BES Analysis Memo

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$\psi_{2S} \to \gamma\eta'$ and $\gamma\eta$

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-ABSTRACT-

We report the first observation of $\psi_{2S} \to \gamma\eta'$ in the 3.6 million ψ_{2S} event sample collected by the BES detector. Using the $\eta' \to \pi^+\pi^-\eta$ and the $\eta' \to \gamma\rho$ decay channels, we determine a branching fraction $\mathcal{B}(\psi_{2S} \to \gamma\eta') = 1.44 \pm 0.29 \pm 0.28 \times 10^{-4}$. We also see a marginal signal for $\psi_{2S} \to \gamma\eta$ that is used to establish a 90% CL upper limit of $\mathcal{B}(\psi_{2S} \to \gamma\eta) < 1.0 \times 10^{-4}$. If the signal is treated as real, we find $\mathcal{B}(\psi_{2S} \to \gamma\eta) = 0.56 \pm 0.31 \pm 0.11 \times 10^{-4}$.

1 Introduction

Both Ye Shuwei [1] and I [2] have prepared analysis memos for the measurement of $\mathcal{B}(\psi_{2S} \to \gamma\eta')$ using the decay chains

$$\begin{array}{llllllll} \psi_{2S} & \to & \gamma\eta' & & & & & \\ & & \eta' & \to & \pi^+\pi^-\eta & & & \\ & & & & \eta & \to & \gamma\gamma, & \end{array} \tag{1}$$

where Shuwei gets $\mathcal{B}(\psi_{2S} \to \gamma\eta') = (7.8 \pm 3.7 \pm 2.6) \times 10^{-5}$ and I got $(1.98 \pm 0.67) \times 10^{-4}$, and

$$\begin{array}{llllllll} \psi_{2S} & \to & \gamma\eta' & & & & & \\ & & \eta' & \to & \gamma\rho^0 & & & \\ & & & & \rho^0 & \to & \pi^+\pi^-, & \end{array} \tag{2}$$

where Shuwei gets $\mathcal{B}(\psi_{2S} \to \gamma\eta') = (1.15 \pm 0.25 \pm 0.35) \times 10^{-4}$, and I got $(1.46 \pm 0.61) \times 10^{-4}$. For the $\eta' \to \gamma\rho$ mode, my signal was marginal while Shuwei's was quite distinct. In the $\eta' \to \pi^+\pi^-\eta$ case I had more events than Shuwei.

Shuwei also investigates the decay chain:

$$
\begin{array}{llllll}
\psi_{2S} & \rightarrow & \gamma\eta & & & \\
& & \eta' & \rightarrow & \pi^+\pi^-\pi^0 & \\
& & & & \pi^0 & \rightarrow \gamma\gamma,
\end{array}
\tag{3}
$$

and derives a 90% CL upper limit of $\mathcal{B}(\psi_{2S} \rightarrow \gamma\eta) < 5.4 \times 10^{-5}$.

In this note I report results of my attempts to rationalize the difference between the two analysis. I concentrate on the cuts and various distributions. I do not reproduce most of the text of the two previous memos.

2 The $\eta' \rightarrow \gamma\rho^0$ measurement

I incorporated Shuwei's opening angle cuts and limit on the total energy in the charged tracks. I did not include Shuwei's tight restriction on the number of extra γ's or unmatched γ energy. I removed my cut that required $E^{BSC}_{\pi^+,\pi^-} > 0.05$ GeV. For the $\pi^+\pi^-$ mass cut, I use $M_\rho \pm \Gamma^{tot}_\rho$. I think Shuwei's cut of $0.4 < M_{\pi^+\pi^-} < 0.9$ is too broad.

The numbers of events that pass each preselection and selection criterion are listed in Table 1. The relevant distributions before the application of the selection cut are shown in We use Monte Carlo simulated events to evaluate the acceptance and the effects of the selection criteria. The events are generated with a $1 + \cos^2\theta$ angular distribution for the γ in the $\psi_{2S} \rightarrow \gamma\eta'$ decay, and with helicity conserving $\rho \rightarrow \pi^+\pi^-$ decays for the ρ-mesons from the $\eta' \rightarrow \gamma\rho$ decay. Fig. 1 for the simulated Monte Carlo events and Fig. 2 for the data.

In Fig. 3, I show the $\gamma\rho$ mass distribution resulting from these cuts together with a fit to a gaussian and third-order polynomial background function. The fit gives $N_{evt} = 26.6 \pm 7.1$ events. The background function underestimates the background in the $\pi^+\pi^-\gamma$ mass region around 1.35 GeV. However, limiting the fit to $M_{\pi^+\pi^-\gamma} < 1.2$ GeV changes N_{evt} by less than 5%.

A similar fit to the Monte Carlo distribution gives $N^{MC}_{evt} = 186$. I use the latter to infer an acceptance of $accept_{\gamma\rho} = 0.19 \pm 0.02$, where the 10% error reflects both the Monte Carlo statistics and the difference in acceptance that is determined when isotropic decay distributions are used for the $\psi_{2S} \rightarrow \gamma\eta'$ and $\rho \rightarrow \pi^+\pi^-$ decays. Shuwei uses a wider ρ mass cut and has a higher efficiency (22.1%).

