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THE CROSS SECTION OF DIFFRACTION DISSOCIATION AT THE CERN SPS COLLIDER

UA4 Collaboration

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ABSTRACT

Single diffraction dissociation was measured in the reaction $\bar{p}p \rightarrow \bar{p}X$ at the centre-of-mass energy $\sqrt{s} = 546$ GeV. The mass M of the system X was deduced from the pseudorapidity distribution of the observed charged tracks. The cross section of single diffraction dissociation for $M^2/s \leq 0.05$ is $\sigma_{sd} = 9.4 \pm .7$ mb. Comparison to the ISR data shows that σ_{sd} increases with energy less fast than the total and the elastic cross sections.

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The process of single diffraction dissociation has been already studied at the SPS Collider by the UA4 Experiment. The double differential cross section $d^2\sigma/dtdM^2$ of the reaction $\bar{p}p \rightarrow \bar{p}X$ was measured for momentum transfer $-t > 0.5 \text{ GeV}^2$ and for $M^2/s < 0.1$ [1]. The mass M of the system X was derived from the relation $M^2 = s(1 - x)$, where x is the ratio of the antiproton momentum to the beam momentum. The fragmentation of the X -system was also studied in the same kinematical range by measuring the pseudorapidity distribution of the charged secondaries [2].

The results mentioned above were obtained with the collider operated in the so-called low- β mode, which allows an accurate measurement of the antiproton momentum in a t -range which is, however, limited to relatively large values ($-t > 0.5 \text{ GeV}^2$). As a consequence, the diffraction dissociation cross section σ_{sd} could not be extracted from those data.

Detection of low $-t$ events which constitute the bulk of the cross section is possible in the high- β mode. The results presented in this letter were obtained during a special high- β run which was primarily devoted to the measurement of low $-t$ elastic scattering and of the total cross section [3]. The antiproton scattered at small angles (few mrad) was observed in a spectrometer consisting of very forward detectors placed inside "Roman pots" [4]. The $\bar{p}$ momentum was obtained from two position measurements after deflection of the trajectory by the machine quadrupoles and from the known position of the interaction vertex. The momentum interval accepted by the apparatus extended down to about $x = 0.5$. The observed momentum resolution, evaluated from a sample of elastic events has a r.m.s. value of 8%, much poorer than the value of 0.6% reached in the low- β mode, where the quadrupoles have a much higher strength. The momentum transfer, as determined from the observed scattering angle, was in the range $0.04 < -t < 0.3 \text{ GeV}^2$. Charged particles produced by the fragmentation of the proton were observed in a vertex detector consisting of the UA4 forward drift chamber telescopes [3, 4] and of the central detector of the UA2 Experiment [5]. This system covered the full angular range, with the exception of two gaps at intermediate angles, for θ between 10° and 20° and between 160° and 170° (corresponding to the pseudorapidity interval $1.7 < |\eta| < 2.5$) and of the forward regions, for θ within 0.4° from the beam direction ($|\eta| > 5.6$). The trigger required a particle

through a "Roman pot" telescope in coincidence with at least one charged particle in the pseudorapidity range $2.5 < \eta < 5.6$ in the opposite hemisphere. More details about the apparatus, the beam properties and data reduction are given in refs. [3, 4].

The single diffraction dissociation cross section σ_{sd} can in principle be obtained from the observed differential cross section $d^2\sigma/dtdM^2$ by two successive integrations, over the diffraction region, usually defined by $M^2/s < 0.05$ (or $M^2/s < 0.1$) and over the momentum transfer. This procedure was used by the CHLM Experiment at the ISR [6]. It cannot, however, be applied to the data of the present experiment where the antiproton momentum was not measured with sufficient accuracy.

A different method was used here, which is based on the existence of a relationship between the mass of the diffractively produced system and the rapidity interval covered by its decay products.

