1-1-2004

Two nucleon momentum distributions mea sured in 3He(e; e0pp)n

R. A. Niyazov

Angela Biselli
Fairfield University, abiselli@fairfield.edu

CLAS Collaboration

Published Citation

R. A. Niyazov et al. [CLAS Collaboration], "Two nucleon momentum distributions mea sured in 3He(e; e0pp)n", Phys. Rev. Lett. 92, 052303 (2004) [Erratum-ibid. 92, 099902 (2004)] DOI: 10.1103/PhysRevLett.92.052303

Two-Nucleon Momentum Distributions Measured in ^{3}He$(e, e'pp)n$

R. A. Niyazov,[1] L. B. Weinstein,[1,*] G. Adams,[27] P. Ambrozewicz,[11] E. Anciant,[3] M. Anghinolfi,[16] B. Asavapibhop,[22] G. Asryan,[37] G. Audit,[3] T. Auger,[3] H. Avakian,[32] H. Bagdasaryan,[1] J. P. Ball,[2] S. Barrow,[12] M. Battaglieri,[16] K. Beard,[19] M. Bektasoglu,[25] M. Bellis,[27] N. Benmouna,[13] B. L. Berman,[13] W. Bertozzi,[21] N. Bianchi,[15] A. S. Biselli,[5] S. Boiarinov,[18] B. E. Bonner,[28] S. Bouchigny,[17] R. Bradford,[5] D. Branford,[10] W. K. Brooks,[32] V. D. Burkert,[32] C. Butuceanu,[36] J. R. Calarco,[23] D. S. Carman,[25] B. Carnahan,[6] C. Cetina,[13] S. Chen,[12] L. Ciciani,[1] P. L. Cole,[31] A. Coleman,[36] D. Cords,[32] P. Corvisiero,[16] D. Crabb,[35] H. Crannell,[6] J. P. Cummings,[27] E. De Sanctis,[15] N. Dashyan,[37] R. DeVita,[16] P. V. Degtyarenko,[32] H. Denizli,[26] L. Dennis,[12] K. V. Dharmawardane,[1] K. S. Dhuga,[13] C. Djalali,[30] G. E. Dodge,[1] D. Doughty,[7] P. Dragovitsch,[12] M. Dugger,[2] S. Dytman,[26] O. P. Dzyubak,[30] M. Eckhause,[36] H. Egiyan,[32] K. S. Egiyan,[37] L. Elouadrhiri,[7] A. Empl,[27] P. Eugenio,[12] R. Fatemi,[35] R. J. Feuerbach,[5] J. Ficenec,[34] T. A. Forest,[1] H. Funsten,[36] G. Gavalian,[23] S. Gilad,[21] G. P. Gilfoyle,[29] K. L. Giovanetti,[19] P. Girard,[30] C. I. O. Gordon,[14] R. W. Gothe,[30] K. Griffioen,[36] M. Guidal,[17] M. Guillo,[30] L. Guo,[32] V. Gyurjyan,[32] C. Hadjidakis,[17] R. S. Hakobyan,[6] J. Hardie,[7] D. Heddle,[7] F. W. Hersman,[23] K. Hicks,[25] M. Holtrop,[23] J. Hu,[27] C. E. Hyde-Wright,[1] Y. Ilieva,[13] W. Ingram,[14] M. M. Ito,[32] D. Jenkins,[34] K. Joo,[8] H. G. Juengst,[13] J. H. Kelley,[9] J. Kellie,[14] M. Khandaker,[24] D. H. Kim,[20] K. Y. Kim,[26] K. Kim,[20] M. S. Kim,[20] W. Kim,[20] A. Klein,[1] F. J. Klein,[6] A. V. Klimenko,[1] M. Klusman,[27] M. Kossov,[18] L. H. Kramer,[11] Y. Kuang,[36] S. E. Kuhn,[1] J. Kuhn,[5] J. Lachniet,[5] J. M. Laget,[3] J. Langheinrich,[30] D. Lawrence,[22] Ji Li,[27] K. Livingston,[14] K. Lukashin,[32] J. J. Manak,[32] C. Marchand,[3] S. McAleer,[12] S. McLauchlan,[14] J. W. C. McNabb,[5] B. A. Mecking,[32] S. Mehrabyan,[26] J. J. Melone,[14] M. D. Mestayer,[32] C. A. Meyer,[5] K. Mikhailov,[18] M. Mirazita,[15] R. Miskimen,[22] L. Morand,[3] S. A. Morrow,[3] V. Muccifora,[15] J. Mueller,[26] G. S. Mutchler,[28] J. Napolitano,[27] R. Nasseripour,[11] S. O. Nelson,[9] S. Niccolai,[13] G. Niculescu,[25] I. Niculescu,[19] B. B. Niczyporuk,[32] M. Nozar,[32] G. V. O'Rielly,[13] M. Osipenko,[16] K. Park,[20] E. Pasyuk,[2] G. Peterson,[22] S. A. Philips,[13] N. Pivnyuk,[18] D. Pocanic,[35] O. Pogorelko,[18] E. Polli,[15] S. Pozdniakov,[18] B. M. Preedom,[30] J. W. Price,[4] Y. Prok,[35] D. Protopopescu,[14] L. M. Qin,[1] B. A. Raue,[11] G. Riccardi,[12] G. Ricco,[16] M. Ripani,[16] B. G. Ritchie,[2] F. Ronchetti,[15] P. Rossi,[15] D. Rowntree,[21] P. D. Rubin,[29] F. Sabatié,[3] K. Sabourov,[9] C. Salgado,[24] J. P. Santoro,[34] V. Sapunenko,[16] R. A. Schumacher,[5] V. S. Serov,[18] A. Shafi,[13] Y. G. Sharabian,[37] J. Shaw,[22] S. Simionatto,[13] A. V. Skabelin,[21] E. S. Smith,[32] L. C. Smith,[35] D. I. Sober,[6] M. Spraker,[9] A. Stavinsky,[18] S. Stepanyan,[37] P. Stoler,[27] I. I. Strakovsky,[13] S. Strauch,[13] M. Taiuti,[16] S. Taylor,[28] D. J. Tedeschi,[30] U. Thoma,[32] R. Thompson,[26] L. Todor,[5] C. Tur,[30] M. Ungaro,[27] M. F. Vineyard,[33] A. V. Vlassov,[18] K. Wang,[35] H. Weller,[9] D. P. Weygand,[32] C. S. Whisnant,[30] E. Wolin,[32] M. H. Wood,[30] A. Yegneswaran,[32] J. Yun,[1] and B. Zhang[21]

