Producing Radioactive Ion Beams

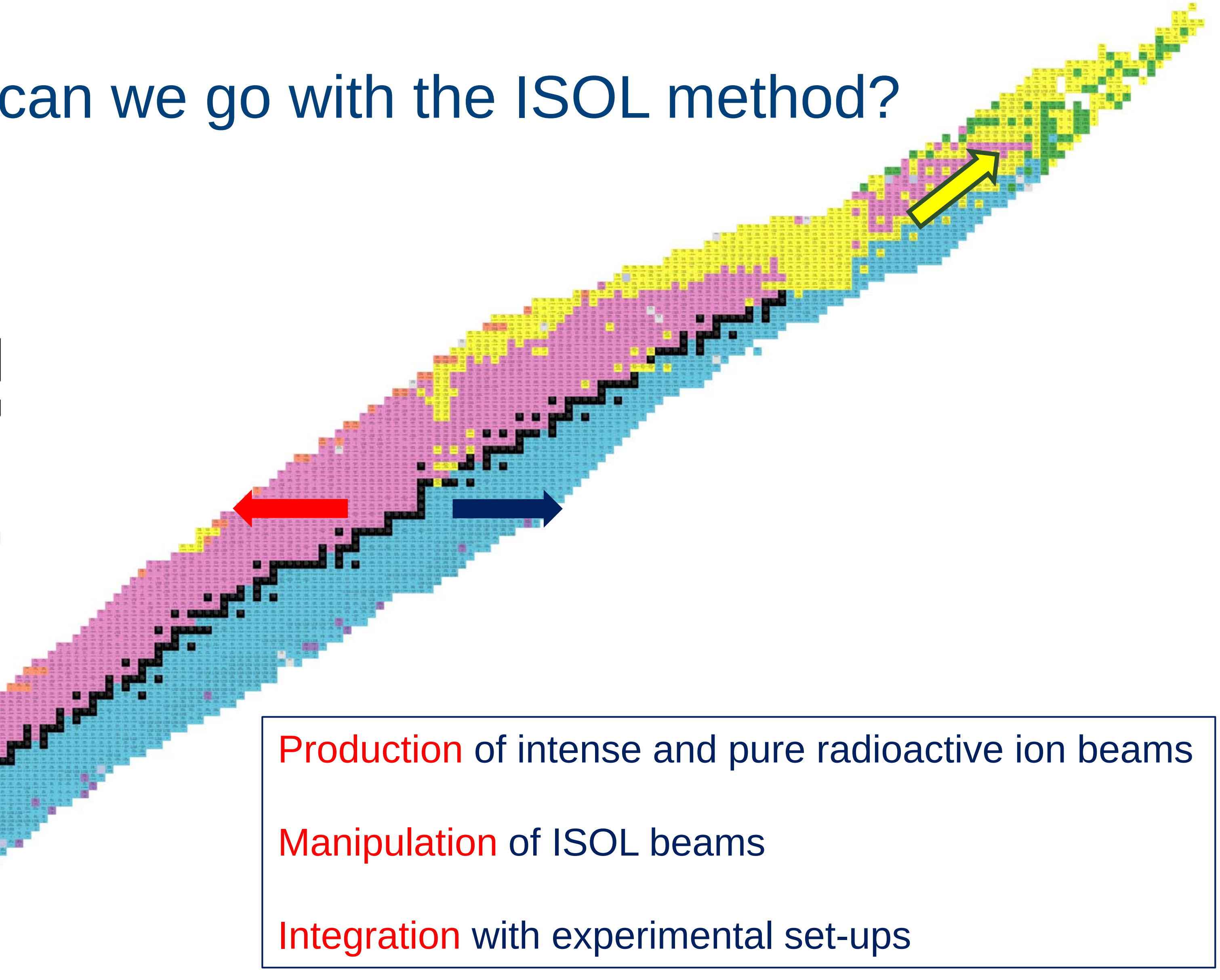
through the ISOL Method:

Advances, challenges and opportunities.

Mark Huyse
KU Leuven, Instituut voor Kern- en Stralingsfysica, Belgium

KU LEUVEN

How far can we go with the ISOL method?

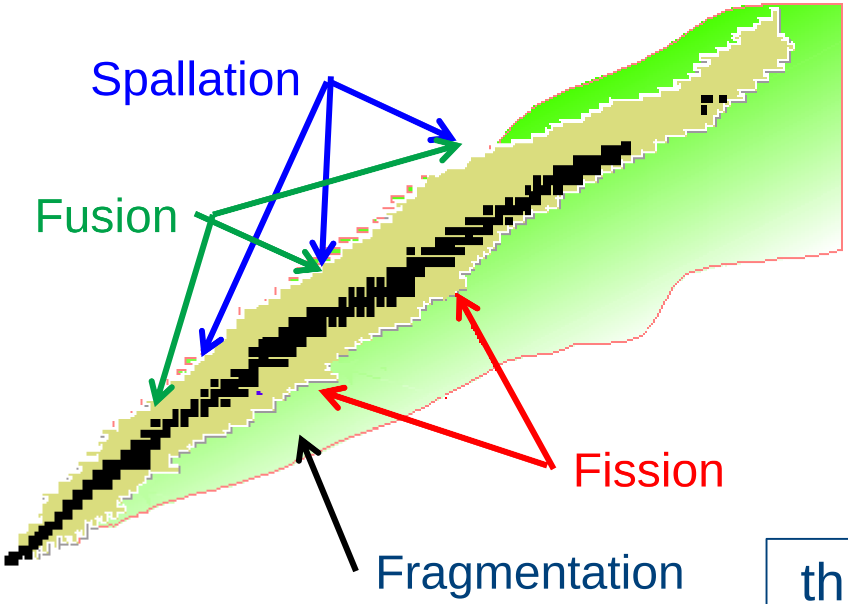


Production of intense and pure radioactive ion beams

Manipulation of ISOL beams

Integration with experimental set-ups

Production of intense and pure radioactive ion beams



Choice of the reaction

- intensity of primary beam
- target thickness
- cross section
- selectivity of the reaction

