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SUMMARY OF THE SESSIONS ON LEPTON-HADRON PHYSICS

by

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Introduction

This report gives a short résumé of the two sessions on lepton-hadron scattering. Three topics, namely structure functions, hadronic final states and prompt leptons in beam dump experiments, are summarized here, other topics are found in the summaries of L. Sehgal and V. Barger.

1. Structure Functions

Summary of the sessions on Lepton-Hadron Physics

D. Haidt, DESY

Deep inelastic lepton scattering off nucleons or nuclear targets has revealed the composite structure of nucleons. The lepton interacts with the quarks inside the nucleon through neutral and charged spacelike currents. All electroweak phenomena are so far well described by the standard model based on the gauge group $U(1) \times SU(2)$. These electroweak currents are therefore ideal tools to investigate the structure of the nucleon. The given gauge structure implies relations between the structure functions observed in charged lepton experiments and in charged and neutral current induced neutrino and antineutrino experiments. The major interest in measuring structure functions is the understanding of their scaling violation. Rather good and consistent data exist from various experiments on isoscalar targets. Least known is the longitudinal structure function related to the exchange of helicity 0 gauge bosons. Another class of experiments deals with lepton scattering off simple targets like hydrogen and deuterium. Although such experiments are based on smaller statistics they are of importance in disentangling the flavour composition of the quarks in the nucleon. Furthermore, in comparing measurements on deuterium with measurements on complex (almost isoscalar) targets nuclear effects may be tested.

This topic can be kept short, since F. Eisele is dealing extensively with structure functions in his plenary talk. Table 1 summarizes the contributions to this Conference.

(a) Gross-Llewellyn-Smith sumrule

This sumrule, $\int_0^1 F_3(x) dx = 3(q - \bar{q})$ ($Q^2 \rightarrow \infty$), originally derived from current algebra measures the number of valence quarks in the nucleon, which equals 3 in the quark model. Fig. 1 shows the data of two experiments [3,4]. The errors are statistical. The sumrule is satisfied even at low Q^2 , provided the contribution of elastic events is included. No or little variation with Q^2 is observed. It should, however, be noted that the integral gets important contributions at small x . For fixed Q^2 and given neutrino energy spectrum there is a smallest value of x . The small x region is therefore parametrized as $x F_3(x) = Ax^a$ with $a = 0.5$.

(b) R

New data were presented by CDHS [8], EMC μH_2 and μFe [10] and BCDMS [10]. $R = \sigma_L / \sigma_T \approx F_L / F_2$ is related to the longitudinal structure function $F_L \equiv F_2 - 2xF_1$. In the naive quark parton model $F_L = 0$ (Callan-Gross relation). R is important for the extraction of F_2 . The differential μ and $\nu + \bar{\nu}$ cross sections are proportional to $1 + (1-y)^2 - y^2 R$ and thus rather insensitive to R . The CDHS collaboration has

presented considerably improved values for R at large x (see fig. 2). The idea of the new method consists in exploiting the quantity

$$A \equiv \frac{d^2\sigma^{\bar{\nu}} - (1-y)^2 d^2\sigma^{\nu}}{d^2\sigma^{\bar{\nu}} + (1-y)^2 d^2\sigma^{\nu}} = \frac{(1-y)F_L + (1+(1-y)^2)\frac{1}{2}(2xF_1 - xF_3)}{(1-y)F_L + (1+(1-y)^2)\frac{1}{2}(2xF_1 + xF_3)} \approx$$

$$\approx \frac{\bar{q}(x) + \frac{1-y}{1+(1-y)^2} \frac{F_L}{xq(x)}}{xq(x)}$$

At large x the quantity A is known experimentally to be nearly zero, thus a tight upper limit can be obtained for R. Averaging over $0.4 < x < 0.7$ gives $\langle R \rangle \leq 0.006 \pm 0.012 \pm 0.025$. In the region $x < 0.4$ R is still badly measured.

(c) F_2, xF_3

New results from various experiments (see table 1) were presented. The high statistics experiments with final results agree in shape with each other at the 10-15% level. However, the preliminary data presented by the CCFRR collaboration [4] disagree systematically when compared, for instance, with the data of the CDHS collaboration [5]. Already the quantities $\frac{1}{E}(\sigma^{\nu} + \sigma^{\bar{\nu}})$ measured in the CCFRR experiment show a substantial energy dependence, unless the deviation from constant behaviour be ascribed to normalization differences. It should be noted that this experiment consists of a combination of 5 independent beam settings.

The new, preliminary data of the BCDMS collaboration [10] will be discussed in context with other data by F. Eisele.

The EMC collaboration [10] has extracted the structure function F_2 both from their iron and deuterium data. The ratio is plotted in fig. 3 versus the scaling variable x and is not constant, as naively expected, but decreases systematically with increasing x by about 30%. No explanation has as yet been put forward. This effect underlines the importance of lepton scattering experiments using simple targets like hydrogen and deuterium.

(d) NC x-distribution

The CHARM collaboration [9] has contributed a new piece of information in measuring the x distributions in ν and $\bar{\nu}$ neutral current reactions. Under simplifying assumptions one obtains:

$$F_{\pm}^{NC} \equiv \frac{1}{\sigma_0} \frac{d\sigma^{NC}}{dx} = \left(\frac{4}{3}\right) (u_L^2 + d_L^2 + u_R^2 + d_R^2) F_2^{\pm} \pm \left(\frac{2}{3}\right) (u_L^2 + d_L^2 - u_R^2 - d_R^2) x F_3^{\pm}$$

where $u_{R,L}, d_{R,L}$ are the neutral current couplings and \pm referring to ν resp. $\bar{\nu}$. The nucleon structure functions in neutral current interactions (see fig. 4) show

