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Inclusive ϕ meson production, the parton fusion model and strange quark structure functions

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The ACCMOR Collaboration

ABSTRACT

The parton fusion model is used to describe the longitudinal differential cross section ($d\sigma/dx_F$) of hadronic ϕ production. The $d\sigma/dx_F$ for ϕ production in π^+p , $p\bar{p}$ and K^+p interactions is evaluated in the model by using structure functions for the constituents of the interacting particles. A comparison between the model and high statistics data in the Feynman x range $0. < x_F(\phi) < 0.4$ allows the determination of the strange valence quark distribution in K mesons and the strange sea quark distribution in π mesons, which appears to be harder than the light sea quark distribution. The comparison also shows that a significant part of inclusive ϕ production is due to the OZI allowed fusion of strange quarks, while the OZI inhibited fusion diagrams are strongly suppressed.

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1. Introduction

In 1964 Gell-Mann [1] and Zweig [2] introduced the idea of quark structure of hadrons. This model has now developed into a theory of strong interactions called Quantum Chromo Dynamics (QCD). In practice QCD predictions are restricted to processes where the parameter that determines the scale of the process (Q^2 or M^2) is large, thus allowing a perturbative approach. However the success of the quark parton model in describing the hadronic interactions at low momentum transfer has led to phenomenological models based on the quark parton concept to describe such processes as well. A review of such models is given in reference [3].

In previous experiments (WA3 and NA11) the ACCMOR collaboration had already made a systematic study of the inclusive production of ϕ mesons [4,5,6]. The data were successfully interpreted in terms of the parton fusion model in which in particular the fusion of strange quarks plays an important role. In order to test the parton fusion model in more detail and possibly extract the momentum distribution functions for strange quarks in the interacting hadrons, a significant increase in statistics as well as a larger x_F range than previously accessible ($0.0 < x_F < 0.2$) was called for. The experimental results discussed in this paper are based on a sample of 600,000 ϕ mesons in the kinematic range $0.0 < x_F < 0.4$ and have been presented elsewhere [7,8]. This model also explains naturally the observed enhanced production of strange particles jointly with the ϕ meson [4,9] as well as the different shapes of the differential cross sections $d\sigma/dx_F$ for incident π mesons, protons and K mesons.

In this paper inclusive ϕ data will be interpreted in terms of the parton fusion model [10], which relates the differential cross section $d\sigma/dx_F$ of inclusive ϕ meson production to the parton distributions in the interacting hadrons. The distribution of the momentum of a nucleon over its partons has been parameterized by several authors (section 3). The parameters are adjusted to give agreement with the parton distributions measured in deep inelastic lepton scattering (DIS), Drell-Yan processes and ψ production experiments. In section 3 the validity of the parameterizations at low momentum transfer is checked. Those parameterizations which also give an acceptable description of DIS data at low momentum transfer will be used as an input to the parton fusion model. In section 4 the prediction of the parton fusion model is compared with our inclusive ϕ meson data. The conclusions which can be drawn from this comparison are presented in section 5.

2. The parton fusion model

The parton fusion model [10] is an extension of the model first discussed by Drell and Yan [11] to describe the production of lepton pairs in hadronic interactions. The model has been developed to explain ψ meson production. In the Drell-Yan model a quark from one of the interacting hadrons fuses with an antiquark from the other hadron to form a virtual photon which couples to a lepton pair. The inclusive cross section $d\sigma/dx_F$ of the lepton pair is thought not to be altered by additional interactions between the initial state or final state particles. The differential cross section is related to the distributions of partons in the initial hadrons by:

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9M^2} \sum_q \frac{Q_q^2}{x_1 x_2} \{ F_1^q(x_1) \cdot F_2^{\bar{q}}(x_2) + F_1^{\bar{q}}(x_1) \cdot F_2^q(x_2) \} \quad (1)$$

Here x_1 and x_2 are the fractional momenta of the partons in the initial hadrons and M is the mass of the produced lepton pair. The sum is over the quark flavours $q=u,d,s,c,\text{etc.}$, Q_q is the charge of quark q and $F_i^q(x_i)$ are the momentum distributions for quarks of flavour q in the initial hadrons. The quark distribution functions $F_i^q(x_i)$ can be determined by measuring the differential cross section $d\sigma/dx_F$ of the lepton pair. Such experiments yield quark distributions of the nucleons which are similar to the distributions measured in DIS experiments. Up to now the Drell-Yan mechanism is the only source of information for the quark distributions in the π and K mesons.

In formula (1) it is assumed that the structure functions $F_i^q(x)$ are only a function of x . In practice however, there is a small Q^2 dependence, the exact form of which is given by QCD. These scaling violations are neglected in our further discussion. Expression (1) leads to a good description of the observed differential cross section in Drell-Yan processes, however it underestimates the absolute normalization by a factor of about 2, generally referred to as the K factor.

