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UNIVERSALITY OF CHARGED MULTIPLICITY DISTRIBUTIONS

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ABSTRACT

We show that the charged multiplicity distributions of the diffractive and non-diffractive components of hadronic interactions, as well as those of hadronic states produced in a variety of other reactions, follow a universal function which depends only on the mass available for pionization. This function is Gaussian, peaks at $n_o \cong 2M^{\frac{1}{2}}$, where M is the available mass in GeV, and has a width $D = (\overline{n^2} - n_o{}^2)^{\frac{1}{2}}$ such that $n_o/D \cong 2$.

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It was reported recently[1] that the charged multiplicity distributions of high mass pion, kaon and nucleon states produced diffractively in the reaction

$$h + p \rightarrow X + p \quad (h = \pi^{\pm}, K^{\pm}, p^{\pm}) \tag{1}$$

are described well by a Gaussian function which depends only on the mass available for pion production, $M = M_x - M_h$, as follows:

$$P_n = \frac{2}{\sqrt{2\pi}\, D} \; e^{-\frac{(n-n_o)^2}{2D^2}}$$

$$n_o = 2M^{\frac{1}{2}} \tag{2}$$

$$n_o/D = 2 \;, \quad \text{where} \quad D = (\overline{n^2} - n_o{}^2)^{\frac{1}{2}}$$

For singly charged hadrons, at any given mass M, the sum of P_n over odd values of n should be normalized to unity. The nominal normalization constant given above is good to $\sim 1\%$. KNO scaling[2], which states that the product $P_n \cdot \langle n \rangle$ is a function of $n/\langle n \rangle$ only, is manifestly satisfied by Eq. 2, as can be seen by rewriting it as

$$P_n \cdot n_o = \sqrt{\frac{8}{\pi}} \; e^{-2\left(1-\frac{n}{n_o}\right)^2} \tag{3}$$

The diffractive data of Ref. 1 agree well with this formula. In comparing experimentally measured multiplicity moments with those calculated using Eq. 2, care must be taken to sum only over the allowed positive values of n. This prodedure increases the calculated average multiplicity and

decreases the width of its distribution so that $\langle n \rangle$ is generally somewhat larger than n_o and $\langle n \rangle / D$ greater than 2.

It is well known[3,4,5] that charged multiplicity data of inclusive hadronic reactions do not agree with Eq. 2. For example, for pp → anything[3,4,5,6], the increase of the average multiplicity with energy is slower than $2\ s^{1/4}$ (see Fig. 1a), the $\langle n \rangle / D$ ratio decreases as the energy increases (see Fig. 1b), and the KNO distribution of the data is asymmetric about $n/\langle n \rangle = 1$ (see Fig.2), in disagreement with Eq. 3. On the other hand, data on e^+e^- → anything are consistent[7] with $\langle n \rangle = 2\ s^{1/4}$ (see Fig. 3) and their KNO scaling curve is symmetric[8].

In this paper, we analyze the inclusive pp → anything charged multiplicities, recognizing that they derive from two distinct parts of the inelastic cross section: the diffractive component, for which the available mass is $M = M_x - M_p$, and the non-diffractive "hard core" for which $M = \sqrt{s} - 2M_p$. We then find that Eq. 2, which describes well the diffractive multiplicities, also provides a good description of the multiplicities of the hard core. After an examination of data from several other reactions, we come to the conclusion that the distribution represented by Eq. 2 is universal, describing to a good approximation all known hadronic charged multiplicities up to and including ISR energies. This suggests that gluons may play an important role in the hadronization process. Small differences in the multiplicities between certain reactions, such as between pp and $\bar{p}p$, which cannot be explained by our procedure of applying Eq. 2 at the appropriate available mass of each identifiable component of the inelastic cross section, may then be attributed to the difference in the quark content of the initial states.

