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

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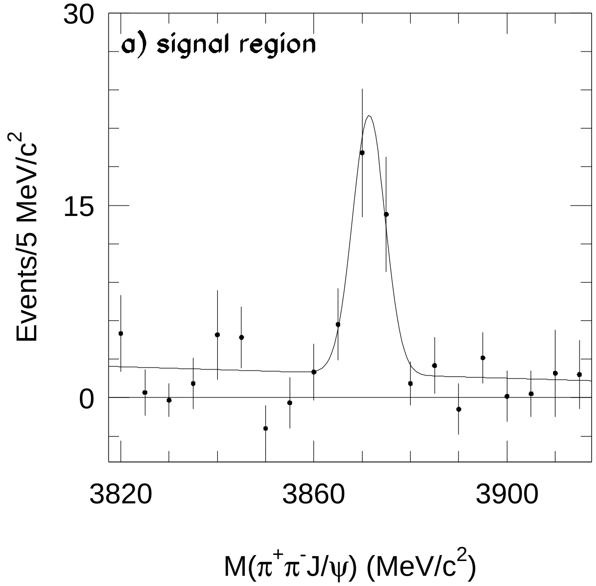
**March 26, 2008**
SPS Annual Meeting

- 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 $3871.4 \pm 0.6\,\mathrm{MeV}$
  - mass is very close to $D\bar{D}^*$ threshold. Above or below?
- Various hypotheses on its nature
  - charmonium state $c\bar{c}$ ?
  - deuson $D\bar{D}^*$ ?
  - tetraquark state ?

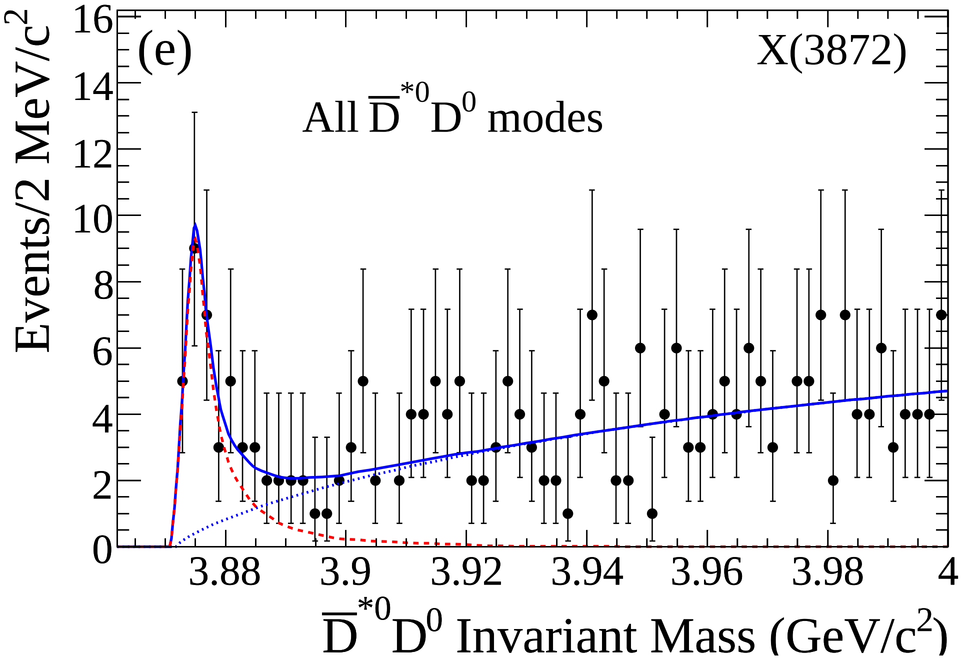



- observed by Belle in $B \to D^0\bar{D}^0\pi^0 K$
- observed by BaBar in $B \to D^{*0}\bar{D}^0 K$ in 2007
- $X$ decay width and branching fractions are not well known
- only $J^{PC} = 1^{++}$ or $2^{-+}$ are compatible with data

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)




