BES Analysis Memo
MEMO # 1: **release 0.1**
χ_c Decays to High Multiplicity $\pi^+\pi^-$ Pairs

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Abstract

An analysis is performed of χ_c decays to high multiplicity $\pi^+\pi^-$ pairs. Numerous techniques for removing γ conversion background from $\psi' \rightarrow n(\pi^+\pi^-)\pi^0$ were evaluated, necessitated by the low momentum spectrum of mimimum mass pairs for such a large number of $m_{\pi\pi}$ combinations. Re-analysis of the $3(\pi^+\pi^-)$ channel indicates that the dominant decay is not a direct decay to $6\pi^\pm$, but mediated by intermediate resonances. Despite intensive efforts to isolate the exclusive mode, only semi-inclusive decay subcompents are identified. First observation of $\chi_{c0,1,2}$ decays to the $4(\pi^+\pi^-)$ final state is reported. Upper limits are reported for $\chi_{c0,1,2}$ decays to the $5(\pi^+\pi^-)$ final state.

1 Introduction

Utilizing the world's largest sample of resonant ψ' decays, as measured by the BES collaboration during 1993-1995, a detailed study of the hadronic decay modes of the χ_c states has been undertaken. Compared with the data set for the Mark I detector[1], roughly an order of magnitude larger data set has been obtained.

Taking advantage of these larger statistics, many new modes have been observed[2], while others have been refined. In particular, the analysis of hadronic decay modes with a high multiplicity of $(\pi^+\pi^-)$ pairs in the final state has benefitted from larger statistics.

While reconstruction of the χ_c states is contaminated with background from direct ψ' decays ($\psi' \rightarrow \pi^0 n(\pi^+\pi^-)$), the level of contamination is manageable. In these background events, one of the γ's from the π^0 decay converts in the beampipe/detector and is mis-identified as a $\pi^+\pi^-$ pair, while the other γ is reconstructed as if from a radiative ψ' decay. Techniques for and results from removing such background are discussed below.

2 Event Selection

The entire BES ψ' data set has been used for this analysis, which corresponds to $(3.67 \pm 0.03 \pm 0.36) \times 10^6$ produced ψ's[3]. For the determination of the number of $\chi_{c_{0,1,2}}$ produced from the radiative decays of the ψ's, results from the Crystal Ball detector[4] are used. This choice is dictated by the much better γ detection efficiency and uniformity of this non-magnetic detector measurement. The values used are tabulated below:

Mode	$Value \pm \sigma_{stat} \pm \sigma_{syst}$
$\psi' \rightarrow \gamma + \chi_{c_0}$	$9.9 \pm 0.5 \pm 0.8$ %
$\psi' \rightarrow \gamma + \chi_{c_1}$	$9.0 \pm 0.5 \pm 0.7$ %
$\psi' \rightarrow \gamma + \chi_{c_2}$	$8.0 \pm 0.5 \pm 0.7$ %

Analysis proceeds on events in the event summaries which contain 5 or more charged tracks (`5PRN`). Events are selected with exactly the number of charged tracks sought, with zero net charge, and with at least one of the γ's within the detector barrel region $|cos\theta| < 0.8$. Events are rejected where the highest momentum charged track pair are identified as muons or where these tracks leave excessive energy $E_{BSC} > 0.8GeV$. For the remaining events, kinematical fitting is performed in two separate ways, and the results of the two fits are compared for consistency.

2.1 Fitting

A full ψ' kinematic fit and a partial $n(\pi^+\pi^-)$ kinematic fit is performed for each event. For these tasks the BES standard routines *NEWSQUID* and *SQUIDJR*, respectively, are used. For a $\gamma\ n(\pi^+\pi^-)$ final state, the *NEWSQUID* fit is a (4)C-fit (including the "best" γ in the event), while the *SQUIDJR* fit is a (1)C-fit reconstructing only the χ_c mass from the charged pions. The motivation for considering the two fits separately is to compare the performance of the charged tracking fit both with and without reconstruction of the neutral energy in an event, since the γ reconstruction efficiency of BES is relatively modest[5] and not well characterized[6].

For the full kinematic fit, in the case of events with more than one accepted photon candidate, the fits are applied for each γ candidate and the one that gives the best fit is chosen. In the partial reconstruction, the mass of the resonance is varied from $2.9 - 3.7 GeV$, and the resonance mass giving the best χ^2 fit is accepted.

