Lasers in gas cells and jets for the production and spectroscopy of exotic nuclei

Overview

Production of pure radioactive ion beams

Principles of laser ionization

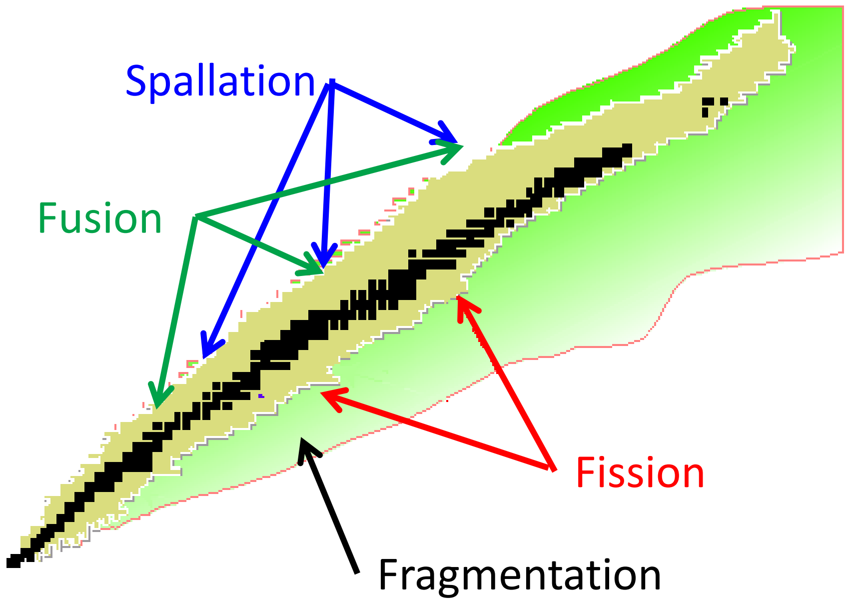
Resonance Ionization Laser Ion Source (RILIS)
- gas cell =>LISOL

Laser spectroscopy

New developments

Conclusions

Production of pure radioactive ion beams



- Choice of the reaction
  - Heavy-ion fusion most selective
- Purification **in flight (IF)** or after stopping

ISOL technique

thick target <=> thin target

solid catcher <=> gas catcher

neutralisation

ion survival

IGISOL

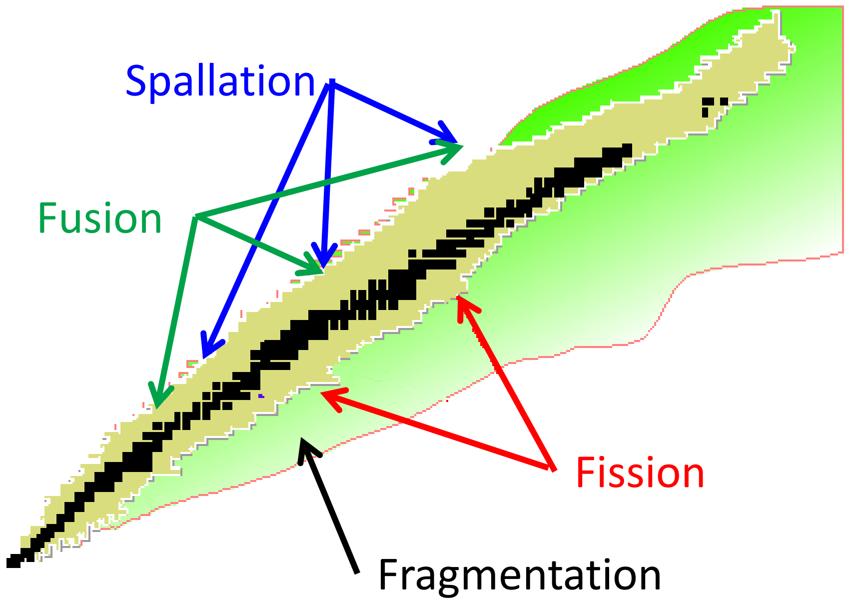
diffusion out of the target
transfer to the ion source
Z & $T_{1/2}$ dependence

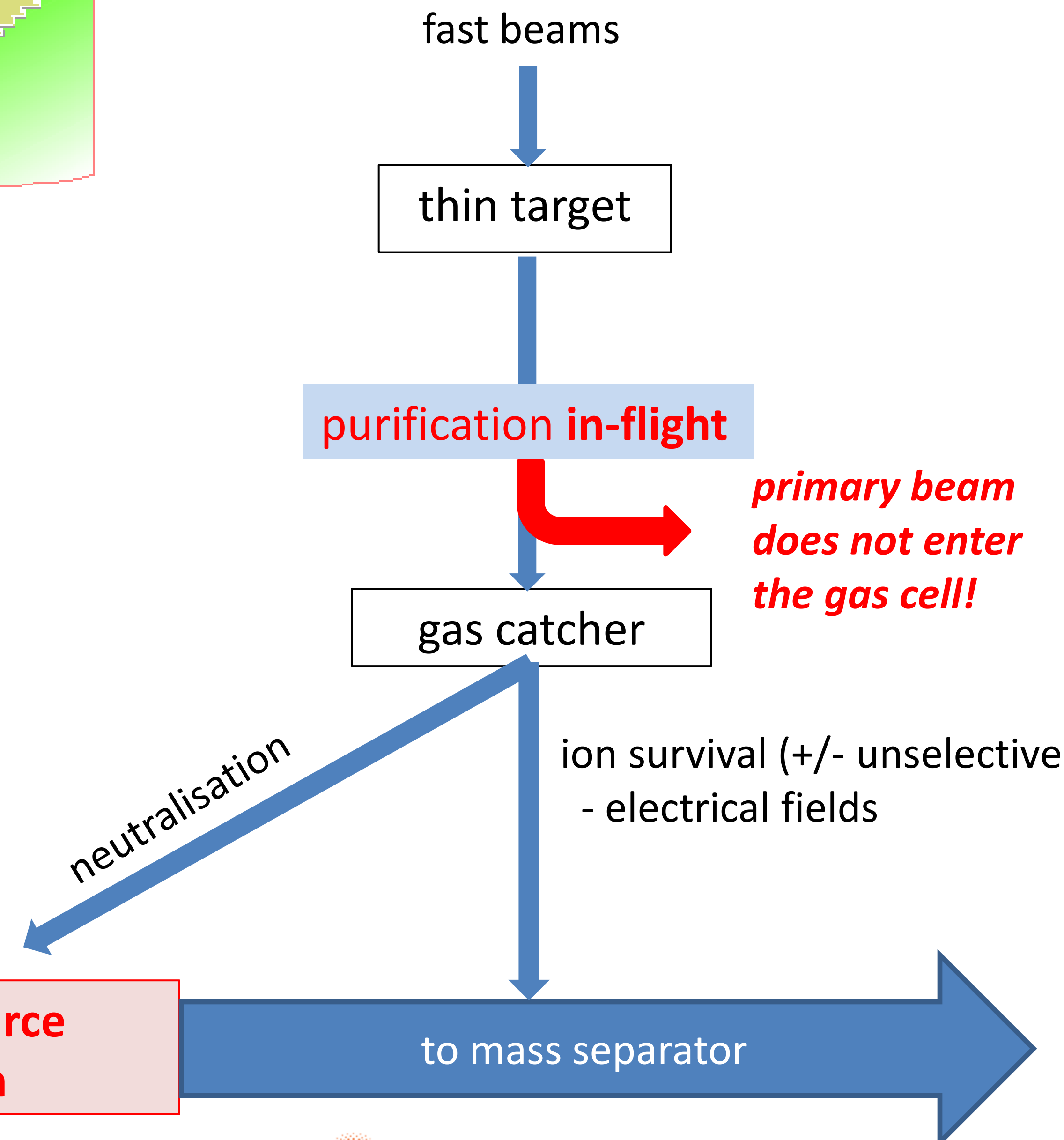
diffusion out of the catcher
transfer to the ion source
Z & $T_{1/2}$ dependence

Laser Ion Source
Z selection

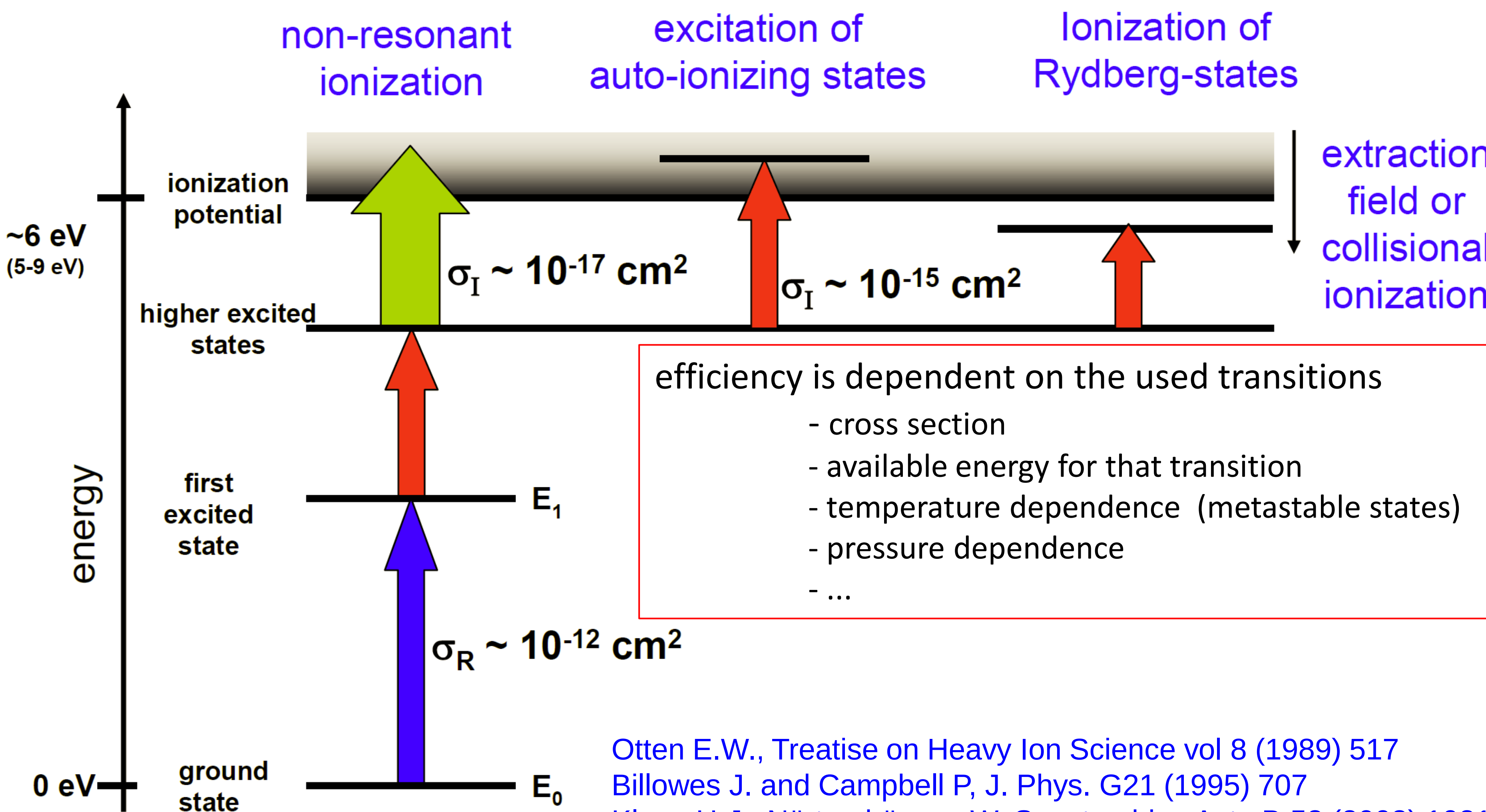
to mass separator

Production of pure radioactive ion beams





Principles of laser ionization



efficiency is dependent on the used transitions

- cross section
- available energy for that transition
- temperature dependence (metastable states)
- pressure dependence
- ...

courtesy I. Moore

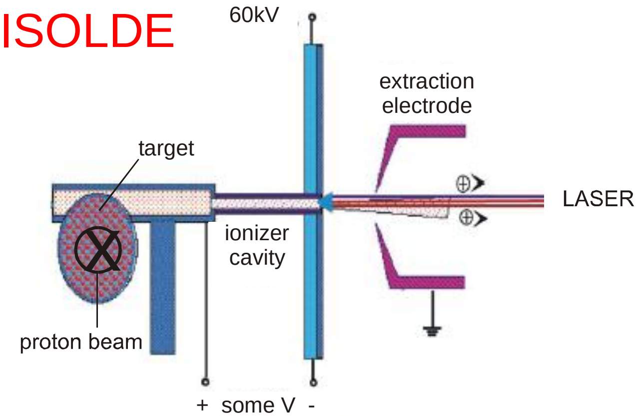
Otten E.W., Treatise on Heavy Ion Science vol 8 (1989) 517
Billowes J. and Campbell P, J. Phys. G21 (1995) 707
Kluge H-J., Nörtershäuser, W. Spectrochim. Acta B 58 (2003) 1031
Kluge H-J., Hyperfine Interact. 196 (2010) 295
Cheal B. and Flanagan K., J. Phys. G. 37 (2010) 113101

The Z selectivity of the RILIS approach

Possible sources of contamination **=> Solution**

- Hot cavity
  - **Thermo-ionization** => LIST (see Daniel Fink)
    activity on RFQ rods

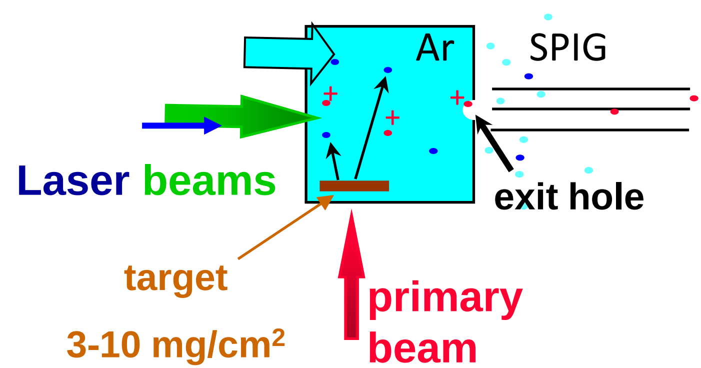
ISOLDE



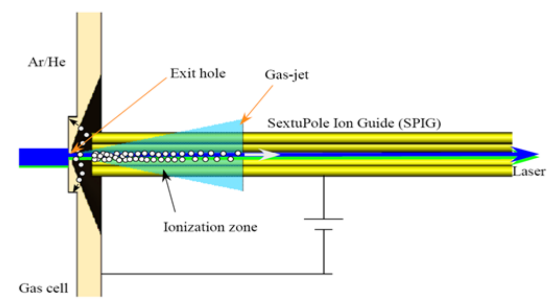
- Gas cell
  - **Surviving ions**
  - **Re-ionization by radiation**
  - **Ionization in the decay**

  => Dual chamber
  Ion collector

LISOL



- Gas jet
  - **Activity on RFQ rods** => ?

