# The Analysis of Decay Channels $J/\psi \to \gamma\gamma V(\rho, \phi)$ —- BES Analysis Memo —-

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December 4, 1998

**Abstract**

Based on the $7.8 \times 10^6$ $J/\psi$ events collected by BES experiment, $J/\psi$ radiative decay channels $J/\psi \to \gamma\gamma V(\rho, \phi)$ have been studied. The $\eta(1410)$ resonance has been observed in these two channels respectively. Its mass and width are $1414 \pm 16$ MeV and $90 \pm 19$ MeV from $J/\psi \to \gamma\gamma\rho$ mode, $1410 \pm 7$ MeV and $80 \pm 10$ MeV from $J/\psi \to \gamma\gamma\phi$ mode.

**Key words:** $J/\psi$,Resonance,Meson,Glueball

## 1 Introduction

Up to now ,the structure of $\iota/\eta(1440)$ is not very clear. The existence of two overlapping pseudo-scalar states has been suggested, one of which around 1410 MeV decays into both $K\bar{K}\pi$ and $\eta\pi\pi$, and the other one around 1470 MeV decays only to $K\bar{K}\pi$. It is therefore conceivable that the higher mass state is the $s\bar{s}$ member of the $2^1S_0$ nonet[1]. Is the lower mass state a meson, glueball, or hybrid? it should be further investigated in different decay channels.

The radiative decay of $\eta(1440) \to \gamma\rho$ have been analysed in the process of $J/\psi \to \gamma\gamma\rho(\rho \to \pi^+\pi^-)$ by Crystal-Ball[2], MarkIII[3] and DM2[4] respectively(see Tab. 1).

Table 1: Experimental results of $X(1440) \to \gamma\rho$

| Mass (MeV) | Width (MeV) | Br$(J/\psi \to \gamma X)Br(X \to \gamma\rho)$ $(\times 10^{-4})$ | Exp. |
|---|---|---|---|
| $1390 \pm 25$ | $185^{+110}_{-80}$ | $1.9 \pm 0.5 \pm 0.4$ | Cry. Ball |
| $1432 \pm 8$ | $90 \pm 26$ | $0.64 \pm 0.12 \pm 0.07$ | MarkIII |
| $1401 \pm 18$ | $174 \pm 44$ | $0.9 \pm 0.2 \pm 0.14$ | DM2 |

The analysis of the $\gamma\rho$ decay angular distribution agrees with a spin $0^-$ interpretation but spin $1^+$ cannot be excluded.

Reference [5] pointed out that the glueball can be distinguished from $q\bar{q}$ and hybrid by the analysis of $J/\psi \to \gamma\gamma\rho$ and $J/\psi \to \gamma\gamma\phi$. For a glueball, it should have the same mass value regardless of where it comes from ($\gamma\rho$ or $\gamma\phi$ ). but for the $q\bar{q}$ and $q\bar{q}g$ states, it has been predicted that the mass peak position from $\gamma\phi$ should higher than that from $\gamma\rho$ about 300 MeV.

## 2 Event Selection

In this paper we mainly analyse the following channels :

$$J/\psi \to \gamma X(X \to \gamma V)$$

where $V$ includes vectors $\rho$ and $\phi$,and their decay modes as follow:

$$\rho \to \pi^+\pi^-$$
$$\phi \to K^+K^-$$

According to above processes, two oppositely charged particles should be detected by MDC (Main Drift Chamber), and the total charges of these two tracks should equal to zero. For one track fit the $M_{fit} = 2$ or $-19$ was required.

The BES detector , fully described elsewhere [7], the BSC (Barrel Shower Counter), which covers 80% of $4\pi$ solid angle, has an energy resolution of $\delta E/E = 22\%/\sqrt{E}$.

The selection of photon should be carefully, especially for high energy photons. Considered these characteristics of BSC, electric noise, the energy deposit in BSC of each neutral tracks $E_{sc} > 70MeV$. The photon is also required to be isolated from two charged tracks ($cos(\theta_{\gamma\pi(K)}) < 0.98$ ) and come from the interaction point. The photon with maximum energy among all of those neutral tracks has been selected as the $J/\psi$ radiative photon .

