Experimental report

22/02/2016

Proposal: 3-01-637 **Council:** 10/2014

Title: Application of Calorimetric Low Temperatur Detectors for investigation of Z-distributions of fission fragments

Research area: Nuclear and Particle Physics

This proposal is a new proposal

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Samples:

Instrument	Requested days	Allocated days	From	To
PN1	50	43	16/04/2015	22/05/2015
			27/11/2015	04/12/2015

Abstract:

The investigation of mass, charge and energy distributions of fragments from thermal neutron induced fission is of high interest for our understanding of the fission process. We propose to use the new detector technology of calorimetric low temperature detectors for the investigation of nuclear charge distributions by applying the well-known degrader method at LOHENGRIN. Due to its excellent performance with respect to energy resolution and energy linearity this detector technology has the potential to substantially improve the experimental
conditions as compared to earlier measurements, and to give access to the mass region of symmetric fission and the heavy mass group.
The present proposal covers detailed isotopic fission yield measurements of the masses dominating the heavy mass peak (A=128 to A=152), complementary light masses for the validation of the method plus exploratory measurements in the valley of symmetry.

Report on the experiment 3-01-637

Our first ILL beam time in December 2014 demonstrated successfully the first ever operation of a new system for determination of nuclear charge yields with the passive absorber method [1-3] at LOHENGRIN. The innovations in the experimental setup are the application of calorimetric low-temperature detectors (CLTDs) as residual energy detectors and the usage of very homogeneous silicon nitride (Si_3N_4) foils as passive absorbers. However, in this first run the adaption of the cryogenic system to the 35° beam line of the LOHENGRIN led to an increased heat radiation on the CLTDs, resulting in reduced energy resolution and a limitation of the entrance window size to 30 mm². Also positioning of the Si_3N_4 absorbers outside the cryostat, i.e. 95 cm upstream of the detector array, resulted in considerable intensity loss (about a factor 25) by small angle scattering and an increased background from undesired masses that are scattered towards the detectors from the edges of the absorber foils.

To counter these problems for the second run in April 2015, that is reported here, several Si_3N_4 foils with a total thickness of 4.4 µm were placed inside the cryostat at a distance of 9 cm in front of the CLTD array. The heat absorption of the Si_3N_4 foils improved the thermal stability of the detectors and enabled an increase of the entrance window size to 160 mm², given by the size of the absorber foils. In addition, the transmission of the fragment beam has been increased by a factor of about 20 as compared to the December run, due to the reduced distance between detectors and absorber foils. However, with the absorbers fixed inside the cryostat we lost the possibility for an energy measurement of the un-attenuated fragment beam. To keep flexibility in optimizing the absorber thickness with respect to the Z-resolution for different mass and energy ranges, additional removable Si_3N_4 foils have been mounted outside the cryostat (95 cm upstream), giving the option to increase the total absorber thickness to 5.5 µm and 6.5 µm at the cost of significantly reduced transmission.

With the improved setup the Z-resolution depending on different parameters as mass and energy range, absorber thickness or target size has been investigated. For heavy fragments the obtained Z-resolution was insufficient to resolve individual lines in the residual energy spectra (see fig.1b). Anyway, the measured energy distributions show asymmetric shapes that enable a Z-yield determination, if parameters as peak width and energy loss difference of adjacent Z could be fixed. Different fits to the measured energy distributions, assuming 2 or 3

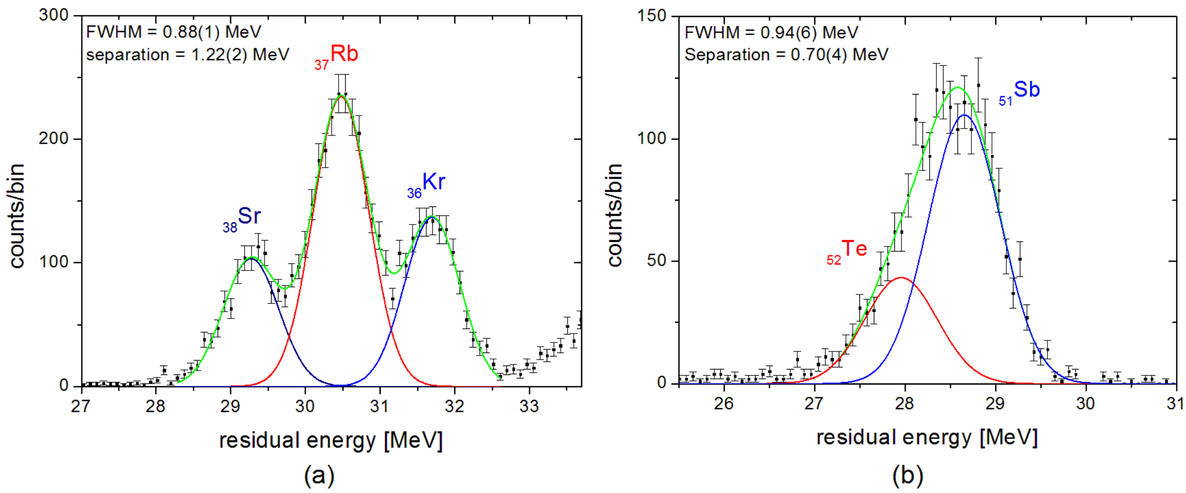

Figure 1: Residual energy spectra for fission fragments from $^{235}U(n_{th},f)$. (a) A = 92, E = 97 MeV with 6.5 µm of Si_3N_4. (b) A = 132, E = 74 MeV with 4.4 µm of Si_3N_4.

contributing charges or fixing the fractional yields using JEFF tables, give resolutions of $Z/\Delta Z$=32-39 for Z=51, demonstrating a significant improvement in this mass and energy range as compared to previous measurements [1-3]. Despite this progress we still could not reach the Z-resolution obtained in the test run at the tandem accelerator at MLL Garching with ^{109}Ag and ^{127}I ions ($Z/\Delta Z$=55 at Z=50, see proposal 3-01-637). The decreased resolution results mainly from a 10% lower ion velocity in the ILL experiment and the additional contribution of the fragment energy distribution to the line widths in the residual energy spectra. Changing the ^{235}U-target size from 4 cm to 2 cm indeed improved the Z-resolution by about 10%, showing a non-negligible contribution of the beam energy distribution to the total energy resolution of the system. Also a worse CLTD energy resolution as well as a different homogeneity of the Si_3N_4 foils stacks used at ILL and MLL cannot be excluded as additional contributions to the decreased energy resolution.

