Jefferson Lab
Proposal Cover Sheet (Generic)

Experimental Hall: ____________

Days Requested for Approval: ________

Submission Date: 5/24/94

Other: PAC 8

☐ New Proposal Title:

☒ Update Experiment Number: 89-046

☐ Letter-of-Intent Title:

(Choose one)

Proposal Physics Goals

Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

Contact Person

Name: B. Frois

Institution: DAPNIA/SPhN

Address: BAT 703 RM 106

Address: CEN SACLAY

City, State, ZIP/Country: 91191 Gif-sur-Yvette France

Phone: b.frois@cea.fr Fax: 011-331-69-087584

E-Mail:

Jefferson Lab Use Only

Receipt Date: 5/94 PR 94-029

By: ____________

Study of Quasi-Particle Orbits in Closed Shell Nuclei with (e,e'p)

L.S. Cardman, J. Gomez, J. LeRose, R. Michaels, S. Nanda, A. Saha
CEBAF, Newport News, Virginia
M.K. Brussel, R. Laszewski, C.N. Papanicolas, S.E. Williamson
University of Illinois at Urbana Champaign, Champaign, Illinois
R. Deleo
INFN-Bari, Italy
A. Leone, R. Perrino
INFN-Lecce, Italy
O. Benhar, E. Cisbani, F. Garibaldi, S. Frullani, M. Iodice, G. M. Murciuli
INFN-Sezione Sanita, Rome, Italy
E.A.J.M. Offerman
University of Mainz, Germany
H. Blok, C.W. de Jager, L. Lapikas, G. van der Steenhoven,
H. de Vries, P.K.A. de Witt Huberts
NIKHEF-K, Amsterdam, The Netherlands
A. Fabrocini
University of Pisa, Italy
J.E. Ducret, B. Frois, J.M. Le Goff, A. Magnon, C. Marchand,
J. Mougey, S.K. Platchkov, S. Kerhoas, P. Vernin
DAPNIA, Centre d'Etudes de Saclay, Gif sur Yvette, France.
S. Fantoni
Interdisciplinary Laboratory for Advanced Studies, Trieste, Italy
R. Lourie
University of Virginia, Charlottesville, Virginia

May 24, 1994

EXPERIMENT PR-89-046

"Study of quasi-particle orbits in closed-shell nuclei with $(e, e'p)$"

Collaboration: CEBAF, Illinois, INFN, Mainz, NIKHEF-K,
Pisa, Saclay, Trieste, Virginia.

Spokespersons: B. Frois (Contact), L. Lapikas, S. Nanda, C. N. Papanicolas.

SUMMARY

The goal of this experiment is to study the high momentum components of quasiparticle orbits in heavy nuclei with the $(e, e'p)$ reaction. If successful, this experiment will provide the first determination for the shape of a quasiparticle orbit in a quantum liquid. Knowledge of this shape will provide a detailed test of microscopic many body theory and the effect of nucleon-nucleon correlations.

The results of the $(e, e'p)$ experiments carried out thus far at Saclay and NIKHEF with 1% duty factor beams have shown that, up to the Fermi momentum ($k_F = 250$ MeV/c), mean-field theory reproduces the shape of momentum distributions of transitions to valence states in medium and heavy nuclei quite well. However, the amplitude of these distributions indicates a sizable depletion of the strength compared to the mean-field values. The origin of this depopulation is attributed to nucleon-nucleon correlations not accounted for in the mean-field theory. The present proposal seeks to measure these components in the momentum region between k_F and $2k_F$ for the doubly closed- shell nuclei ^{40}Ca, ^{90}Zr and ^{208}Pb. These measurements require the measurement of small cross sections and need a good separation of valence orbits. The most stringent requirements are for the $^{208}\mathrm{Pb}(e, e'p)$ reaction where one needs a missing mass resolution of 0.35 MeV to separate the $3s_{1/2}$ and $2d_{3/2}$ shells. The experiments recently performed at NIKHEF indicate that about 200 keV is necessary, thus, the high performances of the hall A spectrometers are imperative.

