B lifetime at Belle II

[arxiv: 2005.07507]

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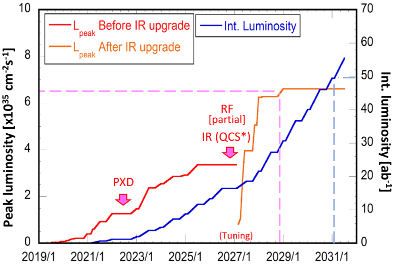
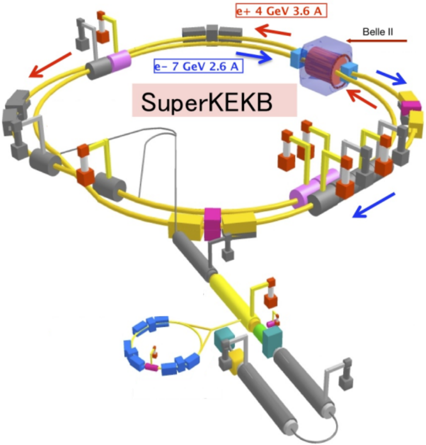
ICHEP 2020 | PRAGUE

Outline

SuperKEKB

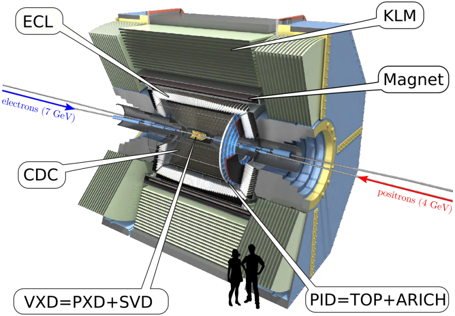
- e^+e^- collider.
- $\sqrt{s} = 10.6\,\mathrm{GeV} = \mathrm{m}(\Upsilon(4S))c^2$.
- $\mathrm{BR}(\Upsilon(4S) \to B\bar{B}) > 96\%$.

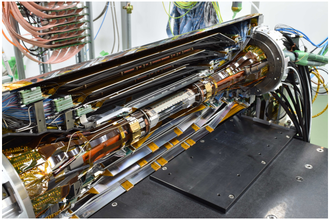




The Belle II detector

- Pixel detector (PXD).
- Silicon Vertex Detector (SVD).
- Central Drift Chamber (CDC).
- Calorimeter (ECL).
- Aerogel Ring-Imaging Cherenkov (ARICH).
- Time-Of-Propagation (TOP) counter.
- K_L^0 and μ detection (KLM).

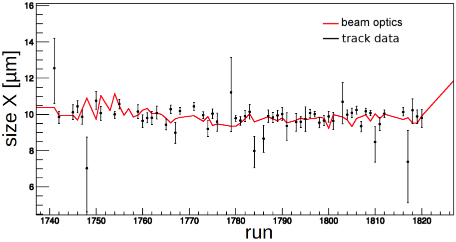




Introduction

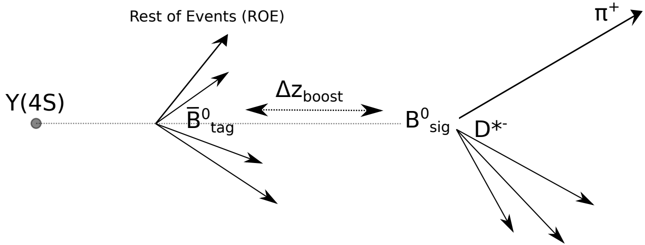
- B^0 lifetime measurement using 2019 Belle II data ($\mathcal{L} = 8.7 \pm 0.2\,\mathrm{fb}^{-1}$).

- Belle II has a smaller boost compared to Belle, but a better impact parameter resolution (factor $\sim 1.5 - 2$) thanks to the pixel detector.
  - $(\beta\gamma)_{\mathrm{Belle\,II}} \approx 0.28 < 0.42 \approx (\beta\gamma)_{\mathrm{Belle}}$.
  - A good vertex separation is crucial for time-dependent studies.
  - CP violation results will be presented by N. Rout [link].
  - The Belle II tracking allows for a measurement of the beamspot size:



B^0 lifetime measurement strategy

- B^0 hadronic decays fully reconstructed.
- Other B vertex from the remaining tracks in the event.



