In-Gas Laser Ionization and Spectroscopy experiments at S^3-GANIL

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Low-Energy Radioactive Isotope Beam Production by In-Gas Laser Ionization for Decay Spectroscopy at RIKEN

December 10-11, 2012

RIKEN-Wako

OUTLINE

- Motivation
- In-Gas-Cell Laser Spectroscopy @ LISOL
- Progress on the implementation of In-Gas-Jet Laser Spectroscopy
- Summary and Outlook

KATHOLIEKE UNIVERSITEIT LEUVEN

BriX

MOTIVATION

Strategic areas of chart of nuclides → understand nuclear structure effects

- **N = Z nuclei** - Study role of proton-neutron correlations -
- **Proton drip line** - rp process, nuclei far off stability -
- **Proximity doubly magic N = Z = 50** - strong shell correction effects -
- **SHE** - understanding of SHE and those at the limit of nuclear existence -

DAY 1 @ S3 → In Gas Laser Ionization and Spectroscopy experiments of:

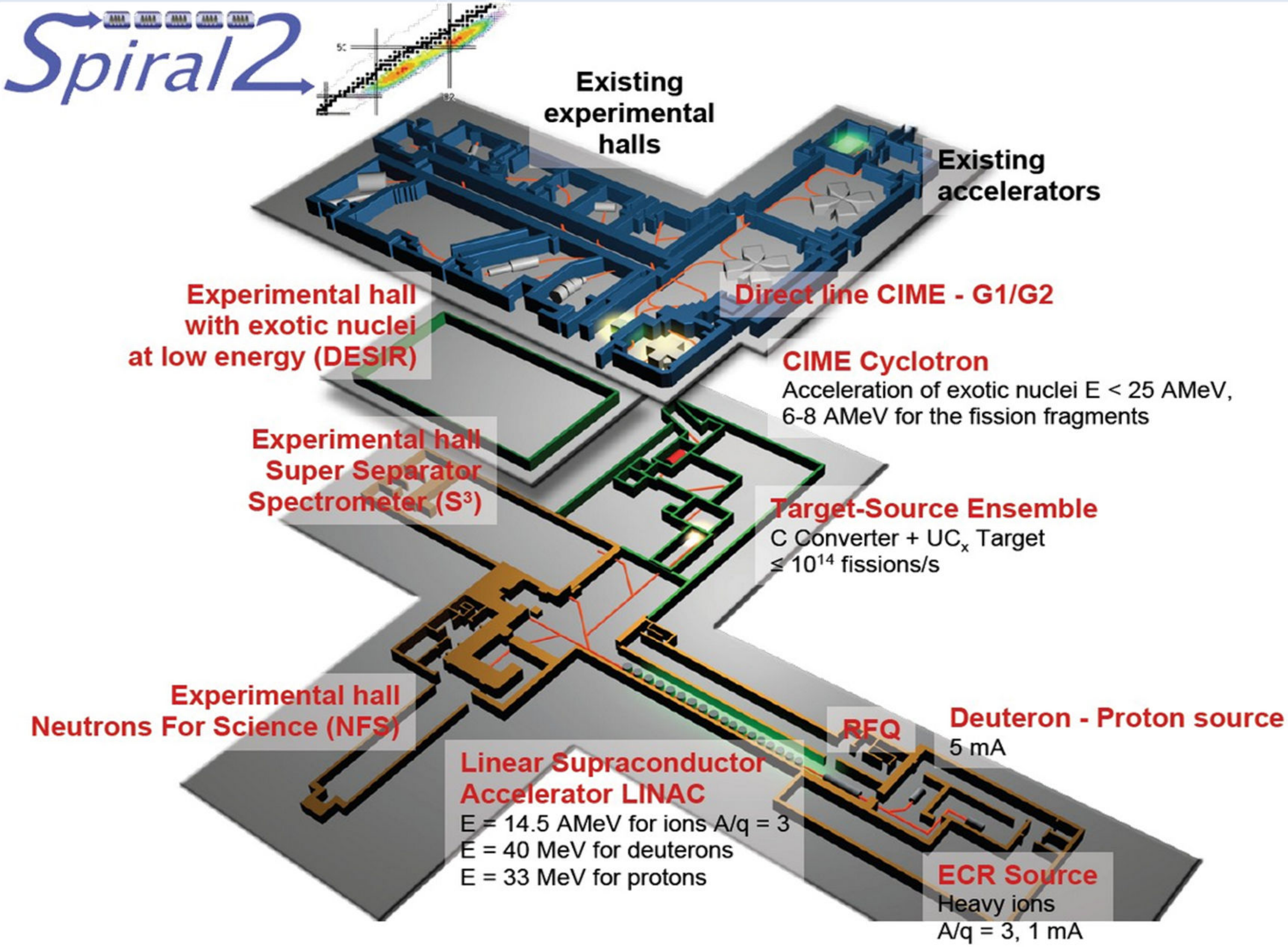
❑ **^{94}Ag**
High-spin isomerism, β-delayed p, 1- and 2-p emission

❑ **^{80}Zr** (spk. person: B. Bastin)
Single particle behavior and effective interactions

❑ **$^{107-101}$Sn**
Test validity of shell-model predictions

❑ **VHE (Z ~ 89 - 102)**
Validate nuclear and atomic theory

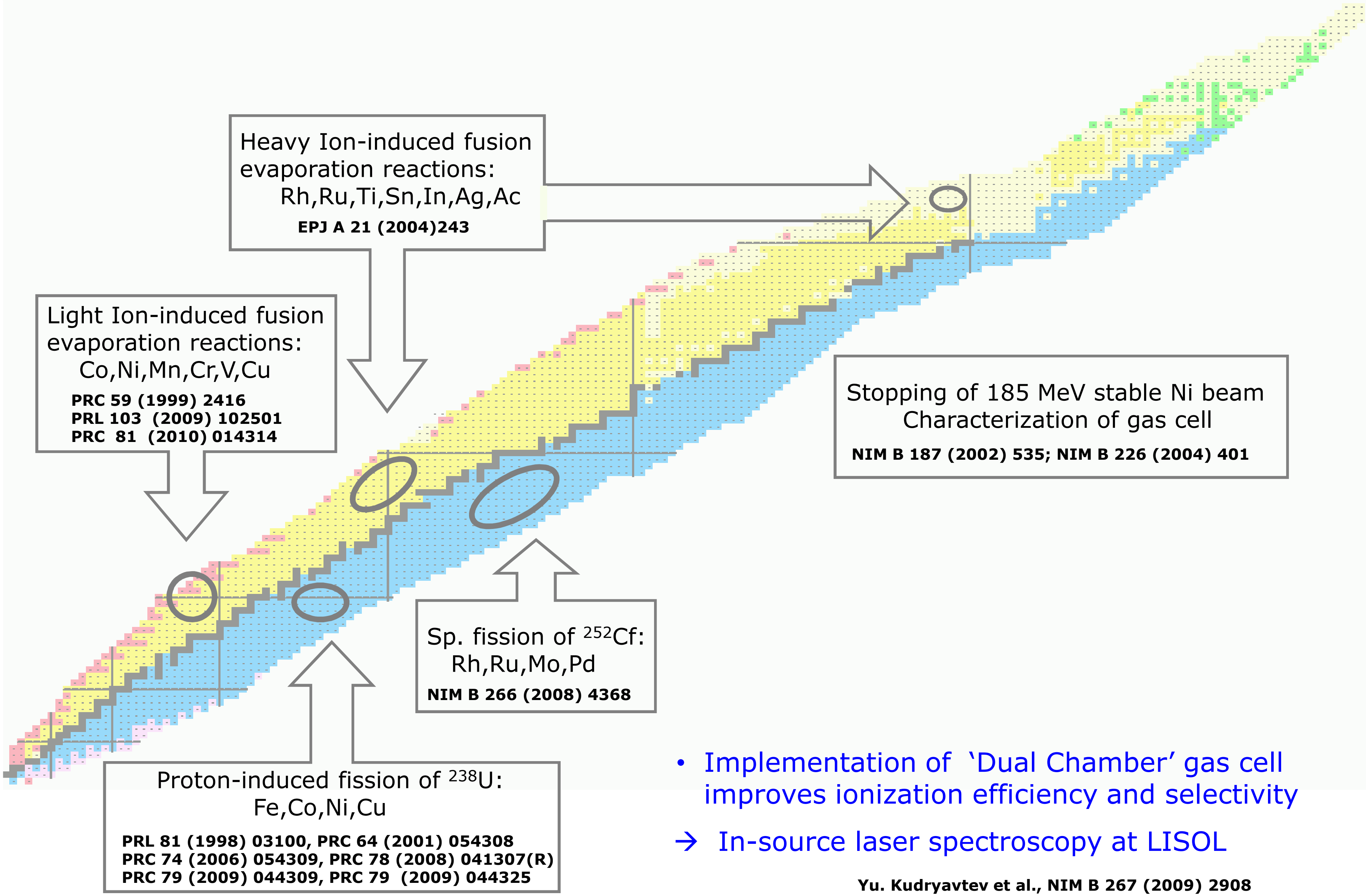
S³ @ SPIRAL2



- Very high intensity primary beams
- Full range of primary beams (H to U)

