Early Charm Results @ Belle II

XXVIII Cracow EPIPHANY Conference

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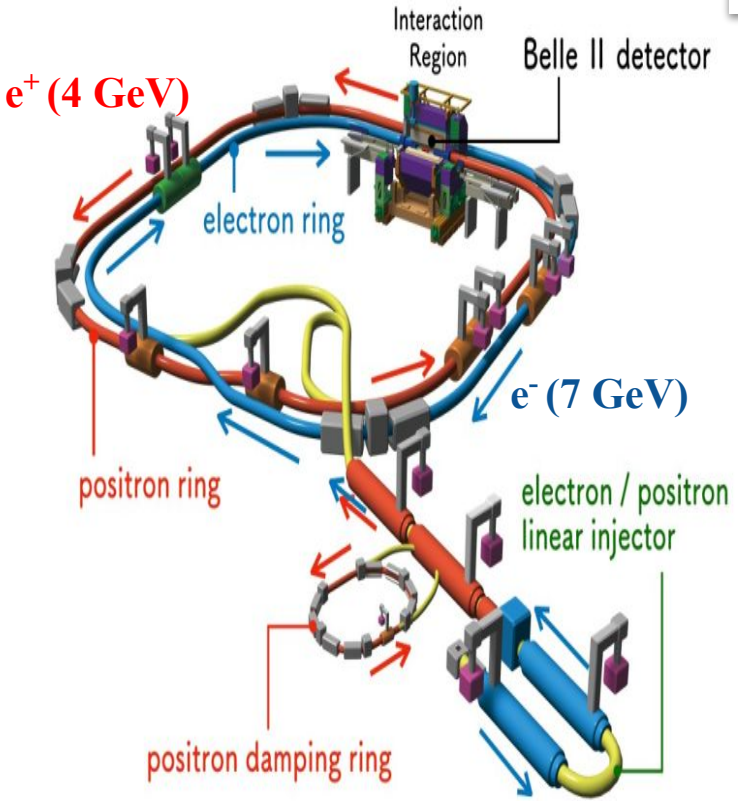
(On Behalf of the Belle II Collaboration)

Outline

- *SuperKEKB & Belle II*
- *Belle II Vertex Detector*
- *$D^{0/+}$ lifetime measurements*
- *CPV and charm mixing*
- *Summary*

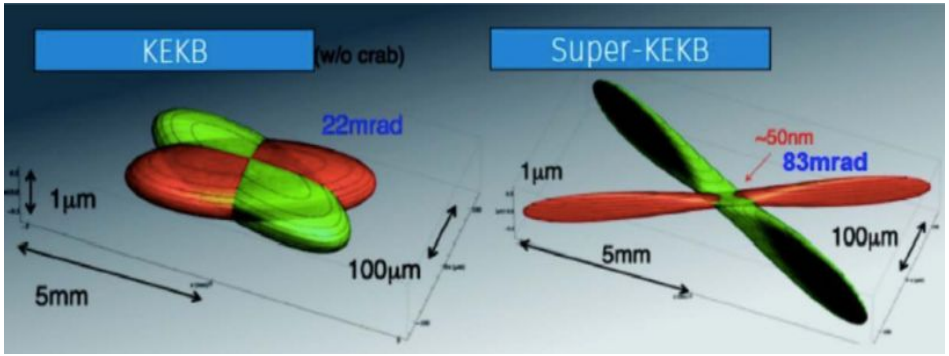
SuperKEKB



Design luminosity: 6.5 x 10^{35} $cm^{-2}s^{-1}$

WORLD RECORD: 3.81 x 10^{34} $cm^{-2}s^{-1}$

- Nano beams with the help of super-conducting final focus quadrupoles.

