targets ($N_h > 7$). (e) Multiplicity (n_s) distributions of all the white stars with $L \leq 2.5$ cm peak at a lower n_s value than for white stars with $L > 2.5$ cm.

In conclusion, our data indicate a diminution in the measured mfp of secondary fragments in the first few centimeters (or $\sim 10^{-11}$ sec) of their path length after their production. The energy of the primary beam plays an important part in the production of anomalous nuclei, as we did not observe any anomalous effect[7] with a ^{56}Fe beam of about 1 GeV/nucleon. In our present investigation, we did not include the PF's of charge 2, i.e., α particles, from the Fe and Ar primary beams which are under investigation for the observation of the anomalous effect. The analysis of the primary stars (interactions) seem to indicate that lighter targets favor the production of abnormal nuclei and these nuclei produce more white stars (interactions) than the regular nuclei. We are continuing our present investigations about the primary and secondary interactions connected with these fragments to understand the origin of the anomalous effect.

We are very grateful to the staff of Bevalac at Lawrence Berkeley Laboratory for their help with the exposure of emulsion stacks. We also thank Dr. M. M. Aggarwal and Dr. K. B. Bhalla for their help in collecting data. This research work was supported in part by Grant No. R01-CA24878 awarded by the National Cancer Institute, U. S. Department of Health, Education, and Welfare, and by the State University of New York Research Foundation.

[1]B. Judek, Can. J. Phys. 46, 343 (1968), and references therein, and 50, 2082 (1974); T. F. Cleghorn *et al.*, Can. J. Phys. Suppl. 46, 572 (1968).

[2]E. M. Friedlander *et al.*, Phys. Rev. Lett. 45, 1084 (1980).

[3]P. L. Jain, G. Das, B. T. Cheng, and Y. Aliakbar, Phys. Lett. 88B, 189 (1979).

[4]P. L. Jain, Nuovo Cimento 13, 839 (1959).

[5]The values of λ_0 and b were found by using the mfp's of four primary beams as a function of Z. These values will depend upon the scanning efficiencies of individual experiments.

[6]P. J. Karol, Phys. Rev. C 11, 1205 (1975). H. L. Bradt and B. Peters, Phys. Rev. 77, 54 (1950).

[7]M. M. Aggarwal, K. B. Bhalla, G. Das, and P. L. Jain, in Proceedings of the Fifth Heavy-Ion Conference, University of California at Berkeley, Berkeley, California, 18–22 May 1981 (to be published).

Bremsstrahlung from ^{12}C + p near the 461-keV Resonance

P. M. S. Lesser, C. C. Trail, C. C. Perng, and M. K. Liou
Department of Physics, Brooklyn College of the City University of New York, Brooklyn, New York 11210
(Received 1 December 1981)

The spectrum of bremsstrahlung radiation emitted by the scattering of protons by ^{12}C near the 461-keV resonance has been studied at bombarding energies 130, 235, and 335 keV above the resonance. The measured spectra were analyzed and compared with the theoretical predictions calculated from the soft-photon approximation and the Feshbach-Yennie approximation.

PACS numbers: 25.40.Ep, 24.30.-v

In an earlier paper[1] we reported good agreement between theory (the Feshbach-Yennie approximation[2]) and experiment for the bremsstrahlung cross sections measured near the 1.7-MeV resonance in the proton-carbon (p-^{12}C) scattering. In this Letter we wish to report our new measurements of the bremsstrahlung cross sections near the 461-keV resonance in the p-^{12}C scattering and to point out some disagreements between the Feshbach-Yennie approximation and the experimental data.

The bremsstrahlung process has attracted much attention during the past two decades not only because it is the ideal process for the study of the off-shell effects[3] but also because it can be used to study the electromagnetic properties of resonant states[4] and nuclear reactions.[5-7] The idea of using bremsstrahlung emission as a tool for investigating nuclear reactions was first proposed by Eisberg, Yennie, and Wilkinson,[5] whose classical treatment of the bremsstrahlung process was extended later to a quantum mechanical treatment by Feshbach and Yennie.[6] The idea works as follows: Given the p-^{12}C γ process near a scattering resonance, for example, one measures the bremsstrahlung cross sections of the process as a function of the photon energy k at an incident scattering energy above the resonance. If this incident energy is very far from the resonance, one obtains a typical bremsstrahlung spectrum with a characteristic $1/k$ dependence since the contribution from the resonance is very small. In the energy region of the resonance, however, the contribution from such effects becomes significant and one expects a resonant structure to appear in the bremsstrahlung spectrum. If the measured spectrum can be completely described by the Feshbach-Yennie approximation, then one can apply this approximation to extract the nuclear reaction time from the data. This useful information about the time delay can be used, for example, to distinguish unambiguously between direct nuclear reactions and compound-nuclear reactions.

