

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



TECHNISCHE
UNIVERSITÄT
DRESDEN



Federal Ministry
of Education
and Research

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



QUANTUM PHYSICS
WAVEFUNCTION REALITY CHECK
Mathematical tools – or are they for real?
PAGE 278

BIOTECHNOLOGY
TROUBLE BREWING
Regulation needed to contain opiate-producing yeasts
PAGES 267 & 281

CRYSTALLOGRAPHY
MAPPING OUT DISORDER
The next challenge for structure determination
PAGE 303

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Old tools and new tools



Göbekli Tepe, 10000 BC



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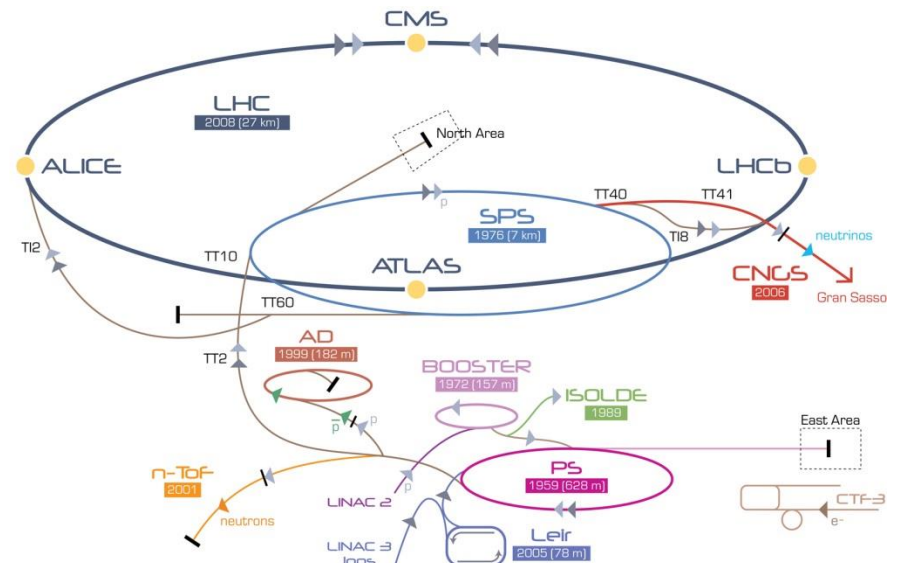
Old tools and new tools



Göbekli Tepe, 10000 BC



CERN, 2000 AD



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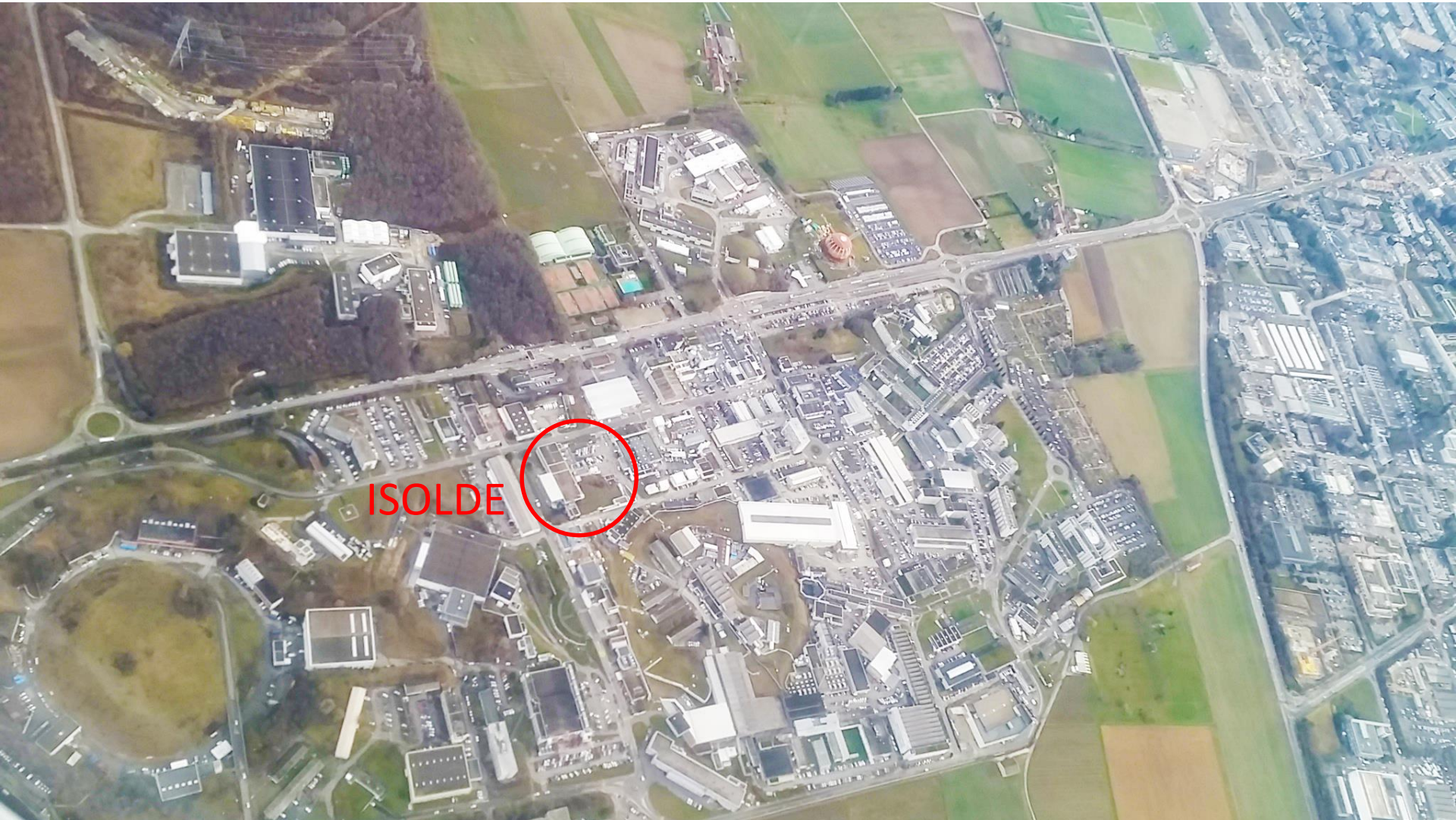
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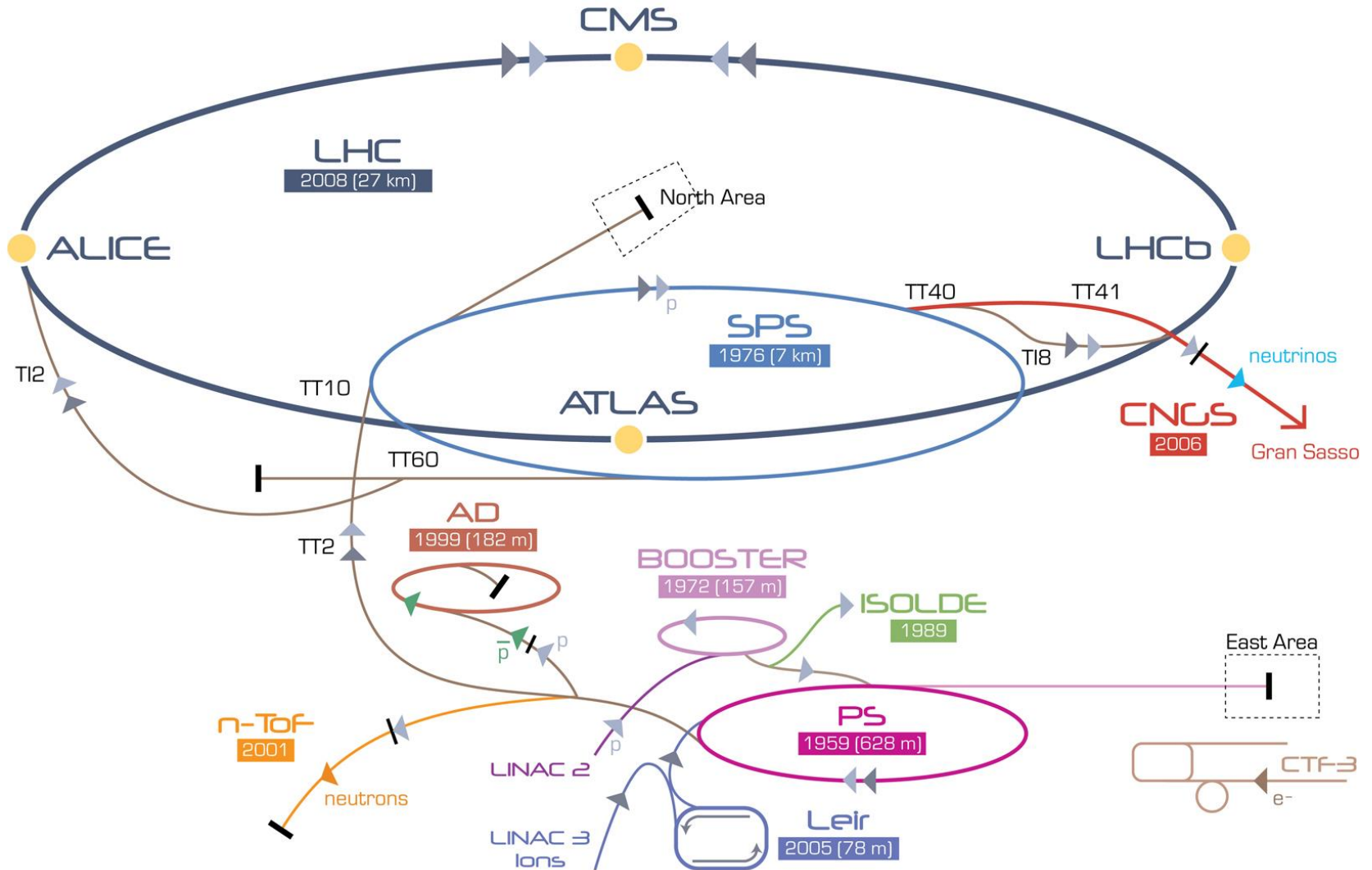
ISOLTRAP@ISOLDE@CERN



