SLAC-PUB-1198
(T-E)
March 1973

EVIDENCE FOR A DUAL TRIPLE POMERON COUPLING FROM INCLUSIVE ISR DATA*

A. Capella†

Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

ABSTRACT

The proton inclusive spectrum in the diffractive region is described by a triple Pomeron term with no free parameters. Our input is the cross sections for the production of N*'s at CERN accelerator energies which, according to duality rules for Pomeron-particle reactions, are related to the triple Pomeron coupling via finite mass sum rules. The extrapolated value of this coupling to $t = 0$ induces rather weak constraints on the parameters of the Pomeron, and thus <u>no</u> sharp turnover of the proton spectrum near $t = 0$ is expected.

(Submitted for publication)

---

* Supported in part by the U. S. Atomic Energy Commission.

† On leave of absence from the Laboratoire de Physique Theorique et Particules Elementaires, Orsay (France).

In a recent phenomenological analysis of $p + p \to p + X$ inclusive reaction it has been shown[1] that most of the ISR proton spectrum in the diffractive region has to be due to a triple Pomeron term — in contrast with previous works that attempted to describe it with a PPR term. This conclusion is supported by a recent experiment at $s = 929.5\ \text{GeV}^2$.[2] On the one hand, from the comparison with the results obtained at $s = 1995\ \text{GeV}^2$,[3] "one observes quantitative agreement between the two spectra all the way out to $x \equiv 2p_L/\sqrt{s} = 1$."[2] On the other hand, the new results, which are very detailed in the diffractive region, $0.95 \lesssim x \lesssim 1$, show the following features:

i) An e^{at} dependence at fixed missing mass, M, for $|t| \lesssim 0.5\ \text{GeV}^2$, with the slope parameter a independent of M.

ii) An approximate M^{-2} dependence at fixed t, for $10 \lesssim M^2 \lesssim 50\ \text{GeV}^2$.

Property i) is in agreement with the small slope of the Pomeron. With $\alpha'_P(0) \sim 0$ and $\alpha_P(0) \sim 1$, property ii) favors a triple Pomeron term, which behaves like M^{-2}, versus a PPR, which behaves like M^{-3} with $\alpha_R(0) \sim 1/2$.

In this note we describe the above results in terms of a PPP term with no free parameters. At the same time we check the duality rules for Pomeron-particle amplitudes based on perturbative dual models. These rules state[4] that the resonances in the s-channel are dual to the Pomeron in the t-channel and that the PPR terms are small since one cannot draw dual diagrams for such terms — which thus can only appear as a non-leading contribution of a PPP term. With these duality rules, one can deduce the triple Pomeron coupling from the production cross sections $pp \to pN^*$. The latter will be our only input, and we shall use for their values the results of reference 5 at 24 GeV/c.

With $\alpha_P(t) \sim 1$, the finite mass sum rules (FMSR) in the narrow width approximation lead to the following relation[6]

$$\sum_i \nu_i \frac{d\sigma_i}{dt} = (\bar{\nu} - \nu_0)\, G_P(t) \quad , \tag{1}$$

where $\nu \equiv M^2 - M_P^2 - t$, $d\sigma_i/dt$ is the cross section for the production of N_i^* and $\bar{\nu}$ is the cut in the FMSR. The quantity $G_P(t)$ is related to the triple Pomeron coupling, $g_P(t)$,[7] by

$$g_P(t) = \frac{(16\pi)^{\frac{1}{2}}\, G_P(t)}{\sqrt{\sigma_T}\, \sqrt{d\sigma/dt_{el.}}} \quad , \tag{2}$$

where σ_T and $d\sigma/dt$ are the asymptotic values of the total and elastic differential pp cross sections, and the equality is strictly true only for $\alpha_P(0) = 1$. The normalization of $G_P(t)$ is:

$$E \frac{d\sigma_D}{d^3 p} = \frac{1}{\pi}\, G_P(t)\, \frac{s}{M^2} \quad . \tag{3}$$

