Baryon Spectroscopy at BESIII

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on behalf of the BESIII Collaboration

BARYONS 2016
International Conference on the Structure of Baryons
Tallahassee, Florida, USA
May 16-20, 2016
• All ground baryonic states are well established
  ➢ Good agreement between experimental data and quark model

• The excited spectrum is much less clear
  ➢ Many more states predicted than observed

• Insight to hadron structure

Up to 2.5 GEV:
45 N states predicted
15 established
10 tentative

Missing Resonances

- Many of the predicted resonances were not observed experimentally
- Experimental and theoretical efforts

- Experimentally:
  baryon resonances may couple very weakly to single pions
- Theoretically:
  the baryon spectrum can be modeled with fewer effective
degrees of freedom (quark-diquark or Ψ/Δ-type models)

Relativistic quark model

Δ-resonance spectrum

Potential model: A

EPJ A10, 395-446 (2001)
Missing Resonances

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- Experimental and theoretical efforts

- Experimentally:
  baryon resonances may couple very weakly to single pions

- Theoretically:
  the baryon spectrum can be modeled with fewer effective degrees of freedom (quark-diquark or Υ/Δ-type models)

Lattice QCD

Δ and N spectrum

\( m_\pi = 396 \text{ MeV} \)

Phys Rev D84, 074508 (2011)
BESIII: Baryon Production

- Charmonium decays offer complementary information to existing data
- Coupling of unobserved states through conventional production channels could be small, but coupling may be large to $gggN$: $\psi \rightarrow N\bar{N} (\pi/\eta/\eta'/\omega/\phi), \bar{p}\Sigma\pi, \bar{p}\Lambda K$
- High statistics available at BESIII

From PDG

- $1.3 \times 10^9$ MeV
- $5 \times 10^8 \psi(2S)$
- $3773$ MeV
- $2.9$ fb$^{-1}$
- $4040$ MeV
- $0.5$ fb$^{-1}$
- $4600$ MeV
- $0.5$ fb$^{-1}$
- $4360$ MeV
- $2.3$ fb$^{-1}$
- R scan $1.3$ fb$^{-1}$

BEPCII can reach here!
 Beam energy:  
1.0-2.3 GeV

 Design Luminosity:  
$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

 Achieved Luminosity:  
$\sim 1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

 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
The BESIII Spectrometer @ IHEP

BEijing Spectrometer III

e^+e^- collisions

\( \sqrt{S} \) tuned depending on energy

Physics program

- Charmonium Physics
- D-Physics
- Light Hadron Spectroscopy
- \( \tau \)-Physics
- ...

ψ(3686) \rightarrow \bar{p}K^+\Sigma^0 \text{ and } \chi_{cJ} \rightarrow \bar{p}K^+\Lambda

- ψ(3686) \rightarrow \bar{p}K^+\Sigma^0: \text{ first measurement}
- \chi_{cJ} \rightarrow \bar{p}K^+\Lambda: \text{ BR improvement}
- \chi_{c0} \rightarrow \bar{p}K^+\Lambda: \text{ anomalous enhancement close to threshold}
- Possible reasons:
  - quasi bound dibaryon state
  - final state interactions
  - interference of high mass N* and Λ* states
$\psi(3686) \rightarrow \Lambda \bar{\Sigma}^{\pm}\pi^{\mp}$

- BR first measurements:
  $B(\psi(3686) \rightarrow \Lambda \bar{\Sigma}^{+}\pi^{-} + cc) = (1.40 \pm 0.03 \pm 0.13) \times 10^{-4}$
  $B(\psi(3686) \rightarrow \Lambda \bar{\Sigma}^{-}\pi^{+} + cc) = (1.54 \pm 0.04 \pm 0.13) \times 10^{-4}$

- PWA used to determine detection efficiency
  - Includes 16 possible intermediate excited states with at least two stars according to the PDG, with parameters fixed to world averages
\( \psi(3686) \rightarrow (\gamma)K^\pm \Lambda \Xi^\pm \)
Intermediate state
N(1535) \rightarrow p\eta is dominant

