Recent developments at Isotope Separator On Line based facilities

Piet Van Duppen
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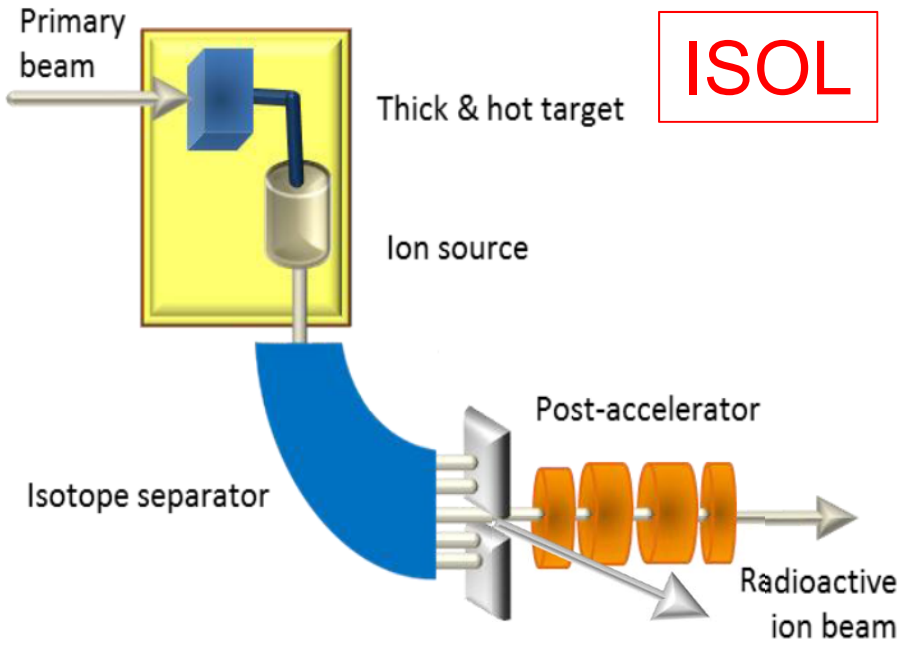
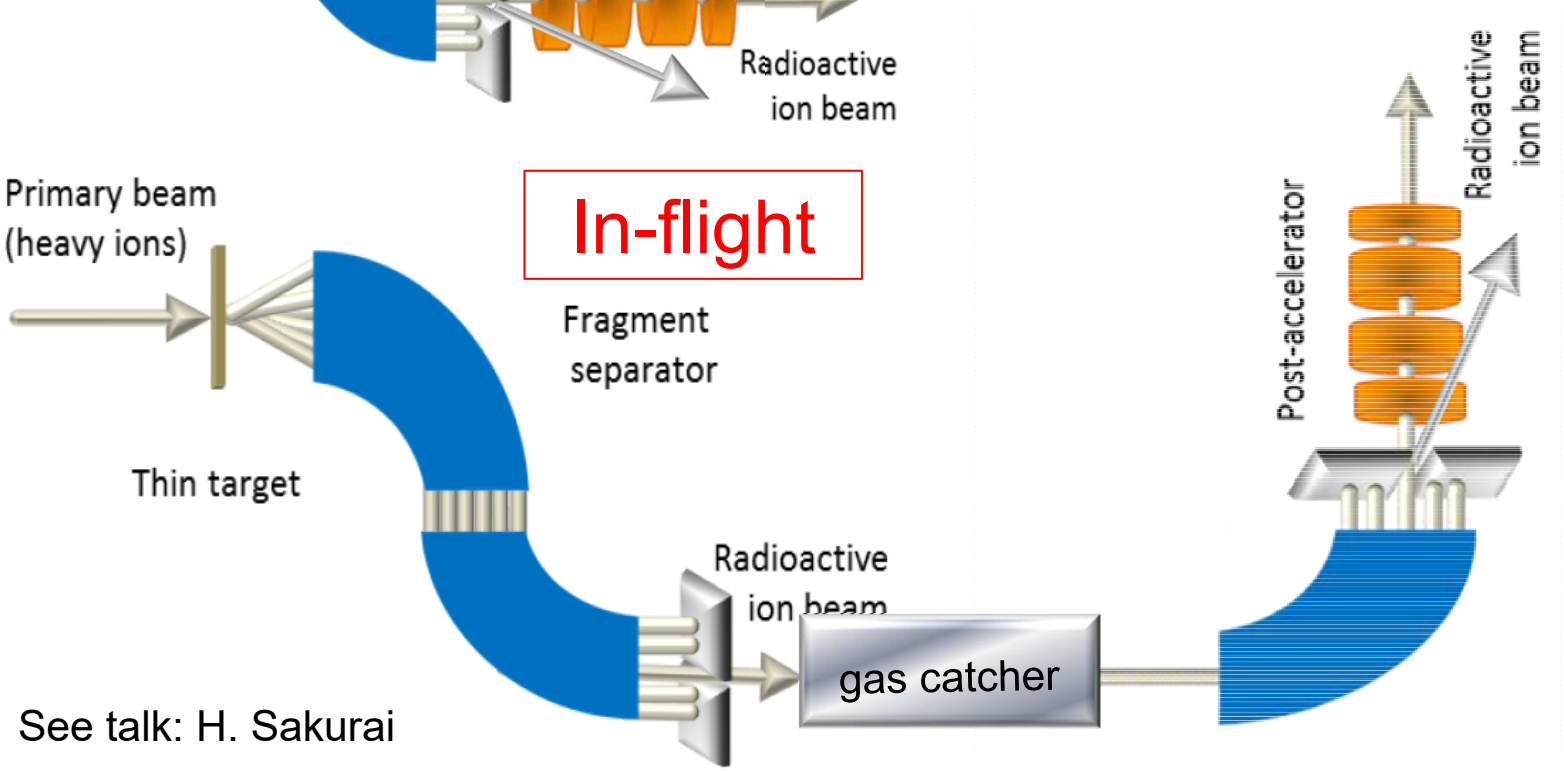
- Introductory remarks on RIB research
- Target materials
- Laser Ion Sources and Ion Manipulation
- Gas-cell based approach: IGLIS
- Isomeric beams
- Conclusion and outlook

- Radioactive beam production

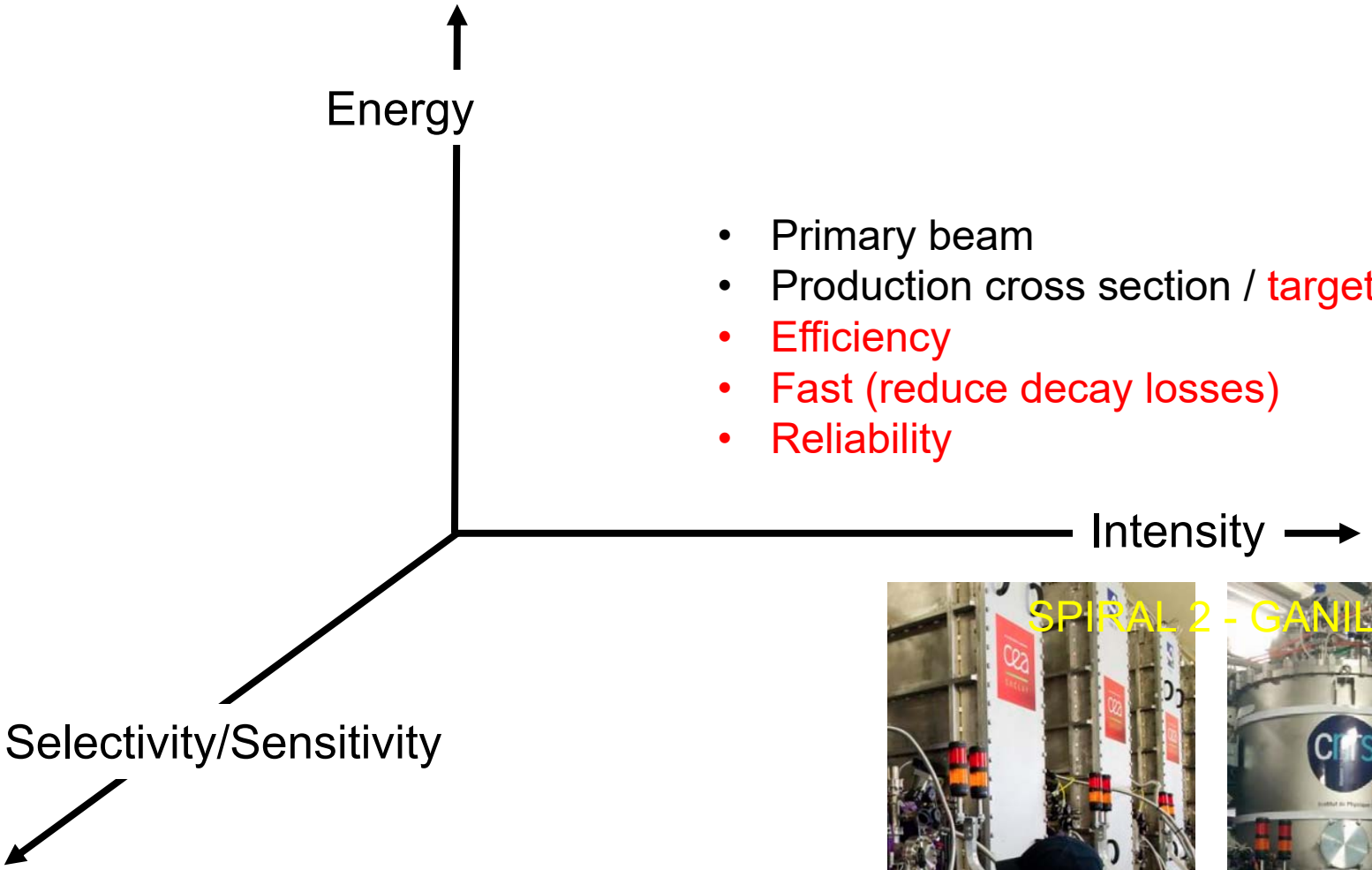




See talk: H. Sakurai

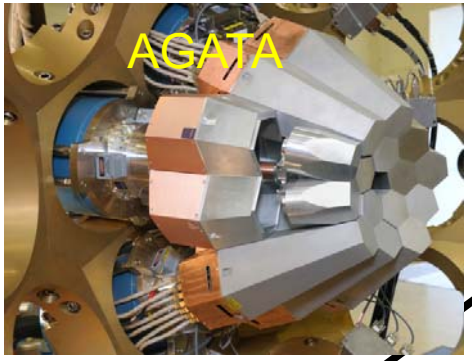
Y. Blumenfeld, T. Nilsson T. and PVD, Physica Scripta T152 *(2013)* 014023

