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HELICITY-CONSERVING AND HELICITY-NONCONSERVING POMERON EXCHANGE AMPLITUDES IN THE DUAL ABSORPTIVE MODEL†

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ABSTRACT

The predictive power of the dual absorptive model for Pomeron exchange amplitudes is critically studied. Applications are made to the helicity conserving amplitudes in $pp \to pp$, and to the helicity nonconserving amplitudes in $\gamma p \to \rho^o p$.

The dual absorptive model[1] was recently applied to a fairly large number of two body meson-baryon processes,[2] including photoproduction of ρ^o mesons.[3] This model specifies the form of the imaginary part of two body amplitudes in the impact parameter (b) space. The t dependence of these amplitudes is obtained by performing a Bessel transform:

$$\mathrm{Im}\, f(t) = \int_0^\infty db\, b\, F(b)\, J_{\Delta\lambda}(b\sqrt{-t}) \tag{1}$$

where $\Delta\lambda$ is the net helicity flip in the s-channel, F(b) is the profile function, and both F and f depend implicitly on s.

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Since the model utilizes two-component duality, it treats separately the nondiffractive -- and the diffractive -- amplitudes. It is assumed that the profile $F_R(b)$ of a nondiffractive amplitude is peripheral, i.e., concentrated around $b \simeq R$, with $R \simeq 1$ fermi. A profile of the form $F_R(b) = \delta(b - R)$ would lead to $\mathrm{Im}\, f(t) \propto J_{\Delta\lambda}(R\sqrt{-t})$. It was found that in the realistic cases of two body meson-baryon processes,[2] where $F_R(b)$ has a finite width, but is still peripheral, $\mathrm{Im}\, f(t)$ has the same gross features as $J_{\Delta\lambda}(R\sqrt{-t})$. In particular, $\mathrm{Im}\, f(t)$ has zeroes at the same values of t where $J_{\Delta\lambda}(R\sqrt{-t})$ vanishes. The connection of the shape "$J_{\Delta\lambda}$" as a function of t, with peripherality in b-space, is reasonable and intuitive.

The situation is entirely different for diffractive amplitudes, which are assumed to be central in b space. We will show that the dual absorptive model has no predictive power with respect to the existence of zeroes in pomeron exchange amplitudes. This is due to the lack of any correlation between the property of an amplitude being central in b-space and being structureless (having no zeroes) in t. Thus, the correct description of the t dependence of the diffractive amplitudes in meson-baryon reactions[1-3] should not be considered as an intrinsic success of the model. On the other hand, since very small changes in the profile can produce zeroes, the possible existence of a zero at $t = -.8\ \mathrm{BeV}^2$ in the diffractive amplitudes of $pp \to pp$ (Ref. 4), should not be considered as a failure of the model, unlike what has recently been claimed.[4]

We will first discuss in detail helicity conserving diffractive amplitudes. We will then also comment on helicity nonconserving diffractive amplitudes. These amplitudes have not yet been discussed at all in the framework of the dual absorptive model, but the recent possible observation of helicity nonconservation in $\gamma p \to \rho^0 p$ at 4.7 and 9.3 BeV (Ref. 5), makes such a discussion of interest.

For helicity conserving diffractive amplitudes the model basically assumes central profile $F_p(b)$ -- possibly smooth, monotonic decreasing, and going to 0 faster than any power as $b \to \infty$. In the phenomenological analyses of meson-baryon processes,[1-3] it was assumed that the resulting amplitude is structureless as a function of t for $|t| \leq 1\ \mathrm{BeV}^2$. These two assumptions are consistent, as shown by the well known example

$$F_p(b) \propto e^{-b^2/\rho^2}; \qquad f_p(t) \propto e^{\rho^2 t/4} \tag{2}$$

We claim, however, that the above assumptions are independent, and furthermore, that a very tiny modification of $F_p(b)$ can produce significant structure in $f_p(t)$. We prove this by giving another example

$$F_p(b) \propto e^{-b^2/\rho^2} I_0(rb); \qquad f_p(t) \propto e^{\rho^2 t/4} J_0\left(\frac{\rho r}{2}\ \rho\sqrt{-t}\right) \tag{3}$$

If $\frac{\rho r}{2} < 1$, $F_p(b)$ is smooth, monotonic decreasing and goes to 0 faster than any power as $b \to \infty$. But $f_p(t)$ is of the "J_0" type, and may have zeroes for $|t| \leq 1\ \mathrm{BeV}^2$.

