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DEVELOPMENTS IN STRONG INTERACTION PHYSICS*

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ABSTRACT

Some recent results on high-energy collisions are reviewed. Regularities of total and elastic cross sections are summarized in light of theoretical ideas. New indications of the structure of events with large transverse momentum particles receive brief attention. The general features of nondiffractive particle production are emphasized.

INTRODUCTION

In this year of new particles, the study of the old particles has flourished as well. Many beautiful experimental results have been presented for the first time at this meeting or at the recent Palermo meeting of the European Physical Society. These come, for the most part, from high-precision counter experiments or large statistics bubble chamber experiments at Fermilab and from second-generation ISR experiments. At both laboratories, experiments have come a long way from the pioneering exploratory studies of two or three years ago.

I shall speak first of the new results on forward scattering, i.e., of total and elastic cross sections and the real parts of forward amplitudes. An intermezzo on large transverse momentum phenomena will indicate the character of the investigations now underway. Finally, I shall summarize our knowledge of nondiffractive particle production. This selection of topics leaves a number of notable omissions: The theory of strong interactions has been the subject of a lively parallel session.[1,2] New studies of diffraction dissociation and nonforward elastic scattering are discussed in Derrick's report,[3] and my own thoughts on the study

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of diffractive final states have advanced little since Berkeley.[4] Two-body reaction mechanisms,[5] the blossoming subject of particle production in nuclei,[6] and sub-Fermilab energies have also been neglected.

FORWARD SCATTERING

Precise total cross section measurements have been carried out at Fermilab for $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ on protons and deuterons from 23 to 280 GeV/c,[7] for neutrons on protons, deuterons, and large nuclei from 80 to 280 GeV/c,[8] and for Λp interactions from 70 to 250 GeV/c.[9] A new measurement[10] of the pp total cross section at ISR energies is in agreement with the memorable results of the CERN-Rome and Pisa-Stony Brook experiments.[11]

The linear combinations of cross sections which isolate specific nonvacuum t-channel quantum numbers contain no surprises. All[12] are power-behaved and correspond to Reggeon intercepts which are in reasonable (but not perfect) agreement with inferences from the boson spectrum and from inelastic two-body reactions. [This is a very restrained assessment! In calmer times, the successful application of Regge pole ideas up to nearly 300 GeV/c would have been recognized as a major triumph.] For example, the ρ-intercept determined from the $\pi^{\pm}p$ total cross section difference between 6 and 280 GeV/c is $\alpha_{\rho}(0) \doteq 0.57 \pm 0.03$, whereas the value inferred[13] from forward $\pi^- p \rightarrow \pi^0 n$ is $\alpha_{\rho}(0) = 0.50 \pm 0.02$. The differences $\sigma_t(\bar{p}d) - \sigma_t(pd)$ and $\sigma_t(K^- d) - \sigma_t(K^+ d)$ isolate ω-exchange quantum numbers. Over the Fermilab energy regime, these yield $\alpha_{\omega}(0) = 0.43 \pm 0.02$ and $\alpha_{\omega}(0) = 0.43 \pm 0.04$, respectively. From measurements of the coherent regeneration reaction $K_L d \rightarrow K_S d$ between 12 and 50 GeV/c at Serpukhov,[14] the intercept is $\alpha_{\omega}(0) = 0.46 \pm 0.06$. Fermilab measurements[15] of $K_L C \rightarrow K_S C$ between 30 and 120 GeV/c give a value of $\alpha_{\omega}(0) = 0.41 \pm 0.03$.

To go with these intercepts, there is a new entry on the ρ-f-g trajectory, called h(2 GeV/c^2) and identified as an isoscalar, spin

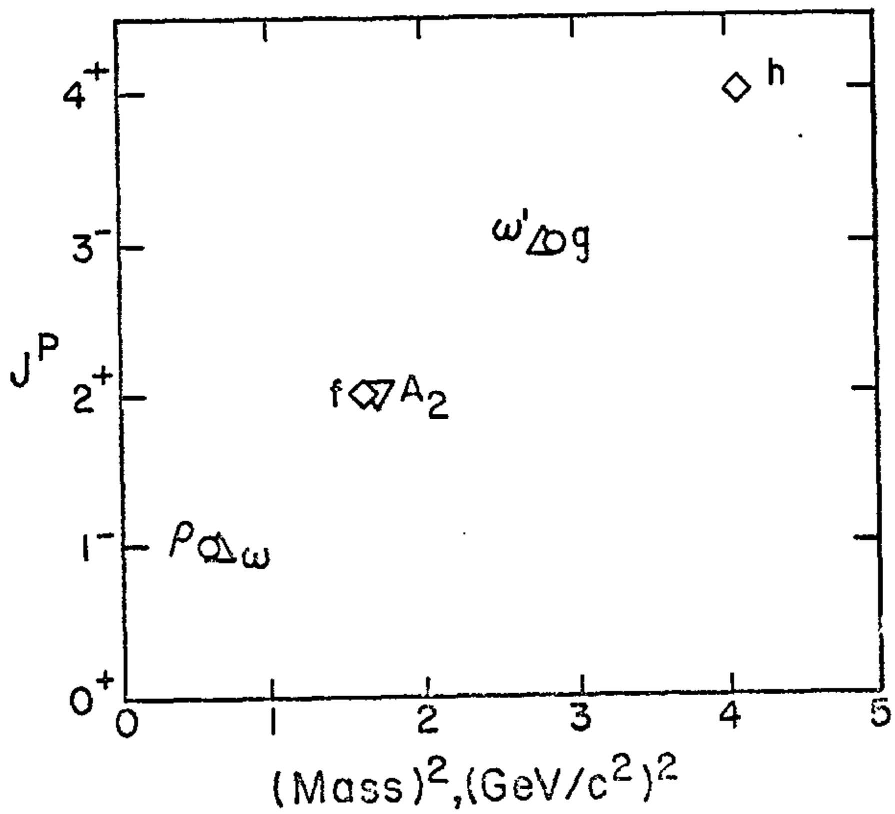


Fig. 1: Chew-Frautschi plot of mesons on the leading Regge trajectory.

4^+ object.[16] It has now been seen in 40 GeV/c $\pi^- p \to \pi^0 \pi^0 n$ [17] and in 18.4 GeV/c $\pi^- p \to K^+ K^- n$.[18] In the $\pi^0\pi^0$ final state the mass and width are reported as $M = 2020 \pm 30$ MeV/c^2, and $\Gamma = 180 \pm 60$ MeV. In the $K\overline{K}$ mode the parameters are given as $M = 2050 \pm 25$ MeV/c^2 and $\Gamma = 225^{+120}_{-70}$ MeV. The new resonance, which is tentatively identified as the recurrence of the f^0, is shown in the company of its well-established companions in Fig. 1. Explicit dual models[19] and finite energy sum rules for $\pi\pi$ scattering[20] suggest a partial width of $\Gamma(h \to \pi\pi) \simeq 50$ MeV. It will be interesting to learn whether this new resonance, which comes at the right place, will also have the right properties.

Many symmetry relations exist between total cross section differences.[21] This is not the place to discuss them all in detail, but I will comment that they are in good general agreement with the new data.[22] For example, the SU(3) relation for ρ-exchange, the ω-universality relation, and the $(\rho+\omega)$-universality relation are well satisfied. The Johnson-Treiman relation

$$\tfrac{1}{2}[\sigma_t(K^-p)-\sigma_t(K^+p)] = [\sigma_t(K^-n)-\sigma_t(K^+n)] = [\sigma_t(\pi^-p)-\sigma_t(\pi^+p)] \qquad (1)$$

is in satisfactory agreement with the data in this energy regime, although the energy dependence of the last term is more gentle than the common energy dependence of the first two.

The new high-energy measurement of the Λp total cross section provides a test of the additive quark model expectation[23]

$$\sigma_t(\Lambda p) = \sigma_t(pp) + \sigma_t(K^-n) - \sigma_t(\pi^+p) \;. \qquad (2)$$

Figure 2 shows that the quark model passes this test.

The vacuum exchange contributions to total cross sections, which are plotted in Fig. 3, raise questions of basic importance.[1,24] What is the asymptotic nature of the energy dependence? What is its origin? In the f-dominated Pomeron scheme,[25] the energy dependence of the vacuum exchange contribution should be the same in πN, KN, and NN scattering. That this is not exactly so can be seen in Fig. 4, in which I have plotted the ratios $\sigma_{VACUUM}(\pi N)/\sigma_{VACUUM}(KN)$ and $\sigma_{VACUUM}(NN)/\sigma_{VACUUM}(KN)$. These would

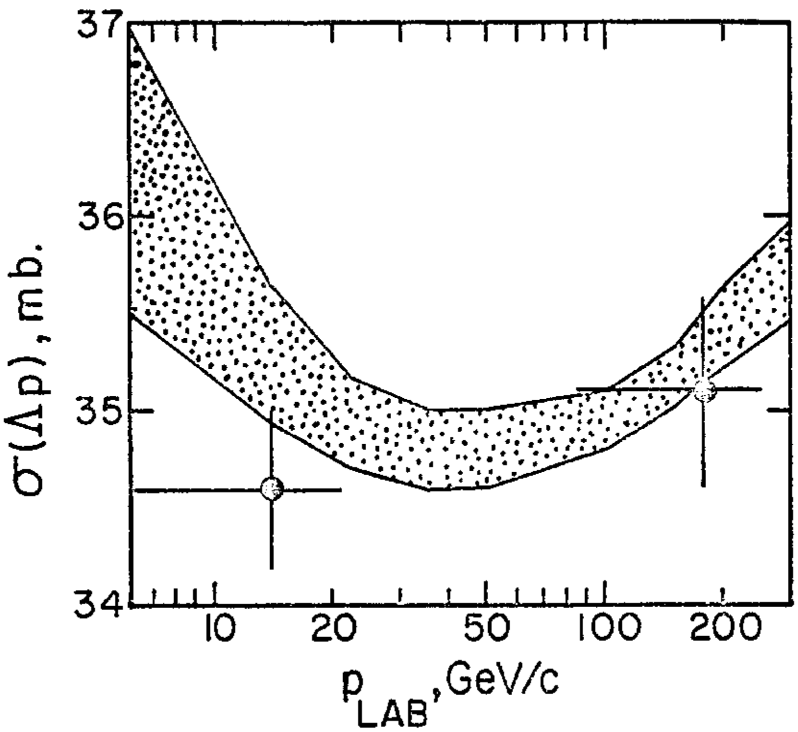


Fig. 2: Comparison of the quark-model prediction (2)[shaded band] with the data on the Λp total cross section. The low-energy point is from S. Gjesdal, et al., Phys. Lett. 40B, 152 (1972), and the high-energy point from Ref. 9.