## 2.1 The event selection of $J/\psi \to \gamma\gamma\rho(\rho \to \pi^+\pi^-)$

For this $J/\psi$ decay channel, background channels are mainly include : $J/\psi \to \rho\pi$, $J/\psi \to \omega\pi^+\pi^-$, $J/\psi \to \omega f_2(1270)$, $J/\psi \to K^+\bar{K}^*(892)^- + cc$, $J/\psi \to b_1(1235)^\pm\pi^\mp$, $J/\psi \to \omega K\bar{K}$, $J/\psi \to \omega\eta$, $J/\psi \to \phi\eta$, $J/\psi \to \omega\pi^0$, $J/\psi \to \phi\eta'$, $J/\psi \to \rho\eta$, $J/\psi \to \omega\eta'$, $J/\psi \to \rho\eta'$, $J/\psi \to \pi^0\pi^+\pi^-$, and $J/\psi \to \gamma\eta\pi\pi$.

A cut of $P_{miss} \leq 1.25GeV/c$ is required, this criterion rejects the background channel $J/\psi \to \rho\pi^0$ effectively(See Fig. 1). The $P_{miss}$ is defined as the missing momentum of all charged particles.

If the weight of $\pi$ which was identified by TOF great than that of $K$, we assume this track as $\pi$ . Finally require at least one $\pi$ track in one enevt.

Taking one of photons we selected do loop with the maximum energy photon and two charged particles , After the kinematically fit (4C-FIT), we select the minimal $\chi^2(\chi^2_{min})$ as a good event, and require $\chi^2_{min} \leq 10$ . In order to suppress background channels which final states include $2\gamma K^+K^-$, $\pi^0\pi^+\pi^-$, $\eta\pi^+\pi^-$, $3\gamma\pi^+\pi^-$, and $\gamma\pi^+\pi^-$, the event we selected above has been forced to do 4C-FIT for above final states, if its $\chi^2 < \chi^2_{min}$, it will be rejected as background. Another useful cut,which can effectively suppress multi-photon backgrounds, is the total energy of rest "good" photons $E_{rest} \leq 130MeV$. Fig. 2 shows the invariant mass spectrum of $\pi^+\pi^-$. The $\rho$ signal is selected as $|M_{\pi^+\pi^-} - M_\rho| \leq 0.14GeV/c^2$ , the invariant mass spectrum of $\gamma\rho$ shows in Fig. 3.

The detection efficiency is determined from Monte Carlo simulation. After the same selections as real data , we obtain the detection efficiency which is about 6.4%. The systematic error listed in Tab. 2 are determined by adding the error in our event selections(6%), the different background shape in BW fit(3%) , the uncertainty of the Monte Carlo simulation in the detection efficiency (14%), and the uncertainty

