Direct CP Violation in B Decays
Status and Prospects for Belle II

Pablo Goldenzweig

Flavour Physics with High-Luminosity Experiments
MIAPP, Munich
Oct. 24 - Nov. 18, 2016

Karlsruhe Institute of Technology
Belle II

Outline

- Conditions for Direct CPV.
- $K\pi$-puzzle:
  - Test-of-sum rule for $B \to K\pi$.
  - Extension to $B \to K^*\pi$ and $B \to K^{(*)}\rho$ systems.
  - Comparison with (N)NLO calculations.
- Triple product asymmetries in $B \to VV$ decays.
- Large local CP asymmetries in 3-body final states.
- $DCPV$ in B_s decays.
- Expectations from Belle II, both with increased data and detector improvements will be discussed throughout.

- Direct CPV is observed by comparing the decay rate of particles $\Gamma(P \to f)$ and anti-particles $\Gamma(\overline{P} \to \overline{f})$, where f and $\overline{f}$ are CP-conjugate final states.
- Stated simply, if

  $\Gamma(P \to f) \neq \Gamma(\overline{P} \to \overline{f}) \quad \Rightarrow \quad CP$ Violation in decay

  We can express this as an asymmetry:

$$\mathcal{A}_{CP} = \frac{\Gamma(P\to f)-\Gamma(\overline{P}\to\overline{f})}{\Gamma(P\to f)+\Gamma(\overline{P}\to\overline{f})}$$

$$= \frac{|\overline{A}|^2-|A|^2}{|\overline{A}|^2+|A|^2} = \frac{2|a_1||a_2|\,\sin(\phi_1-\phi_2)\,\sin(\delta_1-\delta_2)}{|a_1|^2+|a_2|^2+|a_1||a_2|\,\cos(\phi_1-\phi_2)\,\cos(\delta_1-\delta_2)}$$

- To observe CP-violating effects by comparing $\Gamma(P \to f)$ and $\Gamma(\overline{P} \to \overline{f})$ we need:
  1. A minimum of 2 amplitudes contributing to a given decay process.
  2. *Both* CP-violating and non-CP-violating phases.

$B \to K\pi$

Belle, Phys. Rev. D **87**, 031103(R) (2013)

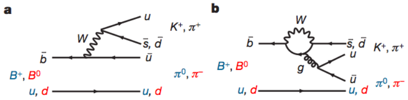
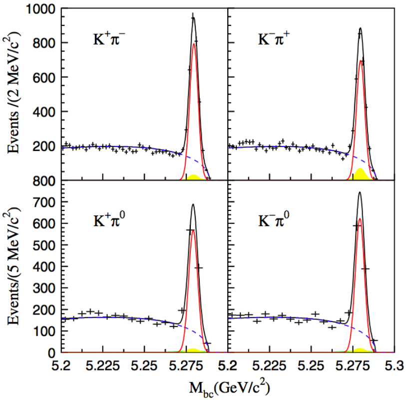


Figure 17.4.4. The dominant Tree-level (a) and Penguin-loop (b) Feynman diagrams in the two-body decays $B \to K\pi$ and $B \to \pi\pi$ (Lin, 2008).



- Measurements of $DCPV$ in $B^+ \to K^+\pi^0$ found to be different than the same quantity in $B^0 \to K^+\pi^-$, contrary to the naive expectation from the presence of electroweak penguin diagrams.

$$\mathcal{A}_{K^+\pi^0} - \mathcal{A}_{K^+\pi^-} = 0.112 \pm 0.027 \pm 0.007 \ \ (4\sigma)$$

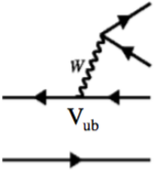
- The difference could be due to:
  - Neglected diagrams contributing to $B^\pm$ decays (theoretical uncertainty is still large).
  - Some unknown NP effect that violates isospin.

$\Rightarrow$ *In combination with other $K\pi$ measurements and with the larger Belle II dataset, strong interaction effects can be controlled and the validitiy of the SM can be tested in a model-independent way.*

Additional diagrams

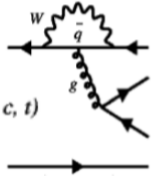
Dominant

T



P

(q = u, c, t)



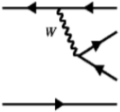
Tree

Penguin

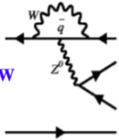
Additional diagrams

Sub-dominant

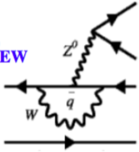
C



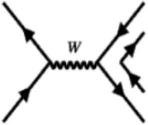
$\mathbf{P^{C}_{EW}}$



$\mathbf{P_{EW}}$



A



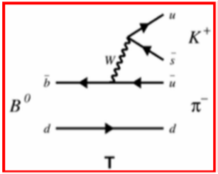
C = color suppressed

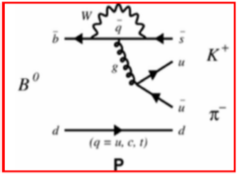
P_{EW} = electroweak penguin

P^{C}_{EW} = color suppressed electroweak penguin

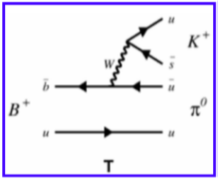
A = annihilation

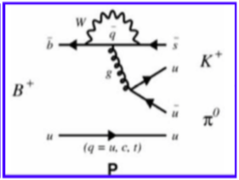
New Physics here?

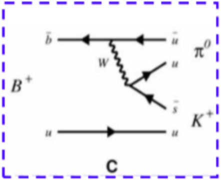


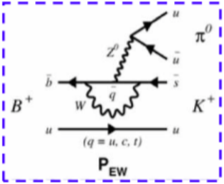


Mode	Contributing diagrams
$B^0 \to K^+\pi^-$	$T + P + P^C_{EW}$
$B^+ \to K^+\pi^0$	$T + P + C + P_{EW} + P^C_{EW} + A$









- Enhancement of **C** is required

  C > T

  ⇒ *breakdown of theory understanding*

- Enhancement of P_{EW}

  ⇒ *would indicate new physics*

Many theory papers trying to explain the data...

- C.-W.Chaing, et al., PRD 70, 034020
- Y.-Y.Charng, et al., PRD 71, 014036
- W.-S.Hou, et al., PRL 95, 141601
- S.Baek, et al., PRD 71, 057502
- S.Baek, et al., PLB 653, 249
- H.-n.Li,et al., PRD 72, 114005

Karlsruhe Institute of Technology

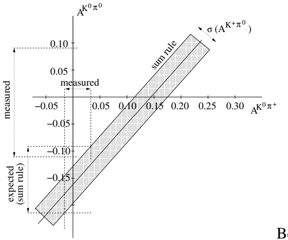
Belle II

Test-of-sum (isospin) rule for NP nearly free of theoretical uncertainties, where the SM can be tested by measuring all observables:

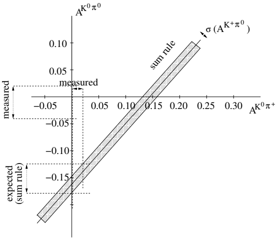
$$I_{K\pi} = \mathcal{A}_{K^+\pi^-} + \mathcal{A}_{K^0\pi^+} \frac{\mathcal{B}(K^0\pi^+)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\pi^0} \frac{\mathcal{B}(K^+\pi^0)}{\mathcal{B}(K^+\pi^-)} \frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\pi^0} \frac{\mathcal{B}(K^0\pi^0)}{\mathcal{B}(K^+\pi^-)}$$

$$I_{K\pi} = -0.270 \pm 0.132 \pm 0.060 \ \ (1.9\sigma)$$

Isospin sum rule can be presented as a band in the $\mathcal{A}_{K^0\pi^0}$ vs. $\mathcal{A}_{K^0\pi^+}$ plane.



