τ-lepton lifetime measurement at Belle II

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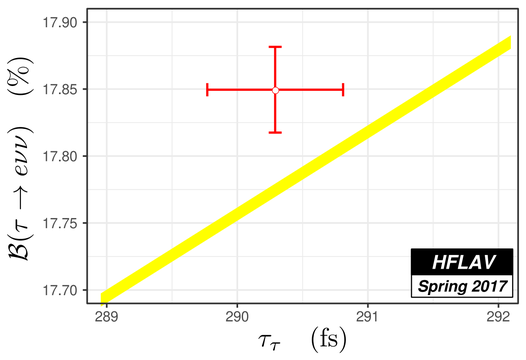
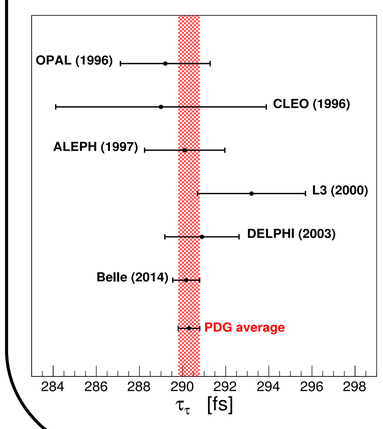
Physics motivation

The τ-lepton parameters (lifetime τ_τ, mass m_τ, leptonic BR) can be used to test **lepton flavor universality** in the Standard Model.



τ lifetime



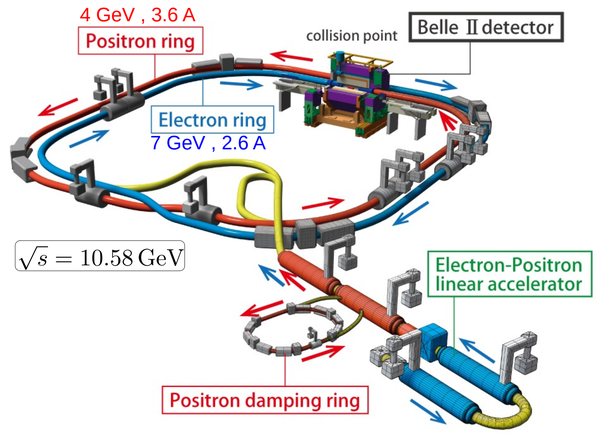
Best measurement at **Belle**:

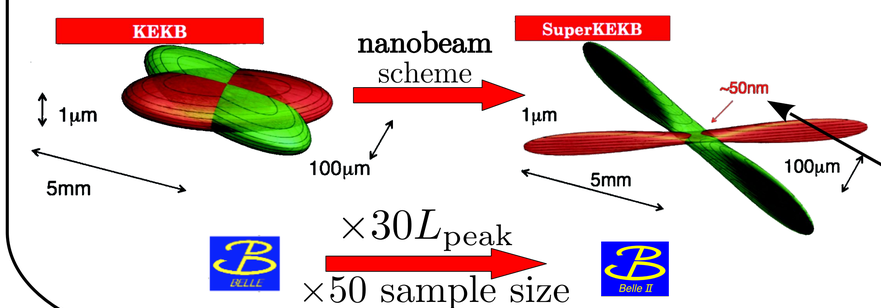
$$\tau_\tau = (290.17 \pm 0.53_{\text{stat}} \pm 0.33_{\text{syst}})\,\text{fs}$$

- Integrated luminosity → 711 fb^{-1}
- Event topology → both τ decay to 3 charged π
- Uncertainty → statistically dominated

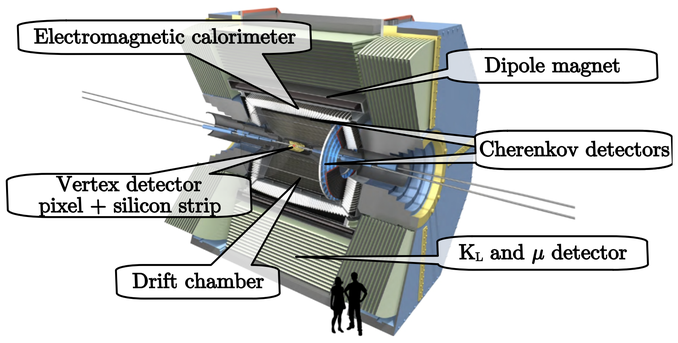
The Belle II experiment

SuperKEKB





Belle II detector



Good for τ physics:

- High τ-pair cross section: $\sigma(e^+e^- \to \tau^+\tau^-) = 0.919\,\text{nb}$
- Clean environment
- Small beam spot region → primary vertex constraint

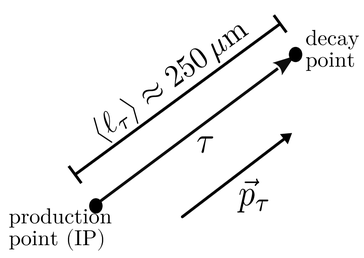
Measurement method

Reconstruct **proper decay time**

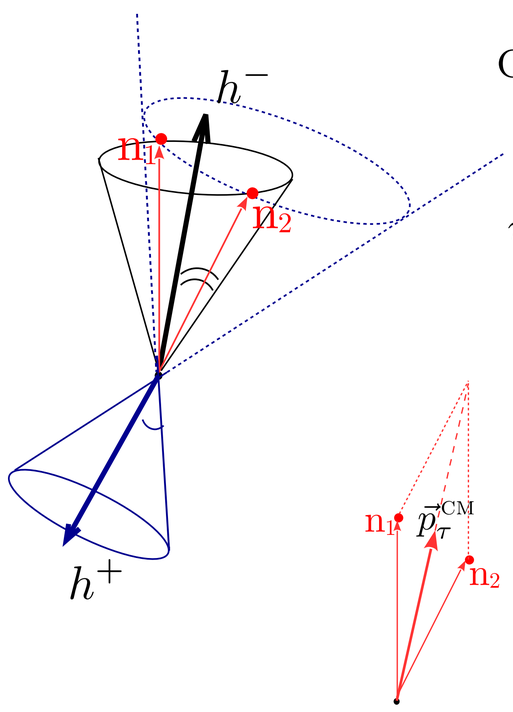
$$t = \frac{\ell_\tau}{\beta\gamma c} = \ell_\tau \frac{m_\tau}{p_\tau c}$$

