Measurement of τ Lifetime at Belle

Simon Eidelman
(for the Belle Collaboration)

Budker Institute of Nuclear Physics,
Novosibirsk, Russia

Outline

1. Motivation
2. Belle analysis
3. Lifetime difference
4. Conclusions

Why Is τ Lifetime Important?

- Lifetime is a basic property of any fundamental particle:

Particle	τ, s	$\Delta\tau/\tau$,
μ	$(2.197034 \pm 0.000021) \cdot 10^{-6}$	$9.6 \cdot 10^{-6}$
τ	$(290.6 \pm 1.0) \cdot 10^{-15}$	$3.4 \cdot 10^{-3}$

- In SM we can test lepton universality

$$\tau_\tau = \tau_\mu \Big(\frac{G_{\tau \to e\nu_\tau \bar{\nu}_e}}{G_{\mu \to e\nu_\mu \bar{\nu}_e}}\Big)^2 \Big(\frac{M_\mu}{M_\tau}\Big)^5 \frac{F_{\mathrm{cor}}(M_\mu, M_e)}{F_{\mathrm{cor}}(M_\tau, M_e)}$$

- The current world-average τ lifetime is dominated by LEP experiments

Test of Lepton Universality with G_τ/G_μ

$r = (\frac{G_{\tau\to e\nu_\tau\bar{\nu}_e}}{G_{\mu\to e\nu_\mu\bar{\nu}_e}})^2$ (Leptonic universality implies $r = 1$)

r	t_τ, fs	$\mathcal{B}(\tau \to e\nu_\tau\bar{\nu}_e)$, %	M_τ, MeV	Comments
0.9405	305.6 ± 6.0	17.93 ± 0.26	$1784.1^{+2.7}_{-3.6}$	PDG, 1992
± 0.0249	± 0.0185	± 0.0136	$^{+0.0071}_{-0.0095}$	-2.4σ
0.9999	291.0 ± 1.5	17.83 ± 0.08	$1777.0^{+0.30}_{-0.27}$	PDG, 1996
± 0.0069	± 0.0052	± 0.0045	± 0.0008	-0.01σ
1.0020	290.6 ± 1.1	17.84 ± 0.06	$1776.99^{+0.29}_{-0.26}$	PDG, 2004
± 0.0051	± 0.0038	± 0.0034	± 0.0008	$+0.4\sigma$
1.0034	290.6 ± 1.0	17.85 ± 0.05	1776.82 ± 0.16	PDG, 2010
± 0.0045	± 0.0034	± 0.0028	± 0.0004	$+0.76\sigma$

