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Theoretical predictions for extraction of $G_E^n$ from semi-inclusive electron scattering on polarized $^3\text{He}$ based on various nucleon-nucleon interactions

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The process $^3\text{He}(e,e'\pi^n)$ is theoretically analyzed with the aim to search for sensitivity to the electric form factor of the neutron, $G_E^n$. Faddeev calculations based on five high precision nucleon-nucleon force models are employed, and stability versus exchange of the nucleon-nucleon forces is demonstrated.

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In a recent paper [1] we investigated the sensitivity of the process $^3\text{He}(e,e'\pi^n)$ to the extraction of the electric form factor of the neutron. That study was based on the AV18 [2] nucleon-nucleon (NN) force and related meson exchange currents (MEC’s) and Faddeev calculations for $^3\text{He}$ are consistent with the final state continuum. We found that final state interaction (FSI) effects were quite important and an analysis without FSI cannot be recommended. Though we know from most of our experience that the theoretical results are quite stable under exchange of one of the high precision $NN$ potentials by another one, we would like to supplement our previous paper [1] by explicitly demonstrating the independence of the $NN$ interaction for that specific process. We refer to Ref. [1] for all information about the formalism and the definitions of the asymmetries $A_1$ and $A_2$. Since in contrast to AV18 there are no consistent MEC’s worked out for the other four high precision NN potentials, CD Bonn [3], Nijmegen 93, and Nijmegen I and II [4], we show only the asymmetries evaluated with those NN potentials based on the standard nonrelativistic single-nucleon current operator.

The important ratio $A_1/A_2$ for the extraction of $G_E^n$ is displayed in Fig. 1 for the same $q^2$ values as in Ref. [1]. This figure corresponds to Fig. 8 of Ref. [1]. It shows the five predictions (including AV18) for a fixed choice of $G_E^n$ as used in Ref. [1]. In order to provide the necessary information on the sensitivity with respect to $G_E^n$, we include also three additional curves, where $G_E^n$ is multiplied by 0.75, 1.25, and 1, respectively, and this for the choice of AV18 + MEC. These additional three curves are the same as in Fig. 8 of Ref. [1]. We see in all cases a rather narrow spread of the five $NN$ force predictions that document the expected stability of the results under exchange of one $NN$ force by another one. However, we had to reduce somewhat the energy range near the upper end of the neutron energies in order to keep that spread small. Especially for the higher $q^2$ values, the spread increases quite a bit for the lower neutron energies (not shown). Experimentally it should be possible to concentrate on that restricted upper energy range, where the cross section is anyhow largest.

Now the narrow spread is meant in relation to the variation of the predictions by changing $G_E^n$ by $\pm 25\%$. From the three added curves we see that the shifts caused by the changes of $G_E^n$ is by far larger than the spread induced by varying the $NN$ forces. For example, at $q^2 = 0.45$ (GeV/c)$^2$ and $E_n = 260$ MeV, the spread due to different NN potentials is about 13\%, whereas the shifts caused by the $G_E^n$ variations reach 70\%. We did not repeat the calculations by varying $G_E^n$ for the $NN$ force predictions with a single nucleon current alone, since one can safely expect that corresponding shifts would result, as for AV18 + MEC. Figure 1 shows that the sensitivity to a $G_E^n$ extraction would not suffer from a theoretical uncertainty induced by the choice of the $NN$ force. However, one also sees that MEC effects can only be neglected near the very upper end of that neutron energy spectrum. They are quite significant for $q^2 = 0.05$–0.2 (GeV/c)$^2$. The filled square is the result for the scattering on a free neutron at rest. This is treated fully relativistically and will be referred to as the pure neutron result. Clearly, an analysis of data with such an oversimplified picture would be meaningless.

For the sake of completeness we also display $A_1$ and $A_2$ separately in Figs. 2 and 3 (corresponding to Figs. 5 and 6 of Ref. [1]), now again, as in Fig. 1, restricted to that upper $E_n$ energy range. The spread among all curves for $A_1$ is quite small and MEC effects for AV18 are also minor. The filled square is the pure neutron result. For $A_2$, which carries the dependence on $G_E^n$, we see again only small spreads. MEC effects are quite noticeable only for $q^2 = 0.1$–0.2 (GeV/c)$^2$. Clearly FSI is mandatory: the pure neutron result, which is reached by antisymmetrized plane wave approximation (PWIAS) calculations [1] is far off. For the highest $E_n$ values $A_2$ is very stable under exchange of the $NN$ forces (effects below 1\%). This observable is also insensitive to the $G_E^n$ variations (changes are below 2\%). That is why the ratio $A_1/A_2$ reflects the sensitivity of $A_1$ to both effects.
Summarizing, we conclude that theoretical uncertainties arising from replacing one of the modern high precision NN potentials by another one in the ratio $A'/A_i$ are much smaller than the changes sought due to $G_E$ variations. MEC effects, as evaluated in conjunction with AV18, decrease strongly at the upper end of the neutron spectra. Measurements concentrated to the upper end of the neutron energies would be ideal and could provide important information on $G_E''$.

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FIG. 3. $A_\perp$ as a function of the neutron energy $E_n$ for different $q^2$ values. Curves and the symbols are as in Fig. 2.