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PARTICLE RATIOS AND LEPTON PRODUCTION AT LARGE p_T IN A SIMPLE PARTON MODEL

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We estimate particle ratios and lepton production in a simple model in which the observed particles result from the SU(6) symmetric fragmentation of a quark with large p_T. The invariant cross-section for the parton production at 90° is of the form $p_T^{-\varkappa} f(x_T)$ and the parton fragments to mesons, baryons and antibaryons from SU(6) 35- and 56-plets. In this way the model leads to a copious production of resonances at large p_T and the resonance decays represent an important contribution to observed ratios of stable particles.

The results are in a rough qualitative agreement with the recent Chicago-Princeton and British-Scandinavian data on particle ratios. The model can account for about one half of the observed lepton to pion ratio at large p_T.

ЧИСЛО ЧАСТИЦ И ЛЕПТОННАЯ ПРОДУКЦИЯ ПРИ БОЛЬШИХ ЗНАЧЕНИЯХ p_T В ПРОСТОЙ ПАРТОННОЙ МОДЕЛИ

В работе оценено число частиц и лептонная продукция в случае простой модели, в которой наблюдаемые частицы получаются в результате SU(6) — симметричной фрагментации кварка с большим значением p_T. Инвариантное поперечное сечение продукции партонов при 90° имеет форму $p_T^{-\varkappa} \cdot f(x_T)$ и партоны фрагментируются на мезоны, барионы и антибарионы из 35-плета и 56-плета SU(6)-симметрии. Модель приводит к обильной продукции резонансов при больших значениях p_T, причём распады резонансов представляют важный вклад в наблюдаемое число стабильных частиц.

Результаты находятся в грубом качественном согласии с последними данными о числе частиц, полученными группами «Чикаго-Принстон» и «Англия-Скандинавия».

Модель может объяснить приблизительно одну половину из наблюдаемого соотношения лептонов и пионов при больших значениях p_T.

I. INTRODUCTION

The parton model [1, 2] was extremely successful in describing the deep inelastic eN scattering and in predicting the general features of deep νN and $\bar{\nu} N$ collisions

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[3, 4, 5]. The assumptions of the parton model were corroborated by early ISR [6] experiments showing that inclusive production at large p_T is much larger than a simple extrapolation of low p_T data.

The detailed development of the parton model is to some extent hampered by the lack of information about parton-hadron and parton-parton interactions and by the difficulties in estimating the relative importance of various subprocesses.

Models based on hard parton-parton collisions [7, 8] usually assume that the parton-parton cross-section $d\sigma/d\Omega$ behaves like $1/s$. This leads to inclusive cross-sections (at $\Theta^* = 90°$)

$$E\frac{d^3\sigma}{dp^3} \sim p_T^{-N} f(x_T)$$

with $N=4$, in clear contradiction to experimental data [6, 9].

This trouble is avoided in the CIM [10, 11, 12] (constituent interchange model), where the hard parton-parton scattering is assumed to be absent and the underlying subprocess is given by the hard parton-hadron scattering. The general features of the subprocess follow from the dimensional counting rules [13].

The CIM has correctly predicted $N=8$ for the inclusive pion production in the SR experiments [6]. Other predictions of the model are compared with the data in 10, 11] and in reviews of large p_T processes [14, 15, 16]. The most detailed and up o date description of the CIM model and its comparison with the data may be ound in the recent review by Sivers, Brodsky and Blankenbecler [12]. similar approach was studied in detail by the Cambridge group [17—20]. The asic subprocess in this approach is the fusion of a quark from one hadron with an ntiquark from another, resulting in the formation of two mesons. The first alculations of the pseudoscalar [17, 18] and vector meson production [19] were erformed within this framework. The model predicts the π^-/π^+ ratio at $\Theta^* = 90°$ be about 0.85, which is in agreement with the data of the British-Scandinavian llaboration [21] at the CERN-ISR.

The "$N=4$ trouble" is also avoided in the quasi-exclusive parton model [22], in e multiperipheral model [23] and in the approach by Bander, Barnett and lverman [24] for further references see reviews [12, 14, 15, 16].

The data on large p_T reactions are generally believed to be an evidence in favour parton models but a complete theory will be possible only after a deeper derstanding is reached of the structure of hadrons and of interactions of hadron stituents. In spite of this one can believe that some features of the data can be derstood without such a complete theory. This may concern in particular the a on hadron ratios [9, 21] at large p_T and the direct production of leptons —29].

n some of the parton models mentioned above the hard subprocess leads nediately to a quark and a constituent. A hadron with large p_T in the final state is then either identical with the constituent which took part in the subprocess or appears as a result of quark fragmentation.

In the present paper we shall study the consequences of the assumption that the dominant contribution of the production of particles at large p_T is provided by the quark fragmentation and the quark fragmentation is an SU(6) symmetric process.

In the calculations we shall explicitly use the Ellis "quasi-exclusive" model, in which the hadrons with large p_T appear only as a result of the quark fragmentation. In models where tha basic subprocess is the quark-hadron scattering our model can at most roughly represent only that part of the final state which is due to the quark fragmentation. The specific SU(6) symmetric prescription for the fragmentation of a quark to hadrons roughly corresponds to a simple picture used earlier by Bjorken and Farrar [30]. Our prescription for the quark fragmentation roughly corresponds to a picture in which a hard parton moves across the SU(6) symmetric $Q\bar{Q}$ reservoir and picks up at random the partners from the "sea".

Particles produced "directly" (parents) are supposed to be members of 35-plet of mesons and 56-plets of baryons and antibaryons. The observed particles (children) are produced either directly or come from decays of resonances. Branching ratios for decay of resonances were taken from tables of the Particle Data Froup [31]. The assumption of the SU(6) symmetric quark fragmentation is motivated by the qualitative agreement of the results of Refs. [30, 32] with various data on multiparticle production and by the growing evidence [33] for the production of resonances in high energy collisions. A recent results pointing in the same direction is the significant η-production at large p_T [34].