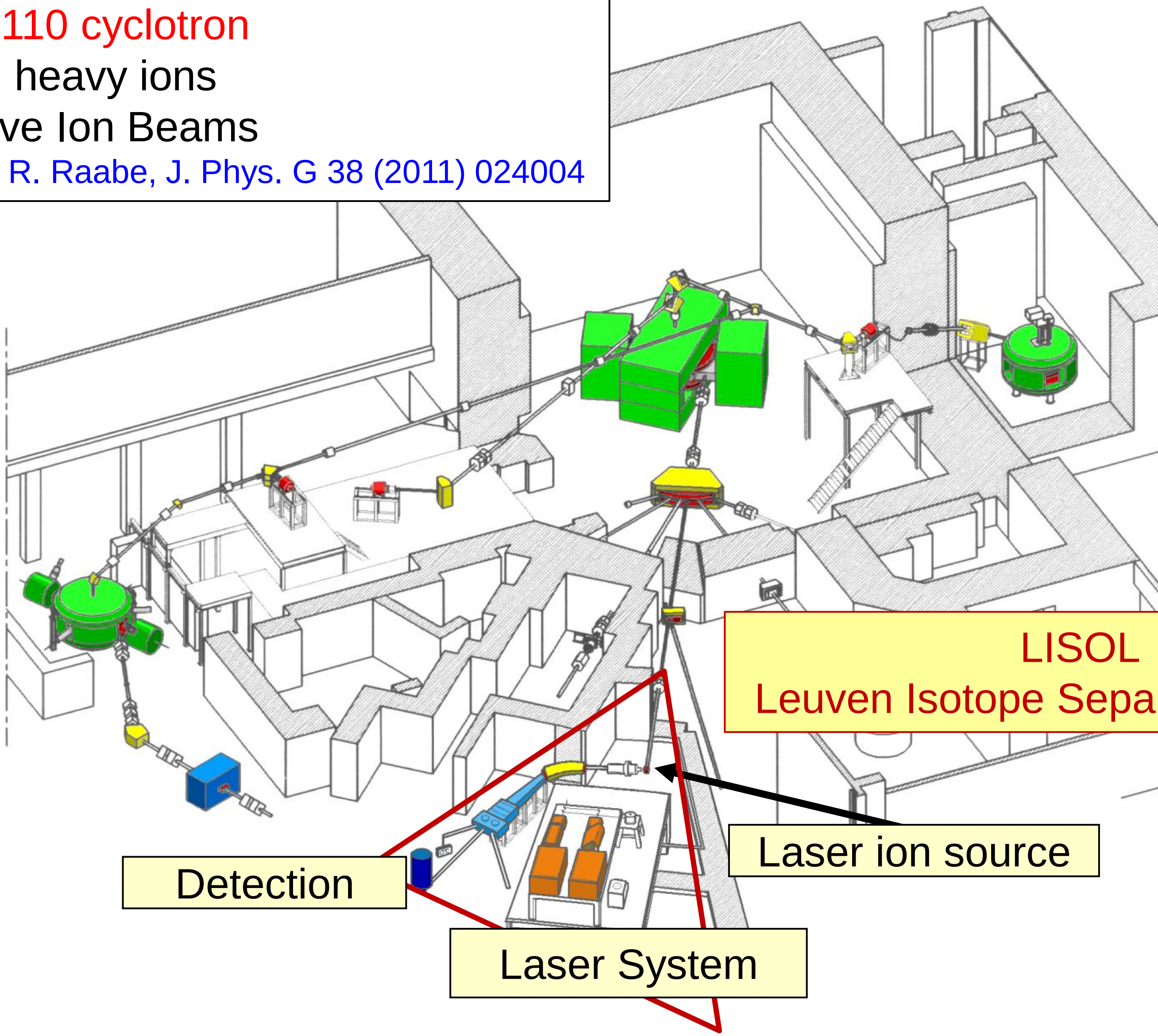


Decay spectroscopy with In Gas Laser Ionization and Spectroscopy (IGLIS) technique

CYCLONE110 cyclotron

- p,d,α and heavy ions
- Radioactive Ion Beams

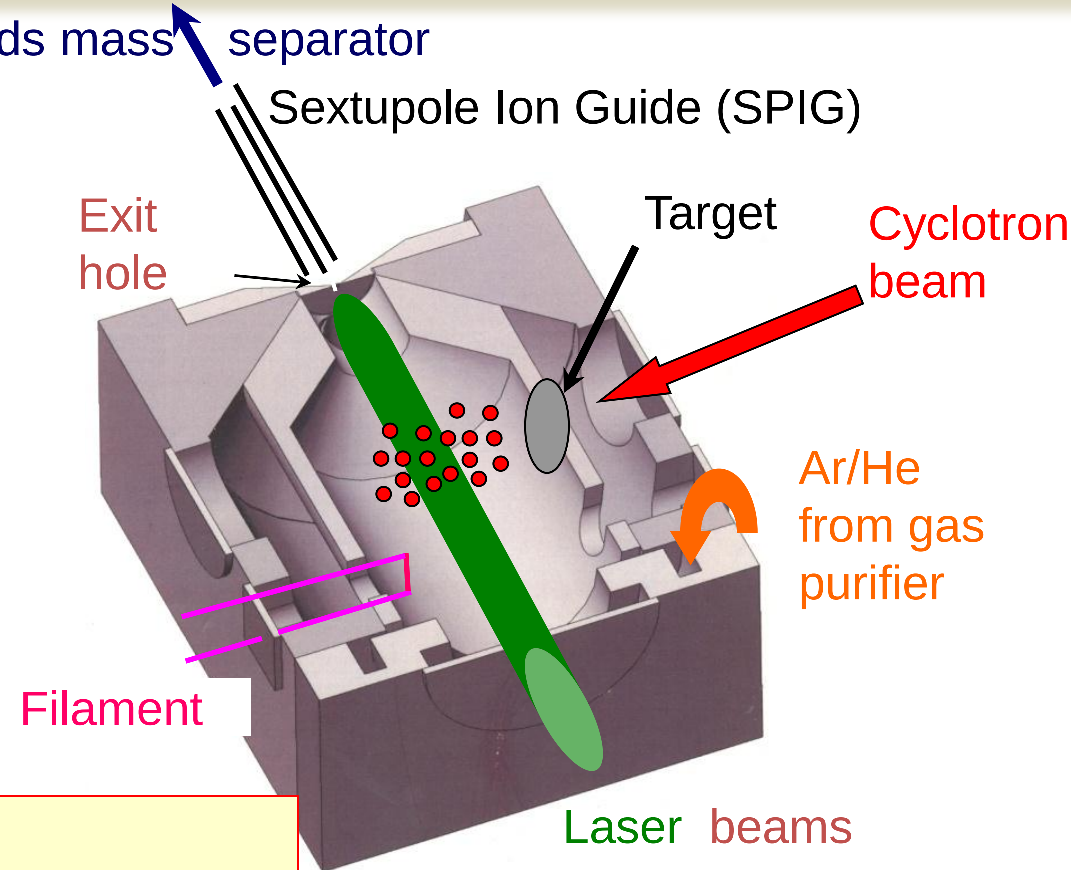
M. Huyse and R. Raabe, J. Phys. G 38 (2011) 024004



LISOL Laser Ion Source

Laser requirements
- two-step ionization
- 200 Hz pulse repetition rate
- 50 ns pulse 60 mJ/pulse
- Tunable range 205 - 800 nm

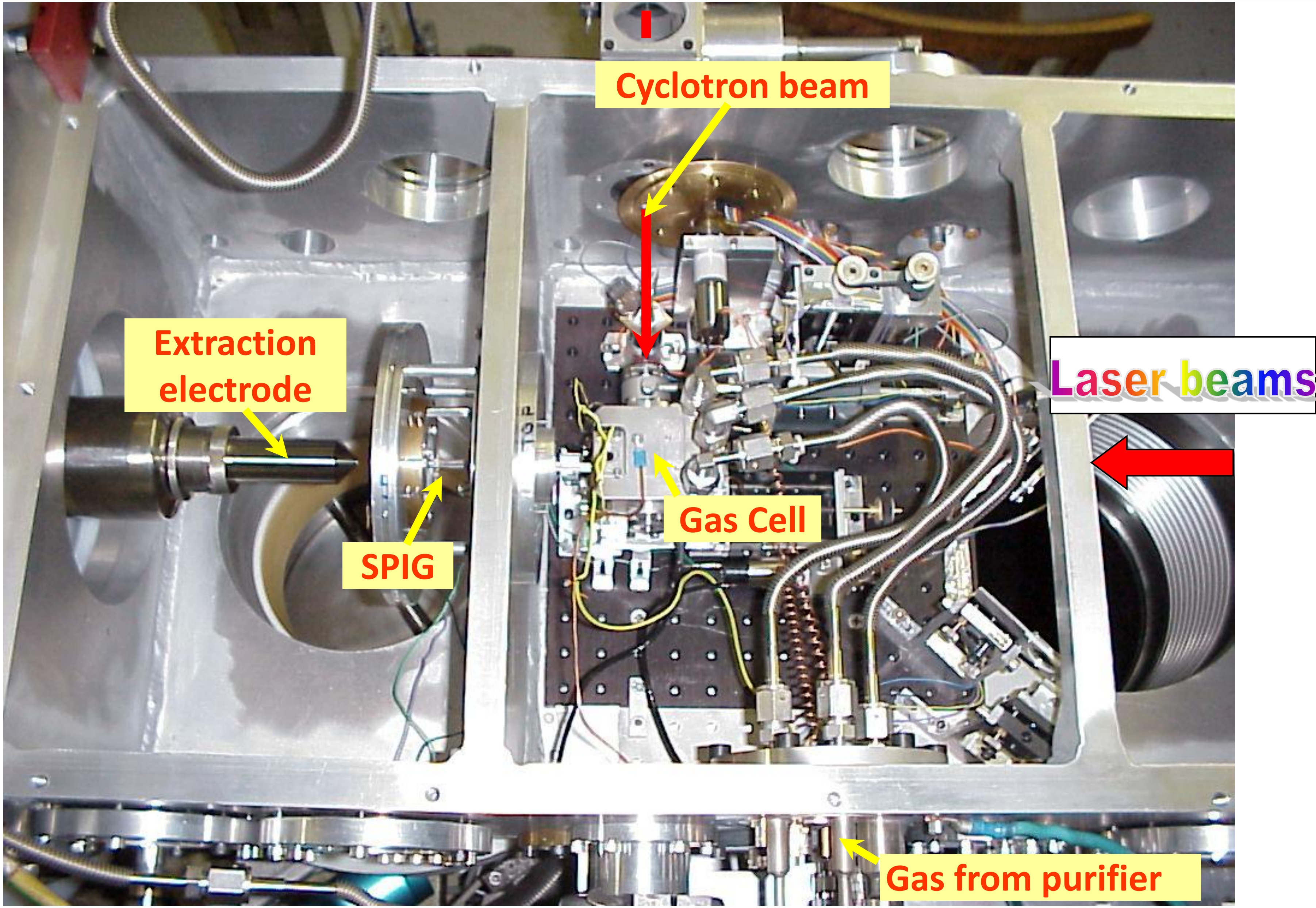
Gas requirements
- He/Ar
- < 500 mbar
- **ppb purity**
- 1 mm exit: 140 cm^3Ar/s



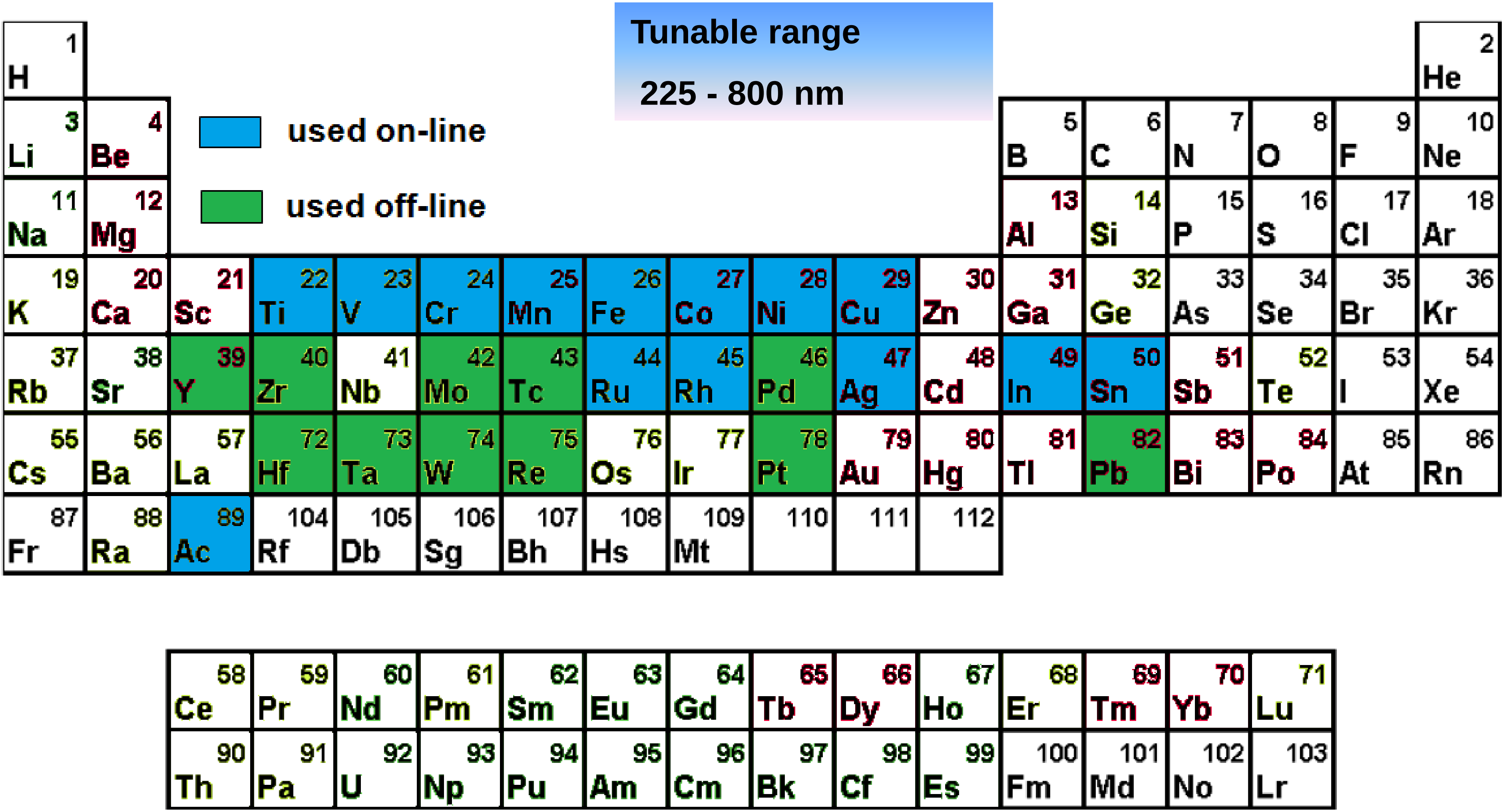
- 'Reasonable' efficiency
  - 0.1 – 5 %
- Selective ionization: laser on/off
  - 30-80 p-induced fission reactions
  - 100-200 H.I. fusion evaporation reactions
- Refractory elements (buffer gas cell)
- 'Short' delay times: 100-400 ms

A gas cell for thermalizing, storing and transporting radioactive ions and atoms.
Part I: Off-line Y. Kudryavtsev et al., NIMB179 (2001) 412
Part II: On-line M. Facina et al. , NIMB 226 (2004) 401

