Final CATHI Review **– Barcelona – 2014-09-24**

MR-ToF as a high resolution mass separator

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- Mass Separation using Time of Flight
- Specs of ISOLTRAP's MR-ToF
- Applicable for ISOLDE?
- Summary

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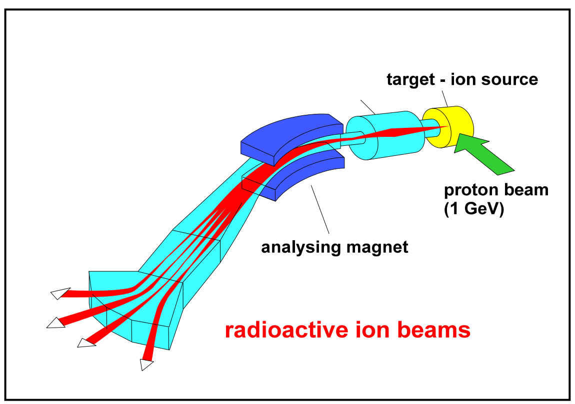
Separating nuclei

Magnetic separation

Same intial energy
→Velocity is different
→Different bending radii

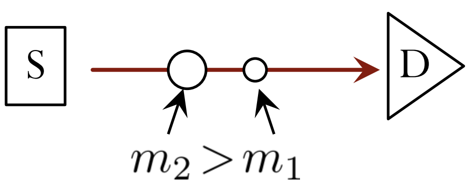
At ISOLDE:
- HRS
- GPS



Time of Flight separation

Same intial energy
→Velocity is different
→Different arrival
times at the detector

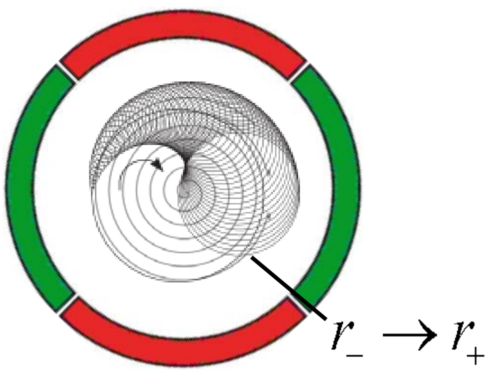
At ISOLDE:
- ISOLTRAP MR-ToF



Resonant separation

Same intial energy
→Applying an excitation at
a mass dependend eigenfrequency

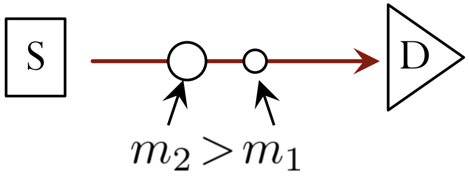
At ISOLDE:
- ISOLTRAP cooler trap
- REXTRAP



Separating nuclei

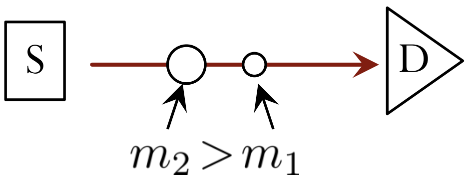
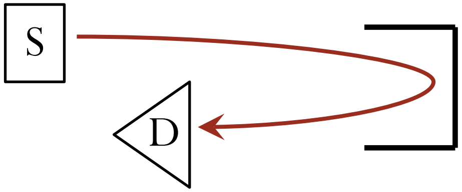
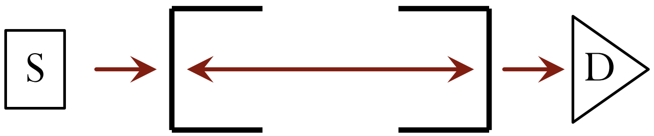
Time of Flight separation

Same intial energy
→Velocity is different
→Different arrival
times at the detector



Time-of-Flight Mass Spectrometry (ToF MS)

multi-reflection time-of-flight MS

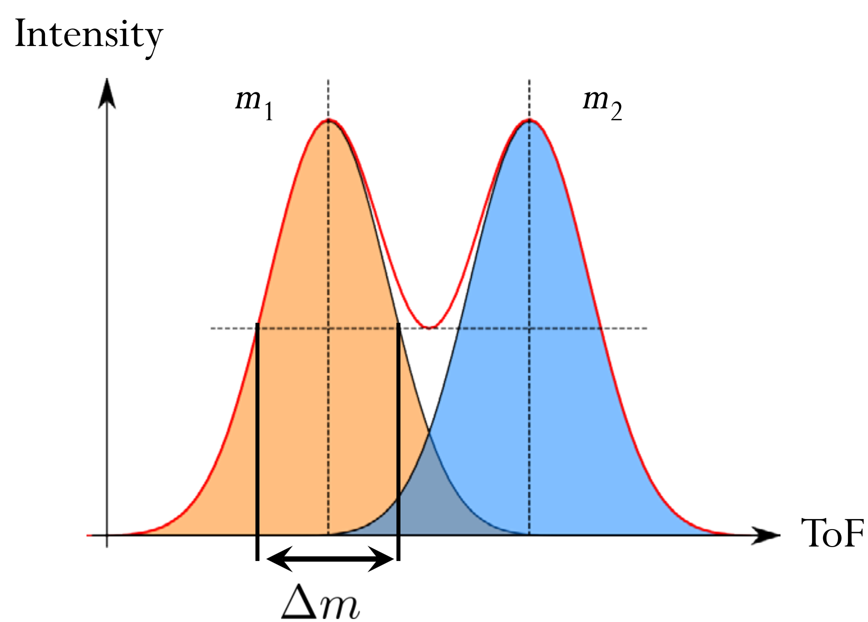
ToF MS	R-ToF MS	MR-ToF-MS
		
$t \sim 0.01\,\mathrm{ms},\ \ R \sim 500$	$t \sim 0.1\,\mathrm{ms},\ \ R \sim 5000$	$t \sim 10\,\mathrm{ms},\ \ R \sim 100\,000$

