MENU 2007
11th International Conference
on Meson-Nucleon Physics and
the Structure of the Nucleon
September10-14, 2007
IKP, Forschungzentrum Jülich, Germany

BARYON RESONANCES OBSERVED AT BES

B. S. Zou
Institute of High Energy Physics, Chinese Academy of Sciences,
P.O.Box 918(4), Beijing 100049, China

Abstract

The ψ decays provide a novel way to explore baryon spectroscopy and baryon structure. The baryon resonances observed from ψ decays at BES are reviewed. The implications and prospects at upgraded BESIII/BEPCII are discussed.

1 Introduction

Although the quark model achieved significant successes in the interpretation of a lot of static properties of nucleons and the excited resonances, our present knowledge on baryon spectroscopy is still in its infancy [1]. Many fundamental issues in baryon spectroscopy are still not well understood [2].

On theoretical side, an unsolved fundamental problem is: what are proper effective degrees of freedom for describing the internal structure of baryons? Several pictures based on various effective degrees of freedom are shown in Fig.1.

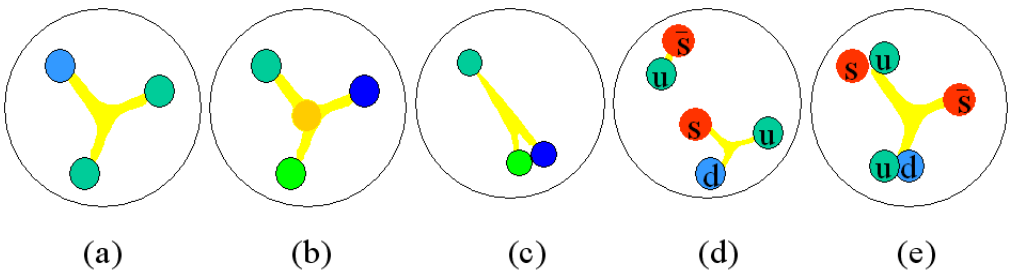

Figure 1: Various pictures for internal quark-gluon structure of baryons: (a) $3q$, (b) $3qg$ hybrid, (c) diquark, d) meson-baryon state, (e) pentaquark with diquark clusters.

The classical simple 3q constituent quark model as shown by Fig.1(a) has been very successful in explaining the static properties, such as mass and magnetic moment, of the spatial ground states of the flavor SU(3) octet and decuplet baryons. Its predicted Ω baryon with mass around 1670 MeV was discovered by later experiments. However its predictions for the spatial excited baryons are not so successful. In the simple 3q constituent quark model, the lowest spatial excited baryon is expected to be a (uud) N^* state with one quark in orbital angular momentum $L = 1$ state, and hence should have negative parity. Experimentally [1], the lowest negative parity N^* resonance is found to be $N^*(1535)$, which is heavier than two other spatial excited baryons : $\Lambda^*(1405)$ and $N^*(1440)$. In the classical 3q constituent quark model, the $\Lambda^*(1405)$ with spin-parity $1/2^-$ is supposed to be a (uds) baryon with one quark in orbital angular momentum $L = 1$ state and about 130 MeV heavier than its N^* partner $N^*(1535)$; the $N^*(1440)$ with spin-parity $1/2^+$ is supposed to be a (uud) state with one quark in radial $n = 1$ excited state and should be heavier than the $L = 1$ excited (uud) state $N^*(1535)$, noting the fact that for a simple harmonic oscillator potential the state energy is $(2n + L + 3/2)\hbar\omega$. So for these three lowest spatial excited baryons, the classical quark model picture is already failed.

The second outstanding problem in the classical 3q quark model is that in many of its forms it predicts a substantial number of 'missing N^* states' around 2 GeV/c^2, which have not so far been observed [2]. Since the more number of effective degrees of freedom the more predicted number of excited states, the 'missing N^* states' problem is argued in favor of the diquark picture as shown in Fig.1(c) which has less degree of freedom and predicts less N^* states [3]. For example, in diquark models, the two quarks forming the diquark are constrained to be in the relative S-wave, and hence cannot combine the third quark to form $(20,1_2^+)$-multiplet baryons. Experimentally, not a single $(20,1_2^+)$-multiplet baryon has been identified yet [1]. However, non-observation of these 'missing N^* states' does not necessarily mean that they do not exist. In the limit that the γ or π couples to one quark in the nucleon in the γN or πN reactions, the $(20,1_2^+)$-multiplet baryon cannot be produced [4]. Considering higher order effects, they may have weak coupling to πN and γN, but maybe too weak to be produced by presently available πN and γN experiments [2, 4]. Other production processes should be explored. Moreover the diquark models are only successful for very limited aspects.

