ERRATUM

MEASUREMENT OF THE NUCLEON STRUCTURE FUNCTION F_2 IN
MUON-IRON INTERACTIONS AT 120, 250 AND 280 GeV

The European Muon Collaboration

CERN¹-DESY(Hamburg)²-Freiburg³-Kiel⁴-Lancaster⁵-LAPP(Annecy)⁶-Liverpool⁷
-Oxford⁸-Rutherford⁹-Sheffield¹⁰-Turin¹¹ and Wuppertal¹².

J.J. Aubert^{6*}, G. Bassompierre⁶, K.H. Becks^{1,2}, C. Best⁹, E. Böhm⁴, X. de Bouard⁶,
F.W. Brasse², C. Broll⁶, S. Brown⁷, J. Carr⁹, R.W. Clift⁹, J.H. Cobb^{1,2},
G. Coignet⁶, F. Combley¹⁰, G.R. Court⁷, J.M. Crespo^{6**}, G. D'Agostini⁶,
P.E. Dalpiaz¹¹, P. Dalpiaz¹¹, W.D. Dau⁴, J.K. Davies⁸, Y. Déclais⁶, R.W. Dobinson¹,
U. Dosselli¹, J. Drees^{1,2}, A. Edwards⁷, M. Edwards⁹, J. Favier⁶, M.I. Ferrero¹¹,
W. Flauger², E. Gabathuler¹, R. Gamet⁷, J. Gayler², V. Gerhardt², P. Ghez⁶,
C. Gössling², P. Gregory¹, J. Haas¹, U. Hahn^{3***}, K. Hamacher^{1,2}, P. Hayman⁷,
M. Henckes^{1,2}, J.R. Holt⁷, H. Jokisch⁴, V. Korbel², U. Landgraf³, M. Leenen¹,
M. Maire⁶, L. Massonnet⁶, H. Minssieux⁶, W. Mohr³, H.E. Montgomery¹, K. Moser³,
R.P. Mount⁸, P.R. Norton⁹, J. McNicholas⁸, A.M. Osborne¹, P. Payre⁶, C. Peroni¹¹,
H. Pessard⁶, U. Pietrzyk^{1,2}, K. Rith³, E. Schlösser³, M. Schneegans⁶, T. Sloan⁵,
H.E. Stier³, W. Stockhausen^{1,2}, J.M. Thénard⁶, J.C. Thompson⁹, L. Urban⁶⁺,
M. Villers⁸, H. Wahlen^{1,2}, M. Whalley¹⁰, D. Williams⁷, W.S.C. Williams⁸,
J. Williamson¹⁰, S.J. Wimpenny¹⁰.

ABSTRACT

A measurement of the nucleon structure function F_2 on iron is presented. The data cover a kinematic range of $3.25 \leq Q^2 \leq 200 \text{ GeV}^2$ and $0.05 \leq x \leq 0.65$. The data clearly show scaling violation. Fits in leading-order QCD have been made and values for the scale breaking parameter Λ are given.

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(*) now also at Faculté des Sciences de Luminy, Université d'Aix-Marseille II, France.

(**) now at Junta de Energia Nuclear, Madrid, Spain.

(***) now at Rheinmetall, Düsseldorf, Germany.

(+) now at Central Research Institute for Physics of the Hungarian Academy of Sciences, Budapest, Hungary.

Table 3: Parameter of QCD fit for data having $x \geq 0.25$

R	Λ [MeV]	Error Stat. Syst. [MeV]	A	α $Q_0^2 = 4 \text{ GeV}^2$	β	γ	χ^2 Stat. error only	Degrees of freedom
0.0	122	+22 +114 -20 -70	0.91	0.26	2.7	0.35	211	102
[0.0]	[122]		[0.80]	[0.20]	[2.87]	[0.0]	[211]	[103]
0.2	41	+12 +78 -11 -32	0.92	0.24	2.6	0.55	286	102

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ABSTRACT

A measurement of the nucleon structure function F_2 on iron is presented. The data cover a kinematic range of $3.25 \leq Q^2 \leq 200 \text{ GeV}^2$ and $0.05 \leq x \leq 0.65$. The data clearly show scaling violation. Fits in leading-order QCD have been made and values for the scale breaking parameter Λ are given.

