Study of $B \rightarrow X(3872)(D^*D)K$ at Belle

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- motivation
- decay channels
- event selection
- Monte Carlo efficiencies
- fitting functions
- expected signal from Monte Carlo
- fits of $D^0\gamma$ and $D^0\pi^0$ data
Motivation

- New state: $X(3872)$
  - one of many new and unexpected states: $X(3872), Z(3930), Y(3940)$ etc.
  - first observed in 2003 by Belle in $J/\psi \pi \pi$ (plot)
  - current PDG mass $3871.4 \pm 0.6$ MeV
  - mass is very close to $D\bar{D}^*$ threshold.

- Various hypotheses on its nature
  - charmonium state $c\bar{c}$ ?
  - deuson $D\bar{D}^*$ ?
  - tetraquark state ?

- observed by Belle in $B \to D^0\bar{D}^0\pi^0K$
- observed by BaBar in $B \to D^{*0}\bar{D}^0K$ in 2007
- $X$ decay width and branching fractions are not well known
- only $J^{PC} = 1^{++}$ or $2^{--}$ are compatible with data

Search for $B \to X(3872)(D^{*0}D^0)K$ with $D^{*0} \to D^0(\gamma, \pi^0)$ to get more information on the properties of the $X(3872)$. 
Recent BaBar publication

Recent publication by BaBar (hep-ex 0708:1565)

- 33 ± 7 events in $B \rightarrow X(3872)(D^*D^0)K$
- 4.6σ significance on 347 fb$^{-1}$ of data
- mass $3875.1 \pm 1.1 \pm 0.5$ MeV, width $3.0^{+4.6}_{-2.3} \pm 0.9$ MeV
- mass is significantly higher than current value!

Is this really the $X(3872)$? Or yet another state?
Decay channels

$B$ candidates are reconstructed from the following channels:

- Charge conjugated modes are also included.
- At least one of $D^0$ or $\bar{D}^0$ is required to decay to $K^-\pi^+$. 
- Use both $D^*$ channels, since their branching fractions are well known (good constraint on data fit).
- Large Monte Carlo samples were generated for both $D^*$ channels to study the event selection procedure and optimize the cuts.
Selection cuts

<table>
<thead>
<tr>
<th>channel</th>
<th>$D^*(D^0\gamma)\bar{D}^0$</th>
<th>$D^*(D^0\pi^0)\bar{D}^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>photon momentum</td>
<td>$p &gt; 100$ MeV</td>
<td>$p &gt; 50$ MeV</td>
</tr>
<tr>
<td>photon quality</td>
<td>$E_9/E_{25} &gt; 0.8$</td>
<td></td>
</tr>
<tr>
<td>$K^0_S$ mass</td>
<td>±15 MeV; goodKs</td>
<td></td>
</tr>
<tr>
<td>$\pi^0$ mass</td>
<td>±16 MeV</td>
<td></td>
</tr>
<tr>
<td>$D^0$ mass</td>
<td>±14 MeV</td>
<td></td>
</tr>
<tr>
<td>$D^0(K\pi\pi^0)$ mass</td>
<td>±26 MeV</td>
<td></td>
</tr>
<tr>
<td>$D^0$ vertex fit $\chi^2$</td>
<td>&lt; 25</td>
<td></td>
</tr>
<tr>
<td>$D^{*0}$ mass</td>
<td>±27.5 MeV</td>
<td>±6.0 MeV</td>
</tr>
<tr>
<td>$X(3872)$ mass</td>
<td>$m(X) &lt; 4.0$ GeV</td>
<td></td>
</tr>
<tr>
<td>$\Delta E$</td>
<td>$</td>
<td>\Delta E</td>
</tr>
<tr>
<td>signal box</td>
<td>$M_{bc} &gt; 5.27$ GeV</td>
<td>$m(X) &lt; 3.89$ GeV</td>
</tr>
</tbody>
</table>

$$\Delta E = \sum E_i - E_{\text{beam}}^{\text{CM}} \approx 0 \quad M_{bc} = \sqrt{(E_{\text{CM}}^{\text{beam}})^2 - (\sum \vec{p}_i)^2} \approx M_B$$