$$t \propto \sqrt{\frac{m}{q}\frac{1}{U}}$$

mass resolving power

$$R = \frac{m}{\Delta m} = \frac{t}{2\Delta t}$$

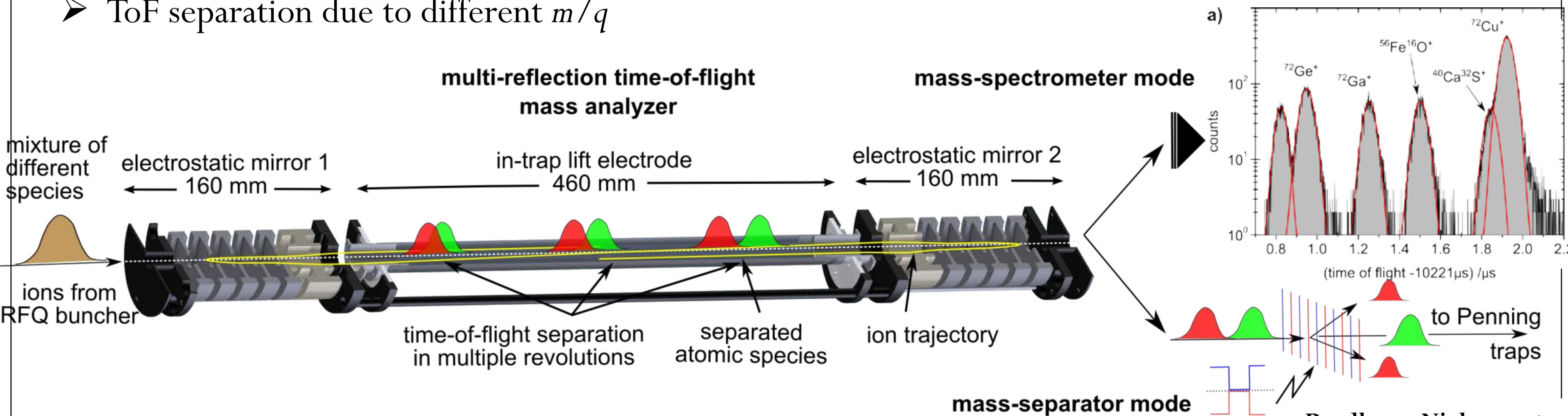
$$R_{\mathrm{FWHM}} = \frac{t}{2\Delta_{\mathrm{FWHM}} t}$$



Wollnik & Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990)

Overview: ISOLTRAP MR-ToF MS[1]

- mean kinetic energy E_{kin}=2.1keV
- ToF separation due to different m/q



Bradbury-Nielsen gate (BNG)[2,3]

> **several applications possible:**
>
> - high-resolution mass separation with Bradbury-Nielsen gate for subsequent experiments
> - observing and gating on separated ion-of-interest to perform further studies
> - high-precision mass measurements with reference masses

MR-ToF-MS

mass resolving power (FWHM)

