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ABSTRACT

We present a model describing recent experimental results on the reaction $p + d \rightarrow X + d$ between 50 and 400 GeV/c. In the region $M_X^2 < 6\ \mathrm{GeV}^2$ the essential features of the data can be described by a Deck-type mechanism, while in the high-mass region ($6 < M_X^2 < 25\ \mathrm{GeV}^2$) the data can be described by a triple-Pomeron term. The triple Pomeron term is constructed with finite mass sum rules (FMSR) from elastic and Deck amplitudes. We find the Pomeron-proton total cross section is about 2 mb at large M_X. The calculation of shadow corrections due to diffractive dissociation are in good agreement with elastic p-d scattering data.

I. INTRODUCTION

In an experiment performed at the Fermi National Accelerator Laboratory the reaction

$$p + d \rightarrow X + d$$

has been studied, and the results of this experiment are presented in separate contributions to this conference.[1] To facilitate comparison of data on $pd \rightarrow Xd$ with existing data on $pp \rightarrow Xp$ the authors of Ref. 1 have recalculated their results in terms of the cross section "per nucleon". The data have the following essential features:

1. The low-mass spectrum is dominated by a large peak with its maximum at $M_X^2 \sim 1.8\ \mathrm{GeV}^2$. At higher masses the cross section decreases as $\sim M_X^{-2}$.

2. The t-dependence is very sharp at low M_X where the slope, b, is $\approx 20\ (\mathrm{GeV/c})^{-2}$. At larger M_X, b decreases and at $M_X^2 > 6\ \mathrm{GeV}^2$ b becomes approximately constant and equal to $5.5\ (\mathrm{GeV/c})^2$.

3. There is no significant s-dependence in the measured M_X interval.

In this paper we present a comparison of our data with a simple version of the model developed by one of us.[2]

Briefly, the model assumes that in the low-mass region the main contribution to the cross section comes from a Deck-type diagram[3] shown in Fig. 1. Two phenomenological form factors, $\exp(\delta_1 t')$ and $\exp(\delta_2 t)$, are introduced into upper and lower parts of the diagram. For on-shell πN-scattering amplitude the form

$$T_{\pi N} = i\sigma_{\pi N}\, e^{b_{\pi N} t}$$

is used with experimental values $\sigma_{\pi N}(s') \simeq \text{const} = 24$ mb and $b_{\pi N}(s') \simeq \text{const} = 9\ (\text{GeV}/c)^{-2}$. πNN coupling constant is $G^2_{\pi NN}/4\pi = 14.4$.

The cross section calculated from the diagram shown in Fig. 1 is:

$$\frac{d^2\sigma}{dt\,dM_X^2} = \left(8M_X s^2 p_1\right)^{-1} \left(\frac{\sigma_{\pi N}}{4\pi}\right)^2 \frac{G^2_{\pi NN}}{4\pi}\, e^{(b_{\pi N}+\delta_2)t} \left[\phi(x_+) - \phi(x_-)\right]$$

where

$$\phi(x) = e^{\delta_1 x}\left[\frac{\gamma}{\delta_1}x - \frac{\gamma}{\delta_1^2} + \frac{\beta+\mu^2\gamma}{\delta_1} - \frac{\mu^2\delta_1}{x} + \right] \quad (1)$$

$$+ E_i(\delta_1 x)\left[\alpha + \mu^2(\beta + \alpha\delta_1)\right]. \quad (2)$$

$E_i(x)$ is the exponential integral function and

$$\begin{aligned}
x_\pm &= a - \mu^2 \pm b \\
a &= 2M^2 - 2q_{10}p_{10} \\
b &= 2qp_1 \qquad\qquad (3) \\
\alpha &= A_+A_- + \frac{C^2}{2}\left(1 - \frac{d^2}{b^2}\right) + B\frac{2d^2}{b^2} - \frac{d}{b}B(A_+ + A_-) \\
\beta &= \frac{B}{b}(A_+ + A_-) - \frac{2d}{b^2}\left(B^2 - \frac{C^2}{2}\right)
\end{aligned}$$

$$\gamma = \frac{B^2 - C^2/2}{b^2}$$

$$d = a - \mu^2$$

$$A_\pm = A - (M \pm \mu)^2$$

$$A = s + M^2 - 2q_{10}(p_{10} + p_{20})$$

$$B = 2q\,[p_1 + p_2 \cos(\vec{p}_1, \vec{p}_2)]$$

$$C = 2qp_2 \sin(\vec{p}_1, \vec{p}_2)\,.$$

Here kinematical variables are calculated in the system where $\vec{q}_1 + \vec{q} = 0$.

