Tests of lepton universality with τ decays

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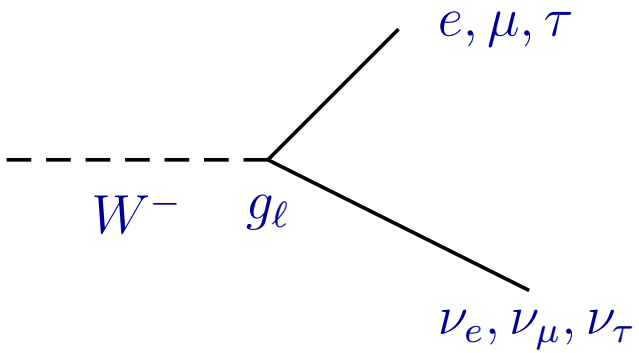
- Motivation
- Measurement of τ mass by Belle
- Measurement of τ lifetime by *BABAR*
- Search for CPT violation
- Test of lepton universality

Lepton universality $g_e = g_\mu = g_\tau$



$$\Gamma(\ell_i \to \ell_f \nu\nu) = \frac{g_i^2 g_f^2}{192\pi^3} \frac{m_i^5}{32 M_W^4} C_{if}^{rad}$$

$$C_{if}^{rad} = F(\tfrac{m_f^2}{m_i^2}) r_{EW} r_\gamma,$$

$$C_{\mu e}^{rad} = 0.9956,\ C_{\tau e}^{rad} = 0.9960 \text{ and } C_{\tau\mu}^{rad} = 0.9687.$$

Lepton universality from τ decays

Leptonic decays $\tau \to \ell\nu\nu$

$$(\frac{g_e}{g_\mu})^2 = \frac{\mathcal{B}(\tau \to e\nu\nu)}{\mathcal{B}(\tau \to \mu\nu\nu)} \frac{C^{rad}_{\tau\mu}}{C^{rad}_{\tau e}}$$

$$(\frac{g_\mu}{g_\tau})^2 = \frac{C^{rad}_{\tau e}}{C^{rad}_{\mu e}} \frac{\tau_\tau}{\tau_\mu} (\frac{m_\tau}{m_\mu})^5 \frac{1}{\mathcal{B}(\tau \to e\nu\nu)}$$

Semileptonic decays $\tau \to h\nu$

$$(\frac{g_\mu}{g_\tau})^2 = \frac{1}{2}(\frac{m_\tau}{m_\mu})^2 \frac{H_\pi + H_K}{\mathcal{B}(\tau \to \pi\nu) + \mathcal{B}(\tau \to K\nu)},$$

$$H_h = (\frac{\tau_\tau}{\tau_h})(\frac{m_\tau^2 - m_h^2}{m_h^2 - m_\mu^2})^2 \mathcal{B}(h \to \mu\nu)(1 + \mathcal{O}_h^{rad})$$

Experimental ingredients in the calculations

- $m_\tau^{Belle} = (1776.71 \pm 0.25_{stat} \pm 0.62_{sys})$ MeV - preliminary measurement by Belle (hep-ex/0511038)
  Averaged with PDG is $m_\tau = (1776.95 \pm 0.26)$ MeV

- $\tau_\tau^{Babar} = (289.40 \pm 0.91_{stat} \pm 0.90_{sys})$ fs - preliminary measurement by *BABAR* (NPPS144(2005)105);
  Averaged with PDG is $\tau_\tau = (290.1 \pm 0.83)$ fs.

- leptonic and semileptonic τ decays - PDG-2002 values (LEP and CLEO measurements) - no updates from B-factories and none is expected soon (may be except $\tau \to K\nu$).