$m/\Delta m$=100 000 at 12ms

$m/\Delta m$=200 000 at 30ms

transmission

≈50% at 30ms

ion capacity

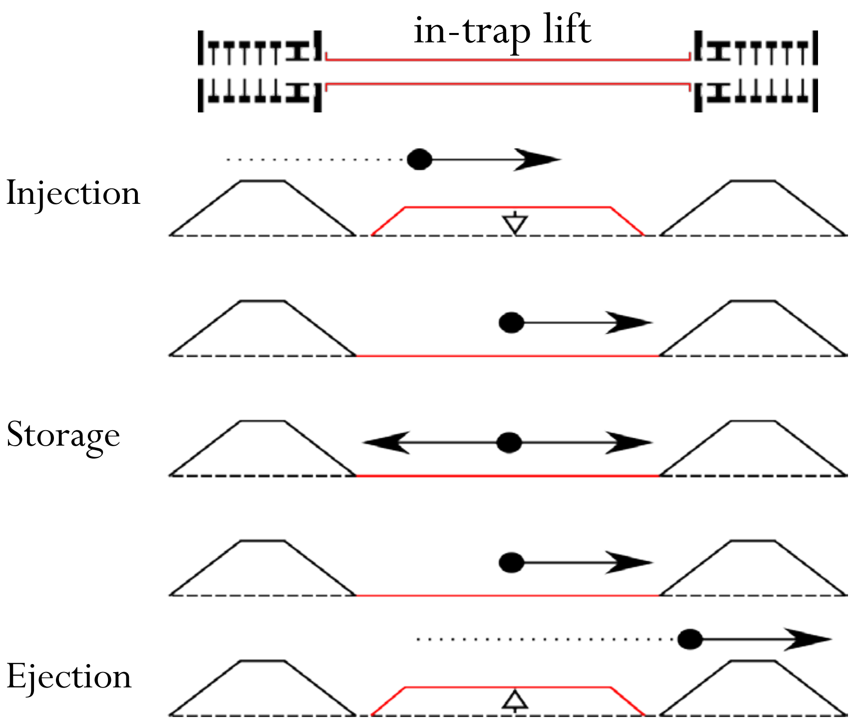
≈1000 per cycle

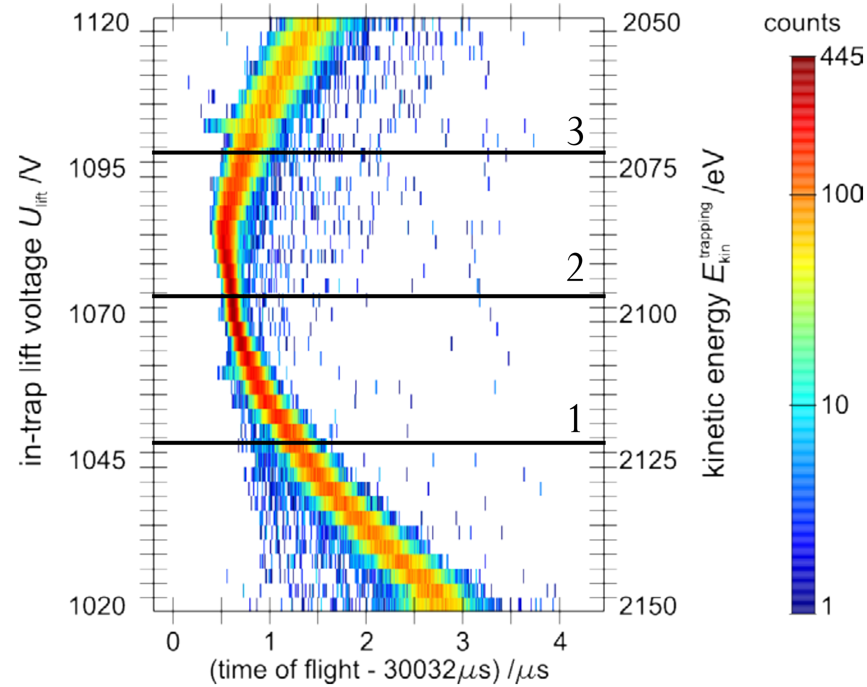
≈100 000 per second

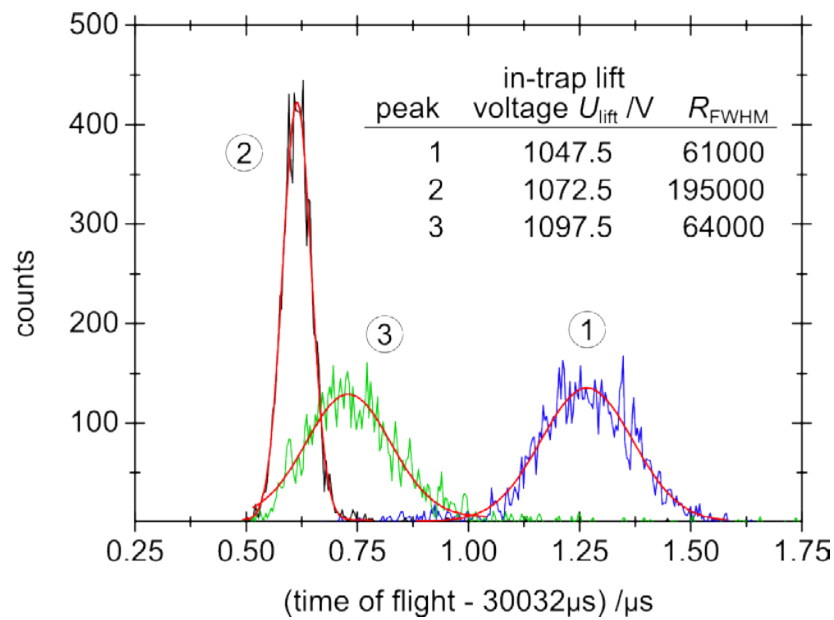
1: Wollnik & Przewloka, Int. J. Mass Spectrom. Ion Proc. 96, 267 (1990); 2: Bradbury & Nielsen, Phys. Rev. 49, 388 (1936); 3: Plass *et al.*, NIM B 266, 4560 (2008)
Wolf *et al.*, IJMS **313**, 8 (2012); Wolf *et al.*, IJMS 349-350, 123 (2013);

MR-ToF-MS at ISOLTRAP: in-trap lift

- capture and ejection with one electrode
  ➔ **simple technique, stable mirror potentials**
- decouple MR-ToF-MS and adjacent beamline
  ➔ **independent optimization**
- adjust ions' kinetic energy
  ➔ **ToF focusing, max. mass resolving power**





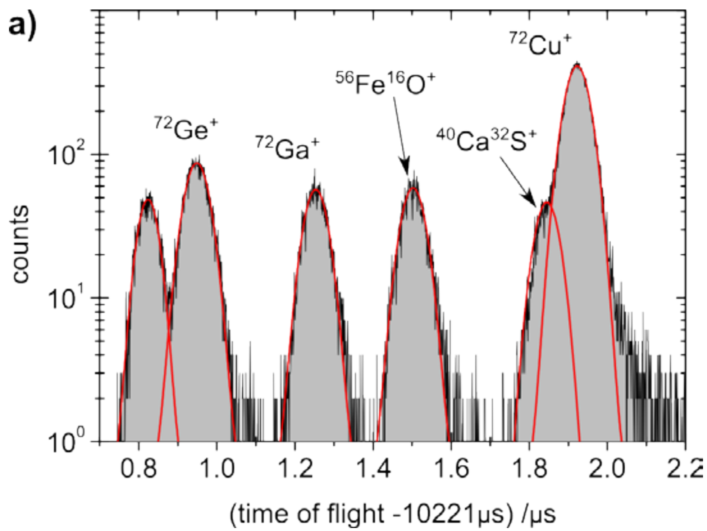


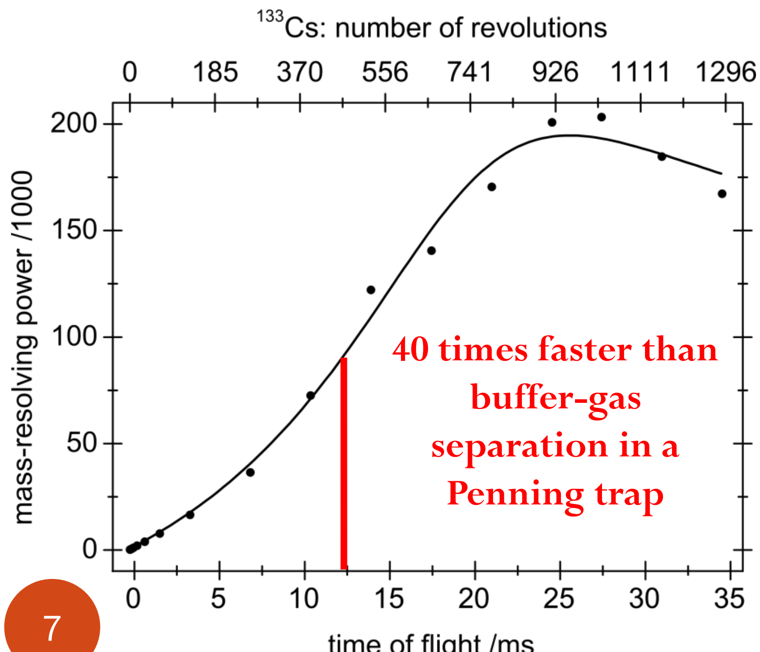
➔ **only one parameter to adjust**

Wolf *et al.*, IJMS 313, 8 (2012)

MR-ToF-MS: performance

MR-ToF-MS





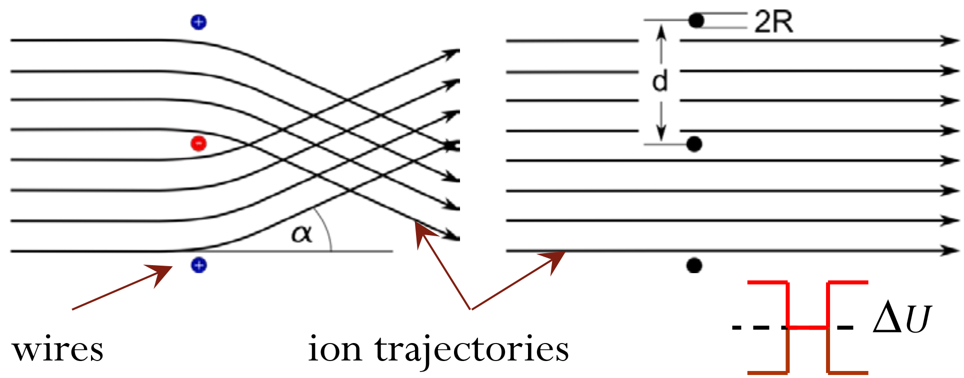
Bradbury-Nielsen gate (BNG)[1,2]

