2 - 7 Charge and Frequency Resolved Isochronous Mass Spectrometry in Storage Rings: First Direct Mass Measurement of the Short-lived Neutron-deficient ^{51}Co Nuclide*

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Isochronous mass spectrometry in storage rings is a successful technique for the precision mass measurements of the nuclides with half-lives down to tens of microseconds[1]. Since the isochronous condition $\gamma = \gamma_t$ greatly reduces the influence of the velocity difference on the ion revolution periods, the revolution period difference $\Delta T = T - T_R$ of a stored ion with respect to a reference time T_R is directly related to its mass-to-charge ratio difference $\Delta(m/q)$, written in the first order as:

$$\frac{\Delta T}{T_R} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{(m/q)_R} \quad , \tag{1}$$

where γ_t is the transition point of the storage ring.

According to Eq. (1), the determination of the revolution times is crucial for mass measurements, and the precision not only affects the statistic error of mass values, but also limits the mass resolving power of the isochronous mass spectrometry. Therefore, ions with very close mass-to-charge ratios can not be identified exclusively via their revolution periods. However, our observations show that the mean signal amplitude of ions penetrating the carbon foil of the TOF detector is related to their charge states (Fig. 1(a)). This fact can be used to determine the charge states of the stored ions, which provides supplementary information for particle identification in addition to the precise measurements of revolution periods.

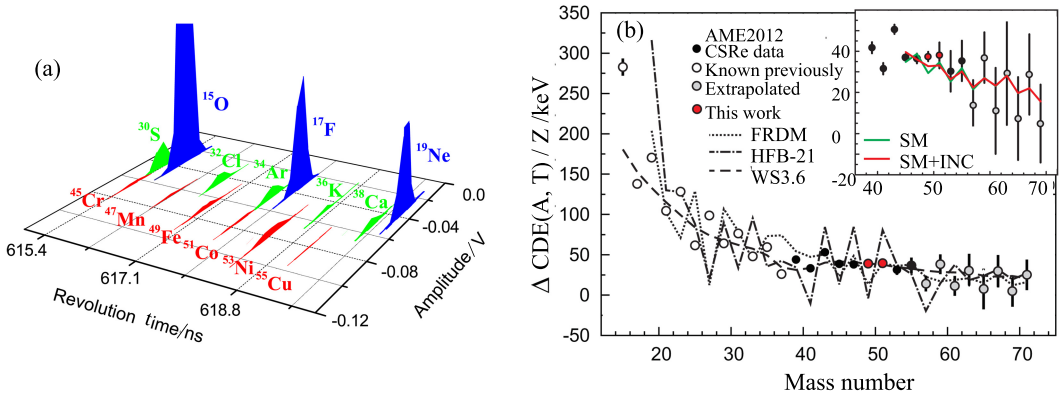

Fig. 1 (color online) (a): Three dimensional plot (average signal amplitude vs revolution time and vs the number of stored ions) of $^{51}Co^{27+}$, $^{34}Ar^{18+}$ and neighbouring ions. (b): Experimental and theoretical ΔCDE values for the $T = 3/2$ nuclei. The theoretical data are obtained from the FRDM, HFB-21 and WS3.6 mass models. The experimental data are from the latest mass evaluation AME'12, of which the data measured at CSRe, known previously before the CSRe experiments, and extrapolated are marked explicitly. This work contributes to two new points (red full circles). The insert shows a zoom on the heavier mass region together with shell model calculations without (SM) and with (SM+INC) isospin-nonconserving nuclear forces.

Applying this new technique, we successfully separate the $^{51}Co^{27+}$ ions from $^{34}Ar^{18+}$ ions, and consequently, for the first time determine the mass excess of ^{51}Co to be $ME(^{51}Co) = -27342(48)$ keV. The details of the experimental setup and data analysis can be found in Ref. [2].

