ISOLTRAP the mass measurement tool of ISOLDE/CERN and its power to enhance the radio isotope production for medical purposes

Andree Welker

09.09.2016

1st MEDICIS-Promed general training

Outline

Motivation

- What about masses?

Setup

- Overview of ISOLDE
- ISOLTRAP-Tools:
  - Multi Reflection Time-of-Flight Separator/Spectrometer (MR-ToF)
  - Decay spectroscopy outlet
  - Precision Penning-Traps
  - Medical perspectives

Old tools and new tools

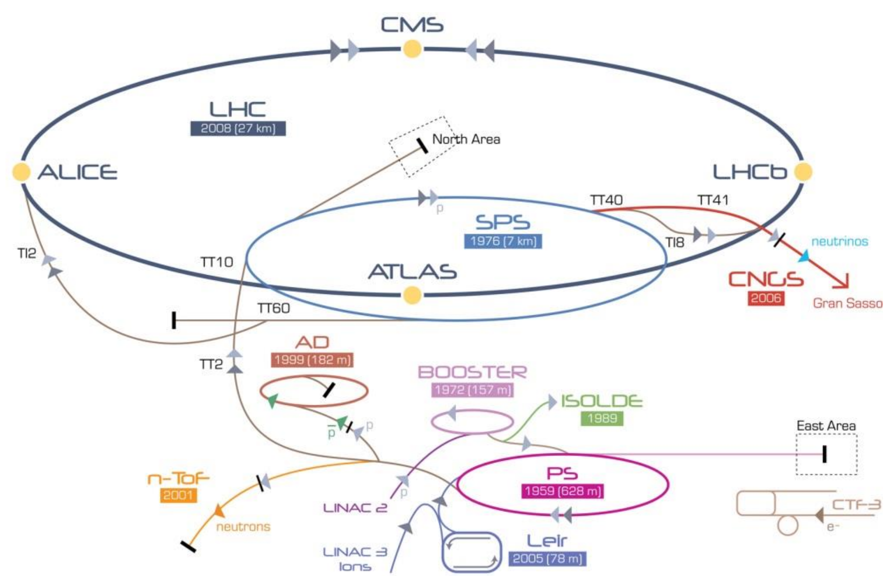
Old tools and new tools

Göbekli Tepe, 10000 BC

Old tools and new tools

Göbekli Tepe, 10000 BC

CERN, 2000 AD



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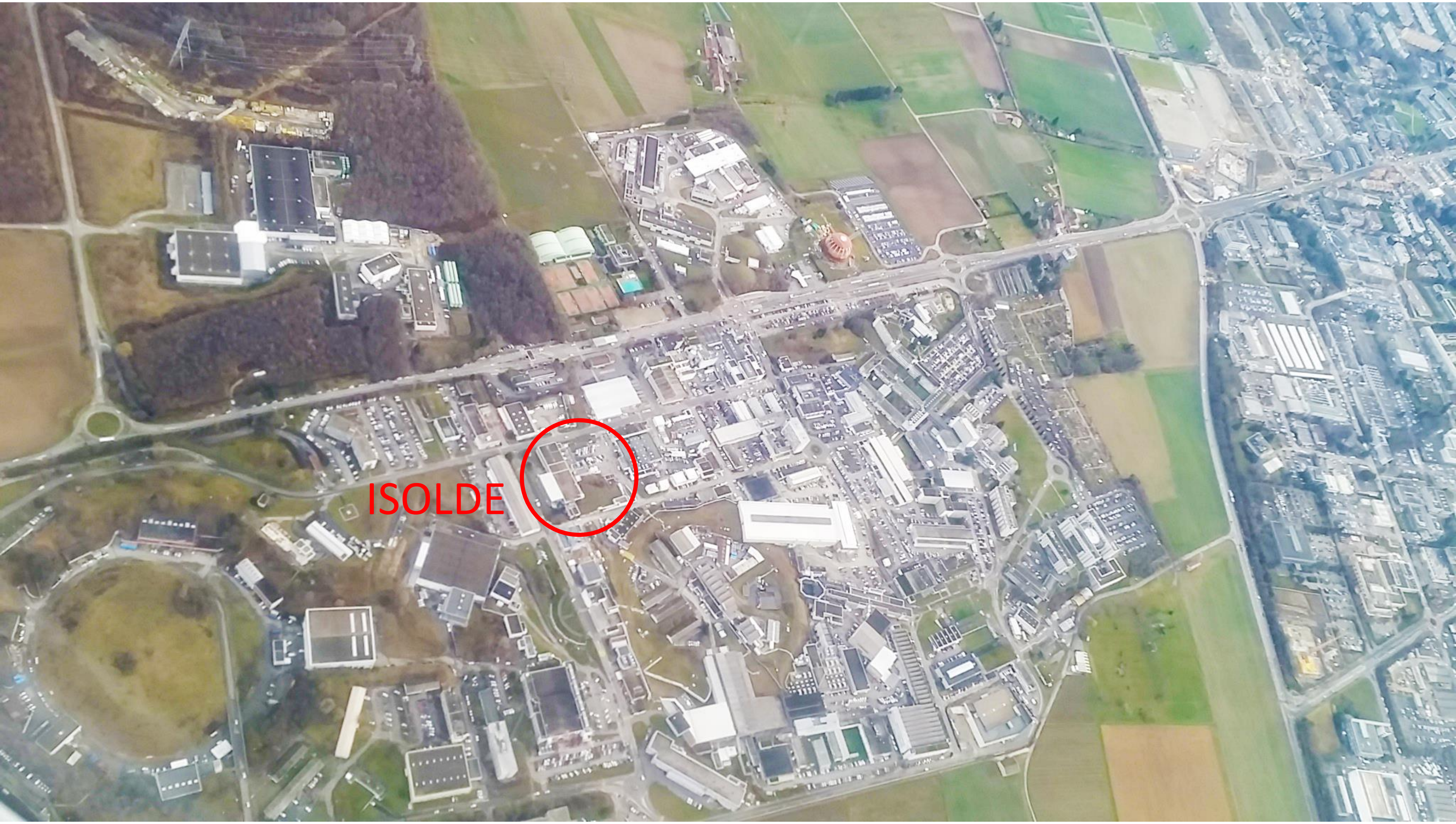

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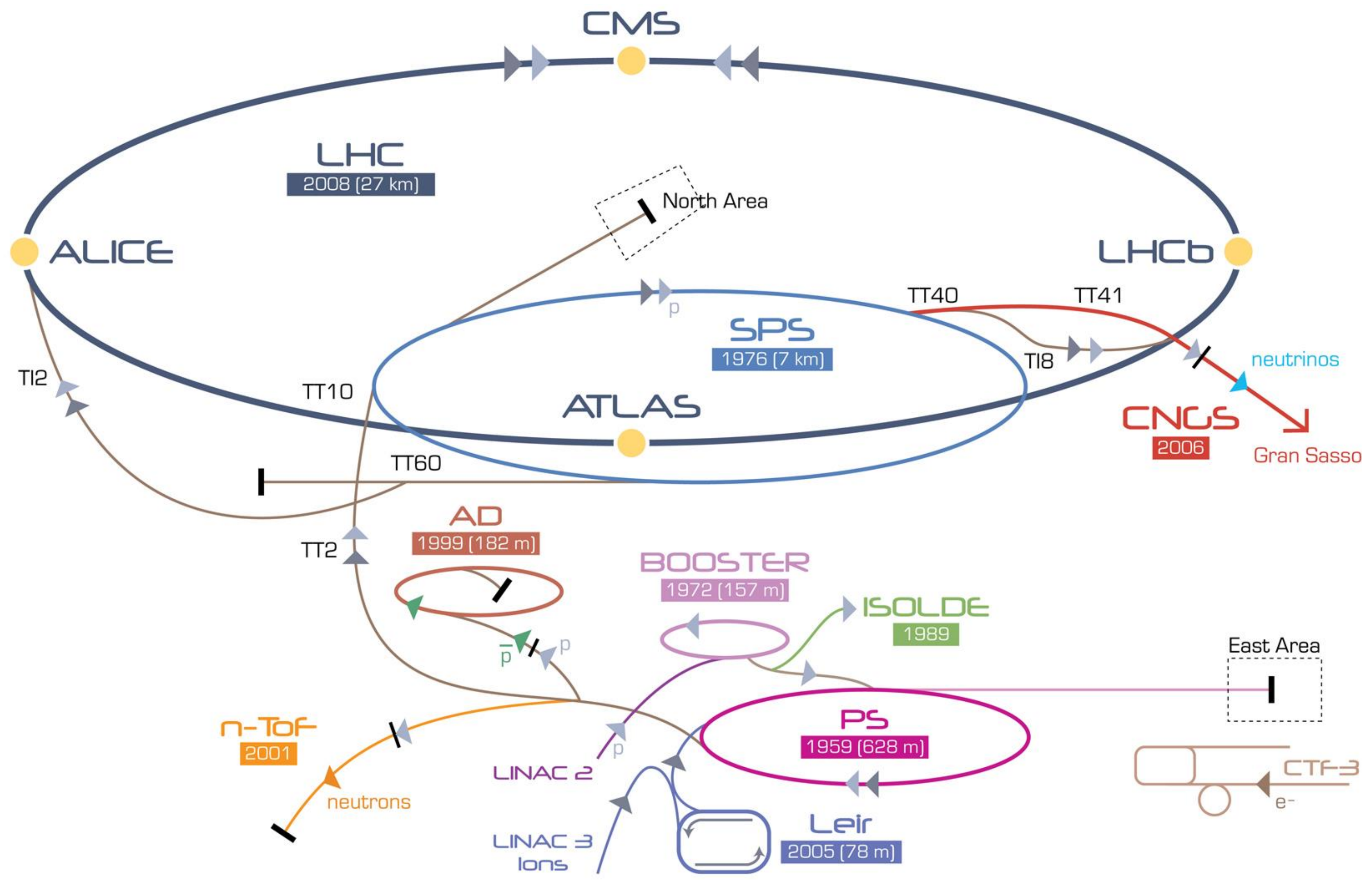

