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B Meson Hadronic Decays and Charm Physics Results at Belle II

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On behalf of Belle II Italia

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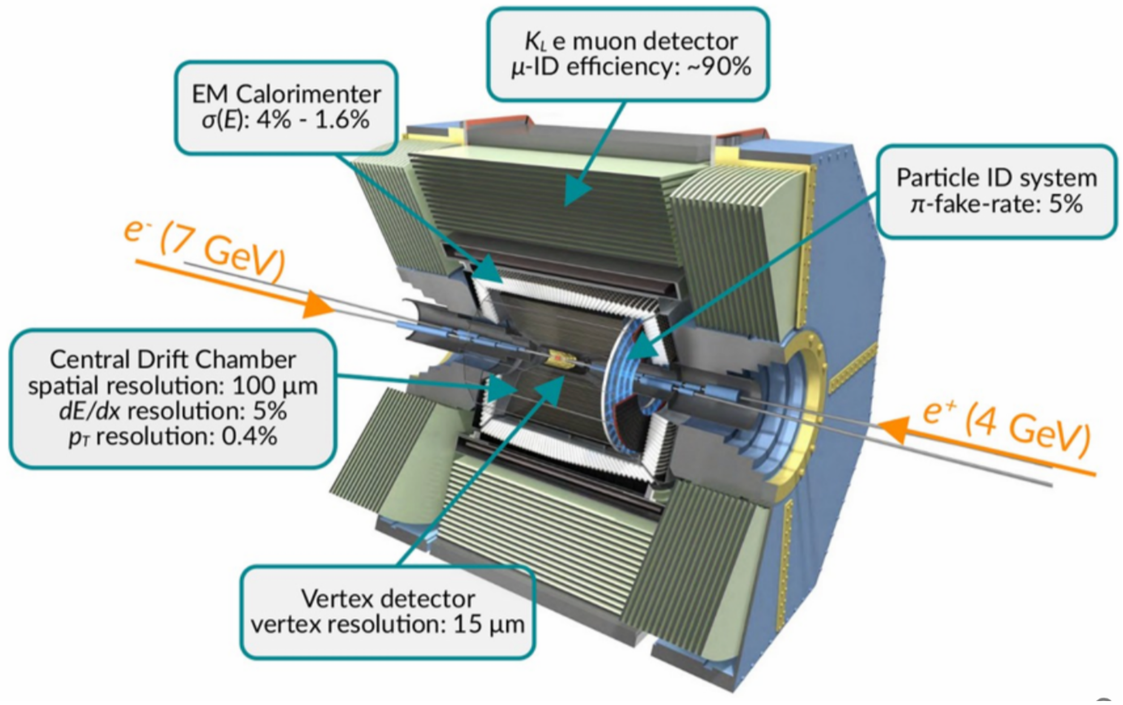
Belle II Experiment

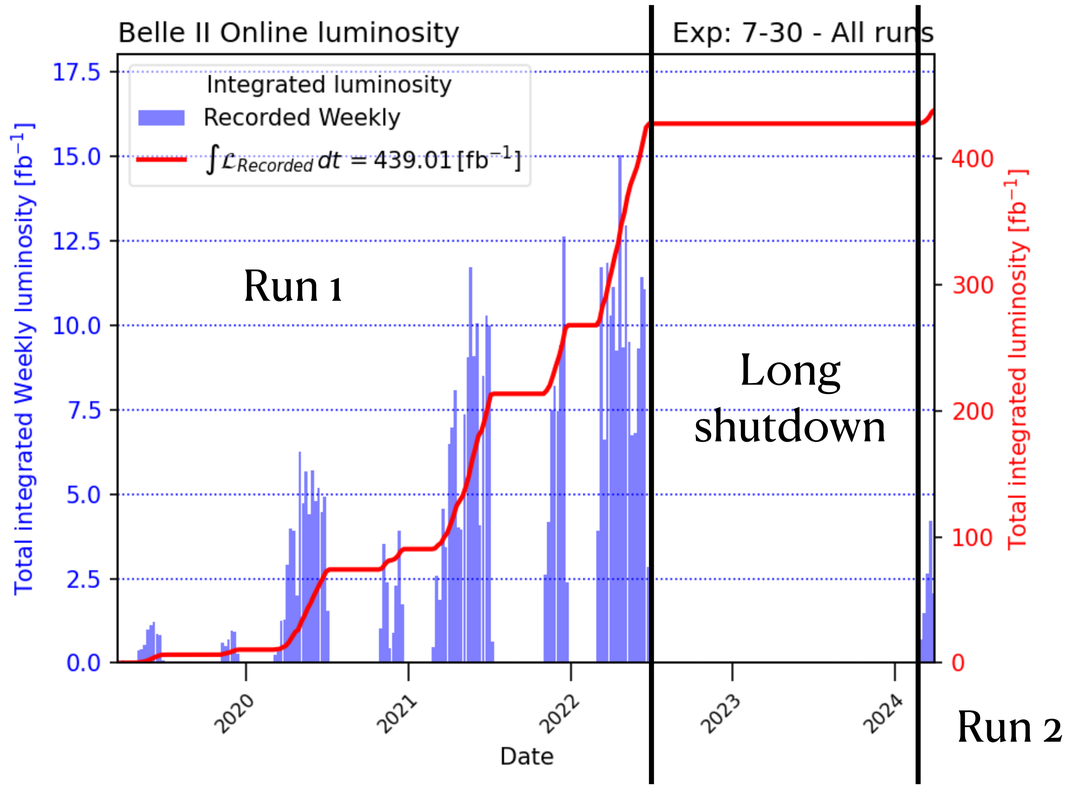
- Asymmetric-energy e^+e^- collisions at $\Upsilon(4S)$
  - $\sqrt{s} = 10.58\ \text{GeV} \approx 2m_B$
  - $B\bar{B}$ pairs production
  - Light $q\bar{q}$ pairs production
    (significant fraction of $e^+e^- \to c\bar{c}$)

- Run 1: $\int \mathscr{L} dt = 426\ \text{fb}^{-1}$

  $\sim 390\ \text{M}\ B\bar{B}$ pairs

  $\sim 560\ \text{M}\ c\bar{c}$ pairs
- Run 2: data taking resumed on 20 Feb.