[The symbol D stands for diffractive contribution.] In the sum in Eq. (1) we include, besides the nucleon itself, the 1400 enhancement, the N*(1520), the N*(1690), and N*(2190), and the cut is taken at M = 2.4 GeV after the last broad bump at M = 2.2 GeV. The FMSR is saturated in an essentially local way.[8] The values of $G_P(t)$ obtained from Eq. (1) are given in Table 1. The results, when the 1400 enhancement is not included in Eq. (1), are also given. For $|t| \gtrsim 0.25\ \mathrm{GeV}^2$, where ISR data exist, the results are the same in both cases. The values of the triple Pomeron coupling are also given.

The values of $G_P(t)$ in Table 1 are plotted in Figure 1 and compared with the t-dependence of the data of reference 2.

The values of $G_P(t)$ are subject to uncertainties due to error bars in $d\sigma_i/dt$. These are random errors of the order of 6-10% and normalization errors of 10-15%. Besides, another 10-15% normalization error due to arbitrariness in the choice of $\bar{\nu}$ is possible. To facilitate the comparison with experiment, and in view of the uncertainty in the normalization, from now on for both $G_P(t)$ and $g_P(t)$ we take the values in Table 1 multiplied by a factor 0.75.

Using these values of $G_P(t)$ in Eq. (3) we obtain the dashed curves shown in Figure 2.

To be able to compare with the experimental results at smaller values of x and to have an estimation of the possible modifications in our results due to the contribution of the non-diffractive terms, we use the parametrization of these terms obtained in reference 1 from a fit of the proton spectrum at CERN accelerator energies:

$$E\frac{d^3\sigma_{ND}}{d^3p} = \frac{1}{\pi}\left[\frac{\gamma(t)}{s}\left(\frac{s}{M^2}\right)^{1+2t}\nu^{\frac{1}{2}} + \beta(t)\, e^{(C_1 - C_2 t)(M^2/s)}\right]\left[\frac{s}{s-4M_P^2}\right]^{\frac{1}{2}}, \qquad (4)$$

with

$$\gamma(t) = 79\, e^{0.13t} + 250\, e^{11.9t}$$

$$\beta(t) = 13\, e^{6.7t + 2.8t^2}$$

$$C_1 = 7.5 \qquad C_2 = 0.28 ,$$

and the invariant cross section in Eq. (4) is in units of mb/GeV^2. The first term reduces to an RRP term for $s/M^2 \to \infty$ and $t \sim 0$; a possible interpretation of this term is given in reference 9. The second term is an RRR term; its contribution at $s = 929.5\ (GeV)^2$ is negligibly small.

Adding the diffractive and non-diffractive contributions, Eqs. (3) and (4), we obtain the full curves in Figures 2 and 3.

Our parametrization also describes the ISR results at $s = 1995\ (\mathrm{GeV})^2$ since these results scale with the ones considered here and our model has scaling built in — except for the RRR term which is only a few percent of the cross section at $s = 929.5\ \mathrm{GeV}^2$. It also describes the existing results at lower energies; the parametrization (4) was indeed obtained from a fit of the data at CERN accelerator energies outside the resonance region, and the extrapolation at smaller M [11] satisfies the FMSR in the way described above.

We turn now to a discussion of the triple Pomeron coupling. One can see from Table 1 that it has some turnover near $t = 0$ when the 1400 enhancement is not included. This turnover is due to the vanishing of the nucleon contribution at $t = 0$ in Eq. (1) ($\nu_i = -t$ for the nucleon). However, its value at $t = 0$ is not zero unless all other $d\sigma_i/dt$ vanish at $t = 0$, which does not appear to be the case. When the 1400 enhancement is included the turnover almost disappears, and one gets a value for the triple Pomeron coupling which approximately coincides with the one obtained by extrapolating exponentially to $t = 0$ the ISR data in the diffractive region — under the assumption that these data are essentially due to a PPP term (see Figure 1). The value of the triple Pomeron coupling at $t = 0$ is related to the parameters of the Pomeron trajectory as follows[7]

$$\eta_P(0) \equiv \frac{1}{16\pi}\,\frac{1}{2\alpha'_P(0)}\,g_P^2(0) \lesssim 1 - \alpha_P(0)\ . \tag{5}$$

