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Status report to the ISOLDE and Neutron Time-of-Flight Committee

Study of the Di-nuclear System ^{A}Rb + ^{209}Bi ($Z_1 + Z_2 = 120$)

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Abstract

We present the status of our experiment IS550, collisions of ^{A}Rb + ^{209}Bi, aiming to the search for possible new shell closures in the region of superheavy elements at Z=120, N=184. For this experiment, a total of 12 shifts was granted, based on the letter of intent from October 1, 2012 **(CERN-INTC-2012-043, INTC-P-344).**

Total of granted shifts: 12
Remaining shifts: 12

I. Experimental program

The location of the next spherical shell closures beyond Z = 82, N = 126 is still an open question. According to model predictions, shell closures are expected in the region of superheavy nuclei at Z = 114 or 120 or 126 and N = 184 and should lead to a so-called "island of stability". The available experimental data do not yet allow to answer the question. Known nuclei with Z = 114 are too neutron-deficient with respect to the N = 184 shell and nuclei with Z = 120 and beyond are still unknown. Figure 1 (left) shows the presently known isotopes of superheavy elements.

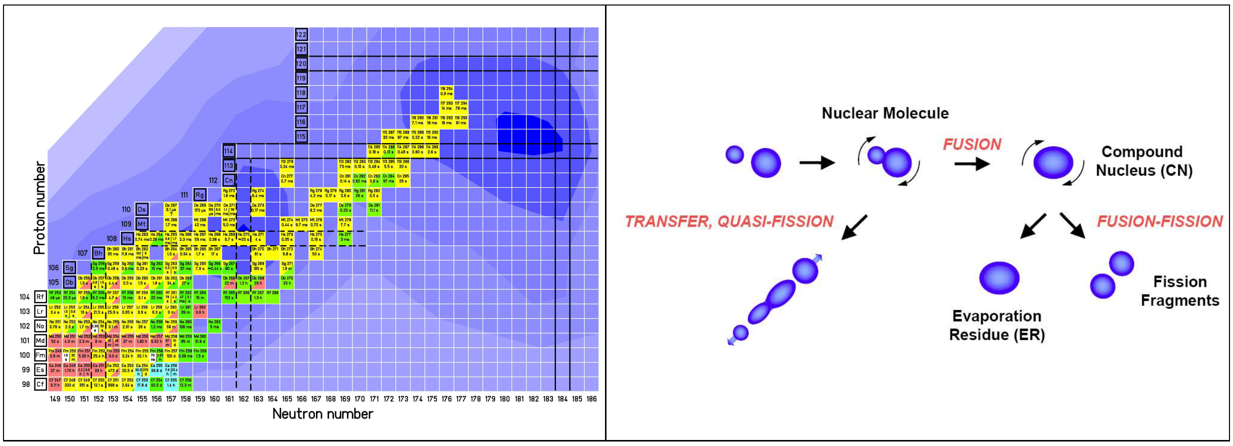

Figure 1. left: Presently known isotopes of superheavy elements. The blue background represents the expected stability of the nuclei and the location of the "island of stability" according to one of the theoretical models, which assumes the magic number at Z=114. If the next magic number is 120, the island would be shifted upwards, accordingly. right: Illustration of nuclear reaction paths in collisions of heavy ions at Coulomb-barrier energies.

Presently, the only method to synthesize superheavy nculei is complete fusion reactions. However, fusion reactions with stable projectile and target nuclei do not provide enough neutrons to reach the N=184 shell. Fusion reactions with neutron-rich radioactive ion beams (RIBs) would in principle solve the problem. However, the realization of fusion-evaporation reactions with RIBs is prevented by the still much too low intensities of appropriate neutron-rich projectiles, regarding the tiny production cross-sections of superheavy evaporation residues.

We proposed the so-far unique approach to explore a possible influence of shell closures at Z = 120, N = 184. This is: by studying quasi-fission (QF) and fusion-fission (FF) reactions with very neutron-rich ion beams. The processes of QF and FF are illustrated in Fig. 1, right, which shows the evolution of a heavy nuclear system at Coulomb barrier energies. The first step is the mutual capture of projectile and target nuclei, leading to the formation of a molecule-like nuclear system. After capture, the system evolves by exchanging nucleons. In the extreme case, the nuclei fuse and a compound nucleus (CN) is formed. The CN de-excites by evaporating nucleons or by fission (equivalently**,** FF). But the nuclear system can also re-separate before CN formation, resulting in QF. The capture cross-section is the sum of QF, FF and fusion-evaporation residue (ER) cross-sections:

$$\sigma_{capture} = \sigma_{QF} + \sigma_{FF} + \sigma_{ER}$$

For light nuclear systems, $\sigma_{capture} \approx \sigma_{ER}$. But in very heavy systems the strong Coulomb repulsion and large angular momenta lead to tiny probabilities for CN formation and survival, and with this to the tiny values of σ_{ER}. In this case, $\sigma_{fusion} \approx \sigma_{QF} + \sigma_{FF}$. The capture cross-section can adopt values up to ~100 mb, which leads to the same large values for the sum ($\sigma_{FF} + \sigma_{QF}$); this makes experiments with low-intensity RIBs feasible. Especially Rb beams are very suitable, because relatively high intenstities are still available for the needed very neutron-rich Rb isotopes.

The idea behind the experiment is that shell effects are not only revealed by the properties of ER, but act already in the molecule-like nuclear system before it approeaches complete statistical equilibrium. If shell effects occur, they should be reflected by the mass (charge) and total kinetic energy (TKE) distributions of the QF fragments. As well, they would be revealed by the respective distributions of FF fragments. Our experimental program comprises the study of mass and TKE distributions of QF and FF fragments as a function of projectile neutron-number and beam energy at energies around 5 MeV/nucleon.

II. Experimental setup and technique

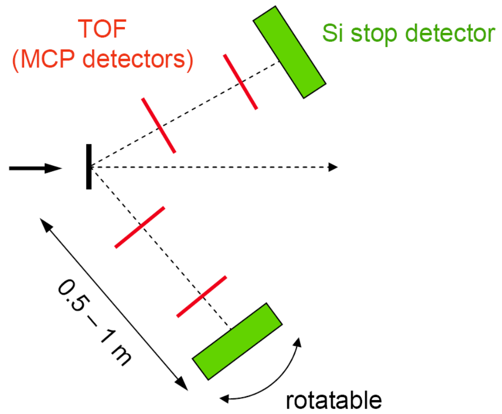

Figure 2. Scheme of the CORSET detection system.

To measure the mass and TKE spectra, we will use the CORSET (CORrelation SETup) detector system from JINR Dubna [1] (Fig. 2). The original CORSET has two TOF-E arms, which can be positioned at different angles with respect to the beam axis. Each arm consists of a micro-channel plate (MCP) based start detector, a position sensitive MCP based stop detector and a silicon strip detector where the particles are implanted and their energy is measured. The time resolution is typically 150 ps which allows for setting the TOF distance to (10 – 20) cm, such providing a mass resolution of $\Delta A/A \approx 1.5\%$ corresponding to three to four units for very heavy nuclei.

III. Relevance and status of the experiment

Originally, the experiment IS550 was planned for October-November 2018, but finally did not match the beamtime schedule. Therefore, the 12 originally granted shifts are still remaining.

The **scientific relevance** of the experimental program is unchanged since our proposal in 2012. Till today, the question of magic shells in the region of superheavy nuclei is open. And there is no other presently possible approach to investigate the region of the N=184 neutron shell.

HIE-ISOLDE is so far the unique facility which provides the necessary infrastrucutre and very neutron-rich beams at energies around 5 MeV/u.

The following upgrades / changes of the detection system were performed:

1. New detectors, based on microchannel plates (MCP) to measure fragment velocities using the time-of-flight (TOF) technique, were designed and produced specially for this task. The registration efficiency of these new detectors is 2 times higher. Two vertical arms were also added to the setup. With this, the registration efficiency of CORSET setup increased by 4 times.

2. To measure the fragment energy (TOF-E technique), strip detectors were added in each vertical arm of the spectrometer. The use of strip detectors and the TOF-E method allows to increase considerably the quality and reliability of the experimental data.

3. A new reaction chamber was designed and produced.

4. Preliminary tuning and calibration of the CORSET spectrometer to prepare for the experiment at CERN were performed at the Department of Physics of Jyvaskyla University.

5. We prepared a new DAQ and data analysis system, based on the MBS and GO4 system, respectively, from GSI Darmstadt.

References:

[1] E.M.Kozulin et al. The CORSET Time-of-Flight Spectrometer for Measuring Binary Products of Nuclear Reactions, Instruments and Experimental Techniques, 2008, Vol. 51, No.1, pp. 44–58.