However, the applicability of this new technique to the measurement of the short nuclear time delay depends upon the existence of a resonant structure in the bremsstrahlung cross section and upon the validity of the Feshbach-Yennie approximation. Thus, attention has now been focused on the test of the Feshbach-Yennie approximation.

A serious attempt to test the Feshbach-Yennie approximation and to extract important information about the reaction time was made recently by both Maroni, Massa, and Vannini[8] and by Trail and co-workers.[1,2,9] These two groups have carefully measured the proton-carbon bremsstrahlung (p-^{12}C γ) cross sections near the 1.7-MeV resonance. The most important conclusions obtained from these experiments were the following: (i) The structure due to the resonance effects was clearly observed in the measured p-^{12}C γ spectra near 1.7 MeV; (ii) the measured bremsstrahlung spectra with structure were well described by the Feshbach-Yennie approximation, using the results of the elastic scattering amplitudes[10] as input; and (iii) a delay time of the order of 10^{-20} s was extracted from the data. These results provided not only the first experimental test of the Feshbach-Yennie approximation but also the first positive proof that bremsstrahlung process can be used to measure the nuclear time delay.

The levels associated with the 1.7-MeV resonance are two closely spaced levels of $\frac{5}{2}^+$ and $\frac{3}{2}^-$ in the compound nucleus ^{13}N. The structure observed in this energy region is therefore a result of the interference effects between these two levels. Also, there is another excited state ($J^\pi = \frac{1}{2}^+$) of ^{13}N at 461 keV. Since this state is a well-isolated excited state, we expect that the resonant structure that results from this single state can be interpreted theoretically more simply than the results from the double resonant states near 1.7 MeV. Thus the measurement of the bremsstrahlung spectrum near 461 keV can provide not only another sensitive test of the Feshbach-Yennie approximation but also additional data for understanding the effect of a resonance on the bremsstrahlung process.

Our experimental arrangement has been described earlier.[1] Briefly, proton beam currents of typically 400 nA from the Brooklyn College Dynamitron were incident upon a 20-μg/cm^2 carbon target. The scattered protons were stopped by a surface-barrier detector at a laboratory angle of 155°. The bremsstrahlung photons were detected by a NaI(Tl) crystal 76 mm in diameter and 6 mm thick, located 28 mm above and normal to the scattering plane. To increase the rate of our data collection we used two surface-barrier detectors each at ± 155°.

Coincident events between a photon and a scattered proton were identified with a fast-slow coincidence circuit with a time resolution of 8 ns. These events were recorded on a floppy disk by a PDP-11/20 computer. The data were analyzed off-line as described earlier[1] with a suitable correction for the efficiency of the NaI detector, and for the transmission of the detector housing. The detector efficiencies were about 95% at 100 keV, 70% at 200 keV, and 50% at 300 keV. The transmission was 90% at 100 keV, 95% at 200 keV, and 97% at 300 keV.

Our results are shown in Fig. 1. In this figure, the ratio of the p-^{12}C γ cross section to the elastic p-^{12}C scattering cross section,

$$\frac{d^3\sigma}{d\Omega_\gamma\, d\Omega_{p'}\, dK}\left(\frac{d\sigma_{\rm el}}{d\Omega_{p'}}\right)^{-1} \equiv \sigma_{\rm rel}\,,$$

is plotted as a function of the photon energy for three different bombarding energies, 130, 235, and 335 keV above the resonance. The error bars include statistical uncertainties, typically about 30%, and systematic errors, typically about 10%, due to the uncertainties in the detector efficiencies. These cross sections are compared

