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Pion-Nucleon Charge Exchange Scattering in a New Regge Pole-Cut Model

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We have obtained a fit to most of the available data on pion-nucleon charge exchange scattering using a new Regge pole-cut model. This shows quantitatively the importance of the double Regge cuts, as opposed to the Regge-Pomeron cuts.

For a long time pion-nucleon charge exchange scattering has been a favorite reaction for testing models with Regge poles and cuts. Recent polarization data[1] have, however, shown violent disagreement with the predictions of the two of the currently popular Regge cut models, namely the weak cut or Argonne model[2] and the strong cut or Michigan model.[3] These models differ in detail but basically include the contributions of the Regge cut due to the simultaneous exchange of the Rho and the Pomeron trajectories. Sometime back one of us (K.V.) had suggested that the non-Pomeron cuts could also play an important role in high energy scattering.[4,5] In the present work, we have successfully fitted most of the available world data on this reaction for the pion lab energy

region from 4.8 GeV to 20 GeV and up to a very large momentum transfer ($\sim 4(\text{GeV/c})^2$) using that model. The fits indeed establish quantitatively the importance of the non-Pomeron cut contributions.

To calculate Regge cut contributions from first principles has been found to be extremely involved and intractable from a practical point of view. Models based on eikonals, box diagrams etc. work in some cases and do not work in other cases. In ref. 4, in order to simplify phenomenological discussions, the cuts were replaced by effective poles at the branch points, having the same signature and the nonsense choosing mechanisms at the negative integers. Thus the residues are to be regarded as some effective average quantities. In the following, we define the quantities relevant to the present consideration. For details we refer the reader to ref. 4.

We consider ρ and p' as exchange degenerate trajectories given by

$$\alpha_1(t) = \alpha_o + \alpha' t \ , \ \alpha' = (1-\alpha_o)/m_\rho^2 \qquad (1)$$

The Pomeron trajectory is taken to be

$$\alpha_P(t) = 1 + \alpha'_P t \qquad (2)$$

The non-Pomeron branch points ρp', $\rho\rho$p'(or ρp'p') etc are given by

$$\alpha_2(t) = 2\alpha_o - 1 + \alpha' t/2 \qquad (3)$$

$$\alpha_3(t) = 3\alpha_o - 2 + \alpha' t/3 \qquad (4)$$

etc.

We simulate possible absorptive or diffractive corrections by considering the ρp branch point

$$\bar{\alpha}(t) = \alpha_o + \frac{\alpha'\alpha'_P}{\alpha'+\alpha'_P} t \tag{5}$$

The last one is just one of the several possibilities that can be considered and our model is not particularly dependent on this way of representing absorption effects. The Pomeron trajectory also could be given a $\sqrt{-t}$ form, so that multi-Pomerons give rise to the same trajectory. The main idea in the present model is that the $\rho p'$ cut makes significant contribution for low values of t and the various non-Pomeron cuts dominate different t- regions. In addition the Pomeron-absorptive correction could be expected to fall rapidly as a function of t.

We use the standard A' and B amplitudes defined by Singh.[6] The expressions for the differential cross-section, the polarization of the recoil nucleon and the difference of the $\pi^- p$ and $\pi^+ p$ total cross-sections are well known and, for brevity, are not quoted here.

Various contributions to the amplitudes are given by

$$A_i'(s,t) = \gamma_i e^{p_i t} (1-e^{-i\pi\alpha_i(t)}) \, \Gamma(1-\alpha_i(t)) \left(\frac{\nu}{\nu_i}\right)^{\alpha_i(t)} \tag{6}$$

$$B_i(s,t) = \beta_i e^{q_i t} (1-e^{-i\pi\alpha_i(t)}) \, \Gamma(1-\alpha_i(t)) \left(\frac{\nu}{\nu_i}\right)^{\alpha_i(t)-1} \tag{7}$$

where $\nu = (s-u)/4m$. Note that apart from an exponentially decreasing function for negative values of t, we take the residues as constants. This is to be contrasted with a number of previous works on the subject where complicated residue functions are used. Also we take the nonsense choosing mechanisms for both A' and B. This is consistent with the exchange degeneracy hypothesis. The usual logarithmic terms associated with the cuts are omitted for the following reason. Various theoretical models give different constants in the denominator along with the log $(\frac{\nu}{\nu_0})$ term and are such that the logarithmic dependence may become noticeable only at asymptotic energies.