- High primary beam rejection
- High acceptance spectrometer

LISOL Beams since 1994

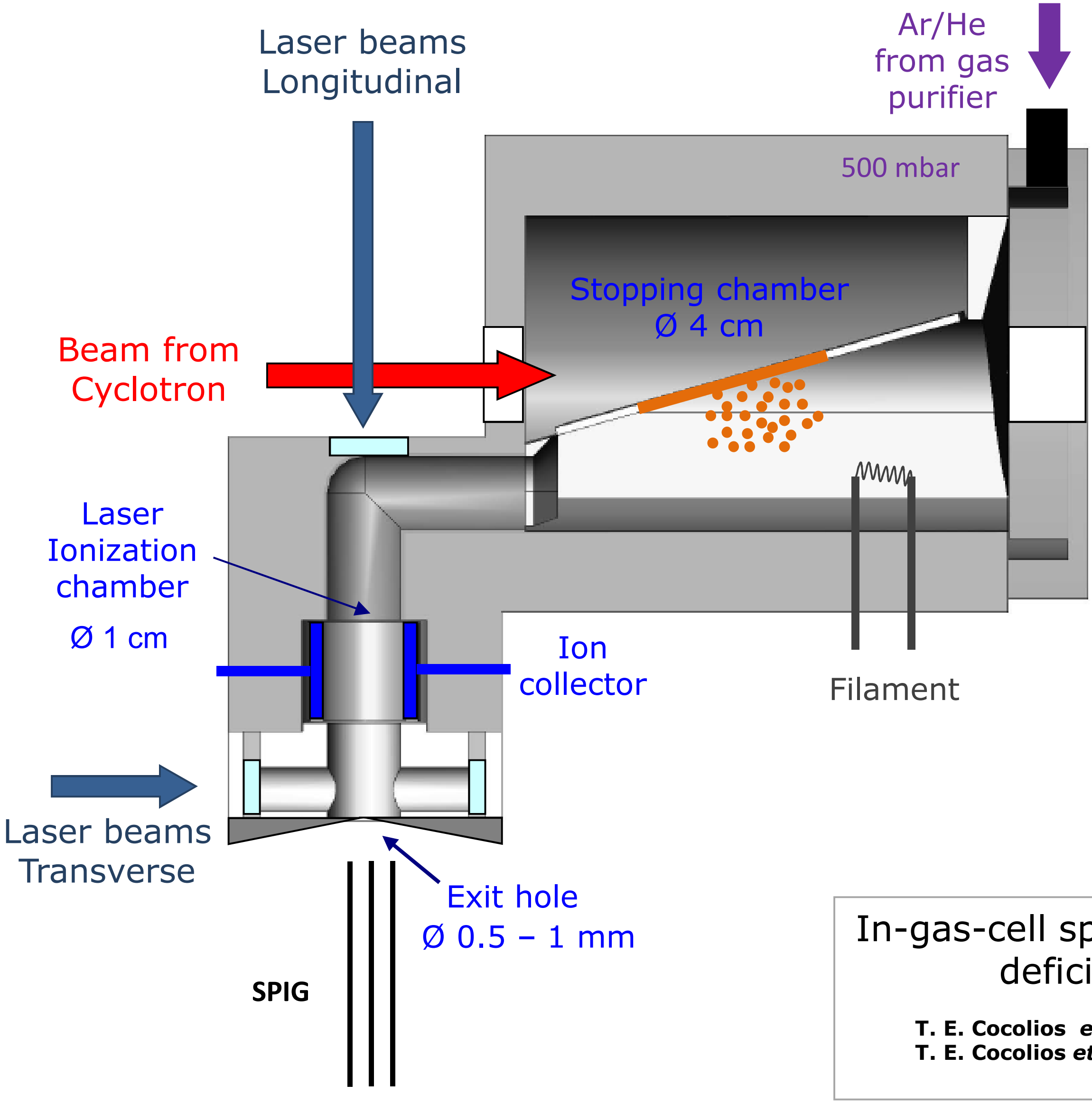


- Implementation of 'Dual Chamber' gas cell improves ionization efficiency and selectivity

→ In-source laser spectroscopy at LISOL

Yu. Kudryavtev et al., NIM B 267 (2009) 2908

Dual Chamber Gas Cell



Separation of stopping and laser ionization volumes improves:

- Laser ionization efficiency for high cyclotron beam current
- Ion selectivity

Production of ^{94}Rh

Selectivity:

[Laser(on)/Laser(off)]

Ion Collector OFF = 450

Ion Collector ON = 2200

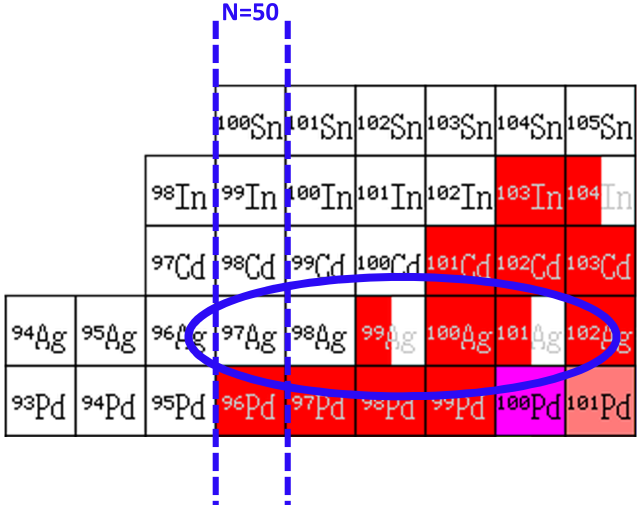
In-gas-cell spectroscopy of neutron deficient Cu isotopes

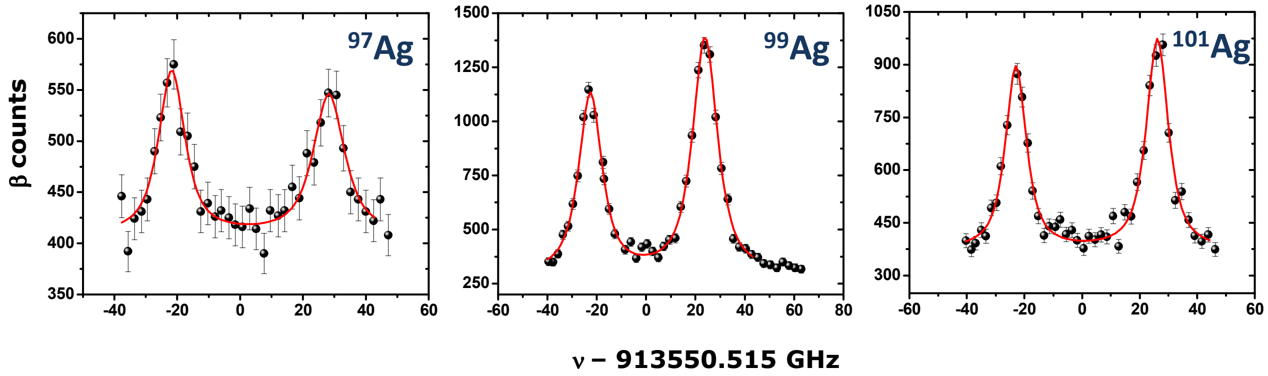
T. E. Cocolios *et al.*, PRL 103, 102501 (2009)
T. E. Cocolios *et al.*, PRC 81, 014314 (2010)

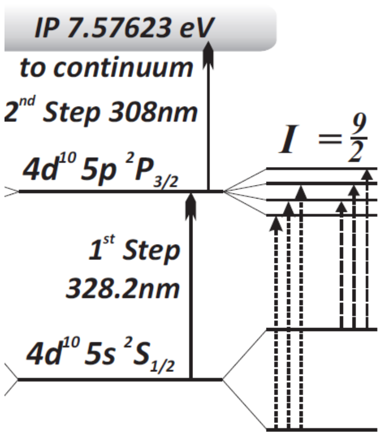
In-Gas-Cell Laser Spectroscopy of Ag

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

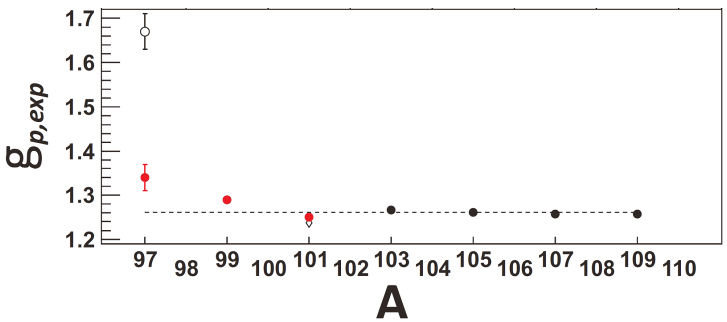
$^{64,nat}Zn(^{36}Ar - 125\ MeV, pxn)^{101-97}Ag$







Derived experimental proton g-factors
Open circle calculated value assuming I=7/2+



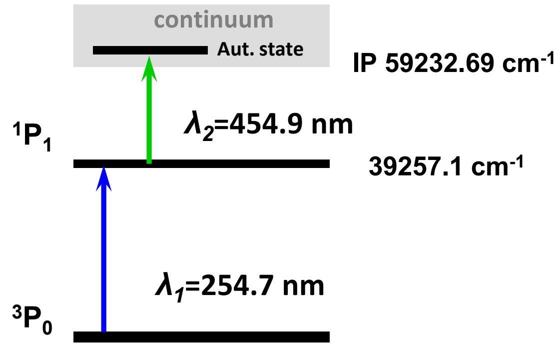
	Splitting (GHz)	I^π	μ_{exp}(st+sys) (nm)	μ_{exp}^{lit} (nm)
100	36.2(2)	6^+	4.42(2)	--
98	38.3(6)	5^+	4.60(7)	--
	38.3(6)	6^+	4.67(7)	--
101	46.8(2)	$9/2^+$	5.57(2)	5.7(4)
99	48.7(3)	$9/2^+$	5.80(3)	--
97	50.6(9)	$9/2^+$	6.0(1)	--
	50.6(9)	$7/2^+$	5.9(1)	

U. Dinger et al., Nucl. Phys. A 503 (1989) 331

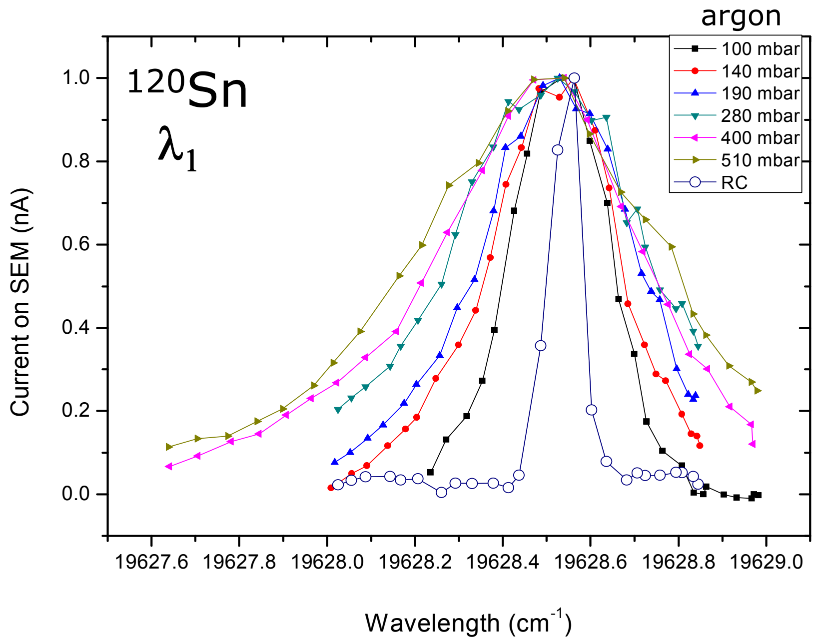
R.F. Phys. Lett. B (in preparation)

