EuNPC Master Class, 2015

"Basics of Precision Nuclear and Atomic Mass Measurements for Fundamental Studies – Part 2"

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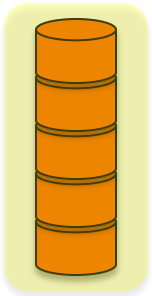
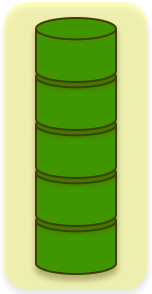
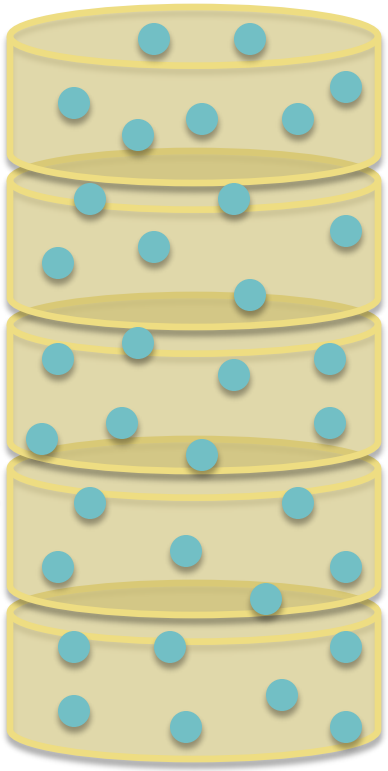
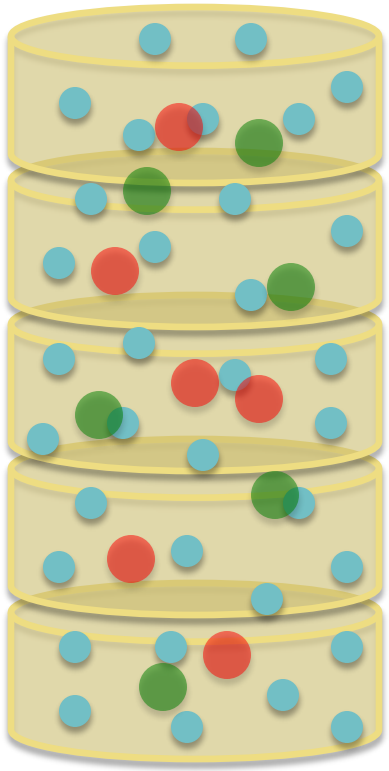
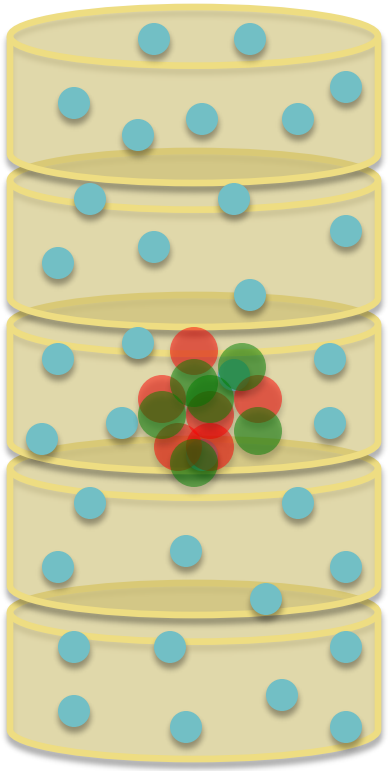
Ion preparation and cooling

- Buffer-gas (He) in preparation trap
- Motional amplitudes are reduced
- Well-controlled conditions

buffer-gas (He)
contaminent ions
Ions of interest

Ion beam cocktail: R=10^2-10^3 (Selection by dipole magnets)