The inclusive momentum distribution of antiprotons from the reaction $\bar{p}p \rightarrow \bar{p}X$, corrected for acceptance and integrated over the observed momentum transfer range is shown in fig. 1 in terms of the variable $1 - x = M^2/s$. There is clear evidence for a quasi-elastic peak around $x \approx 1$ of width similar to the experimental resolution. Three different sets of data are displayed in fig. 1. Events were selected according to the value of the rapidity gap g between the antiproton and the charged particle produced in the fragmentation of the system X which is closest in rapidity space to the antiproton itself. Denoting by y_{min} the rapidity of this particle, the rapidity gap is given by $g = y_{min} - y_p$, where $y_p \approx -\log(\sqrt{s}/m) = -6.35$, m being the proton mass. In the present experiment where only the direction of charged tracks is measured, the rapidity gap is defined in terms of the pseudorapidity variable. Events were selected for a rapidity gap g larger than a given minimum value g_{min} . In fig. 1 the set of data for $g_{min} = 0$ is the fully inclusive distribution. The other two distributions are subsets of data referring to $g_{min} = 2$ and $g_{min} = 5$. As the rapidity gap increases, the distribution becomes more and more depleted in the region $M^2/s > 0.1$. Diffraction dissociation events are left while non-diffractive events with a leading antiproton are removed. This observation clearly shows the existence of a correlation between mass M and rapidity gap g , as expected on the basis of the results of ref. [2].

Our earlier measurement [2] has shown that the fragmentation of diffractively produced systems is approximately described by longitudinal phase space. In that case the secondaries from the dissociation of X are centred in rapidity space around $y_X = \log (\sqrt{s}/M)$ and cover the region from a minimum value $y_{\min} = \log (m \sqrt{s}/M^2)$ up to a maximum given by $y_{\max} = \log (\sqrt{s}/m)$, which is independent from M and coincides with the beam rapidity. As a consequence the rapidity gap is related to M by the relation $g = \log (s/M^2)$. Integration of the observed differential cross section up to a maximum value of the mass, $M_{\max}$, is therefore equivalent to integrating over values of the rapidity gap larger than $g_{\min} = \log (s/M_{\max}^2)$.

In ref. [1] it was also shown that, at fixed t , the mass spectrum of the diffractive system decreases, for large masses, approximately as $1/M^2$. In that case the diffraction dissociation cross section integrated for $M^2 \leq M_{\max}^2$ is expected to rise as $\log (M_{\max}^2)$ while, if the integration is carried out on the rapidity gap variable for $g \geq g_{\min}$, the cross section should show a linear dependence on $g_{\min}$.

A quantitative explanation of the fragmentation data of ref. [2] was given in ref. [7] in the framework of the dual parton model [8], where the interaction is described by the exchange of two quark-antiquark chains between the proton and the antiproton. In the present analysis a Monte-Carlo simulation based on this model with chain fragmentation calculated from the standard Lund program [9] was used. This model which reproduces well also the fragmentation data of the CHLM Experiment at the ISR [10], gives for the correlation between rapidity gap g and the variable M^2/s the results shown in fig. 2(a). There is a small but significant difference with respect to longitudinal phase space.

In order to extract the diffraction dissociation cross section from the data, a full Monte-Carlo simulation of the experiment was made. Events were generated with a mass spectrum that decreases as $1/M^2$ at large masses, but allowance was made for an extra yield above the $1/M^2$ spectrum at low masses, i.e. for $1.4 < M < 4$ GeV. Therefore, the comparison of the Monte-Carlo simulation with the data involves the determination of two parameters, the magnitude of the $1/M^2$ term which is fixed at large masses and the extra contribution at low masses. An example of the results of the simulation is

given in fig. 2(b), where calculated values of σ ($g \geq g_{\min}$) are plotted versus $g_{\min}$ both for an ideal detector of charged particles with full angular coverage and for the actual detector which has dead regions. For an ideal detector one gets approximately a straight line as expected, while distortions are predicted in the actual data around those values of the rapidity which correspond to dead regions. The detection efficiency of the vertex detector was found to be above 95% for $M > 4$ GeV, $\sim 75\%$ for $M = 3$ GeV and $\sim 25\%$ for $M < 2$ GeV.

