UM-P-98/51

THE UNIVERSITY OF MELBOURNE
SCHOOL OF PHYSICS

The School of Physics
The University of Melbourne
PARKVILLE 3052
AUSTRALIA

MULTINUCLEON PROCESSES IN (e,e′p): STATUS AND FUTURE OF SEARCHES AT HIGH MISSING ENERGY

A.J. Sarty[1], R. Florizone[2], J. Templon[3], K. Aniol[4], W. Bertozzi[2], J.-P. Chen[5]
D. Dale[6], L. Dennis[1], M. Distler[2], P. Dragovitsch[1], M. Epstein[4], K. Fissum[2],
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J. Zhao[2], Z.-L. Zhou[2], and the MAMI A1 Collaboration.

[1] *Florida State University, Tallahassee, FL 32306*
[2] *Massachusetts Institute of Technology, Cambridge, MA 02139*
[3] *University of Georgia, Athens, GA 30602*
[4] *California State University at Los Angeles, CA 90032*
[5] *Thomas Jefferson National Accelerator Facility, Newport News, VA 23606*
[6] *University of Kentucky, Lexington, KY 40506*
[7] *Technische Universitat Darmstädt, Germany*
[8] *University of Melbourne, Australia*

Over the past decade, experiments which have measured $(e, e'p)$ cross sections out to high missing energies, in kinematics near the quasielastic ridge, have shown an excess strength above and beyond that expected from a DWIA framework. While some of this excess has been shown to be accounted for by meson-exchange currents, there remains a substantial amount of data in which the excess is not yet accounted for and which may be a signature of multinucleon processes. In this talk, the results from many of the recent high missing energy $(e, e'p)$ measurements will be reviewed, and possible interpretations discussed. Some focus will be given to an ongoing experimental program at Mainz to systematically study the high missing energy regime for ^{3}He and ^{4}He (MAMI Experiments A1/1-93 and A1/3-96). The future plans for continuation of such studies, including reference to two-nucleon knockout, will be briefly presented in conclusion.

Published in Proceedings of the BLAST Workshop
May 28-30 1998
M.I.T. Cambridge

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1 Introduction

In the conventional picture of many-body nuclear systems, the understanding is that most observables in nuclear reactions and in spectroscopy are "well described" in terms of one-body densities through a mean-field description of the nucleus. A prime question of interest in our field remains to understand how far this simple mean-field picture can be pushed before it breaks down. One expects deviations from the mean-field in the form of short-range correlations because of the strong nucleon-nucleon interaction at short distances. Such "true" two-body correlations can then be manifest as deviations - $C(r_1,r_2)$ - of the two-body density from the product of one-body densities: $\rho(r_1, r_2) = \rho(r_1)\rho(r_2) + C(r_1, r_2)$. One also expects mean-field deviations in the form of longer-range two-nucleon correlations arising from pion exchange (MEC).

Measurements of $(e, e'p)$ reactions contribute importantly to the process of understanding how far the mean-field framework can be pushed. At quasielastic (QE) kinematics with $\omega = {q_\mu}^2/2m_p$ (q_μ and ω are the four-momentum and energy transfers), interactions with single-nucleon currents are expected to dominate the nuclear electromagnetic response. In the simplest PWIA framework, the electron interaction is with a free proton inside the nucleus, and that struck proton is then detected; in this picture, the experimental missing momentum ($\vec{P}_{miss} = \vec{P}_p - \vec{q}$) equals the primordial proton momentum, and the missing energy ($E_{miss} = \omega - T_p - T_{A-1}$) is directly proportional to the excitation energy of the *A-1* system. This IA picture, combined with a mean-field independent-particle shell model (IPSM), has been successful in developing our understanding of many-nucleon systems - giving a good understanding of the ground-state and low-lying excited states; enabling a mapping of the single-nucleon momentum distributions; indicating that the bulk of the reaction strength is concentrated at low E_{miss} and P_{miss} (below K_{fermi}). However, this simple picture is complicated by the observation that the IPSM states are not fully occupied, and are depleted by up to 35%[1]. This depletion is a result of pairwise interactions which alter the single-nucleon wave-functions and shift strength to higher E_{miss} and P_{miss}[2,3].

