Internal report to E89-003 collaboration

Comments on Juncai Manuscript dated July 26

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This is my final attempt to salvage Juncai's manuscript. The present version still contains many inaccurate or misleading statements, the stuff about "whole operator structure" is practically meaningless, and the long discussion of factorization is completely irrelevant (no one does factorized calculations anymore, not for 15 years or so). Furthermore, no physics conclusion worthy of PRL is drawn.

I have exchanged many e-mail messages with Udias over the last 10 days or so in order to clarify exactly how our models differ and to initiate a project which will produce a truly quantitative test of the effect upon $(e,e'p)$ calculations of approximating lower components in EMA form. I discovered that our calculations are much more similar than I supposed from reading nucl-th/9905030 — I was misled by space-saving shortcuts in the presentation and discussion that made Udias' calculational method appear to be closer to van Orden's method than to mine. It turns out that most of his approach really does use a coordinate-space representation, with momentum space operators used primarily for projection (a variation that I did not consider). He does include electron distortion, but uses EMA just like I do (his lower energy calculations did use partial-wave expansion, but that method becomes impractical at several GeV.) When computing the cc1 current, he also uses EMA as I do — gradients do not appear in his current operators. Aside from small technical differences in recoil and choices for wave functions, form factors, and other adjustable assumptions, the only significant difference in our calculational methods is his use of lower components from solutions of the Dirac equation versus my effective-momentum approximation to the lower components. Therefore, once we agree on all other ingredients and establish quantitative agreement on baseline calculations, we will be able to test the accuracy of that approximation rigorously.

In the meantime, I have made a preliminary comparison using the same NLSH bound-state wave function (bswf) he used and supplied to me. My nucl-th/9905024 used the same HS wave function as van Orden. Fig. 1 shows that the choice of bswf is the most important difference that affects momentum distributions and normalization factors. The NLSH momentum distribution in PWIA is lower at the peak and broader in momentum than HS, resulting in a better fit to the data and larger normalization factors. Thus, when I use the same bswf I obtain the same normalization factors and equivalent fits to the cross section data.

Before leaving the cross section, it is important to recognize that the present manuscript describes the cross section comparison inaccurately. Udias' results for the $1p_{3/2}$ peak include an incoherent contribution from the positive-parity contaminants as parametrized by

