Review of Light Hadron Spectra at BESIII

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(on behalf of BESIII Collaboration)

Guangxi Normal University

Moriond QCD and High Energy Interactions
March 9th - March 16th 2013
OUTLINE

- Introduction
- Latest results on hadron spectroscopy
- Summary and prospects
Bird view of BEPCII

- Storage ring
- Linac

τ–charm physics

- Charmonium decays/transitions
- Light hadron spectroscopy
  - ...
  - $\eta$ and $\eta'$ physics
- Charm physics
- $\tau$ physics
So far BESIII has collected:

- 2009: 106 Million \( \psi' \)
- 2012: 0.4 Billion \( \psi' \)
- 2009: 225 Million \( J/\psi \)
- 2012: 1 Billion \( J/\psi \)

The results in this talk are based on the data sample of 106M \( \psi' \) events and 225M \( J/\psi \) events.
Confirmation of $p\bar{p}$ mass threshold enhancement

Confirmation of $X(1835)$ and observation of two new structures

- $X(1870)$ in $J/\psi \rightarrow \omega X$, $X \rightarrow a_0(980)\pi$
- $X(1840)$ in $J/\psi \rightarrow \gamma 3(\pi^+\pi^-)$
- $M\omega\phi$ threshold enhancement in $J/\psi \rightarrow \gamma \omega \phi$
- $N^*$ baryons in $\psi' \rightarrow p\bar{p}\eta$, $p\bar{p}\pi^0$ decays
Confirmation of $p$ $\bar{p}$ mass threshold enhancement

$J / \psi \rightarrow \gamma p\bar{p}$

Theoretical interpretation:
- conventional meson?
- $pp\bar{p}$ bound state/multiquark
- glueball
- Final state interaction (FSI)
- ...

$M=1859 \pm 3 \pm 5 \text{ MeV/c}^2$

$\Gamma < 30 \text{ MeV/c}^2 \text{ (90\% CL)}$

PRL 91 (2003) 022001
Confirmation of $p \bar{p}$ mass threshold enhancement

Fit with one resonance at BESII did:

\[ \psi' \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \gamma p \bar{p} \]

- $\psi' \rightarrow \pi^+ \pi^- J/\psi$ / $J/\psi \rightarrow \gamma p \bar{p}$

$M=1861^{+6}_{-13}^{+7}_{-26}$ MeV/c$^2$

$\Gamma < 38$ MeV/c$^2$ (90% CL)

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Chinese Physics C 34, 421 (2010)  
PRD 82, 092002(2010)
Several non-observations

$Y(1S) \to \gamma pp$@CLEO

$J/\psi \to \omega pp$@BESII

$\psi' \to \gamma pp$@BESII

$\psi(2S) \to \gamma pp$ @CLEOc

Pure FSI interpretation is disfavored
PWA on the $p \bar{p}$ mass threshold structure in $J/\psi \rightarrow \gamma p\bar{p}$

**Partial Wave Analysis (PWA):**

- Concentrate on dealing with the $p\bar{p}$ mass threshold structure, especially to determine the $J^{PC}$.

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**Evident narrow $pp\bar{b}ar$ mass threshold enhancement in $J/\psi$ decays.**

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BESIII

**Event/(0.02GeV/c^2)**

- X(1S)
- $\eta$

**M($pp$)(GeV/c^2)**

- 0
- 2.0
- 2.5
- 3.0

**M$_{J/\psi}^2$(GeV/c^2)^2**

- 1.0
- 1.5
- 2.0
- 2.5
- 3.0
- 3.5
- 4.0
- 4.5

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PWA results and projections in $J/\psi \rightarrow \gamma p\bar{p}$

- The fit with a BW and S-wave FSI(I=0) factor can well describe ppb mass threshold structure.

