A New Approach to Isobar Separation and Mass Measurements of Low Energy Radioactive Ion Beams

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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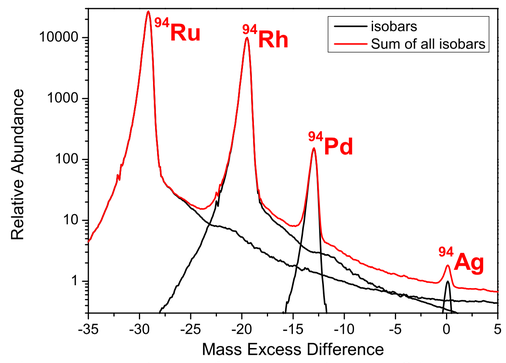
1. Summary

Many experiments at low energy radioactive ion beam facilities are currently limited by the available mass measurement methods and the amount of isobaric contamination. The multiple reflection time-of-flight mass spectrometer (MR-TOF-MS) presented here offers a solution to these challenges, due to the worldwide unique combination of mass resolving power (600,000 FWHM), measurement times (~ ms), ion capacity (>10^6 ions/s), mass measurement accuracy (~ 10^{-7}) and transmission efficiency (up to 70%) [1,2]. The system can be used as (i) broadband mass spectrometer with high resolving power (4,000 FWHM) for diagnosis of experimental setups located in front of the MR-TOF-MS, (ii) mass spectrometer for high accuracy mass measurements and (iii) isobar separator with high ion capacity. The MR-TOF-MS is the first TOF-based system that has demonstrated spatial separation of isobars. The present MR-TOF-MS system is envisaged to be used at different facilities, such as the FRS Ion Catcher, TITAN, SHIPTRAP or in the future at the LEB of the Super-FRS at FAIR. The online test of the system has been performed at the FRS Ion Catcher in October of 2011 and summer of 2012.

2. Motivation

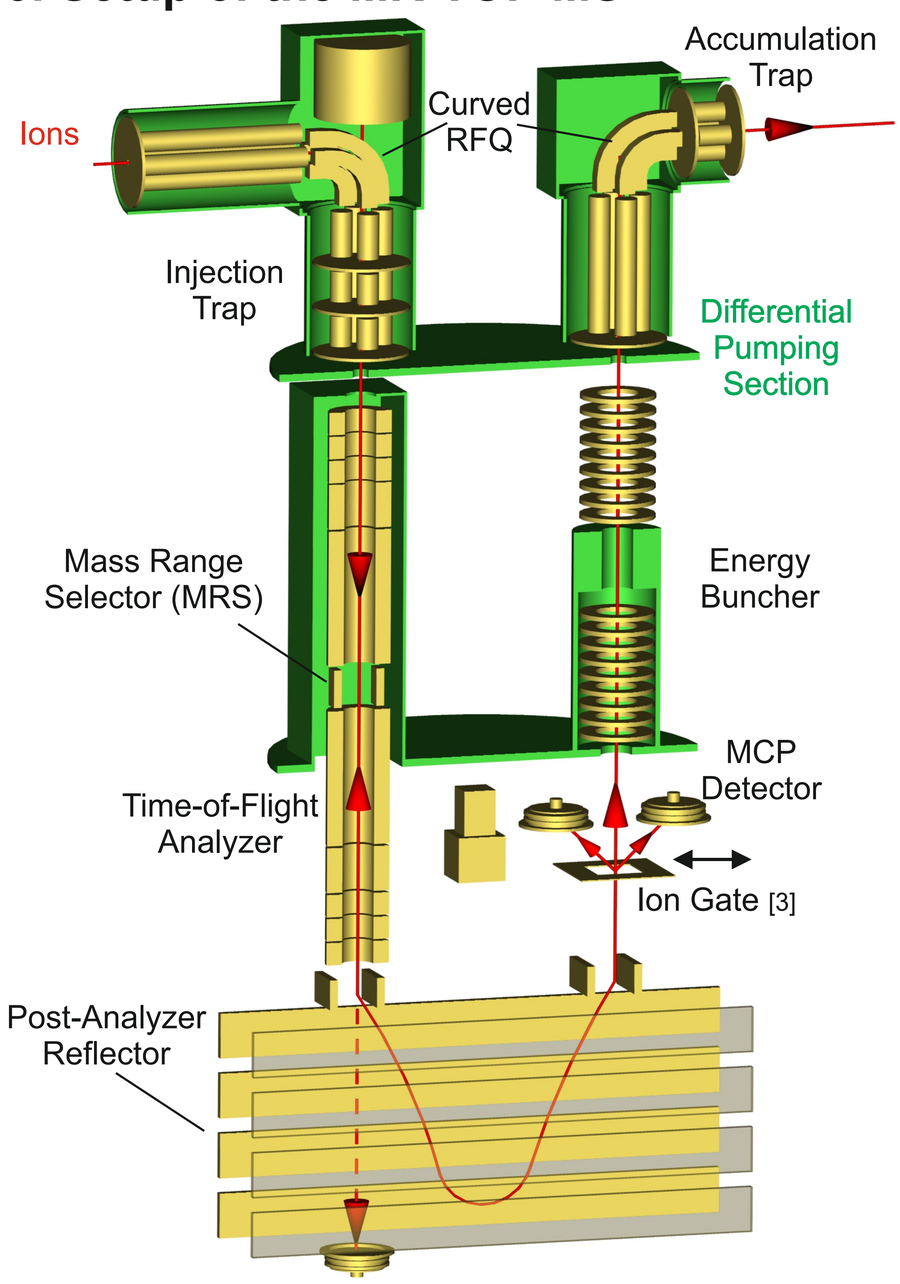
Envisaged applications:

- Separation of isobaric reaction products at in-flight and ISOL facilities
- Removal of molecular contamination ions created during ion stopping and extraction in gas-filled stopping cells
- Direct mass measurements of very-short-lived nuclides
- Ion identification and diagnosis by high-resolution broadband mass spectrometry



Expected mass spectrum of isobars at mass 94 u produced in the fusion-evaporation reaction ^{58}Ni(^{40}Ca, p3n)^{94}Ag. The relative abundances have been calculated with PACE4 and peak shapes measured with the MR-TOF-MS for ^{133}Cs have been used. It is apparent that a direct mass measurement of ^{94}Ag ($t_{1/2}$ = 34 ms) would be possible with the MR-TOF-MS.

3. Setup of the MR-TOF-MS

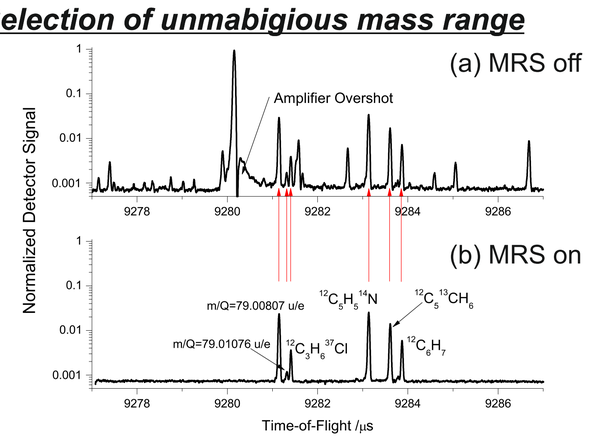


Schematic figure of the MR-TOF-MS system. The main functional elements are shown only. Overall height ~ 2 m, ion kinetic energy 750 eV

4. Mass Spectrometer with Very High Resolving Power

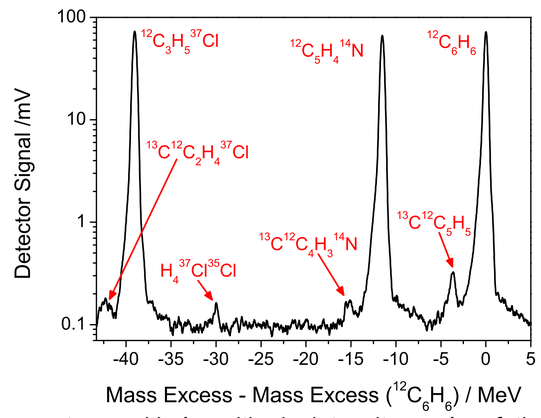
The ions travel for a selected number of turns inside the analyzer and impinge on the detector in the time focus. The mass range of an unambiguous time-of-flight spectrum is limited, but the resolving power and mass accuracy are very high.

