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MULTIPLICITY OF CHARGED PARTICLES IN 800 GeV p-p INTERACTIONS

LEBC-MPS Collaboration

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ABSTRACT

Results are reported concerning the charged particle multiplicity distribution obtained in an exposure of the high resolution hydrogen bubble chamber LEBC to a beam of 800 GeV protons at the Fermilab MPS. This is the first time that such data have been available at this energy. The distribution of the number n_{ch} of charged particles produced in inelastic interactions obeys KNO-scaling. The average multiplicity is $\langle n_{ch} \rangle = 10.26 \pm 0.15$. For $n_{ch} \geq 8$ the data can be well fitted to a negative binomial. The difference between the overall experimental multiplicity distribution and that resulting from the latter fit is in agreement with the contribution expected from diffractive processes.

The Fermilab experiment E743 is designed to study the production and decay properties of charm particles in 800 GeV pp interactions (corresponding to a centre-of-mass energy $\sqrt{s}$ = 38.8 GeV). The apparatus consists of a multiparticle spectrometer (the Fermilab MPS), Cerenkov and transition radiation charged particle identifiers and a high resolution vertex detector, the CERN bubble chamber LEBC. In this paper we confine ourselves to a study of n_{ch}, the charged particle multiplicity of the primary interactions, as observed in the vertex detector.

The LExan Bubble Chamber (LEBC) was filled with liquid hydrogen. It has a high optical resolution (resolved bubble diameter) of 20 μm in space. LEBC has been used earlier at CERN in experiments to investigate the properties of short lived particles in 360 GeV $\pi^- p$ and 360 and 400 GeV pp interactions [1]. In all experiments LEBC has been positioned outside the spectrometer magnet to give straight track images, thus improving the scanning efficiency for detecting the vertices of short lived particles. The chamber has a useful visible volume of 10 x 5 x 0.4 cm^3 and was cycled at 20Hz. A conventional optical system was used for the photography with a demagnification factor of 1.1 on 50 mm film. Due to the high resolution optics the depth of field is limited to about ± 2 mm, the 800 GeV proton beam being focussed within this visible region. For the data sample used in the present analysis, pictures were taken with a simple incoming beam count triggering device during the 20 s beam spill. Approximately 10 in-time beam tracks were available for scanning in each photograph taken in synchronisation with the expansion cycle of the chamber. A total of 81 000 good quality pictures of this type were taken in the spring of 1985, yielding in all about 16 000 interactions of 800 GeV protons in hydrogen. The information provided by the downstream multiparticle spectrometer and particle identifiers has not been used for this analysis.

The bubble chamber pictures, available in two views, were inspected at magnifications in the range 20 to 40 on scanning tables. Every interaction occurring in the fiducial volume of the chamber was examined carefully in order to count and record the multiplicity of the tracks issuing from the primary vertex. Two independent scans were made(*) and

(*) Only 67% of the frames have been scanned for 2-prong events.

any disagreement on the multiplicity count was resolved by a physicist scan. However, due to the high resolution of the LEBC optical system and the high magnification used on the scan table, there were few instances of ambiguous multiplicity count. Cases of odd multiplicity (< 1% of events) were rounded up to the next higher even multiplicity. A scan efficiency was calculated bin-by-bin from the independent scans and was used to correct the numbers in each bin of multiplicity. Double scan efficiencies $\simeq$ 100% were found for $n_{ch} \geq 8$.

Since beam particles arrive at varying times with respect to the expansion cycle of the bubble chamber, the bubble sizes vary. The bubble size of tracks produced by early beam particles is large, that of the late ones being small with a lower bubble density and poor contrast. As the track count could be systematically wrong for these out of time events, they were eliminated from the multiplicity distribution.

Table 1 gives the number of interactions recorded at various multiplicities and the corresponding numbers of interactions corrected for scan efficiency, systematic 2-prong losses, δ-ray contamination and π^o Dalitz pair contributions(*). The Dalitz pair correction was based on the linear behaviour of the π^o production rate as a function of n_{ch} [2]. The table also lists the corresponding cross sections.

