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Development of a Penning trap system in Munich

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Abstract. The MLLTRAP (Maier-Leibnitz-Laboratory TRAP) Penning trap system at the FRM-II research reactor in Munich is presented. Its planned developments to reach very high "relative atomic mass" measurement precision (*e.g.*, below 10^{-10} for stable ions) are described.

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The MAFF facility (Munich Accelerator for Fission Fragments) —planned at the new research reactor FRM-II in Munich— is dedicated to produce, cool, and accelerate high-intensity beams of fission fragments of up to 10^{14}/s. Recently a significant progress was achieved: the FRM-II reactor has reached its final power of 20 MW. Within one year we expect a building permit from the German technical supervision for MAFF itself. The experimental hall for both low- and high-energy beams of MAFF is in a final planning stage and should be available by the end of 2006.

The experimental activities at MAFF will focus on nuclear spectroscopy studies and nuclear mass measurements. One of the experimental devices serving this purpose will be the Penning trap system MLLTRAP [1]. Its main tasks are to decelerate, cool, bunch, and purify the radioactive beam delivered by the MAFF facility and to perform high-precision mass measurements. In order to achieve that, very exotic n-rich, or superheavy, nuclei resulting from fusion reactions are mass-selected and separated from the beam (about 6 MeV/u) by the recoil mass separator MORRIS. Furthermore, they are decelerated to low (eV range) energies in a gas stopping chamber [2], extracted with an RFQ ion guide system, transferred to the EBIS charge-breeder to create high charge states, sympathetically cooled in a bath of singly charged Mg ions and finally injected into the Penning trap system for the precise nuclear mass measurements. The latter is possible also for the primary, low-energy (30 keV), fission product beam.

The challenges of present-day physics impose high requirements on the nuclear mass measurements. On the one hand, a more precise determination of the hyperfine structure constant, or a microscopic definition of the mass unit, demand uncertainties at 10^{-10} in the mass determination for stable nuclei. On the other hand, weak interaction studies (*e.g.*, the unitarity of CKM matrix, or testing the CVC hypothesis) must be supplied with data on nuclei far from stability measured with relative precision better than 10^{-8}. With the new trap set-up, two main goals are envisaged:

– High-precision ($\Delta m/m \leq 10^{-10}$) mass measurements of stable nuclei, as well as fusion residua from (HI, xn) reactions, at the MLL. As an example, the presently existing Penning trap system for stable, higly charged nuclei SMILETRAP [3] has a mass measurement accuracy between 10^{-9} and 10^{-10}.
– Precise ($\Delta m/m \approx 10^{-9}$) mass measurements of short-lived exotic nuclei produced at MAFF. At present, the existing Penning trap systems for mass measurements on radioactive nuclei (ISOLTRAP, CPT, SHIPTRAP, JYFLTRAP, LEBIT, see these proceedings) work with singly charged ions. The most advanced system, ISOLTRAP at CERN, has reached a residual systematic uncertainty of 8×10^{-9} [4].

In order to achieve these goals, several developments are foreseen, combining three technologies:
1) The use of a cryogenic FT-ICR (Fourier Transform Ion Cyclotron Resonance) technique with a single ion stored in a Penning trap. This non-destructive detection method should allow for very sensitive mass measurements [5].
2) Using a charge breeder —Electron Beam Ion Source EBIS ($I = 3$ A, $U = 6$ kV)— to convert the radioactive ions of interest into highly charged ones (HCI), in order to improve both the mass measurement precision and the signal-to-noise (S/N) ratio, thus the measurement sensitivity. This technique is already applied in case of stable ions [3]. In this way an S/N improvement by more than an order of magnitude is expected.
3) Sympathetic cooling of highly charged ions of interest with laser-cooled Mg^+ ions. Sympathetic cooling reduces

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Fig. 1. The 7 T superconducting magnet with two homogeneous field centers for the operation of the double-Penning-trap system.

Fig. 2. Electrode structure of the double-Penning-trap system.

the ion energy from an initial value after the EBIS of about 100 eV/q down to the Doppler limit of about 10^{-6} eV (temperature of about 10 mK). As a container for both HCI and Mg^+ ions, it is planned to use a linear RFQ trap, with the trap for Mg^+ ions nested inside the trap for HCI. By sweeping the storage potential for Mg^+ ion with respect to the one for HCI a fast sympathetic cooling of the latter ions is possible. An effective rejection of Mg^+ ions from the ions of interest during extraction will be achieved by placing the latter ones in a potential well at the RFQ end. Subsequent ejection through the narrow diaphragm and TOF separation of both ion species should allow for an injection of the practically clean highly charged ion sample into the Penning trap. There is a long-term experience at the LMU in laser cooling of Mg^+ ions [6]. A recently developed, much more compact laser system, based on Er-fiber laser and frequency quadrupling, will be used.

Apart from the developments mentioned above, in order to reach high-precision additional precautions will be needed, like temperature stabilization inside the magnet bore and pressure stabilization in the liquid helium tank.

At present, there are other planned Penning trap systems, like for example HITRAP [7], TITAN [8], MATS/FAIR [9], where using HCI, FTICR and HCI cooling are also foreseen.

As the present status of MLLTRAP is concerned, a superconducting $B = 7$ T magnet (Magnex Scientific) was installed already at MLL in Garching, see fig. 1. It was energized and shimmed to reach maximum field inhomogeneity of 3×10^{-7} within 1 ccm in two places lying 20 cm apart on the B-field axis.

These two places may host two Penning traps for precise mass measurements. In a first step, it is planned to build the MLLTRAP in a conventional way and to work with singly charged ions. The system will consist of a cooling/purification Penning trap, using the mass-selective buffer gas cooling scheme for rejection of isobaric contaminants [10], and a precision Penning trap, where the main mass measurement, involving the TOF technique, is performed.

The corresponding electrode structure was machined in the LMU workshop and is shown in fig. 2. Other parts of both vacuum system and electronics are being completed. First tests of the set-up are foreseen at the end of 2005. Subsequently, an upgrade is planned aiming at including the components mentioned in points 1)–3).

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