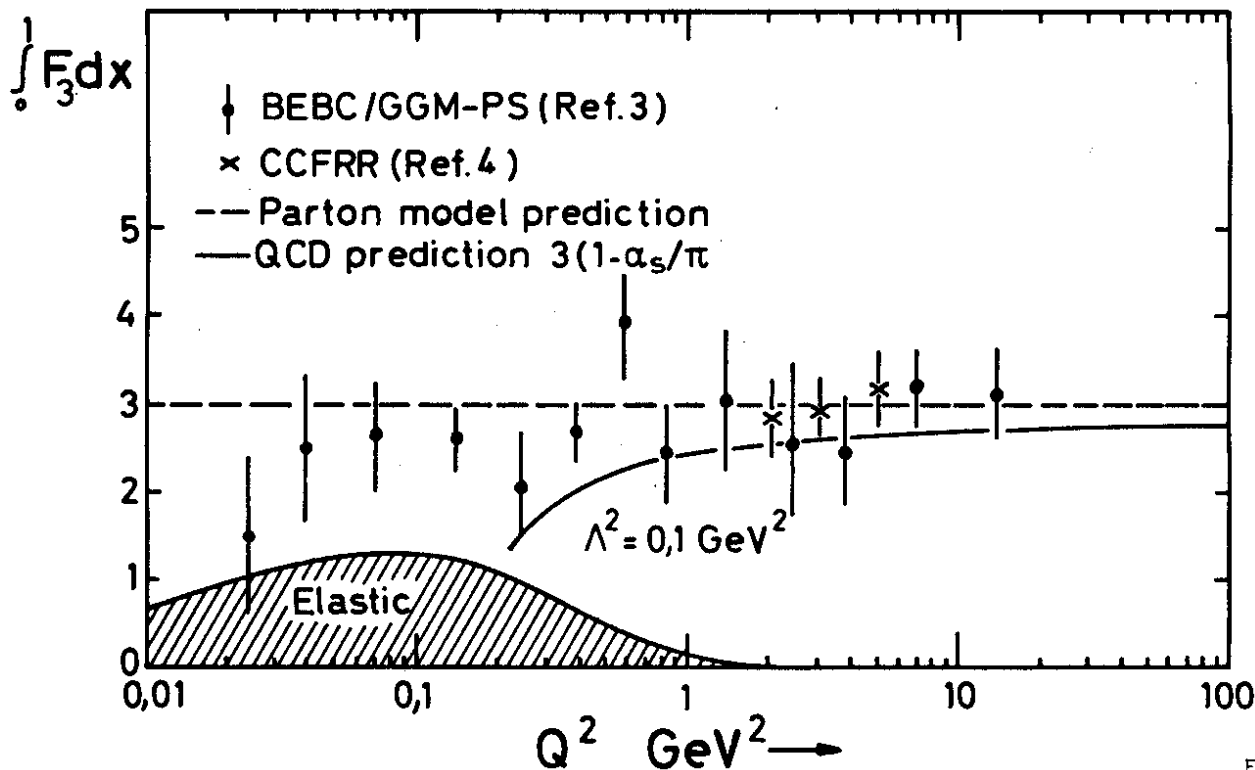


Fig. 1

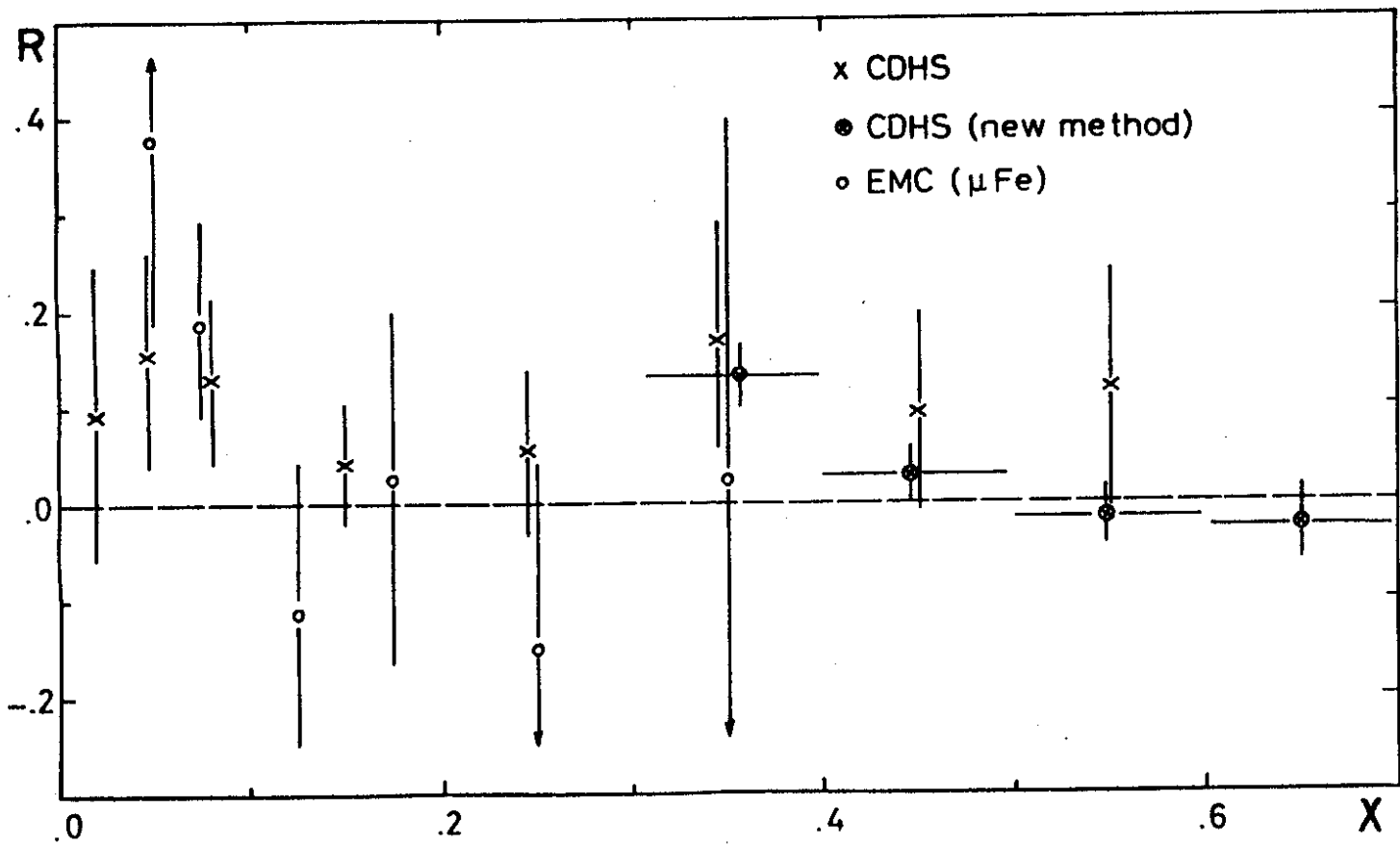


Fig. 2

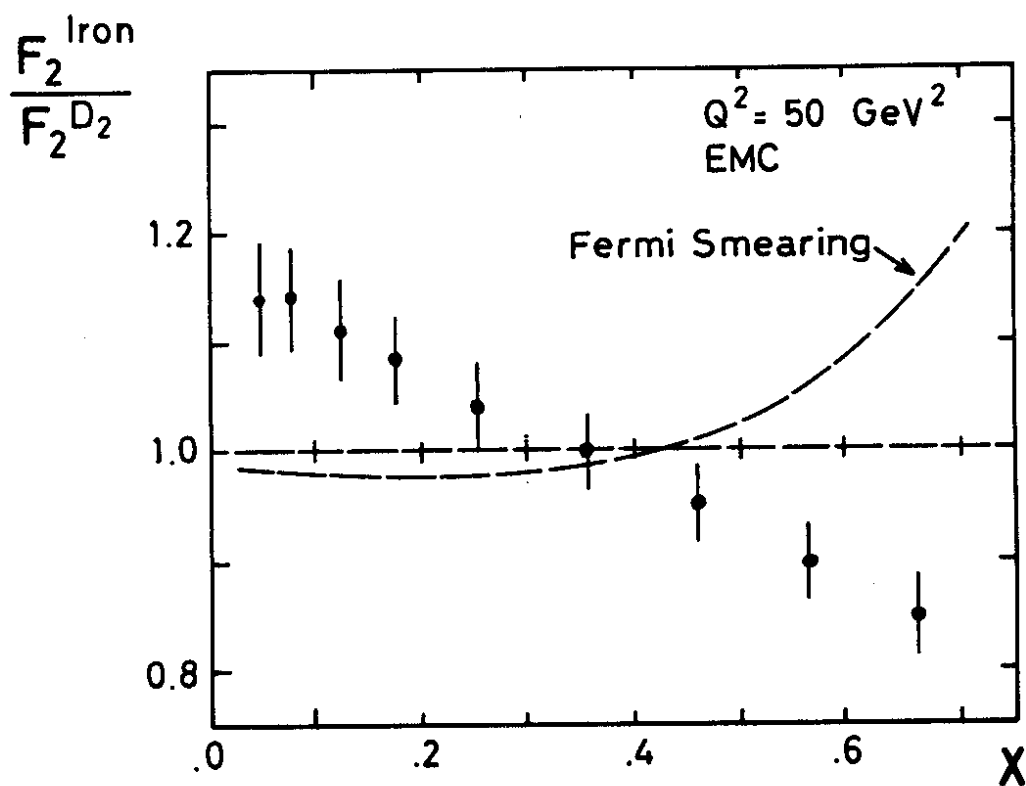


Fig. 3

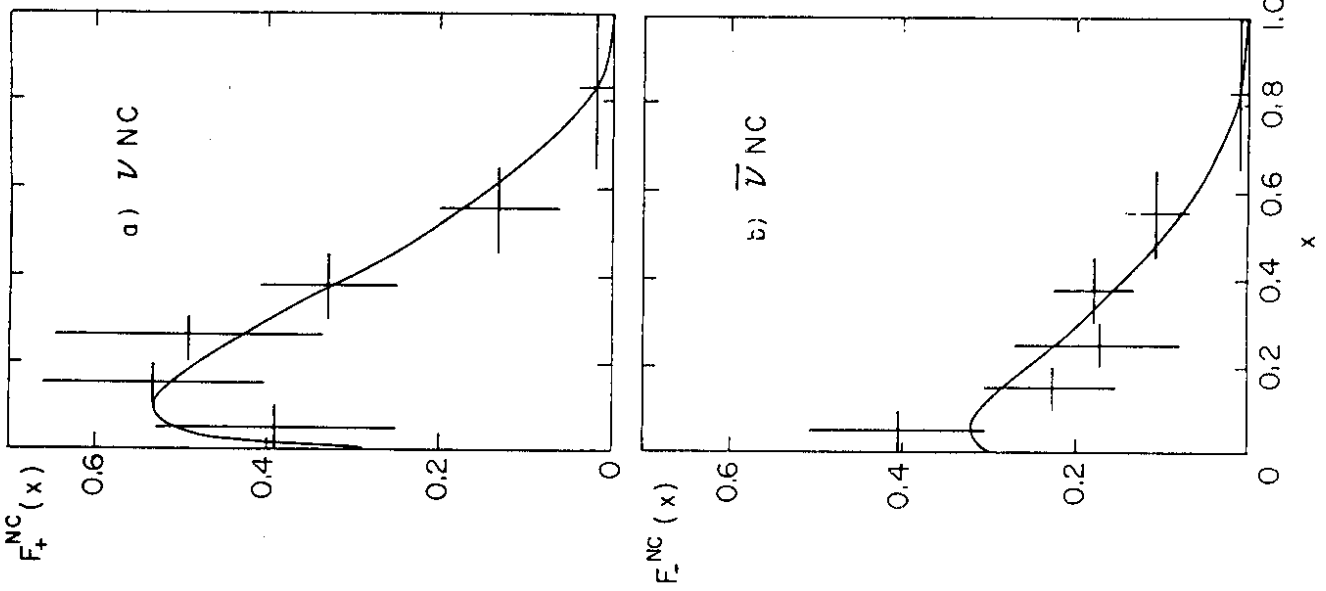


Fig. 4

no significant difference to those measured in charged current interactions as expected by the quark model and the standard model of electroweak interactions.

(e) Parton structure functions

The sea quark distribution $\bar{x}\bar{q}(x, Q^2) = x(\bar{u} + \bar{d} + 2\bar{s})$ is well measured [5]. With their \bar{v} induced opposite sign dimuon sample the CDHS collaboration has deduced the structure function of the strange sea [7]. It agrees in shape with the measured anti-quark distribution \bar{q} . Using further assumptions they get

$$\frac{2s}{\bar{u} + \bar{d}} = 0.52 \pm 0.09$$

which suggests a nonsymmetric sea. However, \bar{d}/\bar{u} is compatible with 1 within 30% [8].

Three collaborations have presented results on the ratio of the d and u structure functions [1,8,10]. The data agree with each other (fig. 5) for $x > 0.3$. The CDHS group deduced the valence distributions. No data exist beyond $x = 0.8$, where theoretical models give different predictions.

