Измерение времени жизни τ лептона в эксперименте Белль

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K. Belous, M. Shapkin, A. Sokolov et al (Belle collaboration)

Measurement of the τ-lepton lifetime at Belle,
arXiv:1310.8503v1 [hep-ex] 31 Oct 2013,
submitted to PRL

The lifetime of the τ-lepton is measured using the process $\boldsymbol{e^+e^- \to \tau^+\tau^-}$ where both τ-leptons decay to $\boldsymbol{3\pi\nu_\tau}$. The result for the mean lifetime, based on **711 fb^{-1}** of data collected with the Belle detector at the $\Upsilon(4S)$ resonance and 60 MeV below, is $c\tau = (290.17 \pm 0.53(\mathrm{stat.}) \pm 0.33(\mathrm{syst.})) \cdot 10^{-15}$ s. **The first measurement** of the **lifetime difference** between τ^+ and τ^- is performed. The upper limit on the relative lifetime difference between positive and negative τ-leptons is **$|\Delta\tau|/\tau < 7.0 \times 10^{-3}$ at 90% CL**.

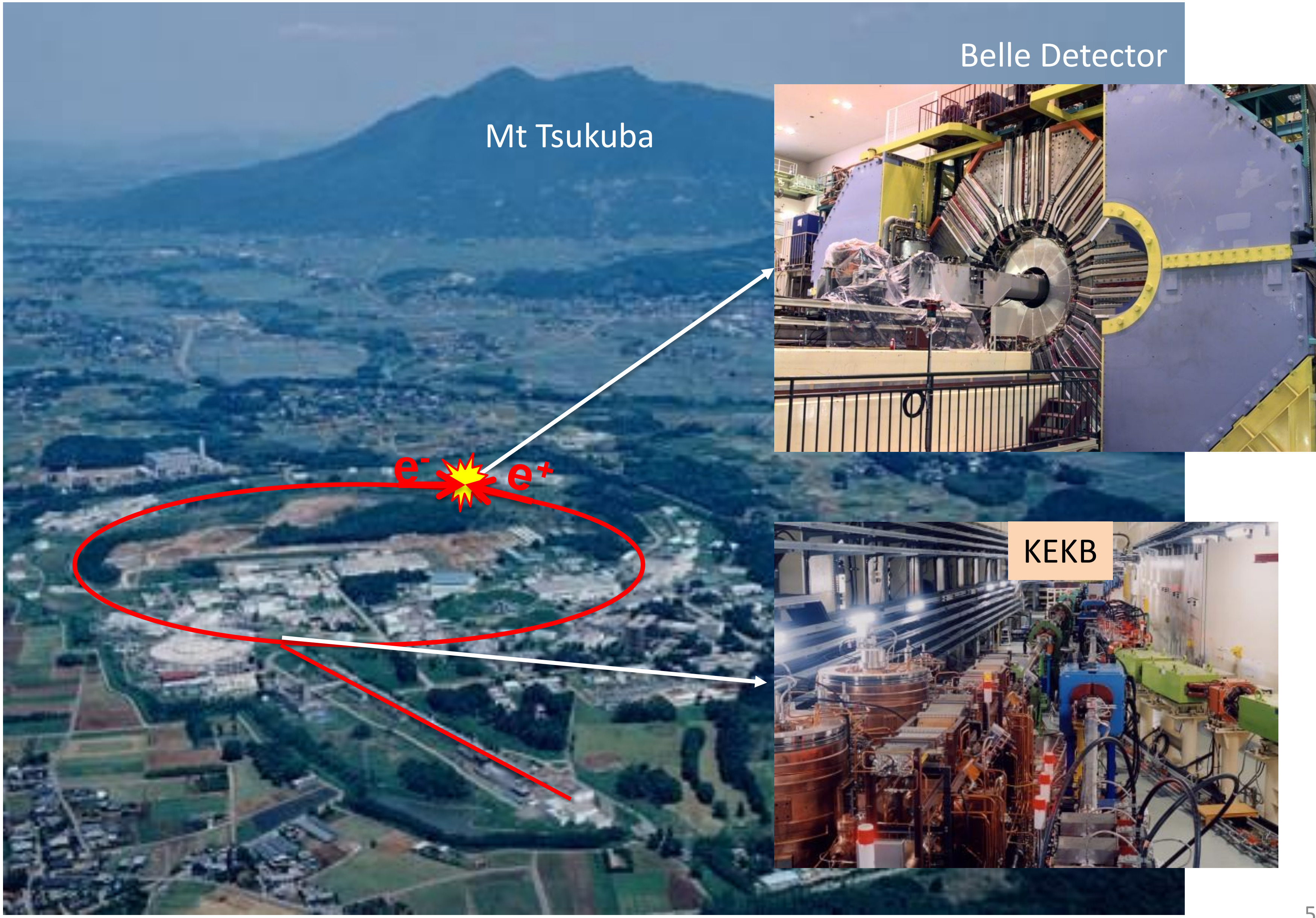
Outline

- Belle experiment
- Method of the measurement
- Data and event selection
- Experimental study
- Systematic uncertainty
- Summary

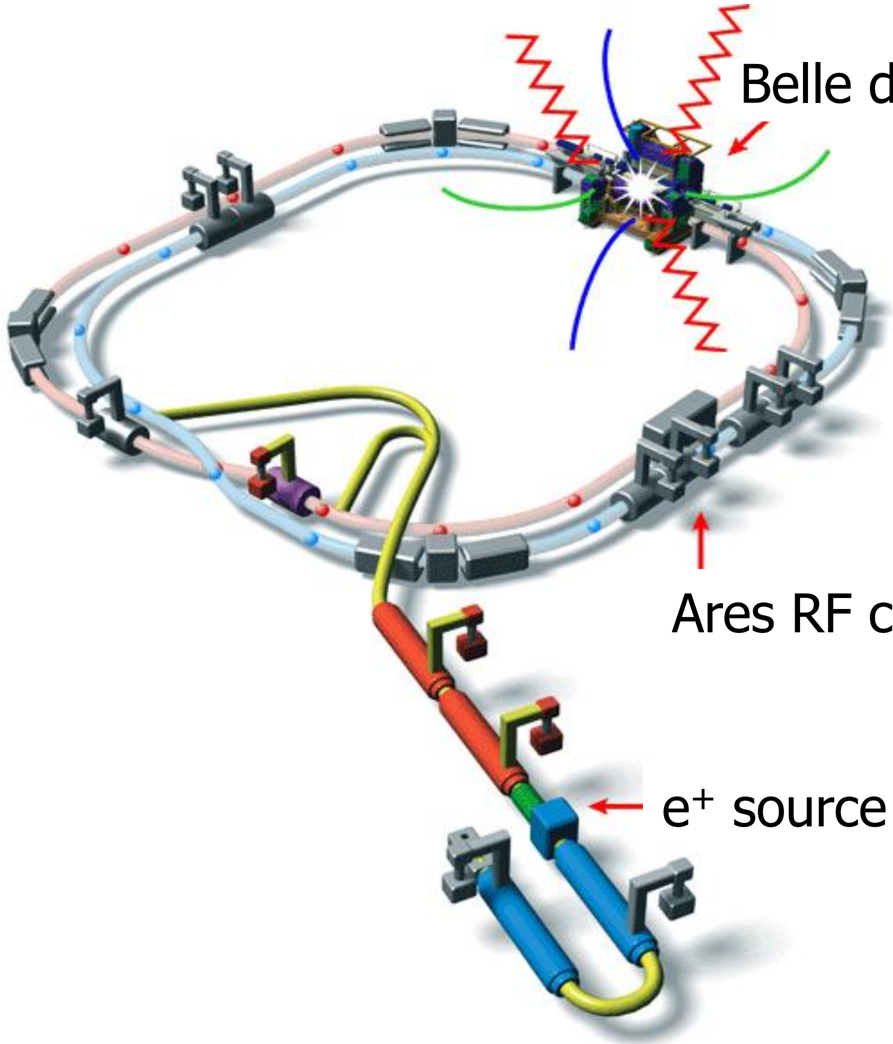
Tau-lepton lifetime

- The present PDG value of the τ-lepton lifetime is dominated by the results obtained by LEP experiments.
- Present Belle analysis uses technique different from those of LEP experiments and is based on much higher statistics.