The total, elastic, and inelastic pp cross sections are shown in Figure 4. The inelastic cross section is consistent[9] with being composed of a hard core, σ_o = 26.3 mb, and a diffractive component, σ_D , which consists of the contribution of single diffraction dissociation, $2\sigma_{SD}$, and that of double diffraction dissociation, σ_{DD} :

$$\sigma_i = \sigma_o + 2\sigma_{SD} + \sigma_{DD} \tag{4}$$

In calculating charged multiplicity distributions, we assume that the inelastic cross section in excess of σ_o is all due to single diffraction dissociation with a $1/M_x^2$ mass dependence. The double diffractive process which becomes important only at very high energies, is approximated well by this assumption, since there is only a small probability for both diffractive masses to be large. Multiplicity distributions for pp are then generated using Eq. 2 separately for the diffractive and non-diffractive components at the appropriate available mass:

$$P_{\substack{n+2 \\ (n=0,2,4\ldots)}} = \frac{1}{\sigma_i}\left[\sigma_o P_{n+2}(\sqrt{s}-2M_p) + \frac{\sigma_D}{\ln(0.1s)}\int_1^{0.1s} \frac{1}{M_s^2} P_{n+1}(M_x-M_p)\, dM_x^2\right] \tag{5}$$

The average multiplicity, the $\langle n \rangle/D$ ratio and the KNO distribution calculated using this equation are in good agreement with the data, as shown in Figure 1 and 2. For $\bar{p}p$, we add the annihilation cross section, $\bar{\sigma} = \sigma_T(\bar{p}p) - \sigma_T(pp)$, to the pp inelastic cross section and use the distribution

$$P_n = \frac{1}{\sigma_i}\left[\sigma_o P_n(\sqrt{s} - 2M_p) + \frac{\sigma_D}{\ln(0.1s)}\int_1^{0.1s} \frac{1}{M_x^2}\, P_{n-1}(M_x - M_p)\, dM_x^2 + \bar{\sigma}\, P_n(\sqrt{s})\right] \quad (6)$$

where the second term is not included for $n=0$. The $\langle n \rangle$ and $\langle n \rangle/D$ calculated using this distribution function agree well with the data[4,10] (see Figure 1). However, at high energies, there remains a small but significant difference between the average pp and $\bar{p}p$ multiplicities which is not predicted by the equations given above. If this difference were due to the annihilation cross section, its average multiplicity would have to be larger than $2s^{1/4}$ by more than 50%. We prefer the interpretation that this disparity arises from a small difference in the pp and $\bar{p}p$ hard cores and that the annihilation multiplicities follow the distribution given by Eq. 2.

A similar analysis of $pp \rightarrow$ anything in terms of diffractive and non-diffractive components was performed previously[11] and led to the same conclusions about the multiplicities of the hard core. More recently, an ISR experiment[12] which removed leading particle effects obtained similar results. Our contribution in this area is that we have demonstrated that the same function that describes the multiplicity distribution of diffractive high mass states also describes the pp and $\bar{p}p$ hard cores and $\bar{p}p$ annihilation.

By applying the same ideas to $\pi^{\pm}p$ reactions, treating the non-diffractive inelastic cross section as a hard core with available mass $M = \sqrt{s} - M_p$, we have obtained good agreement of our calculated $\langle n \rangle$, $\langle n \rangle/D$ and KNO scaling distributions with existing data. We have also

investigated the reactions $\nu_\mu + p \to \mu^- + X^{++}$ and $\bar{\nu}_\mu + p \to \mu^+ + X^o$. Again, the multiplicity distributions reported for these reactions[13] are in good agreement with our predictions. In particular, the higher average multiplicity and $\langle n \rangle / D$ ratio of X^{++} relative to that of X^o arise naturally as a consequence of summing over $n = 2,4,6...$ for X^{++} and $n = 0,2,4...$ for X^o. A determination[14] of the average multiplicity of the state X in $pp \to \mu^+\mu^- X$ at ISR is also consistent with $2s^{1/4}$ behavior.

Recently, two $\bar{p}p$ experiments being performed at the CERN SPS Collider at $\sqrt{s} = 540$ GeV reported the values 3.9 ± 0.3[15] and 3.0 ± 0.1[16] for $d\langle n \rangle / d\eta|_{\eta=0}$, the average charged multiplicity per unit rapidity in the central region. At ISR energies, the values of the rapidity plateau are lower. Typically, at $\sqrt{s} = 30.8$ and 62.8 GeV, $d\langle n \rangle / d\eta|_{\eta=0} = 1.67$ and 2.03, respectively[5]. Since the rapidity interval increases with energy as ℓns and the charged multiplicity as $s^{1/4}$, we expect $d\langle n \rangle / d\eta$ to vary as $Cs^{1/4}/\ell ns$. Setting $C = 2.1$ gives 1.71, 2.00 and 3.91 at $\sqrt{s} = 30.8$ 62.8 and 540 GeV, in excellent agreement with the ISR measurements and the SPS Collider result of Ref. 15.

