NUCLEAR EFFECTS ON THE NUCLEON STRUCTURE FUNCTIONS IN HADRONIC HIGH-MASS DIMUON PRODUCTION

NA10 Collaboration

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We compare the differential cross sections of high-mass muon pair production on deuterium and tungsten by incident negative pions of 140 and 286 GeV We find an indication of a nuclear effect on the nucleon quark distributions comparable in magnitude to what is observed in muon–iron deep inelastic scattering, whereas the pion–quark distribution is unaffected, compatibly with QCD factorization

The nuclear dependence of the nucleon structure functions has been widely studied in the past few years Since the discovery of the "EMC effect" by the European Muon Collaboration [1], numerous experiments using muon [2–4], electron [5] or neutrino [6–8] beams have compared in different nuclei the distributions of the quark momentum fraction x over a wide range of momentum transfers (Q^2)

At high x ($x \geqslant 0\ 3$), the data [1–8] show a decrease of the cross section for heavy nuclei as compared to those for the proton or the deuteron This effect does not appear to depend on Q^2 and increases only logarithmically with the mass number A At low x ($0\ 1 \leqslant x \leqslant 0\ 3$), a slight enhancement of the cross section is observed for heavy nuclei in the high-Q^2 range ($Q^2 \geqslant 10$ GeV$^2/c^2$) [2,4] but is not seen at lower Q^2 [5]

Up to now, this nuclear dependence of the structure functions has never been studied in processes other than deep inelastic lepton scattering We present here the first detailed comparison of the distributions of high-mass dimuons produced in π^-–tungsten and π^-–deuterium interactions Within

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Table 1
Data summary

π^- energy (GeV)	Number of W events	Number of D events
286	49600	7800
140	29300	3200

the framework of the parton model this provides a study of the "EMC effect" in the time-like region The acceptance of our detector covers a wide range of the nucleon x distribution ($0\ 1 \leqslant x \leqslant 0\ 5$) and of Q^2 ($18 \leqslant Q^2 \leqslant 225$ GeV^2/c^2)

The data were taken at the CERN SPS with the NA10 Spectrometer, using 140 and 286 GeV π^-'s The detector, described in ref [9], was modified as follows [10] a 120 cm long (0 22 interaction lengths) deuterium target was added with its centre 2 m upstream of a tungsten target (mostly 12 cm, occasionally 5 6 cm), and the trigger was changed in order to accept dimuons coming from either of the two targets For the comparison, we only use W data taken with the D target full The simultaneous exposure of both targets minimizes most systematic uncertainties

The dimuons from the two targets were reconstructed with a single pattern recognition program The origin of the events, in W or D, could be attributed without ambiguity To eliminate the J/ψ and the ϒ-family resonances, events with masses $M<4\ 2$ GeV/c^2(286 GeV) or $M<4\ 35$ GeV/c^2 (140 GeV), and $8\ 5<M<11$ GeV/c^2 were excluded Fake dimuons, due to randomly associated tracks, were rejected by a set of fiducial and geometrical cuts, the residual contamination being at the level of 0 1% The final numbers of events are shown in table 1 The acceptances were computed with a Monte Carlo program The physical inputs were the same for both targets, except for the Fermi motion distribution, which was assumed to be that corresponding to the Hulthén wave function [11] for deuterium and to be that of a Fermi gas with a momentum tail up to 700 MeV/c [12] for tungsten That tail is poorly known, but fortunately its effect on the acceptance is very small The differential acceptance for a given variable was computed after integration over the other variables We verified that that integration (especially over the dimuon transverse momentum P_T for which a nuclear effect is observed [13]) does not bias

Table 2
Reinteraction contributions (%)

π^- energy (GeV)	D target	W target (12 cm)	
		internal	initiated in the D target
286	$2\ 7 \pm 0\ 5$	6 ± 2	8 ± 2
140	$2\ 3 \pm 0\ 5$	3 ± 2	1 ± 1

the results significantly The Monte Carlo was checked by comparing the J/ψ yields from two W targets, the standard one and an additional one placed immediately upstream of the D target The agreement between the cross sections measured with these two targets showed that the acceptance is well understood