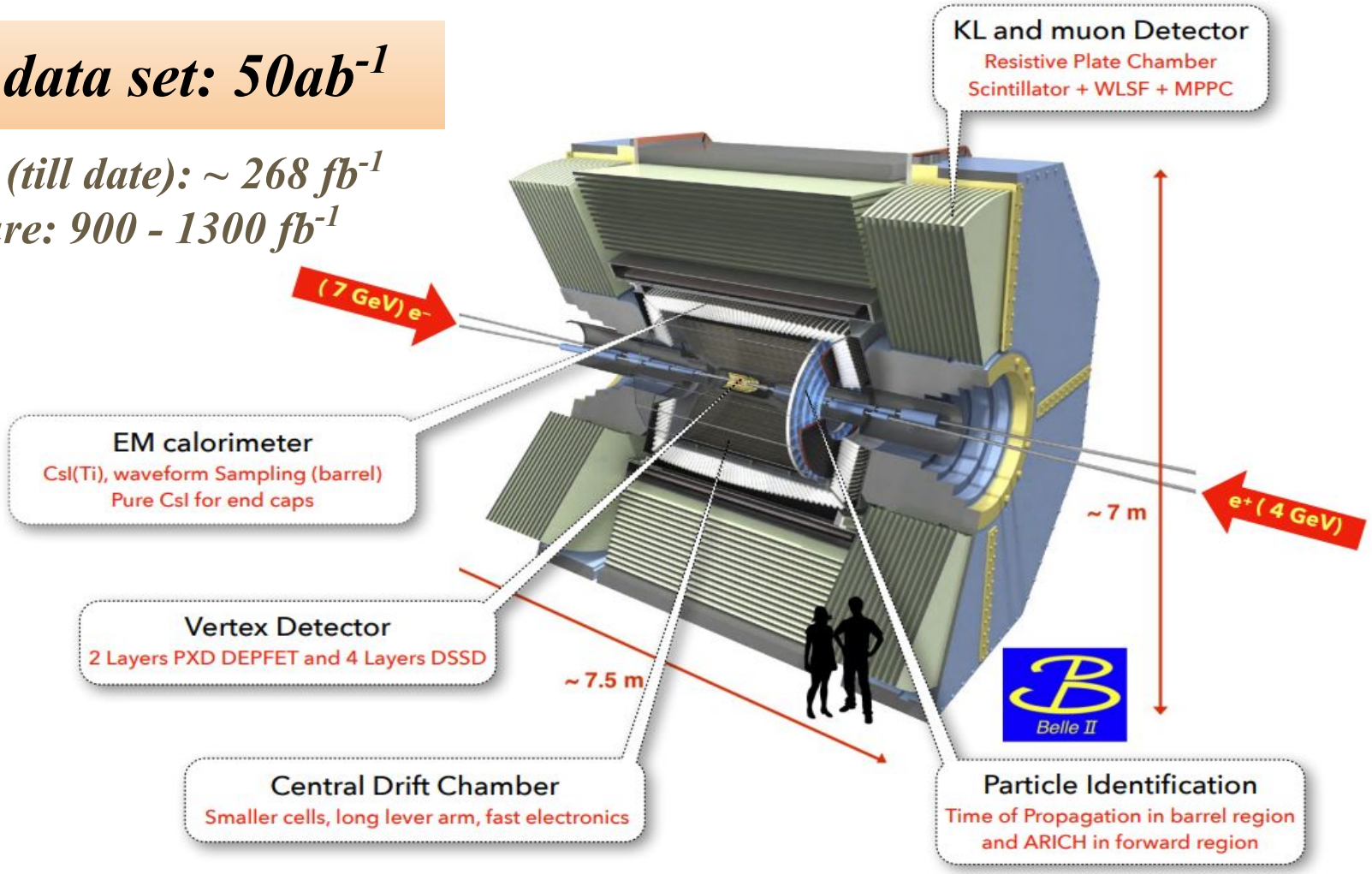


- Luminous region dimensions (x/y/z) at:
  Belle II: 10/0.2/250 μm
  Belle : 100/1/6,000 μm
- Beam spot ***y*** size is expected to be decreased to ~60 nm.
- Provide effective constraint on the D production vertex.

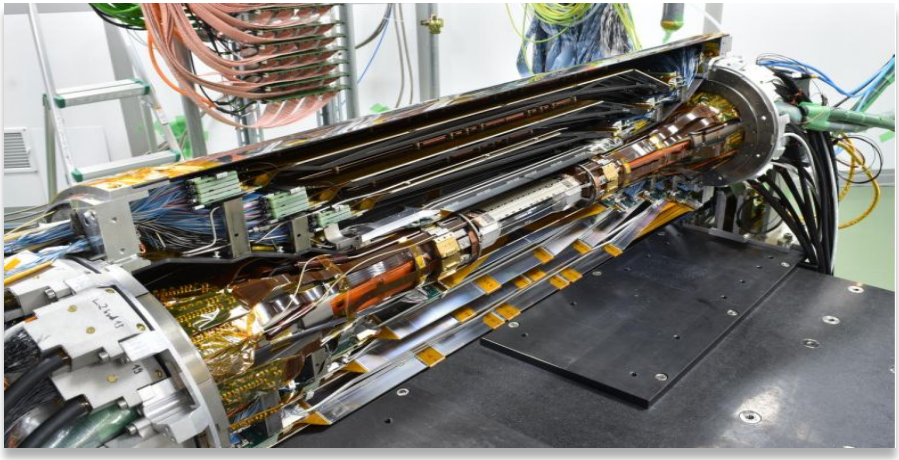
Belle II Detector

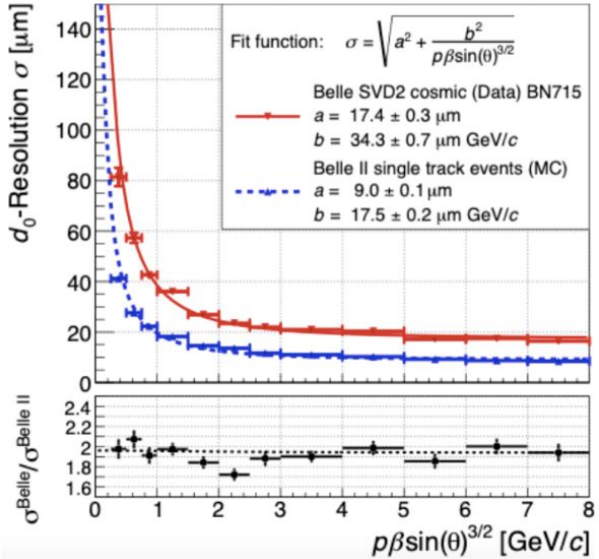
Target data set: 50ab^{-1}

Collected (till date): ~ 268 fb^{-1}
Near future: 900 - 1300 fb^{-1}



Belle II Vertex Detector (VXD)

