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STUDY OF NUCLEAR EFFECTS IN NUCLEON STRUCTURE FUNCTIONS UP TO AND BEYOND THE KINEMATIC LIMIT

1985

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INTRODUCTION

As is well known, an investigation of deep inelastic scattering (DIS) of leptons on nucleons and nuclei in the range of 4-momentum transfers Q^2* up to 200 GeV^2 has yielded extremely valuable information on nucleon structure and scaling violation hypothesis. Important results demonstrating the existence of nuclear effects in the x-behaviour of nucleon structure functions (EMC effect) have been also obtained. Unfortunately, high energy muon and neutrino experiments have been carried out in a rather limited range of the Bjorken variable x below $x = 0.7$. Data that can be obtained over a range of $x > 0.7$ cannot be considered only as complementary to those already obtained in a low x region. They are essential for accurate determination of the QCD parameter Λ and are expected to be decisive for understanding a quark-parton picture of the nucleus.

We therefore propose to carry out dedicated measurements of nuclear structure functions in a high x range, that is, out of reach for present high energy DIS experiments.

Three principal points of such a study are listed below.

i) Study of the x-dependence of nucleon structure functions in a region of $0.4 < x < 1.0$ and their sensitivity to atomic weight A and Q^2 over ranges of $A = 2$-207 and $Q^2 = 50$-200 GeV

ii) Measurement of the x-dependence of nucleon structure functions on deuterium and iron nuclei up to the highest possible x, tentatively up to $x = 2$ for iron and $x = 1.5$ for deuterium.

iii) Study of the x-dependence of the ratio of iron to deuterium structure functions over the range up to $x = 1.5$.

All the measurements can be performed with the BCDMS setup [1] after minor modifications. We are going to exploit main advantages of the existing apparatus: a) high luminosity, b) high and flat acceptance at large Q^2 and x, and c) selective Q^2 and x trigger. A principal change in the setup will be the addition of a hadron calorimeter to measure the energy of hadrons produced in DIS.

* We use standard notation for kinematic variables of muon-nucleon DIS: $E(E')$, $P(P')$ and $\theta(\theta')$ are the energy, momentum and angle of incident (scattered) lepton, M is the nucleon mass, $Q^2 = 4EE'\cdot\sin^2(\theta'/2)$, $\nu = E - E'$ and $x = Q^2/2M\nu$.

The programme of the measurements including calibrations and data taking needs two years starting from 1986.

2. PHYSICS MOTIVATIONS

2.1. Nucleon Structure Functions Near The Kinematic Limit $x \sim 1$

The discovery of the EMC effect [2] has taught us that a number of features of deep inelastic scattering of leptons on nuclei can be very important for understanding nuclear structure. A number of theoretical models describing the EMC effect has been developed. Most of them [3,4] explain the effect inside the explored kinematic range, but they can be critically tested only outside the region of measurements performed. It is quite natural therefore to extend investigations to the range of the Bjorken variable x, where either no or only poor information on structure functions is available. First of all, it is a small x region that will be studied thoroughly in the experiment proposed recently [5] at CERN. The region of large x is assumed to be investigated in the framework of the present proposal. It should be noted that single nucleon kinematics allows for $x_{max} = 1$. Calculating the Bjorken x for nuclear targets, we shall use $M = 1$ instead of $M = A$. Then for the kinematic limit of the nucleus we obtain $x_{max} = A$. Estimates of the x-dependence of structure functions for $x > 1$ are strongly model-dependent, but it is clear that for present muon and neutrino beams the region beyond $x = 2$ remains inaccessible due to statistical limitations.

The European muon collaboration (EMC) demonstrated in 1983 that there existed a difference in the x-dependence of nucleon structure functions measured on free nucleons and on those bound in nuclei. It has been also found that nuclear medium does not affect the Q^2-dependence of structure functions. The ratio of structure functions measured on iron and deuterium and integrated with respect to the Q^2 range is shown in fig.1. The same result was obtained in 1984 by the Bologna-CERN-Dubna-Münuch-Saclay (BCDMS) collaboration [6]. The BCDMS has also measured the ratio of nitrogen to deuterium structure functions (fig.2) that is also sensitive to binding effects. The results of SLAC measurements carried out with an electron beam at transferred momenta Q^2 by an order of magnitude smaller are shown for comparison [7]. They also indicate that the Q^2-dependence of the effect (at least within the range of medium x) is negligible. On the other hand, the SLAC results cannot be considered as precise since the ratio R of longitudinal (σ_L) to transverse (σ_T) virtual photon absorption cross sections, which is poorly known in the region of small Q^2 and x, can significantly modify the x-dependence of structure functions [8].

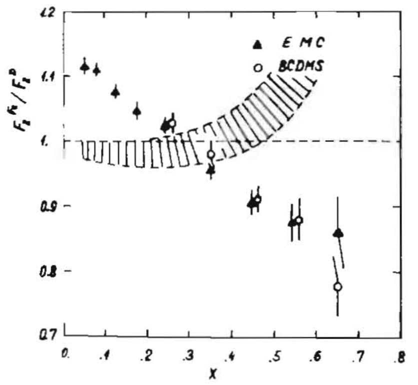

Fig.1. The ratio F_2^{Fe}/F_2^D nucleon structure functions obtained in high energy muon experiments. Dashed area shows predictions that took into account the effect of nucleon Fermi-motion.

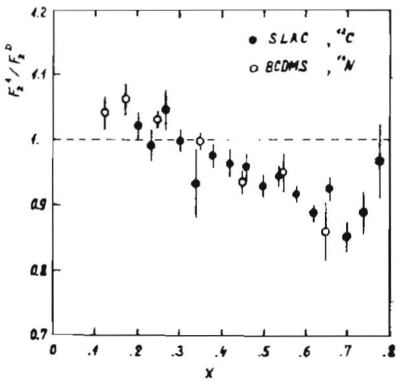

Fig.2. The ratio F_2^N/F_2^D as obtained by the BCDMS [6] compared to the ratio σ^C/σ^D (SLAC [7]).

