Partial wave analysis of $J/\psi \to p\bar{p}\pi^0$ and measurement of $J/\psi \to p\bar{p}\eta, p\bar{p}\eta'$ *

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Abstract Based on 58 million J/ψ data collected with the BESⅡ detector at the BEPC, Partial Wave Analysis(PWA) is performed on $J/\psi \to p\bar{p}\pi^0$. The new excited baryon N(2065) is confirmed. Clear signals for other N* states are observed and the corresponding masses, widths and spin-parity are also measured. Processes such as $J/\psi \to p\bar{p}\eta, p\bar{p}\eta'$ are also studied and the branching ratios are measured.

Key words J/ψ Decays, PWA, Excited Baryon states, N(2065)

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1 Introduction

Nucleons are the basic building blocks of our world and the simplest system in which the three colors of QCD neutralize into colorless objects and the essential nonabelian character of QCD is manifest. The understanding of the internal quark-gluon structure of baryons is one of the most important tasks in both particle and nuclear physics. The systematic study of the baryon spectroscopy, various production and decay rates will provide us important information in understanding the nature of QCD in the confinement domain.

The J/ψ decays provide us a good laboratory for studying excited baryon states, excited hyperons and so on...So we try to search for those "missing baryons" which have been predicted by theory but not observed by experiment, study the masses, widths and spin-parity of those not well established states.

The upgraded Beijing Spectrometer(BESⅡ[1]) detector, is a large solid-angle magnetic spectrometer. There are total of 58 million J/ψ data has been collected for physics analysis. BESII has reported a "new" excited states as N(2065)[2] with mass equals $2065\pm3^{+15}_{-30}$ MeV, width equals $175\pm12\pm40$ MeV, the spin-parity is $\frac{1}{2}^+$ or $\frac{3}{2}^+$. The analysis of $J/\psi \to p\bar{p}\pi^0$, $J/\psi \to p\bar{p}\eta$, $p\bar{p}\eta'$ is reported here. PWA is performed on $J/\psi \to p\bar{p}\pi^0$. The new excited baryon N(2065) is confirmed. Clear signals for other N* states are observed and the corresponding masses, widths and spin-parity are also measured. In $J/\psi \to p\bar{p}\eta$ and $p\bar{p}\eta'$, there are obvious excited states and the branching ratios are also measured.

2 PWA of $J/\psi \to p\bar{p}\pi^0$

There are clear peaks for π^0 and η (Fig. 1). Only those events under π^0 peak is analysised, and the background is estimated with side-band method. Fig. 2 shows the invariant mass spectra of $mp\pi^0$, $m\bar{p}\pi^0$. Clear N* bumps are seen at around 1.5 GeV and 1.7 GeV of the $p\pi^0$ mass region. The Dalitz plot

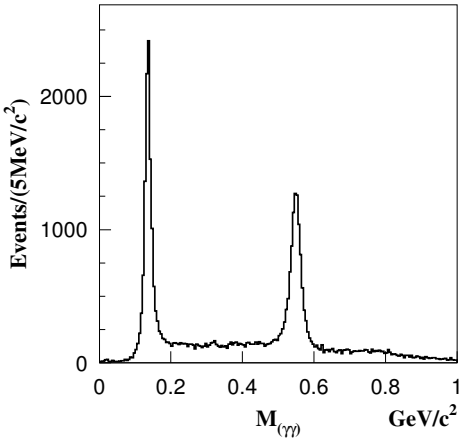

Fig. 1. Invariant mass spectrum of γγ, where are clear peaks for π^0 and η.

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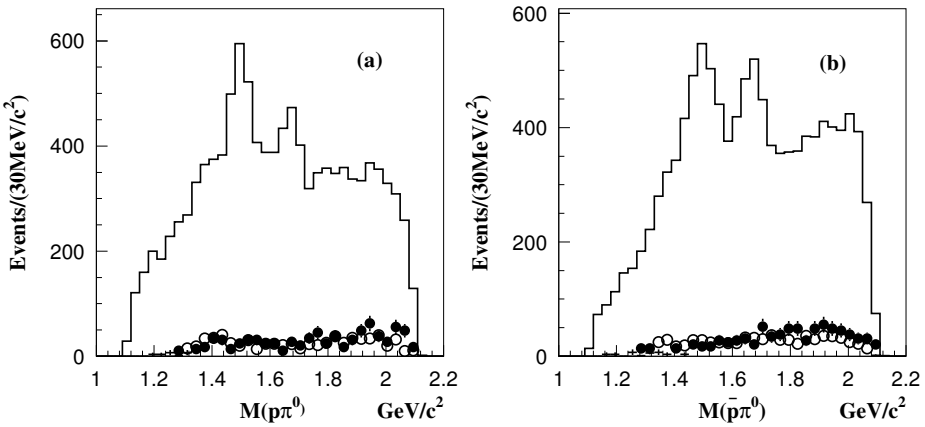

