Study of $J/\psi \to \pi^0\pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$

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Abstract

The branching ratio of $J/\psi \to \pi^0 3(\pi^+\pi^-)$ and $J/\psi \to \omega 2(\pi^+\pi^-)$ are calculated with much more events than before. Two interesting signals are observed. one is at 1.74 Gev in mass $(\pi^+\pi^-\pi^+\pi^-)$, another is at 1.89 Gev in Mass $(\omega\pi^+\pi^-)$. We also find strong signal of ρ come from unknown decay processes.

Introduction

The main motivation of this work is to search for exotic states with $J^{pc} = 1^{-+}$.Exotic state is predicted by QCD, it has different quantum numbers, such as 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}... with normal mesons. So it can be told from normal mesons easily. Especially for a exotic state with isospin=1, it can not be a glueball, but a hybrid or a multiquark state.
Some theory models have predicted the mass of exotic state (table 1). Bag Model predicted the mass of $1-+$ state in early years, but recent predictions are thought more reasonable. The mass of 1^{-+} state may be at about 1.9 Gev. Meanwhile, some experiments have been carried out(table 2). Their preliminary results gave several exotic state candidates. GAMS observed the signal of 1^{-+} state in 1988. But the method of analysis and the conclusions were seriously disputed by some of same authors later. Evidence for a $J^{pc} = 1^{-+}$ isovector resonance $\hat{\rho}(1405)$ at 1.4 Gev in the reaction $\pi^- p \to \pi^-\eta p$ has been published recently by BNL-E852. The mass and width quoted are 1370 ± 16Mev and 385 ± 40Mev. At the same time,Crystal Barrel group claimed that there is evidence for the same resonance in $p\bar{p}$ annihilation with the mass of 1400 ± 20Mev and the width of 310 ± 50Mev. But, It's not seen as a peak in $\eta\pi$ mass distribution, it's deduced from interference in Dalitz plot. In addition, a heaver isovector $J^{pc} = 1^{-+}$ exotic resonance $\hat{\rho}(1600)$ in the reaction $\pi^- N \to \pi^+\pi^-\pi^- N$ is recently reported by BNL-E852. The mass and width are 1593 ± 8Mev and 168 ± 20Mev. These parameters are consistent with the preliminary claim by VES group of a resonance at 1620 ± 20Mev with a width of 240 ± 50Mev. In both cases PWA method was performed and the decay mode $\rho^0\pi^-$ was observed. There are also evidence for $\hat{\rho}(1600)$ in decay mode $\pi\eta'$ peaking at 1.6 Gev.

Flux Tube model predicted $\hat{\omega}(1900)$ and $\hat{\rho}(1900)$. $\hat{\omega}(1900)$ decays to $\pi a_1(1260)$ dominantly and $\hat{\rho}(1900)$ decays to $\pi b_1(1235)$ dominantly. Thus we try to find some interesting resonances with $J/\psi \to \omega\hat{\omega}(1900) \to \pi^0 3(\pi^+\pi^-)$ and $J/\psi \to \rho\hat{\rho}(1900) \to \pi^0 3(\pi^+\pi^-)$ in 7π final states.

Table 1: Theory prediction

Theory Model	Mass(Gev)
Bag Model[1]	$1.3 \sim 1.8$
Lattice Gauge[2]	$1.9 \sim 2.1$
Flux Tube Model[3]	$1.8 \sim 2.0$
Flux Tube Model of Close[4]	$1.8 \sim 1.9$
QCD sum rules[5]	$2.1 \sim 2.5$

Table 2: Experiment results

Coll. Group	Mass(Mev)	Width(Mev)	Channel	Time of pub
GAMS[6]	1406 ± 20	180 ± 30	$\pi^- p \to \pi^0 \eta p$	1988 P.L.
VES[7]	1620 ± 20	240 ± 50	$\pi^- N \to \eta(\eta')\pi^- N$	1993 P. L.
KEK[8]	1323.1 ± 4.6	143.2 ± 12.5	$\pi^- p \to \eta\pi^- p$	1993 P.L.
BNL_E818[9]	$1900 \sim 2000$		$\pi^- p \to f_1(1285)\pi^- p$	1994 P.L.
BNL_E852[10]	$1370 \pm 16^{+50}_{-30}$	$385 \pm 40^{+65}_{-105}$	$\pi^- p \to \eta\pi^- p$	1997 P.L.
BNL_E852[11]	1593 ± 8	168 ± 20	$\pi^- N \to \pi^+\pi^-\pi^- N$	1997 Proc.
C.B.[12]	$1400 \pm 20 \pm 20$	$310 \pm 50^{+50}_{-30}$	$\bar{p}n \to \pi^-\pi^0\eta$	1998 P.L.

