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A search for non-$q\overline{q}$ mesons in the WA102 experiment at the CERN Omega Spectrometer

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Abstract. A study of central meson production as a function of the difference in transverse momentum (dP_T) of the exchanged particles shows that undisputed $q\overline{q}$ mesons are suppressed at small dP_T whereas the glueball candidates are enhanced.

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INTRODUCTION

There is considerable current interest in trying to isolate the lightest glueball. Several experiments have been performed using glue-rich production mechanisms. One such mechanism is Double Pomeron Exchange (DPE) where the Pomeron is thought to be a multi-gluonic object. Consequently it has been anticipated that production of glueballs may be especially favoured in this process [2].

The Omega central production experiments (WA76, WA91 and WA102) are designed to study exclusive final states formed in the reaction

$$\mathrm{pp} \longrightarrow \mathrm{p}_f X^0 \mathrm{p}_s,$$

where the subscripts f and s refer to the fastest and slowest particles in the laboratory frame respectively and X^0 represents the central system. Such

reactions are expected to be mediated by double exchange processes where both Pomeron and Reggeon exchange can occur.

The trigger was designed to enhance double exchange processes with respect to single exchange and elastic processes. Details of the trigger conditions, the data processing and event selection have been given in previous publications [3].

A GLUEBALL-$Q\overline{Q}$ FILTER IN CENTRAL PRODUCTION ?

The experiments have been performed at incident beam momenta of 85, 300 and 450 GeV/c, corresponding to centre-of-mass energies of $\sqrt{s}$ = 12.7, 23.8 and 28 GeV. Theoretical predictions [4] of the evolution of the different exchange mechanisms with centre of mass energy, $\sqrt{s}$, suggest that

$$\sigma(\mathrm{RR}) \sim s^{-1},$$
$$\sigma(\mathrm{RP}) \sim s^{-0.5},$$
$$\sigma(\mathrm{PP}) \sim \text{constant},$$

where RR, RP and PP refer to Reggeon-Reggeon, Reggeon-Pomeron and Pomeron-Pomeron exchange respectively. Hence we expect Double Pomeron Exchange (DPE) to be more significant at high energies, whereas the Reggeon-Reggeon and Reggeon-Pomeron mechanisms will be of decreasing importance. The decrease of the non-DPE cross section with energy can be inferred from data taken by the WA76 collaboration using pp interactions at $\sqrt{s}$ of 12.7

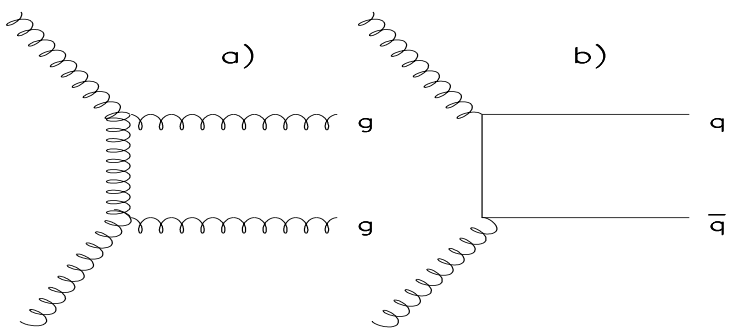

FIGURE 1. Schematic diagrams of the coupling of the exchange particles into the final state meson for a) gluon exchange and b) quark exchange.

GeV and 23.8 GeV [5]. The $\pi^+\pi^-$ mass spectra for the two cases show that the signal-to-background ratio for the $\rho^0(770)$ is much lower at high energy, and the WA76 collaboration report that the ratio of the $\rho^0(770)$ cross sections at 23.8 GeV and 12.7 GeV is 0.44 ± 0.07. Since isospin 1 states such as the $\rho^0(770)$ cannot be produced by DPE, the decrease of the $\rho^0(770)$ signal at high $\sqrt{s}$ is consistent with DPE becoming relatively more important with increasing energy with respect to other exchange processes.