Purification **in flight (IF)** or after stopping

ISOL

thick target <=> thin target

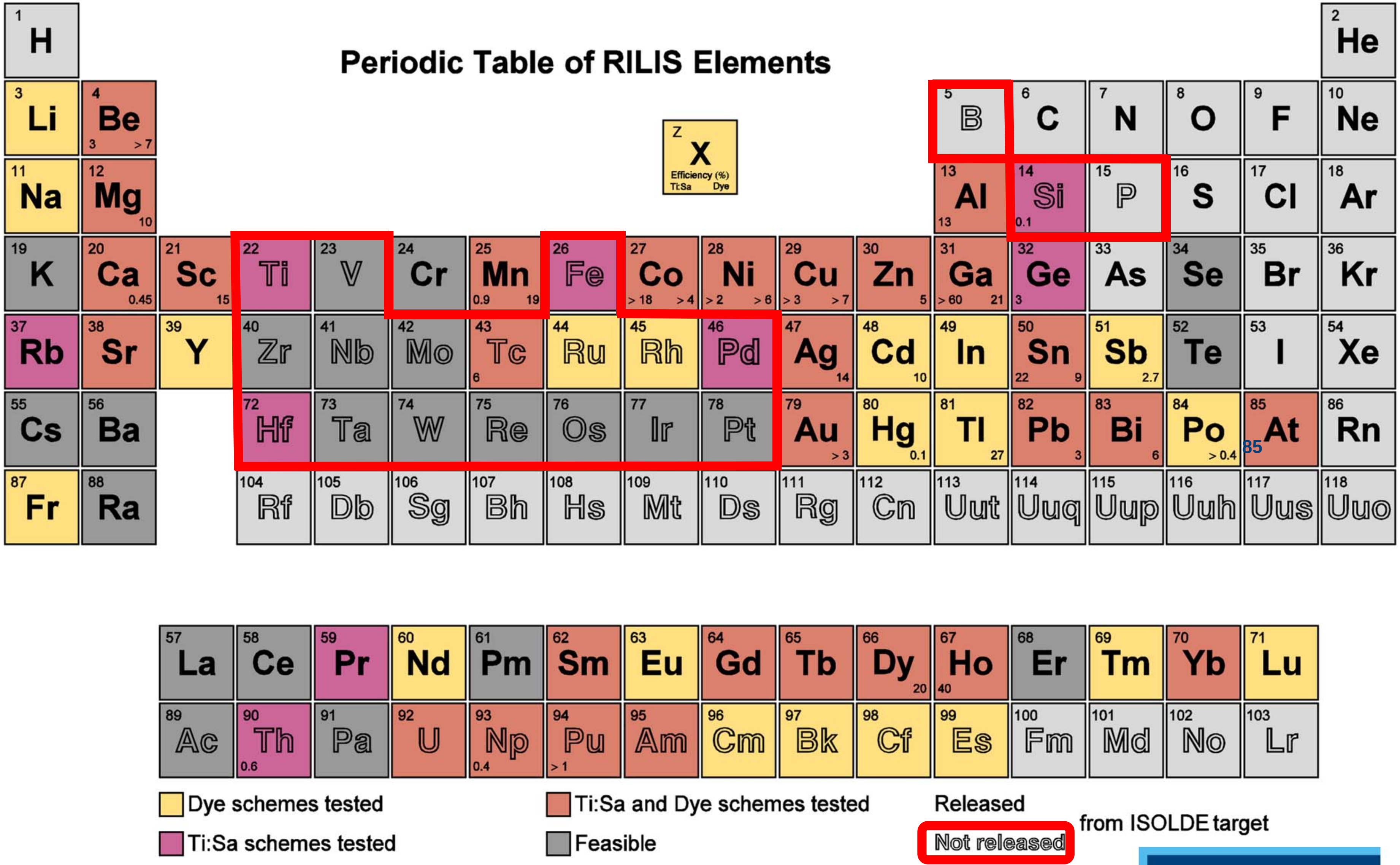
solid catcher

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

ion source
Z selection

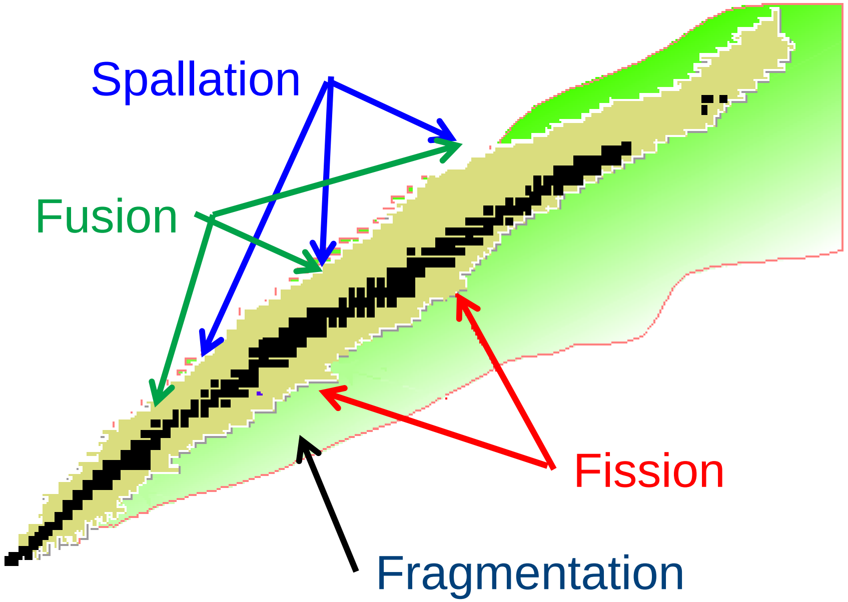
mass separator

The release problem



courtesy B. Marsh

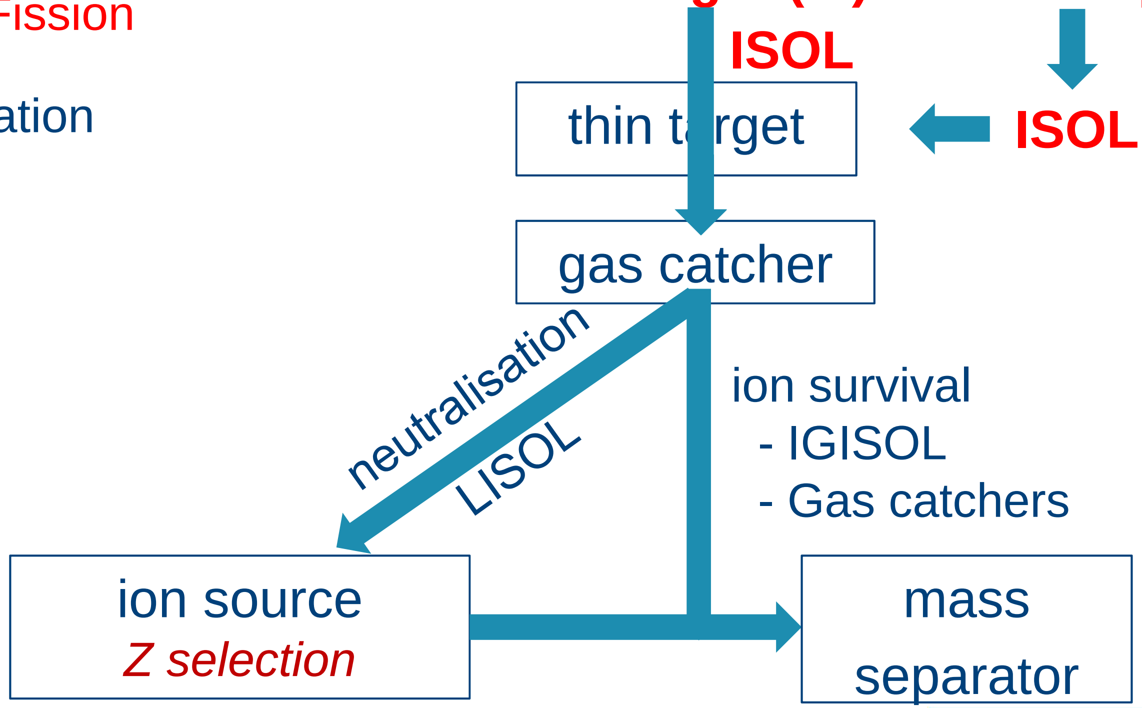
Production of intense and pure radioactive ion beams



Choice of the reaction

- intensity of primary beam
- target thickness
- cross section
- selectivity of the reaction

