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ON THE EXISTENCE OF PEAR-SHAPED NUCLEI

J. Blons, B. Fabbro, J.M. Hisleur, J. Julien, C. Mazur, Y. Patin*, D. Paya, M. Ribrag
DPh-N/MF, CEN Saclay, 91191 Gif-sur-Yvette Cedex, France

Abstract

Both, neutron and deuteron induced fission reactions on ^{230,232}Th can lead to the same excited compound nucleus ^{231,233}Th. However, in the former (n,f) reaction one is limited to rather small angular momentum transfers, $\ell \lesssim 3$, near the fission threshold, whereas in the latter (d,pf) case ℓ values of about 6 can be attained. In this paper we present results for the ^{230}Th (d,pf) reaction, around 5.9 MeV excitation energy, obtained with an appropriate proton-fission time coincidence and an overall energy resolution of FWHM ≃ 6 keV. The resulting data shows the very same fine structure previously observed for the lower ℓ values in the corresponding ^{230}Th (n,f) reaction, but an additional set of higher spin states, not accessible with (n,f) reaction also appears. These new results support and confirm our previous interpretation of the (n,f) data, namely that we are again observing two close-lying rotational bands with opposite parities but this time for ℓ values up till 5 (at least), a fact which can best be understood in terms of a "triple humped potential barrier", theoretically expected for an asymmetric, pearlike deformation of the excited compound nucleus.

I. INTRODUCTION

Over the years, both theoretical and experimental investigations of the fission process suggested that the potential energy surfaces, associated with fissioning compound nuclei, are far more complex than it was originally supposed.

One could thus consider the evolution of our actual understanding of the fission process, within the framework of the liquid-drop model, to have passed through three main stages. Fission data was originally interpreted in terms of a simple, single minimum, potential fission barrier. Later on, a more detailed description, obtained by considering certain shell and pairing corrections to the simple liquid-drop model, led to the by now classical concept of a "two-well" potential barrier. Finally, by taking into account some further refinements, such as the mass asymmetry of the excited compound nucleus, represented

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*PCN. CEN Bruyères-le-Châtel.

by the pear-like deformation, one was compelled to adopt a three-minimum potential barrier in order to obtain a satisfactory description of the fission process.

The experimental evidence of the third potential well is found in the Saclay results on ^{230,232}Th (n,f) reaction [Bl 78, Bl 82]. Fig. 1 shows the fission cross of ^{230}Th for neutrons with energies in the vicinity of 720 keV and the corresponding anisotropy results obtained in other laboratories [Br 80, VM 81]. We have shown that the fine structure appearing in the broad resonance is caused by a set of narrower resonances whose spin values increase with excitation energy. We have also shown that the experimental data could not be fitted by a calculed curve when a single rotational band with definite parity is assumed. Such a result is in contradiction with the hypothesis of the observed resonances corresponding to levels in the second well of the fission barrier. Conversely in the third well, the fissioning nucleus has an octupole deformation and the necessity of good parity for the wave functions imposes the presence of both the positive and negative parities. In fig. 1, the result of the simultaneous analysis of the fission cross section and the anisotropy measurement in the framework of two rotational bands with different parities is presented. Individual partial fission cross sections, $\sigma_{CN}^{J\pi}(E_n)$ are also shown. The energy positions of their respective components are used to determine the rotational parameters. If these energies are written in the standard form for a K=1/2 rotational band,

$$E(J) = E_o + \hbar^2/2\mathcal{J} \left[J(J+1) - K(K+1) + a(-1)^{J+1/2} (J+1/2) \right]$$

the inertia parameter, $\hbar^2/2\mathcal{J}$, and the decoupling parameter, a, are for positive and negative parities respectively :

$\hbar^2/2\mathcal{J}\ (K^\pi = 1/2^+) = (1.9 \pm 0.3)$ keV $\quad a(K^\pi = 1/2^+) = 0.2 \pm 0.2$

$\hbar^2/2\mathcal{J}\ (K^\pi = 1/2^-) = (2.1 \pm 0.1)$ keV $\quad a(K^\pi = 1/2^-) = -\,0.3 \pm 0.2$.

