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MEMORANDUM

To/A: J. Lefrançois, Chairman of the SPSC

From/De: C. Zupancic, NA4

Subject/Concerne: Experimental program for the coming years and requests

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1. INTRODUCTION

The NA4 experimental apparatus has been designed for large acceptance at high Q^2 and high luminosity with a very long hydrogen target. The NA4 physics program has been approved by SPSC (CERN/SPSC/74-79/P19 and CERN/SPSC/74-103/P19 Add.1) with these characteristics in mind. Since then, the development of physics has led to a shift of interest such that the largest range in log Q^2 is of greater interest than the highest attainable Q^2-value, at least for structure function determination in hydrogen. Also structure function measurements with nuclear targets have reached a certain maturity with results of several groups agreeing among each other at the level of ca. 10%. In the near future, results of comparable quality in hydrogen and deuterium will become available.

These developments have led us to modify and extend our original goals. We have modified our apparatus along the lines of CERN/SPSC/74-120/P19 Add.3 in order to extend our kinematical range as much as feasible (Fig. 1 and Fig. 2). In addition, we took a number of steps to improve the accuracy of measurements. The redundancy of the trigger has been greatly increased by introducing additional trigger counters and more sophisticated triggering electronics. The maximum tolerable beam intensity has been very substantially increased by using the information from the MWPC in the event accepting decision and by increasing the data taking speed. Provisions are being made for precise calibrations of beam energy, spectrometer magnetic field, experimental resolution etc. Last, not least, our 40 m long H_2/D_2 target has been installed and is functionning perfectly.

The aim of these improvements is the capability to measure structure functions with substantially better precision than has been achieved till now and therefore, to be able to extract more accurate physical quantities e.g. $R = \sigma_L/\sigma_T$. With accurate structure functions perturbative QCD could be subject to more stringent tests than till now and a better value of Λ_{QCD} could be extracted. Our physics program for the coming years is:

a) Accurate determination of the structure function F_2 in hydrogen in a wide kinematical range and an accurate measurement of R in a region $.2 < x < .4$, $20\ \mathrm{GeV}^2 < Q^2 < 50\ \mathrm{GeV}^2$.

b) Accurate determination of the structure function F_2 in deuterium in the same kinematical range as for hydrogen.

2. SYSTEMATIC ERRORS

The most serious known sources of systematic errors are uncertainties in the following parameters: average beam energy, spectrometer magnetic field and its spatial dependence, beam phase space, luminosity, triggering and reconstruction efficiency, smearing corrections (i.e. effects of finite resolution) and muons from hadronic decays. Our experiment on +/- asymmetry of structure functions in carbon has let us gain considerable experience in the control of these systematic errors.

The characteristics of our apparatus are such that systematic errors due to uncertainties in beam phase space, triggering and reconstruction efficiency, and decay muons are negligible.

The effects of small changes in beam energy or spectrometer magnetic field on measured yields are dramatic, due to the strong Q^2 and x-dependence of the deep inelastic cross section. This is shown in fig. 3. However, we can keep our spectrometer magnetic field stable and reproducible over long periods to better than $5 \cdot 10^{-4}$ (essentially because the iron is in saturation). Also, we have learned how the nominal beam energy could be kept stable and reproducible to better than $5 \cdot 10^{-4}$. Fortunately, the absolute values of either nominal beam energy or average magnetic field do not have to be known with the same precision, provided we move the spectrometer across the beam and intercalibrate the two. Then the uncertainty in the absolute values has negligible influence on R and Λ_{QCD} and reduced influence on the x-dependence of the structure functions. Nevertheless, we plan to make an absolute calibration of the beam momentum station to better than 10^{-3} using a field-mapped air gap magnet with high resolution proportional chambers. The effect of the spatial variation of the spectrometer magnetic field will be determined with muon tracks using a newly developed algorithm promising precisions of 10^{-3} or better. In summary, the relevant remaining uncertainties should correspond at most to a $5 \cdot 10^{-4}$ variation of the nominal beam energy and an independent 10^{-3} variation of the spectrometer magnetic field. They are important only at low Q^2/Q^2max and high x.

As to luminosity, its absolute value is of less interest than its relative accuracy for different beam energies. Our experience with counting positive and negative muons at a given beam energy but varying intensities indicates that the counting is accurate to considerably better than 1%. There is no reason to expect that counting at different beam energies should present unsurmontable problems at the level of 1%. With the accurately known beam phase space and small multiple scattering, beam losses from the target are no problem. The H_2/D_2 length in g/cm^2 is monitorable to much better than 1%.

