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Introduction

Demands to improve the nuclear data basis are observed in numerous fields of nuclear applications. In particular, in the field of nuclear energy, high precision data with low uncertainties for minor actinides and fission products are urgently needed. Similar requirements exist in nuclear astrophysics, where reaction cross sections of key isotopes necessary to interpret stellar evolution processes have to be known much better than presently possible. In some cases, one isotope is even relevant in both of the mentioned application fields. A prominent example is the neutron capture cross section of ^{135}Cs which is important both for the determination of the amount of radioactive cesium in burnt fuel elements of fast reactors, and it contributes to a quantitative interpretation of the isotopic Ba abundances in terms of the temperature during stellar He-burning, as well as of the presence of radioactive isotopes in the Early Solar System.

A considerable number of these reactions is not possible to study, because the target isotope cannot be produced in pure form. Stable isotopes of the same element produce a background in the measurement, and often this can be much bigger than the "signal" itself. This was well illustrated by the just recently performed ^{63}Ni neutron capture cross section measurement, where the presence of ^{62}Ni masks, except for the largest resonances, the capture yield on ^{63}Ni. An isotopically pure ^{63}Ni would have gained a much higher outcome of this important measurement. In worst case, the measurement is impossible. Key players in the corresponding fields name $^{238/236}$U, ^{245}Cm, $^{239/240/242}$Pu as relevant for minor actinides, Cs, Mo and other element isotopes as examples for fission products as well as ^{41}Ca, ^{79}Se, ^{85}Kr, ^{93}Zr, ^{107}Pd, ^{134}Cs as examples for the so-called “branching points” in the s-process. This list is of course not complete. A dedicated mass separator (superconducting calutron) designed for these special applications would improve the situation essentially, and, in a certain number of cases, would allow measurements with these isotopes for the first time.

Realization

In the frame of the SANDA project, money has been allocated for the preparation of the design and installation of such a dedicated isotope separator. Since the available starting material for these special applications is normally limited, the machine has to be designed meeting the specific requirements, e.g. high current, high efficiency and the possibility for recovering the remaining sample material after implantation. We proposed to perform feasibility studies to investigate principles, development of the design for a test facility and optimization of parameters for universal use, meeting the requirements of different users (e.g. for energy-related applications, to address questions in nuclear

astrophysics as well as contribute to ensure the production and characterization of medically relevant radionuclides).

While the design development was performed by the experienced colleagues at University Mainz (see Deliverable 3.4.), the final installation of the machine has been foreseen to be realized at PSI. This location is ideally suited as it offers all the prerequisites with regard to the availability of isotopes and the permissions to handle the necessary activities.

To finance the built-up of the Preparative Offline MAss Separator (PROMAS) in the hotlaboratory facility of PSI, part of the funding is allocated by the European Commission in the follow-up project APRENDE, a R'Equip-proposal has been submitted to the Swiss National Science Foundation (SNSF), and the matching part will be covered by the PSI-NES department and the directorate of PSI. Meanwhile, the preparation of site has been started in the hotlaboratory facilities of PSI. A dedicated laboratory space is under preparation. Therefore, in a multimillion decommissioning project co-financed by PSI and the Swiss Nuclear Decommissioning Funds the former "Pu-zone" of the hotlaboratory is decommissioned and emptied to make space for the PROMAS separator. This governmental project requires a WTO tender which is ongoing.

This project was prepared within the scope of the SANDA project, where this site has been selected and promoted. Additionally, the installation of a new online isotope production facility (TATTOOS) at PSI's high energy high-power proton accelerator (HIPA) in the framework of a Swiss Infrastructure Roadmap project 2025-2030 (SERI2023) under the acronym IMPACT (https://www.psi.ch/en/impact) will make the PSI site outstanding in Europe and worldwide providing on-line and offline mass separated radionuclides for science.