- $33 \pm 7$ events in $B \to X(3872)(D^{*0}\bar{D}^0)K$
- $4.6\sigma$ significance on $347\,\mathrm{fb}^{-1}$ of data
- mass $3875.1 \pm 1.1 \pm 0.5\,\mathrm{MeV}$, width $3.0\,^{+4.6}_{-2.3} \pm 0.9\,\mathrm{MeV}$
- 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:

$$
\begin{aligned}
&\Upsilon(4\mathrm{S}) \to B^+ B^- \\
&\quad \hookrightarrow X(3872)\, K^+ \\
&\qquad \hookrightarrow D^{*0}\, \bar{D}^0 \\
&\qquad\quad \hookrightarrow D^0 (\gamma, \pi^0) \\
&\qquad\qquad \to K^- \pi^+ \\
&\qquad\qquad \to K^- \pi^+ \pi^0 \\
&\qquad\qquad \to K^- \pi^+ \pi^+ \pi^- \\
&\qquad\qquad \to K^0_S \pi^+ \pi^- \\
&\qquad\qquad \to K^- K^+
\end{aligned}
$$

- 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

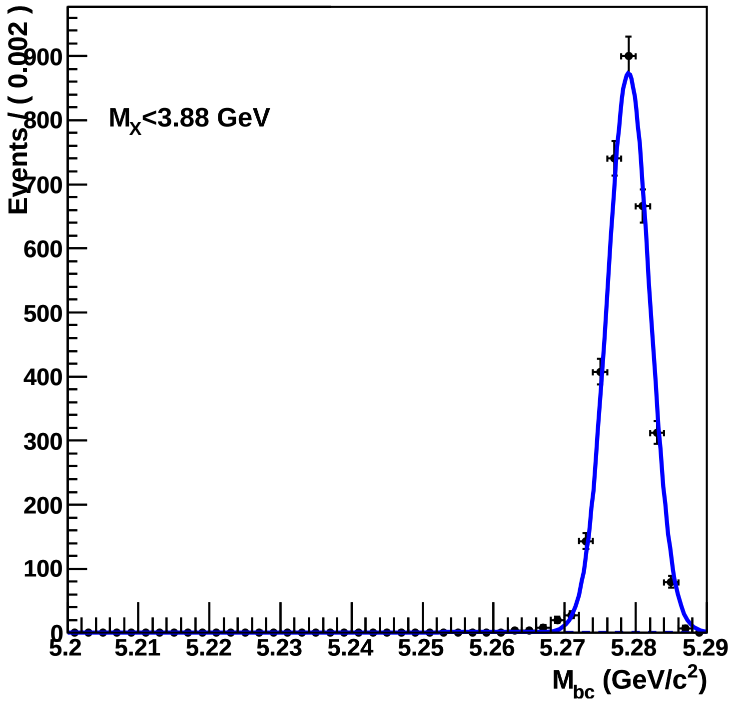
| channel | $D^{*0}(D^0\gamma)\bar{D}^0$ | $D^{*0}(D^0\pi^0)\bar{D}^0$ |
|---|---|---|
| photon momentum | $p > 100\,\mathrm{MeV}$ | $p > 50\,\mathrm{MeV}$ |
| photon quality | $E_9/E_{25} > 0.8$ | |
| $K_S^0$ mass | $\pm 15\,\mathrm{MeV}$; goodKs | |
| $\pi^0$ mass | $\pm 16\,\mathrm{MeV}$ | |
| $D^0$ mass | $\pm 14\,\mathrm{MeV}$ | |
| $D^0(K\pi\pi^0)$ mass | $\pm 26\,\mathrm{MeV}$ | |
| $D^0$ vertex fit $\chi^2$ | $< 25$ | |
| $D^{*0}$ mass | $\pm 27.5\,\mathrm{MeV}$ | $\pm 6.0\,\mathrm{MeV}$ |
| $X(3872)$ mass | $m(X) < 4.0\,\mathrm{GeV}$ | |
| $\Delta E$ | $\lvert\Delta E\rvert < 9\,\mathrm{MeV}$ | $\lvert\Delta E\rvert < 12\,\mathrm{MeV}$ |
| signal box | $M_{\mathrm{bc}} > 5.27\,\mathrm{GeV}$, $m(X) < 3.89\,\mathrm{GeV}$ | |