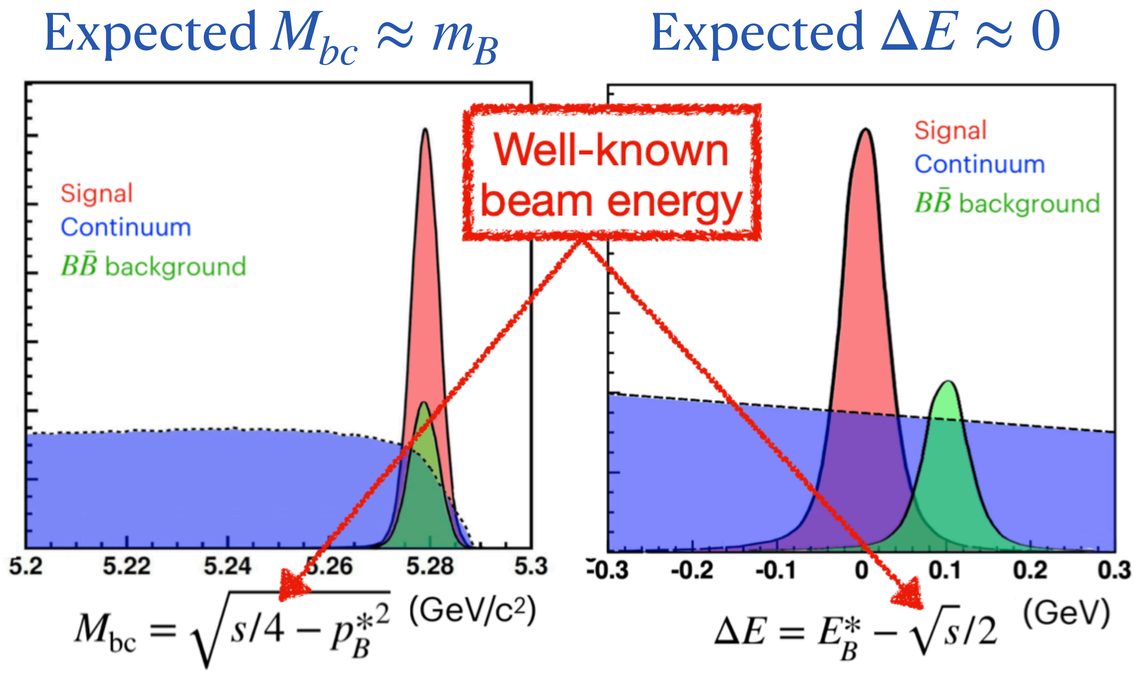




B Hadronic Decays

B Physics at Belle II

- Threshold and coherent production of $B\bar{B}$ pairs
- Precise knowledge of the collision energy
  - M_{bc}: beam-constrained mass
  - ΔE: difference in the reconstructed and expected B energy

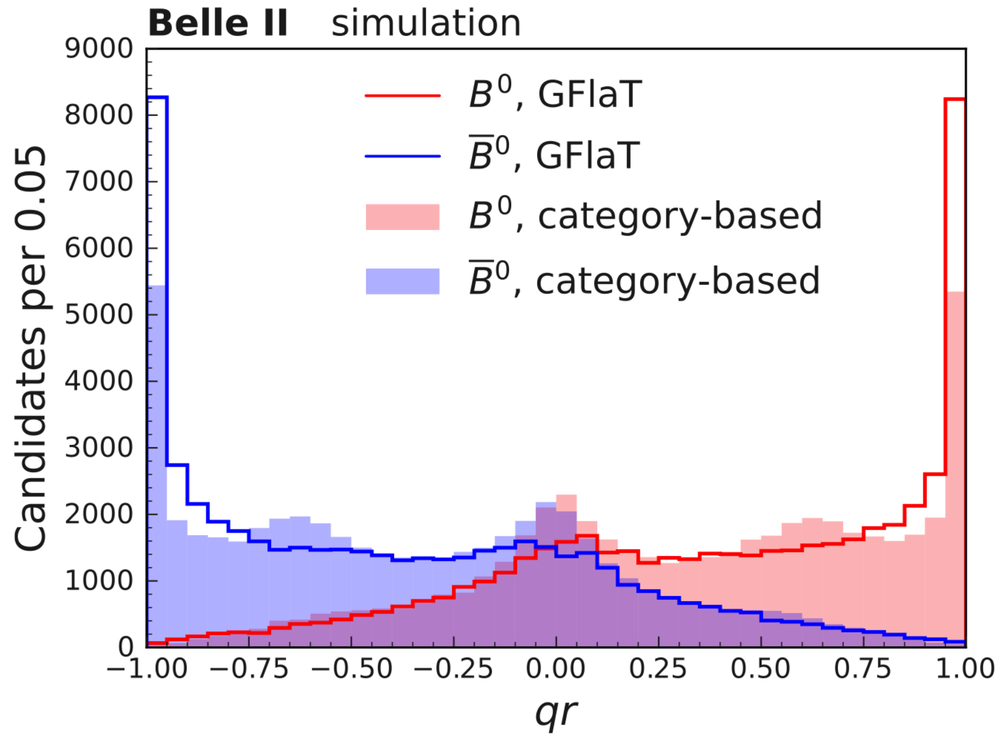


- Excellent vertexing ($\sigma \sim 15\ \mu$m)
- Determine flavour of signal B using features of the other B (tag) in the pair *[arXiv:2402.17260]*