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(*) now also at Faculté des Sciences de Luminy, Université d'Aix-Marseille II, France.

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(+) now at Central Research Institute for Physics of the Hungarian Academy of Sciences, Budapest, Hungary.

We present a measurement of the nucleon structure function F_2 in muon-iron scattering at incident energies of 120, 250 and 280 GeV. The different energies used permitted a wide range of Q^2 and x to be explored, while the high luminosity provided by the iron target gave precise measurement of F_2 up to very high values of Q^2 (*). In our accompanying letter [1] measurements of the proton structure function are presented.

The experiment was performed in the muon beam of the CERN SPS. The apparatus used was the same as in ref. [1] except for the target, which was a sampling total absorption calorimeter (STAC) of iron and plastic scintillator (fig. 1); the summed pulse height from the scintillators gave the hadronic energy deposited. The target fiducial volume excluded the last six STAC elements which had thicker iron plates and were used to absorb the hadronic showers which extended beyond the fiducial volume. The first ten elements of the STAC (fig. 1) were not present at 120 GeV. Further details of the STAC and the rest of the apparatus may be found in ref. [2].

The electronic trigger signalling a scattered muon was the same as for the hydrogen data [1], except that a minimum energy deposition of 20 GeV (5 GeV at 120 GeV) was demanded in the STAC. Data were taken simultaneously with different minimum muon scattering angles. All events satisfying a 2° cut were retained, together with a prescaled sample of events between 1° and 2° . The beam fluxes, fiducial target lengths and trigger rates for the three beam energies are shown in Table 1.

The reconstruction and fitting of the scattered muon track have been described in the preceding letter [1]. The resolution on the measured muon scattering angle was dominated by multiple scattering in the iron. The values of Q^2 and v for use in the subsequent analysis were calculated from the incoming and outgoing muon track parameters, each corrected for the energy loss in the target [3].

*) Preliminary results from these measurements have been presented previously [4].

Cuts were applied to the data (see Table 1) as follows:

To ensure a 100% trigger efficiency a cut at low v was made slightly above the STAC threshold of minimum energy deposition. In order to define the fiducial volume a cut was also made on the reconstructed vertex position near the downstream end of the target. Low momentum outgoing muons were rejected restricting the analysis to a kinematical region where radiative corrections are reliable and the contamination from hadron decay is small. From the number of μ^- in the final sample this contamination has been estimated to be less than 1%.

The acceptance was calculated by the same method as in [1], and the procedure for extracting F_2 was also the same. Radiative corrections were applied, including the contribution of radiative coherent μ -Fe scattering, quasi-elastic μ -nucleon scattering and inelastic tails. These were all computed using the 'exact' formula of Tsai [5], not the peaking approximation.

The structure function F_2 we present is the average per nucleon, with no corrections made for the Fermi motion or for the binding of the nucleons. Estimates of these corrections have been made by Bodek and Ritchie [6]. These calculations are sensitive to the high momentum tail of the Fermi distribution and to details of the nuclear breakup after the inelastic collision. For the specific model of Bodek and Ritchie the corrections to F_2 vary from about +4% for $x \leq 0.25$ to about -15% for $x = 0.65$ with only little dependence on Q^2 .

The results on F_2 are presented in Table 2 for the three energies separately. As in [1] values are given for $R = 0$ and $R = 0.2$. In fig. 2 the results are shown for $R = 0$ with the 250 and 280 GeV data combined. The pattern of scaling violation in F_2 is very clear, and similar to that observed on hydrogen [1]. Because of the small overlap between the 120 GeV and higher energy data it is not possible to determine a value for R from these data. Further measurements, presently being analysed, have been made at a beam energy of 200 GeV which will enable us to give results on R . The errors shown are purely statistical. Besides an overall normalisation error of $\pm 3\%$, the major systematic errors arise from the beam energy calibration, spectrometer energy calibration, resolution, uncertainties in radiative corrections, efficiencies and acceptance [1]. For the data points presented here each

individual correction was smaller than 25% and the overall systematic error was smaller than 15%. The magnitude of these errors in F_2 as a function of Q^2 and x is shown in fig. 3, superimposed on a parameterisation of the data.