In the laboratory frame:

- τ-momentum p_τ
- decay length ℓ_τ



τ-momentum reconstruction



Consider τ-pair events where both τ decay to hadrons

↓

τ-pair decay kinematic can be solved in CM frame: **2 distinct solutions** n_1, n_2

↓

Estimate $\vec{p}_\tau^{\,\text{CM}}$ as **mean vector** of the 2 solutions

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Boost $\vec{p}_\tau^{\,\text{CM}}$ to lab frame

Decay length reconstruction

Fit **decay vertex** for 3-prong τ

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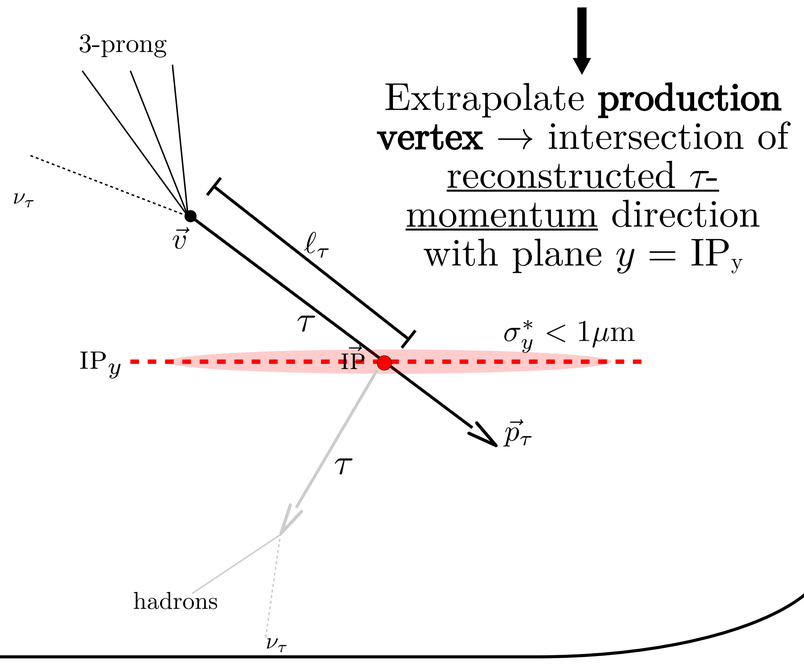
Extrapolate **production vertex** → intersection of reconstructed τ-momentum direction with plane $y = \text{IP}_y$



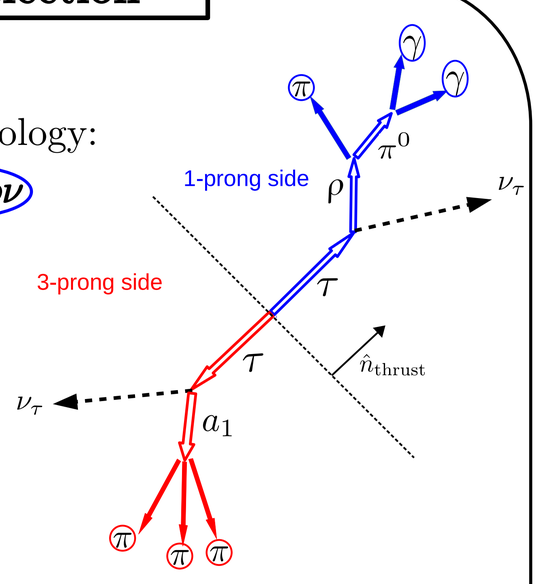
Signal selection

Signal:

3-prong×1-prong event topology:

$\tau \to \pi\pi\pi\nu \times \tau \to \rho\nu$

- Good signature of $\rho \to \pi\pi^0$ (ρ-peak)
- $\text{BR}(\tau \to \rho\nu) \simeq 25\%$ as compared to $\text{BR}(\tau \to 3\pi\nu) \simeq 9\%$



Background:

- $e^+e^- \to q\bar{q}$ events, with $q = u,d,s,c,b$
- τ-pair events of non-signal topology → proper decay time reconstructed with worse resolution

Simulation study on 100 fb^{-1} of MC:

$N_{\text{events}} \simeq 271$ k

- **τ pair events → 99.2%**
  - signal topology → 87.8%
  - non-signal $\tau\tau$ → 11.4%
- **$e^+e^- \to q\bar{q}$ background → 0.8%**
  - $q = u,d,s$ → 0.8%
  - $q = c,b$ → <0.1%

Lifetime extraction

1) For each event → compute proper decay time of 3-prong τ

Proper decay time resolution

- $\sigma = (79.2 \pm 0.7)\,\text{fs}$
- ×2 narrower than @ Belle → new vertex detector

2) Fit proper time distribution, subtracting $q\bar{q}$ backgrounds

Extracted τ lifetime

$$\tau_\tau = (285.85 \pm 0.64)\,\text{fs}$$

- **Statistical uncertainty** competitive with Belle
- **Negative bias**: due to radiative corrections → p_τ overestimation → proper time underestimation
- **Systematic** evaluation is ongoing