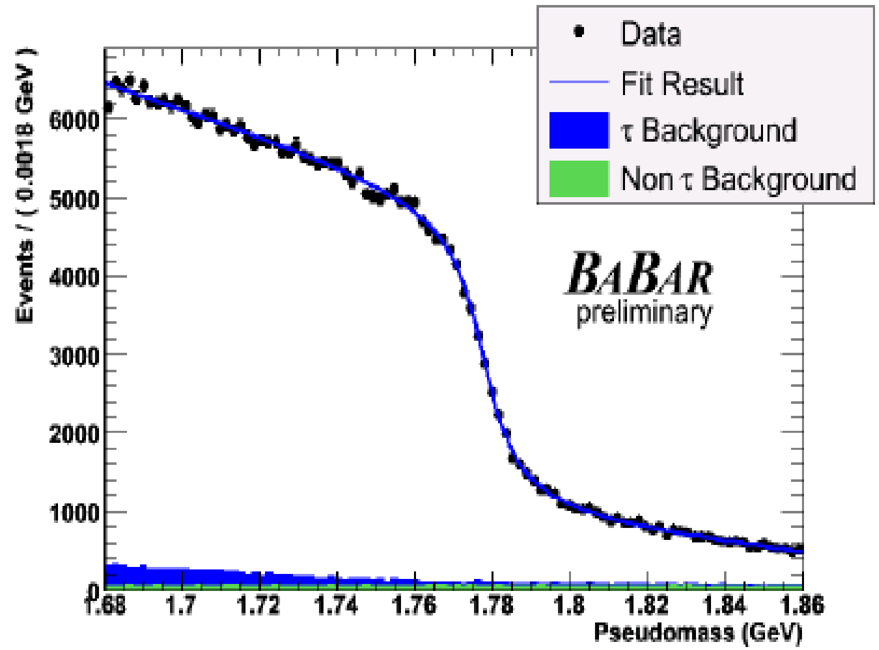
Pseudomass: Assume ν is colinear with hadronic system h

$$M_p \equiv \sqrt{M_h^2 + 2(\sqrt{s}/2 - E_h^*)(E_h^* - P_h^*)} \leq M_\tau$$

τ^+



τ^-



$$M^\tau_{AVG} = 1776.68 \pm 0.12(stat) \pm 0.41(syst)\ \ \text{MeV}$$

$$(M_{\tau^+} - M_{\tau^-})/M^\tau_{AVG} = (-3.4 \pm 1.3(stat) \pm 0.3(syst)) \times 10^{-4}$$

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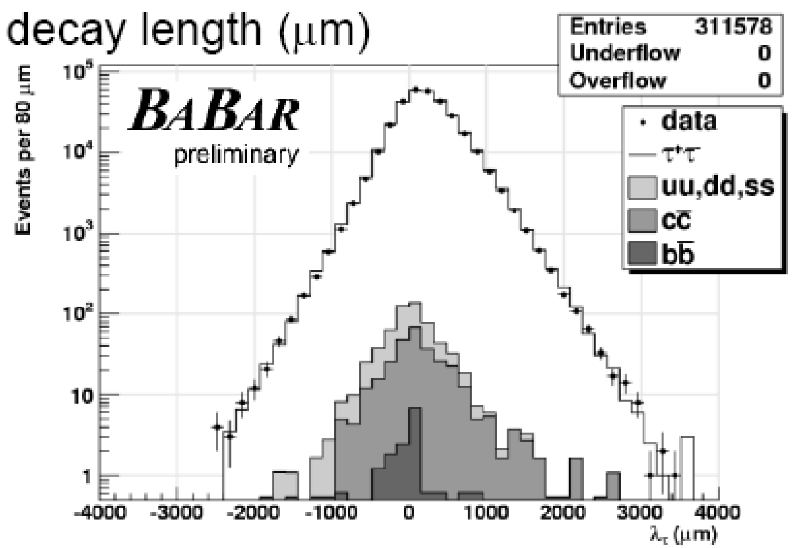
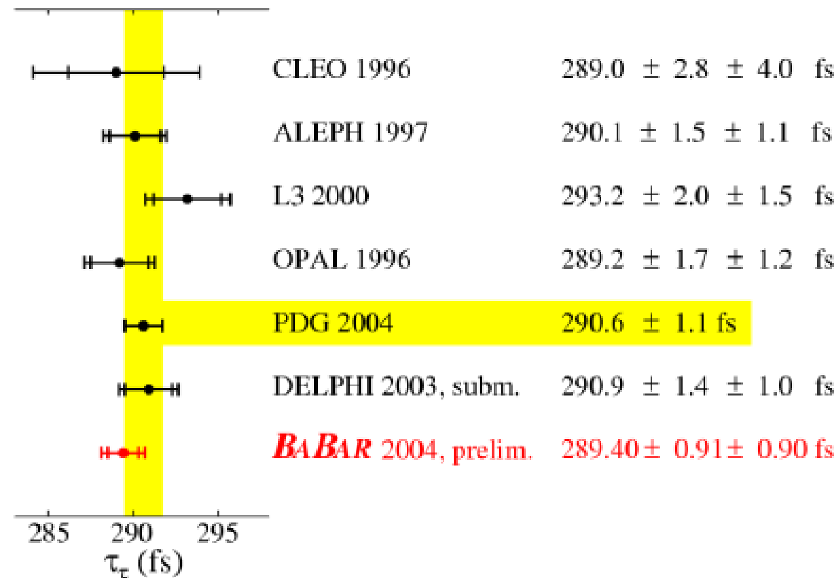
Tau lifetime





$$\frac{\tau_{\tau^-}-\tau_{\tau^+}}{\tau_{\tau^-}+\tau_{\tau^+}} = (0.12 \pm 0.32_{stat})\%$$

NPPS144(2005)105, *BABAR* Preliminary, $\mathcal{L} = 80\ \mathrm{fb}^{-1}$

CPT tests

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  … unless they turn out to be non-zero

SM: Lepton Universality

- Many tests of LU using tau data (with related μ and e data)
- Precision of lepton universality tests now limited by precision of τ leptonic BFs and τ lifetime →

$$\tau_\tau = \tau_\mu \left(\frac{g_\mu}{g_\tau}\right)^2 \left(\frac{m_\mu}{m_\tau}\right)^5 B\left(\tau^- \to e^- \bar{\nu}_e \nu_\tau\right) \frac{f(m_e^2/m_\mu^2)\, r_{RC}^\mu}{f(m_e^2/m_\tau^2)\, r_{RC}^\tau}$$

Test of lepton universality (g_μ / g_τ)

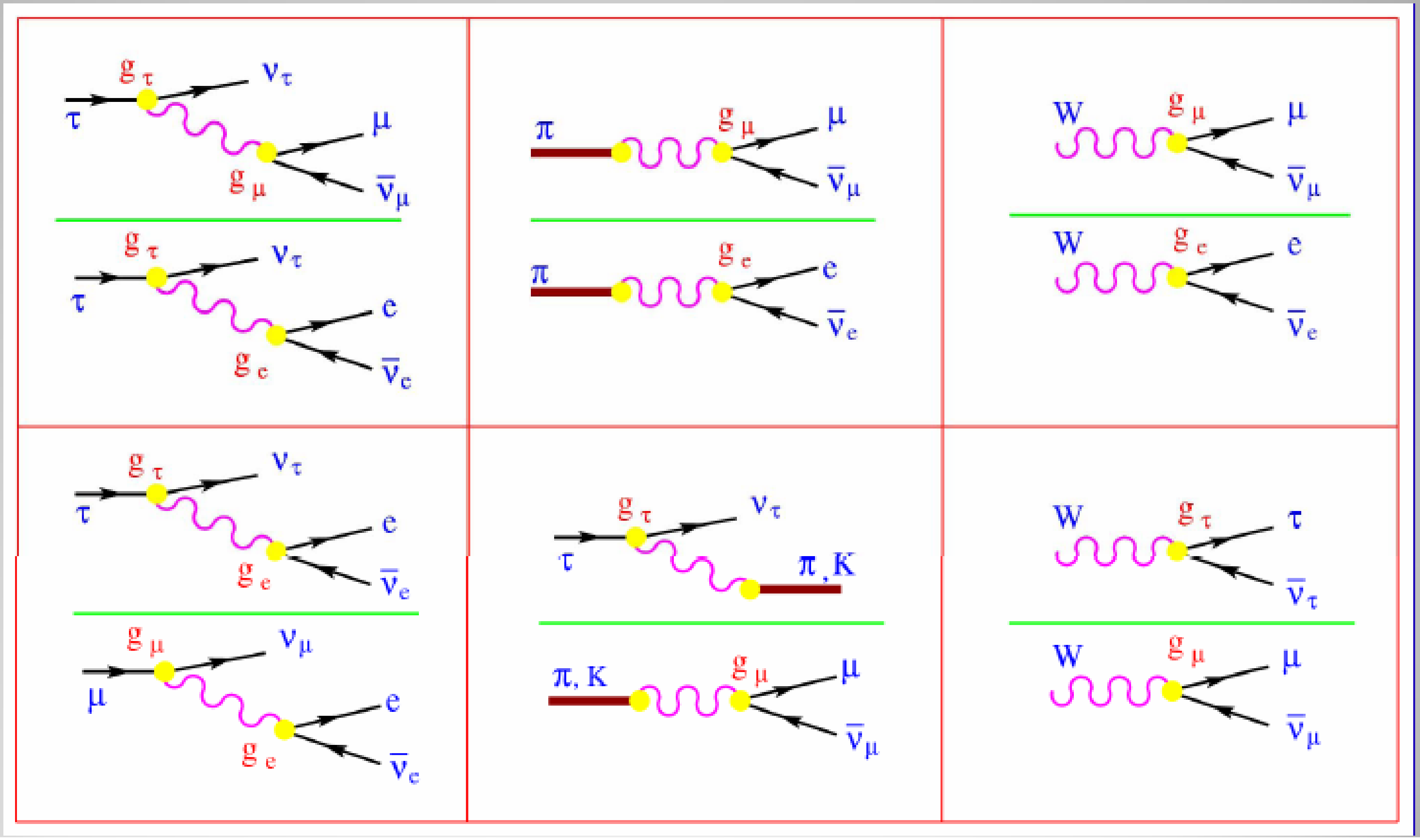
- Tau lifetime
  - It is clearly difficult at B factories (no publication yet)
    - Short flight distance, backgrounds, alignment
    - But there are good prospect for improvement in τ lifetime at B factories, giving more precise lepton universality tests
  - ILC/GigaZ could give further step improvement
- Leptonic Branching Fractions
  - Currently measured to 0.3%
  - Prospects to improve this at BESIII and τCF

