Veni, Vidi, Vici Regge Theory

Regge theory has, in the past few years, been compared with essentially all available data on two-body scattering at high energies. Indeed it is the only formalism (theory?) that is sufficiently flexible for such comprehensive quantitative tests to be feasible. Experimental data exist for so many reactions, and are now of sufficient precision, that the large number of parameters, inherent in Regge-pole theory, is no longer a hindrance in judging the scope of its validity. Let us define three possible models. Firstly we have the simple Regge-pole model in which no cuts are allowed. Secondly we consider the (as yet theoretically unjustified) absorption prescription for generating Regge-cut corrections to simple Regge poles. Finally we have the general framework of Regge poles (defined, say, by the particles created along the trajectory) plus arbitrary Regge cuts, restricted only by known general principles. We now state without proof three, almost everywhere valid, theorems.

(i) *The (cut) corrections to Regge-pole theory are at least as large as predicted by the absorption model.*

We point out that an absorptive-cut correction to, say an elastic amplitude, is some 20% of the pole at $t = 0$, while the cut becomes equal to the pole somewhere between $-t = 0.5$ and 1.0 $(\mathrm{GeV}/c)^2$. If this is to be judged an important discrepancy, one can conclude that simple Regge-pole theory is insufficient.

(ii) *The predictions of the absorptive-cut model are generally incorrect.*

Although this model has had some interesting qualitative successes, most of these are shared by rather general models. In particular it is clear that Regge-pole predictions are generally *un*reliable for *low* (direct channel) partial waves. In fact, experimentally, these low partial waves are typically smaller than their Regge-pole values.

(iii) *The present fund of knowledge on the general properties of cuts is insufficient for meaningful phenomenology.*

Given the failure of the pole model and the inadequacy of the absorptive prescription, it is necessary to find a less specific framework with which to describe the increasingly accurate high-energy data. Such a formalism does not exist at present, as restricting a Regge-cut fit with

known principles, allows a ridiculous number of parameters. This is the essential difference between Regge cut and pole phenomenology. The latter had sufficiently few unknown parameters that fits to the data could determine them and hence properties of the poles without specific theoretical assumptions.

We will now discuss three examples that illustrate our three theorems.

(a) πN charge exchange

As van Hove has described,[1] the energy dependence, at fixed t, of the experimental $d\sigma/dt$ for πN charge exchange (CEX) is well described by

$$\frac{d\sigma}{dt} = A(t)\,(p_{\mathrm{lab}})^{2\alpha_{\mathrm{eff}}(t)-2}\,.$$

In fact, such a form gives an adequate fit to $d\sigma/dt$ for almost all reactions,‡ in the present high-energy range of $5 \leqslant p_{\mathrm{lab}} \leqslant 30$ GeV/c. If there is but one pole exchanged, then of course Regge-pole theory would predict that $\alpha_{\mathrm{eff}}(t) = \alpha(t)$, the trajectory function of the exchanged pole. However, for any data, $\alpha_{\mathrm{eff}}(t)$ proves very useful for judging the relative contributions of cuts and/or different trajectories.

Figure 1 shows a plot of the experimental $\alpha_{\mathrm{eff}}(t)$ versus t for πN CEX. As is well-known, this agrees remarkably well with a simple pole (the ρ-trajectory) which is roughly given by $\alpha_\rho(t) = 0.58 + t$. This was historically the first and, unfortunately, still essentially the only successful application of Regge-pole theory to fitting data over a wide range of t. The observation of nonzero polarization in this reaction led to a modification of this simple one-pole description.[2] In particular, various versions of the reggeized absorption model were advanced to successfully explain this anomaly. In Fig. 1, we have also shown the theoretical α_{eff} predicted by the two most popular of these calculations. The solid curve, marked E, uses exchange-degenerate (EXD) pole residues and so explains the dip in $d\sigma/dt$ for πN CEX at $t \sim -0.6$ $(\mathrm{GeV}/c)^2$ by an intrinsic zero in the pole residue. The dashed curve, marked M, uses a model advocated by the Michigan group. Here the absorptive cut is much larger and so generates a greater deviation from a straight line in the theoretical α_{eff}. The dip in $d\sigma/dt$ is explained, quite differently, as the interference between the cut and a pole whose residue is nonvanishing at $t \sim -0.6$.