The paper is organized as follows: the model is described in some detail in the next section. The results for the particle ratios are compared with the Chicago-Princeton [9] data in Sect. III. and with the British-Scandinavian data [21] in Sect. IV. Comparison of the lepton/pion data with our calculations is presented in Sect. V. The last section contains some comments and conclusions.

II. MODEL FOR THE INCLUSIVE PRODUCTION OF HADRONS

We shall start with recalling some standard formulae for particle production in the parton model. The details omitted here can be found in [8]. In the course of calculations we shall, as usually neglect masses of partons and of hadrons with large p_T.

The probability that a hadron "a" contains a parton "i" with a fraction x of its momentum is

$$\frac{1}{x} F_i^a(x)\, dx$$

and the probability of the fragmentation of a parton "i" into a hadron "h" with a momentum fraction y is

$$\frac{1}{y} G_i^h(y)\,\mathrm{d}y.$$

Within this framework the inclusive production of a hadron becomes

$$E\frac{\mathrm{d}\sigma}{\mathrm{d}^3p} = \frac{1}{p_T^2}\int \frac{F(x_1)}{x_1}\mathrm{d}x_1 \frac{F(x_2)}{x_2}\mathrm{d}x_2 \frac{\mathrm{d}\sigma}{\mathrm{d}\hat{t}} G(y)\, s2\left(\frac{\tan\Theta/2}{x_2}+\frac{\cot\Theta/2}{x_1}\right)^2, \tag{1}$$

where $\mathrm{d}\sigma/\mathrm{d}\hat{t}$ is the cross section for the parton-parton scattering, $\hat{t}$ is the parton-parton Mandelstam variable, Θ is the production angle in the hadron-hadron c.m.s. and y can be rewritten as

$$y = \frac{x_T}{2}\left|\frac{\tan\Theta/2}{x_2}+\frac{\cot\Theta/2}{x_1}\right|, \qquad x_T = \frac{2p_T}{s}.$$

Owing to the condition $y \leqslant 1$ the region of integration in Eq. (1) is limited to

$$0 \leqslant x_1 \leqslant 1,$$

$$\frac{x_1 x_T \tan\Theta/2}{2x_1 - x_T \cot\Theta/2} \leqslant x_2 \leqslant 1.$$

In calculating the production of a specific hadron "h" we have to make the following replacement in Eq. (1)

$$F(x_1)\,F(x_2)\frac{\mathrm{d}\sigma}{\mathrm{d}\hat{t}}G(y) \to \sum_{ij} F_i^a(x_1)\,F_j^b(x_2)\left[\frac{\mathrm{d}\sigma_{ij}}{\mathrm{d}\hat{t}}G_j^h(y) + \frac{\mathrm{d}\sigma_{ij}}{\mathrm{d}\hat{u}}G_i^h(y)\right], \tag{3}$$

where "a", "b" refer to the incoming hadron and we have neglected possible interference terms [8]. In the numerical calculations, detailed below, we have used the parton distribution functions $F(x)/x$ form the McElhaney and Tuan modification of the Kuti and Weisskopf analysis [35].

$$u_v(x) = 1.74\frac{1}{\sqrt{x}}(1-x)^3\,(1+2.3x), \tag{4}$$

$$d_v(x) = 1.11\frac{1}{\sqrt{x}}(1-x)^{3.1},$$

$$u_c(x) = 0.1\frac{1}{x}(1-x)^{3.5},$$

here u_v and d_v refer to up and down valence quarks in the proton and u_c represents the contribution of individual "sea" quarks and antiquarks. We shall now pass to some more specific assumptions used in the present model.

II.1. The fragmentation of quarks into hadrons

The essential contribution to the production of hadrons with large p_T is due to fragmentations in which a single hadron takes almost the whole momentum of the original parton*). In our simple-minded model we shall take into account only these hadrons and write the fragmentation function as follows

$$G_i^h(y) = g_i^h \delta(1-y), \tag{5}$$

where g_i^h is independent of y. In the quasi-exclusive parton model [22] g_i^h depends on t. We shall presently return to this point.

In order to evaluate g_i^h we shall use the SU(6) symmetry somewhat in the spirit of Refs. [30, 32].

The naive picture behind the model assumes that a hard parton Q_i moves across the sea of soft quarks and antiquarks and picks up at random partners to form mesons from the 35-plet or baryons (antibaryons) from the 56-plet.

Suppose, for instance, that the hard parton is of the type "i" with the spin S_i and the spin projection (on the z-axis) denoted by s_i. The probability of its fragmentation into a particular meson M with the spin S_M and the spin projection s_M is then supposed to be given by the relation

$$g_i^h \equiv P(MS_M s_M / iS_i s_i) = C_M \sum_{js_j} |\langle MS_M s_M | iS_i s_i, jS_j s_j\rangle|^2,$$

where C_M is the overall normalization factor and i, j run over 1 to 6 (including both quarks and antiquarks). In the following we shall delete spins (but not spin projections) and write the preceeding formula in the form

$$g_i^h \equiv P(Ms_M / is_i) = C_M \sum_{js_j} |\langle Ms_M | is_i, js_j\rangle|^2. \tag{6}$$

We are not interested in polarization of the outgoing mesons and we suppose the incident hadrons (and consequently also incident partons) to be unpolarized. We shall therefore average over spin projections. The resulting coefficients g_i^h are thus actually given by the SU(3) CG coefficients multiplied by $(2S_M+1)$ weight factors due to possible spin orientations of outgoing mesons.

The term SU(6) symmetry is in the present paper used only in this connection and only in this sense. It would be (actually) probably more appropriate to speak

*) This point was already emphasized by Ellis [22].

about the SU(3) symmetry with spin weights included. In the following we shall in spite of that speak of the SU(6) symmetry hoping that this will cause no confusion.