Front end of the LISOL mass separator

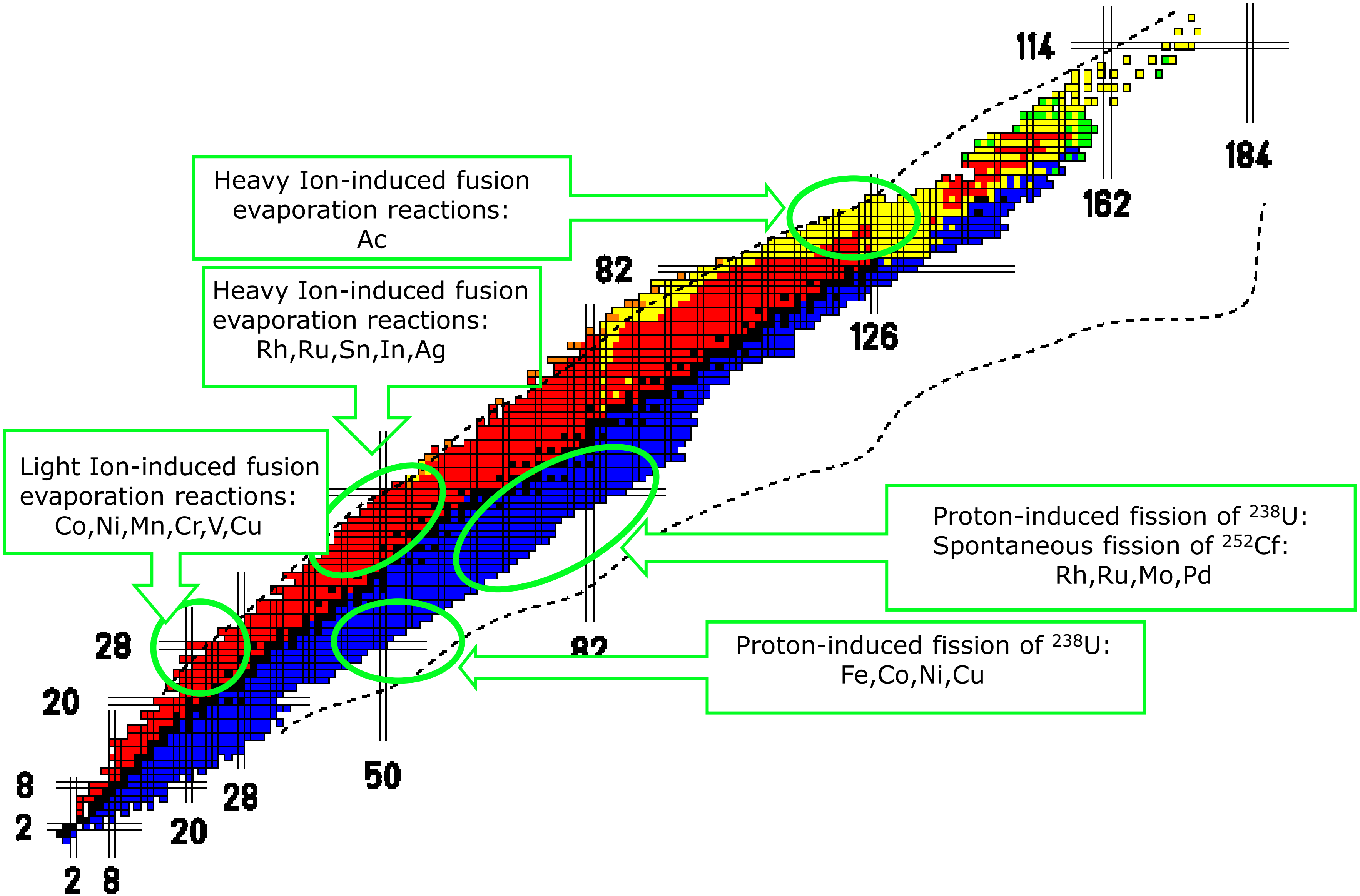


Two-step laser ionization schemes used

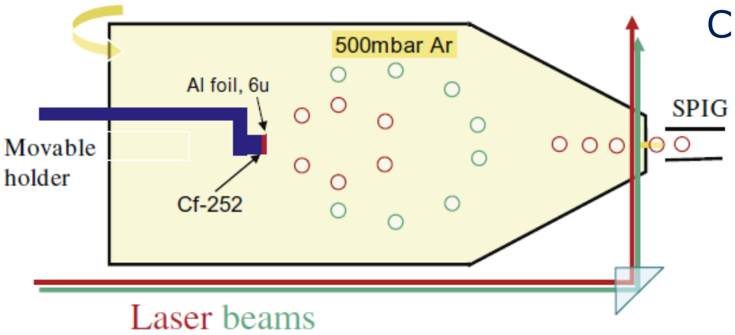


80% of all elements can in principle be ionized by the LISOL laser system

LISOL Radioactive Ion Beams since 1994

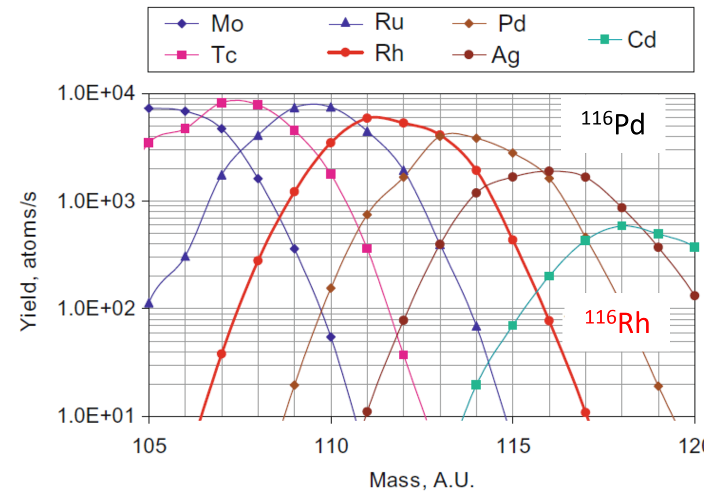


The quest for pure Radioactive Ion Beams

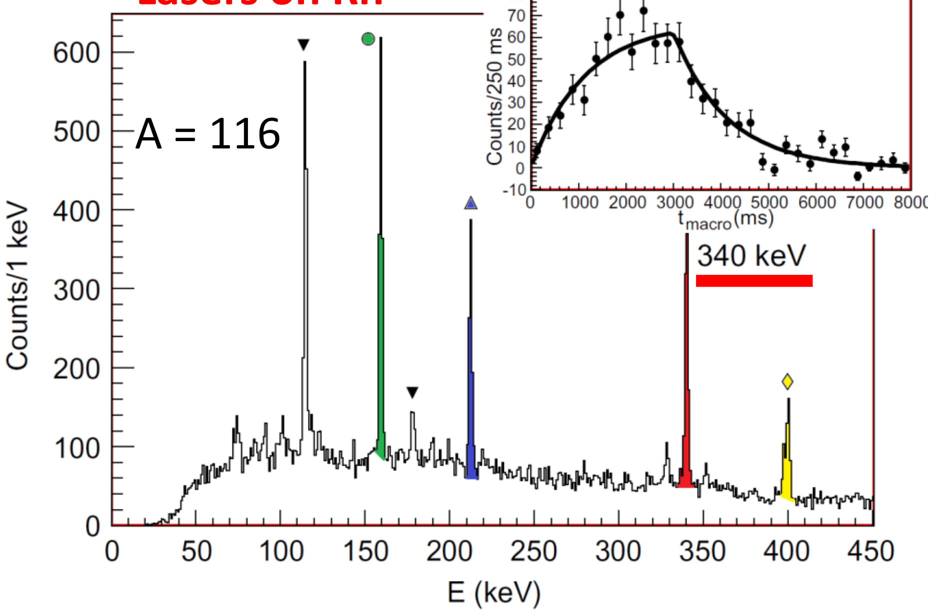


Characterization of the gas cell with a 0.78 mCi ^{252}Cf source

Yu. Kudryavtsev et al., NIMB266 (2009) 4368

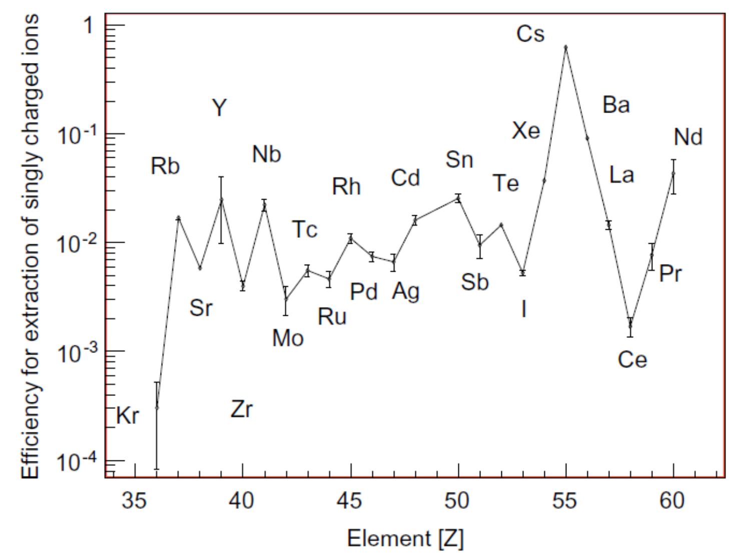


Lasers on Rh

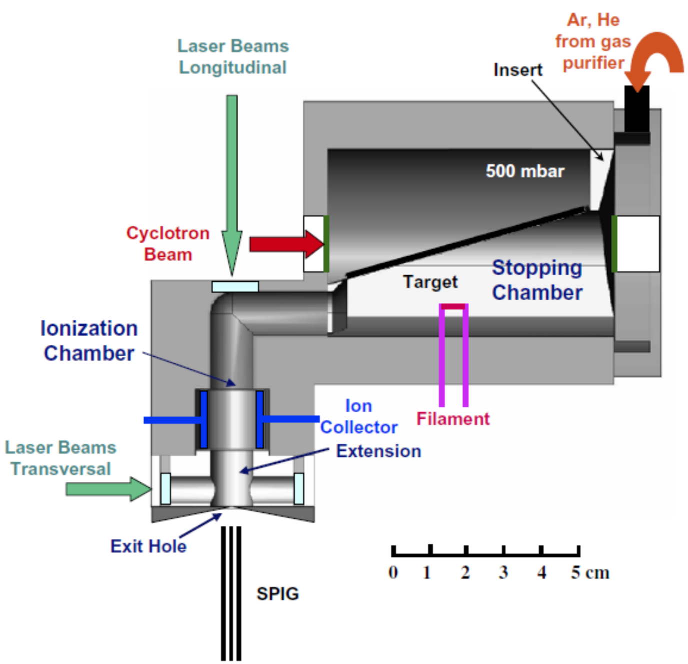


unwanted activity

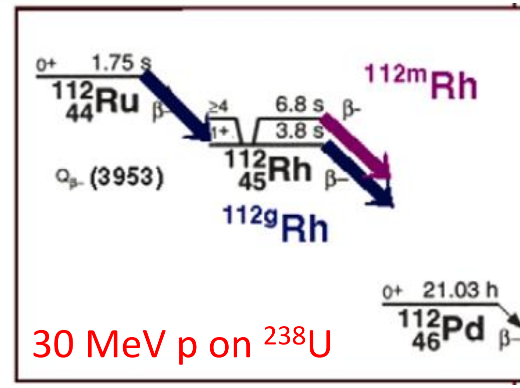
▼-^{116}Pd, ●-^{100}Nb, ▲-^{100}Y, ◆-^{100}Zr



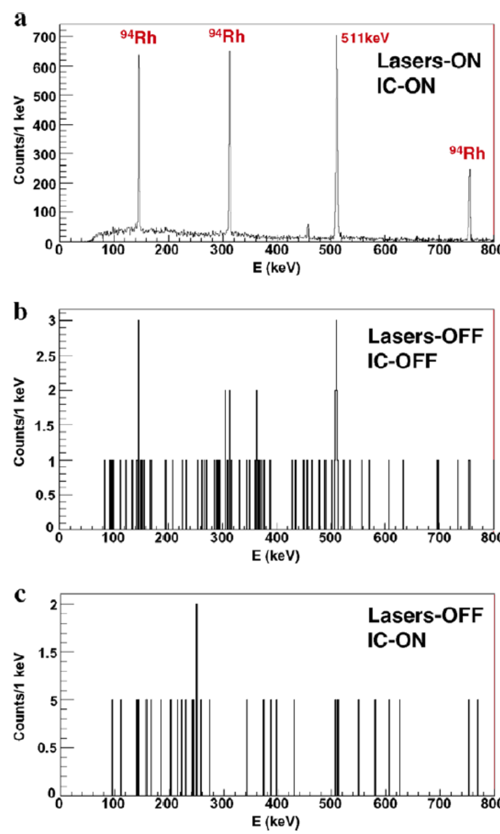
The quest for pure Radioactive Ion Beams

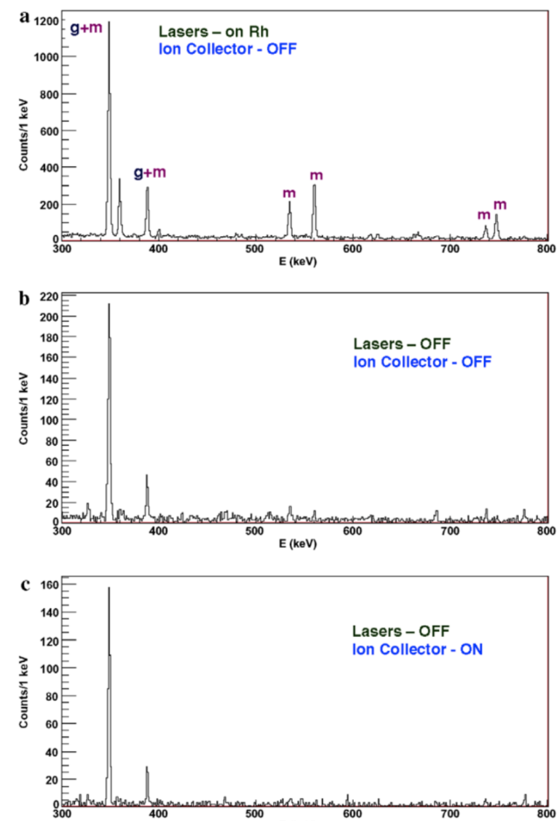


a remaining problem:
ionization after decay



^{40}Ar on ^{58}Ni





Dual Chamber gas cell

screen the laser ionization region from the stopping region

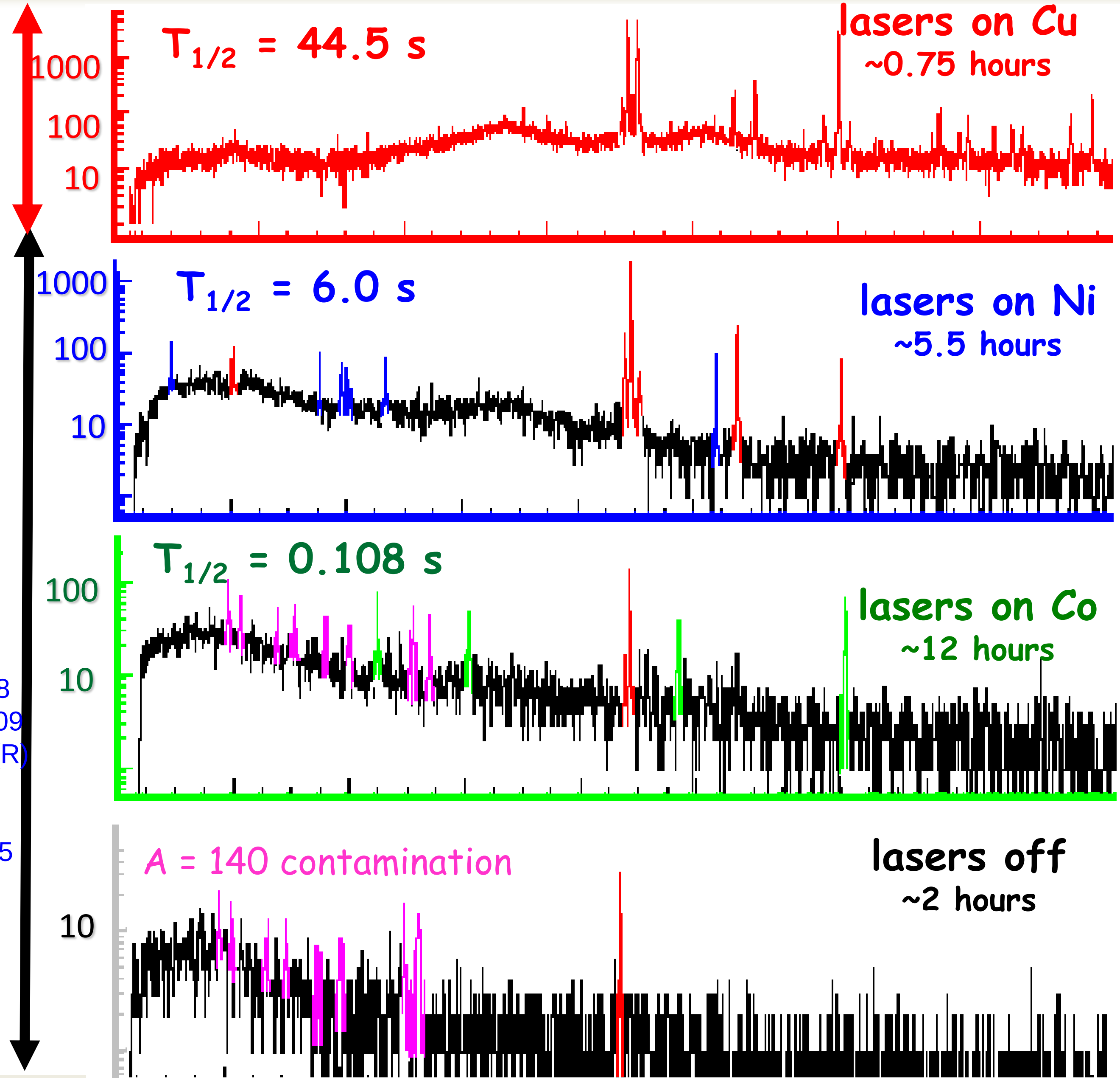
collect the surviving ions before they enter the laser ionization region