Fig. 2. Invariant mass spectrum of (a) $p\pi^0$, (b) $\bar{p}\pi^0$ in $J/\psi \to p\bar{p}\pi^0$, where the circles are invariant mass spectrum from π^0 sideband, and black dots are the background estimated from $J/\psi \to p\bar{p}\pi^0\pi^0$.

of this decay is shown in Fig. 3 and some N* bands are also present obviously.

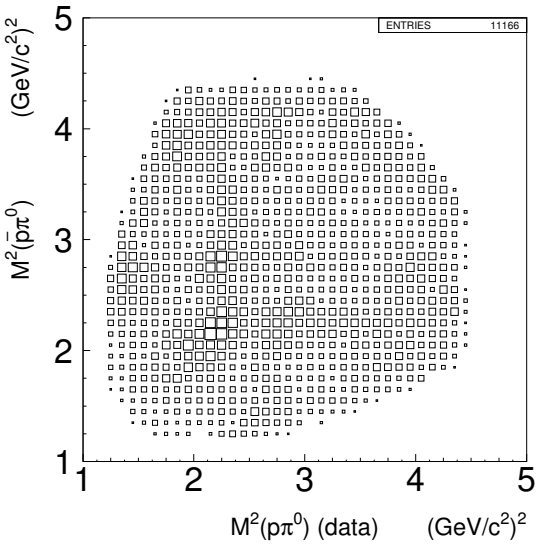

Fig. 3. Dalitz plot of $J/\psi \to p\bar{p}\pi^0$. There are clear bands and clusters for excited baryon states.

2.1 Intermediate resonances

The intermediate resonances considered in the PWA are listed in Table 1 with the masses, widths, spin-parities fixed to be their Particle Data Group values[3]. Among these states, only a few of them are (well) established states. N(1885) is one of the 'missing' N* states predicted by quark model and has not been observed experimentally yet. N(2065) is also a 'missing' N* observed recently by BES II [2]. As introduced in the framework of soft π meson theory[4], the off-shell decay process is needed in this decay mode. Therefore, N(940) (M = 940 MeV, $\cdots$ = 0.0 MeV) is used in this analysis.

In fact, some of these resonances which have low significance or less contribution to the total process can be ignored in PWA. After careful analysis of each states, only those marked with ▲ are included in the final fit.

2.2 Partial wave analysis result

Figure 4 shows comparison between the PWA reuslt and the data distribution. The fitting result agrees with the data distribution pretty well. PWA result shows that N(2065) has a mass as $2040^{+3}_{-4} \pm 25$ MeV and width as 230±8±52 MeV. The spin-parity favors $\frac{3}{2}^+$, and it has a high significance($\gg 5\sigma$s). Table 2 shows the masses, widths, spin-parity, fractions and branching ratios for some resonances.

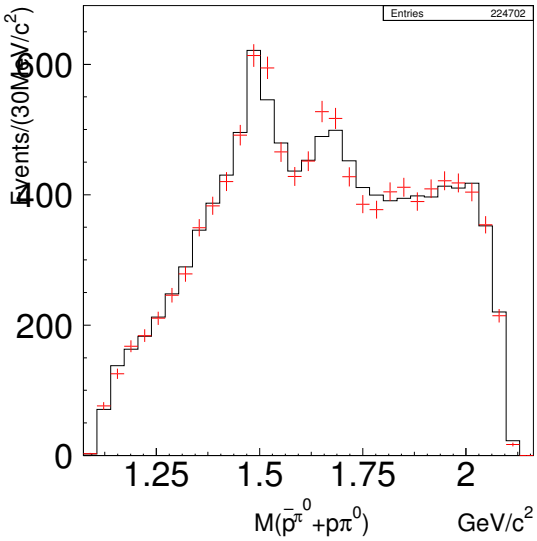

Fig. 4. The invariant mass spectrum of $M_{p\pi^0}$ and $M_{\bar{p}\pi^0}$ in the final fit. The crosses are real data and histograms are fit results.