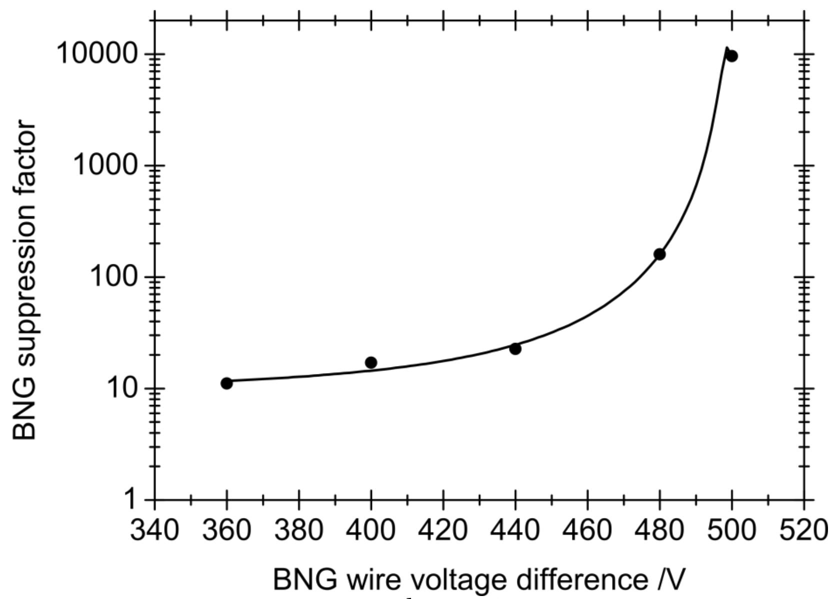
contamination suppression

1:10000

R=0.005mm

d=0.5mm





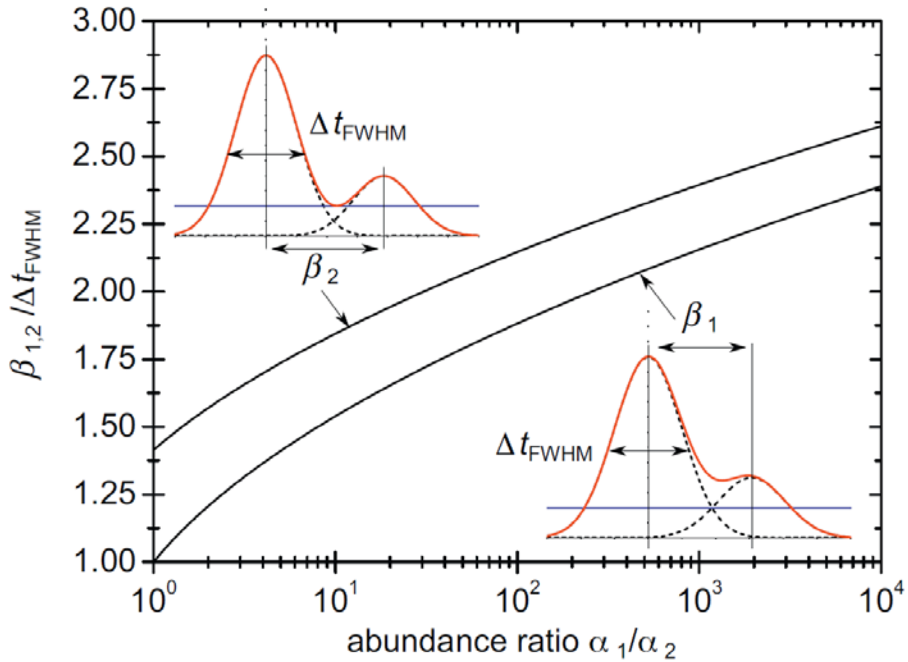
Wolf *et al.*, NIM A 686, 82 (2012); 1: Bradbury & Nielsen, Phys. Rev. 49, 388 (1936); 2: Plass *et al.*, NIM B 266, 4560 (2008)

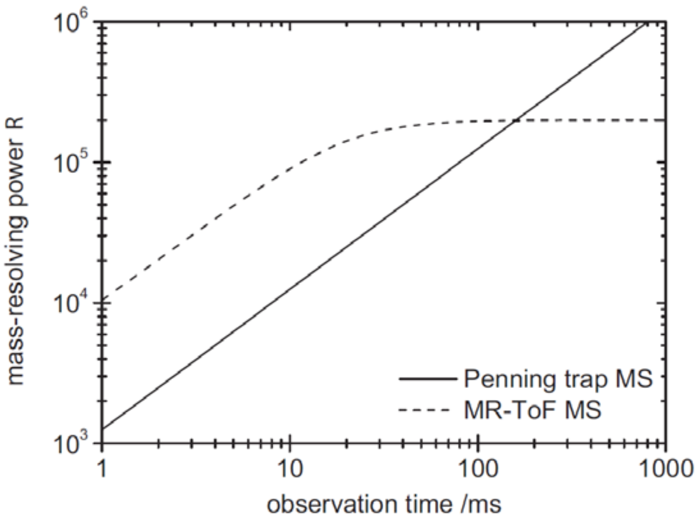
MR-ToF-MS: Some limits to mass resolving power

A cocktail beam

$$R = \frac{m}{\Delta m} = \frac{t}{2\Delta t}$$

$$R_{\mathrm{FWHM}} = \frac{t}{2\Delta_{\mathrm{FWHM}} t}$$





$$R_\beta = \beta \cdot R_{\mathrm{FWHM}}$$

α_1 contamination

α_2 ion of interest

Note:

Reduction to similar amounts

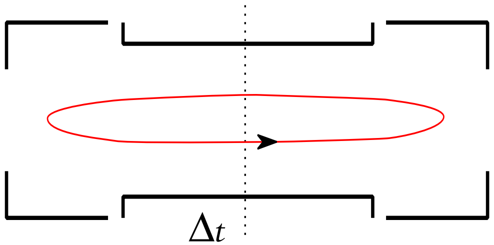
(not complete suppression)

Wolf *et al.*, IJMS 349-350, 123 (2013);

