In-Gas Laser Ionization and Spectroscopy (IGLIS) of radioactive atoms at LISOL

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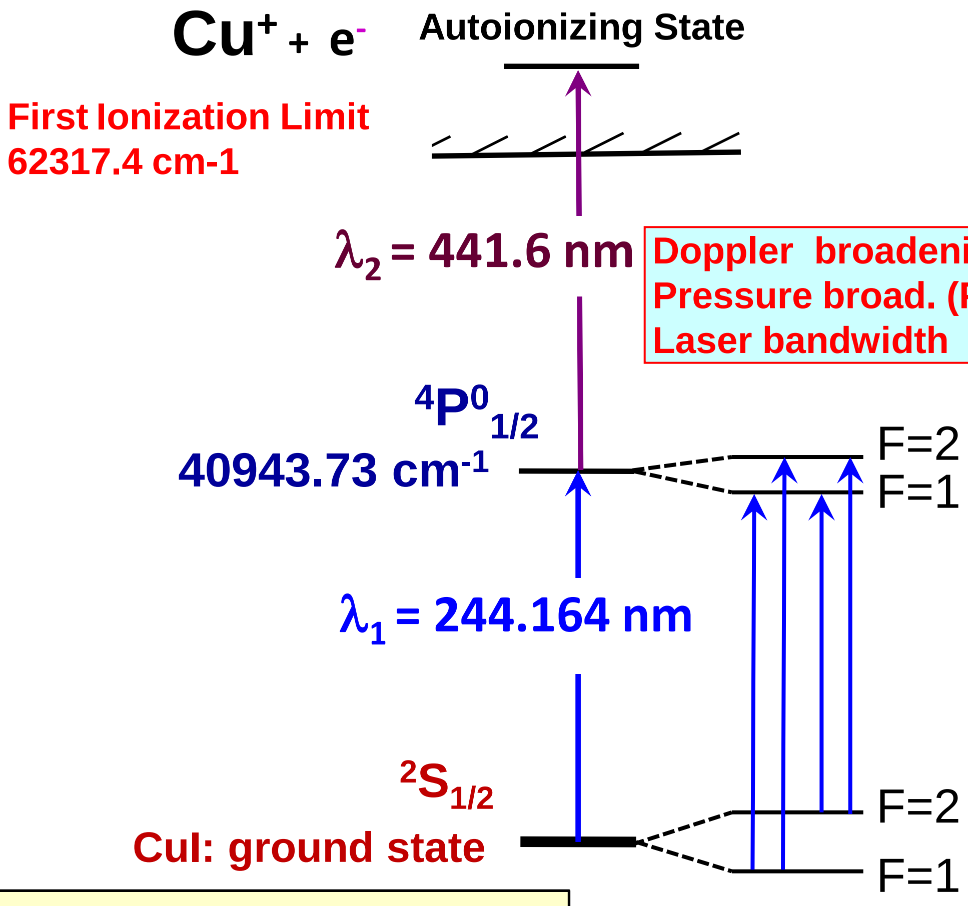
1. In-Gas-Cell Laser Ionization, selective production of RIB for nuclear spectroscopy
2. In-Gas-Cell Laser Spectroscopy , $^{57-59}$Cu, $^{97-101}$Ag
3. In-Gas-Jet Laser Spectroscopy