PROMAS: Mass separator site specification

The R'Equip proposal concerns the funding of the high-resolution mass separator PROMAS in combination with the RILIS setup built with state-of-the-art solid-state lasers, as well as the required hot-cavity ion source, the ion optical and diagnostic elements, and an ion collection device inside a dedicated shielded cell in conjunction with the required ultrahigh vacuum system. We proposed having a target and ion-source coupling system similar to many online facilities to enable research and developments for improving the design of the various ion sources proposed and used in the radioactive ion beam (RIB) community. This system will have to play a crucial role in guiding the design and development of new species of ion sources, quantifying through iterative studies and with purpose-built measurement instrumentation in an accessible area. The advantages of placing PROMAS into the PSI hotlaboratory facility were compromised with a required slight modification of the separator design to meet the space availability in the only suitable large class-A laboratory as shown below. The procurement and commissioning of the hot laboratory are scheduled to be

completed by the end of 2028. Due to resulting scheduling conflicts, it is temporarily planned to relocate the mass separator to another PSI laboratory within the building of the decommissioned zero-power reactor PROTEUS at PSI. The transfer of the offline mass separator to the hot laboratory will occur following the completion of the decommissioning project in the hotlaboratory.

Laser resonance ionization (RILIS) equipment

The new species of ion sources will have emphasis on improving the quantity of delivered longer-lived isotopes vital for medical applications and nuclear data measurements. Studies of the ion source are then required to optimize production of the targeted species while also ensuring longer stable operation than normally expected. The laser system in RILIS consists of several tunable pulsed Ti:Sa lasers (Mostamand2020,Mostamand2022). For the purpose of research spectroscopy, one of these lasers is grating tuned to provide long-range continuous-wavelength scans (Li2017). It allows continuous tuning over 200 nm and provides a powerful tool to search for unknown atomic transitions and study Rydberg and AI states. The output power of the grating-tuned Ti:Sa laser is lower than that of the birefringent-filter-tuned (BRF-tuned) Ti:Sa lasers due to the higher intra-cavity losses. For this reason, typically BRF-tuned lasers are employed for laser ion source operations. They are all pumped by a high power Q-switched Nd:YAG laser at 532 nm and 10 kHz repetition rate. To investigate non-resonant ionization schemes, a frequency doubled Nd:YVO4 laser will be employed. All laser beams are spatially overlapped in the ionization region using dichroic mirrors. To house the laser system a cleanroom and dust control must be implemented. The environmental conditions such as room temperature must be stabilized to a delta temperature of 0.1-0.5 °C to maintain the laser frequency within 1.5 GHz of the resonance frequency (Lassen2023).