QCD fits in leading order [7-9] have been made according to the Altarelli-Parisi equations [10]. Assuming that the valence quarks dominate F_2 at large x , the evolution equation is independent of the gluon and sea distribution. The structure function was parameterised at a fixed $Q_0^2 = 4 \text{ GeV}^2$ in the form $F_2 = Ax^\alpha(1-x)^\beta(1-\gamma x)$ and the value of F_2 at all Q^2 computed using the non-singlet evolution equations. A fitting procedure was used to extract the parameterised form of $F_2(x, Q_0^2)$ and Λ , the scale parameter of QCD. The results of these fits in leading-order QCD in the range $x \geq 0.25$ are given in Table 3 for both assumptions on R . The values of Λ were insensitive to the parameterisation of F_2 used (see Table 3 for a fit with $\gamma = 0$) and also to the choice of Q_0^2 . Also given are the errors on Λ originating from statistics and those derived from systematic errors on the data. The systematic error on Λ was obtained by taking each component separately into account in the fit and adding the differences in $\log \Lambda$ quadratically. The normalization between the different energy data sets was kept fixed for these results. Leaving this relative normalisation free changed Λ by -9 MeV. Moving the lowest x bin to $x = 0.35$ changed Λ by +104 MeV (for $R = 0$), and subtracting a sea contribution [11] changed Λ by +60 MeV. Applying the Fermi motion corrections of Bodek and Ritchie [6] changed Λ by +30 MeV.

The curves shown in fig. 2 for $x < 0.25$ were obtained by fitting F_2 with the evolution equation of the singlet structure function [12]. The scale breaking parameter Λ was set to the value obtained from the fit above and the gluon distribution was fixed to $xG(x) = C(1-x)^3$ at $Q_0^2 = 4 \text{ GeV}^2$. The parameter C was fixed by the momentum sum rule.

In an attempt to explain all the scaling violation of F_2 for $x \geq 0.25$ by higher twist [13] a fit of the form $F_2 = F_2(x) (1 + \frac{\mu^2}{Q^2(1-x)})$ was performed with the result of $\mu^2 = (1.16 \pm .07) \text{ GeV}^2$ and $\chi^2 = 360$. This fit is much less probable than the QCD fit.

In conclusion the structure function F_2 on iron shows scaling violation over the entire range $3.25 \leq Q^2 \leq 200 \text{ GeV}^2$ and $0.05 \leq x \leq 0.65$. It can be explained by leading order quantum chromodynamics with a scale breaking parameter $\Lambda = 122^{+22}_{-20} {}^{+114}_{-70} \text{ MeV}$ assuming $R = 0$.

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Table 1

Energy (GeV)	120	250	280
Beam flux	0.44×10^{11}	3.1×10^{11}	0.8×10^{11}
Fiducial target ($\text{g} \cdot \text{cm}^{-2}$)	950	1250	1250
Trigger rate/incident μ $\theta > 2^\circ$ $\theta_\mu > 1^\circ$	2×10^{-5} 8×10^{-5}	3×10^{-6} 2×10^{-5}	3×10^{-6} 2×10^{-5}
ν cut (GeV)	10	25	25
p_μ cut (GeV)	20	40	45
Events after cuts	532K	177K	71K

