Technical Improvements in the Experiment of Isochronous Mass Measurement of ^{58}Ni Projectile Fragments

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Abstract：The combination of in-flight fragment separator and the isochronous mass spectrometry(IMS) in storage rings have been proven to be a powerful tool for the precision mass measurements of short-lived exotic nuclei. In IMS, the mass-over-charge ratio is only related to the revolution period of stored ions, and the relative mass resolution can reach up to the order of 10^{-6}. However, the instability of the magnetic field of storage ring deteriorates the resolution of revolution period, making it very difficult to distinguish the ions with very close mass-over-charge ratio via their revolution periods. To improve the resolution of revolution periods, a new method of weighted shift correction (WSC) has been developed to accurately correct the influence of the magnetic field instabilities in the isochronous mass measurements of ^{58}Ni projectile fragments. By using the new method, the influence of unstable magnetic fields can be greatly reduced, and the mass resolution can be improved by a factor up to 1.7. Moreover, for the ions that still cannot be distinguished after correcting the magnetic field instabilities, we developed a new method of pulse height analysis for particle identification. By analyzing the mean pulse amplitude of each ion from the timing detector, the stored ions with close mass-over-charge ratios but different charge states such as ^{34}Ar and ^{51}Co can be identified, and thus the mass of ^{51}Co can be determined. The charge-resolved IMS may be helpful in the future experiments of isochronous mass measurement even for $N = Z$ nuclei.

Key words: nuclear mass; storage ring; isochronous mass spectrometry; mass measurement

1 Introduction

The mass of an atomic nucleus, reflecting the sum of all the interactions among the component nucleons, plays an important role on research of nuclear structure, nuclear astrophysics. Precision mass measurements of nuclei provide a sensitive probe to reveal fine interactions and structures of nuclei to test the theories from nuclear models to the Standard Model[1−3]. Therefore, various of new facilities and technologies have been developing for precision mass measurements of nuclei[4]. For the stable nuclei, the precision of measurements now reach a relative uncertainty of about 10^{-11} by using Penning Trap[5]. However, the mass measurements for the nuclides far-off stability are still difficult due to the tiny production rates and/or short half-lives. The combination of in-flight fragment separa-

rator and the isochronous mass spectrometry(IMS) in storage rings, which has single-ion sensitivity and requires no beam cooling, is an ideal tool for performing precise mass experiments with short-lived rare ions[6−7] and has great potential to improve the precision forward.

In IMS, the relative mass-over-charge ratio $\Delta(m/q)$ for a stored ion with respect to a reference nuclide $(m/q)_0$ is directly determined by the revolution time difference $\Delta t = t-t_0$ as the following equation[8−9]:

$$\frac{\Delta t}{t_0} = \frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{(m/q)_0} - (1-\frac{\gamma^2}{\gamma_t^2})\frac{\Delta v}{v_0} , \qquad (1)$$

where γ_t denotes the transition point of the storage ring, and γ is the Lorentz factor. Apparently, if the velocities of the stored ions satisfy the so-called isochronous condition $\gamma = \gamma_t$, the revolution periods

of the stored ions are independent of their momentum spread and only related to their mass-over-charge ratios. However, the isochronous condition can only be satisfied for the ions with specific mass-over-charge ratio, while for other ions it cannot be satisfied. For one ion species with a certain mass-over-charge ratio ($\Delta(m/q) = 0$), the spread of revolution times are determined by the frequency dispersion (η) and the acceptance of magnetic rigidity ($B\rho$) in the first-order approximation[8]:

$$\frac{\delta t}{t_0} = -(1 - \frac{\gamma^2}{\gamma_t^2})\frac{\Delta v}{v_0} = -\eta\frac{\delta(B\rho)}{B\rho_0} \ , \qquad (2)$$

where $\eta = 1/\gamma^2 - 1/\gamma_t^2$.

Since the IMS was pioneered at the experimental storage ring (ESR) facility of GSI[8, 10–12] and then developed in the Institute of Modern Physics (IMP)[13], the IMS has been successfully applied to measure/improve plenty of mass values of exotic nuclei[14–15]. However, there are still some difficulties to overcome in order to increase the mass resolution of the IMS further. In this article we will introduce two important technical improvements in the experiments of IMS. The first improvement is a new algorithm of correcting the influence of the drift of magnetic fields and effectively increase the mass resolution. Another is pulse height analysis for the identification of ions with very close mass-over-charge ratios.