The charmed sea is still rather badly known.

The gluon distribution function is derived by the CDHS collaboration [6] from the Q^2 evolution of F_2 and $\bar{x}\bar{q}$.

Experiment	Quantity	Speaker	Contr. Paper	Reference
BEBC	d/u	Schmid	# 596	1
ABCMO $\nu, \bar{\nu}$ H ₂	F_2, xF_3			2
ABCDLOS $\nu, \bar{\nu}$ Ne	F_3			3
BEBC-GGM				4
CCFR $\nu, \bar{\nu}$ Fe	F_2, xF_3, \bar{F}_3	Shaevitz		5
CDHS $\nu, \bar{\nu}$ Fe	F_2, xF_3, \bar{q}		# 708	6
	$xg(x)$		# 706	7
	$x_s(x)$		# 318	8
	R	Merlo		8
	$d_V/u_V, \bar{d}/\bar{u}$	Merlo		8
CHARM $\nu, \bar{\nu}$	NC x-distr.		# 590	9
BCDMS μC	F_2, R	Edwards		10
EMC $\mu Fe, H_2, D_2$	F_2^{IRON}, D_2	Edwards		10
	$F_2^P, F_2^N, d/u$	Edwards		10
	F_2	Edwards	# 749	11

Table 1: Contributions to this Conference

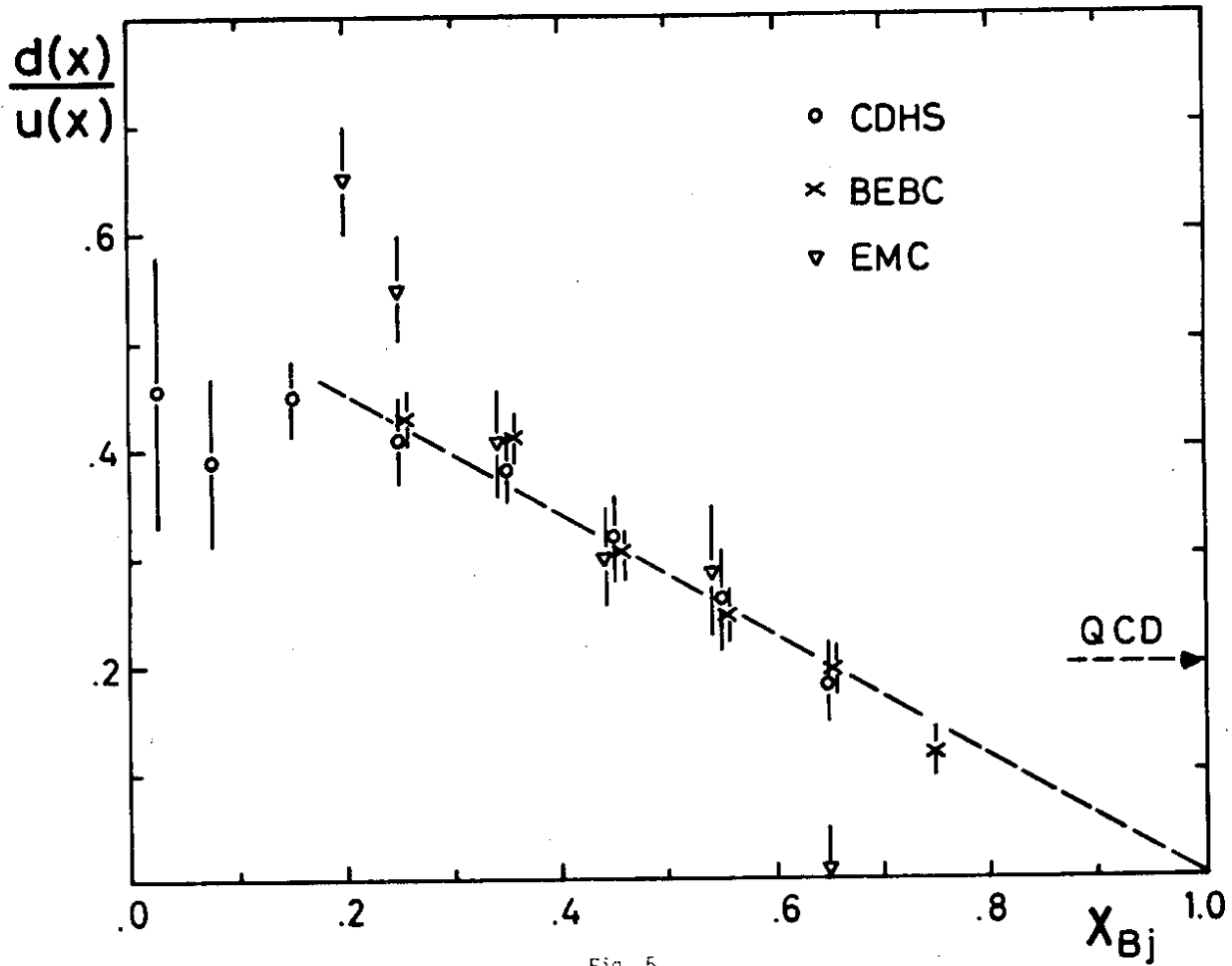


Fig. 5

2. Results on Hadronic Final States

New results on final states in lepton-hadron scattering experiments are summarized in table 2. Some contributions are already in their final form and published. They will not be commented here.

