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Jan W. Dash and S. T. Jones

July 12, 1976

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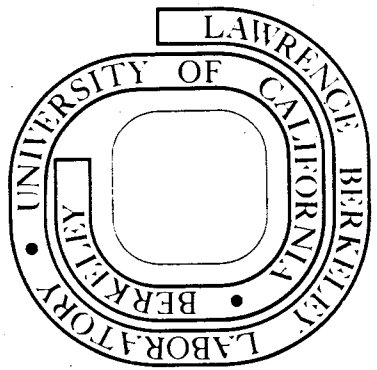

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RISING TOTAL CROSS SECTIONS AND THE FLAVORING OF THE POMERON*†

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ABSTRACT

The relationship of the non-diffractive renormalization of the bare Pomeron via $K\bar{K}$ and $B\bar{B}$ production - or its "flavoring" by λ quark loops and di-quark loops - and the shape of the NN total cross section is studied in some detail. The "unflavored" bare Pomeron $\hat{P}$ generated by nonstrange quark loops with intercept $\hat{\alpha} = 0.85$ is non-diffractively renormalized into the "flavored" (Gribov) bare Pomeron P with intercept α above one ($\alpha = 1.06$ here). We utilize inclusive data on $K\bar{K}$ and $B\bar{B}$ production as well as inelastic diffraction to constrain parameters, and we fit the combination $1/2\ (\sigma_{pp} + \sigma_{p\bar{p}})$ from $s = 10\ GeV^2$ through ISR energies, including the new Fermilab data, to high accuracy. No pronounced long wavelength oscillations are observed. We suggest that these data favor the Chew-Rosenzweig realization of the topological expansion over that of Harari-Freund. We show that our scheme is consistent with the rising behavior of $2\sigma_{KN} - \sigma_{\pi N}$.

The nature of the rise in total cross sections has been a source of theoretical uncertainty. Gribov's Reggeon field theory[1] (RFT) is consistent with the infinite energy behavior $(\ell ns)^{\eta}$ with $0 < \eta \leq 2$, and the Eikonal model[2] yields the same form with $\eta = 2$. However, in the finite energy region of FNAL-ISR both theories probably reduce to finite and highly truncated series[2,3]. A common feature of both approaches involves the use of a first approximation $\sigma \approx \beta\, s^{\alpha - 1}$ to the total cross section σ. This corresponds to a bare pole P in an approximate partial wave amplitude $A_j = \beta(j - \alpha)^{-1}$. Absorptive P cuts of various kinds are then added (self-interacting for the RFT result and disconnected non-self-interacting for the Eikonal result). The parameter α is required to be above one because the cuts are absorptive and σ rises at high energies.

An apparently different idea correlates the rise in σ with the experimental observation of the rise in inelastic production of pairs of particles ($K\bar{K}$, $B\bar{B}$) possessing quantum numbers (strangeness, baryon number) not found at low energies to any appreciable extent[4,5]. The simplest multiperipheral realization of this approach uses inherent t_{min} kinematic effects to provide the delayed effective thresholds.

Our purpose here is to examine this second approach in greater detail than has been done previously. We do not mean to imply that our calculation will be inconsistent with the first approach. On the contrary, we believe that the correct interpretation is a mélange of all the ideas. The key to the resolution lies in the observation that the bare Pomeron can undergo non-diffractive renormalization - which we shall call "flavoring" - as well as diffractive renormalization due to j-plane cuts. The nomenclature "flavoring" arises from the different

quark flavors, e.g. strangeness. At low energies, the "unflavored" bare Pomeron $\hat{P}$ is visualized as being generated by iterating non-strange quark q loops - i.e. the unitarity sum contains only non-strange particles away from the fragmentation region. This is due to the suppression of strange quark λ loops (i.e. of $K\bar{K}$ production) due to the higher mass of the λ over the q and some dynamical mechanism (e.g. t_{min} effects). Indeed, production of $K\bar{K}$ pairs is observed[6] to be an insignificant effect below some effective threshold (around $s = 40$ GeV^2). Above this energy λ quark loops occur and the bare Pomeron becomes "flavored" by them. The same effect occurs for $B\bar{B}$ pair production, with a somewhat higher effective threshold, corresponding to the suppression of diquark (qq) loops. We shall (somewhat loosely) use the word flavoring for this effect as well. Of course, one can go on to add charmed quark loops. It is possible that flavoring by these (and any higher mass quarks) have an insignificant effect even at very high energies so that the Pomeron flavoring converges rapidly. The completely flavored bare Pomeron is the Gribov bare Pomeron[3].