The analysis of the data was carried out as follows. The momentum transfer distributions corresponding to given values of the rapidity gap g were first corrected for the acceptance of the "Roman pot" telescopes and for smearing due to the t -resolution. In the explored low $-t$ region the data can be fitted by the exponential form $\exp(bt)$. In the diffractive region the typical value of the slope is around $b \simeq 8 \text{ GeV}^{-2}$, as shown in table 1.

The differential cross section for $g_{\min} = 3.2$ which, according to the calculation of fig. 2(a), corresponds to $(M^2/s)_{\max} = 0.05$, is plotted in fig. 3 together with results from our earlier experiment [1] at larger momentum transfer, as obtained by integrating the published cross sections $d^2\sigma/dtdM^2$ in the same kinematical interval, i.e. for $M^2/s < 0.05$. The absolute normalization of the present data was obtained from the final result on σ_{sd} . The two sets of data were fitted to the form $\exp(Bt + Ct^2)$ which was already used at the ISR [6] in a similar t -range. The result of the fit was $B = 8.0 \pm 0.1 \text{ GeV}^{-2}$ and $C = 2.3 \pm 0.1 \text{ GeV}^{-4}$, with $\chi^2 = 23$ for twenty degrees of freedom. The low value of the χ^2 indicates that the two sets of data join together quite well. Numerical values of the cross section are given in table 2.

Integrating the momentum transfer distributions in the full t -range and multiplying by a factor of two to account for dissociation of both proton and antiproton, one obtains the observed cross sections $\sigma_{\text{obs}} (g \geq g_{\min})$, which are plotted in fig. 4 as a function of $g_{\min}$. Only events where the $\bar{p}$ momentum is not too small ($x > 0.75$) were retained. This selection allows rejecting non-diffractive events, which dominate at small values of the rapidity gap, but affects the data for $g_{\min} > 5$ by less than a per cent.

The full line in fig. 4 is the result of the model calculation discussed above with normalization constants adjusted to fit the observed cross sections in the region $g_{\min} > 5$. The measured cross sections at low masses, $M < 4$ GeV, was found to be higher by about a factor of two than the $1/M^2$ form which reproduces the large mass data.

At small values of $g_{\min}$ the data points lie above the expectation for a diffractive process. This is naturally interpreted as due to the contamination by non-diffractive events. However, it is gratifying to see that in the range of $g_{\min}$, where the fit was done, the data points indeed follow the expected trend very well, including the dead regions of the detector. This gives confidence in the validity of the present procedure to extract the diffraction dissociation cross section σ_{sd} from the data.

The final results on σ_{sd} for different values of $(M^2/s)_{\max}$, as obtained from our model calculation after correction for detector efficiency, are presented in table 3. The efficiency correction amounts to about 1 mb and is mainly due to the losses of low-mass events. The quoted error of about $\pm 7\%$ takes into account the uncertainties on the absolute normalization of the event rate ($\pm 2.5\%$), on the integration of the t -distributions ($\pm 3\%$) and on the acceptance calculation ($\pm 5\%$). A result with the lower limit $M > 4$ GeV, which is not affected by the acceptance uncertainty at low-mass, is also given in table 3.

In the kinematical range defined by $M^2/s \leq < 0.05$ our result on the diffraction dissociation cross section is $\sigma_{sd} = 9.4 \pm 0.7$ mb. It is plotted in fig. 5(a) together with the ISR data [6] on proton-proton collisions which refer to the same interval of M^2/s . Our result is considerably lower than the prediction given in ref. [11]. The measured ratio between the value of σ_{sd} at the collider and at the maximum ISR energy of 63 GeV [6] is 1.25 ± 0.10 . This is smaller than the corresponding ratios for the total and the elastic cross sections which are 1.42 ± 0.03 and 1.74 ± 0.08 , respectively [3]. This is illustrated in a different way in fig. 5(b) where the ratios σ_{el}/σ_{tot} and σ_{sd}/σ_{tot} are plotted as a function of $\sqrt{s}$. We conclude that the single diffraction dissociation cross section rises with energy more slowly than the total and the elastic cross

sections. In the diffractive region, as defined by a low value of M^2/s , the t -dependence of the differential cross section shows shrinking with respect to the ISR data. The forward slope is about one half of that observed for elastic scattering [3].

