Progress in light hadron spectroscopy at BESIII

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OUTLINE

Introduction

Latest results on hadron spectroscopy

- \( p \bar{p} \) mass threshold enhancement
- Confirmation of \( X(1835) \) and observation of two new structures
  - \( X(1870) \) in \( J/\psi \rightarrow \omega X, X \rightarrow a_0(980)\pi \)
  - \( \eta(1405) \) in \( J/\psi \rightarrow \gamma f_0(980)\pi^0, f_0(980) \rightarrow \pi\pi \)
  - N* baryon in \( \psi' \rightarrow \eta p \bar{p} \) decay

Summary
Satellite view of BEPCII /BESIII

2004: start BEPCII construction
2008: test run of BEPCII
2009-now: BECPII/BESIII data taking
Beam energy: 1.0-2.3 GeV
Design Luminosity: $1 \times 10^{33}$ cm$^{-2}$s$^{-1}$
Optimum energy: 1.89 GeV
Energy spread: $5.16 \times 10^{-4}$
No. of bunches: 93
Bunch length: 1.5 cm
Total current: 0.91 A
Circumference: 237 m
BESIII Detector

Magnet: 1 T  Super conducting

MDC: small cell & Gas: He/C$_3$H$_8$ (60/40), 43 layers
$\sigma_{xy} = 130 \ \mu m$
$\sigma_{p}/p = 0.5\% \ @1GeV$
$dE/dx = 6\%$

TOF:
$\sigma_T = 100 \ \text{ps} \ \text{Barrel}$
$110 \ \text{ps} \ \text{Endcap}$

EMC: CsI crystal, 28 cm
$\Delta E/E = 2.5\% \ @1 \ \text{GeV}$
$\sigma_z = 0.6 \ \text{cm}/\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume $\sim 50 \ \text{MB/s}$

Muon ID: 9 layers RPC
8 layers for endcap

BESIII detector: all new!

CsI calorimeter
Precision tracking
Time-of-flight + dE/dx PID
Data samples

- So far BESIII has collected:
  - 2009: 225 Million J/ψ
  - 2009: 106 Million ψ’
  - 2010-11: 2.9 fb⁻¹ ψ(3770)
    (3.5 × CLEO-c 0.818fb⁻¹)
  - May 2011: 0.5fb⁻¹ @4010 MeV (one month) for Ds and XYZ spectroscopy

- BESIII will also collect:
  - more J/ψ, ψ’, ψ(3770)
  - data at higher energies (for XYZ searches, R scan and Ds physics)
Observation of $p\bar{p}$ mass threshold enhancement at BESII and BESIII

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

**BESII**

$$M = 1859^{+3}_{-10}^{+5}_{-25} \text{ MeV/c}^2$$

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

PRL 91 (2003) 022001

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

**BESIII**

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

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

Chinese Physics C 34, 421 (2010)

2011/9/19
Evident narrow $pp\bar{p}$ mass threshold enhancement in $J/\psi \rightarrow \gamma p\bar{p}$ decays.

**Partial Wave Analysis (PWA):**

- Concentrate on dealing with the $p\bar{p}$ mass threshold structure, especially to determine the $J^{PC}$.
PWA results and projections in $J/\psi \rightarrow \gamma p\bar{p}$

<table>
<thead>
<tr>
<th>Component</th>
<th>$J^{PC}$</th>
<th>$M$ (GeV)</th>
<th>$\Gamma$ (GeV)</th>
<th>Stat. sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X(p\bar{p})$</td>
<td>0$^{--}$</td>
<td>$1.832 \pm 0.005$</td>
<td>$0.013 \pm 0.020$</td>
<td>$\gg 30\sigma$</td>
</tr>
<tr>
<td>$f_0(2100)$</td>
<td>0$^{++}$</td>
<td>2.103</td>
<td>0.209</td>
<td>$11.2\sigma$</td>
</tr>
<tr>
<td>$f_2(1910)$</td>
<td>2$^{++}$</td>
<td>1.903</td>
<td>0.196</td>
<td>$7.7\sigma$</td>
</tr>
<tr>
<td>phase space</td>
<td>0$^{++}$</td>
<td>--</td>
<td>--</td>
<td>$6.3\sigma$</td>
</tr>
</tbody>
</table>

Preliminary results

- 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, and $\Delta 2\ln L=51 \Rightarrow 7.1\sigma$. 