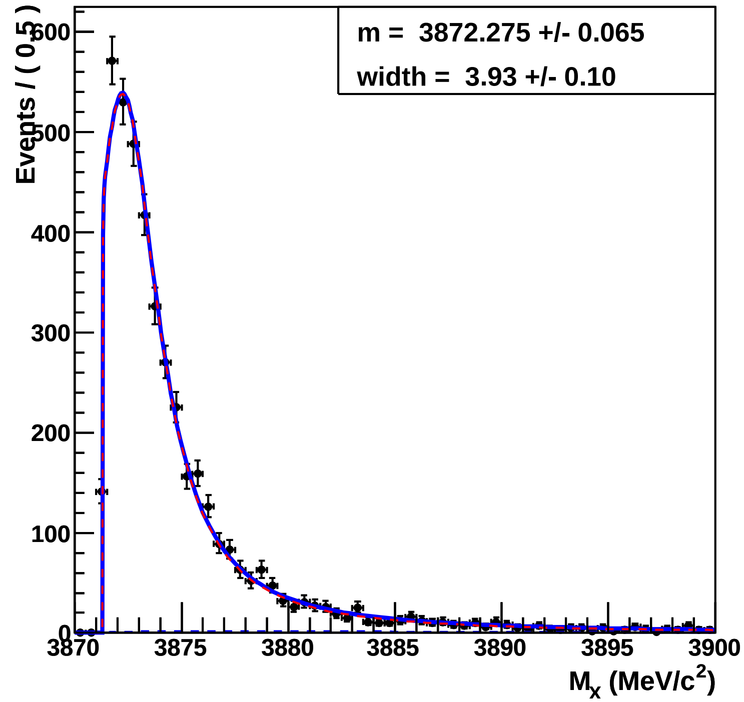
$$\Delta E = \sum E_i - E_{\mathrm{CM}}^{\mathrm{beam}} \approx 0 \qquad M_{\mathrm{bc}} = \sqrt{\left(E_{\mathrm{CM}}^{\mathrm{beam}}\right)^2 - \left(\sum \vec{p}_i\right)^2} \approx M_B$$

