Study of K_x-Ray Multiplicities of Evaporation Residues from Fusion Using the MINIBALL Clusters at the MLL

S. Reichert, C. Berner, D. Mücher, R. Gernhäuser, W. Henning, S. Klupp, K. Nowak, L. Maier, D. Seiler
Physikdepartment E12, Technische Universität München

Abstract

The production of heaviest elements is usually done by fusion of accelerated ions with heavy nuclei as targets. The initial decay of the highly excited compound nucleus is very fast and takes place in general by particle emission. Below the particle thresholds the remaining evaporation residues decay by electromagnetic transitions to their ground states, mostly by fast gamma-ray emission. Detection of characteristic γ-rays is in principle an elegant method for the identification of the fusion evaporation residue. Unfortunately, for exotic nuclei, the energies of the γ-rays are often not known and typical peak efficiencies strongly decrease for higher energy transitions. An alternative for element identification represents the measurements of prompt characteristic K_x-rays which originate from internal conversion of electromagnetic transitions. Theoretical considerations provide estimates for the multiplicity M of K_x-rays in the deexcitations of the evaporation residues as a function of mass number A. In the framework of a Bachelor- (C. Berner) and a Master- (S. Reichert) thesis we investigated the K_x-multiplicity of medium heavy and heavy isotopes to study the influence of nuclear structure systematically.

EXPERIMENTAL SETUP

For the production of super heavy elements very intense beams (approx. 1 particle-μA) are requested and large scale separators are used for the experiments. Although super heavy elements can't be sufficiently produced at MLL facility, we performed an experiment to study the method of element identification by K_x-rays in a similar harsh environment at the production target.

One major problem is the rate of γ-decays from fission, which produce such a large background in the γ-ray detectors that in-beam spectroscopy is hardly possible. A reduction of fission γ-rays might be achievable by exploiting the angular distribution of the fission and fusion products. An appropriate shielding which suppresses more photons from the fission than from the fusion is supposed to reduce the background and to increase the contribution of fusion γ-rays in the spectra.

MINIBALL-detectors and electronics

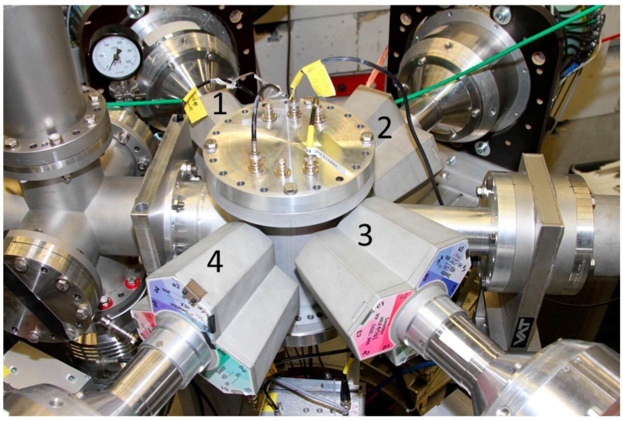

Figure 1: Detector array. The beam line is from left to right. The detectors are numbered clock-wise.

Fig. 1 shows the setup for the experiments. Four MINIBALL- detectors surround a newly- designed chamber optimized for this special challenge. The centers of the detectors are directed on the target position and are symmetrical with respect to the beam line. The detectors, labelled with 1 and 4, are positioned in backward direction, the detectors 2 and 3 in forward direction. The energy signals are filtered by analogue fast shapers (STM-16, Mesytec) and digitized by standard VME peak sensing ADCs.

Target chamber and implantation plate

The target chamber is a new design and optimized for K_x-ray experiments, utilizing aluminum and a wall thickness of 2 mm for an optimized transmission of the low energy K_x-rays. Most of the beam is elastically scattered at small angles and not stopped in the thin target ($d < 1\ mg/cm^2$). On the exit side a long vacuum pipe ($\varnothing$ 100 mm) was mounted to guide unreacted beam and reaction products to the beam dump three meters downstream.

For the correct recording of decays of evaporation residues an implantation plate was mounted at a distance of 10 cm from the target which catches evaporation residues. The plate can be seen in Fig. 2. A hole in the plate was necessary to let the beam pass and as a consequence also a part of the evaporation residues. Hence, only nuclei that deviate at least $1.2°$ from the beam direction are implanted. This ensures that isomeric states are also recorded. For the analysis of well known nuclei we determine the number of produced evaporation residues by counting low lying transitions. To achieve this the level scheme with the isomer states has to be known and the angular distribution of the cross section is necessary.

Lead Shielding

A great challenge for fusion- experiments with heavy nuclei is the detection of rare events in a spectrum with very high fission background radiation. The kinematics of fission and fusion events shows a significant difference. In contrast to the evaporation residues with forward momentum, fission products are emitted more isotropically. Therefore, the shielding "pot" (see Fig. 2) was developed with a slit and a beam entrance and exit. The shielding is provided by $1\ cm$ thick lead and corresponds to an absorption of 90% for γ-rays with an energy of $500\ keV$.