Thus, interesting physics beyond PWIA (and thus beyond the mean-field) can be accessed in $(e, e'p)$ by probing at higher P_{miss} or higher E_{miss} (or both). Contributions may be expected from final-state interactions of the proton (which isn't technically "beyond the mean-field", but just extends PWIA to DWIA), MEC and Δ-excitation (both longer-range 2N correlation phenomenon), short-range NN correlations (SRC), or even many-N currents. The choice of kinematics and/or the specific electromagnetic response function can emphasize or limit these various effects to some degree. For the rest of this talk, focus will be given to those $(e, e'p)$ measurements probing high missing energy in the near-QE kinematical regime. There is a difficulty associated with such measurements probing the high E_{miss} or P_{miss} regions to which 2N correlations are expected to shift strength: in the IA picture, accessing these regions requires sampling very small components of the nuclear wavefunction, leading to small cross sections. Thus, signatures of such 2N correlations likely also lead to small cross sections. It is therefore necessary to consider *all possible* reaction mechanisms which could possibly contribute (even, in some cases, when measuring directly on the QE peak) before attributing any observation to one particular mechanism[4,5].

2 Two-Nucleon Knockout

When searching at high E_{miss} and/or P_{miss} for "beyond the mean-field" processes, it is reasonable to expect that two nucleons may have been ejected - particularly if the detected proton was a member of a correlated pair of nucleons inside the target nucleus. In the case that the detected proton does indeed originate from a 2N-correlated pair, and the other pair-member is also ejected, then the following relationship can be derived [3,6,7]:

$$E_{miss} \approx \frac{A-2}{A-1} \cdot \frac{P_{miss}{}^2}{2M} + E_{thresh} \tag{1}$$

where M is the nucleon mass, and E_{thresh} is the energy required to eject two nucleons. This type of functional dependence will hold for *all* processes which knock out 2 nucleons. To demonstrate how this relation is manifest, Fig. 1 illustrates a model [7] for the spectral function of ^{16}O. In the PWIA picture,

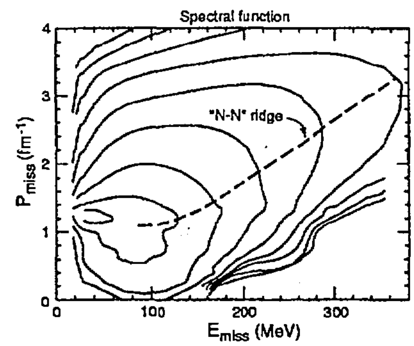

Figure 1: Contour plot of the ^{16}O spectral function as calculated by Sick, Fantoni, Fabrocini and Benhar (adapted from Ref. 7). The dashed line roughly indicates the position of the so-called "NN-ridge", where the spectral function is locally maximum due to correlated NN knockout (c.f. Eq. 1).

the $(e, e'p)$ differential cross section factorizes into a product of the elementary $ep \longrightarrow ep$ amplitude times the spectral function, $S(P_{miss}, E_{miss})$; the spectral function is thus interpreted (in PWIA) as the probability for finding a nucleon in the nucleus with momentum and energy P_{miss} and E_{miss}, respectively. Fig. 1 thus shows how a model with processes beyond the simple mean-field distributes strength out to higher energies and momenta.

The theory group of Ryckebusch *et al.* at Gent have developed a formalism for 2N knockout which allows illustration of the different roles of one-body mechanisms, longer-range MEC and Δ-excitation, and SRC [4]. In the Gent group's model (which uses the correlated basis function method), the transition matrix element $M_{fi}(\lambda)$ for 2N knockout via one- and two-body currents can be written as[4]:

$$\begin{aligned} &M_{fi}\ (\lambda) = \langle\Psi_i|J_\lambda{}^{[1]} + J_\lambda{}^{[2]}|\Psi_f\rangle \qquad\qquad (\lambda = 0, +1, -1)\\ &\bullet\quad |\Psi_i\rangle = \textstyle\prod_{i<j=1}^{A} C(r_{ij})\\ &\bullet\quad |\Psi_f\rangle = |N_a, N_b\rangle \textstyle\prod_{i<j=1}^{A-2} C(r_{ij})|J_R, M_R\rangle \end{aligned} \tag{2}$$

where $|\Psi_i\rangle$ and $|J_R, M_R\rangle$ are the initial and *(A-2)* IPSM states, respectively; and $C(r_{ij})$ is a Jastrow-type central 2N correlation function. This is then shown to lead to a calculable form of:

$$M_{fi}(\lambda) = \langle N_a, N_b; J_R, M_R|H_\lambda{}^{eff}|\Psi_i\rangle \qquad with:$$

$$\begin{aligned} H_\lambda{}^{eff} \sim & \textstyle\sum_{i=1}^{A} J_\lambda{}^{[1]}(i)\\ & + \textstyle\sum_{i<j=1}^{A}(J_\lambda{}^{[1]}(i) + J_\lambda{}^{[1]}(j)) \cdot (1 - C(r_{ij}))\\ & + \textstyle\sum_{i<j=1}^{A} J_\lambda{}^{[2]}(i,j)C(r_{ij}). \end{aligned} \tag{3}$$

The first term in the expansion of $H_\lambda{}^{eff}$ in Eq. 3 above is the pure one-body process, and does not contribute to two-nucleon knockout; the second term is the SRC current; and the third term is the longer-range MEC (and Δ-excitation) current. Reference will be made to these terms in comparison to $(e,e'p)$ data in the subsequent section.