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

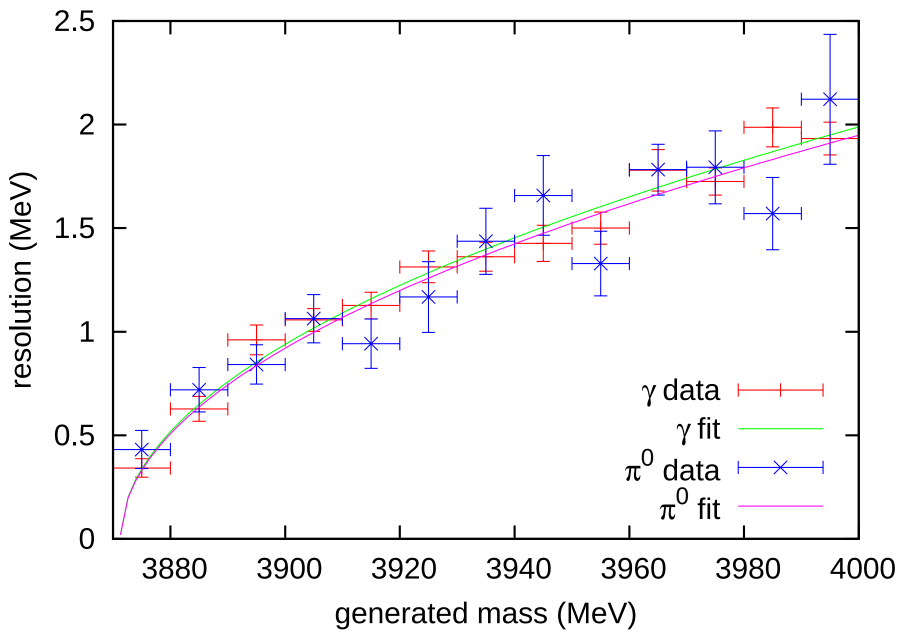


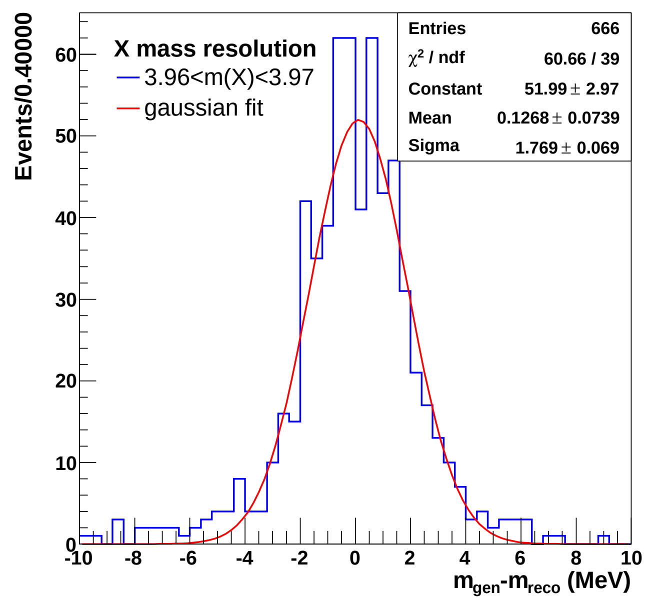




Monte Carlo sample generated with above-threshold mass and $4\,\mathrm{MeV}$ width

| channel | $D^{*0}(D^0\gamma)\bar{D}^0$ | $D^{*0}(D^0\pi^0)\bar{D}^0$ |
|---|---|---|
| multiplicity | 1.7 | 2.1 |
| best cand. selection eff. | 79 % | 62 % |
| total efficiency | $4.0 \cdot 10^{-4}$ | $4.1 \cdot 10^{-4}$ |
| $\Delta E$ resolution | $4.5 \pm 0.1\,\mathrm{MeV}$ | $6.1 \pm 0.1\,\mathrm{MeV}$ |
| $M_{\mathrm{bc}}$ resolution | $2.78 \pm 0.01\,\mathrm{MeV}$ | $3.09 \pm 0.03\,\mathrm{MeV}$ |

# $X$ mass resolution

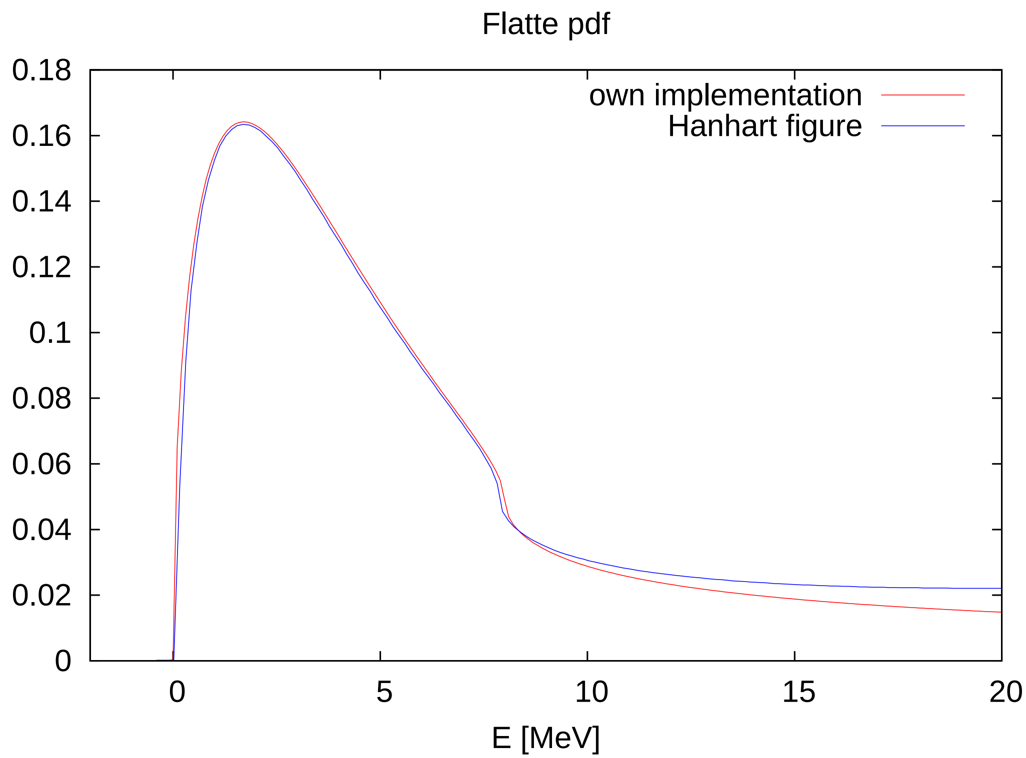



$X$ mass resolution as a function of the mass:

- generated 200k $B^+ \to D^{*0}\bar{D}^0 K^+$ events (half $\gamma$, half $\pi^0$)
- look at generated $D^{*0}\bar{D}^0$ invariant mass in bins of $10\,\mathrm{MeV}$
- in each bin, fit $m(D^*D)_{\mathrm{gen}} - m(D^*D)_{\mathrm{reco}}$ 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 $3872\,\mathrm{MeV}$ the resolution is about $0.2\,\mathrm{MeV}$, which is exceptional!
- $X(3872)$ decay width could be measured with a good precision.

# Flatté distribution



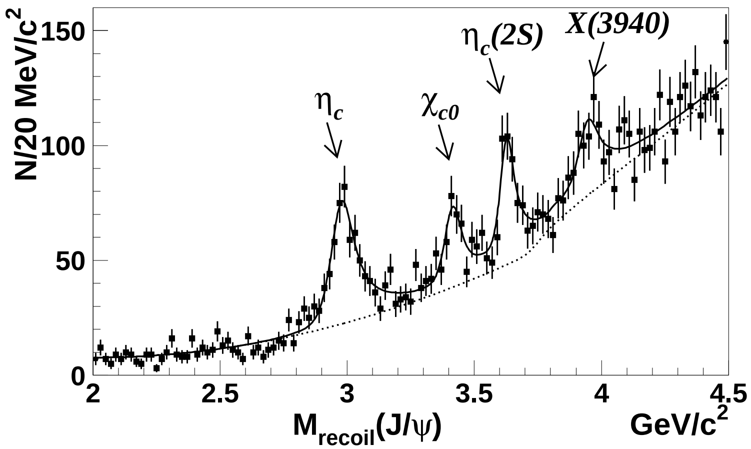

Flatté distribution from Hanhart, Kalashnikova et al (hep-ph 0704.0605)

- 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 $8\,\mathrm{MeV}$ is due to the $D^{*+}D^-$ threshold.
- $X$ mass and width are not parameters in this case

# Fitting function

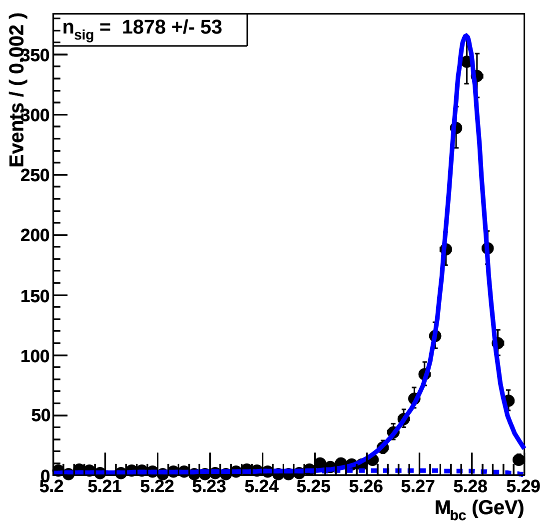
PDF components:

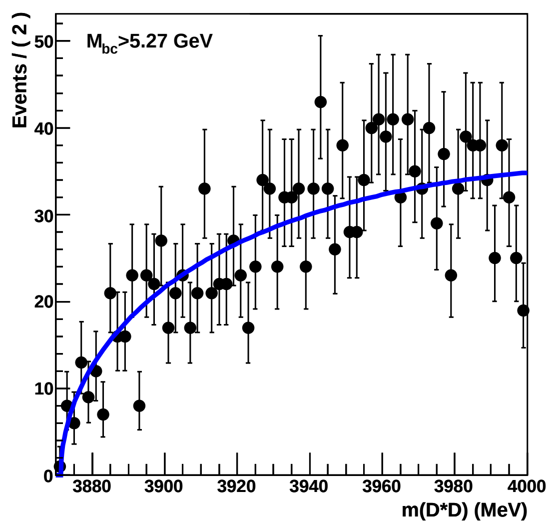
- $X(3872)$ signal: relativistic Breit-Wigner (or Flatté) convoluted with resolution function