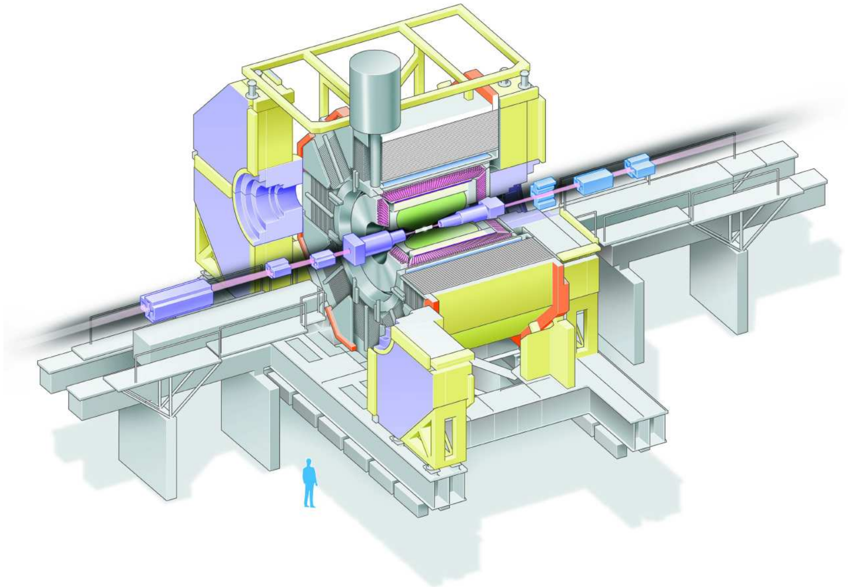
Measurements of τ Lifetime

Group	$N_{\tau\tau}, 10^6$	τ, fs
CLEO, 1996	3.4	$289.0 \pm 2.8 \pm 4.0$
OPAL, 1996	0.070	$289.2 \pm 1.7 \pm 1.2$
ALEPH, 1997	0.115	$290.1 \pm 1.5 \pm 1.1$
L3, 2000	0.060	$293.2 \pm 2.0 \pm 1.5$
DELPHI, 2004	0.150	$290.9 \pm 1.4 \pm 1.0$
PDG-10	–	290.6 ± 1.0
BaBaR, 2004	71.2	$289.40 \pm 0.91 \pm 0.90$
Belle, 2010	653.4	–

Results of BaBaR and Belle are preliminary

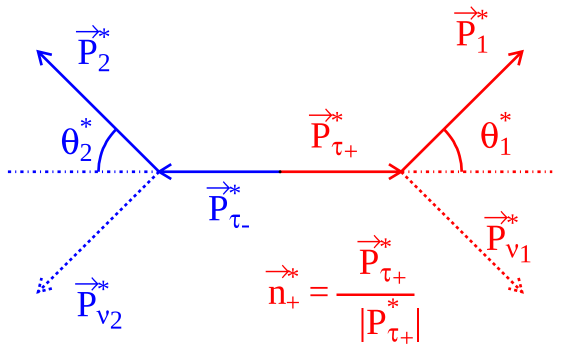
Belle Measurement

- KEKB: 3.5 GeV $e^+ \times$ 8.0 GeV e^-
- $\mathcal{L}_{\max} = 2.11 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
- Continuous injection $\to$ 1.52 fb^{-1}/day
- $\int \mathcal{L}dt \approx 1014\,\text{fb}^{-1}$ Operation stopped in June 2010
- Belle – 370 physicists from 60 Institutes in 15 countries
- 711 fb^{-1} at $\Upsilon(4S)$ and 60 MeV below



- 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

Analysis Method – I



In the center-of-mass (CM) frame:
$\vec{P}^*_1,\ \vec{P}^*_2,\ \vec{P}^*_{\nu_1},\ \vec{P}^*_{\nu_2}$ – 3-momenta of
the hadronic system and neutrino in τ decay

For the angle between the vectors of the τ and hadronic system

$$\cos\theta^* = \frac{2E^*_\tau E^*_h - m^2_\tau - m^2_h}{2P^*_\tau P^*_h} = \frac{2E^*_\tau E^*_h - m^2_\tau - m^2_h}{2\sqrt{E^{*2}_\tau - m^2_\tau}P^*_h}$$

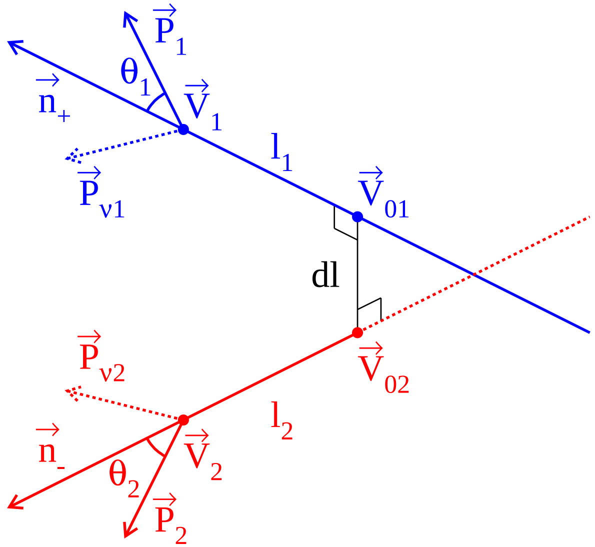
For the unit vector $\vec{n}^*_+ = \vec{P}^*_{\tau+}/|P^*_{\tau+}|$