It is important to keep in mind that the flavoring renormalization takes place within traditional Reggeon language, i.e. the intercept is not energy dependent. What happens is that the unflavored and flavored poles occur in different approximate partial wave amplitudes; the Mellin transform generates the energy dependence, and a smooth transition occurs in energy. We shall see this explicitly later.

Our picture is that the unflavored bare Pomeron $\hat{P}$ has an intercept $\hat{\alpha}$ below 1. This is consistent with (and even suggested by)

two body data below $s = 60$ GeV^2 [7] and with inclusive $ab \to aX$ near $x = 1$[8]. With the onset of flavoring effects the $\hat{P}$ is renormalized into the P with intercept α above one yielding high energy rising cross sections. We shall see that the inclusive data constraining the flavoring and the shape of the total NN cross section are consistent. We shall not include any j-plane cuts, other than an absorptive inelastic diffraction term. Other cuts should be added. Our attitude is that we want to keep things simple. In the end we shall see that additional absorptive effects are indeed called for, i.e. more cuts will improve the calculation.

Quigg and Rabinovici[9] have made the interesting observation that the vacuum exchange piece of the combination $2\sigma_{KN} - \sigma_{\pi N}$ of total cross sections has a monotonically rising behavior, to which they ascribe a fundamental significance. We show that their interpretation is by no means required. Extending our NN results to make a simple assumption on the meson-baryon renormalizing thresholds, coupled with previous phenomenology[7], allows a description of these data also.

We close this section with some general remarks. The bare Pomeron is generated by the multiperipheral sum of planar and cylinder terms within the topological expansion[10]. Two schemes are consistent with this approach. The first due to Chew and Rosenzweig[11] corresponds to our parametrization, and an account of this is contained in Ref. (12). This approach identifies the f and Pomeron as the same object. The unitarized Harari-Freund scheme[10,13] makes a different assumption about the j-plane structure of the cylinder and produces a distinct Pomeron and f. We shall not dwell on the formidable

difficulties of phenomenologically distinguishing between these approaches. We only wish to state that flavoring is an effect that should be present in addition to topological arguments and questions of j-plane singularities in the cylinder kernel. We believe, in fact, that the substantial flavoring indicated by the data favors the Chew-Rosenzweig approach over that of Harari-Freund. This is because the pole renormalization effects due to flavoring are on the order of $\Delta\alpha = 0.2$. Such an effect cannot be accomodated by the more traditional scheme almost by construction, relying as it does on a leading singularity practically at 1 and not undergoing any significant renormalization of any sort. Thus, the Harari-Freund scheme requires the simultaneous existence of some absorptive effect to cancel out the flavoring renormalization. It is probably very difficult to arrange this without spoiling simple j-plane structure. We, along with other authors[4], believe that subenergy unitarity considerations[14] cannot prevent flavoring without breaking down the whole picture of simple Regge phenomenology at moderate (e.g. BNL) energies[15]. We see no general reason why unitarity, which is by no means saturated at present energies, should prevent flavoring renormalization. Indeed, we are in some sense merely counting different types of quark loops whose mass splittings provide the relevant thresholds. We find this a satisfying parallel to quark model phenomenology in general.

We now proceed with the model, a treatment closely following earlier work[4,5]. We write the approximate t-channel $I = 0$ positive signatured partial wave amplitude $A_j(t)$ at $t = 0$ as

$$A_j = N_j / D_j \tag{1}$$

Here

$$D_j = j - \hat{\alpha} - \frac{g_K e^{-b_K j}}{(j - j_K)^{n_K}} - \frac{g_B e^{-b_B j}}{(j - j_B)^{n_B}} \tag{2}$$

and

$$N_j = \beta e^{-b_Q j} \left[1 + \frac{g_\Lambda e^{-b_\Lambda j}}{(j - j_\Lambda)^{n_\Lambda}} - \frac{g_D e^{-b_D j}}{(j - j_D)^{n_D}} \right] \tag{3}$$

We shall explain the significance of the parameters momentarily.

