MUON PHYSICS AND STRUCTURE FUNCTION

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There have been many contributions to the SPS Workshop on muon physics and structure function and I have the hard task of resuming them. If this summary is not perfect, it is my responsability and it might not reflect the work of contributors.

The resumé is also schematic and does not cover all arguments, more detailed information is available from the sub-group's contributions.

Hopefully, in order to provide a useful manuscript, I have made a summary of what is known, what is little known, and what can be improved upon. In what is known, I have given a list of published results but have only given reference to the collaboration involved in this field at CERN.

1. STRUCTURE FUNCTION

1.1 What is known

1.1.1 Measurement of F_2, xF_3 $\bar{q}$

The structure function have been extensively measured on isoscalar target and H_2 or D_2 targets (example in Fig. 1). The range covered in x is 0.05 to 0.65 and in Q^2 from 2 $GeV^2/_c$ to 200 $GeV^2/_c$.

The limitations are mainly due to systematic error*. Normalization errors are still in the range of 2.5 to 5% depending on the experiment. Calibration errors, mainly on the hadronic energy measurement induce systematic uncertainties, the measurement with a calorimeter provide a lower uncertainty than the substraction method ($E_h = E_\ell - E_\ell'$) as long as the absolute errors are the same. In practice, energy is easily measured in air gap magnet and the two approaches (one being used by neutrino experiment, the other by muon experiments) are similar.

More precisely, F_2 on isoscalar target (Iron, C....) is limited by systematic, F_2 on H_2 and D_2 is statistically limited at large x, $xF_3(x,Q^2)$ and q (x) measured on heavy targets by neutrinos are limited by systematics and by statistics.

1.1.2 Q^2 Evolution of structure function

The Q^2 evolution is predicted by QCD and can be computed without any assumption with the Altarelli-Parisi equation. The experimental data supports the QCD picture and αs (or equivalently Λ) is determined.

We should point out

- that the value of αs is mainly determined by the behaviour of $F_2(x,Q^2)$ for large x i.e. for singlet structure function even if at large x the sea contribution is small;
- that non-singlet structure function xF_3 and $F_2^p - F_2^n$ do not give yet an accurate value for Λ;
- that the error on Λ (αs) is mainly induced by the systematic error on F_2 and by theoretical uncertainty on higher twist;
- that the nucear effect $F_2^{Fe}/F_2^{D^2}$ observed by EMC still allow a QCD test with structure function measured on nucleus provided it is not a higher twist effect.

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* G. Smadja, private communication in a Luminy workshop, Nov. 82, unpublished.

Nevertheless, the Q^2 evolution of the structure function has provided the best evaluation of αs, this is certainly true if the three to two jets ratio observed in e^+e^- annihilation depend strongly on fragmentation.

1.1.3 Gluon structure function

In deep inelastic scattering one cannot measure directly the gluon structure function, it appears in the Q^2 evolution of $F_2(x)$ correlated with αs and also in a less correlated way with the distribution of the sea $\bar{q}$ (x,Q^2). Furthermore, it has been measured only on nuclear target which might not be the same as for the proton. Nevertheless, since $\bar{q}$ (x) is very small at large x it constrains the gluon distribution, excluding broad distributions. The overall momentum carried by gluons is around 50%. This information is confirmed from the open charm muon production analysis with the photon gluon fusion model.

1.1.4 σ_L/σ_T measurement - R -

At large x $(x > 0.35)$ CDHS has shown that using a depletion of events at large y provides a very good limit on R measurement, the error on R is then around 0.03.

At medium x it is measured by the classical method where systematical errors dominate over statistical ones and R is determined with an accuracy of 0.1 in both muon and neutrino experiment. Overall R is compatible with zero for $x \geqslant 0.1$.

1.1.5 The distribution of the strange quark and charm quark

From charm production induced in neutrino interactions the strange quark is measured, from the open charm production in muon nucleus scattering C(x) is measured with its Q^2 evolution; strong limit on intrinsic charm has been given. Some warning should be given as all these measurements have been carried out on nuclear targets.

1.1.6 Ratio of u valence over d valence

$\frac{uv}{dv}$ can be measured by comparing F_2 results on H_2 and D_2

from muon and neutrino measurement or by a direct comparison of $F_2^{\nu p}$ with $F_2^{\mu p}$. A typical result at high Q^2 is shown in Figure 3, d/u = 0.57 (1-x).

1.1.7 The ratio $F_2^{Fe}/F_2^{D^2}$

F_2^{Fe}/F^{D_2} behaves differently than expected from the naive quark parton model (Fig. 4).

For large ν ($< \nu > \simeq 60$ GeV), large Q^2 ($< Q^2 > = 50$ GeV) i.e. small distance $\Delta r = 1.310^{-14}$ the additive quark parton model cannot predict correctly the quark density inside the nucleus. It is a disruptive observation and even if it should not be so suprising it will be of practical importance (H_2 targets are light and not as easy to handle as nuclear targets).

1.1.8 The structure function G_1 and G_2

A combinaison of G_1 and G_2 has been measured at SLAC at small Q^2 and at medium x.

1.2 What is poorly known

1.2.1 The shape of the gluon distribution

It is very difficult to measure on H_2 because of statistical limitations with neutrino experiment and even on nuclear target the shape of the gluon distribution has to be put by an ad hoc method in the analysis of $\bar{q}$ (x,Q^2). Technical progress in the analysis suggested by Fumansky, Petronzio and reported by the charm collaboration might improve the situation. Nevertheless, the gluon distribution is not coming from a straight direct measurement.

1.2.2 R with high accuracy

At moderate x, $0.1 < x < 0.3$ neutrino experiment can improve the situation.

At small x, $x < 0.1$ nothing of good standing exists and this can be done with muon experiments to an absolute accuracy of 0.1.

1.2.3 Q^2 evolution of non singlet structure function

- $xF_3(x,Q^2)$ can certainly be improved with higher statistics, and better experimental conditions (better resolution from the hadronic calorimeter and broad band beams or better quad band beam). These measurements will also improve the measurement of $\bar{q}(x,Q^2)$.
- $(F_2^n - F_2^p)(x,Q^2)$ is unlikely to compete with xF_3 due to smearing correction in extracting F_2^n from $F_2^{D_2}$ at large x, still at low x the limitation is statistical.

1.2.4 Uv/dv is poorly known at large x and small x

At large x it is difficult but not impossible to improve the situation for $x > 0.65$. It is difficult if one uses $F_2^{\nu p}$ and $F_2^{\mu p}$ because neutrino interactions on Hydrogen provide poor statistics and if one uses $F_2^{\mu p}$, $F_2^{\mu D_2}$ then smearing correction and Fermi motion effect in deuterium have to be taken into account. It might even be impossible if the quark inside D_2 do not behave as predicted by the naive additive quark parton model.

At small x it can be improved up to a limitation due to sea contribution and it would be interesting to see how it reaches 1 when x goes to zero.

1.2.5 $\bar{u}/\bar{d}$ is poorly known

Improvement would need high statistics neutrino experiment with hydrogen target. It is not easy.

1.2.6

F_2^p structure function is limited by statistics at large x $0.3 < \nu < 0.7$. This indeed can be improved in a μH_2 experiment with a long target, typical work which will be achieved by BCDMS.

1.2.7

F_2 have not yet been properly measured at low x, $x < 0.05$. It should be done and can be done to understand

- the behaviour of $R = \sigma L/\sigma T$ which should strongly differ from zero (otherwise it will contradict present knowledge on QCD, intrinsic transverse momentum...);
- the Q^2 behaviour can indeed confirm QCD but could also disproove QCD;
- the shadowing on nuclear target is not really understood as far as x or $Q^2 \to 0$.

1.2.8

F_2 has not been determined at x close to 1. It is interesting for the separation of higher twist terms but is is also prohibited by smearing correction up to now, either by $\Delta\nu$ at small y or by Δp_ν at large y. The charm detector with its nice hadron calorimeter could do some good up to x = 0.8?

1.2.9

The low W region has not been measured except at SLAC.

1.2.10

$F_2^{iron}/F_2^{D_2}$ is not understood. (See paragraph 5).

1.2.11 Structure function $G_1 - G_2$

Only the combination corresponding to longitudinal polarisation is known, nothing is known for the transverse polarisation nor any information on neutron polarisation. Improvements are possible on longitudinal polarisation at low x and for higher Q^2.

1.3 What can be improved

TABLE 1

Experiment	Beam	Improvement Expected	Year
CDHS and CHARM	improved set up run in broad beam	$xF_3(x,Q^2)$ $\bar{q}(x,Q^2)$	1983-1984
BCDMS	muon beam 40 meter H_2 target	F_2^p high statistics $0.1< x <0.7$	Still 110 days approved 1983-1984
EMC Shadowing NA28	new trigger system to reach small x and Q^2 $x \geqslant 0.0003$ $Q^2 \geqslant 0.15$ GeV	$F_2^A(x,Q^2)$ x and $Q^2 \to 0$	21 days approved 1983
EMC Structure function on polarized target	a longitudinaly polarized target exist with a polarised muon beam	measurement of G_1, G_2 on proton mainly at low x but with a large Q^2 range	need ∿ 100 days of running time

1.3.2 What can be done with more running time by existing set-up

TABLE 2

Experiment	Beam Improvement	Improvement	Beam Requested
EMC	use NA28 set-up	$F_2^p(x,Q^2)$ R(x) at smaller x	80 days running at 120,200,280 GeV
BEBC	data on H_2, D_2 (with the calorimeter)	- $xF_3{}^{p,n}$ - $\bar{q}^{p,n}$ - xG(x) 40000 events ν_p 20000 events $\bar{\nu}_p$	$8 \cdot 10^{18}$p
CHARM	quad neutrino beam (improved the neutrino means energy compared to a broad band beam without loosing too much in intensity)	$xF_3(x,Q^2)$ $\bar{q}(x,Q^2)$ at larger Q^2	$5 \cdot 10^{18}$p

1.3.3 Conclusion

There has been a large amount of work carried out on structure function at SPS with first class results. Nevertheless, to complete what can be done will certainly need more than the approved program which already extends beyond 1984. As seen as an example in fig. 5 for the improvement which will be achieved in the Q^2 evolution of F_2 at large x by BCDMS, the effort is worth it. Furthermore, new achievements will come mainly from high statistic, good understanding of systematic error which can be best achieved at SPS.

