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DIMUON PRODUCTION IN νN AND $\bar{\nu}N$ INTERACTIONS AT HIGH ENERGIES IN A SIMPLE QUARK-PARTON MODEL WITH CHARM

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It is assumed that dimuons observed recently in νN and $\bar{\nu}N$ interactions at high energies are caused by the chargedcurrent weak interactions in which charmed mesons are produced. The second muon appears as a decay product of the charmed meson. The model assumes the SU (3) symmetry for the fragmentation of "ordinary" partons to "ordinary" meson resonances. The fragmentation of ordinary partons into charmed mesons and the charmed parton content in the nucleon are suppressed by a phenomenological parameter, estimated from the $\mu^-\mu^-/\mu^+\mu^-$ production ratio. The model is in a qualitative agreement with the available data and makes a couple of predictions: the trimuon production should be present with the rate of about 1/10 of the $\mu^-\mu^-$ production; the $\mu^+\mu^+$ production in $\bar{\nu}N$ should be smaller by a factor of about 6 than the $\mu^-\mu^-$ production in νN; the dimuon production should decrease with increasing x_{BJ} in the way explicitly given by the parton distribution functions.

РОЖДЕНИЕ ДИМЮОНОВ В νN И $\bar{\nu}N$ ВЗАИМОДЕЙСТВИЯХ ПРИ БОЛЬШИХ ЭНЕРГИЯХ В ПРОСТОЙ КВАРКО-ПАРТОННОЙ МОДЕЛИ С ОЧАРОВАНИЕМ

Предполагается, что димюоны, недавно наблюдаемые в νN и $\bar{\nu}N$ взаимодействиях при больших энергиях, обусловлены заряжённым током слабых взаимодействий, в которых рождаются очарованные мезоны. Модель предполагает для фрагментации «обычных» партонов на «обычные» мезонные резонансы SU(3)-симметрию. Фрагментация обычных партонов на очарованные мезоны и очарованное партонное содержание в нуклоне подавляется феноменологическим параметром, который вычислен из соотношения $\mu^-\mu^-/\mu^+\mu^+$. Модель находится в качественном согласии с доступными данными и делает два предсказания: тримюонное рождение должно происходить с интенсивностью приблизительно 1/10 от интенсивности рождения $\mu^-\mu^-$; продукция $\mu^+\mu^+$ в $\bar{\nu}N$ должна быть примерно в шесть раз меньше продукции $\mu^-\mu^-$ в νN; продукция димюонов должна уменьшаться с ростом x_{BJ} образом явно данным партонными функциями распределения.

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I. INTRODUCTION

Recent experiments [1, 2] in νN and $\bar{\nu}N$ interactions at high energies give evidence of an unexpectedly high production of dimuon pairs. The Harvard-Pensylvania-Wisconsin-Fermilab collaboration [1] observed 61 $\mu^+\mu^-$, $8\mu^-\mu^-$ and $2\mu^+\mu^+$ events in the broad band beam of ν and $\bar{\nu}$ at FNAL. The rate of the $\mu^+\mu^-$ events is about 1 % of the total number of νN and $\bar{\nu}N$ interactions. The HPWF group selected only those dimuon events which originated in about the same place. In this way they have left out the events in which one of the muons is due to pion or kaon decays. The residual contamination from π or K decays is apparently negligible in the $\mu^+\mu^-$ events, but may be still relevant for the $\mu^+\mu^+$ and the $\mu^-\mu^-$ events.

The SLAC-Fermilab [2] collaboration observed 19 dimuon events in a narrow-band beam at FNAL. The rate of the dimuon events is about 2 %.

It the present note we shall try to describe these results within the framework of a very simple parton model with charm. We shall also make a number of predictions which may confirm or destroy this naive picture.

We assume that dimuons originate from charged-current weak interactions in which a charmed meson is produced:

$$\nu N \to \mu^- + \text{charmed meson} + X \tag{1}$$

$$\nu N \to \mu^+ + \text{charmed meson} + X. \tag{2}$$

The second muon appears as a decay product of the charmed meson.