The adjustable parameters δ_1 and δ_2 can be found from comparison with experimental data. δ_2 has a relatively weak effect on the t-dependence and does not change the shape of M_X distribution. In contrast δ_1 strongly suppresses the cross section, especially at high M_X resulting in a narrowing of the peak and shifting of the maximum to lower M_X.

The data indicate that in the high-mass region, $6 < M_X^2 < 25\ \mathrm{GeV}^2$, the main contribution comes from the PPP coupling. The cross section is then given by

$$\frac{d^2\sigma}{dt\, dM_X^2} = \frac{G_{PPP}(t)}{M_X^2} \left(\frac{s}{M_X^2}\right)^{2\alpha'_P t} \approx \frac{G_{PPP}(t)}{M_X^2}\,, \qquad (4)$$

and in our t range the small effect of α' (the slope of the Pomeron trajectory) can be neglected. To find $G_{PPP}(t)$ the first moment finite mass sum rule can be used

$$I \equiv \int_0^{\nu_o} \nu \frac{d^2\nu}{dtd\nu} d\nu = \nu_o \cdot G_{PPP}(t) \tag{5}$$

where $\nu = M_X^2 - M^2 - t$ is the cross-symmetric variable. We saturate the integral[5] with the nucleon pole term (i.e., by the elastic cross section) and the Deck-contribution (1-3) and choose the cut-off at $M_X = 1.7$ GeV.

Finally, the total Pomeron-proton cross section can be calculated as

$$\sigma_{Pp}(M_X, t=0) = \frac{16\pi M_X^2}{2,55\, \sigma_{tot}(pp)} \frac{d^2\sigma}{dtdM_X^2} . \tag{6}$$

II. RESULTS

Figures 2-4 show the data from Ref. 1 together with the results of Eqs. 1-5. Agreement in the low-mass region is obtained when the parameters δ_1 and δ_2 are set to the values $\delta_1 = 2$ (GeV/c)$^{-2}$ and $\delta_2 = 3$ (GeV/c)$^{-2}$.

For the elastic contribution we use $b_{pp} = 11$ (GeV/c)$^{-2}$ and $\sigma_T(pp) = 38.5$ mb and neglect their weak s-dependence. Then

$$I_{el} = (-t)\left(\frac{d\sigma}{dt}\right)_{el} \simeq (-t)\,(82.5)\,e^{11t} \text{ mb}. \tag{7}$$

The result of the numerical integration at the Deck contribution is

$$I_d \simeq 8.6e^{(14.5)t} \text{ mb}. \tag{8}$$

Note that I_{el} disappears at $t \to 0$ while I_d has a sharp peak at $t = 0$. The two contributions (I_{el}/ν_o) and (I_d/ν_o) are shown in Fig. 5 together with their sum which gives $G_{PPP}(t)$:

$$G_{PPP}(t) \simeq 4.3e^{(5.8)t} \text{mb}/(\text{GeV}/c)^2. \tag{9}$$

The corrections to Eq. 4 due to the other Regge terms could be important in the other kinematical regions and are calculated in Ref. 2.

There is a transition region (near M ~2 GeV) between the "Deck" region and the Regge region, where there also may be some resonance contributions [N(1500), N(1680)].

It should be noted that this sum rule can be evaluated also by numerically integrating the low-mass data itself. These integrated data points are in good agreement with the model calculation as can be seen in Fig. 5. The Pomeron-proton cross section obtained from Eq. 6 is shown in Fig. 6.

An important feature of our result is the large value for the G_{ppp} coupling, which we compare in Fig. 7 with results of other analyses compiled in Ref. 6. Our result should probably be treated as an upper limit for $G_{ppp}(0)$ because the experimental data are restricted to the region close to $t = 0$, and because of our neglect of other Regge terms.

We do not see any indication for a turnover or vanishing of $G_{ppp}(t)$ as $t \to 0$.[4]

The contribution to the single diffractive dissociation total cross section from the PPP term is approximately

$$\sigma_D(s) \simeq \frac{1}{\alpha'_p} G_{ppp}(t = 0) \ \ln\left(\frac{b + 2\alpha' \ln s}{b}\right), \tag{10}$$

where b is the slope of $G_{ppp}(t)$. Given the values obtained in Eq. 9 the resulting increase in σ_D from $s = 200\ (\mathrm{GeV})^2$ to $s = 2000\ (\mathrm{GeV})^2$ is approximately 2.3 mb.

