ψ' decay to $\gamma\pi^+\pi^-$ — Analysis memo

Wei Yang
Department of Physics
Colorado State University
wyang@omega.physics.colostate.edu

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Abstract

Using the 3.7×10^6 ψ' data collected by the BES detector, we studied the $\psi' \to \gamma\pi^+\pi^-$ at the region where the $\pi^+\pi^-$ invariant mass is smaller than 3 GeV. The $f_2(1270)$ signal has seen and the branch fraction of the $\psi' \to \gamma f_2(1270)$ is measured, which is consistent with the "15% rule". It is also consistent with the result we got from $\psi' \to \gamma\pi^0\pi^0$ channel.

With the assumption that the dominant process of J/ψ and ψ' hadronic decay are through three gluons, and that the strong coupling constant α_s doesn't change significantly from the J/ψ mass to the ψ' mass, the lowest order perturbative QCD predicts the "15% rule":

$$Q = \frac{B(\psi' \to X)}{B(J/\psi \to X)} = \frac{B(\psi' \to ggg)}{B(J/\psi \to ggg)} = \frac{B(\psi' \to l^+l^-)}{B(J/\psi \to l^+l^-)} = (14.6 \pm 2.2)\%$$

where X is an arbitrary non-charmonium state. Results from the Mark II experiment and the BES experiment shows that most of the ψ' decay channels follow the theoretical prediction. But ψ' decay to vector-pesudo scalar modes such as $\psi' \to \rho\pi$ and K^*K, as well as ψ' decay to vector-tensor modes are suppressed from the "15% rule".

The "15% rule" is extended to ψ' radiative decay modes where one of the gluon is replaced by a photon. And it is believed that the "15% rule" should also hold for radiative decay modes[1]. In this studying, we use the 93/94/95 ψ' data sets collected at BES to study the $\psi' \to \gamma\pi^+\pi^-$ process with $\pi^+\pi^-$ invariant mass below 3GeV.

We start from ψ' events with two opposite charged tracks and at least one neutral tracks. For the neutral tracks, we request:

- Hit at BSC for more than 2 layers and 3 cells with energy deposited in BSC larger than 60 MeV.

For the charged tracks, we imposed the following cuts:

- mfit = 2 or –19.
- The transverse momentum p_t of each tracks is larger than 60 MeV to avoil events with tracks that can't fly out of the main drift chamber.
- TOF (with tqual=1,2,7) and dE/dx information are used for tracks with p < 750 MeV and p < 600 MeV respectively. No events should be used with a track being identified as none-π by both TOF and dE/dx at 3σ.
- $|\cos(\theta)|<0.85$ where θ is track's polar angle.
- R_{xy} < 2cm and z < 10cm for each track.

In order to further reject (radiative) bhabha events and $e^+e^- \to \mu^+\mu^-$ events, we also ask that:

- Angle between charged tracks are smaller than 160^o and angle between radiative γ and charged tracks are smaller than 175^o (see Fig 2).
- $|z_1 - z_2| < 5$ cm.
- For any track with p > 700 MeV, E/p < 1 is imposed. If both tracks satisfy p > 700 MeV, impose $(E_+/p_+-1)^2+(E_-/p_--1)^2 > 0.4$ also, provide that shower counter information are abailable.
- No events should have more than total of 3 μ-counter hits for tracks with $|\cos\theta| < 0.6$ and p > 600 MeV.

Events that survive the above cuts are fed to a $\gamma\pi^+\pi^-$ 4C kinematic fit. Up to three highest energy photons will be used as radiative photon candidate and we let the kinematic fit to decide which one is the right one. A γK^+K^- 4C fit is also done on the events and we ask that $\chi^2(\pi^+\pi^-) < \chi^2(K^+K^-)$ and $\chi^2(\pi^+\pi^-) < 35$.

The upper figure in Fig 3(a) shows that invariant mass of the $\pi^+\pi^-$. The $f_2(1270)$ signal is clearly there. Also shown in the histogram is a clear ρ signal plus continuos background. To understand this anonying QED background, we fed the τ scan data collected by the BES detector into our program. The result is shown in the lower figure in Fig 3(b). The scatter plots of the polar angle of the recoil photon vs that $\pi^+\pi^-$ invariant mass are shown in Fig 4 (a) and (b) for ψ' data and τ data respectively. It is clear now that the initial state radiation process of $e^+e^-\rightarrow\gamma\rho^0\rightarrow\gamma\,\pi^+\pi^-$ contributes to the ρ signal in both mass plots, and the $e^+e^-\rightarrow\mu^+\mu^-$ contribes to the continuos background.