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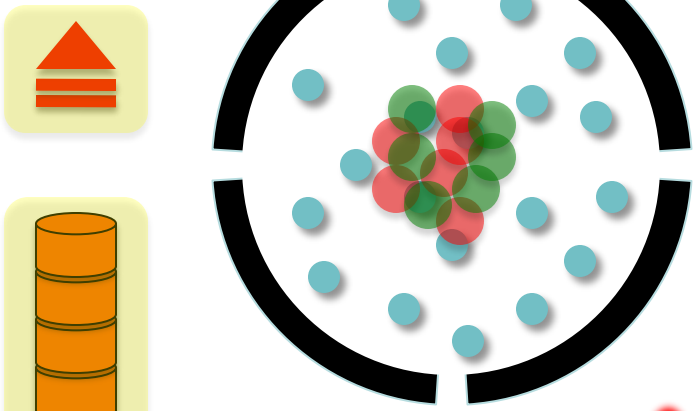
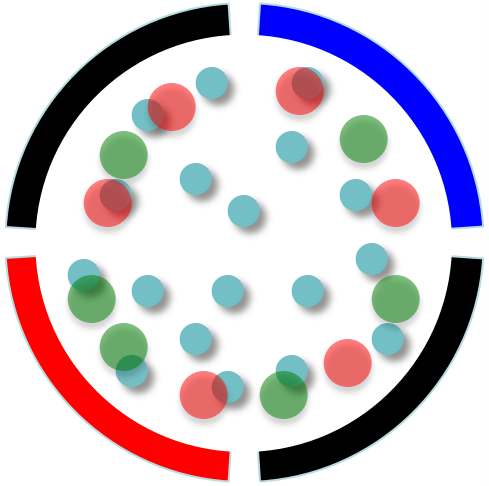
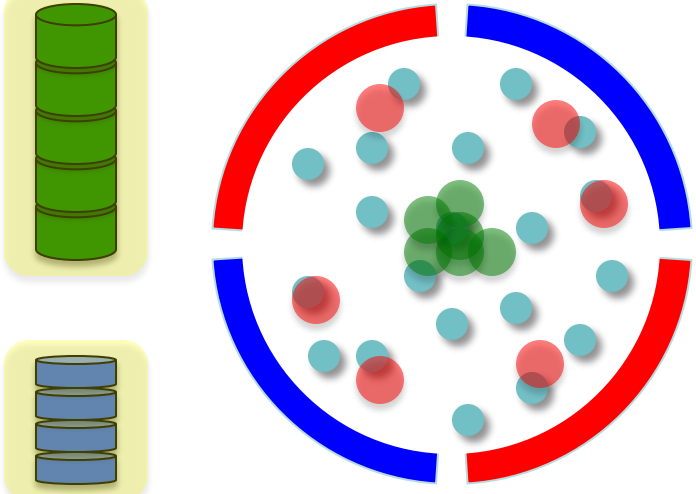
Mass selective buffer-gas cooling



- Resolving Power $R=10^5$
- Cooled ions



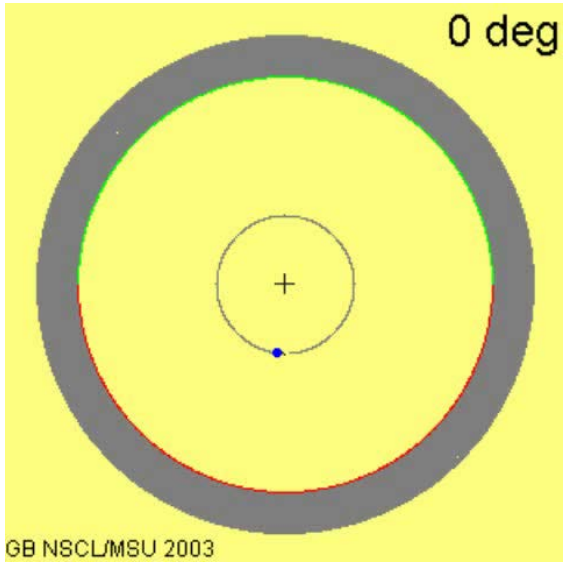
- Dipolar excitation at magnetron frequency (≈ mass independent)



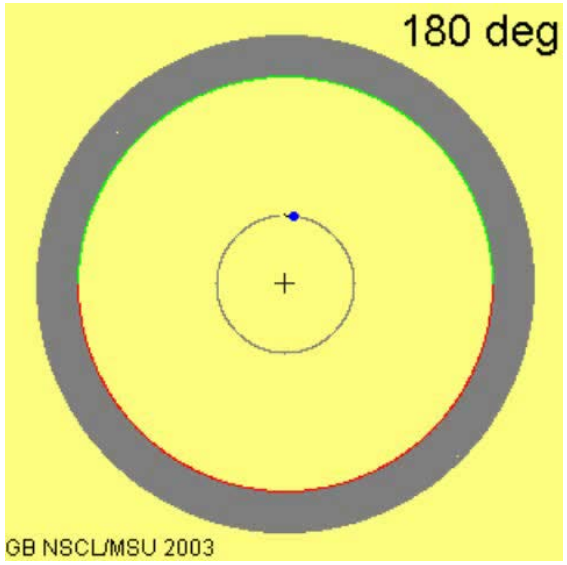
- Quadrupolar excitation at the cyclotron frequency (mass selective recentering)

