S-CHANNEL PHENOMENOLOGY OF DIFFRACTION SCATTERING
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A fruitful way to look at diffraction scattering is to consider it as a shadow of inelastic processes. S-channel unitarity gives:

\[
\text{Im } T_{fi} = |T_{fi}|^2 + \sum_n T_{nf}^* T_{ni} \tag{1}
\]

where \( T_{fi} \) is elastic amplitude and \( T_{nf} \) the amplitude of the production process \( i \rightarrow n \) \( (f \rightarrow n) \). The quantities \( G_i, i = el, \text{inel} \), are called the elastic and inelastic overlap functions, respectively.

Diffraction scattering has been studied for a long time with the help of the Eq.(1) but the progress has not been very rapid – partially due to lack of knowledge of the particle production amplitudes which are the input in the approach, partially because Eq.(1) is in spite of its simple appearance actually a very complicated relation. In the last year a new wave of enthusiasm in the above "shadow approach" has grown. This enthusiasm has been triggered by the results of the experiments at the NAL and the ISR: rising total cross-sections, detailed measurements of the s- and t-dependence of the elastic differential cross-section in proton-proton scattering and – of course – by the enormous flow of data on multiparticle production which has greatly improved the understanding of the dynamics of multi-body processes.

1. The Three-Component Pomeron: The measurements of the inclusive proton spectra at the NAL and the ISR show that at high energies inelastic diffraction and non-diffractive production populates to a large extent different regions of the phase space. This suggests that it might be useful to consider their contributions to elastic scattering separately. Hence we split \( G_{\text{inel}}(t) \) into two parts:

\[
G_{\text{inel}}(t) = G_e(t) + G_C(t) \tag{2}
\]

Here, \( G_e(t) \) is the shadow of the non-diffractive production \( (\approx \text{"pionization"}) \) and \( G_C(t) \) that of diffractive production. Combining Eqs.(1) and (2) one has

\[
\text{Im } T_{fi}(t) = G_{el}(t) + G_{\text{inel}}(t) + G_C(t) \tag{3}
\]

This "three-component structure" of the Pomeron is illustrated below:

In the forward direction Eq.(1) reduces to the Optical Theorem. Thus at \( t=0 \) the size of the individual components are known: \( G_{el}(0) = 7 \text{ mb} \), \( G_e(0) = 25 \text{ mb} \) and \( G_C(0) = 7 \text{ mb} \) at 200 GeV/c. A question of great interest is: How do these three components build up the t-dependence of the elastic amplitude, especially the interesting structures observed experimentally (the break at \( t = -0.1 \text{ GeV}^2 \) and the dip at \( t = -1.3 \text{ GeV}^2 \)?)

2. \( G_{\text{inel}}(t) \) from Experiment: The inelastic component of the Pomeron can be directly solved from experimental data. One rewrites Eq.(1):

\[
G_{\text{inel}}(t) = \text{Im } P \quad \text{and } P \quad P \quad P \quad P \quad P
\]
H. I. MIETTINEN solves Im $T_{fi}$ and Re $T_{fi}$ from elastic scattering data with a reasonable assumption on the elastic phase and performs the loop integration. The result of this exercise is shown in Fig. 1.

A striking observation is that $G_{\text{inel}}(t)$ changes sign at $t = -0.6$ GeV$^2$. This result has several important consequences. If $G_{\text{inel}}(t)$ would be a pole as is assumed e.g. in the old AFS approach, this zero would be a property of the residue of the pole. Hence it should propagate over to other processes staying at a fixed value of $t$. Such a result is in apparent disagreement with the experimental data (repeating the above exercise in $Kp$ scattering gives the zero at much larger $t$-values $t \approx -1.3$ GeV$^2$) Another important point is that the change of sign of $G_{\text{inel}}(t)$ provides strong constraints on theoretical multi-particle models; it turns out not to be easy to generate negative shadows.