TABLE 2

THE NUCLEON STRUCTURE FUNCTION F_2 WITH STATISTICAL ERROR σ
EXTRACTED BY ASSUMING $R = 0.0$ and 0.2

x	Q ² GeV ²	Beam Energy GeV	R = 0.0		R = 0.2	
			F ₂	σ	F ₂	σ
0.050	3.25	120	0.3077	0.0079	0.3119	0.0080
	3.75	120	0.3385	0.0073	0.3445	0.0075
	4.50	120	0.3414	0.0051	0.3502	0.0052
	5.50	120	0.3459	0.0049	0.3597	0.0051
	6.50	120	0.3446	0.0044	0.3647	0.0047
	8.00	120	0.3474	0.0040	0.3753	0.0043
	10.00	120	0.3510	0.0095	0.3880	0.0105
	12.50	250	0.3816	0.0095	0.4045	0.0100
	12.50	280	0.3650	0.0269	0.3834	0.0283
	17.50	250	0.3812	0.0073	0.4179	0.0080
	17.50	280	0.3754	0.0122	0.4072	0.0133
	22.50	280	0.4267	0.0182	0.4743	0.0202
0.080	3.25	120	0.3168	0.0105	0.3184	0.0105
	3.75	120	0.3200	0.0081	0.3221	0.0082
	4.50	120	0.3353	0.0055	0.3385	0.0055
	5.50	120	0.3501	0.0056	0.3549	0.0057
	6.50	120	0.3527	0.0055	0.3597	0.0056
	8.00	120	0.3518	0.0036	0.3630	0.0037
	10.00	120	0.3481	0.0039	0.3661	0.0041
	12.00	120	0.3504	0.0054	0.3754	0.0058
	15.00	120	0.3516	0.0076	0.3854	0.0083
	17.50	250	0.3477	0.0088	0.3619	0.0091
	17.50	280	0.3899	0.0196	0.4016	0.0202
	22.50	250	0.3579	0.0060	0.3827	0.0065
	22.50	280	0.3479	0.0123	0.3664	0.0129
	27.50	250	0.3809	0.0057	0.4151	0.0062
	27.50	280	0.3575	0.0116	0.3849	0.0125
	35.00	250	0.3857	0.0063	0.4281	0.0070
	35.00	280	0.3598	0.0104	0.3964	0.0115
0.125	3.75	120	0.3150	0.0120	0.3161	0.0121
	4.50	120	0.3127	0.0071	0.3141	0.0071
	5.50	120	0.3242	0.0070	0.3260	0.0070
	6.50	120	0.3329	0.0071	0.3354	0.0071
	8.00	120	0.3347	0.0049	0.3385	0.0050
	10.00	120	0.3334	0.0046	0.3394	0.0047
	12.00	120	0.3313	0.0049	0.3403	0.0050
	15.00	120	0.3302	0.0045	0.3447	0.0047
	17.50	280	0.3249	0.0283	0.3279	0.0286
	20.00	120	0.3368	0.0067	0.3630	0.0073
	22.50	250	0.3214	0.0112	0.3288	0.0114
	22.50	280	0.2896	0.0184	0.2943	0.0187
	27.50	250	0.3175	0.0088	0.3283	0.0091
	27.50	280	0.3134	0.0161	0.3216	0.0166
	35.00	250	0.3307	0.0041	0.3517	0.0043
	35.00	280	0.3146	0.0104	0.3292	0.0109
	50.00	250	0.3418	0.0042	0.3747	0.0046
	50.00	280	0.3181	0.0068	0.3460	0.0074
0.175	3.75	120	0.2592	0.0149	0.2597	0.0149
	4.50	120	0.2785	0.0089	0.2793	0.0089
	5.50	120	0.2941	0.0088	0.2951	0.0088
	6.50	120	0.3007	0.0088	0.3019	0.0088
	8.00	120	0.3063	0.0063	0.3080	0.0063
	10.00	120	0.3017	0.0059	0.3041	0.0059
	12.00	120	0.2936	0.0058	0.2971	0.0059
	15.00	120	0.2919	0.0046	0.2976	0.0047
	17.50	280	0.2891	0.0380	0.2904	0.0382
	20.00	120	0.2963	0.0056	0.3074	0.0059
	22.50	250	0.2836	0.0172	0.2859	0.0173
	22.50	280	0.2320	0.0225	0.2338	0.0227
	26.00	120	0.2938	0.0094	0.3139	0.0100
	27.50	250	0.2640	0.0122	0.2682	0.0124
	27.50	280	0.3133	0.0234	0.3168	0.0237
	35.00	250	0.2739	0.0068	0.2813	0.0070
	35.00	280	0.2856	0.0143	0.2912	0.0146
	50.00	250	0.2930	0.0033	0.3106	0.0035
0.250	4.50	120	0.2400	0.0113	0.2387	0.0112
	5.50	120	0.2377	0.0075	0.2373	0.0074
	6.50	120	0.2425	0.0072	0.2424	0.0072
	8.00	120	0.2414	0.0050	0.2417	0.0050
	10.00	120	0.2545	0.0050	0.2551	0.0050
	12.00	120	0.2414	0.0047	0.2424	0.0047
	15.00	120	0.2373	0.0035	0.2392	0.0035
	20.00	120	0.2380	0.0037	0.2418	0.0038
	22.50	250	0.2136	0.0181	0.2130	0.0181
	22.50	280	0.2139	0.0207	0.2145	0.0207
	26.00	120	0.2272	0.0055	0.2341	0.0057
	27.50	250	0.1993	0.0106	0.2001	0.0106
	27.50	280	0.2313	0.0191	0.2323	0.0192
	32.00	120	0.2338	0.0082	0.2455	0.0087
	35.00	250	0.2191	0.0063	0.2216	0.0063
	35.00	280	0.2250	0.0117	0.2267	0.0118
	50.00	250	0.2164	0.0030	0.2222	0.0031

