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A search for charmonium states produced in central pp interactions at 450 GeV/c

The WA102 Collaboration

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Abstract

A search for centrally produced charmonium states has been presented. There is no significant evidence for any charmonium production. An upper limit of 2 nb is found for the cross section of χ_c production using the decay $\chi_c(1P) \rightarrow J/\psi\gamma$.

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The WA102 collaboration have studied centrally produced final states formed in the reaction

$$pp \rightarrow p_f(X^0)p_s \tag{1}$$

at 450 GeV/c. The subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. By measuring the cross section as a function of energy it has been possible to deduce that a large number of the final states are compatible with being produced by Double Pomeron Exchange (DPE). Apart from kinematical factors DPE should be effectively flavour blind in the production of resonance states. However, Donnachie and Landshoff [1] have recently claimed that in order to describe data from HERA they need to introduce two Pomerons; a so-called soft Pomeron with y axis intercept at 1.08 on the Chew-Frautschi plot and a hard Pomeron with intercept at 1.4. In addition, they have claimed [2] that the soft Pomeron has a very weak coupling to $c\overline{c}$ pairs.

To date no evidence has been observed for charmonium production in DPE. These states will be heavily suppressed due to the mass reach of the experiment, hence a search for charmonium states is limited to the lightest. Possible candidates are the $\eta_c(1S)$, the J/ψ and the $\chi_c(1P)$ states.

The J/ψ can not be exclusively produced in DPE due to C-parity. It has been observed previously that $J^{PC} = 0^{-+}$ states are suppressed in DPE [3] therefore it is likely that the $\eta_c(1S)$ is also suppressed. $J^{PC} = 0^{++}$, 1^{++} and 2^{++} states are seen prominently in DPE therefore it may be interesting to search for the χ_c states. The dominant decay mode for the $\chi_1(3510)$ and $\chi_2(3555)$ is $J/\psi\gamma$. This decay has the advantage that it could be isolated from the normal hadronic background using the leptonic decay mode of the J/ψ.

In this paper a search is presented for the χ_c states in the reaction

$$pp \rightarrow p_f(J/\psi\gamma)p_s \tag{2}$$

with $J/\psi \rightarrow e^+e^-$. Reaction (2) has been isolated from the sample of events having four outgoing charged tracks and one isolated γ, not associated with a charged track impact, reconstructed in the GAMS-4000 calorimeter, by first imposing the following cuts on the components of missing momentum: $|\text{missing } P_x| < 14.0$ GeV/c, $|\text{missing } P_y| < 0.20$ GeV/c and $|\text{missing } P_z| < 0.16$ GeV/c, where the x axis is along the beam direction. A correlation between pulse-height and momentum obtained from a system of scintillation counters was used to ensure that the slow particle was a proton.

One or both of the centrally produced charged tracks are required to impact on the calorimeter. The shower profile associated with the charged track is required to be consistent with being an electromagnetic shower. Fig. 1 shows a plot of the energy deposited in the GAMS calorimeter divided by the momentum of the charged track detected in Omega. A clear peak can be observed centred at $E/p = 1.0$ due to electrons. The electrons have been selected by requiring $0.9 \leq E/p \leq 1.1$. At least one charged track per event is required to be identified as an electron. If the other charged track hits the calorimeter it is required to be compatible with being an electron ($E/p \geq 0.8$). Fig. 2a) shows the resulting e^+e^- mass spectrum which peaks near zero consistent with the the majority of the electrons being due to γ conversions. These γ conversions were selected by requiring $M(e^+e^-) \leq 0.1$ GeV. The momentum vector of the converted γ has been combined with the γ reconstructed in GAMS. Fig. 2b) shows the resulting $\gamma\gamma$ mass spectra where clear peaks can be observed at the π^0 and η masses.

Fig. 3a) shows the e^+e^- mass spectrum for m(e^+e^-) $\geq$ 2.0 GeV. There is no evidence for a statistically significant peak at the mass of the J/ψ. Superimposed on the mass spectrum is a Monte Carlo prediction for a J/ψ peak coming from χ_c decays. Possible J/ψ events have been selected by requiring $3.05 \leq$ M(e^+e^-) ≤ 3.15 GeV. Fig. 3b) shows the resulting $J/\psi\gamma$ mass spectra. The mass resolution has been calculated from Monte Carlo to be σ = 55 MeV.

