FURTHER EVIDENCE ON GLUONIC STATES FROM THE WA102 EXPERIMENT

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representing the WA102 Collaboration [1]

A study of central meson production is a convenient way of investigating gluonic matter. In addition to the expected enrichment of glueball production via the Double Pomeron process, it also shows some kinematic peculiarity which can be used to separate all glueball candidates from undisputed $q\bar{q}$ mesons. The difference in transverse momentum (dP_T) of the exchanged particles can be considered as a possible glueballs-$q\bar{q}$ filter.

1 Introduction

For more than a decade experimental attempts to detect glueballs, in particular the lightest scalar glueball, have not yet brought a final success. Glueball discovery remains an experimental challenge although the existence of such objects is certain from the QCD point of view.

The situation can be well illustrated by the scalar glueball case. The scalar glueball mass predictions made by different models [2] are rather consistent and point to about 1500 MeV with typically 100-150 MeV errors and about 200 MeV spread over different predictions. This mass region is very well investigated by several generations of experiments and one can take as a realistic approximation that all scalar states between 1 and 2 GeV are already observed. The number of established scalars is greater than what is needed to fill the 0^{++} quark model nonet. This fact is considered as a clear indication of the existence of the scalar gluonic state in 1-2 GeV mass region. But none of the observed scalar mesons can be unambiguously identified as a glueball although some of them have exotic properties. This can be understood if the scalar glueball is strongly mixed with the quark neighbours and instead of pure gg state we have a certain fraction of glue in several $q\bar{q}$ scalar states. Hence the subject of "glueball spectroscopy" is not a search for new particles with fully exotic properties but the detailed investigation of all meson states in the given mass region in preferably all decay modes in order to quantify glue-induced discrepancies with the standard quark model predictions.

Mixed $q\bar{q}$-gg states can be produced via their quark or glue component in practically any hadroproduction reaction. However it is preferable for glueball spectroscopy experiments to use some of the glue-rich production mechanisms, like $p\bar{p}$-annihilation or Double Pomeron exchange (DPE) to ensure the presence of the subject of investigation in the collected data sample.

2 The WA102 experiment

The WA102 experiment was designed to study exclusive final states formed in the reaction

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

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. Assuming the Pomeron is a colour singlet gluonic system all meson states, pure $q\bar{q}$ or gg and mixed $q\bar{q}$-gg, should be produced in such a reaction. Theoretical predictions [3] of the evolution of the different exchange mechanisms with centre of mass energy, $\sqrt{s}$, suggest that

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

where RR, RP and PP refer to Reggeon-Reggeon, Reggeon-Pomeron and Pomeron-Pomeron exchange respectively. Hence the glueball-contained states produced via DPE should have a production cross section energy dependence different from the pure quark states produced via Double Reggeon exchange. This effect, specific to central production, gives an additional very useful tool for the identification of gluonic states. But the most promising peculiarity of the central production is the recently observed kinematic filter.

3 A kinematic filter

The basis of the possible glueball-$q\bar{q}$ filter suggested recently by the WA102 collaboration is the experimental observation that the central production of meson states

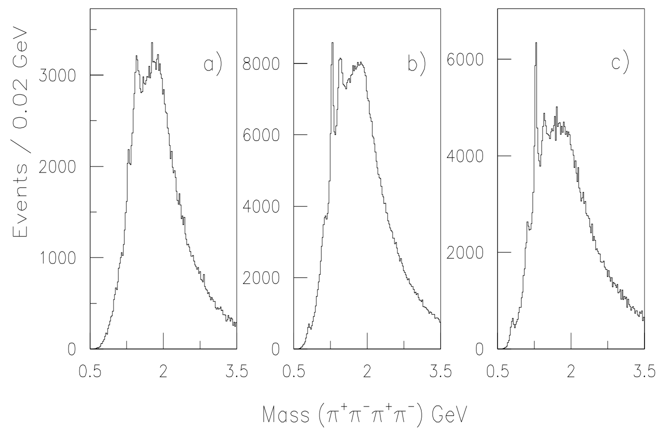

Figure 1: The $\pi^+\pi^-\pi^+\pi^-$ mass spectrum for a) $dP_T < 0.2$ GeV, b) $0.2 < dP_T < 0.5$ GeV and c) $dP_T > 0.5$ GeV

is sensitive to the kinematic variables representing production particles - Reggeons and/or Pomerons. The variable currently used for analysis is the difference of the exchange particles transverse momentum, defined as

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

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. Although other relevant variables, as for example, the angle between exchange particles can be used as well.

