Baryonic spectroscopy at BESIII

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Status of BEPCII/BESIII

Baryonic spectroscopy

- Two hyperons in $\psi(3686) \rightarrow K^- \Lambda \Xi^+$
- Two new baryonic excited states in $\psi(3686) \rightarrow p \bar{p}\pi^0$
- $N(1535)$ in $\psi(3686) \rightarrow p \bar{p}\eta$
- Excited strange baryons in $\psi(3686) \rightarrow \Lambda \bar{\Sigma}^+\pi^-$

Summary and perspective
The BEPCII Collider

BEMS (beam energy measurement system): based on Compton backscattering

Beam energy: 1.0 - 2.3 GeV
Peak Luminosity: achieved: $0.85 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}@3770 \text{ MeV}$
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 detector

**Solenoid Magnet**: 1 T Super conducting

**MDC**: small cell & He gas
- $\sigma_{xy} = 130 \mu m$
- $\delta p/p = 0.5\%$ @1GeV
- $dE/dx = 6\%$

**TOF**:
- $\sigma_T = 90$ ps
- **Barrel**: 110 ps
- **Endcap**: 110 ps

**EMCAL**: CsI crystal
- $\Delta E/E = 2.5\%$ @1 GeV
- $\sigma_{\varphi,z} = 0.5$~0.7 cm/$\sqrt{E}$

**Data Acquisition**:
- Event rate = 3 kHz
- Throughput ~ 50 MB/s

**Muon ID**: 8~9 layer RPC
- $\sigma_{R\Phi} = 1.4$ cm~1.7 cm

**Trigger**: Tracks & Showers
- Pipelined; Latency = 6.4 $\mu$s

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.
The established baryons are described to 3-quark (qqq) configurations

Non-relativistic quark model is successful in interpreting of the excited baryons

Also provides an explicit classification for light baryons in terms of group symmetry

Predicts more excited stated and the number of observed baryons is significantly small (“miss resonance problem”)

Are the states missing because our models do not capture the correct degrees of freedom?

Or have the resonances simply escaped detection?
High statistics of charmonium @BESIII provide an opportunity to study the baryon
Baryon spectroscopy

JLab, ELSA, MAMI, ESRF, Spring-8, ....

Not only N*, but also Λ*, Σ*, Ξ* @ BESIII

J/ψ(ψ') → B̅B̅M → N*, Λ*, Σ*, Ξ*

N', N, Λ, Σ...

N, Λ, Σ...

M (π, η, ω, φ, ρ, K ...)

γ

✓ Pure isospin 1/2 filter → easier analysis
✓ Missing N* with small couplings to πN & γN, but large coupling to gggN: ψ → N̅Nπ/η/η'/ω/φ, ρΣπ, ρΛK ...
✓ Interference between N* and N*bar bands in ψ → N̅Nπ Dalitz plots may help to distinguish some ambiguities in PWA of πN

Not only N*, but also Λ*, Σ*, Ξ* @ BESIII

Charmonium decays can give novel insights into baryons and give complementary information to other experiments
Observation of two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686) \rightarrow K^-\Lambda \Xi^+ + c.c.$

- Two hyperons $\Xi^-(1690)$ and $\Xi^-(1820)$ are observed in $\psi(3686) \rightarrow K^-\Lambda \Xi^+ + c.c.$
- Resonance parameters consist with PDG

Data sample: $106 \times 10^6 \psi'$

arXiv:1504.02025 is accepted by PRD

<table>
<thead>
<tr>
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<th>$\Xi(1690)^-$</th>
<th>$\Xi(1820)^-$</th>
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<tbody>
<tr>
<td>$M$ (MeV/c$^2$)</td>
<td>1687.7±3.8±1.0</td>
<td>1826.7±5.5±1.6</td>
</tr>
<tr>
<td>$\Gamma$ (MeV)</td>
<td>27.1±10.0±2.7</td>
<td>54.4±15.7±4.2</td>
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<tr>
<td>Event yields</td>
<td>74.4±21.2</td>
<td>136.2±33.4</td>
</tr>
<tr>
<td>Significance(σ)</td>
<td>4.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Efficiency(%)</td>
<td>32.8</td>
<td>26.1</td>
</tr>
<tr>
<td>$B \times 10^{-6}$</td>
<td>5.21±1.48±0.57</td>
<td>12.03±2.94±1.22</td>
</tr>
<tr>
<td>$M_{PDG}$ (MeV/c$^2$)</td>
<td>1690±10</td>
<td>1823±5</td>
</tr>
<tr>
<td>$\Gamma_{PDG}$ (MeV)</td>
<td>&lt;30</td>
<td>24$^{+15}_{-10}$</td>
</tr>
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Observation of two hyperons $\Xi^{-}(1690)$ and $\Xi^{-}(1820)$ in $\psi(3686) \rightarrow K^{-}\Lambda\bar{\Xi}^{+} + c.c.$