The third outstanding problem for the classical 3q quark model is that from deep inelastic scattering and Drell-Yan experiments the number of $\overline{d}$ is found to be more than the number of $\overline{u}$ by 0.12 in the proton [5]. This is argued in favor of a mixture of the meson-baryon states as shown by Fig.1(d). With this picture, the excess of $\overline{d}$ over $\overline{u}$ in the proton is explained by a

mixture of $n\pi^+$ with the π^+ composed of $u\overline{d}$ [6]; the $N^*(1535)$ and $\Lambda^*(1405)$ are ascribed as quasi-bound states of $K\Sigma$ and $\overline{K}N$, respectively [7]. The extreme of this picture is that only the ground state baryon-octet $1/2^+$ and baryon-decuplet $3/2^+$ are dominated by qqq while all excited baryons are generated by meson-baryon coupled channel dynamics [8, 9]. However the mixture of the pentaquark components with diquark clusters as shown by Fig.1(e) can also explain these properties [10–13].

Another possible configuration for baryons is $gqqq$ hybrid as shown by Fig.1(b) with various phenomenological models reviewed by Ref. [14].

In reality for a baryon state around 2 GeV, it could be a mixture of all five configurations shown in Fig.1.

On experimental side, our present knowledge of baryon spectroscopy came almost entirely from partial-wave analyses of πN total, elastic, and charge-exchange scattering data of more than twenty years ago [1]. Only recently, the new generation of experiments on N^* physics with electromagnetic probes at CEBAF at JLAB, ELSA at Bonn, GRAAL at Grenoble and SPRING8 at JASRI have been producing some nice results. However, a problem for these experiments is that above 1.8 GeV there are too many broad resonances with various possible quantum numbers overlapping with each other and it is rather difficult to disentangle them. Moreover resonances with weak couplings to πN and γN will not show up in these experiments.

Joining the new effort on studying the excited nucleons, N^* baryons, BES started a baryon resonance program [15] at Beijing Electron-Positron Collider (BEPC). The J/ψ and ψ' experiments at BES provide an excellent place for studying excited nucleons and hyperons – N^*, Λ^*, Σ^* and Ξ^* resonances [16].

Comparing with other facilities, our baryon program has advantages in at least three obvious aspects:

(1) We have pure isospin 1/2 πN and $\pi\pi N$ systems from $J/\psi \to \overline{N}N\pi$ and $\overline{N}N\pi\pi$ processes due to isospin conservation, while πN and $\pi\pi N$ systems from πN and γN experiments are mixture of isospin 1/2 and 3/2, and suffer difficulty on the isospin decomposition;

(2) ψ mesons decay to baryon-antibaryon pairs through three or more gluons. It is a favorable place for producing hybrid (qqqg) baryons, and for looking for some "missing" N^* resonances, such as members of possible $(20,1_2^+)$-multiplet baryons, which have weak coupling to both πN and γN, but stronger coupling to g^3N;

(3) Not only N^*, Λ^*, Σ^* baryons, but also Ξ^* baryons with two strange quarks can be studied. Many QCD-inspired models [2] are expected to be more reliable for baryons with two strange quarks due to their heavier quark mass. More than thirty Ξ^* resonances are predicted where only two such states are well established by experiments. The theory is totally not chal-

lenged due to lack of data.

In this paper, we review baryon resonances observed by BESI and BESII, and discuss the prospects for baryon spectroscopy at BESIII.

2 Baryon Spectroscopy at BESI and BESII

BESI started data-taking in 1989 and collected 7.8 million J/ψ events and 3.7 million ψ' events. BESII has collected 58 million J/ψ events and 14 million ψ' events since 1998.

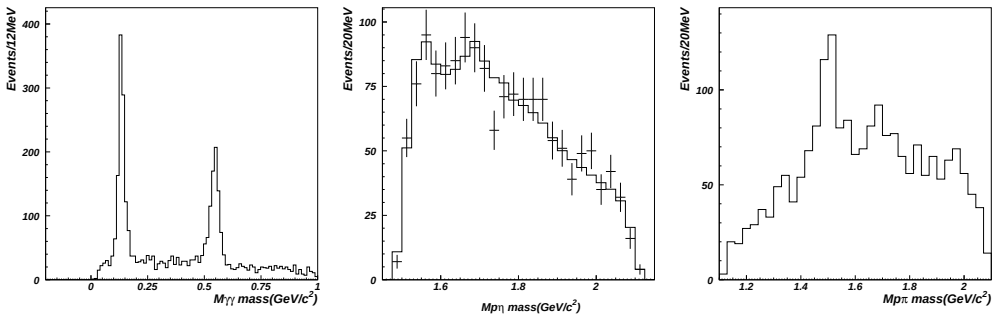

Figure 2: BESI data for $\gamma\gamma$ invariant mass of $J/\psi \to \overline{p}p\gamma\gamma$ (left); $p\eta$ (middle) and $p\pi$ (right) invariant mass spectra of $J/\psi \to \overline{p}p\eta$ and $\overline{p}p\pi^0$.

