Upgrade of electronics components for spectroscopy of superheavy atomic nuclei

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Since the dawn of the field of nuclear physics in the 1930s, the understanding of the atomic nucleus has grown fast. Today, the primary focus of both experimentalists and theorists is nuclear matter at its extreme. The most prominent is the research on superheavy nuclei and the quest to find the heaviest element that can exist in nature. In 2016, elements with $Z = 113, 115, 117$ & 118 received the names nihonium (Nh), moscovium (Mc), tennessine (Ts) and oganesson (Og), respectively. While the search continues for elements heavier than Og, the search for nuclei displaying an increased stability due to shell effects at the upper end of the chart of nuclides[1], continues in parallel. The large quantum systems formed by the superheavy nuclei are challenging to model precisely with existing theoretical approaches. To gain an increased understanding, insights from spectroscopic experiments are crucial.

Led by scientists from the Lund Nuclear Structure group, a first glimpse into the nuclear structure of isotopes along decay chains starting with $Z > 112$ could be made with an experiment conducted in 2012. The experiment was conducted at the GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany. The fundamental experimental method relied on α-photon coincidence spectroscopy with a set-up comprising silicon and germanium detectors, called *TASISpec*. Following this very successful experiment, the Lund research group was able to land a grant from *Knut & Alice Wallenbergs Stiftelse* (KAW) in 2015[2]. The money is currently used to upgrade the detector set-up from the previous TASISpec to the new *Lundium*. The main upgrade involves a complete set of new High Purity Germanium (HPGe) detectors, denoted *Compex*. Besides providing outstanding spectral qualities, the Compex detectors further enable a much more compact set-up due to their cubic-like shape and therefore a substantial increase in detection efficiency.

As part of the KAW grant, my role as a PhD student involves the construction and characterisation of the Lundium set-up with a special focus on the new Compex detectors. Naturally, the PhD studies circle around conducting new experiments on superheavy nuclei and move the research field closer to the long sought 'Island of Stability'. In competition with many other research groups, the Lund Nuclear Structure group has been granted new experimental beam time at GSI. With an improved set-up, we now aim to shed light on the nuclear structure along decay chains of $^{287}_{114}$Fl and $^{289}_{114}$Fl.

The importance of a successful experiment cannot be underestimated. This is not just from a personal perspective, but also from the perspective of the Lund Nuclear Structure group and the scientific community. Stepping from this argument, we strive to minimise all risks which possibly may contribute to (partially) unsuccessful experiment and we ask for 225 kkr for new electronics modules. Table 1 presents costs in detail based on recent quotations. It should be noted that these modules are not subject to the KAW grant.

Optimal data acquisition directly leads to optimal scientific output of experiments. In this sense, reliable trigger electronics is extremely important. Typical experiments on superheavy nuclei run 24/7 over weeks of time. All hours count, while the typical operational cost for running UNILAC experiments at GSI is $\sim$ 30 kkr/h. Failing components do not only require a replacement, it can furthermore require a lot of expensive debugging time. It might even proceed unnoticed for some time and result in faulty data. In this application we therefore ask for money to replace some of our ageing NIM trigger electronics modules ($\sim$ 1980's), see Table 1(a), which threatens a successful experiment.

In the current version of the Lundium set-up, both the silicon and germanium detectors are read out with digitised electronics. The silicon detectors employ a modern GSI-developed digitising system

[1] Sven-Gösta Nilsson *et al.*, On the Nuclear Structure and Stability of Heavy and Superheavy Elements, 1969.
[2] http://kaw.wallenberg.org/forskning/de-utforskar-de-tyngsta-amnena-i-varlden

Table 1: Detailed information on the (a) NIM electronics and (b) FEBEX modules that we want to purchase. The second column describes in brief the function of the module and the third column presents costs based on recent quotations. The last row presents the total asking cost.

(a) NIM electronics		
2x Logic fan-in-fan-out	Multiply and distribute logic trigger signals	3040€
1x Quad coin	Coincidence gates to derive experiment trigger	2240€
1x TTL-NIM-TTL adapter	Convert between logic signal standards	2030€
1x NIM-ECL-NIM FIFO	Distribute logic signals with different standards	2550€
1x Dual timer	Advanced delay-gate generator for beam shut-off logic	2190€
		12050€ ·10.34 = 124600 kr
(b) FEBEX modules		
1x FEBEX crate	Frame which holds the FEBEX digitiser cards	1234€
1x FEBEX cable	Connection to DAQ computer	282€
1x FEBEX backplane	Power supply for the FEBEX crate	383€
4x FEBEX cards	Digitiser cards, 4x16=64 channels for Compex Ge	7100€
1x Levcon	GSI converter box for beam shut-off signal	716€
		9715€ ·10.34 = 100400 kr
Total:		225000 *kr*

denoted *FEBEX*, while the germanium detectors are read out with commercial *STRUCK SIS3302* digitisers. The SIS3302 modules present the possibility to record raw preamplifier traces from the germanium detectors, but it has not been viable to employ this feature: radiation bursts during beam-on periods cause high count rates in the HPGe detectors, which has resulted in large dead time in that part of the – to some extent outdated – data acquisition system. A shielding upgrade at the experimental cave at GSI has been installed to reduce Ge-detector rates, but the SIS3302 dead time remains a problematic issue. The GSI-developed FEBEX digitisers have been established as modules that solve this problem of dead time. In addition, the cost per channel is much less compared to any commercial system. Hence, we ask for money to upgrade the digital read-out electronics for our new germanium detectors, see Table 1(b), to achieve full and up-to-date GSI compatibility.

Why is it further important to record preamplifier traces? Fundamentally, by reading the traces one has access to the detector events in great detail. With access to the raw detector signal, signals, otherwise neglected or corrupt with for instance an analogue electronics set-up, may be investigated in detail. An example are pile-up events. Starting in my master thesis work, I have worked on pulse-shape analysis applied to digitised preamplifier pile-up traces[3]. Applying tailor-made algorithms to the recorded pulse shapes enabled the extraction of structural information of microsecond α-decaying nuclei from the pile-up signals. This work recently resulted in my first scientific article in Physical Review C[4].

In the case of the Compex detectors, besides providing the possibility to properly handle pile-up signals, the raw signals give access to detailed detector characteristics. If the detector characteristics are well evaluated, they can be utilised in further optimisation of the Compex detector performance, with for instance a potentially improved energy resolution.

We ask for in total 225 kkr to purchase new NIM trigger electronic modules for the data acquisition system and FEBEX digitisers for our top-notch HPGe detectors. A lot of time and money has been invested in this research project. We want to minimise the risk of the coming experiment going bad due to a failing trigger module and utilise the Compex detectors to its full potential, as they deserve. Ultimately, the experiment on the decay chains of ^{287,289}Fl will provide us essential information to bring the research on superheavy nuclei forward.

[3] A. Roth, Master Thesis `http://lup.lub.lu.se/student-papers/record/8882017`, Lund University (2016).
[4] A. Såmark-Roth *et al.*, Phys. Rev. C, in press, (2018).