Purification **in flight (IF)** or after stopping



Production: Target Developments => *brute* force

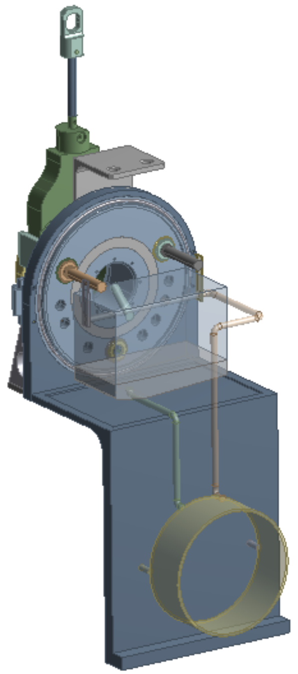
Recent developments of target and ion sources to produce ISOL beams

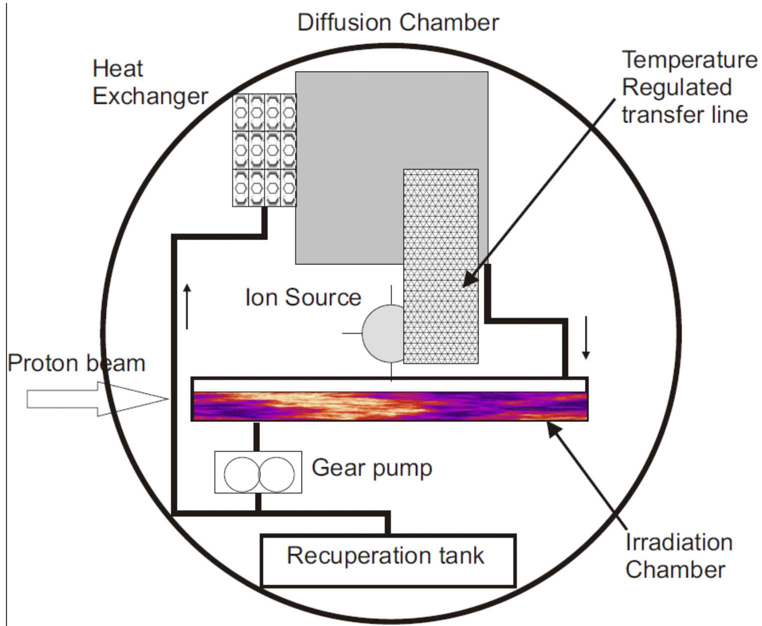
T. Stora *

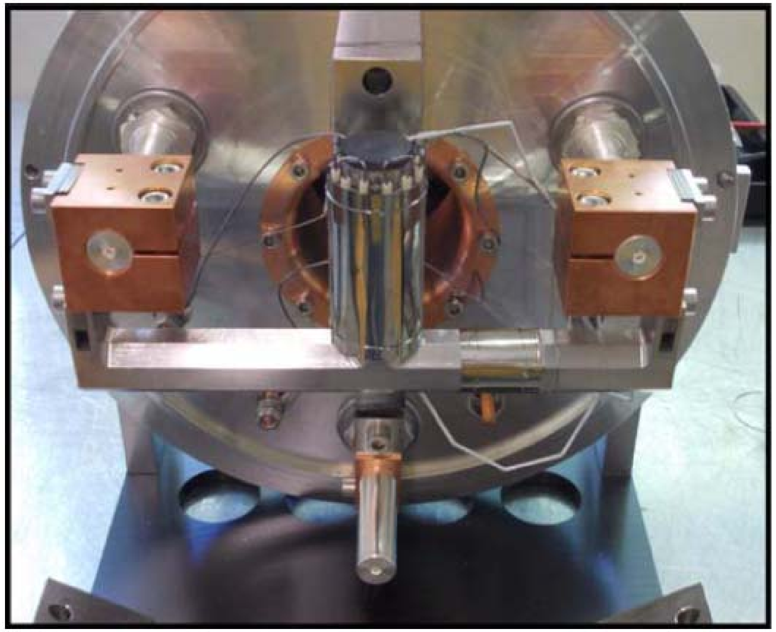
Nuclear Instruments and Methods in Physics Research B 317 (2013) 402–410

CERN, CH-1211 Geneva 23, Switzerland

Higher in primary beam intensity (now 100 μA at ISAC)
From kW towards MW on target





