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HIGH ENERGY HADRON-HADRON COLLISIONS

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ABSTRACT

Work on high energy hadron-hadron collisions in the geometrical model, performed under the DOE Contract No. DE-AS09-76ER00946, is summarized. Specific items studied include (a) the elastic hadron-hadron scattering at ultrahigh energies and the existence of many dips, (b) the computation of meson radii, (c) the hadronic matter current effects on inelastic two-body processes, and (d) the diffraction dissociation processes in hadron-nucleus and hadron-hadron collisions.

(I) Introduction

The geometrical description of high energy hadron-hadron collision was developed at first to account for the elastic phenomena. The physical picture[1] which underlies the discussion of high energy scattering envisages a hadron as an extended object with many degrees of freedom. Elastic scattering is then described[2] as two objects going through each other with attenuation and scattering each other by a diffraction process. A mathematical formalism has been developed which provides a direct link between the hadronic form factors and the elastic differential cross section. This model of elastic scattering which contains no adjustable parameters works extremely well at high energies. It predicted[3,4] the existence of a dip in elastic pp scattering, which has subsequently been found in experiments[5] at CERN-ISR.

As two hadrons pass through each other, they may not remain in their original states after scattering. In fact either or both hadrons may become excited and then fragment into pieces. Geometrical reasoning along this line has led us naturally to the speculation that for inelastic processes the fragments from either the target or the projectile will approach a limiting distribution in their respective rest frames at high energies. This hypothesis, referred to as the hypothesis of limiting fragmentation[6], has been confirmed by experiments[7] at CERN-ISR.

Pursuance of the geometrical description has also generated some additional ideas and concepts[8-12] which are useful in high energy collisions. An especially interesting one is the concept of hadronic matter current distribution[11,12]. Experimental test of this idea is expected to be carried out in the near future.

Since main results of the geometrical model have been stated and discussed in the previous proposals, we shall not review them here in any detail. In the following, work performed and results published by the Principal Investigator during the past two years under the DOE contract are summarized. Research proposed for the coming years will be stated below in Section B.

(II) Elastic hadron-hadron scattering at Isabelle energies

The development of the geometrical model came in two stages. When the model was first proposed, experimental trend seemed to indicate that the pp total cross section and the differential cross section would approach a limit at high energies. The discussions were then centered on the physical interpretation[2] of the shape of the differential cross section and its relation to hadronic structure. Based on the proposed theory we further predicted[3,4] the existence of diffraction maximum and minimum. Early experiment[5] at ISR in 1972 has beautifully verified our predictions; the quantitative agreement[13] between theory and experiment was truly impressive. Then in 1973, following the experimental discovery[14] of increasing total cross section, the model was generalized[15] to accommodate this new phenomena by allowing the opaqueness function to have a separable energy dependence. This generalization is consistent with the spirit of the original model, and it has yielded additional predictions: the shrinkage of the diffraction structure and the concurrent rise of the second maximum with energy. The series of experiments[16] performed at CERN-ISR in the past years has clearly confirmed the validity of these two additional predictions of the geometrical model.

Reprint #1 discusses the behavior of the various hadron-hadron elastic processes in the energy region much above the ISR range. Our theory predicted the existence of a second dip in pp elastic collision which has so far eluded experimental search[17]. We believe the reason for this is simply that the present experimental data are not at high enough energies. In comparing the change of slope at two different t regions between the 200 GeV data[18] and 1500 GeV data[16], we concluded[19] that perhaps there are already hints in the present data of the existence of the second dip in pp elastic scattering. An additional test of this conjecture that can be carried out at CERN-ISR has been suggested in Reprint #1. In the same paper[20] we have computed differential cross section curves and several important parameters for various values of σ_t in pp, πp, Kp and $\pi\pi$ using the geometrical model. So far πp and Kp elastic scattering have not shown any dips at all. We believe, however, that the reason for this is the same as for the case of the second dip in pp scattering. According to the geometrical picture, when the total cross section is sufficiently high, many dips would develop in all hadronic elastic scatterings. It is not surprising that this should be the case, since increasing opaqueness would produce an effective black disc[21] as the scattering center at sufficiently high energies.

(III) Meson Radii

The geometrical picture of hadron-hadron collisions can be applied to compute matter distribution inside hadrons. Using this model we have calculated from pp scattering data at ISR energies the proton matter form factor and found it in close agreement[22] with the proton G_E form factor measured in ep scattering experiments. We have also up-dated our computation[23] of the meson form factors using the new meson-proton scattering data[24]. (See Reprints #2 and #3.) To avoid possible biases in our analysis, we have adopted the parametrization and numerical fits to the differential cross section data provided by the experimentalists in their paper. We believe our recent analysis[25,26] is useful and results are more reliable. Experimental values for meson radii are now available for comparison with theoretical predictions. A direct measurement[27] of the pion radius by electron scattering has been published. The same experimental group has also carried out a kaon experiment at Fermilab. Their preliminary data on the kaon radius was announced[28] at the Tokyo Conference in 1978. At the same conference our theoretical results[29] were also presented. The good agreement of the geometrical model prediction with the direct measurements is especially encouraging, and certainly demonstrates the usefulness of our model. In fact, few other theoretical models have predictions to make about meson radii. Although models of the vector meson dominance variety have yielded some values for the pion radius, definitive prediction about the kaon radius does not exist as far as we know.

