PROPAGATION OF BARYONS IN THE MEDIUM within A REALISTIC MANY-BODY APPROACH

Università degli Studi di Perugia

M. ALVIOLI*, C.CIOFI DEGLI ATTI* AND H.MORITA†

∗ University of Perugia & INFN, Perugia, Italy
† Sapporo Gakuin University, Sapporo, Japan

BARYONS 04 October 25-29,2004

ABSTRACT

A new linked cluster expansion for the calculation of ground state observables of complex nuclei with realistic interactions has been developed [1, 8]; using the V8′ potential the ground state energy, density and momentum distribution of complex nuclei have been calculated and found to be in good agreement with the results of [3], obtained within the Fermi Hyper Netted Chain approach. Using the same cluster expansion with wave function parameters wich minimize the ground state energy the semi-inclusive reaction of type $A(e,e'p)X$ has been calculated taking final state interaction effects into account within a Glauber type calculation [5]; the comparison between the resulting distorted and undistorted momentum distributions provides an estimate of the transparency of the nuclear medium to the propagation of the hit proton. The effect of color transparency has also been considered in particular by the Finite Formation Time approach of [6]; it is shown that at high values of Q^2 the effects of FFT strongly reduce the final state interaction consistently with the idea of a reduced interaction of the hadron produced inside the nucleus [7].

1 - CALCULATING GROUND STATE PROPERTIES OF COMPLEX NUCLEI: *CLUSTER EXPANSION*

- The nuclear wave function is

$$|\Psi\rangle = \hat{\mathbf{F}}\,|\phi\rangle = \prod_{i<j}^{A} \hat{f}_{ij}\,|\phi\rangle$$

where $\hat{f}_{ij}$ is the state-dependent correlation operator

$$\hat{f}_{ij} = \sum_n f^{(n)}(r_{ij})\,\hat{\mathbf{O}}^{(\mathbf{n})}_{\mathbf{ij}}$$

and ϕ is a shell model, Slater determinant wave function.

- A proper cluster expansion for a given operator $\hat{O}$

$$\langle\hat{O}\rangle = \frac{\langle\Psi|\,\hat{O}\,|\Psi\rangle}{\langle\Psi|\Psi\rangle} = \frac{\langle\phi|\,\hat{\mathbf{F}}^{\dagger}\hat{O}\,\hat{\mathbf{F}}\,|\phi\rangle}{\langle\phi|\hat{\mathbf{F}}^{\dagger}\hat{\mathbf{F}}|\phi\rangle}\;;$$

has been developed;

- expanding

$$\hat{\mathbf{F}} = \prod_{i<j}\hat{f}^{\,2}(ij) = \prod_{i<j}\Big(1+\hat{\eta}(ij)\Big) = 1+\sum_{i<j}\hat{\eta}(ij)+\sum_{ij<lk}\hat{\eta}(ij)\hat{\eta}(lk)+\ldots$$

where $\hat{\eta}(ij) = \hat{f}^2(ij)-1$;one obtains for $\langle\hat{O}\rangle$, up to second order in $\hat{\eta}$:

$$\mathcal{O}_0 \equiv \langle\hat{O}\rangle\,, \qquad \mathcal{O}_1 = \langle\sum_{ij}\hat{\eta}_{ij}\,\hat{O}\rangle - \mathcal{O}_0\,\langle\sum_{ij}\hat{\eta}_{ij}\rangle\,,$$

$$\mathcal{O}_2 = \langle\sum_{ij<kl}\hat{\eta}_{ij}\,\hat{\eta}_{kl}\,\hat{O}\rangle - \langle\sum_{ij}\hat{\eta}_{ij}\,\hat{O}\rangle\,\langle\sum_{ij}\hat{\eta}_{ij}\rangle$$

$$-\,\mathcal{O}_0\left(\langle\sum_{ij<kl}\hat{\eta}_{ij}\,\hat{\eta}_{kl}\rangle - \langle\sum_{ij}\hat{\eta}_{ij}\rangle^2\right)\;;$$

where

$$\langle\ldots\rangle \equiv \langle\phi|\ldots|\phi\rangle\,.$$

is the expectation value over the shell model wave function.