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TABLE CAPTIONS

Table 1 Results of the $\exp(bt)$ fit in the range $0.04 < -t < 0.3 \text{ GeV}^2$.

Table 2 Differential cross section of the reaction $\bar{p}p \rightarrow \bar{p}X$ for $M^2/s \leq 0.05$.

Table 3 Results on the single diffraction dissociation cross section σ_{sd} .

TABLE 1

g	M^2/s	$b \text{ (GeV}^{-2}\text{)}$
> 9.5	$< 10^{-4}$	8.3 ± 0.3
$5 - 7.5$	$10^{-3} - 10^{-2}$	7.3 ± 0.3

TABLE 2

$-t \text{ (GeV}^2\text{)}$	$d\sigma/dt \text{ (mb/GeV}^2\text{)}$	Error (mb/GeV ²)
0.05	23.93	0.47
0.07	19.24	0.42
0.09	17.39	0.43
0.11	14.80	0.43
0.13	12.79	0.45
0.15	11.19	0.47
0.17	9.16	0.46
0.19	7.27	0.45
0.21	6.24	0.44
0.23	5.58	0.45
0.25	5.43	0.48
0.27	4.63	0.47
0.29	4.26	0.52
0.55	0.90	0.03
0.65	0.48	0.02
0.75	0.33	0.02
0.85	0.19	0.01
0.95	0.14	0.01
1.05	0.095	0.008
1.15	0.075	0.007
1.25	0.058	0.006
1.35	0.044	0.007
1.45	0.036	0.006

TABLE 3

$g_{\min}$	$(M^2/s)_{\max}$	$\sigma_{sd}(\text{mb})$
3.2	0.05	9.4 ± 0.7
2.5	0.1	10.0 ± 0.7
3.2 ($M > 4 \text{ GeV}$)	0.05	6.4 ± 0.4

FIGURE CAPTIONS

- Fig. 1 Inclusive distributions of antiprotons in the reaction $\bar{p}p \rightarrow \bar{p}X$ are plotted versus M^2/s . The experimental resolution on x is 8%. Events were selected for values of the rapidity gap g larger than a given minimum $g_{\min}$. Definition of g is given in the text and also shown in the inset.
- Fig. 2 Results of the calculations using the model discussed in the text:
- (a) Correlation between rapidity gap g and M^2/s : LPS is the prediction of the longitudinal phase-space model.
 - (b) The diffraction cross section integrated for $g \geq g_{\min}$ is plotted versus $g_{\min}$ for an ideal detector (dashed line) and for the actual UA4 detector (solid line). The scale is arbitrary.
- Fig. 3 Present data on the differential cross section at low $-t$ for $g_{\min} = 3.2$, i.e. $(M^2/s)_{\max} = 0.05$ and the results at larger values of $-t$ from our earlier experiment [1] are shown together with the overall fit.
- Fig. 4 The observed cross sections for $g \geq g_{\min}$ are plotted versus $g_{\min}$ together with the best fit to the data in the diffractive region.
- Fig. 5 (a) The cross section of single diffraction dissociation at the SPS Collider is plotted together with the pp data of the CHLM Experiment at the ISR [6]. The data refer to the same kinematical range, $M^2/s \leq 0.05$.
- (b) The ratios $\sigma_{\text{el}}/\sigma_{\text{tot}}$ and $\sigma_{\text{sd}}/\sigma_{\text{tot}}$ are plotted as a function of energy.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5