Attempt at Laser Spectroscopy of Sn

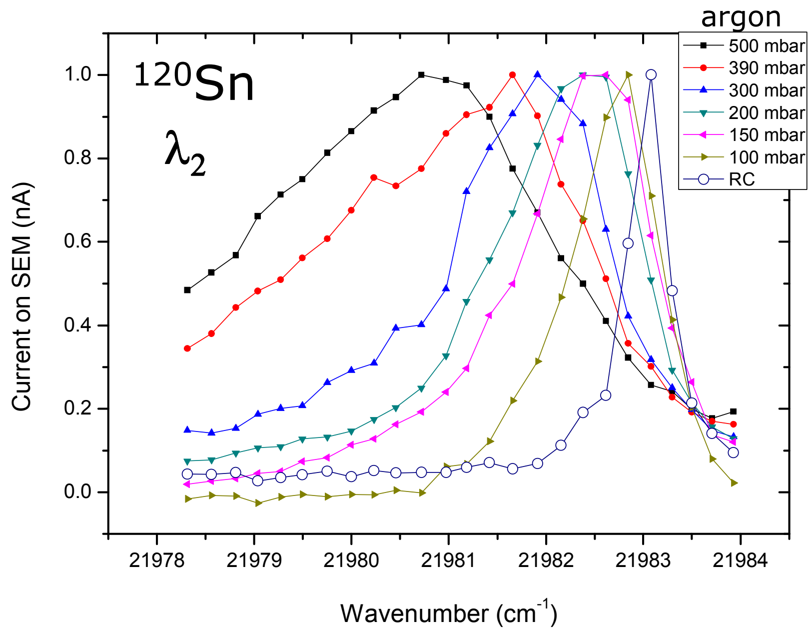
$^{92}Mo(^{16}O\text{-}100\ MeV,2\text{-}3n)^{105,106}Sn$



- Strong ν-dependence on gas cell pressure
- Not possible HFS measurements (FWHM~15GHz)

