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Inelastic P-P Scattering at 200 GeV *

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We have measured the doubly differential cross section $sd^2\sigma/dtdM^2$ for the reaction $p + p \to p + X$ using 200 GeV incident protons in the external beam at the National Accelerator Laboratory. Here t is the square of the four momentum transfer to the target proton, M^2 is the mass squared of X, and s is the total center of mass energy squared. We cover the region of $0.019 < |t| < 0.19$ GeV^2 and $1 < M^2 < 60$ GeV^2. Interesting structure is observed at low $|t|$ and M^2 values.

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We have studied the reaction $p + p \rightarrow p + X$ at 200 GeV laboratory incident energy. We select this reaction by detecting the recoil proton in one of 18 telescopes each consisting of two solid state detectors. In this way we can identify each proton and measure its kinetic energy T in the range $10 < T < 100$ MeV. Our accuracy in T is typically better than 10 %. The four momentum transfer squared is given by $t = 2 M_p T$ where M_p is the proton mass. The measured value of T and the telescope angular position θ together determine M^2, the square of the mass of X. Each telescope subtends an angular opening in θ of 0.46° and accepts a solid angle of approximately 6.4×10^{-5} steradians. The 18 telescopes are uniformly spaced in θ between 48° and 89°. Thus our telescopes actually cover only about 20% of the angular range spanned. As a result we have not measured the inelastic cross section continuously in M^2. We might thus be missing interesting structure in the cross section which we would hopefully cover in the future.

In order to obtain the free proton cross section we have used polyethylene $(CH_2)_n$ and carbon targets and performed a subtraction. The normalization of polyethylene and carbon runs before the subtraction was obtained by identifying deuterons and tritons from proton-carbon interactions in the two targets. Such deuterons and tritons were counted <u>simultaneously</u> with the proton recoils. The data which we present were obtained during a run of approximately 10 hours using the extracted proton beam in the Neutrino Laboratory at NAL. For many reasons the data were collected with large deadtimes. However, our interesting conclusions are not affected by the corrections applied for such effects.[1]

The layout of the experiment is shown in Fig. 1. It should be noted that the detectors are located approximately 100cm from the extracted proton beam which, during the run discussed, had an intensity of 3×10^{10} protons/pulse. It was thus very important to obtain an extremely clean beam since interaction of a very small fraction of the beam hundreds of feet upstream of our location would have produced background orders of magnitude larger than our target signal. The fact that such a beam was made available to us is a tribute to the National Accelerator Laboratory, its accelerator, the beam extraction staff, and the staff of the Neutrino Laboratory.

The targets used were $13 mg/cm^2$ foils of polyethylene and carbon approximately 5mm wide and placed at a 45° angle to the beam. Approximately 3×10^{-4} of the beam interacted in our target, the remainder being used by the Neutrino Lab for other experiments. During the run we collected approximately 5×10^{6} triggers of which approximately 25% were due to target interactions. The remainder were accidentals due to an extremely lax trigger requirement. Comparison of the energy loss signals in the two detectors of each telescope completely removed such accidentals.

The first (thin) detector of each telescope is a 500 micron totally depleted silicon surface barrier detector. The second (thick) is a 5000 micron lithium drifted silicon detector. A specific ionization measurement is performed in the thin detector and the total energy is measured in the thick detector for T up to approximately 30 MeV. For higher energies the proton does not stop in the second detector but a measurement of the energies E_1 and E_2 lost in the two detectors still allows a good determination of the proton kinetic energy up to approximately 100 MeV. Scatter plots in the E_1-E_2 plane for events collected in a few minutes of running are shown in Fig. 2 for two telescopes and two targets. Protons are clearly identified both when stopping and when traversing the thick detector. The proton-proton elastic scattering peaks are clearly visible with the polyethylene targets. Deuterons and tritons are copiously produced and appear in the plot as bands above the proton band.

We perform the following steps to obtain the free hydrogen event distribution:

(a) Divide the E_1-E_2 plane into a rectangular grid.

(b) Identify protons, deuterons and tritons by their grid positions.

(c) Count the deuterons and tritons.

(d) Determine T of the protons from E_1 and E_2.

(e) Normalize the carbon event density in T from the carbon target to the carbon event density from polyethylene using (c).

(f) Obtain the hydrogen event distribution by subtracting the carbon distribution from the polyethylene distribution.