Experimental ISOL-based RIB research



- Primary beam
- Production cross section / target material
- Efficiency
- Fast (reduce decay losses)
- Reliability

Experimental RIB research



Energy

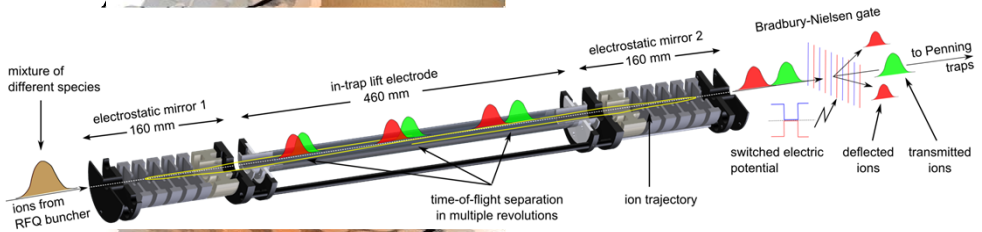
- Charge-state breeding (ECR, EBIS)
- Post acceleration

- Primary beam
- Production cross section / target material
- Efficiency
- Fast (reduce decay losses)
- Reliability

Intensity

- Beam purification (laser ion source, MR-TOF, High Resolution Separator)
- Adapted Instrumentation (identification of reaction products, detection of weak signals)

Selectivity/Sensitivity



Experimental RIB research

Energy

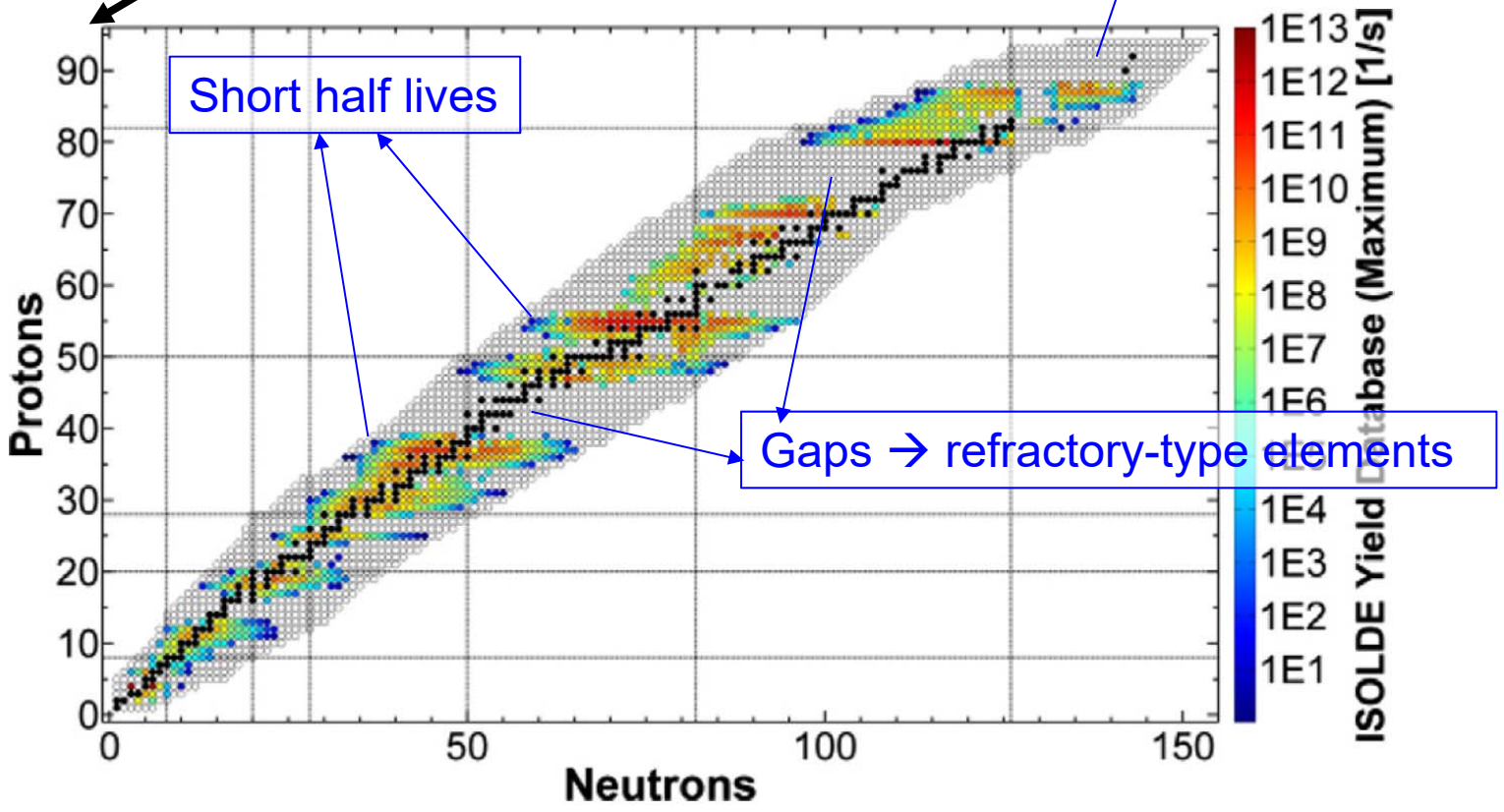
Universality

Intensity

Selectivity/Sensitivity

Efficient, Selective and Fast

Production mechanism



A. Gottberg,- NIMB 376 (2016) 8 – ISOLDE yield database

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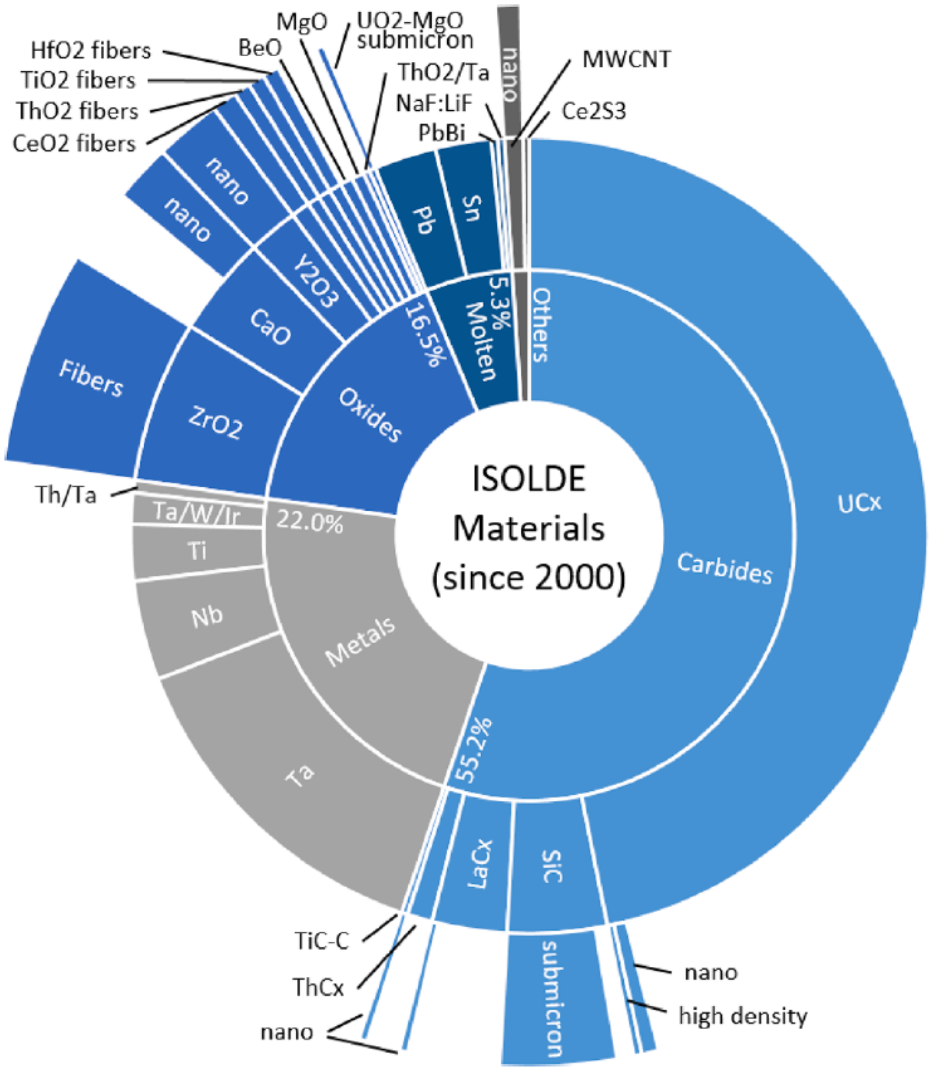
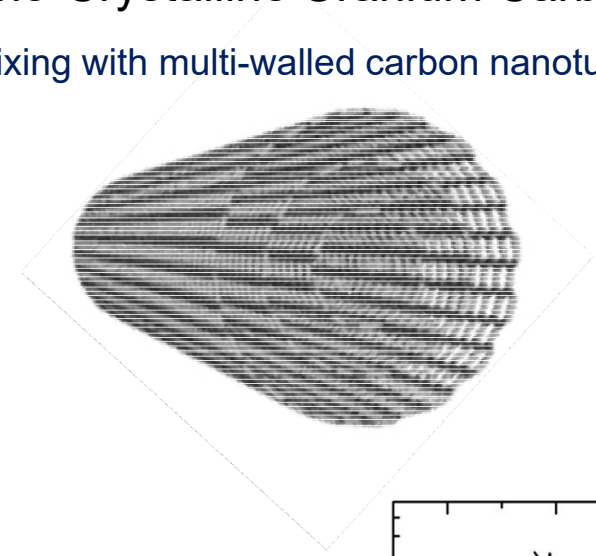
Target material used at ISOLDE (since 2000)

