

Interference of the π^\pm from ω decay with the π^\mp from decays of other meson and baryon resonances

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The π^\pm from the relatively “long-lived” ω meson decay and the π^\mp from decays of other “short-lived” meson and baryon resonances form the $\pi^+\pi^-$ -pairs in such domain of interaction region where the $\pi^+\pi^-$ -atoms might be produced. Therefore their relative contribution to the total number of the $\pi^+\pi^-$ -pairs from resonance decays is of importance for the DIRAC experiment at CERN whose aim is to detect these atoms and to study their properties.

In this note, the relative contribution of the $\pi^+\pi^-$ -pairs resulting from decays of ω and other meson and baryon resonances in pp interactions at 24 GeV/c is estimated from the available experimental data on inclusive production of meson and baryon resonances. In section 1, the experimental results on inclusive ω , ρ^0 , ρ^\pm and $f_2(1270)$ production obtained in different reactions and in a broad energy range are analysed. From these data the ω/ρ^0 , ρ^\pm/ρ^0 and $f_2(1270)/\rho^0$ ratios in pp interactions at 24 GeV/c are obtained. Section 2 is devoted to the experimental results on the vector and tensor $K^*(890)$ and $K_2^*(1430)$ production and the $K^*(890)/\rho^0$ and $K_2^*(1430)/\rho^0$ ratios. In section 3, the experimental data on the $\Sigma^{*\pm}(1385)$ and $\Delta(1232)$ production are presented and discussed. In section 4 we summarize the results and draw our conclusions.

1. Experimental results on ω , ρ^0 , ρ^\pm and $f_2(1270)$ production

1.1 Hadronic experiments at low energy

The inclusive ρ^0 production cross-section in pp interactions at 24 GeV/c,

$$\sigma(pp \rightarrow \rho^0 + \textit{anything}) = 3.49 \pm 0.42 \text{ mb}, \quad (1)$$

has been measured by the Bonn-Hamburg-Münich Collaboration in an experiment with the 2m hydrogen bubble chamber at CERN [1]¹.

The measurement of charged ρ^\pm production requires efficient neutral pion detection, not possible in bubble chamber experiments. However, the final states

$$pp \rightarrow ppk(\pi^+\pi^-\pi^0), \quad k \geq 1, \quad (2)$$

with a single π^0 , can be reconstructed using the energy and momentum conservation with one constraint (1C) fit. The production cross-sections for ρ^\pm in such “quasi-inclusive” reaction (2) were measured in [2]. The total ρ^\pm inclusive cross-sections in pp interactions at 24 GeV/c,

$$\sigma(pp \rightarrow \rho^+ + \textit{anything}) = 3.2 \pm 0.8 \text{ mb} \quad (3)$$

$$\sigma(pp \rightarrow \rho^- + \textit{anything}) = 3.0 \pm 0.7 \text{ mb}, \quad (4)$$

were determined by extrapolation of the “quasi-inclusive” ρ^\pm cross-sections. Since ρ mesons in pp interactions are dominantly produced in the central region, these extrapolated ρ^+ and ρ^- production rates were found compatible within errors with the measured ρ^0 rate:

$$\sigma(\rho^+)/\sigma(\rho^-) = 0.92 \pm 0.25, \quad \sigma(\rho^-)/\sigma(\rho^0) = 0.86 \pm 0.23 \quad (5)$$

as could be expected.

Notice that it is not necessary the case for the meson-induced reactions. Thus, for example, in π^+p interactions, an important fraction of the ρ^+ and ρ^0 (ρ^- and ρ^0 in π^-p interactions, respectively) results from the valence quark fragmentation of incident pion, while ρ^- (respectively ρ^+) is dominantly produced in the central region from the sea quarks.