(a) Multiplicity

Four bubble chamber experiments presented data on charged hadron multiplicities. The following table shows that the sizes of the ν and $\bar{\nu}$ event samples are quite substantial.

Experiment	SKAT	15'	BEBC	BEBC
Liquid	Freon	D ₂	H ₂ -TST	H ₂
# ν	4940	11467	1000	11400
# $\bar{\nu}$	1493		400	4120
Contr. Paper	348	456	612	712

Two groups emphasize the importance of correct mass assignment. The BEBC-TST group has developed a method to identify protons in the final state [15]. The ABCMO collaboration [13] (BEBC-WA21) performed a thorough study using the LUND Monte Carlo [20] and found that about 17% of the positive and about 8% of the negative hadrons migrate from the backward to the forward hemisphere in the hadrons' centre of mass system, on account of systematics, whereas only 2% from forward to backward. Due to the poor detection of neutrals in bubble chambers filled with light liquids the effect of the neutrino energy estimation must be carefully taken into account. As a consequence the multiplicity distributions of forward and backward particles are now modified compared to the results presented at the Bonn conference [36]. Fig. 6 shows their corrected multiplicity distributions [13] with the observation that for νp $\langle n_F^+ \rangle$ less than $\langle n_B^+ \rangle$ and for $\bar{\nu} p$ $\langle n_F^+ \rangle \approx \langle n_B^+ \rangle$. The ν -data of the BEBC-TST collaboration confirm this behaviour.

The experiment in the SKAT bubble chamber [24] provides data at smaller centre of mass energies ranging from threshold until $W^2 \approx 15 \text{ GeV}^2$. The dispersion D_- depends linearly upon $\langle n_- \rangle$ except for very low average multiplicities of negative hadrons. In the experiment using the FNAL 15' bubble chamber [18] filled with deuterium multiplicity distributions on protons and neutrons are obtained (fig. 7).

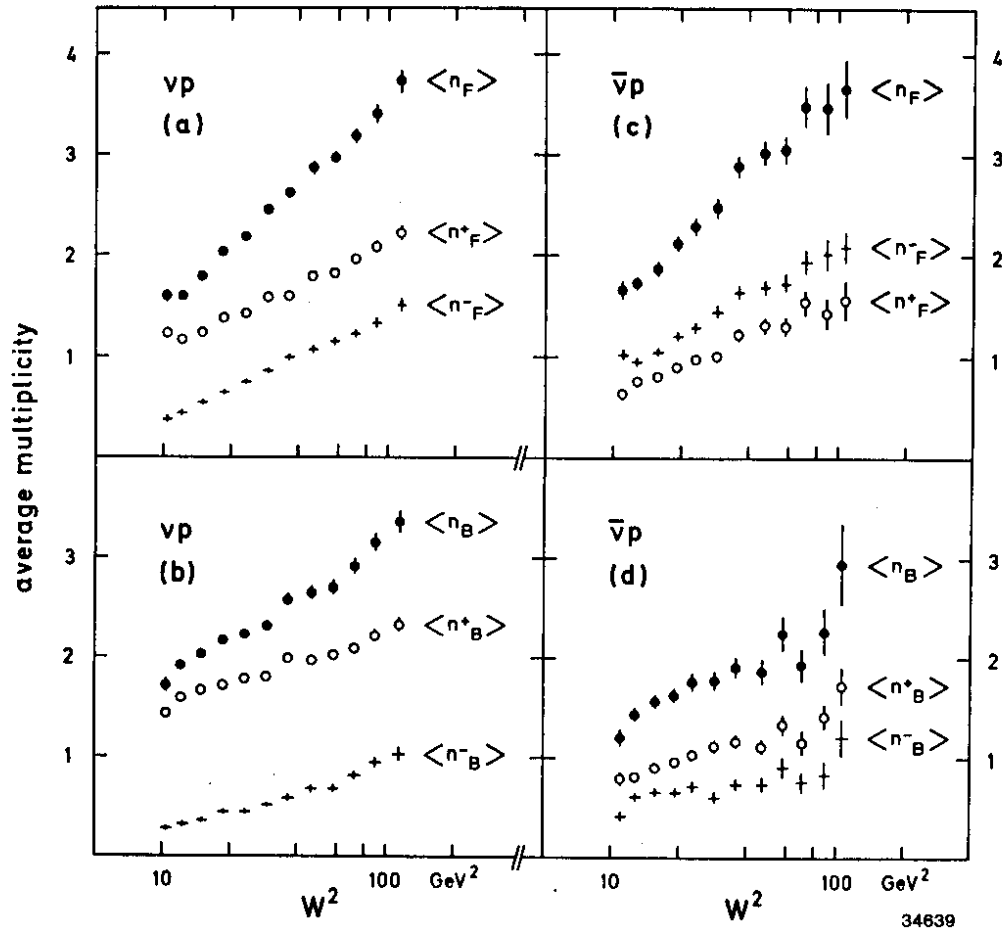


Fig. 6

Many features of the data can be qualitatively understood in terms of q - and $q\bar{q}$ -fragmentation [37]. For instance, the multiplicity of forward hadrons (u -quark fragments) should be the same in νp and νn , whereas the backward multiplicity in νp (due to $u\bar{u}$ -fragments) should be bigger than in νn (due to $u\bar{d}$ -fragments). This is born out in fig. 7. The relation between dispersion D_{-} and $\langle n_{-} \rangle$ appears to be the same for νp and νn [18].

(b) Charm Fragmentation

The CDHS [7] and the EMC [31] collaborations have presented measurements of the charm fragmentation function using their multi-muon data. The momentum spectrum of μ^{+} in ν_{μ} -induced charged current interactions contains information on charm fragmentation. The basic process is $\nu_{\mu}(d,s) + \mu^{+}c + \mu^{+}v_{\mu}(s,d)$. Fig. 8 shows fits to the measured μ^{+} distribution and the extracted charm distribution. The average fractional momentum of the charmed hadron is $\langle z \rangle = 0.68 \pm 0.08$ including uncertainties due to branching ratios of D-mesons, π/K background and charmed quark mass.

The EMC collaboration finds also that the charm fragmentation function is hard as opposed to the soft u,d,s quark fragmentation functions. Their data on dimuons and trimuons are well described by the photon gluon fusion model [30,31]. Fitting the function $D_c(z) \sim \exp(az)$ they obtain $a = 1.6 \pm 1.6$, where the error contains systematic uncertainties of the model parameters, in particular the shape of the gluon distribution function. In the fig. 9 two fragmentation schemes are shown.