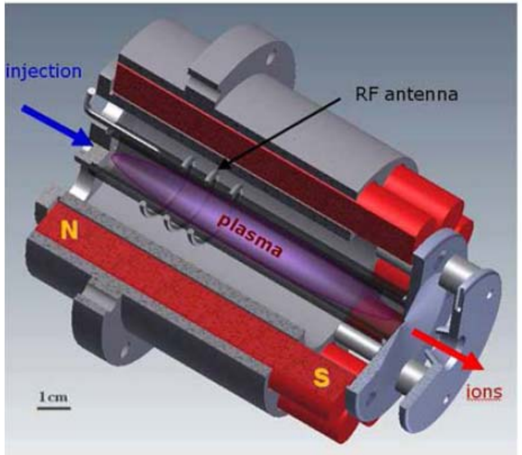


LIEBE: a study for a Pb-Bi loop target

NaF salt target for intense production of ^{18}Ne

Production: Target-Ion-Source developments: focused approach

Release => **molecular sidebands**

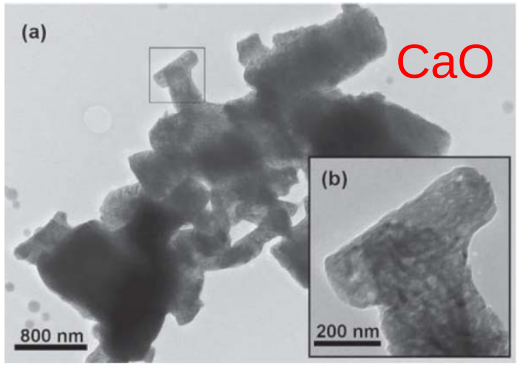


HELICON-type ion source for molecular sidebands

M. Kronberger et al. / Nuclear Instruments and Methods in Physics Research B 317 (2013) 438–441

50-fold enhancement of $^{10\text{-}11}CO^{+}$ with nanostructured CaO target

Fast release **=> $T_{1/2}$** => **nanostructured materials**



J.P. Ramos et al. / Nuclear Instruments and Methods in Physics Research B 320 (2014) 83–88

fast diffusing => shorter $T_{1/2}$
lower temperatures => higher reliability

Selectivity => **lasers and physico-chemical properties**

Production: Gas stoppers for high-energy recoils

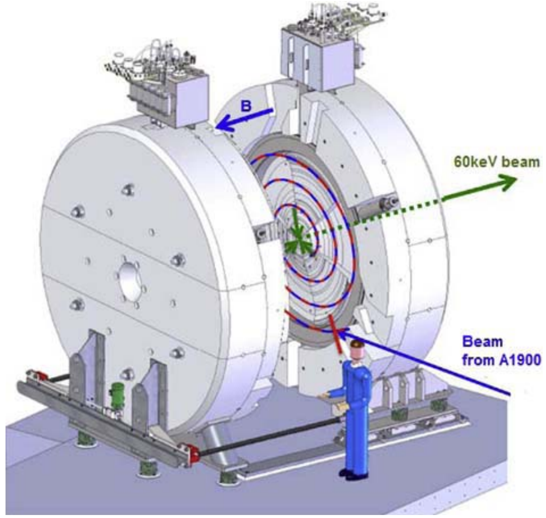
Challenge: large stopping volume is needed

=> minimize neutralization & diffusion losses and delay times using electric fields