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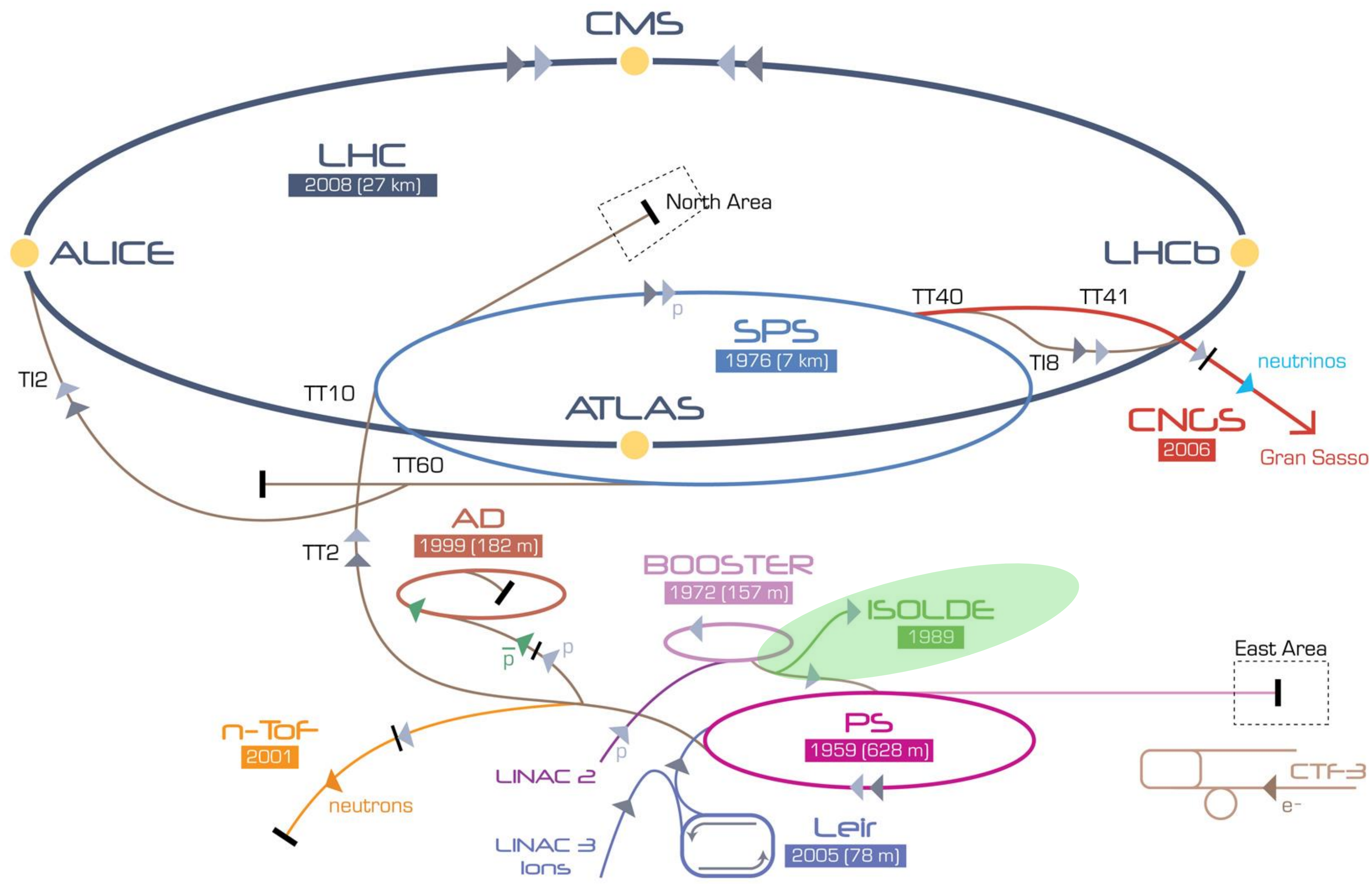

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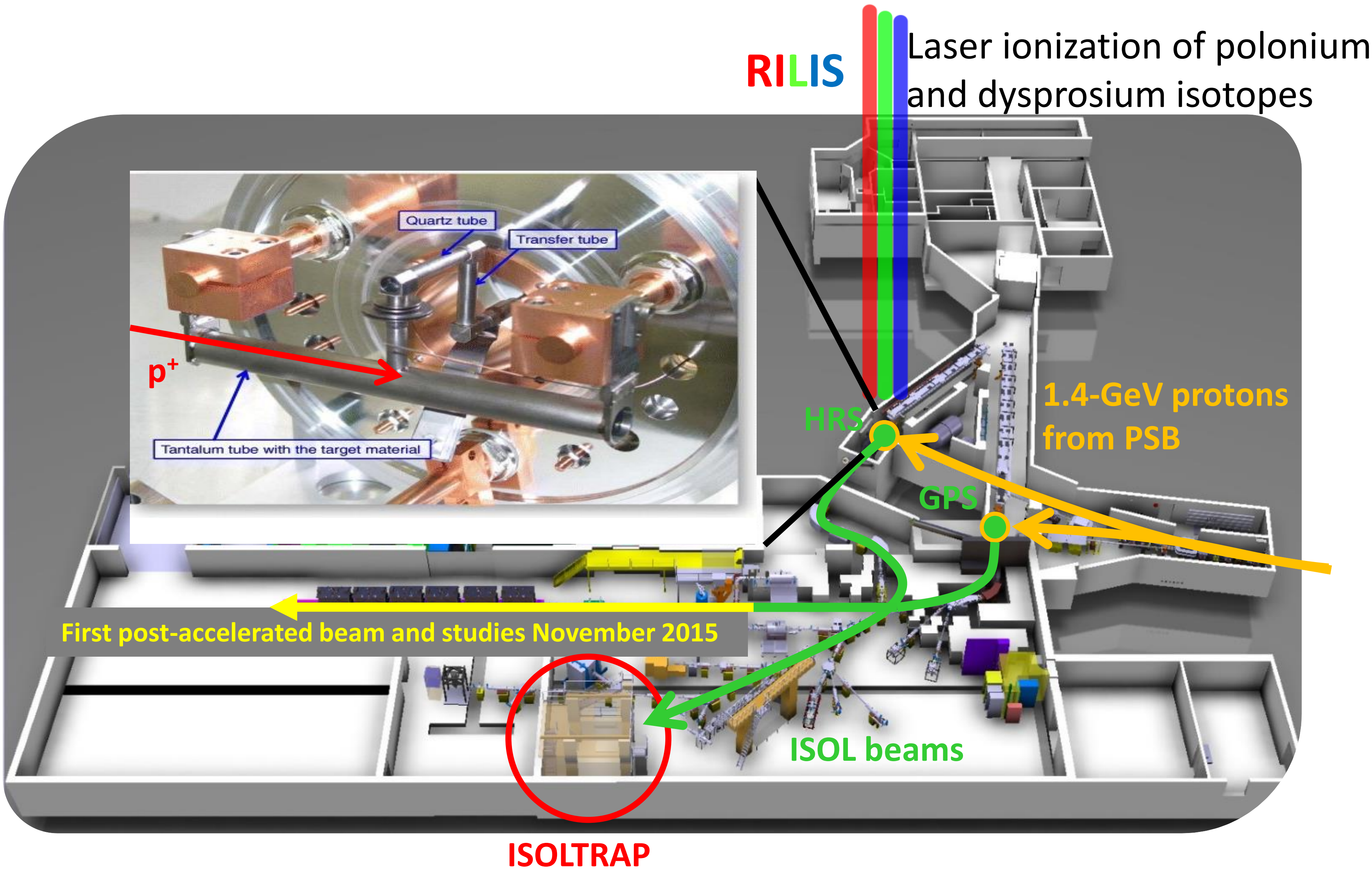
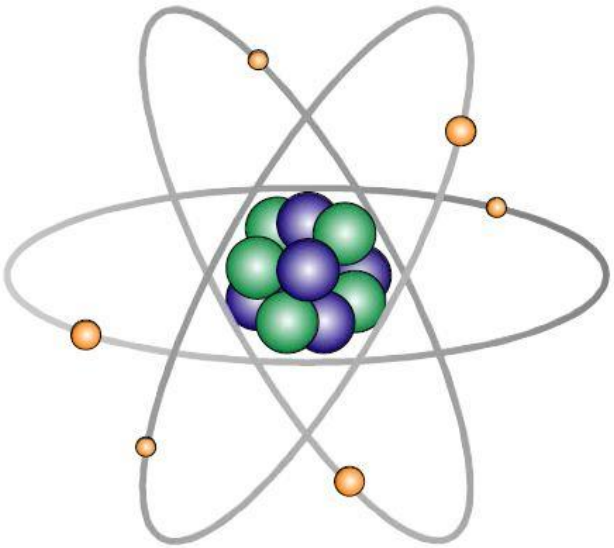
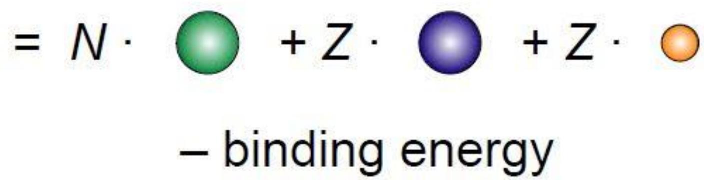


Nuclides

Masses determine the atomic and nuclear binding energies reflecting all forces in the atom/nucleus.





$$M_{\text{Atom}} = N{\bullet}m_{\text{neutron}} + Z{\bullet}m_{\text{proton}} + Z{\bullet}m_{\text{electron}} - (B_{\text{atom}} + B_{\text{nucleus}})/c^2$$

$\delta m/m < 10^{-10}$

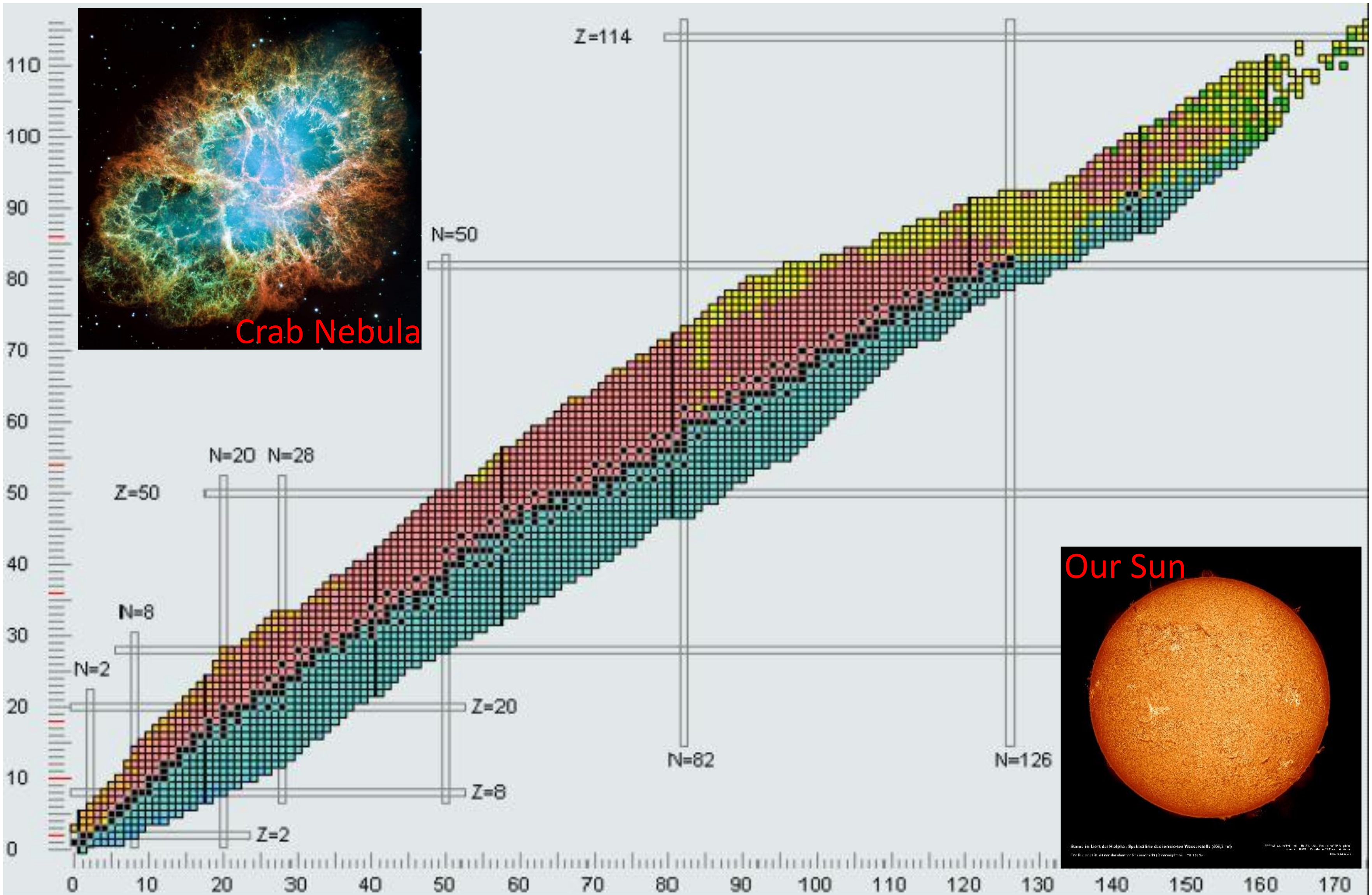
$\delta m/m = 10^{-6} – 10^{-8}$

K.Blaum

Table of Nuclides

Masses help to understand:

