$\psi\prime$ Decays to Multi Prongs Final States

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Abstract

The charged multi prongs decays $\psi\prime \to 3(\pi^+\pi^-), 4(\pi^+\pi^-)$ and $2(\pi^+\pi^-)K^+K^-$ have been studied using the $\psi\prime$ data collected by BES detector from 1993 to 1995. Measurements of their branching fractions are presented, the preliminary branching ratios are calculated. Some intermediate dacays $J/\psi \to 2(\pi^+\pi^-), J/\psi \to 3(\pi^+\pi^-)$ and $J/\psi \to \pi^+\pi^-K^+K^-$ are also studied, yielding the information of their branching ratios.

1 Motivation and Introduction

- According to perturbative QCD, there is a direct parallel between the decay of $\psi\prime$ and J/ψ to three massless gluons:

$$Q_h \equiv \frac{Br(\psi\prime\to ggg)}{Br(J/\psi\to ggg)} = \frac{Br(\psi\prime\to e^+e^-)}{Br(J/\psi\to e^+e^-)} = (14.1 \pm 1.2)\%$$

  where the leptonic branching fractions from PDG[1] are used. It's so-called "14% rule". Most of the hadronic channels satisfy this rule; however, some large discrepancy was found in some VP channels[2] and VT channels (by BES Group). No satisfactory explanation is accepted by now. It is important to testify the "14% rule" in more decays such as the multi prongs decays in the current analysis.

- The efficiency of decays to multi prongs is relatively small. In PDG, compared to J/ψ decay, much less $\psi\prime$ decaying to final channels have been studied, especially in multi prongs decays. Since there are about $3.79 \times 10^6 \psi\prime$ to events in BES, it's possible to analyze the decays of $\psi\prime$ to multi prongs final states.

- The analysis is based on $(3.79 \pm 0.01 \pm 0.31) \times 10^6 \psi\prime$ events in BES collected from 1993 to 1995. The $\psi\prime \to \pi^+\pi^- J/\psi$ events are $(1.227 \pm 0.003 \pm 0.017) \times 10^6$.[3]

2 General Event Selection Criteria

Magnetic field correction is made to the momentum of charged tracks. Momuntum corrections are further made for energy loss and multiple Coulomb scatters in the material before charged particles enter the drift volume in BES detector.

A.$\psi\prime \to 3(\pi^+\pi^-)$

(a) The number of charged tracks is required to be six with net charge zero and each track with high quality in track fitting (MFIT=2).

(b) $|cos(\theta)| < 0.84$, where θ is the polar angle relatives to the beam axis.

(c) The vertex of the selected events has z position within 15cm to the interaction point, and the distance to the beam axis less than 1.5cm.

(d) Events are kinematically 4C fitted to $3(\pi^+\pi^-)$ and the probability of the fit is required to be greater than 0.01.

(e) dE/dx information is used for particle identification. The particle identification $\chi^2(dE/dx)$ values (number of σ from hypothesis) corrected using subroutine developed by $\psi\prime$ Group. π tracks are selected with confidence level larger than 0.003 for each track and 0.01 for all tracks combined.

B.$\psi\prime \to 4(\pi^+\pi^-)$

(a) The number of charged tracks is required to be eight with net charge zero and each track with high quality in track fitting (MFIT=2).

Other selections are same as those of $\psi\prime \to 3(\pi^+\pi^-)$.

C.$\psi\prime \to 2(\pi^+\pi^-)K^+K^-$

(a)-(c) Same as those of $\psi\prime \to 3(\pi^+\pi^-)$.

(d) Events are kinematically 4C fitted to $\psi\prime \to \pi^+\pi^-\pi^+\pi^-K^+K^-$ in order to get better separation among differeent track assignment (9 assignments of $\psi\prime \to \pi^+\pi^-\pi^+\pi^-K^+K^-$ track per event). We include the dE/dx information in the fit: the χ^2 of the 4C-fit is combined with the χ^2 of the track identification with dE/dx information. The total χ^2 is defined as:

$$\chi^2 = \chi^2(4C\_fit) + \sum_{i=1}^{6} \chi^2(dE/dx)$$

The total degree of freedom becomes 10 after including the $\chi^2(dE/dx)$ term. The track assignment with highest combined probability is selected as $\pi^+\pi^-\pi^+\pi^-K^+K^-$ candidate among 9 assignments. The combined probability of fit

$$(prob(\chi^2(4C\_fit) + \sum_{i=1}^{6} \chi^2(dE/dx), 10))$$

is also required to be greater than 0.01.