As can be seen in fig. 1 the spin values which can be reached in (n,f) reaction are limited to $J=7/2^-$. This is so because the probability for forming a compound nucleus, at $E_n \sim 720$ keV, by means of neutron interaction decreases drastically for all transferred angular momenta, ℓ, greater than 3.

It would be very interesting to investigate higher J states of the rotational bands. This can be achieved provided certain experimental restraints are satisfied : one would thus require first, a high transferable angular momentum ℓ, second, reasonable compound nucleus formation cross sections (i.e. in the input channel) so as to obtain statistically significant counting rates and third, sufficient energy resolution for the expected high J states to be separable.

Fig. 2 presents the calculated ^{230}Th (d,pf) cross section. In a first step, the DWUCK code was used to calculate the level feeding as a function of the excitation energy for each spin and parity of ^{231}Th compound nucleus. Then, the fission probability was obtained through the RDF code [Ja 81, Ja 82]. The fission barrier and the rotational bands parameters used in this calculation are those deduced from the (n,f) results. The calculation indicates that states up to $J=11/2^+$ might be observable in (d,pf) reaction. The same fig. 2 shows also the experimental and calculated ^{230}Th (n,f) cross section.

In order to see if such high spin-states could indeed be seen, a series of ^{230,232}Th (d,pf) experiments was recently performed at the Saclay Van de Graaff tandem. Should these higher spin states of the rotational bands show up in the data, one could then not only confirm the previous conclusion, obtained with (n,f) reactions for low J values, but greatly increase the reliability of these conclusions for all J values ranging from $J=1/2$ to $11/2$.

II. EXPERIMENTAL SET-UP

The ^{230}Th (d,pf) reaction has been investigated in the 5.5 to 6.2 MeV excitation energy range.

The deuteron energy, $E_d = 12$ MeV, was choosen after experimental tests and theoretical calculations.

The fission fragments were detected in two parallel plate avalanche detectors (PPAD) the anodes of which were divided in 7 sectors corresponding to different angular bands relative to the recoil direction (fig. 3). All angles, θ, from 0° to 90° were covered permitting the measurement of the angular distribution of the fission fragments.

The proton energy was measured, at 130°, by means of a gas counter set on the focal surface of a QD3 magnetic spectrometer. Due to the high counting rate in the fission detectors a fast coincidence was required between the PPAD and a plastic scintillator set behind the gas counter. The coincidence time was reduced by taking into account the different times of flight of the protons in the QD3. This was achieved by the use of two counters in order to identify the proton trajectory, which gave also a more precise determination of its intercept with the curved focal surface.

RESULTS

Since the measurement was just completed last week, only raw data, uncorrected for solid angle and chance coincidence, will be presented here. The fission counts are shown as functions of excitation energy between 5.8 and 5.9 MeV in figs. 4a,b,c, where a, b and c refer to $0° < \theta < 30°$, $30° < \theta < 90°$ and $0° < \theta < 90°$ respectively (θ is the fission fragment angle relative to the recoil direction). The solid line results from the smoothing of the data by a 4 keV wide gaussian function.

Narrow peaks, about 6 keV wide are clearly seen. Furthermore, as expected, additional levels are found on the high energy side of the rotational bands previously observed in (n,f) reaction. Presumably, they constitute the prolongation of the rotational bands towards higher spins. Indeed, their energies (indicated by arrows) are in agreement with the rotational law deduced from the (n,f) analysis. A tentative spin assignment based on this rotational law is given in the figures. Although, the data are not yet corrected for solid angle, the relative intensities of the peaks seem in fair agreement with the calculated one (see fig. 2). Also, the comparaison of figs. 4a and 4b shows that the peaks are enhanced for the $0° < \theta < 30°$ angles, as expected for $K=1/2$ bands.

