Recent Belle II results on hadronic *B* decays

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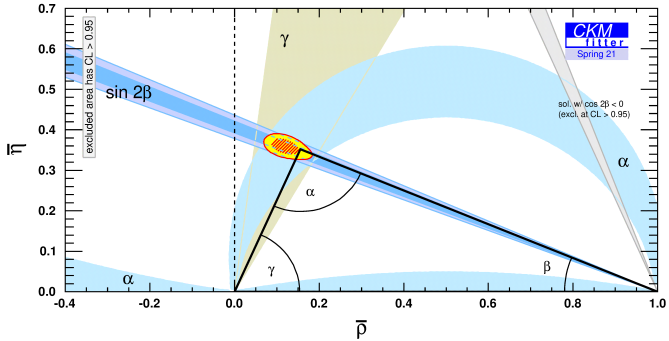
Motivation

CKM angles α and γ are significantly less well measured than CKM angle β.



Strength of Belle II: can access a very wide variety of decays, in particular final states with neutrals

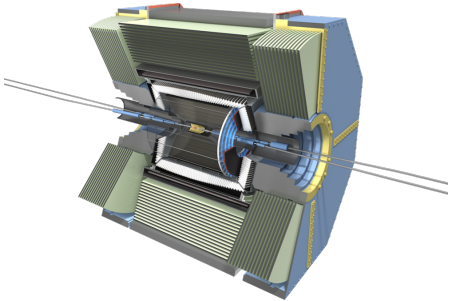
SuperKEKB and Belle II

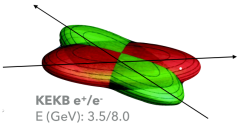
Belle II: general purpose detector situated at the interaction point of SuperKEKB.

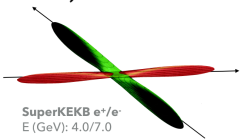
SuperKEKB: asymmetric $e^+ - e^-$ collider operating at $\Upsilon(4S)$ resonance.

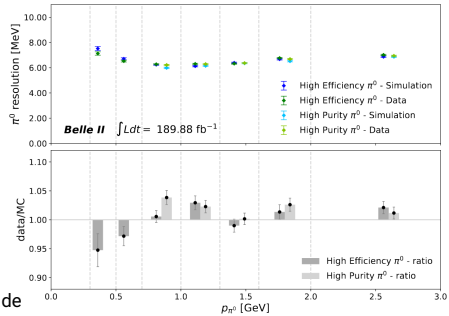
Operation:

- Recorded $\approx$ 424 fb^{-1}
- Achieved world record:
  $\mathcal{L} = 4.7 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
  (more than twice of KEKB/Belle)









Measurement of γ in $B^+ \to D(K^0_S h^+ h^-)K^+$

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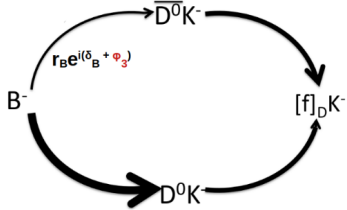
Measure γ via interference of $b \to c$ and $b \to u$ transition.



Measurement dependent on D decay physics:

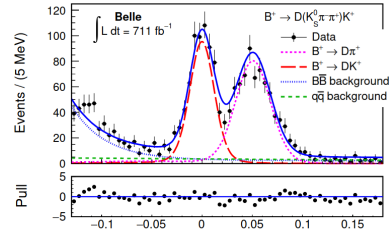
- Bin D Dalitz plot (model-independent)
- Require external input (BESIII, CLEO)

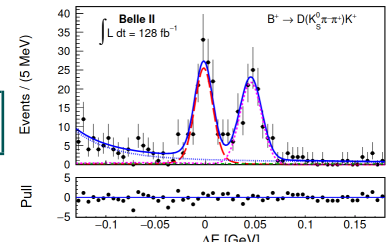
$$\gamma = (78.4 \pm 11.4\ (\text{stat.}) \pm 0.5\ (\text{syst.}) \pm 1.0\ (\text{ext.}))^\circ$$

WA: $\gamma = 65.9^{+3.3}_{-3.5}$

First joint Belle (711 fb^{-1}) and Belle II (128 fb^{-1}) analysis!