Figure 1 demonstrates that only the EXD version of the absorption model is consistent with πN CEX data. Even here, it is worth noting that this sophisticated cut model gives a fit to α_{eff} that is somewhat worse than in the original, pole only, model.

‡ I have collected empirical values of $\alpha_{\mathrm{eff}}(t)$ for some 20 reactions in my Stony Brook talk.

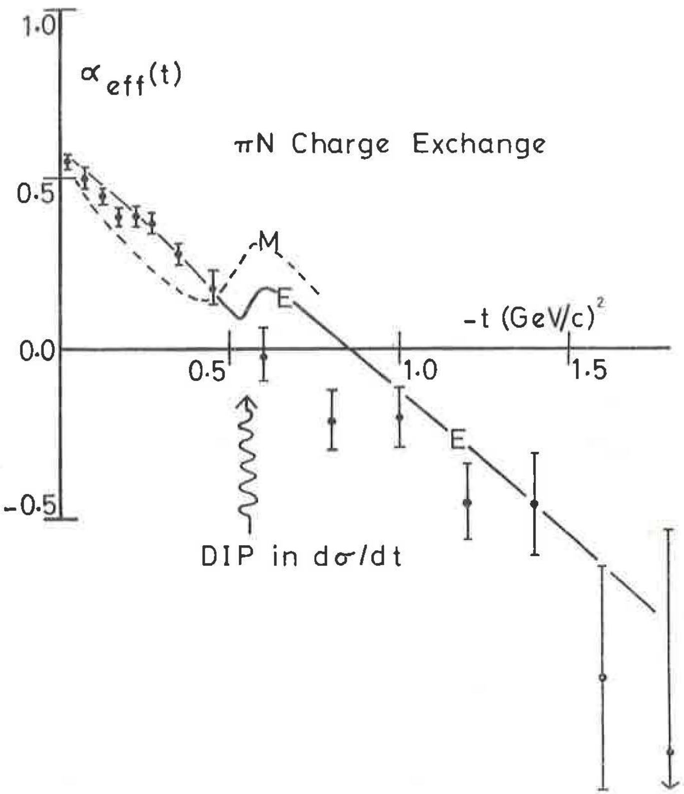

FIGURE 1

(b) Photoproduction

There is now an enormous amount of beautiful data on both forward[3] and backward photoproduction. Let us say, at once, that there is as yet no theoretical model which can explain anything but the very gross features of these data.

First of all we may dispose of Regge-pole theory. The π-exchange reactions, $\gamma p \to \pi^+ n$ and $\gamma p \to \pi^- \Delta^{++}$ are predicted to vanish at $t = 0$ if there are but well-behaved Regge poles exchanged. The size of $d\sigma/dt$ at $t = 0$ is thus a direct measure of the (cut) correction, and this is found to be from 1.5 to 3 times the simple absorption prediction. This allows us to confirm theorem (i) and further to rule out the EXD reggeized absorption model. Thus only the Michigan model which predicts such enhanced absorption to be universal remains to be considered.