KEK Laboratory, Tsukuba Japan



The KEKB Collider



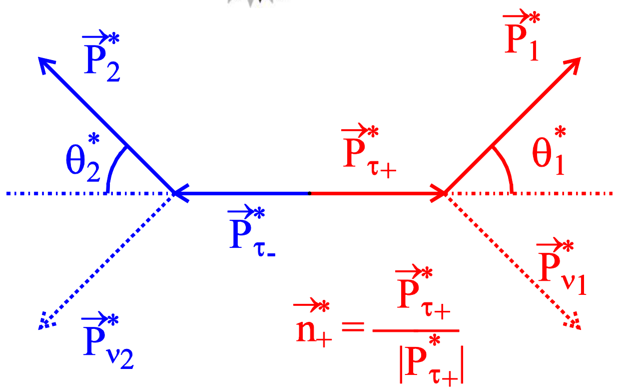
- Asymmetric energy collider
  (8 GeV e^- x 3.5 GeV e^+)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$ $(\Upsilon(nS), n=1,2,3,5)$
  - Lorentz boost: $\beta\gamma = 0.425$
- Finite angle beam crossing
  (22mrad)

Peak luminosity (WR!) :
2.1×10^{34} cm^{-2}s^{-1}
=2x design value

First physics run on June 2, **1999**
Last physics run on June 30, **2010**
$L_{peak} = 2.1\times10^{34}/cm^2/s$

$\int \mathcal{L}\, dt = 1.04\ ab^{-1}$

Analysis method



- We consider $e^+e^- \to \tau^+\tau^- \to 3\pi\nu\ 3\pi\nu$ events
- In **CM frame**:
  - Flight directions of τ^+ and τ^- are back-to-back;
  - Energy of each tau-lepton is $\sqrt{s}/2$;
  - Assuming neutrino mass to be zero, the angle between τ flight direction and momentum of the corresponding 3π-hadronic system (P_x) is determined as:

$$\cos\theta^* = \frac{2E_\tau^* E_x^* - m_\tau^2 - m_x^2}{2P_\tau^* P_x^*} = \frac{2E_\tau^* E_x^* - m_\tau^2 - m_x^2}{2\sqrt{\left(E_\tau^{*2} - m_\tau^2\right)}P_x^*}$$

  - **The unit vector in the direction of the** positive **tau-lepton can be obtained** as a solution of the following system of equations:

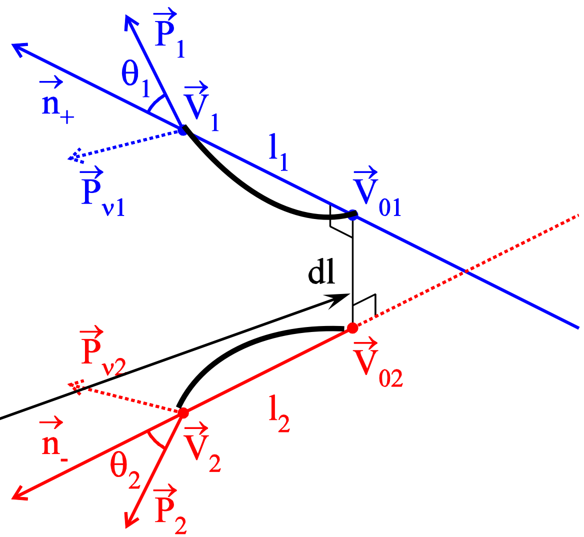
$$\begin{cases} \left(\vec{P}_1^* \cdot \vec{n}_+^*\right) = x^* P_{x1}^* + y^* P_{y1}^* + z^* P_{z1}^* = \left|P_1^*\right| \cos\theta_1^* \\ \left(\vec{P}_2^* \cdot \vec{n}_+^*\right) = x^* P_{x2}^* + y^* P_{y2}^* + z^* P_{z2}^* = -\left|P_2^*\right| \cos\theta_2^* \\ \left(\vec{n}_+^*\right)^2 = \left(x^*\right)^2 + \left(y^*\right)^2 + \left(z^*\right)^2 = 1 \end{cases}$$

Analysis method (cont.)