A consequence of a large G_{ppp} on elastic pd scattering data is the importance of inelastic shadow effects. As shown in Ref. 2, at the Fermilab energies the entire shadow correction including elastic and diffractive contributions, can be approximated as

$$f(t) \sim 0.9 e^{2t}, \tag{11}$$

so that

$$\left(\frac{d\sigma}{dt}\right)_{pd} = 4F(t)\ f(t) \left(\frac{d\sigma}{dt}\right)_{pp} \tag{12}$$

where the deuteron form factor squared is[6]

$$F_D(t) = \exp\left[(25.9 \pm 1.2) + 60t\right] t \tag{13}$$

and

$$\left(\frac{d\sigma}{dt}\right)_{pp} = A\ e^{b_{pp} t}. \tag{14}$$

With $b_{pp} = 8.23 + 0.557\ \ell n s$, as determined in Ref. 7, we find from Eq. 12 the value $36.13 \pm 1.47\ (\mathrm{GeV}/c)^{-2}$ for the s-independent part of the slope of the pd elastic cross section which is in good agreement with the experimental value (1) $35.7 \pm 1.1\ (\mathrm{GeV}/c)^{-2}$.

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[4] Our data indicate that $G_{PPP}(t)$ continues to rise with decreasing $|t|$ as low as 0.025 $(\mathrm{GeV/c})^2$. The model predicts that this behavior persists down to $t \simeq 0$. In principle the presence of terms other than PPP can cancel this effect. More data at higher masses could clarify this point.