TABLE 2 (Continued)

x	Q ² GeV ²	Beam Energy GeV	R = 0.0		R = 0.2	
			F ₂	σ	F ₂	σ
0.250	50.00	280	0.2164	0.0080	0.2206	0.0082
	70.00	250	0.2287	0.0027	0.2415	0.0029
	70.00	280	0.2274	0.0067	0.2376	0.0070
	90.00	250	0.2274	0.0051	0.2472	0.0055
	90.00	280	0.2137	0.0073	0.2300	0.0078
	120.00	280	0.2078	0.0123	0.2298	0.0136
0.350	6.50	120	0.1723	0.0102	0.1713	0.0101
	8.00	120	0.1636	0.0050	0.1631	0.0050
	10.00	120	0.1688	0.0048	0.1686	0.0048
	12.00	120	0.1635	0.0046	0.1635	0.0046
	15.00	120	0.1651	0.0035	0.1655	0.0035
	20.00	120	0.1640	0.0034	0.1651	0.0035
	26.00	120	0.1609	0.0049	0.1629	0.0049
	27.50	250	0.1306	0.0124	0.1308	0.0124
	27.50	280	0.1033	0.0165	0.1034	0.0165
	32.00	120	0.1536	0.0065	0.1569	0.0067
	35.00	250	0.1516	0.0070	0.1519	0.0070
	35.00	280	0.1495	0.0125	0.1500	0.0126
	40.00	120	0.1449	0.0072	0.1502	0.0074
	50.00	250	0.1415	0.0036	0.1432	0.0037
	50.00	280	0.1257	0.0078	0.1268	0.0079
	70.00	250	0.1457	0.0026	0.1495	0.0026
	70.00	280	0.1423	0.0075	0.1449	0.0077
	90.00	250	0.1439	0.0030	0.1506	0.0031
	90.00	280	0.1302	0.0046	0.1348	0.0048
	120.00	250	0.1398	0.0040	0.1503	0.0043
	120.00	280	0.1332	0.0051	0.1418	0.0055
	160.00	280	0.1426	0.0191	0.1575	0.0211
0.450	8.00	120	0.1104	0.0078	0.1098	0.0078
	10.00	120	0.1063	0.0043	0.1060	0.0043
	12.00	120	0.1079	0.0042	0.1077	0.0042
	15.00	120	0.1053	0.0031	0.1052	0.0031
	20.00	120	0.1048	0.0030	0.1051	0.0030
	26.00	120	0.1019	0.0040	0.1025	0.0041
	27.50	250	0.0934	0.0140	0.0939	0.0141
	27.50	280	0.0582	0.0150	0.0582	0.0150
	32.00	120	0.0967	0.0054	0.0978	0.0054
	35.00	250	0.0845	0.0063	0.0849	0.0063
	35.00	280	0.0855	0.0118	0.0856	0.0118
	40.00	120	0.0811	0.0053	0.0827	0.0054
	50.00	250	0.0810	0.0077	0.0813	0.0077
	50.00	280	0.0877	0.0036	0.0883	0.0036
	55.00	120	0.1028	0.0085	0.1066	0.0088
	70.00	250	0.0863	0.0025	0.0875	0.0026
	70.00	280	0.0784	0.0071	0.0792	0.0072
	90.00	250	0.0827	0.0024	0.0847	0.0024
	90.00	280	0.0847	0.0071	0.0863	0.0073
	120.00	250	0.0848	0.0026	0.0886	0.0027
	120.00	280	0.0689	0.0036	0.0714	0.0037
	160.00	250	0.0880	0.0068	0.0954	0.0074
	160.00	280	0.0793	0.0073	0.0849	0.0078
0.550	10.00	120	0.0712	0.0063	0.0713	0.0063
	12.00	120	0.0679	0.0037	0.0681	0.0037
	15.00	120	0.0637	0.0026	0.0639	0.0026