(CLAS Collaboration)

[1]*Old Dominion University, Norfolk, Virginia 23529, USA*
[2]*Arizona State University, Tempe, Arizona 85287-1504, USA*
[3]*CEA-Saclay, Service de Physique Nucléaire, F91191 Gif-sur-Yvette, Cedex, France*
[4]*University of California at Los Angeles, Los Angeles, California 90095-1547, USA*
[5]*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*
[6]*Catholic University of America, Washington, D.C. 20064, USA*
[7]*Christopher Newport University, Newport News, Virginia 23606, USA*
[8]*University of Connecticut, Storrs, Connecticut 06269, USA*
[9]*Duke University, Durham, North Carolina 27708-0305, USA*
[10]*Edinburgh University, Edinburgh EH9 3JZ, United Kingdom*
[11]*Florida International University, Miami, Florida 33199, USA*
[12]*Florida State University, Tallahassee, Florida 32306, USA*
[13]*The George Washington University, Washington, D.C. 20052, USA*
[14]*University of Glasgow, Glasgow G12 8QQ, United Kingdom*
[15]*Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, Frascati, Italy*
[16]*Istituto Nazionale di Fisica Nucleare, Sezione di Genova, 16146 Genova, Italy*
[17]*Institut de Physique Nucleaire ORSAY, Orsay, France*
[18]*Institute of Theoretical and Experimental Physics, Moscow, 117259, Russia*
[19]*James Madison University, Harrisonburg, Virginia 22807, USA*
[20]*Kungpook National University, Taegu 702-701, South Korea*
[21]*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139-4307, USA*
[22]*University of Massachusetts, Amherst, Massachusetts 01003, USA*
[23]*University of New Hampshire, Durham, New Hampshire 03824-3568, USA*

