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Fission yield measurements at IGISOL with PI-ICR technique and MR-TOF device (Task 2.5.)

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Description of the work:

Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR), has been developed for Penning traps. It allows faster and more accurate measurement of atomic masses, as compared to the more traditional techniques. The achieved high mass resolving power allows to resolve isomers separated only by a few tens of keV's. JYU has begun to apply a pioneering technique called Phase-Imagin Ion-Cyclotron-Resonance (PI-ICRS) for determining isomeric yield ratios (IYR) in fission. In a CHANDA-supported experiment isomeric ratios of neutron rich indium and cadmium isotopes in proton-induced fission were measured. JYU will develop a method based on the PI-ICR technique for general fission product yield studies.

What has been done:

- Experiment I-286: ”Independent fission yields in 25 MeV proton induced fission of 232Th – A test for applying PI-ICR technique to fission yield measurements” proposed and performed at IGISOL in JYU-ACCLAB 10.-15.3.2023
- Fission yields were measured using PI-ICR technique, MR-TOF device, and traditional gamma ray spectroscopy
- MR-TOF and gamma ray data analysed, PI-ICR analysis in progress

- D.2.8 “Report on the method based on the PI-ICR technique for general fission product yield studies at JYFL”, due M36 – delayed, delivered 7.12.2023 (M51) or 10. June 2024 (M58)

- MSc Thesis: Rami Korkiamäki, "Thorium-232 protoni-indusoidun fission tuottojakauma" (Thorium-232 proton induced fission yield distribution), in Finnish, MSc Thesis 10.6.2024

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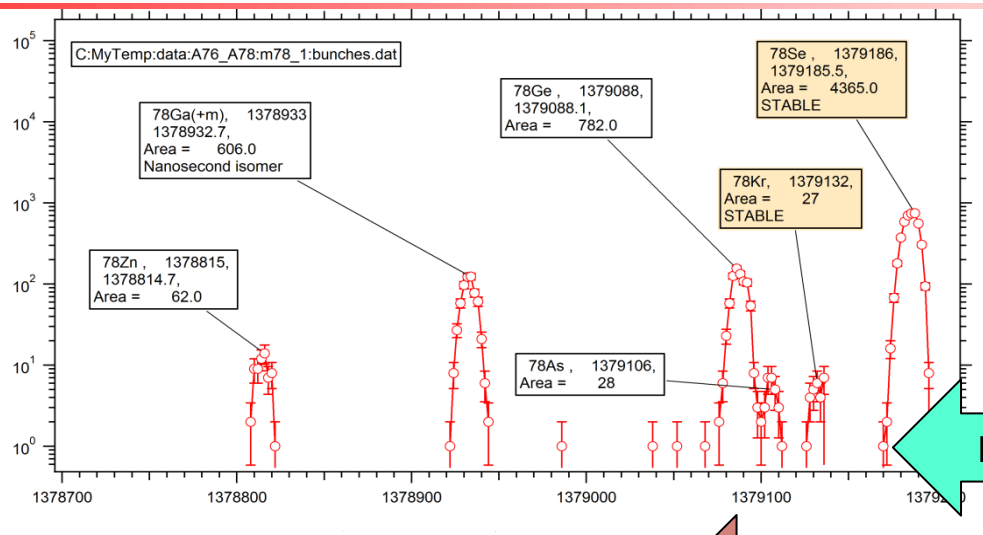


The ion guide technique produces $q = +1$ ion beams from **all elements**

+

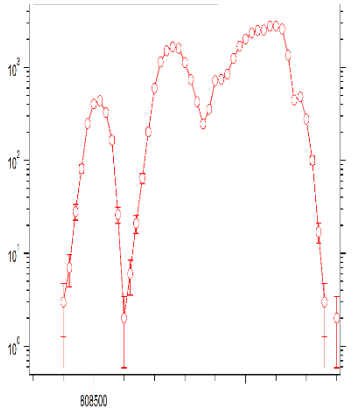
The JYFLTRAP provides unique identification of **all ions** based on their mass

=

Which, as combined, allows determination of the independent isotopic fission yields

