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Evidence for Scaling of Semi-Inclusive Cross Sections Between 13 and 205 GeV/c

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ABSTRACT

Semi-inclusive invariant cross sections for π^- produced in pp interactions at 205 GeV/c are compared, at fixed $n_-/\langle n_-\rangle$, with data at lower energies ranging from 13 to 28.4 GeV/c. Except in the central region ($x \approx 0$), the data are found to be in good agreement with KNO predictions for semi-inclusive scaling.

Since the ISR at CERN and the 300 GeV Synchrotron at NAL came into operation, a great deal of interest and effort have been concentrated on the search for systematics in high energy collisions. It is now commonly accepted that for inclusive reactions such as

$$pp \to \pi^- + \text{anything}, \tag{1}$$

the scaling of invariant cross sections in the fragmentation region seems to be a valid principle and that in the pionization region ($x \approx 0$), the invariant cross sections are approaching asymptotic scaling[1] at a rate of roughly $p_{lab}^{-1/4}$. When a 4π solid angle detector such as a bubble chamber is used to study reaction (1), one of the most accurately determined quantities is the total number of charged particles, n, in a given event. This quantity is not an explicit variable in most models for inclusive reactions.

It was proposed about a year ago by Koba, Nielsen and Olesen[2] (KNO) that there exist scaling laws applicable to the so-called "semi-inclusive reaction". A semi-inclusive reaction is an inclusive reaction, such as reaction (1), for a particular topology. An example would be

$$pp \to \pi^- + (n-1) \text{ charged} + \text{anything neutral} \tag{2}$$

Assuming that Feynman's scaling function,

$$f^{(q)}(x_1, p_{\perp 1}, x_2, p_{\perp 2} \ldots x_q, p_{\perp q}) \equiv \frac{1}{\sigma_{inel}} \frac{d^3q\sigma}{\frac{d^3p_1}{2\omega_1}\frac{d^3p_2}{2\omega_2}\cdots\frac{d^3p_q}{2\omega_q}} \tag{3}$$

is non-singular at $x_1 = x_2 = \ldots x_q = 0$, and that it approaches scaling rapidly as $s \to \infty$, KNO proved that

$$P_n(s) \equiv \frac{\sigma_n}{\sigma_{inel}} = \frac{1}{\langle n \rangle} \Psi\left(\frac{n}{\langle n \rangle}\right) + \phi(\ln^{-2} s) \tag{4}$$

to the highest order in $\ln s$. In equation (4), Ψ is an unknown function of $n/\langle n\rangle$ only and $\phi(\ln^{-2}s)$ represents a correction which varies, at most, as fast as the inverse of $\ln^2 s$. In spite of the explicit asymptotic nature of equation (4), KNO's first semi-inclusive scaling law (hereafter referred to as KNO-I) appears to be satisfied in the 50 to 303 GeV/c region. Slattery[3] has shown that the product $\langle n\rangle P_n$ when plotted versus $n/\langle n\rangle$ follows a universal curve independent of s.

KNO further predicted[4] that the semi-inclusive invariant cross sections should also scale asymptotically. For reaction (2), the semi-inclusive π^- invariant cross section, defined by

$$g_n^-(s,x_-,p_\perp^-) \equiv \frac{1}{\sigma_n}\frac{d\sigma}{d^3p_-/2\omega_-} \quad , \tag{5}$$

should scale as

$$g_n^-(x_-,p_\perp^-) = h(x_-,p_\perp^-,\ n_-/\langle n_-\rangle)\ [1 + \phi(\frac{1}{\ln s})] \tag{6}$$

where the subscript and superscript "-" stand for π^-'s, and h is an unknown function independent of s. Equation (6) is referred to as KNO-II.

In this letter, we report a test of this scaling law using pp interactions at 205 GeV/c as compared to data from similar reactions between 13.0 and 28.4 GeV/c. The high energy data were obtained from an exposure of the 30-inch hydrogen bubble chamber at NAL to a proton beam of 205 GeV/c incident momentum[5] and the lower energy data were obtained using the Brookhaven AGS and the 80-inch hydrogen bubble chamber. Measurements for the 13.0 to 28.4 GeV/c events were done at LBL and processed through the TVGP system at MSU. Since K^- and $\bar{p}$ contaminations below 30 GeV/c are believed[6] to be no more than ~3%, all negative tracks were interpreted to be due to

π^-'s. Partially integrated invariant cross sections for 6 through 14 prongs from the 205 GeV/c data are shown in Figure 1 as open circles.

