ISOLDE
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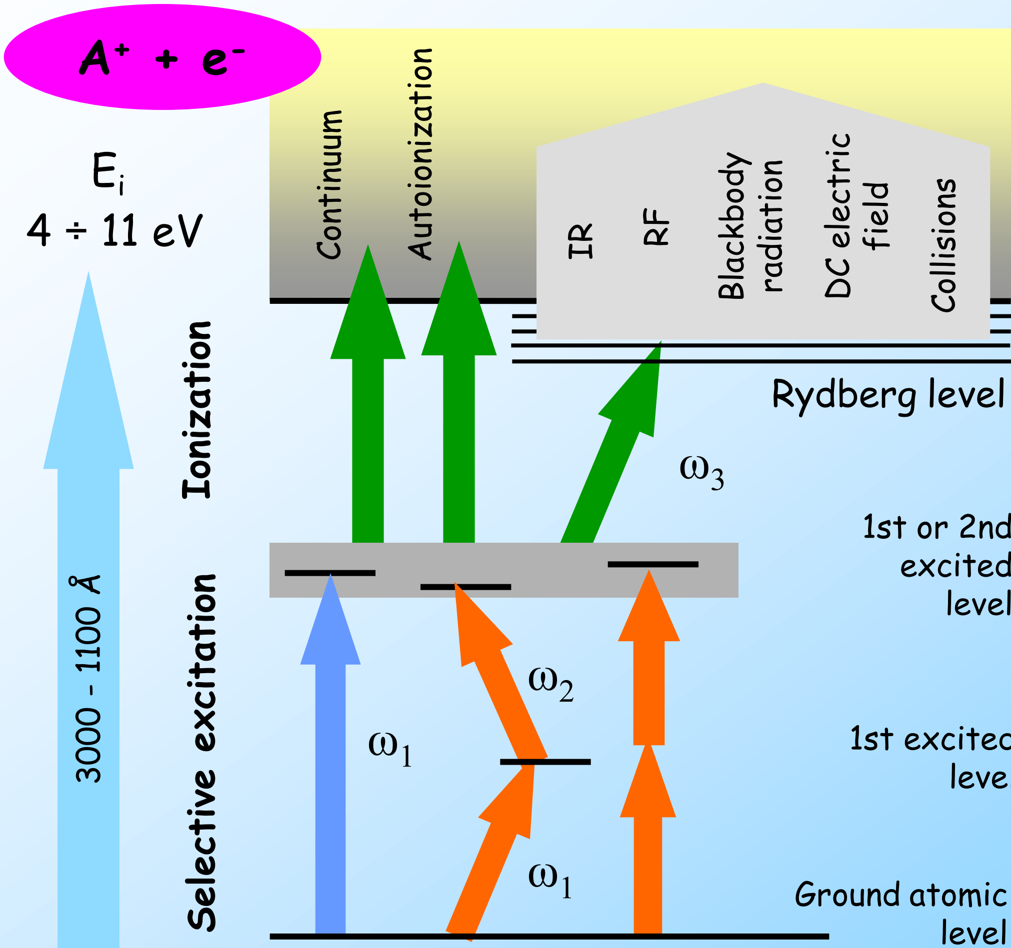
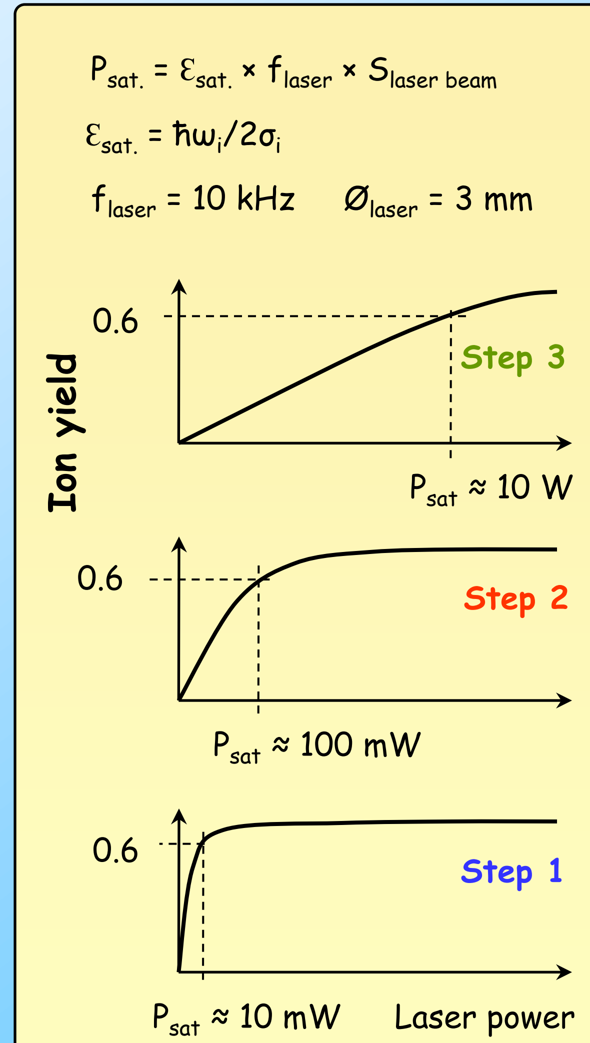
# ISOLDE RILIS:
# from proof of principle to a standard versatile technique

