p_t and E_t multiplicity correlations in p-p, p-α, and α-α interactions at $\sqrt{s}=31.5$ and 44 GeV

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(Received 4 April 1983)

Measurements of the central multiplicity associated with high-p_t particles up to 2 GeV/c in p-p, p-α, and α-α collisions, and measurements of $d\sigma/dE_t$ are presented. The difference in associated multiplicity, $n(p\text{-}\alpha)-n(p\text{-}p)$, is independent of p_t while $n(\alpha\text{-}\alpha)-n(p\text{-}p)$ rises with p_t, providing new information on the "anomalous" p_t dependence of nuclear inclusive cross sections.

I. INTRODUCTION

Recently there have been experimental studies of the central multiplicity distributions[1] in p-p, p-α, and α-α collisions at CERN ISR energies and of correlations between energy deposition in the fragmentation region and high central multiplicity,[2] in an effort to understand the mechanisms for nuclear hadron production. This paper extends these studies to p_t multiplicity correlations and to comparisons of the toward- and away-side associated multiplicities in p-p, p-α, and α-α interactions. We also present measurements of the cross sections as a function of the total charged-particle transverse energy E_t in the central rapidity region and of the mean multiplicities and transverse momenta as a function of E_t.

It is well known[3] from single-particle inclusive measurements, mainly at laboratory energies of 400 GeV [$\sqrt{s}$ (p-p c.m.)$=27.4$ GeV], that the low-p_t nuclear cross sections are below A times the nucleon-nucleon cross section, but that above about 1.8 GeV/c they are enhanced. The 31.5-GeV-p–63-GeV-α data represents $\sqrt{s}=44$ GeV in the p-p c.m., while the 63-GeV-α–63-GeV-α data is $\sqrt{s}=31.5$ GeV in the p-p c.m. Thus the ISR measurements extend the $\sqrt{s}$ dependence of the nuclear inclusive cross sections. They have also, for the first time, allowed study of the structure of the event accompanying the high-p_t particle.[4]

II. EXPERIMENTAL METHODS

The Axial Field Spectrometer (AFS), described previously,[5] is the source of the data. Charged particles are measured in drift chambers having a ϕ acceptance of 344° located in a 0.5-T axial magnetic field. All the data are taken with a "minimum-bias" trigger which accepts 95% of the inelastic events. The intersection is surrounded with a "barrel" of 44 scintillation counters covering a rapidity range of about ± 1.6 units, while downstream are located "beam" counters that are sensitive to the beam "jets" produced in inelastic reactions. The minimum-bias trigger is satisfied if one of the 44 barrel strips or a beam-beam coincidence is registered. The details of the track and vertex acceptances are described in Ref. 1, with only the following minor modifications for this paper: The pseudorapidity cut of ± 0.8 is now made in the c.m. instead of the laboratory reference frame. The $p_t<2.0$