Example of easy to extract yields -spectrum

A=133 mass spectrum

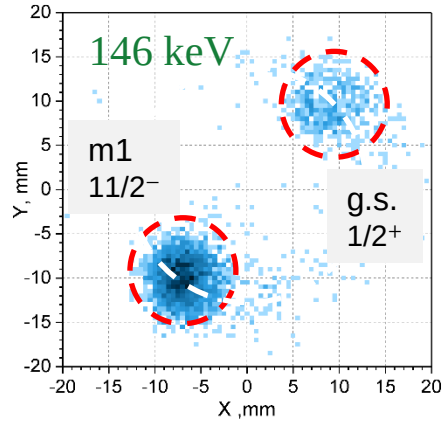


Example of hopeless to extract yields -spectrum

The IR-PCI technique separates mass differences down to tens of keV's: isomer separation shown as an example

Technique is shown to work well to determine the isomeric yield ratios.

$^{119}Cd^{+}$, t_{acc} = 416 ms



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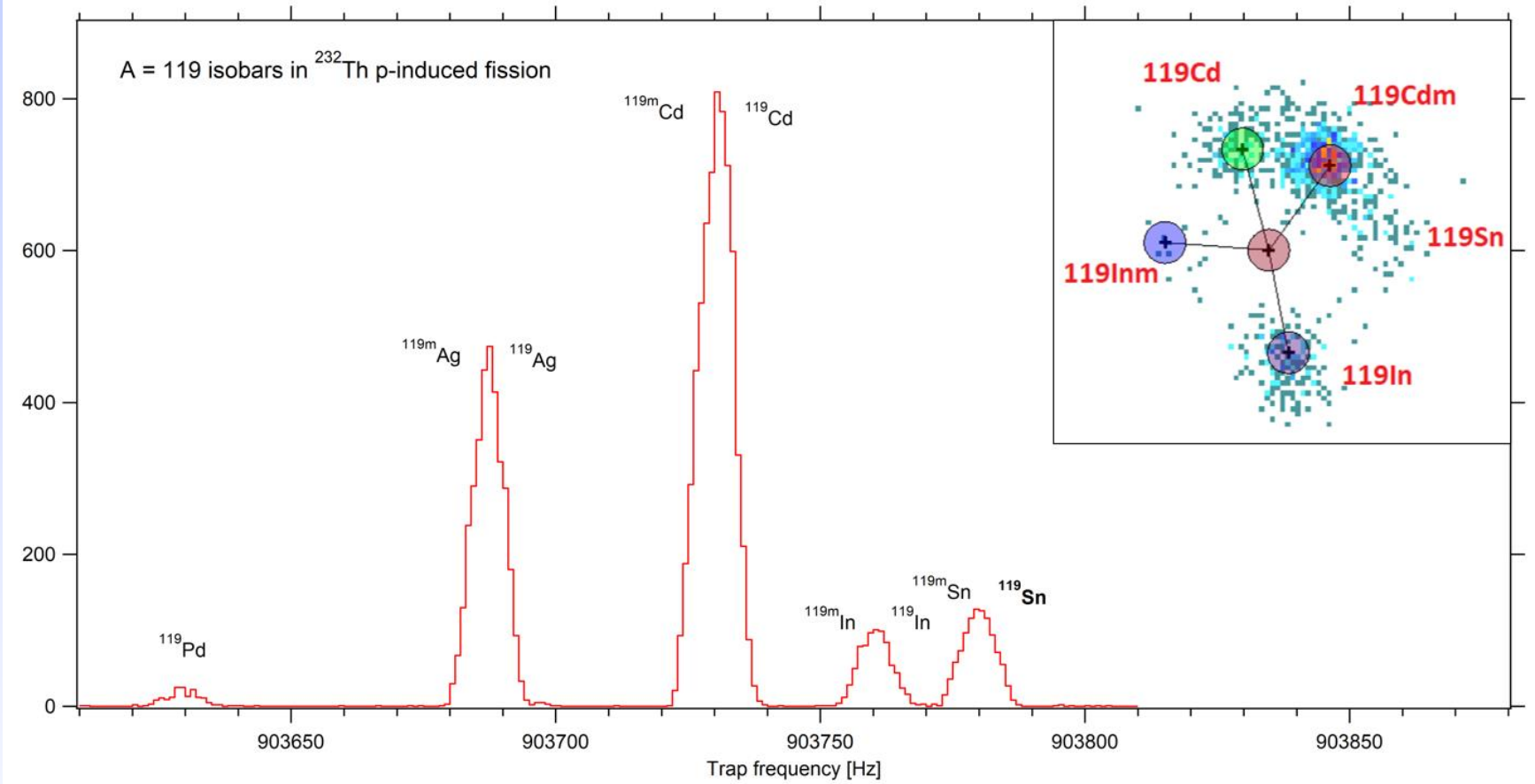

