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Angular distribution of inelastic diffraction

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Abstract

Models for inelastic diffraction based on s-channel absorptive unitarity predict a structure in the angular dependence at $t=2$ that is not apparent in the data collected so far at collider energies. Compatibility with the available data is obtained by allowing for a 30% contribution from events with helicity flip.

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$\sigma_{\text{diff}}/\sigma_{\text{tot}}$ smaller but very close to .163, and indeed the data of ref.6 give for this ratio the value .16 with an error of the order of 10%.

The model developed in ref. 1 and 2 gives an upper bound on the amount of inelastic diffraction cross section at each value of the impact parameter b and , by integration, on the global value of σ_{diff} . The values of σ_{diff} measured in ref. 3,4 and 6 correspond to 90% or more of the integrated bound. Therefore if our model is right the bound is nearly saturated at each value of b , and the shape of the b dependence of σ_{diff} cannot be much different from the shape of the bound that looks like a cusp peaked around $b=1$ F. We stressed in ref. 2 that this feature should produce a structure in the t dependence of σ_{diff} at $t=-2$ GeV² that is not apparent in the data of ref. 3 (reproduced for convenience in fig. 1). Since the connection between impact parameter and momentum transfer dependence is not as straightforward for σ_{diff} as it is for σ_{el} , we intend to study quantitatively in this paper the consequences of our bound for the t dependence of σ_{diff} .

We first looked for a better way to parametrize the imaginary part of the elastic amplitude than the one used in ref. 2. In the following we are going to use for the UA4 and UA5 data the parametrization

$$\sigma_{\text{tot}}(b) = 2(1 - \exp[-c b/R - (p b/R + (b/R)^2)]) \quad (1)$$

where the parameters c, R and p are determined by fitting the behavior of the elastic cross section at $s = (546 \text{ GeV})^2$ in the range $0 < t < .5 \text{ GeV}^2$ and turn out to have the numerical values $c=2.56$, $p=1.68$ and $R=1.38$ F. Repeating the calculations of ref. 2 with the parametrization of eq. (1) we obtain an upper bound on $\sigma_{\text{diff}} < 9.8 \text{ mb}$, very close to the value measured in ref. 3 and 4.

We now come to the real problem. If the diffractive cross section were given by the square of a single amplitude (that we assume purely imaginary and corresponding to no helicity flip in the spirit of our model) the J_0 Bessel transform of $\sqrt{\sigma_{\text{diff}}(b)}$ would give us the t dependence of the amplitude and we would obtain for $\sigma_{\text{diff}}(t)$ the behavior shown in fig. 2 that exhibits the expected dip at $t=-2 \text{ GeV}^2$. This dip will naturally be filled up to some extent by the contribution of the real part and of processes with a non zero helicity flip $\Delta\lambda$. Note however that

At collider energy hadronic reactions are mainly inelastic. The final states contain a host of particles, and no specific channel contributes to the total cross section more than a fraction of a millibarn. A remarkable exception is represented by the elastic channel that contributes by itself more than 20% of the total cross section. The special role of the elastic channel is easily understood in terms of the optical theorem: elastic scattering is generated by the shadow of the many inelastic processes that are present at these energies. The fact that the elastic scattering amplitude is dominated by its imaginary part and that it is mainly helicity conserving confirms its interpretation in terms of shadow scattering.

An interesting class of events that also contributes a large share of the total cross section is in a sense intermediate between these two extremes: one of the incoming particles is diffracted essentially elastically (but for a small energy loss in the c.m. system) while the other breaks up into a system of particles the invariant mass of which ranges from the mass of the incoming one to a fraction of the order of 20-30% of the available c.m. energy. These events show many of the characteristic features of elastic diffraction- little energy dependence for the production of a specific system and a clear diffraction peak. It is natural to assume that they share with elastic scattering also the properties of being mainly imaginary and helicity conserving and to construct models in which these two classes of events are generated by related mechanisms.

A t-channel analysis based on a factorizable Pomeron singularity easily accounts for the required features, but also leads to immediate trouble. Each channel should exhibit the same energy dependence of elastic scattering. The number of open channels increases with energy hence the ratio $\sigma_{\text{diff}}/\sigma_{\text{el}}$ should increase with energy in contrast with experiment.

A model for inelastic diffraction based on absorption and s-channel unitarity was presented several years ago (ref. 1) and more recently updated in ref. 2 in order to study the data collected in the meantime at the CERN proton-antiproton collider (ref. 3 and 4). It is based on a bound advocated by Pomplun⁵⁾, supplemented with an extra "physical" assumption, described in detail in ref. 1 and 2, that makes it numerically much tighter. The main feature of the whole scheme is that it makes it natural that the ratio $\sigma_{\text{diff}}/\sigma_{\text{tot}}$ should decrease when $\sigma_{\text{el}}/\sigma_{\text{tot}}$ increases, at variance with what one would expect in t-channel oriented models. This prediction is in very good qualitative and quantitative agreement also with the data recently collected by the E710 collaboration at $\sqrt{s}=1.8 \text{ TeV}$ (ref. 6). They find a value of $\sigma_{\text{el}}/\sigma_{\text{tot}} = .23 \pm .01$. It was anticipated in ref. 2 that this value of $\sigma_{\text{el}}/\sigma_{\text{tot}}$ should correspond to a value of

at this small value of t the shoulder after the dip is only 2-3 orders of magnitude smaller than the value at $t=0$. It would take a large real part to wipe out completely the structure at $t=2$, and this would contradict our main assumption on the shadow nature of inelastic diffraction. In the same spirit it is unnatural in our framework to have large contributions from processes with helicity flip $\Delta\lambda$. We will consider this possibility at the end.