The cross section values were determined from a comparison of the corrected total number of events observed and the value of the total cross section σ_{tot} = (41.0 ± 0.3)mb estimated from a linear fit to existing pp data [3] in the centre-of-mass energy region (30.7 < $\sqrt{s}$ < 45.0) GeV.

(*) Because of the high resolution we have practically no contribution to the multiplicities from strange particle decays near the production vertex. Only approximately 0.1% of the neutral strange particles give a V^o within 1 mm of the production vertex.

The momenta of slow protons can in general not be measured due to the absence of a magnetic field in LEBC and hence we lack an important constraint for the unambiguous identification of elastic events. We have therefore estimated the number of inelastic 2-prongs in our sample by comparing the corrected(*) <u>total</u> 2-prong cross section found in this experiment to the <u>elastic</u> cross section (7.3 ± 0.1)mb obtained from a smooth interpolation between values measured at surrounding energies [3].

The KNO representation [4] of the corrected multiplicity distribution is shown in fig. 1. The curve is not a fit but gives the KNO scaling prediction of [5]. We have compared the data with several other expected multiplicity distributions based on KNO scaling fits to data at different energies [6]. There is little to choose between different predictions, our data showing no clear deviations from KNO scaling.

Various statistical parameters characterising the multiplicity distribution displayed in table 1 are given in table 2.

We can compare our result for the average number of charged particles in inelastic interactions, $\langle n_{ch} \rangle = 10.26 \pm 0.15$, to the expectation based on other experimental results. Breakstone et al. [7] have fitted the available data on charged particle multiplicities in inelastic pp interactions up to the highest ISR energies. For the mean charged particle multiplicity they obtain the expression:

$$\langle n_{ch} \rangle = (0.80 \pm 0.12) + (0.47 \pm 0.05)\ln s + (0.114 \pm 0.005)\ln^2 s$$

from which we would expect $\langle n_{ch} \rangle = 10.34 \pm 0.15$ at $\sqrt{s} = 38.8$ GeV.

(*) A systematic loss of short range protons, estimated to be as small as 0.3 mb in view of the high spatial resolution obtained in this experiment, was taken into account. The contamination of the two-prong sample by high energy knock on electrons on beam tracks was estimated to be ~ 6% of the total two-prong sample.

The values of the $<n_{ch}>/D$ ratio, skewness, kurtosis and the normalized moment C2 given in table 2 smoothly interpolate the existing data [7,8,9] which show little energy dependence for inelastic interactions in the energy domain $15 \leq \sqrt{s} \leq 60$ GeV. It has been pointed out in [8] that the corresponding high energy data on the moments C3 and C4 exhibit a definitely rising trend violating the predictions of pure KNO scaling. Breakstone et al. have shown [7] that deviations from KNO scaling in inelastic pp interactions for $\sqrt{s} < 60$ GeV are reduced when the moments are computed excluding single diffractive events.

On the other hand, the UA5 group has published [10] evidence for the breaking of KNO scaling in inelastic $\bar{p}p$ reactions (without single diffractive events) for $200 \leq \sqrt{s} \leq 900$ GeV. The pp (and $\bar{p}p$ CERN collider) data excluding single diffractive events in the energy range $10 \leq \sqrt{s} \leq 900$ GeV are, however, well described by a negative binomial function. According to such a distribution the probability P of observing a charged multiplicity n is given by:

$$P(n, <n>, k) = \frac{k(k+1)\ \ldots\ (k+n-1)}{n!} \ \frac{<n>^n k^k}{(<n>+k)^{(n+k)}} .$$

The energy dependence of the two parameters <n> and k can be described by the expressions [10]:

$$<n> = (2.7 \pm 0.7) - (0.03 \pm 0.21)\ln s + (0.167 \pm 0.0162)\ln^2 s$$

and

$$k^{-1} = -(0.104 \pm 0.004) + (0.058 \pm 0.001)\ln\sqrt{s}$$

which at our energy ($\sqrt{s} = 38.8$ GeV) would yield:

$$<n> = 11.5 \pm 0.1$$

$$k = 9.2 \pm 0.1$$

where the correlation between the fitted parameters has been taken into account in the error computation.