It was found that the mass spectra of the centrally produced systems like 2π, $2K$ or 4π depend dramatically on dP_T. This effect is illustrated in fig 1. In the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum the $f_1(1285)$ signal disappears as dP_T goes to zero while the two structures at 1.5 and 2.0 GeV regions, attributed to $f_0(1500)$ and $f_2(1930)$, remain.

The full setup Monte-Carlo simulation, including trigger, detector acceptance, reconstruction procedure and applied off-line cuts shows practically no or very small dependence of the acceptance as a function of dP_T for the given channel and hence the observed resonance production dP_T dependence cannot be explained as acceptance effects. It is also not an artifact of the WA102 experiment since the effect was confirmed by the NA12/2 experiment.

4 Summary of the dP_T filtering

In order to understand the nature of the kinematic filtering, production of all resonances detected by WA102 experiment was investigated as a function of dP_T. Due to the limited statistics dP_T dependence was presented as a relative production cross-section in three intervals: less than 0.2 GeV, 0.2 to 0.5 GeV and more than 0.5 GeV. Results are summarized in the Table 1.

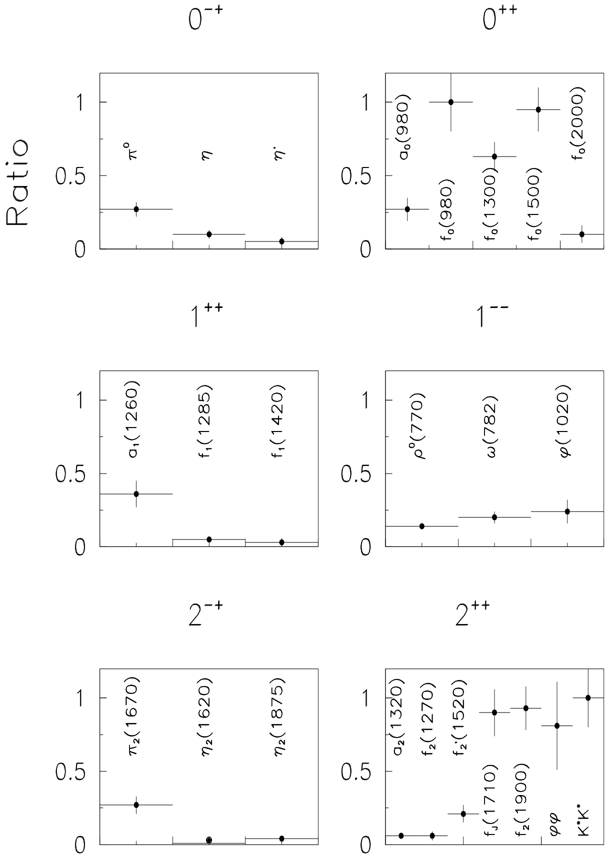

Figure 2: The ratio of the amount of resonance with $dP_T < 0.2$ GeV to the amount with $dP_T > 0.5$ GeV.

It can be noticed that all undisputed $q\bar{q}$ states, i.e. $\rho^0(770)$, $f_2(1270)$, $f_1(1285)$, $f_2'(1525)$ etc., are suppressed at low dP_T, whereas all glueball candidates $f_0(1300)$, $f_0(1500)$, $f_J(1710)$ and $f_2(1930)$ survive. Figure 2 shows the ratio of the number of events for $dP_T < 0.2$ GeV to the number of events for $dP_T > 0.5$ GeV for each resonance considered. All states can be arranged into three groups by the value of this ratio: all undisputed $q\bar{q}$ states which can be produced via DPE have the ratio value about 0.1. States with I=1 or G parity negative, which can not be produced by DPE, have slightly higher value around 0.25. All states with suspected gluonic com-

Table 1: Resonance production as a function of dP_T expressed as a percentage of its total contribution

