RISING at Relativistic Energies

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The RISING (Rare ISotope INvestigations at GSI) project [1] combines the EUROBALL Cluster Ge-detectors [2] and the fragment separator FRS [3] for high-resolution γ-ray spectroscopy measurements after in-flight isotope separation. In a first campaign relativistic Coulomb excitation of radioactive projectiles and the spectroscopy of nuclei excited in secondary fragmentation reactions were examined and first preliminary results of the data analysis are reported.

The exotic beams were produced by fragmentation of a heavy stable primary beam on a ^9Be target at the entrance of the FRS. The FRS was operated in a standard achromatic mode, which allowed a separation of the beam of interest by combining magnetic analysis with energy loss in matter. The transmission through the FRS was typically $20 - 50\%$ depending on the actual isotope. The separated ions were identified on an event-by-event basis with respect to mass and atomic number via combined time-of-flight, position tracking, and energy loss measurement. The standard particle identification setup consisted of plastic scintillators, multiwire proportional chambers (MWPC) and a MUSIC ionisation chamber, which were optimised for high event rates ($\leq 50\ kHz$). After passing the identification system the radioactive ions at relativistic energies were focussed onto a secondary target of 7x7 cm^2 dimension, positioned approximately 4 m behind the last FRS magnet in the experimental area S4. For the excited fragments moving at a high velocity ($\beta = 0.43$ at a fragment energy of 100 $A \cdot MeV$) the Ge detectors had to be positioned at forward angles in order to maximize the effective solid angle affected by the Lorentz boost and to minimize the Doppler broadening. For optimum packing the 15 Cluster Ge-detectors were arranged in three rings around the beam pipe, with the axis of the central detectors in each ring positioned at 15^o, 33^o and 36^o. A design goal for the array was to obtain about 1% energy resolution for a γ transition, emitted from a nucleus moving at $\beta = 0.43$. This criterion defined the target distance of the first, second and third ring to 68 cm, 112 cm and 137 cm, respectively. If all rings were placed at a minimum distance of $\sim 70\ cm$, the configuration would reach a maximum total efficiency of 2.9%, however the resolution of the detectors in the 2^{nd} and 3^{rd} rings would be significantly worse. Behind the target the calorimeter telescope, CATE, was used for reaction channel selection. CATE consists of an array of 9 pairs of position sensitive Si $\triangle E$ detectors (lab. angular range $\pm 3^o$) and thick CsI scintillators for total energy measurement E with a measured resolution of $\approx 1/100$. The element number was determined from the $\triangle E/E$ correlation between both detectors (see figure 2). For the mass identification the combined $\triangle E + E$ information was used to extract from the total kinetic energy the mass number assuming the same fragment velocity. The mass resolution should be sufficient to discriminate single masses for medium heavy nuclei ($A \approx 60$).

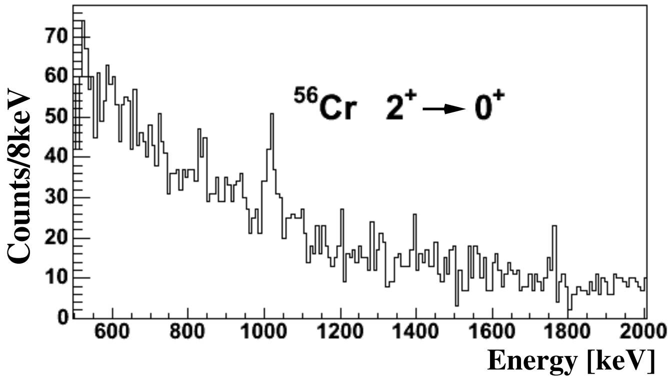

Figure 1: Doppler corrected γ-ray spectrum from intermediate-energy Coulomb excitation of a ^{56}Cr beam on a 700 mg/cm^2 gold target at 136 $A \cdot MeV$.

After the successful RISING commissioning beam time with a stable ^{84}Kr beam, two relativistic Coulomb excitation experiments with secondary beams were performed to measure $B(E2; 2^+ \rightarrow 0^+)$ values of transitions depopulating the first excited state to the ground state in ^{56}Cr and ^{108}Sn.