Table 1: A tabulation of the $\psi_{2S} \to \pi^+\pi^-\gamma\gamma$ selection cuts.

The number of events surviving each requirement

	data	Monte Carlo
Generated		1000
Preselection		
2 chrgd trks		
$\sum q = 0$		
$2 \geq N_\gamma \leq 10$	940920	628
$N_\mu < 2$	911868	628
$N_{e^+,e^-} < 2$	705285	626
$\lvert\cos\theta_{trk}\rvert \leq 0.8$	534749	476
$E_\gamma > 0.05$GeV		
$\lvert\cos\theta_\gamma\rvert \leq 0.8$	461431	438
$\chi^2_{4c} \leq 50$	62616	312
Selection		
$p_{\pi^+,\pi^-} > 0.08$	62226	312
$M_{\pi^+\pi^-} < 3.0$	50670	312
$\theta_{\pi^+\pi^-} < 130^0$	13901	312
$E^{BSC}_{\pi^+,\pi^-} < 0.80$	11170	312
$\lvert\cos\theta_{\gamma\pi}\rvert < 0.98$	10146	297
$E_{\pi^+} + E_{\pi^-} < 2.2$	6331	278
$\theta_{\gamma\gamma} > 110^0$	4443	260
$\chi^2_{4c} < 15$	1774	229
$\lvert M_{\pi^+\pi^-} - M_\rho\rvert < 0.15$	630	197

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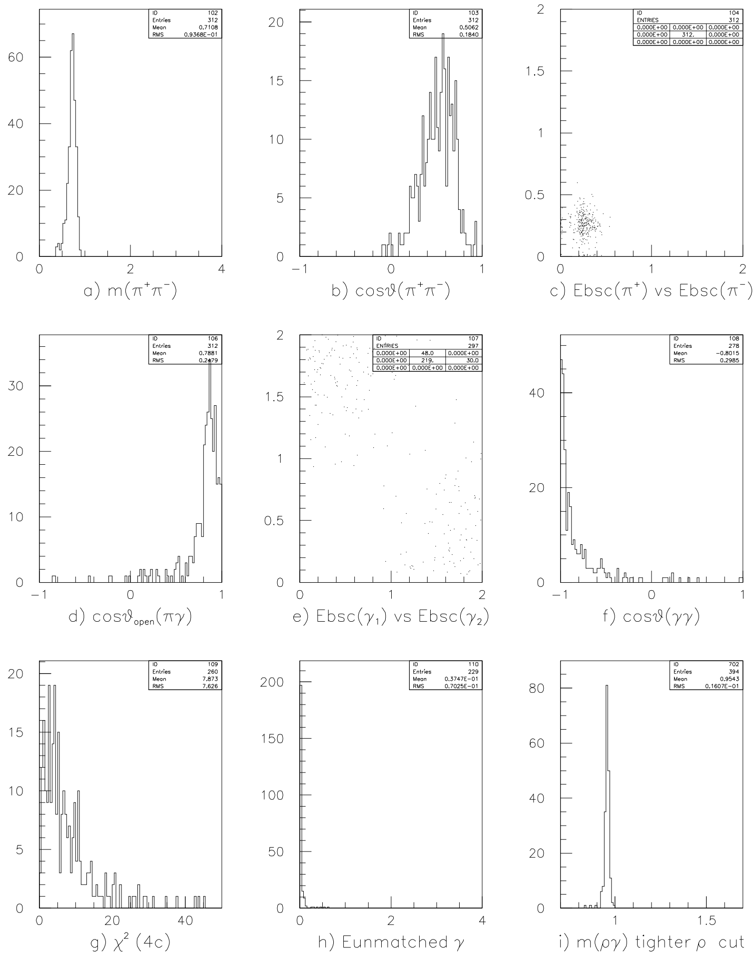

Figure 1: The distributions of the selection cut variables prior to the application of the cut. Simulated Monte Carlo $\psi_{2S} \to \gamma\gamma\rho$ events.

