Analysis Note: Update on the Number of ψ' Events and $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and $B(J/\psi \to l^+l^-)$

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Introduction

This analysis note is an update on the analysis notes on the Number of ψ' [1] and on $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and $B(J/\psi \to l^+l^-)$ [2]. The purpose of this note is to report the changes made since the first notes and to report the results obtained.

Changes

The following changes have been made in the analysis.

1. Mn_fit [3] is the fitting package used to determine the number of ψ's. While doing some tests, I found that the integrate command that I was using gave slightly incorrect results (1 - 1.5 %). Rather than use the integrate command in Mn_fit, I now sum the distribution and multiply by the normalization factor.

2. Previously, I included the Monte Carlo statistical errors in the statistical errors in the number of ψ' and in the branching ratio calculations. I now include these errors as part of the systematic errors. This has only a minimal effect.

3. I have increased the number of MC events generated for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$. I now generate 200000 each for ee and mumu for the old data and 370000 each for ee and mumu for the new data. This is approximately double what was used earlier.

4. I have switched from cutting on the $\pi\pi$ invariant mass to eliminate photon conversions to cutting on the cosine of the angle between the two pions, $\cos\theta_{\pi\pi}$, as is being done at IHEP. This makes no difference on the branching ratios but does allow comparing the $m_{\pi\pi}$ distribution to lower masses.

5. I have switched to the cuts agreed upon at IHEP during the BES collaboration meeting, which are $|\cos\theta_\mu| < 0.6$, $|\cos\theta_e| < 0.75$, $|\cos\theta_\pi| < 0.75$, and $p_{l^+} > 1.3$ or $p_{l^-} > 1.3$ or $p_{l^+} + p_{l^-} > 2.4$ GeV/c. Indicated below are comparisons of results using the old cuts and the new cuts. All runs use the new high statistics MC samples and cut on $\cos\theta_{\pi\pi}$.

Table 1: BR Results using $|\cos\theta_\pi| < 0.8$, $|\cos\theta_e| < 0.75$, $|\cos\theta_\mu| < 0.65$, P_{l^+} or $P_{l^-} > 1.4$ GeV/c.

Data	$N(\psi')$	$B(ee)(\%)$	$B(\mu\mu)(\%)$
1993	1.278×10^6	5.91 ± 0.10	6.08 ± 0.10
1995	2.382×10^6	6.02 ± 0.07	5.87 ± 0.07

Table 2: BR Results using $|\cos\theta_\pi| < 0.75$, $|\cos\theta_e| < 0.75$, $|\cos\theta_\mu| < 0.60$, P_{l^+} or $P_{l^-} > 1.3$ or $P_{l^+} + P_{l^-} > 2.4$ GeV/c.

Data	$N(\psi')$	$B(ee)(\%)$	$B(\mu\mu)(\%)$
1993	1.286×10^6	5.96 ± 0.10	6.12 ± 0.11
1995	2.403×10^6	6.06 ± 0.08	5.86 ± 0.08

Comparison of Fitting Methods

Derrick brought up a new PAW that includes BWFIT. I have written a series of KUMACS to do the fitting in a similar way to what is used by Wang Meng. The method is to fit the combined $\pi^+\pi^-l^+l^-$ recoil mass distributions to a Breit Wigner smeared by a Gaussian and a 3rd degree polynomial. The $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to$ anything recoil mass distribution is then fit with a smeared B-W with the same shape parameters and a 4th order polynomial. The $\pi^+\pi^-e^+e^-$ and $\pi^+\pi^-\mu^+\mu^-$ distributions are fit in a similar fashion but with a 3rd order polynomial rather than a 4th order polynomial. The results are shown in Table 3. Even more comparisons are given in Table 4.

I will switch to using the BWFIT approach below. This allows better comparison with IHEP results. It also seems to give slightly smaller errors and slightly better agreement between results. However forcing the m_{reciol} distribution with its muon tails to fit some function seems rather arbitrary. I still like the idea of fitting one histogram with another.

Table 3: Fitting Method Comparison. Cuts: $|\cos\theta_\pi| < 0.75$, $|\cos\theta_e| < 0.75$, $|\cos\theta_\mu| < 0.60$, P_{l^+} or $P_{l^-} > 1.3$ or $P_{l^+} + P_{l^-} > 2.4$ GeV/c.

