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Diffraction Dissociation in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

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ABSTRACT

We have studied single diffraction dissociation ($\bar{p}p \rightarrow \bar{p}X$) in proton-antiproton collisions at $\sqrt{s} = 1.8$ TeV, covering the ranges $3 \lesssim M_x \lesssim 200$ GeV and $0.05 \lesssim |t| \lesssim 0.11$ $(GeV/c)^2$. Parameterizing the production to be of the form $d\sigma/(dt dM_x^2) = (M_x^2)^{-\alpha} \cdot \exp(bt)$, we obtain $\alpha = 1.13 \pm 0.07$ and $b = 10.5 \pm 1.8$ $(GeV/c)^{-2}$. The total single diffraction dissociation cross section is $2\sigma_{SD} = 8.1 \pm 1.7$ mb. Comparisons are made to previous lower energy data, and to an earlier measurement by us at the same energy.

We report here a study of single diffraction dissociation, $\bar{p}p \rightarrow \bar{p}X$, at $\sqrt{s} = 1.8$ TeV. Our data cover the range $3 \lesssim M_x \lesssim 200$ GeV and $0.05 \lesssim |t| \lesssim 0.11$ $(GeV/c)^2$. The apparatus, shown schematically in Figure 1, is part of the equipment used to study $\bar{p}p$ elastic scattering and total cross sections at the Fermilab Tevatron Collider.[1-5] Data were taken in a small number of special runs with a trigger specific for this process. Referring to Figure 1, the trigger required a particle (antiproton) in Detector 2, together with at least one particle in the annular counters R_3, R_4 or R_5

which covered the pseudorapidity range $5.2 \leq \eta \leq 6.5$. In the software analysis, the antiproton which triggered Detector 2 was also required in Detector 4, and no particle was present in counters on the scattered proton side which could be consistent with elastic scattering. The 91 meters of horizontally bending 4T magnets between Detectors 2 and 4 allowed a measurement of the momentum of each antiproton which determined M_x for each event. The scattering angle, obtained from the antiproton position in Detector 4, gave the four momentum transfer t.

In our analysis, we follow previous practice (see, for example, Reference 6) and assume M_x and t independence in the cross section, i.e.

$$d\sigma/(dtdM_x^2) = A\, f(t)\, g(M_x^2) \tag{1}$$

we use

$$f(t) = e^{bt} \tag{2}$$

$$g(M_x^2) = (M_x^2)^{-\alpha} \tag{3}$$

and use our data to obtain b, α and the total cross section for diffraction dissociation given by

$$2\sigma_{SD} = 2 \iint (d\sigma/(dtdM_x^2)dtdM_x^2 \tag{4}$$

where the integrations are carried out over all values of t and over

$$2\ \mathrm{GeV}^2 < M_x^2 < 0.05s \tag{5}$$

The factors of two in Equation (4) give the total diffraction dissociation cross section, which is the sum of the diffraction dissociation of the proton and that of the antiproton. These are always taken to be equal; our experiment only measures the dissociation of the proton. The total cross section for diffraction dissociation (Equation 4) is generally written as $2\sigma_{SD}$.

Previous studies of diffraction dissociation have been carried out at fixed target accelerators, and the CERN ISR and SPS colliders. In addition, we have previously reported (3) a measurement of $2\sigma_{SD} = 11.7 \pm 2.3$ mb at the Fermilab Tevatron Collider at $\sqrt{s} = 1.8$ TeV using a different experimental technique to that reported here.

