Belle II results on Heavy Flavor Physics

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CKM & CKM triangle

complex phase

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

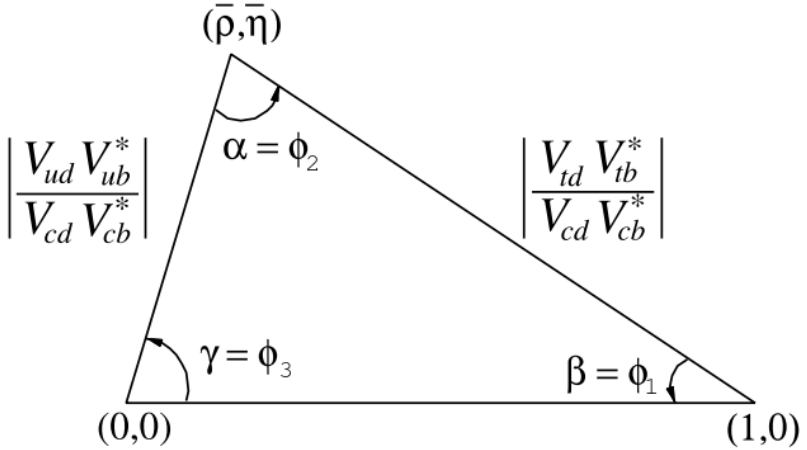
-*CKM* matrix

Wolfenstein parameters

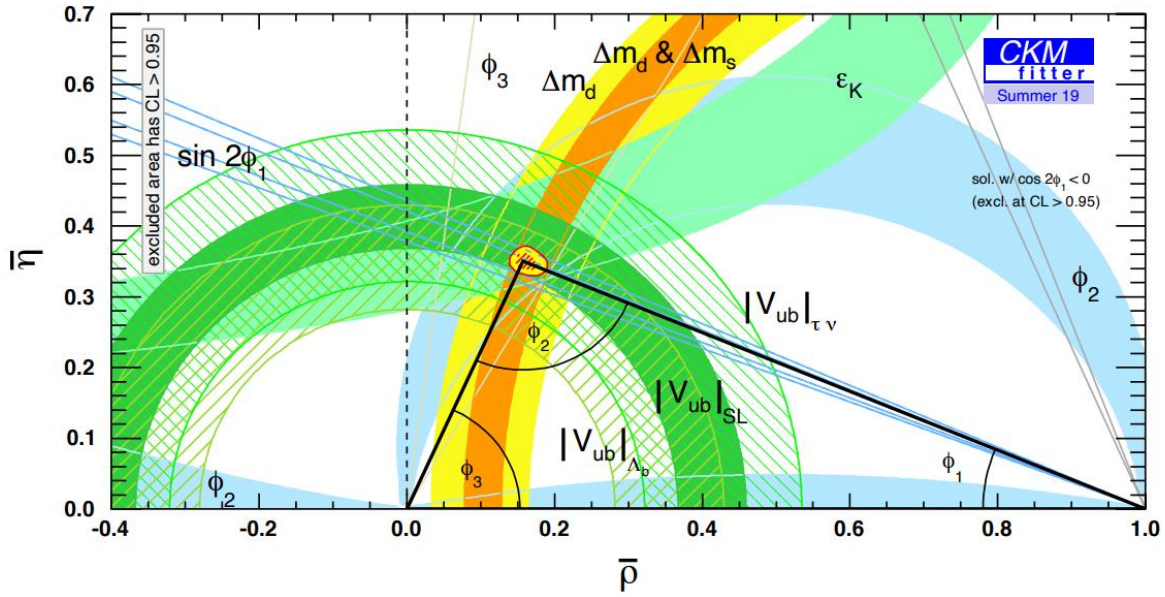
$$\alpha \equiv \phi_2 \equiv \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right) = \arg\left(-\frac{1-\bar{\rho}-i\bar{\eta}}{\bar{\rho}+i\bar{\eta}}\right), \rightarrow B \rightarrow \pi\pi, \rho\rho$$

$$\beta \equiv \phi_1 \equiv \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right) = \arg\left(\frac{1}{1-\bar{\rho}-i\bar{\eta}}\right), \rightarrow B \rightarrow J/\psi K_S^0$$

$$\gamma \equiv \phi_3 \equiv \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right) = \arg\left(\bar{\rho}+i\bar{\eta}\right). \rightarrow B \rightarrow DK$$



-*CKM* triangle



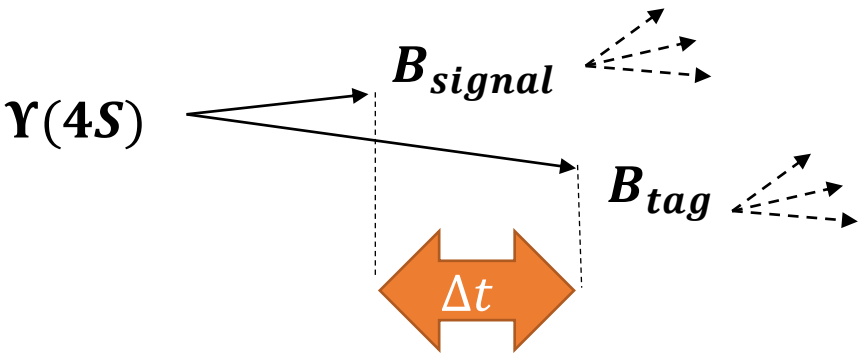
-*CKM* fitter

Analysis overview

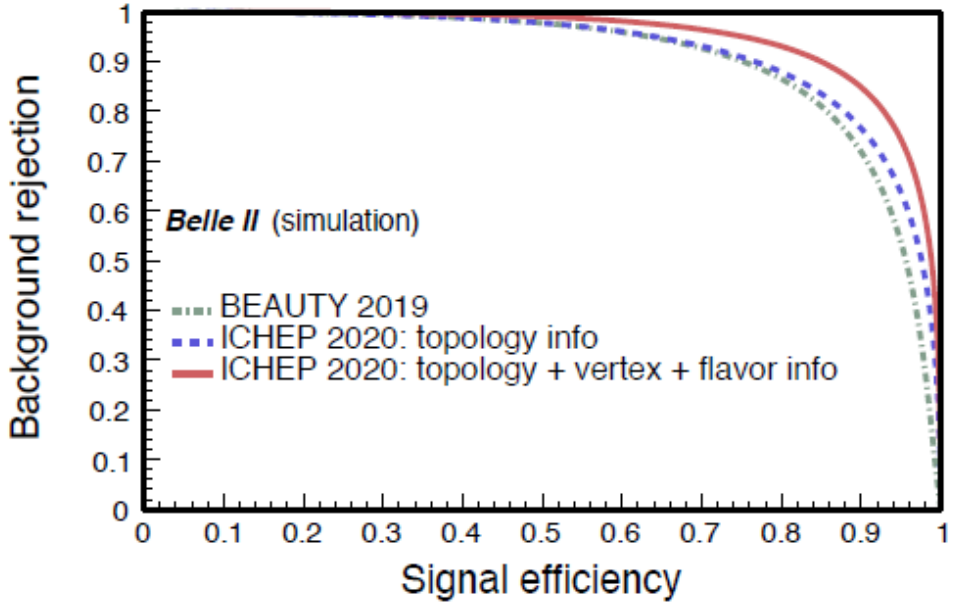
- Selection
  - Final state particles $(K, \pi, \gamma, etc..)$
- Background
  - For continuum bkg. $(q\bar{q} = u, d, s, c)$
  - Using multivariate tool (MVA)
- Signal extraction
  - Energy difference: $\Delta E \equiv E_B^* - E_{beam}$
  - Beam-energy-constrained mass:

$$M_{bc} \equiv \sqrt{E_{beam}^2 - (p_B^*/c)^2}$$

  - E_B^* & p_B^* = energy and momentum of the reconstructed B in $\Upsilon(4S)$ frame
  - E_{beam} = beam energy



$\Delta t = \Delta z/\beta\gamma c$, $\Delta z \approx 100\ \mu m$
$\beta\gamma$ = boost factor 0.29 (0.45 @ Belle)



