EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/89-163

15 December 1989

BREMSSTRAHLUNG AND DIFFRACTIVE DISSOCIATION

K.H. Dederichs and M.A. Faessler

Physics Dept., University of Munich, Fed. Rep. Germany

and

CERN, Geneva, Switzerland

ABSTRACT

Diffraction dissociation is described as a process where virtual quanta are released from a strong field. The bremsstrahlung spectrum of these quanta leads to the $1/M^2$ -dependence of the cross-section—as observed for $p\bar{p}$ -interactions—and the same dependence for proton-nucleus interactions. Confinement of the field quanta (quarks or gluons) explains the general properties of the multiparticle final state into which the excited state of mass M dissociates.

(Submitted to Physics Letters B)

1. INTRODUCTION

Elastic diffraction exhibits the wave character of the incoming particle. Inelastic diffraction reveals the quantum mechanical nature of the incoming wave. The wave function can be represented as a superposition of states coupled to the incoming particle by its interaction with the vacuum. In the language of optical models, these states are diffracted into existence through the differences of their absorption probabilities. Inelastic diffraction of hadrons, coherent (diffractive) photoproduction of vector mesons, and the K_S^0 regeneration provide examples for this mechanism, which is well known in high-energy physics. Optical models are able to explain the angular distribution (t-dependence) of diffraction. However, other features of diffraction have been outside the scope of these models. The inclusive differential cross-section for inelastic diffraction of protons (with initial mass m) is experimentally found to have a very simple dependence on the invariant mass M of the diffractively excited proton p^* (fig. 1) [1, 2], for M above the region of nucleon resonances:

$$\frac{d\sigma(pp \rightarrow pp^*)}{dM^2} \propto \frac{1}{(M^2 - m^2)} . \quad (1)$$

This M^2 -dependence, which strongly reminds us of the $1/M^2$ -dependence of coherent photoproduction of vector mesons [3], has never been explained in optical models. Moreover, they have so far not been able to predict the properties of the states (p^*) produced in the diffractive dissociation of hadrons, such as multiplicities, and rapidity or transverse momentum distributions of secondaries.

With respect to these two features of inelastic hadron diffraction— M -dependence and the properties of the produced states—the Reggeon-exchange models have had more predictive power. According to these models, elastic and inelastic diffraction is mediated by the exchange of the Pomeron, a Regge trajectory with the quantum numbers of the vacuum. Since no particles or resonances have been identified that could be safely attributed to this trajectory, the Pomeron must be considered as a hypothetical object. It has been suggested that the Pomeron corresponds to multigluon-exchange (without net colour transfer) [4], and that glueballs (searched for in many present experiments) are the missing particles of the Pomeron trajectory.

The Regge model leads to the $1/M^2$ -dependence of the inclusive differential cross-section through the triple-Pomeron diagram [2], and to the prediction that the final state in diffractive dissociation has properties similar to those of the final state in normal inelastic interactions at corresponding c.m. energy ($s = M^2$), in agreement with experimental data. More details of diffractively excited states are predicted in a model that is based on a pomeron-photon analogy [5].

We propose a mechanism for diffraction excitation that is based on QCD phenomenology and can be inserted into an optical model of diffraction. The composite structure of the incoming hadrons is described by the most economical and, for this process, sufficient assumption that each hadron consists of two coloured constituents and that one of them (which may be thought of as representing the gluon field) is distributed in momentum according to a bremsstrahlung spectrum. We show where coherence applies, and how to explain the $1/M^2$ -dependence of the inclusive differential cross-section as well as the longitudinal phase-space distribution of the products of dissociation.

2. COHERENCE AND THE M^2 -DEPENDENCE OF INELASTIC DIFFRACTION

One of the essential features of diffraction is coherence. The coherence condition for the reaction $h_1 + h_2 \rightarrow h_1 + h_2^*$ (single-diffractive excitation of the hadron h_2) is

$$\Delta p_z r < 1 , \quad (2)$$

with r being the radius of h_1 and

$$\Delta p_z = \frac{M^2 - m^2}{2p_{in}} \quad (3)$$

being the minimum momentum transfer in the beam (z) direction onto h_1 in its rest system, which is necessary in order to excite the projectile h_2 with momentum p_{in} from mass m to mass M . With increasing p_{in} , higher masses can be excited coherently.