3. Models for $G_{\text{inel}}(t)$: Let us see how some popular particle production models build up the $t$-dependence of $G_{\text{inel}}(t)$. In general the slope receives contributions from three different sources: the magnitudes of the production amplitudes, the phases of the production amplitudes and the spins of the produced particles. In different models these effects combine in different ways.

In the uncorrelated jet model (UJM) the produced particles do not have any mutual correlations in the momentum space. In position space, however, they are strongly correlated clustering around the position of the initial state particles. The model gives – ignoring phases and spins – an overlap function of roughly Gaussian shape in $b$-space.\[1\]

The RMS radius of this overlap function can be measured by measuring the transverse momentum dependence of the spectra of the produced particles. The experimentally observed value of the average transverse momentum of the particles, $<p_T> \approx 350$ MeV, corresponds to a radius of the production volume of less than 1/2 fermi. This value is much too small to fit the data,\[2\] it corresponds to a slope of the elastic differential cross-section of the order of $2$ GeV$^{-2}$, whereas experimentally $b \approx 10$ GeV$^{-2}$. Hence the model is in violent disagreement with experiment.

This unhappy situation can be avoided by including momentum dependent phases in the model.\[3\] Such phases correspond to translations in $b$-space.\[4\] Thus the phases can spread out the $b$-space volume occupied by the produced particles (see the figure below). It is obvious that by including phases the model can be brought into agreement with the data, but the results thus obtained depend completely on how the phases are handled. This means that the model has essentially no predictive power concerning elastic scattering. It can accommodate, for example, an arbitrarily fast shrinkage as well as no shrinkage at all.

In the multiperipheral model (MPM) the relevant variables are not the transverse momenta of the produced particles but the momentum transfers of the virtual particles (or Reggeons) exchanged. In simple versions of the MPM the amplitude is assumed to factorize into a product of the momentum transfers $t_j$ (short-range order):

$$T(ab \rightarrow 1 \ldots n) = \prod_{i=1}^{n-1} e^{bi}$$
The impact parameter structure of the MPM is very different from that of the UJM. In the MPM the natural b-space variables are the impact parameter steps $\Delta b_j$, i.e., the differences between the impact parameters of the particles produced next to each other in the chain. The assumption that the $t_j$'s factorize implies that the impact parameter steps are independent. This means that the MPM is equivalent to a random walk in impact parameter.

The parameters characterizing the b-space walk of the MPM, the steplength $\langle \Delta b_j \rangle$ and the total number of steps, can be estimated from particle production data. Numerically the above naive version of the MPM turns out to be in strong disagreement with experiment: the differential cross-section given by the model has much too steep t-dependence ($t \propto 3 \text{GeV}^{-2}$ at 100 GeV/c) and shrinks much too fast ($a' / a \propto 3 \text{GeV}^{-2}$). These troubles can be cured at least partially by introducing clustering effects into the model. Qualitatively it is obvious that clustering works in the right direction: it reduces the number of steps in the chain. Thus it reduces both the t-slope and the speed of the shrinkage. Quantitatively, however, it is not clear if the clustering effects are enough to bring the model into agreement with experiment.

Another possible way to modify the simple MPM is to introduce unitarity corrections. They cause long-range correlations among the produced particles. Hence the walk in the unitarized MPM is not random but correlated. Quantitative studies of the b-space structure of the unitarized versions of the multiperipheral model would be very interesting.

The problem of how to build up the Pomeron (and the meson trajectories) in the dual models has been actively studied in the last year. Several very interesting new ideas has been presented. They will be reviewed in the theoretical sessions so we shall not discuss them here.

4. The Diffractive Component $G_D(t)$: The shadow of the inelastic diffraction $G_D(t)$ can be calculated assuming:

i) the excitation spectrum,
ii) the phase of the excitation and
iii) the decay of the diffractively produced systems.

$G_D(t)$ is then obtained by calculating the loop integral.

