Charmless two-body decays at Belle and prospects at Belle II

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on behalf of the Belle and Belle II Collaborations

Contents

- Recent measurements of two-body hadronic B decays at Belle
- Belle II prospects of such decays

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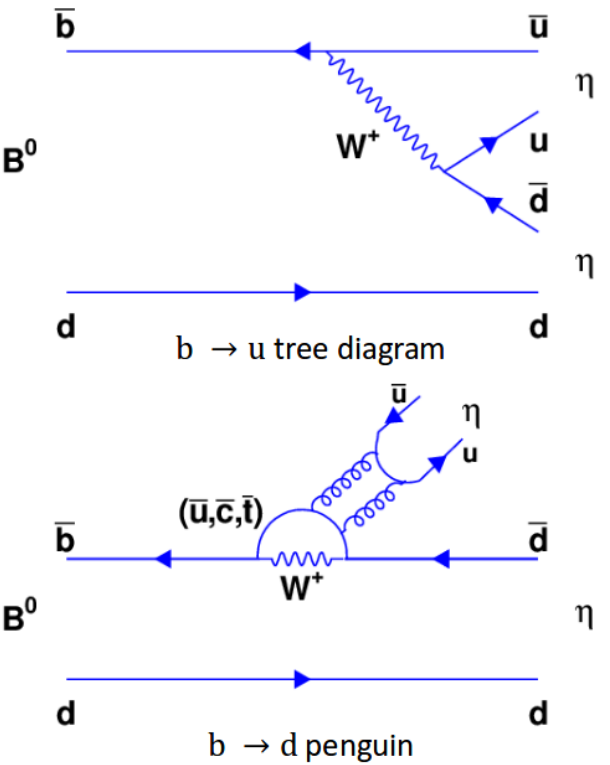
BELLE Belle II

BROOKHAVEN NATIONAL LABORATORY

Why charmless decays?

- Rare decays
- Small branching fractions (~10^{-6}) in Standard Model
- Mediated via b→u transition and/or b→d or b→s penguin transitions
  - Possibility of having Non-Standard Model particle in the loop, sensitive to new physics contribution
- Many such decays are useful for CPV measurements



- I will be focusing on two-body decays with one or both daughters are neutral (Please see Peicheng Lu's talk on Tuesday 12:30)
- Most of these decays are difficult in LHCb

Recent Belle Measurements

- $B^0 \to \eta\pi^0$
- $B^0 \to \eta\eta$
- $B^0 \to \pi^0\pi^0$
- $B_s \to K_S K_S$

All measurements shown here are based on the final set of Belle data set [711/fb for Y(4S) and 121/fb for Y(5S)]

B. Pal et al,
PRD 92, 011101 R (2015)

$B^0 \to \eta\pi^0$

Analysis Technique

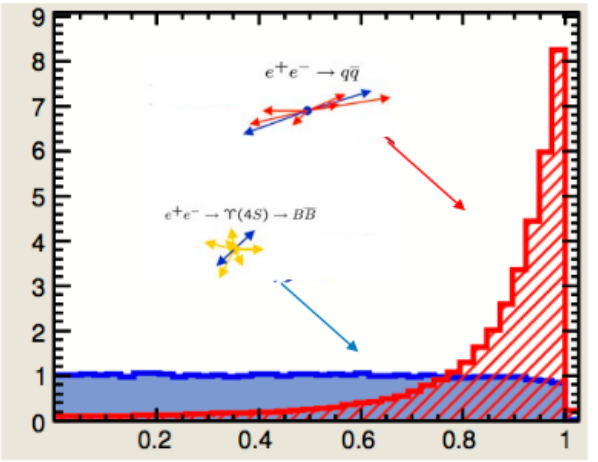
- Highly suppressed decay
- Predicted branching fraction: (2-12)X10^{-7}
- The branching fraction of this decay is useful to constrain the isospin-breaking effects on the value of CP-violating phase sin $2\Phi_2$ (= sin 2α) measured in $B \to \pi\pi$ decays. [M. Gronau, J. Zupan, PRD 71, 074017(2005); S. Gardner, PRD 72, 034015(2005)]

- Two η sub-decay modes are used: $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$
- Combined branching fraction is obtained by performing a simultaneous fit
- Continuum background (dominant background) is suppressed using a multivariate analyzer based on Neural Network (NN); input variables are the event shape variables

- Modified NN output is employed as one of the fit variable

$$C'_{NB} = \log\left(\frac{C_{NN} - C_{min}}{C_{max} - C_{NN}}\right)$$

- The Fit model is studied in MC simulations, peak position and resolutions are then calibrated using high statistics control sample.



