Proper time measurement

in charmless charged two-body B meson decays

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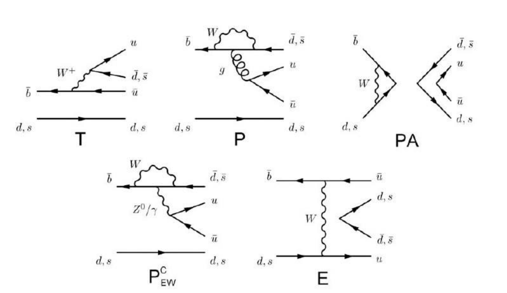
What's the aim?

- The family of B hadrons decaying into pairs of charmless charged mesons or baryons comprises a rich set of channels.
- Each one is characterized by charge or time dependent ***CP*** asymmetries, precise measurements of which play an important role in the quest for New Physics.
- LHCb has a great potential for triggering, reconstructing and selecting an unprecedented number of such decays.
- Today we want to describe some results regarding measurements and theoretical expectations of proper time of those particles, which is essential for ***CP*** violating observables

Charmless two-body B decays

The family of charmless two-body B decays can be described by $H_b \to h^+ h^-$:

- $B^0 \to p^+ p^-$
- $B^0_{(s)} \to \pi^+ \pi^-$
- $B^0 \to K^+ \pi^-$
- $B^0_s \to \pi^+ K^-$
- $B^0_{(s)} \to K^+ K^-$
- $\Lambda_b \to p\, \pi^-$
- $\Lambda_b \to p\, K^-$



Charmless two-body B decays

- Such decays are sensitive probes of the Cabbibo-Kobayashi-Maskawa matrix. However due to "penguin pollutions" the CKM parameters are hard to determine accurately.
- On the other hand, such "pollutions" may be an interesting opportunity to reveal New Physics.

The possibilities of LHCb detector

- LHCb detector can reconstruct some 10^5 $H_b \to h^+h^-$ per year which can be exploited for $\boldsymbol{CP}$ violation measurements.
- These unprecedented sample sizes are a consequence of the large beauty production cross section at LHC, which is expected to be around 0.5 mb, and the excellent vertexing, triggering and particle identification capabilities of LHCb.
- Within a few months of commencing LHC operation at nominal luminosity, the collected sample became larger than those available at previous experiments: B factories and the Trevatron.

Proper time measurement

- Precise measurements of B hadrons decay time is essential for determining time-dependent ***CP*** violating observables.
- bad proper time resolution $\longrightarrow$ poor ***CP*** sensitivity
- Besides, average lifetimes are quite interesting observables themselves.

Determining proper decay time

- Due to trigger and offline selection cuts (to reject primary vertex particles) – shape of decay time is noticeably distorted (especially for low proper time)
- Proper decay time may be expressed as:

$$\tau_B = m_B \frac{L_B}{p_B}, \tag{1}$$

  where m_B, L_B, p_B are the mass, flight distance and momentum of the B meson.
- Experimentally, the proper time is obtained from decay rate function (dependent on resolution and acceptance):

$$\Gamma_{exp}(t) \propto [\Gamma_{th}(t') \otimes R_t(t - t')]\epsilon_t(t) \tag{2}$$

Determining proper decay time

The theoretical decay rate depends on the channel:

- for $B^0 \longrightarrow \pi^+\pi^-$ and $B_s^0 \longrightarrow K^+K^-$ it's quite complex:

$$\Gamma_{th}(t) \propto e^{-\frac{t}{\tau}} \left[(1+|\lambda|^2) cosh\left(\frac{\Delta\Gamma}{2} t\right) - 2Re\lambda sinh\left(\frac{\Delta\Gamma}{2} t\right) \right] \quad (3)$$

- for $B^0 \longrightarrow K^+\pi^-$ and $B_s^0 \longrightarrow \pi^+K^-$ it simplifies a lot:

$$\Gamma_{th}(t) \propto e^{-\frac{t}{\tau}} cosh\left(\frac{\Delta\Gamma}{2} t\right) \quad (4)$$