- Evolution of Universe
- Shell structure of Nuclides
- Possible Neutrino masses
- CKM matrix element calculation



Nucleonica.net
sdo.gsfc.nasa.gov

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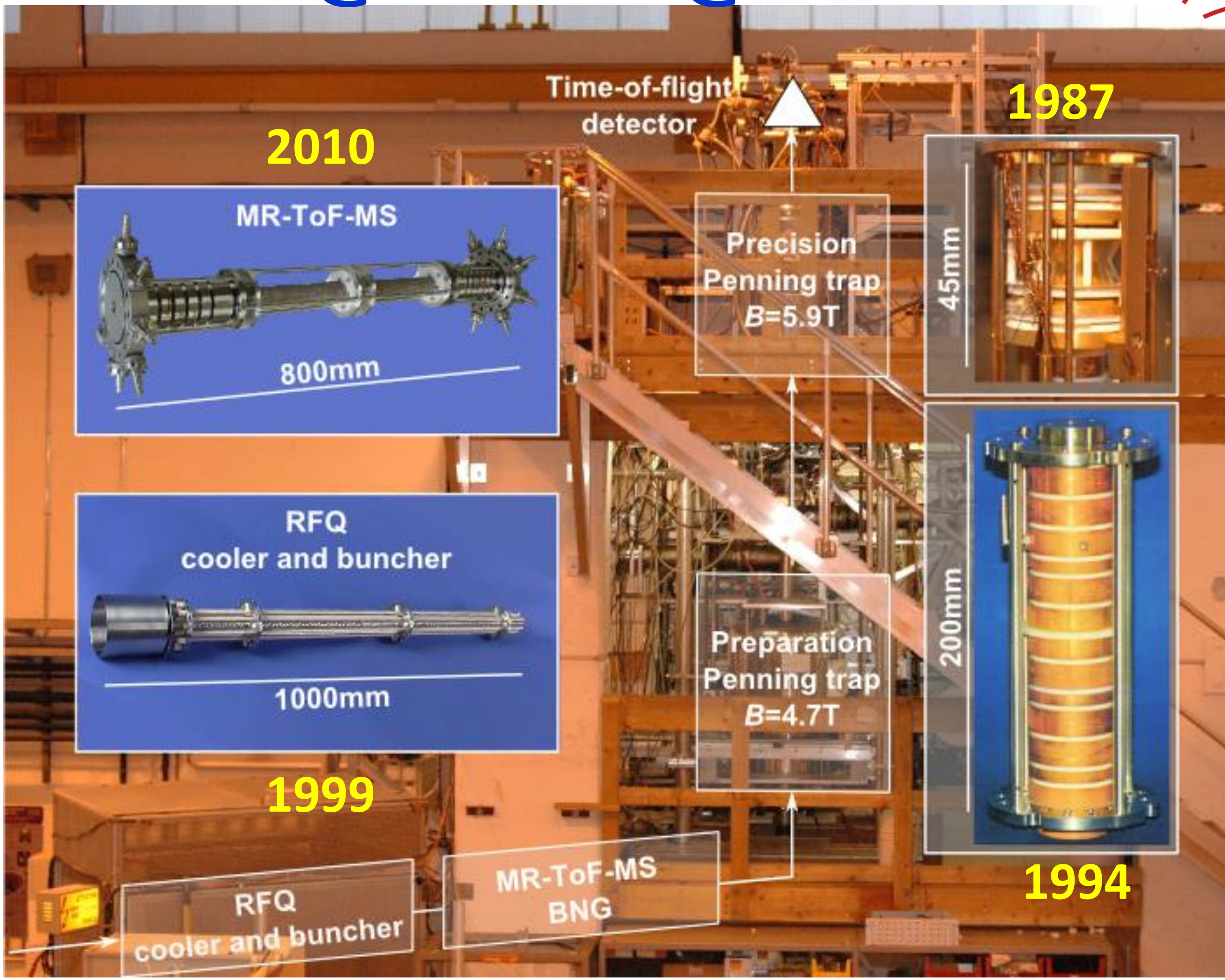
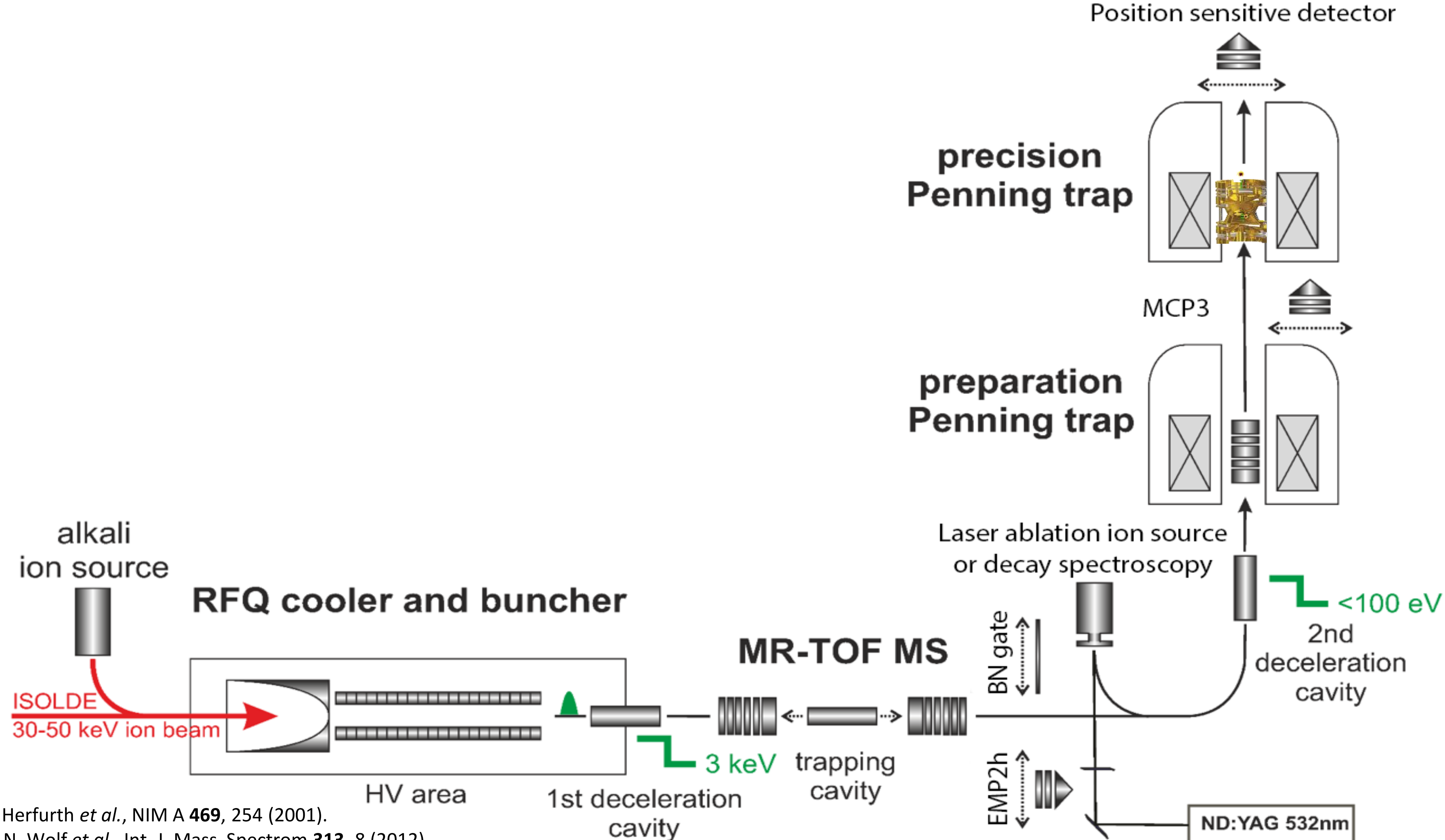


M. Mukherjee *et al.*, Eur. Phys. J. A **35**, 1 (2008). S. Kreim *et al.*, Nucl. Instrum. Methods B **317**, 492 (2013).

Tools of ISOLTRAP



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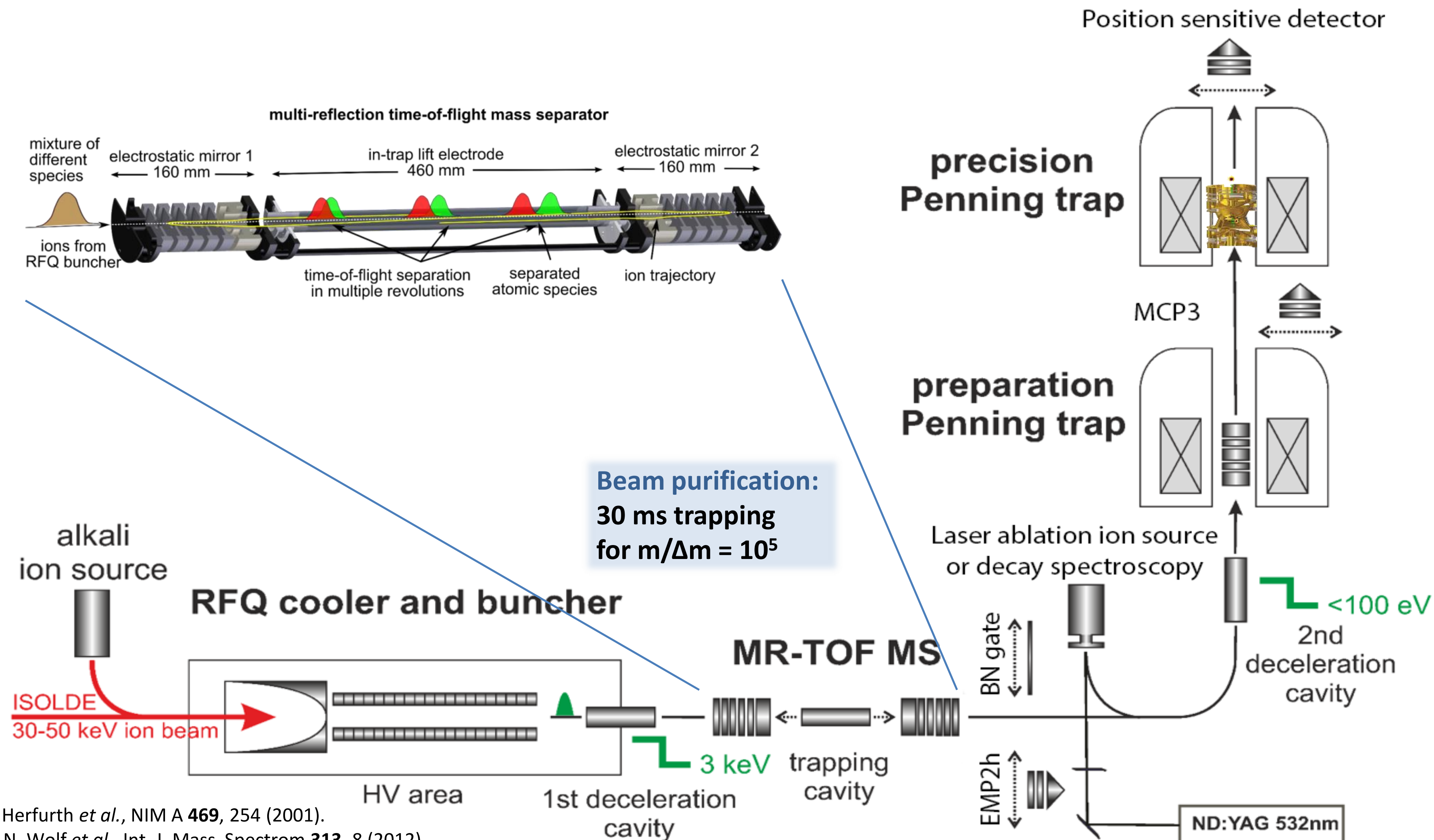
Tools of ISOLTRAP