Due to the absence of a magnetic field in LEBC we are unable to perform an inclusive study of the missing mass with respect to slow protons and thereby identify non diffractive events. We have therefore fitted a negative binomial to our multiplicity data in the range $8 \le n_{ch} \le 28$ for which the bubble chamber observations indicate that the slow proton contribution becomes negligible.

Our result(*) is:

$$\langle n \rangle = 11.0 \pm 0.1$$

$$k = 8.5 \pm 0.5$$

with $\chi^2 = 5.4$ for ND = 8 degrees of freedom.

The corresponding negative binomial function is compared to the data in fig. 2. The difference between the distributions could be due to diffractive particle production. It amounts to ~ 3.5 mb, which is the order of magnitude expected [11] at $\sqrt{s} = 38.8$ GeV. The value of $\langle n \rangle$ estimated from the fit of our data to the negative binomial distribution is increased by 0.7 ± 0.2 as compared to the value $\langle n_{ch} \rangle = 10.26 \pm 0.15$ for inelastic events. Such an effect is again expected [11] when the diffractive contribution is removed. The values of the first moments of the negative binomial distribution implied [10] by the results of the fit are:

$$C2 = 1.21 \pm 0.01$$

$$C3 = 1.70 \pm 0.03$$

$$C4 = 2.69 \pm 0.08.$$

They are in excellent agreement with those estimated [7] for non diffractive events from the ISR data at comparable energies.

In conclusion, we have investigated the multiplicity distribution in 800 GeV/c pp interactions. These are the first reported data at this energy from a fixed target experiment. Because of our high resolution

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(*) A fit to the data for $10 \le n_{ch} \le 28$ gives similar results, viz: $\langle n \rangle = 11.2 \pm 0.2$ and $k = 9.3 \pm 0.9$ (χ^2/ND = 3.4/7).

4π charged particle detection technique, systematic problems are kept to a minimum. The entire multiplicity distribution is in reasonable agreement with the predictions of KNO scaling. However, for multiplicities greater than 8 the distribution also agrees with the negative binomial function; differences observed for multiplicities less than 8 can be interpreted in terms of diffractive events.

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TABLE 1

Multiplicity distribution of charged particles in 800 GeV pp interactions

Charged topology n_{ch}	Recorded numbers of events	Corrected numbers of events	Cross sections (mb)
2 (all)	1670 [(a)]	2758 ± 183	8.9 ± 0.6
2 (inelastic)	-	(510 ± 191)	(1.6 ± 0.6)
4	1221	1238 ± 35	3.88 ± 0.11
6	1478	1490 ± 39	4.67 ± 0.12
8	1582	1590 ± 40	4.98 ± 0.12
10	1535	1539 ± 39	4.82 ± 0.12
12	1413	1404 ± 37	4.40 ± 0.12
14	1094	1078 ± 33	3.38 ± 0.10
16	747	734 ± 27	2.30 ± 0.07
18	487	478 ± 22	1.50 ± 0.07
20	232	312 ± 18	0.98 ± 0.06
22	176	170 ± 13	0.53 ± 0.04
24	102	97 ± 10	0.30 ± 0.03
26	44	43 ± 7	0.13 ± 0.02
28	29	27 ± 5	0.08 ± 0.02
30	12	11 ± 3	0.03 ± 0.01
32	6	6 ± 3	0.02 ± 0.01
All	11828	12975 ± 209	(41.0 ± 0.3) [(b)]

(a) Recorded in 67% of the data sample.

(b) Cross section normalization (see text).

TABLE 2

Parameters characterising the distribution of the multiplicity n_{ch} of charged particles in inelastic interactions

Average multiplicity $<n_{ch}>$	10.26 ± 0.15
Dispersion D	5.19 ± 0.08
$<n_{ch}>/D$	1.98 ± 0.06
Skewness = $<(n_{ch} - <n_{ch}>)^3>/D^3$	0.66 ± 0.03
Kurtosis = $<(n_{ch} - <n_{ch}>)^4>/D^4$	3.27 ± 0.08
C2 = $<n_{ch}^2>/<n_{ch}>^2$	1.26 ± 0.01
C3 = $<n_{ch}^3>/<n_{ch}>^3$	1.85 ± 0.05
C4 = $<n_{ch}^4>/<n_{ch}>^4$	3.09 ± 0.12

FIGURE CAPTIONS

Fig. 1 KNO representation of the corrected charged particle multiplicity distribution. The curve shows the KNO scaling prediction of Slattery [5]. The χ^2 probability for the curve to describe the data is 70%.