The determination of the quark distribution in a hadron by using a quark (Drell-Yan) or a lepton (DIS) as a probe is assumed to be valid only when the momentum transfer is sufficiently large. However as shown in the next section, it is found for neutrino data that the DIS formalism is already applicable at small values of the momentum transfer, i.e. $Q^2 \approx 1 \text{ GeV}^2$. This led us to the assumption that the parton fusion model may be applied to a low Q^2 process such as inclusive ϕ meson production. Furthermore, we assume that within the x -range ($0.0 < x < 0.5$) of our experiment, the structure functions obtained with a Be target instead of with nucleons are not influenced by the EMC effect, which follows from measurement [12].

Figure 1 shows the parton fusion diagrams to be considered for ϕ meson production. In figure 1-a two s quarks combine to produce the hidden strangeness $\phi(s\bar{s})$ meson. The coupling constant ($g_A^2/4\pi$) of this process is expected to be large compared to that for the non-strange quark fusion process (figure 1-b) ($g_1^2/4\pi$) reflecting the empirical rule invented by Okubo, Zweig and Iizuka [13] (OZI) that disconnected quark diagrams, like the one in figure 1-b, are inhibited. The $C=+1$ ϕ meson cannot be directly produced by the fusion of two gluons. Only $C=+1$ $s\bar{s}$ states are allowed by this process. However such a $C=+1$ state may radiate off a photon or gluon to produce the ϕ meson. Indeed in inclusive ψ meson production it has been observed that a large fraction of the cross section can be accounted for by the production of $C=+1$ x states and their subsequent decay into $\psi\gamma$. In order to take such an admixture of gluon diagrams into account the diagram of figure 1-c has been included in our expression for the ϕ meson cross section. In (2) the differential cross section $d\sigma/dx_F$ for inclusive ϕ meson production is therefore expressed in terms of the quark distribution functions $F_{b,t}^q(x)$, where $q=u,d,s$ for the three quark flavours considered and b and t denote the beam and target hadron, and gluon distributions $G_{b,t}(x)$:

$$\begin{aligned} \frac{d\sigma}{dx_F} = \frac{\sqrt{s}}{2E} \cdot \frac{4\pi^2}{3M_\phi^2} \cdot \left\{ \frac{g_A^2}{4\pi} \cdot (F_b^s(x_1) \cdot F_t^{\bar{s}}(x_2) + F_b^{\bar{s}}(x_1) \cdot F_t^s(x_2)) + \right. \\ \left. + \frac{g_1^2}{4\pi} \cdot \sum_{a=u,d} (F_b^a(x_1) \cdot F_t^{\bar{a}}(x_2) + F_b^{\bar{a}}(x_1) \cdot F_t^a(x_2)) + \right. \\ \left. + \frac{g^2}{4\pi} \cdot G_b(x_1) \cdot G_t(x_2) \right\} \quad (2) \end{aligned}$$

Here x_F is the Feynman x of the ϕ meson, E is the energy of the ϕ meson in the overall centre of mass system and x_1 and x_2 are the fractional momenta of the partons in the beam and target hadrons respectively. The three coupling constants $g_A^2/4\pi$, $g_1^2/4\pi$ and $g^2/4\pi$ do not only determine the relative contributions of the OZI allowed fusion, (OZI) inhibited fusion and gluon fusion respectively, but also insure the overall normalization, i.e. the equivalent of the K factor in Drell-Yan processes.

The fractional longitudinal momenta x_1 and x_2 are related to the x_F of the ϕ meson by the following expressions:

$$\begin{aligned} x_F &= x_1 - x_2 \\ x_1 x_2 s &= M_\phi^2 - 2M_q^2 \end{aligned}$$

where s is the total centre of mass energy squared and M_ϕ is the mass of the ϕ meson. The parton mass M_q is taken to be $0.5 \text{ GeV}/c^2$ for the s quark and zero for the other partons. Figure 2 shows the relation between x_F and x_1 and x_2 . The fractional longitudinal momentum x_1 is almost equal to the Feynman x of the ϕ meson, while the $d\sigma/dx_F$ is rather insensitive to the shape of the structure function of the target since x_2 is almost independent of x_F . Figure 2 furthermore shows that the evaluation of $d\sigma/dx_F$ is not strongly influenced by the choice of the value of the s quark mass.

Apart from the three unknown coupling constants we are left with the parton distribution functions $F_{b,t}^q(x)$ and $G_{b,t}(x)$. The choice made for these functions is described in the next section.

