ISOLTRAP Reaches a New Era of Mass Spectrometry

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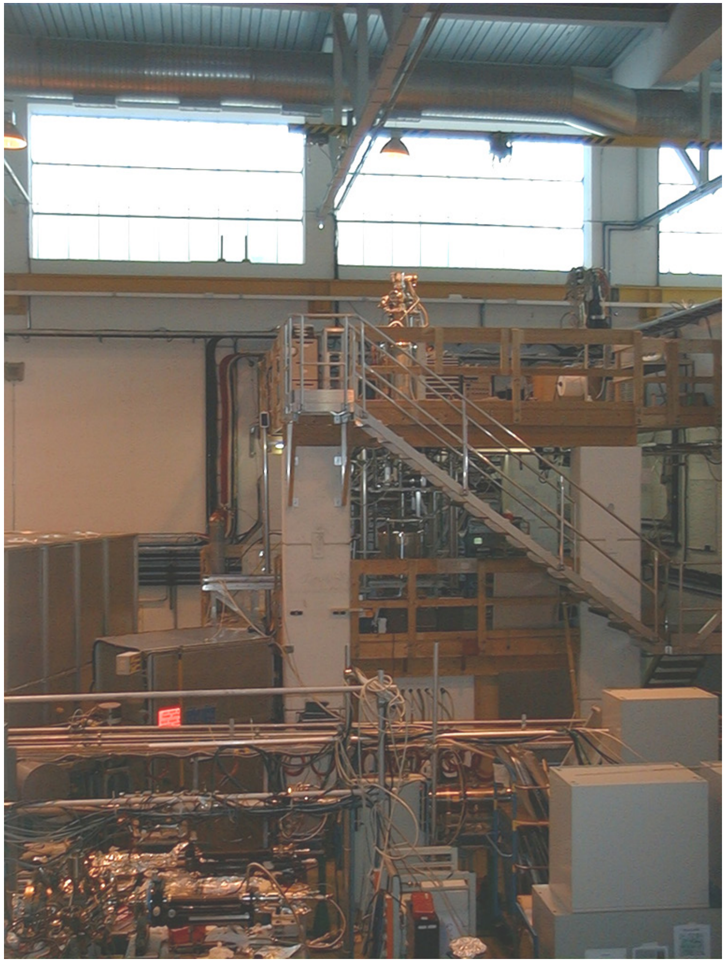
Overview



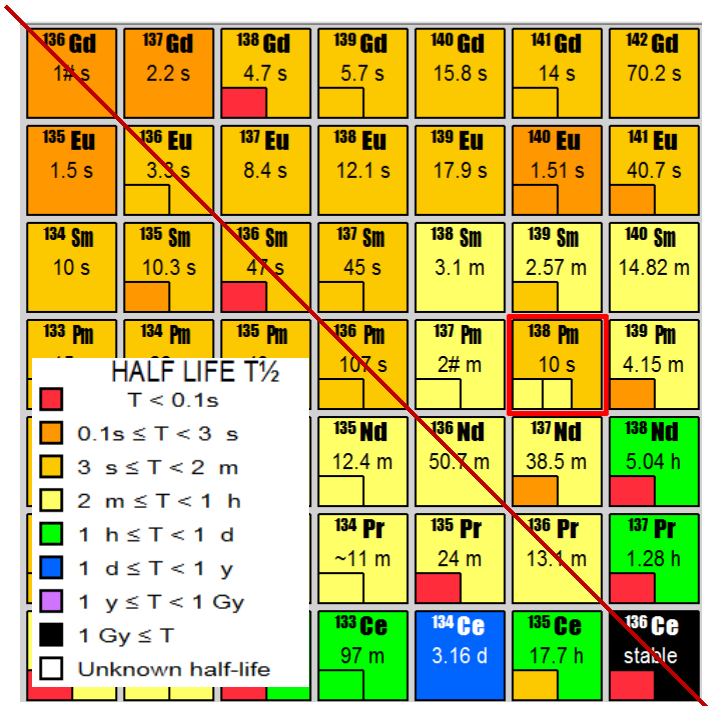
- Introduction to the ISOLTRAP experiment
- Penning-trap mass spectrometry on radioactive beams
- Technical developments
- Physics results – a selection