The calculation is easy and all what one needs are the expressions of mesons in terms of the $Q\bar{Q}$ states (given for instance in [36]).

In the same way we calculate the coefficients g_i^h for the fragmentation of the quark "i" into the baryon "h":

$$g_i^h \equiv P(B, s_B/i, s_i) = C_B \sum_{j,s_j} \sum_{K,s_K} |\langle B, s_B | i, s_i ; j, s_j ; k, s_k \rangle|^2. \tag{7}$$

The coefficients g_i^h averaged over spins are listed in Table I. The numbers given there correspond to $C_M = 1$, $C_B = 1$.

Inserting Eqs. (2), (3) and (5) into Eq. (1) one obtains the inclusive cross section for the production of the hadron "h"

$$E\frac{d\sigma}{d^3p} = \sum_{i,j} \int_A^1 dx_1 F_i^a(x_1) F_j^b(x_2) \left[\frac{d\sigma_{ij}}{d\hat{t}} g_i^h + \right.$$
$$\left. + \frac{d\sigma_{ij}}{d\hat{u}} g_j^h \right] \frac{2x_2^2}{\pi x_T \tan\Theta/2}, \tag{8}$$

where

$$A = \frac{x_T \cot\Theta/2}{2 - x_T \tan\Theta/2}, \qquad x_2 = \frac{x_1 x_T \tan\Theta/2}{2x_1 - x_T \cot\Theta/2}.$$

II.2. Parton-parton cross section

On the basis of dimensional arguments we expect for pointlike partons the cross section

$$\frac{d\sigma}{d\hat{\Omega}} = \frac{4\alpha}{\hat{s}} = \frac{4\alpha}{s x_1 x_2},$$

where $\hat{\Omega}$ is the scattering angle in the parton-parton rest frame and the normalization is chosen so that $\alpha = 1$ would correspond to the unitarity limit in the pure s-wave scattering. Since $\hat{t} = -(1/2) s x_1 x_2 (1 - \cos\Theta)$, we obtain in this case

$$\frac{d\sigma}{d\hat{t}} = \frac{16\pi\alpha}{(s x_1 x_2)^2}. \tag{9}$$

Inserting such a cross section into Eq. (8) we immediately obtain

$$I^h \equiv E\frac{d\sigma^h}{d^3p}\bigg|_{90°} = (\sqrt{s})^{-4} \sum_{i,j} \int_A^1 \frac{dx_1}{x_T x_1^2} F_i^a(x_1) F_j^b(x_2) [g_i^h + g_j^h] 32\alpha, \tag{10}$$

where $A = x_T/(2 - x_T)$ and $x_2 = x_1 x_T/(2x_1 - x_T)$.

Table 1

Coefficients g_i^h

	ϱ^+	π^+	ϱ^0	π^0	ϱ^-	π^-	K^{*+}	K^+	K^{*0}	K^0	K^{*-}	K^-	$\bar{K}^{*0}$	$\bar{K}^0$	ω	Φ	η	Δ^{++}	Δ^+	p
u	3	1	3/2	1/2	0	0	3	1	0	0	0	0	0	0	3/2	0	1/6	4	8/3	4/3
d	0	0	3/2	1/2	3	1	0	0	3	1	0	0	0	0	3/2	0	1/6	0	4/3	2/3
s	0	0	0	0	0	0	0	0	0	0	3	1	3	1	0	3	2/3	0	0	0
$\bar{u}$	0	0	3/2	1/2	3	1	0	0	0	0	3	1	0	0	3/2	0	1/6	0	0	0
$\bar{d}$	3	1	3/2	1/2	0	0	0	0	0	0	0	0	3	1	3/2	0	1/6	0	0	0
$\bar{s}$	0	0	0	0	0	0	3	1	3	1	0	0	0	0	0	3	2/3	0	0	0

	Δ^0	n	Δ^-	Y^{*+}	Σ^+	Y^{*0}	Σ^0	Λ	Y^-	Σ^-	Ξ^{*0}	Ξ^0	Ξ^{*-}	Ξ^-	Ω^-
u	4/3	2/3	0	8/3	4/3	4/3	2/3	2/3	0	0	4/3	2/3	0	0	0
d	8/3	4/3	4	0	0	4/3	2/3	2/3	8/3	4/3	0	0	4/3	2/3	0
s	0	0	0	4/3	2/3	4/3	2/3	2/3	4/3	2/3	8/3	4/3	8/3	4/3	4

This, however, clearly contradicts the data [12, 18], requiring

$$I \sim (\sqrt{s})^{-n} f(x_T) \tag{11}$$

with n considerably higher than 4 in Eq. (10). The Chicago-Princeton data [9] indicate that the parametrization (11) is in general not particularly suitable and the coefficient n depends on x_T. For the pion production it starts with $n \sim 4$ at $x_T \sim 0$, climbs to $n \sim 8$ at $x_T \sim 0.2$ and then levels off at $n \sim 11$ at higher x_T.

This behaviour of n will hardly be explained without a deeper understanding of the basis of the parton model. A step in this direction is the recent analysis [11, 12] of the particle production within the framework of the CIM model. For phenomenological applications one could perhaps consider $n \sim 8$ as a rough parametrization of the energy dependence of the inclusive meson production. This value was also obtained by the British-Scandinavian group [21] within the ISR energy range.

The value $n=8$ for the pion production was predicted by CIM [10, 11] (and earlier references quoted therein). As an approximative and transient feature it is also obtained in the quasi-exclusive parton model [22] which we shall follow here. In this model, roughly speaking, the outgoing hard parton has to join one of his previous companions and this is being penalized by a factor proportional to the pionic formfactor $F_\pi(\hat{t}) \sim 1/\hat{t}$ in the amplitude*).