3. The parton distribution in hadrons

As input for the parton fusion model we need the parton distributions in π^+ , K^+ , p and $\bar{p}$. In the quark model the hadrons contain valence quarks which give the hadron its quantum numbers, virtual quark anti quark pairs continuously created out of the vacuum called sea quarks, and gluons. For our purpose we need the parton distributions at $Q^2 = 1 \text{ GeV}^2$ in the x range $0.0 < x < 0.5$. The DIS experiments have accumulated large statistics measurements of quark distribution functions in nucleons (see [14] for a review). Parameterizations which describe these distributions are discussed in the next section. The distribution of partons in π^+ and K^+ obtained by the Drell-Yan mechanism and ψ meson production are presented in section 3.2.

In the following the structure functions of valence quark a and sea quark b in hadron h are denoted by $V_{a,h}^h(x)$ and $S_{b,h}^h(x)$ respectively. The gluon structure function in hadron h is denoted by $G^h(x)$. The structure functions are normalized as follows:

$$\int_0^1 V_{u,\pi^+}^{\pi^+}(x)/x \, dx = \int_0^1 V_{\bar{u},\pi^+}^{\pi^+}(x)/x \, dx = 1 \quad (3-a)$$

$$\int_0^1 V_{d,\pi^+}^{\pi^+}(x)/x \, dx = \int_0^1 V_{\bar{d},\pi^+}^{\pi^+}(x)/x \, dx = 1 \quad (3-b)$$

$$\int_0^1 V_{u,\pi^+}^{K^+}(x)/x \, dx = \int_0^1 V_{\bar{u},\pi^+}^{K^+}(x)/x \, dx = 1 \quad (3-c)$$

$$\int_0^1 V_{s,\pi^+}^{K^+}(x)/x \, dx = \int_0^1 V_{\bar{s},\pi^+}^{K^+}(x)/x \, dx = 1 \quad (3-d)$$

$$\int_0^1 V_{u,p}^p(x)/x \, dx = \int_0^1 V_{\bar{u},p}^p(x)/x \, dx = 2 \quad (3-e)$$

$$\int_0^1 V_{d,p}^p(x)/x \, dx = \int_0^1 V_{\bar{d},p}^p(x)/x \, dx = 1 \quad (3-f)$$

The above valence quark distributions are the only ones to be considered in π^+ , K^+ , p and $\bar{p}$. The normalization of the sea quarks and gluons are obtained from momentum conservation, i.e.

$$\int_0^1 (v^h + s^h + G^h) dx = 1 \quad (4)$$

where v^h and s^h represent the summations over all valence quarks and all sea quarks respectively.

3.1 The parton distribution in protons

Several authors have given a parameterization for the parton distribution function in terms of x and Q^2 in nucleons. They are Buras-Gaemers (BG) [15], Gluck-Hoffmann-Reya (GHR) [16], Duke-Owens [17], who give two parameterizations (DO1) and (DO2), Eichten et al. [18], who also give two parameterizations (EHLQ1) and (EHLQ2), and Mahapatra [19]. The parameters are determined by comparing the distributions to experimental results. Most authors only give distributions for Q^2 above some lower limit Q_0^2 . The parameterizations make use of different data sets and use different lower limits on Q^2 ($=Q_0^2$).

To compare the various parameterizations we show the parton distribution functions of the models at their lowest $Q^2 = Q_0^2$ value in figure 3. For the model of Mahapatra we have taken $Q^2 = 1 \text{ GeV}^2$. Figure 3 shows $v_u^p, v_d^p, s_u^p, s_d^p, G^p, 2S_u^p$ and G^p for the various models.

In the low Q^2 region ($Q^2 < 5 \text{ GeV}^2$) the contribution of the quarks which are heavier than the s quark is negligible, and these distributions are assumed to be zero. The s quark distribution cannot be determined unambiguously by DIS experiments and consequently the various quark distribution parameterizations differ mainly in the s quark distribution. In addition the shape of the gluon distribution cannot be measured directly by DIS experiments. The method explored to extract the gluon distribution is the use of the Q^2 evolution of the sea quark distributions, to which that of the gluon distribution is related.

We assume that we may extend these distributions down to $Q^2 = 1 \text{ GeV}^2$. To check this assumption we have compared the prediction of the models, in the x range of our experiment $0.0 < x < 0.5$, with available data from two neutrino experiments, Abramowicz et al. (CDHS collaboration) [20] and Ailasia et al. (WA25 experiment) [21]. WA25 and CDHS give structure functions for Q^2 values down to 1.5 and 1.13 GeV^2 respectively. To allow for a systematic uncertainty in the absolute normalization we minimized the χ^2 with a normalization factor N as a free parameter. Apart from DO2 all parameterizations give a reasonable χ^2 for all Q^2 values. Details of the comparison are given in reference [8].