Lepton Universality

- Universal W couplings … relations among many processes

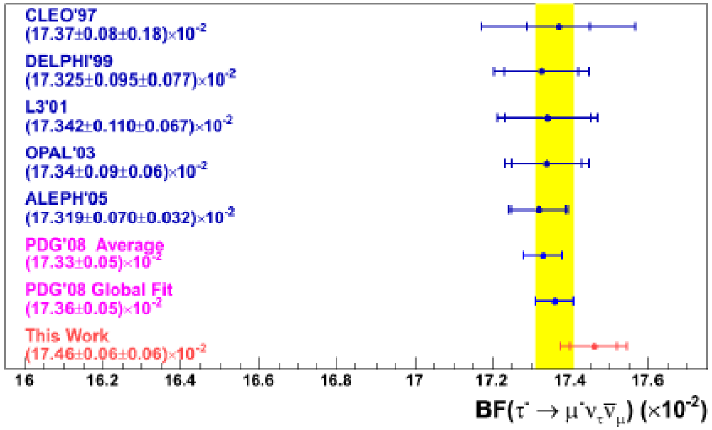
g_μ/g_e

g_τ/g_μ



Recent BaBar measurements of 1-prong modes

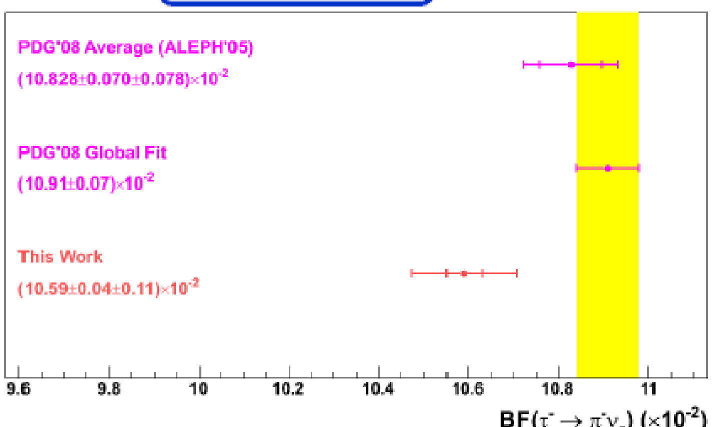
$\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu$



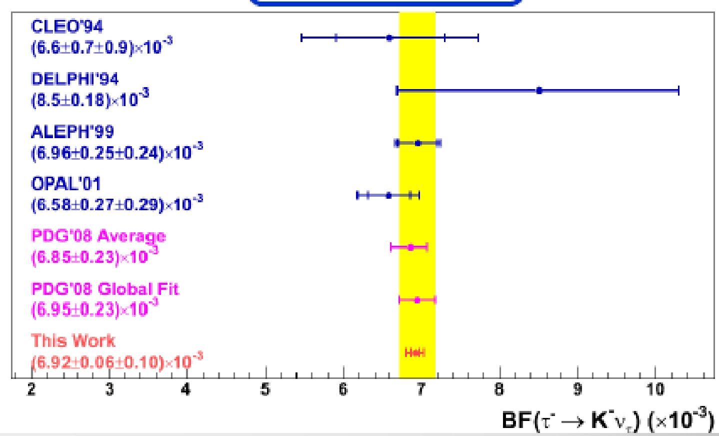
Branching fractions determined from the branching ratio using $B(\tau^- \to e^- \nu_\tau \nu_e) = (17.82 \pm 0.05)\%$

Particle Data Group, Phys. Lett. B 667, 1 (2008).

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



$\tau^- \to K^- \nu_\tau$



Lepton Universality

Using BaBar measurements of one-prong branching fractions

$B(\tau^- \to \mu^- \nu_\tau \bar{\nu}_\mu)/B(\tau^- \to e^- \nu_\tau \bar{\nu}_e)$: $g_\mu/g_e = 1.0036 \pm 0.0020$

$B(\tau^- \to \pi^- \nu_\tau)/B(\pi^- \to \mu^- \nu_\mu)$: $g_\tau/g_\mu = 0.986 \pm 0.006$

$B(\tau^- \to K^- \nu_\tau)/B(K^- \to \mu^- \nu_\mu)$ $g_\tau/g_\mu = 0.983 \pm 0.009$

Combining π and K results: $g_\tau/g_\mu = 0.985 \pm 0.005$

(3σ below SM expectation)

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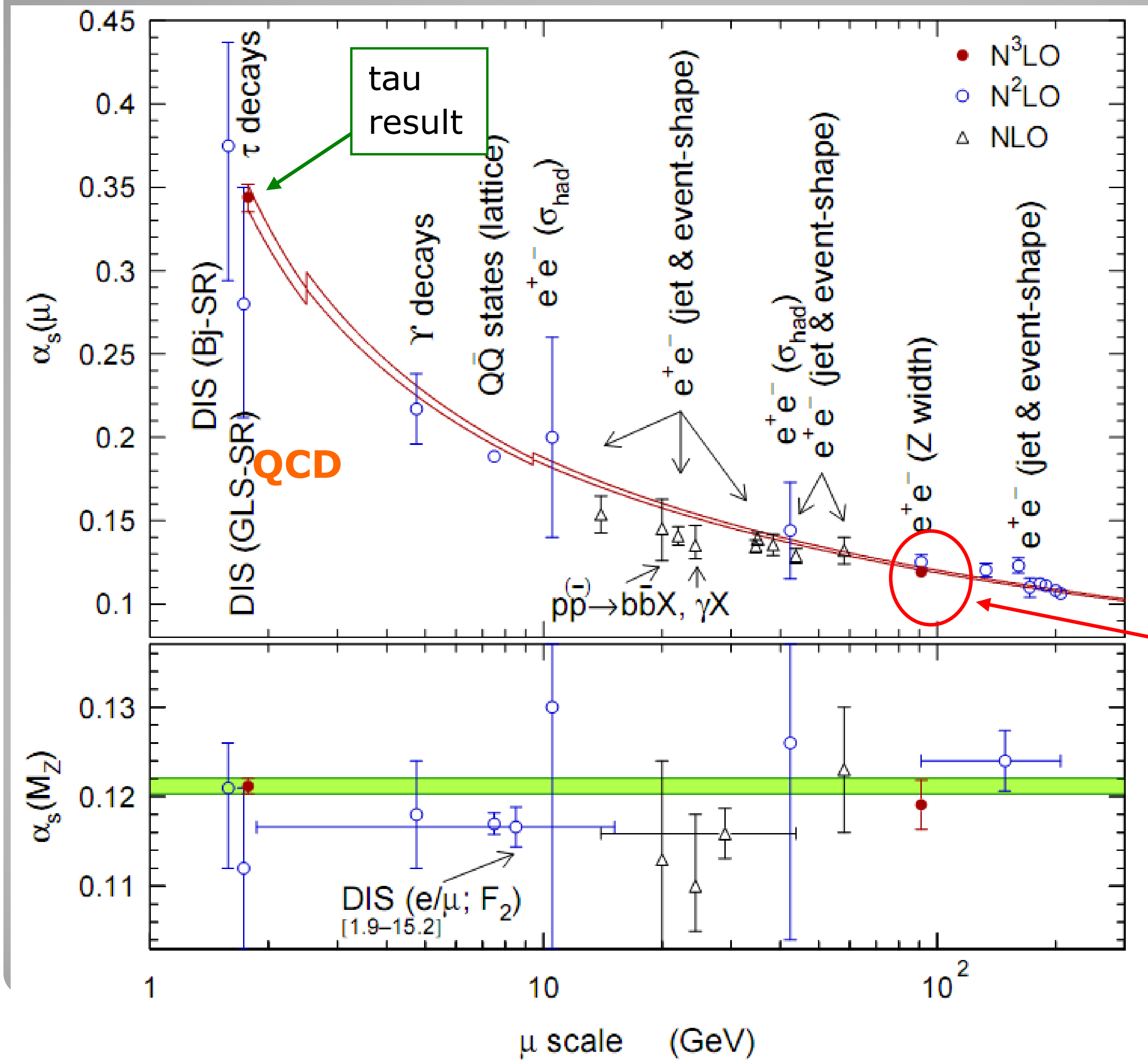
  - GigaZ could give further step improvement

- Leptonic Branching Fractions
  - Currently measured to 0.3%
  - Prospects to improve this at BESIII and τCF

Standard Model: QCD

- Chiral perturbation theory allows precision application of QCD
- Measurement of α_s →
  - Error now dominated by theory
  - But more BaBar and Belle data analysis will help

- Monte Carlo simulations
  - Tauola now has a C++ universal interface
  - Good prospects for better simulations of hadronic states with
    - Input from experimentalists
    - Further theoretical progress in $\pi\pi$, $KK\pi$ etc.