At $\Theta = 90°$

$$\hat{t} = -sx_1 \frac{x_1 x_2}{x_1 + x_2}$$

and $F_\pi^2(\hat{t})$ thus brings an additional factor of $(\sqrt{s})^{-4}$ into the cross section, restoring the rough agreement with the data. Inserting a factor $\beta \hat{t}^{-2}$ into Eq. (9) we obtain the inclusive production cross-section for mesons from 35-plet.

$$I^h_M = (\sqrt{s})^{-8} \sum_{ij} \int_A^1 dx_1 \frac{32\alpha\beta(x_1+x_2)^2}{x_T x_1^2 (x_1^2 x_2)^2} F^a_i(x_1) F^b_j(x_2) [g^h_i + g^h_j]. \tag{12}$$

It should be mentioned that the introduction of the factor $\beta \hat{t}^{-2}$ is equivalent to the modification of the parton-parton cross-section. The same form of the cross-section would be obtained also for parton scattering off a mesonic constituent [10, 11,]. In these models one should, of course, also change the distribution function.

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*) In the quark model the formfactor describes the following process: the photon hits a meson knocking out one of the quarks. Due to interaction of quarks the meson does not break up and moves further as a single particle. The same situation occurs also in the present model, where the fast moving quark picks up a slow companion.

The energy dependence of the inclusive proton production found in the Chicago-Princeton [9] experiment shows similar peculiar features.

The fits [9] to baryon data by Eq. (11) show again strong dependence of n on x_T. At $x_T \sim 0$ n starts at about 4 and grows up to about 14 at $x_T \sim 0.5$. For a rough qualitative description of the data we can proceed as below and multiply $d\sigma/d\hat{t}$ as given in Eq. (9) by $\gamma \hat{t}^{-3}$, which corresponds to $n \sim 10$ and leads to

$$I^h_B = (\sqrt{s})^{-10} \sum_{ij} \int_A^1 dx_1 \frac{32\alpha\gamma(x_1+x_2)^3}{x_T x_1^2 (x_1^2 x_2)^3} F^a_i(x_1) F^b_j(x_2) [g^h_i + g^h_j]. \tag{13}$$

The factor $\gamma \hat{t}^{-3}$ is a purely phenomenological device lacking in the present context a physical interpretation. One might perhaps hope that the interpretation would be easier for $\gamma \hat{t}^{-4}$ (the square of the form-factor), but the latter leads to manifest contradictions with the data on the x_T dependence of baryon to meson ratios.

We shall make a few further comments on this point in the last section. The formulae (12) and (13) give explicitly the production of mesonic and baryonic resonances. In order to obtain inclusive cross sections for stable particles we have to take into account decays of resonances.

II.3. Decays of unstable particles

Let a resonance with the mass M decay into two particles with the masses m_1 and m_2. The momenta of decay products in the rest frame of the resonance are denoted as q. The energy and momentum of the resonance in the c.m.s. of the hadron-hadron collision are denoted by E, P. The longitudinal momentum $q_\parallel = xP$ of its decay product is given by the Lorentz transformation

$$xP = \frac{E}{M} q^* \cos\vartheta^* + \frac{P}{M} E^*, \tag{14}$$

where ϑ^* is the angle of the decay and E^* the energy of the product, both in the rest frame of the resonance. From Eq. (14) we get for large P

$$d(\cos\vartheta^*) = \frac{M}{q^*} dx.$$

If the decay is isotropic in the resonance rest frame,

$$dw = \frac{1}{4\pi} d\Omega^* \sim \frac{M}{2q^*} dx, \tag{15}$$

where dw is the angular distribution of decay products. According to Eq. (14) x varies within the interval (x_1, x_2), where

$$x_1 = \frac{E^*}{M} - \frac{q^*}{M} \qquad x_2 = \frac{E^*}{M} + \frac{q^*}{M}. \tag{16}$$

The decay of the resonance is thus described by the function

$$g(x) = \frac{M}{2q^*}\,\Theta(x_2 - x)\,\Theta(x - x_1). \tag{17}$$

Let $(E\,\mathrm{d}\sigma/\mathrm{d}^3P)^R$ be the inclusive cross section for the production of the resonance. Then

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Theta\,\mathrm{d}P_T}\right)^R = \frac{2\pi P_T}{\sin\Theta}\left(E\frac{\mathrm{d}\sigma}{\mathrm{d}^3P}\right)^R.$$

If the resonance is very fast in the hadron-hadron rest frame, then its decay products will move in the same direction. For $\Theta^* \sim 90°$ we get

$$\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Theta\,\mathrm{d}P_T}\right)^C = \int g(x)\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Theta\,\mathrm{d}P'_T}\right)^R \frac{\mathrm{d}P'_T}{P'_T},$$

where x denotes the ratio of child's to parent's momentum and C denotes the decay product (the child). Coming back to invariant cross-sections

$$\left(E\frac{\mathrm{d}\sigma}{\mathrm{d}^3p}\right)^C = \frac{1}{p}\int g(x)\left(E\frac{\mathrm{d}\sigma}{\mathrm{d}^3p'}\right)^R \mathrm{d}p'. \tag{18}$$

Because of Θ-functions in Eq. (17), the integration in Eq. (18) extends over ($P_{\min}$, $P_{\max}$), where

$$P_{\min} = \frac{p}{x_2} = p\left(\frac{E^*}{m} + \frac{q^*}{M}\right)^{-1}$$

$$p_{\max} = \frac{p}{x_1} = p\left(\frac{E^*}{M} - \frac{q^*}{M}\right)^{-1}.$$

Vithin this interval $g(x) = M/2q^*$.

