Deuteron photodisintegration cross-sections 50-155 MeV

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The study of the photodisintegration of the deuteron should be a rewarding area over the next few years both as a result of the increased sophistication of recent theoretical treatments and also because of the potential, which has only just begun to be realised, of much more accurate and reliable photoreaction data.

Photoreaction calculations are being carried out at a much more realistic level, now including mesons and excited nucleons in addition to the nucleons and the coupling of photons to all of these constituents. The deuteron is an obvious choice of target on which to test our theoretical understanding of these non-nucleonic contributions, since two-body wavefunctions can be calculated reliably within a non-relativistic framework for both bound and continuum states.

The simplest deuteron photodisintegration process, $^{2}H(\gamma,p)n$, still deserves and continues to receive considerable attention, both experimental and theoretical. A plot of the energy dependence of the total cross-section in the E_γ = 100 MeV region, fig. 4.1, serves to illustrate the point. It is clear that for this relatively simple process, various theoretical treatments show significant disagreement. Reliable data are clearly required to guide these theoretical efforts, but unfortunately experimental consensus is still far from being reached, in spite of extensive work by many groups. Most of the existing measurements have been made with bremsstrahlung and many of the inconsistencies can be traced to errors in determining the incident flux. A tagged photon measurement, in which the flux at a precise energy can be accurately monitored, eliminates such systematic errors. Therefore when the GEM tagging spectrometer (section 2) was installed at the MAMI-A accelerator, it was natural that the deuteron photodisintegration experiment should be one of the first projects planned and executed on the facility.

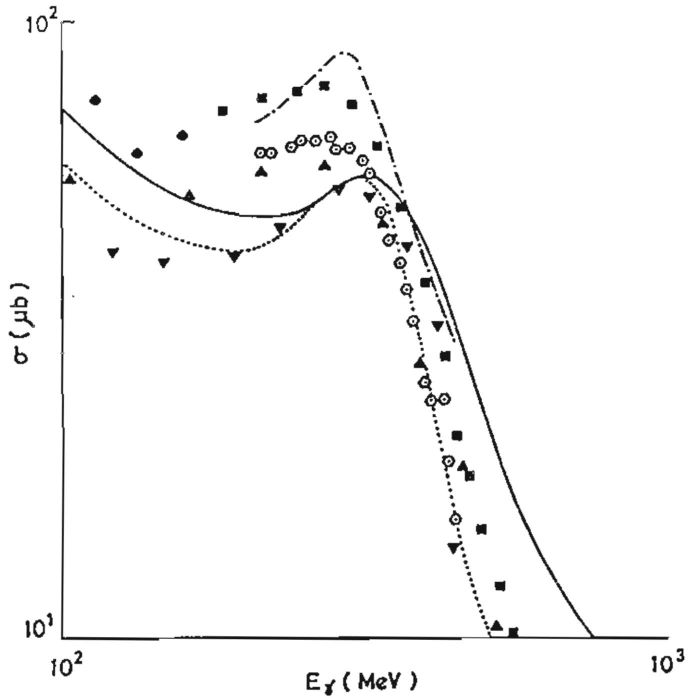

Fig. 4.1 Total cross-section for $^2H(\gamma,p)$ from the literature ● Alexandrov (1956), ▲ Keck (1956), ▼ Kose (1967), ■ Dougan (1966), ⊙ Arends (1984). Calculations by Laget (solid line 1978, dotted line 1985) and Arenhovel (dot-dash line 1985) are also shown.

Two separate experiments have been carried out, each using different proton detection apparatus, one to measure the angular distribution of the two-body breakup reaction $D(\gamma,p)n$ and the other to measure the total photodisintegration cross-section. The differential cross-section measurement used a relatively conventional target detector geometry, employing a liquid D_2 cell and a large solid angle $E,\Delta E$ telescope. The second apparatus, an "active target", was less conventional, and used a deuterated liquid scintillator, which acted both as the deuterium target and as a 4π proton detector for measuring $\sigma_{total}(E_\gamma)$.

