MAX PLANCK INSTITUTE FOR NUCLEAR PHYSICS

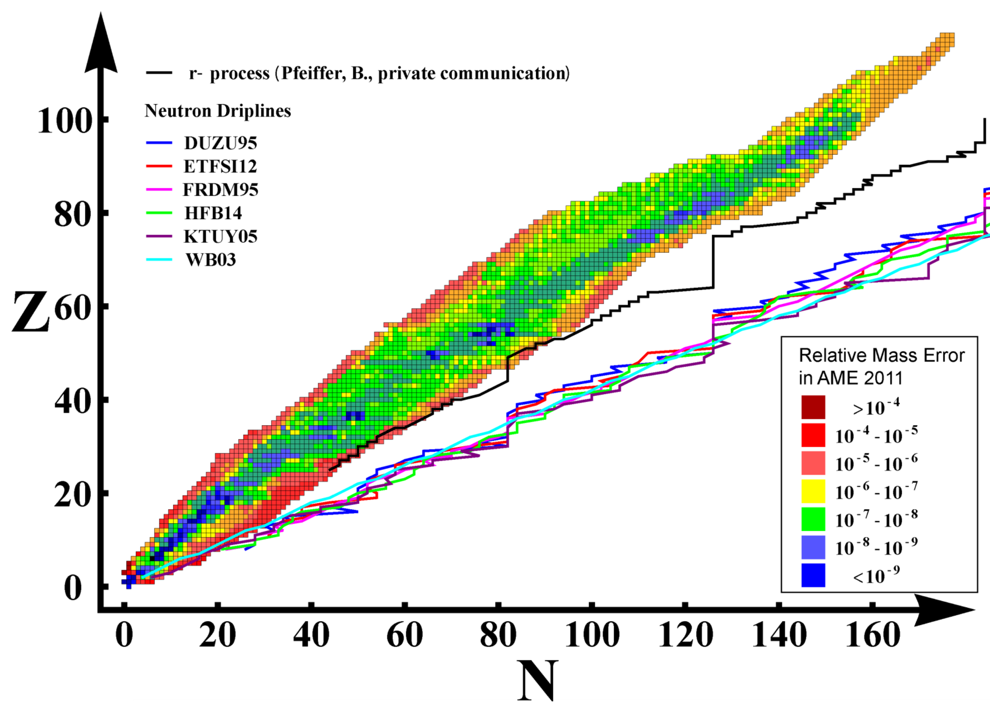
High-precision mass spectrometry and laser spectroscopy at the nuclear research reactor TRIGA Mainz

Sz. Nagy[1,2], T. Beyer[1,3], K. Blaum[1,3], M. Block[2], Ch. E. Düllmann[2,4,5], K. Eberhardt[4,5], M. Eibach[3,4], N. Frömmgen[4], C. Geppert[2,4], M. Hammen[4], A. Krieger[4], W. Nörtershäuser[2,4], D. Renisch[4], C. Smorra[3,4]

[1] *Max-Planck-Institut für Kernphysik, D-69117 Heidelberg.*
[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt.*
[3] *Ruprecht-Karls-Universität Heidelberg, Fakultät für Physik und Astronomie, D-69117 Heidelberg.*
[4] *Johannes Gutenberg-Universität Mainz, Institut für Kernchemie, D-55128 Mainz.*
[5] *Helmholtz-Institut Mainz, D-55099 Mainz.*

Nuclear ground state properties of the neutron-rich nuclides

- The binding energy $B(Z,N) = [Zm_e+Zm_p+Nm_N-M(Z,N)]c^2$ reflects all interactions in a nucleus.