1.1 - THE GROUND STATE ENERGY

- The expectation value of the many-body hamiltonian

$$\hat{H} = \hat{T}+\hat{V} = -\frac{\hbar^2}{2\,m}\sum_{i=1}^{A}\hat{\nabla}_i^2 + \frac{1}{2}\sum_{i<j}\hat{v}_{ij}$$

is obtained by means of the *one-body mixed* and *two-body* density matrices:

$$\langle\hat{H}\rangle = -\frac{\hbar^2}{2\,m}\int d\boldsymbol{r}\left[\hat{\nabla}^2\rho^{(1)}(\boldsymbol{r},\boldsymbol{r}')\right]_{\boldsymbol{r}=\boldsymbol{r}'} + \sum_n\int d\boldsymbol{r}_1 d\boldsymbol{r}_2\,\hat{v}^{(n)}\rho^{(2)}_{(n)}(\boldsymbol{r}_1,\boldsymbol{r}_2)$$

where the index n denotes the corresponding operator of the realistic potential:

$$\hat{V} = \frac{1}{2}\sum_{i<j}\hat{v}(ij) = \frac{1}{2}\sum_{i<j}\sum_n v^{(n)}(r_{ij})\,\hat{\mathbf{O}}^{(\mathbf{n})}_{\mathbf{ij}}$$

V8′ benchmark calculation

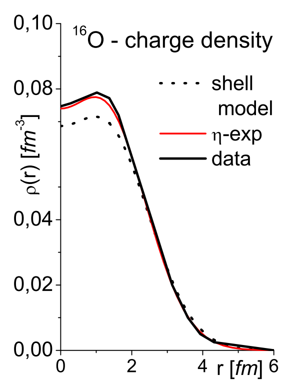
approach		⟨V⟩	⟨T⟩	E	E/A
η-exp (*this work*)	Ref. [1]	-389.40	323.50	-65.90	-4.12
FHNC/SOC	Ref. [3]	-390.30	325.18	-65.12	-4.07

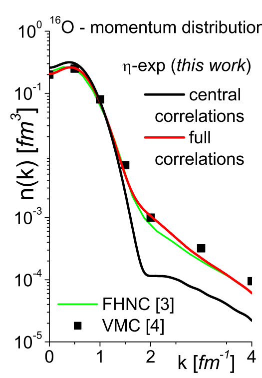
1.2 - DENSITIES & MOMENTUM DISTRIBUTIONS

- Using the *Argonne V8′* two-body interaction and the correlation functions from

Phys. Rev. **C61** (2001) [3]

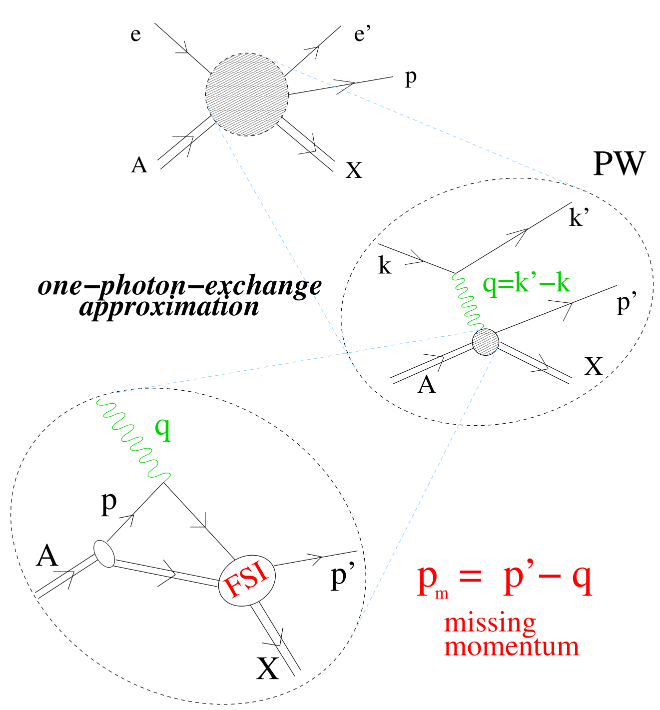
we have calculated the binding energy, momentum distributions, charge densities and mean radii of light and medium-weight nuclei, finding good agreement with experimental data.