Earlier studies[3,7-16] have not always used consistent definitions of diffraction dissociation, giving rise to apparent disagreement between measurements. In addition, differences in M_X coverage and sometimes indirect methods of measuring M_X, have also made comparisons between experiments difficult. Generally, experiments have found that the M_X dependence is consistent with M_x^{-2} (i.e., $\alpha = 1$ in Equation (3)), as expected by some theoretical models (see, for example, Reference 6). The M_X range of the integration in Equation (4), given in Equation (5), has been used in many experiments, but other ranges have also been used in the past. The t dependence of diffraction dissociation, if parameterized as in Equation (2), has been found to have a value of b, in the small $|t|$ region, of about half of that measured for elastic scattering at the same energy. However, some experiments have found the need for a quadratic exponential term at larger $|t|$, and there is some evidence of a dependence of b on M_x^2, i.e., the simplification represented by Equation (1) may not be valid; Reference 7 contains a discussion of these features.

Our analysis is based on about 13000 diffraction events. During data taking, we simultaneously observed elastic scattering events using a detector for the scattered proton not shown in Figure 1, but described in References 1 and 3; elastic events were prescaled by a factor of 30, and our final elastic total was approximately 2000. In both cases, the numbers of events are after all selection and fiducial cuts; the fiducial cuts were made in order to avoid possible detector edge effects. We used the elastic events to normalize the diffraction cross section, since we have previously measured the elastic scattering distribution and cross section at this energy.[5]

Contamination of the diffraction sample by elastic events could be determined off-line by examination of hits in the various detectors, and was found to be essentially zero. Other background in the diffraction sample could be determined from the number of events in the negative (non-physical) M_x^2 region, (i.e., the measured $\bar{p}$ momentum greater than the beam momentum) and was ~0.25%. The t acceptance of the data was determined by the vertical placement of the Detectors 2 and 4; the lower M_x limit was determined using Monte Carlo simulation, requiring a hit in at least one of the three annular counters R_3, R_4 or R_5. Our results were found to be insensitive to reasonable changes in the Monte Carlo assumptions. Our upper M_x limit of 200 GeV was due to event statistics rather than acceptance. Our resolution in M_x was obtained from elastic events, where the width of the correlation between hits in Detector 2 and Detector 4 should be zero in the absence of resolution broadening effects. Our resolution in M_x^2 was $\sim\pm(64\ \mathrm{GeV})^2$, and the resolution in t was $\sim\pm 8\times 10^{-3}$ $(\mathrm{GeV}/c)^2$.

We obtained the x (horizontal) and y (vertical) calibrations of the detectors using the calibration scintillation counter in each detector; these had accurately machined holes in their faces, and several accurately machined edges. The x calibration (based on charge division) is known with substantially less accuracy than the y calibration. The data reduction steps needed to arrive at the final event sample were similar to those in our earlier work.[1-5] The parameters b and α could each be obtained from our data in several ways, and the results obtained were consistent within the errors. For example, α could be derived from the correlation between the x coordinates of events in Detectors 2 and 4, together with knowledge of the transfer functions of the accelerator magnetic lattice between the two detectors. The value of b could be obtained from the x or y distributions of events in either Detector 2 or Detector 4, as could also B (the slope of the elastic scattering distribution). Figure 2 shows the observed M_x^2 distribution of single diffractive events along with predicted

curves for α = 1.03, 1.13, and 1.23. Figure 3 shows the observed t distribution in Detector 4 along with predicted curves for b = 5.5, 10.5 and 15.5 GeV^{-2}. These predicted curves are Monte Carlo generated using Equation (1), with the measured x and y resolutions folded in and taking into account the fiducial cuts; they are normalized to the total number of events.

The method used to obtain our final values of α and b combines all the information into one joint two-parameter least squares analysis. The predicted (x2,y2), (x4,y4) and (x2,x4) two dimensional distributions of events are Monte Carlo generated for given values of α and b using Equations 1, 2, and 3 (taking into account the measured x and y resolution smearing). The total chi-squared for the three distributions is evaluated, and then α and b are varied to find the least squares solution and statistical errors in α and b. As a check on our x calibrations of the detectors, these were also varied. The solutions for α and b are almost independent of the calibration constants; the minimum chi-squared gave calibration constants within 5% of those measured.