ISOLTRAP at ISOLDE / CERN

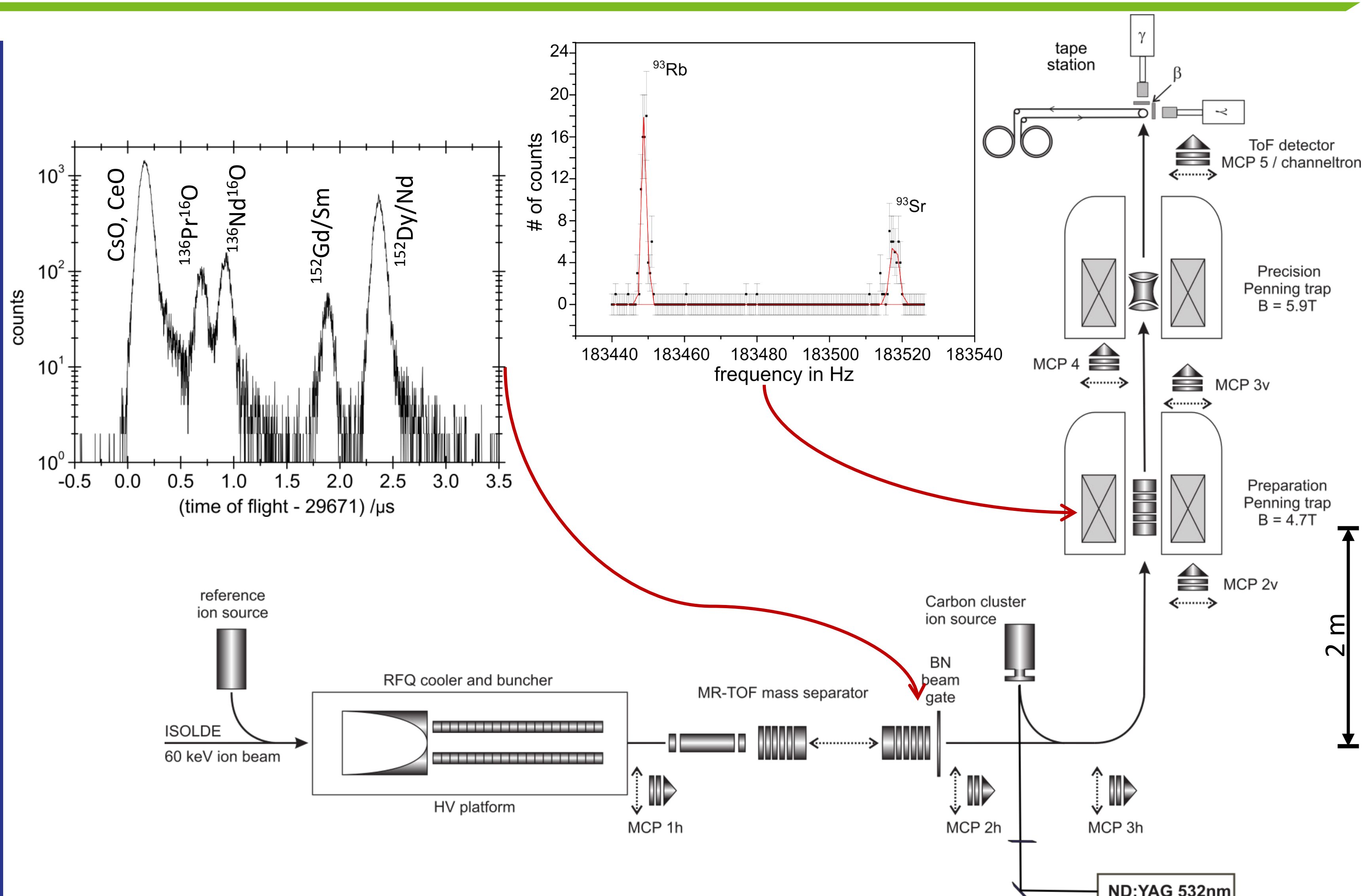
- Goal: precision Penning-trap mass spectrometry on pure samples of exotic nuclei
  - Mass of over 500 radioactive isotopes determined

- Radioactive beam is provided by ISOL technique:
  - Low-energy beam
  - Singly-charged ions
  - Exotic nuclei with ms half-lives
  - Isotopically pure beam
  - Mixture of isobars

- Challenges at the outskirts of the nuclear chart:
  - Half-lives of only few ms
  - Minute production rates
  - High yield of contaminating ions



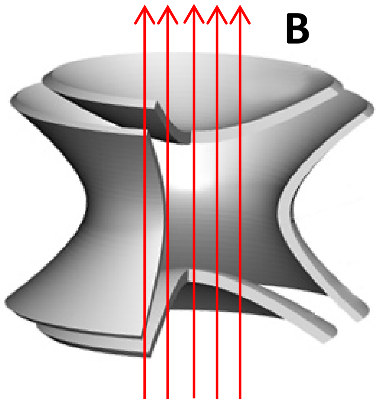
Purification and Preparation



M. Mukherjee *et al.*, Eur. Phys. J A **35**, 1 (2008)
G. Savard *et al.*, Phys. Lett. A **158**, 247 (1991)
F. Herfurth *et al.*, NIM A **469**, 254 (2001)
R. N. Wolf *et al.*, IJMS **313**, 8 (2012)

Measurement Technique

- Particle stored by superposition of strong homogeneous magnetic field in z direction and weak, electrostatic potential for axial confinement

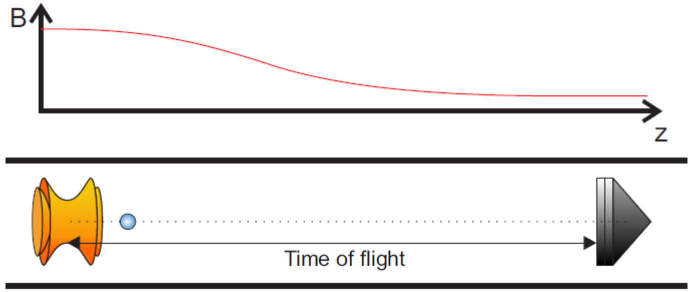


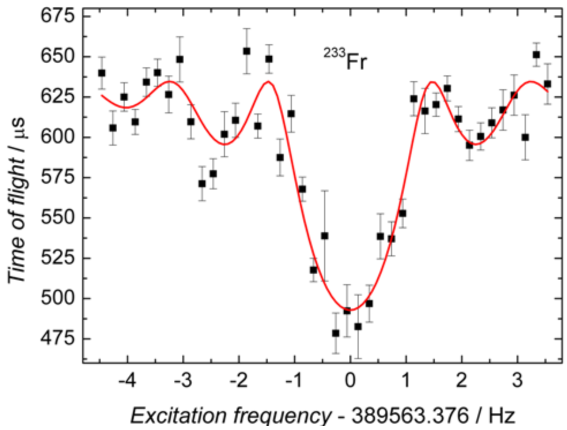
$$\omega_c = \omega_+ + \omega_- \quad \Rightarrow \quad \omega_c = \frac{q}{m} B$$

$$m = \frac{\nu_c^{ref}}{\nu_c}(m_{ref} - m_e) + m_e$$

L. S. Brown and G. Gabrielse , Rev. Mod. Phys. **58**, 233 (1986)

- From frequency to mass using time-of-flight ion-cyclotron resonance technique
- Single-ion experiment



