Measurement of short-range correlations in nuclei at $x > 1$ in inclusive quasi-elastic electron scattering

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We present new results of short-range correlations (SRC) with the measurement of electron scattering off high-momentum nucleons in a wide range of nuclei performed in Hall A at Jefferson Lab. The inclusive cross section ratio of ^{4}He to ^{3}He conforms the well-known two-nucleon short-range correction (2N-SRC) plateau in $1 < x < 2$ but yields a different pattern when extending to the $x > 2$ regime where previous measurements claimed an onset of the three-nucleon short-range correlation (3N-SRC) under a similar kinematic region. The ^{12}C to ^{3}He and ^{12}C to ^{4}He cross section ratios also show no indication of 3N-SRC plateau.

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Understanding the complex structure of nuclei remains one of the major tasks in nuclear physics. In the dense nuclear medium, constantly moving nucleons have a significant probability to overlap and therefore create the so-called short-range correlations (SRC). The strong repulsive core of the nucleon-nucleon (NN) interactions at short distance boosts the correlated nucleons well above the Fermi momentum, while the nucleus remains in its ground state due to momentum conservation. Without involving these high momentum components, the mean field calculation using the distorted wave impulse approximation [1] underestimated the nuclear strength which had been observed by many proton knock-out experiments [2–4].

Previous data revealed a universal form of the momentum distributions of the struck nucleons [5] in the momentum range from 300 MeV to 600 MeV, i.e. the distributions of all nuclei scale to the one of the deuteron. It could be easily understood if the SRC pair (2N-SRC) shares the similar features among different nuclei. One also suggested that the momentum distributions should scale to the one of ^{3}H or ^{3}He for momentum above 600 MeV, where 3N-SRC configuration should dominate [6].

Instead of direclty investigating the momentum distribution of the nucleus which is not an experimental observable, one can study the SRC via inclusive electrons quasi-elastic (QE) scattering off nuclei [7]. During the scattering, the electron gives up its energy by emitting a virtual photon with four momentum transfer $q^2 = -Q^2 = \nu^2 - |\vec{q}|^2$, where $\vec{q}$ and ν are the momentum and energy of the virtual photon.

Compared with the electron elastic scattering process which is well peaked at $x = Q^2/2Mv = 1$ (M is the proton mass), the QE process yields a much broader peaks at $x = 1$ due to the Fermi motion of the nucleon inside the nucleus. By measuring the inclusive QE cross section at $x > 1$ with $Q^2 > 1\ GeV^2$, one can carefully map out the SRC in different nuclei by taking the cross section ratio of the heavy nucleus, A, to the light nuclei, e.g. deuteron or ^{3}He:

$$a_2(A) = \frac{2}{A}\frac{\sigma_A(x,Q^2)}{\sigma_D(x,Q^2)}, \quad a_3(A) = \frac{3}{A}\frac{\sigma_A(x,Q^2)}{\sigma_{^3He}(x,Q^2)}, \quad (1)$$

where $2/A$ or $3/A$ accounts for the possibilities of forming SRC configurations in different nuclei similar to deuteron or ^{3}He.

The first evidence of SRC in inclusive scattering was revealed by the SLAC data [8] with $a_2(A)$ exhibiting a plateau between $x \sim 1.5$ and $x \sim 2$, where 2N-SRC is expected to dominate. A recent measurement from the CLAS data in Hall B at JLab [9] also reported the 2N-SRC plateau in the $a_3(A)$ distribution. The latest measurement from the E02-019 experiment in Hall C at JLab with better precision and a wider range of nuclei, and both $a_2(A)$ and $a_3(A)$ show clear 2N-SRC plateau [10]. In the $x > 2$ region, while the CLAS data claimed a second plateau at $x > 2$ in the $\sigma_{^4He}/\sigma_{^3He}$ ratio, E02-019 sees, despite the large error bars, clearly a rise in the $a_3(A)$ distribution. It should be noted that both experiments reported data at very different Q^2 and the kinematical requirement in performing a clean measurement of 3N-SRC is not yet well understood.