Our value $g_P(0) \sim (0.3 \times 0.75)\ \mathrm{GeV}^{-1}$ gives a rather weak constraint on $\alpha'_P(0)$ and $\alpha_P(0)$:

$$1 - \alpha_P(0) \gtrsim \frac{10^{-3}}{2\alpha'_P(0)}\ .$$

With $0.05 \lesssim \alpha'_P(0) \lesssim 0.5\ \mathrm{GeV}^{-2}$, one can have $0.990 \lesssim \alpha_P(0) \lesssim 0.999$. If the contribution of the 1400 enhancement is not included, the constraint is even weaker. These values of $\alpha_P(0)$ are so close to one, that no zero or sharp turnover of the triple Pomeron coupling at $t = 0$ appears to be required by Eq. (5). Therefore, a sharp turnover near $t = 0$ of the proton inclusive spectra in the diffractive region is not required either. In fact, with our dual triple Pomeron coupling such a sharp turnover does not occur — one might observe at most the flattening out or slight turnover of the curves in Figure 1.

A very recent theoretical value of the integrated triple Pomeron coupling, with a maximum estimated error of a factor 2, is given in reference 10:

$$\int_{-\infty}^{0} dt\, e^{\frac{b}{2}t}\, g_P(t) \approx \frac{2\alpha'_P}{b^2}\left[\sigma_T\right]^{\frac{1}{2}}, \tag{6}$$

where b is the slope parameter of the pp elastic differential cross section. With our values of $g_P(t)$[12] one gets $\alpha'_P \sim 0.3$.[13]

As for the possible presence of a PPR term, it is clear from the uncertanties in absolute normalization, together with the factor 0.75 discussed above, that one cannot exclude the existence of such a term with a residue of the order to 10-50% of the triple Pomeron one. This would, however, alter very little both our general scheme and the quantitative values discussed above. As far as the comparison with the ISR results is concerned, such a PPR term, due to its extra M^{-1} power as compared to a PPP one, would affect our figures by 3-17% at $M^2 = 10$ ($x \sim 0.99$) and 1.5-7% at $M^2 = 50$ ($x \sim 0.95$) GeV^2.

Our results, relating experimental results at ISR and CERN accelerator energies without any free parameter, provide in our opinion, a striking confirmation of a (dominating) triple Pomeron term in the diffractive region. This term appears to be dual to the diffractively produced resonances in the s-channel in agreement with duality rules for inclusive reactions. The model leads to a non-vanishing triple Pomeron coupling at $t = 0$, and predicts no sharp turnover near $t = 0$ of the proton inclusive spectrum in the diffractive region.

Acknowledgements

It is a pleasure to acknowledge frequent discussions with M. - S. Chen and M. Schmidt and the warm hospitality of the SLAC Theoretical Group.

Figure Captions

Figure 1 The values of $G_P(t)$ in Table 1 are plotted against t and compared with the t dependence of the data of reference 2 at several values of M^2. The dashed curve is obtained when the 1400 enhancement is not included. In this figure the normalization of the data has been arbitrarily chosen.

Figure 2 Missing mass spectra at $s = 929.5\ \text{GeV}^2$ from reference 2. The dashed line is obtained from the triple Pomeron term, Eq. (3). The full line is obtained by adding to this PPP term the non-diffractive contribution, Eq. (4).

Figure 3 Inelastic proton spectra at $s = 929.5\ \text{GeV}^2$. The full curves are obtained by adding the diffractive and non-diffractive contributions, Eqs. (3) and (4). The dashed curve is the contribution of the triple Pomeron terms, Eq. (3), at $p_T^2 = 0.525\ \text{GeV}^2$.