- sideband cooling spectrum of A = 119 showing no effect on the mass peak shape of Ag, Cd, In and Sn having isomers at 33, 146, 311 and 90 keV excitation energy, respectively.
- The PI-ICR spectrum of the three lightest mass peaks (Sn, In, Cd) in A = 119 collected when the sideband cooling mass filter window was continuously scanned over the frequency region of interest.
- Yield determination directly from PI-ICR spectra way is however seems to be unreliable (too tedious as well) and does not really work
- PI-ICR spectrum anyways allows determining the isomeric ratio; the total yield of all isomers is then determined from sideband cooling spectrum **or** from MR-TOF spectrum

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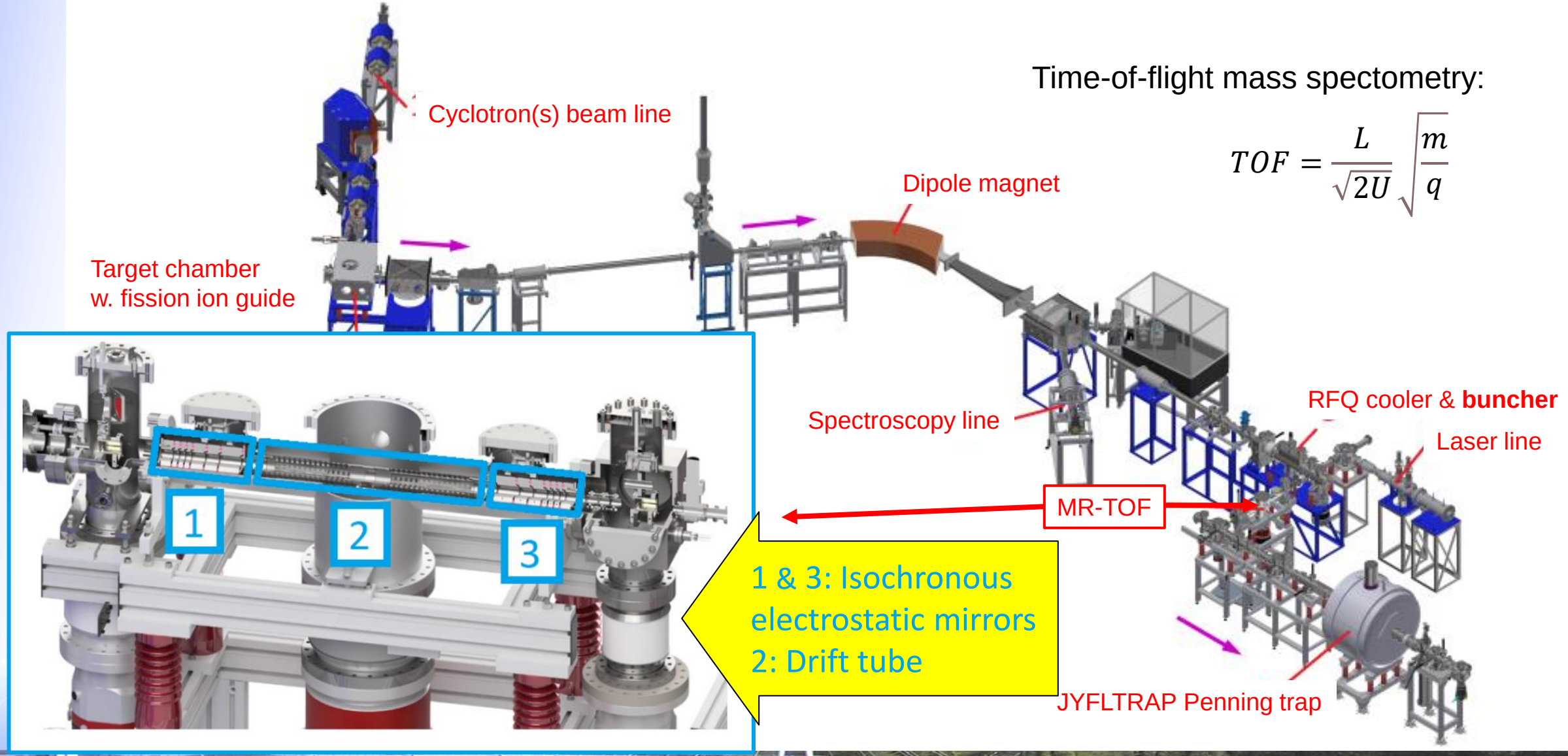
Time-of-flight mass spectometry:

$$TOF = \frac{L}{\sqrt{2U}}\sqrt{\frac{m}{q}}$$



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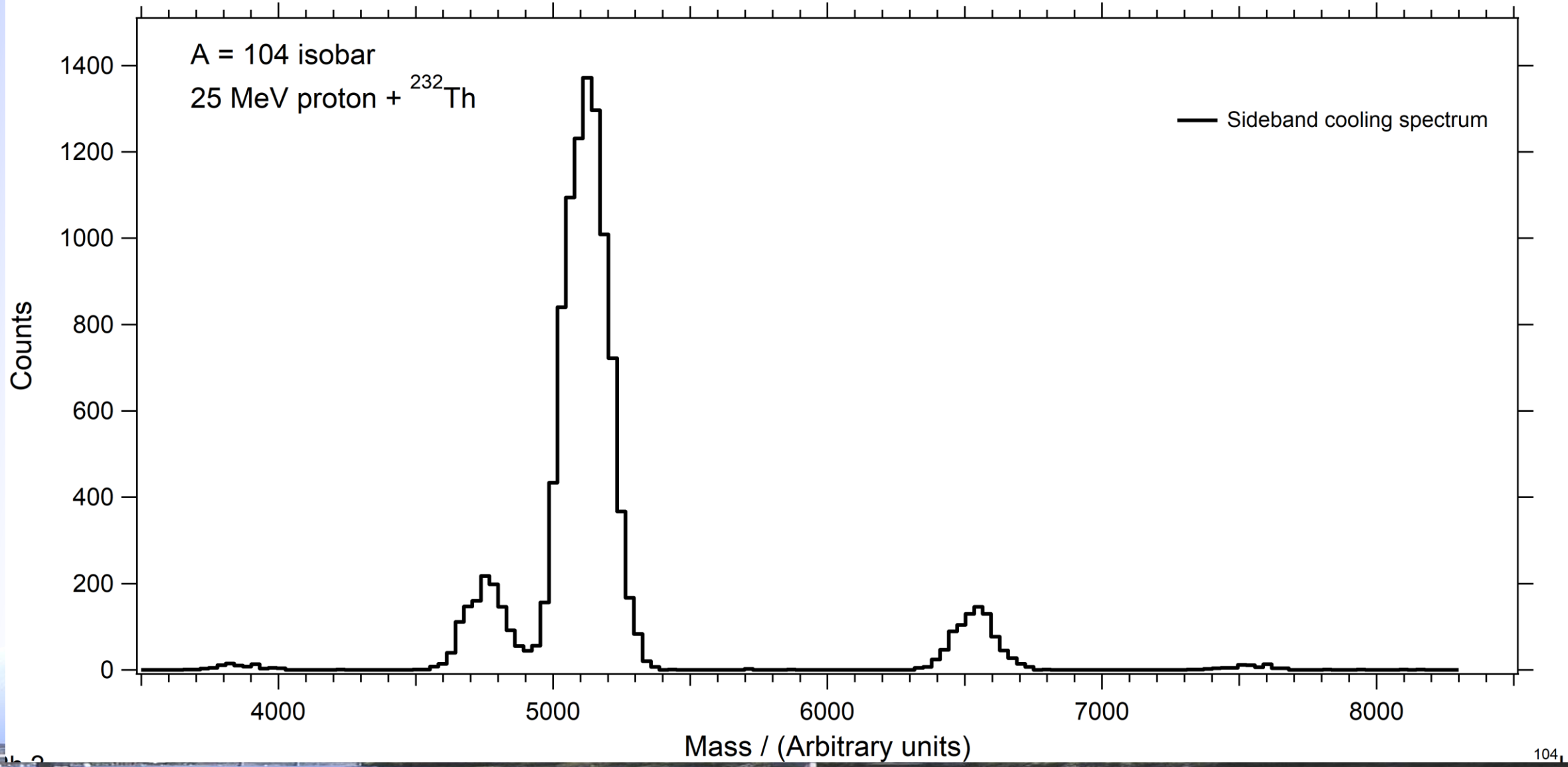