$B(\psi(3686) \rightarrow K^{-}\Lambda\bar{\Xi}^{+} + c.c.) = (3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$

Measurement of the branching fraction for the first time
Measurement of $\psi(3686) \rightarrow \gamma K^- \Lambda$ $\Xi^+$+c.c.

Measurement of the branching fractions of $\psi(3686) \rightarrow K^- \Sigma^0$ $\Xi^+$+c.c. and
$\psi(3686) \rightarrow \gamma \chi_{cJ} \rightarrow \gamma K^- \Lambda$ $\Xi^+$+c.c. (J=0,1,2) for the first time

arXiv:1504.02025
Observation of two new baryonic excited states in $\psi(3686) \rightarrow p \bar{p} \pi^0$

2-body decay:
$\psi(2S) \rightarrow X\pi^0, X \rightarrow p\bar{p}$
$\psi(2S) \rightarrow p\bar{N}^*, \bar{N}^* \rightarrow \bar{p}\pi^0 + c.c.$

isospin conservation
$\Delta$ suppressed

$M^2(p\pi^0)$

$M(p\bar{p})$
Observation of two new baryonic excited states $N(2300)$ and $N(2570)$ in $\psi(3686) \rightarrow p\bar{p}\pi^0$

- Five well known $N^*$ are measured
- Two new baryonic excited states $N(2300) (1/2^+)$ and $N(2570) (5/2^-)$ are observed!
- The $pp\bar{p}$ threshold enhancement most likely is due to interference of $N^*$ intermediate resonance
Observation of $N(1535)$ in $\psi(3686) \rightarrow p \bar{p} \eta$

data sample: $106 \times 10^6 \psi'$
Observation of $N(1535)$ in $\psi(3686) \rightarrow p \bar{p} \eta$

For $N(1535)$ with its mass close to the threshold of its dominant decay channel $N\eta$, the approximation of a constant width is not very good. Thus, a phase-space-dependent width for $N(1535)$ is also used

$$BW(s) = \frac{1}{M_{N^*}^2 - s - iM_{N^*}\Gamma_{N^*}(s)}.$$ 

The phase-space-dependent widths can be written as

$$\Gamma_{N^*}(s) = \Gamma_{N^*}^0 \left(0.5 \frac{\rho_{N\pi}(s)}{\rho_{N\pi}(M_{N^*}^2)} + 0.5 \frac{\rho_{N\eta}(s)}{\rho_{N\eta}(M_{N^*}^2)} \right),$$

where $\rho_{N\pi}$ and $\rho_{N\eta}$ are the phase space factors for the $N\pi$ and $N\eta$ final states, respectively,

$$\rho_{NX}(s) = \frac{2q_{NX}(s)}{\sqrt{s}} = \frac{\sqrt{(s - (M_N + M_X)^2)(s - (M_N - M_X)^2)}}{s}.$$
Observation of N(1535) in \( \psi(3686) \rightarrow p \bar{p} \eta \)

- N(1535) and PHSP(1/2-) are dominant
- No evidence for a ppbar resonance

**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:**
- \( M = 1525 \) to 1545 MeV/c^2
- \( \Gamma = 125 \) to 175 MeV/c^2

**Branching fraction:**
\[ B(\psi' \rightarrow N(1535)p) \times B(N(1535) \rightarrow p\eta) + \text{c.c.} \]
\[ = (5.2 \pm 0.3^{+3.2}_{-1.2} \times 10^{-5}) \]

Explained by interference between N(1535) and phase space
Observation of excited strange baryons \( \Lambda^* \) and \( \Sigma^* \) in \( \psi(3686) \rightarrow \Lambda \overline{\Sigma}^+ \pi^- + \text{c.c.} \).