Events selection

To select $\pi^0 3(\pi^+\pi^-)$ events, only events with six good charged tracks and at least two good photons are accepted. For a good charged track, it must meets the following conditions. 1)One-track fit: mfit=2 or mfit=-19. 2)A good track must come from origin, the vertex is limited with $R_{xy} < 2cm$ and $|Z| < 20cm$. 3)The momentum in x-y plane must be larger than 60 Mev, and $|P_z/P| < 0.8$. As a good photon, it is required: 1)Hit in BSC and the energy deposited in BSC is larger than 50 Mev. 2)It should hit at least two layers in BSC and the first hit layer number is less than 5. 3)The number of paired-hits in BSC $N_{paired-hits} \geq 3$. 4)The angle between it and the nearest charged track is greater than 23 degrees. $\theta_{neu,charg} > 23^0$. 5)The angle between the cluster direction and the emit direction is limited less than 30 degrees. For every event, the total number of charges is required to be 0. At least two tracks are identified as π by TOF. After 4c fit, it is demanded that it is much like to be seven π events than other possible background events: $\chi^2_{\pi^0 3(\pi^+\pi^-)} < 40$ and $\chi^2_{\pi^0 3(\pi^+\pi^-)} < \chi^2_{Others}$.

Backgrounds study

J/ψ decays to $\pi^0 3(\pi^+\pi^-)$ with large branching ratio $(2.9 \pm 0.7\%)$. It is partly from $J/\psi \rightarrow \omega 2(\pi^+\pi^-)(Br = (8.5 \pm 3.4) \times 10^{-3})$. There are also other channels decay to the same final state $\pi^0 3(\pi^+\pi^-)$ as following, but with small branching ratios.
1)$J/\psi \rightarrow \rho a_2(1320) \rightarrow \pi^0 3(\pi^+\pi^-), Br = 2.57 \times 10^{-4}$;
2)$J/\psi \rightarrow \phi 2(\pi^+\pi^-) \rightarrow \pi^0 3(pi^+\pi^-), Br = 2.48 \times 10^{-4}$;
3)$J/\psi \rightarrow \omega f_J(1710) \rightarrow \pi^0 3(\pi^+\pi^-), Br = 1.75 \times 10^{-4}$.
There are four most possible background channels.
1)$J/\psi \rightarrow \omega K^\pm {K_s}^0 \pi^\mp \rightarrow \pi^0\pi^\mp k^\pm 2(\pi^+\pi^-), Br = 1.83 \times 10^{-3}$;
2)$J/\psi \rightarrow \pi^0 4(\pi^+\pi^-), Br = (9.0 \pm 3.0) \times 10^{-3}$;
3)$J/\psi \rightarrow 3(\pi^+\pi^-), Br = (4.0 \pm 2.0) \times 10^{-3}$;
4)$J/\psi \rightarrow 2(\pi^+\pi^-)K^+K^-, Br = (3.1 \pm 1.3) \times 10^{-3}$.
According to MC simulation, few background events can pass the event selection program(table 3).

Table 3: Background events after selection.

Condition	pre	cut 1	cut 2	cut 3	cut 4	cut5
$\omega k^\pm {k_s}^0 \pi^\mp$	21	7	5	4	1	0
$3(\pi^+\pi^-)$	0	0	0	0	0	0
$\pi^0 4(\pi^+\pi^-)$	1	0	0	0	0	0
$2(\pi^+\pi^-)k^+k^-$	1	1	1	0	0	0

cut1: $-50Mev < M_{J/\psi} - E_{tot} < 90Mev$. E_{tot} is the calculated energy of event supposing as $\pi^0 3(\pi^+\pi^-)$ event
cut2: $\chi^2 < 15$.
cut3: $|\Delta M_{\pi^0}| < 40Mev$ and $|\Delta M_\omega| < 40Mev$
cut4: $|\Delta M_{{k^0}_s}| > 10Mev$.
cut5: $M_{p-\beta} < 400Mev$. $M_{p-\beta}$ is the calculated mass from momentum and time of flight.