3.2 The parton distribution in π^+ and K^+

The distribution of the valence quarks in π mesons is taken from Badier et al. [22], who have determined $V_{u,d}^{\pi^+}$ at $Q^2 = 25 \text{ GeV}^2$, assuming that the distribution of u and d valence quarks in the π meson is equal. The distribution is parameterized with

$$V_{u,d}^{\pi^+}(x) = V_{u,d}^{\pi^-}(x) = 0.571 x^{0.41} (1-x)^{0.95} \quad (5)$$

The Q^2 dependence of the structure function as measured by Badier et al. is small and we will assume the distribution to be valid at $Q^2 = 1 \text{ GeV}^2$.

The sea structure function of the π mesons as measured by Badier et al. will not be adopted by us to evaluate the differential cross section of ϕ meson production for the following reasons:

- The x_F region covered by Badier et al., i.e. $x_F > 0.2$, is dominated by valence-valence annihilation, introducing large errors in the sea quark distribution evaluation.
- According to the parton fusion model the ϕ meson cross section is sensitive to the s quark distribution in the incident hadrons, while the sea quark distribution as measured in di-muon production via the Drell-Yan process will be dominated by light quark anti quark annihilation.

We will leave the shape of the sea quark distribution in the π meson as a free parameter, to be determined by the inclusive ϕ meson data. To limit the number of free parameters, the sea in the π meson is assumed to be symmetric in u, d and s quarks and will be parameterized with

$$S_{u,d,s,u,\bar{u},\bar{d},\bar{s}}^{\pi^+}(x) \propto (1-x)^7 \quad (6)$$

As has been shown in section 3.1 the present data on the parton distributions in nucleons do not allow an unambiguous determination of the gluon distribution functions. For this reason the choice for the gluon distribution in the π meson is somewhat arbitrary. Moreover in our experiment the transition of the $C=1$ $q\bar{q}$ system into the $C=-1$ ϕ meson will further obscure the picture. The gluon distribution in π mesons has been measured [23,24] using hadronic ψ meson production in π^+p interactions, and folding in the known branching ratios of $\chi \rightarrow \psi\gamma$. The two experiments agree within errors on the shape of the gluon distribution and we will use the distribution obtained by Badier et al [23]

$$G^{\pi^+}(x) = 1.69 (1-x)^{2.38} \quad (7)$$

in which 50% of the π meson momentum is carried by the gluons. The normalization of the sea quark distribution in the π meson (expression (6)) is thus constrained by the momentum sum rule given in expression (4).

The valence u quark distribution in the K meson is obtained from the measurement of the ratio $V_U^{K^-}(x)/V_U^{\pi^-}(x)$ [25] using Drell-Yan data with incident π and K . This gives

$$V_U^{K^-}(x)/V_U^{\pi^-}(x) \propto (1-x)^{0.18} \quad (9)$$

leading to the following distribution for the valence u quark in the K meson, using expression (5):

$$V_U^{K^-}(x) = V_U^{K^+}(x) = 0.571 x^{0.41} (1-x)^{1.13}$$

The distribution of strange valence quarks in the K meson will be parameterized with:

$$V_S^{K^-}(x) = V_S^{K^+}(x) = x^\alpha (1-x)^\beta / B(\alpha, \beta) \quad (9)$$

where B is Euler's beta function which ensures the correct normalization given by expression (3-d). The parameters will be determined by our data.

The shape of the sea quarks distribution in the K meson is assumed to be the same as in the π meson (6):

$$S_{u,d,s,\bar{u},\bar{d},\bar{s}}^{K^\pm}(x) = A^K (1-x)^\gamma \quad (10)$$

The gluon distribution in the K meson has been determined by Badier et al. [23] in the same way as in the π meson. A good fit to the data was obtained if it was assumed that G^K is identical to G^π , i.e.

$$G^{K^\pm}(x) = G^{\pi^\pm}(x) = 1.69 (1-x)^{2.38} \quad (11)$$

Then, the gluons and the valence u quark carry 50% and 15.6% respectively of the momentum of the K meson. The way in which the residual 34.4% of the momentum is distributed over the valence s quark and the sea quarks is left as a free parameter to be determined by the inclusive ϕ meson data.

