Recent Belle II results on hadronic B decays

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On behalf of the Belle II Collaboration

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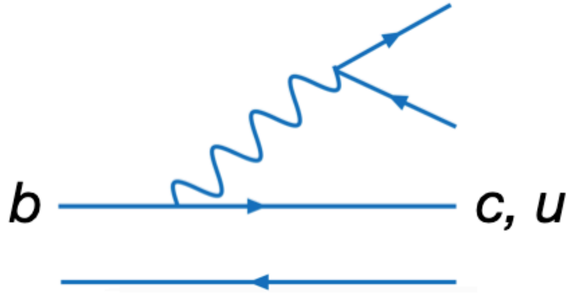
Hadronic B decays

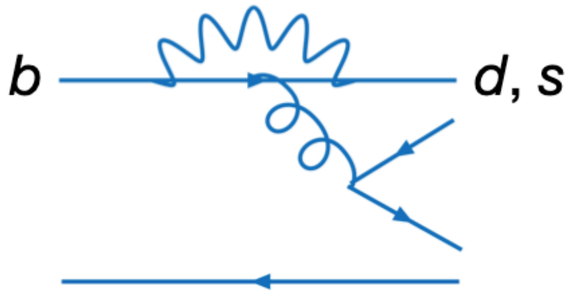
$b \to c, u$ trees and $b \to d, s$ penguins.



Measure all three CKM angles:

- ϕ_1 with $B^0 \to J/\psi K_S^0, B^0 \to \phi K_S^0, B^0 \to K_S^0 K_S^0 K_S^0, B^0 \to K_S^0 \pi^0 \ldots$
- ϕ_2 with $B \to \rho\rho, B \to \pi\pi$ isospin analysis,
- ϕ_3 with $B^\pm \to DK^\pm$, few different methods,

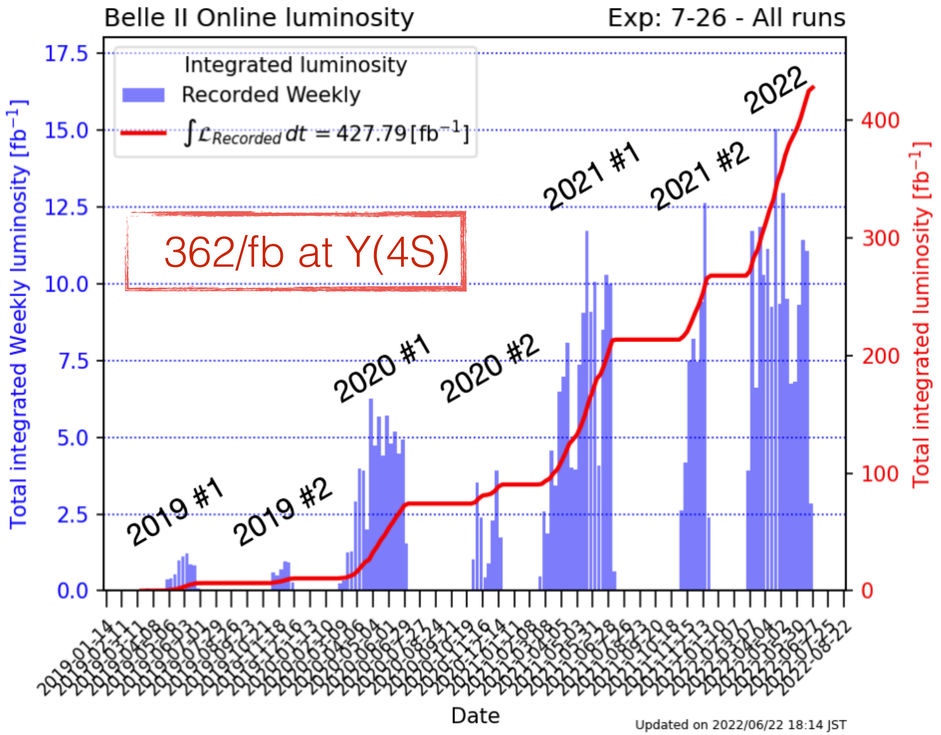
and test Isospin sum rules, …



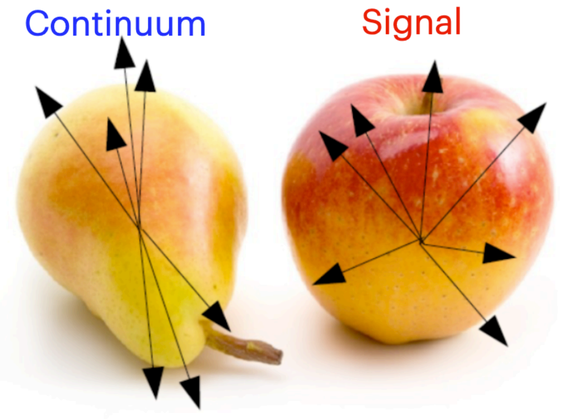
In my talk:

- ϕ_3 results with GLW and GLS methods,
- ϕ_2 results with $B \to \pi\pi$,
- $K\pi$ sum rule test,
- observation of new $B \to D^{(*)} K^- K_S^0$ decays.

For ϕ_1 results: see Michele's talk today 2:45 PM@Flavour.



Analysis workflow



~20% of hadronic events from e^+e^- are $B\bar{B}$.

10 tracks/clusters on average → easy to trigger on unbiasing variables (e.g. number of tracks)

Main backgrounds: $e^+e^- \to q\bar{q}$ (collimated jets); B process due to misID.

