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THEORETICAL PARTICLE PHYSICS

Progress Report

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ABSTRACT

Work in theoretical particle physics was done in a variety of subjects. A major effort went into a phenomenological description of high-energy elastic scattering. Using an s-channel description in which the partial wave amplitudes were parametrized as smooth functions in impact parameter space, good fits to the differential cross sections and polarizations were obtained, including the πp and pp data of the Indiana University spark-chamber group (Task A of this Contract). Phenomenological work was also done in characterizing strong-interaction resonances. Empirical relations among the masses, widths, and elasticities of resonances were found, and these relations were partially accounted for in terms of the Veneziano model. Further work on resonances was the development of a new parametrization which emphasizes the position of the pole in the relevant S-matrix. Finally, a new approach to five-dimensional general relativity was proposed.

This Report describes the research work performed during the past year or so which was supported by the AEC Contract No. AT(11-1) - 2009, Task B. Below, we discuss in turn the various topics in which we have been actively engaged.

1. AN S-CHANNEL APPROACH TO HIGH ENERGY SCATTERING (Chu and Hendry)

This work was originally stimulated some time ago by the increasing amount of experimental data, for several processes, in which measurements were made to cover most of the scattering region $0 \leq \theta_{\text{cm}} \leq 180^\circ$. These experiments have been mainly carried out at CERN¹ and Argonne^{2,3}. In particular, of course, were the results³ of the Indiana University Spark Chamber Group (Task A of this Contract) for all-angle $\pi^\pm p$ elastic scattering between 3 and 5 GeV/c; one of our intentions therefore was to attempt a theoretical analysis of the local data.

Traditionally, high energy reactions have been analyzed in terms of crossed channel Regge poles and cuts. This approach has been particularly successful in describing the energy s-dependence of the data. However, it suffers from two main drawbacks: (1) it applies to only the extreme ends of the scattering region, and (2) there is a considerable ambiguity in the interpretation of the experimental t-dependent structures. As a consequence, we have attempted a different, though complimentary, approach, namely one written directly in terms of the s-channel.

(a) Energy independent fits. The method we first developed was in analogy to scattering in optics. We used s-channel helicity amplitudes

(these amplitudes have subsequently become popular with t , u -channel Reggeologists), expanding them in terms of d -functions and parametrizing the corresponding partial wave amplitudes as smooth distributions in b , the impact parameter. Direct use of b -distributions makes the physical interpretation particularly clear; in practice, a Fermi distribution in b was used for the partial waves $j \leq kR$ in the diffraction amplitude, and an s -channel Regge pole (complex pole in b) to describe the peripheral scattering (as for grazing rays in optics).

With these parametrizations, we have been able to fit the data ($d\sigma/dt$ for all angles, polarization, etc.) for many processes⁴, primarily $\pi^\pm p$ elastic and $\pi^\pm p$ CEX scattering 2.74 - 5.0 GeV/c, $K^\pm p$ and $\bar{p}p$ elastic at 5.0 GeV/c, and pp elastic 3.0 - 24.0 GeV/c. The fitting was done one energy at a time where the data existed, just as is usually done now-a-days for determining the phase shifts at lower energies. Our investigations reveal many correlations throughout the scattering region - for example, the dips at $u = -.2$ in the $d\sigma/dt$ for backward $\pi^+ p$ and $\pi^- p$ CEX are strongly correlated to well-known structures in $d\sigma/dt$ and the polarization at $t = -.6$ (GeV/c)².

Much of this fitting is already published (see end of Report). This work also includes a comparison⁵ of our model with the usual t , u -channel Regge models, and we have suggested certain connections between the two approaches - for example, how Schmid loops are related to our peripheral scattering.

(b) A model with energy dependence built in. Obviously it is highly desirable to have a model which incorporates energy dependence as well as

t-dependence, and we have spent a considerable part of our time recently trying to develop just such a model. We have, in fact, succeeded in obtaining a new type of model, again based on an s-channel approach, and at present are completing our fits to π^-p CEX scattering.