3 Review of Existing (e,e'p) Data at High E_{miss}

Much of the current interest in effects at high E_{miss} was generated from a series of measurements made on ^{12}C at the MIT-Bates Linear Accelerator Center during the period 1986-1991[8,9,10,11,12,13]. Following this set of Bates ^{12}C experiments, results have since been reported for ^{12}C from other labs as well as for other lighter nuclei (^6Li, ^4He and ^3He). In this section, a summary and brief description of these experimental results is provided, starting with the Bates ^{12}C series.

The Bates ^{12}C measurements together span the QE peak region, from the low-ω side to the peak of the Δ. Momentum transfers ranging from $q =$ 400 - 700 MeV/c were covered. Differential cross sections were measured for all experiments, with one extraction of R_L and R_T [8], and one extraction of R_{LT} [13]. All of these experiments were done in so-called "parallel kinematics" ($\theta_{pq} = 0°$), except for the R_{LT} experiment[13] which sampled $\theta_{pq} = 11°$. In Fig. 2, the results from the separated responses - R_L, R_T [8] and R_{LT} [13] - are shown. The full Gent-group calculation reasonably reproduces both the R_L and the R_{LT} responses, while the R_T is underpredicted for E_{miss} greater than about 35 or 40 MeV. These data are consistent with the longitudinal response going to zero around $E_{miss} = 50$ MeV - and thereby driving R_{LT} to zero - which is consistent with expectations from one-body mechanisms. Also note that 2N knockout via MEC appears to play a very small role in these parallel (or near-parallel) kinematics, and thus cannot explain the R_T discrepancy at higher E_{miss}.

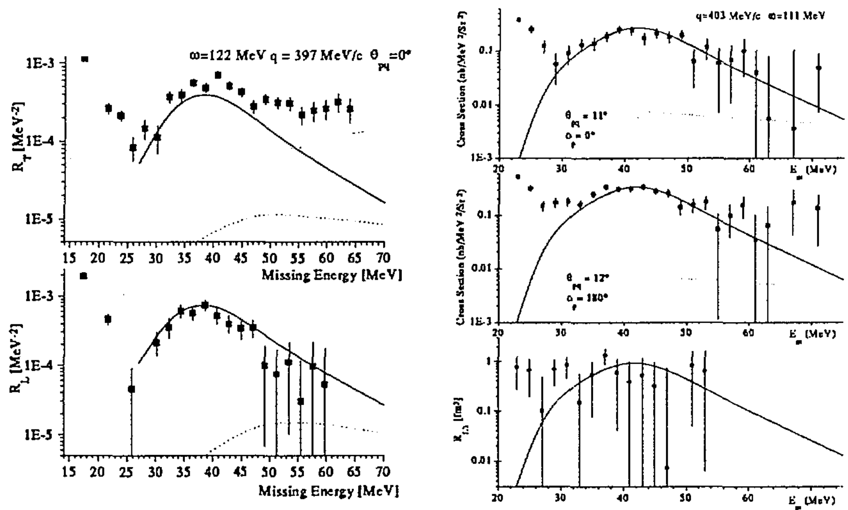

Figure 2: Response functions for $^{12}C(e,e'p)$ in QE kinematics. **Left-column:** plots taken from Ref. 5 (data from Ref. 8); the solid line is the full calculation of the Gent group, and the dashed line shows the small contribution from 2N knockout via the $J_\lambda^{[2]}$ (MEC) term. **Right-column:** data and plots from Ref. 13, with the same Gent calculations. Note that the Gent calculations are relevant only for E_{miss} above 25 MeV, since single-nucleon knockout from the p-shell is not considered.

The QE cross section data of Weinstein *et al.*[10] at a higher q is shown in Fig. 3 as representative of the observations for the other Bates experiments. The individual contributions from direct *pn* and *pp* knockout via MEC are shown for the Gent calculations in Fig. 3, as well as from the one-body and SRC processes (1st and 2nd term in Eq. 3). The one-body and SRC currents are able to produce strength out to relatively high E_{miss} by considering knockout from the 1s-shell and using a phenomenological energy spreading[14] of the 1s hole strength in ^{11}B. Nonetheless, there remains unexplained strength above $E_{miss} \approx 50$ MeV.

Two other ^{12}C measurements were performed at NIKHEF. The first done by Steenhoven *et al.*[15] was similar to the Ulmer measurement at Bates[8] in the sense that R_L and R_T were extracted as a function of E_{miss} in QE kinematics.

