QCD effects in $B$-meson decays at Belle

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Hadron structure and QCD: from Low to High Energies
Gatchina, Russia, June 30 - July 4, 2014
$D^{**}$ production and light hadronic current in $\bar{B}^0 \to D^{*+}\omega\pi^-$ decays, never been reported before

- $D^{**}$ review
- Motivation
- Analysis strategy
- Signal and background
- Matrix element
- Preliminary results

Angular analysis of $B^0 \to \phi K^+\pi^- (\phi K^*)$ decays, PRD 88, 072004 (2013)

- Motivation
- Analysis strategy
- Signal and background
- Matrix element
- Results

Summary
\[ B\bar{B} \text{ luminosity } \int \mathcal{L} \approx 711 \text{ fb}^{-1} \text{ corresponds to } (772 \pm 11) \times 10^6 \ B\bar{B} \text{ pairs recorded on } \Upsilon(4S). \]

Both presented analyses use the full \( B\bar{B} \) data sample collected at Belle.

Detector Belle at the KEKB asymmetric \( e^+ e^- \) (3.5 on 8 GeV) collider.

KEKB is a B-factory operating mainly on the \( \Upsilon(4S) \).
$D^{**}$ are produced with different angular momenta

\[
\begin{array}{ccc}
B \rightarrow D^{**}\pi & B \rightarrow D^{**}\omega \\
D^*_0 & S\text{-wave} & P\text{-wave} \\
D_1 & P\text{-wave} & S, P, D\text{-waves} \\
D'_1 & P\text{-wave} & S, P, D\text{-waves} \\
D^*_2 & D\text{-wave} & P, D, F\text{-waves} \\
\end{array}
\]

Spin-parity of the $D^{**}$ determines properties of their decays

\[
\begin{align*}
D^*_2 & \rightarrow D\pi & & D^*_\pi & \text{in } D\text{-wave} \\
D_1 & \rightarrow D^*_\pi & & \text{in } D\text{-wave} \\
D'_1 & \rightarrow D^*_\pi & & \text{in } S\text{-wave} \\
D^*_0 & \rightarrow D\pi & & \text{in } S\text{-wave} \\
\end{align*}
\]
D** production in hadronic B decays

- D** production in the $\bar{B}^0 \rightarrow \bar{D}(*)^0 \pi^+ \pi^-$, $B^- \rightarrow D(*)^+ \pi^- \pi^-$ modes.

- D** production in the $\bar{B}^0 \rightarrow D(\pi)^+ \pi^- \omega$ mode.

never been reported before

**386 M B\bar{B}**

**PRD, 76, 012006 (2007)**

**65 M B\bar{B}**

**PRD, 69, 112002 (2004)**
Study of the color-suppressed $D^{**}$ dynamics.

HQET (Phys. Rept. 245, 259 (1994)) predicts the significant suppression of the narrow states in comparison with the broad ones in the color-suppressed channel.

SCET (PRD, 70, 114006 (2004)) predicts the equality of branching fractions to the narrow states, $D_1^0$ and $D_2^0$, and strong phases in decay amplitudes.

Relative partial-wave fractions of the $D^{**}$ production.

Factorization hypothesis in the $D^{**}$ production region.
Study of the resonance structure of the $\omega\pi$ system. Search for the second-class current mediated by the $b_1(1235)^- (b_1)$.

CLEO (PRD, 64, 092001 (2001)) and BaBar (PRD, 74, 012001 (2006)) $B^0 \rightarrow D^{*+}\omega\pi^-$ measurements validate the factorization hypothesis in the color-favored channel.

SND $e^+e^- \rightarrow \omega\pi^0$ data (PRD, 88, 054013 (2013)) indicate the large contributions of the $\rho(1450)$ ($\rho'$) and off-shell $\rho(770)$ ($\rho$).

CLEO $B \rightarrow D^*\rho \rightarrow D^{*}\pi\pi$ data (PRD, 67, 112002 (2003)) require nontrivial strong helicity phases.

Relative partial-wave fractions of the $\rho$-like production.

Interference effects between $\rho$ and $\rho'$.

