NEW FLAVORS FROM NEUTRINOS

Douglas R.O. Morrison
CERN, Geneva, Switzerland

ABSTRACT

A review is made of recent results of studying new flavors using neutrino beams and also of hopes for future experiments. Results are given on charm by direct observation and from measurements of strange particles where in νp interactions it is found that $(10 \pm 2)\%$ of CC events contain charm. In neutral current reactions J/ψ production has been observed with a cross section inconsistent with Vector Dominance but consistent with a Gluon-fusion model. Like-sign dileptons are observed more frequently than predicted by first order QCD gluon bremsstrahlung. Determinations of the distributions of strange and charmed quarks and of gluons in the nucleon are given.

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1. INTRODUCTION

Neutrino beams are particularly important in the production of new flavors for two main reasons.

(a) The rate of production is high, e.g. for charm

Neutrinos-charm production in 10^{-1} of interactions
Photons-charm production in 10^{-2} of interactions
Hadrons-charm production in 10^{-3} of interactions.

(b) Apart from the interest in the new flavors themselves, the object of the study is to test theories and to understand the structure of the nucleon. Neutrino interactions only involve the weak force and therefore are cleaner for testing theories as no electromagnetic or strong force are involved. Also, neutrino interactions are point-like and hence are good for probing the structure of the proton - as Feynman said if you wish to study the working of a watch you do not bang two watches together.

Let us recall, in fig. 1, a simple model of the proton where there are three valence quarks, u_V, u_V and d_V and many quark-antiquark pairs in

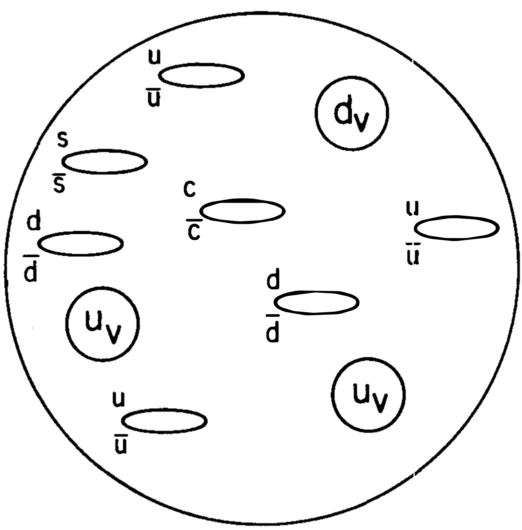


Fig. 1

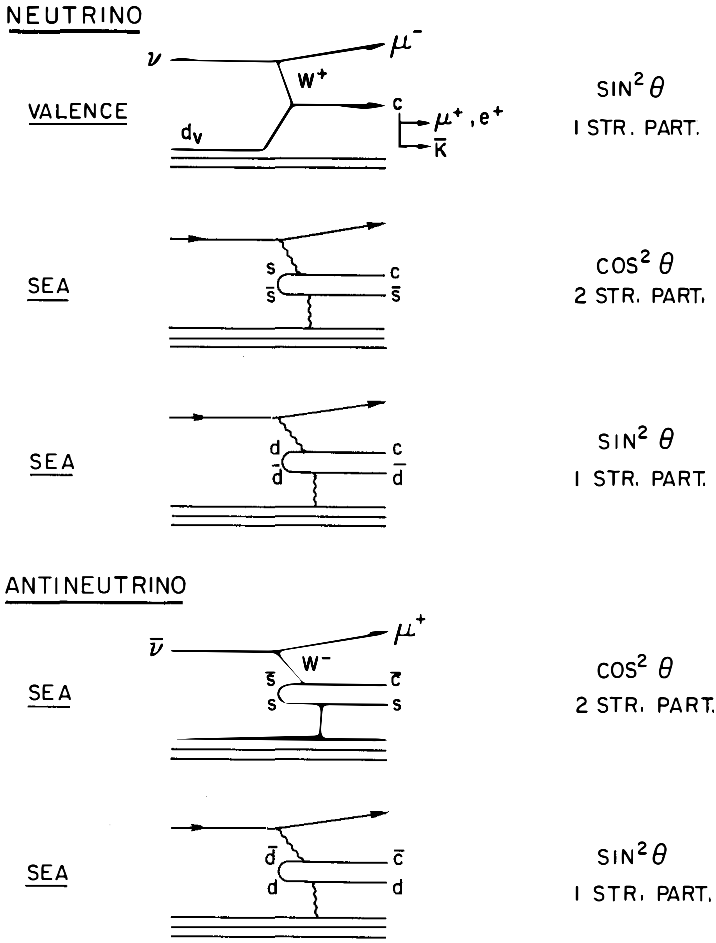

NEUTRINO
VALENCE
ν
μ⁻
W⁺
c
μ⁺, e⁺
K̄
d_V
SIN²θ
1 STR. PART.
SEA
s
s̄
c
s̄
COS²θ
2 STR. PART.
SEA
d
d̄
c
d̄
SIN²θ
1 STR. PART.
ANTINEUTRINO
SEA
ν̄
μ⁺
W⁻
s̄
s
c̄
s
COS²θ
2 STR. PART.
SEA
d̄
d
c̄
d
SIN²θ
1 STR. PART.

Fig. 2

the sea which could be $u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, etc. Also there are many gluons which carry $\sim$ 55% of the momentum of all the particles (partons) inside the proton (this at moderate values of $q^2 \sim 10$ GeV^2).

There exist interesting theories of weak interactions so that detailed calculations can be done, but the theories are not (yet) complete. In this paper are presented the latest results on the production of new flavors and the information deduced on the structure of the nucleon.

2. CHARM AND STRANGE PARTICLE PRODUCTION

When charm particles decay, they either do so semi-leptonically when a μ or e are emitted or hadronically. In both cases strange particle emission is strongly favoured. Thus charm production can be studied either by dilepton events (in charged current reactions) or by strange particles.

The Aachen-Bonn-CERN-Munich-Oxford Collaboration, WA21[1], have studied charm and strange particle production in hydrogen by neutrinos and antineutrinos. The basic Feynman graphs for charm production are shown in fig. 2 together with the number of strange particles and the Cabibbo suppression factor, where θ is the Cabibbo angle (assuming SU(3) invariance). While it is well known that valence quarks contribute only in neutrino interactions, the sea quarks are also important and give appreciable charm production also in antineutrino interactions.