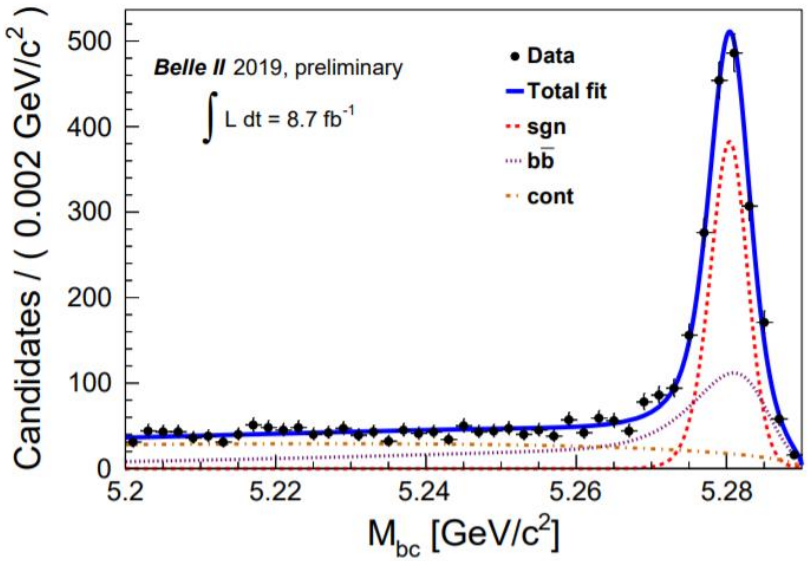
-Continuum background rejection

arXiv:2005.07507

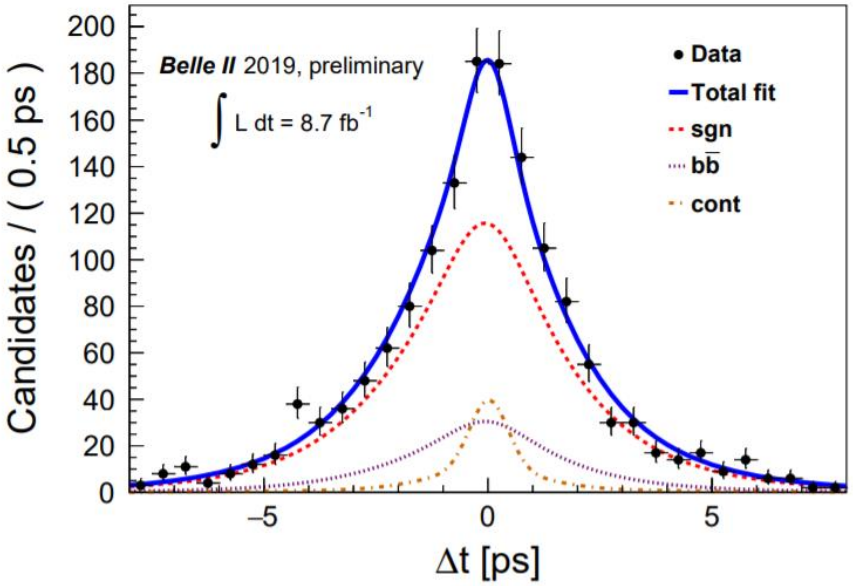
B^0 lifetime measurement

- Demonstration of
  - Vertex fitting tools
  - Time resolution modeling
- Data set: 8.8 fb^{-1}
  - $B^0 \to D^{*-}\pi^+$ and $B^0 \to D^{*-}\rho^+$
  - 2D fit (M_{bc} & ΔE)
- Results
  - $\tau_{B^0} = [1.48 \pm 0.28(stat.) \pm 0.06(syst.)]$ ps
  - PDG = $[1.519 \pm 0.004]$ ps
  - Belle = $[1.534 \pm 0.008 \pm 0.010]$ ps (140 fb^{-1})
  - Compatible with PDG & Belle result

- Signal extraction



-Δt distribution

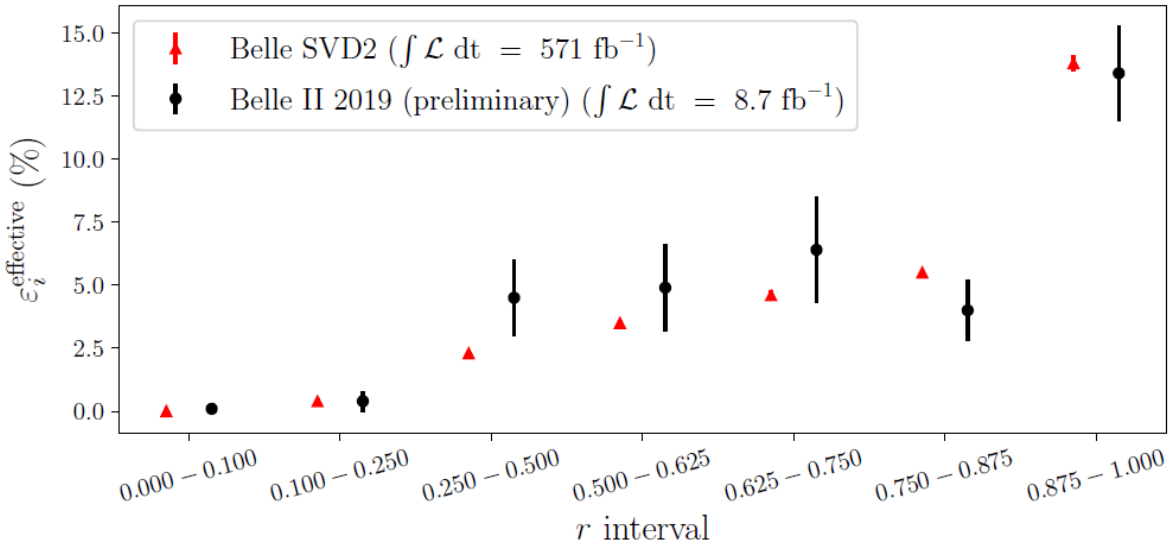


arXiv:2008.02707

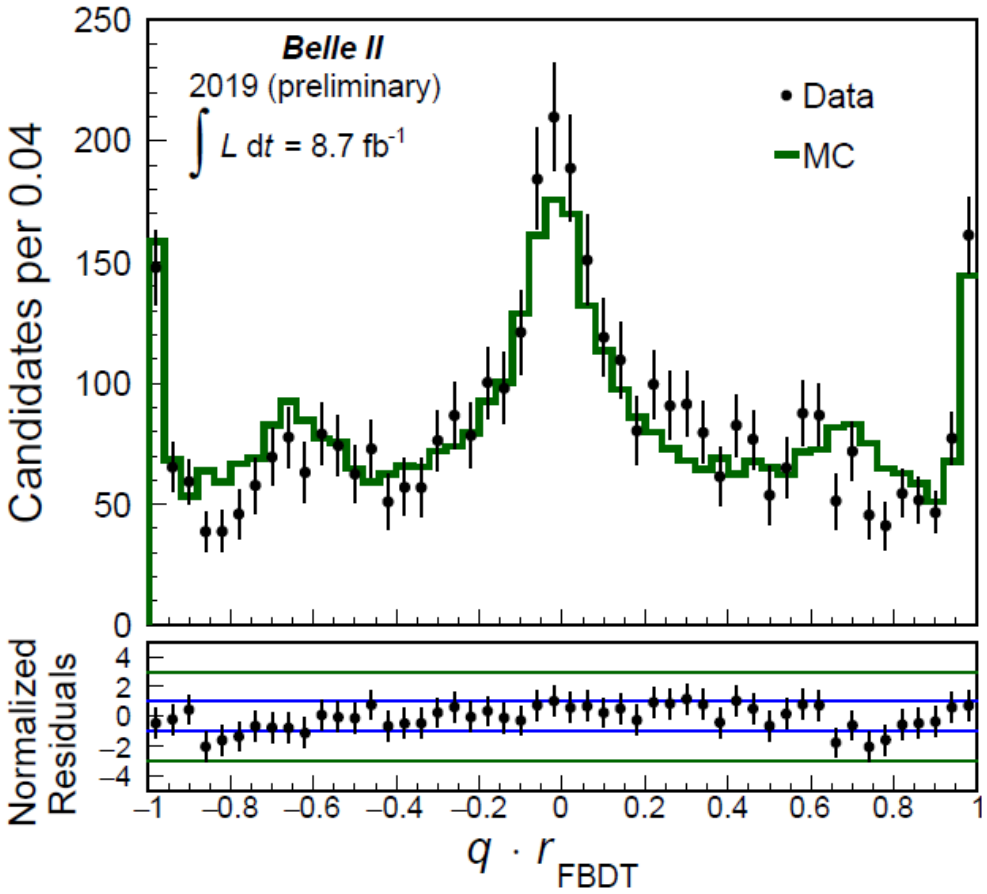
Flavor tagging

- Determination of flavor of tag-side B
  - Wrong tag fraction: w
  - Tagging efficiency: $\epsilon_{eff} = \epsilon_{tag} \cdot (1-2w)^2$
- Results
  - $\epsilon_{eff} = [33.8 \pm 3.6(stat.) \pm 1.6(syst.)]\%$
  - Belle $= [30.1 \pm 0.4]\%$ (571 fb^{-1})
  - Good agreement with MC
  - Compatible with Belle result

- ϵ_{eff} performance of the Belle & Belle II



- $q \cdot r$ distribution for signal

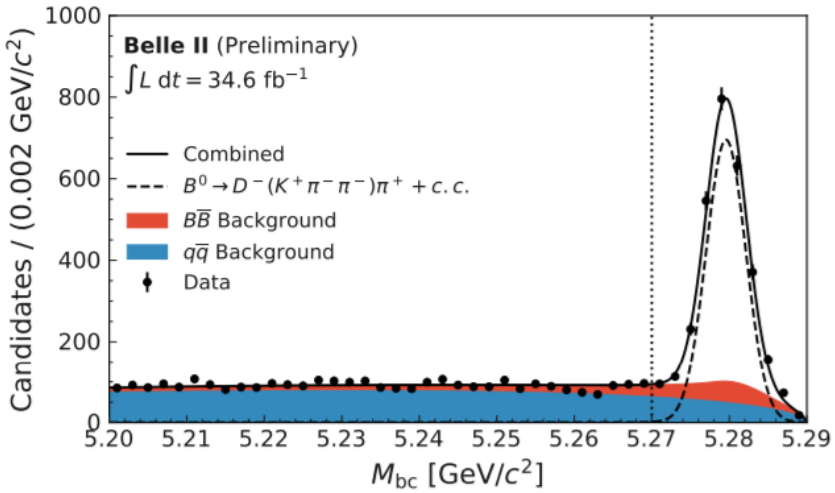


q: flavor of $+1(-1)$ for tag-side $B^0(\bar{B}^0)$
r: a dilution factor (0~1, 1= perfectly tagged)