- We perform **Lorentz boost of τ-lepton 4-momenta from CM to Laboratory frame**.
- **τ decay vertices** (V_1 and V_2) are determined as the 3D-points of intersections of the pions triplets momenta.
- For **the τ production point** of each τ-lepton we take the points (V_{01} and V_{02}) which are the points of the closest approach of the two crossing lines defined by τ decay vertices and flight directions.

reconstructed $$ct_1 = \frac{l_1}{(\beta\gamma)_1}, ct_2 = \frac{l_2}{(\beta\gamma)_2}$$

dl = 0 for ideal case



No information about the beam spot position is needed in this approach

Event selection

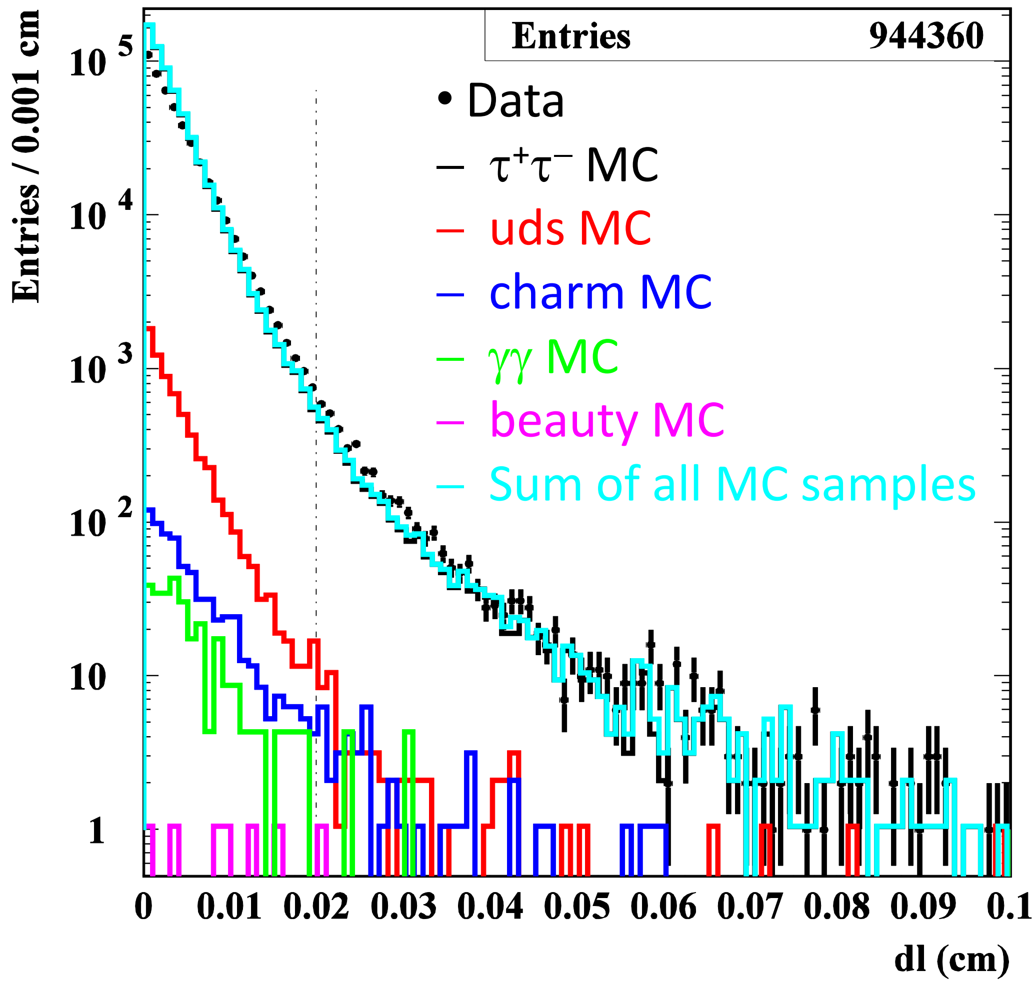
- **The analyzed topology is 3-3 without π^0's.**
- **In addition to τ pair selection the following cuts are applied:**
  1. There are exactly 6 charged tracks compatible with the π hypothesis with zero net charge;
  2. There are no K^0_s, Λ and π^0;
  3. Thrust value (in CM frame) is greater than 0.9;
  4. P_t^2 of the pion system is greater than 0.25 GeV^2;
  5. 4 GeV/c^2 < m(6π) < 10.25 GeV/c^2;
  6. Event is divided into two hemispheres by the plane perpendicular to the thrust axis. In each hemisphere there should be 3 π's with the net charge ±1;
  7. Pseudomass of each triplets of pions : $M_{min}(3\pi) < 1.8$ GeV/c^2
     $M_{min}^2 = M_x^2 + 2(E_\tau^* - E_x^*)(E_x^* - P_x^*)$;
  8. Each triplet should be fitted to the vertex with $\chi^2 < 20$;
  9. System of equations for τ-lepton flight direction can be solved and discriminant D > -0.05;