In actual calculations the right-hand side in Eq. (18) has to be multiplied by the ranching ratio of the particular decay. Eq. (18) as it stands corresponds only to wo-body decays. Three-body decays like $\omega \to \pi^+\pi^-\pi^0$ were treated like effective wo-body decays. In calculating the π^+ yield from $\omega \to \pi^+\pi^-\pi^0$ we have formally onsidered $(\pi^-\pi^0)$ as a stable particle (a dipion) and assigned to it, somewhat rbitrarily, $m = 400$ MeV. Three pion decays of η and ϕ were dealt with in similar way with effective dipion masses equal to 300 and 770 MeV, respectively.

III. PARTICLE RATIOS IN PROTON-NUCLEUS COLLISIONS AT 400 GeV/c

The inclusive production of a particular stable particle consists of two parts: the former is the „direct" production given by Eqs. (12) (for mesons) and (13) (for baryons) and the latter represents the decay of unstable resonances. The production of resonances is again given by Eqs. (12) and (13) and the production of their decay products is then calculated by using Eq. (18).

The invariant cross section for the inclusive production of positive pions is compared with the data in Fig. 1. The agreement is quite satisfactory. The energy dependence is also more or less correct, since the appropriate factor n (see Eq. (11)) was built already into the model. The copious production of resonances which forms the essential assumption of our model cannot be directly tested since

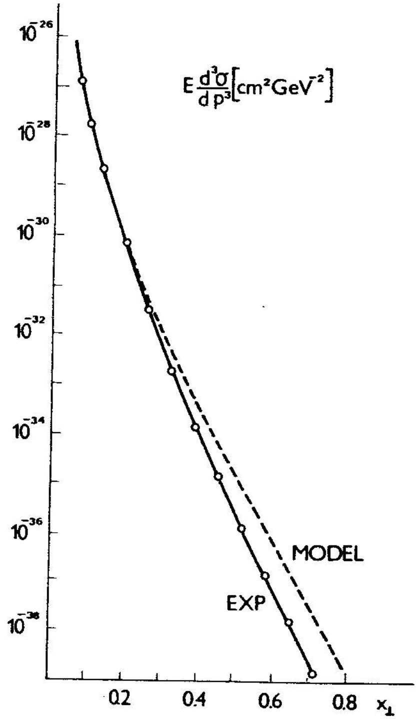


Fig. 1a. π^- production in proton nucleus collision at 300 GeV/c. The continuous line with data points represents the CP results [9], the short dashes show results of our model.

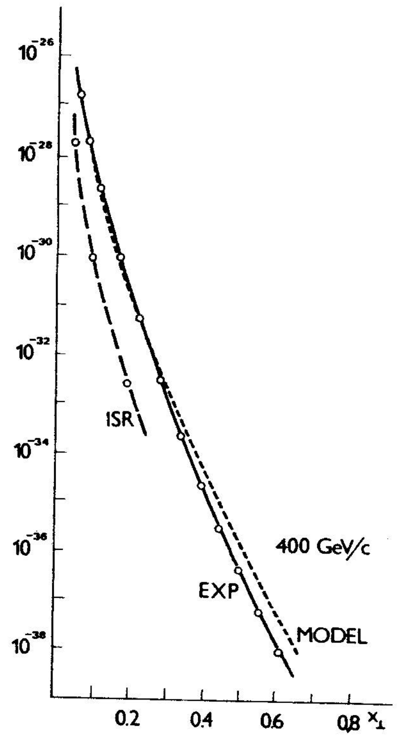
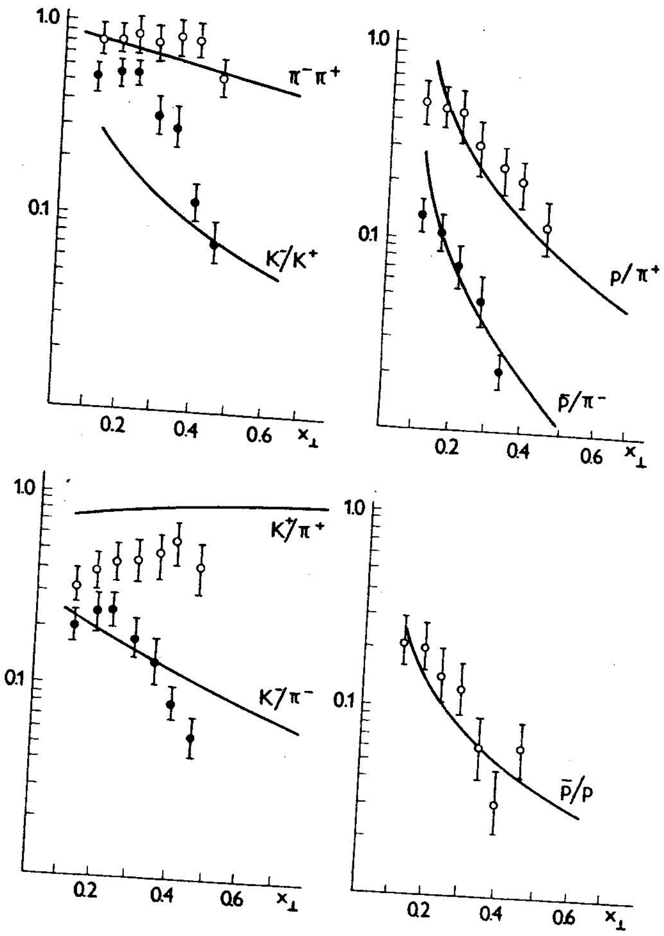


Fig. 1b. π^- production in proton nucleus collisions at 400 GeV/c [9] and at $\sqrt{s} = 52.8$ GeV [21]. The line with short dashes shows our calculations at $\sqrt{s} = 52.8$ GeV and data points are from Ref. [21].

the data are not available. If, however, the resonances are produced by an SU(6) symmetric mechanism, then the agreement of the pion production with the data indicates that the resonance production might also be adequately described in the present model. It should be stressed that a realistic description of the resonance production is essential for the correct evaluation of the contribution from resonance decays. The curves describing roughly the CP data in Fig. 1 correspond to $\alpha\beta = 2.09$ GeV^4, $\alpha\beta = 52.7$ GeV^6 (with $C_M = C_B = 1$).