We have plotted in Fig. 1 two profile functions given by the above examples. Profile A corresponds to equation (2) with $\rho = .89$ Fermi. Profile B is given by equation (3) with $\rho = .6$ Fermi and $r = 3\ \mathrm{Fermi}^{-1}$. The parameters were chosen so that both profiles have a radius $R_p = 1$ Fermi. (We define R_p arbitrarily but sensibly as $2\langle b\rangle$.) There is little numerical difference between the two profiles, and neither shape is preferred a priori. In Fig. 2 we plotted the resulting amplitudes. Amplitude A is the well known structureless exponent. Amplitude B has a zero at $t = -.8\ \mathrm{BeV}^2$. Note that this zero originates neither from a sharp-edge effect, nor from a profile which is constant over a range of b.

We conclude that in the framework of the dual absorptive model, helicity conserving diffractive amplitudes with zeroes (even for $|t| \leq 1\ \mathrm{BeV}^2$) are as natural as amplitudes having no structure. A priori the model has therefore no predictive power on the presence of zeroes in t for these amplitudes, and the smooth behavior of such amplitudes in meson-baryon processes[1-3] should not be considered as a success of the model.

Since very small difference in $F_p(b)$ may produce or eliminate zeroes, it may easily happen that in some reactions, diffractive amplitudes are structureless, while in other reactions they possess zeroes in the range $|t| \leq 1$ BeV^2. It has been suggested[4] that a zero at $t = -.8$ BeV^2 in the diffractive amplitudes of $pp \rightarrow pp$ is necessary to explain the break in the differential cross section and the double zero in the polarization, which are observed near $t = -.8$ BeV^2. This zero was claimed to disprove the dual absorptive model.[4] We have shown that the possible existence of this zero is perfectly consistent with the model. Unfortunately, this consistency is due to the weakness of the model in predicting shapes of pomeron exchange amplitudes.

We next turn to helicity flip diffractive amplitudes, and for definiteness we shall specialize to the $\Delta\lambda = 1$ amplitudes which may have been observed in $\gamma p \rightarrow \rho^o p$.[5]

In trying to predict the form of these amplitudes, the dual absorptive model has an ambiguity which is even more serious than the one mentioned above. It is not clear a priori whether the profile function in b space should be central or peripheral. The reason for this ambiguity is that those amplitudes are of a mixed nature. They are diffractive or quasi-elastic as far as the energy dependence and internal quantum numbers are concerned. But they are at the same time inelastic in helicity space. The dual absorptive model in its present form does not specify the form of helicity flip pomeron exchange amplitudes.

On the other hand, the dual absorptive model does specify the form of the imaginary part of the $\Delta\lambda = 1$ nondiffractive amplitudes. Thus the model may have considerable importance in trying to understand the nature of the observed helicity nonconserving amplitude, and in deciding whether it is due to P exchange or due to an ordinary exchange.

The helicity nonconservation[5] in $\gamma p \to \rho^o p$ is manifested in the density-matrix element $\mathrm{Re}\rho^o_{1,0}$.[6] Under the following set of zeroth order assumptions:

1. The dominant contribution to the process is Pomeron exchange.
2. The Pomeron is purely imaginary, and conserves helicity at the meson- and at the nucleon-vertex.
3. Double flip amplitudes may be neglected.

The first order expression for $\mathrm{Re}\rho^o_{1,0}$ is

$$\sqrt{\frac{d\sigma}{dt}}\ \mathrm{Re}\rho^o_{1,0} = \frac{\sum_\lambda P_\lambda \mathrm{Im}\, T_{0,\lambda;1,\lambda}}{2\sqrt{2}\left[\sum_\lambda P_\lambda^2\right]^{1/2}} \qquad \lambda = \pm\frac{1}{2} \qquad . \qquad (4)$$

where in zeroth order $iP_\lambda = T_{1,\lambda;1,\lambda}$ is a pomeron contribution. $\sqrt{\frac{d\sigma}{dt}}\ \mathrm{Re}\rho^o_{1,0}$ is the imaginary part of an "effective" (average) single flip amplitude, as demonstrated in equation (4). It is therefore the relevant quantity in studying the problem which we face: understanding the nature of the helicity-nonconservation, and determining whether it is due to P exchange or due to an ordinary exchange, such as the f and A_2. Four criteria may be used for such an analysis.