The next fundamental generation of experiments concerning structure function will come from ep collider.

It should also be noticed and it should be stressed in Chapter 5 that we might not have yet fully appreciated the consequence of the $F_2^{Fe}/F_2^{D^2}$ abnormal behaviour.

2. WEAK INTERACTION

2.1 What has been learnt

In muon nucleon scattering there are interferences between the electromagnetic and weak processes. There are different experimental ways of looking at this. One is to measure the asymmetry in cross section corresponding to μ^+ and μ^- with opposite helicity.

$$B = \frac{\sigma^{\mu+}(-\lambda) - \sigma^{\mu-}(\lambda)}{\sigma^{\mu+}(-\lambda) + \sigma^{\mu-}(\lambda)} = - K \quad (a_\mu - \lambda v_\mu) \; A_O \; g(y) \; Q^2$$

where

$$KQ^2 = \frac{G}{\sqrt{2} \; 2\pi\alpha} \quad Q^2 \quad = 1.79 \; 10^{-4} \quad Q^2$$

a_μ
v_μ) axial and vector lepton coupling, in the standard model (G.W.S.) $a_\mu = - 1/2$
$v_\mu = - 1/2 + 2 \sin^2 \theta_w$

$A_o = \frac{6}{5} \; (a_d - 2a_u) \; a_d, \; a_u$ are the axial coupling, of quark u and d

$v_\mu \simeq 0$ so B is essentially parity conserving.

BCDMS has done the B measurement with a very interesting result

slope = $(-1.47 \pm .37) \; 10^{-4} \; GeV^{-2}$

$\sin^2 \phi_w = 0.23 \pm 0.07$ (st) ± 0.04 (syst).

2.2 What can be done with the existing set-up

Instead of comparing cross section of $\mu^{+}(\mu^{-})$ at a given helicity, one can compare the cross section at different helicities λ_1 and λ_2.

Then one defines A±

$$A^{\pm} = \frac{\sigma^{\pm}(\lambda_1) - \sigma(\overset{\pm}{\lambda}_2)}{\sigma^{+}(\lambda_1) - \sigma^{+}(\lambda_2)} = - K\left(\frac{\lambda_1 - \lambda_2}{2}\right) .(v_\mu A_o\, g(y) \pm a_\mu V)\, Q_o^2$$

$$V = \frac{6}{5}\,(2v_u - v_d) \rightarrow \text{in the standard model } V = \frac{6}{5}\left(\frac{3}{2} - \frac{10}{3}\sin^2\theta_w\right)$$

$A^{\pm}$ are parity violating asymmetries.

The A measurement is more difficult than B since the effect is smaller by a factor 2 to 3 and it requires μ coming from backward decays of the π.

With a denser target, 40 meters of Cu BCDMS can do the A^{+} and A^{-} measurement. A^{-} would repeat the Slac measurement at Q^2 much larger (x100) it will give an accurate measurement of $\sin^2\theta_w$. A^{+} is insensitive to $\sin^2\theta_w$ but is needed to measure the coupling in a model independent way ($a_\mu \nu$ and $v_\mu A_o$).

Table 3 shows what could be needed and the accuracy achieved.

TABLE 3

A^{-} 100 days at SPS running at 450 GeV

μ^{-}	$\lambda = 0.8$	$1.6\ 10^{7}$ μ/spill	$2.5\ 10^{12}$ ppp
μ	$\lambda = 0.0$	0.410^{7} μ/spill	$5.7\ 10^{12}$ ppp

→ will give $1.6\ 10^{12}\mu^{-}$ for each polarity for a total of $2.5\ 10^{18}$p

A^{+} 40 days at SPS running at 450 GeV

$\sin^2\theta = 0.23 \pm 0.014$

$a_\mu\,(v_u - 1/2v_d) = -0.333 \pm 0.036$ | | -0.45 ± 0.12

$v\mu\,(a_u - 1/2a_d) = -0.03 \pm 0.05$ |old Slac measurement| -0.23 ± 0.38

Indeed these measurements look feasible, systematics are under possible control and there is no competition from doubler since no high luminosity experiment is approved.

There has been a detailed study of the charged current weak process $\mu N \to \nu$ + "X". It is of interest since muon beam can be, for each sign, of left or right helicity and as only left-handed currents are supposed to exist in the standard model, zero cross sections are expected from right-handed current.

This process is indeed of great interest but a detailed feasability study is still to be carried out, in particular, on the required resolution to be achieved by the hadronic calorimeter.

3. HADRONS PRODUCTION BY MUONS

3.1 What has been learnt

We will not review all the data but just give a few examples of the main results.

3.1.1 The quark parton model picture works well

A typical example is just the scattering of sea quarks at low x which induces an equal rate for π^+ and π^- and the scattering of u quark at large x which gives a higher rate of π^+ compared to π^-.

3.1.2 QCD and gluon effects have been seen

(a) p_T broadening. Without gluon emission the p_T of the observed hadrons would be fixed by the intrinsic transverse momentum of quarks and by the fragmentation process. Including gluon emission broadens the distribution, it is definitely observed in many places and particularly in muon nucleon scattering (Fig. 5);

(b) the quark gluon fusion model work for open charm production, it more or less reproduces the differential cross-section with the right magnitude;

(c) factorisation breaking and scaling violation in the hadronisation. Indeed QCD induced scaling violation also in the hadronic final state. The factorisation breakings are of prime interest since they are induced only by second order QCD effect. The existing data supports this QCD picture even if the statistic significance of the result is not superb;

(d) hard gluon emission and evidence for two forward jets (Fig. 7). In the gluon bremstralhung process, hard gluons are emitted at large angles and will induce a hadron jet. The observation of the forward produced hadrons has shown planar events with a distribution of transverse momentum relative to the plane and in the plane typical of two jets structure. The energy flow of the events where one has a large p_T hadron shows the typical two lobes structure. All these observations support the two forward produced jet mechanisms;

(e) hint on quark and gluon jet difference. Gluon jet emission is characterised by a planar events and/or an event with a large p_T hadron. Therefore, one looks for quantum number behaviour as a function of p_T (or planarity). With 500k events from NA2 one measures 2000 fast p and $\bar{p}$. As an example one can see in Fig. 8 that the ratio

$$\frac{\bar{p}}{\pi^- + K^- + \bar{p}}$$ is around 8% at low p_T and increases to 40% at

large p_T; at large p_T one gets predominantly quark and gluon jets and one measures roughly as many antiprotons as $(\pi^- + K^-)$. This is an interesting evidence for quark gluon differences. It should be pointed out that this result needs a huge statistic to get significant results.

3.2. What is poorly known and can be improved

3.2.1 The difference between quark and gluon jets:

(a) with the completion of the analysis of NA2 more information is to come on this sujbect. Nevertheless, NA2 data has only forward hadrons only poorly identified and this is a strong limitation;

(b) with the completion of NA9 data taking and analysis, it looks promising since NA9 is a 4π detector with good particle identification. The main limitation will come from the statistic 50000 events on H_2 target and 80000 events on D_2 target.

3.2.2. Scaling violation, factorisation breaking in the hadronic final state

Actually $e^+ e^-$ data can be explained by non-perturbative effects, it needs no QCD evolution, ν N data show only scaling violation with low W events. μ N data have weak Q^2 dependence (and within systematic error could allow for no dependence), the behaviour can be understood together with x,z non factorization in next to leading order QCD.

Further investigations are highly desirable, factorisation breaking in x, y is introduced by next to leading order QCD and lepto-production are unique (x variable). Also higher twists will yield x,z factorisation breaking but for high x and low Q^2.

Future measurements need high statistics, high z and particle identification in the full range with a minimum correlation between variables. This can be achieved with either an improved NA2 set-up (better particle indentification obtained with more Cerenkov counter or imaging Cerenkov), or an improved NA9 set-up and runs at different beam energies (e.g. 90, 120, 200, 320 GeV).

3.2.3. Study of muo-production of $B \bar{B}$

In a 4 effective day of running with a calorimeter target ($2 kg/cm^2$) the NA2 experiment has been looking for $B \bar{B}$ production through their semi--leptonic decay $B_1 \rightarrow C\mu^\pm + \ldots$ and $B_2 \rightarrow \underset{\hookrightarrow \mu^\pm + \ldots}{C + \ldots}$ ending with $\mu^+ \mu^+ \mu^+$ or $\mu^+ \mu^- \mu^-$, very specific final state. One candidate has been observed in the range of the expected cross section. It is proposed to improve the statistical significance of this result by a factor 500 to end up with a clean sample of 1000 $B \bar{B}$ events. This will allow the same study on $B \bar{B}$ muoproduction than it has been achieved on $C \bar{C}$ production. A 8 m uranium target calorimeter is proposed to decrease the background contamination from delayed events arising from π or K decays. The apparatus (Fig. 9) is an improved version of the EMC set-up which will allow the measurement of low Q^2 events and will be able to stand 10^8 μ per burst. In a 40 day running period it will be possible to measure

- the Upsilon muoproduction
- the open $B \bar{B}$ production
- the $D \bar{D}$ mixing up to a level of 0.1%
- very high statistics open $C \bar{C}$ studies.

A good uranium calorimeter and an air gap magnet will allow to compete effectively with the approved FNAL experiments.