Aim of the first experiment was the investigation of possible sub-shell closures at N=32,34. The neutron rich ^{56}Cr nuclei were produced following the projectile fragmentation of a 419 $A \cdot MeV$ ^{86}Kr primary beam impinging on a 4 g/cm^2 ^9Be target. After fragment identification (FRS), the ^{56}Cr ions with an energy of 136 $A \cdot MeV$ were scattered on a 1 g/cm^2 Au target at the final focal plane. Inelastic scattering was selected by impact parameter measurement and identification of the element number after the target (CATE). The scattering angle was determined by tracking the incoming projectiles with two multi-wire proportional chambers and the outgoing particles with the position sensitive Si-detectors of the CATE array. For the Coulomb excitation an angular range between 0.3 and 2.0 degrees in the laboratory system was selected in order to separate elastic scattering and nuclear reactions. Since various fragments are produced in the target, the Cr ions must be identified among the out-going particles. In the current analysis, the element number Z=24 was selected in the CATE array using the $\triangle E/E$ measurement. Since the energy of the ^{56}Cr secondary beam was not well defined, having an energy distribution with a $FWHM \sim 3\%$, the velocity β was calculated from the TOF measured with two plastic scintillators. The measured velocity β was used for the Doppler shift correction. Figure 1 shows a Doppler corrected γ-ray spectrum for ^{56}Cr. A γ-ray line of the first $2^+ \rightarrow 0^+$ transition at 1006 keV is clearly seen and its FWHM and significance of the peak are 1.5% and 8σ, respectively.

Main motivation for another experiment was the search for excited states in exotic proton-rich nuclei in the

$f_{7/2}$ shell. In particular, the principal aim was to detect excited states in N=Z-3 ($T_z = -3/2$) nuclei such as ^{53}Ni and to investigate, through comparison with the mirror nuclei (e.g. $T_z = +3/2$ ^{53}Mn), the Coulomb energy differences. In this way one can study the extent to which isospin symmetry holds as the drip-line is approached. To study ^{53}Ni, a secondary fragmentation experiment was performed. A primary beam of 600 $A \cdot MeV$ ^{58}Ni impinged on a 2.3 g/cm^2 ^9Be primary target. The produced fragments were separated, identified and selected by the FRS to yield a secondary beam of ^{55}Ni at 171 $A \cdot MeV$. These ions were bombarded on a second ^9Be target with a thickness of 0.7 g/cm^2 at the target position of RISING. Fragmentation reactions occurred in the secondary target, the prompt γ-rays from which were recorded in Cluster Ge-detectors. The final nuclei produced were identified with the CATE array, as can be seen in figure 2 for reactions with ^{55}Ni on a ^9Be target at a beam energy of 171 $A \cdot MeV$.

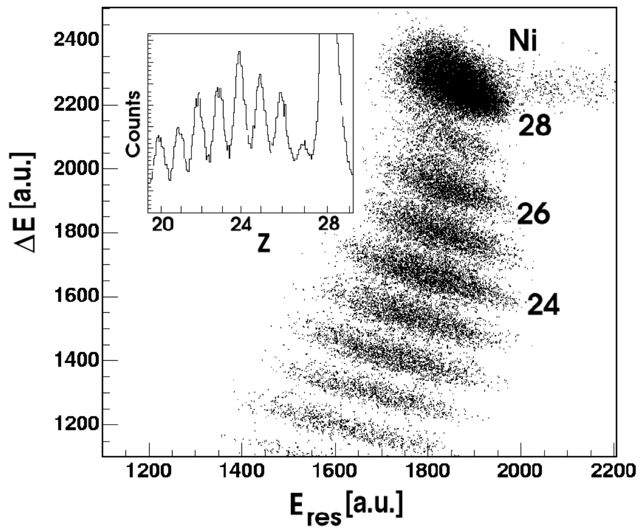

Figure 2: Particle identification with CATE using the $\triangle E/E$ correlation for reactions of a ^{55}Ni beam on a Be target at a beam energy of 171 $A \cdot MeV$.