In-Gas-Cell Laser Spectroscopy of ^{57,59}Cu



$Cu^{+} + e^{-}$

Autoionizing State

First Ionization Limit
62317.4 cm-1

λ_2 = 441.6 nm

$^{4}P^{0}_{1/2}$
40943.73 cm^{-1}

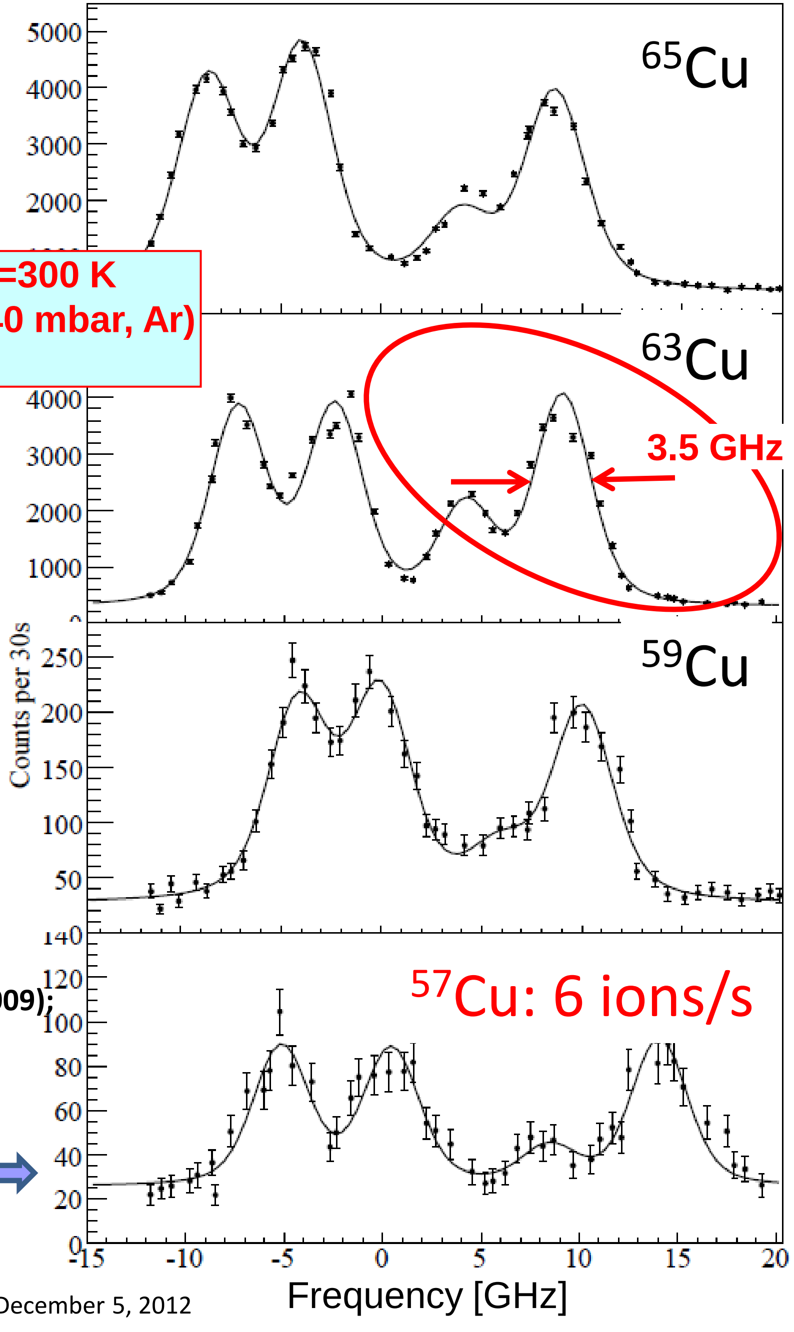
F=2
F=1

λ_1 = 244.164 nm

$^{2}S_{1/2}$
CuI: ground state

F=2
F=1

Doppler broadening, T=300 K
Pressure broad. (P = 140 mbar, Ar)
Laser bandwidth



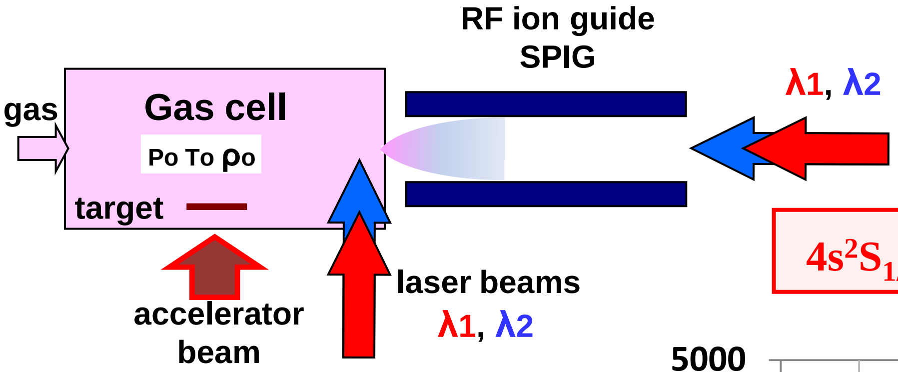
^{57}Cu: 6 ions/s

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

T. Cocolios et al.PRL 103, 102501 (2009);
Phys. Rev. C 81, 014314 (2010)

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

Doppler and Collision Contributions to the Spectral Line Width



$4s^2S_{1/2} – 4p^2P_{1/2}$, 327.4 nm ^{63}Cu transition, ν_0= 30535.3 cm^{-1}

Collision/pressure contribution

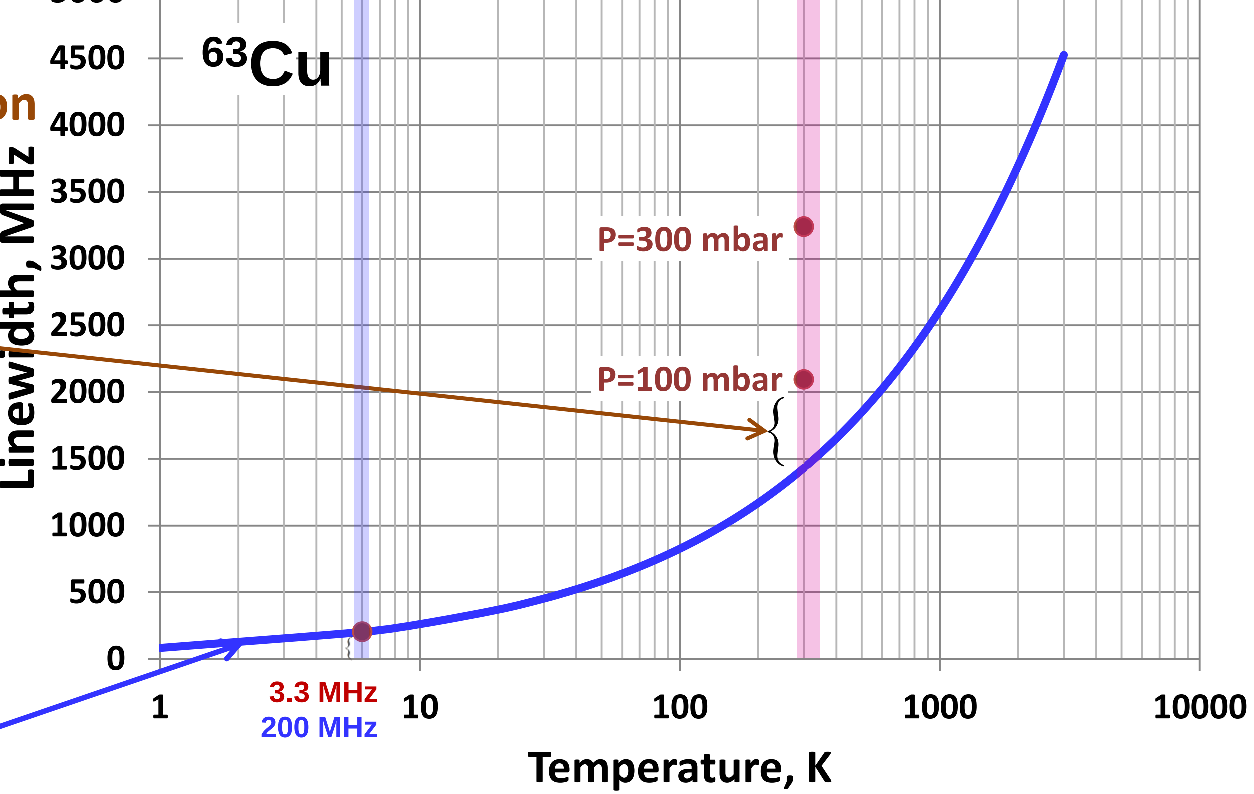
$$\Delta\nu_{coll} = \gamma_{coll} \times \rho$$

γ_{coll} - collision broadening coefficient, 1.5·10^{-20} cm^{-1}/cm^{-3} (8 MHz/mbar)

ρ – gas density (atom /cm^3)

Doppler contribution

$$\Delta\nu_{Doppler} = 2\sqrt{\ln 2}\,\frac{\nu_0}{c}\sqrt{\frac{2kT}{m}}$$



Schemes of Resonance Laser Ionization in Supersonic Beams

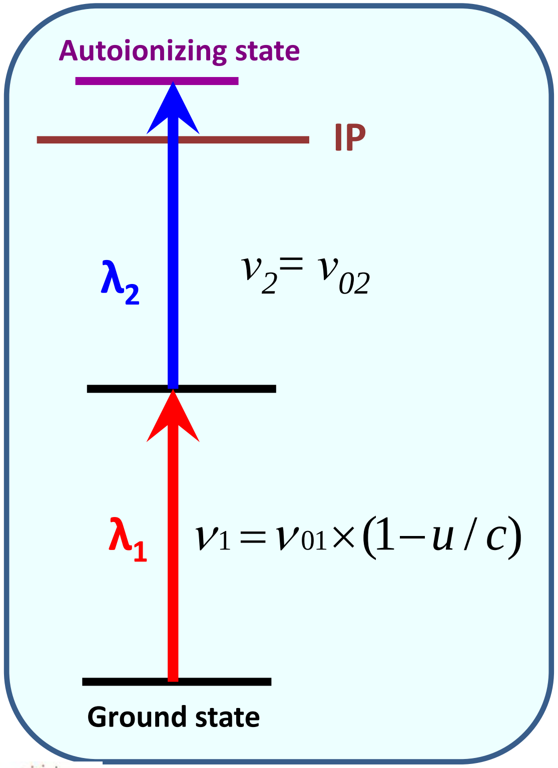
NO laser ionization inside the cell !

Laser ionization only in the cold jet !

λ_2 !

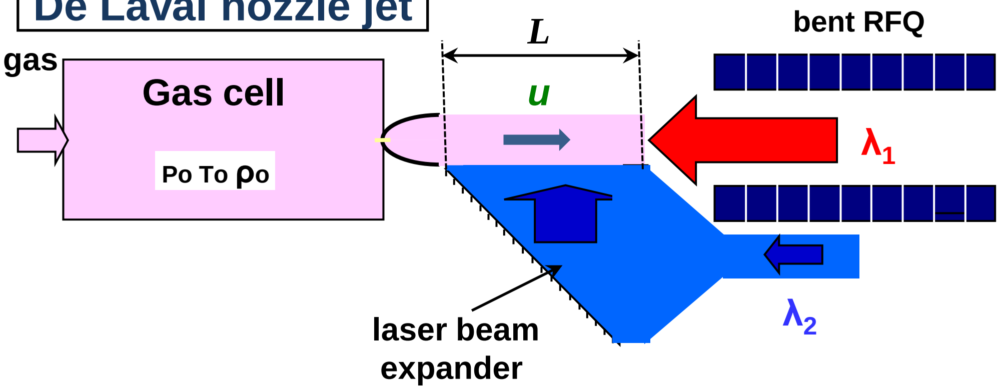
$f_{laser} \geq 1/(L/u)$ **≥ 10 kHz, argon jet - L = 5.5 cm**

u **– stream velocity, 550m/s**



Crossed laser beams with supersonic jet

De Laval nozzle jet

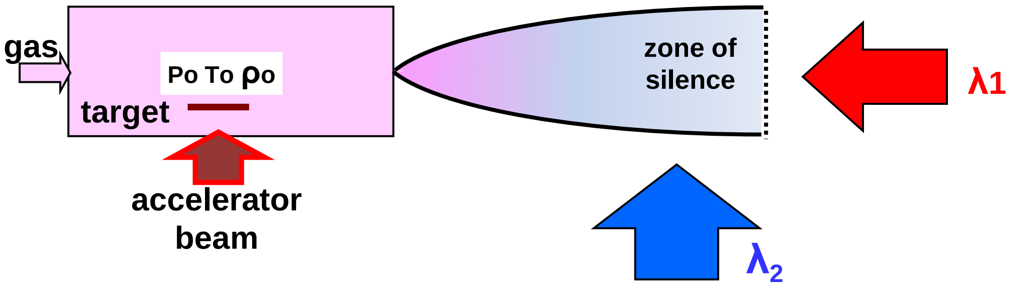


The parallel beam from de Laval nozzle !