$$(\vec{P}^*_1 \cdot \vec{n}^*_+) = x^* P^*_{x1} + y^* P^*_{y1} + z^* P^*_{z1} = |P^*_1| \cos\theta^*_1$$

$$(\vec{P}^*_2 \cdot \vec{n}^*_+) = x^* P^*_{x2} + y^* P^*_{y2} + z^* P^*_{z2} = -|P^*_2| \cos\theta^*_2$$

$$(\vec{n}^*_+)^2 = (x^*)^2 + (y^*)^2 + (z^*)^2 = 1$$

Analysis Method – II



We perform a Lorentz boost of τ momenta from the CM to laboratory frame

τ decay vertices are determined as the 3D-points of intersection of the two pion triplets.

For the production point of each τ we take the points (V_{01}, V_{02}) of closest approach of two lines defined by the τ decay vertices and flight directions

$c\tau_1 = l_1/\beta\gamma_1, \ c\tau_2 = l_2/\beta\gamma_2$

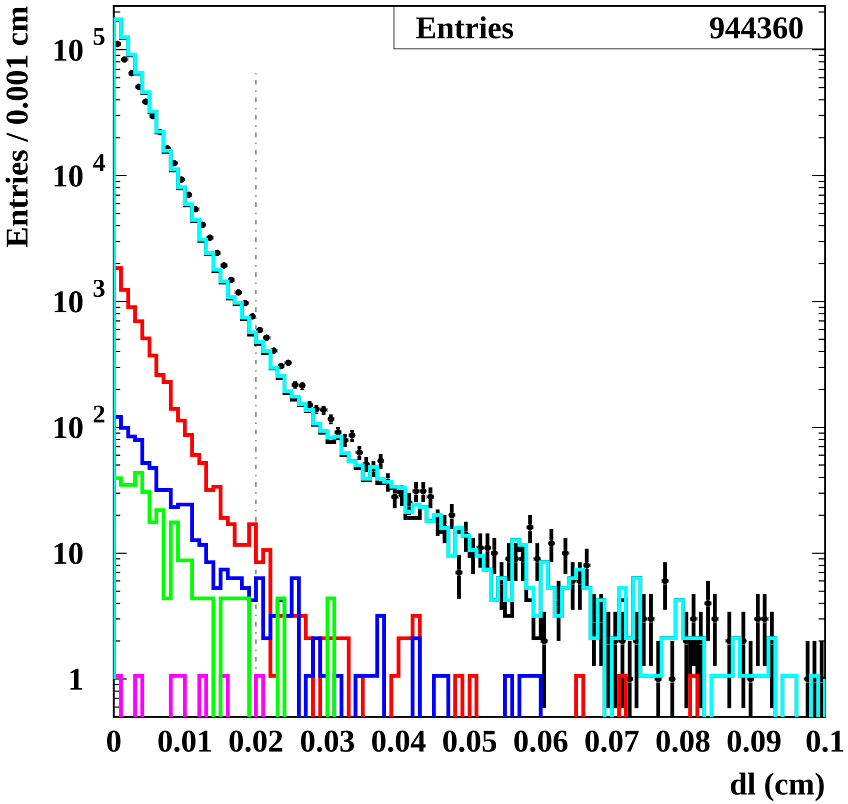
Two-fold ambiguity from the system of equations is resolved by requiring the minimal value of $\vec{dl}$