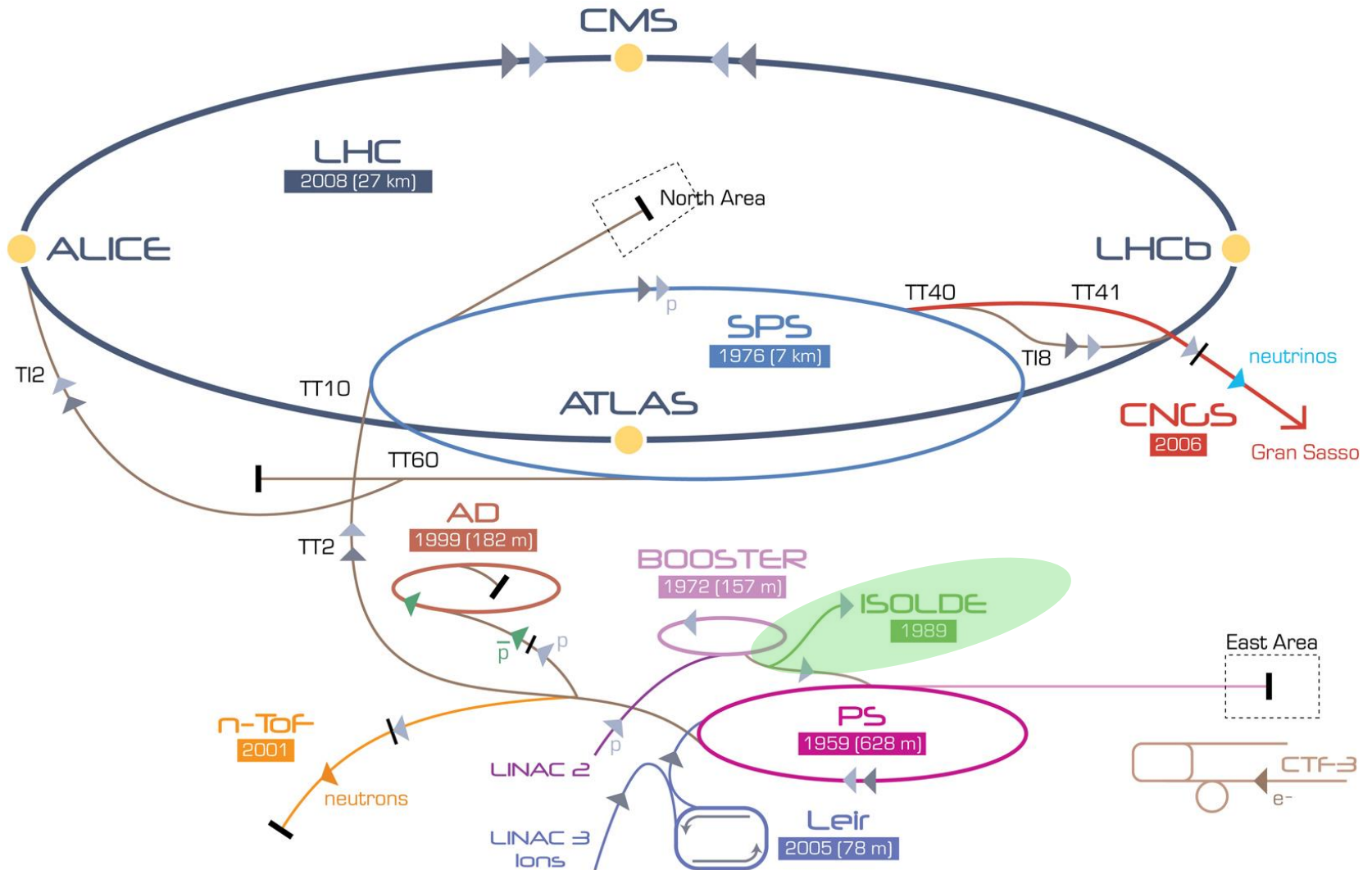
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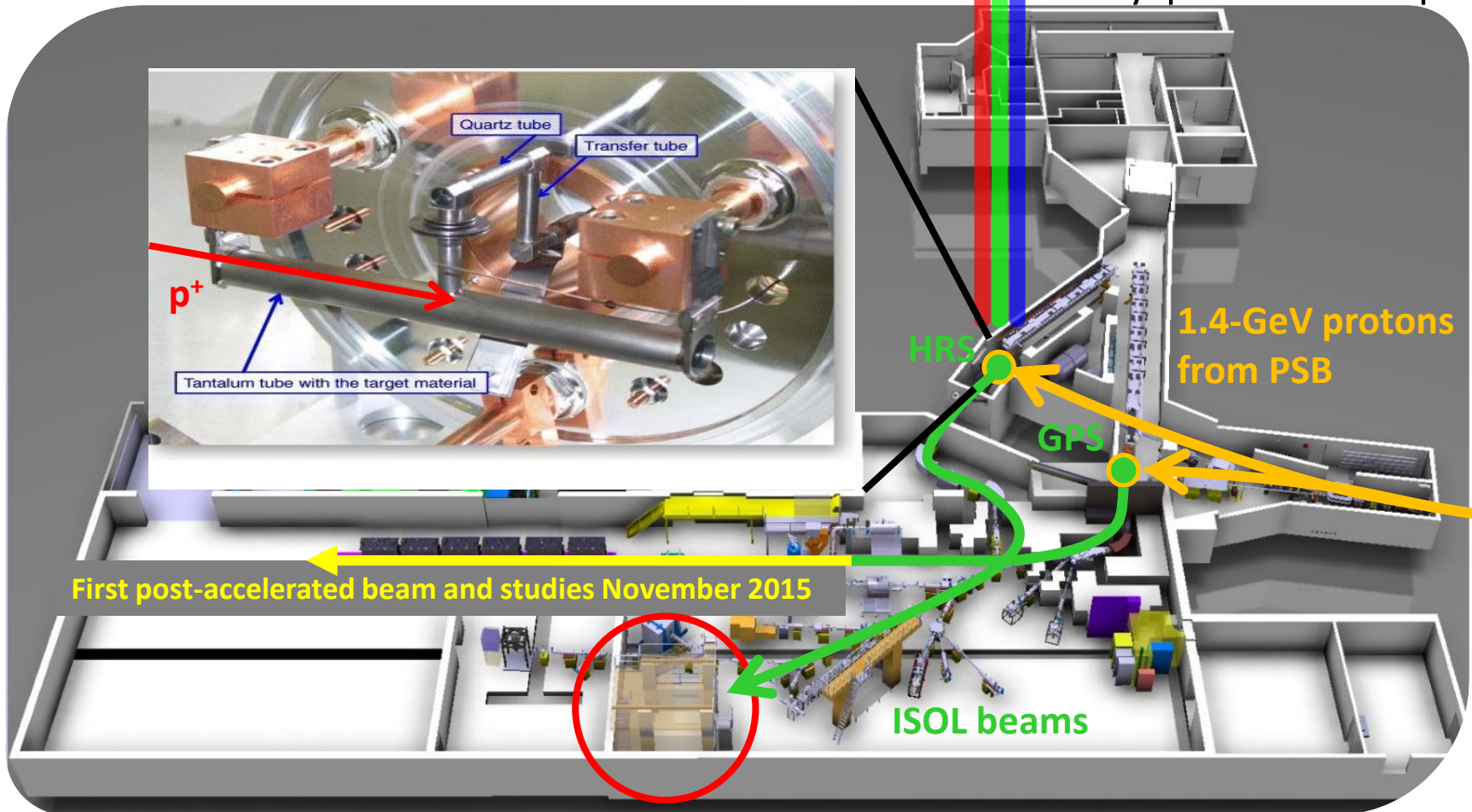
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RILIS Laser ionization of polonium and dysprosium isotopes

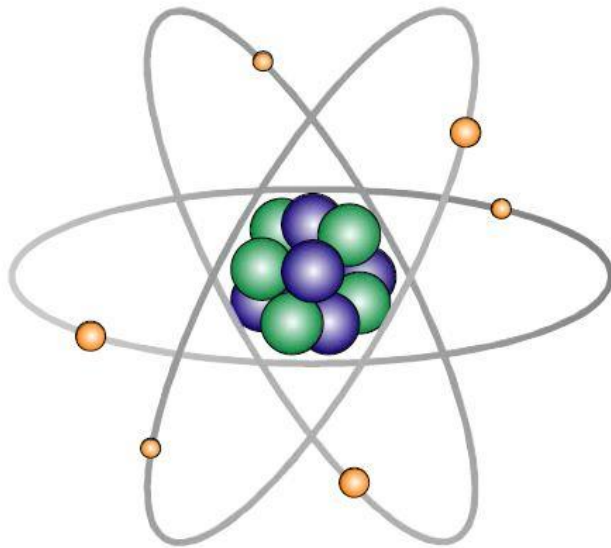


First post-accelerated beam and studies November 2015

ISOLTRAP

Nuclides

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



$$= N \cdot \text{green sphere} + Z \cdot \text{purple sphere} + Z \cdot \text{orange sphere} - \text{binding energy}$$