The new JLab experiment, E08-014, was carried out in Hall A in 2011 [11] and focused on the measurements of inclusive cross sections at large x with high precision. An high intensity electron beam with a constant energy of 3.356 GeV struck on fixed targets, and the scattered electrons were simultaneously detected by two identical High-Resolution Spectrometers (HRSs) [12]. Three 20 cm long cryogenic targets, the ^{2}D liquid, the ^{3}He gas and the ^{4}He gas, were used, in addition to thin foils of ^{12}C, ^{40}Ca and ^{48}Ca. Each HRS consists of a pair of vertical drift chambers (VDCs) for particle tracking, two scintillator planes for triggering and timing measurements, and a gas Čerenkov counter and two layers of lead-glass calorimeters for particle identification. The spectrometers were positioned at $\theta_0 = 21^\circ$, 23°, 25°, and 28° with total of 9 different central momentum settings, which cover the Q^2 range from 1.1 $(\mathrm{GeV/c})^2$ up to 2.5 $(\mathrm{GeV/c})^2$. The detailed description of the experiment and the data analysis can be found in Ref. [13].

The HRS detectors had very high electron detection capability and the event rate of this experiment was low since the cross section drops exponentially away from the QE peak. Events with only one-track from the VDCs' tracking reconstruction were kept for analysis, while the zero-track and multi-track events were less than 1%. The efficiencies of the detectors were carefully evaluated and turned out to be close to 100%. The electrons were identified by applying combination cuts on the calibrated signals from both the Čerenkov detector and the calorimeters. The cuts were able to keep above 99% electrons while the pion to electron ratio was estimated to be better than 10^{-4} level The overall dead-time of the data acquisition system (DAQ) was evaluated and corrected for each run.

The scattered electron's outgoing momentum, in-plan and out-of-plan angles and its vertex position on the target can be reconstructed with the optics matrices of the HRSs using the tracking information from the VDCs as inputs. The optics matrices have been well calibrated by many previous Hall A experiments and it were also optimized with the new calibration data taken during this experiment. The uncertainty from the optics reconstruction is believed to be better than 99% [12]. To reduce the edge effects due to the spectrometers' geometries, only the central acceptance regions were chose by cutting on these reconstructed quantities. A Monte Carlo (MC) simulation of the HRSs [13] was employed to evaluate and correct for the residual acceptance effect.

For the cryogenic targets, we removed the contaminated events from electrons scattering off the end-cups of the target cells by applying a cut on the reconstructed vertex position of the scattered electron on the target. A dummy target of two thin aluminum foils with 20 cm apart was used to evaluate the level of residual contamination after the cut. With the precise optics reconstruction, a cut of ± 7 *cm* at the center part of the target is able to remove $> 99.9\%$ of the events from target end-cups.

One of the largest sources of systematic uncertainty comes from the target densities of ^{2}D, ^{3}He and ^{4}He due to the non-uniformely distributed coolant flow. We took the boiling study data on these targets with varying beam currents, and extrapolated the density profiles when the beam was off and normalized the distribution to the values obtained during the target installation. We assigned a conservative uncertainty of 5% on the target density for each cryogenic target.

(FIX-HERE: Discuss more about the systematic uncertainties from different sources and make a table).

The cross sections were extracted by binning the data in x. A yield ratio method was developed to only apply all necessary corrections on the MC data until the MC yield converges to the experimental yield in the same x-bin. A cross section model was developed based on the $F(y)$ scaling and the peaking-approximation method was used to calculate the radiation effect [13]. The experimental cross section for the ith bin is then given by:

$$\sigma_{EX}(E, E'_i, \theta_0) = \frac{Y^i_{EX}}{Y^i_{MC}} \cdot \sigma_{model}(E, E'_i, \theta_0), \qquad (2)$$

where E is the beam energy fixed at 3.356 GeV, θ_0 is the central scattering angle, E'_i, the scattered energy, is calculated based on x_i, and $\sigma_{model}(E, E'_i, \theta_0)$ is the cross section of the bin calculated from the model with the radiation effect corrected. In this method, the bin-centering correction was automatically applied for choosing the center of the x-bin. The cross sections of different targets were extracted with exactly the same bins and the same acceptance cuts. Their statistical and systematic errors were individually calculated before taking the cross section ratio.

Talk about isoscalar correction not being apply because of the np dominance. Coulomb correction.