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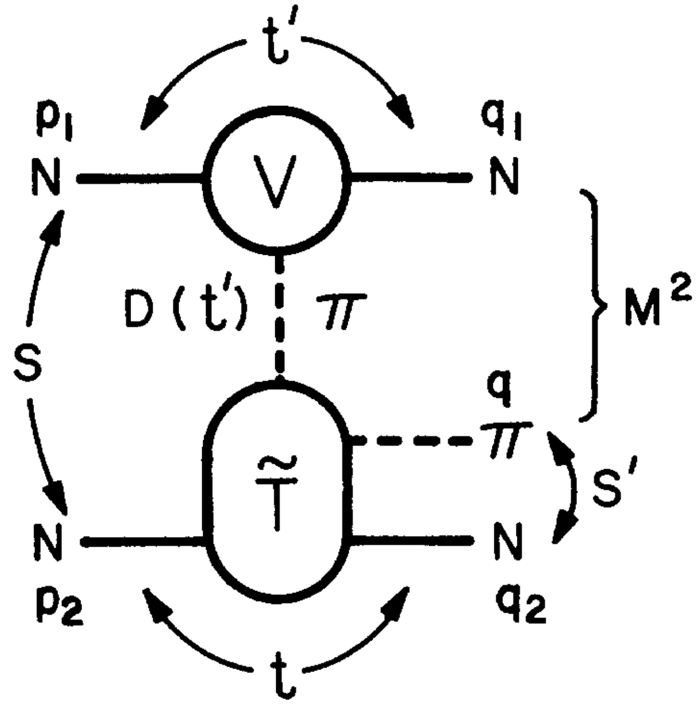