[24]Norfolk State University, Norfolk, Virginia 23504, USA
[25]Ohio University, Athens, Ohio 45701, USA
[26]University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
[27]Rensselaer Polytechnic Institute, Troy, New York 12180-3590, USA
[28]Rice University, Houston, Texas 77005-1892, USA
[29]University of Richmond, Richmond, Virginia 23173, USA
[30]University of South Carolina, Columbia, South Carolina 29208, USA
[31]University of Texas at El Paso, El Paso, Texas 79968, USA
[32]Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA
[33]Union College, Schenectady, New York 12308, USA
[34]Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0435, USA
[35]University of Virginia, Charlottesville, Virginia 22901, USA
[36]College of William and Mary, Williamsburg, Virginia 23187-8795, USA
[37]Yerevan Physics Institute, 375036 Yerevan, Armenia
(Received 15 August 2003; published 6 February 2004; corrected 27 February 2004)

We have measured the ^{3}He$(e, e'pp)n$ reaction at 2.2 GeV over a wide kinematic range. The kinetic energy distribution for "fast" nucleons ($p > 250$ MeV/c) peaks where two nucleons each have 20% or less, and the third nucleon has most of the transferred energy. These fast pp and pn pairs are back to back with little momentum along the three-momentum transfer, indicating that they are spectators. Calculations by Sargsian and by Laget also indicate that we have measured distorted two-nucleon momentum distributions by striking one nucleon and detecting the spectator correlated pair.

DOI: 10.1103/PhysRevLett.92.052303 PACS numbers: 21.45.+v, 25.30.Dh

One of the fundamental problems of nuclear physics is to understand precisely the structure of the nucleus in terms of nucleons and, more specifically, to understand the momentum distribution of nucleons in the nucleus. The momentum distributions of single nucleons are reasonably well measured but the joint momentum distributions of nucleon pairs are not.

The independent particle model, that describes the motions of the nucleons in the nucleus by representing the sum of their interactions by a mean field, is a surprisingly good approximation. Among other successes, it describes the shapes of the single-nucleon momentum distributions in nuclei as measured by $(e, e'p)$ nucleon knockout reactions [1–3]. However, discrepancies between the measured and calculated magnitudes suggest that two-nucleon knockout processes, especially those involving two-nucleon (NN) short range correlations, are important. These short distance nucleon pairs are primarily responsible for the high momentum components of the nuclear wave function [4].

In addition, recent $A(e, e')$ measurements [5,6] and theoretical calculations [4,7] indicate about a 5 times higher probability per nucleon to find an NN pair with large relative momentum and small total momentum (i.e., in a short range correlation) in nuclei ($A \geq 12$) than in deuterium. We also know that nucleons in nuclei overlap each other a significant fraction of the time. Taken together, these imply that we now need to understand correlated NN pairs, the next term in the mean-field expansion of the nuclear wave function.

Unfortunately, measuring the momentum distribution of these NN correlations directly is very difficult because their signals are frequently obscured by effects such as final state interactions (FSI) and two-body currents, such as meson exchange currents (MEC) [8]. To date, there have been only a few measurements of $(e, e'pp)$ or $(e, e'np)$ two-nucleon knockout from nuclei [9–12]. The effects of correlations can only be inferred from these experiments by comparing them to detailed calculations which include both NN correlations and two-body currents. However, "exact" (e.g., Faddeev) calculations are possible only for light nuclei at low energies [13].

