CERN-INTC-2014-040 (INTC-P-412) Beta-delayed Neutron Spectroscopy of 130−132Cd Isotopes with the ISOLDE Decay Station and the VANDLE array

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The proposal aims at measuring beta-delayed neutron emission of 130-132Cd. The Oak Ridge neutron detector VANDLE will be used along with the ISOLDE Decay Station. Neutron emission of the above isotopes was already studied at ISOLDE, addressing the astrophysics motivation, but without the gamma detection capability.

The committee noted that to have more experimental data in the region of 132Sn and to learn more about shell structure and single particle structure in particular is extremely valuable. However, a number of experimental concerns and theoretical uncertainties combined to make a final informed assessment of this proposal impossible. Therefore a Clarification Letter was requested, covering the following points. (i) Based on the theoretical work cited in the proposal and the presentation, it was somewhat difficult to judge the relative merits of the competing theories and hence to what extent the distinction between the two particular theories shown would advance the situation more widely. The direct links between the new spectroscopic information learnt here about the Gamow-Teller strength and the new conclusions to be drawn regarding the shell structure should be developed more clearly, as well as the relative roles likely to be played by the Gamow-Teller strength distribution and the bound state spectroscopy. (ii) In addition, the justification concentrated on 132Cd decay whereas the 131Cd decay requires a similar beam time. The 131Cd case is certainly different but, since it was not discussed in detail, it was not clear that the experimental resolution would be sufficient to learn anything specific or useful. (iii) The characterization of the experimental response function and the background in the ISOLDE implementation, and whether the 49K data would be sufficient to achieve this properly, was generally accepted but was a matter for some minor concern and the arguments could usefully be clarified at the same time as the physics case, especially if the spectra to be deconvolved are likely to be complex.

The INTC requested a Clarification Letter covering the above-mentioned points.

(i) Discussion of theoretical models.

We would like to thank the committee for giving us the opportunity to clarify our theoretical interpretation of the $^{130-132}$Cd beta-decays. In our view the experimental study of neutron resonances and the BGT distribution is required to achieve a quantitative understanding of the structure of the N>82 Cd isotopes. In the GT-type decay of even-even Cd isotopes, the 1+ states in In will be populated. Because of the proximity of the ^{132}Sn double shell closure, the structure of these states should be particularly simple and can be related directly to e.g. ordering of the single particle orbitals. Our proposal is aiming to investigate the effects of the N=82 shell gap, which will manifest themselves in beta decays to neutron unbound states. The aim of the ^{132}Cd measurement is to investigate the symmetry of the feeding to single-particle-state-driven 1^+ In states in the decay of even Cd 0^+ states.. The first 1^+ in ^{130}In, a 2 quasi-particle (QP) state($\pi g_{7/2}$ $\nu g_{9/2}$), was observed to be at a considerably higher energy than shell-model (Oxbash) predictions, and interpreted to be driven by the proton-neutron interaction [Dil03]. In the decay of ^{132}Cd, the same 2QP 1^+ state in ^{132}In is predicted to be unbound, due to the N=82 shell gap energy. Both models presented in our proposal predict this state to have the largest feeding to an unbound state in ^{132}In, observed as a large neutron resonance at 2-2.5 MeV (see also Figure 1 with the Time of Flight spectrum). It is thus of high interest to pinpoint the exact location of this resonance, as it will allow us to observe the systematic effect of the size of the shell-gap and how the proton-neutron interaction will affect the 1+ position in the In isotopic chain. There are also other large feedings to ^{130,132}In 1^+ states at the lowest unbound energies, as shown in Fig. 1, in our model they correspond to other QP configurations and can provide similar quantitative information to compare to theoretical models.

At higher excitation energies other unbound levels populated in $^{130\text{-}132}$Cd correspond to highly fragmented configurations and could be more difficult to interpret in a simple QP interpretation. The shell model provides a more realistic prediction of what will be the real fragmentation of the strength. Because of the proximity to the doubly magic ^{132}Sn, even at high energies, we observe that shell model predicts strong maxima in the highly fragmented BGT distribution which is due to the constrains of the amount of available configurations, which can be populated in the Gamow-Teller decays. These BGT resonant maxima correspond well to almost pure 2QP (even), 3QP (odd) configurations of core excitations as predicted by the QRPA models. These were previously observed in our measurement of the neutron emission of ^{83,84}Ga. The observation or lack of, these resonances, and their evolution in the In isotopic chain can therefore provide crucial information on the systematic behavior of single particle evolution of states near ^{132}Sn isotopes as they become more neutron rich. While VANDLE resolution won't be able to resolve individual resonances at high-energies, it will provide sufficient information of the energetics of the decay strength distribution and this will be an important step to reconcile the experimental data and theory. However, the decays of Cd being so close to ^{132}Sn are uniquely important because of the relative purity of the wave-functions which were involved.