Selection of unmabigious mass range



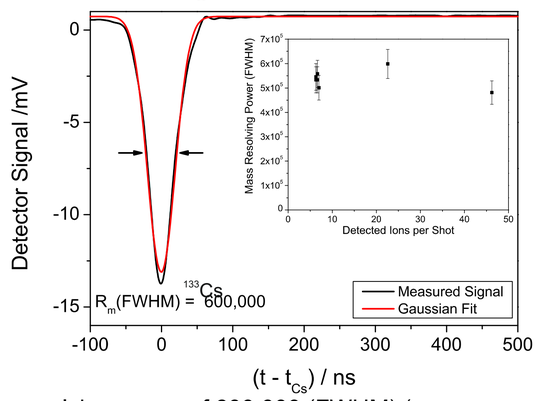
Time-of-flight spectra for mass 79 u of the mixture of benzene, pyridine and dichloropropane ionized by electron-impact ionization. (a) an identification of different masses is not possible because ions with different mass numbers have different number of turns. (b) Mass Range Selector (MRS) was set to exclusively transmit ions with mass 79 u. An unambiguous spectrum is obtained and the masses are measured and identified.

Logarithmic Mass Spectrum



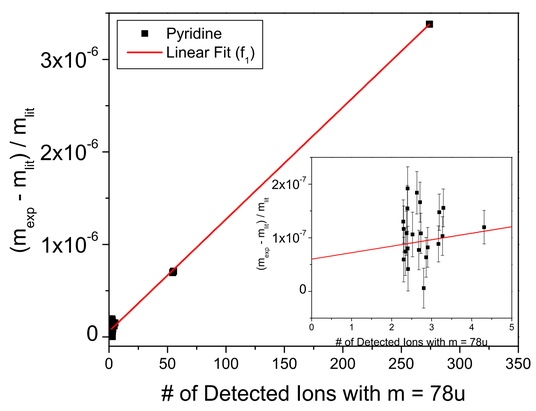
Mass spectrum with logarithmic intensity scale of the mixture discussed before at mass 78 u. The MRS is used to ensure a correct assignment of the peaks. Mass resolving power of 200,000 is reached in less than 10 ms flight time.

Mass Resolving Power



Mass resolving power of 600,000 (FWHM) (measurement time: 49 ms) is comparable to a 7 Tesla TOF-ICR-MS (measurement time: 1 s). The peak has a Gaussian-like shape even at this high resolving powers. This allows the separation of nearby peaks with largely different intensities. Inset: The measurement is independent of the number of detected ions, thus space charge effects do not influence the resolving power in this measurement.

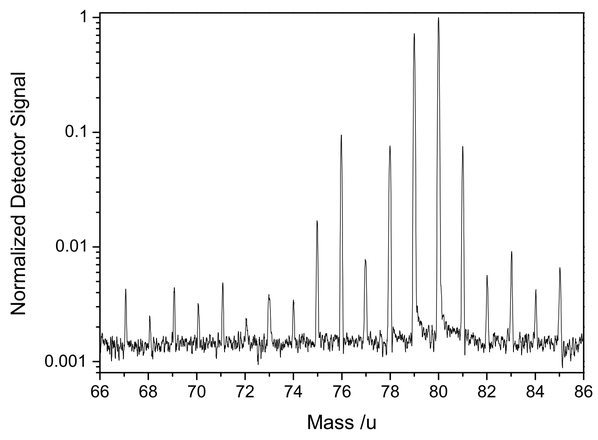
Mass Measurement Accuracy



The three main isobars (see top figure) are used to determine the mass measurement deviations versus number of detected isobaric ions per cycle (at mass 78 u). The inset shows a zoom of the lower left part. The intercept of the linear fit represents the residual systematic error without ion-ion interaction. Note: One detected ion at mass 78 u is accompanied by 45 ions of different mass ejected from the trap system. Thus, more than 10^4 ions per shot or 10^6 per second can be processed and a mass measurement accuracy down to 10^{-7} has been achieved.

