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# Precision experiments with rare isotopes with LEBIT at MSU

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**Abstract.** The Low-Energy Beam and Ion Trap facility LEBIT at the NSCL is in the final phase of commissioning. Gas stopping of fast fragment beams and modern ion manipulation techniques are used to provide beams for high-precision mass measurements and other experiments. The status of the facility and the result of first test mass measurements on stable krypton isotopes are presented.

**PACS.** 21.10.Dr Binding energies and masses – 34.50.Bw Energy loss and stopping power – 41.85.Ja Beam transport – 29.25.Rm Sources of radioactive nuclei

## 1 Introduction

The Low-Energy beam and Ion Trap facility LEBIT opens the door to a new class of experiments with projectile fragment beams. The Coupled Cyclotron Facility at the NSCL delivers a large range of rare isotopes with high intensities, produced by the in-flight separation method. LEBIT converts these beams into low-energy beams with excellent quality by using gas stopping and advanced ion guiding, cooling, and bunching techniques. Penning trap mass measurements are the first experiments to be carried out with LEBIT, but in the future other experiments may profit from low-energy beams at the NSCL as well.

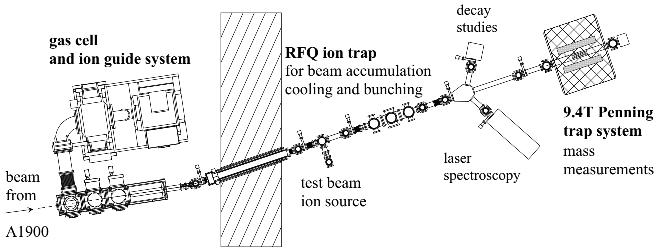


**Fig. 1.** Layout of the LEBIT facility at the NSCL/MSU.

## 2 The LEBIT facility

Figure 1 shows a schematic view of the LEBIT facility. The main components are a gas stopping station, an ion beam cooler and buncher, and a Penning trap system for high-precision mass measurements. The system has been designed to be expandable. Stations for decay studies and laser spectroscopy are indicated as examples of future experimental opportunities.

### 2.1 The gas stopping station

The gas stopping station converts the fast fragment beams coming from the A1900 fragment separator into low-energy beams. A set of flat and wedged glass degraders, a Be entrance window and high-purity helium gas at a pressure of up to 1 bar are employed to slow down, stop, and thermalize the high-energy beam. A combination of DC electric fields, created by a set of focusing electrodes inside the gas cell, and gas flow through an extraction nozzle is used to transport ions out of the gas cell. An RFQ-ion guide system transfers the ions into high vacuum and forms a continuous low-energy ion beam. A number of tests have been performed to investigate the stopping and extraction performance of this system. They include range measurements [1,2] in the gas cell employing energy bunching [3] by means of a wedged degrader, and ion stopping and extraction of the rare isotopes [4,5]. As an example, for a mixed $^{38}$Ca/$^{37}$K beam a stopping efficiency of 50% was observed. Extraction efficiencies up to 8% were measured for beam rates up to 100 pps and found to decrease for increasing beam rates.

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### 2.2 The ion cooler and buncher

The ion accumulator and buncher in the LEBIT project has the task to convert the continuous 5-keV ion beam from the gas cell or from an off-line test ion source into cold ion pulses with excellent ion optical properties. The system is based on an advanced linear RFQ trap concept. It has been designed as a cryogenic two-stage system in order to optimize the cooling and extraction processes: A high-pressure part allows for fast cooling whereas in a low-pressure trapping region ion bunches with low energy-spread are formed. The two sections are separated by a miniature RFQ providing differential pumping. Both the cooler and the trap section have been built as cryogenic devices and can be cooled with $LN_2$. Such a cooling should increase the acceptance of the system, decrease the cooling time and significantly reduce the emittance of the resulting pulse compared to an operation at room temperature. The cooler-buncher has been extensively tested and provides an overall efficiency of 30% in pulsed mode and 80% if operated as a continuous beam cooler. For a detailed discussion of the LEBIT cooler-buncher system, see [6].

### 2.3 The Penning trap

The first experimental program to benefit from the low-energy beams produced will be high-accuracy mass measurements on very short-lived isotopes. These measurements will be carried out with a 9.4 T Penning trap system. Compared to the usual 6-7 T systems, the main advantage of the 9.4 T system is a reduction of the measurement time for obtaining a given statistical uncertainty by a factor of roughly two. The LEBIT Penning trap has undergone extensive testing with stable beams from the test ion source or the gas cell. The details of the design of the system and its performance are given in [7]. Here we present the result of first test mass measurements on stable krypton isotopes. Singly-charged krypton and $^{40}$Ar ions were provided from the test ion source. They were cooled and bunched and captured in-flight in the high-precision trap. Here their cyclotron frequency $\omega_c$ was measured. Simultaneously captured ions of undesired isotopes were removed from the trap by selective excitation of their motion prior to the cyclotron frequency measurement. The cyclotron frequency of $^{40}$Ar was used to calibrate the magnetic field required for the mass determination. Figure 2 shows the result of this mass determination as the difference between the mass values measured for the krypton isotopes and values from the most recent mass evaluation [8]. Within the measurement uncertainty of about $6 \cdot 10^{-8}$ very good agreement is observed for $^{78,80,82,86}$Kr, isotopes for which the previous mass values are determined predominately by other Penning trap results. $^{83}$Kr and $^{84}$Kr have not yet been determined by a direct technique and the large deviation from our results could be an indication that their mass values are wrong. The observed averaged relative deviation from the literature values is less than $2 \cdot 10^{-8}$, if $^{83,84}$Kr are excluded. The mass of the reference ion $^{40}$Ar is about 40 mass units away from the measured candidates.

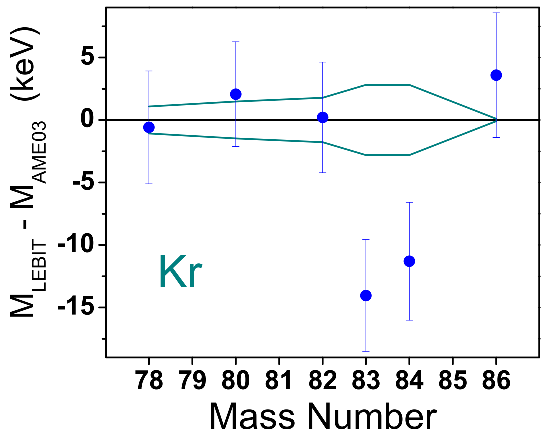


**Fig. 2.** Difference between the mass values measured with LEBIT for different krypton isotopes and the results of the most recent mass evaluation [8].

This together with the observed small deviation translated into a limit for mass dependent systematic effects which is smaller than $1 \cdot 10^{-9}/u$.

## 3 Summary and outlook

The LEBIT facility at the NSCL is undergoing final commissioning. The gas stopping cell has been shown to efficiently stop relativistic ions and convert them into a low energy continuous beam. The cooler-buncher shows excellent performance in converting such beams into brilliant pulses. Still under commissioning, the Penning trap system already provides a very good mass accuracy.

The experimental program of LEBIT will start with high-precision mass measurements on nuclides along the $N = Z$ line and on neutron-rich isotopes in the vicinity of $N = 28$. Other experiments envisaged are in-trap decay studies. Provisions are made for a future extension of the experimental activities towards laser spectroscopy and towards post-accelerated beams.

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