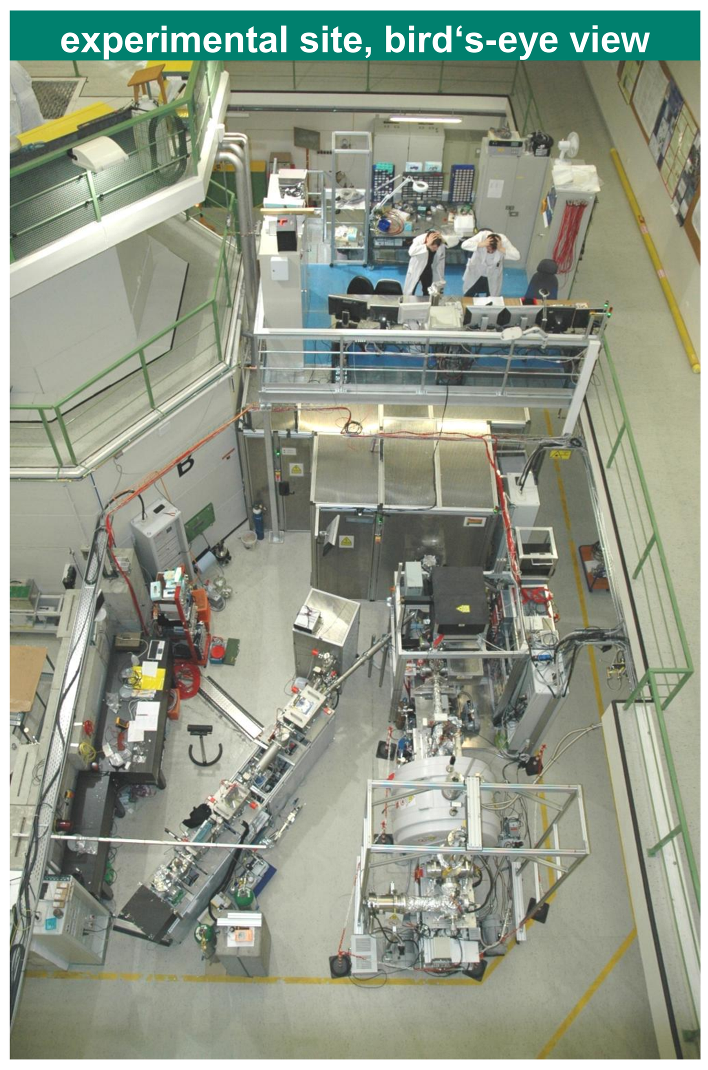


- The nuclear mass models deviate from each other by several MeV in the neutron-rich region. New mass measurements are needed to benchmark the predictive power of mass models.
- Laser spectroscopic measurements will yield model-independent information on nuclear ground-state properties such as nuclear moments and charge radii of neutron-rich nuclei of refractory elements far from stability.
- Accessing the region closer to the r-process path will help to answer fundamental questions like:

Why are there heavy elements at all and how did they come into existence?

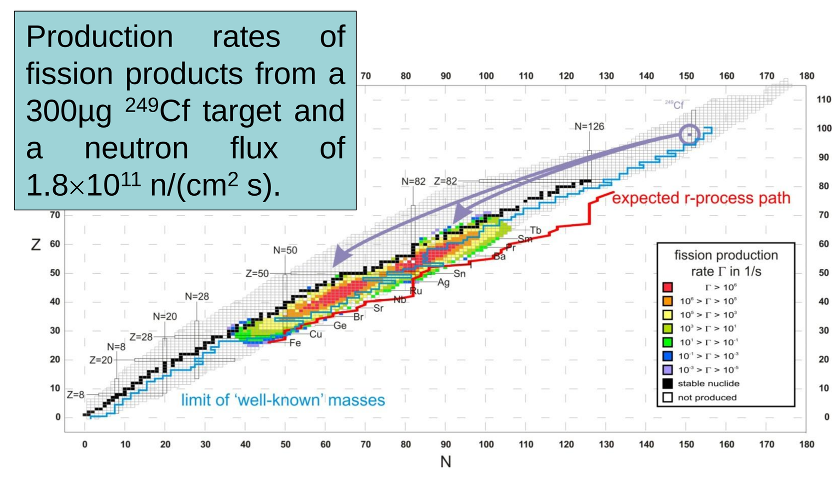
The TRIGA Mainz reactor and accessible nuclides

experimental site, bird's-eye view



A fissionable actinoid target (^{235}U, ^{239}Pu, ^{249}Cf) is placed close to the reactor core, where it is exposed to thermal neutrons.