Event selection (cont.)

10. Distance between two crossing lines
dl < ***dl***$_{cut}$ = 0.03 cm.

- Integrated luminosity of the data is 711 fb^{-1};
  Nev = $1.1 \cdot 10^6$

- All the MC samples are normalized to the luminosity of the data.



Lifetime resolution

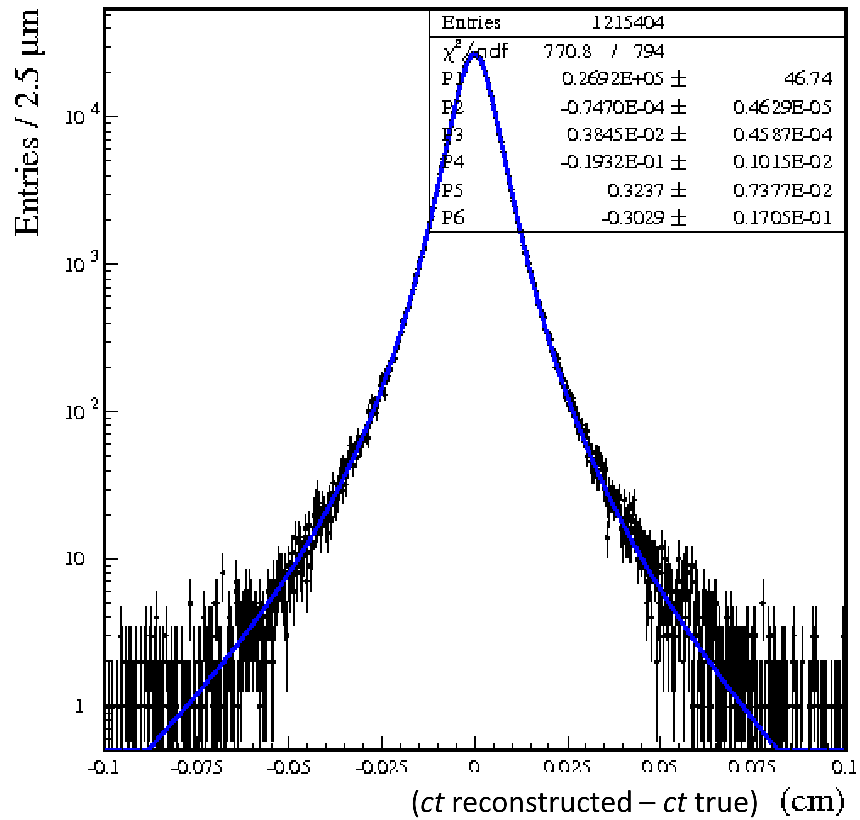
Resolution function

is obtained by the fit

of the **$(ct_{rec} - ct_{true})$**

MC distribution

standard MC (SVD1+SVD2) with cτ=87.11 μm



$\chi^2/NDF = 0.971$

Fitting function ***res(x)*** = $p_1 \cdot R(x, p_2, ..., p_6) = p_1 \cdot (1 - 2.5 \cdot x) \cdot \exp\left(-\frac{(x - p_2)^2}{2 \cdot \sigma^2}\right)$

$\sigma = p_3 + p_4 \cdot |x - p_2|^{1/2} + p_5 \cdot |x - p_2| + p_6 \cdot |x - p_2|^{3/2},$ p_i are free parameters.