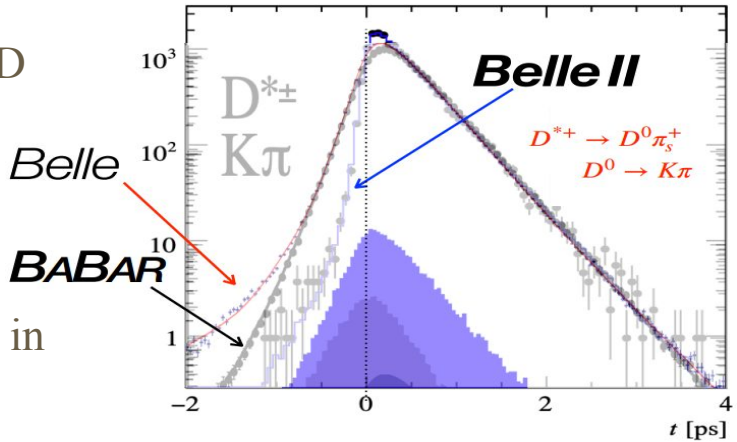




- The VXD is made up of:
  - Pixel Detector (PXD): 2 Layers of DEPFET
  - Silicon Vertex Detector (SVD): 4 Layers of DSSD

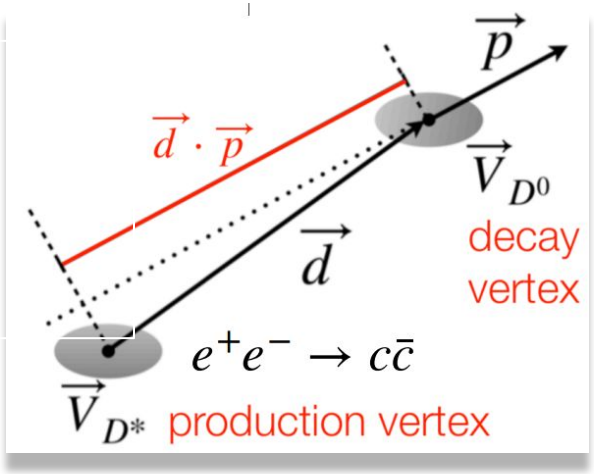
- First layer of PXD is at 1.4 cm from interaction point. 2nd layer of PXD is not complete.

- 2x better impact parameter resolution which shows up in the decay time distribution of D^0 meson.



Measurement of $D^{0/+}$ Lifetime

- Decay time is calculated using the displacement between the production and the decay vertices (***d***), projected along the direction of momentum (***p***).



$$t = \frac{m_D}{p}\left(\vec{d} \cdot \hat{p}\right)$$

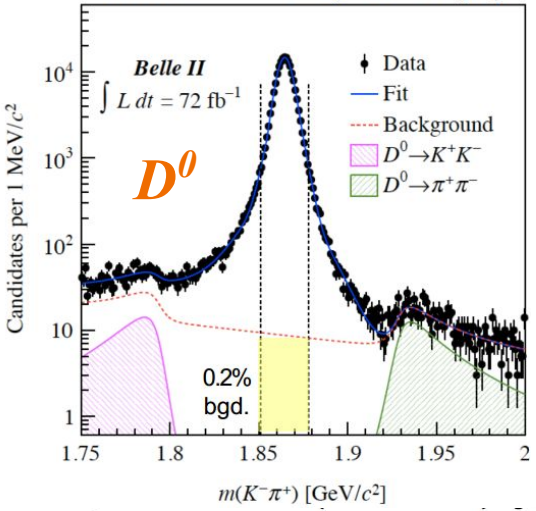
- At Belle II, the decay vertices are displaced on average by 200 (500) μm for $D^0(D^+)$.

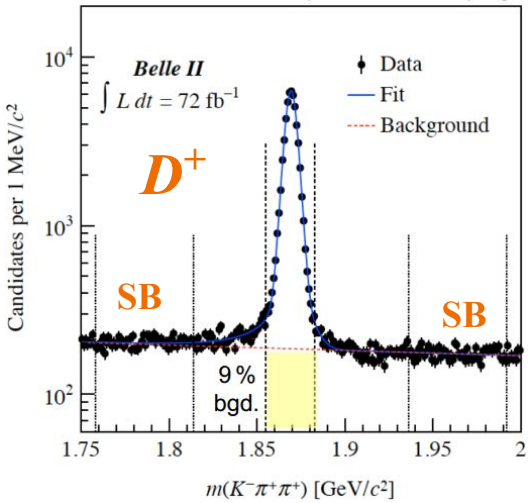
- D lifetime is extracted from fit to (t , σ_t).