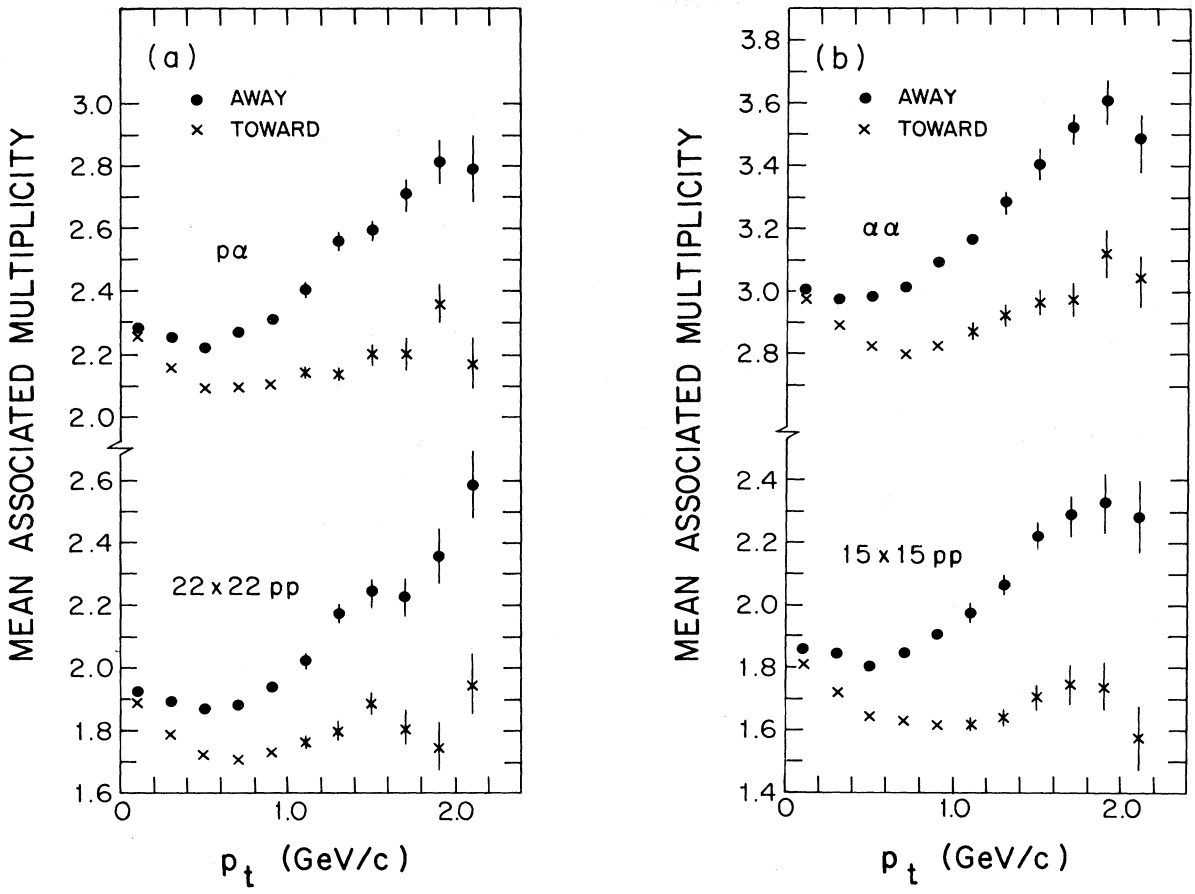

FIG. 1. Toward- and away-side mean multiplicities vs p_t of a selected particle. (a) Comparison of p-α and p-p data; $\sqrt{s}=44$ GeV. (b) Comparison of α-α and p-p data; $\sqrt{s}=31.5$ GeV.

GeV/c cut is removed, and tracks with $p_t > 2.0$ GeV/c are now accepted provided $\sigma(1/p) < 0.03$. These new cuts modify the mean multiplicities reported in Ref. 1 by only 2%. The results presented in this paper are based on analysis of 102×10^3 p-p ($\sqrt{s}=31.5$ GeV), 137×10^3 p-p ($\sqrt{s}=44$ GeV), 152×10^3 p-α, and 140×10^3 α-α events.

III. MEAN MULTIPLICITY ASSOCIATED WITH PARTICLES OF GIVEN p_t

Figures 1(a) and 1(b) show the mean charged multiplicites associated with a selected particle of transverse momentum p_t. (To simulate a p_t trigger with a minimum-bias trigger, each particle in an event is used once.) The "toward" distribution is obtained by choosing those particles with a c.m. azimuthal angle of $\phi=90°$ with respect to the direction of the selected particle; the "away" distribution is obtained choosing particles with ϕ greater than 90°. The sum of the toward- and away-side mean associated multiplcities is called $\langle n_{\text{assoc}}\rangle$. Throughout this paper the α-α data at a nucleon-nucleon $\sqrt{s}=31.5$ GeV and p-α data at nucleon-nucleon $\sqrt{s}=44$ GeV are compared with p-p data at the appropriate $\sqrt{s}$.

The data for the p-p interactions show the characteristic p_t dependence of the toward- and away-side multiplicities previously observed,[6] and which are understood not to be a purely kinematic effect. The interesting feature of Fig. 1 is the observation that the p-α and α-α data appear to differ from the p-p data, to first order, by an additive constant. This is what one would expect if the contributions from different struck nucleons were independent and if multiple scattering of the nucleons did not affect the p-α and α-α spectra. In this case a particle of particular p_t would show the p-p multiplicity-p_t correlation of a single encounter and any additional independent nucleon-nucleon collisions would distribute particles randomly in azimuth.