The magnetic strength of dipoles at storage rings changes persistently during the experiments due to the instability of the power supply for magnets in isochronous mass measurements (see Ref. [13]). According to Eq. (2), this provides additional momentum spread of stored ions and deteriorates the resolving power of revolution time spectra, thus prevents us obtaining high precision of masses especially for the stored ions satisfying the isochronous condition.

In some experiments of IMS, the data acquired during a shot period (several minutes or longer) were grouped together in a sub-spectrum, and different sub-spectra were superimposed into a total spectrum by polynomial fitting e.g. gain matching correction (GMC)[16], then the mean revolution time and standard deviation for each peak in the total spectrum was used to calculate the mass values and corresponding errors[10, 17]. Another method to deal with the sub-spectra is the correlation-matrix approach[12], which was developed and firstly used in Schottky Mass Spectrometry (SMS) in GSI[18]. Both methods can somehow correct the magnetic drift, but not thoroughly.

To overcome the disadvantage induced by grouping data, Tu[13] developed a third method in isochronous mass measurements of ^{78}Kr fragments

performed in the Cooler Storage Ring (CSRe) of IMP[13, 15]. His method was based on the assumption that the instability of magnetic fields can be neglected in one injection (200 μs). Seven ions which have the highest counts were chosen to be reference. For one reference, the relative revolution times of other ions simultaneously stored with the reference in each injection were accumulated into a sub-spectrum. Since the revolution time spectra of stored ions follow the Gaussian distribution approximately, the difference of mean revolution times for stored ions remains the same during the process of correction, which makes sure the average mass values for all nuclides are unaltered. Without grouping data, this method can effectively narrow down the width of revolution time spectra compared to uncorrected data.

Unfortunately, the uncertainties of revolution times of reference nuclides will be transfer to all the other nuclides, and the injections in which no reference nuclides exist will be thrown away. Therefore, this method may not be suitable for such experiments in which even the references are hard to be chosen due to small statistics, e.g. the mass measurements for very neutron-rich nuclei along the path of the r-process nucleosynthesis.

Compared these methods mentioned above to each other, the question become how to correct the drift of magnetic fields at the utmost without losing much statistics for general experiments of IMS. Basing on the assumptions in Ref. [13], we developed a universal method WSC to reduce the influence of unstable magnetic fields irrespective of accelerator facilities in IMS. Taking the mass measurement of ^{58}Ni projectile fragments conducted in the CSRe as a example, we will describe the algorithm of WSC and explain the reason why the WSC method can solve this problem excellently.

In the experiments of IMS, the revolution difference of ion species are mainly determined by the mass-over-charge ratio of ions. For most of the stored ions, identification is usually not a problem, the revolution periods are just sufficient to determine the ion species. However, for some special cases that when ions have very close mass-over-charger ratios (such as $N = Z$ nuclei, low-lying isomers et al.), their peaks in the revolution period spectra overlaps and thus can not be separated from each other. Noticing that the timing detector in the IMS not only record the timing signals when the stored ions penetrating the thin carbon foil of the detector, but also record the signal pulse heights which are related to the charge states of the stored ions. The additional information of signal pulse heights allows us to identify the ions with very close mass-over-

charge ratios but different charge states. We also use the mass measurement of ^{58}Ni projectile fragments as an example to show the details of pulse height analysis for the ion identification of ^{34}Ar and ^{51}Co ions.

2 Experiment setup

In the ^{58}Ni experiment, we aimed at measuring the masses of the nuclei with $T_z = -3/2$ in fp shell using the IMS technique. For this purpose, the ^{58}Ni^{19+} beams of 463.36 MeV/u were chosen in order to fulfill the isochronous condition of $\gamma = \gamma_t = 1.395$[8, 13] for the ions of ^{47}Mn^{25+}. The beam was accelerated by the main ring CSRm and focused onto a $\sim$15 mm beryllium target placed at the entrance of RIBLL2. The exotic nuclei were produced by fragmentation of the energetic projectile ^{58}Ni and emerged from the target predominantly as bare ions. After in-flight separation of the fragments in RIBLL2, the cocktail beam of exotic nuclei within a Bρ-acceptance of $\sim \pm 0.2\%$ was injected into the CSRe. RIBLL2 and CSRe were set to a magnetic rigidity of $B\rho = 5.6770$ Tm to optimize the transmission of the $T_z = -3/2$ nuclides around ^{47}Mn. The magnetic rigidity of RIBLL2 and CSRe was checked up by the primary beam with corresponding energy at the beginning of the experiment. Other nuclides within the acceptance of the RIBLL2-CSRe system were also transmitted and stored in CSRe. Typically, about ten ions were stored simultaneously in one injection.