The situation of the BES calorimeter at the time the τ scan data was taken was poor and this provent us from scaling the two histograms of the $\pi^+\pi^-$ invariant mass by using the known integrated luminosities of the ψ' data and τ data. Instead we used the number of events with $\pi^+\pi^-$ invariant mass lower than 850 MeV on the two mass plots to scale them and subtract them. The result is shown in Fig 5.

At here we adopted a special form of Breit-Wigner function for the $f_2(1270)$ signal[2]. The cross section describing the decay of $f_2(1270)$ is:

$$\frac{d\sigma}{d\Omega} = C\,|T|^2\,\frac{P}{m_{\psi'}}\frac{Q}{m}$$

where:

- C is a constant that compute numerically.
- P is the momentum of the $\pi^+\pi^-$ in ψ' rest frame.
- Q is the momentum of the π^+/π^- in $\pi^+\pi^-$'s rest frame.
- T is the invariant amplitude describing the production and decay of the $f_2(1270)$.

If we think T has the form:

$$T = \frac{Q^\ell}{m_0{}^2 - m^2 - i m_0 \Gamma_{total}(E)}$$

l is the spin of the resonant which is 2 here for $f_2(1270)$ ($J^{PC}=2^{++}$). Consider that $f_2(1270)\rightarrow\pi\pi$ and $K\bar{K}$ has 90% of its total decay branching ratio, we can make a good approximation on $\Gamma_{total}(E)$:

$$\Gamma_{total}(E) = \Gamma_0 \frac{m_0}{m} \frac{B(f_2\rightarrow\pi\pi)\left[\dfrac{Q_\pi(m)}{Q_\pi(m_0)}\right]^{(2l+1)} + \theta B(f_2\rightarrow K\bar{K})\left[\dfrac{Q_K(m)}{Q_K(m_0)}\right]^{(2l+1)}}{B(f_2\rightarrow\pi\pi)+B(f_2\rightarrow K\bar{K})}$$

$$\theta = \theta\left(m - (m_k + m_{\bar{k}}) \right)$$

The backgound function we used is a Legrede polynomial functions multiplied by P×Q in order to keep the Lorentz invariant phase space behavior. The normalization is done numerically.

With the mass and width of $f_2(1270)$ fixed at PDG values, we fit the histogram with the D-wave Breit-Wigner function, which give us 137.3±11.1 events. The efficiency of the analysis is 28.4% calculated from the uniform phase space Monte Carlo simulation with D-wave Breit-Wigner included. The branch fraction of the $\psi' \to \gamma f_2(1270)$ we obtain, with the assumption of 2:1 isospin ratio for $f_2(1270) \to \pi^+\pi^-$ and $f_2(1270) \to \pi^0\pi^0$, is

$$B(\psi' \to \gamma\, f_2(1270)) = (2.40 \pm 0.19 \pm 0.54) \times 10^{-4}$$

where the first error is statistic error and the second one is the systematic error. The main source of the systematic error are from the cuts (21.9%), the Monte Carlo's efficiency (1.9%) and the error of the total number of ψ' data (6%). The systematic error is obviously larger then the statistic error here, which is understandable because the method we used at here to remove the ISR and other QED backgrounds.

With the available of $B(J/\psi \to \gamma f_2(1270)) = (13.8 \pm 0.14) \times 10^{-3}$ on PDG, we also obtain the ratio of the two branching fraction:

$$Q = \frac{B(\psi' \to \gamma f_2)}{B(J/\psi \to \gamma f_2)} = (17.4 \pm 1.4 \pm 4.3)\%$$

The PDG value of $B(J/\psi \to \gamma f_2(1270))$ is actually obtained from a slightly improperly handled analysis. If we use the Mark III's result $B(J/\psi \to \gamma f_2(1270)) = (1.56 \pm 0.14) \times 10^{-3}$[3], we then have:

$$Q = \frac{B(\psi' \to \gamma f_2)}{B(J/\psi \to \gamma f_2)} = (15.4 \pm 1.2 \pm 3.8)\%$$

These results are well consistent with the result we got from the $\psi' \to \gamma f_2(1270) \to \gamma\pi^0\pi^0$ analysis.

In summary, we measured the branching fraction of $\psi' \to \gamma f_2(1270)$ with the 3.7×10^6 ψ' events from the BES experiment. The result, combining with the PDG value of the branching fraction of $J/\psi \to \gamma f_2(1270)$, clearly shows that the theoretic prediction of the "15% rule" is hold for this ψ' radiative mode.