Final-state interaction (FSI) phases in the $\omega\pi$ production.
Partial-wave analysis of $\bar{B}^0 \rightarrow D^{*+} \omega \pi^-$ with the following contributions

- $\bar{B}^0 \rightarrow \rho^- D^{*+}$
- $\bar{B}^0 \rightarrow \rho'^- D^{*+}$
- $\bar{B}^0 \rightarrow b_1^- D^{*+}$
- $\bar{B}^0 \rightarrow D_1^0 \omega$
- $\bar{B}^0 \rightarrow D_2^0 \omega$

Partial-wave analysis allows one to distinguish the contributions of different intermediate states ($D^{**}$ and $\rho$-like), describe their interference and the effective parameters.

- Angular distributions in basis with the fixed angular orbital momenta in the $B$- and studied resonances rest frames.
- Background description with using control sideband regions of data.
- Unbinned-likelihood fit in the signal region.
The signal density function is parameterized: an amplitude of the three-body $B^0 \to D^* \omega \pi$ decay is written as a sum of quasi-two-body amplitudes ($D^{**} \omega$, $D^* \rho$, $D^* \rho'$)

$$M = \sum_{R=\omega \pi} a_R e^{i\phi_R} M_R + \sum_{R=D^{**}} a_R e^{i\phi_R} M_R$$

Each resonant amplitude is written as a relativistic spin-dependent Breit-Wigner (BW) amplitude with angular dependencies.

$$M_{RJ} = \sum_{L_1 L_2} F_{L_1}(q^2) F_{L_2}(q^2) P_{L_1 L_2} A_{L_1 L_2} / D_R(q^2)$$

$F_L(q^2)$ is a transition form factor in the partial wave $L$ expressed via Isgur-Wise function in the helicity basis for the $\omega \pi$ production and the Blatt-Weisskopf factors for the $D^{**}$. $P_{L_1 L_2}$ and $A_{L_1 L_2}$ are the momentum and angular dependencies. $D_R(q^2)$ is the BW propagator.

6D fit using the observables
- $M_{\omega \pi}^2$, $\rho$-like invariant mass squared
- $M_{D^* \pi}^2$, $D^{**}$ invariant mass squared
- $\cos \theta$, helicity angle in the $\omega$ rest frame
- $\phi$, azimuthal angle in the $\omega$ rest frame
- $\cos \beta$, helicity angle in the $D^*$ rest frame
- $\psi$, azimuthal angle in the $D^*$ rest frame
Preliminary results \( m_{\omega\pi}^2 \) structure

\[ \mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\omega\pi^-) = (2.31 \pm 0.11 \text{ (stat.)} \pm 0.14 \text{ (syst.)}) \times 10^{-3} \]

\[ FF_{\rho(770)^-} = (64.2 \pm 10.7 \text{ (stat.)} +5.0_{-0.1} \text{ (syst.)} +8.7_{-24.3} \text{ (model)}) \% \]

\[ FF_{\rho(1450)^-} = (46.3 +6.0_{-13.4} \text{ (stat.)} +0.0_{-4.8} \text{ (syst.)} +17.6_{-0.7} \text{ (model)}) \% \]

\[ FF_{\rho(770)^-+\rho(1450)^-} = (82.2 \pm 2.2 \text{ (stat.)} +0.0_{-3.6} \text{ (syst.)} +0.4_{-2.3} \text{ (model)}) \% \]

\[ FF_{b^-} < 3.1\% \text{ (90\% C.L.)} \]

Total BF consistent with CLEO and BaBar
Preliminary results \( m^2_{D^*\pi} \) structure

\[
\mathcal{B}(\bar{B}^0 \rightarrow D^{*+}\omega\pi^-) = (2.31 \pm 0.11 \text{ (stat.)} \pm 0.14 \text{ (syst.)}) \times 10^{-3}
\]

\[
\begin{align*}
FF_{D_1^{*0}} &= \left( 10.8 \pm 1.8 \text{ (stat.)} \pm^{2.8}_{-0.0} \text{ (syst.)} \pm^{1.9}_{-0.4} \text{ (model)} \right) \\
FF_{D_0^{*1}} &= \left( 2.9 \pm 0.8 \text{ (stat.)} \pm^{0.5}_{-0.0} \text{ (syst.)} \pm^{0.5}_{-0.2} \text{ (model)} \right) \\
FF_{D_2^0} &= \left( 1.8 \pm 0.6 \text{ (stat.)} \pm^{0.0}_{-0.1} \text{ (syst.)} \pm 0.1 \text{ (model)} \right)
\end{align*}
\]
$\bar{B}^0 \rightarrow D^{*+}\omega\pi^-$ preliminary results (1)