Life time fitting function

- To describe the data $\tau\tau$-contribution as well as $\tau\tau$- Monte Carlo events we use convolution of exponent function with life time resolution function:

$$\mathrm{ctau}(P_1, P_2, \ldots, P_7, x) = P_1 \cdot \int \mathrm{e}^{-t/P_2} \cdot \mathrm{R}\left(\left(t - x\right), P_3, \ldots, P_7\right) dt$$

- ***P_2*** (free) – **τ-lepton lifetime;**
  P_1, P_3,…, P_7 (free) – parameters of the resolution function.
- Real Data is fitted with the following function:

$$\mathrm{ctau}\left(P_1, P_2, \ldots, P_7, x\right) + A_{q\bar{q}} \cdot R\left(x, P_3, \ldots, P_7\right) + Bkg_{c\bar{c}+b\bar{b}}(x)$$

P_i – free parameters; $A_{q\bar{q}}$, $Bkg_{c\bar{c}+b\bar{b}}(x)$ = *Two_Gaussian* – fixed from MC.

Experimental *ct* distribution

- It was fitted by:

$$F(x) = P_1 \int e^{-t/P_2} R((x-t), P_3, \ldots, P_7)\, dt +$$

$$+ A_{q\bar{q}} R(x, P_3, \ldots, P_7) + Bkg_{c\bar{c}+b\bar{b}}(x)$$

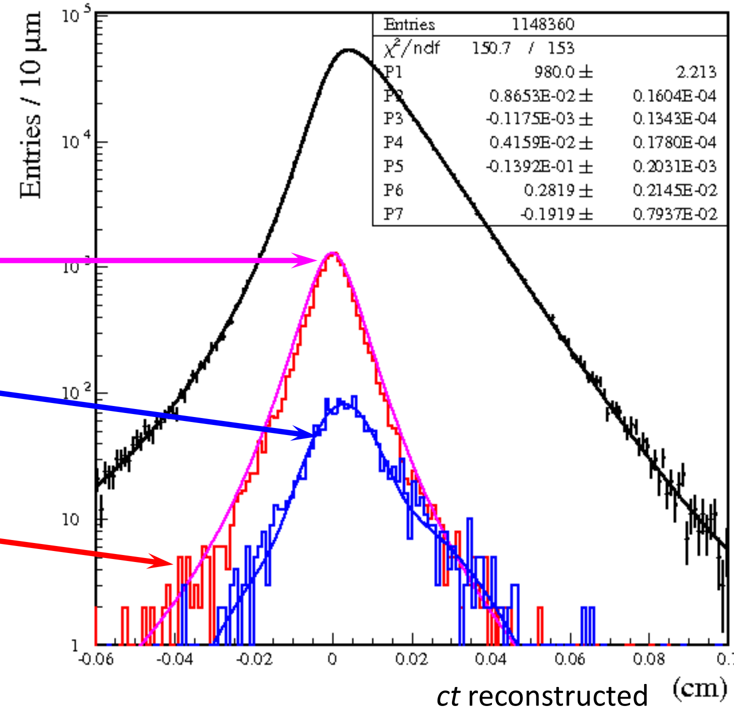
$P_1, \ldots, P_7$ – are free parameters,

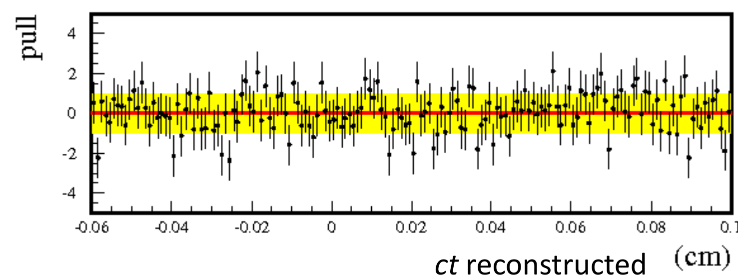
- $A_{q\bar{q}}$ is fixed at MC prediction, $Bkg_{c\bar{c}+b\bar{b}}(x)$ is fixed from MC.

