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Belle II

SM Compatibility of $B \to K^{(*)}\pi$ Measurements and Analysis on $B^+ \to K^*(892)^+[K_S^0\pi^+]\pi^0$ in Belle II

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IMPRS recruiting workshop

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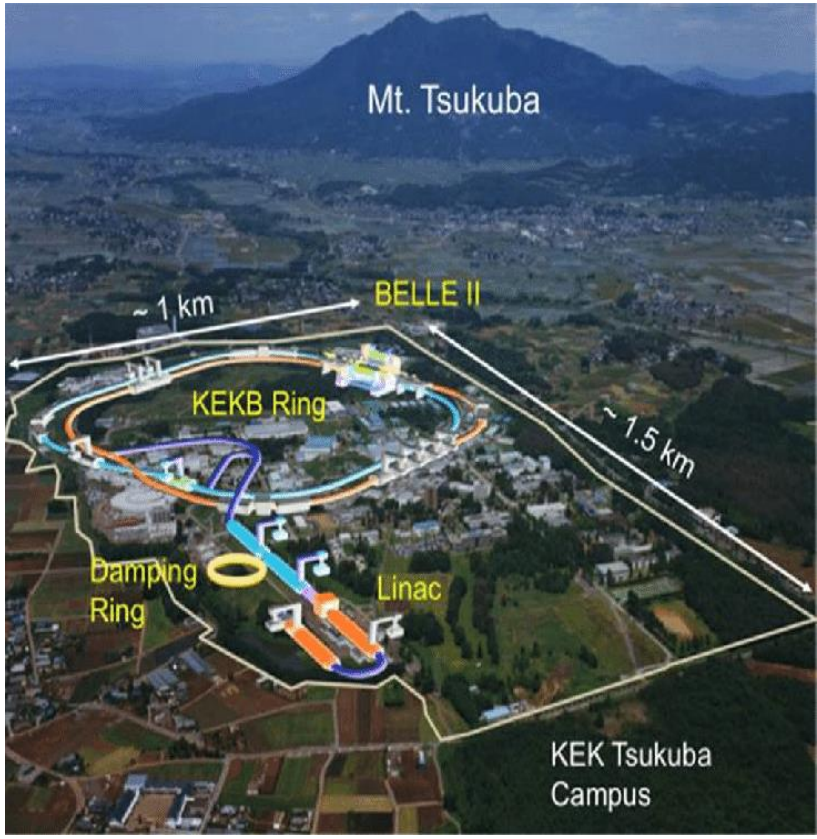
The Belle II experiment



Experiment on the intensity frontier of the search for new physics (NP)

e^+- e^- collisions at $\sqrt{s} = m\big(\Upsilon(4S)\big) = 10.58$ GeV

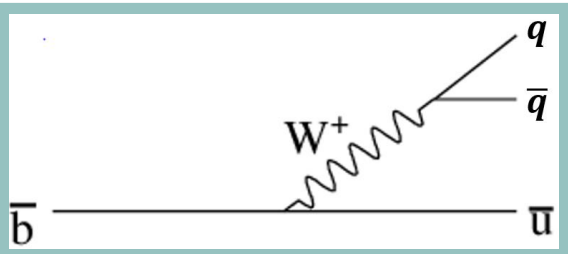
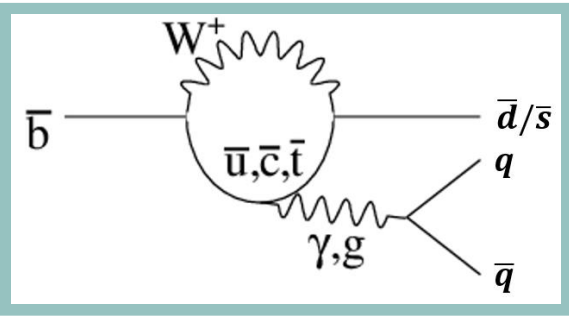
$\Upsilon(4S)$ decays into B-meson pair → B factory

Goal:

Perform most precise measurements of Standard Model (SM) parameters

- 30 x Belle peak luminosity ($\mathcal{L} = 6 \times 10^{35} cm^{-2} s^{-1}$)
- 50 x Belle integrated luminosity ($\mathcal{L}_{int} = 50 ab^{-1}$)

Hadronic Charmless B-Decays

Tree diagram	Penguin diagram
	
BR $\sim 10^{-5}$	BR $\sim 10^{-5}$

→Potentially find new physics (NP) in loop contributions

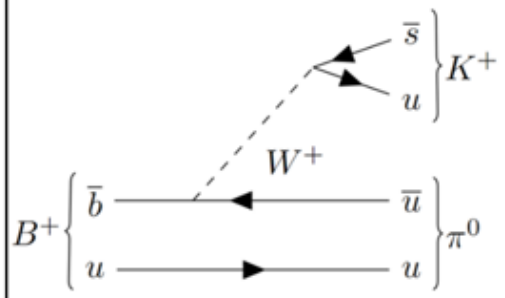
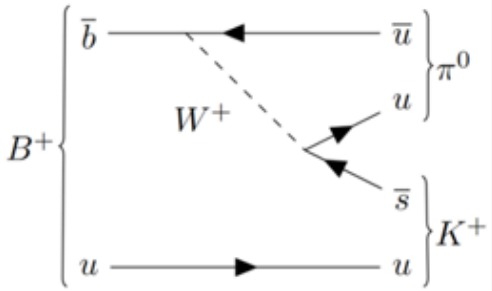
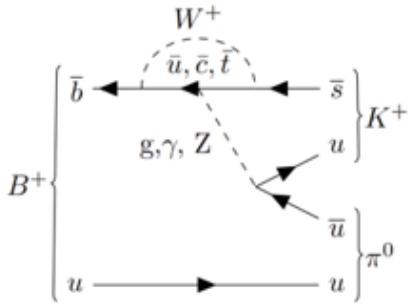
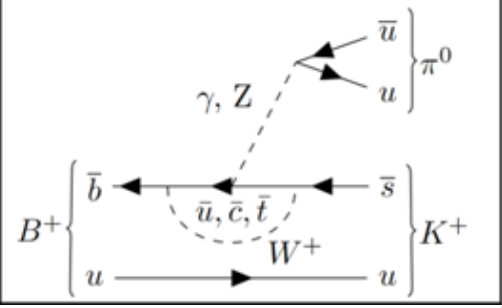
My work on the $B \to K^{(*)}\pi$ system:

- Investigate amplitudes of $B \to K^{(*)}\pi$ decays ($B^+ \to K^0\pi^+$, $B^+ \to K^+\pi^0$, $B^0 \to K^+\pi^-$, $B^0 \to K^0\pi^0$)

  →Extract parameter values, visualize the results and identify important measurements

- Perform analysis on $B^+ \to K^*(892)^+[K_S^0\pi^+]\pi^0$

Amplitudes of $B \to K\pi$ Decays

Decay	T′	C′	P′, P'^{C}_{EW}	P'_{EW}
$B^+ \to K^+\pi^0$				

Tree diagrams

Penguin diagrams

Neglect annihilation, exchange and penguin-annihilation diagrams

1. Order: $|P'_{tc}|$ 2. Order: $|T'|,\ |P'_{EW}|$ 3. Order: $|C'|,\ |P'_{uc}|,\ |P'^{C}_{EW}|$

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Amplitudes of $B \to K\pi$ Decays

$$A^{0+} = -P'_{tc} + P'_{uc}e^{i\gamma} - \frac{1}{3}P'^{C}_{EW}$$

$$\sqrt{2}A^{+0} = -T' e^{i\gamma} - C' e^{i\gamma} + P'_{tc} - P'_{uc}e^{i\gamma} - P'_{EW} - \frac{2}{3}P'^{C}_{EW}$$

$$A^{+-} = -T' e^{i\gamma} + P'_{tc} - P'_{uc}e^{i\gamma} - \frac{2}{3}P'^{C}_{EW}$$

$$\sqrt{2}A^{00} = -C' e^{i\gamma} - P'_{tc} + P'_{uc}e^{i\gamma} - P'_{EW} - \frac{1}{3}P'^{C}_{EW}$$

