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Letter of clarification to the

ISOLDE - Neutron Time-of-flight Committee

We are writing to clarify doubts around our proposal INTC-P-210 submitted before the previous INTC meeting in May 2006. The proposal suggested a feasibility of Coulomb Excitation measurement of the electromagnetic properties of the unstable ^{94}Kr nucleus.

Presented proposal demonstrates the possibility of observing Coulomb Excitation of the first excited 2^+ state of this nucleus. Data collected during an experiment will most probably be sufficient to derive the reduced E2 matrix element of the related $2^+ \rightarrow 0^+$ transition and a slight chance to achieve an experimental sensitivity to the diagonal E2 matrix element of the 2^+ state was mentioned.

The nuclear structure of neutron rich krypton isotopes was extensivly discused in various papers, the newest being published only a few weeks ago providing new mass measurements of neutron-rich Kr-isotopes using the ISOLTRAP mass spectrometer [1].

The nuclei of interest are located roughly in the middle of the Z=28 and Z=50 shell closures, where competition of various structures and shapes at low-excitation energy occurs. Adding only a few neutrons to the N=50 shell gap, collective features should quickly occure. Such behaviour is known from the Z=42 molybdenum isotopes. In contrast, especialy in the Z=38 isotopes a strong shell closure at N=56 (filled $2d_{5/2}$ shell) were found (^{96}Zr). The N=56 sperical gap was interpreted to be reinforced by the Z=40 shell gap, i.e. it should quickly disappear moving away from Z=40. In fact, no influence of this shell gap was found in Z>40 isotopes like molybdenium and rutenium. In the case of krypton isotopes this picture seems not to be valid anymore, because the 2_1^+ energy peaks at N=56 again. This peak is not as strong as in the case of the Z=38,40 isotopes, but as mentioned in [2], the effective N=56 shell gap in ^{92}Kr has to be considered even more than the apparent increase of E(2_1^+) due to the opposite behaviour of the molybdenium and strontium isotopes.

On the other hand, in reference [2] it was pointed out that ^{92}Kr seems to be quasi-spherical what again raises the question about an interpretation of the observed increase of E(2_1^+). It was mentioned, that octupole instability may be responsible for this effect.

This leads to another important topic of neutron-rich krypton isotopes, namley the onset of deformation. In the Sr and Zr nuclei the behaviour of B(E2) values is unique. In [3] it was pointed out that no other nuclei exhibit such an abrupt and large change in B(E2) values from spherical values of about 8 W.u. to deformed values of about 100 W.u. leading to a suggested phase transition in the Sr and Zr collectivity. In the case of krypton isotopes, the ground state deformation seems to be placed at higher masses. In [4] the authors expect shape coexistence for krypton nuclei with masses A≥94 from finding similarities of ^{95}Sr and ^{93}Kr nuclei.

In [4] (in contrast to the above) the N=56 shell gap was mentioned to be still effective for the Z=36 krypton isotopes. Because in the Sr isotopes the onset of deformation starts at N=58 and the phase transition is already through at N=60, our proposed experiment on ^{94}Kr deals with the first candidate for this onset of deformation. In contrast, in [5] no deformation was found for this nucleus from laser spectroscopy data and was suggested to take place for nuclei at higher masses.

To conclude, both the role of the N=56 shell closure and the onset of deformation in neutron-rich krypton isotopes is not understood. This situation of lacking data for neutron-rich krypton nuclei was summarized in [4]: *"Hence, it would be of great interest to search for fingerprints of deformation in even heavier Kr isotopes, although still today this represents a real experimental challenge"*. From our point of view, the meassurement of the ^{94}Kr B(E2) value is an important step to search for this fingerprint. It would give deeper insight into the complicated interplay between N=56 shell closure and onset of deformation in neutron-rich krypton isotopes.

The proposed experiment should be understood as a contribution to systematic measurements of reduced transition probabilities in the neutron-rich krypton chain and as a first step towards possible experimental shape determination giving basic results for a future measurements. These would employ wider variety of beam energies and target masses. Further beam intensity increase would be the most desirable improvement of experimental opportunities.

To be more specific, we show the results of theoretical calculations assuming the Raman systematics (see original proposal) value of transitional $\langle 2_1^+ \| E2 \| 0_{gs}^+ \rangle$ matrix element (0.44 eb) and a bit optimistic value of diagonal $\langle 2_1^+ \| E2 \| 2_1^+ \rangle$ matrix element based on rotational model assumption (-0.52 eb). Putting this positive one may calculate the 2^+ state population cross section and compare it to the original result for the negative value. This is a measure of a "pure" sensitivity to the diagonal matrix element and was plotted on Figure 1. below.

As it can be noted, while the relative sensitivity to the absolute value of diagonal matrix element seems to have a peak in the intermediate beam energies around 230 MeV, higher beam energies are favoured due to higher counting rates.