No broadening due to the beam divergence

Very careful design of the nozzle is required

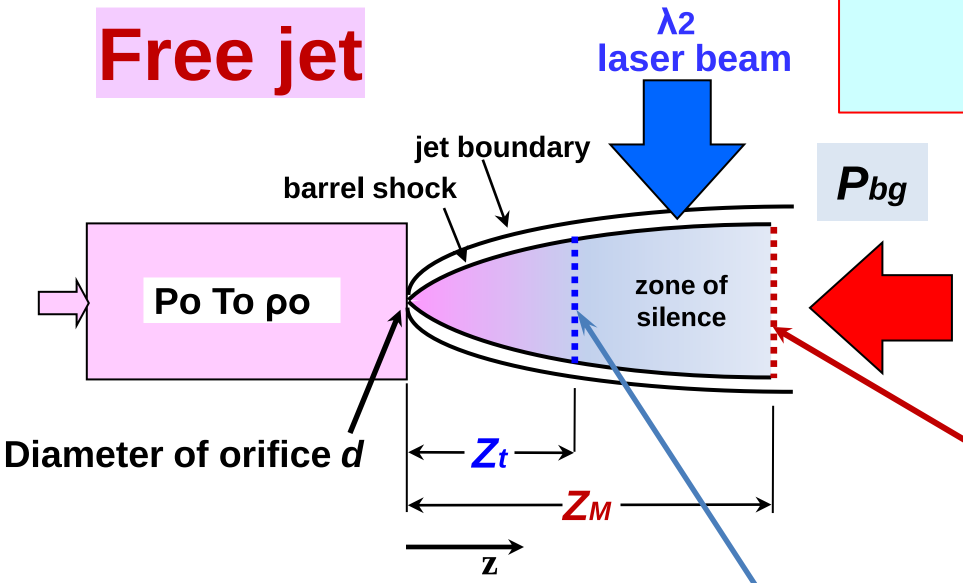
Free jet



Two-Step Laser Ionization in a Free Jet

1951 free jet – A. Kantrowitz, J. Grey

Free jet



λ1 laser beam

Mach disk, T, ρ ↑

Z_M – position of the Mach disk

$$\frac{Z_M}{d} = 0.67\sqrt{\frac{P_0}{P_{bg}}}$$

***M_t* - terminal Mach number**

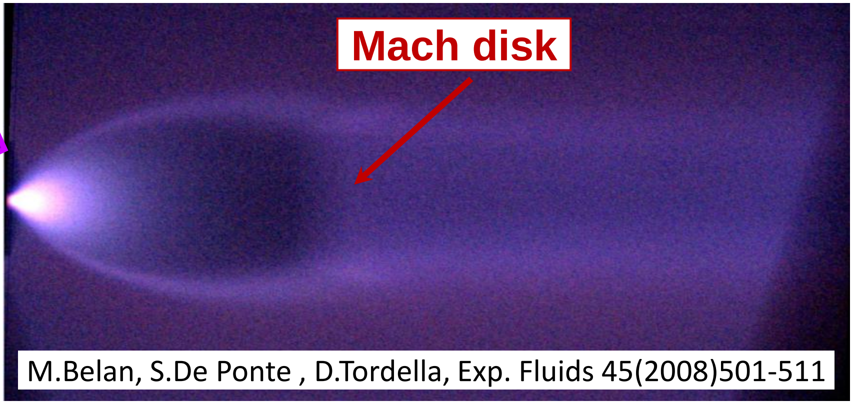
***Z_t* – position of terminal Mach number**

$$M_t = 3.32\left(P_0 d\right)^{0.4}$$

(mbar, mm)

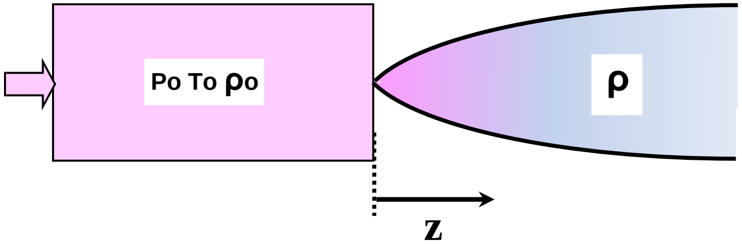
$$\frac{Z_t}{d} = \left(\frac{M_t}{3.26}\right)^{1.5}$$

Visualization of free jet

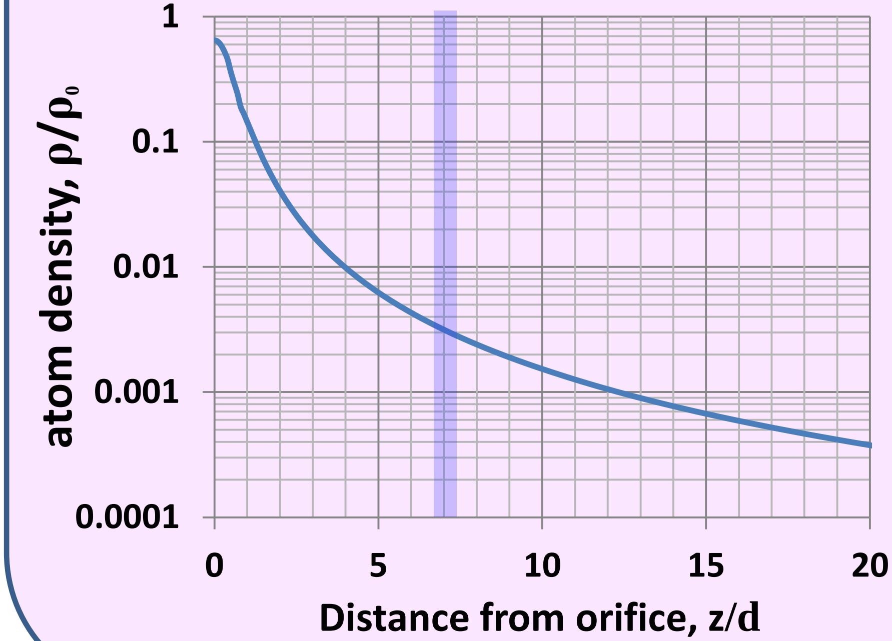


M.Belan, S.De Ponte , D.Tordella, Exp. Fluids 45(2008)501-511

Properties of Free Jet



$\Gamma coll = \gamma coll \times \rho$ → 3.3 MHz Mach=12

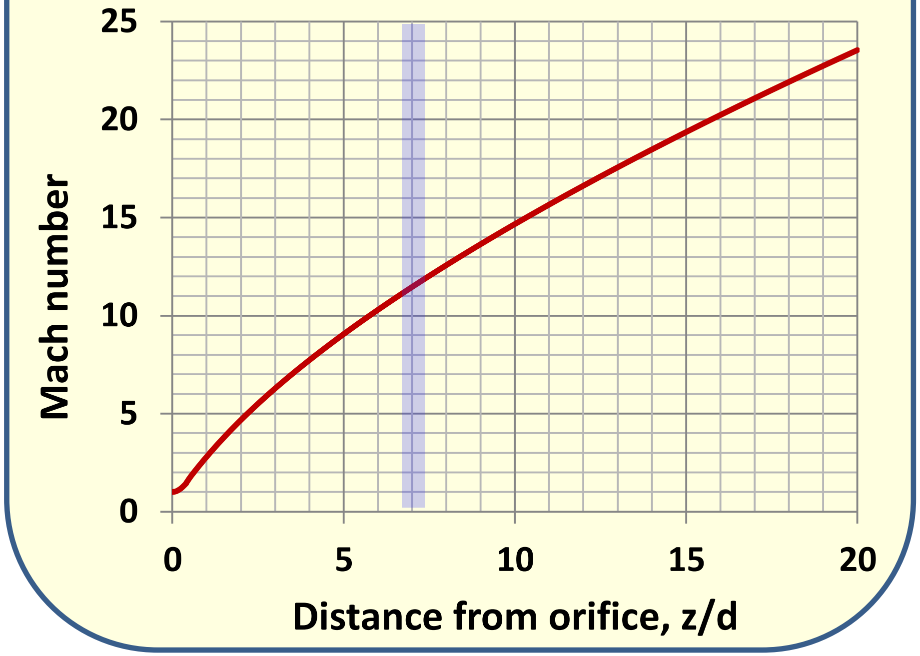


Centerline Mach number calculation

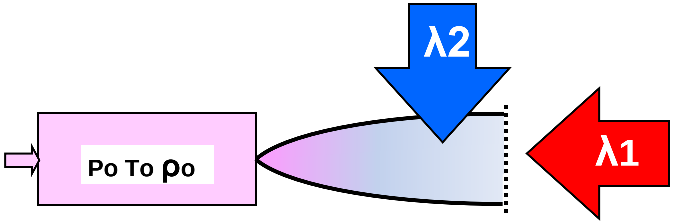
A	*B*	*C1*	*C2*	*C3*	*C4*
3.337	-1.541	3.232	-0.7563	0.3937	-0.0729

$$0 < \frac{Z}{d} < 1.0 \qquad M = 1.0 + A\left(\frac{Z}{d}\right)^{-2} + B\left(\frac{Z}{d}\right)^{3}$$