Relation (2) is frequently quoted in the literature as a condition for diffraction but, to our knowledge, its implication for inelastic diffraction has not been followed up; we will discuss it in the following and start with a consideration of the kinematics. The momentum transfer in the projectile (h_2) rest system,

$$\Delta p_z = \frac{M^2 - m^2}{2m} \quad , \quad (4)$$

depends only on the masses m and M . For large M the coherence condition is not satisfied in this reference system. It appears as if the coherence were only one-sided. In the case of single-diffractive excitation this conclusion is acceptable, since the momentum transfer of the elastically scattered hadron h_1 is small and satisfies relation (2) whereas it is large for the excited hadron h_2 , in their respective rest systems. However, for double-diffractive dissociation, where both hadrons are excited to higher masses ($h_1 + h_2 \rightarrow h_1^* + h_2^*$), the situation is more complicated and it appears as if this were not a coherent process at all. The momentum transfer for double-diffractive dissociation has a simple form in the centre-of-mass (c.m.) system:

$$\Delta p_z = \frac{M_1^2 + M_2^2 - m_1^2 - m_2^2}{2\sqrt{s}} \quad , \quad (5)$$

where $\sqrt{s}$ is the c.m. energy. In the rest system of particle 1 it is

$$\Delta p_z = \frac{M_1^2 - m_1^2}{2m_1} + \frac{(M_1^2 + M_2^2 - m_1^2 - m_2^2)}{s} \cdot \frac{M_1^2 + m_1^2}{2m_1} \quad . \quad (6)$$

To obtain the corresponding momentum transfer in the rest system of particle 2, we have only to interchange the indices. Thus, apparently, in either reference system the momentum transfers for producing large masses M are too high to satisfy the coherence condition.

We will show the role played by coherence, by relating diffractive dissociation to the emission of hadronic bremsstrahlung. Consider the reaction pictured in fig. 2a. A fast hadron h_1 passes a hadron h_2 that is at rest. Think of the analogous situation of an electron passing the Coulomb field of a nucleus. The field of h_2 as seen by h_1 is equivalent to a spectrum of virtual field quanta distributed in energy ω approximately as:

$$\frac{dN}{d\omega} \propto \frac{1}{\omega} \quad (7)$$

up to a maximum energy ω_{max} . (This distribution corresponds to a flat rapidity distribution up to a maximum rapidity y_{max} since $dy/d\omega = 1/\omega$.)

A familiar property of electromagnetic (and gluon) bremsstrahlung (known since the method of virtual quanta was developed by Weizsäcker and Williams) is that a probabilistic picture applies: The interaction cross-section—including bremsstrahlung—factorizes into the probability of emission of the bremsstrahlung quantum and the interaction cross-section of the new state (after the emission of bremsstrahlung). A known example of this factorization is shown in fig. 3a. The two diagrams in

fig. 3b describe the interaction of a hadron h_2 with h_1 , subsequent to the emission of bremsstrahlung. In this case, both the parent constituent and the virtual bremsstrahlung quantum interact strongly with the target hadron h_1 . Hence, we propose the following model to describe non-diffractive inelastic, diffractive inelastic, and elastic interactions.

The wave function of h_2 is expressed as a superposition of two-constituent states, where one of the constituents ('q', representing the valence quarks) is at rest and the other one ('g', representing the field) has an energy ω with the probability $dN \propto d\omega/\omega$. In addition to the energy ω and transverse mass $m_\perp$ of the g-constituent, the spatial separation between the two constituents is to be taken as a variable. We identify the corresponding two-constituent configurations with the eigenstates of diffraction in an optical model that is similar to the one by Miettinen and Pumplin [6] except for the different basis of eigenstates. The significance of the 'eigenstates of diffraction' is that in the interaction these states are either absorbed or transmitted but do not mix. Assuming that the interaction proceeds predominantly by the exchange of colour, the interaction shown in fig. 3b is considered as being non-diffractive or absorptive. Owing to colour confinement, the new state thus created will fragment into a multiparticle state. However, the different diffractive eigenstates are absorbed with different probability, depending on the spatial separation between the two constituents g and q and, possibly, their momenta. Different absorption probabilities may, for instance, arise from a mechanism of colour compensation as proposed by Pumplin and Lehmann [7]. Thus the transmitted wave of h_2 has a different composition in terms of the eigenstates as compared with the incoming wave. This is equivalent to a non-zero amplitudes for the transition to diffractive eigenstates. For the extreme case of equal absorption of all configurations, the transmitted wave would have the same relative composition as the incoming wave, leading to purely elastic scattering. A calculation of absolute diffractive cross-sections and their t-dependence, based on the optical model outlined above, will be presented in a separate paper [8]. In this paper, we are concerned only with the M^2 -dependence.