$Br(J/\psi \rightarrow \pi^0 3(\pi^+\pi^-))$, $Br(J/\psi \rightarrow \omega 2(\pi^+\pi^-))$

The branch ratios of $J/\psi \rightarrow \pi^0 3(\pi^+\pi^-)$ and $J/\psi \rightarrow \omega 2(\pi^+\pi^-)$ in PDG are from MARKI. MARKI has not more than 0.2M[13] J/ψ events to calculate the Branch ratios. Now we have 7.8 million J/ψ events, so the BESI results should be more accurate. After the preliminary event selection, some other condition limited were added. The final events are required: 1)χ^2 of telesis fit less than 15. 2)$-50Mev < M_{J/\psi} - E_{tot} < 90Mev$. After B-W fit, we got 3290 ± 43 π^0 events(Fig. 1 a). There are 9 entries of $m(\pi^0\pi^+\pi^-)$ in one event. At last, we found 1275 ± 86 ω events(Fig. 1 b). 0.4 million $J/\psi \rightarrow \pi^0 3(\pi^+\pi^-)$ events and 0.5 million $J/\psi \rightarrow \omega 2(\pi^+\pi^-)$ events are generated to calculate the efficiencies ε_{π^0} and ε_ω. The results are listed in table 4.

Table 4: Branch ratios

Decay modes	N_{data}	N_{MC}	N_{MCevt}	ε	$Branchratio$
$J/\psi \to \pi^0 3(\pi^+\pi^-)$	3290 ± 43	$0.4M$	7737 ± 62	1.712%	$2.52 \pm 0.06\%$
$J/\psi \to \omega 2(\pi^+\pi^-)$	1275 ± 86	$0.5M$	6890 ± 124	1.378%	$1.31 \pm 0.09\%$

N_{data} is the events number of selected data
N_{MC} is the events number generated by MC
N_{MCevt} is the events number of MC after selected
ε is Efficiency derived from MC

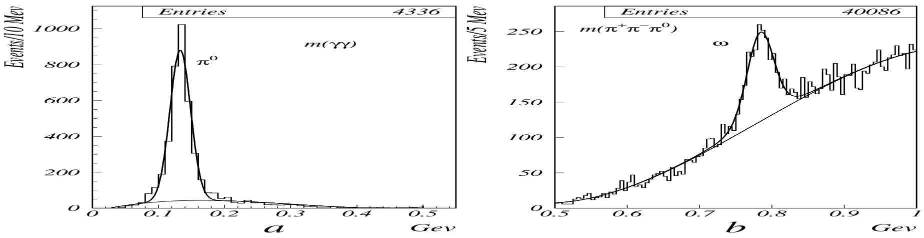

Figure 1: π^0 and ω

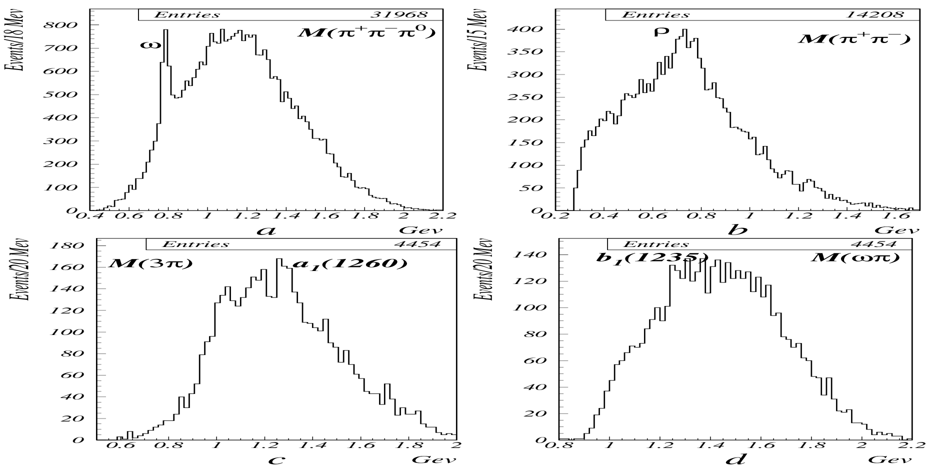

Figure 2: a. mass($\pi^+\pi^-\pi^0$) , b. mass($\pi^+\pi^-$), c. mass(3π), d. mass($\omega\pi$)

Resonances

We observed the signal of ω in the invariant mass spectrum of $\pi^+\pi^-\pi^0$(Fig. 2 a) and ρ in mass($\pi^+\pi^-$)(Fig. 2 b). Fig. 2 c is the invariant mass of $\rho\pi$, the signal of $a_1(1260)$ is expected in this plot. Because of small branch ratio and large width, it is not very clear. Fig. 2 d is the invariant mass of $\omega\pi$, the signal of $b_1(1235)$ should appear in this plot.