The reactions that give strange particles in charged current νp reactions are listed in table 1 together with their percentage contribution. It may be noted that 34.4% of the strange particles come from charm-producing reactions. Experimentally the ABCMO Collaboration found for CC interactions

$$\frac{\sigma(\text{strange particles})}{\sigma(\text{all CC events})} = (30 \pm 5)\% \quad \text{for } W > 3 \text{ GeV.}$$

This then determines that (10 ± 2)% of all CC events give charm production. It has also been shown by the ABCMO Collaboration that

$$\alpha(D^*) \gtrsim \sigma(K^*)$$

– at first sight a surprising result in view of the much greater mass of the D^*.

A similar analysis has been made recently by the Aachen-Bonn-CERN-Democritos-London-Oxford-Saclay Collaboration WA47[2], in νN and $\bar{\nu}N$ CC interactions in a Neon-Hydrogen mix (an iso-scalar target). They find that the contribution of charm to strange particle production is 23.3% and that 8 ± 2% of all CC events give charm production. For antineutrinos on an isoscalar target, charm is calculated to be 27.9% of strange particle production and from the measurements of observed strange particles deduce that 6 ± 3% of all CC events produced charm.

When dileptons (μe and $\mu\mu$) are observed in bubble chambers, the strange particle production rate is relatively high. Thus in antineutrino interactions in a neon-hydrogen mix, the BNL-Columbia Collaboration[3] found 1.2 strange particles per μ^+e^- event instead of the normal 0.3 for CC events.

A point of importance that will re-occur later, is the lab. momentum spectrum of the lepton from the charm decay e.g. the e^- in $\bar{\nu}N$ CC events which is sketched in fig. 3. In heavy liquid bubble chambers the

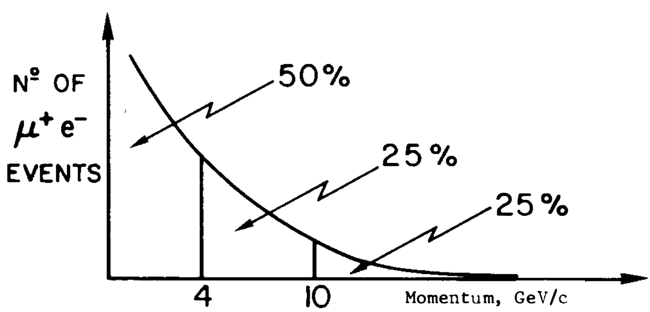


Fig. 3

electron can be identified with little background down to 0.3 GeV/c but with counter techniques the background is so severe that the muon from charm decay can only be measured above some high value of 4 to 10 GeV/c depending on the experiment. Thus in comparing dilepton rates attention must be paid to the lower limit of lepton detection.

3. EXCLUSIVE CHANNELS-VISUAL OBSERVATION

In bubble chambers filled with hydrogen, three-constraint fits can be obtained corresponding to exclusive channels in νp interactions. The most frequent 3C fit reaction is $\nu p \to \mu^- \Delta^{++}$ where a valence d-quark is converted into a u-quark. Recently the ABCMO Collaboration[4] have found an example of the reaction $\nu p \to \mu^- \Sigma_c^{++}$ where a valence d-quark is converted into a charm quark as illustrated in fig. 4, giving the doubly charged charmed baryon Σ_c^{++}.

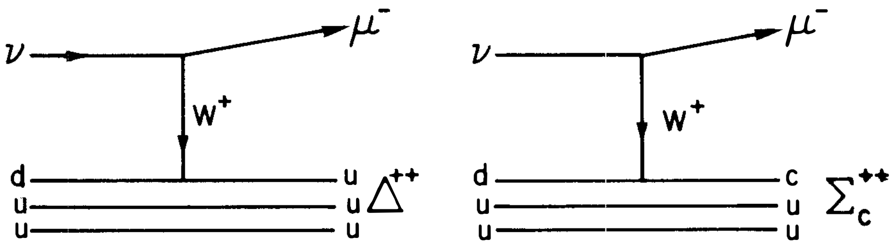


Fig. 4

This 3C fit gives precise determination of the masses of Λ_c^+ and Σ_c^{++} and of their difference. Examples of Λ_c^+, Σ_c^+, $(D^* \to D)$ production have been observed as 3C fits and have also given accurate mass determinations e.g. 3 events give a Λ_c^+ mass determination of 2283 ± 3 MeV which is the most accurate value so far.

However, statistics of 3C events are low compared with the ∿ 10% of events with charm production. To obtain good statistics visual observation of the decay is needed. However, this is technically difficult as with neutrino beams large target volumes are necessary and this is generally incompatible with the high optical resolution needed to observe the decay of the short-lived charm particles.

With Emulsion targets, excellent resolution, ∿ 1 μm can be obtained but the target mass tends to be small e.g. WA17 and E531.

With bubble chambers, extensive tests of Holography are being made and it is hoped to have 30 to 50 μm resolution over a volume of 1 to 4 m^3 in BEBC.

4. ψ-PRODUCTION BY NEUTRINOS IN NEUTRAL CURRENT REACTIONS

The CERN-Dortmund-Heidelberg-Saclay Collaboration, WA1[5] have obtained interesting new results on J/ψ production in studying wideband neutrino interactions produced by 5.2×10^{18} protons of 350 and 400 GeV. They obtained $\sim 10^7$ events with at least one muon of which $\sim$ 16 000 were $\mu^+\mu^-$ events. With the requirement that the muon momenta $P_\mu > 5$ GeV/c and fiducial volume cuts, finally 10 177 events were used with an average visible energy, $\langle E_{vis} \rangle = 90$ GeV.

The $(\mu^+\mu^-)$ mass spectrum is shown in fig. 5(a) and no peak at 3.1 GeV can be seen. The CDHS Collaboration expect the process to be "diffractive", (quoting Gaillard et al., Kuhn and Rückl, and Rückl[6]) and hence have tried the selection $E_{Hadron} < 10$ GeV giving fig. 5(b) where a peak is visible at 3.16 ± 0.05 GeV of 45 ± 13 events. The reaction is assumed to correspond to the neutral current reaction shown in fig. 6.

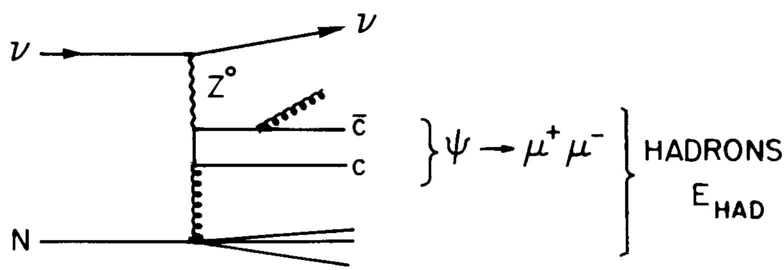


Fig. 6

The emission of at least one gluon from the $c\bar{c}$ pair is necessary for color conservation.