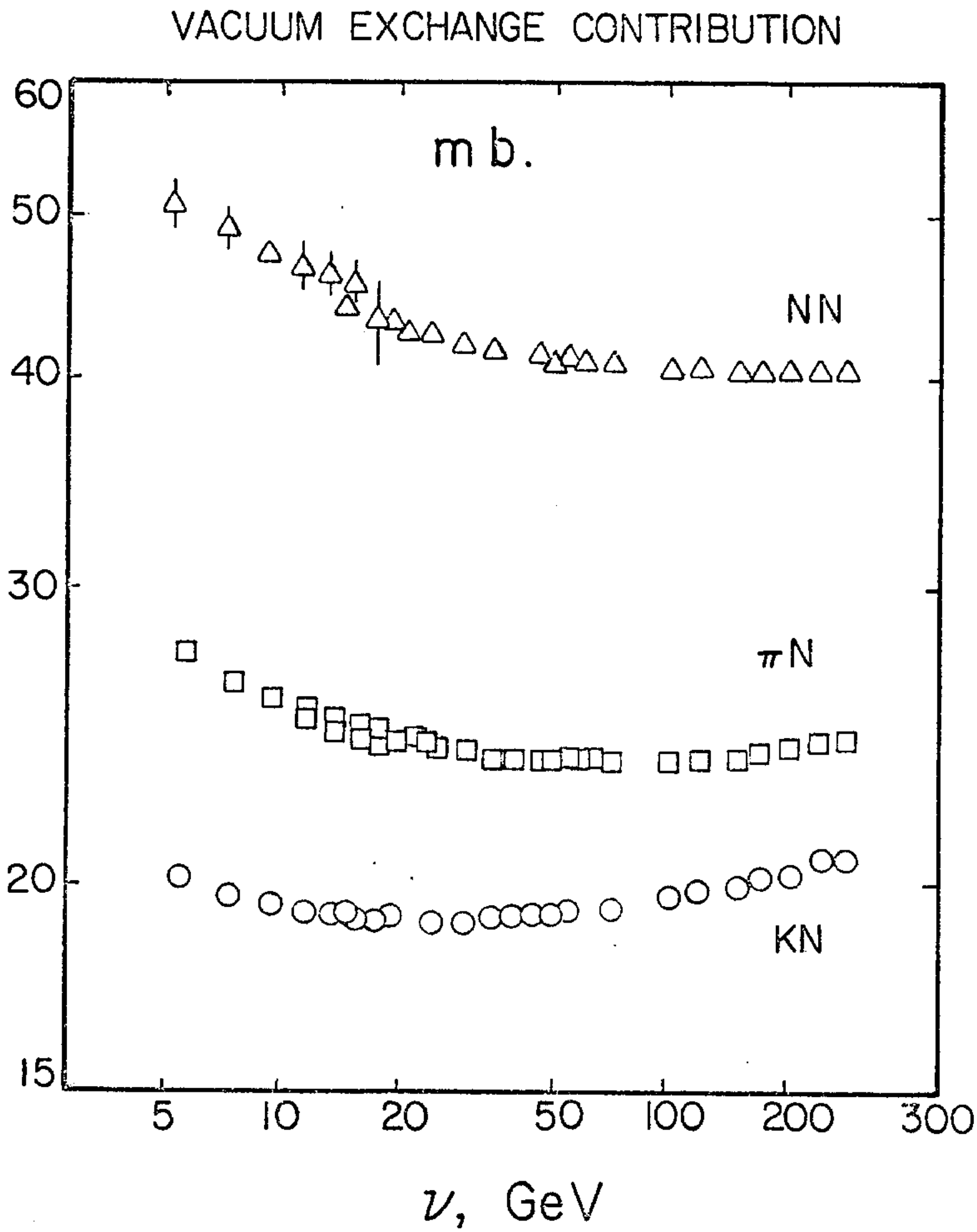


Fig. 3: Vacuum quantum number exchange contributions to πN, KN, and NN scattering. The data are from the classical BNL and Serpukhov experiments, and from Ref. 7. The abscissa is $\nu \equiv (s-u)/4M$.

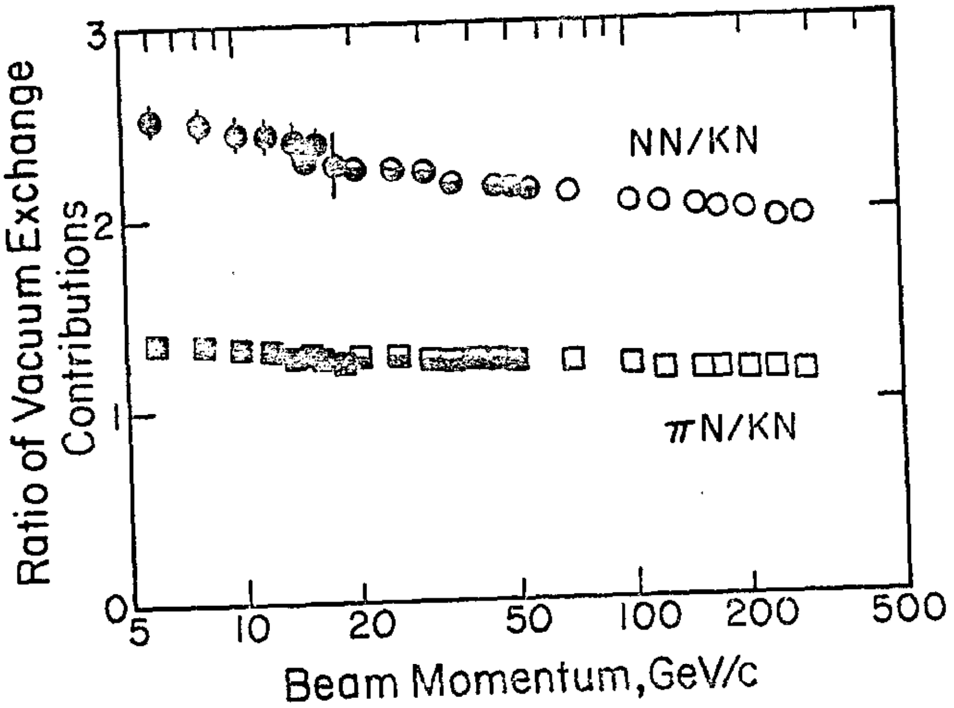


Fig. 4: Ratios of the vacuum exchange contributions plotted in Fig. 3.

be energy-independent if Pomeron and f couplings were identical, but both change by about 20% between 6 and 280 GeV/c. Although Chew and Rosenzweig[26] identify the Pomeron and f as a single vacuum trajectory, their "Pomeron" has an energy-dependent SU(3) content as well as an energy-dependent intercept. Thus the results of Fig. 4 can do them no harm. How (and perhaps whether) to separate the P- and f - exchange pieces remains a vexing problem.

Real parts of forward elastic scattering amplitudes have been measured in pp collisions from 50 to 400 GeV/c, [27] and at this conference very preliminary results on real parts in $\pi^{\pm}p$, $K^{\pm}p$, and $p^{\pm}p$ collisions from 70-150 GeV/c have been presented by a Fermilab-Yale Collaboration.[28] Together with the total cross section measurements, these allow a test of dispersion relations (for experimenters) or of data (for theorists). In anticipation of these measurements a number of new evaluations of forward dispersion relations have been made,[29] all of which are (to my eye) in close agreement. As examples, I show in Fig. 5 the measured real to imaginary ratio in pp scattering along with a computation based on the measured NN total cross sections from 6 to 2000 GeV/c. The agreement is excellent. In the case of π^-p scattering, shown in Fig. 6, there is some discrepancy between dispersion relations and the data around 30 GeV/c. Professional dispersers[31] blame the offending data points.

