EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Addendum to the ISOLDE and Neutron Time-of-Flight Committee

MIRACLS- the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy of radionuclides

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S. Malbrunot-Ettenauer[1], S. Sels[1], M. K. Vilen[1] for the MIRACLS collaboration

[1] *Experimental Physics Department, CERN, CH-1211 Geneva 23, Switzerland*

Spokesperson: Stephan Malbrunot-Ettenauer, stephan.ettenauer@cern.ch
Contact person: Stephan Malbrunot-Ettenauer, stephan.ettenauer@cern.ch

Abstract: This addendum to INTC-M-019 of the MIRACLS project provides an update on the required resources in terms of space in the ISOLDE hall, electrical power, additional lab space for testing of equipment and UHV assembly, and DAQ room. For the progress of the project, we re-iterate the importance of having lab infrastructure such as electrical power, cooling water, air conditioning etc. available during the entire long shutdown LS2. Moreover, the commissioning of the apparatus with ISOLDE beam of stable (magnesium) isotopes during LS2 is crucial (see also our previous Letter of Intend INTC-I-197).

Requested shifts: 3x 4 days of offline ISOLDE beam during LS2 as discussed previously in INTC-I-197 and INTC-M-019

1 MIRACLS overview

As introduced in our previous reports INTC-I-197 and INTC-M-019, The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) is a novel approach for highly sensitive, high resolution collinear laser spectroscopy (CLS) of short-lived radionuclides at ISOLDE. For this purpose, CLS is preformed inside a Multi Reflection Time of Flight (MR-ToF) device. There, the ions are probed by the spectroscopy laser during each revolution inside the MR-ToF device which increases the experimental sensitivity by a factor of 20-600 depending on mass and half-life of the nuclide of interest. In order to maintain the high resolution of conventional CLS, MIRACLS' MR-ToF device will operate at an unprecedented ion beam energy of 30 keV. Such a fast MR-ToF operation also offers new opportunities for purified ISOLDE beams for experiments downstream of MIRACLS. To this end, MIRACLS' MR-ToF device will serve as a prototype for a future general purpose ISOLDE MR-ToF instrument for highly selective mass separation.

In addition to the 30-keV MR-ToF device, the main components of the MIRACLS setup will be a cryogenic Paul trap for optimal beam preparation, the transfer beamlines to the individual ion traps hosting the ion optics as well as ion beam diagnostics, and the laser system. The cryogenic Paul trap will provide excellent beam emittance necessary for MIRACLS operation but will also beneficial for other experimental programs, e.g. for emission channeling.

A schematic overview of the MIRACLS setup is shown in Figure 1 as it could be integrated into the ISOLDE hall. This area, next to the ISOLDE Decay Station (IDS), is currently occupied by the NICOLE setup but will be cleared in the very near future. In summary, the ion beam delivered by ISOLDE passes a first section with ion optics and beam diagnostics before it is injected into the cyrogenic Paul trap. The latter is hosted inside a high-voltage (HV) cage such that the trap can be floated just below the ion beam's acceleration voltage which allows the deceleration and subsequent stopping of the ISOLDE beam inside the buffer-gas filled Paul trap. Alternatively, the Paul trap can receive beam from MIRACLS' offline ion source which is floated via a high voltage duct to the main high voltage cage of the Paul trap. Cryogenic trap temperatures ($<$40 K) are achieved through a closed-loop cryocooler which is located outside the HV cage. The thermal link from the cryocooler's cold head (on ground potential) to the trap structure (floated to 40-60 kV) is established via a thermal link made out of Sapphire. The trap axis is rotated by 10 degrees in respect to the upstream ISOLDE or offline ion-source beamline in order to provide axial laser access into the Paul trap, e.g. for optical pumping. Once the ions have thermalised with the cold He gas inside the Paul trap, the ion bunch is extracted, accelerated and transported into the MR-ToF device via a transfer beamline including ion optics and beam diagnostics. The ions are captured into the 30-keV MR-ToF device via the in-trap lift technique. Laser spectroscopy and/or mass separation is performed with the trapped ion ensemble. Finally, the ions are released from the opposite end of the MR-ToF instrument where they impinge on an ion detector or can be sent to downstream experiments. For laser access the axis of the MR-ToF device is rotated by 10 degrees in respect to the Paul trap.

