IMPROVEMENTS in the RILIS SELECTIVITY and SPECTRAL RESOLUTION by the use of TIME-OF-FLIGHT TECHNIQUES

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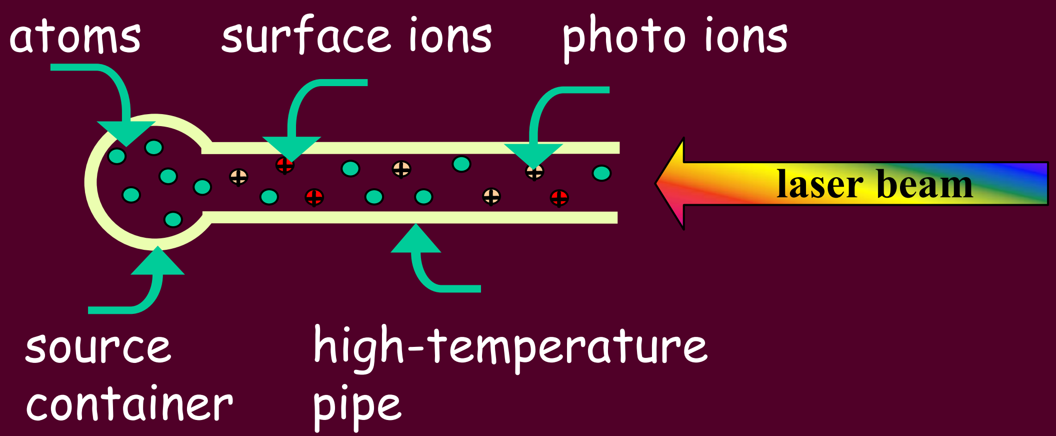
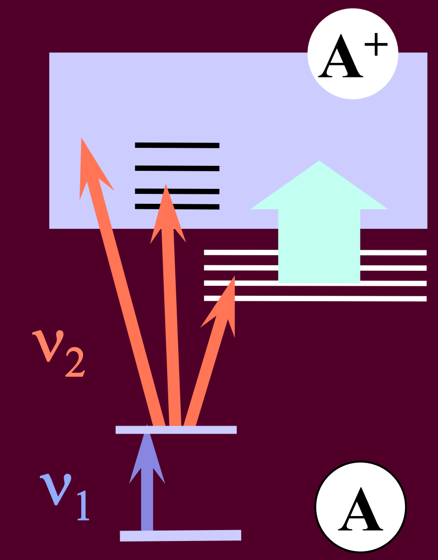
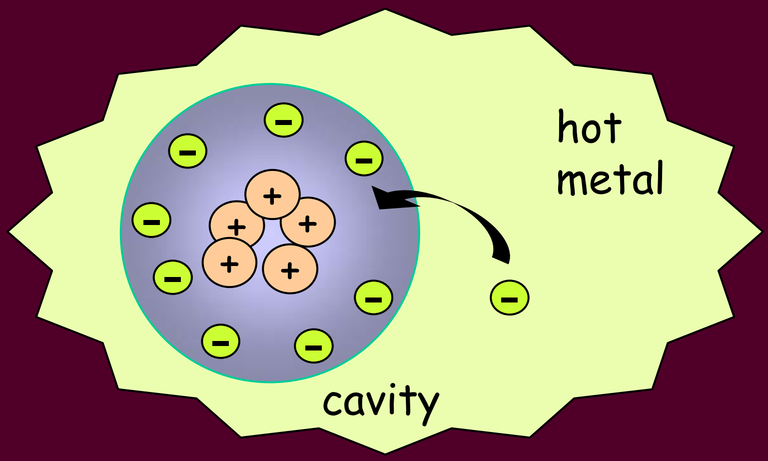
Operation of RILIS