The discovery of the EMC came as a surprise to many theorists. But soon enough several models explaining the effect were proposed. Though they are sometimes very different, they are united by the idea that the standard picture of nuclear structure considering the nucleus as a system of bound nucleons is not accurate enough. Indeed, if the momentum transfer from muon to nucleus is large enough (≥ 1 GeV/c), the latter has to be considered as a relativistic bound state of quantized fields, i.e., as a system with infinite degrees of freedom. The "valence" nucleons of the system carry only a part of its total momentum (in the infinite momentum frame of reference). The rest has to belong to the particle-antiparticle "sea" (mesons, quarks, gluons) due to vacuum polarization effects (production and absorption of virtial particles). This results in a decrease of the fraction of momentum of valence quarks in the nucleus (per nucleon) and in an increase of the fraction of momentum of sea quarks and gluons. These general features of the relativistic state are common to all models proposed to explain the EMC effect. For instance, in some of them one assumes:

a) An increase of the size of nucleons in the nucleus [9] or an increase of the colour confinement radius in the nucleus [10] that leads to softening the valence quark spectrum and, consequently, brings about an increase of the sea of quark-antiquark pairs and/or gluons.

b) An admixture of Δ-isobars [11] that results in the same effect due to a softer valence quark distribution in Δ-resonance.

c) An increase of the density of pions surrounding a nucleon in the nucleus[12] that, on the one hand, means an increase of sea quark density and, on the other hand, a decrease of momentum fraction related to nucleons or softening of the valence quark distribution.

d) The existence of multi-quark configurations[13-16] inside the nucleus that are considered as a transition state between hadronic matter and quark-gluon plasma. Such states are responsible for the redistribution of valence quarks from the medium x-range to a range of $x > 1$ that brings about a decrease in mean x and an increase of the sea quark and gluon contribution to the total momentum carried by nucleon constituents.

All these and many other models[3,4] suggested for explanation of the EMC effect demonstrate a qualitative agreement over a range of $x < 0.7$ where experimental data on the F_2^A/F_2^D ratio have been already obtained by the EMC and BCDMS collaborations. On the other hand, predictions of models for x above 0.7 (so far unexplored except at SLAC) differ considerably (fig.3). We therefore propose to extend measurements of the ratios of structure functions to a range of $x > 0.7$.

Measurements of nucleon structure functions alone over a range of $0.7 < x < 1.0$ are of interest from the point of view of determination of the QCD parameter Λ. First of all, according to[17], the amount of scaling violation of the nonsinglet structure function, observed over a range of $0.3 < x < 0.5$, is controlled by the size of the structure function in a region of $x > 0.6$. Secondly, it is a well-established fact that the sea quark and gluon contribution to a range of $0.5 < x < 1.0$ is negligible. This provides better conditions for the determination both of the shape of the valence quark distribution and the parameter Λ.

Important information of the nature of the EMC effect can be obtained by studying the A-dependence over a wide range of atomic weights. Such measurements have been first carried out by a SLAC[7] group in deep inelastic electron-nucleus scattering experiments. It has been found that the depletion in F_2^A/F_2^D grows approximately like $\log A$, and it is the strongest at $x \approx 0.65$. The SLAC results on the A-dependence of cross section ratios at $x = 0.3$ and 0.62 along with those obtained by the BCDMS in deep inelastic scattering of muons on deuterium, nitrogen and iron are shown in fig.4. It is of importance to obtain results on the A-dependence of the F_2^A/F_2^D ratio in an $x \approx 1$ region. Such results must help to understand whether the Fermi-motion of nucleons at high x or few nucleon correlations[18] or some other nuclear effects are responsible for the observed rise in the ratio σ^A/σ^D at $x > 0.7$. We propose to carry out measurements on deuterium and on such nuclei as N_2, Al, Fe, Sn, and Pb.

The setup that is supposed to be used makes it possible to collect data simultaneously on two targets.

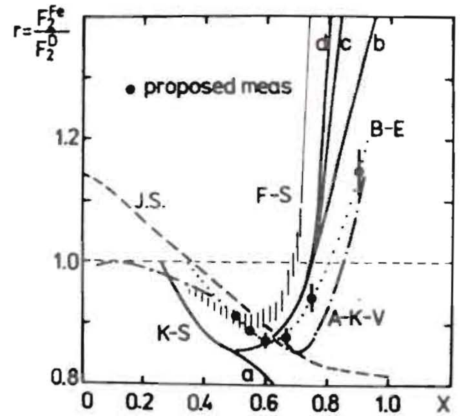

Fig.3. The ratio of nucleon structure functions measured on iron and deuterium nuclei calculated by different approaches: J.S.[11]*, F-S*[30]*, B-E*[15]*, K-S (a, b, c, d)*[14] *and A-K-V*[31]*. The statistical accuracy expected in the proposed experiment is shown by the points with error bars.*

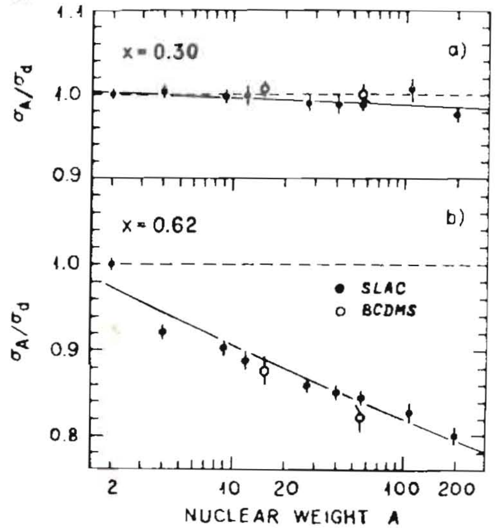

Fig.4. Ratios σ^A/σ^D (SLAC[7]*) and F_2^A/F_2^D (BCDMS*[6]*) as a function of nuclear weight* A.

2.2. Nuclear Structure Functions beyond the Single Nucleon Kinematic Limit x = 1

As has been mentioned already, the kinematic limit $x = 1$ for deep inelastic scattering of a muon on a free nucleon becomes $x = A$ if the scattering occurs on nuclei. This means that the nucleon structure functions $F_2(x)$ have nonzero values at $x > 1$. Since nuclear medium can be, to a great extent, responsible for the shape of the nucleon structure function beyond $x = 1$, it is reasonable to introduce the term of "nuclear structure function" $F_2^A(x)$. This region unexplored so far in deep inelastic lepton-

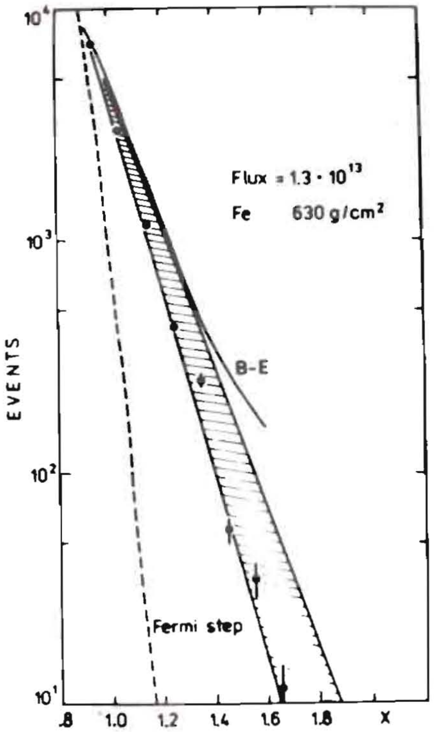

Fig.5. Predictions for the rate in deep inelastic muon-iron scattering beyond the single nucleon kinematic limit: a) the dashed line corresponds to the nucleon Fermi-motion model with k_F = = 190 MeV; b) the curve B-E is obtained assuming the existence of quark-parton configurations in the nucleus [15]*; c) the shaded area is restricted by the exponentials* $\exp(-x/b)$ *with* b = = 0.105 [27] *and* b = 0.12 [28]*. Predictions of the few nucleon correlation model* [18] *lie within the area.*

