Analysis Note: Number of ψ' Events

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Introduction

The number of ψ' events obtained by BES is important to all ψ' analyses. However, one of the most important applications for this number is the determination of the branching ratio, $B(J/\psi \to l^+l^-)$, which will be the subject of another analysis note. In this informal analysis note, the determination of the number of ψ' events found in both the 1993 and the 1995 ψ' data will be summarized. This paper is an update of work that was reported at the 1995[1] and 1996[2] BES Annual Meetings.

Method

The approach of IHEP[3] is followed. The idea is to use $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to$ anything. The mass recoiling against the π's is plotted, and the J/ψ peak is used to determine the number of J/ψ events, $N_{J/\psi}$, and

$$N_{\psi'} = \frac{N_{J/\psi}/\epsilon}{B(\psi' \to \pi^+\pi^- J/\psi)},$$

where ϵ is the acceptance for the π's in $\psi' \to \pi^+\pi^- J/\psi$ and $B(\psi' \to \pi^+\pi^- J/\psi)$ is the branching ratio for this process.

Analysis

Reconstruction

The data are reconstructed in Hawaii using version 8.6 of the BES software. No filter is used, but events are required to satisfy:

1. $|z_{min}| < 0.15$ m
2. $r_{min} < 0.015$ m

where z_{min} and r_{min} are the minimum values of z_m and r_m found for all the tracks in the event.

Track Corrections

The track momenta are first corrected by the magnetic field correction (0.9970*p)[4] and then the beam pipe correction (BPCORR). In addition, the dE/dx and TOF corrections of Bill Dunwoodie and Li Xinhua[5] are made.

Cuts

The analysis loops over the $\pi^+\pi^-$ combinations[6] where the π's have:

1. good run (ppruns: status $>$ 0 or 1).
2. mfit = 2, -9, or -19.
3. $|\cos\theta| < 0.8$.
4. $p_\pi < 0.5 GeV/c$. p_π is the π momentum.
5. $pxy_\pi > 0.1 GeV/c$. pxy_π is the momentum transverse to the beam direction.
6. $\Sigma Hit_\pi^{dE/dx} > 13$. $\Sigma Hit_\pi^{dE/dx}$ is the number of hits used in the dE/dx calculation.
7. $|\chi_\pi^{dE/dx}| < 3.0$. $\chi_\pi^{dE/dx} = \frac{(dE/dx)_{meas} - (dE/dx)_{exp}}{\sigma}$. See below for more detail on this cut.
8. $m_{\pi\pi} > 0.35 GeV/c^2$ to eliminate gamma conversions.

$|\chi_\pi^{dE/dx}| < 3.0$ Cut

For the $|\chi_\pi^{dE/dx}|$ cut, where the Monte Carlo does not model the dE/dx distribution well, a routine, OKXSPI[7], was written to make equivalent cuts (3σ) on both data and Monte Carlo events. Ideally the $|\chi_\pi^{dE/dx}|$ distributions should have a mean of 0.0 and a σ of 1.0. Unfortunately they do not, so it is necessary to measure the mean and the σ's of each distribution. Since the distributions are asymmetric, the positive-side σ's and negative-side σ's are measured separately. In addition, positive and negative tracks are treated separately. In Figs. 1 and 2 are the $\chi_\pi^{dE/dx}$ distributions for the 1995 positive and negative tracks, respectively. Both data and Monte Carlo $\chi_\pi^{dE/dx}$'s are corrected for their mean shift from zero, and the cuts are applied in terms of the measured positive-side and negative-side sigmas determined for each distribution. In Table 1 are the measured means and standard deviations of $\chi_\pi^{dE/dx}$ for '93 data, '95 data, and Monte Carlo data.

Fitting

For each $\pi^+\pi^-$ combination satisfying cuts, the mass recoiling against the π's, m_{recoil}, is calculated, and the m_{recoil} distribution is fitted using MinFit[8] to determine the amount of J/ψ signal and background, as shown in Fig. 3. The J/ψ line shape, shown in Fig. 4, is determined from $\psi' \to \pi^+\pi^- J/\psi$ events, where $J/\psi \to l^+l^-$[9]. The line shapes are determined separately for '93 and '95 data. In addition to the other cuts used to define the $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ sample[9], a cut is made on the lepton invariant mass