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REFERENCES

[Bl 78] J. Blons, C. Mazur, D. Paya, M. Ribrag and H. Weigmann, Phys. Rev. Lett. 41 (1978) 1282.

[Bl 82] J. Blons, Thesis University of Paris-Sud (1982).

[Br 80] B. Bruneau, Thesis University of Bordeaux (1980) n°1567.

[VM 81] L.R. Veeser and D.V. Muir, Phys. Rev. C24 (1981) 1540.

[Ja 81] J. Jary, P2N Report 145/81 (1981).

[Ja 82] J. Jary, EANDC (E) Report 232 "L" (1982) 147.

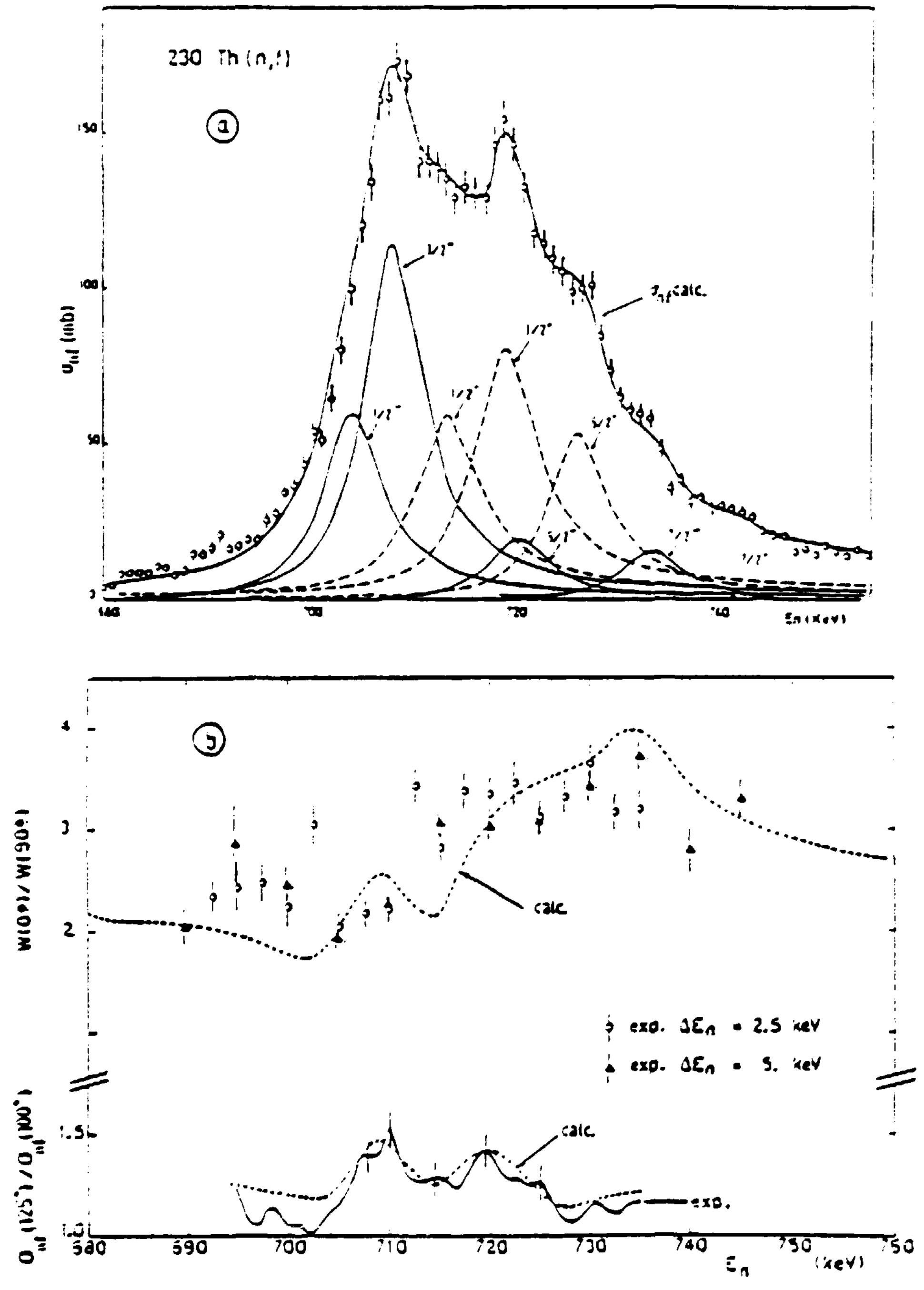

Fig. 1 – a) ^{230}Th (n,f) cross-section calculated as a superposition of two rotational bands with opposite parities and K = 1/2 as compared with the Saclay-Geel experimental data (o) [Bl 78]. b) Calculated W(0°)/W(90°) and $\sigma_{nf}(125°)/\sigma_{nf}(100°)$ ratios as compared with the Bordeaux experimental data (o, ▲) [Br 80] and with the $\sigma_{nf}(125°)/\sigma_{nf}(100°)$ ratio obtained by the author from the raw IASI experimental data [IM 81].

