An Interpretation of the Multiplicity Distribution at 200 GeV/c*

Edmond L. Berger†
High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60439
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Data on charged-particle multiplicities in 200-GeV/c pp interactions are compared with data at lower energies and with predictions of current models. Fragmentation models are shown to be in substantial agreement with present results, but a multiperipheral view cannot be excluded. Further tests are suggested.

Advent of new data[1] on charged-particle multiplicities from 200-GeV/c pp interactions provides a unique opportunity to reassess the success of current models of multiparticle production and to suggest further studies to probe present understanding. A striking feature of the 200-GeV/c results is the very broad nature of the prong distribution σ_n versus n. As is discussed below, these relatively large fluctuations about the mean support a fragmentation picture[2] of collision phenomena, but they are still not inconsistent with a two-component view,[3] in which both multiperipheral[4] and diffractive processes contribute to particle production. Another notable aspect of the data is the energy dependence of σ_4, the four-charged-particle cross section, which falls roughly in proportion to $p_{\rm lab}^{-0.4}$ from 28 to 200 GeV/c.[5,6] This new result shows that the limiting diffractive (energy independent) contribution to small-multiplicity processes may be much smaller than postulated in some diffractive fragmentation models.[2]

A comparison of multiplicity distributions from pp interactions[1,5,6] at 28.5, 70, and 200 GeV/c is presented in Fig. 1. For purposes of illustrating the variation in shape of these prong distributions as energy changes, Poisson distributions are also given. It will be noted that at 28.5 GeV/c, the experimental σ_n is narrower than the corresponding Poisson form. At 70 GeV/c, the Poisson form gives an excellent fit. However, at 200 GeV/c, the data are flatter and broader than the corresponding Poisson form. A more quantitative way in which to state these results is to use correlation parameters, especially $f_2 \equiv \langle n(n-1)\rangle - \langle n\rangle$,[2] which is identically zero for a Poisson distribution. For negative tracks, $f_2 = -0.25 \pm 0.03$, 0.1 ± 0.1, and $+0.95 \pm 0.21$ at 28.5, 70, and 200 GeV/c, respectively.[1,5,6]

The relatively large values of σ_n for $n > \langle n\rangle$ at 200 GeV/c support the relevance at this energy of a fragmentation view of collision processes.[2] Indeed, the form $\sigma_n \propto 1/n^2$ is usually adopted for the asymptotic large-n behavior of σ_n in fragmentation models,[2] implying an asympotic behavior $f_2 \to +k\sqrt{s}$, where s is the square of the total c.m. energy. The trend of experimental values of f_2 from 10 to 200 GeV/c, and, in particular, the definitely positive value at 200 GeV/c, agree with calculations in the framework of the nova model,[7] a specific fragmentation model. By contrast, an independent emission view, or multiperipheral configuration with single emission of pions along a chain, invariably predicts distributions narrower than Poisson (e.g., $f_2 \to -|k| \log s$).[8] It is possible that consistency with these data may yet be obtained with a multiperipheral model in which clusters of two or three pions, rather than a single pion, are emitted along the multiperipheral chain. Another way in which to retain some features of a multiperipheral-Poisson description is to adopt the two-component—multiperipheral plus diffractive dissociation—model suggested by Wilson.[3] Such a model provides a mechanism for broadening prong distributions, and, in fact, an

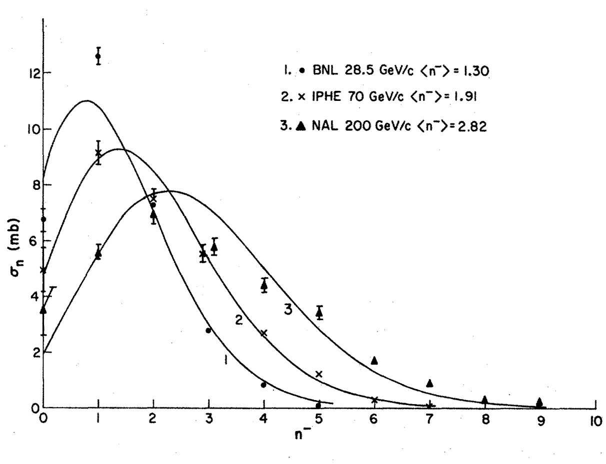

FIG. 1. Charged prong cross sections σ_n from pp interactions at 28.5 GeV/c (Ref. 5), 70 GeV/c (Ref. 6), and 200 GeV/c (Ref. 1) plotted versus the number of negative prongs $n_- = 0.5(n_{\rm ch} - 2)$. Also given for each momentum is a Poisson distribution $\sigma_n = \sigma_{\rm inel}\langle n\rangle^n \exp(-\langle n_-\rangle)/n!$ determined by the experimental $\langle n_-\rangle$ and normalized to the observed total $\sigma_{\rm inel}$.