Tau provides:

- among most precise $\alpha_s(M_Z^2)$ determinations;

- with $\alpha_s(M_Z^2)_Z$, the most precise test of asymptotic freedom

Z result

$$\alpha_s(m_Z^2)_Z = 0.1191 \pm 0.0027_{fit} \pm 0.0001_{trunc}$$

$$\alpha_s(M_Z^2)_\tau = 0.1212 \pm 0.0011$$

$$\alpha_s(M_Z^2)_\tau - \alpha_s(m_Z^2)_Z = 0.0021 \pm 0.0029$$

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SM: Second-class currents

Weak hadronic currents in τ decays can be classified as:

- first-class currents: $J^{PG} = 0^{++}, 0^{--}, 1^{+-}, 1^{-+}$
- second-class currents: $J^{PG} = 0^{+-}, 0^{-+}, 1^{++}, 1^{--}$

$$\hat{G} = \hat{C}\, e^{i\pi \hat{I}_2}$$

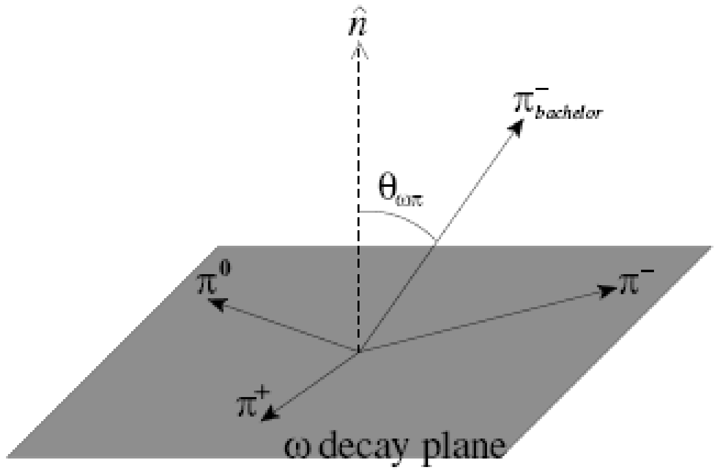
S. Weinberg (Phys. Rev. **112**, 1375 (1958))

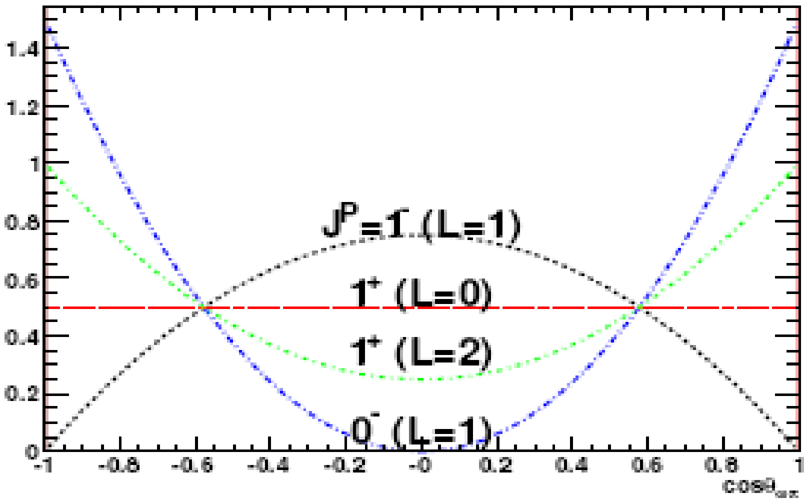
- Expect signal at $\sim O(10^{-5})$ level, from u-d mass difference
- It would have been nice to have seen SSC around the golden jubilee year of Weinberg’s 1958 paper

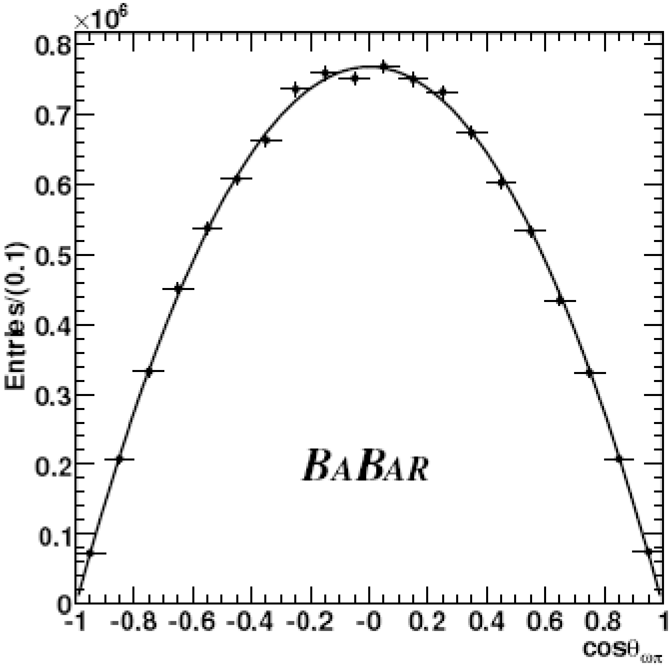
SM: Second-class currents

- Three classic channels to search for SCCs

- $\tau^- \to \omega\pi^- \nu$ $\longrightarrow$
  - Limit currently well above 10^{-5}
  - Best prospect may be GigaZ
- $\tau^- \to \eta\pi^- \nu$
  - Limit currently above 10^{-4}
  - Dominated by systematics and backgrounds (e.g. $\eta\pi^-\pi^0 \nu$, $\eta\pi^- K^0_L \nu$)
  - Need to reduce backgrounds and their errors (progress from Belle)
  - Prospects at BaBar and Belle, but not likely before SBF
  - High luminosity near-threshold measurement (BESIII + τCF) could defeat the backgrounds
- $\tau^- \to \eta^/\pi^- \nu$
  - Limit currently $<10^{-5}$
  - Low backgrounds, dominated by statistics
  - Possibility for observation by Belle (and maybe BaBar)
  - Good prospect to observe this mode at a SBF







$$\mathcal{B}(\tau^- \to \pi^- \omega \nu_\tau(\text{second-class})) < 1.3 \times 10^{-4} \text{ at } 90\% \text{ C.L.}$$

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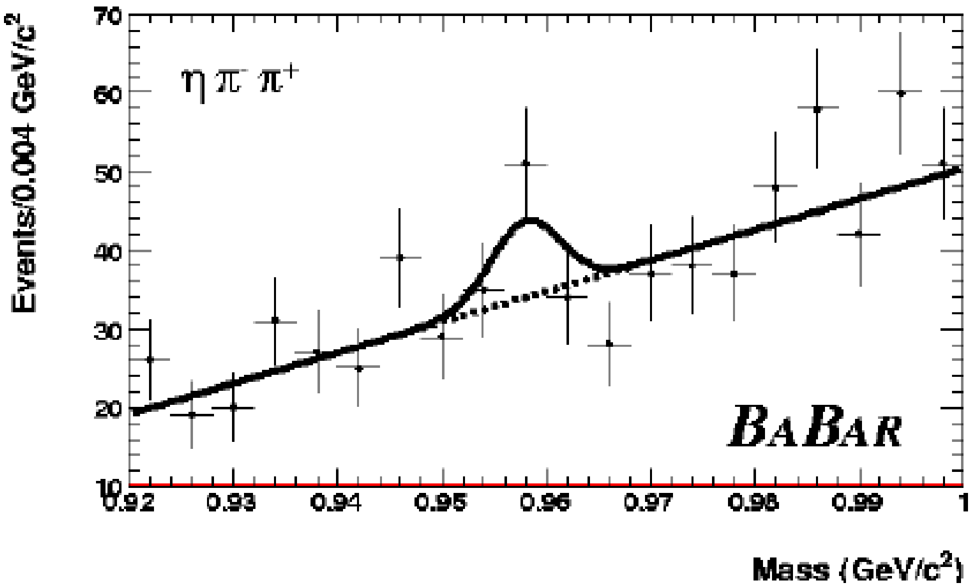
Mass spectrum of $\eta\pi^-\pi^+$ in $\tau^- \to \eta\pi^-\pi^+\pi^-\nu$ candidates