Yu. Kudryavtsev et al., NIMB267 (2009) 2908

Production of neutron-rich A=70 isotopes by fission

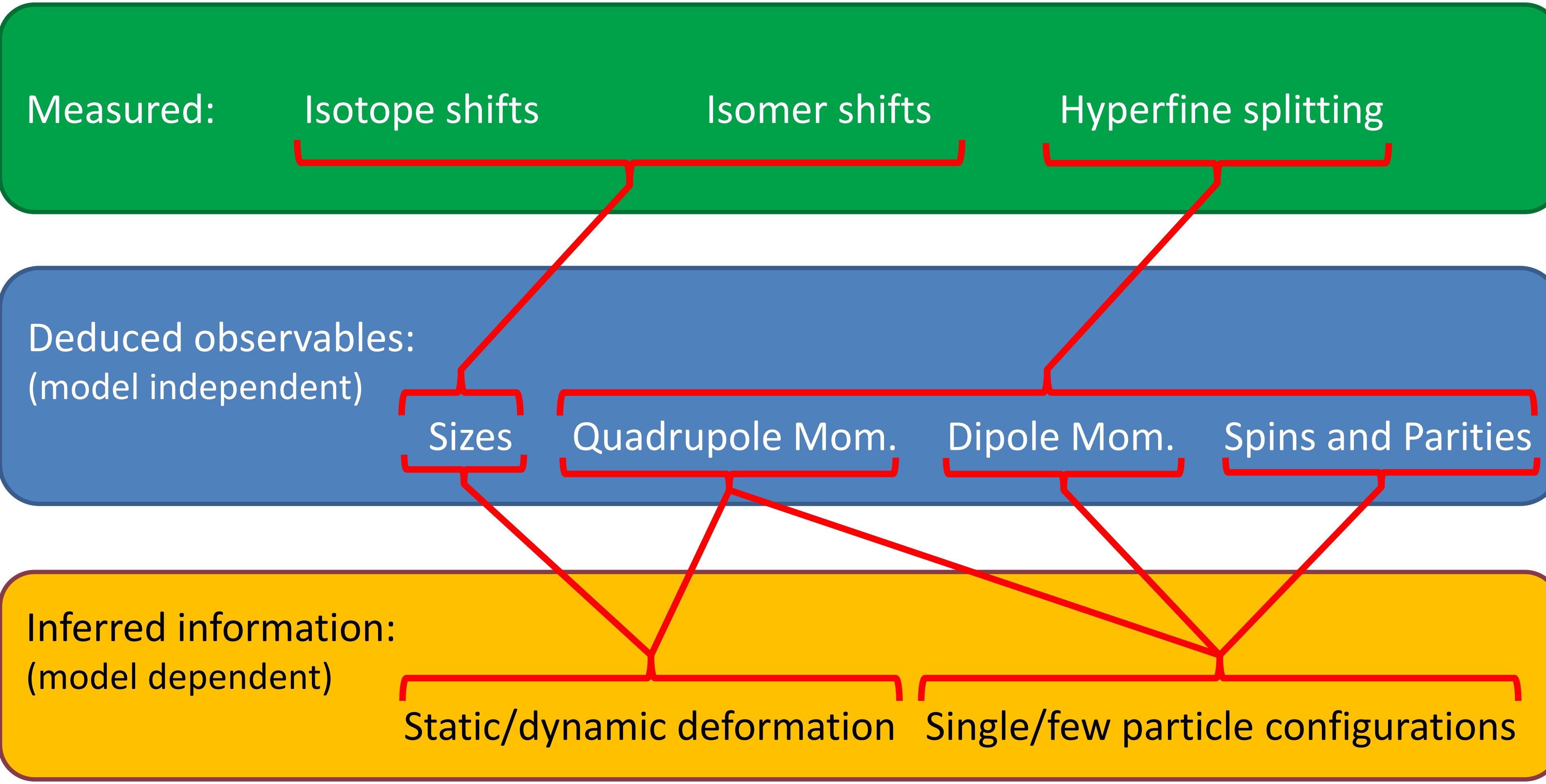
ISOLDE
1 GeV p on ^{238}U

LISOL
30 MeV p on ^{238}U



S. Franchoo et al., PRL 81 (1998) 03100
L. Weissman et al., PRC59 (1999) 2004
W. Mueller et al., PRL83 (1999) 3613
W. Mueller et al., PRC61, (2000) 054308
S. Franchoo et al., PRC 64 (2001) 054308
J. C. Thomas et al., PRC 74 (2006) 054309
D. Pauwels et al.,PRC 78 (2008) 041307(R)
D. Pauwels et al., NIMB266 (2008) 4600
D. Pauwels et al., PRC79 (2009) 044309
I. Stefanescu et al., PRC79 (2009) 044325

Laser spectroscopy for nuclear physics

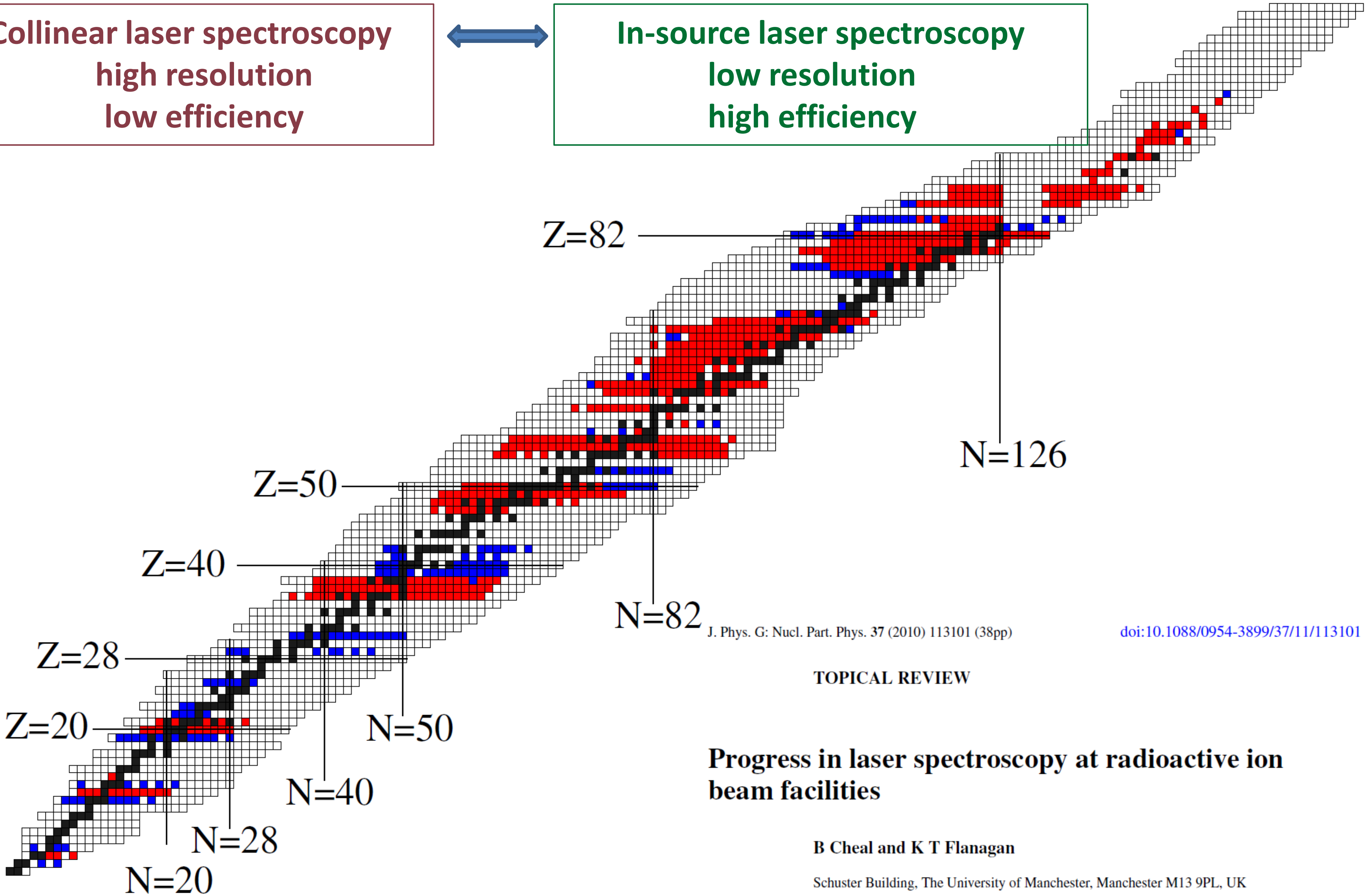


Laser spectroscopy

Collinear laser spectroscopy
high resolution
low efficiency

↔

In-source laser spectroscopy
low resolution
high efficiency



J. Phys. G: Nucl. Part. Phys. 37 (2010) 113101 (38pp)
doi:10.1088/0954-3899/37/11/113101

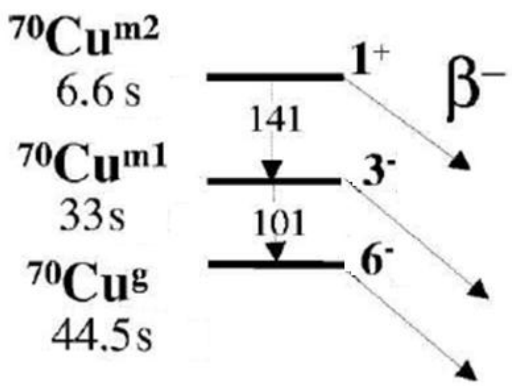
TOPICAL REVIEW

Progress in laser spectroscopy at radioactive ion beam facilities

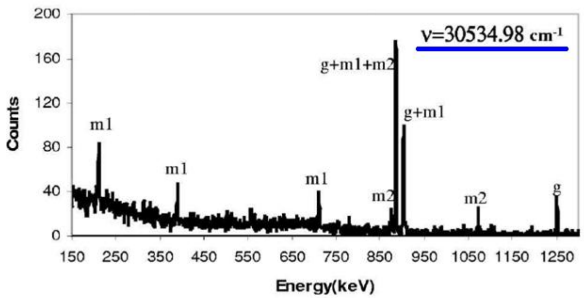
B Cheal and K T Flanagan

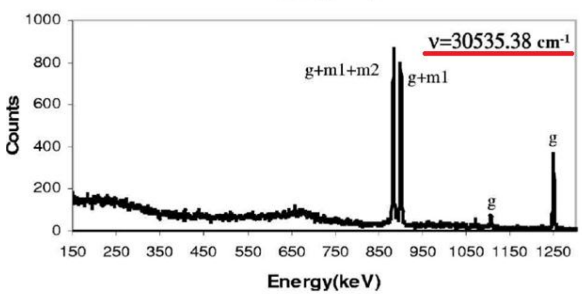
Schuster Building, The University of Manchester, Manchester M13 9PL, UK

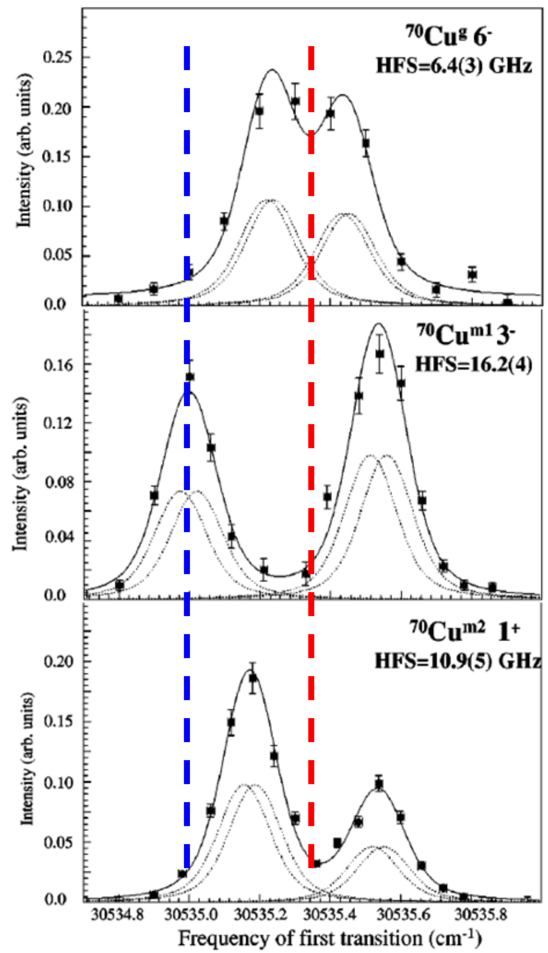
Hot-cavity isomer- and laser spectroscopy at ISOLDE



L. Weissman et al., PRC65 (2002) 024315

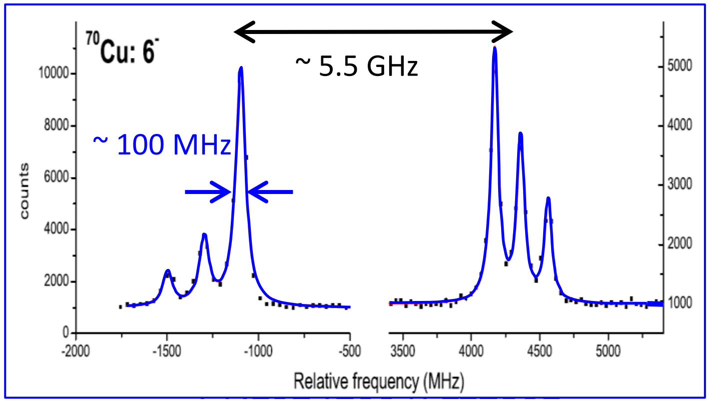


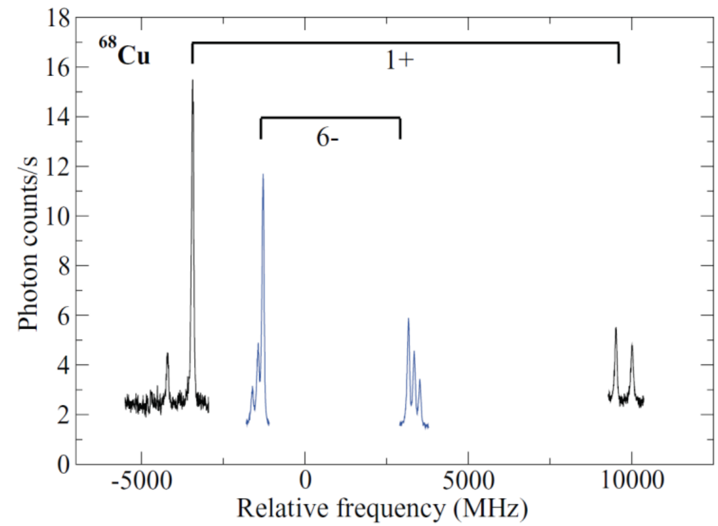




Collinear laser spectroscopy

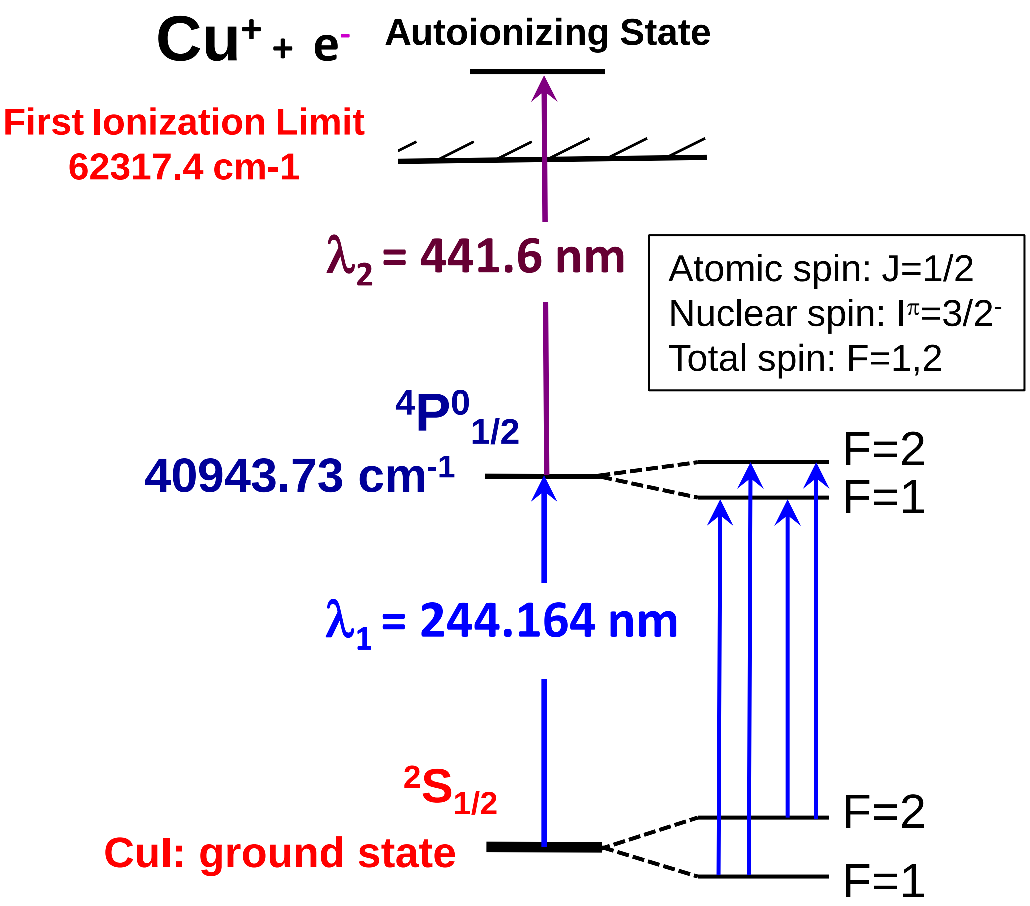
P. Vingerhoets et al., PRC82 (2010) 064311