  $\mathcal{B}(\tau \to e\nu\nu)$ $(17.84 \pm 0.06)\%$
  $\mathcal{B}(\tau \to \mu\nu\nu)$ $(17.36 \pm 0.06)\%$
  $\mathcal{B}(\tau \to h\nu)$ $(11.75 \pm 0.11)\%$

τ Mass Measurement

hep-ex/0511038, Belle Preliminary, $\mathcal{L} = 253$ fb^{-1}

Pseudomass technique :

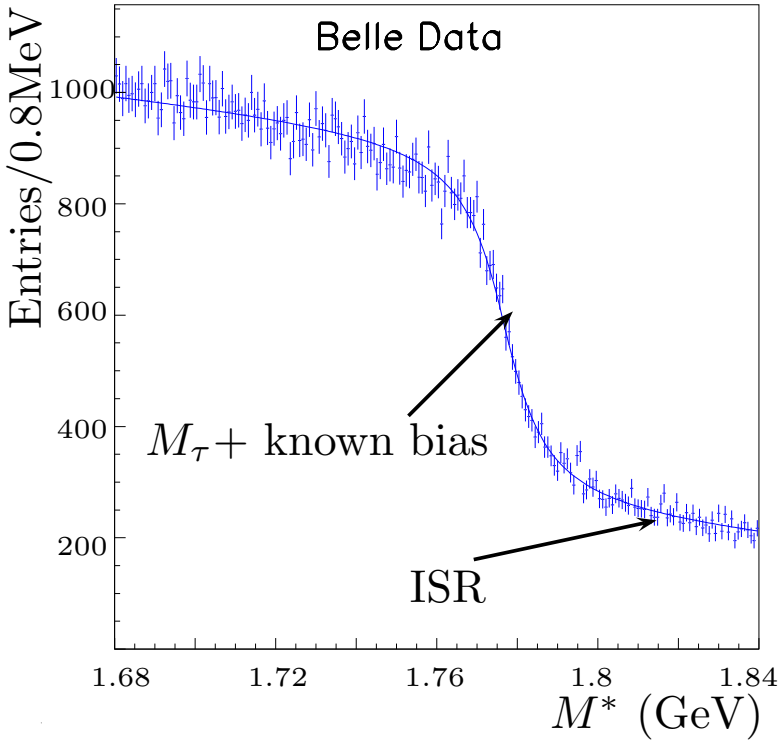
$M^* = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - p_{3\pi})}$

$M_\nu = 0$, $M^* < M_\tau$,

applied to $\tau \to 3\pi\nu$,

check with $\tau \to 3\pi\pi^0\nu$

Systematics	uncertainty(MeV)
Track momenta	0.39
Fit, MC stat	0.41
E_{beam}	0.25
PID, backgrounds	negligible
Total	0.62