Table 1. Resonances considered in the partial wave analysis.

resonance	mass/MeV	width/MeV	J^P	C.L.
▲N(940)	940	0	$\frac{1}{2}^+$	off-shell
▲N(1440)	1440	350	$\frac{1}{2}^+$	****
▲N(1520)	1520	125	$\frac{3}{2}^-$	****
▲N(1535)	1535	150	$\frac{1}{2}^-$	****
▲N(1650)	1650	150	$\frac{1}{2}^-$	****
▲N(1675)	1675	145	$\frac{5}{2}^-$	****
▲N(1680)	1680	130	$\frac{5}{2}^+$	****
N(1700)	1700	100	$\frac{3}{2}^-$	***
▲N(1710)	1710	100	$\frac{1}{2}^+$	***
N(1720)	1720	150	$\frac{3}{2}^+$	****
N(1885)	1885	160	$\frac{3}{2}^-$	'missing' N*
N(1900)	1900	498	$\frac{3}{2}^+$	**
N(2000)	2000	300	$\frac{5}{2}^+$	**
▲N(2065)	2065	150	$\frac{3}{2}^+$	'missing' N*
▲N(2080)	2080	270	$\frac{3}{2}^-$	**
N(2090)	2090	300	$\frac{1}{2}^-$	*
▲N(2100)	2100	260	$\frac{1}{2}^+$	*

**** Existence is certain, and properties are at least fairly well explored.

*** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers,branching fractions, etc. are not well determined.

** Evidence of existence is only fair.

* Evidence of existence is poor.

2.3 Branching ratio

The π^0 signal is fitted with a histogram of π^0 shape obtained from $J/\psi \to p\bar{p}\pi^0$ MC simulation. The total number of signal is 11166. 100K $J/\psi \to p\bar{p}\pi^0$ MC events including the intermediate excited states are generated to estimate the detection efficiency and the result is 13.77%. Finally , the branching ratio of $J/\psi \to p\bar{p}\pi^0$ is determined to be $(1.33 \pm 0.02 \pm 0.11) \times 10^{-3}$.

Table 2. Masses and widths optimized results.

resonance	mass/MeV	width/MeV	J^P	fraction(%)
N(1440)	1455^{+2}_{-7}	316^{+5}_{-6}	$\frac{1}{2}^+$	16.37
N(1520)	1513^{+3}_{-4}	127^{+7}_{-8}	$\frac{3}{2}^-$	7.96
N(1535)	1537^{+2}_{-6}	135^{+8}_{-8}	$\frac{1}{2}^-$	7.58
N(1650)	1650^{+3}_{-6}	145^{+5}_{-10}	$\frac{1}{2}^-$	9.06
N(1710)	1715^{+2}_{-2}	95^{+2}_{-1}	$\frac{1}{2}^+$	25.33
N(2065)	2040^{+3}_{-4}	230^{+8}_{-8}	$\frac{3}{2}^+$	23.39

3 Measurement of $J/\psi \to p\bar{p}\eta, p\bar{p}\eta'$

In this analysis, the decay modes such as $\eta \to \gamma\gamma$, $\eta \to \pi^+\pi^-\pi^0$, $\eta' \to \eta\pi^+\pi^-$ and $\eta' \to \gamma\rho$ are included. Fig. 5 shows clear signals in the invariant mass spectrum of $\gamma\gamma$ and $\pi^+\pi^-\pi^0$ in $J/\psi \to p\bar{p}\eta$ process. There are also peaks in the invariant mass spectrum of $\eta\pi^+\pi^-$ and $\gamma\rho$ in $J/\psi \to p\bar{p}\eta'$ process in Fig. 6. The signals of η and η' are fitted and the numbers of η is 12220±149 for $\gamma\gamma$ process and 954±45 for $\pi^+\pi^-\pi^0$. The number of η' is 65 ± 12 for $\pi^+\pi^-\eta$ process and 200 ± 29 for $\gamma\rho$. Then branching ratios are obtained as listed in Table 3. We also try to find excited states int both processes. Fig. 7 shows the invariant mass spectrum of $p\bar{p}$, $p\eta$, $\bar{p}\eta$ and dalitz plot of $J/\psi \to p\bar{p}\eta$. They differ much to the expected phase space distribution, that means intermediate states in the process. For $J/\psi \to p\bar{p}\eta'$ process, there seems to be some resonances in the invariant mass spectrum, but there are not enough events to make sure the existence (Fig. 8).