Let us see how the diffractively excited states will appear, long after the interaction. The invariant mass of the excited hadron h_2^* is given by

$$M^2 = (p_q + p_g)^2 = 2\mu\omega, \quad (8)$$

where p_q and p_g are the four-momentum vectors, and μ and ω the energies (in the rest system of h_2) of the constituents q and g, respectively. We can calculate the mass (M) spectrum from the energy (ω) spectrum of the field quanta, and obtain

$$\frac{dN}{dM^2} \propto \frac{dN}{d\omega} \propto \frac{1}{\omega} \propto \frac{1}{M^2}. \quad (9)$$

Thus the bremsstrahlung emission spectrum (P_{qg} , see fig. 3b) leads to the same M-dependence as that of the experimentally observed inclusive diffractive pp cross-section shown in fig. 1. However, we have not yet shown that the M^2 -dependence of the cross-section follows from formula (9). To link one to the other, it is essential that the absorption probabilities (for the interaction shown in fig. 3b) be independent of M. This requires that $\sigma(qh)$ and $\sigma(gh)$ be independent of the momenta of the constituents q and g—an assumption that is commonly made and justified in quark-model calculations of hadronic cross-sections [9].

3. COHERENCE LIMITS AND EXTENSION TO HADRON-NUCLEUS INTERACTIONS

We now address the question of coherence, and of the coherence limit in energy of the bremsstrahlung quantum ($\omega_{\max}$). As for classical electromagnetic bremsstrahlung, the easiest approach is to transform to a reference system where the problem can be treated non-relativistically [10]. For the process $h_1 + h_2 \rightarrow h_1 + h_2^*$, this is the rest system of the unexcited hadron h_1 (see fig. 2b). In this case, the dipole approximation applies. For simplicity, we assume that the acceleration is along the beam direction. The bremsstrahlung intensity is then given by the integral

$$\frac{dI}{d\omega} \propto \left| \int \mathbf{n} \times \left(\mathbf{n} \times \frac{d\beta}{dt} \right) \exp(i\omega t) dt \right|^2, \quad (10)$$

where $d\beta/dt$ is the acceleration of h_1 , and $\mathbf{n}$ is the direction unit vector to the observer.

It is in this integral that the coherence enters. The radiation from various points of the interaction (i.e. acceleration) adds up coherently in the low-frequency range $\omega < 1/T$ and interferes destructively in the high-frequency range $\omega > 1/T$ [10]. The interaction time T is in our case $T = r_1/c$ (with r_1 being the radius of h_1). Thus the energy limit of the radiation, imposed by coherence, is

$$\omega_{\max} = \frac{c}{r_1} \approx 0.2 \text{ GeV}. \quad (11)$$

To transform back to the reference system where h_1 is the beam and h_2 is at rest, we boost with the factors $\gamma = E_{\text{in}}/m_1$, and $\eta = p_{\text{in}}/m_1$, and obtain for the energy of the bremsstrahlung quanta $\omega' = \gamma\omega$ with a corresponding energy loss of h_1 . The dipole characteristics of the radiation justifies our simplifying assumption that the quantum is emitted perpendicularly to the beam direction (see fig. 2b). Hence the maximum energy is

$$\omega_{\max} = \frac{E_{\text{in}} c}{r_1 m_1}. \quad (12)$$

Surprisingly, at first sight, the bremsstrahlung spectrum, as a function of energy, has the same form in every reference system, up to the maximum energy (which depends on the reference system), since

$$\frac{dN}{d\omega'} = \frac{dN}{d\omega} \frac{d\omega}{d\omega'} \propto \frac{\gamma/\omega'}{\gamma} = \frac{1}{\omega'}. \quad (13)$$

For a fixed lower cut-off value $\omega_0 = \omega_0'$, the integral of this spectrum rises logarithmically with the beam energy E_{in} of h_1 . In fig. 4a we sketch the distribution of bremsstrahlung quanta in the variable $\ln(\omega)$ together with the locations of the incoming hadrons. The corresponding maximum rapidity $y_{\max} = \ln(2\omega_{\max}/m_{\perp}) = \ln(2\gamma c/r_1 m_{\perp})$ coincides approximately with the beam rapidity $y = \ln(2\gamma)$, since the transverse mass $m_{\perp}$ of the (dipole) radiation is approximately equal to ω in the rest system of h_1 (see fig. 2b).