To examine this feature more closely, we display in Fig. 2 the differences

$$N(p\text{-}\alpha)=\langle n_{\text{assoc}}\rangle(p\text{-}\alpha)-\langle n_{\text{assoc}}\rangle(p\text{-}p)$$

and

$$N(\alpha\text{-}\alpha)=\langle n_{\text{assoc}}\rangle(\alpha\text{-}\alpha)-\langle n_{\text{assoc}}\rangle(p\text{-}p)$$

vs p_t. For comparison, we show on the same figure plots

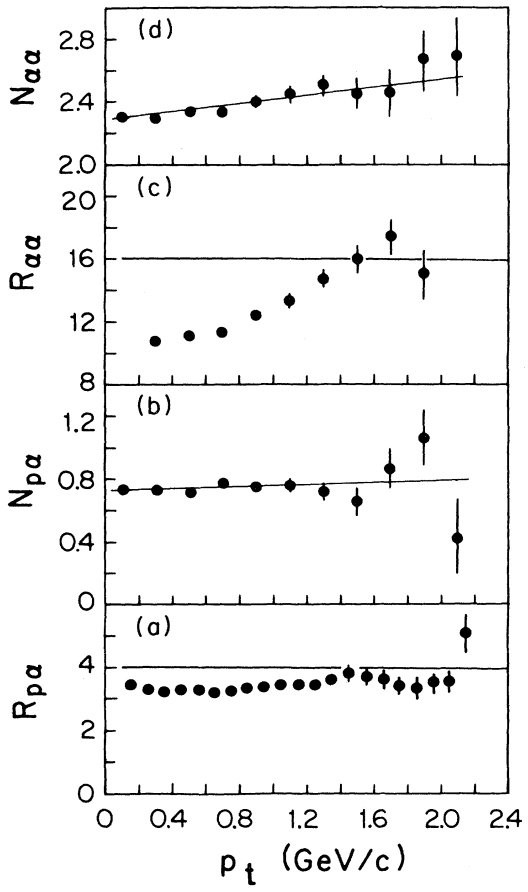

FIG. 2. Comparison of associated multiplicity differences and cross-section ratios as functions of p_t. (a) $R(p\text{-}\alpha)$ vs p_t; (b) $N(p\text{-}\alpha)$ vs p_t; (c) $R(\alpha\text{-}\alpha)$ vs p_t; (d) $N(\alpha\text{-}\alpha)$ vs p_t.

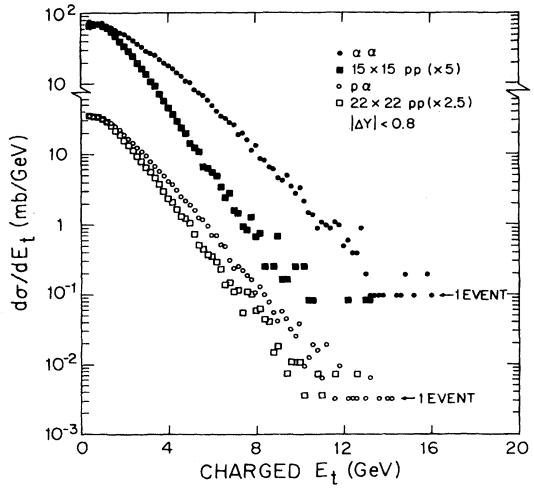

FIG. 3. $d\sigma/dE_t$ vs E_t for p-p, p-α, and α-α interactions in the central rapidity range $|y|<0.8$. The p-p cross sections are multiplied by 2.5 and 5.0 for the $\sqrt{s}=31.5$ and 44 GeV data, respectively.