($\Delta\Gamma \rightarrow 0$ for the former one, so it yields pure exp)

- for $\Lambda_b \longrightarrow p\,\pi^-$ and $\Lambda_b \longrightarrow p\,K^-$ (Λ_b baryons are not subject to mixing) it's pure exponential

$$\Gamma_{th}(t) \propto e^{-\frac{t}{\tau}} \quad (5)$$

Determining proper decay time

- In order not to rely on the mass it's useful to use such parametrisation:

$$\xi = \frac{t}{m_B c^2} = \frac{L_B}{p_B c^2} \tag{6}$$

- and this abbreviation: $\tau_\xi = \frac{\tau}{(m_B c^2)}$
- Then the p.d.f.'s become, respectively:

$$f(\xi) = \frac{1}{C} e^{-\frac{\xi'}{\tau_\xi}} \left[(1+|\lambda|^2) cosh \left(\frac{\Delta\Gamma m_B c^2}{2} \xi' \right) - 2Re\lambda sinh \left(\frac{\Delta\Gamma m_B c^2}{2} \xi' \right) \right] \otimes R_\xi(\xi - \xi')] \epsilon_\xi(\xi) \tag{7}$$

$$f(\xi) = \frac{1}{C'} e^{-\frac{\xi'}{\tau_\xi}} cosh \left(\frac{\Delta\Gamma m_B c^2}{2} \xi' \right) \otimes R_\xi(\xi - \xi')] \epsilon_\xi(\xi) \tag{8}$$

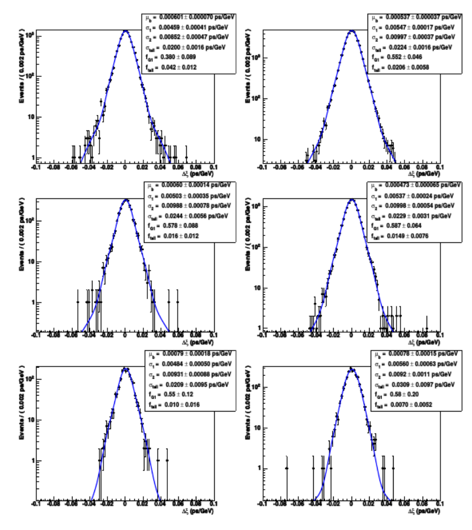
$$f(\xi) = \frac{1}{C''} e^{-\frac{\xi'}{\tau_\xi}} \otimes R_\xi(\xi - \xi')] \epsilon_\xi(\xi) \tag{9}$$

Resolution of the proper time

Offline-selected events analysis accurately describes the resolution in terms of 3 gaussians with common mean:

$$R_\xi(\Delta\xi) = \frac{f_1}{\sqrt{2\pi}\sigma_1} e^{-\frac{(\Delta\xi - b_\xi)^2}{2\sigma_1^2}} + \frac{1-f_1-f_{tail}}{\sqrt{2\pi}\sigma_2} e^{-\frac{(\Delta\xi - b_\xi)^2}{2\sigma_2^2}} + \frac{f_{tail}}{\sqrt{2\pi}\sigma_{tail}} e^{-\frac{(\Delta\xi - b_\xi)^2}{2\sigma_{tail}^2}} \tag{10}$$

Resolution of the proper time



- $B^0 \rightarrow \pi^+\pi^-$ (top left)
- $B^0 \rightarrow K^+\pi^-$ (top right)
- $B^0_s \rightarrow \pi^+K^-$ (middle left)
- $B^0_s \rightarrow K^+K^-$ (middle right)
- $\Lambda_b \rightarrow p\,\pi^-$ (bottom left)
- $\Lambda_b \rightarrow p\,K^-$ (bottom right)

Resolution of the proper time

The results are within statistical errors, but they show a bias of for ξ of roughly 0.6 fs/GeV ($\rightarrow$ 3.2 fs bias for time). This shouldn't have any significant impact on ***CP*** violation measurements, but its origin is not understood.