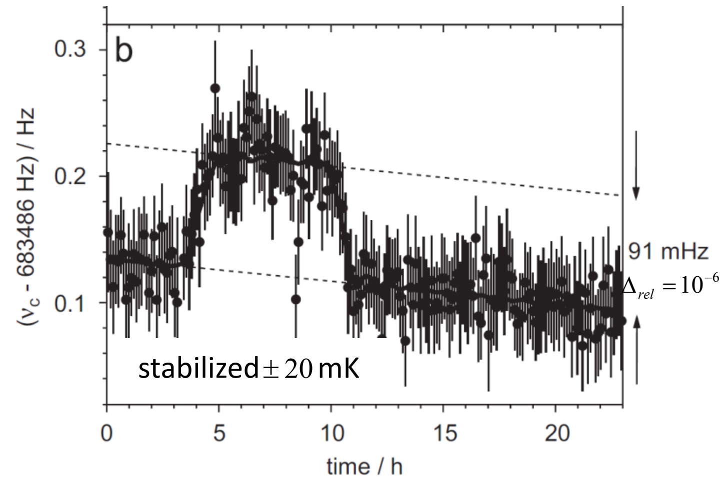


M. König *et al.*, Int. J. Mass Spectrom. **142**, 95 (1995)

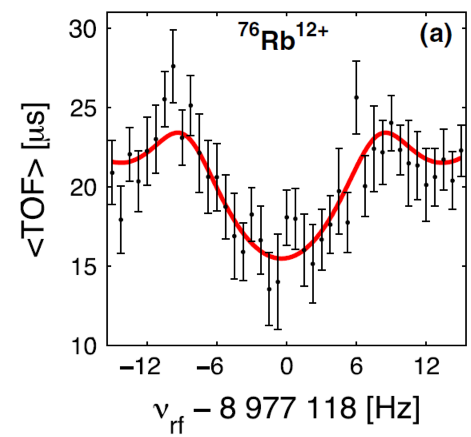
Recent Developments in PTMS

- Penning-trap mass spectrometry (PTMS) – „high-precision measurements“
  - Relative uncertainties ≤ 10^{-8}
  - Application: subtle nuclear-structure effects and fundamental tests

- Technical Achievements
  - Low 10^{-9} even 10^{-10} vacuum at 300K
    - ✓ allows for long excitation times
  - Cryogenic buffer gas
    - ✓ limits charge-exchange losses
  - T-/p-stabilization – limits systematic shifts
    - ✓ M. Marie-Jeanne *et al.*, NIM A **587**, 464 (2008)
  - Charge breeding – enhances accuracy
    - ✓ S. Ettenauer *et al.*, PRL **107**, 272501 (2011)

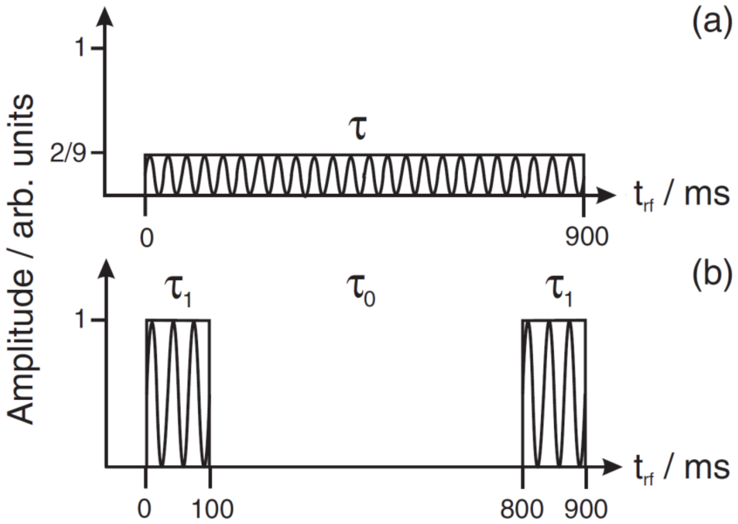


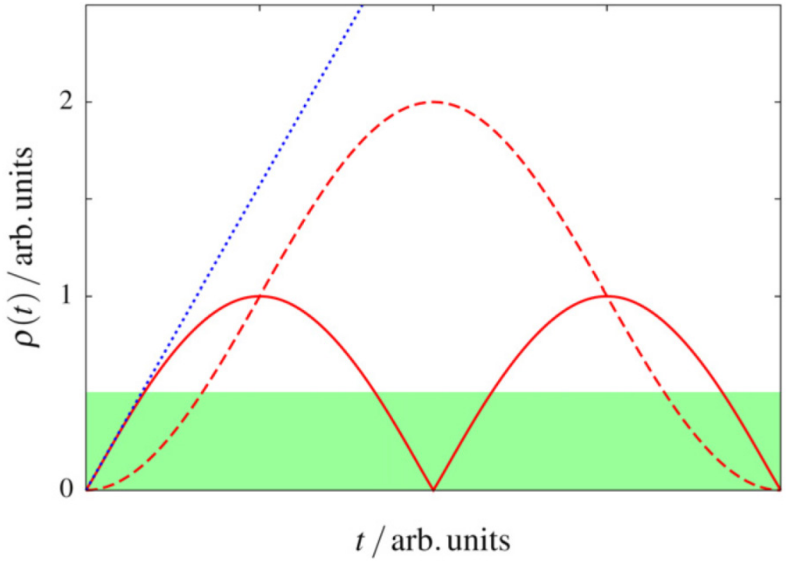
$$\frac{\partial m}{m} \propto \frac{m}{qBT_{rf}\sqrt{N_{ion}}}$$