J^{PC}	Resonance	$dP_T < 0.2$ GeV	$0.2 < dP_T < 0.5$ GeV	$dP_T > 0.5$ GeV
0^{-+}	π^0	12 ± 2	44 ± 2	44 ± 2
	η	6 ± 2	34 ± 2	60 ± 3
	η'	3 ± 2	32 ± 2	64 ± 3
0^{++}	$a_0(980)$	14 ± 4	35 ± 4	51 ± 7
	$f_0(980)$	22 ± 2	56 ± 3	22 ± 3
	$f_0(1300)$	20 ± 2	48 ± 2	32 ± 4
	$f_0(1500)$	23 ± 2	53 ± 3	24 ± 4
	$f_0(2000)$	5 ± 3	43 ± 5	52 ± 5
1^{++}	$a_1(1260)$	13 ± 3	51 ± 4	36 ± 3
	$f_1(1285)$	3 ± 1	35 ± 2	61 ± 4
	$f_1(1420)$	2 ± 2	38 ± 2	60 ± 4
1^{--}	$\rho(770)$	8 ± 2	38 ± 2	54 ± 3
	$\omega(782)$	10 ± 2	40 ± 2	49 ± 3
	$\phi(1020)$	10 ± 3	48 ± 3	42 ± 4
2^{-+}	$\pi_2(1670)$	11 ± 2	48 ± 4	40 ± 4
	$\eta_2(1620)$	2 ± 1	42 ± 6	54 ± 5
	$\eta_2(1875)$	1 ± 1	36 ± 7	63 ± 7
2^{++}	$a_2(1320)$	4 ± 4	35 ± 3	61 ± 5
	$f_2(1270)$	4 ± 2	25 ± 2	71 ± 3
	$f_2'(1520)$	11 ± 3	37 ± 3	52 ± 4
	$f_J(1710)$	26 ± 3	45 ± 2	29 ± 4
	$f_2(1900)$	26 ± 2	46 ± 3	28 ± 4
	$\phi\phi$	22 ± 5	51 ± 4	27 ± 4
	$K^*(892)\bar{K}^*(892)$	23 ± 3	54 ± 3	23 ± 2

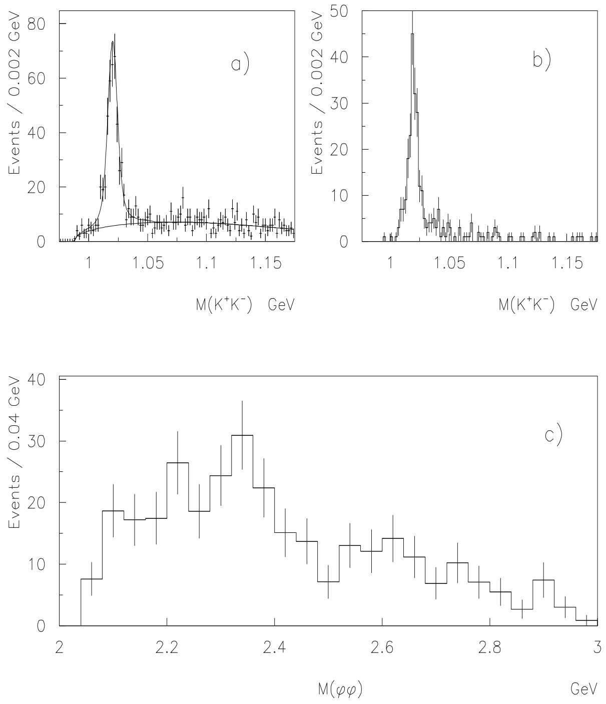

Figure 3: a) the K^+K^- mass spectrum (four combinations per event) for the data sample with at least three central particles identified as kaons, b) the K^+K^- effective mass of one K^+K^- combination if the other lie in ϕ mass band, c) the $\phi\phi$ effective mass spectrum

ponent have a significantly higher value of this ratio.

The separation of states by this ratio is valid for all resonances considered. It is interesting to note that enigmatic $f_0(980)$ has a "glueball-like" ratio value as well as the $\phi\phi$ and $K^*(982)\bar{K}^*(982)$ systems.

4.1 $\phi\phi$ and $K^*(982)\bar{K}^*(982)$ systems

It was recently suggested that the observed dP_T effect could be due to the fact that the production mechanism is through the fusion of two vector particles[4,5] and, hence it is interesting to study the dP_T dependence of systems decaying to two vectors. Two such systems, $\phi\phi$ and $K^*(982)\bar{K}^*(982)$ have been studied. The $\phi\phi$ system has the added interest that the observation of glueball candidates has been claimed in this channel[7].