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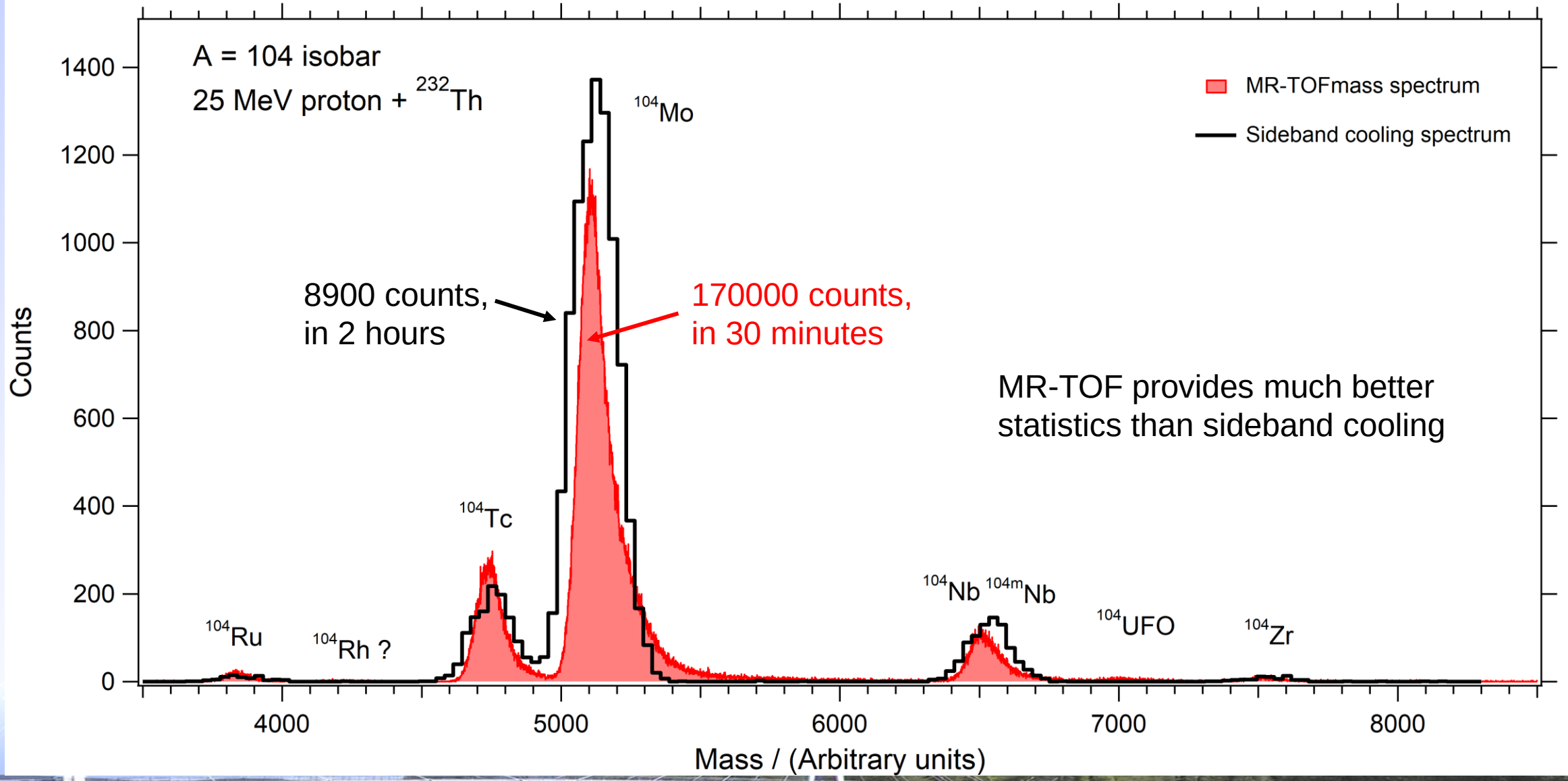