According to KNO-II [equation (6)], these cross sections should scale with the reduced negative multiplicity, $n_-/\langle n_-\rangle$, that is, should be identical to those at a different s, and a different topology but the same $n_-/\langle n_-\rangle$ ratio. Table I shows the averaged negative multiplicity for pp interactions at 13.0, 18.0, 21.1, 24.2, 28.4 and 205 GeV/c. Holding $n_-/\langle n_-\rangle$ constant, 6 prongs at 205 GeV/c are to be compared with 4 prongs at 28.4 GeV/c, 8 prongs at 205 GeV/c with 18 GeV/c 4 prongs and so on. Figure 1 (a,d,g,k,p) show the π^- semi-inclusive cross sections integrated over $p_\perp^2$ and folded and averaged about 90° in the c.m. system. Here one finds good agreement between the high and lower energy data except in the central region ($x \approx 0$). This is similar to discrepancies observed[5] in comparing π^- inclusive cross sections at 28.5 and 205 GeV/c. Figure 1 indicates that the non-scaling behavior in the central region is not restricted to particular topologies. In the fragmentation region, the good agreement between these two sets of data is remarkable in view of the fact that comparisons are being made between different energies and different topologies. It should be noted that comparisons made between semi-inclusive invariant cross sections at fixed n show poor agreement. Comparisons of the laboratory rapidity distributions are given in Figure 1 (b,e,h,m,r). The cutoff on the left side of the figure is at 90° in the c.m. for the lower energy data. Again, discrepancies in the central region exist, while good agreement is observed in the fragmentation region. In Figure 1 (c,f,j,n,s), semi-inclusive cross sections integrated over x are plotted versus $p_\perp^2$. The KNO scaling prediction is well satisfied for all values of this variable.

In view of the fact that Feynman's scaling hypothesis fails in the central region and one of the basic assumptions of the KNO predictions is the rapid approach of asymptotic scaling as $s \to \infty$, it is interesting to ask if the apparent success of the two KNO semi-inclusive scaling laws can be induced by physical pictures other than Feynman's scaling hypothesis. KNO[2] have pointed out that the energy independence of the ratios $\langle n^q \rangle / \langle n \rangle^q$, $q = 2,3,4....$ is equivalent to KNO-I [equation (4)]. Published data[3] from 19 to 303 GeV/c indicate that the ratios $\langle n^q \rangle / \langle n \rangle^q$ are approximately constant above 50 GeV/c for all q values. Arnold[7] has argued that the success of KNO-I in the 50 to 303 GeV/c region is only a low energy phenomenon and the asymptotic form of the scaling function is that of a delta function. The energy dependence of Ψ can be seen in Figure 2. Open points are from the low energy data and the solid curve is from Slattery's fit to the 50 to 303 GeV/c data. Values from 50 and 69 GeV/c are shown as black circles. It is obvious that 50 and 69 GeV/c data are well-described by the curve, whereas the lower energy points indicate a narrower distribution. Therefore, one may conjecture based on data below 303 GeV/c, that the width of Ψ grows larger for increasing s. Such a trend has been shown[8-10] to be consistent with a two component picture, that is, an energy independent diffractive component plus an energy dependent non-diffractive part. However, within the spirit of such a model, the asymptotic form of Ψ is expected to be two delta functions, one at $n/\langle n \rangle = 0$ for the diffractive component and one at $n/\langle n \rangle = 1$ for the non-diffractive component. Therefore, according to the two-component picture, the shape of the Ψ function shown in Figure 2 merely indicates that asymptopia for semi-inclusive scaling is

still far off. Turning to KNO-II, equation (6) is a mathematical consequence of KNO-I being true and the energy independence of the ratio

$$\frac{\tilde{f}^{(q+1)}(x_-, p_\perp^-, 0, 0 \ldots 0)}{[\tilde{f}^{(1)}(0)]^q} \rightarrow \text{constant for all } q, \qquad (7)$$

where $\tilde{f}^{(q+1)}(x_-, p_\perp^-, 0, 0 \ldots 0)$ stands for the Feynman scaling function [equation (3)] integrated over transverse momenta for all particles other than the π^- and evaluated at $x_1 = x_2 = \ldots x_q = 0$. Since KNO-I is known not to be valid below 50 GeV/c, the agreement with KNO-II from 13 to 205 GeV/c can be induced by the function Ψ and the ratio given in equation (7) having similar energy dependence. The apparent success of KNO-II should be viewed as an empirical fact and may serve as a constraint to theoretical models such as the two component model.

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REFERENCES AND FOOTNOTES

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1 T. Ferbel, Phys. Rev. Letters 29, 448 (1972).