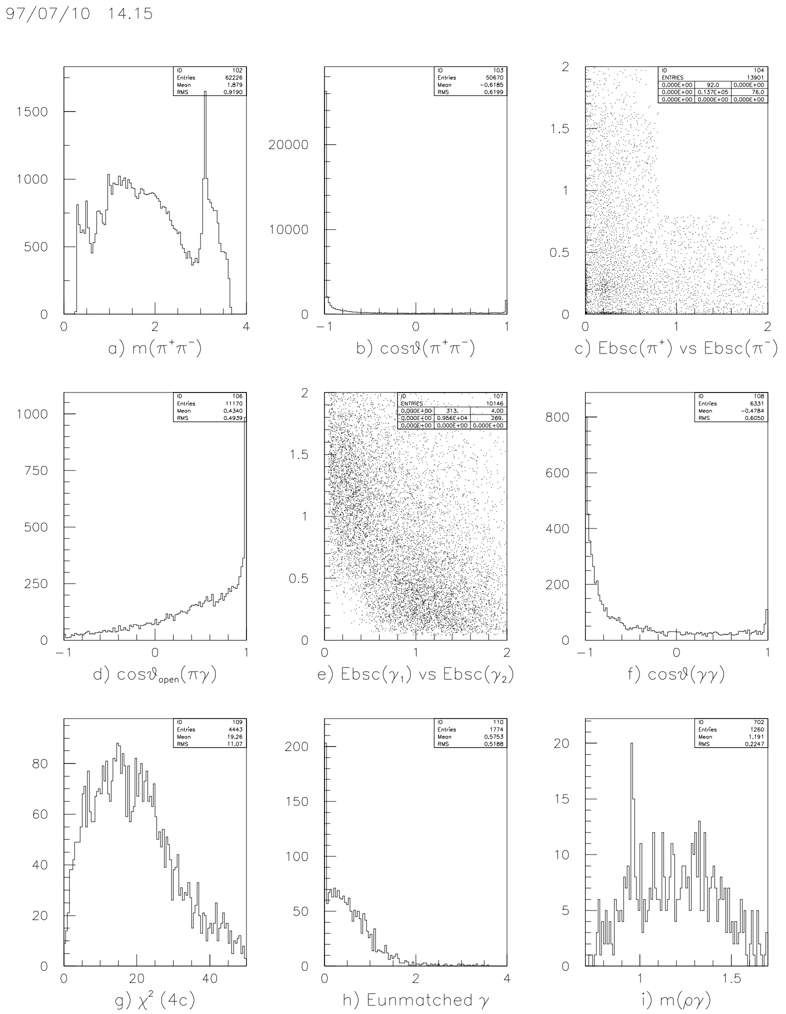

Figure 2: The distributions of the selection cut variables prior to the application of the cut. The $\pi^+\pi^-\gamma\gamma$ data.

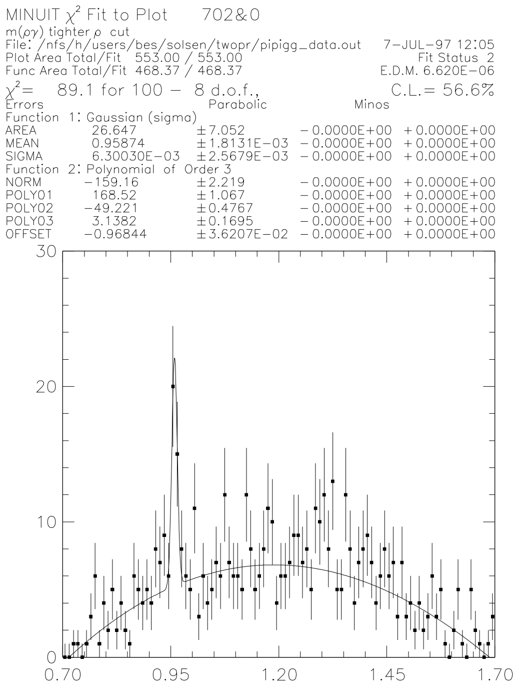

Figure 3: The $\gamma\pi^+\pi^-$ mass distribution for selected events. The smooth curve is the fit described in the text.

The $\psi_{2S} \rightarrow \gamma\eta'$ branching ratio is determined from the relation

$$\begin{aligned} \mathcal{B}(\psi_{2S} \rightarrow \gamma\eta' \rightarrow \gamma\gamma\rho) &= \frac{N_{evts} - N_{bkg}}{N_{\psi_{2S}} \mathcal{B}(\eta' \rightarrow \gamma\rho) accept_{\gamma\rho}} \\ &= (1.29 \pm 0.34 \pm 0.22) \times 10^{-4}, \end{aligned} \tag{4}$$

where N_{evt} is the number of background events from $\psi_{2S} \rightarrow J/\psi$ cascade decays that peak in the η' mass region. For this, I used $N_{bkg} = 1.4 \pm 0.5$, which was determined by Ye for a similar set of cuts [1]. where the first error is statisical and the second error the systematic error due primarily to uncertainties in $N_{\psi_{2S}}$, the acceptance and the effect of the choice of selection cuts, which is estimated to be 10% [4]. (I use $N_{\psi_{2S}} = (3.44 \pm 0.31) \times 10^6$, rather than the "official" number of 3.73M events, because I only use the two-prong DST files for my analysis, and my determination of the 3.44M includes a correction for the number of real two-prong events that end up in other DST files [3].)

The branching fraction I determine is higher than Shuwei's. This difference is essentially all attributable to his cut on the energy of γ's that are not used in the analysis. Figure 4 shows the $\gamma\rho$ mass distribution when Shuwei's $E_{nunk} < 0.2$ GeV is applied. Here the background is substantially reduced, but so is the signal: the fit gives $N_{evt} = 22.1 \pm 5.1$ events. The MC shows no loss of signal associated with this cut. (The E_{nunk} distribution for MC events is shown in Fig. 1h.) Using this result in eqn. 4 above reduces the branching fraction by 17% to 1.13×10^{-4}, which reproduces Shuwei's result.