5. Broadband Mass Spectrometer

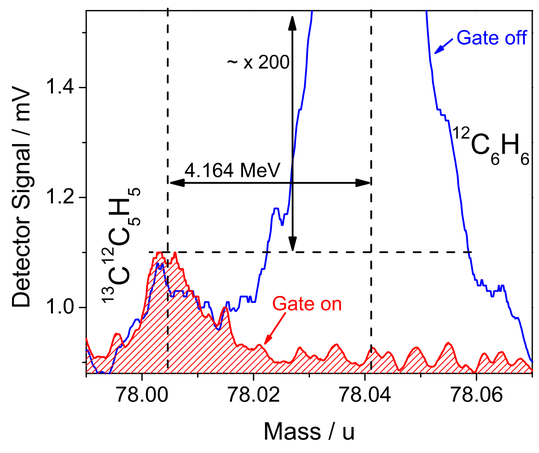
The analyzer is switched off and the time-of-flight detector is in the time focus. Because the analyzer is not used, the ions have an open flight path and the time-of-flight spectrum can be unambiguously converted into a mass spectrum. This broadband mode can be used for diagnosis of devices upstream the beam-line. A mass resolving power of up to 4000 (FWHM) has been achieved, which is sufficient to resolve many molecular isobars.



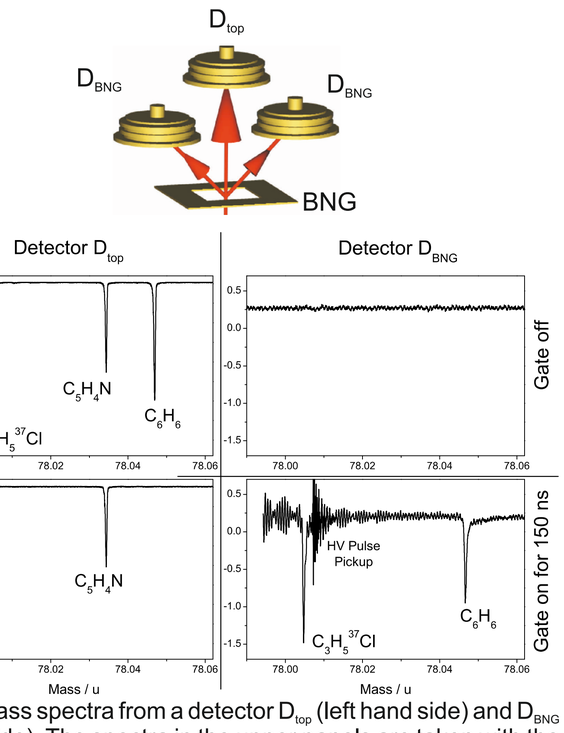
Measured broadband mass spectrum (pass-through mode) with logarithmic intensity scale of a mixture of benzene, pyridine and dichloropropane ionized by electron-impact ionization.

6. Isobar Separator

For isobar separation, the analyzer is used as in the very high resolving mode, but instead of the detector a Bradbury-Nielsen gate (BNG) is placed at the time focus to convert the temporal dispersion into a spatial separation. The unwanted ions are deflected and the ions of interest are delivered to other experiments following the MR-TOF-MS.



Separation of close-lying isobars (4.164 MeV) with large intensity ratio (200). It can be clearly seen that the BNG deflects all $^{12}C_6H_6$ without disturbing the $^{13}C^{12}C_5H_5$. Note: The background is caused by electrical noise.



Measured mass spectra from a detector D_{top} (left hand side) and D_{BNG} (right hand side). The spectra in the upper panels are taken with the BNG off and in the lower panels the BNG is switched off only while the C_5H_4N ions pass through.

7. References

[1] W.R. Plaß et al., *Nucl. Instrum. Methods B* 266 (2008) 4560.
[2] T. Dickel, doctoral thesis, Justus-Liebig-Universität Gießen, 2010.
[3] N.E. Bradbury et al., *Phys. Rev.* 49 (1936) 388.

8. Acknowledgements

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