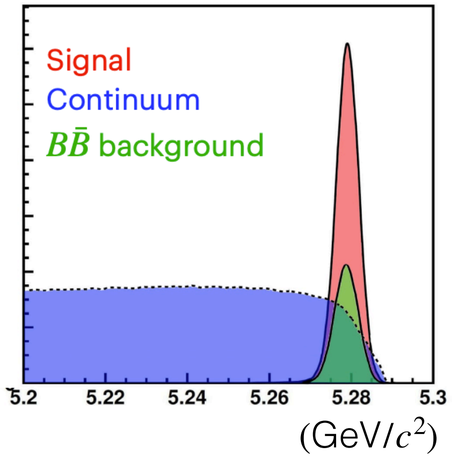
Reconstruction: all final state particle formed to B meson

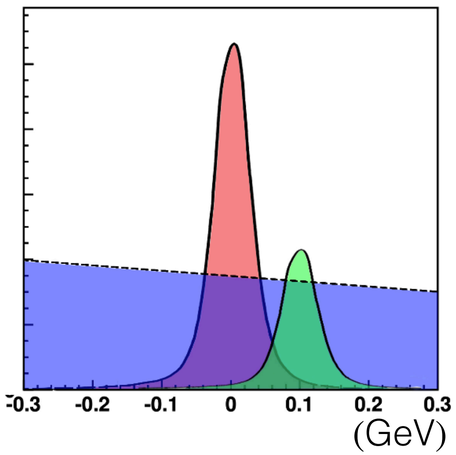
Selection: event-shape variables based classifier to suppress $q\bar{q}$ background; particle ID criteria

Fit: usually on ΔE, M_{bc}classifier output (C'), etc…

Systematic uncertainties: toy studies, control modes

Validation & unblinding: validate the full analysis on a control channel; frozen all procedure when open box.



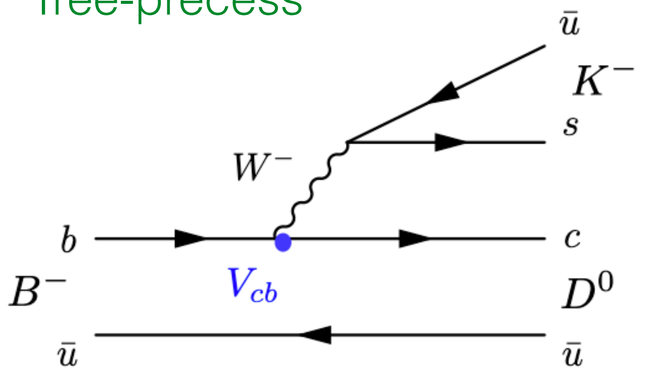


$M_{\mathrm{bc}} = \sqrt{s/4 - p_B^{*2}}$ $\Delta E = E_B^* - \sqrt{s}/2$

well-known knowledge of initial state

ϕ_3 from $B^{\pm} \to DK^{\pm}$ decays

Tree-precess



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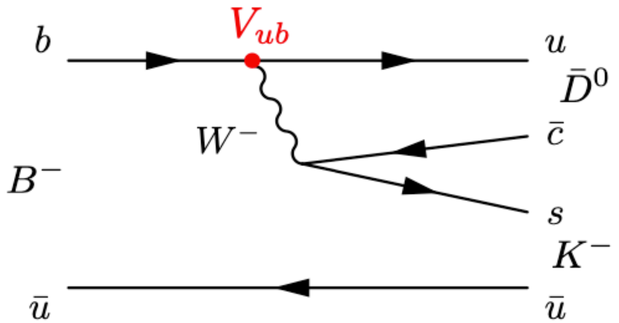
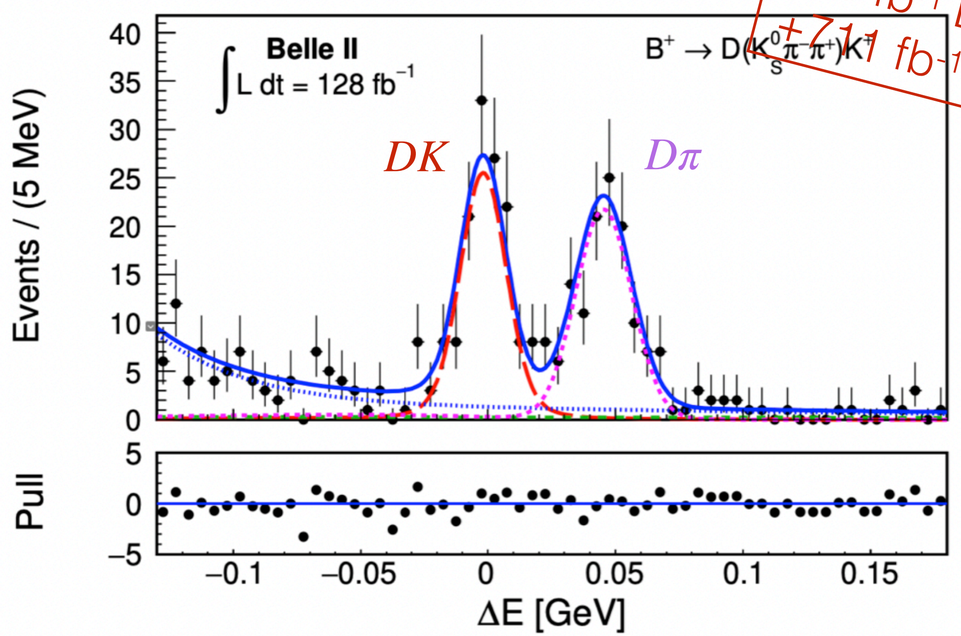


suppressed

- CPV in the interference between $b \to c\bar{u}s$ and $b \to u\bar{c}s$
- Irreducible error in SM calculation ~10^{-7} [arXiv:1308.5663]
- W.A. $\phi_3 = (65.9^{+3.3}_{-3.5})°$ [HFLAV], dominated by LHCb.