References and Footnotes

1. A. Capella, H. Hogaasen and V. Rittenberg, SLAC PUB-1176 (1973).
2. M. G. Albrow et al., CERN preprint, December 1972.
3. M. C. Albrow et al., Nucl. Phys. B51, 388 (1973).
4. See for instance M. B. Einhorn, M. B. Green and M. A. Virasoro, Phys. Letters 37B, 292 (1971).
5. J. V. Allaby et al., contribution to the Fourth International Conference on High Energy Collisions, Oxford, 1972, and CERN preprint (1972).
6. The details of its derivation in a slightly different case can be found in reference 1.
7. H.D.I. Abarbanel, G. F. Chew, M. L. Goldberger and L. M. Saunders, Phys. Rev. Letters 26, 937 (1971).
8. Local duality works essentially as in reference 1, where a different sum rule was considered.
9. A. Capella, H. Hogaasen and B. Petersson, Orsay 72/73 preprint (July 1971).
10. G. F. Chew, LBL-1556 preprint (1973).
11. To be consistent with the FMSR (1), the variable M^2 in Eq. (3) should be replaced by ν when dealing with small values of M.
12. For $|t| < 0.8$ GeV^2, our values of $g_P(t)$ are smaller than the upper limit for this quantity obtained by Rajamaran under very different assumptions. However, our $g_P(t)$ is much flatter and the two curves cross over at $t \sim -0.8$ GeV^2. See R. Rajamaran, Phys. Rev. Letters 27, 693 (1971).
13. If some preliminary results on the total proton-proton cross section at the ISR were confirmed, Eq. (6) should be replaced by an inequality with the ℓ.h.s. larger than the r.h.s. (G. F. Chew, private communication). The

value $\alpha'_P(0) \sim 0.3\ \mathrm{GeV}^{-2}$ would then give an upper limit for the Pomeron slope. It is also worth noticing that our integrated triple Pomeron term increases by about 2 mb between $s = 50$ and $s = 3000\ \mathrm{GeV}^2$. This might provide an explanation for the observed increase in the proton-proton total cross section. This remark arose during a conversation with M.-S. Chen and M. Kugler.