3.2.4 Study of quark interaction in nuclear target

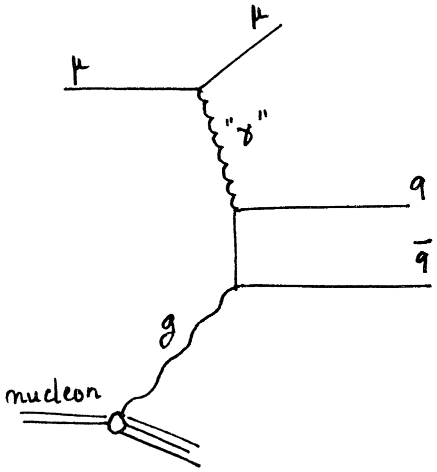
It has been proposed for a long time that the nuclear target could be a good tool for studying the space-time evolution of hadronic final state formation. At Slac[*] it has been seen in electroproduction that forward hadrons are diminished as if there would be reinteraction inside the nucleus, preliminary results from EMC at higher W do not show very striking effect. An approved program with the NA9 set-up will give more information on the forward and backward hadron than the low statistic data being already analysed from an NA2 test run. As we shall see later, a comprehension of the ratio $F_2^{D_2}/F_2^{iron}$ will also need a study of the hadronic final state.

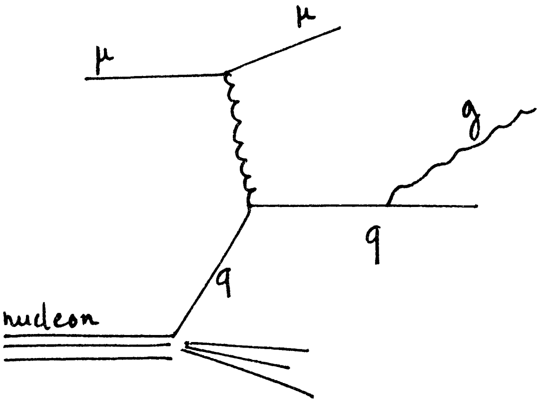
It has been proposed to run with a NA9 set-up (or an improved one) a high statistic (an order of magnitude improvement) measurement on xenon, argon and helium targets.

4. JET STUDY IN 1984-1985

4.1 Physics interest in muoproduction

There are two QCD graphs which will contribute to topological events





with two jets in the forward direction.

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[*] L.S. Osborne et al. Phys. Rev. Lett. 40 (1978) 1624.

It will be possible to study the difference between u, $\bar{u}$ and gluon jets.

- u jets are mainly seen as a single jet for $xB_j > .1$
- $\frac{u\,\bar{u}}{u\,g}$ jet decreases when xB_j increases
- the ratio of 2 forward jets/1 jet is proportional to αs so it is possible to study the structure of three different jets (u, $\bar{u}$, g) and the flavour charge properties of these jets. This requires a high statistic experiment with 4π coverage and good particle identification. Neither NA2 nor NA9 fulfill these requirements.

4.2 Jet factories

Table 4 shows where the competition is.

TABLE 4

Comparison of Different Jet Factories

	$\sqrt{s}$ in GeV	W effective	Statistic
e^+e^- Petra-Pep	40	40	∼20-30k now
ν SPS or FNAL		5 - 10	∼ 10k
ISR p p	62	∼ 15	?
p p collider	540	∼ 100	Large
μ SPS NA9 future possible experiment	23	∼ 15	−50k already taken 500k
μ FNAL	38	∼ 23	50k in 1986?

One can certainly raise the question on the field left by the p $\bar{p}$ collider. If it is difficult to make a firm statement about the years 1984-1985 the collider will certainly give high statistics and superb jets but will not have charged particle identification and will mainly have gluon jets. As far as ISR is concerned, it will probably be closed by that time.

As far as FNAL muon experiment is concerned, clearly the physics is the same and one should weigh a few arguments:

- Who will first give a high statistic experiment with 4π coverage and identification?
- How critical is W the effective energy?
- How critical is the number of events?

The first point is rather easy to answer, CERN beam exists and as it has been studied (see later) possibilities exist to achieve this program before FNAL.

On the second point, if the larger the W the better off one should be, how critical it is, is a question of taste. With the same number of incidents muons on the same target and with the same trigger requirement ($x_{Bf} \geqslant 0.01$, $\Theta_{\mu} > 1/2$) the integrated number of events with W > 10 GeV is larger at SPS than at FNAL, for W > 20 GeV the situation is reversed. With 10 times more events at SPS than FNAL there would be 15 times more interesting events where QCD effects are observable. Furthermore, for the separation of the two forward jets one has just been looking at Monte Carlo simultation and it is not absolutely clear that for a good separation of dijet events at high W one should not increase the p_T cut, which could reduce the useful sample.

On the third point, it is clear that the rate is critical, competition with $e^+ e^-$.... means a large sample of events. Furthermore, we have learnt with NA2 that very large statistics can show new features with have not been seen before.

4.3 Conclusion

There is for 1984-1985 a clear physics interest in carrying out a high statistic muon nucleon experiment with 4π coverage and charged particle identification. Competitition from the collider is serious but it may not sweep the field since the physics is different and since charged particle identification is important. The doubler at FNAL will come later and as far as the approved program is concerned there is no high statistic experiment. This study will, at the same time, achieve the goal defined in 3.2.2, namely a study of the scaling violation and factorisation breakdown.

4.4 Proposal

Two ideas have been studied, the first one would just replace the streamer chamber which limits actually the luminosity and increases the target length. (The streamer chamber can be replaced by 20 proportional chambers (u, v, t) inside the vertex magnet).

The second idea is well studied and proposes to replace the streamer chamber by a modern tracking chamber, a TPC. Existing prototypes for a LEP experiment might even be well suited. A more or less complete particle identification can be achieved with three rich counters (2 gases and 1 liquid).

Overall, a gain of 10 over NA9 can be achieved in both proposals.

5. $F_2^{Fe}/F_2^{D^2}$ BEHAVIOUR

It has been observed that the structure function in the nucleus behaves differently than expected from the additive quark parton model. It cannot be attributed to Fermi motion effect (in fact, it will reinforce the difference at large x), it is likely that there is not a higher twist effect as it is observed at large Q^2 but from present data this cannot be excluded.

The observed difference implies that:

- the valence quark is softer in iron than deuterium;
- the sea carries more momentum in iron than deuterium;
- the glue carries 10% less momentum in iron.

At this stage it is certainly of prime importance to confirm the measurement. BCDMS can do a very good job for $x > 0.1$ in a little running time. They can eliminate most of the systematic errors by using a split target of iron and deuterium. The run can be carried out by 1983 and the results will appear in 1984. There have been different suggestions by C. Llewelyn Smith at this workshop and we can point out a few obvious measurements to be done.

5.1 Repeat the measurement on different nuclear targets

Find out if the magnitude of the effect depends on the nucleus. Run on D_2, He^4, Li, C, Ne, Ar, Xe, W... are easy to do but for running time.

5.2 Check if the effect comes from D_2

$$F_2^{\bar{\nu} p} = F_2^{\nu n} \qquad \text{so}$$

$$\frac{F_2^{\nu p} + F_2^{\bar{\nu} p}}{F_2^{\nu D_2}} = 1$$ if there is no nuclear effect in deuterium, any departure from 1 (apart the Fermi motion) would be an evidence for a nuclear effect in D_2. The number of events needed to get the statistical accuracy has not yet been sorted out. Neutrino interaction on p and D_2 cost a lot of protons.

5.3 More sea in iron than in deuterium

Looking in the hadronic final state for K/π ratio would be an indication on the behaviour of $\frac{s + \bar{s}}{u + d}$, it would need the measurement of K^+ and K^- particles or J/Ψ production ratio Fe/H_2 (being worked on)

5.4 Look for prediction of specific models

In the model presented by C. Llewelynn Smith where the virtual photon interact on pion from the nucleus one should have a typical hadronic final state with two rather small mass forward jets. Typically one should look in the same experiment for the complete hadronic final state to correlate eventual hadronic effect to the structure function.

5.5 Conclusion

It may be too early to conclude on this subject, more ideas will certainly develop in the coming years. Nevertheless, it would be worthwhile to think of an experiment with high statistics on nuclear targets;

- with 4π acceptance for the hadronic final state
- particle identification
- with mixed nuclear target in the same running time to eliminated some systematic errors (ex: D_2, He^4, Xe...).

In a NA9 type set-up (existing one or even better an upgraded version) 60 days running time would give more than 100k events. Indeed, such an experiment will be fine for the study of interaction in nucleus.

CONCLUSION

These conclusions are obviously schematic and subject to personal appreciation.

(a) Structure function

- A lot is known, final progress is expected from 1983-1984;
- further development might be needed if nuclear effect disqualifies iron targets (it should be noticed that QCD analysis may not be affected);
- understanding of $F_2^{Fe}/F_2^{D_2}$ is urgently needed

BCDMS can confirm this measurement.

"NA9" set-up can look for associated hadronic effect (it will also study the space time evolution of hadronic final state formation in nucleus).

(b) Weak interaction

- B is measured
- $A^{\pm}$ can also be measured, improved $\sin^2\theta$ measurement down to 0.01.

(c) Hadronic final state

- A lot is known and NA9 will give full topology events;
- upsilon and open $B\,\bar{B}$ muoproduction can be achieved in a high statistic experiment;
- high statistic jet study is still to be done. 500000 events with 4π coverage and full identification. This will give the flavour and charge content of q, g jets, it will also give a detailed study of fragmentation breaking, scaling violation, higher twist.....

(d) Time schedule

- The approved program is unlikely to fit into 1983-1984. Further studies would have to carry on into 1985-1986.