However, even in the case of pure DPE the exchanged particles still have to couple to a final state meson. The coupling of the two exchanged particles can either be by gluon exchange or quark exchange. Assuming the Pomeron is a colour singlet gluonic system if a gluon is exchanged then a gluonic state is produced, whereas if a quark is exchanged then a $q\overline{q}$ state is produced (see figures 1a) and b) respectively). It has been suggested recently [6] that for small differences in transverse momentum between the two exchanged particles an enhancement in the production of glueballs relative to $q\overline{q}$ states may occur.

Recently the WA91 collaboration has published a paper [7] showing that the observed centrally produced resonances depend on the angle between the outgoing slow and fast protons. In order to describe the data in terms of a physical model, Close and Kirk [6], have proposed that the data be analysed in terms of the difference in transverse momentum between the particles exchanged from the fast and slow vertices. The difference in the transverse momentum vectors (dP_T) is defined to be

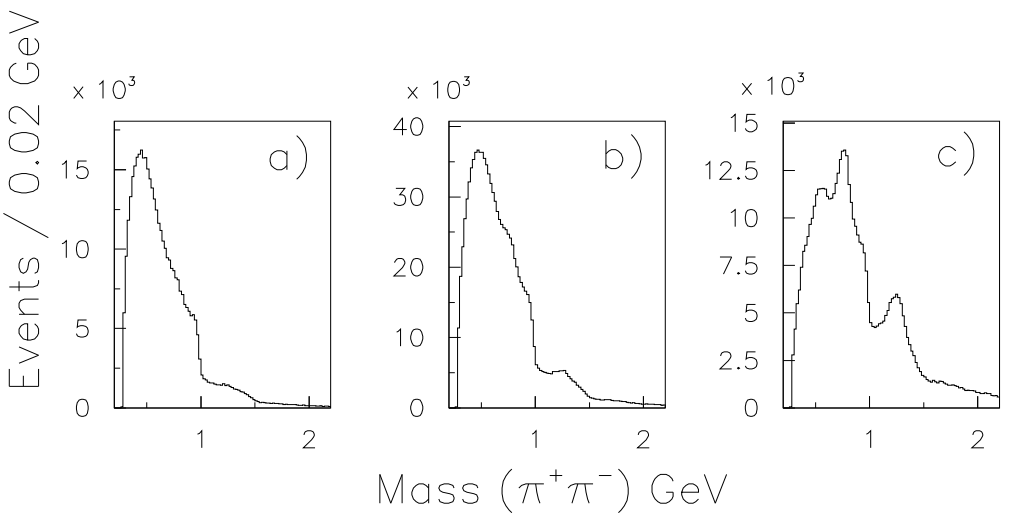

FIGURE 2. The $\pi^+\pi^-$ mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV.

$$dP_T = \sqrt{(P_{y1} - P_{y2})^2 + (P_{z1} - P_{z2})^2}$$

where Py_i, Pz_i are the y and z components of the momentum of the *ith* exchanged particle in the pp centre of mass system [8].

The effect that different cuts in dP_T have on the $\pi^+\pi^-$ mass spectrum are shown in figures 2a), b) and c). As can be seen, for $dP_T < 0.2$ GeV there is effectively no $\rho^0(770)$ or $f_2(1270)$ signals. These signals only become apparent as dP_T increases. However the $f_0(980)$, which is responsible for the sharp drop in the spectrum around 1 GeV, is clearly visible in the small dP_T sample.