Current data



Belle II $\mathcal{L}$ =50ab^{-1}

→ Most demanding measurement is $K^0\pi^0$ final state. With Belle II, the uncertainty on $\mathcal{A}(B \to K^0\pi^0)$ from time-dep. analyses is expected to reach $\sim 4\%$ ⇒ *sufficient for NP studies.*

More data:

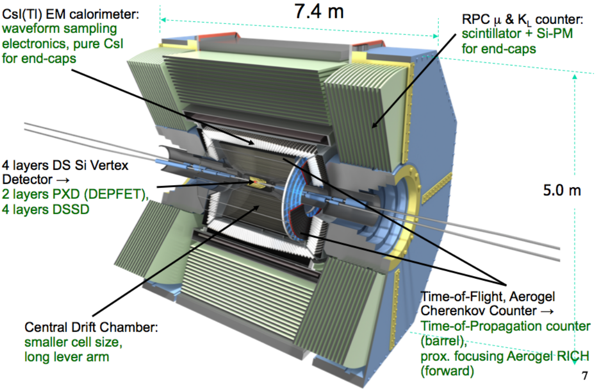
Extrapolate Belle measurements to 5 and 50 ab^{-1}

- Systematic uncertainties scale primarily with integrated luminosity, with the exception of A_{CP} measurements of channels with K_S^0:
  ⇒ *asymmetry of* $K^0/\overline{K}^0$ *interactions in material* ($\sigma_{ired} \approx 0.2\%$)
  Phys. Rev. D **84**, 111501 (2011)
- Ideally separate the reducible and irreducible systematic errors (unchanged throughout data accumulation) when extrapolating.
  - Few modes are systematically limited, so treat all syst. errors as redcible.
  - Apply scaling to all stat. and syst. errors to Belle results via:

$$\sigma_{Belle\ II} = \sqrt{(\sigma_{stat}^2 + \sigma_{syst}^2)\frac{\mathcal{L}_{Belle}}{\mathcal{L}_{BelleII}} + \sigma_{ired}^2}$$

How will Belle II help to improve our measurements?

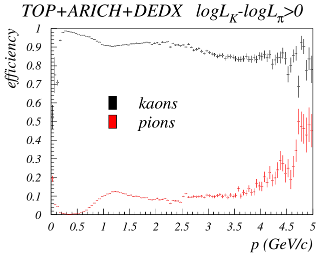
- *Increase hermiticity.*
- *Increase K_S^0 efficiency.*
- *Improve IP and secondary vertex resolution.*
- *Improve K/π separation.*
- *Improve π^0 efficiency.*
- *Add PID in endcaps.*
- *Add μ ID in endcaps.*

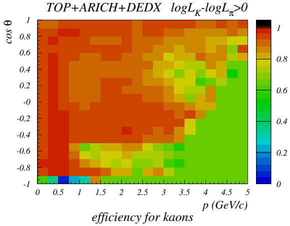


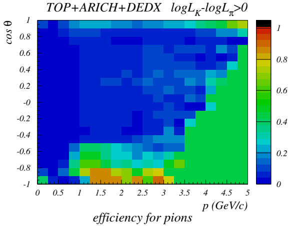
K/π Separation

Two RICH systems covering full momentum range

- Barrel: Time of Propagation (TOP) counter (16 modules)
- Forward Endcap: Aerogel Ring Imaging Cherenkov detector (ARICH)







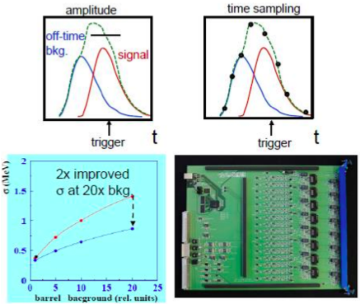
	Belle PID (%)	Belle II PID (%)
Ave. K efficiency	88	94
π fake rate	9	4

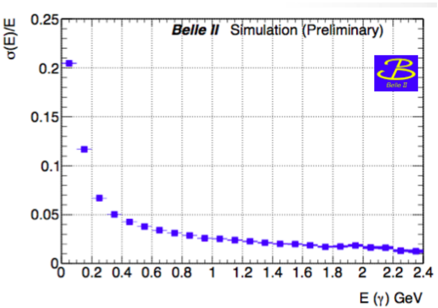
$\Rightarrow$ *Average K efficiency / π fake rate improved: Fake rate decreases by ≈ 2.5 for the same ε.*

π^0 Reconstruction

Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

$\Rightarrow$ *Resolution much better at Belle II*





REF LUIGIS TALK FOR KS, QR AND QQ SUP?

Breakdown of the Systematic Errors in $K\pi$

Systematic errors on $\mathcal{B}$ (in %):

- Most of the multiplicative errors, such as those due to tracking and PID are obtained from data control samples, and scale with luminosity.
- There is also room for improvement with the error due to π^0 reconstruction, with more data, improved detector, and more sophisticated methods.

Belle, Phys. Rev. D **87**, 031103(R) (2013)

Source	$K^+\pi^-$	$K^+\pi^0$	$K^0\pi^+$	$K^0\pi^0$
Tracking	0.70	0.35	0.35	...
PID	1.65	0.78	0.86	...
$R > 0.2$	0.55	0.59	0.80	1.04
MC statistics	0.16	0.18	0.19	0.23
$N_{B\bar{B}}$	1.37	1.37	1.37	1.37
π^0	...	4.0	...	4.0
K_S^0	...	...	1.68	1.68
Signal PDF	0.28	0.43	0.18	1.80
Feed-across	0.49	0.42	0.18	...
Fit bias	0.45	...	...	...
PHOTOS	1.20	...	1.20	...
Charmless B	1.25	0.35	0.97	0.51

- For the systematic error on A_{CP}, fit PDF and detector bias due to tracking acceptance and PID selection will improve.
- Improvements to K_s reconstrction (ε: 86.9%$\to$ 93.6%), signal & tag-side vertex resolution, flavour tagging (ε: 29%$\to$ 32%). (See talk by Luigi Li Gioi)
- Ongoing studies with deep neural networks for flavor tagging and continuum suppression are showing great promise.

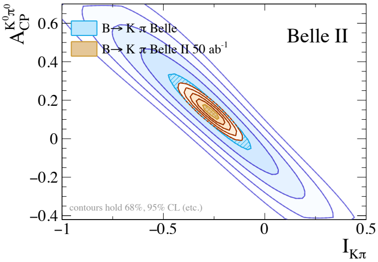
Complete set of measurements from Belle and BaBar.