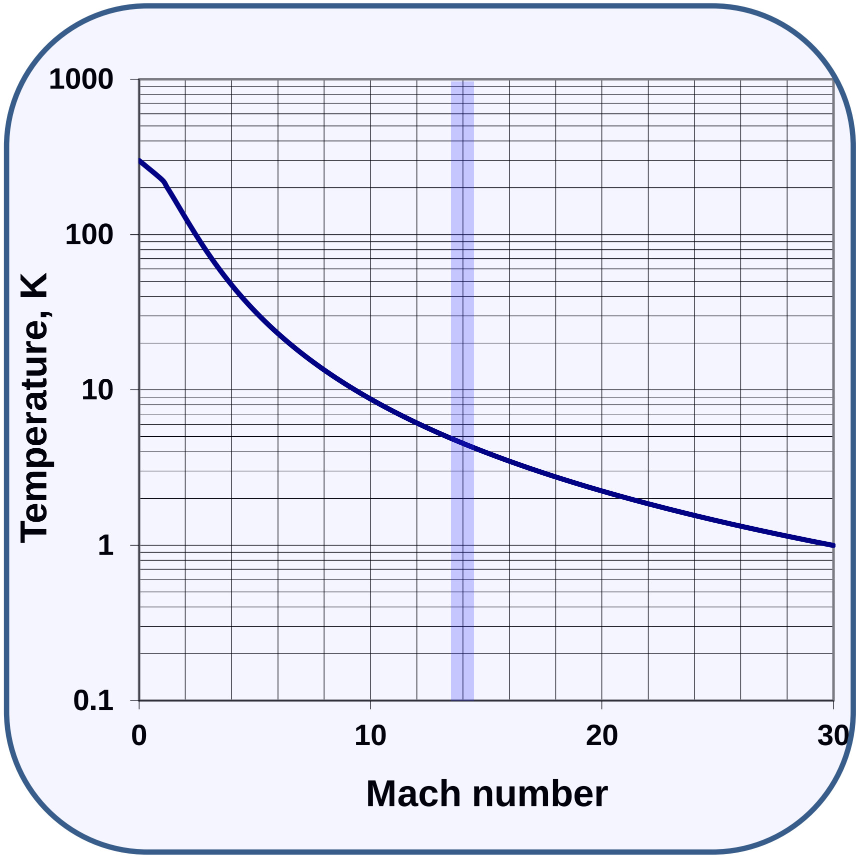
$$\frac{Z}{d} > 0.5 \qquad M = \left(\frac{Z}{d}\right)^{(\gamma-1)}\left[C_1 + \frac{C_2}{\left(\frac{Z}{d}\right)} + \frac{C_3}{\left(\frac{Z}{d}\right)^2} + \frac{C_4}{\left(\frac{Z}{d}\right)^3}\right]$$

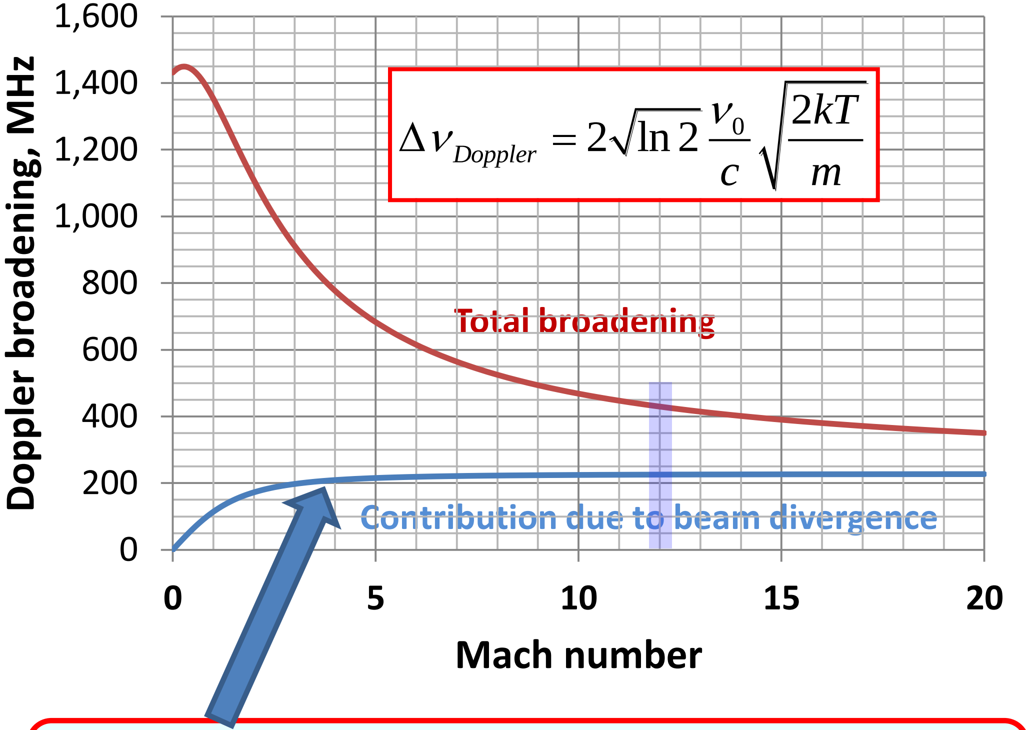


Doppler Broadening in the Free Jet Supersonic Beam



$4s^2S_{1/2} – 4p^2P_{1/2}$, 327.4 nm ^{63}Cu transition, ν_0= 30535.3 cm^{-1}





$$\Delta\nu_{Doppler} = 2\sqrt{\ln 2}\,\frac{\nu_0}{c}\sqrt{\frac{2kT}{m}}$$

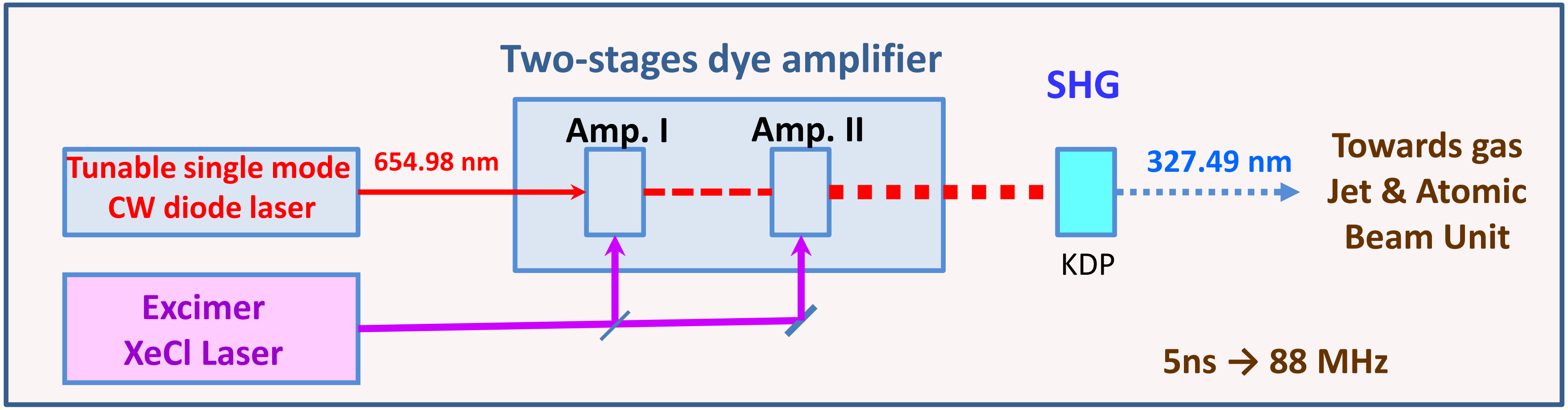
$\Delta^{ax}_{Doppler} = \nu_0 \cdot u\left(1-\cos\theta\right)/c$ - axial laser beam direction

