Hadronic B decays related to QCD at Belle

Outline:
- introduction
- Inclusive $B \rightarrow X_s \eta$
- $B \rightarrow VV$
- $B \rightarrow D_s^{(*)} K \pi$
- conclusions
KEKB B-factory and Belle detector

\[ e^+ e^- \rightarrow \gamma(4S) \rightarrow B\bar{B} \]

clean source of exclusive B meson pairs
Belle kinematic variables $\Delta E$ and $M_{BC}$

\[ \Delta E = \sum_i E_i - E_{beam} \]

\[ M_{bc} = \sqrt{E_{beam}^2 - (\sum_i p_i)^2} \]

$E_{beam}$ - beam energy in the CM frame

$\sum_i E_i$ - total energy of the B products

$\sum_i p_i$ - total momentum of the B products
Inclusive $B \to X_S \eta$ decays

Motivation:

- Charmless B decays
  $(b \to s$ penguins $)$ - precise tests of the Standard Model and possible indications of the new physics

- Interesting properties of the decays that involve $\eta$ and $\eta'$ due to interference effects between the underlaying pseudoscalar octet and singlet components
  $\to$ well understood in the exclusive $B \to K^{(*)}\eta'$ (arXiv:1005.1968)
  $\to$ less clear in the inclusive $B \to X_S \eta'$ modes
Unexpected features for $B \rightarrow X_S \eta'$ measured by CLEO and BaBar:

→ large branching fraction
→ peak at high $X_S$ mass spectrum

Possible theoretical explanations:

• QCD anomaly mechanism – couples two gluons to the singlet components of $\eta'$

• The $\eta'$ contains an intrinsic charm component

• Large contributions from non-perturbative charming penguin amplitudes
  → needs further confirmation!

Disfavored by existing data (CLEO):

($\eta'$ energy spectra in $\Upsilon(1S)$ decays compared with models of the $\eta' g^*g$ form factor)

$B \rightarrow \eta_c K$

Studies on $B \rightarrow X_S \eta$ can clarify the situation!
B → X_S η: 18 channels involved

semi-inclusive method

\[\begin{align*}
B^+ & \rightarrow K^+(\pi^0)\eta \\
B^+ & \rightarrow K^0_S\pi^+(\pi^0)\eta \\
B^+ & \rightarrow K^+\pi^+\pi^-(\pi^0)\eta \\
B^+ & \rightarrow K^0_S\pi^+\pi^-\pi^+(\pi^0)\eta \\
B^+ & \rightarrow K^+\pi^+\pi^-\pi^- \eta \\
B^0 & \rightarrow K^0_S(\pi^0)\eta \\
B^0 & \rightarrow K^{-}\pi^-(\pi^0)\eta \\
B^0 & \rightarrow K^0_S\pi^+\pi^-(\pi^0)\eta \\
B^0 & \rightarrow K^+\pi^-\pi^+\pi^-(\pi^0)\eta \\
B^0 & \rightarrow K^0_S\pi^+\pi^-\pi^+\pi^- \eta
\end{align*}\]

where \(\eta\) is reconstructed from \(2\gamma\).

- veto on charm contribution \((D^0, D^+, \eta_c)\)
- veto on \(\eta' \rightarrow \eta\ \pi^+\pi^-\)

Signal yield obtained by extended unbinned maximum likelihood fit to \(M_{bc}\) for 1.0 GeV < \(m(X_S)\) < 2.6 GeV

Overall fit

signal

Combinatory background

B\(\bar{B}\) background

Belle measurement

Data sample:

\(657 \times 10^6\) B\(\bar{B}\) pairs

arXiv: 0910.4751
$B \rightarrow X_s \eta$

- Signal yields were fitted in bins of $X_s$ mass:

$B \rightarrow K^*(892)\eta$
$B \rightarrow K^*(1430)\eta$
$B \rightarrow K\pi\ldots\eta$

Not yet explained
$B \to X_S \eta$

Partial branching fraction in the range of $0.4 \text{ GeV} < m(X_S) < 2.6 \text{ GeV}$:

$$\mathcal{B}(B \to X_S \eta) = \left(25.5 \pm 2.7 \pm 1.6^{+3.8}_{-14.1}\right) \times 10^{-5}$$

High branching fraction for $m(X_S) > 2 \text{ GeV}$

$\Rightarrow$ comparable to respective $B \to X_S \eta'$ result from BaBar!

B → V V V decays

proceed mainly via $b \to s\bar{q}q$ penguins (dominating) and $B \to uW$ tree diagrams.

