Accurate mass measurements of very short-lived nuclei at ISOLDE with MISTRAL[a]

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The MISTRAL project is scheduled to begin data acquisition at the ISOLDE PS Booster facility at CERN in late-1997. MISTRAL has been conceived for direct measurements of very short-lived nuclides ($T_{1/2} < 1\ s$) as it has good sensitivity (10 atoms/s). The spectrometer resolution of 10^5 and potential measurement accuracy of 5×10^{-7} should be sufficient to evidence nuclear structure, reduce the large divergence between various model predictions, and provide interesting data for possible halo nuclei.

1 Introduction

Accurate knowledge of the atomic mass has important consequences for nuclear structure. Deviation from mass surface regularity indicates shell and sub-shell closures as well as nuclear deformation and shape transitions. Prediction of masses and other properties of nuclides far from stability is also important for models of stellar nucleosynthesis. The rapid neutron-capture process, for example, responsible for the production of heavy elements in the universe, follows a path that involves nuclides that will probably never be produced in the laboratory. Improving the predictive power of existing mass models is therefore excellent motivation for extending the domain of precisely measured values.

With these goals in mind, the MISTRAL project (Mass measurements at ISolde using a Transmission and RAdiofrequency spectrometer on Line),[1–2] recently approved for installation at the new ISOLDE PS Booster facility at CERN, will use a direct measurement technique to concentrate on very short-lived nuclides. Thus, MISTRAL will complement existing mass measurement programs providing extremely accurate data closer to stability, such as the ISOLTRAP collaboration,[3] and those concerned with more exotic nuclides but having slightly greater uncertainties, such as the double cyclotron project at GANIL.[4]

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2 Description of the MISTRAL experiment

In this experiment, the mass is obtained by comparison of the cyclotron frequency of the unknown mass in the homogeneous magnetic field to that of a reference mass. The frequencies are measured by modulating the kinetic energy of the ions orbiting inside the spectrometer using a radiofrequency voltage.

A schematic overhead view of the MISTRAL apparatus is shown in figure 1. Ions are injected electrostatically into the annular magnetic field ($B \leq 0.8$ T) of the spectrometer at the full ISOLDE transport energy (60 keV). As shown in the center inset in figure 1, the ions take two helicoidal turns inside the spectrometer, traversing the entrance slit, the upper RF modulator, a modulation phase-definition slit, the lower RF modulator, and finally the exit slit. Details of the modulator geometry are shown in the right inset of figure 1 (the gaps are 0.4 mm wide and the RF electrode is about 1.5 mm long).

The principle of the modulation is illustrated in figure 2. Injected ions are modulated after one half-turn. After a further turn, the ion kinetic energy is demodulated by the same rf voltage. In resonance, when the rf modulating frequency corresponds to an integer plus one-half multiple of the cyclotron frequency, the net modulation is zero so that the ion trajectories again follow the nominal 1-m diameter circular path and are transmitted through the narrow exit slit of 0.4 mm. Note than in figure 2, the harmonic $n = 1$ is taken for illustration. Under normal operation, this value will be about 2000, corresponding to a frequency range of 250-500 MHz (for the mass range of A =7-250).

Scanning the beam transmission versus the modulation frequency thus provides a mass peak as shown in the left inset of figure 1. Previous measurements using a 200 keV H^- test beam have demonstrated a resolving power of more than 10^5 and a potential accuracy (given sufficient statistics) of 5×10^{-7}. Since the ISOLDE beam will be used directly, the measurement technique is universal and free from losses due to re-ionisation. As the flight time through the apparatus is only about 50 μs, the only limitation on half-life is the ISOLDE target release time.

3 Perspectives

Recent emittance measurements of the ISOLDE beam [5] together with spectrometer simulations and transmission measurements with the H^- beam, indicate that a transmission of 1% and thus, a sensitivity of 10 atoms/s should be possible. These two features - high sensitivity and no additional delay - make MISTRAL particularly suitable for the measurement of nuclides very far from stability as they are generally short-lived and poorly produced. Based on the older ISOLDE-II yields, there are over 50 new measurements possible with MISTRAL of isotopes with half-lives less than one second and another 50 such isotopes for which mass accuracy may be improved.

Among these 100 nuclides, particular emphasis will be placed on so-called halo nuclei. Important input parameters for neutron halo models are the one- and two-neutron separation energies, quantities derived directly from the mass. There are several neutron halo candidates falling into the MISTRAL measurement domain for which these separation energies are poorly known.