Isospin sum rule: $\sqrt{2}A^{00} + A^{-+} = \sqrt{2}A^{0+} + A^{+0}$

[1]: Nicolas Boisvert Beaudry et al. The B →πK Puzzle Revisited. 2018. arXiv: 1709.07142 [hep-ph]

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Fitting to the Measured Values

Fit the theory parameters to the existing data using a least squares method:

$$BR = \frac{\tau p}{8\pi m_B^2}|A|^2 \qquad A_{CP} = \frac{BR(B^- \to \bar{f}) - BR(B^+ \to f)}{BR(B^- \to \bar{f}) + BR(B^+ \to f)} \qquad S_{CP} = \sin(2\beta)\sqrt{1 - A_{CP}^2}$$

Used Data for $B \to K\pi$ [1], [2]:

	BR	A_{CP}	S_{CP}
$B^+ \to K^0\pi^+$	23,8±0,4	-0,020±0,034	
$B^+ \to K^+\pi^0$	12,9±0,2	0,037±0,021	
$B^0 \to K^+\pi^-$	19,6±0.5	-0,083±0,004	
$B^0 \to K^0\pi^0$	9,93±0,49	-0,08±0,14	0,58±0,17

[2]: Particle Data Group et al. “Review of Particle Physics”. In: Progress of Theoretical and Experimental Physics 2020.8 (Aug. 2020). 083C01. issn: 2050-3911. doi: 10.1093/ptep/ptaa104. eprint: https://academic.oup.com/ptep/article-pdf/2020/8/083C01/34673722/ptaa104.pdf. url: https://doi.org/10.1093/ptep/ ptaa104.

[3]: Will Parker. “Direct CP violation in the decay B+ to K+ pi0 at LHCb. Direct CP violation in the decay B+ to K+ pi0 at LHCb”. In: (Dec. 2020). url: https://cds.cern.ch/record/2746303.

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Simplifications

Define strong phase $\delta_{T'}$ as 0, so $T' = T'_0$, while $C' = C'_0 e^{i\delta_{C'}}$ etc.

Use relation $P'_{EW} = \frac{3c_9}{2c_1} RT'$[1], where c_i are Wilson coefficients and $R \equiv |(V^*_{tb}V_{ts})/(V^*_{ub}V_{us})|$

Only consider contributions up to the second order for now

$$A^{0+} = -P'_{tc}$$

$$\sqrt{2}A^{+0} = -T' e^{i\gamma} + P'_{tc} - \frac{3}{2}\frac{c_9}{c_1} RT'$$

$$A^{+-} = -T' e^{i\gamma} + P'_{tc}$$

$$\sqrt{2}A^{00} = -P'_{tc} - \frac{3}{2}\frac{c_9}{c_1} RT'$$

[1]: Nicolas Boisvert Beaudry et al. The B →πK Puzzle Revisited. 2018. arXiv: 1709.07142 [hep-ph]

