INVESTIGATION OF COLOR TRANSPARENCY BY HIGH TRANSVERSE MOMENTUM PP ELASTIC SCATTERING INSIDE NUCLEI*

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(Presented by A.S. Carroll)

ABSTRACT

Following a suggestion of Mueller and Brodsky, we have measured (p,2p) quasielastic scattering in nuclei at 90° CM at momentum transfers of Q^2 = 4.8, 8.5 and 10.4 $(GeV/c)^2$. In a perturbative QCD model of large transverse momentum exclusive reactions, the hadrons which scatter are anomalously "small", and hence have a reduced absorption in nuclear matter over distances comparable to nuclear radii. At sufficiently high momentum, the absorption should vanish completely and lead to complete "color transparency".

The absorption of the initial and final state protons are they pass through nuclear matter is determined from the ratio of the differential cross section for elastic scattering from protons in nuclei to that from free protons. The kinematic constraints of the experiment allow a clear extraction of the (p,2p) quasielastic signal, and a good measurement of the target proton momentum spectrum as probed by large momentum transfers. In contrast to a conventional Glauber picture of constant transparency, a striking energy dependence is observed in this experiment.

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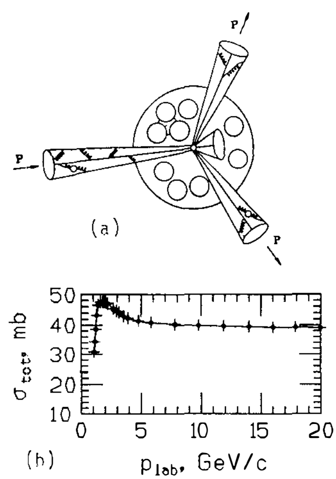
Protons, and hadrons in general, are composite dynamical systems of quarks and gluons and hence are expected to fluctuate in size. The question which we tried to answer in this experiment (AGS Exp. 834) was whether particular interactions favor particular quark configurations. For example, are compact configurations ever favored? Conceptually a way of studying this question is to use a filter after the interaction which allows only particular configurations to pass.

Mueller made the suggestion at the 1982 Moriond meeting that such a filtering scheme would be a very useful test of models of large angle exclusive scattering.[1] In a perturbative QCD picture developed by Brodsky and others, the hadrons which scatter at large angles for incident momenta of greater than 5 GeV/c are thought to be hadrons which have fluctuated to small size.[2] Following the interaction, the hadrons expand back to their normal sizes in distances compared to nuclear radii if the final state particles are few GeV/c as shown in Fig. 1a. Most other models shown involve configurations of quarks which are of normal hadronic size.[3] To distinguish between these two models we measure a quantity known as the transparency for pp elastic scattering for a small range of angles near 90° CM.

$$T = \frac{\frac{d\sigma}{dt}(t)\ (\text{In nuclei})}{\frac{d\sigma}{dt}(t)\ (\text{In hydrogen})} \qquad (1)$$



This quantity measures the ratio of the pp differential cross section from protons in a nucleus to that from free protons. As shown in Fig. 1b, the total cross section for pp interactions is essentially independent of energy above a few GeV/c. For the pQCD model, the transparency will increase with incident momentum as the size of the interaction shrinks and the expansion distance lengthens. For other models of exclusive interactions, the hadronic sizes are constant and the constant total cross section results in fixed transparency for a given nucleus. For aluminum, the transparency would be a constant 12% in the conventional picture.

Fig. 1(a) Schematic view of an elastic scattering from a proton inside a nucleus in the pQCD picture. (b) A plot of σ_{tot} for pp scattering vs. p_{lab}.

The apparatus was originally designed to measure a number of two-body exclusive reactions at large momentum transfer.[4] A magnetic spectrometer with a horizontal acceptance of ± 2.5° in the lab was set at lab angles corresponding to 90° CM. A side array of three large area wire chamber modules provided acceptance from 5° to 75° for the other quasielastically scattered particle. The trigger requirement was based solely on a p_t measurement in the magnetic spectrometer which included nearly all of the proton momenta corresponding to quasielastic scattering. If the binding energy of proton in the nucleus is neglected, then the energy of the proton passing through the side array is determined by

$$E_{side} = E_{incident} - E_{spectrometer} - m_p \quad (2)$$

Since we know the direction of the side track, the initial momentum of the target proton can be determined from the equation:

$$\vec{p}_{target} = \vec{p}_{incident} - \vec{p}_{spectrometer} - \vec{p}_{side} \quad (3)$$

A more complete description of this procedure in terms of light cone variables can be found in Ref. 5. Applying this same procedure to free pp scattering indicates an uncertainty in the longitudinal momentum (p_z) of 5 MeV/c and 30 MeV/c in the component normal to the scattering plane (p_y).

The distribution of target momenta normal to the scattering plane, p_y, is shown in Fig. 2. Above and below the segmented nuclear targets were three layer scintillator counters interspersed with 0.75 radiation length sheets of lead. Signals from counters were tagged to identify events with extra charged particles or high energy photons from π°'s. The lower curve in Fig. 2 indicates the events with tags in ≳ 2 layers of scintillator corresponding to background. This curve is nearly flat and reflects the smooth acceptance of the apparatus. The remaining events with one or no scintillator counter hits correspond to the quasielastic signal. After normalizing in the regions below -0.5 and above 0.5 GeV/c, the background is subtracted.

