RAPID COMMUNICATIONS

PHYSICAL REVIEW C, VOLUME 63, 051303(R)

Corrections to the one-photon approximation in the $0^+ \rightarrow 2^+$ transition of ^{12}C

P. Guèye,* M. Bernheim, J. F. Danel, J. E. Ducret, L. Lakéhal-Ayat, J. M. Le Goff, A. Magnon, C. Marchand,
J. Morgenstern, J. Marroncle, P. Vernin, and A. Zghiche-Lakéhal-Ayat†
DAPNIA, Service de Physique Nucléaire, CEA-Saclay, F-91191 Gif-Sur-Yvette Cedex, France

V. Breton
Laboratoire de Physique Corpusculaire, Université Blaise Pascal, Institut de Physique Nucléaire et de Physique des Particules,
F-63177 Aubière Cedex, France

S. Frullani, F. Garibaldi, F. Ghio, and M. Jodice
Laboratorio di Fisica, Istituto Superiore di Sanità e Istituto di Fisica Nucleare, Sezione Sanità, I-00161 Roma, Italy

Z. E. Meziani
Department of Physics, Temple University, Philadelphia, Pennsylvania 19122

E. Offermann‡
Thomas Jefferson National Accelerator Facility (TJNAF), 12000 Jefferson Avenue, Newport News, Virginia 23606

M. Traini
Dipartimento di Fisica, Università degli Studi di Trento, I-38050 Povo (Trento), Italy
and INFN, G.C. Trento, Italy

(Received 1 November 2000; published 18 April 2001)

Contribution of higher order effects to the one-photon exchange approximation were studied in the first excited state of ^{12}C by comparing inclusive inelastic scattering cross sections of electrons and positrons obtained at the Saclay Linear Accelerator. The data were compared to a distorted wave Born approximation (DWBA) calculation. The results indicate an effect less than 2% within 2σ, compatible with what was observed in recent elastic scattering measurements.

DOI: 10.1103/PhysRevC.63.051303 PACS number(s): 25.30.Hm, 24.10.Ht, 27.20.+n

Comparison between electron and positron elastic cross sections is known to be a powerful tool for obtaining information on the contribution of higher order effects to the one-photon exchange diagram (Coulomb corrections, dispersive effects, . . .). For the study of dispersive effects, one has to use light nuclei because Coulomb corrections become comparably very large for high-Z nuclei and collect the data in the minima of form factor [1,2]. Several experiments on electron and positron scattering [3–9] have confirmed the predicted contributions of these effects [10–12], although their energy dependence is still not very well understood [13].

Experimental data are usually analyzed within the Born approximation, which provides a useful framework to discuss the different aspects of the electron-nucleus interaction. For inelastic or heavy nuclei, the distorted wave Born approximation (DWBA) replaces the first-order plane wave Born approximation (PWBA) diagram where only one hard virtual photon is exchanged between the incident probe and the target.

This Rapid Communication reports on the first experimental measurements performed in the four-momentum range, $0.95 < q_{eff}$ (fm^{-1})<1.66 for the $0^+ \rightarrow 2^+$ transition of ^{12}C located 4.43 MeV from the ground state.

This experiment was performed at the 700 MeV Saclay Linear Accelerator (ALS), which can provide a 30 nA positron beam with energies up to 600 MeV and a $\Delta E/E$ of 2×10^{-3}. The scattered particles were detected in the HE1 (electron-positron) hall and analyzed by the 900 magnetic spectrometer (SP900) described in [14] (momentum resolution $\Delta P/P_0 = 2 \times 10^{-4}$, maximum momentum of 900 MeV/c) equipped with a detector package consisting of (i) two planes (R,Y) of plastic scintillators, (ii) a Čerenkov counter (C) filled with freon gas (index $n = 1.0013$) corresponding to electron and pion thresholds of 10 MeV/c and 2.7 GeV/c, respectively, and (iii) two planes of drift chambers, both with horizontal and slanted wires for track reconstruction. The trigger was given by an RYC coincidence signal eliminating pions. The other spectrometer (SP600) [14] was positioned at 45° with respect to the beam direction and used as a luminosity monitor. The fluctuation of the SP600 monitoring was found to be of the order of 1%, and all the

---

*Present address: Hampton University, Nuclear High Energy Research Physics Center, Hampton, VA 23606.

