Search for h_c and Measurement of $B(\psi(2S) \to \eta J/\psi)$

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SEARCH FOR H_C

The h_c is supposed to be a $^1P_1$ $c\bar{c}$ state. Although it has been seen by E760 [1], it is not listed in the PDG summary table as, according to the PDG, it requires confirmation [2]. It is therefore an interesting state to look for, and George Hou has suggested that it be looked for using BES data. The mass and width of the h_c are 3526.14 ± 0.24 MeV/c^2 and < 1.1 MeV/c^2, respectively, and the decay mode seen was $h_c \to \pi^o J/\psi$ [2].

This analysis uses the same data sample that is used in the $\psi^{'} \to \pi^+\pi^- J/\psi$ analysis [3]. The only cut that is changed is the cut on the mass recoiling against the $\pi\pi$ system in order to allow searching for higher mass states than the J/ψ. Only charged tracks in four prong events are used in this preliminary analysis.

$\psi(2S) \to \pi^+\pi^- h_c$

Although not allowed kinematically for the h_c mass value listed by the PDG (3526 GeV/c^2), the process $\psi(2S) \to \pi^+\pi^- h_c$ was searched for in the distribution of the mass recoiling against the $\pi^+\pi^-$ system, m_{recoil}. The scatterplot of the invariant mass of the $\pi^+\pi^-$ system, $ivmass$, versus m_{recoil} is shown in Fig. 1. A large cluster of events corresponding to the $\psi^{'} \to \pi^+\pi^- J/\psi$ process is clearly visible. The m_{recoil} distribution for $m_{recoil} > 3.14$ GeV/c^2 is shown in Fig. 2. No events are seen (or expected) at $m_{h_c} = 3526$ MeV/^{2}, but there is an interesting enhancement at $\sim 3250 MeV/c^2$!

FIGURES

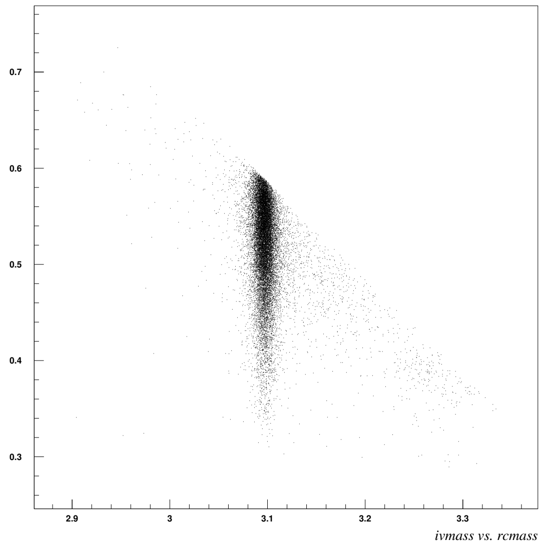

FIG. 1. Plot of $ivmass$, which is the invariant mass of the $\pi^+\pi^-$ system, versus m_{recoil}. The large cluster of events is due to $\psi^{'} \rightarrow \pi^+\pi^- J/\psi$.

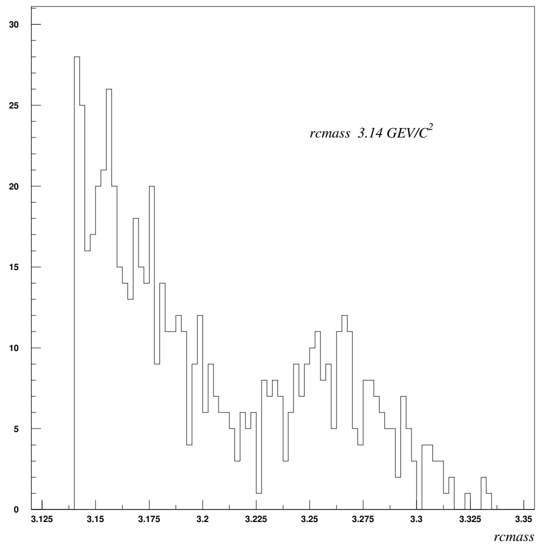

FIG. 2. Distribution of mass recoiling against the $\pi^+\pi^-$, m_{recoil}, in $\psi(2S) \rightarrow \pi^+\pi^- X$ events for $m_{recoil} > 3.14 MeV/c^2$. No events are seen corresponding to the expected h_c mass of 3526 MeV/c^2, but there is a peak $\sim 3250 MeV/c^2$.