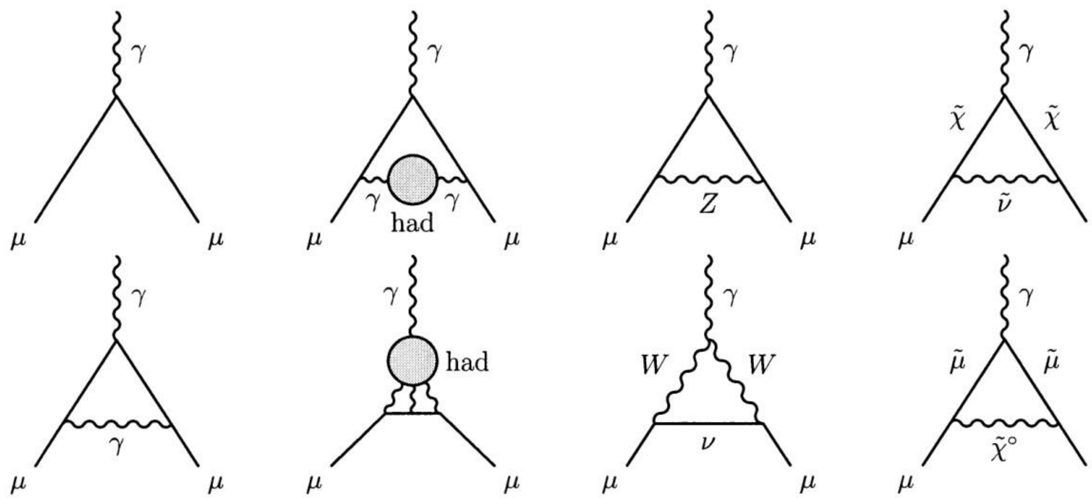


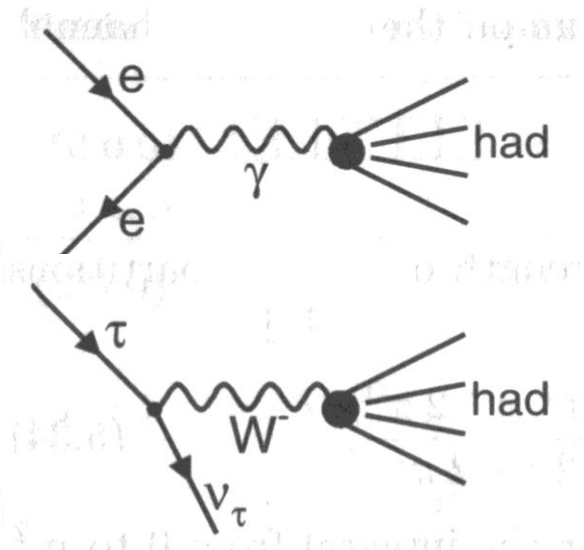
BF($\tau^- \to \eta'(958)\pi^-\nu_\tau$) < 7.2 x 10^{-6} at 90% confidence level

$\tau^- \to \pi^- \pi^0 \nu$ decays and muon g-2

Muon magnetic moment anomaly given by $a_\mu = (g_\mu - 2)/2$

$$a_\mu^{SM} = a_\mu^{QED} + \left(a_\mu^{had,LO} + a_\mu^{had,HO} + a_\mu^{had,LBL} \right) + a_\mu^{weak}$$





$$\sigma_{e^+e^- \to \pi^+\pi^-}^{I=1} = \frac{4\pi\alpha^2 m_\tau^2}{6|V_{ud}|^2(1+C^{rad})\; s} \frac{\mathcal{B}(\tau \to \pi^-\pi^0\nu)}{\mathcal{B}(\tau \to e\nu\nu)} \frac{dN_{\pi^-\pi^0}}{N_{\pi^-\pi^0} ds} \left((1 - \frac{s}{m_\tau^2})(1 + \frac{2s}{m_\tau^2}) \right)^{-1}$$

Situation at ICHEP-Tau06

a_μ^{had} [ee] = (690.9   4.4) × 10^{-10}

a_μ [ee] = (11 659 180.5   4.4$_{had}$ 3.5$_{LBL}$ 0.2$_{QED+EW}$) × 10^{-10}

inclu-
ding:

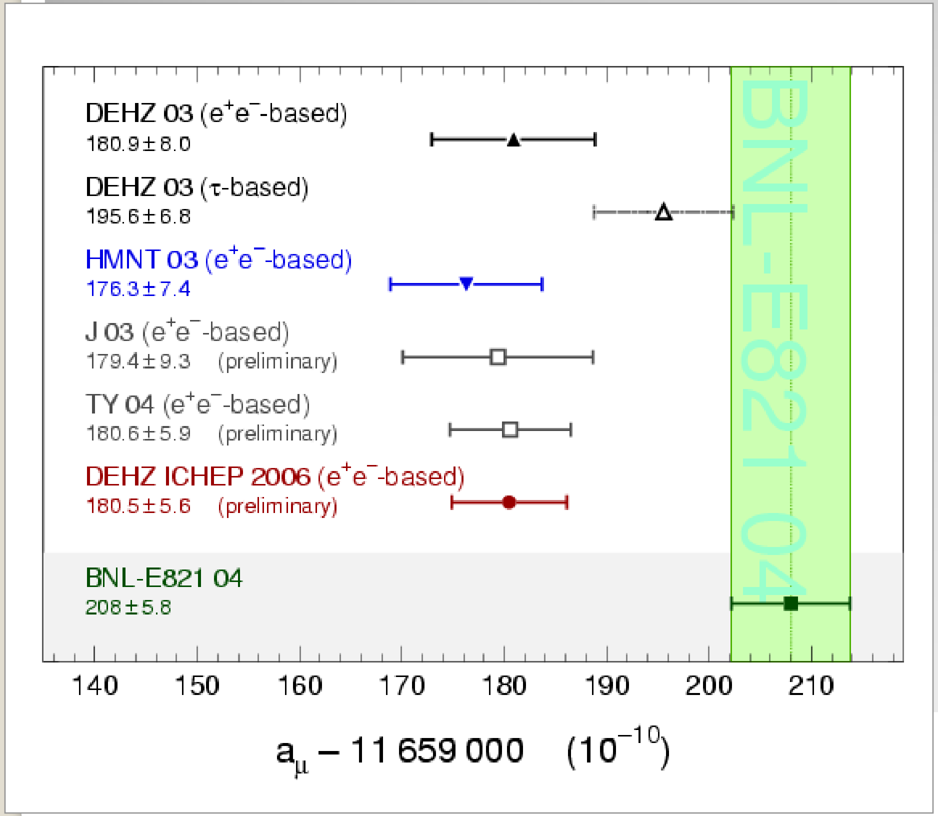
Hadronic HO	– (9.8 0.1) × 10^{-10}
Hadronic LBL	+ (12.0 3.5) × 10^{-10}
Electroweak	(15.4 0.2) × 10^{-10}
QED	(11 658 471.9 0.1) × 10^{-10}

Knecht-Nyffeler, Phys.Rev.Lett. 88 (2002) 071802

Melnikov-Vainshtein, hep-ph/0312226

Davier-Marciano, Ann. Rev. Nucl. Part. Sc. (2004)

Kinoshita-Nio (2006)



BNL E821 (2004):
a_μ^{exp} = (11 659 208.0 ± 6.3) 10^{-10}

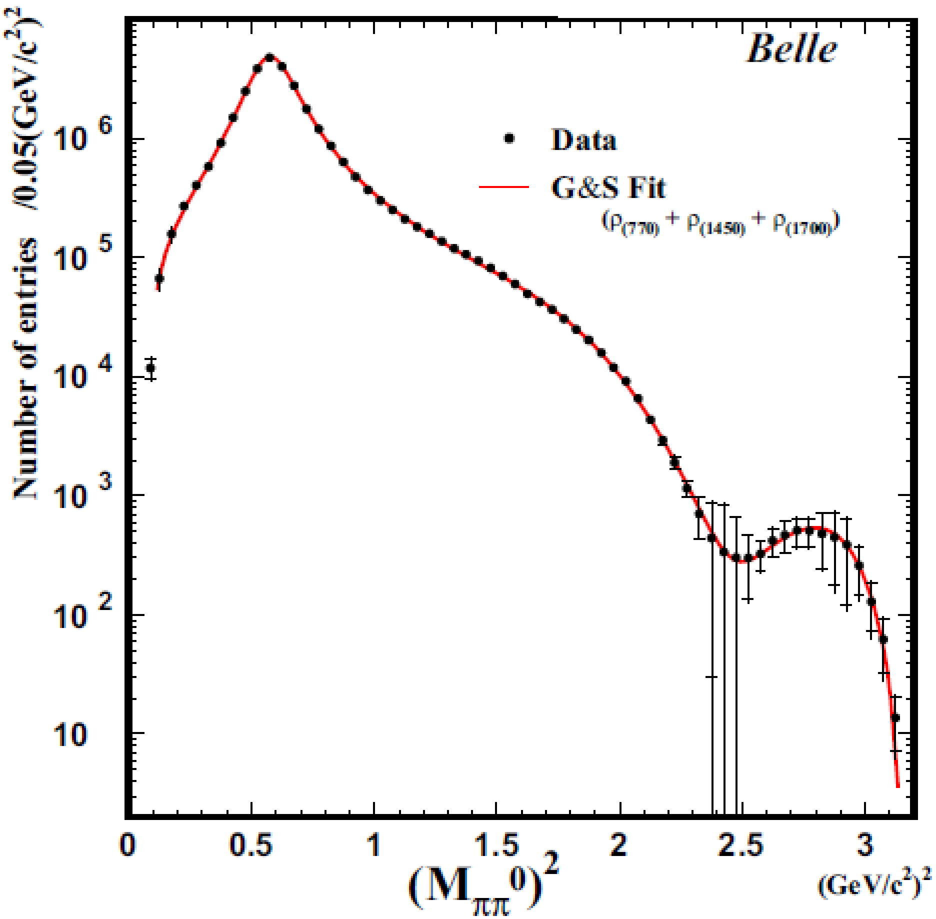
Observed Difference with BNL using e⁺e⁻:

a_μ [exp] – a_μ [SM] = (27.5   8.4) × 10^{-10}

➡ 3.3 „standard deviations“

Belle analysis of $\tau^- \to \pi^- \pi^0 \nu$ decays

$$a_\mu^{\pi\pi}[2m_\pi, 1.8\ \mathrm{GeV}/c^2] = (523.5 \pm 1.5(\mathrm{exp.}) \pm 2.6(\mathrm{Br.}) \pm 2.5(\mathrm{isospin})) \times 10^{-10},$$