- It is much better than that without FSI effect ($\sim 7 \sigma$).
Measurement for $X(p \bar{p})$

- PWA results are carefully checked from different aspects:
  - Contribution of additional resonances
  - Solution with different combinations
  - Different background levels and fitting mass ranges
  - Different BW formula
  
  All uncertainties are considered as systematic errors

- Different FSI models $\Rightarrow$ Model dependent uncertainty

- Spin-parity, mass, width and B.R. of $X(pp)$:
  
  $J^{PC} = 0^{-+}$

  $>6.8 \sigma$ better than other $J^{PC}$ assignments.

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (MeV/c²)</th>
<th>Width (MeV/c²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(pp\bar{p})$</td>
<td>$1832^{+19}<em>{-5}^{+18}</em>{-17} \pm 19$(model)</td>
<td>$13 \pm 39^{+10}_{-13} \pm 4$(model)</td>
</tr>
</tbody>
</table>

$\text{BR}[J/\psi \to \gamma X(p\bar{p})] \times 10^{-5}$
Obviously different line shape of ppbar mass spectrum near threshold from that in $J/\psi$ decays.

**PWA results:**
- Significance of $X(ppbar)$ is $> 6.9\sigma$.
- The production ratio $R$:
  \[
  R = \frac{B(\psi' \to \gamma X(ppbar))}{B(J/\psi \to \gamma X(ppbar))}
  \]
  \[
  = (5.08^{+0.71}_{-0.45}\text{ (stat)}^{+0.67}_{-3.58}\text{ (syst)} \pm 0.12\text{(mod)})\% 
  \]
- It is suppressed compared with “12% rule”.

**PWA Projection:**

**PRL 108,112003(2012)**
Confirmation of $X(1835)$ and Observation of two new structures

$\sigma = \pm \Gamma = \pm \text{(Stat. sig. ~ 7.7$\sigma$):}$

$M = 1833.7 \pm 6.1(stat) \pm 2.7(syst)\text{MeV}$

$\Gamma = 67.7 \pm 20.3(stat) \pm 7.7(syst)\text{MeV}$

$J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$

$\eta' \rightarrow \eta \pi^+ \pi^-$

$\eta' \rightarrow \gamma \rho$

$\text{BESII result}$

$\text{PRL 95, 262001(2005)}$

$\text{BESIII}$

$\text{PRL 106, 072002(2011)}$

$f_{1}(1510)$

$\text{two news!}$
Confirmation of $X(1835)$ and Observation of two new structures

BESIII fit results:

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$M$ (MeV/c$^2$)</th>
<th>$\Gamma$ (MeV/c$^2$)</th>
<th>Stat. Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(1835)$</td>
<td>$1836.5 \pm 3.0^{+5.6}_{-2.1}$</td>
<td>$190.1 \pm 9.0^{+38}_{-36}$</td>
<td>$&gt;20 \sigma$</td>
</tr>
<tr>
<td>$X(2120)$</td>
<td>$2122.4 \pm 6.7^{+4.7}_{-2.7}$</td>
<td>$83 \pm 16^{+31}_{-11}$</td>
<td>$7.2 \sigma$</td>
</tr>
<tr>
<td>$X(2370)$</td>
<td>$2376.3 \pm 8.7^{+3.2}_{-4.3}$</td>
<td>$83 \pm 17^{+44}_{-6}$</td>
<td>$6.4 \sigma$</td>
</tr>
</tbody>
</table>

PWA is needed to understand these structures.

$X(1835)$ consistent with 0$^{-+}$
X(1870) in J/ψ → ωX, X → a₀(980)π

- X(1835) observed at BESII and then confirmed at BESIII in J/ψ → γ π⁺π⁻ η′
- theoretical interpretations: pseudoscalar glueball, η/η′ excited states..
- study of its production in hadronic decays
- to our surprise, we observed a new structure around 1.87 GeV

PRL 107, 182001(2011)
$X(1870)$ in $J/\psi \rightarrow \omega X, \ X \rightarrow a_0(980)\pi$

Identification of $X(1870)$: $0^-(?)$
It is $X(1835)$? Need PWA!