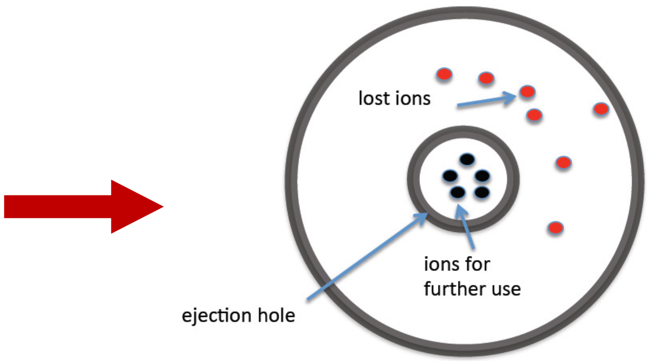


Recent Developments in PTMS

- Technical Achievements
  - Ramsey/octupole excitation
    - ✓ Gain in precision or faster measurement
    - ✓ S. George *et al.*, PRL **98**, 162501 (2007)
    - ✓ M. Kretzschmar, IJMS **264**, 122 (2007)
    - ✓ R. Ringle *et al.*, IJMS **262**, 33 (2007)
    - ✓ S. Eliseev *et al.*, IJMS **262**, 45 (2007)
  - Ramsey/octupole/SIMCO cleaning
    - ✓ T. Eronen *et al.*, NIM B **266**, 4527 (2008)
    - ✓ M Rosenbusch *et al.*, IJMS **314**, 6 (2012)
    - ✓ M. Rosenbusch *et al.*, IJMS **325**, 51 (2012)



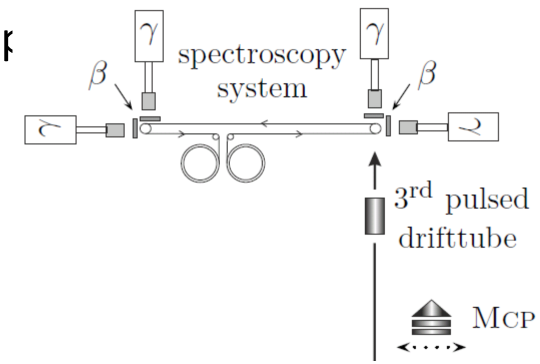




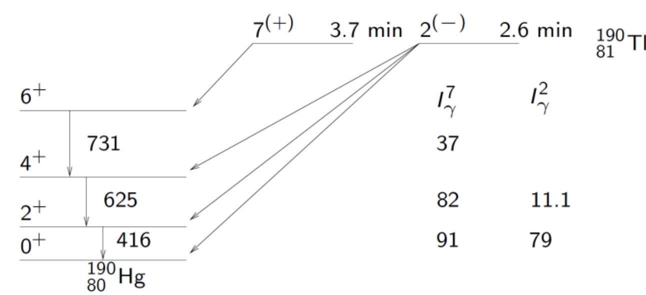
Pure Samples for Spectroscopy

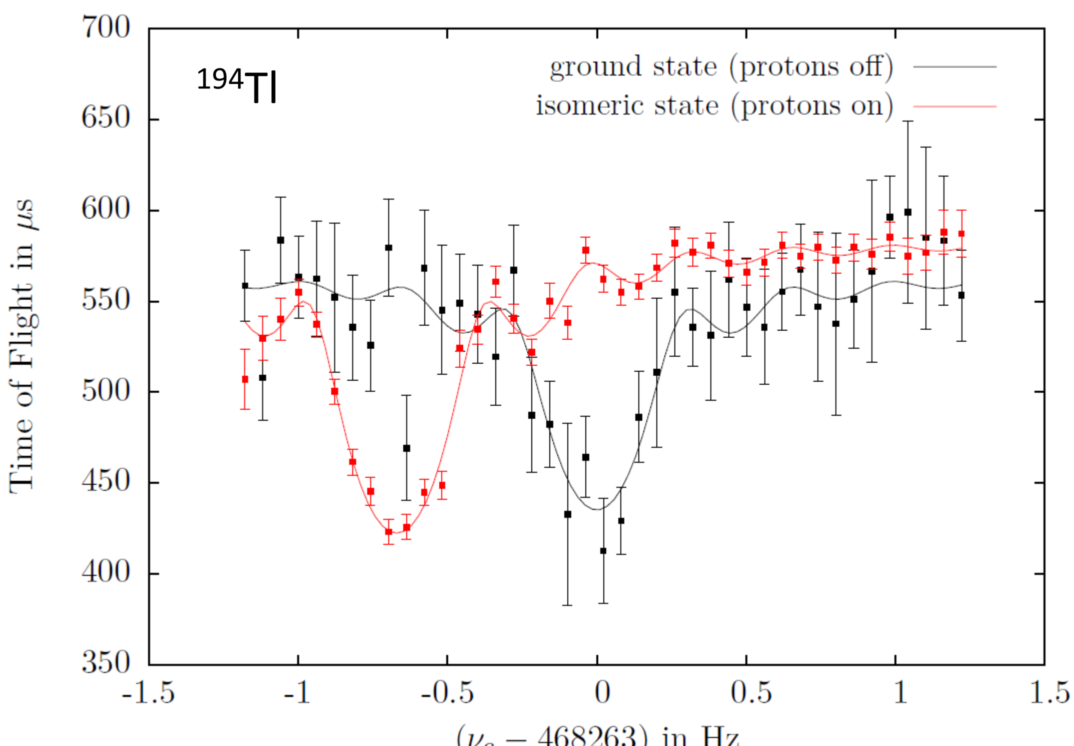
Poster by T. Cocolios

- Isomeric mixtures can be purified in the precision trap
  - Masses of ground and isomeric state can be measured
  - Excitation energies can be determined