Based on 7.8 million J/ψ events collected at BESI from 1990 to 1991, the events for $J/\psi \to \overline{p}p\pi^0$ and $\overline{p}p\eta$ have been selected and reconstructed with π^0 and η detected in their $\gamma\gamma$ decay mode [15]. The invariant mass of $\gamma\gamma$ is shown in Fig. 2 (left) with two clear peaks corresponding to π^0 and η. The $p\eta$ invariant mass spectrum is shown in Fig. 2 (middle) with two peaks at 1540 and 1650 MeV. Partial wave analysis has been performed for the $J/\psi \to \overline{p}p\eta$ channel [15] using the effective Lagrangian approach [17,18] with Rarita-Schwinger formalism [19–22] and the extended automatic Feynman Diagram Calculation (FDC) package [23]. There is a definite requirement for a $J^P = \frac{1}{2}^-$ component at $M = 1530 \pm 10$ MeV with $\Gamma = 95 \pm 25$ MeV near the ηN threshold. In addition, there is an obvious resonance around 1650 MeV with $J^P = \frac{1}{2}^-$ preferred, $M = 1647 \pm 20$ MeV and $\Gamma = 145^{+80}_{-45}$ MeV. These two N^* resonances are believed to be the two well established states, $S_{11}(1535)$ and $S_{11}(1650)$, respectively. In the higher $p\eta(\overline{p}\eta)$ mass region, there is an evidence for a structure around 1800 MeV; with BESI statistics one cannot determine its quantum numbers. The $p\pi^0$ invariant

mass spectrum from $J/\psi \to p\overline{p}\pi^0$ is shown in Fig. 2 (right) with two clear peaks around 1500 and 1670 MeV, and some weak structure around 2 GeV.

With 58 million new J/ψ events collected by BESII of improved detecting efficiency, one order of magnitude more reconstructed events can be obtained for each channel. Results for J/ψ to $p\overline{n}\pi^- + c.c.$, $pK^-\overline{\Lambda} + c.c.$ and $\Lambda\overline{\Sigma}\pi$+c.c. channels are shown in Figs.3,4,5, respectively. These are typical channels for studying N^*, Λ^* and Σ^* resonances. For $J/\psi \to p\overline{p}\pi^0$ channel, the $N\pi$ invariant mass spectrum looks similar to the BESI data, but with much higher statistics.

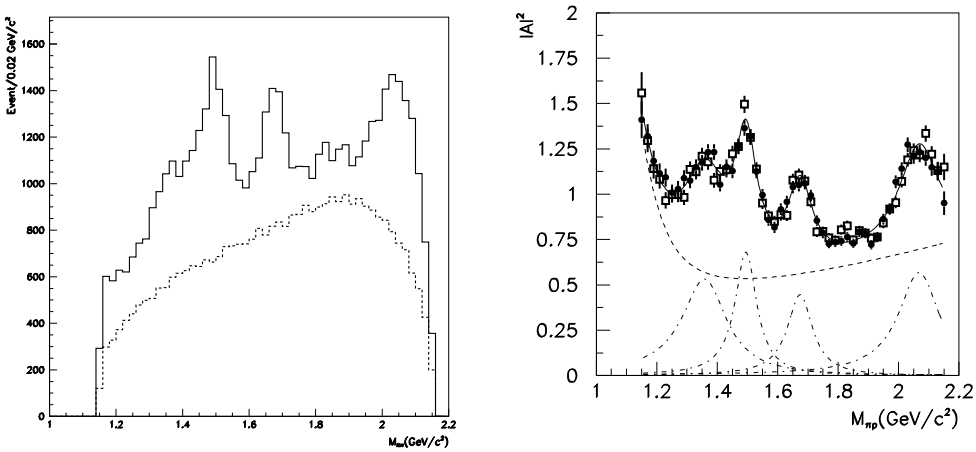

Figure 3: $p\pi^-$ invariant mass spectrum for $J/\psi \to p\pi^-\overline{n}$ compared with phase space distribution (left); And data divided by MC phase space vs $p\pi$ invariant mass for $J/\psi \to \overline{p}\pi^-\overline{n}$ (solid circle) and $\overline{p}\pi^+n$ (open square).

