**PEAKS IN THE VALLEY: SEARCHING FOR
RESONANCES IN LARGE ANGLE EXCLUSIVE SCATTERING***

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INTRODUCTION

The problem we pose for this talk is how to find high mass, relatively broad width, low spin resonances in the midst of very large diffractive backgrounds in hadronic interactions. One possible answer is to study large angle exclusive scattering where the forward diffraction has gone away and the background is small. Moreover, this background may be at least partially understood in the context of perturbative Quantum Chromodynamics (pQCD). In this talk, we describe results from AGS Experiment 834.[†]

Two types of resonance production at large angles have been discussed. Brodsky and de Teramond [1] have considered the case of resonance formation in the case of pp interactions

$$pp \rightarrow X(uuduud\bar{Q}\bar{Q}) + pp \quad [1]$$

in the region from 5 to 20 GeV/c incident momentum. Farrar has discussed the case of resonance production for the case of possible production of possible glueballs.² For example:

$$\pi^+ n + p \xrightarrow{G} \pi^+ \pi^- \text{ or } K^+ K^- \quad [2]$$

We shall emphasize resonance formation in this talk. Considerations in development of pQCD by Brodsky and Farrar,³ and Mueller⁴ lead to the idea of "Color Transparency". In this picture, the background processes of pQCD arise from hadrons scattering in small configurations of quarks, where as, resonances come from configurations of quarks which have normal hadronic sizes. The use of nuclear matter to distinguish these two configurations allows us to distinguish resonances from the background.

The probable applicability of pQCD in the momentum range above 5 GeV/c comes from an examination of the dimensional scaling law of Brodsky and Farrar.³ The differential cross section for pp scattering at a fixed center of mass angle (fixed t/s) is plotted versus s ($\propto$ lab momentum). Then the differential cross section is seen to fall as $1/s^{10}$. A similar plot for πp elastic scattering indicates a $1/s^8$ behavior. The power law is believed to be

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directly related to the sum of the number of quarks in initial and final state. This dimensional scaling is illustrated in Fig. 1.

Fig. 1. The pp elastic differential cross section at various center-of-mass angles scaled to 10 GeV/c by multiplying by $(s/s_{10})^{10}$. The data are derived from the compilation given in Ref. 12.

In Fig. 1, the differential cross section at any lab momentum is scaled to that at 10 GeV/c by multiplying by $(s/s_{10})^{10}$. At a laboratory momentum of about 5 GeV/c, and $\theta_{cm} = 90^\circ$, the scaled differential cross section becomes nearly flat except for some small but significant oscillations. At smaller center of mass angles, the flat scaled cross section region begins at a higher momenta. The flattening of these curves may be indicative of the beginning of the region where pQCD is applicable. Related behavior is seen in an appropriately scaled measurement of the proton magnetic form factor.⁵

A physical picture of this large angle exclusive scattering has been given by Mueller.⁶ The hadrons which scatter exclusively have their quarks confined to a small area within their Lorentz contracted disks. This dimension of this area is small compared to the size probed by the interaction, $1/\sqrt{|t|}$. In this case, the scattering at fixed large angle (t/s) is the same as for point particles. The probabilities for finding all of its quarks within these small areas of the initial and final states leads to the dimensional scaling law:³

$$\frac{d\sigma}{dt} = s^{-(n_a + n_b + n_c + n_d - 2)} \quad [3]$$

This picture can be tested by elastically scattering hadrons from protons inside nuclei. Figure 2, illustrates that as the energy of the scattering increases, the size of the hadrons involved decreases. Furthermore, since the hadrons take a finite time to fluctuate downward in size in the initial state and upward in the

The target momentum distribution in the out of scattering plane direction y is shown in Fig. 3 for 6 GeV/c protons on aluminum.

Fig. 3. The out of scattering plane momentum (p_y) distributions of the target proton for 6 GeV/c protons on carbon. Background has been subtracted according to the procedures of Ref. 8. The center (< 200 MeV/c) portion of the distribution has been fit with a harmonic oscillator model derived from electron scattering data.

After applying corrections for the target momentum and geometric acceptance,⁹ the transparency to pp elastic scattering in lithium, carbon, aluminum, copper and lead nuclei is shown in Fig. 4(a) at 6 and 10 GeV/c. At 12 GeV/c the transparency was measured for carbon and aluminum. Since we determine the z component of the target momentum on an event-by-event basis, we are able to assign the value of s or an effective incident momentum to each event. To lowest order in p_z , the s of an event compared to the s_0 of the nominal momentum is given by:

$$s = s_0(1 - p_z/m_p) \quad [5]$$

This technique allows us to trace out the momentum dependence of the transparency in considerable detail. This is shown in Fig. 4b for aluminum, the element for which the statistical accuracy was greatest. These data show a sharp rise to 9.5 GeV/c and then an abrupt fall between 10 and 13 GeV/c.

Farrar has calculated the expected transparency for a conventional Glauber model and two possible pictures of hadronic contraction and expansion before and after the interactions.⁹ The transparency will remain constant in the Glauber model due to the very nearly constant total cross section above 3 GeV/c. As seen in Fig. 5, our transparency is somewhat above the transparency calculated by the Glauber picture at 6 GeV/c and about consistent with the linear expansion of the protons in the "quantum diffusion" picture for a momentum of 10 GeV/c. Up to this point, the data

final state, they will be considerably smaller than normal over distances larger than nuclear radii. The reduced size leads to reduced attenuation of the scattered hadrons by the nuclear material.

Fig. 2. An illustration of pp elastic scattering inside a nucleus in the "Color Transparency" picture.