- B mesons nearly at rest in the $\Upsilon(4S)$ frame.
  - Flight distance in the transverse plan neglected.
  - $\Delta t \approx \frac{\Delta z_{\mathrm{boost}}}{c(\beta\gamma)_{\Upsilon(4S)}}$, $\quad \Delta z_{\mathrm{boost}} = \mathcal{O}(100\,\mu\mathrm{m})$.

$$p_{\mathrm{na\ddot{i}ve}}(\Delta t, \tau_B) = \int_0^\infty \mathrm{d}t_1 \int_0^\infty \mathrm{d}t_2 \, \frac{1}{\tau_B^2}\, \mathrm{e}^{\frac{-(t_1+t_2)}{\tau_B}}\, \delta(t_2 - t_1 - \Delta t) = \frac{1}{2\tau_B}\, \mathrm{e}^{-\frac{|\Delta t|}{\tau_B}} \, .$$

Reconstruction of the signal B^0

- Hadronic final states used to reconstruct B^0 decays.

Decay	Selection Criteria
	B^0 decays
$B^0 \to D^-\pi^+$ $B^0 \to D^-\rho^+$ $B^0 \to D^{*-}\pi^+$ $B^0 \to D^{*-}\rho^+$	$M_{\rm bc} > 5.2$ GeV/c^2 and $-0.2 < \Delta E < 0.2$ GeV
	D decays
$D^{*+} \to D^0\pi^-$	$0.143 < m_{D^{*+}} - m_{D^0} < 0.147$ GeV/c^2
$D^- \to K^+\pi^-\pi^-$	$\lvert m - m_{PDG}\rvert < 0.015$ GeV/c^2
$D^0 \to K^-\pi^+$ $D^0 \to K^-\pi^+\pi^0$ $D^0 \to K^-\pi^+\pi^+\pi^-$	$\lvert m - m_{PDG}\rvert < 0.015$ GeV/c^2
	ρ decay
$\rho^+ \to \pi^+\pi^0$	$\lvert m - m_{PDG}\rvert < 0.10$ GeV/c^2

- $M_{\rm bc} \equiv \sqrt{E^{*2}_{\rm Beam} - p^{*2}_{B^0}}$; $\Delta E \equiv E^*_{B^0} - E^*_{\rm Beam}$.

Model for the total probability density

$$p_{\mathrm{all}}(\Delta t) \equiv n_{\mathrm{sig}} p_{\mathrm{sig}}(\Delta t, \tau_{B^0}) + n_{\mathrm{b\bar{b}}} p_{\mathrm{b\bar{b}}}(\Delta t, \tau_{\mathrm{eff}}) + n_{\mathrm{cont}} p_{\mathrm{cont}}(\Delta t).$$

- Contributions:
  - Basic Δt density $\rightarrow p_{\mathrm{naïve}}(\Delta t, \tau_B) = \frac{1}{2\tau_B}\, \mathrm{e}^{-\frac{|\Delta t|}{\tau_B}}$.
  - Resolution density $\rightarrow \mathcal{R}(\delta_{\Delta t}) =$ sum of 3 Gaussian densities.
  - Signal density $\rightarrow p_{\mathrm{sig}}(\Delta t, \tau_{B^0}) = (p_{\mathrm{naïve}}(\cdot, \tau_{B^0}) * \mathcal{R})(\Delta t)$.
  - B background density $\rightarrow p_{\mathrm{b\bar{b}}}(\Delta t, \tau_{\mathrm{eff}}) = (p_{\mathrm{naïve}}(\cdot, \tau_{\mathrm{eff}}) * \mathcal{R})(\Delta t)$.
  - Continuum density $\rightarrow p_{\mathrm{cont}}(\Delta t) =$ sum of 3 Gaussian densities.