Smearing corrections are obviously more of a problem in our experiment than with magnetic field in air. Our resolution in Q^2 and scattered energy is of the order of 7%. The latter resolution leads to poor resolution at small ν, i.e. large x and small Q^2. However, recently we have made great progress in experimentally measuring our resolution. A further determination of the resolution will be obtained as a by-product of the beam-spectrometer intercalibration. We feel confident that we shall know the resolution to better than 10% of its value. This leaves us with systematic errors presented in Fig. 4.

In summary the most serious known sources of systematic errors are the uncertainties about incident energy, spectrometer magnetic field and smearing corrections. They all contribute mainly at high x and low Q^2, with a known dependence on these variables. In a large fraction of the available kinematical range the known systematic errors are smaller than 2%.

There are certainly other error sources ranging from suspected (e.g. randoms at high intensities) to completely unknown ones. Measures have been or will be taken to minimize their influence: good on-line control of the equipment, fast feed-back from off-line analysis, extensive testing and auxiliary measurements before the main data taking and, most important, sufficient statistics so that statistical errors are substantially smaller than the final desired accuracy. This makes the detection of at least some unknown sources of systematic errors possible and the final result credible.

3. STATISTICAL ERRORS

We have made tests at 120 GeV showing that with a restrictive trigger we can stand incident intensities as high as $5 \cdot 10^7$/burst with an acceptable lifetime of ca. 70%. Substantial improvements are still possible but will be used mainly to make the trigger less restrictive, i.e. to enlarge the kinematical region of full acceptance. Table I shows the expected yields of scattered muons at different incident energies assuming intensities of $\leq 5 \cdot 10^7$ incident muons/burst and $\leq 4 \cdot 10^{12}$ protons/bursts on T6. The numbers in the table are based on yield calculations such as reported in fig. 2 with conservative cuts to exclude regions of strongly varying acceptance. It must also be remarked that table I makes some optimistic assumptions about the efficiency of SPS and beam line, the time spent for short tests, and access time. These assumptions correspond to the best data taking efficiency achieved in 1980.

Using the numbers from the table, $R = 0$, and $\Lambda = 100$ MeV, the statistical errors of R and Λ have been computed (with QCD fits in the case of Λ). The statistical error of the average R is of the order $\Delta\bar{R} = \pm 0.03$ assuming three measured energies: either 100, 120, 200 GeV or 120, 200, 280 GeV (the Q^2,x domain where R is accurately determined is slightly different in the two cases). The statistical error of Λ is of the order of $\Delta\Lambda = \pm 20$ MeV when averaging the values obtained at the three energies. The systematic errors due to incident energy, spectrometer magnetic field, and smearing corrections are not important for R, as expected from figs. 3 and 4. They are serious for Λ and amount to about $\Delta\Lambda = \pm 20$ MeV. The normalisation error is serious for R, 1% corresponding to about $\Delta R = 0.03$ and not important for Λ unless one tries to improve its accuracy by simultaneously fitting data obtained at different incident energies. We conclude:

a) The statistical errors corresponding to luminosities as assumed in table I are of the same order of importance as the expected systematic errors. However, as explained before, this means that considerably longer times should be spent taking data in order to make statistical errors less important and to test against the existence of unknown systematic errors.

b) The incident energy of 280 GeV is not well suited for our physics program, and is practically unusable at the 1981 intensities, corresponding to 3-4 10^{12} of 400 GeV protons/bursts on T6. If the intensity could be increased by a factor of 2 we would still need 3 times the data taking time required at each of the lower energies. However, in that case data taking at 280 GeV may start to become attractive because of the extension of the Q^2 and x-range as compared to energies $E \lesssim 200$ GeV.

4. REQUESTS

To achieve our physics goals we should like to take data mainly at three incident energies: 100 GeV, 120 GeV and 200 GeV and at intensities up to $5 \cdot 10^7$/burst. At energies lower than 100 GeV the acceptance of our apparatus starts shrinking rather rapidly due to the cuts on scattered energy (20 GeV) and on the length of track in iron (ca. 12 m). The energy of 120 GeV splits the total available range in the Rosenbluth parameter ε in two approximately equal parts for the Q^2,x range where our R-determination should be most accurate. The time spent for data taking at each energy in hydrogen should be of the same order of magnitude. In deuterium, we do not aim at measuring R and two incident energies (120 GeV and 200 GeV) could suffice. The minimum number of incident muons we need to reach sufficiently small statistical errors is $1.5 \cdot 10^{13}$ at each incident energy and target, i.e. $7.5 \cdot 10^{13}$ incident muons for the structure function measurements in hydrogen and deuterium. This corresponds to $4.3 \cdot 10^{18}$ protons on T6 and approximately 270 days of data taking time. In addition we estimate that we need 60 days for auxiliary measurements, tests, and checks under various beam conditions concerning energy, intensity, halo contamination etc.