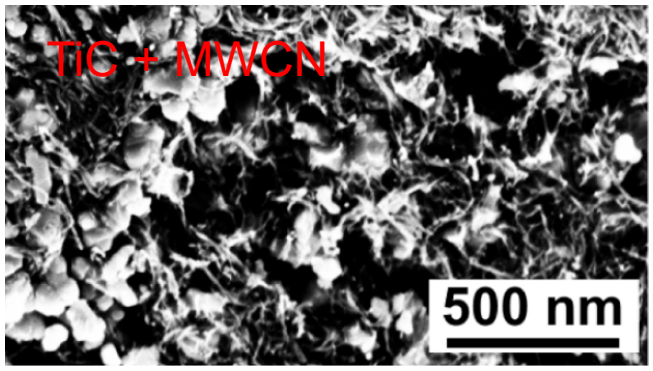


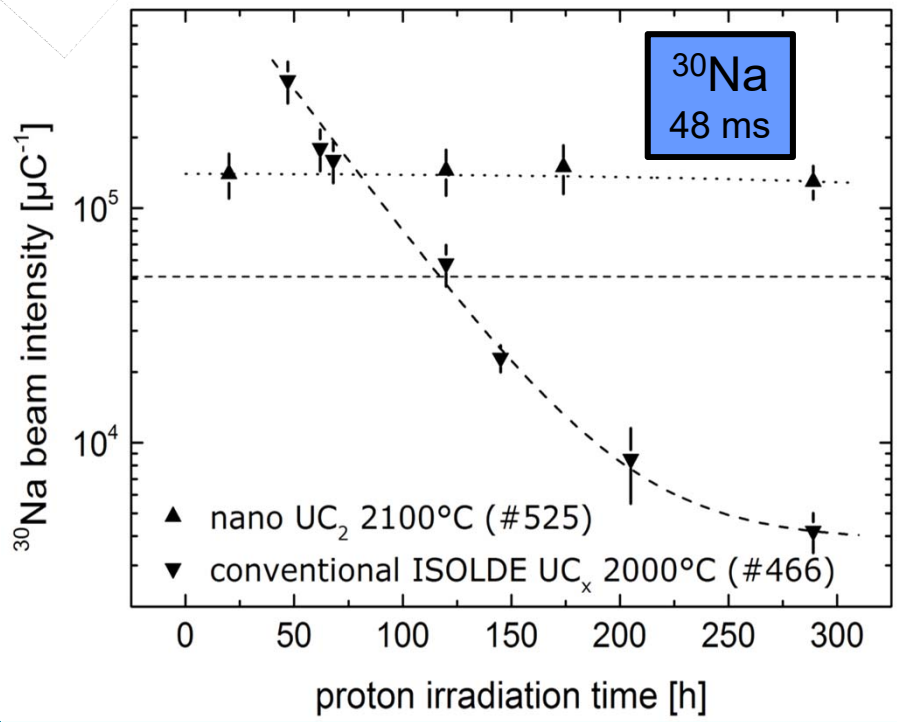
J.P. Ramos NIM B (2019)

Nano - target materials

- Nano-Crystalline Uranium Carbide and Titanium Carbide
  - ➢ mixing with multi-walled carbon nanotubes (MWCN)



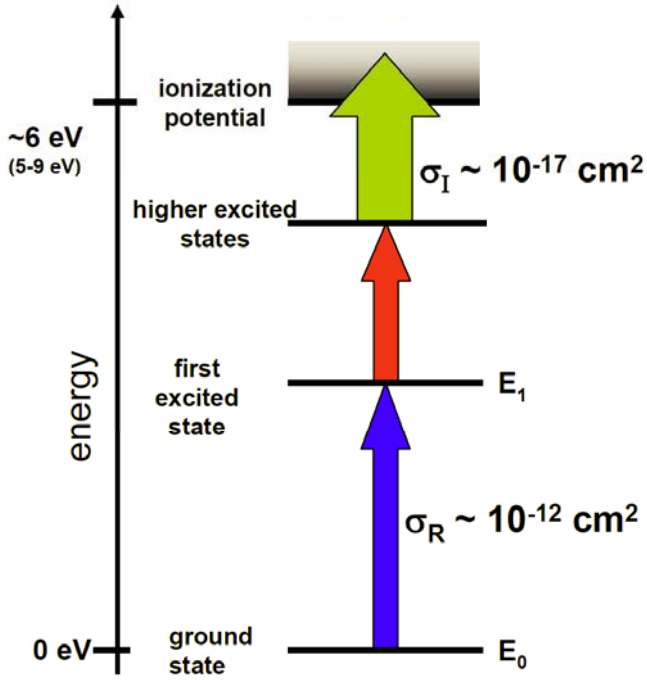




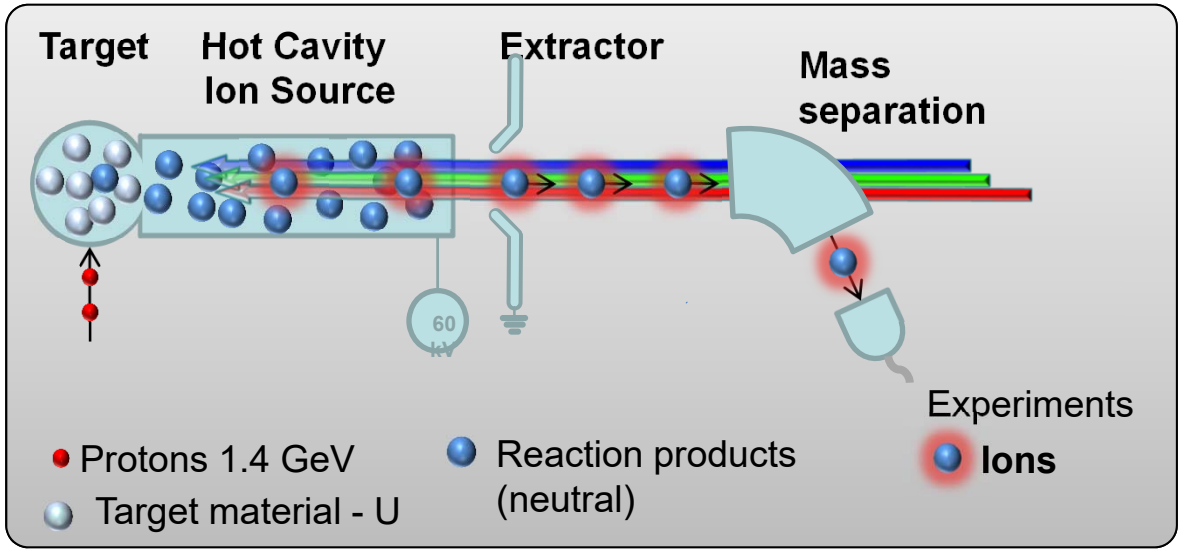
courtesy A. Gottberg
A. Gottberg,- NIMB 376 (2016) 8; J. Ramos NIMB (2019)

Resonance Laser Ionization

- Developments in the resonance laser ion source (> 50% beam time at ISOLDE)



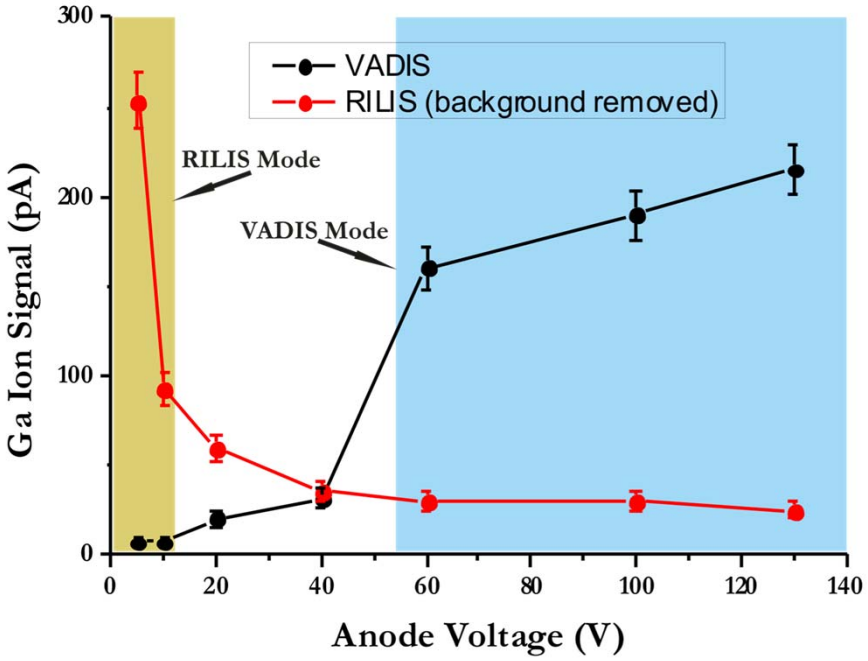
courtesy I. Moore



ISOLDE, JYFL, SPES, TRIUMF, GANIL, ALTO, RIKEN,...

V. Fedosseev,- J. Phys. G. 44 (2017) 084006
K. Blaum,- Phys. Scr. T152 (2013) 014017
Kluge H-J., Hyperfine Interact. 196 (2010) 295
Cheal B.and Flanagan K., J. Phys. G. 37 (2010) 113101

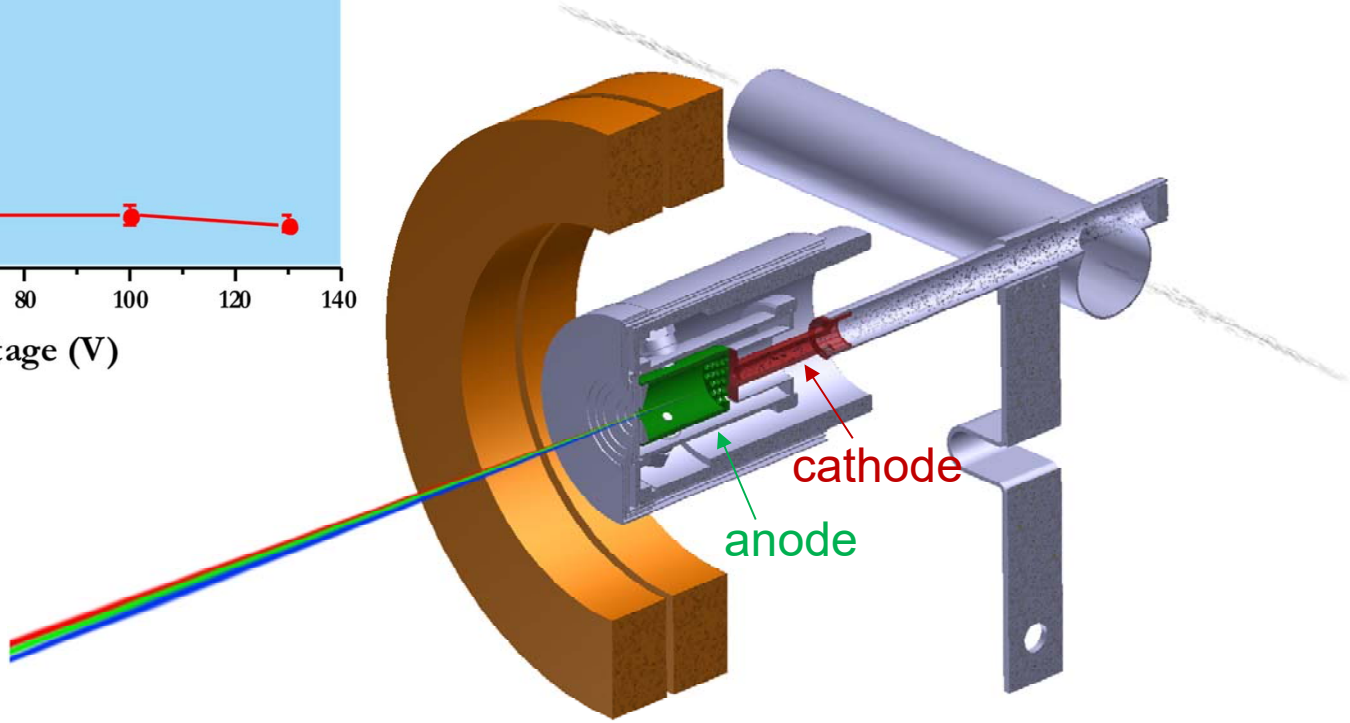
- VADLIS — RILIS inside a FEBIAD ion source