To complete our discussion on coherence, we consider the case of double inelastic diffraction. In order to show how coherence is still relevant for this process, we may divide it into two subsequent steps. Assuming that the first one, the single excitation of h_1 , has already been achieved, we consider the next step by starting in the rest system of h_1^* and repeating the same arguments as for the first excitation. When we thereafter transform to the rest system of h_2 , the only change is that the maximum energy of the bremsstrahlung quanta, given by the coherence requirement, is $\omega_{\max} = \gamma' c/r_1$, where $\gamma' = E_{\text{in}}/M_1$ (instead of $\gamma = E_{\text{in}}/m_1$ as before). The kinematics for this process is sketched in fig. 4b.

Let us now consider the consequences of our considerations for diffractive proton-nucleus interactions. Both the proton and the nucleus can be excited. For the excitation of the nucleus, we have to identify h_1 with the proton and h_2 with the nucleus in fig. 2b. The acceleration of h_1 by the nucleus will, of course, depend on the nuclear mass number A ; but the shapes of the bremsstrahlung spectrum and the coherence limit (11) are expected to be the same as for h_2 being identified with a proton. Thus the model predicts the same M^2 -dependence — where M is now the invariant mass of the excited nucleus — and the same coherence limit. Alternatively, for single dissociation of the proton, h_1 in fig. 2b represents the nucleus, and the coherence limit changes as r_1 is now $A^{1/3} r_p$ and the mass $m_1 = Am_{\text{nucleon}}$.

The coherence limits estimated above for the energy of the bremsstrahlung are associated with expected cut-off values for the diffractive part of the differential cross-section as a function of M^2 or of Feynman- x_F shown in fig. 1a. They are obtained from the relations

$$\frac{M_{\text{max}}^2 - m^2}{s} = 1 - x_{F\text{min}} = \frac{\omega_{\text{max}}}{E_{\text{in}}} \approx \frac{0.2 \text{ GeV fm}}{r_1 m_1} \quad (14)$$

and are indicated in fig. 1a for the various energies of the data sets. The cut-off values are given below for various diffraction processes:

Reaction	$(M_{\text{max}}^2 - m^2)/s$
$pp \rightarrow pX$	~ 0.2
$pA \rightarrow pX$	~ 0.2
$\pi p \rightarrow \pi X$	~ 1
$Ap \rightarrow AX$	$\sim 0.2/A^{4/3}$

For double-diffractive dissociation — supposing that h_1 has already been excited — the above values for $1 - x_{F\text{min}}$ refer to the momentum of h_1^* which is situated at $x_F = 1 - (M^2 - m^2)/s$ relative to its momentum before excitation.

These limits could not be seen in past experiments because, before M^2 approaches the coherence limit (e.g. at $1 - x_F \approx 0.2$ for $pp \rightarrow pX$), the background from inelastic non-diffractive interactions (which increases as $1 - x_F$) becomes comparable to the diffractive cross-section [which decreases as $(1 - x_F)^{-1}$] already at $1 - x_F \approx 0.1$ (see fig. 1b). Only in the case of $Ap \rightarrow AX$ does there seem to be a chance of detecting the coherence limit. However, the difficulty that may be encountered in a corresponding experiment is to make sure that the nucleus remains in its ground state.

4. DISCUSSION

We have shown how the known $1/M^2$ -dependence of the inelastic diffractive pp cross-section can be related to bremsstrahlung emitted from the strongly interacting fields of hadrons. The same $1/M^2$ -dependence is predicted for inelastic pA diffraction. The coherence conditions for single and double diffraction, and for diffractive excitation of protons and nuclei in pA interactions, have been examined and upper mass limits for diffraction have been derived.

The confinement of the bremsstrahlung quanta leads to predictable dissociation properties of the excited hadrons. The state with invariant mass M , consisting of two coloured constituents, will fragment like a $q\bar{q}$ pair produced, for instance, in e^+e^- annihilation at $\sqrt{s} = M$. The jet axis will be close to the beam axis since the transverse mass of the bremsstrahlung quantum is small, less than $\omega_{\text{max}} = 0.2 \text{ GeV}$ [Eq. (11)]. More details on the fragmentation that are experimentally accessible, such as the quantum number flow within the jet, will follow if one associates the bremsstrahlung

quanta with the gluon field or sea quarks, and the parent constituent with the valence quarks. Under this assumption the quantum numbers of the excited hadron h_2 are expected to be found on the low-energy side in the reference system of fig. 2a, whereas the high-energy side should carry, on the average, no flavour. This conclusion can be tested experimentally.