In order to measure the revolution times of stored ions in the CSRe, a dedicated timing detector, which is equipped with a 19 μg/cm^2 carbon foil of 40 mm in diameter, was installed inside the aperture of the CSRe. The details of this TOF system have been described in Ref. [19]. In brief, each passage of the stored ions through the carbon foil could release secondary electrons which were guided isochronously by perpendicularly arranged electrostatic and magnetic fields to a set of micro-channel plates (MCP), thus giving a timing signal of the passing ions. The signals from the MCPs were directly sampled by using a commercial digital oscilloscope Tektronix DPO 71254.

These recorded digital signals were analyzed off-line, then the penetration times of stored ions in each revolution were extracted using the constant fraction algorithm. In this experiment, the acquisition time of the digital oscilloscope was set to 200 μs for each injection corresponding to about 320 revolutions of the ions in the CSRe. The timing signals are periodic; this property was used to determine the revolution times T_i of each individual ion in the same way described in Ref. [10, 13]. Only those particles which were stored for more than 300 revolutions in the CSRe were used in the analysis. This condition is important for the precise determination of the corresponding revolution times. Differing from the conventional methods, the revolution times in each injection was treated as a sub-spectrum for ion identification[10, 13], and the WSC method was applied to superimpose all available sub-spectra into a total spectrum (see Fig. 1). Here, "available" refers to the injections in which two or more ions were stored simultaneously.
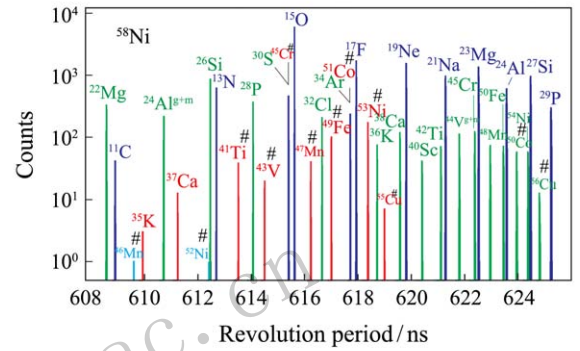

Fig. 1 (color online) Part of the revolution time spectrum zoomed in a time window of 608 ns $\leqslant t \leqslant$ 625 ns.

3 Weighted shift correction

Let us define the revolution periods of the i-th ion species ($i = 1, 2, 3, \cdots, N_s$, with N_s being the total number of different ion species) in the j-th measurement ($j = 1, 2, 3, \cdots, N_m$, with N_m being the total number of measurements) as $T_{i,j}$. The magnetic fields of the storage ring vary slowly in time around a central mean value B_0. The variation of the magnetic field in the j-th measurement with respect to B_0 is $\Delta B_j = B_j - B_0$. The $T_{i,j}$ data in this measurement can be written as:

$$T_{i,j} = T_{i,j}^0 - \Delta T_j , \qquad (3)$$

where $T_{i,j}^0$ are the revolution periods in the absence of magnetic field variations and ΔT_j is the drift due to ΔT_{B_j}.

The $T_{i,j}^0$ follow the normal distribution, $N(\mu_{T_i}, \sigma_{T_i}^2)$ with expectation mean values μ_{T_i} and their standard deviations σ_{T_i}. Here, the σ_{T_i} include all the other uncertainty factors of the measurements except for the instabilities of magnetic fields. In real measurements, due to the isochronicity conditions, the σ_{T_i} depend on μ_{T_i}. The goal of the following analysis procedure is to determine the μ_{T_i} and σ_{T_i} for all ion species ($i = 1, 2, 3, \cdots, N_s$), which can then be used for the mass determination. Details of the mathematical derivations can be found in Ref. [20].