The scale factors ν_i can be all taken to be the same or preferably related to ν_1 (scale factor for the rho pole) by some theoretical relations. Then the dependence on t can be absorbed in the exponentials. A Veneziano type of ansatz[7] for the effective cut contributions, for example, gives $\nu_1 = \frac{1}{2m\alpha'}$, $\nu_2 = 2\nu_1$, $\nu_3 = 3\nu_1$, $\bar{\nu} = \frac{\alpha' + \alpha'_P}{\alpha'_P}\nu_1$ etc. During the course of fitting we varied α_0, but found that in all cases it settled to a value close to 0.48. Similarly ν_1 was kept as a variable parameter initially but amazingly enough, the fitted value came extremely close to the value given above.

The experimental data are taken from the sources mentioned in ref. 1 and 8. Some of the fits are shown in Figs. 1 and 2. Altogether we have used 86 data points for differential cross-sections (including 12 points from Case-Western Reserve (CWR) data at large $|t|$), 16 points for polarization and 10 points for difference of $\pi^- p$ and $\pi^+ p$ total cross-sections ($\Delta\sigma$).

First of all, we ignored the Rho-Pomeron cut term ($\bar{\gamma}=\bar{\beta}=0$). Then, just with $\rho(\gamma_1, \beta_1, p_1, q_1)$ and $\rho p'(\gamma_2, \beta_2, p_2, q_2)$ (8 parameters) we could get a fit with $\chi^2(\frac{d\sigma}{dt}) = 189$, $\chi^2(\text{pol}) = 12.6$ and $\chi^2(\Delta\sigma) = 6.5$. The fit to polarizations and $\Delta\sigma$ is adequate. To improve $\chi^2(\frac{d\sigma}{dt})$ without using complicated residue functions, we add the ρP cut term $(\bar{\gamma}, \bar{\beta})$. Doing this we find $\chi^2(\frac{d\sigma}{dt}) = 174$, $\chi^2(\text{pol}) = 9.4$ and $\chi^2(\Delta\sigma) = 5.2$ for the best fit. Next we notice that a very large part of $\chi^2(\frac{d\sigma}{dt})$ comes from the fit to the CWR data. From the discussion in ref. 4 we realize that we are approaching the t-region where the triple Regge cut ($\rho p' p'$ or $\rho p p'$) can be expected to make significant contribution[9]. We add such a term and find a fit with $\chi^2(\frac{d\sigma}{dt}) = 151$, $\chi^2(\text{pol}) = 9.0$ and $\chi^2(\Delta\sigma) = 4.9$. This case is shown in the figures[10].

We also tried fitting without the $\rho p'$ cut (γ_2, β_2 term). The best fit we obtained had $\chi^2(\frac{d\sigma}{dt}) = 433$, $\chi^2(\text{pol}) = 37$ and $\chi^2(\Delta\sigma) = 41$. This clearly establishes the importance of the double Regge cut term and verifies within the context of our model the fact that both weak and strong cut models fare poorly in explanation of the complete set of data. Our results are in agreement with the qualitative discussion given in ref. 4. Recently some other authors have also looked at double Regge (particle) exchange with somewhat different points of view [11].

It should also be mentioned that, although only values of $\Delta\sigma$ up to the lab momentum of 20 GeV/c were used in fitting, the resulting values of $\Delta\sigma$ are in reasonable agreement with the data up to the lab momentum of about 60 GeV/c .

We do not plot our amplitudes here, but just mention that Im $A'(s,t)$ passes through zero around $|t| = 0.2\ (\text{GeV/c})^2$. As is well known, this behaviour produces the well established crossover effect when the pion-nucleon elastic scattering is considered.

Now we make a brief comparison with some of the pole models. Barger and Phillips [12] introduce a zero in the residue function for the ρ to produce the crossover effect and also assume existence of a ρ' trajectory with zero intercept and slope equal to that of the ρ. Unless both of these are considered as effective poles representing the combined effects of poles and cuts, the former fact leads to the factorization difficulty and the latter to the problem of identification of a particle lying on the ρ' trajectory. We prefer to parameterize the pole and cut terms separately so that at least in some approximation, we can make contact with theory. Furthermore, the Barger and Phillips model requires ρ as sense choosing, whereas we have the nonsence choosing mechanism. Finally their model would predict a rapid and t-independent decrease of polarization with energy, whereas the present model would predict a slow decrease with energy which is dependent on the momentum transfer. Future experiments could test this.