The requirement that E_{Hadron} be less than 10 GeV is a surprisingly high value for a "diffractive" process. This may indicate that high masses are produced in diffractive processes or may indicate some problem in statistics or interpretation. Further data on this would be of interest.

Since the peak of 45 events comes from an initial selection of 10^7 events, the problem of background is important. The main background reaction is the CC one

$$\nu + Fe \rightarrow \mu^- + (\psi \rightarrow \mu^+\mu^-) + X. \qquad (1)$$

For 1/2.8 of the total flux,an upper limit of 3.5 trimuon events was obtained which would then correspond to a total NC background on u or d quarks of < 3 events.

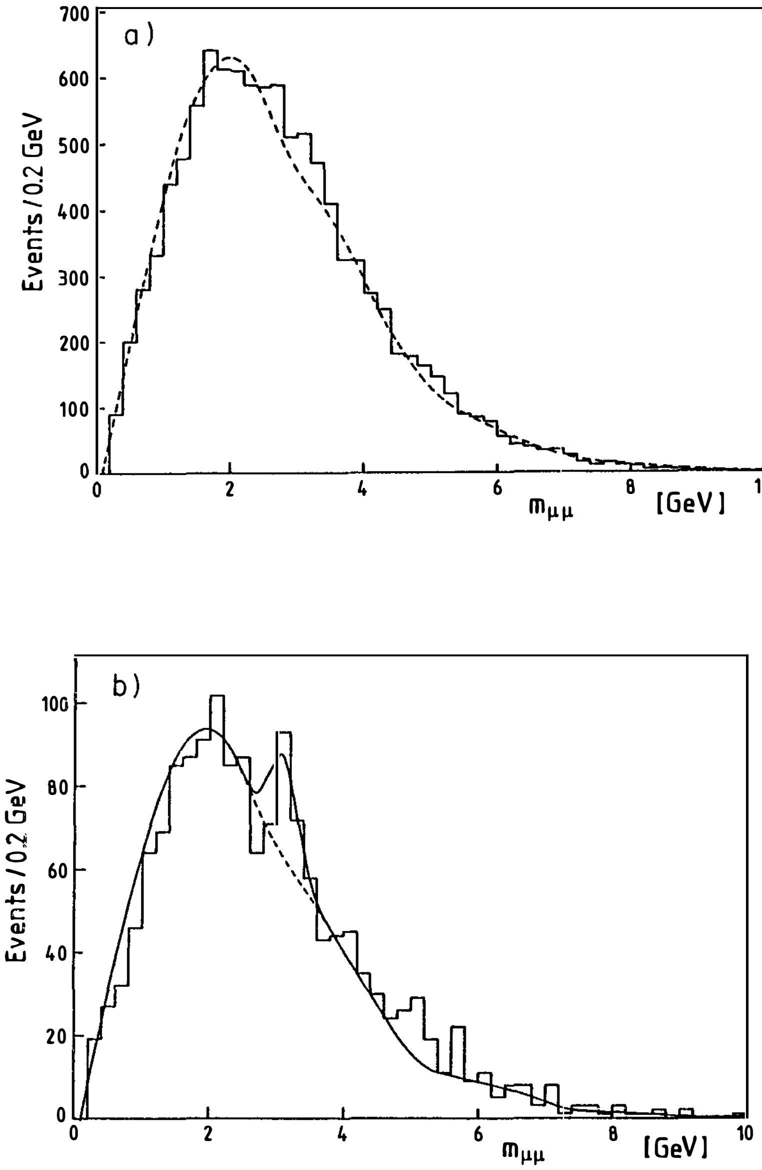

a)
Events / 0.2 GeV
700
600
500
400
300
200
100
0
0
2
4
6
8
10
$m_{\mu\mu}$
[GeV]
b)
Events / 0.2 GeV
100
80
60
40
20
0
0
2
4
6
8
10
$m_{\mu\mu}$
[GeV]

Fig. 5

The cross section for the reaction is then

$$\sigma_{DIFF}(\nu N \to \nu\psi X) = (4.2 \pm 1.5).10^{-41}\,\mathrm{cm}^2/\mathrm{nucleon}. \tag{2}$$

There is the question as to whether the Gluo-Fusion or the Vector Dominance Model, VDM applies. With the former both vector C_V and axial C_A coupling are involved while with VDM there is only vector coupling

$$C_V = \frac{1}{2} - 4/3\ \mathrm{Sin}^2\theta_w = 0.19 \pm 0.02$$

$$C_A = 1/2.$$

The ratio of the weak to the electromagnetic ψ production cross sections is

$$R = \frac{\sigma(\nu N \to \nu\psi X)}{\sigma(\mu N \to \mu\psi X)} = \frac{(G^2 ME_\nu/\pi).f_2^\nu}{Q^{-4}(2ME_\mu 4\pi\alpha^2)f_2^\mu}. \tag{3}$$

Using muoproduction results of the Berkeley-Fermilab-Princeton[7] and EMC Collaborations[8], the gluon fusion model gives $\sigma(\nu N \to \nu\psi X) = 2.10^{-41}\mathrm{cm}^2$ in agreement with the data while the VDM is in disagreement as is shown in fig. 7, where it may also be seen that experiments with muon beams cannot easily distinguish between the processes.

In conclusion neutral currents couple to charmed quarks with the strength expected in the standard model.

5. LIKE-SIGN DILEPTONS

The great problem for like-sign dimuons is background from CC events where a same sign muon comes from a π or K decay, e.g.

$$\nu N \to \mu^- + \underset{\hookrightarrow \mu^-}{\pi^-} + X.$$

However, several counter groups report a significant signal above background and some bubble groups report a few events

FIIM Collaboration[9] $\bar{\nu} \to$ 4 events of μ^+e^+, background 1.1 ev.

BFHSW Collaboration[10] $\begin{cases} \bar{\nu} \to \text{1 events of } \mu^+e^+\text{, background 3.6 ev.} \\ \nu \to \text{3 events of } \mu^-e^-\text{, background 0.3 ev.} \end{cases}$

BNL Columbia[3] $\nu \to$ 20 events of μ^-e^-, background 9 ev.