Beam purification:
30 ms trapping
for m/Δm = 10^5

F. Herfurth *et al.*, NIM A **469**, 254 (2001).
R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).
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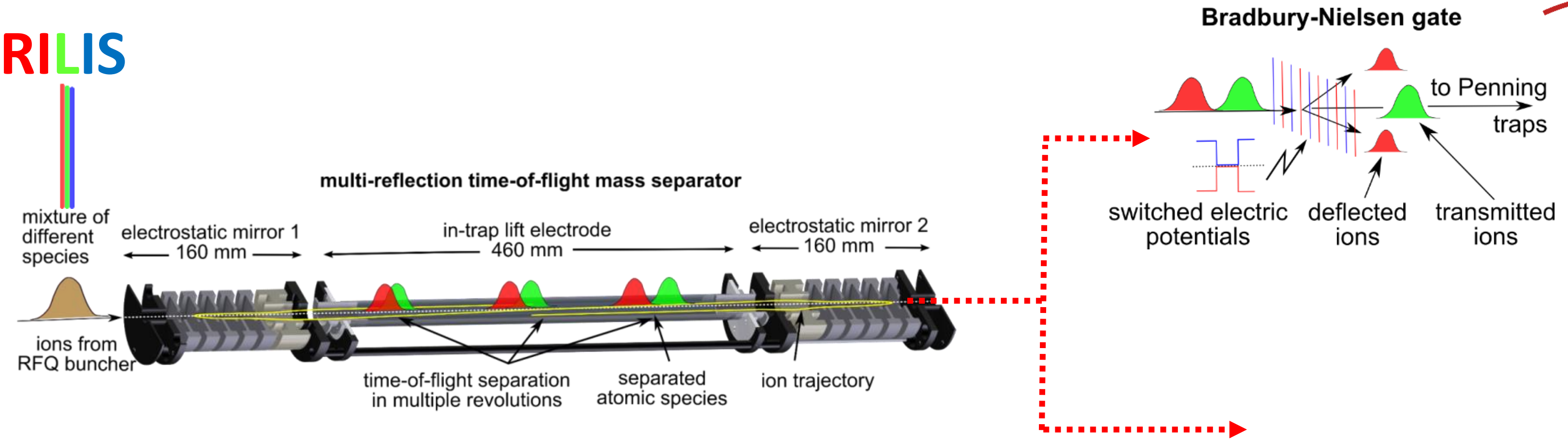

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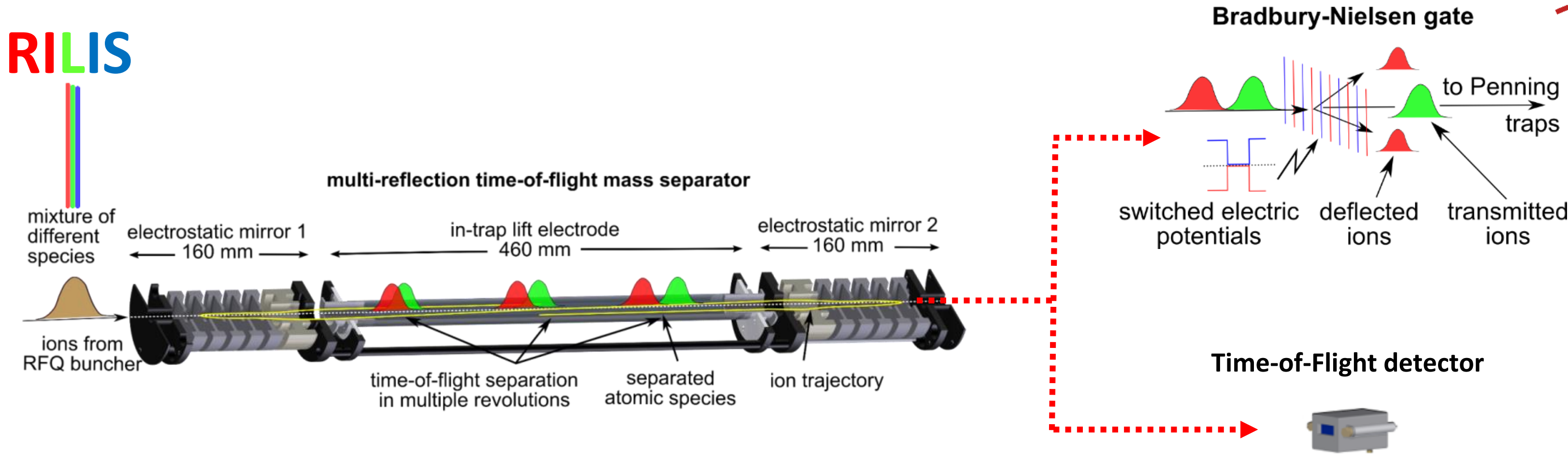
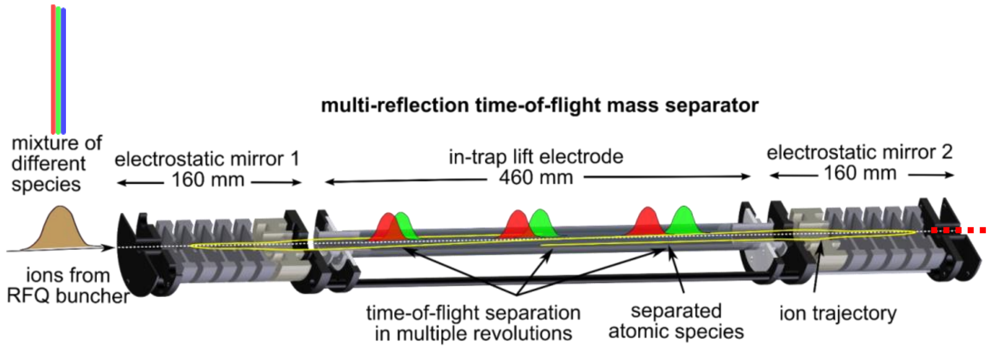
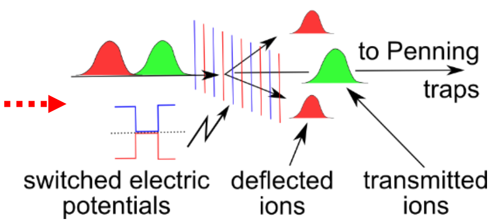


Tools of ISOLTRAP

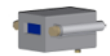
RILIS



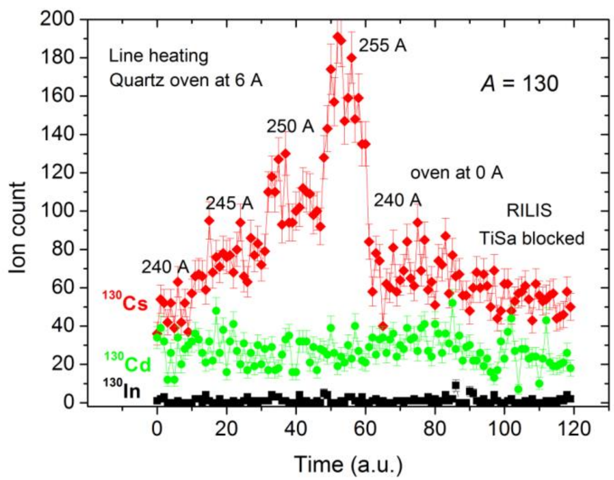
Bradbury-Nielsen gate



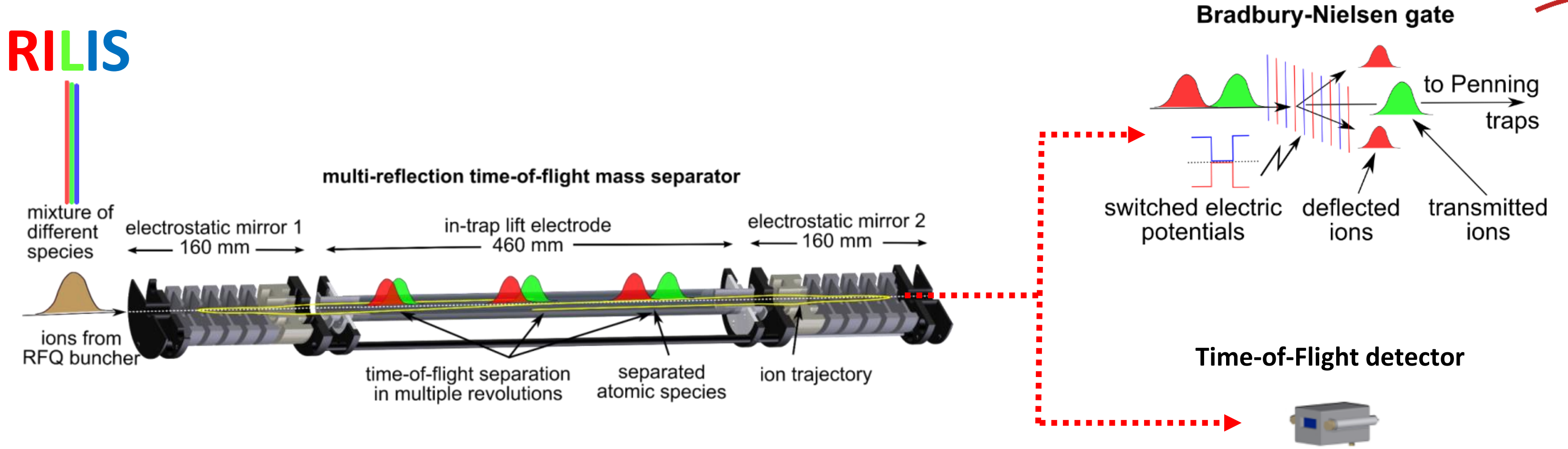
Time-of-Flight detector



Yield studies



Tools of ISOLTRAP



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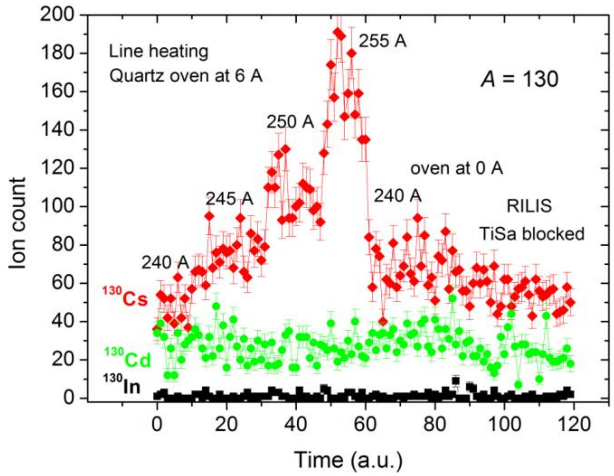
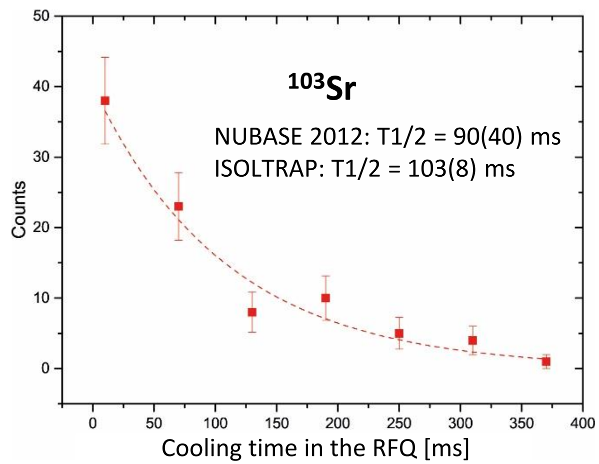
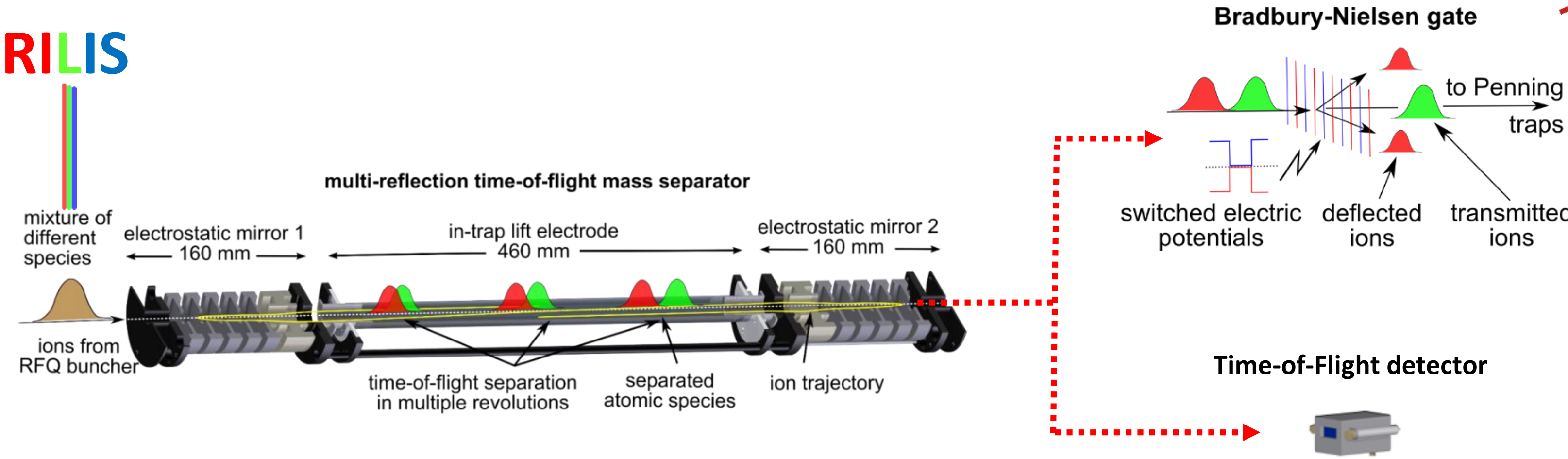