2.2 General Cuts

Below are listed the general cuts used for analyzing all of the high-multiplicity $\pi^+\pi^-$ modes. In addition to the constraints mentioned briefly above, specific cuts are applied as tabulated below:

Cut Parameter	**Value**	**Comment**
mfit	2, -9, -19	use only tracks with good fits
$\mathrm{CL_{fit}}$	$> 1\%$	ensure good reconstructed track fits
# of $\mu^\pm$	< 2	remove μ pairs as seen by the muon chambers
E_{BSC}	< 0.8 GeV	remove e^+e^- via EM showers in the Barrel Shower Counter (BSC)
$\lvert cos\theta \rvert$	< 0.8	acceptance cut on charged and neutral reconstructed tracks
$\lvert m_{rec}$ - $m_{\psi'} \rvert$	> 25 MeV	remove ψ' background
$\lvert m_{rec} - m_{\pi\pi}$ - $m_{J/\psi} \rvert$	> 25 MeV	remove decays involving J/ψ's

Making use of these generic cuts, a separate π^0 rejection cut is applied to each of the modes subsequently considered. The general strategy for π^0 rejection is considered below.

2.3 π^0 Rejection

In the high multiplicity $n(\pi^+\pi^-)$ modes, a modest and rather uniform background is seen as in Figure 1a. To attempt to remove these background events, cuts on the details of the event kinematics and topology, such as the following items were tried:

- Straightforward cuts
    - $M_{\pi\pi}^{min}$ - Minimum $\pi\pi$ mass
    - $cos(\pi\pi)_{max}$ - $\pi\pi$ opening angle cut
- Slight variants
    - $M_{\pi\pi}^{min}$ for $cos(\pi\pi)_{max}$
    - $cos(\pi\pi)_{max}$ for $M_{\pi\pi}^{min}$
- Other techniques
    - Use Drift Chamber $\frac{dE}{dx}$
    - Fox-Wolfram analysis
- π^0 Reconstruction
    - Calc. *vs.* Measured $cos(\gamma, \pi^+\pi^-)$
    - Apply for both $cos(\pi\pi)_{max}$, $M_{\pi\pi}^{min}$
    - $\Delta(\vec{p}_{\pi^+} - \vec{p}_{\pi^-})$ for $cos(\pi\pi)_{max}$, $M_{\pi\pi}^{min}$