Analogies with electromagnetic bremsstrahlung have been frequently used from the very first attempts onwards in order to understand strong interactions at high energies [11–14]. Multiparticle production has been described as a process where the strong fields are radiated off, like bremsstrahlung. The concept of a formation zone has been taken over from electromagnetic bremsstrahlung to explain characteristics of particle production from nuclear targets [15].

The earlier bremsstrahlung analogy had been applied to ‘normal’, i.e. non-diffractive, inelastic interactions. It predicted a flat rapidity distribution for the produced secondaries, with energy-independent height and a logarithmic growth of the total multiplicity—because, with increasing energy, the length of the plateau, i.e. the rapidity span of secondaries, increases logarithmically. However, the observation of an increasing height of the rapidity distribution, up to the highest accelerator energies available at present, led to these bremsstrahlung models being abandoned.

Today, multiparticle production in non-diffractive interactions is best described by QCD-inspired models, where colour is exchanged between the two interacting hadrons and the subsequent break-up of colour strings leads to multiparticle production. The perhaps most successful model, the Dual Parton Model (DPM) [16] is based on simplifying assumptions that are similar to ours: protons are made of a valence diquark and a valence quark, mesons of a quark and antiquark. In pp interactions, for instance, colour is exchanged between the quark of one proton and the diquark of the other, leading to two colour strings which in turn fragment into secondary particles. Sea quarks with a bremsstrahlung-like distribution eventually become involved in the interaction, e.g. in subsequent collisions with other nucleons when the proton interacts with a nucleus.

The essential feature of our model is that it combines the (old) bremsstrahlung analogy with the (new) mechanism of colour exchange. As proposed in the earlier models, the bremsstrahlung quanta are distributed homogeneously in rapidity between the rapidities of the incoming particles. We associate such a quantum (g) with a parent (q) constituent (representing the valence quarks) in each incoming hadron. Colour plays a twofold role: when it is exchanged between incoming hadrons (in non-diffractive interactions) it leads to colour strings, which fragment and yield a new state. When the two hadrons do not exchange colour (as in the case of diffractive interactions), colour confines the bremsstrahlung to the associated hadron. The colour string decays, producing secondaries that populate the rapidity range between the g and q constituents. In the case of single-diffractive dissociation, the dissociating hadron displays the virtual states of hadrons at the interaction; the momentum distribution of the non-excited hadron has the significance of a radiative tail.

Some time ago, Desai and Sukhatme [17]—and, later, other authors [18]—proposed a mechanism, within the framework of the Dual Parton Model, which explains the $1/M^2$ -dependence of diffractive dissociation in a somewhat different way than ours. They assume that the hadron h_1 in fig. 2a breaks up into two colour singlets, with one of them having a bremsstrahlung distribution that is typical for sea quarks, i.e. $dN/dx \propto 1/x_F$. This object then interacts with hadron h_2 according to the DPM mechanism for inelastic non-diffractive interactions [16]. The essential difference between our mechanism and the DPM diffraction is the following: we associate the bremsstrahlung with the field of the hadron which is excited, and the bremsstrahlung quantum may have colour and be confined. The DPM associates bremsstrahlung with the sea of the unexcited hadron, and the bremsstrahlung quantum therefore has to be a colour singlet and extended hadron-like object that collides with the other hadron and thereby excites it. Obviously, the fragmentation of the

diffractively excited hadrons will have very similar features in both models, and the two mechanisms are presumably indistinguishable in this respect. They may perhaps be distinguished by comparing the predictions for the A-dependence of inelastic diffraction. However, we did not attempt to extend the DPM diffraction mechanism to make a prediction for pA collisions.

Acknowledgement

We thank Dr. Kersten Braune for a critical discussion of the manuscript.