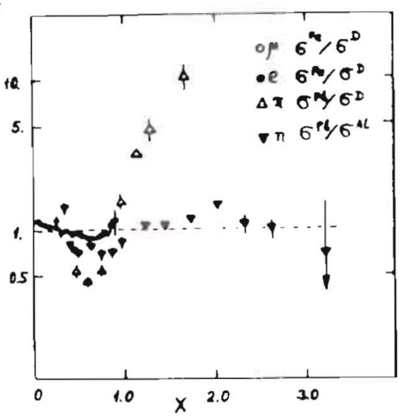

Fig.6. Results of measurements of the structure functions by the methods of relativistic nuclear physics [25] *along with those obtained in muon and electron deep inelastic scattering.*

nucleus scattering experiments is the subject to be investigated in the framework of the present proposal.

It is reasonable to assume that the EMC effect is closely related to phenomena occurring at x beyond 1. So the models explaining the EMC effect can be tested after data on nuclear structure functions are obtained over a wider range of x. Many of the models, however, consider the nucleon Fermi motion alone to be responsible for nonzero values of the nuclear structure function $F_2^A(x)$ at $x > 1$. In such a case $F_2^A(x)$ must be very small (practically zero) at $x \approx 1.2$ (dashed line in fig.5). If an evidence for nonzero $F_2^A(x)$ were found at large x, it would witness in favour of the few-nucleon correlation model [18] and those of multi-quark configurations [13-16].

The idea of multi-quark configurations in the nucleus can be considered as the development of the idea of "fluctons" [19] or short-time fluctuations of nuclear matter. Such a hypothesis proved to be useful in explaining a high emission rate of light nuclei (d, t, α) produced in collisions between fast protons and heavy nuclei. Later on the idea took the form of "few nucleon correlations" [18] and "multi-quark fluctons" [20] in explaining cumulative hadron production in hadron-nucleus collisions. Hadrons emitted far beyond the single nucleon kinematic limit were called cumulative ones.

A special approach [21] has been developed justifying the use of experimental information on cumulative hadron production in studies of quark distributions in nuclei. Its essential assumption is the requirement of the limiting fragmentation cross section of the nucleus to mesons to be proportional to the nuclear quark-parton structure function just as this occurs for deep inelastic lepton-nucleus scattering. This, in turn, can be justified if one considers quarks as quasi-free particles in the nucleus.

Long since experiments on the limiting fragmentation of nuclei have provided exciting data on nuclear structure [22-24]. Even if one can argue about the validity of such an approximation, one cannot deny a good qualitative agreement between the results obtained in deep inelastic lepton scattering experiments and those obtained earlier in experiments on the limiting fragmentation of nuclei. Figure 6, for example, shows results on the ratio of inclusive hadron production cross sections interpreted in terms of structure functions. Common features observed in hadron and lepton experiments over a range of $x < 1$ is an indication of the validity of the approach [21]. It also seems reasonable to regard the results obtained by nuclear physicists over a range of $x > 1$ as a good indication of the manifestation of the quark-parton structure of nuclei.

Below we present a list of principal features of nuclear structure functions obtained experimentally [25].

1. The nuclear quark-parton structure function is greater than 0 up to x = 3.

2. The nuclear structure function of medium and heavy nuclei can be fitted by an exponential law $a \cdot \exp(-x/b)$ with b = 0.14.

3. The ratio F_2^{Pb}/F_2^D is well above units over a range of $1 < x < 2$ (fig.6).

4. At $x < 1$ for nuclei heavier than Al the ratio of structure functions to that measured on Pb is practically unity over a range of $1 < x < 3$ (fig.7).

An attempt has been already made by the BCDMS collaboration to observe some of these features in deep inelastic muon scattering on carbon [26]. We took advantage of the fact that the geometrical efficiency of the NA-4 setup does not decrease with

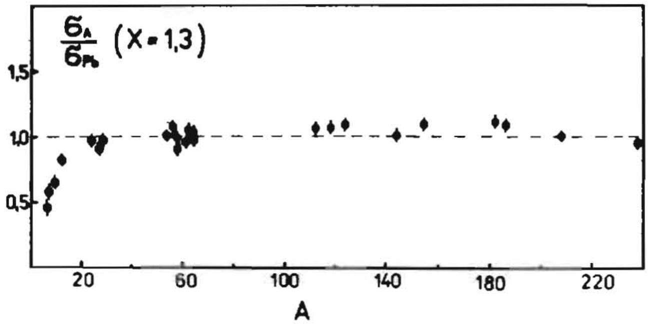

Fig.7. A-dependence of the cross-section ratios at x =1.3 *obtained in experiments on limiting fragmentation*[25]. *The result is to be checked in deep inelastic scattering of muons on nuclei.*

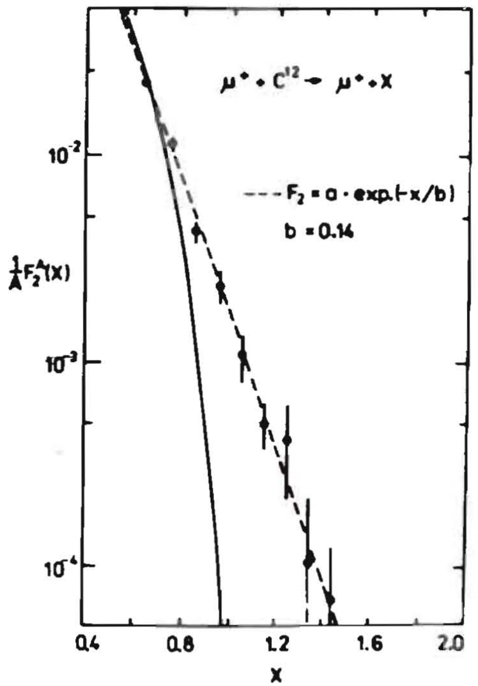

Fig.8. Preliminary results on the $F_2^A(x)$ *structure function measured by the BCDMS on the carbon target*[26]. *The solid line is obtained by extrapolating to* $x = 1$ $F_2(x)$ *measured for* $x < 0.7$ *assuming* $F_2(x) \sim x^A(1-x)^B$.

increasing x. Over a period from 1979 to 1980 a large amount of data on carbon target were obtained in the range of x close to unity what, in principle, could provide a high statistical accuracy. Unfortunately, large smearing with respect to x makes it practically impossible to analyse the data in a model-independent way which results in considerable systematic errors. To take into account smearing effects in the data analysis, a model with an exponential structure function $F_2 \sim \exp(-x/b)$ with $b = 0.16$ was used. As a result, the structure function (fig.8) integrated with respect to Q^2 was obtained. It is well fitted

by the exponential with $b = 0.14 + 0.01$(stat.)[26]. This preliminary result is nevertheless a proof of the possibility of investigating nuclear structure functions providing the x resolution is improved.