- Depends on the D decay final states, different methods:
  - BPGGSZ: self conjugated multi-body decays, e.g. $K^0_S h^+ h^-$
  - GLW: CP eigenstates, e.g. $K^0_S \pi^0, K^+K^-$
  - GLS: SCS decays, e.g. $K^0_S K^{\mp}\pi^{\pm}$
  - ADS: CF & DCS decays, e.g. $K^{\mp}\pi^{\pm}$
  - …



$\phi_3 = (78.4 \pm 11.4 \pm 0.5 \pm 1.0)°$

[JHEP 02 2022, 063 (2022)]

ϕ_3 with GLW method (CP eigenstates)

189 fb^{-1} Belle II + 711 fb^{-1} Belle

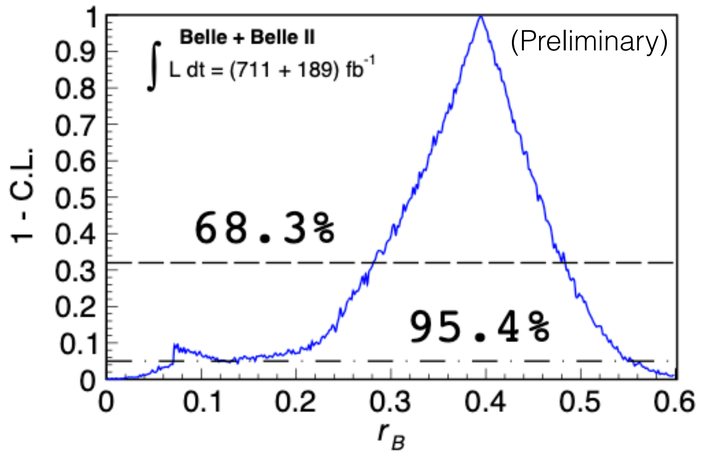
$B^\pm \to DK^\pm$ with $D \to K^+K^-$ (CP-even) or $D \to K^0_S\pi^0$ (CP-odd)

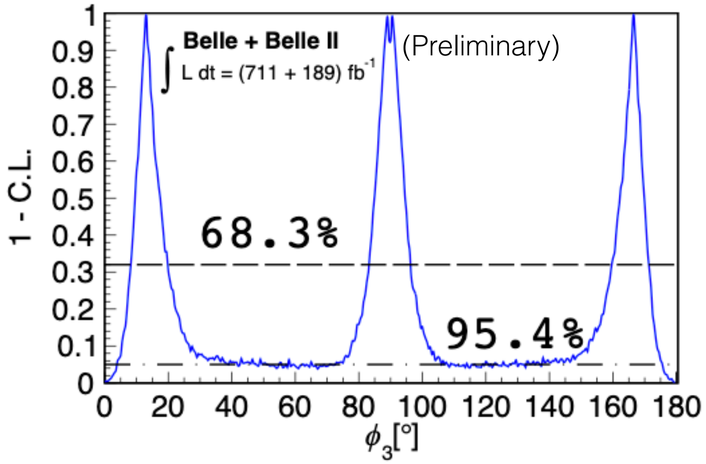
Belle(II)'s advantage

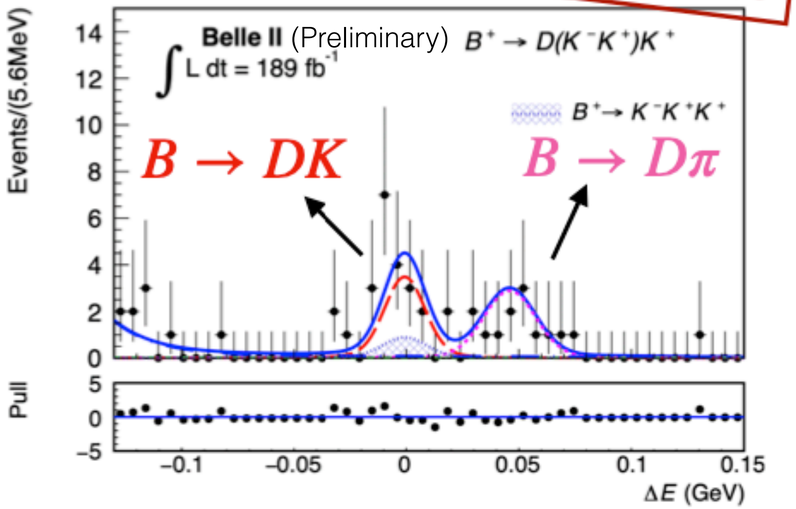
$$R_{CP\pm} = \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D^0K^-) + \mathcal{B}(B^+ \to \bar{D}^0K^+)}$$