For the angular distribution measurement, the target consisted of a thin windowed cell, cooled below 20°K and filled with liquid D_2. This assembly was held in a vacuum chamber with thin windows for entrance and exit of the photon beam and exit of the photo-protons. Operating at a pressure of 1.1 bar the average target thickness was 9.2 mm. The E,ΔE telescope for detecting protons [1] consisted of three banks of plastic scintillator subtending a solid angle of ~0.7 sr. It had an energy resolution of ~5% and an angular resolution of ~3°, more than adequate for this particular experiment. Measurements were made for E_γ = 80-155 MeV and θ = 30-150° necessitating two settings of the tagging spectrometer and three telescope positions. Much of the primary data reduction is complete and preliminary differential cross-sections have already been reported [2]. A detailed Monte Carlo simulation of the experiment has still to be carried out in order to evaluate the effective target thickness and proton detector solid angle. Thus the differential cross-sections shown in fig. 4.2 are not fully corrected and the error bars reflect the 3% statistical uncertainties only. Bearing this in mind, the data are consistent with a recent measurement at 140 MeV by de Sanctis et al. [3] and with a recent calculation by Arenhovel [4]. This basically follows the Partovi method, in which a multipole expansion of the reaction amplitude is made in configuration space, but has been extended to include the effects of meson exchange currents, isobar configurations (NΔ) and relativistic order corrections to the charge density operator. The calculations of Laget [5], which nominally include the same physics, but differ technically in using a momentum space expansion of the photodisintegration amplitude in terms of leading diagrams, produce somewhat different results. At this stage, before the data are fully corrected, they do not suggest a firm preference for one method of calculation or the other.

The total cross-section measurements employed the active target technique which offers the obvious advantage of guaranteed 4π detection and the equally obvious disadvantage that atomic interaction processes also produce a signal in the detector. Since Compton and pair production cross-sections are five orders of magnitude larger than nuclear cross-sections the main features of the experiment design were determined by the requirement to separate proton and electron events.