Current mass models seem to have greatest difficulty in regions of light nuclei where description of the "core" is significant compared to the valence nucleons. ISOLDE yields are particularly good for neon and sodium isotopes, providing several suitable candidates for model improvement in this region.

Concerning extrapolation, it is especially necessary to extend measurements as far as possible from stability as the ensemble of current nuclear models tends to diverge quite rapidly away from known values. An example of this problem is shown for the tin isotopes in figure 3. Again, looking at the ISOLDE yields, we find good possiblities for extending mass values of Rb and Cs as well as Ag, Cd, In, Sn and Sb where there are candidates around $N = 82$ that closely approach the r-process path.

MISTRAL is presently set up in Orsay for testing and preparation. Installation at ISOLDE is scheduled for the Spring of 1997. We hope to schedule first experiments for late 1997, and thus, initiate an exciting long-term program.

Acknowledgments

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References

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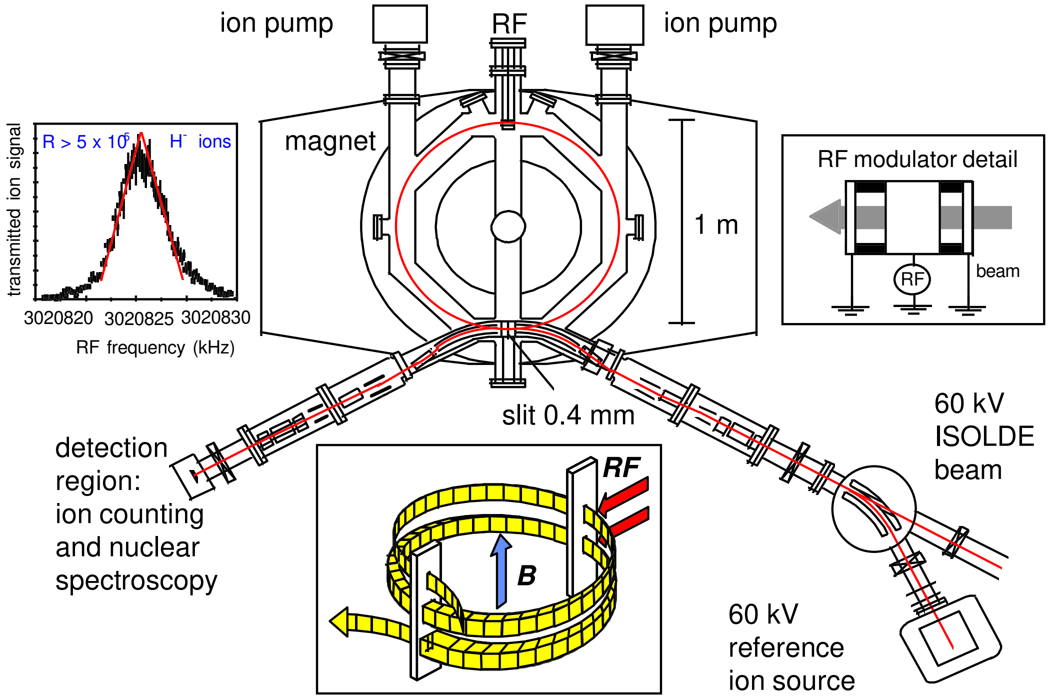

Figure 1: Schematic overhead view of the MISTRAL spectrometer layout. Insets show (center) isometric view of trajectory, (right) modulator detail and (left) transmitted ion signal for H^- ions.

