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Searching for Short Range Correlations with BigBite

Peter Monaghan
for the Jefferson Lab Hall A Collaboration and the E01-015 Collaboration
Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Overview

One aspect of nuclear physics involves the study of the strong interaction between protons and neutrons within the nucleus. This research requires a suitable instrument to *see* inside the nucleus and examine the details. An electron beam provides the ideal probe for investigating the nucleus at extremely small distance scales; the higher the energy, the finer the detail probed. The Thomas Jefferson National Accelerator Facility (JLab) can provide a continuous wave electron beam with an energy of up to 6 GeV allowing the quark structure of the nucleus to be examined.

Physics Motivation

The strong repulsive internucleon forces within a nucleus require detailed nuclear wavefunctions to describe them. The short range correlations (SRC) between the nucleons are another feature of the strong interaction which contribute to the finer details of the nuclear wavefunctions. A nucleon-nucleon short range correlation occurs when the nucleon wavefunctions strongly overlap inside the nucleus. In the impulse approximation, a virtual photon is absorbed by one nucleon and the correlated partner is emitted in the opposite direction, as illustrated. The correlated pair of nucleons are emitted with large *back-to-back* momenta.

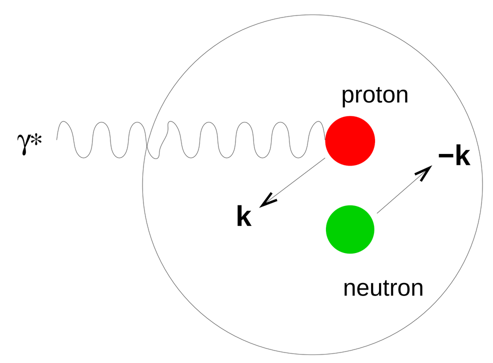

Figure 1: An illustration of the two nucleon knock-out process.

Previous Experiments

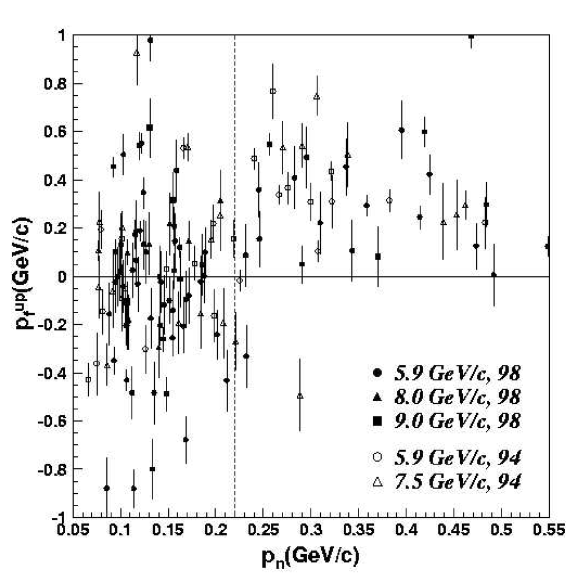

Figure 2: A plot of the upward momentum of the proton against the neutron momentum for $^{12}C(p,2p+n)$ events; directional correlation observed above the Fermi momentum [1].

An experiment to study n-p short range correlations through the $^{12}C(p,2p+n)$ reaction was performed at the Brookhaven National Laboratory. The momentum of the knocked out proton and the recoil neutron were measured and compared. For neutron momenta above the Fermi level ($K_F = 0.220$ GeV/c), a strong *back-to-back* correlation between the proton and neutron momenta is observed; see figure 2. This is an indication of two-nucleon short range correlations [1].

An experiment in Hall B at JLab studied both the (e,e'pp) and (e,e'pn) reactions. It was found that the cross-section was dominated by final state interactions and meson exchange currents which masked the short range properties of the nucleon-nucleon pairs. The data also indicated that these properties should be more easily accessible with kinematics of $X_B > 1$.

$^{12}C(e,e'pN)$ Experiment at JLab

In the proposed experiment in Hall A at JLab [2], the fraction of (e,e'p) events in which nucleon-nucleon short range correlations are observed as a function of the initial momentum of the proton shall be measured.

This experiment will study short range correlations in ^{12}C. A *triple coincidence* measurement will be made in Hall A, using both high resolution spectrometers (HRS) and a third spectrometer called *BigBite*. A ^{12}C target was chosen since it is a dense nuclear target which is simple and robust to use. The scattered electrons are detected in one HRS, the momentum of the recoil proton is measured in the other HRS and the correlated partner nucleon is measured by BigBite. Thus, BigBite will detect both protons and neutrons.