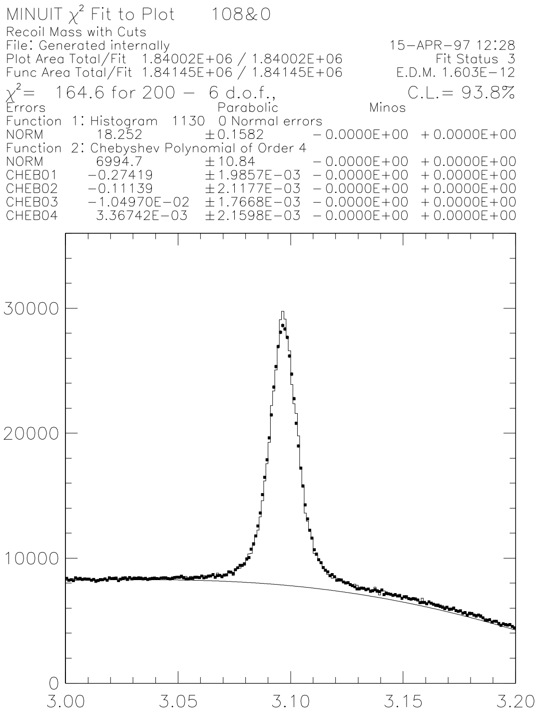

Figure 1: Distribution of $\chi_\pi^{dE/dx}$ for positive tracks in the 95 data sample. The distribution is fitted with a bifurcated Gaussian in the region of small $|\chi_\pi^{dE/dx}|$. The fit is the smooth curve under the data distribution. Note that the mean is shifted from zero and that the distribution is asymmetric.

($|M_{J/\psi} - m_{l^+l^-}| < 0.25 GeV/c^2$). A 4th order polynomial is used to describe the background. MinFit allows fitting one histogram with another directly; no fit to a Breit-Wigner smeared by a Gaussian is required, as is done at IHEP.

Calculation of ϵ

The method described in various IHEP preprints[10] is used. A modified Howl generates $\psi' \to \pi^+\pi^- J/\psi$ events with the correct $m_{\pi\pi}$ distribution ($\frac{d\sigma}{dm_{\pi\pi}} \propto$ phasespace $\times (M_{\pi\pi}^2 - 4m_\pi^2)^2$). Separate samples of events with $J/\psi \to 0(\pi^+\pi^-), 1(\pi^+\pi^-), 2(\pi^+\pi^-)$, etc. are generated. This is necessary since ϵ depends on multiplicity. The generated events are reconstructed with DRUNK. For each multiplicity sample, the m_{recoil} distribution is fit with the line shape obtained from Monte Carlo $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events (4 prongs) plus background, as described in the previous section[11]. This determines the efficiency for each multiplicity sample generated. Lastly the efficiencies for $J/\psi \to 0(\pi^+\pi^-), 1(\pi^+\pi^-), 2(\pi^+\pi^-)$, etc. are combined using weights from the literature to obtain an overall efficiency[10]. The results for this calculation are given in Tables 2 and 3. Note that Wang Meng determines the weights directly from the data. However the final overall efficiency determined using his weights is essentially the same (within 0.3%).

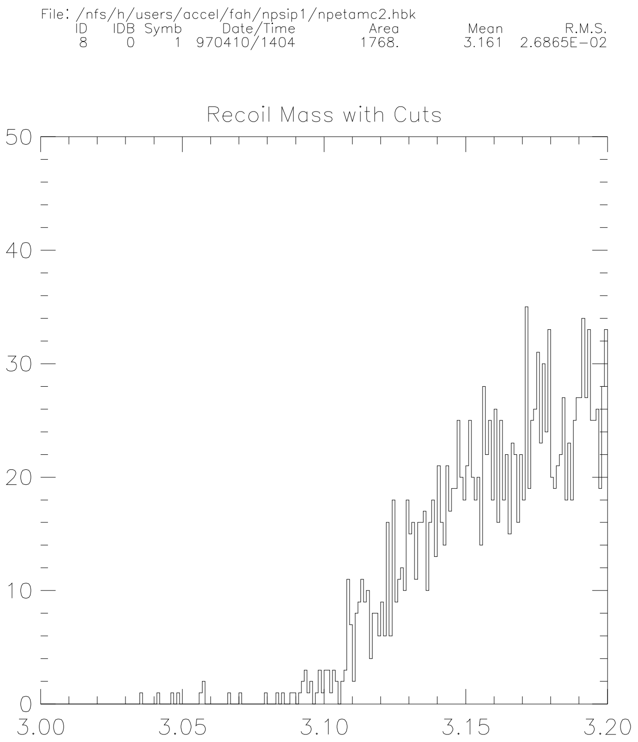

Figure 2: Distribution of $\chi_{\pi}^{dE/dx}$ for negative tracks in the 95 data sample. The distribution is fitted with a bifurcated Gaussian in the region of small $|\chi_{\pi}^{dE/dx}|$. The fit is the smooth curve under the data distribution. Note that the mean is shifted from zero and that the distribution is asymmetric.