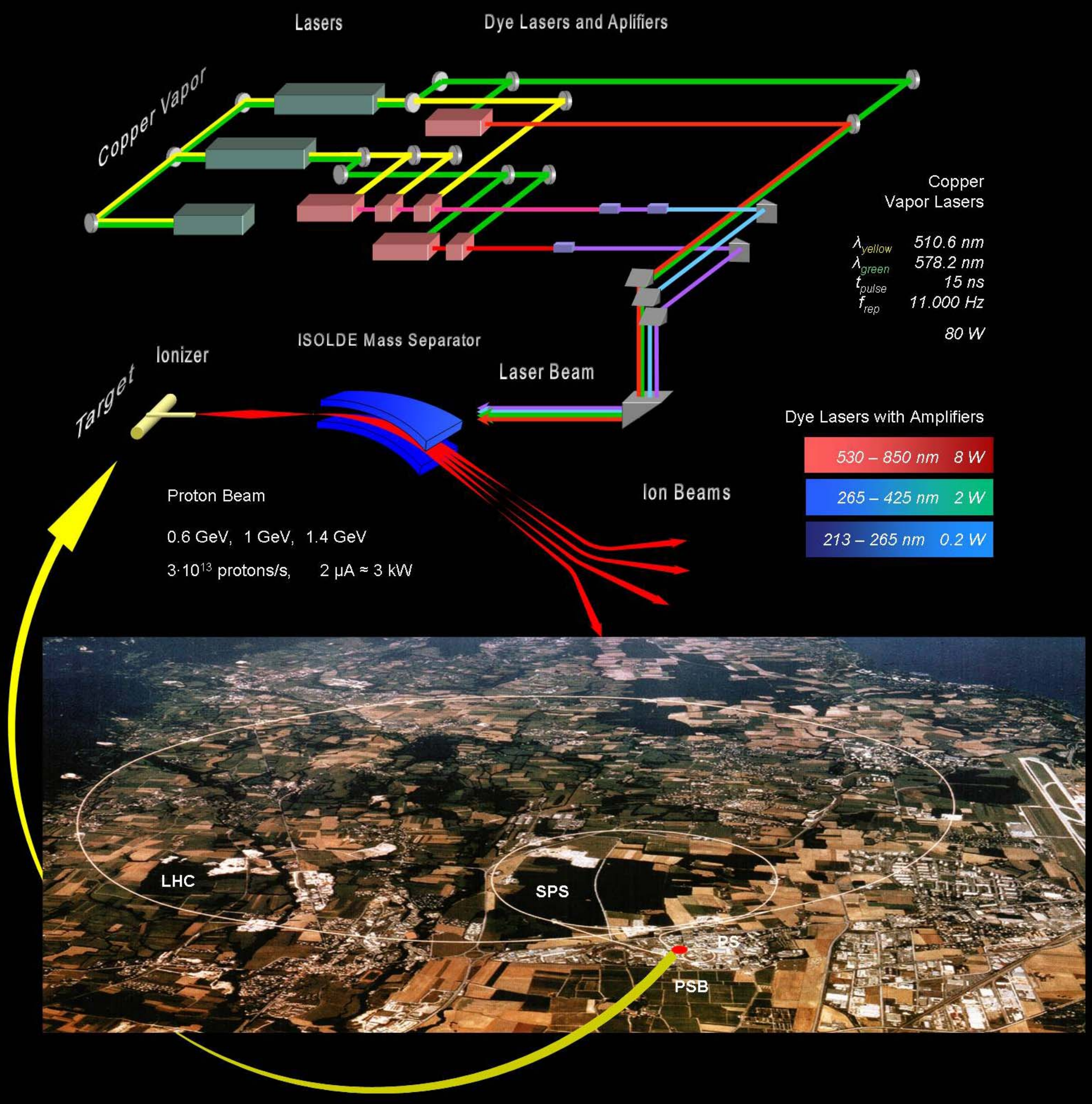
RESONANT LASER IONIZATION of ATOMS



TRAPPING of IONS by CAVITY PLASMA



RILIS-ISOLDE and CERN Particle Accelerators



A collection of the RILIS critical parameters

- Universality: *most part of the periodic table elements can be ionized*
- High ionization efficiency *for isotopes and nuclear isomers*
- High ionization selectivity *for isobars, isotopes and nuclear isomers*
- In-source laser spectroscopy: *study of radioactive atoms with ultra-high sensitivity*
- Fast changing of ion beam structure: *isobaric or isomeric*
- In-source preparation of polarized nuclear: *in the future*
- Simplicity of RILIS components are placed in the radioactive region ➞ *low servicing costs for RILIS over a plasma ion source if high current proton beams are used*

Selectivity of RILIS

Two basic factors define the RILIS selectivity:

LASER IONIZATION of studied (wanted) atoms and

SURFACE IONIZATION of interfering (unwanted) atoms

Surface Ionization of Atoms

$$\alpha_s = \frac{n_{is}}{n_{os}} \approx \exp\left(\frac{\varphi - W_i}{kT}\right)$$

Langmuir equation

W_i - the ionization potential of atoms

φ - the work function of the electron emitting surface

Wall sticking times

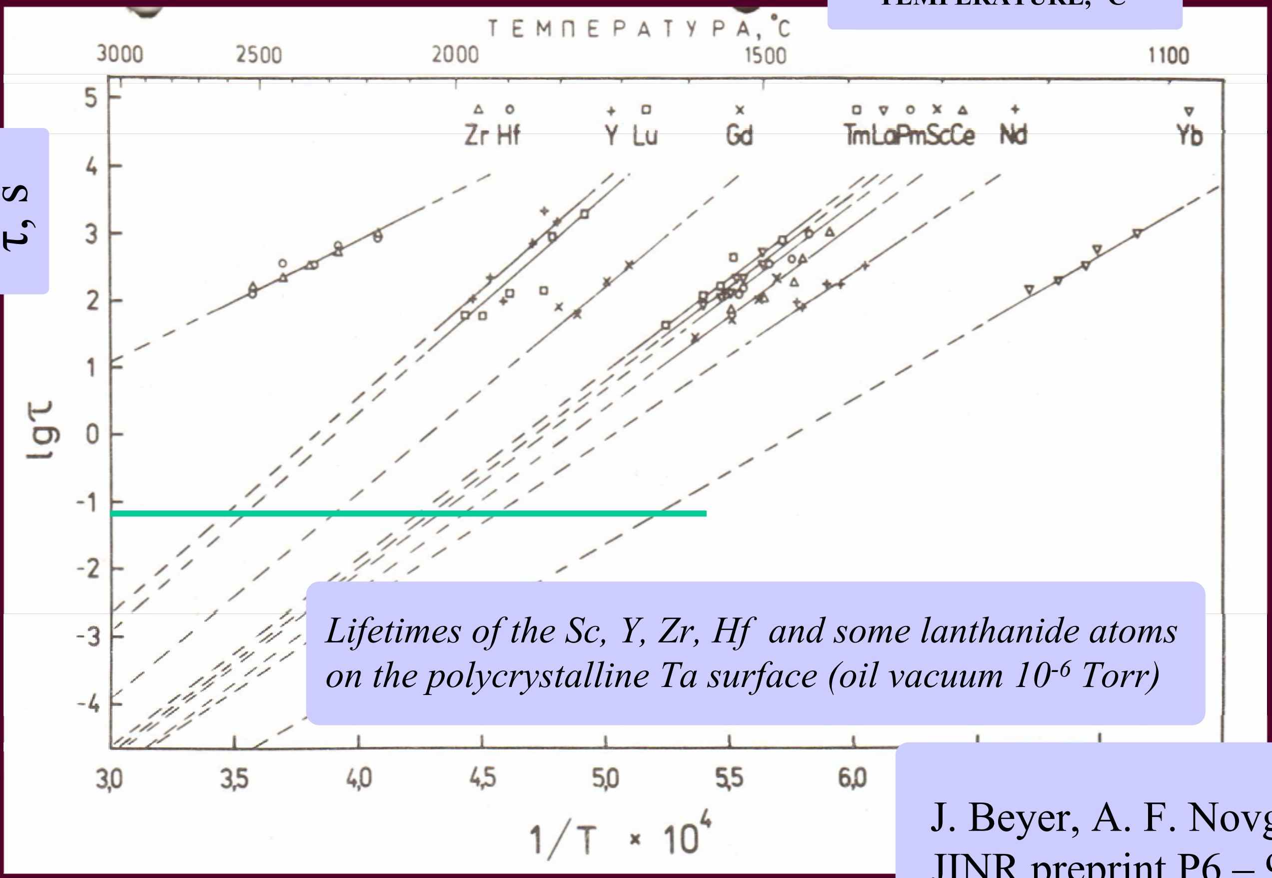
$$\tau_{sorp} = \tau_0 \exp(-\frac{E_d}{kT})$$

Frenkel equation

$1/\tau_0$ – frequency factor
E_d – interaction energy of the atom with the surface

TEMPERATURE, °C

τ, s



Lifetimes of the Sc, Y, Zr, Hf and some lanthanide atoms on the polycrystalline Ta surface (oil vacuum 10^{-6} Torr)

The number of collisions of the atom with a wall of the RILIS ionizer prior to it fly out is

$$N = \frac{S_{wall} = \pi DL}{S_{hole} = \pi D^2/4} = 4L/D$$

L = 3 cm, D =3 mm (length and diameter of the ionizer)

N = 40

J. Beyer, A. F. Novgorodov and V. A. Halkin. JINR preprint P6 – 9917, 1976

Selectivity of RILIS can be increased considerably providing laser produced ions are separated from thermal ions