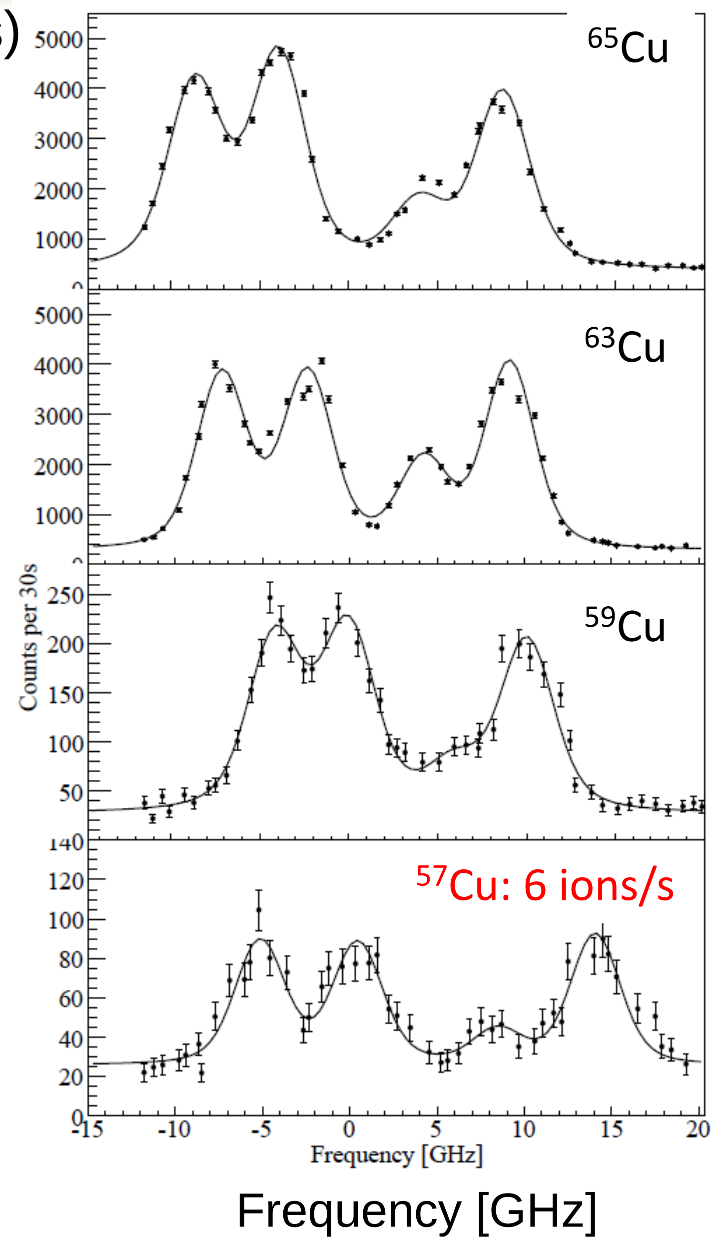


In-gas-cell laser spectroscopy: $^{57,59}Cu$

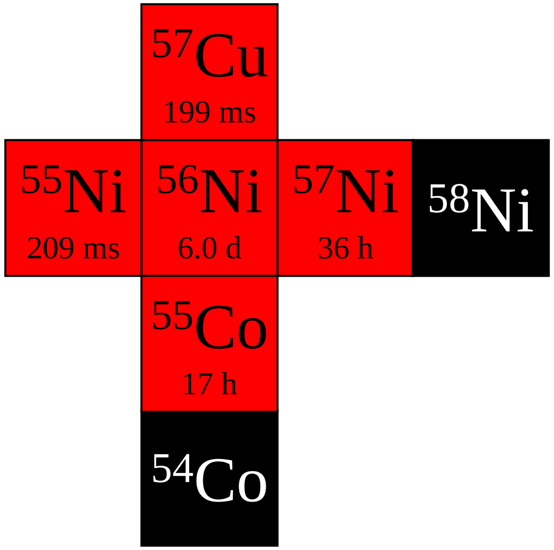
$^{58}Ni(p, 2n)^{57}Cu$ ($T_{1/2}$=199 ms)

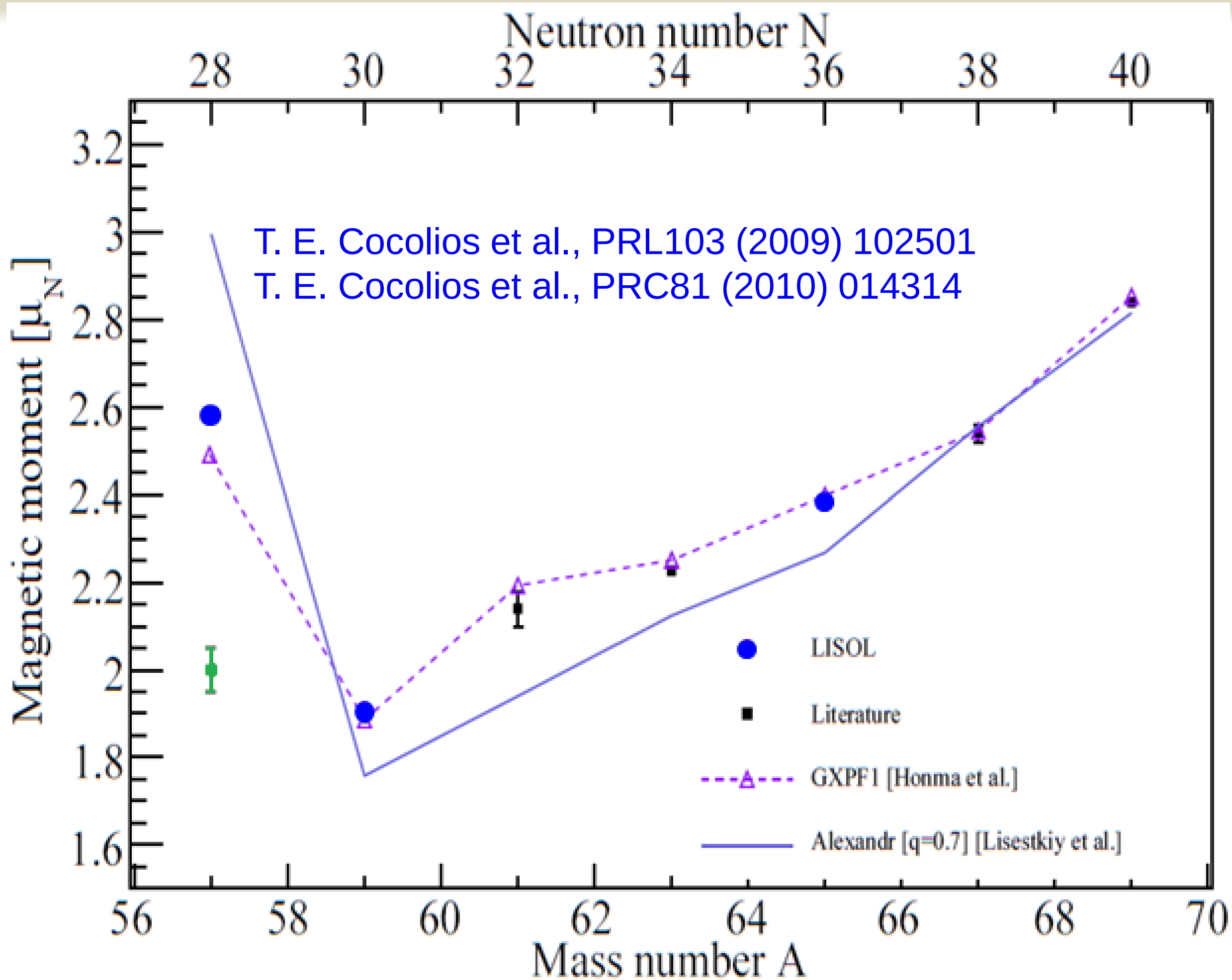


$$\mu(^{A}Cu) = \frac{A_{hf}(^{A}Cu)}{A_{hf}(^{63}Cu)}\mu(^{63}Cu)$$



Results



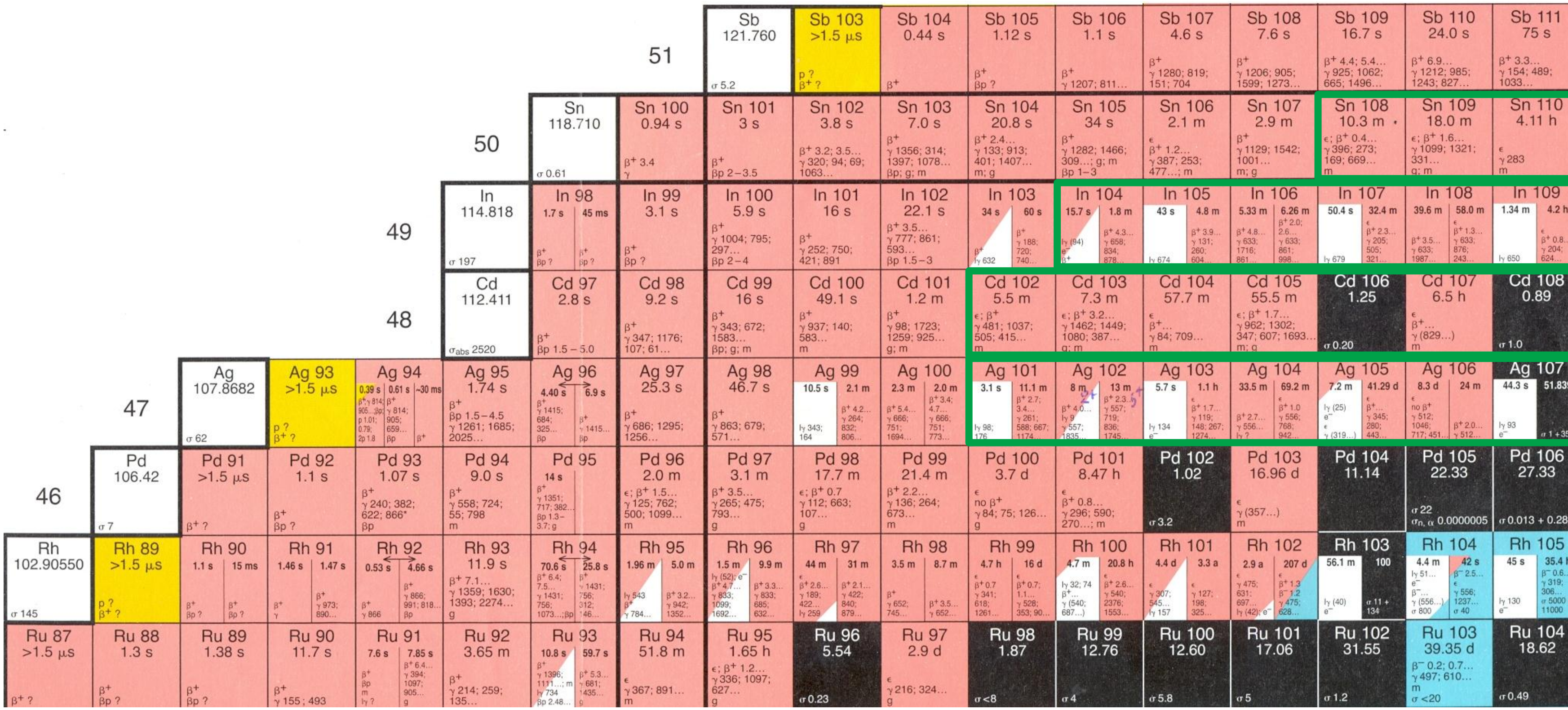


Magnetic moment of ^{57}Cu isotopes using the β-NMR technique — K. Minamisono et al., PRL 96 (2006) 102501

In source laser spectroscopy at ISOLDE down to ^{58,59}Cu — N.J. Stone et al., PRC 77 (2008) 014315

Collinear laser spectroscopy at ISOLDE on $^{58-62}$Cu — P. Vingerhoets et al., PLB 703 (2011) 34

The tin region



http://www.uni-mainz.de/FB/Chemie/AK-Noertershaeuser/en/experiments/laserspectroscopy/survey.html

Laser spectroscopy of $^{97-101}Ag$

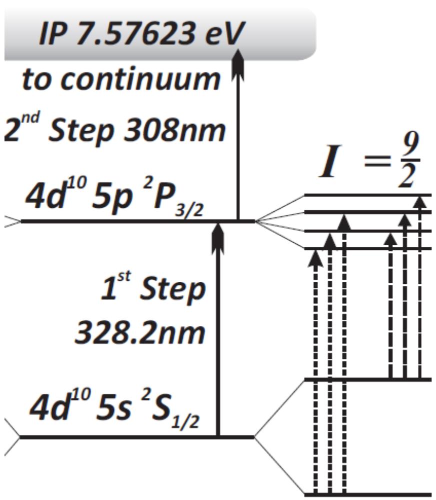
- Production

$^{92}Mo(^{14}N$ – 130 MeV,2pxn$)^{104-x}Ag$

$^{64,nat}Zn(^{36}Ar$ – 125 MeV,pxn$)^{101-97}Ag$
Laser ionization efficiency ~ 2%

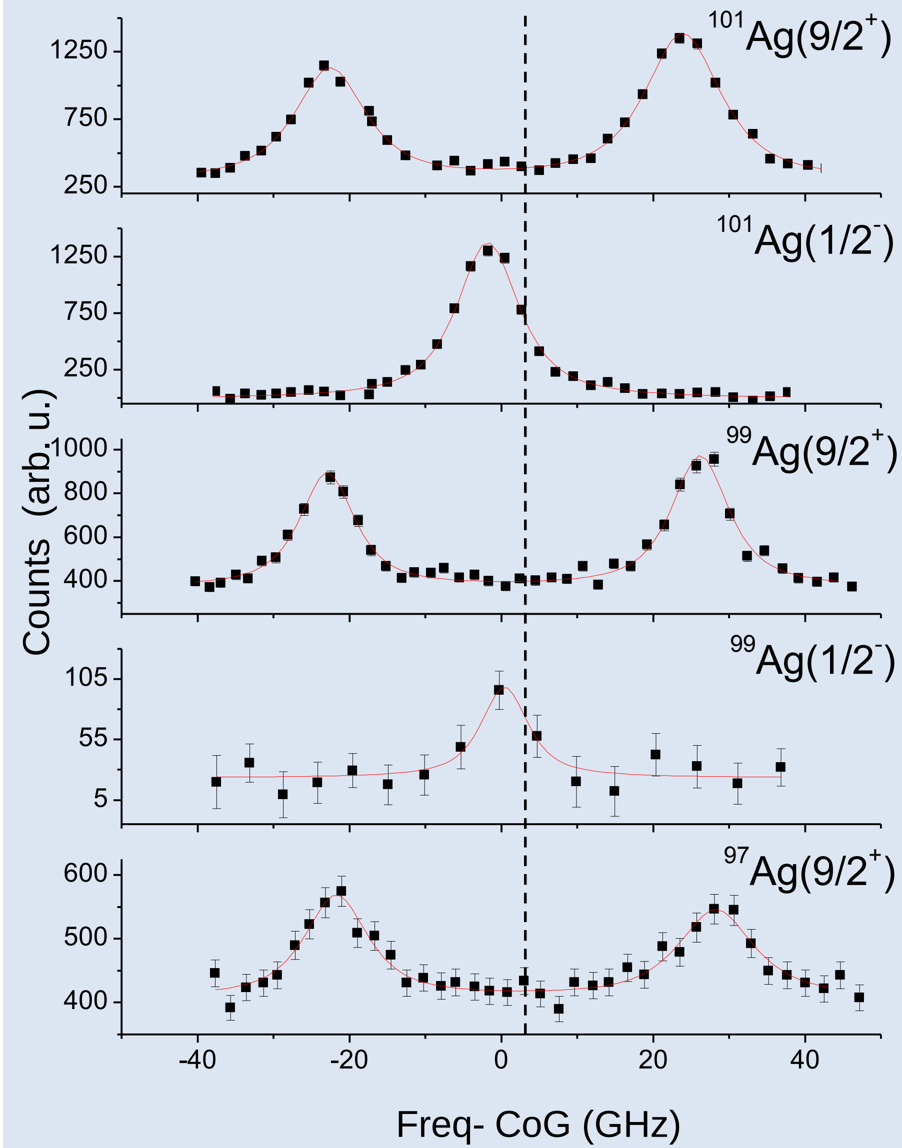
- In-gas cell laser spectroscopy

520 mbar argon
Total width: 9-10 GHz



- Detection

Beta- and gamma detection



New developments

- **new laser schemes** : problem of lack of stable isotopes for certain elements *(synergy with hot-cavity RILIS)*

- **better efficiency**:
  - more efficient laser schemes
  - higher spatial and temporal overlap (in-jet; high-repetition rate)
  - reduce diffusion losses in gas cell
  - reduce delay time in gas cell
  - limit possible recombination of photo-ions (pre-separation)

- **better selectivity**
  - separate stopping and ionization region (in-jet)
  - reduce radioactivity (pre-separation)

- **better resolution**
  - optimize laser bandwidth
  - reduce Doppler broadening (lower temperatures, cryogenic cell <–> in-jet)
  - reduce pressure broadening (in-jet)

New developments: more elements

In (continuum)

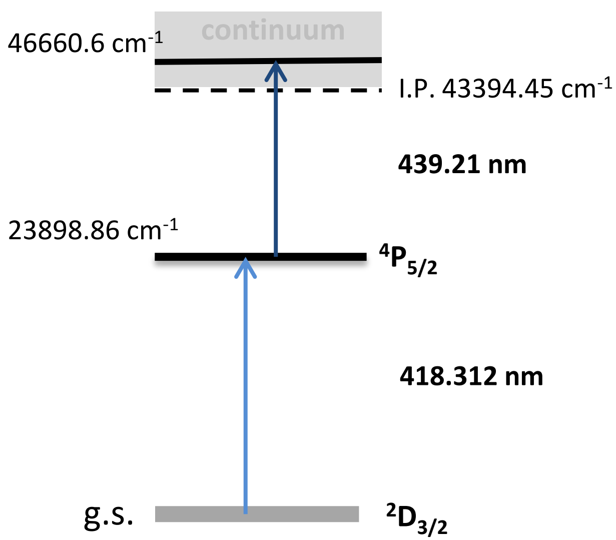
- 115 MeV ^{16}O on 3.3 mg/cm^2 ^{92}Mo => $^{104, 103}In$
- limited laser efficiency => further off-line tests for other transitions

