Observation of the $Y(4140)$ in the $J/\psi\phi$ from $B^+ \rightarrow J/\psi\phi K^+$ Decay at CDF

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Motivation--What is $Y(4140)$?

Charmonium Spectrum  Reported by CDF through B decay.  PRL 102, 242002 (2009)

$Y(4140)$

- Above charm pair threshold
- But “narrow” strong decay
- Expect tiny BF to $J/\psi \phi$ if (cc)
- Close $J/\psi \phi$ threshold like $Y(3940)$, $C=+$

NOT likely to be a conventional charmonium

Some possible theoretical proposals:
Tetraquark: See arXiv of 0903:3107, 0903:2529, 0906:2485,...
Charmonium hybrid: See arXiv of 0903:3107,...
Molecule: See arXiv of 0903:3107, 0903.5424, 0906.0090,0903.2529,...
Rescattering via $D_sD^*$s : See arXiv:0906:2278, 0905.1595, PR D76, 114002
Tevatron and CDF

**Tevatron**

- **CDF**
  - pp at 1.96 TeV
- **DØ**
  - p-bar source
  - Booster
  - Main Injector & Recycler

**CDF detector**

- **Muon**: μ ID
- **ToF**: TOF
- **COT**: track p, dEdx
- **Silicon**: track p, vertex
Y(4140) Evidence Recap—analysis strategy

1) Reconstruct $B^+$ as:

$$B^+ \rightarrow J/\psi \phi K^+$$
$$J/\psi \rightarrow \mu^+ \mu^-$$
$$\phi \rightarrow K^+ K^-$$

II) Search for structure in $J/\psi \phi$ mass spectrum inside $B^+$ mass window

- **Primary vertex**
- **Secondary vertex**
- **Vertex separation $L_{xy}$**
- **Particle Identification**
- **Search?**

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PRL 102, 242002 (2009)
Y(4140) Evidence Recap—result w/ 2.7 fb$^{-1}$

PRL 102, 242002 (2009)

**75±10, purity ~80%**

Yield = 14 ± 5

$\Delta m = 1046.3 \pm 2.9\text{(stat)} \pm 1.2\text{(syst)}$ MeV

Width = $11.7^{+8.3}_{-5.0}\text{(stat)} \pm 3.7\text{(syst)}$ MeV

**Significance:** at least 3.8$\sigma$ for most conservative background

Possible EXOTIC interpretations from theorists: molecule, threshold effect,…

No firm conclusion from Belle due to low efficiency (low $p_T$ track around threshold)

It is important to investigate with CDF new data
CDF update—Dataset and Strategy

- Up to 5.0 fb\(^{-1}\). Note: CDF dimuon trigger is dynamically pre-scaled

- Combined with a slightly different trigger to increase statistics

- Use the same requirements as in the published paper

- \(B^+\) yield increased by 53%
The excess is seen in $B$ mass window
No evidence from $B$ sideband

The excess is enhanced w/ more data
**CDF update—Fit to the $\Delta m$ distribution**

**Signal PDF:** S-wave BW convoluted with resolution (1.7 MeV)

**Background PDF:** 3-body phase space (blue dot)

Fixed component for Bs component (black dot dash)

$\Delta m$, $\Gamma$ consistent with previous result, yield is increased

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**Result w/ 5.0 fb$^{-1}$:**

- **Yield** = $19 \pm 6$
- $\Delta m$ = $1046.7^{+2.9}_{-3.0}$ MeV/c$^2$
- $\Gamma$ = $15.3^{+10.4}_{-6.1}$ (stat) MeV/c$^2$
- $\sqrt{-2\log(L_{\text{max}})/L_0}$ = 5.91

**Result w/ 2.7 fb$^{-1}$:**

- **Yield** = $14 \pm 5$
- $\Delta m$ = $1046.3 \pm 2.9$ (stat) MeV/c$^2$
- $\Gamma$ = $11.7^{+8.3}_{-5.0}$ (stat) MeV
CDF update—Significance from Simulation

- Using three-body decay phase space only to generate the $\Delta m$ spectrum
- Find the most significant fluctuation in $\Delta m$ [1.02, 1.56] GeV with width in [1.7, 120] MeV
- Count the number of trials with $-2\log(L_{\text{max}}/L_0) \geq -2\Delta \ln$ value in data (34.9)

Fit the tail--[2,50] to $\chi^2$ PDF:

$$f(z;n) = \frac{z^{n/2-1}e^{-z/2}}{2^{n/2}\Gamma(n/2)} ; \quad z \geq 0$$

$P$-value = $2.26e-7$, corresponding to $5.04 \sigma$

The $Y(4140)$ significance >5 sigma assuming the $Y(4140)$ only

Consistent with integrated $\chi^2$ PDF

$P$-value from integrated $\chi^2$ PDF: $1.8e-7$, $5.09 \sigma$
Updated result of Y(4140) parameters

Using J/Ψ mass from PDG, including systematic, the Y(4140) parameters are:

Mass: \( 4143.4^{+2.9}_{-3.0}(\text{stat}) \pm 0.6(\text{syst}) \) MeV/c\(^2\)

Width: \( 15.3^{+10.4}_{-6.1}(\text{stat}) \pm 2.5(\text{syst}) \) MeV/c\(^2\)

Yield: \( 19^{+6}_{-5}(\text{stat}) \pm 3(\text{syst}) \)

Relative BF (assume S-wave BW for Y(4140) and phase space for B decays):

\[
\frac{\mathcal{B}(B^+ \to Y(4140)K^+, Y(4140) \to J/\Psi \phi)}{\mathcal{B}(B^+ \to J/\Psi \phi K^+)} = 0.149 \pm 0.039(\text{stat}) \pm 0.034(\text{syst})
\]

Significance: > 5σ

C parity: positive

Width (15 MeV) is relative narrow but much wider than resolution (1.7 MeV) indicating a strong decay
Suggestive evidence of a second peak

√-2Δln: 4.1
Δm: 1177.7^{+8.4}_{-6.7} MeV
Width: 32.3^{+21.9}_{-15.3} MeV
Yield: 22±8

Interesting, but not yet significant enough to be called a 'discovery'.

Fix the parameters for Y(4140)

For the excess around 1.18 GeV:
Signal PDF: S-wave BW convoluted with resolution (3.0 MeV)

Background PDF: 3-body phase space (blue dot)

Fixed component for Bs component (black dot dash)
Second peak significance from simulation

Significance is determined by the same kind of Toy MC as for the first peak

P-value=1.1e-3, corresponding to 3.1 \( \sigma \)

Adding \( J/\Psi \) mass from PDG, including systematic, the parameters are:

- **Mass:** \( 4274.4^{+8.4}_{-6.7} \) (stat) \( \pm 1.9 \) (syst) MeV/c\(^2\)
- **Width:** \( 32.3^{+21.9}_{-15.3} \) (stat) \( \pm 7.6 \) (syst) MeV/c\(^2\)
- **Yield:** \( 22 \pm 8 \) (stat) \( \pm 5 \) (syst)
- **Significance:** 3.1\( \sigma \)
- **C parity:** positive
Similarity between $Y(4140)$ and $Y(3940)$

Almost the same position, both “narrow” but strong decay
Is width connected to decay daughter width?
Summary

- Observed $Y(4140)$ at CDF using more data significance $>5\sigma$

- “narrow” width but a strong decay
  Not likely to be a conventional charmonium

- An excess around 4.28 GeV ($3.1\sigma$)

Stay tuned!
FY11 Luminosity Projections [delivered]

12 fb$^{-1}$ delivered doubles the dataset up to now and results in analyses with about 10 fb$^{-1}$