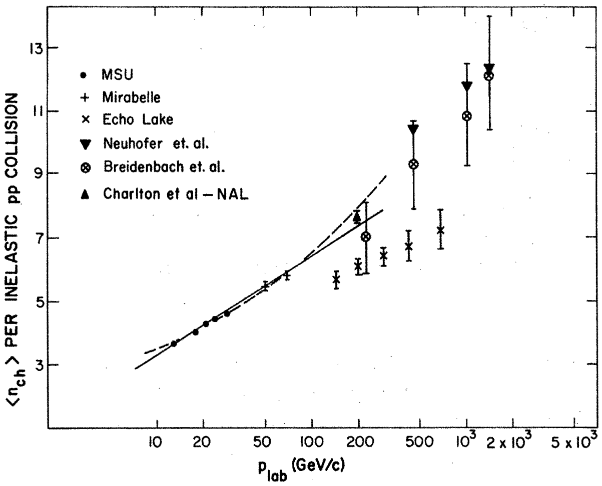

FIG. 2. Mean number $\langle n_{\rm ch}\rangle$ of charged tracks observed per inelastic pp interaction plotted versus lab momentum of the incident proton. Data are from Refs. 1, 5, 6, 9 and 10. Error bars (not shown) for data from Neuhofer *et al*. (Ref. 10) are comparable in size to those for points from Breidenbach *et al*. Solid curve, $-0.88 + 1.38 \log s$, results from minimum χ^2 fit to conventional accelerator data (Refs. 1, 5, 6); $\chi^2 = 8.9$ for 6 degrees of freedom. Dashed curve, $1.49 s^{0.28}$, $\chi^2 = 14$.

excellent fit to the 200-GeV/c data may be obtained in this framework after addition of ≈ 2 mb in σ_2 and in σ_4 to a Poisson distribution whose $\langle n_-\rangle = 3.4$. However, this large value of $\langle n_-\rangle$ implies a very small typical subenergy ($\bar{s}_i \approx 0.4$ GeV^2) in the multiperipheral chain,[4] an average spacing of only ≈ 0.4 between rapidity values of the particles, contrary to the spirit of the approach.

Values of mean charged multiplicity[1,5,6,9,10] $\langle n_{\rm ch}\rangle$ are compiled in Fig. 2. A fit to conventional accelerator data,[11] including the new 200-GeV/c point, with the simple form

$$\langle n_{\rm ch}\rangle = a + b \log s \qquad (1)$$

gives a reasonably good fit. The resulting curve is given in Fig. 2. The value $b = 1.38 \pm 0.02$ determined in the fit agrees quite well with $b = 1.4$ predicted in the nova model.[8] The value of $\langle n_{\rm ch}\rangle$ at 200 GeV/c, lying 6% above a best fit with Eq. (1) through lower-energy points only, indicates that the behavior of $\langle n_{\rm ch}\rangle$ versus $p_{\rm lab}$ is concave upwards (coefficient b increases with energy), a trend enforced by the points from the CERN intersecting storage rings (ISR) in Fig. 2. This important new conclusion about positive curvature in the behavior of $\langle n_{\rm ch}\rangle$ idffers from earlier conclusions of negative curvature based on comparison of Echo Lake data[7] with <30-GeV/c accelerator data. Another fit by the form cs^n to data with $p_{\rm lab} \leqslant 200$ GeV/c gives $c = 1.49$ and $n = 0.28$ for $\chi^2 = 14$. Data are thus consistent with an $\approx s^{1/4}$ or an $s^{1/3}$ multiplicity growth for $p_{\rm lab} < 200$ GeV/c, followed by a $\log s$ behavior at higher energies.[12]