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

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

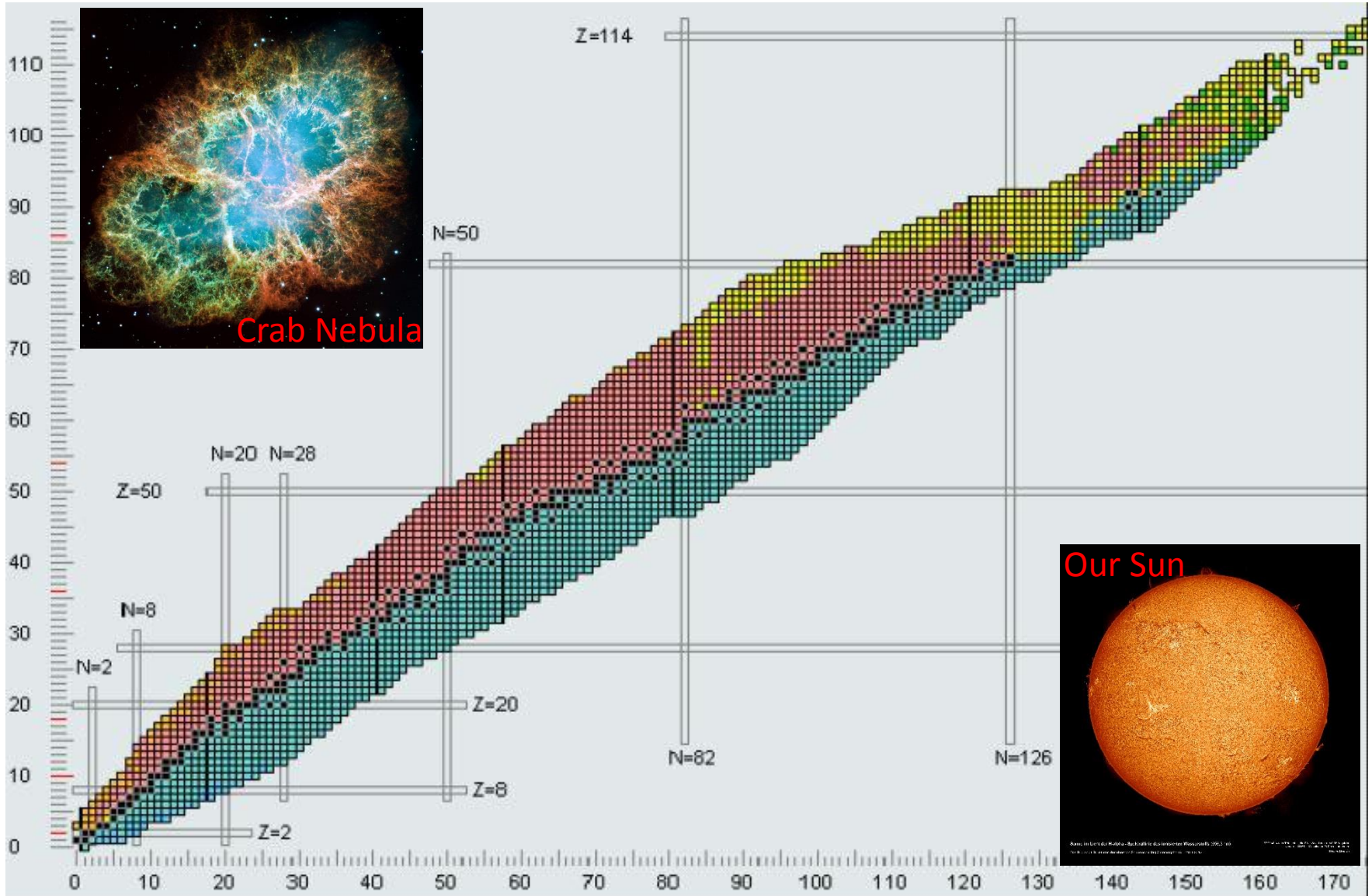
$$\delta m/m = 10^{-6} - 10^{-8}$$

K.Blaum

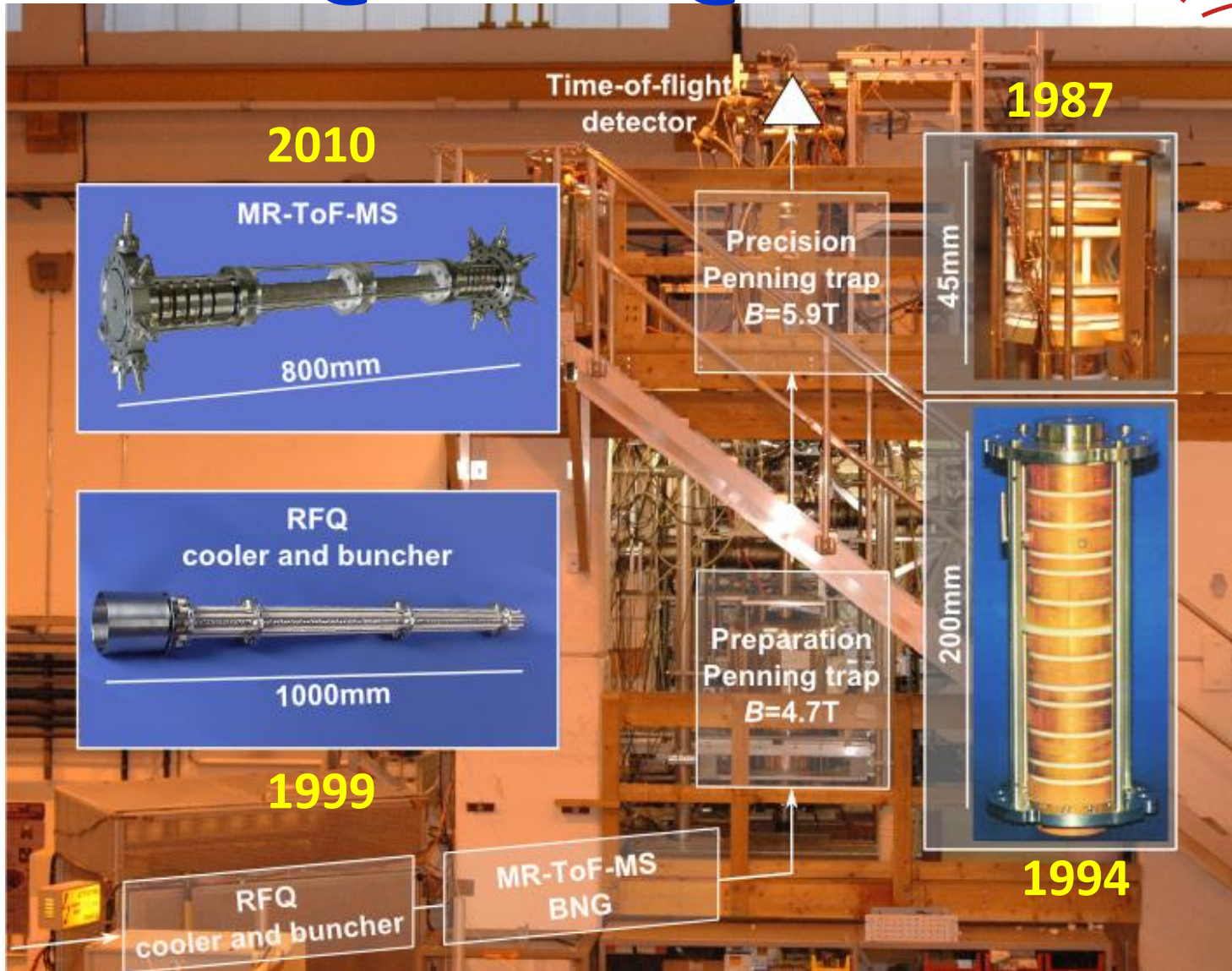
Table of Nuclides

Masses help to understand:

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

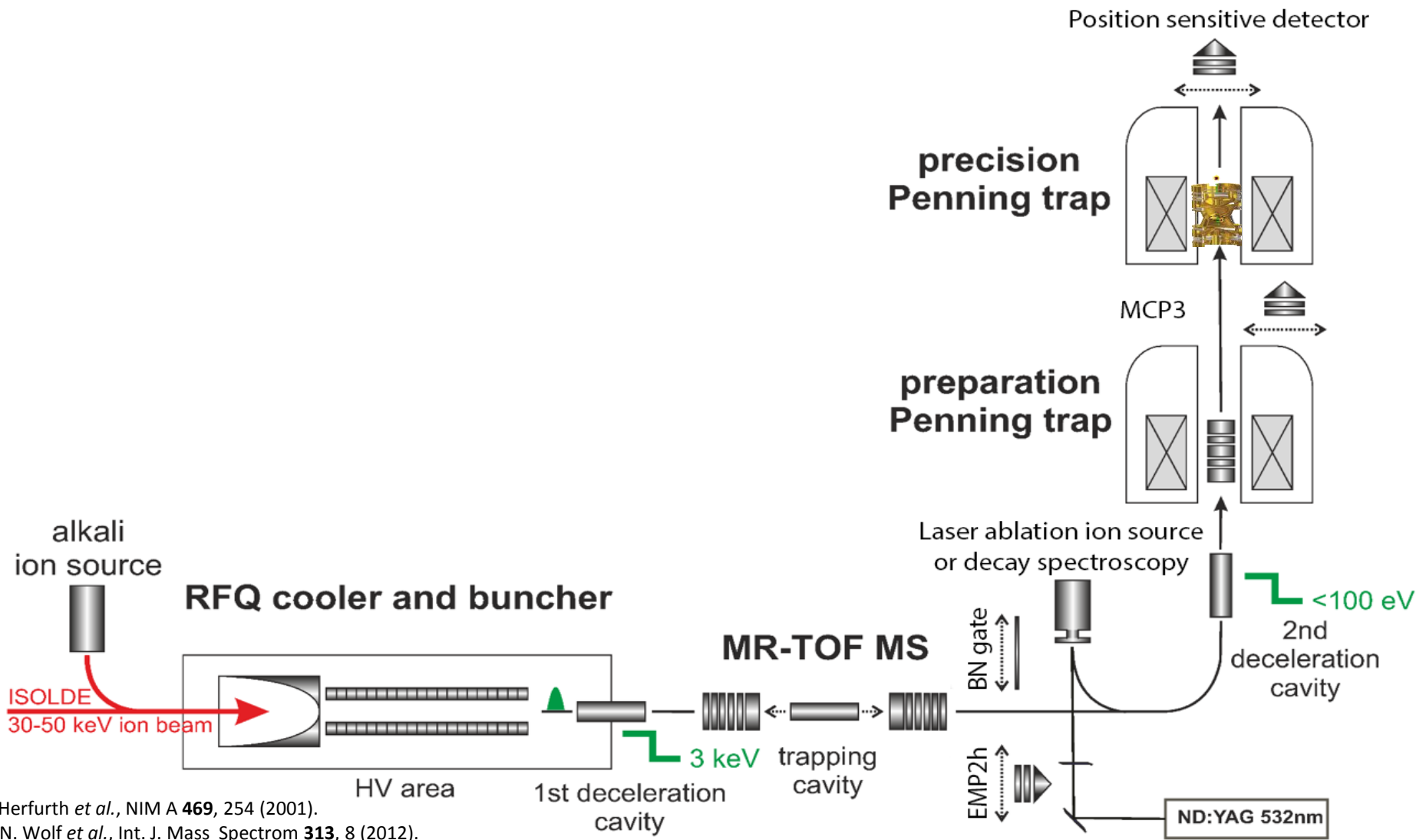


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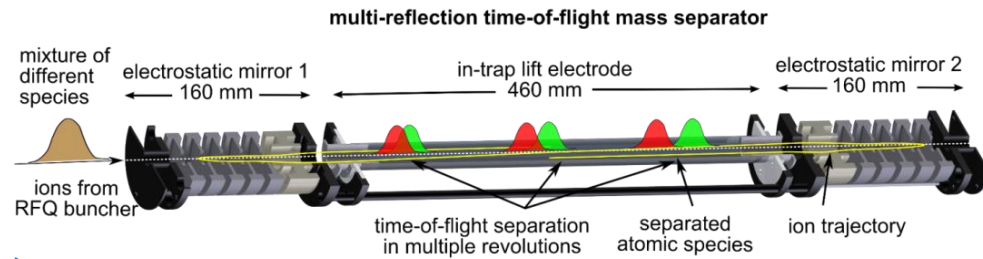
M. Mukherjee *et al.*, Eur. Phys. J. A **35**, 1 (2008). S. Kreim *et al.*, Nucl. Instrum. Methods B **317**, 492 (2013).

Tools of ISOLTRAP

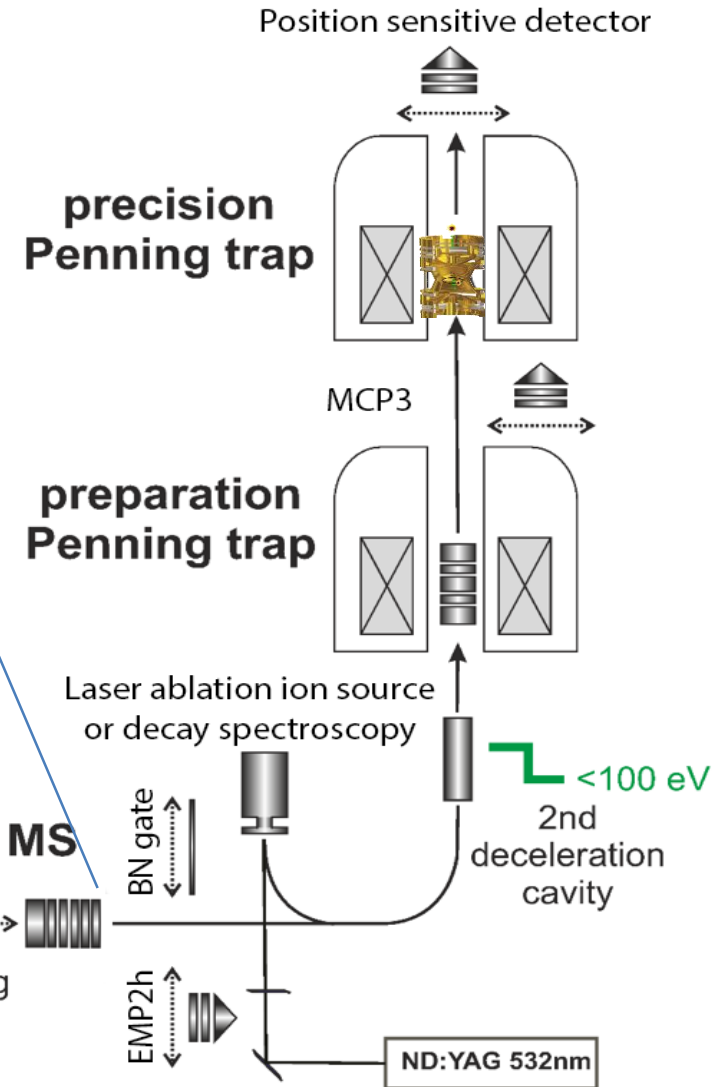
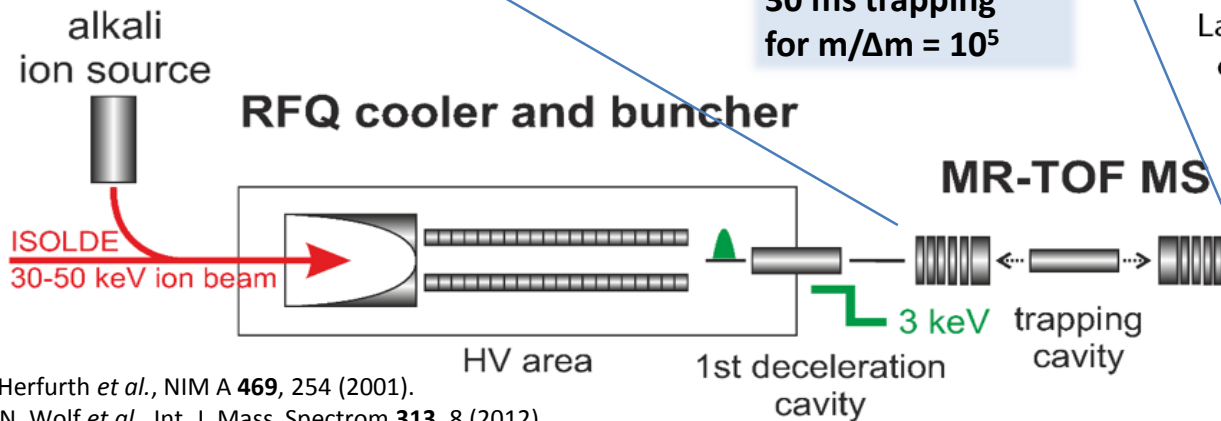