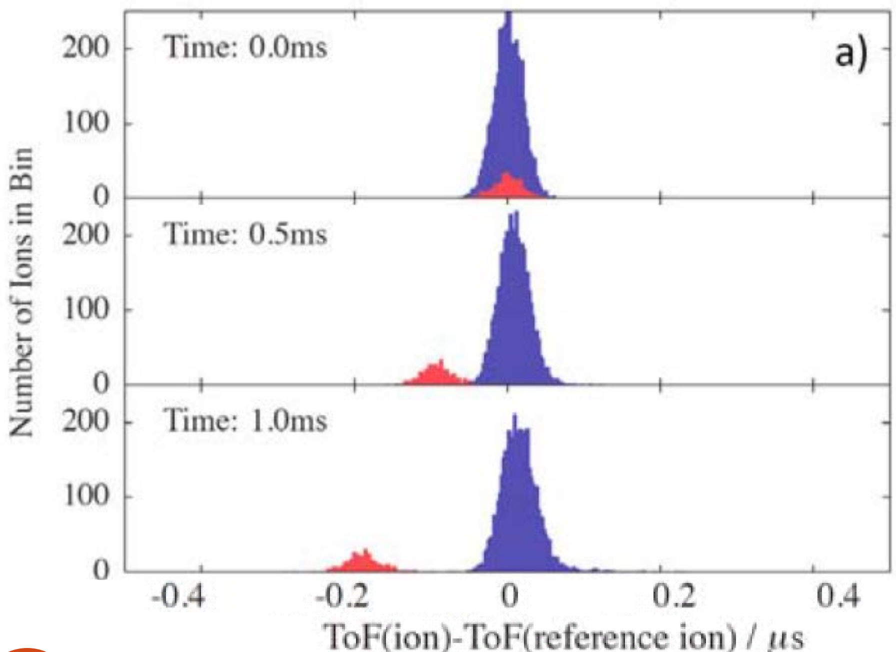
MR-ToF-MS: Coulomb interaction

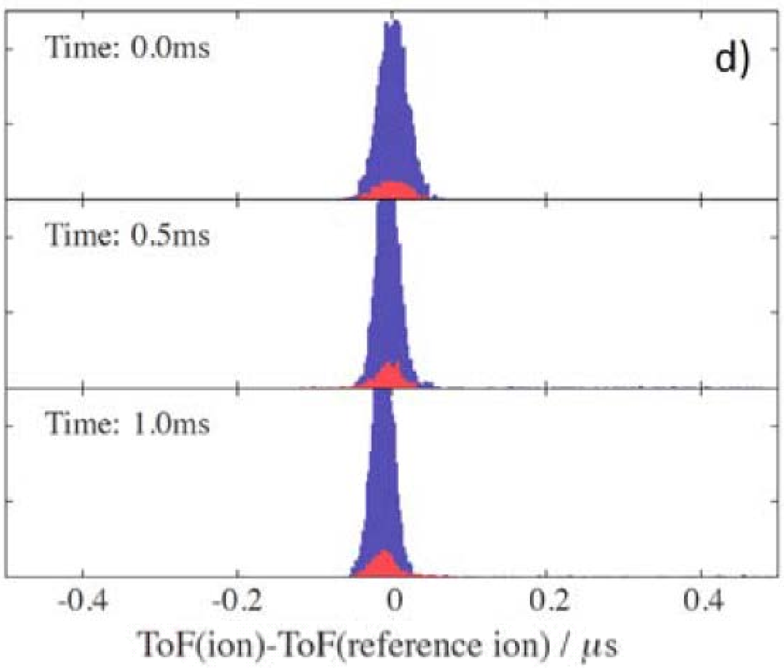
- MR-ToF trajectory calculations with Coulomb interaction for peak coalescence studies[1]
- Using PC graphics card for parallelism, NVIDIA CUDA and SIMBUCA[2]

- Recording spectrum in middleplane every revolution
- 2 species: purple/red=4500/500, $m/\Delta m$=10000
- E_{nom}=2110eV, ΔE_{FWHM}=20eV, $\Delta x,y,z_{std}$=1mm



without interaction **with interaction**





1: Rosenbusch *et al.*, AIP Conf. Proc. 521, 53 (2013) 2: van Gorp *et al.*, NIM A **638,** 192 (2011)

MR-ToF-MS: A device for ISOLDE?

Can it replace a magnetic separator?

- Surely not with state of the art, too small current:

  1000 ions per cycle (~4ms for R_{FWHM}=20000)

  → 3e5 ions per 1.2s, but usually a huge fraction is contamination!

But the performance could be improved:

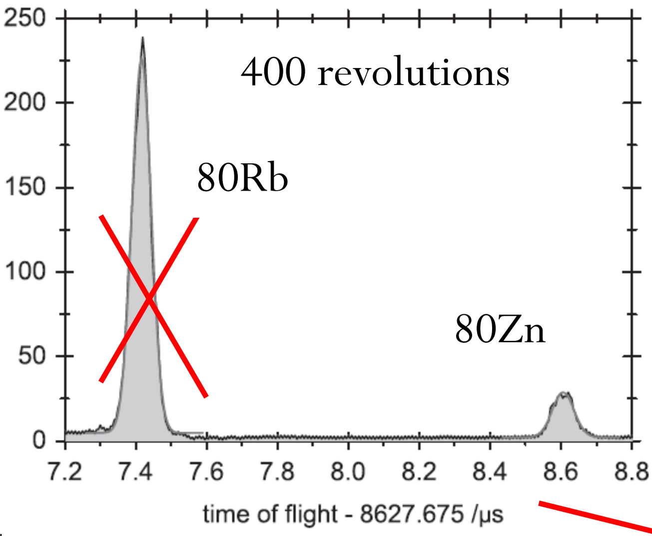
- Higher energy inside the MR-ToF
- Bigger device to reduce density
- Investigations are still ongoing to improve throughput

Required:

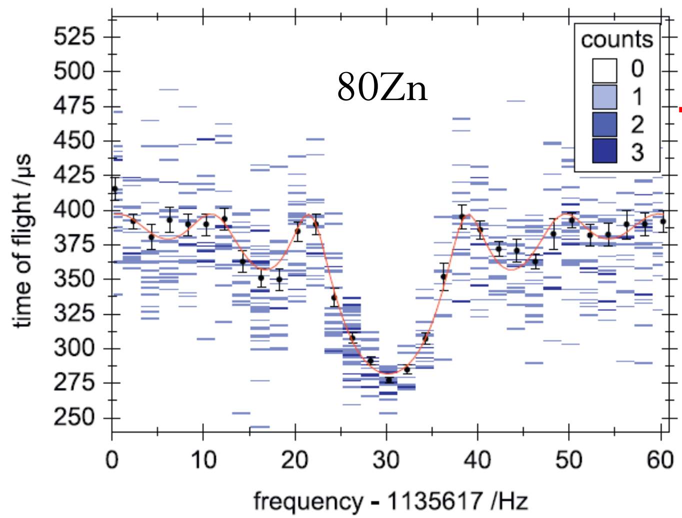
- Short bunch length (>100 ns)