In conclusion, we find that the distribution represented by Eq. 2 provides a good description of the charged multiplicities not only of high mass diffractive states but also of a wide variety of other hadronic states where the available mass for pionization can be identified. This universality of the multiplicity distribution implies that the quark content of the dissociating state does not play an important role in determining the multiplicity and therefore it must be that the gluons dominate the process of hadronization.

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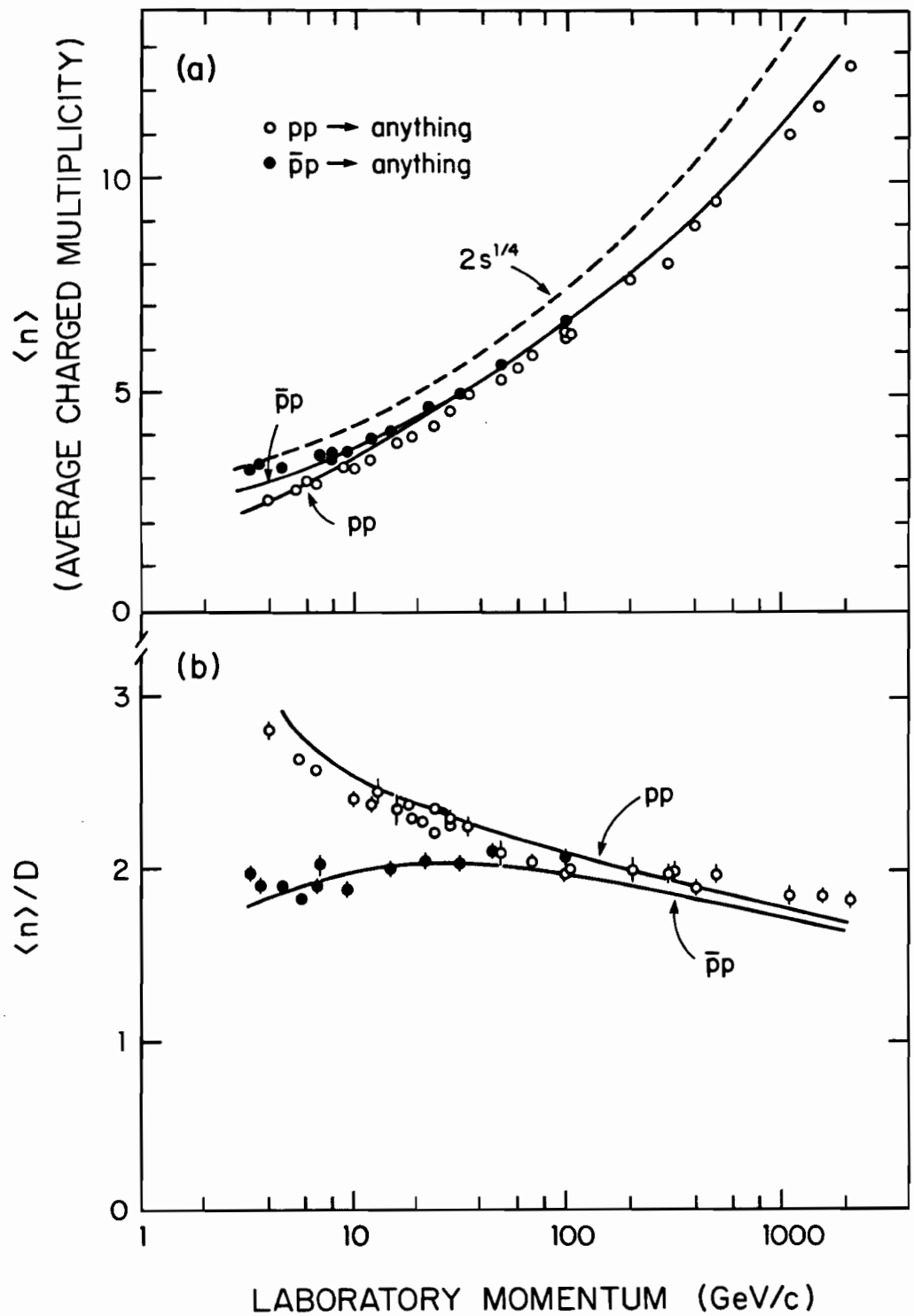
Figure Captions -