Data	MN_FIT (%)	BWFIT (%)
'93 $N(\psi')$	$(1.286 \pm 0.016) \times 10^6$	$(1.281 \pm 0.005) \times 10^6$
'95 $N(\psi')$	$(2.403 \pm 0.022) \times 10^6$	$(2.408 \pm 0.007) \times 10^6$
'93 B(ee)	5.96 ± 0.10	5.98 ± 0.09
'93 B(mm)	6.12 ± 0.11	6.05 ± 0.09
'95 B(ee)	6.06 ± 0.08	6.03 ± 0.06
'95 B(mm)	5.86 ± 0.08	5.87 ± 0.06

Table 4: More Fitting Comparisons. Loose is the standard analysis. Tight means that only mnfit $= 2$ tracks are allowed and vertex cuts are made on the π tracks. Moderate cuts require mnfit $= 2$ tracks but impose less stringent vertex cuts.

Data	MN_FIT (%)	BWFIT (%)
'93 B(ee)-Loose	5.96 ± 0.10	5.98 ± 0.09
'93 B(ee)-Moder.	5.91 ± 0.10	5.95 ± 0.08
'93 B(ee)-Tight	5.94 ± 0.11	5.97 ± 0.09
'93 B(mm)-loose	6.12 ± 0.11	6.05 ± 0.09
'93 B(mm)-Moder.	6.09 ± 0.11	6.08 ± 0.09
'93 B(mm)-Tight	6.03 ± 0.11	6.05 ± 0.09
'95 B(ee)-Loose	6.06 ± 0.08	6.03 ± 0.06
'95 B(ee)-Moder.	6.04 ± 0.08	6.01 ± 0.06
'95 B(ee)-Tight	6.00 ± 0.08	6.01 ± 0.07
'95 B(mm)-Loose	5.86 ± 0.08	5.87 ± 0.06
'95 B(mm)-Moder.	5.86 ± 0.08	5.87 ± 0.07
'95 B(mm)-Tight	5.83 ± 0.08	5.85 ± 0.06

$N(\psi')$ Results

Results for $N_{J/\psi}$, ϵ, and $N_{\psi'}$ are given in Table 5 for the 1993 and 1995 data sets and for status > 0 and status > 1. The cuts agreed upon at IHEP during the collaboration meeting are used in addition to all the other cuts defined previously [1] [2].

Table 5: $N_{J/\psi}$, ϵ, and $N_{\psi'}$ Results

Data	Status	$\epsilon(\%)$	$N_{J/\psi}$	$N_{\psi'}$
1993	> 1	44.24	178773 ± 670	$(1.247 \pm 0.005 \pm 0.102) \times 10^6$
1995	> 1	43.97	330456 ± 924	$(2.320 \pm 0.007 \pm 0.197) \times 10^6$
1993	> 0	44.24	183644 ± 680	$(1.281 \pm 0.005 \pm 0.105) \times 10^6$
1995	> 0	43.97	343076 ± 943	$(2.408 \pm 0.007 \pm 0.204) \times 10^6$

The effect of changing cuts has also been studied. The results are shown in Table 6, along with the uncertainties due to the efficiency, fitting method, and $B(\psi' \to \pi^+\pi^- J/\psi)$ uncertainty [4]. Combining the results in quadrature, we obtain the systematic errors given in Table 5. The dominant systematic error is due to $B(\psi' \to \pi^+\pi^- J/\psi)$.

Table 6: Systematic Studies of $|\Delta N_{\psi'}|/N_{\psi'}$ (Status > 0)

Variable	Variation	'93 Data (%)	'95 Data (%)
$\lvert\cos\theta_\pi\rvert$ cut	$0.75 \to 0.80$	0.09	1.68
$\cos\theta_{\pi\pi}$ cut	$0.9 \to 0.85$	0.06	0.02
χ_π cut	$3.0 \to 5.0$	0.06	0.03
m_{recoil} cut	$\pm 0.1 \to \pm 0.15$	1.35	1.98
pxy_π cut	turn off	0.61	0.69
$\Sigma Hit_\pi^{dE/dx}$	$> 13 \to > 19$	0.35	0.58
Fitting Method		0.36	0.23
Efficiency Uncertainty		0.26	0.18
$\Delta B(\psi' \to \pi^+\pi^- J/\psi)$		8.02	8.02
Combined		8.17	8.48

Branching Ratio Results

The branching ratio results are given in Table 7. NOTE: The small corrections for backgrounds and for data-Monte Carlo efficiency differences have not been put in. These differences are included in the systematic errors.