2 - FINAL STATE INTERACTION IN THE A(e,e′p)X PROCESS

- the PWIA picture is invalidated by the *final state interaction* (FSI), which takes place after the quasi-elastic *e*-*p* scattering:



2.1 - *FSI*: DISTORTED MOMENTUM DISTRIBUTION

- within the factorization approximation, the cross section for the process $A(e,e'p)X$ reads as follows:

$$\frac{d\sigma}{dQ^2\,d\nu\,d\boldsymbol{p}'} = K\,\sigma_{ep}\,P_D(E_m,\boldsymbol{p}_m)\,,\qquad \boldsymbol{p}_m = \boldsymbol{p}'-\boldsymbol{q}\;;$$

- the distorted nucleon *spectral function* can be expressed as

$$P_D \propto \sum_f\left|\langle\boldsymbol{p}_m\,S\,\psi_f^{A-1}\,|\psi_o^A\rangle\right|^2\delta(E_m-E)$$

where $E = E_{A-1}-E_A$ and S takes FSI into account; summing over the final states:

$$\sum_f|\psi_f^{A-1}\rangle\langle\psi_f^{A-1}| = 1\,,$$

one obtains the distorted momentum distribution:

$$n_D(\boldsymbol{p}_m) = n_D(p_m,\theta) = \int d\boldsymbol{r}d\boldsymbol{r}'\,e^{i\boldsymbol{p}_m\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho_D(\boldsymbol{r},\boldsymbol{r}')$$

- let us define the *transparency* as the ratio:

$$T(p_m,\theta) = n_D(p_m,\theta)/n(p_m)$$

2.2 - *FSI*: GLAUBER APPROACH

- in the Glauber *multiple scattering* approach, S reads:

$$S \longrightarrow S_G = \prod_{i<j}G(ij) = \prod_{i<j}\left(1-\theta(z_j-z_i)\Gamma(\boldsymbol{b}_i-\boldsymbol{b}_j)\right)\;;$$

- the function $\Gamma(\boldsymbol{b}) = \frac{\sigma_{tot}}{4\pi B}(1-i\,\alpha)e^{-\boldsymbol{b}^2/2B^2}$ describes the p-N scattering.
- The distorted one-body mixed density matrix is obtained by cluster expanding

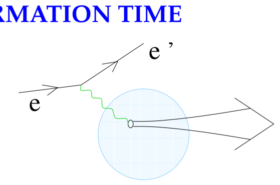
$$\rho_D(\boldsymbol{r},\boldsymbol{r}') = \frac{\langle\phi|\,\hat{\mathbf{F}}^{\dagger}\,S^{\dagger}\,\hat{\rho}(\boldsymbol{r},\boldsymbol{r}')\,S\,\hat{\mathbf{F}}\,|\phi\rangle}{\langle\phi|\,\hat{\mathbf{F}}^{\dagger}\,\hat{\mathbf{F}}\,|\phi\rangle}\,.$$

The distorted momentum distribution is then obtained:

$$n_D(\boldsymbol{p}_m) = \int d\boldsymbol{r}d\boldsymbol{r}'\,e^{i\boldsymbol{p}_m\cdot(\boldsymbol{r}-\boldsymbol{r}')}\rho_D(\boldsymbol{r},\boldsymbol{r}')\;;$$