Let us assume that all the N_s ions are present in each measurement j. If the μ_{T_i} and σ_{T_i} are known, then we can re-construct a new variable $T'_{i,j}$, which can be calculated directly from experimental data, through a linear transformation of the variable $T_{i,j}$, i.e.,

$$T'_{i,j} = T_{i,j} - \sum_{i=1}^{N_s} \frac{1}{\sigma_{T_i}^2}(T_{i,j} - \mu_{T_i}) / \sum_{i=1}^{N_s} \frac{1}{\sigma_{T_i}^2}$$
$$(i=1,2,3,\cdots,N_s, \quad j=1,2,3,\cdots,N_m) . \quad (4)$$

In case of the $N_s \to \infty$, the standard deviations of T'_i distributions should approach σ_{T_i}. However, since the number of ion species, N_s, is finite, the standard deviations $s_{T'}$ of the resulting distributions T'_i are smaller than σ_{T_i}. In other words, the distributions T'_i are "overcorrected". For more details see Ref. [20].

Using Eq. (3) and given the fact that ΔT_j is a constant for all the ion species in the j−th measurement, it can be shown that $T'_{i,j}$ are related to $T^0_{i,j}$ as:

$$T'_{i,j} = T^0_{i,j} - \sum_{i=1}^{N_s} \frac{1}{\sigma_{T_i}^2}(T^0_{i,j} - \mu_{T_i}) / \sum_{i=1}^{N_s} \frac{1}{\sigma_{T_i}^2} = T^0_{i,j} - \delta T_j$$
$$(i=1,2,3,\cdots,N_s, \quad j=1,2,3,\cdots,N_m) , \quad (5)$$

where δT_j is the term accounting for the "overcorrection" of the T'_i distributions. The variance of the δT_j values is given by

$$V(\delta T_j) = 1 / \sum_{i=1}^{N_s} \frac{1}{\sigma_{T_i}^2} , \quad (6)$$

which approaches 0 when $N_s \to \infty$.

Under the condition that $T'_{i,j}$ and δT_j are independent variables one can write:

$$T'_i = \langle T'_{i,j} \rangle = T_i = \langle T_{i,j} \rangle = \langle T^0_{i,j} \rangle = \mu_{T_i}$$
$$(i=1,2,3,\cdots,N_s) , \quad (7)$$

and

$$\sigma_{T_i}^2 = s_{T'_i}^2 + V(\delta T_j) \quad (i=1,2,3,\cdots,N_s) . \quad (8)$$

To find the unknown μ_{T_i} and σ_{T_i} in a real data analysis, the Eqs. (4)∼(8) are solved iteratively. The important starting step is to provide externally an initial reference set of $\mu_{T_i}^*$ and $\sigma_{T_i}^*$. For this purpose, simulated values of the revolution periods[10, 13] or the ones obtained from the raw experimental data can be used.

The second step is to calculate the $T'_{i,j}$ values for all ions present in all individual measurements. This can be done with Eq. (4) by substituting μ_{T_i} and σ_{T_i} in Eq. (4) with $\mu_{T_i}^*$ and $\sigma_{T_i}^*$. From the set of $T'_{i,j}$ values, one can calculate the mean revolution periods, T'_i, and the corresponding standard deviations, $s_{T'_i}$[20]:

$$T'_i = \mu'_{T_i} = \frac{\sum_j T'_{i,j}}{M_i}, \quad s_{T'_i}^2 = \frac{\sum_j (T'_{i,j} - \mu'_{T_i})^2}{M_i - 1}$$
$$(i=1,2,3,\cdots,N_s) , \quad (9)$$

where M_i is the number of occurrences of the i-th ion species in all N_m measurements. We note, that the calculated $s_{T'_i}^2$ values with Eq. (9) are different from those calculated with Eq. (8). They would be the same if the initial parameters $\mu_{T_i}^*$ and $\sigma_{T_i}^*$ are exactly equal to μ_{T_i} and σ_{T_i}, respectively.

Therefore, in the next step, the results of Eq. (9) are used as the new $\mu_{T_i}^* = T'_i$ and $\sigma_{T_i}^{*2} = s_{T'_i}^2 + V(\delta T_j)$. This procedure is performed until the convergence is reached. Thus the last $\mu_{T_i}^*$ and $\sigma_{T_i}^{*2}$ values correspond to the best approximation, as allowed by the statistics in a particular experiment, of the expected μ_{T_i} and σ_{T_i} which can be used for the mass determination.

