Commissioning of the MLLTRAP System ◇

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The MLLTRAP at the Maier-Leibnitz-Laboratory (Garching) is a double Penning trap facility designed to isobarically purify low-energy ion beams and perform high-precision nuclear mass measurements.

During 2008 a pumping barrier has been installed between the two traps preventing the buffer gas used in the purification trap to diffuse into the measurement trap. The trap system has been successfully commissioned and the studies for systematic uncertainties are going on. The mass resolving power achieved with the first trap for ^{85}Rb ions was improved to be R=139(2) $\cdot\, 10^3$, see Fig. 1, and the annual report 2007 [1]. A relative mass uncertainty of $\delta m/m = 2.9 \cdot 10^{-8}$ was reached with the second trap (no analysis of systematic uncertainties included) when using ^{87}Rb as a reference ion for ^{85}Rb.

The ion motion in a Penning trap consists of two cylindrical eigenmotions, a low frequency magnetron motion and high frequency reduced cyclotron motion with frequencies of ω_- and ω_+, respectively. These frequencies are coupled in the ideal Penning trap by $\omega_- + \omega_+ = qB/m = \omega_c$. In our 7 T magnet for an A=100 in the measurement trap (10 V deep potential) typical frequencies are $f_- \approx$200 Hz, $f_+ \approx$1 MHz, and $f_c \approx$1 MHz.

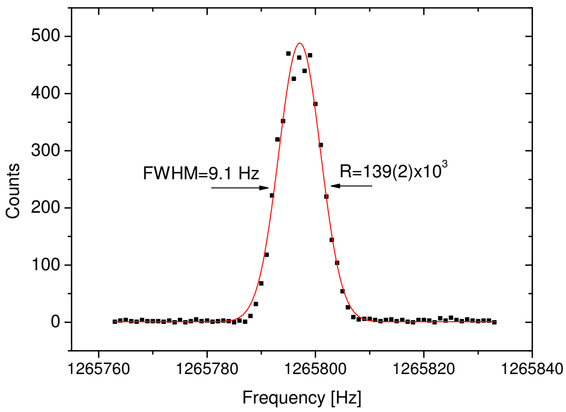

Fig. 1: Frequency scan in the purification trap for determining the cyclotron frequency for ^{85}Rb. The mass resolving power in the scan was R=139(2) $\cdot\, 10^3$. Black dots are the measured points and the line is a Gaussian fit with a width of 9.10(15) Hz.

In the absence of the buffer gas as it is in the measurement trap, the quadrupole excitation at the cyclotron frequency couples the radial eigenmotions, magnetron motion and the reduced cyclotron motion, together leading into a periodic conversion between these two motions. This conversion from the magnetron motion to the cyclotron motion will increase the radial energy of the ions, resulting in a stronger acceleration at the magnetic field gradient. This will lead to shorter flight times of the ions from the trap to the detector. Figure 2 shows an example of the beating curve of ^{85}Rb ions at the frequency of f_c=1 266 324.3 Hz using 100 ms excitation time. The best resonance conditions are reached at the first minimum. In this case the conversion constant corresponds to $c = T_{rf} \cdot A_{rf} = 0.1$ s $\cdot$ 105 mV= 10.5 mVs. In order to achieve the optimum resolving power, one should use long excitation times ($\sim$ 1 s) at small amplitudes ($\sim$ 10 mV).

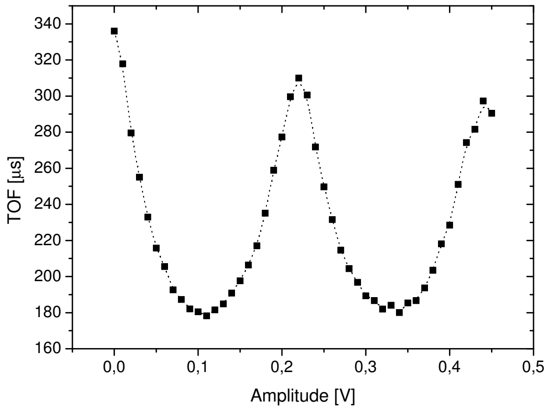

Fig. 2: Beating curve of ^{85}Rb, showing the periodic conversion between the magnetron and reduced cyclotron motion. The first minimum is located at 105 mV.