Effective efficiency: 31.68 % → 37.40 %

Improved by 18 % using a new algorithm

✳ See poster on time-dependent *CP* violation by Cecilia Antonioli



- Continuum background ($e^+e^- \to q\bar{q}$) suppression

  ⇒ MVA trained with **event shape variables**

$B^- \to D^0\rho^-$

New for IFAE

362 fb^{-1}

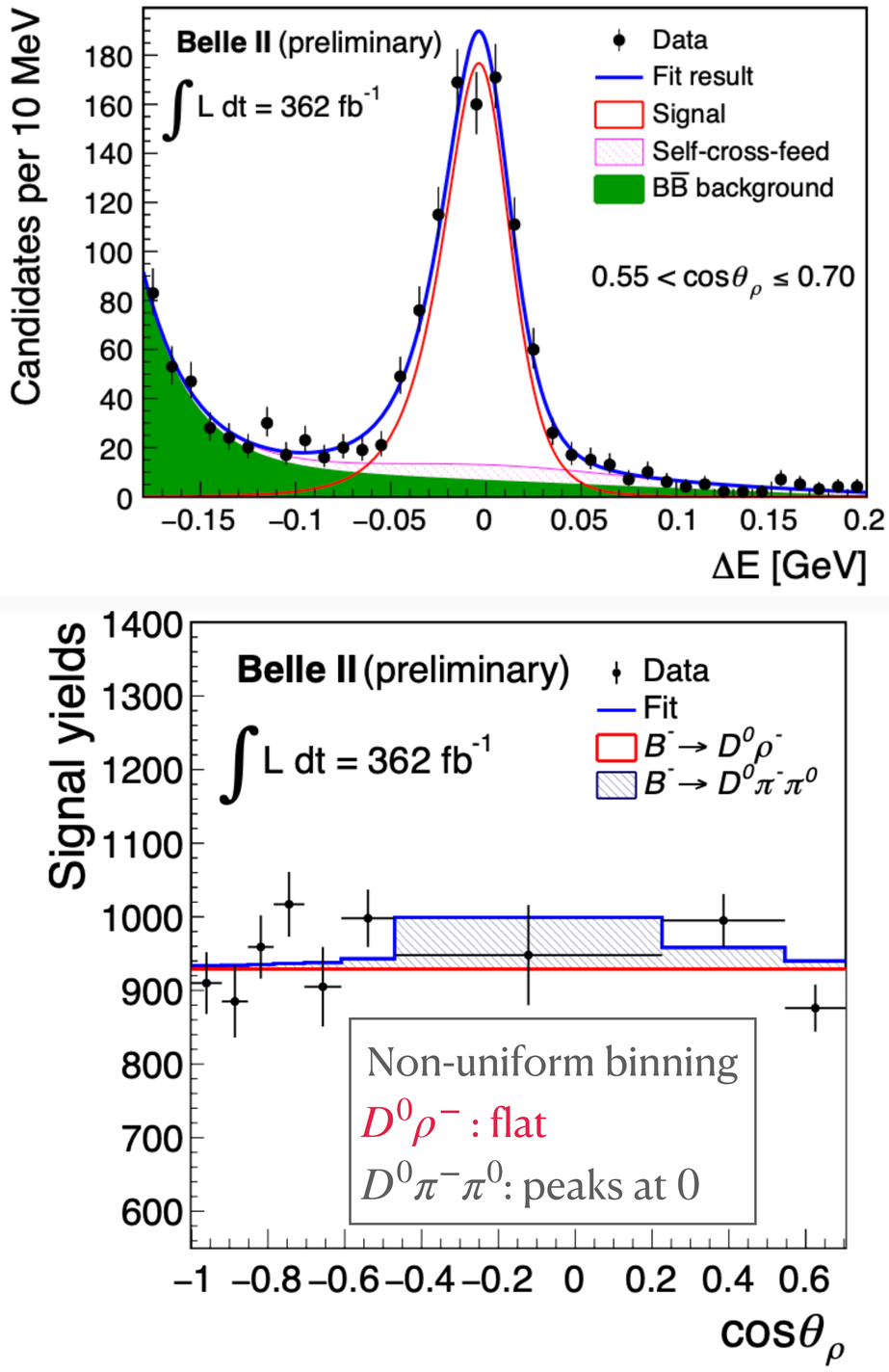
- One of the the main channels for **hadronic tag**
  [Comp. Softw. Big Sci. 3, 6 (2019)]
- WA dominated by 1994 CLEO measurement
  [PRD, 50, 43 (1994)]
- Signal extracted from fit to ΔE
- Separate signal and **non-resonant**
  $B^- \to D^0\pi^-\pi^0$ using angular distribution of ρ

$$\mathcal{B}(B^- \to D^0\rho^-) = (0.939 \pm 0.021 \pm 0.050)\,\%$$

More than a factor of 2 improvement in precision

- Systematically limited by π^0 efficiency knowledge

[2024 Moriond EW]

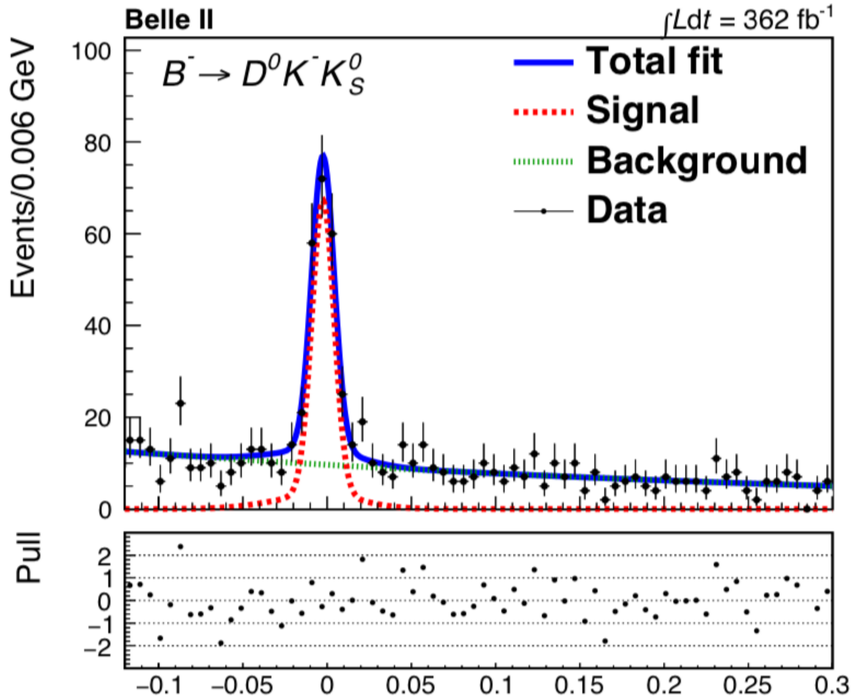


$B \to D^{(*)}K^-K^{*0}$

New for IFAE

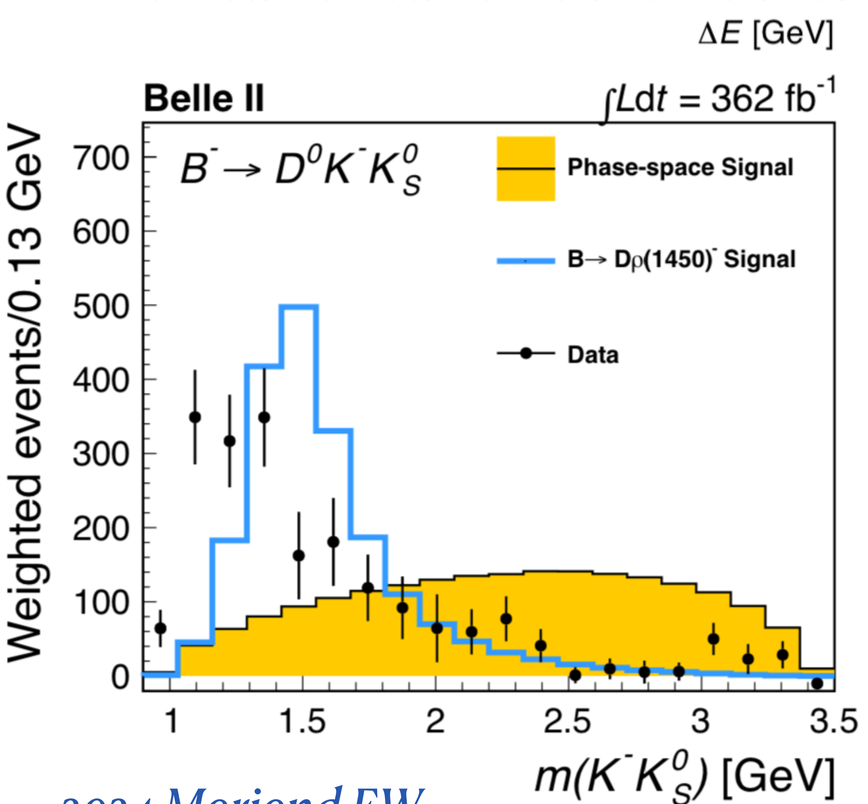
362 fb^{-1}

- $B \to DKK$: mostly unexplored sector
- Branching fractions measured with ΔE fit
- For final states with a K^*, fit $m(K\pi)$ to constrain non-resonant contribution
- 3 new DKK^0_S channels observed, precision improved by a factor of 3 in other DKK channels *[PLB 542, 171-182 (2002)]*