- Increased efficiency and selectivity
- RILIS coupled with liquid targets
- So far demonstrated for:

Ga, Cd, Hg, Ba, Ba+, Sn, Mg

- Particle-in-cell modeling using e.g. VSim

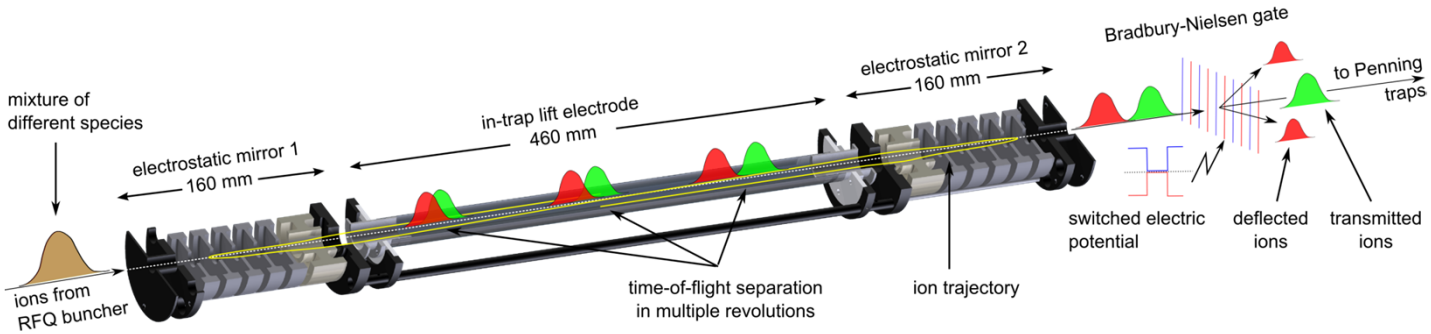


Versatile Arc Discharge Ion Source (VADIS)

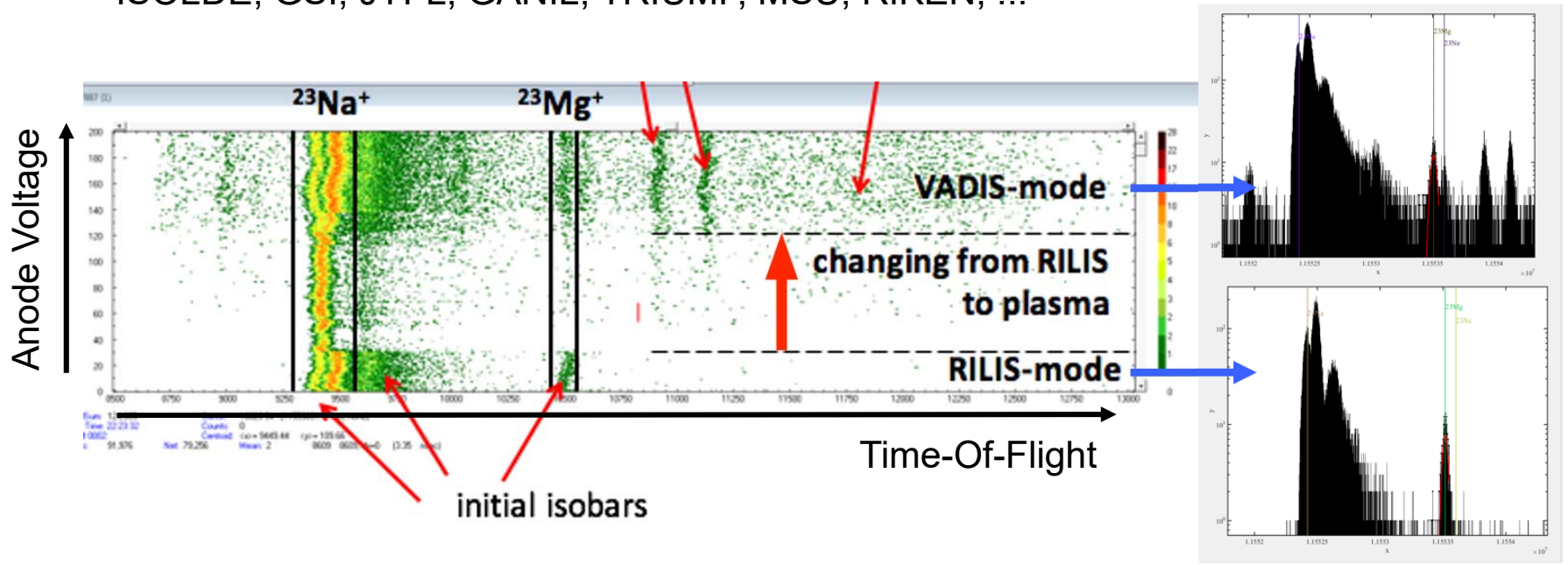
T. Day Goodacre,- NIM B 376 (2016) / Y. Martines,- NIM B 431 (2018) courtesy B. Marsh, Y. Martinez

- Multi-Reflection Time of Flight:

mass measurements – beam purification – beam diagnostics

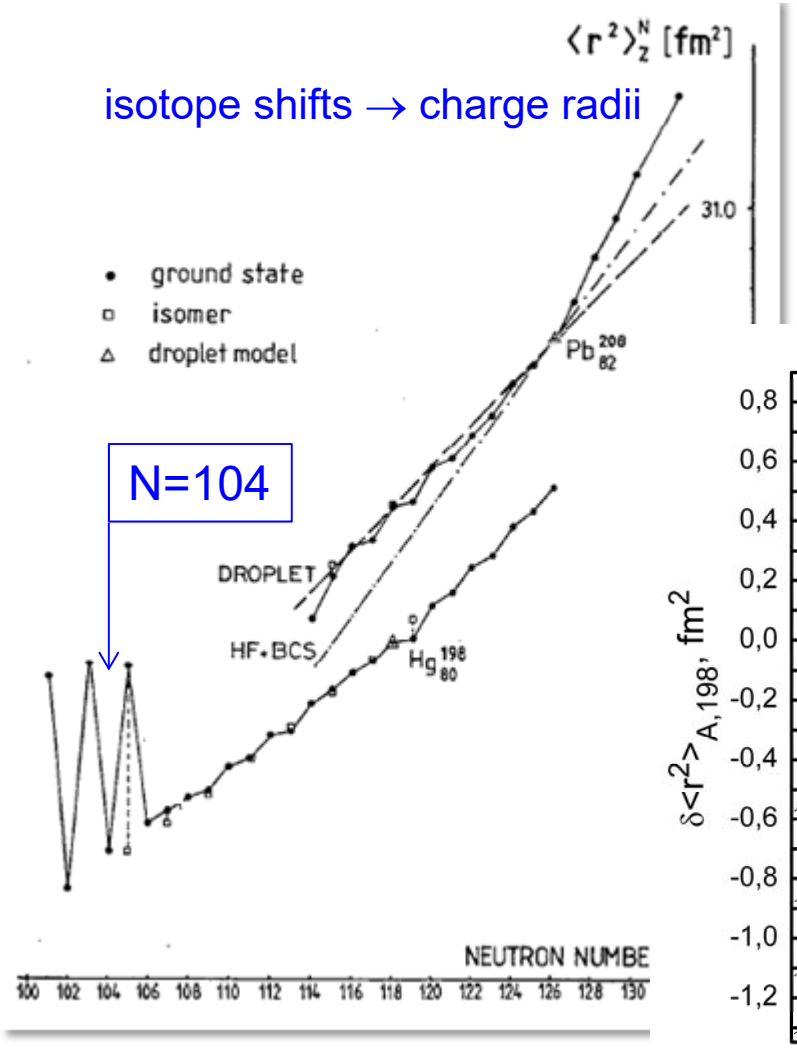


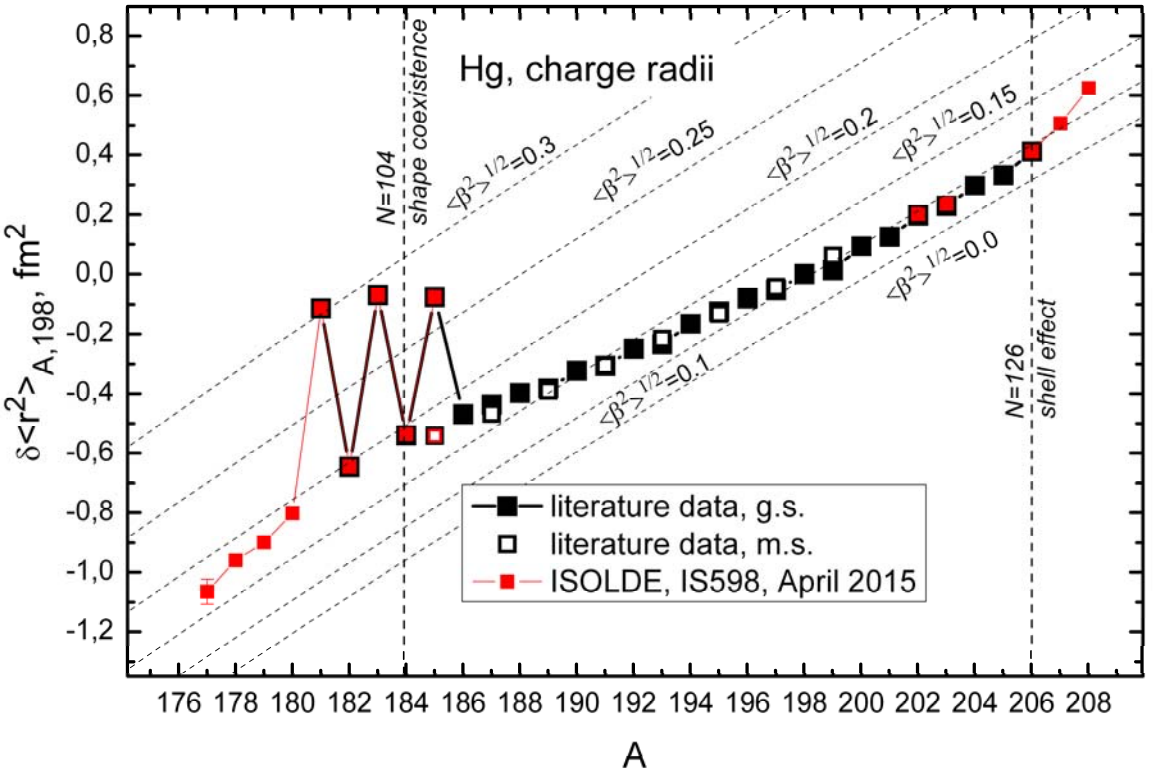
ISOLDE, GSI, JYFL, GANIL, TRIUMF, MSU, RIKEN, ...