The CHARM Collaboration report[11] that from 271 000 CC neutrino events, 74 ± 17 $\mu^-\mu^-$ events were obtained and from 215 000 CC antineutrino events, 52 ± 13 $\mu^+\mu^+$ events were deduced. The kinematics of the events suggest a hadronic origin. The cross section ratio was $\sigma(\mu^+\mu^+)/\sigma(\mu^-\mu^-) = 0.50 \pm 0.20$ which is close to the ratio obtained for CC events,

$$\sigma(\nu N \to \mu^+ X)/\sigma(\nu N \to \mu^- X) = 0.489 \pm 0.019.$$

It is interesting to study the results for $\mu^-\mu^-$ as a function of time. Fig. 8 gives first results[12] from several collaborations - it can be seen that they agree but the cross section ratios are much higher than predicted by a first order QCD calculation[13]. In a later publication[11] containing the latest CHARM results, fig. 9, the experimental points agree surprisingly well despite the different cut-off values of the muon momentum, p_μ - see fig. 3. The QCD curve has been recalculated and is now an order of magnitude higher than in fig. 8. Very recently the CDHS results[14] have been added to fig. 9 giving fig. 10 where it can be seen that the new CDHS results are in disagreement with previous results (including their own), but are still somewhat higher than the latest QCD prediction.

In conclusion it is clear that the situation is unclear. Further work, both experimental and theoretical is required. A possible new handle to the subject might be to study strange particle production (coming partly from charm decay) in high energy bubble chamber experiments at the Tevatron.

6. TRILEPTONS

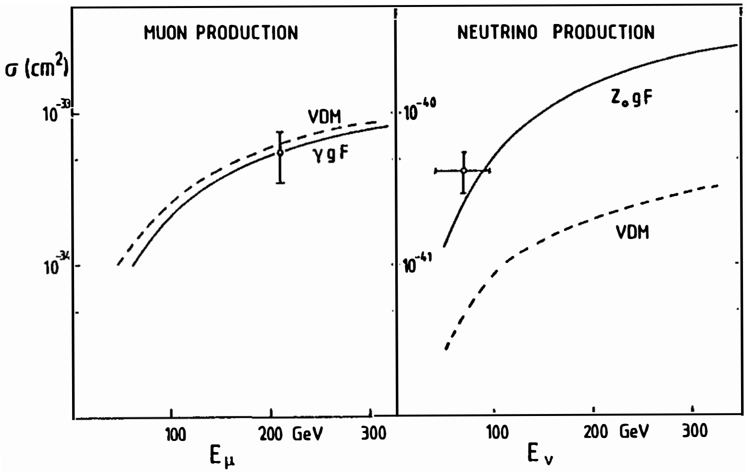
For trileptons there is no new data yet and the results published are consistent with conventional sources which are given by the CDHS Collaboration[15] as:

E-M muon pair production in CC reactions, ∿ 25% of trileptons
Hadronic muon pair production in CC reactions ∿ 75% of trileptons.

The ratio of trilepton to CC production found are

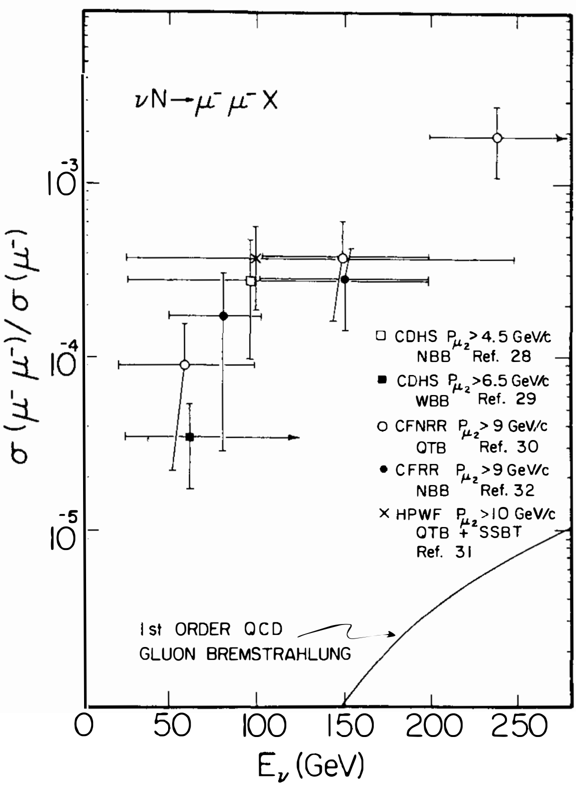
$$\frac{\sigma(\nu N \to \mu^-\mu^+\mu^- + X)}{\sigma(\nu N \to \mu^- X)} = (3.0 \pm 0.4).10^{-5}$$ CDHS[15], 76 events, $E_\nu > 30$ GeV

$$= (1.1 \pm 0.5).10^{-4}$$ HPWFOR[16], 39 events, $E_\nu > 100$ GeV .



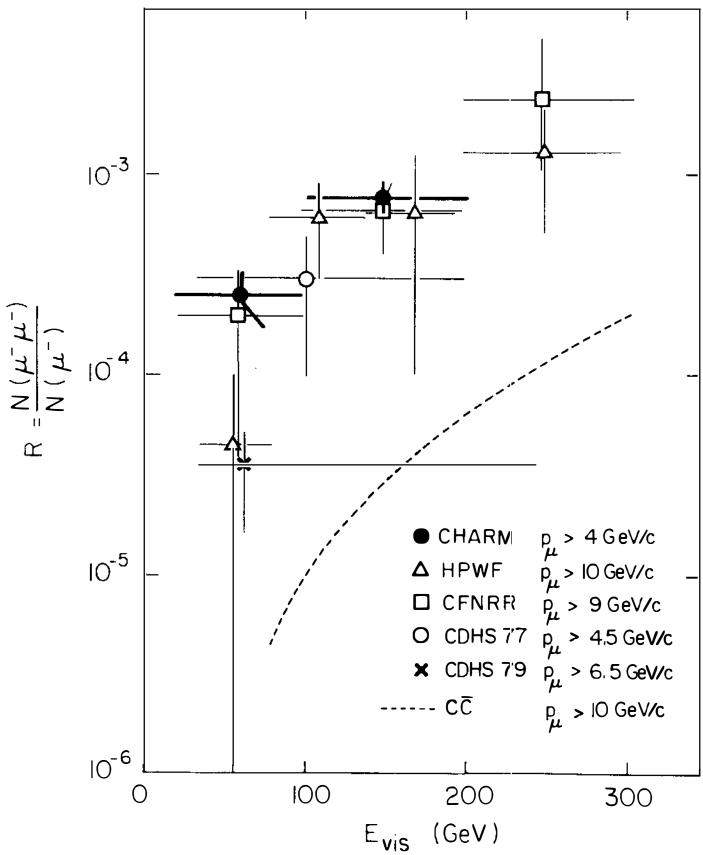
MUON PRODUCTION
NEUTRINO PRODUCTION
σ (cm²)
10⁻³³
10⁻³⁴
VDM
γgF
10⁻⁴⁰
10⁻⁴¹
Z₀gF
VDM
100
200 GeV
300
Eμ
100
200 GeV
300
Eν