Since there is no significant evidence for χ_c production only an upper limit can be calculated. After correcting for geometrical acceptances, detector efficiencies, losses due to cuts, and unseen J/ψ decay modes, the cross-section for the χ_c resonances decaying to $J/\psi\gamma$ at $\sqrt{s} = 29.1$ GeV is $\sigma(\chi_c \to J/\psi\gamma) <$ 2.0 nb (90 % CL).

A search has also been made for the reaction

$$pp \to p_f(J/\psi)p_s \quad (3)$$

with $J/\psi \to e^+e^-$. Reaction (3) has been isolated from the sample of events having four outgoing charged tracks by first imposing the cuts on the components of missing momentum described above. Fig. 4a) shows a plot of the energy deposited in the GAMS calorimeter divided by the momentum of the charged track detected in Omega. In this case there is a shoulder at 1.0 due to electrons. Electron candidates have been selected by requiring $0.9 \leq E/p \leq 1.1$. At least one charged track per event is required to be identified as an electron. If the other charged track hits the calorimeter it is required to be compatible with being an electron ($E/p \geq 0.8$). Fig. 4b) shows the resulting e^+e^- mass spectrum for M(e^+e^-) above 2 GeV. There is no sign of a peak in the J/ψ region.

A study of other final states has been performed in order to search for $J/\psi\pi^0$, $J/\psi\eta$, $J/\psi\pi^+\pi^-$ and $J/\psi\pi^0\pi^0$. In all cases there is no sign for a peak in the e^+e^- mass spectrum at the J/ψ mass.

In order to search for the production of the $\eta_c(1S)$ we have studied the channels constituting its dominant decay modes, namely: $\eta\pi^+\pi^-$ and $K^0_S K^\pm\pi^\mp$. The selection of the $\eta\pi^+\pi^-$ and $K^0_S K^\pm\pi^\mp$ channels have been described in refs. [4] and [5] respectively. Fig. 4c) shows the $\eta\pi^+\pi^-$ mass spectrum and fig. 4d) shows the $K^0_S K^\pm\pi^\mp$ mass spectrum above 2 GeV. There is no evidence for any $\eta_c(1S)$ signal above the background.

In summary, a search for centrally produced charmonium states has been presented. There is no significant evidence for any charmonium production. In particular we have calculated an upper limit of 2 nb for the cross section for χ_c production using the decay $\chi_c(1P) \to J/\psi\gamma$ with the J/ψ decaying to e^+e^-. This upper limit could be used as a test of the hypothesis that the soft Pomeron has a very weak coupling to $c\bar{c}$ pairs [2]. There is also evidence that in central pp collisions $s\bar{s}$ production is much weaker than $n\bar{n}$ production. This evidence comes from the fact that the cross section for the production of the $f_2(1270)$, whose production has been found to be consistent with DPE [6], is more than 40 times greater than the cross section of the $f_2'(1525)$. Hence there could be some strong dependence on the mass of the quarks which could explain the lack of $c\bar{c}$ in DPE.

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References

[1] A. Donnachie and P.V. Landshoff, Phys. Lett. **B437** (1998) 408.

[2] A. Donnachie and P.V. Landshoff, Phys. Lett. **B470** (1999) 243.

[3] D. Barberis *et al.,* Phys. Lett. **B427** (1998) 398.

[4] D. Barberis *et al.,* Phys. Lett. **B440** (1998) 225.

[5] D. Barberis *et al.,* Phys. Lett. **B413** (1997) 225.

[6] D. Barberis *et al.,* Phys. Lett. **B462** (1999) 462.