Recently Leader and Nicolescu[13] have proposed a model with the ρ' having an intercept close to zero and slope less than half of that of ρ. They identify a recently discovered resonance of mass 1968 MeV as a particle lying on this trajectory. Since the intercept and the slope of this ρ' are quite close to the corresponding parameters of our ρ-p' cut, evidently the two models give very similar results. The points of view are different however. Note that, if these authors take the ρ' slope as similar to that of the ρ, the two intercept will lie too low to fit the data. Irregardless of the fact whether such a ρ' trajectory with correct quantum numbers is established in the future or not, the question of a ρ-p' cut contribution will still remain. In Regge theory, once the existence of the pole trajectories is granted, one has to accept the existence of the cuts. In addition we find the notion of trajectories having universal slope (except for Pomeron which is special anyway) as too attractive to give up, unless one has to. Finally, in the Leader-Nicolescu model the I = 1 amplitude does not vanish for very low values of t. Thus unless the I = 0 amplitude has a subtle structure, their model would have difficulty in explaining the elastic scattering crossover phenomenon.

In our case, the crossover zero was not imposed but was the natural result of fitting other data.

Another recent model including a background term representing a fixed pole has been proposed by Kogitz and Logan[14]. They use a complicated residue function chosen precisely to peak at the correct position to produce dip-bump structure. Their work does show that the background term is indeed necessary to produce such a structure. But it seems to be preferable to parameterize the background directly in terms of effective cut contributions, in order to make greater connection with theory.

It is clear that some improvements in our χ^2 values is possible if we introduce more complicated residue functions e.g. those with linear and higher terms in t. A large part of $\chi^2(\frac{d\sigma}{dt})$ does come from the low t-region. Another possibility is to introduce an extra phase difference between the pole and the cut term. Eikonal models, for example, give this phase difference to be proportional to $\frac{\pi}{2\log(\nu/\nu_o)}$.

In the present work we have made no attempt to calculate the residue functions for the cuts (effective poles) in terms of the corresponding functions for the poles. It may be possible to do this within the framework of various theoretical models[7] and it remains to be seen if the effective contributions of comparable magnitude can be generated in this way. Our aim in the present work has been to find out the strengths of the various contributions required by the data, keeping power behavior, signature factors etc. given by the usually accepted theoretical considerations.

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6. V. Singh, Phys. Rev. 129, 1479 (1963).
7. See, for example, K. V. Vasavada, Phys. Rev. D3, 2442 (1971).
8. Differential cross sections are taken from A. V. Stirling et al., Phys. Rev. Lett. 14, 763 (1965), P. Sonderegger et al., Phys. Lett. 20, 75 (1966), and W. S. Brockett et al., Phys. Rev. Lett. 26, 527 (1971). Total cross sections are taken from A. Citron et al., Phys. Rev. 144, 1101 (1966), and K. J. Foley et al., Phys. Rev. Lett. 19, 330 (1967).

9. If we go to still larger values of $|t|$, it may be necessary to include u-channel exchanges.
10. The values of the parameters in the appropriate units with $\hbar = c = \text{GeV} = 1$ are : $\gamma_1 = 2.98$, $\gamma_2 = 41.18$, $\gamma_3 = 0.22$, $\bar{\gamma} = 2.73$, $\beta_1 = 60.66$, $\beta_2 = 33.68$, $\beta_3 = 0$, $\bar{\beta} = 6.10$, $p_1 = 4.86$, $p_2 = 5.00$, $p_3 = -0.19$, $\bar{p} = 5.36$, $q_1 = 1.39$, $q_2 = 1.22$, $q_3 = -0.19$, $\bar{q} = 1.13$, $\alpha_0 = 0.48$, $\alpha'_P = 0.5$, $\nu_1 = 0.63$. These parameters are given in this form only for the sake of convenience of presentation. Actual number of parameters used through various combinations is 14 in the most general case and 8 in the case ($\bar{\gamma} = \bar{\beta} = \gamma_3 = \beta_3 = 0$) which gives a fairly good fit to the data.

11. See, for example, H. Harari, Phys. Rev. Lett. 26, 1079 (1971); F.S. Henyey, G. L. Kane and J. J. G. Scanio, Phys. Rev. Lett. 27, 350 (1971).