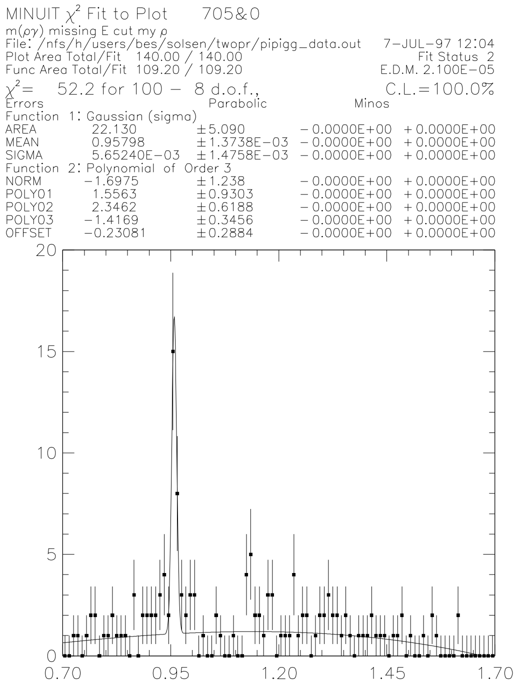

Figure 4: The $\gamma\pi^+\pi^-$ mass distribution for selected events with the unmatched γ energy cut applied.

3 The $\eta' \rightarrow \pi^+\pi^-\eta$ analysis

Here I incorporate Shuwei's opening angle and charged track energy and invariant mass cuts. I do not restrict the number or energy of unused $\gamma's$. Instead, to enhance signal to noise I make tighter $\chi^2 < 12$ and a tighter $|M_{\gamma\gamma} - M_\eta| < 0.03$ GeV cuts. The latter cut is twice the MC-determined resolution.

The numbers of events that pass each preselection and selection criterion are listed in Table 2. A sample of Monte Carlo simulated events is used to evaluate the acceptance and effects of the cuts. The relevant distributions before the application of the selection cut are shown in Fig. 5 for the simulated Monte Carlo events and Fig. 6 for the data.

Figure 7 shows the $\pi^+\pi^-\eta$ mass distribution resulting from these cuts. The smooth curve is the result of a fit to the measured mass distribution with the $\eta(958)$ represented

Table 2: A tabulation of the $\psi_{2S} \to \gamma\pi^+\pi^-\eta$ selection cuts.

The number of events surviving each requirement

	data	Monte Carlo
Generated		1000
Preselection		
2 chrgd trks		
$\sum q = 0$		
$3 \geq N_\gamma \leq 10$	556619	600
$N_\mu < 2$	538954	600
$N_{e^+,e^-} < 2$	468850	600
$\lvert\cos\theta_{trk}\rvert \leq 0.8$	371013	480
$E_\gamma > 0.05$GeV		
$\lvert\cos\theta_\gamma\rvert \leq 0.8$	288974	343
$\chi^2_{4c} \leq 50$	81734	280
Selection		
$p_{\pi^+,\pi^-} > 0.08$	81332	278
$M_{\pi^+\pi^-} < 0.42$	6865	277
$\theta_{\pi^+\pi^-} < 70^0$	6190	277
$E_{\pi^+} + E_{\pi^-} < 1.2$	4899	276
$\theta_{\gamma\pi} > 5^0$	4653	261
$\theta_{\gamma\gamma} > 30^0$	4096	254
$\chi^2_{4c} < 12$	1333	190
$\lvert M_{\gamma\gamma} - M_\eta\rvert < 0.03$	135	139

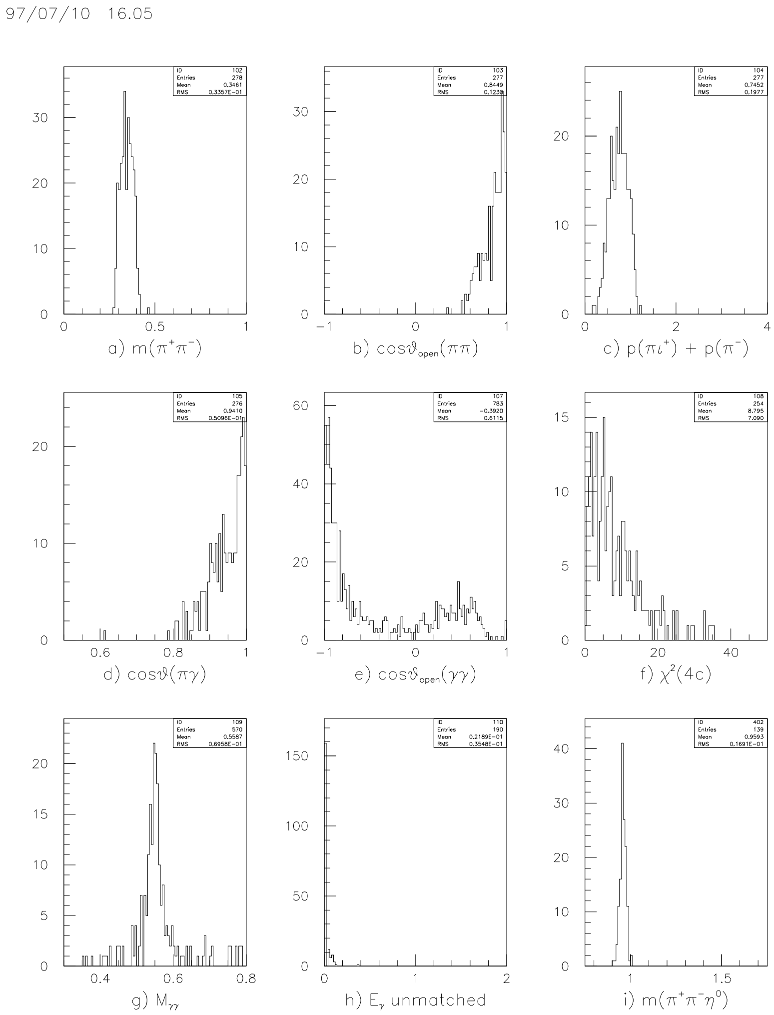

Figure 5: The distributions of the selection cut variables prior to the application of the cut. Simulated Monte Carlo $\psi_{2S} \to \gamma\pi^+\pi^-\eta$ events.