In the second trap we used a dipole excitation at the frequency of 170 Hz for the magnetron excitation during $T_{\omega-}$= 3 ms at $A_{\omega-}$= 91 mV amplitude to increase the magnetron radius of the motion of the ions. Then the quadrupole excitation was applied for T_{ω_c}=900 ms with an amplitude of A_{ω_c}=11.5 mV while scanning the cyclotron frequency. The pressure in the gas feeding line during the measurements was $4 \cdot 10^{-4}$ mbar. Fig. 3 shows two examples of resonances that were used to determine the achievable mass uncertainty in the measurement trap. The measured data was analysed by using the z-class method [2], where each measurement was divided into 3 classes according to the count rate to avoid the frequency shift coming from the Coulomb interaction between the trapped ions. The measured mass value of the ^{85}Rb, however, differed from the very accurate litterature value $(m_{lit} - m_{meas})/m_{lit} = 3.6 \cdot 10^{-8}$ [3]. For the detailed description of the setup and experimental results, see [4].

Frequency measurements of the same ion species were performed over several days to obtain information on the short term fluctuations in the magnetic field. During these runs the pressure in the helium exhaust line of the magnet was measured by using a capacitance pressure gauge, the bore temperature of the magnet and air temperature in the experimetal hall were measured by using PT-102 sensors. It was found that the changes in the cyclotron frequency correlate with the variations in the room temperature, see Fig. 4.

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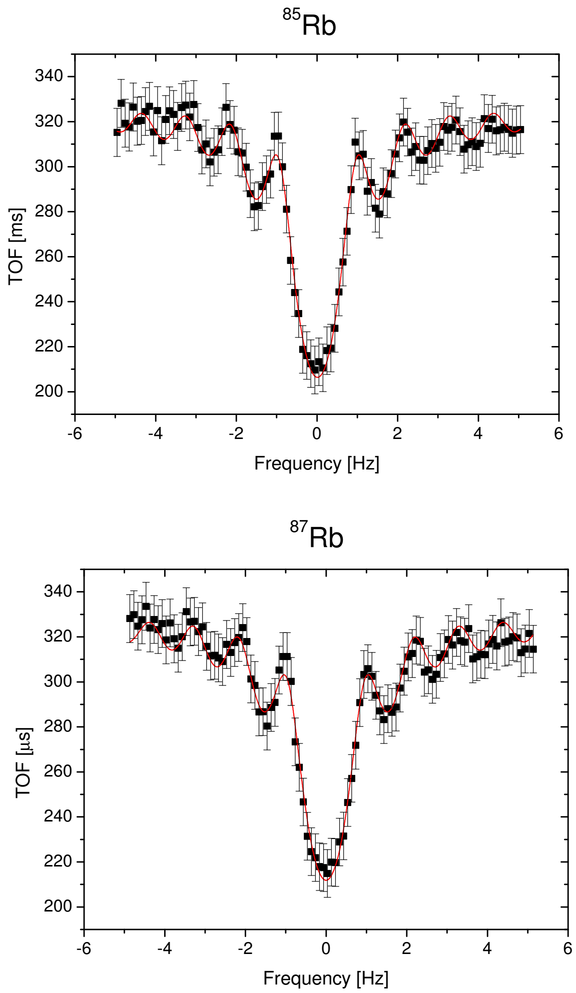

Fig. 3: An example of frequency scans in quadrupole mode in the measurement trap for the determination of the cylotron frequencies by using 900 ms excitation time and 11.5 mV amplitude. Above: ^{85}Rb. The frequency axis is scaled such that 0 corresponds to 1 266 324.354 Hz. Below: ^{87}Rb. The frequency axis is scaled such that 0 corresponds to 1 237 220.865 Hz. Black dots are measured points and the line corresponds to the fit function of the expected line shape.