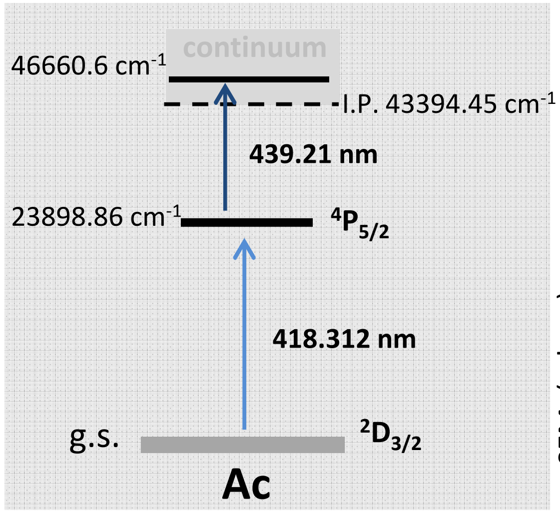


Shift = -4.0(0.3) MHz/mbar
Broadening=32(4) MHz/mbar



Shift = -150(10) MHz/mbar
Broadening=210(25) MHz/mbar

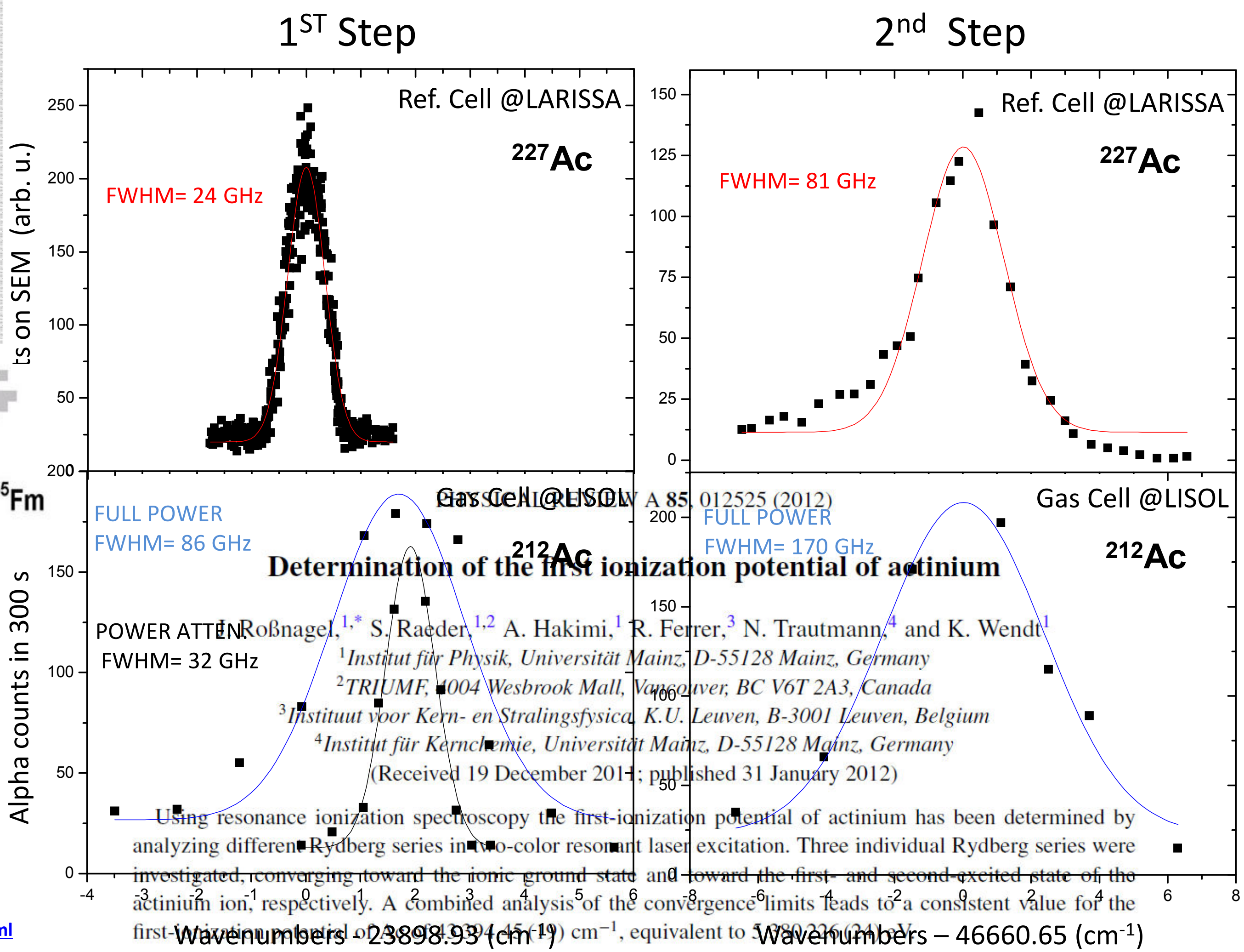
Broadband Spectroscopy on Ac

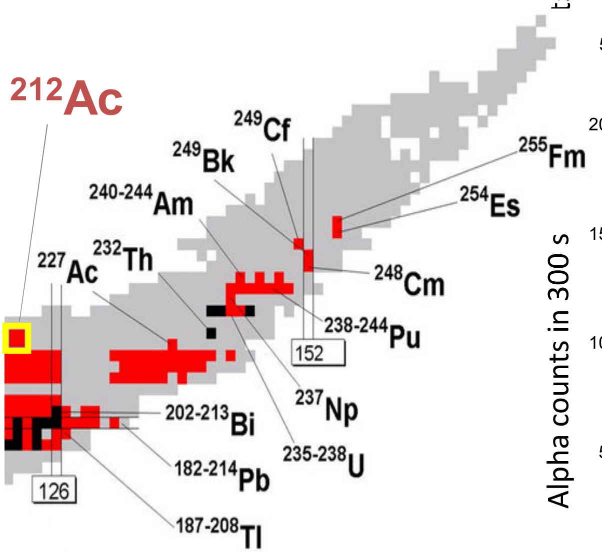


$^{197}Au(^{20}Ne$-145 MeV,4-5n$)^{212,213}Ac$

Cross section 2.3 mb for $^{212,213}Ac$

A. Andreyev *et al.* Nucl. Phys. A 568 (1994) 323



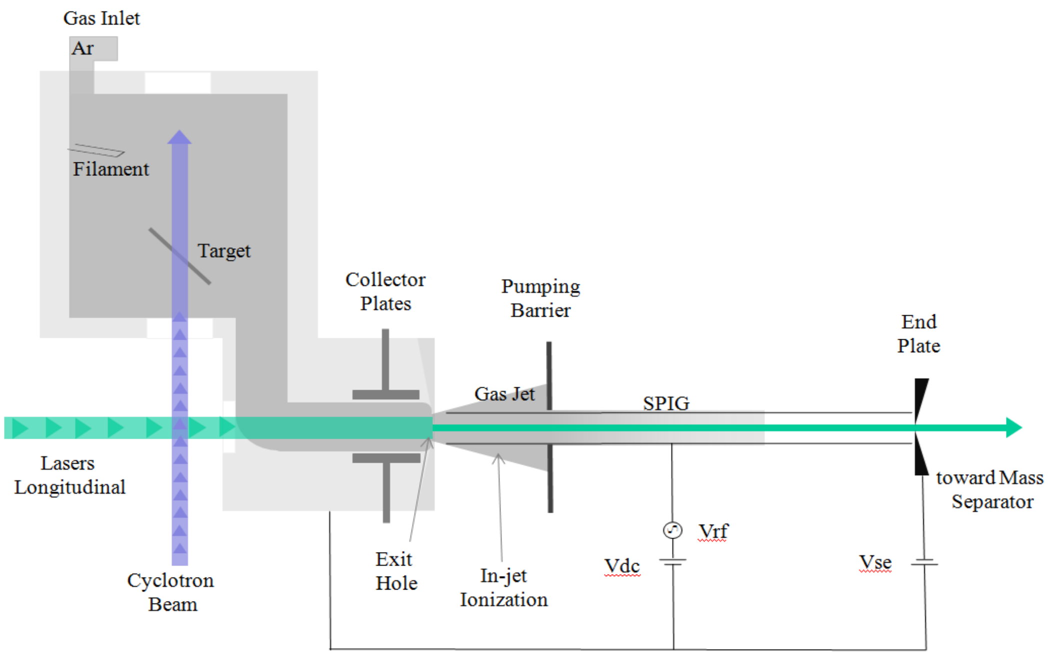


http://www.gsi.de/forschung/ap/projects/laser/survey.html

In-Gas-Jet Laser Spectroscopy

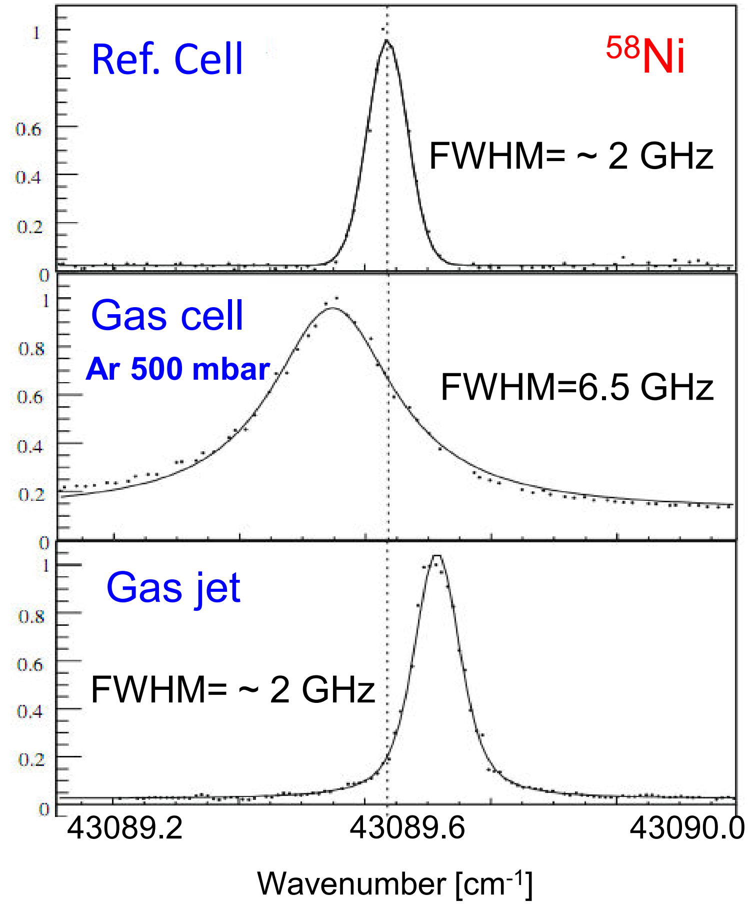
- Increase Resolution
  - Ionization in cold jet expanding out of the gas cell
- and Selectivity
  - Ionization in LIST mode

K. Blaum *et al.*, NIM B204 (2003) 331



Demonstrated proof of principle @ LISOL

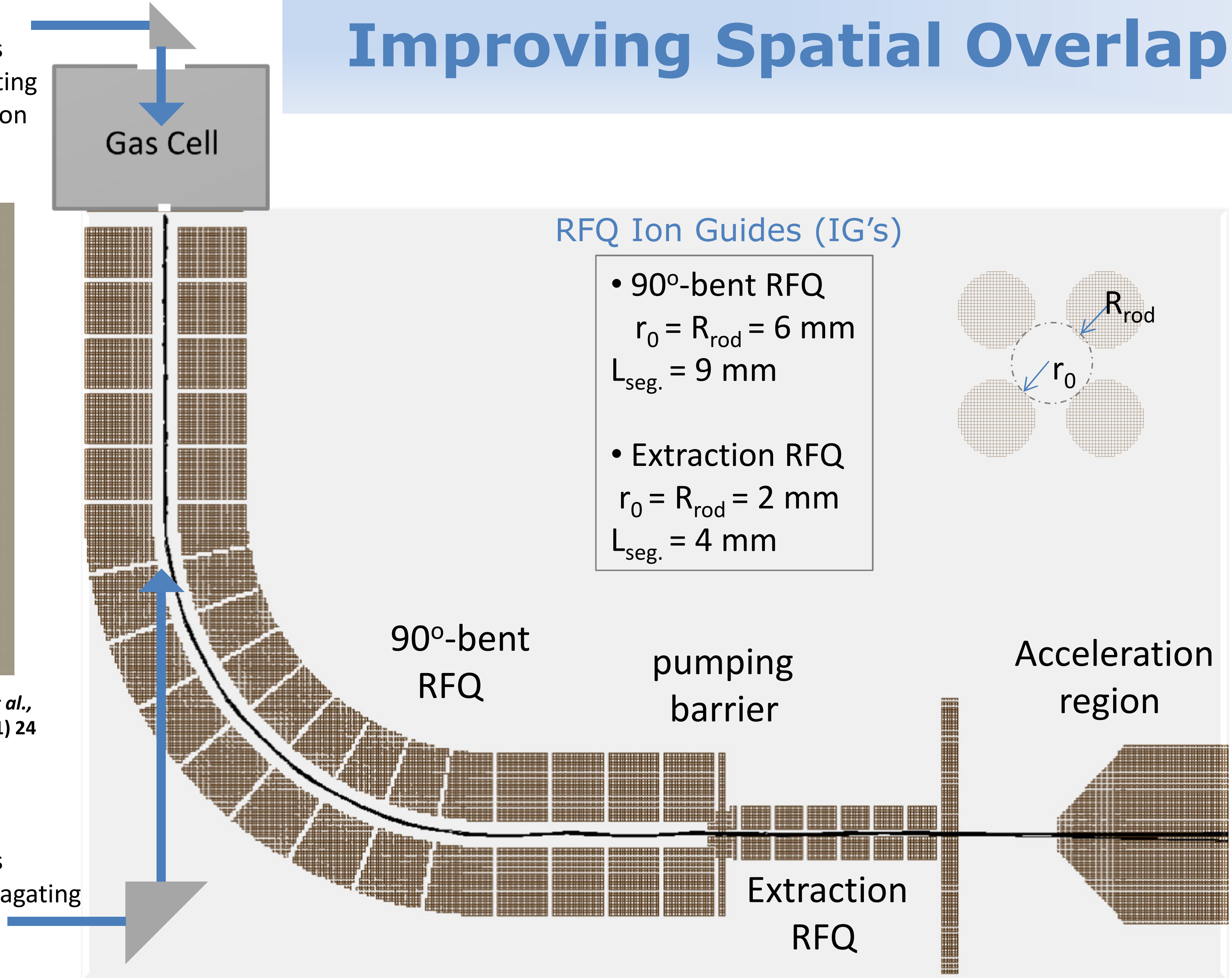
T. Sonoda *et al.* NIM B267 (2009) 2918



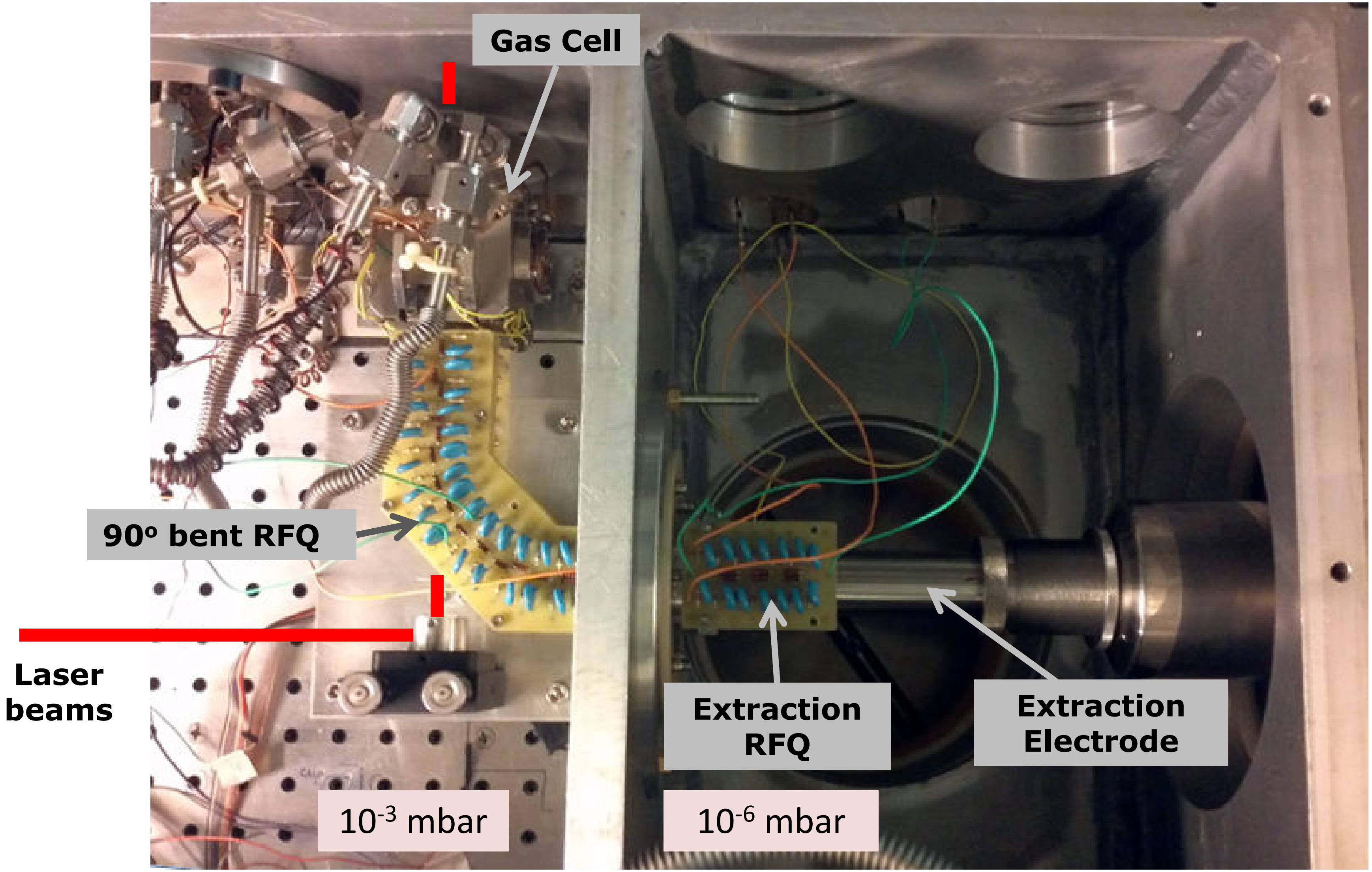
- Requirements to obtain maximum benefits:
  - **Improve spatial overlap and temporal overlap**
  - **Reduce laser bandwidth**