(c) Inclusive Particle Production

The LUND model [20] describes fairly well deep inelastic lepton hadron scattering. It treats both quark and diquark fragmentation and accounts, therefore, for meson and baryon production. The ABBPPST collaboration [16] (BEBE-WA 25) with their ν and $\bar{\nu}$ interactions on deuterium has a unique testing ground for the flavour dependence of quark and diquark fragmentation. Rather than comparing the corrected, unfolded data with the model predictions, they have built into the model all known experimental uncertainties, like neutrino energy correction, mass assignments, resolution, kinematical cuts etc. and compare directly with the uncorrected data. Based on about 6500 $\nu p + \nu n$ and 3800 $\bar{\nu} p + \bar{\nu} n$ after cuts ($W^2 > 5 \text{ GeV}^2, Q^2 > 1 \text{ GeV}^2$) the prediction of the LUND model for the Feynman x_F -distributions agrees well with the data both for $x_F > 0$ (current fragmentation region) and $x_F < 0$ (target fragmentation region). A detailed study of strange particle production has been carried out. The observed rates and x_F -distributions for K^0 and Λ production are well reproduced provided the fragmentation parameter describing the fraction of $s\bar{s}$ pairs compared to any $q\bar{q}$ pairs in the cascade is assumed to be 0.15. Features like the narrow x -distribution of Λ 's produced in $\bar{\nu} n + \mu^{+}\Lambda$ + anything, ascribed to interactions with the