Although both multiperipheral and fragmentation models are constructed to provide the asymptotic form $\langle n\rangle \approx \log s$, both can accommodate positive curvature of the type observed. In the multiperipheral framework, upward curvature signals *negative* coupling of secondary trajectories in the Mueller graph in the central region.[13] Negative coupling also predicts that, as energy increases, inclusive single-particle distributions in the central region should approach their scaling limit from below, as is observed in results from the ISR.[10,14] After expressing $\langle n\rangle$ as an integral over the single-particle inclusive distribution,

$$\langle n\rangle = \sigma_{\rm inel}^{-1} \int dy\, dp_T^2 \,(d^2\sigma/dy\,dp_T^2), \qquad (2)$$

and assuming the existence at large energy of a plateau in rapidity, we can also derive[15]

$$b = \sigma_{\rm inel}\,(d\sigma/dy)\big|_{\rm plateau\ value}. \qquad (3)$$

Previous determinationa of b based on Echo Lake multiplicity values[7] gave $b \simeq 0.9$, consistent with values of $\sigma_{\rm inel}^{-1}\, d\sigma/dy$ near 30 GeV/c.[15] However, the new larger value of b forced by Serpukhov[6] and the National Accelerator Laboratory data[1] is welcomed and required by the observation at ISR of a rapidity plateau[10,14] whose height is 1.5 to 2 times that at 30 GeV/c.

In contrast to $\langle n_{\rm ch}\rangle$, current models differ significantly in their predictions for energy dependence of $\langle n_{\rm ch}(n_{\rm ch}-1)\rangle$. In Fig. 3, values of $\langle n_{\rm ch}(n_{\rm ch}-1)\rangle$ are given as a function of energy. In this note,

$$\sigma_{\rm inel}\langle n_{\rm ch}(n_{\rm ch}-1)\rangle = \textstyle\sum_n n_{\rm ch}(n_{\rm ch}-1)\sigma_{n_{\rm ch}} \qquad (4)$$

is computed with respect to the total inelastic cross section. In fragmentation models,[2,8] because $\sigma_n \propto 1/n^2$ at large n, $\langle n(n-1)\rangle$ grows asymptotically as $\sqrt{s}$. In multiperipheral models and in two-component models, $\langle n(n-1)\rangle$ has leading behavior[3] $(\log s)^2$. To test these two predictions, fits to data in Fig. 3 (exclusive of Echo Lake points) were tried with two forms:

$$\langle n(n-1)\rangle = A + B\sqrt{s} \qquad (5)$$

and

$$\langle n(n-1)\rangle = C + D \log s + E(\log s)^2. \qquad (6)$$

With s measured in GeV^2, Eq. (6) can be considered as an expansion in terms of the dimensionless rapidity interval $\log s$. Both Eqs. (5)

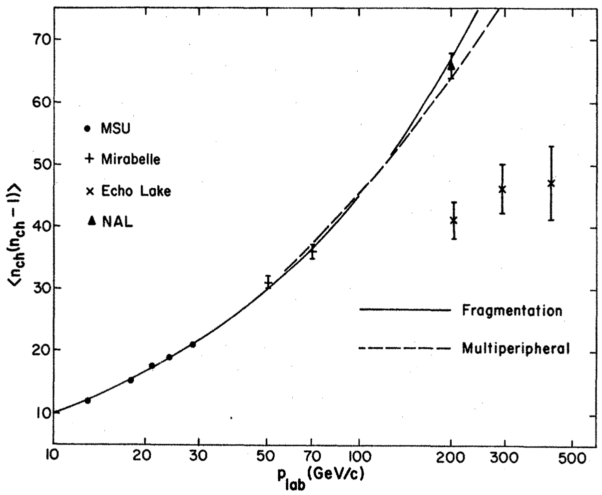

FIG. 3. Mean of $n_{ch}(n_{ch}-1)$ per inelastic pp interaction plotted versus lab momentum. Data are from Refs. 1, 5, 6, and 9. The two curves are fitted to accelerator data, Refs. 1, 5, and 6. The solid curve, with form suggested by fragmentation models, is $-7.56+3.84\sqrt{s}$ and has $\chi^2=5.5$ for 6 degrees of freedom. The dashed curve, as suggested by multiperipheral type models, is $22.5-15.7\log s+3.83(\log s)^2$ and gives $\chi^2=6.7$ for 5 degrees of freedom. Extrapolated values at 300 GeV/c are 83.7 (fragmentation) and 76.9 (multiperipheral).

and (6) give excellent fits. Resulting curves are shown in Fig. 3.