Our final chi-squared per degree of freedom was 3.5 for all 643 data points. This high value is very probably due to a breakdown of the assumption that M_x and t are independent in the cross section, as given in Equation (1). For the data points corresponding to $M_x > 65$ GeV the solution for b was $4 \pm 3(GeV/c)^{-2}$ as opposed to $10.5 \pm 1.8\ (GeV/c)^{-2}$ when all the data are lumped together. Cuts were made in the data to avoid edge effects; their effect was checked by repeated analyses using less conservative cuts. We note that at the lowest values of M_x, the M_x distribution observed in lower energy experiments is not a simple power law, but shows resonance bumps near the low mass cutoff in Equation (5). If we use the most extreme amount of those bumps allowed by existing data, our cross section would increase by 7%. Our quoted error of 18% includes this uncertainty and also the uncertainty caused by the lower M_x cutoff used in Equation (5).

Our solution for the elastic slope parameter using the above procedures is $B = 17.9 \pm 2.5$ $(GeV/c)^{-2}$ which agrees well with our published value of 17.0 ± 0.5 $(GeV/c)^{-2}$.[5] This gives us confidence in the results for α and b. Our final errors are obtained by combining quadratically our systematic and statistical errors, with the major contribution being systematic. Our results are

$$\alpha = 1.13 \pm 0.07$$

$$b = 10.5 \pm 1.8 \ (GeV/c)^{-2}$$

$$2\sigma_{sd}/\sigma_{el} = 0.49 \pm 0.09$$

Taking $\sigma_{el} = 16.6 \pm 1.6$ mb from Reference 3, we obtain $2\sigma_{sd} = 8.1 \pm 1.7$ mb. This result is plotted in Figure 4, along with previous results from lower energies[7-15] and our earlier result[3] at this energy obtained using a different experimental method.

We can make the following observation about our results.

(i) The value of b observed for diffraction dissociation ($b = 10.5 \pm 1.8$ $(GeV/c)^{-2}$) is about half of the elastic slope B at the same energy ($B = 17.0 \pm 0.5$ $(GeV/c)^{-2}$), as has been found previously at lower energies. There is some indication that b becomes smaller at higher M_x^2, as has been found at lower energies.

(ii) The M_x dependence observed ($\alpha = 1.13 \pm 0.07$, or $M_x^{(-2.26\pm0.14)}$) is similar to the $\sim M_x^{-2}$ observed at lower energies,[16] and to the M_x^{-2} predicted by some models.

(iii) Our value for $2\sigma_{SD}$, 8.1 ± 1.7 mb, is consistent with our earlier value,[3] 11.7 ± 2.3 mb, obtained using a completely different technique. Since they are independent measurements, we can combine them to give a value for $2\sigma_{SD}$ at $\sqrt{s} = 1.8$ TeV of 9.4 ± 1.4 mb. As seen in Figure 4, it is difficult to draw conclusions on the energy

dependence of $2\sigma_{SD}$, although the data are consistent with an increase of $2\sigma_{SD}$ with energy at roughly the same rate as the $\bar{p}p$ total cross section.

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REFERENCES

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1. N. A. Amos et al., Phys. Rev. Lett. 61, 525 (1988).
2. N. A. Amos et al., Phys. Rev. Lett. 63, 2784 (1989).
3. N. A. Amos et al., Phys. Lett. B243, 158 (1990).
4. N. A. Amos et al., Phys. Lett. B247, 127 (1990).
5. N. A. Amos et al., Phys. Rev. Lett. 68, 2433 (1992).
6. K. Goulianos, Phys. Rep. 101, 169 (1983).
7. M. G. Albrow et al., Nucl. Phys. B108, 1 (1976).
8. J. W. Chapman et al., Phys. Rev. Lett. 32, 257 (1974).
9. J. Schamberger et al., Phys. Rev. Lett. 34, 1121 (1975).
10. S. Barish et al., Phys. Rev. D9, 2689 (1974).
11. J.C.M. Armitage et al., Nucl. Phys. B194, 365 (1982).
12. J. Whitmore et al., Phys. Rep. 10, 273 (1974).
13. R. E. Ansorge et al., Z. Phys. C33, 175 (1986).
14. G. J. Alner et al., Phys. Rep. 154, 247 (1987).
15. D. Bernard et al., Phys. Lett. B186, 227 (1987).
16. M. Bozzo, Phys. Lett. B136, 217 (1984).