$\tau_{\text{ions creation time}} = \tau_{\text{laser pulse duration}}$ $\quad$ T laser pulse-repetition interval

Maximum RILIS selectivity, which can be reached by laser ions separation from thermal ions, is equal to

$$S = T / \tau_{ions}$$

$f_{laser} = 10^4$ pps

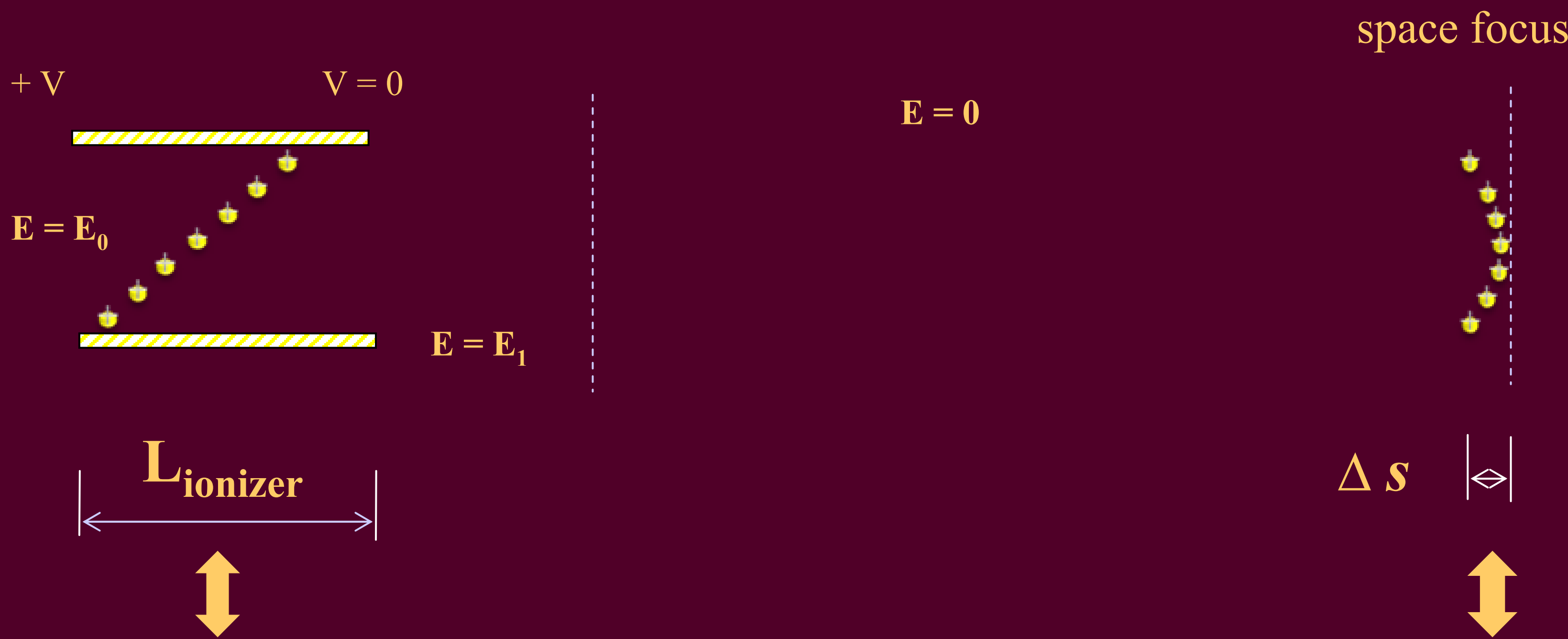
$T = 1/f_{laser} = 100\ \mu s$

$\tau_{ions} = \tau_{laser} \approx 10$ ns

$S \approx 10000$

It makes sense to hunt for this number

Time-of-flight compression of RILIS ion pulses



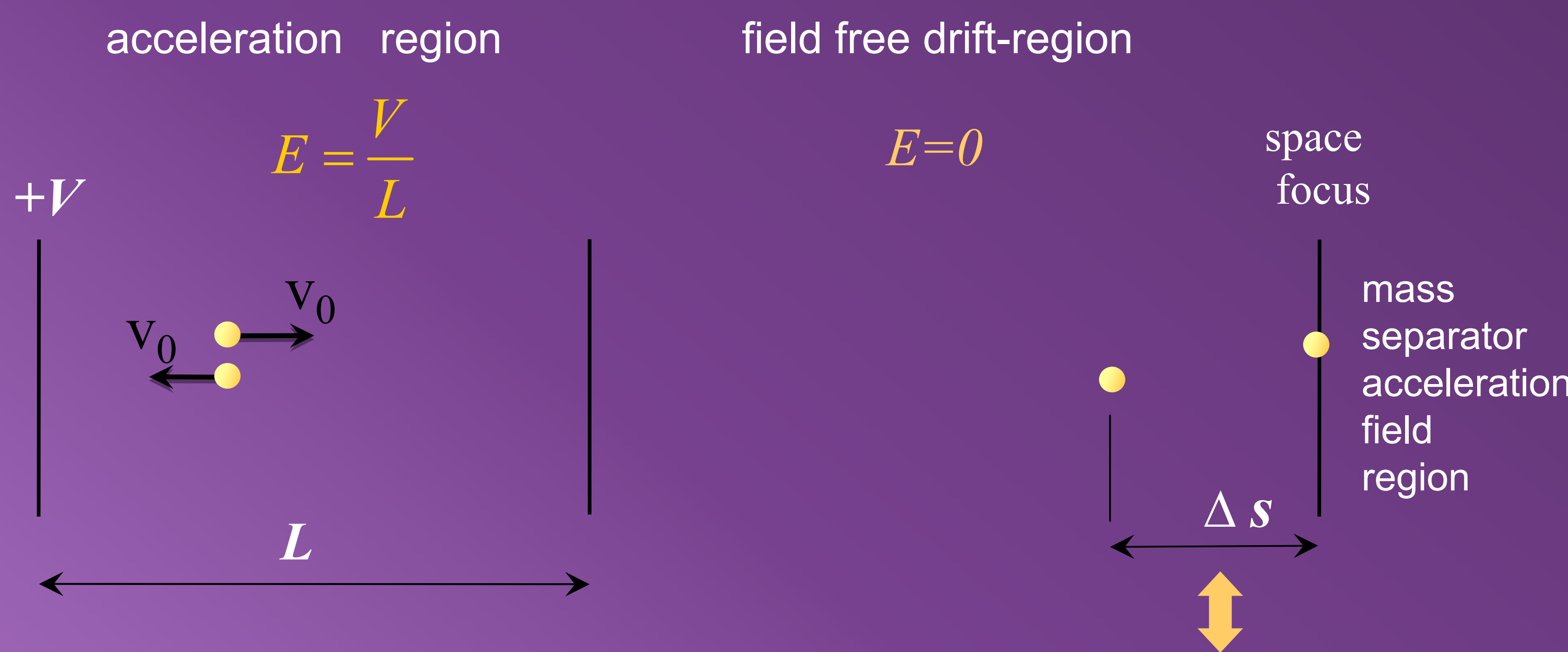
$$\tau_{\text{ionizer}} \approx L\sqrt{\frac{2m}{eE}}$$

$$\tau_{\text{time-of-flight}} = \frac{\tau_{\text{ionizer}}}{S(L, E_0, E_1)}$$

Ion peak width

$$\tau_{\text{ion peak}} \approx \tau_{\text{spatial distribution}} + \tau_{\text{turn-around}}$$

