Prospects for ϕ_3 and Charmless B Decay Measurements at Belle II

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On behalf of the Belle II Collaboration

8th International Workshop on the CKM Unitarity Triangle
Vienna University of Technology
Vienna, Austria
September 8-12, 2014

Outline

Belle II

- Improvements in K/π separation and π^0 efficiency

ϕ_3

- Current measurement
- Prospects at Belle II:
  $B^{\pm} \to D^{(*)} K^{(*)\pm}$

$DCPV$ in Charmless B Decays

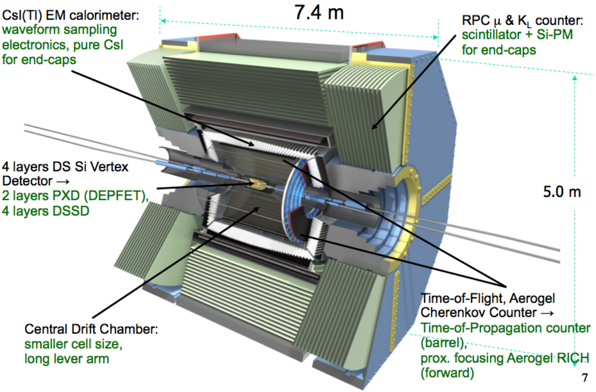
- $B \to K\pi$, $K^*\pi$, $K\rho$
- $B \to VV$ decays
- 3-body decays

Belle II

Upgrade for SuperKEKB and Belle II to achieve 40x peak $\mathcal{L}$ under 20x bkgd

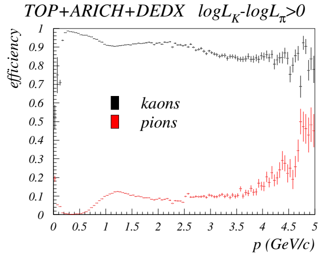
Targeted improvements:

- *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.*

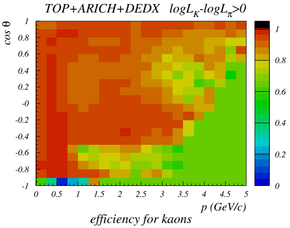


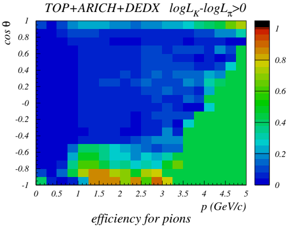
Two RICH systems covering full momentum range

- 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



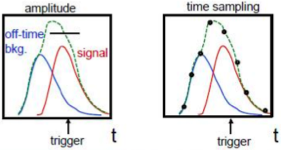


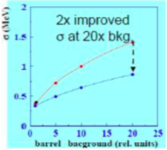
$\Rightarrow$ *Average K efficiency / π fake rate improved: Fake rate decreases by ≈ 2.5 for the same ε.*

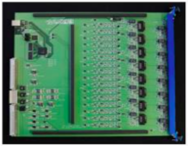
π^0 Reconstruction

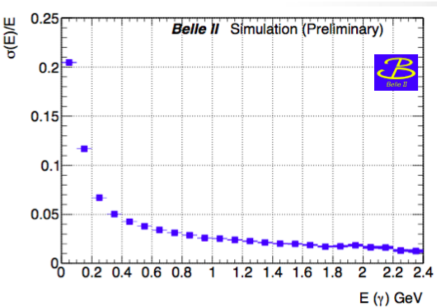
Re-usage of Belle's CsI(TI) crystal calorimeter, but with new electronics with 2MHz wave form sampling to compensate for the larger beam-related backgrounds and the long decay time of CsI(TI) signals.

⇒ Resolution much better at Belle II





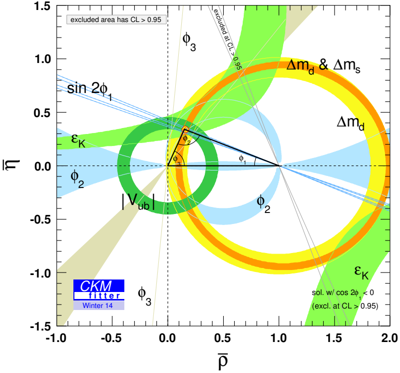




$$\phi_3 = \gamma \equiv \arg \frac{-|V_{ud}||V_{ub}^*|}{|V_{cd}||V_{cb}^*|} \approx \arg|V_{ub}^*|$$

- The standard candle along with $|V_{ub}|/|V_{cb}|$.
- Still almost an order of magnitude less precise than ϕ_2.
  - Limited by the small $\mathcal{B}$ of the processes used in its measurement.