4. Confrontation of model and measurement

4.1 The decay angular distribution

In a parton fusion model the mass of the fusing partons (M_q) can be related to the decay angular distribution at $p_T \approx 0.0 \text{ GeV}/c$ by [26]

$$\frac{1-3\rho_{11}}{\rho_{11}} = \frac{1-4M_\phi^2/M_q^2}{1+4M_\phi^2/M_q^2} \quad (12)$$

where M_ϕ is the mass of the ϕ meson. In the evaluation of expression (12) the other two independent elements of the density matrix ($\rho_{1,-1}$ and $\text{Re}\rho_{10}$) are zero at $p_T = 0 \text{ GeV}/c$. The values of M_q obtained from the ρ_{11} values given in reference [7] are tabulated in table 1.

The mass value obtained is an average over the masses of the partons in the three diagrams (see figure 1) which contribute to ϕ meson production. The average mass of the fusing partons is $\sim 390 \text{ MeV}/c^2$, suggesting that the OZI allowed fusion of strange quarks plays an important role in the production process, irrespective of the incident particle.

4.2 The longitudinal momentum distribution

The evaluation of the longitudinal momentum distribution in our model is given by expression (2). The structure functions of the interacting hadrons discussed in section 3 are used with the following free parameters:

- the coupling constants for OZI allowed ($q_A^2/4\pi$), OZI inhibited ($q_I^2/4\pi$) and gluon fusion ($g_G^2/4\pi$).
- the shape of the sea quark distribution in π and K mesons, γ in expressions (6) and (10),
- the fraction of the K meson momentum carried by the K meson sea quarks, which is determined by A^K in expression (10) and
- the shape of the valence s quark in the K meson, α in expression (9). The value of β in expression (9) is determined using the momentum sum rule, i.e. $\beta = \alpha(1/R - 1) - 1$ where $R = 1 - \int_0^1 (V_U^{K^-} + 6S^{K^-} + G^K) dx$.

Introducing a larger number of free parameters, for instance by allowing the strange component in the π meson sea to be determined separately by our data, would mean that some parameters are no longer determined independently by the fit to our longitudinal momentum distributions. The motivation for our choice of free parameters is the following. The parameters which influence the $\langle J \rangle$ allowed ss

fusion and which are difficult to probe by Drell-Yan experiments are left free, i.e. the strange quark components in π and K mesons. Distributions which are not well known, but only contribute to the OZI inhibited light quark fusion, as for instance the light quark sea in π and K mesons, are not allowed to vary independently.

We will use the inclusive ϕ meson data from π^+p , $\bar{p}p$ and K^+p interactions at 100 GeV/c and π^+p , pp and K^+p interactions at 120 GeV/c incident momentum [7] to determine the free parameters listed above. The use of the 200 GeV/c incident π^+ , p and K^+ data (also given in reference [7]) gives only a small contribution to the statistical significance of the cross sections, but would introduce extra free parameters to allow for different systematics. In the comparison of the data samples for incident $\pi^+(\pi^+)$, $\bar{p}(p)$ and $K^+(K^+)$ at a given beam momentum the systematic error should almost completely cancel. However the relative error in the normalization of the 100 GeV/c and 120 GeV/c data samples could be of the order of 10%. To eliminate a possible effect of a systematic shift in the cross sections we introduce an extra free parameter (N), which allows for a different normalization for the 100 GeV/c and 120 GeV/c data samples.

The free parameters are determined by a χ^2 minimization, where χ^2 is given by:

$$\chi^2 = \sum_{h=\pi^+, \bar{p}, K^+} \sum_i \frac{(m_i^h(x) - c_i^h(x))^2}{\sigma_i^h(x)^2} + \sum_{h=\pi^+, \bar{p}, K^+} \sum_i \frac{(m_i^h(x) - N \cdot c_i^h(x))^2}{\sigma_i^h(x)^2} \quad (13)$$

where $m_i^h(x)$ and $c_i^h(x)$ represent the measured and calculated $d\sigma/dx_F$ values respectively, σ_i^h is the error on m_i^h and N is the parameter which allows for a different normalization of the 100 GeV/c and 120 GeV/c data samples.

A simultaneous fit to the pp and $\bar{p}p$ data samples determines the coupling constants and the normalization N. These distributions do not depend on other free parameters. Table 2 lists the results obtained for this fit for the various structure function parameterizations described in section 3.1. Only the Buras-Gaemers parameterization is unable to describe the data satisfactorily. The gluon distribution proposed by BG is so steep that it excludes a possible contribution of gluon-gluon fusion to ϕ meson production. To describe the data at higher x_F values BG need a significant OZI inhibited contribution, which results in a difference in the pBe and $\bar{p}Be$ cross sections ($N=1.22$), which is much larger than the expected systematic uncertainty.

Another extreme is the result of the Mahapatra parameterization, which explains the ϕ meson production process mainly by gluon-gluon fusion. The sea and gluon distributions of the proton proposed by Mahapatra are similar in shape and consequently the correlation coefficients for the coupling constants are close to one.