Sn (Rydberg state)

- 100 MeV ^{16}O on 3.3 mg/cm^2 ^{92}Mo => $^{105, 106}Sn$
- laser efficiency = 0.4 % => *strong pressure broadening*

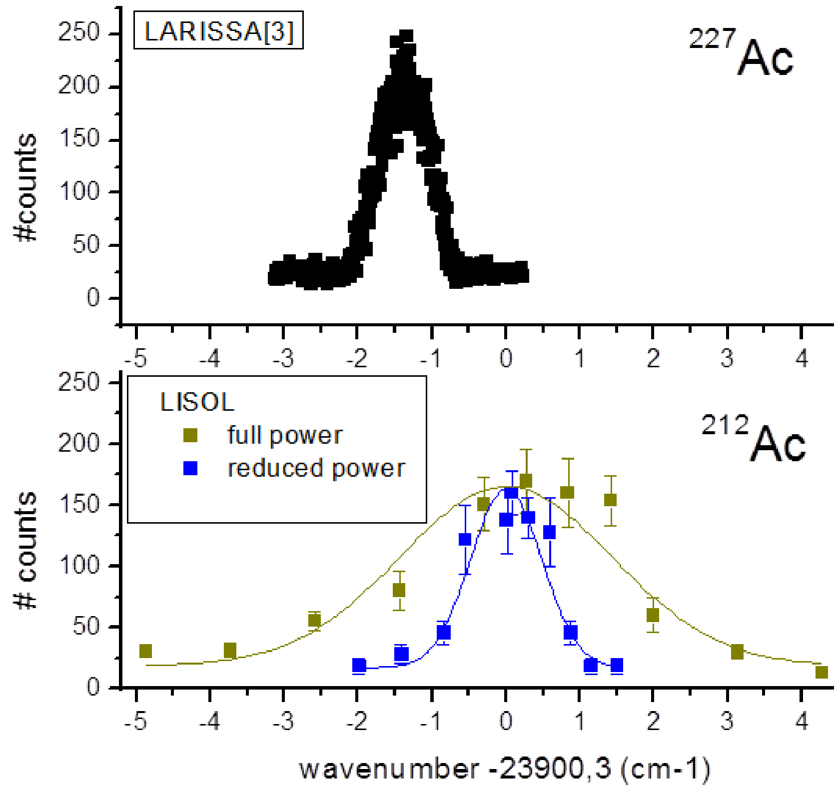
Ac (continuum)

- off-line tests in **Mainz** (22 year ^{227}Ac)
- 145 MeV ^{20}Ne on 0.19 mg/cm^2 ^{197}Au => $^{212,213}Ac$
- laser efficiency = 0.8 % => room for improvement



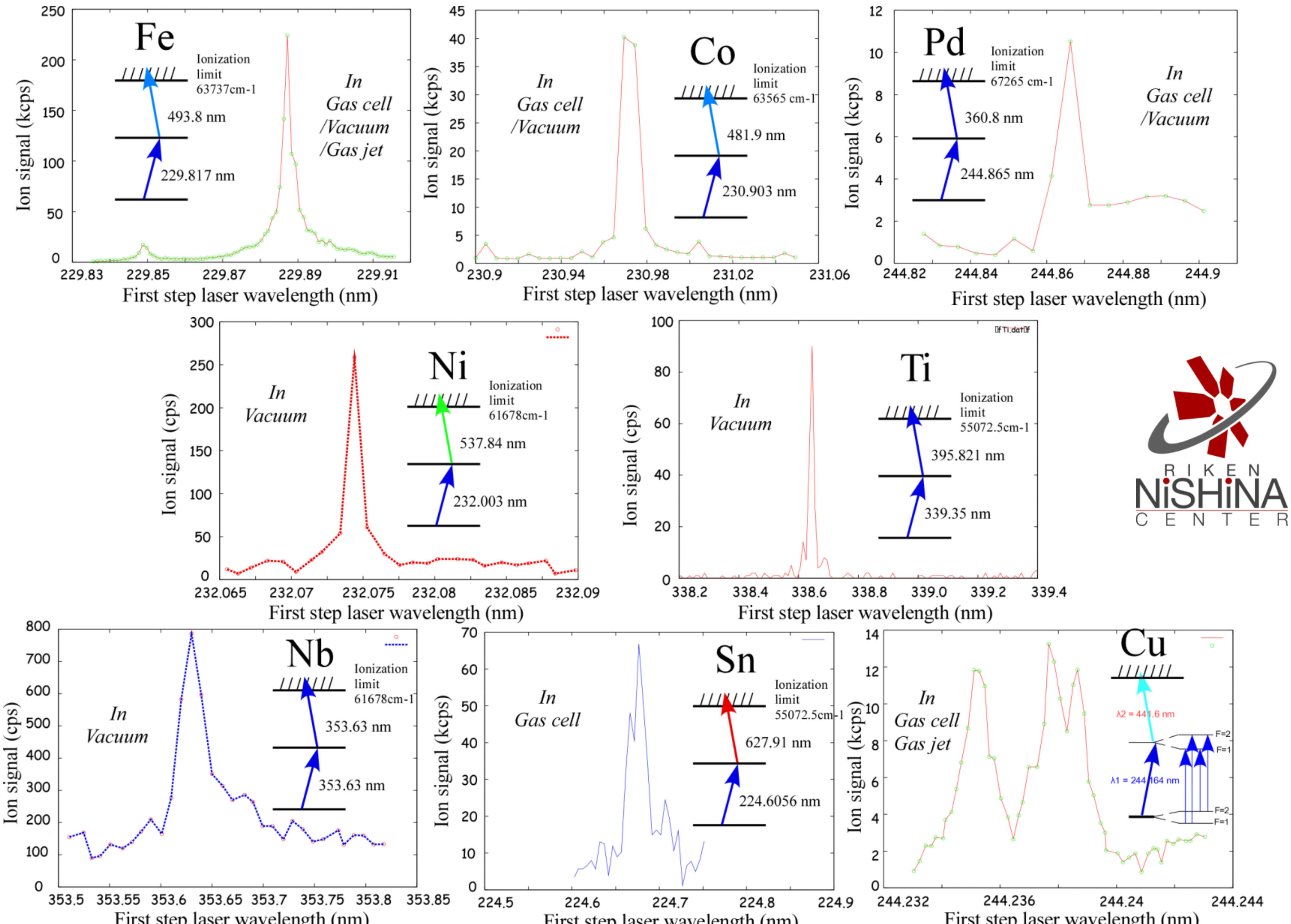
Ac

J. Roβnagel et al., PRA85 (2012) 012525



New developments: test of laser schemes at RIKEN

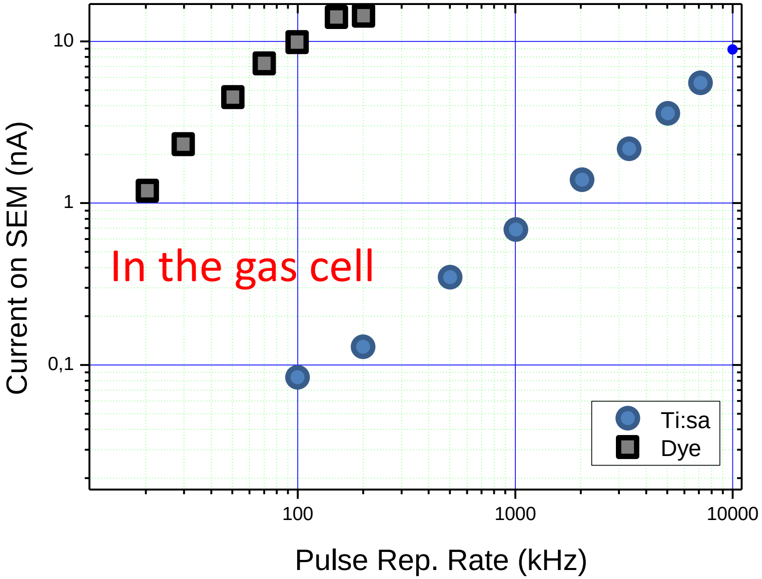
courtesy of Tetsu Sonoda

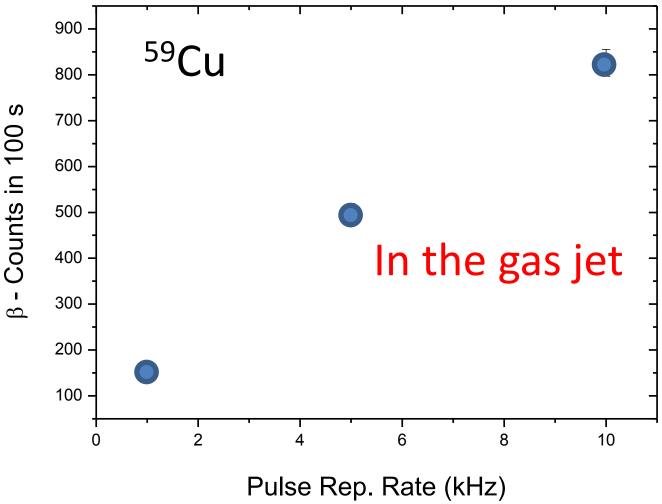


New developments: higher efficiencies

Repetition rate: from 200 Hz (Dye lasers) to 10 kHz (Ti:Sa)

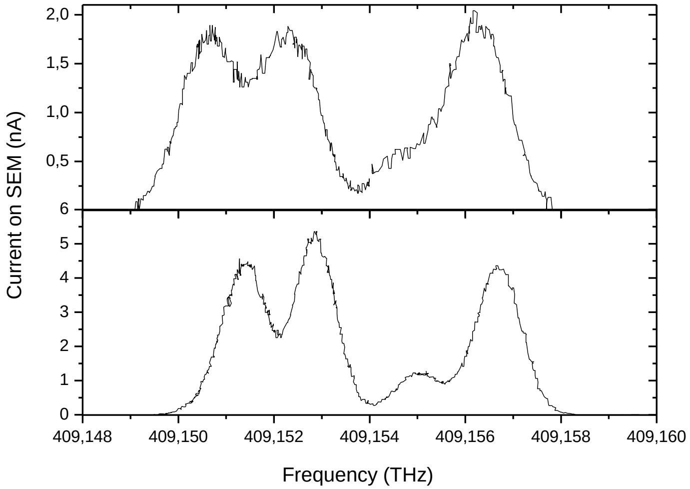
K.U.Leuven -Mainz – GANIL - Orsay - JYFL - RIKEN - JINR Dubna





Reduction factor when compared to the gas cell is a factor 60

(a factor 450 for the Dye lasers)



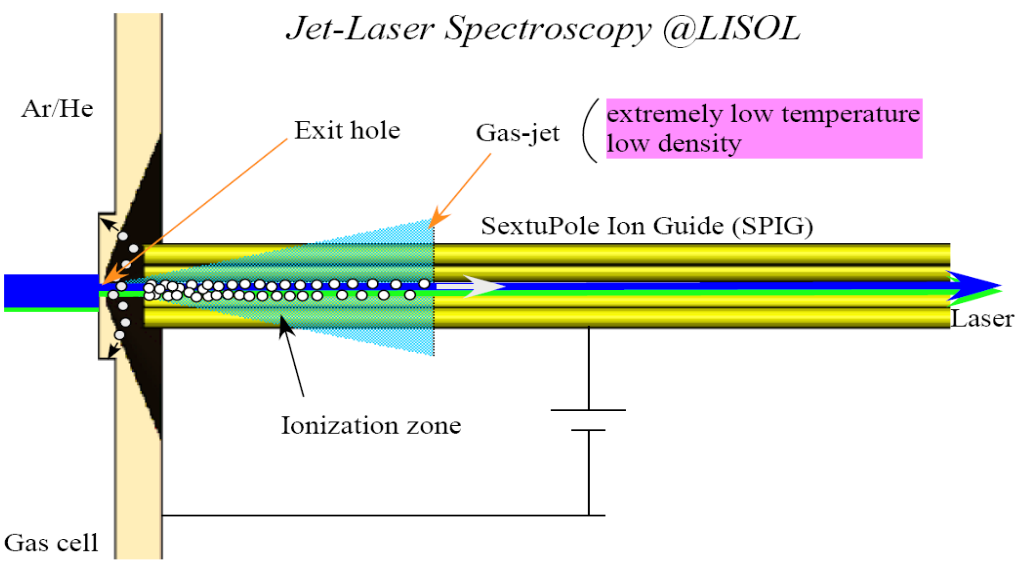
In the gas cell

First step scanning of ^{63}Cu

In the gas jet

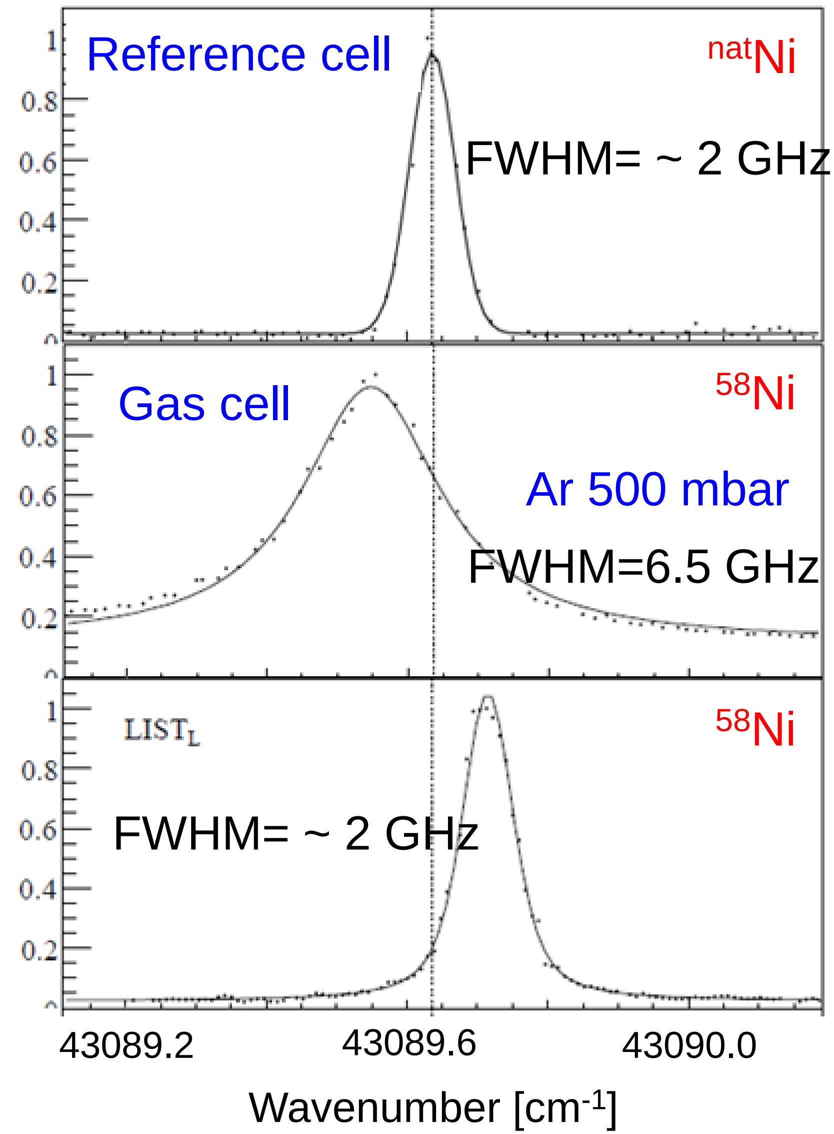
R. Ferrer et al., NIMB291 (2012) 29

New developments: better resolution



The Laser Ion Source Trap (LIST) coupled to a gas cell catcher

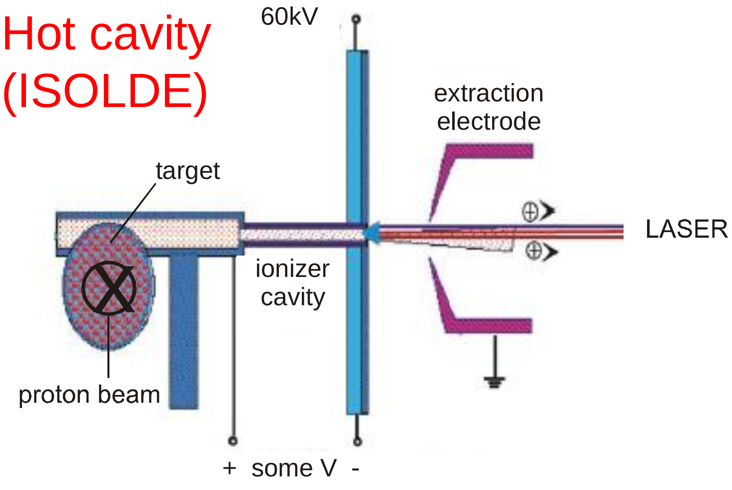
T. Sonoda et al.; NIMB267 (2009) 2908



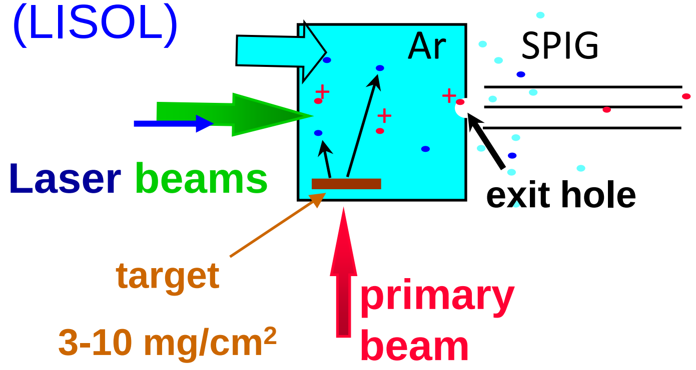
For the most recent developments
see talk of Yuri Kudryavtsev