The data had to be corrected for the nuclear reinteractions, that is for the production of high-mass dimuons by secondary hadrons produced in π^- interactions These reinteractions are of three kinds

(1) Reinteractions within the D target

(2) Reinteractions within the W target Their percentage was determined by comparing the data obtained from the 12 and 5 6 cm long targets

(3) Reinteractions in the W target of secondaries produced in the D target Their yield was determined by comparing W data taken with the D target full and empty

The reinteractions were also estimated by a Monte Carlo simulation, in which the spectrum of the D-secondaries was taken from measurements of π^-–p interactions [14], and that of the W-secondaries computed with a cascade program [15] The Monte Carlo and the direct determinations were in good agreement The results are quoted in table 2 Using the Monte Carlo predictions, the reinteraction contribution was subtracted globally and differentially The differential correction has a negligible effect on the ratio of the x_2 distribution and never exceeds 5% for the others

The data were also corrected for the non-isoscalarity of W This correction is very small differentially and amounts globally to 7%

Finally, the ratios of the distributions were not corrected for the contamination by heavy-flavour decays, since the contributions of the like-sign dimuons were identical for W and D and moreover quite small (less than 1% in the worst bin)

We first compare the total cross sections, which are usually parametrized as a function of the mass number A as $\sigma = A^{\alpha}\sigma_0(Z/A)$ Our measurements of the ratios of the cross sections per nucleon together with the corresponding values of α are shown in table 3 These ratios are free of the beam flux uncertainty their accuracy is limited only by the uncertainties in the D density (0 6%), in the absorption lengths of the targets (1 7%) and in the reinteraction subtractions (~4%), only the latter being uncorrelated for the two beam energies

In the common domain of $\sqrt{\tau} = M/\sqrt{s}$, viz 0 27–0 37, the values of α measured at 286 and 140 GeV agree within the errors and are compatible with 1 This result is in good agreement with a preliminary result [10] as well as with previous less accurate measurements [16,17]

The agreement between the result at the two beam energies becomes less good when their entire $\sqrt{\tau}$ domains are compared This is to be correlated with the differential effect that we observe on the $\sqrt{\tau}$ distributions (see below), the 286 GeV data extending to lower values of $\sqrt{\tau}$ than the 140 GeV data

In order to investigate nuclear effects in the structure functions, we now compare the W and D distributions of the scaling variables

$$x_1 = M^2/2p_1\, q, \quad x_2 = M^2/2p_2\, q\,,$$

$$\sqrt{\tau} = M/\sqrt{s} \cong \sqrt{x_1 x_2}, \quad x_F = 2P_L^*/\sqrt{s} \cong x_1 - x_2\,,$$

where M, q, P_L^* are the dimuon mass, four-momentum and CM longitudinal momentum, respectively, and p_1 (p_2) the four-momentum of the incident pion (target mucleon) In the quark model, x_1 and x_2 are the momentum fractions of the projectile and target quarks Thus x_2 corresponds to the Bjorken variable x measured in deep inelastic scattering

For each target, the kinematical region is restricted to the domain of (x_1,x_2) or $(\sqrt{\tau},x_F)$ where the two-dimensional acceptance is greater than 3% Fig 1a and 1b show the ratios of the differential cross sections at the two energies versus the scaling variables, the systematic uncertainty on the overall normalization is ~6% (see above) The two energies give very similar results Fig 1c shows the same ratios for the combined data, here, the ratio of the total cross sections at 140 GeV was fixed to be the same as at 286 GeV in the common domain of each kinematical variable Table 4 displays the slopes resulting from linear fits to these ratios The major sources of systematic errors in these slopes are the reinteraction subtraction for the $\sqrt{\tau},x_F,x_1$ distributions, and the uncertainty on the acceptance computation for x_2

The x_1 distribution shows no effect, in agreement with QCD factorization the pion structure function should not be affected by nuclear effects Conversely, the $\sqrt{\tau}$ distribution shows a depletion for $\sqrt{\tau} \geqslant 0\ 45$, and the x_2 distribution indicates an effect (slope) quite similar in shape and magnitude to that reported from deep inelastic scattering experiments [1–8] For a more precise comparison with those data, we have predicted the ratios of the distributions presented here on the basis of the recent BCDMS result [4], the most accurate measurement of the "EMC effect" available in our Q^2 range (although the BCDMS data were obtained on Fe and not W, the SLAC data [5] show that the EMC effect