Half-life or release studies

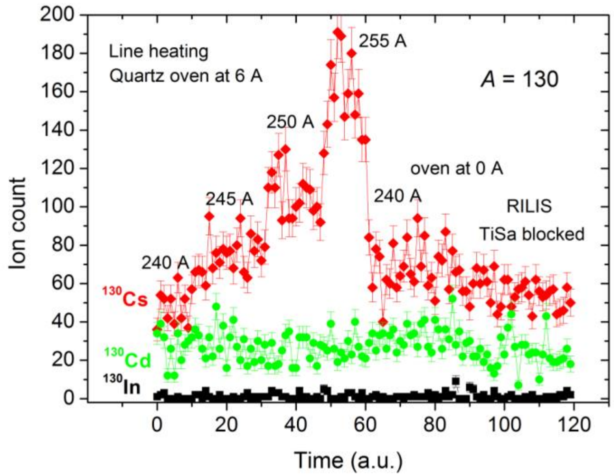


R. Wolf et al., Nucl. Instr. Meth. B, in press (2016)

Tools of ISOLTRAP



Yield studies



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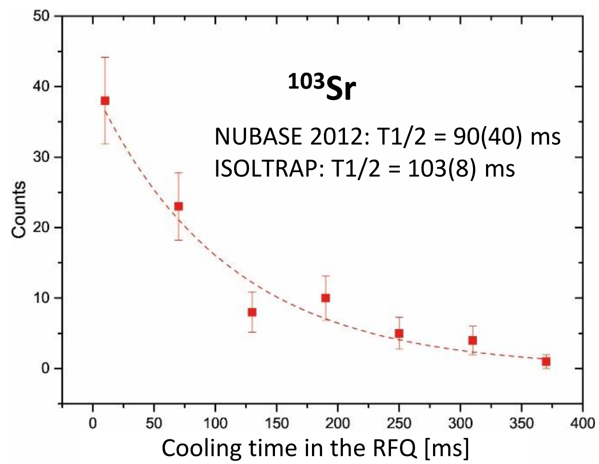

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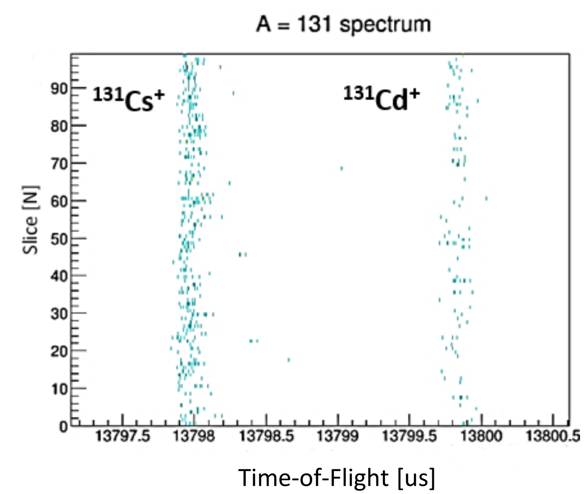
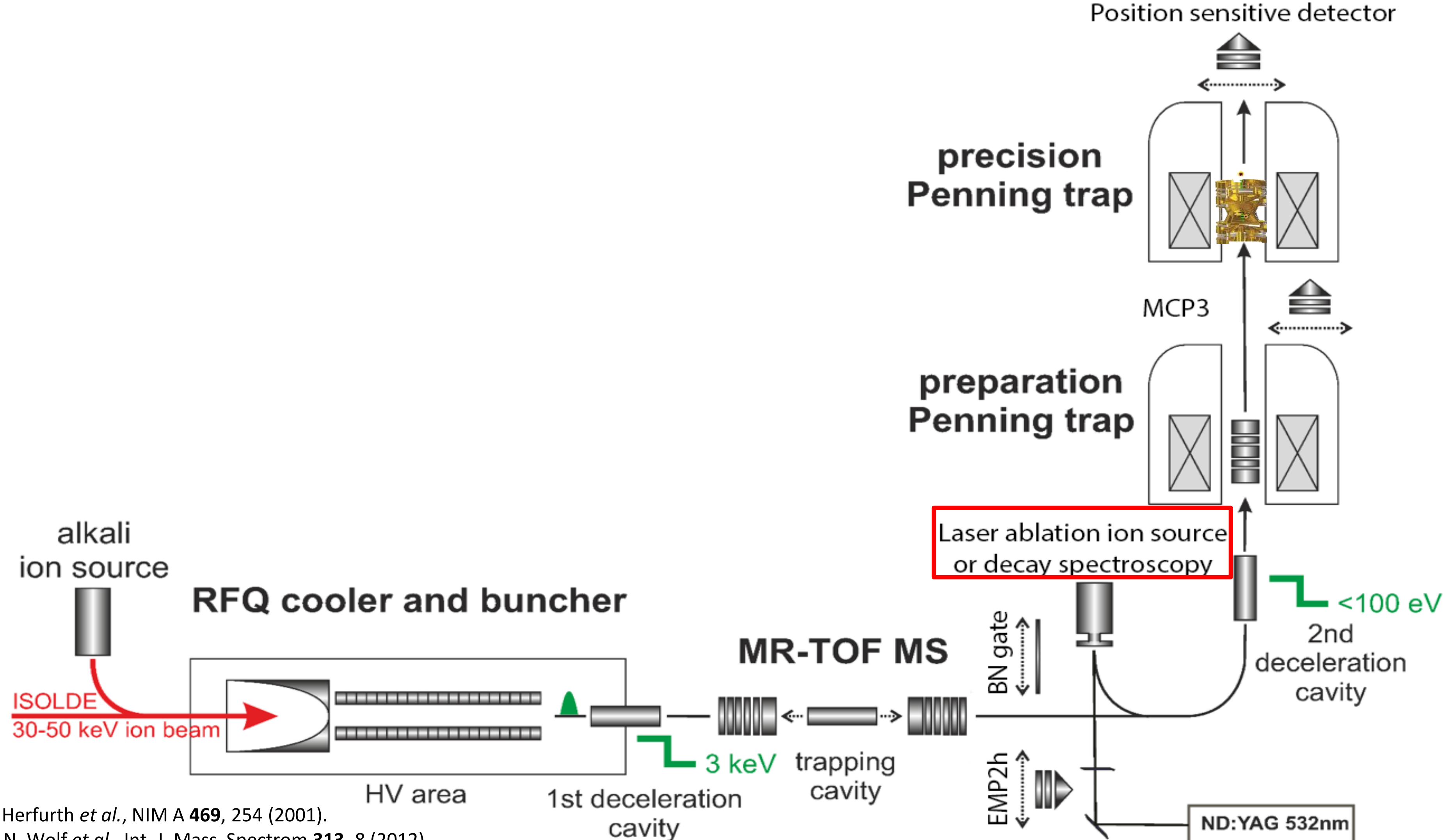
Mass measurements



D. Atanasov et al, Phys. Rev. Lett. 115, 232501 (2015)

Tools of ISOLTRAP



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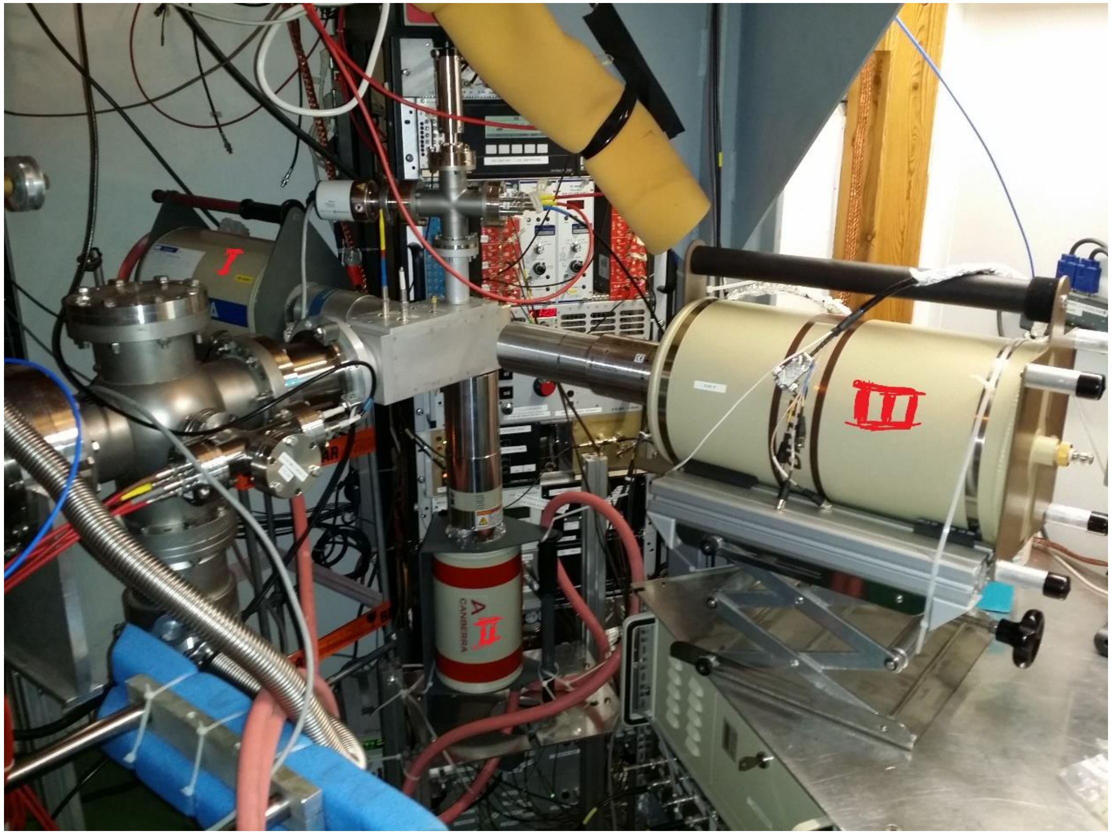
Decay spectroscopy