(IV) Hadronic matter current distribution

Since geometrical concepts such as sizes, matter distribution, or the opaqueness distribution of hadron are very useful in discussing high energy collisions, one may raise the interesting question[11] whether matter current exists inside a polarized hadron. Once we have accepted the concept of an extended hadron with a matter density in it, it seems to us inevitable that we must also accept the existence of a matter current in a polarized hadron. These two concepts necessarily complement each other, and they together form a four-vector. The existence of matter current may actually produce observable effects. Experimental test of this idea is now possible if one utilizes the rising total cross section[14] with increasing incoming energies. It has been shown[12] that the presence of hadronic current will result in a non-vanishing Wolfenstein parameter R in elastic scattering. We also believe, for very high energies, the spin dependence in elastic hadron-hadron scattering is solely due to this non-vanishing R parameter. Therefore, this spin effect can provide a way to experimentally test the concept of matter current in elastic collisions. The possibility of testing the concept with inelastic collisions has been suggested in the previous proposals. The main idea is that, if the final state of the target is unstable against weak decays, its spin direction can be determined from the distribution of the decay products. The R parameter for inelastic collisions can be readily estimated that it has the same values as for elastic collisions, if one makes use of the simple assumption that the G_E and G_M form factors are proportional. In Reprint #4 a detailed analysis[30] of the spin rotation effect in inelastic collisions is presented. Numerical computations indicate that, while two-body inelastic collisions with polarized hadron target can provide an alternative way to detect the matter current, accuracy of the measurement may be limited by the rapidly decreasing two-body inelastic cross sections at high energies.

(V) Diffraction dissociation processes

In recent years there has been experimental data[31] accumulated concerning the angular distribution of hadron-nucleus and hadron-hadron diffraction dissociation. One of the conspicuous features of all these experiments is the existence of dip or kink structures similar to that observed in pp elastic scattering. The dip in diffraction dissociation occurs generally at a smaller $|t|$ value than the dip in elastic scattering. These aspects of the diffraction dissociation process can be naturally accounted for in the geometrical picture. (See Preprint #1.)

Consider the passage of an incoming hadron through an extended target. At an impact parameter b the dissociation can take place at any point along its path during its traversal. The probability for the process to occur is approximately proportional to the thickness of the material traversed, or $\Omega(b)$. There is also absorption of the incoming wave before dissociation, and of the outgoing wave after dissociation. Assuming equal means free path for incoming and outgoing waves, the total absorption factor can be written as $\exp[-\Omega(b)]$. Thus the source function for the outgoing hadron in diffraction dissociation may be approximated by $\Omega\exp(-\Omega)$. This approximation was first used in charge exchange scattering[32] and was given the name "coherent droplet model." It was later utilized in meson photoproduction[33] and diffractive excitation processes[34].

With Ω determined from electron scattering experiments together with hadron-hadron total cross sections, numerical computations for differential cross section in diffraction dissociation processes have been made. It should be emphasized that using the geometrical picture, without adjustable parameters, the computed dip positions in pp, πCu and πPb elastic and diffraction dissociation collisions are in remarkable agreement with experiments.

To compare dip positions for elastic and diffraction dissociation scatterings, the two extreme cases of an opaque target and a transparent target may be considered. We can prove that in each instance the first dip for diffraction dissociation appears at a smaller $|t|$ value than that for elastic scattering.

To summarize, the essential point of Preprint #1 is that the dip and kink structures in both elastic and diffraction dissociation collisions are due to the shielding of the back part of the target by the front part, and therefore are geometric in origin.

(VI) Report on the current status of the geometrical model

A review of the results obtained from the geometrical model for high energy hadron-hadron collisions is given in Preprint #2, an invited talk presented at the Canton Conference on Theoretical Particle Physics, January 1980. The discussions there were focused on elastic scattering, diffraction dissociation process and the concept of matter current distribution inside a polarized hadron or nucleus.

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List of Articles Published
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Reprint #1 Elastic Hadron-Hadron Scattering at Ultrahigh Energies and Existence of Many Dips, T. T. Chou and C. N. Yang, Phys. Rev. D19, 3268 (1979).

Reprint #2 Calculation of Meson Radii in the Geometrical Model, T. T. Chou, Proceedings of the International Meeting on Frontier of Physics, Singapore (pub. by the Singapore National Academy of Science, Singapore) pp. 931-937 (1978).

Reprint #3 Radii of the Pions and the Kaons, Phys. Rev. D19, 3327 (1979).

Reprint #4 Study of Matter Current Effects in Two-body Inelastic Reactions, M. K. Rulison (M.S. thesis, University of Georgia, 1979).

List of Preprints
under DOE Contract No. DE-AS09-76ER00946

Report #1 Dip and Kink Structures in Hadron-Nucleus and Hadron-Hadron Diffraction Dissociation, T. T. Chou and C. N. Yang (submitted to Phys. Rev. for publication).

Report #2 The Geometrical Model of Hadron-Hadron Collisions, T. T. Chou and C. N. Yang (submitted to the Proceedings of the Canton Conference on Theoretical Particle Physics, Canton, China 1980).