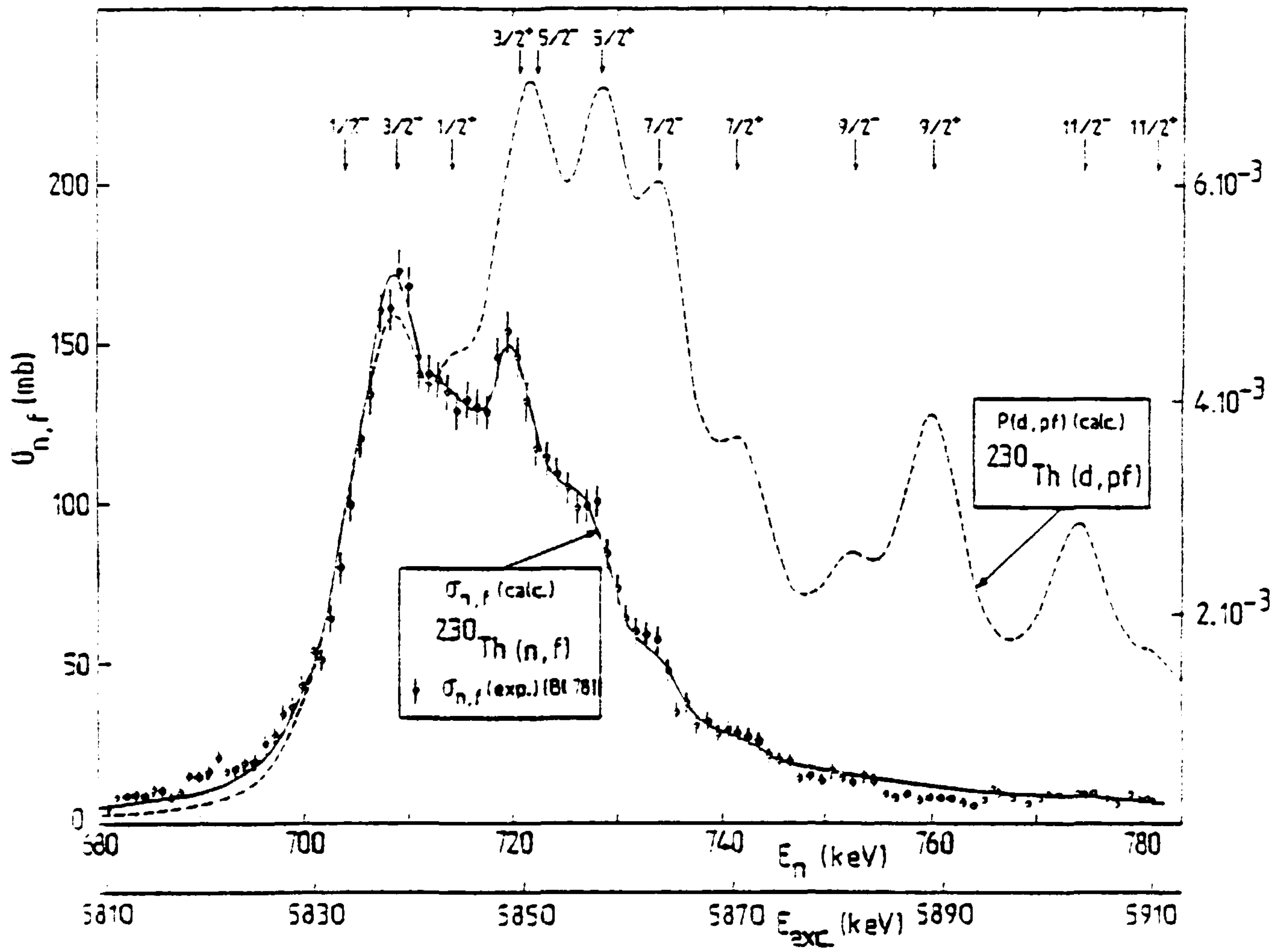

Fig. 2 - —— Calculated ^{230}Th (d,pf) cross section. —— Calculated ^{230}Th (n,f) cross section. o Experimental ^{230}Th (n,f) data [BL 78].