Table 7: FINAL RESULTS - icode > 0.

Result	'93 Data (%)	'95 Data (%)
$B(ee)$	$5.98 \pm 0.09 \pm 0.07$	$6.03 \pm 0.06 \pm 0.13$
$B(\mu\mu)$	$6.05 \pm 0.09 \pm 0.13$	$5.87 \pm 0.06 \pm 0.13$

In order to determine the systematic error, we have made many variations of our cuts. The results, along with the uncertainties in the efficiency and fitting method, are given in Table 8.

Table 8: Branching Ratio Systematic Errors (%)

Variable	Change	'93 $B(ee)$	'93$B(\mu\mu)$	'95 $B(ee)$	'95$B(\mu\mu)$
Run Status	$> 0 \rightarrow > 1$	0.39	0.08	0.13	0.86
$\lvert\cos\theta_\pi\rvert$ cut	$0.75 \rightarrow 0.80$	0.30	1.14	0.48	0.29
$\cos\theta_{\pi\pi}$ cut	$0.9 \rightarrow 0.85$	0.02	0.02	0.02	0.07
χ_π cut	$3.0 \rightarrow 5.0$	0.23	0.83	0.86	1.23
m_{recoil} cut	$\pm 0.1 \rightarrow \pm 0.15$	0.50	0.53	1.18	1.01
p_{xy} cut	turn off	0.20	0.23	0.28	0.51
$\Sigma Hit_\pi^{dE/dx}$	$> 13 \rightarrow > 19$	0.40	0.36	0.41	0.35
$\lvert\cos\theta_\mu\rvert$ cut	$0.6 \rightarrow 0.65$	0.34	0.12	0.08	0.15
$\lvert\cos\theta_e\rvert$ cut	$0.75 \rightarrow 0.7$	0.17	0.02	0.40	0.05
$\cos\theta_{l^+l^-}$ and $\cos\theta_{l^+l^-}^{cm}$ cuts	turn off	0.29	0.26	0.48	0.47
p_l^+ or p_l^-	$> 1.3 \rightarrow > 1.4$ GeV/c	0.37	0.13	0.42	0.15
Fitting Method		0.33	1.14	0.50	0.17
Efficiency Uncertainty		0.46	0.49	0.34	0.35
PID Uncertainties		0.10	0.55	0.90	0.90
Combined		1.20	2.08	2.09	2.23

The '95 data shows a large change for $B(\mu\mu)$ in going from $icode > 0$ to $icode > 1$. I have investigated the ratio of 4 prong ee events to 4 prong $\mu\mu$ events by run number for the old and new data. The plots for $icode > 0$ and $icode > 1$ for the '93 data are shown in Figs. 1 and 2, respectively. The corresponding plots for $icode > 0$ and $icode > 1$ for the '95 data are shown in Figs. 3 and 4, respectively. We obtain better consistency from run to run in the '95 data if we impose $icode > 1$.

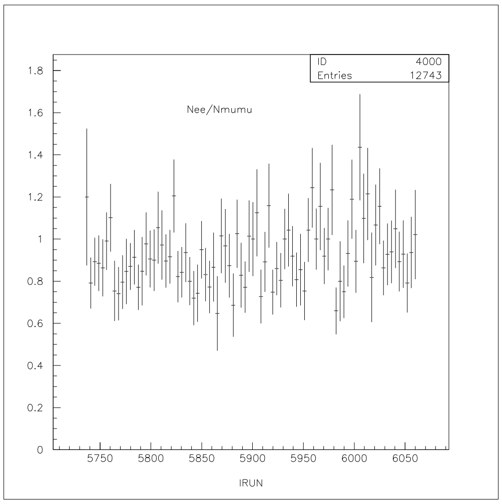

Figure 1: Number of 4 prong ee events divided by the number of 4 prong $\mu\mu$ events by run for $icode > 0$ in the '93 data.