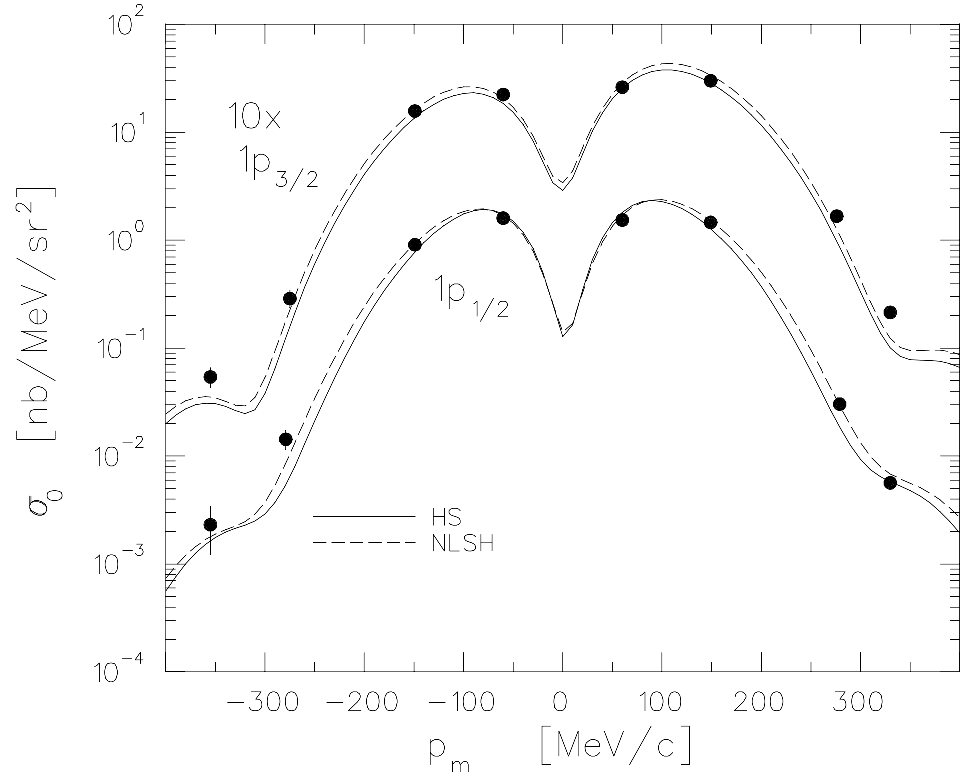

FIG. 1. Calculations of the differential cross section for ^{16}O$(e, e'p)$ in quasiperpendicular kinematics with $Q^2 = 0.8$ (GeV/c)^2 using the EMA-SV approximation. Solid curves use HS wave functions with normalization factors of 0.61 and 0.62 for $1p_{1/2}$ and $1p_{3/2}$. Dashed curves use NLSH wave functions with a common normalization factor of 0.75 as suggested by Udias and Gao. Postive-parity contributions are omitted here.

Leuschner. I provided similar calculations to Juncai but he chose to plot my curves **without** the positive-parity contribution despite my protests. (The text says that the positive-parity contributions are included, but the curves shown actually omit them!) This contribution fills in the $p_m \to 0$ dip, so that there is much less difference between my cross section and Udias' than suggested by Juncai's Fig. 2. Furthermore, my normalization factors were deduced including that contribution.

Fig. 2 shows that the NLSH and HS bswf's give very similar results for A_{LT}, which is more sensitive to the structure of the current operator and dynamic enhancement of lower components than to details of the momentum distribution. It is this quantity which is most sensitive to the EMA approximation to the lower components. Although we have not completed the rigorous comparison, I believe that it is safe to conclude that the remaining difference between the A_{LT} results from Udias and myself can be attributed to this approximation, which begins to break down for $p_m > 300$ MeV/c. His approach is more accurate, but I believe that my comparsion between SVb, SVc, and SV approximations (nucl-th/9905024) provides more insight into the physics of relativistic corrections. We both (and van Orden) agree that the dynamic enhancement of lower components by nuclear scalar and vector potentials is responsible for the enhancement of A_{LT} for modest p_m relative to NRDWIA. We also agree that oscillations at large p_m are sensitive to many details of the calculation, such as choice of optical model, which makes reliable interpretation more difficult, but that the enhancement for modest p_m is stable.

