Coupling Between the 1p1h and 2p2h Sectors Experimental Constraints form $(e, e'p)$ data

Omar Benhar

INFN and Department of Physics, "Sapienza" University
I-00185 Roma, Italy

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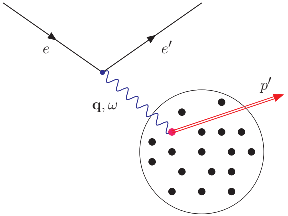
Preamble

- An accurate description of the 2p2h sector, providing $\sim 20\%$ of the nuclear cross section is only relevant to the extent to which the remaining $\sim 80\%$, arising from processes involving 1p1h final states, is fully understood
- $(e, e'p)$ experiments, in which the scattered electron and the outgoing proton are detected in coincidence, have provided ample evidence of the coupling between the 1p1h and 2p2h sectors
- The wealth of available $(e, e'p)$ data—mainly collected at Saclay, NIKHEF-K and Jefferson Lab data—must be exploited to test the theoretical approaches employed to study neutrino-nucleus interaction, and assess their predictive power

THE $(e, e'p)$ REACTION

- Consider the process

$$e + A \to e' + p + (A-1)$$



in which both the outgoing electron and the proton, carrying momentum p', are detected in coincidence, and the recoiling nucleus can be left in a any (bound or continuum) state $|n\rangle$ with energy E_n

- In the absence of final state interactions (FSI)—which can be taken into acount as corrections—the the *measured* missing momentum and missing energy can be identified with the momentum of the knocked out nucleon and the excitation energy of the recoiling nucleus, $E_n - E_0$

$$\mathbf{p}_m = \mathbf{p}' - \mathbf{q} \quad , \quad E_m = \omega - T_{\mathbf{p}'} - T_{A-1} \approx \omega - T_{\mathbf{p}'}$$

The $(e, e'p)$ Cross Section

- ⋆ The $(e, e'p)$ cross section is determined by the nuclear spectral function, yielding the probability of removing a nucleon of momentum $\mathbf{p}_m$ leaving the residual system with excitation energy E_m

$$d\sigma_A \propto d\sigma_N P(\mathbf{p}_m, E_m)$$

$$P(\mathbf{k}, E) = \sum_{h \in F} Z_h |M_h(\mathbf{k})|^2 F_h(E - e_h) + P_B(\mathbf{k}, E)$$

- ⋆ Interaction effects described by the spectroscopic factors $Z_h < 1$, the finite lifetime τ_h, and the continuum contribution $P_B(\mathbf{k}, E)$
- ⋆ Within the Independent Particle Model (IPM)
  - $P_B(\mathbf{k}, E) = 0$
  - $Z_h = 1$
  - $|M_h(\mathbf{k})|^2 = |\langle h | a_{\mathbf{k}} | 0 \rangle|^2 \to |\phi_h(\mathbf{k})|^2$
  - $F_h(E - e_h) = \frac{1}{\pi} \frac{\tau_h}{(E - e_h)^2 + (\tau_h^{-1})^2} \to \delta(E - e_h)$

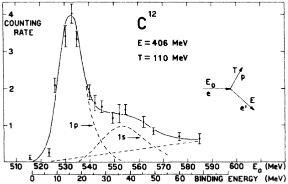
The 1p1h sector

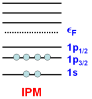
- At moderate missing energy—typically $E_m \lesssim 50$ MeV—the recoiling nucleus is left in a bound state
- The final state is a 1p1h state of the A-nucleon system
- The missing energy spectrum exhibits spectroscopic lines, corresponding to knock out from the shell model states
- Consider ${}^{12}\mathrm{C}(e,e'p)^{11}\mathrm{B}$, as an example. The expected 1p1h final states are

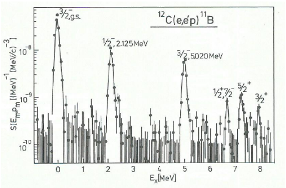
$$|{}^{11}\mathrm{B}(1/2^-),\ p\rangle \ , \ |{}^{11}\mathrm{B}(3/2^-),\ p\rangle \ , \ldots$$

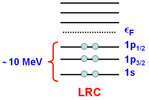
$(e, e'p)$ AT MODERATE MISSING ENERGY

- Missing energy spectrum of ^{12}C (U. Amaldi, Jr, et al, 1964; G. van der Steenhoven et al, 1988)

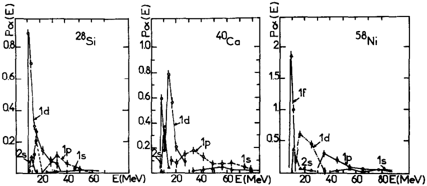








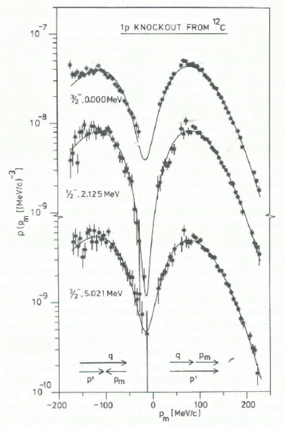
- Missing energy spectra of ^{28}Si, ^{40}Ca, and ^{56}Ni measured at Saclay (J. Mougey et al, 1976)