ACKNOWLEDGEMENT

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A LIST OF CONTRIBUTIONS TO THE WORKSHOP

- Structure function resumé by F. Eisele
  - The ratio $F_2^{F^2}/F_2^{D^2}$ by K. Rith
  - CDHS prospective by A. Para
  - EMC prospective by A. Edwards
  - CHARM prospective by P. Longo
  - BEBC prospective by G. Myatt
  - BCDMS prospective by A. Staude

- Weak effect resumé by A. Benvenuti
  - $A^{\pm}$ measurement by M. Klein
  - direct charged current weak cross section measurement by G. Vesztergombi
  - beam polarisation measurement by F. Navarria

- Hadronic final state resumé by H. Montgomery
  - $B\ \bar{B}$ production by K. Goesling
  - scaling violation, factorisation breaking by W. Stockhausen
  - heavy target measurement by G. Coignet
  - FNAL planes by V. Eckardt
  - comparison of ν and μ possibilities by W. Wittek
  - proposal for a new improved set-up for jet studies by H. Braun.

A LIST OF PUBLISHED RESULTS BY CDHS, CHARM, BEBC, BCDMS, EMC COLLABORATIONS

CDHS

1. Is there a high-y anomaly in anti-neutrino interactions? by M. Holder et al. Physics Review Letter 29, 433 (1977) (29 authors).

2. A detector for high energy neutrino interactions by M. Holder et al. Nucl. Instr. Methods 148, 235 (1978) (39 authors).

3. Performance of a magnetized total absorption calorimeter between 15 GeV and 140 GeV by M. Holder et al. Nucl. Instr. Methods 151, 69 (1978) (30 authors).

4. Inclusive interactions of high energy neutrinos and anti-neutrinos in iron by H. de Groot et al. Zeitschr. für Physik C1, 143 (1979) (37 authors).

5. Comparison of moments of the valence structure functions with QCD prediction by H. de Groot et al. Physics Letters 82B, 292 (1979) (37 authors).

6. QCD analysis of charged current structure functions by H. de Groot et al. Physics Letters 82B, 456 (1979) (37 authors).

7. The response and resolution of an iron-scintillator calorimeter for hadronic and electromagnetic showers between 10 GeV and 140 GeV by H. Abramowicz et al. Nucl. Instr. Methods 180, 429 (1981) (34 authors).

8. A measurement of the ratio of longitudinal and transverse structure functions in neutrino interactions between 30 and 200 GeV by H. Abramowicz et al. Physics Letters 107B, 141 (1981) (37 authors).

9. Determination of the gluon distribution in the nucleon from deep inelastic neutrino scattering by H. Abramowicz et al. Zeitschr. für Physik C 12 (1982) 289-295 (35 authors).

10. Tests of QCD and non-asmyptotically free theories of the strong interaction by an analysis of the nucleon structure.functions xF_3, F_2 and q by H. Abramowicz et al. Zeitschr. für Physik C 13 (1982) 199-204.

CHARM

CERN-EP/80-46	Performance of a large system of proportional drift tubes for a fine-grain calorimeter	NIM 176 (1980) 189
CERN-EP/80-63	A detector for neutral-current interactions of high-energy neutrinos	NIM 178 (1980) 27
CERN-EP/81-16	Experimental study of differential cross-sections $d\sigma/dy$ in neutral current neutrino and antineutrino interactions	Phys. Lett 102B (1981) 67
CERN-EP/81-95	Experimental study of opposite-sign and same-sign dimuon events produced in wide-band neutrino and antineutrino beams	Phys. Lett 107B (1981) 241
CERN-EP/81-135	Experimental study of differential cross-sections in charged-current neutrino and antineutrino interactions	Phys. Lett 109B (1982) 133
CERN-EP/82-08	The reponse and resolution of a fine-grain marble calorimeter for hadronic and electromagnetic showers	NIM 200 (1982) 183
CERN-EP/82-194	Experimental study of the nucleon structure functions and of the gluon distribution from charged-current neutrino and antineutrino interactions	Phys. Lett.

BEBC and GGM

WA19 Bosetti et al. 1978 Nucl. Phys. B 142 (1978) 1.

WA21 Determination of the quark density ratio d(x)/u(x) in the proton. ABCMD. Allen et al. Phys. Lett. 103B (1981) 71.

WA24 Measurement of the total and differential cross section on neutrons and protons for charged current neutrino events. BEBC-TST. Armenise et al. Phys. Lett 102B (1981) 374.

WA25 Measurement of the ratios of $\overset{\leftrightarrow}{\nu}\mu$ n to $\overset{\leftrightarrow}{\mu}\nu$ p charged current cross sections at high energies. DphPE 81-07, (Saclay preprint).

WA47 Comparison of nucleon structure functions in bubble chamber neutrino experiments with QCD predictions. ABCDLOS. Bosetti et al. Nucl. Phys. B (1981).

WA47 Bosetti et al. Nucl. Phys. B 203 (1982) 362.

GGM J. Morfin et al. Phys. Lett. 104B (1981) 235.

NB BEBC-GGM results combined (WA19/47) by G. Myatt, reported at 21st International Conference on high energy physics Paris 1982. Barker et al. QCD analysis of non-singlet neutrino structure functions.

NA4 - BCDMS

1. D. Bollini et al., Phys. Lett. 104B (1981) 403. A measurement of the nucleon structure function from muon carbon deep inelastic scattering at high Q^2.

2. D. Bollini et al., Nucl. Phys. B 199 (1982) 27. Muon pairs and upper limit for upsilon production by 280 GeV muons.

3. D. Bollini et al., Preprint CERN/EP/82-55, subm. to Nucl. Instr. Meth. A high luminosity spectrometer for deep inelastic muon scattering experiments.

4. A. Argento et al., Preprint CERN/EP/82-149, subm. to Phys. Lett. B. Electroweak asymmetry in deep inelastic muon-nucleon scattering.

EMC

1980	Measurement of J/D Production in 280 GeV/c μ+ Iron Interactions The EMC	79-140	Phys. Lett. 89B 2 (1980) 267
8/05	A Study of Dimuon Events in 280 GeV Muon Interactions The EMC	80-61	Phys. Letters 94B 1 (1980) 96
2/06	A Study of Trimuon Events in 280 GeV Muon Interactions The EMC	80-62	Phys. Letters 94B 1 (1980) 101
3/06	Inelastic J/ψ Production in 280 GeV Muon Iron Interactions The EMC	80-84	Phys. Lett. 89B (1980) 267
4/07	Transverse Momentum of Charged Hadrons Observed in Deep Inelastic Muon Scattering The EMC	80-119	Phys. Letters 95B 2 (1980) 306
29/07	A Large Magnetic Spectrometer System for High Energy Muon Physics The EMC	80-134	NIM 179 (1981) 445

1981

2/02	Evidence for Planar Events and a Forward Double Jet Structure in Deep Inelastic Muon Scattering The EMC	81-10	Phys. Lett. 100B 5 (1981) 433
3/04	A Measurement of Wide Angle Bremsstrahlung in a High Energy Muon Scattering Experiment as a Check on the Consistency of Radiative Correction Calculations The EMC	81-29	Z. für Phys. C Part. and Fields 10 (1981) 101
6/06	Forward Produced Protons and Antiprotons in Deep Inelastic Muon Proton Scattering The EMC	81-53	Phys. Lett. 103B (1981) 388
4/08	Measurement of the Proton Structure Function F_2 in Muon-Hydrogen Interactions at 120 and 280 GeV. The EMC	81-84	Phys. Lett. 105B (1981) 315
4/08	Measurement of the Nucleon Structure Function F_2 in Muon-Iron Interactions at 120, 250 and 280 GeV. The EMC	81-85	Phys. Lett. 105B (1981) 322
4/08	Observation of Wrong-Sign Tri-Muon Events in 250 GeV Muon-Nucleon Interactions The EMC	81-87	Phys. Lett. 106B (1981) 419

7/12	An Experimental Limit on the Intrinsic Charm Component of the Nucleon The EMC	81-161	Phys. Lett. 110B (1982) 73

1982

26/04	Measurement of the Q^2, x and W^2 Dependence of Single Hadron Production in Deep Inelastic Muon Scattering The EMC	82-47	Phys. Lett. 114B (1982) 373
29/04	QCD Analysis of the Structure Function F_2 in Muon Nucleon Scattering The EMC	82-48	Phys. Lett. 114B (1982) 291
16/09	Balance of Transverse Momentum of Hadrons Produced in Deep Inelastic Muon Proton Scattering (Submitted to Physics Letters) The EMC	82-146	
4/10	Production of Charmonium in 250 GeV μ^+-Iron Interactions The EMC	82-152	
4/10	Production of Charmed Particles in 250 GeV μ^+-Iron Interactions The EMC	82-153	
15/10	Measurement of $R = \sigma_L/\sigma_T$ in Deep Inelastic Muon-Proton Scattering The EMC	82-159	
20/10	The Vertex and Large Angle Detectors of a Spectrometer System for High Energy Muon Physics The EMC	82-160	

FIGURE CAPTIONS

Fig. 1 Example of structure function determination F_2^{iron} by EMC, xF_3 and $\bar{q}$ by CDHS.

Fig. 2 S(x) and C(x) measured by CDHS and EMC.

Fig. 3 F_2^n/F_2^p measured by EMC.

Fig. 4 Ratio and $F_2^{iron}/F_2^{D_2}$ measured by EMC.

Fig. 5 Expected result on the measurement of the slope of the structure function

$$\frac{\delta \operatorname{Log} F_2(x,Q^2)}{\delta \operatorname{Log} Q^2}$$ by BCDMS approved program.

Fig. 6 p_T broadening observed in μ proton scattering.

Fig. 7 Evidence for two jets structure
- Σp_T^2 on the plane or out of the plane of the two jets events
- energy flow of the forward produced hadrons.

Fig. 8 Forward production of fast antiproton normalised to all negative particules in the same momentum range.

Fig. 9 Proposed set-up for B $\bar{B}$ studies.