Improving Spatial Overlap

M. Reponen *et al.*,
NIM A 635 (2011) 24

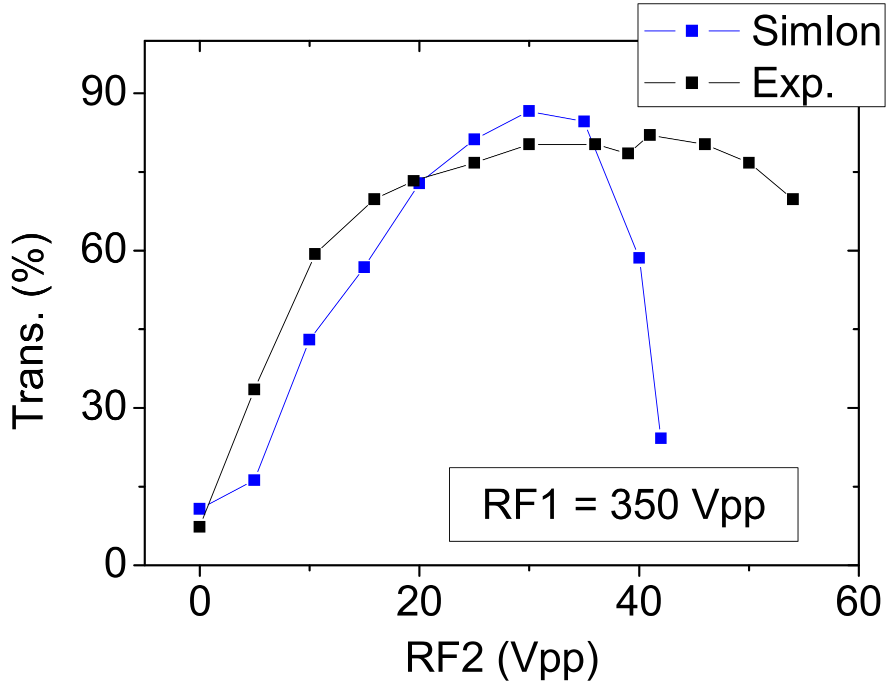


Commissioning of the RFQ IG's



Transmission through RFQ IG's

Comparison experiment vs. simulation (bkg p = 1e-3 mbar)



Copper filament:

A/Q= 63, 65,
81, 83,
99, 101

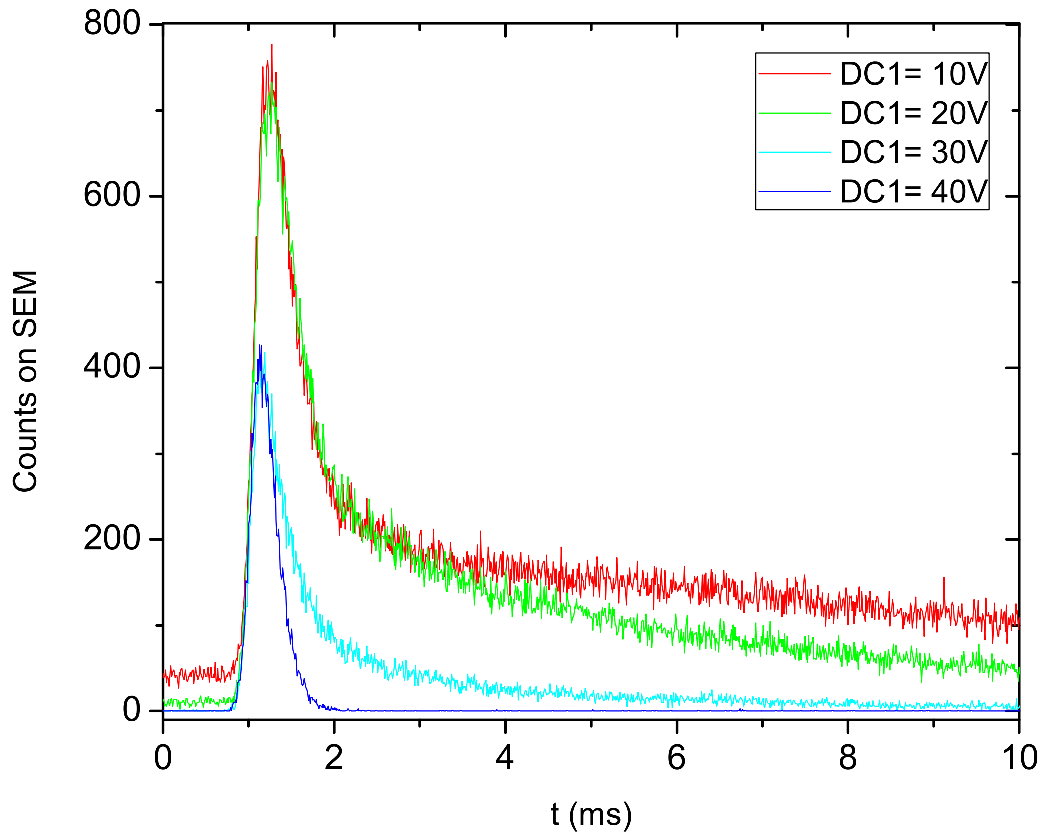
- Performance of ion guides found to be in agreement with expectation
- Transmission efficiency ε= 80%
- Similar transmission found for bkg p=0.1 mbar