This paper reports new ^{3}He$(e, e'pp)n$ results that provide a cleaner measurement of two-nucleon momentum distributions. Measuring these distributions will greatly aid our understanding of short range correlations.

We measured inelastic scattering of 2.261 GeV electrons from ^{3}He, using a 100% duty factor beam at currents between 5 and 10 nA incident on a 4.1-cm long liquid ^{3}He target. We detected almost all outgoing charged particles in the Jefferson Lab CLAS (CEBAF Large Acceptance Spectrometer), a nearly 4π magnetic spectrometer [14]. The data were taken in 1999.

The CLAS uses a toroidal magnetic field and six independent sets of drift chambers and time-of-flight scintillation counters for charged particle identification and trajectory reconstruction. Momentum coverage extends down to 0.25 GeV/c for protons over a polar angular range of $8^\circ < \theta < 140^\circ$ while spanning nearly 80% of the azimuthal angle. Electron triggers are formed from the coincidence between signals from a gas threshold Čerenkov counter and those from a sampling electromagnetic calorimeter (EC). Regions of nonuniform detector response are excluded by software cuts, while acceptance and tracking efficiencies are estimated using GSIM, the CLAS GEANT Monte Carlo simulation.

We identified electrons using the energy deposited in the EC and protons using time of flight. We identified the neutron using missing mass to select $^3\mathrm{He}(e, e'pp)n$ events. We used vertex cuts to eliminate the target walls. Figures 1(a) and 1(b) show the electron acceptance ($Q^2 = -q_\mu q^\mu = \vec{q}^2 - \omega^2$, ω is the energy transfer, and $\vec{q}$ is the three-momentum transfer) and missing mass resolution, along with the result from a $^3\mathrm{He}(e, e'pp)n$ GSIM simulation that includes detector resolution but not electron radiation. For $^3\mathrm{He}(e, e'pp)n$ events, the momentum transfer Q^2 is concentrated between 0.5 and 1 $(\mathrm{GeV}/c)^2$. ω is concentrated slightly above but close to quasielastic kinematics ($\omega = Q^2/2m_p$).

We checked the data normalization by comparing the $^3\mathrm{He}(e, e'p)$) cross sections at $\vec{q} = 1.5\ \mathrm{GeV}/c$ and $\omega = 0.837$ GeV measured here and in Jefferson Lab Hall A [15]. The ratio of the cross sections is 1.00 ± 0.15, where the error bar is due primarily to kinematical uncertainties.

In order to understand the energy sharing in the reaction, we plotted the kinetic energy of the first proton divided by the energy transfer (T_{p1}/ω) versus that of the second proton (T_{p2}/ω) for each event [Fig. 2(a)]. (The assignment of protons 1 and 2 is arbitrary.) Since the proton detection threshold is $p_p = 250\ \mathrm{MeV}/c$, we also cut on neutron momentum $p_n \geq 250\ \mathrm{MeV}/c$. There are three peaks at the three corners of the plot, corresponding to events where two nucleons each have less than 20% of ω and the third "leading" nucleon has the remainder. We cut on these peaks, as shown in Fig. 2(a). The solid lines indicate the "leading n plus pp pair" cut and the dashed lines indicate the "leading p plus pn pair" cut.

Then we looked at the opening angle of the NN pair. Figure 2(b) shows the opening angle for pp pairs with a leading neutron (the pn pair opening angle is almost identical). Note the large peak at 180° ($\cos\theta_{NN} \approx -1$). The peak is not due to the cuts, since we do not see it in a simulation which assumes three-body absorption of the virtual photon followed by phase space decay [16]. It is also not due to the CLAS acceptance since we see it for both pp and pn pairs. This back-to-back peak is a very strong indication of correlated NN pairs.