χ^2/Ndf = 143 / 153

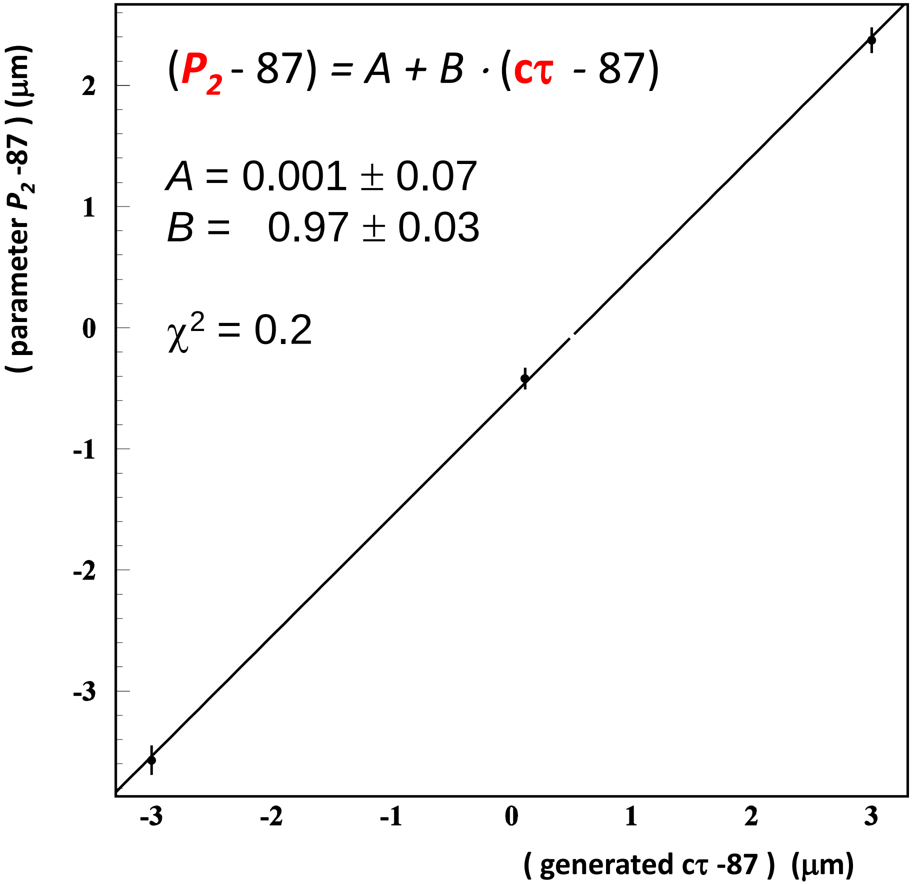
- From the fit we obtain **the value of the τ-lepton lifetime estimator**

P_2 = 86.53 ± 0.16(stat.) μm





MC based correction



MC samples with different **generated** τ-lepton lifetimes (cτ = **84.00, 87.11, 90.00** μm) processed in the same way as Data. (The background contamination $A_{q\bar{q}}$, $Bkg_{c\bar{c}+b\bar{b}}(x)$ for them is fixed to zero.) We obtain the $\boldsymbol{P_2}$ value for each MC sample.

- Three points of $\boldsymbol{P_2}$ value versus generated **cτ** are fitted to linear function $\boldsymbol{P_2} = A + B \cdot \mathbf{c\tau}$

Correction of the data result

From the fit of the **data** *ct* distribution we obtain **the value of the τ-lepton lifetime estimator *P2(data)*** $= 86.53 \pm 0.16(\text{stat.})\ \mu\text{m}$

The value of the ***P_2(data)*** is translated to the **$c\tau$** corrected value by the formula **$c\tau$** = (***P_2(data)*** – A)/B.