$\rho(1450)$ ($\rho'$) parameters

$$m_{\rho'} = (1543.7 \pm 22.2^{+11.4}_{-1.0}(\text{stat.})^{+0.5}_{-45.6}(\text{syst.})^{+0.5}_{-45.6}(\text{model.})) \text{ MeV}/c^2$$

$$\Gamma_{\rho'} = (303.2^{+30.7}_{-52.3}(\text{stat.})^{+2.8}_{-3.7}(\text{syst.})^{+68.6}_{-6.1}(\text{model.})) \text{ MeV}$$

Helicity phases

$$\phi_+ = (0.87 \pm 0.29^{+0.12}_{-0.07}(\text{stat.})^{+0.12}_{-0.07}(\text{syst.}) \pm 0.06(\text{model.})) \text{ rad.}$$

$$\phi_- = (-0.02 \pm 0.13(\text{stat.}) \pm 0.02(\text{syst.}) \pm 0.05(\text{model.})) \text{ rad.}$$

Longitudinal polarizations

$$P_{D_1'}^0 = (63.0 \pm 9.1(\text{stat.}) \pm 4.6(\text{syst.})^{+4.6}_{-3.9}(\text{model.})) \%$$

$$P_{D_1}^0 = (67.1 \pm 11.7(\text{stat.})^{+0.0}_{-4.2}(\text{syst.})^{+2.3}_{-2.8}(\text{model.})) \%$$

$$P_{D_2}^0 = (76.0^{+18.3}_{-8.5}(\text{stat.}) \pm 2.0(\text{syst.})^{+2.9}_{-2.0}(\text{model.})) \%$$
FSI phases have the following hierarchy: $\phi_+ > \phi_-$

<table>
<thead>
<tr>
<th>Phase</th>
<th>$\bar{B}^0 \rightarrow D^{*+}(\rho^- \rightarrow \omega\pi^-)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_+$</td>
<td>$0.87 \pm 0.29^{+0.12}_{-0.07} \pm 0.06$</td>
</tr>
<tr>
<td>$\phi_-$</td>
<td>$-0.02 \pm 0.13 \pm 0.02 \pm 0.05$</td>
</tr>
</tbody>
</table>

$\bar{B}^0 \rightarrow D^{*+}(\rho^- \rightarrow \pi^-\pi^0)$ (CLEO)

<table>
<thead>
<tr>
<th>Phase</th>
<th>$\bar{B}^0 \rightarrow D^{*+}(\rho^- \rightarrow \pi^-\pi^0)$ (CLEO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_+$</td>
<td>$1.02 \pm 0.28 \pm 0.11$</td>
</tr>
<tr>
<td>$\phi_-$</td>
<td>$0.65 \pm 0.16 \pm 0.06$</td>
</tr>
</tbody>
</table>

$D^{**}$ longitudinal polarizations are less than factorizable QCD estimations

<table>
<thead>
<tr>
<th>Long. polarization</th>
<th>$\bar{B}^0 \rightarrow D_1'^0\omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{P}$, %</td>
<td>$63.0 \pm 9.1 \pm 4.6^{+4.6}_{-3.9}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Long. polarization</th>
<th>$\bar{B}^0 \rightarrow D^{*0}\omega$ (BaBar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mathcal{P}$, %</td>
<td>$66.5 \pm 4.7 \pm 1.5$</td>
</tr>
</tbody>
</table>

$D_1'^0$ partial waves

\[ S = (38.9 \pm 10.8(\text{stat.})^{+4.3}_{-0.7}(\text{syst.})^{+1.2}_{-1.1}(\text{model}))\% \]
\[ P = (33.1 \pm 9.5(\text{stat.})^{+2.4}_{-5.5}(\text{syst.})^{+3.0}_{-4.0}(\text{model}))\% \]
\[ D = (28.3 \pm 8.9(\text{stat.})^{+3.0}_{-0.8}(\text{syst.})^{+3.9}_{-2.9}(\text{model.}))\% \]

$S$, $P$, $D$-wave rates are comparable.
Search for New Physics in $b \to s$ penguin loop transition (direct CP violation).