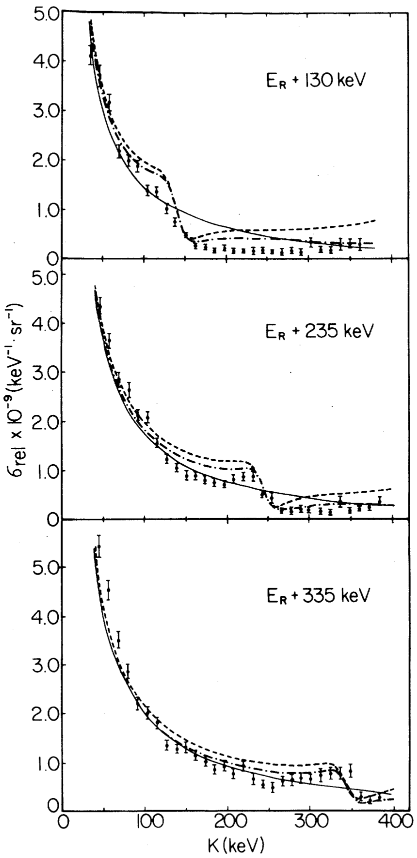

FIG. 1. The bremsstrahlung cross section relative to the elastic scattering cross section. Three sets of data are plotted on the same γ-ray energy scale in order to show the shift of the resonant structure with the incident proton energy. The dashed curves represent the cross section calculated from the full Feshbach-Yennie approximation, which includes both the principal term and the correction term. The dash-dotted curves represent the calculation using the principal term of the Feshbach-Yennie approximation. The solid curves represent the calculation using the leading term of the soft-photon approximation.

with the theoretical predictions calculated from the soft-photon approximation and the Feshbach-Yennie approximation. We point out here that these sets of data at three different bombarding energies are plotted on the same γ-ray energy scale so that the shift of the resonant structure with incident energy can be seen clearly from the figure.

As we can see from Fig. 1, the agreement between the soft-photon approximation and the data is satisfactory at an energy far from the resonant state. In the vicinity of the resonance, however, this approximation fails to predict the structure due to the resonance which is clearly observed in the experiment.

The Feshbach-Yennie approximation, on the other hand, does predict the structure in the energy region of the resonance. However, the calculation using the leading term alone is in better agreement with the experimental data than the full Feshbach-Yennie approximation, which includes both the leading term and the correction term. This result may arise from the following possibilities: (i) The contribution from the higher-order terms of the expansion of the bremsstrahlung cross section (or amplitude) may be important in this particular case because the ratio of the photon energy, k, to the incident proton energy, E_p, is not small for large k ($0.03 \leq k/E_p \leq 0.57$). Unfortunately, there is no way to estimate the contribution from these higher-order terms without use of a model-dependent calculation. (ii) Coulomb effects may be very important in the low-energy region. These effects have not been treated exactly in our calculation. (iii) Photon emission from the resonant state (^{13}N) may be important. Contributions from this kind of emission are not properly treated in either the soft-photon approximation or in the Feshbach-Yennie approximation. (iv) The parameters for the resonant state $J^\pi = \frac{1}{2}^+$, which are the most important parameters used in our calculation, may not be well determined since these parameters were obtained from only one measurement of the scattering cross section at only two angles.[11] We emphasize that in these calculations all parameters used are fixed by the elastic-scattering data.[10,11]

In conclusion, we have verified experimentally the existence of the resonant structure in the p-^{12}C γ spectrum near the 461-keV resonance. The observed structure can be described by the Feshbach-Yennie approximation but the calculation using the leading term of the approximation turns out to be in better agreement with the measurement than the full approximation. This result, which is contrary to our previous p-^{12}C γ case near the 1.7-MeV resonance, strongly suggests that the validity of the Feshbach-Yennie approximation for describing bremsstrahlung emission has as yet not been satisfactorily established, thus warranting further study.

We gratefully acknowledge the assistance given us by Janet Easton who wrote the event-mode listing program and by Don King and Mark Mernyk who operated and maintained the accelerator. This work was supported in part by the U. S. Department of Energy under Contract No. DE-AC02-81ER40023 and by the City University of New York Professional Staff Congress–Board of Higher Education Faculty Research Award Program.