However, let us complete the case for the prosecution by remarking that there is quite outstanding evidence that photoproduction is

dominated not by cuts at all, but rather by fixed poles in the j-plane. Drell[3] has described how fixed singularities, forbidden in strong interactions, are allowed in weak processes like photoproduction. In Figs. 2 and 3, we show the experimental α_{eff} for forward $\gamma p \to \pi^0 p$ and backward $\gamma p \to n\pi^+$, respectively. I believe that these are quite typical, and that all photoproduction data are as consistent with a fixed power in their energy dependence (i.e. a flat α_{eff}) as these two examples indicate. Notice the shift of the fixed power from $j = 0$ in forward processes (corresponding to the energy independence of $s^2 d\sigma/dt$) to $j = -1/2$ in the backward data (corresponding to the constancy of $s^3 d\sigma/dt$). This is an expected theoretical property of fixed poles in, respectively, meson and baryon exchange reactions. It is, of course, possible that these flat α_{eff} plots are not due to fixed poles but rather to some kinematic quirk of photoproduction. However, this seems unlikely, for, in $\gamma p \to \pi^0 p$, most theoreticians agree that one may expect the ω trajectory to dominate. Given this, it is easy to show that the kinematic structure of the unabsorbed ω in $\gamma p \to \pi^0 p$ is essentially identical to that of the embryo ρ in πN CEX. Moreover, the absorption is expected to be the same, and we at once predict roughly the same α_{eff} in both reactions. Of course, Figs. 1 and 2 are quite different.