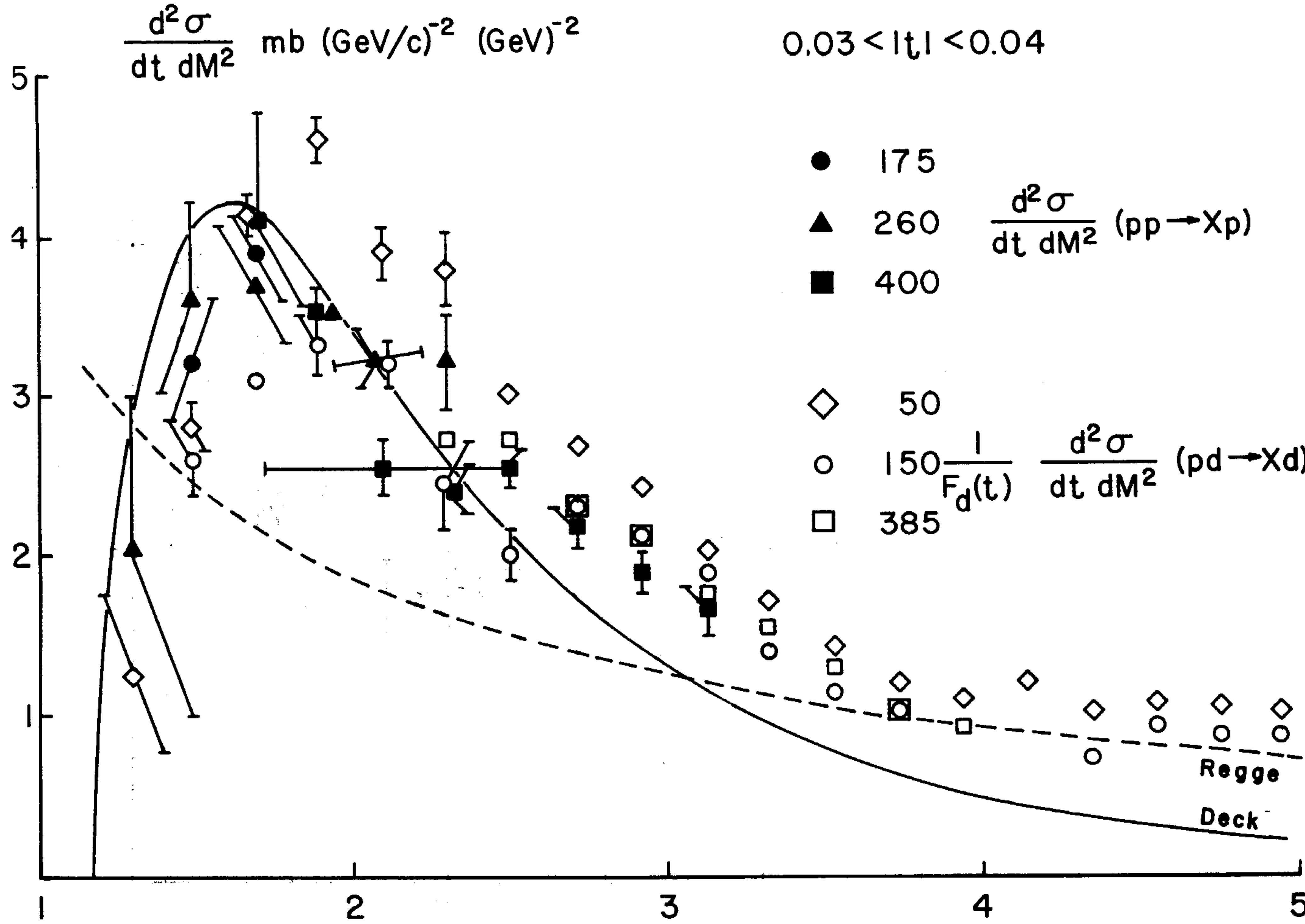
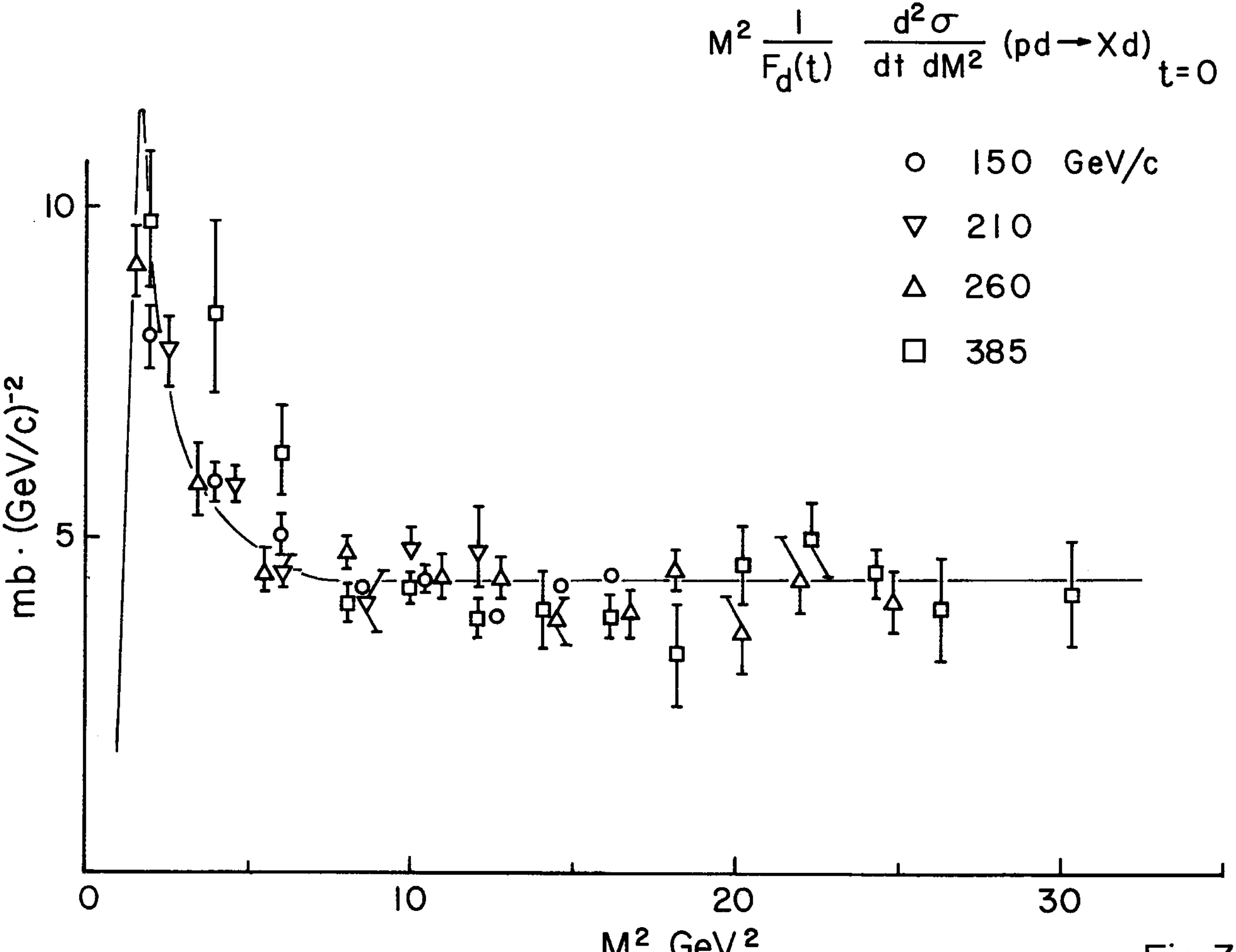