FIGURE CAPTIONS

Figure 1. Schematic side view of the experiment. Detectors 2 and 4 are "Roman Pots" containing drift chambers and scintillation counters. R_3, R_4 and R_5 are annular scintillation counters placed around the Tevatron beam pipe.

Figure 2. Distribution of diffraction events vs M_x^2. The curves are those predicted for the values of α shown; see text for details.

Figure 3. Distribution of diffraction events vs -t. The curves are those predicted for the values of b shown; see text for details.

Figure 4. The total single diffraction cross section result from this experiment together with previous pp[7-12] and $\bar{p}p$[13-15] data, and our earlier result.[3]

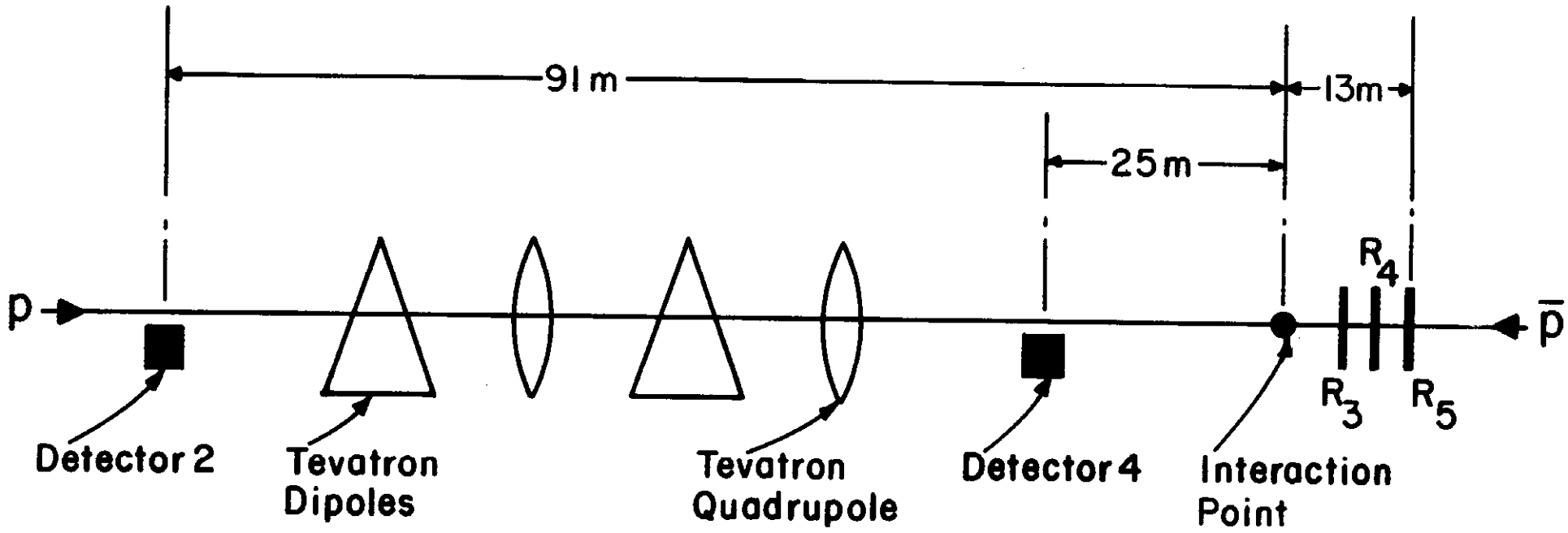
91 m
13m
25 m
p
$\bar{p}$
R_4
R_3
R_5
Detector 2
Tevatron Dipoles
Tevatron Quadrupole
Detector 4
Interaction Point