[1]C. C. Trail, P. M. S. Lesser, A. H. Bond, Jr., M. K. Liou, and C. K. Liu, Phys. Rev. C 21, 2131 (1980).

[2]M. K. Liou, C. K. Liu, P. M. S. Lesser, and C. C. Trail, Phys. Rev. C 21, 518 (1980).

[3]M. I. Sobel and A. H. Cromer, Phys. Rev. 132, 2698 (1968). An extensive list of references can be obtained from the following review articles: M. L. Halbert, in *Proceedings of the Gull Lake Symposium on the Two-body Force in Nuclei, Gull Lake, Michigan, 1971*, edited by S. M. Austin and G. M. Crawley (Plenum, New York, 1972); M. J. Moravcsik, Rep. Prog. Phys. 35, 587 (1972); E. M. Nyman, Phys. Rep. 9, 179 (1974).

[4]S. Barshay and T. Yao, Phys. Rev. 171, 1708 (1968); Nyman, Ref. 3; B. M. K. Nefkens *et al.*, Phys. Rev. D 18, 3911 (1978), and references therein.

[5]R. M. Eisberg, D. R. Yennie, and D. H. Wilkinson, Nucl. Phys. 18, 338 (1960).

[6]H. Feshbach and D. R. Yennie, Nucl. Phys. 37, 150 (1962).

[7] F. Janouch and R. Mach, Nucl. Phys. A158, 193 (1970); A. M. Green, in *Proceedings of the International Conference on Few-Body Problems in Nuclear and Particle Physics, Laval University, Quebec City, Canada, 1974*, edited by R. J. Slobodrian, B. Cujec, and K. Ramavataram (Les Presses de l'Université Laval, Quebec, 1975).

[8]C. Maroni, I. Massa, and G. Vannini, Nucl. Phys. A273, 429 (1976), and references therein.

[9]C. K. Liu, M. K. Liou, C. C. Trail, and P. M. S. Lesser, to be published.

[10]J. C. Armstrong, M. J. Baggett, W. R. Harris, and V. A. Latonne, Phys. Rev. 144, 823 (1966).

[11]H. L. Jackson and A. I. Galonsky, Phys. Rev. 89, 370 (1953); H. L. Jackson, A. I. Galonsky, F. J. Eppling, R. W. Hill, E. Goldberg, and J. R. Cameron, Phys. Rev. 89, 365 (1953).

Search for Dibaryon Signals by the Measurement of the Tensor Polarization t_{20} in π-d_{pol} Scattering

J. Ulbricht, V. König, W. Grüebler, P. A. Schmelzbach, B. Jenny, F. Sperisen, K. Elsener, and C. Schweizer

Laboratorium für Kernphysik der Eidgenössische Technische Hochschule, CH-8093 Zürich, Switzerland

and

A. Chisholm

Physics Department, University of Auckland, Auckland 1, New Zealand

(Received 5 November 1981)

The angular distribution of the tensor polarization t_{20} in π-d_{pol} elastic scattering has been measured in the backward angular region at an incident pion energy of 138 MeV. Large oscillations have been found which are in disagreement with all theoretical calculations even when effects of the presently suggested dibaryon resonances with the assumed standard parameters are explicitly included.

PACS numbers: 24.70.+s, 13.75.Gx, 21.30.+y, 25.80.+f

For more than a decade polarization effects in π-d elastic scattering have been the subject of an intense theoretical investigation. While in the earlier calculation the interest was focused mainly on the two-nucleon interaction and the sensitivity of particular details of this fundamental force, such as the D-state probability of the deuteron,[1-4] recently the interest has been directed mainly toward the absorption process of a pion by the two nucleons and possible dibaryon resonances in this system. The first theoretical calculations of polarization observables used multiple-scattering theory[1]; at present the theoretical studies have reached a high level of sophistication, incorporating complex nucleon-nucleon interactions in relativistic three-body Faddeev-type calculations. As long as only the simple three-body problem is treated the results of all these calculations are fairly similar for the tensor polarization t_{20} at backward angles; however, the results change drastically in this angular region when absorption is taken into account. Recently Grein and Locher[5] have calculated a complete set of π-d observables using Faddeev