Elastic differential cross sections have been measured for $\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$ on protons at 50, 100, and 200 GeV/c by a Michigan-Fermilab-Argonne-Indiana group[32] and at 50, 70, 100, 140, and 170 GeV/c by the Fermilab Single Arm Spectrometer Consortium.[33] New results of the CERN-Hamburg-Orsay-Vienna Collaboration on large t elastic pp scattering at the ISR have also been presented by Winter.[34] Some details of the differential cross sections are discussed by Derrick.[3] Here let us merely remark on the near constancy of $\sigma_{elastic}/\sigma_t$ in the Fermilab-ISR energy regime, which is shown in Fig. 7 for all six reactions. [The small (~10%) difference between the values reported by the two Fermilab experiments appears to be an artifact of the different parametrizations used to evaluate $\sigma_{elastic}$.] The quantity $\sigma_t/16\pi b$, where $b \equiv d(\log d\sigma/dt)$ at $t = 0$, displays a similar energy independence. For both parameters,

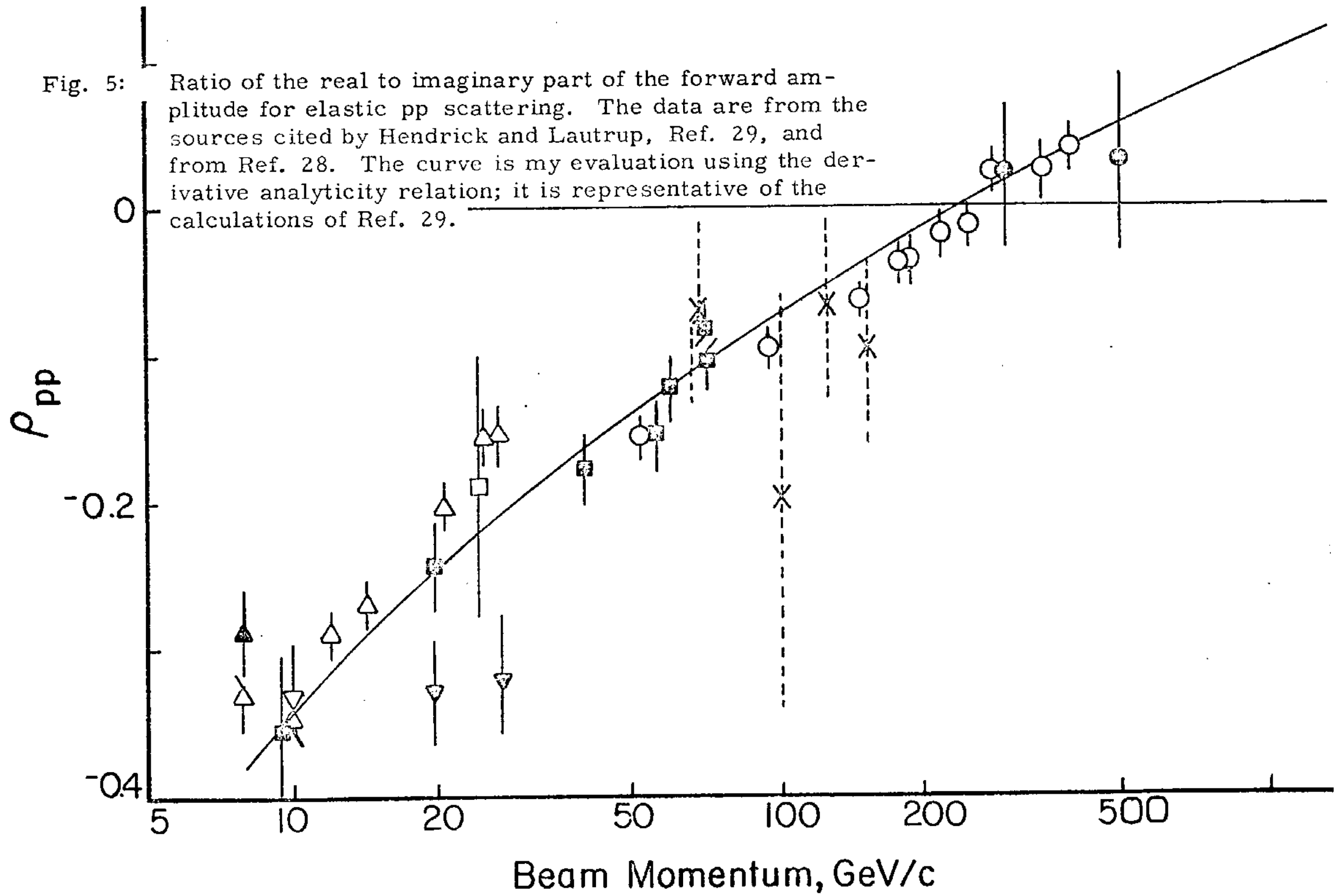


Fig. 5: Ratio of the real to imaginary part of the forward amplitude for elastic pp scattering. The data are from the sources cited by Hendrick and Lautrup, Ref. 29, and from Ref. 28. The curve is my evaluation using the derivative analyticity relation; it is representative of the calculations of Ref. 29.

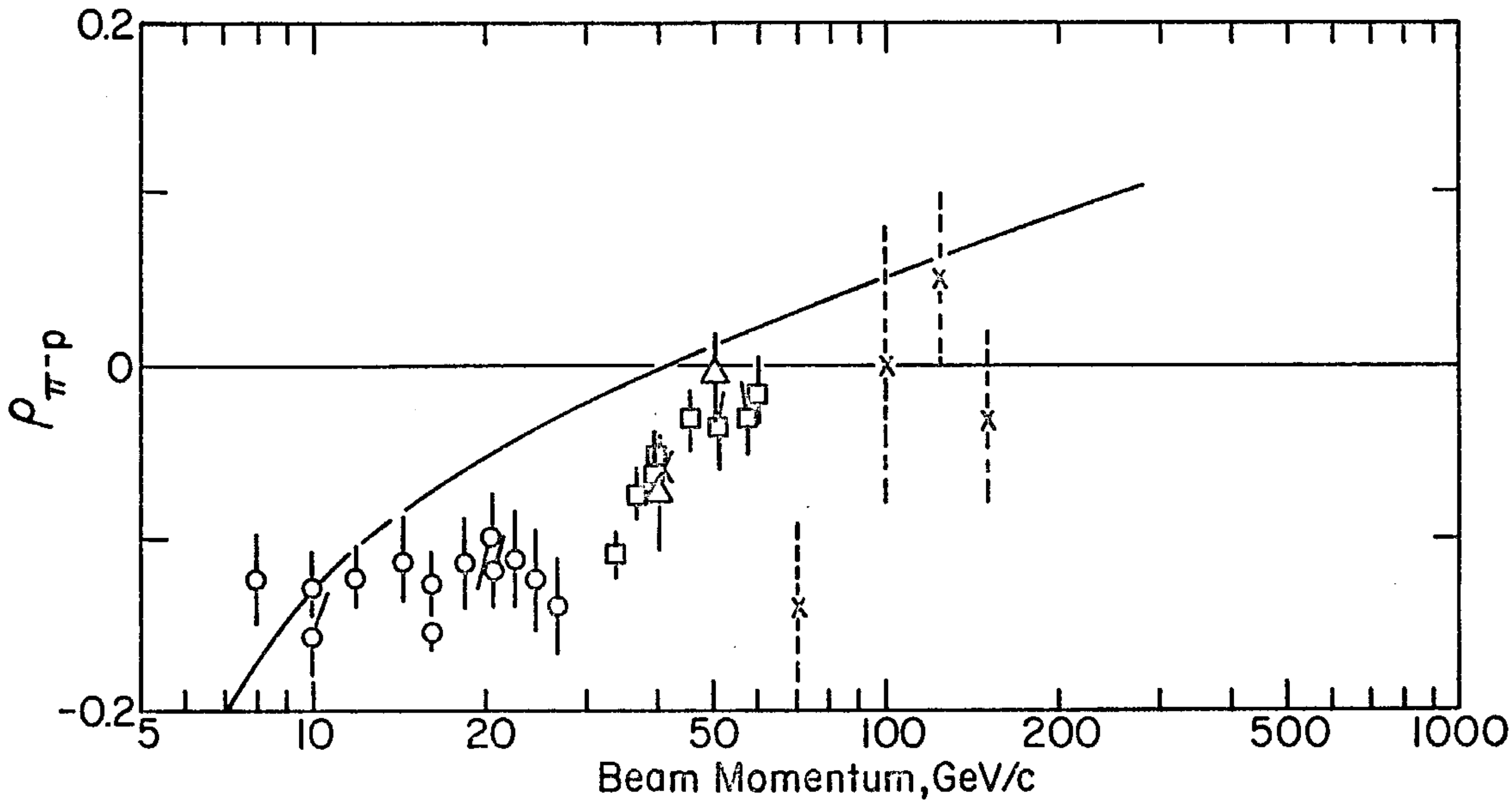


Fig. 6: Ratio of the real to imaginary part of the forward amplitude for elastic $\pi^- p$ scattering. The data are from the sources cited by Hendrick and Lautrup, Ref. 29, and from Ref. 28. The curve is my evaluation using the derivative analyticity relations; it is representative of the calculations of Ref. 29.