$B \to \rho^0 K^*$

$B \to \rho^0 K^*$

$B^0 \to \rho^0 K^*$

Suppressed → sensitive to non-SM contributions

• Puzzling results on $B \to \phi K^*$: large transverse polarizations found:

  $F_1 \sim 0.5$

  → disagreement with naive SM prediction which says: *longitudinal component should dominate* ($F_1 \sim 95\%$)

• measurements of other penguin modes ($B \to \rho^0 K^{*0}, B \to K^{*0} \overline{K}^{*0}$) should shine some light on the situation
\[ B \rightarrow \rho^0 K^{*0} \]

- \( \rho^0 \) reconstructed from \( \pi^+ \pi^- \)
- \( K^* \) reconstructed from \( K^+ \pi^- \)

In addition, 5 more channels sharing the same final state were taken into account:

Challenging measurement due to large non-resonant contribution

Understanding of these processes and clear distinction between B \( \rightarrow \) V V and non-resonant decays could enhance our understanding of strong and weak interaction dynamics.
$B \rightarrow \rho^0K^{*0}$

Results from the 4D extended unbinned maximum-likelihood fit to $\Delta E$, $M_{bc}$, $m(\pi\pi)$, $m(K\pi)$
**B → ρ⁰K*⁰ results**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Y (events)</th>
<th>ε (%)</th>
<th>S (σ)</th>
<th>B (10⁻⁶)</th>
<th>B_{UL} (10⁻⁶)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ρ⁰K*⁰$</td>
<td>77.6⁺²8.⁶⁻²⁷.⁹</td>
<td>5.73</td>
<td>2.7</td>
<td>2.1⁺⁰.⁸⁺⁰.⁹⁻⁰.⁷⁻⁰.⁵</td>
<td>&lt;3.⁴</td>
</tr>
<tr>
<td>$f₀(980)K*⁰$</td>
<td>51.2⁺²⁰.⁴⁻¹⁹.³</td>
<td>5.56</td>
<td>2.⁵</td>
<td>1.⁴⁺⁰.⁶⁺⁰.⁶⁻⁰.⁵⁻⁰.⁴</td>
<td>&lt;2.²</td>
</tr>
<tr>
<td>$ρ⁰K⁺π⁻$</td>
<td>207.⁸⁺³⁹.⁸⁻³⁹.²</td>
<td>11.¹⁵</td>
<td>5.⁰</td>
<td>2.⁸ ± ⁰.⁵ ± ⁰.⁵</td>
<td>⋯</td>
</tr>
<tr>
<td>$f₀(980)K⁺π⁻$</td>
<td>106.⁹⁺³¹.⁶⁻²⁹.⁹</td>
<td>11.⁴³</td>
<td>3.⁵</td>
<td>1.⁴ ± ⁰.⁴⁺⁰.³⁻⁰.⁴⁻⁰.⁴</td>
<td>&lt;2.¹</td>
</tr>
<tr>
<td>$π⁺π⁻K⁰$</td>
<td>200.⁷⁺⁴⁶.⁷⁻⁴⁴.⁹</td>
<td>⁶.⁷⁴</td>
<td>⁴.⁵</td>
<td>⁴.⁵⁺¹.¹⁺⁰.⁹⁻¹.⁰⁻¹.⁶</td>
<td>⋯</td>
</tr>
<tr>
<td>$π⁺π⁻K⁺π⁻$</td>
<td>−5.⁴⁺⁵⁴.⁹⁻⁴⁴.⁹</td>
<td>⁶.⁸⁴</td>
<td>⁰.⁰</td>
<td>−⁰.¹⁺¹.²⁺¹.⁴⁻¹.¹⁻¹.⁸</td>
<td>&lt;2.¹</td>
</tr>
</tbody>
</table>

**first observation!**

**not seen by Belle!**

**PRL 97, 201801, 2006**

**BaBar result:**

\[\mathcal{B}(B \rightarrow ρ⁰K*⁰) = 5.6 \pm 0.9 \pm 1.3 \times 10⁻⁶\]

\[S(σ): 5.3\]

\[f_L \sim 0.57\]

→ Needs further investigation
B → D_{s}^{(*)} K \pi


Data sample: $657 \times 10^6$ B\bar{B} pairs

B^{+} \rightarrow D_{s}^{(*)-} K^{+} \pi^{+}$ process mediated by the $b \rightarrow c$ quark transition and includes the production of an additional $\bar{s}s$ pair

Reconstructed in three $D_{s}$ channels:

$D_{s} \rightarrow \phi \pi$

$D_{s} \rightarrow K^{*0}K$

$D_{s}^{*} \rightarrow D_{s} \gamma$

$D_{s} \rightarrow K_{0}sK$

The intermediate resonances could be formed from the three final-state particles

Possible studies of the invariant mass distributions for the two-body subsystems to search for new resonances.
$B^+ \rightarrow D_s^{(*)} K^+ \pi^+$ - fit parametrization

3D unbinned extended maximum likelihood fit to the $(\Delta E, M_{BC}, m_{Ds(*)})$ variables

Signal parametrization: Gaussian

Peeking background in $M(D_s^{(*)}) - D_s^{(*)}$ randomly combined with $K, \pi$ -- Double Gaussian

Comb. background parametrization: 2nd order polynomials $(\Delta E, m_{Ds})$ and Argus function $(M_{BC})$
$\mathbf{B \rightarrow D_s^{(*)} K \pi}$

Clear enhancement near the threshold in the invariant mass of the two-body subsystem $D_s K$ and $D_s^* K$