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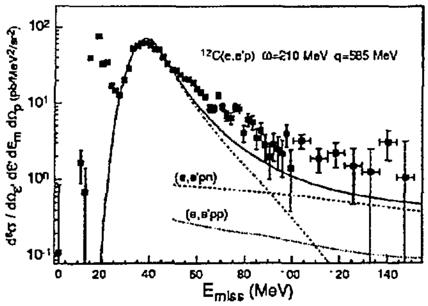

Figure 3: Cross section for QE $^{12}C(e,e'p)$ at $\theta_{pq} = 0°$, taken from Ref. 5 (data from Ref. 10). Solid line is full Gent calculation. Dotted and short-dashed lines indicate contributions of direct pp and pn knockout, respectively, via the MEC term. The dash-dotted line shows the contribution from the one-body term, including SRC, for s-shell knockout.

The same basic result as displayed in Fig. 2 was observed: an apparent excess strength in R_T is evident above an E_{miss} of approximately the 2N-emission threshold. Indeed, NIKHEF measurements on ^{6}Li by Lanen [16] and ^{10}B by de Bever [17] also show this same phenomenon. The second ^{12}C experiment of Kester *et al.* was more extensive in nature [18]: this measurement was above the QE peak (in the so-called "dip" region between the QE peak and the Δ-peak) at $q = 270$ MeV/c. As shown below in Fig. 4, a wide range of proton angles were covered, from $\theta_{pq} = 27° \rightarrow 162°$. The Kester data shows that the longer-range correlations as included in the $J_\lambda{}^{[2]}$ term (third term in Eq. 3) are important as the proton emission angle θ_{pq} increases. SRC become increasingly important as θ_{pq} decreases, coming closer to parallel kinematics. Also note that the overall description of the data is not as good at smaller angles compared to the larger angles.

For completeness, note that another measurement of high E_{miss} in ^{12}C was reported for much higher q's (1200-4500 MeV/c) in the NE18 results from SLAC [19]. At these higher momentum transfers, no dramatic deviation from PWIA was noted out to E_{miss} of 150 MeV, and no need to include effects of MEC or SRC was concluded within the statistical accuracy of the data at these high E_{miss}. Moving down to the helium isotopes, measurements from ^{4}He have been reported from Saclay [20], NIKHEF [21], and Bonn [22]. The Saclay measurement of Le Goff spanned from QE to dip electron kinematics from q = 300-650 MeV/c, and covered θ_{pq}'s from 4° to 101°. When this data was compared to the diagrammatic expansion calculation of Laget [23], the data at larger angles ($\theta_{pq} > 50°$) showed roughly the same peaking in E_{miss} for MEC and SRC as the theory predicted (c.f. Eq. 1); however, the data at

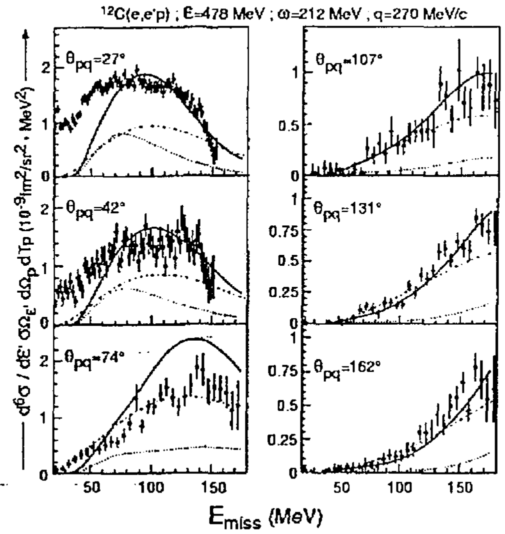

Figure 4: Cross sections for dip-region $^{12}C(e,e'p)$ at various values of θ_{pq}, taken from Ref. 4 (data from Ref. 18). The solid line is the full Gent calculation, the dotted line is the contribution from the SRC current only (second term in Eq. 3), and the dash-dotted line is the $J_\lambda{}^{[2]}$ (MEC) contribution only.

high E_{miss} (roughly 30-100 MeV) for the smaller angles was essentially "flat" compared to the peaking behaviour predicted. A more recent measurement has been reported from NIKHEF by van Leeuwe *et al.*[21] for ^{4}He, which was also performed in the dip region at $q = 400$ MeV/c. Data from this measurement is shown in the left-hand column of Fig. 5 for three θ_{pq} angles (35°, 70°, and 89°). The illustrated comparison to Laget's predictions[23] indicate a good qualitative description of the data *except* at the high E_{miss} for the smallest angle, where there appears to be excess strength. Similar observations were seen in a series of ^{4}He measurements performed at Bonn by de Vries[22]. The Bonn measurements spanned from the dip to Δ electron kinematics for $q =$ 290-430 MeV/c, and for a big range in θ_{pq}. De Vries concludes that the data roughly indicate the presence of the maximum due to NN knockout as predicted by Laget (again, c.f. Eq. 1), but that Laget's model mostly underestimates the data at high E_{miss}. There is also an indication of an ω-dependence to the data at high E_{miss} which appears missing in Laget's calculations, possibly indicating the neglect of some important reaction mechanism.