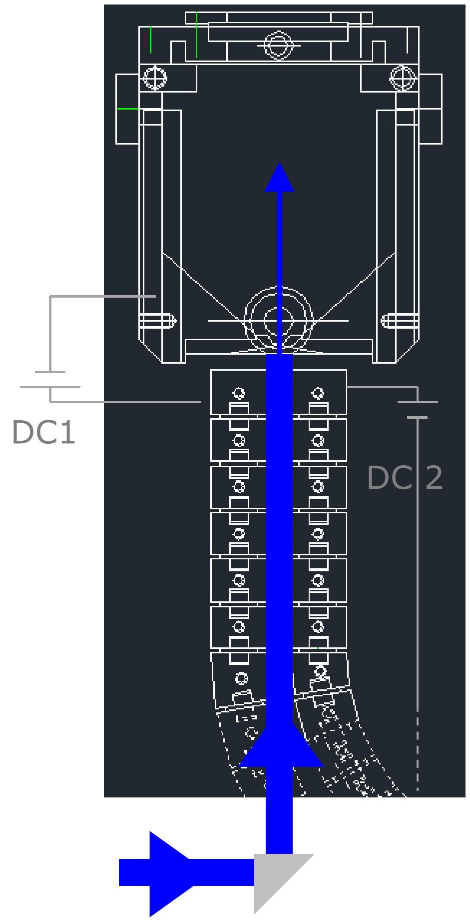
Selection of Ions from the Gas Jet

- Determine the blocking potential

- Time profiles with lasers in counterpropagating direction

A/Q= 63
DC2= -10 V
$1*10^{-1}$ mbar

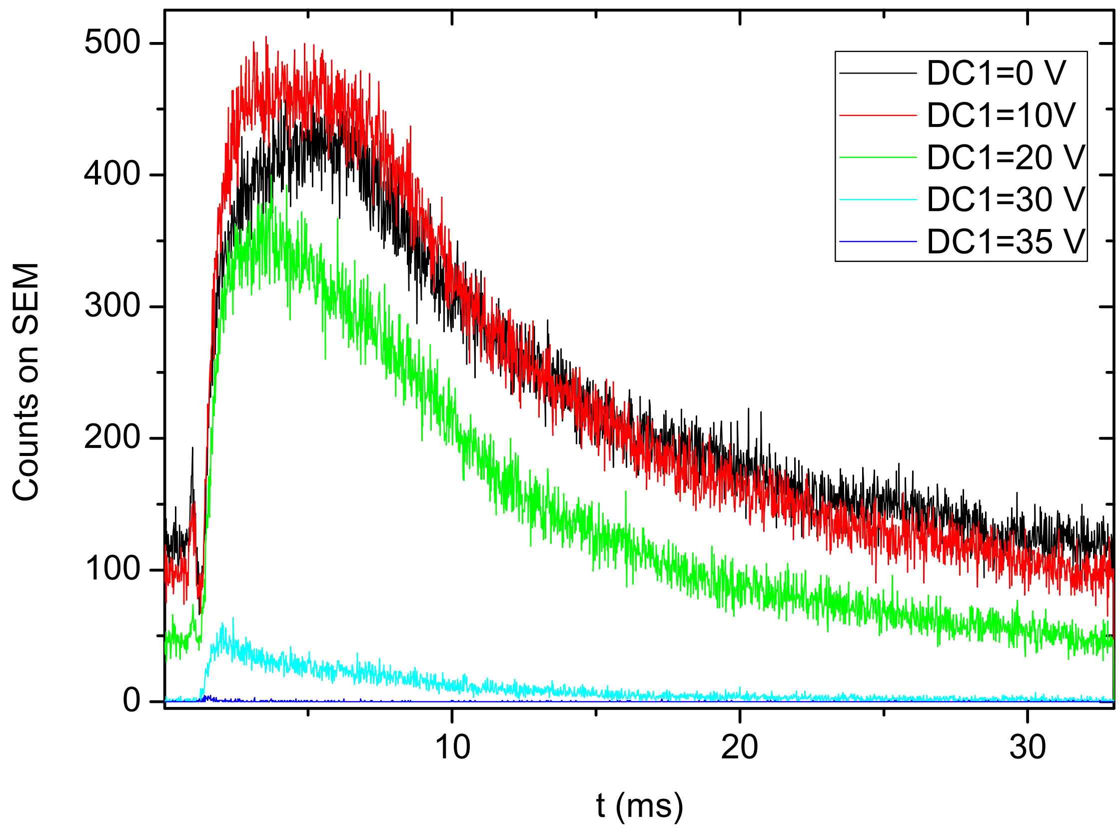


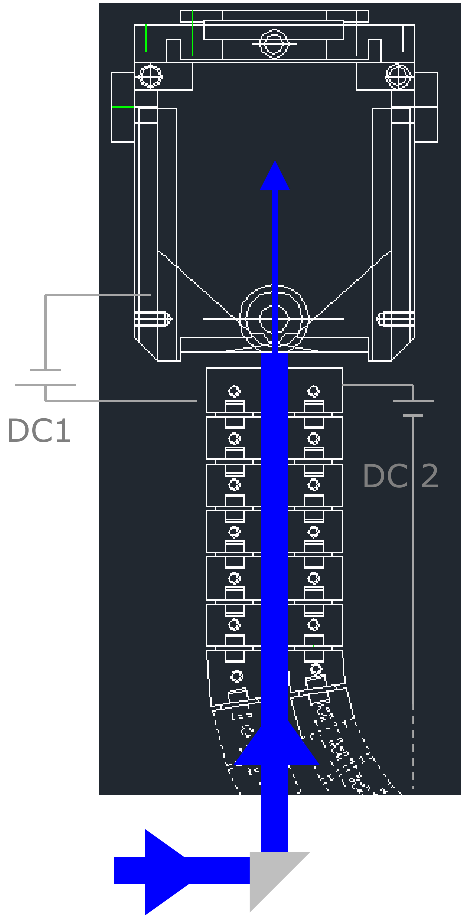


- Bias voltage of 40 V block all ions from gas cell

Sideband Formation

A/Q= 81 [$^{63}Cu\ H_2O]^+$
DC2= -10 V
1*10^{-1} mbar



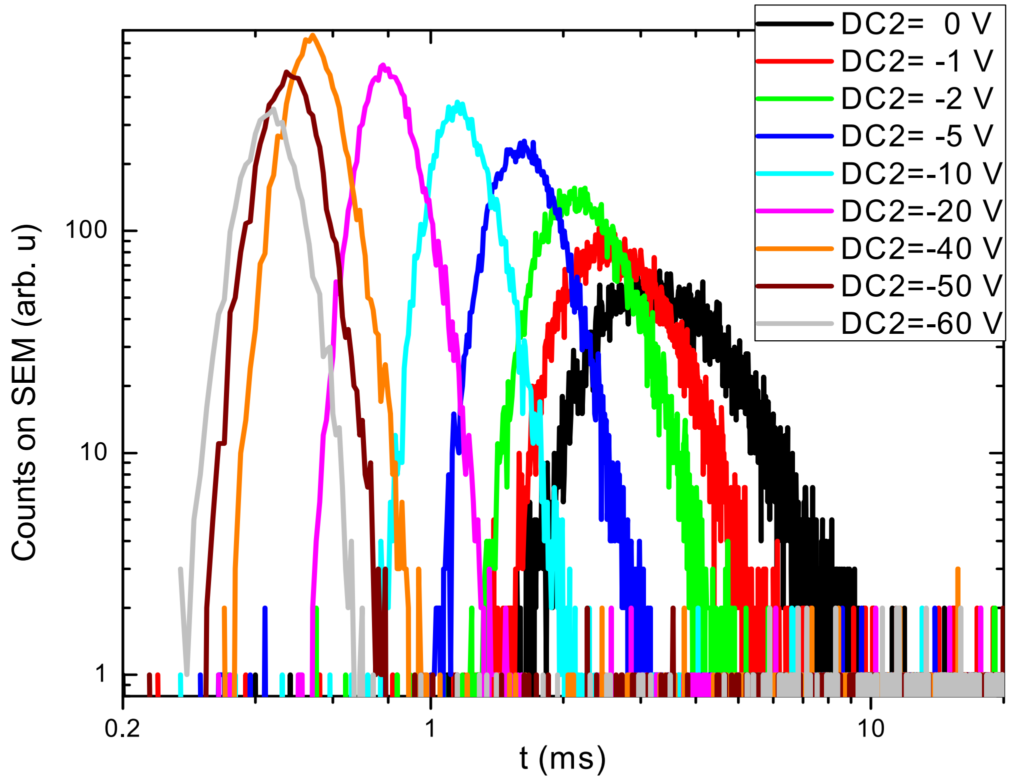


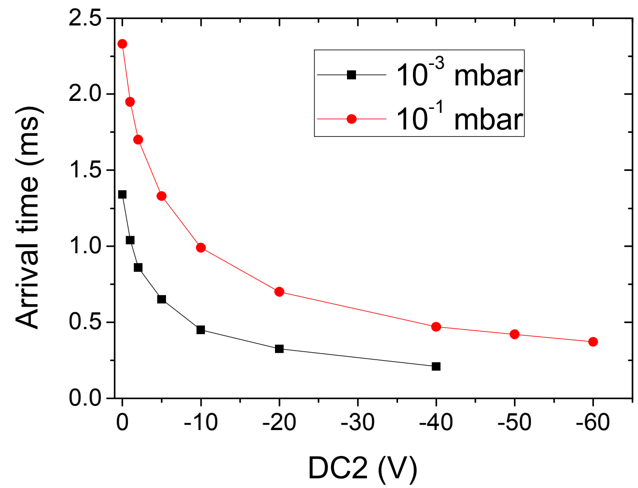
- Molecule formation occurs in the GC (short mfp) and not in the gas jet (long mfp)

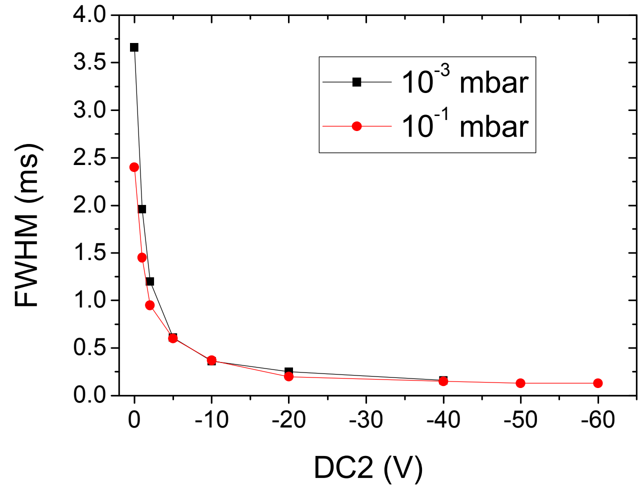
Effect of dc gradient on the Ion Beam

- Time profiles with lasers in counterpropagating direction

A/Q= 63
DC1= 40 V
$1*10^{-1}$ mbar



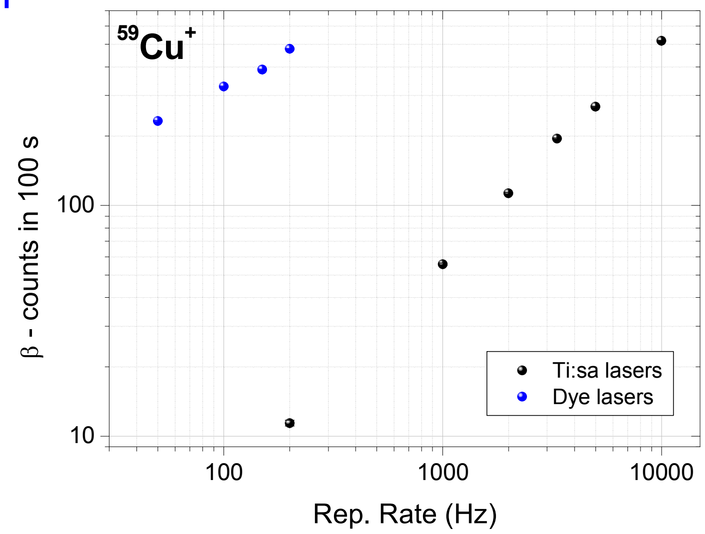


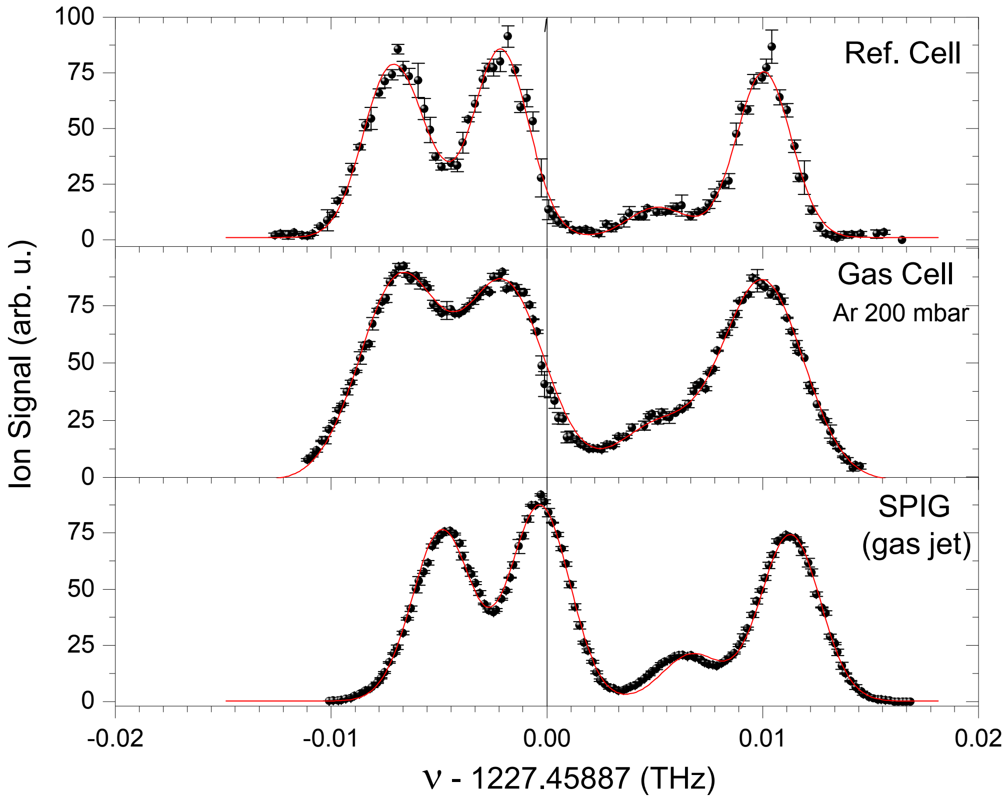


✓ Manipulation of ions by dc gradient

Improving Time Overlap

- Test of a high pulse repetition rate laser system (Uni-Mainz, GANIL, JYFL, RIKEN, IPNO, JINR)
  - Performance comparison between high repetition Ti:sa lasers and LISOL dye lasers
  - Comparable results for in-gas-cell ionization