It should point out that, although not accomplished by an analysis memo, Li Xinhua and Bill Dunwoodie had made pioneer work in the studying and their idea are adopted in this studying[4].

Reference:

1. T.Appelquist, A. De Rujula, H.D. Politzer. S.L. Clashow. Phys. Rev. Lett. 3.4(1975) 363; M. Chanowitz. Phys. Rev. D 12(1975) 918; L. Okun and M. Voloshin, ITEP-95-1976(unpublished); S.J. Brodsky, T.A. DeGrand. R.R. Horgun, D.G.Coyne, Phys. Lett. 73B(1978) 203; K. Koller and T. Walsh. Nucl. Phys. B140(1978) 449.
2. Communication with Bill Dunwoodie.
3. Bill Dunwoodie and Liangpeng Chen, SLAC-PUB 7163.
4. Communication with Bill Dunwoodie and Li Xinhua.

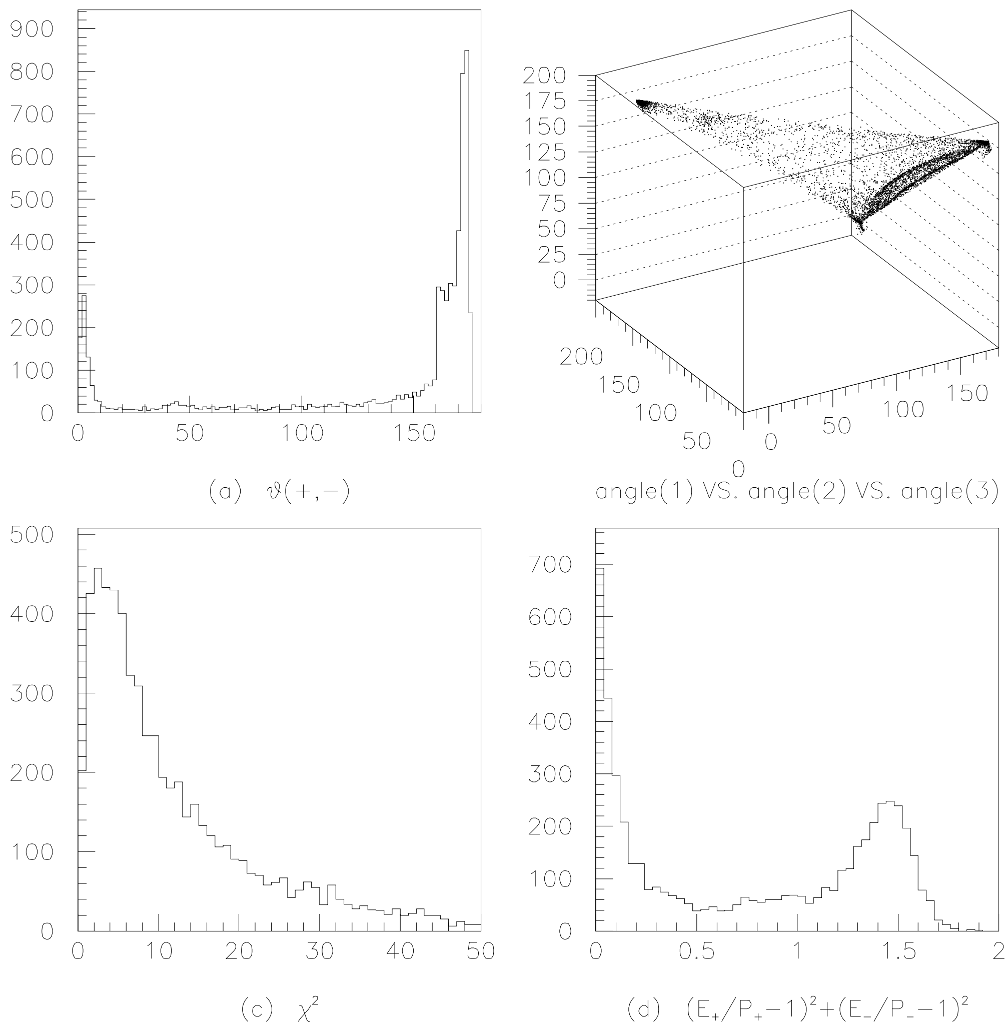

Figure 1. Various cuts used

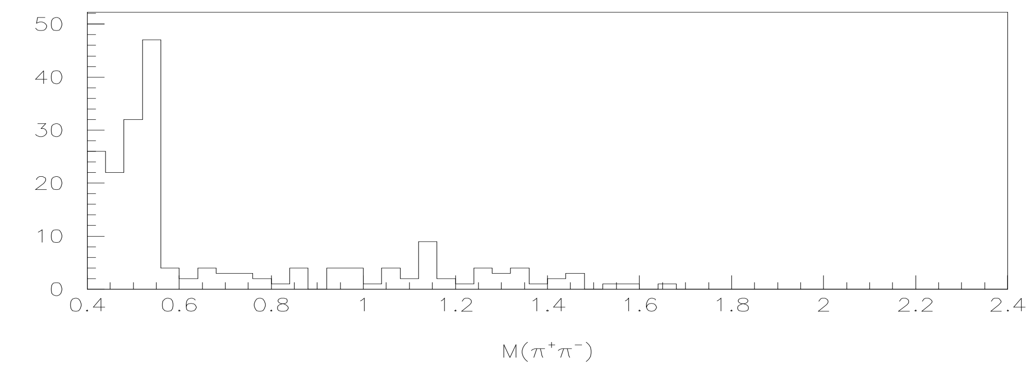

Figure 2 Rejected events that have angles between photon and charged > 175°

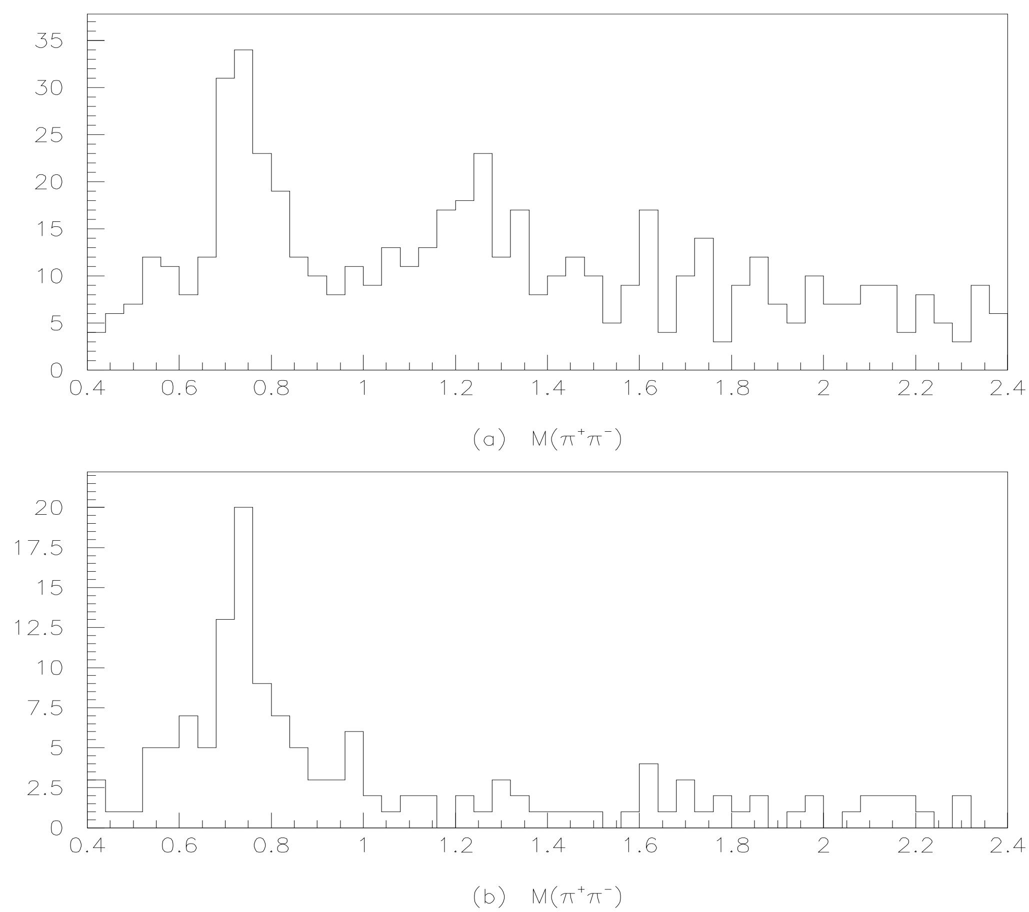

Figure 3 (a): invariant mass of $\pi^+\pi^-$ from ψ' data. (b): invariant mass of $\pi^+\pi^-$ from τ data