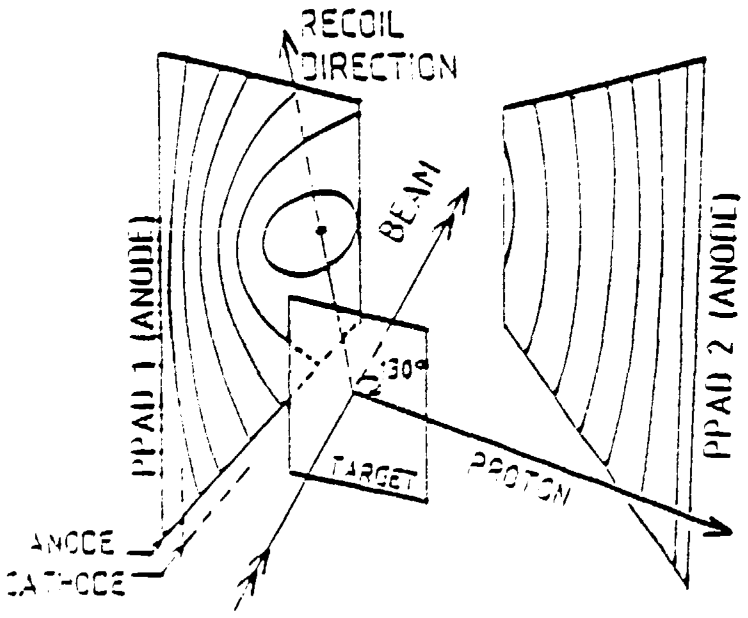

Fig. 3 - Fission fragments detection. The curves (made with insulator) on the anodes separate the sectors which correspond to 10 degrees wide angular bands.