Extraction of yields

- 2D extended maximum likelihood fit to the unbinned M_{bc} and ΔE.
  - Extraction of n_{sig}, $n_{\mathrm{b\bar{b}}}$ and n_{cont}.

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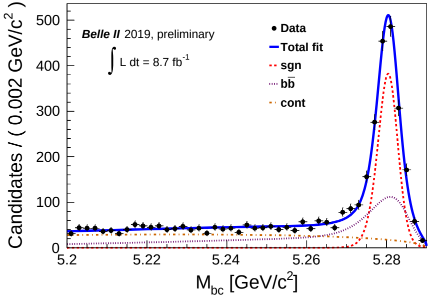

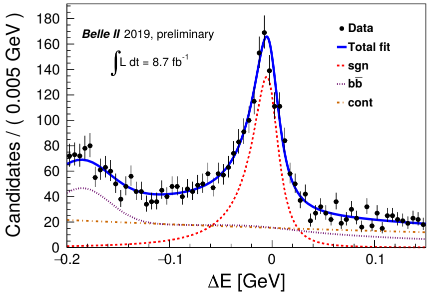

Continuum shape

- Fit to Δt of the sideband in simulation (left) and data (right).
  - Extraction of the continuum shape parameters.
  - $\{f_{1,2,3},\ s_{2,3},\ \Delta\mu\}$ from simulation, $\{\mu_1,\ \sigma_1\}$ from data.

$$p_{\mathrm{cont}}(\Delta t) = f_1\mathcal{G}(\Delta t;\mu_1,\sigma_1)+f_2\mathcal{G}(\Delta t;\mu_1+\Delta\mu,s_2\times\sigma_1)+(1-f_1-f_2)\mathcal{G}(\Delta t;\mu_1,s_2\times s_3\times\sigma_1) \quad (1)$$

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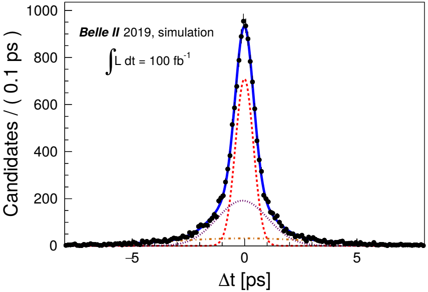

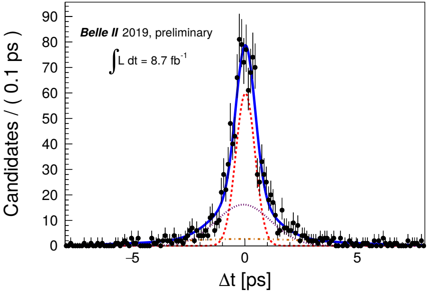

Resolution function shape

- Fit to Δt residual for the signal contribution of the simulated sample.
  - Extraction of the resolution parameters.

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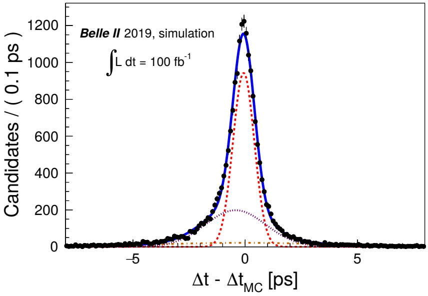

- After this step, τ_{eff} can be fixed from $b\overline{b}$ simulated events.

Systematic studies

- Systematic uncertainty sources considered:
  - Fit parametrisation.
    - Reproduce fit on 10k simulated bootstrap samples $\rightarrow \sigma = 0.05\,\mathrm{ps}$.
    - Check what happens when τ_{eff} is left free $\rightarrow \sigma = 0.01\,\mathrm{ps}$.
  - Calibration and alignment constants in data.
    - Reproduce study on a data subsample with different constants $\rightarrow \sigma = 0.03\,\mathrm{ps}$.

Final result

- Fit to Δt for all $B^0 \to D^{(*)}h$ of the selected decay candidates.
  - 3 free parameters: τ_{B^0}, $\mu_{1,\text{resolution}}$ and $\sigma_{1,\text{resolution}}$.
  - $\tau_{B^0} = 1.48 \pm 0.28\,(\text{stat}) \pm 0.06\,(\text{syst})\,\text{ps}$.
  - Reduced $\chi^2 = 0.83$.