G. Savard *et al.*, Phys. Lett. A 158 (1991) 247.

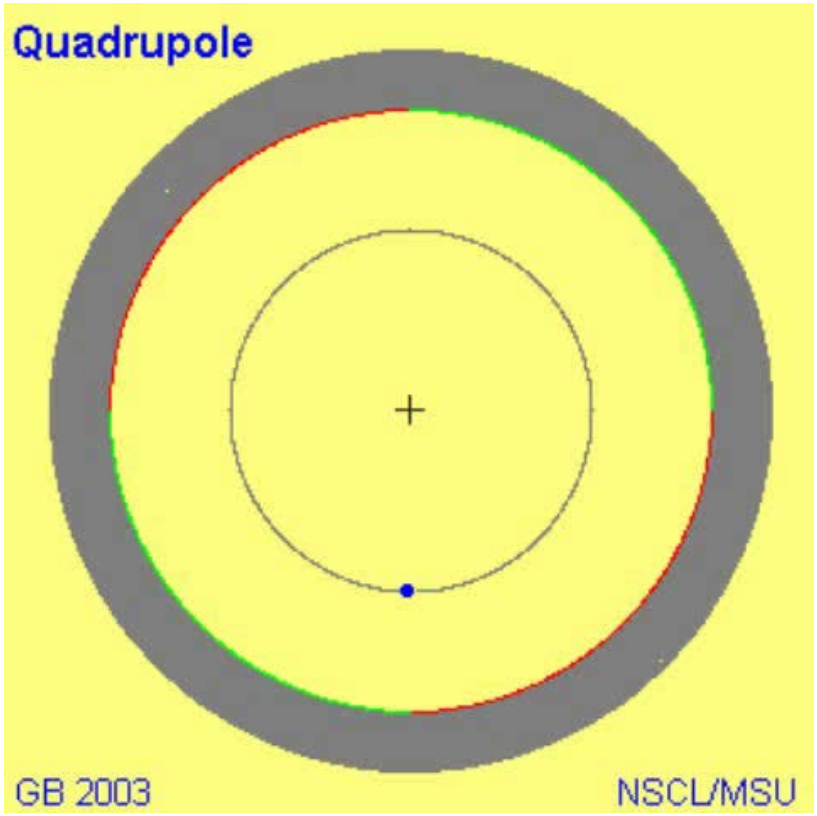
Manipulation of ion motions



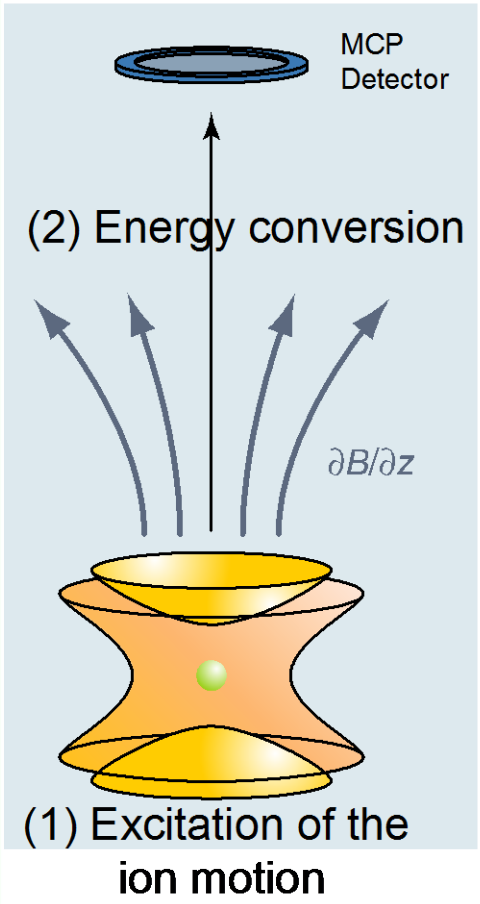
Dipolar excitation

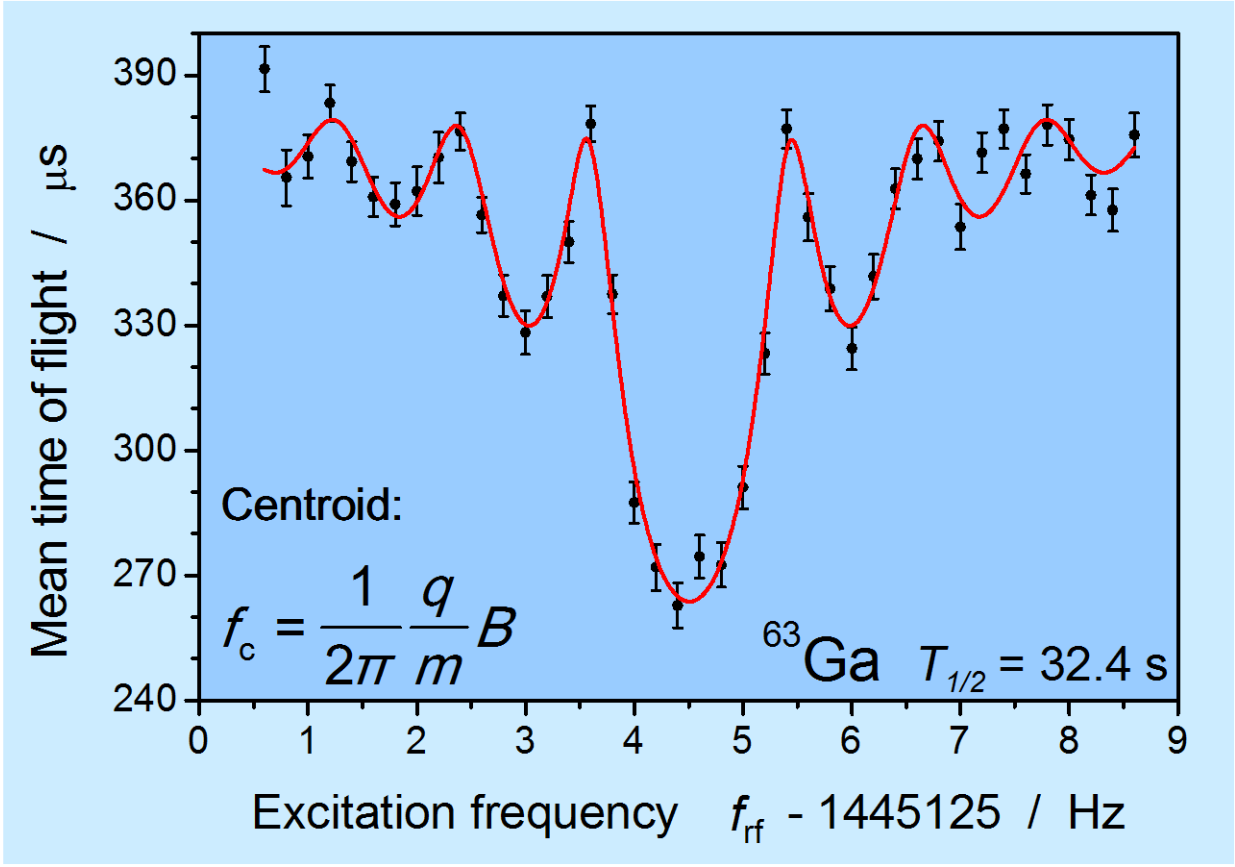