†Present address: Center de Recherches Nucléaires Cronenbourg, F-67037 Strasbourg Cédex, France.

‡Present address: Renaissance Technologies Corp., 600 Rt. 25A, East Setauket, NY 11733.

runs agree within less than one standard deviation. Three different target thicknesses (30×50 mm^2 plane foils) of natural carbon were used: 96, 296, and 500 mg/cm^2. Uniform beam illumination of the targets was achieved through their rastering. The uncertainty on the target thickness was 1%.

The positron beam was created by interaction of a 100 MeV electron beam on a 2 mm tungsten radiator located between the 6 and 7 sections of the accelerator. Its emittance is 6 times larger than the emittance of the direct electron beam. In order to minimize systematic effects, the emittance of the electron beam was degraded by installing a 17 μm aluminum foil after the last section of the accelerator. The emittance of both beams ($\sim 2\pi$ mm mrad) was defined by the same mechanical slit system, and we monitored the beam emittance during the experiment by measuring the beam profiles using a pair of highly sensitive scanning wire systems. The first one located about 2 m upstream of the target was made out of two perpendicular 300 μm copper wires mounted on a fork. Via secondary emitted electrons, the beam horizontal and vertical profiles were reconstructed with an accuracy of 0.5 mm. The second monitor was located 7.8 m downstream of the target in front of the Faraday cup. A 16×16 array of 300 μm copper wires was used to measure the beam profile with an accuracy of 1 mm.

We found that, due to misalignment in the beam tuning, our beam spots were positioned about 5 mm under the intersection of the line defined by the center of rotation of the spectrometer and the central ray of the spectrometer collimator. This brings a correction of 0.5% on the solid angle for both spectrometers and 6×10^{-4} on the momentum reconstructed in the electron spectrometer.

Special care was taken to measure the small ($\simeq 30$ nA) beam current. The Faraday cup used was drained and dried prior to the experiment which reduced its leakage current to $\simeq 30$ pA. A ferrite-core induction monitor located upstream of the target provided a redundant charge determination. The charge measurements of the Faraday cup and the ferrite-core monitor were in agreement within 2%.

Electron and positron cross sections were measured for a q_{eff} range from 1.14 fm^{-1} to 1.66 fm^{-1} at 450 MeV incident energy, and from 0.95 fm^{-1} to 1.54 fm^{-1} at 262 MeV. The scattering angles covered a region from 29° to 72°. Our experimental cross sections were corrected for dead time which contributes to 11% at 450 MeV and 14% at 262 MeV. Pair annihilation (for positrons) was found to be negligible.

The events in the first excited state peak were corrected from radiative effects by first subtracting the elastic radiative tail underneath the peak and then correcting for the tail that extended to higher energy transfer. We have used the method developed by Mo and Tsai [15,16]: the measured spectra were corrected for Landau straggling, thick target bremsstrahlung, and Schwinger corrections. Coulomb corrections to the radiative corrections were taken into account using the effective momentum approximation (EMA) [1]. The radiative corrections never contribute more than 20% to our elastic cross sections for both electrons and positrons, the subtraction of the elastic tail constitutes a 5% effect, and the correction for the first excited state radiative tail to about 40%. The overall systematic effects were estimated to be about 2%.

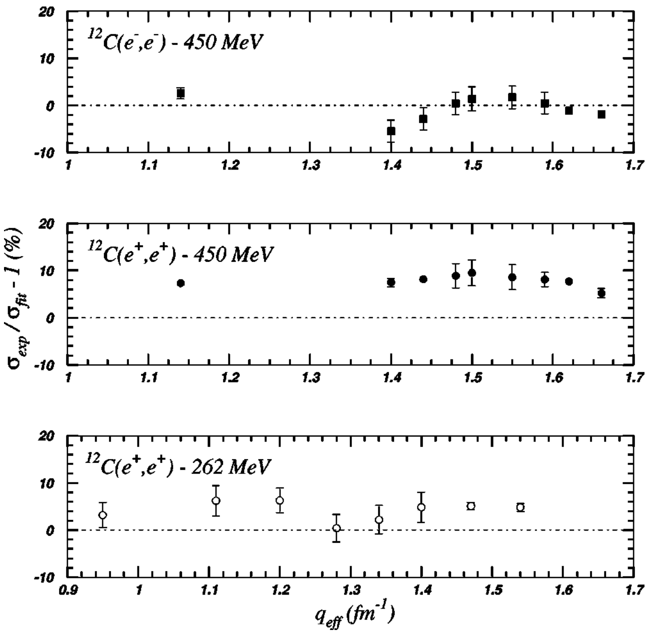

FIG. 1. Comparison between the experimental data of this experiment and the DWBA fit of [17].