Deviation from QCD factorization for $K^*(892)^0$ longitudinal polarization.

$$\mathcal{P}(K^*(892)^0) = 0.45 \pm 0.05 \pm 0.02 \text{ (Belle, PRL 94, 221804 (2005))}$$

$$\mathcal{P}(K^*(892)^0) = 0.494 \pm 0.034 \pm 0.013 \text{ (BaBar, PRD 78, 092008 (2008))}$$

Factorization-consistent result for $K_2^*(1430)^0$ longitudinal polarization.

$$\mathcal{P}(K_2^*(1430)^0) = 0.901^{+0.046}_{-0.058} \pm 0.037 \text{ (BaBar, PRD 78, 092008 (2008))}$$

Relative partial-wave fractions of the $K^*$ production.

Interference effects between $K^*$-states.
Partial-wave analysis of $B^0 \rightarrow \phi K^*$ via $K^* \rightarrow K^+\pi^-$ with the following contributions.

- scalar $(K\pi)^*_0 = K^*_0(1430)^0 + \text{nonresonant part (S-wave, } J = 0)$
- vector $K^*(892)^0$ ($P$-wave, $J = 1$)
- tensor $K^*_2(1430)^0$ ($D$-wave, $J = 2$)

Angular distributions in the helicity basis.


Background description with using data sidebands and MC samples.

Unbinned extended likelihood fit simultaneously performed for $B^0$ and $\bar{B}^0$ decays, which are measured independently.
Angular distributions are determined by the coherent sum of the $S$-, $P$- and $D$-wave amplitudes in helicity basis $A_J (J = 0, 1, 2)$.

$$A_J = \sum_{\lambda} A_{J\lambda} Y_{J\lambda}^* (\theta_1, \Phi) Y_{-\lambda} (-\theta_2, 0)$$

$A_{J\lambda}$ — in total 14 complex parameters, 7 — for $B^0$, 7 — for $\bar{B}^0$. 28 real parameters $\rightarrow$ 26 free parameters.

Mass distributions (for $J = 1, 2$) are parameterized by relativistic spin-dependent Breit-Wigner (BW) amplitudes. These amplitudes use the Blatt-Weisskopf factors.

LASS parameterization for $J = 0$ ($K\pi$ scattering results in the reaction $K^- p \rightarrow K^- \pi^+ n$; scattering is elastic up to $1.5 - 1.6 \text{ GeV}/c^2$ in $M_{K\pi}$ spectrum): BW description for the resonant part ($K^* (1430)^0$) and effective formula for the nonresonant part.

$9D$ fit to $B^0$ and $\bar{B}^0$ using the observables.

- $M_{bc}$, beam-constrained mass in $e^+ e^-$ C.M. frame
- $\Delta E$, energy difference in $e^+ e^-$ C.M. frame
- $M_{KK}$, $\phi$ invariant mass
- $M_{K\pi}$, $K^*$ invariant mass
- $C_{NB}$, continuum suppression network output
- $\cos \theta_1$, helicity angle in $K^*$ rest frame
- $\cos \theta_2$, helicity angle in $\phi$ rest frame
- $\Phi$, azimuthal angle in $B$ rest frame
- $Q$, charge of primary $K$ from $B$
$B^0 \to \phi K^*$ results (1)

**Polarizations**

<table>
<thead>
<tr>
<th></th>
<th>$\phi K^*(892)^0$</th>
<th>$\phi K_2^*(1430)^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_L$, %</td>
<td>$49.9 \pm 3.0 \pm 1.8$</td>
<td>$91.8^{+2.9}_{-6.0} \pm 1.2$</td>
</tr>
<tr>
<td>$f_\perp$, %</td>
<td>$23.8 \pm 2.6 \pm 0.8$</td>
<td>$5.6^{+5.0}_{-3.5} \pm 0.9$</td>
</tr>
</tbody>
</table>
B^0 \rightarrow \phi K^* results (2)