For light fission fragments on the other hand, a good Z-resolution has been obtained (see fig. 1a), sufficiently high to clearly separate individual charges in the residual energy spectra, and as expected, with an improving Z-resolution towards higher energy losses. However, even with 6.5 µm of Si_3N_4 we had a relative energy loss of 70% what is still lower than the optimum value of 80% found by Quade [1] for best Z-resolution in the light fragment group. As it became apparent that our original ambitious proposal (measurement of a larger number of heavy masses) was not feasible with the current setup, the next step for online improvement was to install additional absorber foils within the cryostat, and therefore, to increase the total absorber thickness without the high loss in transmission due to foils placed upstream.

However, as changes in the cryogenic system are time consuming and go along with a non-negligible risk of a system failure, we decided to postpone this modification. The decision was made with regard to two recent publications [4,5] highlighting the urgent need to re-measure the isotopic fission yield of ^{92}Rb from ^{235}U(n_{th},f), as the decay of this isotope is a main contributor to the integral antineutrino spectra above 4 MeV that are probed by sterile neutrino searches. This nuclear physics input of reliable fission yields is required in the summation method to reduce the uncertainty of synthetic antineutrino spectra. As we had a running system being capable of determining the desired values, we decided to change our proposed beam time schedule and perform first a systematic measurement on the cumulative charge yields of A=92. As a compromise between resolution, transmission and background of contaminating masses these measurements have been performed for various ionic charges and energies (q=17,19,20,21,25; E=77,84,92,97,102 MeV) with the 4.4 µm Si_3N_4 foil stack only, taking altogether 6 days of beam time.

Subsequent to these measurements we warmed up the cryostat, installed 2 additional Si_3N_4 foils close to the detectors, to obtain at this position a total absorber thickness of 6.5 µm, and cooled down again. This modification took 4 days of beam time. The success of this reconfiguration became apparent not only in terms of an increased transmission but also as an improvement of the Z-resolution by 6.5% when comparing the two different configurations of the absorber foils with identical cumulative thickness (6.5 µm at 9 cm in front of the detectors as compared to 4.4 µm at 9 cm + 2.1 µm at 95 cm). The improvement in resolution results mainly from the detection of a smaller fraction of the fragment beam energy distribution with an individual CLTD pixel when the absorbers are placed closer to the array. With the modified setup a Z-resolution of $Z/\Delta Z$=51 at Z=37 (fig.1a) could be achieved what is, as far as measurements with light fragments are concerned, as good as the best previous setups using ionization chambers and Parylene-C absorbers [1-3]. As discussed above, for light fragments an even better resolution is expected for higher energy losses. However, measurements with masses A=92 and A=102 using the additional absorbers placed 95 cm upstream to increase the total Si_3N_4 thickness to 7.6 µm and 8.6 µm have shown the same Z-resolution as for the 6.5 µm foil stack only. Anyway, as we know, that a long distance between absorber foils and detectors reduces the resolution, it is obvious that we still have potential for an improvement on this point by placing all the foils close to the detectors.

In the remaining beam time we started measurements for masses 106 to 109, each for one ionic charge state and an energy with highest intensity, to study the onset of even-odd effects in the transition region from the light fragment group to the symmetry. Due to the reduced intensity in this mass range these measurements took 4 days, despite using the configuration with highest transmission, i.e. with the 6.5 µm foil stack close to the detectors.

Further attempts to push the measurements more towards symmetry and heavier masses, and attempts to find the optimum foil thickness for heavier masses, were cut short by the premature end of the first reactor cycle that stopped our beam time. The remaining days offered to us for end of December 2015 were too short to set up the CLTDs again, but we could validate the full ionic charge state distribution of ^{92}Rb by a relative measurement with gamma spectrometry.

Summary and conclusion

As compared to our beam time in December 2014, where we applied for the first time calorimetric low-temperature detectors and Si_3N_4 absorbers for charge yield determinations at the LOHENGRIN spectrometer, the experimental setup could be significantly improved with respect to transmission and resolution. The results for light fission fragments have shown that the performance of the new setup already now matches the best results obtained with previous experimental systems, even under not yet optimized conditions. Due to recent nuclear physics interest on new data for the isotopic fission yields of ^{92}Rb, the running system has been used for systematic charge yield measurements on A=92, apart from our original proposal. In the heavier mass region, we obtained significant improvements as compared to previous setups, but the promising results from our test experiment at the MLL tandem accelerator could not be reached up to now. Therefore, it was not possible to achieve all our ambitious aims from the proposal to this experiment, which were assessed on the basis of the results from the test experiment at MLL. The data analysis, in particular the final values for the ^{92}Rb yields from $^{235}U(n_{th},f)$, is currently in progress. With the results obtained up to now, the next step for improvement of the experimental setup will be an installation of movable Si_3N_4 absorber foils directly in front of the CLTDs. Such a modification should optimize the setup with respect to transmission, resolution and flexibility for measurements in different mass and energy ranges.

References

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