Though experiments on the limiting fragmentation of nuclei look very promising for the study of nuclear structure, particularly in the range of x as high as 2-3, there remains an open question whether multiquark configurations exist in nuclei or they are created by incident hadrons. Results on structure functions measured in deep inelastic muon-nucleus scattering in the range of x beyond unity will give a definite answer to this question.

A poor x resolution has been so far a main obstacle in deep inelastic scattering experiments to reach a good precision over a range of $x > 0.7$. The following relation

$$x = \frac{Q^2}{2M\nu} \approx \frac{E_0}{M} \cdot \theta'^2 \cdot \left(\frac{E_0}{\nu} - 1\right)$$

holds true in the kinematic range of the measurements proposed. Then the accuracy in Bjorken x can be expressed as

$$\frac{\Delta x}{x} = \left[\left(2 \cdot \frac{\Delta\theta'}{\theta'}\right)^2 + k\left(\frac{\Delta\nu}{\nu}\right)^2\right]^{1/2}.$$

where $k = E_0/\nu/(E_0/\nu - 1)$

A high accuracy in measuring the scattered muon angle can be reached quite easily (except very small angles), and it is of the order of 3% for the front setup of the BCDMS spectrometer[1]. The x resolution is particularly low in the range of low ν, where $\Delta\nu/\nu$ resolution is by an order of magnitude worse than that of $\Delta\theta'/\theta'$. Here there lies a principal limitation of all the experiments on deep inelastic muon and neutrino scattering in reaching the range above $x = 0.7$. So the main purpose of modification of the BCDMS spectrometer is to increase the precision in measuring transferred energy $\nu = E - E'$.

3. PROPOSED MEASUREMENTS

The experimental setup that will suit the purpose of the proposed measurements is the BCDMS spectrometer equipped with a hadron calorimeter as shown in fig.9. The calorimeter is supposed to be installed instead of the first supermodule. It will measure the energy of showers produced in interactions on the target modules of the front setup. The kinematic range that will be covered by such a setup is shown in fig.10 by the area shaded with vertical lines. The geometrical acceptance of the

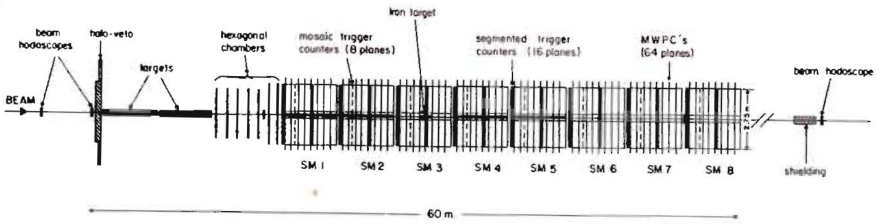

Fig.9. The layout of the BCDMS spectrometer in the present configurations.

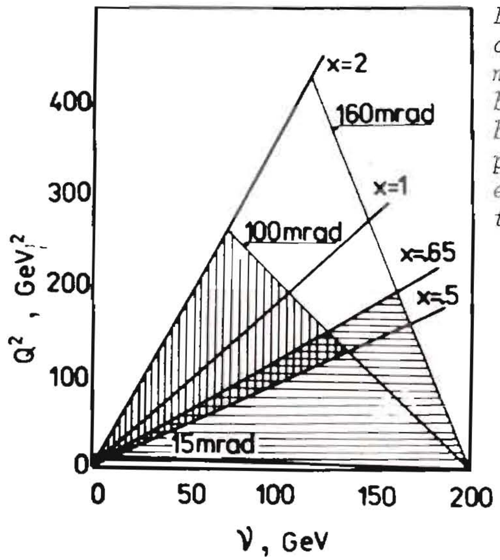

Fig.10. Kinematical diagram of Q^2 vs ν for deep inelastic muon scattering at a 200 GeV beam energy. The area shaded by horizontal lines corresponds to the region already explored and by vertical lines to that to be studied.

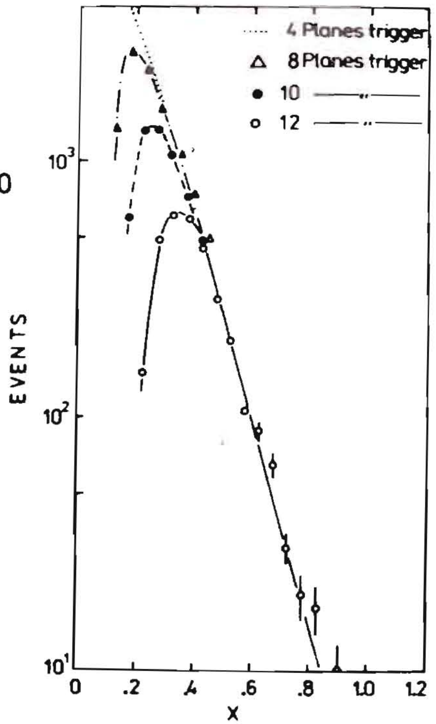

Fig.11. Effect of suppression of low x events by the first-level trigger demonstrated on experimental events registered by the front setup of the BCDMS spectrometer. The number of muons with a particular x traversing 4,8,10 or 12 trigger counter planes is shown by different symbols as a function of x.

apparatus in this region is 80% and practically flat for $Q^2 > 50$ GeV^2. The range of studies is extended to angles larger than 100 mrad by registering the events from the target modules inside the iron toroids. In this case the accuracy in measuring transferred energy decreases.

3.1. Data Taking on D_2, N_2, and Al Targets

The BCDMS spectrometer is usually triggered by muons that transverse more than 10 m of its standard part thus accepting low x events (fig.10). We consider it necessary to modify the triggering system to bring down the event rate from the low x region. Since $x \sim P_T\theta'/\nu$ and P_T is proportional to the track length of a muon oscillating in the magnetic spectrometer, a new trigger could be realized by rejection of short track events or those with high ν. Figure 11 demonstrates the decrease by a factor of 8 in the event rate ($x < 0.4$) achieved by the requirement for muons to traverse 12 planes of ring trigger counters instead of 4 planes. The selectivity of the P_T trigger obtained by simulation is shown in fig.12.