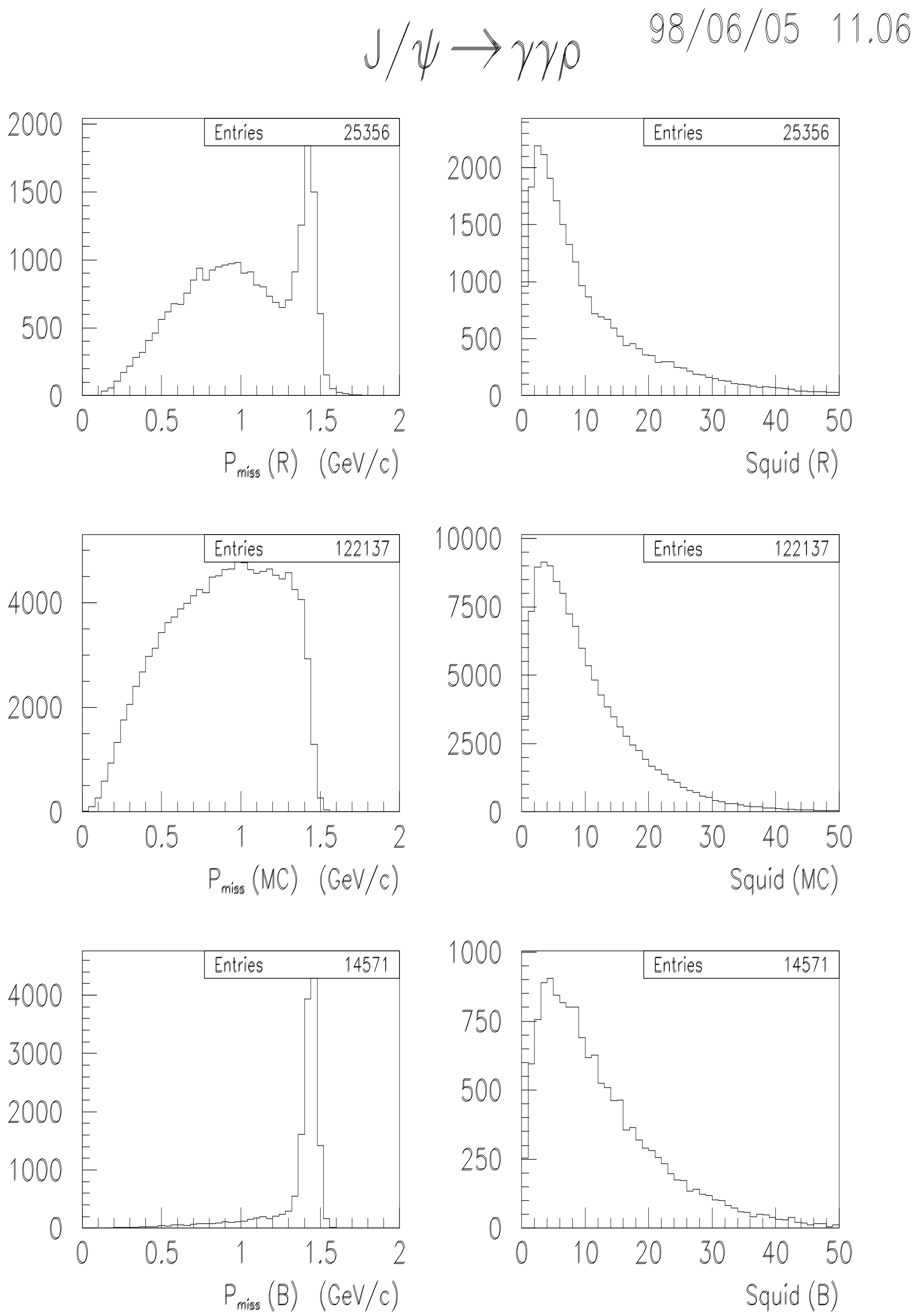



Figure 1: The $P_{miss}$ distributions. R-real data, M-monte carlo, B-backgrounds

in the number of produced $J/\psi$(10%). The systematic error in this $J/\psi$ decay mode is totally about 19%.

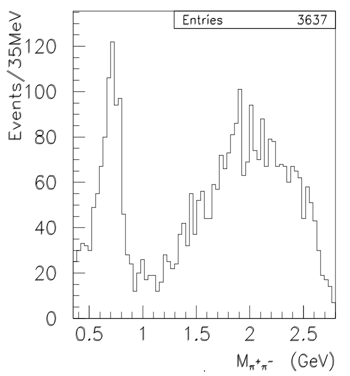



Figure 2: The Invariant Mass Spectrum of $\pi^+\pi^-$

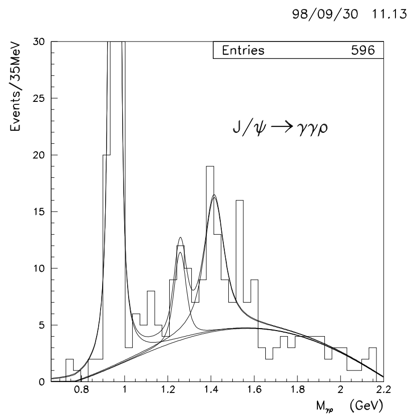



Figure 3: The Invariant Mass Spectrum of $\gamma\rho$(The solid curve is the BW fit result)

As the summary , the total event selections listed in the following.