Now that we have identified correlated pairs, we want to study them. In order to reduce the effects of final state rescattering, we cut on the perpendicular component (relative to $\vec{q}$) of the leading-nucleon's momentum, $p^\perp < 0.3\ \mathrm{GeV}/c$. (The data distributions did not change for values of $p^\perp_{\max} \leq 0.3\ \mathrm{GeV}/c$.) The resulting NN pair opening angle distribution is almost entirely back to back [see Fig. 2(b)]. These paired nucleons are distributed almost isotropically in angle (after correcting for acceptance). The pair average total momentum parallel to $\vec{q}$ ($\sim 0.05\ \mathrm{GeV}/c$) is also much smaller than the average q ($\sim 1\ \mathrm{GeV}/c$). Both of these indicate that the paired nucleons are predominantly spectators and that their measured momentum distributions reflect the pair's initial momentum distribution in the nucleus.

The resulting relative $\vec{p}_{\mathrm{rel}} = (\vec{p}_1 - \vec{p}_2)/2$ and total $\vec{p}_{\mathrm{tot}} = \vec{p}_1 + \vec{p}_2$ momentum distributions of the pn and pp pairs are shown in Fig. 3. Since the NN pairs are spectators, all quantities and cross sections are given in the lab frame. The cross sections are integrated over the experimental acceptance. Radiative and tracking efficiency corrections have been applied [21]. The overall normalization uncertainty is 15%.

The p_{rel} distribution rises rapidly starting at about $0.25\ \mathrm{GeV}/c$ (limited by $p_N \geq 0.25\ \mathrm{GeV}/c$), peaks at about $0.35\ \mathrm{GeV}/c$, and has a tail extending to about $0.7\ \mathrm{GeV}/c$. The p_{tot} distribution rises rapidly from 0, peaks at about $0.25\ \mathrm{GeV}/c$, and falls rapidly. Both distributions have an upper limit determined by the cut $T_N/\omega \leq 0.2$. Note that these distributions are very similar for both pp and pn pairs.

In order to test the reaction model, we compared the data to a model of pion electroproduction on a single

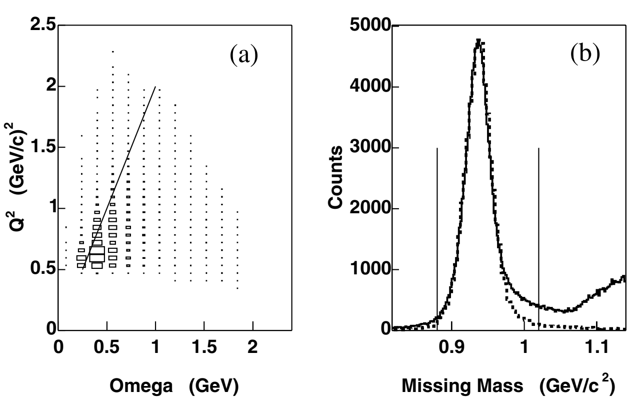

FIG. 1. (a) Q^2 vs ω for $^3\mathrm{He}(e, e'pp)n$ events. The line shows the quasielastic condition $\omega = Q^2/2m_p$. Note the large acceptance. (b) Missing mass for $^3\mathrm{He}(e, e'pp)X$. The vertical lines indicate the neutron missing mass cuts. The dashed histogram shows the result of a GEANT simulation of the CLAS.

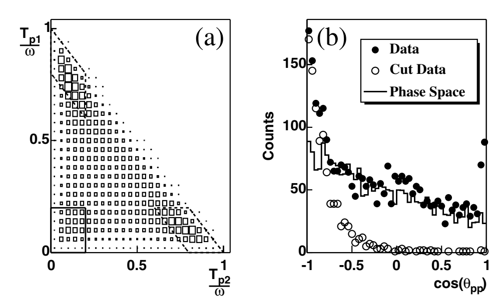

FIG. 2. (a) $^3\mathrm{He}(e, e'pp)n$ lab frame Dalitz plot. T_{p1}/ω versus T_{p2}/ω for events with $p_N > 0.25\ \mathrm{GeV}/c$; (b) the cosine of the pp lab frame opening angle for events with a leading n and a pp pair: $T_{p1}, T_{p2} < 0.2 * \omega$. Filled points show the data, open points show the data cut on $p_n^\perp < 300\ \mathrm{MeV}/c$, and the histogram shows the phase space (normalized to the data).