Sample and Selection

- D* tagged $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ are reconstructed.
- D from B decays are removed with $p_{cms}(D^{*+}) > 2.5(2.6)$ GeV/c for $D^0(D^+)$.
- Background is mainly from random combination of particles.
- Binned least squares fit to $D^{0/+}$ mass.
- Signal yield:
  - $D^0 \to K^-\pi^+$: 171K
  - $D^+ \to K^-\pi^+\pi^+$: 59K
- Purity:
  - $D^0 \to K^-\pi^+$: 99.8%
  - $D^+ \to K^-\pi^+\pi^+$: 90%

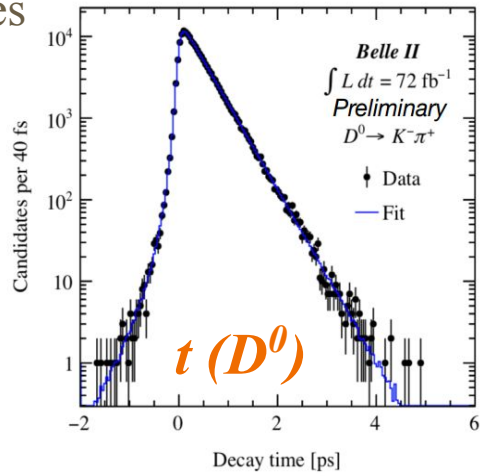
  SB: Side band

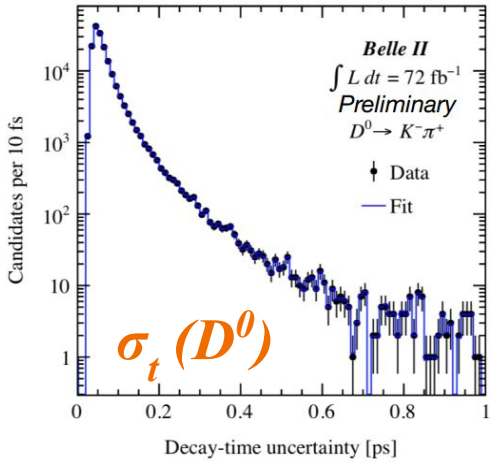


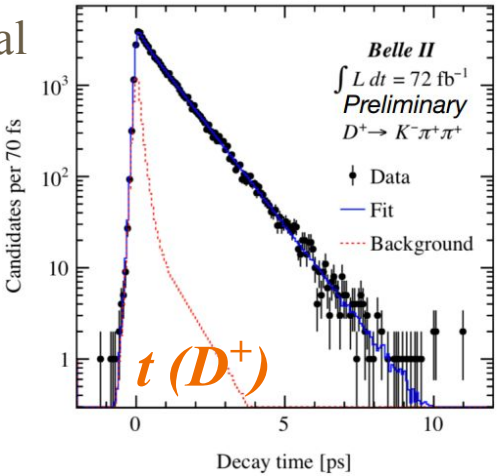


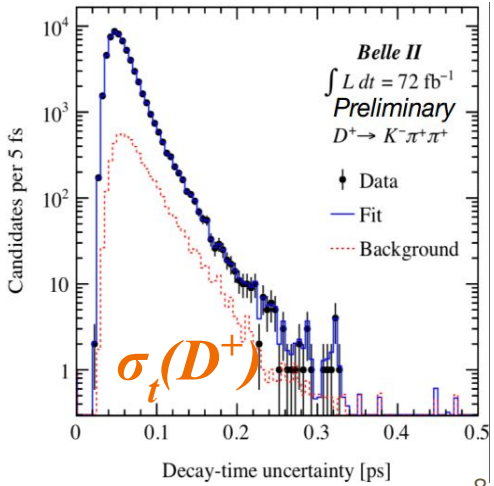
Fit to (t, σ_t)

- Unbinned ML fit to (t , σ_t) for candidates in the signal region.
- Only 0.2% background under the signal peak for D^0:
  - The background is neglected.
  - Systematic assigned.
- For D^+ background, it is assumed that SB events represent background in signal region.
- PDF: Exponential, convolved with a resolution function (R) . R for D^0(D^+) is sum of 2 Gaussians (1 Gaussian).
- t resolution ~ 60-70 fs.









Systematic Uncertainties

Source	$\tau(D^0)$ [fs]	$\tau(D^+)$ [fs]
Resolution model	0.16	0.39
Backgrounds	0.24	2.52
Detector alignment	0.72	1.70
Momentum scale	0.19	0.48
Total	0.80	3.10

- Major sources of systematic error:
  - Alignment of the detector:
    - measuring lifetimes using various misaligned MC samples.
  - Background:
    - data-MC disagreement of **t** distribution in side bands.