Figure 1

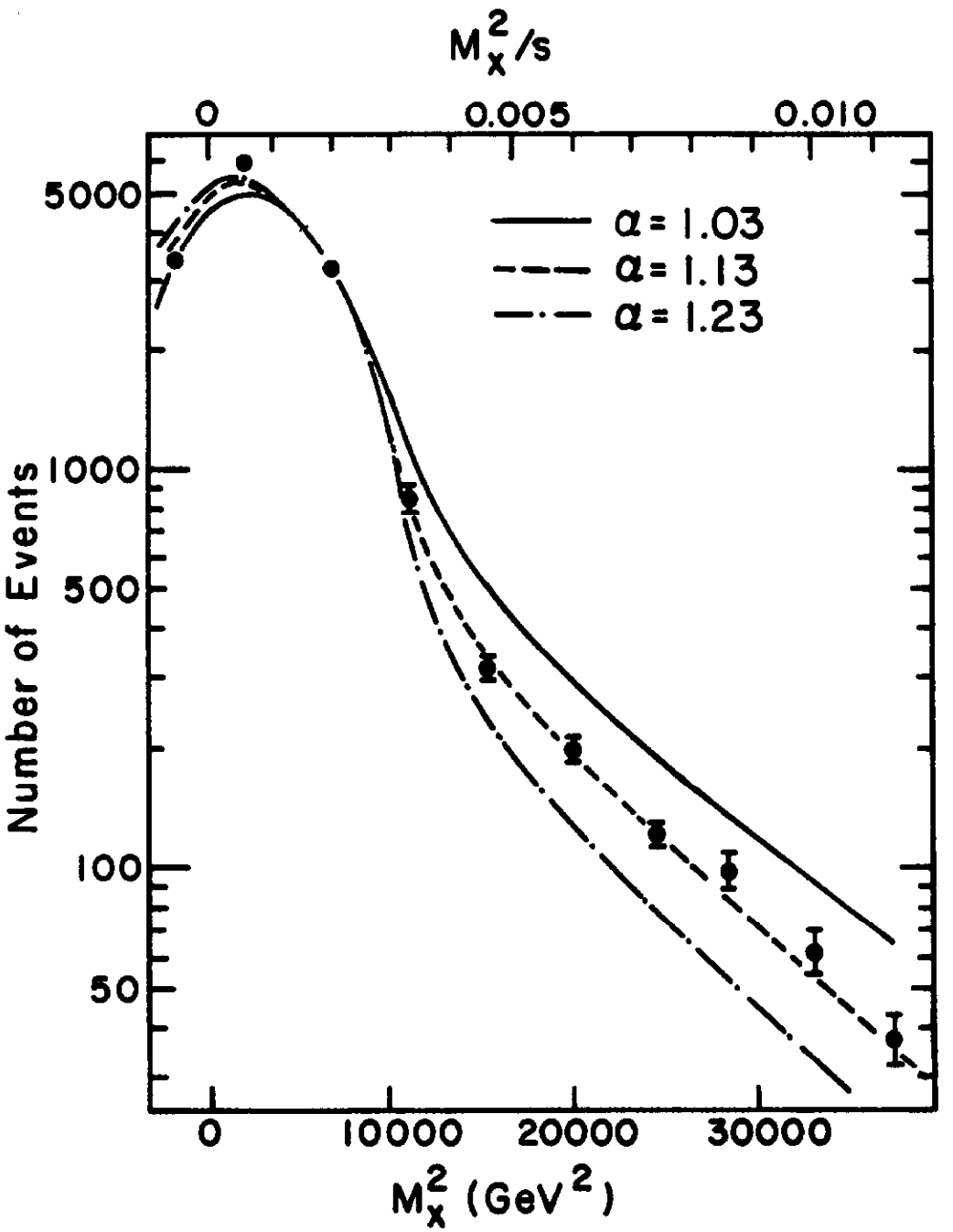
M_x^2/s
0
0.005
0.010
5000
1000
500
100
50
Number of Events
α = 1.03
α = 1.13
α = 1.23
0
10000
20000
30000
M_x^2 (GeV^2)