Our total request is therefore: $8 \cdot 10^{13}$ incident muons
ca. 330 days of running
ca. $5 \cdot 10^{18}$ protons on T6.

5. COMPATIBILITY WITH NA2/NA9 AND PLAN FOR 1982

We have been asked by the Chairman of the SPSC to look into the compatibility of our program with the EMC program. We understand that the EMC group should like to take data with their streamer chamber until the end of 1982 with high beam energies and low intensity ($< 10^7$ μ/burst). This mode of operation is clearly in conflict with our physics program.

However, we could use some running time at 280 GeV for checking our equipment and the preparation of auxiliary measurements. Most auxiliary measurements and tests require varying beam conditions (energies, intensities, halo contamination etc.) but relatively short data-taking times. We request 20 days in 1982 for auxiliary measurements and tests which are vital for our progress. These test periods should have flexible scheduling but we shall try to concentrate them as much as possible in the beginning of 1982. We should like to point out that some of these tests and measurements, such as setting up optimal beams at different energies or absolute calibration of the incident energy, are in the common interest of both groups. We also hope that the EMC group can use, at least partly, such beam conditions for their own tests.

Equally vital for our progress in the years following 1982 is a solid block of data at a set of three different incident energies obtained already in 1982. This would enable us in the winter shutdown 1982/83 to carry out the analysis of these data to its conclusion, i.e. a determination of R and A which, in term, would be extremely important for the planning of data taking in 1983 and beyond. Therefore, we request 50 days of data taking with the H_2 target at the incident energies of 100, 120 and 200 GeV. In this time we would accumulate sufficient statistics to be able to predict the quality of our final result and introduce experimental improvements if found necessary.

Finally, we are asking that in the case of SPS operating at 450 GeV the maximum energy of the muon beam should be kept at 280 GeV with the corresponding increase in intensity in order to enable us to profitably take data at this energy. We reiterate that at high energies and low intensities $< 10^7$ μ/burst data taking is for us wasteful in money and human resources. We hope that this higher intensity is still acceptable to EMC which would make our mutual compatibility as high as possible.

In summary, our requests for 1982 are:

1. 20 days of auxiliary measurements at varying beam conditions.
2. 50 days data taking at 100, 120 and 200 GeV and intensities of ca. $4 \cdot 10^7$ incident muons/burst.
3. 40 days data taking at 280 GeV and at least $1.5 \cdot 10^7$ incident muons/burst.

For us, items 1 and 2 are first priority while item 3 has been included in our request mainly in the interest of compatibility with the EMC program.

6. FINAL REMARKS

As to the long range options of our experiment it is clearly impossible to say anything very definite beyond the present program. However, it seems to us that the perfection of equipment and expertise acquired by the end of the present program, not to mention the investment in our apparatus from 1974 till now, should be an incentive to look into the longer range possibilities. For instance, it probably cannot yet be excluded that weak interaction effects would fade out of interest for the experimentation with our apparatus by the end of our present program. As for the competition from Fermilab we believe that a well debugged equipment brought to a high level of precision over many years can easily compete with an advantage of a factor of two (at most) from higher incident energies.