Belle: $N(K^0_S\pi\pi) = 1467 \pm 53$, $N(K^0_S KK) = 194 \pm 17$

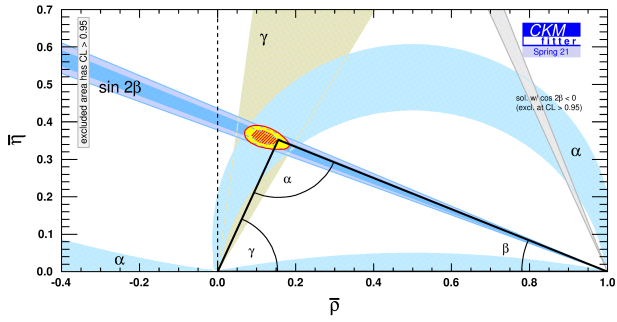




Belle II: $N(K^0_S\pi\pi) = 280 \pm 21$, $N(K^0_S KK) = 34 \pm 7$

Charmless hadronic B decays

Access α in $b \to u$ transition of charmless hadronic B decays ($B \to \rho\rho$, $B \to \pi\pi$, ...).
$\Rightarrow$ Significant penguin pollution



Isospin sum-rules allow to test SM in loop decays at 1% precision.

$K\pi$ puzzle

$K\pi$ puzzle: unexpected large difference between $\mathcal{A}^{CP}_{K^+\pi^-}$ and $\mathcal{A}^{CP}_{K^+\pi^0}$.

Isospin sum rule provides null test of standard model:

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

Belle II is a unique place to measure all involved decays!

Previous tests of sum rule at Belle II using 62.8 fb^{-1}:
Measurements of $B^0 \to K^+\pi^-$, $B^+ \to K^0_S\pi^+$ (arXiv:2106.03766),
$B^0 \to K^0_S\pi^0$ (arXiv:2104.14871) and $B^+ \to K^+\pi^0$ (arXiv:2105.04111).

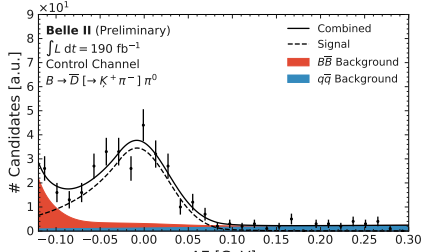
Today: New measurement of $\mathcal{B}$ and $\mathcal{A}^{CP}$ of $B^+ \to K^+\pi^0$ based on 190 fb^{-1}.

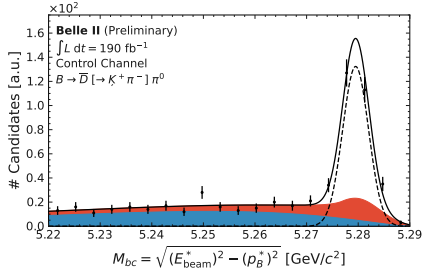
Update on $B^0 \to K^0_S\pi^0$ in Chiara La Licata's talk later today.

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

New for ICHEP

- Reconstruct $B^+ \to K^+\pi^0$ and $B^+ \to \pi^+\pi^0$ events using common selection
- Divide into pion- and kaon-enhanced sample
- Large background from $e^+e^- \to q\bar{q}$
  $\Rightarrow$ Reduced with multivariate algorithm
- Simultaneous fit to both samples
  $\Rightarrow$ All fit shapes but $B\overline{B}$ are controlled from data using off-resonance data and $B \to \overline{D}\pi$ decays





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

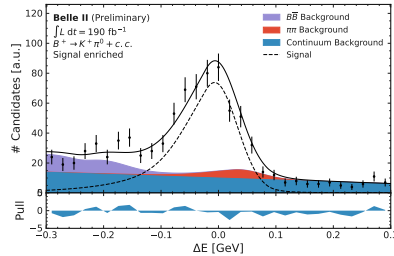
New for ICHEP

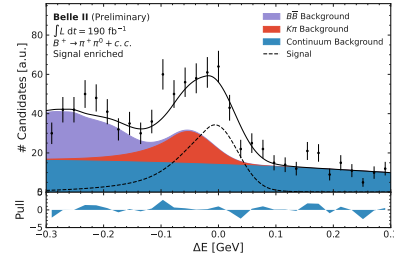
$N(K^+\pi^0) = 887 \pm 43$, $N(\pi^+\pi^0) = 422 \pm 37$

$$
\begin{aligned}
\mathcal{A}^{CP}_{K^+\pi^0} &= 0.014 \pm 0.047\ (\text{stat}) \pm 0.010\ (\text{syst}) \\
\mathcal{B}_{K^+\pi^0} &= (14.30 \pm 0.69\ \ (\text{stat}) \pm 0.79\ \ (\text{syst})) \cdot 10^{-6} \\
\mathcal{A}^{CP}_{\pi^+\pi^0} &= -0.085 \pm 0.085\ (\text{stat}) \pm 0.019\ (\text{syst}) \\
\mathcal{B}_{\pi^+\pi^0} &= 6.12 \pm 0.53\ \ (\text{stat}) \pm 0.53\ \ (\text{syst})) \cdot 10^{-6}
\end{aligned}
$$

WA: $\mathcal{A}^{CP}_{K^+\pi^0} = 0.030 \pm 0.013$, $\mathcal{A}^{CP}_{\pi^+\pi^0} = 0.03 \pm 0.04$

$\mathcal{B}$ precision limited by systematic uncertainties associated to size of control samples.