Background from $\psi' \to \eta J/\psi$.

Sober (HOWL) was used to determine the amount of background expected from $\psi' \to \eta J/\psi$, where $J/\psi \to$ nothing and $\eta \to \pi^+\pi^-\pi^o$ (23.2%) or $\eta \to \pi^+\pi^-\gamma$ (4.78%). For the first case, only 8 events satisfied cuts, including the m_{recoil} cut, out of 5000 events generated. The number of events expected in our final sample from this mode is given by:

$$N_{\psi' \to \eta J/\psi} = N_{\psi'} B(\psi' \to \eta J/\psi) B(\eta \to \pi^+\pi^-\pi^o)(\text{efficiency})$$

$$N_{\psi' \to \eta J/\psi} = (3.7 \times 10^6)(0.027)(0.232)(8/5000) = 37$$

The corresponding number of $\psi' \to \pi^+\pi^- J/\psi$ is

$$N_{\psi' \to \pi^+\pi^- J/\psi} = N_{\psi'} B(\psi' \to \pi^+\pi^- J/\psi)\epsilon$$

$$N_{\psi' \to \pi^+\pi^- J/\psi} = (3.7 \times 10^6)(0.324)(0.5233) = 6.27 \times 10^5$$

The percentage background is then $37/6.27 \times 10^6 = 6 \times 10^{-3}\%$. For $\eta \to \pi^+\pi^-\gamma$ with a branching ratio of 4.78%, 1768 events out of 10000 satisfy cuts. Doing the equivalent calculation to the above, the background due to this mode is estimated to be 0.13%. However

Table 1: Mean, minus-side standard deviation, and positive-side standard deviation of $\chi_\pi^{dE/dx}$ for positive (+) and negative tracks (-).

Data	Mean$^+$	σ_m^+	σ_p^+	Mean$^-$	σ_m^-	σ_p^-
1993	-0.290	1.002	1.305	-0.389	0.993	1.283
1995	-0.299	0.983	1.318	-0.378	1.000	1.308
MC	0.483	1.214	0.801	0.483	1.194	0.800

Table 2: Efficiency Results for '93 Data

$J/\psi \to n\pi$ Mult.	Weight (%)	Events Generated	ϵ (%)
0	1.4	2×10^4	57.62
2	35.2	5×10^4	54.60
4	38.5	5×10^4	51.58
6	22.4	5×10^4	49.60
8	2.5	2×10^4	46.99
combined			52.25

this is an over estimate because the m_{recoil} distribution peaks at high m_{recoil} (see Fig. 5) unlike the distribution shown in Fig. 4. The background obtained by fitting should be much less, which means that the background due to this source is entirely negligible.

Results

Results for $N_{J/\psi}$, ϵ, and $N_{\psi'}$ are given in Table 4 for the 1993 and 1995 data sets and for status > 0 and status > 1.

The effect of changing cuts has also been studied. The results are shown in Tables 5 and 6, for '93 and '95 data samples, respectively. Adding the changes from the "Standard" run in

Table 3: Efficiency Results for '95 Data

$J/\psi \to n\pi$ Mult.	Weight (%)	Events Generated	ϵ (%)
0	1.4	1×10^5	56.96
2	35.2	1×10^5	54.74
4	38.5	1×10^5	52.03
6	22.4	1×10^5	49.97
8	2.5	5×10^4	47.92
combined			52.40