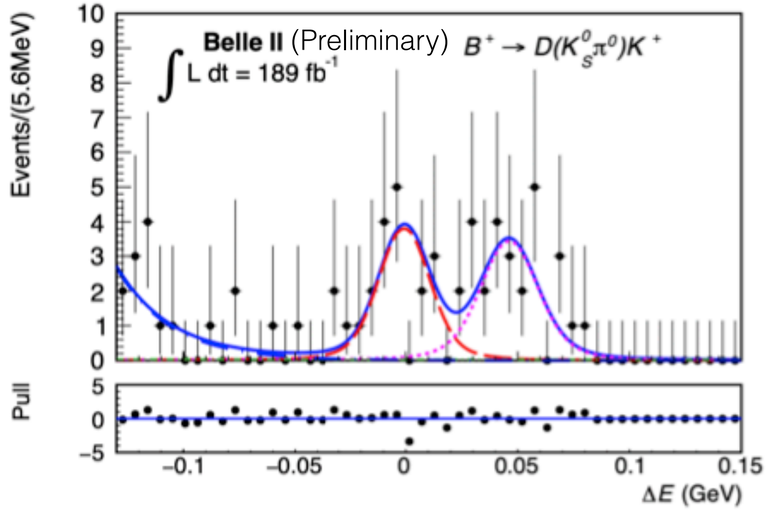
$$A_{CP\pm} = \frac{\mathcal{B}(B^- \to D_{CP\pm}K^-) - \mathcal{B}(B^+ \to D_{CP\pm}K^+)}{\mathcal{B}(B^- \to D_{CP\pm}K^-) + \mathcal{B}(B^+ \to D_{CP\pm}K^+)}$$

$$\mathcal{R}_{CP+} = 1.164 \pm 0.081 \pm 0.036,$$
$$\mathcal{R}_{CP-} = 1.151 \pm 0.074 \pm 0.019,$$
$$\mathcal{A}_{CP+} = (+12.5 \pm 5.8 \pm 1.4)\%,$$
$$\mathcal{A}_{CP-} = (-16.7 \pm 5.7 \pm 0.6)\%.$$









World average: $\phi_3 = (65.9^{+3.3}_{-3.5})^\circ$, $r_B = 0.0994 \pm 0.0026$

Evidence for difference in $A_{CP\pm}$. (3.5 σ)

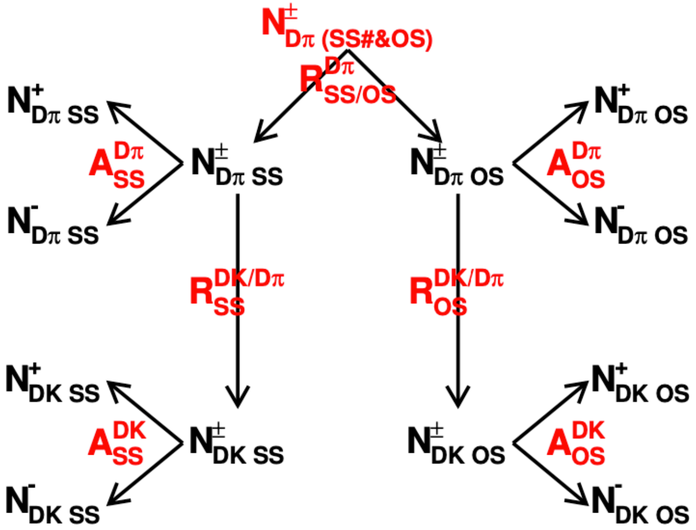
Large R_{CP+} compare to W.A. → large r_B, but consistent with W.A. in 2.5 σ.

ϕ_3 with GLS method (SCS)

$B^{\pm} \to DK^{\pm}, D\pi^{\pm}$ with $D \to K^0_S\, K^{\pm}\pi^{\mp}$: SS: same-sign, OS: opposite sign.

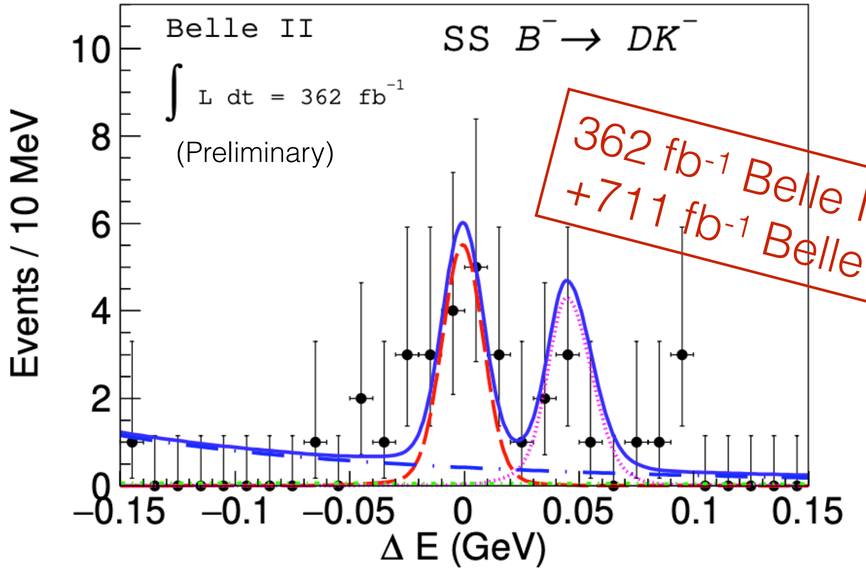
Two sets of results: in full D phase space and in the K*K region (expected large δ_D).

