CHARGED PARTICLE MULTIPLECTIES AT THE CERN SPS COLLIDER

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Abstract

First results from UA5 on charged particle multiplicities from p\bar{p} interactions at $\sqrt{s} = 540$ GeV are presented. A value of $27.4 \pm 2.0$ is obtained for the mean charged multiplicity $\langle n_{\text{ch}} \rangle$ of produced hadrons. This excludes an $s^{1/4}$ behaviour of $\langle n_{\text{ch}} \rangle$ in going from ISR to Collider energies, but is not in disagreement with an extrapolation using a quadratic fit in $\ln s$ to previous lower energy data up to ISR energies.

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Introduction - The CERN SPS Collider has extended the rapidity range of hadronic interactions from 8.4 units at the highest ISR energy to 12.7 units at the Collider c.m. energy $\sqrt{s} = 540$ GeV. If multiplicities of hadron production were to grow approximately as $\ln s$ we would expect an $\sim 50\%$ increase in the charged hadron multiplicity over this energy range. It is known from the ISR experiment of Thomé et al. [1] that the charged hadron multiplicity grows faster than $\ln s$, for the best fit to the data a $\ln^2 s$ term being required.

In cosmic ray experiments there have been indications [2] of events having a very high hadronic multiplicity which could indicate a still more rapid increase with $s$ of the multiplicity. However, a recent balloon flight emulsion chamber experiment, studying hadronic interactions at a laboratory energy of $\sim 20$ TeV [3], finds a mean charged multiplicity consistent with an extrapolation of the fit of Thomé et al. mentioned above. In cosmic ray experiments, with primary flux falling off as $\sim E^{-1.7}$, $E$ being the incident laboratory energy, different detector thresholds might significantly change the phenomena under study.

In view of these conflicting results from the cosmic ray data, the Collider experiments have an opportunity to improve our understanding by providing measurements based on well-controlled experiments in this energy region. In this paper we present the first results on the topological description of $p\bar{p}$ interactions at the Collider energy. The results are based on 340 completely measured and reconstructed events. The data come from a detector consisting of a pair of streamer chambers, 6 m long, placed above and below the beam pipe in the LSS4 experimental area of the CERN SPS Collider. The detector covers almost $4\pi$ in solid angle, and is triggered by planes of scintillator hodoscopes at either end. The triggered data is essentially non-diffractive, as described in the foregoing paper [4]. More information about the experimental set-up, trigger run conditions and the data analysis procedures as well as results concerning rapidity distributions are given there.
Analysis of the data - The dashed histogram of fig. 1(a) shows the charged multiplicity distribution of the raw data which were obtained after associating primary tracks to the interaction vertex. The main source of background to have been removed is electron or positron tracks originating from $\gamma$-rays which convert in the beam pipe. Of the tracks found to point back to the primary vertex typically 20% originate from this source. An algorithm was therefore developed to separate the true primary tracks from these secondaries by reconstructing secondary vertices in the beam pipe, making the appropriate small corrections. The observed primary multiplicity is typically 75% of the true multiplicity because of acceptance losses. Corrections have been made for these acceptance losses using a Monte-Carlo simulation.

Our Monte-Carlo program [4] generates events according to $p_T$-limited phase-space and a KNO distribution following the parametrization of Slattery [5]. It then tracks the particles through the detector configuration. These simulated tracks were analyzed by the same program chain as the real tracks. Fig. 1(a) shows as the full histogram the distribution resulting from this procedure. The two distributions are compatible. Table 1 shows the mean value and the dispersion obtained from the measured distribution before corrections are applied.

Fig. 1(b) shows the multiplicity distribution corrected for acceptances. The values of the mean charged multiplicity and the dispersion for this distribution are also given in table 1 for comparison. The KNO curve using the parameters given by Slattery [5] is superimposed on the distribution.