Broadening of ion pulses by initial thermal energy distributions of ions



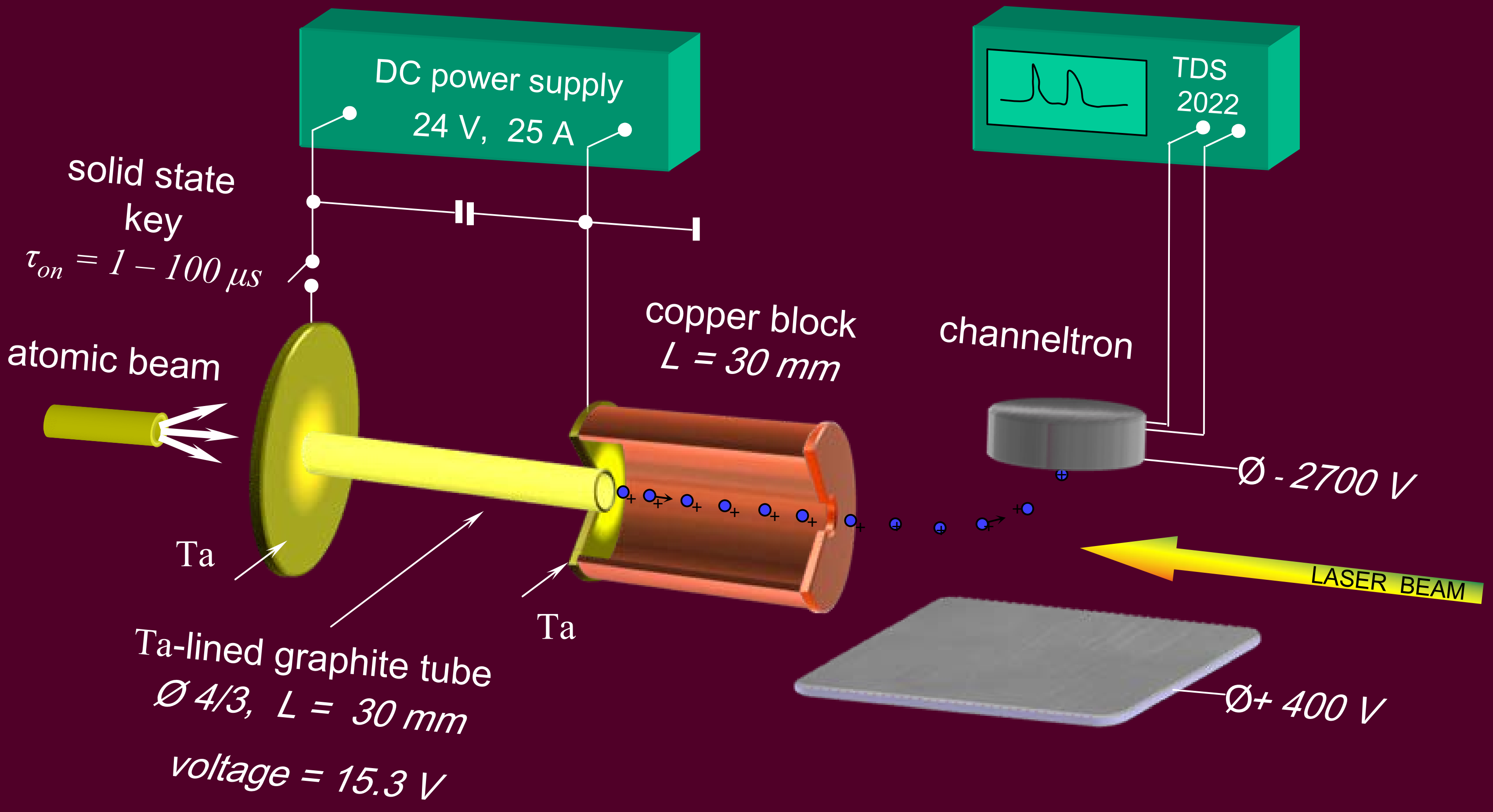
v_0 - initial thermal velocity

m - mass of ions

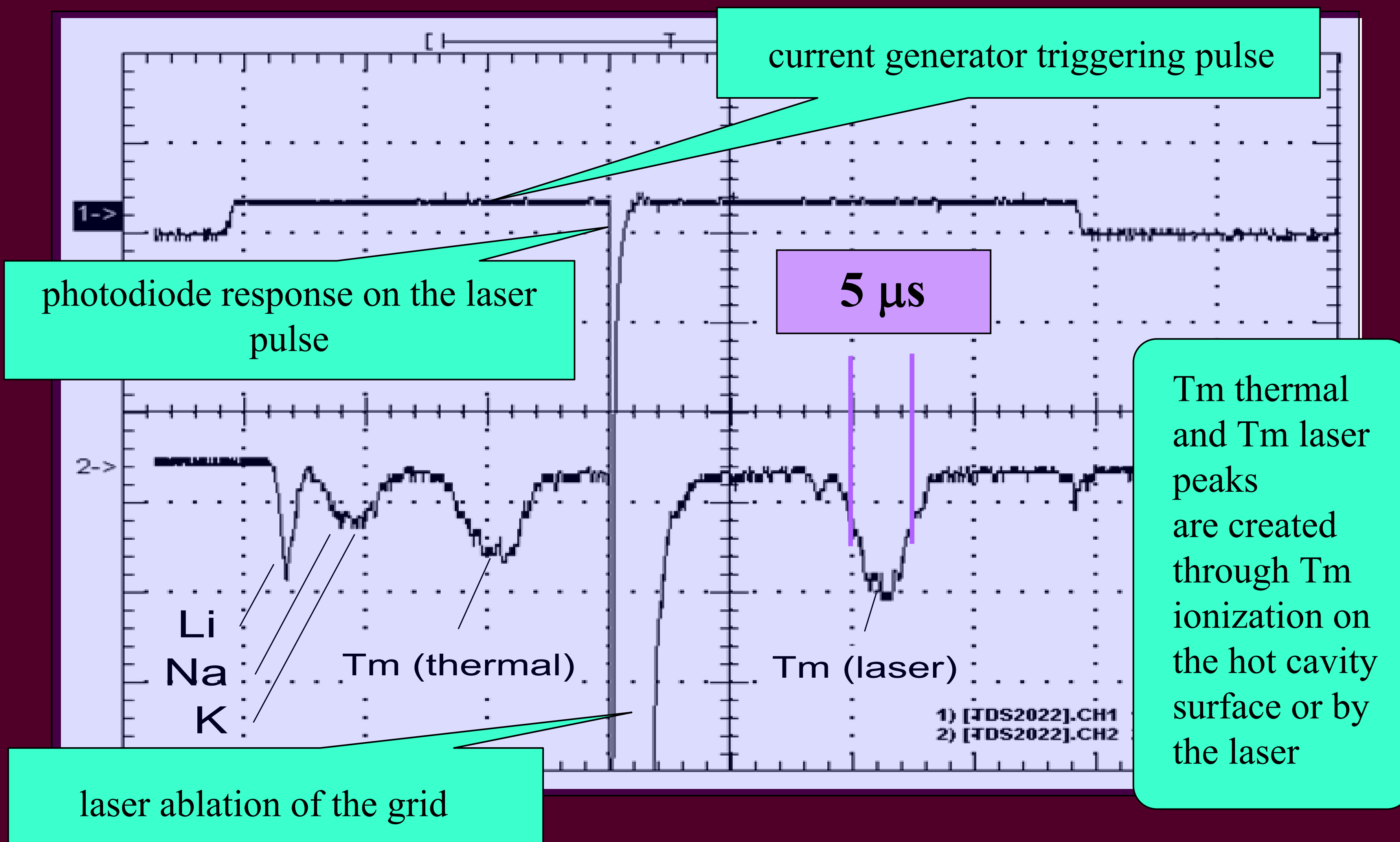
e - charge of electron

$$\tau_{\text{turn-around time}} = \frac{2 v_0 m}{eE}$$

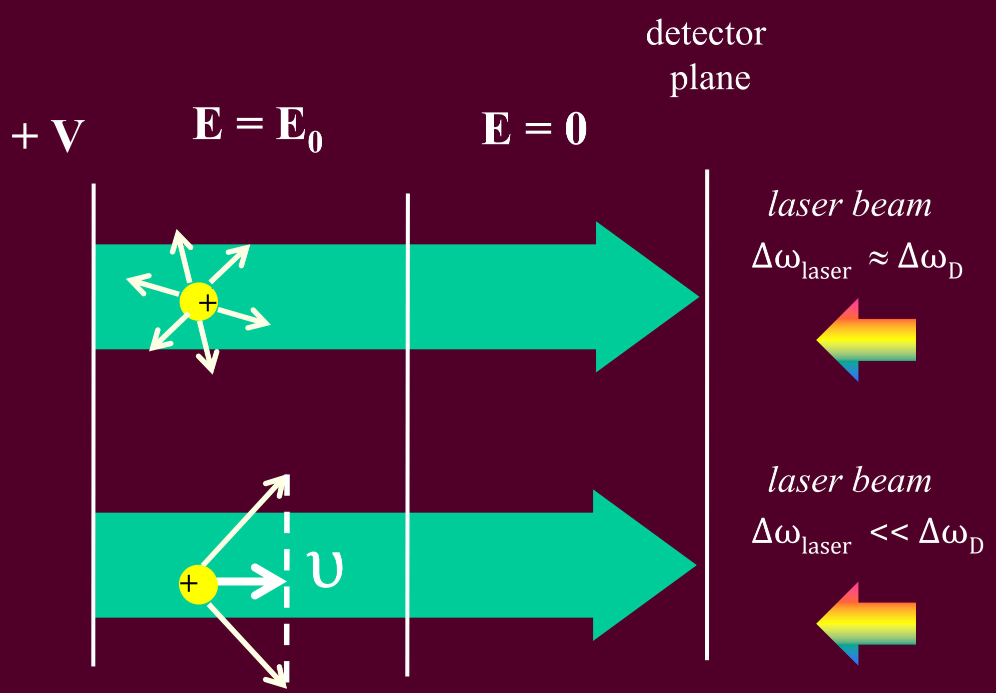
Experimental Setup



Time-of-flight mass spectrum of Li, Na, K and Tm