By V. Fedosseev
CERN, EN-STI-LP

# Laser Resonance Ionization of Atoms



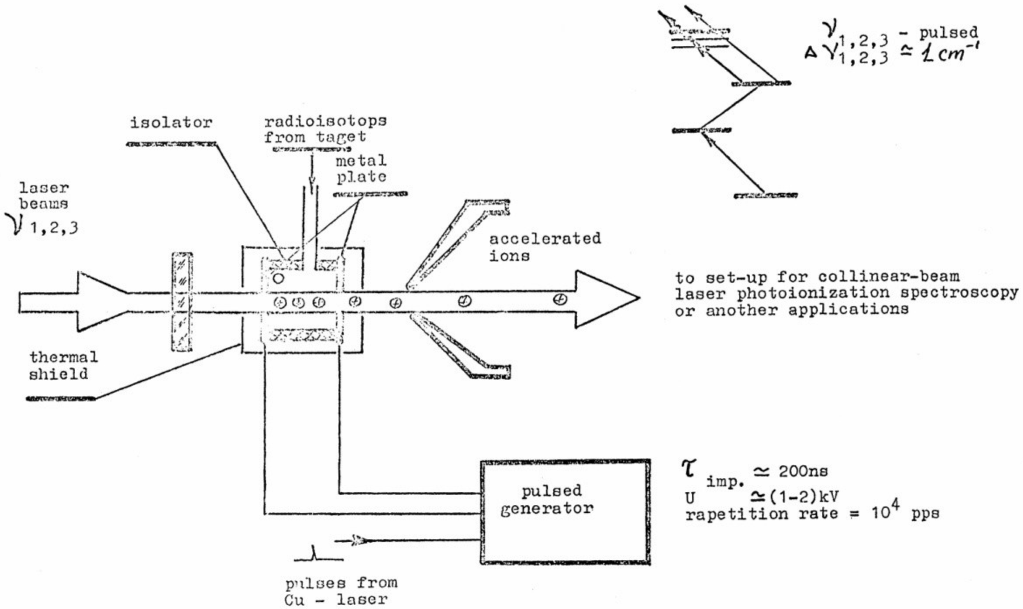

$$\omega_i(\text{laser}) = \omega_i(\text{atom}); \quad P_i(\text{laser}) \geq P_i(\text{saturation})$$