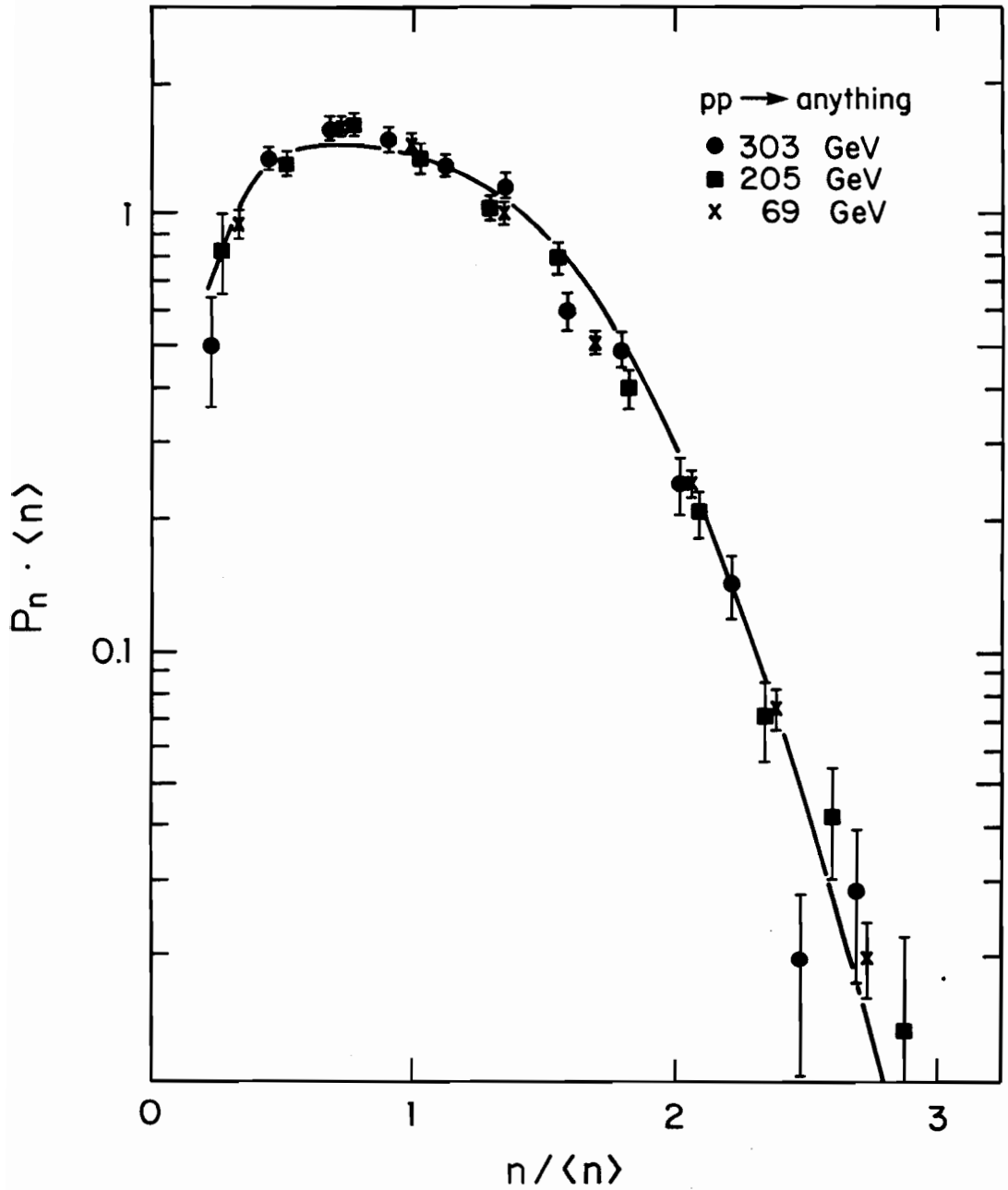
1. The average charged multiplicity and the ratio of the average to the width as a function of laboratory momentum for $pp \rightarrow$ anything and $\bar{p}p \rightarrow$ anything. The solid curves were calculated using Eqs. (5) and (6) in the text.