- Pure samples can be implanted on tape
  - Spin assignment via β-γ coincidences





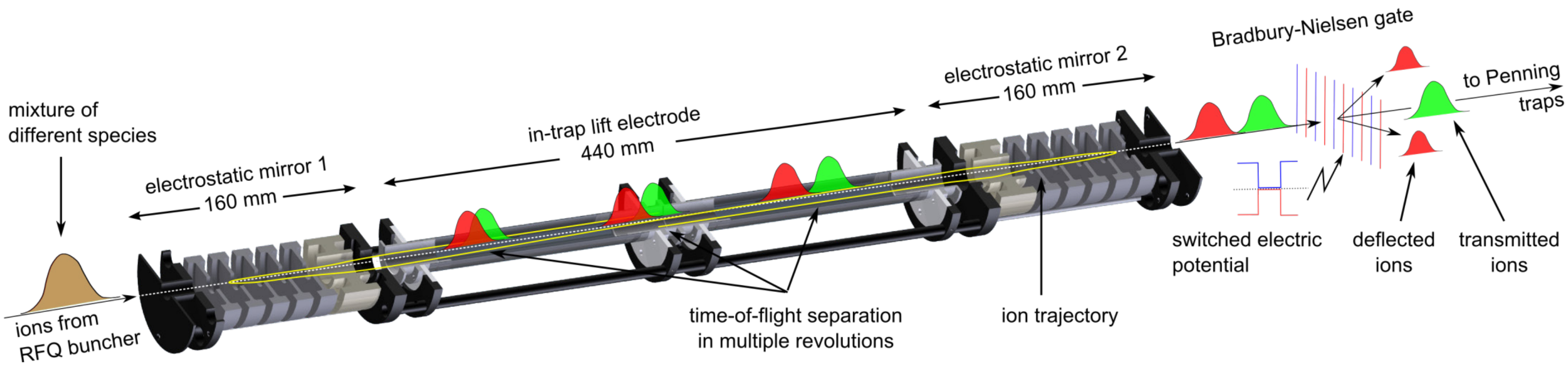
- Pure samples can be guided to flexible decay-spectroscopy station
  - Alpha detector
  - Tape station

M. Kowalska et al., NIMA **689**, 102 (2012)

„First Masses“

- Goal: Precision mass spectrometry on the outskirts of the nuclear chart
  - Applications: pronounced nuclear-structure effects and astrophysics

- Challenges: ms half-lives, minutes production rates, high contamination yield



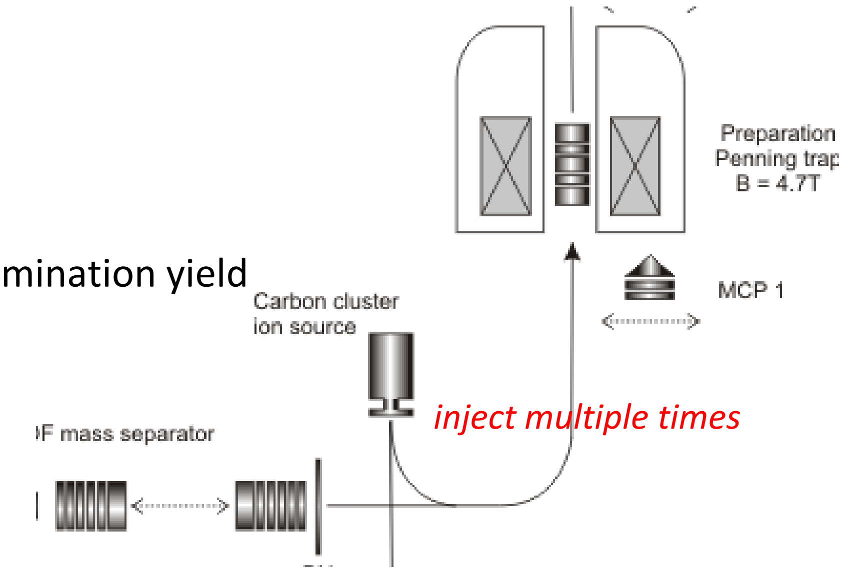
- Implementation of multi-reflection time-of-flight mass separator (MR-TOF MS) has opened a wide range of possibilities
  - Support Penning-trap mass spectrometry on fast time scales
  - MR-TOF plus detector as a stand-alone system