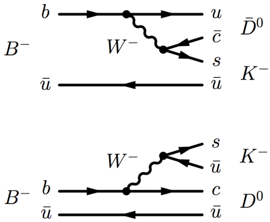
⇒ *Large experimental gain can be made!*



http://ckmfitter.in2p3.fr

Tree-level Determination

- $b \to c\bar{u}s$ and $b \to u\bar{c}s$ tree amplitudes in the charged-B meson decays to open-charm final states.
  - $\Rightarrow$ Interference between same final state for D and $\overline{D}$ $\Rightarrow$ possibility of $DCPV$.



* No penguin contribution (no theoretical uncertainty)

$\Rightarrow$ *All hadronic unknowns obtainable from experiment:*

r_B = magnitude of the ratio of the amplitudes for $B^- \to \overline{D}^0 K^-$ and $B^- \to D^0 K^-$.

δ_B = the relative strong phase between these 2 amplitudes.

! Challenging: Small overall $\mathcal{B}$ from 5×10^{-6} to 10^{-9}.

$\Rightarrow$ *Precise measurement of ϕ_3 requires a very large data sample.*

Three methods according to final state:

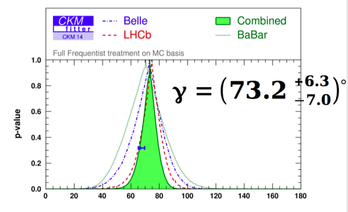
- Cabibbo-suppressed (CS) D decays to CP-eigenstates (K^+K^-, $K_s^0\pi^0$) [GLW]
  Phys. Lett. B **253**, 483 (1991), Phys. Lett. B **265**, 172 (1991)
- Cabibbo-favored and double-CS final states ($K^{\pm}\pi^{\mp}$) [ADS] Phys. Rev. D **63**, 036005 (2001)
- Dalitz plot distribution of the products of D decays to multi-body self-conjugate final states ($K_s^0\pi^+\pi^-$) [GGSZ] Phys. Rev. D **68**, 054018 (2003)

All methods are statistics-limited but have common B parameters

$\Rightarrow$ *Perform a simultaneous fit using the results of all methods.*

CKM 2014

CKM talk by K. Trabelsi

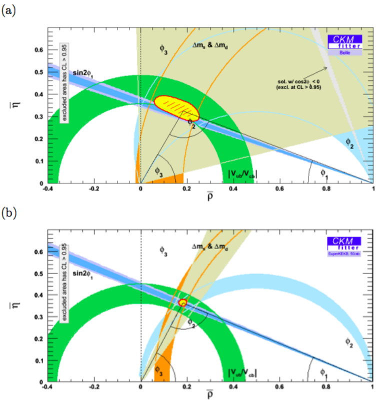


All methods reproducible at Belle II

- Improvements in PID and $q\bar{q}$ suppression using neural networks Nucl. Instrum. Meth. A654: 432 (2011)
- Systematic errors from peaking charmless background, and PDFs from $D\pi$ and sidebands will decrease with statistics.
- Elimination of D model uncertainty using samples of neutral D mesons decaying into CP eigenstates from charm factories CLEO-c and BESIII (via $\psi(3770) \to DD$).

  $\Rightarrow$ *Naive scaling of combination with ADS and GLW yeilds an error of* $1.5°$.

  Physics at Super B Factory, arXiv:1002.5012 (2010)



(a) Belle at 0.5ab^{-1} and (b) Belle II at 50ab^{-1}

Much more!

- Statistical error will be dominant and can be improved by including D decays to, e.g., $K_s^0 K^+ K^-$, $\pi^+\pi^-\pi^0$, $K_s^0\pi^+\pi^-\pi^0$ (2* $\mathcal{B}\,(K_s^0\pi^+\pi^-)$!).
- Use $D\pi$ in addition to DK

  $\to$ Theory: charm mixing has a bigger effect arXiv:1307.4384

$B \to K\pi$

- 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.

$$A_{CP}^{K^+\pi^0} - A_{CP}^{K^+\pi^-} = 0.112 \pm 0.027 \pm 0.007 \;\; (4\sigma)$$

- 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.