(e) dE/dx information is used for particle identification. Tracks are selected with confidence level larger than 0.003 for each track identified as $\pi^+\pi^-\pi^+\pi^-K^+K^-$ respectively, and 0.01 for all tracks combined.

3 Branching ratios calculation

A.$\psi\prime \to 3(\pi^+\pi^-)$
(a) $J/\psi \to 2(\pi^+\pi^-)$
After passing the cut condition listed above, a clear high peak centered at J/ψ mass is seen in the distribtion of the recoil mass of combination of any $\pi^+\pi^-$ track candidate pair (Figure 1). These events proceed via $\psi\prime \to J/\psi$ and $J/\psi \to 2(\pi^+\pi^-)$. $652.7 \pm 21.5 J/\psi \to 2(\pi^+\pi^-)$ events are fitted out (Figure 1). Monte Carlo generates 10,000 $\psi\prime \to J/\psi, J/\psi \to 2(\pi^+\pi^-)$ events, applying the same selection criteria, the efficiency is 13.4%. So the braching ratios is

$$Br(J/\psi \to 2(\pi^+\pi^-)) = \frac{N_{evt}}{\epsilon N_{\psi\prime\to\pi^+\pi^- J/\psi}} = (3.97 \pm 0.13 \pm 0.46) \times 10^{-3}$$

where $N_{\psi\prime\to\pi^+\pi^- J/\psi}$ is the events number of $\psi\prime \to \pi^+\pi^- J/\psi$ in BES, the first error is statistic, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(10.3%), and total events number of $\psi\prime \to \pi^+\pi^- J/\psi$(1.6%)

(b) $\psi\prime \to 3(\pi^+\pi^-)$
We apply a more selection criterion in order to remove J/ψ contamination from data samlpe. The recoil mass of combinations of any $\pi^+\pi^-$ candidate pair are calculated and required to be greater than 3.15 GeV or less than 3.05 GeV. We plot the distribution of the invariant mass of the $\pi^+\pi^-$ track candidate pairs left, and a clear peak centered at K_s^0 mass is seem(Figure 2). Considering that K_s^0 is strange particle while $\psi\prime$ is not, and the final state contain $3(\pi^+\pi^-)$, we think that the K_s^0 is gotten in the process $\psi\prime \to K_s^0 K_s^0 \pi^+\pi^-$, and $K_s^0 \to \pi^+\pi^-$. Applying a more criteria to remove K_s^0, we require the mass of any combination of the the $\pi^+\pi^-$ track candidate pair to be greater than 0.56 GeV or less than 0.48 GeV (Figure 2). 111 events survive all the cuts. Monte Carlo generates 10,000 $\psi\prime \to 3(\pi^+\pi^-)$ events, applying the same selection criteria, the efficiency is 8.8%, so the branching ratios is

$$Br(\psi\prime \to 3(\pi^+\pi^-)) = \frac{N_{evt}}{\epsilon N_{\psi\prime}} = (3.33 \pm 0.31 \pm 0.37) \times 10^{-4}$$

where the first error is statistics, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(5.9%), and total events number of $\psi\prime$(8%).

B.$\psi\prime \to 4(\pi^+\pi^-)$
(a) $J/\psi \to 3(\pi^+\pi^-)$
Applying the selection criteria above, a clear high peak centered at J/ψ mass is seen in the distribution of the recoil mass of combination of any $\pi^+\pi^-$ track candidate pair (Figure 3). They are neat $J/\psi \to 3(\pi^+\pi^-)$ events. $192.4 \pm 29.2 J/\psi \to 3(\pi^+\pi^-)$ events are fitted out (Figure 3). Monte Carlo generates 10,000 $\psi\prime \to J/\psi, J/\psi \to 2(\pi^+\pi^-)$ events, applying the same selection criteria, the efficiency is 5.9%. So the branching ratios is

$$Br(J/\psi \to 3(\pi^+\pi^-)) = \frac{N_{evt}}{\epsilon N_{\psi\prime\to\pi^+\pi^- J/\psi}} = (2.7 \pm 0.4 \pm 0.4) \times 10^{-3}$$

where the first error is statistic, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(13.3%), and total events number of $\psi\prime \to \pi^+\pi^- J/\psi$(1.6%)