The Mellin transform of A_j is given by

$$T(s) = \int_{c - i\infty}^{c + i\infty} \frac{dj}{2\pi i} \left(\frac{s}{s_o}\right)^j A_j \tag{4}$$

$T(s)$ is our approximation to the forward absorptive amplitude related to the vacuum exchange part of the total cross section σ by $T(s) = s\sigma(s)$.

A generalization of the following formula will be used when σ is decomposed into its partial cross sections

$$\int_{c - i\infty}^{c + i\infty} \frac{dj}{2\pi i} \left(\frac{s}{s_o}\right)^j \frac{e^{-bj}}{(j - \alpha)^{n+1}} = \theta(Y) e^{\alpha Y} \frac{Y^n}{n!} \tag{5}$$

where $Y = \ln(s/s_o) - b$. The θ function produces the effective thresholds. This is a particularly simple type of threshold, and is clearly not exact since (e.g.) small amounts of $K\bar{K}$ and $B\bar{B}$ production are observed even at low energies.

0 0 0 0 4 6 0 9 7 8

Equation (5) shows that we can soften the shape above a hard threshold by increasing n. The factors $(j - j_i)^{-n_i}$ in eqs. 2, 3 satisfactorily accomplish this with $n_K = n_B = 1$ and $n_\Lambda = n_D = 2$. There are dynamic and kinematic sources for singularities in N_j and D_j within multiperipheral dynamics, e.g. Regge-Regge cuts near $j = 0$ coupling onto a produced $X\bar{X}$ pair, a pole at $j = 0(m_\pi^2)$ from pion exchange[16], nonsense poles, etc. We shall simply regard them as phenomenological constructs accompanying our somewhat unrealistic hard thresholds. We shall set $j_K = j_B = 0$ and $j_D = 2\hat{\alpha} - 1$, $j_\Lambda = 2\alpha_{K^*} - 1$, the latter being the positions of the $\hat{P} \times \hat{P}$ and $K^* \times K^*$ cuts.[17]

Using these equations yields the familiar results[3,7] that at low energies, $T(s)$ is described by the unflavored pole $\hat{P}$ in the unrenormalized $A_j(g_i = 0)$ amplitude, with terms of $O(g_i)$ appearing at increasing energy. Equivalently, one may describe the amplitude $T(s)$ by the flavored pole in A_j along with an appropriate number of secondary complex poles. The perturbation expansion in the g_i is utilized to produce the $\langle n \rangle$ distributions. For example, g_K^n produces n $K\bar{K}$ pairs (either K^+K^- or $K^0\bar{K}^0$). The coupling g_B represents both $p\bar{p}$, $n\bar{n}$ production and possible annihilation effects[4,5]. g_D and g_Λ are couplings for inelastic diffraction $pp \to pX$ (with the absorptive sign) and associated production $pp \to (\Lambda,\Sigma\ldots)KN$.

We now confront the data[6,18], constraining g_i, b_i ($i = \Lambda$, K, B) by the sizes and effective thresholds of the inclusive K^+, K^- and $\bar{p}$ production data[19], while g_D, b_D are chosen to give qualitative agreement with conventional estimates of inelastic diffraction[20,21]. The parameters β and b_o are constrained by σ at low energies,

while $\hat{\alpha} = 0.85$ was fixed in conformity with previous phenomenology[7,8]

The results for σ are shown in fig. 1. Very good agreement with experiment is found from low energies through ISR energies. Attention should be drawn to several points. First, no pronounced oscillations are present. This is in opposition to statements which have appeared in the literature[22]. It means that the perturbation series in g_i is more accurate than the truncated series of the P and a single pair of secondary complex poles (here located at 0.16 ± 1.0 i). Secondly, the flatness of σ in the Fermilab region is correlated with the gradual rise of $B\bar{B}$ production. These data coupled with the gradual rise at ISR may present difficulty for more conventional approaches[9].

The relative contributions of the various terms to σ at 200 GeV/c are $\sigma(\hat{P})$ = 29.6 mb, σ_K = 11.9 mb, σ_B = 2.4 mb, σ_Λ = 1.8 mb and σ_D = -5.3 mb, where $\sigma_i \propto g_i$. In our parametrization the rise in the cross section is due to $B\bar{B}$ production, but the high energy cross section has a substantial part composed of events that have at least one $K\bar{K}$ pair. The bare flavored P energy dependence (whose intercept turned out to be $\alpha = 1.06$) is softened through ISR energies by the diffractive term[3].