An independent estimate of the average observed charged multiplicity $<n_{ch}>$ is obtained by integrating our pseudorapidity distribution given in [4]. The value obtained is $25.2 \pm 1.4$. The Monte-Carlo simulation suggests that $6 \pm 3\%$ of the charged particles produced non-diffractively have $|\eta| > 5$. Taking this into account, the corrected mean charged multiplicity is therefore

$$<n_{ch}^{nd}> = \frac{1}{n} \sum_{n} n \sigma_{n}^{nd} / \sigma = 26.8 \pm 2.1,$$
where the superscript nd indicates that our trigger excludes single
diffraction dissociation. The above value is also given in table 1. Our
best estimate is \( <n_{ch}^{nd}> = 27.4 \pm 2.0 \) obtained by averaging the
two values in table 1. The fit to the ISR data of Thomé et al. [1] using
an \( s^{1/4} \) dependence gives \( <n_{ch}> = 40 \), a number which even at this
stage we can rule out.

Fig. 2 shows the dependence of \( <n_{ch}> \) on \( s \) for several FNAL [6]
and ISR [1] experiments. The data points are well described by the
parametrization \( <n_{ch}> = a + b \ln s + c \ln^2 s \) determined by Thomé et
al. [1]. The value of \( <n_{ch}> \) for a recent balloon flight experiment
[3] also lies well on the extrapolated curve. However, since our measured
value excludes the single-diffractive cross section it cannot be compared
directly with the other experiments which give a value of \( <n_{ch}> \) for
the whole inelastic cross section.

For FNAL data [6] and for our earlier ISR experiment [7] the values of
\( <n_{ch}^{nd}> \) are also shown in fig. 2. Judging from the observed difference
between \( <n_{ch}^{nd}> \) and \( <n_{ch}> \) over their energy range, the difference
between our measured value and the extrapolation of Thomé et al. can easily
be accounted for by a single diffraction dissociation component.

To estimate the influence of diffraction dissociation [8,9] we assume
that, as observed at the ISR, elastic scattering and single diffraction
dissociation each contributes 18% to the total cross section. Making the
extreme assumptions for the mean charged multiplicity \( 3 \leq <n_{ch}^{sd}> \leq 1/2 <n_{ch}^{nd}> \),
where the superscript sd denotes single diffraction dissociation, this leads
to an estimate for the average inelastic charged multiplicity in the range
\( 21 \leq <n_{ch}> \leq 27 \), in reasonable agreement with the prediction \( <n_{ch}> = 25 \) of
Thomé et al. This result puts in doubt speculations arising from cosmic
ray studies about very high average multiplicities at Collider energies.
We do observe events of very high multiplicity as may be seen from
fig. 1(a) and 1(b), but the high multiplicity tail of the distribution
needs further study.
Multiplicity dependence of pseudorapidity distributions - Fig. 3(a) shows our normalized pseudorapidity distributions for different intervals of the corrected observed multiplicity. For lower multiplicities ($n_{ch} \leq 30$) the distributions are almost flat. Going to higher multiplicities ($n_{ch} \leq 50$) the distributions develop an enhancement around $|\eta| = 1.5$ with a clear indication of lower values in the central region. This observation of lower values in the central region can be indicative of either a change in the relative particle composition ($\pi/K/N$) or an increase in the $<p_t>$ or both.

Fig. 3(b) shows the dependence of the central ($|\eta| \leq 1$) pseudorapidity density on multiplicity $n_{ch}$. It grows linearly over the entire range.

Summary - our first results on a topological description of pp interactions show a number of phenomena, some expected and some unexpected.

- The average charged multiplicity $<n_{ch}>$ does not grow as fast as $s^{1/4}$ from ISR to Collider energies.

- The parametrization of Thomé et al. for lower energies leading to $<n_{ch}> = 25$ at our energy is appropriate to account for the observed $s$-dependence after we allow for single diffraction dissociation.