The preliminary data analysis did not include tracking of the fragments and it was assumed that the out-going fragment travels on the principal axis of the beam optics with a velocity $\beta = 0.45$. In addition the γ-ray multiplicity was set to $M_\gamma = 1$ which was determined for $E_\gamma \geq 500\ keV$ in the laboratory frame. Since the analysis on the mass identification of CATE is still in progress, γ-ray data are only sorted for different element number. Figure 3 and 4 show Doppler corrected γ-ray spectra with selections on Fe and Cr nuclei, respectively. The γ-ray energies are slightly shifted as compared to literature values and the peaks are broader than expected. Nevertheless, even at this preliminary stage and with only a rough Doppler correction applied, the quality of the spectra is very encouraging.

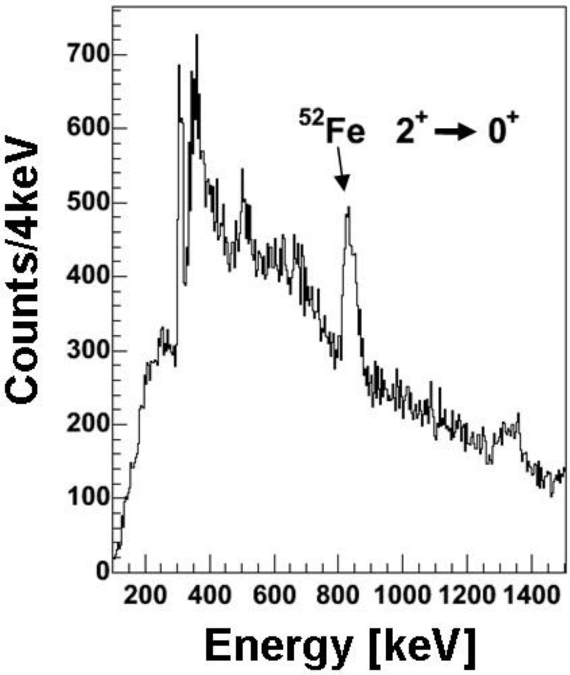

Figure 3: Doppler corrected γ-ray spectrum from the secondary fragmentation reaction of a ^{55}Ni beam on a Be target with a selection on Fe (Z=26) nuclei.

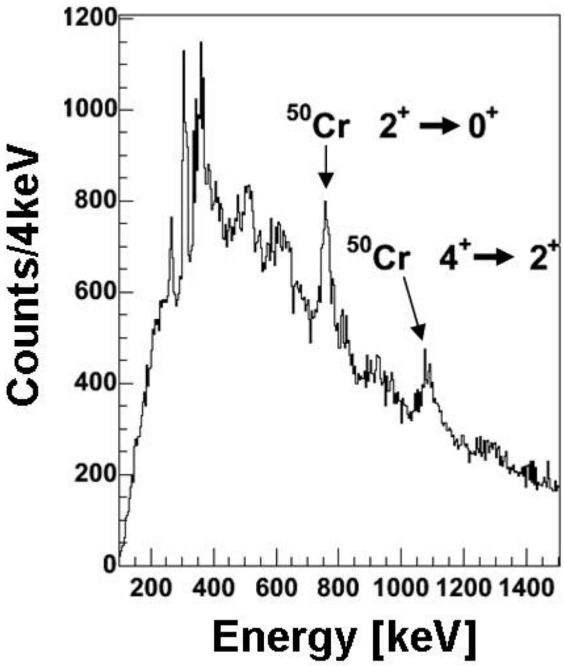

Figure 4: Doppler corrected γ-ray spectrum from the secondary fragmentation reaction of a ^{55}Ni beam on a Be target with a selection on Cr (Z=24) nuclei.

References

[1] http://www-aix.gsi.de/ wolle/EB_at_GSI

[2] J. Simpson et al., Z.Phys. A358 (1997) 139.

[3] H. Geissel et al., Nucl. Instr. Meth. B70 (1992) 286.