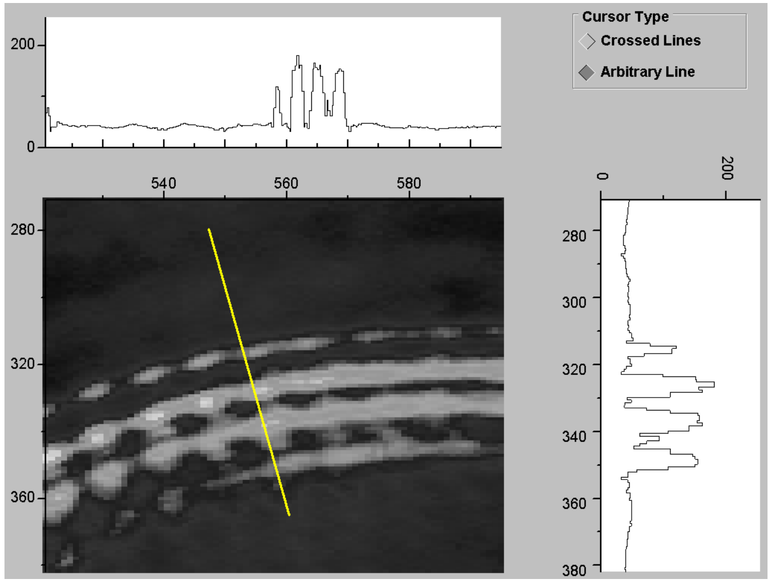


- Resolution of HFS of stable ^{63}Cu in the gas jet mainly limited by laser bandwidth

R. F., V. Sonnenschein *et al.*, NIM B 291 (2012) 29

Reduction of the Laser Bandwidth

- Study of typical LISOL narrow-band pulse using FP interferometer

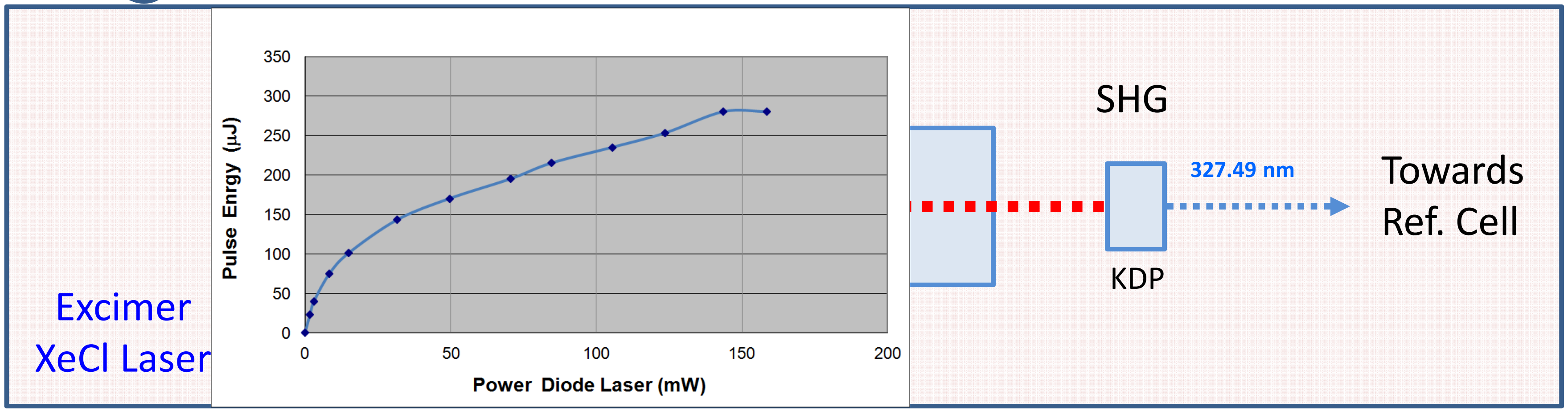


- Radial profile of interference ring shows four oscillation modes

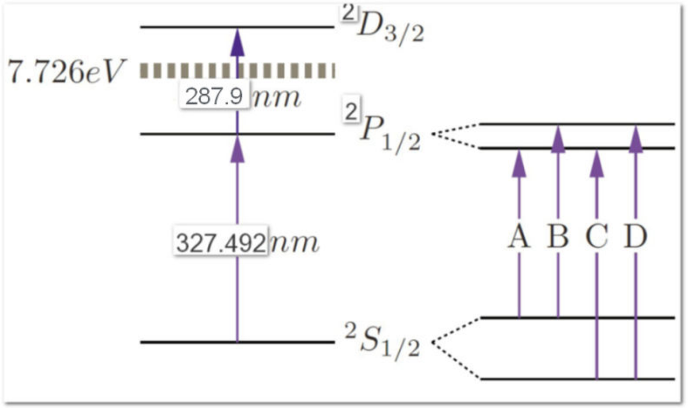
- Separation between modes is 400 MHz
  → mode FWHM= 150MHz
  Laser bandwidth ~1.4 GHz (SHG)

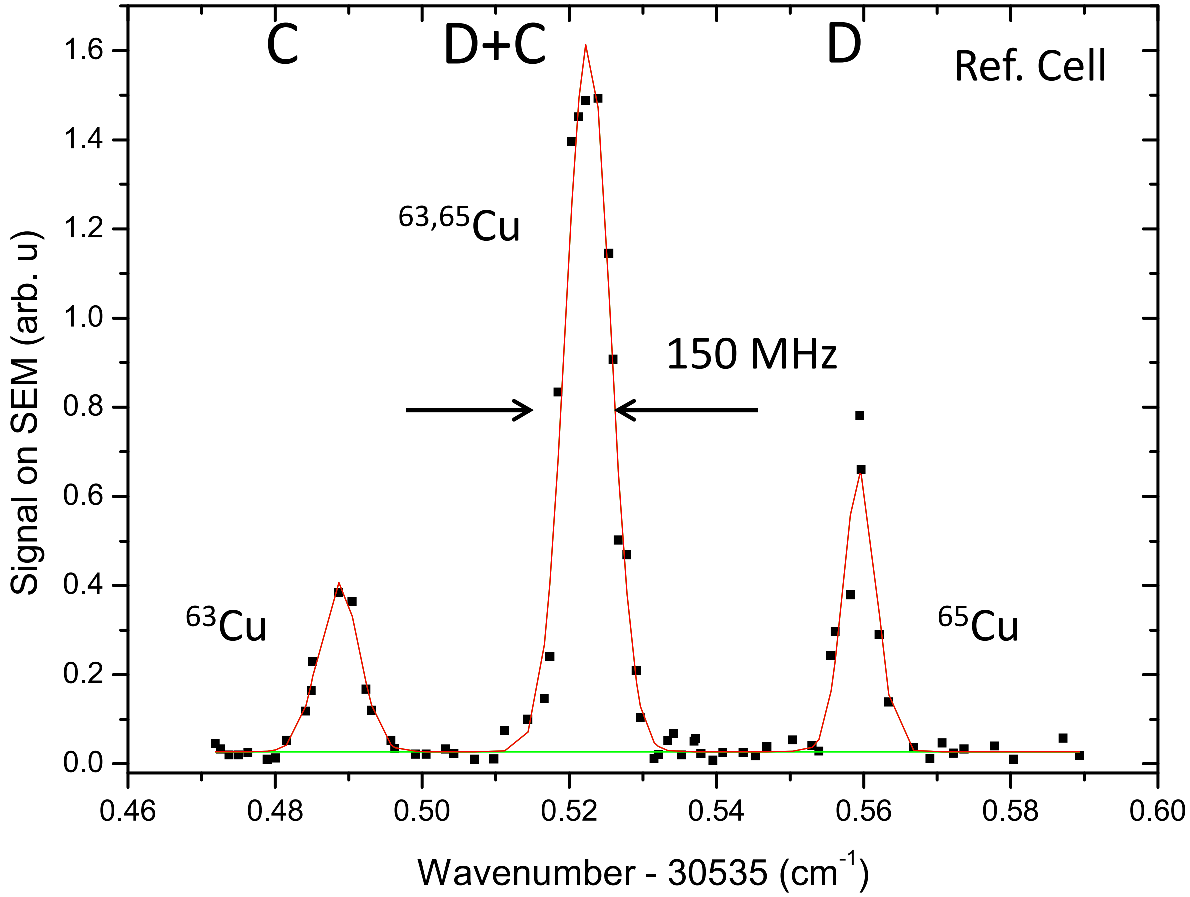
1. Implementation of a thicker etalon (14 mm air spaced) allows selection of a single mode
   → 450 MHz FWHM (Doppler broad.)