Finally, two experiments from ^{3}He which probe high E_{miss} have been performed, both at Saclay. The first early measurement of Marchand *et al.*[24]

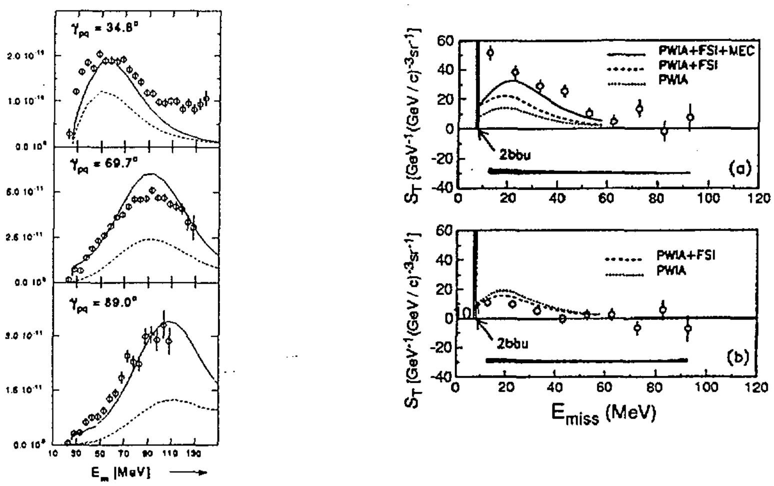

Figure 5: **Left-Hand Column:** Cross sections for $^4He(e,e'p)$ in the dip region for various θ_{pq} angles, taken from Ref. 21. Calculations by Laget show the full calculation with the solid line, and that excluding the contributions of MEC and Δ-excitation by the dashed line. **Right-Hand Column:** Transverse *(a)* and longitudinal *(b)* spectral functions for $^3He(e,e'p)pn$, taken from Ref. 25. Laget's full calculations are shown (solid), without MEC (dashed), and without both MEC+FSI (dotted).

was done in the dip region at $q = 280$ MeV/c. This measurement, like the Le Goff and de Vries ^{4}He results just discussed, roughly showed evidence of the NN-correlation peak, but only qualitative agreement was shown with Laget's model. The more recently reported experiment of Le Goff *et al.* [25] was also performed in the dip region with $q \approx 375$ MeV/c, and extracted R_L and R_T using parallel kinematics. These results are shown in the right-hand column of Fig. 5. It can be seen from these data in comparison to Laget's predictions that there is an excess transverse response (although not as striking as observed in the ^{12}C experiments).

3.1 General Observations and Possible Interpretations

The following general comments can be made with regard to all of the high E_{miss} $(e,e'p)$ data presented above. In non-parallel kinematics (that is, with θ_{pq} angles bigger than about 20°): *(i)* the strength large θ_{pq} is predominantly generated by MEC, and *(ii)* there are indications that the strength at smaller θ_{pq} is generated by SRC. In parallel kinematics ($\theta_{pq} = 0°$): *(i)* there is an unexplained "excess" of data fro E_{miss} greater than the 2N-knockout threshold, *(ii)* there are indications that the excess is transverse in character, and *(iii)* the excess persists to some level in both the QE and dip electron kinematical domains. Possible interpretations of the source of this unexplained excess strength in the parallel kinematics measurements fall into the categories of "exciting" or "not-so-exciting". The "exciting" possibilities are that there are SRC or MEC which are not yet being properly accounted for, that there are 3-body (or N-body) nuclear currents, that Δ-excitation is somehow creating the excess, or there is really some completely new reaction mechanism. On the not-so-exciting side are the related ideas of improperly accounted radiative effects or final-state proton rescattering. While radiative effects are in principle completely understood as a QED process, in these type of continuum $(e, e'p)$ measurements radiation tends to re-distribute strength in (E_{miss}, P_{miss}) phase-space in non-trivial ways, and such that un-measured regions of this phase-space can radiate into the measured regions. Thus, while "not-so-exciting", proper treatment of electron radiation remains crucial in interpreting these type of experiments. Similarly, proton FSI can lead to a re-distribution of strength in (E_{miss}, P_{miss}) via a multi-step process; this could arise from the processes (as suggested by Sick[7]): *(1)* an $A(e, e'p)$ interaction with an initial (E_{miss}, P_{miss}), *(2)* followed by $(A-1)(p, Np)$ rescattering, leading to *(3)* an incorrect measurement of (E_{miss}, P_{miss}). This then leads to a method which could "steal" strength from the locally-maximum NN-ridge region of the spectral function (c.f. Fig. 1) into other regions, and artificially enhance those other regions. So far, no full calculation including such proton FSI processes have been performed, but only schematic calculations have been presented [7]. Note that one issue which is still difficult to understand in terms of either of the "not-so-exciting" possibilities is the fact that the unexplained excess strength appears transverse in character.