$J/\psi \rightarrow \omega \eta \pi^+\pi^-$, $a_0(980)$ reconstructed in $\eta \pi^\pm$

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Mass (MeV/$c^2$)</th>
<th>Width (MeV/$c^2$)</th>
<th>Branch ratio ($10^{-4}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_1(1285)$</td>
<td>$1285.1 \pm 1.0^{+1.6}_{-0.3}$</td>
<td>$22.0 \pm 3.1^{+2.0}_{-1.5}$</td>
<td>$1.25 \pm 0.10^{+0.19}_{-0.20}$</td>
</tr>
<tr>
<td>$\eta(1405)$</td>
<td>$1399.8 \pm 2.2^{+2.8}_{-0.1}$</td>
<td>$52.8 \pm 7.6^{+0.1}_{-7.6}$</td>
<td>$1.89 \pm 0.21^{+0.21}_{-0.23}$</td>
</tr>
<tr>
<td>$X(1870)$</td>
<td>$1877.3 \pm 6.3^{+3.4}_{-7.4}$</td>
<td>$57 \pm 12^{+19}_{-4}$</td>
<td>$1.50 \pm 0.26^{+0.72}_{-0.36}$</td>
</tr>
</tbody>
</table>
A peak around 1.84 GeV is observed!

\[ M = 1842.2 \pm 4.2^{+6.9}_{-1.8} \text{ MeV} \]
\[ \Gamma = 83 \pm 14 \pm 11 \text{ MeV} \]

• Its mass is consistent with that of \( X(1835) \), but the width is much smaller than \( \Gamma_{X(1835)} = 190.1 \pm 9.0^{+38}_{-36} \text{ MeV} \)

• Most likely to be a new decay mode of \( X(1835) \)
$M_{\omega\phi}$ threshold enhancement in $J/\psi \rightarrow \gamma \omega \phi$

For $X(1810)$:

$M = 1812^{+19}_{-26} \pm 18$ MeV/$c^2$

$\Gamma = 105 \pm 20 \pm 28$ MeV/$c^2$

$J^{pc}$ favors $0^{++}$ over $0^{-+}$ and $2^{++}$
Is $X(1810)$ the $f_0(1710)/f_0(1790)$ or new state?

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$J^{PC}$</th>
<th>$M$(MeV/(c^2))</th>
<th>$\Gamma$(MeV/(c^2))</th>
<th>Events</th>
<th>$\Delta S$</th>
<th>$\Delta ndf$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(1810)$</td>
<td>$0^{++}$</td>
<td>1795 ± 7</td>
<td>95 ± 10</td>
<td>1319 ± 52</td>
<td>783</td>
<td>4</td>
<td>&gt; 30σ</td>
</tr>
<tr>
<td>$f_0(1950)$</td>
<td>$2^{++}$</td>
<td>1944</td>
<td>472</td>
<td>665 ± 40</td>
<td>211</td>
<td>2</td>
<td>&gt; 10σ</td>
</tr>
<tr>
<td>$f_0(2020)$</td>
<td>$0^{++}$</td>
<td>1992</td>
<td>442</td>
<td>715 ± 45</td>
<td>100</td>
<td>2</td>
<td>&gt; 10σ</td>
</tr>
<tr>
<td>$\eta(2225)$</td>
<td>$0^{--}$</td>
<td>2240</td>
<td>190</td>
<td>70 ± 30</td>
<td>23</td>
<td>2</td>
<td>6.4σ</td>
</tr>
<tr>
<td>phase space</td>
<td>$0^{--}$</td>
<td>2400</td>
<td>5000</td>
<td>319 ± 24</td>
<td>45</td>
<td>2</td>
<td>&gt; 8σ</td>
</tr>
</tbody>
</table>
Non-relativistic quark model is successful in interpreting of the excited baryons

Predicted more excited stated ("missing resonance problem")

\textit{J/}\psi (\psi') decays offers an window to search for the missing resonance

\textbf{Observation of two N* baryons in }\psi' \rightarrow \pi^0 p \bar{p} \text { decay}

\textbf{arXiv:1207.0223}
Two new baryonic excited states are observed! 

