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IMPORTANT PROBLEMS AND QUESTIONS FOR THE NEW ACCELERATORS* †

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Only on April Fool's Day can one presume to give a talk with this title. Clearly the most significant problems and advances as we jump another decade in accelerator energies will be just the unanticipated and wonderful surprises. We know there are some there[1] and it is this that nourishes our faith as we explore ahead at the frontiers of nature's secrets. This is our religion. We are confident we will find some beautiful surprises that, just as they profoundly advance the status of some existing concepts will just as ruthlessly destroy others. Most exciting of all will be the surprises that will raise even deeper questions for us about the form and substance of nature's laws. But let me go through some of the questions foremost on my mind as I look ahead to higher energies - other than the obvious one of "Will a quark be produced?"

Despite my professed faith or optimism, as we look ahead there are always those long tortured moments of doubting as one explores into unmapped terrain. As we leave behind the rich landscape with its many peaks and valleys of the world of tens of GeV does naught but a desert of asymptopia face us? In the world of 100's of GeV are we to find only the barren flat plains of Pomeron land?

I would say the most important thing to happen this year is that we now know with total confidence that this is not the case. The Serpukhov[2] results have made it unmistakably clear that this new land to which we have now been introduced,

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and which the CERN ISR and NAL will soon explore to a much greater extent, is indeed fertile. Take for example the situation with K^+ vs K^- σ's as so extensively discussed in this conference. It leaves us wondering what and where the asymptotic limit is.

Asymptotic projections are generally based on a physical model and the simplest has been that in hadron processes the incident hadronic wave is absorbed into numerous open, strongly coupled inelastic channels. With an interaction volume that is highly absorptive and of fixed size we are most naturally led to expect that

1) All hadronic total cross sections approach finite constants at high energies.
2) The elastic scattering amplitude for forward directions will be imaginary with the dominant contribution to elastic scattering coming from the diffraction scattering of the initial wave that accompanies absorption.
3) The Pomeranchuk theorem will be true - i.e. total particle and anti-particle cross sections for the same target are equal for s asymptotic:

$$\sigma_{aT} = \sigma_{\bar{a}T}$$

4) The total cross section for all members of an isomultiplet will approach the same limit, and to the extent that SU3 is valid the same will be true for members of an SU3 family.

These ideas are often summarized by assuming that the Pomeron exchange mechanism in Regge theory dominates in the high s limit, and that is all there is to it.[3]

O.K. this has been the lore of asymptopia. And very strikingly the data deny that this is what is going on here in Pomeronia,[4] wherever the asymptopia for which it is designed may be. Let me be more specific about this point. You have seen the data. Here is a summary in Table I; evidently direct channel resonances enter

TABLE I

Process / Properties	pp, np	$\bar{p}p$, $\bar{n}p$	π^+p	π^-p	K^+p	K^-p
Direct Channel Resonance	NO	YES	YES	YES	NO	YES
σ_T falls appreciably between p_{lab} = 10-20 GeV/c	NO	YES (by ~10%)	YES (by ~ 5%)	YES (by ~ 5%)	NO	YES (by ~ 5%)
σ_T falls appreciably between p_{lab} = 20-50 GeV/c	--	YES (by ~10%)	NO	NO	--	NO
$\frac{\sigma_{AP} - \sigma_{\bar{A}P}}{\sigma_{AP} + \sigma_{\bar{A}P}}$	~ 0.1 at p_{lab} = 25 GeV/c		~ 0.03 at p_{lab} = 65 GeV/c		~ 0.1 at p_{lab} = 20 GeV/c	
Shrinkage of Forward Diffraction Peak	YES	NO (anti-)	NO	NO	YES	NO
Structure in $\left.\frac{d\sigma}{dt}\right)_{t \approx -0.6\ (GeV/c)^2}$	NO	YES	YES	YES	NO	YES

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crucially into the comparison. In asymptopia their still prevalent - or at least clearly evident - role should be dimmed. Perhaps for pp and K^+p with no direct channel resonances we are in fact already seeing asymptopia. But not yet for the other process in Table I.

Let me just add one point. I have no idea what the asymptotic limit is - strong cuts plus poles leading to a ≈ 10 mb climb to asymptopia and the Pomeranchuk "theorem" at energies exceeding the total Mc^2 of the universe,[5] or a ln s growth of σ_T as allowed by axiomatic field theory.[6] In the latter case the real and imaginary parts of the forward scattering amplitude tend to a finite ratio; the Pomeranchuk "theorem" is not valid, and there will be an increase in σ_T by about 10 mb at NAL energies.[7] However I do know that we can say with certainty that we are not now asymptotic. Suppose we try to claim that the total cross sections are now asymptotic, will henceforth be flat for higher energies, and will not satisfy the Pomeranchuk "theorem."

This presents no fundamental problem.[6][8] All that is required is that $\mathrm{Re}A/\mathrm{Im}A \sim \ln s$ as $s \to \infty$. This behavior of the scattering amplitude has the following implications. It follows from the formal dispersion relations that it is the odd amplitude under crossing that grows - i.e.

$$\mathrm{Re}\,(A_{ap} - A_{\bar{a}p}) \sim s \ln s$$

so that

$$A_{ap} \sim ias + c\, s \ln s$$

$$A_{\bar{a}p} \sim i\bar{a}s - c\, s \ln s$$

and

$$\frac{d\sigma}{dt} \sim \left[|\overset{(-)}{a}|^2 + |c|^2 \ln^2 s \right]$$

Hence even this "bizarre" behavior, opposite to a diffraction model and denying Pomeranchuk by means of an increasing real amplitude, due perhaps to a long range, expanding real tail on the optical potential, can't be asymptotic till one sees the same shrinking for particle and antiparticle on a given target. And this is also not Regge behavior, but requires $\ln^2 s$ shrinking of the forward peak if the area under it is not to exceed σ_T; this behavior should be clear experimentally by 200 GeV. At present energies Table I shows that we do not observe this behavior by any means for the forward diffraction pattern and hence are not asymptotic. Furthermore the initial indications[9] from Serpukhov are counter to this behavior for ReA. So it will be interesting to establish the "what is" as well as the "where is" of asymptopia!

Let us turn now to the inelastic processes which are indeed the dominant ones at high energies. What are their general characteristics and what universal behavior will they exhibit? What are the variables in terms of which simple behavior can be found? We already have recognized two general features of pions produced in hadron-hadron collisions: They are produced with low transverse momenta $p_\perp < 1/2$ GeV relative to the collision axis. Also in proton-proton collisions the secondary pions are produced with low longitudinal momenta - that is they emerge predominantly with a small fraction of the collision energy in the center of mass system, $x \equiv \frac{p_\parallel}{W} < 1/2$. Perhaps there is a limiting distribution in terms of x and $p_\perp$ independent of $s = 4W^2$ at high collision energies, but if so, when does it set in and what does it look like - and moreover what will it teach us? Perhaps separate distributions of pionization products at small x and of hard components with larger x and different s dependences can be identified.[10]

On the way to a complete study and reconstruction of inelastic processes it is natural to look first at the simplest one - the measurement of a one body distribution via

$$\begin{aligned} p + p &\rightarrow \pi + \ldots \\ \pi + p &\rightarrow \pi + \ldots \end{aligned} \tag{1}$$

where the dots denote that we sum over all other hadronic channels. This is in the terminology of Feynman an "inclusive process" with no constraints on final products other than the one whose distribution is under study.

In fact I want to talk first about a different process that is theoretically much simpler and which permits us to make direct use of the impulse approximation - and that is the deep inelastic electron scattering discussed yesterday by Professors Bjorken and Taylor.[11] In studying those other composite systems - the atom and the nucleus - the natural starting point is to analyze the bound state in terms of its constituents - viz electrons and nucleons, respectively. Then if we consider a scattering process in which we specify the kinematics so that these constituents can be treated as instantaneously free during the sudden pulse carrying a large energy transfer from the projectile, we can neglect the effects of their binding during the interaction and we can treat the kinematics of the collision as between two free particles - the constituent and the projectile. With these conditions the impulse approximation applies - and we learn from a nuclear target, for example, the momentum distribution of its nucleons and hence one important key to the structure of its ground state .

Turning to a nucleon - whose constituents or "partons" have not yet been deciphered, whatever and however numerous they may be, it is in the Bjorken limiting region of deep inelastic scattering with large momentum transfer that we satisfy this condition for applying the impulse approximation. In contrast to the nucleus the "partons" are very strongly bound together by an energy at least comparable to and probably greater than their rest energies as viewed in the proton's rest frame. However we may help our intuition and view them as long lived, almost real states if we take advantage of the time dilation by viewing the proton from an infinite momentum frame. Then, if this bound state describing a proton in the rest system can be formed by momentum components that are limited in magnitude below some fixed maximum - i.e. if there exists a finite k_{max} - then as viewed in an infinite momentum frame $P \to \infty$, the partons will each share a finite fraction $0 < x_i < 1$ of P and move closely parallel to it as illustrated in Fig. 1. The lifetime of these parton states is characterized by

$$\tau_{life} \sim \frac{1}{\Delta E} \sim P/M_{eff}^2 \tag{2}$$

where for finite k_{max} and for a finite fraction x not too close to its end point values of zero or unity, M_{eff} is measured typically in GeV units. Eq. (2) exhibits the time dilation effect.