- Linear gas stoppers

  M. Wada, NIM B317 (2013) 450-456

  see Guy Savard on CARIBU



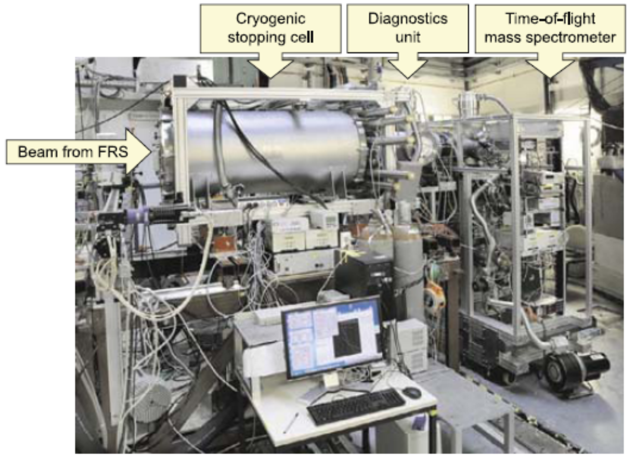
- Circular gas stoppers

  S. Schwarz et al., NIM B317 (2013) 463-467

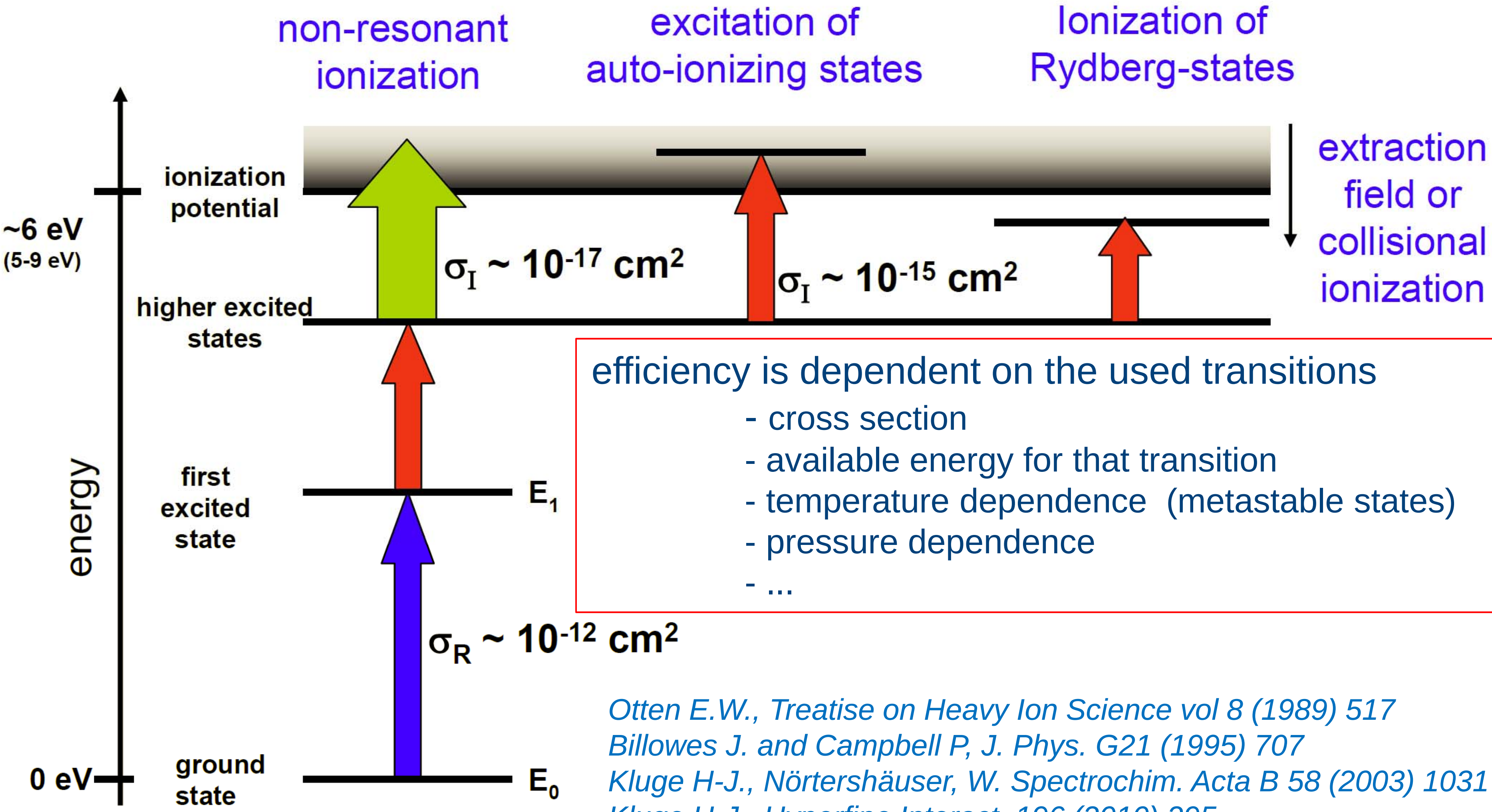
- Challenges: Beam purity and high intensity

  => cryogenic cell

  W. R. Plaß et al., NIM B317 (2013) 457-4612



Production: Resonant Ionization Laser Ion Source (RILIS)



efficiency is dependent on the used transitions

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

courtesy I. Moore

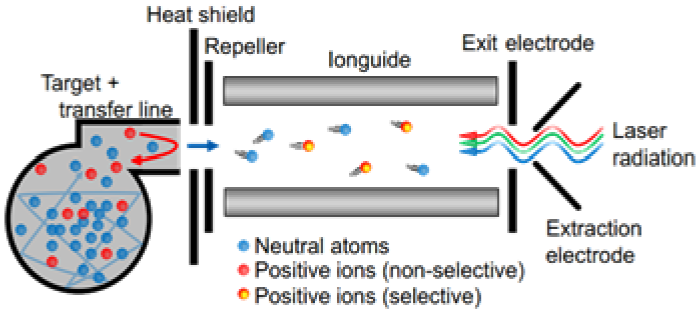
Otten E.W., Treatise on Heavy Ion Science vol 8 (1989) 517
Billowes J. and Campbell P, J. Phys. G21 (1995) 707
Kluge H-J., Nörtershäuser, W. Spectrochim. Acta B 58 (2003) 1031
Kluge H-J., Hyperfine Interact. 196 (2010) 295
Cheal B. and Flanagan K., J. Phys. G. 37 (2010) 113101

Production: The Z selectivity of the RILIS approach

Possible sources of contamination => **Solution**

- Hot cavity
  - Thermo-ionization => **LIST**
  - Activity on RFQ rods => **?**

B. A. Marsh et al., NIMB 317 (2013) 550-556
D. A. Fink et al., NIMB 317 (2013) 417-421
J. Lassen et al., Rev. Sci. Instrum. 85 (2014) 033309



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

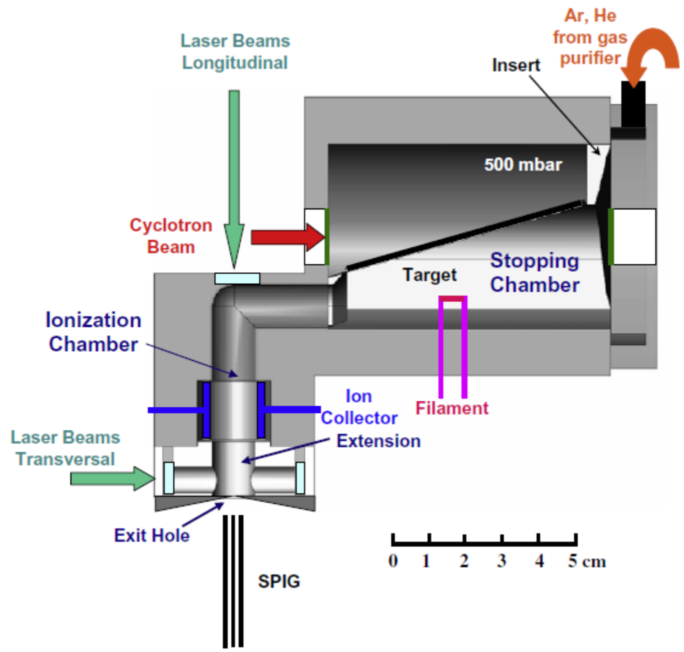
=> **Dual chamber**
Ion collector
LIST

Yu. Kudryavtsev et al., NIMB 267 (2009) 2908-2917

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

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

T. Sonoda et al., NIMB 267 (2009) 2918-2926
Yu. Kudryavtsev et al., NIMB 297 (2013) 7-22
I. D. Moore et al., NIMB 317 (2013) 208



KU LEUVEN

Manipulation of ISOL beams

- cooling
- bunching

=> improving the ion optical properties

- mass separation => optimal mass-resolving power while keeping the efficiency (dipoles M/ΔM ~20.000; cyclotrons and MR-TOF's higher)
- neutralisation => for laser applications
- polarisation => solid-state physics, fundamental physics
- deceleration => injection in traps
- post acceleration => reactions, implantation, …