It will be shown that charmed mesons in reaction (1) prefer decays with μ^- to those with μ^+ in agreement with the experimental data. In a similar way charmed mesons in reaction (2) prefer decays to μ^-. However, the presence of $\mu^-\mu^-$ modes in (1) and of $\mu^+\mu^+$ in (2) falls naturally into the scheme and leads to the prediction of trimuons $\mu^-\mu^+\mu^-$ in (1) and $\mu^+\mu^-\mu^+$ in (2). Such events should appear in (1) and (2) as a consequence of decays of mesons with hidden charm — Ψ (3.1 GeV) — into $\mu^+\mu^-$.

This scheme for the dimuon production is further corroborated by the data on muon momenta. In most of the events observed in [1] one of the muons is fast in the lab. frame and the other is slow. This feature is also obtained from (1) and (2) if the reaction has $x_{BJ} < 0.2$, or so.

Such a picture also qualitatively explains the $\mu^+\mu^-$ mass distribution observed in [1].

It is easy to show that the effective mass of a dimuon with one μ at rest and another one mowing with $p_L = 50$ GeV/c, 100 GeV/c and 150 GeV/c is roughly 3.3, 4.7 and 5.8 GeV, respectively. This is just in the region populated by the data on the dimuon effective mass in [1]. The broad band beam in [1] contains actually ν and $\bar{\nu}$ with energies in the range 50—150 GeV.

A more detailed comparison with the data on dimuon masses will be possible only when the momentum distribution of incident ν and $\bar{\nu}$ in the broad beam [1] will be known in detail.

II. A SIMPLE QUARK PARTON MODEL WITH CHARM

In a simple quark-parton model [3] of deep lepton-nucleon collisions one has to specify three points: the parton distribution functions in the nucleon, the form of the elementary lepton-quark interaction and the parton fragmentation functions.

In the first two items we shall follow the standard way, in the third we shall try to include as much of the SU (3) (or SU (4) symmetry in the case of charm) as possible.

We shall assume that the parton-distribution functions are roughly represented by the McElhaney-Tuan [4] modification of the Kuti-Weisskopf [5] distributions, namely

$$p_V(x) = 1.74 \frac{1}{\sqrt{x}} (1-x)^3 (1+2.3x) \tag{3a}$$

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

$$\lambda(x) = 0.1 \frac{1}{x} (1-x)^{7/2}$$

and that the sea is SU (3) symmetric. The content of the charmed quarks and antiquarks is assumed to be

$$c(x) = \bar{c}(x) = \alpha\lambda(x), \tag{3b}$$

where the parameter α will be determined later on from the data.

The elementary interaction of ν and $\bar{\nu}$ with partons is given by the nowadays usual form [6] summarized in Tables 1a and 1b.

If ν collides with a parton in the column IN in Tab. 1a, the neutrino changes to μ^- and the parton changes to the one given in the column OUT. The third column gives the Cabibbo factor for this type of transition. The column E—0 indicates the value of the total cross section. The transition with the minus sign is suppressed by the factor 1/3 relative to the transition with the + sign. The last column anticipates the model predictions for the fragmentation of the "OUT" parton. The meaning of this column will be described shortly.

In order to complete the picture we have to make now a specific assumption about the fragmentation of partons resulting from the neutrino interaction. We shall assume that the fragmentation is as much SU (6) symmetric as possible and the breaking of the SU (8) symmetry for the case with charm is also rather simple.

Table 1a

ν — quark interactions

IN	OUT	Cabibbo factor	E—0	Muons in the final state
n	p	$\cos\vartheta_c$	+	(− −)
λ	p	$\sin\vartheta_c$	+	(− −)
n	c	$-\sin\vartheta_c$	+	(− +), (− + −)
λ	c	$\cos\vartheta_c$	+	(− +), (− + −)
$\bar{p}$	$\bar{n}$	$\cos\vartheta_c$	−	(− +)
$\bar{p}$	$\bar{\lambda}$	$\sin\vartheta_c$	−	(− +)
$\bar{c}$	$\bar{n}$	$-\sin\vartheta_c$	−	(− +)
$\bar{c}$	$\bar{\lambda}$	$\cos\vartheta_c$	−	(− +)