This procedure is carried out independently for each telescope. Then a deadtime correction (mentioned previously) is applied to each telescope. The final step in the analysis is to compute t, M^2 and the Jacobian $\partial(\theta,T)/\partial(t,M^2)$ from our knowledge of T, θ and the beam momentum. At this point the unnormalized differential cross section $d^2\sigma/dtdM^2$ is obtained in arbitrary units.

The total number of inelastic scattering events on free hydrogen used for the above determination is approximately 35,000. An absolute normalization is obtained from the total number of proton-proton elastic scattering events in each telescope which observes the elastic peak[2]. Some 45,000 elastic scattering events were observed, the elastic peaks being clearly visible in 5 telescopes. Such elastic peaks are also very useful to cross check our energy calibrations[3] and our ability to correctly measure the t dependence of the cross section. To the accuracy of our data we obtain very good agreement with published values[4] for the slope parameter. We find $b = 11.6 \pm 1.4\ GeV^{-2}$.

In Table I and Figs. 3 and 4 we present our measured values of $s d^2\sigma/dt dM^2$ where $s = 377\ GeV^2$ (square of total center of mass energy). The errors quoted are the statistical errors resulting from the subtraction. The limits of the $|t|$ intervals used are shown in Fig. 4. In Fig. 3 we show the M^2 dependence of the cross section in the lowest $|t|$ interval. Table I presents the inelastic data with 6 GeV^2 bins in M^2, coarser binning than used in Fig. 3. The minimum value of $M^2 = 7\ GeV^2$ included in Table I is well outside the region influenced by elastic events even for the data at high $|t|$[5]. In Fig. 4 we plot the data of Table I at the two smallest values of M^2. The most outstanding feature of the data is the peaking of the cross section at $|t| \sim .1\ GeV^2$ and subsequent decrease for lower $|t|$ for $7 < M^2 < 19\ GeV^2$. Around $M^2 = 20\ GeV^2$ there genuinely appears to be a change in the behavior of the cross section dependence versus t.

Previous measurements of the proton-proton inelastic cross section have been performed by Sannes et al.[6] at NAL but at higher values of $|t|$. Measurements have also been performed by Albrow et al.[7] at the ISR but for both higher $|t|$ and s. Both experiments obtain a minimum in the cross section for $x = 1 - M^2/s \simeq 0.9$. Since our minimum for $|t| \simeq 0.03\ \mathrm{GeV}^2$ occurs at $x \simeq 0.97$, apparently the minimum in the cross section moves with $|t|$. It should be pointed out, however, that Albrow et al. have a poorer resolution in x than we do which may affect the position of their minimum. Sannes et al. do not quote their resolution.

We wish to express our thanks to the NAL accelerator, beam extraction and Neutrino Lab staffs. In particular we wish to thank J. R. Orr, on whom we could always call as a member of our team. E. Blesser and H. Edwards were instrumental in obtaining a clean extracted proton beam. The Nevis machine shop constructed most of our mechanical equipment and some parts of the electronics were built at Nevis. We gratefully acknowledge the help of W. Sippach and Y. Au. We wish to thank our theoretical colleagues, particularly C. Quigg and A. Mueller, for their continuous encouragement and interest in our experiment. We also thank Paula and Catfish.

FIGURE CAPTIONS

Fig. 1. Sketch of the apparatus.

Fig. 2. Scatter plots in the E_1-E_2 plane for (a) polyehtylene data at 83° (b) carbon data at 83° (c) polyethylene data at 80° (d) carbon data at 80°.

Fig. 3. Doubly differential cross section versus M^2 for $|t| \simeq 0.03$ GeV^2.

Fig. 4. Doubly differential cross section versus $|t|$ for indicated M^2.