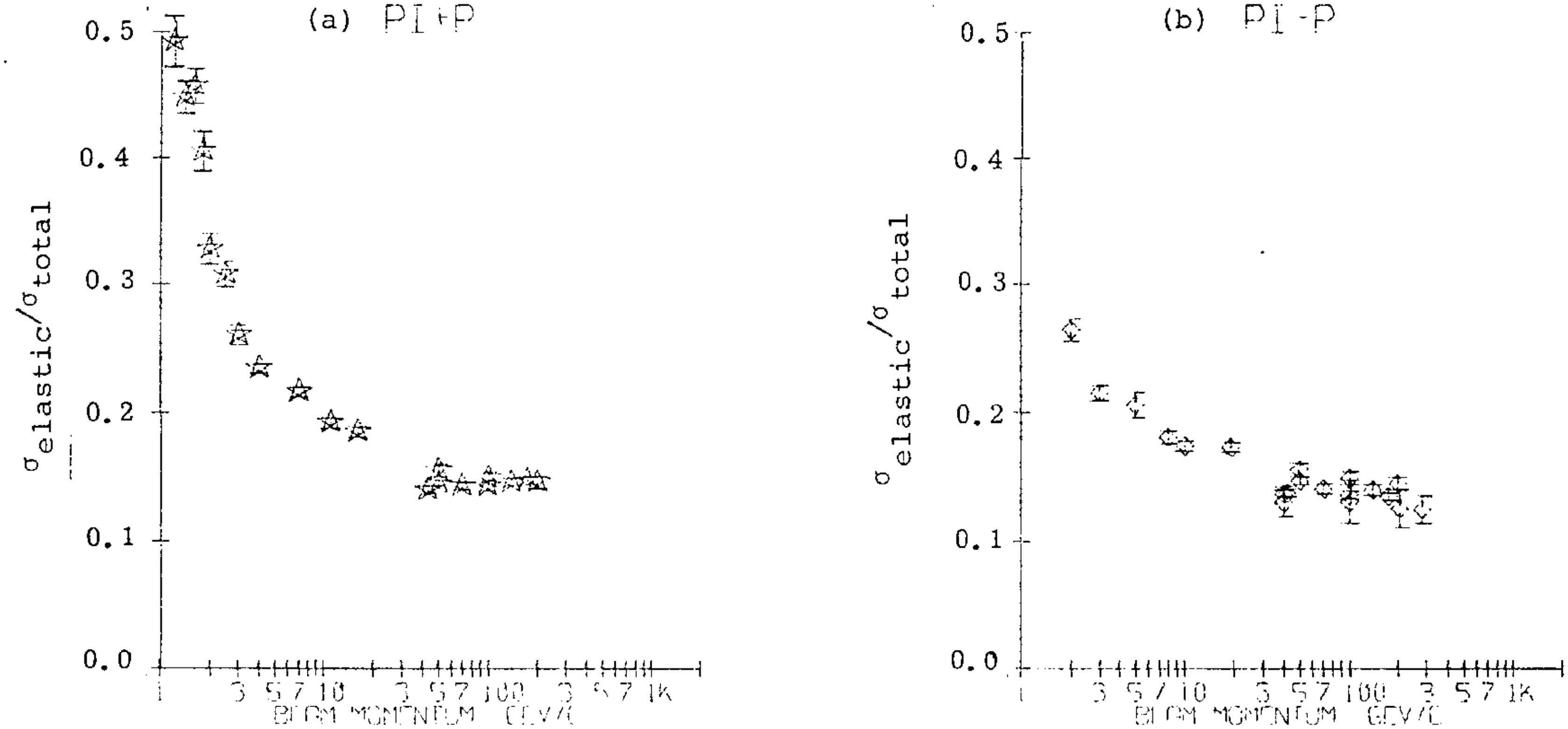
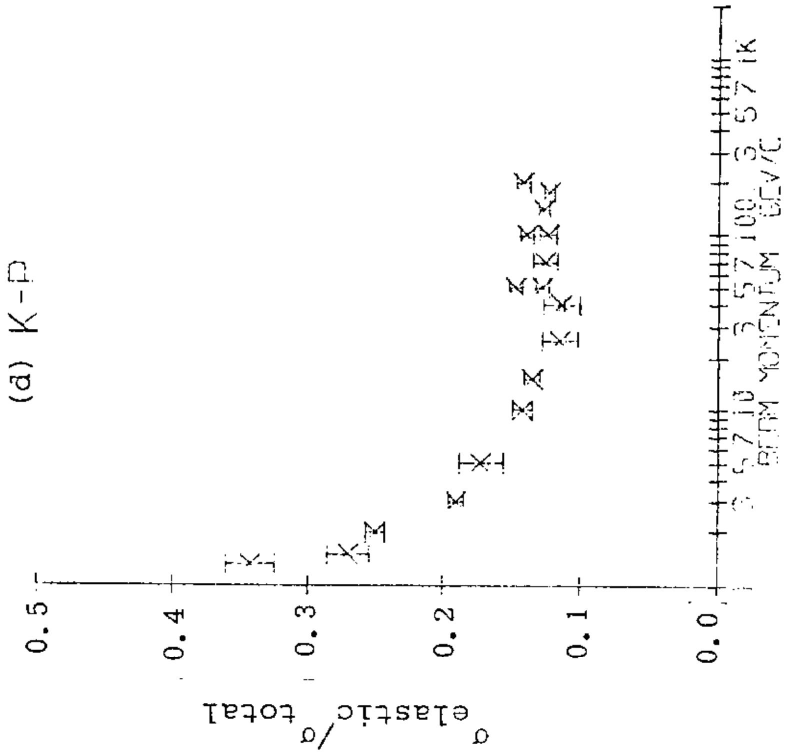
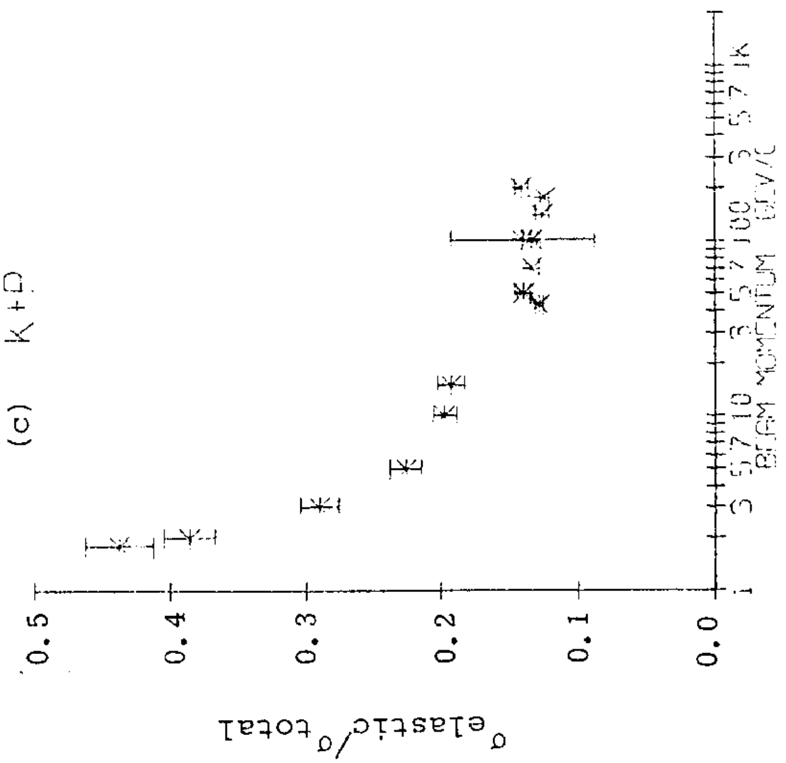
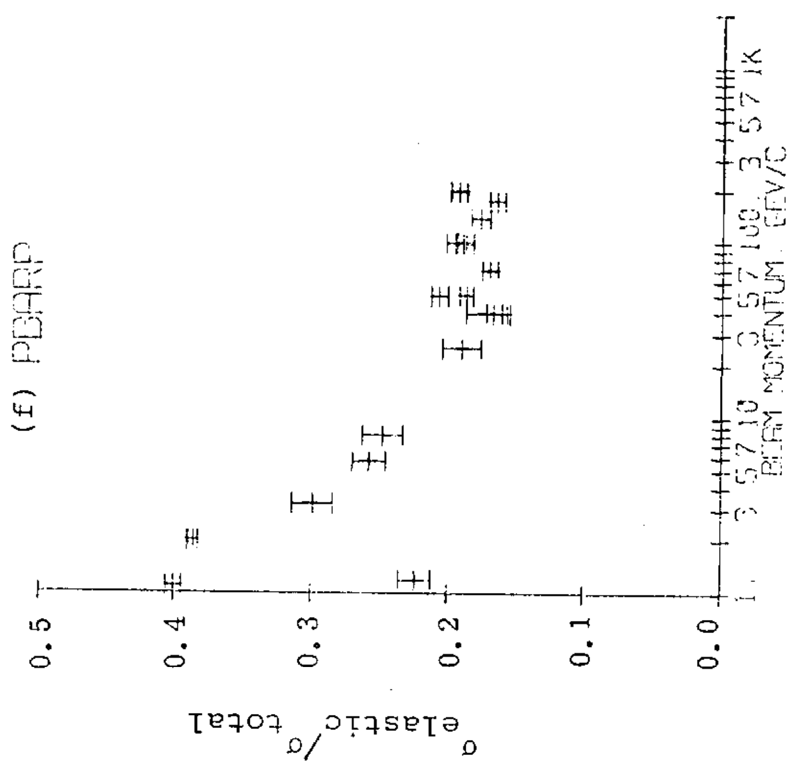


Fig. 7: Ratio of the elastic to total cross section for (a) π^+p, (b) π^-p, (c) K^+p, (d) K^-p, (e) pp, (f) $\bar{p}p$ collisions. The data include the new Fermilab measurements, Refs. 32 and 33.


