INSTITUTO
DE FÍSICA

preprint

Publicado nos "Anais do II Encontro Nacional de Física de Partículas e Campos, pp 104 (1980)

IFUSP/P-247

HIGH ENERGY COLLISIONS AND THE PROTON STRUCTURE: AN AMBIGUITY

by

H. M. França

Instituto de Física - Universidade de São Paulo

UNIVERSIDADE DE SÃO PAULO
INSTITUTO DE FÍSICA
Caixa Postal - 20.516
Cidade Universitária
São Paulo - BRASIL

HIGH ENERGY COLLISIONS AND THE PROTON STRUCTURE: AN AMBIGUITY

H. M. França

Instituto de Física   Universidade de São Paulo

ABSTRACT

We have pointed out an ambiguity in the determination of the sign of the imaginary part of the proton-proton elastic-scattering amplitude for $|t| > |t_{min}|$. We discuss some implications of such an ambiguity concerning the proton structure and, finally, we suggest an experimental analysis which could solve it.

(To be published in the proceedings of the "II Encontro Nacional de Física de Partículas Elementares e Teoria de Campos" - Cambuquira, MG, Brasil - 1980).

NOV/80

Hadrons are extended objects whose internal dynamics is still quite unknown. However a lot of inofrmation concerning its structure can be obtained when we inspect the experimental data from high energy collisions on the light of some simple theoretical model.

This is the case discussed in our preceeding paper(1) in which we have analysed proton-proton elastic collisions in the C.M. energy interval 23 GeV $\leq \sqrt{s} \leq$ 62 GeV and momentum transfer $0 \leq -t \leq$ ≤ 6 GeV^2.

The experimental data we used and the details of the analysis can be found in Ref. 1 and will not be discussed here. We just want to mention that the conclusions we reached are quite general since the assumptions we used (except hypothesis d bellow) are typical approximations(1) of high-energy hadron collisions, namely:

a) we have neglected spin effects;

b) we accepted the dominance of the imaginary part of the elastic-scattering amplitude, $|\mathrm{Im}\ a(\sqrt{s},t)| >> |\mathrm{Re}\ a(\sqrt{s},t)|$, except at the diffraction minimum ($t_{min} \simeq -1.4$ GeV^2 at ISR energies);

c) we have used the eikonal approximation in order to obtain the opacity $\Omega(b,\sqrt{s})$ as a function of the impact parameter b and the energy $\sqrt{s}$:

$$\mathrm{Im}\ a(\sqrt{s},t) = \int_0^\infty b\,db\ J_0(b\sqrt{-t}) \left[1-\exp(-\Omega)\right] \tag{1}$$

$$\simeq \pm \sqrt{\frac{1}{\pi} \frac{d\sigma}{dt} (\sqrt{s},t)} \ ;$$

d) we assumed that Im a has a simple zero when $t=t_{min}$, i.e., $\mathrm{Im}\ a = -\sqrt{\frac{1}{\pi}\ d\sigma/dt}$ for $|t| > |t_{min}|$. Of course the other possibility, i.e., Im a > 0 is also permissible and will be discussed later.

With these assumptions, it is easy to invert expression (1) and compute the opacity $\Omega(b, s)$ which showed the following structure(1) as a function of b and s:

$$\Omega\ (b,\sqrt{s}) = X_f(b) + X_o(b)\ \ell n(s/4m^2) \qquad (2)$$

Here m is the proton mass and the functions $X_f(b)$ and and $X_o(b)$ are such that $X_f >> X_o$ for $b \lesssim 1$ fm but $X_o > X_f$ for $b \gtrsim 2.4$ fm (see Fig. 8 of Ref. 1).

This result was expected by us(2) and one possible physical interpretation was given in detail in Ref.2. We showed there that the energy variation of the opacity can be understood if we admit that particle production is due, in part, to some "classical source" generated(2) by the hadronic-matter overlap of the incident extended protons.

The extrapolation of the result (2) to higher energies is straightforward. At extremely high energies, $\sqrt{s} \sim 10^3$ GeV for instance, we expect that the dominant amplitude is the crossing symmetric one ("antisymmetric" if we use the normalization (1)). This symmetry is realized if we replace s by s $\exp(-i\pi/2)$ in (2) (we call this aditional hypothesis as assumption e). We have verified that this substitution generates the real part of the amplitude which seems correct for two reasons: we get the observed result for Re a / / Im a at t=0; and Re a fill correctely the diffraction minimum at $\sqrt{s}$ = 53 GeV.