The total ω production cross section in pp interactions at 24 GeV/c was not measured. The ω production could be studied only in the decay mode $\omega \rightarrow \pi^+\pi^-\pi^0$ in 1C-fit reaction (2), i.e. in the quasi-inclusive process $pp \rightarrow \omega + \textit{charged particles}$. The corresponding cross-section was found to be [1]

$$\sigma(pp \rightarrow \omega + \textit{charged particles}) = 0.32 \pm 0.03 \text{ mb}. \quad (6)$$

The analogous quasi-inclusive ρ^0 cross-section,

$$\sigma(pp \rightarrow \rho^0 + \textit{charged particles}) = 0.30 \pm 0.05 \text{ mb}, \quad (7)$$

¹In this note, the presented cross-sections for all resonances were corrected for their invisible decay modes, if not specifically stated otherwise.

was the same as the ω cross-section, within the measured errors, and their ratio

$$\sigma(\omega)/\sigma(\rho^0) = 1.07 \pm 0.20. \quad (8)$$

In the same pp experiment [1] but at different beam momentum of 12 GeV/c for the same quasi-inclusive reactions one obtained

$$\sigma(\omega)/\sigma(\rho^0) = 1.00 \pm 0.20. \quad (9)$$

The ω/ρ^0 ratio has been also measured in the $\pi^\pm p$ bubble chamber experiments at 16 GeV/c [3] again from the quasi-inclusive reactions $\pi^\pm p \rightarrow \omega + \text{charged particles}$ and $\pi^\pm p \rightarrow \rho^0 + \text{charged particles}$:

$$\sigma(\omega)/\sigma(\rho^0) = 0.90 \pm 0.15. \quad (10)$$

As was also shown in [3], the longitudinal and transverse momentum squared distributions for the ω and ρ^0 were very similar, apart from the very forward Feynman- x_F and low p_T regions due to the contribution of the peripheral ρ^0 production.

The attempt to measure the ω production cross-section from the inclusive $\pi^+\pi^-\pi^0$ mass distribution, with the π^0 detected from its decay $\pi^0 \rightarrow \gamma\gamma$, has been made in the 32 GeV/c K^-p experiment in the Mirabelle bubble chamber [4]. From the production cross sections of $\sigma(\omega) = 3.7 \pm 1.4$ mb and $\sigma(\rho^0) = 4.32 \pm 0.72$ mb, one obtained

$$\sigma(\omega)/\sigma(\rho^0) = 0.86 \pm 0.35. \quad (11)$$

Thus the ω/ρ^0 ratio appears to be the same, within errors, for different incident particles and different energies in the considered energy range.

1.2. Experiments at high energy

The ρ^0 and ω production in deep inelastic μp interactions at 280 GeV/c was studied by the European Muon Collaboration (EMC) [5]. The $\omega \rightarrow \pi^+\pi^-\pi^0$ decay mode has been observed using the π^0 mesons reconstructed from the gamma detectors in conjunction with data from the charged particle detectors. A comparison of the production rates for ρ^0 and ω mesons as functions of $z = E_{lab}/\nu$, $x_F = 2p_L^*/W$ and p_T^2 (where E_{lab} is the laboratory energy of the hadron, ν is the laboratory energy of the virtual photon, p_T^2 is the transverse momentum squared of the hadron measured with respect to the

virtual photon, W is the mass of the hadronic system and p_L^* is the longitudinal momentum of the hadron in the hadronic center-of-mass system) revealed that they were the same within errors in all three distributions. Unfortunately, the numerical value of the ω/ρ^0 ratio was not given in [5].

The experiments with the European Hybrid Spectrometer (EHS) in CERN, equipped with two gamma detectors, permitted to measure the inclusive production rates of many particles including the ρ^0 , ρ^+ , ρ^- and ω .

Thus in π^-p interactions at 360 GeV/c [6], the values of the ratios ρ^-/ρ^+ and ω/ρ^0 in the π^- fragmentation region $x_F \geq 0.2$ were found equal to

$$\sigma(\rho^-)/\sigma(\rho^0) = 0.86 \pm 0.19, \quad \sigma(\omega)/\sigma(\rho^0) = 0.85 \pm 0.15. \quad (12)$$