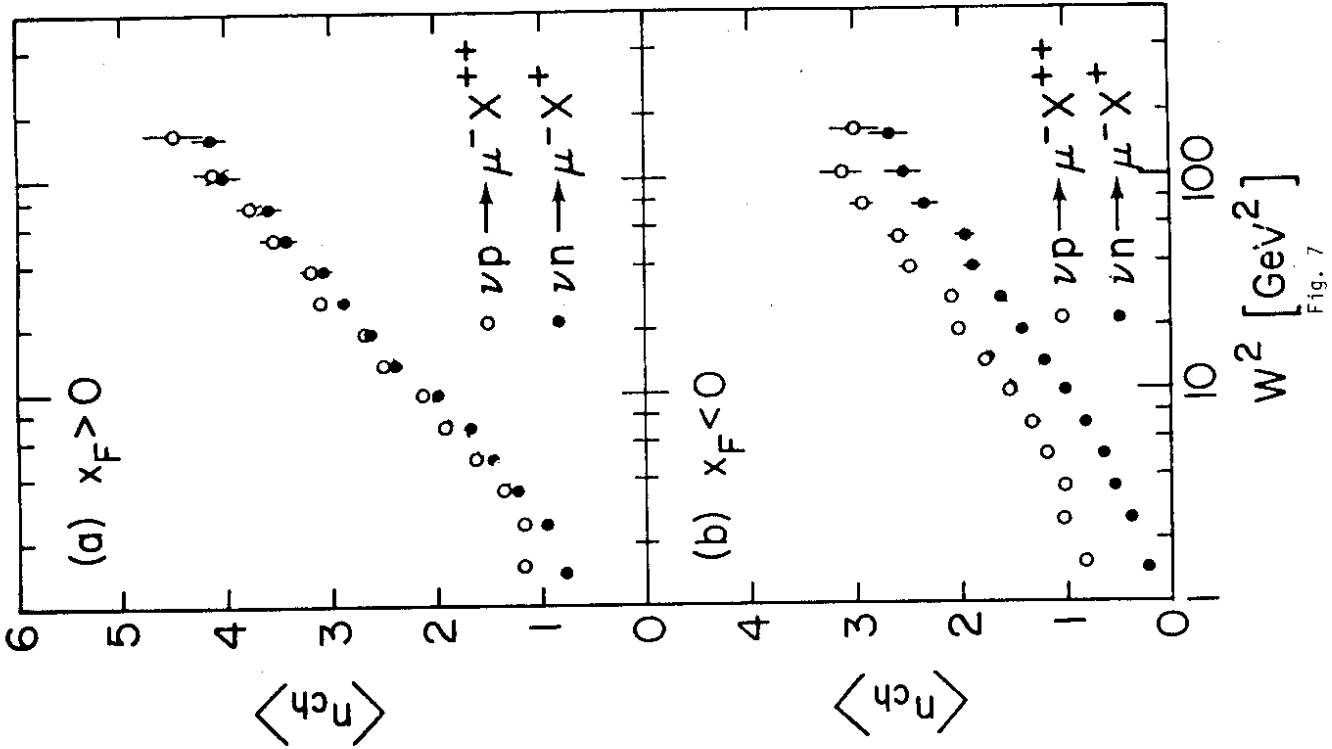


Fig. 7

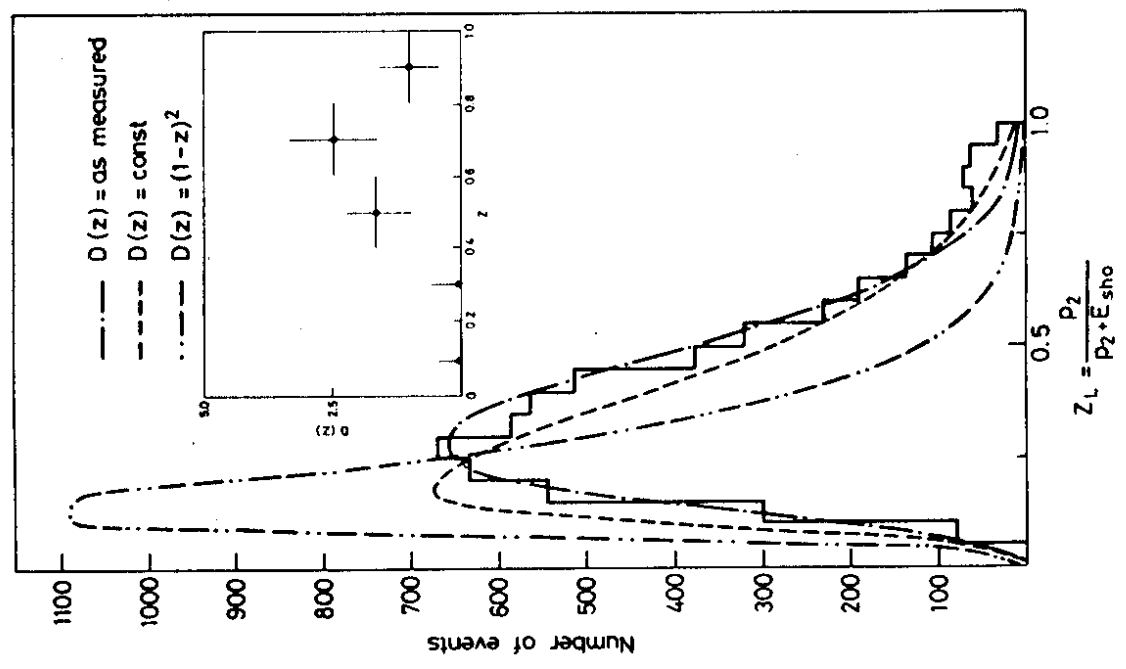


Fig. 8

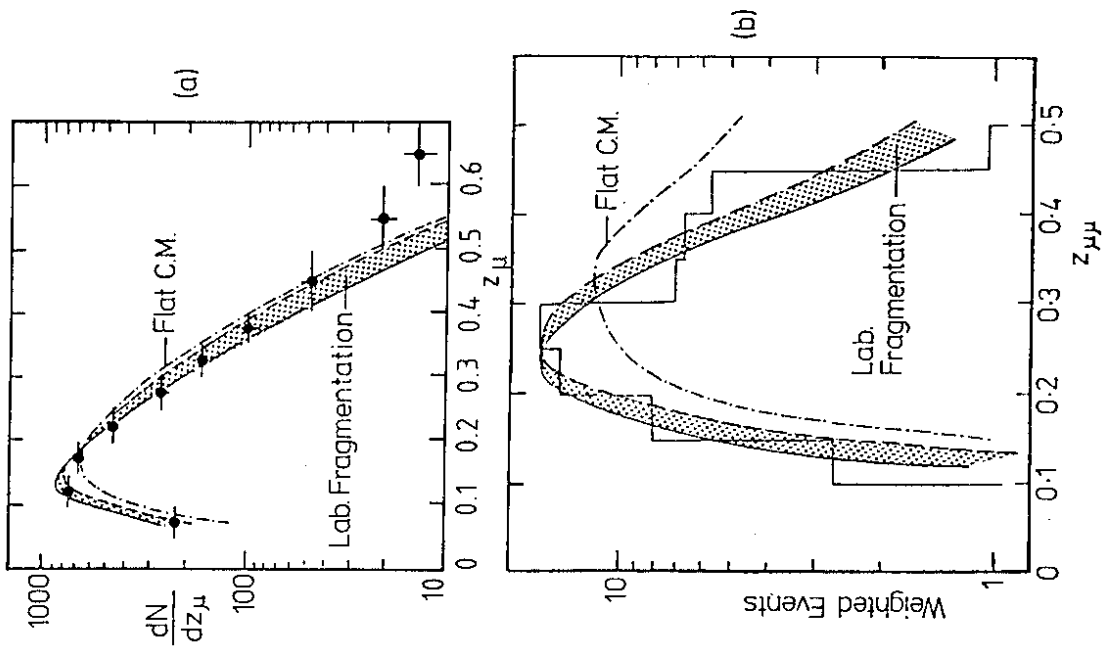


Fig. 9

strange sea in the nucleon, are well reproduced. Incidentally, given this interpretation about 45% of the Λ in $\bar{\nu}n + \mu^+ \Lambda + x$ are predicted to be produced in association with a charmed particle. Also the production of strange resonances (K^{*+} (892), Σ (1385)) has been investigated and found to play an important rôle. Fig. 10 shows the x_F -distribution of K^{*+} and K^{*0} produced in ν charged current interactions. Again, good agreement in rate and shape with the LUND model is found. The data on strange baryon production imply that the diquark does not always fragment as one unit, but breaks up with a probability of about 50%. The EMC collaboration [32] deduced the ratio

$$\rho^0/\pi^0 = 1.0 \pm 0.3 \pm 0.4$$

which implies a production rate of vector to pseudoscalar particles in the Field-Feynman jet model compatible with 1. The EMC-NA9 collaboration has shown first results based on their vertex detector [32]. With this detector it will be possible to investigate also the target fragmentation region.

Λ_c^+ production has been investigated in a neutrino deuterium experiment by the IIMST collaboration [19] yielding

$$\sigma(\nu D \rightarrow \mu^+ \Lambda_c^+ X) / \sigma(\Lambda_c^+ \rightarrow X) = (2.1 \pm 0.7 \pm 0.4)\%$$

More results on proton and antiproton production in the current region have been presented by the EMC collaboration [32]. Fig. 11 shows a strong increase of the relative baryon rates with increasing transverse momentum with respect to the jet axis.

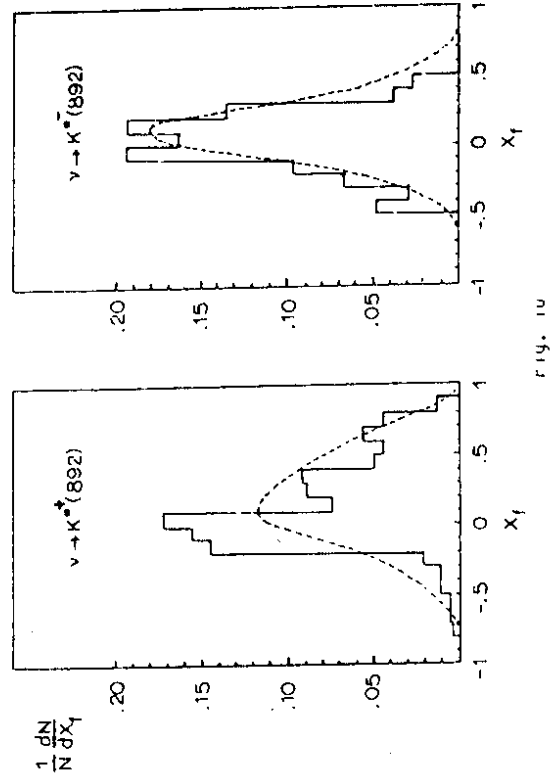
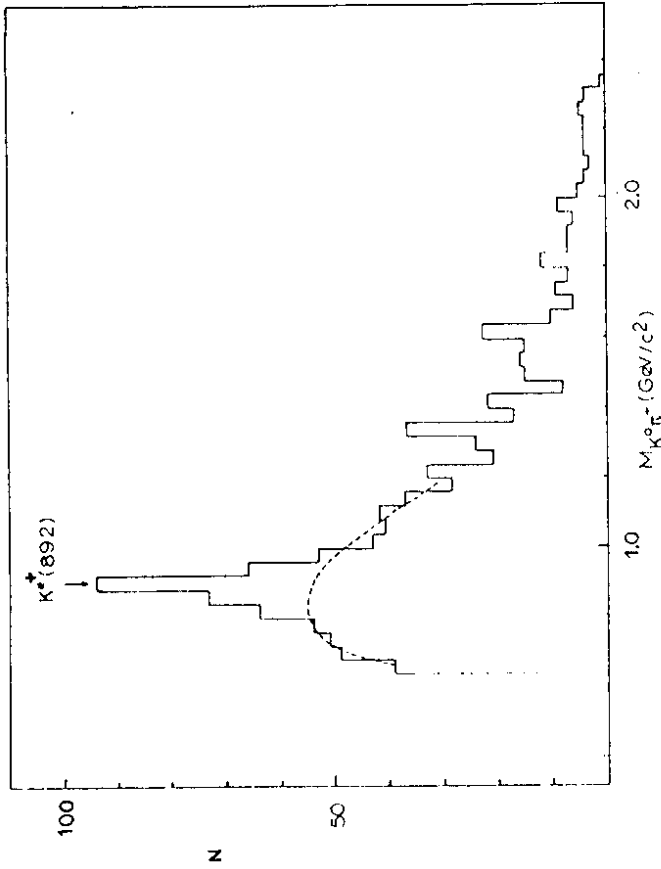
Neutral current induced ψ production has been observed by the CDHS collaboration [22]. Charged and strange particle production has also been studied in low energy ν and $\bar{\nu}$ interactions observed in the bubble chamber SKAT filled with freon [23,24]. At these energies events are not yet jetlike.

(d) $\cos\phi$ distribution

Two collaborations have investigated the azimuthal dependence of charged hadrons in the current fragmentation region with respect to the lepton scattering and the hadron production plane. First order QCD expectation is $\langle \cos\phi \rangle \approx -0.1$, but also on the basis of the quark parton model with primordial k_T an effect proportional to $-k_T/Q$ is predicted.

The BEBC-WA59 collaboration [17] observe in their $\bar{\nu}$ -data the following averages of $\cos\phi$ for π^+ and π^- :

$\langle \cos\phi \rangle$	π^+	π^-	$\pi^+ - \pi^-$
Data	1.10 ± 0.45	-1.52 ± 0.45	-2.62 ± 0.60
MC	0.0 ± 0.7	1.29 ± 0.45	1.30 ± 0.8



Systematic effects have been determined by a Monte Carlo calculation assuming a flat ϕ -dependence. The data show that $\langle \cos\phi \rangle$ is significantly negative. Also π^0 's have been investigated. The invariant mass distribution of γ and μ show an enhancement at $M^2 < 0.014$ ascribed to muon bremsstrahlung. Inner muon bremsstrahlung is studied in a contribution to this conference [21] in the FNAL experiment E 546 (ν Ne/ H_2 15') and found in agreement with the QED prediction.

The EMC collaboration [26] observes clearly a negative $\langle \cos\phi \rangle$. Fig. 12c shows that the effect increases with increasing z . Furthermore, $\langle \cos 2\phi \rangle$ is very small and positive.

(e) Transverse Momentum Flow

The EMC collaboration [27] has found that the transverse momentum of fast forward hadrons is partially compensated by other forward hadrons, as shown in fig. 13. The LUND model accounts for this behaviour by allowing for soft gluon emission [33]. Then, a value of $\langle k_T^2 \rangle$ as low as $0.2 \text{ GeV}^2/c^2$ is sufficient to provide a good fit to the distribution.

