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DEVELOPMENT OF LOW ENERGY BRANCH AT MICRO ANALYTICAL CENTRE, LJUBLJANA, SLOVENIA

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Abstract

A low energy branch is being built at the Micro Analytical Centre in Ljubljana, Slovenia. It will add to the existing facility the capability of supplying keV ion beams to the experimental stations for ion implantation, simulations of the solar wind, ion-optics commissioning and studies of ion-gas interactions.

INTRODUCTION

Currently, the Micro Analytical Centre facility [1] in Ljubljana, Slovenia, can supply only MeV beams produced by a 2MV tandem accelerator to experimental stations. The lack of availability of lower energy beams severely restricts the type of physics experiments that can be performed at the facility.

The existing facility (see Figure 1) relies on three different ion sources: duoplasmatron, sputter and multi-cusp that are sent into tandem accelerator to provide MeV beams. With proper modifications of accelerator infrastructure, these sources can be used to supply low-energy beams through a low energy branch (LEB) to experimental stations:

1. for implantation of gases into solid targets;
2. for the creation of nitrogen-vacancy centres in diamond needed for quantum computing research;
3. for simulation of the effects of the solar wind on the lunar surface;
4. for studies of ion-gas reactions at low energies;
5. for commissioning of ion optics;
6. for testing machine learning algorithms for automatic beam control.

Stations 4 – 5 will serve as development platforms for experimental equipment and simulation software used at the FAIR facility in Germany [2].

In the remainder of the proceedings, we will present the progress made on the accelerator branch and the instrumentation used.

LEB INSTRUMENTATION

The new low energy branch has to provide maximal possible ion beam currents, high purity beams (single charge state, single isotope), small beam kinetic energy spread and the ability to guide the beam on the final target in x and y directions with precision below 1 mm.

The beam type and the current requirements will be satisfied using existing MIC ion sources. Existing sources will allow us to produce a variety of high current (up to 50 μA) ion beams, ranging from light (e.g. H, He, C, B, ^{15}N), mid-mass (e.g. Si) to heavy (Ag, W, Pb, Bi) ion beams in the energy range of 100 eV up to 30 keV. To verify the ion current rates produced by MIC ion sources, a Faraday cup will be installed at the beginning of LEB (see Fig. 2.1).

For the LEB to operate in parallel to the rest of the MIC facility, two ion guns will be installed at the beginning of the branch (Fig. 2.2), and ion gun beams will be guided into the main beam line with the use of electrostatic quadrupole beam bender focused with einzel lenses (Fig. 2.3).

Beams of different types will then be guided either through a gas cell (Fig. 2.4) or high vacuum to the first Faraday cup, einzel lens, x - y electrostatic steerer and slits (Fig. 2.5) for minor beam position and current adjustments. After that the beam will be sent through a 90° dipole magnet (Fig. 2.6.) and a set of x - y slits (Fig. 2.7) to filter from the beam unwanted charged states and isotopes.

After the mass-to-charge selection, the remaining ions are sent through the Wien filter (Fig. 2.8) to minimise the kinetic energy spread of the beam and achieve the highest possible beam mono-chromaticity (this is necessary to achieve high positional ion implantation precision) and then through another x-y steerer for control of implantation position (Fig. 2.9) on the retractable sample target (Fig. 2.10), diagnostics detector or ion optics chamber (Fig. 2.11).

The entire LEB system will be monitored by the locally developed control system, which will provide slow-control capabilities of logging of all ion optics power supply settings and vacuum system conditions into an SQLite database as well as ensure that the system parameters can be set via a computer programable interface in such a manner that a large proportion of LEB operation can be automatised.

Currently, the LEB system is in the commissioning phase. All components have been ordered, and a test line has been built in the lab consisting of a single ion gun, the first Faraday cup, 90° Dipole and the second Faraday cup to test all the essential building blocks.

