The BigBite Spectrometer and (e,e'NN) Studies of Correlations in Nuclei

presented by

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Two Nucleon Short Range Correlations

$\rho_o = 0.17 \text{ GeV/fermi}^3$

Learning about the Strong Short-Range Repulsive Force Between Nucleons
Questions

- What fraction of the momentum distribution is due to 2N-SRC?
- What is the relative momentum between the nucleons in the pair?
- What is the ratio of pp to pn pairs?
- Are these nucleons different from free nucleons (e.g. size)?

Let's build a picture of nucleons in Carbon from \((e,e')\), \((e,e'p)\) and \((e,e'pN)\) Reactions
CLAS A(e,e') Data


\[ x = \frac{Q^2}{2M\nu} > 1.5 \quad \text{and} \quad Q^2 > 1.4 \text{GeV}^2 \]

then

\[ r(A, ^3\text{He}) = a_{2n}(A)/a_{2n}( ^3\text{He}) \]

The observed “scaling” means that the electrons probe the high-momentum nucleons in the 2N-SRC phase, and the scaling factors determine the per-nucleon probability of the 2N-SRC phase in nuclei with \( A > 3 \) relative to \(^3\text{He}\).
Estimate of $^{12}$C 2N-SRC

Convert the $^3$He Ratios to a Deuteron Ratios

$$\frac{a_{2N}(^{12}C)}{a_{2N}(^3He)} \frac{a_{2N}(^3He)}{a_{2N}(D)} = 4.93 \pm 0.39$$

Calculate Percentage of Correlations in Deuterium
Using a Deuteron Wave-Function

$$a_{2N}(D) = 0.041 \pm 0.008$$

$$a_{2N}(^{12}C) = 0.20 \pm 0.045$$

This includes all three isotopic compositions (pn, pp, or nn) for the 2N-SRC phase in $^{12}$C.
Independent-Particle Shell-Model is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons.

The (e,e'p) data for knockout of valence and deeply bound orbits in nuclei gives spectroscopic factors that are 60 – 70% of the mean field prediction.
From the (e,e') and (e,e'p) Measurements

- 80 +/- 5% - single particles moving in an average potential
  - 60 – 70% independent single particles in shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% - two-nucleon short range correlations
- Less than 1% multi-nucleon corrections
A full investigation of two-nucleon correlations would require (e,e'NN) coincidence studies, but these are technically not yet feasible.

Rolf Ent's Ph.D. Thesis 1989
Custom Experiment To Study Nucleon Pairs

\[ Q^2 = 2 \text{ [GeV/c]}^2, \ x = 1.2, \ p_m = 200 - 650 \text{ MeV/c, } E_{2m} < 140 \text{ MeV} \]

Luminosity of \(10^{37} \text{ cm}^{-2} \text{ s}^{-1}\)

- high \(Q^2\) minimizes MEC which are reduced as \(1/Q^2\)
- \(x > 1\) to suppress isobar contributions
- anti-parallel kinematics to suppress FSI

A pair with “large” relative momentum between the nucleons and small CM momentum
The BigBite Spectrometer and (e,e'NN) Studies of Correlations in Nuclei
New Equipment for the Experimental Setup

- New Scattering Chamber
- New BigBite Hadron Spectrometer (100 msr)
- New Low Energy Neutron Detector
Making BigBite A Reality

Physics Division Liaison for the Project (e.g., budget, documentation, coordination)
On-site Supervisor To The Ph.D. Students (both for construction and analysis)
Due To This Work Appointed Adjunct Professor at Kent State University

- Tel Aviv - Auxiliary Plane
- Glasgow - Trigger Plane
- UVa MRI - Scattering Chamber
- Kent State - Neutron Detectors
- future Wire Chambers also from UVa MRI
Performance of the BigBite Spectrometer

- Operated at a luminosity of up to $10^{38}$ cm$^{-2}$ s$^{-1}$
- $\Delta E/E$ Particle Identification
- Timing Resolution of 0.4 ns
- Momentum Resolution $dp/p$ of 2% from time of flight
\(^{12}\text{C}(e,e'pp)\) \textit{Ran Shneor (Tel Aviv University)}

With acceptance corrections, the physics ratio of \((e,e'pp)/(e,e'p)\) is approximately 10%. 

Ratio of detected recoiling protons.

Detected Ratio of \((e,e'pp)/(e,e'p)\)

Missing Momentum [GeV/c]
Deuterium was used to determine the absolute neutron detection efficiency.

After making efficiency and acceptance corrections, we find far more recoiling neutrons than protons.
From the (e,e'), (e,e'p), and (e,e'pN) Results

- 80 +/- 5% single particles moving in an average potential
  - 60 – 70% independent single particle in a shell model potential
  - 10 – 20% shell model long range correlations
- 20 +/- 5% two-nucleon short range correlations
  - from (e,e'pp) 1-2% pp SRC
  - exact ratio for (e,e'pn) / (e,e'pp) not final, but clear pn dominance observed with 10-20% pn SRC
  - combining preliminary results we can deduce 1-2% nn SRC
- less than 1% multi-nucleon correlations
Summary

- Understanding two nucleon correlations was part of the original motivation for building CEBAF.
- The addition of the Big Bite Spectrometer system to Hall A has opened several new research possibilities including making high luminosity measurements of \((e,e'pN)\).
- The Hall A \(^{12}\text{C}(e,e'pN)\) experiment was the first Big Bite Spectrometer experiment in Hall A.
- Many more Hall A Big Bite spectrometer experiments are expected, including measurements with the upgraded accelerator.