→ discrepancy between the mass distributions of $D_s^{(*)} K$ and the distribution expected for the three-body phase space production

→ efficiency variation across $M(D_s^{(*)} K)$ distribution taken into account!
Results for $B \rightarrow D_{s}^{(*)} K \pi$

Branching fractions for separate $D_{s}$ decay modes consistent with each other

Simultaneous fit to three $D_{s}$ modes:

\[
\mathcal{B}(B^{+} \rightarrow D_{s}^{-} K^{+}\pi^{+}) = (1.71^{+0.08}_{-0.07}(\text{stat})^{+0.20}_{-0.20}(\text{syst}) \pm 0.15(\mathcal{B}_{int})) \times 10^{-4}
\]

\[
\mathcal{B}(B^{+} \rightarrow D_{s}^{*-} K^{+}\pi^{+}) = (1.31^{+0.13}_{-0.12}(\text{stat})^{+0.25}_{-0.25}(\text{syst}) \pm 0.12(\mathcal{B}_{int})) \times 10^{-4}
\]

BaBar results:

\[
\begin{align*}
\text{BF}(B^{+} \rightarrow D_{s}^{-} K^{+}\pi^{+}) &= 2.02 \pm 0.13 \pm 0.38 \times 10^{-4} \\
\text{BF}(B^{+} \rightarrow D_{s}^{*-} K^{+}\pi^{+}) &= 1.67 \pm 0.16 \pm 0.35 \times 10^{-4}
\end{align*}
\]

B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. 100, 171803 (2008)

Preliminary studies of two-body subsystems show no evidence for the existence of any new resonance!
conclusions

• $B \rightarrow X_s \eta$ measured using semi-inclusive method. Large branching fraction is found for $m(X_s) > 2 \text{ GeV}$ following similar observation in the channel with $\eta'$.

• penguin dominated $B \rightarrow \rho^0 K^{*-0}$ channel and the associated decays are studied. Disagreement between Belle and BaBar $\rightarrow$ perhaps three body decays contribution should be studied more carefully. The first measurement of $B \rightarrow \rho^0 K^+ \pi^-$ is performed.

• $B \rightarrow D_s^{(*)} K \pi$

Respective branching fractions are measured. No evidence for any new states found in studied data sample. However: peak near the threshold in the invariant mass of the two-body subsystems $D_s K$ and $D_s^* K$ - deviation from the phase space model!
BACKUP
<table>
<thead>
<tr>
<th>Decay</th>
<th>Signal yield</th>
<th>Efficiency [%]</th>
<th>Statistical Signif. [σ]</th>
<th>Branching fraction [(10^{-4})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^+ \to D_s^- (\to \phi\pi^-)K^+\pi^+$</td>
<td>$306.0^{+19.7}_{-19.1}$</td>
<td>$13.09 \pm 1.00$</td>
<td>$31.5$</td>
<td>$1.63^{+0.11}<em>{-0.10}^{+0.18}</em>{-0.18}$ $\pm 0.25$</td>
</tr>
<tr>
<td>$B^+ \to D_s^- (\to K^{*0}K^-)K^+\pi^+$</td>
<td>$281.7^{+24.7}_{-23.6}$</td>
<td>$9.48 \pm 0.67$</td>
<td>$26.5$</td>
<td>$1.74^{+0.15}<em>{-0.15}^{+0.20}</em>{-0.20}$ $\pm 0.27$</td>
</tr>
<tr>
<td>$B^+ \to D_s^- (\to K^0_SK^-)K^+\pi^+$</td>
<td>$179.4^{+16.7}_{-16.0}$</td>
<td>$14.49 \pm 1.11$</td>
<td>$20.4$</td>
<td>$1.82^{+0.17}<em>{-0.16}^{+0.24}</em>{-0.25}$ $\pm 0.11$</td>
</tr>
<tr>
<td>$B^+ \to D_s^{*-} (\to \phi\pi^-)K^+\pi^+$</td>
<td>$59.0^{+9.3}_{-8.6}$</td>
<td>$3.51 \pm 0.52$</td>
<td>$11.0$</td>
<td>$1.24^{+0.20}<em>{-0.18}^{+0.23}</em>{-0.23}$ $\pm 0.19$</td>
</tr>
<tr>
<td>$B^+ \to D_s^{*-} (\to K^{*0}K^-)K^+\pi^+$</td>
<td>$61.7^{+10.6}_{-9.8}$</td>
<td>$2.88 \pm 0.42$</td>
<td>$9.3$</td>
<td>$1.33^{+0.23}<em>{-0.21}^{+0.25}</em>{-0.25}$ $\pm 0.21$</td>
</tr>
<tr>
<td>$B^+ \to D_s^{*-} (\to K^0_SK^-)K^+\pi^+$</td>
<td>$35.7^{+7.7}_{-6.9}$</td>
<td>$4.02 \pm 0.59$</td>
<td>$8.0$</td>
<td>$1.39^{+0.30}<em>{-0.27}^{+0.29}</em>{-0.28}$ $\pm 0.08$</td>
</tr>
</tbody>
</table>