FOOTNOTES

1. S. Childress et al., Proceedings of the Vanderbilt Internationsl Conference on New Results from Experiments on High Energy Particle Collisions, Nashville, 1973.
2. We take the elastic differential cross section $d\sigma/dt$ to be 26 mb/GeV^2 at $|t| = 0.1$ GeV^2 as given by G. Charlton et al., "Two and Four Prong pp Interactions at 205 GeV", contribution to the XVI International Conference on High Energy Physics, Batavia, 1972. The accuracy of our absolute normalization should be better than 30%.
3. The energy scale for each detector is calibrated with a source producing α particles of 5.477 MeV.
4. G. Barbiellini et al., Phys. Letters <u>39 B</u>, 663 (1972). The slope parameter is given by $b = (d/dt) \ln (d\sigma/dt)$.
5. As can be seen from the elastic peak in Fig. 3 our resolution in M^2 is 1 GeV^2 full width at half maximum for $|t| \simeq 0.03$ GeV^2. However, our resolution deteriorates at higher $|t|$. See reference 1 for details.
6. F. Sannes et al., Phys. Rev. Lett. <u>30</u>, 766 (1973).
7. M.G. Albrow et al., Nuclear Physics <u>B 54</u>, 6 (1973).

Table I. $sd^2\sigma/dtdM^2$ (mb/GeV^2) using 6 GeV^2 bins in M^2

M^2	$\|t\| \simeq .03$	$\|t\| \simeq .08$	$\|t\| \simeq .11$	$\|t\| \simeq .14$	$\|t\| \simeq .17$
10	36± 63	308±33	229±28	132±23	183±19
16	33± 59	128±24	133±24	78±31	45±15
22	228± 63	125±36	70±31	23±23	55±18
28	274± 64	163±35	133±33	117±31	86±23
34	251± 77	101±31	179±39	117±31	93±23
40	303±127	117±31	126±26	81±24	109±23