For $J/\psi \to p\overline{n}\pi^-$ channel, proton and π^- are detected [24]. With some cuts of backgrounds, the missing mass spectrum shows a very clean peak for the missing antineutron. In the $p\pi^-$ invariant mass spectrum as shown in Fig.3 (left), besides two well known N^* peaks at 1500 and 1670 MeV, there are two new clear N^* peaks around 1360 and 2030 MeV. Its charge conjugate channel $\overline{p}\pi^+n$ gives very similar results.

To investigate the behavior of the amplitude squared as a function of invariant mass, one should remove the phase space factor and efficiency factor from the invariant mass distribution by dividing the data by Monte Carlo phase space times the detection efficiency. The results are shown in Fig. 3 (right). At low $p\pi$ invariant mass, the tail from nucleon pole term, expected from theoretical considerations [25,26], is clearly seen. There are clearly four peaks around 1360 MeV, 1500 MeV, 1670 MeV and 2065 MeV. Note that the well known first resonance peak ($\Delta(1232)$) in πN and γN scattering data does not show up here due to the isospin filter effect of our J/ψ decay. While

the two peaks around 1500 MeV and 1670 MeV correspond to the well known second and third resonance peaks observed in πN and γN scattering data, the two peaks around 1360 MeV and 2065 MeV have never been observed in πN invariant mass spectra before. The one around 1360 MeV should be from $N^*(1440)$ MeV which has a pole around 1360 MeV [1,27,28] and which is usually buried by the strong Δ peak in πN and γN experiments; the other one around 2065 MeV may be due to the long sought "missing" N^* resonance(s). For the decay $J/\psi \to \overline{N}N^*(2065)$, the orbital angular momentum of $L = 0$ is much preferred due to the suppression of the centrifugal barrier factor for $L \geq 1$. For $L = 0$, the spin-parity of $N^*(2065)$ is limited to be 1/2+ and 3/2+. This may be the reason that the $N^*(2065)$ shows up as a peak in J/ψ decays while only much broader structures show up for πN invariant mass spectra above 2 GeV in πN and γN production processes [29] which allow all 1/2±, 3/2±, 5/2± and 7/2± N^* resonances around 2.05 GeV to overlap and interfere with each other there. A simple Breit-Wigner fit [24] gives the mass and width for the $N^*(1440)$ peak as $1358 \pm 6 \pm 16$ MeV and $179 \pm 26 \pm 50$ MeV. Very recently, CELSIUS-WASA Collaboration [30] also observed the $N^*(1440)$ peak in the $n\pi^+$ invariant mass spectrum for their $pp \to pn\pi^+$ reaction and obtained mass and width consistent with ours. For the new N^* peak above 2 GeV the fitted mass and width are $2068 \pm 3^{+15}_{-40}$ MeV and $165 \pm 14 \pm 40$ MeV, respectively. A partial wave analysis indicates that the $N^*(2065)$ peak contains both spin-parity 1/2+ and 3/2+ components [24].

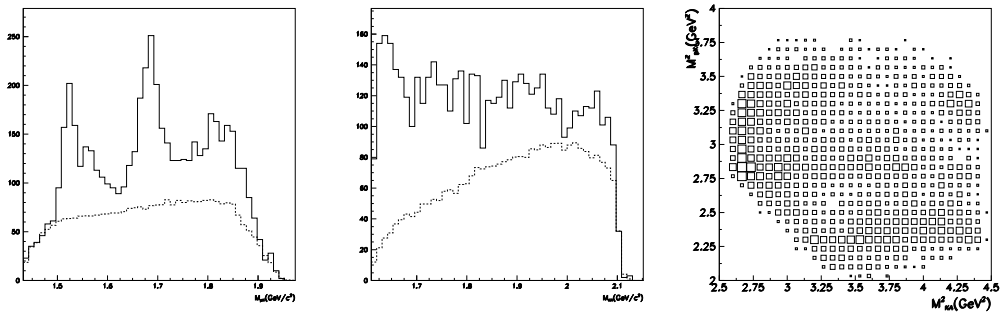

Figure 4: pK (left) and $K\Lambda$ (middle) invariant mass spectra for $J/\psi \to pK^-\overline{\Lambda}$+c.c., compared with phase space distribution; right: Dalitz plot for $J/\psi \to pK^-\overline{\Lambda}$+c.c.

For $J/\psi \to pK^-\overline{\Lambda}$ and $\overline{p}K^+\Lambda$ channels [31], there are clear Λ^* peaks at 1.52 GeV, 1.69 GeV and 1.8 GeV in pK invariant mass spectrum, and N^* peaks near $K\Lambda$ threshold, 1.9 GeV and 2.05 GeV for $K\Lambda$ invariant mass spectrum. The N^* peak near $K\Lambda$ threshold is most probably due to $N^*(1535)$

which was found to have large coupling to $K\Lambda$ [9, 12]. The SAPHIR experiment at ELSA [32] also observed a N^* peak around 1.9 GeV for $K\Lambda$ invariant mass spectrum from photo-production, and the fit [33] to the data reveals large $1/2^-$ near-threshold enhancement mainly due to the $N^*(1535)$. The N^* peak at 2.05 GeV is compatible with that observed in $N\overline{N}\pi$ channels.