⇒ *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.*

⇒ *Look for similar effects in $K^*\pi$ and $K\rho$:*

	$A_{CP}^{K^+\pi^0}$	$A_{CP}^{K^+\pi^-}$
$K^*\pi$	-0.06 ± 0.24 *	-0.23 ± 0.06 **
$K\rho$	$+0.37 \pm 0.11$ *	$+0.20 \pm 0.11$ ***

* BaBar, Phys. Rev. D **84**, 092007 (2011), **HFAG Ave.,
*** BaBar, Phys. Rev. D **78**, 012004 (2008) Belle, Phys. Rev. Lett. **96**, 251803 (2006)
[New $K^*\pi$ BaBar result: Talk by Eli Ben-Haim]

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

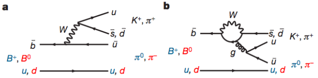
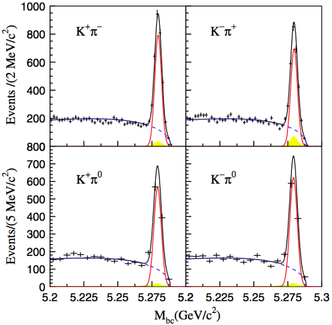


Figure 17.4.4. The dominant Tree-level (a) and Penguin-loop (b) Feynman diagrams in the two-body decays $B \to K\pi$ and $B \to \pi\pi$ (Lin, 2008).



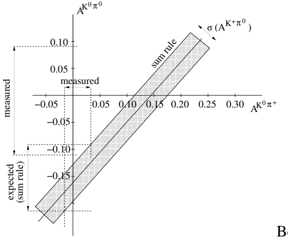
$B \to K\pi$: Test of sum rule

Test of sum rule for NP free of theoretical uncertainties:

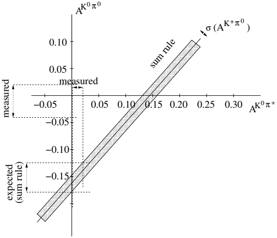
$$A_{CP}^{K^+\pi^-} + A_{CP}^{K^0\pi^+}\frac{\mathcal{B}(B^+\to K^0\pi^+)\tau_{B^0}}{\mathcal{B}(B^0\to K^+\pi^-)\tau_{B^+}} = A_{CP}^{K^+\pi^0}\frac{2\,\mathcal{B}(B^+\to K^+\pi^0)\tau_{B^0}}{\mathcal{B}(B^0\to K^+\pi^-)\tau_{B^+}} + A_{CP}^{K^0\pi^0}\frac{2\,\mathcal{B}(B^0\to K^0\pi^0)}{\mathcal{B}(B^0\to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

$$-0.270 \pm 0.132 \pm 0.060 \;\; (1.9\sigma)$$

- SM can be tested by measuring all observables.
- The isospin sum rule can be presented as a band in the $A_{CP}^{K^0\pi^0}$ vs. $A_{CP}^{K^0\pi^+}$ plane.



Current data



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

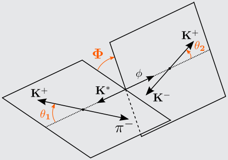
→ Most demanding measurement is $K^0\pi^0$ final state. With Belle II, the uncertainty on $\mathcal{A}(B \to K^0\pi^0)$ from time-dep. analyses is expected to reach $\sim 4\%$ ⇒ *sufficient for NP studies.*

Observables	Belle + BaBar (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
$\mathcal{A}(B \to K^0\pi^0)$	$-0.05 \pm 0.14 \pm 0.05$	0.07	0.04

- 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. *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:

- The SM suppressed decay $B^0 \to K^{*0} K^{*0}$ could appear via an intermediate heavy boson.
- Observation of electro-weak and gluonic $b \to d$ penguin loops to two VV particles in $B^0 \to K^{*0} \overline{K}^{*0}$
- Contribution of electro-weak penguiins 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. $\Rightarrow$ *Require data samples with $\mathcal{L}$ of order 50* ab^{-1}.

