Observation of Increasing Charged Multiplicity as a Function of Transverse Momentum in 28.5-GeV/c pp Interactions*

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We have measured the mean charged multiplicity $\bar{n}_{\rm CH}$ as a function of transverse momentum $p_\perp$ of the forward proton in the reaction $p+p\rightarrow p+{\rm MM}$ for five intervals of missing mass (MM) using our Multiparticle Argo Spectrometer System. We observe an increase of $\bar{n}_{\rm CH}$ for $p_\perp > 1$ GeV/c.

Systematic studies of multiparticle final states in pp collisions around 30 GeV/c have been carried out in bubble chambers.[1] They have covered extensively the large-cross-section peripheral interactions but have had limited access to rare events, e.g., large-momentum-transfer collisions. They have suffered from technical shortcomings in identifying the final-state protons. The simplest features of the data, i.e., single-particle inclusive distributions and two-body correlations, can be understood in terms of the production and decay characteristics of the excited nucleon system (nova model).[2] The data appear insensitive to detailed features of the dynamics. A study of collisions imparting higher transverse momentum to the incident proton may be more sensitive to the dynamics since in that case one is probing a more central region of the proton. With this motivation we have initiated a study of such central collisions with a novel instrument, the Multiparticle Argo Spectrometer System[3] (MASS), at the Brookhaven National Laboratory's alternating-gradient synchrotron. Recent results[4] from the CERN intersecting storage rings on single-pion inclusive measurements at large transverse momentum show surprisingly large cross sections; these data have lent added interest to the observation of the multiparticle final states involved.

We report here the dependence of the mean charged multiplicity $\bar{n}_{\rm CH}$ on the transverse momentum $p_\perp$ of the forward proton in the reaction

$$p+p\rightarrow p+{\rm MM} \tag{1}$$

for five intervals of missing mass (MM). To measure this dependence, we have used two of the three spectrometers constituting the ensemble of MASS. The high-momentum spectrometer (HMS) was used to trigger upon, identify, and momentum analyze the forward proton. In three floor positions, scattering angles in the laboratory frame between 14 and 100 mrad and momenta between 10 and 28.5 GeV/c were covered. The angular and momentum resolutions were ±0.2 mrad and ±0.3% at 20 GeV/c, respectively, and the solid-angle acceptance was 33 mrad horizontally by 10 mrad vertically. The vertex spectrometer[5] (VS) was used to measure the charged multiplicity. It consisted of nine digitized cylindrical wire spark chambers operating in a 10-kG magnetic field and surrounding an 8-in.-long hydrogen target. The chambers subtended a solid angle such that 89% of all charged particles were detected. Track identification in the VS was performed with the automatic track recognition code PITRACK.[6] A subset of the data was scanned by physicists to determine the biases. Approximately 6% of all tracks were not recognized by PITRACK.

The charged-multiplicity distributions for three intervals of $p_\perp$ in the MM interval 2.0 to 3.0 GeV are displayed in Fig. 1. Losses of charged particles have been calculated using charge conservation on an event-by-event basis. The losses of two particles of opposite charge were determined from the known losses of two particles of equal charge.

It is apparent from the data that the multiplicity distribution for high $p_\perp$ differs from the other two distributions, resulting in a higher mean charged multiplicity. Since the average missing-mass value differed by a small amount for different $p_\perp$ intervals, a small correction $\delta\bar{n}_{\mathrm{MM}}$ has been applied (Table I). The correction was based on the observation of a linear relationship between $\bar{n}_{\mathrm{CH}}$ and MM for fixed $p_\perp$ with a slope of 0.75 GeV^{-1}.

In Fig. 2 we show the variation of the mean charged multiplicity $\bar{n}_{\mathrm{CH}}$ with $p_\perp$ for five intervals of MM. While the data show little variation of $\bar{n}_{\mathrm{CH}}$ with $p_\perp$ up to 1 GeV/c, a rapid rise of $\bar{n}_{\mathrm{CH}}$ can be seen for values of $p_\perp > 1$ GeV/c. It is possible that the lowest MM interval does not display this behavior because of insufficient available energy. The errors in Fig. 2 do not include an overall systematic error. We have investigated the systematic error on $\bar{n}_{\mathrm{CH}}$ by comparing subsets of our data at low $p_\perp$ with bubble-chamber information. Our $\bar{n}_{\mathrm{CH}}$ is systematically higher by ~5% compared to the mean charged multiplicity in bubble-chamber data.[7] We attribute this difference to undetected secondary interactions in the hydrogen target, γ conversion close to the vertex, etc. The data have not been corrected for this systematic error.

We have also looked at the corrections as a function of $p_\perp$. Charge corrections are the same within errors for all intervals of $p_\perp$. In other words, the uncorrected data show the same behavior of $\bar{n}_{\mathrm{CH}}$ versus $p_\perp$ as the corrected ones, but the $\bar{n}_{\mathrm{CH}}$ values are lower by about 17% because of solid-angle losses, particles stopping in the hydrogen target, and reconstruction inefficiencies. For detailed information on each datum point, see Table I.