2.3 - *FSI*: FINITE FORMATION TIME

- we take into account the evolution *inside* the nucleus of a point-like, colorless objet hit by the virtual photon into the observed, physical proton: the *FSI* is **strongly reduced**

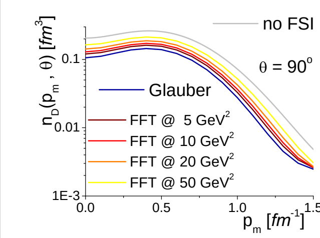


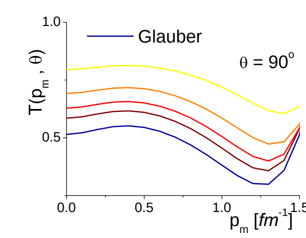
$$S \longrightarrow S_{FFT} = \prod_{i<j}J(ij) = \prod_{i<j}\left(1-\theta(z_j-z_i)\left(1-e^{-x\frac{mM^{\star}}{Q^2}z}\right)\Gamma(\boldsymbol{b}_i-\boldsymbol{b}_j)\right)\;;$$

- with $x \equiv x_{Bj} = Q^2/2m\nu = 1$; one has:

$$Q^2 >> m\,M^{\star}x \longrightarrow \textbf{NO FSI}$$

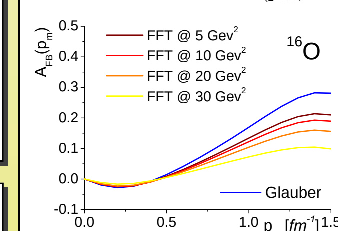
2.4 - THE NON-INTEGRATED NUCLEAR TRANSPARENCY

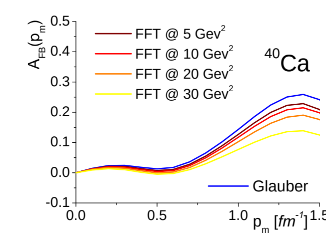




2.5 - FORWARD/BACKWARD ASYMMETRY IN $A(e,e'p)X$

$$A_{FB} = \frac{\sigma(p_m,\theta=0^o)-\sigma(p_m,\theta=180^o)}{\sigma(p_m,\theta=0^o)+\sigma(p_m,\theta=180^o)}$$





- with the inclusion of FFT effect the un-distorted momentum distribution can be recovered, provided Q^2 is sufficiently high, although no experimental data at the necessary Q^2 exist

CONCLUSIONS

- We have developed a linked cluster expansion to calculate the ground state properties of complex nuclei
- the binding energy, densities and momentum distributions have been obtained for ^{16}O and ^{40}Ca
- the cluster expansion has been generalized to take account of the final state interactions in A(e,e'p)X by the Glauber multiple scattering approach
- we can calculate by this procedure the distorted momentum distributions and nuclear transparency for complex nuclei in the Glauber multiple scattering approximation *and* in the Finite Formation Time approach, which is an implementation of the QCD effect called **Color Transparency**

References

[1] M.Alvioli, C.Ciofi degli Atti, H.Morita *(in preparation)*

[2] M.Alvioli, C.Ciofi degli Atti, H.Morita *Fizica* **B13** (2004) *(in press)*

[3] A.Fabrocini, G.Co', *Phys. Rev.* **C61**, 044302 (2000) and *private communication*;

[4] S.Pieper, R.B.Wiringa, V.R.Pandharipande, *Phys. Rev.* **C46**, 1741 (1992);

[5] C.Ciofi degli Atti, D.Treleani *Phys. Rev.* **C60**, 024602 (1999);

[6] M.A.Braun, C.Ciofi degli Atti, D.Treleani, *Phys. Rev.* **C62**, 034606 (2000);

[7] H.Morita, M.A.Braun, C.Ciofi degli Atti, D.Treleani *Nucl. Phys.* **A699**, 328c-331c (2002);

[8] M.Alvioli, **PhD Thesis**, *University of Perugia* (2003)