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A SIMPLE TWO-COMPONENT MODEL FOR INELASTIC DIFFRACTION ON NUCLEON AND NUCLEI

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ABSTRACT

A simple two-component structure for the hadron is shown to reproduce in the Good-Walker scheme the experimental features of diffraction. This model is able to give a physical interpretation of the low absorption of diffractive states in nuclear matter, in terms of a short component of the hadron. Our investigation indicates a new direction in the interpretation of diffraction data and opens new possibilities for testing the confining models of the hadron.

As suggested in recent literature[1], inelastic diffraction can be considered as a consequence of the fluctuating structure of the hadron. This structure can be represented in terms of an expansion of eigenstates of the imaginary part of the T-matrix[2]. Indeed the imaginary part of the hadronic T-matrix, indicated as $\hat{T}$ in the following, has a complete set of eigenstaes. The expansion of the incident hadron is then

$$|H> \ = \ \sum_i c_i \ |\psi_i> \tag{1}$$

$$\hat{T}\ |\psi> \ = t_i \ |\psi_i> \tag{2}$$

The index i could be continuous and denote a spatial configuration of the incident hadron; P.E. for the mesons it could be simply the transverse distance between two point-like costituents, a quark and an anti quark.

The strict connection of these geometrical configurations to the T-matrix is physically understandable, because of the Lorentz dilation of the fluctuation time scale this becomes at high energies much larger than the interaction time as viewed from the target frame and each hadron configuration is frozen through the whole process.

We will now assume that the index is discrete and the expansion is reduced to just two terms, where the first correspond to a contracted configuration and the second to an elongated one. For the first one the average distance between the constituents is smaller than for the second one. It is then assumed that the eigenvalues of the $\hat{T}$ matrix are monotonically increasing with the quark-antiquark distance i.e. $t_1(b)<t_2(b)\forall b$. This last property is actually verfied in the two-gluon approach to diffraction[3] where the $\hat{T}$ matrix becomes 0 for a complete overlap of the color charges. In our formalism we do not consider the longitudinal degrees of freedom for the incident meson and in addition we do not consider the structure of the target nucleon, which is treated as an external field[1]. In this way the eigenstates of the $\hat{T}$ matrix represent only the diffractive excitations of the incident meson.

For two components the expansion of the incident hadron is

$$|H> \ = c_1 \ |\psi_1> + \ c_2|\psi_2> \tag{3}$$

$$\hat{T}\ |\psi_i> \ = t_i \ |\psi_i> \tag{4}$$

obtained calculating the corresponding standard deviation

$$\sigma_i = \int d^2b \, [\langle H \mid \hat{T}^2(b) \mid H\rangle - \langle H \mid \hat{T}(b) \mid H\rangle^2]$$

$$= \int d^2b \, [|c_1|^2 t_1^2(b) + |c_2|^2 t_2^2(b) - (|c_1|^2 t_1(b) + + |c_2|^2 t_2(b))^2] = \quad (5)$$

$$= \int d^2b |c_1|^2 |c_2|^2 [t_1(b) - t_2(b)]^2$$

where we have used that $|c_1|^2 + |c_2|^2 = 1$

It is then obvious that the b-distribution of inelastic diffraction is peripheral as shown on Fig. 1b. The peripherality is one of the most remarkable properties of inelastic diffraction and it is experimentally shown by a positive interference effect in exclusive coherent production on deuteron[4] and by the saturation of the Pumplin bound for the inclusive case[4].

An even more pronounced peripherality has been recently found[5] for double diffraction dissociation in proton proton interactions at ISR energies.

This is reproduced in this model, where double diffraction dissociation can be calculated using a double Good-Walker[3] expansion for the two colliding hadrons A and B

$$|A,B\rangle = \sum_{ij} c_{iA} c_{jB} \mid \psi_{iA}\rangle |\psi_{jB}\rangle \quad (6)$$

and the $\hat{T}$ matrix is factorized

$$\hat{T} \, |\psi_{iA} \, \psi_{jB}\rangle = t_{iA} \, t_{jB} \, |\psi_{iA} \, \psi_{jB}\rangle \quad (7)$$

The expression for double diffraction is obtained subtracting from the total inelastic diffraction, the two types of single inelastic diffraction for A and B respectively

$$\frac{d^2\sigma_{di}}{d^2b} = <\hat{T}^2>_{AB} + <\hat{T}>^2_{AB} - <<\hat{T}>^2_B>_A - <<\hat{T}>^2_A>_B =$$

$$= \left[\sum_\ell t^2_{\ell A}\, c^2_{\ell A} - \left(\sum_\ell t_{\ell A}\, c^2_{\ell A}\right)^2\right] \times \tag{8}$$

$$\times \left[\sum_k t^2_{kB}\, c_{kB} - \left(\sum_k t_{kB} c^2_{kB}\right)^2\right]$$

This result states in general that double diffraction dissociation is just the product of single diffraction for the two hadrons.

When the two hadrons are equal, as for the ISR experiment, the behaviour in b space of double diffraction is given for the two-component model

$$\frac{d^2\sigma_{di}}{d^2b} = |c_1|^2 |c_2|^2 [t_1(b) - t_2(b)]^4 \tag{9}$$

This expression gives a simple explanation of the more pronounced peripherality, found experimentally[5], indeed since $[t_1(b)-t_2(b)]^2 < 1$, the square of this expression favours the values close to 1, with respect to the values close to zero, enhancing relatively the peripheral peak on the non peripheral central background.

There is another experimental feature of inelastic diffraction, which, at first sight, does not seem to have any connection with peripherality. This is found in coherent production of exclusive or inclusive diffractive states, where the absorption of these states in nuclear matter is weaker than expected.