After performing the geometrical corrections due to the spectrometer acceptance and including the emittance of the beams, we compared our experimental data to a fit of all known data using a DWBA calculation [17]. A Fourier Bessel parametrization of the static charge density fitted to the data of [5] was used [18].

The extracted $\sigma_{exp}/\sigma_{fit}$ differential cross section ratios are displayed in Fig. 1 for electrons and positrons at 450 MeV (top and middle panels) and for positrons only at 262 MeV (bottom panel). For each energy and each lepton probe, a weighted mean calculation of the data was performed. For the highest energy, the data averaged at $(-0.8\pm0.6)\%$ in electrons, and at $(7.6\pm0.3)\%$ in positrons. For the lowest energy, the positron data averaged around $(4.5\pm0.6)\%$.

As in the elastic data discussed in [13], the measured $\sigma_{exp}/\sigma_{fit}$ ratios of the cross sections in positron for the two incident energies give a difference of $(3.1\pm0.4)\%$, compatible within 2σ with our $(2.5\pm0.1)\%$ elastic ratio.

The difference in the ratios between electrons and positrons is $(8.4\pm6.3)\%$ at 450 MeV. In the q_{eff} range measured in the experiment described here, the inelastic form factor is at its maximum. Therefore, there is a competition between the (dominant) Coulomb effects [proportional to $(\alpha Z)^2$] and the dispersive effects [proportional to (αZ)] effects [13]. Our result is compatible within 2σ with a 2% effect.

We have reported for the first time positron and electron experimental cross sections for the first excited state of ^{12}C in a four-momentum range between 0.95 and 1.66 fm^{-1}. This $0^+\rightarrow2^+$ transition was studied in terms of higher order contribution to the one-photon exchange diagram. The data were accumulated in a region where dispersive effects are expected to be negligible compared to the Coulomb contribution, and analyzed within a DWBA framework.

An energy dependence of about 3% is observed from the data when comparing our lowest (262 MeV) and highest (450 MeV) data in positrons. The results also indicate that Coulomb corrections are compatible with a 2% effect in the first excited state within 2 standard deviations. Both observations are in agreement with an earlier elastic measurement performed in the same q_{eff} range.

---

[1] P. Guèye *et al.*, Phys. Rev. C **60**, 044308 (1999).
[2] J. M. Eisenberg and W. Greiner, *Nuclear Theory* (North Holland, Amsterdam, 1976), Vol. 2.
[3] V. Breton *et al.*, Phys. Rev. Lett. **66**, 572 (1991).
[4] I. Sick and X. McCarthy, Nucl. Phys. **A150**, 631 (1970).
[5] E. A. J. M. Offermann *et al.*, Phys. Rev. C **44**, 1096 (1991); E. A. J. M. Offermann *et al.*, Phys. Rev. Lett. **57**, 1546 (1986).
[6] N. Kalantar-Nayestanaki *et al.*, Phys. Rev. Lett. **63**, 2032 (1989).
[7] N. Voegler *et al.*, Phys. Rev. C **5**, 2172 (1991).
[8] T. de Forest, Jr., Nucl. Phys. **A414**, 347 (1984).
[9] L. S. Cardman *et al.*, Phys. Lett. **91B**, 203 (1980).
[10] J. L. Friar and M. Rosen, Ann. Phys. (N.Y.) **87**, 289 (1974).
[11] E. Borie and D. Drechsel, Phys. Rev. Lett. **26**, 195 (1971).
[12] G. H. Rawitscher, Phys. Rev. **151**, 846 (1966).
[13] P. Guèye *et al.*, Phys. Rev. C **57**, 2107 (1998).
[14] P. Leconte *et al.*, Nucl. Phys. **A401**, 169 (1980).
[15] L. W. Mo and Y. S. Tsai, Rev. Mod. Phys. **41**, 205 (1969).
[16] Y. S. Tsai, Rev. Mod. Phys. **46**, 815 (1974).
[17] J. Heinsenberg, Adv. Nucl. Phys. **12**, 61 (1981).
[18] I. Sick, Nucl. Phys. **A218**, 509 (1974).