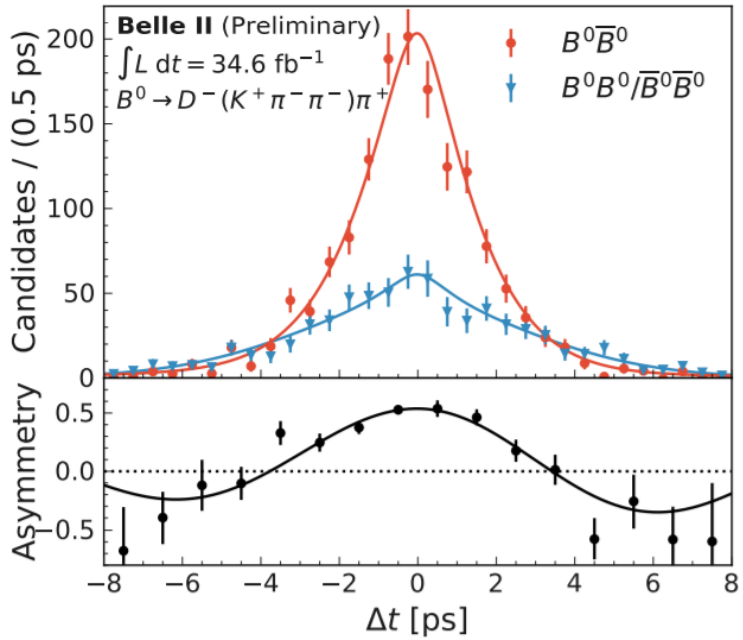
$B^0\bar{B}^0$ mixing frequency

- Measurement of mixing fequency Δm_d
  - $\Delta m_d = m_{B_H^0} - m_{B_L^0}$
  - $A_{mix}(\Delta t) = \frac{P(B\bar{B}) - P(BB,\bar{B}\bar{B})}{P(B\bar{B}) + P(BB,\bar{B}\bar{B})} = \cos(\Delta m_d \Delta t)$
- Data set: 34.6 fb^{-1}
  - $B^0 \to D^-(K^+\pi^-\pi^-)\pi^+$ candidates
- Results
  - $\Delta m_d = [0.531 \pm 0.046(stat.) \pm 0.013(syst.)]\ \text{ps}^{-1}$
  - PDG = $[0.5065 \pm 0.0019]\ \text{ps}^{-1}$
  - Belle = $[0.511 \pm 0.005 \pm 0.006]\ \text{ps}^{-1}$ (140 fb^{-1})
  - Compatible the Belle result

- Signal extraction



-Δt distribution



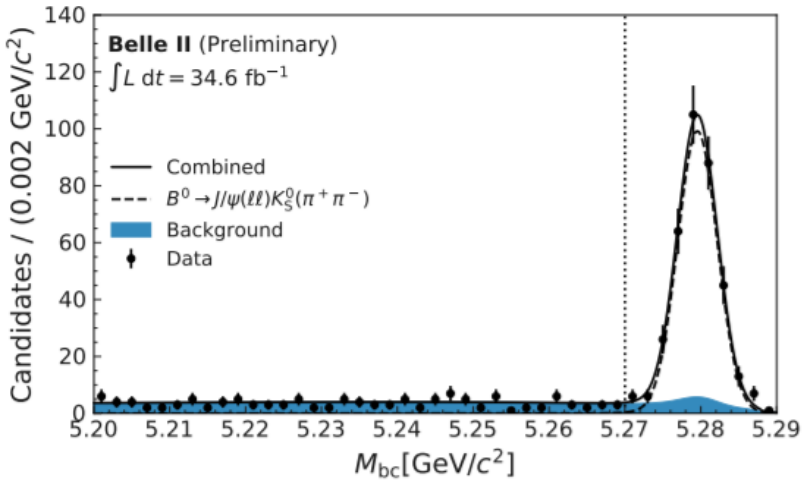
Time-dependent mixing parameter ($\sin 2\phi_1$)

- Measurement of $\sin 2\phi_1$
  - Interference between $B\bar{B}$ mixing and CP eigenstate decay
  - $b \to c\bar{c}s$ tree dominant decay
  - $A_{CP}(\Delta t) = \frac{P(\bar{B}^0_{tag}) - P(B^0_{tag})}{P(\bar{B}^0_{tag}) + P(B^0_{tag})} = \sin 2\phi_1 \sin(\Delta m_d \Delta t)$

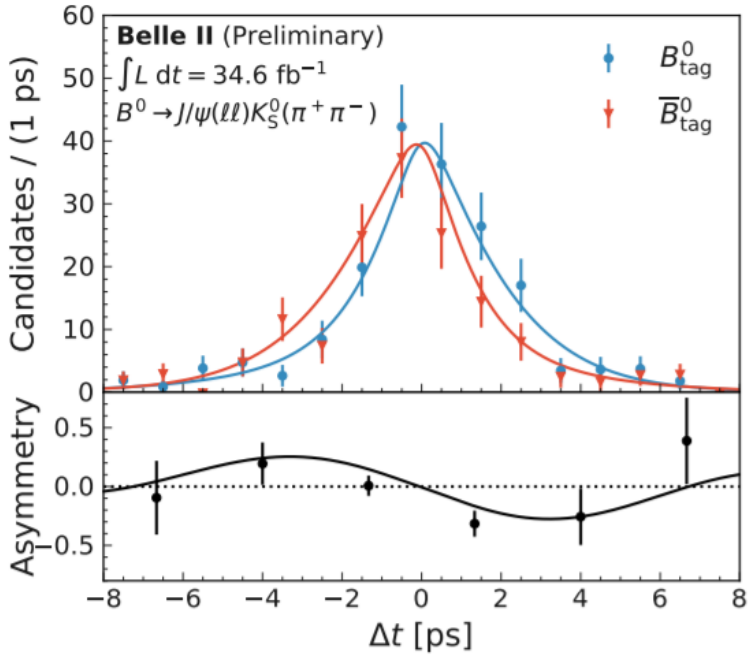
- Data set: 34.6 fb^{-1}
  - $B^0 \to J/\psi(ll)K^0_S(\pi^+\pi^-)$, where $ll = ee,\ \mu\mu$

- Results
  - $\sin 2\phi_1 = 0.55 \pm 0.21(stat.) \pm 0.04(syst.)$
  - PDG = 0.699 ± 0.017 (from $b \to c\bar{c}s$)
  - Belle = $0.670 \pm 0.0.029 \pm 0.013]$ (711 fb^{-1})
  - Compatible with PDG and Belle result

- Signal extraction



-Δt distribution



Charmless B decays

- $B \to \pi\pi$

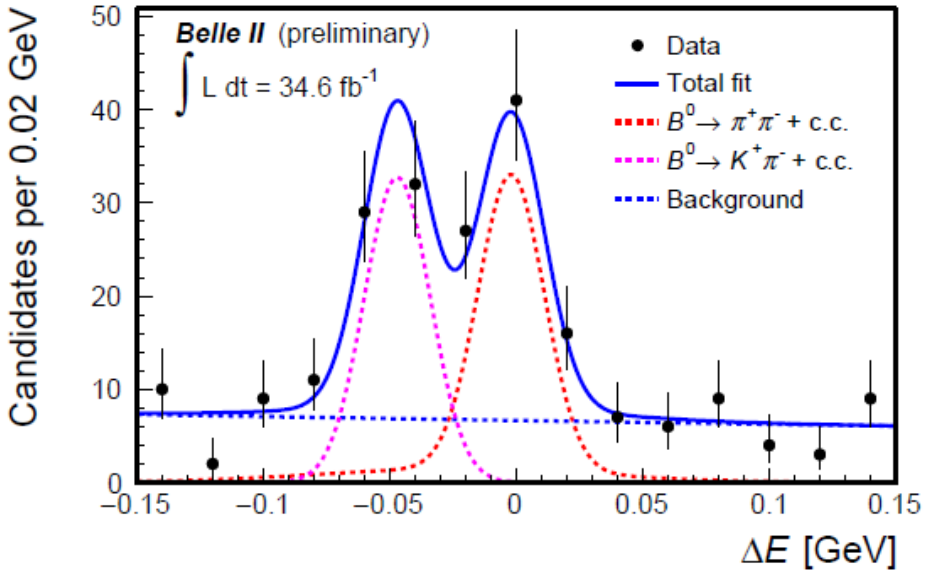
- CKM angle ϕ_2
  - interference between $b \to ud\bar{u}$ tree and $b \to dq\bar{q}$ penguin diagram
  - $B \to \pi\pi$ and $B \to \rho\rho$