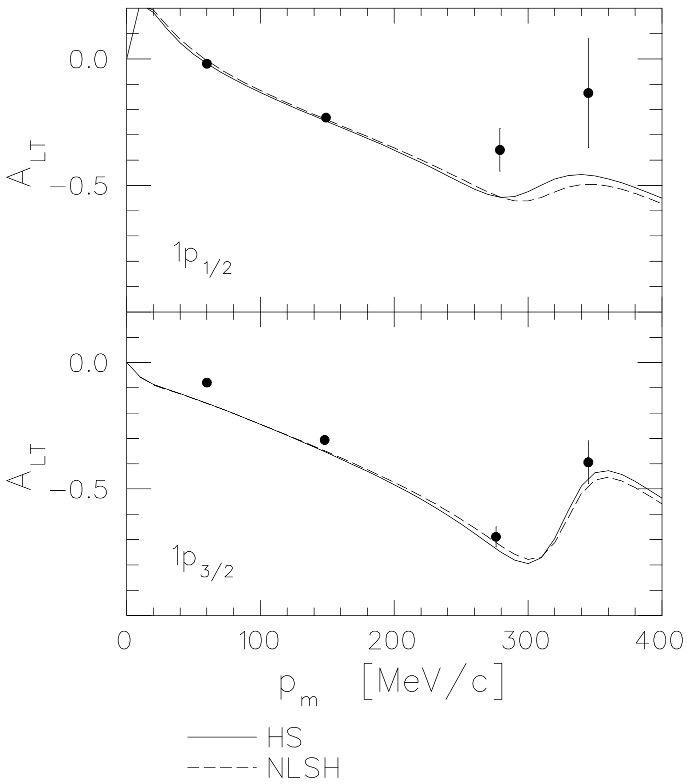

FIG. 2. Calculations of the left-right asymmetry for $^{16}\mathrm{O}(e,e'p)$ in quasiperpendicular kinematics with $Q^2 = 0.8$ $(\mathrm{GeV}/c)^2$ using the EMA-SV approximation. Solid curves use HS and dashed curves use NLSH wave functions.

As presently written, the paper does not draw any useful conclusions about the physics of this reaction. I do not understand why the noSV result has once again disappeared from Juncai's Fig. 3. The curves now shown are similar for modest p_m and diverge at large p_m where sensitivity to model choices and approximations becomes important. If the noSV curve is restored, there would be a clear difference with the SV curves that could be attributed to dynamic enhancement of lower components. A reference to nucl-th/9905024 would then establish that the bound-state spinor is primarily responsible for this effect on A_{LT}. This is the most significant physics conclusion that can be draw from these data and without it there is little chance of acceptance by PRL.

Juncai's Fig. 4 compares response functions with data, but he fails to describe the various curves accurately. Both Udias and I constructed *effective response functions* by performing calculations for two electron energies and performing separations upon the calculations as one would for data, thereby including the effects of distortion. (I was amazed to discover that Udias had done that also!) For unfathomable reasons Juncai compares my response functions without to Udias' with positive-parity contributions even though he has the information needed to compare equivalent results. The remaining difference is then just HS versus NLSH.

I propose modifying the paragraphs comparing theory and experiment along the following lines. Figure 1 can be omitted to save space, if needed, because it provides no useful information in its present form. I attempted to imitate the active voice style of the current manuscript, but forgive me if I lapse into passive voice occassionally. The references are omitted because Juncai already has most of them. In order to make a more useful comparison between my approximation and Udias's more rigorous calculations, I propose replacing my earlier HS calculations with ones using NLSH. If this proposal is accepted (at least in spirit, if not wording), the files needed for construction of figures will be sent separately, with fewer variations to prevent Juncai from using the wrong sets.

A. Proposed revision

We compared our data to three DWIA calculations. Picklesimer and van Orden made the first relativistic calculations for $(e,e'p)$ using a momentum space approach. They used Dirac-Hartree bound-state wave functions from Horowitz and Serot (HS) and an optical potential based upon transforming the Franey and Love nonrelativistic impulse approximation for use in the Dirac equation. Udias *et al* solved Dirac equations in configuration space, using more modern bound-state wave functions (NLSH from Lalazissis *et al.*) and optical potentials (EDAIO from Cooper *et al*). Kelly solved a relativized Schrödinger equation and used the effective momentum approximation (EMA) to incorporate spinor distortion into an effective current operator based upon the method of Hedayati-Poor *et al.* The primary difference between the methods of Kelly and Udias is that the former uses an EMA approximation for lower components of Dirac spinors while the latter uses solutions of the Dirac equation directly. Although Kelly originally used HS wave functions for comparison with van Orden, here his approach is evaluated using NLSH wave functions in order to test the effect of the EMA approximation to lower components by comparison with the results of Udias using the same wave functions and optical potentials. All three calculations employ Coulomb gauge. Both Kelly and Udias include electron distortion using the EMA and use the cc2 vertex function with off-shell extrapolation, whereas van Orden omits electron distortion and off-shell extrapolation. Both Kelly and Udias include incoherent contributions by positive-parity contaminations of the $1p_{3/2}$ peak using the parametrization of Leuschner *et al*, but van Orden omits this contribution.