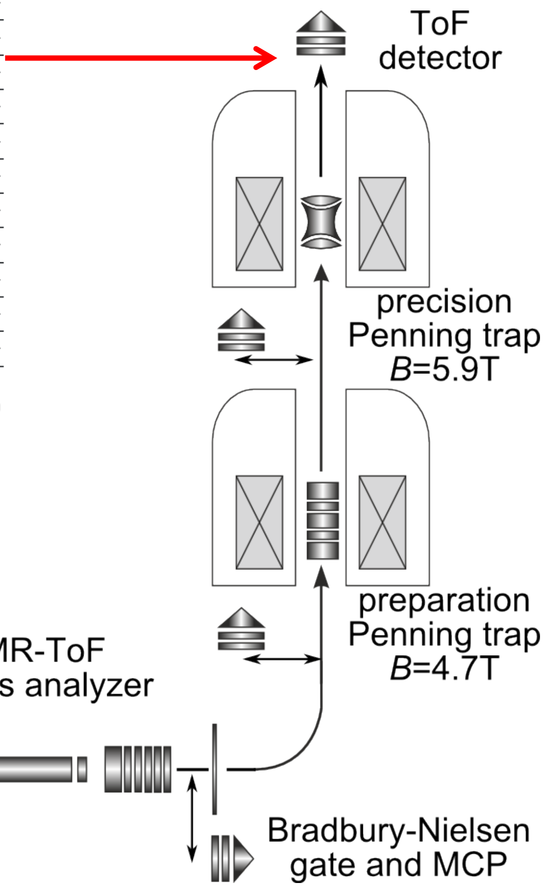
MR-ToF as post separator for downstream experiments

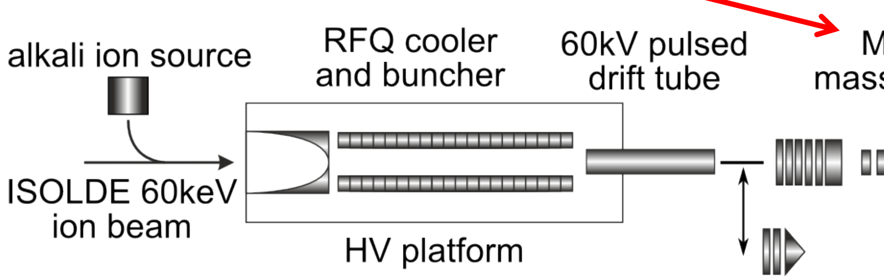
MR-ToF spectrum



ToF-ICR mass measurement







80Zn:

1000/s, $T_{1/2}$=0.55s

80Rb:

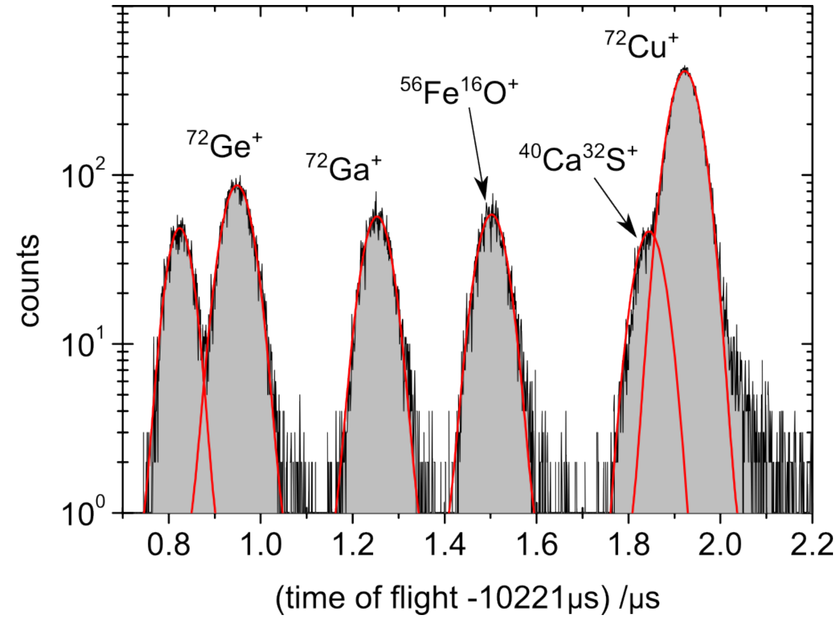
10000/s, $T_{1/2}$=33.4s

Wolf *et al.*, PRL 110, 041101 (2013); NIM A 686, 82 (2012)