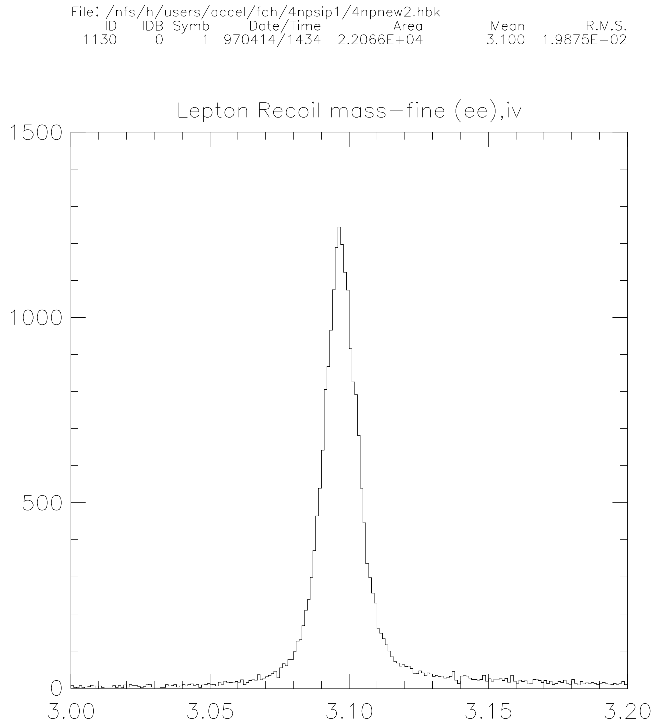

Figure 3: Number of events versus m_{recoil}, the mass recoiling against the two π's. The points with error bars are the 1995 data, and the histogram is the sum of the line shape obtained from $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and a forth order polynomial to represent background. The background is also shown. Note that Minfit allows fitting with histograms.

quadrature and combining this result in quadrature with the $B(\psi' \to \pi^+\pi^- J/\psi)$ uncertainty, we obtain the systematic errors given in Table 4. The dominant systematic error is due to $B(\psi' \to \pi^+\pi^- J/\psi)$, (0.324 ± 0.026) [12].

Summary

The number of ψ' events has been determined for the '93 and '95 data sets. The number does depend on the cuts used. For the cuts used here and for status > 0, the results are: $(1.31 \pm 0.02 \pm 0.13) \times 10^6$ for the '93 data and $(2.36 \pm 0.02 \pm 0.23) \times 10^6$ for the '95 data. The total is $(3.67 \pm 0.03 \pm 0.36) \times 10^6$.

References

[1] Harris, F. A., "Monte Carlo - Data Comparison of $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and the Number of ψ' Events", BES95, 333 (1995).

[2] Harris, F. A., "Study of $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$", Presented at the 5th Annual BES Meeting (1996).

Table 4: $N_{J/\psi}$, ϵ, and $N_{\psi'}$ Results

Data	Status	$\epsilon(\%)$	$N_{J/\psi}$	$N_{\psi'}$
1993	>1	52.23	216168 ± 2480	$(1.28 \pm 0.02 \pm 0.13) \times 10^6$
1995	>1	52.39	385419 ± 3341	$(2.27 \pm 0.02 \pm 0.22) \times 10^6$
1993	>0	52.23	221378 ± 2504	$(1.31 \pm 0.02 \pm 0.13) \times 10^6$
1995	>0	52.39	400775 ± 3422	$(2.36 \pm 0.02 \pm 0.23) \times 10^6$

Table 5: Systematic Studies - '93 Data and Status > 0

Variation	$N_{J/\psi}$	$N_{\psi'}$
Standard	221378	1308161
3rd Order Background	222818	1314680
$\cos\theta < .85$	239490	1298695
$\cos\theta < .75$	201802	1321826
mfit=2	207128	1269193
$\chi_\pi < 2.5$	211490	1290410
rcmass $(2.95 < m < 3.25)$	226988	1326154
no pxy_π cut	239303	1316207
$\Sigma Hit_\pi^{dE/dx} > 19$	219702	1312708
no $\chi_\pi^{dE/dx}$ cut	237160	1363768

Table 6: Systematic Studies - '95 Data and Status > 0

Variation	$N_{J/\psi}$	$N_{\psi'}$
Standard	400775	2361151
3rd Order Background	402728	2363765
$\cos\theta < .85$	430834	2326046
$\cos\theta < .75$	365270	2384883
mfit=2	370569	2271991
$\chi_\pi < 2.5$	383471	2336665
rcmass $(2.95 < m < 3.25)$	416500	2408771
no pxy_π cut	433359	2377573
$\Sigma Hit_\pi^{dE/dx} > 19$	397877	2374950
no $\chi_\pi^{dE/dx}$ cut	427833	2453680