The best candidate is chosen by minimising

$$\chi^2 = \left( \frac{\Delta M_{D_1}}{\sigma_{M_{D_0}}} \right)^2 + \left( \frac{\Delta M_{D_2}}{\sigma_{M_{D_0}}} \right)^2 + \left( \frac{\Delta(M_{D^*} - M_{D_0})}{\sigma_{M_{D^*} - M_{D_0}}} \right)^2 + \left( \frac{\Delta E}{\sigma_{\Delta E}} \right)^2 + \left[ \left( \frac{\Delta M_{\pi^0}}{\sigma_{M_{\pi^0}}} \right)^2 \right]$$
Monte Carlo efficiencies

Monte Carlo sample generated with above-threshold mass and 4 MeV width

<table>
<thead>
<tr>
<th>channel</th>
<th>$D^*(0)(D^0\gamma)\bar{D}^0$</th>
<th>$D^*(0)(D^0\pi^0)\bar{D}^0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>multiplicity</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td>best cand. selection eff.</td>
<td>79 %</td>
<td>62 %</td>
</tr>
<tr>
<td>total efficiency</td>
<td>$4.0 \cdot 10^{-4}$</td>
<td>$4.1 \cdot 10^{-4}$</td>
</tr>
<tr>
<td>$\Delta E$ resolution</td>
<td>$4.5 \pm 0.1$ MeV</td>
<td>$6.1 \pm 0.1$ MeV</td>
</tr>
<tr>
<td>$M_{bc}$ resolution</td>
<td>$2.78 \pm 0.01$ MeV</td>
<td>$3.09 \pm 0.03$ MeV</td>
</tr>
</tbody>
</table>

$m = 3872.275 \pm 0.065$

$width = 3.93 \pm 0.10$
$X$ mass resolution as a function of the mass:

- generated 200k $B^+ \rightarrow D^{*0} \bar{D}^0 K^+$ events (half $\gamma$, half $\pi^0$)
- look at generated $D^{*0} \bar{D}^0$ invariant mass in bins of 10 MeV
- in each bin, fit $m(D^*D)_{\text{gen}} - m(D^*D)_{\text{reco}}$ distribution to get $\sigma_X$.
- $\sigma_X$ is fitted with a square-root function, separately for $\gamma$ and $\pi^0$
- diff. between $\gamma$ and $\pi^0$ is $\sim 2\%$: same function can be used for both channels.
- at 3872 MeV the resolution is about 0.2 MeV, which is exceptional!
- $X(3872)$ decay width could be measured with a good precision.
Flatté distribution from Hanhart, Kalashnikova et al (hep-ph 0704.0605)

- Breit-Wigner with below-threshold mass, cut by threshold
- red curve: own implementation of the pdf
- blue curve: figure from their paper, for comparison
- slight difference is due to different nominal masses of $D$ and $D^*$ mesons.
- the drop at 8 MeV is due to the $D^{*+}D^-$ threshold.
- $X$ mass and width are not parameters in this case
Fitting function

PDF components:

- $X(3872)$ signal: relativistic Breit-Wigner (or Flatté) convoluted with resolution function

- $X(3940)$ signal: Breit-Wigner (small contribution; mass and width fixed from previous analysis, plot on right)

- $B \rightarrow D^*DK$ background: peaking in $M_{bc}$ but not in $X$ mass (bottom plots)
Expected signal and background for $D^0\pi^0$ (real data sidebands)

- left: $M_{bc}$ sidebands, normalised to the $X$ mass signal region
- right: $X$ mass sidebands and expected signal
- blue: signal yield computed from Monte Carlo, assuming that all the signal seen in $B \rightarrow D^0\bar{D}^0\pi^0K$ is resonant, plotted for a 3873 MeV mass and 3 MeV decay width.
Simultaneous Breit-Wigner fit (real data)

Extended log-likelihood 2D fit of $M_{bc}$ and $X$ mass; simultaneous fit of $D^0\gamma$ (top) and $D^0\pi^0$ (bottom).

real data!
$657 \cdot 10^6 B\bar{B}$ pairs

left: $M_{bc}$ for $X$ mass signal region

right: $X$ mass for $M_{bc}$ signal region

Signal box is hidden!
Summary

Data has been fitted, but unfortunately results can’t be shown here

- Both fitting functions (Breit-Wigner and Flatté) have been tested extensively using toy Monte Carlo. These tests show that the pdf’s work.
- Data is fitted using Breit-Wigner and Flatté distributions. Both fits give consistent results.

Expect to finish this analysis for the summer.

- Decay width could be measured precisely thanks to excellent resolution
- Good significance expected from Monte Carlo studies ($> 4\sigma$)

$X(3872)$ is still mysterious in many ways:

- is the mass below or above the $D^*D$ threshold ?
- are there one or two states around 3872 MeV ?