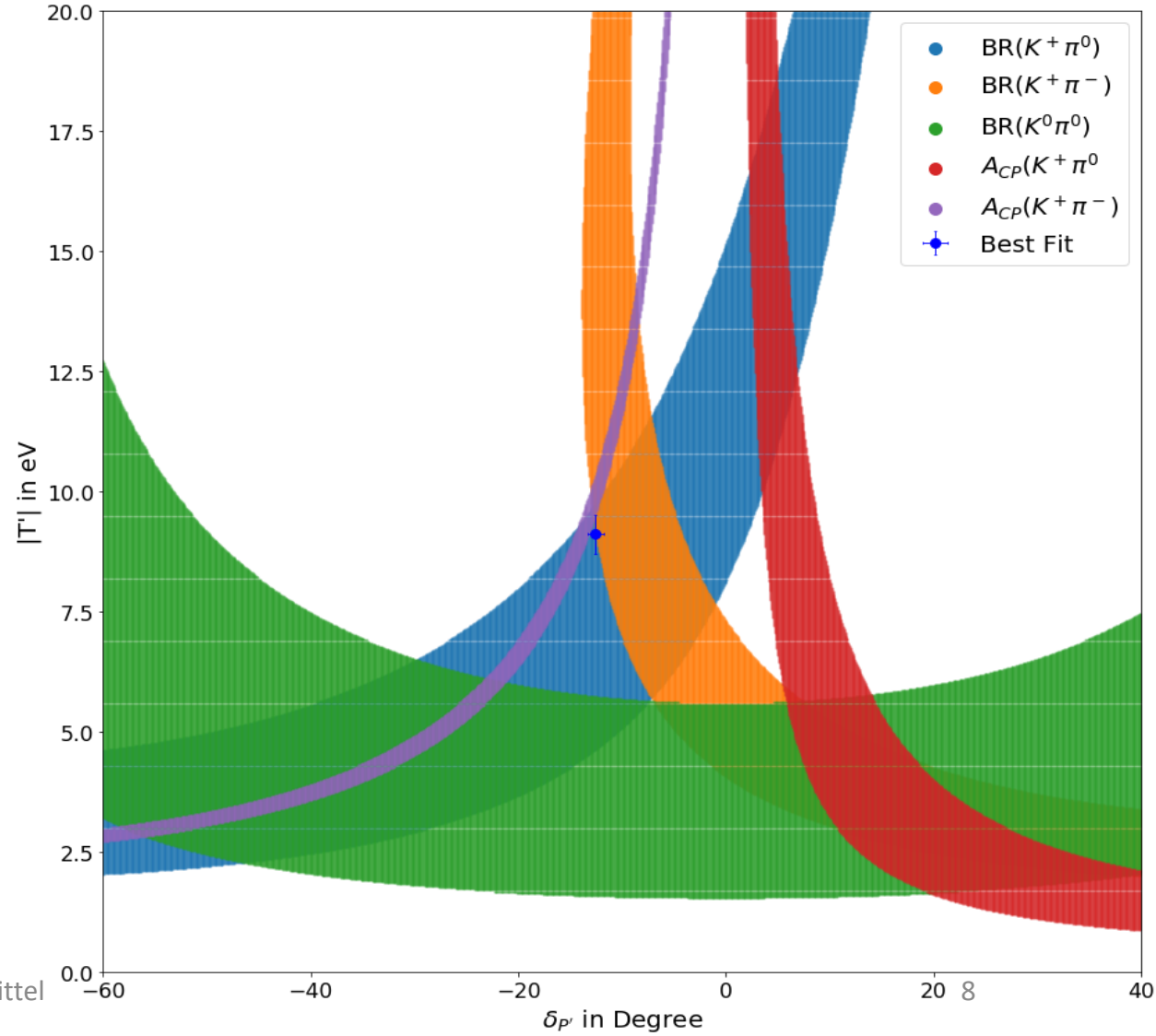
Fit up to second Order for $B \to K\pi$

$\lvert P' \rvert$ [eV]	$\delta_{P'}[^\circ]$	$\lvert T' \rvert$ [eV]	$\gamma[^\circ]$	R	$\frac{\chi^2}{d.o.f.}$	p-value
53.1 ± 0.5	-12.5 ± 0.7	9.1 ± 0.5	61 ± 3	49 ± 1	$66.9/6$	< 0.0001

Goodness of fit indicates large discrepancies between model and data
→several regions of partial agreement

The weak phase is considerably below the measured value of $\gamma = (71.1 \pm 5.3)°$

Measurement of $A_{CP}(K^+\pi^-)$ dominates the result, while $A_{CP}(K^+\pi^0)$ can not be explained ($K\pi$-puzzle)