Table 1b

$\bar{\nu}$ — quark interactions

IN	OUT	Cabibbo factor	E—0	Muons in the final state
$\bar{n}$	$\bar{p}$	$\cos\vartheta_c$	+	(+ +)
$\bar{\lambda}$	$\bar{p}$	$\sin\vartheta_c$	+	(+ +)
$\bar{n}$	$\bar{c}$	$-\sin\vartheta_c$	+	(+ −), (+ − +)
$\bar{\lambda}$	$\bar{c}$	$\cos\vartheta_c$	+	(+ −), (+ − +)
p	n	$\cos\vartheta_c$	−	(+ −)
p	λ	$\sin\vartheta_c$	−	(+ −)
c	n	$-\sin\vartheta_c$	−	(+ −)
c	λ	$\cos\vartheta_c$	−	(+ −)

A simple model with these properties can be obtained as follows. Let us suppose that a fast quark moves across the quarkantiquark sea and picks out antiquarks to form a meson. The probability g_a^M that a quark a with a spin projection s_a becomes a meson*) M with a spin projection s_M is simply

$$g_a^M = \sum_{i,s_i} |\langle M, s_M | a, s_a; i, s_i \rangle|^2, \tag{4}$$

where we sum over all "picked-up" antiquarks i with spin projections s_i. The symmetry SU (3) (or SU (4)) is respected here by the equal probability for picking up any antiquarks. The model is actually a more specific version of the models used

*) A meson means here either a pseudoscalar or a vector meson from the SU (6) 35-plet.

by Bjorken and Farrar [7] and by Anisovich and Shekhter [8] in the multiparticle production in hadron-hadron collisions.

In Eq. (4) we have suppressed the explicit dependence of the coefficient g_a^M on the spin projection s_M and s_a because we shall not be interested in polarizations of outgoing hadrons and we also assume that incoming particles are unpolarized. We shall therefore average over spin projections. The symbol g_a^M will in the following denote only quantities averaged in this way. The resulting coefficients g_a^M are thus actually given by the SU (3) *CG* coefficients. It would be probably more appropriate to speak only of the SU (3) symmetry. We shall, however, use in connection with the pick-up mechanism described earlier the term SU (6) symmetry since this formalism could also be used in the future in attempts to describe polarization phenomena in the lepton-nucleon scattering.

The model predicts copious resonance production.

So far direct evidence in this respect has been rather meagre but the qualitative agreement of the results of [7, 8] with the inclusive data seems encouraging.

Recently, within our version of the model we have calculated [9] particle ratios at large p_T in hadron-hadron collisions and particle ratios in electro- and neutrino-nucleon interactions [10]. Qualitative agreement with the available data is an indirect (and, of course, insufficient) evidence for the SU (3) features of fragmentation functions.

In the previous calculations [9, 10] we assumed the relative fragmentation given by Eq. (4) to be valid only for the leading hadron in the cascade.

Within the present context we assume that the charmed meson is, due to kinematics, the only particle in the parton "cascade".

We assume further that we are dealing only with effects in the current fragmentation region. This may be rather questionable in case when, let's say, p-quark picks up $\bar{c}$ from the sea. The other c should remain presumably in the target fragmentation region and its possible contribution to the muon production is neglected in our model. If taken into account, this would further increase estimates of the trimuon production.

Since the charmed quarks (if existing at all) should be heavier than "ordinary" ones, there are less charmed quark-antiquark pairs available and it is more difficult to pick up a charmed quark. We shall therefore break the SU (4) symmetry in fragmentation functions simply by introducting a penalizing factor α for the probability of a picking-up a charmed quark. In this way any term in the summation in Eq. (4) is multiplied by α if i is a charmed quark. The factor α is the same as that in Eq. (3b) since they both correspond to the same physical mechanism for suppressing the presence of charmed quarks.

The quark content of charmed and ordinary mesons is given in Table 2a for pseudoscalar and in Table 2b for vector mesons. The notation and mixing used are taken from the paper by Gaillard, Lee and Rosner [11].