(d) K-p
$\sigma_{elastic}/\sigma_{total}$
BEAM MOMENTUM GEV/C


(c) K+p
$\sigma_{elastic}/\sigma_{total}$
BEAM MOMENTUM GEV/C


(f) PBARP
σ elastic/σ total
0.0
0.1
0.2
0.3
0.4
0.5
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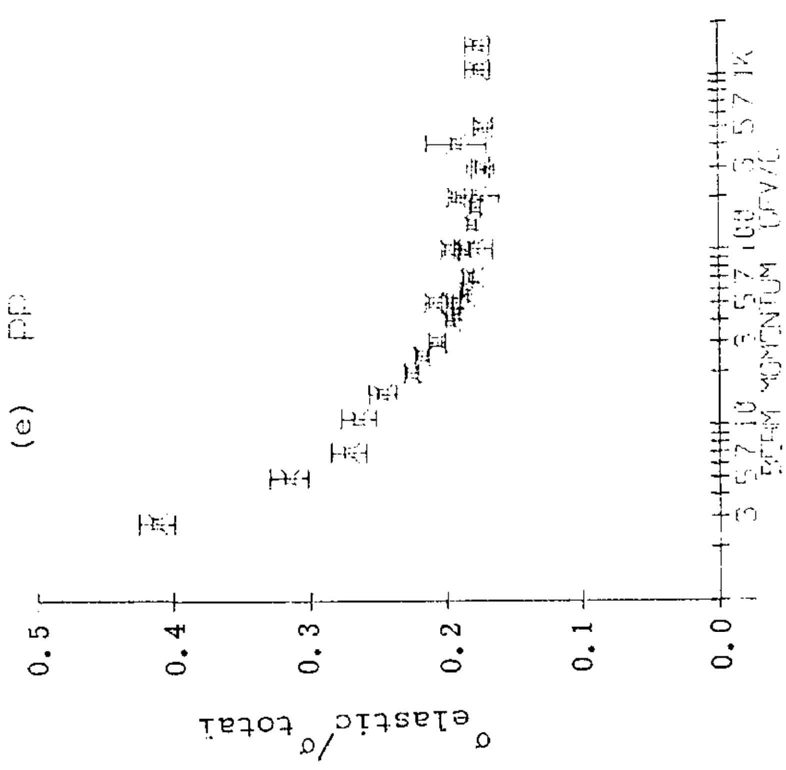

(e) PP
σ elastic/σ total
0.0
0.1
0.2
0.3
0.4
0.5
BEAM MOMENTUM GEV/C

all the meson-baryon reactions converge to common values, and the two nucleon-nucleon reactions attain common limits. These two results hint that in spite of the complications of increasing cross sections some simple pattern may be present. The geometrical scaling[35] interpretation was stressed by Barger in his parallel session report.[24]

Recent studies of multiple production in nuclei within short-range correlation theories[36] raise the question of how opaque nuclei appear to high-energy hadrons. A predicted correlation between the rate of particle production in nuclei and the opacity allows (in principle, at least) a test of the basic theoretical picture. Additional data on elastic and total hadron-nucleus cross sections are needed to complement the ongoing experiments[37] on nuclear multiple production.

A HIGH-$p_\perp$ SAMPLER

Collisions which result in high transverse momentum secondaries have received little attention at this meeting. Nevertheless, a number of very revealing experimental results are beginning to emerge which are worthy of our attention. Very incisive reviews of the new data have been given by Darriulat[38] at Palermo and by DiLella[39] at SLAC. In contrast, my remarks will be extremely superficial, but I cannot let the subject go unmentioned.

In the most practical terms, the old (1972-3) discovery which drew attention to large-$p_\perp$ physics was that the cross sections are large enough to study. The new emphasis in experimentation is on learning what is the structure of high-$p_\perp$ events. This has been pursued in a number of ISR experiments and will also be the goal of new experiments at Fermilab. For example, are high-$p_\perp$ secondaries the products of three dimensional explosions in momentum space, or do they emergy from coplanar jets? Are they accompanied by leading particles?

The new data suggest two very tentative new conclusions: (1) Correlations among the soft particles in the wake of a high-$p_\perp$ particle seem normal; (2) Secondaries accompanying a large-$p_\perp$ particle exhibit a high degree of coplanarity. Let us examine one piece of evidence for each of these interpretations.

The Aachen-CERN-Heidelberg-Munich Collaboration,[40] among

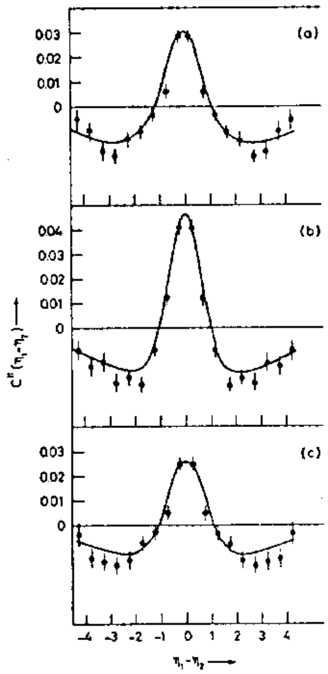


Fig. 8: Two particle correlation function for (a) minimum bias triggers, $|\phi| < 90°$; (b) high $p_\perp$ triggers with $p_\perp >$ 2 GeV/c in the trigger, $|\phi| > 90°$; (c) high $p_\perp$ triggers, $|\phi| < 90°$. The data are from Ref. 40, in which $C^{II}(\Delta\eta)$ is defined. Here $\phi = 0°$ is along the trigger direction.

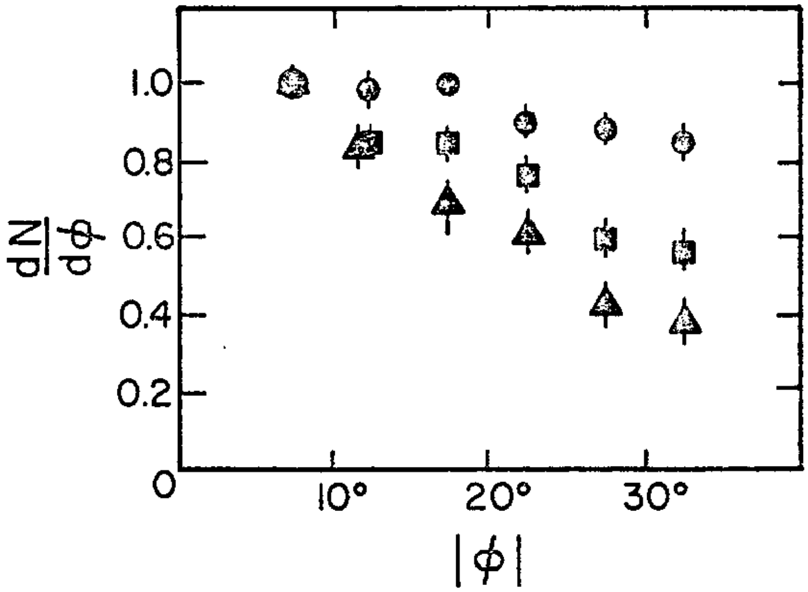


Fig. 9: Distribution in $|\phi|$ for all particles with $0.2 \le p_\perp \le 0.5$ GeV/c (●); with $p_\perp > 0.8$ GeV/c (□); with $p_\perp \ge 1.4$ GeV/c (▲). $\phi = 0°$ is defined opposite to the trigger π°. [From Ref. 41.]

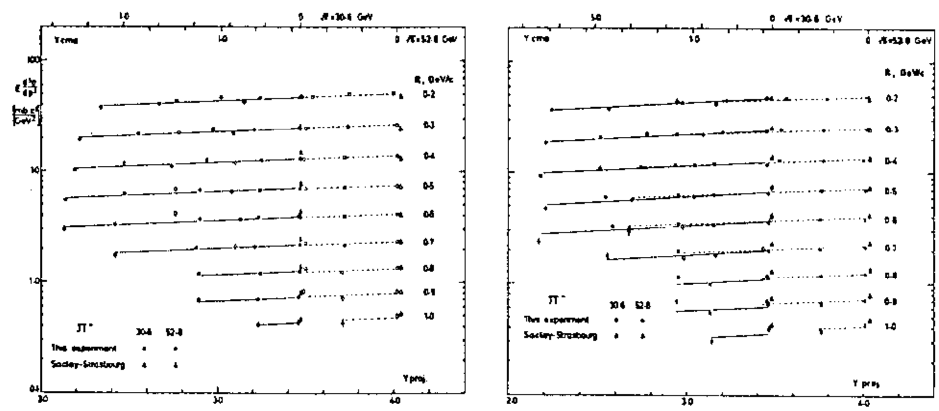


Fig. 10: Rapidity distribution of (a) $pp \to \pi^+$ + anything and (b) $pp \to \pi^-$ + anything in the projectile rest frame at two ISR energies. The data are from the British-Scandinavian Collaboration, Ref. 44, and from the Saclay-Strasbourg Collaboration, M. Banner, et al., Phys. Lett. 41B, 547 (1972).

others, has studied two-particle correlations among the debris accompanying a high-$p_\perp$ secondary in a streamer chamber experiment at the ISR. The two-particle rapidity correlation function is shown in Fig. 8 for three trigger conditions.

Except for the increased multiplicity of particles accompanying a π^0 with $p_\perp > 2$ GeV/c , there is little to distinguish the cases. This suggests that the additional soft particles are correlated in much the same way as those detected with a minimum bias trigger.

One may also study the azimuthal dependence of secondaries accompanying the large-$p_\perp$ trigger particle. The data[41] in Fig. 9 show that, whereas low-$p_\perp$ associates are roughly isotropically distributed, recoiling particles with large $p_\perp$ are confined within a wedge around the trigger azimuth. This is typical of the evidence that (in an average high-$p_\perp$ event) all the large-$p_\perp$ particles lie approximately in a plane although they may range over several units of rapidity.

We may expect in the near future to see even more detailed information on the structure of large transverse momentum events, and to learn better how to isolate the new dynamics which seems to be evident in them.