**PWA results on N* baryons in $\psi' \rightarrow \pi^0 p \bar{p}$**

<table>
<thead>
<tr>
<th>Resonance</th>
<th>$M$(MeV/c²)</th>
<th>$\Gamma$(MeV/c²)</th>
<th>$\Delta S$</th>
<th>$\Delta N_{dof}$</th>
<th>C.L.</th>
</tr>
</thead>
<tbody>
<tr>
<td>N(1440)</td>
<td>1390±11 +21 -21 -30</td>
<td>340±46 +70 -40 -156</td>
<td>72.5</td>
<td>4</td>
<td>11.5σ</td>
</tr>
<tr>
<td>N(1520)</td>
<td>1510±7 +11 -9 -10</td>
<td>115±15 +20 -10 -40</td>
<td>19.8</td>
<td>6</td>
<td>5.0σ</td>
</tr>
<tr>
<td>N(1535)</td>
<td>1535±9 +15 -8 -11</td>
<td>120±20 +10 -20 -42</td>
<td>49.4</td>
<td>4</td>
<td>9.3σ</td>
</tr>
<tr>
<td>N(1650)</td>
<td>1650±5 +30 -8 -50</td>
<td>150±21 +14 -22 -50</td>
<td>82.1</td>
<td>4</td>
<td>12.2σ</td>
</tr>
<tr>
<td>N(1720)</td>
<td>1700±30 +32 -28 -35</td>
<td>450±109 +149 -94 -44</td>
<td>55.6</td>
<td>6</td>
<td>9.6σ</td>
</tr>
<tr>
<td>N(2300)</td>
<td>2300±30 +109 -30 -0</td>
<td>340±30 +110 -30 -58</td>
<td>120.7</td>
<td>4</td>
<td>15.0σ</td>
</tr>
<tr>
<td>N(2570)</td>
<td>2570±10 +34 -10 -10</td>
<td>250±14 +69 -24 -21</td>
<td>78.9</td>
<td>6</td>
<td>11.7σ</td>
</tr>
</tbody>
</table>

**Resonance**

<table>
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<th>$\Gamma$(MeV/c²)</th>
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<tbody>
<tr>
<td>N(2300)</td>
<td>2300±40 -30 ±109 -0</td>
<td>340±30 -30 ±110 -58</td>
</tr>
<tr>
<td>N(2570)</td>
<td>2570±19 -10 ±34 -10</td>
<td>250±14 -24 ±69 -21</td>
</tr>
</tbody>
</table>
Preliminary results on $N^*$ baryon in $\psi' \to \eta p \bar{p}$ decay

$\text{Br}(\psi' \to pp\eta) = (6.6 \pm 0.2 \pm 0.6) \times 10^{-5}$

$\text{PDG 2010}: (6.0 \pm 1.2) \times 10^{-5}$

Mass: $1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV
Width: $0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

$\text{Br}(\psi' \to N(1535)p) \times \text{Br}(N(1535) \to p\eta + c.c.) = 5.5^{+0.3+7.4}_{-0.3-1.1} \times 10^{-5}$

$N(1535)$ is $1/2^-$

$M(p\eta): ~ \text{Dalitz plot}$
$M(pp): ~ \text{Dalitz plot}$

A full PWA is performed.
Background clean!
Summary and Prospects

- Huge data samples collected for charmonium decays at BESIII. A lot of results have been obtained,
  - Confirmation of the $p\bar{p}$ mass threshold enhancement
  - Confirmation of $X(1835)$ and observation of two new structures $X(2120)$ and $X(2370)$
  - Observation of new structure $X(1870)$ in $J/\psi\to\omega\pi\pi\eta$
  - ...
- 1 billion $J/\psi$ events were taken at BESIII
- We expect rich physics results in the coming years from BESIII!

Thanks!