Manipulation: Post acceleration

Challenge: higher charge state is needed for efficient post acceleration

P. Delahaye / Nuclear Instruments and Methods in Physics Research B 317 (2013) 389–394

=> stripper foils

TRIUMF / ISAC

=> Electron Cyclotron Resonance Ion Source (ECRIS)

LLN

TRIUMF / ISAC

GANIL / SPIRAL

=> Electron Beam Ion Source or Trap (EBIS/T)

ISOLDE

NSCL

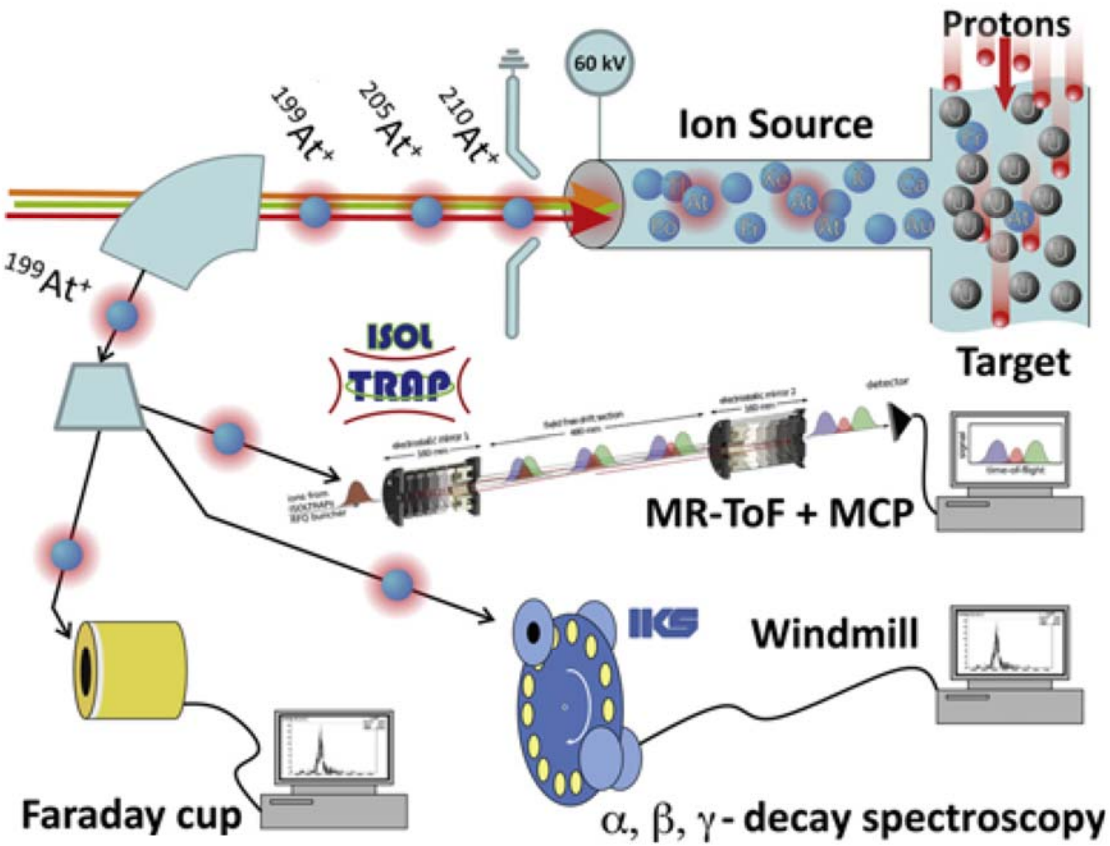
+ more to come

Integration with experimental set-ups

- decay setups
  - different implantation conditions (temperature, material, e.m. fields, …)
  - different detectors
- laser setups
- ion traps
- atom traps
- reaction chambers
- spectrometers
- storage rings

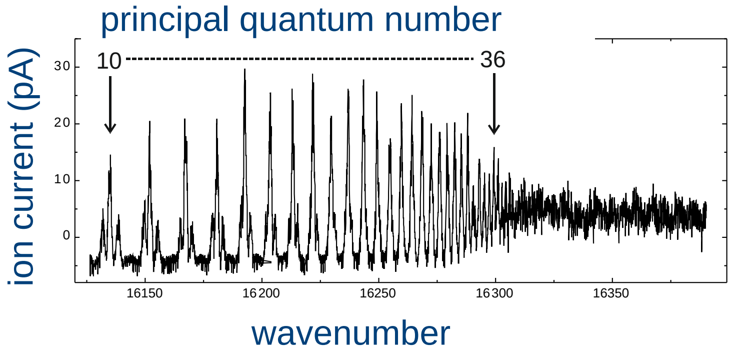
Strong coupling between the production, the manipulation and the experiments