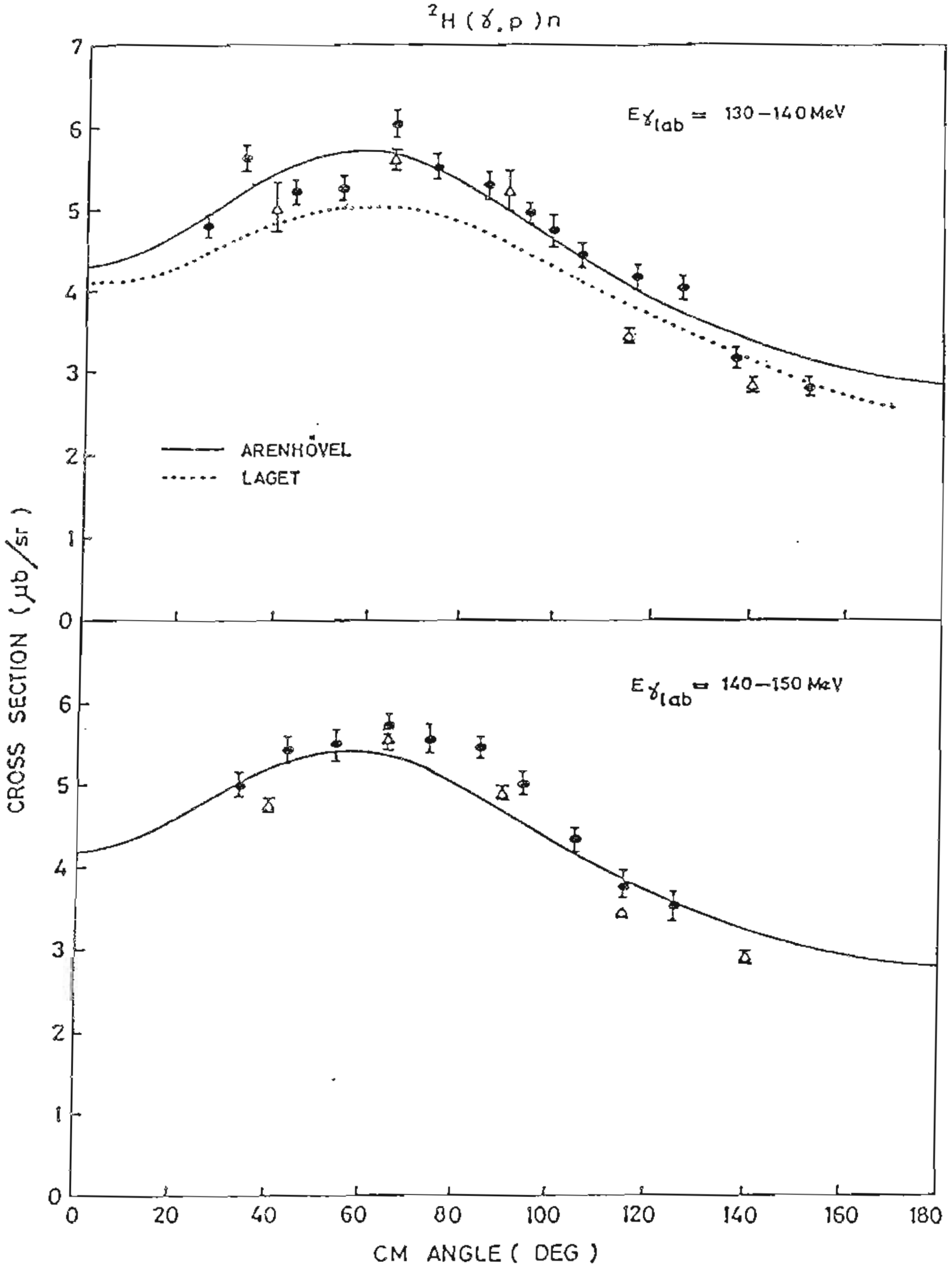

Fig. 4.2 Deuterium angular distributions. The error bars shown on the present data (solid circles) are statistical only. The data of de Sanctis et al. [3] are also shown (open triangles) along with the calculations (lines) due to Arenhovel [4] and Laget [5].

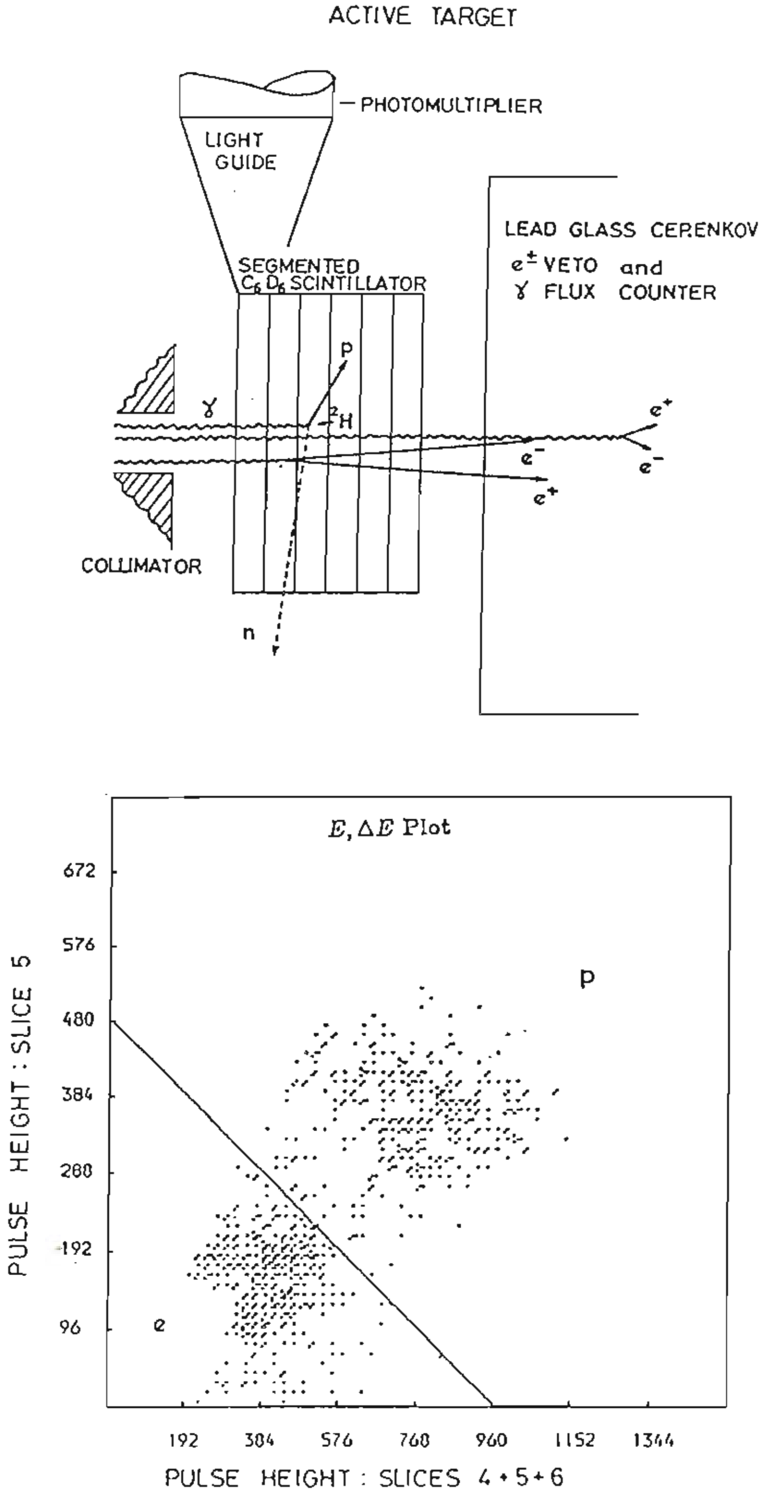

Fig. 4.3 Arrangement of active target experiment and E,ΔE plot for events when several adjacent slices have fired.