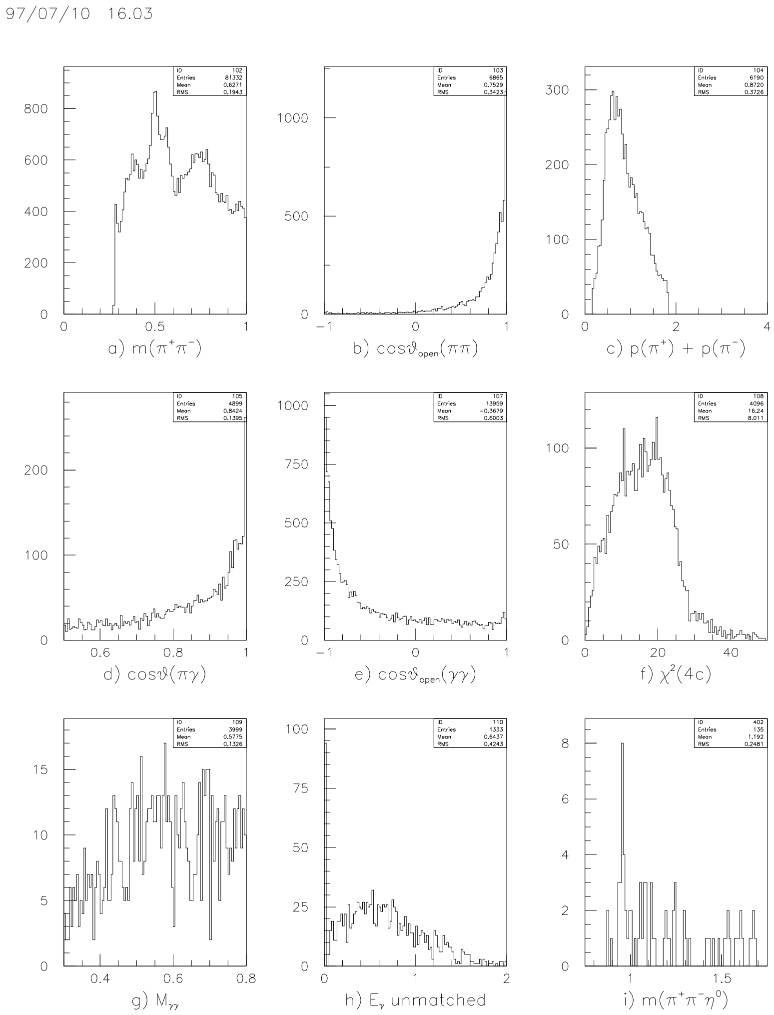

Figure 6: The distributions of the selection cut variables prior to the application of the cut. The $\gamma\pi^+\pi^-\eta$ data.

as a gaussian centered at $M = 0.958$ GeV and a smooth background function of the form

$$\begin{aligned} f_{bkg}(Q) &= p_1(Q^{1/2} + p_2 Q^{3/2} + p_3 Q^{5/2}) \quad Q > 0 \\ &= 0 \qquad\qquad\qquad\qquad\qquad\qquad Q \leq 0, \end{aligned} \tag{5}$$

where $Q \equiv M - (2M_\pi + M_\eta)$. The fitted gaussian has $N_{evts} = 15.3 \pm 4.8$ events. A fit to the simulated Monte Carlo events that survive the same cuts gives $N^{mc}_{evt} =$ 139.7 events. A Monte Carlo simulation using events with an isotropic $\psi_{2S} \to \gamma\eta'$ decay distribution gives an acceptance that is increased by For acceptance we use $accept_{\pi^+\pi^-\eta} = 0.14 \pm 0.02$, where the error includes the MonteCarlo statistics and possible differences in the decay angular distribution. Shuwei's efficiency is 15%.

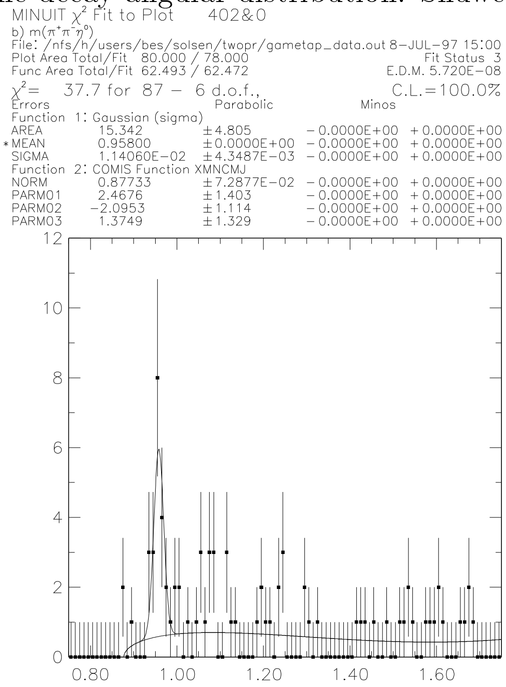

Figure 7: The $\pi^+\pi^-\eta$ mass distribution for selected events. The smooth curve is the fit described in the text.