**The "good" $\gamma$ selections**

- The number of hitted layers by photon in SC should be great than two, and the first fired layer should be less than five
- The energy deposit in SC of photon $E_\gamma \geq 70MeV$
- The angular relation between the direction of $\gamma$ cluster after reconstruction and the direction of line from the collsion point to the first fired point in SC $\Delta = \sqrt{(\Delta cosx)^2 + (\Delta cosy)^2 + (\Delta cosz)^2} \leq 0.35$

Table 2: The resonance parameters of $J/\psi \to \gamma X(X \to \gamma\rho)$

| Mass (MeV) | Width (MeV) | Br$(J/\psi \to \gamma X)Br(X \to \gamma\rho)$ $(\times 10^{-4})$ | Evt. | |
|---|---|---|---|---|
| $954 \pm 1$ | $10 \pm 1$ | $11.7 \pm 0.4 \pm 2.2$ | $391 \pm 13$ | $33\sigma$ |
| $1257 \pm 16$ | $33 \pm 30$ | $0.6 \pm 0.4 \pm 0.1$ | $19 \pm 14$ | $4\sigma$ |
| $1414 \pm 16$ | $90 \pm 19$ | $1.6 \pm 0.4 \pm 0.3$ | $54 \pm 13$ | $5\sigma$ |

- In order to reject the effect of the radiative photon from charged particle , we required $cos\theta_{\gamma q} \leq 0.99$

**The charged particle selections**

- $\sqrt{x_0^2 + y_0^2} < 0.8cm$, $|z| < 14cm$
- Two charged particles , and $\sum Q = 0$
- MFIT=2 or -19 for every charged particle
- at least one pion track per event

**The kinematic fit**

- $P_{miss}$ $\leq$1.25 GeV/c (see See Fig. 1)
- $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} < \chi^2_{J/\psi \to 2\gamma K^+K^-}$
  $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} < \chi^2_{J/\psi \to \pi^0\pi^+\pi^-}$
  $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} < \chi^2_{J/\psi \to \eta\pi^+\pi^-}$
  $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} < \chi^2_{J/\psi \to 3\gamma\pi^+\pi^-}$
  $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} < \chi^2_{J/\psi \to \gamma\pi^+\pi^-}$
  And finally : $\chi^2_{J/\psi \to 2\gamma\pi^+\pi^-} \leq 10$
  (see See Fig. 1)
- $|M_{\pi^+\pi^-} - M_\rho| \leq 0.14GeV/c^2$ (Fig. 2)
- Another useful cut is the total energy of rest "good" photons $E_{rest} \leq 130MeV$ (Fig. 5)

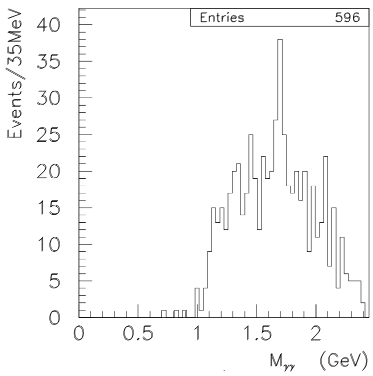



Figure 4: The $M_{\gamma\gamma}$ Spectrum Recoil the $\rho$ Signal

From Fig. 4 we can clearly see after our above cut, $J/\psi \to \rho\pi^0(\pi^+\pi^-\pi^0)$ and $J/\psi \to \rho\eta$ background channels have been suppressed.

Fig. 3 shows our final result.