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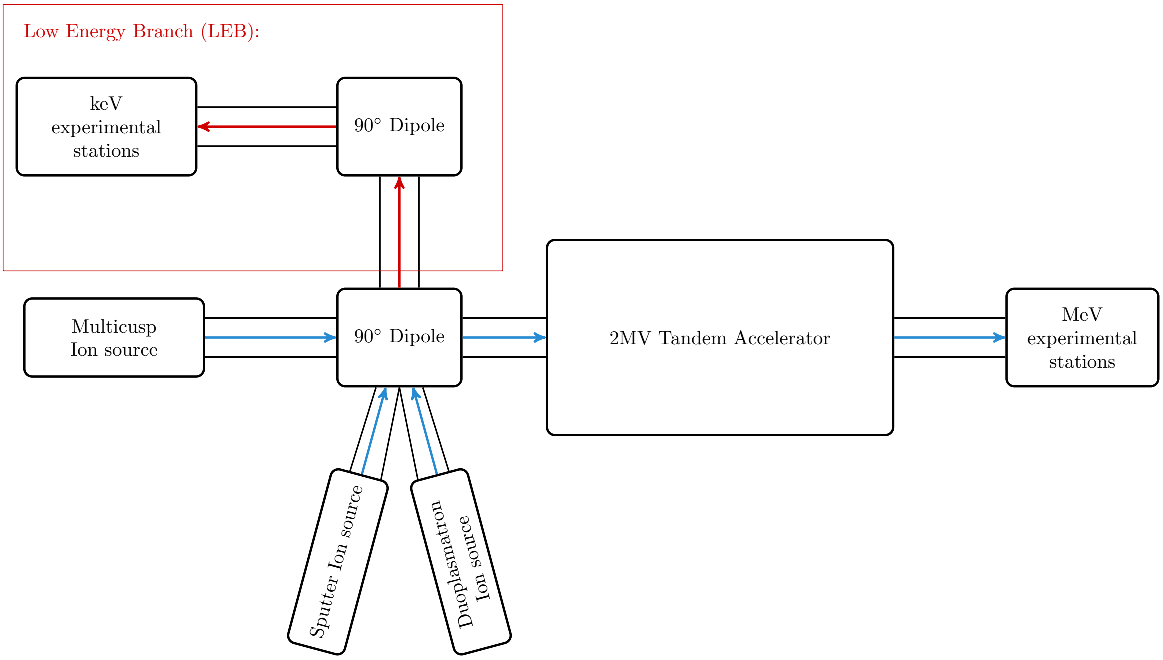

Figure 1: Outline of Micro Analytical Centre with the new low energy branch.