The $\psi_{2S} \to \gamma\eta'$ branching ratio is determined from the relation

$$\begin{aligned} \mathcal{B}(\psi_{2S} \to \gamma\eta') &= \frac{N_{evts} - N_{bkg}}{N_{\psi_{2S}} \mathcal{B}(\eta' \to \pi^+\pi^-\eta)\mathcal{B}(\eta \to \gamma\gamma) accept_{\pi\pi\eta}} \\ &= (1.82 \pm 0.56 \pm 0.46) \times 10^{-4}, \end{aligned} \tag{6}$$

where I use Ye's result of $N_{bkg} = 0.35 \pm 0.3$ for the estimated number of background events from $\psi_{2S} \to J/\psi$ cascade decays [1]. In this analysis, the most sensitive selection requirements are the γ-track opening angle cut and the $\gamma\gamma$ mass cut. Increasing the opening angle cut from $> 5^0$ to $> 11.5^0$ and the $\gamma\gamma$ mass cut from ± 30 MeV around M_η to ± 50 MeV, changes the result by 20%. This has been added in quadrature to the systematic error.

This agrees well with the result determined for the $\eta' \to \gamma\rho$ mode, and about a factor of two higher than Shuwei's result. This difference is also attributable to his cut on the energy of γ's that are not used in the analysis. Figure 8 shows the $M_{\gamma\rho}$ mass distribution when Shuwei's $E_{nunk} < 0.2$ is applied. Here the signal is substantially reduced: the fit gives $N_{evt} = 9.0 \pm 4.3$ events. The MC shows no loss of signal associated with this cut (see Fig. 5h). Using this result in eqn. 6 above reduces the branching fraction by 41% to 1.1×10^{-4}, which is not too different from Shuwei's result.

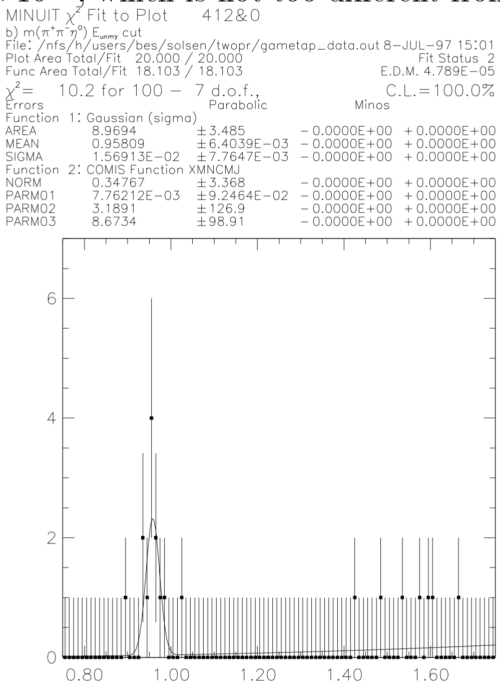

Figure 8: The $\pi^+\pi^-\eta$ mass distribution for selected events with the unmatched γ energy cut applied.

4 The $\psi_{2S} \to \gamma\eta$ analysis

Here I use the same preselect cuts as for the $\eta' \to \pi^+\pi^-\eta$ analysis, with changes in the opening angle and charged track energy and invariant mass cuts to match the

Table 3: A tabulation of the $\psi_{2S} \to \gamma\eta \to \gamma\pi^+\pi^-\pi^0$ selection cuts.

The number of events surviving each requirement

	data	Monte Carlo
Generated		1000
Preselection		
2 chrgd trks		
$\sum q = 0$		
$3 \geq N_\gamma \leq 10$	556619	452
$N_\mu < 2$	538954	451
$N_{e^+,e^-} < 2$	468850	450
$\lvert\cos\theta_{trk}\rvert \leq 0.8$	371013	379
$E_\gamma > 0.05$GeV		
$\lvert\cos\theta_\gamma\rvert \leq 0.8$	288974	252
$\chi^2_{4c} \leq 50$	81734	210
Selection		
$p_{\pi^+,\pi^-} > 0.08$	81332	210
$M_{\pi^+\pi^-} < 0.42$	6865	209
$\theta_{\pi^+\pi^-} < 70^0$	6190	209
$E_{\pi^+} + E_{\pi^-} < 1.7$	6049	208
$\theta_{\gamma\pi} > 5^0$	5695	182
$\chi^2_{4c} < 12$	2045	133
$\lvert M_{\gamma\gamma} - M_{\pi^0}\rvert < 0.025$	96	102

conditions for $\pi^0 \to \gamma\gamma$ decays. I use a $|M_{\gamma\gamma} - M_{\pi^0}| < 0.025$ GeV cuts, which is twice the MC-determined resolution.