The available hardware/1/ makes it possible to realize an 8-plane trigger in the fast first-level triggering system. Further reduction in the event rate can be achieved by the second-level trigger using the available hardware. This will be realized, first of all, by the selection of longer tracks (up to 12 planes of trigger counters). Secondly, the events with shorter tracks will be accepted if they are recognized as high Q^2 events (hits on rings beginning from number 4 and hits on outer mosaic trigger counters). The final validation of an event will be realized by means of an OR logic memory.

Estimating the expected number of events over a range of $x > 0.5$, we relied upon already available data from the NA-4 setup rather than on theoretical expectations. Figure 11 demonstrates the distribution of events versus x registered from two front target modules filled with deuterium. The distribution along the target axis is shown in fig.13. This data sample corresponds to scattered muon angles of $\theta' > 40$ mrad where the reconstruction accuracy is high. If we take for estimations a maximum muon flux of 3.5×10^7/spill and a 70% efficiency of performance both of the SPS and the BCDMS spectrometer, one can expect 25000 events over a range of $x > 0.5$ for 60-day running on deuterium. We suppose to accumulate even higher statistics on the nitrogen target and somewhat smaller on the aluminium one (see the Table).

As for the range close to $x = 1$, both theoretical and experimental estimates cannot be considered as reliable: first, due to model uncertainties and, secondly, due to smearing effects. We can mention, however, that models based on a quark-parton

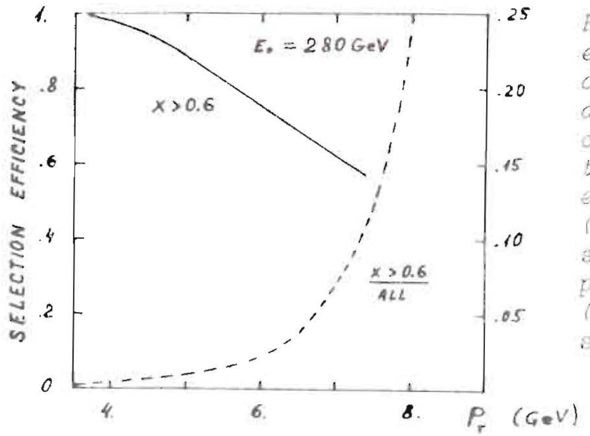

Fig.12. Selection efficiency of events over a range of x 0.6 as function of the P_T cut with respect to the number of events at x 0.6 (solid line, left scale) and with respect to all events (dashed line, right scale).

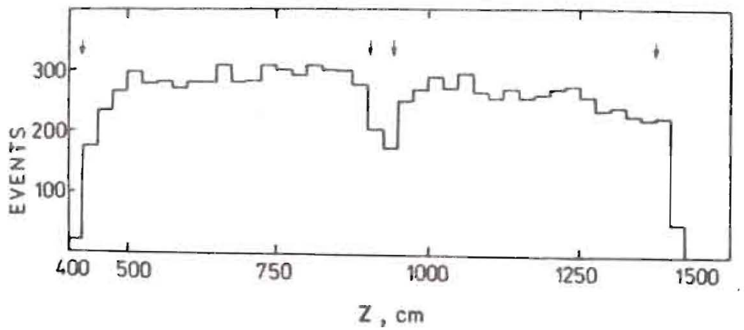

Fig.13. Vertex distribution for the events registered on D_2 at 280 GeV as a function of target length. The arrows indicate the target ends.

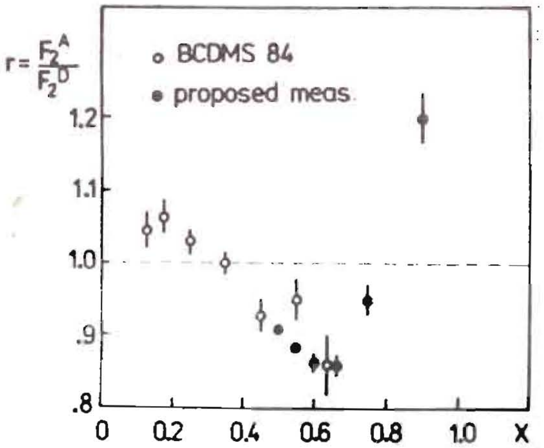

Fig.14. Statistical accuracy in the expected ratio of nitrogen to deuterium structure functions (closed points) compared to that already available from the BCDMS (open points).

Table

Running Time

Target	Days	Useful muons
D_2	60	$6.3 \cdot 10^{12}$
N_2	28	$2.9 \cdot 10^{12}$
Al (1 m)	28	$2.9 \cdot 10^{12}$
Fe	35	$5.4 \cdot 10^{12}$
Sn	28	$2.9 \cdot 10^{12}$
Pb	14	$1.47 \cdot 10^{12}$
Calibrations	7	π-beam
Total	200	

picture of the nucleus predict hundreds of events over a range of $x > 0.8$ for the fluxes presented in the Table. The statistical accuracy that can be reached in measurements of the ratio of nitrogen to deuterium structure functions is shown in fig.14. Systematic errors will be discussed in chapter 4.

3.2. Measurements with Heavy Active Targets (Fe, Sn, and Pb)

Three targets will be performed as calorimeter modules with 20 mm thick iron and stannum plates and 10 mm thick lead plates. The total thickness will be 630 g/cm^2, 550 g/cm^2 and 970 g/cm^2, respectively. One calorimeter module with iron plates will be installed permanently in the beam. The first half of this module will be used as a reference target so that data taking will always take place on two targets simultaneously. This allows one to minimize systematic errors and also to accumulate high statistics on the iron target in the range beyond $x = 1$. To estimate the statistical errors shown in fig.5, we took the exponential form of the structure function $F_2(x) = a\exp(-x/b)$ with $b = 0.105$ as obtained in /27/ below $x = 1$. It is evident that even higher statistics can be reached if the $F_2(x)$ follows the exponential law with $b = 0.12$ /28/ or $b = 0.14$ /28/ After the shape of the nuclear structure function on iron is determined, it will be possible to obtain structure functions on Sn and Pb practically with the same accuracy for shorter time because a major contribution to the errors comes from systematics. Running time is presented in the Table.

We are going to use data obtained on light and heavy targets to estimate whether nucleon Fermi motion or other nuclear effects prevail over a range of $x \approx 1$. If the effect of Fermi motion dominates, it will show up in a sharp depletion of the nuclear structure function above $x = 1.2$ for all nuclei.