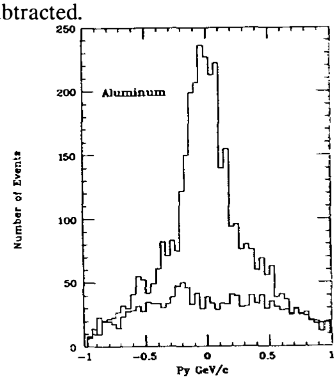


Fig. 2. The distribution of target momenta normal to scattering plane, p_y, for an Al target with an incident momentum of 6 GeV/c.

These curves of the quasielastic signal are interesting in themselves in that the distribution with the background subtracted is a measure of spectral function or target proton momentum spectrum.[6] These spectral functions measured at very high momentum transfers are in agreement with the (e,e'p) measurements at lower energy for the **central peak** $|p_{target}| < 0.2$ GeV/c, but show an excess of about 20% beyond the edge of the Fermi sphere.

Figure 3 displays the transparency after correcting for the observed spectral functions, the acceptance of the apparatus and the known energy dependence of the free pp elastic differential cross section. This procedure is described in more detail in Ref.[5]. The energy dependence of the transparency can also be seen from the uncorrected ratios of (p,2p) events in nuclei to free protons if narrow intervals of p_z are selected. This indicates that the result is not strongly dependent on the corrections.

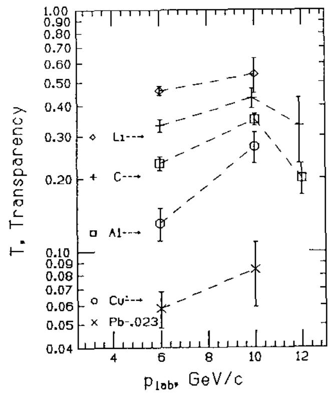


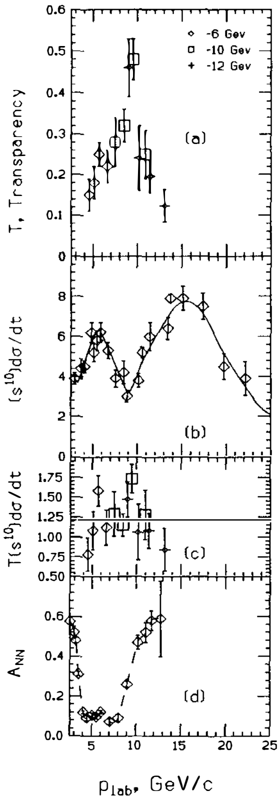
Fig. 3. The transparency versus beam momentum versus beam momentum for targets of Li, C, Al, Cu and Pb. The arrows indicate the calculated values in the Glauber model. There is an estimated overall systematic error of ± 25%.

The errors shown in Fig. 3 are a combination of statistical error and energy dependent systematic error. In addition, there is an overall normalization error of ± 25% and a nucleus to nucleus error estimated to be ± 10% which results from the uncertainty in calculating corrections from off shell scattering.

The transparencies are clearly energy dependent, and larger than the conventional Glauber calculation of this reaction in nucleus. The rise of the transparency between 6 and 10 GeV/c is in agreement with the pQCD picture, but the rapid fall again between 10 and 12 GeV/c is unexpected.

The energy dependence of the transparency is studied in more detail in Fig. 4a by utilizing the fact that different values of the p_z correspond to different values of s. Changing these p_z values into effective incident momenta, we can trace out the energy dependence of the transparency for Al. Now the energy dependence is even more striking.

In Fig. 4b, the pp differential cross section at 90° CM multiplied by the expected s^{10} scaling is plotted. This curve is anticorrelated with the transparency curve above. Ralston and Pire have interpreted this oscillation as an interference between a pQCD amplitude and spatially uncorrelated scattering in the Landshoff process.[8] The protons scattered in pQCD process pass through the nuclear material easily while those scattered by the large proton Landshoff process are preferentially absorbed. Multiplying Fig. 4b by Fig. 4a results in Fig. 4c. The fact that the product of these two curves results in a distribution which is consistent with a constant value raises the very interesting possibility that scattering from protons inside



nuclei may be a way to study essentially pure pQCD processes. It will be useful to test this hypothesis on other pQCD forbidden processes such as spin asymmetries.

Another correlation is with the spin-spin correlation A_{NN} at 90° shown in Fig. 4d.[9] Brodsky and de Teramond have suggested that this rise in A_{NN} and the fall in T are associated with the onset of a resonance in pp scattering, perhaps connected with the charm threshold in this channel.[10]

A new experiment has been approved for the AGS using a large solenoidal detector.[11] This detector, EVA, will be able to study these processes with about 100 times the sensitivity and much better kinematic definition of the quasielastic events.

Fig. 4(a) The transparency for Al at 90° CM vs effective incident momentum by binning in intervals of p_z. (b) The pp differential cross section scaled by S^{10} as given by Ref. 8. (c) The product of Fig. 4a and Fig. 4b. (d) The spin-spin correlation, A_{NN}, at 90° CM vs momentum.

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