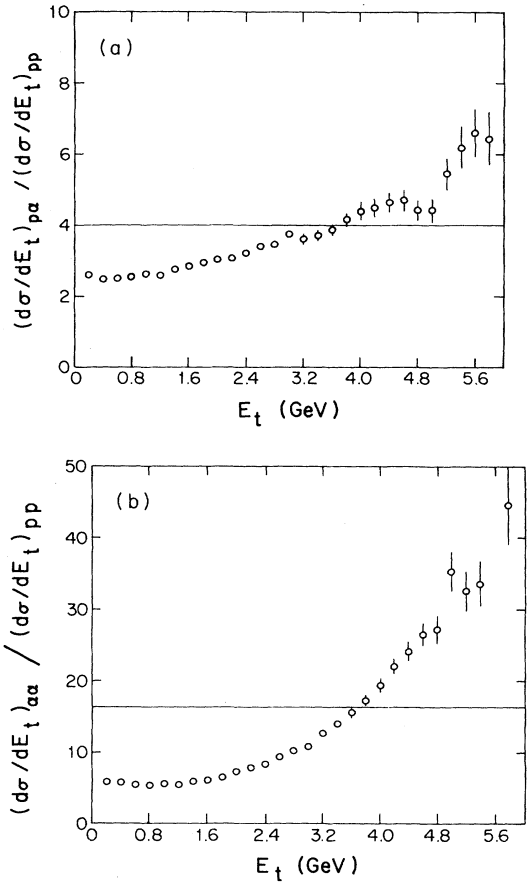

FIG. 4. (a) $(d\sigma/dE_t)(p\text{-}\alpha)/(d\sigma/dE_t)(p\text{-}p)$ vs E_t. (b) $(d\sigma/dE_t)(\alpha\text{-}\alpha)/(d\sigma/dE_t)(p\text{-}p)$ vs E_t.

of the ratios

$$R(p\text{-}\alpha)=\frac{d\sigma/dp_t(p\text{-}\alpha)}{d\sigma/dp_t(p\text{-}p)}$$

and

$$R(\alpha\text{-}\alpha)=\frac{d\sigma/dp_t(\alpha\text{-}\alpha)}{d\sigma/dp_t(p\text{-}p)}$$

vs p_t, at appropriate $\sqrt{s}$. The results of a straight-line fit to the data are superimposed over the data. The calculated slopes are for p-α, 0.030 ± 0.024 $(\text{GeV}/c)^{-1}$ and for α-α, 0.135 ± 0.026 $(\text{GeV}/c)^{-1}$.

The main features to be extracted from the data are (1) there is a rise in both $N(\alpha\text{-}\alpha)$ and $R(\alpha\text{-}\alpha)$ with p_t. (2) Both $N(p\text{-}\alpha)$ and $R(p\text{-}\alpha)$ appear to be independent of p_t. [The luminosity at our intersection was not directly measured for the p-α run, giving rise to an estimated systematic error of $\pm20\%$ in $R(p\text{-}\alpha)$; thus the depression of $R(p\text{-}\alpha)$ below the value $A=4$ may be purely systematic. The luminosities for the 15×15-GeV p-p and α-α runs are accurate to $\pm5\%$.]

There are several multiple-scattering models that attempt to account for the p_t dependence of $R(p\text{-}\alpha)$ and $R(\alpha\text{-}\alpha)$.[7] In these models the steeply falling p_t spectrum resulting from a single scatter is modified by the presence