CHARACTERISTICS OF MULTIPLE PRODUCTION

I do not wish to write history before the event is over, but the temptation to assess where we are in our endeavor to understand production processes is irresistible. In the evolution of our conception of two-body scattering, the great qualitative discovery was the experimental verification of the peripheral exchange picture. This formed the underpinning for subsequent developments which include many quantitative successes — and more than a few failures — of specific dynamical schemes. We seem near a similar watershed in the study of multiple production, one which divides the groping for general features from the investigation of quantitative properties. It is now possible to codify the characteristics of multiple production in terms of traits which two years ago could be identified only tentatively.[4] The step required to complete the historical parallel is the verification that a t-channel exchange picture (or alternatively, some other candidate theory[42]) does underlie these properties. My view today is that the exchange picture will emerge as the correct basis for understanding multiple production, but that a description in detail will not be less complicated than in the case of two-body scattering.[43]

Seven important general features of nondiffractive multiple production may be identified:

(i) Limited transverse momentum of secondaries;
(ii) Leading particle effect (small inelasticity);
(iii) Slowly increasing multiplicity of secondaries (mostly pions);
(iv) Scaling of inclusive cross sections;
(v) Independence of the incident particle ("factorization");
(vi) Short-range order or clustering;
(vii) A stable structure of events for primary energies from 100 to 2000 GeV/c.

The first three were established before the construction of the ISR and Fermilab. The rest represent the distilled essence of experimentation at the new laboratories. I shall mention an example of the evidence for each of them in turn.

Scaling: The density in rapidity of produced pions,

$$\frac{1}{\sigma}\frac{d\sigma}{dy}(y_{LAB}, s) \quad ,$$

is independent of energy s, as indicated by the data[44] in Fig. 10. However, we should not be blind to the fact, recently emphasized by the British-Scandinavian-MIT Collaboration,[45] that the cross section at $y_{CM} = 0$ shows an important rise through the ISR energy range. These new data are summarized in Fig. 11. Whether the rise is a mere detail or an important new clue into the nature of the production process, perhaps signalling the developing importance of long-range correlations, cannot be stated with certainty. It is obvious that the high-precision cross section measurements soon to be carried out at Fermilab are of great interest.

Factorization: Several experimental facts imply that the production of particles is characteristic of the interaction and not of the detailed properties of the incident particles. As Whitmore[46] remarked, we have the suggestion from bubble chamber experiments that the inclusive density for $a + b \rightarrow \pi +$ anything,

$$\frac{1}{\sigma}\frac{d\sigma}{dy}(y_{CM} = 0, \ s)$$

is becoming independent of the incident particles a and b as $s \rightarrow \infty$. A related statement is that the rate of growth of mean multiplicity with energy is the same for all studied sets of incident particles. Indeed, if $\langle n \rangle$ is regarded as a function of the "available energy" Q(defined as $Q = \sqrt{s}$ for $\bar{p}p$ collisions, $Q = \sqrt{s} - M_a - M_b$ for other incident channels), it is to good approximation a universal function (see Fig. 12). The similarity among the final

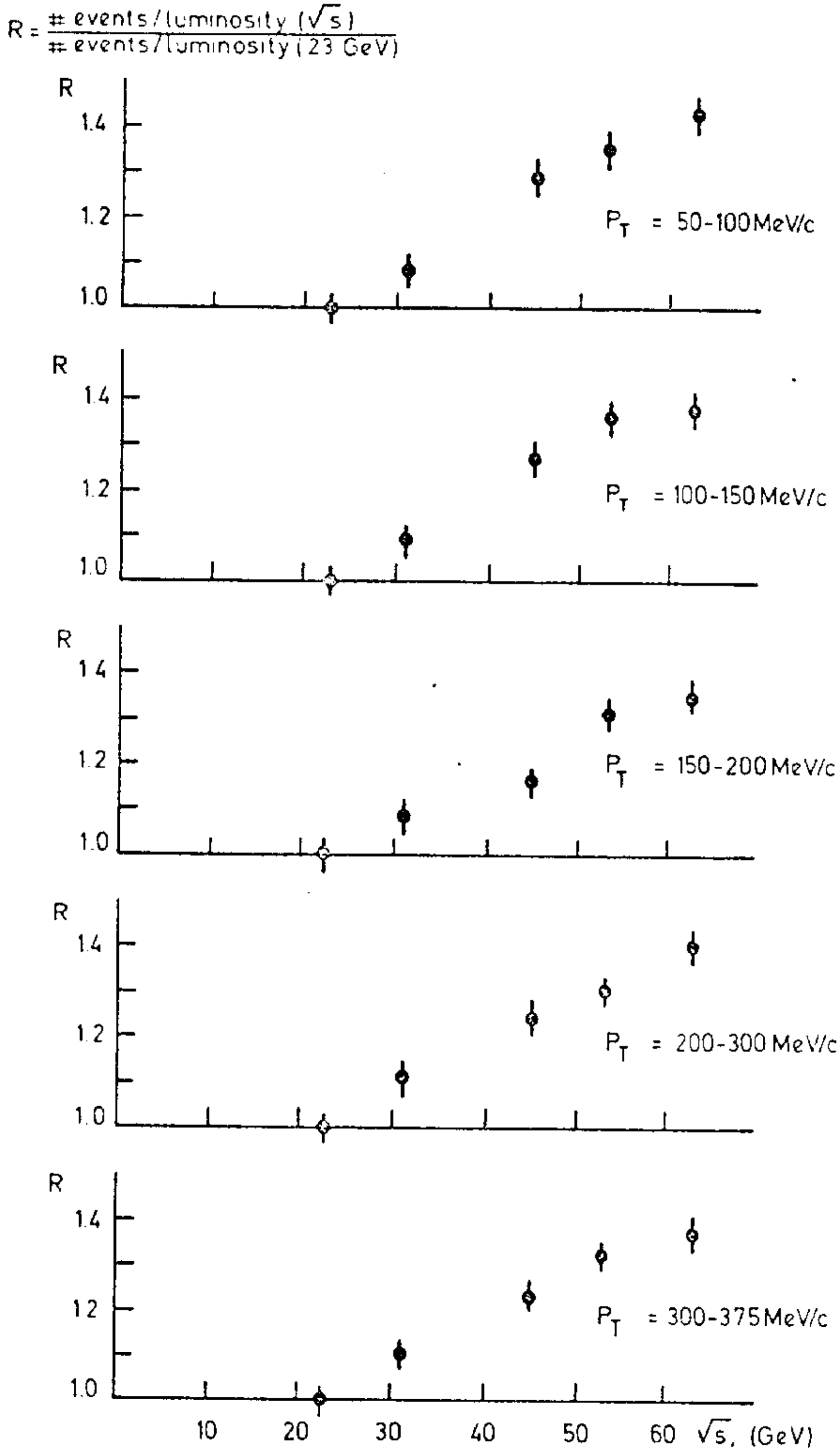


Fig. 11: Energy dependence of inclusive charge-averaged cross sections for pp → π + anything at θ_{CM} = 90°. The data are preliminary results of the British-Scandinavian-MIT Group, Ref. 45.

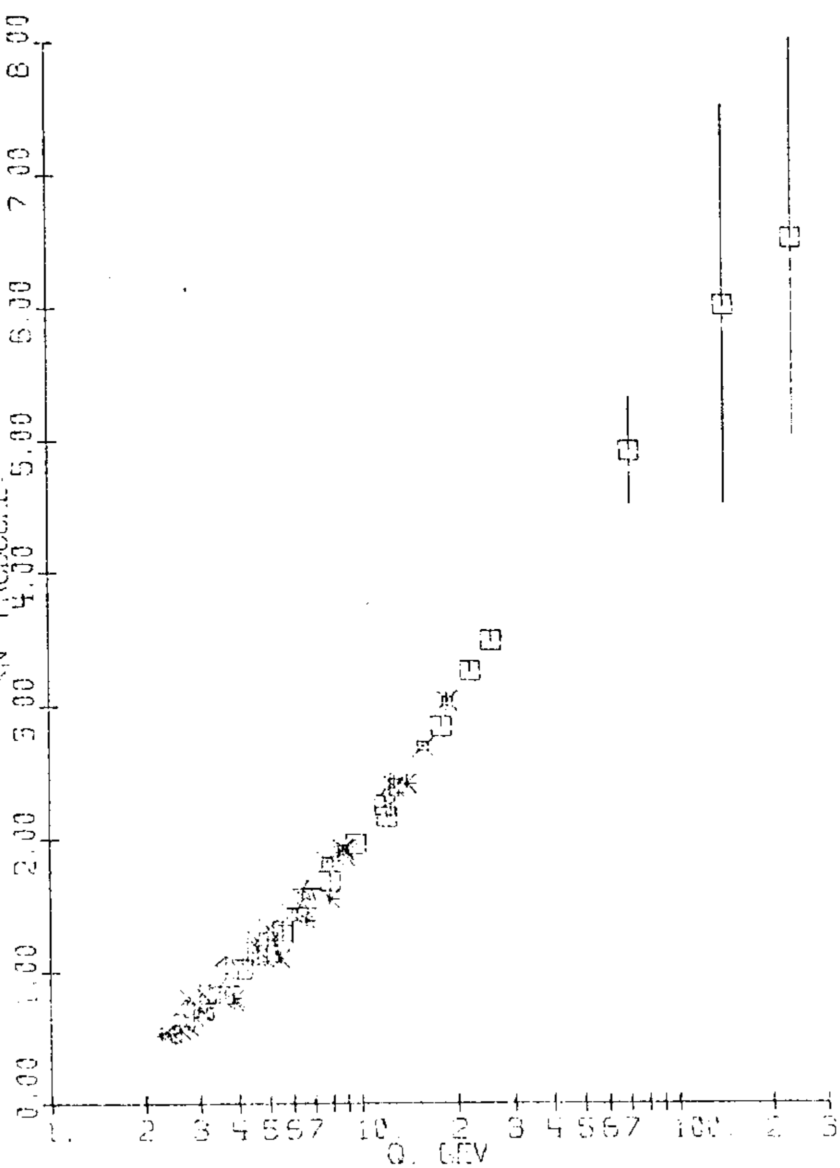


Fig. 12: Mean multiplicity of produced negative particles versus the available energy Q, for π^+p (×), π^-p (⌘), K^+p (◇), K^-p (☆), pp (□), and $\bar{p}p$ (✳) . The data are from the standard set of bubble chamber experiments, except for three cosmic ray measurements at extremely high energies. The latter are from C. B. A. McCusker and L. S. Peak, Nuovo Cimento 31, 524 (1965), at 2800 GeV and from L. S. Peak and R. L. S. Woolcott, Nuovo Cimento 42, 856 (1966), at 11000 and 30000 GeV.

states in various collisions extends further. I show in Fig. 13 the topological distributions observed in 100 GeV/c $\pi^{\pm}p$, $K^{+}p$, and $p^{\pm}p$ bubble chamber exposures[47] at Fermilab. Except for the very lowest multiplicities, the agreement between the five distributions is striking.