Comparison hot cavity / gas cell / LIST

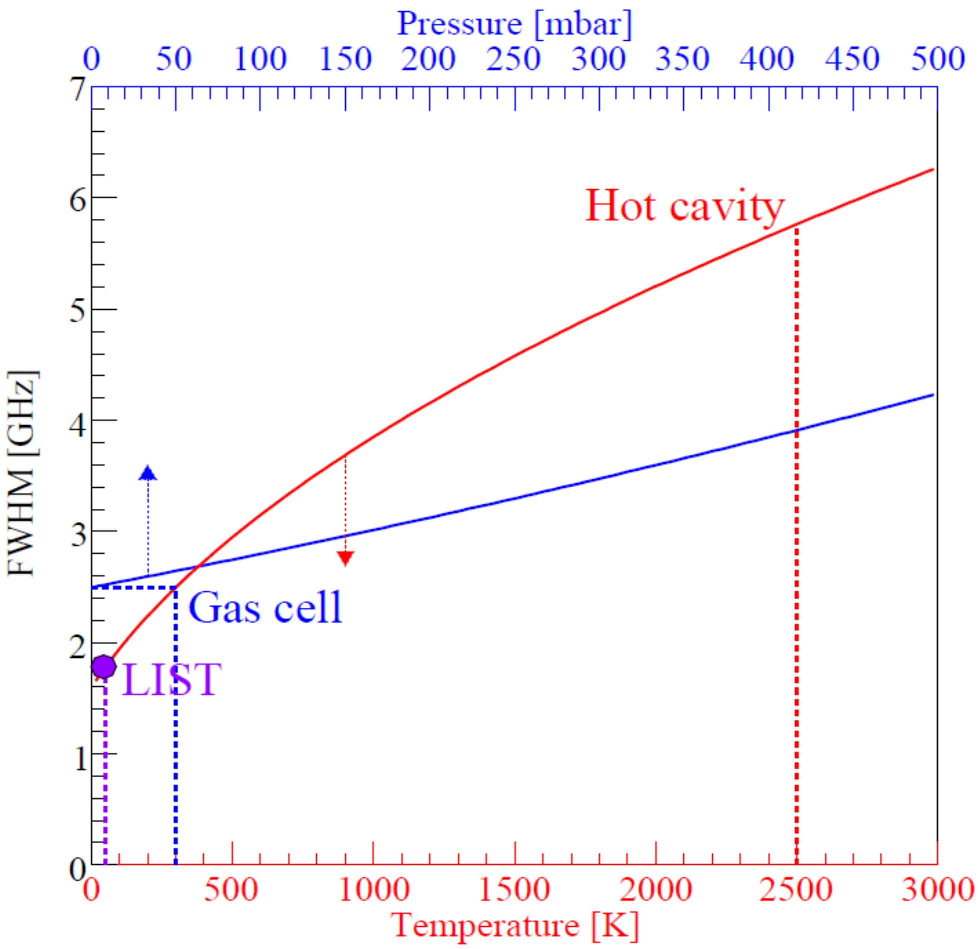
Hot cavity (ISOLDE)



Gas cell (LISOL)

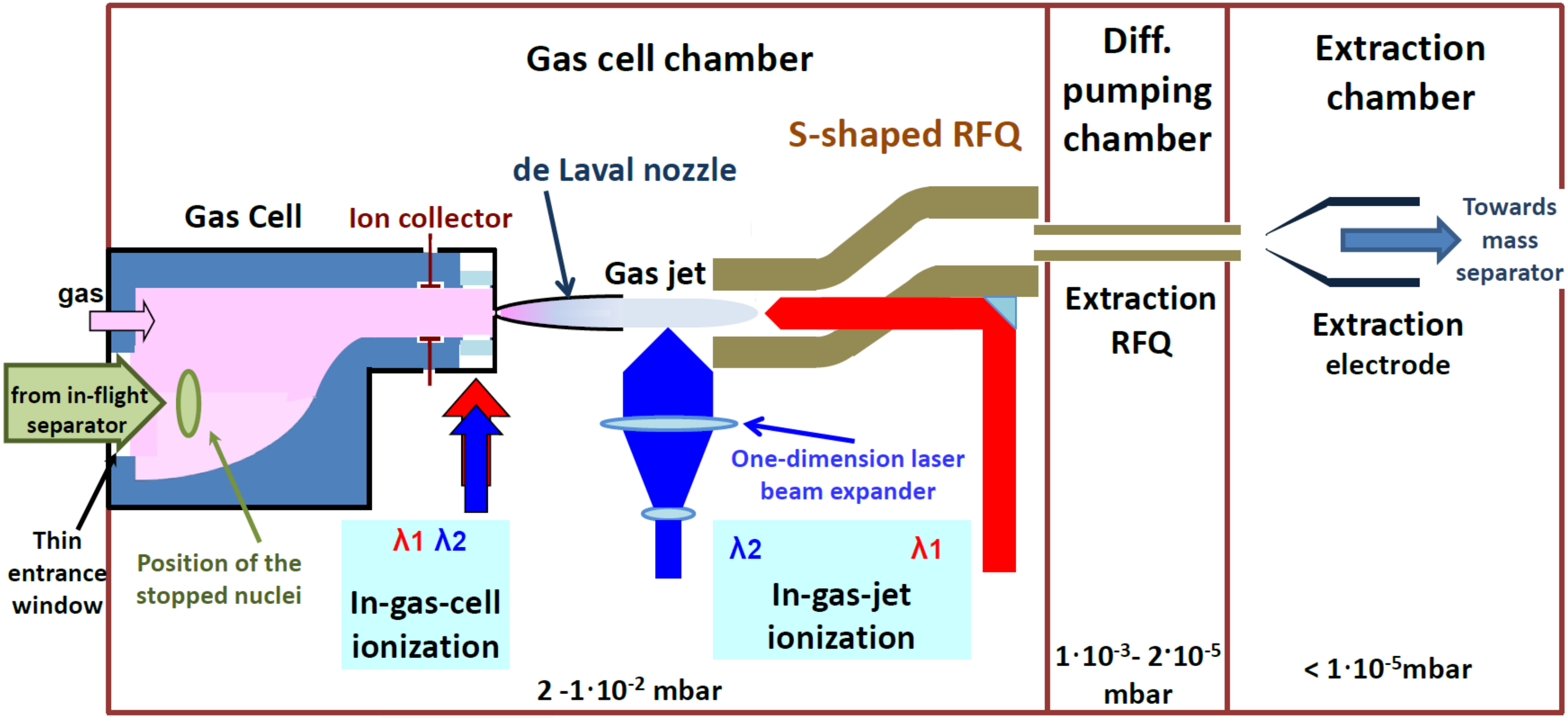


The effect of **pressure** and **temperature** on the FWHM



starting from a laser resolution of 1.8 GHz

The ultimate approach for exotic nuclei with energies ~ 5 MeV/u?



=> pre-separation by low-energy in-flight separators

=>reaction products stopped in < 500 mbar Ar

=> small cell fast evacuation

⇒ ionization zone shielded from stopping zone

⇒ unwanted ions collected

⇒ broadband in-gas cell ionization to find the resonances

⇒ unwanted ions further collected

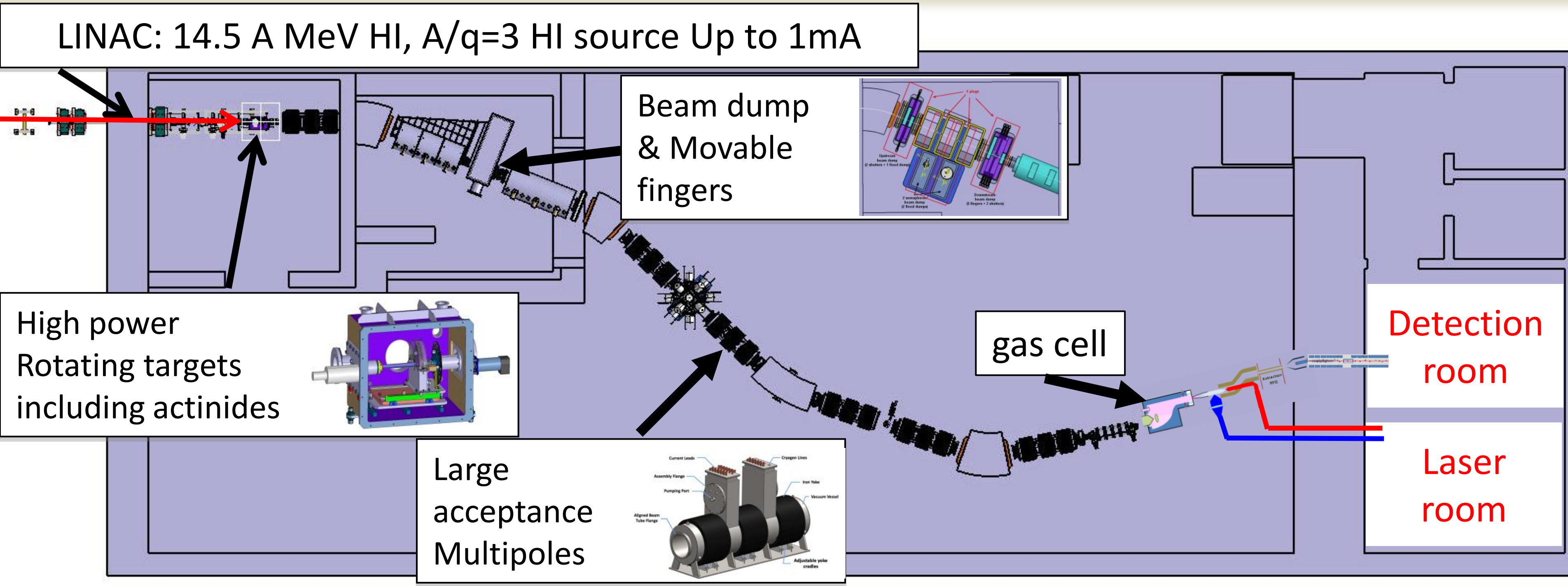
⇒ supersonic jet: extended atomic beam, low pressure, low temperature

⇒ ~ 200 MHZ resolution

⇒ laser spectroscopy

⇒ Isomeric purification

Developments for S3 at SPIRAL2



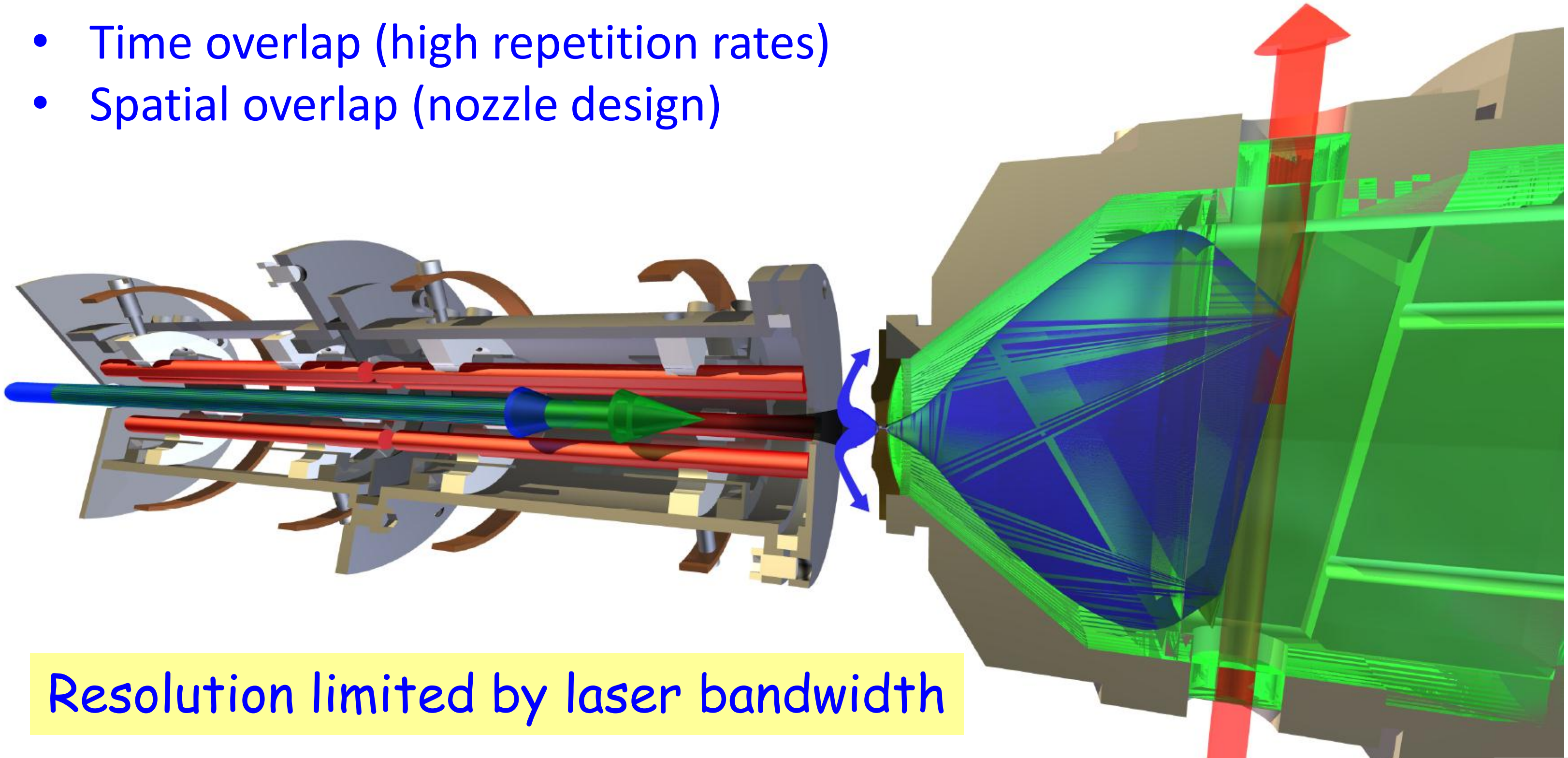
Expected rates: e.g. ^{94}Ag and heavy elements:
S3 transmission: 50% (5 charge states)
Laser ionization: 10 %

^{58}Ni(^{40}Ca,p3n)^{94}Ag: few 10 pps amongst them the 21^{+} isomer 390 ms
^{208}Pb(^{48}Ca,2n)^{254}No: about 1 pps

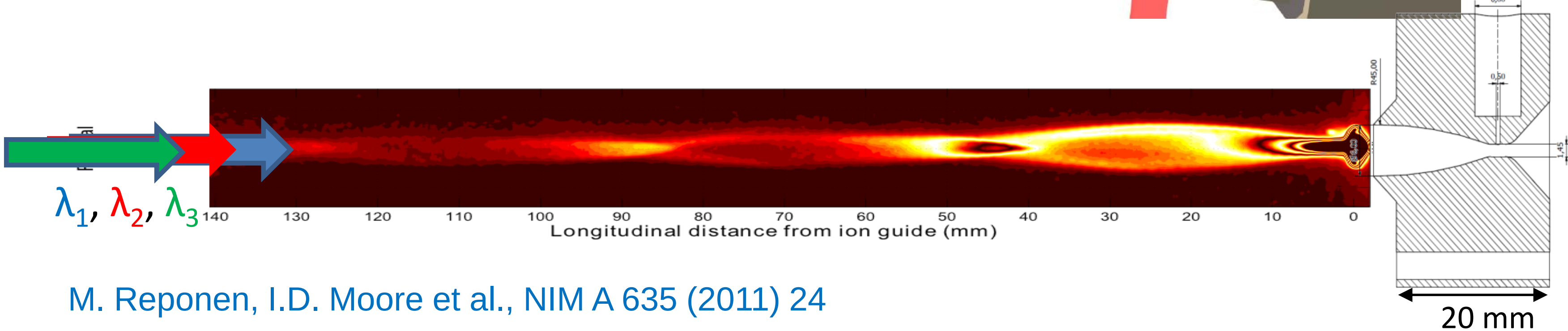
Developments at Jyvaskyla: IGISOL

courtesy of Iain Moore

- Time overlap (high repetition rates)
- Spatial overlap (nozzle design)