We found a print error in Fig. 5 of our proposal. The calculation was designed to show $2x10^4$ neutrons, as expected for the 9 shifts in Table 1. We can use the relation between area of a Gaussian and its amplitude A, $A\sigma(2\pi)^{1/2}$, to confirm the areas presented in the proposal are incorrect. The peak amplitudes presented are ~100 counts, thus the total area of the spectrum as shown was $\sim 2x10^3$ instead of $\sim 2x10^4$ as intended. The correct figure is presented in this letter of clarification as Figure 2.

(ii)The ^{131}Cd case.

The GT decay of the ^{131}Cd will be driven by the same microscopic mechanism as for the 132Sn, however the odd valence particles provides means to create somewhat more complex configurations (3 quasiparticle) and therefore may lead to higher fragmentation of strength. As mentioned above, even if the BGT strength of ^{131}Cd is heavily fragmented the maxima presented in Fig 1 correspond to almost pure 3QP configurations. Confirming the presence of these BGT resonances is important to validate this interpretation. Moreover, the evolution of their energies in the Cd isotopic chain can inform on the proton-neutron interaction as the Cd isotopes become more neutron rich. The measurement of odd and even isotopes decays provides experimental data to test the model predictions in systematic way in order to disentangle the effects of level energies and residual interactions, in case of the shell model.

(iii) Characterization of VANDLE response.

During the original preparation of the proposal we discussed with ISOLDE target group the feasibility of creating in-beam neutron sources of high intensity and a simple well known spectrum. The main goal of such measurement is to provide the a reference that can be compared to Monte Carlo simulations of the detector response. We identified the decay of ^{49}K as a good compromise of high beam intensity with a spectrum were 3 out of 11 resonances will be fully resolved for 100 cm flight path, as demonstrated in the experiment by Perrot and collaborators, see Fig 4. [Per06].

The ISOLDE target group recently alerted us to the possibility of using ^{17}N as reference decay, extracted as nitrogen oxide [Got14]. This would offer an ideal internal calibration source, as the three know neutron emission line will be fully resolved and can be used to directly obtain the detector response function (see i.e. [Miy03] and Fig. 5).

[Dil03] I.Dillman et al. Phys. Rev. Lett. 91, 162503 (2003).
[Got14] A. Gotberg, Private communication.
[Miy03] H. Miyatake et al., Phys. Rev. C 67, 014306 (2003).
[Per06] F. Perrot et al., Phys. Rev. C 74, 014313 (2006).
[Sar15] P. Sarriguren, Private communication.

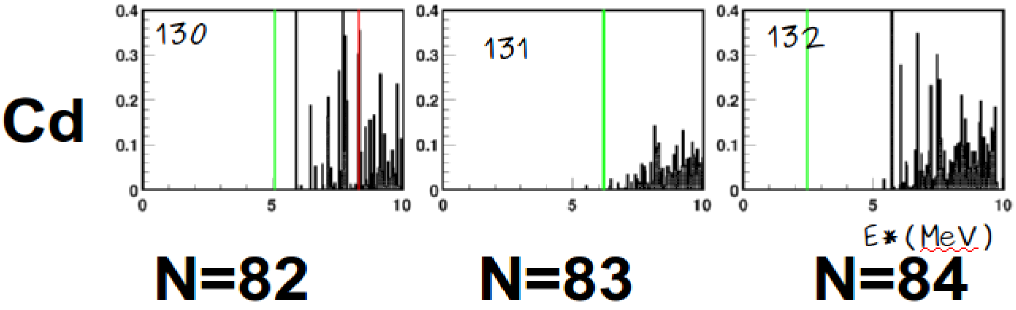

Figure 1: Shell model calculations (this work) of the Gamow-Teller strength in the beta-decay of 130 to 132 Cadmium isotopes presented in Fig. 3 of the proposal. The lowest energy resonances in even In isotopes correspond to individual 2QP states. The resonant maxima at higher energies are almost pure 2QP excitations of the core (see section (i) for more information)