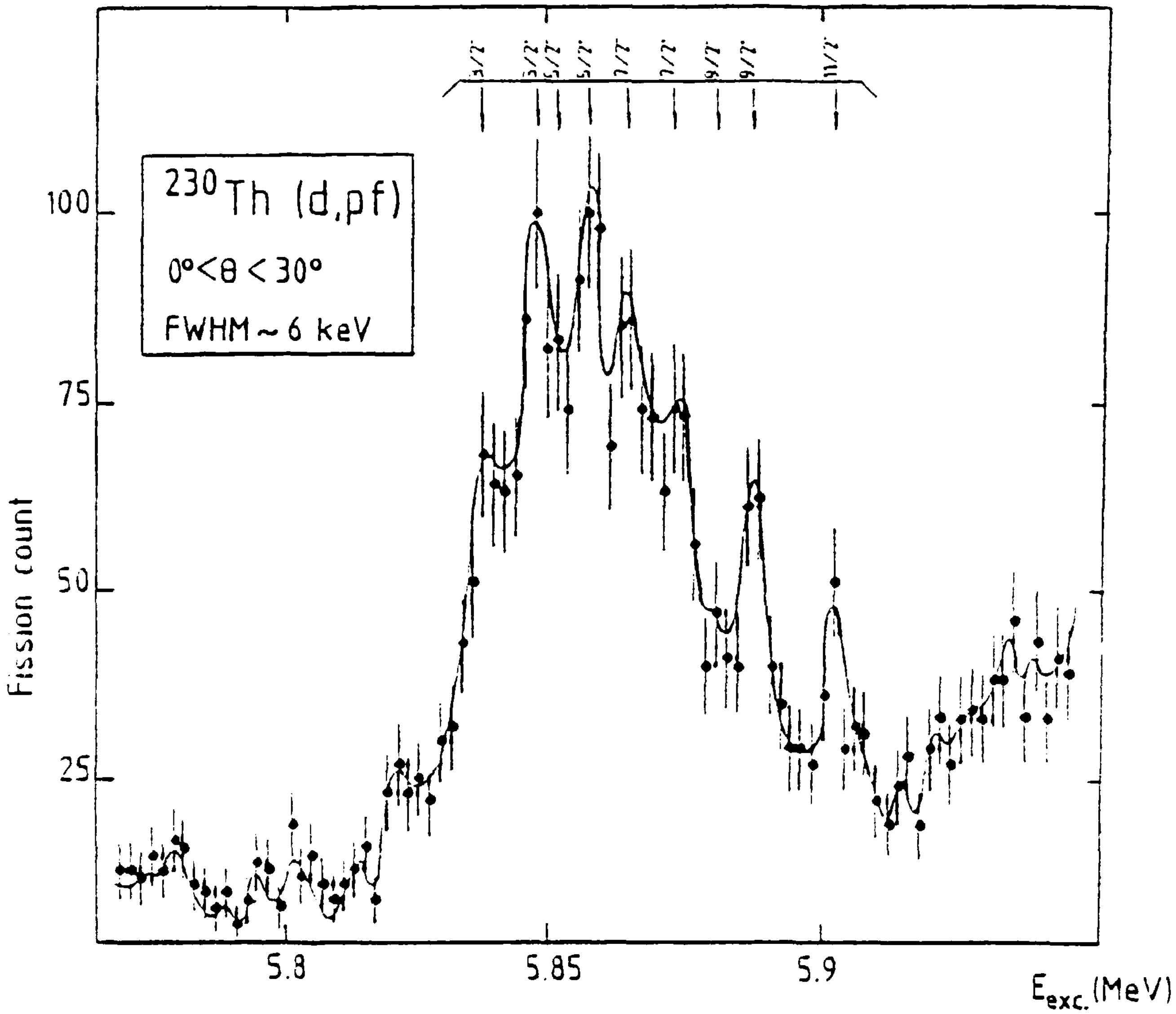

Fig. 4a) - ^{230}Th (d,pf) fission counts, ●, for 0° < θ < 30°, the solid line results from the smoothing of the data by a 4 keV wide gaussian function.