Figure 2 shows cross sections as a function of missing momentum at $E_{beam} = 2.4$ GeV. The calculations of Kelly and Udias provide excellent fits to the data with normalization factors of 0.75 for both $1p_{1/2}$ and $1p_{3/2}$ states. The van Orden calculation also provides a fairly good fit to the data using normalization factors of 0.61 and 0.67 for $1p_{1/2}$ and $1p_{3/2}$, respectively. The most important difference between these calculations is the choice of bound-state wave function — NLSH produces a lower peak but broader momentum distribution that results in larger normalization factors and slightly better fits to the data than HS. Also note that the positive-parity contributions, which are normalized independently according to the Leuschner parametrization, fill in the $p_m \to 0$ dip in the $1p_{3/2}$ momentum distribution but are omitted from the van Orden calculation.

Figure 3 compares data and calculations for the left-right asymmetry, A_{LT}. All three relativistic calculations produce similar predictions for modest p_m, but begin to diverge for $p_m > 280$ MeV/c where sensitivity to details of the models increases. The most important difference between the calculations of van Orden and Kelly was shown (nucl-th/9905024) to be the choice of optical potential. The difference between the calculations of Udias and Kelly can be attributed to the approximation Kelly makes to the lower components of spinors, which is adequate for modest p_m but begins to break down for $p_m > 250$ MeV/c. Also shown is the EMA-noSV approximation of Kelly in which the Dirac scalar and vector potentials are omitted from the spinor-distortion factor in the effective current operator. This calculation is equivalent to a nonrelativistic DWIA that uses the EMA for the relativistic current operator instead of nonrelativistic reduction and demonstrates that dynamic enhancement of lower components of spinors by Dirac scalar and vector potentials is responsible for the enhancement of A_{LT} in relativistic calculations. Furthermore, Kelly (nucl-th/9905024) demonstrated that the dominant effect for A_{LT} arises from distortion of the bound-state spinor with the ejectile spinor being much less important for this quantity.

Figure 4 compares calculations and data for the R_{L+TT}, R_T, and R_{LT} response functions, where $R_{L+TT} = R_L + \frac{V_{TT}}{V_L} R_{TT}$ includes a small contribution ($< 10\%$) from R_{TT} that cannot be separated from R_L using only measurements in perpendicular kinematics. The calculations of van Orden do not account for electron distortion, but Kelly and Udias constructed effective response functions which do include electron distortion by analyzing calculations for two beam energies in the same way that data are analyzed. Furthermore, Kelly and Udias include positive-parity contamination of the response functions for the $1p_{3/2}$ peak. All three calculations produce similar results and good agreement with these data for $Q^2 = 0.8$ (GeV/c)^2. Kelly also performed calculations for the R_{LT} data of Chinitz *et al* at $Q^2 = 0.3$ and Spaltro *et al.* at $Q^2 = 0.2$ (GeV/c)^2, finding good agreement with the former but failing to reproduce the strong enhancement reported by the latter for the $1p_{3/2}$ state. Several authors using nonrelativistic calculations have suggested that meson exchange (MEC) and isobar currents (IC) can be important for R_{LT} at $Q^2 \sim 0.25$ (GeV/c)^2 but there is as yet little agreement over the relative importance of MEC versus IC or differences between $1p_{3/2}$ and $1p_{1/2}$ (cite Boffi, Ryckebusch, Amaro). The good agreement we find between data for $Q^2 = 0.8$ (GeV/c)^2 and relativistic calculations based upon the one-body current suggests that these two-body currents become less important as Q^2 increases, but it remains important to test this hypothesis by extending the relativistic approach to include MEC and IC.

In summary, we have measured cross sections and response functions for $^{16}\mathrm{O}(e,e'p)(1p)^{-1}$ at $Q^2 = 0.8$ (GeV/c)^2 for missing momenta up to 355 MeV/c. Relativistic DWIA calculations describe these data very well, with the enhancement of the left-right asymmetry relative to nonrelativistic calculations demonstrating the importance of dynamic enhancement of the lower components of Dirac spinors, particularly for the bound state, by nuclear scalar and vector potentials.