($A = 0.001 \pm 0.07$ $B = 0.97 \pm 0.03$ from MC)

MC corrected **Data** result (preliminary):

$c\tau = 86.99 \pm 0.16(\text{stat.})$

Systematic uncertainties

Source of Systematics	$\Delta(c\tau)$ in μm
SVD alignment	0.090
Asymmetry fixing	0.030
Beam energy and ISR & FSR description	0.024
Fit range	0.020
Background contribution	0.010
τ-lepton mass	0.009
TOTAL	**0.101** (0.12 %)

The result of the analysis

- Belle value of the τ-lepton lifetime is:

$$\tau = 290.17 \pm 0.53\ (\text{stat.}) \pm 0.33\ (\text{syst.}) \cdot 10^{-15}\ \text{s}$$

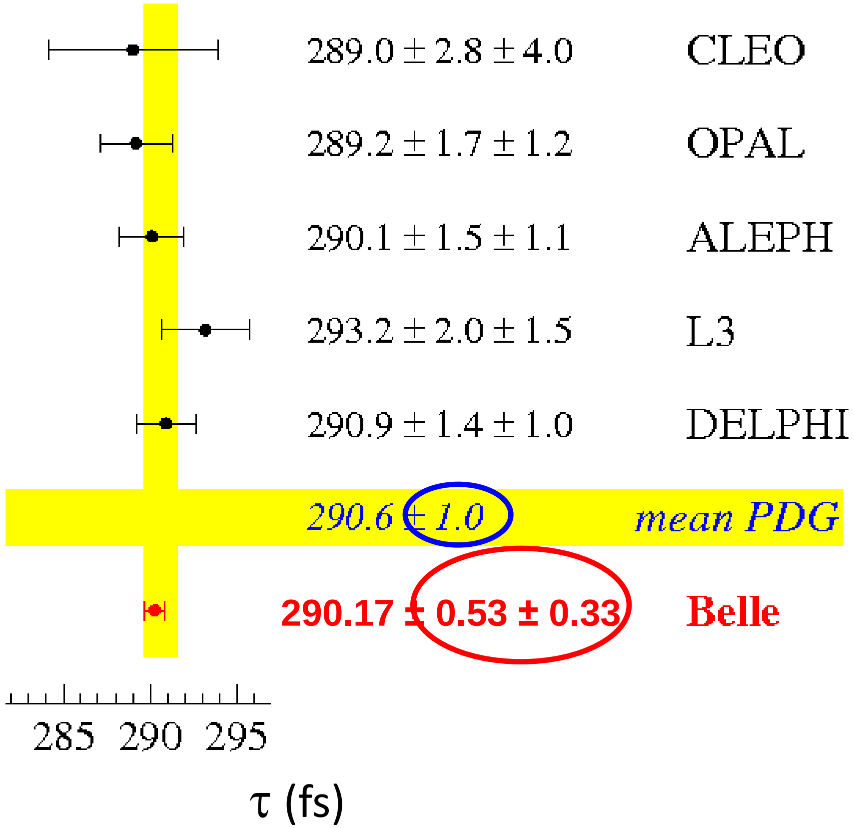
$$c\tau = 86.99 \pm 0.16\ (\text{stat.}) \pm 0.10\ (\text{syst.})\ \mu\text{m}$$

Current PDG value is:

$$\tau = 290.6 \pm 1.0 \cdot 10^{-15}\ \text{s}$$

$$c\tau = 87.11 \pm 0.30\ \mu\text{m}$$

The result of the analysis (cont.)



Summary

- The method of τ-lepton lifetime measurement at Belle is presented.

- Using 711 fb^{-1} of the Belle data we measured τ-lepton lifetime.
  The result is

$$\boldsymbol{\tau = 290.17 \pm 0.53\ (\text{stat.}) \pm 0.33\ (\text{syst.})\ \text{fs}}$$

$$\boldsymbol{c\tau = 86.99 \pm 0.16\ (\text{stat.}) \pm 0.10\ (\text{syst.})\ \mu\text{m}}$$

- The first measurement of the lifetime difference between τ^+ and τ^- is performed. The upper limit on the relative lifetime difference between positive and negative τ-leptons is
  $|\Delta\tau|/\tau < 7.0 \times 10^{-3}$ at 90% CL