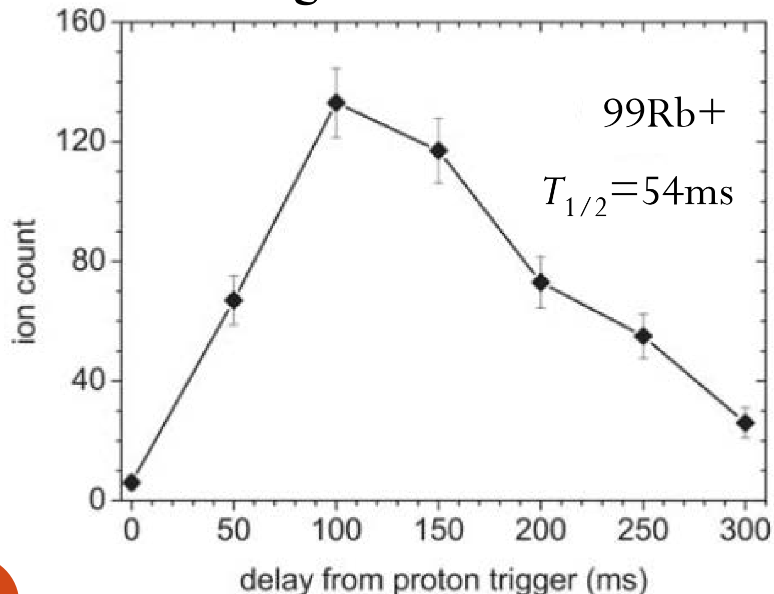
MR-ToF for ion-beam analysis

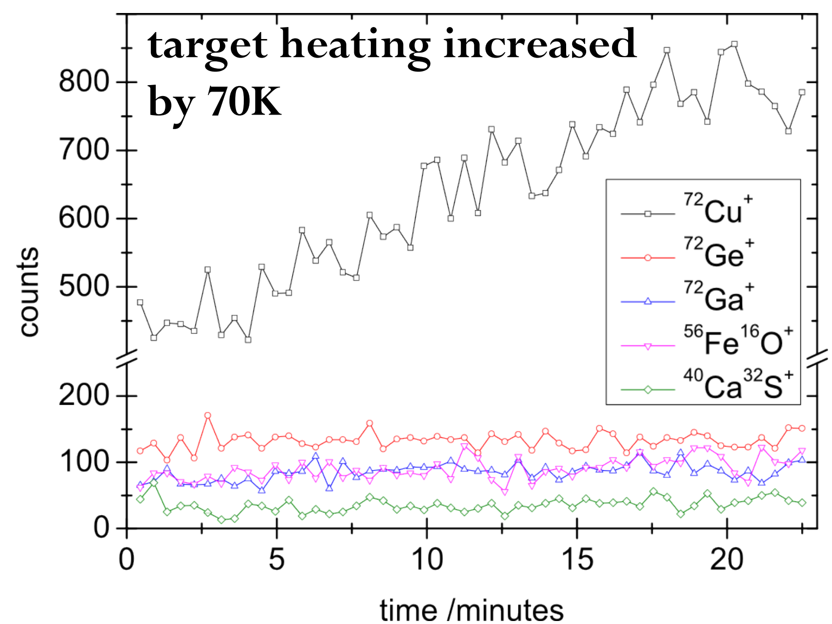
Ion-beam composition analysis

- direct feedback for target/line optimization
- sampling of release curve possible
- single ion sensitivity to detect lowest yields
- no upper limit on half-life as with decay station
- not hindered by decay branching ratio



target release curve



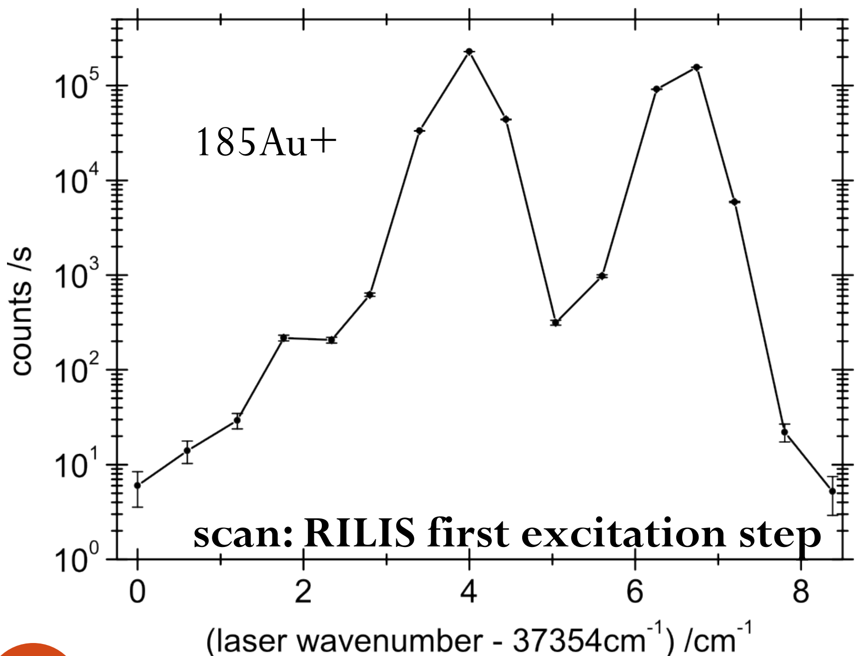


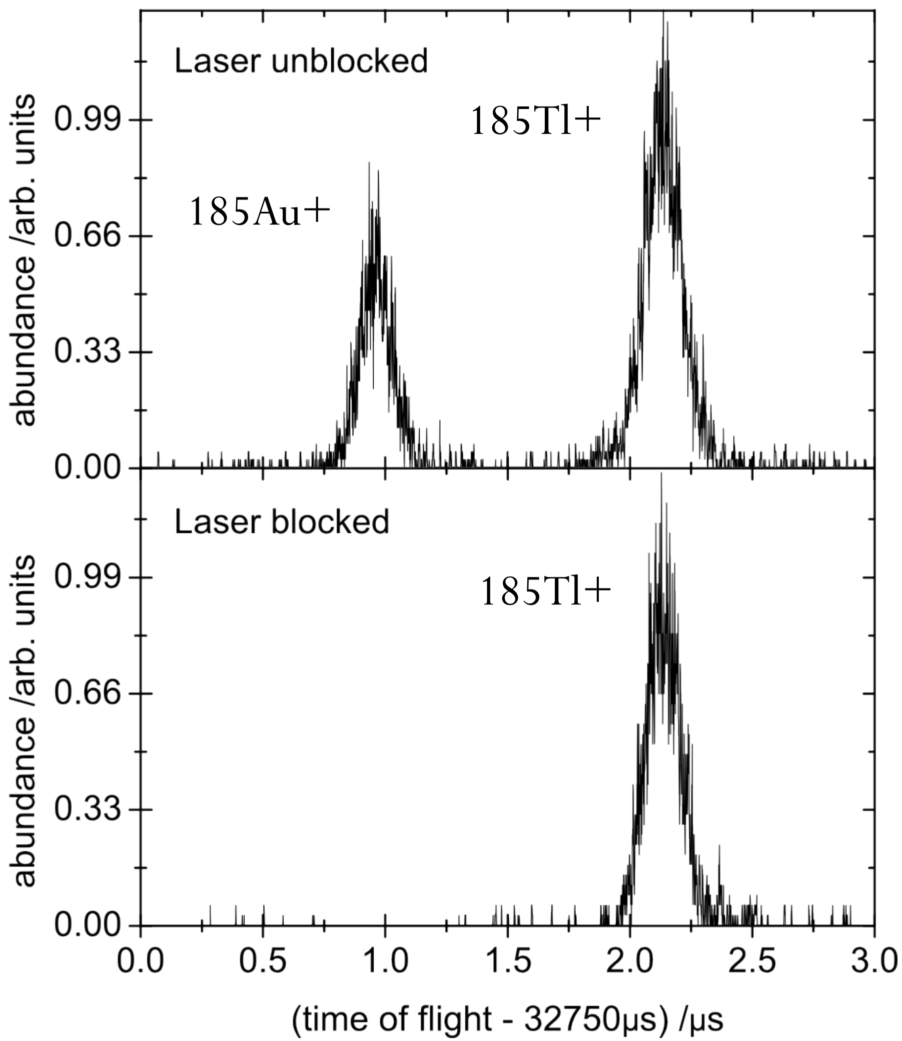
Wolf *et al.*, IJMS 349-350, 123 (2013); Kreim *et al.*, NIM B, accepted for publication (2013)