Table 2a

Wave functions of pseudoscalar mesons

$\pi^- = n\bar{p}$	$D^0 = p\bar{c}$
$\pi^0 = (p\bar{p} - n\bar{n})/\sqrt{2}$	$F^+ = c\bar{\lambda}$
$\pi^+ = p\bar{n}$	$D^0 = c\bar{p}$
$\eta_c' = (p\bar{p} + n\bar{n} + \lambda\bar{\lambda} - 3c\bar{c})/\sqrt{12}$	$D^+ = c\bar{n}$
$\eta' = (p\bar{p} + n\bar{n} + \lambda\bar{\lambda} + c\bar{c})/2$	$K^+ = p\bar{\lambda}$
$\eta = (p\bar{p} + n\bar{n} - 2\lambda\bar{\lambda})/\sqrt{6}$	$K^0 = n\bar{\lambda}$
$F^- = \lambda\bar{c}$	$K^- = \lambda\bar{p}$
$D^- = n\bar{c}$	$\bar{K}^0 = \lambda\bar{n}$

Table 2b

Wave functions of vector mesons

$\varrho^- = n\bar{p}$	$K^{*-} = \lambda\bar{p}$
$\varrho^0 = (p\bar{p} - n\bar{n})/\sqrt{2}$	$\Phi_c = c\bar{c}$
$\varrho^+ = p\bar{n}$	$D^{*+} = c\bar{n}$
$\omega = (p\bar{p} + n\bar{n})/\sqrt{2}$	$D^{*0} = c\bar{p}$
$\varphi = \lambda\bar{\lambda}$	$F^{*+} = c\bar{\lambda}$
$K^{*+} = p\bar{\lambda}$	$\bar{D}^{*0} = p\bar{c}$
$K^{*0} = n\bar{\lambda}$	$D^{*-} = n\bar{c}$
$\bar{K}^{*0} = \lambda\bar{n}$	$F^{*-} = \lambda\bar{c}$

Using these tables it is easy to calculate the coefficients g_a^M in Eq. (4). The coefficients are given in Table 3a for pseudoscalar and in Table 3b for vector mesons*).

Normalizations in these Tables are rather arbitrary. This has to be taken into account in actual calculations of dimuon to single muon rates. It should be further stressed that vector mesons should be enhanced by a factor of 3 (due to spin) relative to pseudoscalar mesons.

The muons in the final state appear as decay products of charmed particles. Here D^+, D^0, F^+, D^{*+}, D^{*0}, F^{*+} decay with the emission of μ^+ and D^-, $\bar{D}^0$, F^-, D^{*-}, $\bar{D}^{*0}$, F^{*-} with the emission of μ^-. Charmonium states Φ_c, η' and η_c' have a $\mu^+\mu^-$ decay channel.

Let us now return to the νN interaction and start with the first row in Table 1a. The probability to find a "neutron" quark in the nucleon is $G_n(x)$. During the interaction it is changed to the "proton" quark with the probability proportional to $\cos^2 \vartheta_c$. According to Table 3b the "proton" quark fragments to vector mesons according to the scheme

$$p \to \omega/2 + \alpha\bar{D}^{*0} + \varrho^+ + \varrho^0/2 + K^{*+} + \{PS \text{ mesons}\}.$$

The $\bar{D}^{*0}$ decays with the emission of μ^-, which thus contributes to the $\mu^-\mu^-$ production in the νN collision. This contribution is explicitly given as

$$3 \times 1 \times \alpha \times G_n(x) \cos^2 \vartheta_c \times \gamma, \tag{5}$$

where 3 is the enhancement factor for vector mesons, explicitly written 1 is due to the plus sign in the E—0 column of Table 1a, $G_n(x)$ is the probability to find the "neutron" quark in the nucleon and γ is the branching ratio for the μ^- decay of $\bar{D}^{*0}$. The last column in Table 1a indicates that this type of neutrino interaction contributes to the $\mu^-\mu^-$ final state.

* The coefficients in Table 3a and 3b are averaged over spins and do not contain spin weight factors (e. g. factor 3 for vector mesons and a factor 1 for pseudoscalars).