Fig. 1



$\frac{d^2\sigma}{dt\,dM^2}$ mb $(GeV/c)^{-2}$ $(GeV)^{-2}$
$0.03 < |t| < 0.04$
175
260
400
$\frac{d^2\sigma}{dt\,dM^2}$ $(pp \to Xp)$
50
150
385
$\frac{1}{F_d(t)}$ $\frac{d^2\sigma}{dt\,dM^2}$ $(pd \to Xd)$
Regge
Deck
M^2 GeV^2

Fig.2



$M^2 \frac{1}{F_d(t)} \frac{d^2\sigma}{dt\,dM^2} (pd \rightarrow Xd)_{t=0}$
○ 150 GeV/c
▽ 210
△ 260
□ 385
mb · (GeV/c)⁻²
10
5
0
10
20
30
M^2 GeV^2

Fig. 3

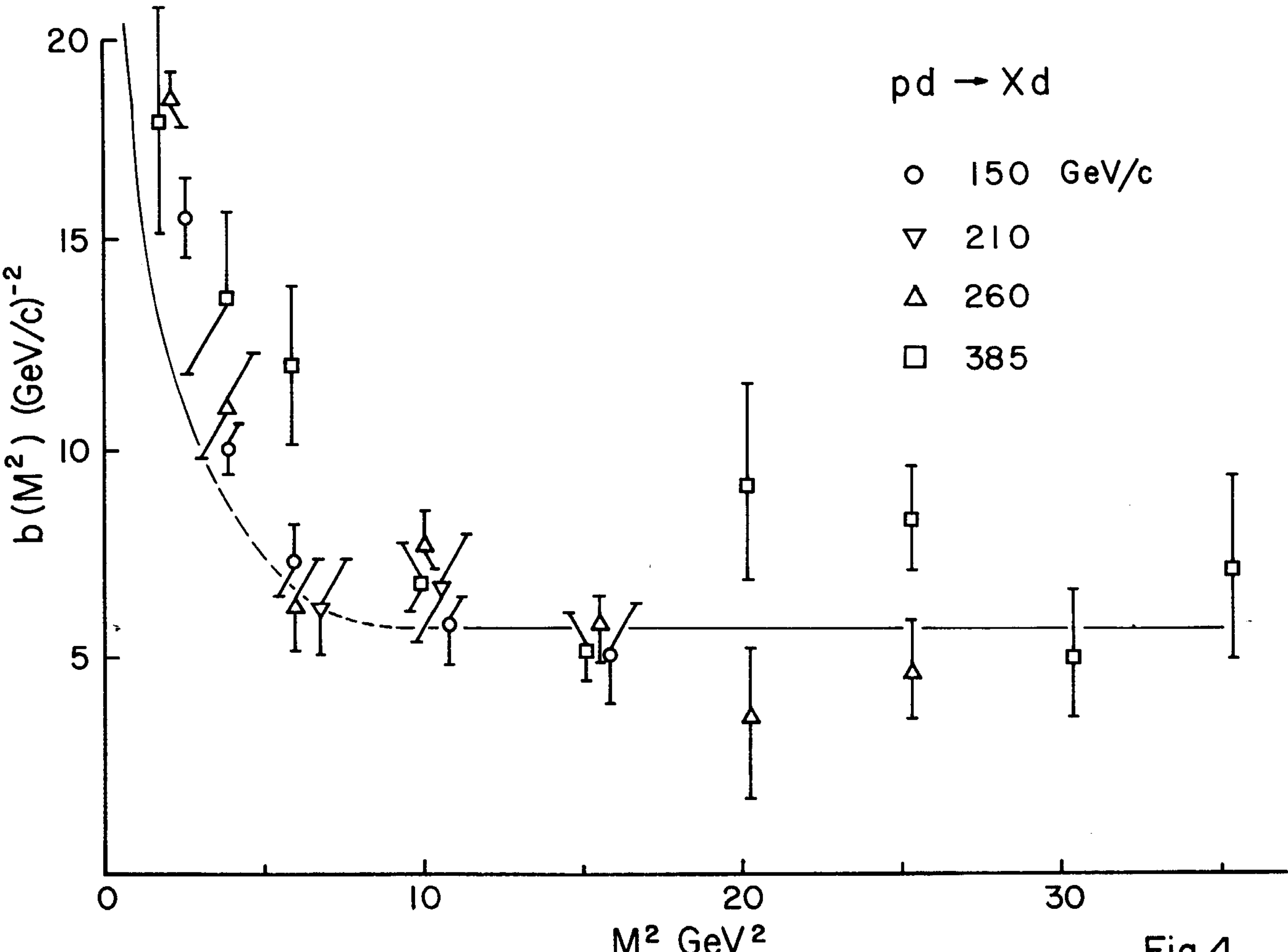


Fig.4

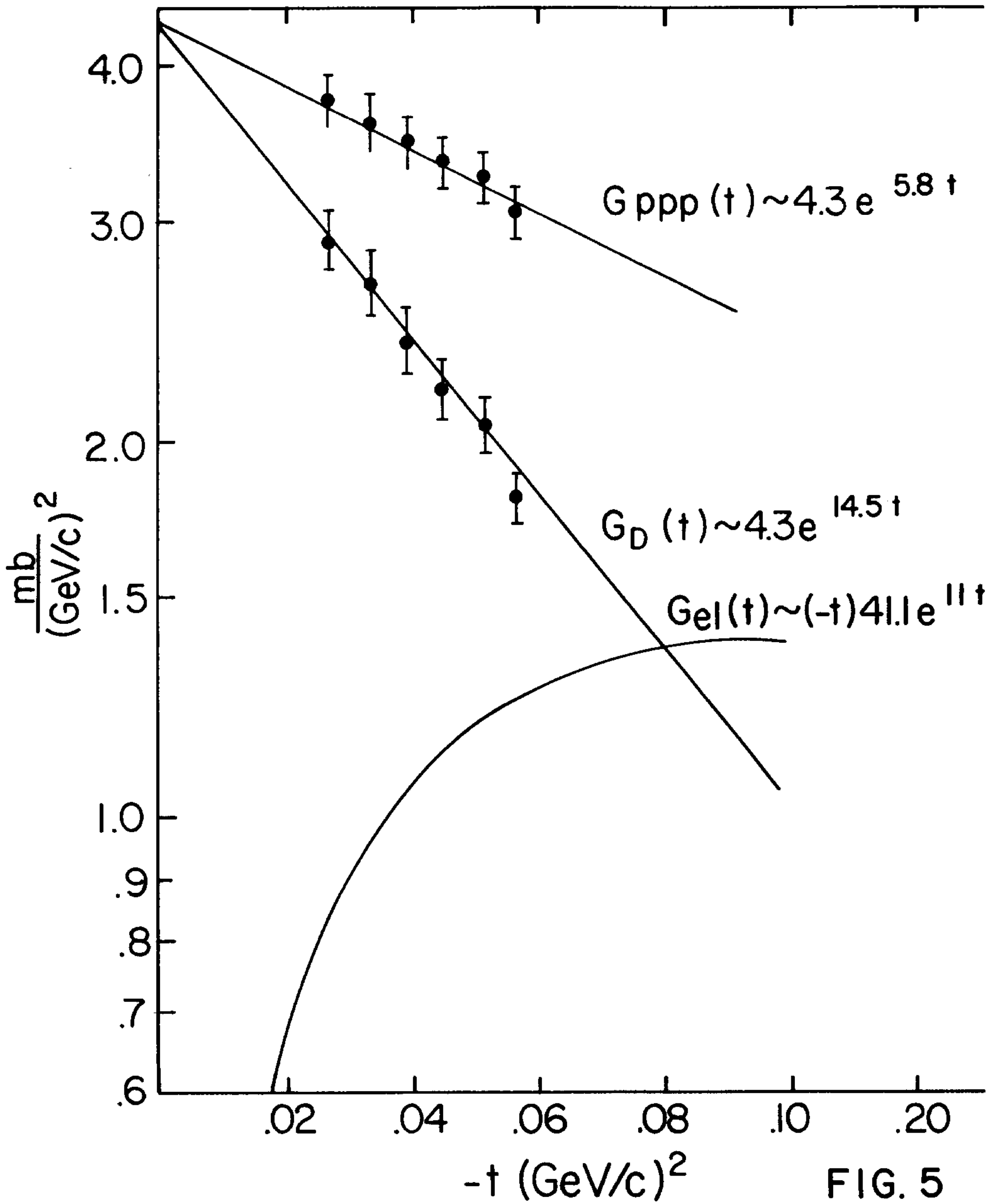

4.0
3.0
2.0
1.5
1.0
.9
.8
.7
.6
mb/(GeV/c)^2
.02
.04
.06
.08
.10
.20
-t (GeV/c)^2
G ppp (t) ~ 4.3 e 5.8 t
G D (t) ~ 4.3e 14.5 t
Gel (t) ~ (-t) 41.1 e 11 t