The kinematics of the experiment is chosen such that the high resolution can be achieved, while the count rate is optimized by going to very forward electron angles. Typical electron spectrometer angles are in the range of $10 \div 40°$. and beam energies of $1 \div 2$ GeV will be needed. The count rate expected is $1 \div 100$ event/h in a 100 MeV/c missing-momentum bin. Several kinematical arrangements will be used to study the effect of final state interactions studied and the Q^2-dependence of the reaction. Longitudinal and transverse structure functions will be separated. The study of proton knockout from the deep lying orbitals is included in the proposed measurements since the missing-energy acceptance of the set-up is about 100 MeV.

The commissioning phase and the detailed beam time request will be determined with the Hall A collaboration. Extensive studies will be pursued with the Hall-A collaboration to establish the required spectrometer optical properties. About 250 hours will be needed to calibrate the apparatus and to perform the first part of the measurements on ^{40}Ca. The proposed measurements on ^{208}Pb will require 420 hours when the performances of the Hall A experimental set-up have reached their design goals.

1 THEORETICAL UPDATE

Correlated Basis Function (CBF) theory and Fermi HyperNetted Chain (FHNC) technique of correlated nuclear matter (NM) has been generalized to perform ab–initio calculations on complex nuclei [?, ?].

The CBF theory is based on a set of correlated A-body wave functions

$$\Psi_n(1,2...A) = F(1,2..A)\Phi_n(1,2...A), \tag{1}$$

where $\Phi_n(1,2...A)$ is the generic mean field state, $F(1,2...A)$ is an A-body correlation operator acting on Φ_n. A correlation operator which has been found to properly take into account the correlations induced by realistic nuclear interactions, has the following form:

$$F(1,...,A) = \prod_{i<j} f(r_{ij})\mathcal{S}[\prod_{i<j} f_{SD}(i,j)]. \tag{2}$$

In the above equation $f(r_{ij})$ is a scalar two-body correlation function depending on the interparticle distance r_{ij} only (Jastrow factor) and $\mathcal{S}$ is the symmetrizer of the product of the state dependent correlation factors $f_{SD}(i,j)$ given by

$$f(r_{ij})f_{SD}(i,j) = 1 + \sum_{n=1} \mathcal{F}^{(n)}(r_{ij})O^{(n)}(i,j). \tag{3}$$

We have for the scalar component $\mathcal{F}^{(n=1)}(r_{ij})= f(r_{ij})-1$. The operators $O^{(n)}(i,j)$ include the central components $(n = 1,4)$,$(1,\ \vec{\sigma}_i \cdot \vec{\sigma}_j,\ \vec{\tau}_i \cdot \vec{\tau}_j,\ \vec{\sigma}_i \cdot \vec{\sigma}_j\vec{\tau}_i \cdot \vec{\tau}_j)$, both the isoscalar and isovector tensor $(n = 5,6)$ and the spin-orbit $(n = 7,8)$ components. The functions $f(r)$ and $\mathcal{F}^{(n)}(r)$ depend upon several variational parameters fixed by minimizing the ground state expectation value of the hamiltonian, $< H >$. For $A \leq 6$ nuclei, $< H >$ and other quantities of interest may be calculated using Monte Carlo techniques to sample the necessary many-body integrals. This is not feasible in larger nuclei and in nuclear matter. In this last system, FHNC theory has been successfully applied [?, ?].

We have explicitly solved the FHNC equations in doubly closed shell nuclei, for semirealistic interactions (without tensor components) and Jastrow correlations. In such nuclei the energy per particle and the momentum distribution have been computed [?, ?] and the accuracy of the method has been satisfactorily verified against variational MonteCarlo calculations, when available.

At present, we are extending the FHNC technique *i)* to deal with the full correlation operator of Eq. ?? and *ii)* to treat nuclei with N≠Z. We plan to have results, in particular for the last case, within the current year.