F. Herfurth *et al.*, NIM A **469**, 254 (2001).
 R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).
 G. Savard *et al.*, Phys. Lett. A **158**, 247 (1991).
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Tools of ISOLTRAP



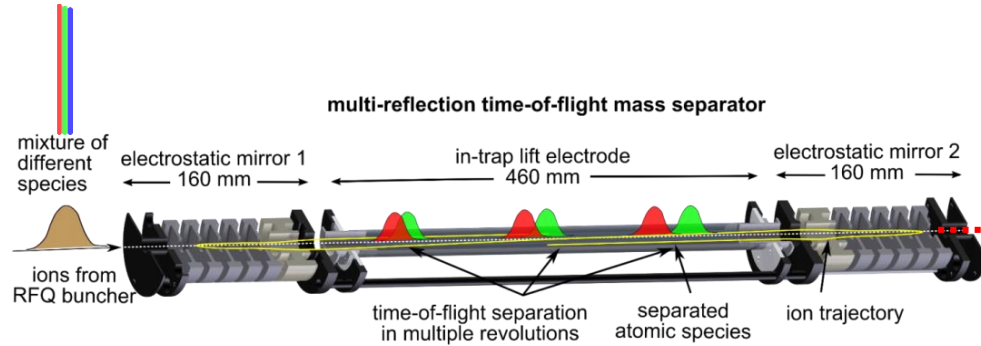
Beam purification:
30 ms trapping
for $m/\Delta m = 10^5$



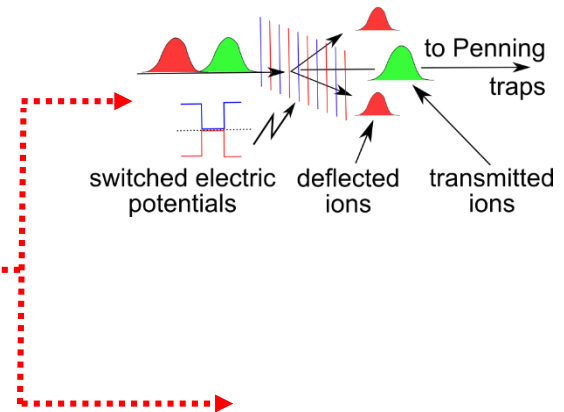
F. Herfurth *et al.*, NIM A **469**, 254 (2001).
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Tools of ISOLTRAP

RILIS

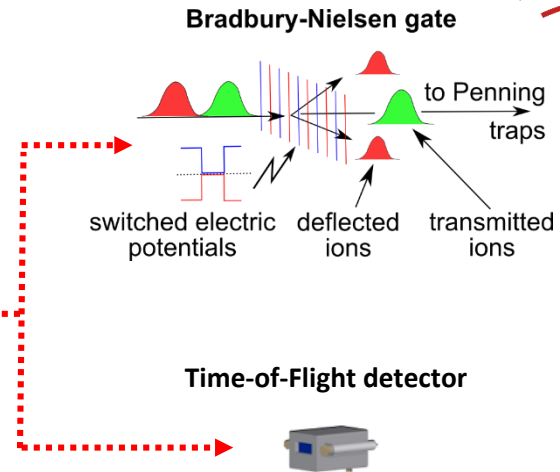
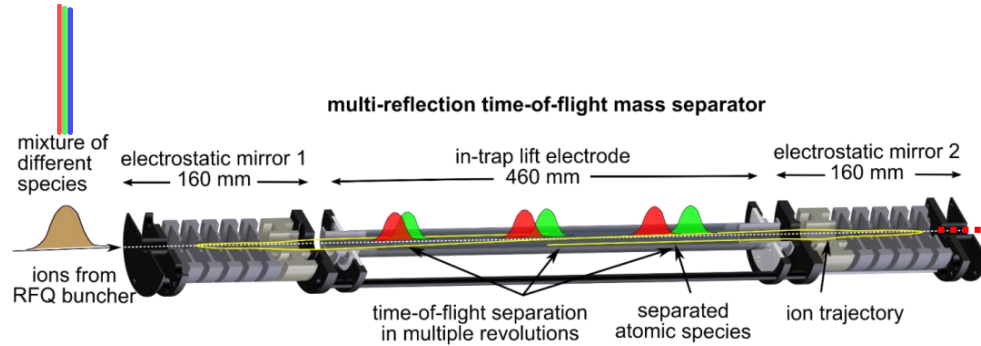


Bradbury-Nielsen gate



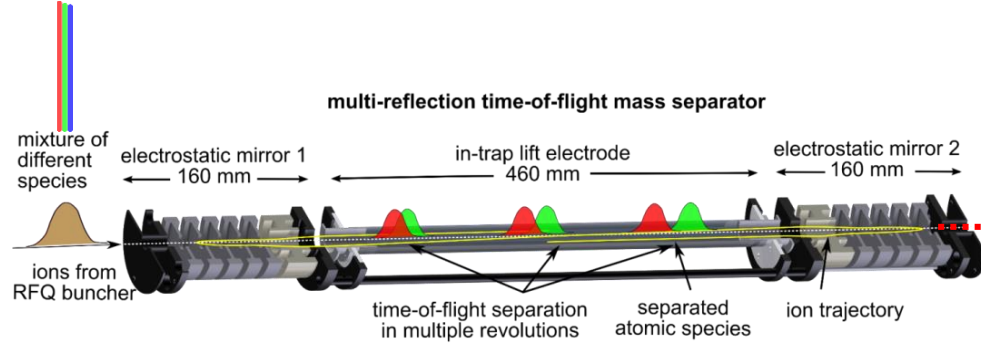
Tools of ISOLTRAP

RILIS

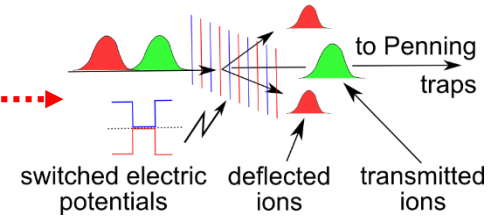


Tools of ISOLTRAP

RILIS



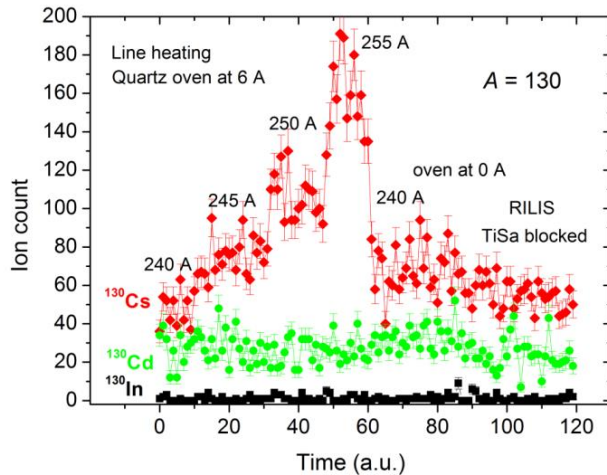
Bradbury-Nielsen gate



Time-of-Flight detector

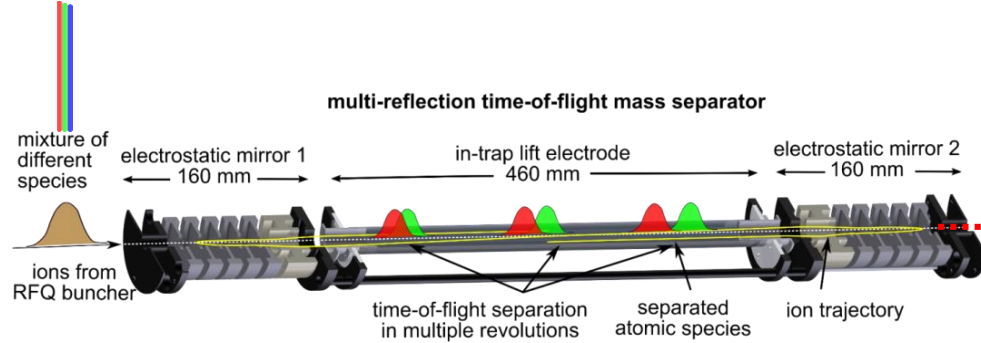


Yield studies

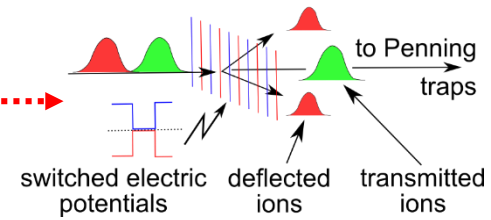


Tools of ISOLTRAP

RILIS



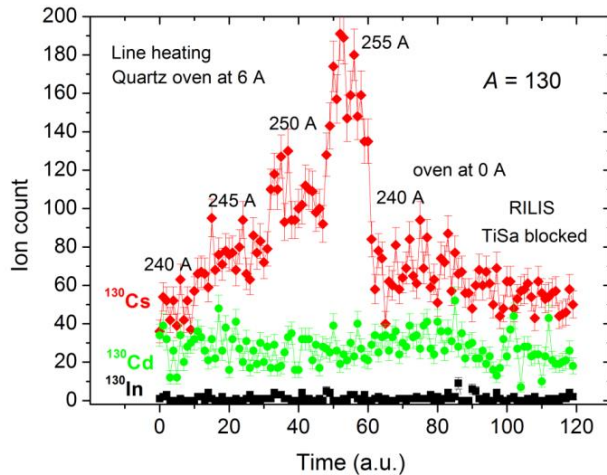
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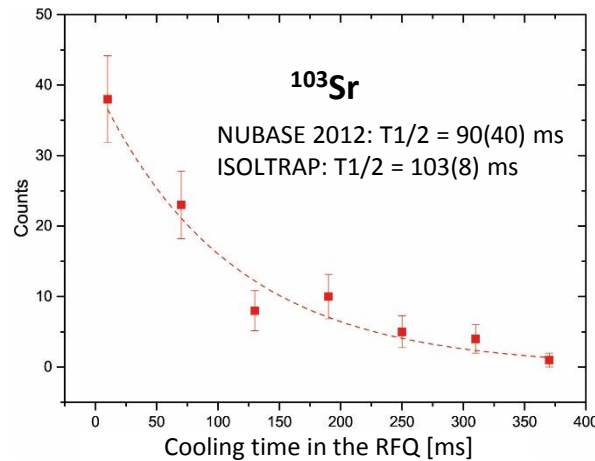
Time-of-Flight detector