In the deep inelastic scattering region τ_{life} is long compared with the duration of the pulse, τ_{int}, from the inelastically scattered electron. In the electron-proton collision center of mass system and in the high energy limit so that in this system $P = \frac{1}{2}\sqrt{s} \to \infty$, τ_{int} is given by

$$\tau_{int} \sim \frac{4P}{2M\nu - Q^2}$$

where $Q^2 > 0$ is the negative of the invariant squared mass transferred to the

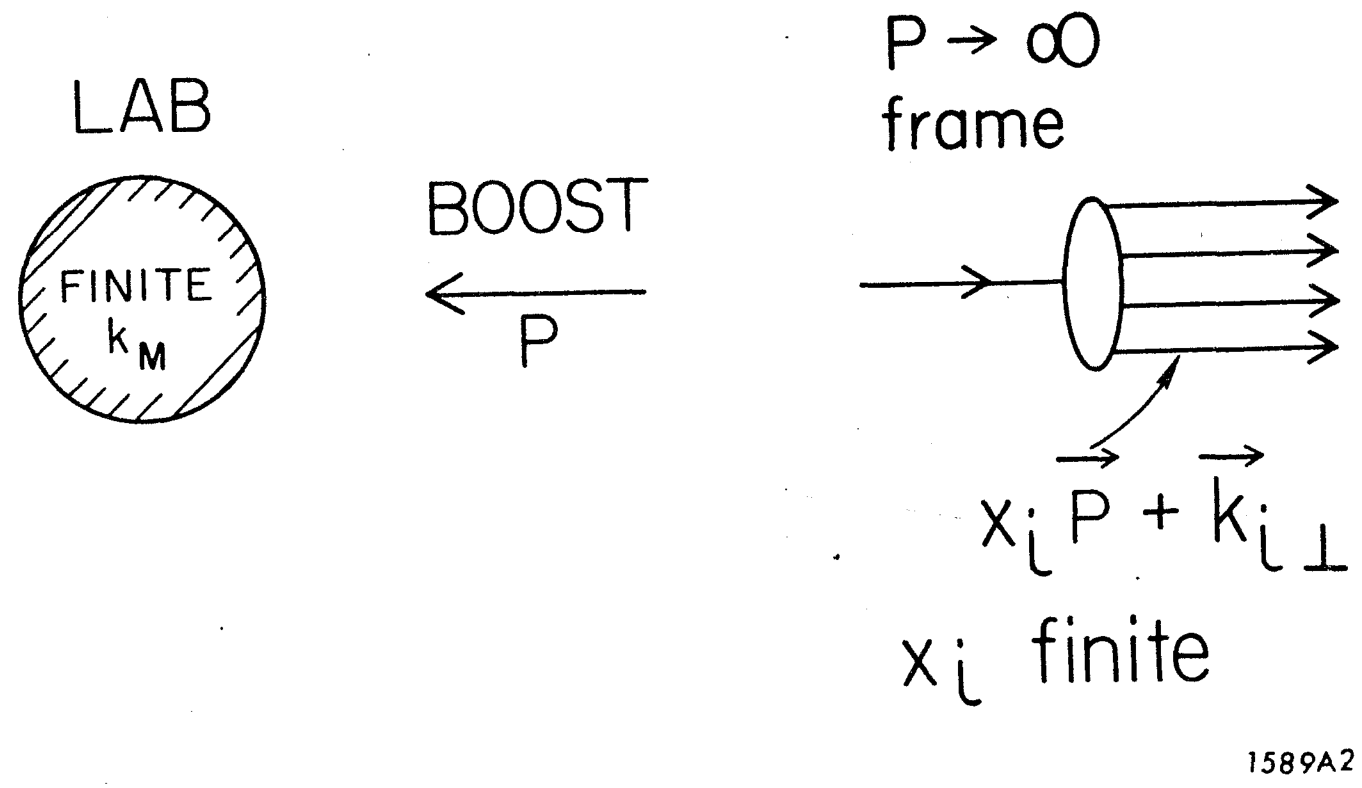

FIG. 1—Proton viewed in the rest frame and in an infinite momentum frame in terms of partons.

proton and $\nu \equiv \frac{1}{M} P \cdot q$ is the frequency transferred in the proton rest system as illustrated in Fig. 2. We see then that

$$\tau_{\text{int}} << \tau_{\text{life}}. \tag{3}$$

provided $2M\nu - Q^2 >> M^2_{\text{eff}}$ (4)

Eq. (4) is the condition for applying the impulse approximation. The current interaction is sudden relative to the lifetime of the partons, which are essentially free, and the energy introduced across the current vertex in Fig. 2 is large enough so that energy conservation for the overall process can be approximated by energy conservation across the vertex.

Since as first discussed by Feynman the fraction, x, of longitudinal momentum on the parton in the $P \rightarrow \infty$ frame from which the electron scatters is given by

$$x = \frac{Q^2}{2M\nu} \tag{5}$$

the condition for applying the impulse approximation is satisfied if we work in the Bjorken region of finite x and at high inelasticities $\nu >> M$. Eq. (5) is just the condition for elastic scattering from the bare parton in a $P \rightarrow \infty$ frame. We have thus satisfied the condition for applying an impulse approximation and determining the longitudinal momentum distribution of a parton which, in terms of the structure functions of e - p inelastic scattering as usually defined, is given by [12]

$$G(x) \equiv \frac{1}{x} \left[\nu W_2 \right]_x \equiv \frac{1}{x} F_2(x) \tag{6}$$

The scaling behavior observed for the structure functions [11] is experimental support for our simple description.

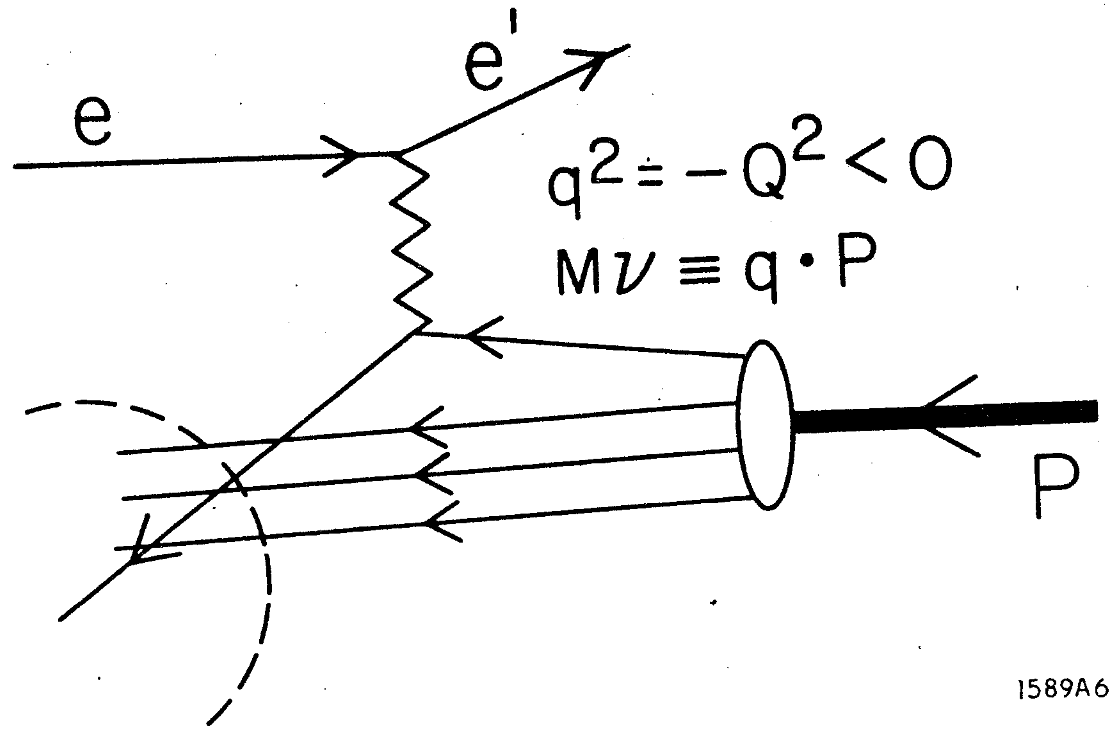

FIG. 2--Inelastic electron-proton scattering viewed in the p ⟶ ∞ frame.