The relative magnitude of β and γ was given by the requirement that the proton to positive pion ratio agrees with the data at $x_T = 0.2$ and $E_{lab} = 400$ GeV. After



2. Calculated particle ratios in proton-nucleus interactions at 400 GeV/c (solid line) compared with the Chicago-Princeton data [9]. The error bars are rough estimates of experimental errors.

having fixed γ/β (the only free parameter) we can calculate particle ratios. The results are compared with the Chicago-Princeton [9] data in Figs. 2.

It should be noted that the data [9] plotted in Figs. 2 are obtained by extrapolating the production on Be, Ti and W targets to $A = 1$. Correspondingly, the distribution functions $F_i^{+}(x)$ in Eqs. (12) and (13) are the average of the distributions in neutron and proton. The overall rough qualitative agreement with the data is an argument in favour of the manifestation of SU(6) in large p_T phenomena. The only obvious discrepancy is in the K^-/K^+ ratio. Some comments on this point will be offered in Section VI.

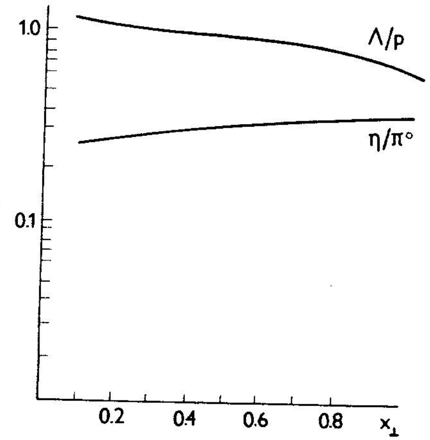


Fig. 3: Ratios p/Λ and η/π^0 predicted by the present model at 400 GeV/c.

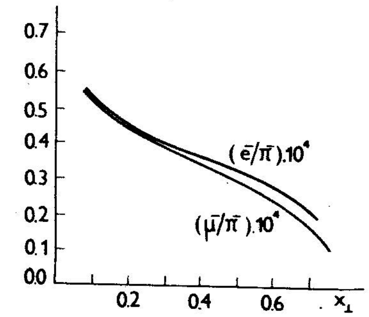


Fig. 4. Lepton/pion ratios at 400 GeV/c.

In Fig. 3 we present predictions of the present model for η/π^0 and Λ/p ratio at 400 GeV/c.

The large Λ/p ratio is typical for the present model and will probably be among the first to be measured. Numerical results for particle ratios are summarized in Table 2.

IV. PARTICLE RATIOS AT ISR ENERGIES

The British-Scandinavian (BS) collaboration [21] has measured the particle ratios for the ISR energies at $\sqrt{s} = 23.4$, 30.6, 44.6, 52.8 and 63 GeV and for $p_T < 4.75$ GeV/c. We shall compare here the data at $\sqrt{s} = 52.8$ with our calculations.

The inclusive π^- production is compared with the data in Fig. 1b. The agreement is, within the limited p_T range over which the data are available, quite good.

Table 2

Particle ratios at $p_{Lab} = 400$ GeV/c (pA collisions)

x_T	π^-/π^+	p/π^+	K^-/K^+	K^+/π^+	K^-/π^-	p/π^-	$\bar{p}/p$	η/π^0	Λ/p	$10^4(e^-/\pi^-)$	$10^4(\mu/\pi^-)$
0.1	0.841	1.85	0.271	0.789	0.254	0.371	0.186	0.275	1.13	0.558	0.527
0.2	0.772	0.451	0.174	0.823	0.185	0.062	0.104	0.275	1.06	0.470	0.449
0.3	0.716	0.197	0.122	0.850	0.145	0.020	0.072	0.279	1.02	0.417	0.397
0.4	0.667	0.106	0.090	0.877	0.117	0.008	0.052	0.287	0.98	0.372	0.349
0.5	0.623	0.065	0.066	0.902	0.095	0.004	0.038	0.299	0.94	0.327	0.295
0.6	0.583	0.042	0.048	0.927	0.077	0.002	0.028	0.312	0.89	0.279	0.237
0.7	0.546	0.029	0.035	0.952	0.062	0.001	0.021	0.325	0.84	0.230	0.176

The parameters $\alpha\beta$ and $\alpha\gamma$ (see Eqs. (12) and (13)) at these energies are: $\alpha\beta = 5.76$ GeV and $\alpha\gamma = 196.5$ GeV^6. Their energy dependence indicates that our model can represent only a rough phenomenological description of the true dynamics of the process.

The BS data are compared with our calculations in Fig. 5. We have also reproduced there the results of calculations by Landshoff and Polkinghorne [17, 18], obtained by using the fusion model and considering only the pseudoscalar mesons and the results by Combridge [19] who extended the fusion mechanism of Refs. [17, 18] by introducing vector mesons.

It is rather difficult to draw any definite conclusions from these figures, since the x_T at ISR is below 0.2 and models based on hard interactions of hadronic constituents can hardly be trusted for $x_T < 0.1$—0.2. The extension of data on particle ratios to higher values of x_T is very desirable.

Our calculations for the Λ/p and η/π^0 ratios are presented in Fig. 6. The data on Λ/p are not yet available and the recent data [34, 43, 12] give $\eta/\pi^0 = 0.55 + 0.11$ for p_T in the interval 3 to 5.6 GeV/c. Numerical results of calculations of particle ratios in pp collisions at $\sqrt{s} = 52.8$ are given in Table 3.