Rather than continually summing a series of partial waves, we write the peripheral contribution in closed form, with energy dependence built in. In the case of spinless particles, one may represent the peripheral amplitude in the form $P_{\alpha(s)}(-\cos \theta_s)/\sin \pi \alpha(s)$, where $\alpha(s)$ is a moving s-channel Regge pole. Since $\alpha(s)$ itself is an analytic function, it is complex for s physical. (Note the important difference between $\alpha(s)$ here and the usual t-channel Regge trajectory $\alpha(t)$ which, in the s-channel physical region (t negative), is a real quantity.) To see that this can represent a peripheral contribution, we recall that

$$-\int_{-1}^{+1} dx P_{\ell}(x) P_{\alpha}(-x)/\sin \pi \alpha = \frac{(2/\pi)}{(\ell - \alpha)(\ell + \alpha + 1)}.$$

Thus, if the real part of $\alpha(s)$ is essentially kR , the major contribution is peripheral in character. The (positive) imaginary part of $\alpha(s)$ then determines the asymptotic behavior, or equivalently the shrinkage of the forward $d\sigma/dt$.

We have generalized this to the case of π^-p CEX scattering, where spin is important, using Jacobi polynomials $P^{(a,b)}$ and functions $Q^{(a,b)}$ of the second kind. Our formalism also incorporates the appropriate s, u crossing properties of the amplitudes. We find that we are able to fit the available experimental data from 5 to 20 GeV/c rather well in both

energy dependence and structure in t . Moreover, our model automatically gives the correct crossover at $t = -.2$ and a non-zero CEX polarization, two major problems with the usual t -channel Regge pole models. This work is almost complete, and a preprint will be forthcoming in the near future.

2. PION-NUCLEON ELASTIC SCATTERING AT LOW AND INTERMEDIATE ENERGIES (Lichtenberg)

Work has been continuing on a model of pion-nucleon scattering which is designed to correlate data in the resonance region and the intermediate-energy region. The model aims at a unified approach, incorporating features of the model of Crittenden et al.,⁶ which is most useful in the resonance region, and a model⁴ by two of us, which is most useful above resonance energies. Progress in working out the consequences of the model has been made, but the work requires fitting a large number of data at different energies, and much further effort will be required to complete the work. Basically, the model is a direct-channel description of elastic scattering, including terms containing resonances lying on direct-channel Regge trajectories plus non-resonant diffraction scattering. It is hoped to obtain a reasonable fit to the data with a smaller number of parameters than perviously used. However, the number of parameters required is still substantial, and this fact makes the amount of numerical work required rather large.

3. RESONANCE SYSTEMATICS (Lichtenberg)

Important empirical regularities have been found in the behavior of

the widths and elasticities of the meson-baryon resonances. It has been found that the widths of these resonances vary approximately linearly with their masses, with proportionality constants which are different for strange and non-strange baryons. It has also been found that the elasticities of the resonances lying on a Regge trajectory appear to vary as the mass squared times an exponentially decreasing function of the mass squared. These results have been discussed in a paper given at the Purdue Baryon Conference.⁷

4. MASS AND WIDTH OF A BROAD RESONANCE (Lichtenberg)

If a resonance has a large width, as do many hadron resonances, then the problem of determining its mass and width from the data is not trivial. The problem is tied up with how to parametrize the resonance. It has been shown⁸ that the mass and width parameters of the $\Delta(1236)$ resonance can vary by 15 MeV or more, depending on the form of the parametrization. However, if the mass and width are assumed to be given by the position of the pole of the S matrix, then the mass and width are much more stable.⁹ A new parametrization of a broad resonance has been proposed,^{10, 11} in which the mass and width parameters entering the resonance formula directly give the position of the pole of the S matrix.