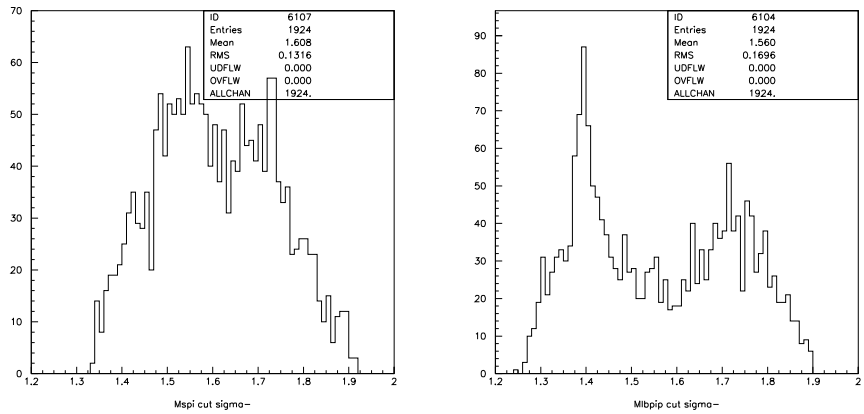

Figure 5: $\overline{\Sigma}\pi$ (left) and $\Lambda\pi$ (right) invariant mass spectrum for $J/\psi \to \Lambda\overline{\Sigma}^+\pi^-$. Preliminary BESII data [34]

For $J/\psi \to \Lambda\Sigma\pi$ channels [34], it seems also Λ^* peaks at 1.52 GeV, 1.69 GeV and 1.8 GeV in $\Sigma\pi$ invariant mass spectra, similar to those in the $pK\Lambda$ channel, although less clear. In $\Lambda\pi$ invariant mass spectra, there is a very clear peak around 1.385 GeV corresponding to the well-established $\Sigma(1385)$ resonance and there is also another Σ^* peak around 1.72 GeV.

In order to get more useful information about properties of the baryon resonances involved, such as their J^{PC} quantum numbers, mass, width, production and decay rates, etc., partial wave analysis (PWA) is necessary. We use event-based standard maximum likelihood method with partial wave amplitudes constructed by the effective Lagrangian approach [17, 18] with Rarita-Schwinger formalism [19–22].

3 Baryon spectroscopy Prospects at BESIII

Recently, empirical indications for a positive strangeness magnetic moment and positive strangeness radius of the proton suggest that the 5-quark components in baryons may be largely in colored diquark cluster configurations rather than mainly in "meson cloud" configurations [10, 11]. The diquark

cluster picture also gives a natural explanation for the excess of $\overline{d}$ over $\overline{u}$ in the proton with a mixture of $[ud][ud]\overline{d}$ component in the proton. More precise measurements and analyses of the strange form factors are needed to examine the relative importance of the meson-cloud components and $q^2q^2\overline{q}$ components in the proton.

For excited baryons, the excitation energy for a spatial excitation could be larger than to drag out a $q\overline{q}$ pair from gluon field with the q to form diquark cluster with a valence quark. Hence the 5-quark components could be dominant for some excited baryons.

The diquark cluster picture for the 5-quark components in baryons also gives a natural explanation for the longstanding mass-reverse problem of $N^*(1535)$, $N^*(1440)$ and $\Lambda^*(1405)$ resonances as well as the unusual decay pattern of the $N^*(1535)$ resonance with a large $|[ud][us]\overline{s}>$ component [10, 12].

The diquark cluster picture predicts the existence of the SU(3) partners of the $N^*(1535)$ and $\Lambda^*(1405)$, *i.e.*, an additional Λ^* $1/2^-$ around 1570 MeV, a triplet Σ^* $1/2^-$ around 1360 MeV and a doublet Ξ^* $1/2^-$ around 1520 MeV [13]. There is indeed evidence for all of them in the data of J/ψ decays at BES. Fig. 4 (left) shows the pK invariant mass spectrum for $J/\psi \to pK^-\overline{\Lambda}$+c.c. and Fig. 5 (right) $\Lambda\pi$ invariant mass spectrum for $J/\psi \to \Lambda\overline{\Sigma}^+\pi^-$ from BES [34]. In the pK invariant mass spectrum, under the narrow $\Lambda^*(1520)$ $3/2^-$ peak, there is a quite obvious broader peak around 1570 MeV. Preliminary partial wave analysis [35] gave its spin-parity as $1/2^-$. This $\Lambda^*(1570)$ $1/2^-$ resonance fits in the new scheme for the $1/2^-$ SU(3) baryon nonet very well. In the $\Lambda\pi$ invariant mass spectrum, under the $\Sigma^*(1385)$ $3/2^+$ peak, there is also a broader peak around 1360 MeV. No partial wave analysis has been performed for this channel yet. But there is a good reason to reckon that there may be $1/2^-$ component underneath the $\Sigma^*(1385)$ $3/2^+$ peak.