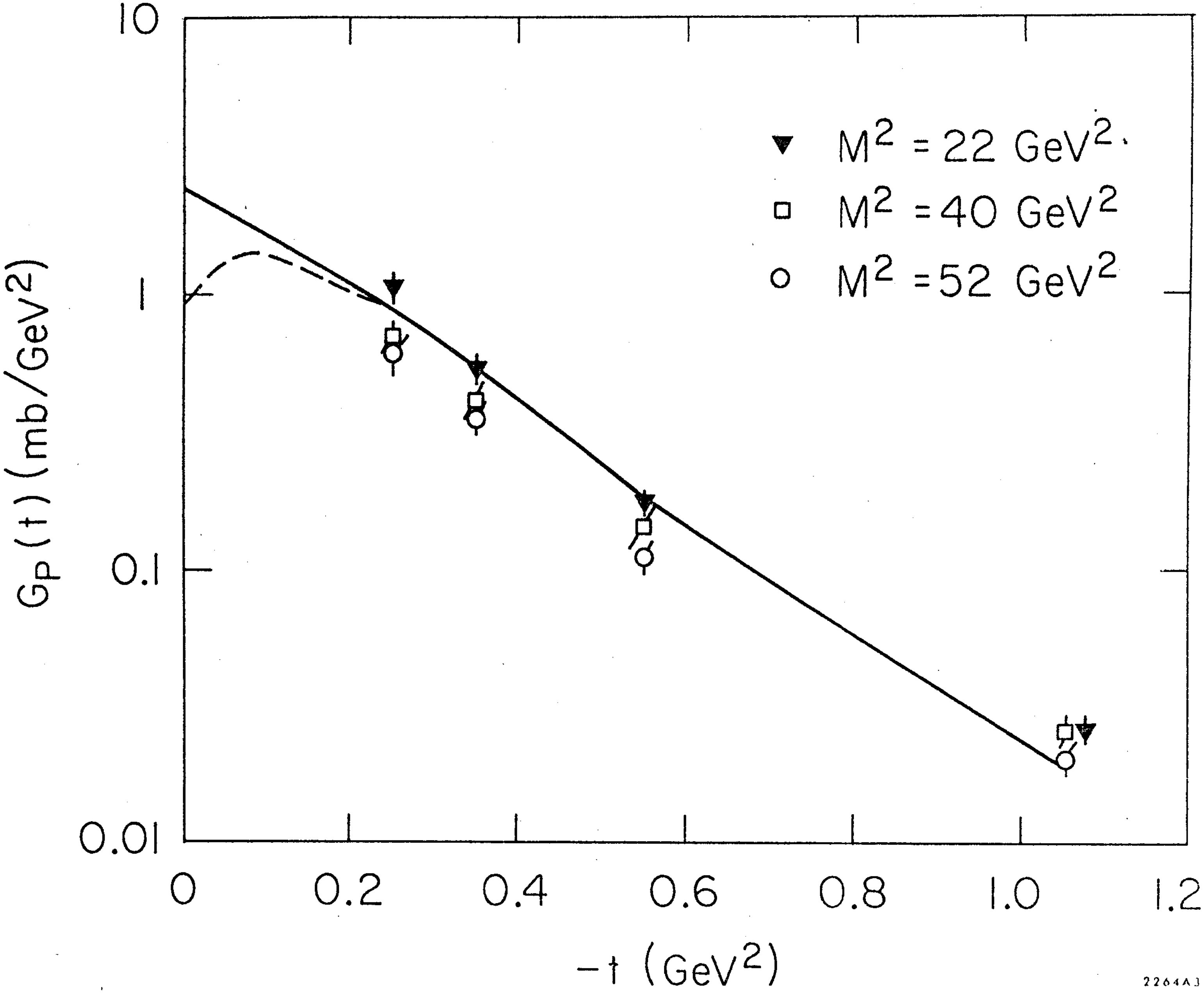
TABLE 1

$-t$ GeV^2	0.005[a]	0.10	0.25	0.35	0.55	0.80	1.05
$G_P(t)$ mb/GeV^2	2.3 (0.9)[b]	1.65 (1.4)[b]	0.9	0.55	0.19	0.058	0.019
$g_P(t)$ GeV^{-1} †	0.3 (0.1)[b]	0.36 (0.31)[b]	0.36	0.33	0.26	0.23	0.22

a For this value of t we have used the data of Belletini et al. at 19.3 GeV/c as given in Table VI of reference 5.