Acceptance

Empirically (MC studies) the acceptance is assumed as:

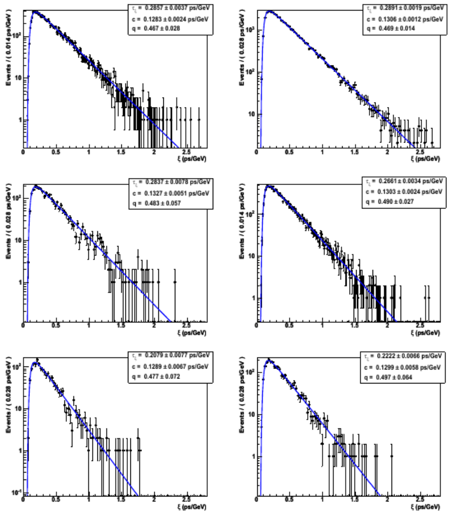
$$\epsilon_\xi(\xi) \propto 1 - Erf\left(\frac{c-\xi}{q\xi}\right), \tag{11}$$

where

$$Erf(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt \tag{12}$$

Now, we are equipped with all pieces of the decay rate eqs., except for acceptance function parameters.

Fitting the ξ



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Fitting the ξ

Below tables show the fit result for 2 cases:

- data only offline-selected

Channel	τ_ξ [ps/GeV]	c [ps/GeV]	q	$\tau_{\xi\,MC}$ [ps/GeV]
$B^0 \to \pi^+\pi^-$	0.286 ± 0.004	0.128 ± 0.002	0.47 ± 0.03	0.291
$B^0 \to K^+\pi^-$	0.289 ± 0.002	0.131 ± 0.001	0.47 ± 0.01	0.291
$B_s^0 \to \pi^+K^-$	0.284 ± 0.008	0.133 ± 0.005	0.48 ± 0.06	0.272
$B_s^0 \to K^+K^-$	0.266 ± 0.003	0.130 ± 0.002	0.49 ± 0.02	0.272
$\Lambda_b \to p\pi^-$	0.208 ± 0.008	0.129 ± 0.007	0.48 ± 0.07	0.219
$\Lambda_b \to pK^-$	0.222 ± 0.007	0.130 ± 0.006	0.50 ± 0.06	0.219

- data both triggered and offline-selected

Channel	τ_ξ [ps/GeV]	c [ps/GeV]	q	$\tau_{\xi\,MC}$ [ps/GeV]
$B^0 \to \pi^+\pi^-$	0.289 ± 0.006	0.144 ± 0.003	0.34 ± 0.03	0.291
$B^0 \to K^+\pi^-$	0.287 ± 0.003	0.149 ± 0.002	0.38 ± 0.02	0.291
$B_s^0 \to \pi^+K^-$	0.272 ± 0.013	0.159 ± 0.011	0.49 ± 0.10	0.272
$B_s^0 \to K^+K^-$	0.273 ± 0.005	0.143 ± 0.003	0.34 ± 0.03	0.272
$\Lambda_b \to p\pi^-$	0.217 ± 0.012	0.144 ± 0.008	0.37 ± 0.07	0.219
$\Lambda_b \to pK^-$	0.222 ± 0.011	0.146 ± 0.008	0.38 ± 0.08	0.219

Conclusion: the decay time results match MC $\rightarrow$ the mathematical model is accurate. Also, fit parameters differ in both tables $\rightarrow$ trigger significantly affects (distorts) the proper time.

Summary and outlook

Although MC data are useful in creating the time resolution model – it's the experiment that may extend the knowledge of lifetimes of $\boldsymbol{CP}$ modes and then to e.g. use this quantity to determine $\Delta\Gamma_s$ and conclude about New Physics and its contributions to various decays.


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