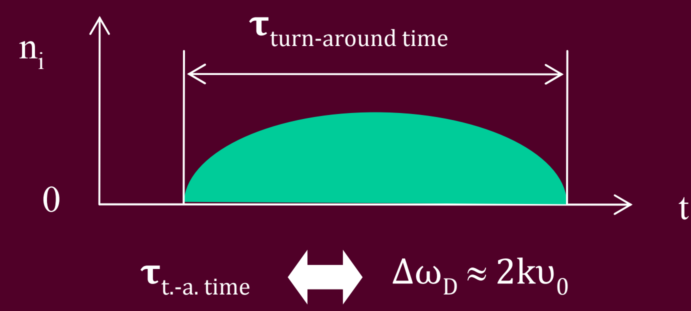
Subdoppler Velocity Selective Resonance Ionization Spectroscopy



$$\omega - \omega_0 = k\upsilon$$

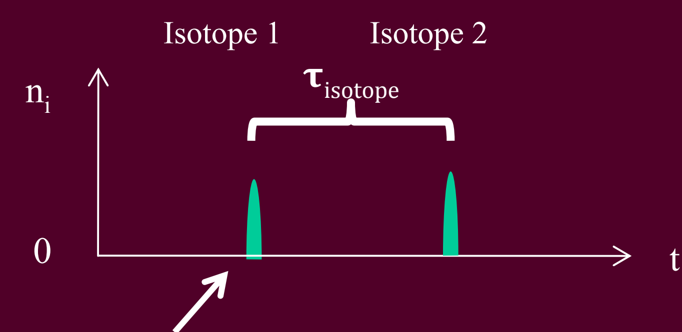
$k = \omega/c$

υ is the velocity projection onto the laser axis



The laser frequency is fixed

$$\omega_{laser} - \omega_1 = k\upsilon_1 \qquad \omega_{laser} - \omega_2 = k\upsilon_2$$