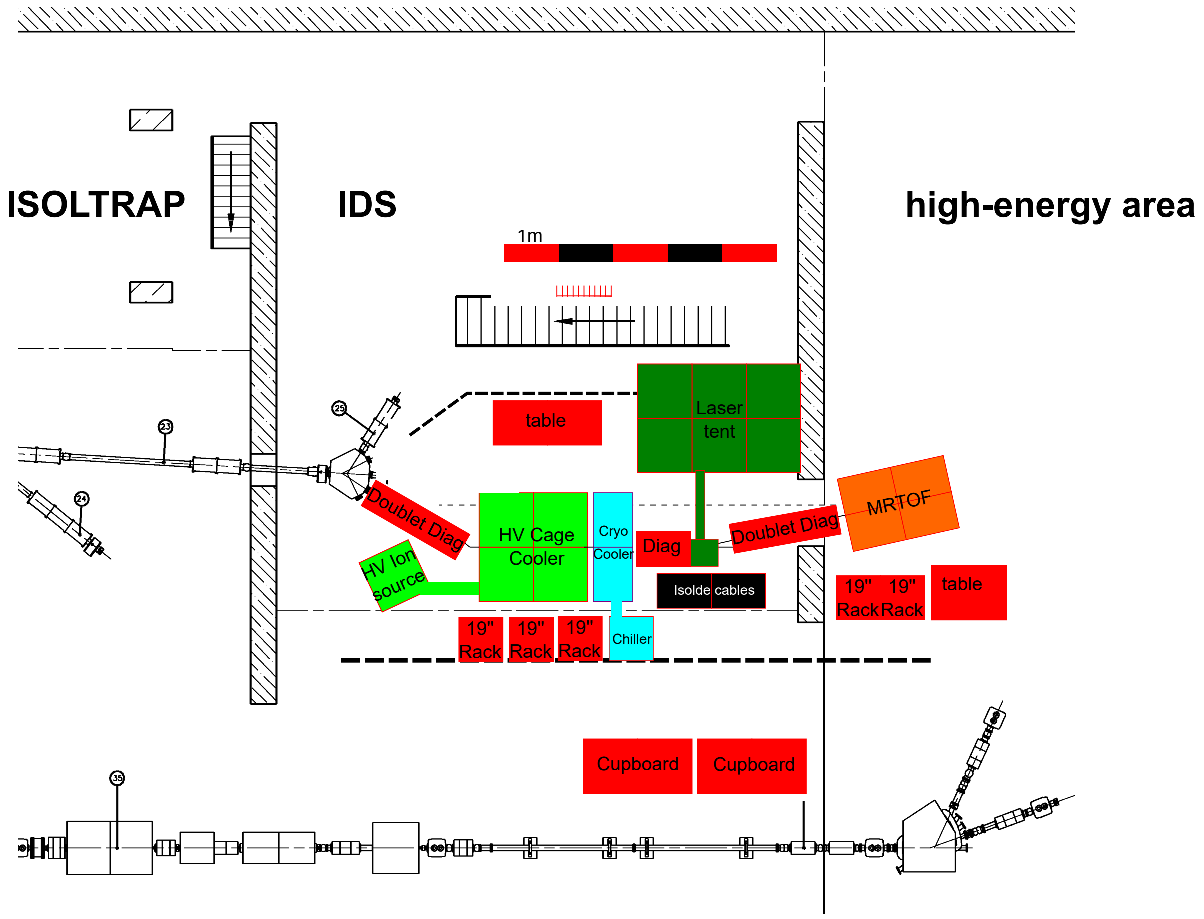

Figure 1: Schematic overview of the MIRACLS setup as it could be integrated into the ISOLDE hall. See text for details.

2 Required resources

2.1 Space requirements in the ISOLDE hall

As indicated in Figure 1, next to the beamline components of the MIRACLS setup, electronic racks, a laser table, a small laser launch platform, and two tables with computers for local experimental control of Paul trap and MR-ToF device are required. Additionally, we require (at least) two cabinets for storage in close proximity to the experimental apparatus. The needed infrastructure includes electrical power (see bellow), pressurised air, and access to the ISOLDE cooling-water circuit.

As indicated in Figure 1, the location next to IDS, currently occupied by the NICOLE setup, could provide the necessary space for the MIRACLS apparatus. The existing beamline right after the switchyard between IDS and NICOLE, hosting ion beam optics and a Faraday cup, might either be rotated or replaced by a more compact transfer beamline and diagnostics setup. Through an existing opening in the concrete wall, the MR-ToF device could be placed at the entrance of ISOLDE's high-energy area from where it could deliver purified beam with excellence emittance to future experiments downstream

of MIRACLS. All of this space in the high-energy area of ISOLDE is currently occupied by storage cabinets.
However, the following constraints need to be considered for this potential MIRACLS site. First, due to the platform above IDS and NICOLE, crane access to this location can only be provided between the cave for the HIE-ISOLDE accelerator and this platform, but not directly to the future MIRACLS beamline itself. Hence, all MIRACLS construction (apart from the MR-ToF device) has to anticipate heavy lifting of vacuum chambers, crycooler etc. by other means than the crane in the ISOLDE hall. Secondly, the lack of commercial solutions for optical fibres for laser light with wavelengths $\leq$280 nm requires the laser system for the first science cases of exotic Mg and Cd isotopes to be in close proximity to the MIRACLS setup. Hence, for this location additional space for a laser table and associated laser-safety installations is required. Discussions about a safe implementation of such a laser table inside the ISOLDE hall are ongoing.
The ISOLDE beamlines LA1 or LA2 could be considered as alternative locations of the MIRACLS setup. These sites can be served by the ISODLE crane. Furthermore, the MIRACLS laser setup could remain in the separate COLLAPS laser laboratory while the laser beam transport into the ISOLDE hall could be integrated analogously to the COLLAPS and CRIS setups. Although both aspects are significant advantages over the previously discussed location next to IDS, the space at LA1 and LA2 is unfortunately very limited. The MIRACLS setup could only be integrated into this area after a careful design of significantly more compact ion beam optics to replace the existing ones in the LA1 or LA2 beamline. Moreover, this option would not provide any space for experimental setups downstream of MIRACLS. Consequently, the preferred MIRACLS location remains the space next to IDS. LA1 or LA2 are however alternatives in case a save implementation of a laser table inside the ISOLDE hall cannot be accomplished. These would be temporary solutions until a separate MIRACLS laser lab could be installed in close proximity to the area next to IDS, for instance as part of a hall extension for a future ISOLDE storage ring.