3.3. Beam Request

In total, we request $3 \cdot 10^{13}$ beam muons. We can run at an energy of 280 GeV in parallel with the team [5] which submitted the proposal p210 to the SPSC. On the other hand, we prefer a 200 GeV muon beam. Measurements could start in 1986.

4. MODIFICATIONS OF THE BCDMS SETUP

The modification of the BCDMS spectrometer suggested by the present proposal will considerably improve the ν resolution and, consequently, the x one at minimal expenses. Only the front part of the setup called a "small angle spectrometer" [1] will be modified. The toroidal iron spectrometer [29] will be left intact except the first supermodule that will be removed to provide some space for the hadron calorimeter.

4.1. Hadron Calorimeter

The small angle spectrometer equipped with the hadron calorimeter is shown in fig.15. The calorimeter that is under construction now will contain about 400 modules with a cross section of 15×15 cm^2. Each module is a sandwich made of 40 iron plates 2 cm thick and plastic scintillator plates 1 cm thick. The light collected by a wavelength shifter is registered by one PM tube. The calculated energy resolution can be described as $\Delta E/E = 0.8/E^{0.5}$.

Scattered muon angles will be determined by five hexagonal multiwire proportional chambers (HMWPC) 1.5 m in diameter. Three target modules shown in fig.15 are supposed to be used in runs with deuterium or nitrogen. While the acceptance of the BCDMS spectrometer for a certain range of scattered muon angles is practically constant along the target length (see fig.13), the acceptance of the calorimeter falls off with the distance from the vertex. The calorimeter acceptance calculated by means of Monte-Carlo is shown in fig.16. We can, in principle, run with all the target modules (including those in the toroids) filled with deuterium (nitrogen). Though measurements of hadron shower energy for last 5 modules are not possible, the data can be useful over a range of $x < 0.8$ where the spectrometer resolution can be computed reliably by means of Monte-Carlo.

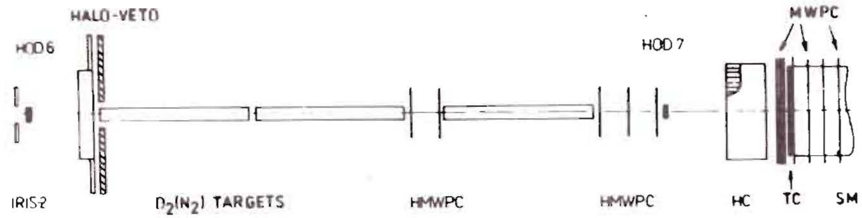

Fig.15. Front part of the modified BCDMS spectrometer equipped with a hadron calorimeter (HC).

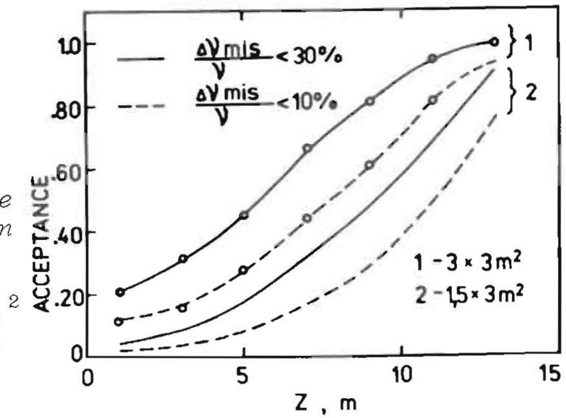

Fig.16. Acceptance of the calorimeter as a function of distance to the vertex. The calorimeters with dimensions of 3x3 m^2 and 3x1.5 m^2 at $z = 15$ m have been used in simulation.

4.2. Live Targets

Three targets made of Fe, Sn, and Pb will perform as calorimeters at the same time. The iron target is designed in the same way as a calorimeter module except that light is collected to 10 PM tubes (see fig.17) to determine the interaction point with a 6 cm accuracy. This provides a certain improvement of the spectrometer resolution. Such a target can operate at beam fluxes as high as $4 \cdot 10^7$ muons/spill provided it is insensitive to beam muons.

The two other targets differ only in plate material. Stannum plates 20 mm thick and 10 mm thick lead plates will be used.

With heavy target modules placed in the beam in front of the hadron calorimeter as shown in fig.17, the BCDMS spectrometer does not use the target modules inside the iron toroids. On the other hand, all its 40 m construction is indespensible for triggering the setup by high x events.

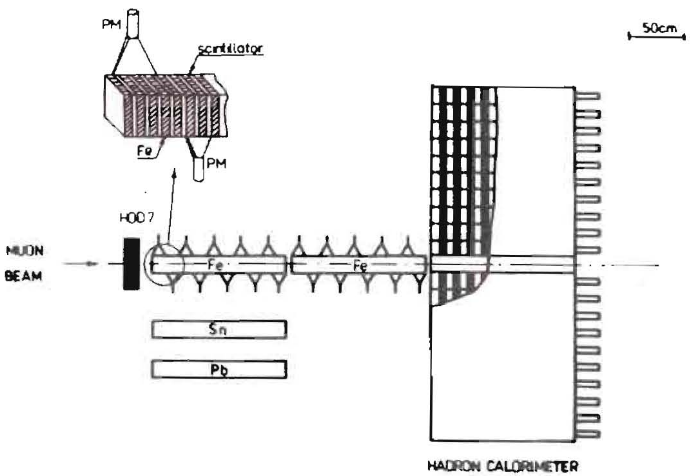

Fig.17. The target configuration for heavy target runs.

4.3. Apparatus Resolution Near $x = 1$

The use of the magnetic spectrometer and the hadron calorimeter together provides the resolution $\sigma(\nu)/\nu$ higher than that of each device separately. The resulting accuracy $\sigma(\nu)$ obtained in such a way is shown in fig.18 by the full line. As is seen, the maximum gain corresponds to a range of $\nu \approx 80$ GeV. This results in a considerable improvement of the resolution $\sigma(x)/x$ as demonstrated by fig.19. The calculation has been performed by means of Monte-Carlo in which a polynomial form of the nucleon structure function, $F_2(x) \sim x^A(1-x)^B$ is used for computations of cross sections. Such a form suggests $F_2 = 0$ at $x = 1$ and beyond $x = 1$. In the latter case we used in Monte-Carlo calculations an exponential form $F_2 \sim \exp(-x/0.14)$. The results obtained for the standard BCDMS spectrometer and for the proposed setup (provided that the calorimeter resolution is $\Delta E/E = 0.8/E^{0.5}$) are shown in fig.20. Note that over the kinematic range of the proposed study ($Q^2 \geq 50$ GeV^2, $\nu \geq 20$ GeV) the resolution $\sigma(x)/x$ for the modified setup is 12-15% independent of x up to $x \leq 2$.