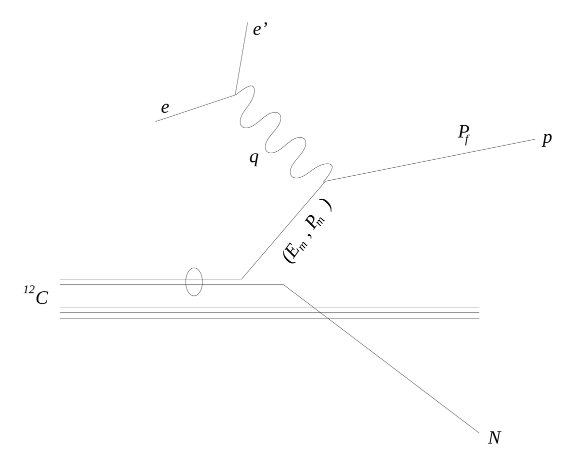

Figure 3: The reaction channel being studied [2].

Kinematic Considerations

Both final state interactions (FSI) and meson exchange currents (MEC) can have large contributions to the scattering cross-sections; these would dominate over the short range correlations. MEC have a $\frac{1}{Q^2}$ dependence and so are reduced at higher Q^2 values. Also, at higher Q^2 values, the energy of the struck proton is increased, making it easier to distinguish from its correlated partner nucleon. Thus, the kinematics have been chosen to reduce the effects of MEC and so $x_B > 1$ at $Q^2 = 2(\frac{GeV}{c})^2$ will be used; recoil proton momenta in the range of 250 - 600 $\frac{MeV}{c}$ are being sought.

The effects of FSI are reduced by using a *parallel* kinematics geometry for the reaction. Unfortunately, parallel kinematics has a large initial proton momentum and a large momentum transfer leading to a small X_B value. For this experiment, this would lead to contamination of the cross-section from resonance production. Instead, an *almost anti-parallel* geometry has been chosen to minimize FSI; this means the BigBite spectrometer and neutron detector will be positioned at approximately 100^o to the target.

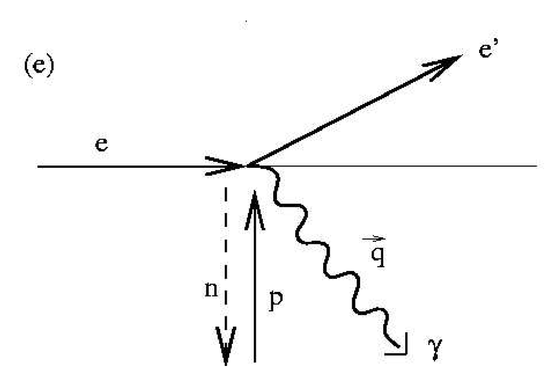

Figure 4: The "almost *anti-parallel* geometry being used.

BigBite Spectrometer

The complete detector package for the correlated partner nucleon consists of the BigBite spectrometer and a neutron detector. BigBite is a large acceptance, non-focusing dipole magnet instrumented with a charged particle detector package. Placed 1m from the target, BigBite will have a solid angle acceptance of 96 msr. The nominal momentum acceptance of BigBite is 250 - 900 $\frac{MeV}{c}$.

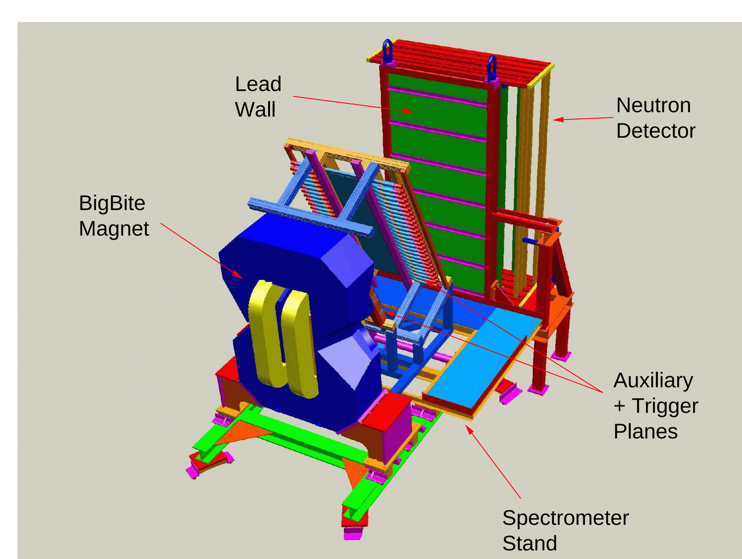

Figure 5: The BigBite spectrometer, showing the magnet, charged particle detector package and the neutron detector.