Quadrupolar excitation



Destructive ion detection

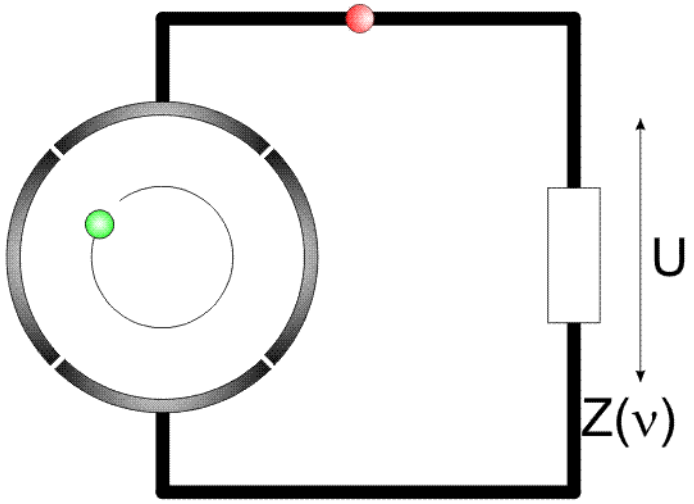




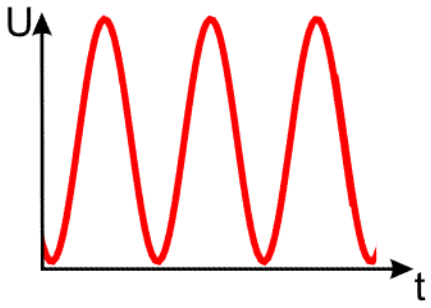
Determine atomic mass from frequency ratio with a well-known "reference mass".