Using Monte-Carlo calculations, we have estimated the possibility to discriminate between two predictions for the x-dependence of the structure function $F_2(x)$. As test versions for the structure functions, we took $F_2 \sim (1-x)^3$ and $F_2 \sim \exp(-x/0.12)$. These parametrizations are close to those determined experimentally in the range below $x = 1$. Simulation was performed both for the present BCDMS spectrometer and for the proposed version of the setup with a resolution of $\sigma(x)/x = 12\%$ independent of x. The results are shown in fig.21. The two hypotheses can

be separated when the differences between event rates incorrected for resolution exceed the experimental errors in corresponding x-bins by a factor of 3. For the version with a calorimeter this becomes possible already at $x = 0.9$-1.0.

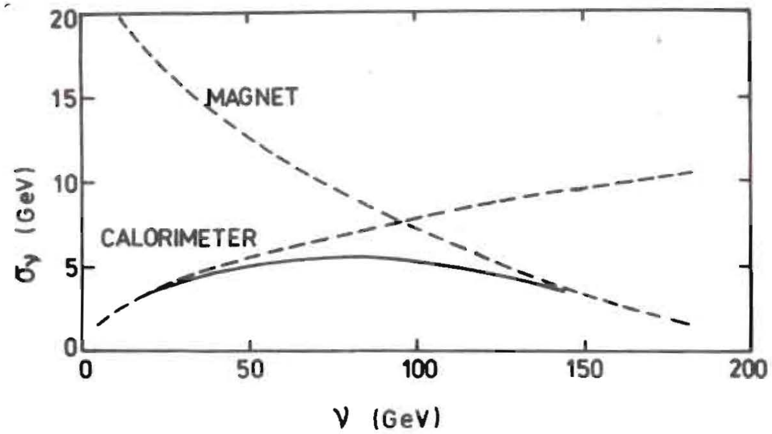

Fig.18. Accuracy $\sigma(\nu)$ in hadron shower energy measurements as determined by the magnetic spectrometer and the calorimeter separately (dashed lines) and by their joint use (solid line).

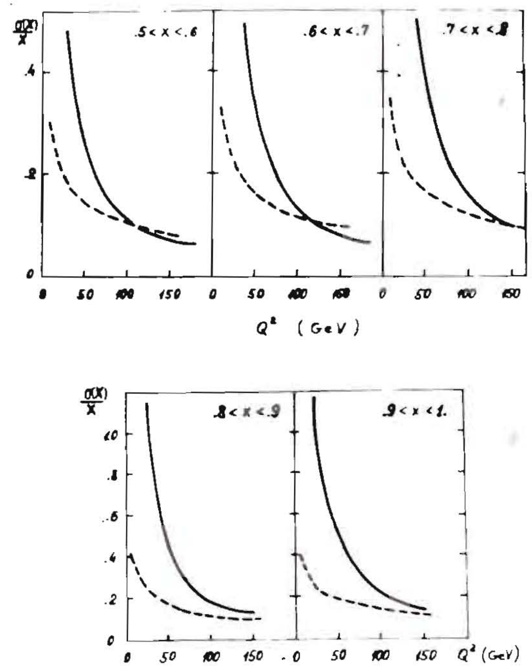

Fig.19. The resolution $\sigma(x)$ of the BCDMS spectrometer as a function of Q^2 for various x-bins in the present configuration (solid lines) and together with the calorimeter (dashed lines) with $\Delta E/E = 0.8/E^{0.5}$.

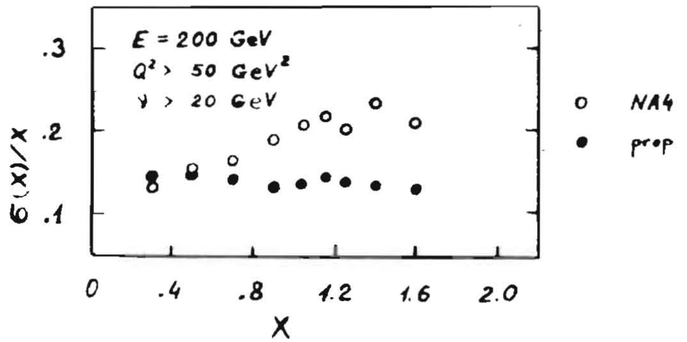

Fig. 20. Resolution $\sigma(x)/x$ of the present BCDMS spectrometer as a function of x over a wide x-range (open points) and of the spectrometer with a calorimeter (closed points).

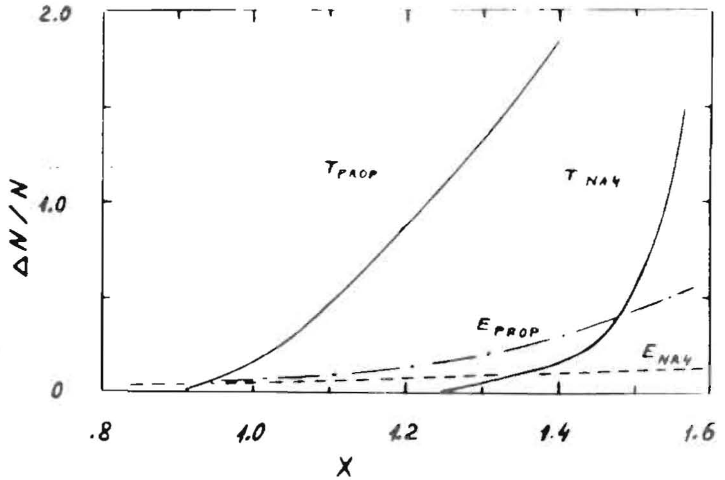

Fig. 21. Full lines demonstrate differences between event rates uncorrected for smearing due to different $F_2(x)$ parametrizations. The differences show up for higher x in the case of larger smearing (T NA-4). The statistical errors in the corresponding bins are shown for the already available statistics (dashed line) and for the estimated statistics during a 25-day run on iron (dash-dotted line).

5. CONCLUSIONS

The proposed measurements of deep inelastic scattering of muons on nuclei at $0.5 < x < 1$ and $50 < Q^2 < 200$ are assumed to yield for the first time high statistics data on nucleon structure functions near the single nucleon kinematic limit. The analysis will be free of uncertainties due to errors in $R = \sigma_L/\sigma_T$ that is negligibly small in the kinematic range under study. The latter is also important for measurements of structure function ratios F_2^A/F_2^D with small systematic errors. The data to be obtained over an $x < 1$ range will help to clarify the situation with explaining the EMC effect since models differ significantly in this very region.