$\mathcal{B}(10^{-6})$			
Mode	BABAR	Belle	LHCb
$K^+\pi^-$	$19.1 \pm 0.6 \pm 0.6$	$20.0 \pm 0.34 \pm 0.60$	
$K^+\pi^0$	$13.6 \pm 0.6 \pm 0.7$	$12.62 \pm 0.31 \pm 0.56$	
$K^0\pi^+$	$23.9 \pm 1.1 \pm 1.0$	$23.97 \pm 0.53 \pm 0.71$	
$K^0\pi^0$	$10.1 \pm 0.6 \pm 0.4$	$9.68 \pm 0.46 \pm 0.50$	

A_{CP}			
Mode	BABAR	Belle	LHCb
$K^+\pi^-$	$-0.107 \pm 0.016^{+0.006}_{-0.004}$	$-0.069 \pm 0.014 \pm 0.007$	$-0.080 \pm 0.007 \pm 0.003$
$K^+\pi^0$	$0.030 \pm 0.039 \pm 0.010$	$0.043 \pm 0.024 \pm 0.002$	
$K^0\pi^+$	$-0.029 \pm 0.039 \pm 0.010$	$-0.011 \pm 0.021 \pm 0.006$	$-0.022 \pm 0.025 \pm 0.010$
$K^0\pi^0$	$-0.13 \pm 0.13 \pm 0.03$	$0.14 \pm 0.13 \pm 0.06$	

- Perform a 2D scan of $\mathcal{A}_{K^0\pi^0}$ vs. $I_{K\pi}$ for different Belle II scenarios.
- The only possible correlated errors for the A_{CP} measurements are caused by the detector bias, which is estimated with different methods for each channel.
  $\Rightarrow$ *Assume that the bias errors are not correlated.*
- Additionaly the systematic uncertainties are conservatively provided and they are still smaller than the statistical errors.

P. Urquijo, BELLE2-NOTE-0021



Projections for the $B \to K\pi$ isospin sum rule parameter, $I_{K\pi}$, at the Belle measured central value.

Scenario	$\mathcal{A}_{K^0\pi^0}$ Value	Stat.	(Red., Irred.)	$I_{K\pi}$
Belle	0.14	0.13	(0.06, 0.02)	-0.27 ± 0.14
Belle + $B \to K^0\pi^0$ at Belle II 5 ab^{-1}		0.05	(0.02, 0.02)	-0.27 ± 0.07
Belle II 50 ab^{-1}		0.01	(0.01, 0.02)	-0.27 ± 0.03

Karlsruhe Institute of Technology

Belle II

Expect analogous sum rules by replacing:

$K \to K^*$

$$I_{K^*\pi} = \mathcal{A}_{K^{*+}\pi^-} + \mathcal{A}_{K^{*0}\pi^+}\frac{\mathcal{B}(K^{*0}\pi^+)}{\mathcal{B}(K^{*+}\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^{*+}\pi^0}\frac{\mathcal{B}(K^{*+}\pi^0)}{\mathcal{B}(K^{*+}\pi^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^{*0}\pi^0}\frac{\mathcal{B}(K^{*0}\pi^0)}{\mathcal{B}(K^{*+}\pi^-)}$$

$\pi \to \rho$

$$I_{K\rho} = \mathcal{A}_{K^+\rho^-} + \mathcal{A}_{K^0\rho^+}\frac{\mathcal{B}(K^0\rho^+)}{\mathcal{B}(K^+\rho^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^+\rho^0}\frac{\mathcal{B}(K^+\rho^0)}{\mathcal{B}(K^+\rho^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^0\rho^0}\frac{\mathcal{B}(K^0\rho^0)}{\mathcal{B}(K^+\rho^-)}$$

$K \to K^*$ & $\pi \to \rho$

$$I_{K^*\rho} = \mathcal{A}_{K^{*+}\rho^-} + \mathcal{A}_{K^{*0}\rho^+}\frac{\mathcal{B}(K^{*0}\rho^+)}{\mathcal{B}(K^{*+}\rho^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^{*+}\rho^0}\frac{\mathcal{B}(K^{*+}\rho^0)}{\mathcal{B}(K^{*+}\rho^-)}\frac{\tau_{B^0}}{\tau_{B^+}} - 2\mathcal{A}_{K^{*0}\rho^0}\frac{\mathcal{B}(K^{*0}\rho^0)}{\mathcal{B}(K^{*+}\rho^-)}$$

For each set of decays[1], perform a 2D scan of A_{CP} (for most limiting final state) vs. the isospin sum rule parameter.

$\Rightarrow$ Compare with (N)NLO calculations[2].

[1] For the PV & VV systems, BaBar $\mathcal{B}$ and A_{CP} used for projections (Belle results n/a) - see BKUP slides.

[2] No NNLO calc. for VV system, as longitudinal A_{CP} fraction n/a for all final states.

Two-loop current–current operator contribution to the non-leptonic QCD penguin amplitude

CrossMark

G. Bell [a], M. Beneke [b], T. Huber [c], Xin-Qiang Li [d,e,*]

[a] Rudolf Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, United Kingdom
[b] Physik Department T31, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany
[c] Theoretische Physik 1, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Strasse 3, D-57068 Siegen, Germany
[d] Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, PR China
[e] State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, PR China

ARTICLE INFO

Article history:
Received 17 July 2015
Accepted 15 September 2015
Available online 24 September 2015
Editor: B. Grinstein

ABSTRACT

The computation of direct CP asymmetries in charmless B decays at next-to-next-to-leading order (NNLO) in QCD is of interest to ascertain the short-distance contribution. Here we compute the two-loop penguin contractions of the current–current operators $Q_{1,2}$ and provide a first estimate of NNLO CP asymmetries in penguin-dominated $b \to s$ transitions.

1. Introduction

Non-leptonic exclusive decays of B mesons play a crucial role in studying the CKM mechanism of quark flavour mixing and in quantifying the phenomenon of CP violation. Direct CP violation is related to the rate difference of $\bar{B} \to f$ decay and its CP-conjugate and arises if the decay amplitude is composed of at least two partial amplitudes with different re-scattering ("strong") phases, which are multiplied by different CKM matrix elements. Very often useful information on the CKM parameters including the CP-violating phase can be obtained from combining different decay modes, whose partial amplitudes are related by the approximate flavour symmetries of the strong interaction [1], which are then determined from data.

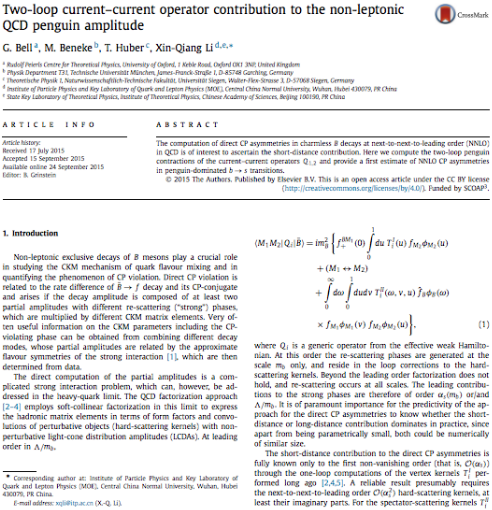
The direct computation of the partial amplitudes is a complicated strong interaction problem, which can, however, be addressed in the heavy-quark limit. The QCD factorization approach [2–4] employs soft-collinear factorization in this limit to express the hadronic matrix elements in terms of form factors and convolutions of perturbative objects (hard-scattering kernels) with non-perturbative light-cone distribution amplitudes (LCDAs). At leading order in Λ/m_b,