## 2.2 The event selection of $J/\psi \to \gamma\gamma\phi(\phi \to K^+K^-)$

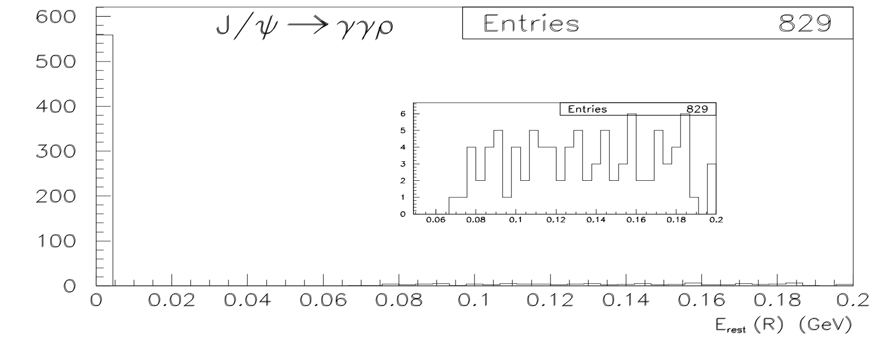
If the weight of $K$ which was identified by TOF great than that of $\pi$, we assume this track as $K$ . Finally require at least one $K$ track in one enevt.

For this $J/\psi$ decay channel, background channels are mainly include: $J/\psi \to \rho\pi$, $J/\psi \to a_2(1320)\rho$, $J/\psi \to K^+\bar{K}^*(892)^- + cc$, $J/\psi \to \phi\eta$, $J/\psi \to \phi\eta'$, $J/\psi \to \gamma f_J(1710) \to \gamma K\bar{K}$, $J/\psi \to K\bar{K}\pi$,and $J/\psi \to \gamma\eta(1440) \to \gamma K\bar{K}\pi$. In order to suppress multi-photon backgrounds, the $P_{miss}$ should be satisfied by $P_{miss} \leq 1.25GeV/c$(See Fig. 6) .

Do loop for photons, and kinematically fit with the maximum energy photon and two charged particles, the $\chi^2_{min} \leq 25$ is required. Further more the $\chi^2$ of the background channels which include the following final states $2\gamma\pi^+\pi^-$, $\gamma K^+K^-$, and $3\gamma K^+K^-$

should be satisfied $\chi^2 > \chi^2_{min}$, otherwise, the event will be rejected as background. Fig. 7 shows the invariant mass spectrum of $K^+K^-$ .

Taking $M_{\gamma\gamma} \geq 0.6GeV/c^2$ ,so that backgrounds $J/\psi \to \phi\eta$ and $J/\psi \to \phi\pi^0$ can be rejected . Taking $|M_{K^+K^-} - M_\phi| \leq 0.02GeV/c^2$ as the $\phi$ signal, The final $\gamma\phi$ spectrum is shown in Fig. 8. Fig. 9 shows the $\phi$ side-band, it can not be seen clear