In fig. 2 the results for the inclusive production of K^+, K^- and $\bar{p}$ are shown. The data are indicated by pluses, minuses and dots, respectively[6, 19]. The curves predicted by the model are all qualitatively correct but are actually too low. In particular the $\bar{p}$ multiplicity curve shown assumes the complete absence of the annihilation effects mentioned earlier. If these effects are present (and they probably should be present) the curve would be lowered

still further since the model would predict that fewer $\bar{p}$'s would actually be seen. This implies that there is indeed room for additional absorptive effects (i.e. j-plane cuts) which we have left out. Additional absorptive cuts will allow more positive $K^{\pm}$, $\bar{p}$ production in the model. In any case it is clear that the flavoring effect as we have described it is very substantial. We believe that it should be included in any discussion of diffraction.

We close with a short description of the meson-baryon cross sections. For illustration we choose a generic softened renormalizing threshold term, equal in both $\sigma_{\pi N}$ and σ_{KN}, of the form

$$\delta\sigma = 1.8 p^{\hat{\alpha}-1} (\ln p - b)^2 \theta(\ln p - b)\ \text{mb} \qquad (6)$$

where $p = p_{lab} / 1(\text{GeV/c})$ and $b = 2.9$. For $p \leq 30$, $\delta\sigma$ is less than 2% of $\sigma_{\pi N}$ or σ_{KN}. Using parameters for the $\hat{P}$ pole and the $\hat{P} \times \hat{P}$ cut strengths identical to within 2% to those of the global fit of Ref. 7[23, 24], we obtain the results shown in fig. 3 for $2\sigma_{KN} - \sigma_{\pi N}$. The agreement of this somewhat oscillatory curve with the data is reasonable. The increasing tendency of the data is reproduced by the combined $\hat{P}$, $\hat{P} \times \hat{P}$, and $\delta\sigma$ terms. The descriptions of $\sigma_{\pi N}$ and σ_{KN} separately are of similar quality. Below $p = 150$, $\delta\sigma$ is too small. The reader who has followed us up to now should agree that the form of $\delta\sigma$ used is undoubtedly too simple. A more detailed analysis is presently underway. Nonetheless the simple exercise shows that the hypothesis of the Pomeron - f identity coupled with flavoring can provide a perfectly plausible interpretation of these data.

0 0 0

and the f. Since flavoring renormalization effects are on the order $\Delta\alpha = 0.2$, the latter is equivalent to an unflavored cylinder pole near the $\hat{P}$ which along with the planar f around 1/2 would supposedly describe low energy data. We find neither of these possibilities esthetic or viable, and conclude that the Pomeron-f identity is more attractive.

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15. Basically the reason is that if, as a function of a subenergy s_i in a multiperipheral chain, one piece of the kernel $K(s_i)$ decreases to offset a large rising threshold effect at $s_i \geq M_o^2$, then $K(s_i)$ must be large for $s_i \leq M_o^2$ also. This will destroy simple Regge behavior at those moderate values of the total energy s such that K cannot be iterated (t_{min} effects are important for such calculations). On the other hand if K is allowed to have a high mass enhancement, renormalization occurs, consistent with Ref. 14.
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21. The values of these parameters were $\beta = 859$, $g_D = 0.1$, $b_D = 0.91$, $g_\Lambda = 0.14$, $b_\Lambda = 0.2$, $g_K = 0.5$, $b_K = 1.2$, $g_B = 2.1$, $b_B = 3.0$. Also $j_D = 0.7$, $j_\Lambda = -0.6$, $b_o = 1.8$, and $s_o = 1$ GeV^2 were kept fixed.

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25. I.e., one would like to have an explicit multiperipheral amplitude yielding the correct b_X for $X\bar{X}$ production. We note that the corresponding effective threshold M^2_{oX} in the kernel may well have to be high in order to accomplish this. For example in pion exchange models the $\pi\pi \to K^*K^*$ kernel may be more important than $\pi\pi \to KK$. For a general discussion of threshold factors, see refs. 3, 16.