5. ELASTICITIES OF RESONANCES IN THE VENEZIANO MODEL (Lichtenberg)

A simple version of the Veneziano model has been applied to pion-nucleon scattering. The partial widths for elastic scattering (elastic widths) of resonances on leading Regge trajectories have been calculated

and compared with experiment. The agreement is fair. Using a modified empirical formula suggested by the model, agreement with experiment is improved.¹²

6. PROTON-PROTON ELASTIC SCATTERING (Chu and Hendry)

During the past few months, the experimental group (Task A) of this Contract have been taking pp elastic scattering data at the Argonne ZGS, measuring the polarization of the recoil proton for beam momenta 5.15 to 12 GeV/c. From the theoretical point of view, this study is extremely interesting since it will provide for the first time pp polarizations at considerable scattering angles.

So far, their results at 5.15 GeV/c ($30^\circ \leq \theta_{\text{cm}} \leq 90^\circ$) are complete¹³. It is very interesting that their polarization does not have the structureless shape one would expect from a simple-minded t-channel Regge picture. In particular, there is a well pronounced dip in the polarization at $t \approx -0.8(\text{GeV}/c)^2$. This, however, is just what one would expect from an optical type of scattering where one has diffraction zeros and possibly appreciable surface scattering. (A very noticeable diffraction dip shows up also in $d\sigma/dt$ at ISR energies).

We have been analyzing this new polarization data from our optical model standpoint. A simple interpretation can be given for the observed dip at $t \approx -0.8 (\text{GeV}/c)^2$. At present, we have fit the 5.15 GeV/c data, and await the results at the other momenta for further analysis. In particular, we expect to see a second dip to develop in the polarization at $t \approx -2.5 (\text{GeV}/c)^2$ as the beam momentum increases.

7. A NEW APPROACH TO FIVE-DIMENSIONAL GENERAL RELATIVITY (Chu)

The motivation of this work¹⁴ is to examine the possibility of whether all interactions can be identified as gauge fields¹⁵ and whether these gauge fields will allow a geometrical interpretation. The remarkable progress of the gauge field theories recently developed in the unification of electromagnetic and weak interactions¹⁶, and the demonstration that non-abelian gauge field theories are asymptotically free¹⁷, suggest that it may be an appropriate time for this kind of investigation.

A reexamination of the ideas of Kaluza¹⁸ and others have led us to the following geometrical postulate: the macroscopic world is a five dimensional Riemannian manifold with constant curvature K and signature $(-,+,+,+,+)$. We have shown that a phenomenological metric theory of macroscopic gravitational observations can then be formulated, based on this postulate. We suggest that K^{-1} is proportional to the Planck constant $\hbar$, or more precisely in cgs units: $K^{-1} \propto (G\hbar/c^3)$ with a proportionality constant of order unity. We have also outlined a possible quantization program in the presence of gravitation with all interactions introduced as gauge fields, and generalized the (strong) principle of equivalence to geometrize the gauge fields. We suggest that a non-zero $\hbar$ (finite K) could be the geometric origin responsible for the breaking of conformal invariance¹⁹ and the emergence of discrete particle attributes.

The three principal investigators are spending 100% of their time during two of the summer months and 40% of their time during the academic year, on the research project.

A number of theoretical physicists from outside institutions have made short-term visits of a day or two to Indiana University during the year to discuss problems of interest to the principal investigators. These visitors were

Dr. D. K. Choudhury, Oxford University

Dr. Gordon Shaw, University of California, Irvine

Dr. Peter Suranyi, University of Cincinnati

Dr. William Frazer, University of California, San Diego

Dr. Steven Pinsky, University of California, Riverside

Dr. Peter Rosen, Purdue University

Dr. Masao Sugawara, Purdue University

Dr. Kenneth G. Wilson, Cornell University

Dr. Richard Eden, Cambridge University

Dr. Lincoln Wolfenstein, Carnegie-Mellon University

Only basic travel, lodging etc. expenses were paid (visitors from the West Coast and abroad for travel within the Midwest).

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19. An s-channel Regge Approach to Pion Nucleon Charge Exchange Scattering (S.-Y. Chu and A. W. Hendry), in preparation.