This problem has been studied in detail by Sakai and White. These authors show that the b-space structure of the diffractive overlap function $G_D(b)$ depends critically on the assumed spin and helicity structures of the excited systems. They determine the excitation vertices from the ISR proton spectra. A calculation with the assumptions of a linear mass-spin relation and of s-channel helicity conservation leads to a very central profile for $G_D(b)$. A similar calculation with the assumption of t-channel helicity conservation, on the other hand, leads to a peripheral profile: the diffractive production is happening at the edge of the absorption region around $b \approx a_0 f$ (see fig. 2).

The experimental data of low mass diffractive production is known to be in rough agreement with t-channel helicity conservation (and to completely disagree with s-channel helicity conservation.). The assumption of exact t-channel helicity conservation is actually not at all crucial for obtaining a peripheral $G_D(b)$. Any combination of amplitudes with a "reasonable" amount of s-channel helicity flip amplitudes would give a peripheral result for the diffractive shadow.
5.- Pomeron Phenomenology: The measurements of elastic differential cross-sections in proton-proton scattering at the ISR have attracted much phenomenological interest. The data show clear structures at small \( t \)-values: a rapid change of the slope of the order of \( \Delta b^2 \simeq 2 \) takes place at \( t \sim -0.1 \text{ GeV}^2 \). Another interesting feature of the data is that the break observed at lower energies at \( t = -1.3 \text{ GeV}^2 \) has developed to a beautiful diffraction minimum at the ISR.

The observed small-\( t \) structure can be simply accommodated by a two-component "disk" + "ring" parametrization of the inelastic overlap function \( G_{\text{inel}}(t) \) (or, alternatively, of the elastic scattering amplitude itself). Several authors have performed such two-component fits \([9,10]\). Their results show that i) it is easy to fit the data well and ii) the relative size of the two components depends critically on their assumed shapes. The small-\( t \) break corresponds to a long tail in \( G_{\text{inel}}(b) \) extending out to \( b \)-values much larger than one fermi. In the two-component fits this large-\( b \) tail can be described either by the "disk" component (see e.g. the fits of Sakai and White \([6]\) and Henzi and Valin \([11]\)) or by the "ring" component (Henyey et al. \([1]\)).

It is very tempting to identify the "ring" component with inelastic diffraction and the "disk" component with non-diffractive production \([3]\). In such an interpretation one should probably blame the non-diffractive component for the large-\( b \) tail. The results of Sakai and White also support this idea.

In their model calculation shown in fig. 2 the diffractive component is essentially a ring centered at 1 fermi and non-diffractive component dominates both at small and at large impact parameters. Henyey et al. have a different interpretation. They associate the "ring" component to "dissociation processes", that is to processes in which the beam particles dissociate into their virtual constituents before scattering and then only some of these constituents interact with the target.

Let us finally comment on the observed energy dependence of the data. A careful study of \( G_{\text{inel}}(b) \) as a function of the incoming energy reveals two very important results (see Ugo Amaldi's review in these proceedings): i) the value of \( G_{\text{inel}}(b=0) \) is essentially constant through the whole ISR energy range at a level which is clearly below the unitarity limit (roughly 92-94% of the unitarity limit) and ii) the observed rise of the proton-proton total cross-section comes from the region around \( b = 1 \) fermi. The first result indicates that the rise of \( \sigma_{\text{tot}} \) is not caused by a "naive" saturation of the unitarity limit (in which the absorption first reaches the 100% ceiling at \( b = 0 \) and then starts to expand out in \( b \)) but is a more complicated effect. After this observation it is natural that the rising contribution is centered at 1 fermi. An expanding "disk" component with a radius of about 1 fermi would obviously give such a rise. Alternatively, the rise could be caused by a growing "ring" contribution centered at 1 fermi. The question of the physical origin of this rise is one of the most exciting problems of today's hadron physics and in solving it one will probably learn quite a lot about the structure of elementary particles.

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REFERENCES:


[6] That the MPM corresponds to a random walk in $b$-space has been known for a long time among the experts. For a recent clear discussion see F.S. HENYEY, Phys. Letters 45B (1973) 469.


[8] See, for example, CANESCHI (L.) and SCHWIMMER (A) Nucl. Phys. B44 (1972) 31.


See also Refs. (3) and (9).