26. The reason that the Pomeron can be renormalized at the K, $\bar{p}$ flavoring thresholds and not, e.g. at the 16π threshold is that the latter can be regarded as a multiperipheral iteration of a single cluster whereas the former cannot.

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FIGURE CAPTIONS

Fig. 1. Results for $\sigma = 1/2\,(\sigma_{pp} + \sigma_{p\bar{p}})$.

Fig. 2. The multiplicities for K^+, K^-, and $\bar{p}$ compared with the data from Ref. 6 normalized to 32 mb. The errors on the data (not shown) are 10-15%.

Fig. 3. Results for $2\sigma_{KN} - \sigma_{\pi N}$.

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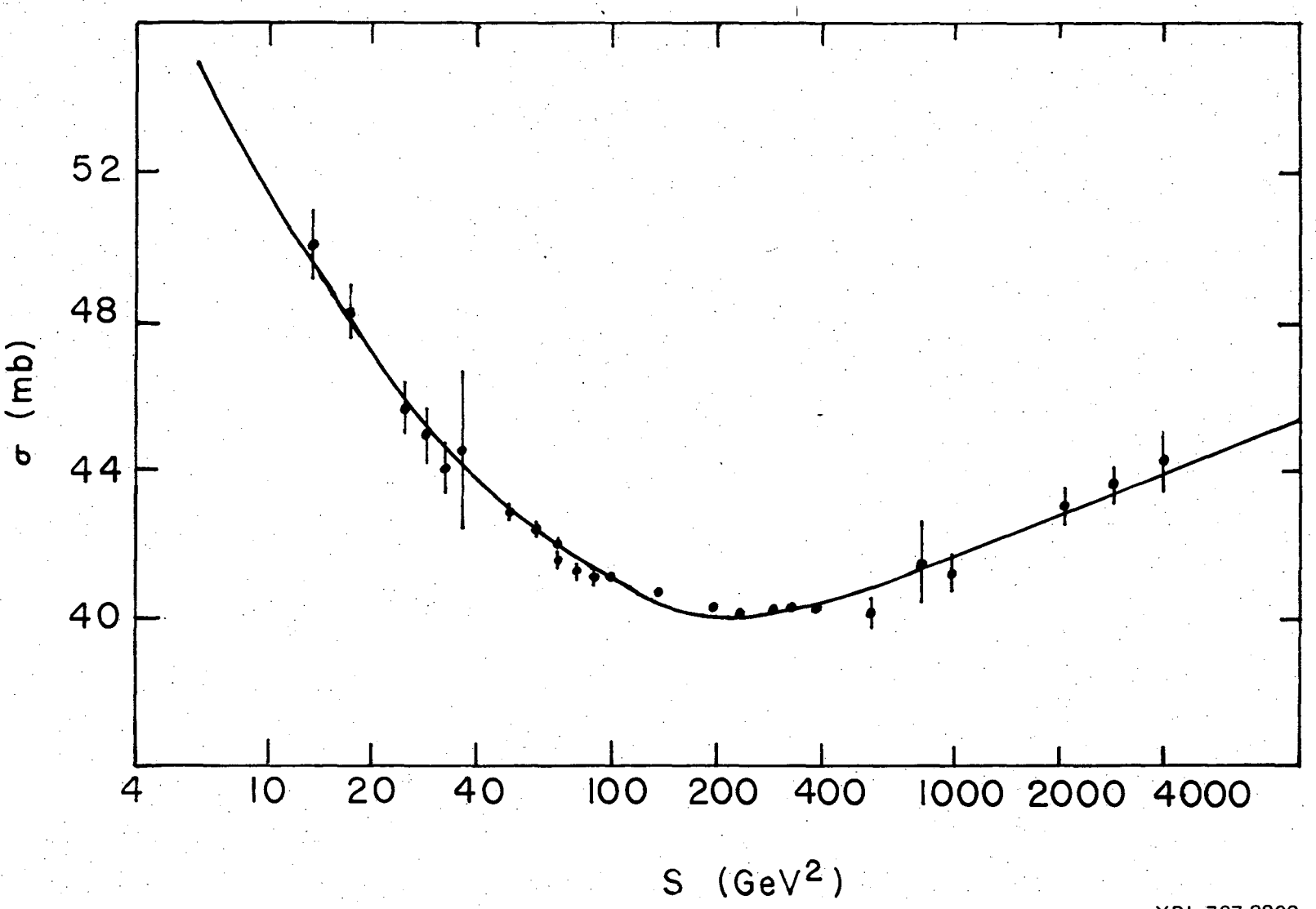