* * *

REFERENCES

- [1] M. Bozzo et al., Phys. Lett. **136** (1984) 217.
- [2] G. Alberi and G. Goggi, Phys. Rep. **74** (1981) 1.
- [3] M.A. Faessler, Nucl. Phys. **A447** (1986) 455, and in Proc. 28th Int. Symp. on Multiparticle Dynamics, Tashkent (USSR), ed. I. Dremin and H. Gulamov (World Scientific, Singapore, 1987), p. 319.
- [4] F.E. Low, Phys. Rev. **D12** (1975) 163.
S. Nussinov, Phys. Rev. Lett. **34** (1975) 1286.
- [5] A. Donnachie and P.V. Landshoff, Nucl. Phys. **B244** (1984) 322.
- [6] M.L. Good and W.D. Walker, Phys. Rev. **120** (1960) 1857.
H.I. Miettinen and J. Pumplin, Phys. Rev. **D8** (1978) 1696.
- [7] J. Pumplin and E. Lehmann, Z. Phys. **C9** (1981) 25.
- [8] K.H. Dederichs and M.A. Faessler, Pomeron-nucleus interactions, to be submitted to Z. Phys. C.
- [9] E.M. Levin and L.L. Frankfurt, Sov. Phys.-JETP Lett. **2** (1965) 108.
H.J. Lipkin and F. Scheck, Phys. Rev. Lett. **16** (1966) 71.
- [10] J.D. Jackson, Classical electrodynamics (John Wiley and Sons, Inc., New York-London-Sidney, 1965), p. 505
- [11] W. Heisenberg, Z. Phys. **126** (1949) 569.
- [12] I.Ya. Pomeranchuk and E.L. Feinberg, Dokl. Akad. Nauk SSSR **93** (1953) 439.
- [13] R.P. Feynman, Phys. Rev. Lett. **23** (1969) 1415.
- [14] L. Stodolsky, Proc. 6th Int. Colloquium on Multiparticle Reactions, Oxford, 1975, eds. C. Hong-Mo, R. Phillips, and D. Roberts (RL 75-143, Rutherford Lab., Chilton, Didcot, 1975), p. 577; and Proc. 7th Rencontre de Moriond, Meribel-Les-Allue, 1972, ed. J. Tran Thanh Van (CNRS, Paris, 1972), Vol. II, p. 37.
- [15] A.B. Migdal, Dokl. Akad. Nauk SSSR **96** (1954) 49; and Sov. Phys.-JETP **5** (1957) 527.
- [16] A. Capella et al., Phys. Lett **81B** (1979) 68.
A. Capella and J. Tran Thanh Van, Z. Phys. **C18** (1983) 85.
A.B. Kaidalov, Phys. Lett **116B** (1982) 459.
- [17] B.R. Desai and U. Sukhatme, A parton approach to peaks at large x in diffractive inclusive reactions, Riverside Univ. preprint 26795 (1983).
- [18] V. Innocenti et al., Phys. Lett. **169B** (1986) 285.
J. Ranft, Z. Phys. **C33** (1987) 517.

Figure Captions

Fig. 1 : The $1/M^2$ -dependence of single inelastic diffraction.

- a) Data from reference [1]. The coherence limits for the various c.m. energies are indicated by dashed vertical lines.
- b) Figure from Alberi and Goggi [2]. The non-diffractive background that decreases as $1 - x_F$ is indicated.

Fig. 2 : a) Diffraction excitation of the target hadron h_2 by a projectile h_1 .

- b) Emission of bremsstrahlung in the reference system with h_1 at rest at three successive steps of the collision (before the interaction, and at the beginning and end of it). The acceleration of h_1 is non-relativistic in this reference system and the dipole approximation applies. The shaded regions indicate the angular distribution of the radiation for an acceleration along the initial momentum.

Fig. 3 : Factorization of bremsstrahlung emission and cross-section.

- a) Deep inelastic virtual photon-quark interaction with gluon emission. $P_{qq'}$ is the probability of gluon emission by the quark; the cross-section is given by the product $P_{qq'} \sigma(\gamma^* q')$, where $\sigma(\gamma^* q')$ is the parton model cross-section for the virtual photon-quark interaction.
- b) Non-diffractive hadron-hadron interaction. P_{qg} is the probability for a particular configuration of hadron h , where the constituent q represents the valence quarks and the constituent g represents the field; $\sigma(qh)$ and $\sigma(gh)$ are the constituent cross-sections with hadron h .

Fig. 4 : The coherence limits of bremsstrahlung in the variable $\ln(\omega)$ for

- a) single-diffraction dissociation,
- b) double-diffraction dissociation.

The vertical lines indicate the locations of the projectile (h_1, h_1^*) and the target (h_2). The curves represent the distribution of the bremsstrahlung quanta. The height of this distribution is given by the absolute cross-section of diffractive dissociation [8]. (The curves also describe the range of the dissociation products emitted from the largest mass that can be coherently excited.)

Fig. 1

Fig. 2

Fig. 3

Fig. 4