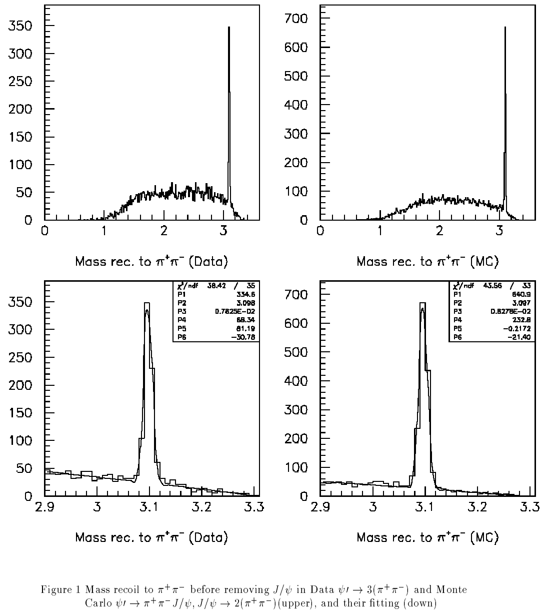

Figure 1: Recoil mass of combination of any $\pi^+\pi^-$ track candidate pair.

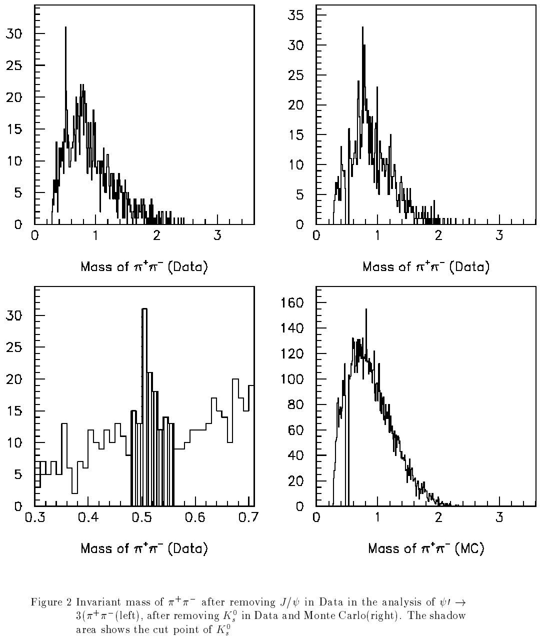

Figure 2: The distribution of the invariant mass of the $\pi^+\pi^-$ track candidate pairs left.

(b) $\psi\prime \to 4(\pi^+\pi^-)$
We apply one more cut to remove J/ψ contamination. The recoil mass of combination of any $\pi^+\pi^-$ track candidate pair are calculated and required to be greater than 3.15 GeV or less than 3.05 Gev. We get 16 $\psi\prime \to 4(\pi^+\pi^-)$ events at last. Monte Carlo generates 10,000 $\psi\prime \to 4(\pi^+\pi^-)$ events, applying the same selection criteria, the efficiency is 3.1%. So the branching ratios is

$$Br(\psi\prime \to 4(\pi^+\pi^-)) = \frac{N_{evt}}{\epsilon N_{\psi\prime}} = (1.4 \pm 0.3 \pm 0.2) \times 10^{-4}$$

where the first error is statistics, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(6.7%), and total events number of $\psi\prime$(8%).

C.$\psi\prime \to 2(\pi^+\pi^-)K^+K^-$
(a) $J/\psi \to \pi^+\pi^-K^+K^-$
After passing the selection criteria, a clear high peak centered at J/ψ mass is seen in the distribution of the recoil mass of combination of any opposite charged track pairs (Figure 4). They are neat $J/\psi \to \pi^+\pi^-K^+K^-$ events. $800.5 \pm 49.8 J/\psi \to \pi^+\pi^-K^+K^-$ events are fitted out (Figure 4). Monte Carlo generates 10,000 $\psi\prime \to J/\psi$, $J/\psi \to \pi^+\pi^-K^+K^-$ events, applying the same cut condition, we get the efficiency 9.2%. So the branching ratios is

$$Br(J/\psi \to \pi^+\pi^-K^+K^-) = \frac{N_{evt}}{\epsilon N_{\psi\prime \to \pi^+\pi^- J/\psi}} = (7.2 \pm 0.4 \pm 0.9) \times 10^{-3}$$