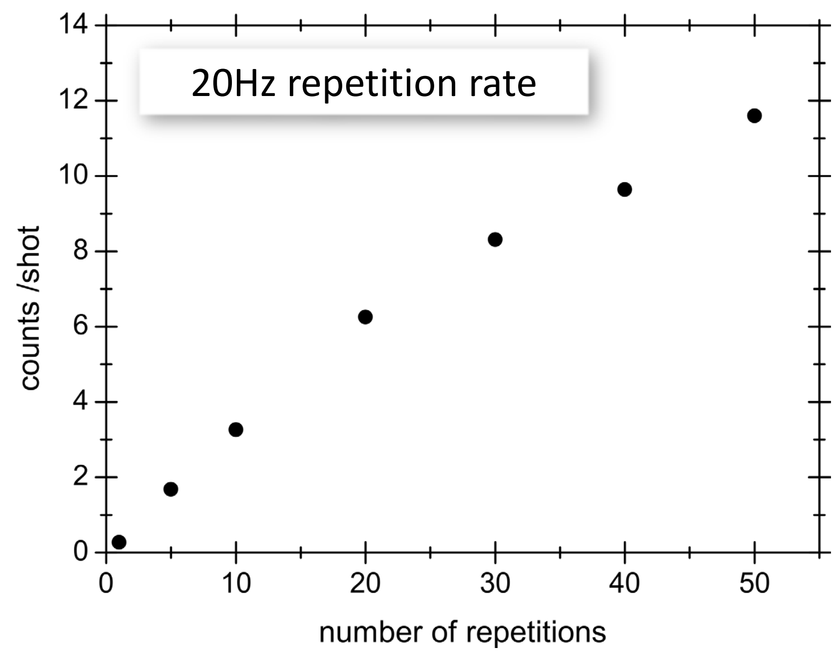
  - Collaboration with TISD: yield measurements for target with new converter geometry
  - Collaboration with Nuclear Medicine Program

Talk by Thiery Stora, Poster by Ulli Koester

Online Operation of MR-TOF MS

- Auxiliary isobaric purification
  - ✓ higher contamination yield
- Stacking
  - ✓ lower production yield, higher contamination yield
- Only purifier for short cycle (tens of ms)
  - ✓ lower half-lives
- Direct mass measurements
  - ✓ few tens of ms half-lives
- „Detector“ in its own right
  - ✓ spectroscopic experiments

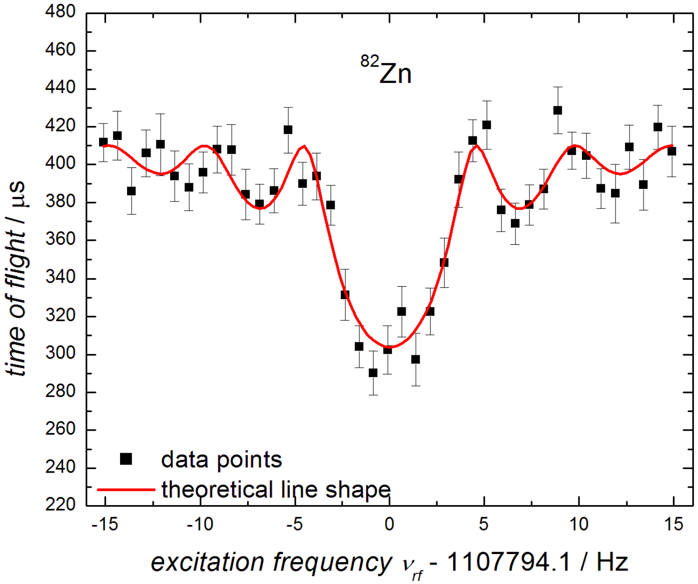


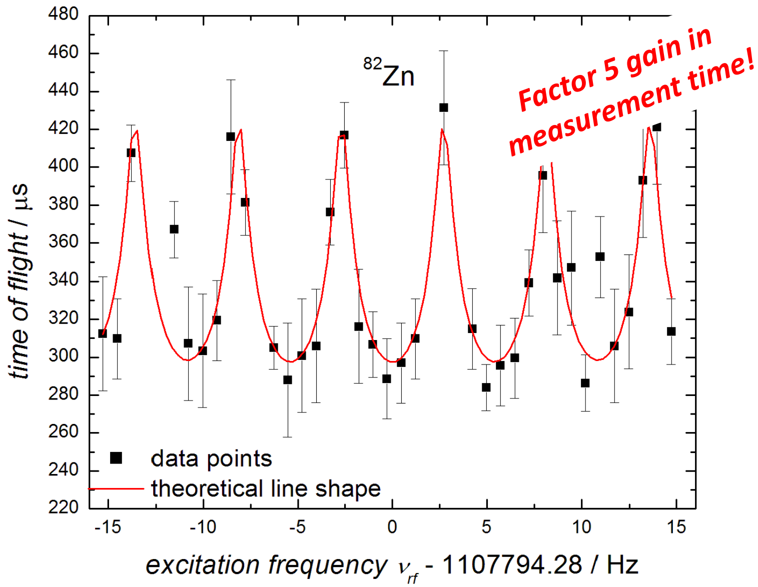


R. N. Wolf *et al.*, NIM A **686**, 82 (2012)
Similar developments:
H. Wollnik and M. Przewloka, IJMS **96**, 267 (1990),
Y. Ishida *et al.*, NIM B **219**, 468 (2004),
A. Verentchikov *et al.*, Tech. Phys. **50**, 82 (2005),
W. Plaß *et al.*, NIM B **266**, 4560 (2008)
P. Schury *et al.*, EPJA **42**, 343 (2009)