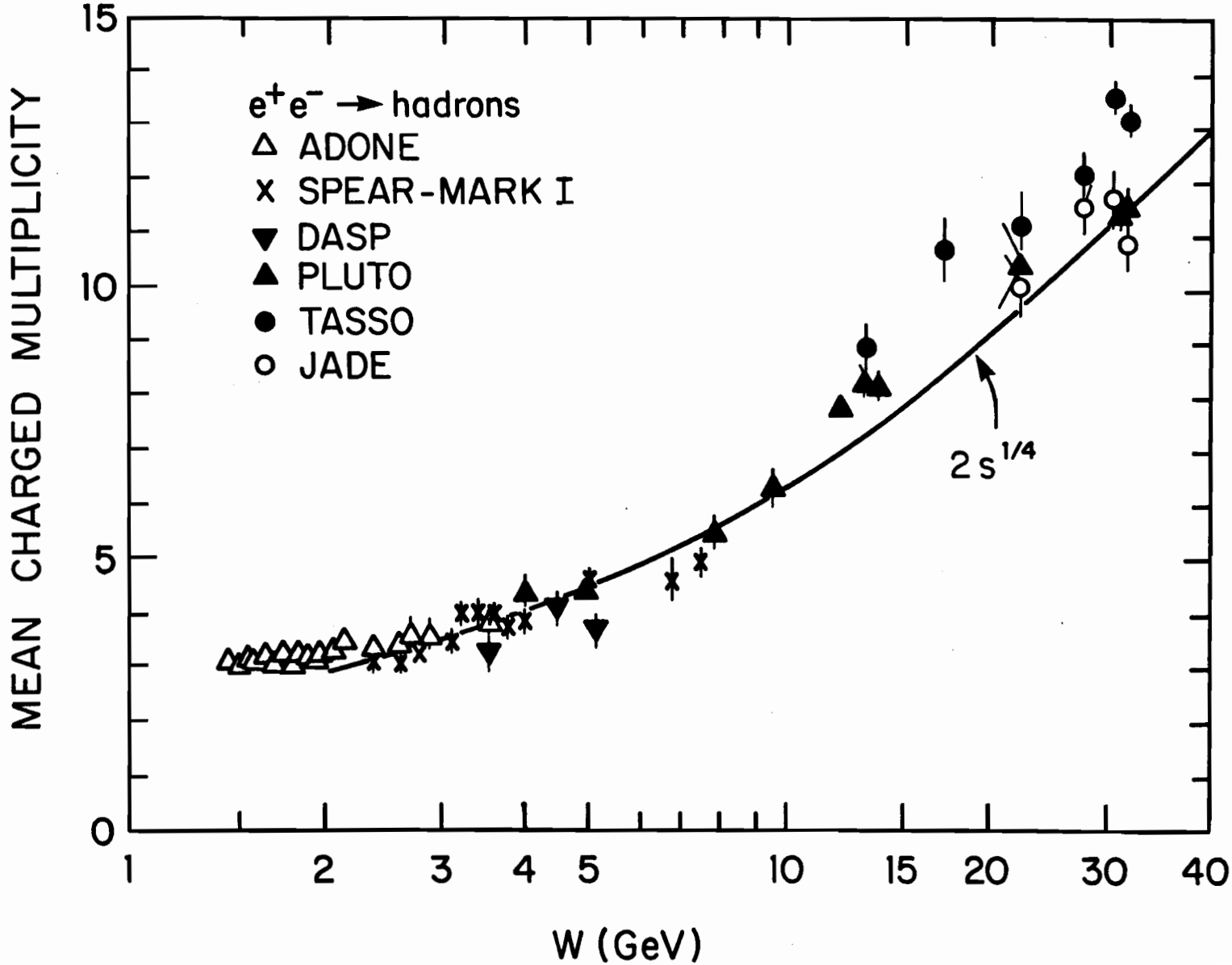
2. The product $P_n \cdot \langle n \rangle$ versus $n/\langle n \rangle$ for charged particles in $pp \rightarrow$ anything. The curve was calculated using Eq. (5) in the text.