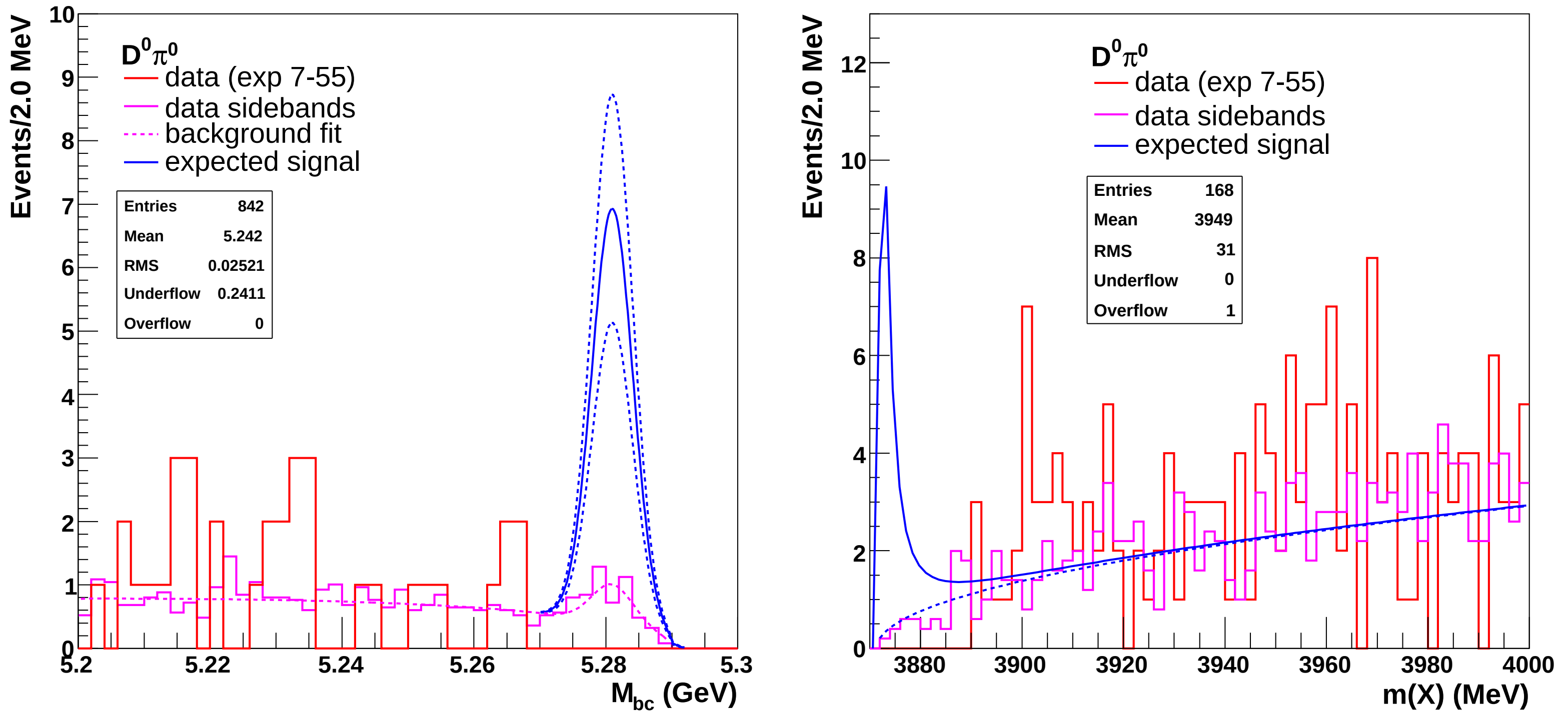

- $X(3940)$ signal: Breit-Wigner (small contribution; mass and width fixed from previous analysis, plot on right)