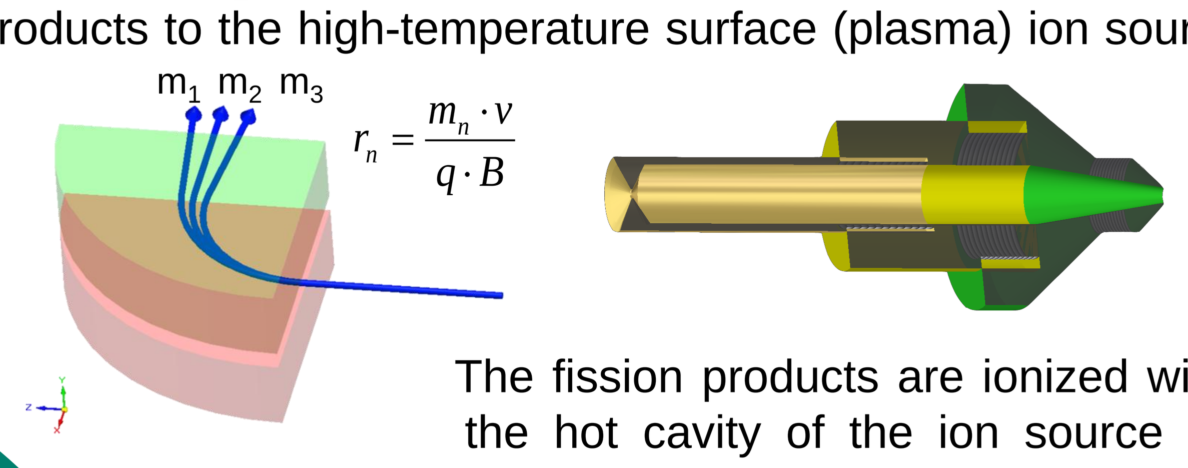
Production rates of fission products from a 300µg ^{249}Cf target and a neutron flux of 1.8×10^{11} n/(cm² s).



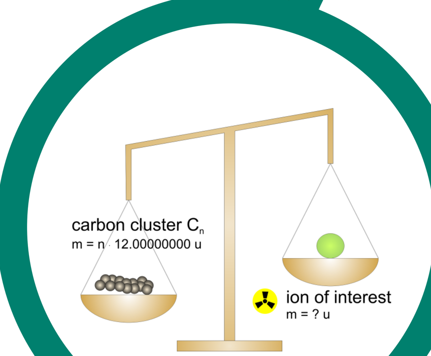
Accessible heavy elements

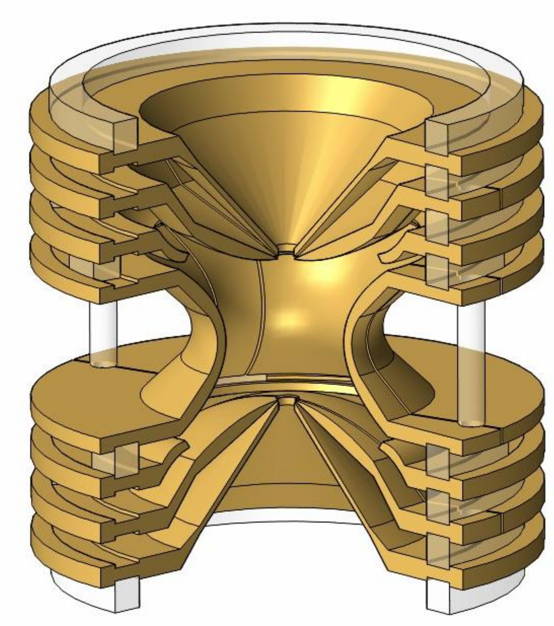
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

A gas-jet system (e.g. N_2 carrier gas with KCl aerosol particles) transports the fission products to the high-temperature surface (plasma) ion source.

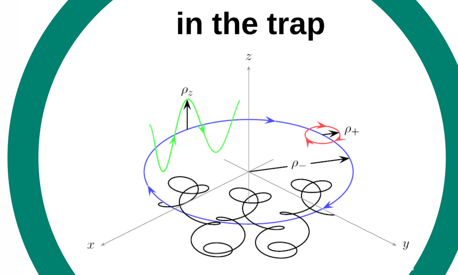


The fission products are ionized within the hot cavity of the ion source and accelerated towards the mass separator magnet. The desired mass will be injected into a gas-filled radiofrequency quadrupole buncher (RFQ) and the extracted cooled and bunched beam is guided towards the experiments.

