Exclusive $\phi$ production in proton-proton collisions in the resonance model

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The production of $\phi$ mesons is strongly suppressed compared to that of $\omega$ mesons. This fact is known under the name "OZI rule". According to the OZI rule, $\phi$ mesons can only be produced due to a small admixture of non-strange light quarks in their wave function. The corresponding mixing angle $\theta_{mix}$ is equal to $\theta_{mix} \approx 3.7^\circ$. A naive estimate based on the OZI expectation underestimates the measured ratio $\phi$ and $\omega$ mesons cross sections should at comparable energies by about one order of magnitude.

In ref. [2] we determined the $\phi$ production in elementary nucleon-nucleon reactions within the framework of the resonance model. Their $\phi$ production is described by a two step mechanism, i.e. the excitation of nucleon resonances and their subsequent decay $pp \rightarrow pR \rightarrow pp\phi$. The cross sections for the resonance production were taken from ref.[3] where they were fitted to describe $\pi, \eta, \rho, \pi\pi$ production in $NN$ collisions. The $\phiNR$ coupling is obtained from the known $\omegaNR$ coupling of the $\omega$ meson [4] and the mixing angle between $\phi$ and $\omega$ mesons. The $\omegaNR$ couplings, in turn, have been determined within the framework of the extended Vector Meson Dominance (eVMD) model by fitting the available data on electro- and photo-production of nucleon resonances as well as their mesonic decays [5]. The description of the $\phi$ and $\omega$ meson production in elementary nucleon-nucleon reactions is then essentially parameter free since all model parameters have already been fixed by other sources. In [4] it was demonstrated that available data on the exclusive $\omega$ production in $pp$ reactions are very accurately reproduced by the present model over a wide energy range, i.e. from extremely close to threshold up to several GeV above threshold.

The $pp \rightarrow pR \rightarrow pp\phi$ cross section is given as follows:

$$\sigma(s) = \sum_R \int_0^{(\sqrt{s}-2m_p)^2} dM^2 \int_{(\sqrt{s}-m_R)^2}^{(\sqrt{s}-m_p)^2} d\mu^2 \times \frac{d\sigma(s, \mu|pp\rightarrow pR)}{d\mu^2},$$

with $M$ being the running mass of $\phi$ meson. The cross sections for the baryon resonances production are given by

$$d\sigma(s, \mu|pp\rightarrow pR) = \frac{|M|\mu}{16\pi\sqrt{s}} |\Phi_2(\sqrt{s}, \mu, m_p)dW_R(\mu)$$

with $\Phi_2(\sqrt{s}, \mu, m_p) = \pi p^2(\sqrt{s}, \mu, m_p)/\sqrt{s}$ being the two-body phase space, $p^2(\sqrt{s}, \mu, m_p)$ the final c.m. momentum, $p$, the initial c.m. momentum, $\mu$ and $m_R$ are the running and pole masses of the resonances, respectively, $m_p$ the proton mass. The mass distribution $dW_R(\mu)$ of the resonances is described by the standard Breit-Wigner formula:

$$dW_R(\mu) = \frac{1}{\pi} \frac{\Gamma_R(\mu) \mu^2}{(\mu^2 - m_R)^2 + (|\mu_R(\mu)|)^2}.$$  

The sum in (1) runs over the same set of nucleon resonances which is responsible for the $\omega$ meson production [4]. This includes all well established $(4\pi) N^*$ resonances quoted by the PDG [7] with masses below 2 GeV. The branching to the $\phi$ decay mode is given by

$$dB(\mu, M|pp\rightarrow pR) = \frac{1}{\Gamma_R(\mu)} \frac{\Gamma_N(\mu, M)}{\Gamma_N(\mu)}$$

with $\Gamma_N(\mu, M)$ calculated the same way as in the case of $\omega$ meson production [4].

The results for cross section $\sigma(pp \rightarrow pp\phi)$ are presented in Fig. 1 in form of the ratio of the $\phi$ over $\omega$ meson production cross sections. The $\omega$ mesons production cross section was shown to agree well with experimental data if one uses a strong $N^*(1535)N\omega$ coupling [4] The dashed line in Fig. 1 corresponds to the idealized case of stable $\phi$ and $\omega$ mesons, i.e. to the limit of zero widths.

Important properties of the $\Gamma_N(\mu, M)$ width are the following ones: the $M$ dependence of magnetic, electric and Coulomb couplings entering into the amplitude and the Blatt-Weisskopf suppression factor which suppresses the width for large off-shell masses $\mu$ of the resonances [4]. Their combined effects lead to an increase of the $\Gamma_N(\mu, M)$ width with $M$ increasing from $m_\omega$ to $m_\phi$ for $\mu > 2$GeV. This effect is finally responsible for the violation of the naive OZI rule estimate.

References
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