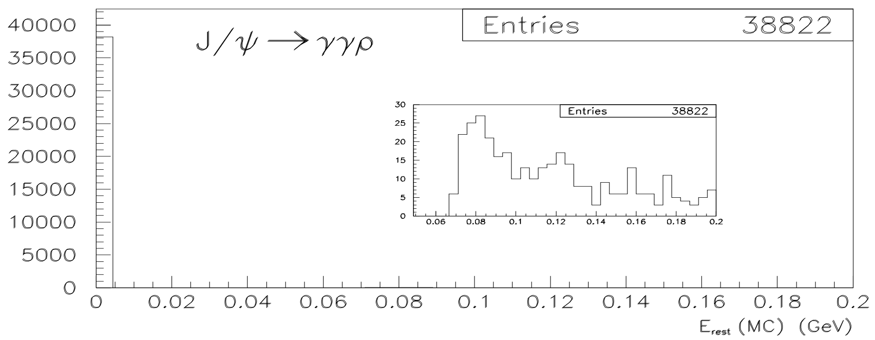




Figure 5: The total energy of rest "good" photons $E_{rest}$

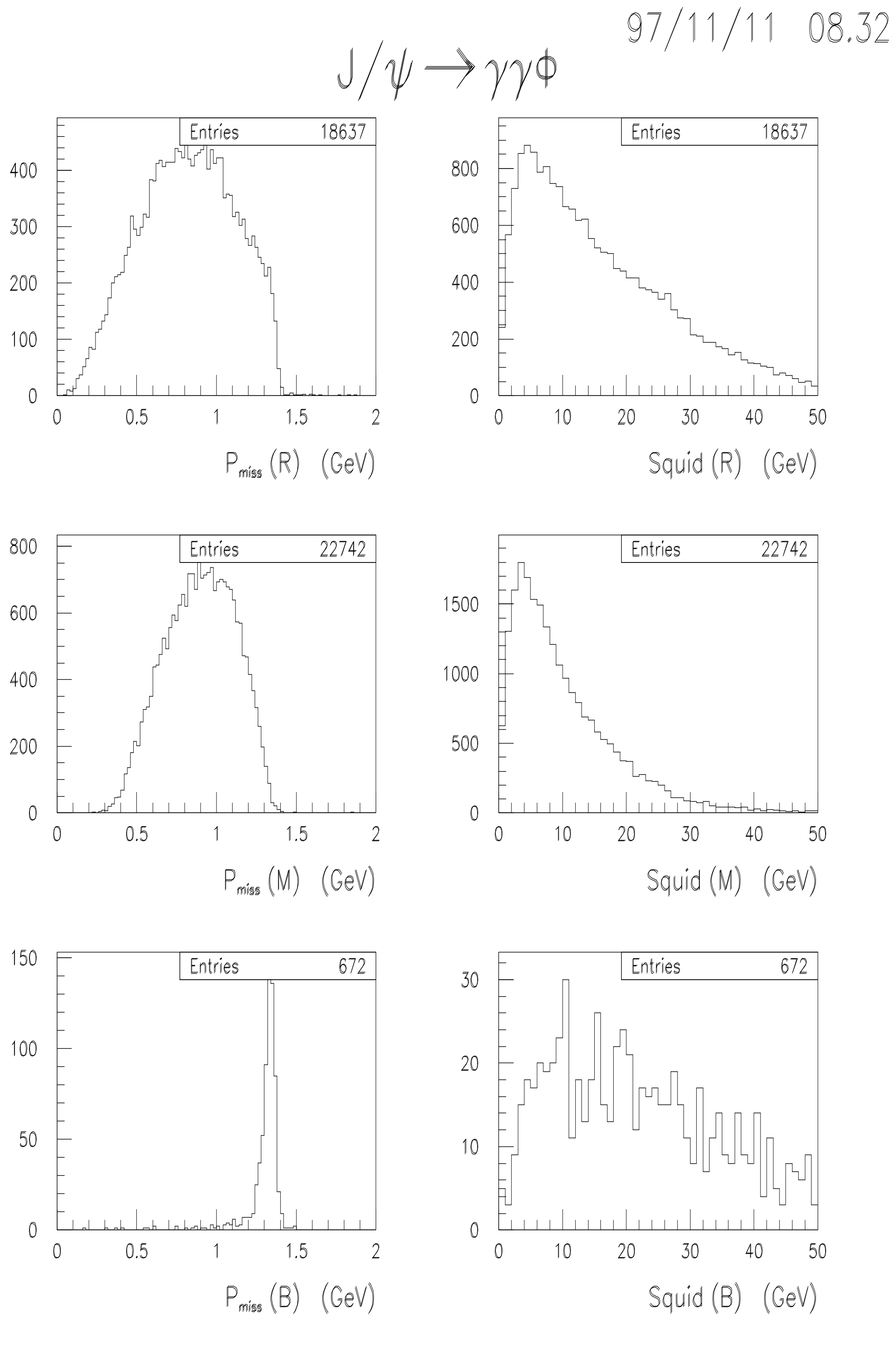



Figure 6: The $P_{miss}$ distributions. R-real data, M-monte carlo, B-backgrounds

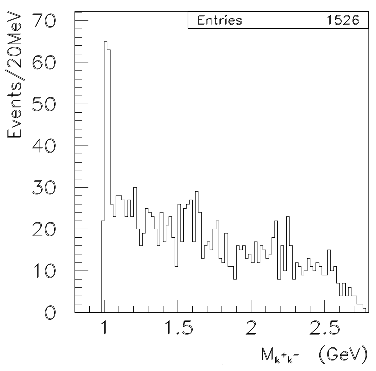



Figure 7: The Invariant Mass Spectrum of $K^+K^-$

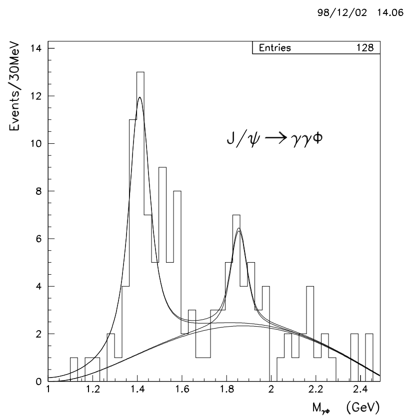



Figure 8: The Invariant Mass Spectrum of $\gamma\phi$(The solid curve is the BW fit result)

structure around 1410 MeV.

