REGGE CUTS, POMERANCHUK THEOREM, AND THE SERPUKHOV TOTAL-CROSS-SECTION DATA

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A quantitative explanation is given, using Regge poles and cuts, for unexpected features of total cross sections in the newly accessible range 25-65 GeV/c. Negative contributions from the leading vacuum cuts explain the leveling out of $\sigma_T(K^-N)$ and $\sigma_T(\pi^-N)$ above 25 GeV/c; they also reconcile the apparently nonconverging $K^\pm N$ results with a common asymptotic limit, in accord with the Pomeranchuk theorem.

Total-cross-section data from the Serpukhov accelerator, at momenta above those previously studied, reveal unexpected features that may lead to revised ideas about asymptotic behavior.[1]

(i) The new meson-nucleon total cross sections ($\pi^-p, \pi^-n, K^-p, K^-n$) remain essentially constant from 25 to 65 GeV/c, in contrast to the decreasing trend at lower momenta. Power-law or Regge-pole fits[2,3] to the previous data extrapolate systematically below the new data at the higher momenta, establishing that a qualitative change in behavior occurs.

(ii) The results for $\sigma_T(\pi^-p)$ and $\sigma_T(\pi^-n)$—equal to $\sigma_T(\pi^+p)$ by charge symmetry—appear compatible with asymptotic equality, in accord with the Pomeranchuk theorem.

(iii) The constant plateau reached by $\sigma_T(K^-p)$ and $\sigma_T(K^-n)$ lies 3-4 mb above the constant values held, from 6 to 20 GeV/c, by $\sigma_T(K^+p)$ and $\sigma_T(K^+n)$. If all these constant values are the asymptotic limits, the Pomeranchuk theorem fails.

A failure of the Pomeranchuk theorem would be surprising, since many apparently successful calculations with dispersion relations depend upon it.[4] It is therefore important to find whether these new data can be accommodated in a more conventional framework, retaining the Pomeranchuk theorem.

A promising explanation for the observed leveling out of π^-N and K^-N total cross sections is provided by Regge cuts. The leading vacuum Regge cuts will dominate over secondary Regge poles at high energy. Thus if the poles contribute positively and the cuts contribute negatively, we may expect $\sigma_T(\pi^-N)$ and $\sigma_T(K^-N)$ to fall initially, then to level out, and finally to rise toward their infinite-energy limits.[5]

If a similar explanation is applied to $\sigma_T(K^+N)$, with secondary poles that approximately cancel through exchange degeneracy, the level region will occur at lower energies, followed again by a rise toward the asymptotic limit. This picture reconciles the $\sigma_T(K^\pm N)$ data with the Pomeranchuk theorem, essentially by displacing asymptopia to higher energies.

There are also new $\sigma_T(\bar{p}p)$ and $\sigma_T(\bar{p}n)$ results from Serpukhov, up to 50 GeV/c.[1] However, since these data show a continued falling trend and are consistent with Regge-pole-model extrapolations,[3] it is hard to assess the quantitative role of Regge cuts in these processes at present.

In this Letter we show that the above description, using Regge poles and the leading vacuum cuts, can be quantitatively applied to the σ_T data,[1,2,6] together with previous measurements of real parts[2,7] and finite-energy sum rules[8] in the πN case. Predictions of total cross sections and real parts above 30 GeV/c are presented, and the theoretical implications of the model are discussed.

We parametrize the vacuum Regge cuts at $t=0$ by a fairly general form, rather than relying on any specific prescription. We take

$$A' = -\gamma_c \int_{-\infty}^{\alpha_c} d\alpha\, \rho(\alpha) \exp(-\tfrac{1}{2} i\pi\alpha)\nu^{\alpha}, \qquad (1)$$

where A' is the usual forward amplitude in terms of which $\sigma_T = \mathrm{Im}A'(t=0)/P_{1\mathrm{ab}}$. ν is the meson lab energy in GeV. We choose the spectral function to be

$$\rho(\alpha) = (\alpha_c - \alpha)^{\lambda} \exp[b(\alpha_c - \alpha)], \qquad (2)$$

where λ and b are continuous parameters and $\alpha_c = 1$ for the leading cuts. This has the advantage of a simple integrated form and gives

$$A' = -\gamma_c \Gamma(\lambda+1) \exp(-\tfrac{1}{2} i\pi\alpha_c)\nu^{\alpha_c} \times [\ln\nu - b - \tfrac{1}{2} i\pi]^{-\lambda-1}. \qquad (3)$$