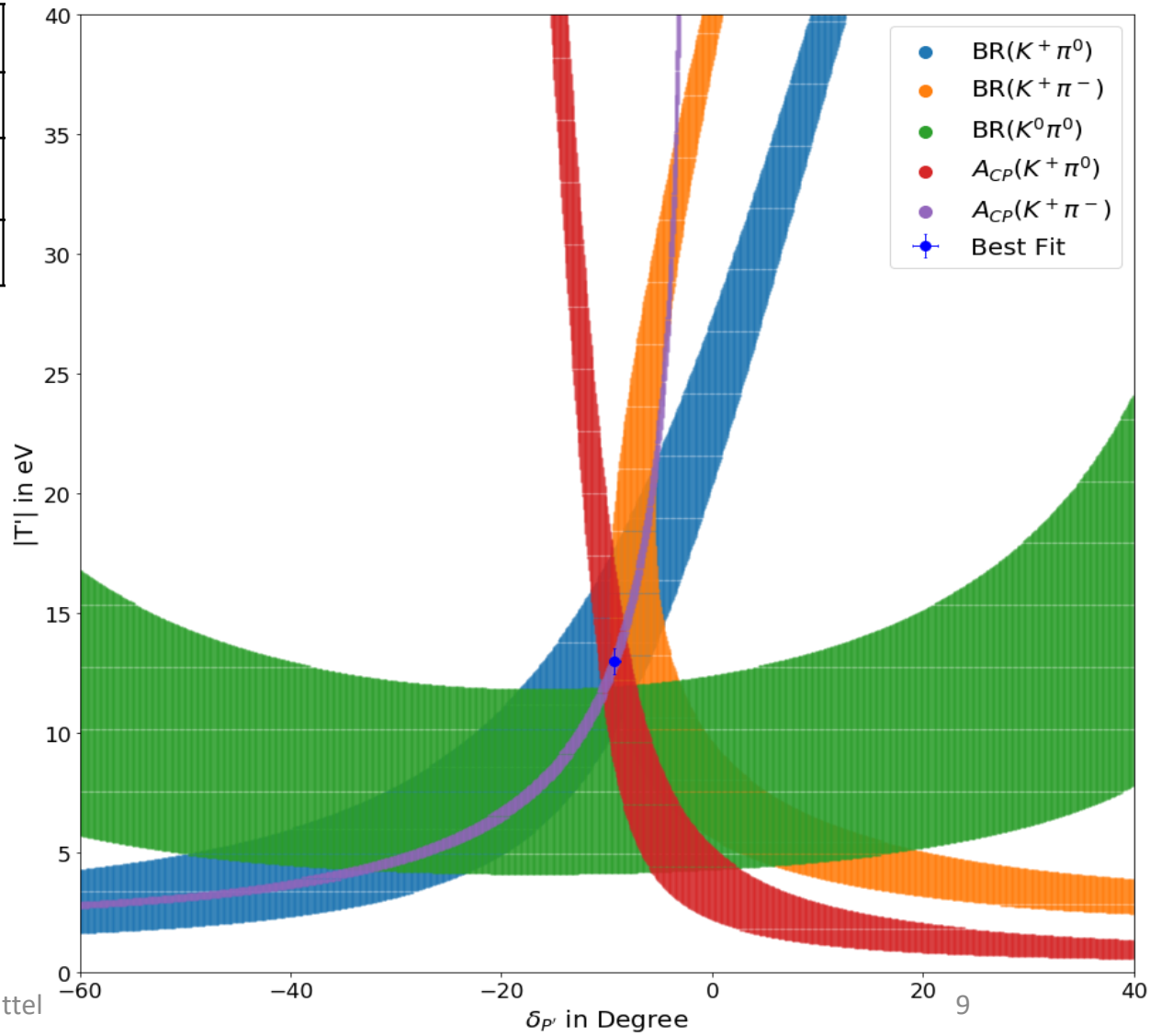


Introduce $|C'| = \frac{|T'|}{3}$ for $B \to K\pi$

$\lvert P' \rvert$ [eV]	$\delta_{P'}[^\circ]$	$\lvert T' \rvert$ [eV]	$\delta_{C'}[^\circ]$	$\gamma[^\circ]$
53.5 ± 0.5	-9.3 ± 0.5	13.0 ± 0.6	-47 ± 6	64 ± 3
$\beta[^\circ]$	R	$\frac{\chi^2}{d.o.f.}$	p-value	
22.2 ± 0.7	49 ± 1	$5.9/5$	0.3161	