MR-ToF and RILIS: ionisation-yield optimization => hfs scans

MR-ToF analyzer to investigate resonant laser ionization of nuclides far from stability

- fast, sensitive tool to improve ionization eff.
- high dynamic range: 1-10e5 counts/s
- counts free from background contamination
- not limited by decay branching ratio
- help to provide isomerically pure beams





Wolf *et al.*, IJMS 349-350, 123 (2013); Kreim *et al.*, NIM B, accepted for publication (2013)

Summary: MR-ToF

Fast device for high mass resolving powers

→ up to 200000 in 30ms has been demonstrated

current limitations are under investigations

Ideas for improvement:

- increase the energy
- increase the size

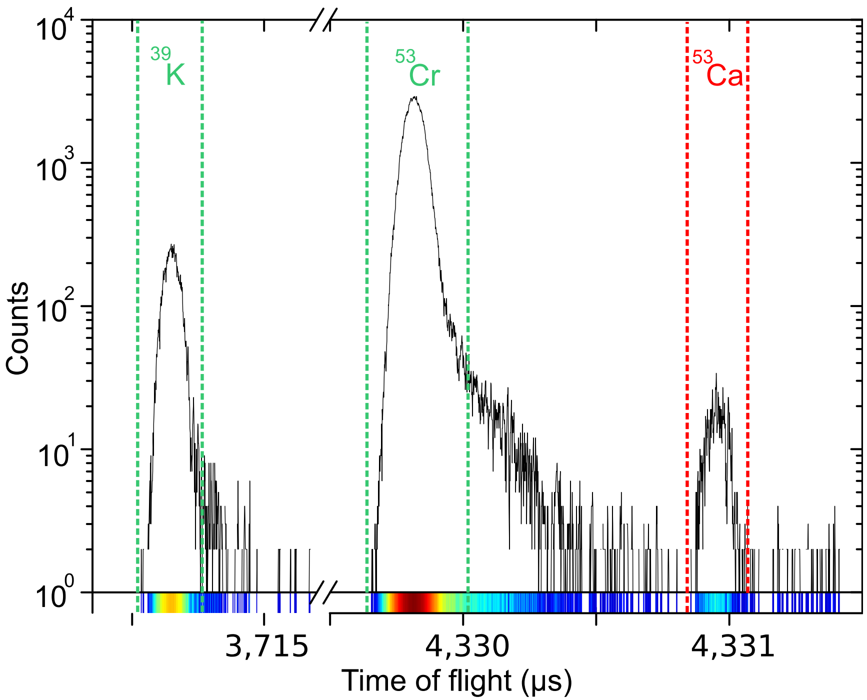
Possible applications at ISOLDE:

- Post separator for down stream experiments
- Beam composition monitor
- To tune beam (high dynamic range)

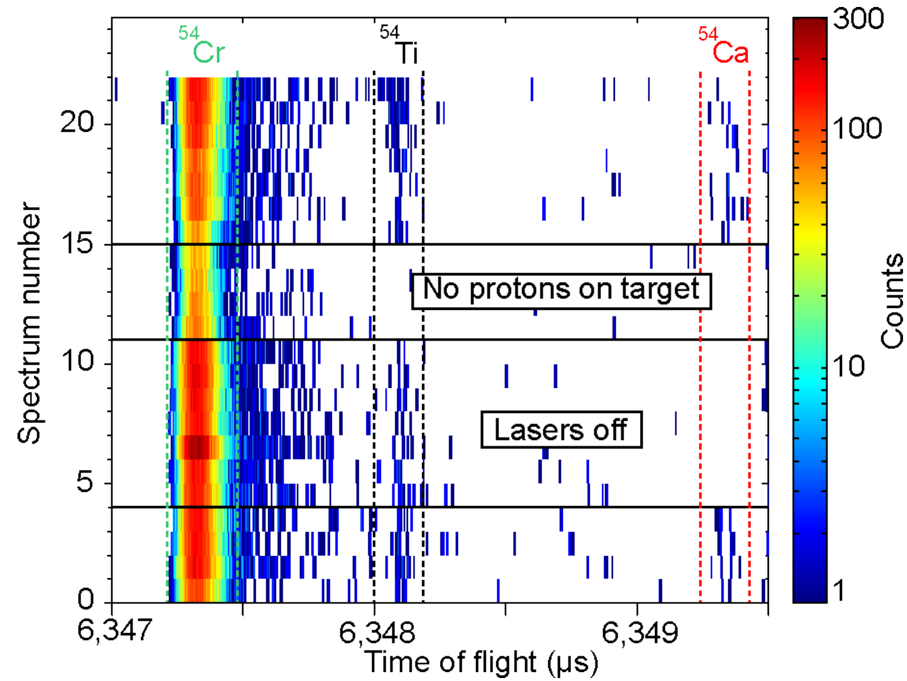
ISOLTRAP setup and the calcium measurements 53Ca and 54Ca

\\ n-rich Calcium isotopes: ^{53}Ca and ^{54}Ca

***A*=53:** measurement cycle ≈ 4ms



***A*=54:** measurement cycle ≈ 6ms



6413 counts/12.6h ➔ 9 counts/minute

2314 counts/18.2h ➔ 2 counts/minute

statistical uncertainty ≈ 45keV ➔ $\delta m/m \approx 9\times10^{-7}$

Wienholtz *et al.*, Nature **498,** 346-349 (2013) DOI/10.1038/nature12226

The End

Thank you for your attention

Thanks to: the ISOLTRAP collaboration

P. Ascher, D. Atanasov, D. Beck, K. Blaum, Ch. Böhm, Ch. Borgmann, M. Breitenfeldt, R. B. Cakirli, T. E. Cocolios, S. Eliseev, T. Eronen, D. Fink, S. George, F. Herfurth, A. Herlert, D. Kissler, S. Kreim, M. Kowalska, Yu. Litvinov, D. Lunney, V. Manea, E. Minaya-Ramirez, S. Naimi, D. Neidherr, M. Rosenbusch, L. Schweikhard, J. Stanja, F. Wienholtz, A. Welker, R.Wolf, K. Zuber

the ISOLDE collaboration, CERN

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http://isoltrap.web.cern.ch