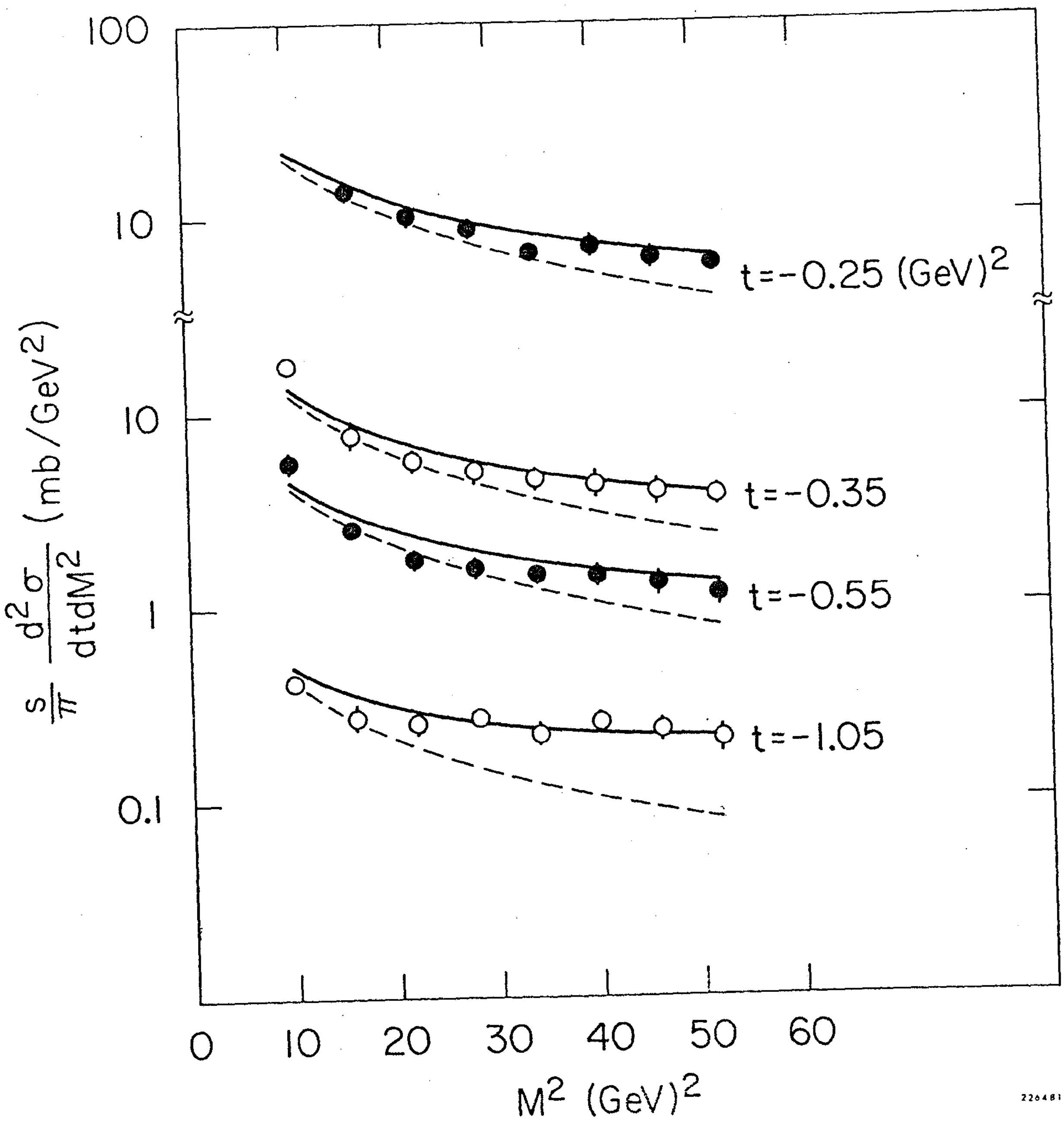
b Values obtained when the 1400 enhancement is not included.

† We have used $\sigma_T = 40$ mb and the values of $d\sigma/dt_{el.}$ of reference 5.