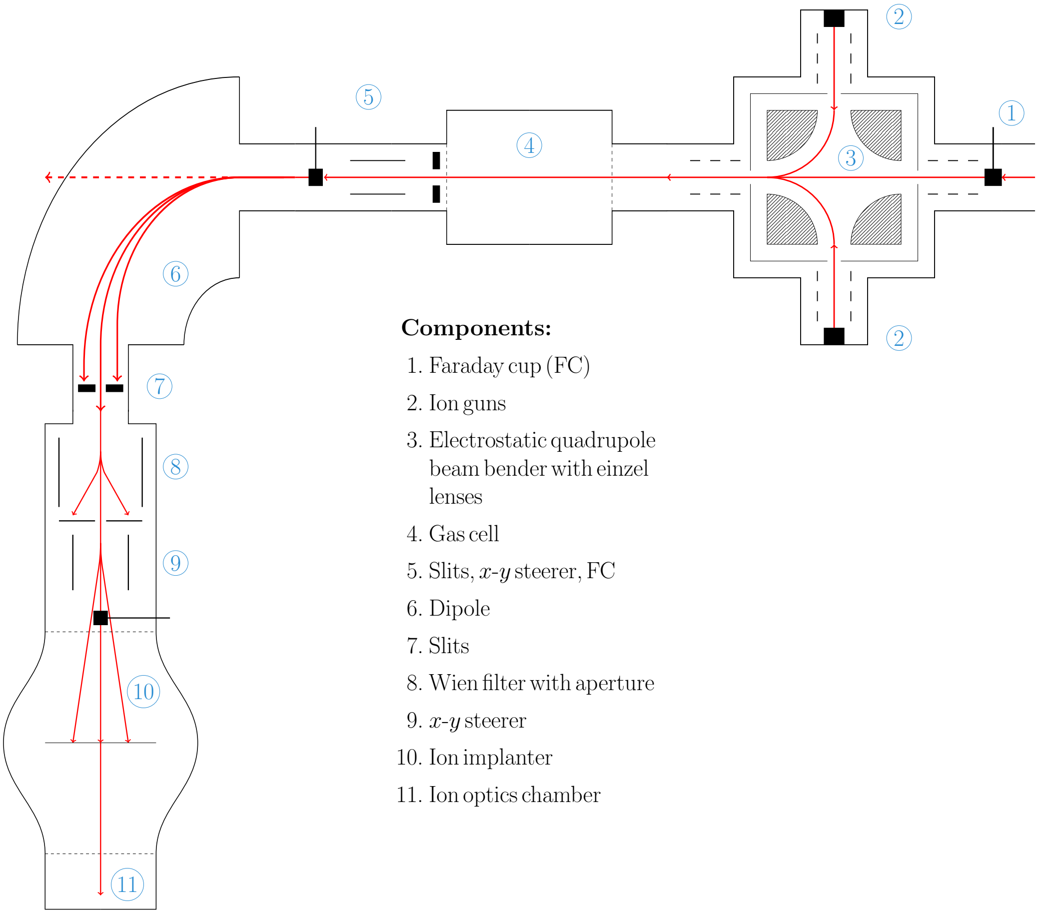

Figure 2: The low energy branch and its components.

EXPERIMENTAL STATIONS

Ion Implantation Station

Deterministic single-ion implantation is a well-recognised technique in the semiconductor industry and a very promising method in novel quantum technologies, including quantum computing and quantum information processing.

Candidate techniques for ion implantation are based on either phosphorous donors in silicon or nitrogen-vacancy (NV) centres in diamond, the former being less suitable due to limited isotopic purity of ^{28}Si [3, 4].

The main requirement for successful qubit production via ion implantation is determinism: a specified number of single ions should be implanted into predetermined positions. This requires a high positional precision of the beam, as well as tightly controlled ion beam intensity [5, 6]. Such criteria will be met by employing the low energy beam-line, where ions in the keV range will be focused on diamond substrates producing NV pairs.

Our goal is to create a stable grid of NV centres with – on average one nitrogen atom in each point defect, which may afterwards be confirmed with high-precision imaging methods, such as scanning electron microscopy, transmission electron microscopy or fluorescence microscopy. Additionally, we will research the possibilities for improving the determinism of ion implantation, allowing significant advances in material science and quantum computing.

Ion Transport Station

In the last two decades, the use of systems like the FRS Ion Catcher (FRS-IC) [7] at FAIR facility [2] has resulted in the measurement of many new exotic isotopes close to the limits of the nuclear chart. Systems like FRS-IC are constructed out of many ion-optical components and represent a complex dynamical system that is hard to optimise due to an incomplete understanding of the ion dynamics in such a system.

When an ion beam occupying a phase space $(\mathbf{x}_i, \mathbf{p}_i)$ passes through a magnet, an electrode or a gas sector, the phase space changes:

$$(\mathbf{x}_i, \mathbf{p}_i) \xrightarrow{M} (\mathbf{x}_f, \mathbf{p}_f).$$

In principle, the transfer map M that maps the initial phase space to the final phase space can be computed using simulation tools. However, magnets, electrodes and gas sectors in the real world behave differently than expected due to imperfections caused by the manufacturing process and external conditions that cannot be controlled. To ensure that the ion transport transfer map M used in simulations is correct, M has to be measured for each sub-part of the ion optical system.

To be able to measure the transfer maps of different ion-optical components, the LEB will have two experimental stations: (1) an electrode test stand, which will employ two Allison emittance scanners [8] before and after the tested component to measure the initial and final phase space and determine M (2) a gas chamber that will allow us to measure ion-gas interactions (charge exchange, collisions, break-up reactions of molecular ions) in desired gas mixtures, and ion energies and help us measure missing knowledge gaps present in the ion-gas transport theory.

Measurements from the two experimental stations can then be incorporated into simulation software to update the theoretical model that describes complex systems like FRS-IC.

The ion transport stand will also serve as a development platform for software-driven ion optics control. Modern ion optical systems like FRS-IC and Super Fragment Separator (SFRS) at FAIR [9] are very complex to optimise and would greatly benefit from the aid of software to achieve consistent optimal performance over long periods. The ion transport station at the LEB is a perfect prototype on which ion optics control software can be developed and trained.

Data needed to develop control algorithms will be logged with the use of the control system being developed for the LEB.

CONCLUSION

We presented the design and status of the new low energy branch being built at the Micro Analytical Centre in Ljubljana. We reviewed the new ion transport and ion implantation experimental stations that will be added to the facility.

ACKNOWLEDGEMENTS

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