The numbers of events that pass each preselection and selection criterion are listed in Table 3. The relevant distributions before the application of the selection cut are shown in Fig. 9 for the simulated Monte Carlo events and Fig. 10 for the data.

Figure 11 shows the $M_{\pi^+\pi^-\pi^0}$ mass distribution resulting from these cuts. The smooth curve is the result of a fit to the measured mass distribution with the $\eta(547)$ represented as a gaussian centered at $M = 0.547$ GeV and a smooth background function of the form given in eqn. 5 above. The fitted gaussian has $N_{evts} = 4.4 \pm 2.6$ events. This corresponds to a 90% CL upper limit of $N^{90\%}_{evt} < 7.7$ events.

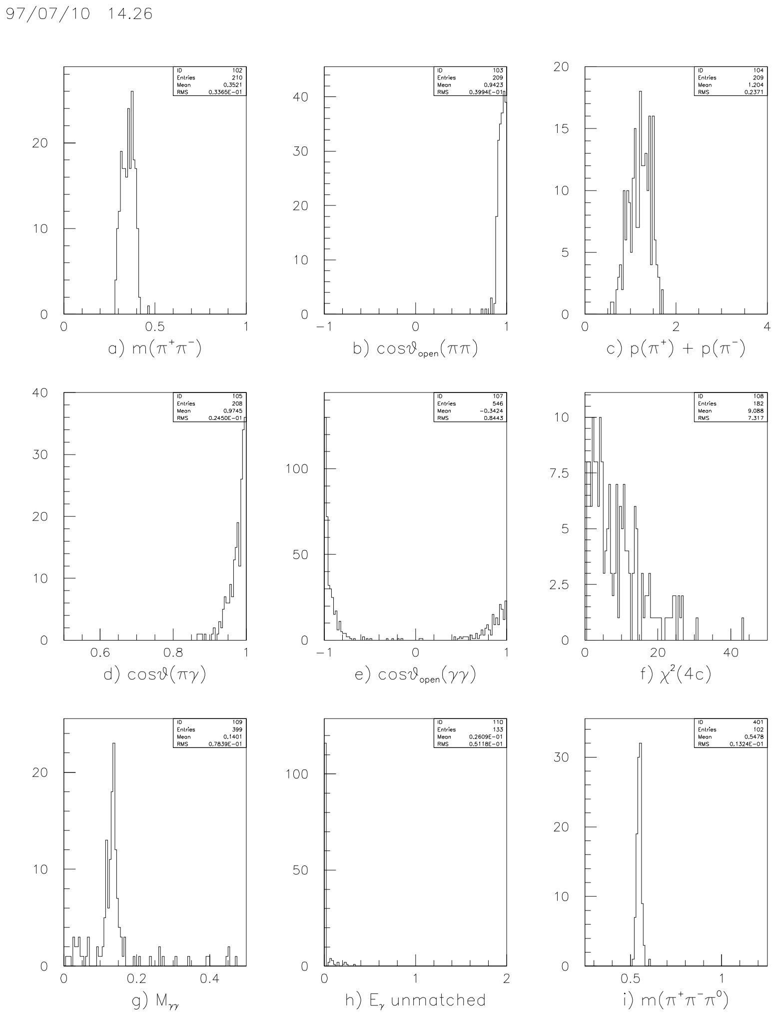

Figure 9: The distributions of the selection cut variables prior to the application of the cut. Simulated Monte Carlo $\psi_{2S} \to \gamma\pi^+\pi^-\pi^0$ events.