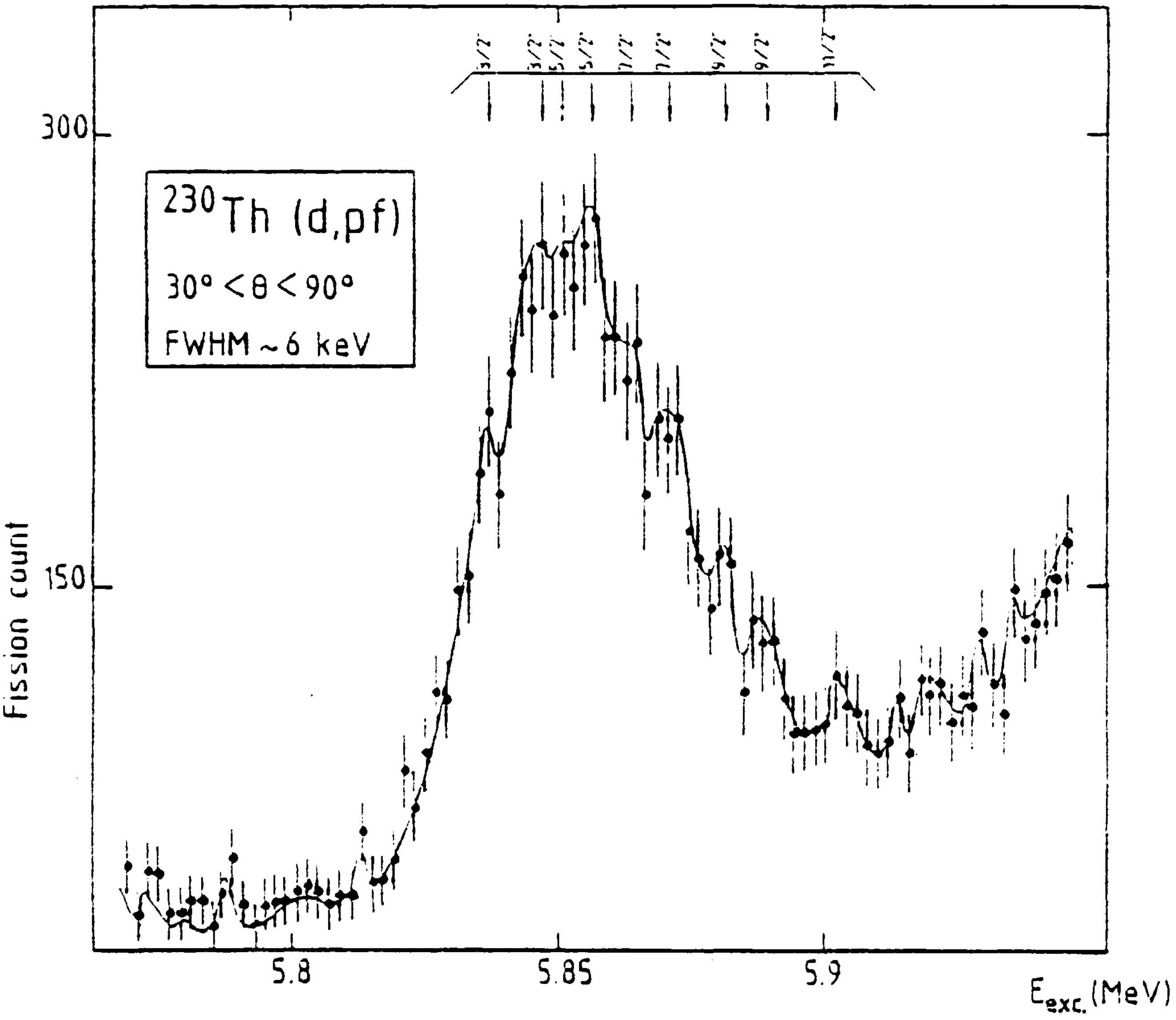

Fig. 4b) ^{230}Th (d,pf) fission counts, ●, for 30° < θ < 90°, the solid line results from the smoothing of the data by a 4 keV wide gaussian function.