- Isospin method for determine ϕ_2
  - $S_{\pi^+\pi^-} = \sqrt{1 - C^2_{\pi^+\pi^-}} \sin(2\phi_2 + 2\Delta\phi_2)$
  - $B^0 \to \pi^+\pi^-, B^0 \to \pi^0\pi^0,\ B^+ \to \pi^+\pi^0$

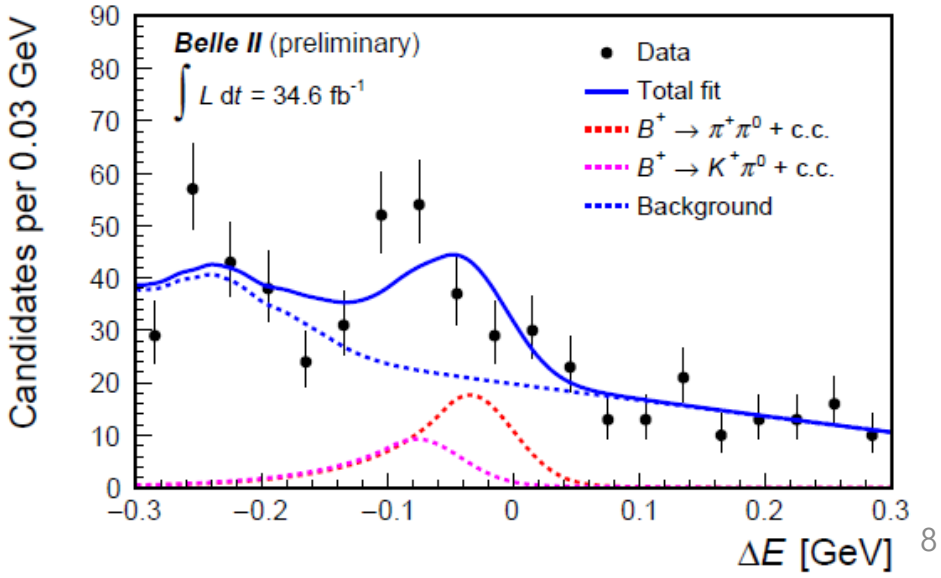
- PDG vlue of $\phi_2 = [84.9^{+5.1}_{-4.5}]°$

arXiv:2009.09452

- ΔE distribution for $B^0 \to \pi^+\pi^-$



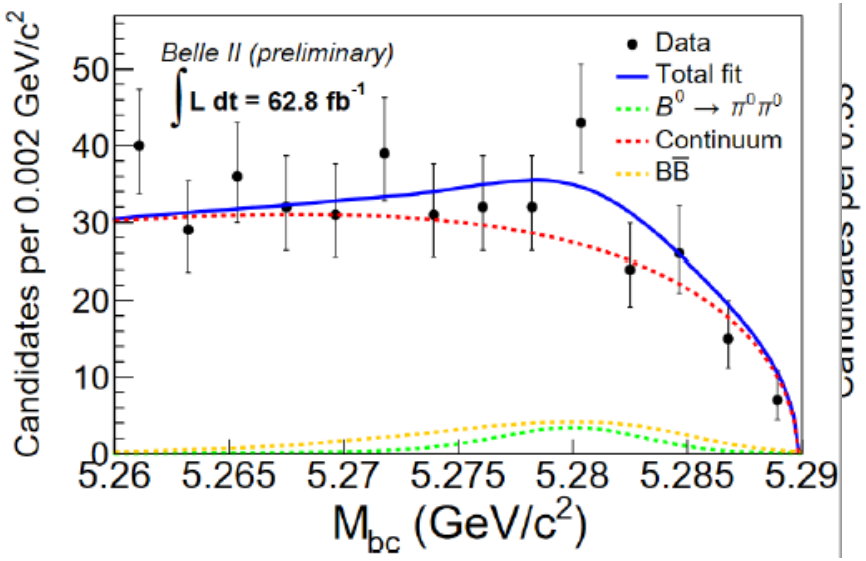
- ΔE distribution for $B^+ \to \pi^+\pi^0$

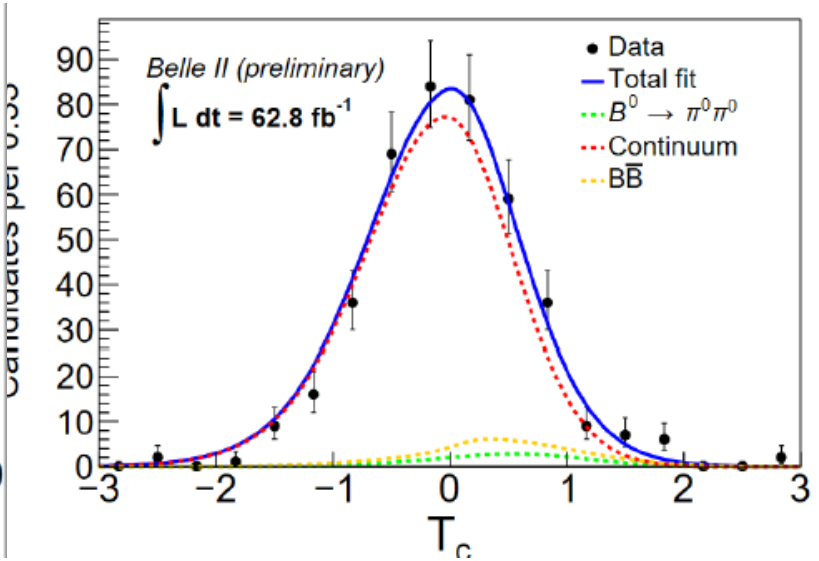


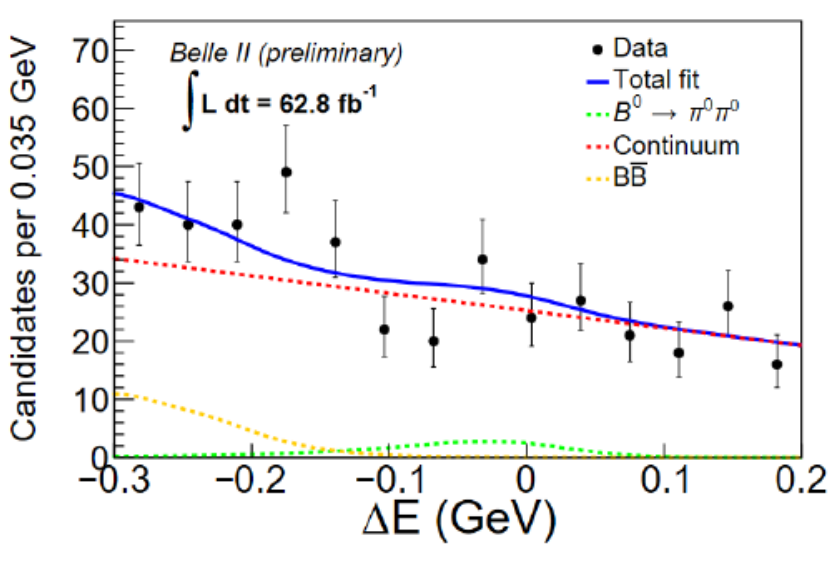
Charmless B decays

- $B \to \pi\pi$

- ΔE & M_{bc} & MVA output distribution for $B^0 \to \pi^0\pi^0$







- Result
  - $B\,(B^0 \to \pi^+\pi^-) = [5.6^{+1.0}_{-0.9}(stat.) \pm 0.3(syst.)] \times 10^{-6}$
  - $B\,(B^+ \to \pi^+\pi^0) = [5.7 \pm 2.3(stat.) \pm 0.5(syst.)] \times 10^{-6}$
  - $B(B^0 \to \pi^0\pi^0) = [0.98^{+0.48}_{-0.39}(stat.) \pm 0.27(syst.)] \times 10^{-6}$
  - Compatible with PDG