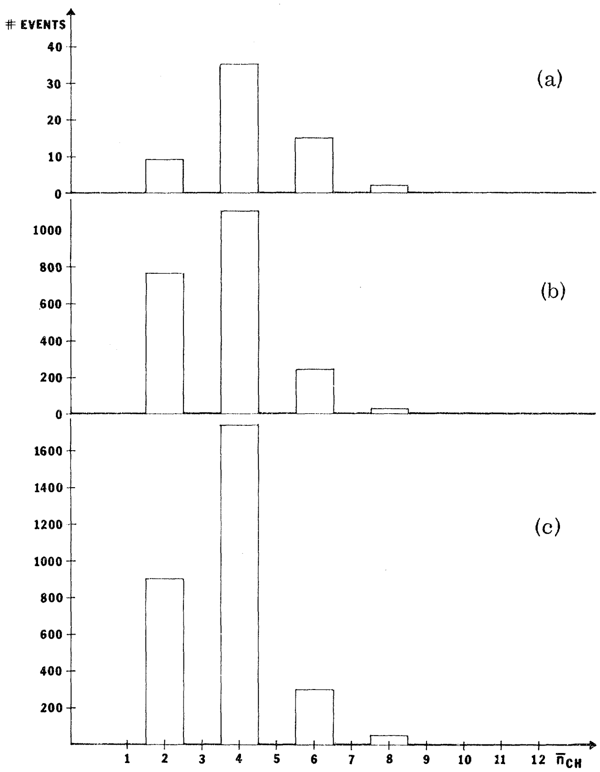

FIG. 1. Corrected charged multiplicity distributions in the MM interval 2.0–3.0 GeV ($\langle$MM$\rangle$ = 2.6 GeV) for three values of transverse momentum to the forward proton: (a) $\bar{p}_\perp = 1.90$ GeV/c, (b) $\bar{p}_\perp = 0.98$ GeV/c, (c) $\bar{p}_\perp = 0.46$ GeV/c.

The data in Fig. 2 suggest that some new phenomenon may be occurring in pp collisions when one of the final-state protons emerges with $p_\perp > 1$ GeV/c; this phenomenon manifests itself in an increasing multiplicity for a fixed $\langle$MM$\rangle$. The prediction of the multiperipheral model is in marked contrast to the data: For a fixed MM this model[8] gives an $\bar{n}$ which decreases. The effect is also unexpected in the framework of a nova model, which gives $\bar{n} \propto$ MM with no dependence on $p_\perp$, assuming that the events involve target fragmentation only. We have experimental indication that such as assumption may be justified for the data with MM < 3 GeV/c: (1) Only 13% of the two-body effective masses of the HMS trigger proton and the negative particle in the VS (assuming it is a π^-) lie below 1.8 GeV, and (2)

TABLE I. Average charged multiplicities and corrections. $\bar{p}_\perp$, average transverse momentum of the forward proton in GeV/c, with the half-width in parentheses; $\overline{\mathrm{MM}}$, average missing mass in GeV in the range of missing mass as indicated; $\delta\bar{n}_{\mathrm{MM}}$, correction of the average multiplicity due to the adjustment of $\overline{\mathrm{MM}}$ to the nominal value; $\bar{n}_0$, charged multiplicity determined by PITRACK and corrected by δn_{MM}; $\delta\bar{n}_1$, correction of charged multiplicity using charge conservation; $\delta\bar{n}_2$, correction of charged multiplicity for losses of two particles with opposite charge; $\bar{n}_{\mathrm{CH}}$, final mean charged multiplicity, and statistical and random systematic error.

Missing Mass in GeV	$\bar{p}_\perp$	$\delta\bar{n}_{\mathrm{MM}}$	$\bar{n}_o$	$\delta\bar{n}_1$	$\delta\bar{n}_2$	$\bar{n}_{\mathrm{CH}}$
$1.3 \leq \mathrm{MM} < 2.0$ $\overline{\mathrm{MM}} = 1.7$	0.49(0.14)	0.03	2.47	0.39	0.07	2.93 ± 0.05
	1.05(0.12)	0.02	2.62	0.32	0.07	3.01 ± 0.05
	2.01(0.10)	0.02	2.31	--	--	2.31 ± 0.61
$2.0 \leq \mathrm{MM} < 3.0$ $\overline{\mathrm{MM}} = 2.6$	0.46(0.15)	0.04	3.28	0.45	0.10	3.83 ± 0.05
	0.98(0.14)	0.01	3.20	0.42	0.10	3.72 ± 0.03
	1.90(0.15)	-0.02	3.78	0.53	0.26	4.57 ± 0.23
$3.0 \leq \mathrm{MM} < 4.0$ $\overline{\mathrm{MM}} = 3.6$	0.46(0.15)	0.06	3.74	0.56	0.11	4.41 ± 0.07
	0.92(0.14)	0.02	3.70	0.56	0.16	4.42 ± 0.02
	1.71(0.12)	-0.03	4.23	0.54	0.16	4.93 ± 0.14
$4.0 \leq \mathrm{MM} < 5.0$ $\overline{\mathrm{MM}} = 4.5$	0.44(0.11)	0.02	4.09	0.70	0.18	4.97 ± 0.06
	0.71(0.03)	-0.13	3.95	0.74	0.28	4.97 ± 0.03
	0.87(0.09)	0.01	4.10	0.68	0.25	5.03 ± 0.02
	1.35(0.08)	-0.15	4.65	0.74	0.32	5.71 ± 0.06
	1.58(0.07)	0.07	4.69	0.75	0.30	5.74 ± 0.13
$5.0 \leq \mathrm{MM} < 5.5$ $\overline{\mathrm{MM}} = 5.2$	0.39(0.06)	-0.01	4.47	0.75	0.24	5.46 ± 0.11
	0.66(0.05)	-0.02	4.37	0.82	0.33	5.52 ± 0.03
	0.79(0.03)	0.08	4.38	0.84	0.36	5.58 ± 0.08
	1.20(0.08)	-0.03	4.98	0.82	0.36	6.16 ± 0.04