The cross sections of ^{3}He, ^{4}He and ^{12}C at scattering angle of 25° are shown in Fig. 1. **say more about the figure when we have the final one**

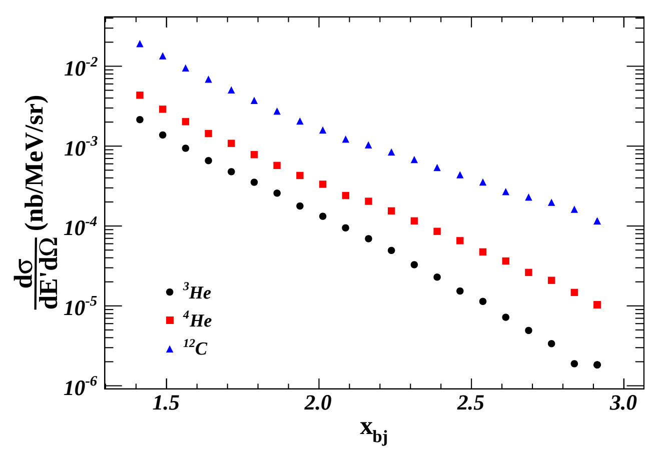

FIG. 1. Cross sections of ^{3}He, ^{4}He and ^{12}C at 25°. Statistical errors and systematic errors from instruments are included.

Fig. 2 presents the cross section ratios of ^{4}He to ^{3}He, ^{12}C to ^{3}He and ^{12}C to ^{4}He as a function of x. In the 2N-SRC region, our data are in great agreement with the data from JLab E02-019 and CLAS, revealing a plateau between $x \approx 1.5$ and $x = 2$. However, at $x > 2$, no hint of a 3N-SRC plateau is visible. Instead our data continue rising up quickly when x approaches 3, showing the same trend the E02-019 data. While E02-019 ran at higher Q^2, our data and the CLAS data were taken in the similar Q^2-range but yield different approaches. A recent publication suggested that the 3N-SRC plateau showed in the CLAS data could be a result of inappropriate binning and bin-centering correction [14].

(Add conclusion here)

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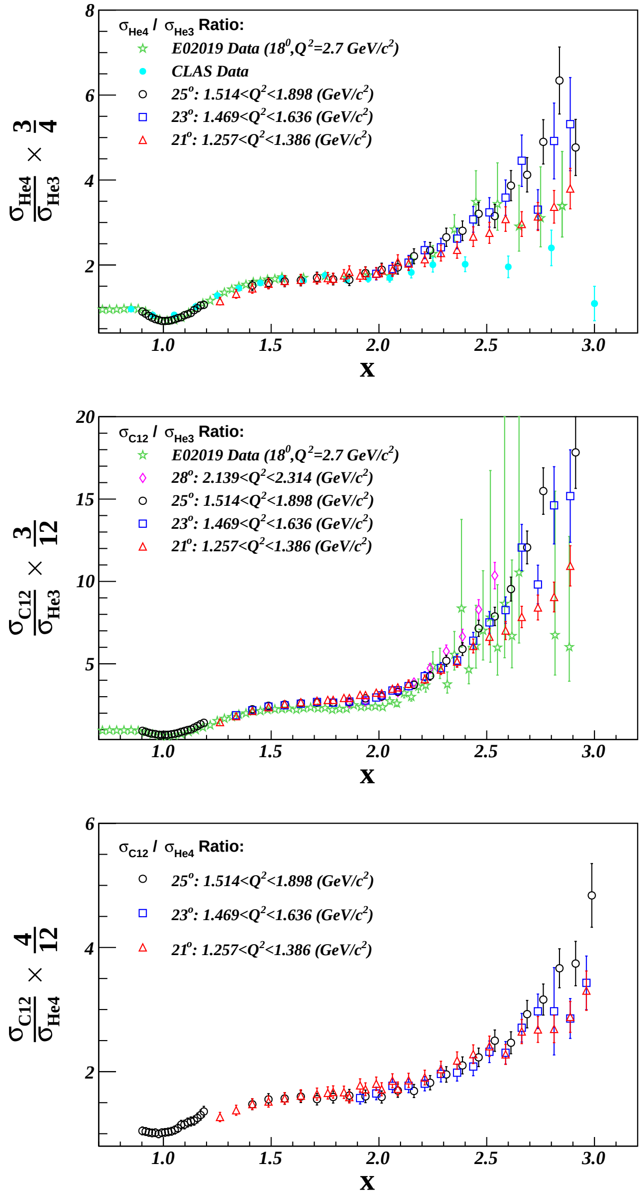

FIG. 2. **Top:** Cross section ratio of ^{4}He to ^{3}He with this experiment at three Q^2 settings and also the results from JLab E02-019 and CLAS. **Middle:** Cross section ratio of ^{12}C to ^{3}He with this experiment at four Q^2 settings and also the results from JLab E02-019. **Bottom:** Cross section ratio of ^{12}C to ^{4}He with this experiment at three Q^2 settings. In all plots, Statistical errors and systematic errors are included.

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