According to PDG [1], the branching ratios for $J/\psi \to \overline{\Sigma}^-\Sigma^*(1385)^+$ and $J/\psi \to \overline{\Xi}^+\Xi^*(1530)^-$ are $(3.1 \pm 0.5) \times 10^{-4}$ and $(5.9 \pm 1.5) \times 10^{-4}$, respectively. These two processes are SU(3) breaking decays since Σ and Ξ belong to SU(3) $1/2^+$ octet while $\Sigma^*(1385)$ and $\Xi^*(1530)$ belong to SU(3) $3/2^+$ decuplet. Comparing with the similar SU(3) breaking decay $J/\psi \to \overline{p}\Delta^+$ with branching ratio of less than 1×10^{-4} and the SU(3) conserved decay $J/\psi \to \overline{p}N^*(1535)^+$ with branching ratio of $(10 \pm 3) \times 10^{-4}$, the branching ratios for $J/\psi \to \overline{\Sigma}^-\Sigma^*(1385)^+$ and $J/\psi \to \overline{\Xi}^+\Xi^*(1530)^-$ are puzzling too high. A possible explanation for this puzzling phenomena is that there were substantial components of $1/2^-$ under the $3/2^+$ peaks but the two branching ratios were obtained by assuming pure $3/2^+$ contribution. This possibility

should be easily checked with the high statistics BESIII data in near future.

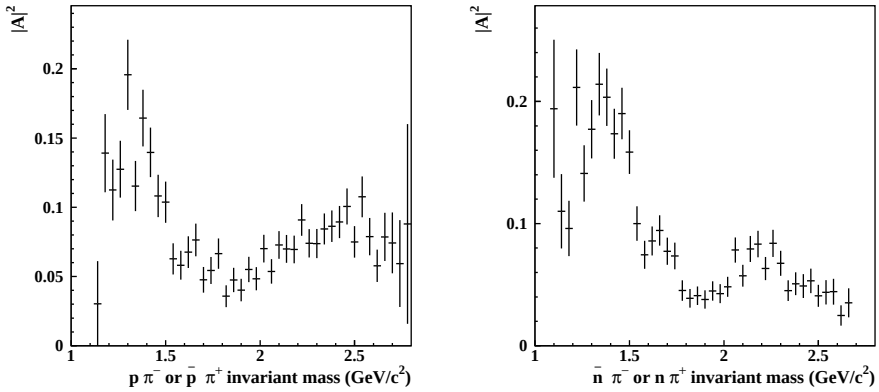

Figure 6: Data divided by efficiency and phase space vs $p\pi^-$ (or $\overline{p}\pi^+$) and $\overline{n}\pi^-$ (or $n\pi^+$) invariant mass for $\psi' \to p\overline{n}\pi^- + c.c.$ candidate events [36].

With two order of magnitude more statistics at BESIII, plenty important channels for baryon spectroscopy can be studied from both J/ψ and ψ' decays. The ψ' data will significantly extend the mass range for the study of baryon spectroscopy. For example, for $\psi' \to p\overline{n}\pi^- + c.c.$ events collected at BESII [36], there are obvious structures for $M_{N\pi} > 2$ GeV in the $N\pi$ invariant mass spectra as shown in Fig. 6. However due to low statistics at BESII, no conclusive information can be drawn for the N^* resonances with mass above 2 GeV from ψ' decays [36, 37]. With BESIII statistics, determination of properties for these high mass N^* resonances can be done. The BESIII ψ' data will enable us to complete the Λ^*, Σ^* and Ξ^* spectrum and examine various pictures for their internal structures, such as simple 3q quark structure and more complicated structure with pentaquark components dominated.

