The MLLTRAP Penning Trap System ◇

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The MLLTRAP Penning trap facility, presently under construction at the Maier-Leibniz-Laboratory (Garching), will combine the well-established Penning trap technique with novel components like a charge-breeding EBIS for creation of highly-charged ions and sympathetic laser cooling with $^{24}Mg^{+}$ ions in a Paul trap. The aim is to reach an accuracy around 10^{-10} needed for precision mass measurements contributing to an improvement of the accuracy of fundamental constants, like the molar Planck constant $N_A h$ and for unitarity tests of the CKM-matrix via a determination of the V_{ud} quark mixing matrix element.

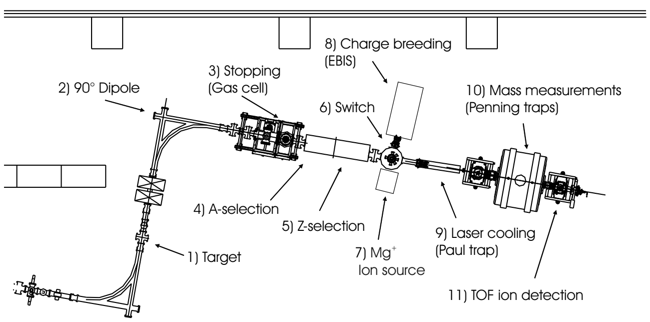

Fig. 1: Layout of the MLLTRAP facility (see text).

Figure 1 shows the MLLTRAP layout. The target is placed in the front of a 90° dipole magnet in order to allow for a separation of the reaction products from the primary beam. Since the Penning trap requires kinetic energies of the injected ions to be in the eV range, energetic (fusion or fission) reaction products that have typically a few hundred keV/u need to be thermalized and transversally cooled. This is achieved via a combination of a buffer-gas stopping cell and an extraction RFQ [1] similar to the one operated at SHIPTRAP [2].

The following section is dedicated to an isobaric purification of reaction products (position 4 and 5 in Fig. 1) which is usually done in the first (purification) trap of the Penning trap system. However, in our case this is not applicable since the highly-charged ions exclude the use of a buffer-gas filled purification trap. Instead both Penning traps will be used as high-precision mass measurement traps, thus allowing to reduce the systematic uncertainties by switching ions between the two traps. Isobaric purification will be performed behind the gas cell, most likely by an RF-mass filter of A selection and a multi-reflection TOF mass spectrometer identifying nuclear charge. A subsequent electrostatic multi-passage switch will allow for the ions to be injected into an Electron Beam Ion Source (EBIS) to produce highly-charged ions (HCIs), which is advantageous when aiming for ultimate mass accuracies according to $\delta m/m \propto \frac{m}{qBT_{rf}\sqrt{N}}$, where m is the mass of the ion of interest, q is the charge state, B is the magnetic field, T_{rf} is the excitation time and N the statistics.

Sympathetic laser cooling of the HCIs prior to their injection into the Penning traps will allow for a significantly improved localization of the ion cloud in the trap center and therefore reduce the systematic uncertainties, again allowing for an improved mass accuracy. Using a novel solid state Er fiber laser sympathetic cooling with a strongly-coupled plasma of laser-cooled $^{24}Mg^{+}$ ions down to mK temperatures will be performed in a Paul trap. The cooling process of HCIs in a strongly coupled $^{24}Mg^{+}$ plasma has been extensively studied and characterized in simulations using a newly developed, highly-parallel molecular dynamic simulation code [3]. Simulations prove that the $^{24}Mg^{+}$ crystal structure is preserved during the stopping and cooling process, distributing the HCI's energy over the whole plasma due to collective effects. Consequently continuous laser cooling of Mg ions is enabled without requiring to scan the laser. Starting with incident kinetic energies of E=100 meV (for A=100, q=40) cooling times of the order of 10 μs could be achieved in the simulations.

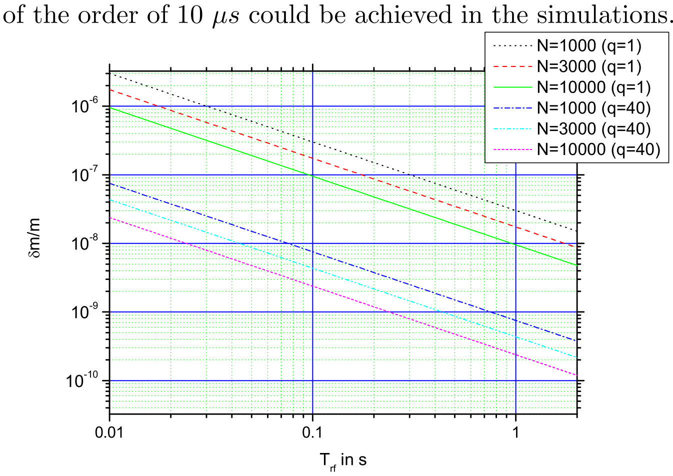

Fig. 2: Achieved mass accuracy as a function of the excitation time for different charge states and statistics (based on A=100 and B=7 T).

The superconducting magnet (B=7 T, from Magnex) was installed already 2004, all mechanical parts for the trap electrodes and the vacuum system are ready for installation and the development has started for the control system (by adapting the control system in operation at SHIPTRAP to our needs). The ion-optical components for off-line testing of the Penning trap have been manufactured and the MCP-detectors and their electronics have been tested.

Moving all components to a new beam line where better beam quality and larger acceptance can be expected together with larger overall space to house the complete set up will be the next step before the commissioning the trap system later in 2006.

References

[1] J. Neumayr *et al.*, Rev. Sci. Submitted (2006)
[2] J. Neumayr *et al.*, Nucl. Instr. Meth. **B244** (2006) 489
[3] M. Bussmann *et al.*, Int. J. of Mass Spect. accepted (2006)

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