Purely on the basis of these numerical fits to $\langle n_{ch}(n_{ch}-1)\rangle$, it is impossible to choose between general fragmentation and multiperipheral-type approaches. However, it is worth inquiring whether the fitted values of parameters in Eqs. (5) and (6) have reasonable values. A specific fragmentation model exists which provides numerical values of A and B in Eq. (5) very close to those determined by the fit. Indeed, based on parameters of the nova model,[8] one obtains $\langle n_{ch}(n_{ch}-1)\rangle=63$ at 200 GeV/c, as well as agreement with lower-energy data. By the same token, it is not clear that the values of C,D,E in Eq. (6) determined by the fit can be reproduced from a reasonable multiperipheral model, with or without an additional diffractive component. In a pure multiperipheral approach, the relation $E=b^2$ constrains parameters in Eqs. (1) and (6). This is not supported by the best fits, where $E>b^2$, implying presence of a diffractive component. Second, the large negative value of D ($|D|\gg 2|a||b|$) in the fit may be worrisome in that a $\log s$ term (with positive coefficient) arises most simply from short-range correlations which are generally expected to be positive.[16] In sum, whereas a large experimental value of $\langle n_{ch}(n_{ch}-1)\rangle$ at 200 GeV/c was predicted by the nova fragmentation model, it remains an interesting challenge to see whether a multiperipheral-type model can be constructed to reproduce all the data shown in Figs. 1–3.

With current data, in an effort to discriminate between broad classes of models, it appears extremely valuable to investigate empirically the *structure of individual events* in, say, the 6- to 10-prong subsamples at 200 GeV/c. Basic to the fragmentation concept[28] is a picture in which particles in the final state cluster strongly together, with a large gap in rapidity separating clusters associated with target and projectile particles, respectively. Do typical individual events have this structure or are final-state particles ordered more uniformly along the rapidity axis, with large gaps relatively rare? The latter view is favored in models based on multiperipheral concepts[4] or on the gas analogy.[17] Rather than rapidity, it may be simpler to measure center-of-mass angles of charged tracks, with respect to the initial beam direction. The question then becomes: In each event, does one find predominantly large and small angles, or else a complete spectrum? A rapidity distribution analysis of low-multiplicity events may also allow separation of the diffractive component from cluster formation with quantum-number exchange, which is relatively important at 28.5 GeV/c.[18]

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†Address after September 1972: Theory Division, CERN, Geneva, Switzerland.

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Search for Narrow Resonances in the *R* Region

D. Bowen, D. Earles, W. Faissler, D. Garelick, M. Gettner, M. Glaubman, B. Gottschalk, G. Lutz, J. Moromisato,* E. I. Shibata, Y. W. Tang, E. von Goeler, and R. Weinstein
Northeastern University at Boston, Boston, Massachusetts 02115†

and

H. R. Blieden,‡ G. Finocchiaro, J. Kirz,§ and R. Thun
State University of New York at Stony Brook, Stony Brook, New York 11790‖
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We report on a measurement of the missing-mass, $(\mathrm{mm})^-$, spectrum from the reaction $\pi^- + p \to (\mathrm{mm})^- + p$ at 8 GeV. The data contain 6500 events in the R peak ($M^2 = 2.72 \pm 0.02\ \mathrm{GeV}^2$, $\Gamma = 139 \pm 31$ MeV). The R shape is consistent with either a single Breit-Wigner or several wide resonances, as suggested by bubble-chamber experiments, but inconsistent with the series of narrow resonances reported by the CERN missing-mass group.

The mass spectrum produced in the reaction $\pi^- + p \to (\mathrm{mm})^- + p$ has been investigated in the region of the R enhancement (mass ~ 1700 MeV) using the missing-mass technique. The data were obtained with the Northeastern–Stony Brook double-arm spectrometer at the Brookhaven alternating gradient synchrotron at a beam momentum of 8 GeV.[1] A description of the method and the apparatus is given in earlier publications and reports.[2,3]

Previously, the CERN missing-mass spectrometer group, CMMS, established the presence of the R enhancement in the missing-mass spectrum.[4] Later publications of the CMMS group[5] reported three narrow resonances in this region, called R_1, R_2, and R_3, with masses of 1632, 1700, and 1748 MeV, and widths with upper limits of 21, 30, and 38 MeV for the R_1, R_2, and R_3, respectively. These widths were consistent with zero. Bubble-chamber groups report mainly wide ($\Gamma \gtrsim 100$ MeV) resonances.[6] A combination of such wide resonances would be expected to show up as a single broad enhancement in a missing-mass experiment. Our data, compared to the CMMS data, have 6.5 times as many R events above background, were taken with better resolution, and are fitted well by a single wide ($\Gamma \sim 140$ MeV)