- The pseudorapidity distributions for different intervals of $n_{ch}$ are almost flat up to $n_{ch} = 30$. At higher multiplicities the distribution develops an enhancement around $\eta = 1.5$.

- Our charged multiplicity is compatible with KNO scaling at this stage, but more accurate data are evidently needed at high multiplicities to confirm this hypothesis.
Acknowledgements

The contributions of all those CERN staff working hard for the so successful bringing into operation of the SPS Collider are gratefully acknowledged. We particularly want to thank SPS Division for their ingenious efforts with the installation of our equipment in the experimental area, and those staff of EF Division who have given their very efficient help in the building and operation of the UA5 detector.

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REFERENCES


[4] K. Alpgård et al., previous paper, First Results on Complete Events from pp collisions at c.m. energy of 540 GeV.


Values of $<n_{ch}>$, $D = [<n(n-1)> - <n>^2]^{1/2}$ and $<n_{ch}> / D$ obtained from the measured charged particle multiplicity at $\sqrt{s} = 540$ GeV. The left-hand column refers to the measured distributions before corrections were applied. The corrected values appear in the next two columns: firstly we give the values under our trigger conditions i.e. single diffraction excluded, and then in the last column we give values of $<n_{ch}>$ allowing for a diffractive component (see text). The results labelled (a) are after unfolding the smearing of multiplicity due to acceptance limitations and (b) from a simple integration of the pseudorapidity distribution.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Raw data</th>
<th>Corrected data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Single diffraction dissociation excluded</td>
</tr>
<tr>
<td>$&lt;n_{ch}&gt;$</td>
<td>$20.0 \pm 0.7$</td>
<td>$28.0 \pm 2.0^a$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$26.8 \pm 2.1^b$</td>
</tr>
<tr>
<td>D</td>
<td>$11.2 \pm 0.5$</td>
<td>$12.5 \pm 1.7^a$</td>
</tr>
<tr>
<td>$&lt;n_{ch}&gt; / D$</td>
<td>$1.8 \pm 0.2$</td>
<td>$2.2 \pm 0.3^a$</td>
</tr>
</tbody>
</table>
FIGURE CAPTIONS

Fig. 1  (a) Charged particle multiplicity for raw data obtained in this experiment by associating observed primary tracks to the interaction vertex, compared with a Monte-Carlo prediction following KNO scaling obtained after tracking through our detector.

(b) Measured multiplicity distribution corrected for acceptances, with KNO prediction superimposed.

Fig. 2  Dependence of $<n_{ch}>$ upon $\sqrt{s}$ as measured in lower energy experiments together with the Thomé et al. [1] fit of the form $<n_{ch}> = a + b \ln s + c \ln^{2} s$ to ISR and lower energy data. The UA5 data point reported here is for single diffraction dissociation excluded, and several lower energy non-diffractive values are also shown for comparison.

Fig. 3  (a) Normalized pseudorapidity distributions for various intervals of corrected observed charged multiplicity obtained in this experiment.

(b) Dependence of central pseudorapidity density on $n_{ch}$. 
Fig. 1

(a) Raw data

KNO Monte-Carlo

(b) KNO fit [5]
All inelastic:
- Thomé et al. [1]
- Balloon data [3]
- FNAL data [6]

Non-diffractive:
- UA5 [7]
- FNAL [6]
- UA5 this expt.

Fig. 2
\[ \frac{1}{\sigma_n} \frac{d\sigma_n}{d\eta} \]

(a)
- \( 2 \leq n_{ch} \leq 17 \)
- \( 18 \leq n_{ch} \leq 31 \)
- \( 32 \leq n_{ch} \leq 45 \)
- \( 46 \leq n_{ch} \leq 60 \)
- \( 60 \leq n_{ch} \leq 90 \)

\[ \frac{1}{\sigma_n} \frac{d\sigma_n}{d\eta} \mid \eta = 0 \]

(b)

- Fig. 3 -