Measurement of α

CKM angle α accessible in combination of sets of three decays:

$$B^+ \to \rho^+\rho^0,\ B^0 \to \rho^0\rho^0,\ B^0 \to \rho^+\rho^- \text{ or}$$
$$B^0 \to \pi^+\pi^-,\ B^+ \to \pi^+\pi^0,\ B^0 \to \pi^0\pi^0$$

Just shown: Measurement of $B^+ \to \pi^+\pi^0$ using 190 fb^{-1}.

Previous Belle II measurements using 62.8 fb^{-1}:

$\Rightarrow$ Measurements of $B^0 \to \pi^+\pi^-$ (arXiv:2106.03766), $B^0 \to \pi^0\pi^0$ (arXiv:2107.02373) and $B^+ \to \rho^+\rho^0$ (arXiv:2206.12362)

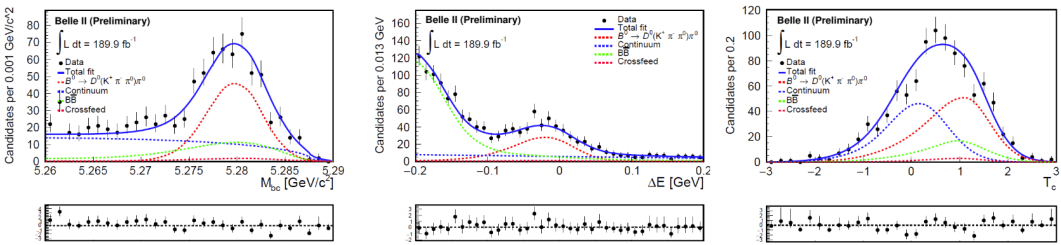
Today: Updated measurement of $B^+ \to \rho^+\rho^0$ and
New measurements $B^0 \to \rho^+\rho^-$ and $B^0 \to \pi^0\pi^0$ based on 190 fb^{-1}

$B^0 \to \pi^0\pi^0$ Analysis

New for ICHEP

- Background from fake photons
  $\Rightarrow$ Dedicated multivariate algorithm
- Need to know flavor of B for $\mathcal{A}^{CP}$
  $\Rightarrow$ Belle II's flavor tagger $\epsilon_{tag} = (30.0 \pm 1.3)\%$
- 3D fit simultaneous in 7 bins of the flavor tagger quality
- Extract data-simulation correction factors using $B^0 \to D^0(\to K^-\pi^+\pi^0)\pi^0$

Control channel:



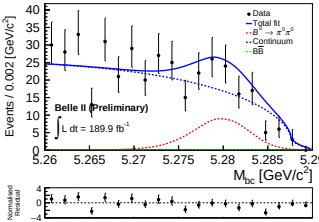
$B^0 \to \pi^0\pi^0$ Result

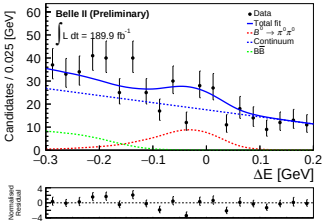
New for ICHEP

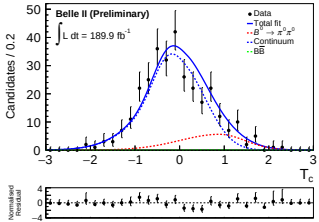
Results competitive with Belle with a data set of less than one third!

$$\mathcal{A}^{CP} = 0.14 \pm 0.46\ (stat) \pm 0.07\ (syst)$$
$$\mathcal{B} = (1.27 \pm 0.25\ (stat) \pm 0.17\ (syst)) \cdot 10^{-6}$$

WA: $\mathcal{A}^{CP} = 0.33 \pm 0.22$, $\mathcal{B} = (1.59 \pm 0.26) \cdot 10^{-6}$