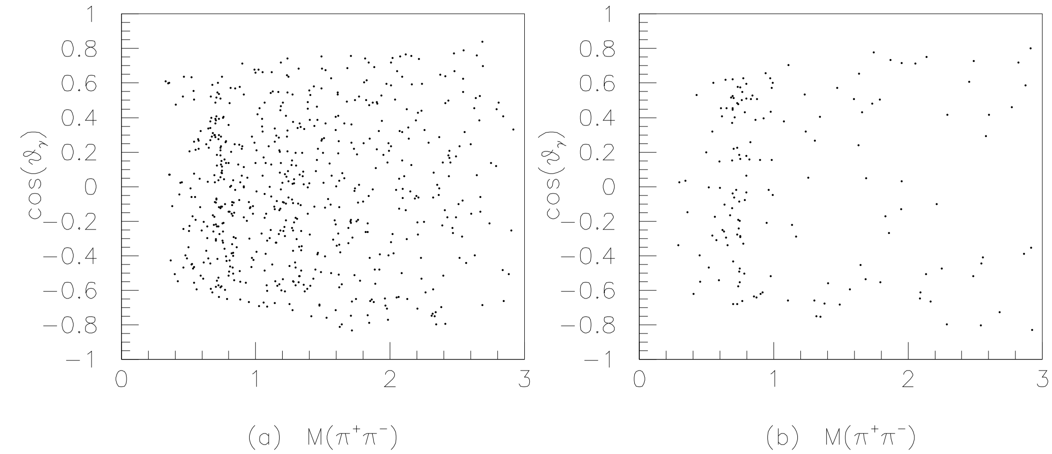

Figure 4 cos θ vs. $\pi^+\pi^-$ mass. (a) in ψ’ data. (b) in τ data

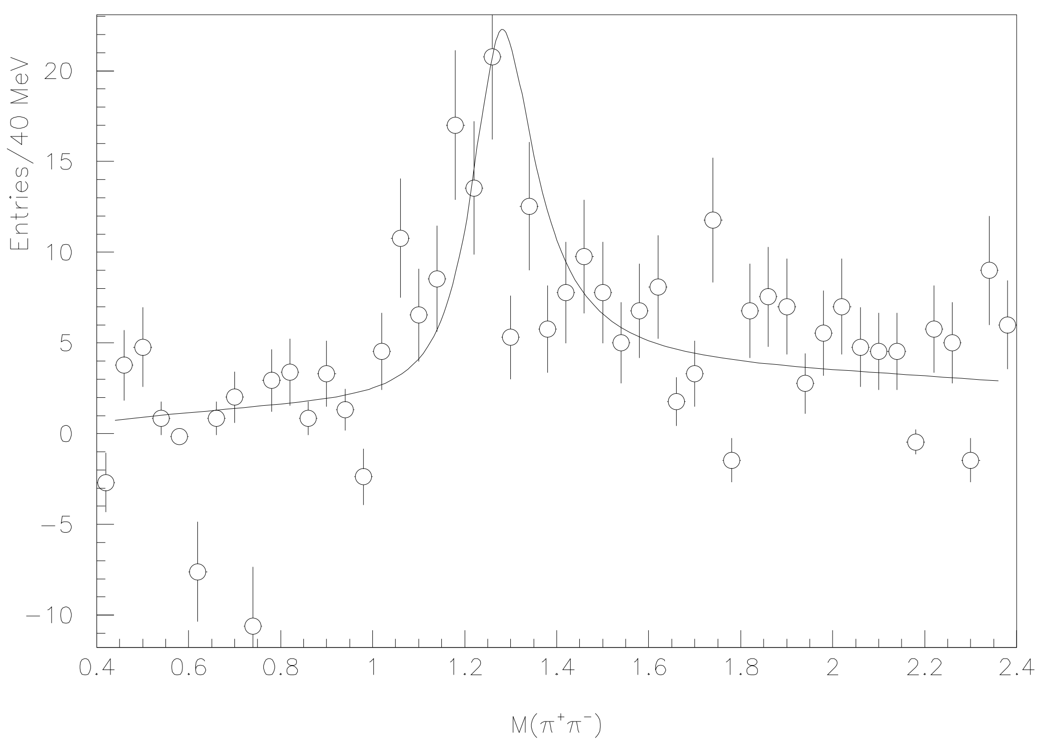

Figure 5 Invariant mass of $\pi^+\pi^-$ after subtracting the background line sharp from τ data