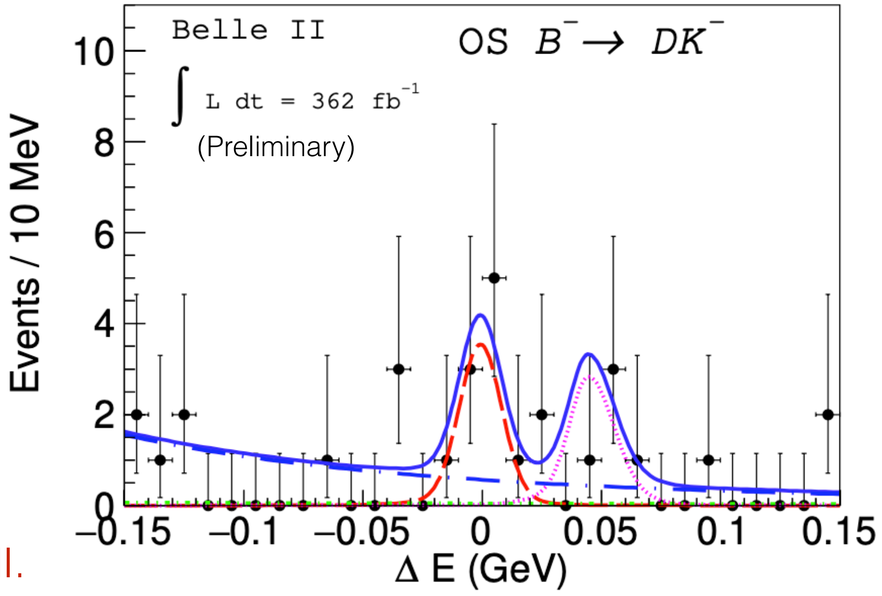
Measure 4 Acp and 3 BR ratios.



In K*K region:

$$A_{SS}^{DK} = 0.055 \pm 0.119 \pm 0.020,$$
$$A_{OS}^{DK} = 0.231 \pm 0.184 \pm 0.014,$$
$$A_{SS}^{D\pi} = 0.046 \pm 0.029 \pm 0.016,$$
$$A_{OS}^{D\pi} = 0.009 \pm 0.046 \pm 0.009,$$
$$R_{SS}^{DK/D\pi} = 0.093 \pm 0.012 \pm 0.005,$$
$$R_{OS}^{DK/D\pi} = 0.103 \pm 0.020 \pm 0.006,$$
$$R_{SS/OS}^{D\pi} = 2.412 \pm 0.132 \pm 0.019,$$





Consistent with LHCb's, but not competitive.

Contribute to constrain ϕ_3 in combination with other ϕ_3-results from Belle and Belle II.

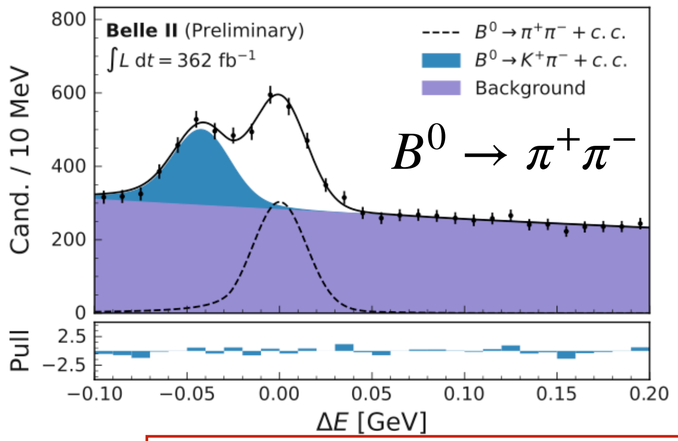
arXiv:2306.02940

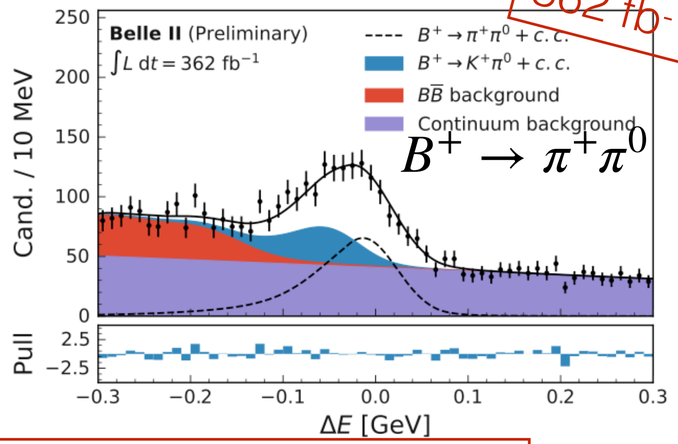
ϕ_2 results with $B \to \pi\pi$

Loop-process

- The CKM angle with most poor precision at the moment:
  W.A. $\phi_2 = (85.2^{+4.8}_{-4.3})^\circ$ [HFLAV].
- Determined using $B \to \rho\rho$, $B \to \pi\pi$ isospin analysis: using the Br and A_{CP} to reduce hadronic uncertainties.