Mass/spectroscopy:

– Setup with Ge-detectors I-II-III (decay-station):



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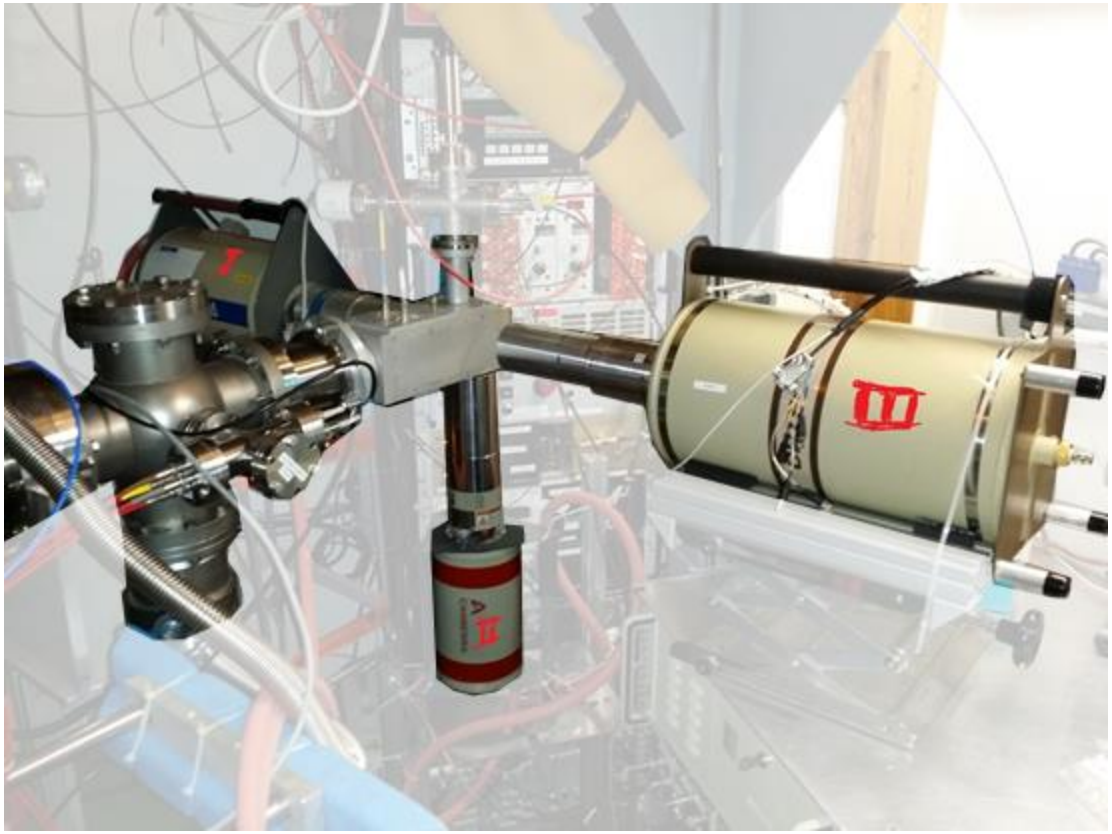
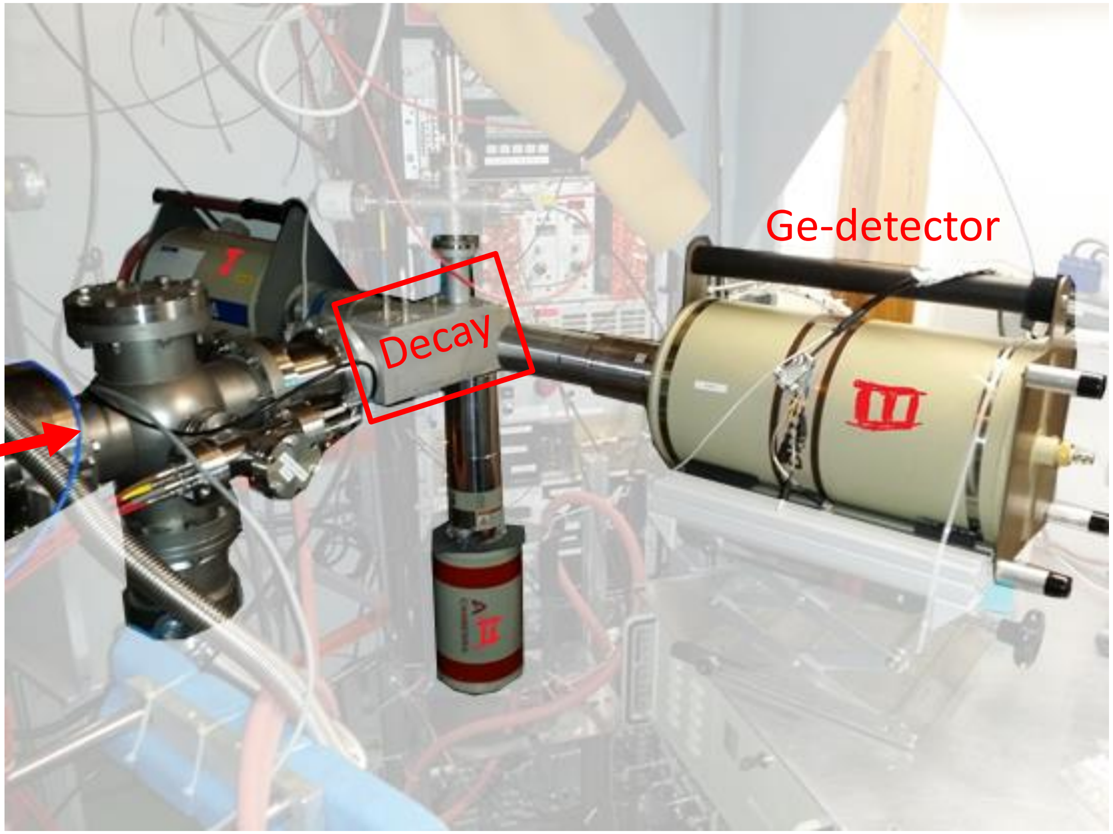


Decay spectroscopy

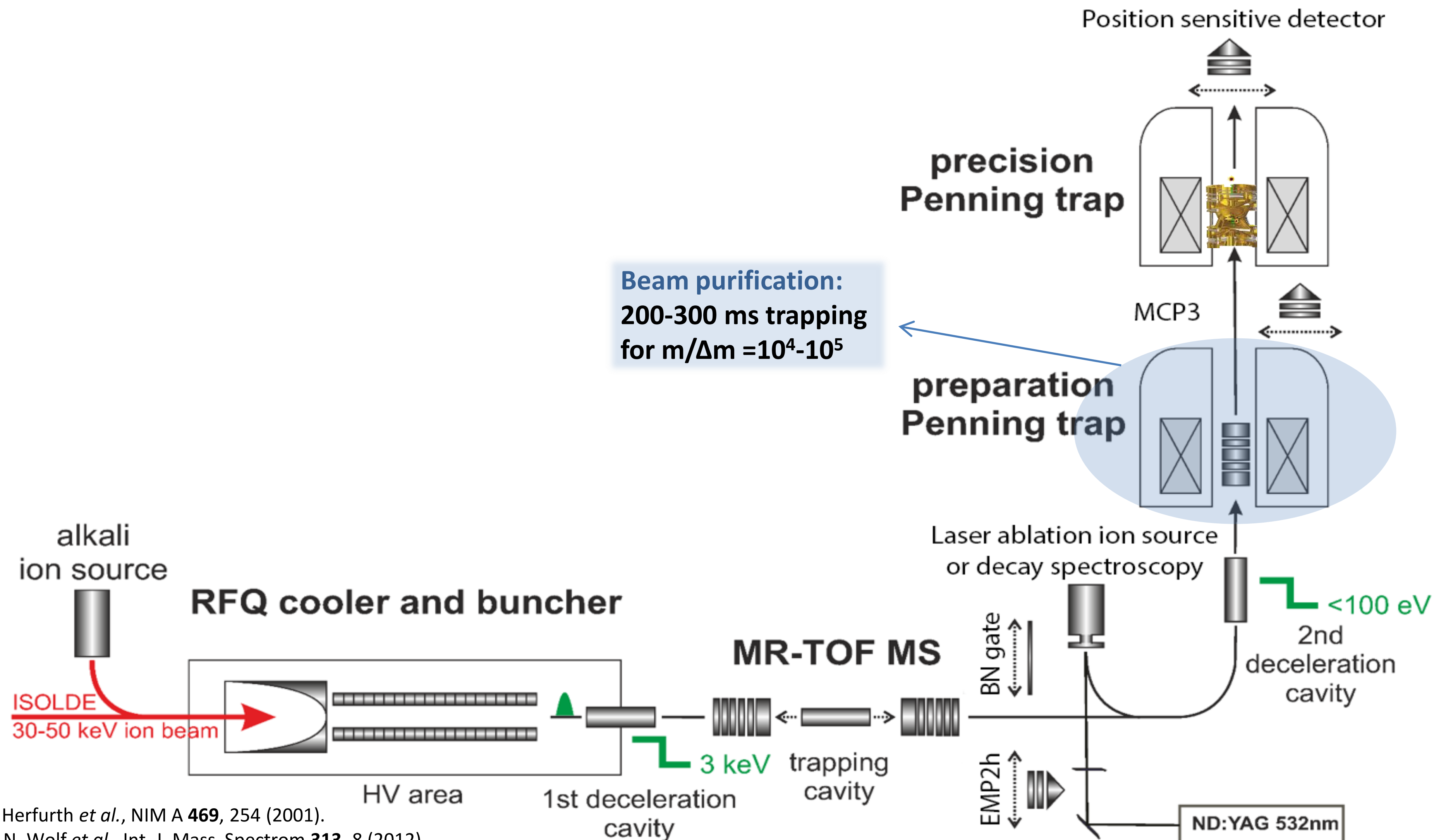
Mass/spectroscopy:

– Setup with Ge-detectors I-II-III (decay-station):