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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 → Model dependent uncertainty

- Spin-parity, mass, width and B.R. of $X(p\bar{p})$:

  Preliminary results

  $J^{pc} = 0^{-+}$  

  $M = 1832 \pm 5^{+19}_{-17} \text{(stat)} \pm 19^{ (mod)} \text{MeV/c}^2$

  $\Gamma = 13 \pm 20^{+11}_{-33} \text{(stat)} \pm 4^{ (mod) \text{MeV/c}^2}$ or $\Gamma < 48 \text{MeV/c}^2 \ @ 90\% \ C.L.$

  $B(J/\psi \rightarrow \gamma X(p\bar{p}))B(X(p\bar{p}) \rightarrow p\bar{p}) = (9.0 \pm 0.7^{+1.5}_{-5.1} \text{(stat)} \pm 2.3^{ (mod) }) \times 10^{-5}$
PWA on the $p\bar{p}$ mass threshold structure in $\psi' \rightarrow \gamma p\bar{p}$

Preliminary results

Obviously different line shape of ppbar mass spectrum near threshold from that in J/$\psi$ decays

PWA results:

- Significance of $X(pp\bar{p})$ is larger than $6.9\sigma$.
- The production ratio $R$:

$$R = \frac{B(\psi' \rightarrow \gamma X(pp\bar{p}))}{B(J/\psi \rightarrow \gamma X(pp\bar{p}))}$$

$$= (5.08 \pm 0.56{\text{(stat)}}^{+0.72}_{-3.83} {\text{(syst)}} \pm 0.12{\text{(mod)}}{\%})$$

- It is suppressed compared with “12% rule”.

PWA Projection:

- PWA results:
  - Significance of $X(pp\bar{p})$ is larger than $6.9\sigma$.
  - The production ratio $R$:

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- It is suppressed compared with “12% rule”.

First measurement
Confirmation of X(1835) and Observation of two new structures

BESII result (Stat. sig. ~ 7.7σ):

\[ M = 1833.7 \pm 6.1 \text{(stat)} \pm 2.7 \text{(syst)} \text{MeV} \]
\[ \Gamma = 67.7 \pm 20.3 \text{(stat)} \pm 7.7 \text{(syst)} \text{MeV} \]

**PRL 95, 262001 (2005)**

**PRL 106, 072002 (2011)**

\[ J/\psi \rightarrow \gamma \eta' \pi^+ \pi^- \]
\[ \eta' \rightarrow \eta \pi^+ \pi^- \]
\[ \eta' \rightarrow \gamma \rho \]

**BESIII**

**two news!**

**f1(1510)**
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 $0^{-+}$
What’s the nature of new structures?

It is the first time resonant structures are observed in the 2.4 GeV/c² region, it is interesting since:

LQCD predicts that the lowest lying pseudoscalar glueball: around 2.4 GeV/c².

J/ψ→γππη' decay is a good channel for finding 0⁺ glueballs.

Nature of X(2120)/X(2370) pseudoscalar glueball? η/η' excited states?

PRD82,074026,2010 (J.F. Liu, G.J. Ding and M.L.Yan)
PRD83:114007,2011 (J.S. Yu, Z.F. Sun, Q.Zhao), and more...
X(1870) in $J/\psi \to \omega X, X \to a_0(980)\pi$

✓ X(1835) observed at BESII and then confirmed at BESIII in $J/\psi \to \gamma \pi^+\pi^-\eta'$
✓ theoretical interpretations: pseudoscalar glueball, $\eta/\eta'$ excited states ..
✓ study of its production in hadronic decays
✓ to our surprise, we observed a new structure around 1.87 GeV

BESIII

arxiv: 1107.1806
Identification of $X(1870)$: $0^{-+}(?)$

It is $X(1835)$? Need PWA!