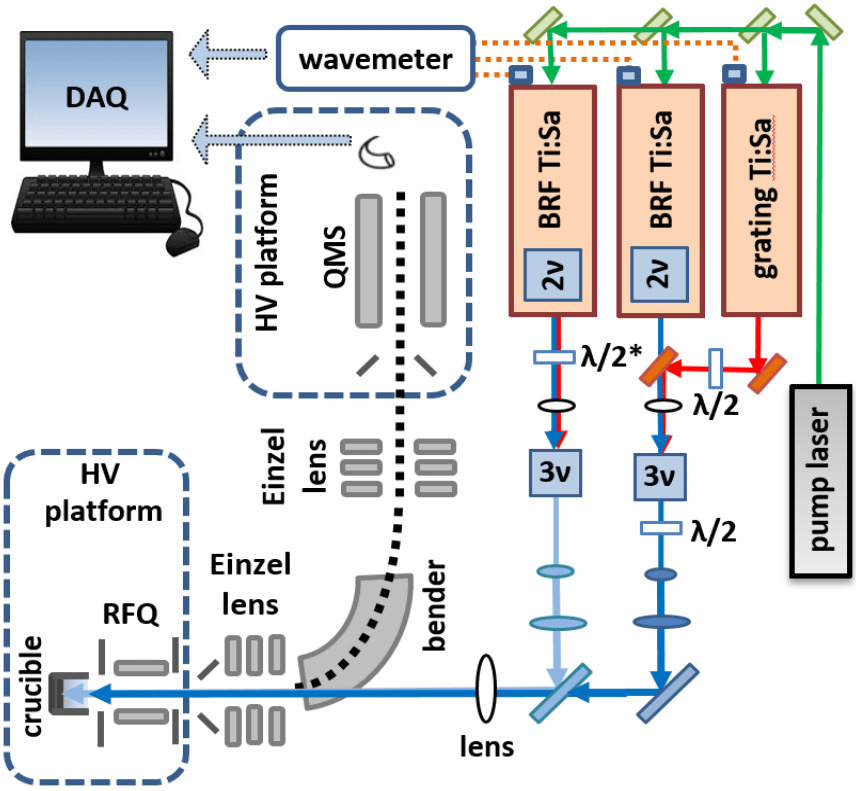

Fig. 3.2.1: Operation principle of a state of the art laser resonance ionization driven by solid state lasers adopted from (Li2020).

Mass separation equipment

The final mass separator will consist of a large 90-degree spectrometer magnet with a bending radius of 1 m and is roughly based upon the OFFLINE 2 (Warren2020) and the design elaborated within WP 3.1. (Studer2023). The core improvements are higher beam capacity, the optics and apertures are designed to handle up to 10 uA of beam before space charge compensation is required, more robust front end beam preparation, and higher resolving capability. Given the layout and typical surface ionizer source beam conditions the separation resolution of dm/m is expected to be 1200, easily capable of resolving heavy masses. This large resolution is deliberately chosen to maximize the transport efficiency without compromising the resolution by using “slits” to minimize horizontal beam width as other designs require. The lack of compromise means, we can expect to collect micromoles of material in hours for properly optimized ion source and samples; this can be pushed significantly higher if a resolution loss is acceptable.

The sample-collection box is planned to be situated in a shielded environment to be able to handle higher-dose radioactivities as well, particularly for radiopharmaceutically-relevant radionuclides.

Figure 3.2.2 shows the proposed mass separator layout with the required equipment framed in the laboratory foreseen within the PSI Hot laboratory with the scale given below in Figure 3.2.3.