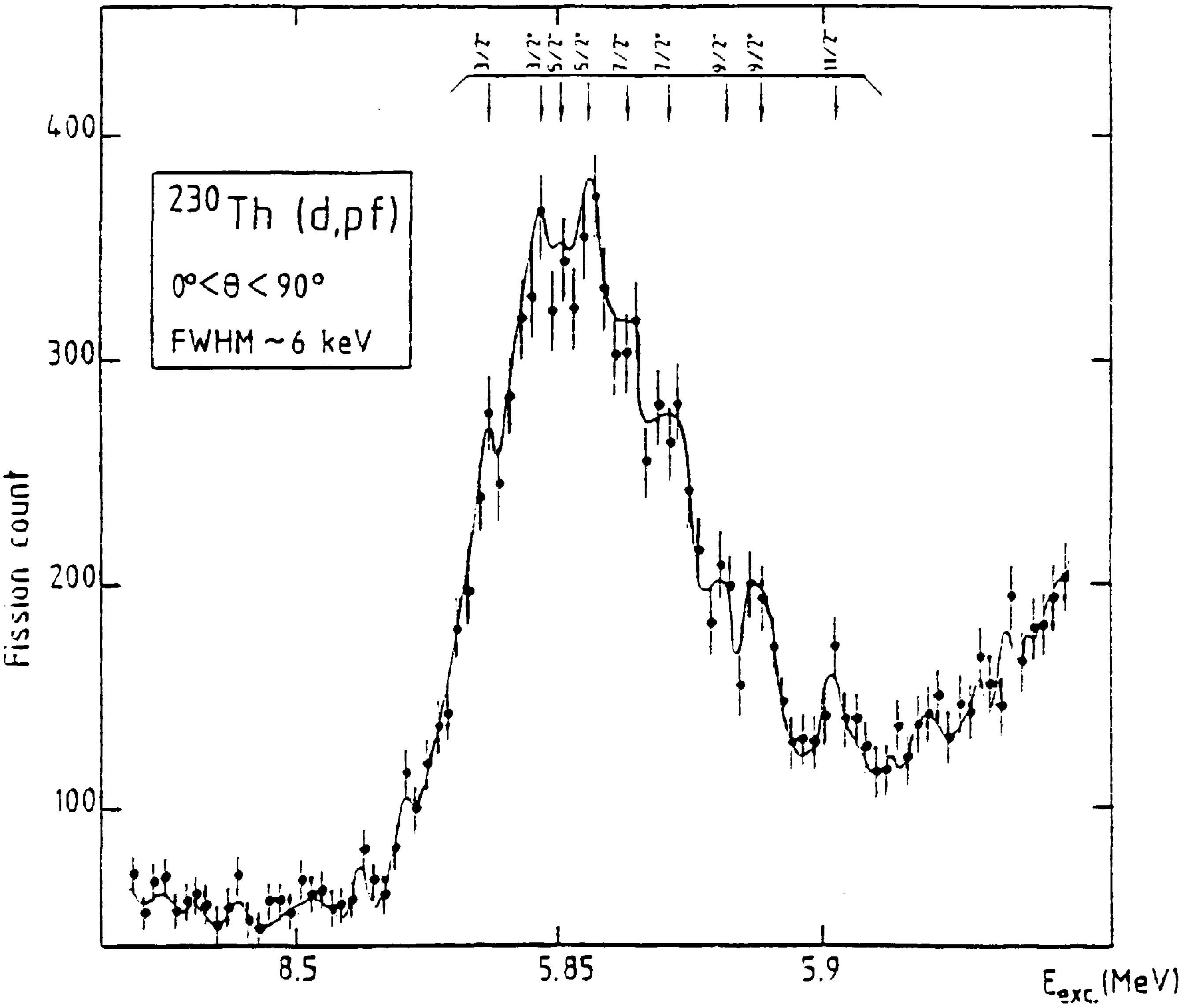

Fig. 4c) - ^{230}Th (d,pf) fission counts, ●, for 0° < θ < 90°, the solid line results from the smoothing of the data by a 4 keV wich gaussian function.