4 MAMI Experiments A1/1-93 and A1/3-96

In view of the above-described state of existing knowledge for high E_{miss} phenomenon, we have embarked on an experimental program with the A1 Collaboration at the Mainz Microtron with the goal of shedding light on the unexplained excess strength in parallel kinematics. Measurements are being made of $^3He(e, e'p)$ and $^4He(e, e'p)$ in identical kinematics. Data will be acquired to allow Rosenbluth separations of R_L and R_T as functions of E_{miss} in parallel kinematics. All measurements will be at a fixed $q = 685$ MeV/c, and as a function of energy-transfer by sampling at three ω-values (one on the low-energy side of the QE peak, one on top of the QE peak, and one on the high-energy side). The rationale behind this program is to utilize the high-resolution/high-precision facility in the MAMI A1 spectrometer hall to try and characterize as fully as possible the L/T behaviour of the $(e, e'p)$ response as functions of E_{miss} and ω in order to (hopefully) disentangle possible contributions to the process. These two light nuclei of ^{3}He and ^{4}He were chosen since full microscopic calculations, with all known reaction mechanisms included, are (in principle) possible, thus avoiding the necessary approximations needed to make the heavier nuclei calculations tractable. Also, the direct comparison between ^{3}He and ^{4}He may be relevant due to the large density difference, if the source of the excess is density dependent. In the end, a determination will be made if the observations from this systematic program of measurements are consistent with our present understanding, or if "new" physics is required.

The status of the program is as follows. In 1995, data was collected on top of the QE peak for both ^{3}He and ^{4}He. The analysis of this data is now essentially complete [26], and all data and figures shown in this section will be from this data set [26]. In the fall of 1996, data was collected for ^{3}He on the high-ω side (y = +140 MeV/c) of the QE peak. In the summer of 1998, measurements were made for ^{4}He at the same high-ω kinematics, plus for ^{3}He on the low-ω side of the QE peak (y = -140 MeV/c). Effects due to MEC and Δ-excitation should be more prominent on the high-ω side, while effects from SRC are expected to be more visible on the low-ω side, and the QE peak should be predominantly DWIA. The enhancement of high E_{miss} may be present throughout all three ω regimes. The 1996 and very recent 1998 data are still under analysis, but preliminary results from the 1995 QE runs will be discussed here.

A sample of the QE ^{3}He data for P_{miss} = 45 MeV/c is shown in Fig. 6 [26]. As mentioned, careful attention must be paid to radiative effects in these measurements, and so Fig. 6 illustrates the magnitude of these effects in two ways. First, through an iterative unfolding procedure, the effects of radiation were removed (left plot); this shows that the measured "raw" cross section strength observed for E_{miss} above 20 MeV is *all* radiative tail. Due to this fact that the correction becomes a 100% effect at high E_{miss}, unfolding above 40 MeV becomes unreliable. The second complementary way to evaluate radiative effects is to "radiate a model" (right plot); using a Monte Carlo routine, the Salme ^{3}He spectral function was radiated [27] and compared to the "raw" extracted experimental spectral function. Good agreement is observed between this radiated spectral function and the data, all the way out 70 MeV in E_{miss}. The agreement between the two methods lends confidence to our radiative unfolding technique. A similar procedure has been followed with the ^{4}He data, with the same observations. This is an indication that no processes beyond PWIA are being observed. The ^{3}He data is also being compared to the