The analysis of experimental data is done using the Kölbig-Margolis model; this model considers only two physical states in the propagation through nuclear matter, the initial hadron and its diffractive excitation. The two-component model is therefore expecially suited for the comparison with the Kölbig-Margolis [6] model, with the warning that the two Good-Walker states are completely different from the two physical states.

The coherent production cross-section is in general given in the Good-Walker scheme as the dispersion of the nuclear T-matrix. This becomes in our model

$$\frac{d^2\sigma_{coh}}{d\,b} = \langle T^2_{nuclear}\rangle - \langle T_{nuclear}\rangle^2 = |c_1|^2|c_2|^2 \times \tag{10}$$

$$\left[\exp(-A\int T(b')t_1(\vec{b}-\vec{b}')d^2b') - \exp(-A\int T(b')t_2(\vec{b}-\vec{b}')d^2b)\right]^2$$

where $T(b) = \int_{-\infty}^{+\infty} \rho(b,z)dz$, being ρ the nuclear density. It is usually assumed in this context that the elementary t-matrix has such a small extension in b-space compared with the thickness function T(b) that we can approximate it as a delta-function. In this hypothesis $t_i(\vec{b}-\vec{b}') \simeq (\sigma_i/2)\,\delta(\vec{b}-\vec{b}')$ where $\sigma_i = 2\int d^2b\ t_i(b)$.

The ensuing expression can be compared with the Kölbig-Margolis model[6], which gives for the above quantity (10) the following form

$$\frac{d^2\sigma_{coh}}{d^2b} = \frac{|F_{in}(o)|^2}{|\sigma-\sigma'|}\left[e^{-\frac{\sigma}{2}T(b)A} - e^{-\frac{\sigma'}{2}T(b)A}\right]^2 \tag{11}$$

For this model σ and σ' are the total cross-sections for the initial and final hadronic states. The analysis of the data[7] using the form (11) has given a value of σ' definitely smaller than σ for all incident hadrons[8]. This result can be interpreted in the two-component model (10), with the existence of a small size component of the hadronic state, as assumed from the outset. Indeed the expression is exactly the same but with different interpretation of the parameters.

This gives for the first time a simple physical interpretation of the results of the coherent production experiments and gives an unexpected connection with the peripherality of inelastic diffraction.

For a more quantitative analysis of data in this new context one has to fix the parameters σ_1 and σ_2, not only consistently with the coherent production data, but one should reproduce the experimental numbers for the elementary total, elastic and inelastic diffraction cross-section.

A gaussian form was assumed for $t_1(b)$ and $t_2(b)$ and the initial determination of the parameters is given by the experimental value of the total cross section. The data for the elastic and the inelastic diffraction cross-section are then easily reproduced. The nuclear thickness functions T(b) are parametrized as functions of b as Wood-Saxon forms with parameters specified in the footnote^{+}.

In table I we report the actual values for the parameters for the πN case at 40 GeV/c and the corresponding values of the cross--sections compared with the experimental numbers. The prediction for the coherent cross sections for different nuclei are compared with the experimental data of Bellini et al.[11] in Fig. 1c. It is fair to say that there is at least qualitative agreement between theory and experiment. On the other side we do not expect that this simple model is able to reproduce the data in a perfect manner.

Fig. 1a shows the behaviour of $t_1(b)$ and $t_2(b)$. In Fig. 1b the profile of inelastic diffraction is showing a distinct peripheral behaviour, as expected from the above discussion.

The existence of a short and a long component of the hadron could be related to the intrinsic oscillating structure of the dual string model[12], which is now being studied in the framework of QCD[13].

This simple application of the Good-Walker scheme reproduces the peripherality of inelastic diffraction, interprets physically the experimental results for coherent production and extablishes an unexpected relation between the two facts. These results indicate a new practical direction in the interpretation of diffraction data and open new possibilities for testing the confining models of hadrons.

$^{+}$ The thickness functions are $T(b) = T_A/(1+\exp[|b - B_A|^{\frac{1}{2}}/C_A])$ where $C_A = 0.545$ fermi and T_A, B_A are 2.22×10^{-3} fermi^{-2} and 3 fermi for A=9; $1{,}95\times10^{-3}$ and 6 for A=12; 1.30×10^{-3} and 9 for A=27; 9.25×10^{-4} and 12 for A=48; 8.07×10^{-4} and 15 for A=64; 5.88×10^{-4} and 18 for A=108; 4.30×10^{-4} and 21 for A=181; 3.96×10^{-4} and 24 for A=207.

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Note added in proof:

After completing this work we became aware of a similar approach developed in a paper by G. Bertsch, S.J. Brodsky, A.S. Goldhaber and J.G. Gunion Phys. Rev. Lett. 47, 297 (1981). This aim of this paper, however is to to calculate diffractive charm production on nuclei.

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TABLE I

a) The values of the parameters in πN diffraction at 40 GeV for the gaussian form $t_i(b) = t_i(0)e^{-b^2/b_i^2}$

	i=1	i=2
b_i (fermi)	0.6265	0.7671
$t_i(0)$	0.7205	0.9613
$\|c_i\|^2$	0.6875	0.3125

b) Comparison with experimental values of πN crcss-sections 9), 10) at 40 GeV.

(mb)	two-components	experimental
σ_t	23.2	24.7
σ_{el}	4.5	3.1
σ_{di}	0.31	0.45

Figure Captions

Fig. 1 a) The behaviour in impact parameter space of the eigenvalues $t_1(b)$, $t_2(b)$ for the πN case at 40 GeV. These correspond respectively to the short and the long component of the hadron

b) The corresponding behaviour in impact parameter space of the profile function for single inelastic diffraction

c) Comparison of the 40 GeV pion coherent production data of Bellini et al.[11] with the prediction of equation (10).