$\psi(2S) \rightarrow \pi^o h_c,\ h_c \rightarrow \pi^+\pi^- J/\psi$

The process $\psi(2S) \rightarrow \pi^o h_c$, $h_c \rightarrow \pi^+\pi^- J/\psi$ would give a peak at $\sim 3250 MeV/c^2$ in the m_{recoil} distribution. To see if the peak is due to this process, the events were fit with Telesis with the π^o taken to be missing (neutrals were not included in the analysis). The $h_c \rightarrow \pi^+\pi^- J/\psi$ and $J/\psi \rightarrow l^+l^-$ decays were also constrained in the fit. The χ^2 distribution is shown in Fig. 3, and the distribution of the $\pi^+\pi^- l^+l^-$ invariant mass is shown in Fig. 4 for events with a $\chi^2 < 12$. Fitting a Gaussian to the distribution for the region below 3.54 GeV/c^2 determines a mass of 3.522 GeV/c^2, which is in close agreement with the PDG mass for the h_c, and a width (σ) of 31 MeV/c^2.

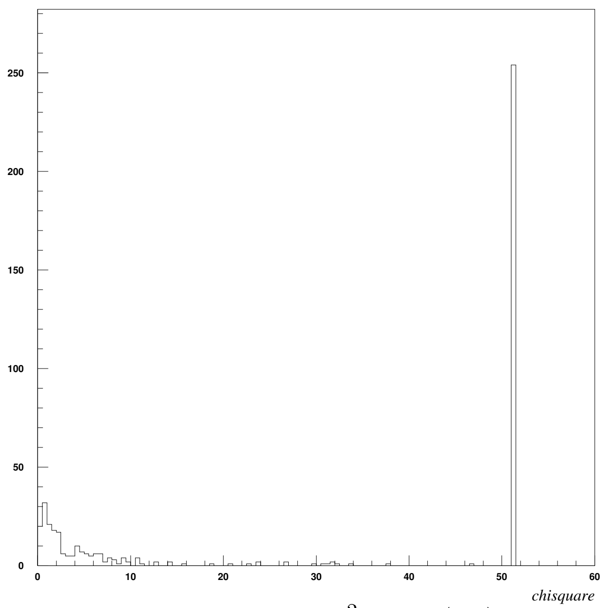

FIG. 3. Distribution of χ^2 for $\psi(2S) \to \pi^o h_c$, $h_c \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$.

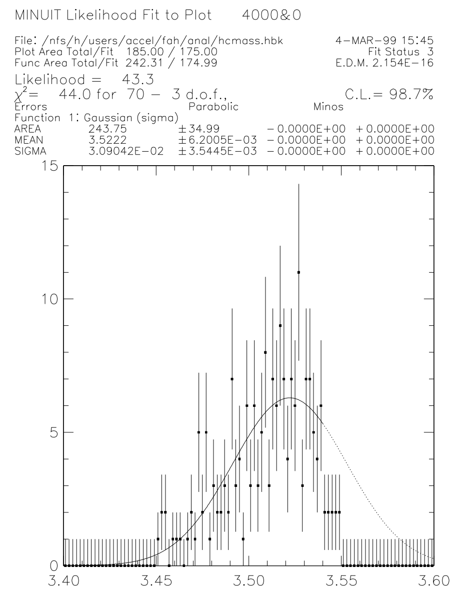

FIG. 4. Distribution of h_c mass (mass of $\pi^+\pi^- l^+l^-$) for $\chi^2 < 12$.

To see if the width found is consistent with our resolution, Howl was used to generate $\psi(2S) \to \pi^o h_c$, $h_c \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events. The width of the MC peak was only 5.6 Mev/c^2, so the peak corresponding to our data is much too wide. Steve suggested that the peak might be due to background from $\psi(2S) \to \eta J/\psi$ with $\eta \to \pi^+\pi^-\pi^0$. So Howl was also used to generate this channel.

We can now use MN_FIT to fit the observed mass distribution using the two Monte Carlo distributions. This fit is shown in Fig. 5. The small peak corresponds to the number of events found for the process of interest and $N(\psi(2S) \to \pi^o h_c,\ h_c \to \pi^+\pi^- J/\psi,\ J/\psi \to l^+l^-) = 7.6 \pm 7.9$

We can also reject events that give good fit to $\psi(2S) \to \eta J/\psi$. Requiring $\chi^2(\psi(2S) \to \eta J/\psi,\ \eta \to \pi^+\pi^-\pi^0,\ J/\psi \to l^+l^-) > 50$ eliminates 2/3 of background but only 1/3 of signal. Fitting this distribution with MN_FIT , we find that the contribution from $N(\psi(2S) \to \pi^o h_c, h_c \to \pi^+\pi^- J/\psi)$ is negative. In fact, we get a better fit using only the $\psi(2S) \to \eta J/\psi$ mass distribution. This fit is shown in Fig. 6. We can use this to set upper limits for this process. Taking the number of events to be zero, gives an 90% CL upper limit of 2.44 events, and $B(\psi(2S) \to \pi^0 h_c)B(h_c \to \pi^+\pi^- J/\psi) < 1 \times 10^{-4}$. Note that the decay $h_c \to \pi^+\pi^- J/\psi$ has not been seen.