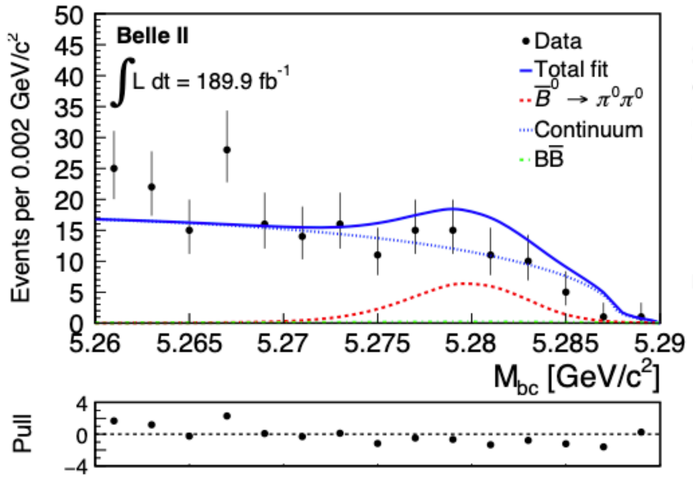
362 fb^{-1}

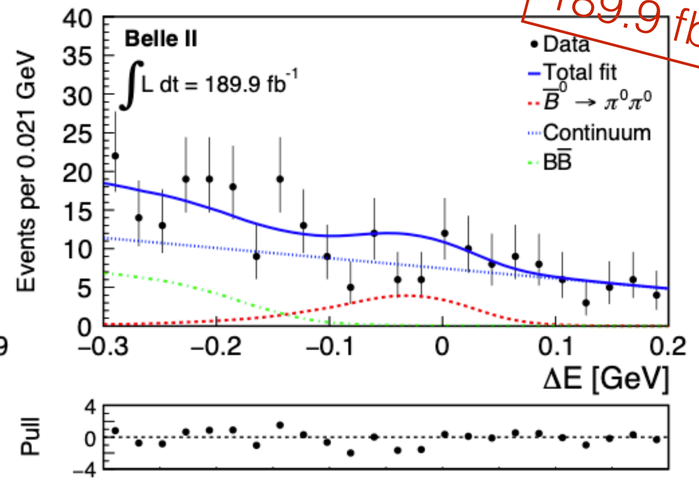




$$\mathrm{Br}(B^0 \to \pi^+\pi^-) = (5.83 \pm 0.22 \pm 0.17) \times 10^{-6}$$
$$\mathrm{Br}(B^+ \to \pi^+\pi^0) = (5.10 \pm 0.29 \pm 0.32) \times 10^{-6}$$
$$A_{CP}(B^+ \to \pi^+\pi^0) = -0.081 \pm 0.54 \pm 0.008$$

189.9 fb^{-1}





$$\mathrm{Br}(B^0 \to \pi^0\pi^0) = (1.38 \pm 0.27 \pm 0.22) \times 10^{-6}$$
$$A_{CP}(B^0 \to \pi^0\pi^0) = 0.14 \pm 0.46 \pm 0.07$$

Unique Belle II capability to study all channels.

Last year: $\rho^+\rho^0, \rho^+\rho^-$[arXiv:2206.12362, 2208.03554]

We have $\pi\pi$ results now.

For $\pi^0\pi^0$, achieve Belle Br precision using only 1/3 of data.

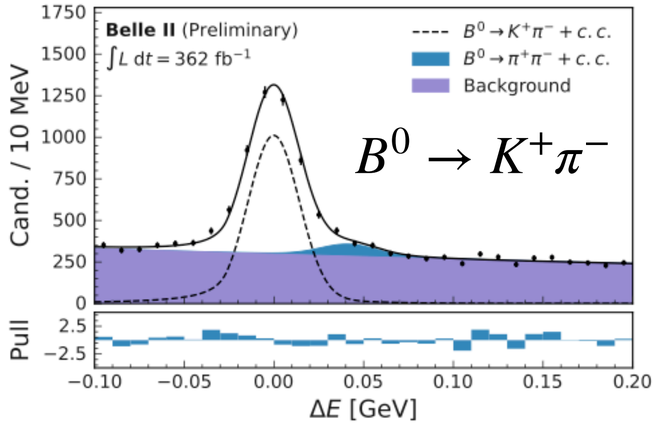
Phys. Rev. D 107, 112009 (2023)

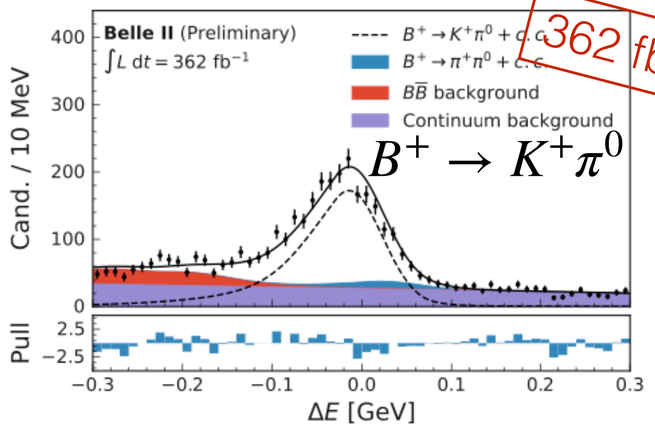
Isospin sum rule test in $K\pi$

arXiv:2207.06307

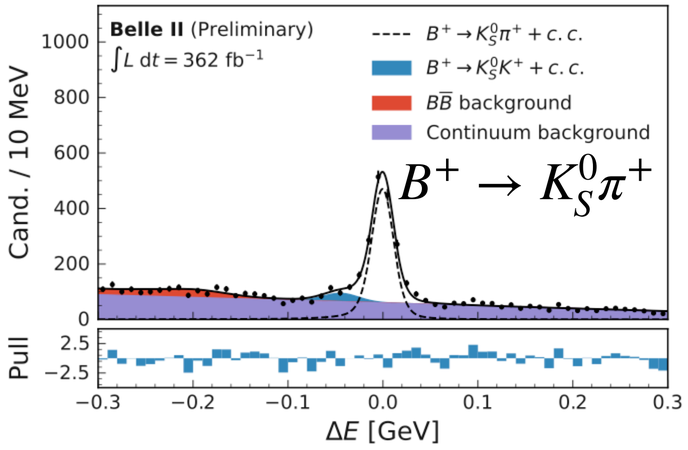
$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+} \cdot \frac{\mathcal{B}_{K^0\pi^+}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0} \cdot \frac{\mathcal{B}_{K^+\pi^0}}{\mathcal{B}_{K^+\pi^-}} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0} \cdot \frac{\mathcal{B}_{K^0\pi^0}}{\mathcal{B}_{K^+\pi^-}} \approx 0$$