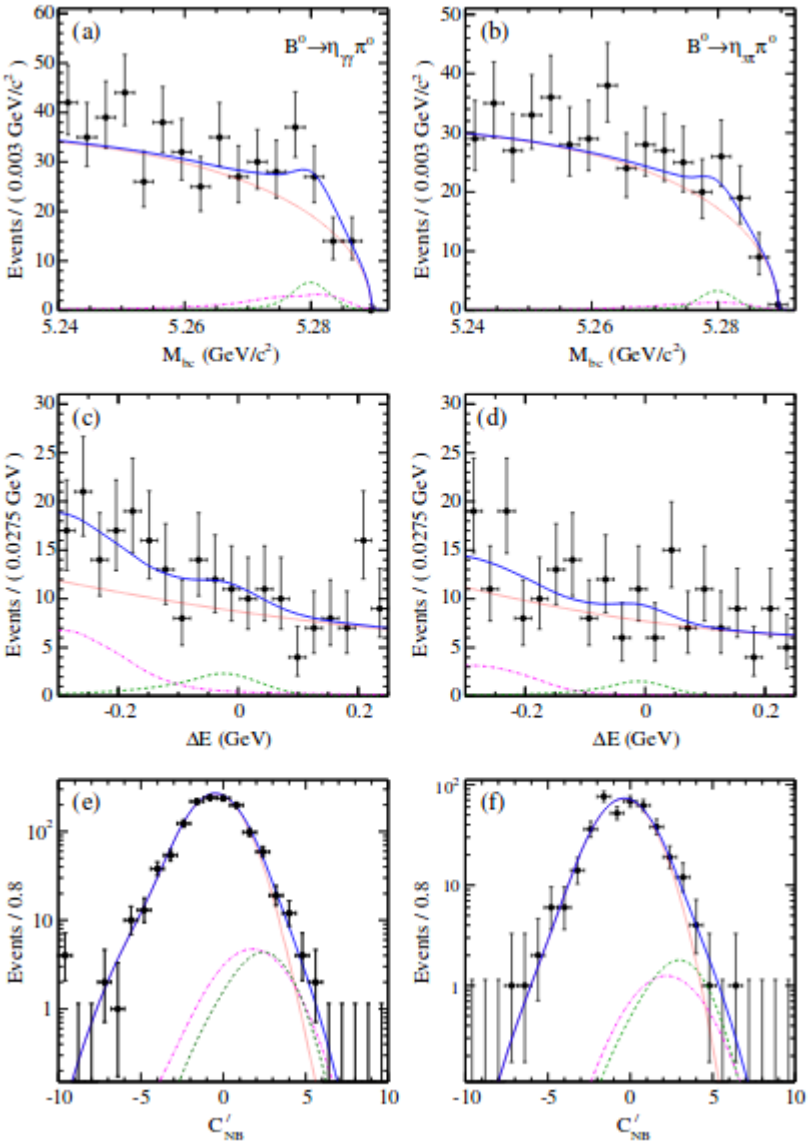
$B^0 \to \eta\pi^0$

B. Pal et al,
PRD 92, 011101 R (2015)

$$M_{\rm bc} = \sqrt{E^2_{\rm beam} - |\vec{p}_B|^2 c^2}/c^2$$

$$\Delta E = E_B - E_{\rm beam}$$

$$C'_{NB} = \log\left(\frac{C_{NN} - C_{min}}{C_{max} - C_{NN}}\right)$$



Mode	$Y_{\rm sig}$	ϵ (%)	$\mathcal{B}_\eta$ (%)	Significance	$\mathcal{B}(10^{-7})$
$B^0 \to \eta_{\gamma\gamma}\pi^0$	$30.6^{+12.2}_{-10.8}$	18.4	39.41	3.1	$5.6^{+2.2}_{-2.0}$
$B^0 \to \eta_{3\pi}\pi^0$	$0.5^{+6.6}_{-5.4}$	14.2	22.92	0.1	$0.2^{+2.8}_{-2.3}$
Combined				3.0	$4.1^{+1.7}_{-1.5}$

1st evidence

$$\mathcal{B}(B^0 \to \eta\pi^0) = \left(4.1^{+1.7+0.5}_{-1.5-0.7}\right)\times 10^{-7}$$
$$\mathcal{B}(B^0 \to \eta\pi^0) < 6.5\times 10^{-7} \text{ at 90\% CL}$$

- Branching fraction is consistent with the SM
- The isospin-breaking correction due to π^0-η-η' mixing in $B \to \pi\pi$ decays improved. Previously the correction was

$$|(\Delta\alpha - \Delta\alpha_0)_{\pi^0-\eta-\eta'}| < 1.6^\circ \text{ at 90\% CL}$$