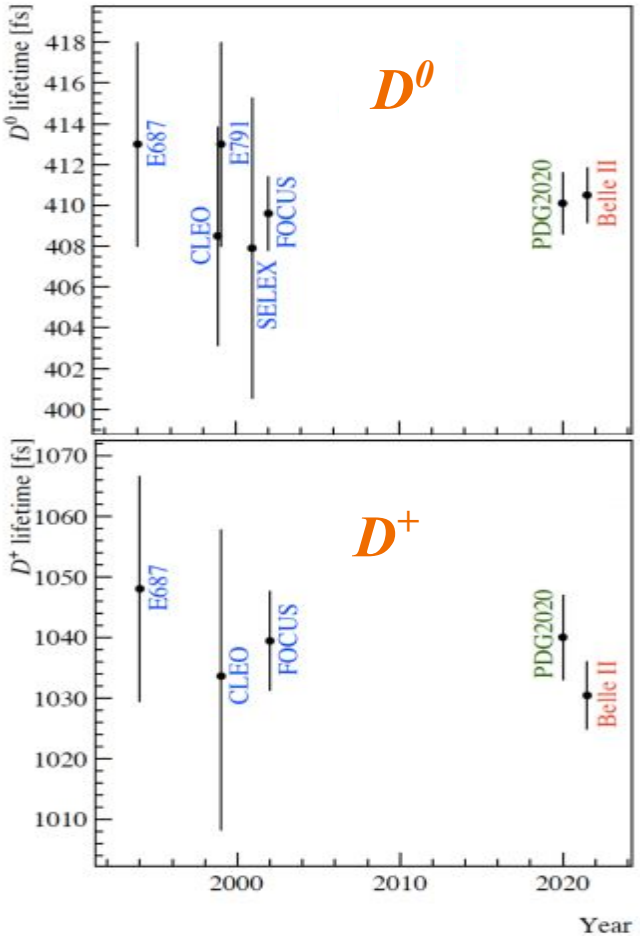
Results

Phys. Rev. Lett. 127, 211801

$\tau(D^0) = 410 \pm 1.1$ (stat.) ± 0.8 (syst.) fs

$\tau(D^+) = 1030.4 \pm 4.7$ (stat.) ± 3.1 (syst.) fs

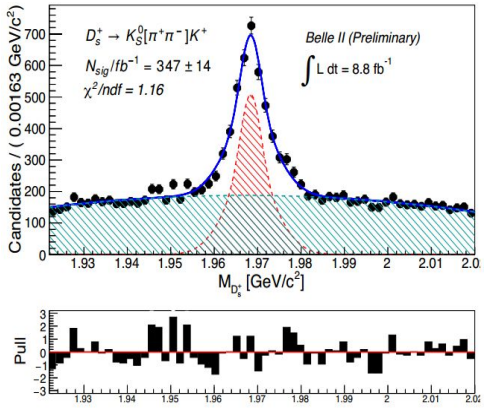
$\tau(D^+) / \tau(D^0) = 2.510 \pm 0.013$ (stat.) ± 0.007 (syst.)



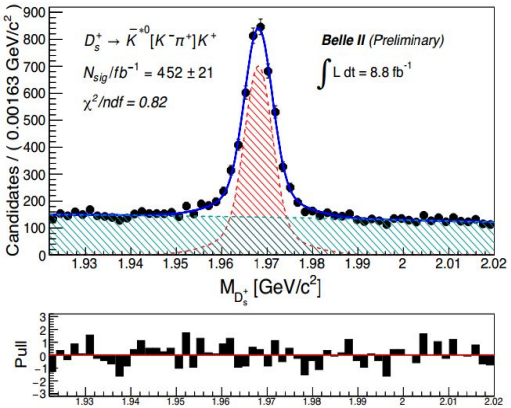
- Most precise measurement till date and consistent with previous measurements.
- Precision is still limited by sample size.
- Shows excellent vertexing capability of Belle II.
- Impact: future decay-time-dependent analyses of neutral-meson mixing and mixing-induced CP violation.