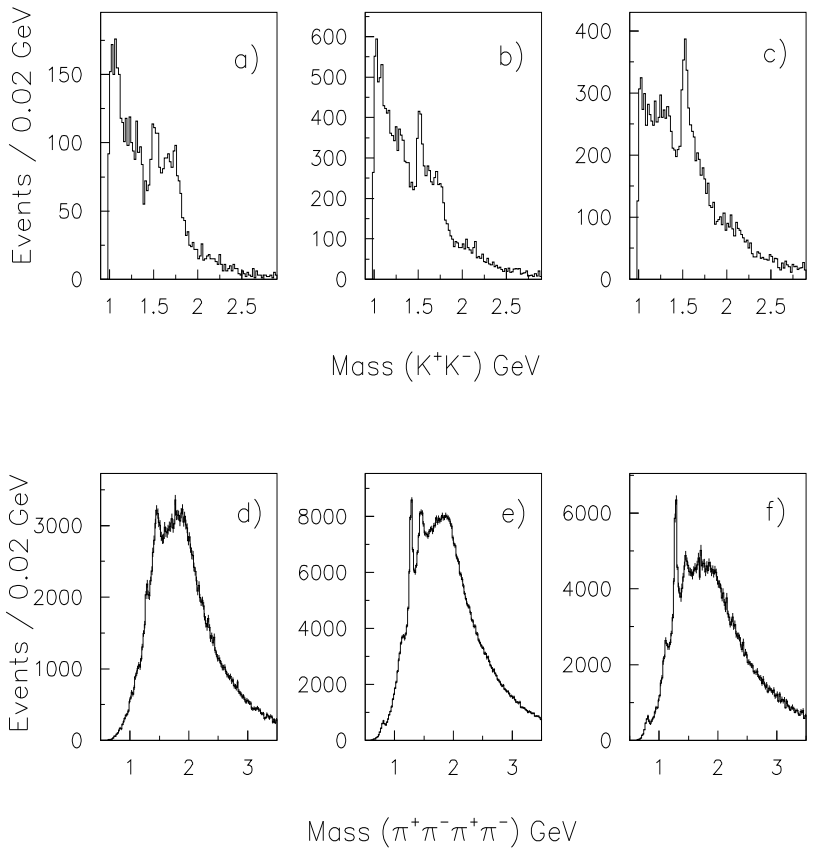

FIGURE 3. K^+K^- mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV and the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for d) $dP_T < 0.2$ GeV, e) $0.2 < dP_T < 0.5$ GeV and f) $dP_T > 0.5$ GeV.

Figures 3a), b) and c) show the effect of the dP_T cut on the K^+K^- mass spectrum where structures can be observed in the 1.5 and 1.7 GeV mass region which have been previously identified as the $f_2'(1525)$ and the $f_J(1710)$ [9]. As can be seen, the $f_2'(1525)$ is produced dominantly at high dP_T, whereas the $f_J(1710)$ is produced dominantly at low dP_T.

In the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum a dramatic effect is observed, see figures 3d), e) and f). The $f_1(1285)$ signal has virtually disappeared at low dP_T whereas the $f_0(1500)$ and $f_2(1930)$ signals remain.

A spin-parity analysis of the $\pi^+\pi^-\pi^+\pi^-$ channel has been performed [10] using an isobar model [11]. The $f_1(1285)$ is clearly seen in the $J^P = 1^+$ $\rho\rho$ and the $f_1(1285)$ signal almost disappears at small dP_T. In the $J^P = 0^+\rho\rho$ distribution a peak is observed at 1.45 GeV together with a broad enhancement around 2 GeV. The peak in the $J^P = 0^+\rho\rho$ wave around 1.45 GeV remains for $dP_T \leq 0.2$ GeV while the $J^P = 0^+$ enhancement at 2.0 GeV becomes less important: which shows that the dP_T effect is not simply a J^P filter.

A fit has first been performed to the total $J^P = 0^+\rho\rho$ distribution using a K matrix formalism [12] including poles to describe the peak at 1.45 GeV as an interference between the $f_0(1300)$, the $f_0(1500)$ together with a possible state at 2 GeV. The resulting resonance parameters for the $f_0(1300)$ and $f_0(1500)$ are very similar to those found by Crystal Barrel [13].