In pp interactions at 400 GeV/c [7], the measured cross-sections for the ρ^0 , ρ^+ , ρ^- and ω in the $x_F \geq 0.1$ region amounted respectively to 3.06 ± 0.12 , 3.56 ± 0.36 , 2.52 ± 0.30 and 2.89 ± 0.20 mb, resulting in the following values of the ρ^+/ρ^0 , ρ^-/ρ^0 and ω/ρ^0 ratios:

$$\sigma(\rho^+)/\sigma(\rho^0) = 1.16 \pm 0.13, \quad \sigma(\rho^-)/\sigma(\rho^0) = 0.82 \pm 0.10, \quad (13)$$

and

$$\sigma(\omega)/\sigma(\rho^0) = 0.94 \pm 0.08. \quad (14)$$

In π^+p interactions at 250 GeV/c in the NA22-EHS experiment [8], the ρ^+ and ρ^0 x_F -spectra in the forward hemisphere were found to be very similar. Their ratio for $x_F \geq 0.3$ was

$$\sigma(\rho^+)/\sigma(\rho^0) = 1.15 \pm 0.14. \quad (15)$$

In K^+p interactions at 250 GeV/c in the same NA22-EHS experiment, the measured ρ^0 , ρ^+ and ω production cross-sections in the kaon fragmentation region $x_F \geq 0.2$ amounted respectively to 1.36 ± 0.14 , 1.28 ± 0.36 and 1.37 ± 0.35 mb [9], resulting in the following values of the ρ^+/ρ^0 and ω/ρ^0 ratios:

$$\sigma(\rho^+)/\sigma(\rho^0) = 0.94 \pm 0.28, \quad \sigma(\omega)/\sigma(\rho^0) = 1.01 \pm 0.28. \quad (16)$$

The inclusive $d\sigma/dx_F$ distributions of the ρ^0 , ρ^+ and ω in the corresponding K^+p reactions were found very similar. Moreover, these distributions were also very similar to the $d\sigma/dx_F$ spectra for the ρ^0 and ω in the EMC experiment, scaled to the total inelastic K^+p cross-section at $\sqrt{s} = 13.3$ GeV, the average hadronic energy $\langle W \rangle$ in the μp experiment [5]. Such a similarity is

not merely accidental. Indeed, a detailed comparison of the K^+p data with the low- p_T models has shown [10] that the production of the $\rho^{+,0}$ and ω in the K^+ fragmentation region ($x_F \geq 0.2$) is dominated by the hadronization of the K^+ u -valence quark, and therefore expected to be similar to μp deep-inelastic scattering.

It is important to notice that the invariant differential cross-sections $f(x) = \int (E^*/p_{inc}^*) (d^2\sigma/dx dp_T^2) dp_T^2$ for different vector mesons studied in the EHS and experiments at lower energies scale (as for example in reactions $K^+p \rightarrow \rho^0 + X$, $K^+p \rightarrow K^{*0}(892) + X$ and $K^+p \rightarrow \phi + X$ at 32, 70, 200 and 250 GeV/ c [10]). The corresponding differential cross-sections, $d\sigma/dx$, also scale in the fragmentation regions and increase in the central region, reflecting the rise of the production rates from sea quarks with increasing energy. This shows that the data at high energies can be indeed safely used for determination of the ω/ρ^0 ratio to be used in the DIRAC experiment.

1.3. LEP experiments

It may look surprising, but the results of the LEP experiments can be also used for this purpose. The rich data accumulated by the LEP experiments allowed to show [11, 12] that the production rates of light-flavour hadrons belonging to the SU(3) nonets of the pseudoscalar and vector mesons and to the octet and decuplet of the baryons at LEP are essentially set by their masses, spins and strangeness suppression. It was also shown [12] that the production rates of hadrons are strongly influenced by the spin-spin interactions of their quarks. Similarities in mass dependence of the production rates of pseudoscalar mesons and octet baryons, vector mesons and decuplet baryons were observed and explained by the relative spin configuration of their quarks. The vector-to-pseudoscalar meson and decuplet-to-octet baryon suppressions were shown to be the same and explained by the hyperfine mass splitting. The strangeness suppression factor, related to the difference in the constituent quark masses, was found to be the same for mesons and baryons, with no evidence for additional suppression of strange baryons. Moreover the mass dependencies of the production rates for the six families of the primary produced mesons: the vector and tensor light-flavour mesons, the vector and P-wave charm, strange charm and bottom mesons were also found very similar [13]. Thus studies of the Z^0 boson hadronic decays at LEP allowed much better understanding of many features of hadron production not only in the processes of e^+e^- annihilations but as well in the hadron-induced reactions.