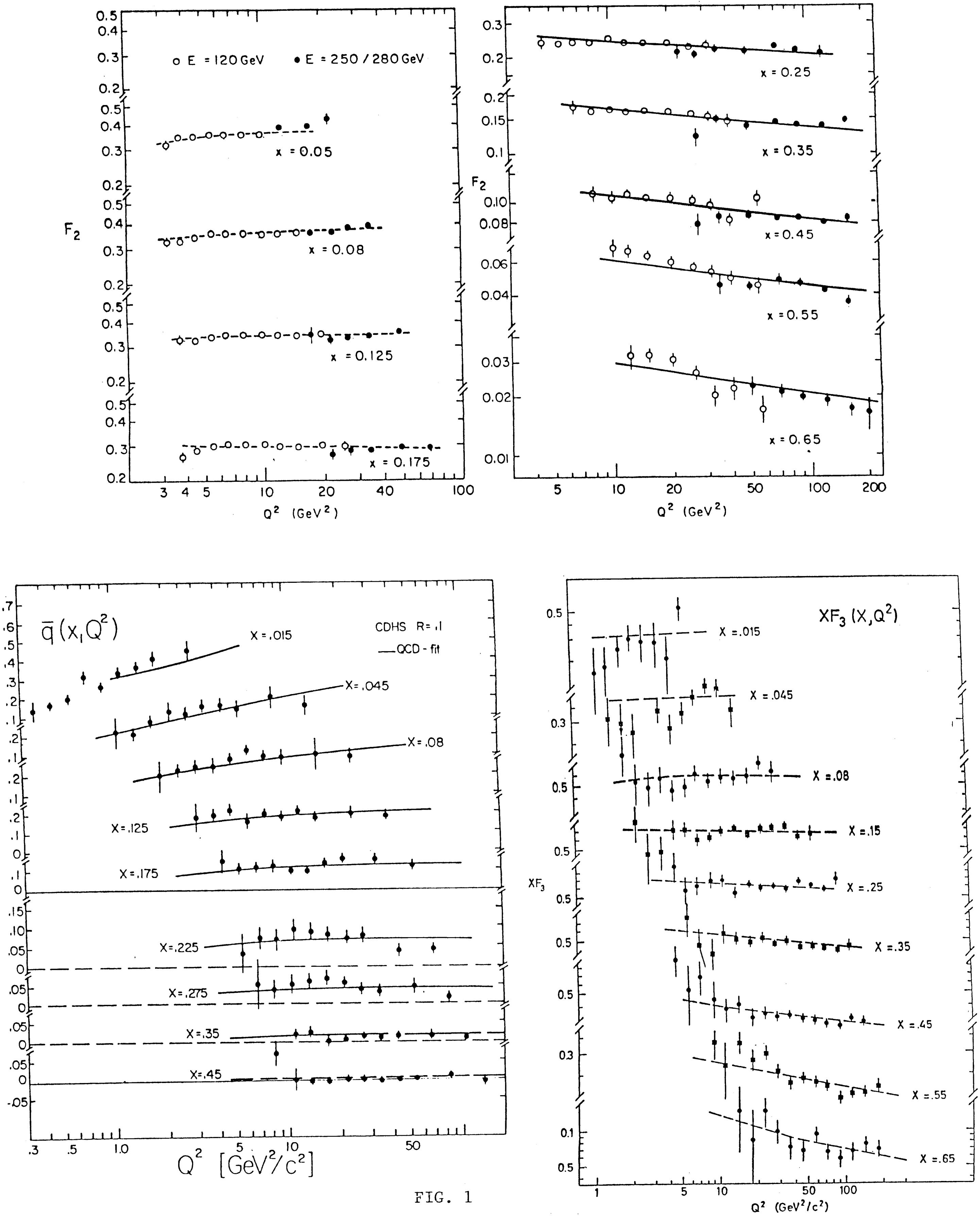
F$_2$
○ E = 120 GeV
● E = 250 / 280 GeV
x = 0.05
x = 0.08
x = 0.125
x = 0.175
Q^2 (GeV^2)
x = 0.25
x = 0.35
x = 0.45
x = 0.55
x = 0.65
Q^2 (GeV^2)
$\bar{q}(x, Q^2)$
CDHS R= .1
—— QCD - fit
X = .015
X = .045
X = .08
X = .125
X = .175
X = .225
X = .275
X = .35
X = .45
Q^2 [GeV^2/c^2]
XF$_3$ (X, Q^2)
XF$_3$
X = .015
X = .045
X = .08
X = .15
X = .25
X = .35
X = .45
X = .55
X = .65
Q^2 (GeV^2/c^2)

FIG. 1

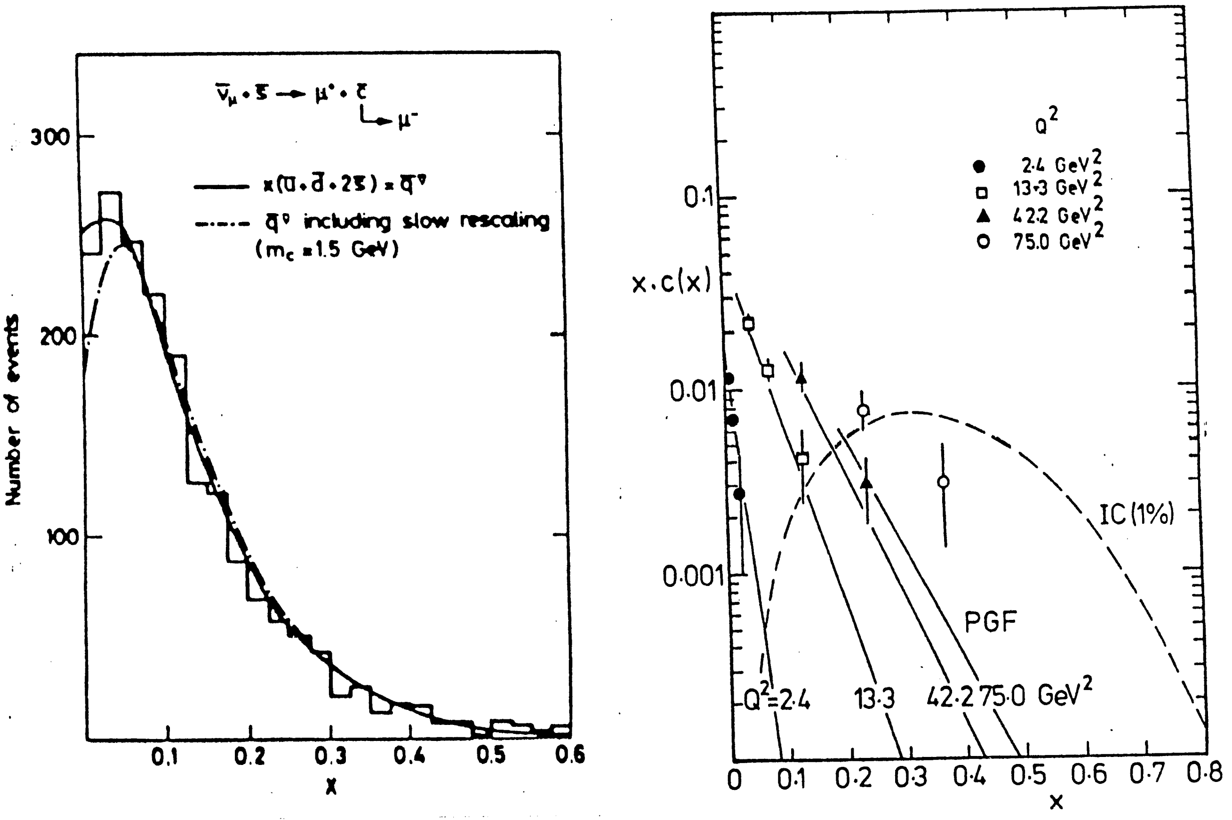
$\bar{\nu}_\mu + \bar{s} \rightarrow \mu^+ + \bar{c}$
$\hookrightarrow \mu^-$
$x(\bar{u}+\bar{d}+2\bar{s}) = \bar{q}^\nu$
$\bar{q}^\nu$ including slow rescaling
(m_c = 1.5 GeV)
Number of events
300
200
100
0.1
0.2
0.3
0.4
0.5
0.6
x
Q^2
2.4 GeV^2
13.3 GeV^2
42.2 GeV^2
75.0 GeV^2
0.1
0.01
0.001
x.c(x)
IC (1%)
PGF
Q^2=2.4
13.3
42.2
75.0 GeV^2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x

FIG. 2

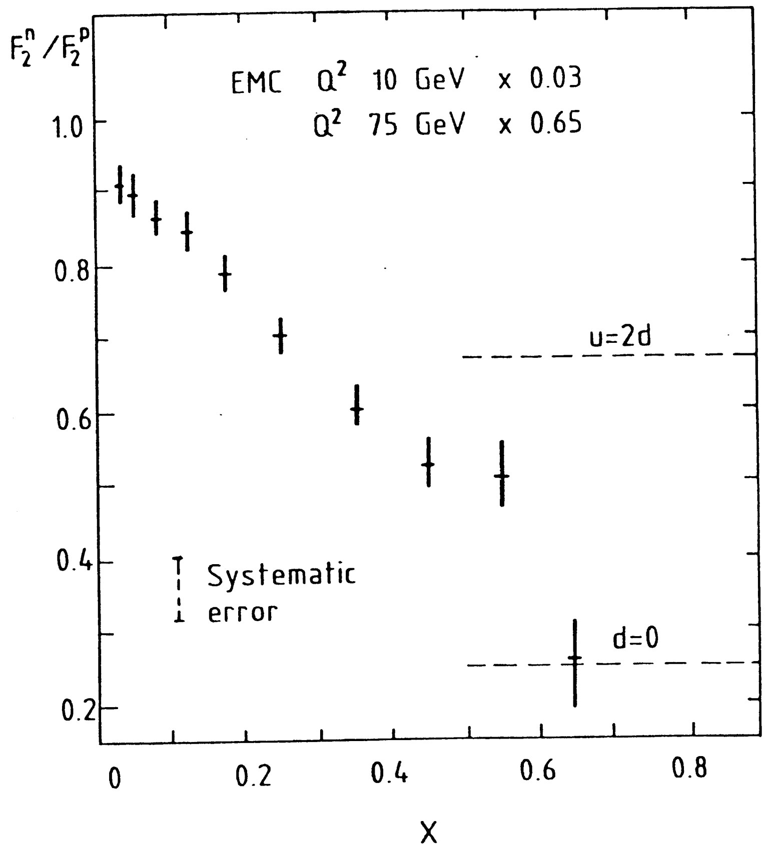
F_2^n/F_2^p
EMC Q^2 10 GeV x 0.03
Q^2 75 GeV x 0.65
1.0
0.8
0.6
0.4
0.2
u=2d
d=0
Systematic error
0
0.2
0.4
0.6
0.8
X