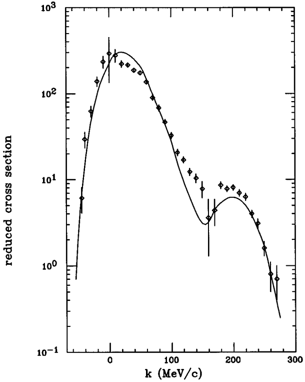
- Spectroscopic lines of valence states clearly seen

Momentum Distributions (FSI Included)

- Knock out of a p-shell proton from carbon (van der Steenhoven, et al, 1988)



- Knock out of a s-shell proton from lead (Quint et al, 1987)

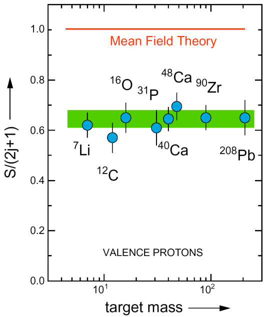


- Strength limited to the region $|\mathbf{p}_m| \lesssim 250$ MeV

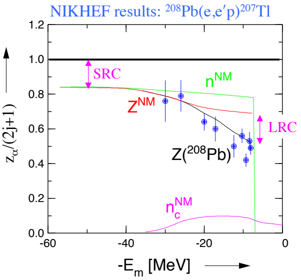
QUENCHING OF THE 1P1H STRENGTH

⋆ Nucleon-nucleon correlations move strength from the 1p1h sector to the 2p2h sector

▶ Spectroscopic factors of valence states (Lapikas, 1993)



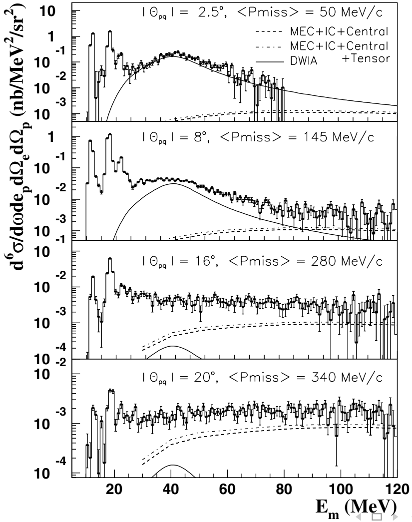
▶ Spectroscopic factors of the shell model states of ^{208}Pb (OB et al, 1991)



⋆ Short range correlations account for more than $\sim$ 70% of the observed quenching

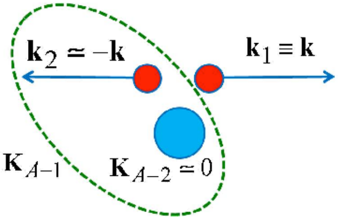
$|\mathbf{p}_m|$-EVOLUTION OF THE E_m SPECTRUM

- ⋆ JLab data, oxygen target (Lyianage et al, 2001)



Where is the Missing 1p1h Strength?

- The correlation strength in the 2p2h sector arises from processes involving high momentum nucleons, with $|\mathbf{p}_m| \gtrsim 400$ MeV. The relevant missing energy scale can be easily understood considering that momentum conservation requires

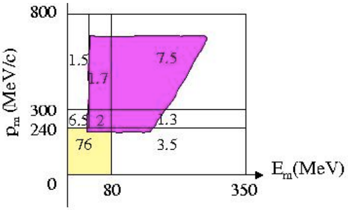


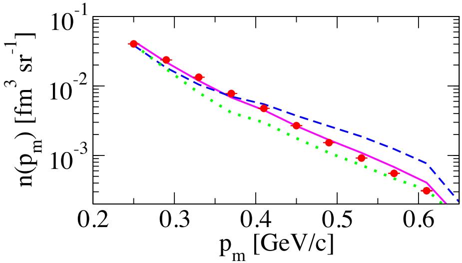
$$E_m = E_{\rm thr} + \sqrt{|\mathbf{p}_m|^2 + m^2} - m$$

- Scattering off a nucleon belonging to a correlated pair entails a strong energy-momentum correlation

Measured Correlation Strength

- ⋆ The correlation strength in the 2p2h sector has been investigated by the JLAB E97-006 Collaboration using a carbon target





- ⋆ Measured correlation strength (Rohe et al, 2005)

Experiment	0.61 ± 0.06
Greens function theory [3]	0.46
CBF theory [2]	0.64
SCGF theory [4]	0.61

SUMMARY

- ⋆ Studies of the $(e, e'p)$ cross section, giving access to the nuclear spectral function, have greatly contributed to identify processes involving 1p1h and 2p2h final states
- ⋆ The availability of $(e, e'p)$ data must be exploited to resolve the degeneracy between model of neutrino nucleus-interactions based on different—or even conflicting—assumptions on both nuclear dynamics and the relevant reaction mechanisms
- ⋆ In view of the use of neutrino detectors based on the liquid argon TPC technology, a dedicated $(e, e'p)$ experiment (JLab Experiment E12-14-012) will also provide new, much needed, information on the argon spectral function