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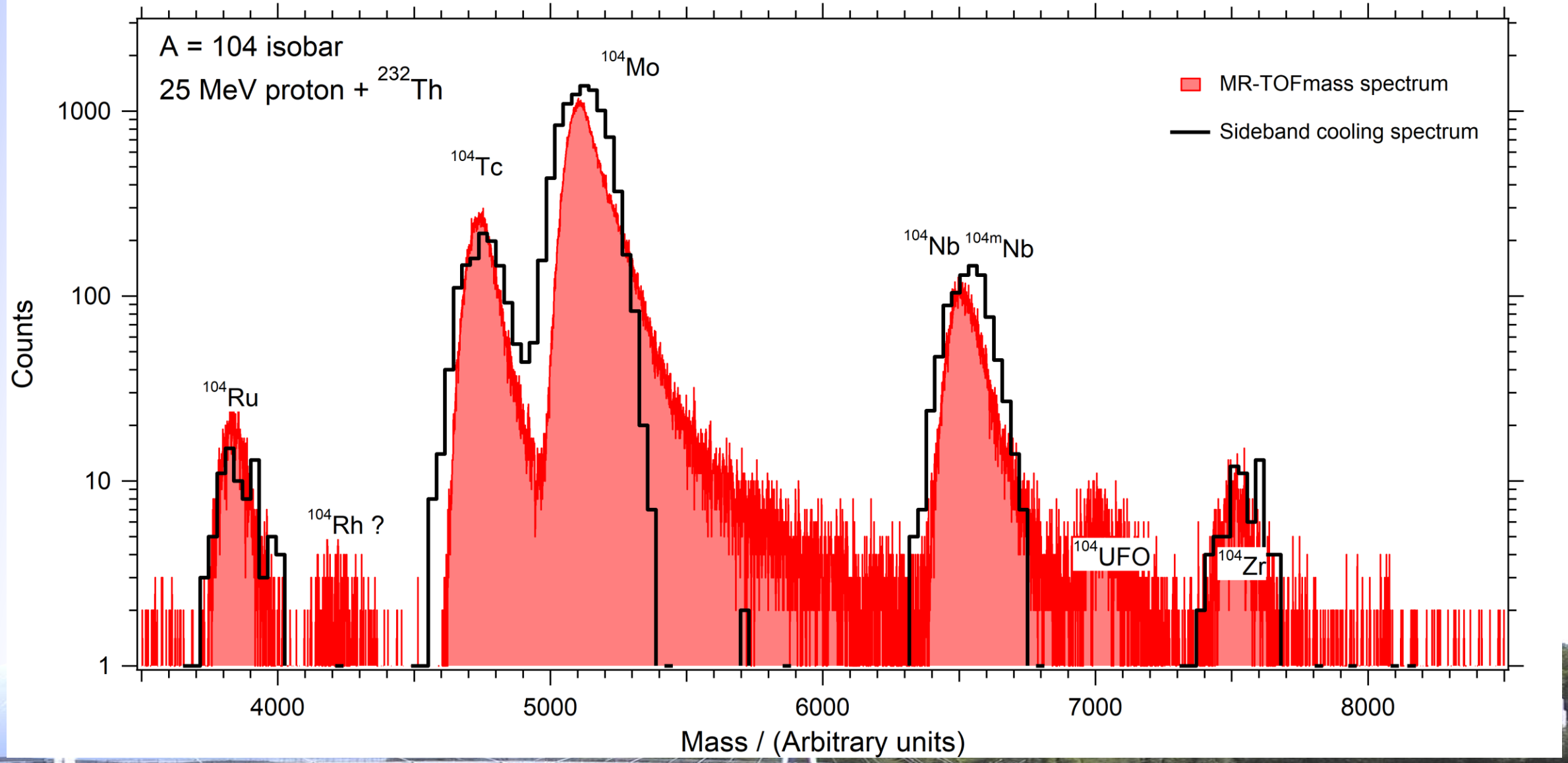