The diffractive cross section is the sum of many contributions from orthogonal channels that can be labeled, among other parameters, by the value of the produced mass. Different channels can have a different impact parameter structure (for instance multiperipheralism goes along with common sense in suggesting that larger masses are produced more centrally), and the sum of many contributions with different t dependence could in principle give a result rather different from fig.1.

In guessing a decomposition of $\sigma_{\text{diff}}(b)$ in the sum of contributions from individual channels that can be transformed into the corresponding $\sigma_n(t)$ we are obviously introducing a very large amount of arbitrariness. We want to see which features of our results will turn out to be essentially independent of the way in which we parametrize this decomposition. For this purpose we consider the partition of $\sigma_{\text{diff}}(b)$ into the sum of N channels given by:

$$\sigma_n(b) = \sigma_{\text{diff}}(b) \frac{e^{-\alpha(b-b_0)^2}}{\sum_{i=1}^N e^{-\alpha(b-b_{0i})^2}} \quad (2)$$

with $b_0 = 2.5 F/N$, and study the dependence of $\sigma_{\text{diff}}(t)$ on the parameters N and α . We find that as soon as N becomes larger than 10 the final result shows very little dependence on N . The dependence on α is such that in the limit $\alpha \rightarrow 0$ all channels are proportional and we reobtain the distribution shown in fig. 2. The dip fills up completely for $\alpha > .5$ and leaves only a pronounced break that does not depend crucially on α any more. We show in fig. 3 the results that correspond to $N=20$ and $\alpha = 1.25$ and 2.5. As it was to be expected a structure at $t=2$ cannot be avoided by any parametrization, and we consider it a genuine feature of our model.

The slope B of $\sigma_{\text{diff}}(t)$ at small t is remarkably stable against changes in N and α and turns out to be of the order of 15 GeV^{-2} in all our parametrizations. This value is incompatible

with the value $B=8.0$ suggested in ref. 3. The stability of B makes sense physically, since this parameter must be connected with a suitably defined average value of b^2 . This connection can be made tight only in the case of a linear relation like in a form factor, or when the b dependence is Gaussian whereas in our case we can only show that

$$B = \pi \sum_n \int \sqrt{\sigma_n(b)} b^2 db^2 \int \sqrt{\sigma_n(b)} db^2 / 8 \sum_n \left(\int \sqrt{\sigma_n(b)} db^2 \right)^2.$$

We want to see now whether it is only the restrictive bound of ref. 1 and 2 that produces a value of B larger than the one observed in ref. 3, and not even the original weaker Pomplin bound. We take therefore the ansatz

$$\sigma_{\text{diff}}(b) = e^{-\gamma b} (.5 \sigma_{\text{tot}}(b) - \sigma_{\text{el}}(b)) \quad (3)$$

with γ chosen equal to .56 in order to reproduce the integrated value of $\sigma_{\text{diff}} = 9.4 \text{ mb}$ keeping the bound as central as reasonably possible. The same decomposition in $N=20$ channels with $\alpha=2.5$ produces now the angular distribution of fig. 4. Again the slope at $t=0$ is far larger than the one observed in ref. 3.

If we want to reconcile the angular dependence of the inelastic diffraction events presented in ref. 3 with the hypothesis that inelastic diffraction is generated by off-diagonal elements of the shadow of inelastic processes we have to allow for effects that do not follow naturally from our hypothesis, namely for contributions from real parts and from processes with a non-zero helicity flip. Little can be said about the former, that have no reasons to be particularly large at $t=2$ where their effect is needed. The helicity flip amplitudes on the contrary are naturally maximal for $\Delta\lambda=1$ and 2 in the sensitive region where the $\Delta\lambda=0$ contribution shows its dip. We have tried therefore to attribute a part of σ_{diff} to processes with $\Delta\lambda \neq 0$. For simplicity we have given to these processes the same impact parameter structure of σ_{diff} and assumed a $\Delta\lambda=1$ dominance. In fig. 5 we see that we can obtain a t dependence that is compatible with the data of ref. 3 by assuming that 30% of the events proceed via $\Delta\lambda \neq 0$.

In conclusion we believe that a better experimental study of inelastic diffraction would be very useful in understanding the nature of diffraction. We should try to obtain at collider energies the angular dependence of inelastic diffraction as a function of the produced mass as was done at ISR ⁷⁾ in order to see if specific channels keep showing the expected structure at $t=2$ as they do at lower energies.

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Figure captions

- 1) Data on the angular dependence of inelastic diffraction from ref. 3
- 2) The J_0 Bessel transform of the bound of ref. 2
- 3) Angular distributions of a $N=20$ channels model for two different values of α
- 4) Angular distribution of the $N=20$, $\alpha = 2.5$ decomposition of eq. 3
- 5) Same as in fig 3 with $\alpha= 2.5$ and with a 30% contribution from events with helicity flip.

Fig. 1

Fig. 4

Fig. 5

Fig. 2

Fig. 3