Fine Structure of the Gamow-Teller and Spin-Dipole Resonances in the $^{90}\mathrm{Zr}(^{3}\mathrm{He},t)^{90}\mathrm{Nb}$ Reaction

Y. Kalmykov[a], T. Adachi[b], G.P.A. Berg[c], H. Fujita[c], K. Fujita[c], Y. Fujita[b], K. Hatanaka[c], J. Kamiya[c], K. Nakanishi[c], P. von Neumann-Cosel[a], V.Yu. Ponomarev[a], A. Richter[a], N. Sakamoto[c], Y. Sakemi[c], A. Shevchenko[a], Y. Shimbara[b], Y. Shimizu[c], F.D. Smit[d], T. Wakasa[c], J. Wambach[a] and M. Yosoi[e]

[a]*Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt 64289, Germany*
[b]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043*
[c]*RCNP, Osaka University, Ibaraki, Osaka 567-0047*
[d]*iThemba LABs, Somerset West, South Africa*
[e]*Department of Physics, Kyoto University, Sakyo, Kyoto 606-8224*

In order to study the fine structure of the Gamow-Teller (GTR) and spin-dipole (SDR) resonances in ^{90}Nb, a $^{90}\mathrm{Zr}(^{3}\mathrm{He},t)$ experiment was performed at RCNP, Osaka by using a 140 MeV/u ^{3}He beam from the $K = 400$ RCNP Ring Cyclotron.

The main aim of the experiment was to search for the fine structure of the Gamow-Teller and spin-dipole resonances which allows to extract characteristic scales. As demonstrated for the isoscalar giant quadrupole resonance in ^{208}Pb, these scales provide a unique insight into the damping of resonances through the internal mixing occurring due to a hierarchy of couplings towards more and more complex degrees of freedom in the nucleus [1]. In addition, through the uncertainty principle, one expects a hierarchy of lifetimes linked to a hierarchy of energy scales. Starting from the typical scale of the order of a few MeV associated with a giant resonance state, the width can go down to scales corresponding to the width of long-lived compound nuclear states, which is of the order of a few eV.

A resolution far better than the momentum spread of the incoming beam was realized by applying the dispersion-matching technique [2] to the system consisting of high-dispersion "WS" course [3] and the Grand Raiden spectrometer [4] placed at 0°. By using the faint beam method to diagnose the matching conditions [5, 6], an energy resolution $\Delta E \leq 50$ keV (FWHM) was achieved and it allowed for the first time to observe the fine structure of the GTR in a heavy nucleus. The energy spectrum is presented in Fig. 1.

In order to extract characteristic scales of the fine structure of the GTR, the entropy index method [1] was utilized. According to this technique, the spectrum is divided in n

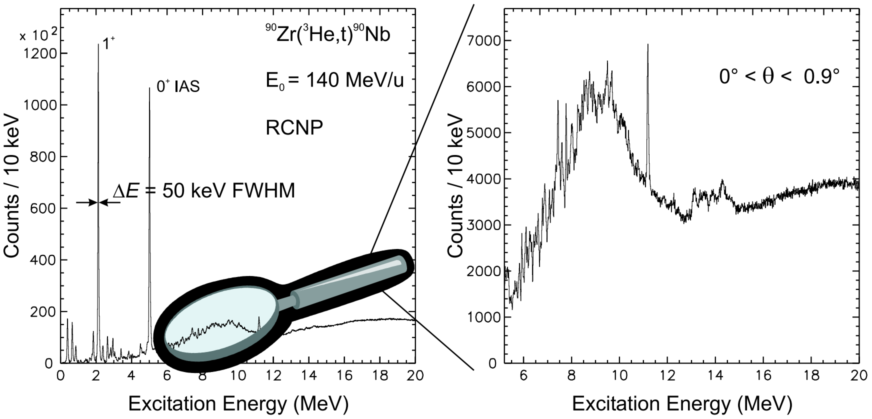

Figure 1: Spectrum of the $^{90}\mathrm{Zr}(^{3}\mathrm{He},t)^{90}\mathrm{Nb}$ reaction at $E_0 = 140$ MeV/u and $\theta = 0°$. A good resolution of less than 50 keV was achieved.

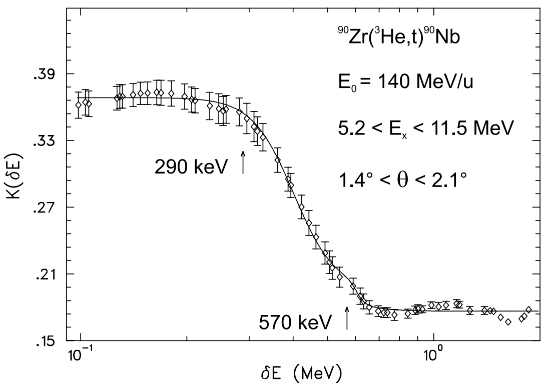

Figure 2: The variation of entropy index as a function of the scale δE for excitation energies $5.2 < E_x < 11.5$ MeV and scattering angles $1.4^\circ < \theta < 2.1^\circ$.

bins of width δE and the so-called entropy index $K(\delta E)$ is calculated at each given scale δE. All necessary details can be found in Ref. [1] and here we summarize the most important properties of $K(\delta E)$ as follows;

- for statistical fluctuations around the mean value $K(\delta E)$ is constant,
- for the appearance of characteristic scales $K(\delta E)$ varies,
- for scales with the most complex configurations $K(\delta E)$ is maximal,
- change of $K(\delta E)$ means onset of a new scale.

In the analysis the excitation energy region $E_x < 5.2$ MeV was excluded since a strong peak like the isobaric analog state at 5.01 MeV is outside the scope of the method. The rest was divided into two parts, below and above 11.5 MeV, and each of them was analyzed separately. In addition, four cuts in the scattering angle were set to see an evolution of the characteristic scales with increasing scattering angle. As an example, the variation of the entropy index is shown for $5.2 < E_x < 11.5$ MeV and $1.4^\circ < \theta < 2.1^\circ$ in Fig. 2. From the bend of the curve, two scales are observed at 290 keV and at 570 keV. They are also observed for other scattering angles in the same region of excitation energy.

Being fast and unrestricted on the number of scales, the entropy-index method is a versatile tool to unravel the fine structure of giant resonances. However, it does not give any information about position of extracted scales in the spectrum, and it is impossible to estimate the importance of different scales because no inverse transform can be carried out. Wavelet analysis [7] is expected to be the most effective tool to gain a deeper insight into different aspects of the fine structure. It enables us not only to localize extracted scales and check their contributions in the spectrum, but also gives us a possibility to investigate self-similarities and fractal nature of the spectrum [8]. Adaption of wavelet analysis to our specific requirements is now in progress.

References

[1] D. Lacroix *et al.*, Phys. Lett. B **479** (2000) 15-20.
[2] Y. Fujita *et al.*, Nucl. Instrum. Meth. Phys. Res. B **126**, 274 (1997); and references therein.
[3] T. Wakasa *et al.*, Nucl. Instrum. Meth. Phys. Res. A **482**, 79 (2002).
[4] M. Fujiwara *et al.*, Nucl. Instrum. Meth. Phys. Res. A **422**, 484 (1999).
[5] H. Fujita *et al.*, Nucl. Instrum. Meth. Phys. Res. A **484**, 17 (2002).
[6] Y. Fujita *et al.*, J. Mass Spectrom. Soc. Jpn. **48(5)**, 306 (2000).
[7] I. Daubechies, Ten lectures on wavelets (SIAM, 1992).
[8] H. Aiba and M. Matsuo, Phys. Rev. C **60** (1999) 034307.