TABLE 1

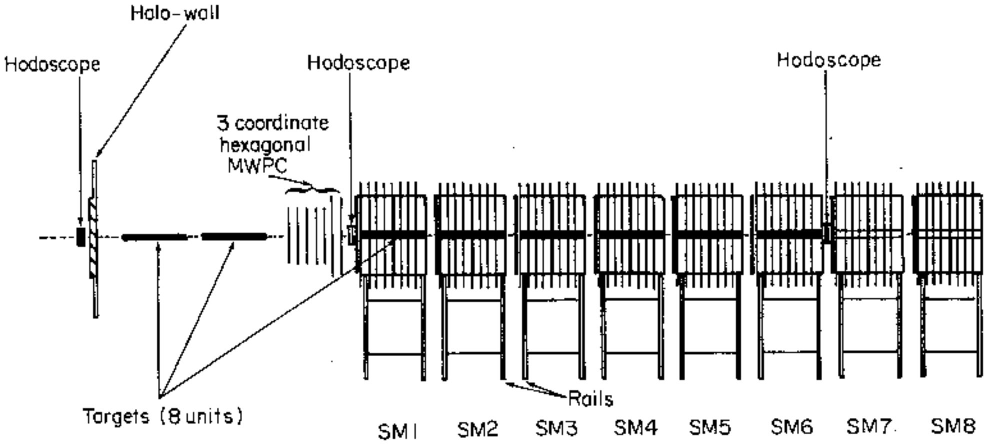
Number of good events/$3 \cdot 10^{12}$ incident muons

Energy	No. of good events	μ/p	p/burst	days	protons on T6
100 GeV	320 000	$2 \cdot 10^{-5}$	$2.5 \cdot 10^{12}$	10	$1.5 \cdot 10^{17}$
120	270 000	2	2.5	10	1.5
200	150 000	1.5	3.3	10	2.0
280	100 000	0.15	4.0	70	20

Assuming μ/burst $\leq 5 \cdot 10^{7}$
p/burst $\leq 4 \cdot 10^{12}$

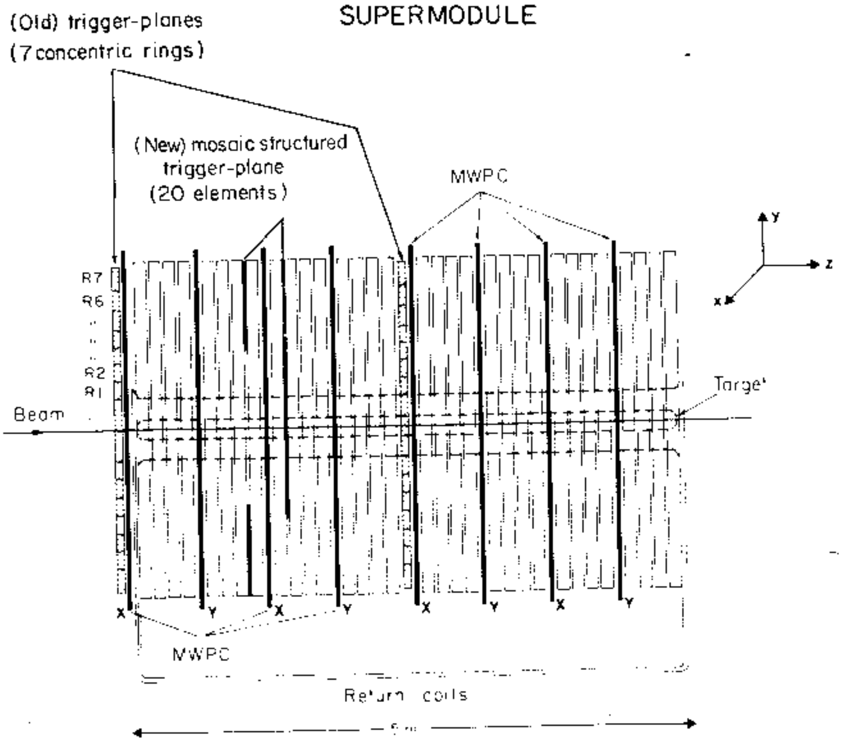
Good events are events accepted in the final analysis, populating the kinematical region sufficiently far away from acceptance boundaries.

EXPERIMENTAL SET-UP (TOP-VIEW)