$$\langle M_1 M_2 | Q_i | \bar{B} \rangle = i m_B^2 \Bigg\{ f_+^{BM_1}(0) \int_0^1 du\, T_i^I(u)\, f_{M_2}\phi_{M_2}(u) + (M_1 \leftrightarrow M_2) + \int_0^\infty d\omega \int_0^1 du dv\, T_i^{II}(\omega, v, u)\, \hat{f}_B \phi_B(\omega) \times f_{M_1}\phi_{M_1}(v)\, f_{M_2}\phi_{M_2}(u) \Bigg\}, \quad (1)$$

where Q_i is a generic operator from the effective weak Hamiltonian. At this order the re-scattering phases are generated at the scale m_b only, and reside in the loop corrections to the hard-scattering kernels. Beyond the leading order factorization does not hold, and re-scattering occurs at all scales. The leading contributions to the strong phases are therefore of order $\alpha_s(m_b)$ or/and Λ/m_b. It is of paramount importance for the predictivity of the approach for the direct CP asymmetries to know whether the short-distance or long-distance contribution dominates in practice, since apart from being parametrically small, both could be numerically of similar size.

The short-distance contribution to the direct CP asymmetries is fully known only to the first non-vanishing order (that is, $\mathcal{O}(\alpha_s)$) through the one-loop computations of the vertex kernels T_i^I performed long ago [2,4,5]. A reliable result presumably requires the next-to-next-to-leading order $\mathcal{O}(\alpha_s^2)$ hard-scattering kernels, at least their imaginary parts. For the spectator-scattering kernels T_i^{II}

* Corresponding author at: Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, PR China.
E-mail address: xqli@itp.ac.cn (X.-Q. Li).



Two-loop current–current operator contribution to the non-leptonic QCD penguin amplitude

G. Bell [a], M. Beneke [b], T. Huber [c], Xin-Qiang Li [d,e,*]

[a] Rudolf Peierls Centre for Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, United Kingdom
[b] Physik Department T31, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany
[c] Theoretische Physik 1, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Strasse 3, D-57068 Siegen, Germany
[d] Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, PR China
[e] State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing 100190, PR China

ARTICLE INFO

Article history:
Received 17 July 2015
Accepted 15 September 2015
Available online 24 September 2015
Editor: B. Grinstein

ABSTRACT

The computation of direct CP asymmetries in charmless B decays at next-to-next-to-leading order (NNLO) in QCD is of interest to ascertain the short-distance contribution. Here we compute the two-loop penguin contractions of the current–current operators $Q_{1,2}$ and provide a first estimate of NNLO CP asymmetries in penguin-dominated $b \to s$ transitions.

1. Introduction

Non-leptonic exclusive decays of B mesons play a crucial role in studying the CKM mechanism of quark flavour mixing and in quantifying the phenomenon of CP violation. Direct CP violation is related to the rate difference of $\bar{B} \to f$ decay and its CP-conjugate and arises if the decay amplitude is composed of at least two partial amplitudes with different re-scattering ("strong") phases, which are multiplied by different CKM matrix elements. Very often useful information on the CKM parameters including the CP-violating phase can be obtained from combining different decay modes, whose partial amplitudes are related by the approximate flavour symmetries of the strong interaction [1], which are then determined from data.

The direct computation of the partial amplitudes is a complicated strong interaction problem, which can, however, be addressed in the heavy-quark limit. The QCD factorization approach [2–4] employs soft-collinear factorization in this limit to express the hadronic matrix elements in terms of form factors and convolutions of perturbative objects (hard-scattering kernels) with non-perturbative light-cone distribution amplitudes (LCDAs). At leading order in Λ/m_b,

$$\langle M_1 M_2 | Q_i | \bar{B} \rangle = i m_B^2 \Big\{ f_+^{BM_1}(0) \int_0^1 du\, T_i^I(u)\, f_{M_2}\phi_{M_2}(u) + (M_1 \leftrightarrow M_2) + \int_0^\infty d\omega \int_0^1 du dv\, T_i^{II}(\omega, v, u)\, \hat{f}_B \phi_B(\omega) \times f_{M_1}\phi_{M_1}(v)\, f_{M_2}\phi_{M_2}(u) \Big\}, \quad (1)$$

where Q_i is a generic operator from the effective weak Hamiltonian. At this order the re-scattering phases are generated at the scale m_b only, and reside in the loop corrections to the hard-scattering kernels. Beyond the leading order factorization does not hold, and re-scattering occurs at all scales. The leading contributions to the strong phases are therefore of order $\alpha_s(m_b)$ or/and Λ/m_b. It is of paramount importance for the predictivity of the approach for the direct CP asymmetries to know whether the short-distance or long-distance contribution dominates in practice, since apart from being parametrically small, both could be numerically of similar size.

The short-distance contribution to the direct CP asymmetries is fully known only to the first non-vanishing order (that is, $\mathcal{O}(\alpha_s)$) through the one-loop computations of the vertex kernels T_i^I performed long ago [2,4,5]. A reliable result presumably requires the next-to-next-to-leading order $\mathcal{O}(\alpha_s^2)$ hard-scattering kernels, at least their imaginary parts. For the spectator-scattering kernels T_i^{II}

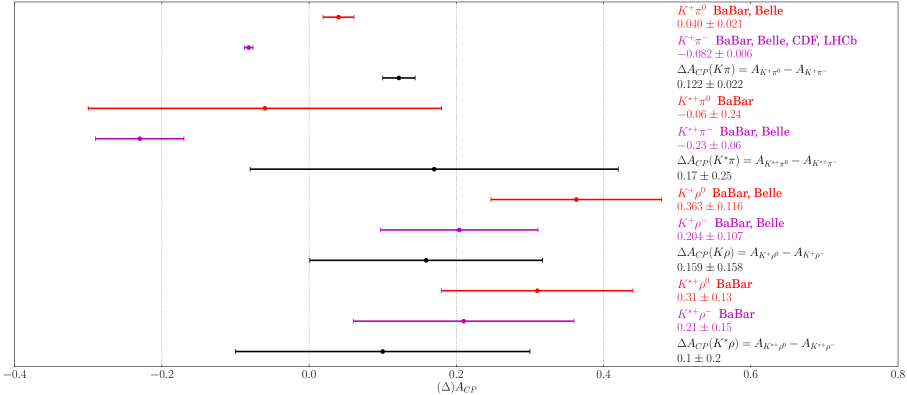
* Corresponding author at: Institute of Particle Physics and Key Laboratory of Quark and Lepton Physics (MOE), Central China Normal University, Wuhan, Hubei 430079, PR China.
E-mail address: xqli@itp.ac.cn (X.-Q. Li).

For table on next slide:

- The A_{CP} and isospin identity parameters listed in the Exp. (WA) column are taken from HFAG 2014 results (arXiv:1412.7515).
- However, the B2 fit projections were computed with results from ***a single experiment***: $K\pi$ Belle; $K^*\pi$ & $K\rho$ BaBar.
- The results of the GammaCombo fits are added in the last column. Also shown are the A_{CP} input used in the 2D fit (A_{CP} vs I_x).
- The results of projecting to 5 and 50 ab^{-1} are shown in ().