Table 3a
Fragmentation on quarks to pseudoscalar mesons

Q	n	p	λ	c	n̄	p̄	λ̄	c̄
PS								
D^+				1	1			
D^0				1		1		
F^+				1			1	
$\bar{D}^0$		1						1
D^-	1							1
F^-			1					1
η	1/6	1/6	2/3		1/6	1/6	2/3	
η'	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
η_c'	1/12	1/12	1/12	3/4	1/12	1/12	1/12	3/4
π^+		1			1			
π^0	1/2	1/2			1/2	1/2		
π^-	1					1		
K^+		1					1	
K^0	1						1	
K^-			1			1		
$\bar{K}^0$		1			1			

The second row in Table 1a is treated in a similar way. The quark fragments to

$$\lambda \to \Phi + \alpha F^{*-} + \bar{K}^{*0} + K^{*-},$$

where α is again the penalizing factor for picking up c, the charmed F^{*-} decays again with the emission of μ^- and the contribution becomes

Table 3b
Fragmentation of quarks to vector mesons

Q	n	p	λ	c	n̄	p̄	λ̄	c̄
V								
φ			1				1	
ω	1/2	1/2			1/2	1/2		
φ_c				1				1
D^{*+}				1	1			
D^{*0}				1		1		
F^{*+}				1			1	
$\bar{D}^{*0}$		1						1
D^{*-}	1							1
F^{*-}			1					1
ρ^+		1			1			
ρ^0	1/2	1/2			1/2	1/2		
ρ^-	1					1		
K^{*+}		1					1	
K^{*0}	1						1	
$\bar{K}^{*0}$			1		1			
K^{*-}			1			1		

$$3 \times 1 \times \alpha G_\lambda(x) \sin^2 \vartheta_c \times \gamma. \qquad (6)$$

The total contribution of *PS*-mesons is just one third of the sum of (5) and (6). Other rows in Table 1a do not contribute to the $\mu^-\mu^-$ production and the total contribution to the $\mu^-\mu^-$ production in νN collisions becomes

$$(\mu^-\mu^-;\ \nu N) = 4(G_n(x) \cos^2 \vartheta_c + G_\lambda(x) \sin^2 \vartheta_c)\ \alpha\gamma. \qquad (7)$$

The third row is more interesting. The charmed quark fragments according to the scheme

$$c \to \Phi_c + D^{*+} + D^{*0} + F^{*+} + \{PS\text{-mesons}\}.$$

The three charmed mesons decay emitting μ^+ and Φ_c has a 7 % probability to decay into $\mu^+\mu^-$. This interaction therefore contributes both to $\mu^-\mu^+$ dimuons and to trimuons $\mu^-\mu^+\mu^-$ in the final state.

Proceeding in this way and summing up all the contributions we obtain

$$(\mu^-\mu^+;\ \nu N) = 12\gamma(G_n \sin^2 \vartheta_c + G_\lambda \cos^2 \vartheta_c) + \qquad (8a)$$

$$+\frac{4}{3}\alpha\gamma G_{\bar{p}} + \frac{4}{3}\gamma\alpha^2 G_{\bar{c}}$$

$$(\mu^-\mu^+\mu^-;\ \nu N) = 4\alpha\gamma_c(G_n \sin^2 \vartheta_c + G_\lambda \cos^2 \vartheta_c) \qquad (8b)$$

$$(\text{all};\ \nu N) = (12 + 4\alpha)\left(G_n + G_\lambda + \frac{1}{3} G_{\bar{p}} + \frac{\alpha}{3} G_{\bar{c}}\right), \qquad (8c)$$

where "all" includes also the single muon production and γ_c is the $\Phi_c \to \mu^+\mu^-$ branching ratio.