In reality the statistics is finite and the number of species in each measurement is not equal to N_s. Therefore, $V(\delta T_j) = 1/\sum_{i=1}^k 1/\sigma_{T_i}^2$ can significantly be different for measurements with significantly different number of present ion species k. The number of individual measurements N_m is several ten thousands while the average number of simultaneously stored ion species k is about 10. One can show mathematically (see Ref. [20]) that in the limit of $M_i \to \infty$, $(\sigma_{T_i}^*)^2 = s_{T'_i}^2 + V(\delta T_j)$ and $(\sigma_{T_i}^*)^2 = s_{T'_i}^2 + V_i(\delta T_j)$ provide the same result, where $V_i(\delta T_j)$ is a value for the i-th ion species obtained by averaging of $V(\delta T_j)$ over all measurements where the i-th ion species is present ($i=$ true):

$$V_i(\delta T_j) = \frac{\sum_j V(\delta T_j)|_{i=\text{true}}}{M_i} \quad (i=1,2,3,\cdots,N_s) . \quad (10)$$

Thus the $\sigma_{T_i}^{*2} = s_{T'_i}^2 + V_i(\delta T_j)$ were used in the iteration procedure above.

4 Pulse height analysis

In order to measure the mass of a stored ion, its mean revolution time (the center of gravity for each peak in Fig. 1) should be determined as precisely as possible from the experiment. The standard deviation of Ts lies at a range of 2∼4 ps for the stored ions. From the systematic trends of production yields for $T_z = -\frac{3}{2}$ nuclides as shown in the time spectrum, one would anticipate that ^{51}Co has been injected and stored in CSRe. However this ion could not be resolved from ^{34}Ar in the time spectrum due to their very close m/q ratios; this prevents us from determining its revolution

times. Nevertheless, given the fact the pulse height from our timing detector depends on Z of the stored ions[19], we have analyzed the pulse heights for all the stored ions.
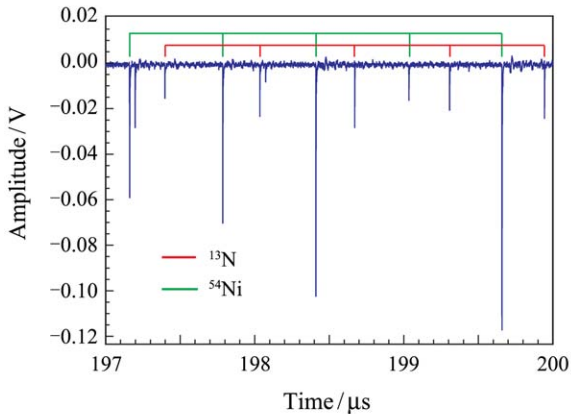

Fig. 2　(color online) Timing signals, as recorded by the time-of-flight detector, of simultaneously stored $^{13}N^{7+}$ and $^{54}Ni^{28+}$ single ions. Only five consecutive revolutions in the CSRe are shown.

We know that a series of periodically appeared timing signals in Fig. 2 are caused by an individual ion, and the corresponding pulse height are different even for the same stored ion in one injection, therefore, we extracted the average pulse heights for each stored ion in the analysis. Same procedure has been applied to all the stored ions, then we obtained a cubic matrix including three parameters: the averaged pulse height (amplitude), the revolution time, and the number of ions. The cubic matrix is plotted in Fig. 3 from which one sees that the stored ions with $T_z = -\frac{1}{2}, -1, -\frac{3}{2}$ can be clearly identified. Of most importance, ^{51}Co and ^{34}Ar has been fairly well resolved although both nuclides have nearly the same revolution times as shown in Fig. 1.
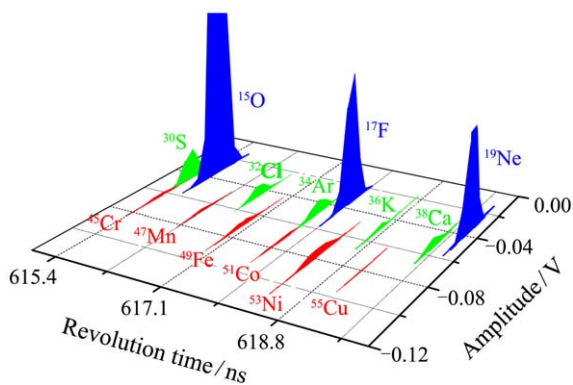

Fig. 3　(color online) Three dimension plot of pulse height, revolution period, and number of ions stored.