$$\frac{f_{c,ref}}{f_c} = \frac{m - m_e}{m_{ref} - m_e}$$

Non-destructive ion detection

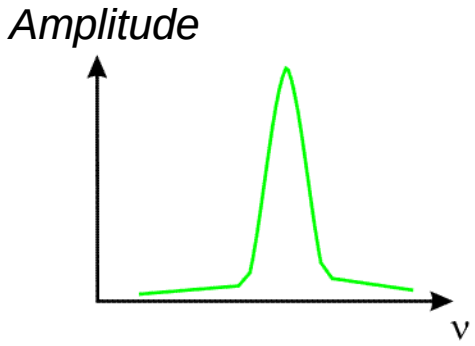


ion signal

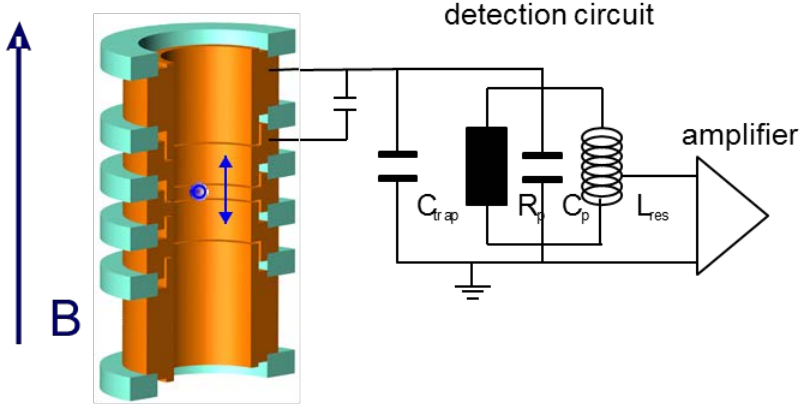


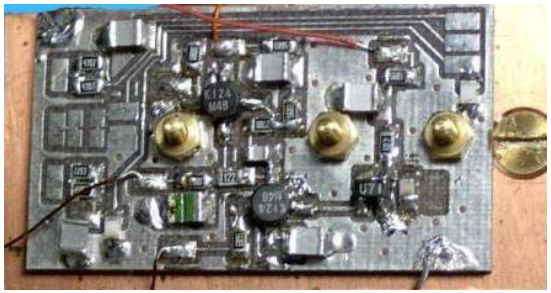
very small signal ~fA

mass/frequency spectrum



„FT-ICR“
Fourier-**T**ransform-
Ion **C**yclotron **R**esonance





Ultra-low noise cryogenic amplifier

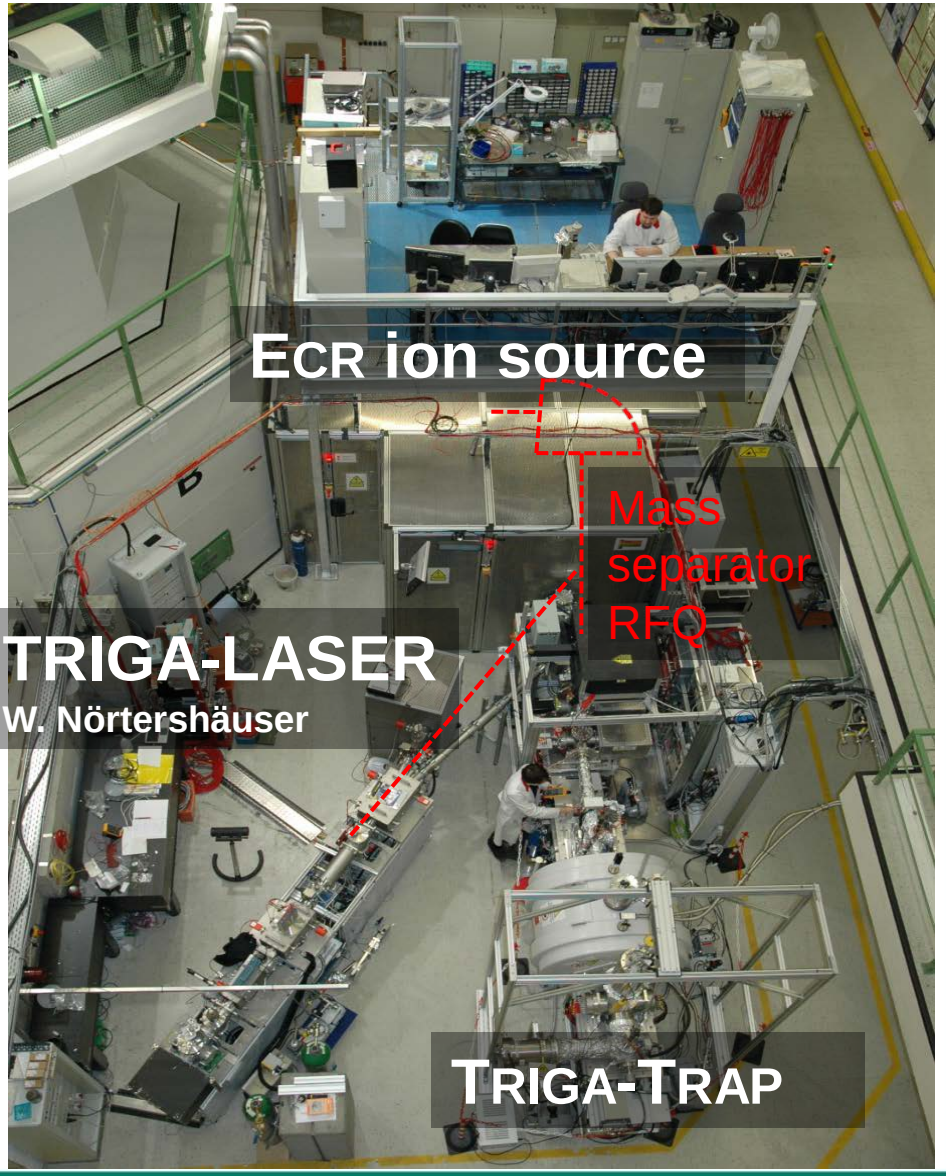
$T = 4$ K
$P = 5.5$ mW
$e_n = 400$ pV/$\sqrt{\text{Hz}}$
$i_n < 2$ fA/$\sqrt{\text{Hz}}$
$\nu_z = 600$ kHz

TRIGA-SPEC: TRIGA-LASER + TRIGA-TRAP

project start @ TRIGA: 01/08
start data taking: 05/09

steady 100 kW,
pulsed 250 MW,
neutron flux 1.8x10^{11} / cm^{2}s

Nucl. Instrum. Meth. A 594, 162 (2008)