In this way the opacity for higher energies can be written approximately as:

$$\Omega(b,\sqrt{s}) \simeq \Omega(b,53) + 2\ X_o(b)\ \ell n\ \left(\frac{\sqrt{s}}{53}\right) - i\frac{\pi}{2}\ X_o(b) \qquad (3)$$

where $\Omega(b,53)$ is computed by using expression (5) of Ref. 1, and the function $X_o(b)$ is parametrized as(1):

$$X_o(b) = .032\ \exp(-.0355b^2) + -.0058\ \exp(-.19b^2) + .0028\ \exp(-.013b^2) \qquad (4)$$

where b is given in GeV^{-1}. The energy $\sqrt{s} = 53$ GeV was chosen as the reference point due to the better quality of the experimental data on $d\sigma/dt$ which, at this energy, cover the t-region up to $|t| \approx 10$ GeV^2.

The calculation of $d\sigma/dt$ for other energies may be done numerically by using:

$$\frac{d\sigma}{dt}(\sqrt{s},t) = \pi\ |a(\sqrt{s},t)|^2 \qquad (5)$$

$$a(\sqrt{s},t) = i\int_0^\infty b\,db\ J_0(b\sqrt{-t})\ \{1-\exp\left[-\ \Omega(b,\sqrt{s})\right]\} \qquad (6)$$

together with expressions (3) and (4).

The result of this computation for $\sqrt{s}=10^3$GeV and 0.6 $\mathrm{GeV}^2 <$ $t<5$ GeV^2 is shown in Fig.1. For comparison we also shown the experimental data at $\sqrt{s} = 53$ GeV. As we can see there, the position of the diffraction minimum is shifted from $t_{min}=-1.35$ Gev^2 at $\sqrt{s}=53$ GeV to $t'_{min} = -1.0$ GeV^2 at $\sqrt{s}=10^3$GeV, while the secondary maximum is shifted from $t_{max} \approx -1.8$ GeV^2 to $t'_{max} \approx -1.3$ GeV^2. The resulting values of the differential cross section at these points are:

$$\frac{d\sigma}{dt}(10^3,t'_{min}) \approx 1.3 \times 10^{-4}\ \mathrm{mb\ GeV}^{-2} \approx 6\ \frac{d\sigma}{dt}(53,t_{min}) \quad \text{and}$$

$$\frac{d\sigma}{dt}(10^3,t'_{max}) \approx 2.4 \times 10^{-4}\ \mathrm{mb\ GeV}^{-2} \approx 4\ \frac{d\sigma}{dt}(53,t_{max}),$$

while the total cross section is 53 mb at $\sqrt{s}=10^3$GeV. We also have verified that $|\mathrm{Im}\ a(10^3,t)| \gg |\mathrm{Re}\ a\ (10^3,t)|$ except for t very close to $t'_{min} \approx -1.0$ GeV^2.

These and other detailed results, as for instance $\sigma_T(s)$, $\sigma_{el}(s)$, $\sigma_{inel}(s)$, Im $a(\sqrt{s},t)$ and Re $a(\sqrt{s},t)$ in the intervals 53 Gev $< \sqrt{s} < 10^3$ GeV and $0 \leq -t \leq 5$ GeV^2, will be published elsewhere(3).

The interest in these results may be understood in view of the new generation of accelerators, which will start running next tities we have calculated. If the quantitative predictions of our calculations are confirmed, we can conclude that the assumptions a, b, c, d, and e mentioned above are correct. Therefore we must justify them more rigorously from the point of view of some theory of strong interactions. Besides this, some effort must be done in order to achieve a better theoretical understanding of the detailed structure of the opacity (see (3) and (4)) in terms of the dynamics of the proton constituents.

If any of our predictions is not verified, it is necessary to identify which are the wrong assumptions.

Concerning to this question we would like to mention that hypothesis d has been criticized by some authors(4,5). Another critical assessment of this hypothesis, and also of other current ideas of high-energy physics, was made very recently(6). We have discussed in Ref.6 the determination of the proton hadronic matter density and its comparison with charge and magnetization densities. We have concluded(6) that the proton charge density is different from the magnetization distribution. However we found that the hadronic matter density becomes more similar to the proton magnetization density when the energy increases, if Im a $(\sqrt{s},t)$ is always positive at the ISR energies. It is important to mention that the proton charge and magnetization densities have been obtained, from the experimental data on elastic electron-proton scattering, by a new method(6) that we have shown to be more consistent than the usual(6,7).