Although this resemblance teaches us a very important fact, we know that it cannot be exact, because different incident particles communicate with different sets of outgoing channels. To cite one specific example, the $\bar{p}p$ annihilation channel is unavailable to pp collisions. Data on the $p^{\pm}p$ topological cross sections are becoming good enough to permit a systematic study of these differences to be initiated.[48] A very crude exchange picture[49] will indicate some interesting questions. Suppose that the cross section to produce n particles in pp collisions is represented by a multiperipheral meson exchange graph as shown in Fig. 14(a), and that the difference between $\bar{p}p$ and pp prong cross sections is given by the annihilation, or baryon exchange, graph of Fig. 14(b). [It is important to remark that the identification of the cross section difference with annihilations is an assumption not justified by experiment. There may well be other channels making up the difference.] In this simple scheme, we have

$$\mathscr{D}_n(s) \equiv \frac{\sigma_n(\bar{p}p) - \sigma_n(pp)}{\sigma_n(pp)} = \frac{K_2}{K_1}\left(\frac{g_B}{g_M}\right)^n s^{2(\alpha_B - \alpha_M)} , \qquad (3)$$

a form which leads to a pair of easily tested predictions. First, using a typical meson intercept of $\frac{1}{2}$ and a typical baryon intercept of $-(\frac{1}{4}$ to $\frac{1}{2})$, we predict that for fixed multiplicity,

$$\mathscr{D}_n(s) \propto s^{-(1.5 \text{ to } 2)} .$$

The available data[50] shown in Fig. 15 are compatible with, but by no means select, such a behavior. Second, at fixed energy, the quantity $\mathscr{D}_n(s)$ should be an exponential function of n. I show in Fig. 16 that the trend of the data at 22.4 and 32 GeV/c is in accord with this expectation and for the higher multiplicities at 100 GeV/c one may easily imagine the same trend. While these recent data do not settle anything, they again evoke interest in studying the roles of baryon number, hypercharge, and charge annihilation in multiple production.

As a final piece of evidence for the unimportance of the initial particles, we may examine the kinematic structure of events

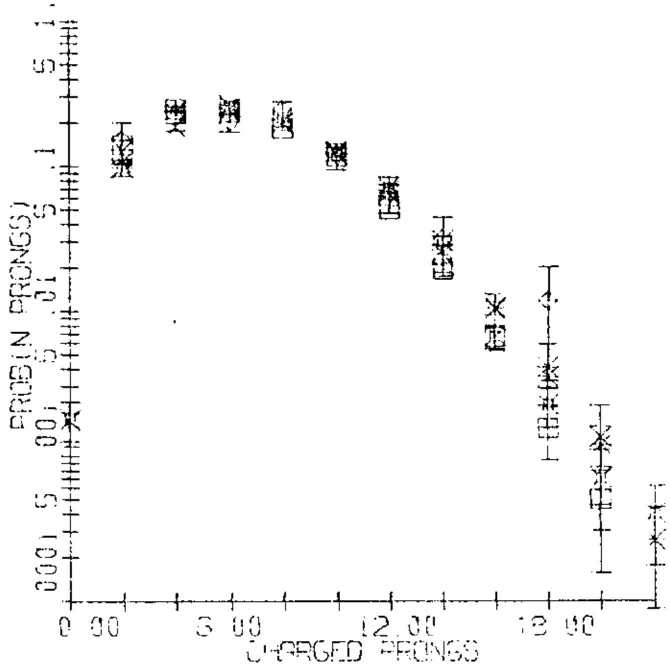
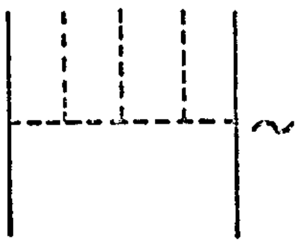


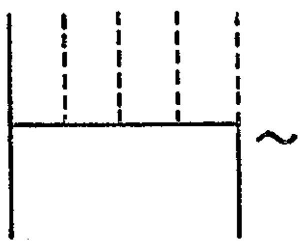
Fig. 13: Topological distributions observed in 100 GeV/c π^+p (×), π^-p (⌘), K^+p (◇), pp(□), and $\bar{p}p$ (✳) collisions. The data are from Ref. 47.

(a)



$$\sim \frac{K_1 (g_M \log s)^n s^{2\alpha_M - 2}}{n!}$$

(b)



$$\sim \frac{K_2 (g_B \log s)^n s^{2\alpha_B - 2}}{n!}$$

Fig. 14: (a) Schematic multiperipheral diagram for meson production in pp collisions; (b) Baryon exchange graph representing the difference between $\bar{p}p$ and pp topological cross sections.

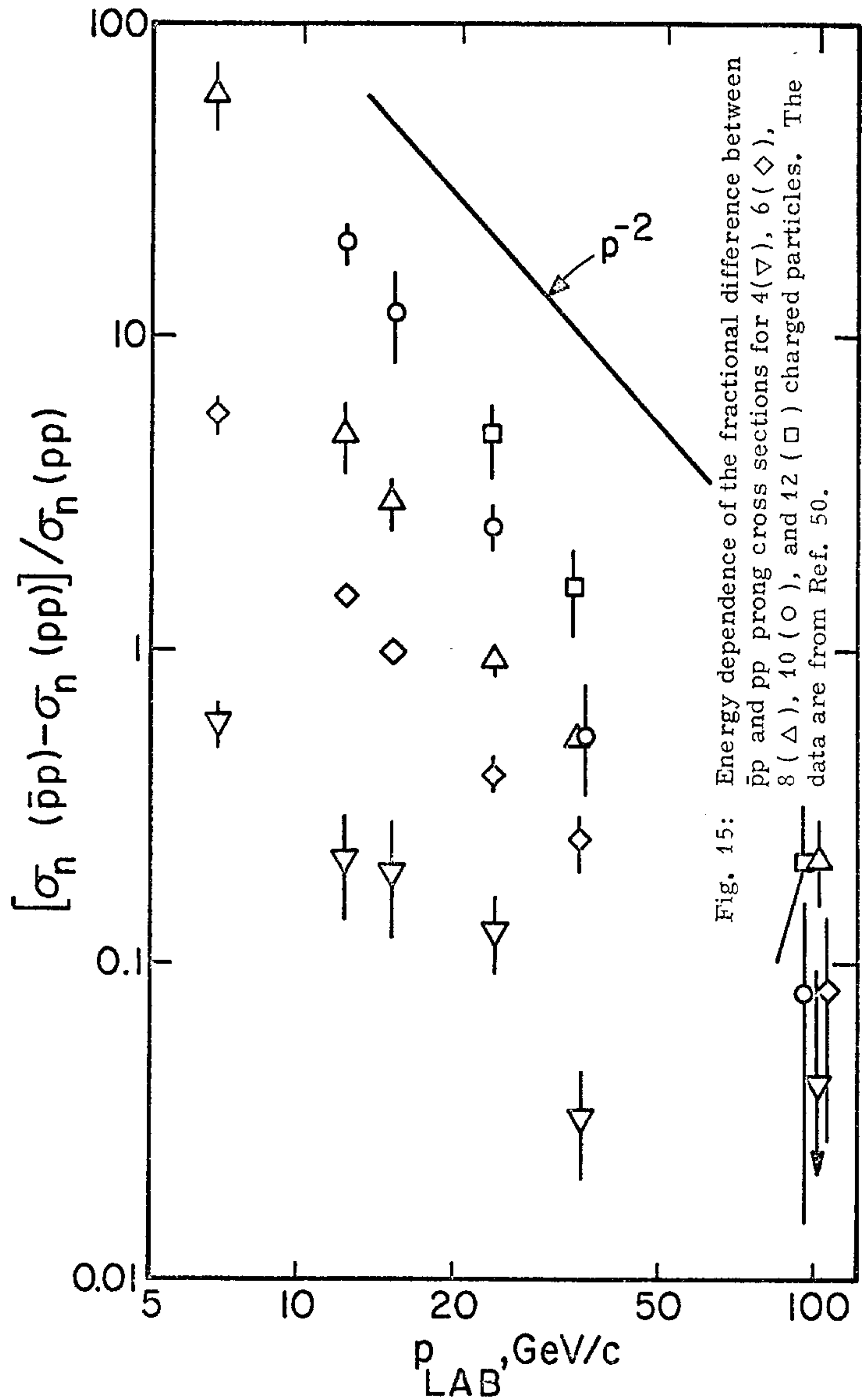


Fig. 15: Energy dependence of the fractional difference between $\bar{p}p$ and pp prong cross sections for 4(▽), 6(◇), 8(△), 10(○), and 12(□) charged particles. The data are from Ref. 50.