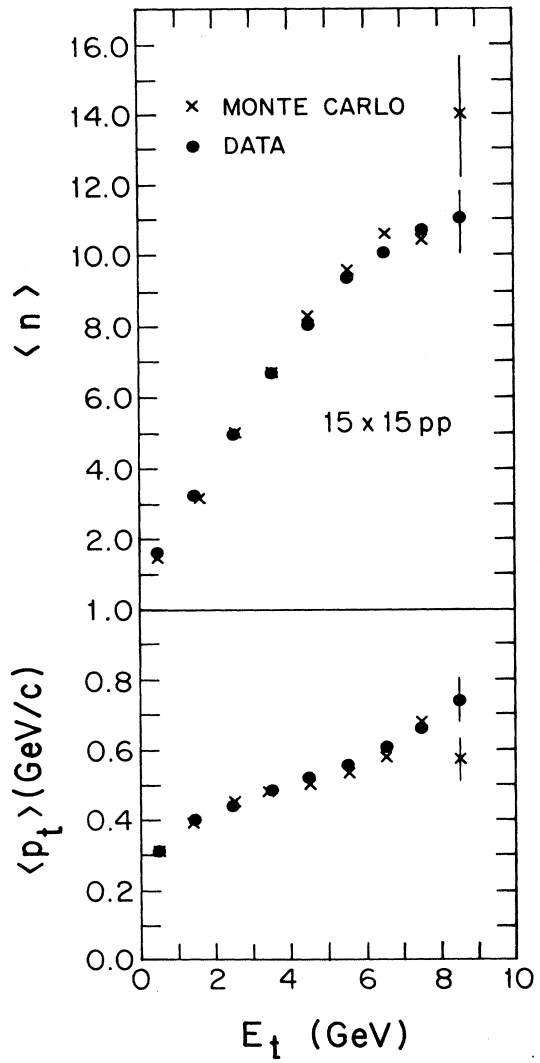

FIG. 5. $\langle n \rangle$ and $\langle p_t \rangle$ vs E_t for p-p $\sqrt{s}=31.5$ GeV data. The crosses are the result of a Monte Carlo calculation choosing particles independently from the multiplicity distribution and the single-particle p_t distributions.

of multiple scatterings of the nucleon (or quark) traversing the nucleus. Convolution of the successive scatters produces the nuclear enhancement at high p_t. Since both the enhancement of the cross section and the production of secondary particles increases with the number of multiple scatters, the enhancements should be correlated with the associated multiplicity. Thus in any multiple-scattering model that purports to account for the p_t dependence of $R(p\text{-}\alpha)$ and $R(\alpha\text{-}\alpha)$, the associated multiplicity would be expected to increase as the observed cross-section ratio increases. This qualitative result appears to be borne out by the data.

IV. MEASUREMENTS OF $d\sigma/dE_t$

Figure 3 presents our data on $d\sigma/dE_t$ for the nuclear cross sections, where we set $m=m_\pi$ for all tracks. The appropriate p-p cross sections have been multiplied by factors (2.5 in the p-α comparison and 5.0 in the α-α comparison) to normalize the curves approximately at $E_t=0.5$ so that the differences in the shapes are apparent to the eye.

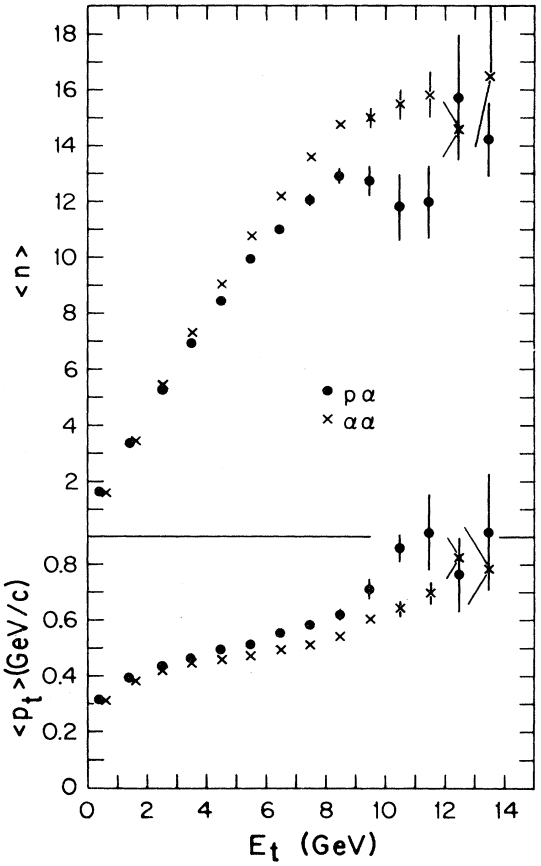

FIG. 6. $\langle n \rangle$ and $\langle p_t \rangle$ vs E_t for the p-α and α-α data.