2.2 Additional space requirements

In 2020 and 2021, we will require additional lab space in a clean and calm lab environment outside the ISOLDE hall for the assembly of ultra-high-vaccum (UHV) components such as the the ion traps or beamline elements. Additionally, we require space for offline testing of electrical components as for instance the high stability 60 kV power supplies for the MR-ToF's mirror electrodes. We estimate that about 1/3 of the space available in 508/R-15 will be sufficient for this purpose. This lab room currently hosts the very successful MIRACLS proof-of-principle experiment which according to our current schedule will be completed in this calendar year.

2.3 Electrical power requirements in the ISOLDE hall

The estimated power consumption for the MIRACLS setup in the ISODLE hall is summarised in Table 1. The power required for the laser system inside the ISOLDE is only required for the location next to IDS. If MIRACLS is first built at LA1 or LA2, the laser

Section	Item	estimated maximal power [kW]
Paul trap and beamlines	Cryocooler	15
	Chiller	5
	vacuum pumps	17
	electronics	5
	other	10
MR-ToF	vacuum pumps	7
	HV power supplies	8
	other	3
laser system		30
Total		**100**

Table 1: Estimated maximal power consumption of the MIRACLS setup in the ISOLDE hall. See text for details.

system would remain in the COLLAPS laser lab.
The upper limit for the peak power consumption accounts for 100 kW which we expect to reduce significantly under normal operation. This power estimate includes a chiller to provide cooling water for the cryocooler. For most of the time, the necessary cooling water will be provided by ISOLDE's cooling-water ciruit. However, due to the long unavailability of cooling water at ISOLDE during parts of the winter shutdown, we will require an alternative source of cooling water. This chiller (estimated 5 kW) as well as the crocooler (15 kW) will require 3 phase 400Vac. All other loads will operate at 1 phase 220 Vac. For the space next to IDS, we have found currently unused power outlets accounting for totally 191 A of 3 phase 400Vac which would fully cover our power requirements. Next to LA1 and LA2, we identified unused power outlets accounting for 127 A of 3 phase 400Vac. As some of them are partially used by COLLAPS or need to also provide electrical power for traveling experiments, additional power installation will be required. Given the sensitive ion-trap electronics, in particular the HV stability of the MR-ToF device, it is critical for both locations that electronic noise also from the power line(s) is minimised. Hence, we will require a solid ISOLDE ground and electrical installations (on the same ground level) have to be checked to eliminate potential sources of ground loops when used for devices of the MIRACLS setup.

2.4 ISOLDE offline beam (in 2020 and 2021)

In order to optimise the transfer of ion beam from ISOLDE and ISCOOL to MIRACLS, offline beam during LS2 (in fall 2020 and early 2021) will be needed (3x 4 days). We refer to our previous letter of intent INTC-I-197 for all details. Most aspects of a related Letter of Intent INTC-I-202 for systematic studies of the use of ISCOOL on collinear

laser spectroscopy at COLLAPS during LS2 are also relevant for MIRACLS. Especially, the development of fast ion extraction from ISCOOL to obtain a narrow ion beam could become crucial for efficient injection of the ISCOOL beam into MIRACLS' Paul trap.
The importance of the commissioning with ISOLDE beam of stable (magnesium) isotopes during LS2 cannot be overstated. If no beam is available during LS2, the beam transfer to MIRACLS has to be established during the online period in 2021, which is also the last year of the ERC funding period. This would threaten the success of the project in two ways. First, it is difficult to obtain sufficient (stable) beamtime during the precious ISOLDE online period. Secondly, in case a major problem is identified in the beam transfer very little time remains to adapt to such an unexpected challenge.
More generally, the long shut down LS2 represents an important period for the development of the novel MIRACLS techniques. Hence, it is imperative for the progress of the project that previously mentioned lab infrastructure and resources (electrical power, air conditioning, pressurised air, cooling water, etc.) are available during LS2.

2.5 DAQ room

Once the MIRACLS apparatus is built and commissioned, the beam setup can be done from the control computers on the tables next to the experimental setup. For online measurements as well as systematic studies with offline beam, a distant DAQ room will be required. This could be a single table of ca. 2.5 m length inside 508/R-15 or 508/1-005, the general ISOLDE DAQ room for online measurements. Especially during the initial phase, systematic studies will be performed on a daily bases and this DAQ room will be used very frequently.

Summary of requested shifts: 3x 4 days of offline ISOLDE beam during LS2 as discussed previously in INTC-I-197 and INTC-M-019