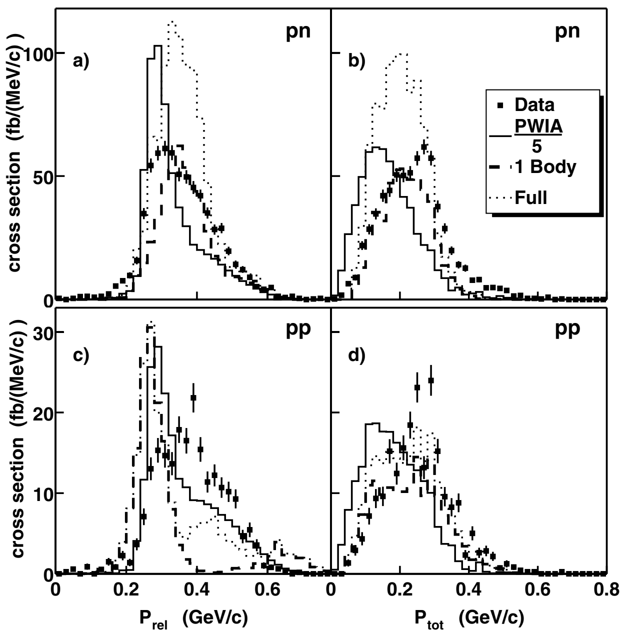

FIG. 3. (a) Lab frame cross section vs pn pair relative momentum. Points show the data, solid histogram shows the PWIA calculation times $\frac{1}{5}$ [17], dashed histogram shows Laget's one-body calculation [18–20], dotted histogram shows Laget's full calculation; (b) the same for total momentum; (c),(d) the same for pp pairs.

moving nucleon followed by absorption of the pion on the residual pair. While this Delta-dominated model did reproduce the back-to-back distribution of the pair, it did not describe the energy and momentum transfer distribution, the relative momentum distribution, or the ratio of pn to pp pairs.

We also compared our data to a plane wave impulse approximation (PWIA) calculation [see Fig. 4(a)] by Sargsian [17] that uses an exact ^{3}He wave function [22] and the De Forest "$cc1$" single-nucleon current operator [23]. We generated events in phase space, weighted them by the PWIA cross section, and applied the same cuts as with the actual data. The results are 4.8 and 4.5 times larger than the data for pp and pn pairs, respectively. The ratio of pn to pp cross sections is the same for data (3.0)

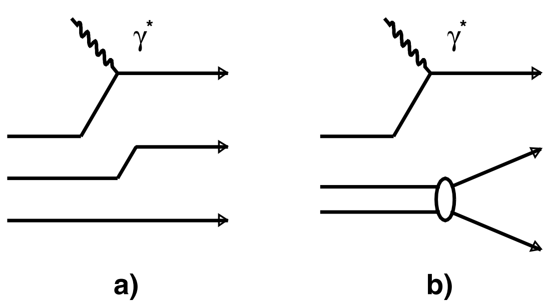

FIG. 4. Feynman diagrams for (a) plane wave impulse approximation and (b) pair distortion.

and for PWIA (2.9) indicating the importance of single particle knockout in the reaction mechanism. The data distributions have similar shapes, including the energy and momentum transfer distribution, the kinetic energy distributions, and the pair opening angles. The p_{rel} distributions are similar but have a different detailed shape (see Fig. 3). The PWIA p_{tot} distributions peak significantly below the data. These discrepancies are discussed below.