The peak observed at 1.9 GeV, called the $f_2(1900)$, is found to decay to $a_2(1320)\pi$ and $f_2(1270)\pi\pi$ with $J^{PC} = 2^{++}$. At small dP_T the $f_2(1900)$ signal is still important. This is the first evidence of a non-zero spin resonance produced at small dP_T and hence shows that the dP_T effect is not just a $J^P = 0^+$ filter.

In addition to these waves, a $J^P = 2^-$ $a_2(1320)\pi$ wave was required in the fit. The $J^P = 2^-$ $a_2(1320)\pi$ wave observed in this experiment is consistent with the two η_2 resonances observed by Crystal Barrel [14] with both states decaying to $a_2(1320)\pi$. The $2^{-+}a_2(1320)\pi$ signal is suppressed at small dP_T. This behaviour is consistent with the signals being due to standard $q\overline{q}$ states [6].

A similar effect is observed in the $K^0_S K^\pm\pi^\mp$ [15] and $\eta\pi^+\pi^-$ [8] channels where the $f_1(1285)$, $f_1(1420)$ and η' are all more prominent in the large dP_T sample and start to disappear at low dP_T.

In fact it has been observed that all the undisputed $q\overline{q}$ states (i.e. $\rho^0(770)$, η', $f_2(1270)$, $f_1(1285)$, $f_2'(1525)$ etc.) are suppressed as dP_T goes to zero, whereas the glueball candidates $f_J(1710)$, $f_0(1500)$ and $f_2(1930)$ survive. It is also interesting to note that the enigmatic $f_0(980)$, a possible non-$q\overline{q}$ meson or $K\overline{K}$ molecule state does not behave as a normal $q\overline{q}$ state.

A Monte Carlo simulation of the trigger, detector acceptances and reconstruction program shows that there is very little difference in the acceptance as a function of dP_T in the different mass intervals considered within a given channel and hence the observed differences in resonance production can not be explained as acceptance effects.

It has previously been observed that the resonances produced in the central region depend on the four momentum transferred from the fast (t_f) and slow