	20.00	120	0.0597	0.0024	0.0600	0.0024
	26.00	120	0.0561	0.0031	0.0564	0.0031
	32.00	120	0.0530	0.0040	0.0534	0.0041
	35.00	250	0.0456	0.0052	0.0459	0.0053
	35.00	280	0.0422	0.0086	0.0423	0.0086
	40.00	120	0.0495	0.0043	0.0502	0.0043
	50.00	250	0.0394	0.0058	0.0395	0.0058
	50.00	280	0.0451	0.0029	0.0453	0.0029
	55.00	120	0.0445	0.0049	0.0456	0.0050
	70.00	250	0.0477	0.0022	0.0481	0.0022
	70.00	280	0.0424	0.0073	0.0426	0.0074
	90.00	250	0.0468	0.0020	0.0475	0.0020
	90.00	280	0.0428	0.0050	0.0433	0.0050
	120.00	250	0.0429	0.0018	0.0441	0.0018
	120.00	280	0.0398	0.0030	0.0407	0.0030
	160.00	250	0.0372	0.0032	0.0394	0.0034
	160.00	280	0.0335	0.0043	0.0350	0.0045
0.650	12.00	120	0.0319	0.0036	0.0327	0.0037
	15.00	120	0.0322	0.0018	0.0329	0.0019
	20.00	120	0.0308	0.0017	0.0313	0.0017
	26.00	120	0.0265	0.0021	0.0268	0.0021
	32.00	120	0.0203	0.0025	0.0206	0.0025
	40.00	120	0.0217	0.0029	0.0220	0.0029
	50.00	280	0.0214	0.0048	0.0215	0.0048
	50.00	250	0.0234	0.0023	0.0236	0.0023
	55.00	120	0.0168	0.0029	0.0172	0.0030
	70.00	250	0.0208	0.0015	0.0209	0.0016
	70.00	280	0.0227	0.0044	0.0228	0.0044
	90.00	250	0.0201	0.0013	0.0203	0.0014
	90.00	280	0.0217	0.0049	0.0219	0.0049
	120.00	250	0.0191	0.0012	0.0195	0.0012
	120.00	280	0.0153	0.0066	0.0155	0.0067
	160.00	250	0.0179	0.0020	0.0186	0.0021
	160.00	280	0.0169	0.0032	0.0174	0.0033
	200.00	250	0.0155	0.0037	0.0165	0.0039
	200.00	280	0.0146	0.0047	0.0153	0.0049

Table 3: Parameter of QCD fit for data having $x \geq 0.25$

R	Λ [MeV]	Error		A	α $Q_0^2 = 4 \text{ GeV}^2$	β	γ	χ^2 Stat. error only	Degrees of freedom
		Stat.	Syst.						
0.0	122	+22	+114	0.91	0.26	2.7	0.35	211	102
[0.0]	[122]	-20	-70	[0.80]	[0.20]	[2.87]	[0.0]	[211]	[103]
0.2	41	+12	+86	2.93	0.24	2.6	0.55	286	102
		-11	-32						

FIGURE CAPTIONS

Fig. 1 Schematic layout of the iron-scintillator STAC target

Fig. 2 The structure function F_2 , with statistical errors, as measured on the iron target at different energies for $R = 0$. The curves are leading-order QCD fits. For the details in the different regions $x \geq 0.25$ and $x < 0.25$ see the text.

Fig. 3 Total excursions in F_2 allowed by a combination of all systematic errors for the low and high energy data separately.

Fig. 2

Fig. 3