Exact calculations by Glöckle *et al.* [24] at much lower momentum transfer and $p_{tot} = 0$ looked at the effects of different reaction mechanisms. They found that neither MEC nor rescattering of the leading nucleon had an effect, and that the continuum-state interaction of the outgoing NN pair ["pair distortion," Fig. 4(b)] decreased the cross section by a factor of approximately 10 relative to the PWIA result. Calculations by Ciofi degli Atti and Kaptari also found that pair distortion significantly decreased the cross section [25].

Calculations by Laget (described in detail below) also showed these effects. His calculation further showed that pair distortion reduces the PWIA cross section for s-wave NN pairs much more than for p-wave pairs, effectively shifting both the p_{rel} and p_{tot} peaks to higher momentum. Laget's one-body p_{tot} distribution peaks at about 250 MeV$/c$, much larger than the PWIA p_{tot} peak and in better agreement with the data [see Figs. 3(b) and 3(d)].

Thus, these calculations suggest that the factor of 5 difference between the data and the PWIA calculation [Fig. 4(a)] is due to the continuum-state interaction of the outgoing NN pair [pair distortion, Fig. 4(b)]. That plus the rough similarity between the data and the PWIA calculation indicates that we may have measured two-nucleon momentum distributions by striking one nucleon and observing the spectator correlated pair.

We also compared our data to a full calculation using a diagrammatic approach by Laget [18–20], integrated over the CLAS acceptance [26]. This calculation includes one-, two- and three-body amplitudes. The one-body amplitudes include diagrams with two spectator nucleons including direct knockout [Fig. 4(a)] plus continuum-state interaction of the spectator NN pair (pair distortion [Fig. 4(b)]. The two-body amplitudes include diagrams with one spectator nucleon including FSI between the struck nucleon and one other, plus two-body currents [20]. The three-body amplitudes include diagrams with no spectator nucleons including three-body currents [18]. The calculation uses the dominant s and p waves for the $T = 1$ pairs and s and d waves for the $T = 0$ pairs that are then coupled to the third nucleon in the bound state wave function. The model made absolute predictions and was not adjusted to fit the data.

The one-body calculations describe the pn pairs well [see Figs. 3(a) and 3(b)]. However, the full calculation overestimates the data by about 60%. The calculation describes p_{rel} for pp pairs badly but p_{tot} well [see

Figs. 3(c) and 3(d)]. The failure is due possibly to the truncation of the wave function to only the lower angular momentum states. Note that Laget predicts three-body effects to be much larger for events with a leading proton and a pn pair than for events with a leading neutron and a pp pair. We do not see this difference in the data.

Laget's calculation shows that (i) the continuum-state interaction of the outgoing NN pair decreases the cross section significantly, and by suppressing the s wave, shifts the peak to larger momenta; (ii) two-body currents plus rescattering of the leading nucleon contribute less than 5% of the cross section; and (iii) three-body currents contribute about 20% of the pp and 50% of the pn cross section, but do not improve agreement with the data.

These results reinforce the conclusions we drew from the data that we are measuring the high momentum part of the distorted NN momentum distribution. Note however, that since two-body currents do not contribute, the only other possible contributions are due to three-body currents, also a subject of great interest.

Calculations with exact wave functions that include pair distortion are clearly needed in order to quantitatively relate the measured distorted NN momentum distributions to short range correlations in the nucleus.

To summarize, we have measured $^3\mathrm{He}(e, e'pp)n$ at 2.2 GeV over a wide kinematic range. The kinetic energy distribution for "fast" nucleons ($p > 250$ MeV/c) peaks where two nucleons each have 20% or less and the third or "leading" nucleon carries most of the transferred energy. These fast pp and pn pairs are back to back, almost isotropic, and carry little momentum along $\vec{q}$, indicating that they are predominantly spectators.

PWIA calculations reproduce the pp to pn pair cross section ratio, indicating the importance of single-nucleon currents. Calculations by Laget with many different diagrams and a truncated bound state wave function predict that leading-nucleon FSI and two-body exchange currents are negligible, and continuum-state interactions of the spectator pair reduce the cross section significantly. However, the predicted three-body exchange current contributions of about 20% for pp pairs and 50% for pn pairs do not improve agreement with the data.