Yield studies



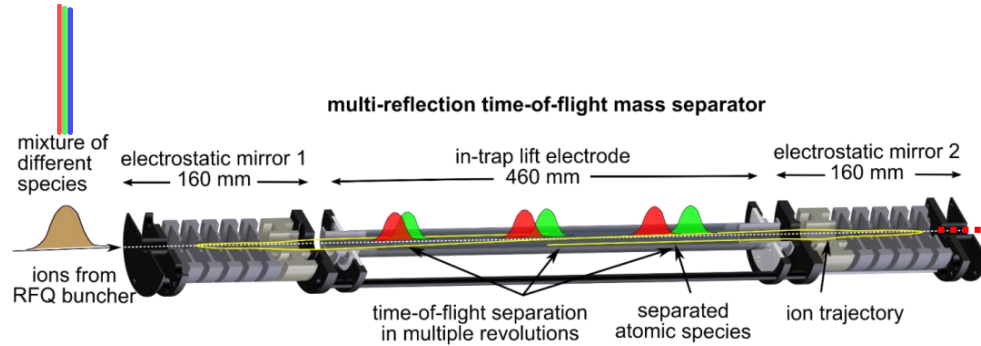
Half-life or release studies



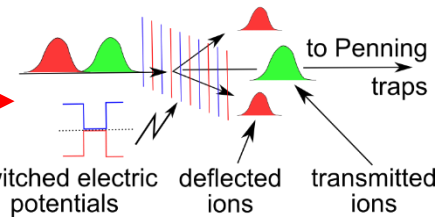
R. Wolf et al., Nucl. Instr. Meth. B, in press (2016)

Tools of ISOLTRAP

RILIS



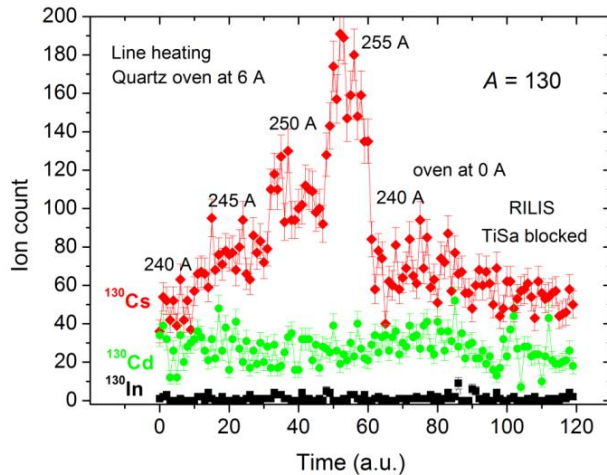
Bradbury-Nielsen gate



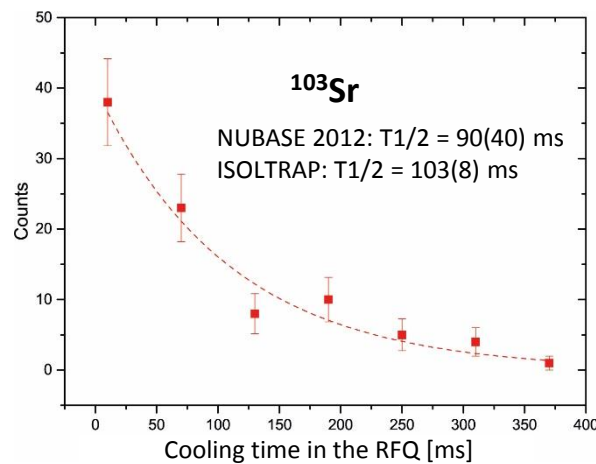
Time-of-Flight detector



Yield studies

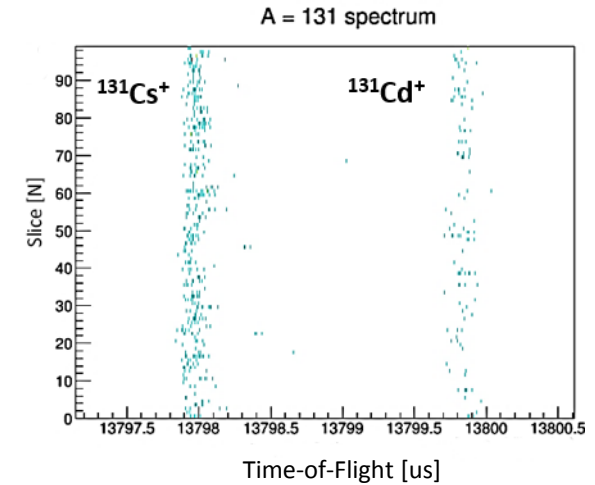


Half-life or release studies



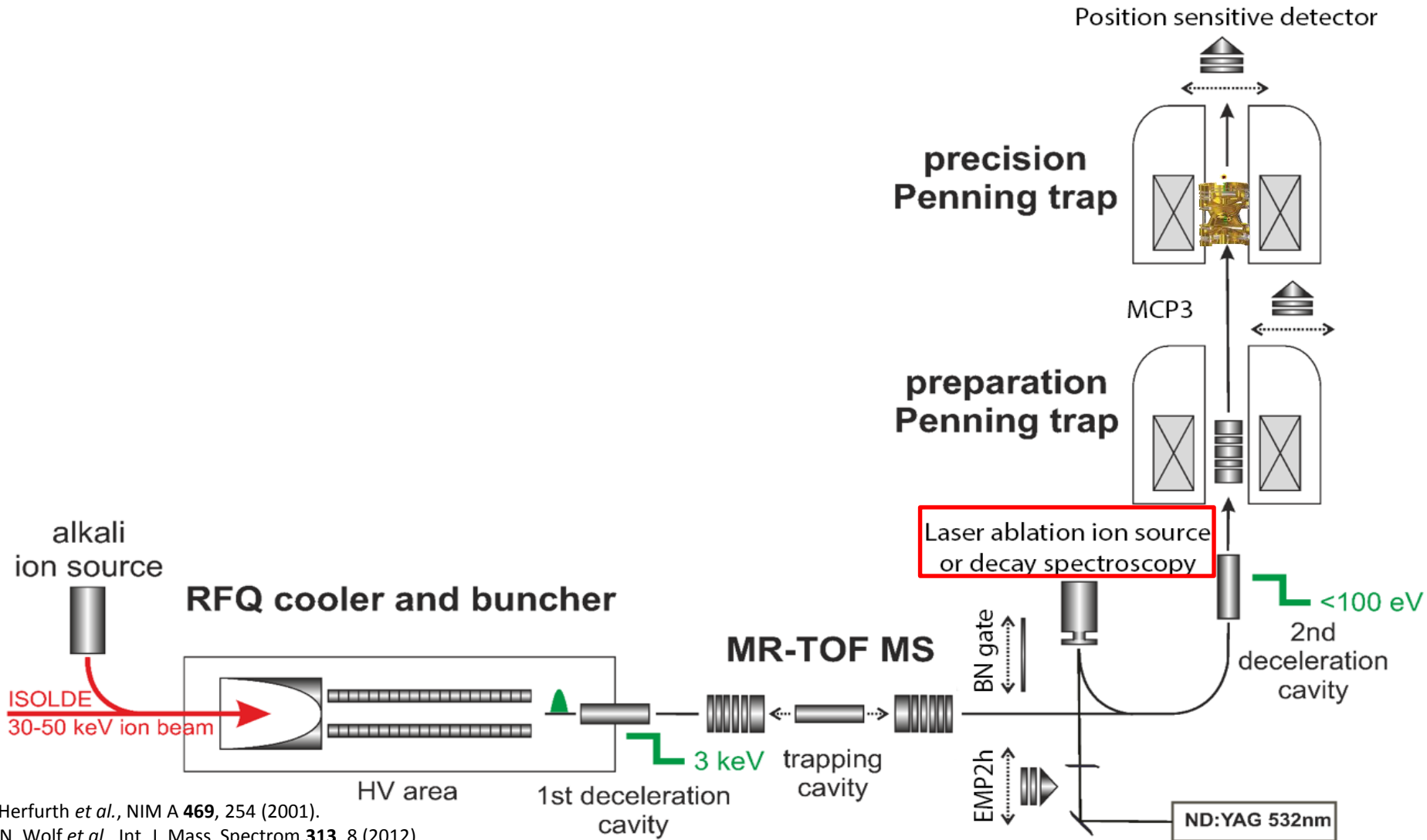
R. Wolf et al., Nucl. Instr. Meth. B, in press (2016)

Mass measurements



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

Tools of ISOLTRAP

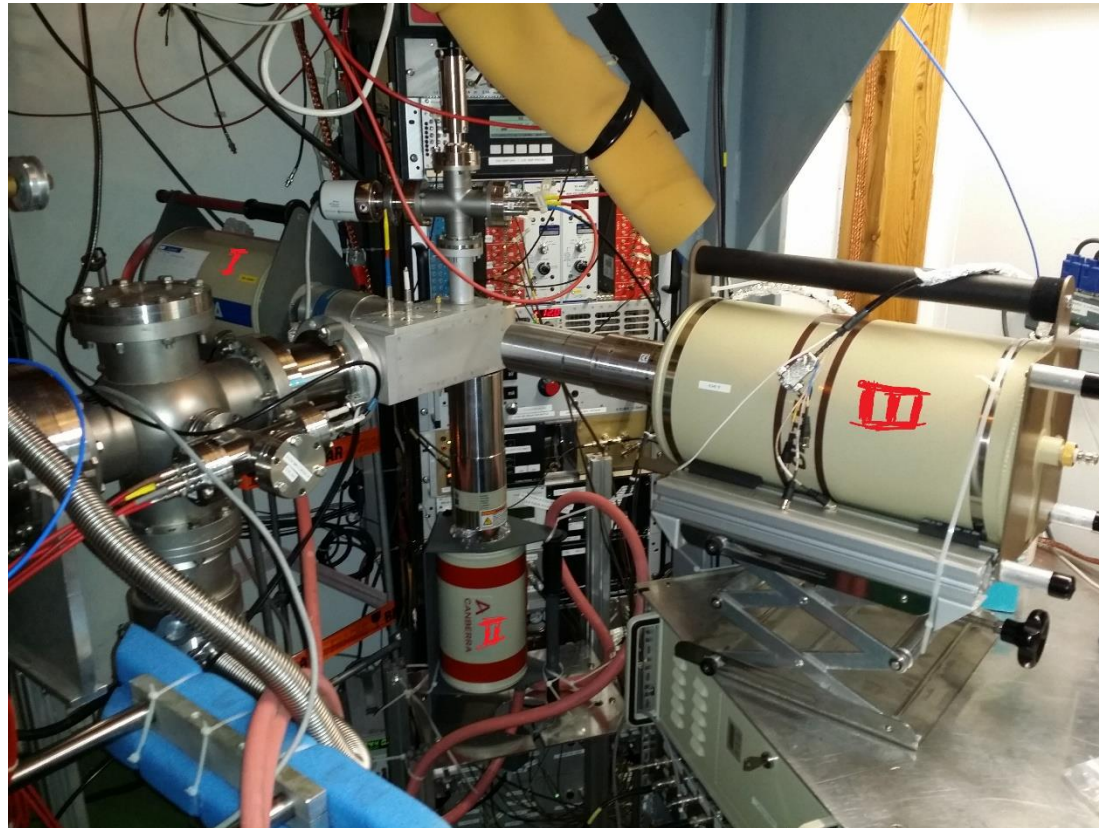


F. Herfurth *et al.*, NIM A **469**, 254 (2001).
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 G. Savard *et al.*, Phys. Lett. A **158**, 247 (1991).
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Decay spectroscopy