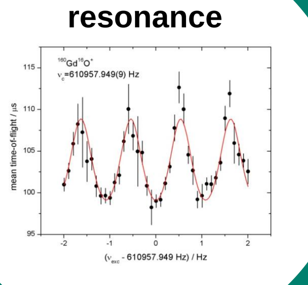




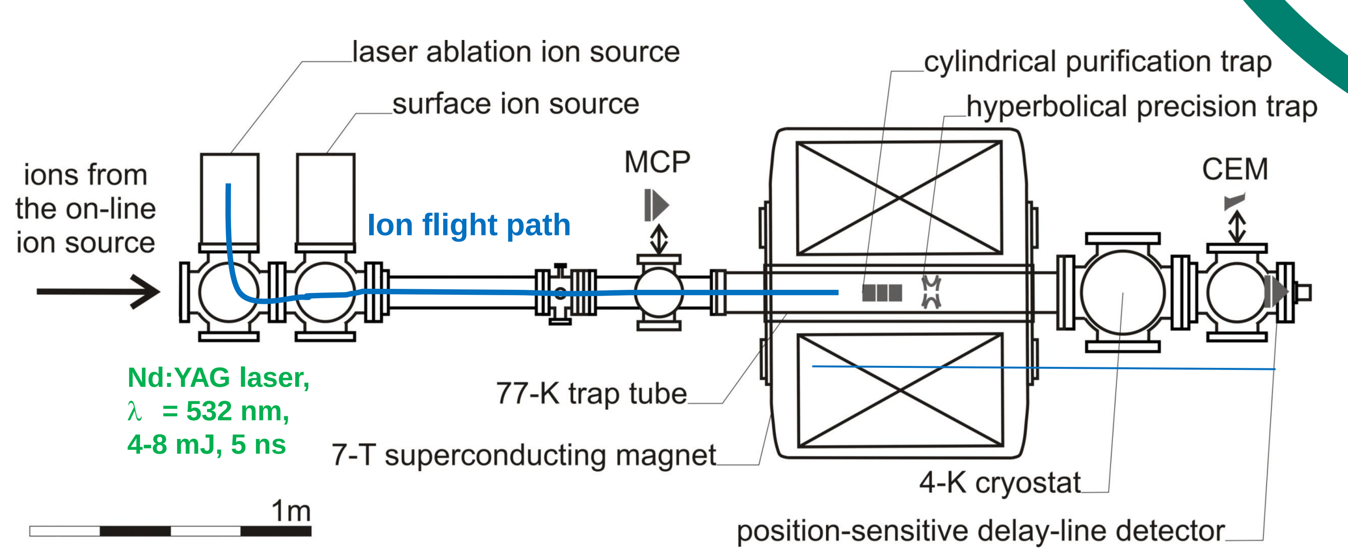
Ion motion in the trap



Time-of-flight resonance

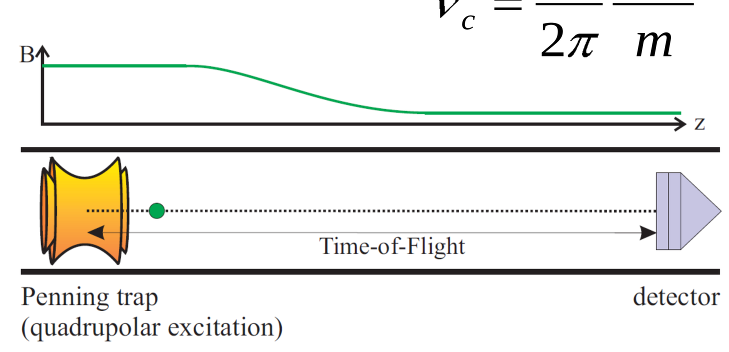


TRIGA-TRAP



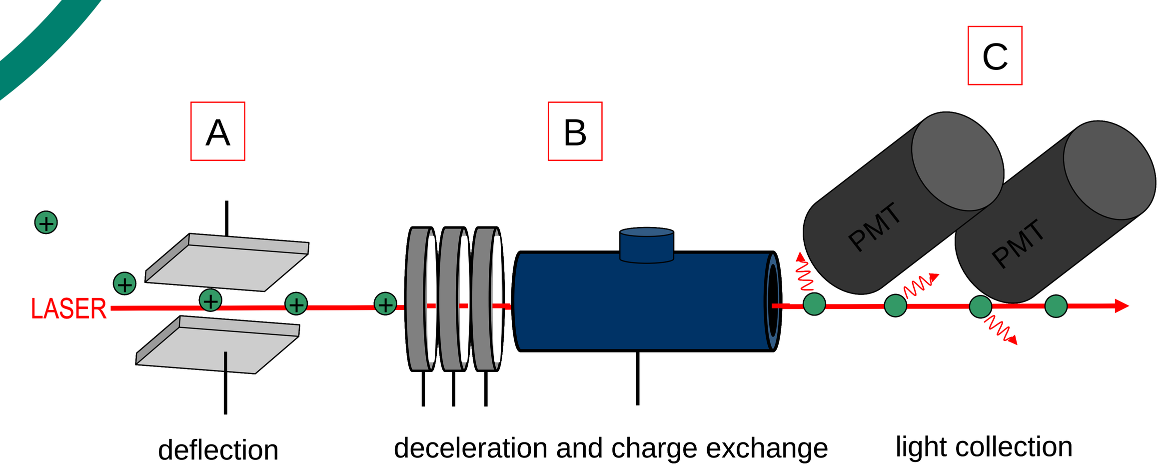
TRIGA-TRAP is worldwide the only Penning-trap mass spectrometer at a nuclear reactor [1]. Absolute mass measurements can be performed using carbon clusters as mass reference. On-line or off-line produced ion species are available.