 V. Manea ISOLTRAP; R. N. Wolf,- NIMA 686 (2012) 82

- Laser ionization spectroscopy of neutron-deficient mercury isotopes using VADLIS and MR-TOF





Bonn,- PLB 38 (1972) / B. Marsh,- Nat. Physics (2018) / S. Sels,- PRC 99 (2019)
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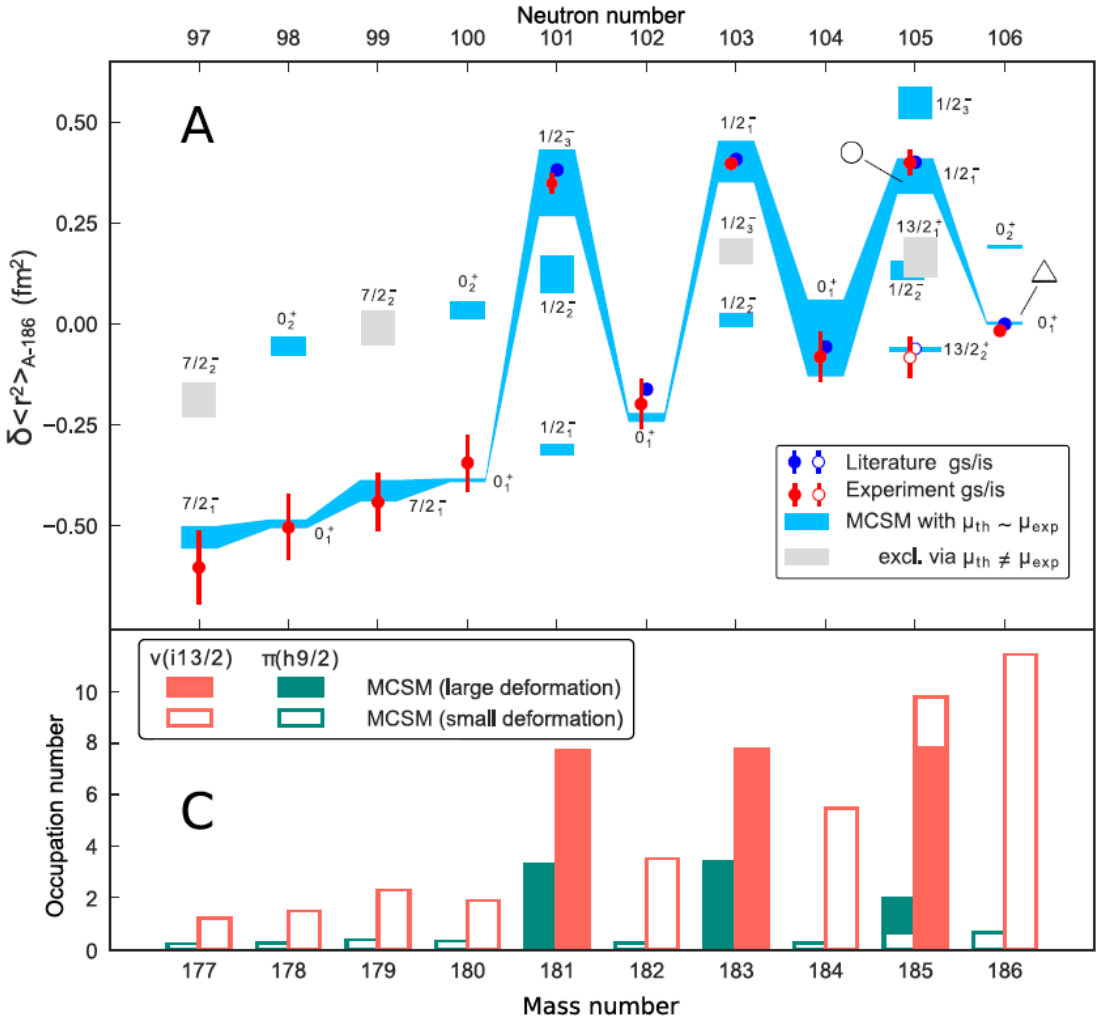
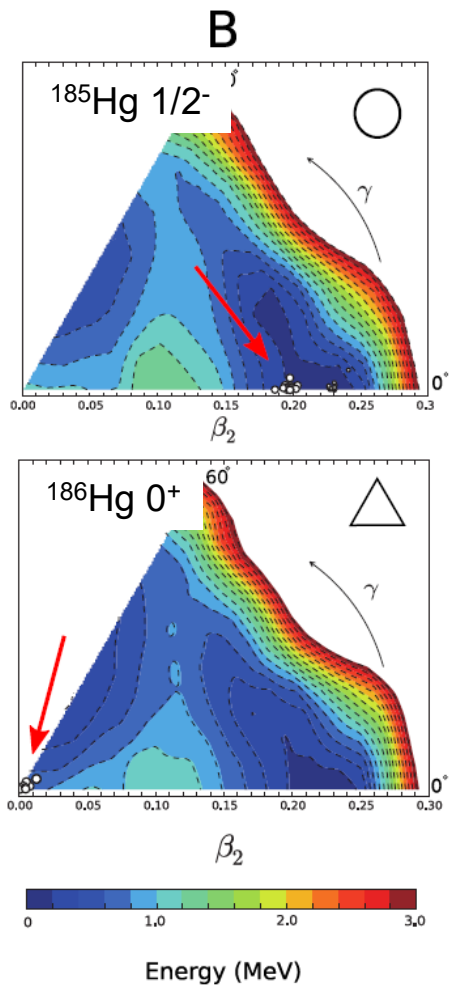
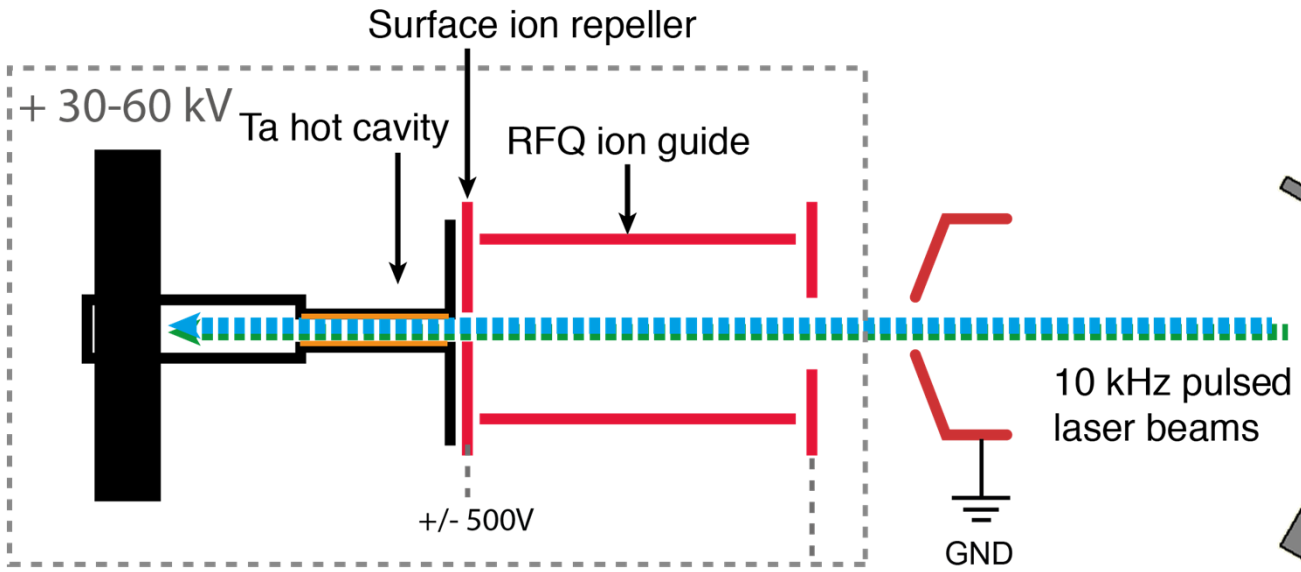
- Monte-Carlo Shell Model calculation (T. Otsuka)
  - ^{132}Sn core
  - π: $1g_{7/2} \rightarrow 1i_{13/2}$ (11 proton orbitals)
  - ν: $1h_{9/2} \rightarrow 1j_{15/2}$ (13 neutron orbitals)

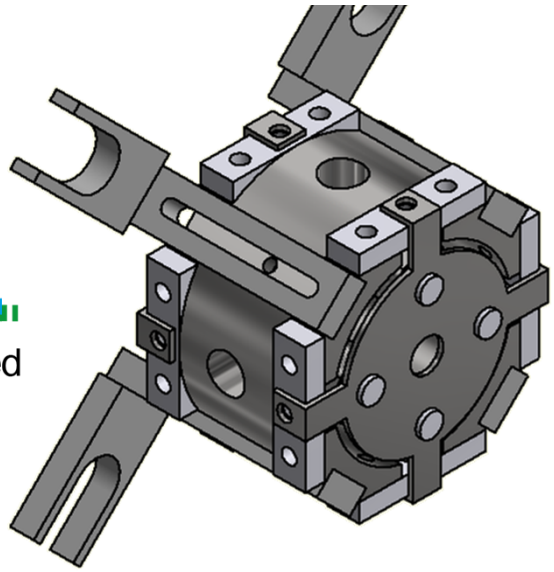




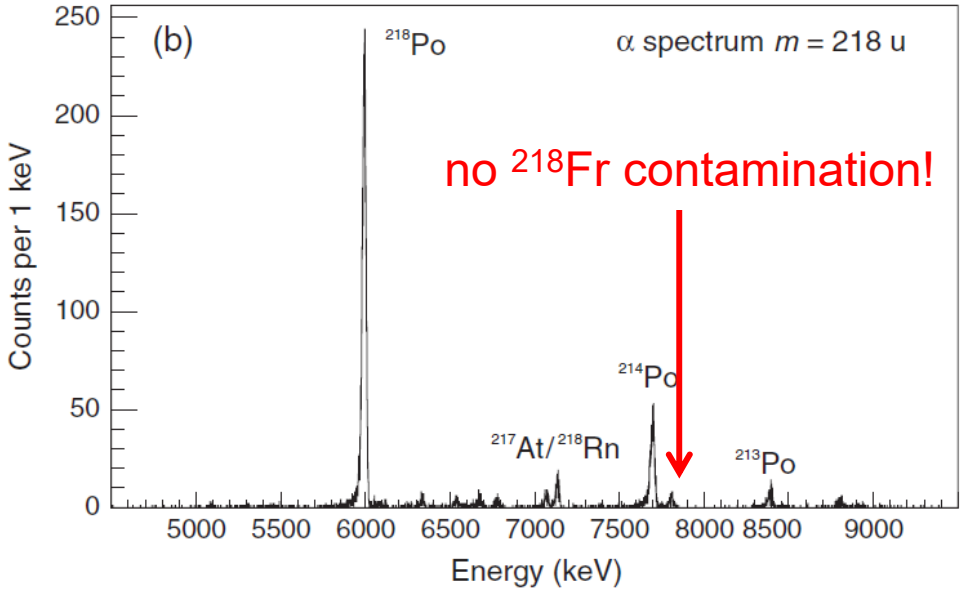
B. Marsh,- Nat. Physics (2018), S. Sels,- PRC 99 (2019)
KU LEUVEN