Figure 2

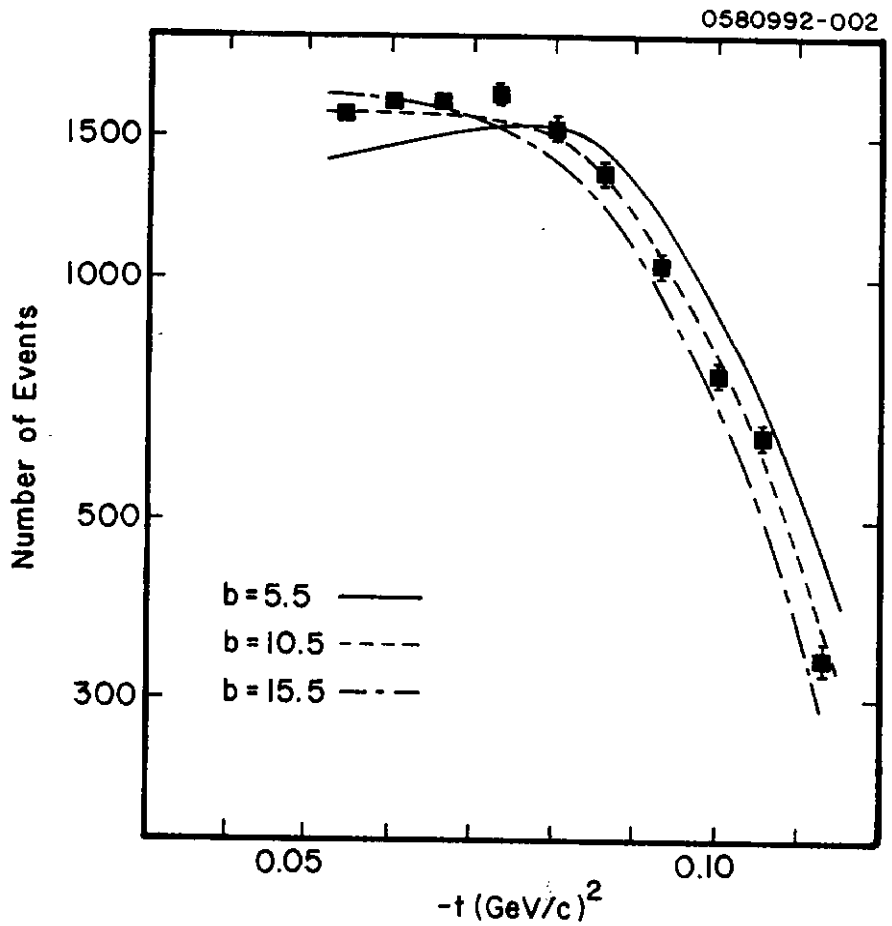
0580992-002
1500
1000
500
300
Number of Events
b = 5.5
b = 10.5
b = 15.5
0.05
0.10
-t (GeV/c)^2