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FIGURE CAPTIONS

Fig. 1. Fit to the differential cross-sections.

Fig. 2. (a) Fit to the new polarization data, (b) Fit to the cross-section difference $(\Delta\sigma = \sigma_{\pi^- p} - \sigma_{\pi^+ p})$

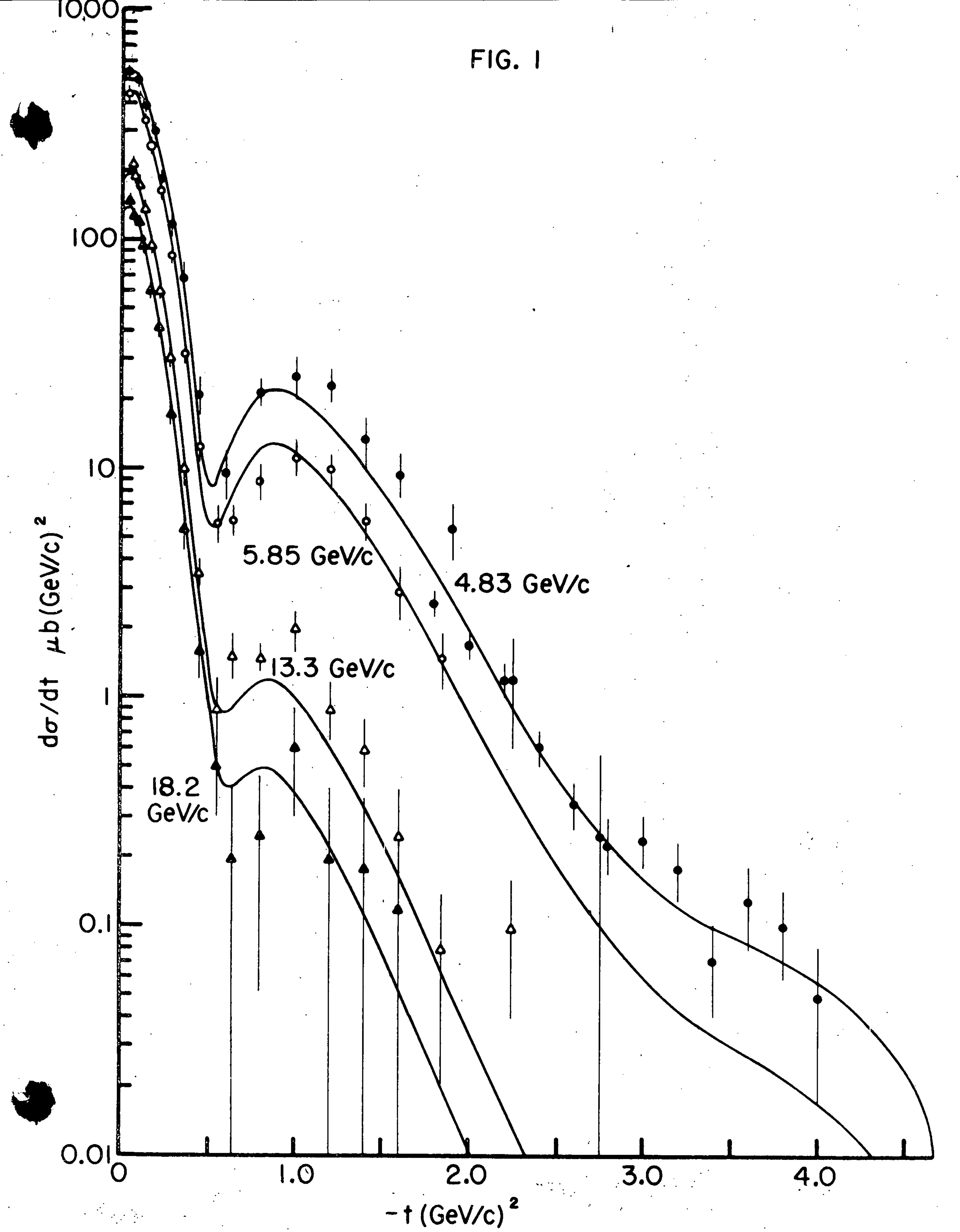