Mass/spectroscopy:

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



Decay spectroscopy

Mass/spectroscopy:

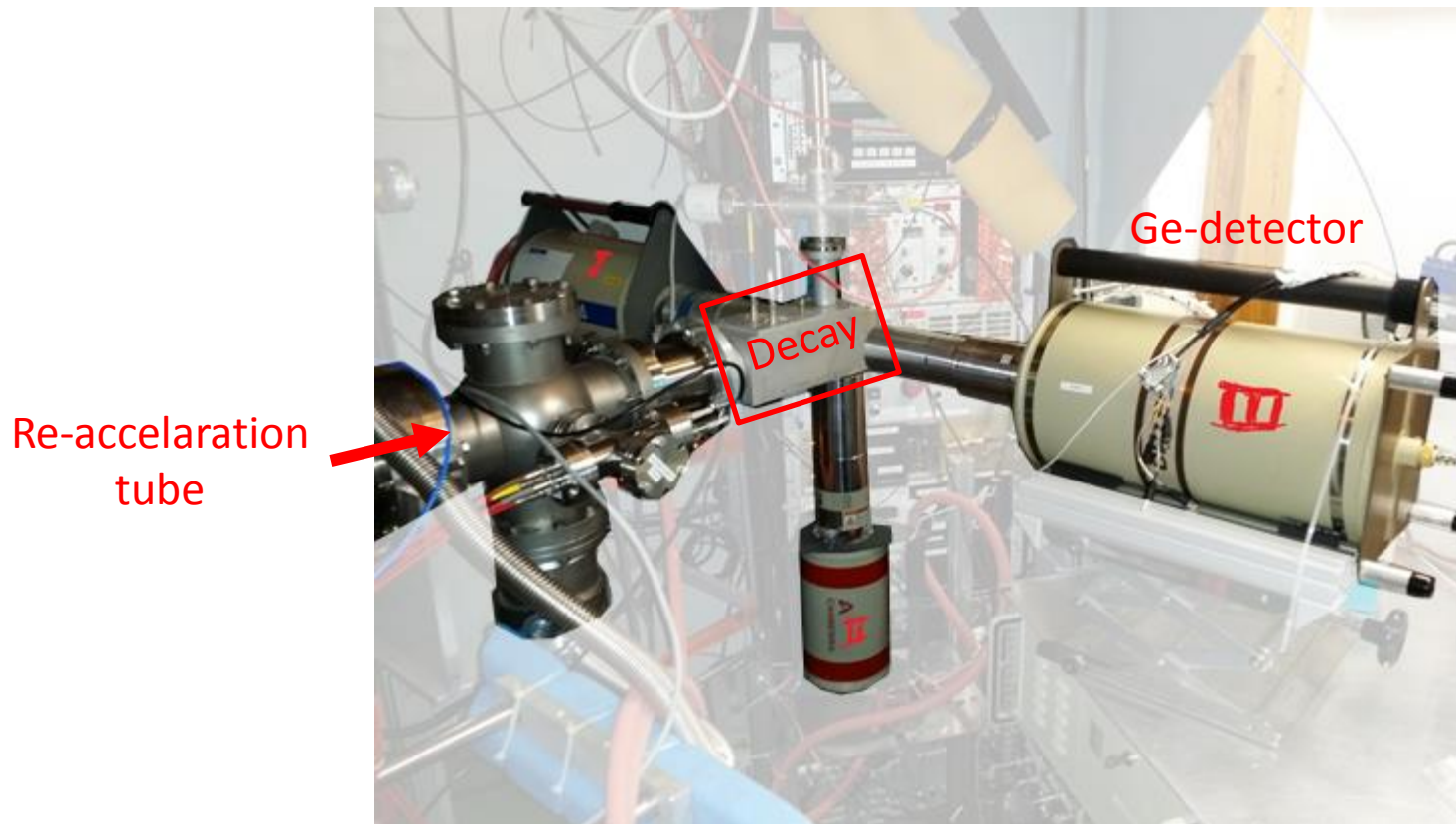
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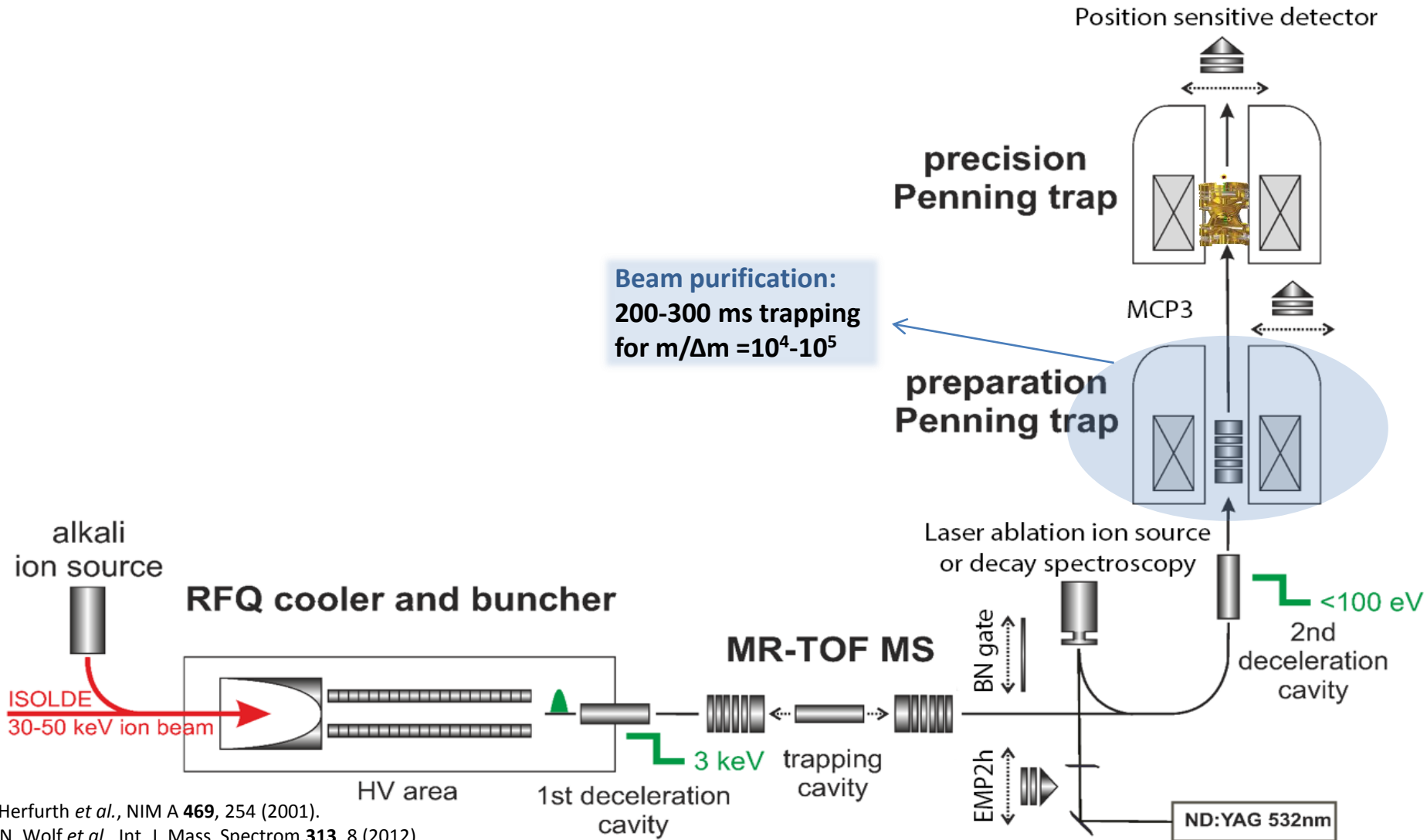
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Tools of ISOLTRAP



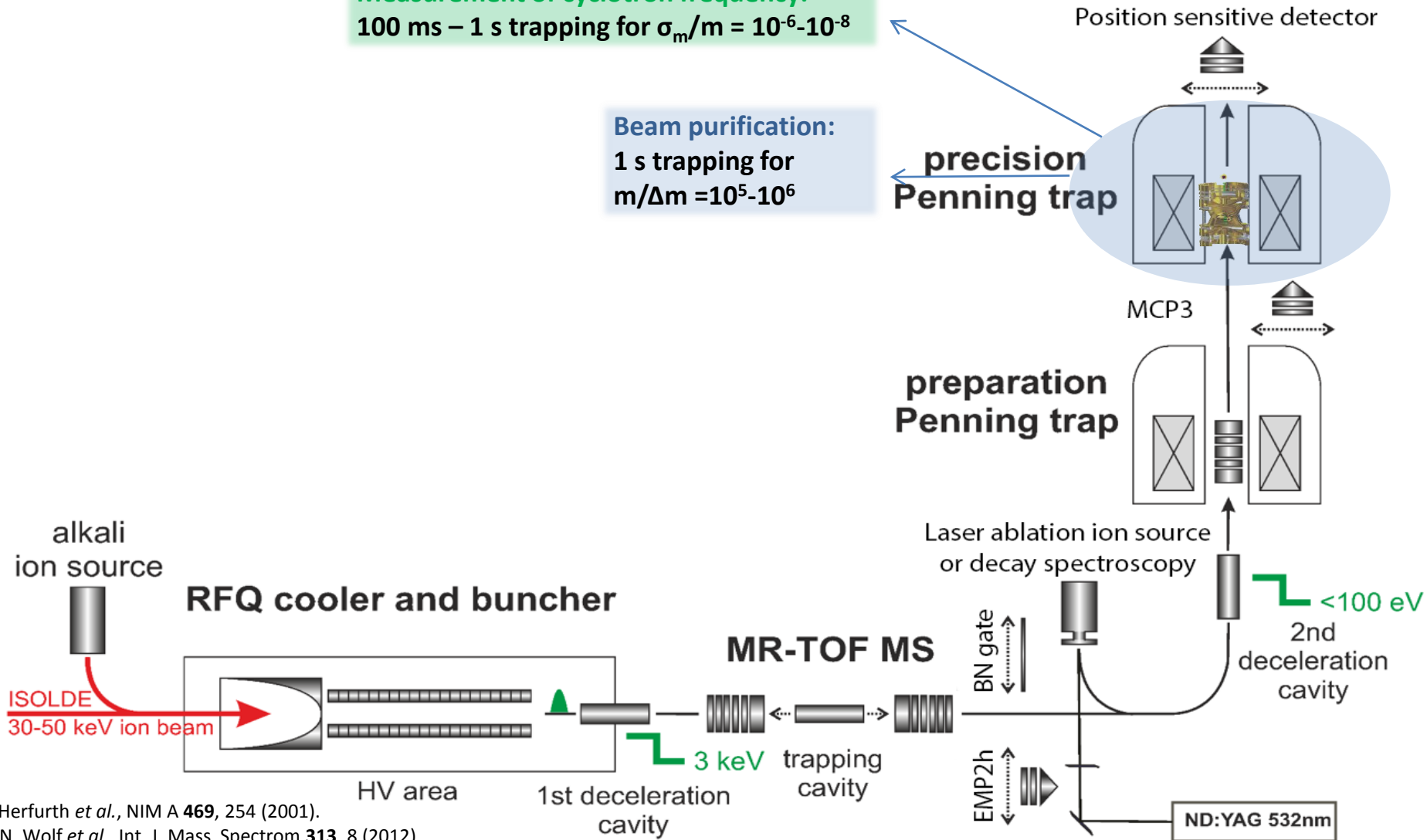
Beam purification:
200-300 ms trapping
for $m/\Delta m = 10^4 - 10^5$

F. Herfurth *et al.*, NIM A **469**, 254 (2001).
 R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).
 G. Savard *et al.*, Phys. Lett. A **158**, 247 (1991).
 M. König *et al.*, Int. J. Mass Spectrom. **142**, 95 (1995).