- $B \to D^*DK$ background: peaking in $M_{\rm bc}$ but not in $X$ mass (bottom plots)



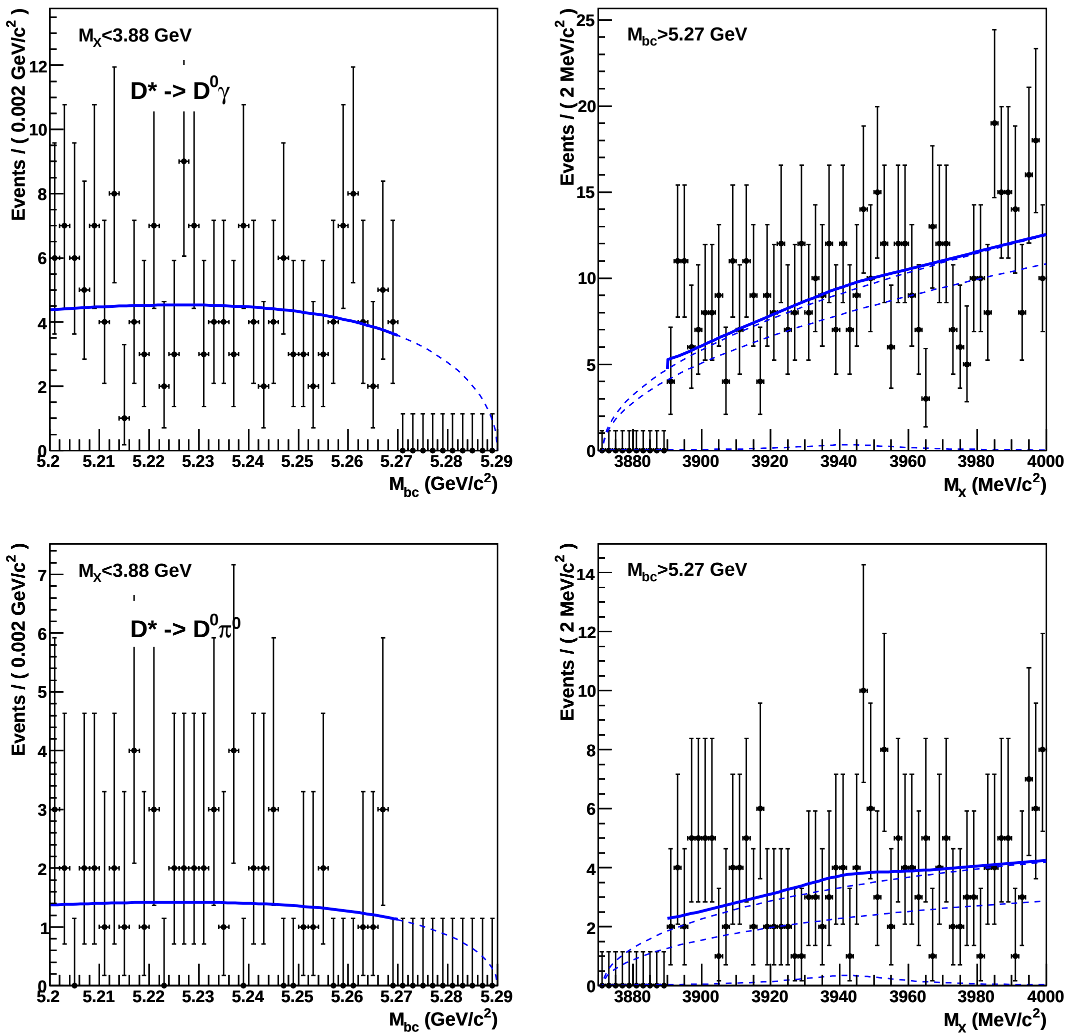
# Expected signal and background




Expected signal and background for $D^0\pi^0$ (real data sidebands)

- left: $M_{\rm bc}$ 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 $B \to D^0\bar{D}^0\pi^0K$ is resonant, plotted for a $3873\,\mathrm{MeV}$ mass and $3\,\mathrm{MeV}$ decay width.

# Simultaneous Breit-Wigner fit (real data)




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

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

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

Signal box is hidden !

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

# 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 $3872\,\mathrm{MeV}$ ?