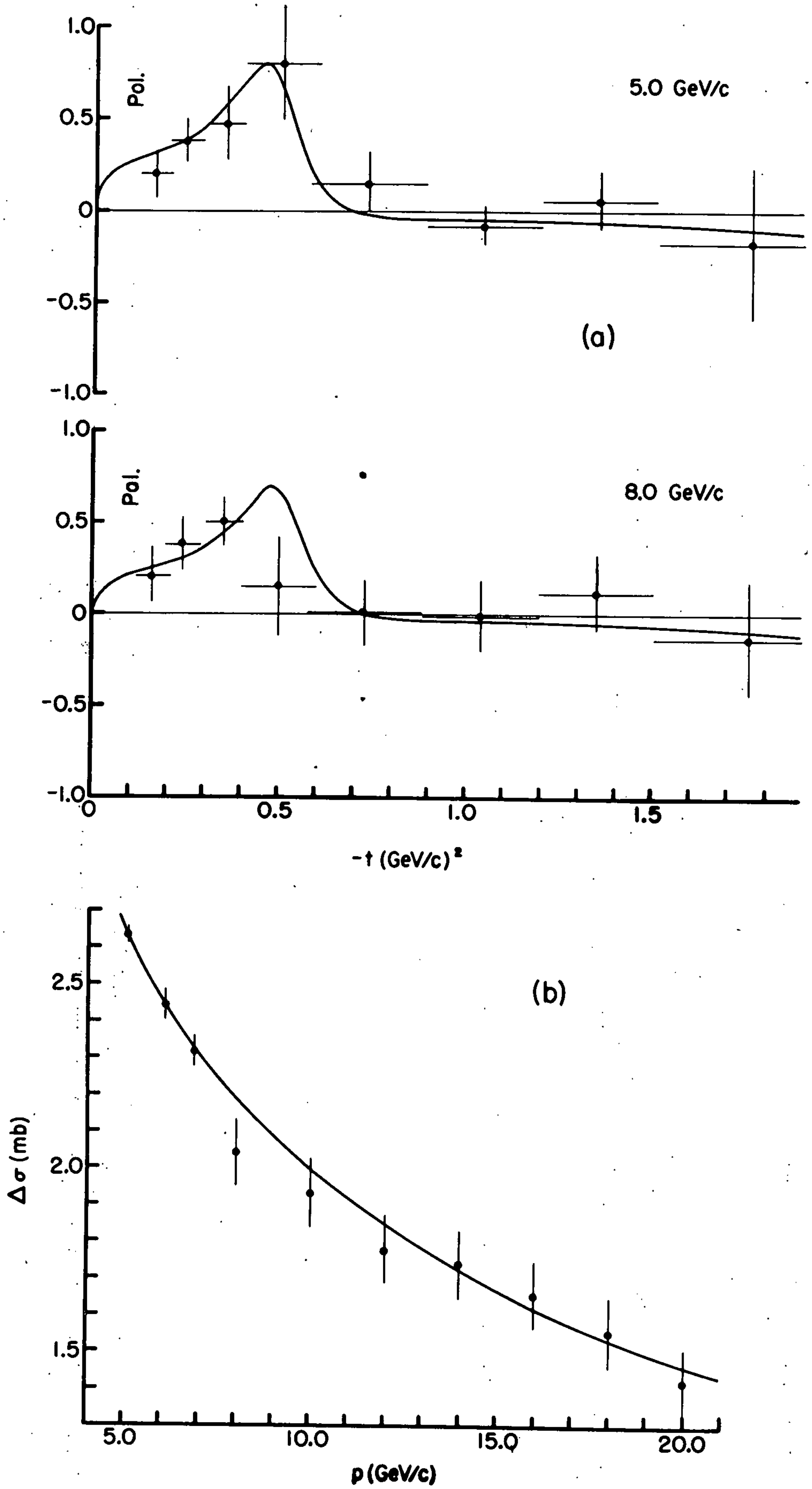


FIG. 1
1000
100
10
1
0.1
0.01
0
1.0
2.0
3.0
4.0
$d\sigma/dt \ \ \mu b(GeV/c)^2$
$-t\ (GeV/c)^2$
5.85 GeV/c
4.83 GeV/c
13.3 GeV/c
18.2 GeV/c

FIG. 2



Pol.
5.0 GeV/c
(a)
8.0 GeV/c
1.0
0.5
0
-0.5
-1.0
0
0.5
1.0
1.5
-t (GeV/c)²
(b)
Δσ (mb)
2.5
2.0
1.5
5.0
10.0
15.0
20.0
p (GeV/c)