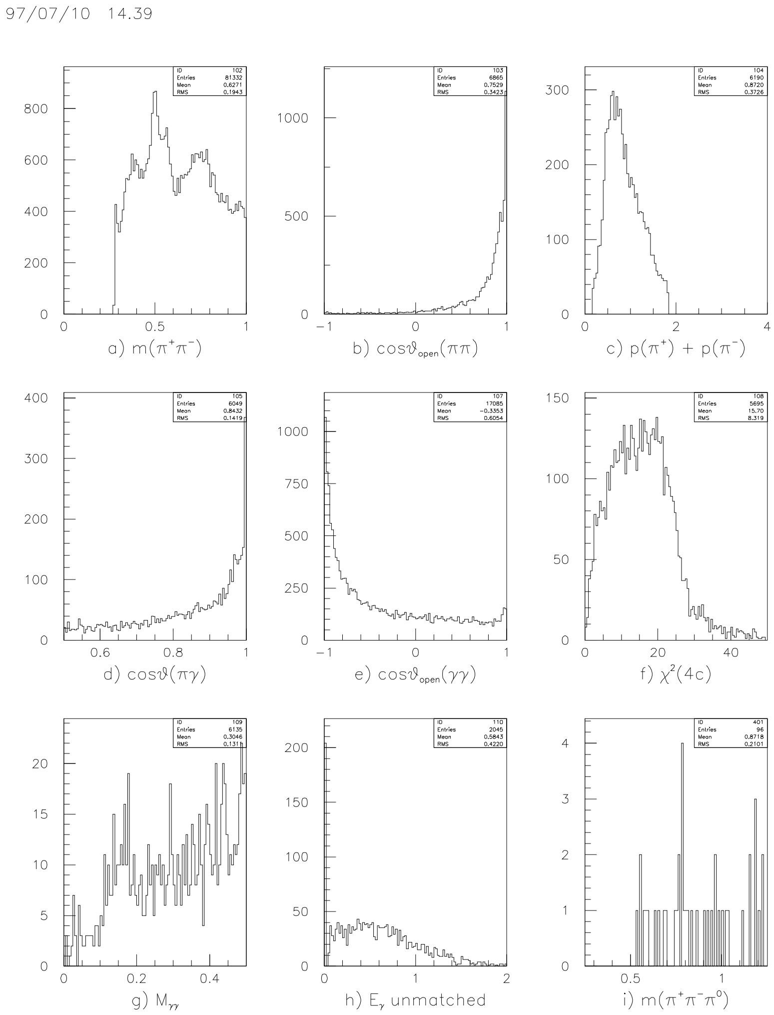

Figure 10: The distributions of the selection cut variables prior to the application of the cut. The $\gamma\pi^+\pi^-\pi^0$ data.

A fit to the simulated Monte Carlo events that survive the same cuts gives $N_{evt}^{mc} = 99$ events. For acceptance we use $accept_{\pi^+\pi^-\pi^0} = 0.10 \pm 0.01$. Shuwei uses an efficiency of 12%.

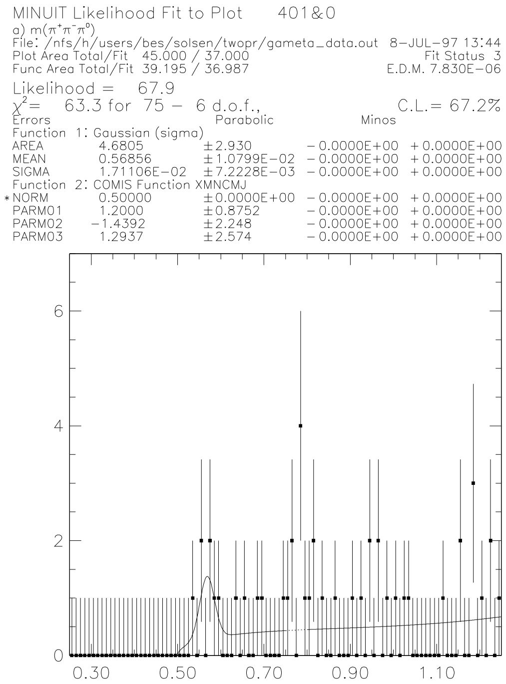

Figure 11: The $\pi^+\pi^-\pi^0$ mass distribution for selected events. The smooth curve is the fit described in the text.

A 90% CL upper limit on the $\psi_{2S} \to \gamma\eta$ branching ratio is determined from the relation

$$\begin{aligned} \mathcal{B}(\psi_{2S} \to \gamma\eta) &< \frac{N_{evts}^{90\%}}{N_{\psi_{2S}}\mathcal{B}(\eta' \to \pi^+\pi^-\pi^0)\mathcal{B}(\pi^0 \to \gamma\gamma)accept_{\pi\pi\pi^0}} \\ &= 1.0 \times 10^{-4}, \end{aligned} \tag{7}$$

which is higher than Shuwei's result, again because of his unmatched γ energy cut. When I apply Shuwei's $E_{nunk} < 0.2$ GeV cut, I am left with only two events in the η region. In this case I would get an upper limit of 6.9×10^{-5}, close to Shuwei's result.

Treating the signal as real results in a branching ratio of $\mathcal{B}(\psi_{2S} \to \gamma\eta) = (5.6 \pm 3.1 \pm 1.1) \times 10^{-5}$.

5 Summary

A close comparison of my analysis with that of Shuwei's indicates quite good agreement in all areas except for the application on the $E_{nunk} < 0.2$ cut. If I apply this cut in my analysis, I find good agreement with Shuwei. However, since the Monte Carlo does not determine the efficiency for this cut, I deem it inappropriate to use.

Combining my two results $\mathcal{B}(\psi_{2S} \to \gamma\eta')$,

$$\mathcal{B}(\psi_{2S} \to \gamma\eta') = (1.44 \pm 0.29 \pm 0.28) \times 10^{-4} \tag{8}$$

6 Acknowledgements

This research is supported by the U.S. Department of Energy research grant number DE-FG03-94ER40833. This work was aided by my colleagues in the Hawaii BES group.

References

[1] S.W. Ye, *Analysis memo of* $\psi(2S) \to \gamma\eta'(958)$, June 18, 1997.

[2] S.L. Olsen, BES Analysis Memo: *Observation of* $\psi' \to \gamma\eta'(958)$, October 24, 1996 (revised November 26, 1996).

[3] J.Z. Bai *et al.* (BES Collaboration), *Branching fractions for* ψ_{2S} *decays to octet-baryon pairs*, paper submitted to the 1995 International Symposium on Lepton and Photon Interactions at High Energies, Beijing, China.

[4] The analysis of the $\eta' \to \gamma\rho$ channel reported in ref. [2] used the same data and very different cuts. The result agrees with the present result to within 10%.