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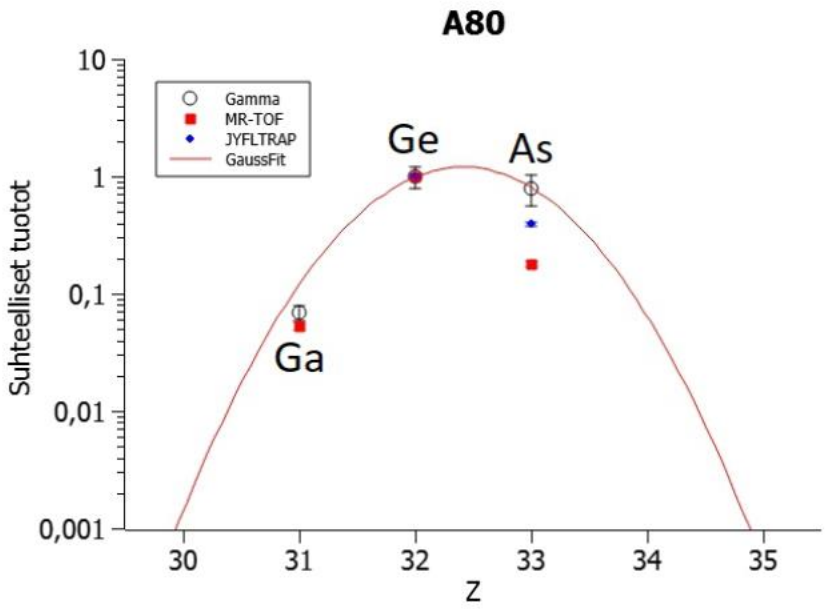

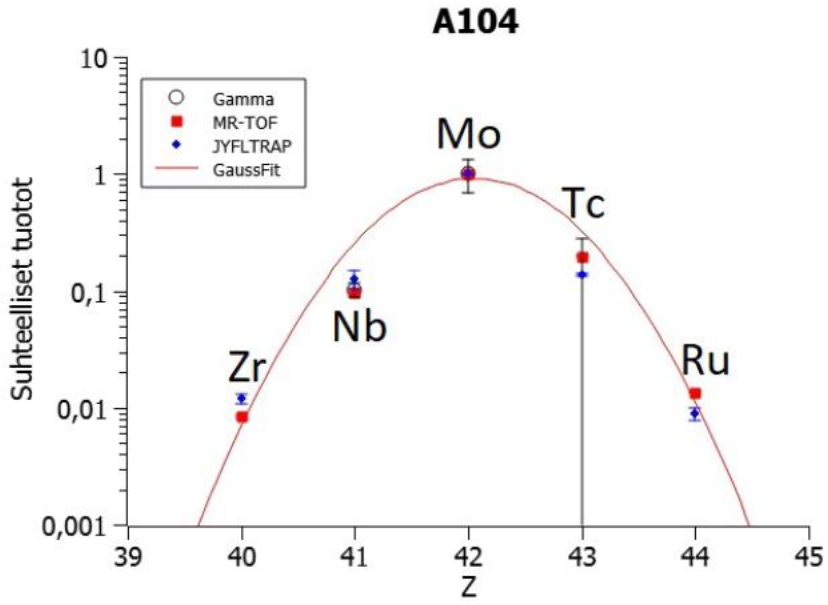

- Comparison of relative isobaric yields determined with
  - Gamma ray spectroscopy of mass number A separated source
  - MR-TOF
  - Penning trap sideband cooling
- Yields normalised to the highest yield isobar

- Conclusion: the efficiency differences between elements are due to **processes already in the ion guide**
  - …maybe except for As