T=4K, Dopp. W.=200 MHz

Tot. broad. = 420 MHz

Yu. Kudryavtsev, EMIS2012, December 5, 2012

Amplification of CW Single Mode Diode Laser Radiation in a Pulsed Dye Amplifier



Two-stages dye amplifier

SHG

Amp. I

Amp. II

Tunable single mode CW diode laser

654.98 nm

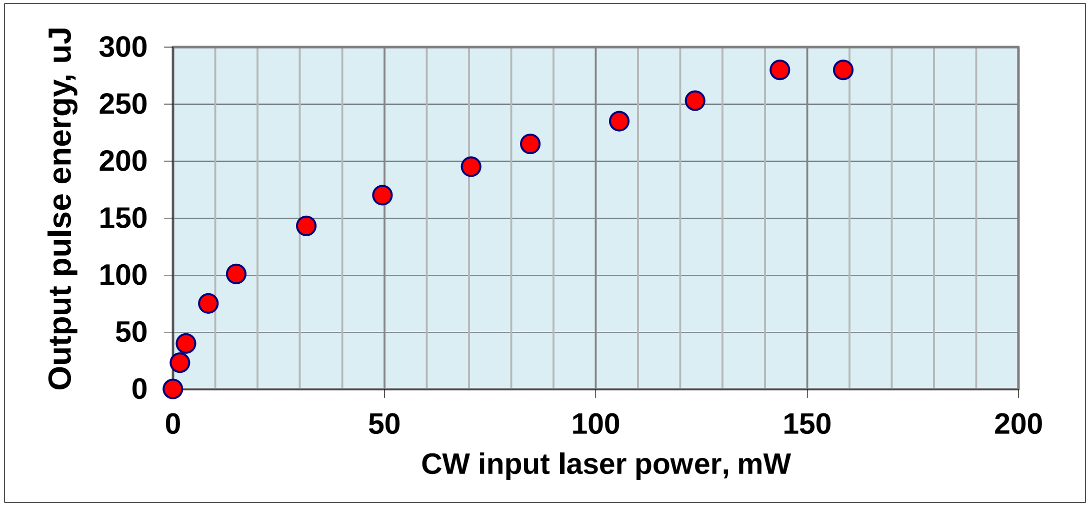
327.49 nm

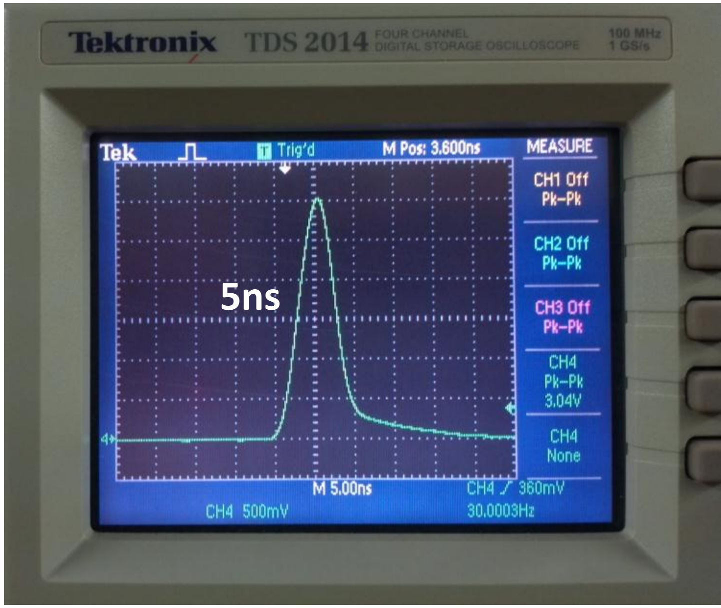
Towards gas Jet & Atomic Beam Unit

KDP

Excimer XeCl Laser

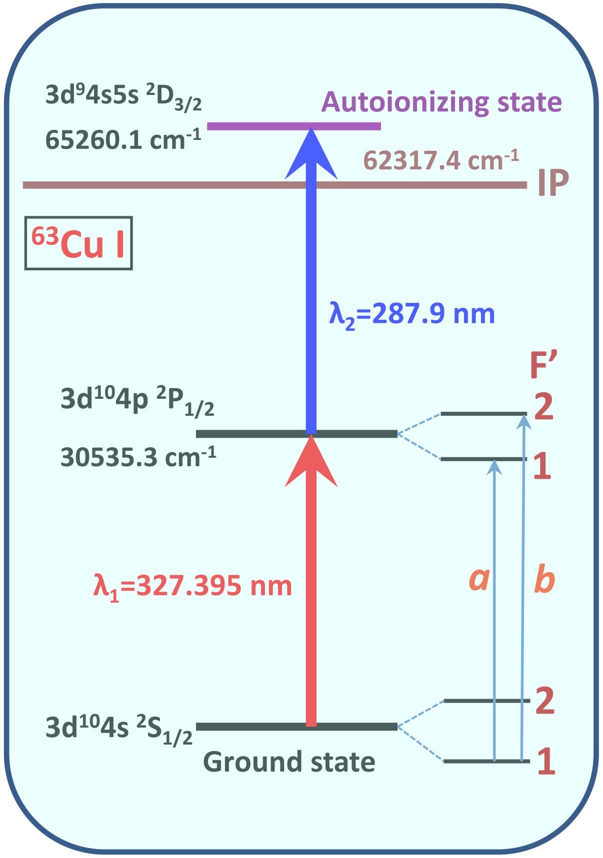
5ns → 88 MHz

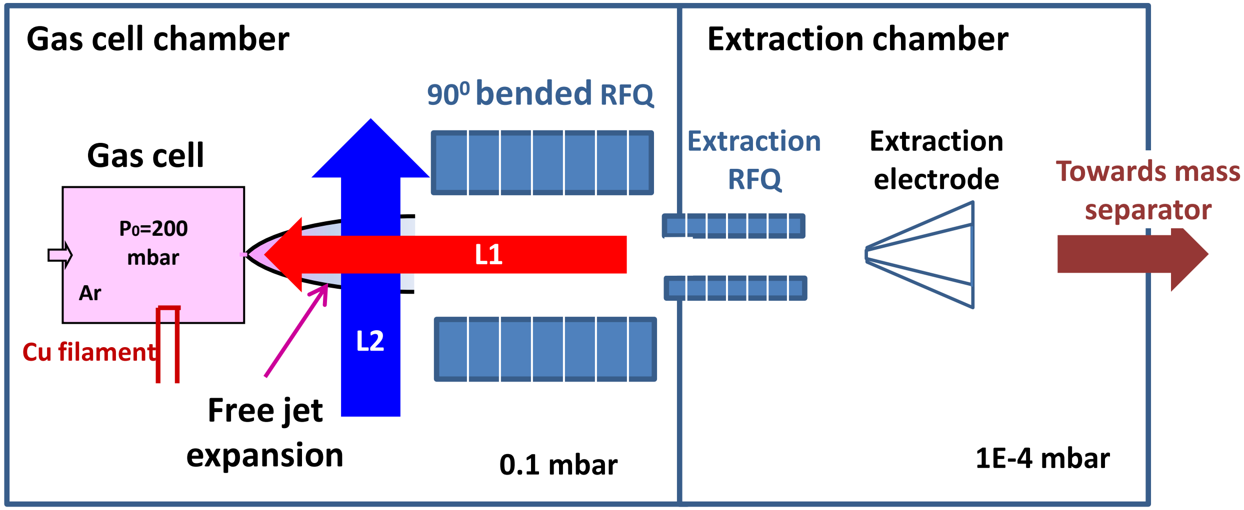


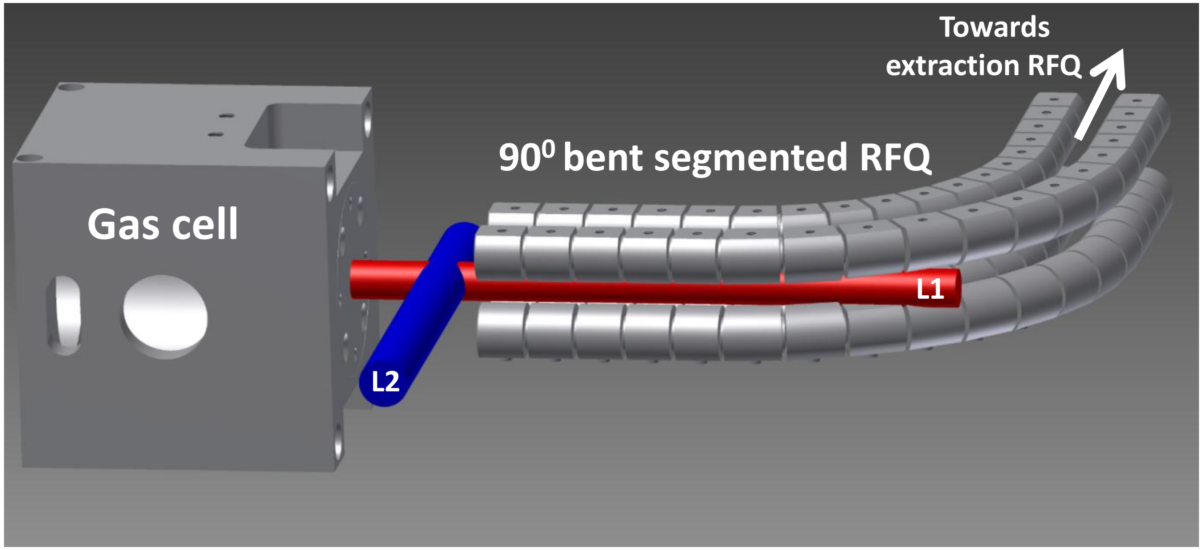


Resonance Ionization Spectroscopy in a Free Gas Jet