In trying to clarify a little more the question of the validity of the hypothesis d, we have made an alternative analysis of the experimental data on pp elastic collisions, now in the energy interval 45 GeV $\leq \sqrt{s} \leq$ 62 GeV, by using derivative analicity relations(8). In summary what has been done is the following: 1) we write down a dispersion relation involving the logarithm of the modulus of the scattering amplitude and the phase $(a = |a| \exp(i\delta))$, by using the assumptions of Ref.4; 2) we have used the tecnique suggested in Ref.8, getting the following relation between δ and $d\sigma/dt$:

$$\delta \approx \frac{\pi}{2} - \frac{\pi}{4}\left(\frac{\partial}{\partial \ell n s}\right) \ell n \left[\frac{d\sigma}{dt}(\sqrt{s},t)\right] \equiv \frac{\pi}{2} - \phi \qquad (7)$$

By using the above expression, we can calculate Im a(53,t) and Re a (53,t) in a simple way, namely

$$\begin{aligned} \text{Im } a(53,t) &\approx \sqrt{\frac{1}{\pi}\frac{d\sigma}{dt}(53,t)} \; \cos \phi \\ \text{Re } a(53,t) &\approx \sqrt{\frac{1}{\pi}\frac{d\sigma}{dt}(53,t)} \; \sin \phi \end{aligned} \qquad (8)$$

We have verified that this method gives the same results as the previous one (which was based on the equations (3), (4) and (6)) for Im a (53,t) and Re a (53,t) in the interval $0 \lesssim -t \lesssim 1$ GeV^2.

Since $d\sigma/dt$ presents appreciable variation with $\sqrt{s}$ for t close to t_{min}, Im a(53,t) could be negative if $\phi > \pi/2$. Therefore the above calculation can be used to check assumption d.

The results of our computation using (7) and (8) is shown in Figs. 2 and 3. As we can see Im a(53,t) is always positive for $0 \lesssim -t \lesssim 5$ GeV^2, but Re a (53,t) change sign at $t \approx -0.2$ GeV^2 and $t \approx t_{min} \approx -1.35$ GeV^2.

However this analyses is not conclusive for two reasons: first we have used a more limited energy interval (45 GeV $\lesssim \sqrt{s} \lesssim$ 62 GeV), second the contribution from the zeroes of $|a(\sqrt{s},t)|$, if any, was assumed to be negligible$^{(4,8)}$ at these energies.

The conclusion we arrive is that the validity or not of the assumption d is an open question whose solution is difficult by using a purely theoretical approach. This is the ambiguity we have mentioned at the begining. As we have shown previously$^{(6)}$ the "a priori" acceptance (or not) of this hypothesis could lead to a distorted conception of the proton hadronic structure.

We suggest that this ambiguity could be clarified if we analyse high-energy proton-deuteron experimental data (probably break-up) by using a simple phenomenological approach like Glauber's model$^{(9)}$.

* * *

ACKNOWLEDGEMENT

The author has benefited from discussions with Y.Hama (who raised many points discussed in this paper) and G.C.Marques.

REFERENCES

(1) H.M.França and Y.Hama: Phys.Rev. D19, 3261 (1979).

(2) H.M.França and Y.Hama: Rev.Bras.Fis. 8, 127 (1978).

(3) H.M.França and Y.Hama: (work in preparation).

(4) P.Kroll: Nucl.Phys. B82, 510 (1974); W.Grein, R.Guigas and P. Kroll: Nucl.Phys. B89, 93 (1975).

(5) E.Leader, U.Maor, P.G.Williams and J.Kasman: Phys.Rev. D14, 755 (1976).

(6) H.M.França, G.C.Marques and A.J.da Silva: "Charge, magnetization and hadronic matter densities inside the proton", report IFUSP/ P-195, Nuovo Cimento 59A, 53 (1980).

(7) R.G.Sachs: Phys.Rev. 126, 2256 (1962).

(8) U.Sukhatme, G.L.Kane, R.Blankenbecler and M.Davier: Phys.Rev. D12, 3431 (1975).

(9) R.J.Glauber: "High-Energy Physics and Nuclear Structure", ed. by S.Devons, Plenun - N.Y. (1970) p.207.