The fit quality improved reasonably, including the estimate for γ

$BR(K^0\pi^0)$ shows the largest discrepancy to the fit result, while imposing possibly the strongest constraint on $|T'|$
→ Key measurement



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Analysis on $B^+ \to K^*(892)^+[K_S^0\pi^+]\pi^0$

1. **Reconstruction**
   combine candidates in kinematic fits to fill list of B-meson candidates
2. **Selection**
   loose baseline selection followed by optimized continuum suppression and particle identification cuts
3. **Modelling**
   use simulated data (MC) to model relevant features and determine selection efficiencies for BR calculations
4. **Fit to data & calculate physics quantities**
5. **Assess systematic uncertainties**

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$$

$$\Delta E = E_{reco} - E_{beam}$$

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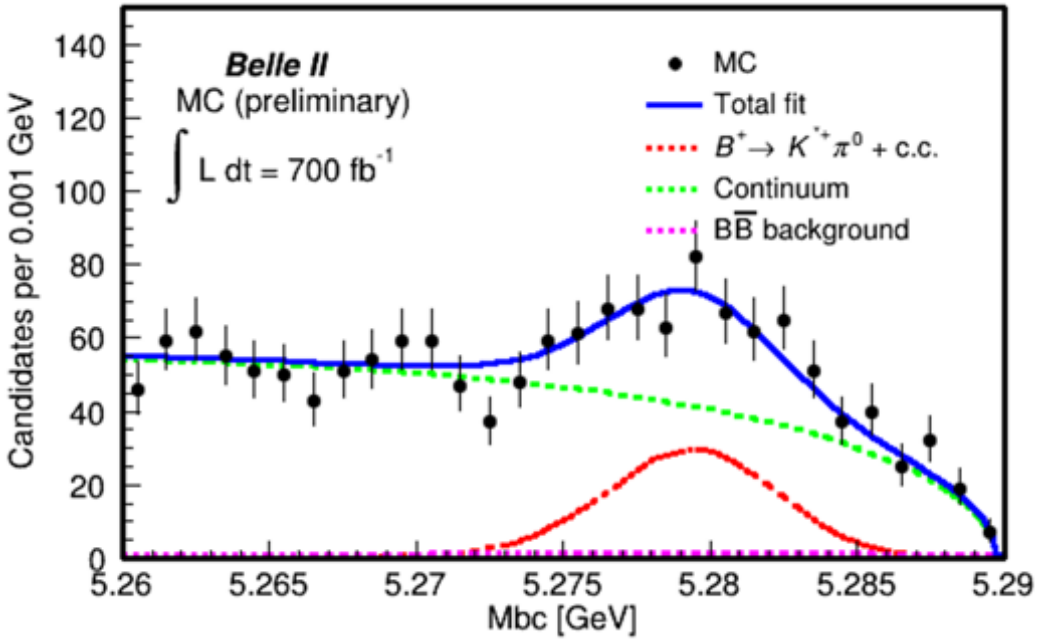
Current Status

Current fits reproduce signal but have problems to distinguish between continuum and $B\bar{B}$ background

Attempts to fit designated $B\bar{B}$ individually failed to improve the result so far

In addition, the calculated direct CP Asymmetry is -0.049 ± 0.109 with a MC truth value of -0.021 → no meaningful result yet

→The modelling and resulting fits need improvements



Component	Fit value	MC truth
Signal	222 ± 26	194
$B\bar{B}$	39 ± 82	266
Continuum	1266 ± 89	1067
Total	1527	1527

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Outlook

More precise measurements can improve the parameter estimation and resolve or strengthen tensions

The analysis on $B^+ \to K^*(892)^+[K_S^0\pi^+]\pi^0$ must still be improved and extended
→4 possible $K^*\pi$ channels

Data: $0.063ab^{-1}$ analyzed, $0.213ab^{-1}$ on tape
→ $0.8 - 1ab^{-1}$ expected until end of 2022