FIG. 3

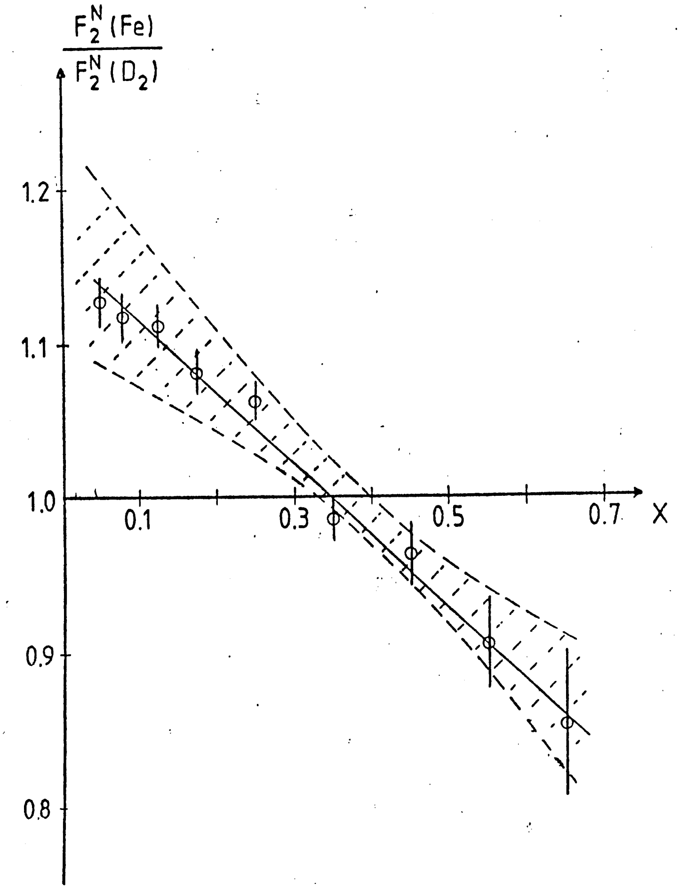
$\frac{F_2^N(Fe)}{F_2^N(D_2)}$
1.2
1.1
1.0
0.9
0.8
0.1
0.3
0.5
0.7
X

FIG. 4

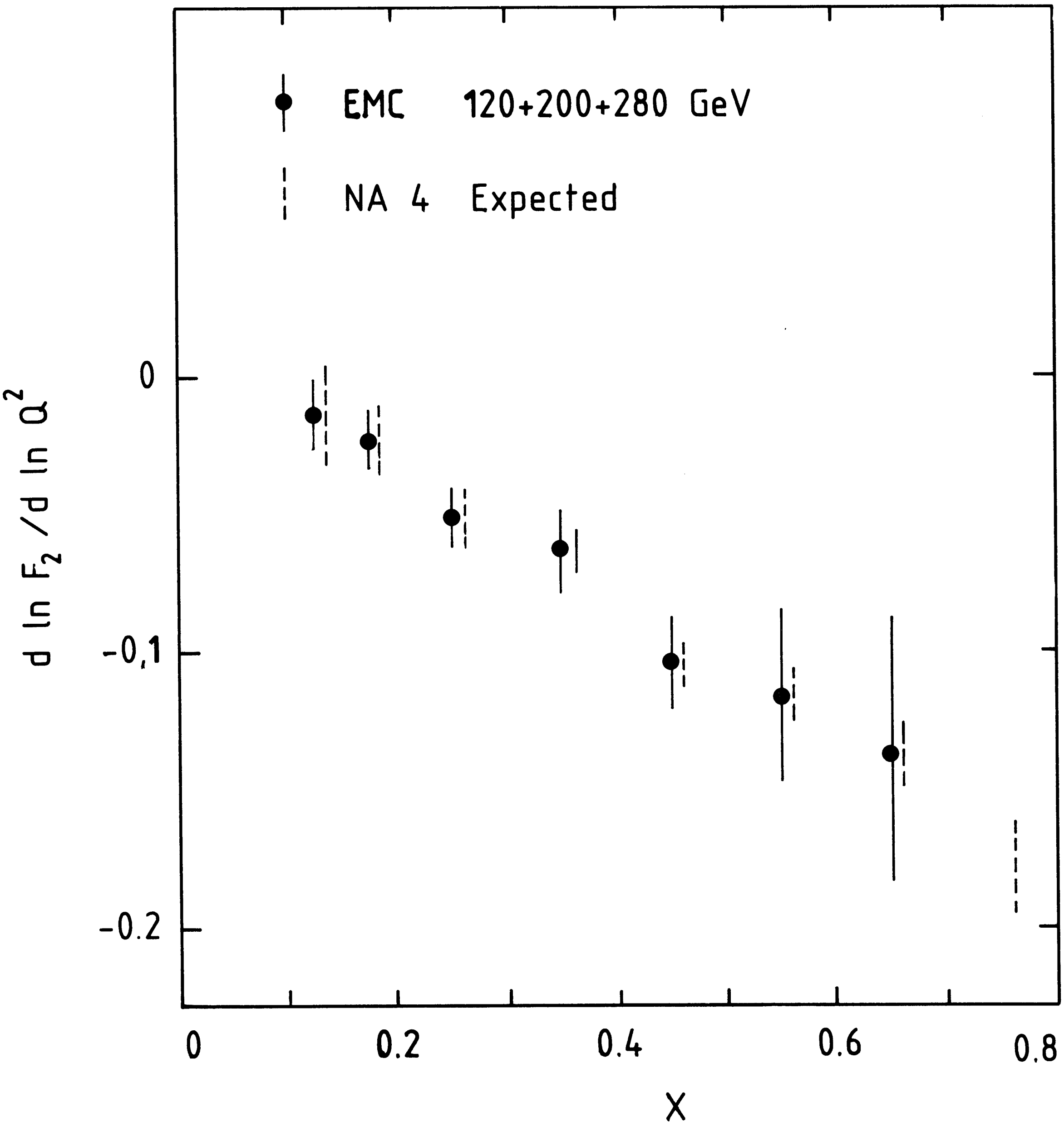
EMC 120+200+280 GeV
NA 4 Expected
0
-0,1
-0.2
d ln F_2 /d ln Q^2
0
0.2
0.4
0.6
0.8
X

FIG. 5

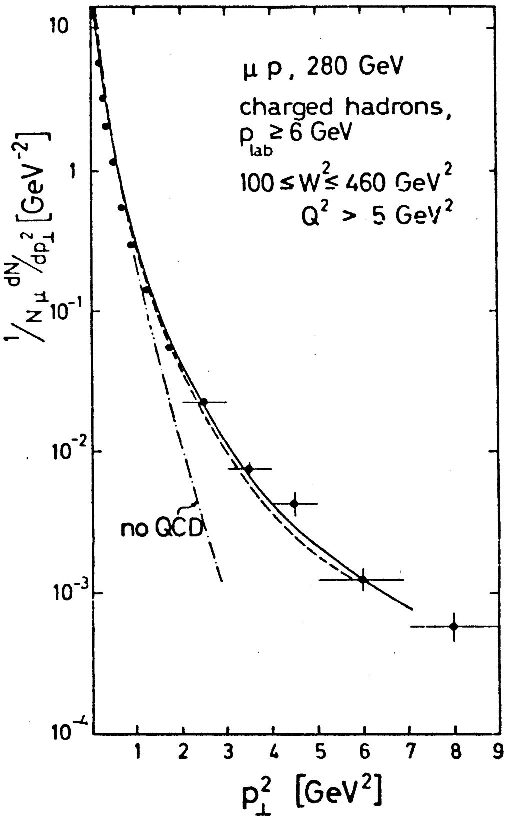
μ p, 280 GeV
charged hadrons,
$p_{lab} \geq 6$ GeV
$100 \leq W^2 \leq 460$ GeV^2
$Q^2 > 5$ GeV^2
no QCD
$1/N_\mu \, dN/dp_\perp^2$ [GeV^{-2}]
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
1
2
3
4
5
6
7
8
9
$p_\perp^2$ [GeV^2]