Comparison w/theory (Modified Table I)

f	NLO	NNLO	NNLO + LD	Exp (WA)	Exp (GC fit and B2 proj.)
$\pi^- \bar{K}^0$	$0.71^{+0.13\,+0.21}_{-0.14\,-0.19}$	$0.77^{+0.14\,+0.23}_{-0.15\,-0.22}$	$0.10^{+0.02\,+1.24}_{-0.02\,-0.27}$	-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	$-27 \pm 14(7)(3)$
$\pi^- \bar{K}^{*0}$	$1.36^{+0.25\,+0.60}_{-0.26\,-0.47}$	$1.49^{+0.27\,+0.69}_{-0.29\,-0.56}$	$0.27^{+0.05\,+3.18}_{-0.05\,-0.67}$	-3.8 ± 4.2	**BaBar input**
$\pi^0 K^{*-}$	$13.85^{+2.40\,+5.84}_{-2.70\,-5.86}$	$18.16^{+3.11\,+\ 7.79}_{-3.52\,-10.57}$	$-15.81^{+3.01\,+69.35}_{-2.83\,-15.39}$	-6 ± 24	-6 ± 24
$\pi^+ K^{*-}$	$11.18^{+2.00\,+\ 9.75}_{-2.15\,-10.62}$	$19.70^{+3.37\,+10.54}_{-3.80\,-11.42}$	$-23.07^{+4.35\,+86.20}_{-4.05\,-20.64}$	-23 ± 6	
$\pi^0 \bar{K}^{*0}$	$-17.23^{+3.33\,+\ 7.59}_{-3.00\,-12.57}$	$-15.11^{+2.93\,+12.34}_{-2.65\,-10.64}$	$2.16^{+0.39\,+17.53}_{-0.42\,-36.80}$	-15 ± 13	
ΔA_{CP}	$2.68^{+0.72\,+5.44}_{-0.67\,-4.30}$	$-1.54^{+0.45\,+4.60}_{-0.58\,-9.19}$	$7.26^{+1.21\,+12.78}_{-1.34\,-20.65}$	17 ± 25	
$I_{K^*\pi}$	$-7.18^{+1.38\,+3.38}_{-1.28\,-5.35}$	$-3.45^{+0.67\,+9.48}_{-0.59\,-4.95}$	$-1.02^{+0.19\,+4.32}_{-0.18\,-7.86}$	-5 ± 45	$69 \pm 32(15)(6)$
$\rho^- \bar{K}^0$	$0.38^{+0.07\,+0.16}_{-0.07\,-0.27}$	$0.22^{+0.04\,+0.19}_{-0.04\,-0.17}$	$0.30^{+0.06\,+2.28}_{-0.06\,-2.39}$	-12 ± 17	**BaBar input**
$\rho^0 K^-$	$-19.31^{+3.42\,+13.95}_{-3.61\,-\ 8.96}$	$-4.17^{+0.75\,+19.26}_{-0.80\,-19.52}$	$43.73^{+7.07\,+\ 44.00}_{-7.62\,-137.77}$	37 ± 11	
$\rho^+ K^-$	$-5.13^{+0.95\,+6.38}_{-0.97\,-4.02}$	$1.50^{+0.29\,+\ 8.69}_{-0.27\,-10.36}$	$25.93^{+4.43\,+25.40}_{-4.90\,-75.63}$	20 ± 11	
$\rho^0 \bar{K}^0$	$8.63^{+1.59\,+2.31}_{-1.65\,-1.69}$	$8.99^{+1.66\,+3.60}_{-1.71\,-7.44}$	$-0.42^{+0.08\,+19.49}_{-0.08\,-\ 8.78}$	6 ± 20	5 ± 26
ΔA_{CP}	$-14.17^{+2.80\,+7.98}_{-2.96\,-5.39}$	$-5.67^{+0.96\,+10.86}_{-1.01\,-\ 9.79}$	$17.80^{+3.15\,+19.51}_{-3.01\,-62.44}$	17 ± 16	
$I_{K\rho}$	$-8.75^{+1.62\,+4.78}_{-1.66\,-6.48}$	$-10.84^{+1.98\,+11.67}_{-2.09\,-\ 9.09}$	$-2.43^{+0.46\,+\ 4.60}_{-0.42\,-19.43}$	-37 ± 37	$-44 \pm 49(25)(11)$

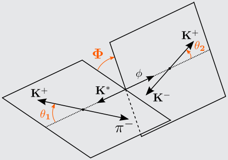


Uncertainty much improved in $K\pi$ but still too large in $K^*\pi$ and $K^{(*)}\rho$ systems to be conclusive.

- Decays to spin-1 final states with pairs formed from ω, K^*, ρ, and ϕ can be used to determine the helicity amplitudes of the decay.
- Channels have low $\mathcal{B}$ and high background.

Full angular analysis requires large statistics (e.g., $B^0 \to \phi K^{*0}$). *With the current datasets most analysis are limited to integrating over the angle between the decay planes Φ, and reporting the longitudinal polarization fraction (f_L)*

$$(1 - f_L)\sin^2\theta_1 \sin^2\theta_2 + 4 f_L \cos^2\theta_1 \cos^2\theta_2$$



Highlights to seach for with more data include:

- Angular analysis of $K^*\rho$ channels.
  - $\Rightarrow$ *Observation that there is an enhanced contribution proportional to electromagnetic penguins, which would be revealed in a polarisation analysis.* hep-ph/0512258
- Contribution of electroweak penguins in the hierarchy of the decays to ωK^{*0} and $\omega\phi$.
- **Triple-product asymmetries, which provide a measure of CP violation that does not require flavor tagging or a time-dependent analysis.**

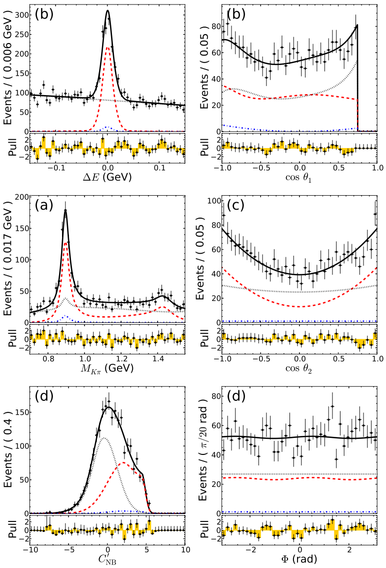
  Phys. Rev. D **84**, 096013 (2011)

Full angular analysis and search for $DCPV$ in $B^0 \to \phi K^{*0}$.

- At Belle/BaBar full angular analysis limited to low-background decays such as $B^0 \to \phi K^{*0}$.
- In the final Belle analysis, a 9D extended unbinned ML fit is used to extract the 26 parameters related to polarization and CPV.
- Figure shows projections onto 6 of the 9 fitted observables.
- All phase ambiguities have been resolved and all parameters related to CP violation are consistent with 0.

$\Rightarrow$ *Belle II's large dataset is needed to perform full angular analyses on many other $B \to VV$ channels.*

Belle, Phys. Rev. D **88**, 072004 (2013)



Statistics-limited for most quantities...

TABLE VII. Summary of the results on the $B^0 \to \phi K^*$ system. See Table II and Eq. (32) for the parameter definition. In this table, we give the fit fraction FF_J per partial wave instead of the branching fraction $\mathcal{B}_J$, which is given in Table VIII together with the yields per partial wave. The first error is statistical and the second is due to systematics.