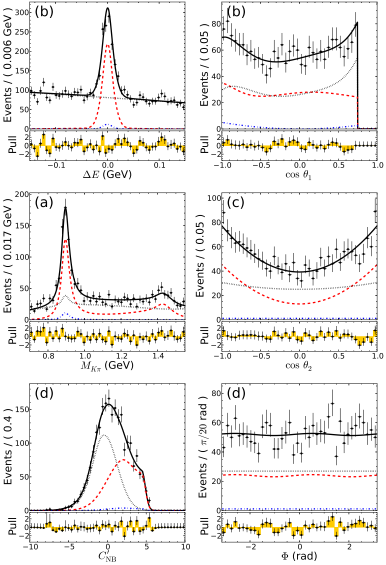
  Belle, Phys. Rev. D **84**, 096013 (2011)

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 Belle analysis, a 9D extended unbinned ML fit is used to extract the 26 parameters related to polarization and CPV.
- Figure show 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.

⇒ *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)



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Belle II

* *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.

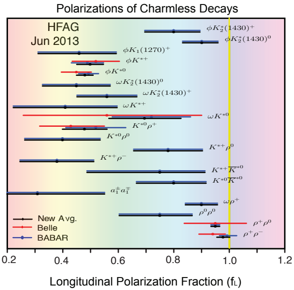
Parameter	$\phi(K\pi)^*_0$ $J=0$	$\phi K^*(892)^0$ $J=1$	$\phi K^*_2(1430)^0$ $J=2$
FF_J	$0.273 \pm 0.024 \pm 0.021$	$0.600 \pm 0.020 \pm 0.015$	$0.099^{+0.016}_{-0.012} \pm 0.018$
f_{LJ}	...	$0.499 \pm 0.030 \pm 0.018$	$0.918^{+0.029}_{-0.060} \pm 0.012$
$f_{\perp J}$	...	$0.238 \pm 0.026 \pm 0.008$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

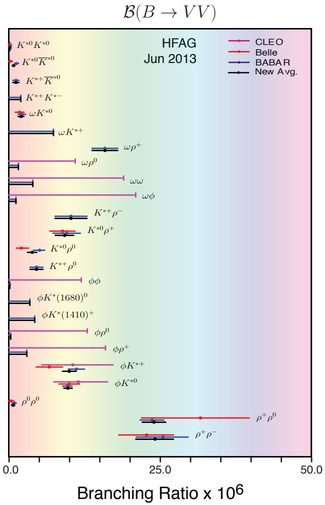
$\Rightarrow$ *Statistical errors* $\approx$ *7x smaller with 50* ab^{-1} *of Belle II data.*

Summary of the $\mathcal{B}$ and f_L for charmless vector-vector decays

- 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.*





CP violation in $B \to 3h$

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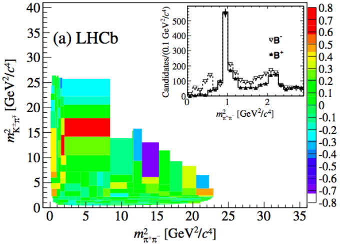
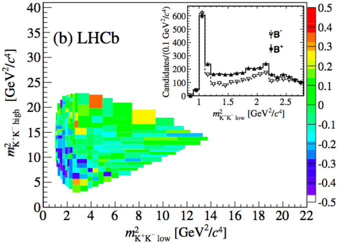
Belle II

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

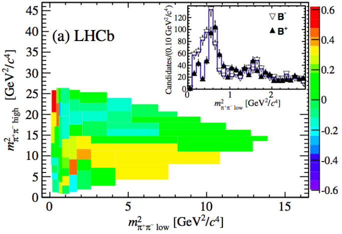
$K\pi\pi$



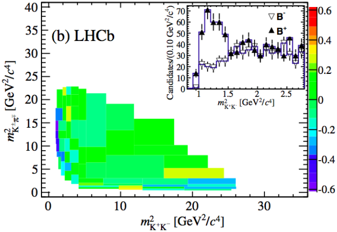
KKK Phys. Rev. Lett. **111**, 101801 (2013)