V. LEPTON TO PION RATIO

One of the unexpected results reported at the London conference was undoubtly he large ratio of directly produced leptons to pions at large p_T [25, 26, 27, 28]. According to the Lederman summary [29] both e/π and μ/π are about 10^{-4} within a factor of 2, at worst) and the ratio seems to be independent of p_T for .5 $< p_T < 5$ GeV and of the cms energy for $7 < s < 53$ GeV. The independence of s ndicates that the observed leptons are not decay products of heavy objects and the onstancy of the lepton to pion ratio points to a similar origin of leptons and pions. he measured lepton yields are considerably higher than predictions of the Drell

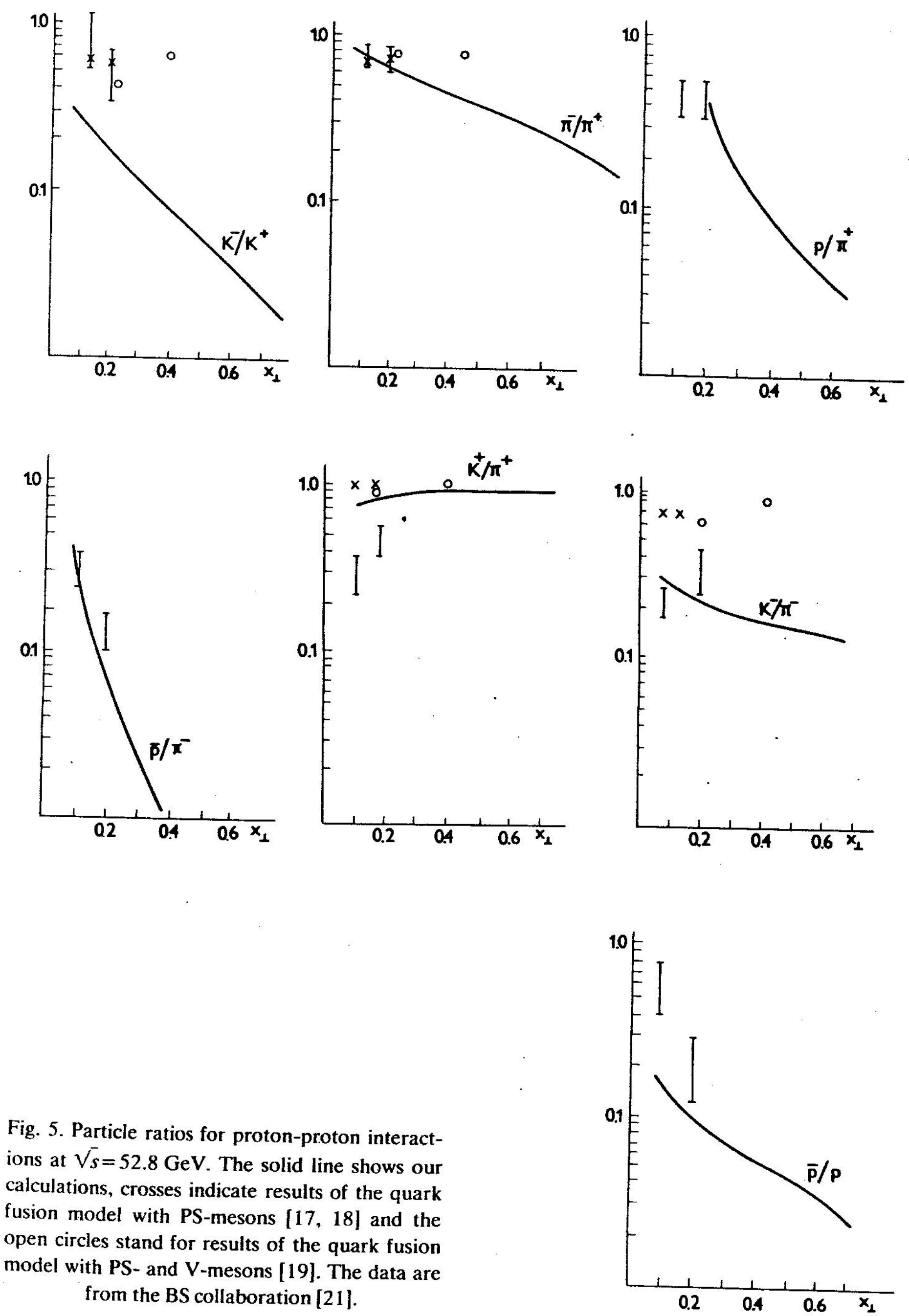


Fig. 5. Particle ratios for proton-proton interactions at $\sqrt{s} = 52.8$ GeV. The solid line shows our calculations, crosses indicate results of the quark fusion model with PS-mesons [17, 18] and the open circles stand for results of the quark fusion model with PS- and V-mesons [19]. The data are from the BS collaboration [21].

and Yan [37] model, where leptons appear as decay products of a virtual photon created in the parton-antiparton annihilation.

Soon after the discovery of the large lepton to pion ratio it was pointed out that the decay of vector mesons to e^+e^- and pairs might be an important contribution to the observed lepton yields [38]. The idea was later on used in more detailed calculations [19, 39, 40] and it was shown that the vector meson decays can provide a correct order of magnitude of the direct lepton production. In a more recent paper [41] it was shown that the ψ (3, 1) decay can also substantially contribute to this ratio.

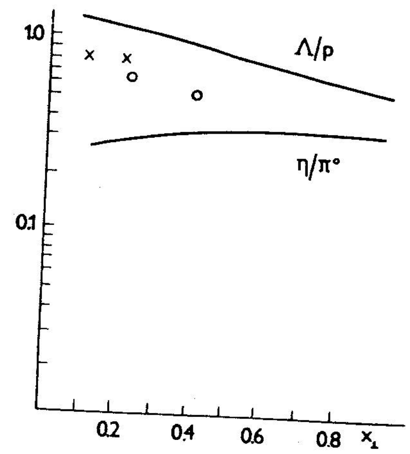


Fig. 6. Predictions for the Λ/p and η/π° ratio: our model (solid line), the Landshofff and Polkinghorne [17, 18] one (crosses) and the Combridge [19] one circles). The exp. result [34] is $\eta/\pi^\circ = 0.55 \pm 0.11$.