Fig. 3 is the invariant mass of four π after ω marked. There is a peak at about 1.74 Gev in the plot. It may be $\hat{\omega}$ or $f_J(1710)$, or other things unknown. As known, $f_J(1710) \to \rho\rho \to \pi^+\pi^-\pi^+\pi^-$, and Flux tube predicts $\hat{\omega} \to \pi a_1(1260) \to \pi^+\pi^-\pi^+\pi^-$.

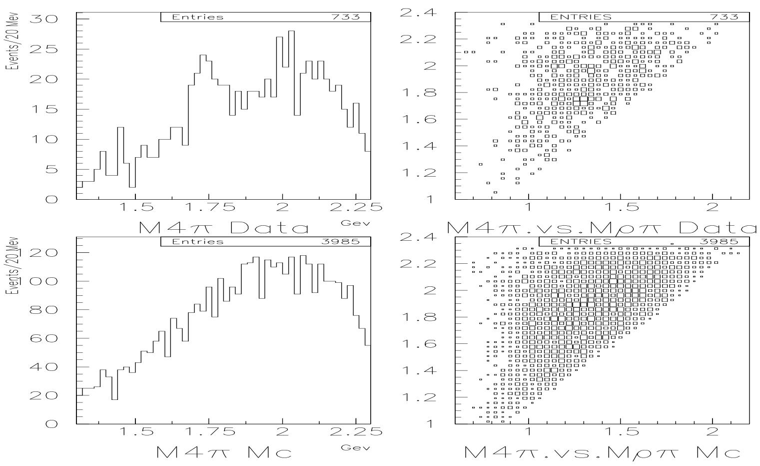

Figure 3: A peak at about 1.74 Gev

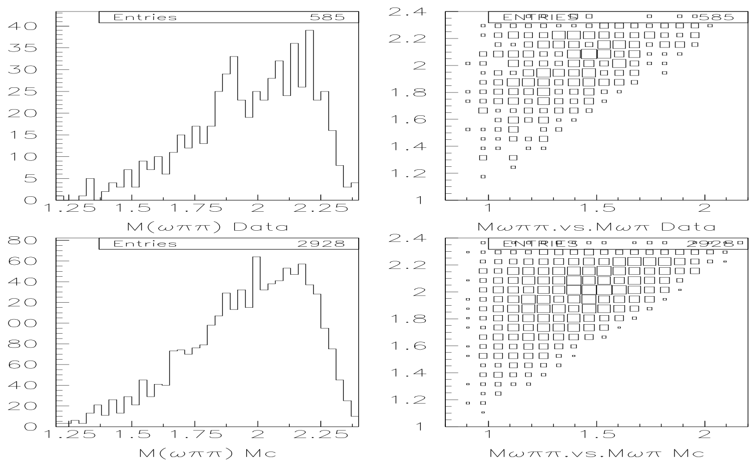

Figure 4: A peak at about 1.9 Gev in Mass($\omega\pi^+\pi^-$)

The right upper plots shows the relation between the invariant mass of 4π and the invariant mass of 3π. The x axis represnets the invariant mass of 3π; the y axis represents the invariant of 4π. There is an enhancement corresponds to $m(4\pi) \approx 1.74Gev$ and $m(3\pi) \approx 1.2 \sim 1.3Gev$. This supports the resonance to be $\hat{\omega}$. We can also deduce the branch ratio of $J/\psi \to \omega f_J(1710) \to \omega\pi^+\pi^-\pi^+\pi^-$.

$$\frac{Br(J/\psi\to\gamma f_J\to\gamma KK)}{Br(J/\psi\to\omega f_J\to\omega KK)} = \frac{Br(J/\psi\to\gamma f_J\to\gamma 2(\pi^+\pi^-))}{Br(J/\psi\to\omega f_J\to\omega 2(\pi^+\pi^-))}[14]$$
$$\Longrightarrow Br(J/\psi \to \omega f_J \to \omega 2(\pi^+\pi^-)) \approx 1.75\times 10^{-4}$$
$$\Longrightarrow \frac{Br(J/\psi\to\omega f_J\to\omega 2(\pi^+\pi^-))}{Br(J/\psi\to\omega 2(\pi^+\pi^-))} \approx 2.1\%$$