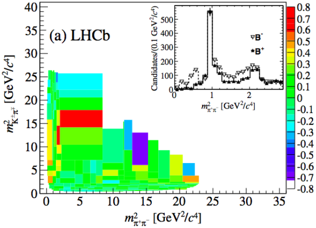
Parameter	$\phi(K\pi)^*_0$ $J=0$	$\phi K^*(892)^0$ $J=1$	$\phi K^*_2(1430)^0$ $J=2$
FF_J	$0.273 \pm 0.024 \pm 0.021$	$0.600 \pm 0.020 \pm 0.015$	$0.099^{+0.016}_{-0.012} \pm 0.018$
f_{LJ}	$\cdots$	$0.499 \pm 0.030 \pm 0.018$	$0.918^{+0.029}_{-0.060} \pm 0.012$
$f_{\perp J}$	$\cdots$	$0.238 \pm 0.026 \pm 0.008$	$0.056^{+0.050}_{-0.035} \pm 0.009$
$\phi_{\parallel J}$ (rad)	$\cdots$	$2.23 \pm 0.10 \pm 0.02$	$3.76 \pm 2.88 \pm 1.32$
$\phi_{\perp J}$ (rad)	$\cdots$	$2.37 \pm 0.10 \pm 0.04$	$4.45^{+0.43}_{-0.38} \pm 0.13$
δ_{0J} (rad)	$\cdots$	$2.91 \pm 0.10 \pm 0.08$	$3.53 \pm 0.11 \pm 0.19$
$\mathcal{A}_{CPJ}$	$0.093 \pm 0.094 \pm 0.017$	$-0.007 \pm 0.048 \pm 0.021$	$-0.155^{+0.152}_{-0.133} \pm 0.033$
$\mathcal{A}^0_{CPJ}$	$\cdots$	$-0.030 \pm 0.061 \pm 0.007$	$-0.016^{+0.066}_{-0.051} \pm 0.008$
$\mathcal{A}^\perp_{CPJ}$	$\cdots$	$-0.14 \pm 0.11 \pm 0.01$	$-0.01^{+0.85}_{-0.67} \pm 0.09$
$\Delta\phi_{\parallel J}$ (rad)	$\cdots$	$-0.02 \pm 0.10 \pm 0.01$	$-0.02 \pm 1.08 \pm 1.01$
$\Delta\phi_{\perp J}$ (rad)	$\cdots$	$0.05 \pm 0.10 \pm 0.02$	$-0.19 \pm 0.42 \pm 0.11$
$\Delta\delta_{0J}$ (rad)	$\cdots$	$0.08 \pm 0.10 \pm 0.01$	$0.06 \pm 0.11 \pm 0.02$

$\Rightarrow$ *Statistical errors* $\approx 7x$ *smaller with 50* ab^{-1} *of Belle II data.*

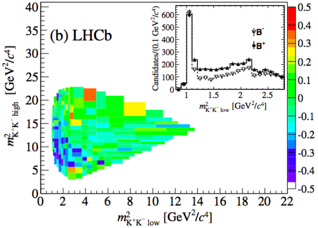
CPV in $B \to 3h$

Large CPV effects not associated with resonances $\Rightarrow$ *QCD effects to be understood*

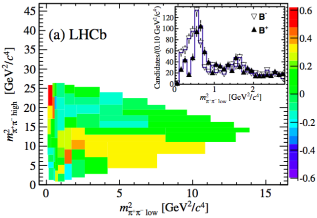
$K\pi\pi$



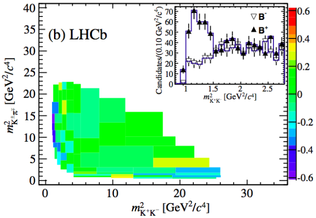
KKK Phys. Rev. Lett. **111**, 101801 (2013)



$\pi\pi\pi$



$KK\pi$ Phys. Rev. Lett. **112**, 011801 (2014)



$\Rightarrow$ *Unidentified structure in the* $m^2_{K^+K^-}$ *projection in* $KK\pi$ *decays at* $< 1.5\ \mathrm{GeV}^2/c^4$. *Only present in the* B^+ *mass projection and gives rise to a large local* CP *asymmetry.* [*Updated measurement: arXiv: 1408.5373]

Karlsruhe Institute of Technology

Belle II

Direct CP violation in 3-body $B_{u,d}$ decays

	Theory (%)	Expt (%)
$\pi^+\pi^-\pi^-$	$8.7^{+1.7}_{-1.9}$	5.8±1.4
$K^+K^-K^-$	$-7.1^{+4.8}_{-4.1}$	-3.6±0.8
$K^-\pi^+\pi^-$	$2.7^{+0.7}_{-0.8}$	2.5±0.9
$K^+K^-\pi^-$	$-10.0^{+2.1}_{-2.7}$	-12.3±2.2
$K^-K^+\pi^0$	$-9.2^{+0.0}_{-0.0}$	
$K^-K^+K_S$	$-5.5^{+1.5}_{-1.1}$	
$K^-K_SK_S$	$3.5^{+0.3}_{-0.2}$	4±5
$K_S\pi^+\pi^0$	$0.64^{+0.07}_{-0.07}$	7±5±3±4
$(\pi^+\pi^-\pi^-)_{\text{region I}}$	$22.5^{+2.9}_{-3.3}$	58.4±8.7
$(K^+K^-K^-)_{\text{region I}}$	$-17.7^{+4.9}_{-2.9}$	-22.6±2.2
$(K^-\pi^+\pi^-)_{\text{region I}}$	$14.1^{+13.9}_{-11.7}$	67.8±8.5
$(K^+K^-\pi^-)_{\text{region I}}$	$-18.2^{+1.8}_{-1.8}$	-64.8±7.2

Inclusive CP asymmetries

predictions

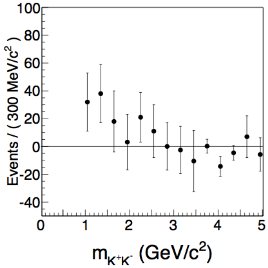
BaBar

not updated yet by LHCb

See talk by Hai-Yang Cheng at first B2TIP workshop

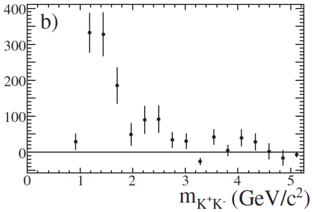
- Enhancement observed by Belle in the $M_{K^+K^-}$ invariant mass in $B^0 \to K^+K^-\pi^0$ decays.

  V. Gaur *et al.*, (Belle Collaboration) Phys. Rev. D **87**, 091101(R) (2013)



- BaBar observes a large enhancement due to a broad structure at low $M_{K^+K^-}$ invariant mass in $B^+ \to K^+K^-\pi^+$ decays, which accounts for half of the total events.