Note however that the ratio x must be finite for this simple result since otherwise in (2) as $x \to 0$ it is easy to show that $M^2_{eff} \sim \frac{1}{x} M^2$ and (4) will not be satisfied.[13] This is because we will be forced to deal with very slow partons in the $P \to \infty$ system, or, as seen in the rest system of the proton, with the high momentum extremities of the bound state structure, and for these the impulse approximation breaks down. The beauty of the electron scattering is that it allows us to tune the mass of the virtual photon line as we choose - either space like for the scattering or time like for the deep inelastic annihilation process

$$e + \bar{e} \to H + \ldots$$

and in this way probe the structure by an impulse treatment and with the aid of concrete models purporting to represent gross features of the proton's structure.[14]

However when we return to the world of only real external hadrons, we have no large mass since $Q^2 \to M^2$ while $2M\nu \to s$, the total collision energy, and thus the fraction of momentum on a parton becomes very small – or "wee."[12] Our condition for applying the impulse approximation as stated in (3) also fails and the value of the parton concept is less certain. Nevertheless, as suggested by Feynman, we may hope for clues to the behavior here by studying $F_2(x)$ in (6) as x decreases to very small values and thus being led to insights into what is going on here in the "wee" region.

Let me return now to these purely hadronic processes and see what we can say. Pursuing our theme we will ask if there is some sort of limiting distribution in this case – some energy independent $\rho(x, p_\perp)$ for the single detected pion in reactions (1).

It has been suggested[12] [15] [16] that this will occur and arguments based on a combination of relativistic covariance, physical intuition applied to composite systems scattering at high energy, and of results from the multi-peripheral model have indicated a form that for small x will be

$$\frac{d^2\sigma}{dx\,dp_\perp^2} = \lim_{\substack{W \to \infty \\ x \ll 1}} \rho\left(p_\parallel, p_\perp\right) dp_\perp^2 dp_\parallel \sim \frac{dp_\parallel}{\sqrt{p_\parallel^{\,2} + p_\perp^2 + M^2}} f(p_\perp)\, dp_\perp^2$$

$$\sim \frac{dx}{x}\left[f(p_\perp)\, dp_\perp^2\right] \frac{1}{\sqrt{1 + \frac{p_\perp^2 + M^2}{x^2 W^2}}} \tag{7}$$

So long as $1 \gg x > \frac{1\,\text{GeV}}{W}$ - i.e. the fraction of longitudinal momentum is small but not very small, or "wee," - the last factor can be dropped leading to an energy independent and factorized distribution. Let me state the physical argument for this distribution in the "parton" language of Feynman.[12]

As viewed from the center-of-mass system there will be an assemblage of right moving partons colliding with left moving ones. How do they interact? In field theory the interactions are due to the exchange of "partons" or the constituents forming the physical state; for QED these are the bare photons and electrons. Without specifying what the partons are for hadrons, in order for there to exist an interaction between (A) and (B) in Fig. (3) there must be some "confused" partons that don't know right from left. These are the "wee" ones with $x \sim 1$ GeV/W, for which relations (2) and (3) are replaced by $\tau_{\text{life}} \sim Px/M^2 \sim 1/\text{GeV} \sim \tau_{\text{int}}$. A normal parton

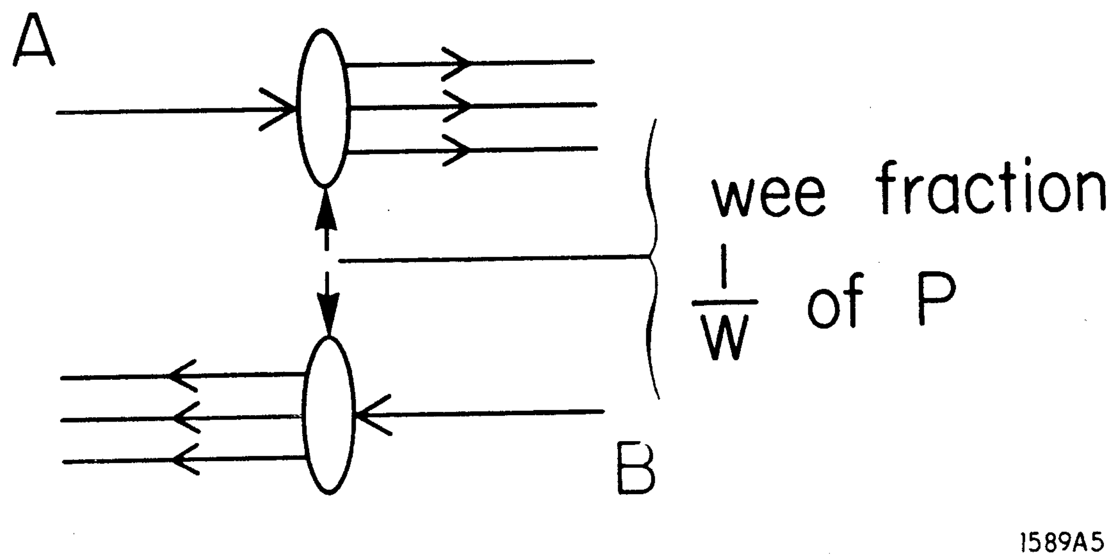

FIG. 3--Hadron-hadron interaction in the center-of-mass system at high energy via "wee" parton exchange.

in (A) with finite fraction x to the right cannot be inserted into the left running state (B) without paying the penalty of a factor $1/s$ as computed directly from the energy denominators. This is the price to introduce a relative momentum of magnitude $2P$ into the wave function of a ground state built predominantly from finite momentum components which we take to be a working hypothesis. We must therefore turn to these "wee" partons with $x \sim \frac{1\,\mathrm{GeV}}{W}$ as being responsible for the hadronic cross sections and recognize that a distribution of the form (7) leads to within logarithmic factors to a constant total cross section at very high energies - viz

$$\sigma_{tot} \sim \left\{\int^{C/E_a} \frac{dx_a}{x_a^{\alpha}}\right\}^2 \left\{\int^{C/E_b} \frac{dx_b}{x_b^{\alpha}}\right\}^2 \sim \left(E_a E_b\right)^{2(\alpha-1)} \sim s^{2(\alpha-1)} \qquad (8)$$

What is the evidence for this distribution with $\alpha = 1$? Electron scattering is consistent with the $\frac{1}{x}$ trend by (6) since νW_2 is relatively constant[11] for $x < \frac{1}{3}$. However we must dream for the day of a super cooled SLAC reaching to 100 GeV or of a good muon beam at this energy at NAL to take over the electron's work for stronger, more conclusive evidence. For p - p scattering the data on single pion distributions are assembled[17] in Fig. (4) and presented as a double differential cross section, multiplied by the denominator factor of interest in (7), $\frac{E}{W} \equiv \sqrt{x^2 + \left(p_\perp^{\,2} + M^2\right)/W^2}$, and divided by an attempt at a universal function of the transverse momentum distribution.

I want to make a number of comments about this figure:

1) We are showing here a decay distribution for pions, not partons. However if (7) is valid it characterizes the emerging pion distribution