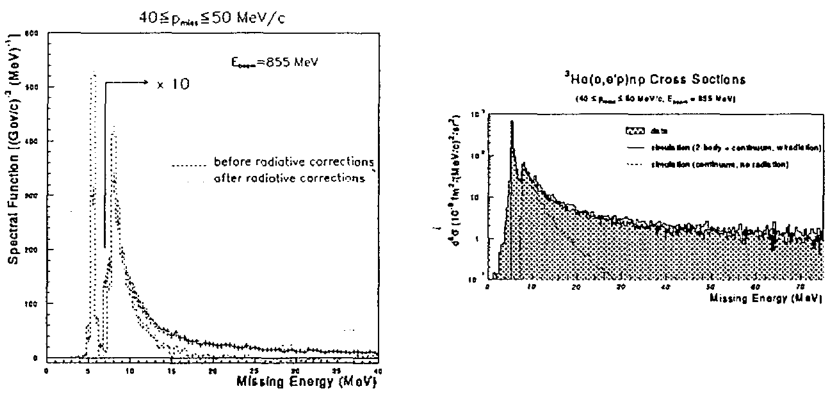

Figure 6: Demonstration of radiative correction effects for a sample of QE $^3He(e,e'p)pn$ data at $\theta_{pq} = 0°$, taken from Ref. 26. The plot on the left shows the extracted spectral function before and after radiative unfolding. The plot on the right shows a comparison between the raw, uncorrected data and the Salme model of the ^{3}He spectral function (both 2-body breakup and continuum 3-body breakup), which has been "radiated" using the AEEXB Monte Carlo routine (from Ref. 26 and 27). The model has been scaled by 0.83 to fit the data.

calculations of W. Glöckle's group [28]; the preliminary comparison indicates a very good agreement with the cross section shape as a function of E_{miss} out to 22 MeV, but with the calculations overestimating the data by about 20%.

The L/T behaviour investigations can be seen demonstrated in Fig. 7. In this figure, sample QE ^{3}He cross sections are shown (left column) as functions of E_{miss} for the three beam energies used to facilitate the Rosenbluth separation. Also shown (right column) are the extracted spectral functions, produced by division of the cross section by a kinematic factor and the elementary σ_{ep}^{cc1} amplitude. The fact that the spectral functions are identical within errors for the three beam energies indicates that the entire L/T behaviour for QE ^{3}He is being accounted for by the elementary amplitude. This is further evidence that, for these kinematics, no processes beyond PWIA are active. Similar results are obtained for the QE ^{4}He data.

Thus, at this stage of analysis, we find no evidence of processes beyond PWIA in QE parallel kinematics for ^{3}He and ^{4}He at q = 685 MeV/c. Within the next year, results will be available to check this statement for the same q but on both the low- or high-ω sides of the QE peak.

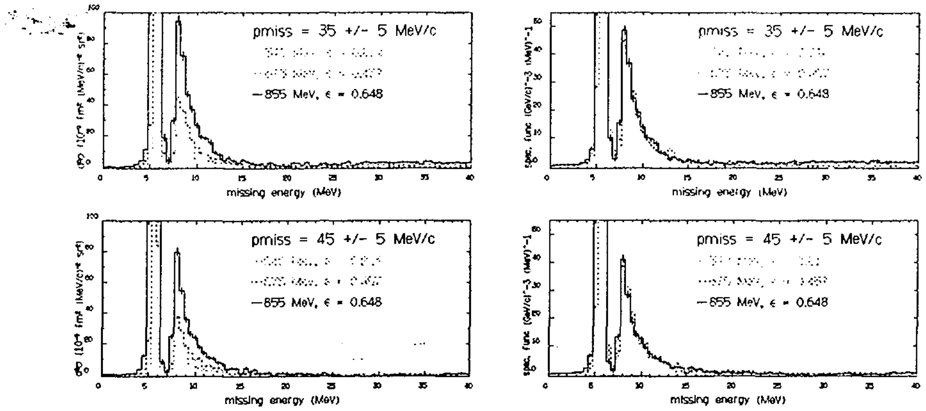

Figure 7: Demonstration of the L/T behaviour (ϵ dependence) of the $^3He(e,e'p)pn$ cross section in QE kinematics for P_{miss} = 35 and 45 MeV/c. Taken from Ref. 26. The left-column plots show the radiatively-corrected cross sections for three measured ϵ-values. The right-column plots then show the extracted spectral functions for the same three ϵ's.

5 Future

Aside from the completion of the just-discussed Mainz measurements, there are two experiments at Jefferson Laboratory which will be directed at addressing the high E_{miss} issues. In Hall C, E-97-006 led by I. Sick will search for the missing (depleted) single-particle strength at high (E_{miss}, P_{miss}) in several nuclei (C, O, Al, Fe, and Au). The planned kinematics have been chosen "above" the NN-ridge to minimize FSI-mediated contamination from the MEC-dominated region. The wide range in nuclei and kinematics to be measured hope to provide good constraints on theoretical subtraction of any MEC contributions, which act as a "background" in the attempt to measure single-particle strengths. In addition, in Hall B using the CLAS detector, the *e2* Multihadron Group within the Hall B Collaboration will be investigating $(e,e'X)$ reactions from ^{3,4}He, C, and Fe (and possibly others). E-89-027 being led by Bertozzi, Boeglin, Weinstein and Hersman is one of the experiments which will look at the *e2* data in terms of the physics issues discussed here. The Hall B measurements will provide complete angular coverage plus many reaction channels beyond $(e,e'p)$, including multiparticle emission.