Measurements were performed for $55<E_{\gamma}<130$ MeV using a target (fig. 4.3) containing C_6D_6 scintillator segemented into 6 slices each 1 cm thick by 12 cm diameter and viewed by two photomultipliers. This arrangement helped the separation of protons from electrons because of their very different ranges and energy losses as shown in fig. 4.3. Pulse shape discrimination was also employed to help separate protons from electrons and special electronic modules were designed and constructed for this purpose [6]. A lead glass Cherenkov detector placed directly behind the active target vetoed forward angle electrons and photons and also acted as continous photon flux monitor.

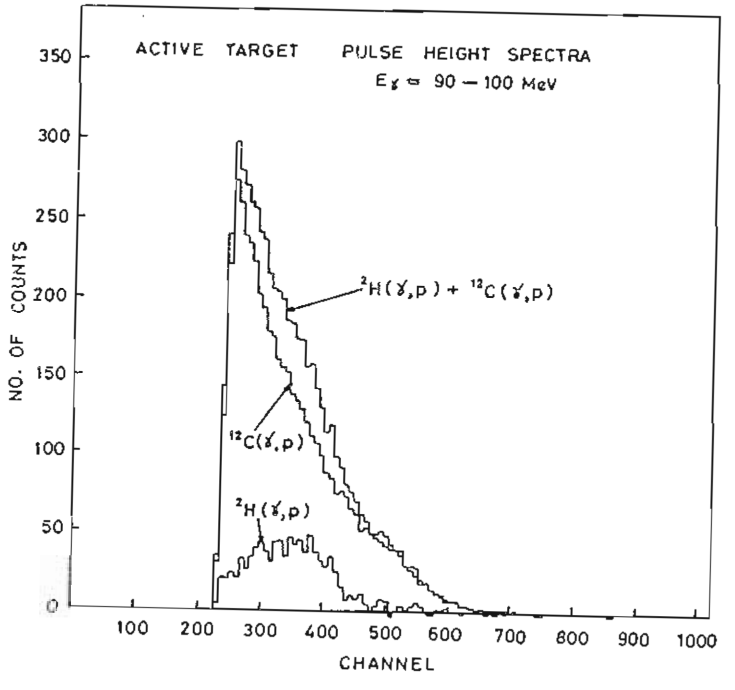

Fig. 4.4 Proton energy spectra from the active target filled with C_6D_6 and C_6H_6 and their difference which is due to deuterium.

In order to take account of the substantial proton yield from the $^{12}C(\gamma,p)$ reaction further data was accumulated after refilling the target with C_6H_6 scintillator. The analysis of the $\sigma_{total}(E_\gamma)$ data is still at an early stage. Fig. 4.4 shows the active target proton energy spectra for ~25% of the data in the energy bin 90-100 MeV. The background subtracted spectrum yields a cross-section of 60 μb with 4% statistical precision. Thus a final 2% statistical uncertainty should be achievable. The corrections for some systematic effects which remain to be evaluated (using Monte Carlo techniques) may account for the discrepancy between this datum and the deductions of De Sanctis et al. (~69 μb) [3].

To summarise the present position, the analysis of the deuteron photodisintegration differential cross-sections is well advanced and has produced data with statistical uncertainties of ~3%. Systematic errors should finally be of this order or less. The total cross-section analysis is less advanced, but has progressed enough to give confidence that $^{2}H(\gamma,p)$ events can be cleanly separated from other processes occurring in the active target. A statistical uncertainty of ~2% is expected for this data. It is hoped that both analyses will be completed and ready for publication during 1988.

[1] I.J.D. MacGregor et al., Nucl. Inst. and Meth. A262 (1987) 347.
[2] P.A. Wallace et al., IOP Conference on Nuclear Physics and Particle Physics, Birmingham, April 1987.
[3] E. De Sanctis et al., Phys. Rev. C34 (1986) 413.
[4] H. Arenhovel, private communication.
[5] J.M. Laget, Nucl. Phys. A312 (1978) 265.
[6] J.R.M. Annand, Nucl. Inst. and Meth. A262 (1987) 371.