(f) A-Dependence

A comparison of charged hadron production in muon nucleus scattering for various nuclei using the EMC apparatus [29] shows no substantial A-dependence (fig. 12a,b).

(g) Q^2 -Evolution

The Q^2 dependence of charged hadron fragmentation functions have been studied by EMC [28] and BEBC-WA25 [16] and appears to be small.

3. Beam Dump Experiments

There were two presentations on prompt lepton production. The Neutrino beam dump experiment E-613 of the MDMF collaboration [34] with a full and a 1/3 density tungsten dump yielded 830 single muon and 752 muonless events. The prompt signal is obtained by extrapolation to infinite density. If central production of $D\bar{D}$ gives rise to the observed prompt neutrino interactions the $D\bar{D}$ production cross section parametrized as

$$\frac{d\sigma}{dp} \sim (1-|x|)^n e^{-a p T}$$

results in $(16 \pm 3 \pm 3) \mu\text{b}$ for $n = 3$ and $a = 2$. There is no evidence for an important $A_C \bar{D}$ diffractive charm production. The rate of $\#_\nu/\#_\mu$ is found consistent with 1 provided $E_\nu > 30 \text{ GeV}$.

Further results dealing with supersymmetry limits [34] are discussed in the talk of L. Sehgal.

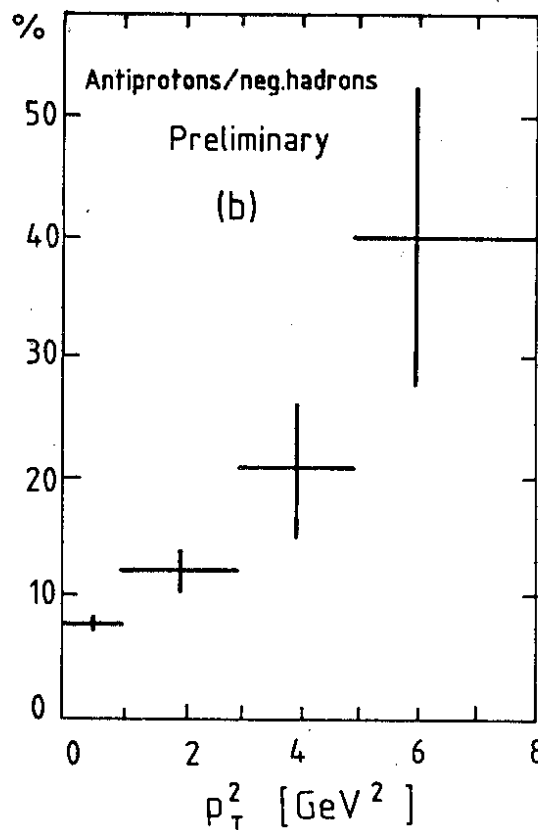
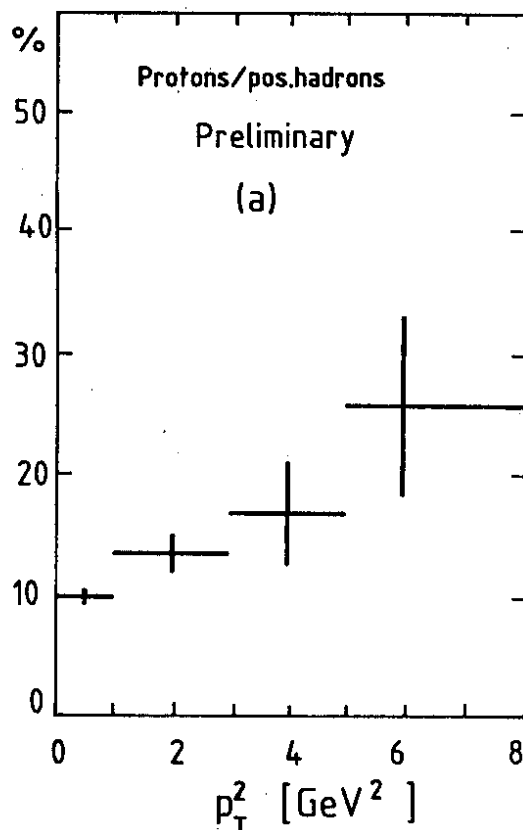


Fig. 11

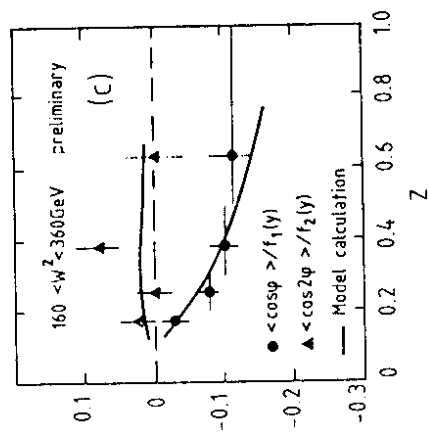
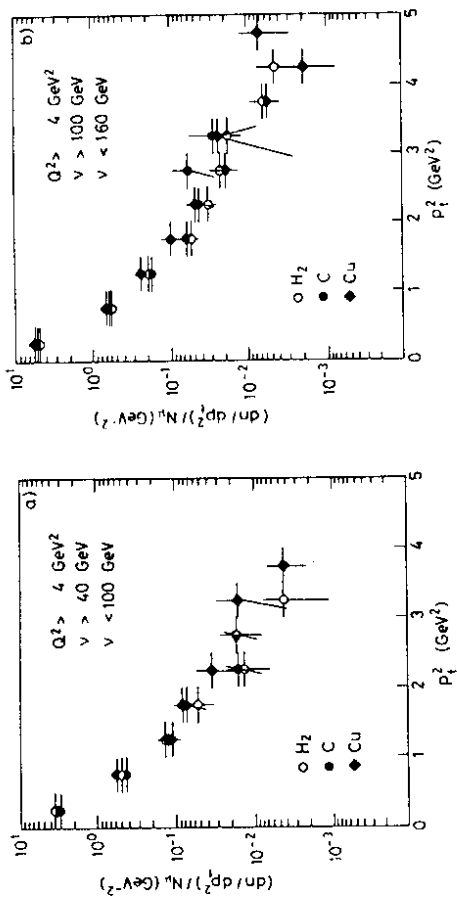