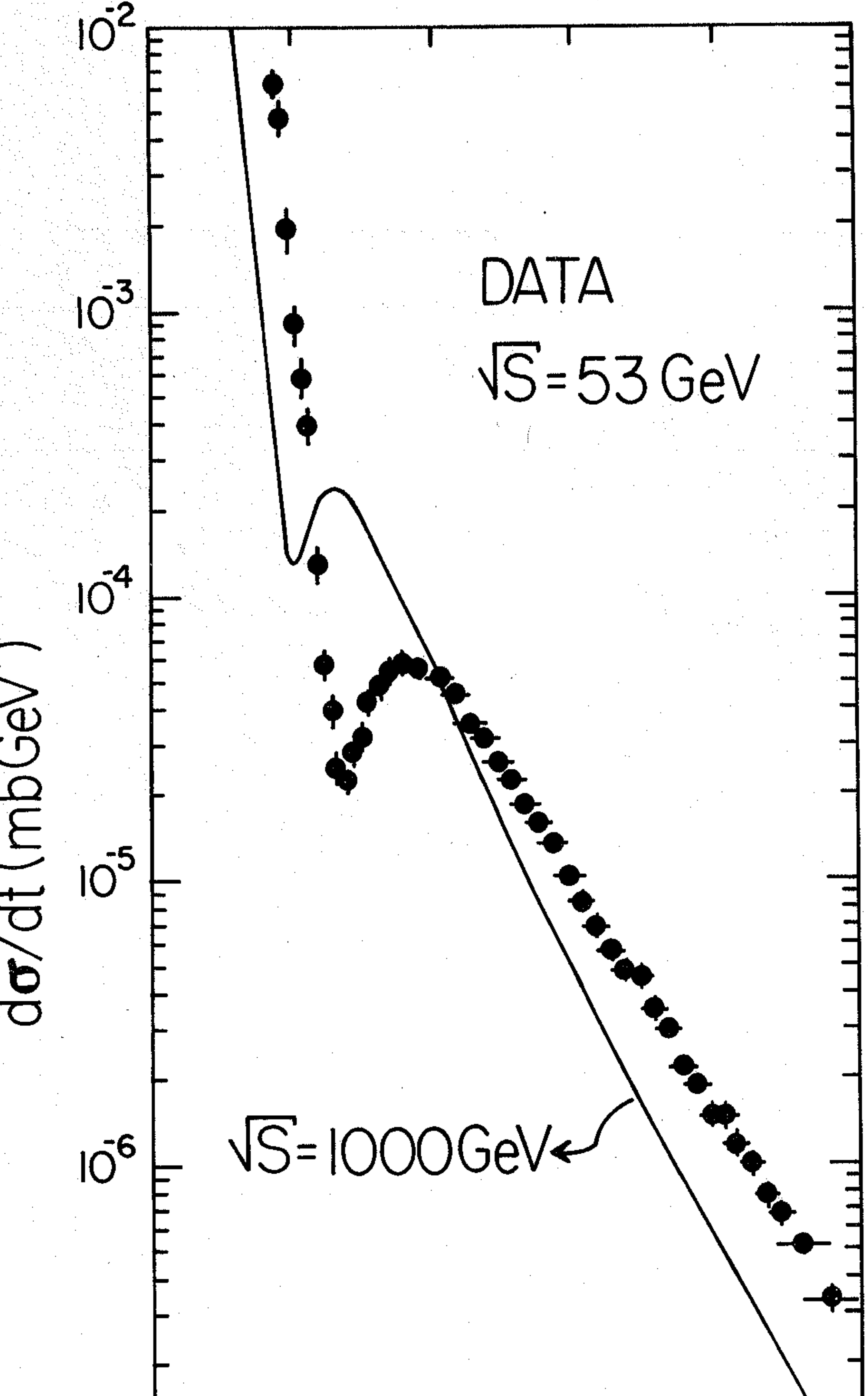
(10) E.Nagy et al.: Nucl.Phys. B150, 221 (1979).

FIGURE CAPTIONS

FIG. 1 - Phenomenological prediction (full curve) for the elastic pp differential cross section at $\sqrt{s}=10^3$GeV by using expressions (5) and (6). The experimental data$^{(10)}$ at $\sqrt{s}=53$ GeV is shown for comparison.