PDG

$(5.12 \pm 0.19) \times 10^{-6}$

$(5.5 \pm 0.4) \times 10^{-6}$

$(1.59 \pm 0.26) \times 10^{-6}$

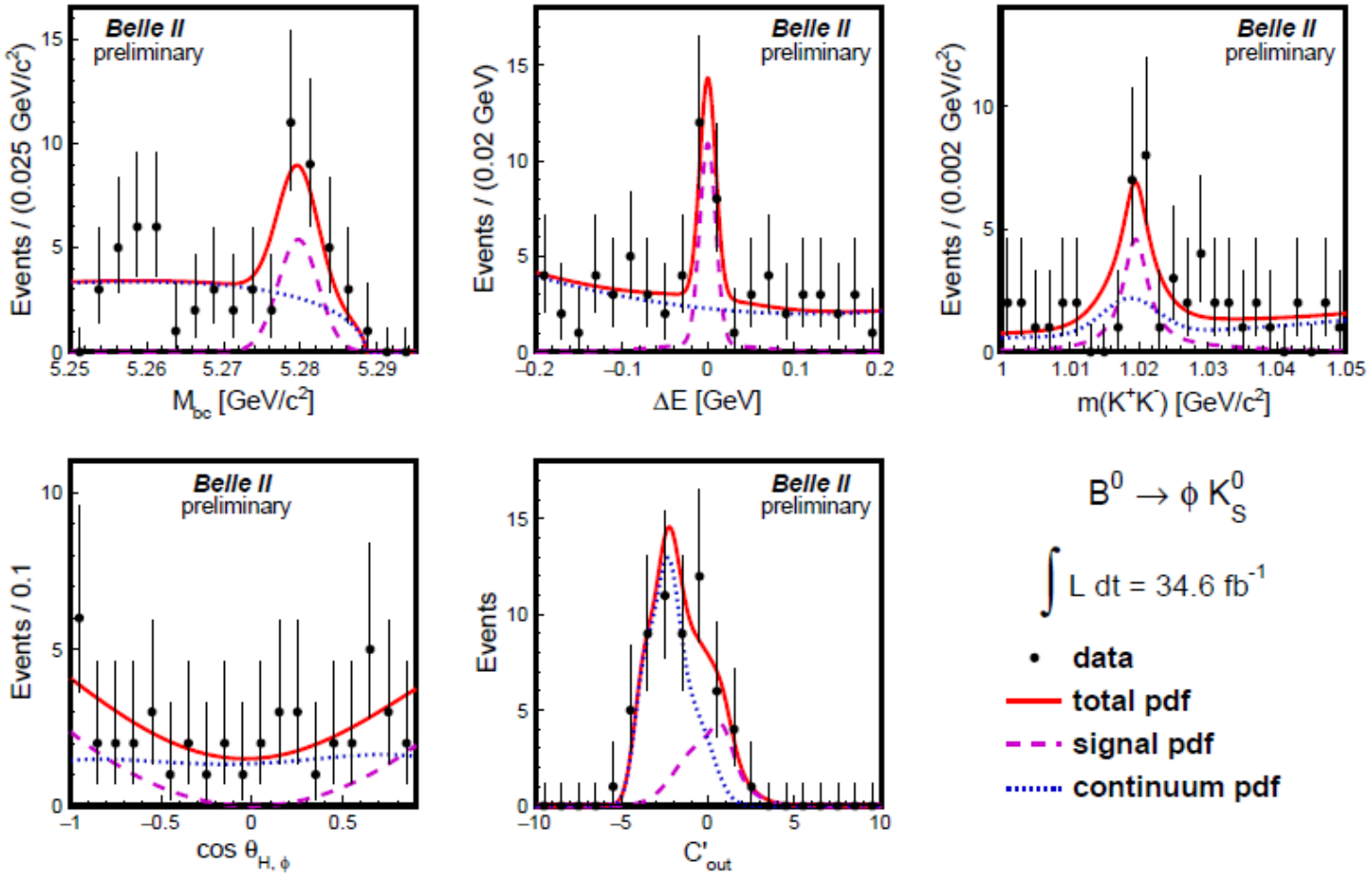
Charmless B decays - $B \to \phi K^0$

arXiv:2008.03873

- Measurement of $\sin 2\phi_1^{eff}$
  - $b \to sq\bar{q}$ penguin decay
- Results
  - $B(5.9 \pm 1.8 \pm 0.7) \times 10^{-6}$
  - PDG:$B(7.3 \pm 0.7) \times 10^{-6}$
  - Compatible with PDG
- TCPV study will be performed
  - To compare with $B \to J\psi/K^0$

Data set: 34.6 fb^{-1}

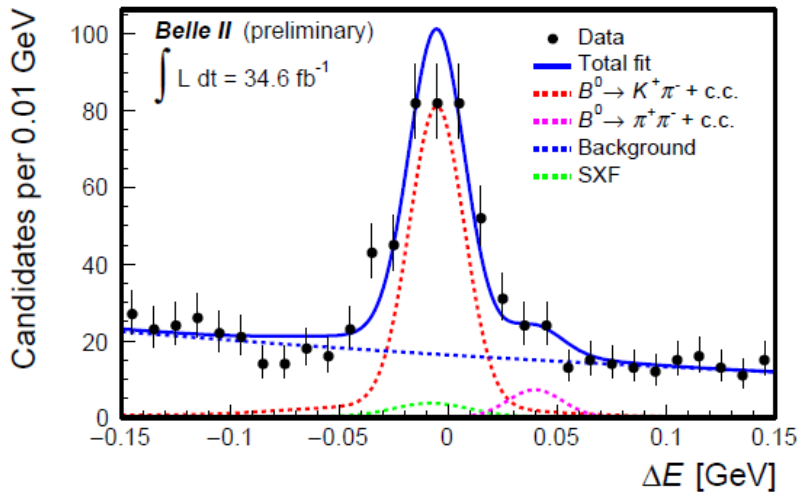
5D fit ($\Delta E, M_{bc}, MVA\ output, m(K^+K^-), \cos\theta_{H,\phi}$)



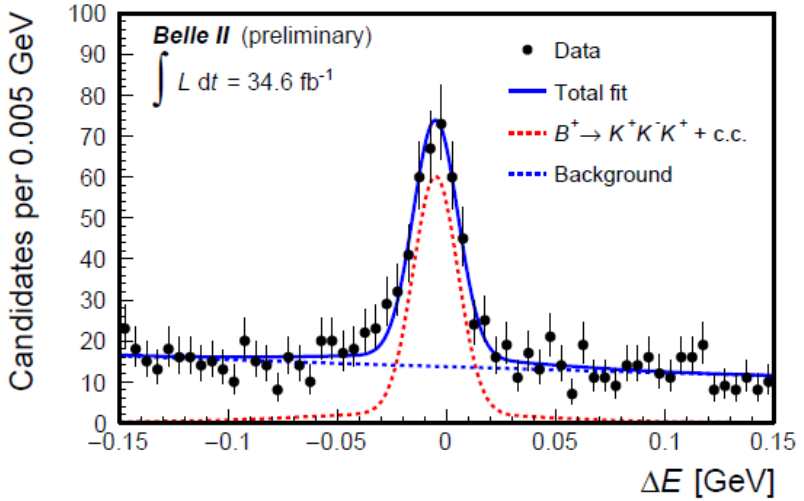
Charmless B decays
- B → $K\pi, B \to Khh$

arXiv:2009.09452

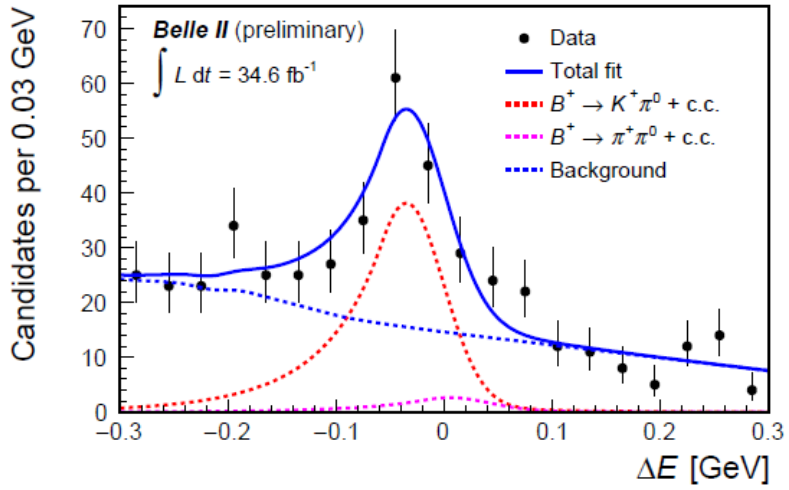
- ΔE distribution for $B^0 \to K^+\pi^-$



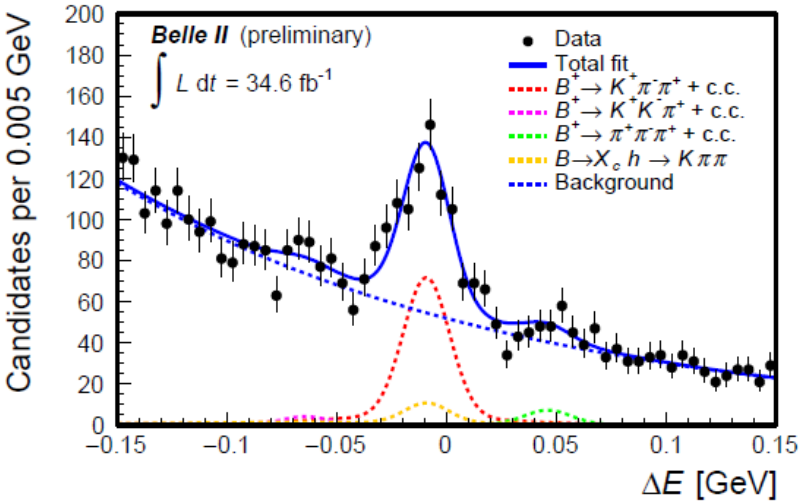
- ΔE distribution for $B^+ \to K^+K^-K^+$