In addition to this vacuum cut we include only the leading Regge poles P, P', ω, ρ, and A_2, fixing the trajectory intercepts at $\alpha_P = 1$, $\alpha_i = 0.4$ for $i \neq P$. This is an oversimplification, but our purpose is to demonstrate this class of solutions to the cross-section puzzle, rather than to pursue finer details. The pole amplitudes are parametrized as

$$A' = -\gamma_i \exp(-\tfrac{1}{2} i\pi\alpha_i)\nu^{\alpha_i}, \quad i = P, P', A_2;$$
$$= i\gamma_i \exp(-\tfrac{1}{2} i\pi\alpha_i)\nu^{\alpha_i}, \quad i = \omega, \rho. \qquad (4)$$

The cut and pole parameters were found by a best fit to the scattering data, with continuous-moment sum rules evaluated at $\nu = 5$ serving as a guide.[8,9] The results were insensitive to λ in the vicinity of $\lambda = 0$; we fixed the value at $\lambda = 0.1$ to meet the theoretical requirement[10] $\rho(\alpha_c) = 0$. For πN the best-fit parameters are as follows, in units $\hbar = c = \text{GeV} = 1$, with the sign of γ_ρ appropriate to $\pi^- p$ scattering:

$$\gamma_P = 84.1, \quad \gamma_{P'} = 176, \quad \gamma_\rho = 12.7, \quad \gamma_c = -215,$$
$$b = -0.94. \qquad (5)$$

The corresponding KN parameters, with signs appropriate to $K^- p$, are

$$\gamma_P = 65.4, \quad \gamma_{P'} = 74.3, \quad \gamma_\omega = 26.8, \quad \gamma_\rho = 6.8$$
$$\gamma_{A_2} = 6.5, \quad \gamma_c = -110, \quad b = 0. \qquad (6)$$

The fits to the scattering data are shown in Fig. 1. Also shown is a somewhat more speculative parametrization of the NN and $\bar{N}N$ data,[1,2,6] with

$$\gamma_P = 119, \quad \gamma_{P'} = 228, \quad \gamma_\omega = 85.5, \quad \gamma_c = -138,$$
$$b = 0, \qquad (7)$$

and with $\gamma_\rho = \gamma_A = 0$, since these residues are not determined by present data.[3] Extrapolations of the models up to 10^4 GeV are given in Fig. 2.

We also investigated the effects of secondary Regge cuts and lower poles, ignored in the analysis above. The inclusion, for example, of small ρ-type cuts can improve the fit to the difference $\sigma_T(\pi^- p) - \sigma_T(\pi^- n)$ at the higher measured momenta, and also reconcile an intercept of $\alpha_\rho = 0.4$ with the energy dependence of the earlier data. We remark also that some of the omitted cuts, such as those from repeated $P' + \omega$ exchange, will break exchange degeneracy[11] and may account for some of the breaking parametrized by our poles.

Among our more interesting results and conclusions are the following:

(a) The extrapolated asymptotic limits in our illustrative fits,

$$\sigma_T^\infty(\pi N) = 33 \text{ mb}, \quad \sigma_T^\infty(KN) = 25 \text{ mb},$$
$$\sigma_T^\infty(NN) = 46 \text{ mb}. \qquad (8)$$