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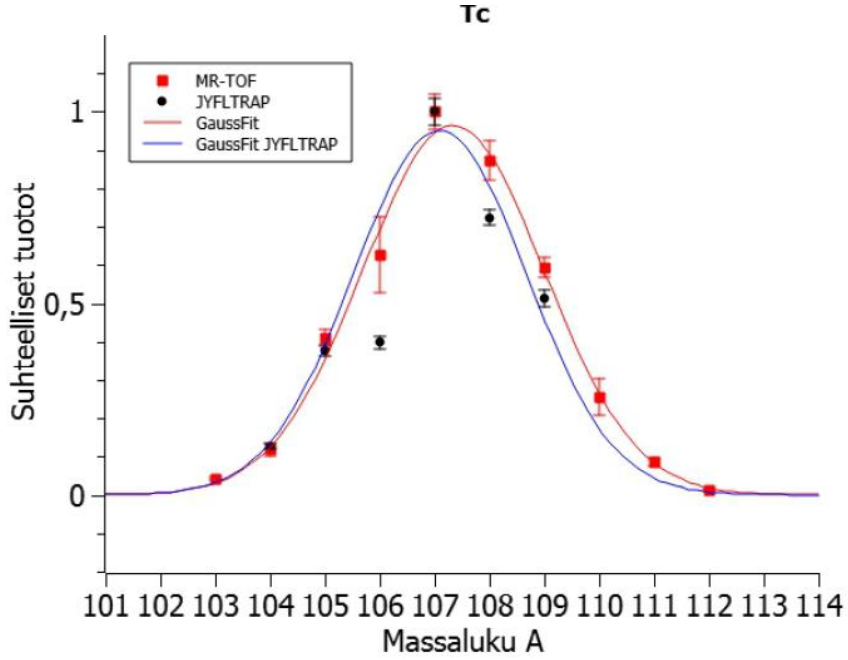

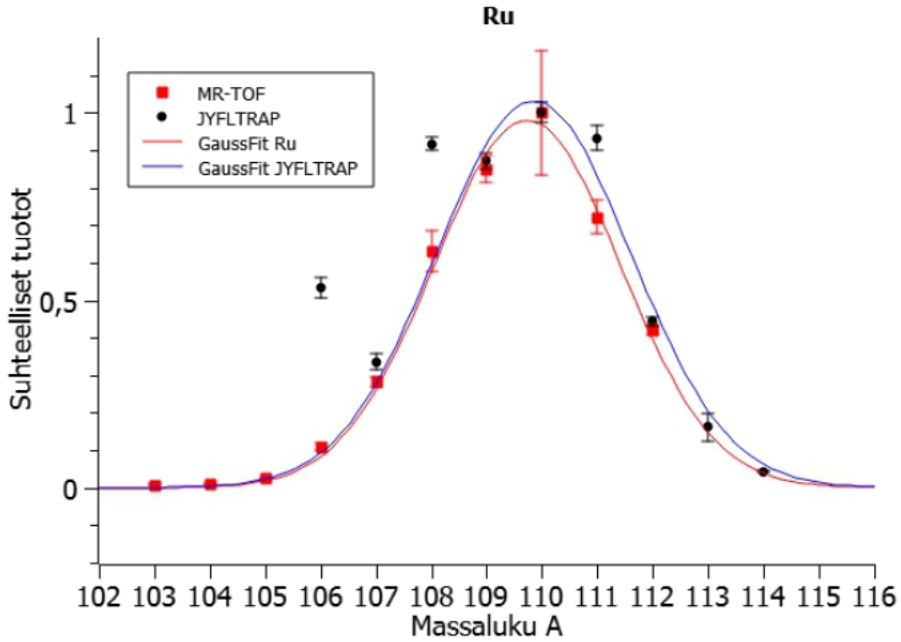

- Comparison of independent isotopic yields determined with
  - MR-TOF
  - Penning trap sideband cooling
- Yields normalised to the highest yield isotope
- Individual yields are not compared but fitted distributions
  - Some very scattered Penning trap data excluded from fit
  - 106Tc oddly low in trap data, also in MR-TOF but less – sign of an unknown isomer?

- Conclusion: techniques are in sufficiently good agreement with each other. MR-TOF data is less scattered – has higher statistics. Large uncertainty in MR-TOF comes from rate variation between measurements of the same isotope.

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What has been done:

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What was concluded:

- Yield determination directly from PI-ICR spectra unreliable. PI-ICR spectrum allows determining the isomeric ratio; total yield of all isomers from sideband cooling spectrum or from MR-TOF spectrum.

- The different techniques tested - gamma spectroscopy, Penning trap, MR-TOF - resulted almost identical **isobaric** yield distributions. This is interpret so that the efficiency differences between elements are born already in the ion guide.

- The **isotopic** yield distributions determined either with sideband cooling in Penning trap or with MR-TOF are in sufficient agreement with each other. MR-TOF data is less scattered – has higher statistics. Large uncertainty in MR-TOF comes from rate variation between measurements of the same isotope, which can be controlled better with more complete automatisation of measurements.