No evidence for a p\bar{p} resonance, indicating that the threshold enhancement in previous results may be explained by interference between the N(1535) and phase space

Mass and width of N(1535)
- \( M = 1524 \pm 5^{+10}_{-4} \text{ MeV/c}^2 \)
- \( \Gamma = 130^{+27+57}_{-24-10} \text{ MeV/c}^2 \)

PDG value:
- \( M = 1525 \text{ to } 1545 \text{ MeV/c}^2 \)
- \( \Gamma = 125 \text{ to } 175 \text{ MeV/c}^2 \)

\[
B(\psi(2S) \rightarrow N(1535)\bar{p}) \times B(N(1535) \rightarrow p\eta) = \frac{N_{\text{obs}}}{\varepsilon \cdot N_{\psi(2S)} \cdot B(\eta \rightarrow \gamma\gamma)} = (5.2 \pm 0.3^{+3.2}_{-1.2}) \times 10^{-5}
\]

\[
Q_{p\bar{p}\eta} = \frac{B(\psi(2S) \rightarrow p\bar{p}\eta)}{B(J/\psi \rightarrow p\bar{p}\eta)} = (3.2 \pm 0.4)\%
\]
\[ \psi(3686) \rightarrow p\bar{p}\pi^0 \]

- In photon or meson beam studies, isospin 1/2 and 3/2 resonances are excited, complicating the analysis
- \( \Delta \) resonances suppressed in charmonium decays to \( p\bar{p}\pi^0 \), giving a cleaner spectrum
  - Thought to be dominated by two body decays involving \( N^* \) intermediate states
  - Also consider \( p\bar{p} \) resonances (\( \psi(3686) \rightarrow R\pi^0 \))
- Seven \( N^* \) states observed in partial wave analysis
  - Two new resonances, \( N(2300) \) with \( J^P = 1/2^+ \) and \( N(2570) \) with \( J^P = 5/2^- \)
  - Other five consistent with previous results

<table>
<thead>
<tr>
<th>Resonance</th>
<th>( M(\text{MeV}/c^2) )</th>
<th>( \Gamma(\text{MeV}/c^2) )</th>
<th>( \Delta S )</th>
<th>( \Delta N_{\text{dof}} )</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N(1440) )</td>
<td>( 1390^{+14+21}_{-21-30} )</td>
<td>( 340^{+46+70}_{-40-156} )</td>
<td>72.5</td>
<td>4</td>
<td>11.5( \sigma )</td>
</tr>
<tr>
<td>( N(1520) )</td>
<td>( 1510^{+3+11}_{-7-9} )</td>
<td>( 115^{+20+0}_{-15-40} )</td>
<td>19.8</td>
<td>6</td>
<td>5.0( \sigma )</td>
</tr>
<tr>
<td>( N(1535) )</td>
<td>( 1535^{+9+15}_{-8-22} )</td>
<td>( 120^{+20+0}_{-20-42} )</td>
<td>49.4</td>
<td>4</td>
<td>9.3( \sigma )</td>
</tr>
<tr>
<td>( N(1650) )</td>
<td>( 1650^{+5+11}_{-5-30} )</td>
<td>( 150^{+21+14}_{-22-50} )</td>
<td>82.1</td>
<td>4</td>
<td>12.2( \sigma )</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>9.6( \sigma )</td>
</tr>
<tr>
<td>( N(2300) )</td>
<td>( 2300^{+10+109}_{-30-30} )</td>
<td>( 340^{+30+110}_{-30-58} )</td>
<td>120.7</td>
<td>4</td>
<td>15.0( \sigma )</td>
</tr>
<tr>
<td>( N(2570) )</td>
<td>( 2570^{+19+34}_{-10-10} )</td>
<td>( 250^{+14+69}_{-24-21} )</td>
<td>78.9</td>
<td>6</td>
<td>11.7( \sigma )</td>
</tr>
</tbody>
</table>

PRL 110, 022001 (2013)
ψ(3686) \rightarrow p\bar{p}a_0(980)

