Three-body force effects in the proton induced break-up of deuterons

A. De[1*], Debakinandan Majee[1], Srijit Bhattacharya[2], S. R. Banerjee[3], Deepak Pandit[3], S. Mukhopadhyay[3], Surajit Pal[3], Debasish Mondal[3], and Balaram Dey[4]
[1]*Department of Physics, Raniganj Girls' College, Raniganj, Burdwan (West) - 713358, W. B., India*
[2]*Department of Physics, Barasat Govt.College, Barasat, N-24 Pgs, Kolkata – 700124,W.B., India*
[3]*Variable Energy Cyclotron centre, 1/AF Bidhan Nagar, Kolkata – 700064, W. B., India*
[4]*Department of Physics, Bankura University, Bankura, W.B,. India*
* *email:akd.panua@gmail.com*

Introduction and Aim

Nucleon-deuteron system, being the lightest few-body (three-nucleon) system, has for a long time been the testing ground for the study of few-body aspects of nuclear forces [1-6]. With the advent of time, there have been a large collection of high precision experimental data along with highly rich different theoretical approaches like those based on Faddeev theoretical calculations. Though the overall agreement between theory and experiment is rather good, there exist certain notable discrepancies, especially at and around the collinear region in the kinematically allowed phase space, where three-body force (3BF) effects are expected to be manifested [3,7] favourably. As a consequence of internal structure of nucleon, three-body force is likely to play an important role in the three-nucleon system. The existing discrepancies around the collinear region point to the necessity of including new ingredient like 3BF in addition to the standard two-body inputs in the 3N calculation. The present article aims at possible reduction/removal of the existing discrepancies [3-6] and to better understand the experimental distribution of three-body correlation cross sections in the proton induced break-up of deuterons at several incident energies and correlated pairs of angles, where notable discrepancies were found, at and around the kinematically predicted collinear regions.

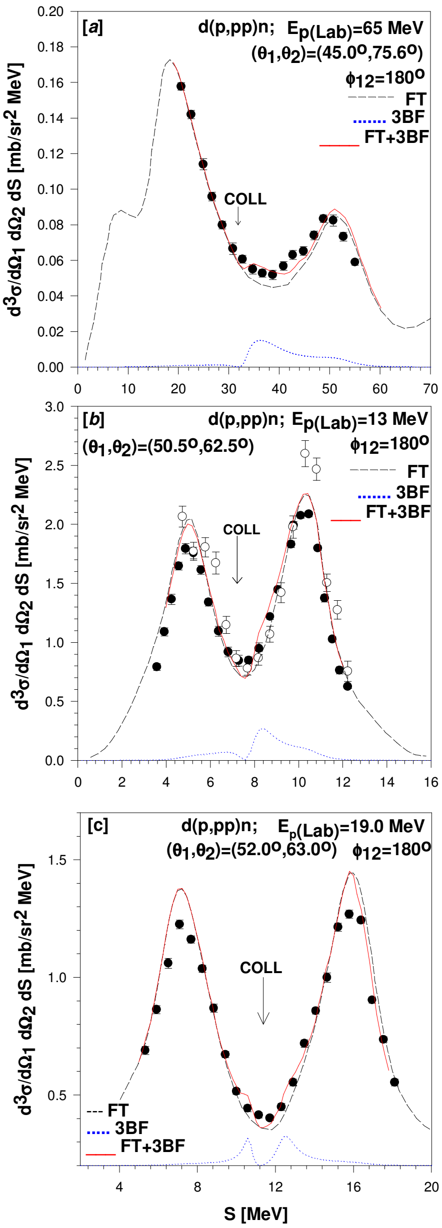
Data Analysis and Discussions

Three-body forces (3BF) are, in general, strongly angle dependent and the interaction is likely to be favoured at low relative energies due to long time of escape from the nuclear interaction volume. Based on this idea, a simple form of 3BF calculation [7] which provided significant result for the alpha-deuteron system, is also applied for the present case. Concentrating on collinear region, we exploited data from the existing literature, at three different incident proton energies, $E_{p(lab)}$ = 65 MeV [3,4], 19 MeV [3,5] and 13 MeV [3,6], with respective correlated pair of angles (θ_1, θ_2) = (45.0°,75.6°), (52.0°,63.0°), and (50.5°,62.5°). Results of our calculations are displayed in figures 1*a*, *b* and *c*, where in each figure black dashed curve corresponds to existing Faddeev type calculations (without 3BF), dotted blue curve corresponds to present 3BF calculation (in arbitrary unit), while the solid red curve represents the incoherent summation of 3BF with FT. Point on the S-axis satisfying collinear condition is indicated by an arrow mark. We summarize our findings as follows.

(i) In all the correlated pairs of angles and incident energies studied, contribution of 3BF effects seem to be positive as shown by the blue dotted curves in the figures.

(ii) For the data at 65 MeV incident energy, with (θ_1, θ_2) = (45.0°, 75.6°), earlier observed large discrepancy between the theoretical prediction (FT, black dashed curve in Fig. 1*a*) and the experimental data at the collinear region and beyond (at higher arc length S) is found to be largely removed when 3BF contribution (blue dotted curve) is taken care of (FT+3BF, red solid curve) with the existing FT [3].

(iii) Effect of 3BF at 13 MeV incident



Figs. 1a, b, c. Three-body correlation cross-sections as a function of arc length (S) for the reaction d(p, pp)n for incident energies and correlated pairs of angles as mentioned in the figures. FT: existing Faddeev type calculations 3BF: three-body force contribution. Experimental data and theoretical FT data are as mentioned in the text.

energy, with (θ_1, θ_2) = (50.5°, 62.5°) [Fig. 1*b*] is found to be weak enough just at the collinear point, and provides slight over prediction at the left wing of the right peak (at higher arc length) (solid red curve, FT+3BF in the figure).

(iv) 3BF effect at 19 MeV incident energy, with (θ_1, θ_2) = (52°, 63°) [Fig. 1*c*] though small, the fit seems to yield positive contribution as is revealed by the solid red curve (FT+3BFN) in the figure.

(v) So far as the incident energy dependence is concerned, better result is achieved with higher incident energies, around the collinear region.

Conclusion

Probable 3BF contributions, in the present work, supplemented with the existing Faddeev type calculations (without 3BF), seems to provide positive result towards removal of the earlier observed discrepancies, pointing towards better reproduction, with higher incident energies, of the experimental three-body correlation cross sections around the collinear region. However, for precise understanding of the problem, it is likely to be most important to analyze the data in the light of the recent state-of-the-art Faddeev type calculations [8, 9], including Coulomb interaction as well as 3BF effects.

References

[1] I Ciepał et al, Phys. Rev. **C 99,** 014620 (2019)

[2] S. Binder et al, Phys. Rev. **C 98**, 014002 (2018)..

[3] W.Glöckle et al, Phys. Reports **274**, 107 (1996)

[4] M. Allet et al,Phys. Rev. **C 50,** 602 (1994).

[5] H. Patberg et al, Phys. Rev. **C 53**, 1497 (1996).

[6] G. Rauprich et al, Nucl. Phys. **A 535**, 313 (1991).

[7]A. De et al, Few Body Systems, **19** (1995) 195; Proc. DAE Symp. Nucl. Phys. **51** (2006) 369; Int. Nucleus-nucleus Conf., Aug 28 – Sep. 31, 2006, Rio-Brazil.

[8]A. Deltuva et al, (a) Phys Rev. **C 87**, 054002 (2013); Phys. Rev. **C93**, 044001 (2016) .

[9] St Kistryn and E Stephan, J. Phys. G, Nucl. Phys. 40, 063101 (2013).