Top view of the experimental set-up

SUPERMODULE

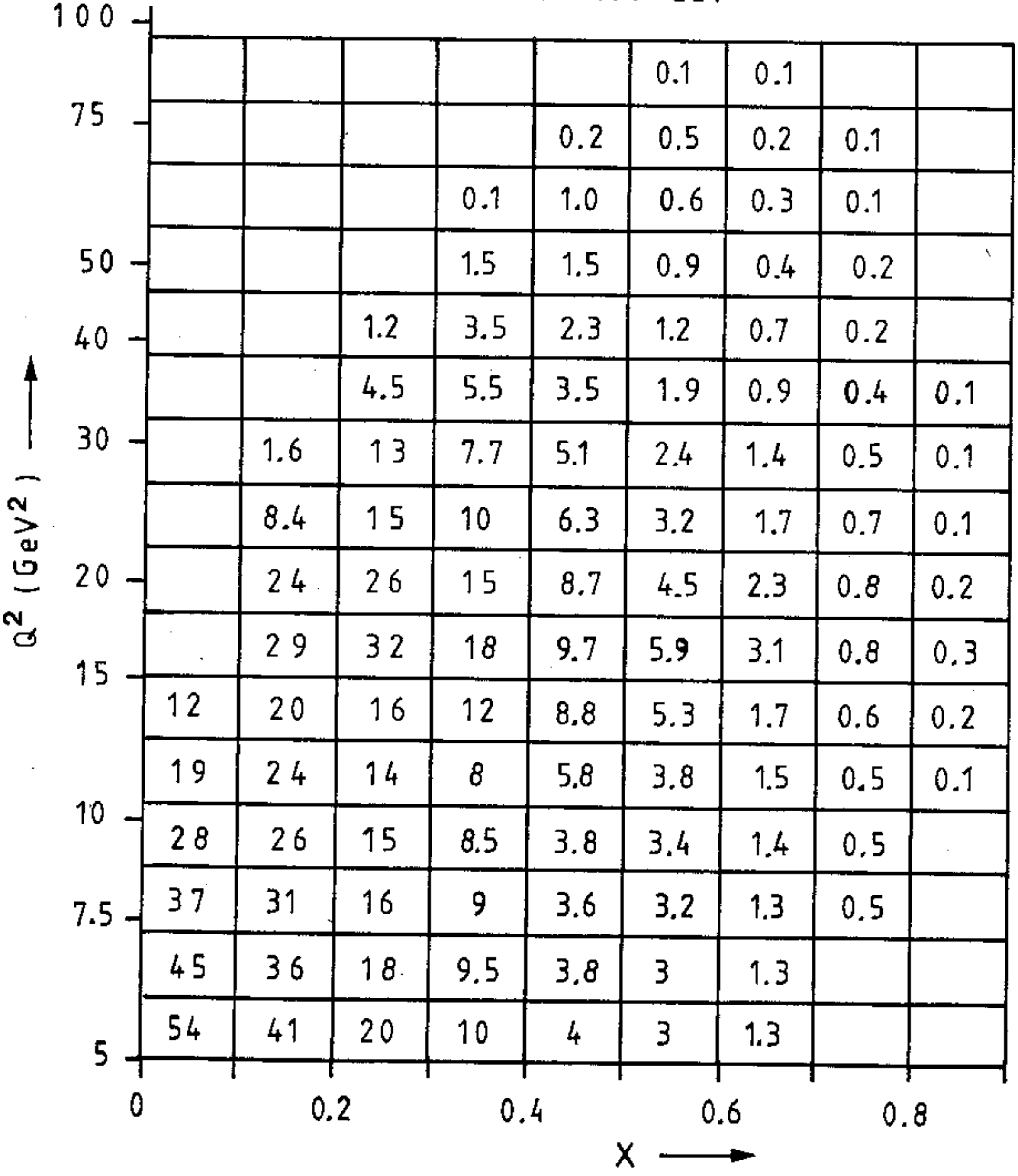


Enlarged view of one super module

Fig. 1

NUMBER OF 10^3 EVENTS PER Q^2-X BIN
FOR 3×10^{12} INCIDENT MUONS

BEAM ENERGY 100 GeV



					0.1	0.1		
				0.2	0.5	0.2	0.1	
			0.1	1.0	0.6	0.3	0.1	
			1.5	1.5	0.9	0.4	0.2	
		1.2	3.5	2.3	1.2	0.7	0.2	
		4.5	5.5	3.5	1.9	0.9	0.4	0.1
	1.6	13	7.7	5.1	2.4	1.4	0.5	0.1
	8.4	15	10	6.3	3.2	1.7	0.7	0.1
	24	26	15	8.7	4.5	2.3	0.8	0.2
	29	32	18	9.7	5.9	3.1	0.8	0.3
12	20	16	12	8.8	5.3	1.7	0.6	0.2
19	24	14	8	5.8	3.8	1.5	0.5	0.1
28	26	15	8.5	3.8	3.4	1.4	0.5	
37	31	16	9	3.6	3.2	1.3	0.5	
45	36	18	9.5	3.8	3	1.3		
54	41	20	10	4	3	1.3		

FIG.2A

NUMBER OF 10^3 EVENTS PER Q^2–X BIN
FOR 3×10^{12} INCIDENT MUONS

BEAM ENERGY 200 GeV

Q^2 (GeV^2)