FIG. 2 - Imaginary part of the elastic amplitude at $\sqrt{s}=53$ GeV extracted from the experimental data$^{(10)}$ on $d\sigma/dt$ in the range 45 GeV $\leq \sqrt{s} \leq$ 62 GeV by using expressions (7) and (8). For $|t| \leq$ 0.85 GeV^2 we have used the data analysed in Ref. 1 and the experimental errors are not shown.

FIG. 3 - The ratio Re a (53,t)/Im a (53,t) calculated in the same way (see also Fig.2).



DATA
$\sqrt{S}=53$ GeV
$\sqrt{S}=1000$ GeV
$d\sigma/dt$ (mbGeV^{-1})
$-t$(GeV^2)
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0
1
2
3
4
5

Fig. 1

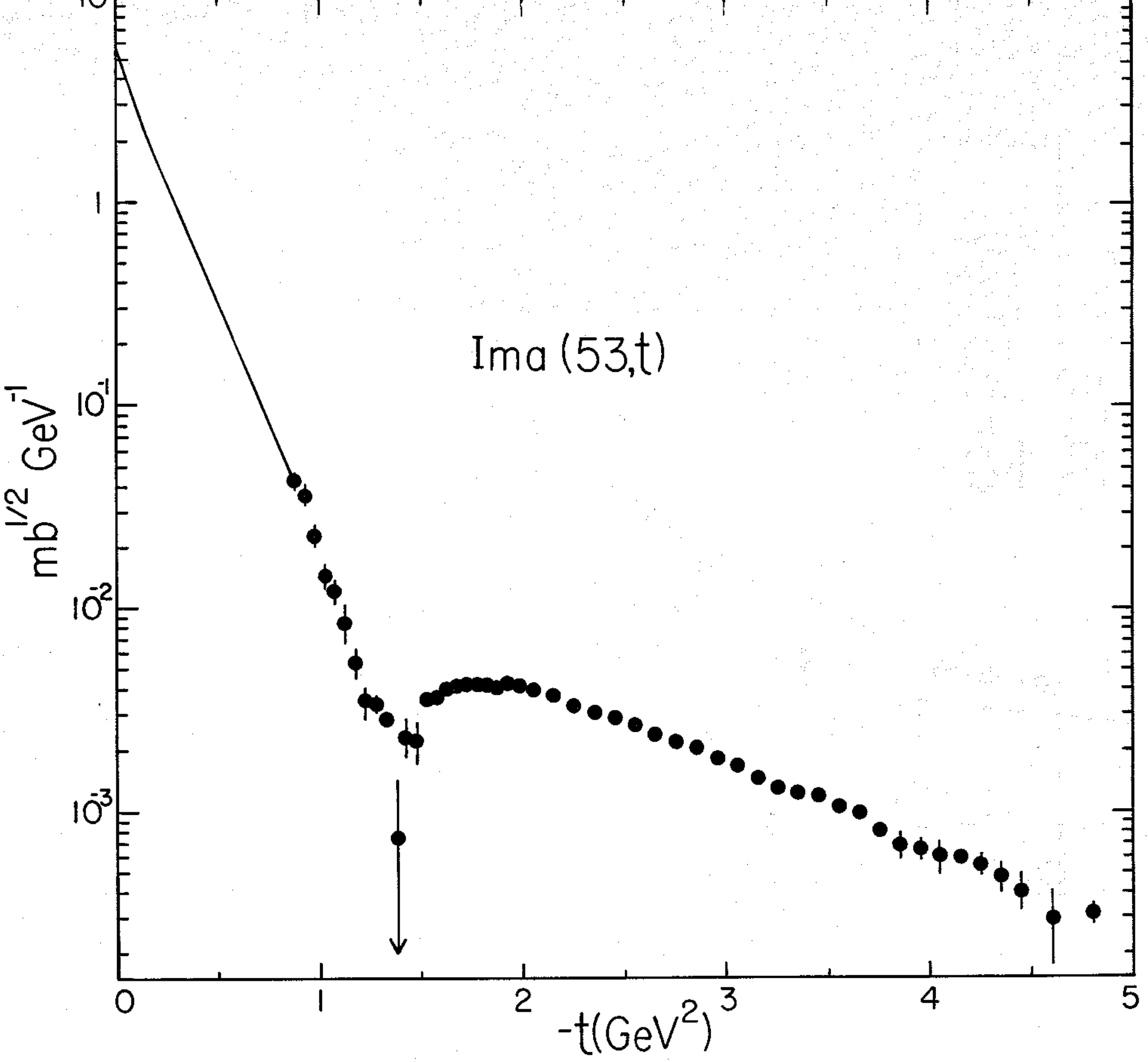


Fig. 2

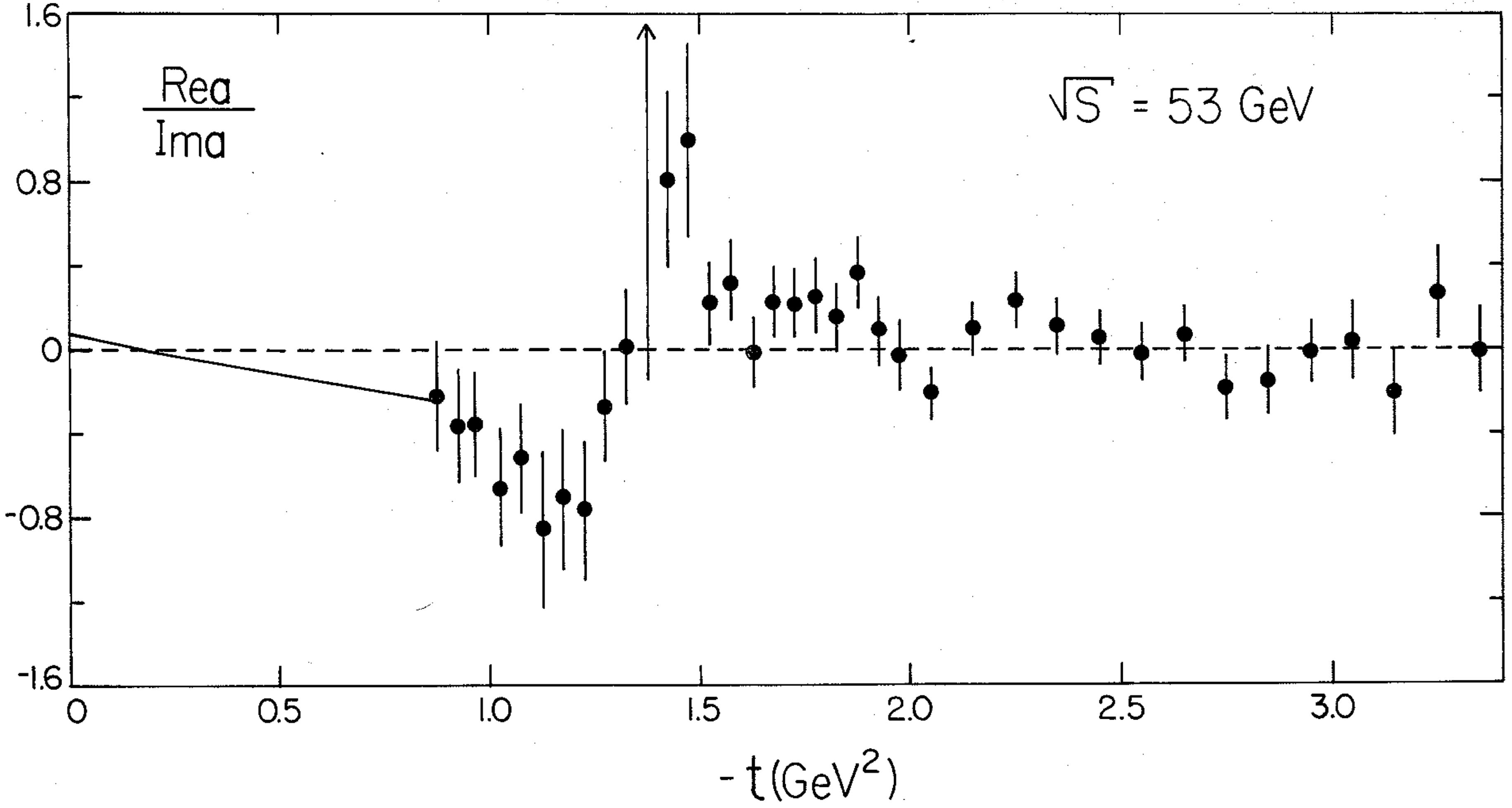

1.6
0.8
0
-0.8
-1.6
$\frac{\mathrm{Re}\,a}{\mathrm{Im}\,a}$
$\sqrt{S} = 53$ GeV
0
0.5
1.0
1.5
2.0
2.5
3.0
$-t\,(\mathrm{GeV}^2)$

Fig. 3