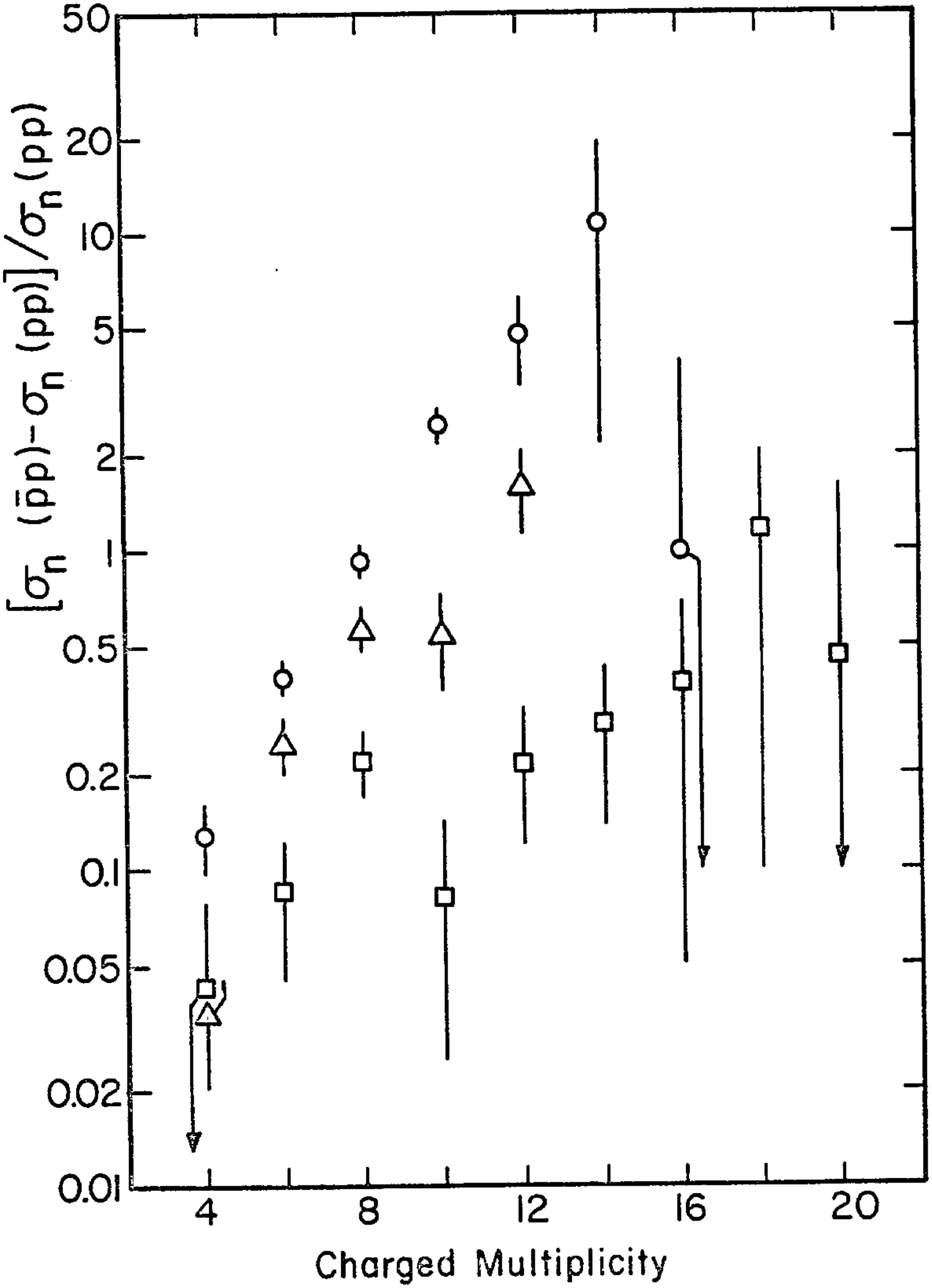


Fig. 16: Charged multiplicity dependence of the fractional difference between $\bar{p}p$ and pp prong cross sections at 22.4 (○) , 32 (△), and 100 (□) GeV/c. The data are from Ref. 50.

initiated by different beams. The rapidity gap distribution[51] is one useful probe of final-state configurations. The distribution of gaps between adjacent charged particles and between adjacent negatively-charged particles in 205 GeV/c $\pi^- p$ collisions have been compared[52] with the corresponding distributions[53] in pp collisions. No difference can be discerned.

Short-range correlations: Short-range order in rapidity is now firmly established,[54, 46] by inclusive and semi-inclusive correlation functions, by rapidity gap distributions, and by the limited mobility of charge, as the dominant feature of nondiffractive multiple production. We do not yet have the information on the mobility of quantum numbers rarer than charge which will become accessible through determinations of the range of πK, $K\bar{K}$, πN, $N\bar{N}$, and other correlations.

An interesting correlation effect seen clearly for the first time during the past year is the strong attraction among negative tracks for small separations in rapidity and azimuth,[55, 54] shown in Fig. 17. Whether this is a manifestation of Bose-Einstein statistics[56] or merely a detail of cluster decays is unknown. To test the Bose-Einstein hypothesis one may look for a further enhancement at small separations in momentum. Observation of a similar attraction between $K^- \pi^-$ would argue against the statistics hypothesis.[57]

Stable event structure: The prominent features of correlations in the central region[54, 58] and the structure of rapidity gap distributions[51, 59] are unchanged from around 100 GeV/c to the highest ISR energies.

This catalog of characteristics is the fruit of multiparticle phenomenology. It neither refers to, nor depends on, any specific theory. Indeed, it constitutes a challenge to candidate theories. Here we have a list of the properties which a theory must explain, a list complete enough that any theory which does predict all the entries will successfully account for every important feature of the data.

All of these characteristics are well summarized by the independent cluster emission model,[60] which is not a candidate for the ultimate theory. Pions are produced as if hadronic clusters are emitted independently with unit density in rapidity. The clusters, which carry less than two units of charge, decay independently and isotropically into about three pions (two charged) on the average. Whether this "as if" model accurately reflects the underlying dynamics or is simply a convenient mnemonic for the data is an important open question.

It is useful to ask what we should expect from the cluster model which embodies, more or less by construction, the prominent aspects

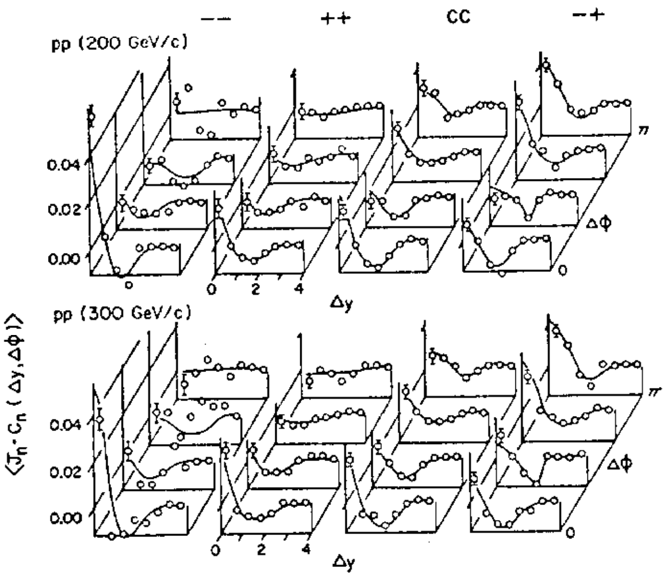


Fig. 17: Dependence of a multiplicity-averaged correlation function on rapidity and azimuth for four charge combinations in pp collisions at 200 and 300 GeV/c. The rapidity of one particle is restricted to $|y_{CM}| < 0.5$.

The data are from Ref. 55, in which the object $< J_n C_n(\Delta y, \Delta\phi) >$ is defined and motivated.

of the data. It is not fundamental, but may pose detailed experimental questions which lead us toward the fundamental. On this basis, I perceive a close analogy between the position occupied by the cluster model as a description of soft collisions and that held by the parton model for deeply inelastic processes. For example, I consider quark distributions inside hadrons on the same footing with the properties of clusters. Both are essential to know roughly and subject to enormous ambiguity if one tries to establish them precisely. The briefest way to convey the analogy is to juxtapose a number of comments frequently overheard about the two models, part of the point of my comparison being the many ways in which both can be regarded.

Parton Model	Cluster Model
Anything the parton model explains can be explained in other ways.	Anything the cluster model explains can be explained in other ways.
Why don't we see partons?	Why don't we see clusters?
Partons are quarks.	Clusters are resonances.
The parton model is just a mechanistic representation for the basic underlying truth, which is the light-cone algebra.	The cluster model is just a mechanistic representation for the basic underlying truth, which is short-range order.
Can partons really act as if they are free? The parton model is but an approximation valid in a large but finite (Q^2,ν) range. According to asymptotically-free field theories, Bjorken scaling will break down.	Can clusters really act independent, while σ_t is increasing? The cluster model is but an approximation, valid in a large but finite energy range. According to Reggeon field theory, the structure of events will be completely different at infinite energy.

On present evidence,[61] I suspect that clusters do have a physical reality as an average representation of the boson resonances, and that an exchange picture will emerge as the dynamical basis for the cluster description. Testing this suspicion will be a demanding and (we may hope) rewarding task.

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