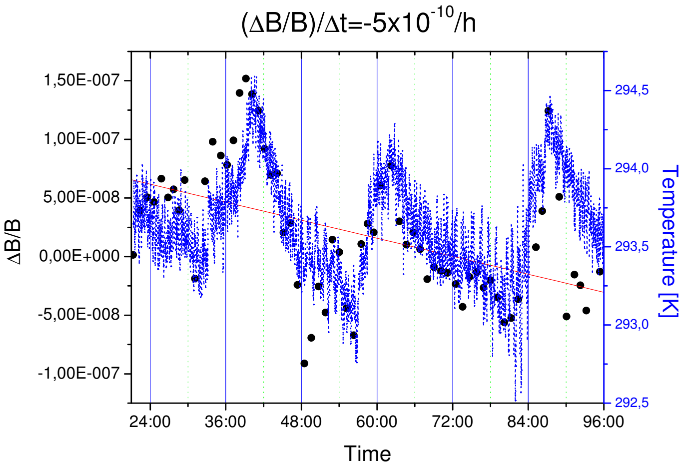

Fig. 4: Relative magnetic field fluctuations measured by using ^{85}Rb ions during 3 days and room temperature showing the correlation between the measured cyclotron frequency and temperature in the experimental hall. The straight line is a linear fit to the frequency data showing the long term decay of the magnetic field.

To be able to correct the reference frequencies in the interpolation process during the data analysis, we made a test measurement by using ^{85}Rb and varying the time intervals between the reference measurements. The standard deviation from the differences between the measured magnetic field strength and the interpolated value was plotted as a function of time difference between the reference measurements, see Fig. 5. A linear fit was applied to this data, resulting in $\delta f/f = 5.4(5) \cdot 10^{-9}/h \cdot \Delta T$. This corresponds to a rather large correction compared to the equivalent quantity $\delta f/f = 1.3(3) \cdot 10^{-9}/h \cdot \Delta T$ [5] measured at SHIPTRAP where a similar magnet in use or the ISOLTRAP value $\delta f/f = 3.8(3) \cdot 10^{-9}/h \cdot \Delta T$ [2].

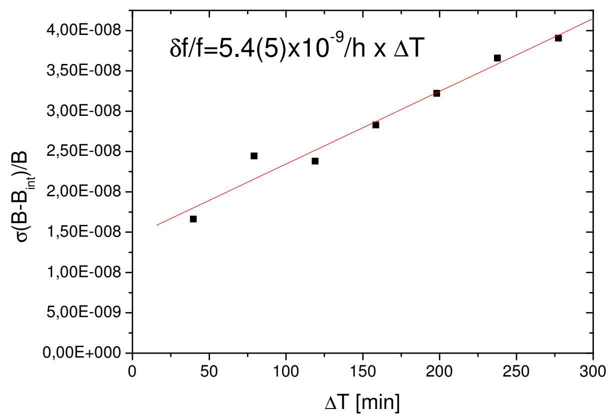

Fig. 5: Standard deviation of the difference between the interpolated magnetic field value and the measured value as a function of the time difference between the reference measurements. The straight line is a linear fit to the data, giving the systematic uncertainty that comes from the short-term fluctuations of the magnetic field.

When one adds this correction to the earlier data one obtains $m(^{85}Rb) + \Delta m_{stat} + \Delta m_{syst}$=84.911 795 7 (24) (4) u. This is still outside the one sigma limit from the literature value 84.911 798 732 (14) u. To obtain an improved estimate of the systematic uncertainty one should still add a mass shift and residual uncertainty to the result. This, however, would require a carbon cluster ion source, which is foreseen only in the later phase of the MLLTRAP. Since the statistics in the mass measurement test was relatively low, we will repeat this test again to get more reliable results. Nevertheless, the accuracy of $4 \cdot 10^{-8}$ is a good start for the measurement program at MLLTRAP, where plan to start the mass measurements of α decay daughter products from actinide nuclei (e.g. ^{244}Pu $\rightarrow$ ^{240}U). Such decays, leading to highly charged decay products via conversion processes, will even allow to develop th e mass measurement techniques with highly charged ions.

References

[1] V.S. Kolhinen *et al.* Annual report 2007, p. 93

[2] A. Kellerbauer *et al.* Eur. Phys. J. **D 22** (2003) 53

[3] M.P. Bradley *et al.* Phys. Rev. Lett. **83** (1999) 4510

[4] V.S. Kolhinen *et al.* Nucl. Instr. Meth. **A 600** (2007) 391

[5] M. Block *et al.* Eur. Phys. J. **D 45** (2007) 39