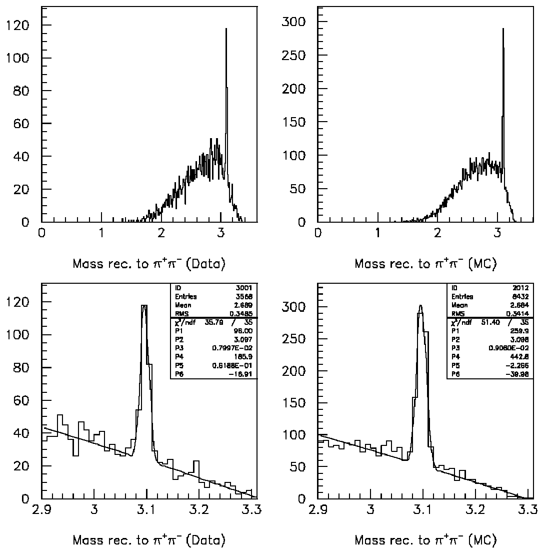

Figure 3 Mass recoil to $\pi^+\pi^-$ before removing J/ψ in Data $\psi\prime \to 4(\pi^+\pi^-)$ and Monte Carlo $\psi\prime \to \pi^+\pi^- J/\psi, J/\psi \to 3(\pi^+\pi^-)$(upper), and their fitting (down)

Figure 3: Neat $J/\psi \to 3(\pi^+\pi^-)$ event.

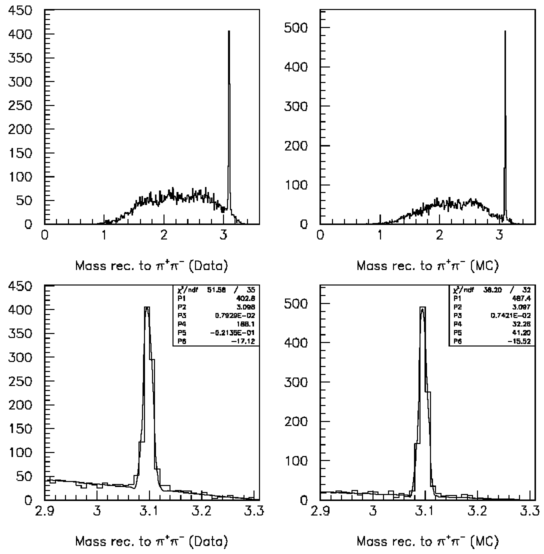

Figure 4 Mass recoil to $\pi^+\pi^-$ before removing J/ψ in Data $\psi\prime \to 2(\pi^+\pi^-)K^+K^-$ and Monte Carlo $\psi\prime \to \pi^+\pi^- J/\psi, J/\psi \to \pi^+\pi^-K^+K^-$(upper), and their fitting (down)

Figure 4: Neat $J/\psi \to \pi^+\pi^-K^+K^-$ events.

where the first error is statistic, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(12.0%), and total events number of $\psi\prime \to \pi^+\pi^- J/\psi$(1.6%)

Table 1: Numbers after ecch selection step $\psi\prime \to 3(\pi^+\pi^-)$

Total events	1749417
Good Run	1717199
NCHRG=6,net charge=0	436828
MFIT=2	240972
$\lvert cos(\theta)\rvert < 0.84$	179096
Vertex Cut	177956
$CL(4C) > 0.01$	1282
$CL(dE/dx) > 0.01$	1009
Remove J/ψ	272
Remove K_s^0	111

(b) $\psi\prime \to 2(\pi^+\pi^-)K^+K^-$

In order to remove $J\psi$ contamination, one more selection criterion is applied. The recoil mass of combination of any opposite charged track pairs are calculated and required to be greater

Table 2: Numbers after ecch selection step $\psi\prime \to 2(\pi^+\pi^-)K^+K^-$

Total events	1749417
Good Run	1717199
NCHRG=6,net charge=0	436826
MFIT=2	240972
$\|cos(\theta)\| < 0.84$	179096
Vertex Cut	177956
$CL(4C + dE/dx) > 0.01$	1136
$CL(dE/dx) > 0.01$	1097
Remove J/ψ	228

than 3.15 GeV or less than 3.05 Gev. 228 events survive this cut. Monte Carlo generates 10,000 $\psi\prime \to 2(\pi^+\pi^-)K^+K^-$ events, applying the same selection criteria, the efficiency is 15.0%. So the branching ratios is

$$Br(\psi\prime \to 2(\pi^+\pi^-)K^+K^-) = \frac{N_{evt}}{\epsilon N_{\psi\prime}} = (4.0 \pm 0.3 \pm 0.8) \times 10^{-4}$$

where the first error is statistics, and the second one is systematic error which includes those arise from efficiency determination(5%), selection criteria(18.2%), and total events number of $\psi\prime$(8%).