2. Amplification of CW Single Mode Diode Laser in Pulsed Dye Amplifier



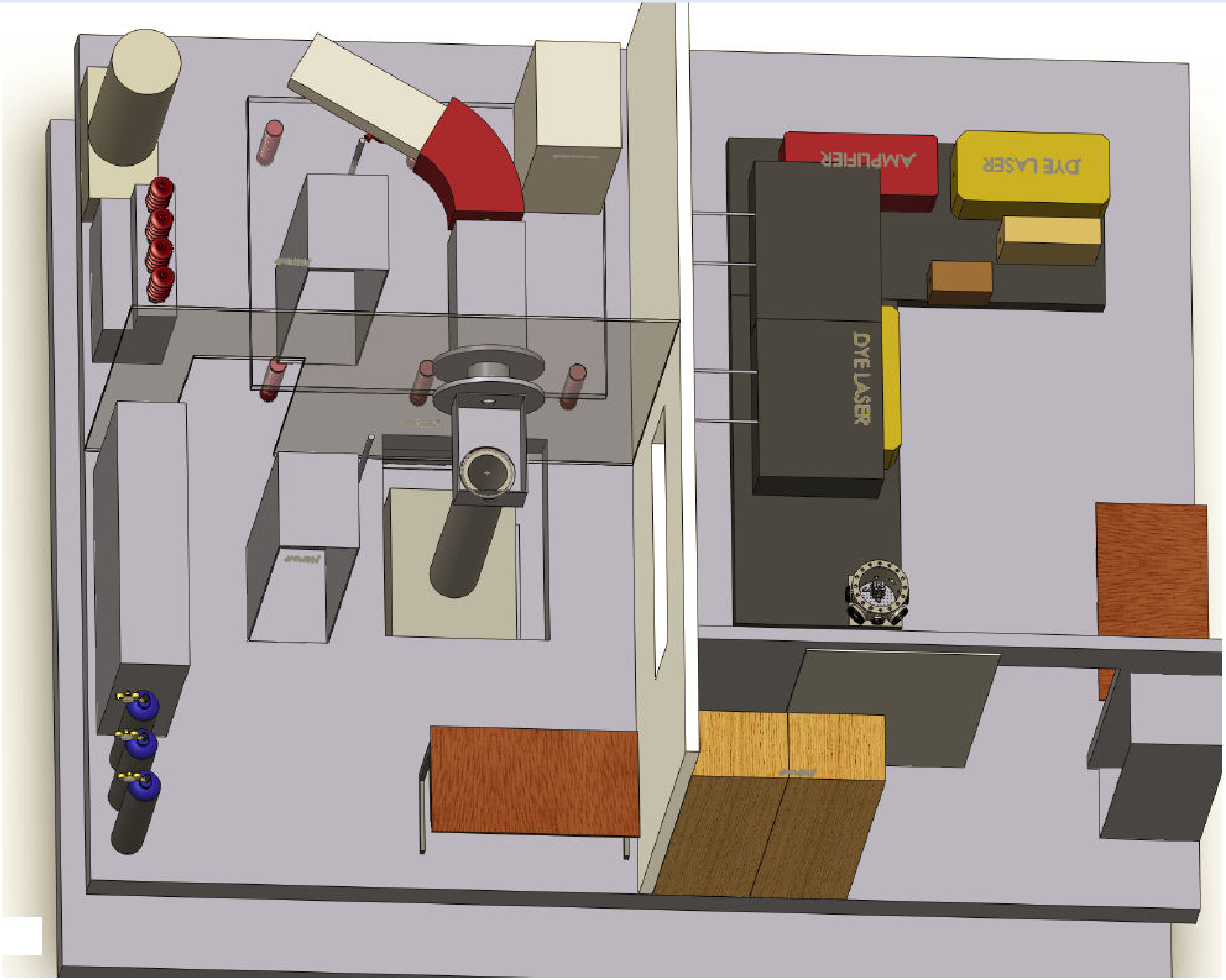
High energy HFS components of the 327 nm line in $^{63,65}Cu$





- Estimated 90 MHz Fourier-limited (5ns) laser bandwidth is affected by residual Doppler broadening resulting in a signal line width of 150 MHz

HELIOS @ KU Leuven



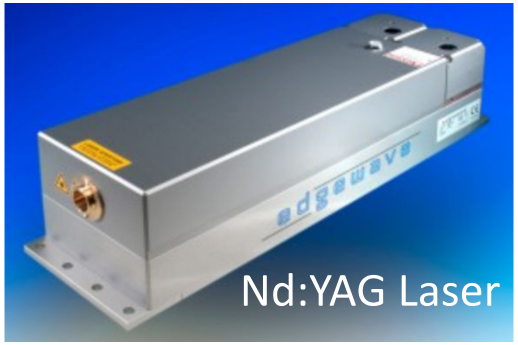
European Research Council

Laser equipment for IGLIS @ HELIOS

Two step laser ionization spectroscopy in the gas cell

- Two high-repetition-high-power Nd:YAG pump Laser
- Max. average power = 100 W (@ 532 nm)
  40 W (@ 355 nm)
- Max. repetition rate = 15 kHz

- Two high repetiton rate dye lasers
- Tunable wavelength from 215 to 900 nm
- Linewidth ~ 0.07 cm^{-1} (2 GHz)



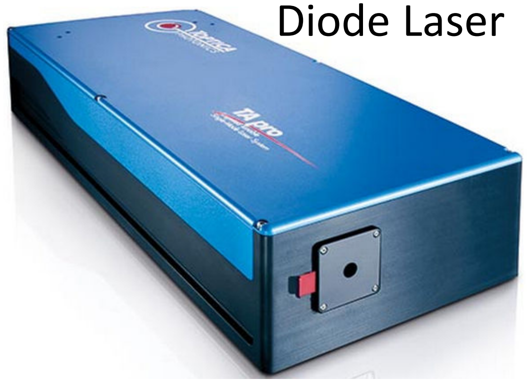
Dye Laser

For high resolution spectroscopy in the gas jet first step will consist of

- A continous wave (CW) single mode tunable diode laser
- Linewidth = 1 MHz
- Typical (mode-hop free) tuning range ~ 20 nm
  Suitable for only one element (requires change of diode depending on adopted ionization scheme)

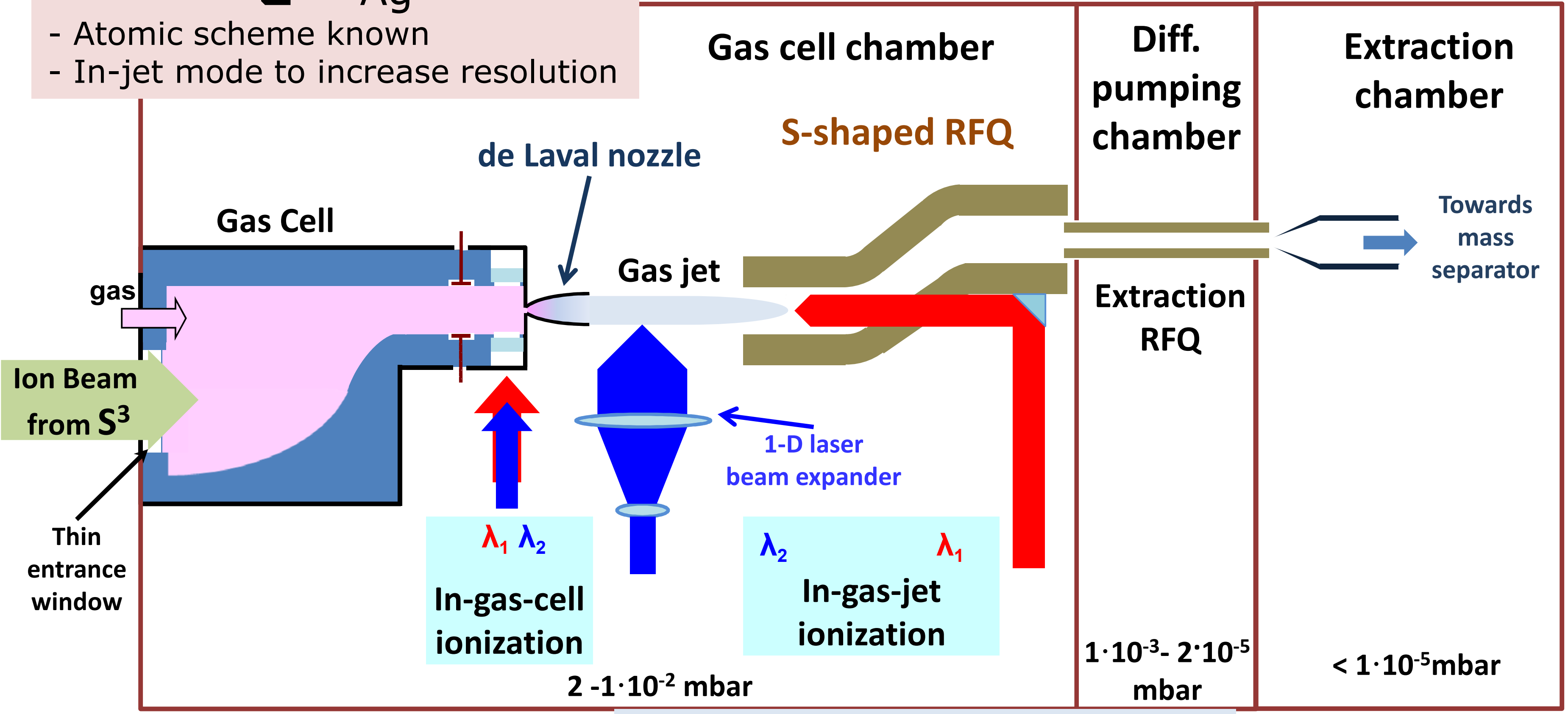
- A pulsed dye amplifier with second harmonic generator

Diode Laser



IGLIS Setup @ S^3

❑ ^{94}Ag
- Atomic scheme known
- In-jet mode to increase resolution



❑ ^{80}Zr
- Atomic scheme unknown
- In-gas cell/In-gas jet spectroscopy

❑ VHE (actinides)
- Atomic scheme known for Ac
- Develop Atomic schemes for other actinides
- In-gas cell/In-gas jet spectroscopy

❑ $^{107-101}$Sn
- Atomic scheme known
- In-gas-jet spectroscopy required owing to p dependence

Summary & Outlook

- In-gas-cell laser spectroscopy of $^{57-59}Cu$ and $^{97-101}Ag$ performed at LISOL
- Similar results are being pursued for the Ac isotopes

- In-gas-jet laser spectroscopy will allow higher resolution & selectivity
  → More isotopes will be accessible
- First implementation @ LISOL → Bent RFQ + Narrow band laser + free jet (de Laval Nozzle)
- RFQ IG's commissioned and tested → Performance according to expectations

- Start construction of HELIOS laboratory @ KU Leuven
- Commission new (high repetition) laser system
- Study gas jet formation and test new gas cell design
- Optimize high-resolution laser spectroscopy in the gas jet (see talk **Yuri**)
- Apply technique on radioactive beams @ S^3

Acknowledgments

LISOL team:

R.F, L. Ghys, M. Huyse, Yu. Kudryavtsev, D. Pauwels, D. Radulov, L. Rens, P. Van den Bergh, C. Van Beveren, and P. Van Duppen

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JYFL University of Jyväskylä
I. Moore, M. Reponen, V. Sonnenschein

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