The coupling constant which governs the OZI allowed quark fusion of the fit to GHR is large as a result of the very small s quark distribution in the proton.

The seven parameterizations all differ in the relative contributions of the OZI allowed, OZI inhibited and gluon fusion diagrams despite the fact that they all give a satisfactory description of the DIFs data, except perhaps for DO II. This is a reflection of the fact that the distributions which are relevant for ϕ meson production, i.e. $s\bar{s}$ fusion and maybe gluon-gluon fusion, are not well measured in DIF experiments.

Table 3 lists the results of the simultaneous fit to the 100 GeV/c and 120 GeV/c data over all incident particles. The BG parameterization, having already a bad χ^2 for the incident p and $\bar{p}$ data, must allow some gluon-gluon fusion to describe the combined data, hence the description of the incident p and $\bar{p}$ data becomes even worse and the total χ^2 is rather large.

GHR is penalized for the small strange quark component in the proton sea. This parameterization must reduce $g_A^2/4\pi$ to describe the incident π^+ and K^+ data. As a result the incident p and $\bar{p}$ data contribute 500 to the total χ^2 of 620.

Both sets of DO give an acceptable χ^2 for the simultaneous fit over all incident beam particles. For both sets the ϕ meson is mainly produced by $s\bar{s}$ fusion, whereas the remaining cross section is due to a light quark anti quark fusion contribution of 10-15% for incident π^+ , p and $\bar{p}$ and $\sim 5\%$ for incident K^+ . The strange sea distribution in the π meson, i.e. $(1-x)^{3.2 \pm 0.2}$, is much flatter than the distribution of light sea quarks determined in a Drell-Yan experiment [22], where $(1-x)^{8.4 \pm 2.5}$ was found.

The EHLQ parameterizations give fits which attribute most of the ϕ meson production with incident π^+ , p and $\bar{p}$ to gluon-gluon fusion. With incident K^+ mesons the ϕ mesons are for 60-70% produced with the valence s quark of the incident K mesons. The OZI inhibited fusion is responsible for less than 10% of the ϕ meson cross section, apart for incident p , where 16% of the cross section is due to light quark fusion. The strange sea distribution in the π meson is consistent with the distribution as derived from the DO parameterization.

Mahapatra ascribes most of the cross section to gluon-gluon fusion, which makes the fit insensitive to the strange sea quark distributions in π mesons and kaons.

Figure 4 shows the inclusive ϕ meson cross section with the parton fusion model fit based on the DO set 1 parameterization of the proton constituents (full line). The dashed, dash-dotted and dotted curves indicate the contributions from the OZI allowed, OZI inhibited and gluon fusion diagrams respectively.

The ratio of the strange valence quark over the up valence quark distribution in the K meson has been determined by Arestov et al. [27] by measuring the invariant cross section $E \cdot d\sigma/dx_F$ for ϕ and ρ production in K^+p interactions for $x_F > 0.4$. For this x_F region the sea and gluon contributions to the ϕ and ρ cross sections are negligible and the ratio of the ϕ and ρ cross sections is proportional to V_s^K/V_u^K . Figure 5 shows the data of Arestov et al. and the ratio V_s^K/V_u^K (full line) as determined by the fits of the seven parameterizations to our inclusive ϕ meson data. The proportionality constant is fitted for each parameterization. The dashed curves indicate the one standard deviation of the ratio. BG, EHLQ 1 and Mahapatra are inconsistent with the data of Arestov et al. The parameterizations which give a good fit to our inclusive ϕ data and also describe the data of Arestov et al. are DO 1 and EHLQ 2. The corresponding strange valence quark distributions in the K mesons are

$$\text{DO 1:} \quad V_s^K(x) = 0.7 x^{0.62} (1-x)^{0.2}$$

$$\text{EHLQ 2:} \quad V_s^K(x) = 2.1 x^{1.03} (1-x)^{0.98}$$

In the fits with both DO 1 and EHLQ 2 the kaon momentum is carried for 50% by the gluons and for 16% by the valence u quark, and the remainder is nearly all assigned to the valence s quark. The fits are insensitive to the sea of the kaon due to the relatively large errors for incident kaons at small x_F values. The parameterizations of DO 1 and EHLQ 2 result in distributions for the strange sea quarks in the π meson which is rather flat compared to the light quark sea distribution as determined by Badier et al. [22]