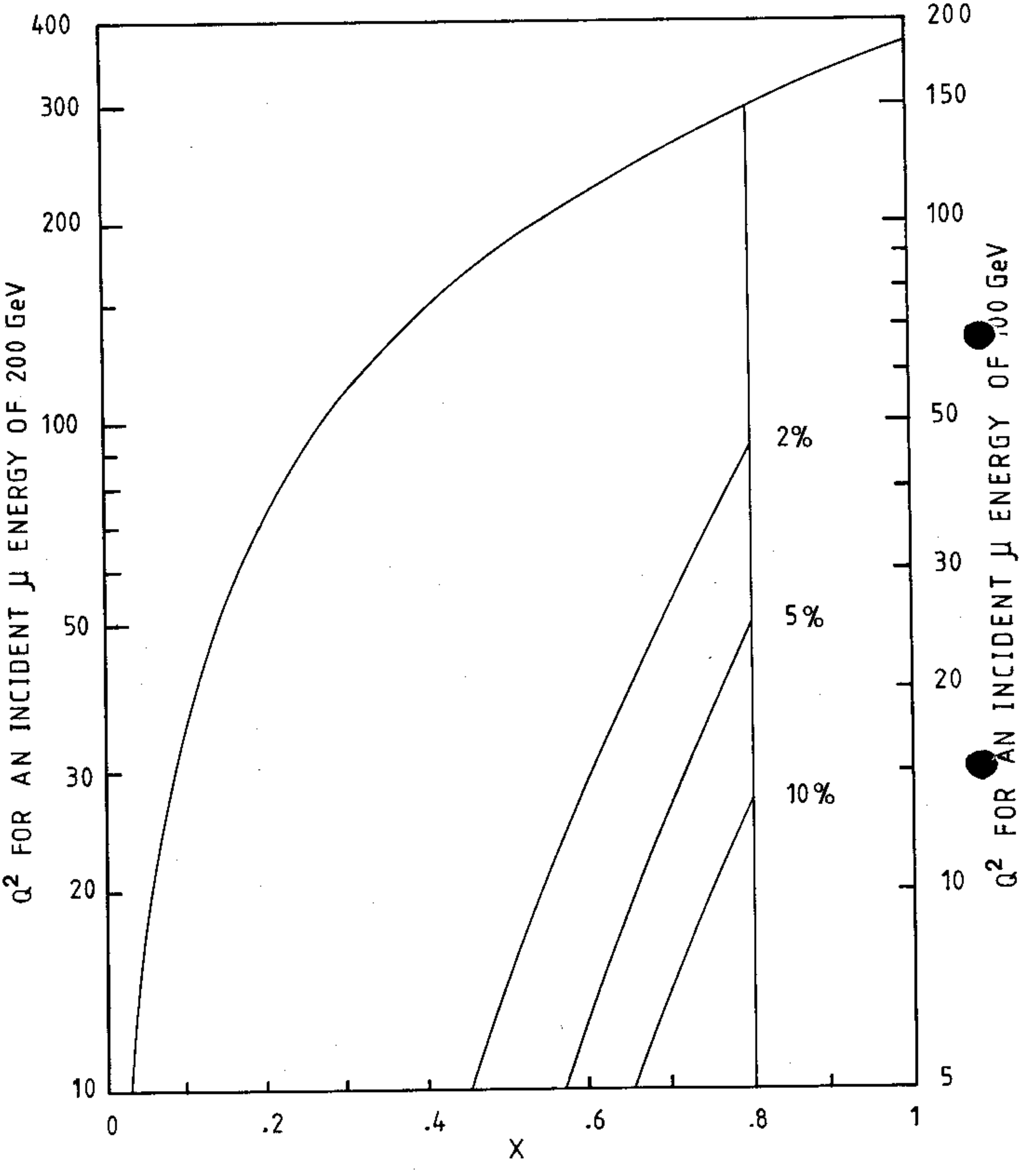
200 150 100 75 50 40 30 20 15

				0.2	0.2	0.1		
			0.2	0.5	0.3	0.1		
			1	0.7	0.4	0.2		
		0.9	1.7	1.2	0.6	0.3	0.1	
		3.3	2.7	1.6	0.8	0.4	0.1	
	1.6	5.9	3.6	2.1	1.1	0.5	0.2	
	5.9	8.2	4.9	3.0	1.4	0.7	0.3	
	14	11	6.2	3.5	1.9	1.0	0.3	0.1
	22	14.5	8.7	5.2	2.3	1.2	0.4	0.1
2.4	24	16	8.7	5.3	3.0	1.2	0.6	0.1
6.0	12	5.4	2.6	1.5	0.8	0.4	0.2	
14	11	4.9	2.5	1.4	0.6	0.3	0.1	
17	12	5.2	2.6	1.3	0.5	0.2		