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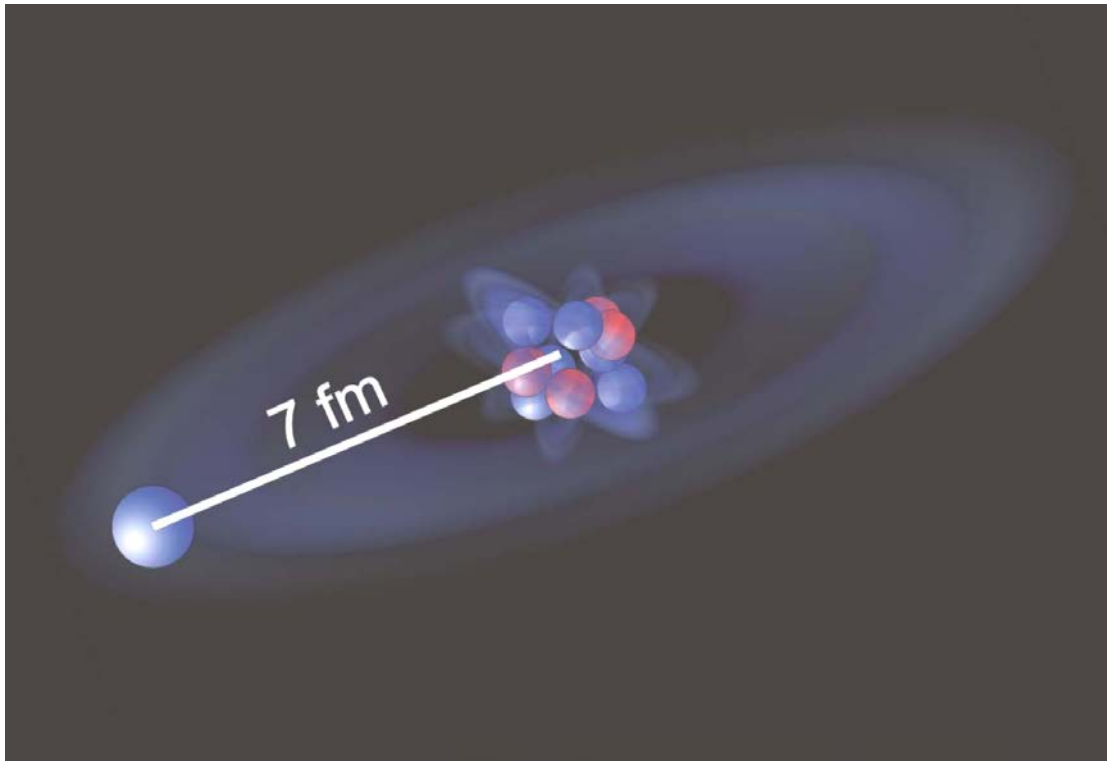
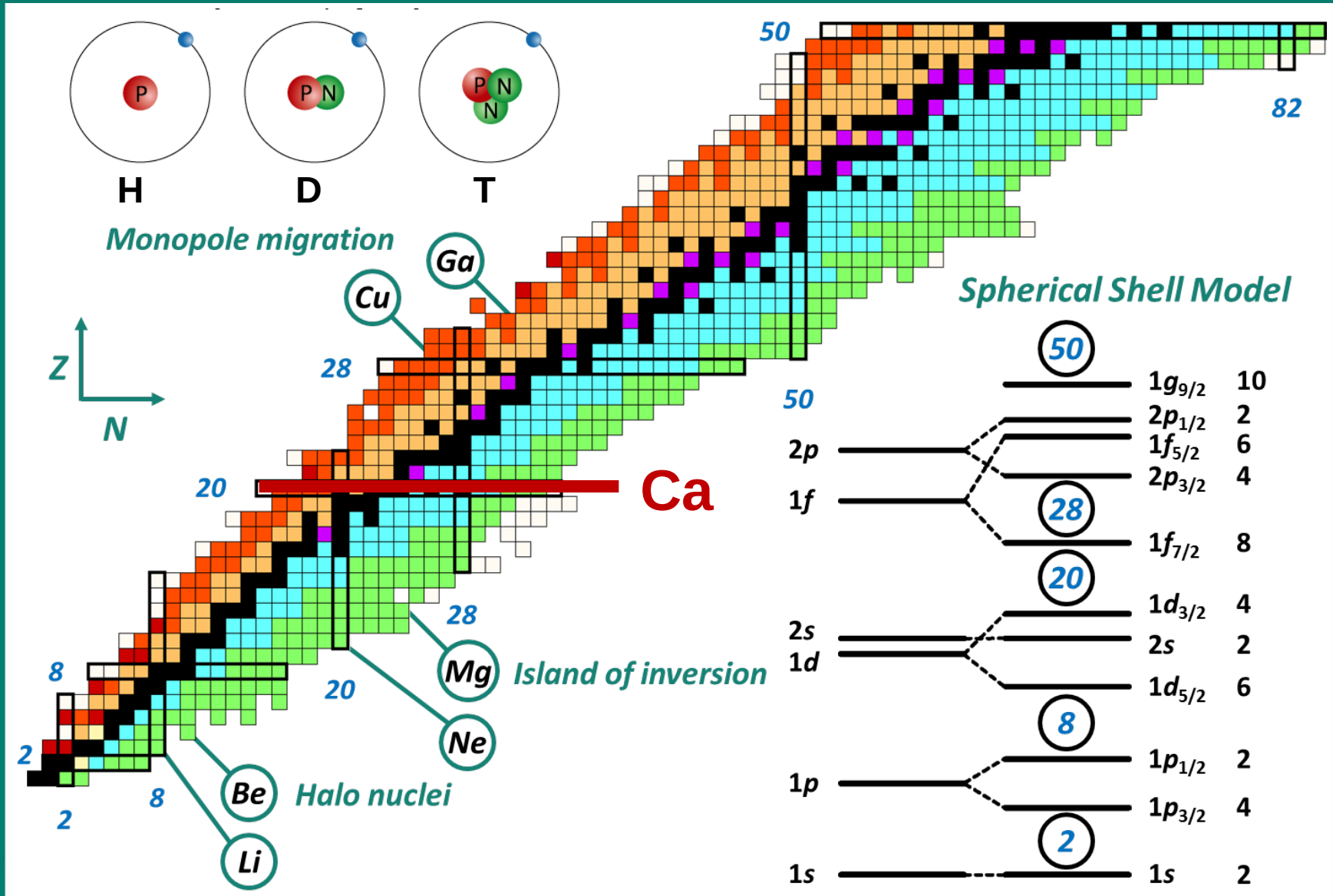
Nuclear structure studies