Yu. Kudryavtsev et al, http://arxiv.org/abs/1211.6649



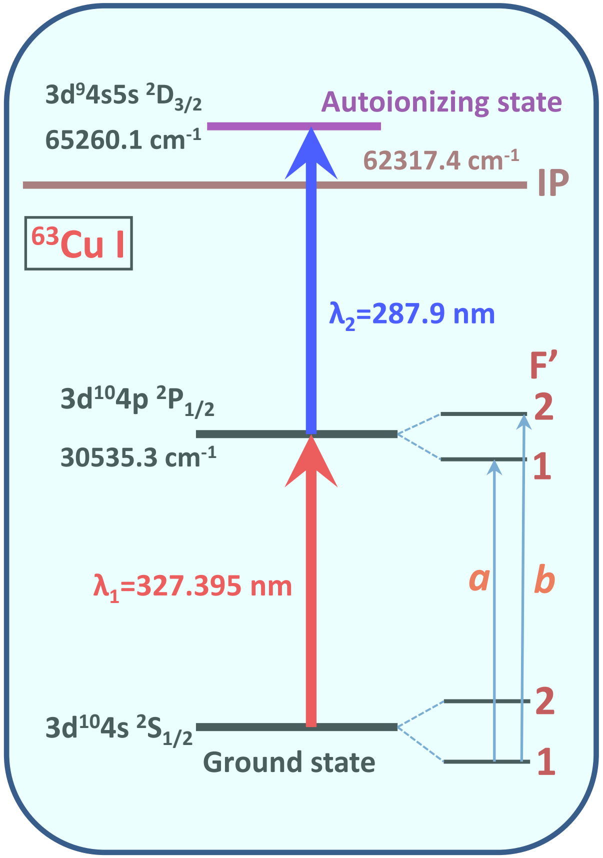


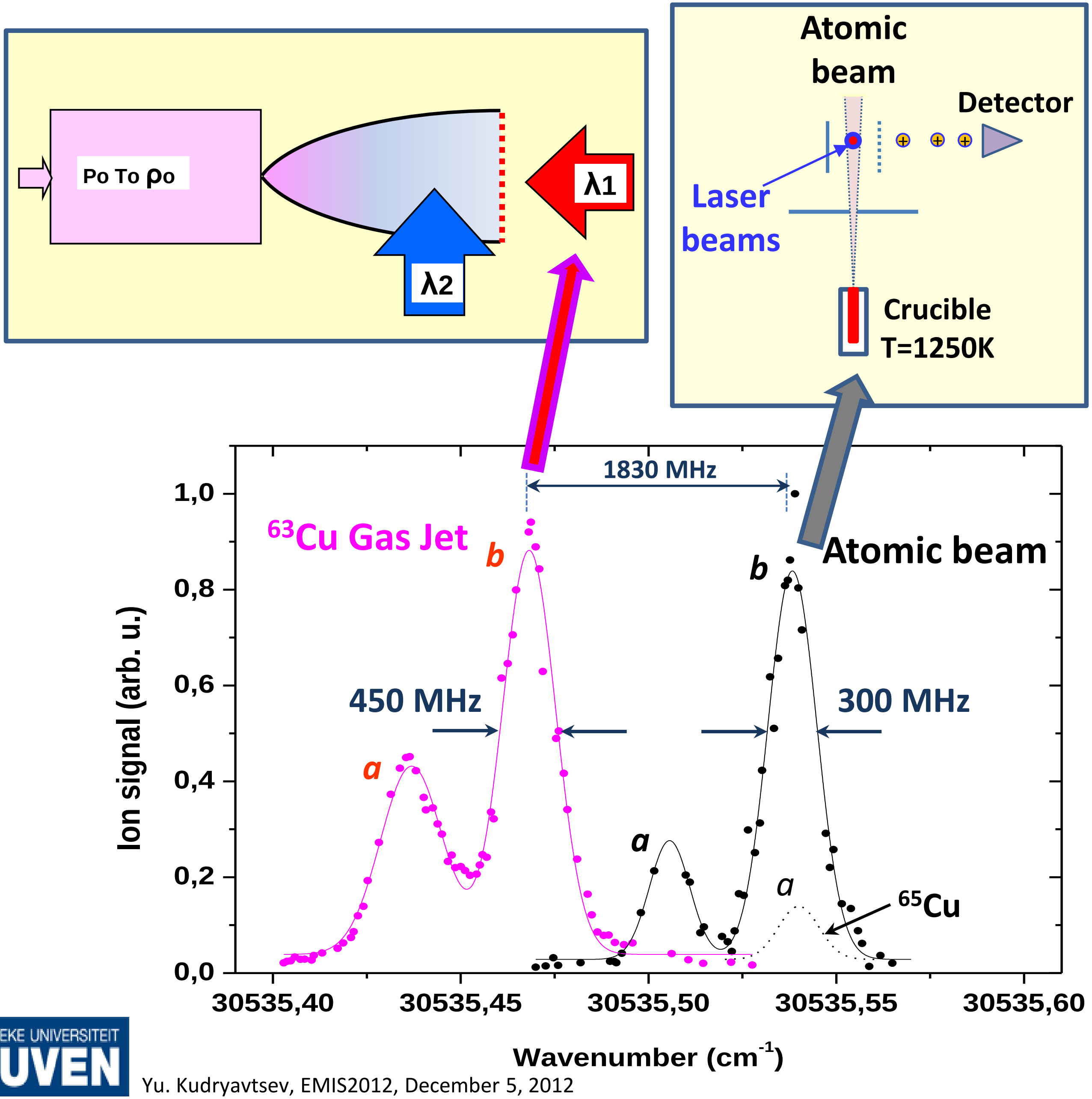


Resonance Ionization Spectroscopy in a Free Gas Jet

$$u=\sqrt{\frac{kT_0\gamma M^2}{m_{ng}\left\{1+\left[(\gamma-1)/2\right]M^2\right\}}}$$

1830 MHz → $T_0 = 355 \pm 3$ K





Yu. Kudryavtsev, EMIS2012, December 5, 2012

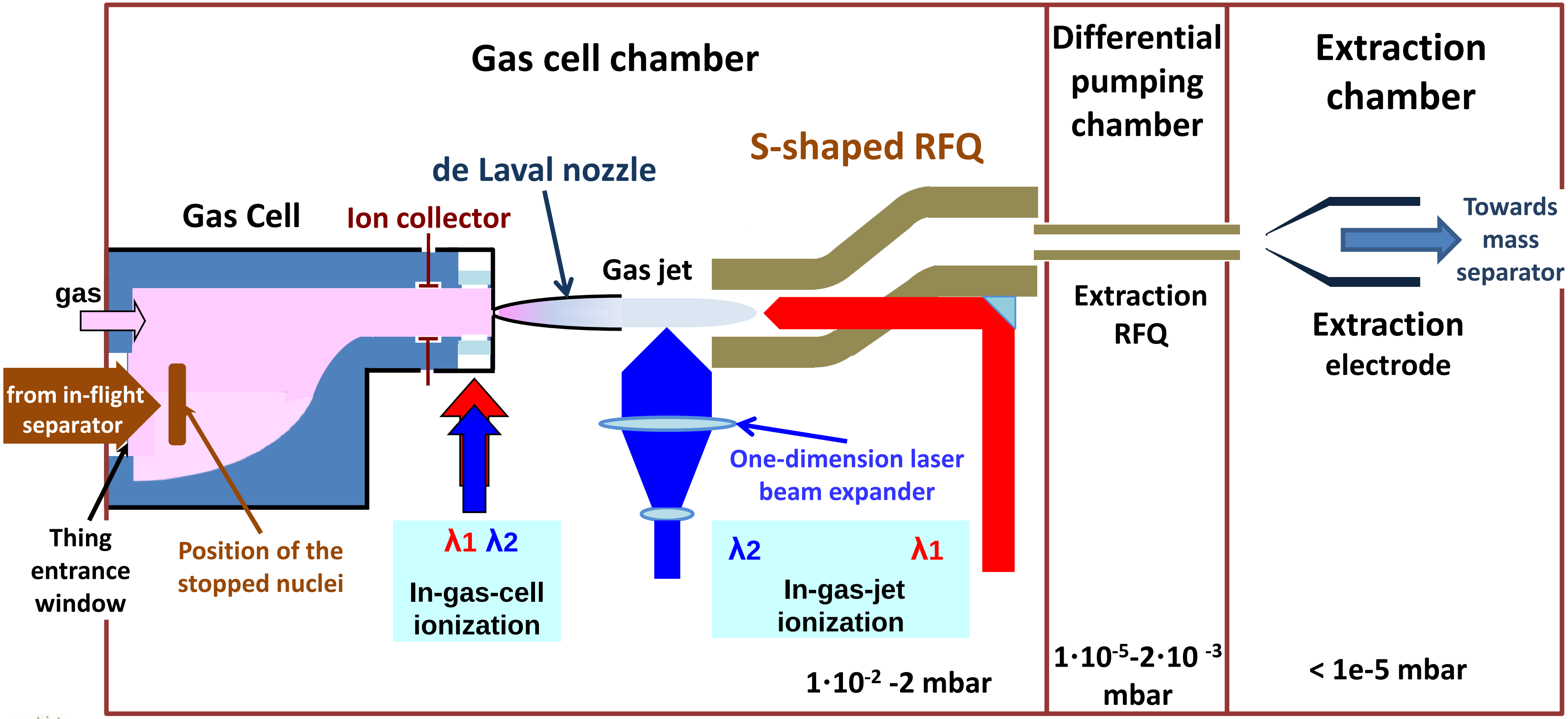
In-gas-cell and in-gas-jet laser RIS setup for HELIOS and S^3 projects

erc grant has been granted, HELIOS

New laser laboratory will be set up at KU Leuven

The tender of the laser equipment has been finished

RILIS at S^3 GANIL
poster #38 by Rafael Ferrer et al.