$\pi\pi\pi$



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

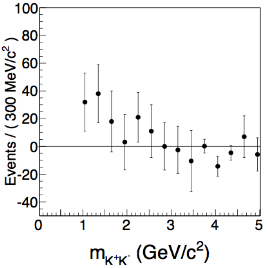


$\Rightarrow$ *Unidentified structure in the $m^2_{K^+K^-}$ projection in $KK\pi$ decays at $< 1.5\ \mathrm{GeV}^2/c^4$. Only present in the B^+ mass projection and gives rise to a large local CP asymmetry.* [*Updated measurement: arXiv: 1408.5373 (Submitted to PRD)*]

Enhancements in $M_{K^+K^-}$

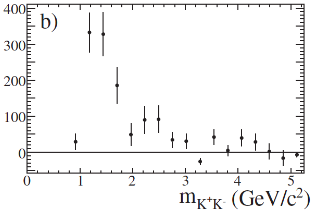
- Enhancement observed by Belle in the $M_{K^+K^-}$ invariant mass in $B^0 \to K^+K^-\pi^0$ decays.

  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.*

Highlights to search for at Belle II

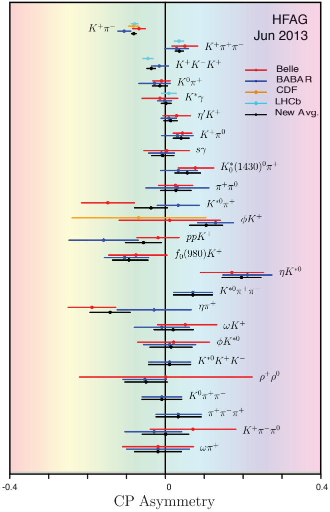
- Large CP asymmetries in $K\pi$ and other final states with an odd number of kaons, e.g.,
  ηK^{*0}
  $K^{*0}\pi^+\pi^-$

  $\Rightarrow$ *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* $A_{CP} = -0.37 \pm 0.09$.

A_{CP}



Most precisely measured modes

Summary and prospects @50 ab^{-1}

Large improvements in PID (K/π separation), and π^0 reconstruction efficiency
$\Rightarrow$ *simulation studies showing increased performance as expected*

ϕ_3

- Combination of measurements from GLW, ADS, and Dalitz methods yields a combined ϕ_3 uncertainty of $1.5°$.
  $\Rightarrow$ *Theoretically clean, reliable test of ϕ_3 in the SM, and to search for NP.*

Charmless B Decays

- New insight into $K\pi$ puzzle with $A_{CP}(\mathcal{B} \to K^0\pi^0)$ reaching 4%. $\Rightarrow$ *Surprises on the way from $K^*\pi$ and $K\rho$?*
- Full angular analysis and triple-product-asymmetries will become feasible in additional $B \to VV$ channels.
  $\Rightarrow$ *More surprises on the way from angular analysis in $b \to s$ penguin decays?*
- Observation of large local A_{CP} in additional 3-body decays? $\Rightarrow$ *New resonances in $M_{K^+K^-}$ spectrum?*

...and much more!

Thank you!

BKUP

Charmless B_s Decays

Mode	Yield	Σ	$\epsilon(\%)$	$\mathcal{B}\ (10^{-5})$
K^+K^-	$23.4^{+5.5}_{-6.3}$	5.8	24.5	$3.8^{+1.0}_{-0.9} \pm 0.5 \pm 0.5$
$K^-\pi^+$	$5.4^{+5.1}_{-4.3}$	1.2	21.0	< 2.6
$\pi^+\pi^-$	$-2.0^{+2.3}_{-1.5}$	–	14.4	< 1.2
$K^0\overline{K}^0$	$5.2^{+5.0}_{-4.3}$	1.2	8.0	< 6.6

$B_s \to hh\ (h = \pi, K)$

- $\Upsilon(5S)$ 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.
- Branching fractions may exhibit direct CP asymmetries, as has been observed for $B_d^0 \to K^\pm\pi^\mp$.
- e^+e^- experiment well-suited to study $\overline{K}^0 K^0$ (advantage over hadron collider).
- Table and figures show the 23.6 fb^{-1} results from Belle. Provide us with normalizations and absolute $\mathcal{B}$ for $\overline{K}^0 K^0$, but likely not competitive with LHCb.