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 $m/\Delta m = 10^5-10^6$



F. Herfurth *et al.*, NIM A **469**, 254 (2001).

R. N. Wolf *et al.*, Int. J. Mass Spectrom **313**, 8 (2012).

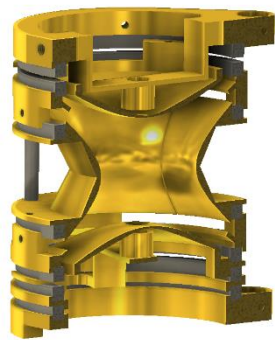
G. Savard *et al.*, Phys. Lett. A **158**, 247 (1991).

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

Tools of ISOLTRAP: Penning trap

Eigen motions:

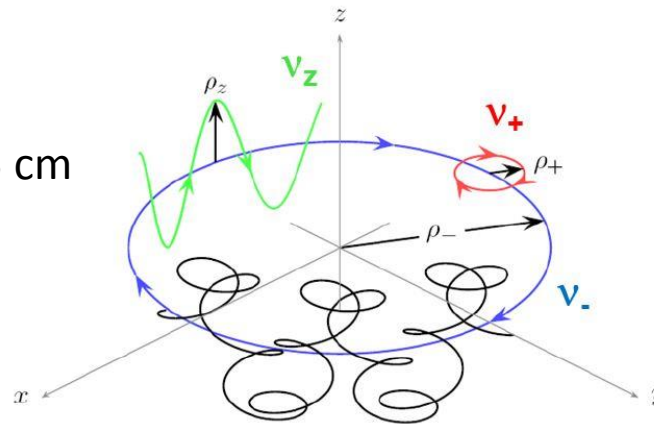
Penning trap:
Storage of ions by the superposition
of electric and magnetic fields



Hyperbolic Penning trap

2,5 cm

Three harmonic oscillators:



$$\omega_c = \sqrt{\omega_+^2 + \omega_-^2 + \omega_z^2}$$



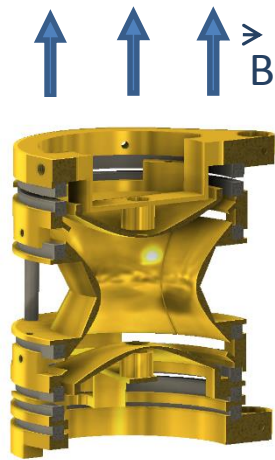
$$v_c = \frac{qB}{2\pi m}$$

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

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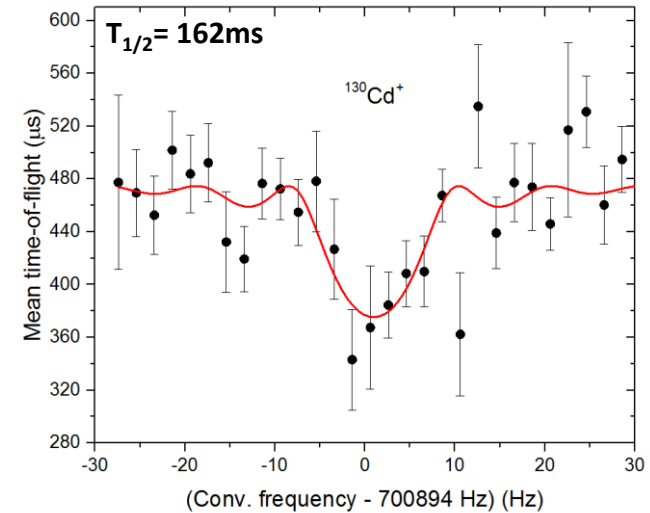
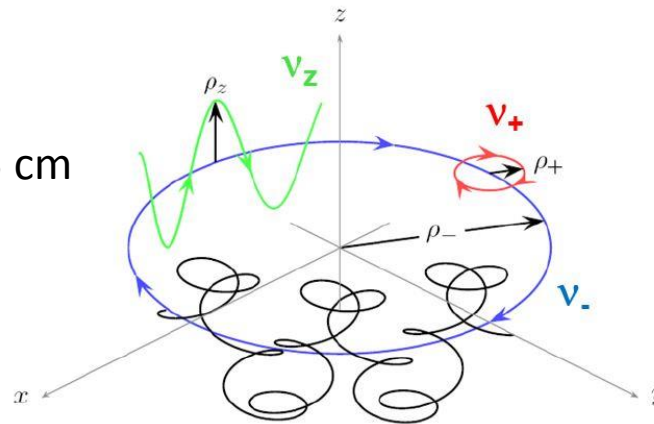
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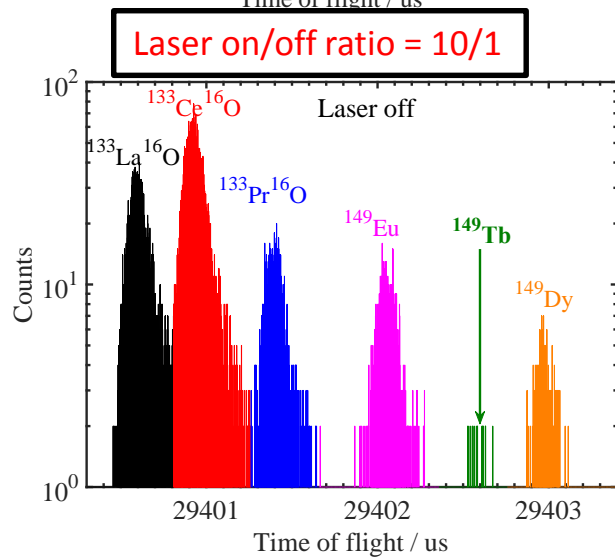
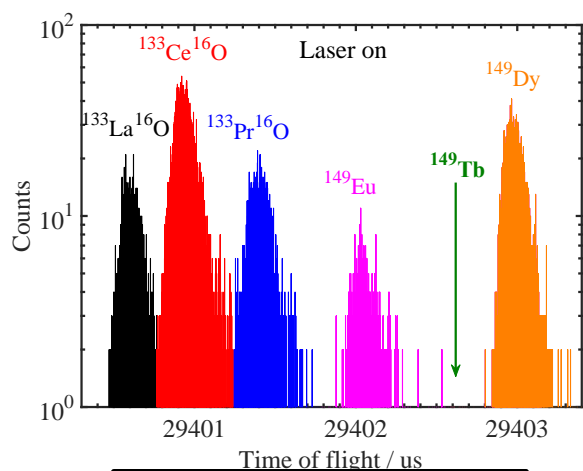


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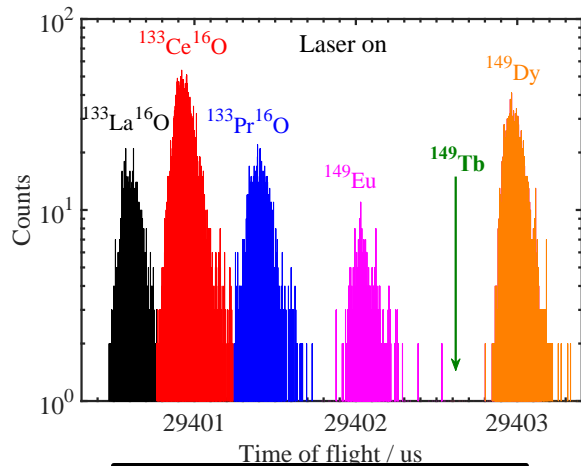
Dy-beam time

Collection example for A=149:

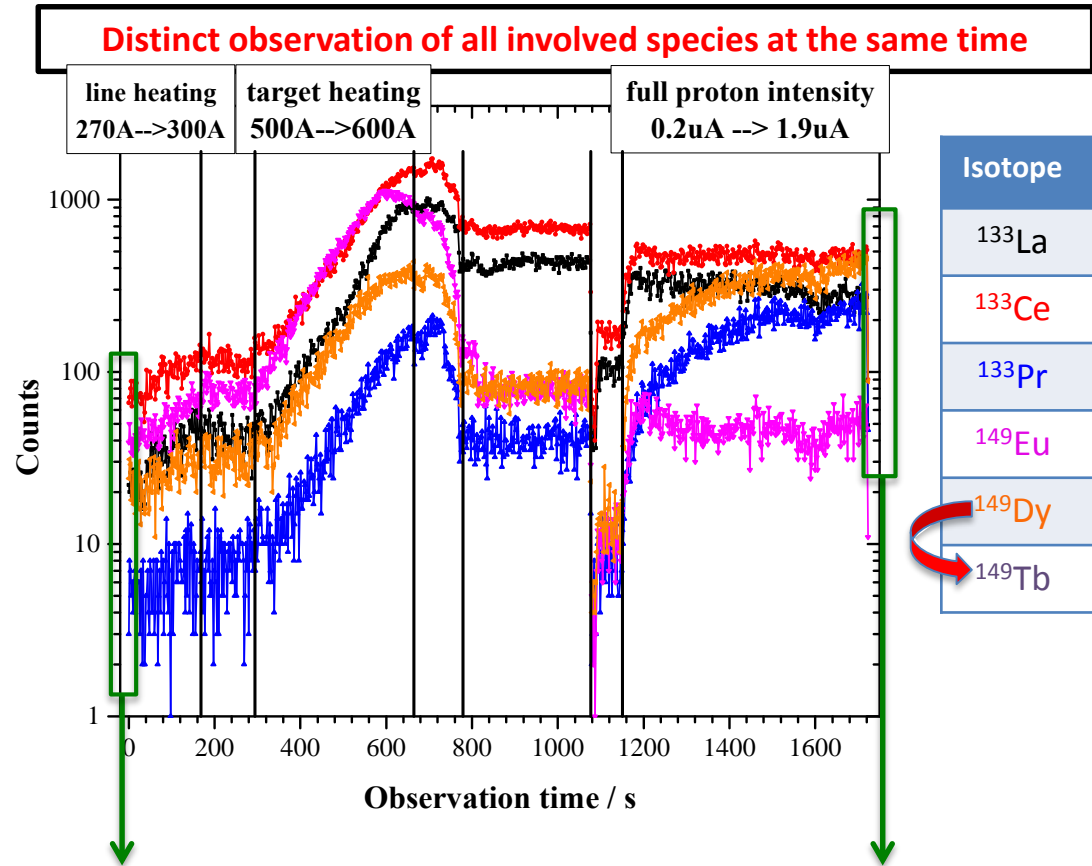
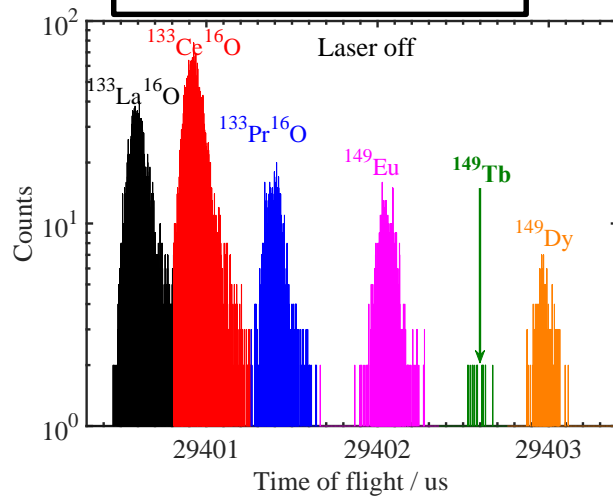


Dy-beam time

Collection example for A=149:



Laser on/off ratio = 10/1



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 / ¹⁴⁹Dy → almost factor 3 improvement!