2 Z. Koba, H. B. Nielsen and P. Olesen, Nucl. Phys. B40, 317 (1972).

3 P. Slattery, Phys. Rev. Letters 29, 1624 (1972) and P. Slattery, Phys. Rev. D7, 2073 (1973).

4 Z. Koba, H. B. Nielsen and P. Olesen, Phys. Letters 38B, 25 (1972).

5 Y. Cho et al., Phys. Rev. Letters 31, 413 (1973).

6 J. V. Allaby et al., CERN Report 70-12 (1970).

7 R. C. Arnold, Multiplicity Distributions In A Mean-Field Approximation, ANL/HEP 7255 (1972).

8 K. Failkowski, Phys. Letters 41B, 379 (1972).
K. Failkowski and H. I. Miettinen, Phys. Letters 43B, 61 (1973).

9 H. Harari and E. Rabinovici, Phys. Letters 43B, 49 (1973).

10 L. Van Hove, Phys. Letters 43B, 65 (1973).

Table I. Averaged Negative Multiplicity $\langle n_- \rangle$

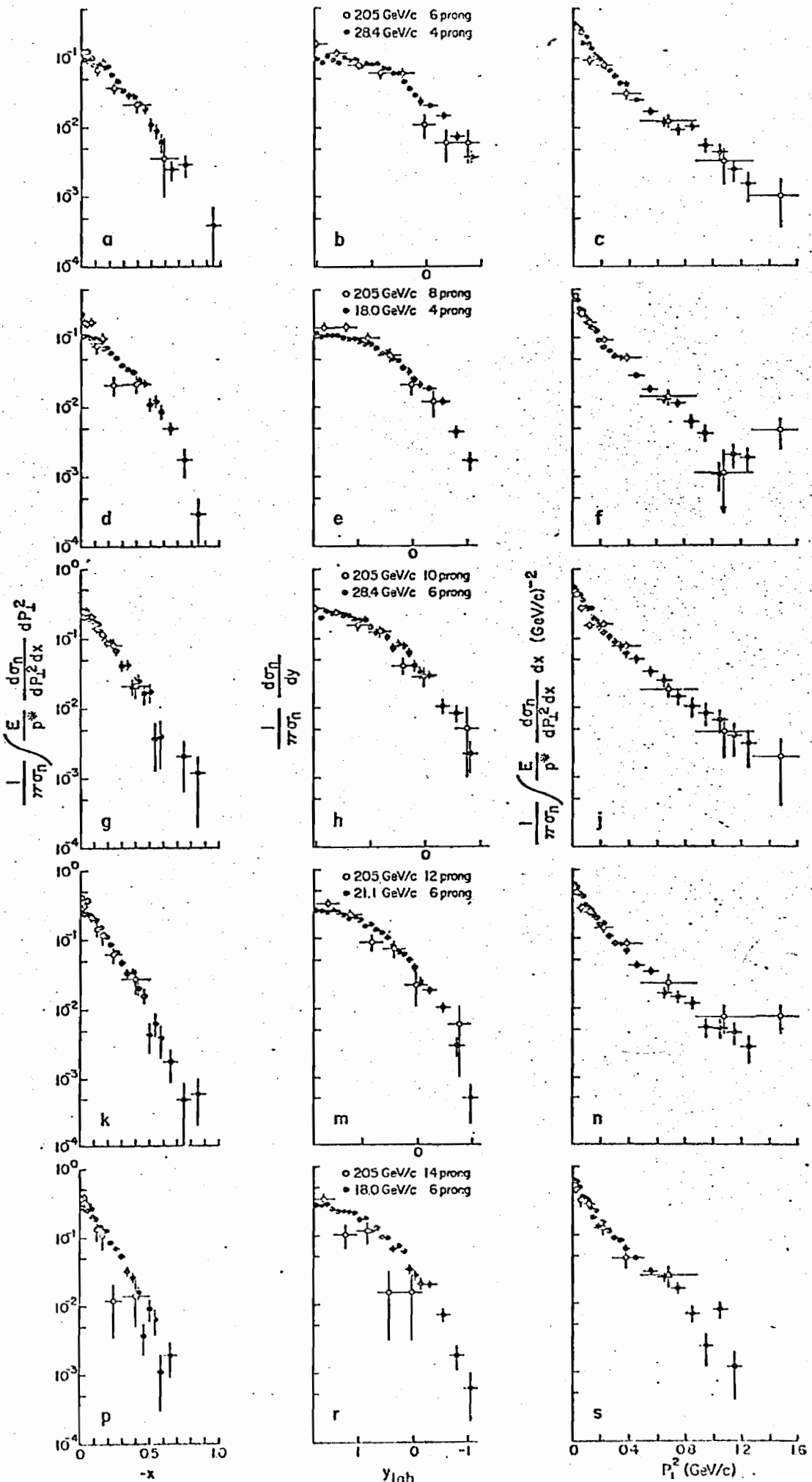
	13.0 GeV/c	18.0 GeV/c	21.1 GeV/c	24.2 GeV/c	28.4 GeV/c	205 GeV/c
$\langle n_- \rangle$	0.83±.02	1.02±.02	1.15±.02	1.24±.02	1.30±.02	2.83±.09