(a) Quantum Numbers.[5] These exclude the possibility of significant A_2 exchange, but cannot distinguish between, and are consistent with P and f exchanges.

(b) Order of Magnitude. Application of Vector Dominance to relate $\gamma p \to \rho^o \rho$ to $\gamma p \to \gamma p$ shows that the ratio of f to P in the helicity-conserving amplitudes at 9.3 BeV is $\sim 20\%$ at $t = 0$. Since $\mathrm{Re}\rho^o_{1,0}$ is at most 5-10% in the $|t|$ range 0-0.8 BeV^2, the detected effect of helicity nonconservation may be due to P exchange which violates helicity conservation by 10-20%, or due to f exchange violating helicity conservation by 50-100%. Both possibilities are interesting, and neither of them is ruled out by considerations of order of magnitude.

(c) Energy Dependence. P exchange should exhibit little energy dependence. It should be constant aside from an effect of "shrinking" in the t-distribution, in analogy with the "shrinking" observed in helicity conserving amplitudes. On the other hand, f exchange should exhibit Regge-like $1/\sqrt{E_\gamma}$ behavior. The data at 4.7 and 9.3 BeV (Ref. 5) are consistent with energy independence, thus favoring P exchange. But a $1/\sqrt{E_\gamma}$ behavior cannot be definitely ruled out becuase of the statistical errors.

(d) t-Dependence. Here we can apply our previous analysis. If $\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\rho^o_{1,0}$ is due to f exchange, it should have a "J_1" $(R\sqrt{-t})$ behavior with $R \simeq 1$ Fermi, and therefore have a zero at $t \simeq -.6\ \mathrm{BeV}^2$. If $\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\rho^o_{1,0}$ is due to P exchange, nothing can be said a priori about its shape from the present dual absorptive model. The only conclusion which we can draw is that if $\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\rho^o_{1,0}$ has no zero at $-t = .6\ \mathrm{BeV}^2$, it cannot be due to f exchange. The experimental data[5] do not exhibit a zero at $.6\ \mathrm{BeV}^2$, and $\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\rho^o_{1,0}$ was reported[5] to be rather flat as a function of t, thus favoring an interpretation in terms of P exchange. Thus with the present data, the s-dependence and the t-dependence of $\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\rho^o_{1,0}$ suggest the existence of small helicity nonconserving pomeron amplitude. Better statistics is clearly needed to put this observation on a firm basis.

Using the dual absorptive model we have shown that the t-dependence of the amplitudes is an additional test, which can be used to supplement the criterion of s-dependence, in analysing the nature of helicity nonconservation. These are the only criteria which may distinguish between P and f exchanges. In contrast to f exchange, we must make additional assumptions for P exchange if we are to proceed further in studying the details of the data. As an illustration, we assume: (1) $\Delta\lambda = 1$ P exchange is central; (2) $\Delta\lambda = 1$ P exchange has the same profile as $\Delta\lambda = 0$ P exchange. Since the $\Delta\lambda = 0$ P exchange amplitudes in $\gamma p \to \rho^o p$ are structureless, we take a Gaussian profile e^{-b^2/ρ^2}, where ρ is determined from the slope of the helicity conserving amplitude as in equation (2). The resulting amplitude is

$$f_p^{\Delta\lambda=1}(t) \propto \sqrt{-t}\, e^{t\rho^2/8} \left[I_0\left(\frac{|t|\rho^2}{8}\right) - I_1\left(\frac{|t|\rho^2}{8}\right)\right] \tag{5}$$

This amplitude is plotted in Fig. 3, curve A, for $\rho = .75$ Fermi as determined from the slope of the differential cross section, and compared with "J_1" amplitudes: curve B is $J_1(5\sqrt{-t})$ and curve C is $e^t J_1(5\sqrt{-t})$. We wish to emphasize again that the dual absorptive model does not necessarily predict the form A, which we use only for purposes of demonstration. However, the flat behavior of the present data agrees qualitatively with curve A and suggests that the observed effect of helicity nonconservation in $\gamma p \to \rho^o p$ is due to a pomeron which is central in b-space <u>and</u> has no zeroes in t for $|t| \leq .8$ BeV^2.