The pulse height distributions for ^{51}Co and ^{34}Ar are presented in Fig. 4(a). We assume that the events with average pulse heights bigger than 64 mV belong to ^{51}Co, while those smaller than 64 mV to ^{34}Ar, then, the mean revolution times for ^{51}Co and ^{34}Ar have been extracted to be 617.7167(38) ns and 617.7152(40) ns, respectively. The corresponding revolution time difference was found to be merely 1.63(35) ps. We notice that the ^{51}Co and ^{34}Ar can not be completely separated from each other in the pulse height distribution spectrum (see Fig. 4(a)); the small overlap may cause additional errors to their revolution times extracted. However, it can be estimated that the mis-assignments may cause an average shift of 0.03 ∼ 0.04 ps in the mean revolution times, which is negligible compared to the statistical error of the obtained time difference of 1.63(35) ps[21].
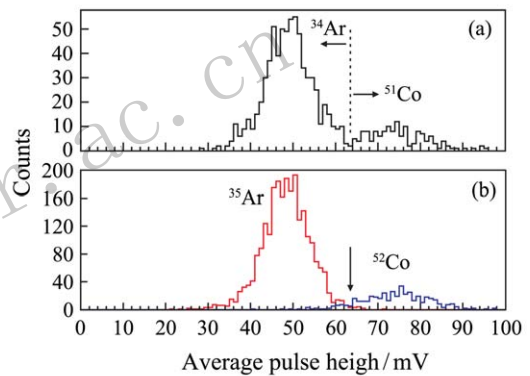

Fig. 4　(color online) Averaged pulse height distributions for (a) ^{34}Ar and ^{51}Co which have very close revolution times. (b) for ^{35}Ar and ^{52}Co which have quite different revolution times.

5　Results and discussion

The data analysis method was applied to the IMS experimental data obtained at the CSRe and results of which were published in Ref. [22]. By using the new method, the re-determined mass values are consistent with the previously published results, and for some nuclei at isochronous region the mass precision is higher than previous one. Furthermore, since the initial $\mu_{T_i}^*$ and $\sigma_{T_i}^*$ sets can be provided from an external simulated spectrum, the new method can be an excellent on-line tool to provide a quick response on the experimental conditions such as, *e.g.*, whether the $B\rho$ setting of the ring is tuned correctly to achieve the "good" isochronous conditions for the nuclides of interest.

Fig. 5 provides a comparison of the obtained intrinsic σ_{T_i} values to those taken from Refs. [17, 22] for the same ion species. As expected, in the "good" isochronous region, the new σ_{T_i} values are smaller than

those from Refs. [17, 22]. This result is easy to understand since the additional uncertainty σ_B is to a large extend (or even completely) removed in our new data analysis. Obviously this leads to a higher precision mass determination in this region.
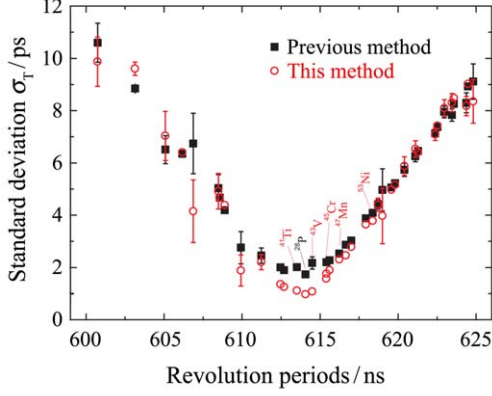

Fig. 5　(color online) The comparison of the standard deviations obtained in this work (red or green filled squares) and in Refs. [17, 22] (black filled circles). A range of revolution periods of $608 \text{ ns} \leqslant t \leqslant 620 \text{ ns}$ is considered.

The original aim in the experiment was to set the "good" isochronous region on the ^{47}Mn ions. However, Fig. 5 shows that the best isochronous condition $(\gamma \approx \gamma_t)$ are fulfilled for the ^{28}P ions, and that the σ_T for the ^{47}Mn ions is about twice of that for the ^{28}P ions. This mismatch translates into a significant increase of statistics, and accordingly the beam time duration, which has to be accumulated for ^{47}Mn ions to achieve the aimed mass uncertainties. This proves that the present method can be valuable as the on-line monitoring tool for checking the correctness of the isochronous setting of the ring. By going to more exotic nuclides with lower production yields, the on-line control of the ring settings will become more and more important.