- High Selectivity RILIS — Laser Ion Source Trap (LIST)



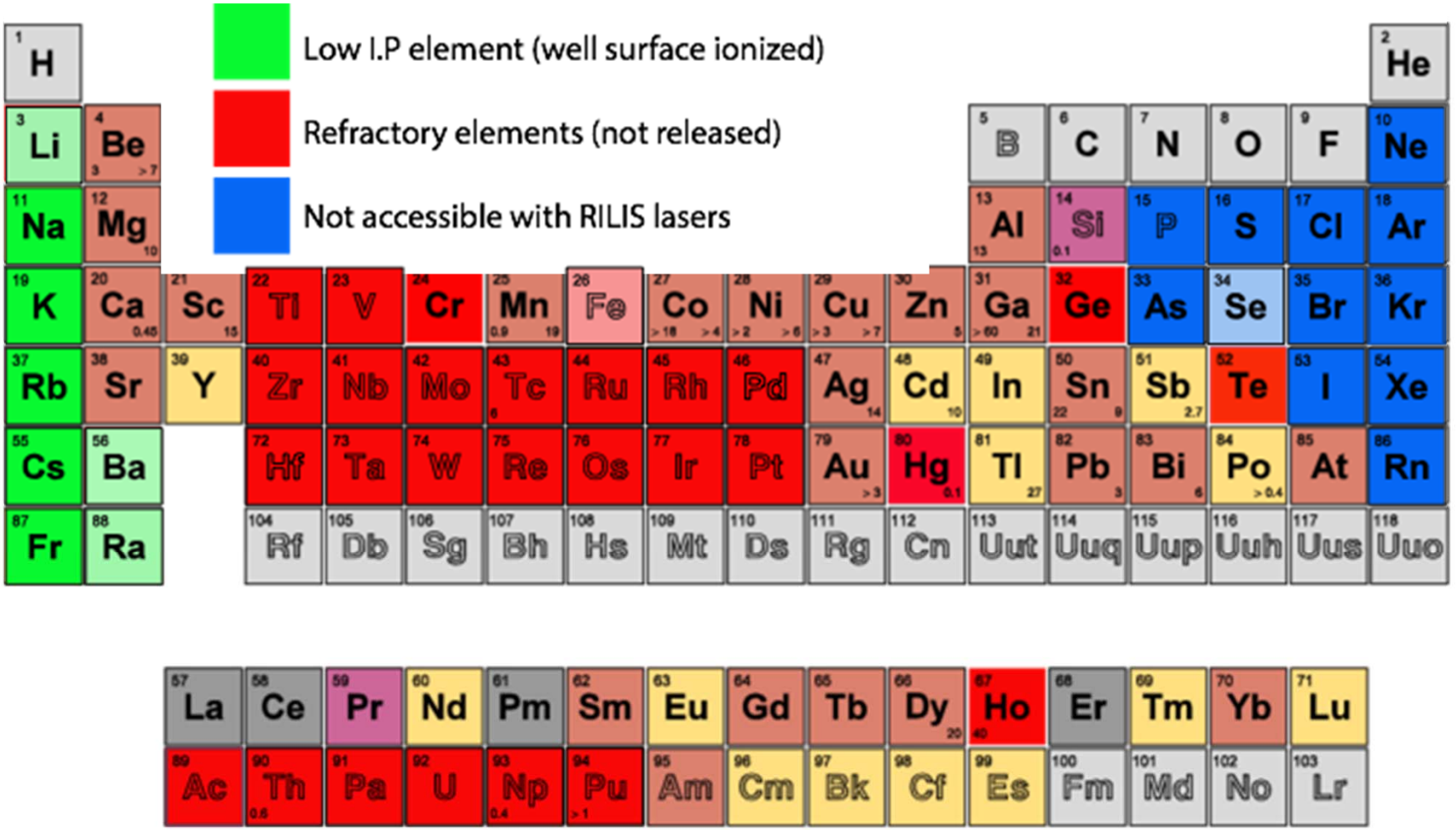


- 2-5 orders of magnitude surface ion suppression in LIST mode
- Efficiency loss factor of ~20



 Fink,- NIMB 344 (2015) 83, Phys.Rev.X5 (2015) 011018

- Inaccessible or problematic elements for ISOLDE RILIS

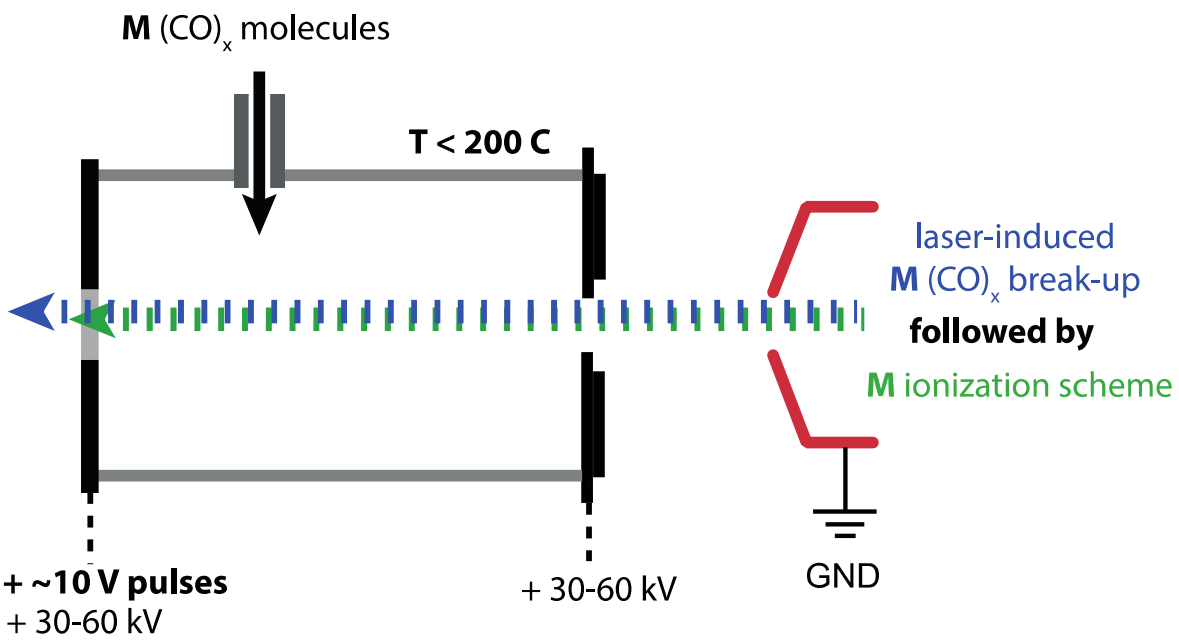


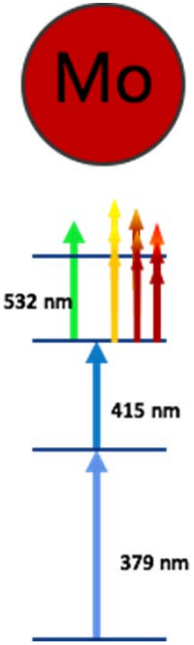
- $Mo(CO)_6$ (Molybdenum hexacarbonyl) - Molecular breakup + ionization

1) Creation and transport of volatile molecules of refractory metals

2) Dissociation by laser pulse

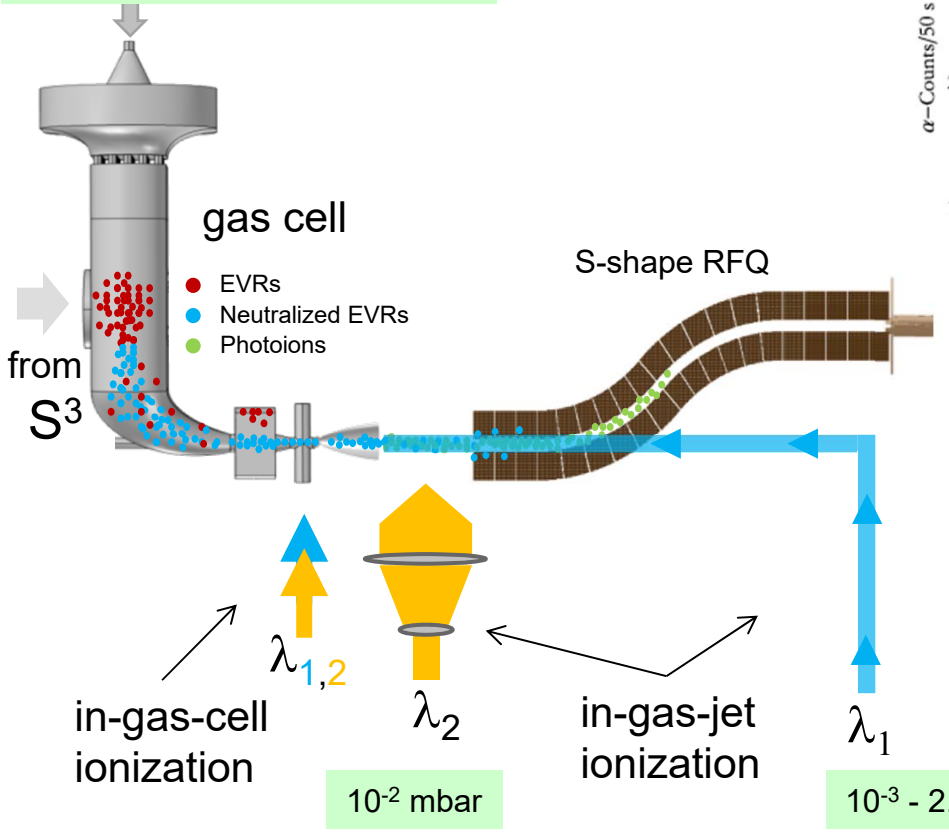
3) Resonance ionisation before atom/wall collision