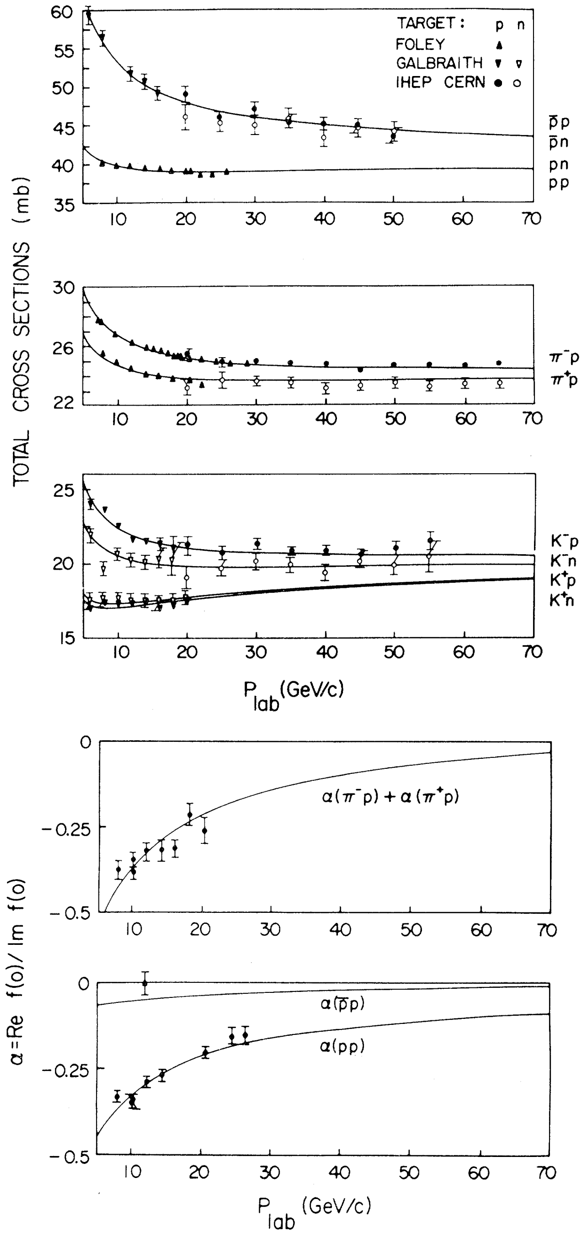

FIG. 1. (a) Fits to total-cross-section data with the pole-plus-vacuum-cuts model described in text. Data from Refs. 1, 2, and 5. The $\sigma_t(pn)$ and $\sigma_t(\bar{p}n)$ data of Ref. 5 have not been plotted since they have relatively large errors. (b) Fits to experimental data of Refs. 2 and 6 for the ratio of real to imaginary parts at $t = 0$. The theoretical model incorporates (P, P', A, ρ, ω) Regge poles and vacuum Regge cuts. The combination $\alpha(\pi^- p) + \alpha(\pi^+ p)$ is nearly free of experimental systematic error (cf. Ref. 6) and depends mainly on the vacuum poles and cuts.

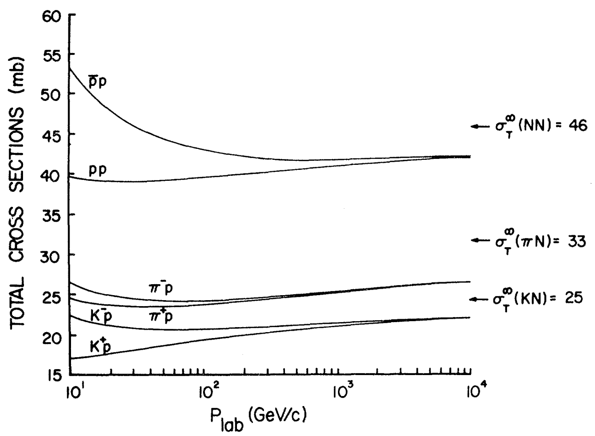

FIG. 2. Projections of total cross sections from pole-cut model to energies of Batavia accelerator (200 GeV) and CERN pp intersecting storage rings (1500 GeV). Infinite energy limits of the σ_T are noted.

are considerably above the plateaus reached by the corresponding data at present energies. The exact numerical values of σ_T^∞ found from the fits are dependent on the trajectory intercepts of the secondary poles (and attendant cuts) and are not intended as firm predictions.

(b) $\sigma_T(K^+N)$ is predicted to rise by ~1 mb through the range 20-60 GeV/c.