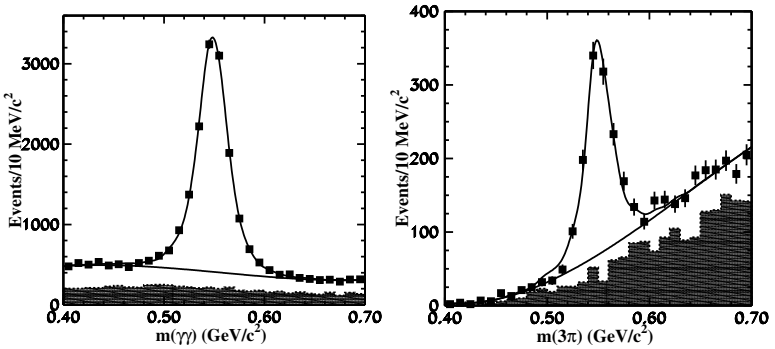

Fig. 5. Signals of η in the invariant mass spectrum of $\gamma\gamma$ and $\pi^+\pi^-\pi^0$.

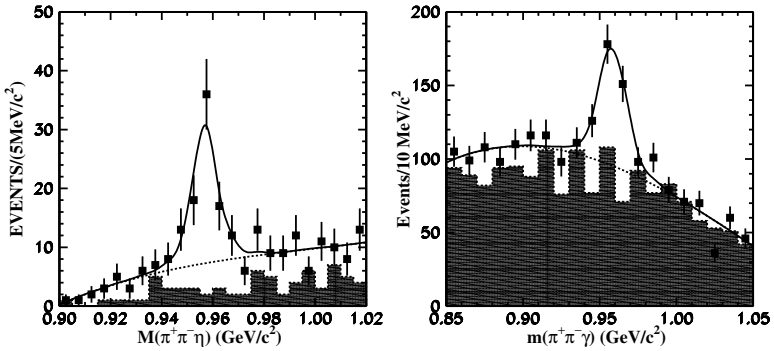

Fig. 6. Signals of η' in the invariant mass spectrum of $\pi^+\pi^-\eta$ and $\gamma\rho$.

Table 3. Branching ratios of $J/\psi \to p\bar{p}\eta$ and $J/\psi \to p\bar{p}\eta'$.

decay modes	$Br(10^{-4})$(PDG)	$Br(10^{-4})$
$J/\psi \to p\bar{p}\eta(\eta \to \gamma\gamma)$	20.9 ± 1.8	$19.2\pm0.2\pm1.8$
$J/\psi \to p\bar{p}\eta(\eta \to \pi^+\pi^-\pi^0)$	20.9 ± 1.8	$18.3\pm0.9\pm2.4$
$J/\psi \to p\bar{p}\eta'(\eta' \to \pi^+\pi^-\eta)$	9 ± 4	$2.3\pm0.4\pm0.4$
$J/\psi \to p\bar{p}\eta'(\eta' \to \gamma\rho)$	9 ± 4	$1.9\pm0.3\pm0.3$