The FHNC scheme has been recast in a form which makes use of analogous NM quantities, at different densities, in the spirit of the Local Density Approximation (LDA). This scheme, called FHNC/LD, has the property of converging to the exact solution in a very few iterations, particularly for large nuclei [?]. FHNC/LD has been checked with the exact FHNC solutions for the above mentioned model nuclei; it has been also used, at its lowest order, with the realistic correlation of Eq. ?? to compute the momentum distribution in ^{16}O and ^{40}Ca. We are presently calculating the energy per particle of medium–heavy nuclei, up to ^{208}Pb, natural orbits and single particle orbitals.

We have compared our results to the predictions of the Independent Particle Model (IPM) estimates, Jastrow correlations and for ^{16}O to the Monte Carlo results of ref. [?]. The Jastrow correlations enhance the momentum distribution at large momenta, with respect to IPM. A further enhancement is provided by the operatorial part of the correlation operator. We find in particular for ^{16}O that an impressive agreement between the FHNC/LD and Monte Carlo predictions.

The experiment proposed here would be an ideal way to check the validity of the description of correlations by modern calculations.

2 EXPERIMENTAL UPDATE

Since the time when this proposal was originally submitted (1989) several CW electron scattering facilities have become available. With the CW beam from the Amsterdam Pulse Stretcher (AmPS) at NIKHEF the first pioneering measurements were performed of high momentum components in the reaction ^{208}Pb$(e, e'p)^{207}$Tl. In the experiment a 488 MeV electron beam ($I = 2\mu$A, duty factor $\simeq$ 50on a water-cooled two-foil ^{208}Pb target 2×42 mg/cm^2 thick. The scattered electrons were detected at forward angle 25.5° and knocked-out 100 MeV protons at backward angles. The two-foil technique allowed to increase the luminosity, while simultaneously the high missing energy resolution ($FWHM$ = 180 keV) could be preserved and accidental coincidences could be further suppressed.

In a preliminary analysis momentum distributions were deduced in the range p_m = $300 \div 500$ MeV/c for the transitions to the first four excited states in ^{207}Tl. There are in particular new data for the $3s_{1/2}$ and $2d_{3/2}$ proton knock-out to the ground-state doublet ($E_x = 0$ and 0.35 MeV). In the final analysis the separate contributions from the two transitions will be resolved. The new NIKHEF data indicate the sensitivity of the momentum distribution at large p_m to different theoretical hypotheses on the effect of correlations. They confirm the estimated values for the momentum distributions used to compute the count rate predictions given in the original proposal. They allow us to conclude that with with the luminosity and kinematic flexibility available in Hall A, it will be possible to probe the momentum distributions to even larger p_m with high statistics and to separate their longitudinal and transverse components. This longitudinal/transverse separation is the fundamental breakthrough possible only at CEBAF. At such high values of the nucleon momentum, various effects, final-state interactions and meson exchanges might also contribute. Such processes will contribute in a different way in the longitudinal and transverse response functions and thus can be separated. In particular the effect of meson-exchange currents is expected to be large in the transverse response while in the longitudinal one they are expected to be small.

2.1 Data taking

Data will be taken mostly at high missing momentum ($P_m > 250$ MeV/c). completing the data already available [?, ?]; additional low P_m data can be collected at CEBAF in a very short amount of time. In order to perform a "model-independent" analysis of the measured momentum distributions (to arrive at a reliable quasi-particle orbital reconstruction in the nuclear interior) the region between $P_m = 300$ and 400 MeV/c is indispensable. For the study of correlations one wants to go as high as 500 MeV/c. Based on experience with the NIKHEF machine (duty factor = 1 %, $E_{max} = 500$ MeV) we know that data at $P_m = 300$ MeV/c are just measurable for an energy resolution of 100 keV and a timing resolution of 1 ns with real accidental ratio smaller than 1. Since the momentum distribution drops two orders of magnitude between 300 and 500 MeV/c, good energy resolution and timing resolution (and therefore accurate flight-path reconstruction) will be needed in addition to 100% duty factor.