  B. Aubert *et al.*, (BABAR Collaboration) Phys. Rev. Lett. **99**, 221801 (2007)



$\Rightarrow$ *Detailed interpretation requires an amplitude analysis with higher statistics at Belle II.*

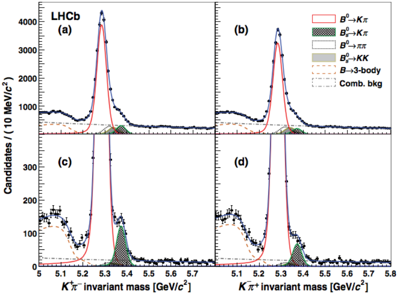
$DCPV$ in B_s Decays

- First measurement of A_{CP} in B_s decays by LHCb: Phys. Rev. Lett. **110**, 221601 (2013)

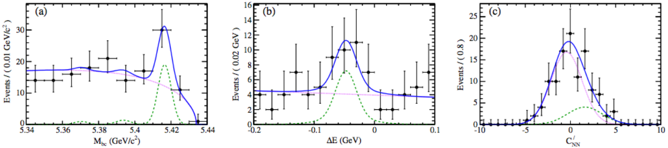
  $A_{CP}(B_s \to K^+\pi^-) =$
  $0.27 \pm 0.04 \pm 0.01 (6.5\sigma)$.
- Allows for a stringent test of (Ref)

  $$\Delta = \frac{A_{CP}(B^0 \to K^+\pi^-)}{A_{CP}(B_s \to K^-\pi^+)} + \frac{A_{CP}(B^0 \to K^-\pi^+)\tau_d}{A_{CP}(B_s \to K^+\pi^-)\tau_s}$$
  $$= -0.02 \pm 0.05 \pm 0.04$$

  No evidence for a deviation from 0 is observed.

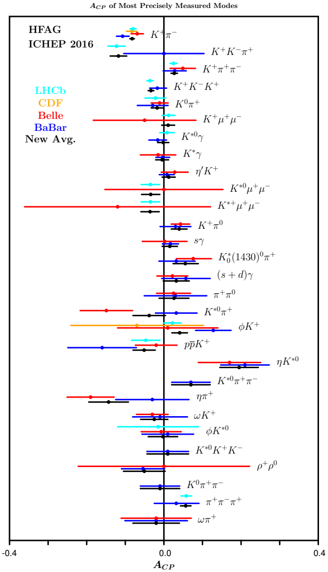


At e^+e^-, $\Upsilon(5S)$ decays are well-suited for studying large multiplicity B_s decays due to the lower particle momenta, the almost 100% trigger ε, and the excellent π/K separation.
First observation of $B_s \to K^0\overline{K}^0$ by Belle with $121 \mathrm{fb}^{-1}$: Phys. Rev. Lett. **116**, 161801 (2016)



Additional Highlights for Belle & LHCb

- Large CP asymmetries in $K\pi$ and other final states with an odd number of kaons, e.g.,
  ηK^{*0}
  $K^{*0}\pi^+\pi^-$
  - $\Rightarrow$ *expected to proceed dominantly via $b \to s$ penguin transitions as the $b \to u$ transition is color-suppressed.*
- Large direct CP asymmetry expected in:
  $B^+ \to \eta\rho^+$
  $B^+ \to \eta\pi^+$
  $B^+ \to \eta'\pi^+$
  - $\Rightarrow$ *where the $b \to u$ and $b \to s$ amplitudes are of similar size to $B^+ \to \eta K^+$, which measured $A_{CP} = -0.37 \pm 0.09$.*



Summary

- New insight into $K\pi$ puzzle with $A_{CP}(\mathcal{B} \to K^0\pi^0)$ reaching 3-4%?
  Surprises on the way from $K^*\pi$ and $K\rho$? Large errors in (N)NLO computations and current experimental results make comparison difficult. Large Belle II dataset required for enough precision to see differences with theory.
- Full angular analysis and triple-product-asymmetries will become feasible in additional $B \to VV$ channels.
  More surprises on the way from angular analysis in $b \to s$ penguin decays, e.g., $K^*\rho$?
- Observation of large local A_{CP} in additional 3-body decays?
  $B^0 \to K^0_S K^+K^-$, $B^0 \to K^+K^-\pi^0$... *New resonances in $M_{K^+K^-}$ spectrum?*
- Large improvements in PID (K/π separation), π^0 and K_s, reconstruction efficiency, tracking, algorithms and more.
  Simulation studies showing increased performance as expected.

BKUP

$K^*\pi$: Status

$\mathcal{B}(10^{-6})$			
Mode	BABAR	Belle	LHCb
$K^{*+}\pi^-$	8.2 ± 0.9	$8.4 \pm 1.1^{+1.0}_{-0.9}$	
$K^{*+}\pi^0$	$8.2 \pm 1.5 \pm 1.1$		
$K^{*0}\pi^+$	$10.8 \pm 0.6^{+1.2}_{-1.4}$	$9.7 \pm 0.6^{+0.8}_{-0.9}$	
$K^{*0}\pi^0$	$3.3 \pm 0.5 \pm 0.4$	< 3.5	

A_{CP}			
Mode	BABAR	Belle	LHCb
$K^{*+}\pi^-$	$-0.24 \pm 0.07 \pm 0.02$	$-0.21 \pm 0.11 \pm 0.07$	
$K^{*+}\pi^0$	$-0.06 \pm 0.24 \pm 0.04$		
$K^{*0}\pi^+$	$0.032 \pm 0.052^{+0.016}_{-0.013}$	$-0.149 \pm 0.064 \pm 0.022$	
$K^{*0}\pi^0$	$-0.15 \pm 0.12 \pm 0.04$		

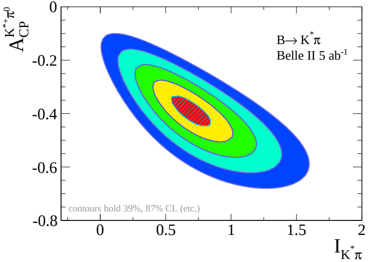
- $\mathcal{A}_{K^{*+}\pi^-}$ measured by both Belle and BaBar with high precision.
- Most challenging mode $K^{*+}\pi^0$.[3]
  $\mathcal{A}_{cp}(K^{*+}(K^+\pi^0)\pi^0)) = -0.06 \pm 0.24 \pm 0.04$

[3] Unpublished BaBar measurement not included [arXiv:1501.00705]: $\mathcal{A}_{cp}(K^{*+}(K_S\pi^+)\pi^0)) = -0.52 \pm 0.14 \pm 0.04 \pm 0.04$

$K^*\pi$: Test of sum rule

- ***Calculate $I_{K^*\pi}$ and projections for Belle II using BaBar's complete set of measurements.***
- Given that $\mathcal{A}_{K^{*+}\pi^0}$ is not systematically limited, treat all errors as reducible for sensitivity study.
- $I_{K^*\pi}$ values result of GammaCombo fit.

$\Rightarrow$ *Large positive identity parameter $I_{K^*\pi}$.*



Projections for the $B \to K^*\pi$ isospin sum rule parameter, $I_{K^*\pi}$, at the BaBar measured central value.