- Low-mass structure in $m(K^-K^{(*)0})$ qualitatively compatible with ρ or a_1 intermediate resonances

Channel	$\mathcal{B}$ $[10^{-4}]$
$B^- \to D^0 K^- K^0_S$	$1.82 \pm 0.16 \pm 0.08$
$\overline{B}^0 \to D^+ K^- K^0_S$	$0.82 \pm 0.12 \pm 0.05$
$B^- \to D^{*0} K^- K^0_S$	$1.47 \pm 0.27 \pm 0.10$
$\overline{B}^0 \to D^{*+} K^- K^0_S$	$0.91 \pm 0.19 \pm 0.05$
$B^- \to D^0 K^- K^{*0}$	$7.19 \pm 0.45 \pm 0.33$
$\bar{B}^0 \to D^+ K^- K^{*0}$	$7.56 \pm 0.45 \pm 0.38$
$B^- \to D^{*0} K^- K^{*0}$	$11.93 \pm 1.14 \pm 0.93$
$\bar{B}^0 \to D^{*+} K^- K^{*0}$	$13.12 \pm 1.21 \pm 0.71$



2024 Moriond EW

Charm Physics

$D^0 \to hh'e^+e^-$

New for IFAE

Belle: 942 fb^{-1}

- Belle only analysis, $h^{(\prime)} = K, \pi$
- FCNC $c \to ull$ are suppressed in SM, probes BSM contributions
- Dominated by SM long distance contributions

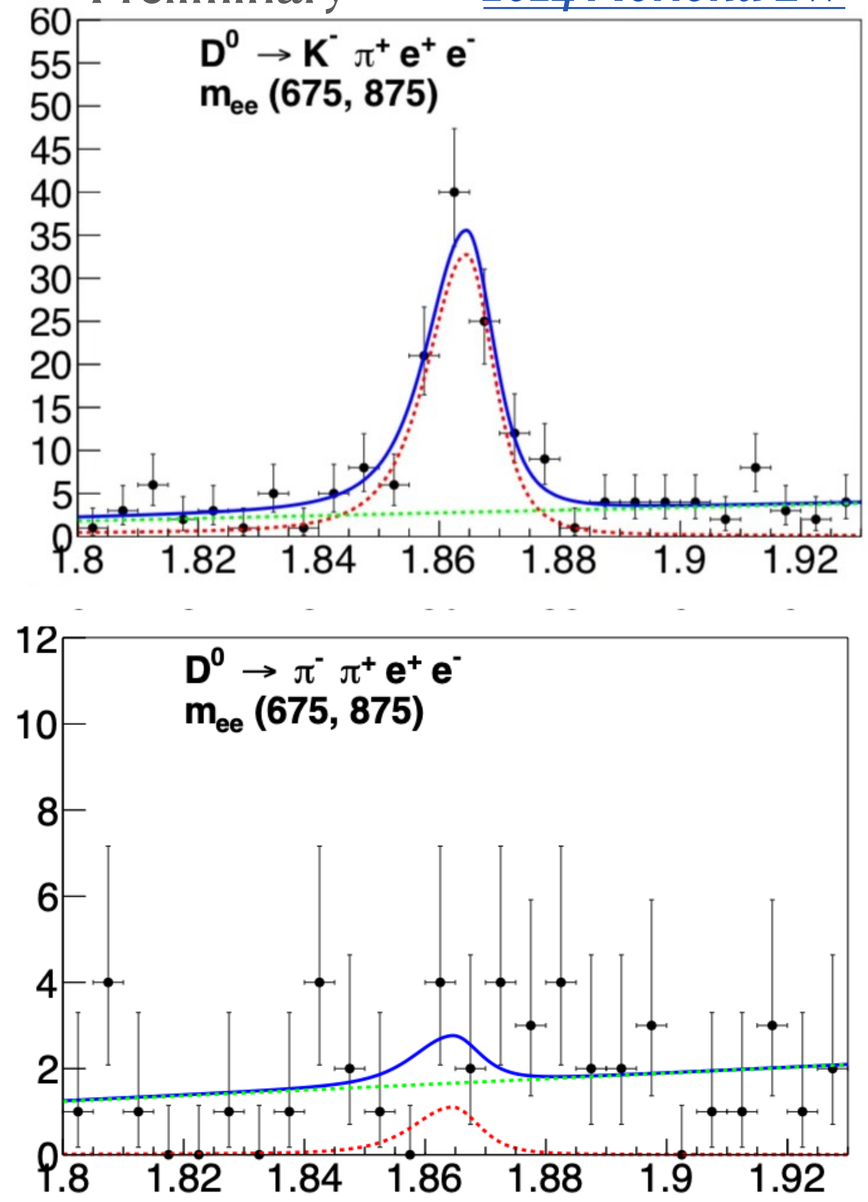
- Reconstruct decays in **different $m(e^+e^-)$ regions:**
  - Near resonance: BF measurement
  - Far from resonance: sensitive to BSM physics
- In the ρ/ω region:

$$\mathcal{B}(D^0 \to K^-\pi^+e^+e^-) = (39.6 \pm 4.5 \pm 2.9) \times 10^{-7}$$

Compatible with BaBar and SM expectations

- No signal observed in other regions and channels
  - Upper limits: $[2 - 8] \times 10^{-7}$ at 90 % CL (best to date)

Preliminary *2024 Moriond EW*



BESIII: *PRD 97, 072015 (2019)*
BABAR: *PRL 122, 081802 (2019)*
LHCb: *PRL 119, 181805 (2017)*, *PLB 757, 558 (2016)*
MSSM: *PRD 66, 014009 (2002)*

$\Xi_c^0 \to \Xi^0\pi^0, \Xi^0\eta, \Xi^0\eta'$

Belle: 980 fb^{-1}+ Belle II: 426 fb^{-1}

2024 Moriond EW | New for IFAE

- First **Belle** + **Belle II** combined analysis in charm
- First measurements of these decays