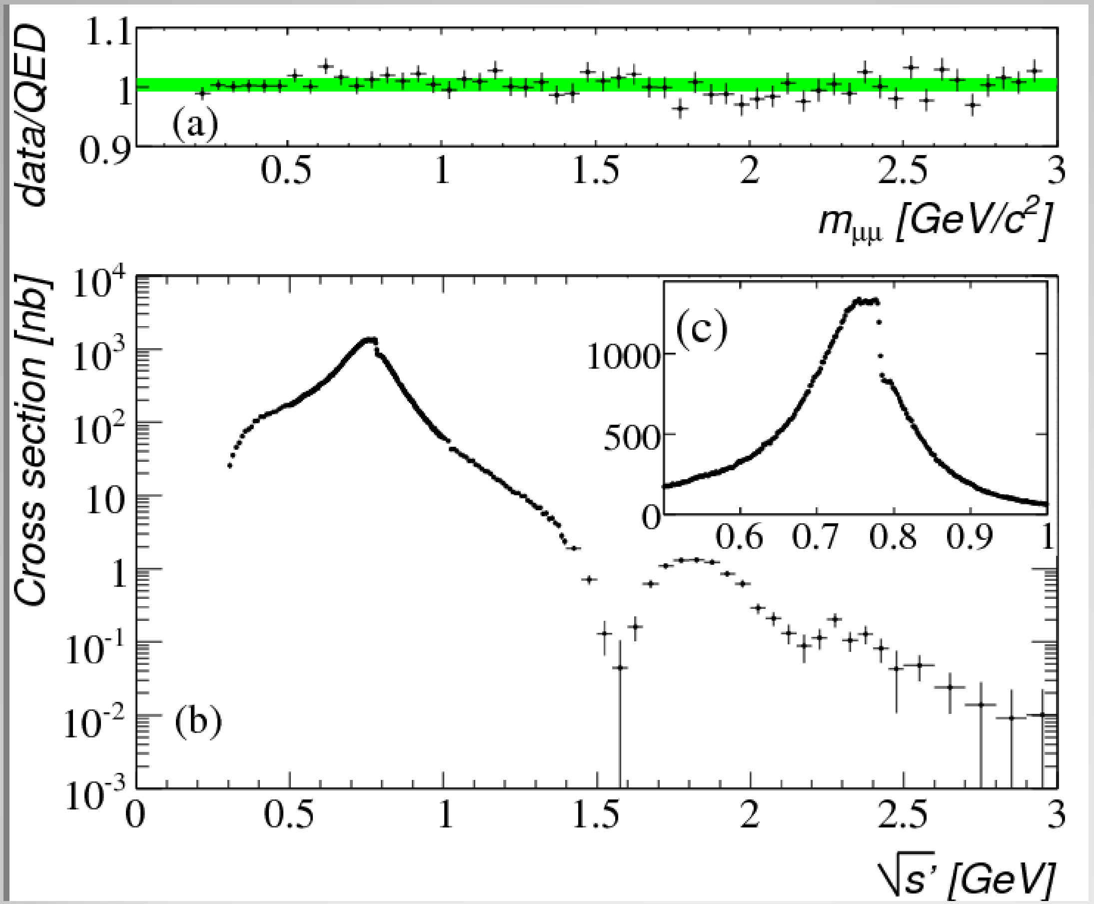


$$(504.6 \pm 3.1(\mathrm{exp.}) \pm 0.9(\mathrm{rad.})) \times 10^{-10}$$

$(e^+e^-$: CMD2, SND)

BaBar analysis of $e^+e^- \to \pi^+\pi^- + \gamma(ISR)$

$$a_\mu^{\pi\pi}[2m_\pi, 1.8\ \mathrm{GeV}/c^2] = (514.1 \pm 2.2(\mathrm{stat}) \pm 3.1(\mathrm{syst})) \times 10^{-10}$$



$$(504.6 \pm 3.1(\mathrm{exp.}) \pm 0.9(\mathrm{rad.})) \times 10^{-10}$$

$(e^+e^-$: CMD2, SND$)$

- BaBar results on $\pi\pi$: precision of 0.6% in ρ region (0.6-0.9 GeV)

- Comparison with results from earlier e^+e^- experiments
  - discrepancy with CMD-2 and SND, mostly below ρ
  - large disagreement with KLOE
  - better agreement with τ results, especially Belle

- Deviation between BNL measurement and theory prediction is significantly reduced using BaBar ISR $\pi\pi$ data

- $a_\mu[\text{exp}] - a_\mu[\text{SM}] = (\mathbf{27.5} \pm \mathbf{8.4}) \times 10^{-10} \rightarrow (14.0 \pm 8.4) \times 10^{-10}$

- But we need to wait for final results and contributions of multi-hadronic modes

g_μ - 2

- Prospects of further input from Belle, Daϕne, VEPP-2000, theory …
- What are prospects for more τ physics input?
  - Will need more precise measurement of BFs
  - Difficult to improve on systematics of LEP
  - $\tau^- \rightarrow \pi^-\pi^0\nu_\tau$ at ILC/GigaZ would help
  - … but that's a long time away
- In a few years we may be limited by light-by-light theory calculations
  - Prospects for help with $\gamma\gamma$ data from Daϕne
  - Ongoing theory work

SM: CKM

- Tau decay is one of the best ways to measure V_{us} and strange quark mass m_s
- New V_{us} result from ratio of $(\tau \to \pi\nu)/(\tau \to K\nu)$ →
- Suggestion of small BSM contributions in comparison of value from unitarity with value from sum of strange τ BFs
  - Error still dominated by data statistics
  - Significant progress still to be made by BaBar and Belle in BFs for strange τ decays
  - $K^0\pi^0\pi^-$, $K3\pi$, $K4\pi$ etc. and higher multiplicity modes
- Prospects are very good for new experimental results V_{us} and m_s with BaBar and Belle data
- On a longer timescale SuperB with good particle ID should significantly improve precision

$|V_{us}|$ from Unitarity

Unitarity constraint in CKM matrix involving $|V_{us}|$:

$$|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2=1$$

Contribution from $|V_{ub}|^2$ is negligible: $|V_{ub}|=(3.93\pm0.36)\times10^{-3}$

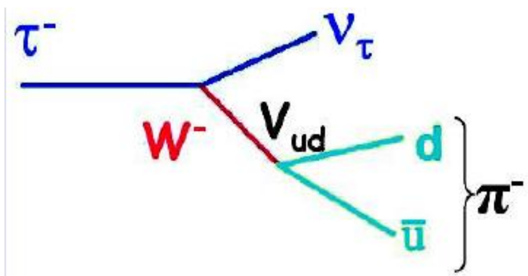
Particle Data Group, Phys. Lett. B 667, 1 (2008).

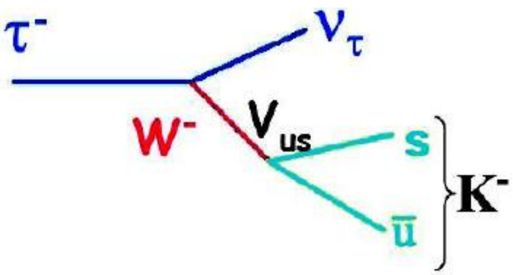
$|V_{ud}|$ is well measured from superallowed beta decays

|Vud = 0.97425 ± 0.00022 (Phys Rev C79, 055502 (2009))

$$|V_{us}| = \sqrt{1-|\mathrm{V}_{\mathrm{ud}}|^2-|V_{ub}|^2} = 0.2255 \quad 0.0010$$

$|V_{us}|$ from tau decays





$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2}{f_\pi^2} \frac{|V_{us}|^2}{|V_{ud}|^2} \frac{(1 - m_K^2 / m_\tau^2)^2}{(1 - m_\pi^2 / m_\tau^2)^2}$$

- Measure $B(\tau^- \to K^- \nu_\tau)/B(\tau^- \to \pi^- \nu_\tau)$
- Take $f_K/f_\pi = 1.189 \pm 0.007$ from Lattice QCD
  E. Follana, et al. PRL 100, 062002 (2008)
- $|V_{ud}| = 0.97408 \pm 0.00026$ from superallowed beta decays
- Electroweak corrections cancel

BaBar measurement:
0.2255 ± 0.0024

Unitarity:
0.2255 ± 0.0010

SM: CKM

- Tau decay is one of the best ways to measure V_{us} and strange quark mass m_s
- New V_{us} result from ratio of $(\tau \to \pi\nu)/(\tau \to K\nu)$ →
- Suggestion of small BSM discrepancy in comparison of value from unitarity with value from sum of strange τ BFs
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  - $K^0\pi^0\pi^-$, $K3\pi$, $K4\pi$ etc. and higher multiplicity modes
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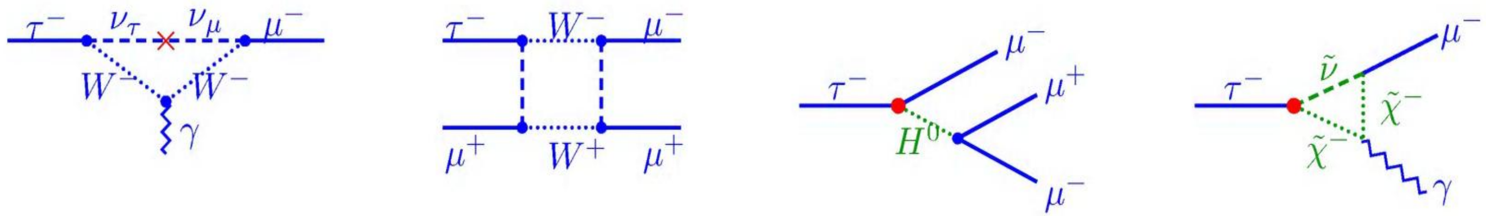
- On a longer timescale SuperB with good particle ID should significantly improve precision