Scenario	$\mathcal{A}_{K^{*+}\pi^0}$ Value	$\mathcal{A}_{K^{*+}\pi^0}$ Stat.	$I_{K^*\pi}$
BaBar	-0.06	0.24	0.69 ± 0.32
Belle II 5 ab^{-1}			0.69 ± 0.15
Belle II 50 ab^{-1}			0.69 ± 0.06

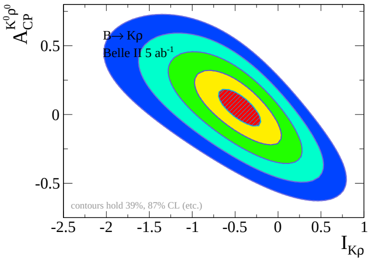
$\mathcal{B}(10^{-6})$		
Mode	BABAR	Belle
$K^+\rho^-$	$6.6 \pm 0.5 \pm 0.8$	$15.1^{+3.4+2.4}_{-3.3-2.6}$
$K^+\rho^0$	$3.56 \pm 0.45^{+0.57}_{-0.46}$	$3.89 \pm 0.47^{+0.43}_{-0.41}$
$K^0\rho^+$	$8.0^{+1.4}_{-1.3} \pm 0.6$	
$K^0\rho^0$	$4.4 \pm 0.7 \pm 0.3$	$6.1 \pm 1.0^{+1.1}_{-1.2}$

A_{CP}		
Mode	BABAR	Belle
$K^+\rho^-$	$0.20 \pm 0.09 \pm 0.08$	$0.22^{+0.22+0.06}_{-0.23-0.02}$
$K^+\rho^0$	$0.44 \pm 0.10^{+0.06}_{-0.14}$	$0.30 \pm 0.11^{+0.11}_{-0.05}$
$K^0\rho^+$	$-0.12 \pm 0.17 \pm 0.02$	
$K^0\rho^0$	$0.05 \pm 0.26 \pm 0.10 \pm 0.03$	$0.03^{+0.23}_{-0.24} \pm 0.11 \pm 0.10$

- Most limiting mode $\mathcal{A}_{K^0\rho^0}$.

- ***Calculate $I_{K\rho}$ and projections for Belle II using BaBar's complete set of measurements.***
- Again, stat. limited so treat all syst. errors as reducible.
- $I_{K\rho}$ values result of GammaCombo fit.

$\Rightarrow$ *Large negative identity parameter $I_{K\rho}$.* Same (different) sign as $I_{K\pi}$ ($I_{K^*\pi}$).



Projections for the $B \to K\rho$ isospin sum rule parameter, $I_{K\rho}$, at the BaBar measured central value.

Scenario	$\mathcal{A}_{K^0\rho^0}$ Value	$\mathcal{A}_{K^0\rho^0}$ Stat.	$I_{K\rho}$
BaBar	0.05	0.26	-0.44 ± 0.49
Belle II 5 ab^{-1}			-0.44 ± 0.25
Belle II 50 ab^{-1}			-0.44 ± 0.11

For $B \to VV$ decays, must separate out the longitudinal and transverse components:

- NNLO computation not possible for transverse amplitudes: power-suppressed and there is no QCD factorization theorem for them.
- For longitudinal component, comparison of NNLO computation to experiment not possible since A_{CP} not available for individual helicity amplitudes in $K^{*+}\rho^-$.
- NLO computation available for comparison.

$\mathcal{B}(10^{-6})$		
Mode	BABAR	Belle
$K^{*+}\rho^-$	$10.3 \pm 2.3 \pm 1.3$	
$K^{*+}\rho^0$	$4.6 \pm 1.0 \pm 0.4$	
$K^{*0}\rho^+$	$9.6 \pm 1.7 \pm 1.5$	
$K^{*0}\rho^0$	$5.1 \pm 0.6^{+0.6}_{-0.8}$	$2.1^{+0.8+0.9}_{-0.7-0.5}$

A_{CP}	
Mode	BABAR
$K^{*+}\rho^-$	$0.21 \pm 0.15 \pm 0.02$
$K^{*+}\rho^0$	$0.31 \pm 0.13 \pm 0.03$
$K^{*0}\rho^+$	$-0.01 \pm 0.16 \pm 0.02$
$K^{*0}\rho^0$	$-0.06 \pm 0.09 \pm 0.02$

- Most limiting mode $\mathcal{A}_{K^{*0}\rho^+}$.

Reducible vs. Irreducible errors

Reducible

- The systematic uncertainties of the PDF parameters.
- Particle identification requirements.
- The possible CP violation effect in the accompanying B meson decays.
- Vertex resolution.
- Δt resolution function parametrization.
- Tag-side interference.

Irreducible

- Uncertainties in the interaction-point profile.
- Dependence on the vertex selection-criteria.
- The effect of detector misalignment.
- Possible bias in the ΔZ determination.
- $K^{\pm}$ $\pi^{\pm}$, π^{0} detection efficiency.
- Uncertainty in branching fraction measurements.
- Asymmetry of charged particle detection efficiency (in A measurements).
- Vertex reconstruction uncertainty originating from the SVD mis-alignment (in S measurements)

$B \to VV$: f_L @ Belle II

- Heirarchy of f_L observed with tree-dominated modes ($\rho\rho$) near 1, and penguin-dominated modes (ϕK^{*0}) near 0.5.
- Hierarchy based on the masses of the vector mesons, with larger masses having smaller f_L.

$\Rightarrow$ *Results from other channels necessary to understand these patterns.*

Mode	BABAR	Belle	Ref.	fb^{-1}	σ_{total}	Belle II (σ_{total}) 5 ab^{-1}	Belle II (σ_{total}) 50 ab^{-1}
ωK^{*0}	$0.72 \pm 0.14 \pm 0.02$	$0.56 \pm 0.29^{+0.18}_{-0.08}$	25	657	0.341	0.124	0.039
$\omega K_2^*(1430)^0$	$0.45 \pm 0.12 \pm 0.02$						
$K^{*0}\rho^0$	$0.40 \pm 0.08 \pm 0.11$						
$K^{*+}\rho^-$	$0.38 \pm 0.13 \pm 0.03$						
ϕK^{*0}	$0.494 \pm 0.034 \pm 0.013$	$0.499 \pm 0.030 \pm 0.018$	22	772	0.035	0.014	0.004
$K^{*0}\overline{K}^{*0}$	$0.80^{+0.10}_{-0.12} \pm 0.06$						
$\phi K_2^*(1430)^0$	$0.901^{+0.046}_{-0.058} \pm 0.037$						
$a_1^\pm a_1^\mp$	$0.31 \pm 0.22 \pm 0.10$						

Mode	BABAR	Belle	Ref.	fb^{-1}	σ_{total}	Belle II (σ_{total}) 5 ab^{-1}	Belle II (σ_{total}) 50 ab^{-1}
ωK^{*+}	$0.41 \pm 0.18 \pm 0.05$						
$\omega K_2^*(1430)^+$	$0.56 \pm 0.10 \pm 0.04$						
$K^{*+}\rho^0$	$0.78 \pm 0.12 \pm 0.03$						
$K^{*0}\rho^+$	$0.52 \pm 0.10 \pm 0.04$	$0.43 \pm 0.11^{+0.05}_{-0.02}$	23	253	0.121	0.027	0.009
$K^{*+}\overline{K}^{*0}$	$0.75^{+0.16}_{-0.26} \pm 0.03$						
ϕK^{*+}	$0.49 \pm 0.05 \pm 0.03$	$0.52 \pm 0.08 \pm 0.03$	22	253	0.085	0.019	0.006
$\phi K_1(1270)^+$	$0.46^{+0.12+0.06}_{-0.13-0.07}$						
$\phi K_2^*(1430)^+$	$0.80^{+0.09}_{-0.10} \pm 0.03$						
$\omega\rho^+$	$0.90 \pm 0.05 \pm 0.03$						