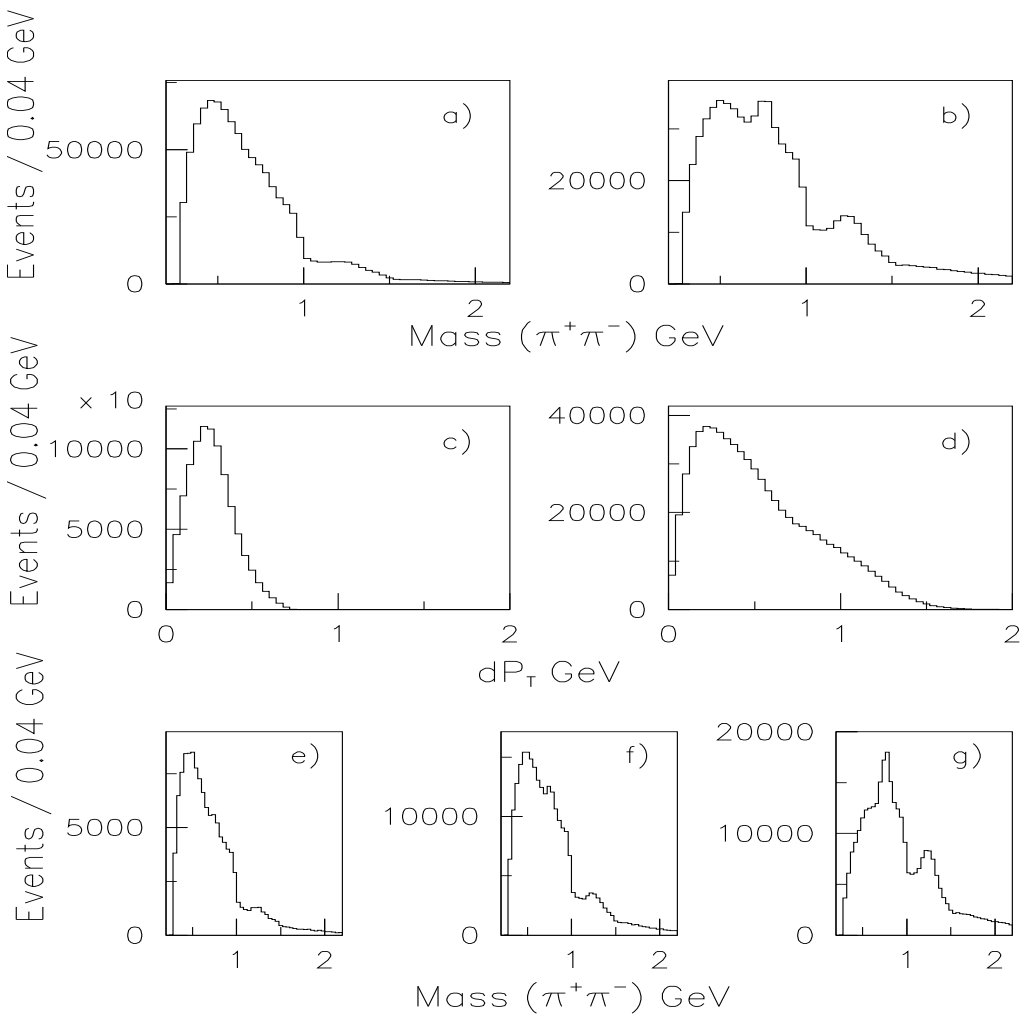

FIGURE 4. Results of cutting on the four momentum transferred at the proton vertices. The $\pi^+\pi^-$ mass spectrum for a) $|t_f| < 0.15$ and $|t_s| < 0.15$ GeV^2 and c) $|t_f| > 0.15$ and $|t_s| > 0.15$ GeV^2. The dP_T distribution for c) $|t_f| < 0.15$ and $|t_s| < 0.15$ GeV^2 and d) $|t_f| > 0.15$ and $|t_s| > 0.15$ GeV^2. The $\pi^+\pi^-$ mass spectrum for $|t_f| > 0.15$ and $|t_s| > 0.15$ GeV^2 and e) $dP_T < 0.2$ GeV, f) $0.2 < dP_T < 0.5$ GeV and g) $dP_T > 0.5$ GeV.

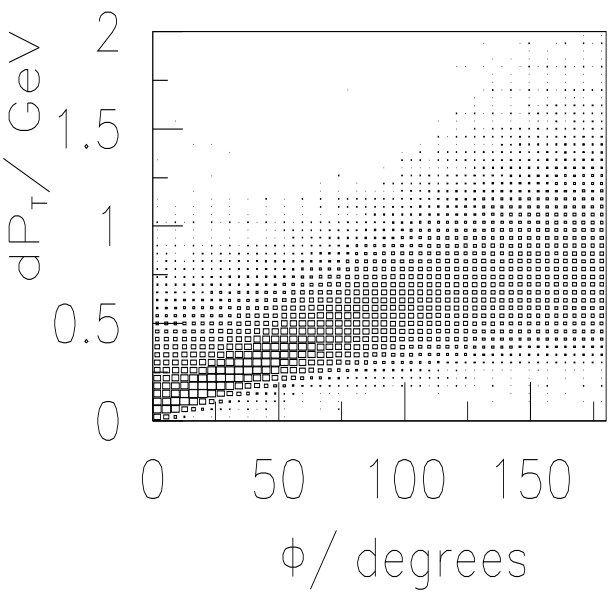

FIGURE 5. dP_T versus the azimuthal angle between the fast and slow protons (ϕ).