Table 1: Measured J/ψ decay branching ratios (BR$\times 10^3$) for channels involving baryon anti-baryon and meson(s) [1, 24]

$p\overline{n}\pi^-$	$p\overline{p}\pi^0$	$p\overline{p}\pi^+\pi^-$	$p\overline{p}\eta$	$p\overline{p}\eta'$	$p\overline{p}\omega$
2.4 ± 0.2	1.1 ± 0.1	6.0 ± 0.5	2.1 ± 0.2	0.9 ± 0.4	1.3 ± 0.3
$\Lambda\overline{\Sigma}^-\pi^+$	$pK^-\overline{\Lambda}$	$pK^-\overline{\Sigma}^0$	$\overline{p}p\phi$	$\Delta(1232)^{++}\overline{p}\pi^-$	$pK^-\overline{\Sigma}(1385)^0$
1.1 ± 0.1	0.9 ± 0.2	0.3 ± 0.1	0.045 ± 0.015	1.6 ± 0.5	0.51 ± 0.32

The measured J/ψ decay branching ratios for channels involving baryon anti-baryon plus meson(s) are listed in Table 1. With 10^{10} J/ψ events, all

these channels will get enough statistics for partial wave analysis. Among these channels, the $\Sigma\overline{\Lambda}\pi + c.c.$ channels should have high priority for pinning down the lowest $1/2^-$ Σ^* and Λ^* as well as other higher excited Σ^* and Λ^* states. Another very important channel is $K^-\Lambda\overline{\Xi}^+ + c.c.$ which is the best channel for finding the lowest $1/2^-$ Ξ^* resonance and many other "missing" Ξ^* states with $\Xi^* \to K\Lambda$. This channel should be rather easy to be reconstructed by BESIII. One can select events containing K^- and Λ with $\Lambda \to p\pi^-$, then from missing mass spectrum of $K^-\Lambda$ one should easily identify the very narrow $\overline{\Xi}^+$ peak.

For 10^9 ψ' events, the $K^-\Lambda\overline{\Xi}^+ + c.c.$ and $p\overline{p}\phi$ channels should have high priority. These two channels are strongly limited by phase space in J/ψ decays. From ψ' decays, the phase space is much increased. The $K^-\Lambda\overline{\Xi}^+ + c.c.$ channel should allow us to discover many "missing" Ξ^* resonances, while the $p\overline{p}\phi$ channel should allow us to find those N^* resonances with large coupling to $N\phi$ [39] and hence large 5-quark components.

After analyzing the easier 3-body final states, 4-body and 5-body channels should also be investigated. Among them, $\Delta(1232)^{++}\overline{p}\pi^-$ in $p\overline{p}\pi^+\pi^-$ and $\Delta(1232)^{++}\overline{\Sigma}^-K^-$ in $p\overline{\Sigma}^-\pi^+K^-$ are very good channels for finding "missing" $\overline{\Delta}^{*--}$ decaying to $\overline{p}\pi^-$ and $\overline{\Sigma}^-K^-$, respectively. The spectrum of isospin $3/2$ Δ^{++*} resonances is of special interest since it is the most experimentally accessible system composed of 3 identical valence quarks. Recently, the lowest $1/2^-$ baryon decuplet is proposed to contain large vector-meson-baryon molecular components [40]. In the new scheme, the $\Xi^*(1950)$ is predicted to be $1/2-$ resonance with large coupling to ΛK^*. The $\psi' \to \overline{\Xi}\Lambda K^*$ will provide a very good place to look for "missing" Ξ^* with large coupling to ΛK^*.

In summary, BESIII data can play a very important role in studying excited nucleons and hyperons, i.e., N^*, Λ^*, Σ^*, Ξ^* and Δ^{*++} resonances.

References

[1] Particle Data Group, *Phys. Rev.* **D66**, 010001 (2002).

[2] S.Capstick and W.Robert, *Prog. Part. Nucl. Phys.* **45**, S241 (2000), and references therein.

[3] K.F.Liu and C.W.Wong, *Phys. Rev.* **D28** (1983) 170; M.Anselmino et al., Rev. Mod. Phys. **65**, 1199 (1993).

[4] Q.Zhao and F.E.Close, Phys. Rev. **D74**, 094014 (2006).

[5] G.T.Garvey, J.C.Peng, Prog. Part. Nucl. Phys. 47 (2001) 203, and references therein.

[6] J.P.Speth and A.W.Thomas, Adv. Nucl. Phys. 24 (1997) 93, and references therein.

[7] N.Kaiser et al., Phys. Lett. **B362**, 23 (1995); Nucl. Phys. **A612**, 297 (1997).

[8] M.F.M.Lutz and E.E.Kolomeitsev, Nucl. Phys. **A700**, 193 (2002); ibid. **A730**, 392 (2004).

[9] E.Oset et al., *Int. J. Mod. Phys.* **A18**, 387 (2003); Phys. Lett. **B527**, 99 (2002); L. Roca et al., Phys. Rev. **C73**, 045 (2006).

[10] B.S.Zou, Nucl. Phys. bf A790, 110c (2007) and reference therein.