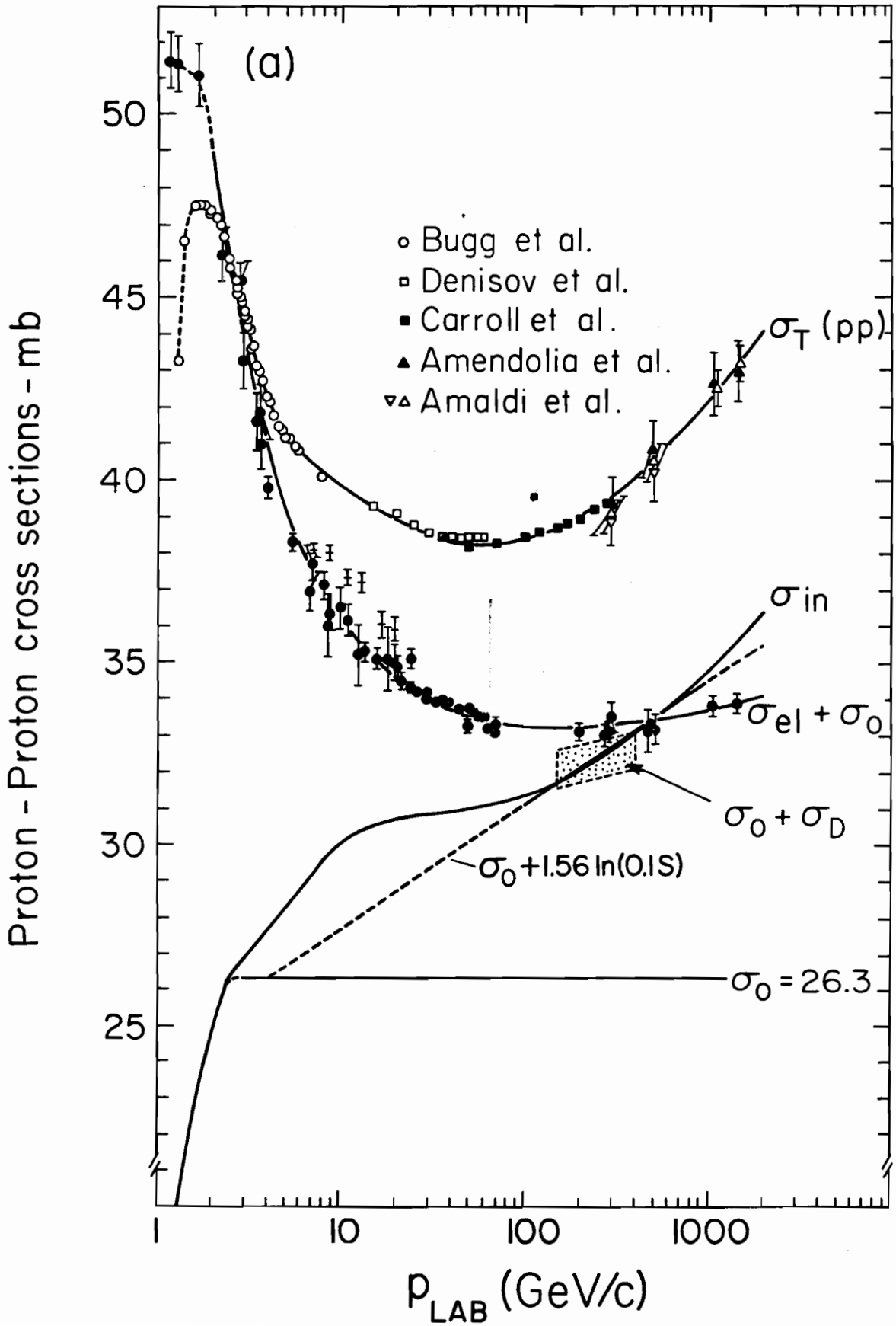
3. Mean charged multiplicity versus available energy for $e^+e^- \rightarrow$ anything.

4. The total, the elastic and the inelastic pp cross sections (from Ref. 9).


(a)
pp → anything
p̄p → anything
2s^1/4
p̄p
pp
⟨n⟩
(AVERAGE CHARGED MULTIPLICITY)
0
5
10
(b)
pp
p̄p
⟨n⟩/D
0
1
2
3
1
10
100
1000
LABORATORY MOMENTUM (GeV/c)


pp → anything
● 303 GeV
■ 205 GeV
× 69 GeV
1
0.1
$P_n \cdot \langle n \rangle$
0
1
2
3
$n/\langle n \rangle$


$e^+e^- \rightarrow$ hadrons
ADONE
SPEAR-MARK I
DASP
PLUTO
TASSO
JADE
$2s^{1/4}$
MEAN CHARGED MULTIPLICITY
W (GeV)
0
5
10
15
1
2
3
4
5
10
15
20
30
40


(a)
Bugg et al.
Denisov et al.
Carroll et al.
Amendolia et al.
Amaldi et al.
σ_T (pp)
σ_{in}
$\sigma_{el} + \sigma_0$
$\sigma_0 + \sigma_D$
$\sigma_0 + 1.56 \ln(0.1S)$
$\sigma_0 = 26.3$
Proton - Proton cross sections - mb
50
45
40
35
30
25
1
10
100
1000
p_{LAB} (GeV/c)