Direct mass measurement of short-lived fission products at FRS-ESR

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Direct mass measurements are key experiments for the exploration of unknown territory in the chart of nuclei. Neutron-rich nuclei are of special interest because they play an important role in stellar nucleosynthesis, which progresses along the r-process path through the area of neutron-rich nuclei.

Many masses of neutron-rich nuclei, produced by fission of an uranium primary beam, have been investigated in a recent FRS-ESR experiment employing isochronous mass spectrometry (IMS) [1]. The nuclei of interest were produced and separated with the FRS, and the ESR was used as a high-resolution time-of-flight mass spectrometer. A peculiarity of the fission kinematics of relativistic projectiles can be used in order to inject efficiently the most neutron-rich isotopes and suppressing at the same time the much more abundantly produced isotopes closer to the stability line. This can be understood from Fig. 1. The figure

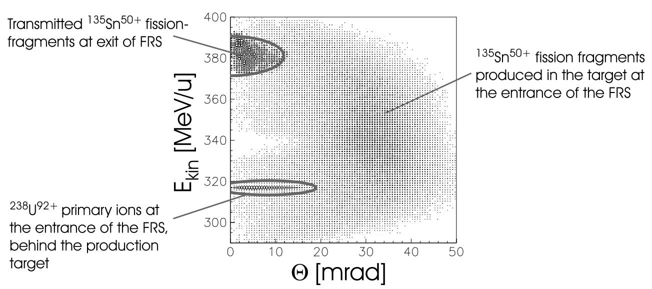

Figure 1: Result of a MOCADI simulation [2]: energy distribution of $^{135}Sn^{50+}$ fission fragments as a function of the spatial angle relative to the direction of the incident primary beam.

shows the kinetic energy of $^{135}Sn^{50+}$ fission fragments as a function of the spatial angle when leaving the production target at the entrance of the FRS. In the center-of-mass system the fission fragments are spatially isotropically distributed and both fragments share unequally the available energy (which is the energy equivalent of the mass difference between the projectile and the sum of both fragments). In the laboratory frame, the fission fragments cover a wide range of kinetic energies, depending on the angle of emission relative to the direction of the primary beam. The fragments emitted in forward direction leave the target with a velocity, which is up to 6 % larger than that of the primary beam. Optimizing the FRS-ESR settings on these 'fast' fragments, the neutron-rich isotopes are preferably transmitted and the less neutron-rich fragments, which are 'slower', are suppressed.

Fig. 2 shows the corresponding mass spectrum for a setting, which is optimized for $^{135}Sn^{50+}$. The spectrum was accumulated during ≈ 50 hours, with a primary beam intensity of constantly $2 \cdot 10^9$ uranium ions per pulse (every 15 s a pulse was fast extracted from the SIS). A large number of nuclides is observed, a large range of ele-

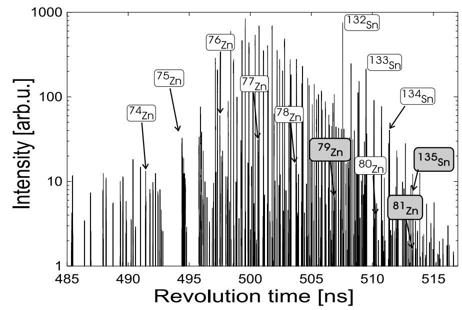

Figure 2: Revolution-time spectrum of fission fragments in the ESR, obtained with Isochronous Mass Spectrometry. The observed zink-(Z=30) and tin-isotopes (Z=50) are labeled. ^{79}Zn, ^{81}Zn und ^{135}Sn are the isotopes of these elements, whose masses are so far unknown.

ments and masses is covered, and thus a large m/q range ($\Delta(m/q)/(m/q) \simeq 13$ %) can be investigated simultaneously.

The mass of many nuclides, which is so far only known from theoretical predictions, is determined for the first time in this experiment. A preliminary overview is given in Fig. 3. These new mass data are of particular in-

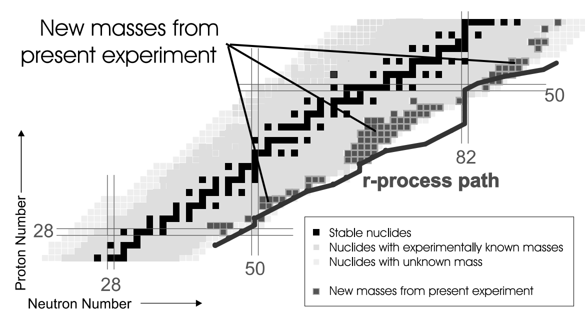

Figure 3: Part of a schematic chart of nuclei. Atomic masses, which have been determined for the first time in this experiment with respect to [3] are indicated.

terest in nuclear astrophysics, where Q-values, neutron-separation energies, and half-lives are needed for nuclear-reaction network calculations, which aim at modeling the true r-process path in nucleosynthesis and the understanding of the observed elemental and isotopic abundances in the solar system [4]. The data in the vicinity of closed shells ($N = 50, 82$, $Z = 28, 50$) and especially in the vicinity of double shell closures will allow the investigation of the isospin dependence of shell effects and possible new phenomena like shell quenching.

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