Gas cell chamber

Differential pumping chamber

Extraction chamber

S-shaped RFQ

de Laval nozzle

Gas Cell

Ion collector

Gas jet

gas

from in-flight separator

Thing entrance window

Position of the stopped nuclei

$\lambda1$ $\lambda2$

In-gas-cell ionization

One-dimension laser beam expander

$\lambda2$ $\lambda1$

In-gas-jet ionization

Extraction RFQ

Towards mass separator

Extraction electrode

$1\cdot10^{-2}$ -2 mbar

$1\cdot10^{-5}$-$2\cdot10^{-3}$ mbar

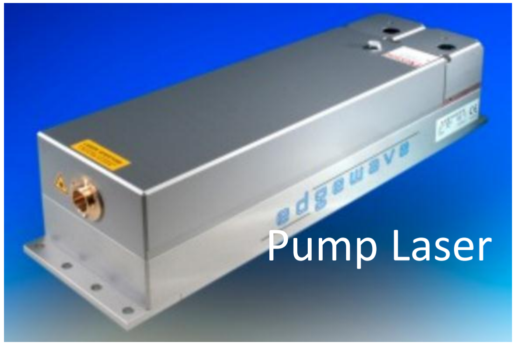
< 1e-5 mbar

Laser equipment for IGLIS experiments @ HELIOS &S^3

Two step laser ionization spectroscopy in the gas cell

- Two high-repetition-high-power Nd:YAG pump Laser

- Max. average power: 90 W (@ 532 nm) or 36 W (@ 355 nm)
- Max. repetition rate: 15 kHz



Pump Laser

- Two high repetition rate dye lasers

- Tunable wavelength from 215 to 900 nm
- Linewidth: 0.06 cm^{-1} (1.8 GHz) – 0.25 cm^{-1} (7.5 GHz)

Dye Laser

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

- A continuous wave (CW) single mode tunable diode laser

- Linewidth: 1 MHz
- mode-hop-free tuning range: 20-30 GHz

- A dye amplifier with second harmonic generator

Diode Laser

Summary

1. **The crossed laser beams with supersonic jet has been proposed and realized off-line for two-step photo ionization in a free jet.**

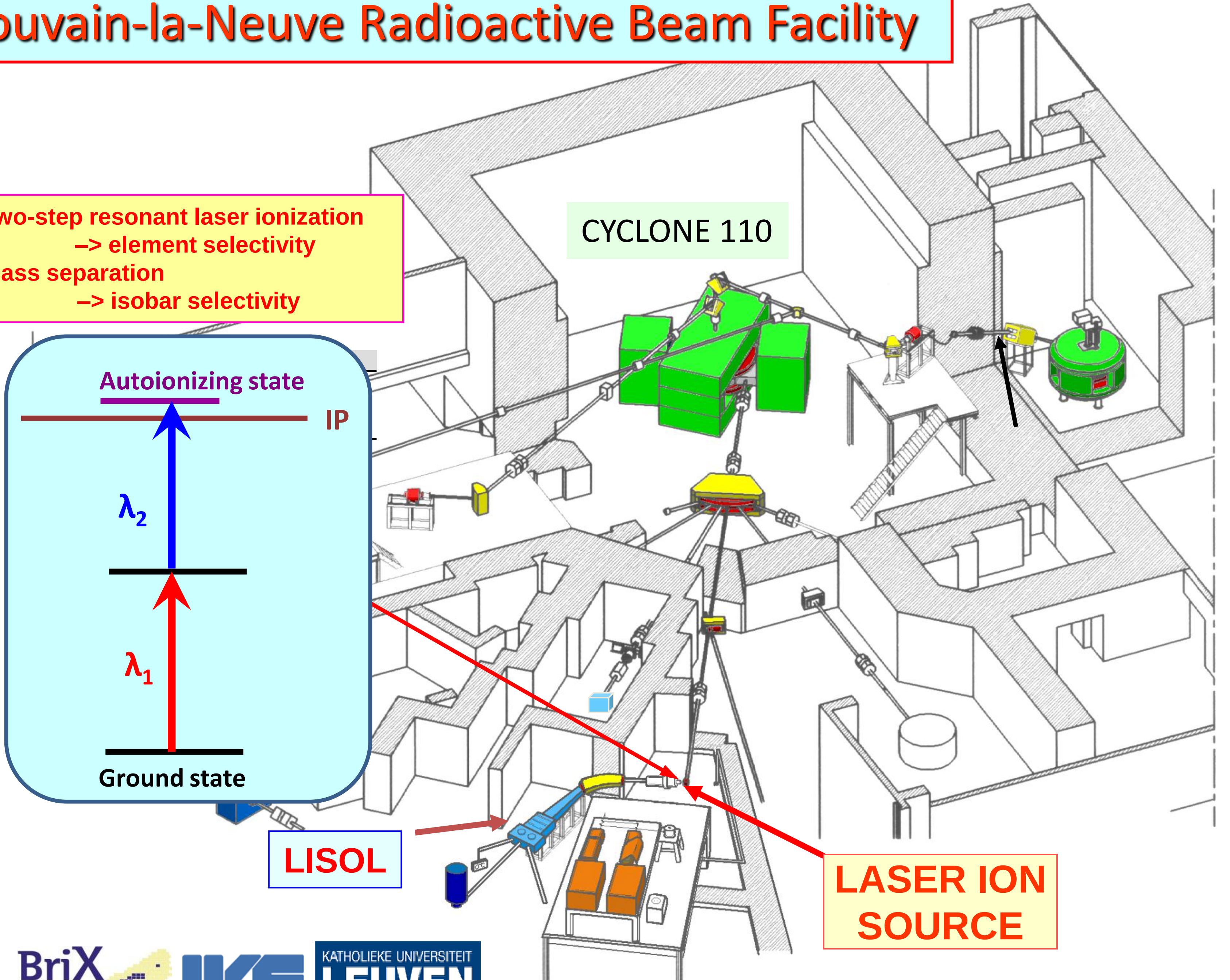
2. **Using this method, the spectral resolution can be improved by one order of magnitude (200 MHz, Δν/ν =2.3E-7) in comparison to the gas cell.**

3. **The IGLIS technique that combines laser ionization in a gas cell and in a gas jet is adapted for production and spectroscopy of rare radioactive isotopes.**

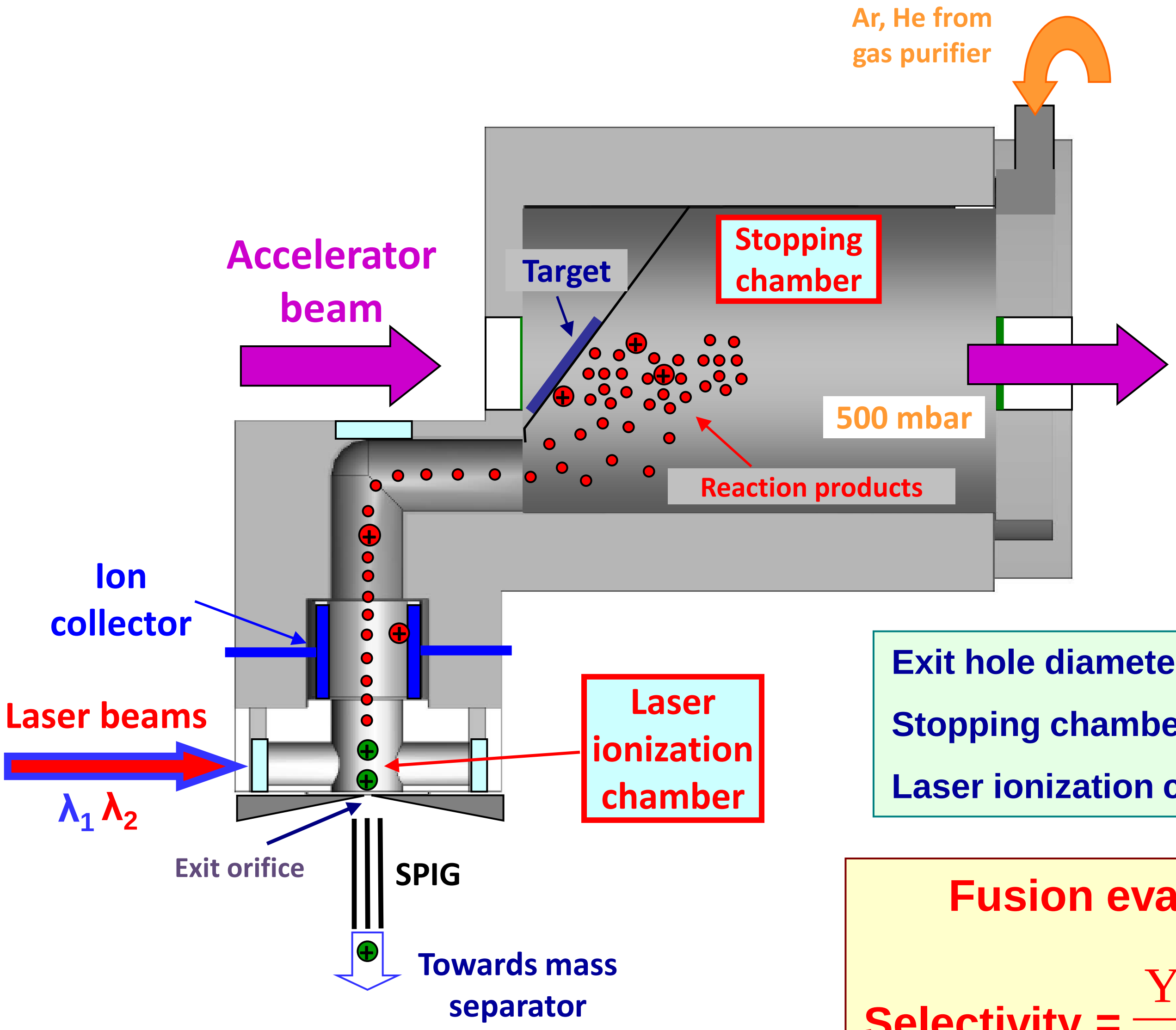
Thank you for your attention

Louvain-la-Neuve Radioactive Beam Facility

Two-step resonant laser ionization
–> element selectivity
Mass separation
–> isobar selectivity