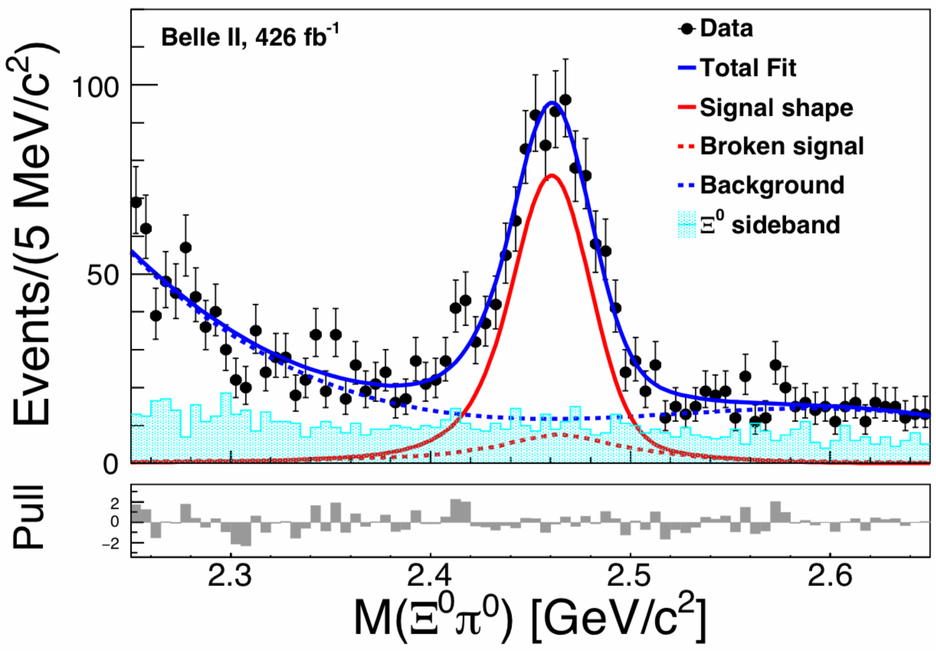
$$\mathcal{B}(\Xi_c^0 \to \Xi^0\pi^0) = (7.2 \pm 0.3 \pm 0.5 \pm \mathbf{1.6}) \times 10^{-3}$$

$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta) = (1.7 \pm 0.2 \pm 0.2 \pm \mathbf{0.4}) \times 10^{-3}$$

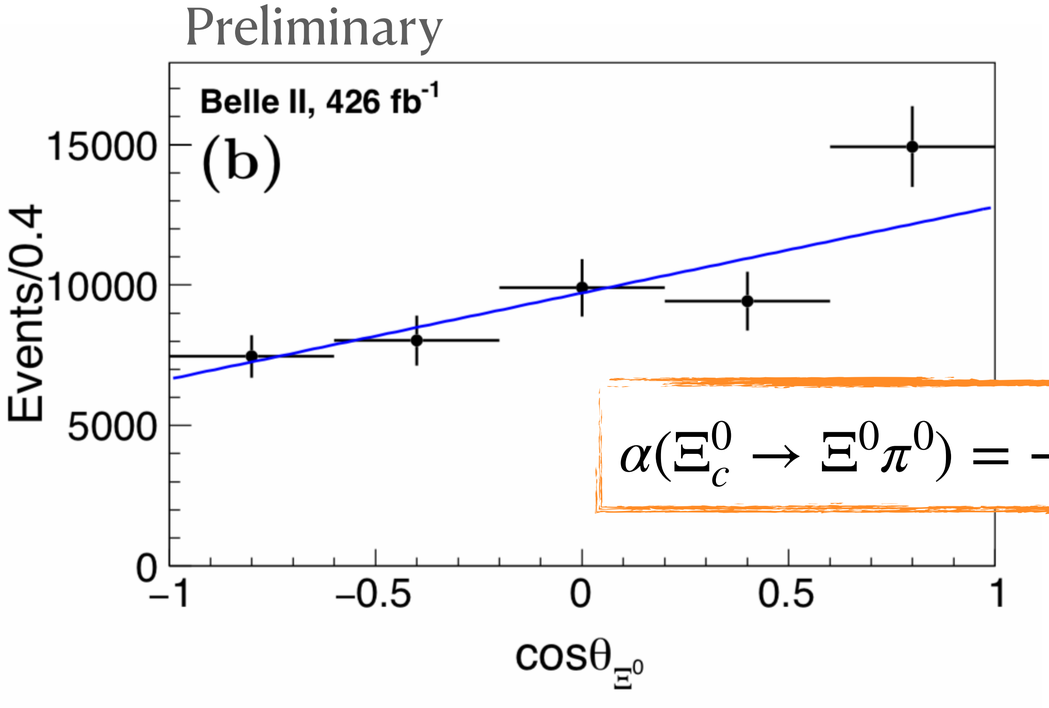
$$\mathcal{B}(\Xi_c^0 \to \Xi^0\eta') = (1.3 \pm 0.3 \pm 0.1 \pm \mathbf{0.3}) \times 10^{-3}$$