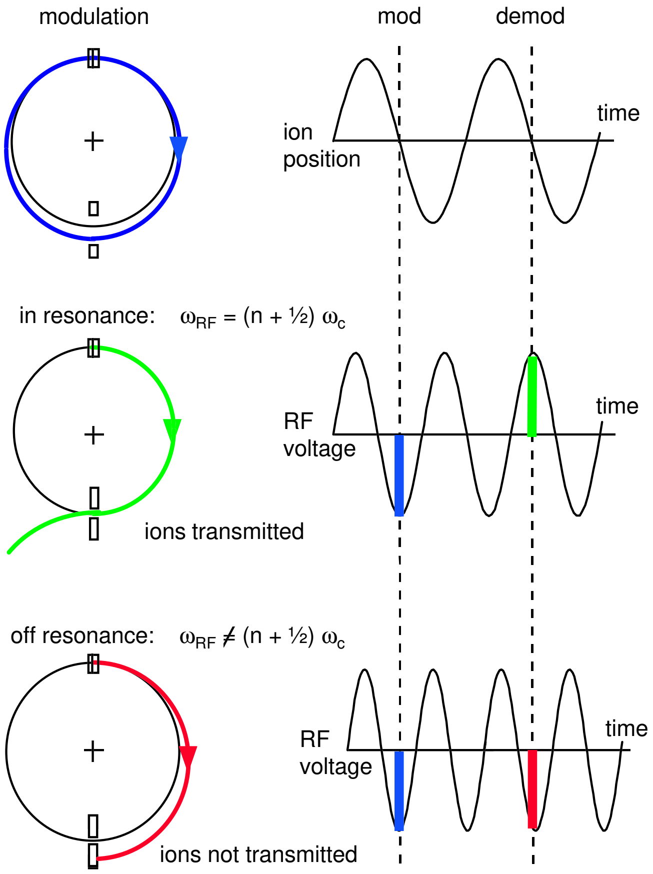

Figure 2: Operating principle of the Smith-type, radiofrequency spectrometer.

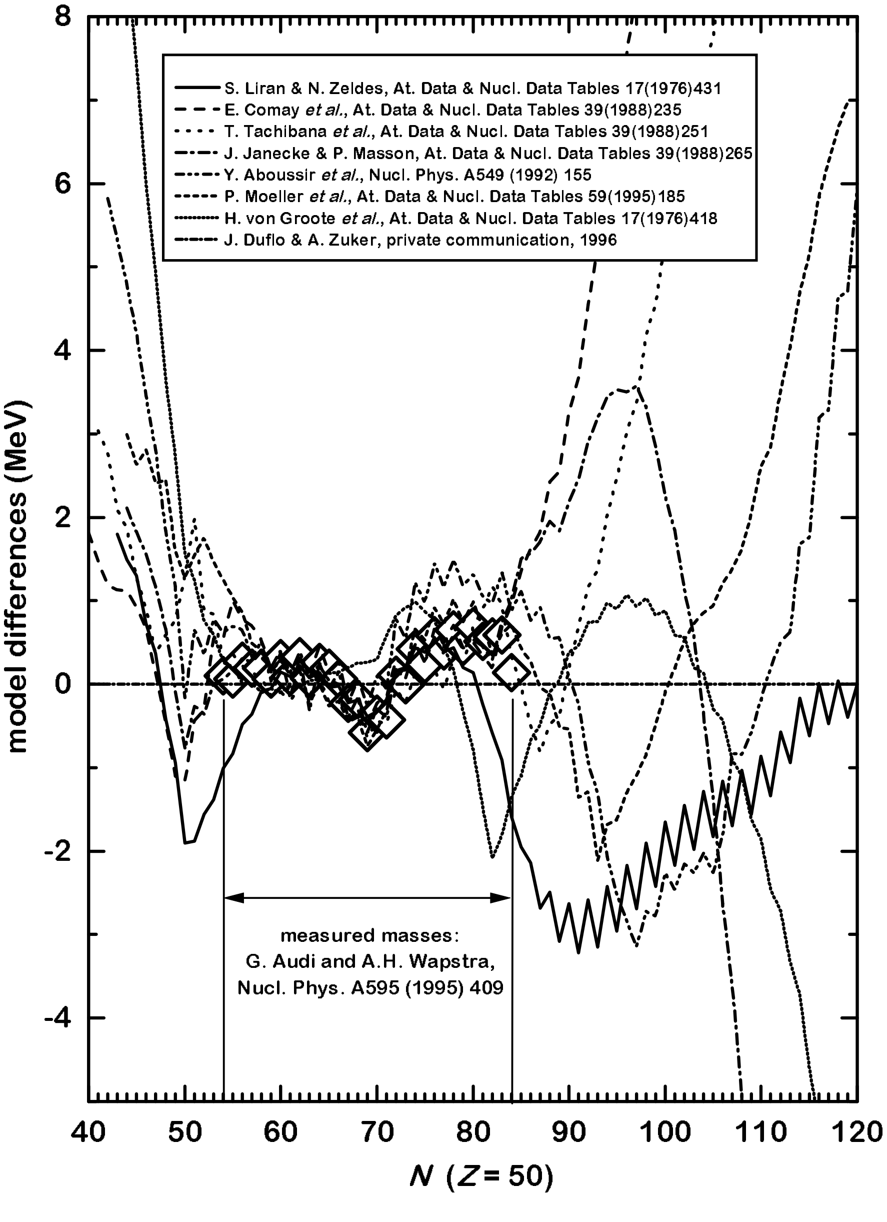

Figure 3: Differences between various nuclear mass models for the tin ($Z = 50$) isotopes. Note that aside from Janecke and Masson, the so-called mass "formulas" are omitted from this comparison, leaving only macroscropic-microscopic models.