- ΔE distribution for $B^+ \to K^+\pi^0$



- ΔE distribution for $B^+ \to K^+\pi^-\pi^+$



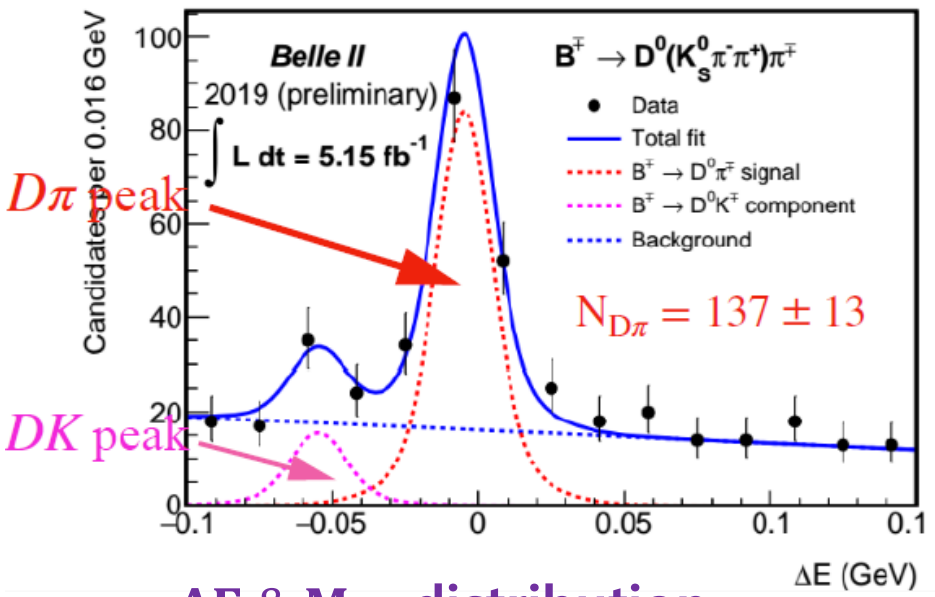
Measurement of ϕ_3

- CKM angle ϕ_3
  - interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$
  - $\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} = r_B e^{i(\delta_B - \phi_3)}$
  - Dalitz-plot GGSZ analysis

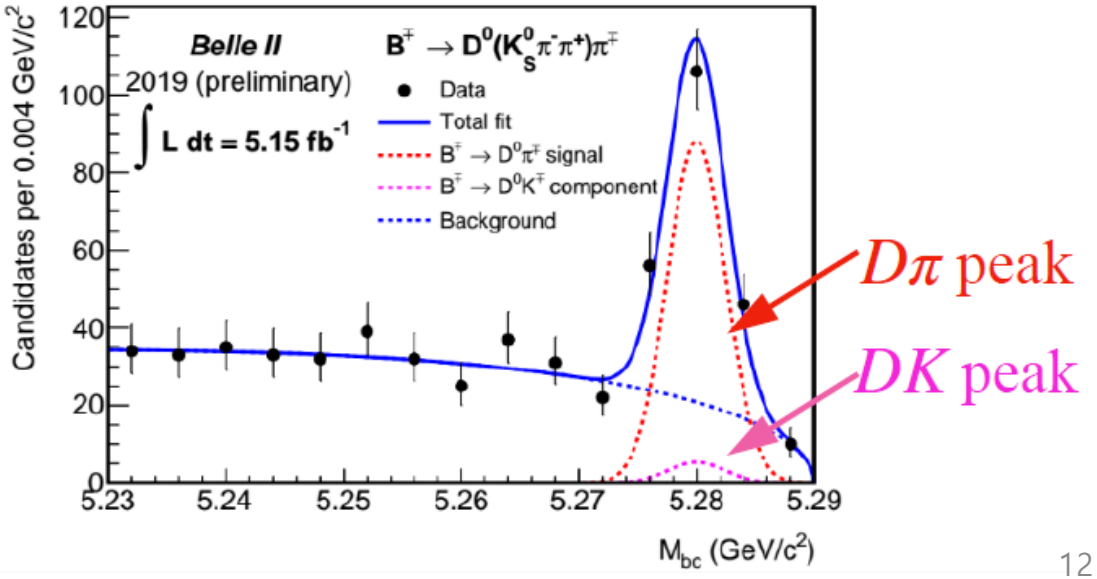
- Data set: 5.15 fb^{-1}
  - Control sample: $B^\pm \to D^0\left(K_S^0\pi^+\pi^-\right)\pi^\pm$

- Results
  - Control sample can be measured
  - Belle = $[77.3^{+15.1}_{-14.9}(stat.) \pm 4.1(syst.) \pm 4.3]°$
  - PDG = $[72.1^{+4.1}_{-4.5}]°$

Due to the precision of strong phase



-ΔE & M_{bc} distribution

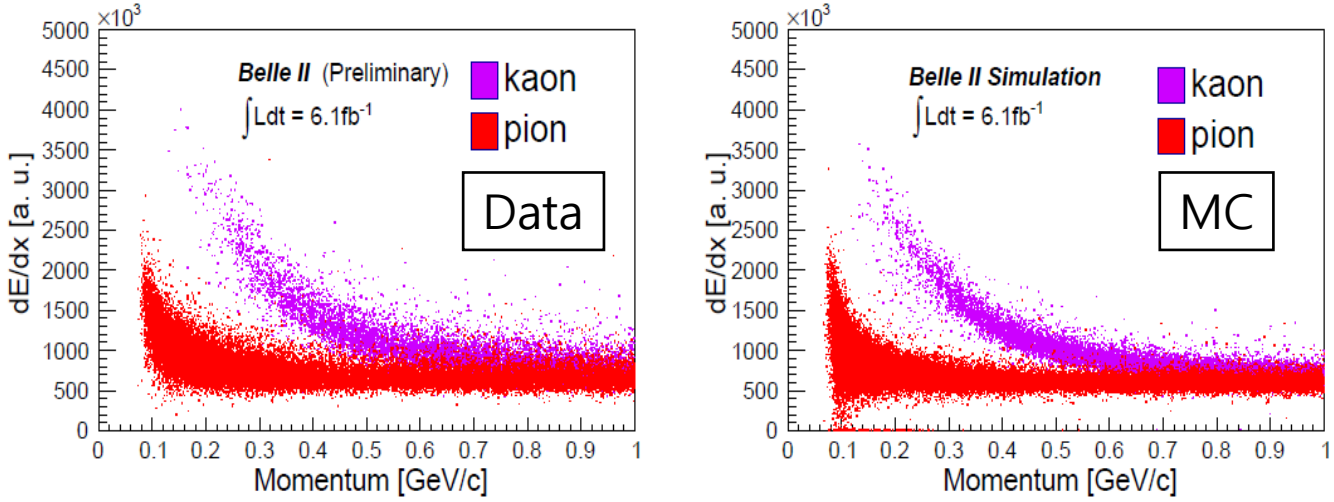


Low-momentum charged hadron identification

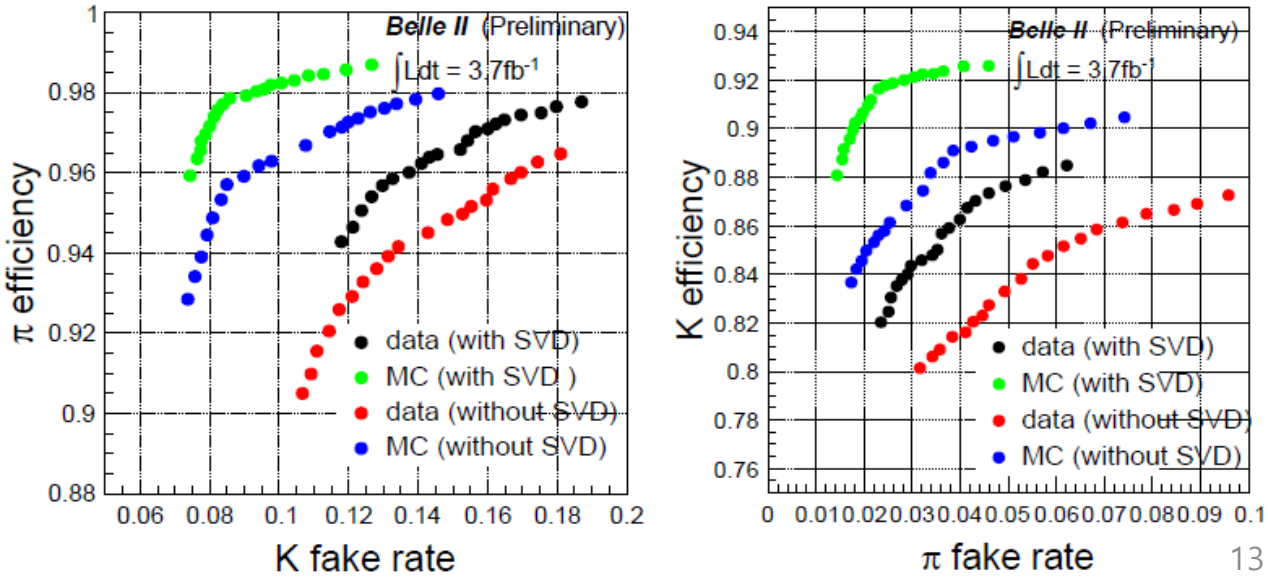
- Improvement of particle identification (PID) using dE/dx from SVD
  - Low momentum charged particle
  - Main PID detectors: CDC, TOP, and ARICH
  - $D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+$ and $\Lambda \rightarrow p\pi$