Fig. 7



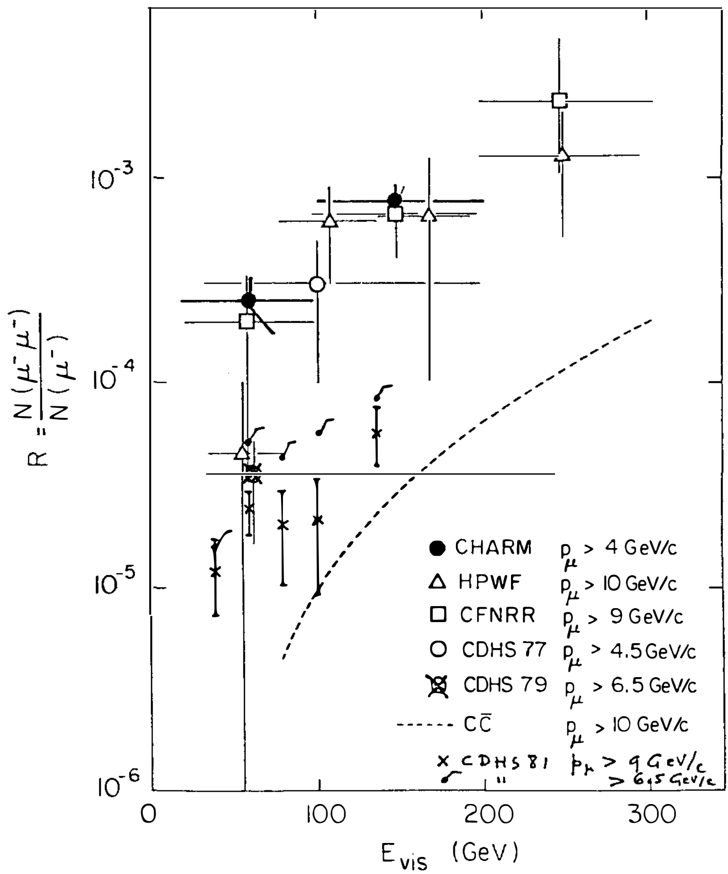
νN→μ⁻μ⁻X
σ(μ⁻μ⁻)/σ(μ⁻)
10⁻³
10⁻⁴
10⁻⁵
□ CDHS Pμ₂>4.5 GeV/c NBB Ref. 28
■ CDHS Pμ₂>6.5 GeV/c WBB Ref. 29
○ CFNRR Pμ₂>9 GeV/c QTB Ref. 30
● CFRR Pμ₂>9 GeV/c NBB Ref. 32
× HPWF Pμ₂>10 GeV/c QTB + SSBT Ref. 31
1st ORDER QCD
GLUON BREMSTRAHLUNG
0
50
100
150
200
250
Eν (GeV)

Fig. 8



10^{-3}
10^{-4}
10^{-5}
10^{-6}
$R = \frac{N(\mu^-\mu^-)}{N(\mu^-)}$
0
100
200
300
E_{vis} (GeV)
CHARM p_μ > 4 GeV/c
HPWF p_μ > 10 GeV/c
CFNRR p_μ > 9 GeV/c
CDHS 77 p_μ > 4.5 GeV/c
CDHS 79 p_μ > 6.5 GeV/c
$C\bar{C}$ p_μ > 10 GeV/c

Fig. 9



$R = \frac{N(\mu^-\mu^-)}{N(\mu^-)}$
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
100
200
300
E_{vis} (GeV)
CHARM p_μ > 4 GeV/c
HPWF p_μ > 10 GeV/c
CFNRR p_μ > 9 GeV/c
CDHS 77 p_μ > 4.5 GeV/c
CDHS 79 p_μ > 6.5 GeV/c
$C\bar{C}$ p_μ > 10 GeV/c
CDHS 81 p_μ > 9 GeV/c
" > 6.5 GeV/c

Fig. 10

While the data are "consistent with" conventional sources, the limits that can be put on "unconventional" sources such as heavy leptons or heavy quarks, are not very restrictive yet.

For antineutrinos, CDHS[17)] find

$$\frac{\sigma(\bar{\nu}N \to \mu^+\mu^+\mu^- + X)}{\sigma(\bar{\nu}N \to \mu^+X)} = (1.8 \pm 0.6) \times 10^{-5}, \quad 8 \text{ events}, E_\nu > 30 \text{ GeV}.$$

More data are awaited from the CDHS Collaboration.

7. TETRALEPTONS

There are still ∿ 3 events from three groups; more data is needed.

8. OPPOSITE SIGN DILEPTONS

Dileptons of opposite sign are important to measure (a) to learn about charm and (b) to determine the strange sea content of the nucleon. On the surface, such determinations seem reasonable, but in fact there are many technical problems and assumptions involved - these are clearly described by Edwards and Gottschalk in ref. 18. There are two new papers on opposite sign dileptons from the CHARM and the CDHS Collaborations.

8.1 CHARM Collaboration

The CHARM Collaboration[11)] have a low density target and can then select "prompt" muons from the distribution of the distance between the muons at the vertex. The event sample obtained is

495 ± 32 events of $\nu N \to \mu^-\mu^+X$

285 ± 29 events of $\bar{\nu}N \to \mu^+\mu^-X$.

One major problem is the background coming from decays of pions and kaons in flight. The other major problem is to correct for the effects of the charm threshold. Here this is done by using the "slow rescaling" variable x',

$$x' = x + \frac{m_c^2}{s.y} \tag{4}$$

(the so-called "fast rescaling" neglects the fact that there are many charm thresholds and neglects phase space effects and is better avoided). Here m_c is the mass assumed for the charm quark.

The results are shown in figs 11 and 12. The ratio $\sigma(\mu^+\mu^-)/\sigma(CC)$ rises with energy to $\sim 4 \times 10^{-3}$ for both neutrino and antineutrinos. The y-distributions, after corrections, agree with theory. The contribution of the strange quarks to the sea is estimated to be 0.050 ± 0.015.

8.2 CDHS Collaboration

The CDHS Collaboration[19] have relatively high statistics, 10110 events of $\nu N \to \mu^-\mu^+X$ and 2003 events of $\bar{\nu}N \to \mu^+\mu^-X$ with $p_\mu > 5$ GeV/c but lose some of this advantage by not being able to separate "prompt" muons. They make extensive use of a Monte-Carlo program which makes a number of assumptions (a) flat y-dependence, (b) sea quarks have $(1-x)^7$ distribution, (c) valence quarks have $\sqrt{x}(1-x)^{3.5}$ distribution, (d) the relative s to d contribution is derived from the dimuon data and therefore depends on the mass m_c, assumed for the charm quark, (e) only D mesons produced (i.e. no charmed baryons), (f) the ratios of decays of D mesons are taken from the DELCO experiment, i.e. $K/K^*/\pi = 0.56/0.37/0.06$.