Normalised to $\Xi_c^0 \to \Xi^-\pi^+$ decay

Preliminary



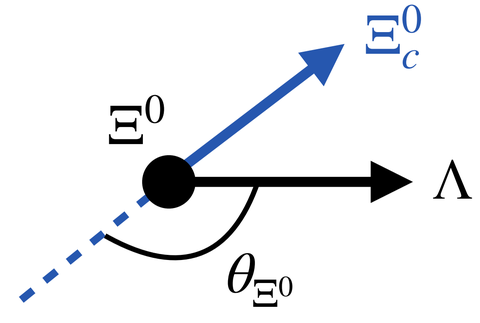
Preliminary



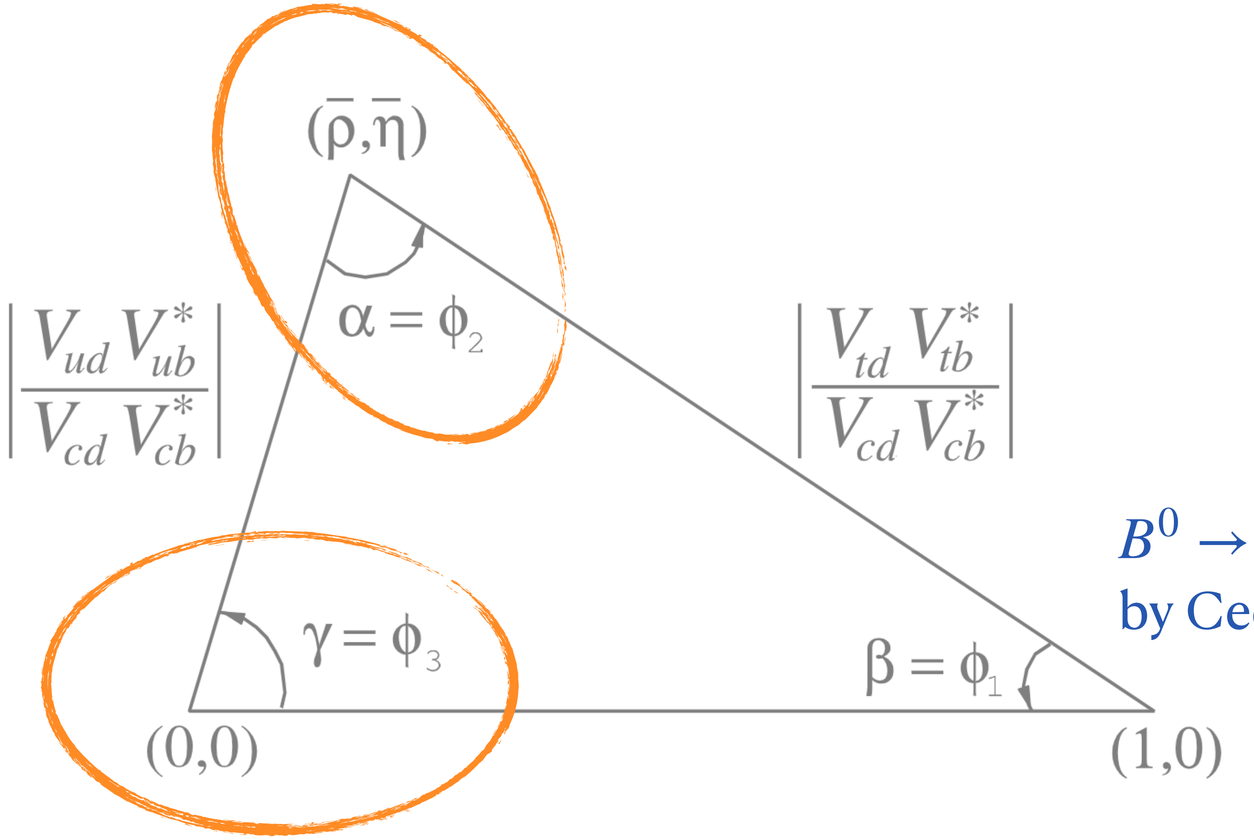
Asymmetry parameter α related to ***P* violation** through differential decay rate:

$$\frac{dN}{d\cos\theta_{\Xi^0}} \sim 1 + \alpha(\Xi_c^0 \to \Xi^0 h^0)\alpha(\Xi^0 \to \Lambda\pi^0)\cos\theta_{\Xi^0}$$

$$\alpha(\Xi_c^0 \to \Xi^0\pi^0) = -0.91 \pm 0.15 \pm 0.23$$



CKM Angles Measurements



$B^0 \to \eta' K_S^0$: TDCPV poster
by Cecilia Antonioli

Towards CKM angle ϕ_2/α

189 fb^{-1}

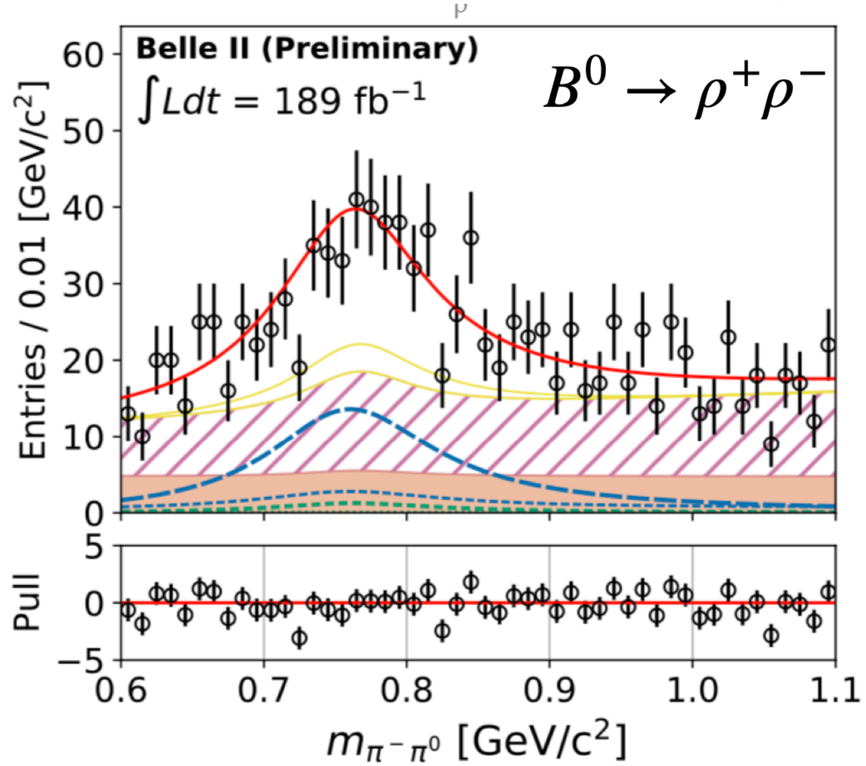
$$\phi_2 = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right)$$

Least precisely known angle

- Current world average: $\phi_2 = (\ 85.2^{+4.8}_{-4.3}\ )^\circ$
- Combine information from BF and $\mathcal{A}_{CP}$ measurement of
  - $B^0 \to \rho^+\rho^-$, $B^+ \to \rho^+\rho^0$, $B^0 \to \rho^0\rho^0$
  - $B^0 \to \pi^+\pi^-$, $B^+ \to \pi^+\pi^0$, $B^0 \to \pi^0\pi^0$

  to reduce impact of hadronic uncertainties exploiting **isospin symmetry**
- Measurements of $B \to \rho\rho$ requires a **complex angular analysis**
- Preliminary results on par with best performances from Belle/ BaBar due to optimised selections and continuum suppression

  Belle: *PRL 91 221801 (2003)*, *PRD 93, 032010 (2016)*
  BaBar: *PRL 102, 141802 (2009)*, *PRD 74, 052007 (2007)*