3 BEAM TIME REQUEST

We base our beam time request for the measurements at high P_m ($300 \div 500$ MeV/c) on a statistics of 100 counts per 25 MeV/c P_m bin. The study of the final state interactions requires a similar amount of beam time for each different T_p. The low P_m data can easily be obtained with an accuracy of < 5 %. The L/T separation requires a large amount of beam time due to the low count rates in the "transverse" kinematics. In summary we request a total of 420 hours of beam time for the first studies on ^{208}Pb. This time will be spent as detailed in Table ??. Studies of the requirements for extending this work to ^{40}Ca and ^{90}Zr will be presented at a later time.

Configuration	E_0 MeV	p_m-range MeV/c	beam time hours
Parallel	750	$0 \div 300$	30
Antiparallel	2000	$-250 \div 0$	50
High P_m	750	$300 \div 500$	70
FSI	750	$300 \div 500$	70
L/T separation	500	$300 \div 500$	200
Total			420

Table 1: Summary of the beam-time request for ^{208}Pb(e,e'p)^{207}TI.

The proposed measurements on ^{208}Pb require 420 hours. It is anticipated that at least another 250 hours will be needed to commission the dispersion matching and to perform the first part of the measurements on ^{40}Ca. The commissioning phase and the beam time request will be determined with the Hall A collaboration at the time of the installation of the Hall-A spectrometers and of the dispersion matching system.

4 CONTRIBUTION TO THE HALL A INSTRUMENTATION

A collaboration between Saclay and INFN has taken the responsibility for the design and the construction of two gas Cherenkov counters for the Hall A magnetic spectrometers. These counters are being built and will be assembled in may 1994. The counters will first be tested with sources. The response to electrons, pions and kaons will be studied in june and september 1994 at CERN. Transport to CEBAF is foreseen in 1995.

The INFN group in collaboration with the University of Regina has designed two aerogel Cherenkov counters. Prototypes of these counters have been tested succesfully at the Saskatchewan electron facility (SAL).

A precise measurement of the beam energy is imperative for the longitudinal transverse separation of the $(e, e'p)$ cross sections. The Saclay group has accepted the responsibility for the development and the construction of the apparatus necessary for this measurement.

Our collaboration will participate in the commissioning of the Hall A detectors and spectrometers.

References

[Be94] A.Belic, O.Benhar, A.Fabrocini and S.Fantoni, in preparation.

[Co92] G.Co, A.Fabrocini, S.Fantoni and I.E.Lagaris, Nucl. Phys. **A549**(1992)439.

[Co94] G.Co, A.Fabrocini and S.Fantoni, Nucl. Phys. **A586**(1994)73.

[La92] L. Lapikas, Proceedings of the International Conference on Nuclear Physics, Wiesbaden 1992.

[PW79] V.R.Pandharipande and R.B.Wiringa, Rev.Mod.Phys. **51**(1979)821.

[PWP92] S.C.Pieper,R.B.Wiringa and V.R.Pandharipande, Phys.Rev. **C46**(1992)1741.

[Qu86] Quint E.N.M., van den Brand J.F.J., den Herder J.W.A., Jans E., Keizer P.H.M., Lapikás L., van der Steenhoven G., de Witt Huberts P.K.A., Klein S., Grabmayr P., Wagner G.J., Nann H., Frois B. and Goutte D., *Phys. Rev. Lett.* **57** (1986) 186.

[Qu87] Quint E.N.M., Barnett B., van den Berg A.M., van den Brand J.F.J., Clement H., Ent R., Frois B. and Goutte D., Grabmayr P., den Herder J.W.A., Jans E., Lanen J.B.J.M., Lapikás L., Nann H., van der Steenhoven G., Wagner G.J., de Witt Huberts P.K.A., *Phys. Rev. Lett.* **58** (1987) 50

[Ro82] S.Rosati, in "From nuclei to particles", Proc.Int.School E.Fermi, course LXXIX, ed. A. Molinari (North Holland, Amsterdam, 1982).