At last the proposed experiment can be considered as a crucial test of the existence of multi-quark configurations in the nucleus. Such models as a few nucleon correlation model and a quark-parton model will be also tested that predict a specific behaviour of nucleon structure functions beyond the single nucleon kinematic limit.

REFERENCES

1. Bollini D. et al. Nucl.Instr.and Meth., 1984, 226, p.330.
2. Aubert J.J. et al. Phys.Lett., 1983, 123B, p.275.
3. Llewellyn-Smith C. Proc. of the 10th Int.Conf. on Part. and Nucl., Heidelberg, 1984.
4. Nikolaev N.N. Proc. of the 7th Int.Seminar on HEP Probl. Dubna, 1984. JINR, D1,2-84-599, Dubna, 1984, p.144.
5. Allasia D. et al. CERN/SPSC 85-18, Geneva, 1985.
6. Benvenuti A.C. et al. Report at the 20th Rencontre de Moriond. Les Arcs, France, March 1985.
7. Arnold R.C. et al. Phys.Rev.Lett., 1984, 52, p.727.
8. Savin I.A., Smirnov G.I. In: JINR Rapid Comm., No.2-83, Dubna, 1983, p.3.
9. Jaffe R.L. Phys.Rev.Lett., 1983, 50, p.228; Frankfurt L.L.. Strikman M.I. Preprint LNPI-886, 1983; Levin E.M., Ryskin M.G. Preprint LNPI-888, 1983; Staszel M., Rozynek J., Wilk G. Preprint IFT 19/83, Warsaw, 1983.
10. Close F.E., Roberts R.G., Ross G.G. Phys.Lett., 1983, 129, p.346; Nachtmann D., Pirner H,J. Preprint HD-THEP-83-8, Heidelberg, 1983.
11. Swed J. Phys.Lett., 1983, 128B, p.245.
12. Llewellyn-Smith C.H. Phys.Lett., 1983, 128B, p.107; Ericson M., Thomas A.W. Phys.Lett., 1983, 128B, p.112; Titov A.I. JINR, E2-83-460, Dubna, 1983.
13. Jaffe R.L. Phys.Rev.Lett., 1983, 50, p.228; Carlson C.E., Havens T.J. Phys.Rev.Lett., 1983, 51, p.261; Pirner H.J., Vary J.P. Preprint UNI-HD-83-02; Faissner H., Kim B.R. Phys.Lett., 1983, 130, p.321; Chemtob M., Peschanski R. Preprint DPh-T/83/116, Saclay, 1983; Data S., Nakamura A. Progr.Theor.Phys., 1983, 69, p.565, ibid, 1983, 70, p.1682.

14. Kondratyuk L.A., Shmatikov M. ITEP Preprints, 114, M., 1983; 13, M., 1984.
15. Efremov A.V., Bondarchenko E.A. JINR, E2-84-124, Dubna, 1984.
16. Gupta S., Sarma K.V.L. Preprint TIFR/TH/85-4, Bombey, 1985.
17. Devoto A., Duke D.W., Owens J.F. Phys.Rev., 1983, D27, p.508.
18. Frankfurt L.L., Strikman M.I. Phys.Rep., 1981, 76, p.215.
19. Efremov A.V. Particles and Nuclei, 1982, 13, p.613.
20. Efremov A.V. Sov.Journ.Nucl.Phys., 1976, 34(6) p.1208.
21. Baldin A.M. JINR, E2-83-415, Dubna, 1983.
22. Baldin A.M. Part.and Nucl., 1977, 8, p.429.
23. Stavinsky V.S. Part. and Nucl., 1979, 10, p.950.
24. Baldin A.M. et al. JINR, E2-82-412, Dubna, 1982.
25. Baldin A.M., Panebratsev Yu.A., Stavinsky V.S. JINR, 1-84-185, Dubna, 1984; Dokl.Akad.Nauk SSSR, 1984, 279, No.6, p.1352.
26. Argento A. et al. The Report at the Conf. High Energy Phys. and Nucl.Struct., Versailles, 1981.
27. UA1 Collab., Arnison G. et al. Phys.Lett., 1984, 136B, p.294.
28. UA2 Collab., Bagnia P. et al. Phys.Lett., 1984, 144B, p.283.
29. Bollini D. et al. Nucl.Instr. and Meth., 1983, 204, p.333.
30. Frankfurt L.L., Strikman M.I. Preprint LNPI-886, Leningrad, 1983.
31. Akulinichev S.V., Kulagin S.A., Vagranov G.M. Preprint NBI-85-08, Copenhagen, 1985.

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Баранов С.П. и др. E1-85-524
Изучение структурных функций нуклона
в ядрах вблизи и выше кинематического предела

Предлагается выполнить эксперимент по глубоконеупругому рассеянию мюонов на нуклонах с целью изучения x-зависимости нуклонных структурных функций и их отношений в кинематической области по Q^2 = 50-200 ГэВ^2 и по x = 0,4-2,0. Проведение таких измерений на ядрах в диапазоне атомных весов от A = 2 до A = 207 даст новую информацию для детального изучения различий между структурными функциями свободных и связанных в ядре нуклонов /EMC-эффект/. Тем самым будет получен материал, необходимый для проверки большого числа моделей, развитых для объяснения x-зависимости отношений структурных функций нуклона. Измерения структурных функций в области переменной x, лежащей вблизи и выше однонуклонного кинематического предела x = 1, могут рассматриваться как решающая проверка существования многокварковых конфигураций в ядре. Для проведения измерений будет использован спектрометр НА-4, обладающий высокой светимостью, с улучшенным разрешением по переданной энергии.

Работа выполнена в Лаборатории высоких энергий ОИЯИ.

Сообщение Объединенного института ядерных исследований. Дубна 1985

Baranov S.P. et al. E1-85-524
Study of Nuclear Effects
in Nucleon Structure Functions up to and beyond the Kinematic Limit

We propose to perform an experiment on deep inelastic muon nucleon scattering in order to study the x-dependence of nucleon structure functions and their ratios over a range of Q^2 = 50-200 GeV^2 and x = 0.4-2.0. Such measurements performed on a number of nuclei with atomic weights from 2 to 207 would provide new information for detailed studies of the EMC effect and tests of many models explaining the x-behaviour of the nucleon structure functions and their ratios. The measurements will be decisive for the proof that a quark-parton model of the nucleus describes adequately nuclear structure probed at high energies. The upgraded high luminosity BCDMS spectrometer with improved resolution in transferred energy ν will be used for the measurements. We request a 280 or 200 GeV muon beam with a total of $3\cdot10^{13}$ muons (200 days).

The investigation has been performed at the Laboratory of High Energies, JINR.

Communication of the Joint Institute for Nuclear Research. Dubna 1985