For our purpose it is important that the results obtained at LEP are also valid for e^+e^- annihilations at lower energies and even for hadronic reactions. In particular, the mass dependence of the production rates in pp interactions at 400 GeV/c [7] are very similar (apart from the overall normalization) to that observed at LEP [11, 12]. In [14] the ratios of the production rates $K^{*0}(892)/K$, ϕ/K , ρ^0/π , ω/π , Δ^{++}/p , $\Sigma^{*+}(1385)/\Lambda$ and their x -dependence obtained from the results of the LEP and SLD experiments in Z^0 hadronic decays were compared with the data from the Mirabelle and BEBC K^+p experiments at 32 and 70 GeV/c. The striking similarity between the e^+e^- and K^+p data was observed in spite of huge difference in energies. These arguments suggest that one can safely use for the DIRAC purpose the values of the ω/ρ^0 and ρ^\pm/ρ^0 ratios derived from the LEP data [15, 16, 17, 18].

Using the averaged values [12] of the total production rates of the ρ^0 , ρ^\pm and ω per hadronic Z^0 decay measured by the LEP experiments

$$\langle\rho^0\rangle = 1.24 \pm 0.10, \quad 1/2(\langle\rho^+\rangle + \langle\rho^-\rangle) = 1.20 \pm 0.22, \quad \langle\omega\rangle = 1.09 \pm 0.09, \quad (17)$$

one arrives to the following values of the $1/2(\rho^+ + \rho^-)/\rho^0$ and ω/ρ^0 ratios:

$$1/2(\sigma(\rho^+) + \sigma(\rho^-))/\rho^0 = 0.97 \pm 0.19, \quad \sigma(\omega)/\sigma(\rho^0) = 0.88 \pm 0.10. \quad (18)$$

1.4. ω/ρ^0 , ρ^\pm/ρ^0 and $f_2(1270)/\rho^0$ ratios

As we have seen, the value of the ω/ρ^0 ratio appears to be the same in hadron-induced reactions, deep inelastic interactions and e^+e^- annihilations in a broad energy range. Therefore it is reasonable to define it as the weighted average of the values (8)-(12), (14), (16) and (18) obtained in different independent experiments. The resulting value is

$$\sigma(\omega)/\sigma(\rho^0) = 0.92 \pm 0.05. \quad (19)$$

Similarly the weighted average for the ρ^\pm/ρ^0 ratio is

$$\sigma(\rho^\pm)/\sigma(\rho^0) = 0.99 \pm 0.06. \quad (20)$$

The production of the tensor $f_2(1270)$ meson was not measured in pp interactions at 24 GeV/c. However, it can not be very different from cross-section $\sigma(f_2(1270)) = 0.88 \pm 0.22$ mb measured in pp experiment at 32 GeV/c [19]. In π^+p interactions at 23 GeV/c [20] one measured $\sigma(f_2(1270)) =$

1.13 ± 0.22 mb. Taking average of these two values one arrives to an estimate $\sigma(f_2(1270)) = 1.01 \pm 0.16$ mb. Then the corresponding $f_2(1270)/\rho^0$ ratio equals

$$\sigma(f_2(1270))/\rho^0 = 0.29 \pm 0.06. \quad (21)$$

2. The data on $K^*(890)/\rho^0$ and $K_2^*(1430)/\rho^0$ ratios

The $K^{*+}(892)$ and $K^{*-}(892)$ inclusive cross-sections measured in pp interactions at 24 GeV/c [1] amounted to

$$\sigma(K^{*+}(892)) = 0.66 \pm 0.06 \text{ mb}, \quad \sigma(K^{*-}(892)) = 0.19 \pm 0.04 \text{ mb}. \quad (22)$$

Significantly larger $K^{*+}(892)$ cross-section at this relatively small energy is not surprising. It can be explained by associated production of $K^{*+}(892)$ with strange baryons, for example in the proton fragmentation process $pp \rightarrow K^{*+}(892) + \Lambda/\Sigma^0$ and, in general, by a possibility of fragmentation of the proton valence u -quark into $K^{*+}(892)$, while $K^{*-}(892)$ can be only produced from the sea quarks. The same excess of the $K^{*+}(892)$ over $K^{*-}(892)$ production is also observed in other hadronic experiments at nearby energies. Thus, for example in π^+p interactions at 16 GeV/c [21], one obtained $\sigma(K^{*+}(892)) = 0.71 \pm 0.10$ mb and $\sigma(K^{*-}(892)) = 0.18 \pm 0.05$ mb. Even at much higher energies, as in pp interactions at 400 GeV/c [7], where contribution of the central production starts to dominate over fragmentation processes, the $K^{*+}(892)$ production rate is still higher: $\sigma(K^{*+}(892)) = 4.33 \pm 0.53$ mb and $\sigma(K^{*-}(892)) = 2.87 \pm 0.39$ mb.