Integration: In-Source Laser Spectrocopy



B. A. Marsh et al.
NIMB 317 (2013) 550-556

see also Jens Lassen

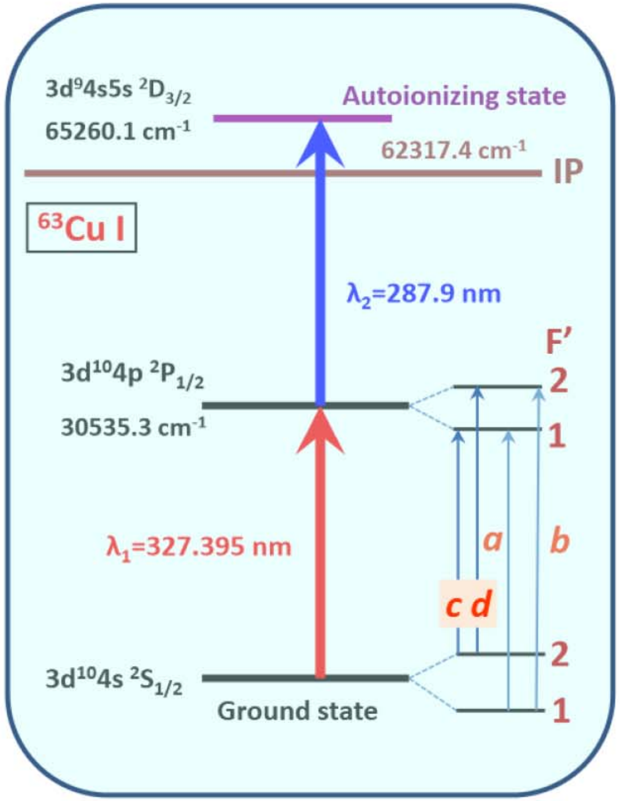


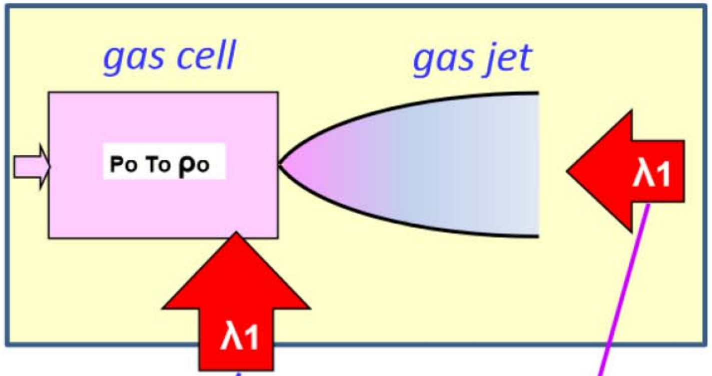
IP(At) = 9.31751(8) eV

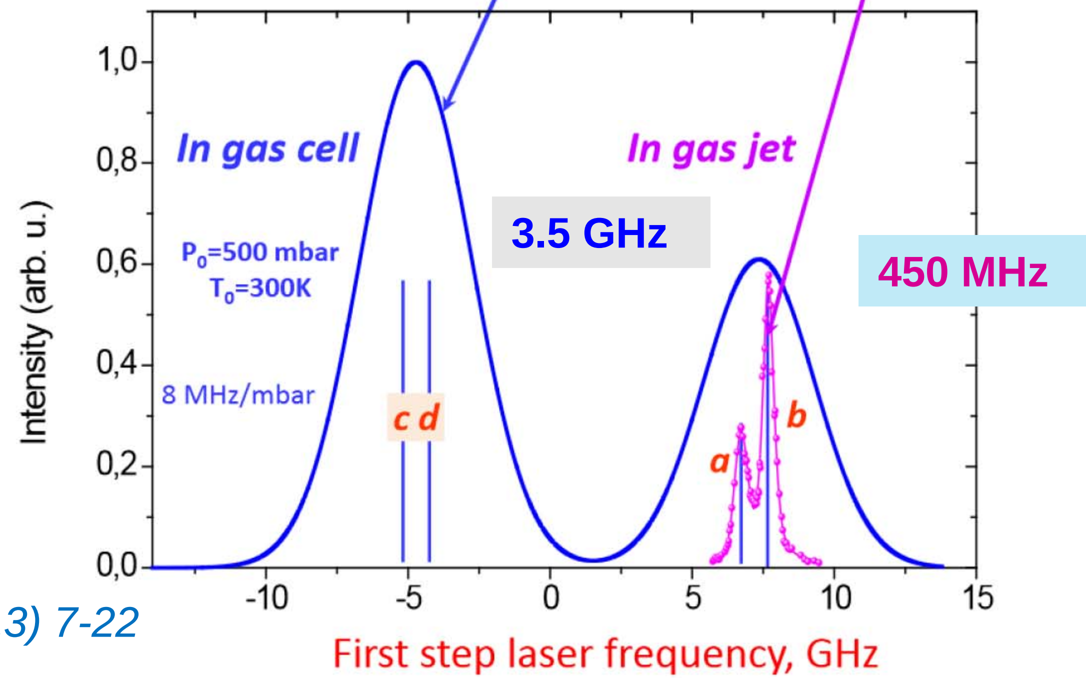
S. Rothe et al., Nature Com. (2013) DOI 10.1038