vertices (t_s) [5]. The $\pi^+\pi^-$ mass spectrum is shown for the case where $|t_f|$ and $|t_s|$ are both less than 0.15 GeV^2 in figure 4a) and in figure 4b) for the case when $|t_f|$ and $|t_s|$ are both greater than 0.15 GeV^2. As can be seen the amount of $\rho^0(770)$ and $f_2(1270)$ does change as a function of this cut. However, in figures 4c) and d) the dP_T distribution for these two cases is shown where it can be seen the events that have small $|t|$ are restricted to small values of dP_T. To show that dP_T is the most important underlying dynamical effect the dP_T cut has been applied to the sample of events with large $|t|$. Figures 4e), f) and g) show the events when $|t_f|$ and $|t_s|$ are both greater than 0.15 GeV^2 for $dP_T \leq 0.2$ GeV, $0.2 \leq dP_T \leq 0.5$ GeV and $dP_T \geq 0.5$ GeV respectively. As can be seen the dP_T cut still works in this sample and hence it would seem that dP_T is the most important cut to be used.

An effect on the resonances observed has also been seen when cuts have been made on the azimuthal angle (ϕ) between the fast and slow proton. This angle ϕ is related to dP_T by

$$cos\phi = \frac{dP_T^2 - P_T^2}{4t_s t_f}$$

where P_T is the transverse momentum of the central system. The correlation between dP_T and ϕ is shown in figure 5. Although cuts in ϕ do produce an

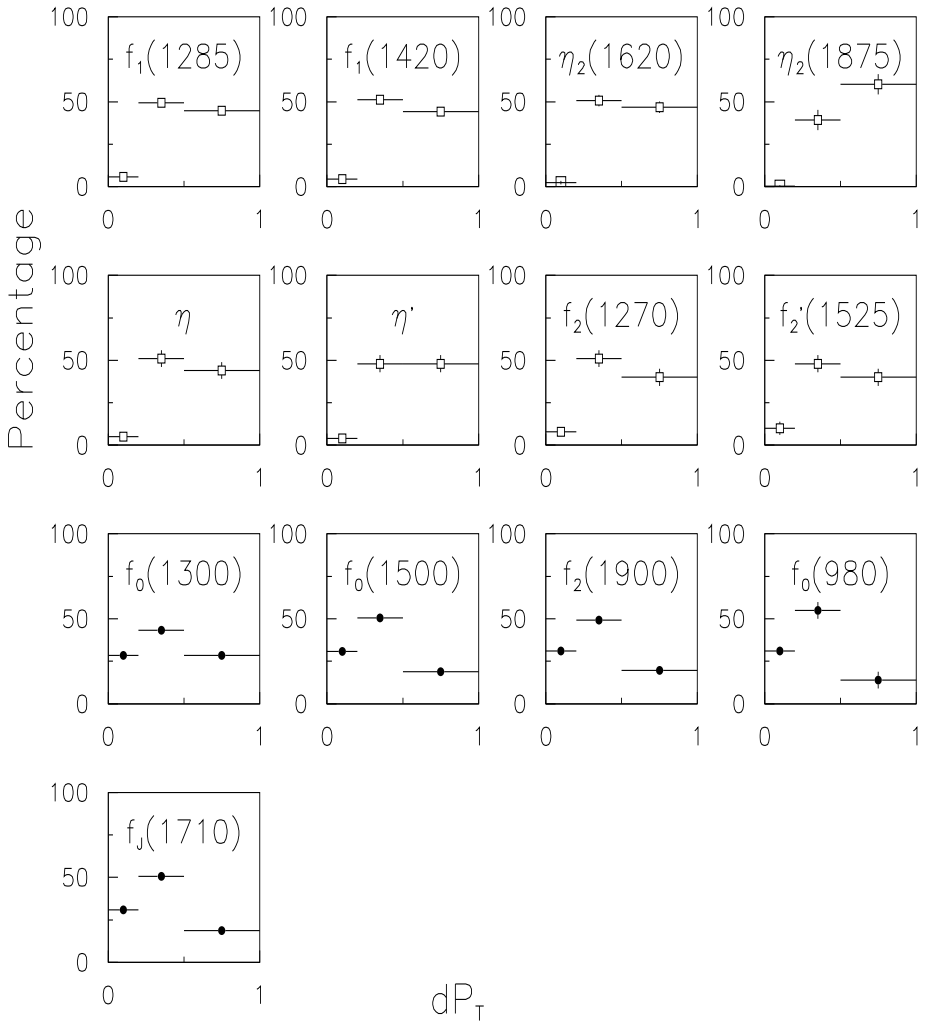

FIGURE 6. The percentage of the resonance as a function of dP_T

effect on the resonances observed the effect is not as clear compared to cuts in dP_T.