As far as I know, there is no experimental results on the $K^{*0}(896)$ and $\bar{K}^{*0}(896)$ production at the DIRAC energies². However one may notice that the $K^{*0}(896)$ and $\bar{K}^{*0}(896)$ cross-sections in pp interactions at 400 GeV/c, $\sigma(K^{*0}(896)) = 3.92 \pm 0.68$ mb and $\sigma(\bar{K}^{*0}(896)) = 2.96 \pm 0.54$ mb [7], are very similar to the $K^{*+}(892)$ and, respectively, $K^{*-}(892)$ production rates, as could be expected from similarities of their production mechanisms. Thus contributions of the proton fragmentation processes $pp \rightarrow K^{*+}(892) + \Lambda/\Sigma^0$ and $pp \rightarrow K^{*0}(896) + \Lambda/\Sigma^+$ to the $K^{*+}(892)$ and $K^{*0}(896)$ production rates are not expected to be very different. It seems therefore reasonable to assume that the $K^{*0}(896)$ and $\bar{K}^{*0}(896)$ production rates in pp interactions at 24 GeV/c are the same as the $K^{*+}(892)$ and $K^{*-}(892)$ rates, respectively, i.e.

$$\sigma(K^{*0}(896)) = 0.66 \pm 0.06 \text{ mb}, \quad \sigma(\bar{K}^{*0}(896)) = 0.19 \pm 0.04 \text{ mb}. \quad (23)$$

²Apart from the results obtained in the kaon-induced reactions where these mesons are dominantly produced from fragmentation of the incident-kaon strange quark.

Thus one has:

$$(\sigma(K^{*+}) + \sigma(K^{*-})) / \rho^0 = (\sigma(K^{*0}) + \sigma(\bar{K}^{*0})) / \sigma(\rho^0) = 0.24 \pm 0.06. \quad (24)$$

There is no data on the tensor meson $K_2^*(1430)$ production, apart from the results obtained in kaon-induced reactions, where these particles are dominantly produced in the fragmentation processes of the valence strange quark of the incident kaon. An estimate of their rates in pp collisions at our energy can be obtained assuming equality of the $f_2(1270)/\rho^0$ and $K_2^*(1430)/K^*(890)$ ratios. This gives a value of

$$(\sigma(K_2^{*+}) + \sigma(K_2^{*-})) / \rho^0 = (\sigma(K_2^{*0}) + \sigma(\bar{K}_2^{*0})) / \sigma(\rho^0) = 0.07 \pm 0.02, \quad (25)$$

implying that the $K_2^*(1430)$ production can be ignored.

4. Experimental data on baryon production

The $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ production rates, $\sigma(\Sigma^{*+}(1385)) = 0.276 \pm 0.026$ mb and $\sigma(\Sigma^{*-}(1385)) = 0.119 \pm 0.018$ mb, were measured in pp interactions at 24 GeV/c [22], giving $\sigma(\Sigma^{*+}(1385)) + \sigma(\Sigma^{*-}(1385)) = 0.40 \pm 0.03$ mb and

$$(\sigma(\Sigma^{*+}(1385)) + \sigma(\Sigma^{*-}(1385))) / \rho^0 = 0.113 \pm 0.016. \quad (26)$$