$B^+ \to \rho^+\rho^0$ *arXiv:2206.12362*

$\mathcal{B} = (23.2^{+2.2}_{-2.1} \pm 2.7) \times 10^{-6}$

$f_L = 0.943^{+0.035}_{-0.033} \pm 0.027$

$\mathcal{A}_{CP} = -\ 0.069 \pm 0.068 \pm 0.060$

$B^0 \to \rho^+\rho^-$ *arXiv:2208.03554*

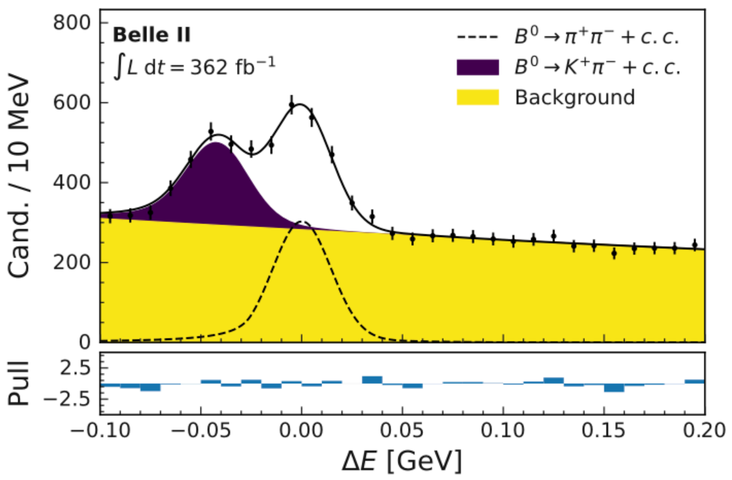
$\mathcal{B} = (26.7 \pm 2.8 \pm 2.8) \times 10^{-6}$

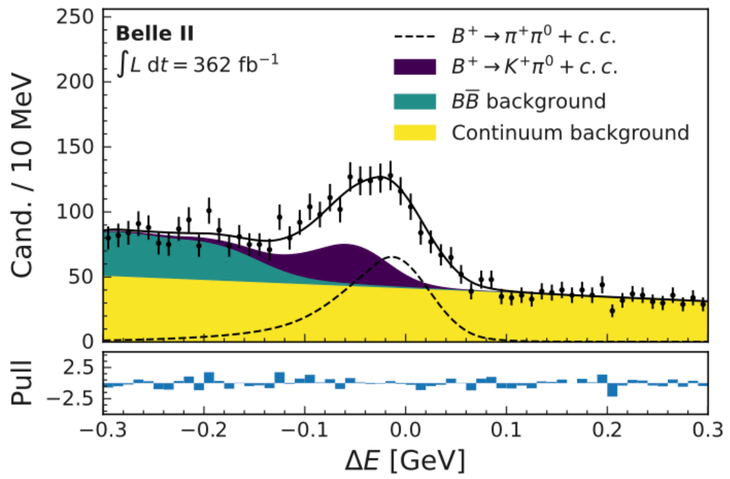
$f_L = 0.956 \pm 0.035 \pm 0.033$

Towards CKM angle ϕ_2/α

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

[Phys. Rev. D 109, 012001 (2024)](#)





362 fb^{-1}

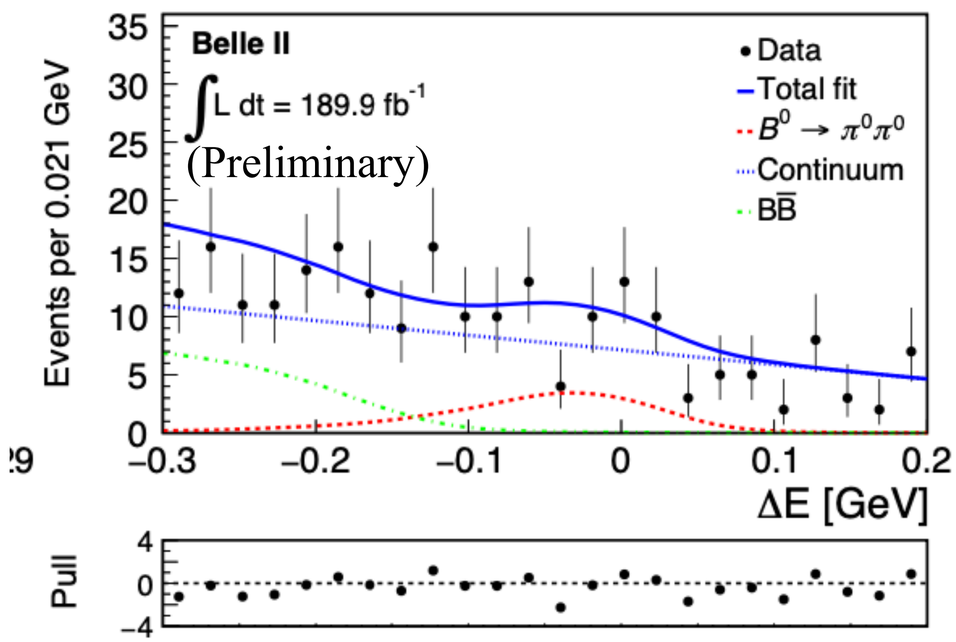
$\mathcal{B}(\pi^+\pi^-) = (5.83 \pm 0.22 \pm 0.17) \times 10^{-6}$
$\mathcal{B}(\pi^+\pi^0) = (5.10 \pm 0.29 \pm 0.27) \times 10^{-6}$
$\mathcal{A}_{CP}(\pi^+\pi^0) = -0.082 \pm 0.054 \pm 0.008$

- $B^0 \to \pi^0\pi^0$
  - Only photons in the final state
    - ➡ MVA trained with ECL variables
  - CKM-suppressed and colour-suppressed
  - Achieves Belle's precision using only 1/3 of data

$\mathcal{B}(\pi^0\pi^0) = (1.38 \pm 0.27 \pm 0.22) \times 10^{-6}$
$\mathcal{A}_{CP}(\pi^0\pi^0) = 0.14 \pm 0.46 \pm 0.07$

189 fb^{-1}

[arXiv:2303.08354](#)



ϕ_3/γ: Belle + Belle II Combination

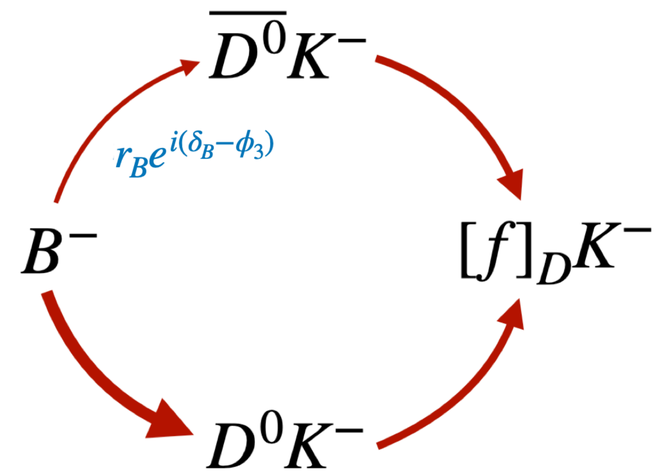
New for IFAE

2024 Moriond EW

- ϕ_3 accessed with interfering decays to the same final states
- Tree-level dominated: no (large) BSM contribution
- First combination of all Belle and Belle II measurements