BSM: Lepton Flavour Violation

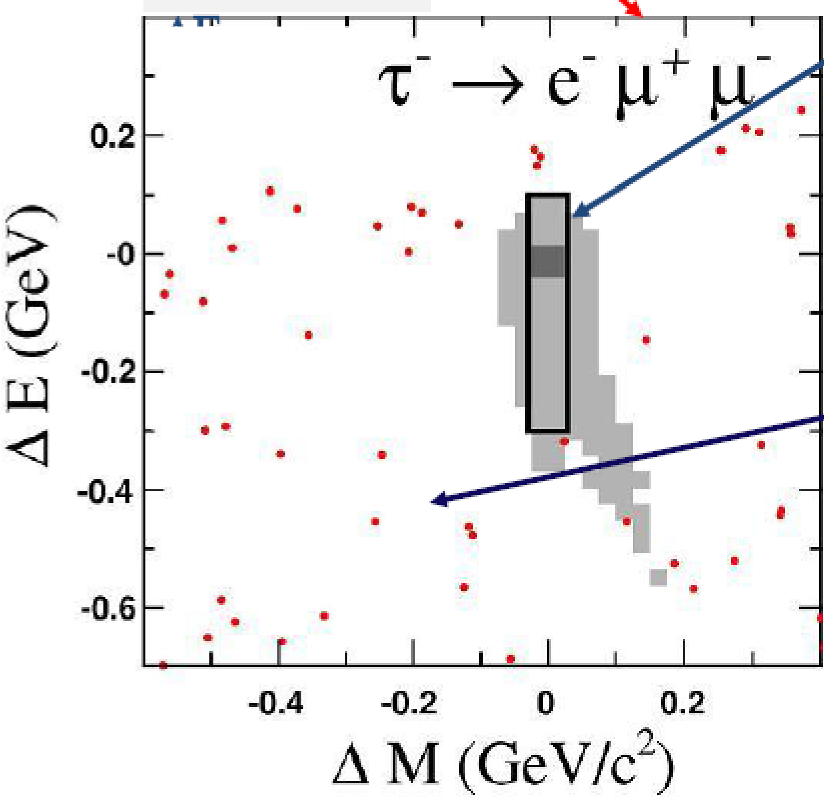


Model	$\tau \to \ell\gamma$	$\tau \to \ell\ell\ell$	Ref.
SM + lepton mixing	10^{-40}	10^{-14}	hep-ph/9810484
SM + left-h. heavy Dirac neutrino	$< 10^{-18}$	$< 10^{-18}$	SJNP25(1977)340
SM + right-h. heavy Majorana neutrino	$< 10^{-9}$	$< 10^{-10}$	PRD66(2002)034008
SM + left and right-h. neutral singlets	$< 10^{-8}$	$< 10^{-9}$	PRD66(2002)034008
mSUGRA + seesaw	$< 10^{-7}$	$< 10^{-9}$	hep-ph/0206110, hep-ph/9911459, etc
SUSY $SU(5)$	$< 10^{-4}$		hep-ph/0303071
SUSY flipped $SU(5)$	$< 10^{-7}$		hep-ph/0304130
SUSY $SO(10)$	$< 10^{-8}$	$< 10^{-10}$	hep-ph/0209303, hep-ph/0304190
SUSY anomalous $U(1)$	$< 10^{-7}$		hep-ph/0308093
neutral SUSY Higgs	$< 10^{-10}$	$< 10^{-7}$	hep-ph/0304081
charged SUSY Higgs triplet		$< 10^{-7}$	hep-ph/0209170
MSSM+nonuniversal soft SUSY breaking	$< 10^{-10}$	$< 10^{-6}$	hep-ph/0305290
Non universal Z' (technicolor)	$< 10^{-9}$	$< 10^{-8}$	PLB547(2002)252
two Higgs doublet III	$< 10^{-15}$	$< 10^{-17}$	hep-ph/0208117
extra dimensions	$< 10^{-11}$		hep-ph/0210021

Selection Strategy

Three regions defined in (ΔMec, ΔE) **plane**

Large Box (LB): identical for all channels. Almost all signal events lie in this region



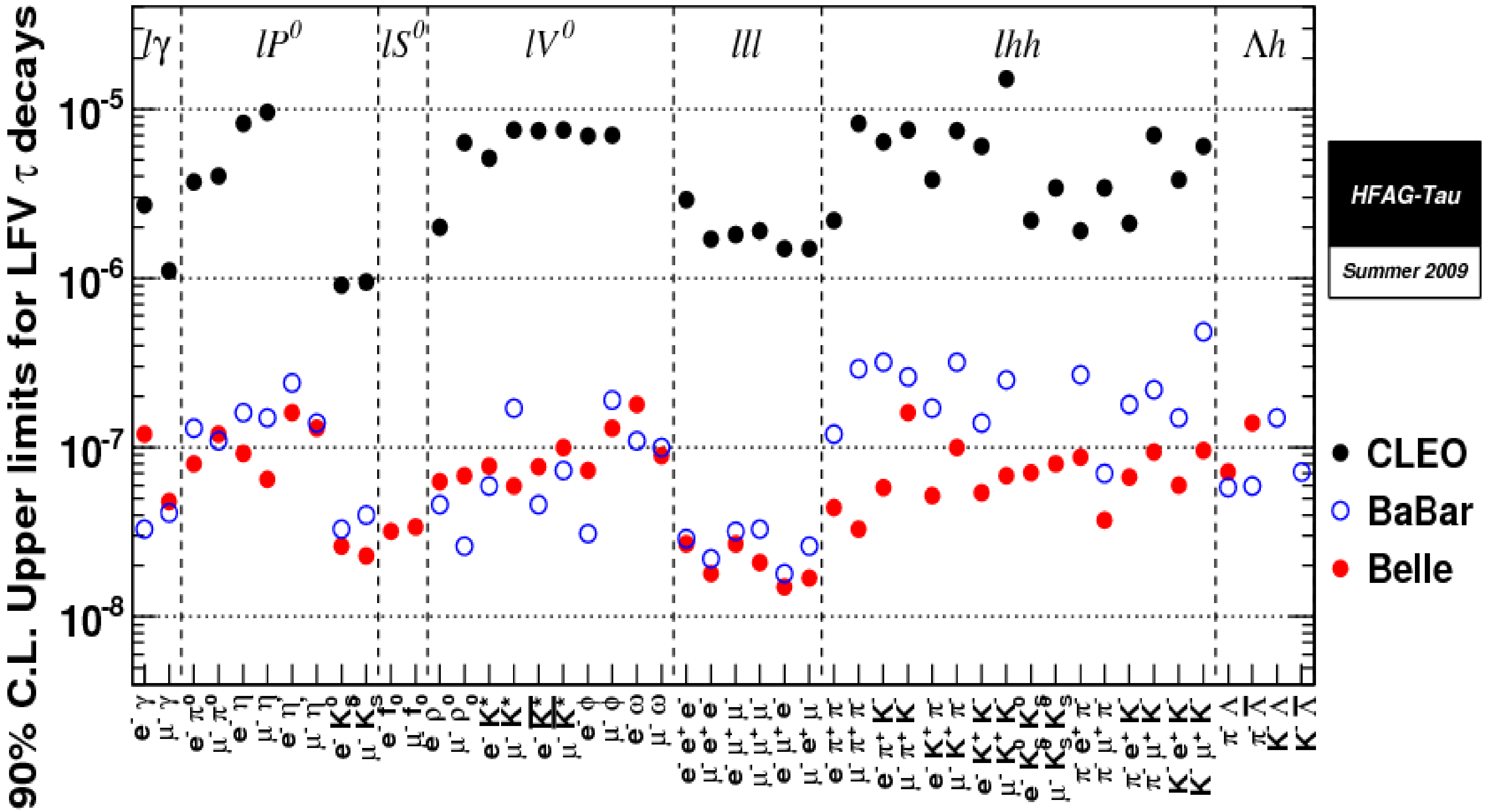
Signal Box (SB): different for each channel, dimension optimized to give the best UL for each channel.

Data events in this region are BLIND

Grand Sideband (GS): is the unblinded region of the LB.