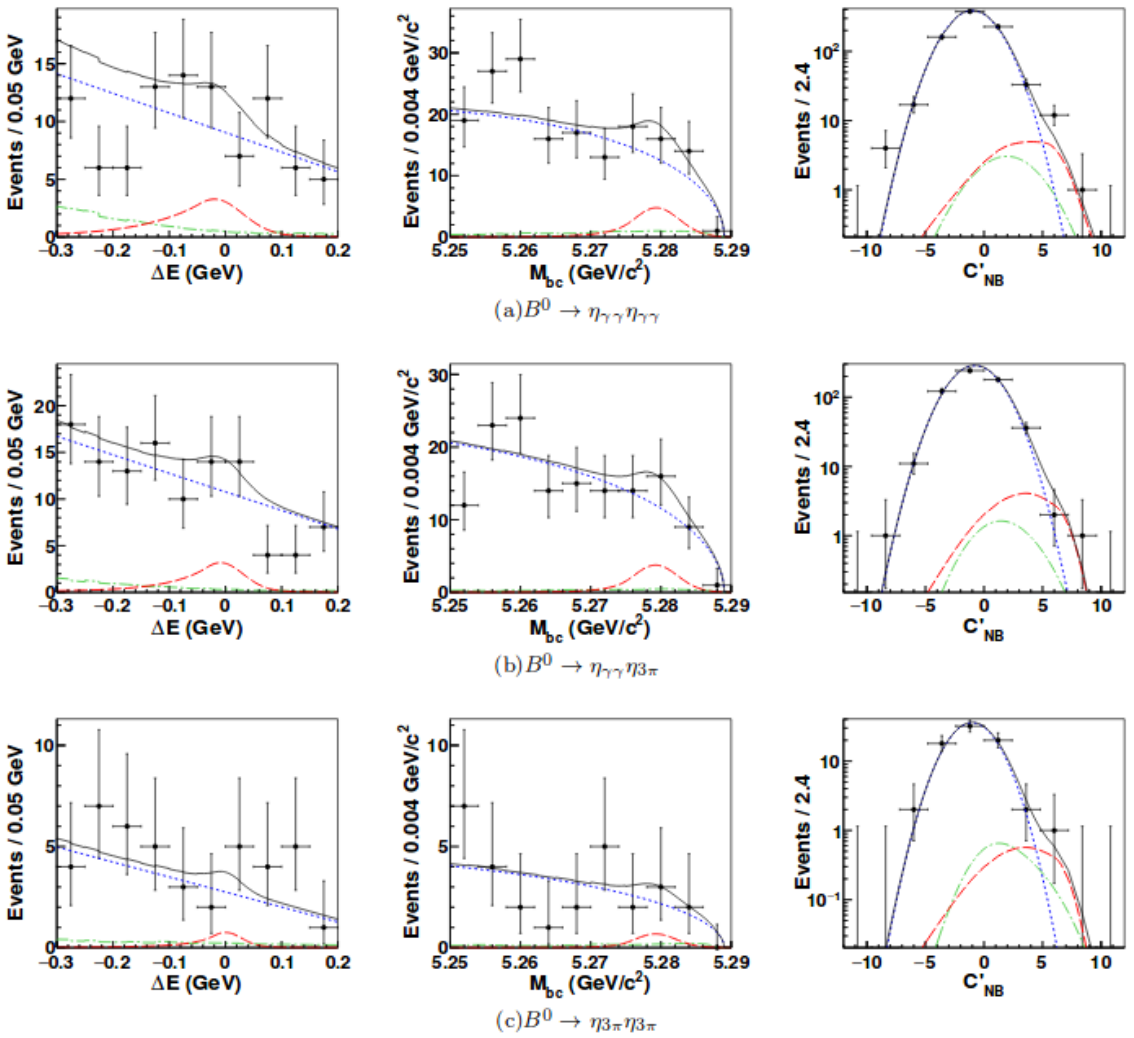
and now

$$|(\Delta\alpha - \Delta\alpha_0)_{\pi^0-\eta-\eta'}| < 0.97^\circ \text{ at 90\% CL,}$$

I.S. Lee et al,
arXiv:1609.03267 [hep-ex]

$B^0 \to \eta\eta$

Similar decay as of $B^0 \to \eta\pi^0$

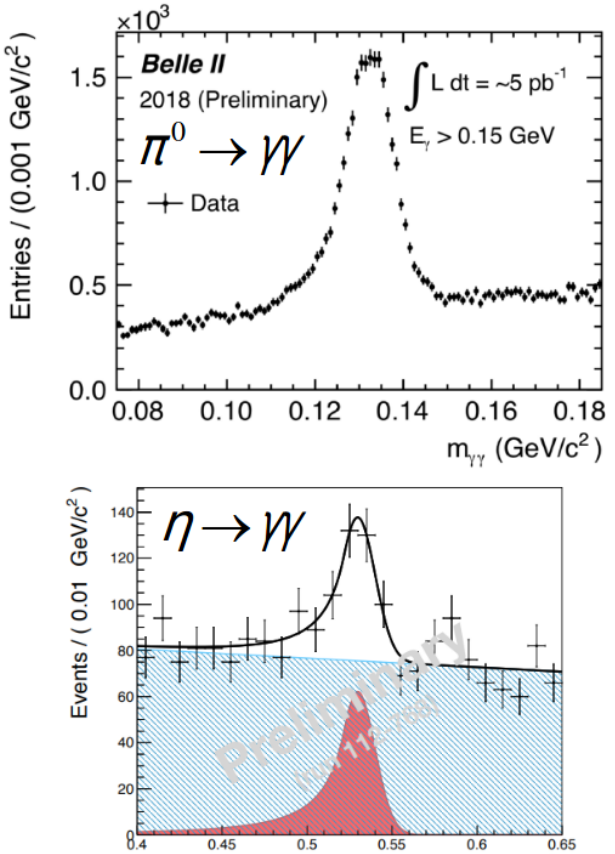


Sub-decay mode	$\eta_{\gamma\gamma}\eta_{\gamma\gamma}$	$\eta_{\gamma\gamma}\eta_{3\pi}$	$\eta_{3\pi}\eta_{3\pi}$
Yields			
Signal	$18.3^{+6.5}_{-5.6}$	$14.4^{+5.4}_{-4.7}$	$2.1^{+0.8}_{-0.7}$
$\mathcal{B}(10^{-7})$		$5.9^{+2.1}_{-1.8} \pm 1.4$	
$\mathcal{B}$ significance $\mathcal{S}(\sigma)$		3.3	