The BW fitted results are listed in Tab. 3.

After the Monte Carlo simulation, we obtain the detection efficiency which is about 7.0%. The systematic error listed in Tab. 3 are determined in a manner similar to that in Tab. 2. It includes the error in our event selections(8%) , the different background shape in BW fit(11%) , the uncertainty of the Monte Carlo simulation in the detection efficiency(10%) , and the uncertainty in the number of produced $J/\psi$(10%) . The The systematic error in this $J/\psi$ decay mode is totally about 20%.

As the conclusion , the total event selections listed in the following.

**The "good" $\gamma$ selections**

- The number of hitted layers by photon in SC should be great than two, and

Table 3: The resonances parameters of $J/\psi \to \gamma X(X \to \gamma\phi)$

| Mass (MeV) | Width (MeV) | $Br(J/\psi \to \gamma X)Br(X \to \gamma\phi)$ $(\times 10^{-4})$ | Events | |
|---|---|---|---|---|
| $1410 \pm 7$ | $80 \pm 10$ | $1.6 \pm 0.4 \pm 0.3$ | $42 \pm 9$ | $6\sigma$ |
| $1856 \pm 10$ | $79 \pm 26$ | $0.7 \pm 0.3 \pm 0.1$ | $20 \pm 7$ | $3\sigma$ |

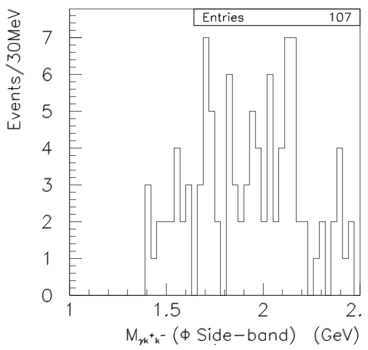



Figure 9: The $\phi$ Side-band

the first fired layer should be less than five

- The energy deposit in SC of photon $E_\gamma \geq 70MeV$
- The angular relation between the direction of $\gamma$ cluster after reconstruction and the direction of line from the collsion point to the first fired point in SC $\Delta = \sqrt{(\Delta cosx)^2 + (\Delta cosy)^2 + (\Delta cosz)^2} \leq 0.35$
- In order to reject the effect of the radiative photon from charged particle , we required $cos\theta_{\gamma q} \leq 0.99$

**The charged particle selections**

- $\sqrt{x_0^2 + y_0^2} < 0.8cm$, $|z| < 14cm$
- Two charged particles , and $\sum Q = 0$
- MFIT=2 or -19 for every charged particles
- at least one $K$ track per event

**The kinematic fit**

- $P_{miss} \leq 1.25$ GeV/c (see See Fig. 6)
- $\chi^2_{J/\psi \to 2\gamma K^+K^-} < \chi^2_{J/\psi \to 2\gamma\pi^+\pi^-}$
  $\chi^2_{J/\psi \to 2\gamma K^+K^-} < \chi^2_{J/\psi \to \gamma K^+K^-}$
  $\chi^2_{J/\psi \to 2\gamma K^+K^-} < \chi^2_{J/\psi \to 3\gamma K^+K^-}$
  And finally : $\chi^2_{J/\psi \to 2\gamma K^+K^-} \leq 25$
  (see See Fig. 6)
- $|M_{K^+K^-} - M_\phi| \leq 0.02 GeV/c^2$ (Fig. 7)

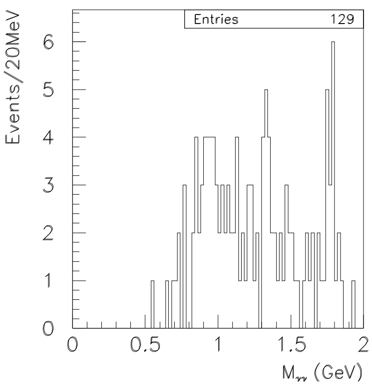



Figure 10: The $M_{\gamma\gamma}$ Spectrum Recoiled the $\phi$ Signal

From Fig. 10 we can clearly see after our above cut, $J/\psi \to \phi\pi^0(K^+K^-\pi^0)$ and $J/\psi \to \phi\eta$ background channels have been suppressed.