$$\text{DO 1:} \quad S_{s,\bar{s}}^{\pi^+}(x) = 0.11 (1-x)^{3.2}$$

$$\text{EHLQ 2:} \quad S_{s,\bar{s}}^{\pi^+}(x) = 0.10 (1-x)^{2.7}$$

5. Conclusions

The average mass of the partons which fuse to form the ϕ meson is determined to be $390 \text{ MeV}/c^2$, using the decay angular distributions. The large mass of the fusing partons favours the OZI allowed fusion of $s\bar{s}$ pairs, irrespective of the incident hadron. This is in agreement with the observed increased production of strange particles in events where a ϕ meson is produced in collisions between non-strange particles [9], confirming the important contribution of the OZI allowed $s\bar{s}$ fusion to ϕ meson production. The fact that the x_F distribution of ϕ mesons produced with incident kaons is much harder than the corresponding distributions for incident π mesons or protons indicates that the valence s quark of the K meson is carried by the ϕ meson. Given the uncertainties in the parton distributions in the interacting hadrons our fusion model is able to give a satisfactory description of the shape of the longitudinal momentum distributions of inclusive ϕ meson production in hadronic interactions. Not all the parameterizations of the nucleon structure functions which have been used can give a simultaneous description of the inclusive ϕ meson data and the ratio V_s^K/V_u^K , despite the large number of free parameters. Duke-Owens 1 and Fichten-Hincliffe-Lane-Quigg 2 give the best simultaneous description of both DIS, inclusive ϕ meson data and the ϕ to ρ cross section ratio. The distributions of the strange valence quark in the kaon are similar in size and shape for these two parameterizations. The same holds for the strange sea quark distributions in the π meson. The contributions to the ϕ meson cross section of the OZI allowed, OZI inhibited and gluon fusion as given by these models are in agreement with the observed associated production of strange particles and the average mass of the fusing partons. These models also give a non-zero gluon-gluon fusion contribution to the ϕ meson cross section. Assuming that the parton fusion model is the correct description of ϕ meson production, the strange components of the π mesons and kaons can be extracted. The distributions found for the strange quarks are much harder than the corresponding light quark distributions.

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Table 1 : The values of the mass of the fusing partons (M_q) obtained from the decay angular distribution of the ϕ meson at $0.0 < p_T < 0.2$ GeV/c.

beam GeV/c	incident particle	ρ_{11}	M_q GeV/c ²
100	π^-	0.311 ± 0.003	0.410 ± 0.007
100	K^-	0.310 ± 0.005	0.405 ± 0.012
120	π^+	0.301 ± 0.005	0.365 ± 0.013
120	p	0.308 ± 0.006	0.396 ± 0.015
200	π^-	0.313 ± 0.008	0.418 ± 0.019
200	p	0.285 ± 0.010	0.29 ± 0.03

Table 2 : The coupling constants $g_A^2/4\pi$, $g_1^2/4\pi$ and $g_C^2/4\pi$ determined in the fit to $d\sigma_\phi/dx_F$ in pBe and pBe interactions. The normalization constant N is defined in expression (13). The parton distribution functions used are described in section 3.1. A^h , I^h and G^h are the contributions (in %) to the inclusive ϕ meson cross section for $0.0 < x_F < 0.5$ by the QZ1 allowed, QZ1 inhibited and gluon fusion diagrams respectively for incident hadron h. The fits are performed with 32 data points.

	BG	GHR	DO I	DO II
$g_A^2/4\pi$	.51 $\pm$.03	3.95 $\pm$.18	.25 $\pm$.04	.25 $\pm$.01
$g_1^2/4\pi$	.0138 $\pm$.0003	.004 $\pm$.002	.006 $\pm$.002	.0 $\pm$.002
$g_C^2/4\pi$	.0 $\pm$.0001	.0015 $\pm$.0007	.0019 $\pm$.0005	.005 $\pm$.001
N	1.22 $\pm$ 0.03	0.97 $\pm$ 0.05	1.02 $\pm$ 0.04	0.91 $\pm$ 0.04
$A/I/G^p$	66/34/ 0	72/11/17	44/13/42	54/ 0/46
$A/I/G^p$	47/53/ 0	65/18/17	38/22/40	50/ 0/50
χ^2	66.3	34.5	35.0	35.3
	EHLQ1	EHLQ2	Mahapatra	
$g_A^2/4\pi$	1.2 $\pm$.4	1.8 $\pm$.3	.0 $\pm$.01	
$g_1^2/4\pi$	.74 $\pm$.3	.9 $\pm$.3	.45 $\pm$.09	
$g_C^2/4\pi$	.14 $\pm$.04	.09 $\pm$.05	.50 $\pm$.02	
N	1.05 $\pm$ 0.06	1.08 $\pm$ 0.06	0.98 $\pm$ 0.03	
$A/I/G^p$	29/14/57	56/18/26	0/ 6/94	
$A/I/G^p$	23/25/51	46/31/23	0/12/88	
χ^2	34.1	35.3	33.1	