4 Conclusion and Discussion

- System error
  System error comes from changing event selection criteria, total $\psi\prime$ events error (8%), total events of $\psi\prime \to \pi^+\pi^-$(1.6%), and the error of efficiency calculation because of insufficient Monte Carlo events generated (we give the unit error 5% to all). The selection criteria includes track fitting changes from MFIT=2 to MFIT=2 or MFIT=-9 or MFIT=-19, CL(4C) or CL(4C+dE/dx) changes from > 0.01 to > 0.04, CL(dE/dx) changes from > 0.01 to > 0.04, the mass description determined by Monte Carlo changes 10% in fitting. The errors are listed in each channel respectively. We think the errors have no effiect to each other in each channel, and calculate as a whole systematic error.

- The results are listed in table 4. The second column is the result we get, and the third column is the branching ratios cited from PDG.

- The reaults of $J/\psi \to 2(\pi^+\pi^-)$, $\psi\prime \to 3(\pi^+\pi^-)$, $J/\psi \to 3(\pi^+\pi^-)$ and $J/\psi \to \pi^+\pi^-K^+K^-$ are in consistence with the PDG values within 1σ, but the errors are less. This shows that the method used there is reasonable.

- We calculate one more fractin of $\psi\prime$ and J/ψ decay to the same hadronic final state

$$\frac{Br(\psi\prime\rightarrow 2(\pi^+\pi^-)K^+K^-)}{Br(J/\psi\rightarrow 2(\pi^+\pi^-)K^+K^-)} = (12.9 \pm 6.5)\%$$

which consists with the so-called "14% rule".

Table 3: Numbers after ecch selection step $\psi\prime \rightarrow 4(\pi^+\pi^-)$

Total events	1749417
Good Run	1717199
NCHRG=8,net charge=0	109000
MFIT=2	37259
$\|cos(\theta)\| < 0.84$	25988
Vertex Cut	25879
$CL(4C) > 0.01$	335
$CL(dE/dx) > 0.01$	223
Remove J/ψ	16

Table 4: Branch ratio of J/ψ and $\psi\prime$ to multi prongs final states

Decay model	*The result calculated in BES*	*PDG*
$J/\psi \longrightarrow 2(\pi^+\pi^-)$ $\psi\prime \longrightarrow 3(\pi^+\pi^-)$	$(3.97 \pm 0.13 \pm 0.46) \times 10^{-3}$ $(3.33 \pm 0.31 \pm 0.37) \times 10^{-4}$ $(1.53 \pm 0.14 \pm 0.17) \times 10^{-4}$ [4,5]	$(4.0 \pm 1.0) \times 10^{-3}$ $(1.5 \pm 1.0) \times 10^{-4}$
$J/\psi \longrightarrow 3(\pi^+\pi^-)$ $\psi\prime \longrightarrow 4(\pi^+\pi^-)$	$(2.7 \pm 0.4 \pm 0.4) \times 10^{-3}$ $(1.4 \pm 0.3 \pm 0.2) \times 10^{-4}$ $(0.6 \pm 0.1 \pm 0.1) \times 10^{-4}$ [4,5]	$(4.0 \pm 2.0) \times 10^{-3}$ -
$J/\psi \longrightarrow \pi^+\pi^-K^+K^-$ $\psi\prime \longrightarrow 2(\pi^+\pi^-)K^+K^-$	$(7.2 \pm 0.4 \pm 0.9) \times 10^{-3}$ $(4.0 \pm 0.3 \pm 0.8) \times 10^{-4}$	$(7.2 \pm 2.3) \times 10^{-3}$ -

Reference

[1] R.M. Barnett et al., Phys. Rev. D54, 1(1996)
[2] T. Applequist and D. Politzer, Phys. Rev. Lett. 34, (1975)43
[3] J.Z.BAi et al., Phys. Rev. D58,92006(1998)
[4] The branching ratios have been corrected in order to remove the nonresonant background. For $\psi\prime \rightarrow 3(\pi^+\pi^-)$ and $4(\pi^+\pi^-)$, which must be second-order electromagnetic decays because of G-parity conservation, the ratio of nonresonant background to resonant $\psi\prime$ decay must be the same as for $\psi\prime \rightarrow \mu^+\mu^-$, for which the noresonant background can be calculated by QED. For $\psi\prime \rightarrow 2(\pi^+\pi^-)K^+K^-$, which can also proceed by strong decay, the nonresonant background cannot be uniquely determined from our data.
[5] W.Tanenbaum et al., Phys. Rev. D17, 1773(1978).