Branching fractions are measured for the first time.

\[
\mathcal{B}(\psi(3686) \rightarrow \Lambda \overline{\Sigma}^+ \pi^- + \text{c.c.}) = (1.40 \pm 0.03 \pm 0.13) \times 10^{-4}
\]

\[
\mathcal{B}(\psi(3686) \rightarrow \Lambda \overline{\Sigma}^- \pi^+ + \text{c.c.}) = (1.54 \pm 0.04 \pm 0.13) \times 10^{-4}
\]

Excited strange baryons around 1.5 to 1.7 GeV/c^2 are observed.

Data sample: \( 106 \times 10^6 \psi' \).
BESIII collected $0.5 \times 10^9 \psi(2S)$ and $1.3 \times 10^9 J/\psi$ events.

Many baryonic states are presented:

- $\Xi^-(1690)$ and $\Xi^-(1820)$ in $\psi(3686) \rightarrow K^-\Lambda \ \Xi^+ + \text{c.c.}$
- Baryon excited states $N(2300)$ and $N(2570)$ in $\psi(3686) \rightarrow p \ \bar{p} \ \pi^0$
- $N(1535)$ in $\psi(3686) \rightarrow p \ \bar{p} \eta$
- Excited strange baryons $\Lambda^*$ and $\Sigma^*$ in $\psi(3686) \rightarrow \Lambda \ \bar{\Sigma}^+ \pi^- + \text{c.c.}$

Charmonium decays have proven to be a good lab for studying not only excited nucleon states, but also excited hyperons.

provide complementary information to other experiment

Expect more results from BESIII.
Back up
Are the states missing in the predicted spectrum because our models do not capture the correct degrees of freedom?

1, 3 quarks
2, quarks and flux tubes
3, quark-diquark
4, multi quarks

\[ N_{\text{predicted}}: N_4 > N_2 > N_1 > N_3, \quad N_{\text{observed}} \ll N_1 \]

Or have the resonances simply escaped detection?

Nearly all existing data result from \( \pi N \) experiments
Observation of two new baryon excited states $N(2300)$ and $N(2570)$ in $\psi(3686) \rightarrow p \bar{p} \pi^0$

Selection of $p \bar{p} \pi^0$

- Proton and anti-proton are identified
- using $dE/dx$ and TOF information

$$Pt > 300 MeV/c^2$$
$$|\cos(\theta)| < 0.8 \quad (\text{for } p, \bar{p})$$

- 4C-kinematic fit:

$$\chi^2_{4C}(\gamma\gamma p\bar{p}) < 20$$

- $$|M_{\gamma\gamma} - M_{\pi^0}| < 15 MeV/c^2$$
- $$|M_{p\bar{p}} - M_{J/\psi}| > 0.04 GeV/c^2$$

Two vertical bands: $\psi' \rightarrow \pi^0 p\bar{p}, \eta p\bar{p}$
Horizontal band: $\psi' \rightarrow X + J/\psi, J/\psi \rightarrow p\bar{p}$
Measurement of $\psi(3686) \rightarrow K^- \Lambda \bar{\Xi}^+ +\text{C.C.}$

$\psi(3686) \rightarrow K^- \Lambda \bar{\Xi}^+ +\text{C.C.}$

$\Lambda \rightarrow p \pi^-$

$\bar{\Xi}^+ \rightarrow \bar{\Lambda} \pi^+, \bar{\Lambda} \rightarrow \bar{p} \pi^+$
N(940) into virtual proton + pi0

are also considered. According to the framework of soft $\pi$ meson theory [22], the off-shell decay process is needed in this channel. Thus, $N(940)$ with a mass of 940 MeV/$c^2$ and zero width is included. The $N(940)$ represents a virtual proton, which could emit a $\pi^0$. The Feynman diagram of this process can be found in Ref. [15].


In summary, we studied the intermediate resonances, including their masses, widths, and spin parities, in the decay $\psi(3686) \rightarrow p\bar{p}\pi^0$. Two new $N^*$ resonances are observed, in addition to five well-known $N^*$ resonances. The masses and widths as well as the spin parities of the two new $N^*$ states have been measured. The branching fractions of $\psi(3686) \rightarrow p\bar{p}\pi^0$ and the product branching fractions through each intermediate $N^*$ state are measured. No clear evidence for $N(1885)$ or $N(2065)$ has been found. The hypothetical $p\bar{p}$ resonance has a significance of less than $4\sigma$, indicating that the threshold enhancement most likely is due to interference of $N^*$ intermediate resonances.