$$\phi_3(^\circ) = 78.6^{+7.2}_{-7.3}$$

HFLAV: $\phi_3^{WA}(^\circ) = 66.2^{+3.4}_{-3.6}$



B decay	D decay	Method	Data set (Belle + Belle II)[fb^{-1}]	Reference
$B^+ \to Dh^+$	$D \to K^0_S h^- h^+$	BPGGSZ	711 + 128	*[JHEP, 02, 063 (2022)]*
$B^+ \to Dh^+$	$D \to K^0_S \pi^- \pi^+ \pi^0$	BPGGSZ	711 + 0	*[JHEP, 10, 178 (2019)]*
$B^+ \to Dh^+$	$D \to K^0_S \pi^0, K^- K^+$	GLW	711 + 189	*[arXiv:2308.05048]*
$B^+ \to Dh^+$	$D \to K^+ \pi^-, K^+ \pi^- \pi^0$	ADS	711 + 0	*[PRL, 106, 231803 (2011)]*
$B^+ \to Dh^+$	$D \to K^0_S K^- \pi^+$	GLS	711 + 362	*[JHEP, 09, 146 (2023)]*
$B^+ \to D^* K^+$	$D^* \to D\pi^0/\gamma, D \to K^0_S \pi^- \pi^+$	BPGGSZ	605 + 0	*[PRD, 81, 112002 (2010)]*
$B^+ \to D^* K^+$	$D^* \to D\pi^0, D \to K^0_S \pi^0, K^0_S \phi, K^0_S \omega, K^- K^+, \pi^- \pi^+$	GLW	210+0	*[PRD, 73, 051106 (2006)]*

Summary

- Measurements made with data collected by Belle II run 1, Belle only, and Belle + Belle II.
- Competitive precisions despite smaller dataset

- Improve B decay knowledge in $B^- \to D^0\rho^-$ and $B \to DKK$ decays
- Study of rare FCNC decay $D^0 \to hh'e^+e^-$

- First measurement of $\Xi_c^0 \to \Xi^0 h^0$ decays
- Contribution towards the determination of ϕ_2/α with measurements of $B \to \pi\pi$ and $B \to \rho\rho$ decays
- Refine ϕ_3/γ measurement strategies by combining all Belle and Belle II measurements

Backup

$B^0 \to \eta' K^0_S$

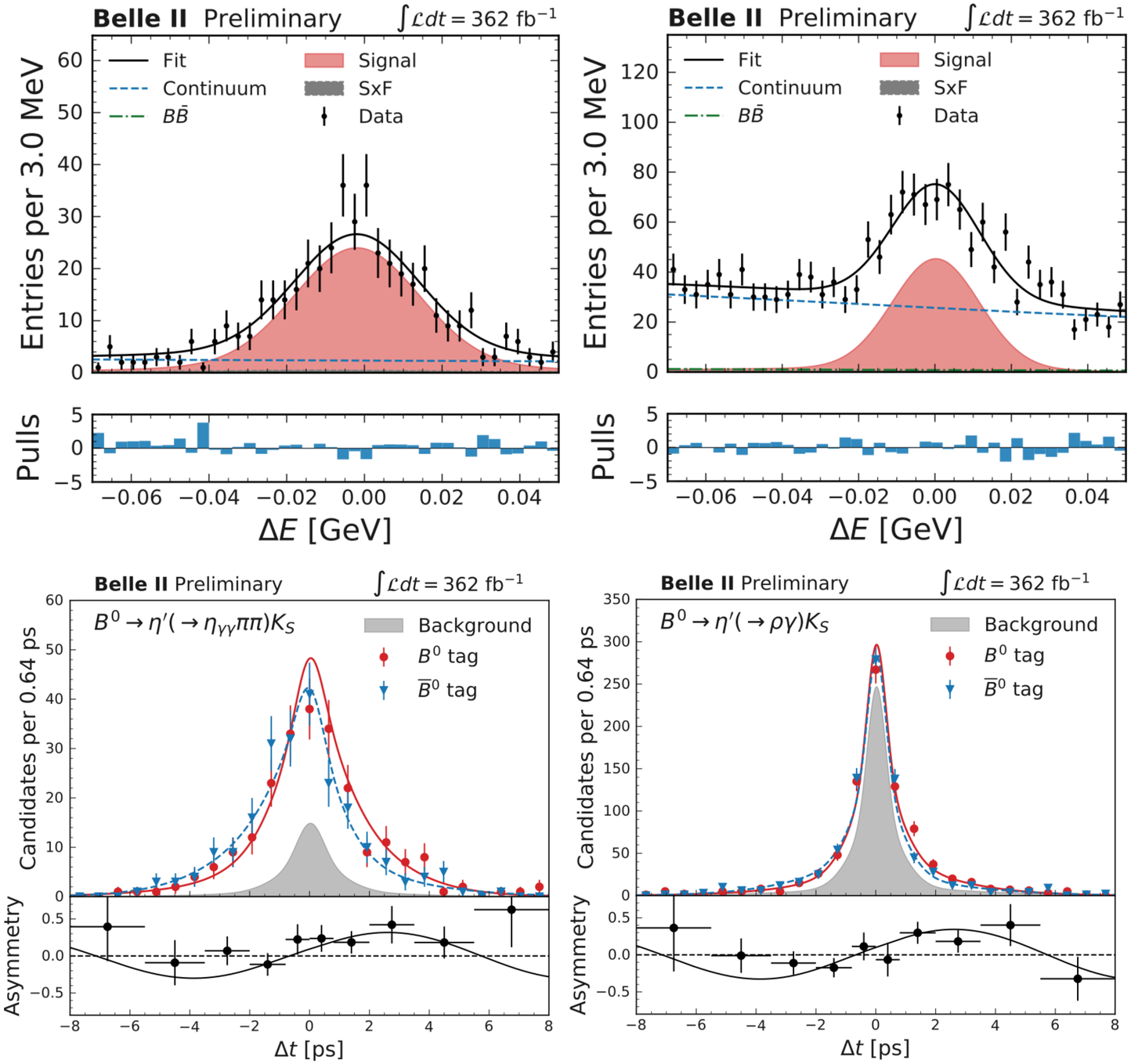
New for IFAE

362 fb^{-1}

- Signal extracted from fit to $\Delta E, M_{bc}, CS$ output
- Validated on control channel $B^+ \to \eta' K^+$

$$\mathcal{S} = 0.67 \pm 0.10 \pm 0.04$$
$$\mathcal{C} = -0.19 \pm 0.08 \pm 0.03$$

- Statistically limited
- Precision comparable to Belle/BaBar despite smaller dataset



[arXiv:2402.03713]