Background estimation made extrapolating data from GS to SB

Lepton Flavour Violation: HFAG Compilation

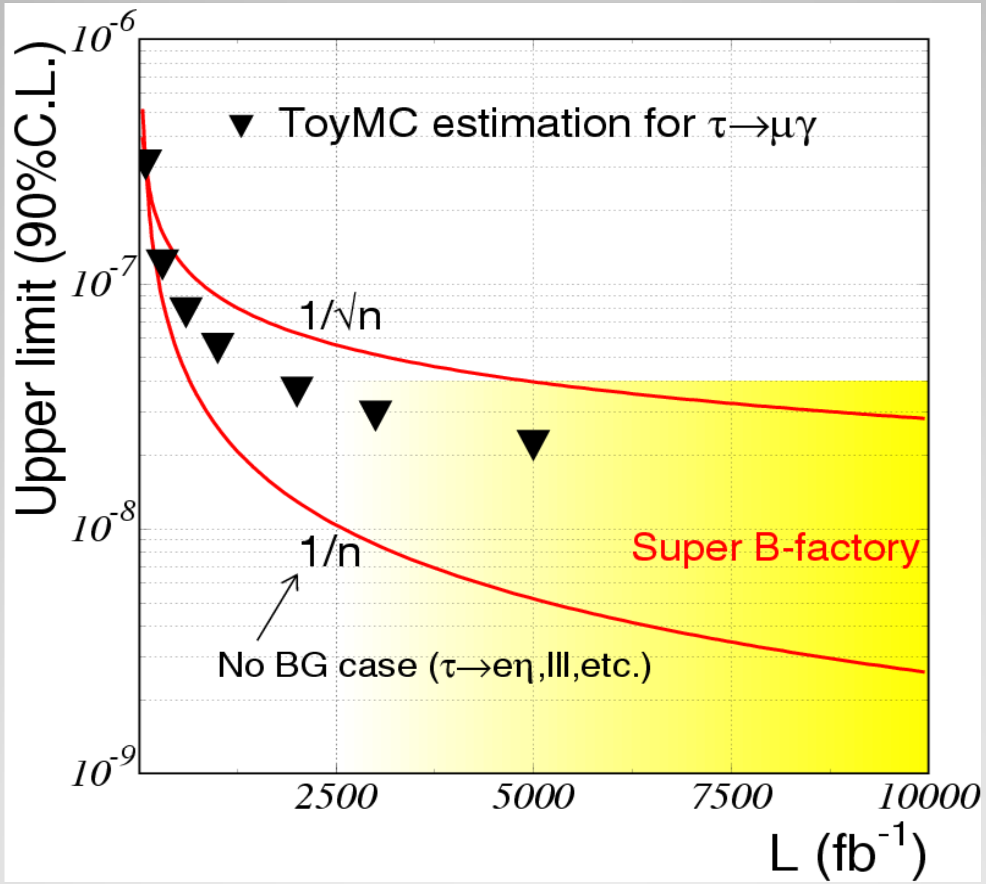


Beyond the SM: Lepton Flavour Violation

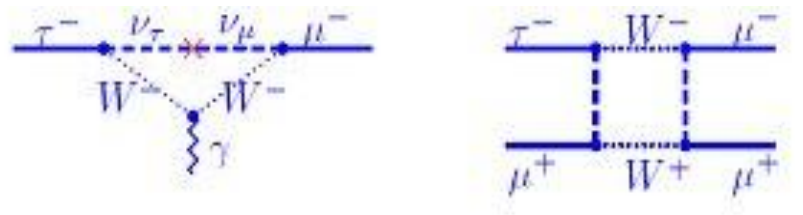
- No signs of any excess in any channels
  - Updates still to come from BaBar and Belle
  - Belle so far uses only ~50% of their dataset
- Prospects for BaBar and Belle to combine limits
  - But should avoid quasi-religious debates about statistics
  - HFAG now doing this
- But we will NOT see LFV at the B factories
- LHC has prospects for $\tau \rightarrow \mu\mu\mu$
  - Could be competitive with BaBar/Belle within a few years
  - Could be comtemporaneously competitive with a Super B Factory

BSM: Lepton Flavour Violation

- B.R. sensitivity: ~1/n for negligible background
  ~1/√n for background-dominated modes

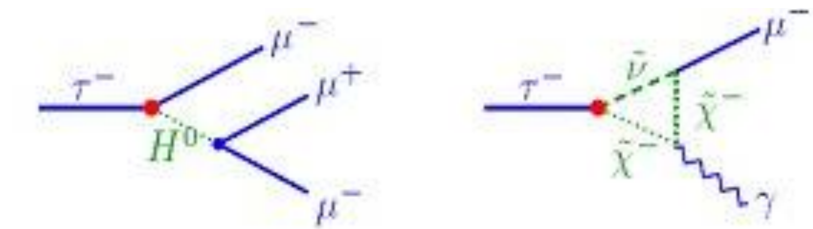


LFV at SuperB Factory

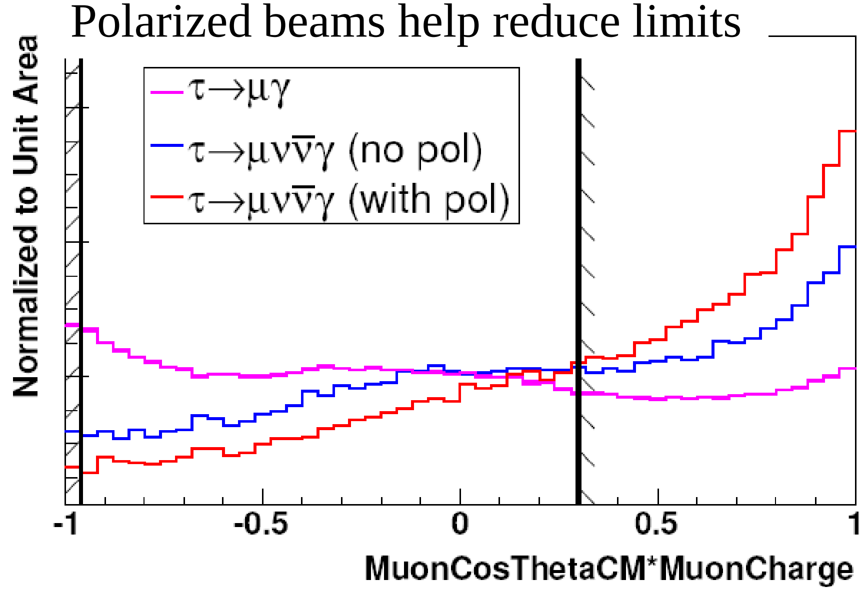


Sensitivity at SBF with 75 ab^{-1}

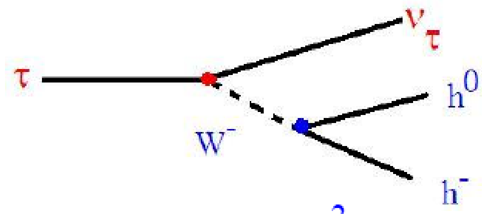
Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_s^0)$	2×10^{-10}

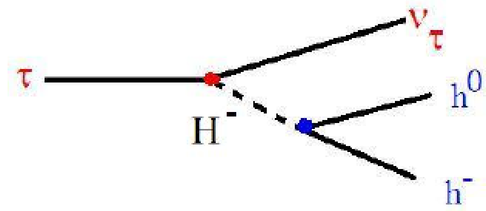


Polarized beams help reduce limits



BSM: CP violation in tau decays …





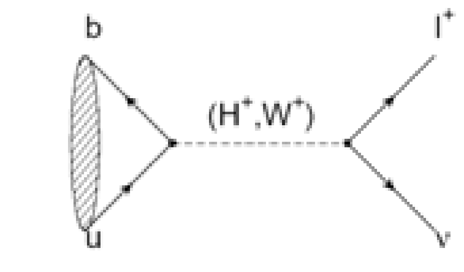
$$F_V = \frac{m_\rho^2}{m_\rho^2 - s - i m_\rho \Gamma_\rho(s)}$$

$$F_S = |\Lambda| e^{i\Theta_{CP}} |f_S| e^{i\delta_S},$$

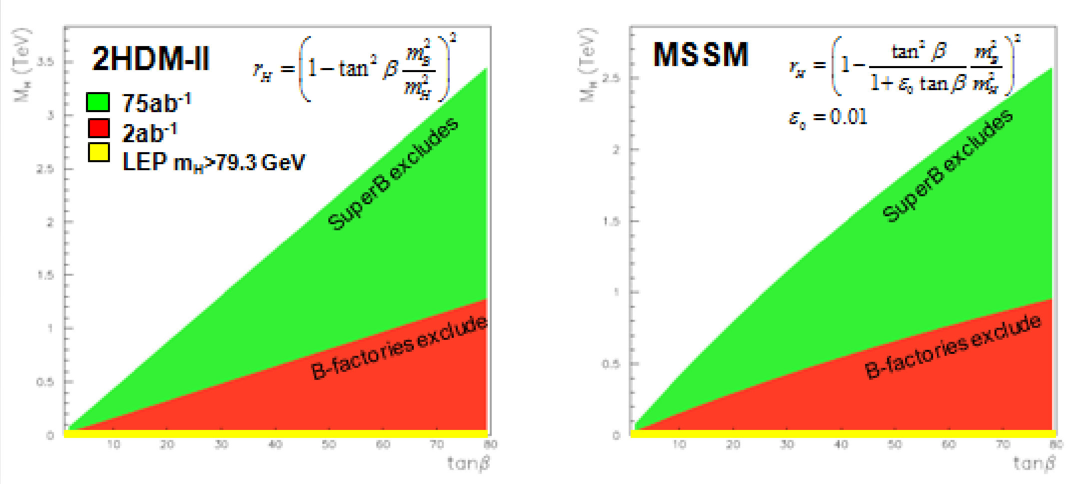
$$f_S = 1 \text{ or BW(scalar } h^0 h^-)$$

- Requires polarized beams, available at SBF
- Interference between F_V and F_S due to CPV produces difference in τ^+ and τ^- decay angle distributions
- Needs good control of detector systematics for any material, tracking, charge asymmetries etc.