Preliminary

1st evidence

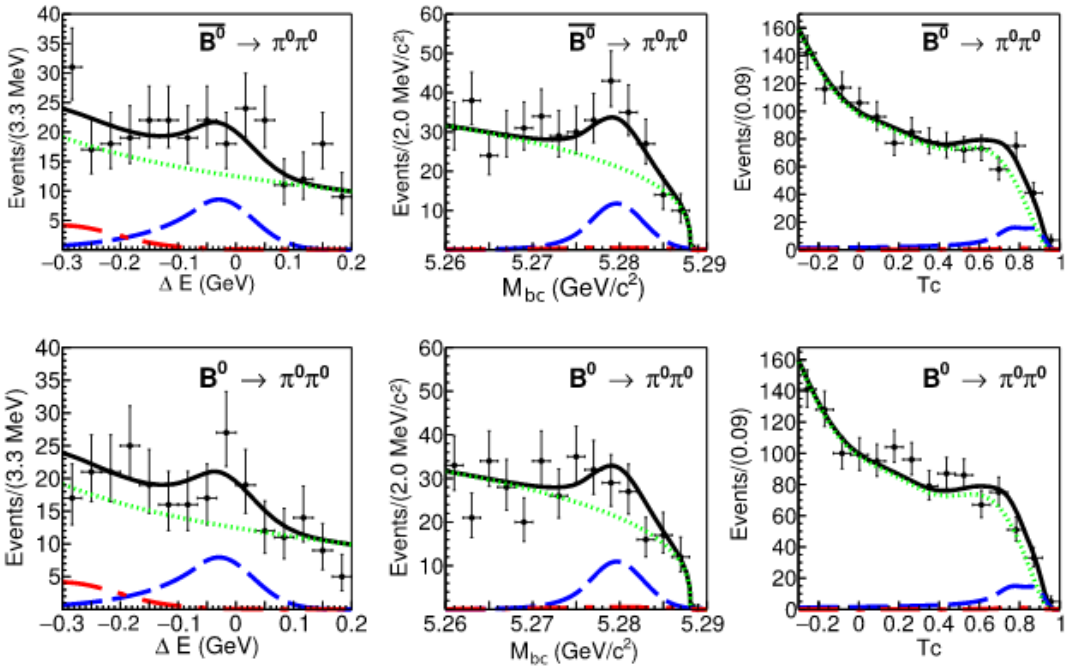
Belle II will be able to observe many similar decay modes where there are one or more neutral particles present in the final state and measure their branching fraction precisely. CP-asymmetries will also be measured.



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

T. Julius et al,
PRD 96, 032007 (2017)

- Similar tree and penguin diagrams contribute as of $B^0 \to \eta\pi^0$
- Important for Φ_2 measurement via isospin analysis of the entire $B \to \pi\pi$ system
- Important to probe the disagreement between the prediction based on QCD factorization (<10^{-6}) and previous measurements



Analysis technique is similar to $\eta\pi^0$ and $\eta\eta$ analyses, except flavor tagging is used to measure the A_{CP}

2017 PDG status

VALUE (10^{-6})	CL%	DOCUMENT ID		TECN
1.91 ± 0.22	**OUR AVERAGE**			
1.83 ±0.21 ±0.13		1 LEES	2013D	BABR
$2.3\ ^{+0.4}_{-0.5}\ ^{+0.2}_{-0.3}$		1 CHAO	2005	BELL

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.31 \pm 0.19 \pm 0.19) \times 10^{-6}$$

$$A_{CP} = +0.14 \pm 0.36 \pm 0.10.$$

- Measured Branching fraction is still larger than QCD factorization based expectation. [H. Li, S. Mishima, PRD 83, 034023(2011)]
- However, it is consistent with the prediction based on perturbative QCD approach. [C.F. Qiao et al, PLB 748, 422(2015); Y.-F. Li, X.-Q. Yu, PRD 95, 034023 (2017)]