Being sensitive to the diagonal matrix element means that two unknown parameters have to be found instead of one. Therefore at least two complementary experiments have to be done to get at least two independent data points. Such experiments may differ with beam energy, target mass or angular range. Since it is not sure if the collected statistics will be enough for the whole task, the safest way is to look for the Q sensitivity in the angular distribution of cross section.

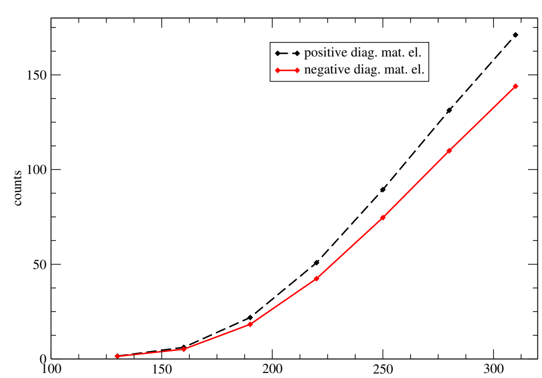
Figure 2. shows the angular distribution of the yield for the positive and negative sign of the diagonal matrix element assumed. It can be noted that low angle scattering is much less sensitive to the sign than the high angle one which can be used for simultaneous fit of

both transitional and diagonal matrix elements.

Whereas obtained theoretical counting rates and sensitivities are encouraging, there are many effects (absolute values of matrix elements, their correlations, radioactive random coincidence background etc.) that are limiting our expectations. Therefore we believe that whilst transitional matrix element is within easy reach, reality may frustrate our desire to measure the diagonal matrix element of the 2^+ state.

It is worth mentioning that we have analysed our data on the ^{88}Kr and ^{92}Kr nuclei succesfully. To do so, we used the newly developed version of the Coulomb Excitation Data Analysis Code GOSIA 2 [7] that allows simultaneous fitting of projectile and target excitation to find the unknown matrix element describing the first 2^+ state excitation properly normalized to the known target excitation probability. It was shown that the GOSIA 2 code is consistent with the original GOSIA code as well as with the "CLX" code, which is widely used in the MINIBALL collaboration.

Our preliminary results were presented on the 28^{th} course of the "Erice International School on Nuclear Physics" at the end of September this year. Our value of 0.51(15) eb for the ^{92}Kr case shows that the estimated value for the ^{94}Kr matrix element of 0.5 eb (see original proposal) is realistic and that the estimate of counting rates given is still valid.



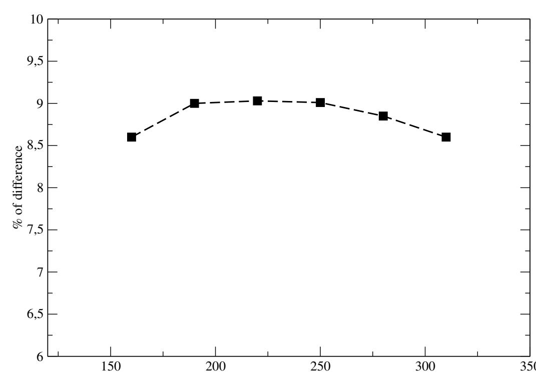


Figure 1: **Left:** Counts per hour expected in the $2^+ \rightarrow 0^+$ line for positive and negative value of the diagonal matrix element as a function of beam energy. 2 mg/cm^2 ^{108}Pd target is assumed.
Right: Difference-to-yield ratio $\left(\frac{Y^+ - Y^-}{Y^+ + Y^-} \times 100\%\right)$ resulting from the data presented in previous figure

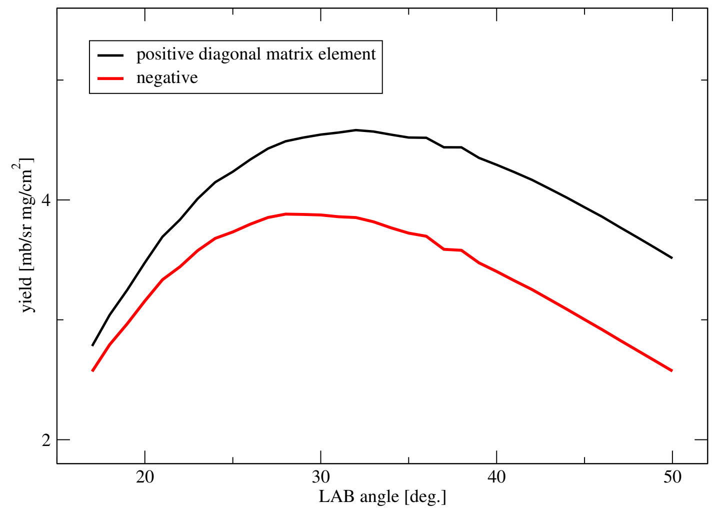


Figure 2: Angular distribution of integrated (over 1° slices and 2 mg/cm^2 target) Coulex yields for positive and negative diagonal matrix element value. 250 MeV beam energy is assumed.

References

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