For the resonance

$$Br(J/\psi \to \omega X \to \omega 2(\pi^+\pi^-)) \approx 9.3\times 10^{-4}$$
$$\Gamma \approx 80Mev$$
$$\Longrightarrow \frac{Br(J/\psi\to\omega X\to\omega 2(\pi^+\pi^-))}{Br(J/\psi\to\omega 2(\pi^+\pi^-))} \approx 11\%$$

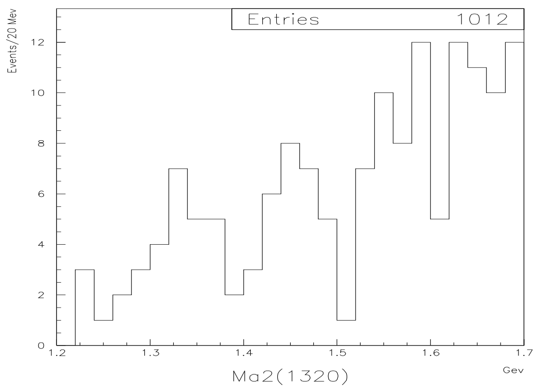

Figure 5: A peak at about 1.32 Gev in Mass($\omega\pi^+\pi^-$), should be $a_2(1320)$

We can conclude that the signal is not fully from $f_J(1710)$

There is also a peak at about 1.9 Gev in the invariant mass of $\omega\pi\pi$ Fig. 4. The right upper plot shows the relation between the invariant mass of $\omega\pi\pi$ and the invariant mass of $\omega\pi$.There are also an enhancement corresponds to $m(w\pi\pi) \approx 1.9Gev$ and $m(\omega\pi) \approx 1.2 \sim 1.3Gev$. This meets the prediction of flux tube model. According to PDG, there are no resonances which decay to $\omega\pi\pi$ in the mass region of $1.7 \sim 2.0Gev$. This peak is very interesting. It is a possible candidate for $\hat{\rho}$.The branch ratio of this possible resonance is about 1.1×10^{-3}. The estimated mass width is $\sim 70Mev$.

According to PDG, $a_2(1320)$ is the only possible signals that can be seen in the invariant mass of $\omega\pi\pi$.

$Br(J/\psi \to \rho a_2(1320) \to \pi^0 3(\pi^+\pi^-)) = 0.228 \times 10^{-3}$

then

$\frac{Br(J/\psi \to \rho X \to \pi^0 3(\pi^+\pi^-))}{Br(J/\psi \to \rho a_2(1320) \to \pi^0 3(\pi^+\pi^0))} \approx 5$

Under the same condition, the numbers $a_2(1320)$ and $X(1890)$ are estimated from the mass spectrum. $N_{a_2(1320)} \approx 4 \sim 5$, $N_{X(1890)} \approx 30$. the ratio of them consists with the calculated result.

Summary

We got $Br(J/\psi \to \pi^0 3(\pi^+\pi^-))$ and $Br(J/\psi \to \omega 2(\pi^+\pi^-))$ with much more events. So the BESI result should be more accurate.

Decay Mode	BESI		PDG(MARKI)	
	N_{evts}	BR	N_{evts}	BR
$J/\psi \to \pi^0 3(\pi^+\pi^-)$	3290 ± 43	$2.52 \pm 0.06\%$	181 ± 26	$2.9 \pm 0.7\%$
$J/\psi \to \omega 2(\pi^+\pi^-)$	1275 ± 86	$1.31 \pm 0.09\%$	140 ± 30	$0.85 \pm 0.34\%$

We saw clear signals of π^0, ω, ρ. Some of ρ come from $J/\psi \to \rho a_2(1320)$ events, but most of them come from unknow decay processes: $J/\psi \to \ unknow \to \rho\pi^+\pi^-\pi^+\pi^-\pi^0 \to \pi^0 3(\pi^+\pi^-)$. it is worth to study. There is a peak at 1.74 Gev in Mass($\pi^+\pi^-\pi^+\pi^-$), it has a pretty large branch ratio, so it is not merely from $f_J(1710)$. May be it is a candidate of 1^{-+} state. There is also a peak at about 1.9 Gev in Mass($\omega\pi^+\pi^-$). Is it a candidate of exotic state 1^{-+} ? PWA is needed to analyze the quantum numbers.

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