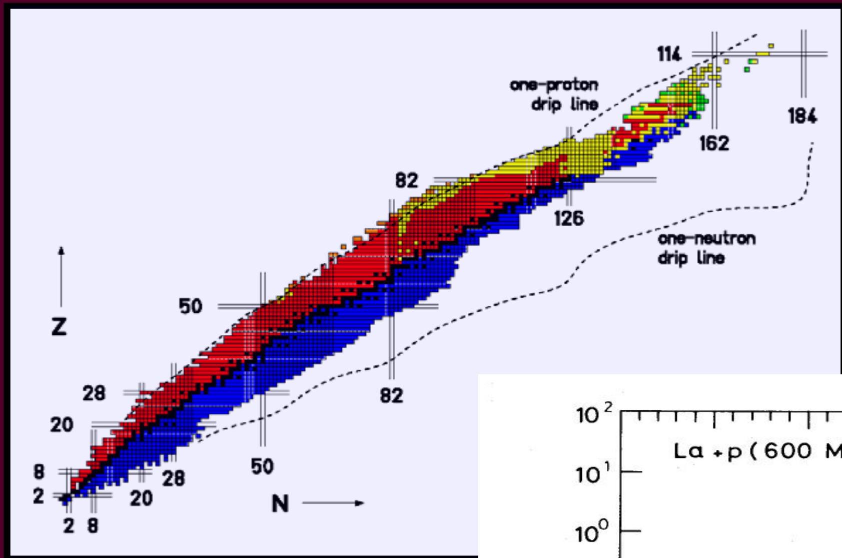


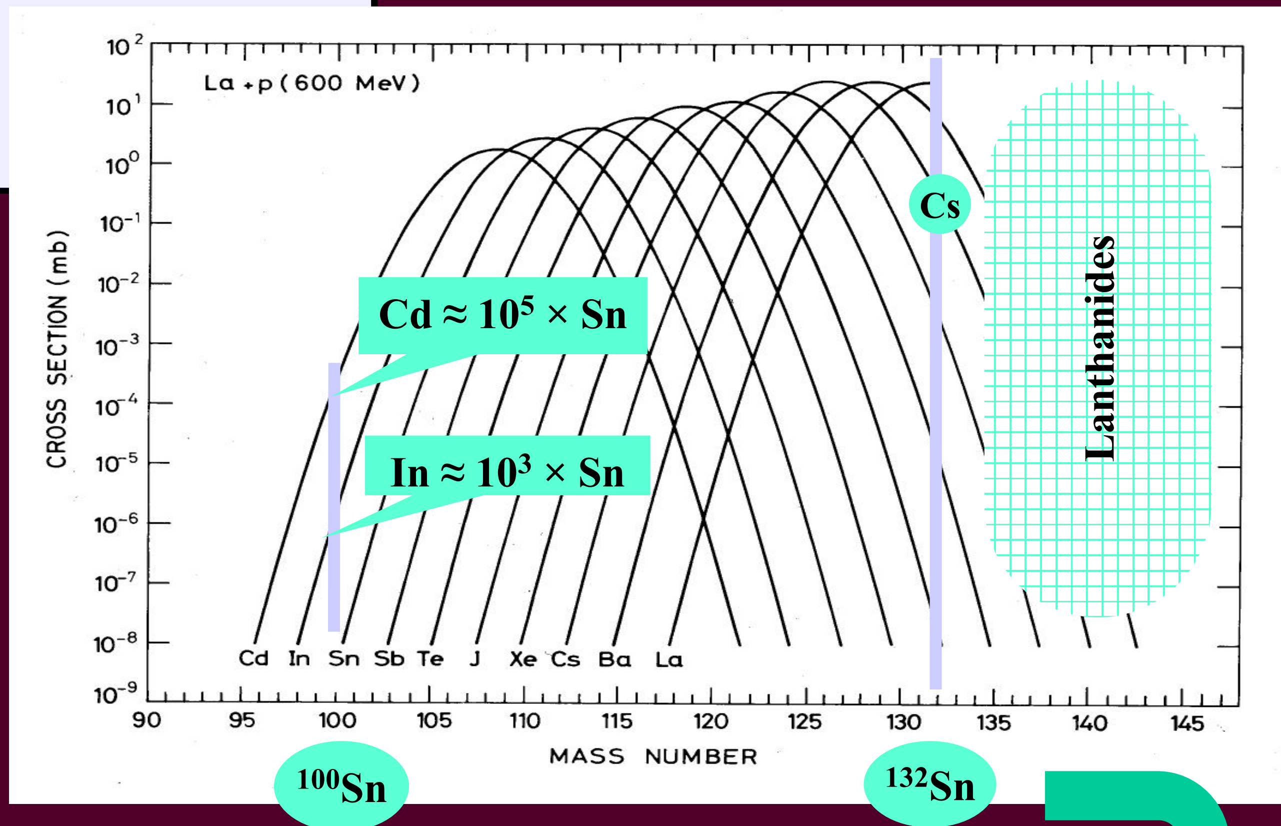
- The duration of the ion peak $\boldsymbol{\tau}_{ion}$ corresponds to the laser line width $\boldsymbol{\Delta\omega}_{laser}$
- The time interval between the ion peaks $\boldsymbol{\tau}_{isotope}$ corresponds to the isotope shift $\boldsymbol{\Delta\omega}_{isotope}$

Conclusions

- *The Resonant Ionization Laser Ion Source, RILIS, can operate in the time-of-flight mode*
- *RILIS operating in the time-of-flight mode has the length rather small, ≈ 60 mm. Therefore it can be installed in front of the mass-separator*
- *For Sn it is possible to obtain the ion pulses with duration below 4 μs down to 500 ns*
- *Selectivity of ISOLDE-RILIS of Sn can be increased by a factor of 25 or more applying this time-of-flight technique*

The need for selectivity

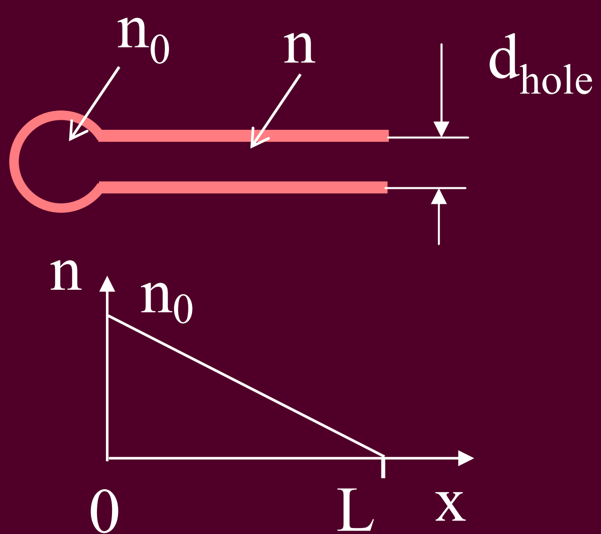




Spallation of La with 0.6 GeV protons

At A = 132 **tin** represents **only 0.24 %** of the observed nuclei

Efficiency of RILIS



outgoing flow of atoms

$$J_{atoms} = \frac{1}{3}(d_{hole}/L)n_0 v_0 S_{hole}$$

outgoing flow of ions

$$J_{ions} = \frac{1}{2} L S_{hole} n_0\, f \times \eta_{phot.} \times \eta_{conf.} \times \eta_{\dots} \times \eta_{\dots} \dots$$