The fully inclusive $\Delta^{++}(1232)$ production at nearby energies was measured only in one K^+p experiment [23] at 32 GeV/c: $\sigma(\Delta^{++}(1232)) = 2.25 \pm 0.30$ mb. The $\Sigma^{*+}(1385)$ and $\Sigma^{*-}(1385)$ production rates also measured in this experiment amounted to $\sigma(\Sigma^{*+}(1385)) = 0.119 \pm 0.014$ mb and $\sigma(\Sigma^{*-}(1385)) = 0.049 \pm 0.011$ mb. A reasonable estimate of the $\Delta^{++}(1232)$ production in pp interactions at 24 GeV/c can be made assuming that the ratios $\Delta^{++}(1232)/\Sigma^{*+}(1385)$ in pp and K^+p experiments are the same. This gives $\sigma(\Delta^{++}(1232)) = 5.2 \pm 1.1$ mb and

$$\sigma(\Delta^{++}(1232)) / \sigma(\rho^0) = 1.50 \pm 0.35. \quad (27)$$

Not surprisingly, production of the $\Delta^{++}(1232)$ dominantly resulting from proton fragmentation is very important. Moreover, production of other isospin states of $\Delta(1232)$ such as $\Delta^+(1232)$ and $\Delta^0(1232)$ should be also accounted for. The production rates of these states were determined only in one pp experiment at 400 GeV/c [7], but have to be treated with a great caution due to obviously grossly underestimated errors. Therefore we can

either ignore these results or assume, relying on the FRITIOF predictions given in [7], that the $\sigma(\Delta^+) = 0.67\sigma(\Delta^{++})$ and $\sigma(\Delta^0) = 0.45\sigma(\Delta^{++})$. In the latter case one has

$$\sigma(\Delta^+)/\sigma(\rho^0) = 1.00 \pm 0.24, \quad \sigma(\Delta^0)/\sigma(\rho^0) = 0.67 \pm 0.17. \quad (28)$$

4. Conclusions

For processes with associated production of meson and baryon resonances, the relative number R_1 of the $\pi^+\pi^-$ pairs, with one pion from the ω and another from the baryon resonances, to the total number of such pairs with one pion from the ω , ρ^0 , ρ^\pm , $f_2(1270)$ and $K^*(890)$ mesons and another from the baryon resonances is

$$R_1 = \frac{\omega/\rho^0}{1 + \omega/\rho^0 + \rho^+/\rho^0 + f_2/\rho^0 + (K^{*+} + K^{*-})/\rho^0}, \quad (29)$$

where by ω , ρ^0 , etc we denote the corresponding cross-sections multiplied by their branching fractions $\omega \rightarrow \pi^+\pi^-X$, $f_2 \rightarrow \pi^+\pi^-X$ and $K^{*\pm} \rightarrow K^0\pi^\pm$. The ratio R_1 is independent of the baryon resonance production rates. With the values of ω/ρ^0 , ρ^+/ρ^0 , f_2/ρ^0 and $(K^{*+}+K^{*-})/\rho^0$ given in this note, one has

$$R_1 = 0.26 \pm 0.02. \quad (30)$$

If one could take into account other meson resonances produced in association with baryon resonances, this will result in smaller value of R_1 . However, not significantly since the relative production rates of such mesons as the $f_0(980)$ and $a_0^\pm(980)$ is expected to be small: $f_0(980)/\rho^0 = 0.065 \pm 0.026$ for pp interactions at 400 GeV/c [7]; $f_0(980)/\rho^0 = 0.119 \pm 0.013$ and $a^+(980)/\rho^0 = 0.11 \pm 0.05$ at LEP [12]. All other meson resonances have higher masses and their production rates are expected to be smaller or even much smaller than the $f_2(1270)$ rate.

In an associated production of the ω with other meson resonances, such for example as $pp \rightarrow \omega + \rho^0 + X$, the $\pi^+\pi^-$ -pair can be created with one pion from the ω and another from the ρ^0 decays. However the associated inclusive production of two resonances has been studied only in one experiment [24]³. Besides, one can easily see that in accounting the contribution of such processes of the associated production of the ω with the ρ^0 , ρ^\pm , $f_2(1270)$,

³In reactions $K^+p \rightarrow K^{*+}(892) + \rho^0 + X$ and $K^+p \rightarrow K^{*0}(896) + \rho^0 + X$ at 32 GeV/c.