We used the new $\mu^*_{T_i}$ and $\sigma^*_{T_i}$ values deduced from the present analysis to re-determine the masses of interest. We used the same reference ions for the calibration as well as the fitting procedure as in Refs. [17, 22]. These fourteen reference nuclides are used to fit m/q versus T employing a third order polynomial function:

$$\frac{m}{q}(t) = a_0 + a_1 \cdot t + a_2 \cdot t^2 + a_3 \cdot t^3, \qquad (11)$$

where a_0, a_1, a_2 and a_3 are free parameters. The systematic error of this experiment is determined using the following equation:

$$\sum_i^{N_{\text{ref}}} \frac{(ME_i - ME_i^{\text{ref}})^2}{(\sigma_i^{\text{ref}})^2 + (\sigma_i^{\text{stat}})^2 + (\sigma_i^{\text{fit}})^2 + (\sigma^{\text{sys}})^2} = N_{\text{ref}} \ . \quad (12)$$

Using the experimental data of reference nuclides and the literature mass error from[23], the systematic error is determined to be 5 keV. Then, we can determine the total error of unknown mass: $\sigma_i^2 = (\sigma_i^{\text{stat}})^2 + (\sigma_i^{\text{fit}})^2 + (\sigma^{\text{sys}})^2$. The re-determined mass excess values and their uncertainties are given in Table. 1. A comparison of the re-determined values with the ones from Refs. [17, 22] is illustrated in Fig. 6. All data points agree within 1σ confidence level.
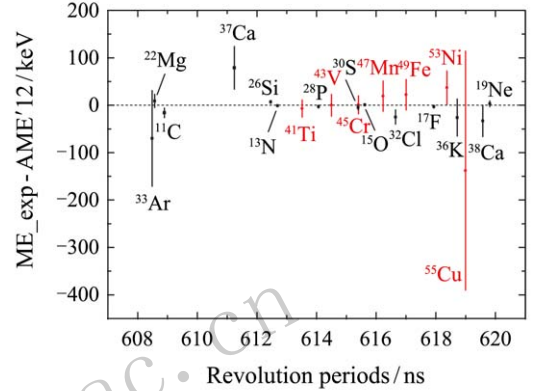

Fig. 6　(color online) Comparison of the masses with error bars determined in this work and those in the AME'12 evaluation[23].

However, a significant improvement of the precision for the masses of ^{41}Ti and ^{43}V is achieved. The mass resolving power of ^{41}Ti is calculated to be $R = m/\Delta m = T/\gamma_t^2/(2.36\ \sigma_T) \approx 1.3 \times 10^5$ which is increased by a factor of ~ 1.7 compared to the previously published one.

Table 1　The mass values for $T_z = -3/2$ nuclides obtained in this work.

Nuclide	Counts	ME/keV	Error/keV
^{41}Ti	57	$-15\,705$	18
^{43}V	35	$-17\,913$	23
^{45}Cr	160	$-19\,512$	35
^{47}Mn	99	$-22\,544$	32
^{49}Fe	180	$-24\,728$	30
^{51}Co	144	$-24\,728$	48
^{53}Ni	311	$-29\,593$	34
^{55}Cu	7	$-31\,766$	240

6　Conclusions

In this article, recent improvements of IMS have been introduced. Firstly, to reduce the impact of the magnetic drift at the utmost, the data-analysis method WSC has been developed. There are three conditions for applying the WSC method: the revolution time for each stored ions should approximately follow the Gaussion distributions; the injections in which two or more ions stored simultaneously are effective; there must be

three or more combinations of different distinguishable ions species stochasticly stored in the ring. These conditions can be easily satisfied in the experiments of IMS, which means the WSC method are suitable for most of isochronous mass measurements. Secondly, the pulse height analysis has been developed for ion identification of the ions with very close mass-over-charge ratios but different charge states. The newly developed method may be applied in future IMS measurements for $Z = N$ nuclides.

By applying the new techniques, the experimental data in the mass measurement of ^{58}Ni fragments have been reanalyzed, the mass resolution has been improved by a factor up to 1.7, and the mass excesses for ^{41}Ti, ^{43}V, ^{45}Cr, ^{47}Mn, ^{49}Fe ^{51}Co, ^{53}Ni and ^{55}Cu are determined. All the newly-determined mass values are within 1σ confidence level compared to those in the AME'12 evaluation. Besides, it is now possible to quickly diagnose the isochronous condition in the future experiments of IMS, which may save the required beam time of experiments. The new method of correcting the magnetic field instabilities open the door for further correcting of the momentum spread of the stored ions by applying the double time-of-flight detectors for velocity measurements.

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