$$\eta_{RILIS} \approx \frac{J_{ions}}{J_{atoms}} = \frac{3}{2}(L^2 f / v_0 d_{hole}) \times \eta_{phot.}\, \eta_{conf.} \cdots$$

is cavity amplification factor **M**

L is cavity length (3 cm)
d is cavity diameter (3 mm)
n_0 is isotope density
v_0 is thermal velocity of isotopes ($\approx 10^5$ cm/s)
f is laser pulse repetition rate (10^4 pps)

$\eta_{conf.}$ is efficiency of ions confinement by thermal plasma
$\eta_{phot.}$ is efficiency of laser photoionization
η_{RILIS} is efficiency of RILIS

Efficiency of RILIS

$$\eta_{RILIS} \approx \frac{J_{ions}}{J_{atoms}} = \frac{3}{2}(L^2 f / v_0 d_{hole})\ \eta_{photoionization}\ \eta_{confinement}$$

$\frac{3}{2}(L^2 f / v_0 d_{hole})$ is cavity amplification factor M

$M(^{14}Be) \approx 3$

$M(^{173}Yb) \approx 10$

M = 5

$\eta_{photoionization}$ = **0.2**

$\eta_{confinement}$ = **1**

$\Rightarrow$ $\boldsymbol{\eta_{RILIS} = 100\%}$

EXPERIMENT

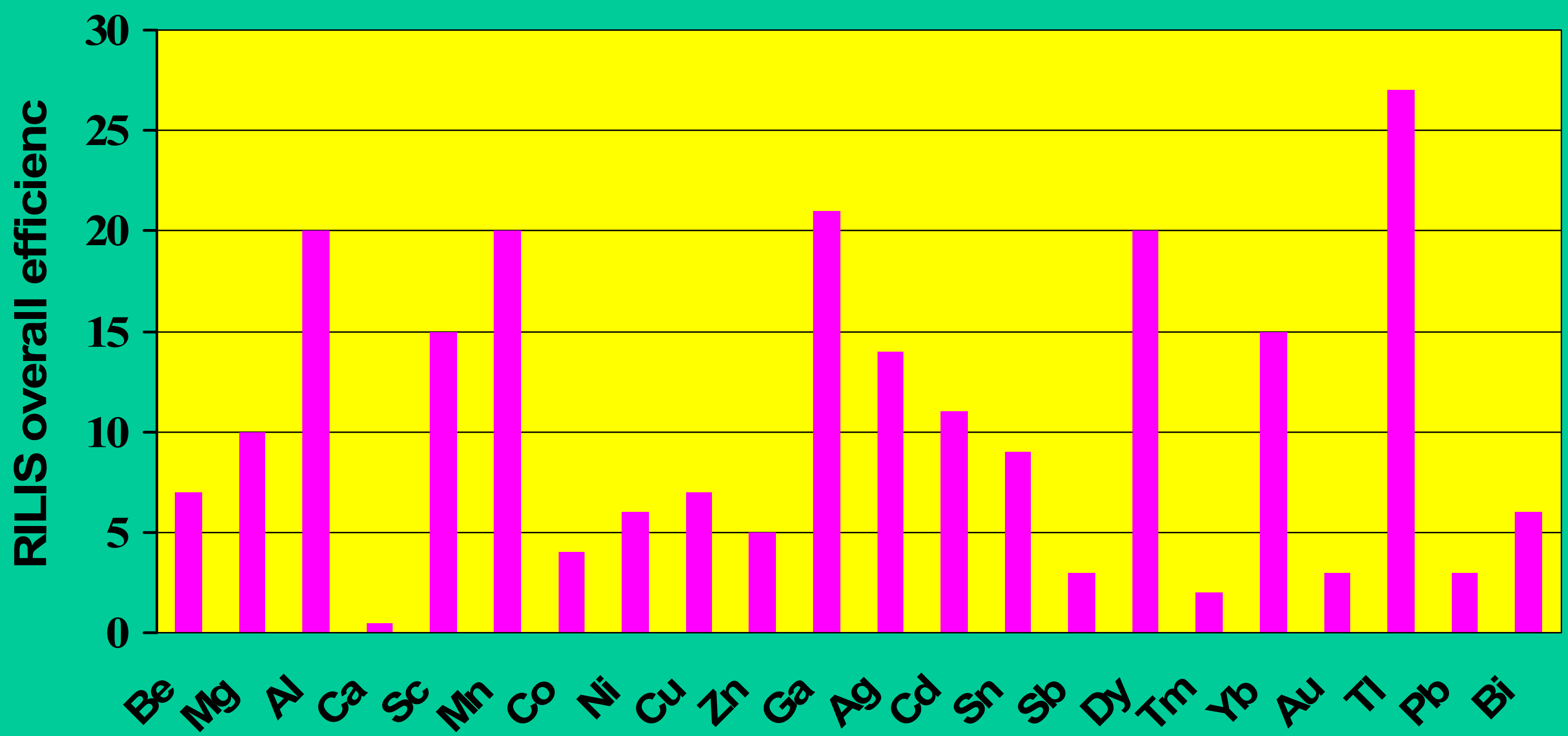
η_{RILIS} (Tl) ≈ **30%** (ISOLDE, L = 3cm)

η_{RILIS} (Ho) ≈ **40%** (HRIBF, L = 8 cm)