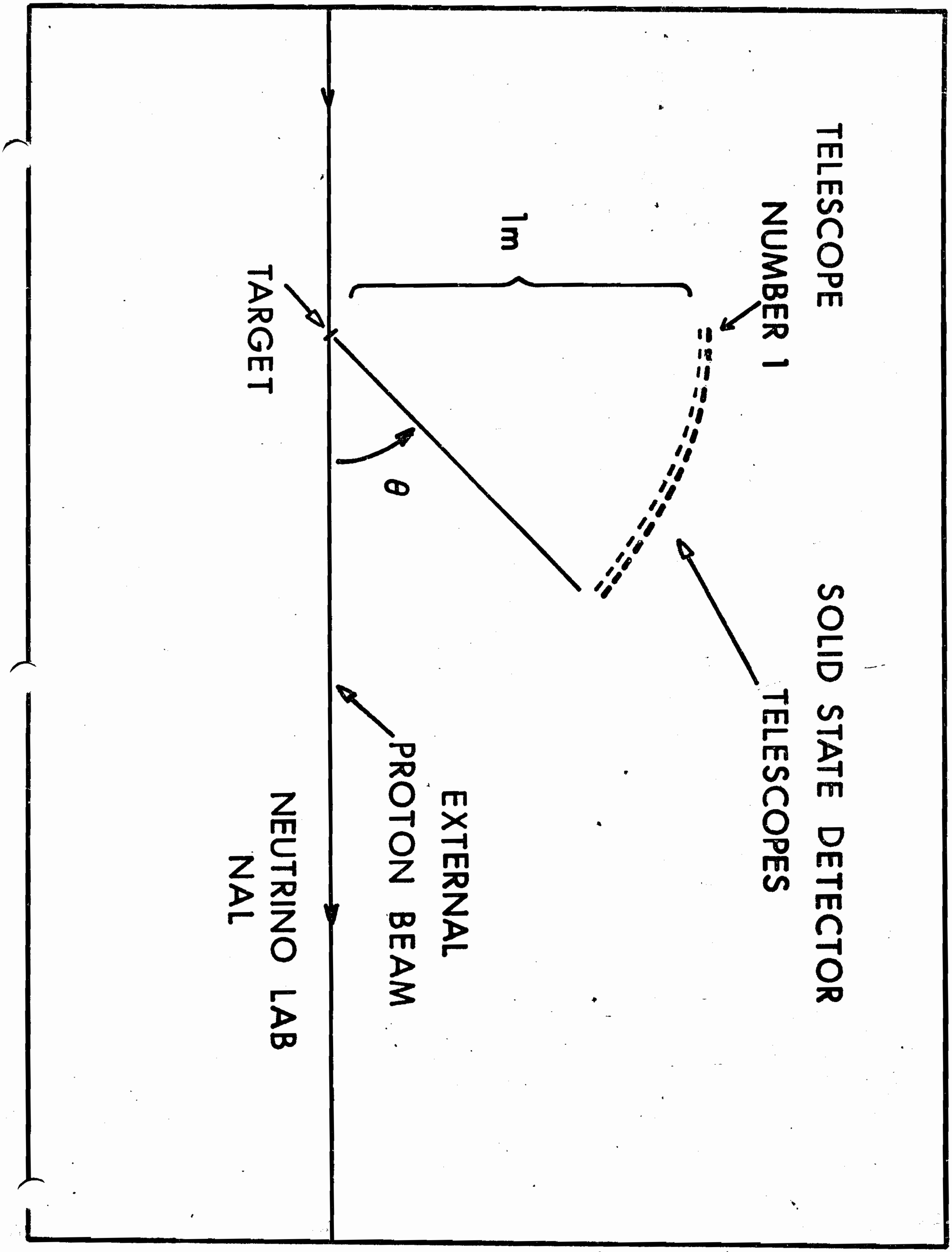

Fig. 1. S. Childress et al. Title: Inelastic P-P Scattering at 200 GeV

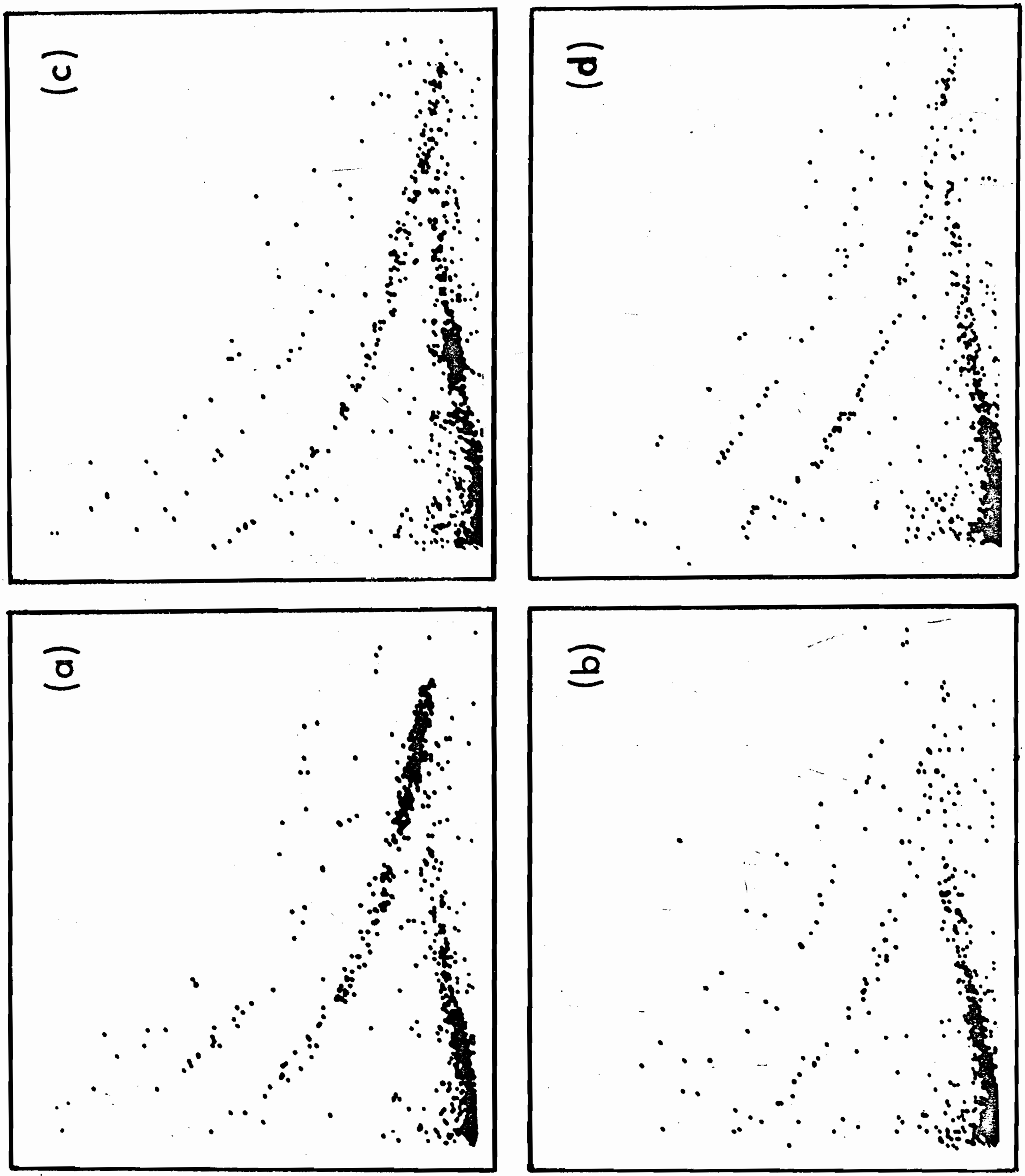