No information about the IP needed in this approach

Event Selection – I

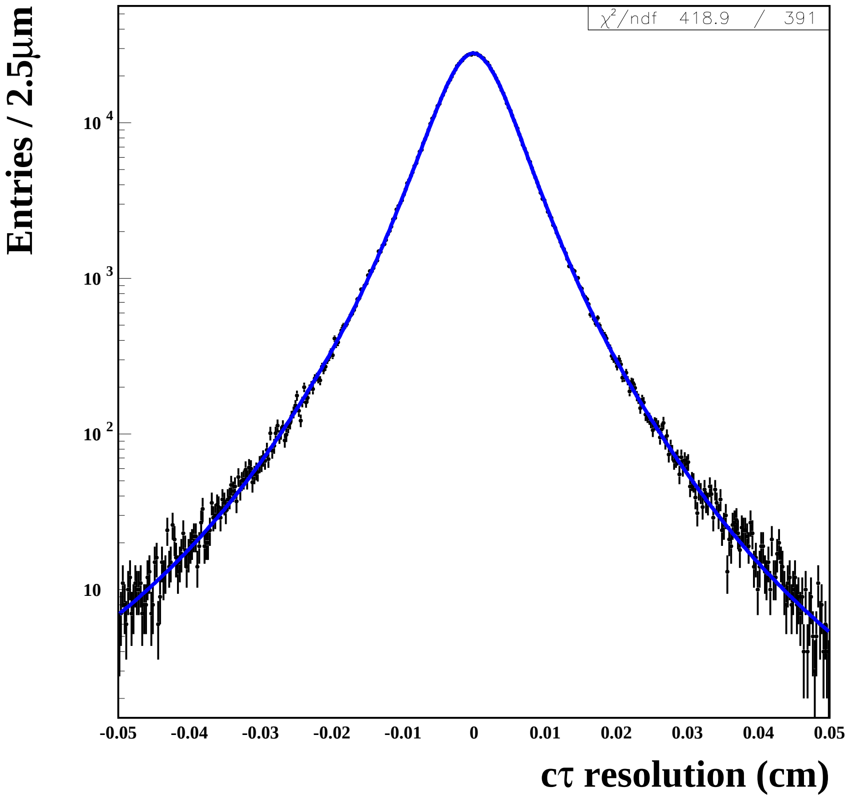
- Exactly 6 charged tracks with zero net charge compatible with pions
- No K_S^0, Λ and π^0
- CM thrust value > 0.9
- $P_T^2(6\pi) > 0.25$ GeV$/c^2$
- 4 GeV$/c^2 < M(6\pi) < 10.25$ GeV$/c^2$
- Each of the two hemispheres formed by the plane $\perp$ to the thrust axis has three pions with net charge ± 1
- Pseudomass of each pion triplet $M_{\rm min} < 1.8$ GeV$/c^2$,
  $M_{\rm min}^2 = M^2(3\pi) + 2(E_\tau^* - E_X^*)(E_X^* - P_X^*)$
- Each triplet fitted to a vertex with $\chi^2 < 20$

Event Selection – II



- Distance between two lines $dl < 0.02$ cm
- All the MC samples are normalized to the data luminosity
- Altogether 512K events selected

Lifetime Resolution

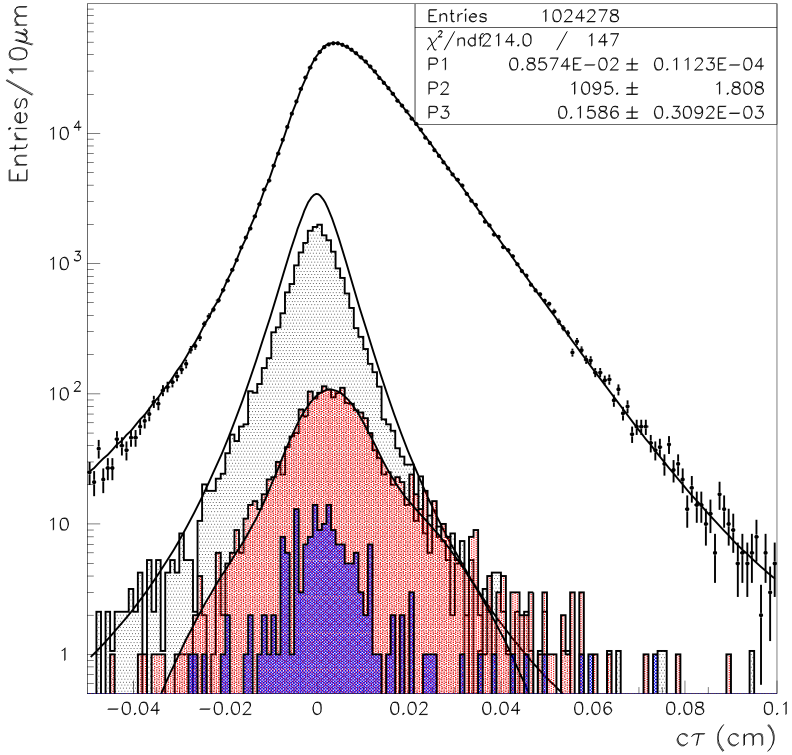


Difference between reconstructed and true values of $c\tau$ for MC events $e^+e^- \to \tau^+\tau^- \to 3\pi\nu_\tau 3\pi\nu_\tau$ is fitted with a function