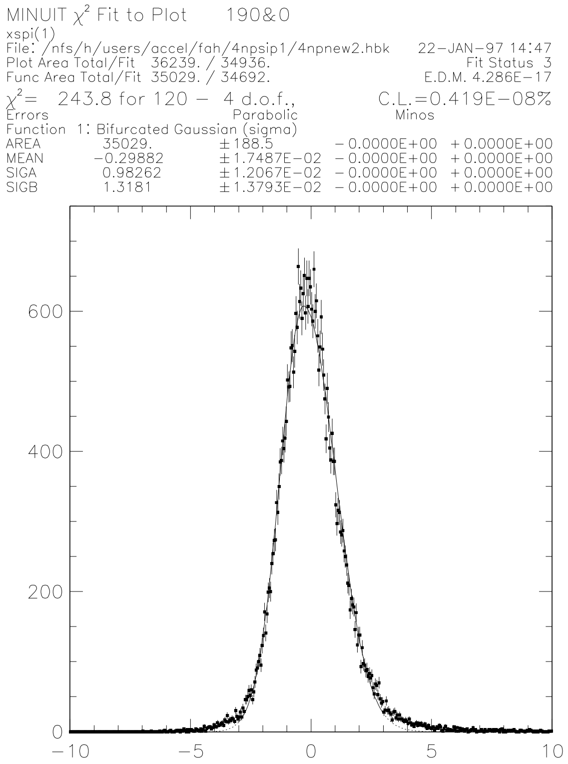

Figure 4: Number of events versus m_{recoil}, the mass recoiling against the two π's, for $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to l^+l^-$ events.

[3] Li, Jin, "Recent Results on ψ' and J/ψ from the BES Experiment at BEPC", Submitted to Glasgow Meeting, July 1994. This method has also been described in the drafts of $\psi' \to \tau^+\tau^-$.

[4] This magnetic field correction was determined from the distribution for the mass recoiling against the $\pi\pi$ system (m_{recoil}) for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to \mu^+\mu^-$. See http://www.phys.hawaii.edu/~fah/jpsimass.html for more detail.

[5] Bill Dunwoodie and Li Xinhua have studied the dE/dx and TOF information for the ψ' data and have written routines to correct it.

[6] There is a limit to how many combinations are allowed. The limit is 20 combinations satisfying cuts.

[7] OKSPI was written by Yuan Changzheng. It corrects for the shift observed and then uses 3 σ cuts in terms of the measured σ for each data set.

[8] Brock, I. C., L3 Note 918, June 1994.

[9] The $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events will be fully described in another analysis note, which is in preparation.

[10] The method used to determine the efficiency for $\psi' \to \pi^+\pi^- J/\psi$ is described in "Determination of the J/ψ Leptonic Branching Fraction via $\psi(2S) \to \pi^+\pi^- J/\psi$", draft of

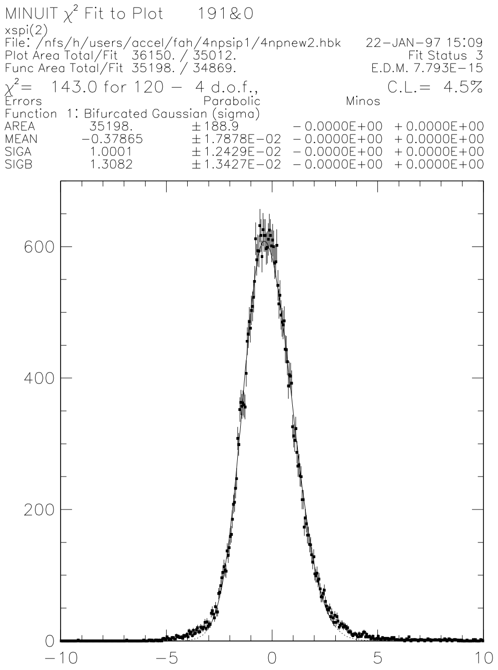

Figure 5: Number of events versus the mass recoiling against the two π's, for $\psi^{'} \rightarrow \eta J/\psi, \eta \rightarrow \gamma\pi^{+}\pi^{-}$ events.

Oct. 94. Weights quoted are 0, 2, 4, 6, and 8 prongs are 1.4%, 35.2%, 38.5%, 22.4%, and 2.5%, respectively.

[11] For the '93 data ('95 data), 100,000 (177,000) $\psi^{'} \rightarrow \pi^{+}\pi^{-}J/\psi$, $J/\psi \rightarrow e^{+}e^{-}$ and 100,000 (177,000) $\psi^{'} \rightarrow \pi^{+}\pi^{-}J/\psi$, $J/\psi \rightarrow \mu^{+}\mu^{-}$ events are generated using PPGEN.

[12] Particle Data Group.