[11] B. S. Zou and D. O. Riska, Phys. Rev. Lett. 95 (1005) 072001; C. S. An, B. S. Zou and D. O. Riska, Phys. Rev. C73 (2006) 035207.

[12] B.C. Liu and B.S. Zou, Phys. Rev. Lett. **96**, 042002 (2006); ibid. **98**, 039102 (2007).

[13] A.Zhang et al., High Energy Phys. Nucl. Phys. **29**, 250 (2005).

[14] T.Barnes, in *Juelich 2000, Baryon excitations* 121-131, and reference therein; P.Page, Int. J. Mod. Phys. **A20**, 1791 (2005).

[15] BES Collaboration, Phys. Lett. **B510**, 75 (2001); H.B.Li et al. (BES), Nucl. Phys. **A675**, 189c (2000); B.S.Zou et al. (BES), *Excited Nucleons and Hadronic Structure, Proc. of NSTAR2000 Conf. at JLab, Feb 2000.* Eds. V.Burkert et al., World Scientific (2001) p.155.

[16] B.S.Zou, Nucl. Phys. **A684**, 330 (2001); Nucl. Phys. **A675**, 167 (2000).

[17] M.Benmerrouche, N.C.Mukhopadhyay and J.F.Zhang, Phys. Rev. Lett. 77, 4716 (1996); Phys. Rev. D51, 3237 (1995).

[18] M.G.Olsson and E.T.Osypowski, Nucl. Phys. B87, 399 (1975); Phys. Rev. D17, 174 (1978); M.G.Olsson et al., *ibid.* 17, 2938 (1978).

[19] W.Rarita and J.Schwinger, Phys. Rev. **60**, 61 (1941).

[20] C.Fronsdal, Nuovo Cimento Suppl. **9**, 416 (1958); R.E.Behrends and C.Fronsdal, Phys. Rev. **106**, 345 (1957).

[21] S.U.Chung, *Spin Formalisms*, CERN Yellow Report 71-8 (1971); Phys. Rev. **D48**, 1225 (1993); J.J.Zhu and T.N.Ruan, Communi. Theor. Phys. **32**, 293, 435 (1999).

[22] W.H.Liang, P.N.Shen, J.X.Wang and B.S.Zou, J. Phys. **G28** (2002) 333.

[23] J.X.Wang, Comput. Phys. Commun. **77**, 263 (1993).

[24] BES Collaboration, Phys. Rev. Lett. 97 (2006) 062001.

[25] R. Sinha and S. Okubo, Phys. Rev. D30 (1984) 2333.

[26] W.H.Liang, P.N.Shen, B.S.Zou and A.Faessler, Euro. Phys. J. A21 (2004) 487.

[27] R.A. Arndt et al., Phys.Rev.C69, 035213 (2004); M.Manley, talk at NSTAR2004, Grenoble, March 2004.

[28] T.P.Vrana, S.A.Dytman and T.S.H.Lee, Phys. Rep. 328 (2000) 181.

[29] L.Y.Zhu et al., Phys. Rev. Lett 91 (2003) 022003.

[30] H.Clement et al. (CELSIUS-WASA Collaboration), nucl-ex/0612015.

[31] H.X.Yang et al., (BES Collaboration), Int. J. Mod. Phys. A20 (2005) 1985; BES Collaboration, Phys. Rev. Lett. 93 (2004) 112002.

[32] K.H.Glander et al., Euro. Phys. J. **A19**, 251 (2004); R.Lawall et al., Euro. Phys. J. **A24**, 275 (2005).

[33] G.Penner and U.Mosel, Phys. Rev. **C66**, 055211 (2002); ibid. **C66**, 055212 (2002); V.Shklyar, H.Lenske and U.Mosel, Phys. Rev. **C72**, 015210 (2005); B.Julia-Diaz et al., Phys. Rev. **C73**, 055204 (2006).

[34] B.S.Zou (for BES), *Proc. of NSTAR2004, Grenoble, France.* Eds. J.P.Bocquet et al., World Scientific (2004) p.271.

[35] H.X.Yang, IHEP Ph.D thesis (2001).

[36] BES Collaboration, Phys.Rev. D74 (2006) 012004.

[37] BES Collaboration, Phys.Rev. D71 (2005) 072006.

[38] S. Capstick and N. Isgur, Phys. Rev. D34 (1986) 2809.

[39] F.Huang, Z.Y.Zhang and Y.W.Yu, Phys. Rev. **C73**, 025207 (2006); J.J.Xie, B.S.Zou and H.C.Chiang, arXiv:0705.3950 [nucl-th].

[40] J.J.Xie and B.S.Zou, Phys. Lett. **B649** (2007) 405.