Integration: In-Source Laser *High-Resolution* Spectrocopy

From 3.5 GHz to 450 MHz due to T↓ & p ↓

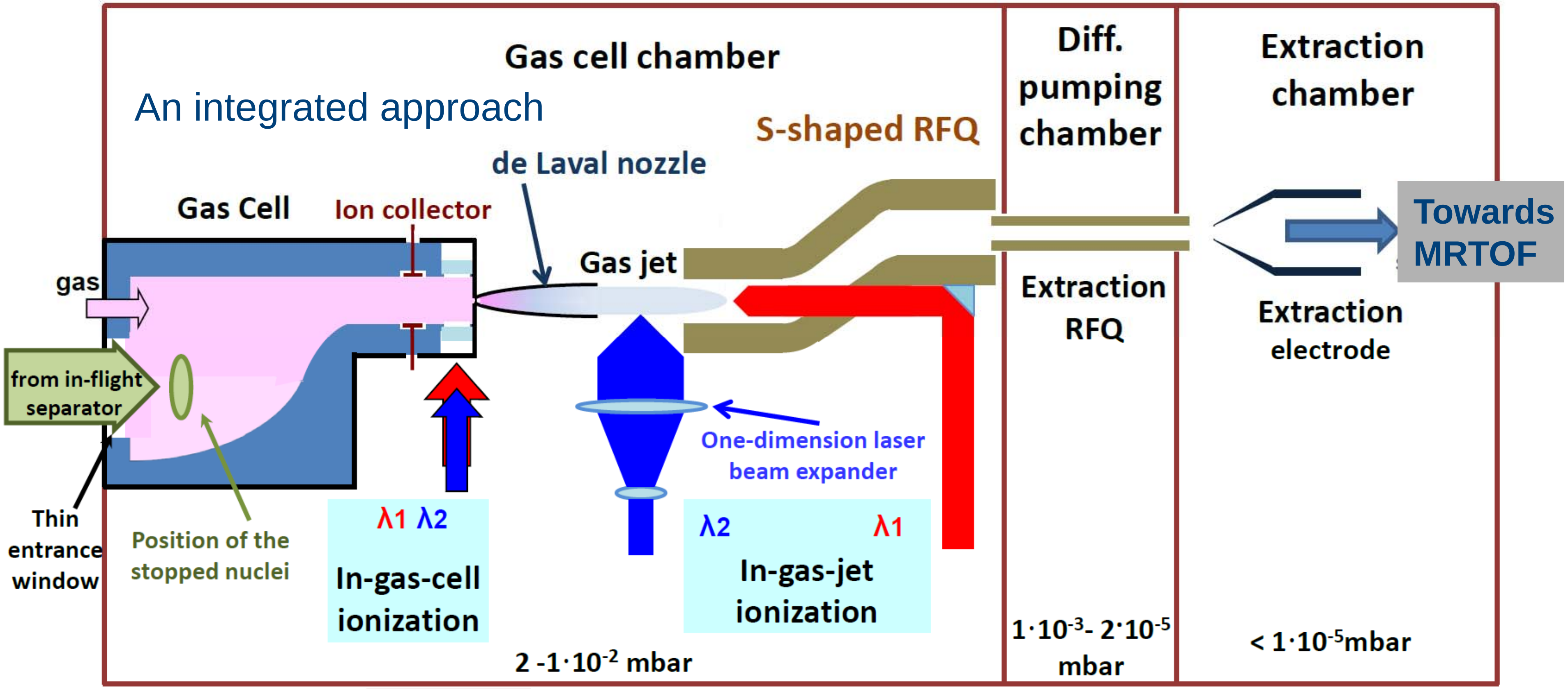






Y. Kudryavtsev et al.; NIMB297 (2013) 7-22

An integrated approach



=> 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 atom beam, **low pressure**, **low temperature***

⇒ ~ 200 MHZ resolution

⇒ laser spectroscopy

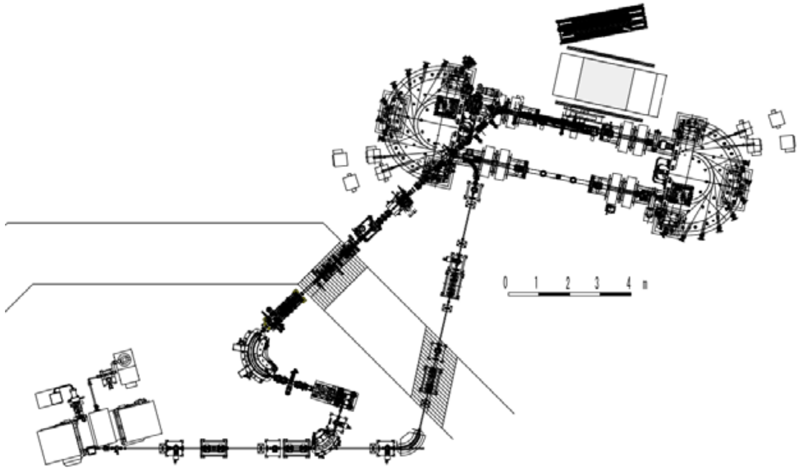
⇒ Isomeric purification

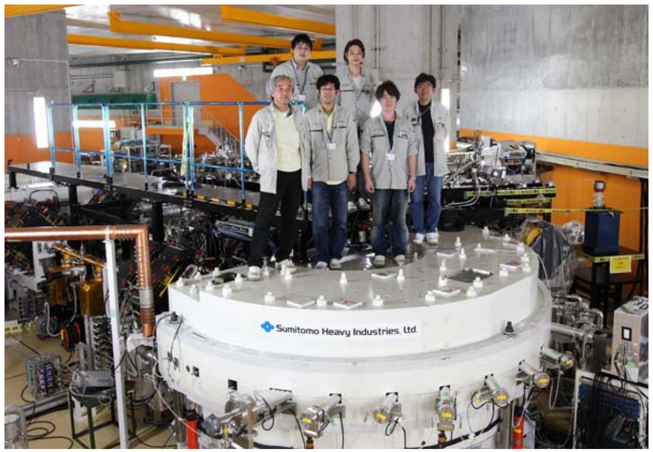
R. Ferrer et al., NIMB 317 (2013) 570-581 **REGLIS@S³** see also H. Savajols

KU LEUVEN

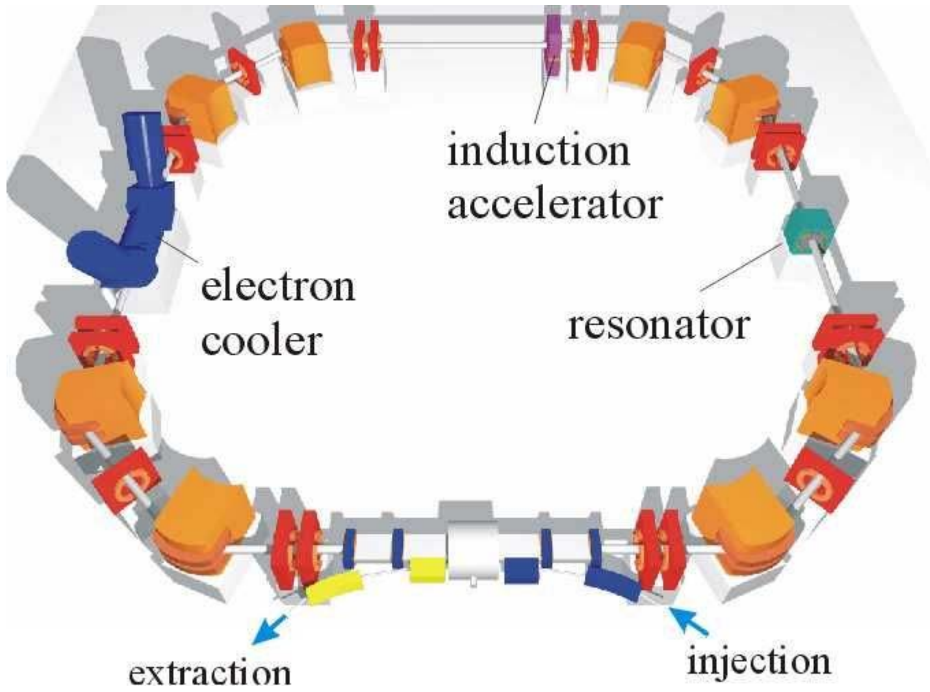
Integration: Coupling to storage rings

ERIS for SCRIT at RIKEN





M. Wakasugi et al., NIMB 317 (2013) 668-673



M. Grieser et al.
Eur. Phys. J. Special Topics 207 (2012) 1–117

Outlook: after half a century still alive and kicking!

An ISOL facility: stopped radioactive nuclei, reaccelerated and mass separated