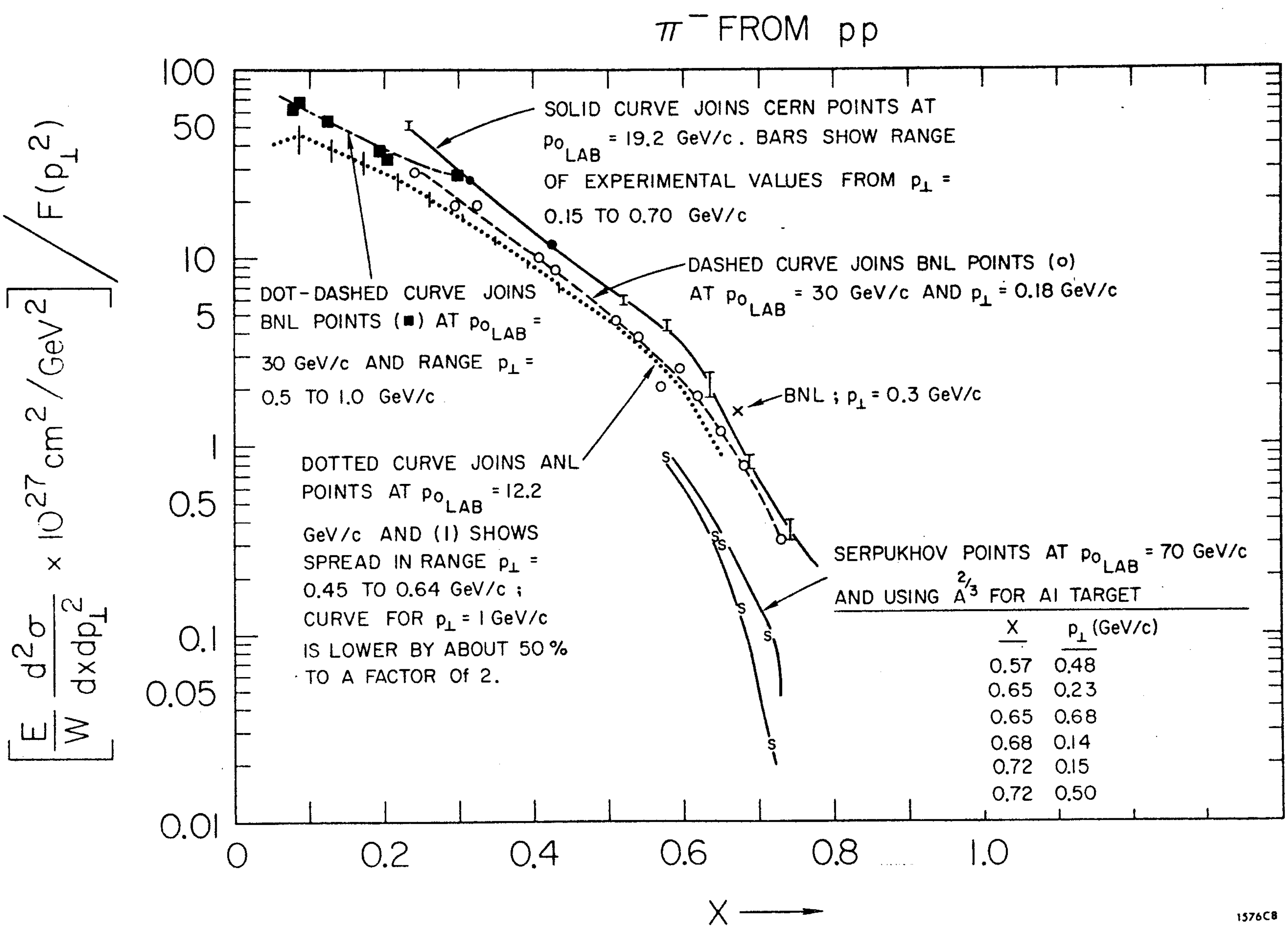

FIG. 4--π^- production from high energy p-scattering.

for small fractions x if the parent parton also is described by a $1/x_1$ spectrum for small x_1. This spectrum thus perpetuates itself through successive decays in the soft particle region. This is not true however for large fraction x.

2) A single $f(p_\perp)$ can be fit to the CERN data at $p_{lab} = 19.2$ GeV/c for a fixed inelasticity x and covering the range $0.15 \text{ GeV} < p_\perp < 0.7$ GeV. To the indicated accuracy it accommodates the full range of x indicating the factoring of the $p_\perp$ from the $p_\parallel$ dependence not only for small x as postulated in (7) but up to large fractions $x \sim .7$.

3) Energy variations of this distribution are within the factor of 2 agreement illustrated in the comparison of the ANL, BNL, and CERN data.

4) Only the lower $p_\perp$ values from ANL were included as commented in the figure in order to avoid our getting too near the outside edge of a $(p_\parallel, p_\perp)$ Peyrou plot where $p_\perp \gtrsim \frac{1}{2} p_\parallel$; but, if drawn in, these points would drop down to join with the Serpukhov data and fall a factor 3 - 5 below the BNL and CERN curves in this region. In fact it scales with an added factor of $1/E$ introduced into (7) as noted by Liland and Pilkuhn.[18] The Serpukhov data it must be noted are "inferred" from $A\ell$ targets merely by dividing $A^{2/3}$ but CERN data at 19.2 GeV comparing results from $A\ell$ and H targets show this to be a valid "inference" at least at that lower energy.[19] Perhaps we have to conclude that we are not yet asymptotic in s for the one body distribution, at least for hard pions. When we are asymptotic, Feynman[12] has suggested that as $x \to 1$ the remaining small energy fraction $(1 - x)$ of the momentum on the incident or target hadron lines will reside on slow to "wee" partons that are emitted. Hence

if $\alpha(t)$ describes the highest lying trajectory that can bear the quantum numbers by which, for this example, the P and π^- differ one should observe a $(1 - x)^{2[1-\alpha(t)]}$ variation toward the high x end of the curve, where t is their invariant momentum difference. Such a factor, being energy independent, will not explain the Serpukhov results however. On the other hand versions of the multi-Regge model discussed by Zachariasen[20] lead one to expect that the upper end of the curve in Fig. 4 should decrease with increasing s rather than approaching a limiting distribution. In such versions the quantum number difference (between P and π^-) defines the trajectory exchanged between projectile and target particle instead of a radiated particle, thereby introducing a factor $s^{2[\alpha(t)-1]}$. It should also be mentioned that other and non-factorable forms for $\rho(p_\parallel, p_\perp)$ than the one used in Eq. 7 will lead to different apparent energy variations. Perhaps for large x the factoring assumption in (7) must be abandoned. The arguments of Wilson[15] based on the multiperipheral model require small x for factoring. There is still much to do in this region.

5) Since we have multiplied through by

$$\frac{E}{W} = \sqrt{x^2 + \frac{p_\perp^2 + M^2}{W^2}}$$

the curves should be relatively flat for small x values. Within a factor of better than 2 they are in fact flat out to $x = 0.2$ before dropping off more rapidly. The simplest theoretical suggestion for such a fall-off is that in the peripheral part of a collision leading to high energy secondaries at low momentum transfer the π emerges from an isobar or cascade of isobars excited by the interaction. Then straight from the kinematics of the isobar decay we know that $x_{max} \lesssim \frac{2(M^* - M)}{M^*}$ or $< 1/2$ for most familiar low lying isobars and so the rapid fall-off may be largely a kinematic effect. Recall moreover from the remark (1) that the parton spectrum (6) and the final pion distribution are not identical for larger fractions x. Incidentally x_{max} will be larger for π's from incident π beams which are excited, perhaps to ρ and higher mass meson states, and so we might anticipate a family of secondary pion patterns of the qualitative form shown[21] in Fig. 5. Although of common form for $x \ll 1$, they have different characters for larger x.

We can conclude this part of our discussion by looking forward to additional hadron experiments and analyses to test this picture of nucleons and their partons.

If we want to find other processes which satisfy the same kinematical constraints as in (4) and (5) and allow application of the impulse picture of partons in an infinite momentum frame we need look for interactions at high energies s which absorb or produce a lepton system of huge mass Q^2 such that the ratio $\frac{Q^2}{s}$ is finite. We confine our attention here to massive lepton systems which can be safely treated by perturbation theory in the electromagnetic or weak couplings although by further extending the assumptions for the theoretical framework massive hadron systems could be included in the same kinematical framework just as well. Beyond the deep inelastic neutrino processes and electron-positron annihilation cross sections: $\nu + p \rightarrow e + \ldots$ and $e + \bar{e} \rightarrow$ hadron $+ \ldots$ which have already been discussed and analyzed an additional observable cross