$$A \cdot R(x) = A \cdot (1 + B \cdot x) e^{\frac{-(x-x_0)^2}{2\cdot(\sigma_0+\sigma_1\cdot|x-x_0|)^2}}$$

B, x_0, σ_0 and σ_1 later fixed to the values from this fit

Results



- Data
- $uds + \gamma\gamma$ contribution
- charm contribution
- beauty contribution

Data fitted with function

$$F(x) = A \int e^{-t/c\tau} R((t-x)(1+\delta))dt +$$
$$A_{uds} R(x(1+\delta)) + Bkg_{cb}(x)$$

From the fit $\Delta c\tau_{\rm stat} = 0.11\ \mu$m

or $\Delta\tau_{\rm stat} = 0.37$ fs

MC resolution underestimated, $R(x)$ 15% wider in data

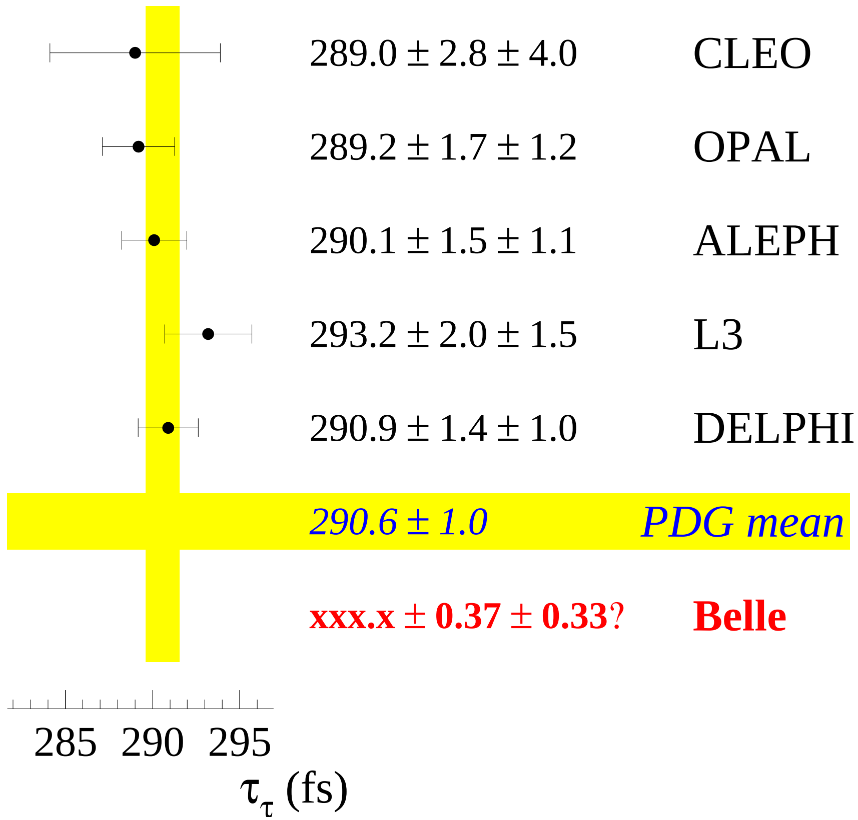
The *uds* contribution underestimated by 1.5

Systematic Uncertainties

Source	$\Delta c\tau$, nm
MC statistics	88
Fit range	20
ISR & FSR	18
Beam energy	16
SVD alignment	15
Background	10
Δm_τ	9
Current total	96