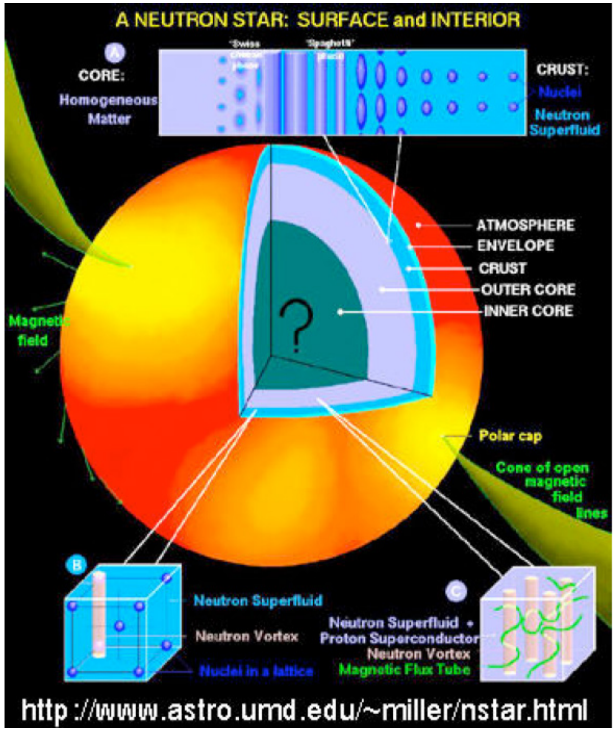
Poster by Robert Wolf

^{82}Zn Mass for Astrophysics





- Combined all ISOLDE know-how to realize this measurement
  - UCx target with quartz transfer line
  - neutron converter and RILIS



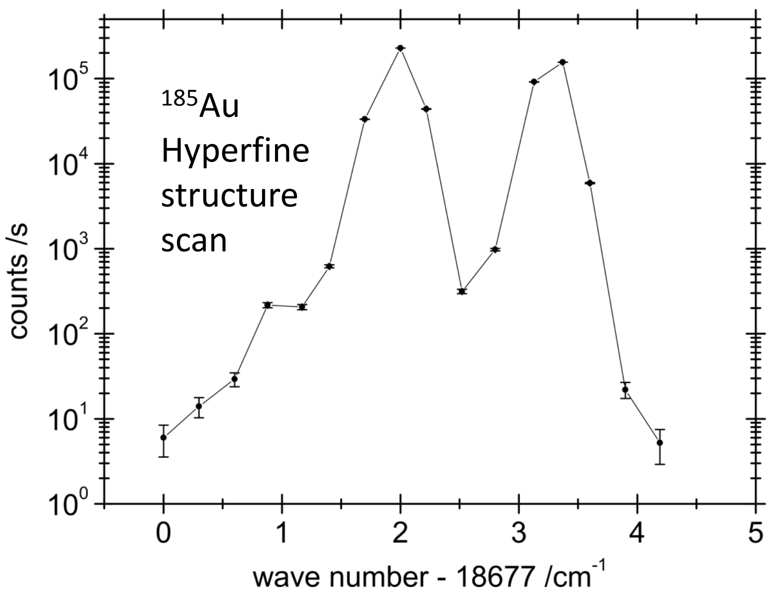
- Its determination is important for modelling of the crust of neutron stars

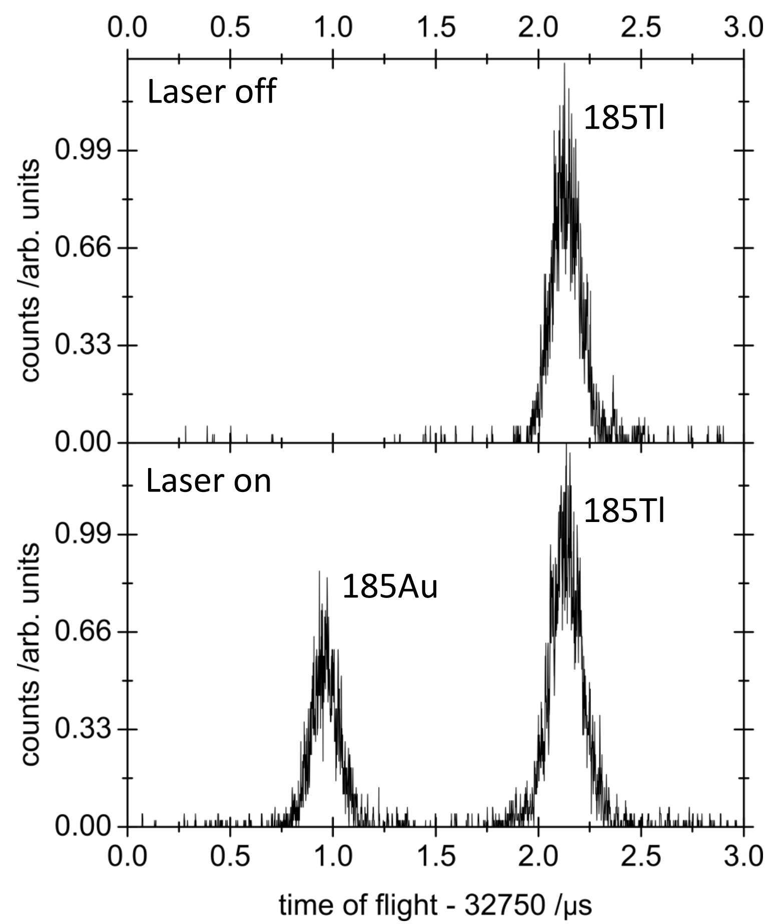
R. N. Wolf *et al.*, PRL, submitted (2012)

MR-TOF MS for Spectroscopy

Poster by Ralf Rossel, talk by Bruce Marsh

- Investigate ionization efficiency with RILIS lasers for HFS information
  - Direct ion detection (FC or MCP) — BUT: Background not separated
  - Detection of decay products — BUT: limited by decay branch, half-life, background
- ISOLTRAP's MR-TOF
  - single-ion sensitivity
  - High dynamics: 1 - 10^5 ions/s
  - Background separation
  - Automated DAQ with RILIS



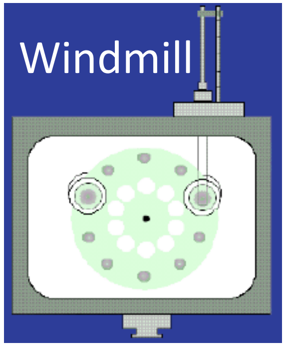


S. Kreim *et al.*, INTC-P-299, IS 518 (2011)

Isomerically Pure Beams

- Synergy with Windmill Experiment and RILIS

Results omitted in online version.