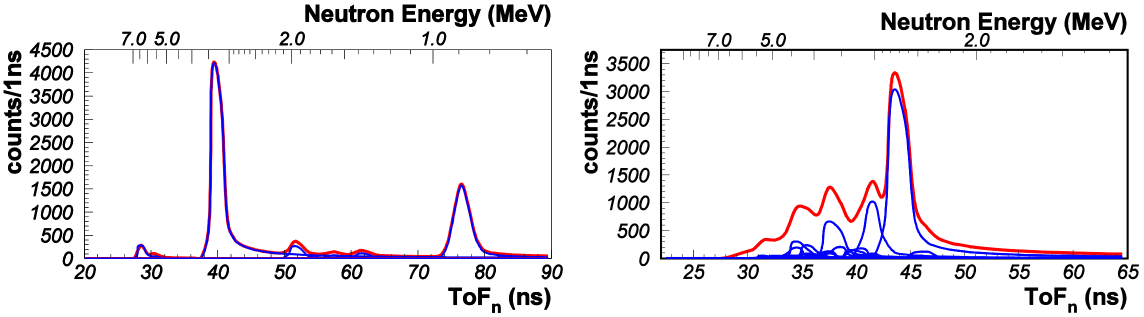

Figure 2: Time of flight distributions from Fig. 5 of the proposal corrected to show 2x10^4 *neutron events.*

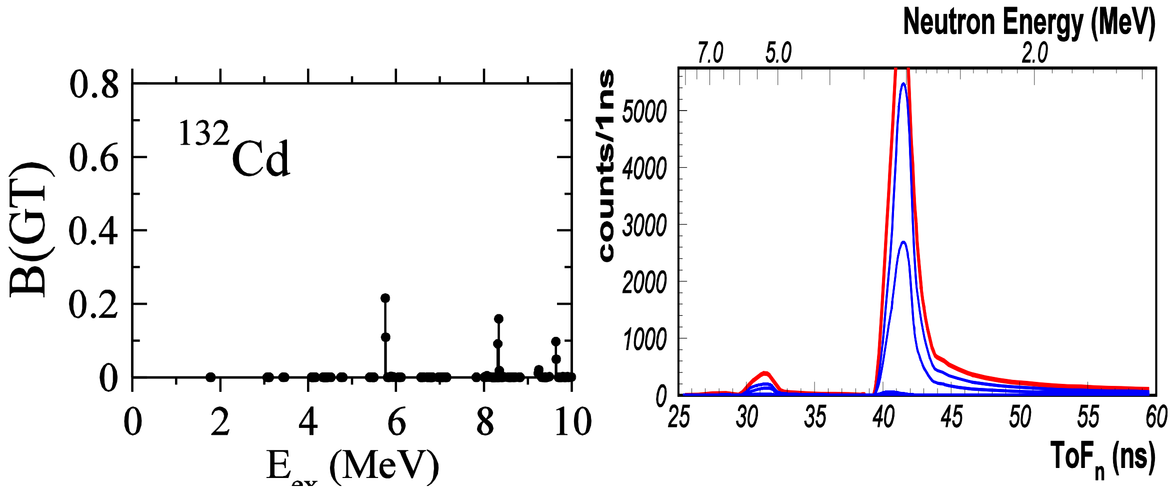

Fig3: Left: Results from QRPA calculations based on a self-consistent mean field obtained with the Skyrme interaction SLy4 and including pairing correlations in BCS approximation [sar15]. A quenching factor q=0.77 is also included. Right: Neutron Time of Flight calculation using the BGT distribution from the right.

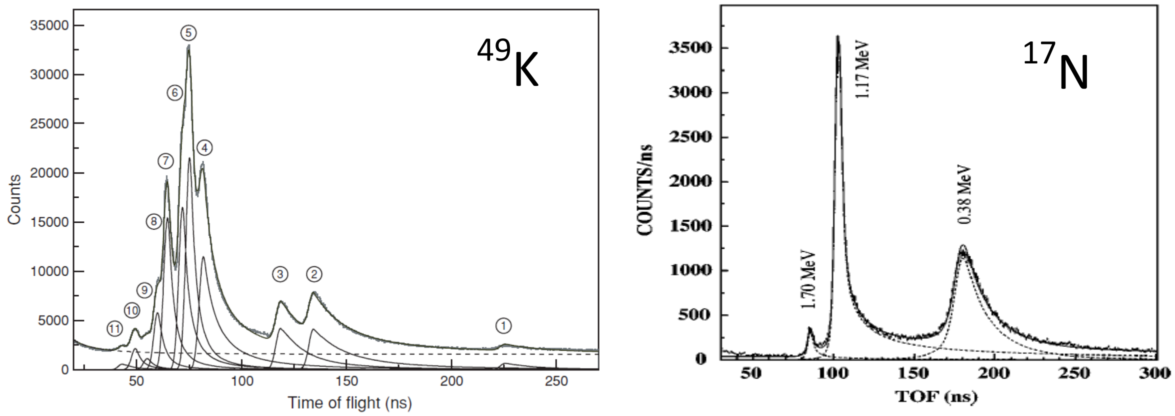

Figure 4: Left: beta-delayed neutron time of flight spectrum of ^{49}K [Per06]. Three resonances at low energy are fully resolved. Right: neutron time of flight for beta decay of ^{17}N [Miy03]. The three resonances are fully resolved at 100 cm flight path.