0 0.2 0.4 0.6 0.8

X →

FIG. 2 B



ERROR ON F_2 DUE TO A SYSTEMATIC UNCERTAINTY OF 1‰ ON THE INCIDENT MUON ENERGY

FIG. 3A

ERROR ON F_2 DUE TO A 1‰ UNCERTAINTY OF THE MAGNETIC FIELD

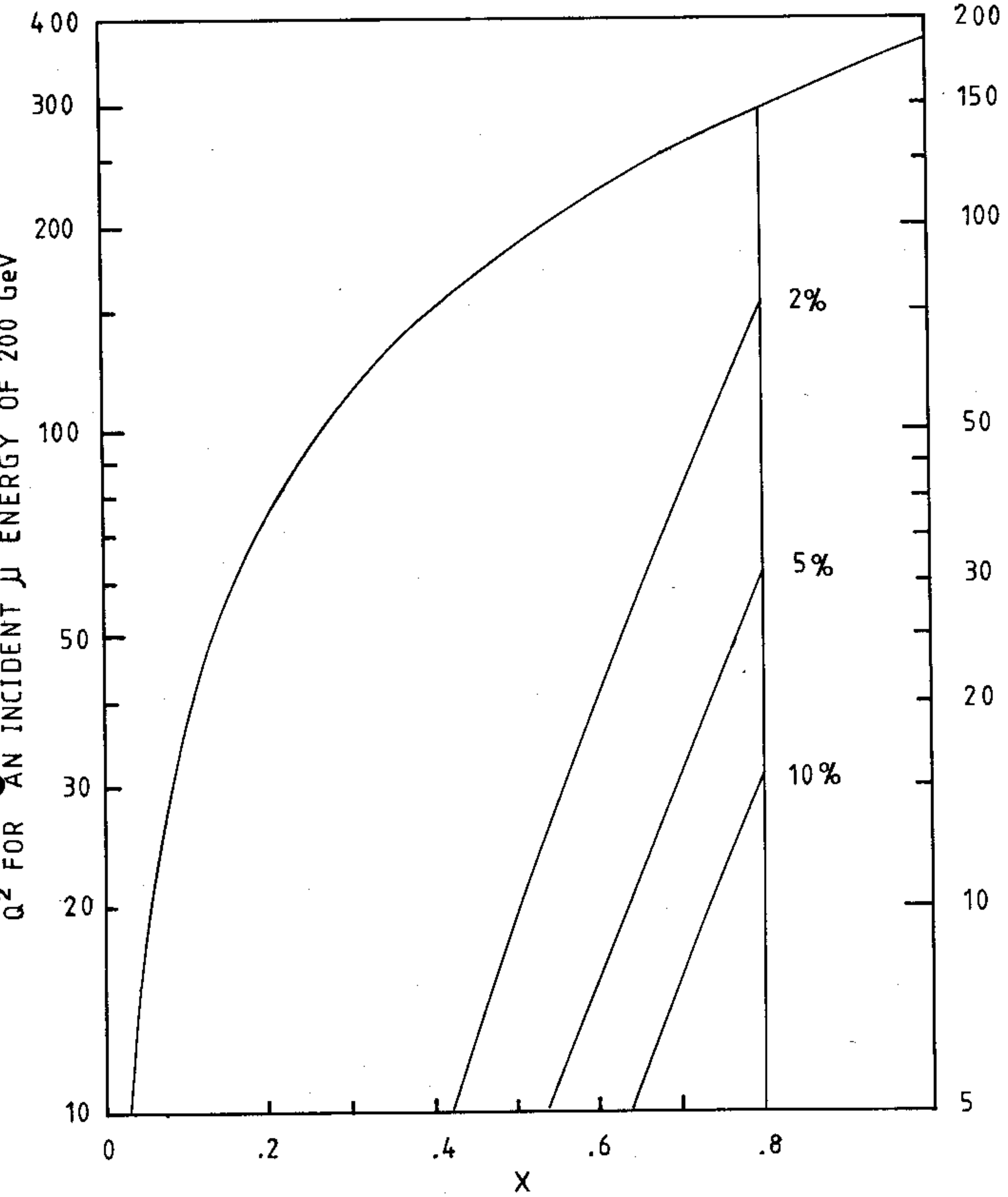


FIG. 3 B

CHANGE OF F_2 DUE TO AN INCREASE OF THE MOMENTUM RESOLUTION OF THE SCATTERED μ BY A FACTOR 1.1

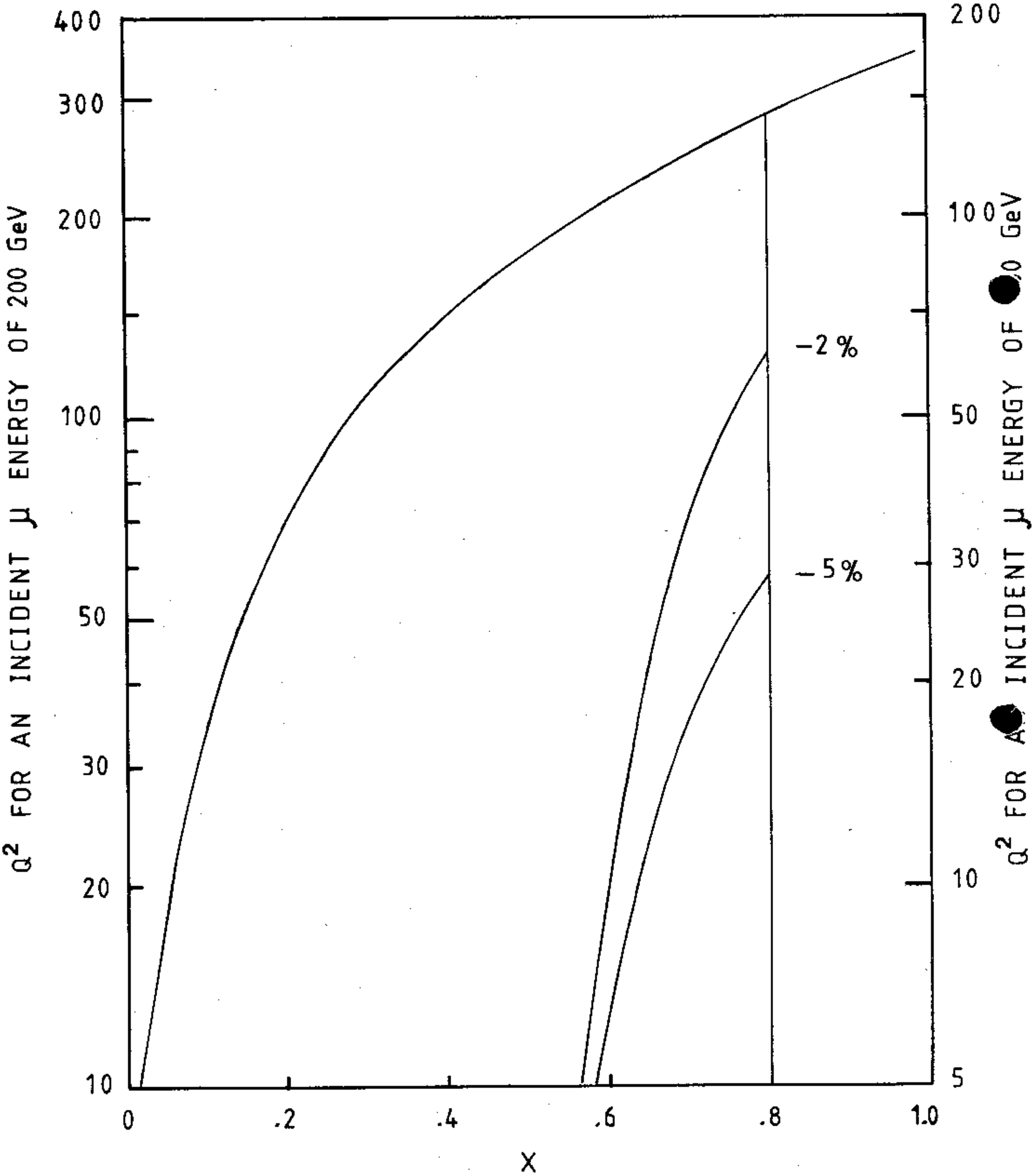


FIG. 4