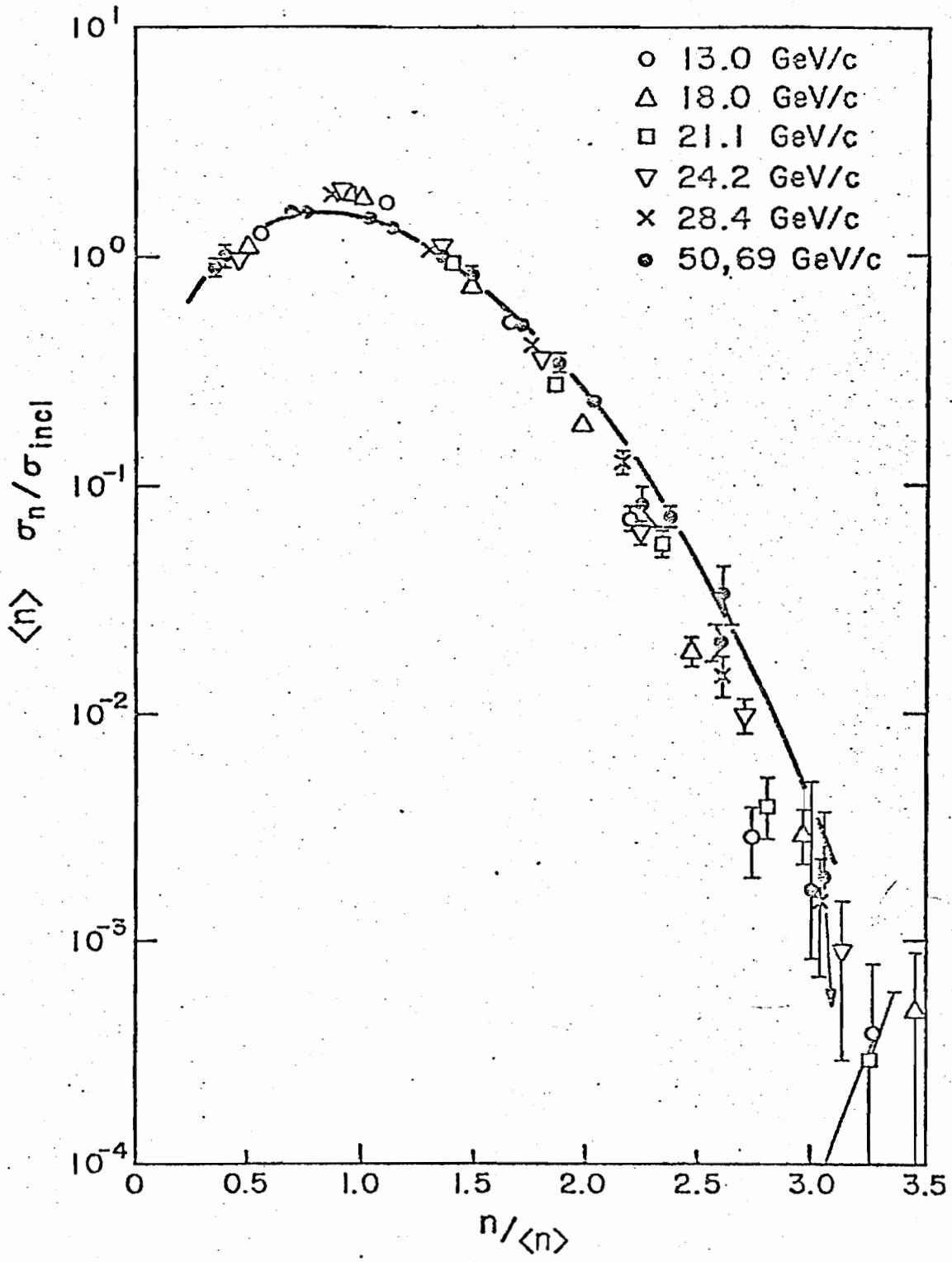
FIGURE CAPTIONS

Figure 1. Comparisons of semi-inclusive invariant cross sections at fixed $n_-/\langle n_- \rangle$. Data shown in the x and y_{lab} distributions have been folded and averaged about 90° in the c.m. system. In the P_1^2 distributions, data have been integrated over x. Good agreement with KNO-II is seen in the data except near x=0.

Figure 2. Energy dependence of the KNO-I scaling function. The solid curve is from a fit to 50-303 GeV/c data by Slattery. A trend for the distribution to become broader with increasing s is observed.

$pp \to \pi^- + (n-1)$ charged + anything neutral




13.0 GeV/c
18.0 GeV/c
21.1 GeV/c
24.2 GeV/c
28.4 GeV/c
50,69 GeV/c
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$\langle n \rangle \quad \sigma_n / \sigma_{incl}$
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
$n/\langle n \rangle$