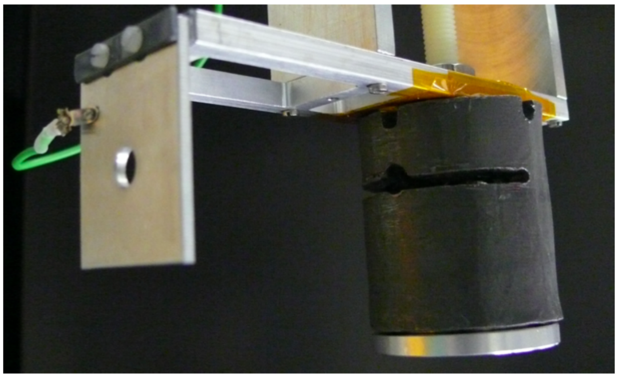

Figure 2: Installation of the lead pot together with the implantation plate.

The slit is necessary to detect decays from the forward boosted fusion compounds which take place still in the pot. While the detectors in the horizontal plane have a nearly open view on the trajectories of the forward emitted fusion components, the fission products have the visible area at large angles. With this configuration, the observed yield of the γ-rays from fission is more reduced than the inevitably reduced yield of the photons emitted from evaporation residues.

From a comparison of photons from fusion and fission before and after mounting the shielding, a remarkable reduction factor $r = 7$ for the background was derived.

Analysis method

By $\gamma - \gamma$ coincidences the energy spectrum is sufficient purified and the number of evaporation residues N is determined by appropriate counting of the occurring lines which belong unambiguously to the evaporation residue and, since both the transition lines and the K_x-rays radiate isotropic, the multiplicity M_K results from the quotient of the number N_K of detected K_x-rays and the amount of evaporation residues N_γ: $M_K = N_K/N_\gamma$.

The great advantages of this method are a purified spectrum and the elimination of the absolute efficiency, as only relative efficiencies are used. A further important aspect is that cascades which do not emit K_x-rays are included in the statistics. The described approach is suitable for nuclei where the energies of the low lying states and also their branching ratios are known. For heavy and super heavy nuclei, where no appropriate level-schemes are known, the so called K_x-ray- K_x-ray- coincidence method has to be used: Instead of setting the gate on γ-lines, one is explicitly interested in simultaneous occurring K_x-rays.

$^{209}\mathrm{Rn}$ *as an example*

The proton rich $^{209}\mathrm{Rn}$ was produced by fusion of $^{16}\mathrm{O}$ at $87\ MeV$ with a target of $^{198}\mathrm{Pt}$. PACE4 predicts a specific fusion cross section of $99\ mbarn$.

A strong transition at $667.7\ keV$ from the $13/2^- \rightarrow 9/2^-$ state is the precursor of the ground state transition $9/2^- \rightarrow 5/2^-$ at $797.8\ keV$, defining the number of produced $^{209}\mathrm{Rn}$ nuclei in excited states. Direct transitions to the ground state are nearly excluded by the production mechanism. Gating on the $667\ keV$-transition produces the X-ray spectrum shown in Fig. 3.

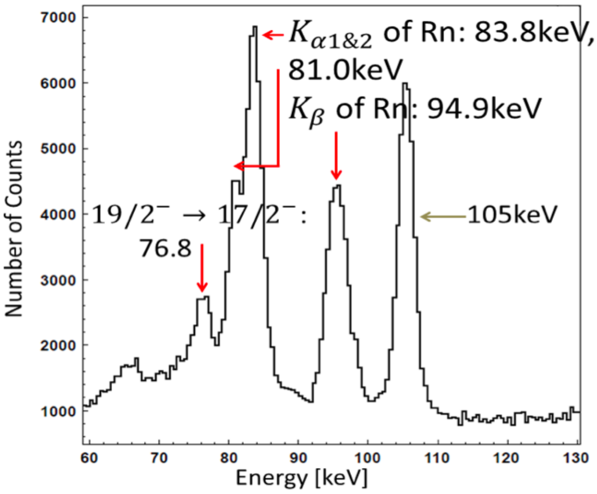

Figure 3: Zoom into K_x-ray range of gated spectrum of $^{209}\mathrm{Rn}$ on $667\ keV$-transition.

Another transition $13/2^+ \rightarrow 9/2^-$ with the energy of $376.2\ keV$ decays into the lowest excited state, too. The state $13/2^+$ is an isomer with a half life of $13.4\ \mu s$. Therefore a second gate of the lowest lying transition into the isomeric state is necessary to take into account the two different decay paths of the $^{209}\mathrm{Rn}$-isotope properly. The multiplicity from the weighted sum of the two decay paths is calculated to $M = 1.27(42)$.

OUTLOOK AND ACKNOWLEDGEMENT

Using the powerful detector array, several different projectile-target systems have been tested. A large data volume is currently systematically analyzed. In addition, the shielding geometry and the overall experimental setup has to be optimized by computer simulations.

The present setup can thus be seen as a preliminary step towards fusion experiments in international facilities. A first tentative experiment has been discussed with the GARIS SHE team at RIKEN in Japan.

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