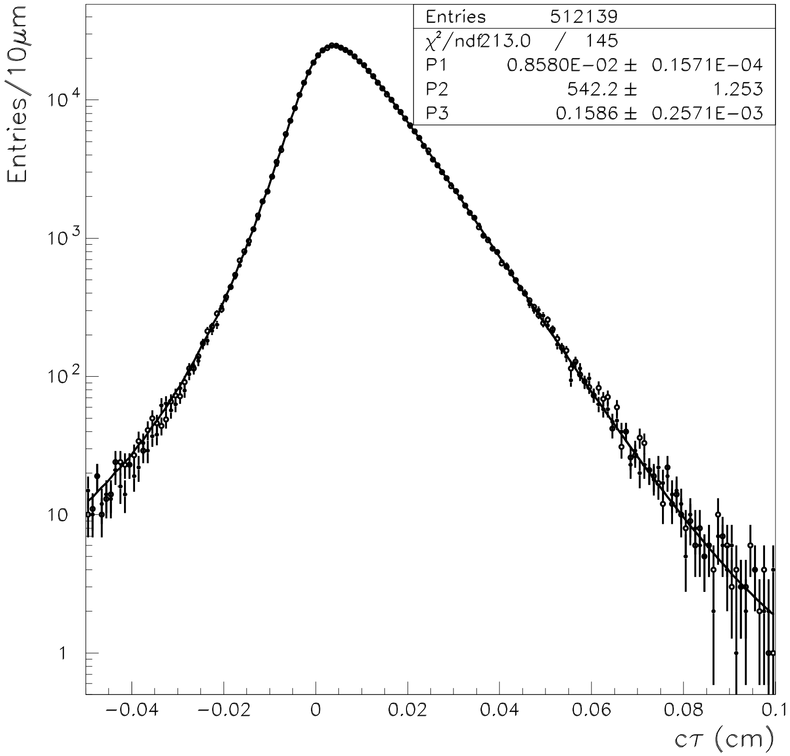
Analysis of systematics in progress

Summary of τ_τ Measurements



With $\Delta\tau_{\tau\,\mathrm{syst}} \sim \Delta\tau_{\tau\,\mathrm{stat}}$ the final result of Belle will be twice more precise than the current PDG mean.

Lifetime Difference for τ^+ and τ^-



- $D(c\tau) = c\tau_+ - c\tau_- = 0.16 \pm 0.22\mu\mathrm{m}$
- $\Delta D_{\mathrm{syst}} \ll \Delta D_{\mathrm{stat}}$
- $|\tau_+ - \tau_-|/\tau_{\mathrm{av}} < 6 \cdot 10^{-3}$ @ 90% CL
- $\tau_{\mu^+}/\tau_{\mu^-} = 1.00002 \pm 0.00008$

Conclusions

- A new high-statistics and high-precision measurement of the τ lifetime was performed at Belle with 711 fb^{-1} (653.4M $\tau^+\tau^-$ pairs)
- The achieved accuracy is $\pm 0.37(stat) \pm 0.33(syst)$ fs
  Analysis of systematics is in progress
- With $\Delta\tau_{\tau\,\mathrm{syst}} \sim \Delta\tau_{\tau\,\mathrm{stat}}$ the final result will be twice more precise than the current PDG mean
- The expected improvement of the world-average τ_τ will result in a factor of 1.5 more precise test of leptonic universality $\Delta(G_\tau/G_\mu)^2 = 0.0045 \to 0.0032$
- Comparison of the lifetime for τ^+ and τ^- allows a CPT test:
  $|\tau_+ - \tau_-|/\tau_{\mathrm{av}} \; < \; 6 \cdot 10^{-3}$ @ 90% CL

Back-up

Analysis of systematic effects

- Limited MC statistics (correction for $c\tau$)
- Fitting (variation of the fit range by $\pm 30\%$)
- ISR/FSR (from $e^+e^- \to \mu^+\mu^-$)
- Beam energy (accuracy about 1 MeV)
- SVD alignment (calibration by cosmic muons)
- Background estimation (variation of A_{uds} by $\pm 50\%$)
- Accuracy of m_τ ($\Delta m_\tau / m_\tau \sim 10^{-4}$)

Main Parameters – 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