$$\nu_c = \frac{1}{2\pi}\frac{q\,B}{m}$$

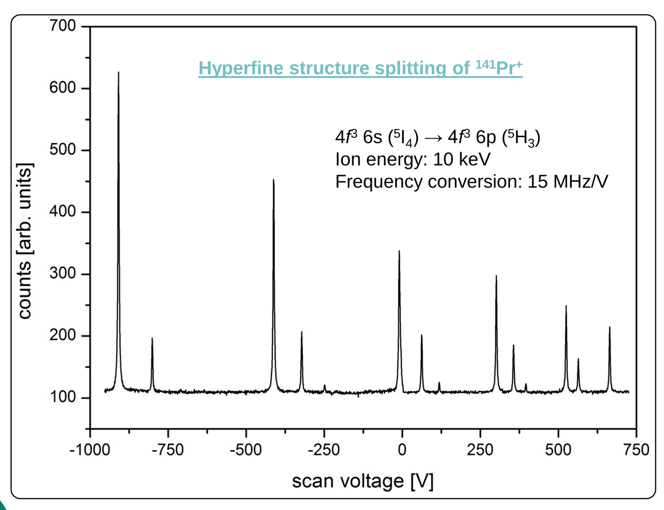


By measuring the cyclotron frequency ν_c of a trapped ion the mass m is obtained ($\delta m/m \approx 10^{-8}$). For the actual mass measurement, the ion sample prepared in the first buffer-gas-filled trap is transferred to the hyperbolical precision trap where the Time-of-Flight Ion-Cyclotron-Resonance (TOF-ICR) technique is applied. Trapped ions subjected to an RF-excitation are dumped into the B-field gradient and the time of flight to an MCP detector is recorded. ν_c is determined from the ToF resonance by scanning the RF-excitation frequency around the expected ν_c. More on www.triga-trap.com

TRIGA-LASER



The ion beam is overlapped with the laser beam (A). Spectroscopy can be performed either on the ions or on neutral atoms after charge exchange collisions, e.g. with Na atoms (B). The velocity of the atom beam can be fine-tuned by applying a deceleration voltage to the charge exchange cell. In the following region (C) the atoms or ions are excited and their fluorescence light is detected by photomultipliers [2].



The nuclear magnetic moment of the isotope ^{140}Pr is of particular interest due to its connection to the „GSI Oscillations" [3]. As a preparation for the measurements of the radioactive isotope, collinear laser spectroscopy of the stable isotope ^{141}Pr$^+$ was performed at TRIGA-LASER. The studied transition is perfectly suitable for online measurements.

References

[1] J. Ketelaer et al., Nucl. Instr. Meth. A **594** (2008) 162.
[2] S.L.Kaufman, Opt.Commun. **17**, 3, 309 (1976).
[3] Yu.A. Litvinov et al., Phys. Lett. B **664** (2008) 162.

Acknowledgements

The Max-Planck Society is acknowledged for financial support. Funding by the Helmholtz Association for National Research Centres (HGF) under contracts VH-NG-037 and VH-NG-148 is acknowledged, as well as by the Stiftung Rheinland-Pfalz für Innovation under contract 961-386261/854. N. Frömmgen is a recipient of a fellowship through GRK *Symmetry Breaking* (DFG/GRK 1581). A. Krieger acknowledges support from the Carl-Zeiss-Stiftung (AZ:21-0563-2.8/197/1). Sz. Nagy acknowledges support from the Alliance Program of the Helmholtz Association (HA216/EMMI).

MAX-PLANCK-GESELLSCHAFT