This points to perhaps the real future of investigations of the phenomenon responsible for the high E_{miss} enhancement: two-nucleon knockout measurements. Indeed, many (γ,pp), (γ,pn) and $(e,e'pp)$ measurements have already been done or are underway.

The real photon (γ, NN) experiments have a longer history than electron-induced NN knockout. In the real photon experiments, pn knockout is driven by "quasi-deuteron" absorption (c.f. the MEC $J_\lambda^{[2]}$ operator in Eq. 3). However, pp knockout should be more sensitive to effects such as SRC since: *(i)* a pp-pair has no dipole moment, thereby suppressing E1 absorption, *(ii)* there is no charged MEC between the two protons, and *(iii)* Δ excitation is suppressed at first order from spin-isospin selection rules. The early (γ, NN) experiments (1980's) were done at Saclay, Saskatoon and Illinois using small solid-angle detectors [29]. However, mature programs evolved through the 1990's utilizing near 4π angular coverage at both Saskatoon (see for example Ref. 30) and at Mainz (again, for example, see Ref. 31). Some general observations can be made regarding these (γ, NN) results: *(i)* at low E_{miss}, process is dominated by quasi-deuteron absorption, and pp knockout is dominantly pn-absorption followed by (n,p) FSI; *(ii)* at high E_{miss}, the mechanisms are more complicated and not as of yet fully understood (note: these are referring to E_{miss} of the $(A-2)$ system now). The future of these type of real-photon measurements - which is already underway - is using polarized photons to extract polarization asymmetries.

Measurements of the electron-induced $(e,e'pp)$ reaction are also now underway, although these programs are not as mature as the real photon ones. The pp-knockout channel is preferred because it is expected to be very sensitive to the presence (and form) of SRC; this is because MEC are suppressed (same reasons as for real photons above), and thus the longitudinal contribution is predicted to be entirely from SRC. These measurements are being done both to examine transitions to specific excited states of the $(A-2)$ system, and as a function of E_{miss}. As with the early (γ, pp) measurements, $(e,e'pp)$ measurements using small solid-angle detectors can focus on specific kinematical regimes to maximize the SRC effects. Pioneering experiments have been performed at NIKHEF on ^{12}C in the Δ region [32] and dip region [33], and at Bonn on ^{4}He [22]. Another NIKHEF measurement on ^{16}O has demonstrated the observation of direct pp-pair knockout (predominantly coupled to $^1S_0$) from the 1p-shell [34]. More recent measurements led by Rosner and the MAMI A1 Collaboration have been made at Mainz. First, an experiment on ^{12}C was done using the near-4π BGO ball detector [35]. This ^{12}C experiment showed an exquisite sensitivity within specific restricted kinematical regions to the form of the SRC used. Also, a pilot-study was done using an ^{16}O target using the three high-resolution magnetic spectrometers in the Mainz A1 hall to study a specific kinematical region ("back-to-back" kinematics).

6 Summary

Signatures of multinucleon effects - those beyond the mean-field approximation - are expected at the high (E_{miss}, P_{miss}) region of the $(e,e'p)$ experiments. Untangling the role of specific processes in this region (such as short-range correlations, meson-exchange currents, final-state rescattering, etc.) requires a full theoretical treatment. The $(e,e'p)$ data acquired over the past decade has indeed revealed evidence for such effects, but there remains some outstanding discrepancies between theory and data, particularly at the high E_{miss} region of parallel-kinematics experiments. Programs of $(e,e'p)$ are underway (or planned) at the Mainz Microtron and at Jefferson Lab with an aim to clarify the origin of the outstanding discrepancies.

Recent (and planned) $(e,e'pp)$ measurements give a cleaner insight into 2N-knockout mechanisms (particularly short-range correlations), and may assist in understanding the present discrepancies at high E_{miss} in $(e,e'p)$ due to the increased exclusivity. However, a bigger challenge will lie ahead as the CLAS detector in Hall B at Jefferson Lab - and the BLAST detector at the MIT-Bates Linear Accelerator - begin to produce simultaneously large numbers of reaction channels, including multiple nucleon knockout.

Acknowledgments

We would like to thank the Mainz Microtron staff and A1 Collaboration for working with us to make experiments A1/1-93 and A1/3-96 possible. R. Florizone and J. Templon are thanked for their help in preparation for this talk, and for allowing early release of their figures. This work is supported in parts by the National Science Foundation and the US Department of Energy.

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