SM: As a tool … B → τν



- Standard Model BF = 1×10^{-4}
- BSM searches at BaBar, Belle, LHC, SBF



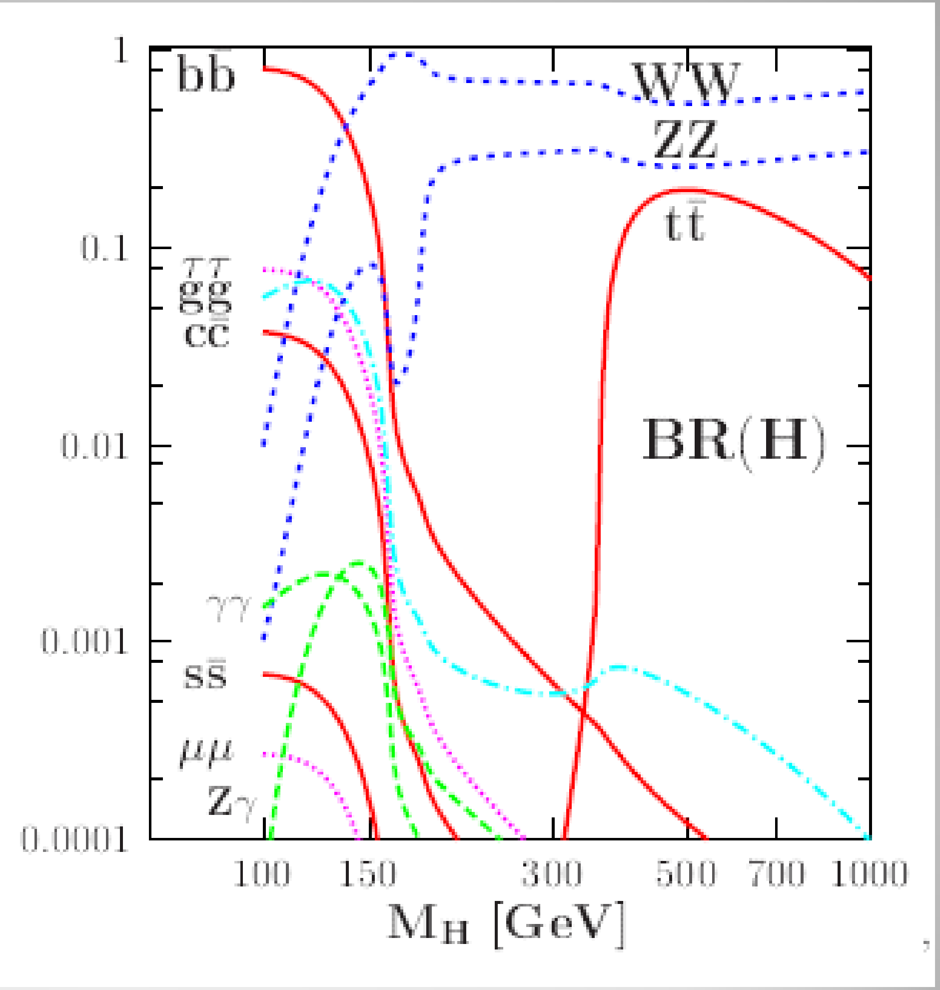
- BUT …
  - B → τν becomes systematics limited at ~$10fb^{-1}$, and B → μν (BF=4×10^{-7}) takes over as golden channel
  - Potential large LFV at one loop level from SUSY affects (B→μν)/(B→τν) ratio

SM: As a tool to study Higgs at ILC

- CP-nature of Higgs at ILC can be deduced from couplings to τ for $m_H<140$ GeV
- Example:
  - Measuring polarization of τ allows to probe CP-contributions
  - Where each tau decays via $\rho\nu$, acoplanarity between the two ρ decay planes discriminates powerfully between CP-even and CP-odd Higgs (ILC Reference Design Report)

SM: As a tool to study Higgs at ILC

- $H \to \tau^+\tau^-$ is an important decay mode up to mass of ~140 GeV, before WW and ZZ channels open up



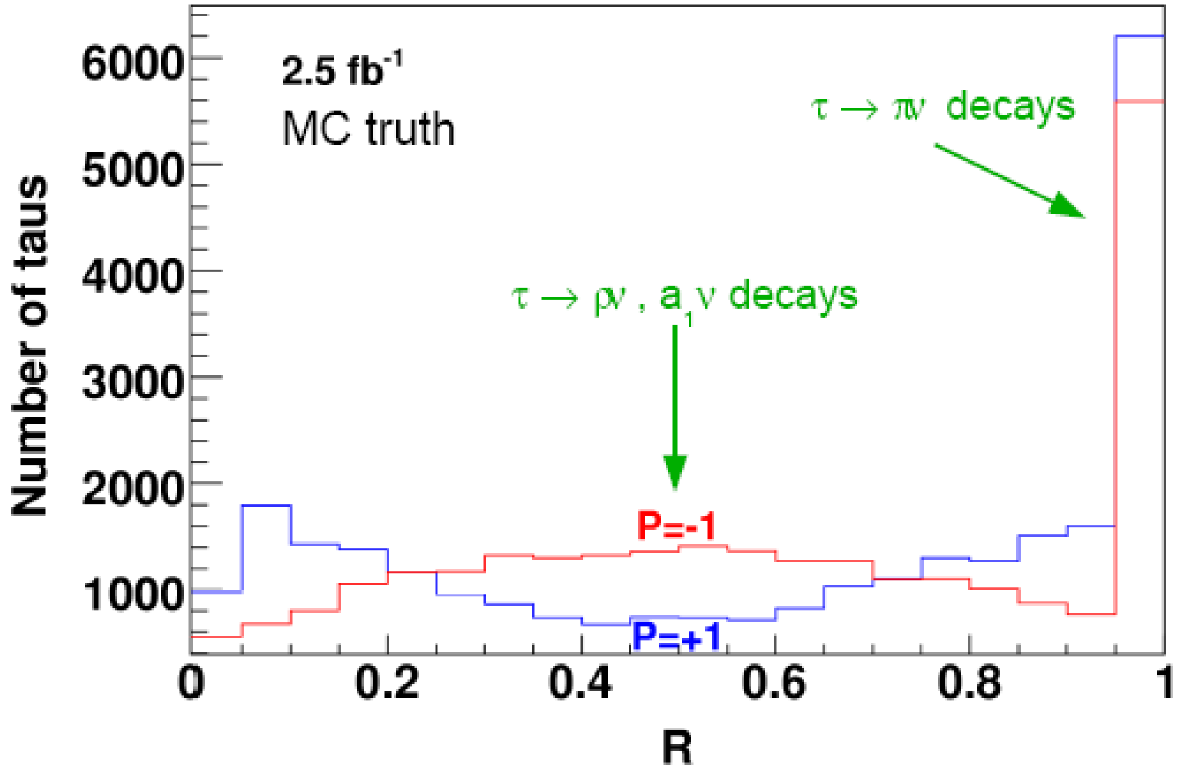
BSM: The tau as a tool … example

- ILC can discriminate SUSY models and determine parameters
- Over a large range ($\tan\beta>5$) of SUSY parameters in MSSM, the lightest sfermion and NLSP is expected to be
  - $\tilde{\tau}_1 = \tilde{\tau}_R \sin\theta + \tilde{\tau}_L \cos\theta$
- SUSY signature $e^+e^- \rightarrow \tilde{\tau}_1^+ \tilde{\tau}_1^-$ followed by $\tilde{\tau}_1^\pm \rightarrow \tau^\pm \tilde{Z}_1$
- With P=+1 polarized electron beam, the mixing angle θ can be determined from production cross section
- Tau polarization measured on statistical basis using classic method of track momentum in one-prong decays
  - $P\tau \approx +1$ for universal SUGRA
  - $P\tau \approx -1$ for anomaly-mediated SB
  - $P\tau \approx \cos^2\theta - \sin^2\theta$ for nonuniversal SUGRA
  - $P\tau \approx \sin^2\theta - \cos^2\theta$ for gauge-mediated SB
  - See Godbole et al., Phys. Lett. B618(2005)193-200

BSM: The tau as a tool … polarisation

$$R = p_{\pi^\pm}/p_{\tau-\text{jet}}$$

~ boost invariant



Some other topics ...

- LFV in B decays such as $B^0 \to \tau\mu$
  - Reach $\sim 10^{-7}$ at Super B Factory
- Standard Model CP-violation in $\tau^- \to K^0\pi^-\nu$ should be accessible at Super B Factory but perhaps better at tauCharm Factory
- g_τ-2
  - With polarized beam at Super B Factory
- BSM CP-violation in $\tau \to K^0\pi^-\nu$
  - Very small effect, needs feasibility study
- τ electric dipole moment
  - Some prospect at Super B Factory to 10^{-20} e cm

The University of Manchester

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Caveat …

G.D. Lafferty / Nuclear Physics B (Proc. Suppl.) 189 (2009) 358–365

the B factories has taught us that the eventual physics output often greatly exceeds our original expectations, so we may look forward to even more that we currently expect. At the same time, in any forward look such as this, one must also stress the important caveat [36]:

The best laid schemes o' mice an' men
Gang aft agley

and J. H. Kühn, I
(2008) 012002; K. M
arXiv:0807.0650v1.
16. G. W. Bennett et al.
(2004) 1618102.
17. M. Davier, "Measure
tion $e^+e^- \to \pi^+\pi^-\gamma$(I
4 GeV using radiativ
presented at the Tau0
18. M. Fujikawa et al., I

36. R. Burns, *To a mouse, on turning up her nest with the plough*, in *Poems, Chiefly in the Scottish Dialect*, John Wilson, Kilmarnock, 1786.

Further information will be available at

Tau 2010

The 11th International Workshop on Tau Lepton Physics

Manchester, 13th-17th September 2010