FIG. 6

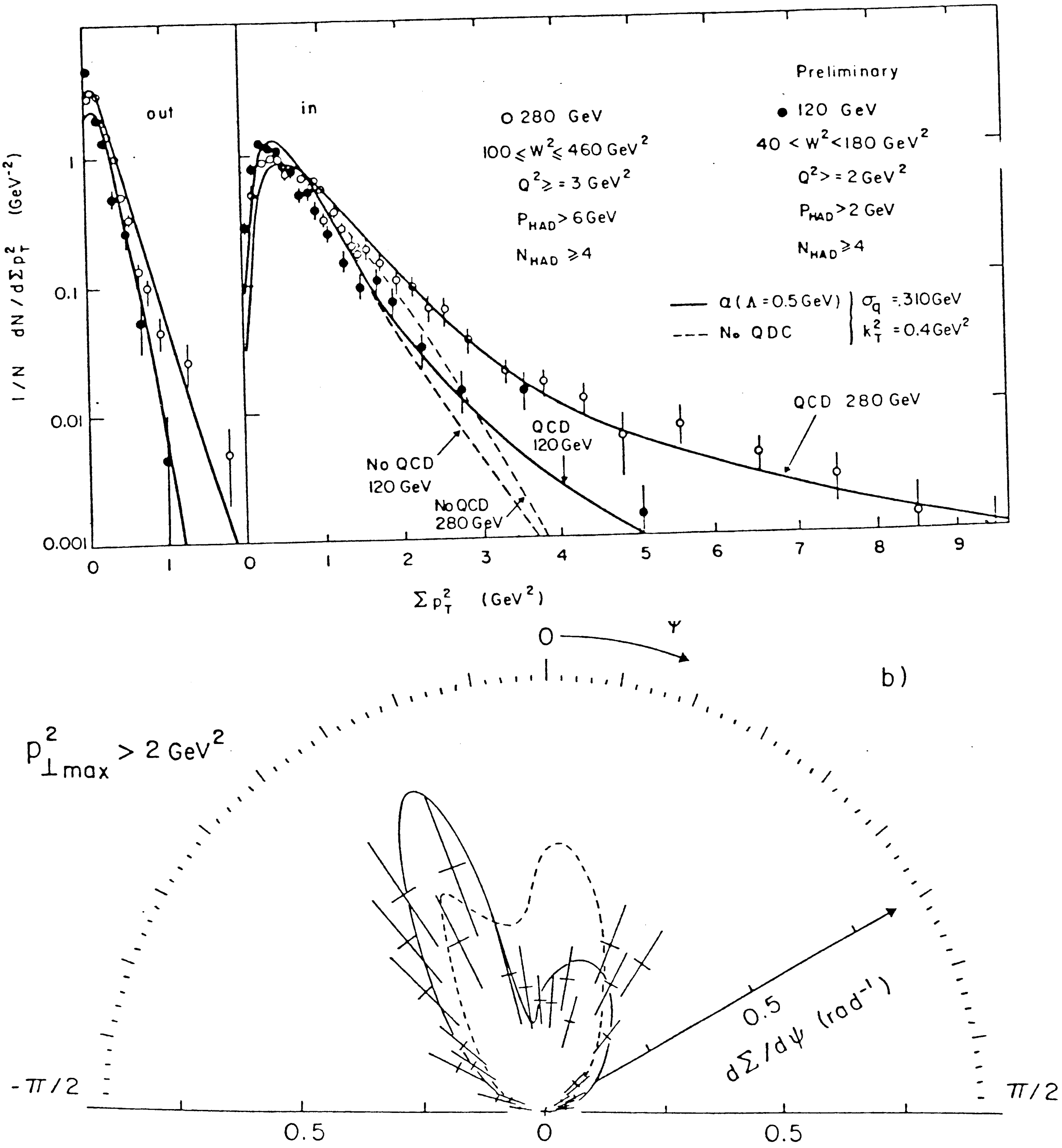
out
in
Preliminary
○ 280 GeV
$100 \leq W^2 \leq 460\ \mathrm{GeV}^2$
$Q^2 \geq = 3\ \mathrm{GeV}^2$
$P_{HAD} > 6\ \mathrm{GeV}$
$N_{HAD} \geq 4$
● 120 GeV
$40 < W^2 < 180\ \mathrm{GeV}^2$
$Q^2 > = 2\ \mathrm{GeV}^2$
$P_{HAD} > 2\ \mathrm{GeV}$
$N_{HAD} \geq 4$
—— $\alpha(\Lambda = 0.5\ \mathrm{GeV})$
--- No QDC
$\sigma_q = .310\ \mathrm{GeV}$
$k_T^2 = 0.4\ \mathrm{GeV}^2$
QCD 280 GeV
QCD 120 GeV
No QCD 120 GeV
No QCD 280 GeV
$1/N\ dN/d\Sigma p_T^2\ (\mathrm{GeV}^{-2})$
1
0.1
0.01
0.001
0
1
0
1
2
3
4
5
6
7
8
9
$\Sigma p_T^2\ (\mathrm{GeV}^2)$
0
Ψ
b)
$p^2_{\perp max} > 2\ \mathrm{GeV}^2$
$-\pi/2$
$\pi/2$
0.5
$d\Sigma/d\psi\ (\mathrm{rad}^{-1})$
0.5
0
0.5