Results are obtained for the "effective" charm fragmentation function defined as

$$z = \frac{p(\mu^+)}{p(\mu^+) + E(\text{shower})}$$

and this is shown in fig. 13. Care must be taken in using this z distribution as it is called "effective" as there is no correction for unseen neutrals, but it clearly shows that charm quarks are produced at unusually high z values. The only other results on this subject were obtained by the Canada-Japan-USA emulsion collaboration[20], who give distributions in Q^2, x_F and z_F for D, Λ_c and F charmed particles as shown in fig. 14 where it may be seen that D mesons are produced dominantly forwards together with a few of the charmed baryons.

The CDHS collaboration find, as shown in figs 15 and 16 that the ratio R, of dimuons to charged current cross section rises to a value of 7×10^{-3} above 100 GeV for both ν and $\bar{\nu}$. This is almost twice the value found by the CHARM collaboration, but the explanation is probably that CDHS accept more low momentum muons, as explained with fig. 3.

The amount of <u>strange sea in the nucleon</u>, η_s where

$$\eta_s = \frac{2\int x.s(x).dx}{\int x[u(x) + d(y)]dx} \tag{6}$$

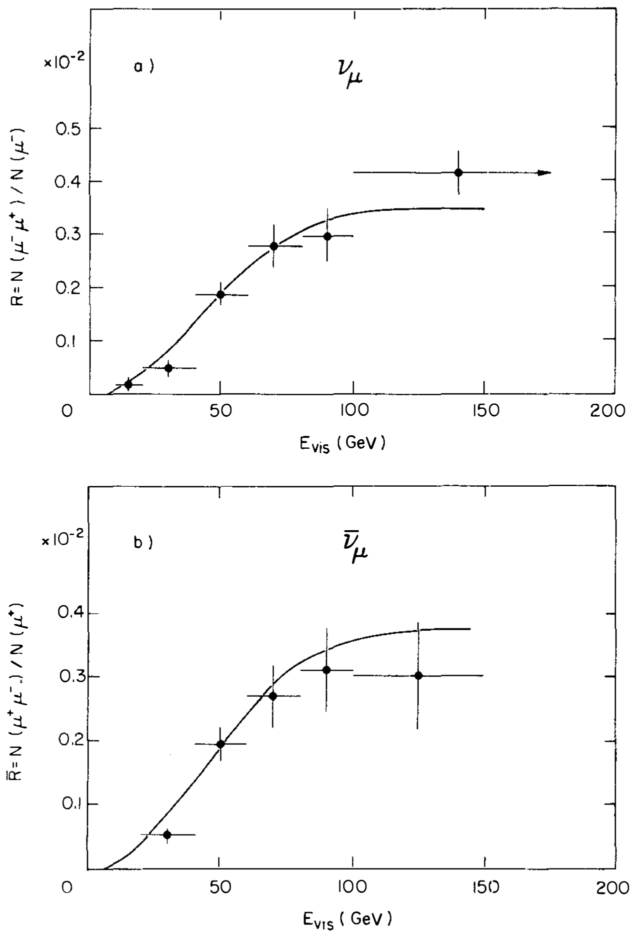

a)
ν_μ
$\times 10^{-2}$
0.5
0.4
0.3
0.2
0.1
0
50
100
150
200
$R = N(\mu^-\mu^+)/N(\mu^-)$
E_{vis} (GeV)
b)
$\bar{\nu}_\mu$
$\times 10^{-2}$
0.4
0.3
0.2
0.1
0
50
100
150
200
$\bar{R} = N(\mu^+\mu^-)/N(\mu^+)$
E_{vis} (GeV)

Fig. 11

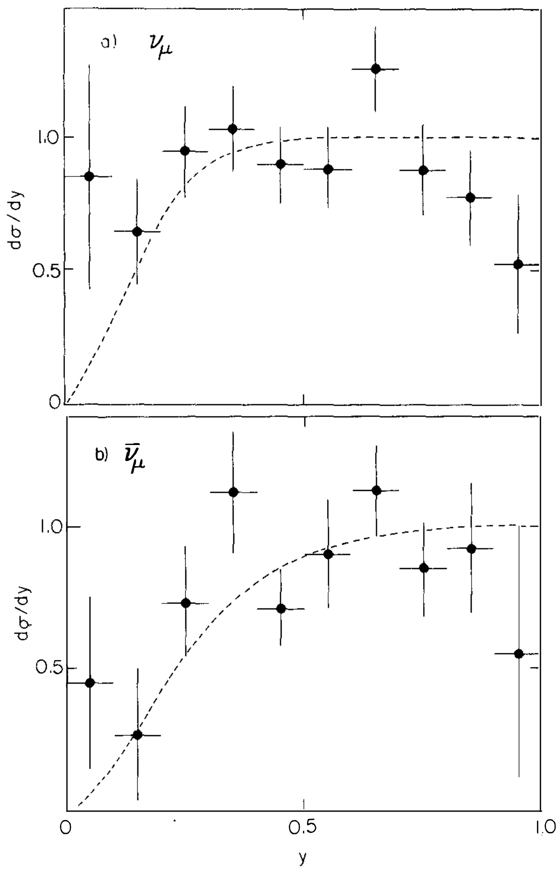
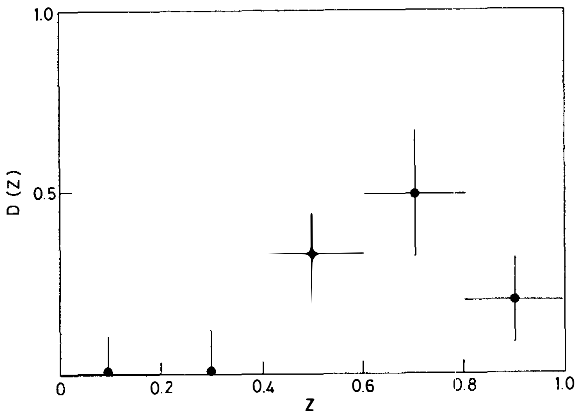