Towards measurement of D_s & Λ_c lifetime

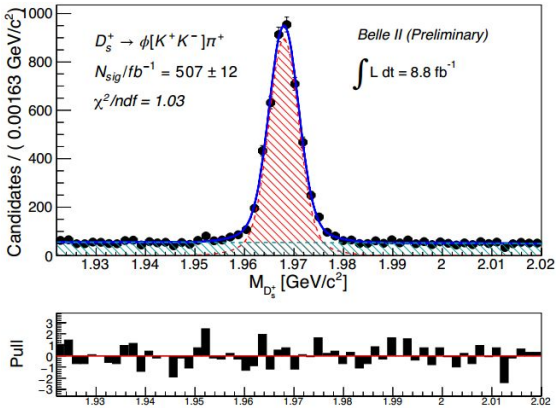
$D_s^+ \to K_S K^+$



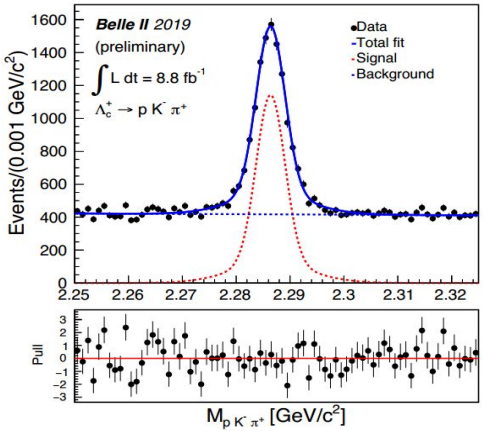
$D_s^+ \to \bar{K}^{*0} K^+$



$D_s^+ \to \phi \pi^+$



$\Lambda_c \to pK^-\pi^+$



- First reconstruction of Λ_c and D_s^+ decays at Belle II.
- D_s^+, Λ_c and Ω_c lifetime analyses are ongoing.

CPV and charm mixing

Time integrated CPV measurements @ 50 ab^{-1}

- First observation of time integrated CPV in charm was by LHCb in $D^0 \to K^+K^-$ and $D^0 \to \pi^+\pi^-$ decays.
  PRL 122, 211803 (2019)
- Important to look for CPV with other final states to understand origin of CPV.
- Belle II will specially contribute to the decays with neutrals in the final state.
- A_{CP} is expected reach a precision of $o(10^{-3}\text{-}10^{-4})$.
- Will also explore CPV measurements with charmed baryons.

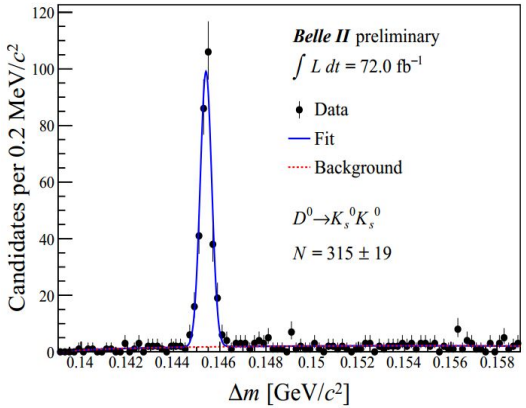
Belle Results

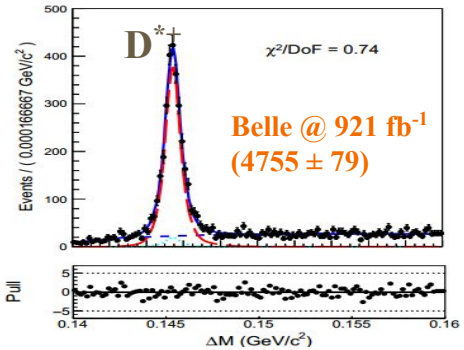
Mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	966	$-0.03 \pm 0.64 \pm 0.10$	± 0.09
$D^0 \to K^0_S\pi^0$	966	$-0.21 \pm 0.16 \pm 0.07$	± 0.02
$D^0 \to K^0_S K^0_S$	921	$-0.02 \pm 1.53 \pm 0.02 \pm 0.17$	± 0.23
$D^0 \to K^0_S\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K^0_S\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \pi^+\pi^0$	921	$+2.31 \pm 1.24 \pm 0.23$	± 0.17
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K^0_S\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.02
$D^+ \to K^0_S K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.04
$D^+_s \to K^0_S\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D^+_s \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

Time integrated CPV (ongoing analyses)

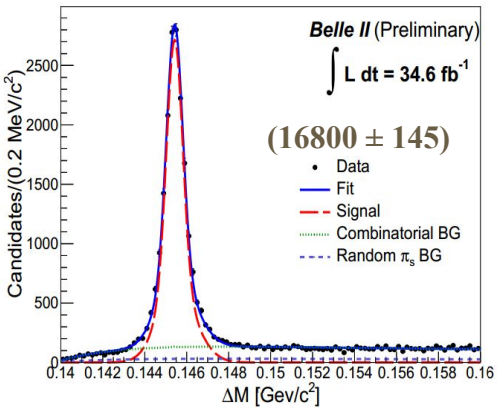
First reconstructions at Belle II. All D^0 channels are D tagged.*