Fig. 2. S. Childress et al. Title: Inelastic P-P Scattering at 200 GeV

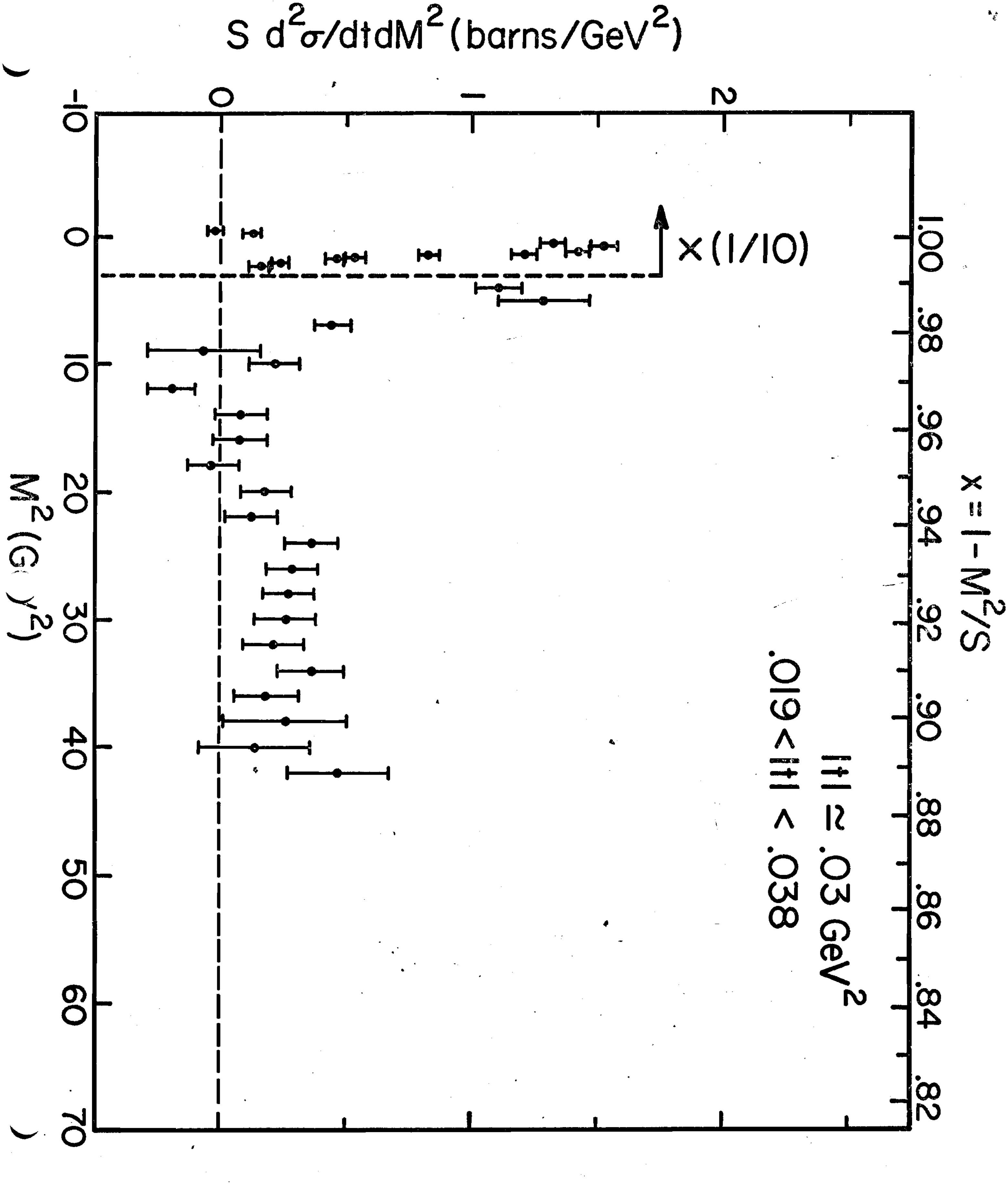

Fig. 3. S. Childress et al. Title: Inelastic P-P Scattering at 200 GeV.