<table>
<thead>
<tr>
<th>Phases</th>
<th>\phi K^*(892)^0</th>
<th>\phi K_2^*(1430)^0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parallel φ_∥, (rad.)</td>
<td>2.23 ± 0.10 ± 0.02</td>
<td>3.76 ± 2.88 ± 1.32</td>
</tr>
<tr>
<td>Perpendicular φ_⊥, (rad.)</td>
<td>2.37 ± 0.10 ± 0.04</td>
<td>4.45^{+0.43}_{-0.38} ± 0.13</td>
</tr>
<tr>
<td>Strong δ_0, (rad.)</td>
<td>2.91 ± 0.10 ± 0.08</td>
<td>3.53 ± 0.11 ± 0.19</td>
</tr>
</tbody>
</table>

Total PDF
Continuum background

B^0 \rightarrow f_0(980)K^*(892)^0

B^0 \rightarrow \phi K^*
$B^0 \rightarrow \phi K^*$ results (3)

Total PDF
Continuum background

$B^0 \rightarrow f_0(980)K^*(892)^0$
$B^0 \rightarrow \phi K^*$

<table>
<thead>
<tr>
<th>Fractions</th>
<th>$\phi(K\pi)_0^*$</th>
<th>$\phi K^*(892)^0$</th>
<th>$\phi K_2^*(1430)^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$FF_J, \ %$</td>
<td>$27.3 \pm 2.4 \pm 1.3$</td>
<td>$60.0 \pm 2.0 \pm 1.2$</td>
<td>$9.9^{+1.6}_{-1.2} \pm 1.2$</td>
</tr>
<tr>
<td>$B_J \ (10^{-6})$</td>
<td>$4.3 \pm 0.4 \pm 0.3$</td>
<td>$10.4 \pm 0.5 \pm 0.5$</td>
<td>$5.5^{+0.9}_{-0.7} \pm 0.7$</td>
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</table>
\( B^0 \rightarrow \phi K^* \) results (4)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>( \phi(K\pi)_0^* )</th>
<th>( \phi K^*(892)^0 )</th>
<th>( \phi K_2^*(1430)^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_L, % )</td>
<td>—</td>
<td>49.9 ± 3.0 ± 1.8</td>
<td>91.8_{-6.0}^{+2.9} ± 1.2</td>
</tr>
<tr>
<td>( f_\bot, % )</td>
<td>—</td>
<td>23.8 ± 2.6 ± 0.8</td>
<td>5.6_{-3.5}^{+5.0} ± 0.9</td>
</tr>
<tr>
<td>( \phi_{\parallel}, ) (rad.)</td>
<td>—</td>
<td>2.23 ± 0.10 ± 0.02</td>
<td>3.76 ± 2.88 ± 1.32</td>
</tr>
<tr>
<td>( \phi_\bot, ) (rad.)</td>
<td>—</td>
<td>2.37 ± 0.10 ± 0.04</td>
<td>4.45_{-0.38}^{+0.43} ± 0.13</td>
</tr>
<tr>
<td>( \delta_0, ) (rad.)</td>
<td>—</td>
<td>2.91 ± 0.10 ± 0.08</td>
<td>3.53 ± 0.11 ± 0.19</td>
</tr>
<tr>
<td>( B_J ) (10^{-6})</td>
<td>4.3 ± 0.4 ± 0.3</td>
<td>10.4 ± 0.5 ± 0.5</td>
<td>5.5_{-0.7}^{+0.9} ± 0.7</td>
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BR and polarization parameters consistent with other experiments
**B^0 \rightarrow \phi K^* results (5)**

### CP violation parameters consistent with zero

<table>
<thead>
<tr>
<th>Direct CP asymmetry</th>
<th>( \phi(K\pi)_0^* )</th>
<th>( \phi K^*(892)^0 )</th>
<th>( \phi K^*_2(1430)^0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mathcal{A}_{CP} )</td>
<td>0.093 ( \pm ) 0.094 ( \pm ) 0.017</td>
<td>( -0.007 \pm 0.048 \pm 0.021 )</td>
<td>( -0.155^{+0.152}_{-0.133} \pm 0.033 )</td>
</tr>
</tbody>
</table>