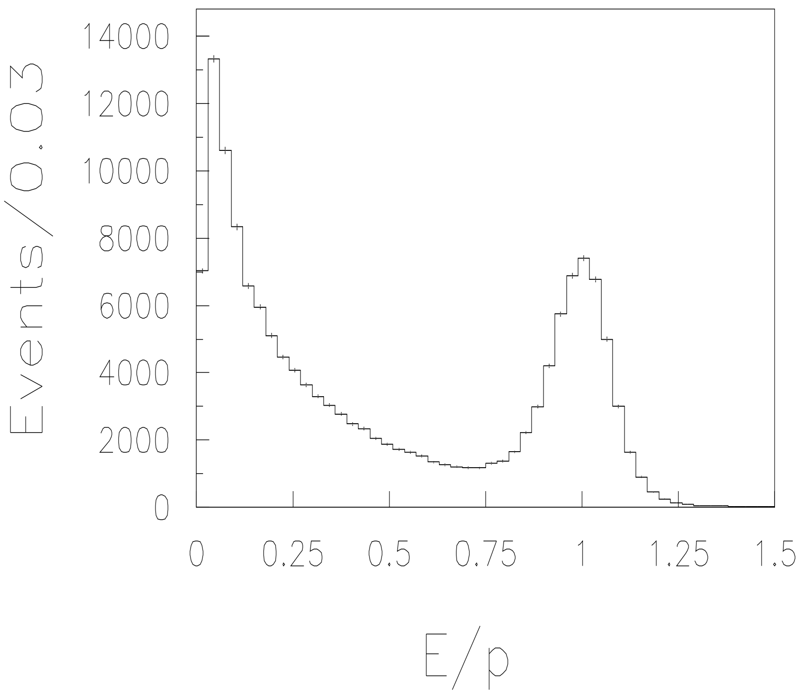
Figures

Figure 1: The energy associated with a charged track impact deposited in the GAMS-4000 calorimeter divided by the momentum of the track measured in Omega for reaction (2).

Figure 2: a) The e^+e^- mass spectrum. b) The $\gamma\gamma$ mass spectrum when one of the γ is observed decaying to e^+e^-.

Figure 3: a) The e^+e^- mass spectrum. Superimposed is the J/ψ signal expected from a Monte Carlo simulation. b) The $e^+e^-\gamma$ mass spectrum for $3.05 \leq \mathrm{M}(e^+e^-) \leq 3.15$ GeV.

Figure 4: The energy associated with a charged track impact deposited in the GAMS-4000 calorimeter divided by the momentum of the track measured in Omega for reaction (3) and b) the e^+e^- mass spectrum. c) The $\eta\pi^+\pi^-$ and d) $K^0_S K^\pm \pi^\mp$ mass spectra.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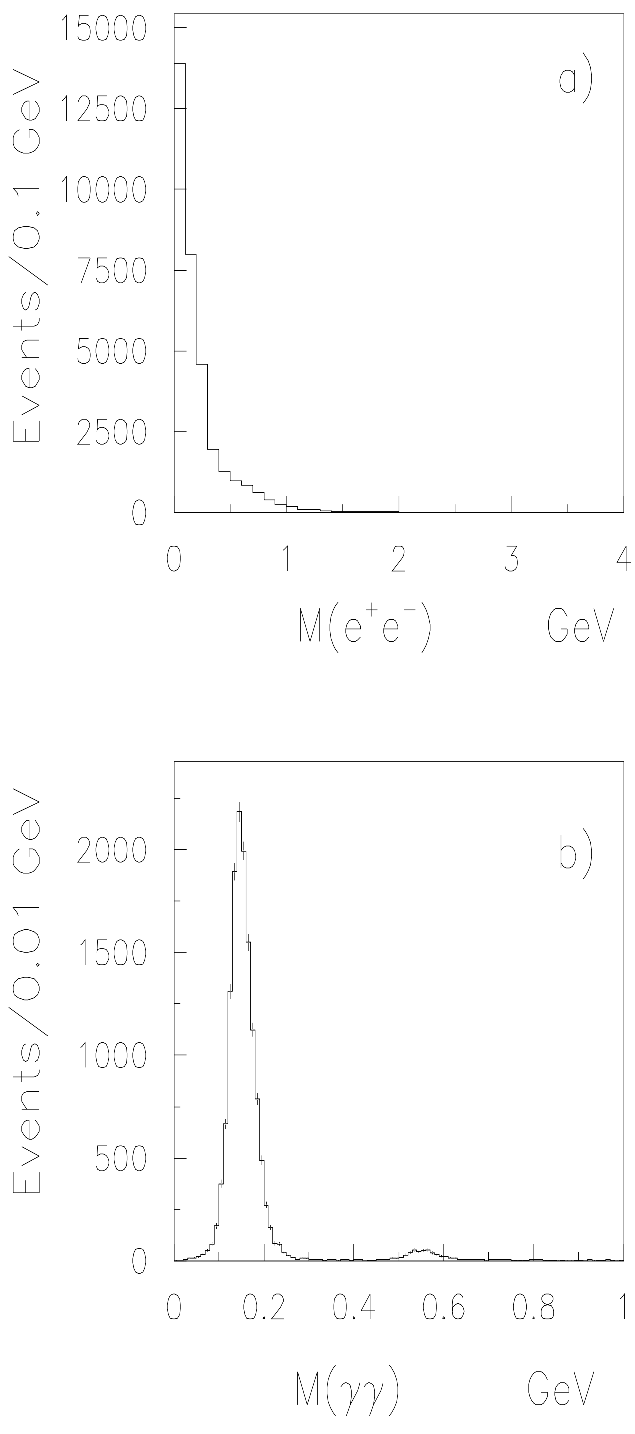
1
1.25
1.5
E/p