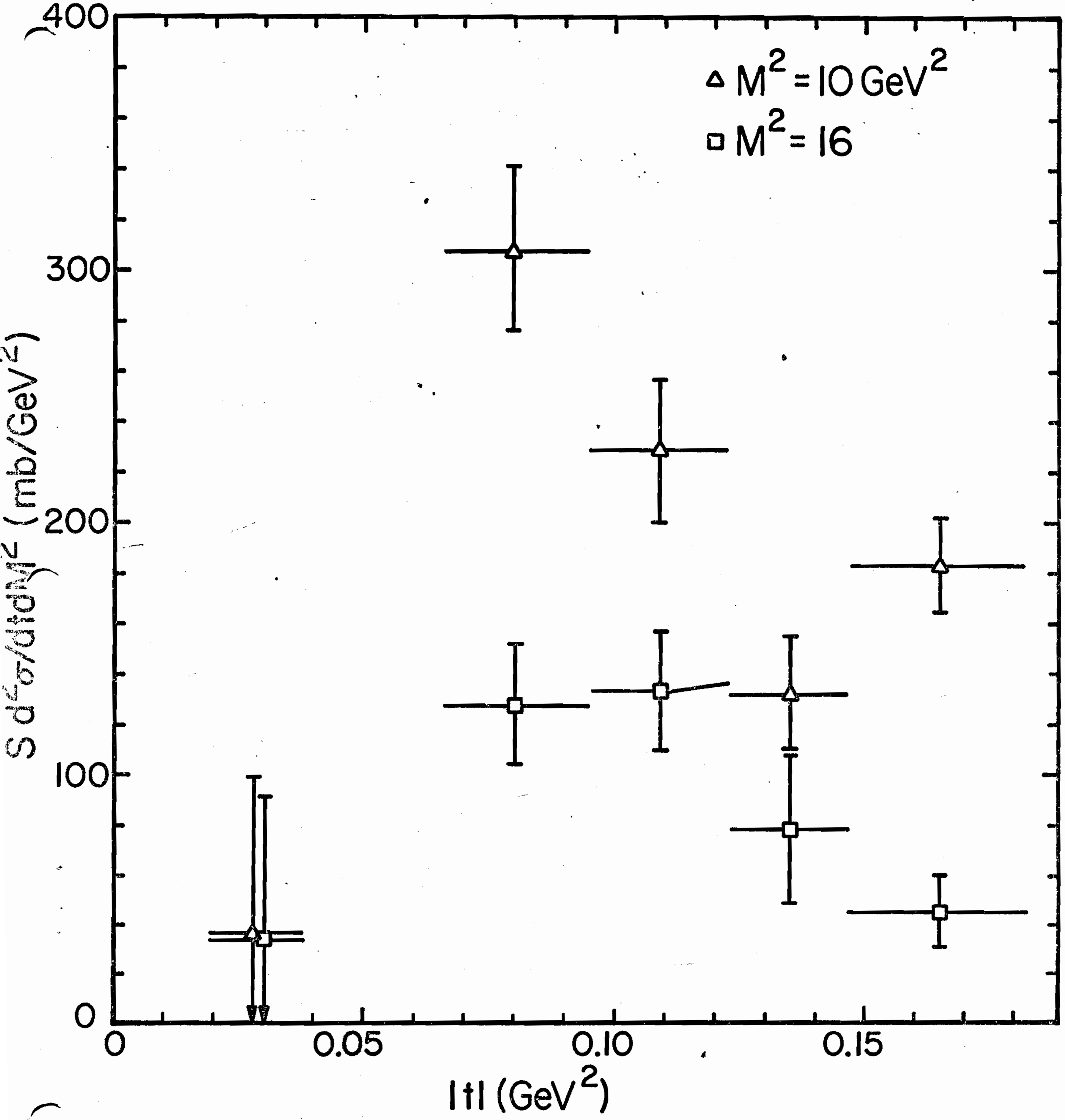

Fig. 4. S. Childress et al. Title: Inelastic P-P Scattering at 200 GeV.