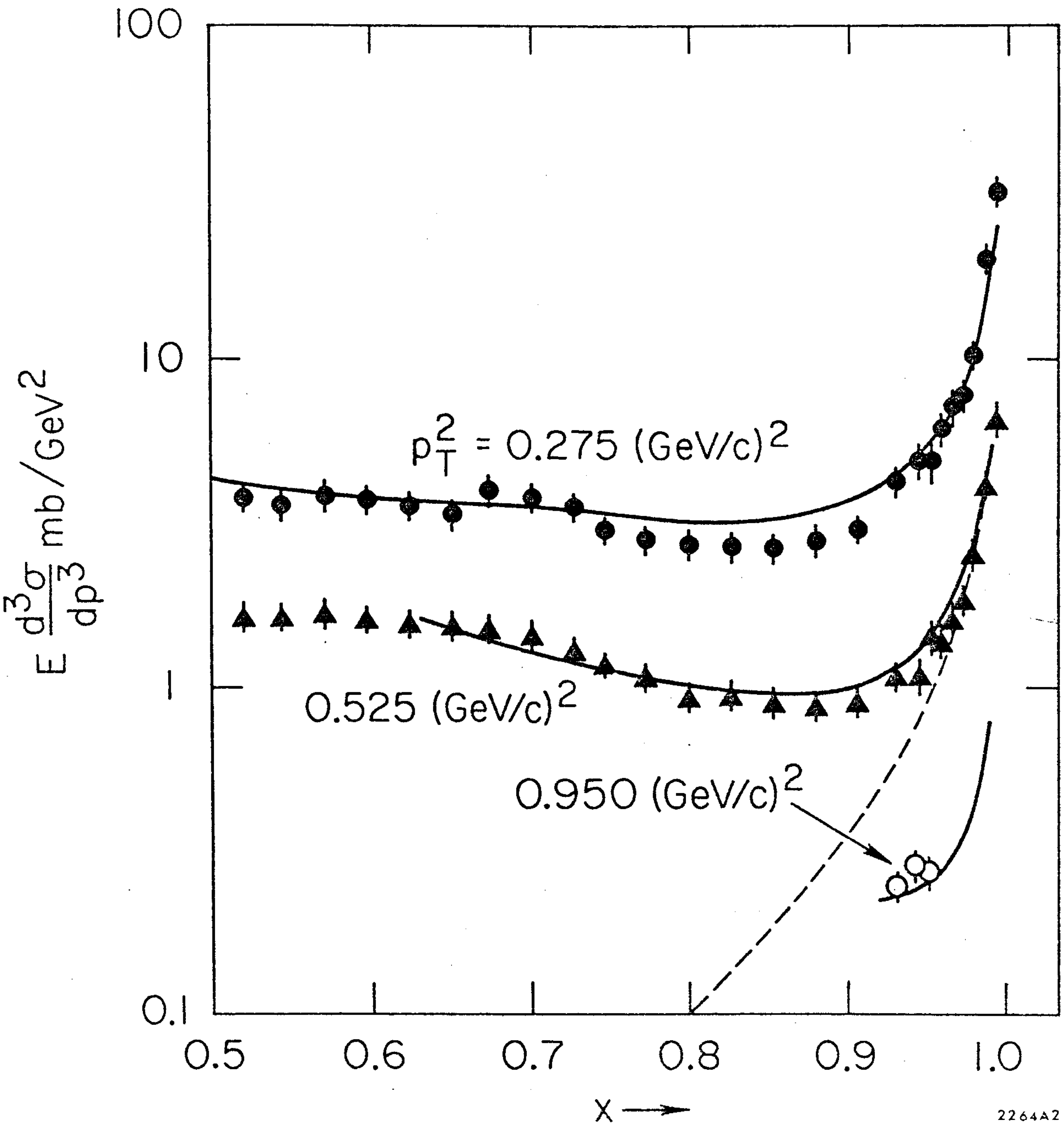
10
1
0.1
0.01
$G_P(t)$ (mb/GeV^2)
M^2 = 22 GeV^2
M^2 = 40 GeV^2
M^2 = 52 GeV^2
0
0.2
0.4
0.6
0.8
1.0
1.2
$-t$ (GeV^2)
2264A3

Fig. 1



100
10
10
1
0.1
$\frac{s}{\pi} \frac{d^2\sigma}{dtdM^2}$ (mb/GeV^2)
t=-0.25 (GeV)^2
t=-0.35
t=-0.55
t=-1.05
0
10
20
30
40
50
60
M^2 (GeV)^2
226481

Fig. 2



100
10
1
0.1
$E \frac{d^3\sigma}{dp^3}$ mb/GeV^2
p_T^2 = 0.275 (GeV/c)^2
0.525 (GeV/c)^2
0.950 (GeV/c)^2
0.5
0.6
0.7
0.8
0.9
1.0
X ⟶
2264A2

Fig. 3