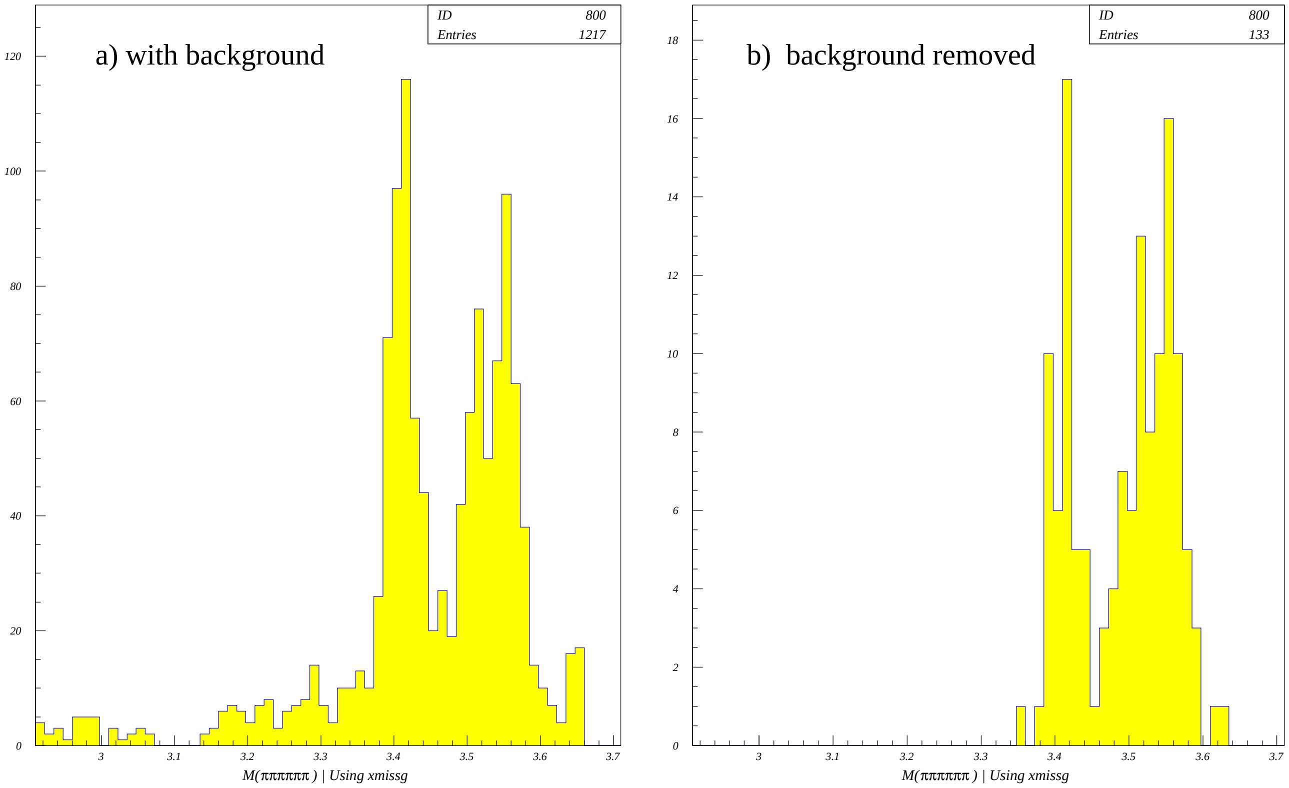

Figure 1: (a) Figure showing the χ_c spectrum of events for decays to the $3(\pi^+\pi^-)$ mode with a uniform background due to π^0 γ conversions. In (b) showing the same χ_c spectrum as that for (a) with cuts to remove π^0 γ conversion background, leaving clean χ_c signatures, but at a significant penalty in statistics.

In Figure 1(a) data before and Figure 1(b) data after π^0 rejection cuts. The success of these combined cuts are shown, with a clear removal of all of the low and high mass background around the χ_c peaks. However, this reduction is observed to be essentially consistent with the reduction of phase space. Each of the techniques itemized above were tried with rather mixed results. A detailed analysis of these parameters for simulation data, as well as for in peak and out of peak data indicate little discriminatory power. This is at first suprising, given that one might expect the minimum mass pair cut to be more effective in removing background. Especially in light of the fact that the conversion electron pair would be expected to be reconstructed as a low mass π pair. However, this cut criterion also cuts most of the good events, as the probability of a low mass combination, with such a large number of permutations, is sizeable.

An extensive and ultimately unproductive line of attack was to attempt to "reconstruct" the π^0 from the candidate radiative γ and a back-calculated conversion γ, in terms of the candidate fake $\pi^+\pi^-$ pairs. Again, because of the large number of combinations, imprecision in the tracking due to ignorance of the conversion point, and the low momentum and spherical nature of the event, little discrimination between real and background events is obtained.

3 Inclusive $n(\pi^+\pi^-)$ Analysis

Utilizing the general cuts listed in the previous section, in conjunction with a few cuts to improve the signal-to-noise ratio in each mode, analysis is performed for χ_c decays to 3, 4 and 5 pairs of charged pions. In these analyses it is naively assumed that the inclusive decay is generated from direct $n(\pi^+\pi^-)$ production. Simulation indicates that the constraint of adding a ρ^0 adds about 1% to the BES acceptance per ρ^0.

This acceptance issue will be discussed in further detail in the following section on exclusive decays. Applying more severe cuts to remove π^0 contaimination has been done in the case of the $4(\pi^+\pi^-)$ mode to provide a strong case for the existence of this mode. In constrast, the constraints for the $3(\pi^+\pi^-)$ mode has been made less severe to minimize the error from a lack of statistics.

In all of these analyses there is a significant concern about the differences in the track reconstruction between data and Monte Carlo[6]. The systematic error values applied are detailed elsewhere[7] and subject to further refinement.

3.1 $3(\pi^+\pi^-)$ Analysis

Taking the 6 charged pion final state as being the direct decay, and using the additional cut directly below, Figure 2 shows the results for data and MC. These results are transformed to a branching ratio in Figure 3 below.

$3(\pi^+\pi^-)$ Cut Values

Cut Parameter	Value	Comment
$m_{\pi\pi}$	$\geq$ 300 MeV	cut on minimum mass pair