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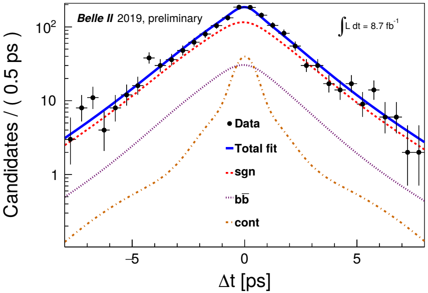

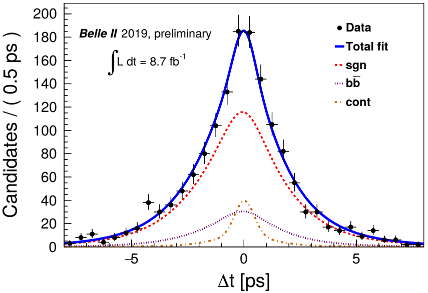

Conclusion

- B^0 lifetime was measured using 2019 Belle II data ($\mathcal{L} = 8.7 \pm 0.2\,\text{fb}^{-1}$).
  - $\tau_{B^0} = 1.48 \pm 0.28\ (\text{stat}) \pm 0.06\,(\text{syst})\,\text{ps}$.
  - Good agreement with world average ($\tau_{B^0} = 1.519 \pm 0.004\,\text{ps}$).
  - Assess the accuracy of vertex fitting tools, time resolution modeling and detector alignment.
  - Conference note available online: [arxiv: 2005.07507].
- See also D^0 lifetime study in G. Casarosa's talk [link].
  - Larger data sample, time resolution $\times 2$ better than Belle and BaBar.

Questions

Thank you for your attention.

Details on fit parameters

- Fit 1: M_{bc} and ΔE.
- Fit 2: Δt of the sideband events.
- Fit 3: Δt residual.
- Final fit: Δt of the signal region.

$$\mathcal{R}(\delta_{\Delta t}) = f_1 \mathcal{G}(\delta_{\Delta t}; \mu_1, \sigma_1) + f_2 \mathcal{G}(\delta_{\Delta t}; \mu_1 + \Delta\mu, s_2 \times \sigma_1) + (1 - f_1 - f_2) \mathcal{G}(\delta_{\Delta t}; \mu_1, s_2 \times s_3 \times \sigma_1) \quad (2)$$

	Fit parameter	value
Fit 1	n_{sgn} fit region	$(1.22 \pm 0.04) \times 10^3$
	$n_{b\bar{b}}$ fit region	$(1.29 \pm 0.07) \times 10^3$
	n_{cont} fit region	$(1.14 \pm 0.06) \times 10^3$
	n_{sgn} signal region	$(1.10 \pm 0.04) \times 10^3$
	$n_{b\bar{b}}$ signal region	270 ± 32
	n_{cont} signal region	140 ± 21
Fit 2	μ_{1cont} [ps]	0.021 ± 0.021
	σ_{1cont} [ps]	0.429 ± 0.015
Final fit	μ_{1res} [ps]	-0.03 ± 0.06
	σ_{1res} [ps]	0.56 ± 0.18
	τ_{B^0} [ps]	1.48 ± 0.28

	Fit parameter	value
Fit 2	$\Delta\mu_{cont}$ [GeV/c^2]	-0.0846 ± 0.026
	f_{1cont}	0.468 ± 0.021
	f_{2cont}	0.357 ± 0.017
	s_{2cont}	2.88 ± 0.096
	s_{3cont}	3.02 ± 0.11
Fit 3	$\Delta\mu_{res}$ [GeV/c^2]	-0.360 ± 0.031
	f_{1res}	0.561 ± 0.016
	f_{2res}	0.336 ± 0.014
	s_{2res}	2.84 ± 0.079
	s_{3res}	2.99 ± 0.13
	τ_{eff} [ps]	1.31 ± 0.03