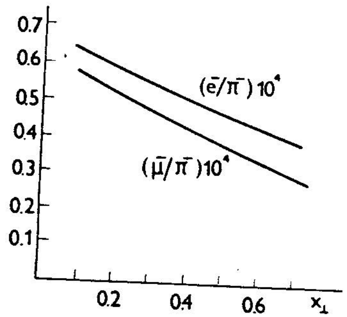


Fig. 7. Lepton to pion ratios in pp interactions at $\sqrt{s} = 52.8$ GeV. Our calculations (solid line), the Combridge [19] result for e/π (circles).

The inclusive production of leptons from decays of vector mesons is calculated in our model by Eq. (18) (branching ratios for the vector meson decay to the lepton-antilepton pair are taken from [31]). In this way the model gives unique predictions for lepton/pion ratios. The results shown in Figs 4 and 7 indicate that the vector meson decay can provide for about one half of the observed values of the lepton/pion ratios*). This is in accord with the qualitative analysis by Sivers, Brodsky and Blankenbecler (Sect. II.D in [12]) and with Combridge's

*) Due to a programming error the results on the lepton/pion ratio contained in the preprint version of the present paper, circulated earlier, were incorrectly enhanced by a factor of about 2. Other results were influenced by the error to a smaller extent.

Table 3

Particle ratios in pp collisions at $\sqrt{s} = 52.5$ GeV and $\Theta^* = 90°$

x_T	π^-/π^+	p/π^+	K^-/K^+	K^+/π^+	K^-/π^-	p/π^-	$\bar{p}/p$	η/π^0	Λ/p	$10^4(e^-/\pi^-)$	$10^4(\mu^-/\pi^-)$
0.1	0.70	1.85	0.26	0.77	0.28	0.42	0.159	0.28	1.07	0.62	0.59
0.2	0.59	0.45	0.16	0.81	0.22	0.07	0.097	0.28	0.99	0.56	0.53
0.3	0.50	0.19	0.11	0.83	0.18	0.025	0.067	0.28	0.94	0.52	0.50
0.4	0.43	0.10	0.08	0.86	0.16	0.011	0.048	0.29	0.90	0.50	0.47
0.5	0.36	0.06	0.06	0.88	0.14	0.006	0.035	0.30	0.86	0.47	0.42
0.6	0.31	0.04	0.04	0.92	0.12	0.003	0.026	0.31	0.81	0.44	0.37
0.7	0.26	0.03	0.03	0.94	0.11	0.002	0.019	0.33	0.76	0.40	0.30

calculations [19]. The remaining half has to be looked for either in the production of the $\psi(3.1)$ particle [41] or, if this is also insufficient [12], in some completely different process, unknown at present.

VI. COMMENTS AND CONCLUSIONS

The present model based on an SU(6) mechanism for particle production at large p_T gives a rough qualitative agreement with the data on particle ratios in proton-nucleus collisions.

The essential feature of the model is a prediction of a copious resonance production at large p_T. Such data of the resonance production would be, in general, an essential contribution to our understanding of the large p_T phenomena.

In dynamical questions the present model is purely phenomenological and significant developments in this respect will probably be possible only after a deeper understanding of the hadron structure and dynamics has been reached*).

In this situation it is rather difficult to find a plausible interpretation of the cases in which our model disagrees with the data (like the K^-/K^+ ratio in Fig. 2a). We have completely neglected the gluons. If they carry about one half of the hadron's momentum they have probably full right to contribute somehow also to large p_T phenomena. Unfortunately we have no idea of how to estimate these effects. Furthermore, even at the phenomenological level, the parton distributions in hadrons are not particulary well known in the whole x-region. Then, the present model is very rough in the delicate question of the parton fragmentation. We actually take into account only the first step in the fragmentation chain. This may seriously underestimate the production of K^- mesons which cannot be formed in

*) It seems at present that the most promissing way is an attempt to disentangle contributions from various subprocesses by using effective exponentials [11, 12].

this way if the fragmentation is initiated by a valence quark. Sticking literally to this explanation of the K^- suppression might be rather dangerous since it would be difficult to explain why the $\bar{p}/p$ calculation agrees with the data. The specific phenomenological assumption used in the model would be clarified by the data on inclusive production at $\Theta_{cms} \neq 90°$.

We have also completely neglected the charm. A possible presence of a charmed particle can significantly influence the K^-/K^+ ratio at large p_T and the lepton/pion ratio. The most drastic of our phenomenological assumptions concerns the production of baryons. The point is a serious problem in parton models and the recent proposal [42] assumes that baryons are produced by a mechanism rather different from the one responsible for the meson production. It should be also stressed that our model is applicable only to large p_T processes and it apparently cannot explain the $\bar{p}/p$ ratio close to one [21] at $p_T \sim 1.7$ GeV/c.

An independent check of the basic features of the model can also be obtained from the data on the production of particles at large p_T in pion-nucleon collisions. In such a calculation an ansatz, or preferably, an information about the parton distribution in the pion is a necessary prerequisite.

In concluding, we should perhaps add that models like the present one cannot hope to agree with the data better than to a factor of 2—3 or so and from this point of view the agreement with the data is surprisingly good. The basic features of this and other similar models [30, 32] will be tested unambiguously only by the data on resonance production at large p_T. Such data are really needed.

For the clarification of the basic features of the parton constituent interactions the data with full information on the final state in events with a large p_T particle would be extremely helpful. Let us hope that such data will come from the next generation of streamer chambers or other devices.

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