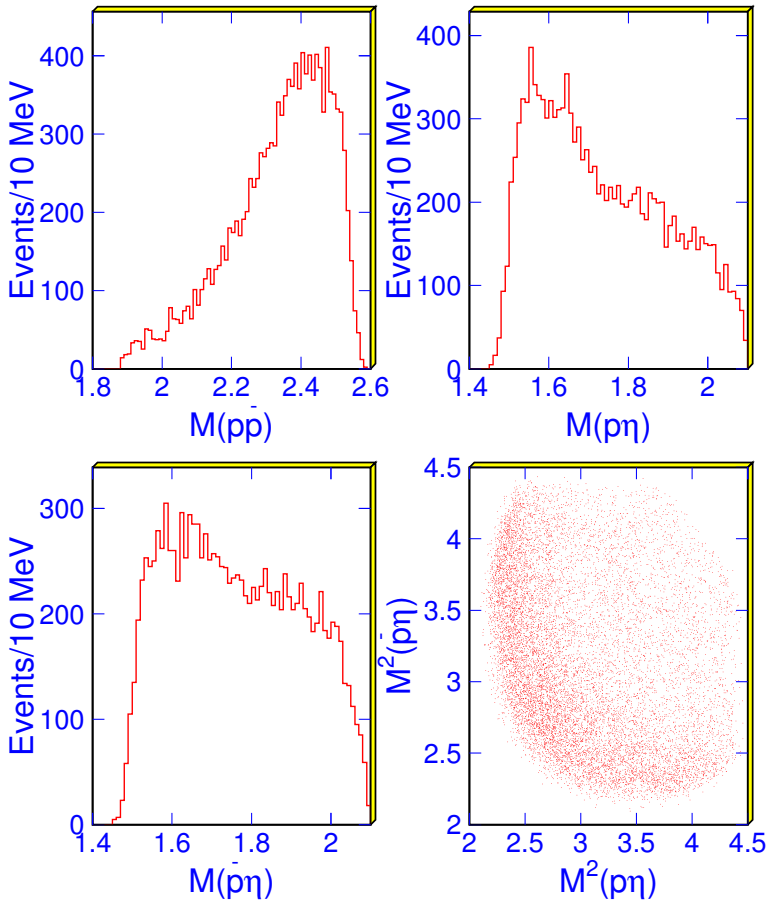

Fig. 7. Invariant mass spectrum of $p\bar{p}$, $p\eta$, $\bar{p}\eta$ and dalitz plot for $J/\psi \to p\bar{p}\eta$. There are obvious structures for excited states.

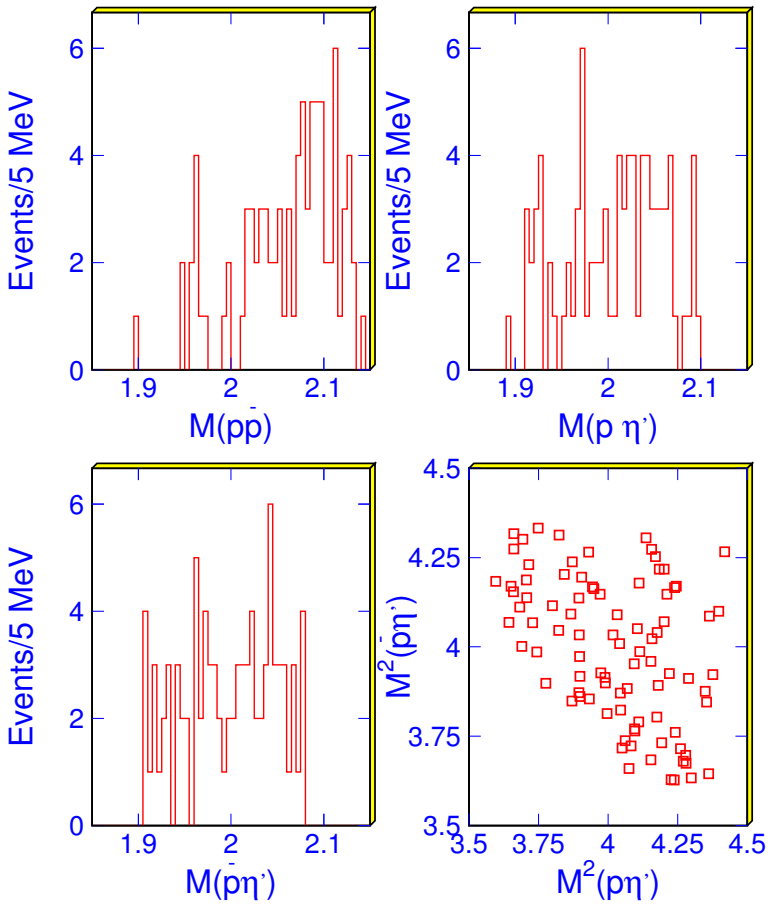

Fig. 8. Invariant mass spectrum of $p\bar{p}$, $p\eta'$, $\bar{p}\eta'$ and dalitz plot for $J/\psi \to p\bar{p}\eta'$. There seem to be structures for excited states.

4 Summary

Based on the J/ψ data sample collected at BES II, $J/\psi \to p\bar{p}\pi^0$ and $J/\psi \to p\bar{p}\eta, p\bar{p}\eta'$ are analyzed. PWA are performed on $J/\psi \to p\bar{p}\pi^0$, a new excited state N(2065) is confirmed and the masses,widths, spin-parity and branching ratios of some excited states are studied. Obvious signals for ecxited states are also observed in $J/\psi \to p\bar{p}\eta, p\bar{p}\eta'$, and the branching ratios of these two processes are measured.

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