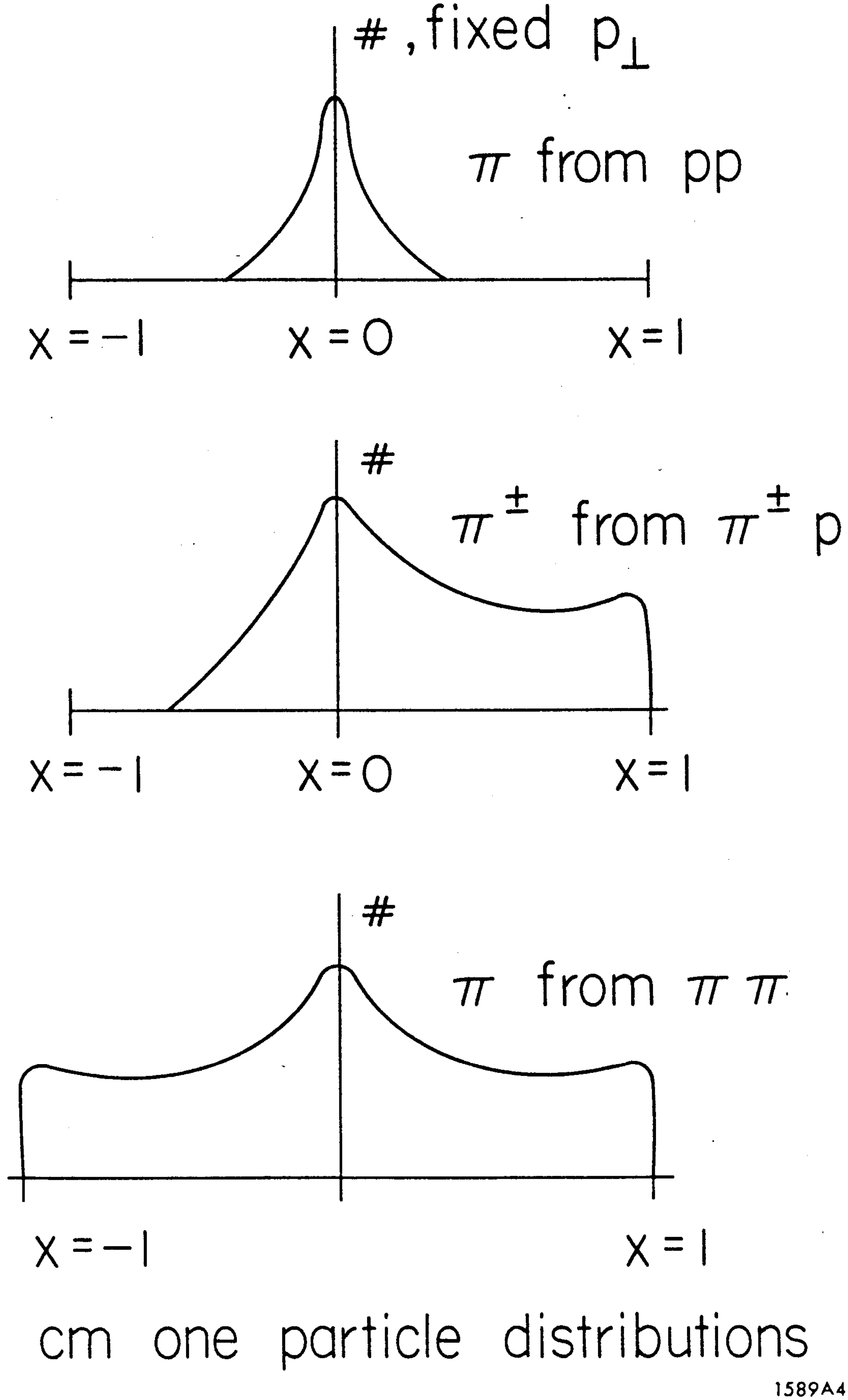

FIG. 5--Single π distributions in the center-of-mass for the collisions as indicated. The three spectra have common small $|x|$ behavior.

section that meets the conditions for applying an impulse analysis is

$$\left.\begin{array}{l} p+p \\ \bar{p}+p \\ \pi+p \\ \gamma+p \end{array}\right. \longrightarrow (\mu\bar{\mu}) + \ldots \; ; \text{ or } \longrightarrow (\mu\nu) + \ldots \qquad (10)$$

Preliminary measurements[22] of this process for incident protons on uranium nuclei with energies ranging from 22 to 30 GeV (or $s \sim 44 - 60\ \text{GeV}^2$) and pair masses from $Q^2 = 4 - 36\ \text{GeV}^2$ have been reported.

What is going on here can be best illustrated in a center-of-mass frame. Let me start with a purely kinematic statement. If a massive state with $Q^2 \sim s$ emerges from one of the colliding protons (A) and (B) as in Fig. 6, it is impossible to satisfy both energy and momentum conservation in the overall collision and at the same time exchange only "wee" partons between (A) and (B) as in Fig. 3. Clearly then this process will not be directly related to the total nucleon cross section.[23] In fact the dominant amplitude in a model of the nucleon with a finite momentum k_{max} in its ground state structure as in Fig. 1 will be the production of the massive pair by annihilation of an anti-parton — parton pair as illustrated in Fig. 7. Viewed from the center-of-mass frame a hard parton moving to the right, say, annihilates on a similar anti-parton headed to the left and the resulting system is very massive since their energies add whereas their momenta subtract. In fact, if a pair of mass Q^2 is formed it is easy to show that

$$Q^2 = x_a x_b s \quad ; \qquad 0 < x_{a,b} < 1 \qquad (11)$$

where $x_{a,b}$ are the fractions of the longitudinal momenta of their respective hadrons carried by the annihilating parton pair. Clearly for finite Q^2/s, one

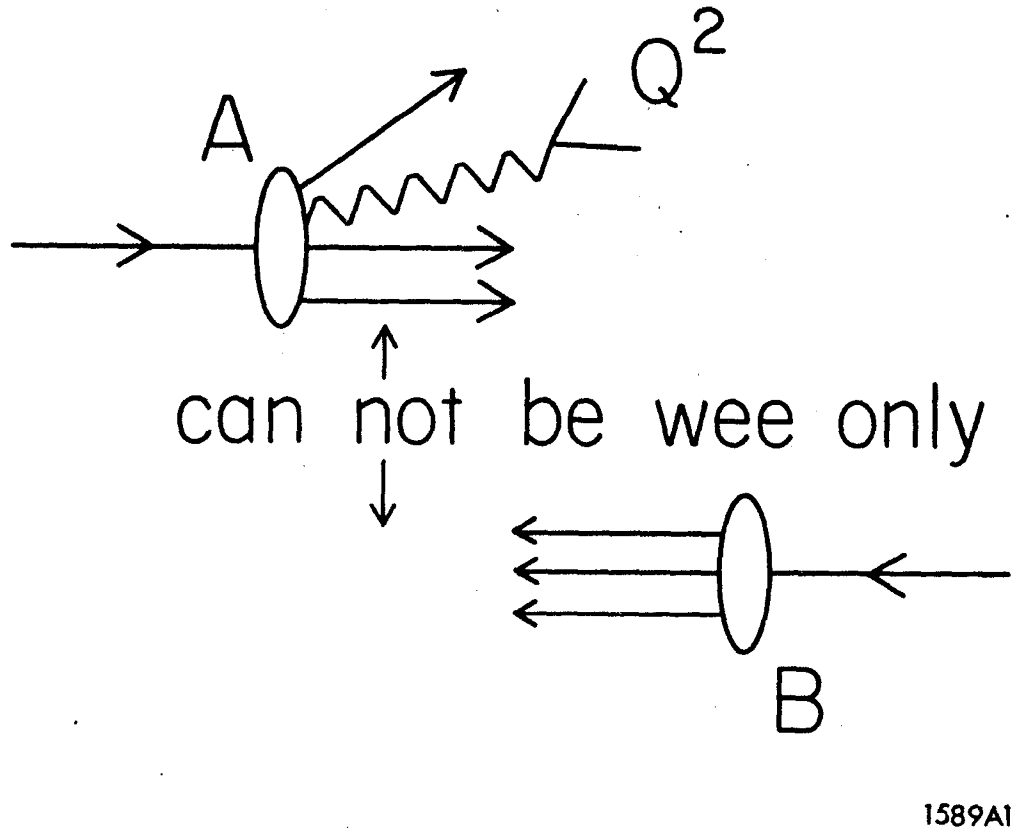

FIG. 6--Production of a massive pair Q^2 from one of the hadrons in a high energy collision. In this case it is kinematically impossible to exchange "wee" partons only.

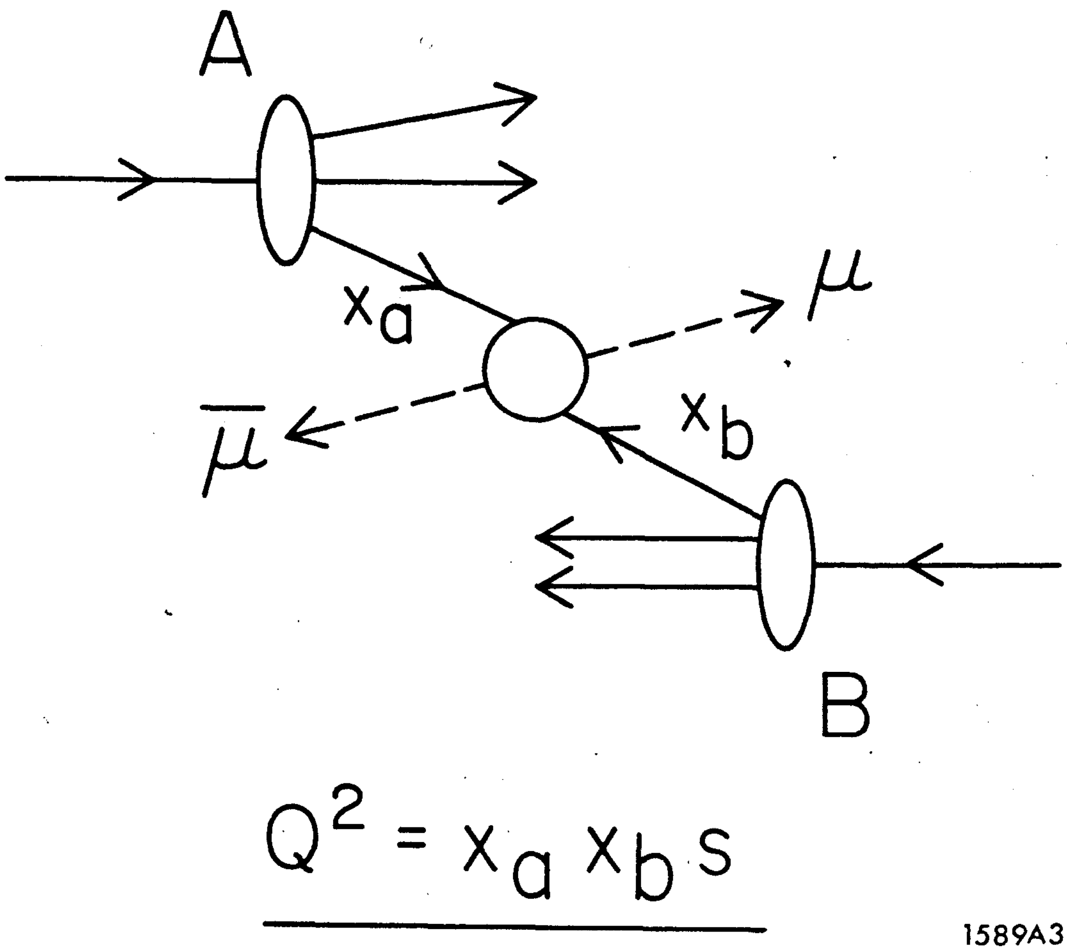

FIG. 7--Production of a massive pair by parton anti-parton annihilation.