The $\phi\phi$ system decaying to $K^+K^-K^+K^-$ produced in central pp interaction was studied[6] with a factor ten increase over previously published data samples. Kaons where identified by the threshold Cherenkov detector. The K^+K^- combinatorial mass and the $\phi\phi$ effective mass spectrum are shown in fig. 3. It was found that $\phi\phi$ production dominates in the $K^+K^-K^+K^-$ central pro-

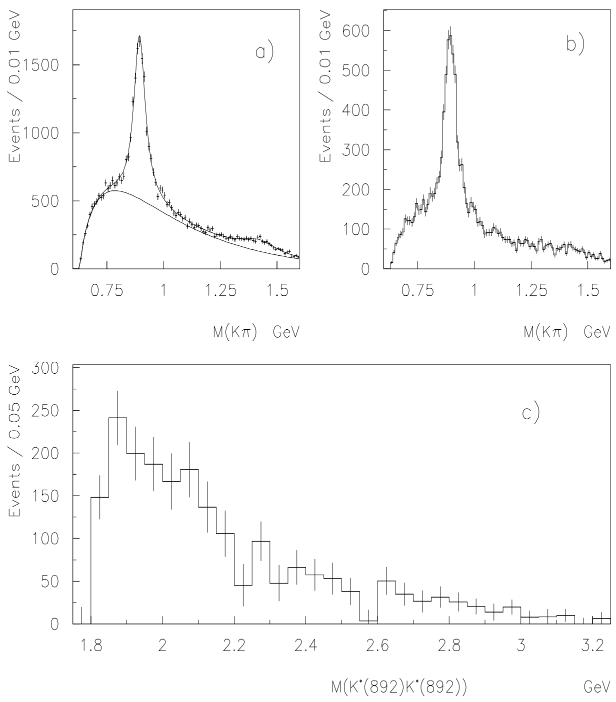

Figure 4: a) the $K^{\pm}\pi^{\mp}$ mass spectrum, b) the $K^{\pm}\pi^{\mp}$ mass spectrum after selecting the $K^{\mp}\pi^{\pm}$ to lie in $K^*(892)$ mass band, c) the $K^*(982)\bar{K}^*(982)$ effective mass spectrum

duction at 450 GeV and the ratio of the ϕK^+K^- to $\phi\phi$ cross sections was estimated to be $\sigma(\phi K^+K^-)/\sigma(\phi\phi) \approx 0.8$. The $K^+K^-K^+K^-$ system angular distributions where analyzed to determine the spin-parity of the intermediate $\phi\phi$ states. The analysis shows the best chi-squared for $J^{PC} = 2^{++}$ (with $J^{PC} = 0^{++}$ and $J^{PC} = 0^{+-}$ ruled out).

A study of the reaction $pp \rightarrow p_f p_s(K^+K^-\pi^+\pi^-)$ shows evidence for the $K^*(982)\bar{K}^*(982)$ system production[8]. The $K\pi$ combinatorial mass and $K^*(982)\bar{K}^*(982)$ mass spectra are shown in fig. 4. The angular analysis suggests $J^P = 2^+$ for the $K^*(982)\bar{K}^*(982)$ intermediate states.

Although the effect of kinematic filtering is well established experimentally, the underlying physics behind it is not fully understood. Close and Kirk[9] have suggested that low dP_T can favour gluon coupling of the exchange particles (Pomerons or Reggeons) into the final state, enriched by gg in this case. It was also pointed out that the results may be explained if the particles exchanged in the formation of the central system carry non-zero spin[4,5]. Hence the results may have implication for the spin structure of the Pomeron. The $\phi\phi$ and $K^*(982)\bar{K}^*(982)$

data fit well to this scheme.

5 Conclusions

A study of central pp interactions performed by the WA102 experiment show that central production of meson states is sensitive to the kinematic variables representing the exchanged particles, in particular dP_T. This possible glueball-$q\bar{q}$ filter together with the production cross section energy dependence could bring to "glueball spectroscopy" new information capable of resolving the long-standing glueball puzzle.

The ratio of the production cross section at low and high dP_T intervals separate all undisputed $q\bar{q}$ states from glueball candidates. The underlying physics behind the dP_T effect is still not fully understood, although some models are already proposed.

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