Fig. 8 shows our final result.

# 3 Results and Discussions

By using the fit method of spin-parity as mentioned in Ref. [5], we simulate the angular distribution of resonances listed in Tab. 2 and Tab. 3. we find the spin of X(1410) state listed in Tab. 2 is mainly associated with $0^-$, and also the spin of X(1410) state listed in Tab. 3 is most likely a $0^-$ state. It is failed for A single $1^+$ fit to the X(1410) state both in Tab. 2 and Tab. 3, therefore we think the dominant component of X(1410) is $\eta(1410)$. Fig. 11 shows the fitted results of X(1410).

Table 4: Results of $\eta(1410)$ from tha analysis of $J/\psi \to \gamma\gamma V$ in BES

| Decay Modes | Mass (MeV) | Width (MeV) | $\mathrm{Br}(J/\psi \to \gamma X)Br(X \to \gamma\omega)$ $(\times 10^{-4})$ | |
|---|---|---|---|---|
| $X \to \gamma\rho$ | $1414 \pm 16$ | $90 \pm 19$ | $1.6 \pm 0.4 \pm 0.3$ | $5\sigma$ |
| $X \to \gamma\phi$ | $1410 \pm 7$ | $80 \pm 10$ | $1.6 \pm 0.4 \pm 0.3$ | $6\sigma$ |

In order to check the fit method in Ref. [5], we also analysed the resonance X(954) listed in Tab. 2, we find its spin is very close to $0^-$, this result is consistent with that of $\eta'(958)$ in 98'PDG.

About the X(1257) listed in Tab. 2, because of not enough statistical value , its spin-parity can not be analysed. MarkIII also obtained this resonance in $J/\psi \to \gamma\gamma\rho$, they thought that it is the signal of $f_1(1285)$, but they also can not rejected the possibility of $\eta(1295)$.

From Tab. 4 we can clearly see the following relations:

$Br(J/\psi \to \gamma X \to \gamma\gamma\rho) \approx Br(J/\psi \to \gamma X \to \gamma\gamma\phi)$

$M_{\gamma\rho} \approx M_{\gamma\phi}$

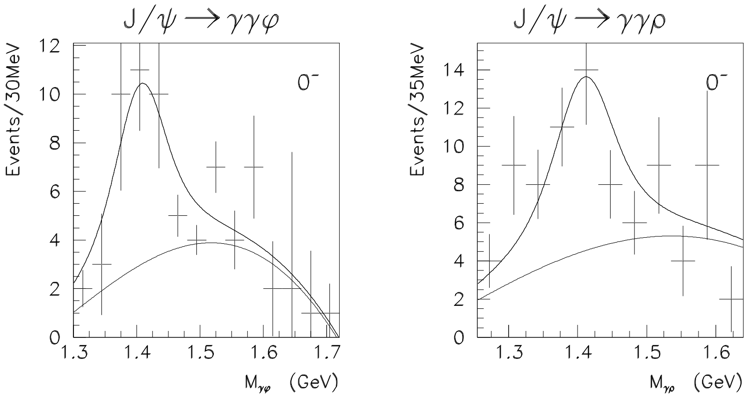



Figure 11: The Spin-Parity analysis of the X(1410) state

Our final results are listed in Tab. 4. these features of $\eta(1410)$ are consistent with the glueball interpretation in Ref. [5]. Could we say the $\eta(1410)$ is the candidate of glueball(or it contains the component of glueball)? the further investigation on other channels ,such as $J/\psi \to V\gamma V$ will be helpful to understand it.

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