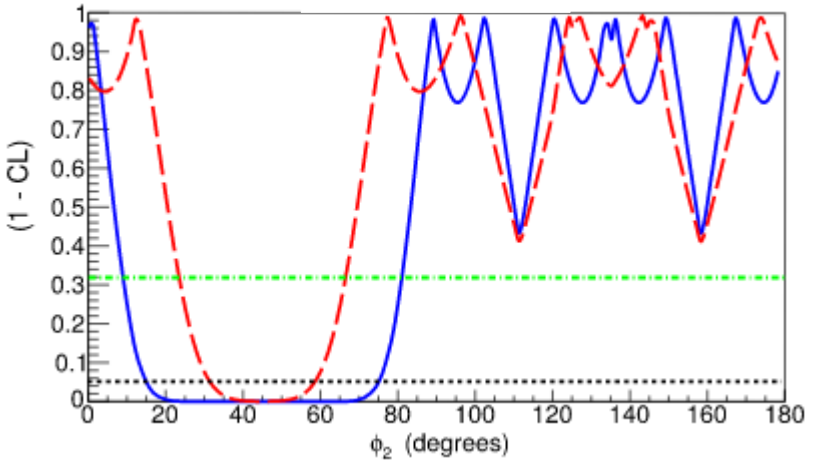
Constraint on Φ_2

T. Julius et al, PRD 96, 032007 (2017)

This analysis

$$\mathcal{B}(B^0 \to \pi^0\pi^0) = (1.31 \pm 0.19 \pm 0.19) \times 10^{-6}$$

$$A_{CP} = +0.14 \pm 0.36 \pm 0.10$$



Red represents the previous Belle constraint
Blue includes the newly measured Br and A_{CP}

Excluded region (9.5 – 81.6)° at 68% CL and (15.5 – 75.0)° at 95% CL

Previous Belle Analyses: PRD 87, 031103 R (2013); PRD 88, 092003 (2013)

$A_{CP}(B^0 \to \pi^+\pi^-) = +0.33 \pm 0.06 \pm 0.03$

$S_{CP}(B^0 \to \pi^+\pi^-) = -0.64 \pm 0.08 \pm 0.03$

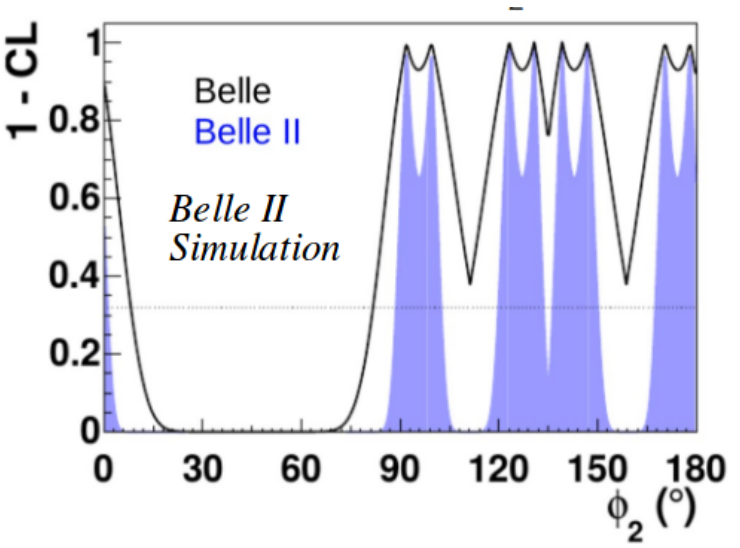
$B(B^0 \to \pi^+\pi^-) = (5.04 \pm 0.21 \pm 0.18) \times 10^{-6}$

$B(B^+ \to \pi^+\pi^0) = (5.86 \pm 0.26 \pm 0.38) \times 10^{-6}$

$A_{CP}(B^+ \to \pi^+\pi^0) = +0.025 \pm 0.043 \pm 0.007$

All these used to perform an isospin analysis to constrain Φ_2 (α)