- Results
  - Improvement of the overall PID performance in the low mentum region

-dE/dX vs p_t scatter plot

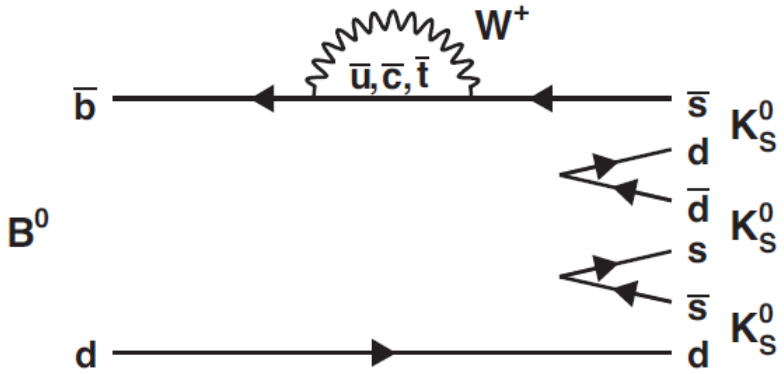


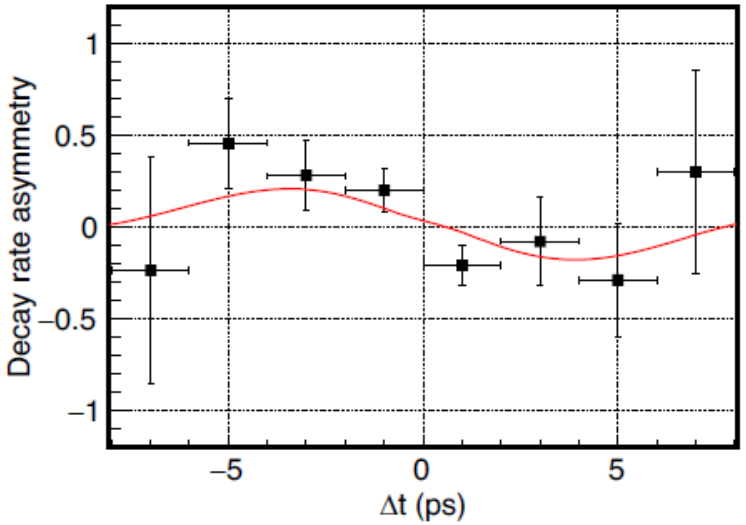
- $\pi(K)$ efficiency vs $K(\pi)$ fake rate ($p < 1$ GeV/c)



Time-dependent mixing parameter ($\sin 2\phi_1$) – $B^0 \to K_S^0 K_S^0 K_S^0$ (Belle result)

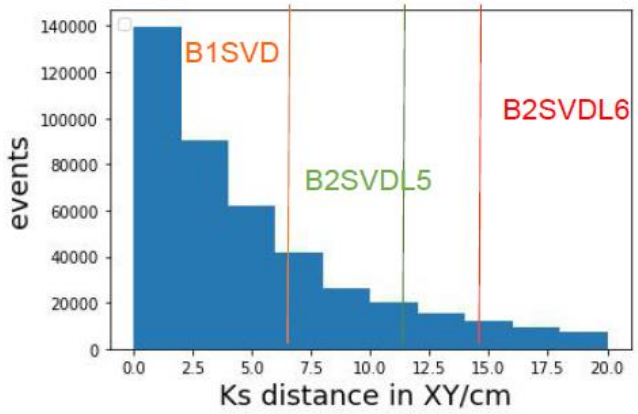
PRD103, 032003



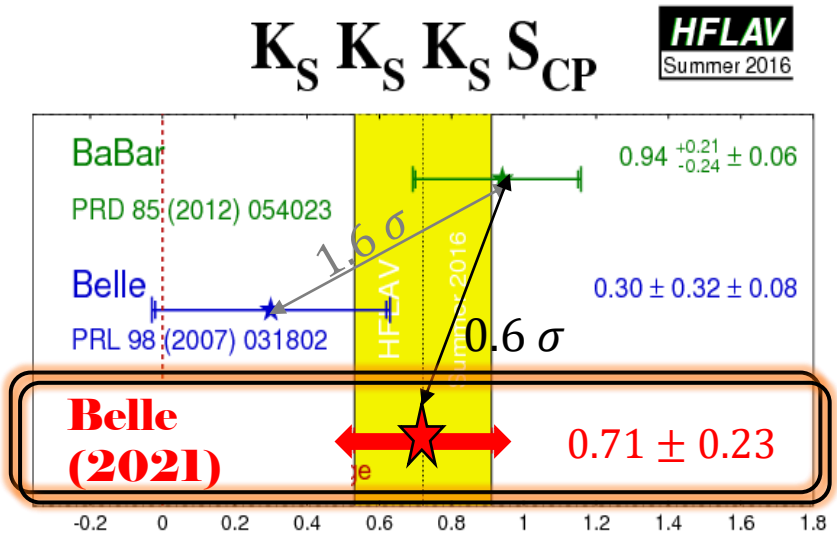


-Decay rate asymmetry

Pure $b \to sq\bar{q}$ penguin transition by loop diagram
→ Sensitive to new physics