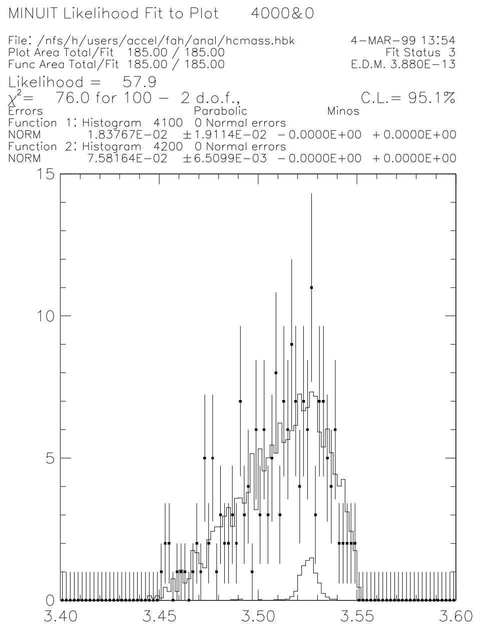

FIG. 5. Fit of the $\pi^+\pi^-l^+l^-$ mass distribution (dots with error bars) using the Monte Carlo mass distributions for $\psi(2S) \to \pi^o h_c,\ h_c \to \pi^+\pi^- J/\psi$ (lower histogram) and $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$ (upper histogram).

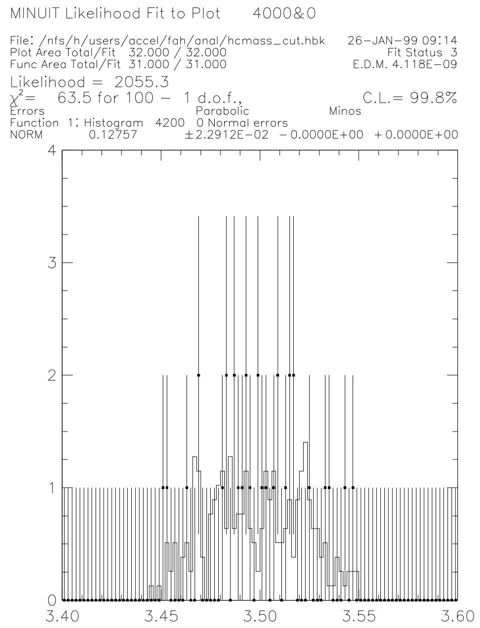

FIG. 6. Fit of the $\pi^+\pi^-l^+l^-$ mass for $\chi^2(\psi(2S) \to \eta J/\psi) > 50$ with the Monte Carlo distribution for $\psi(2S) \to \eta J/\psi$.

$\boldsymbol{\psi(2S) \to \eta J/\psi}$

Since we have found many $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$ events, we can use them to measure

$$\frac{B(\psi(2S) \to \eta J/\psi)}{B(\psi(2S) \to \pi^+\pi^- J/\psi)}$$

It is advantageous to measure the ratio of branching ratios since $B(\psi(2S) \to \pi^+\pi^- J/\psi)$ has a large uncertainty in the PDG [2]. Defining N_η and $N_{\pi\pi}$ to be the number of our $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^o$, $J/\psi \to l^+l^-$ and $\psi(2S) \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events, respectively, then

$$N_\eta = N_{\psi(2S)} B(\psi(2S) \to \eta J/\psi) B(\eta \to \pi^+\pi^-\pi^o) B(J/\psi \to l^+l^-)\epsilon_\eta$$

$$N_{\pi\pi} = N_{\psi(2S)} B(\psi(2S) \to \pi^+\pi^- J/\psi) B(J/\psi \to l^+l^-) \epsilon_{\pi\pi}$$

and finally

$$\frac{B(\psi(2S) \to \eta J/\psi)}{B(\psi(2S) \to \pi^+\pi^- J/\psi)} = \frac{N_\eta \epsilon_{\pi\pi}}{N_{\pi\pi} \epsilon_\eta B(\eta \to \pi^+\pi^-\pi^o)}$$

Telesis is used to determine N_η. Yuan Changzheng has found that Telesis does a poor job determining the χ^2 distribution because the track errors are not correct [4], and the distributions are different for Monte Carlo data and regular data. Therefore, we underestimate or overestimate the efficiency-corrected number of events found for a process when Telesis is used. In order to reduce this problem, I fit both N_η and $N_{\pi\pi}$ events with Telesis. Note that the number of fitted events is very different than the number of events found without fitting for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$. As in the previous section, the π^0 is taken as missing in the $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$ fit in Telesis.