Figure 3

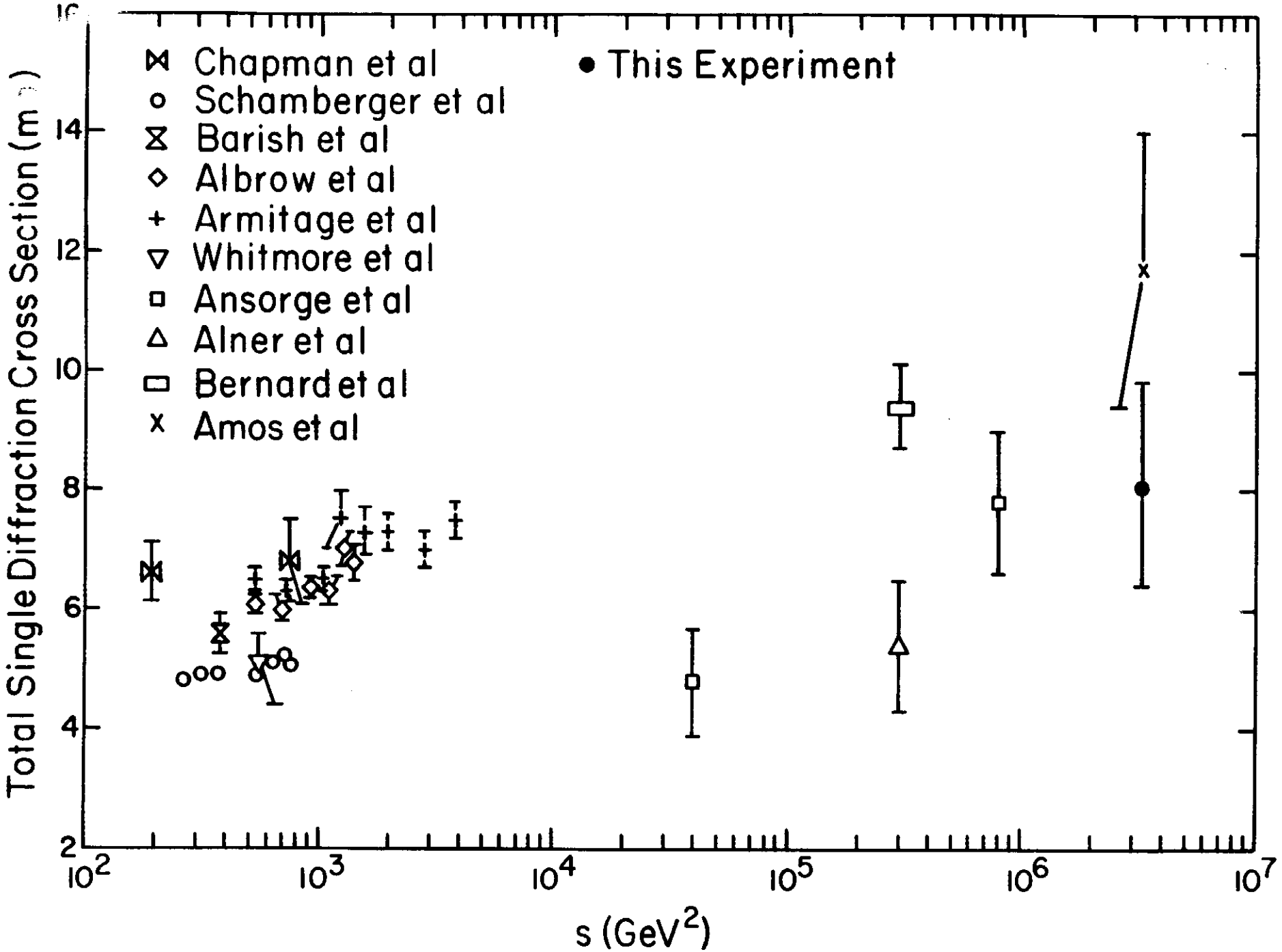
Chapman et al
Schamberger et al
Barish et al
Albrow et al
Armitage et al
Whitmore et al
Ansorge et al
Alner et al
Bernard et al
Amos et al
This Experiment
Total Single Diffraction Cross Section (mb)
s (GeV^2)
2
4
6
8
10
12
14
16
10^2
10^3
10^4
10^5
10^6
10^7

Figure 4