A. Andreyev *et al.*, INTC-P-319 (2012), S. Kreim *et al.,* INTC-P-299, IS 518 (2011)

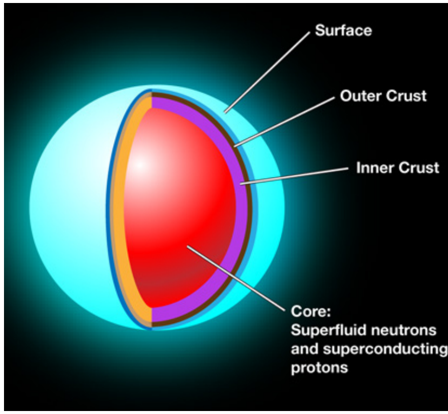
Direct Mass Measurements

- Direct time-of-flight mass measurements with one well-known isobaric reference

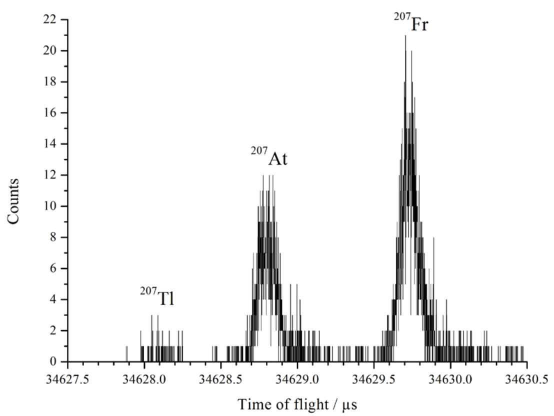
Results omitted in online version.

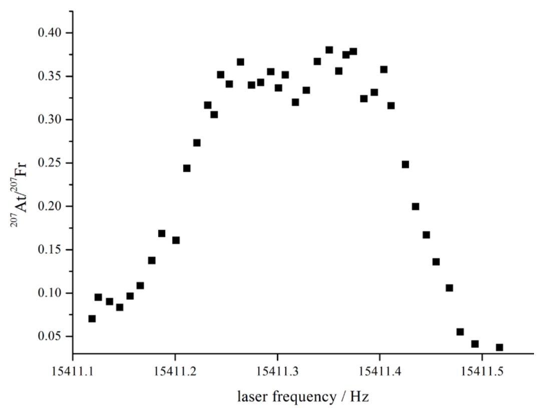
S. Kreim *et al.,* INTC-P-317, IS 532 (2011)

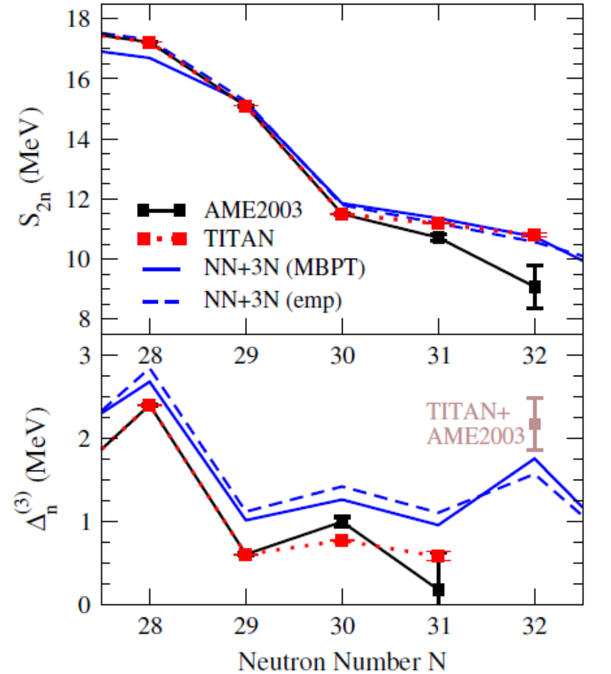
Summary and Outlook



- Great advances in PTMS experiments
  - High-precision mass measurements
  - Techniques for fast measurement of „first masses“
- MR-TOF MS is a versatile tool which offers new possibilities
  - Support existing PTMS program
    - ✓ ^{82}Zn for astrophysics
    - ✓ ^{54}Ca for nuclear-structure studies
  - MR-TOF MS plus detector as stand-alone system
  - Decay spectroscopy setup behind MR-TOF MS
  - MR-TOF MS @ S^{3} at GANIL







A. T. Gallant *et al.,* Phys. Rev. Lett. **109**, 032506 (2012)

ISOLTRAP Collaboration

D. Atanasov, K. Blaum, Ch. Böhm, Ch. Borgmann, R. B. Cakirli, S. Eliseev

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S. Schwarz, G. Bollen

M. Breitenfeldt

S. Naimi

Thanks...

- ... the ISOLDE Target, RILIS and Technical Team
- ... for funding: BMBF, GSI, CERN, ISOLDE, MPG

Part of... EuroGENESIS — Origin of the Elements and Nuclear History of the Universe

NAVI @ GSI

ENSAR — European Nuclear Science and Applications Research — Within the Seventh Framework Programme of the European Commission

Thank you for your attention!

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