FIG. 7

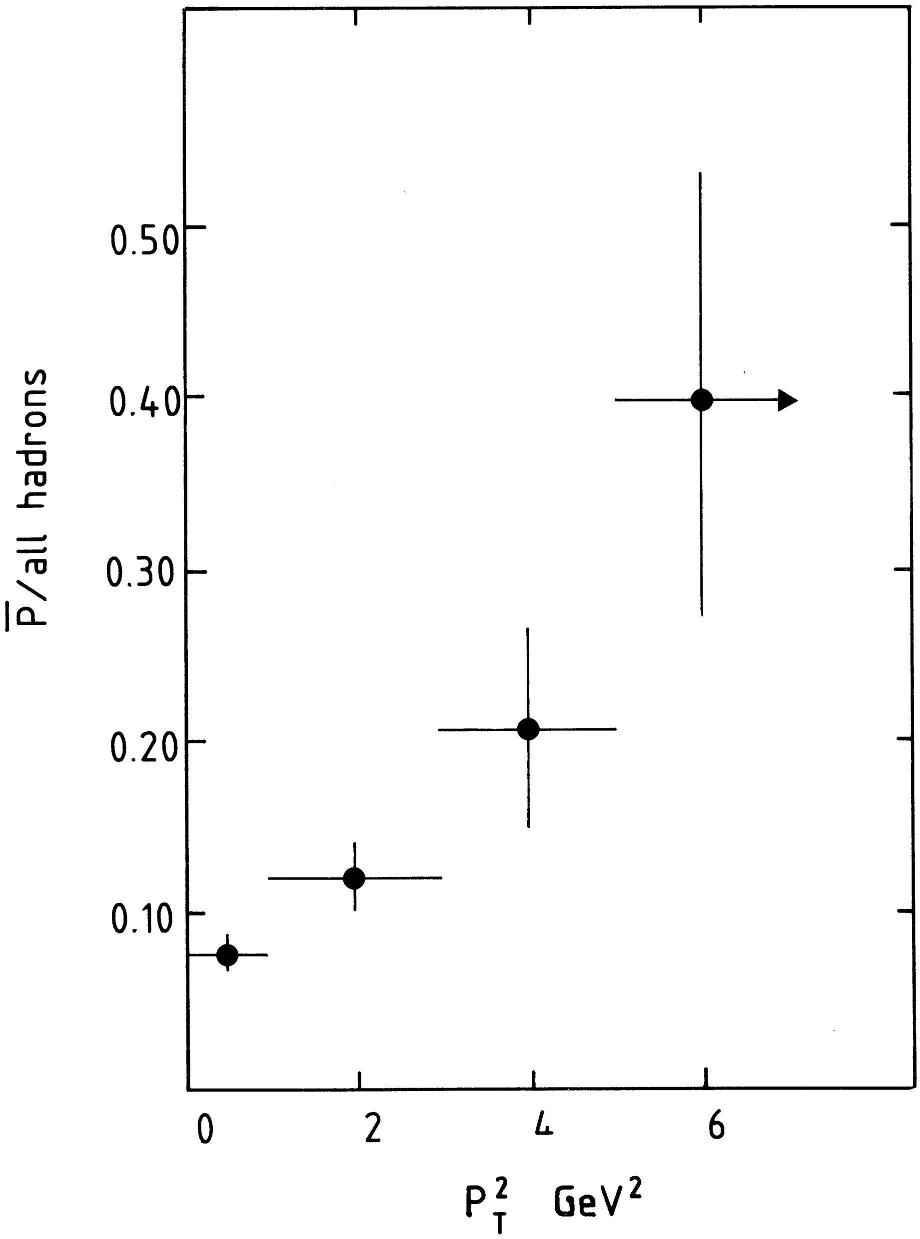

FIG. 8

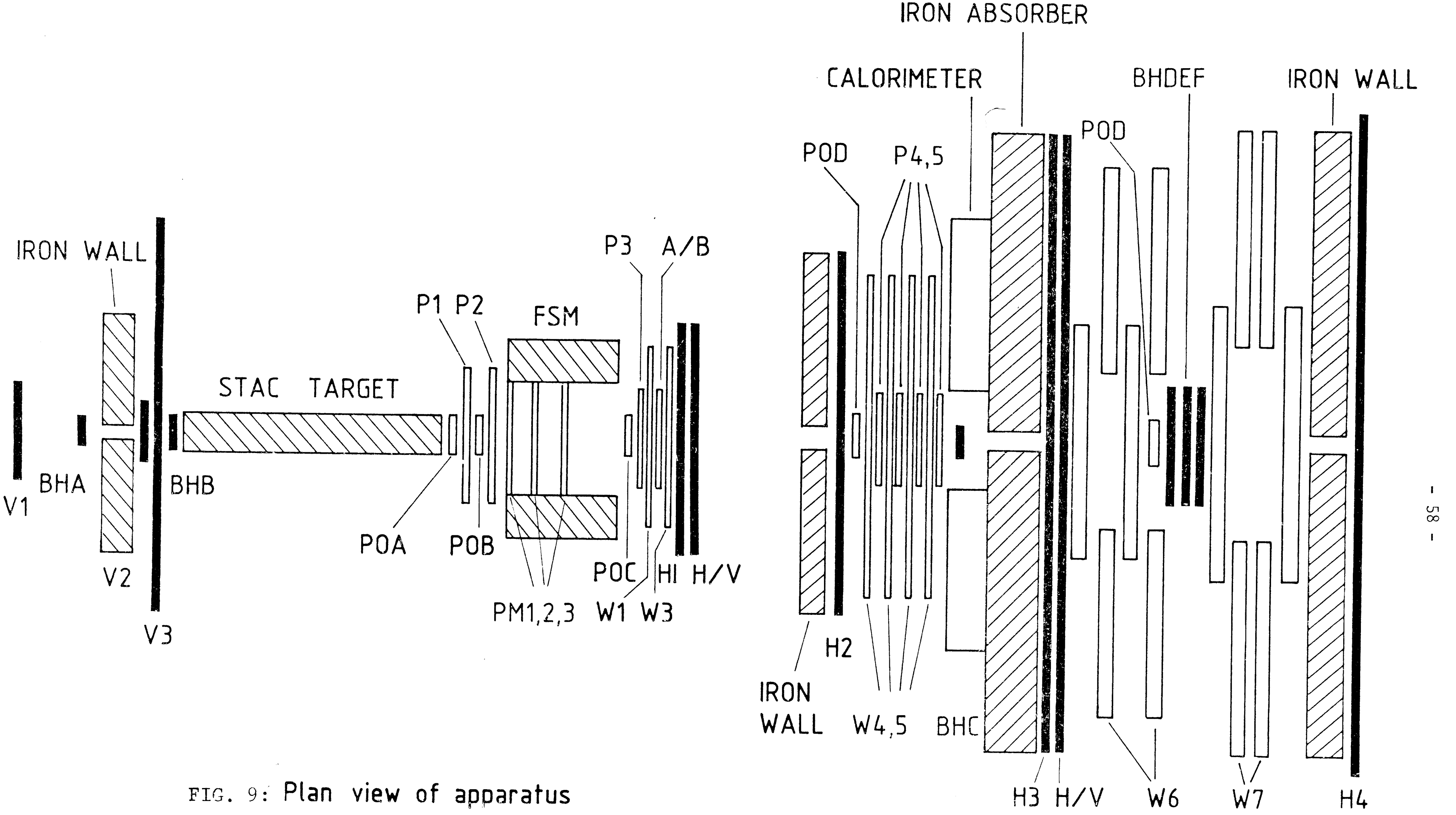

FIG. 9: Plan view of apparatus

DISCUSSION

A. Para: I have a comment on the possible improvement in the measurement of structure functions. At present, the longitudinal structure function is particularly badly known and this causes several limitations on the measurements of F_2 and $\bar{q}$. Recently, CDHS has invented a new method to determine R which is much more precise in principle. For the moment we are limited by statistics, therefore we hope in the next two-three years, with the wide-band beam exposure, to be able to measure R with a much better precision and are going to much smaller values of x, down to 0.1 probably, and the absolute error on q_1 should be of the order of several per cent, which is comparable to your aim.

J.J. Aubert: I appreciate that. If I have not stressed it enough in my talk, it is my mistake. The only thing that I want to add is that, clearly you will do a very good job down to $x = 0.1$. However, if one wants to go below $x = 0.1$ (and I think this is interesting because there is not a clean agreement with the sharp increase which you expect on R for $x < 0.1$), this probably should be done with muon beam and definitely the accuracy is worse and is limited by systematics to the level of 0.1. On the other hand, it is clear that the neutrino will probably clear up the problem of the R value for x between 0.1 and 0.6 or 0.7.

E. Leader: If I were to play the devil's disciple and to ask you in a totally objective fashion why you want to measure $F_2(x)$, I presume the answer would be because you essentially want to know about the structure of a hadron, and I think something which has been totally failed to be stressed, is that it is just as important to learn about G_1 and G_2 as it is to learn about F_1, F_2 and F_3. If your interest is in learning about what is inside a hadron, then the distribution of spin of constituents inside a hadron is as fundamental a question as the distribution of the momentum inside it.

J.J. Aubert: I appreciate that. If I have not overstressed this measurement on polarized target, where there is access to, in fact, more or less only one structure function, it is because it is a very difficult experiment and that you cannot do on G_1 and G_2 measurement as good a job as you can do on F_1, F_2 and xF_3. This is the fact of life and there are some improvements which we can think of. For example, when we think of putting this polarized target in front of a NA4 set-up, and to run with 3×10^8 incident muon per pulse and collect very high statistics, but still, if one does this measurement I believe clean determination on the x dependence will be done, but only a poor determination of q^2 evolution can be achieved and for the time being, if you are only looking for log q^2 effect, the life is very difficult in polarized experiments.

K. Pretzl: I wonder why, in your jet factory you left the photoproduction out - after all, they have much higher luminosities in a certain energy range.

J.J. Aubert: I have not thought about the photoproduction, and I apologize. There will be a talk on that later to-day by Daniel Treille, but my feeling is still that if you do a good job on something like muon event, it would be very difficult to do much better in the same energy range.

J. Lefrançois: I would like to be your devil's advocate in your comparison with Fermilab. There are two subjects in connection with which I would like to question what you said. One is the fact that one experiment could do some $B\bar{B}$ production by looking at multi-muon here. Now they have a very good spectrometer for multi-muon at Fermilab which is the transformer-type experiment, which produced already some good results, and their muon beam will be of high energy and that, obviously for $B\bar{B}$, is the kind of thing you'd like to do, so it seems to be a point.

J.J. Aubert: As far as cross-section is concerned, there is no question. At SPS the $B\bar{B}$ production is near threshold, so definitely, the rate is higher if you go at higher energies. Physicswise, as far as the gluon fusion model is concerned, the measurements at threshold are very interesting. On the other hand, if one looks at what has previously been done with the existing set-up, there have been limitations for the same set-up which they have now; for example with high luminosity they have not been able to look for $\mu^+\mu^+\mu^+$ events. It might just be that they have not thought about it, or might also be due to real limitations. This set-up is not as good as you think!

J. Lefrançois: I would also like to question your relative appreciation of statistics and W. I do not have exact numbers for what has happened at PETRA, but I have the feeling that when they increased the energy from running at 12 against 12 GeV or something like that to running at 17 against 17 GeV, it made a dramatic improvement on the measurements of their gluon jets; so it would seem to me that the increase in W at Fermilab might be more important than you said.

J.J. Aubert: It is always a question of taste in the end, but I will stress the following 1) First the time scale: I mean this kind of physics may not still be so interesting in the 1990's. 2) Statistics is fundamental and this we have seen in NA2. You never have large enough statistics, even out of a large sample of events, as soon as you want to look for quantum numbers and flavour identification! Apart from that, it is clear that it would certainly be better to have larger W-values but that is not possible at SPS energies.

H. Montgomery: I have a comment to Pretzl's question: I think it is clearly interesting to do the jets study in many different interactions but the point here is that with a virtual photon you have a *a priori* argument that you have a point interaction, whereas with the incident photon you have to work harder and at least start with a high p_t^2, whereas the fact that you have a finite q^2 in the virtual photon interaction gives you *a priori* the knowledge that you are working with the Parton model.

D. Morrison: In your list of structure functions, there is perhaps one thing that has not been emphasized enough that although we know very good structure functions for iron, it is very important to know the structure function for protons, as protons are the most fundamental thing. And to give you a very elementary illustration to this, there was a lecture by someone from the UA2 Collaboration trying to interpret the high p_t data from the $p\bar{p}$ collider, and he did not know which gluon structure functions to use, so he used three different ones, but they differed by a factor of 4 at $x = 0$. This is to give you some idea of the uncertainty, that we just do not know what the proton is like. Now, the question how to do it: you must have a hydrogen target if you want to have F_2 and xF_3 and the only way is with neutrinos and antineutrinos. So I think that major experiments with ν and $\bar{\nu}$ on hydrogen targets are necessary.

J.J. Aubert: Indeed, I would also like to stress the fact that if this nuclear effect is confirmed, one certainly would have to do more work on hydrogen. I would still, nevertheless question one point. That is, I think F_2 for proton is better measured in a muon beam. It is already well measured and its study will be completed with the BDCMS determination and the low x measurements which can be done by EMC. I do not know what kind of accuracy can be reached on the shape of the G(x) with 40 K events, but this just lies in your hands, and it has not been shown at this Workshop.

M. Albrow: Do I understand correctly that your definition of W in hadron-hadron collisions producing two high p_t jet events is the effective mass of the pair of jets? Is that how you define W, or is it q^2 or something like that? Is it not the p_t of one jet?

J.J. Aubert: No, no. What is called W, if you take for example the case pp collision, is $x_1 \cdot x_2 \cdot \sqrt{s}$.

M. Albrow: Then I must question your comparison of the jet factory transparency where you say W is abut 15 GeV for the ISR. We have estimated that in a few months of special running we can get the order of 10000 jets with W > 40 GeV and these are 80% u-quark jets.

J.J. Aubert: I appreciate that - I am also aware of it. I do not know if you will have them, but OK.

I. Mannelli: Because of the machine closure?

J.J. Aubert: Yes, and this does not depend on us....

L. van Rossum: The SLAC results on the helicity of the valence u-quarks in protons of definite helicity has become a fundamental piece of information on the structure of nucleons. Now, concerning the equivalent of d-quarks in neutrons: From the point of view of time scale, it looks as if the polarized target in the muon beam at CERN is a perfectly good competition with the corresponding SLAC experiment with polarized electrons. At the level of special techniques, they are also exactly equal. In both cases it would simply mean to go from NH_3 to ND_3 targets, so the question is if this has been considered in the context with the use of polarized target in muon beam to study the spin structure function of d-quarks in neutrons.

J.J. Aubert: I am not able to answer - perhaps Al Edwards could answer that.

A. Edwards: If you wanted to do that, you would need to have a deuterated material, and the neutrino polarization is not too high - 25 to 30%. If you put the polarized target in front of NA4 and run with a beam of $3 \cdot 10^8$ μ per pulse, it may barely be a possible experiment.

I. Mannelli: Anyhow, there is progress in this material for polarized target and evidently you are considering the possibility of also having higher intensity in a new situation, so presumably it is not a lost remark.

F. Dydak: We have heard that 40 days of data taking would enable BCDMS next year to confirm the nuclear effect of EMC. Could we have an estimate of the time needed for analysis; in other words, at which point in time could we have a confirmation of these results?

J.J. Aubert: Feltesse, do you want to answer?

J. Feltesse: ....

I. Mannelli: So, the answer is middle of 1984.