Table 3
Ratio $\sigma(W)/\sigma(D)$ of the total cross sections

π energy (GeV)	Domain in $\sqrt{\tau}$	σ_W/σ_D [a]	α [a]
286	$0\ 27 < \sqrt{\tau} < 0\ 37$	$0\ 992 \pm 0\ 027 \pm 0\ 059$	$0\ 998 \pm 0\ 007 \pm 0\ 013$
140	$0\ 27 < \sqrt{\tau} < 0\ 37$	$0\ 912 \pm 0\ 021 \pm 0\ 053$	$0\ 980 \pm 0\ 006 \pm 0\ 013$
286	$0\ 18 < \sqrt{\tau} < 0\ 37$ and $0\ 47 < \sqrt{\tau} < 0\ 65$	$0\ 991 \pm 0\ 014 \pm 0\ 068$	$0\ 998 \pm 0\ 003 \pm 0\ 015$
140	$0\ 27 < \sqrt{\tau} < 0\ 53$	$0\ 896 \pm 0\ 018 \pm 0\ 052$	$0\ 976 \pm 0\ 004 \pm 0\ 013$

[a] The first error is statistical the second one is systematic

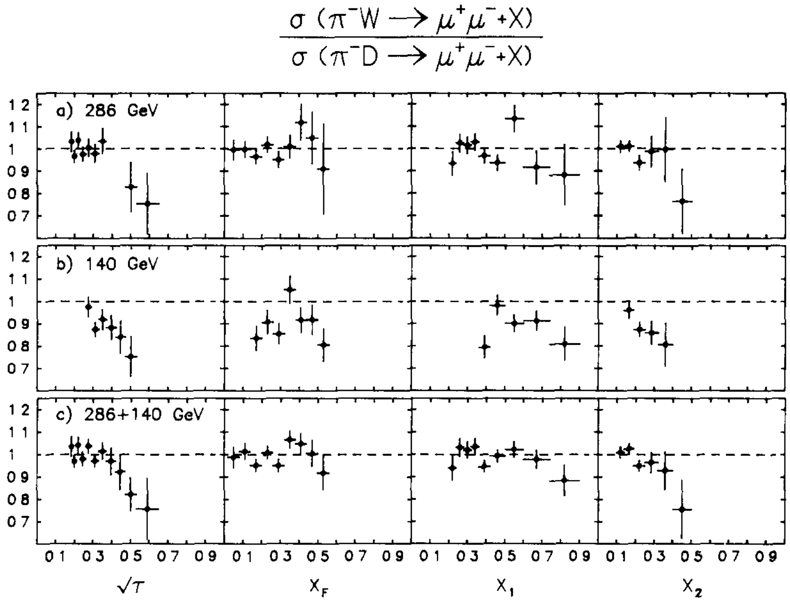

Fig 1 Ratios of the differential cross sections measured on W and D as functions of $\sqrt{\tau}$ x_F, x_1, x_2 (a) 286 GeV data (b) 140 GeV data (c) Both energies combined Only statistical uncertainties are shown

Table 4
Slopes from linear fits to the ratios $d\sigma(W)/d\sigma(D)$ The first error is statistical, the second one is systematic

Data	$\sqrt{\tau}$	x_F	x_1	x_2
286 GeV	−0 32±0 21±0 11	0 07±0 15±0 12	−0 09±0 13±0 09	−0 51±0 26±0 12
140 GeV	−0 65±0 32±0 10	0 08±0 19±0 10	−0 02±0 17±0 09	−0 81±0 41±0 18
all data	−0 34±0 15±0 08	0 06±0 10±0 07	−0 08±0 09±0 07	−0 55±0 21±0 12

does not depend strongly on A in the x range covered by our experiment) The prediction was made using the following model QCD factorization was assumed and the nucleon quark distributions $q(x)$ modified for tungsten according to the difference in the structure function F_2 between iron and deuterium as reported in ref [4], without making any distinction between the valence and sea components [#1]