Figure 1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10000
7500
5000
2500
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Events/0.1 GeV
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1
2
3
4
M(e+e−) GeV
2000
1500
1000
500
0
Events/0.01 GeV
b)
0
0.2
0.4
0.6
0.8
1
M(γγ) GeV

Figure 2

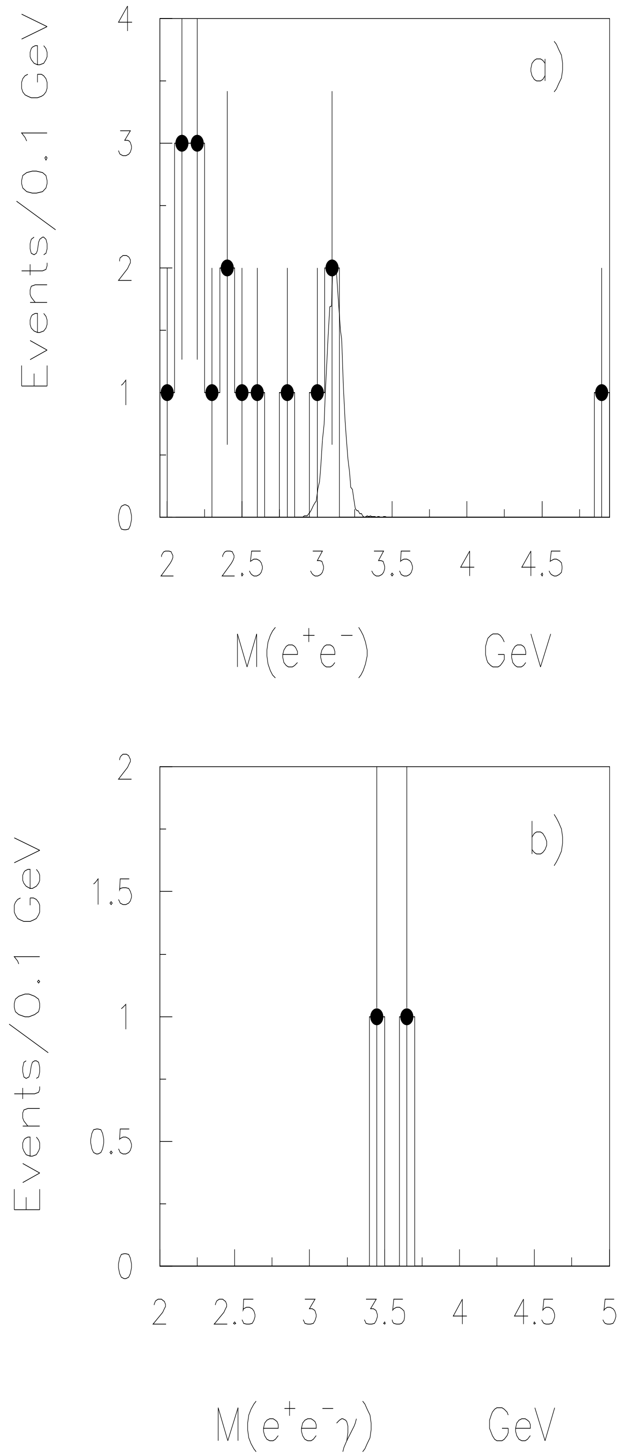