The factor $4\gamma_c$ in Eq. (8b) should actually be written as $3\gamma_c + \gamma_{c'}$, where $3\gamma_c$ was explicitly calculated from the Φ_c decays and $\gamma_{c'}$ is our intuitive estimate of the contribution from pseudoscalar mesons containing the *cc* pair. Proceeding in the same way in the case of $\bar{\nu}N$ interactions we obtain

$$(\mu^-\mu^+;\ \bar{\nu}N) = 12\gamma(G_{\bar{n}} \sin^2 \vartheta_c + G_{\bar{\lambda}} \cos^2 \vartheta_c) + \qquad (9a)$$

$$+\frac{4}{3}\gamma\alpha G_p + \frac{4}{3}\gamma\alpha^2 G_c$$

$$(\mu^+\mu^+;\ \bar{\nu}N) = 4(G_{\bar{n}} \cos^2 \vartheta_c + G_{\bar{\lambda}} \sin^2 \vartheta_c)\ \alpha\gamma \qquad (9b)$$

$$(\mu^+\mu^-\mu^+;\ \bar{\nu}N) = 4(G_{\bar{n}} \sin^2 \vartheta_c + G_{\bar{\lambda}} \cos^2 \vartheta_c)\ \alpha\gamma_c \qquad (9c)$$

$$(\text{all};\ \bar{\nu}N) = (12 + 4\alpha)\left(G_{\bar{n}} + G_{\bar{\lambda}} + \frac{1}{3} G_p + \frac{1}{3}\alpha G_c\right), \qquad (9d)$$

where the factor $4\gamma_c$ was obtained in the same way as in Eq (8b). The present data [1, 2] do not permit a detailed comparison with Eqs. (8) and (9). Still, a rough estimate of the parameters in the model is possible and enables us to make a few qualitative predictions which could test the general features of the present picture.

The ratio $\mu^-\mu^-/\mu^+\mu^-$ leads to an estimate of α. Using Eqs. (7) and (8a) and neglecting the last two terms on the right hand side in (8a), we get

$$\frac{(\mu^-\mu^-;\ \nu N)}{(\mu^-\mu^+;\ \nu N)} \sim \frac{1}{3}\frac{G_n \cos^2\vartheta_c + G_\lambda \sin^2\vartheta_c}{G_n \sin^2\vartheta_c + G_\lambda \cos^2\vartheta_c}\,\alpha .$$

Inserting the distribution functions (3) and, somewhat naively, assuming that the bulk of the data comes from the region $\langle x_{BJ}\rangle \sim 0.2$, we obtain

$$\frac{(\mu^-\mu^-;\ \nu N)}{(\mu^-\mu^+;\ \nu N)} \sim 2\alpha . \qquad (10)$$

Just to get an order of magnitude estimate we can take the ratio on the left-hand side as $\sim 8:61 \sim 13\ \%$, hence $\alpha \sim 7\ \% \sim 0.1$.

If this model has something to do with reality, the branching ratio of charmed meson decays to μ^+ anything has to be rather large.

Using Eqs. (8) and the distribution functions (3) one easily obtains

$$\frac{(\mu^+\mu^-;\ \nu N)}{(\text{all};\ \nu N)} \sim (0.10-0.15)\,\gamma \qquad \text{for } 0.1<x<0.2 .$$

The experimental data [1, 2] indicate the value 1—2 %, which leads to $\gamma \sim 0.1$.

This is a bit higher than the estimate $\gamma \sim 4\ \%$ of Gaillard et al. [11] but the more recent arguments [12] seem to prefer even higher values of γ.

III. PREDICTIONS OF THE MODEL

The model leads to a few rather definite qualitative predictions:

i) production of trimuon events. The observation of $\mu^-\mu^-$ and $\mu^+\mu^+$ events can be interpreted within the present model only as a possibility of picking up charmed quarks or antiquarks by the outgoing parton. Table 1 shows that also charmed quarks can appear as a result of the primary νN or $\bar{\nu} N$ interaction. If they pick up an additional charmed antiquark they form charmonium particles with the $\mu^+\mu^-$ decay mode $\sim 7\ \%$.