Nuclear structure studies



In collaboration with CERN, GSI, TU Darmstadt, Greifswald, Dresden, Paris.

Chart of nuclides and magic numbers



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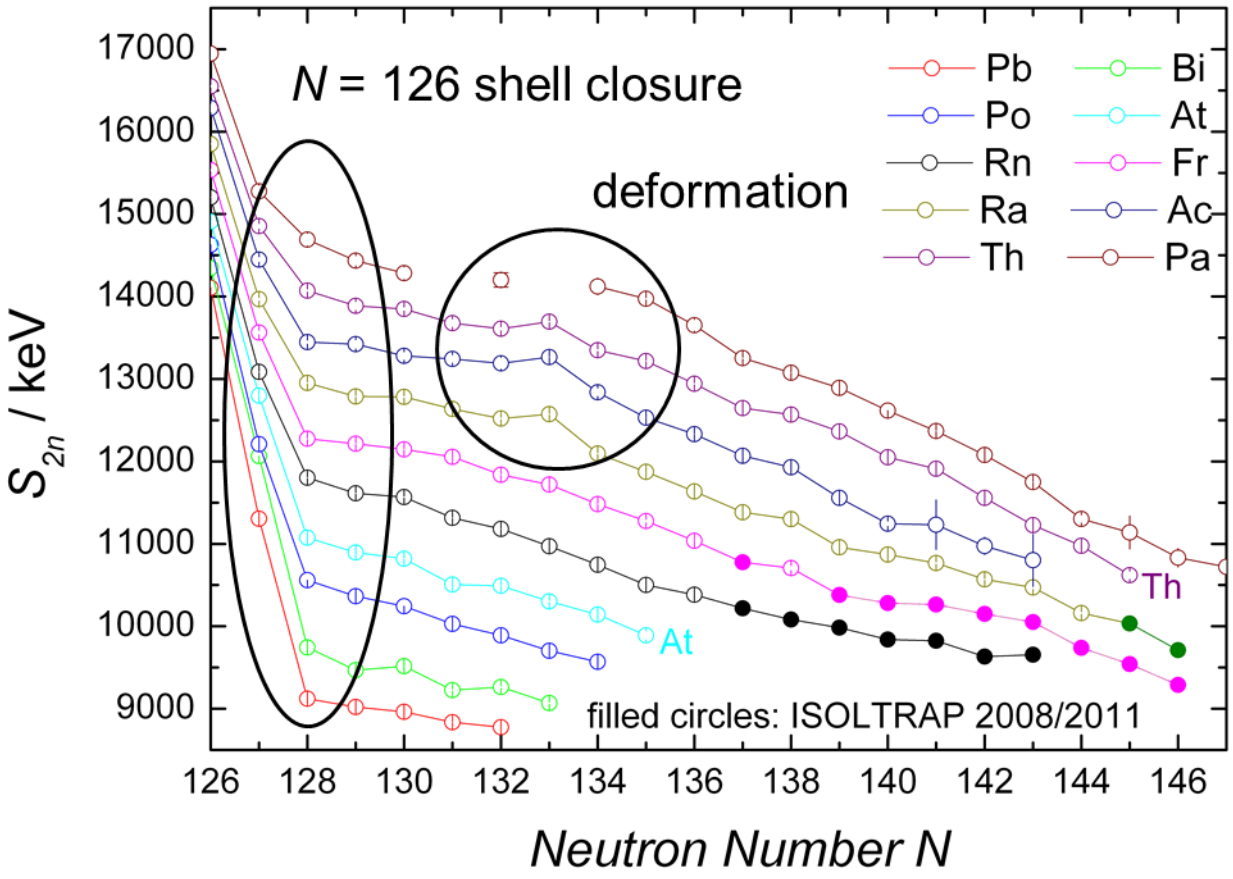
Nuclear structure studies