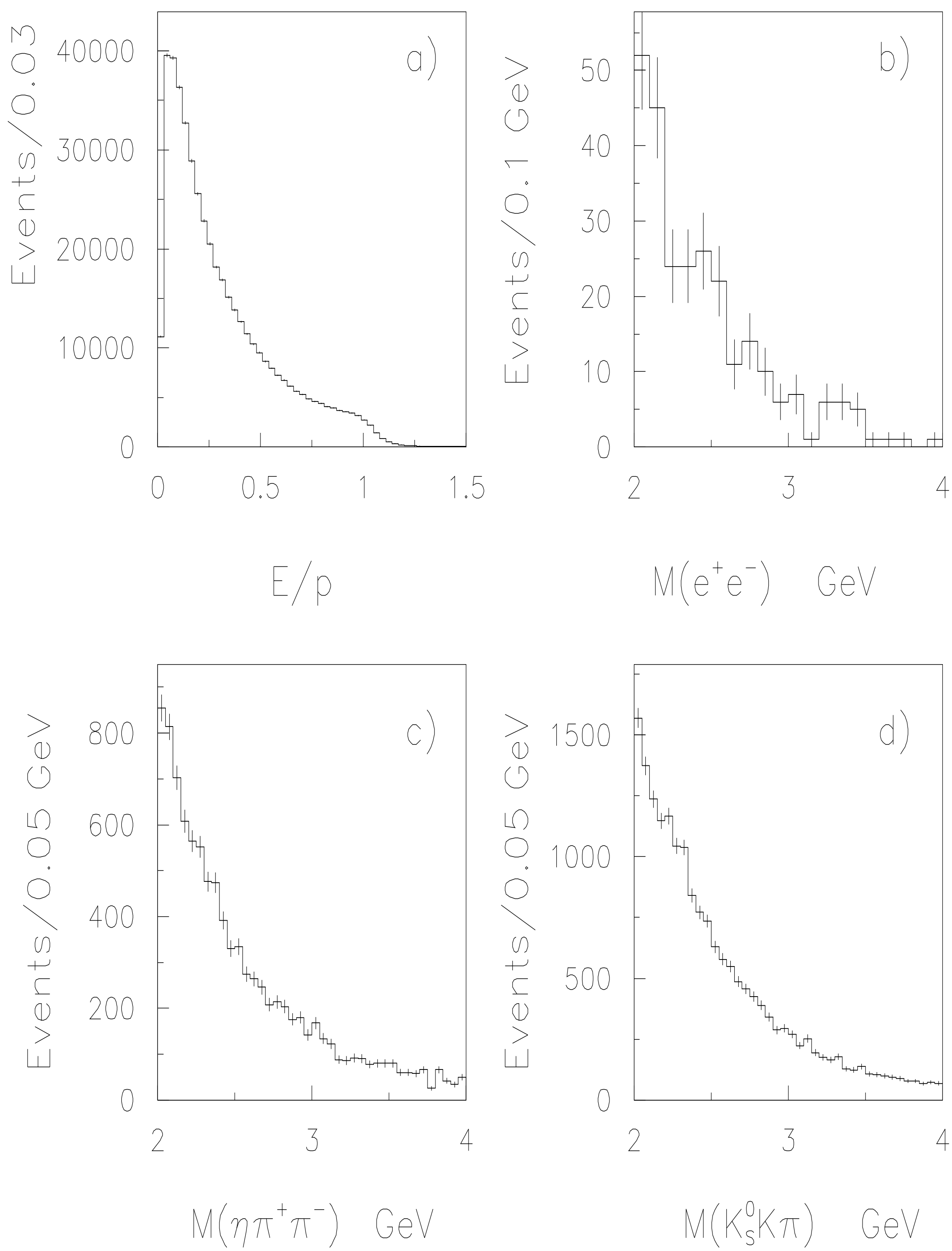


Figure 3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E/p
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30
20
10
0
b)
2
3
4
M(e+e−) GeV
Events/0.05 GeV
800
600
400
200
0
c)
2
3
4
M(ηπ+π−) GeV
Events/0.05 GeV
1500
1000
500
0
d)
2
3
4
M(K0sKπ) GeV

Figure 4