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Using the new mass excess of ^{51}Co, we investigate the Coulomb displacement energy for $|T_z| = 3/2$ in the *sd*- and lower *fp*-shell nuclei. Fig. 1(b) illustrates the comparison between the experimental data and theoretical results obtained from the FRDM[3], HFB-21[4] and WS3.6[5] mass models. It is striking that all considered mass models fail to describe the feature that the staggering of the ΔCDE values is washed out for $A = 45-51$ nuclides. However, by performing the shell-model (SM) calculations as in Ref.[6] including the isospin-nonconserving (INC) nuclear interactions for the $f_{7/2}$-shell, the description of staggering of the experimental ΔCDE is improved considerably, while without the INC forces some staggering of ΔCDE values for $A = 45-51$ still exists. This results are consistent with the recent calculation for the $T = 1/2$ chain [6], pointing to the necessity to include INC interactions in the calculations of *fp*-shell nuclei.

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2 - 8 SimCSR Program for the Simulation of the Isochronous Mass Spectrometry at the HIRFL-CSR*

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Until now, several isochronous mass spectrometry (IMS) experiments have been successfully performed using various primary beams at the HIRFL-CSR and masses of both proton-rich and proton-deficient exotic nuclei have been measured. In order to improve the performance of the IMS experiments and to provide a reliable tool for designing and preparing the future experiments, a simulation code, named SimCSR is developed.

Presently, six-dimension phase-space linear transmission theory is applied to simulate the transmission of ions in the experimental storage ring (CSRe). The basic algorithm is $B_f = MB_i$. The B_i and B_f are six-dimension phase-space vectors of ions at the entrance and exit of each element of the CSRe lattice, respectively. M is a 6-by-6-dimension first-order transfer matrix of each element. M is calculated using formulas described in Ref.[1]. In the simulations, the ring lattice is considered in detail, and the same magnetic setting as in our previous experiment with ^{58}Ni projectile fragments[2] is considered. The ions are assumed to circulate 300 turns inside the CSRe.

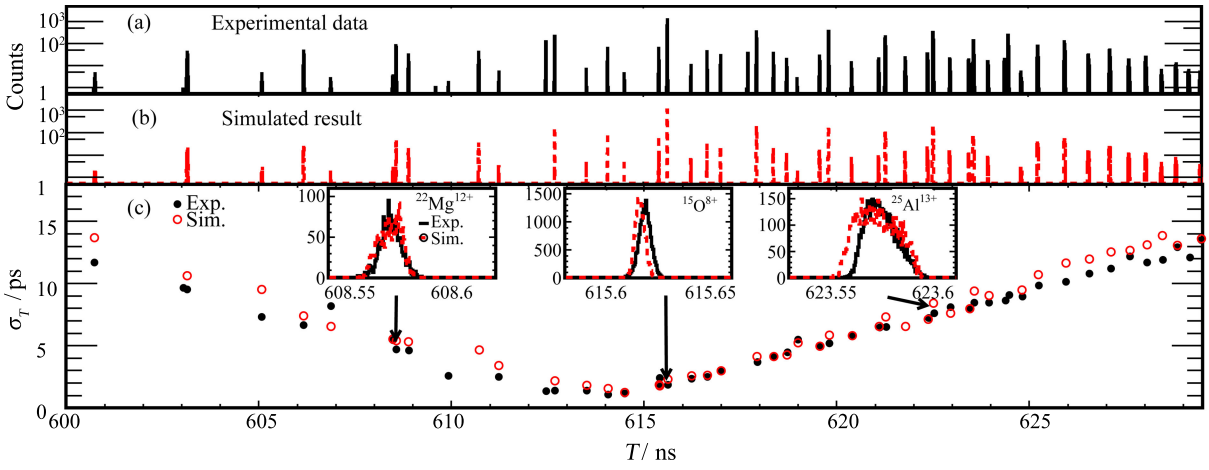

Fig. 1 (color online) Experimental (a) and simulated (b) revolution time spectra. The comparison of the standard deviation of revolution time (σ_T) between the experimental and simulated results is shown in (c). The inserted figures in (c) are the zoomed revolution time spectra for ^{22}Mg^{12+}, ^{15}O^{8+} and ^{25}Al^{13+} ions.