For the Monte Carlo generator, I use PPGEN, which has a $1 + \cos^2\theta$ distribution for the η (or J/ψ) angular distribution. Figs. 7 and 8 show the confidence level (CL) distributions for $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$ data and Monte Carlo events, respectively. Figs. 9 and 10 show the CL distributions for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ data and Monte Carlo events, respectively. The number of constraints is taken to be 3 for the first process and 5 for the last. As can be seen, the distributions are not flat as one would expect.

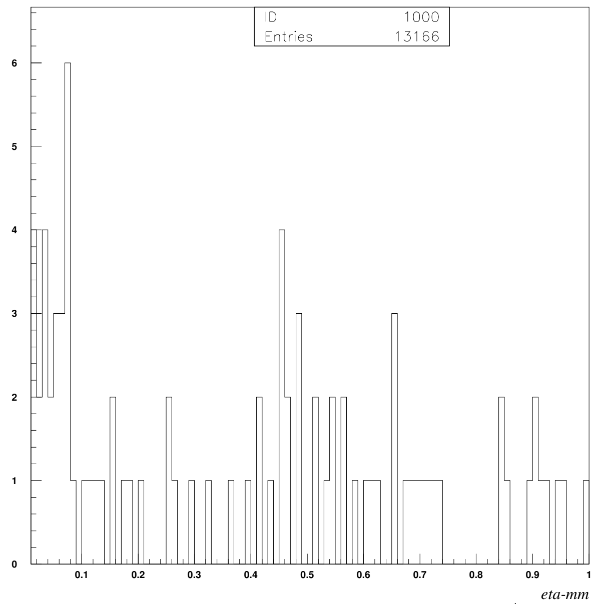

FIG. 7. Confidence level distribution (CL > 1 %) for $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$ events.

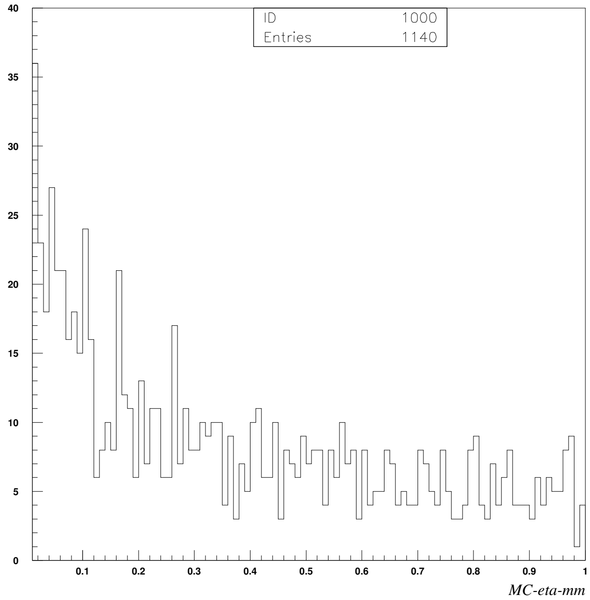

FIG. 8. Confidence level distribution (CL > 1 %) for $\psi(2S) \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$, $J/\psi \to l^+l^-$ Monte Carlo events.

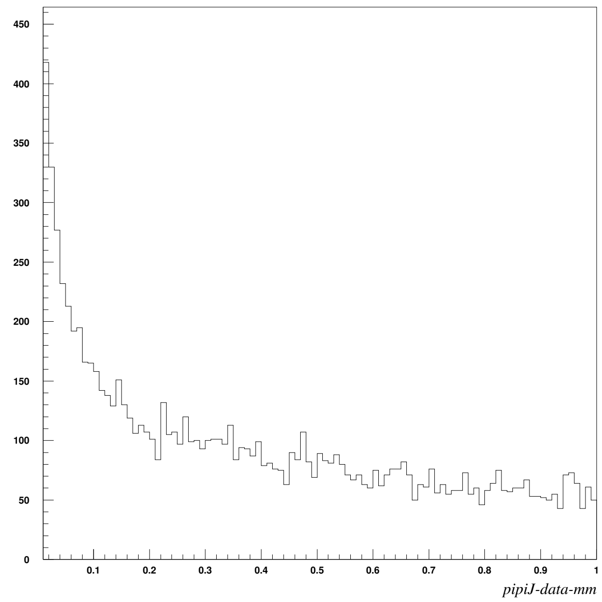

FIG. 9. Confidence level distribution (CL > 1 %) for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ events.