Resolution limited by laser bandwidth



M. Reponen, I.D. Moore et al., NIM A 635 (2011) 24

Developments at RIKEN: SLOWRI/PALIS

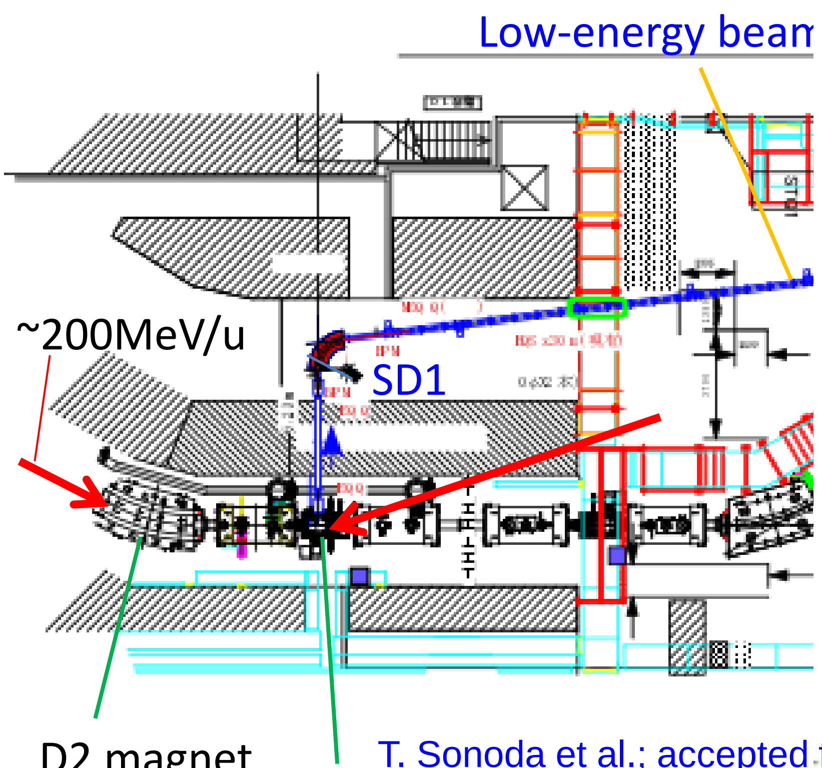
courtesy of Tetsu Sonoda

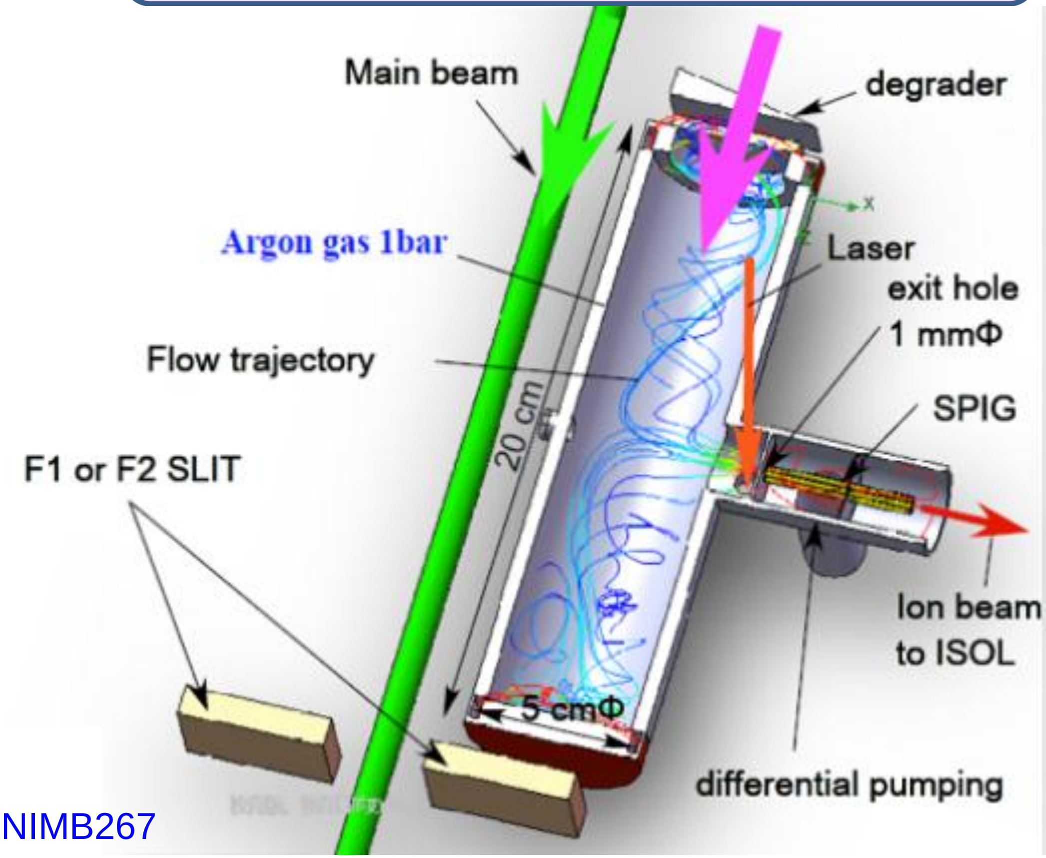
Actual construction will be started soon.!!

How to transform the high-energy in-flight beam into low

Resonant ionization gas cell
(Parasitic / Main beam)

RF-c





T. Sonoda et al.; accepted for NIMB267

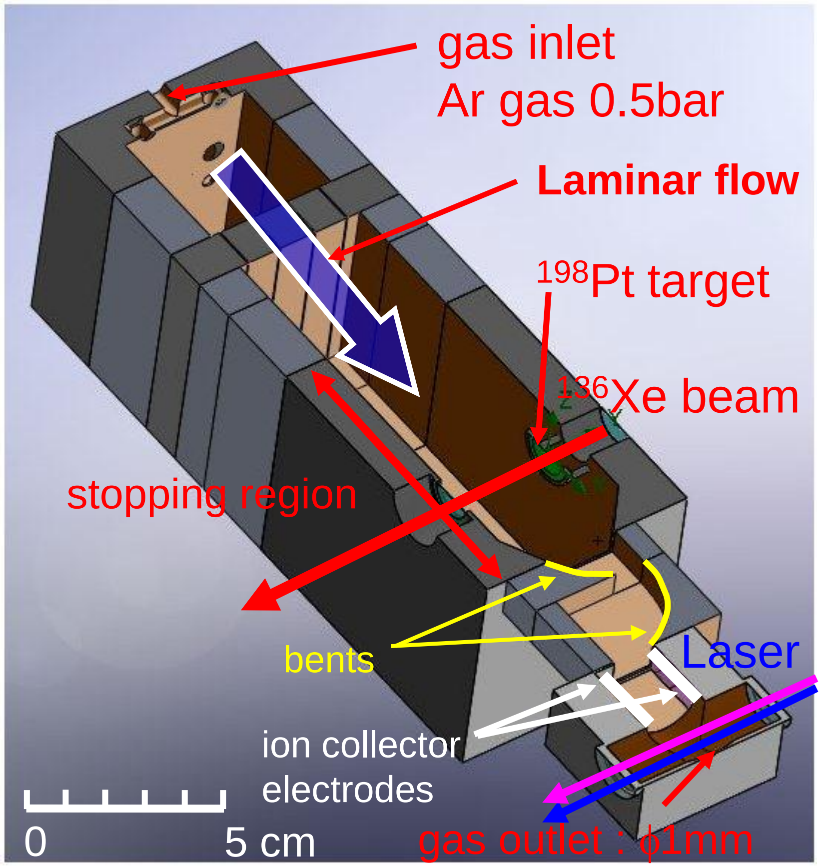
Developments at KEK: KISS

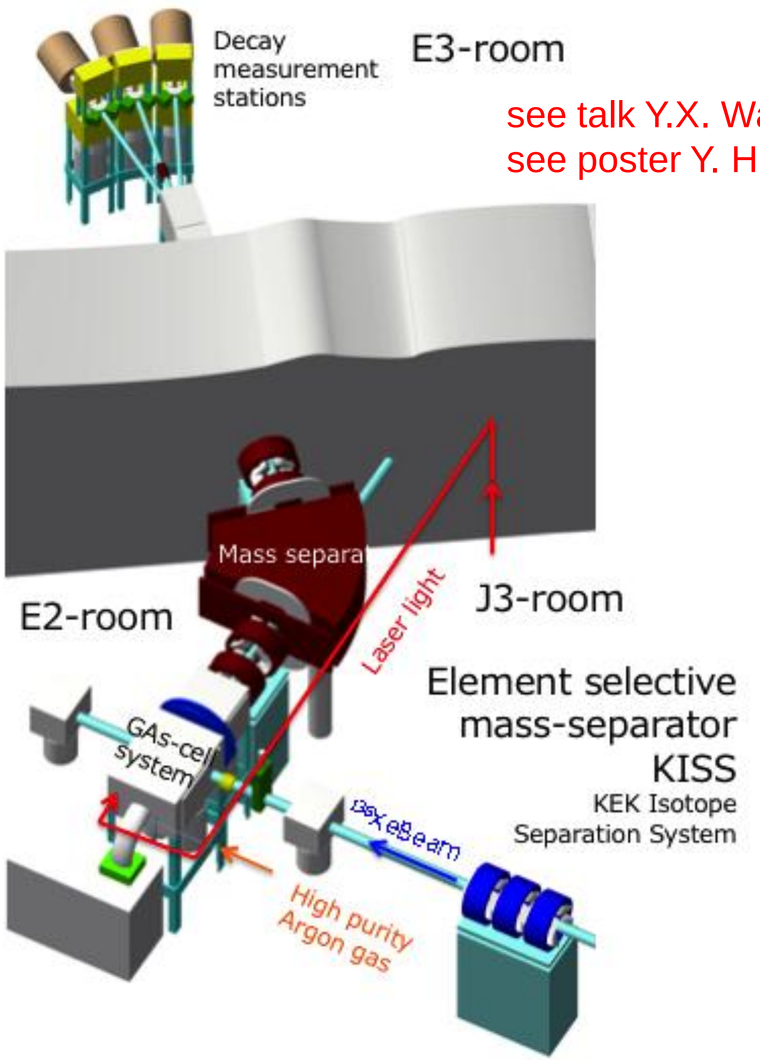
courtesy of Hiroari Miyatake

Argon-gas catcher cell
+ Laser resonant ionization (Z)
+ Mass separation (A)
+ Low-background det. system

S.C. Jeong et al., KEK Report 2010-2

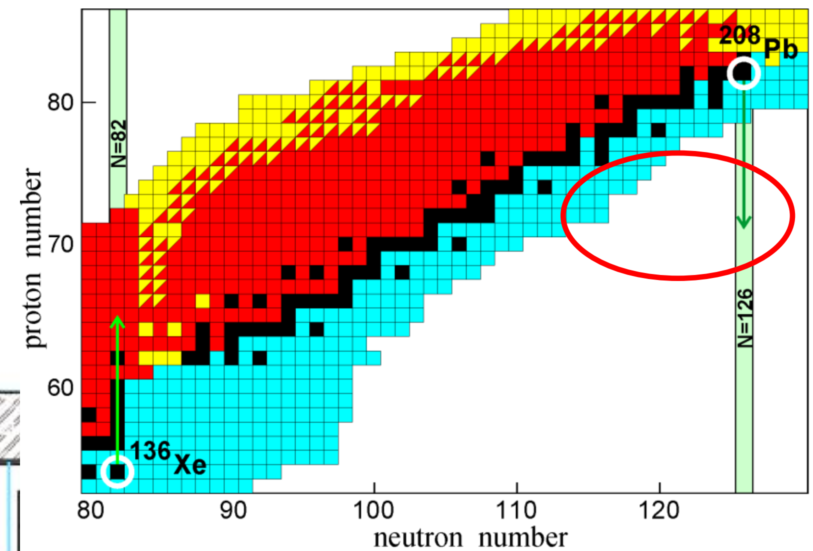
see talk Y.X. Watanabe
see poster Y. Hirayama

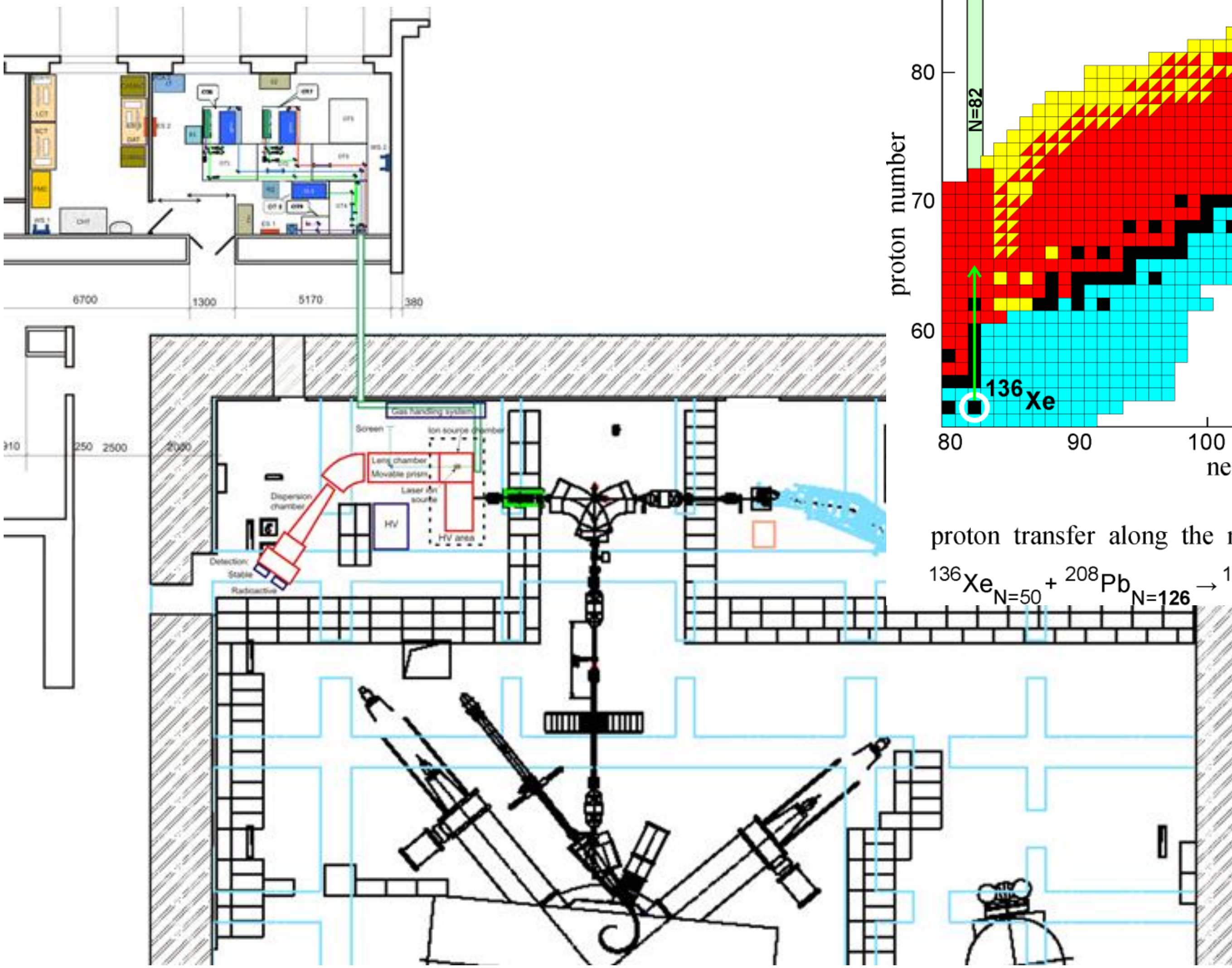




Development at Dubna: GALS

Courtesy of Sergey Zemlyanoy





proton transfer along the neutron closed shells:

$$^{136}Xe_{N=50} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=50} + {}^{208-\Delta Z}Y_{N=126} + Q \approx 0$$

Possible position of SETUP at cyclotron U400M

In Gas Laser Ionization and Spectroscopy

worldwide possibilities

With pre-Separator

Without pre-Separator

"Gas-Cell-Based Laser Ionization Spectroscopy Developments"

Leuven, May 30 – June 1, 2012

Dedicated workshops

Workshop on Low-Energy Radioactive Isotope Beam (RIB) Production by In-Gas Laser Ionization for Decay Spectroscopy at RIKEN
December 10-11, 2012, RIKEN-Wako

This workshop will be held after the EMIS12 conference on the low-energy RIB production by in-gas laser ionization for decay spectroscopy. This workshop is primarily motivated as an international collaboration meeting between Japan (KEK, RIKEN) and Belgium (KU Leuven) on the development of the IGLIS (In-Gas Laser Ionization and Spectroscopy) method for the study of r-process nuclei. However, we are going to use this opportunity to discuss other physics cases and to define the technical issues to be addressed, by calling for special attention of the EMIS2012 participants interested in the subject.

Top

- Program (tentative)
- Workshop venue
- Accommodation

Organizers

- Sunchan Jeong (KEK)
- Piet Van Duppen (KU Leuven)
- Mark Huyse (KU Leuven)
- Michiharu Wada (RIKEN)
- Hiroari Miyatake (KEK)

Dedicated workshop

Dedicated workshop