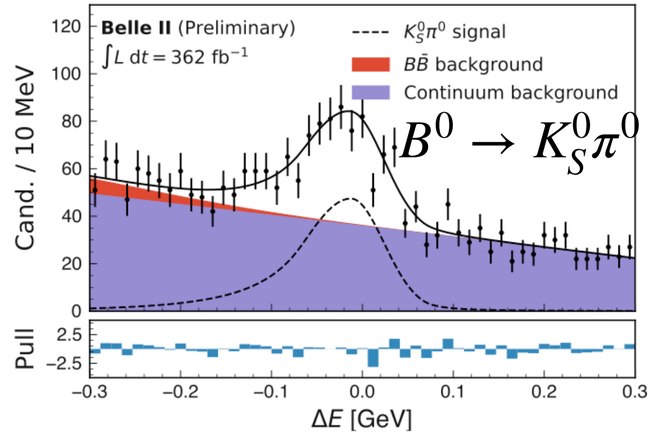
- SM prediction: 0 within 1% precision. [Phys. Lett. B627 (2005) 82-88]
- Current W.A.: $I_{K\pi} = -0.13 \pm 0.11$, major limitation from the $A_{K^0_S\pi^0}$.

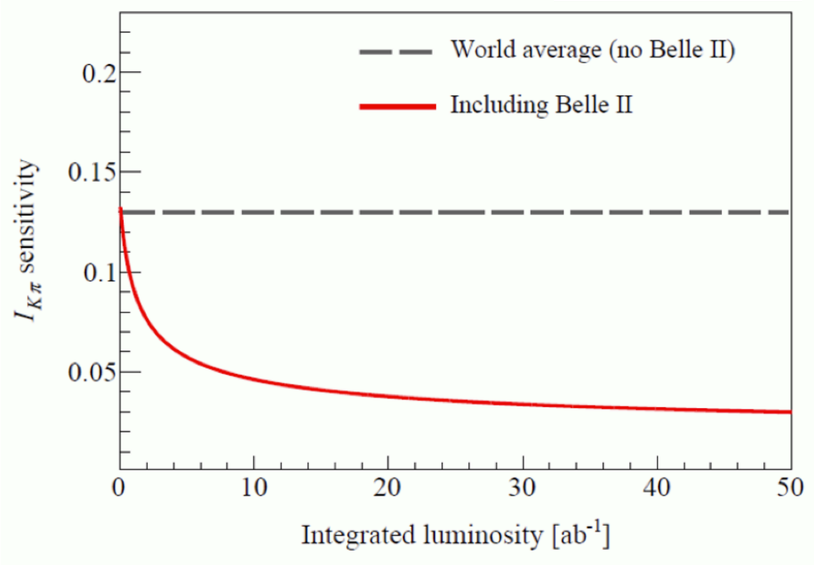




362 fb^{-1}







Belle II unique possibility!

Isospin sum rule test in $K\pi$

$B^0 \to K^+\pi^-$

Br = $(20.67 \pm 0.37 \pm 0.62) \times 10^{-6}$
$A_{CP} = -0.072 \pm 0.019 \pm 0.007$

$B^+ \to K^+\pi^0$

Br = $(14.21 \pm 0.38 \pm 0.85) \times 10^{-6}$
$A_{CP} = 0.013 \pm 0.027 \pm 0.005$

$B^+ \to K^0_S\pi^+$

Br = $(24.40 \pm 0.71 \pm 0.86) \times 10^{-6}$
$A_{CP} = 0.046 \pm 0.029 \pm 0.007$

$B^0 \to K^0_S\pi^0$

Br = $(10.16 \pm 0.65 \pm 0.65) \times 10^{-6}$
$A_{CP} = -0.06 \pm 0.15 \pm 0.05$

All results agree and are competitive with world's best.

Br systematically limited, major ones: π^0, $f^{+-/00}$.

$B^0 \to K^0_S\pi^0$ result combined with time-dependent analysis [arXiv:2206.07453]

→world's best $A_{CP}(K^0_S\pi^0) = -0.01 \pm 0.12 \pm 0.05$

$I_{K\pi} = -0.03 \pm 0.13 \pm 0.05$ (W.A. $I_{K\pi} = -0.13 \pm 0.11$)

Competitive precision to world's best with 362 fb^{-1} data set.

More details in Michele's talk today 2:45 PM@Flavour.

$B \to D^{(*)} K K_S^0$ study

$B \to D^{(*)} K K_S^0$ makes up few % BR, but only 0.28% measured.