is here dealing with hard partons and with the same region of momenta as probed by deep inelastic electron scattering experiments which measure the parton distribution in $x \equiv Q^2/2M\nu$. In this process we are measuring over a range of their values as constrained by (11) for fixed Q^2/s.

T. M. Yan[24] and I have studied this in detail and found a scale invariant relation

$$\frac{d\sigma}{dQ^2} = \left(\frac{4\pi\alpha^2}{3Q^2}\right)\frac{1}{Q^2}\ \bar{\mathscr{F}}(\tau) \tag{12}$$

where $\tau \equiv Q^2/s$ and $\bar{\mathscr{F}}(\tau)$ is an integral over the product of structure functions F(x) as in (6) for parton and anti-parton:

$$\mathscr{F}(\tau) = \int_{\tau}^{1} \frac{dx}{x} \sum_{\lambda} \lambda^{-2} F_2^{\lambda}(x)\ \widetilde{F}_2^{\lambda}(\tau/x) \tag{13}$$

where the label λ denotes the contribution to F_2 (or $\widetilde{F}_2$ for the anti-parton) from a parton of charge λ. If we assume that the parton and anti-parton have identical momentum distributions in the proton we can compute the behavior of $\mathscr{F}(\tau)$ and of $d\sigma/dQ^2$ with increasing Q^2, or τ, for fixed s, in terms of known structure functions from deep inelastic electron scattering. The rapid decrease observed in $F_2(x)$ as $x \to 1$ leads in (12) and (13) to the prediction of a very rapid fall off in the cross section with increasing Q^2. This characteristic is in accord with the preliminary experimental findings.[22] Since we are again dealing with hard partons the cross section is scale invariant as in the inelastic electron scattering in the Bjorken limit. This is in contrast with the hadron-hadron total and inelastic cross sections discussed earlier which relied on "wee" partons.

It will be crucial for the concepts on which I have focused in this report to verify the general behavior of (12) and (13) and its relation to electron and neutrino scattering at the higher energies becoming available. The full range of processes in (10) afford the interesting possibility of comparing the parton and anti-parton structure of different hadrons as well as of the photon. In particular no relation between parton anti-parton spectra need be assumed in the calculations for a $p\bar{p}$ initial state and the comparison with electron scattering can be made directly. Not only functional dependences but also absolute magnitudes of the cross section are important as measures of the effective λ's.

The hard parton region and scaling behavior will also stand critical challenge from electron clashing rings through the study of

$$e + \bar{e} \rightarrow H + \ldots$$

in the deep inelastic region. This reaction is related by crossing to the deep inelastic scattering region and predictions[25] of the magnitude of this cross section as well as of its scaling behavior and of its ratios for different hadrons according to the unitary symmetry scheme have been derived for experimental test. We mention here only the general results that the cross section has a dependence on the colliding ring energy that is the same as for point particles for fixed momentum fraction x, and that the magnitude is characteristically 4 orders of magnitude larger than predicted two-body "elastic" events, such as $e\bar{e} \rightarrow p\bar{p}$, at total colliding ring energies of 6 BeV as presently in construction and/or planning.

Having discussed now some important new possibilities in the region of hard and of "wee" partons we can turn to another class of processes — elastic scattering — where Fig. 8 makes it not unthinkable to suggest that we are, at least in one process, already seeing asymptopia. It was first suggested by Wu

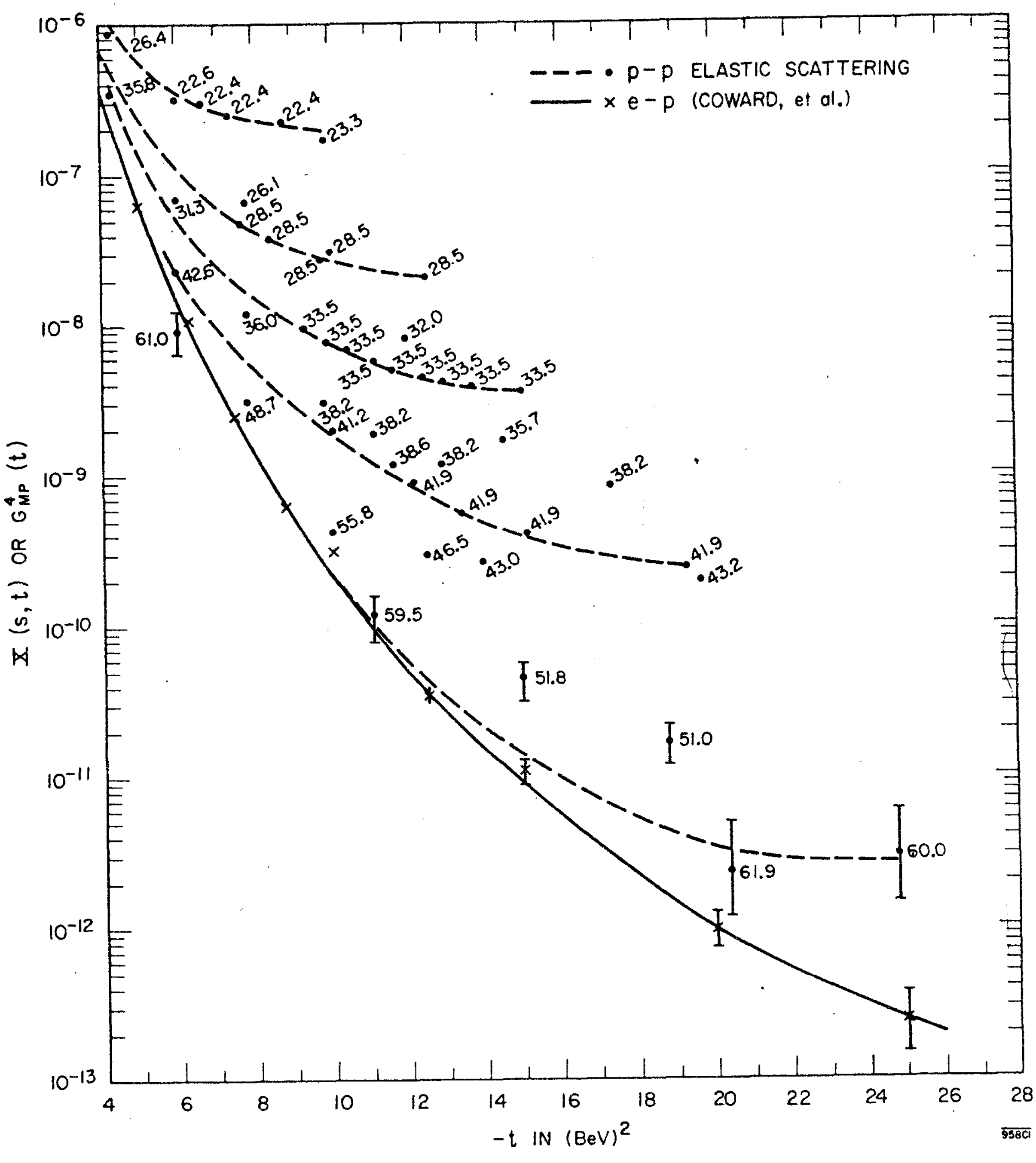

FIG. 8--Normalized differential cross section $X(s,t) = (d\sigma/dt)/(d\sigma/dt)_{t=0}$ for p-p scattering and the fourth power of $G_{Mp}(t)/G_{Mp}(0)$ plotted against t. The experimental points are labeled by the corresponding values of the square of the c.m. energy s. Equal s contours are shown by dotted lines.

and Yang[26] in 1965 that there should be a qualitative connection between high energy and large momentum transfer hadron-hadron scattering and the structure of the proton as revealed in elastic electron-proton scattering at large t. This graph shows normalized invariant differential cross sections

$$X(s,t) \equiv \left[d\sigma/dt\right] / \left[d\sigma/dt\right]_{t=0}$$

as a function of t for different values of s, along with the plot of the fourth power of the magnetic form factor measured in e-p scattering. Perhaps the coincidence of these curves for some four decades is not at all accidental, but is evidence that the elastic pp cross section is already asymptotic at $p_{o_{lab}} \sim 30$ GeV/c.