Current PDG average is, $\alpha = 93 \pm 5$ degrees

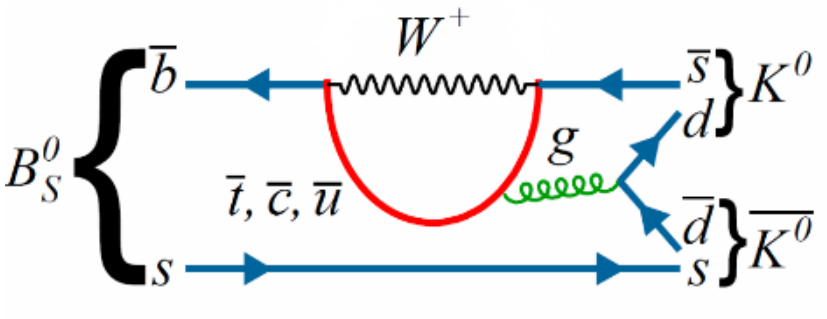


See also Benjamin Oberhof's talk on Wednesday 9:50 at WG4

$B_s \to K_S K_S$

B. Pal et al,
PRL 116, 061801 (2016)

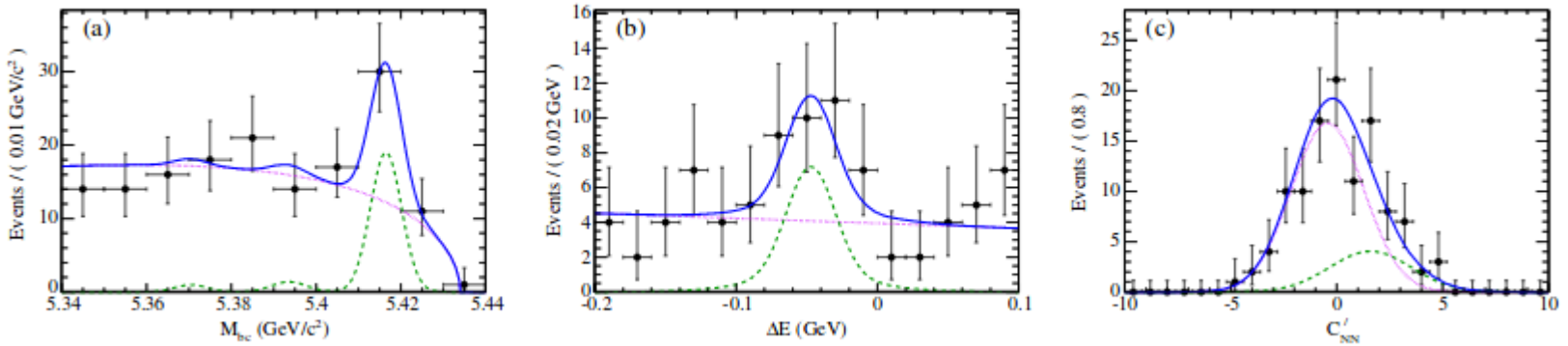
- Mainly b→s penguin decay; measurement of this decay is of considerable interest due to the potential new physics sensitivity.



- Predicted branching fraction is (1.6-2.7)x10^{-5}
- The presence of non-standard model particles or couplings such as model with Z' coupling may enhance the branching fraction. [Q. Chang et al, J Phys. G41, 105002 (2014)]
- PTEP 2014, 023B04 (2014) by A. Hayakawa et al, and in JHEP 0612, 019 (2006) by S. Baek et al: the direct CP asymmetry (A_{CP}) of this decay mode is very promising observable to search for the new physics. It was shown that the A_{CP} is not more than 1% in SM, can be as large as 10% in the presence of SUSY, while the branching ratio remain unaffected.

$B_s \to K_S K_S$

B. Pal et al,
PRL 116, 061801 (2016)



- We observed 29.0(+8.5,-7.6) signal events with a significance of 5.1 standard deviations including the systematic uncertainties

$$\mathcal{B}\left(B_s^0 \to K^0\overline{K^0}\right) = \left[19.6^{+5.8}_{-5.1}(stat) \pm 1.0(syst) \pm 2.0\left(N_{B_s\overline{B_s}}\right)\right]\times 10^{-6}$$

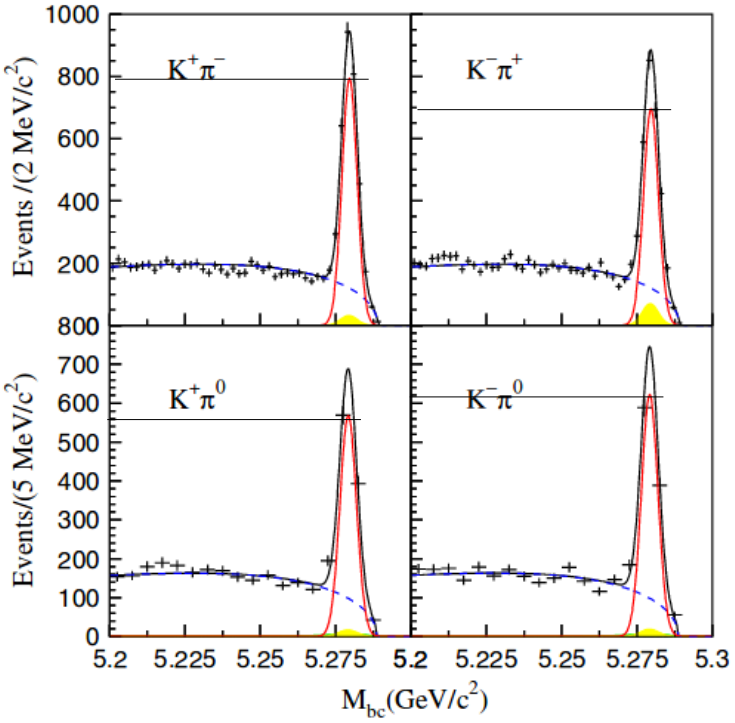
1st observation

- This measurement is in good agreement with the SM expectation and is the first observation of a charmless two-body B_s decays involving only neutral hadrons.
- Because of low statistics we haven't performed the CP violation measurement. However at high luminosity Belle II, we will have sufficient statistics (~1000 signal events) to perform the CPV measurement.