The ratio of the elastic cross sections for scattering protons inside nuclei to that from free protons is defined as the transparency of the nuclear.

$$T = \frac{d\sigma/dt \text{ (In nucleus)}}{d\sigma/dt \text{ (In hydrogen)}} \quad [4]$$

In actual practice, this simple equation must be modified for effects due to the momentum and binding of the target protons.

The apparatus for carrying out these transparency measurements was a single arm magnetic spectrometer with an array of large wire chambers for detecting the recoil particles. This equipment has been used for an extensive set of measurements on exclusive reactions by the BNL-Minnesota-Penn State-Southeastern Mass collaboration.⁷ Protons in the 0°, Cl beam line are identified by use as a differential Cerenkov counter. A correlation of hits in hodoscope and wire chambers after the spectrometer sets a minimum momentum on the scattered proton for triggering. No conditions are placed on the recoil proton so that a very broad range of target momenta are accepted.

In the absence of the Fermi motion of the target proton, we would have a three constraint fit to elastic scattering. Assuming that the binding energy is negligible, these three constraints can be used to determine the three components of the moments of a proton inside a nuclei. This procedure described in Ref. 8 allows a determination of the z component to better than 10 MeV/c and the y component to within 30 MeV/c. Automatic normalization of the transparency ratio is performed by placing the nuclear scattering targets between blocks of CH₂ which serve as a targets of free protons.

would support the Brodsky and Farrar, pQCD view of the scattering. The other important conclusion is that the conventional wisdom of a constant transparency, expected from a constant hadronic size, is found to be untrue.

Fig. 4(a) The transparency versus incident proton momentum for five different nuclear targets.

Fig. 4(b) The transparency versus effective incident momentum for protons incident on aluminum. Each beam momentum has been subdivided into four effective momenta from a determination of the z component of the target momentum.

Fig. 5. Transparency as calculated by the conventional Glauber model (solid curve) and by a linear "quantum diffusion" expansion model at 6 and 20 GeV/c (dotted curves) (Ref. 9). Transparencies measured at 6, 10 and 12 GeV/c by Experiment 834. In addition to the point-to-point statistical and systematic error, there is an overall scale error of $\pm 25\%$.

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The abrupt fall of the transparency between 10 and 13 GeV/c indicates that the picture is complicated, but opens up the possibility for discovery of new phenomena, possibly resonances. Brodsky and de Teramond¹ noted that there was a near correlation between the rapidly rising spin-spin parameter A_{nn} (Fig. 6)¹⁰ and the falling transparency observed in this experiment. The presence of a resonance (possibly associated with the threshold for charm production), would add another amplitude to the scattering. Unlike the pQCD amplitude, there is no requirement for the protons involved in producing a resonance to be small compared to a normal proton size. So if the resonance amplitude is dominant, the transparency reverts to its usual Glauber value.

Fig. 6. The prediction of the resonance model of Brodsky and de Teramond compared to the spin-spin data (A_{nn}) at 90° CM.

An alternative picture is presented by Ralston and Pire, in which the amplitudes corresponding to normal sized protons arise from "Landsoff" diagrams in which the quarks scatter independently of one another.¹¹

It is clearly important that the measurement of transparency be carried beyond this first oscillation. Our collaboration is planning a new detector based on a solenoidal magnetic field.¹² The full azimuthal acceptance, plus measurement of both final state particles will allow us to extend the measurement to above 20 GeV/c

This new apparatus will also allow searches for the production of new resonances such as that given by Eq. [2]. Determination of both momenta in a solenoid from the two-body decay of a parent particle will allow an accurate determination of the invariant mass of the particle. At large momentum transfer, diffractive scattering has gone away, and the pQCD scattering mechanisms suppress the production of resonances with non-zero orbital momentum. So there is a distinct possibility that high mass, scalar resonances become more prominent than in low momentum transfer processes.

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REFERENCES

1. S.J. Brodsky and G.F. de Teramond, Phys. Rev. Lett. 60, 1924 (1988).
2. G.R. Farrar (private communication).
3. S.J. Brodsky and G.R. Farrar, Phys. Rev. Lett. 31, 1153 (1973).
4. A.H. Mueller, Proceed. of the XVII Rencontre de Morion, ed. J. Tran Thanh Van, Editions Frontieres, Gif-sur-Yvette, France, 1982, p. 13; S.J. Brodsky, Proceedings of the XIII International Symposium on Multiparticle Dynamics, eds. W. Kittel, W. Metzger and A. Stergiou, World Scientific, Singapore, 1983, p. 963. G.R.
5. R.G. Arnold et al., Phys Rev. Lett. 57, 174 (1986).
6. A.H. Mueller, Workshop on Short Distance QCD with Nuclear Targets, University of Minnesota, May 1987 (unpublished).
7. B. Baller et al., Phys. Rev. Lett. 60, 1118 (1988).
G.C. Blazey et al., Phys. Rev. Lett. 55, 1820 (1985).
8. A.S. Carroll et al., Phys. Rev. Lett. 61, 1698 (1988).
S. Heppelmann et al. (to be published).
9. G.R. Farrar et al., Phys. Rev. Lett. 61, 686 (1988).
10. E.A. Crosbie et al., Phys Rev. D23, 600 (1981).
11. J. Ralston and B. Pire, Phys. Rev. Lett. 61, 1923. (1988).
12. M.K. Carter, PDB Collins and M.R. Whalley, Compilation of Nucleon-Nucleon and Nuclear-Antinucleon Elastic Scattering, Rutherford-Appleton Laboratory Report RAL-86-002 (1986).
13. Proposal for AGS Experiment 850, Arizona, BNL, Michigan, Minnesota, Mt. Holyoke, Penn St., Southeastern Mass Collaboration (1986) (unpublished).