83% of the particles in the VS are on the side of the beam opposite to the HMS proton. Both observations are consistent with a calculation[9] based on the assumption that only the target proton is excited in the collision and subsequently decays according to phase space into five bodies. This consistency does not rule out that beam-proton fragmentation or double fragmentation possibly simulates unscathed HMS protons by a two-step process which might compete with the very low-cross-section,[10] single-step, large-$p_\perp$ events.

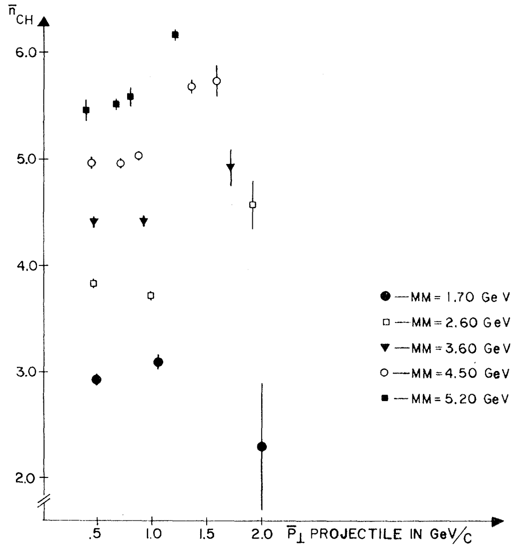

FIG. 2. Variation of the average charged multiplicity $\bar{n}_{\mathrm{CH}}$ with $p_\perp$ for five intervals of MM.

If, as indicated by data at National Acceleration Laboratory energies,[11] one needs a combination of multiperipheral and diffraction-dissociation models, then it may be possible to obtain our effect if the cross sections for the two mechanisms have different $p_\perp$ dependencies.

In the limiting fragmentation picture,[12] the proton is an extended object of limited rigidity, and an increase of $\bar{n}$ with $p_\perp$ is expected and has been conjectured[13] to be (assuming there is enough available energy)

$$\bar{n} \simeq p_\perp / \langle p_\perp \rangle , \tag{2}$$

where $\langle p_\perp \rangle$ is the average transverse momentum in hadron-hadron collisions.[14] A bremsstrahlung mechanism[15] of pion production would also favor increasing $\bar{n}$; in fact, a fitting to inclusive proton spectra[16] leads to an expression similar to Eq. (2). How such pictures alone would give constant $\bar{n}$ for $p_\perp < 1$ GeV/c is not obvious.

In conclusion, we have observed a distinct increase of $\bar{n}_{\text{CH}}$ in pp collisions at 28.5 GeV/c when the $p_\perp$ given to the trigger proton is larger than 1 GeV/c. There is an indication from the data that one is observing mainly target fragmentation, at least for MM < 3 GeV. The observed dependence of $\bar{n}_{\text{CH}}$ on $p_\perp$ is not predicted by existing models. Whether one is seeing evidence of some new phenomenon associated with close collisions, e.g., proton substructure, is a matter of speculation; what does seem clear is that this is an important new area of investigation.

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[7] The bubble-chamber mean charged multiplicity for $\langle \text{MM} \rangle = 2.6$ GeV is lower by 4.7% and for $\langle \text{MM} \rangle = 3.6$ GeV by 6.8%. We thank J. Hanlon and R. Panvini for giving us access to their unpublished data.

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[14] Making the usual assumption for π^0's, one can write Eq. (2) for $\bar{n}_{\text{CH}}$ as $\bar{n}_{\text{CH}} = \frac{2}{3} p_\perp / \langle p_\perp \rangle$, hence $(d\bar{n}_{\text{CH}}/dp_\perp)^{-1} = \frac{3}{2} \langle p_\perp \rangle = 0.6$ GeV/c; a crude evaluation of $(d\bar{n}_{\text{CH}}/dp_\perp)^{-1}$ from the data of Fig. 2 for $p_\perp > 1$ GeV/c yields 0.7 GeV/c.

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