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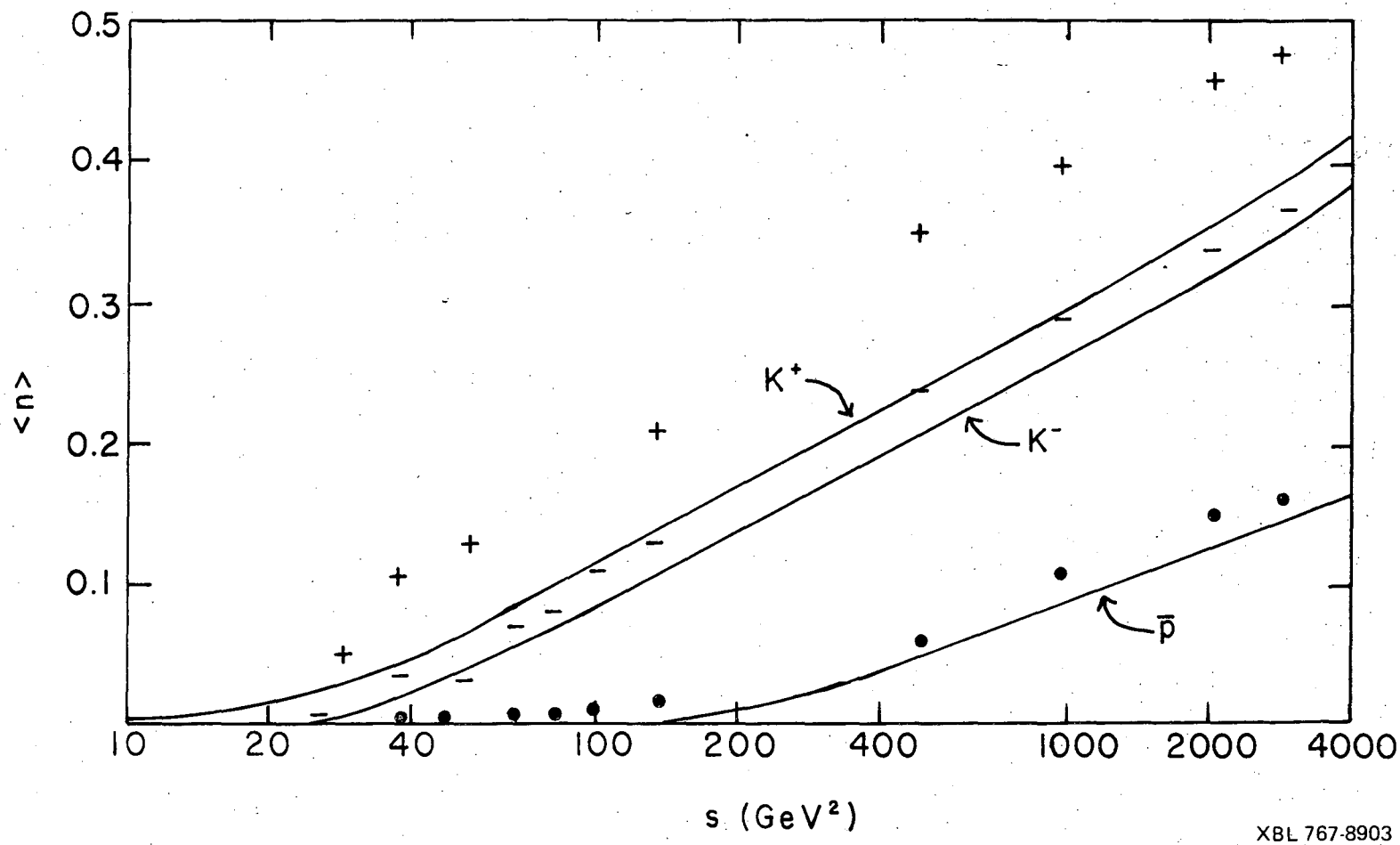
0.5
0.4
0.3
0.2
0.1
$\langle z \rangle$
K^+
K^-
$\bar{p}$
10
20
40
100
200
400
1000
2000
4000
s (GeV²)
XBL 767-8903