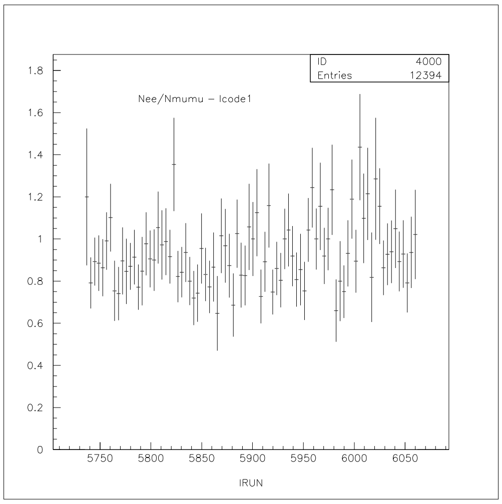

Figure 2: Number of 4 prong ee events divided by the number of 4 prong $\mu\mu$ events by run for $icode > 1$ in the '93 data.

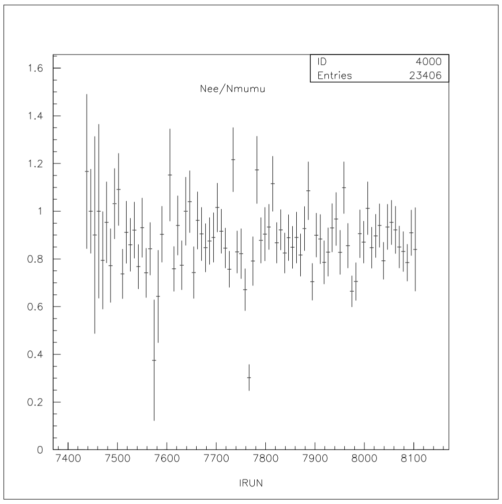

Figure 3: Number of 4 prong ee events divided by the number of 4 prong $\mu\mu$ events by run for $icode > 0$ in the '95 data.

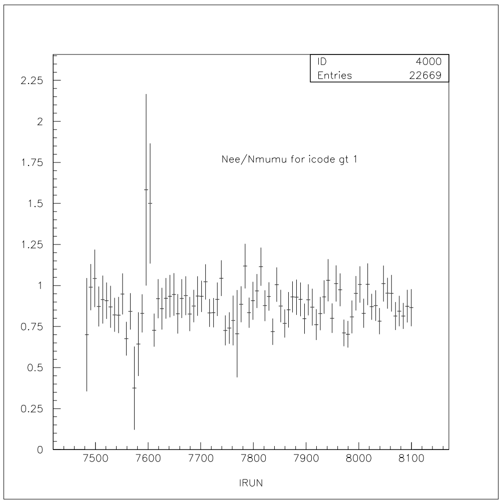

Figure 4: Number of 4 prong ee events divided by the number of 4 prong $\mu\mu$ events by run for $icode > 1$ in the '95 data.

Table 9: FINAL RESULTS - icode > 1.

Result	'93 Data (%)	'95 Data (%)
$B(ee)$	$5.96 \pm 0.09 \pm 0.07$	$6.01 \pm 0.06 \pm 0.13$
$B(\mu\mu)$	$6.05 \pm 0.09 \pm 0.13$	$5.92 \pm 0.07 \pm 0.13$

Combining for *icode* > 1, we obtain:

$$BR(ee) = (6.00 \pm 0.05 \pm 0.10)\%$$

$$BR(\mu\mu) = (5.96 \pm 0.05 \pm 0.13)\%$$

$$BR(ll) = (5.98 \pm 0.04 \pm 0.12)\%$$

Using the statistical errors only, we can calculate the χ^2:

$$\chi^2 = 1.9$$

$$CL \approx 60\%$$

References

[1] See: "Analysis Note: Number of ψ' Events", F. A. Harris, 5/1997.

[2] See: "Analysis Note: $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ and $B(J/\psi \to l^+l^-)$, F. A. Harris, 5/1997.

[3] MnFit: Brock, I. C., L3 Note 918, June 1994.

[4] Particle Data Group