Prospects at Belle II

Direct CPV in B → Kπ decays: K-π puzzle

Belle results: PRD 87, 031103 R(2013)



$A_{CP}(B^0 \to K^+\pi^-)$

VALUE		DOCUMENT ID		TECN
−0.082 ± 0.006	**OUR AVERAGE**			
−0.083 ±0.013 ±0.004		AALTONEN	2014P	CDF
−0.080 ±0.007 ±0.003		AAIJ	2013AX	LHCB
−0.069 ±0.014 ±0.007		DUH	2013	BELL
$-0.107 \pm 0.016\ ^{+0.006}_{-0.004}$		LEES	2013D	BABR
−0.04 ±0.16	1	CHEN	2000	CLE2

$A_{CP}(B^+ \to K^+\pi^0)$

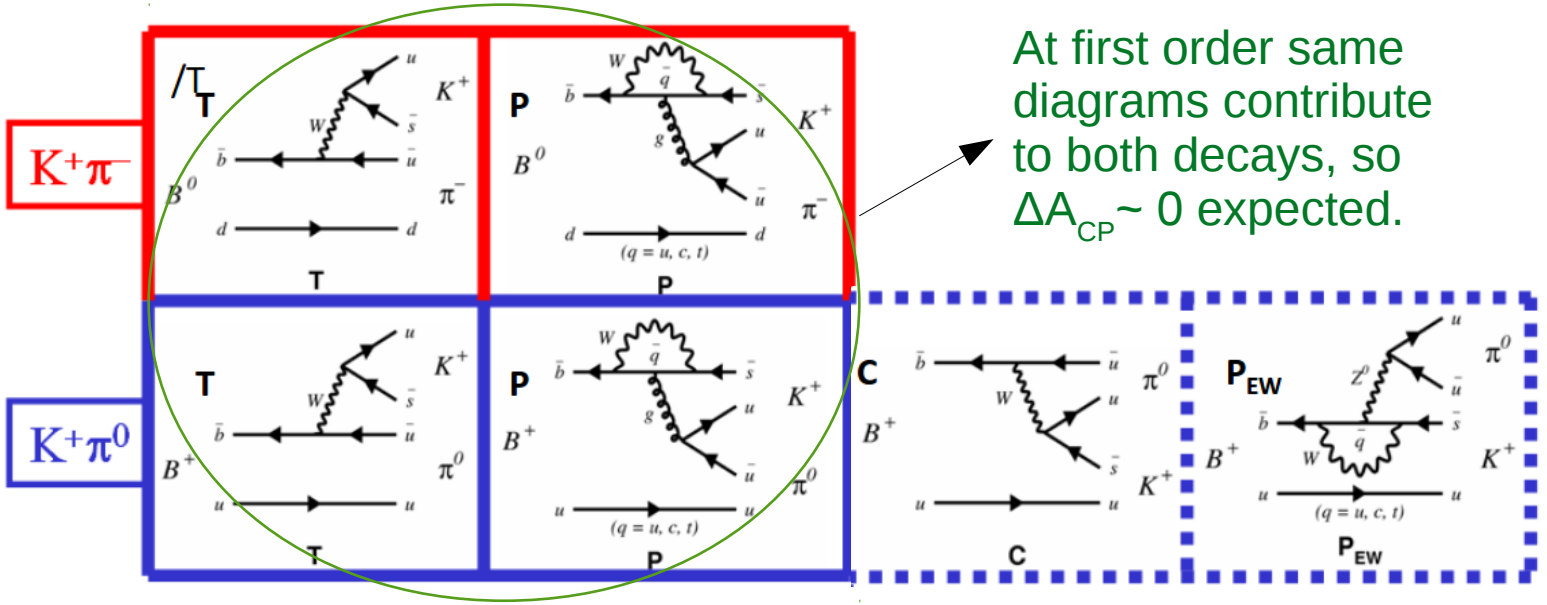
VALUE		DOCUMENT ID		TECN
0.037 ± 0.021	**OUR AVERAGE**			
0.043 ±0.024 ±0.002		DUH	2013	BELL
0.030 ±0.039 ±0.010		AUBERT	2007BC	BABR
−0.29 ±0.23	1	CHEN	2000	CLE2

$\Delta A_{CP} = A_{CP}(K^+\pi^-) - A_{CP}(K^+\pi^0)$

$= -0.119 \pm 0.022$

~5.4 σ discrepancy!

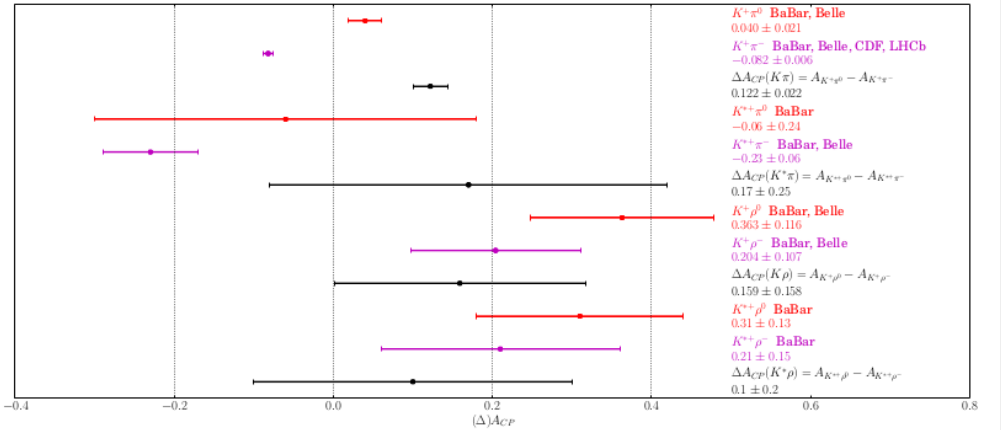
Possible solution to Kπ puzzle



At first order same diagrams contribute to both decays, so $\Delta A_{CP} \sim 0$ expected.