Thus we appear to have measured distorted NN momentum distributions in $^3\mathrm{He}(e, e'pp)n$ by striking one nucleon and detecting the spectator correlated pair.

We acknowledge the outstanding efforts of the staff of the Accelerator Division and the Physics Division (especially the CLAS target group) at Jefferson Lab that made this experiment possible. This work was supported in part by the Italian Istituto Nazionale di Fisica Nucleare, the French Centre National de la Recherche Scientifique, the French Commissariat à l'Energie Atomique, the U.S. Department of Energy, the National Science Foundation, an Emmy Noether grant from the Deutsche Forschungsgemeinschaft, and the Korean Science and Engineering Foundation. The Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility for the United States Department of Energy under Contract No. DE-AC05-84ER40150.

*Corresponding author.
Email address: weinstei@physics.odu.edu

[1] S. Frullani and J. Mougey, in *Advances in Nuclear Physics*, edited by J.W. Negele and E. Vogt (Plenum Press, New York, 1984), Vol. 14, p. 1.
[2] J. J. Kelly, in *Advances in Nuclear Physics*, edited by J.W. Negele and E. Vogt (Plenum Press, New York, 1996), Vol. 23, p. 75.
[3] J. Gao *et al.*, Phys. Rev. Lett. **84**, 3265 (2000).
[4] A. Antonov, P. Hodgson, and I. Petkov, *Nucleon Momentum and Density Distributions in Nuclei* (Clarendon Press, Oxford, 1988).
[5] K. Egiyan *et al.*, Phys. Rev. C **68**, 014313 (2003).
[6] L. Frankfurt, M. Strikman, D. Day, and M. Sargsyan, Phys. Rev. C **48**, 2451 (1993).
[7] J. Forest *et al.*, Phys. Rev. C **54**, 646 (1996).
[8] S. Janssen *et al.*, Nucl. Phys. **A672**, 285 (2000).
[9] G. Onderwater *et al.*, Phys. Rev. Lett. **78**, 4893 (1997).
[10] G. Onderwater *et al.*, Phys. Rev. Lett. **81**, 2213 (1998).
[11] D. Groep *et al.*, Phys. Rev. Lett. **83**, 5443 (1999).
[12] D. Groep *et al.*, Phys. Rev. C **63**, 014005 (2000).
[13] J. Golak *et al.*, Phys. Rev. C **51**, 1638 (1995).
[14] B. Mecking *et al.*, Nucl. Instrum. Methods Phys. Res., Sect. A **503**, 513 (2003).
[15] D. Higinbotham, in *Proceedings of the International Symposium on Electromagnetic Interactions in Nuclear and Hadronic Physics, Osaka, Japan, 2001*, edited by M. Fujiwara and T. Shima (World Scientific, Singapore, 2002), p. 291.
[16] K. Hagiwara *et al.*, Phys. Rev. D **66**, 010001 (2002).
[17] M. Sargsian (private communication).
[18] J. Laget, J. Phys. G **14**, 1445 (1988).
[19] G. Audit *et al.*, Nucl. Phys. **A614**, 461 (1997).
[20] J. Laget, Phys. Rev. C **35**, 832 (1987).
[21] R. Niyazov, Ph.D. thesis, ODU, 2003.
[22] A. Nogga, H. Kamada, and W. Glöckle, Nucl. Phys. **A689**, 357 (2001).
[23] T. De Forest, Nucl. Phys. **A392**, 232 (1983).
[24] W. Glöckle *et al.*, Acta Phys. Pol. B **32**, 3053 (2001).
[25] C. Ciofi degli Atti and L. Kaptari, Phys. Rev. C **66**, 044004 (2002).
[26] J.-M. Laget, nucl-th/0303052.