Fig. 12


1.0
0.5
D (Z)
0
0.2
0.4
0.6
0.8
1.0
Z

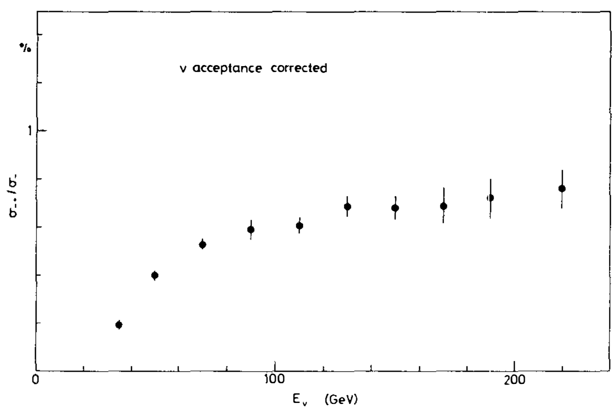

%
ν acceptance corrected
1
0
100
200
E_ν (GeV)

Fig. 13

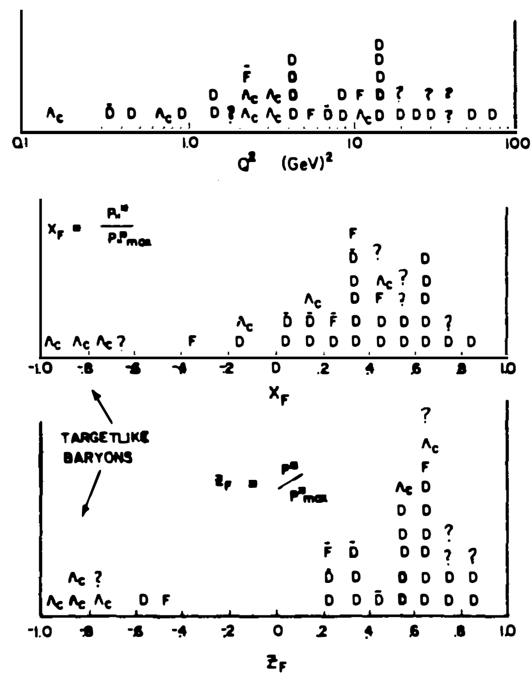
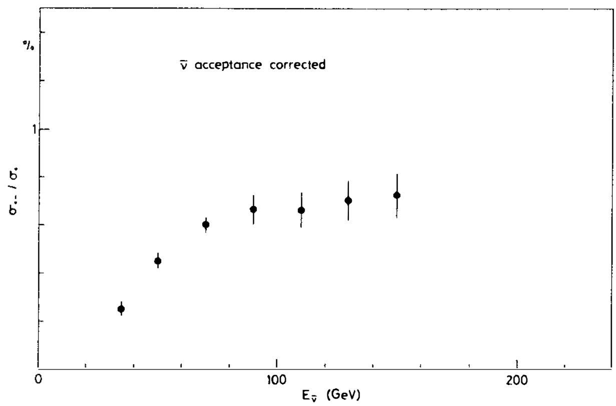
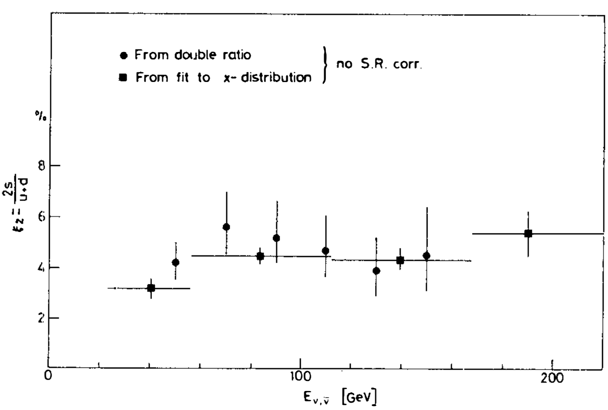

Q^2 (GeV)^2
0.1
1.0
10
100
X_F = P_L* / P_L*max
X_F
TARGETLIKE BARYONS
Z_F = P^B / P^B_max
Z_F

Fig. 14



%
$\bar{\nu}$ acceptance corrected
1
σ_{+-}/σ_{+}
0
100
200
$E_{\bar{\nu}}$ (GeV)

Fig. 15



● From double ratio
■ From fit to x- distribution
no S.R. corr.
%
8
6
4
2
$\xi_z = \frac{2s}{u+d}$
0
100
200
$E_{\nu,\bar{\nu}}$ [GeV]

Fig. 16

Two methods have been used:

(a) From x distributions where $s(x)$ is obtained from results from opposite sign dimuons in antineutrinos (not from neutrinos as valence quarks contribute as well as sea quarks - see table 1).

(b) By a double ratio method where $R_2 = R(\bar{\nu})/R(\nu)$ for opposite sign dileptons. Then

$$\eta_s = \tan^2\theta_c \frac{R_1 R_2 - \eta_1}{1 - R_1 R_2} \qquad (7)$$

where $\tan^2\theta_c = 0.057$, $R_1 = \sigma(\bar{\nu})/\sigma(\nu) = 0.48$ and $\eta_1 = (\bar{u} + \bar{d})/(u + d) = 0.12$.

This gives $\eta_s \sim 0.05$ and is constant above 70 GeV. Caution must be used as if m_c is taken as 1.5 GeV instead of 1.8 GeV, then slow rescaling effects doubles the value of η_s.

9. DISTRIBUTION OF GLUONS IN THE NUCLEON

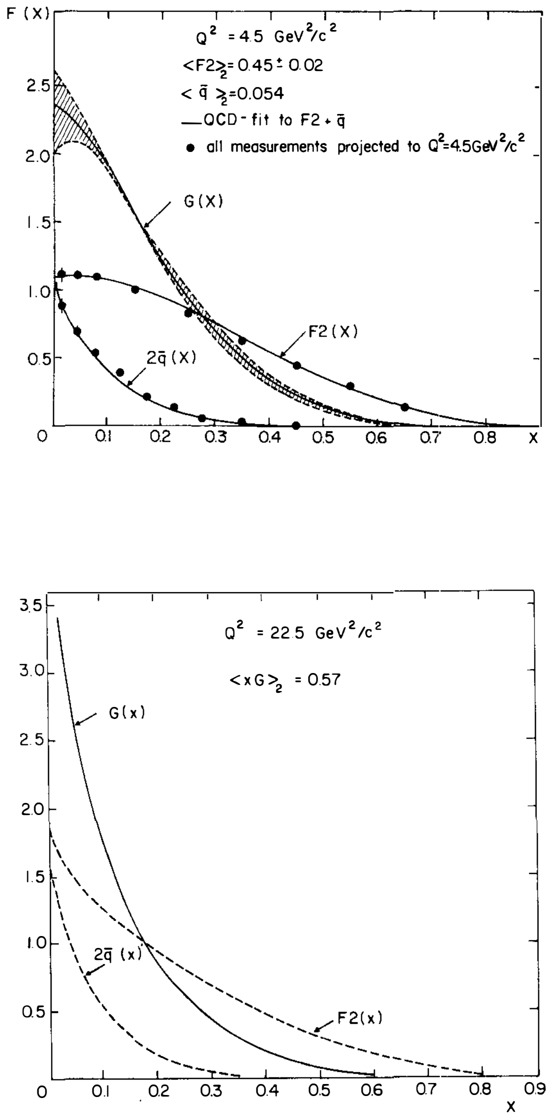
Since gluons carry about half the momentum in a nucleon, it is important to learn about gluon distributions. Although with BEBC a rough estimate has been made[21)], the first high quality estimate of gluon distributions has been made by the CDHSB collaboration[22)] (where B stands for Beijing).