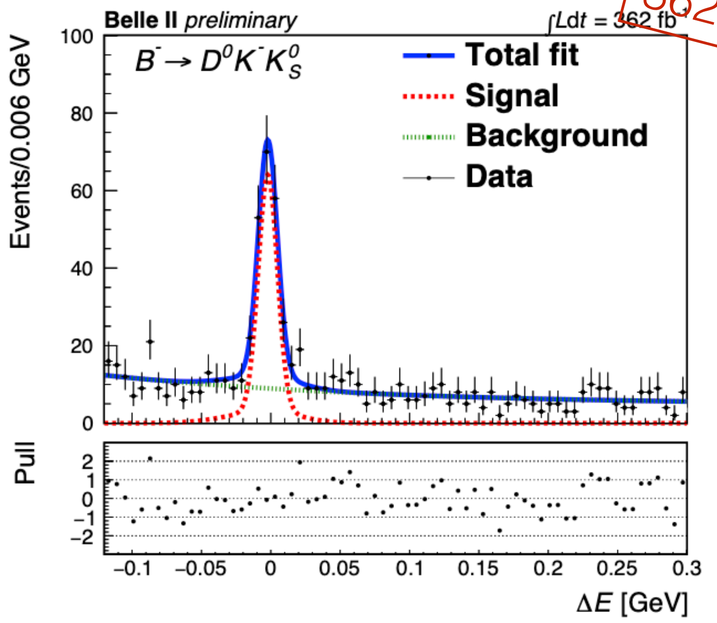
3 **new** observations modes (D^+, D^{*0}, D^{*-}); **x3** precision of D^0 mode.

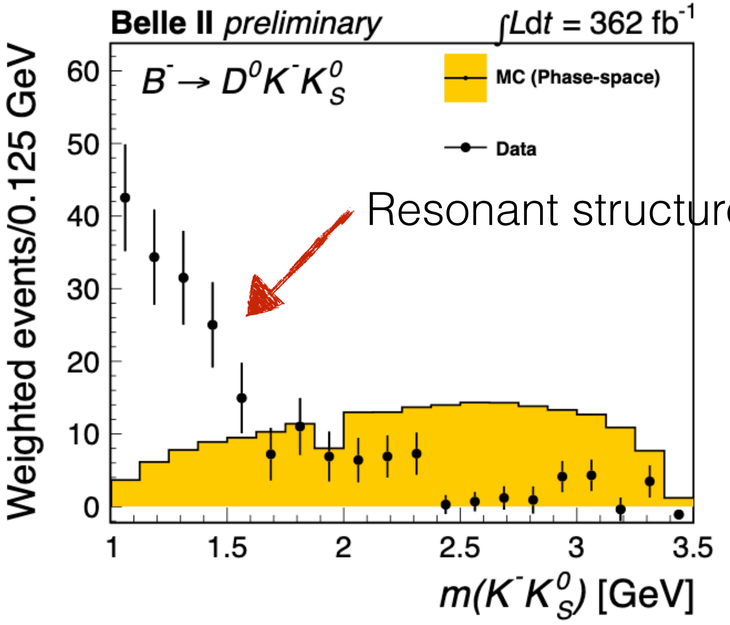
arXiv:2305.01321

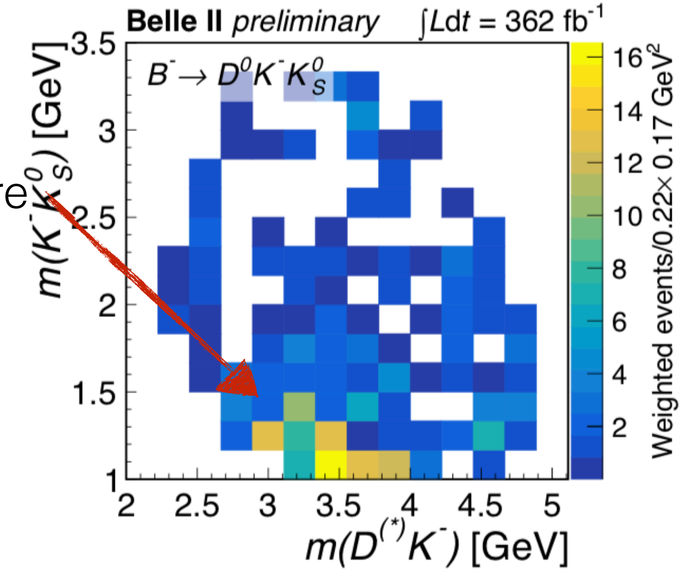
$$\mathcal{B}(B^- \to D^0 K^- K_S^0) = (1.89 \pm 0.16 \pm 0.10) \times 10^{-4}$$
$$\mathcal{B}(\overline{B}^0 \to D^+ K^- K_S^0) = (0.85 \pm 0.11 \pm 0.05) \times 10^{-4}$$
$$\mathcal{B}(B^- \to D^{*0} K^- K_S^0) = (1.57 \pm 0.27 \pm 0.12) \times 10^{-4}$$
$$\mathcal{B}(\overline{B}^0 \to D^{*+} K^- K_S^0) = (0.96 \pm 0.18 \pm 0.06) \times 10^{-4}$$

Improve simulation and help in B-tagging tool.

362 fb-1







Summary

With 362/fb data set, new recent results from Belle II:

- ϕ_3 results with GLW, GLS methods.
- ϕ_2 results with $B \to \pi\pi$, with π^0 final states.

  Get same level Br($B^0 \to \pi^0\pi^0$)'s precision with only 1/3 data set.
- Sum rule test in $K\pi$: world's best $A_{CP}(K^0_S\pi^0)$, competitive $I_{K\pi}$ precision.
- $B \to D^{(*)}KK^0_S$: there decay channels observed for first time.

More results coming from Belle II! Stay tuned!