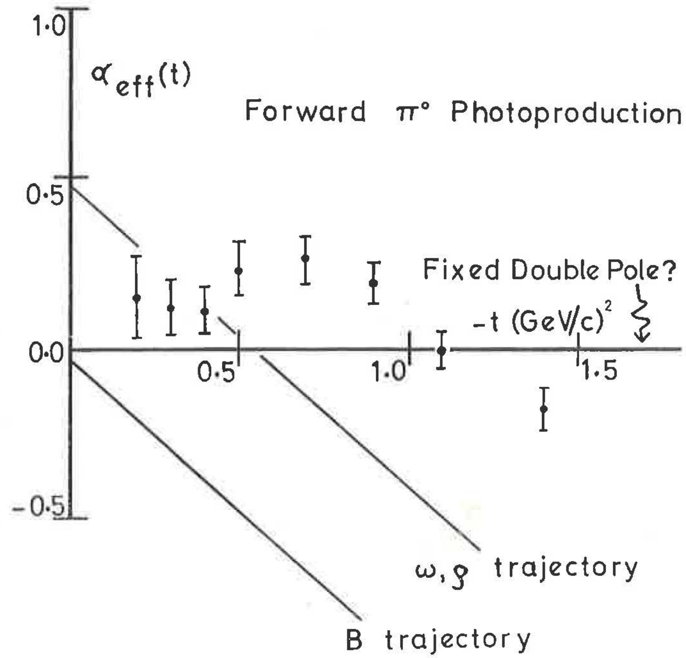

FIGURE 2

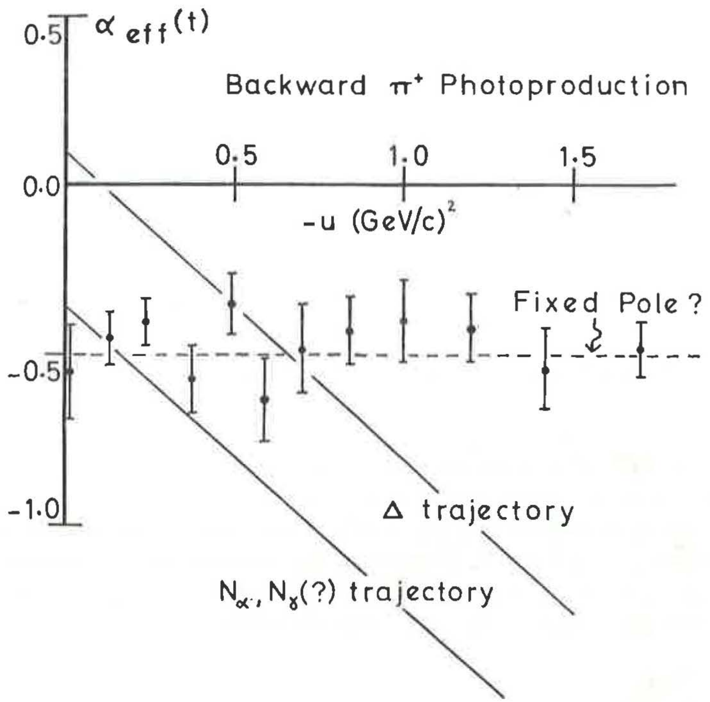

FIGURE 3

So it seems that present photoproduction data show that not only is the *absorption model wrong* but also that fixed poles are present. The latter, of course, means that the *vector dominance model* (VDM) must also be *incorrect*. Thus fixed singularities cannot be tolerated in the strong-interaction vector-meson production which VDM claims to be simply proportional to photoproduction.

While we are on this subject, let us nip in the bud any hope that the EXD absorption model might fit all strong-interaction processes. (Remember it did fit one, πN CEX.) Thus $\pi N \rightarrow \rho N$, like photoproduction (VDM is not that bad!), needs the large absorption characteristic of the Michigan model.

(c) p–p elastic scattering

Figure 4 shows, with the solid lines, pp elastic $d\sigma/dt$ at a lab momentum of 7 and 19.2 GeV/c. We have also shown a simple exponential fit (dashed line) to the forward points which emphasizes the well-known change of slope in pp $d\sigma/dt$. This occurs at $t \sim -0.6$ (GeV/c)^2 at the lower energy and moves out to $t \sim -1.1$ at 19.2 GeV/c. In the absorption picture, the simple forward exponential [$d\sigma/dt \underset{\sim}{\propto} \exp(8t)$] corre-