One of the suggestions[27] for correlating and interpreting these data has taken the following form: In the amplitude for pp scattering there is a piece, the "diffractive tail," which dies precipitously for fixed t as s grows plus, in addition, a point current-current interaction which emerges as dominant as s becomes asymptotic. According to this suggestion one is seeing a power-law-approach to the asymptote as consistent with one dominant Regge trajectory, and the current-current interaction has emerged at $s = 60$ $(\mathrm{GeV}/c)^2$. For large $s \gg t \gg M^2$ it was suggested that this interaction could originate in analogy with the weak interactions. One is in a kinematic region where masses are negligible relative to s and t and just as in the weak interactions for a massless neutrino we may postulate that there is no s-channel helicity flip. This means to leading order in $M^2/s \ll t/s \ll 1$ that the interaction will resemble two vector densities probing each other. A properly unitarized amplitude was constructed[27] for the high energy limit and to a close approximation the differential cross section was found to be proportional to $G_M^4(t)$.

An additional statement is needed for the axial currents which are unknown and cannot be dismissed a priori by our assumptions of no helicity flip and of keeping only leading order terms in t/s. Perhaps they are described by currents with the same form factor structure as the vector currents; this may be so from neutrino results as reviewed by Derrick,[28] but is certainly not at all established. Perhaps the contact interaction cannot distinguish between right- and left-handed protons in which case the axial term goes away. Perhaps this hypothesis is dead wrong. On one score the notion of no helicity flip at large s has recent experimental support[29] from photoproduction of ρ^0's at 4.7 GeV.

Different theories of the connection between elastic hadron cross sections and the proton current distribution probed by electrons have been developed by Chou and Yang and by Durand and Lipes.[30] They build up the connection exclusively from a multiple scattering series in which the diffraction amplitude itself is identified with the charge distribution and there is no additional non-helicity flip contact interaction. Figures (9) and (10) show their predictions and indicate that we can hope to learn about this important connection before long from Serpukhov, the ISR, and NAL.

As to when we are asymptotic in this elastic – or "exclusive" – interaction the following kinematic point is important to keep in mind: For hadron-hadron interactions producing a large mass Q^2 so that Q^2/s is finite, we argued that it is hard partons that compose the interactions; wee ones can't do it.

For inclusive type hadron-hadron interactions such as the total cross sections or the inelastic ones in which we detect one (or a few) secondary particles but leave all other final channels open, we have seen that it is the wee partons with a fraction $x \sim 1/\sqrt{s}$ of the momentum that are exchanged. Kinematically we can

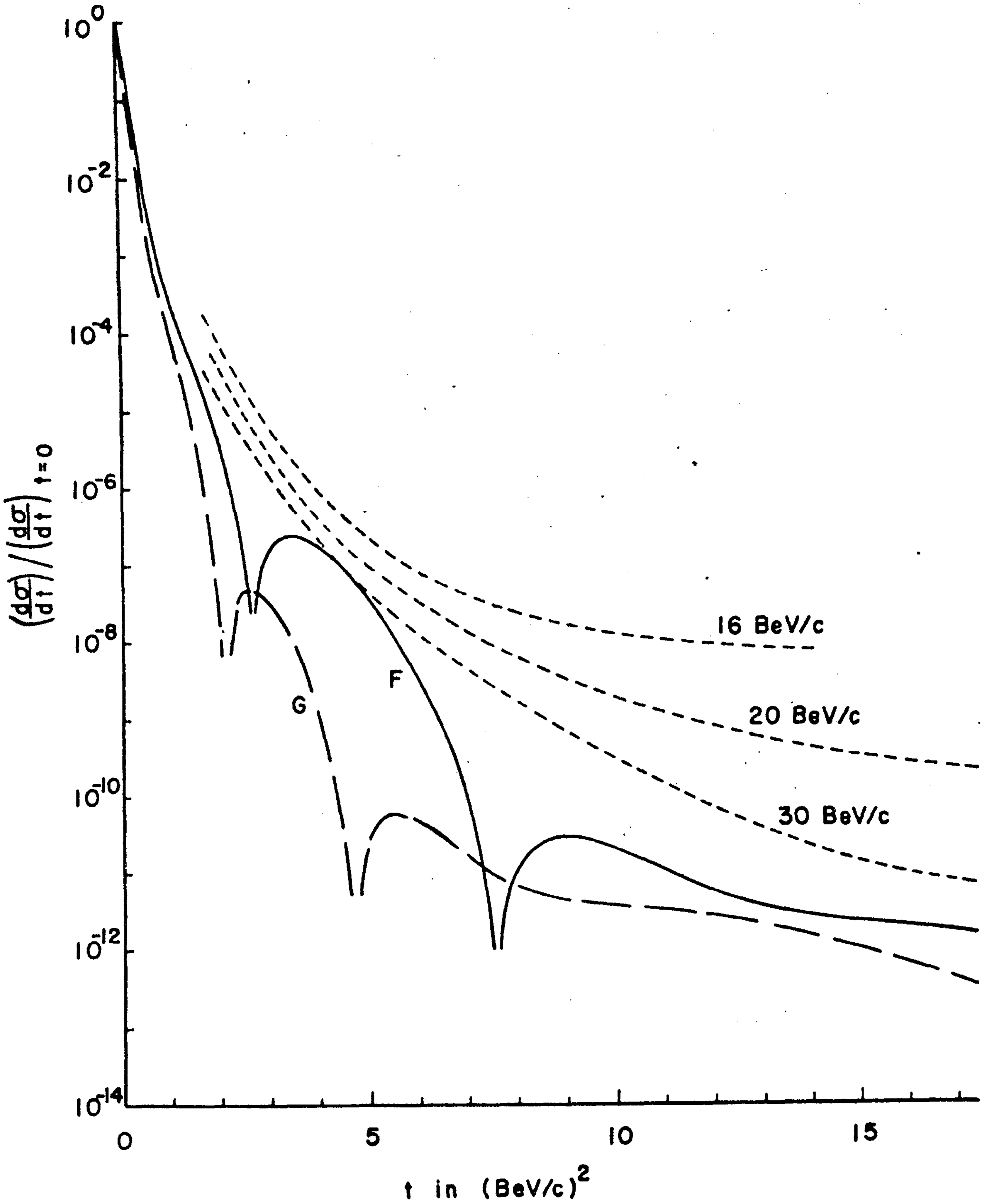

FIG. 9--Elastic pp scattering vs. t at infinite energy as calculated by Chou and Yang. F and G refer to fits based on the form factors, F_1 and G_M respectively. Short dashed curves represent existing data at energies as labelled.