Dual-Chamber Gas Cell Laser Ion Source



Exit hole diameter – 0.5 mm/1mm

Stopping chamber – 4 cm in diameter

Laser ionization chamber – 1 cm in diameter

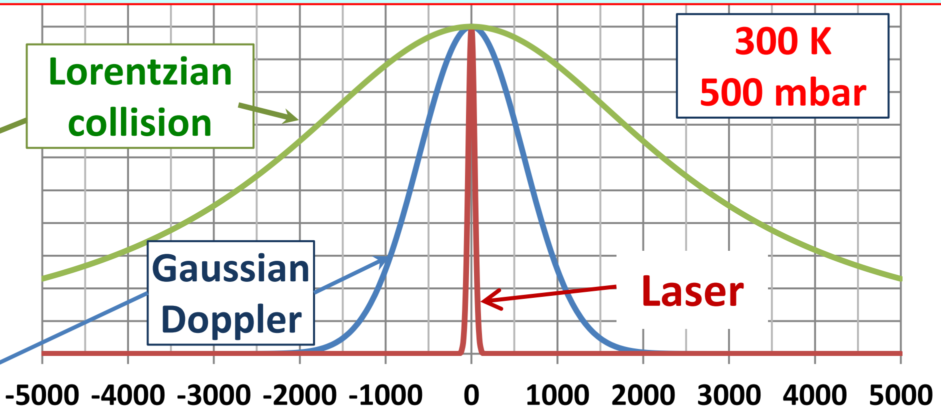
Fusion evaporation reactions:

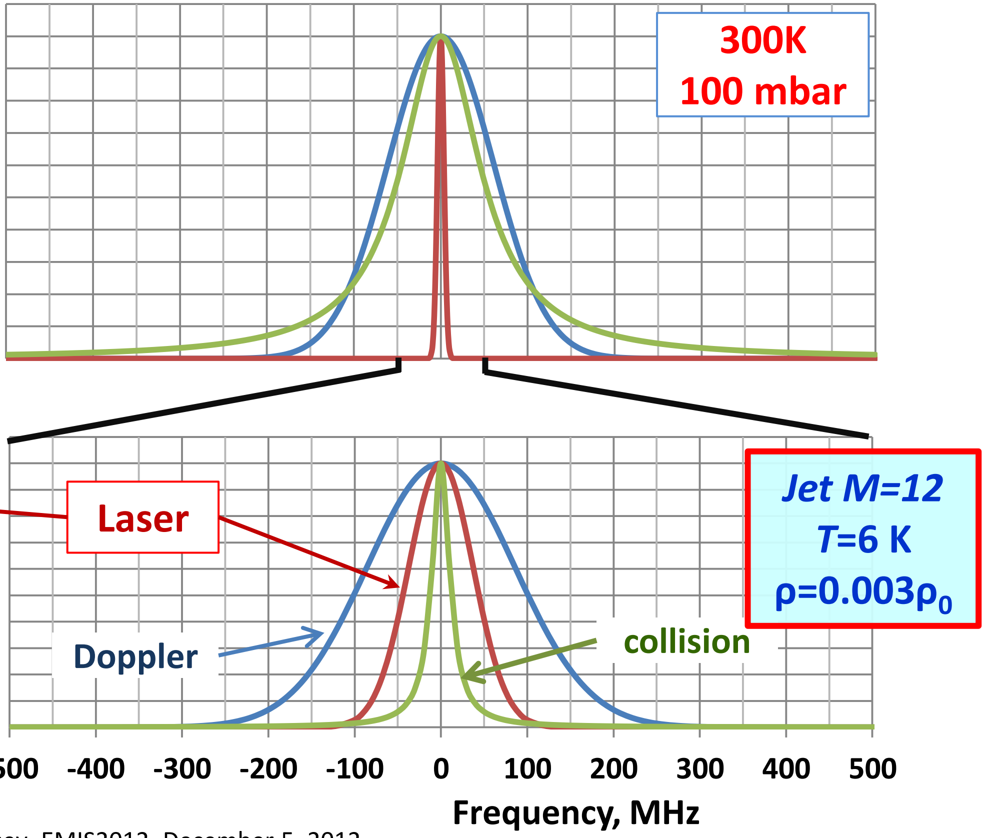
$$\text{Selectivity} = \frac{\text{Yield-LaserON}}{\text{Yield-LaserOFF}} > 2200$$

Doppler Gaussian and collision- and natural Lorentzian contributions to the spectral line shape

$$L(\nu-\nu_0)=\frac{1}{2\pi}\frac{\Gamma}{(\nu-\nu_0+\Gamma sh)^2+(\Gamma/2)^2}$$

$$G(\nu)=G_0\exp\left[-\frac{c^2(\nu-\nu_0)^2}{\nu_0^2\,\dfrac{2kT}{m}}\right]$$





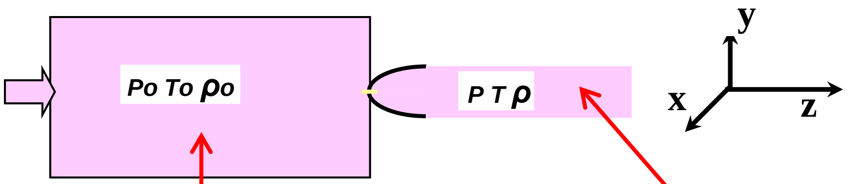
Laser bandwidth – δ_{laser} Gaussian if laser time profile is Gaussian

$\delta_{laser}=441/\tau_{pulse}$

τ_{pulse} = 5 ns δ_{laser} =88 MHz

Laser pulse length should short to provide interaction with all atoms!

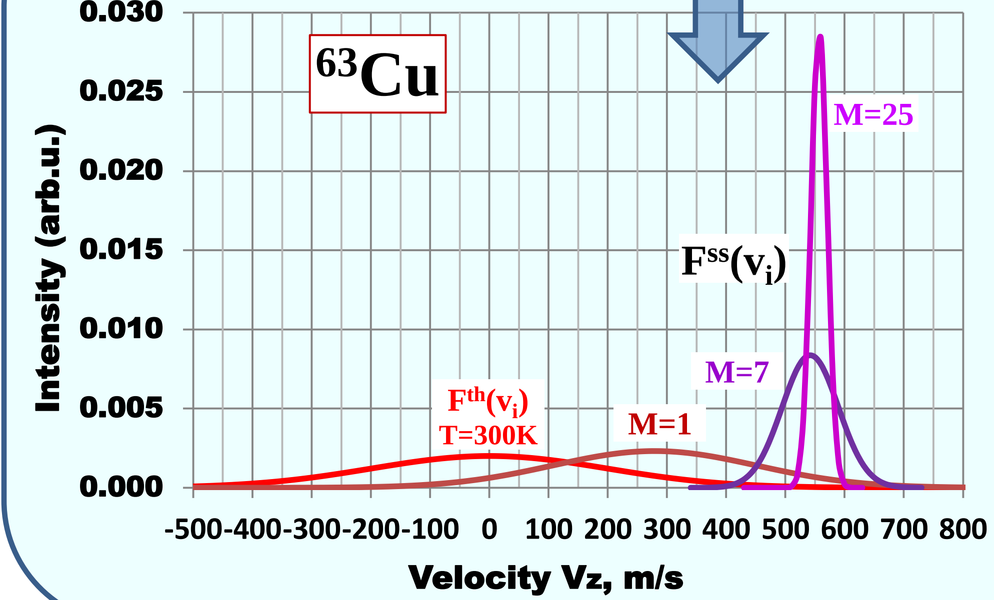
Supersonic Beam from de Laval Nozzle



$$F^{th}(v_i) = \sqrt{\frac{m}{2\pi kT_0}}\exp\left(\frac{-mv_i^2}{2kT_0}\right)$$

$$F^{ss}(v_z) = \sqrt{\frac{m}{2\pi kT}}\exp\left(\frac{-m(v_z-u)^2}{2kT}\right)$$

One dimensional Maxwell-Boltzmann velocity distribution



Mach number - $M = u/a$

u **- gas stream velocity**

a **- local speed of sound**

T **- gas temperature**

m_{ng} **- mass of the noble gas**

$$a = \sqrt{\frac{\gamma kT}{m_{ng}}}$$

$$u = \sqrt{\frac{kT_0\gamma M^2}{m_{ng}\left\{1+\left[(\gamma-1)/2\right]M^2\right\}}}$$

$\gamma = Cp/Cv$ **- ratio of specific heat capacities =5/3**