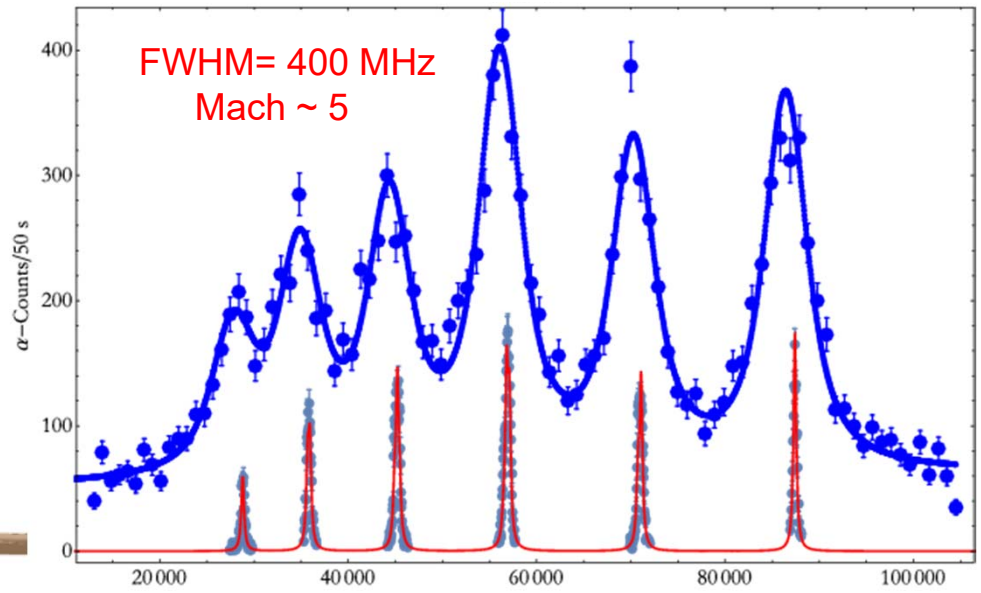


- In Gas Laser Ionization and Spectroscopy (IGLIS) @ S3 (GANIL), GSI (see talk M. Block), MARA (JYFL), RIKEN

200 - 500 mbar Ar or He



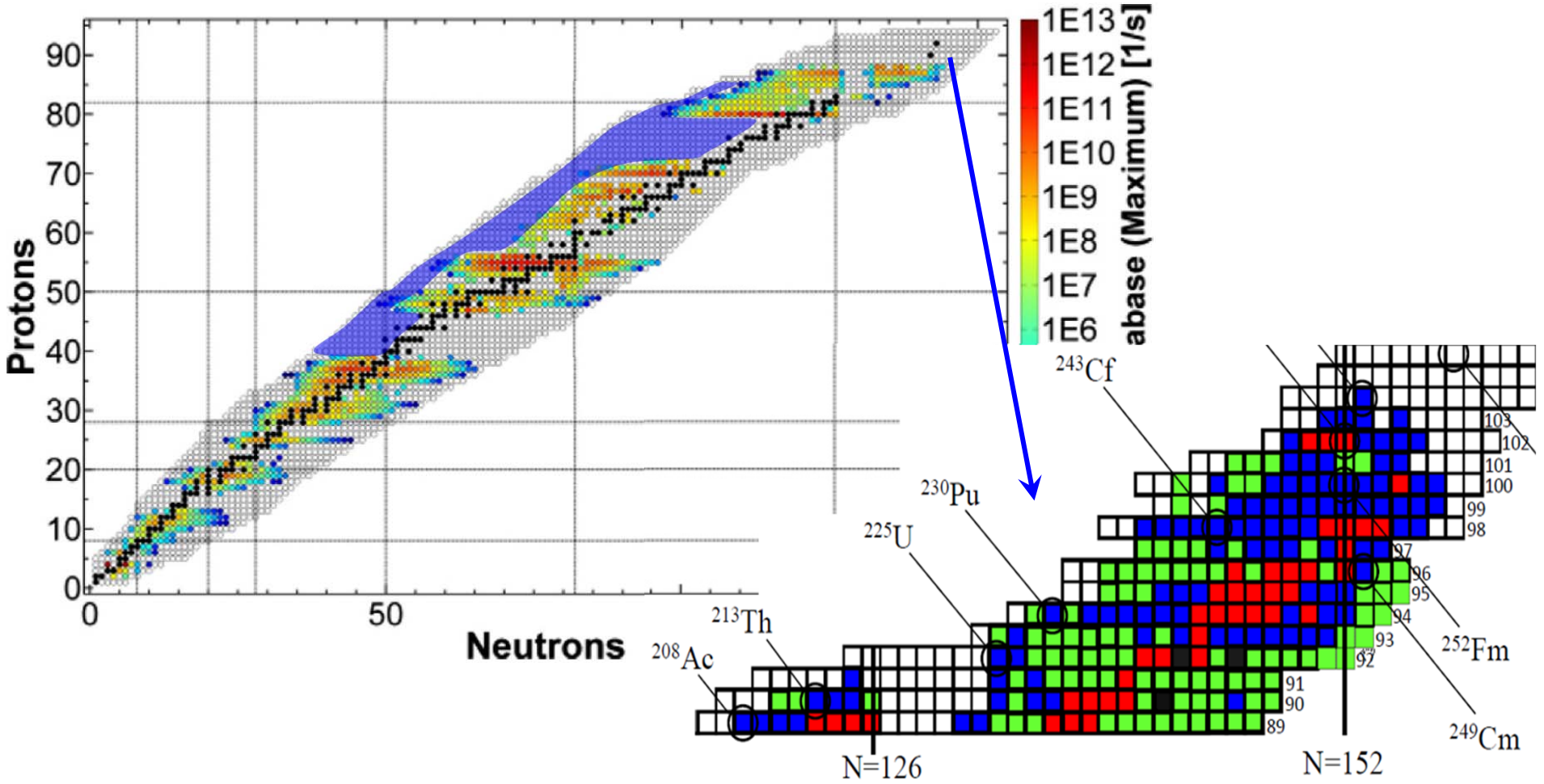
^{215}Ac $T_{1/2}$ = 0.17 s J_π = (9/2$^-$)



Ferrer,- NIM B317 (2013) 570 Kudryavtsev,- NIM B297 (2013) 7

IGLIS @ S3

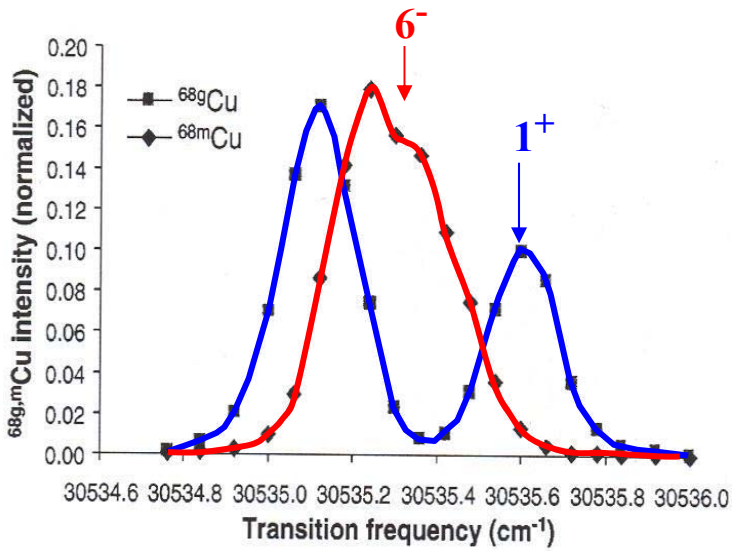
- High intensity heavy-ion LINAC: >10 pμA
- Super Separator Spectrometer (S3)
- N=Z nuclei (towards ^{100}Sn) and heavy and Super Heavy Elements

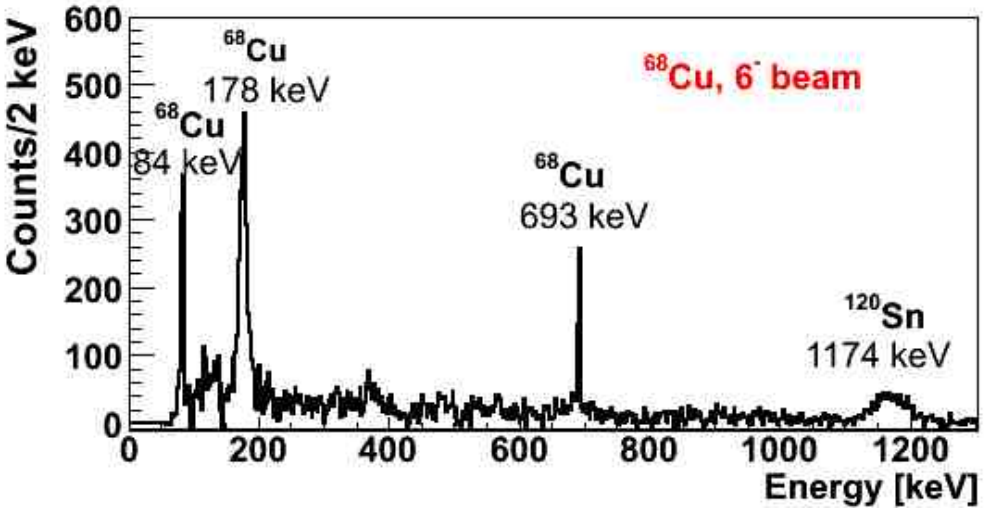


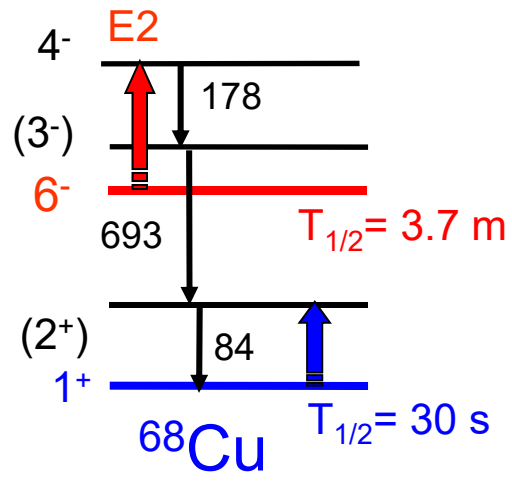
Kudryavtsev NIM B297 (2013), Ferrer NIMB317 (2014) and Nat. Comm. (2017)