The central and structureless amplitude and the peripheral amplitude are very similar for $|t| \lesssim .2$ BeV^2. Both vanish at $t = 0$ like $\sqrt{-t}$, as required by angular momentum conservation. The difference between them is mostly significant for $|t| \gtrsim .3$ BeV^2. Since the basic assumptions of our analysis are not expected to hold for very large values of $|t|$, we suggest that the t range $.3 \lesssim |t| \lesssim .8$ BeV^2 is the best place for analysing the nature of the helicity nonconserving amplitudes in $\gamma p \to \rho^o p$, in future experiments.

In conclusion, we have shown that the present dual absorptive model has no predictive power with respect to the presence of zeroes (in t) in diffractive amplitudes. Thus, the correct description of the t-dependence of the diffractive amplitudes in meson-baryon reactions should not be considered as a success of the model, and the possible existence of a zero in the diffractive amplitudes of $pp \to pp$ should not be considered as a failure of the model. The strong predictive power of the dual absorptive model for nondiffractive amplitudes may, however, serve as a very useful tool in deciding whether the possible helicity nonconservation in $\gamma p \to \rho^o p$ is a property of diffractive amplitudes.

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Figure Captions

1. Impact parameter profiles for helicity conserving Pomeron exchange amplitudes. Both profiles correspond to a radius of 1 Fermi.
2. Helicity conserving Pomeron exchange amplitudes which result from the profiles plotted in Fig. 1.
3. Helicity flip amplitude resulting from a central Gaussian profile (curve A), compared with "J_1" type amplitudes (curves B and C) corresponding to peripheral profiles. The normalization was chosen in accordance with the average flip amplitudes reported in Ref. 5.