The production of charm is a major problem in the analysis as one first needs to know the strange quark content of the sea. The analysis uses $F_2(x, Q^2)$ and $\bar{q}^{\bar{\nu}}(x, Q^2) = x(\bar{u} + \bar{d} + 2s)$. The data used comes from:

Narrowband beam, 94 000 ν and 25 000 $\bar{\nu}$ events
Wideband beam, 35 000 ν and 155 000 $\bar{\nu}$ events.

Three different sets of structure functions have been used with varied assumptions about the strange and charmed sea.

Fit 1 assumed the strange sea and $x(\bar{u} + \bar{d})$ have the same x distributions but xS is suppressed by a factor $2(S-1)/(\bar{u} + \bar{d}) = 0.4$, i.e. there is no correction for charmed thresholds and the charmed sea contributions (i.e. $c\bar{c}$) is assumed to be negligible. Here xS is defined as $xS(x, Q^2)$ = strange quark structure function in the nucleon as seen by the weak charged current (the difference of $S(x)$ from $s(x)$ is that $S(x)$ takes into account threshold behaviour).



F (X)
Q^2 = 4.5 GeV^2/c^2
$<F2>_2$ = 0.45 ± 0.02
$<\bar{q}>_2$ = 0.054
—QCD-fit to F2 + $\bar{q}$
● all measurements projected to Q^2=4.5GeV^2/c^2
G(X)
F2(X)
$2\bar{q}$(X)
X
Q^2 = 22.5 GeV^2/c^2
$<xG>_2$ = 0.57
G(x)
$2\bar{q}$ (x)
F2(x)
x

Fig. 17

The following results are obtained assuming there are 4 flavors and all are taken to contribute in the sea, then for a standard Q_0^2 value of 5 GeV^2, Λ_{LO} = Λ (leading order) = 0.18 ± 0.02 GeV

$\langle F_2\rangle_2$	$= 0.45 \pm 0.02$	$\langle x\rangle_{F_2}$	$= 0.25 \pm 0.02$
$\langle\bar{q}\rangle_2$	$= 0.055 \pm 0.002$	$\langle x\rangle_{\bar{q}}$	$= 0.095 \pm 0.002$
$\langle G\rangle_2$	$= 1-\langle F_2\rangle_2 = 0.55 \pm 0.11$	$\langle x\rangle_{glue}$	$= 0.16 \pm 0.012$

That is, 55% of the nucleon momentum is carried by gluons and the average gluon momentum is less than that of valence quarks but more than that of sea quarks.

In Fit II and Fit III corrections were introduced using slow rescaling according to eq. (4) with m_c = 1.5 and 1.8 GeV respectively. The corresponding values of 2s/(u + d) were 0.5 and 1.0. Three quark flavors were taken and the charmed sea set to zero at Q_0^2 = 1 GeV and then increased according to the results obtained from Fit I. For data with x > 0.3 it was then found that:

Fit II $\quad \Lambda_{LO}$ = 0.20 ± 0.02 GeV
Fit III $\quad \Lambda_{LO}$ = 0.206 ± 0.02 GeV.

Thus the results do not vary greatly with the assumptions (except the amount of the strange sea).

The x distributions are illustrated in fig. 17 for two different values of the reference four-momentum transfer, Q_0^2. As explained by Kogut and Susskind[23] with higher Q_0^2, the effective wave length of the investigation is smaller and hence more low momentum partons can be seen. Thus more partons (quarks plus gluons) are obtained at low x for Q_0^2 = 22.5 GeV in fig. 17.

10. CONCLUSIONS

(1) In neutrino-proton reactions, by measuring strange particles it is found that (10 ± 2)% of all CC interactions give charm.

(2) From exclusive channels in νp and $\bar{\nu}p$ reactions, accurate masses of Σ_c^{++}, Σ_c^+, Λ_c and (D^*-D) have been obtained.

(3) High resolution visual detectors (emulsion, bubble chambers with classical or holographic optics) are used to study charm production and properties.

(4) J/ψ production has been observed "diffractively" in neutral current interactions and gives evidence against Vector Dominance and in favour of the standard Gluo-fusion model.

(5) Trileptons can be accounted for by "conventional" sources.

(6) Tetraleptons are very few - wait for more data.

(7) The existence of like-sign dileptons is confirmed while the experimental results are inconsistent, they disagree with first order QCD gluon bremsstrahlung - is theory wrong or results or both?

(8) Opposite sign dileptons give (a) an "effective" charm fragmentation function peaked at high z, (b) a flat y-distribution confirming V-A theory, (c) the amount of the strange sea is 0.05.

(9) The distribution in momentum of gluons in nucleons has been determined and it is found that 55% of the momentum is carried by gluons. Also $\Lambda_{LO} = 0.2 \pm 0.02$ GeV.

(10) Beauty production may be observed at the Tevatron but there is no evidence for it at present SPS or FNAL energies.

(10) The tau neutrino ν_τ is being searched for in a presently running beam dump experiment (with normal neutrino beams the background from charm decays is probably too high) but the energy may be too low to produce sufficient F-mesons in the dump which decay to ν_τ. However, ν_τ should be discovered at the Tevatron.

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TABLE 1

Neutrino reaction in hydrogen	% of strange particle production	
$\nu d_v \to \mu^- u + s\bar{s}$	47.1%	
$\nu d_s \to \mu^- u + s\bar{s}$	12.3%	
$\nu\bar{u} \to \mu^- \bar{d} + s\bar{s}$	4.2%	
$\nu\bar{u} \to \mu^- \bar{s}$	1.1%	
$\nu u\ (+\bar{s}) \to \mu^- u\ (+\bar{s})$	1.1%	
$\nu d_v \to \mu^- c$ $\quad\hookrightarrow s$	11.8%	
$\nu d_s \to \mu^- c$ $\quad\hookrightarrow s$	3.1%	34.4% from CHARM
$\nu s\ (+\bar{s}) \to \mu^- c\ (+\ \bar{s})$ $\quad\hookrightarrow s$	19.5%	