A quantitative estimate based on Eqs. (8) gives at $x \sim 0.2$

$$\frac{(\mu^-\mu^+\mu^-;\ \nu N)}{(\mu^-\mu^+;\ \nu N)} \sim \frac{1}{4}\,\alpha\,\frac{\gamma_c}{\gamma} \sim \frac{1}{4}\,\alpha \sim \frac{1}{8}\frac{(\mu^-\mu^-;\ \nu N)}{(\mu^-\mu^+;\ \nu N)}, \qquad (11)$$

where the last estimate is based on Eq. (10). With the present statistics [1] one thus expects about one trimuon event. For antineutrino interactions the trimuon production should be even higher. Using Eqs. (9) one finds

$$\frac{(\mu^+\mu^-\mu^+;\ \bar{\nu} N)}{(\mu^+\mu^+;\ \bar{\nu} N)} \sim 1, \qquad \text{independent od } x.$$

With the present observation of two $\mu^+\mu^+$ events [1] we should soon see a trimuon.

ii) Relationship between trimuon production in νN and $\bar{\nu} N$ interactions. If the parameters α and γ are once inferred from νN interactions, the model gives a unique prediction for the dimuon production in $\bar{\nu} N$ collisions. Using again distribution functions in Eq. (3) we obtain at $x_{BJ} \sim 0.2$

$$\frac{(\mu^+\mu^+;\ \bar{\nu} N)}{(\mu^+\mu^-;\ \bar{\nu} N)} \sim 0.3\alpha ,$$

which is to be compared with the estimate in Eq. (10) for the νN case. For the beam which consists of equal amounts of ν and $\bar{\nu}$ the $\mu^-\mu^-$ pairs should be about 6 times more frequent than the $\mu^+\mu^+$ pairs. Note that in the HPWF experiment [1] there were $8\mu^-\mu^-$ and $2\mu^+\mu^+$ pairs detected so far.

iii) The dependence of dimuon over single muon production on x_{BJ}.

The $\mu^-\mu^+$ production in both Eqs. (8) and (9) is given by expressions, where distribution functions of valence quarks are multiplied by small numbers ($\sin^2\vartheta_c$ or α). Because of that the ratio of $(\mu^-\mu^+)$/(single muon) will decrease with increasing x_{BJ}.

iv) The energy dependence of dimuon production in $\bar{\nu} N$ interactions. One might well expect that the parameter which determines the picking up of charmed partons is connected with some threshold effect and consequently depends on the energy of the incident neutrino (for instance, due to the high mass of charmed partons, the appearance of the charmed part of the sea may start being significant only at relatively high energies).

In the $\mu^+\mu^-$ production in an νN interaction α multiplies $G_{\bar{p}}$ (see Eq. (8)), while in $\bar{\nu} N$ interactions α multiplies G_p. Since G_p is much higher at larger values of x than $G_{\bar{p}}$, one can expect an increase of the dimuon production with an increasing energy in $\bar{\nu} N$ interactions with $x \geqslant 0.3$.

IV. COMMENTS AND CONCLUSIONS

The dimuon production in νN and $\bar{\nu} N$ interactions is probably one of the most interesting recent experimental results. It is also very attractive from the theoretical point of view, since at least within the simple-minded parton model the elementary interaction of the incident neutrino with a parton is probably rather clear and relatively simple. If this is the case, then the dimuon production may be an extremely useful situation for testing both the simple parton model and at the same time the present ideas about the charmed particles.

In the naive parton model presented above we have assumed that dimuons appear as a result of charmed particle decays in νN and $\bar{\nu} N$ interactions mediated by the charged weak current.

The essential ingredient of our model is the SU (3) symmetry for the fragmentation of partons into ordinary hadrons and a specific form for a large SU (4) symmetry breaking in the parton fragmentation into charmed particles.

The basic idea of this model will be tested by the data on resonance production in eN and hadron-hadron interactions.

The model leads to a couple of testable predictions in νN and $\bar{\nu} N$ collisions.

The qualitative features of these predictions are

— production of trimuon with the rate of about one order of magnitude smaller than the production of $\mu^-\mu^-$ and $\mu^+\mu^+$ pairs

— decrease of the $\mu^-\mu^+$ production with increasing x_{BJ}.

— the $\mu^-\mu^-$ production at $x_{BJ} \sim 0.2$ for νN interactions should be about 6 times larger than the corresponding production of the $\mu^+\mu^+$ production in $\bar{\nu} N$.

These predictions are only very weakly dependent on the assumed distribution functions of partons in a hadron.

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