Dy-beam time

Collection example for A=149:

Foil holder for deposition of ion beam



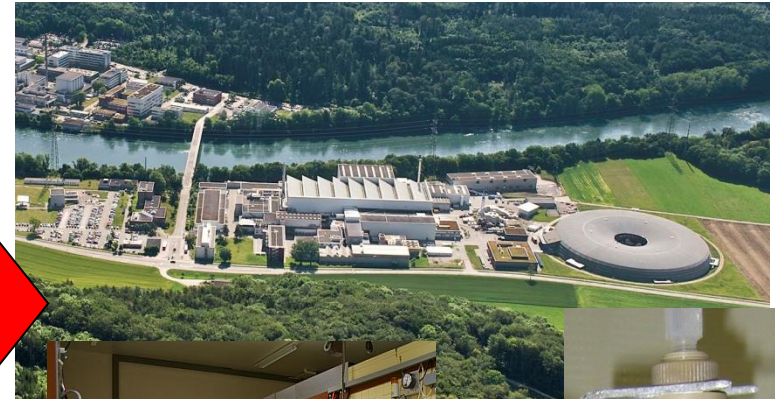
Foils are gold plated with zinc.



Dy-beam time



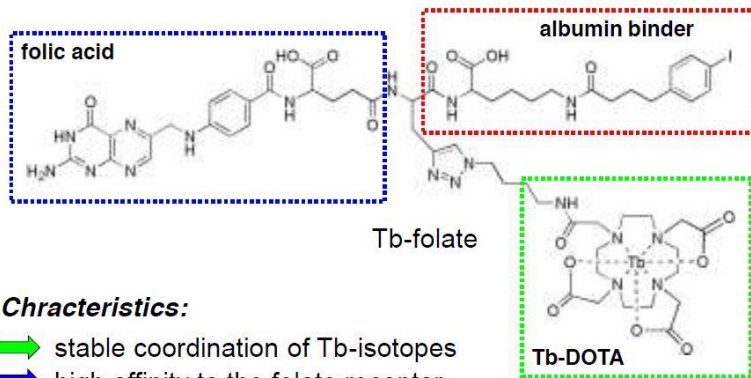
Dy 150 7.2 m ε; β ⁺ ... α 4.23 γ 397	Dy 151 17 m ε; α 4.07 γ 386; 49; 546; 176... σ _n	Dy 152 2.4 h ε α 3.63 γ 257	Dy 153 6.29 h ε; β ⁺ ... α 3.46... γ 81; 214; 100; 254	Dy 154 3.0 · 10 ⁶ a α 2.87	Dy 155 10.0 h ε β ⁺ 0.9; 1.1... γ 227...	Dy 156 0.056 σ _n 33 σ _n , α < 0.009	Dy 157 8.1 h ε γ 326...	Dy 158 0.095 σ _n 33 σ _n , α < 0.006	Dy 159 144.4 d ε γ 58; β ⁻ σ 8000	Dy 160 2.329 σ _n 60 σ _n , α < 0.0003	Dy 161 18.889 σ _n 600 σ _n , α < 1E-6	Dy 162 25.475 σ _n 170	Dy 163 24.896 σ _n 120 σ _n , α < 2E-5
Tb 149 4.2 m ε α 3.97... β ⁺ 1.8... γ 796; 165...	Tb 150 4.1 h ε; β ⁺ 3.1; h 49; 25 s α 3.41; γ 232; 287; 496...	Tb 151 3.67 h ε; β ⁺ 3.1; h 49; 25 s α 3.41; γ 232; 287; 496...	Tb 152 4.2 m 4.1 h ε; β ⁺ 2.8... α 3.44; γ 344; 566; 271	Tb 153 2.34 d ε α 2.12; 170; 110; 102; 83...	Tb 154 23 h 9.0 h 21 h ε α 1.1; 248; 347; 123; 1420; 346; 1274	Tb 155 5.32 d ε γ 87; 105; 180; 262...	Tb 156 5.4 h ε γ 54 h 5.4 d h 58 e ⁻ 534; 199; 1222	Tb 157 99 a ε γ (54) e ⁻	Tb 158 10.5 s 180 a ε β ⁻ 0.9 γ 944; 862; 80	Tb 159 100 σ _n 23.2	Tb 160 72.3 d β ⁻ 0.6; 1.7... γ 879; 299; 966... σ 570	Tb 161 6.90 d β ⁻ 0.5; 0.6... γ 26; 49; 75... e ⁻	Tb 162 7.76 m β ⁻ 1.4; 2.4... γ 260; 808; 888...
Gd 148 74.6 a α 3.183 σ 14000	Gd 149 9.28 d ε; α 3.016 γ 150; 299; 347...	Gd 150 1.8 · 10 ⁶ a α 2.72	Gd 151 120 d ε; α 2.60 γ 154; 243; 175...	Gd 152 0.20 1.1 · 10 ¹² a α 2.14; σ 700 σ _n , α < 0.007	Gd 153 239.47 d ε γ 97; 103; 70... σ 20000 σ _n , α 0.03	Gd 154 2.18 σ _n 60	Gd 155 14.80 σ _n 61000 σ _n , α 0.00008	Gd 156 20.47 σ _n ~ 2.0	Gd 157 15.65 σ _n 254000 σ _n , α < 0.05	Gd 158 24.84 σ _n 2.3	Gd 159 18.48 h β ⁻ 1.0... γ 364; 58...	Gd 160 21.86 σ _n 1.5	Gd 161 3.66 m β ⁻ 1.6; 1.7... γ 361; 315; 102... σ 20000



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

Dy-beam time

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

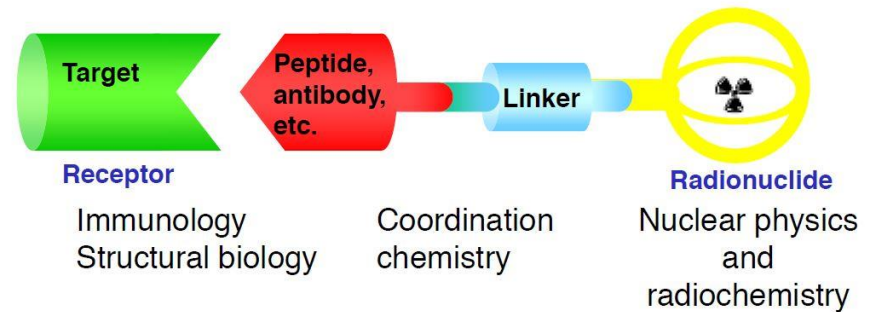


Characteristics:

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

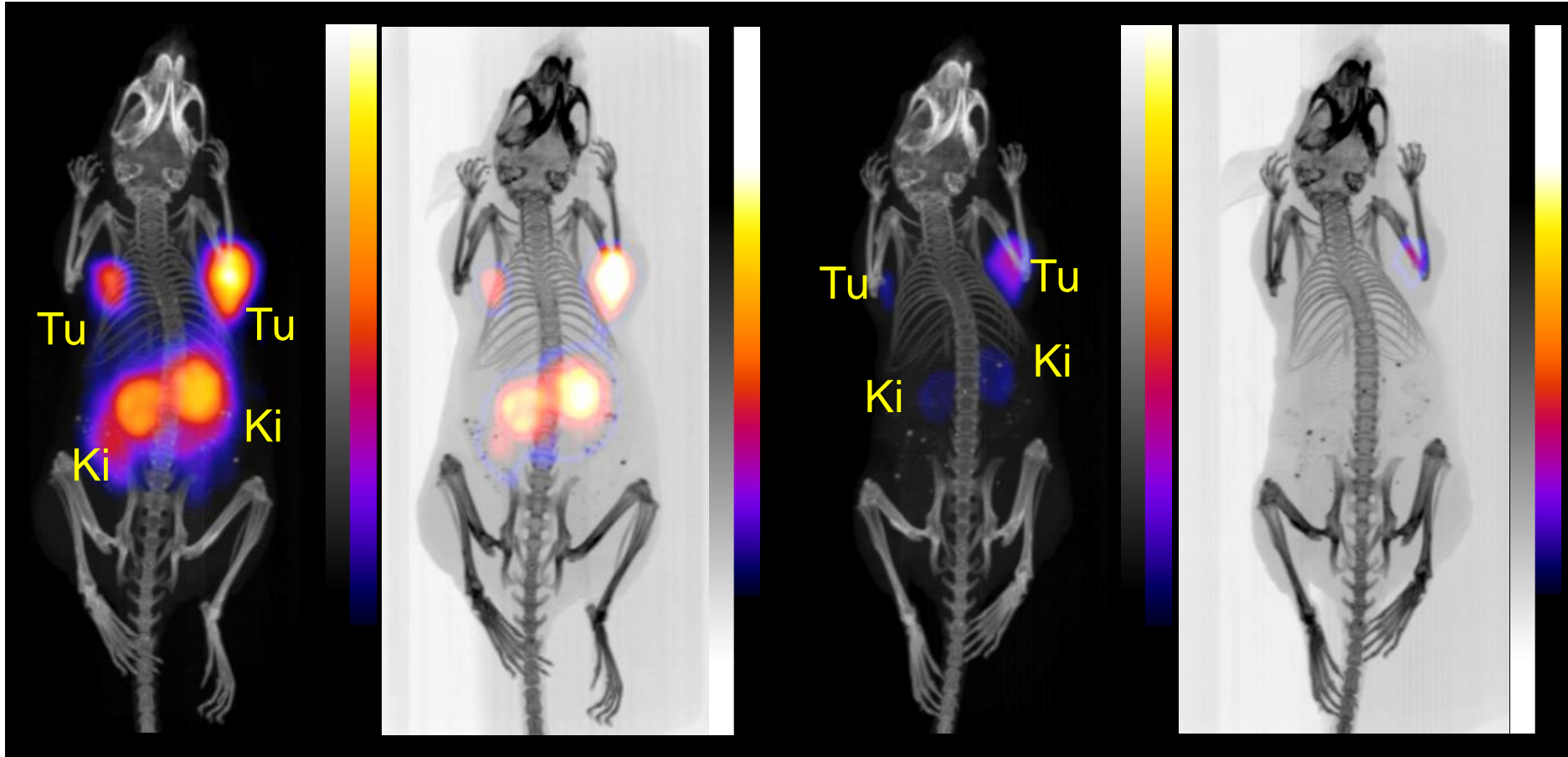
C. Müller et al., J Nucl Med 2012;53:1951.

Multidisciplinary collaboration to fight cancer



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

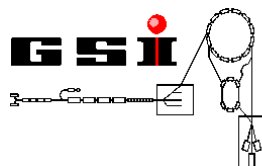
Thank you very much for your attention!



ERNST MORITZ ARNDT
UNIVERSITÄT GREIFSWALD

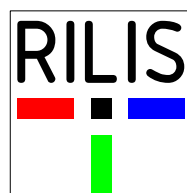


Federal Ministry
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Grants No.:
05P12HGCI1
05P12HGFNE
05P15ODCIA

ISOLDE Target
and Technical Group



<http://isoltrap.web.cern.ch>