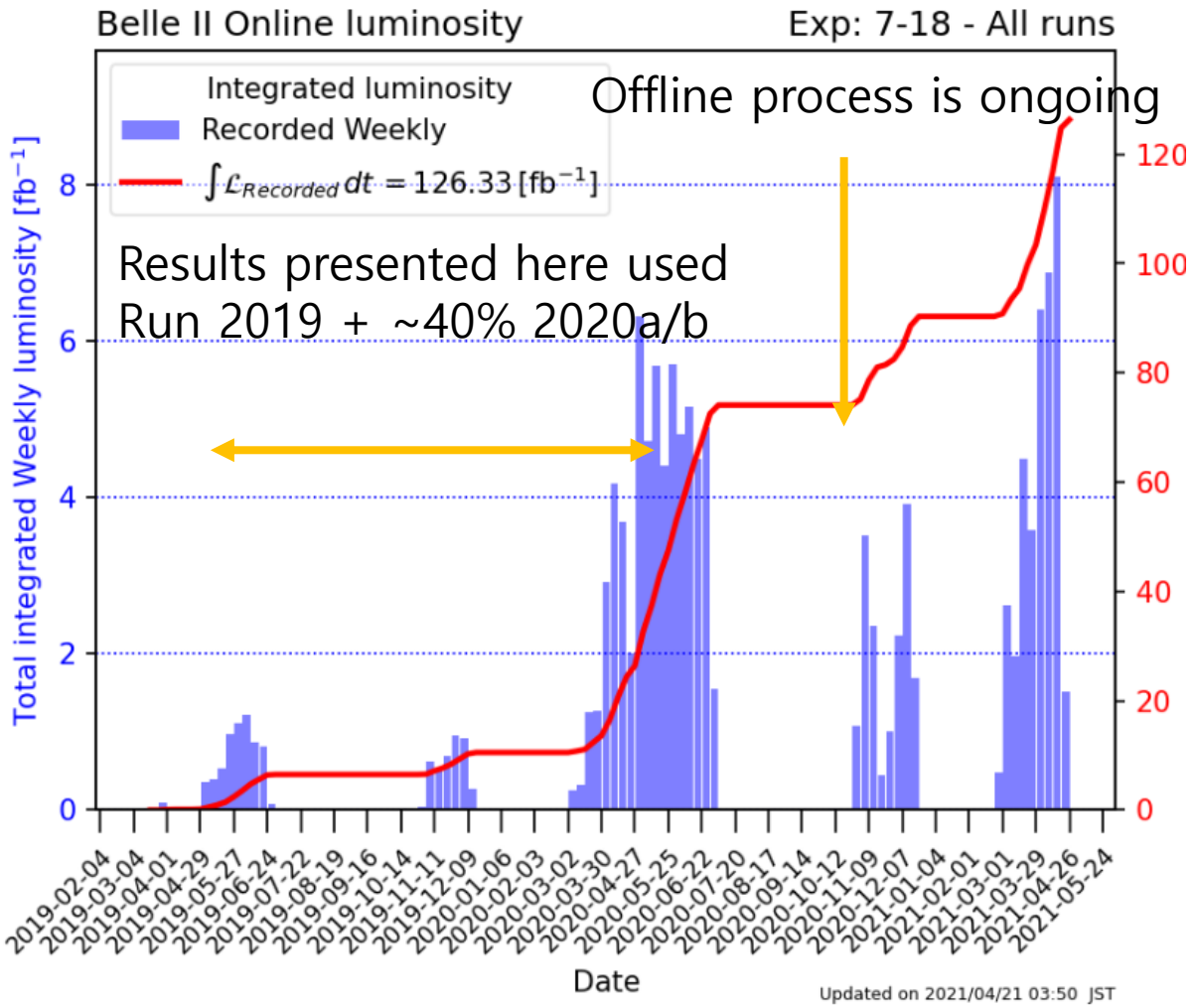


K_S^0 flight length in SVD



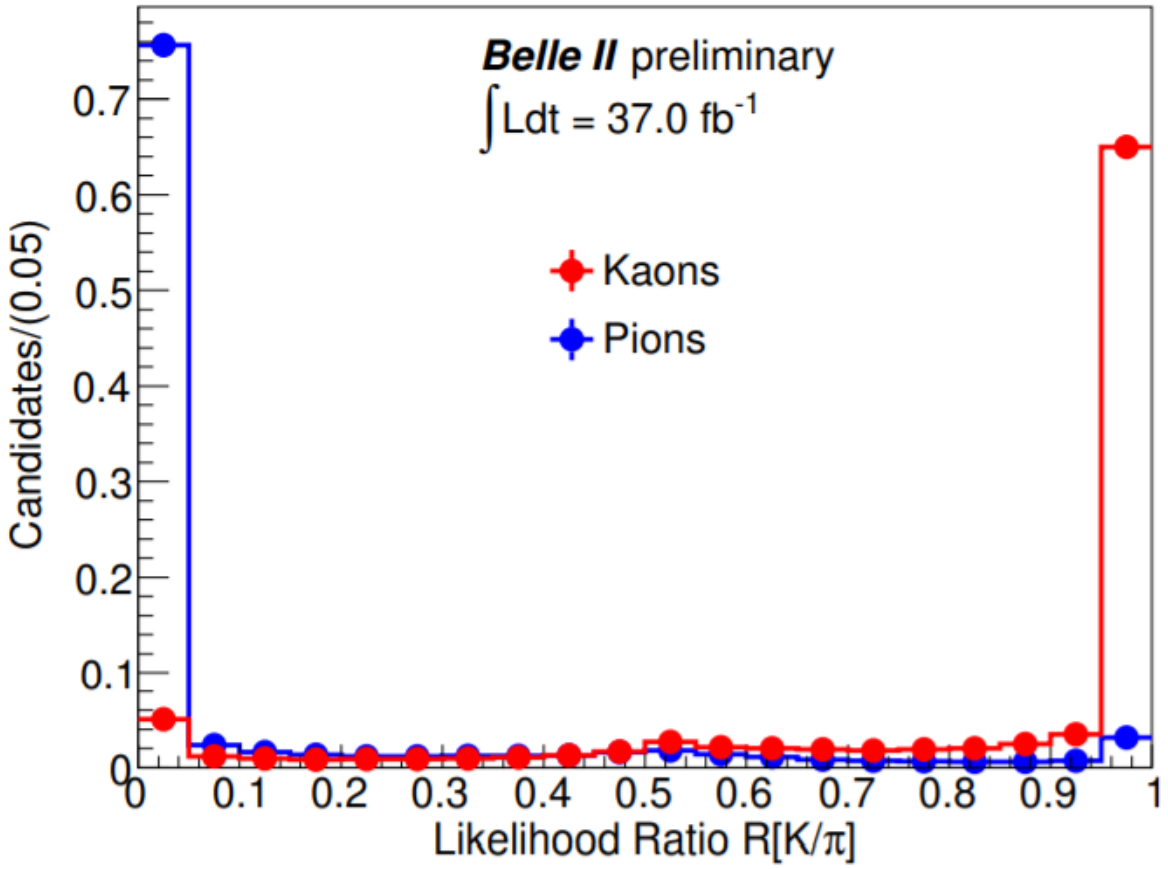
Summary

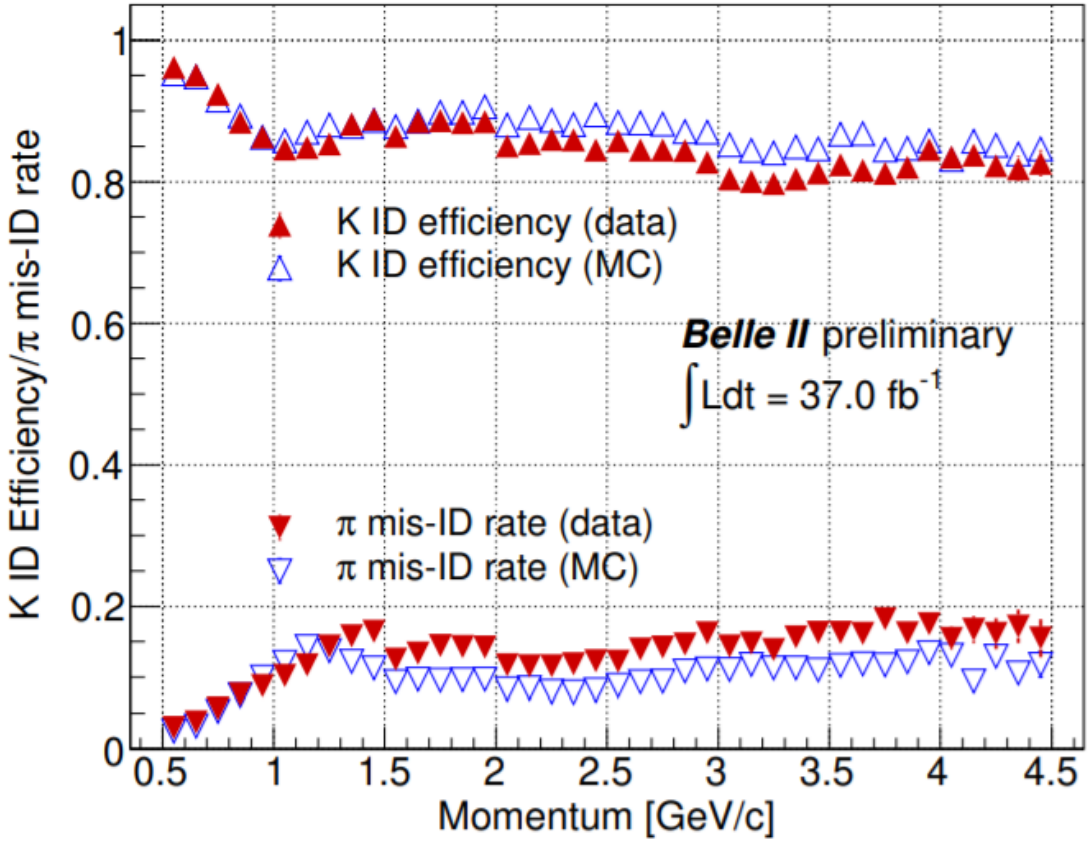
- Measurement results to extract CKM angles are comparable with Belle
- Belle II aims to collect 50 ab^{-1} data (Belle: ~1 ab^{-1})
- Improvement of detector and analysis tools is ongoing



Backup

PID performance



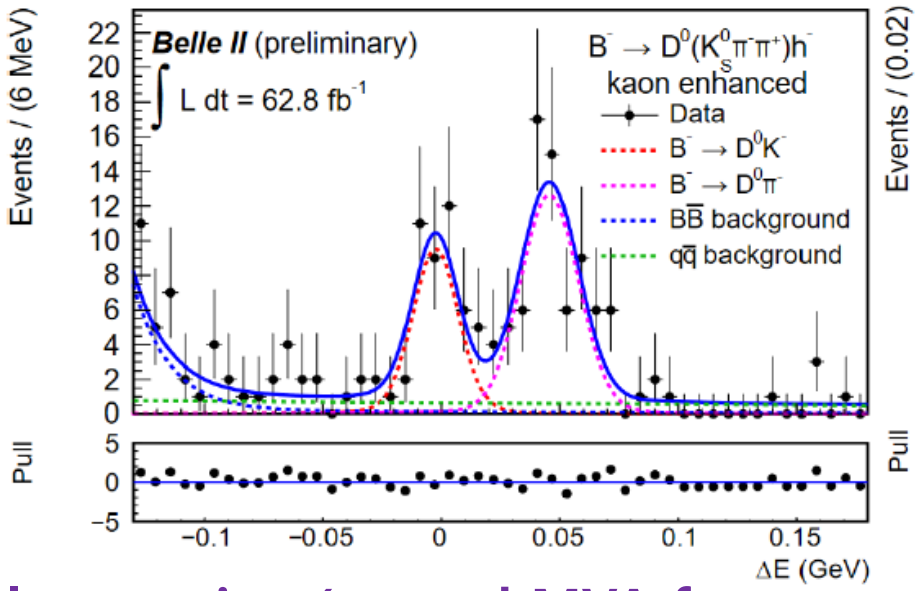


ϕ_3 measurement

- CKM angle ϕ_3
  - Appears in the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$
  - $\frac{A(B^- \to \bar{D}^0 K^-)}{A(B^- \to D^0 K^-)} = r_B e^{i(\delta_B - \phi_3)}$
  - Dalitz-plot GGSZ analysis

- Data set: $62.8\ \text{fb}^{-1}$
  - $B^- \to D^0 h^-,\ h^- = K, \pi$

- Results
  - $\frac{\Gamma(B^- \to D^0 K^-)}{\Gamma(B^- \to D^0 \pi^-)} = [6.23 \pm 0.81^{+0.09}_{-0.11}] \times 10^{-2}$



- Signal extraction (ΔE and MVA for qq sup.)