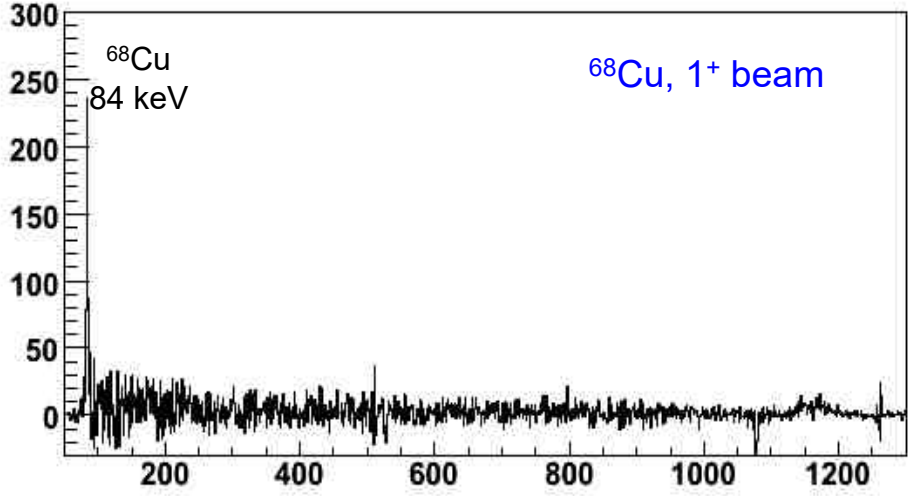
Production/study of Isomeric Beams – the Spin Degree of Freedom

- Use the hyperfine structure to produce isomeric beams (for decay studies, mass measurements and Coulomb excitation/transfer reactions after post-acceleration)







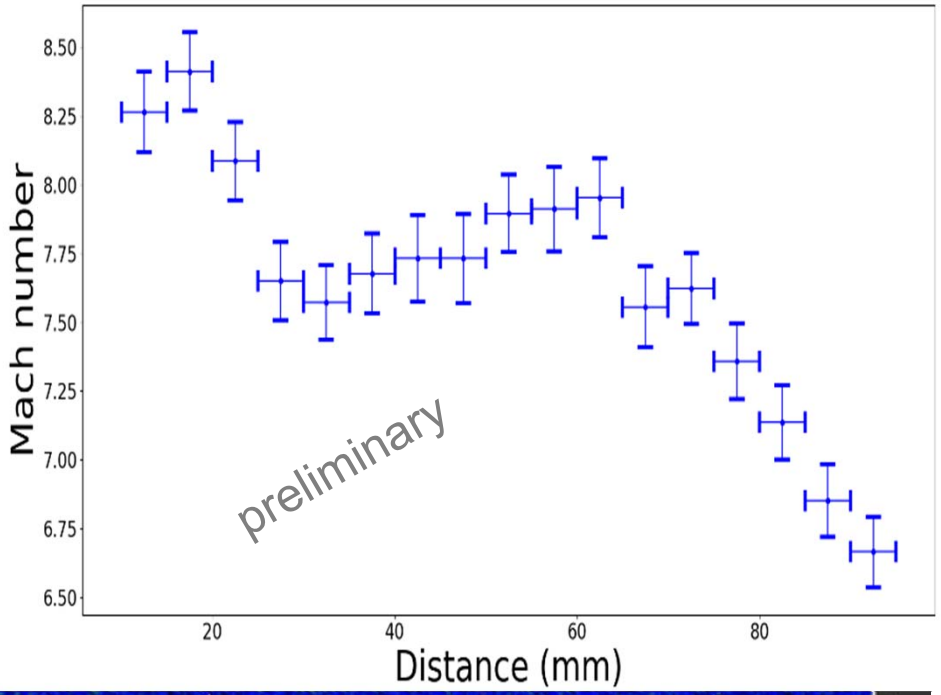


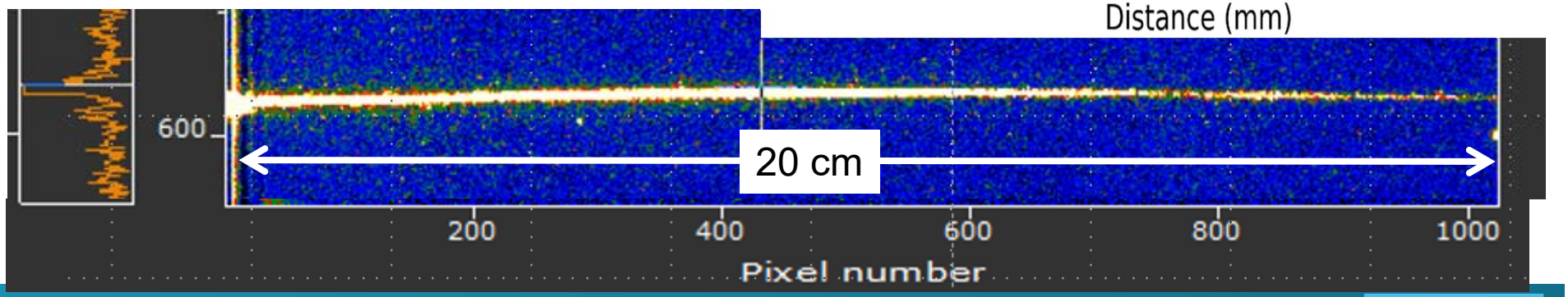
I. Stefanescu,- PRL (2007)

Production/study of Isomeric Beams – the Spin Degree of Freedom

- Use the hyperfine structure to produce isomeric beams (for decay studies, mass measurements and Coulomb excitation/transfer reactions after post-acceleration)
- Limited by the Doppler broadening and the hyperfine structure

- Reduce the Doppler effect:
  - CRIS experiment at ISOLDE
    (Garcia Ruiz,- Nat. Phys. (2016))
  - Doppler-free two-photon in-source laser spectroscopy at ISOLDE
    (Chrysalidisa,- NIM B (2019))
  - S3-LEB at GANIL (in-gas jet laser ionization)
    (Ferrer,- Nat. Comm. (2017))



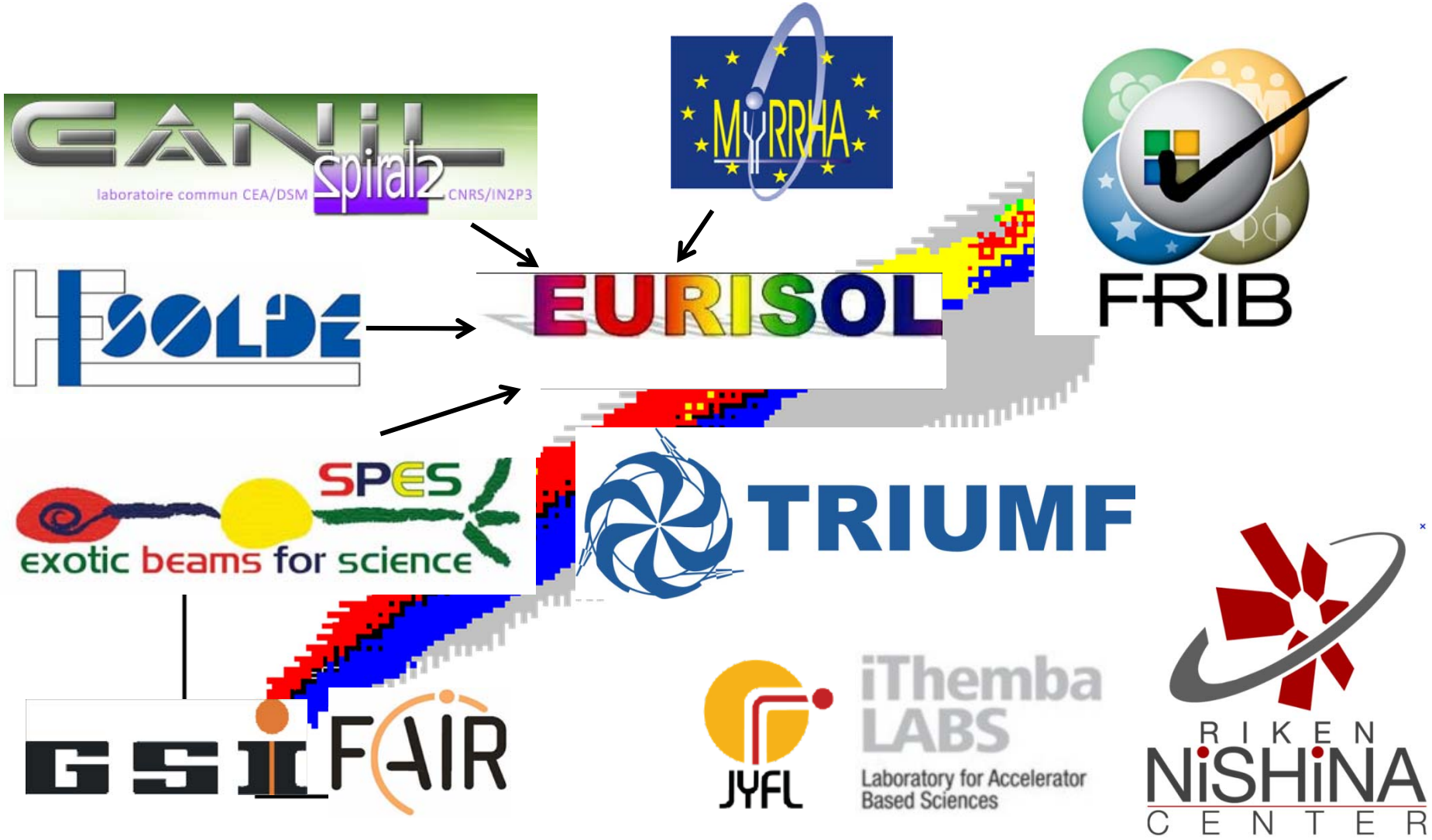


S. Zadvornaya, PRX9 (2018)

Conclusion and Outlook

- Substantial progress in ISOL-based facilities leading to new, more intense RIB with increased purity and improved ion beam properties
  - Target materials
  - Laser ionization
  - Ion manipulation / charge breeding
  - Gas-cell based systems
  - Post acceleration
- Strong cross fertilization between target-ion source developments and developments in instrumentation (e.g. lasers, ion manipulation, MR-TOF,...)
- Crucial next steps:
  - further optimization of efficiency/selectivity
  - developments to cope with the higher primary beam intensities

Coordinated action between different Radioactive Ion Beams Factories



Thanks to:
Bruce Marsh, Fredrik Wenander, Thierry Stora, Pierre Delahaye, Alex Gottberg

see talk Wednesday : R. Bark – South African Isotope Facility