[#1] This would be an approximation in the case that the EMC effect would affect the distributions of these two components differently, since their relative contributions for dimuon production by π^-'s and muon deep inelastic scattering differ $q_v(x)$ and $q_s(x)$ being the valence and sea quark densities of the proton, and neglecting the π^- sea, the cross sections for the two processes (on isoscalar targets) are proportional to $q_v(x)+q_s(x)/2$ and $q_v(x)+q_s(x)$, respectively However, altering the valence quark distribution only does not change the prediction significantly

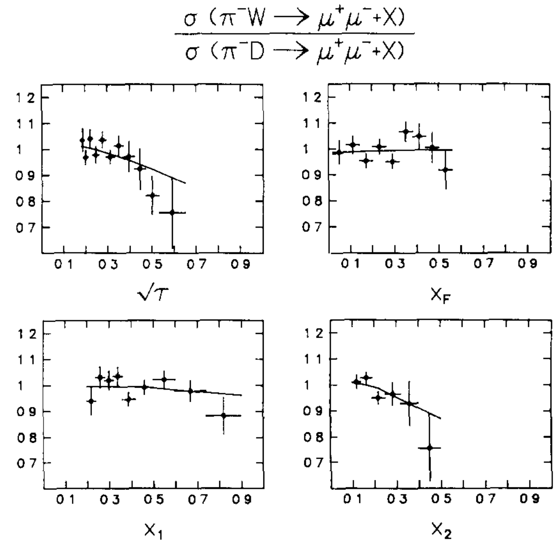

Fig 2 Comparison of our data (286+140 GeV) with the model predictions based on the BCDMS result [4] (full line)

$$q^{W}(x)/q^{D}(x) = F_2^{Fe}(x)/F_2^{D}(x)$$

The predicted ratios were obtained using simulated events analysed in the same way as the real data Those ratios are compared to our data in shape, but not in absolute normalization The model is in good agreement with our results, as shown in fig 2 However, there is an indication for a depletion larger than expected at high $\sqrt{\tau}$ ($\sqrt{\tau} \geqslant 0$ 45), which goes in the same direction as the disagreement observed [18] in this region between our W data and QCD predictions

In summary, the comparison of high-mass dimuons produced on W and D by π^-'s indicates a nuclear effect on the x_2 and $\sqrt{\tau}$ distributions comparable in magnitude to the effect observed in muon–iron deep inelastic scattering The absence of a nuclear effect in the x_1 distribution supports QCD factorization

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References

[1] EM Collab , J J Aubert et al , Phys Lett B 123 (1983) 275
[2] EM Collab presented 23rd Intern Conf on High energy physics (Berkeley, CA, July 1986)
[3] G Bari et al , Phys Lett B 163 (1985) 282
[4] A C Benvenuti et al Phys Lett B 189 (1987) 483
[5] R G Arnold et al Phys Rev Lett 52 (1984) 727
[6] A M Cooper et al , Phys Lett B 141 (1984) 133, J Guy et al , CERN-EP/86-217, submitted to Z Phys C
[7] H Abramowicz et al , Z Phys C 25 (1984) 29
[8] T Kitagaki et al Proc 12th Intern Conf on Neutrino physics and astrophysics (Sendai, June 1986)
[9] L Anderson et al , Nucl Instrum Methods 223 (1984) 26
[10] M Guanziroli, Thesis Diss Nr 7989, Swiss Federal Institute of Technology, Zurich (1986), unpublished
[11] L Hulthen and M Sugarawa, Encyclopaedia of Physics Vol 39 (Springer Berlin, 1957)
[12] A Bodek and J L Ritchie, Phys Rev D 23 (1981) 1070
[13] P Bordalo et al , Phys Lett B 194 (1987) 373
[14] W Morris et al Phys Lett B 56 (1980) 395
[15] A Grant, Workshop on Shower simulation for LEP experiments, Part 1 (January 1985)
[16] NA3 Collab J Badier et al , Phys Lett B 104 (1981) 335
[17] S Falciano et al , Phys Lett B 104 (1981) 416
[18] B Betev et al Z Phys C 28 (1985) 15, NA10 Collab , presented 23rd Intern Conf on High energy physics (Berkeley CA, July 1986)