Comments and Addenda

The Comments and Addenda section is for short communications which are not of such urgency as to justify publication in **Physical Review Letters** *and are not appropriate for regular Articles. It includes only the following types of communications: (1) comments on papers previously published in* **The Physical Review** *or* **Physical Review Letters**; *(2) addenda to papers previously published in* **The Physical Review** *or* **Physical Review Letters**, *in which the additional information can be presented without the need for writing a complete article. Manuscripts intended for this section should be accompanied by a brief abstract for information-retrieval purposes. Accepted manuscripts will follow the same publication schedule as articles in this journal, and galleys will be sent to authors.*

Further Neutron-Proton Bremsstrahlung Results*

F. P. Brady
Crocker Nuclear Laboratory and Department of Physics, University of California, Davis, California 95616

and

J. C. Young
Physics Department, California State University, Chico, California 95926

(Received 14 June 1972)

Neutron-proton bremsstrahlung calculations predict cross sections integrated over the photon angle, θ_γ, which show rather modest model dependence. However, the predicted photon angular distributions manifest a large model dependence. Unpublished data from a previous experiment were integrated over positive and negative photon angles and the ratio compared with model predictions. The results are that the potential model calculations of Brown and Franklin are favored.

Nucleon-nucleon bremsstrahlung remains one of the most promising ways of investigating that relatively unexplored region of the nucleon-nucleon interaction: its off-shell behavior. As predicted by the low-energy theorem,[1] off-shell effects are relatively small until one goes far off shell. In the case of proton-proton bremsstrahlung ($pp\gamma$) the coplanar cross sections, either as a function of the photon angle θ_γ or integrated over θ_γ, show about the same sensitivity to off-shell effects.[2-7] The difference between on- and off-shell predictions is generally $\lesssim 25\%$[6,7] for the symmetric case of $\theta_p \gtrsim 25°$ and E(lab) $\lesssim$ 200 MeV; and the off-shell differences among various models are generally less than this amount.

For the case of $np\gamma$, present calculations[5,8,9] of integrated cross sections also show modest model dependence. However, the photon angular distributions appear to provide a considerably more sensitive basis for model discrimination. An example of the use of this fact is presented in this comment. It is based on a more detailed analysis of data used previously[10,11] for the purpose of comparing experimental integrated cross sections with model predictions.

Table I summarizes the calculated and experimental values for the coplanar, symmetric $np\gamma$ cross sections integrated over θ_γ. The differences among the integrated predictions of the various models is moderate, $\simeq 25\%$. The calculation of McGuire[8] labeled O, contains off-shell effects of the pole terms but only on-shell contributions from the internal terms. In the calculation a modified one-pion exchange model is used to extrapolate the current elastic-phase parameters off-shell. Suppressing off-shell effects results in the predictions denoted by O_{el}. MI refers to Nyman's "model-independent" calculations[2] which like O_{el} contain no off-shell effects. Unlike O_{el} they are covariant, but use a single energy approximation. Brown and Franklin's calculations[9] are based on the Bryan-Scott III (BS) potential and they include contributions from the rescattering and exchange type of internal terms. The one-boson-exchange (OBE) calculations of Baier, Kühnelt, and Urban,[5] based on the OBE model, include the effects of internal terms and are relativistic and gauge invariant. It can be seen that the cross sections integrated over θ_γ show only moderate off-shell differences at least for $\theta_n = \theta_p \gtrsim 30°$, and the data[10,11] are not precise enough to distinguish among them.

In Fig. 1 can be seen the large model dependence of the photon angular distributions for the case of 200 MeV and $\theta_p = \theta_n = 30°$. Although each of the cal-

TABLE I. Calculated and experimental values for coplanar, symmetric $np\gamma$ cross sections at 200 MeV.