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

$X(1870)$: 7.2$\sigma$

Resonance | Mass (MeV/$c^2$) | Width (MeV/$c^2$) | Branch ratio ($10^{-4}$)
--- | --- | --- | ---
$f_1(1285)$ | 1285.1 ± 1.0$^{+1.6}_{-0.3}$ | 22.0 ± 3.1$^{+2.0}_{-1.5}$ | 1.25 ± 0.10$^{+0.19}_{-0.20}$
$\eta(1405)$ | 1399.8 ± 2.2$^{+2.8}_{-0.1}$ | 52.8 ± 7.6$^{+0.1}_{-7.6}$ | 1.89 ± 0.21$^{+0.21}_{-0.23}$
$X(1870)$ | 1877.3 ± 6.3$^{+3.4}_{-7.4}$ | 57 ± 12$^{+19}_{-4}$ | 1.50 ± 0.26$^{+0.72}_{-0.36}$

$BR(J/\psi \rightarrow \omega X, \ X \rightarrow a_0^{\pm}(980)\pi^\mp)$
\[ \eta(1405) \text{ in } J/\psi \rightarrow \gamma f_0(980)\pi^0, f_0(980) \rightarrow \pi\pi \]

**Charged:**
\[ f_0(980) \rightarrow \pi^+\pi^- \]

**Neutral**
\[ f_0(980) \rightarrow \pi^0\pi^0 \]

Helicity analysis indicates that peak at 1400MeV is from \( \eta(1405) \rightarrow f_0(980)\pi^0 \) not from \( f_1(1420) \):

First observation of \( \eta(1405) \rightarrow f_0(980)\pi^0 \) (isospin violated decays) and \( J/\psi \rightarrow \gamma f_0(980)\pi^0 \)

**Preliminary results:**

\[
Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0\pi^0 \rightarrow \gamma \pi^0\pi^+\pi^-) = (1.48 \pm 0.13(stat.) \pm 0.17(sys.)) \times 10^{-5}
\]

\[
Br(J/\psi \rightarrow \gamma \eta(1405) \rightarrow \gamma f_0\pi^0 \rightarrow \gamma \pi^0\pi^0\pi^0) = (6.99 \pm 0.93(stat.) \pm 0.95(sys.)) \times 10^{-6}
\]
New results on $\eta' \rightarrow 3\pi$ in $J/\psi \rightarrow \gamma \pi\pi\pi$

Preliminary results:

$Br(\eta' \rightarrow \pi^+\pi^-\pi^0) = (3.83 \pm 0.15(stat.) \pm 0.39(sys.)) \times 10^{-3}$

PDG2010: $(3.6^{+1.1}_{-0.9}) \times 10^{-3}$ (2009 CLEO-c)

$Br(\eta' \rightarrow 3\pi^0) = (3.56 \pm 0.22(stat.) \pm 0.34(sys.)) \times 10^{-3}$

PDG2010: $(1.68\pm0.22)\times10^{-3}$ (1984: GAM2)
Preliminary results on N* baryon in $\psi' \rightarrow \eta p \bar{p}$ decay

BESIII Preliminary Dalitz plot data

Dalitz plot MC fit

A full PWA is performed.
Background clean!

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

Mass: $1.524^{+0.005+0.010}_{-0.005-0.004}$ GeV/C$^2$

Width: $0.130^{+0.027+0.061}_{-0.027-0.014}$ GeV

Br($\psi' \rightarrow pp\eta$) = $(6.6\pm0.2\pm0.6) \times 10^{-5}$

PDG2010: $(6.0\pm1.2) \times 10^{-5}$

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

- Huge data samples collected for charmonium decays at BESIII. A lot of results have been obtained,
  - The spin-parity of the $p \bar{p}$ mass threshold enhancement in $J/\psi \rightarrow \gamma p \bar{p}$ was first determined as $0^{-+}$
  - Confirmation of $X(1835)$ in $J/\psi \rightarrow \gamma \eta \pi^+ \pi^-$ and observation of two new structures $X(2120)$ and $X(2370)$ in $J/\psi \rightarrow \gamma \pi \pi \eta'$ decays
  - Observation of new structure $X(1870)$ in $J/\psi \rightarrow \omega \pi \pi \eta$
  - $N^*$ in $\psi' \rightarrow \eta p \bar{p}$
- We expect rich physics results in the coming years from BESIII.
many thanks for your attention!