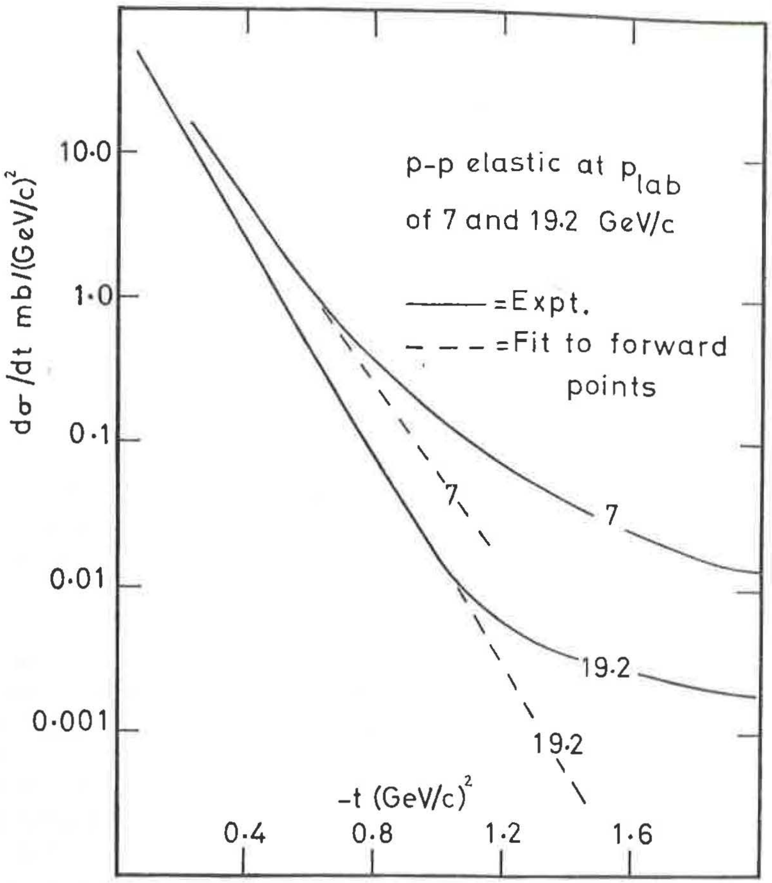

FIGURE 4

sponds to the Pomeron pole and the break is due to multiple scattering described by the Pomeron–Pomeron (P–P) Regge cut. However, this is clearly a quite oversimplified model. For instance, if the Pomeron had zero slope, then the pole and the cut would have the same energy dependence and thus the break should occur at the *same* t-value for all energies. Secondly, if the Pomeron has a nonzero positive slope, the cut lies higher in the j-plane than the pole and the multiple scattering becomes more important as energy increases. In particular, the break should move in to lower $|t|$ as we go up in energy. Manifestly the data agree with neither prediction and further there is tremendous shrinkage in the data at large $|t|$ [$\alpha_{\text{eff}} \lesssim 0$ for $1 \leqslant -t \leqslant 2$ (GeV/c)^2]. This indicates, and a more detailed analysis confirms, that both the P–P cut and the secondary P' and ω trajectories are of importance in describing multiple scattering at present energies. This suggests that poles and cuts must be closely correlated in any dynamical scheme, and not quite different entities as imagined in all models so far used to fit data.

Chan and Morrison[4] pointed out that many processes (elastic and inelastic) exhibit structure in $d\sigma/dt$ for $-t \sim 0.5\ (\mathrm{GeV}/c)^2$. Thus our study of multiple scattering in pp elastic $d\sigma/dt$ may then be easily generalized and the conclusions shown to hold for a wide class of experimental data.

Finally we consider the current status of the Pomeron. The new Serpukhov data show that for small t $[|t| \lesssim 0.12\ (\mathrm{GeV}/c)^2]$ and energies up to 70 GeV, α_{eff} for pp scattering has a slope of 0.4. Any conclusion from this on the detailed structure of a short-range force like the Pomeron, requires a definite model for cuts. However, the absorption model generates corrections that make the output α_{eff} smaller than the input slope α'_P. Detailed calculations, within this model, indicate that the range $0.6 \lesssim \alpha'_P \lesssim 0.8$ will fit the present Russian data. Supporters of other slopes for the Pomeron will clearly have to supply a new model for cuts.

Conclusions

We remember that most recent theoretical effort in Regge theory has been on beautiful, but idealized, properties of Regge poles (e.g. resonance saturation, Veneziano model, multi-Regge model, and the generalized Veneziano model for production processes, etc.). Unfortunately it is often impossible to give meaningful tests of the characteristic predictions of these new schemes, simply because the basic Regge pole fits, so poorly, present experimental data. It is clear that a realistic model can only emerge from a dynamical study that includes all the relevant singularities—poles, cuts, and fixed poles—in the j-plane.

Experimentally there are many particular reactions for which new data would be very useful. For instance, it would be nice to find $\alpha_{\mathrm{eff}}(t)$ in the single-Regge-pole exchange processes, π–p backward scattering, and $\pi^- p \to (\pi\pi)_{S\text{-wave}} n$. More generally, the studies of data at high energies and "large" t $[\sim -1\ (\mathrm{GeV}/c)^2]$ should be extremely informative. This will be especially true above $p_{\mathrm{lab}} = 20$ GeV/c when the contribution of, say the P' and ω, trajectories will be quite small and one should really see the asymptotic structure of the cuts governing multiple scattering.

Geoffrey C. Fox
Cavendish Laboratory, Cambridge

References

1. L. van Hove, Comments Nuclear Particle Phys. **1**, 191 (1967).
2. L. van Hove, Comments Nuclear Particle Phys. **2**, 10 (1968).
3. S. D. Drell, Comments Nuclear Particle Phys. **1**, 196 (1967); *ibid.* **2** Suppl., *The Vienna Conference on High-Energy Physics* (Gordon and Breach, 1968), p. 1.
4. H. M. Chan and D. R. O. Morrison, Comments Nuclear Particle Phys. Suppl., *The Vienna Conference on High-Energy Physics* (Gordon and Breach, 1968), p. 14.