SUMMARY OF THE EFFECTS OF THE DP_T FILTER

In order to calculate the contribution of each resonance as a function of the dP_T the mass spectra have been fitted with the parameters of the resonances fixed to those obtained from the fits to the total data. The results of these fits are summarised in figure 6 where the percentage of each resonance as a function of dP_T is presented. Figure 7 shows the ratio of the number of

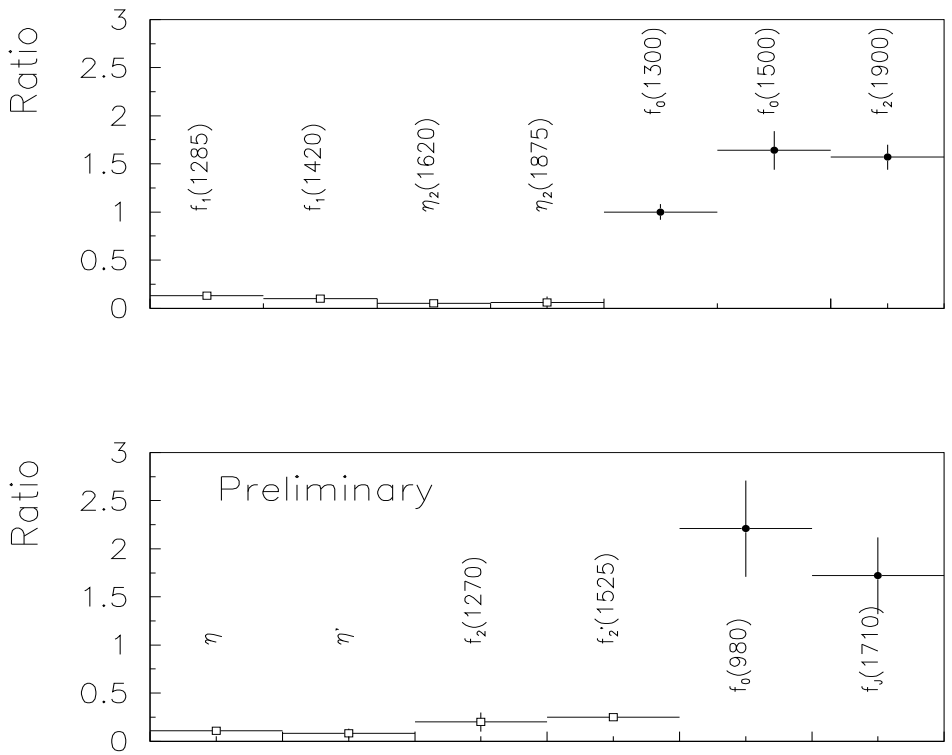

FIGURE 7. The ratio of the amount of resonance with $dP_T \leq 0.2$ to the amount with $dP_T \geq 0.5$ GeV.

events for $dP_T < 0.2$ GeV to the number of events for $dP_T > 0.5$ GeV for each resonance considered. As can be seen all the undisputed $q\overline{q}$ states have a small value for this ratio whereas the interesting states have a high value.

CONCLUSIONS

Preliminary results show that there is the possibility of a glueball-$q\overline{q}$ filter mechanism in central production. All the undisputed $q\overline{q}$ states are observed to be suppressed at small dP_T, but the glueball candidates $f_0(1500)$, $f_J(1710)$,

and $f_2(1930)$, together with the enigmatic $f_0(980)$, survive.

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