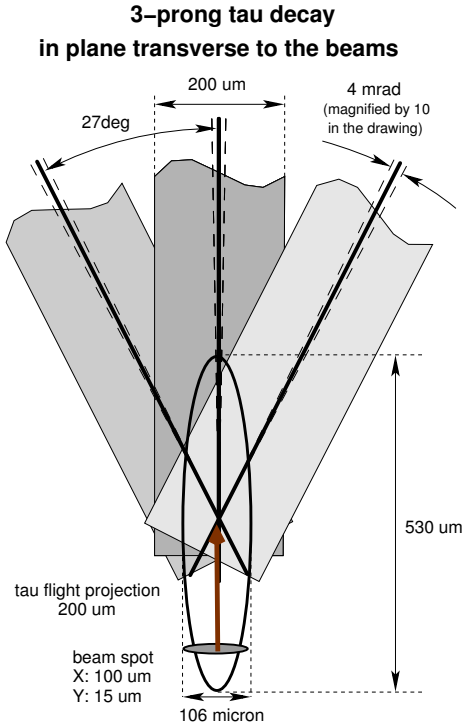


$M_\tau = (1776.71 \pm 0.25_{stat} \pm 0.62_{sys})$MeV

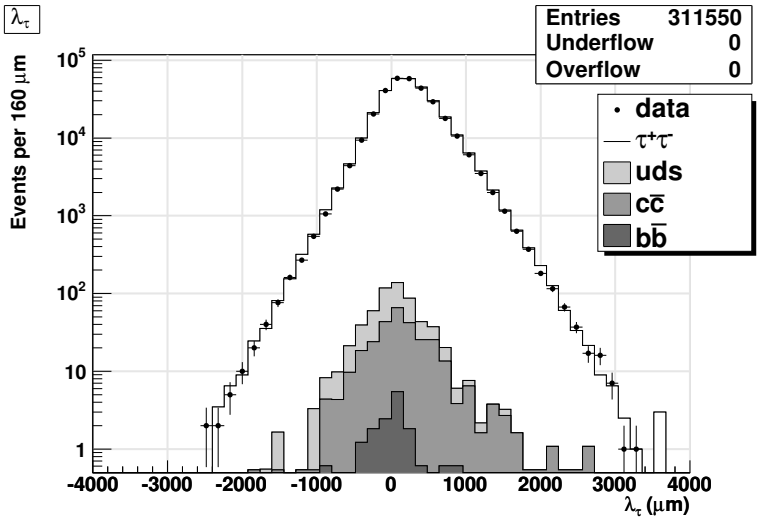
PDG: $M_\tau = 1776.99^{+0.29}_{-0.26}$MeV

can be improved with $\mathcal{L}$

τ Lifetime Measurement



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



calculate $\lambda_\tau = \frac{\lambda_T}{\sin\Theta_{3pr}}$ and then fit $\lambda_\tau(\phi)$ to minimize systematics

$\tau_\tau = (289.40 \pm 0.91_{stat} \pm 0.90_{sys})$fs

PDG: $\tau_\tau = (290.6 \pm 1.1)$fs

Can be improved with $\mathcal{L}$

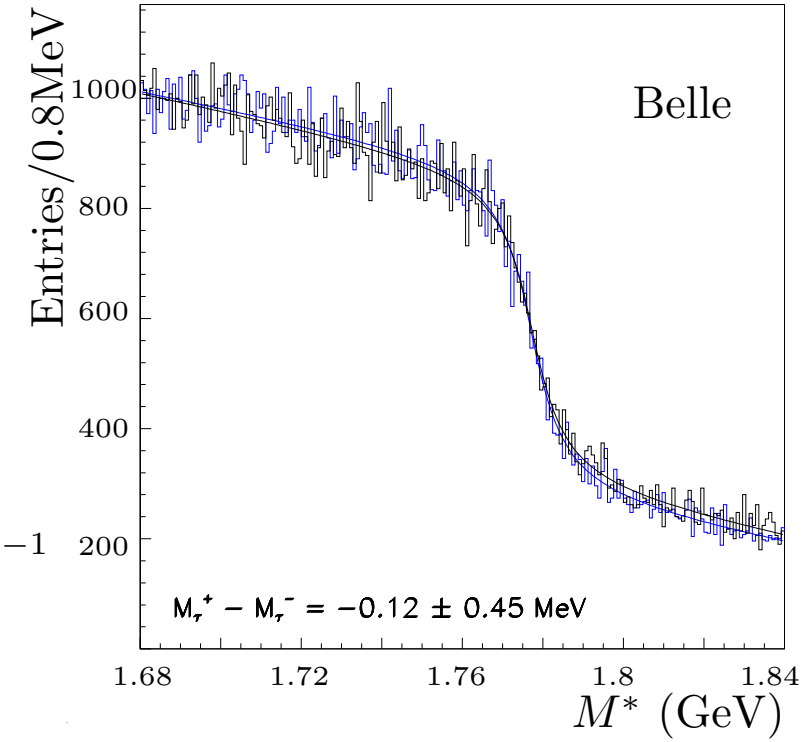
Systematics			$\Delta\tau_\tau$(%)
Measurement bias	0.336	±	0.220
Background	-0.428	±	0.142
Alignment		±	0.111
Beam spot position		±	0.043
Beam spot size		±	0.044
Beam momenta		±	0.043
τ mass		±	0.006
τ momentum		±	0.100
Total	-0.092	±	0.310