K^{*+} and K^{*-} , one adds the same term⁴ to the nominator and denominator of (29):

$$R_1 = \frac{\frac{\omega}{\rho^0} + \frac{2(\omega'\rho^{0'} + \omega'\rho^{+'} + \omega'f_2' + \omega'K^{*+'} + \omega'K^{*-'})}{\rho^0(\Delta^{++} + \Delta^+ + \Delta^0 + \Sigma^{*+} + \Sigma^{*-})}}{1 + \frac{\omega + \rho^+ + f_2 + K^{*+} + K^{*-}}{\rho^0} + \frac{2(\omega'\rho^{0'} + \omega'\rho^{+'} + \omega'f_2' + \omega'K^{*+'} + \omega'K^{*-'})}{\rho^0(\Delta^{++} + \Delta^+ + \Delta^0 + \Sigma^{*+} + \Sigma^{*-})}}. \quad (31)$$

This can only increase the value of R_1 .

In another approach, one may consider the interference of π_ω^\pm from the ω decay with all π^\mp in the final states with n charged particles. The number of $\pi^+\pi^-$ pairs with one pion from the ω decay are $\Sigma_n(\sigma_n/\sigma_{inel})(\sigma_n(\omega)/\sigma_n)P_n = (1/\sigma_{inel})\Sigma_n\sigma_n(\omega)P_n$, where σ_n and σ_{inel} are topological and inelastic cross-sections, $\sigma_n(\omega)$ is the topological ω cross-section multiplied by branching fraction $BR(\omega \rightarrow \pi^+\pi^-X)$, P_n is the number of $\pi_\omega^\pm\pi^\mp$ combinations⁵ and $n = 6, 8, 10, \dots$. The corresponding number of $\pi^+\pi^-$ pairs without pions from ω decay is $\Sigma_n(\sigma_n/\sigma_{inel})Q_n = (1/\sigma_{inel})\Sigma_n\sigma_nQ_n$, where $n = 4, 6, 8, \dots$ and Q_n is the number of possible $\pi^+\pi^-$ combinations. From this one gets:

$$R_2 = \frac{1/(\sigma_{inel})\Sigma_n\sigma_n\sigma_n(\omega)P_n}{1/(\sigma_{inel})\Sigma_n\sigma_n\sigma_n(\omega)P_n + (1/\sigma_{inel})\Sigma_n\sigma_nQ_n} = \frac{1}{1 + \frac{\Sigma_n\sigma_nQ_n}{\Sigma_n\sigma_n(\omega)P_n}}. \quad (32)$$

The values of σ_n and σ_{inel} for pp collisions at 24 GeV/c are given in [25], but there are no data on $\sigma_n(\omega)$ at 24 GeV/c or any other energies. However, as follows from (19), one can safely assume that $\sigma_n(\omega) = (0.92 \pm 0.05)\sigma_n(\rho^0)$ and use the available data on $\sigma_n(\rho^0)$ [19] and σ_n [26] from pp experiment at nearby beam momentum⁶ of 32 GeV/c. Then one arrives to the value

$$R_2 = 0.46 \pm 0.04, \quad (33)$$

almost twice higher than the value R_1 in (30). On the other hand, if one assumes⁷ that cross-sections in reactions $pp \rightarrow r_1 + r_2 + X$ with double resonance production are equal to $\sigma(r_1)\sigma(r_2)/\sigma_{inel}$, where $\sigma(r_1)$ and $\sigma(r_2)$ are cross-sections in reactions $pp \rightarrow r_1 + X$ and $pp \rightarrow r_2 + X$, then one finds from (31) that $R_1 = 0.51 \pm 0.07$, i.e. very close to R_2 .

⁴Notice that the ω' , $\rho^{0'}$, $\rho^{+'}$, ... in (31) are not the total inclusive cross-sections but these for reactions $pp \rightarrow \omega + \rho^0 + X$, $pp \rightarrow \omega + \rho^+ + X$, ...

⁵We assume that there are two protons in each final state.

⁶The average charged particle multiplicities, $\langle n_{ch} \rangle$, are 4.25 ± 0.03 at 24 GeV/c [25] and 4.67 ± 0.03 at 32 GeV/c [26] so that one can indeed safely use the 32 GeV/c data.

⁷This assumption is valid for reactions $K^+p \rightarrow K^{*+}(892) + \rho^0 + X$ and $K^+p \rightarrow K^{*0}(896) + \rho^0 + X$ at 32 GeV/c [24], but it is not necessary true in our case.

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