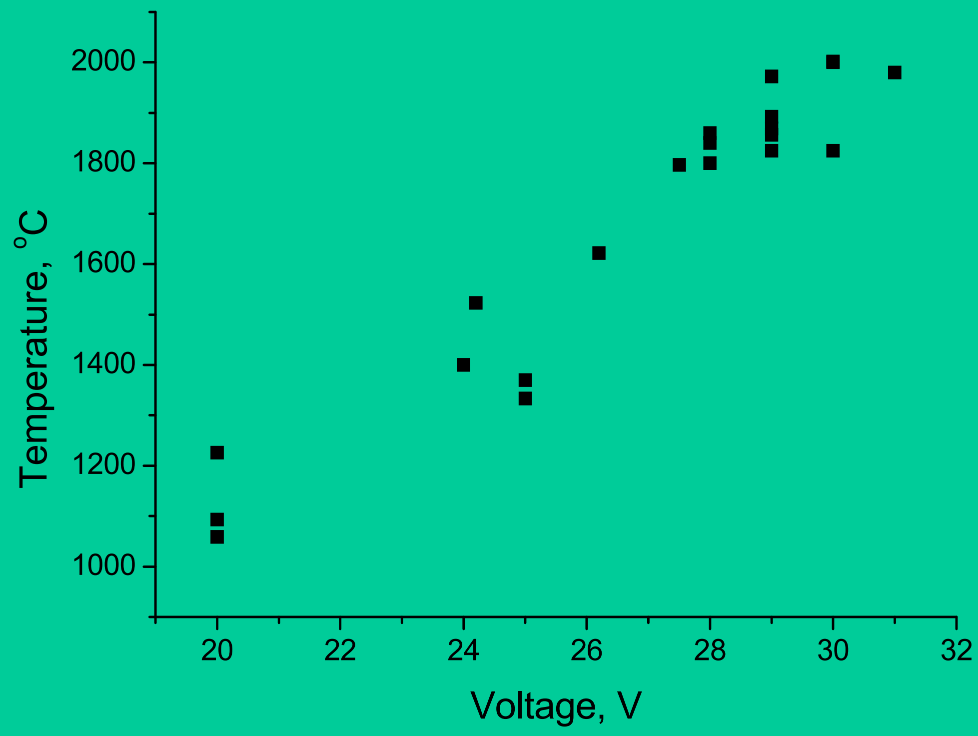
A higher approximation is

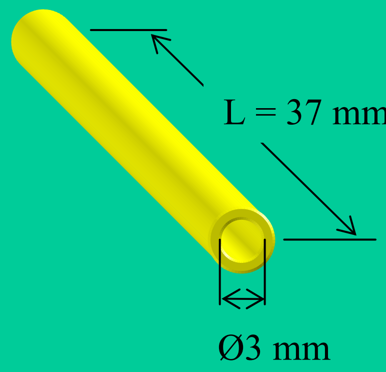
$$\eta_{RILIS} \approx \frac{J_{ions}}{J_{ions} + J_{atoms}}$$

Overall RILIS efficiencies for elements available at ISOLDE



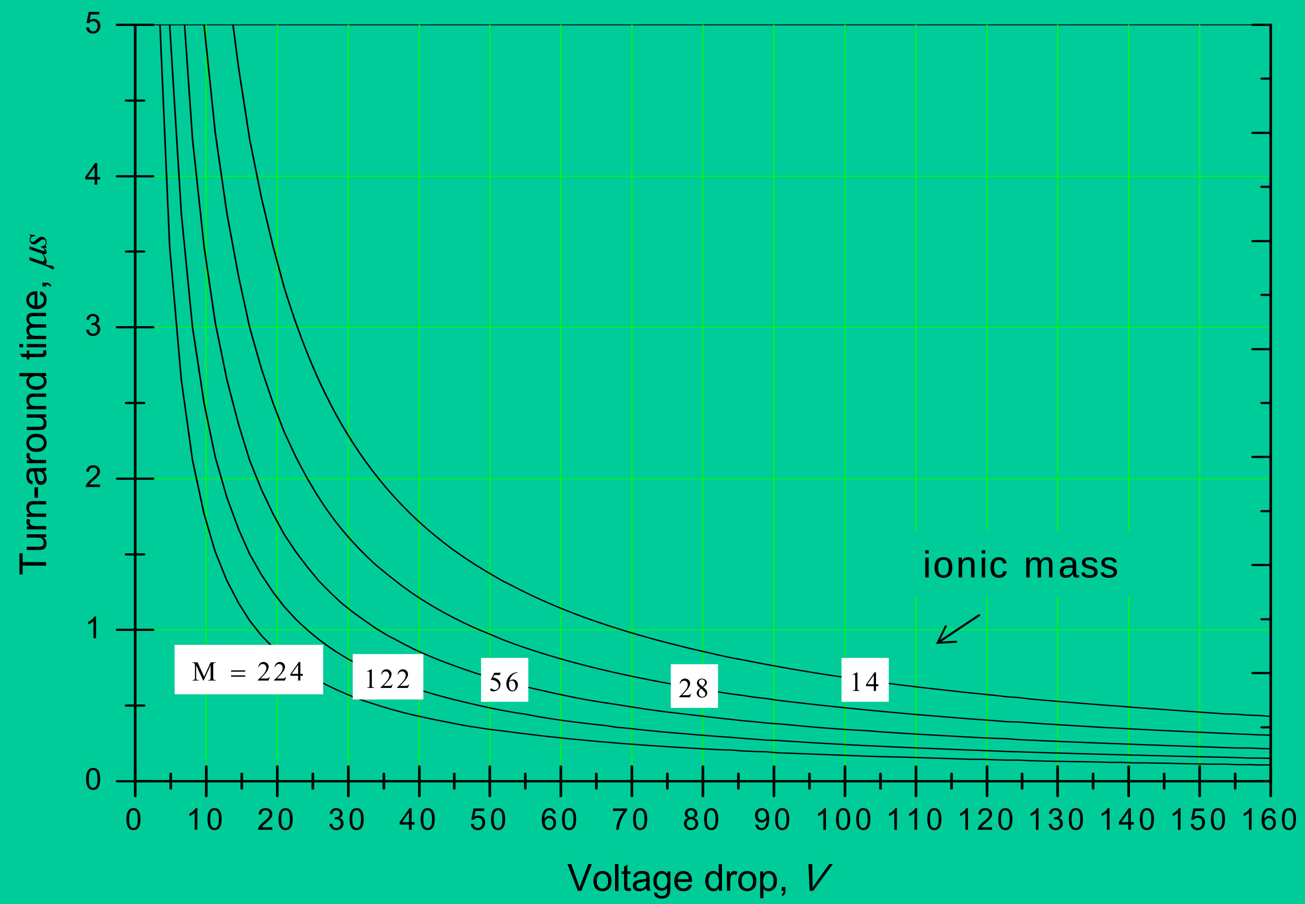
The plot shows the temperature of a graphite pipe in relation to the voltage drop produced by the DC current





The plot shows the turn-around time in relation to the voltage drop across the RILIS ionizer (L = 30 mm)

$$\tau_{\text{turn-around time}} = \frac{2 v_0 m}{eE}$$



OVERVIEW of CHEMICAL ELEMENTS

which are available with RILIS,

which have been ionized by the use of high pulse repetition rate frequency-tuned lasers,

which can be ionized by the use of high pulse repetition rate frequency-tuned lasers,

which may be ionized by the use of high pulse repetition rate frequency-tuned lasers following atomic level structure identification