Fig. 12

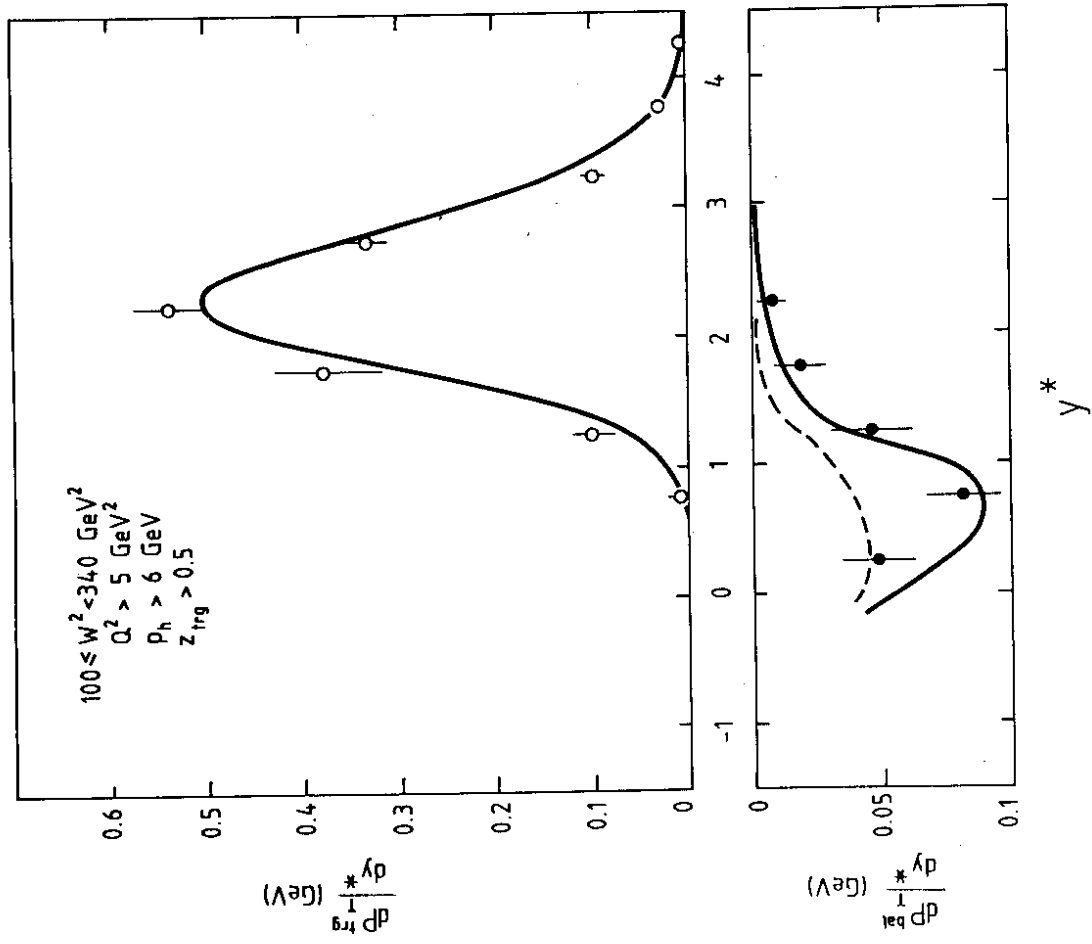


Fig. 13

Forward production of charmed particle states and prompt muons have been studied in 350 GeV p iron and 278 GeV π^- iron beam dump experiment E - 595 [35]. The prompt muon rates were found to be

$$\frac{\# \mu^-}{\# \mu^+} = 1.10 \pm 0.21 \text{ in } p \text{ Fe} \text{ and } \frac{\# \mu^-}{\# \mu^+} = 2.23 \pm 0.29 \text{ in } \pi^- \text{ Fe}$$

for $E_\mu > 20$ GeV. The observed momentum distributions are fit, as above, to $(1-x)^n$ resulting in $n = 6 \pm 0.8$ for μ^+ in p Fe, but $n = 3.4 \pm 1.0$ resp. 1.3 ± 0.8 for μ^+ resp. μ^- in π^- Fe. From the data with $p_\mu > 50$ GeV it can be concluded that the intrinsic charm component in the proton and pion wavefunctions is less than $2 \cdot 10^{-4}$.

Table 2

Experiment	Quantity	Speaker	Contr. Paper	Ref.
BERC WA21	multiplicity charge properties	Schmid	# 712	13
WA24			# 711	14
WA25			# 612	15
WA59			# 543	16
	fragmentation	Vignaud	# 737	17
	cos ϕ			
15' FNAL IMSTT νD_2	multiplicity Λ_c ρ^- exclusive μ bremsstrahlung	Snow Snow	# 456	18
			# 756	19
IIF $\bar{\nu}$ Ne			# 303	21
CDHS	ψ NC production c-fragmentation		# 704 # 318	22 7
SKAT	K^0, Λ h^\pm production		# 504 # 347, # 348	23 24
GGM			# 747	25
EMC - NA2	cos ϕ, p_T	Becks	# 750, # 795	26,27
	Q^2 evolution		# 748	28
	nuclear targets		# 751	29
	heavy quarkonium		# 752	30
	open charm		# 773	31
EMC - NA9	$\rho/\pi, p, \bar{p}$	Becks		32
	p_T^+, y	Becks		32

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Figure Captions

- Fig. 1 The Gross-Llewellyn-Smith sumrule as a function of Q^2 .
- Fig. 2 Measurements of $R = F_L/2xF_1$ averaged over the hadron energy as a function of the Bjorken variable x . The data from CDHS with the new method are upper limits.
- Fig. 3 Ratio of the function F_2 measured on iron and deuterium vs x . The dashed line represents the effect due to Fermi motion. The systematic error (not included) amounts to about 0.1.
- Fig. 4 Neutral current x-distributions for ν and $\bar{\nu}$ interactions.
- Fig. 5 Ratio of quark structure functions $d(x)/u(x)$ vs x .
- Fig. 6 Average charged multiplicities in forward and backward hemispheres vs W^2 . Data from ref. 1.
- Fig. 7 Average charged multiplicities in forward and backward hemispheres vs W^2 . Data from ref. 18.
- Fig. 8 Distribution of neutrino dimuon events as a function of z_L determined by the momentum of the decay muon and the hadron shower energy. The curves are comparisons with Monte Carlo predictions. The inset shows the fitted charm fragmentation function.
- Fig. 9 Energy distributions of decay muons from charmed meson decays
a) $Z_\mu = E_\mu/E_{had}$ for dimuon events
b) $Z_{\mu\mu} = (E_{\mu 1} + E_{\mu 2}) / E_{had}$ for trimuon events.
- Fig. 10 Invariant mass distribution of K^0 and π^+ with $(K^*)^+$ peak and x-Feynman distributions of $(K^*)^\pm$ observed in ν -induced interactions. Data from ref. 16.
- Fig. 11 Relative proton and antiproton production observed by EMC (ref. 32).
- Fig. 12 Data from EMC
a,b) hadron production off 3 different nuclei versus p_T^2 (ref. 25).
c) Moments of the azimuthal distribution of charged hadrons vs fractional energy (ref. 26).
- Fig. 13 Transverse momentum flow and balancing component vs cms rapidity (ref. 27).

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- [1] Talk by P. Schmid
Contr. Paper # 596, Direct determination of the quark density ratio $d(x)/u(x)$ in the proton from νp and $\bar{\nu} p$ interactions, ABCMO Collaboration (BEBC-WA 21)
- [2] P.C. Bosetti et al., PITHA 82-04 (Aachen Preprint 1982)
- [3] T. Bolognese et al., CERN-EP/82-78
- [4] Talk by M.H. Shaevitz
R.E. Blair et al., Neutrino Charged Current Structure Functions, UR-831 C00-3065-339
- [5] H. Abramowicz et al., (CDHS), Z. Phys. C13 (1982) 199, Contr. Paper # 708
- [6] H. Abramowicz et al., (CDHS), Z. Phys. C12 (1982) 289, Contr. Paper # 706
- [7] H. Abramowicz et al., (CDHS), Experimental Study of opposite sign dimuons produced in ν and $\bar{\nu}$ interactions, CERN-EP/82-77 and Contr. Paper # 318
- [8] Talk by J.P. Merlo
- [9] Contr. Paper # 590, J.V. Allaby et al., (CHARM), CERN-EP/82-85
Experimental Study of x-distributions in semileptonic neutral current neutrino reactions
- [10] Talk by A. Edwards
- [11] Contr. Paper # 749, J.J. Aubert et al., (EMC), CERN-EP/82-48
- [12] H. Abramowicz et al., (CDHS), PL 107 8 (1981) 141
- [13] Talk by P. Schmid
Contr. Paper # 543, Multiplicities of secondary hadrons produced in νp and $\bar{\nu} p$ charged current interactions, ABCMO Collaboration (BEBC-WA21)
- [14] Contr. Paper # 711, P. Allen et al., Charge Properties of the hadronic system in νp and $\bar{\nu} p$ interactions, MPI-PAE/Exp. E1. 103
- [15] Contr. Paper # 612, Results on the identification of protons produced in νp interactions in BEBC equipped with a TST, BBB EP R UCL Collaboration (BEBC-WA24)
- [16] Talk by D. Vignaud
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- [17] Contr. Paper # 737, A. Vayaki et al., Azimuthal asymmetry of hadrons produced in ν -reactions, BBBCD-EP-IC-MORS-UCL Collaboration (BEBC-WA59)
- [18] Talk by G.A. Snow
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