- First observation of \( J/\psi \rightarrow p\bar{p}a_0(980), a_0(980) \rightarrow \pi^0\eta \)
- Applies a chiral unitary coupled channel approach
  - Four-body decays \( J/\psi \rightarrow NNMM \)
  - \( a_0(980) \) generated through Final State Interactions
  - Provides useful information on dynamics of four-body FSI processes

\[ \text{Br}(J/\psi \rightarrow p\bar{p}a_0(980) \rightarrow p\bar{p}\pi^0\eta) \]
\[ = (6.8 \pm 1.2 \pm 1.3) \times 10^{-5} \]
$J/\psi(\psi(3686)) \rightarrow \Xi^-\Xi^+$ and $\Sigma(1385)^+\Sigma(1385)^-$

- First observation of $\psi(3686)$ into $\Sigma(1835)$ states
- Single tag method
- BR and angular distribution investigations
- Most precise measurements available

$\Xi^-\Xi^+$  $\Sigma(1385)^-\Sigma(1385)^+$  $\Sigma(1385)^+\Sigma(1385)^-$
$J/\psi(\psi(3686)) \rightarrow \Xi^-\bar{\Xi}^+ \text{ and } \Sigma(1385)^-\bar{\Sigma}(1385)^+$

12% rule

$\Xi^-\bar{\Xi}^+$  $\Sigma(1385)^-\bar{\Sigma}(1385)^+$  $\Sigma(1385)^+\bar{\Sigma}(1385)^-$

26.73%  7.76%  6.68%

Branching Ratios

<table>
<thead>
<tr>
<th>Mode</th>
<th>$J/\psi \rightarrow$</th>
<th>$\psi(3686) \rightarrow$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Xi^-\bar{\Xi}^+$</td>
<td>$\Sigma(1385)^-\bar{\Sigma}(1385)^+$</td>
</tr>
<tr>
<td>This work</td>
<td>10.40 ± 0.06 ± 0.74</td>
<td>10.96 ± 0.12 ± 0.71</td>
</tr>
<tr>
<td>MarkI [5]</td>
<td>14.00 ± 5.00</td>
<td>...</td>
</tr>
<tr>
<td>MarkII [6]</td>
<td>11.40 ± 0.80 ± 2.00</td>
<td>8.60 ± 1.80 ± 2.20</td>
</tr>
<tr>
<td>DM2 [7]</td>
<td>7.00 ± 0.60 ± 1.20</td>
<td>10.00 ± 0.40 ± 2.10</td>
</tr>
<tr>
<td>BESII [8,12]</td>
<td>9.00 ± 0.30 ± 1.80</td>
<td>12.30 ± 0.70 ± 3.00</td>
</tr>
<tr>
<td>CLEO [9]</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>BESI [26]</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>PDG [3]</td>
<td>8.50 ± 1.60</td>
<td>10.30 ± 1.30</td>
</tr>
</tbody>
</table>

Angular distributions

<table>
<thead>
<tr>
<th>Mode</th>
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<th>$\psi(3686) \rightarrow$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\Xi^-\bar{\Xi}^+$</td>
<td>$\Sigma(1385)^-\bar{\Sigma}(1385)^+$</td>
</tr>
<tr>
<td>This work</td>
<td>0.58 ± 0.04 ± 0.08</td>
<td>−0.58 ± 0.05 ± 0.09</td>
</tr>
<tr>
<td>BESII [8]</td>
<td>0.35 ± 0.29 ± 0.06</td>
<td>−0.54 ± 0.22 ± 0.10</td>
</tr>
<tr>
<td>MarkIII [6]</td>
<td>0.13 ± 0.55</td>
<td>...</td>
</tr>
<tr>
<td>Claudson et al. [10]</td>
<td>0.16</td>
<td>0.11</td>
</tr>
<tr>
<td>Carimalo [11]</td>
<td>0.27</td>
<td>0.20</td>
</tr>
</tbody>
</table>
Summary

• BESIII collected $0.5 \times 10^9 \psi(3686)$ and $1.3 \times 10^9 J/\psi$ events

• Overview of our recent measurements

• Charmonium decays as powerful tool to investigate excited nucleons and hyperons
  - Discover new states
  - Provide complementary information to other experiments

• Stay tuned for new results!!