Table 3 : $g_A^2/4\pi$, $g_1^2/4\pi$, $g_2^2/4\pi$, N , γ , α and A^K determined in the fit to $d\sigma_\phi/dx_F$ in $\pi^+\pi^+\text{Be}$, $K^+\text{Be}$ and $\bar{p}\text{Be}$ interactions. The normalization constant N is defined in expression (13), γ is defined in (6) and (10), α in (9) and A^K in (10). The parton distribution functions used are described in section 3. A^h , I^h and G^h are the contributions (in %) to the inclusive ϕ meson cross section for $0.0 < x_F < 0.5$ by the OZI allowed, OZI inhibited and gluon fusion diagrams respectively for incident hadron h . The fits are performed with 98 data points.

BG	GHR	DO I	DO II
$g_A^2/4\pi$	.17 ± 0.02	.75 ± 0.03	.30 ± 0.02
$g_1^2/4\pi$	.0149 ± 0.0003	.0060 ± 0.0009	.007 ± 0.001
$g_2^2/4\pi$	.0010 ± 0.0001	.0037 ± 0.0003	.0015 ± 0.0003
N	1.11 ± 0.01	1.07 ± 0.02	1.03 ± 0.02
γ	5.4 ± 0.4	3.0 ± 0.2	3.2 ± 0.2
α	1.5 ± 0.2	0.87 ± 0.05	0.62 ± 0.06
A^K	.020 ± 0.006	0. ± 0.0006	.001 ± 0.009
$A/I/G^{\pi^+}$	30/26/43	44/13/43	59/13/29
$A/I/G^p$	21/36/43	19/23/58	52/15/33
$A/I/G^{K^+}$	66/5/29	70/2/28	80/2/19
$A/I/G^{\pi^-}$	21/32/42	42/15/43	56/15/29
$A/I/G^p$	15/55/31	15/32/53	44/25/31
$A/I/G^{K^-}$	66/9/24	72/4/24	80/4/16
χ^2	283.6	619.9	132.4
	EHLQ1	EHLQ2	Mahapatra
$g_A^2/4\pi$	.45 ± 0.02	.53 ± 0.02	.145 ± 0.005
$g_1^2/4\pi$	.46 ± 0.08	.41 ± 0.08	.59 ± 0.05
$g_2^2/4\pi$	.202 ± 0.009	.25 ± 0.01	.406 ± 0.006
N	1.02 ± 0.02	1.03 ± 0.01	1.03 ± 0.01
γ	3.2 ± 0.2	2.7 ± 0.2	41. ± 7.
α	1.30 ± 0.09	1.03 ± 0.07	3.5 ± 0.3
A^K	0. ± 0.002	0. ± 0.0004	0. ± 0.008
$A/I/G^{\pi^+}$	33/8/59	39/7/54	2/6/92
$A/I/G^p$	11/8/80	17/9/75	12/8/80
$A/I/G^{K^+}$	61/1/38	65/1/34	40/1/59
$A/I/G^{\pi^-}$	32/9/59	31/8/54	2/7/91
$A/I/G^p$	9/16/75	14/16/70	10/16/74
$A/I/G^{K^-}$	65/2/32	68/2/30	46/3/51
χ^2	137.1	168.4	135.2

Figure captions

Figure 1 : Diagrams for ϕ meson production in the parton fusion model. The three diagrams which contribute to ϕ meson production are: a) OZI allowed $s\bar{s}$ fusion, b) OZI inhibited light quark fusion and c) gluon fusion.

Figure 2 : Fractional longitudinal momenta x_1 and x_2 as a function of x_F

Figure 3 : Structure functions of the proton as parameterized by BG (1), GHR (2), DO set I (3), DO set II (4), EHLQ set I (5) and EHLQ set 2 (6) for $Q^2 = Q_0^2$. Mahapatra (7) is evaluated at $Q^2 = 1 \text{ GeV}^2$. The functions are indicated in each figure.

Figure 4 : The parton fusion model compared with $d\sigma/dx_F$ of the ϕ meson. The incident particles are indicated in each figure. The full line is the fit of the parton fusion model to the data with the DO I parameterization for the proton. The dashed, dash-dotted and dotted curves indicate the contribution of OZI allowed, OZI inhibited and gluon fusion respectively.

Figure 5 : The ratio of invariant cross sections for ϕ and ρ as measured by Arestov et al. [27] compared with the ratio of the valence quark distributions V_s^K/V_u^K in the kaon as determined from the inclusive ϕ data. The proportionality constant between the data and V_s^K/V_u^K has been fitted for each parameterization. The parameterization which is used for the parton structure functions in nucleons is indicated in each figure.

Figure 1.

Figure 3.

Figure 4.

Figure 5.