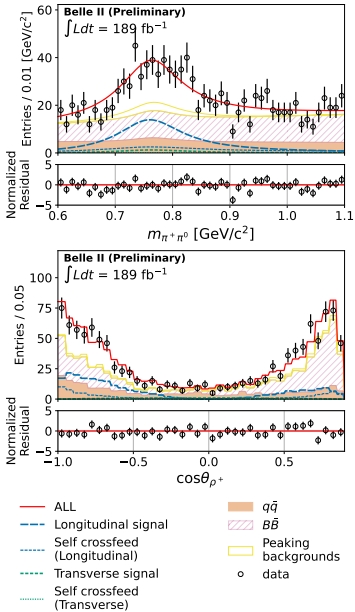


$N(\text{sig}) = 93 \pm 18$

$B^0 \to \rho^+\rho^-$ Analysis

New for ICHEP

- Intermediate ρ is a vector meson:
  $\Rightarrow$ Need longitudinal polarization fraction f_L
  $\Rightarrow$ Fit helicity angle of $\rho \to \pi\pi^0$
- 6D (ΔE, CS, $2{\cdot}m(\pi\pi)$, $2{\cdot}\cos(\theta_\rho)$) fit taking correlations into account
  $\Rightarrow$ Peaking background has a similar final state as signal ($2\pi^0, 1\pi^+ + 1h^+$)
  $\Rightarrow$ Yields of measured peaking backgrounds are fixed in the fit



$B^0 \to \rho^+\rho^-$ Result

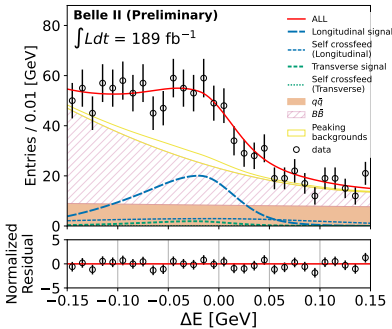
New for ICHEP

$N(\text{long.}) = 235^{+24}_{-23}$, $N(\text{trans.}) = 21^{+19}_{-17}$

$$\mathcal{B} = (2.67 \pm 0.28 \quad (\text{stat}) \pm \quad 0.28 \quad (\text{syst})) \cdot 10^{-5}$$
$$f_L = 0.956 \pm 0.035 \ (\text{stat}) \pm 0.033 \ (\text{syst})$$

WA: $\mathcal{B} = (2.77 \pm 0.19) \cdot 10^{-5}$

Measurement of $\mathcal{B}$ limited by systematic uncertainty.
Largest contribution associated to π^0 reconstruction.



$B^+ \to \rho^+\rho^0$

$N(\text{sig}) = 345 \pm 31$

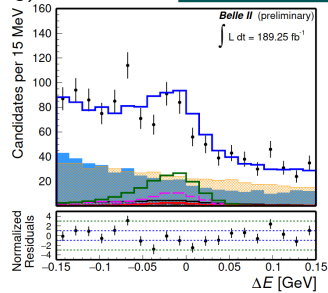
arXiv:2206.12362

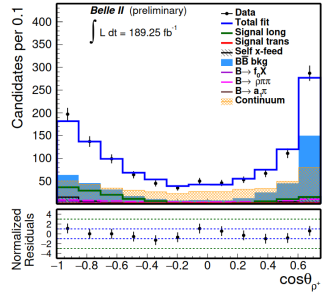
- Similar analysis strategy as $B^+ \to \rho^+\rho^-$
- 6D (ΔE, CS, $2{\cdot}m(\pi\pi)$, $2{\cdot}\cos(\theta_\rho)$) template fit taking correlations into account
  $\Rightarrow$ Fit distribution of helicity angles of π^+

$$\mathcal{A}^{CP} = -0.069 \pm 0.068\ (\text{stat}) \pm 0.060\ (\text{syst})$$
$$\mathcal{B} = (23.2^{+2.2}_{-2.1}\ (\text{stat}) \pm 2.7\ (\text{syst})) \cdot 10^{-6}$$
$$f_L = 0.943^{+0.035}_{-0.033}\ (\text{stat}) \pm 0.027\ (\text{syst})$$

WA: $\mathcal{A}^{CP} = -0.05 \pm 0.05$, $\mathcal{B} = (24.0 \pm 1.9) \cdot 10^{-6}$

- Largest systematic uncertainty from data-simulation discrepancies





Conclusion

- Study of hadronic B decays gives access to γ and α and probes non-SM in subleading amplitudes

- Showed five measurements:
  $\Rightarrow$ Measurement of γ using $B^+ \to D(K^0_S h^+ h^-)K^+$
  $\Rightarrow$ New Branching ratio and CP asymmetry of $B^+ \to \pi^+\pi^0$ and $B^+ \to K^+\pi^0$
  $\Rightarrow$ New Branching ratio and CP asymmetry of $B^0 \to \pi^0\pi^0$
  $\Rightarrow$ New Branching ratio and polarization of $B^0 \to \rho^+\rho^-$
  $\Rightarrow$ Branching ratio and CP asymmetry of $B^+ \to \rho^+\rho^0$

- Results demonstrate Belle II's capability to measure decays with neutrals
  $\Rightarrow$ Belle II is ready to offer key contributions