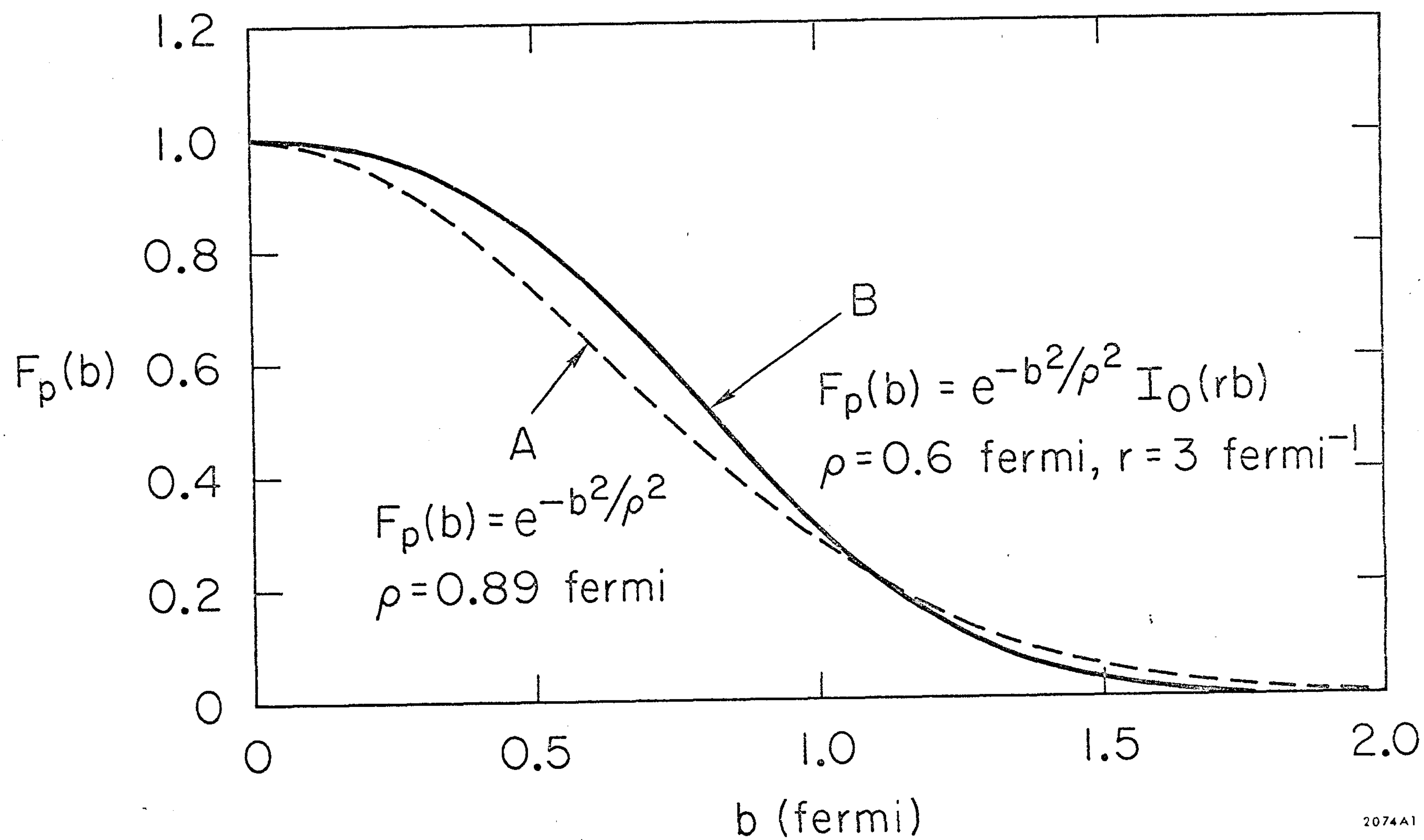
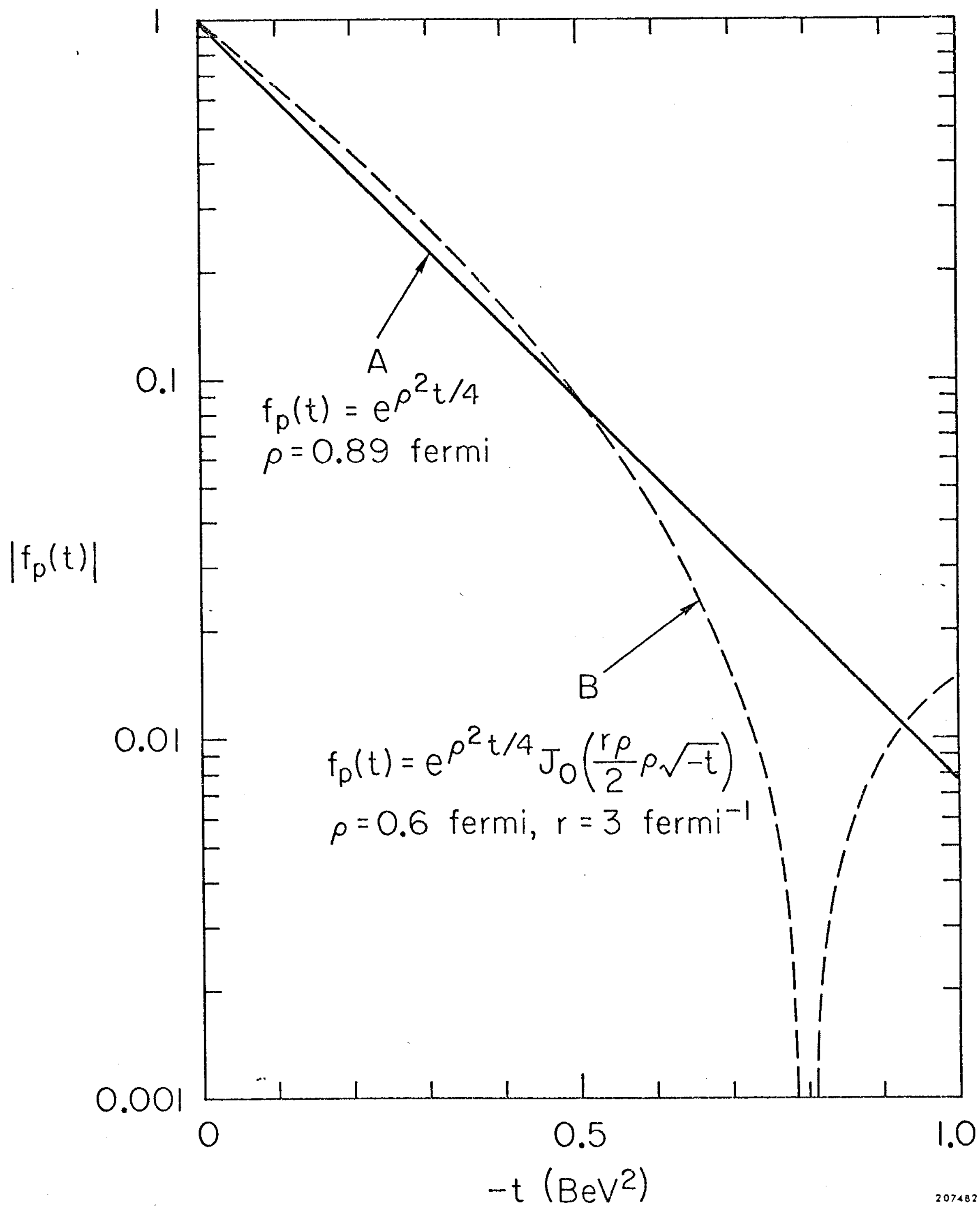
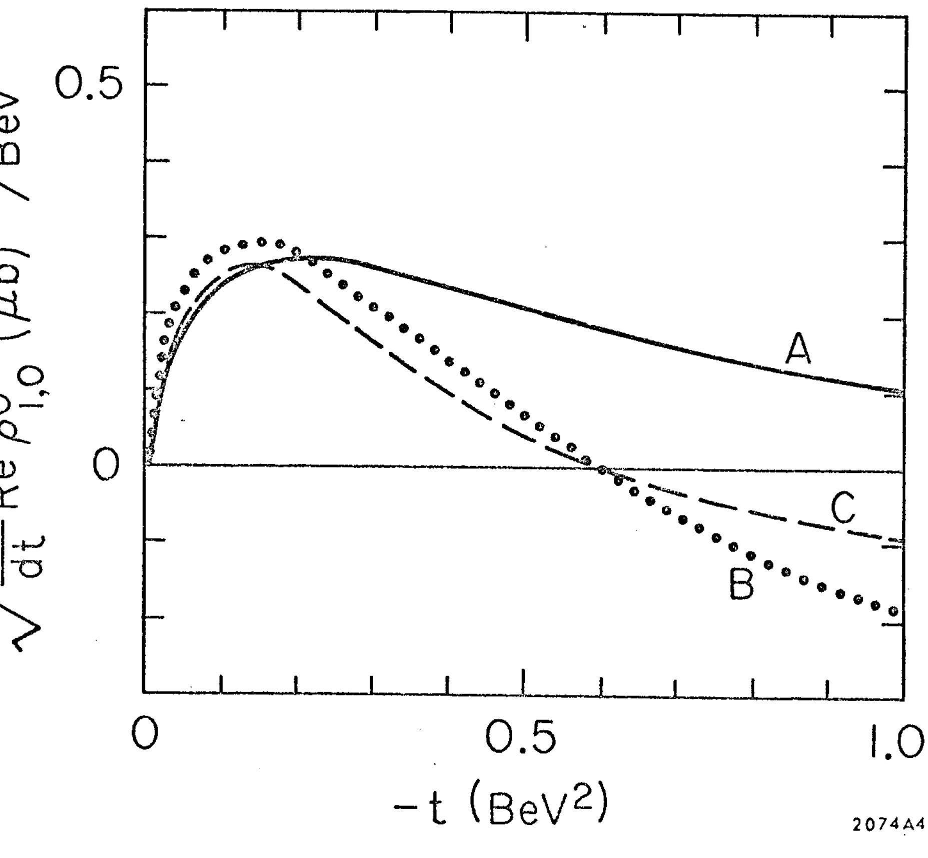

1.2
1.0
0.8
0.6
0.4
0.2
0
$F_p(b)$
0
0.5
1.0
1.5
2.0
b (fermi)
A
$F_p(b) = e^{-b^2/\rho^2}$
$\rho = 0.89$ fermi
B
$F_p(b) = e^{-b^2/\rho^2} I_0(rb)$
$\rho = 0.6$ fermi, $r = 3$ fermi^{-1}
2074A1

Fig. 1



1
0.1
0.01
0.001
0
0.5
1.0
$|f_p(t)|$
$-t$ (BeV^2)
A
$f_p(t) = e^{\rho^2 t/4}$
$\rho = 0.89$ fermi
B
$f_p(t) = e^{\rho^2 t/4} J_0\left(\frac{r\rho}{2}\rho\sqrt{-t}\right)$
$\rho = 0.6$ fermi, $r = 3$ fermi^{-1}
207482

Fig. 2



0.5
0
$\sqrt{\frac{d\sigma}{dt}}\,\mathrm{Re}\,\rho^0_{1,0}\ (\mu b)^{1/2}/\mathrm{BeV}$
A
B
C
0
0.5
1.0
$-t\ (\mathrm{BeV}^2)$
2074A4

Fig. 3