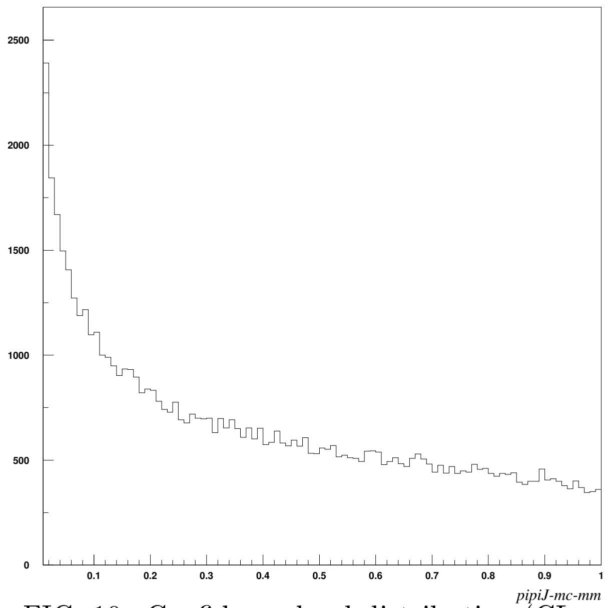

FIG. 10. Confidence level distribution (CL > 1 %) for $\psi' \to \pi^+\pi^- J/\psi$, $J/\psi \to l^+l^-$ Monte Carlo events.

TABLES

TABLE I. Results for $J/\psi \to e^+e^-$

CL cut	N_η	N_η/ϵ_η	$N_{\pi\pi}$	$N_{\pi\pi}/\epsilon_{\pi\pi}$	$B(\psi(2S) \to \eta J/\psi)/B(\psi(2S) \to \pi^+\pi^- J/\psi)$
1 %	60	1707	7912	56498	0.131
5 %	53	1806	6666	56254	0.139
10 %	47	1832	5872	56778	0.140

The results are given in Tables I and II for events where $J/\psi \to e^+e^-$ and $\to \mu^+\mu^-$, respectively. The results are different for the two cases and depend somewhat on the CL cut.

TABLE II. Results for $J/\psi \to \mu^+\mu^-$

CL cut	N_η	N_η/ϵ_η	$N_{\pi\pi}$	$N_{\pi\pi}/\epsilon_{\pi\pi}$	$B(\psi(2S) \to \eta J/\psi)/B(\psi(2S) \to \pi^+\pi^- J/\psi)$
1 %	85	2007	9501	53939	0.161
5 %	73	1965	8244	52938	0.161
10 %	60	1840	7313	52763	0.151

We can pick a central value and use the variation in values to estimate the systematic uncertainty. We find a preliminary result:

$$\frac{B(\psi(2S) \to \eta J/\psi)}{B(\psi(2S) \to \pi^+\pi^- J/\psi)} \approx 0.146 \pm 0.012 \pm 0.015 \ (\approx 13\%),$$

which can be compared with the PDG [2] and E760 values [5]:

$$\text{PDG: } 0.0833 \pm 0.013 \ (16\%)$$

$$\text{E760: } 0.113 \pm 0.036 \ (32\%)$$

Our result is higher than their values.

FUTURE PLANS

The next step will be to include γ's in the analysis in order to allow the π^0 to be included in the fits above. This effort will then be expanded in order to look for $\psi(2S) \rightarrow \pi^0 h_c$, $h_c \rightarrow \pi^0 J/\psi$, $\psi(2S) \rightarrow \pi^o \pi^o J/\psi$, $\psi(2S) \rightarrow \pi^o J/\psi$, $\psi(2S) \rightarrow \eta J/\psi, \eta \rightarrow \gamma\gamma$, etc. The most interesting channel is the first one.

REFERENCES

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[4] C. Z. Yuan, "Is Telesis Reliable?", Analysis Note, Nov. 1997.

[5] T. A. Armstrong *et al.* , (E760), Phys. Rev. **D 55**, 1153 (1997).