Re-accelaration tube



Tools of ISOLTRAP



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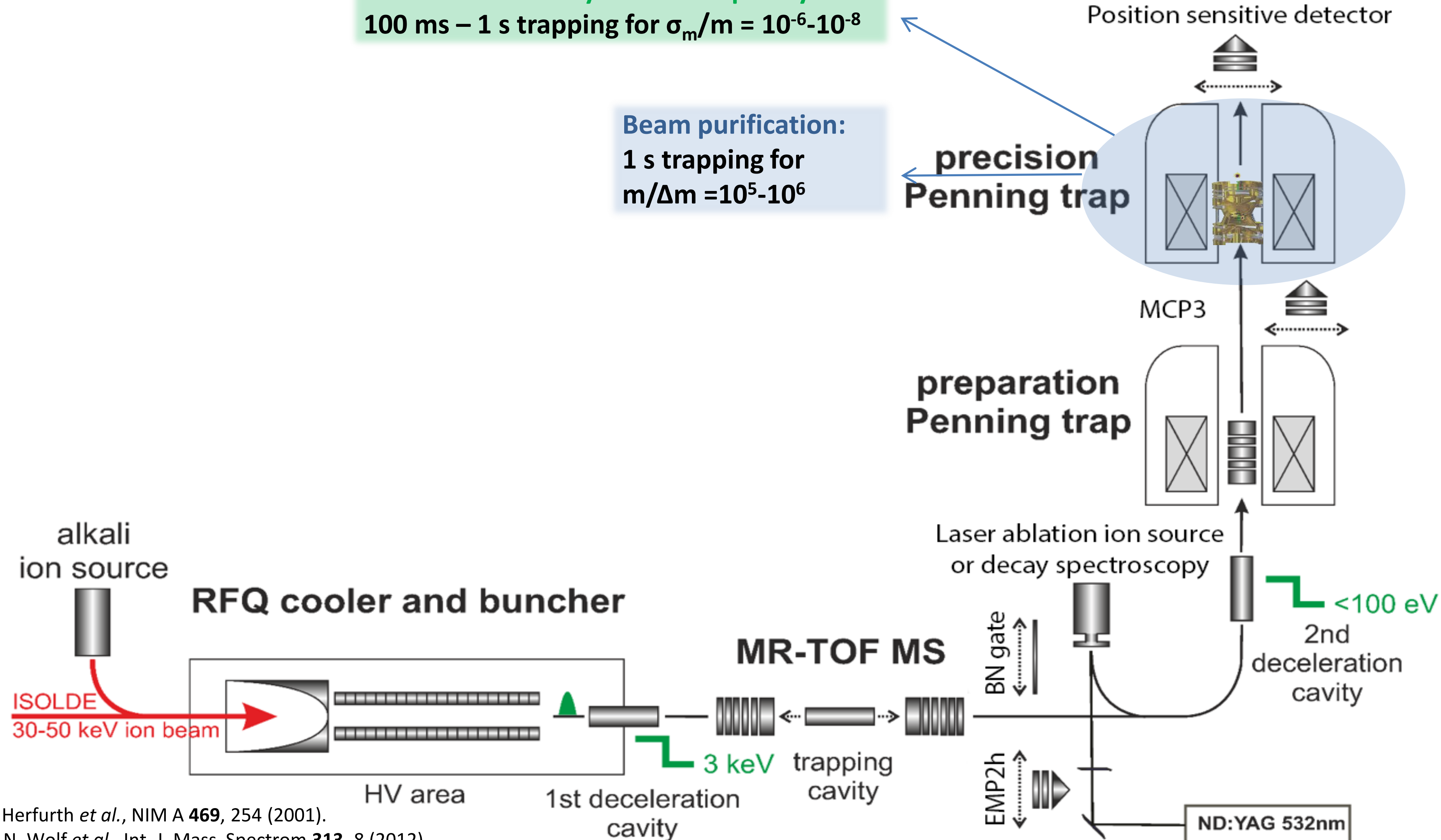
Tools of ISOLTRAP

Measurement of cyclotron frequency:
100 ms – 1 s trapping for $\sigma_m/m = 10^{-6}$-10^{-8}

Beam purification:
1 s trapping for $m/\Delta m = 10^5$-10^6



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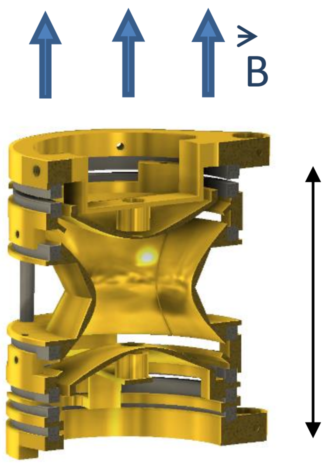
Tools of ISOLTRAP: Penning trap

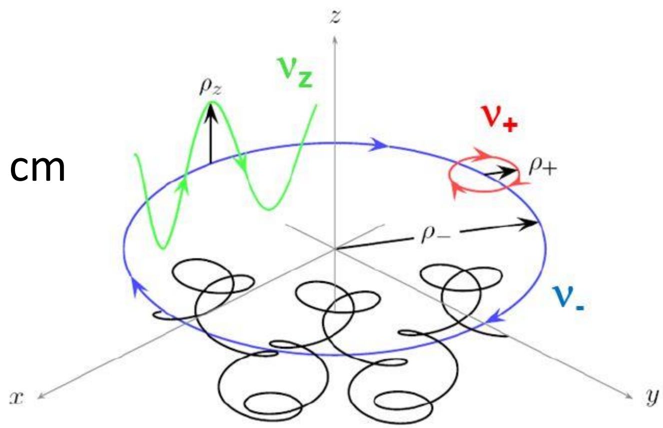
Eigen motions:

Penning trap:
Storage of ions by the superposition of electric and magnetic fields



Hyperbolic Penning trap

Three harmonic oscillators:



$$\omega_c = \sqrt{\omega_+^2 + \omega_-^2 + \omega_z^2} \rightarrow \nu_c = \frac{qB}{2\pi m}$$

Brown & Gabrielse, Rev. Mod. Phys. 58, 233 (1986).
Gräff *et al.*, Z. Physik A - Atoms and Nuclei 297, 35 (1980).
S. George et al., Phys. Rev. Lett. 98, 162501 (2007).

Tools of ISOLTRAP: Penning trap

Eigen motions:

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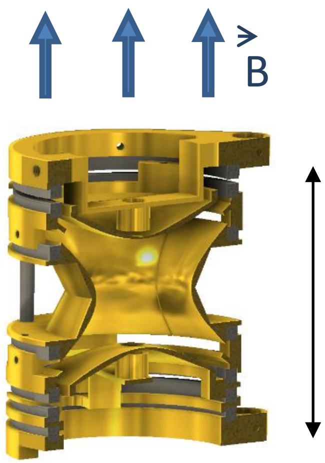
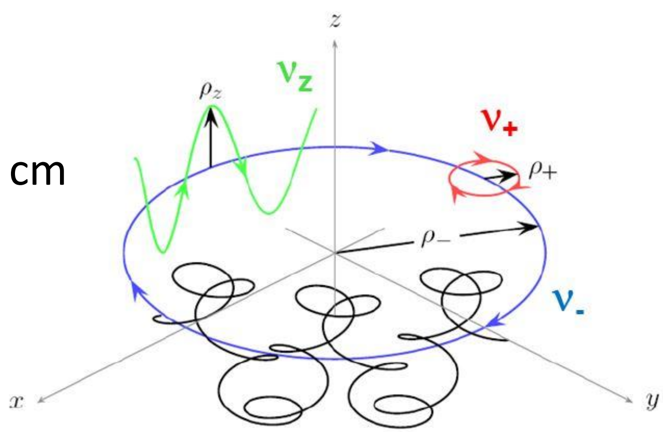
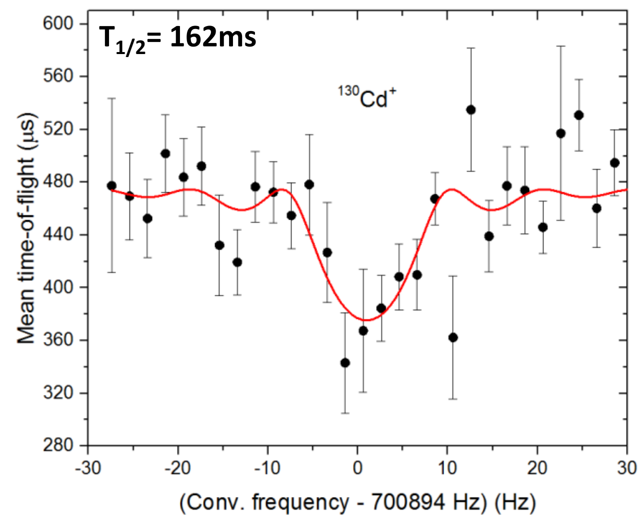


2,5 cm

Hyperbolic Penning trap

<u>Three harmonic oscillators:</u>





$$\omega_c = \sqrt{\omega_+^2 + \omega_-^2 + \omega_z^2} \quad \Rightarrow \quad \nu_c = \frac{qB}{2\pi m}$$

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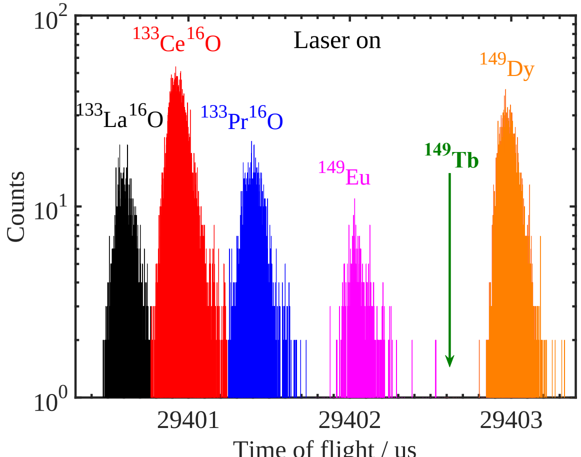
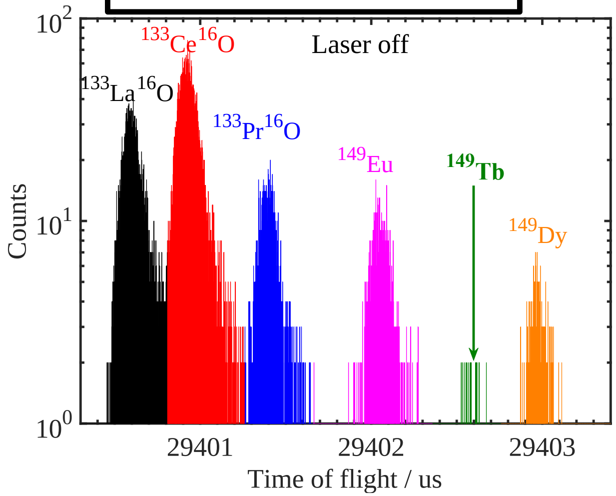
S. George et al., Phys. Rev. Lett. 98, 162501 (2007).

Dy-beam time

Collection example for A=149:

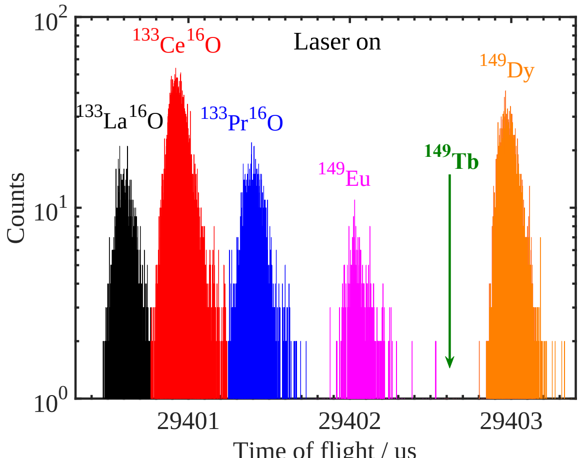


Laser on/off ratio = 10/1



Dy-beam time

Collection example for A=149:



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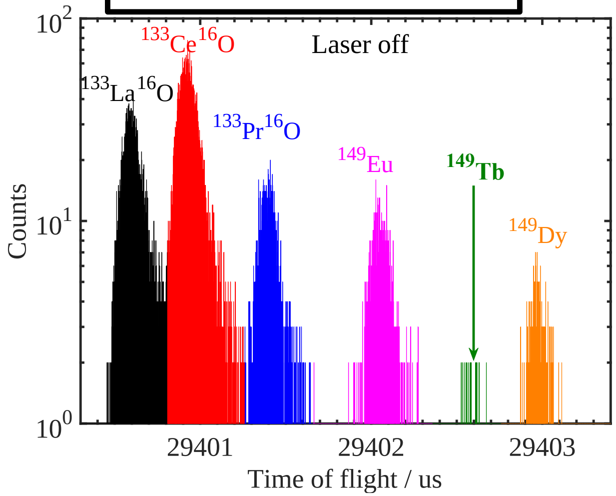
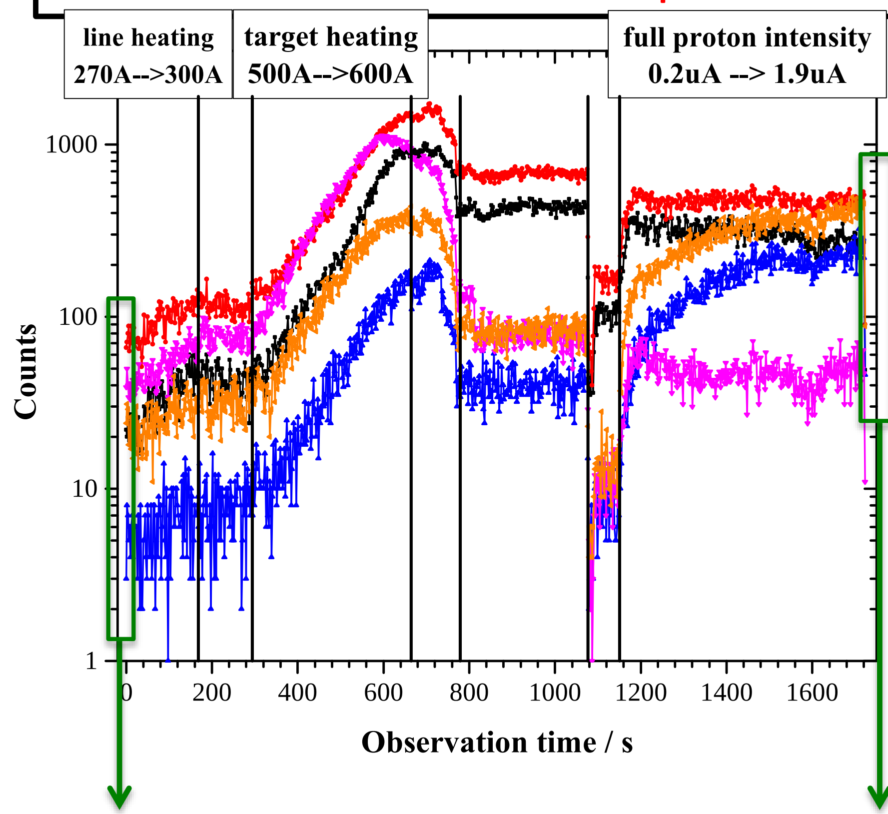


Distinct observation of all involved species at the same time



Isotope	Half life
^{133}La	3.912h
^{133}Ce	97m
^{133}Pr	6.5m
^{149}Eu	93.1d
^{149}Dy	4.2m
^{149}Tb	4.118h

Before optimization: 6.3/1 After optimization: 2.3/1

contaminants / ^{149}Dy → almost factor 3 improvement!

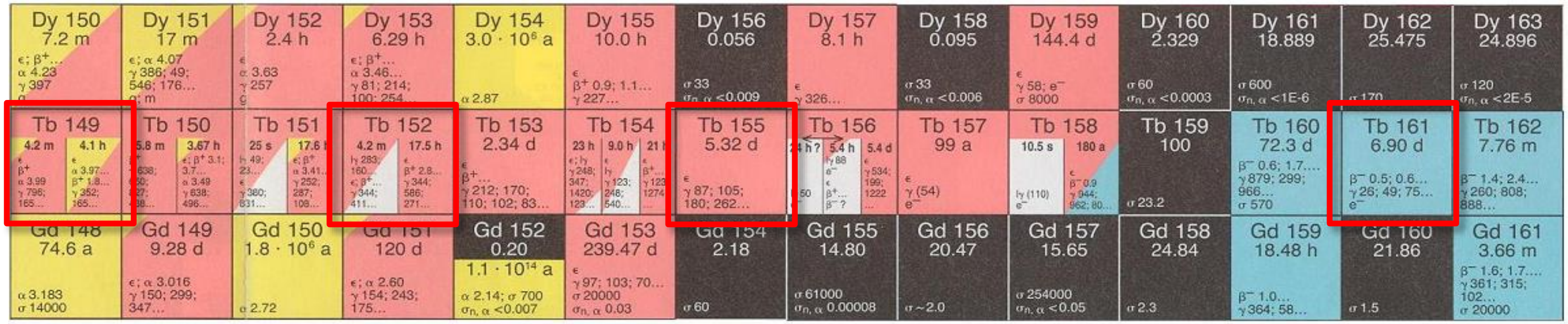
Dy-beam time

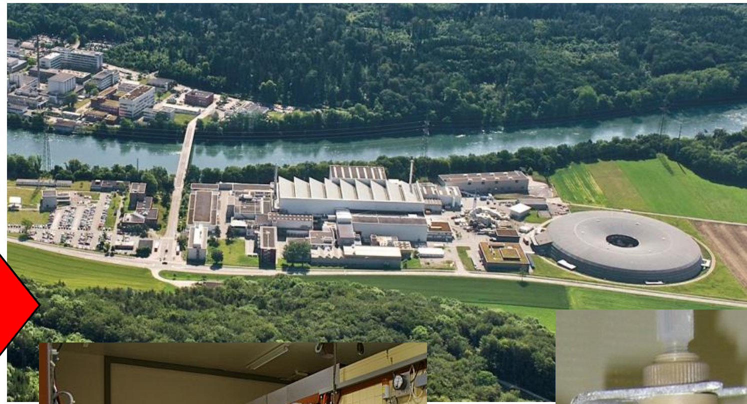
Collection example for A=149:

Foil holder for deposition of ion beam

Foils are gold plated with zinc.

Dy-beam time

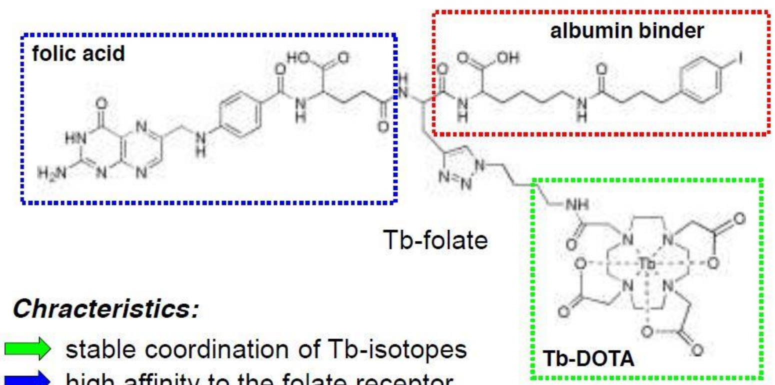




Müller *et al.*, J. Nucl. Med. 54: 124 (2013).

Dy-beam time

Tumor Tageting Agent for Tb-Coordination
Chemical Structure with 3 Functionalities

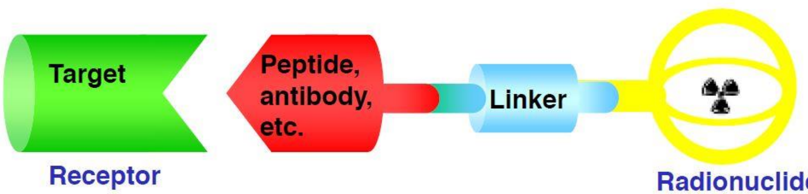


Chracteristics:

- stable coordination of Tb-isotopes
- high affinity to the folate receptor
- prolonged blood circulation time

C. Müller et al., J Nucl Med 2012;53:1951.

Multidisciplinary collaboration
to fight cancer



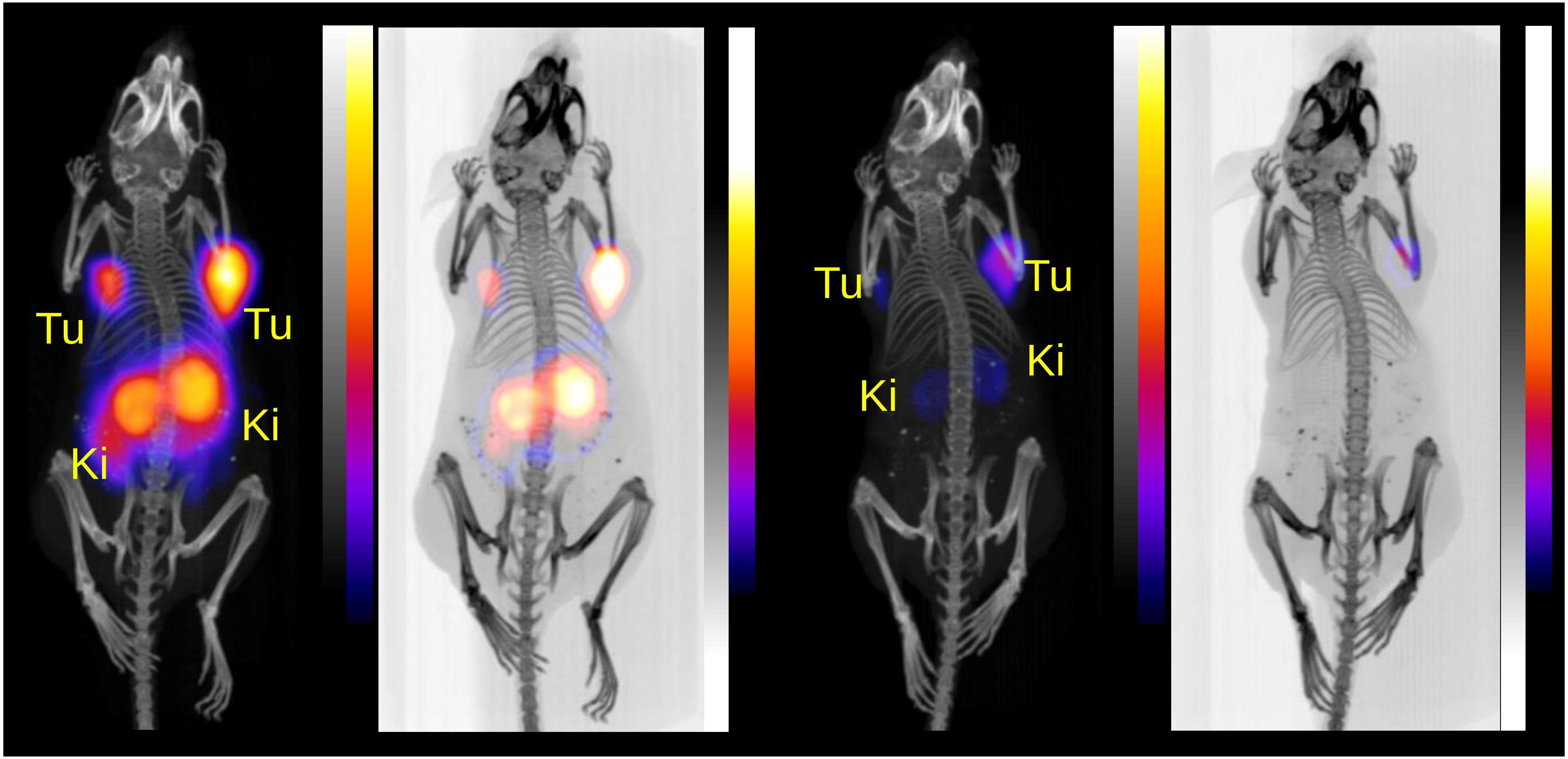
Immunology
Structural biology

Coordination
chemistry

Nuclear physics
and
radiochemistry

Dy-beam time

Müller et al., submitted to Eur J Nucl Med Mol Imaging Research, Nov 2015



PET/CT 5 h after Injection of ^{152}Tb-DOTANOC

PET/CT 22 h after Injection of ^{152}Tb-DOTANOC

Acknowledgments

N. Althubiti, P. Ascher, **D. Atanasov**, D. Beck, K. Blaum, T. Cocolios, S. Eliseev, S. George, F. Herfurth, A. Herlert, D. Kisler, M. Kowalska, Yu. A. Litvinov, D. Lunney, **V. Manea**, E. Minaya-Ramirez, **M. Mougeot**, D. Neidherr, M. Rosenbusch, H. Schmidt-Böcking, L. Schweikhard, **F. Wienholtz**, M. Wang, **A. Welker**, R. Wolf, K. Zuber

Thank you very much for your attention!

ISOLDE Target and Technical Group

Federal Ministry of Education and Research

Grants No.:
05P12HGCI1
05P12HGFNE
05P15ODCIA

http://isoltrap.web.cern.ch