$$S_{2n} = B_{nucl}(Z,N) - B_{nucl}(Z,N\text{-}2)$$

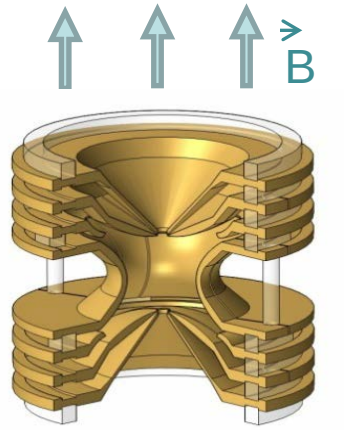


D. Yordanov *et al.*, Phys. Rev. Lett. 110, 192501 (2013)
M.L. Bissell *et al.*, Phys. Rev. Lett. 113, 052502 (2014)
Z. Meisel *et al.*, Phys. Rev. Lett. 114, 022501 (2015)
J. Papuga *et al.*, Phys. Rev. Lett. 110, 172503 (2013)
R.F. Casten *et al.*, Phys. Rev. Lett. 113, 112501 (2014)
M. Rosenbusch *et al.*, Phys. Rev. Lett. 114, 202501 (2015)

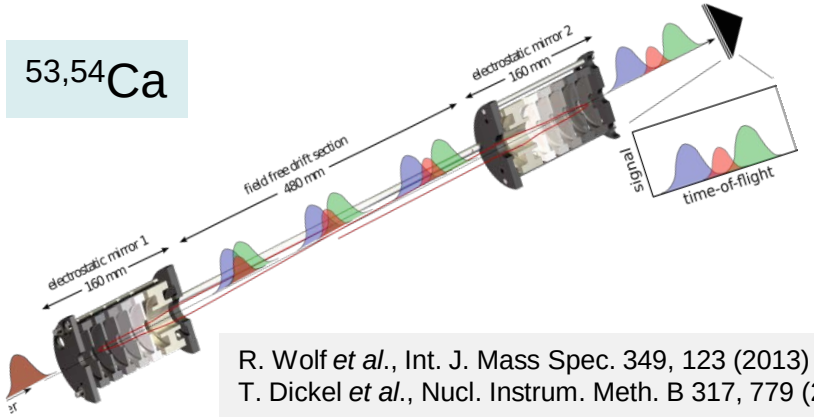
Ca masses pin down nuclear forces

Multi-reflection time-of-flight and Penning-trap mass spectrometry

^{51,52}Ca

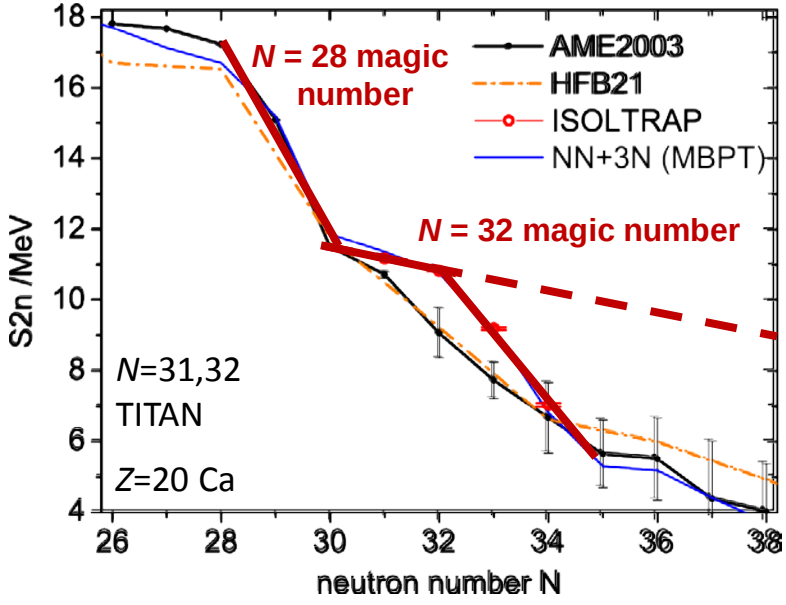


^{53,54}Ca



R. Wolf *et al.*, Int. J. Mass Spec. 349, 123 (2013)
T. Dickel *et al.*, Nucl. Instrum. Meth. B 317, 779 (2013)

- Production rates of ~10 ions/s
- Mass measurements via S_{2n} establish new magic number at N = 32
- Correct prediction from 3N-forces (A. Schwenk *et al.*, TUD)



F. Wienholtz *et al.*, Nature 498, 346 (2013)

ISOLTRAP (CERN), TITAN (TRIUMF)

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End of Lecture 2

What did we learn?

1) Storage, manipulation, detection of stored ions
2) Frequency measurement techniques
3) Applications of precision nuclear mass data
    - Nuclear structure studies

What comes next?

1) Further applications of precision nuclear mass data
    - Nuclear astrophysics studies
    - Test of fundamental symmetries
2) Future facilities