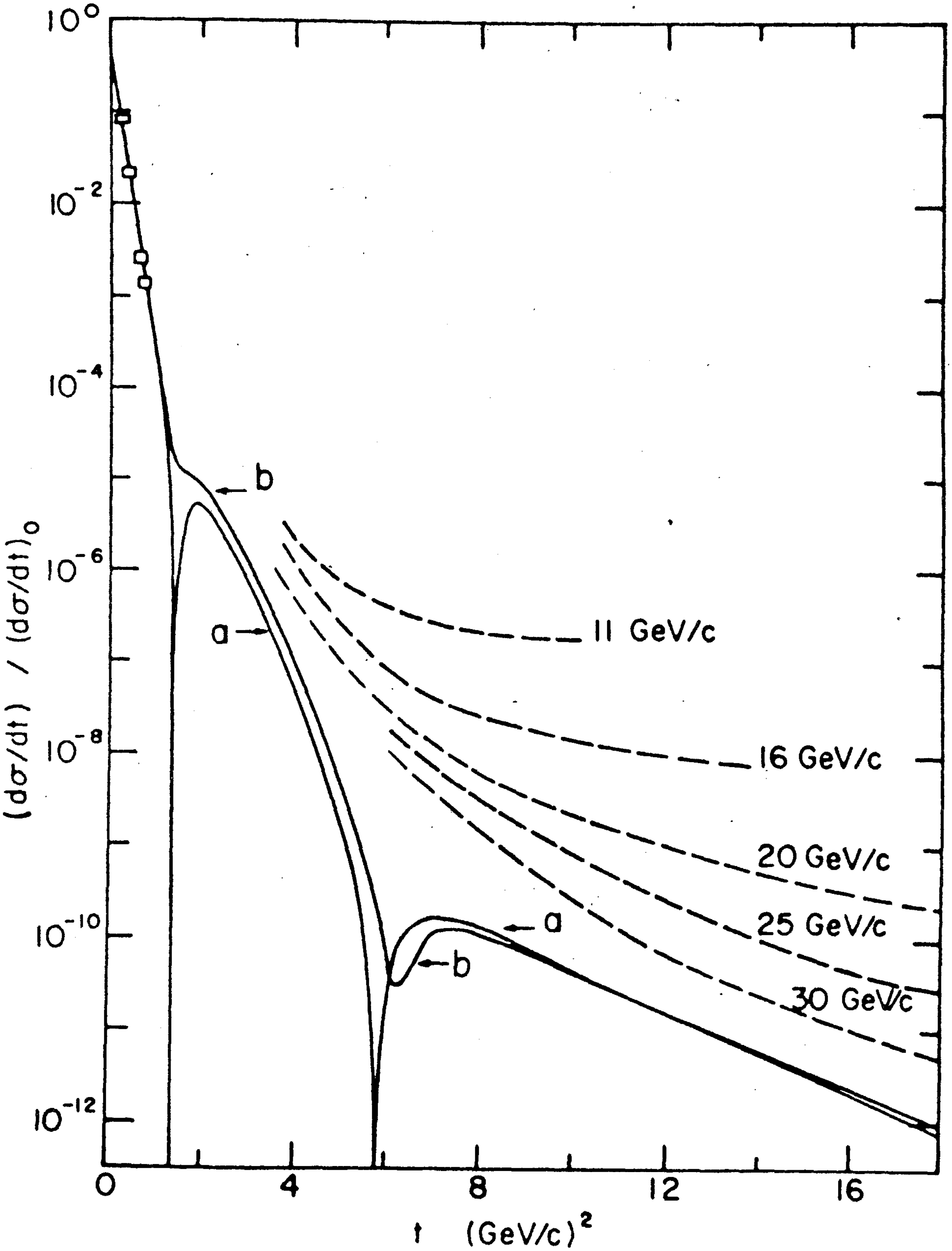

FIG. 10—Elastic pp scattering vs. t at infinite energy as calculated by Durand and Lipes. a and b refer to fits based on pure absorption, and including a real amplitude respectively. Dashed curves represent existing data at energies as labelled.

also remark that the final state in these cases will contain pionization products – or particles with wee momentum as required by energy momentum conservation.

Finally, for elastic or "exclusive" type interaction events with no final pionization products it is easy to verify that purely on kinematic grounds the exchanged momentum between A and B in Fig. 3 will be $x \sim 1/s$, not $1/\sqrt{s}$; i.e., "super wee." These three regions of parton physics all have their own stories to tell – they may well have their own private asymptopias, etc., and they must be analyzed individually. How smoothly one can join them will be only learned after we have studied these very high energy domains very carefully.

There is another class of elastic processes that the new accelerators will expose to experimental probing and which will give interesting new ideas –[31] these are essentially zero-energy experiments using electrons in the atom as knock-on targets: viz, for example

(a)	$\pi^\pm + e \to \pi^\pm + e$ $K^\pm + e \to K^\pm + e$	for accurate determination of charge radii
(b)	$K_L + e \to K_s + e$	for measuring the transition radii between these states of opposite CP
(c)	$\Lambda_0 + e \to \Lambda_0 + e$	for measuring the magnetic moment with high accuracy

To see why a high energy beam is necessary for these experiments we compute that for an incident projectile of mass M and lab energy E_{lab} the maximum invariant square of the momentum transfer to the target electron is

$$t_{max} = \frac{2 m_e E_{lab}}{1 + M^2/2m_e E_{lab}}$$

and for an incident π beam of 100 BeV/c momentum, $t_{max} \sim (300\ \text{MeV})^2$. The most immediate study along these lines is anticipated to be an accurate measurement of the pion's electromagnetic radius at Serpukhov to see if as anticipated it is smaller than the measured proton radii and closer to a vector dominance prediction of $6/m_\rho^2 \sim 0.4\, f^2$.

In conclusion let me remind you that QED has entranced us by her beauty and successes extending for 24 decades from $\sim 10^{10}$ cm or tens of earth radii down to the finest probes at 10^{-14} cm. We have made enormous extrapolations of our classical relativistic concepts of local point interactions in a space-time continuum free from any "granularity" or "ether." In fact, Einstein's theory grew out of this very absence of any such evidence. But maybe as we study immense energy globs in detail in the laboratory and probe with momentum transfers of 100's of GeV, and as we peek into regions as small as 10^{-15} cm we'll find some "handedness" or "sense of rotation" or "backward running clock" in an elementary granule of space or time, leading to an observable and "unwanted" polarization or asymmetry. We must be ready for anything. When the energy got low enough, we first saw super conductivity and superfluidity. When energy gets high enough – who knows?

ACKNOWLEDGEMENTS

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FOOTNOTES AND REFERENCES

1. We heard our first great surprise in Dr. Walker's report on Monday that the NAL accelerator has jumped from 200 to 500 GeV.
2. See the report to this conference of J. V. Allaby.
3. From this model there also follow additional results such as dominance of the diffractive dissociation cross sections and factorizability. The question of shrinkage of the forward diffraction peak then additionally depends on the slope of the Pomeron trajectory.
4. A term coined by N. W. Dean in his interesting contribution to this conference "Physics in Pomeronia."
5. V. Barger and R.J.N. Phillips, Phys. Rev. Letters **24**, 291 (1970).
   A. I. Lendel and K. A. Ter-Martirosyan, Preprint ITF-69-89, Kiev (1969).
6. Axiomatic field theory will tolerate growth rates for σ_T up to the Froissart bound of $\ln^2 s$. See the general review of high energy theorems presented to this conference by R. Eden.
7. V. Barger and R.J.N. Phillips, University of Wisconsin preprint C00-887-262, (1970) to be published.
8. See for example the discussion in Relativistic Quantum Fields, J. D. Bjorken and S. D. Drell (Mc Graw Hill, New York), Chapter 18, p. 262.
9. See the report to this conference by T. Fields.
10. For a general discussion of various aspects of this problem see the Proceedings of the Third International Conference on High Energy Collisions at Stony Brook, September 5-6, 1969, published by Gordon and Breach. A summary is found in Vol. III, No. 6 of "Comments on Nuclear and Particle Physics."
11. See the reports to this conference of J. D. Bjorken and R. E. Taylor.

12. R. P. Feynman (unpublished), and in Ref. 10, Phys. Rev. Letters 23, 1415 (1969).

13. This is also true if $1 - x \to 0$ so that the other partons forming a proton have a very small fraction of P. At this limit $M_{eff}^2 \sim M^2/1-x$.

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16. J. Benecke, T. T. Chou, C. N. Yang, and E. Yen, Phys. Rev. 188, 2159 (1969). See also Ref. 10.

17. I thank Professors Nagashima and Tollestrup of CalTech for compiling the tables and data from which this graph was made. For references to the original data see Ref. 2.

18. A. Kiland and H. Pilkuhn, Phys. Letters 29B, 663 (1969).

19. I thank Dr. J. Allaby for this comment.

20. I thank Dr. Fred Zachariasen for a discussion on this point.

21. See Dr. A. R. Erwin's report to this conference analyzing data on pion production in pion-nucleon collisions.

22. Report of L. Lederman to the 4th International Symposium on Electron and Photon Interactions at High Energies, Liverpool, September 1969.

23. For a different interpretation see S. Berman, D. Levy, and T. Neff, Phys. Rev. Letters 23, 1363 (1969). For a different application to photoproduction with a large momentum transfer as opposed to a large mass Q^2 see J. Bjorken and E. Paschos, Phys. Rev. 185, 1975 (1969).

24. S. Drell and T.-M. Yan, to be published.

25. S. Drell, D. Levy, and T. M. Yan, Report No. SLAC-PUB-685 (1969), to be published in Phys. Rev.

26. T. T. Wu and C. N. Yang, Phys. Rev. 137, B708 (1965).

27. H. Abarbanel, S. Drell, and F. Gilman, Phys. Rev. 177, 2485 (1969).

28. See report to this conference by M. Derrick.

29. J. Ballam *et al.*, Report No. SLAC-PUB-728 (1970), to be published. F. Gilman *et al.*, Report No. SLAC-PUB-719 (1970), to be published.

30. T. T. Chou and C. N. Yang, Phys. Rev. Letters 20, 1213 (1968); Phys. Rev. 170, 1591 (1968). L. Durand and R. Lipes, Phys. Rev. Letters 20, 637 (1968).

31. For a more detailed discussion of the experimental possibilities and theoretical factors see Vol. 3 of the N.A.L. 1968 Summer Study (p. 327, "Remarks on Experiments at N.A.L., by S. D. Drell, Report T-68-107).