Charged Particle Detector

Figure 6: Photograph of the completed charged particle detector package.

The charged particle detector consists of two scintillator detectors, the *auxiliary plane* and the *trigger plane*. The auxiliary plane is closest to the magnet and consists of 56, 2.5mm thick scintillator bars. The trigger plane consists of two planes of scintillators. The front layer, called the δE plane, has 24 scintillators, each 3 mm thick. The rear layer, called the E plane, has 24, 30 mm thick scintillator bars. The planes are oriented such that a proton with momentum of 500 $\frac{MeV}{c}$ will be bent by the magnet through the center of the detector package. The auxiliary and trigger planes together can measure the time of flight and the energy (and thus momentum) of the incident protons; timing resolution is better than 250ps and momentum resolution is 12%.

Neutron Detector

The neutron detector consists of 4 planes of scintillators with a layer of thinner *veto* scintillators in front. The scintillators behind the veto layer are all 10 cm thick and 1m across and together will provide an active detection volume of 1 x 3 x 0.4 m^3. The veto layer will consist of overlapping scintillator bars, 2cm thick and 70cm long. The neutron detector will be placed 6 meters from the target, centered on the magnet with a direct line of sight to the target. The acceptance of the neutron detector will then be matched to the magnet acceptance.

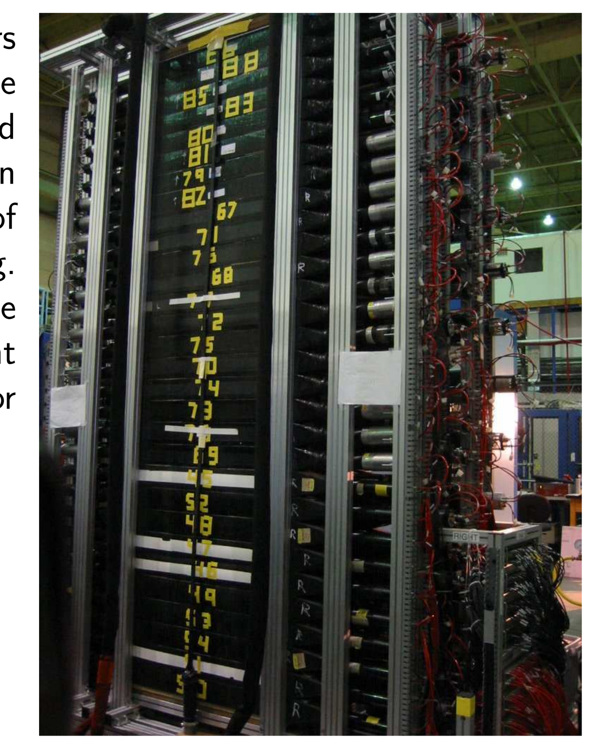

Figure 7: Photograph of the neutron detector standing upright in the test lab; note veto layer is missing.

Summary

The BigBite magnet has been tested to 10% power; a complete test will be carried out later in the year. The auxiliary and trigger planes have been completely tested with a running DAQ system. The neutron detector has been tested with a DAQ and now requires the veto layer to be assembled on it and tested. Since BigBite is a much larger acceptance spectrometer than the two HRS spectrometers in Hall A, a new scattering chamber with larger exit windows has also been built. The software for use during the experiment is currently under development. BigBite will be installed in Hall A at JLab in December 2004 with this short range correlations experiment taking place in January - March 2005.

References

[1] A. Tang, J. Watson *et al.*, Phys. Rev. Lett., **90** 042301 (2003)
[2] W. Bertozzi, E. Piasetsky, J. Watson, S. Wood, *Studying the Internal Small Distance Structure of Nuclei via the Triple Coincident (e,e'pN) Measurement*, Jefferson Lab Hall A Proposal E01-015

For further information please see the BigBite website:
http://hallaweb.jlab.org/equipment/BigBite/index.html