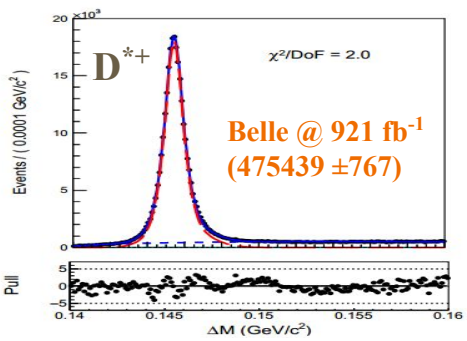
$D^0 \to K_S K_S$



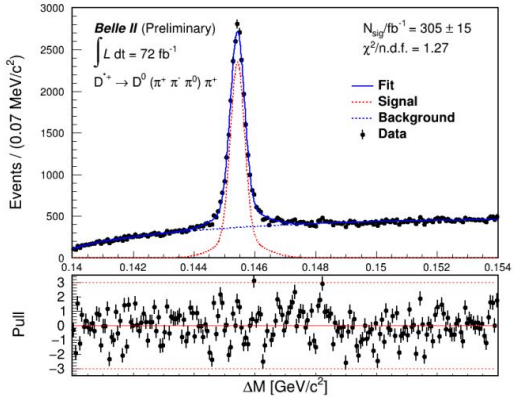


$D^0 \to K_S \pi^0$

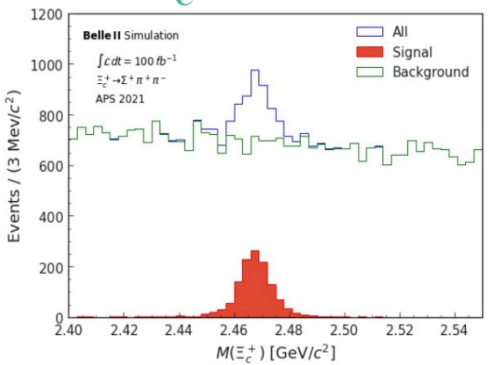




$D^0 \to \pi^+ \pi^- \pi^0$



$\Xi_C \to \Sigma^+ \pi^+ \pi^-$



[Phys. Rev. Lett. 119, 171801]

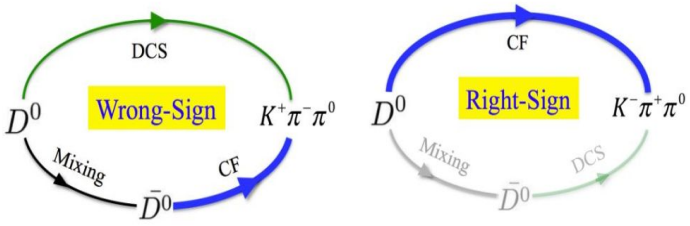
CP Violation in mixing

- Charm is the only up-type quark that exhibits mixing.
- The eigenstates of the neutral D meson are a mixture of the flavor states:

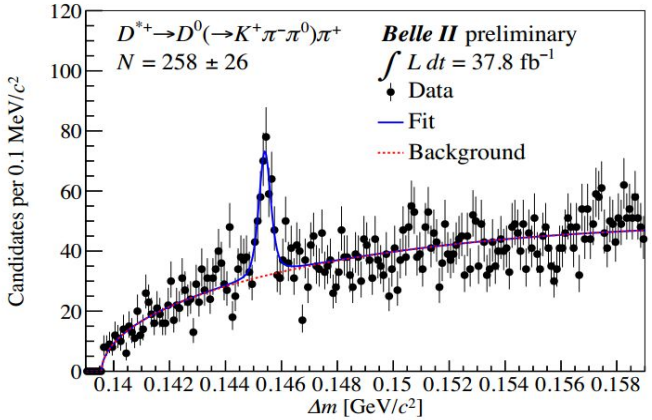
$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\bar{D}^0\rangle$$

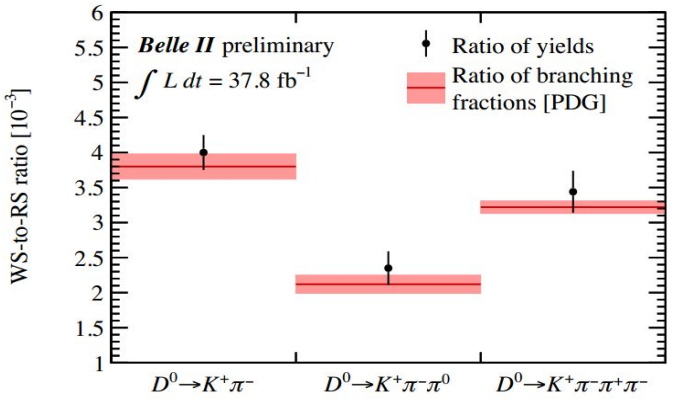
$$x = \frac{2(m_1 - m_2)}{\Gamma_1 + \Gamma_2}, \quad y = \frac{\Gamma_1 - \Gamma_2}{\Gamma_1 + \Gamma_2}$$

- WS decays provides sensitivity to the mixing.
- No experimental evidence of CPV in mixing till date.
- Measured ratio of WS-to-RS yields is compatible with world average.
- Analysis to measure mixing and CPV in $D^0 \to K^+\pi^-\pi^0$ is ongoing.



$D^{*+} \to D^0(K^+\pi^-\pi^0)\,\pi^+$





Summary

- World's most precise charm lifetime measurements.
  - Shows excellent vertexing capabilities of the Belle II VXD.
  - Impact: future decay-time-dependent analyses of neutral-meson mixing and mixing-induced CP violation.

- Reconstruction performance is improved as compared to Belle.