- Discrepancy may be due to the neglected diagrams, which are expected to be small in the standard model or some unknown new physics, which violates isospin symmetry.
- Many theoretical interpretations, but not so conclusive.
- Conclusive answer might be provided by model independent sum rule, see next slide.

Exp. status of ΔA_{CP} in similar PV, VV decays; currently statistically limited, but can be precisely measured in Belle II and could provide additional insights on the pattern of ΔA_{CP}.



Possible solution to Kπ puzzle

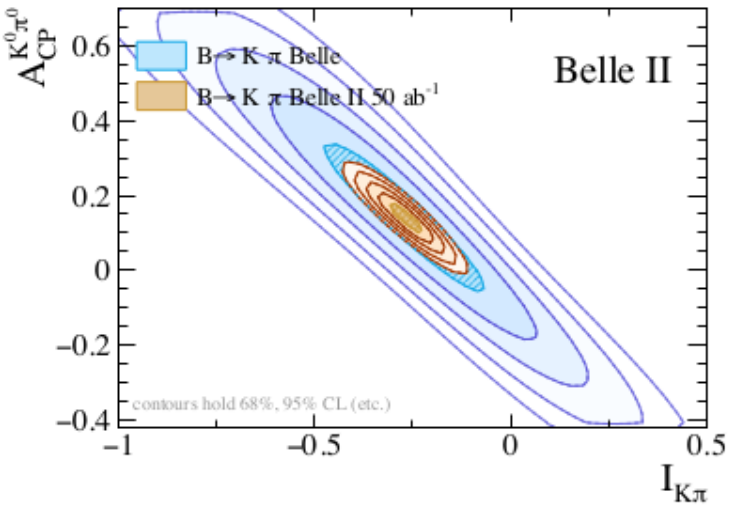
$$I_{K\pi} = A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^+\pi^0}\frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2A_{CP}^{K^0\pi^0}\frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

- Proposed by M. Gronau, PLB 627, 82 (2005) and this parameter is expected to be small
- Deviation would indicate the existence of new physics
- But it requires all four A_{CP} must be measured to high precision

	NLO	NNLO	NNLO + LD	Exp (WA)	Exp (Belle II)
$\pi^-\bar{K}^0$	$0.71^{+0.13+0.21}_{-0.14-0.19}$	$0.77^{+0.14+0.23}_{-0.15-0.22}$	$0.10^{+0.02+1.24}_{-0.02-0.27}$	-1.7 ± 1.6	Belle input
$\pi^0 K^-$	$9.42^{+1.77+1.87}_{-1.76-1.88}$	$10.18^{+1.91+2.03}_{-1.90-2.62}$	$-1.17^{+0.22+20.00}_{-0.22-\ 6.62}$	4.0 ± 2.1	
$\pi^+ K^-$	$7.25^{+1.36+2.13}_{-1.36-2.58}$	$8.08^{+1.52+2.52}_{-1.51-2.65}$	$-3.23^{+0.61+19.17}_{-0.61-\ 3.36}$	-8.2 ± 0.6	
$\pi^0\bar{K}^0$	$-4.27^{+0.83+1.48}_{-0.77-2.23}$	$-4.33^{+0.84+3.29}_{-0.78-2.32}$	$-1.41^{+0.27+5.54}_{-0.25-6.10}$	1 ± 10	-14 ± 13
ΔA_{CP}	$2.17^{+0.40+1.39}_{-0.40-0.74}$	$2.10^{+0.39+1.40}_{-0.39-2.86}$	$2.07^{+0.39+2.76}_{-0.39-4.55}$	12.2 ± 2.2	
$I_{K\pi}$	$-1.15^{+0.21+0.55}_{-0.22-0.84}$	$-0.88^{+0.16+1.31}_{-0.17-0.91}$	$-0.48^{+0.09+1.09}_{-0.09-1.15}$	-14 ± 11	$-27 \pm 14(7)(3)$

Belle II physics Book: arXiv:1808.10567

- arXiv:1806.08783 R. Fleischer et al:
  if this puzzle originates from New Physics, then this could be explained by models with extra Z' bosons (in modified electroweak penguin sector)
- Currently, π^0K^0 measurement is statistically limited. This is one of the key measurements in Belle II and hope to resolve the puzzle



Summary

- Some of the recent measurements of two-body charmless hadronic B decays are discussed
- Some prospects of these decays at Belle II are also discussed.
- Belle II with partial vertex detector successfully recorded first collision data this year. Full detector operation early next year.