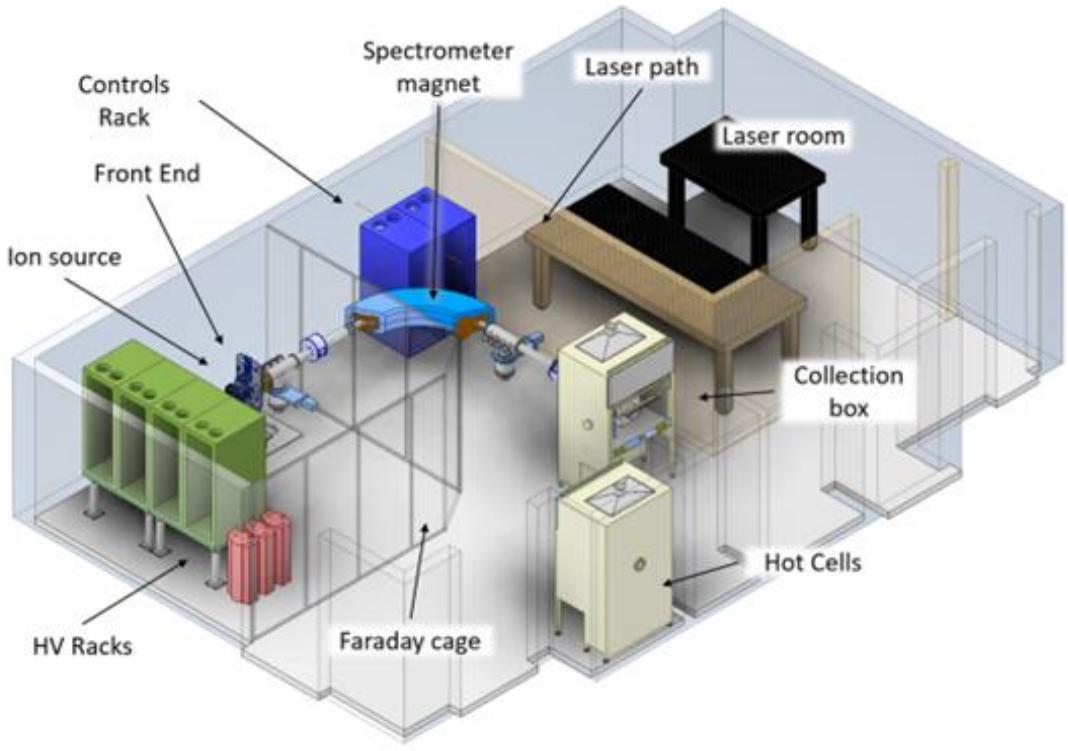

Fig. 3.2.2: Proposed mass separator with layout of equipment in the laboratory foreseen within the PSI Hot laboratory.

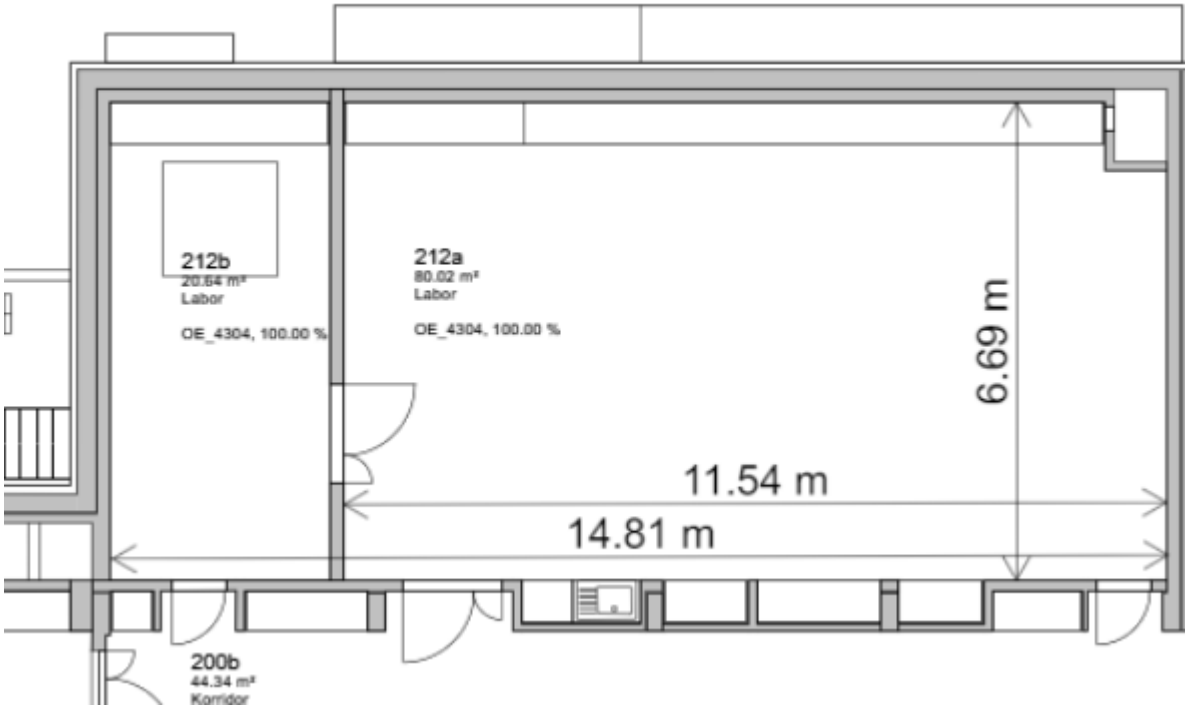

Fig. 3.2.3: The floor plan of the laboratory foreseen within for the PROMAS separator.

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