θ_n, θ_p	O [a]	O_{el} [a]	MI [b]	BS [c]	OBE [d]	Expt. [e]
30, 30	35	24	25	34	46	35 ± 14
35, 35	40	29	33	50	60	57 ± 13

[a] See Ref. 8.
[b] See Ref. 2.
[c] See Ref. 9.
[d] See Ref. 5.
[e] See Refs. 10 and 11.

culations[5,8,9] predicts qualitatively a dipole-type distribution the latter are quantitatively quite different for the three calculations. Due to statistical errors and the large energy spread of the incident neutron beam it was not possible in our experiment at Berkeley to obtain good photon angular distributions and only cross sections integrated over θ_γ were reported.[10,11] However, it is possible to obtain from the data[12] the ratio of the cross section integrated, respectively, over positive (proton side) and negative photon angles. This is found to be 0.57 ± 0.36 at 208 MeV for $\theta_p=\theta_n=30°$, where the error quoted is statistical only. Predictions of the models denoted O,[8] BS,[9] and CBE[5] at $\theta_p=\theta_n=30°$ and 200 MeV are 1.54, 0.70, and 1.41, respectively. Thus, the potential model calculations[9] of Brown and Franklin are favored.

The above ratio is not as model-dependent; it appears from Fig. 1, as a ratio taken at carefully chosen photon angles. Thus, it seems that measurements of $np\gamma$ photon angular distributions or measurements at specific angles would provide reasonable tests for the off-shell behavior of n-p interaction models.

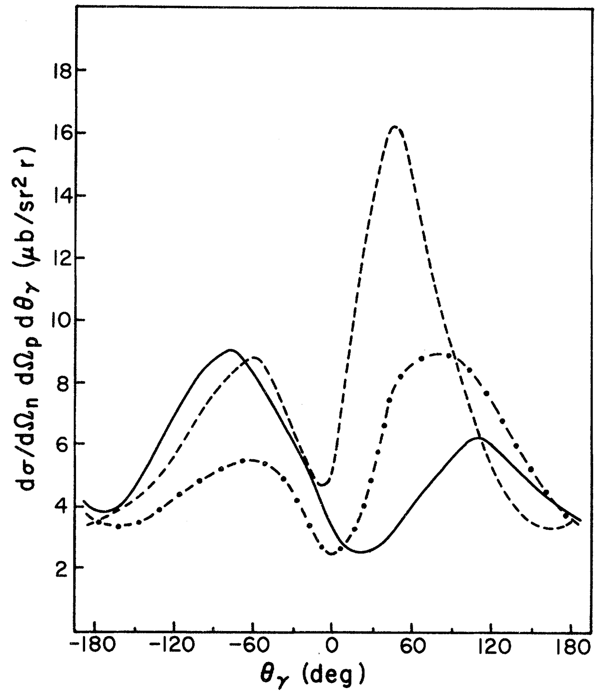

FIG. 1. The calculated $np\gamma$ photon angular distributions for $\theta_p=\theta_n=30°$ and E(lab) = 200 MeV. The solid curve is that of Brown and Franklin (Ref. 9); the dash-dot line that of McGuire (Ref. 8); and the dashed line that of Baier, Kühnelt, and Urban (Ref. 5).

*Work supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.

[1]F. E. Low, Phys. Rev. 110, 974 (1958).
[2]E. Nyman, Phys. Rev. 170, 1628 (1968).
[3]V. R. Brown, Phys. Letters 25B, 506 (1967); Phys. Rev. 177, 1498 (1969). The corrected predictions for BS III can be obtained from V. R. Brown, Lawrence Livermore Laboratory.
[4]J. H. McGuire, A. H. Cromer, and M. I. Sobel, Phys. Rev. 179, 948 (1969).
[5]R. Baier, H. Kühnelt, and P. Urban, Nucl. Phys. B11, 675 (1969).
[6]J. H. McGuire and A. H. Cromer, Phys. Rev. 184, 1018 (1969).
[7]D. Marker and P. Signell, Phys. Rev. 185, 1286 (1969).
[8]J. H. McGuire, Phys. Rev. C 1, 371 (1970).
[9]V. R. Brown and J. Franklin, Bull. Am. Phys. Soc. 16, 560 (1971); in *Gull Lake Symposium on the Two Body Force in Nuclei, 7–10 September 1971,* edited by S. M. Austin and G. M. Crawley (Plenum, New York, 1972), p. 123; and private communications.
[10]F. P. Brady, J. C. Young, and C. Badrinathan, Phys. Rev. Letters 20, 750 (1968).
[11]F. P. Brady and J. C. Young, Phys. Rev. C 2, 1579 (1970).
[12]J. C. Young, Ph.D. thesis, University of California, Davis, 1968 (unpublished).