FIG. 5

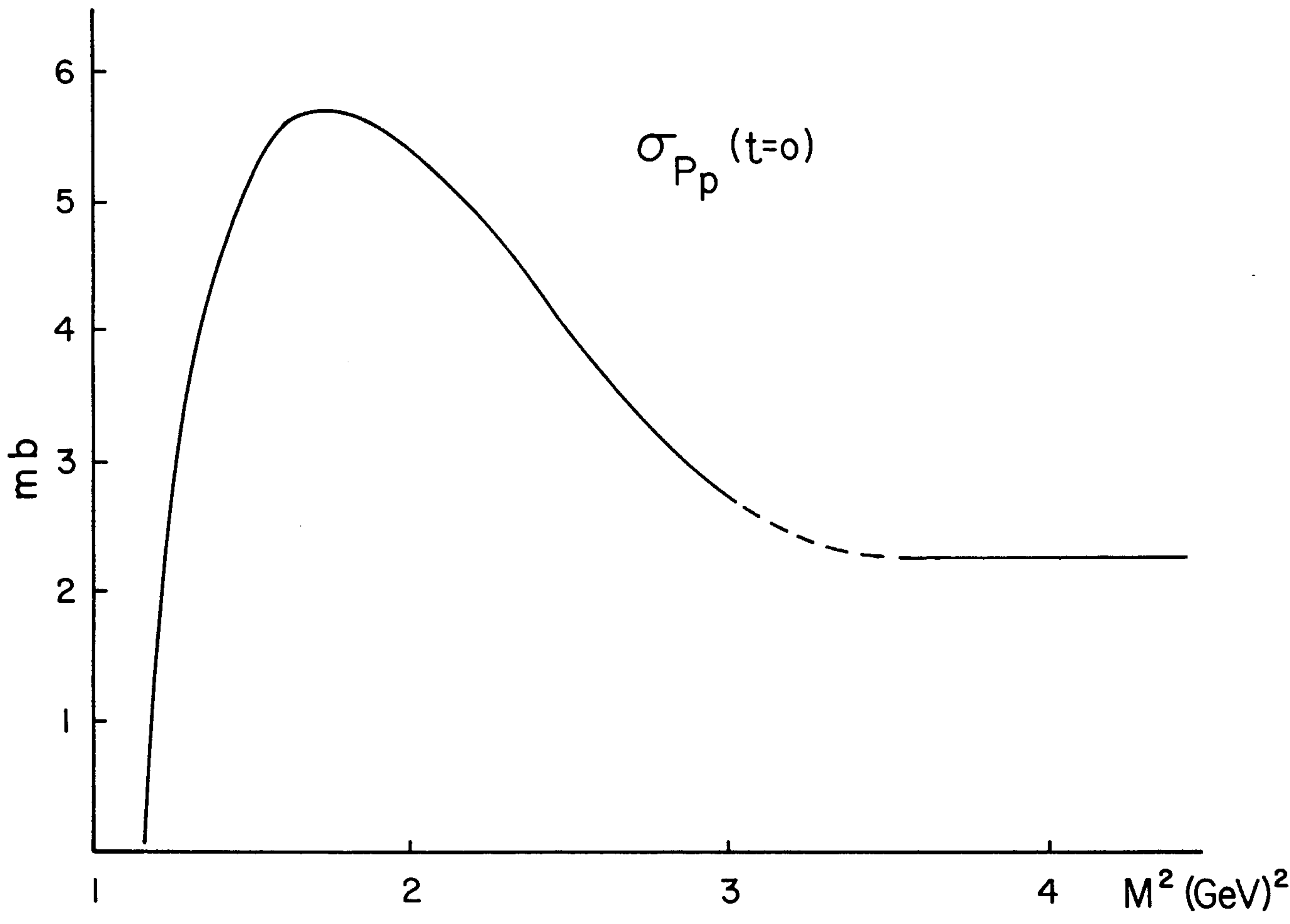
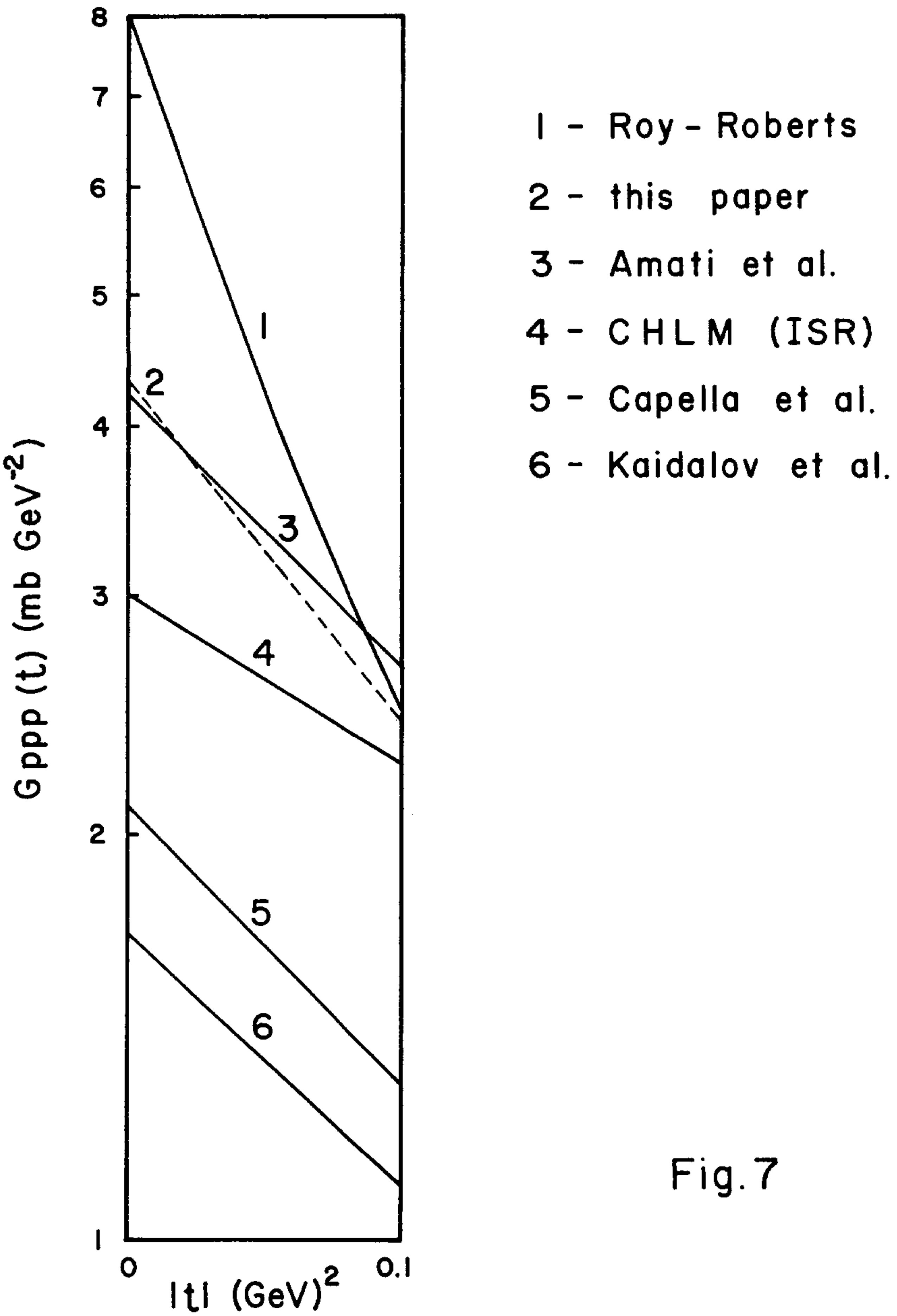


Fig. 6



8
7
6
5
4
3
2
1
0
0.1
Gppp (t) (mb GeV^{-2})
|t| (GeV)^2
1
2
3
4
5
6
1 - Roy - Roberts
2 - this paper
3 - Amati et al.
4 - CHLM (ISR)
5 - Capella et al.
6 - Kaidalov et al.

Fig. 7