Fig. 2 Corrected charged particle multiplicity distribution. The histogram shows the results of a fit of the data in the range $8 \leq n_{ch} \leq 28$ to a negative binomial.

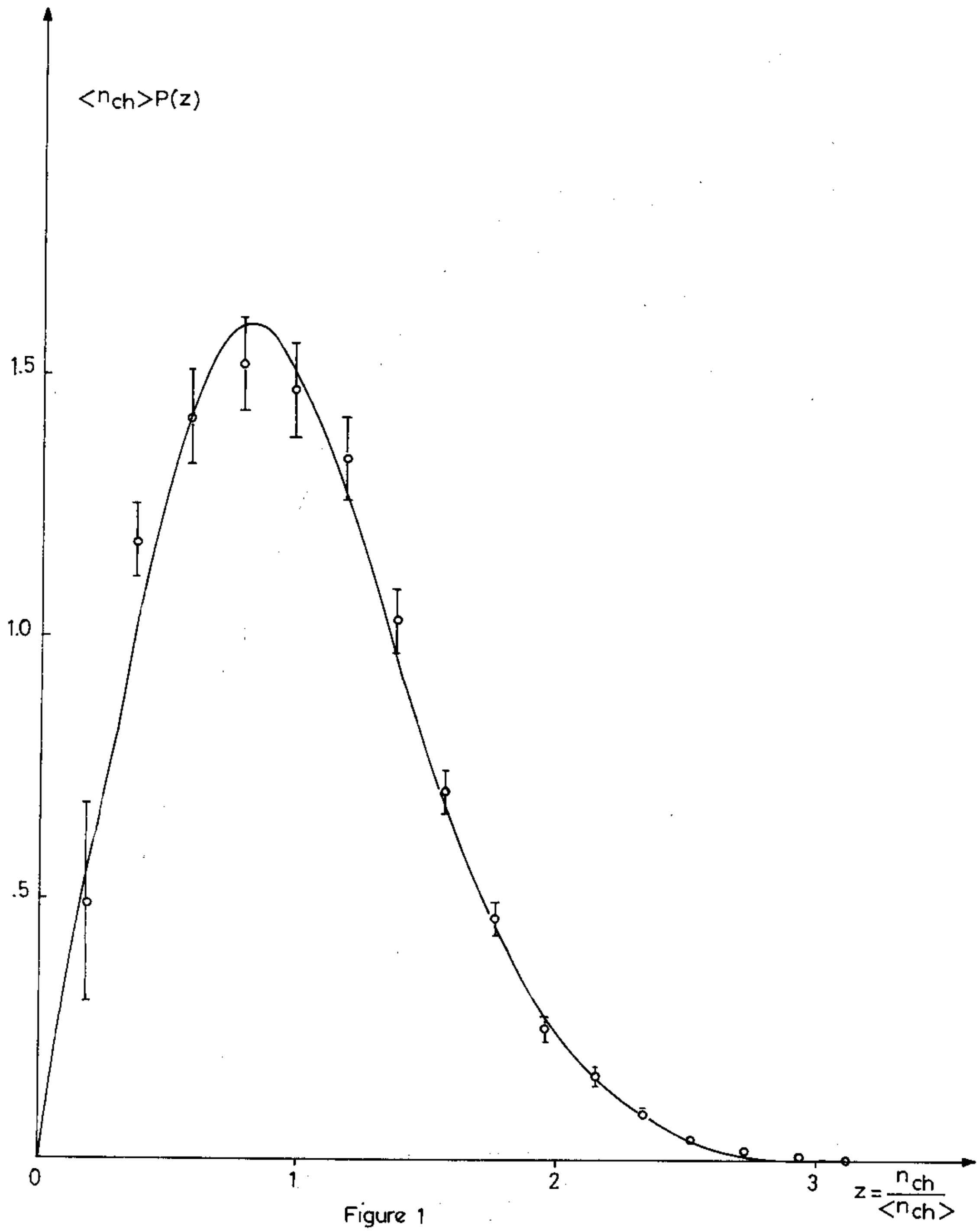

Figure 1

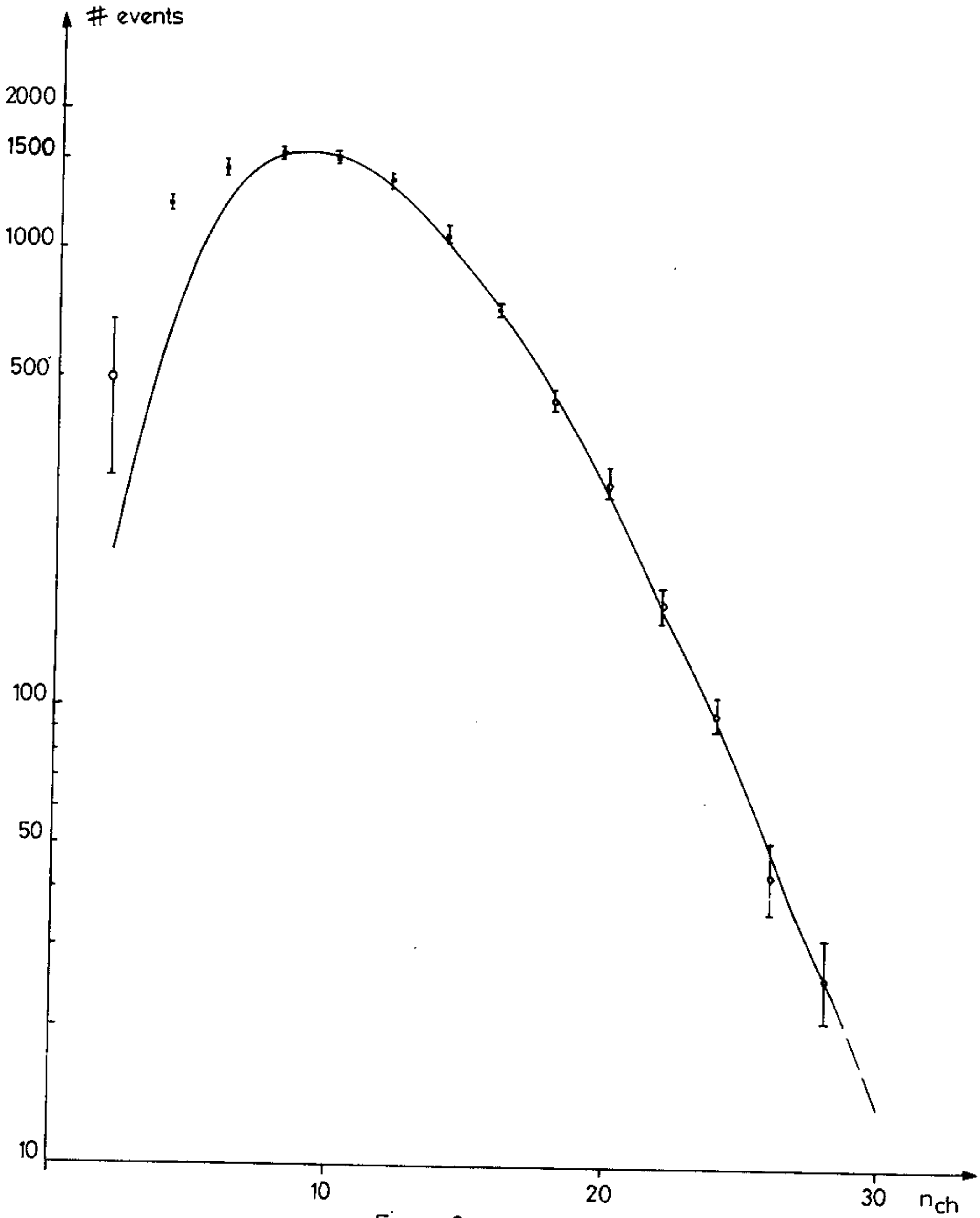

Figure 2