Tests of CPT violation

- $M_{\tau^+} - M_{\tau^-} = -0.12 \pm 0.45_{stat} \pm 0.15_{sys}$

  $\frac{|M_{\tau^+} - M_{\tau^-}|}{M_\tau} < 5.0 \cdot 10^{-4}$ at 90% CL

  hep-ex/0511038, Belle Preliminary, $\mathcal{L} = 253$ fb^{-1}



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

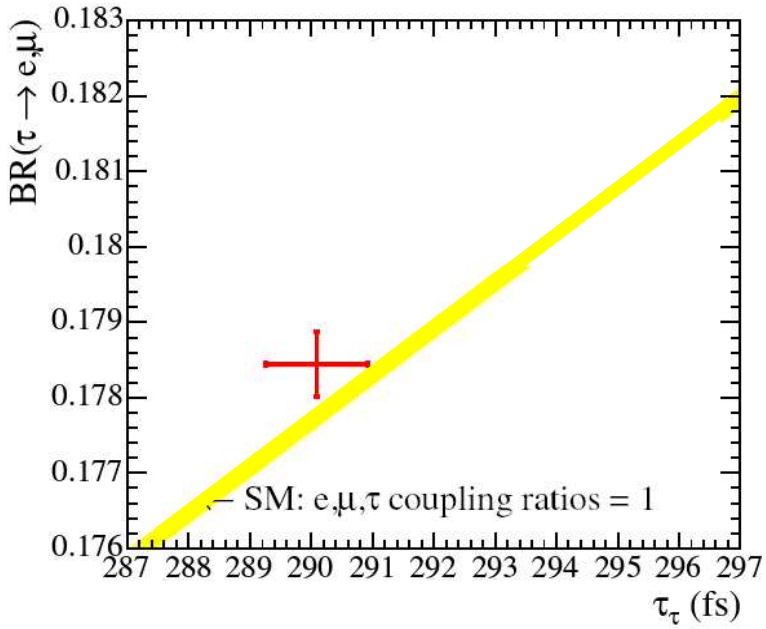
  NPPS144(2005)105, *BABAR* Preliminary, $\mathcal{L} = 80$ fb^{-1}

the measurements are statistically limited,
as many systematic uncertainties are canceled

Results from leptonic τ decays

Extract lepton charged current coupling constants from τ leptonic decays.

Combing old τ leptonic decays and new τ_τ, m_τ averaged with PDG04:



courtesy of A.Lusiani

$$\frac{g_e}{g_\mu} = 0.9997 \pm 0.0024 \qquad \frac{g_\mu}{g_\tau} = 0.9981 \pm 0.0022$$

Perfect agreement with SM

Main systematics for g_e/g_μ is $\delta\mathcal{B}(\tau \to \ell\nu\nu)$.
For g_μ/g_τ the main uncertainties are :
$Br(\tau \to e\nu\nu)$ $(1.7 \cdot 10^{-3})$, τ_τ $(1.4 \cdot 10^{-3})$

Results from semileptonic τ decays

Combining old τ semileptonic decays and new τ_τ, m_τ averaged with PDG04:

$$\frac{g_\mu}{g_\tau} = 0.9937 \pm 0.0049$$

Good agreement with SM

Main systematics are from:

$Br(\tau \to h\nu)$	:	$4.5 \cdot 10^{-3}$
τ_τ	:	$1.4 \cdot 10^{-3}$
$\mathcal{O}_\pi$	:	$0.7 \cdot 10^{-3}$

Average value from $\tau \to \ell\nu\nu$ and $\tau \to h\nu$:

$$\frac{g_\mu}{g_\tau} = 0.9976 \pm 0.0021$$

Summary and outlook

- No deviation from lepton universality is found in τ decays.
  $g_e/g_\mu = 0.9997 \pm 0.0024$, $g_\mu/g_\tau = 0.9976 \pm 0.0021$

- While quite precise, the numbers did not improve significantly for a long time, main uncertainties are on 1-prong τ decays branching fractions . Hard to expect B-factories to improve these tests significantly.

- In future (new experiments?), g_e/g_μ could become better, however, systematics in muon identification are not easy to avoid. For g_μ/g_τ, τ_τ needs to be improved (not mentioning 1-prong branching fractions).