(c) If asymptopia is defined as the region where σ_T differs from σ_T^∞ by less than experimental error (say ±0.2 mb), it will not be reached until 10^{98} GeV/c for πN and 10^{53} GeV/c for KN scattering, at least in the fit to data given here.

(d) The presence of substantial Regge cuts in the total cross sections weakens the experimental basis of the Freund-Harari conjecture,[12] that Regge poles are built from resonances and are exchange degenerate, while the Pomeranchuk pole is built from background. In our fit, the constancy of $\sigma_T(K^+N)$ at present energies is an "accident," achieved by a balance between pole and cut terms of opposite signs, not simply by a cancellation among poles alone.

(e) Although the pp and $\bar{p}p$ situation is less well defined, our results suggest that $\sigma_T(pp)$ may rise asymptotically, possibly to 9 mb above its present value.

(f) The negative sign for the cut contribution, required by our fit, agrees with theoretical expectations.[13]

(g) Since our cuts are destructive in sign, the real parts from our extrapolations are predicted to change from negative to positive at ~10^3 GeV for $\alpha(pp)$ and at ~104 GeV for $\alpha(\pi^-p)+\alpha(\pi^+p)$.

(h) A ν^{-1} decrease with energy is predicted for $d\sigma(K_2p\rightarrow K_1p)/dt$ at $t=0$ from our pole-plus-cuts interpretation of the total cross sections in contrast to a $(\ln\nu)^2$ increase with energy that would be expected for this reaction if the Pomeranchuk theorem is violated and KN asymptopia has been reached at Serphukov energies.[14]

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[1] J. V. Allaby, Yu. B. Bushnin, S. P. Denisov, A. N. Diddens, R. W. Dobinson, S. V. Donskov, G. Giacomelli, Yu. P. Grorin, A. Klovning, A. I. Petrukhin, R. S. Shivolov, G. A. Stahlbrandt, and D. A. Stovanova, Institute for High Energy Physics-CERN Collaboration, to be published; in Proceedings of the Lund International Conference on Elementary Particles, Lund, Sweden, 25 June-1 July 1969 (to be published).

[2] K. J. Foley et al., Phys. Rev. Letters 19, 330, 857 (1967).

[3] V. Barger, M. Olsson, and D. Reeder, Nucl. Phys. B5, 411 (1968).

[4] Actually critical experimental tests now exist only for πN dispersion relations [W. Galbraith et al., Phys. Rev. 138, B913 (1965)]. However, a violation of the Pomeranchuk theorem for KN, but not for πN, is an equally unsatisfying prospect.

[5] S. Frautschi and B. Margolis, Nuovo Cimento 56A, 1155 (1968).

[6] Galbraith et al., Ref. 4.

[7] K. J. Foley et al., Phys. Rev. Letters 19, 193 (1967).

[8] M. Olsson, Nuovo Cimento 57A, 420 (1968), and Phys. Rev. 171, 1681 (1968).

[9] Since the continuous-moment sum rules are sensitive to the presence of lower lying singularities (cf. Ref. 7), the sum rules were used as a qualitative guide, rather than as a χ^2 constraint, in the fits presented here. We also have constructed more detailed models with secondary cuts or poles that quantitatively reproduce the πN sum rules, but give essentially the same σ_T at high energies.

[10] J. B. Bronzan and C. E. Jones, Phys. Rev. 160, 1494 (1967).

[11] V. Barger and R. J. N. Phillips, Phys. Letters 29B, 676 (1969).

[12] P. G. O. Freund, Phys. Rev. Letters 20, 235 (1968); H. Harari, ibid. 20, 1395 (1968).

[13] V. N. Gribov, Zh. Eksperim. i Teor. Fiz. 53, 654 (1967) [Soviet Phys. JETP 26, 414 (1968)]; V. N. Gribov et al. Physica 2, 361 (1965).

[14] Since positive beams are not to be extracted at Serpukhov for some time, a $K_2p\rightarrow K_1p$ measurement may allow a more immediate test of the Pomeranchuk theorem. We thank Professor D. D. Reeder for calling our attention to the feasibility of such an experiment at Serpukhov.