Figure 4 displays the ratios

$$r(p\text{-}\alpha)=\frac{d\sigma/dE_t(p\text{-}\alpha)}{d\sigma/dE_t(p\text{-}p)}$$

and

$$r(\alpha\text{-}\alpha)=\frac{d\sigma/dE_t(\alpha\text{-}\alpha)}{d\sigma/dE_t(p\text{-}p)}\ ,$$

showing that below about $E_t=4$ GeV they are below the value $r=A^1$ for the p-α and $r=A^2$ for α-α. Above this energy they are enhanced. This is the behavior observed at Fermilab in studies of $d\sigma/dE_t$ for Cu, Al, and Pb at $\sqrt{s}=27.4$ GeV.[8]

V. MEAN MULTIPLCITY AND MEAN TRANSVERSE MOMENTUM vs E_t

Figure 5 shows $\langle n \rangle$, the mean multiplicity, and $\langle p_t \rangle$, the mean p_t, of charged particles entering into events of fixed E_t vs E_t for $\sqrt{s}=31.5$ GeV p-p data. $\langle n \rangle$ appears to rise almost linearly from $\langle n \rangle \simeq 1$ at low E_t over a large range of E_t. This rise was also observed in πp and pp collisions at 300 GeV/c.[9] Over the same E_t range the $\langle p_t \rangle$ per particle rises by about a factor of 2. Note that for any

E_t, by definition, $E_t = \langle p_t \rangle \times \langle n \rangle$, if $E_t = \sum p_{ti}$.

It is instructive to determine whether there are strong correlations in the *magnitudes* of p_t in an event of fixed E_t. To study this possibility, we have calculated $\langle n \rangle$ and $\langle p_t \rangle$ using a simple assumption, that the observed multiplicity distribution $M(n)$ and the cross section $d\sigma/dp_t$ are uncorrelated. We have carried out a Monte Carlo calculation, generating events selected at random from the observed parent distributions. The crosses in Fig. 5 show the results of our Monte Carlo calculation of $\langle n \rangle$ and $\langle p_t \rangle$ as a function of E_t demonstrating that an event structure without correlation in $|p_{ti}|$ reproduces the observed behavior. A similar Monte Carlo calculation for the α-α events also reproduced the $\langle n \rangle$ and $\langle p_t \rangle$ vs E_t dependence. The differences in the p-α and α-α data are illustrated in Fig. 6. The observed rise in $\langle p_t \rangle$ with E_t is not of itself a signal for the onset of new mechanisms. It reflects the fact that, because of the rapid falloff of $M(n)$ at high n, there is a larger probability of obtaining an event of fixed E_t with particles of larger $\langle p_t \rangle$.

We have previously observed[1] that in the same minimum-bias events from which $d\sigma/dE_t$ is determined, the average value of p_t is identical for p-p, p-α, and α-α interactions. Thus the ratios of the mean multiplicities (p-α/p-p and α-α/p-p) should be the same as the ratios of mean transverse energies. We find that the $\langle E_t \rangle$ ratios for p-α (1.15) and α-α (1.49) are essentially identical with those obtained from the mean multiplicity ratios (p-α, 1.16 and α-α, 1.49) previously reported.[1] (Note that the measurements are not statistically independent and that we expect small differences since we did not set the mass equal to zero in the definition of E_{ti}.)

VI. CONCLUSIONS

We have compared the variations in the ratios of nuclear to p-p cross sections with p_t with the behavior of the associated multiplicity differences. The results are qualitatively in accord with the behavior expected if multiple scattering underlies the deviation of the nuclear cross sections from the expected A^1 dependence.

It appears from the agreement between our Monte Carlo calculation, based on the assumption that the multiplicity and p_t distributions are independent, and the data on $\langle n \rangle$ and $\langle p_t \rangle$ vs E_t that no sign of the onset of appreciable correlated behavior among the absolute values of p_t, such as might appear with the onset of appreciable jet production, appear at the values of E_t studied.

We emphasize, especially as shown by the low $\langle p_t \rangle$, even at $E_t = 12$ GeV, that our data covers low-p_t interactions in nuclei. Thus the depressions and enhancements in the ratio of the nuclear $d\sigma/dE_t$ to the p-p $d\sigma/dE_t$ shown in Fig. 4 do not appear to be related to the depressions and enhancements in the ratios of the high-p_t single-particle inclusive cross sections. The "crossover" point in Fig. 4 near 4 GeV, where the ratios are $A = 4$ for p-α and $A^2 = 16$ for α-α, corresponds with an average p_t of only approximately 0.4 GeV/c.

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