Fig. 12

0 0 0 0 4 6 0 0 9 8 2

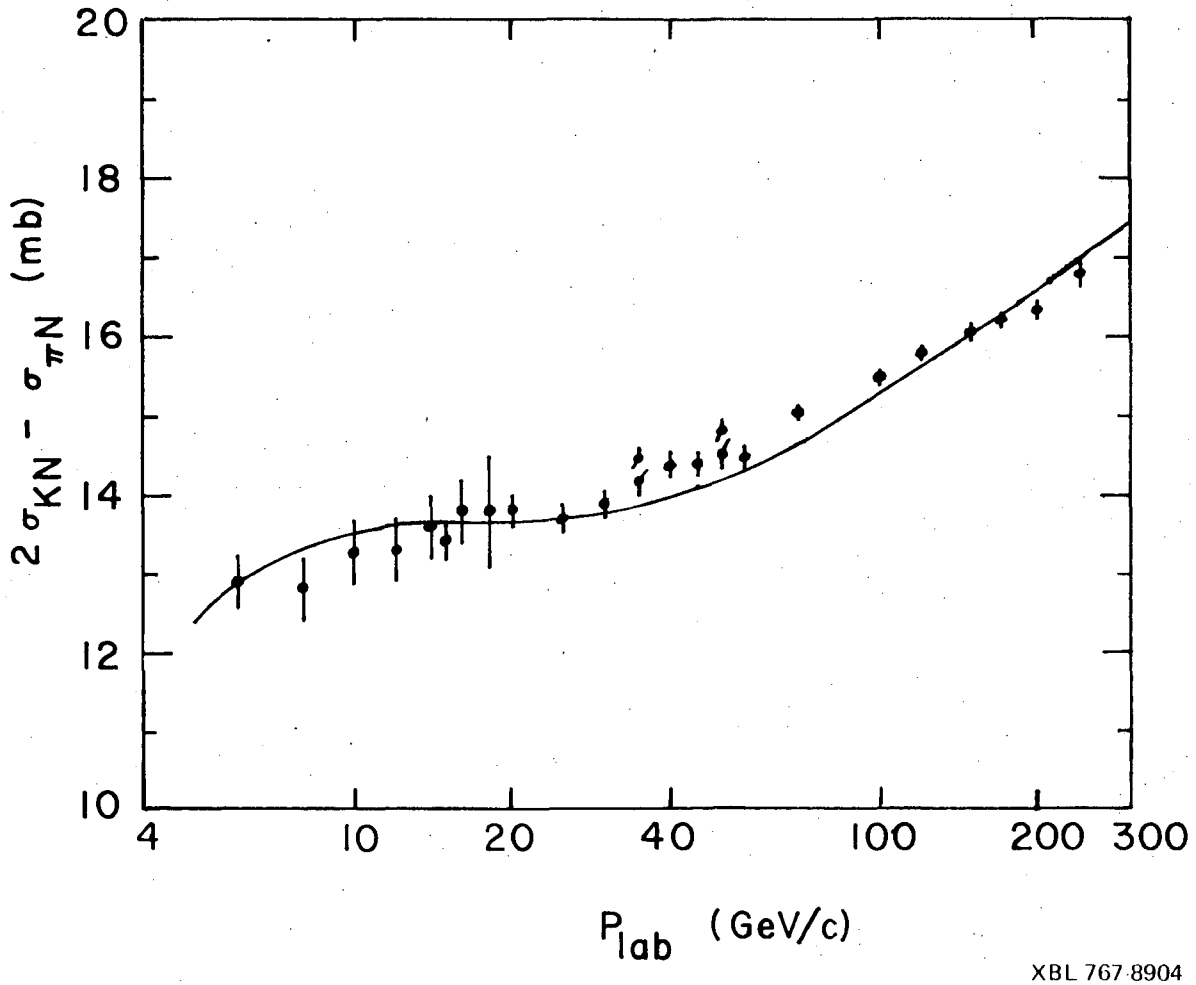

Fig. 3

0 0 0 4 6 0 0 9 8 3

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