### Comparison of \( B^0 \rightarrow \phi K^*(892)^0 \) measurements

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<tr>
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</thead>
<tbody>
<tr>
<td>( f_L ), %</td>
<td>49.7 ( \pm ) 1.9 ( \pm ) 1.5</td>
<td>49.9 ( \pm ) 3.0 ( \pm ) 1.8</td>
<td>49.4 ( \pm ) 3.4 ( \pm ) 1.3</td>
</tr>
<tr>
<td>( f_\perp ), %</td>
<td>22.1 ( \pm ) 1.6 ( \pm ) 1.3</td>
<td>23.8 ( \pm ) 2.6 ( \pm ) 0.8</td>
<td>21.2 ( \pm ) 3.2 ( \pm ) 1.3</td>
</tr>
<tr>
<td>( \phi_{</td>
<td></td>
<td>} ), (rad.)</td>
<td>2.562 ( \pm ) 0.069 ( \pm ) 0.040</td>
</tr>
<tr>
<td>( \phi_{\perp} ), (rad.)</td>
<td>2.633 ( \pm ) 0.062 ( \pm ) 0.037</td>
<td>2.37 ( \pm ) 0.10 ( \pm ) 0.04</td>
<td>2.35 ( \pm ) 0.13 ( \pm ) 0.09</td>
</tr>
</tbody>
</table>
Summary

- $\bar{B}^0 \to D^{*+}\omega\pi^-$ study.
  - Partial wave analysis of $\bar{B}^0 \to D^{*+}\omega\pi^-$.  
  - The consistent study of the $\rho$ and $\rho'$-states. Large destructive interference between $\rho$-like states.
  - Search for second-class current (upper limit for the $b_1(1235)$ production).
  - Dominance of the $D'_1$ relative to the $D_1$ in $\bar{B}^0 \to D^{*0}\omega$ decays consistent with HQET studies.
  - Evidence of $\bar{B}^0 \to D_2^0\omega$ not contradicting to SCET predictions.
  - Evidence of non-trivial FSI phases for the $\omega\pi$ production.
  - Comparable partial-wave rates for the $D^{**}$ production of order $30 - 35\%$
  - Observation of non-factorizable polarizations in the $D^{*+}$ sector.

- Angular analysis of $B^0 \to \phi K^*$
  - Partial wave analysis of $B^0 \to \phi K^*$
  - Branching fraction and polarization measurements for $B^0 \to \phi K^*(892)$ consistent with LHCb, BaBar and previous Belle results.
  - Dominant long. polarization for $B^0 \to \phi K_2^*(1430)^0$ consistent with BaBar result.
  - No evidence for $CP$ violation.
Backup
$\bar{B}^0 \rightarrow D^{*+} \omega \pi^-$ background structure (Backup)

- $4\pi$ comb. — combinatoric background with the misreconstructed $\omega$ candidates.
- $D^*4\pi$ signal — $(\bar{B}^0 \rightarrow D^{*+}\pi^-\pi^0\pi^+\pi^-)$ events without the $\omega$ in the intermediate state. Its interference with signal is assigned as systematics.
- $\omega\pi$ comb. — combinatoric background with the correctly reconstructed $\omega$ candidates.
\( B^0 \rightarrow \phi K^* \) background (Backup)

- \( e^+ e^- \rightarrow q\bar{q} \) (\( q \in u, d, s, c \)) continuum events is the dominant bkg. Neural network is used to suppress it. The rest bkg is estimated from \( M_{bc} \) sidebands. \( M_{bc} = \sqrt{(E^*_{\text{beam}})^2 - (P^*_B)^2} \).

- \( B^0 \rightarrow f_0(980)K^*(892)^0 \) is the dominant peaking bkg. Its interference with signal is assigned as systematics.

- \( B \rightarrow D_s^-K^+ \), \( D_s^- \rightarrow \phi \pi^- \) is rejected with using kinematic conditions.

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