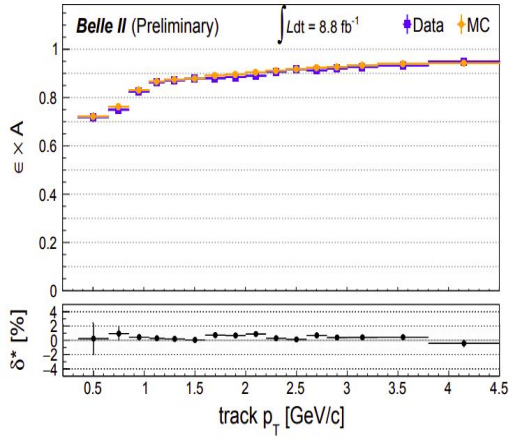
- SuperKEKB and Belle II are in great shape:
  - Achieved world record peak luminosity: $3.81 \times 10^{34}\ cm^{-2}s^{-1}$.
  - Collected ~268 fb^{-1} of data.

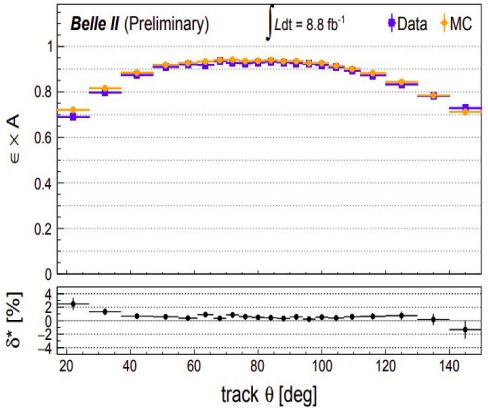
- ***Stay tuned for more results!!***

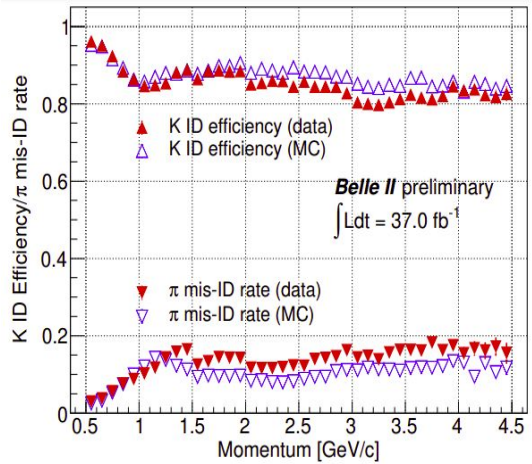
Thank you.

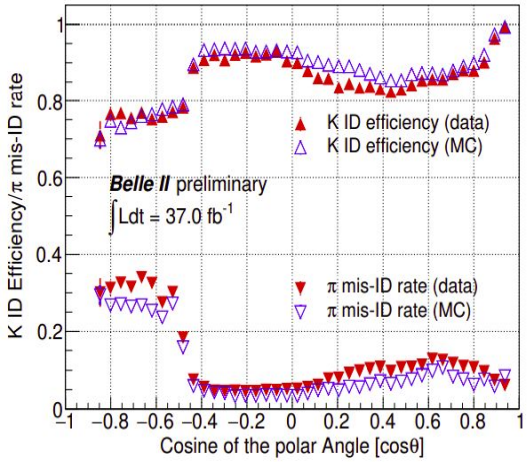
Backup Slides

Belle II Performance



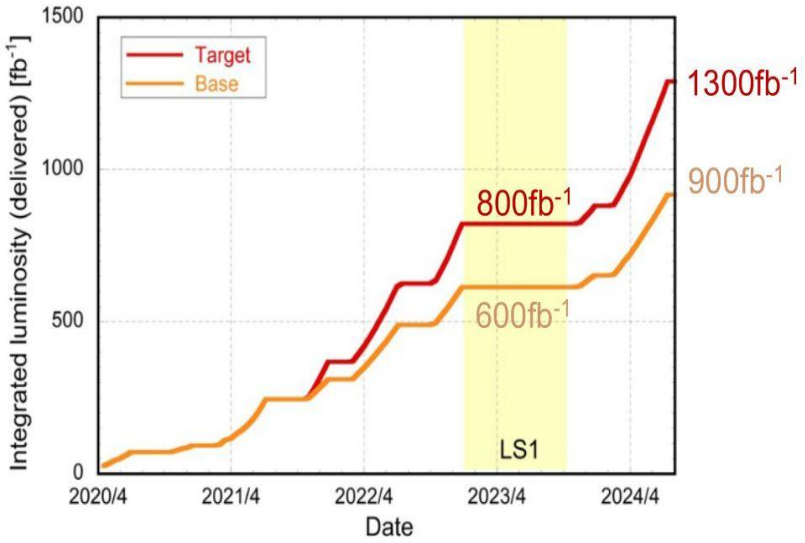






Projections of luminosity

- Target scenario: extrapolation from early 2021 run including expected improvements
- Base scenario: conservative extrapolation of SuperKEKB parameters from early 2021 run



Long Shutdown 1 (LS1) is currently scheduled to start January 2023

If SuperKEKB performance indicates that insufficient integrated luminosity will be collected before LS1 or COVID-19 travel restrictions persist, the option exists to postpone the start of LS1 to July 2023