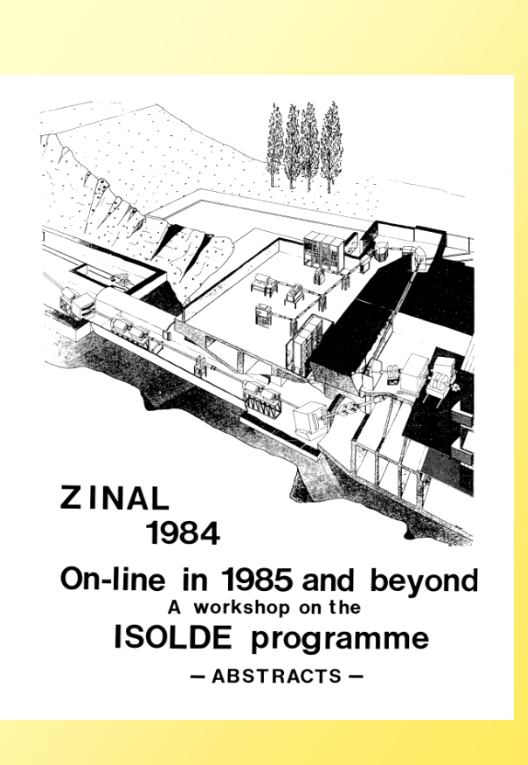
# Early proposals: 1984

PROPOSAL
of the Institute of Spectroscopy, Acad.Sci. USSR
for experiments with ISOLDE-CERN Facility
(V. S. Letokhov and V. I. Mishin)

LASER PHOTOIONIZATION PULSED SOURCE OF
RADIOACTIVE ATOMS

I. Purpose The development of a pulsed isobar-selective effective source of ions at the mass-separator inlet on the basis of the method of laser resonant atomic photoionization.



# Early proposals: 1988

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/ISOLDE
IP 50

PROPOSAL TO THE ISOLDE COMMITTEE

DEVELOPMENT OF A LASER ION SOURCE

F. Ames, E. Arnold, H.J. Kluge, Y.A. Kudryavtsev,
V.S. Letokhov, V.I. Mishin, E.W. Otten, H. Ravn,
W. Ruster, S. Sundell and K. Wendt

University of Mainz, F.R.G.,
Institute of Spectroscopy, Troitzk, USSR
and the ISOLDE Collaboration, CERN, Switzerland

Spokesman: K. Wendt
Contactman: E. Arnold

SUMMARY

Test experiments at Troitzk and Mainz have demonstrated the feasibility of step-wise multi-photon excitation and final ionisation by pulsed lasers as a selective and efficient tool for the production of isobarically pure ion beams. The development of a new type of ion source based on this concept is proposed. In combination with existing targets, this will open up the way to a further extension in respect to purity and availability for a number of elements at on-line mass separator facilities. The collaboration proposes to use the CERN-ISOLDE off-line separator for tests of appropriate target ion source configurations with respect to efficiency and purity. After succesful development the laser ion source shall be installed as an additional facility at the IS-3 separator.

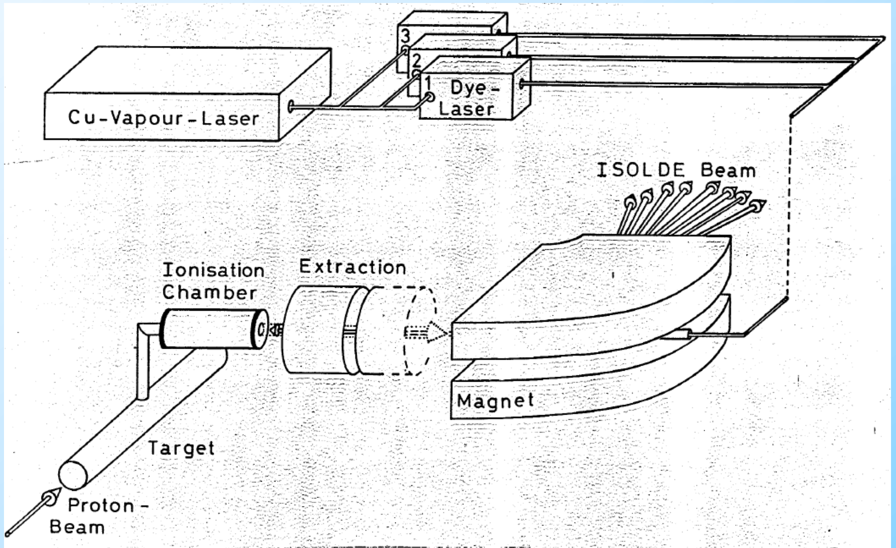
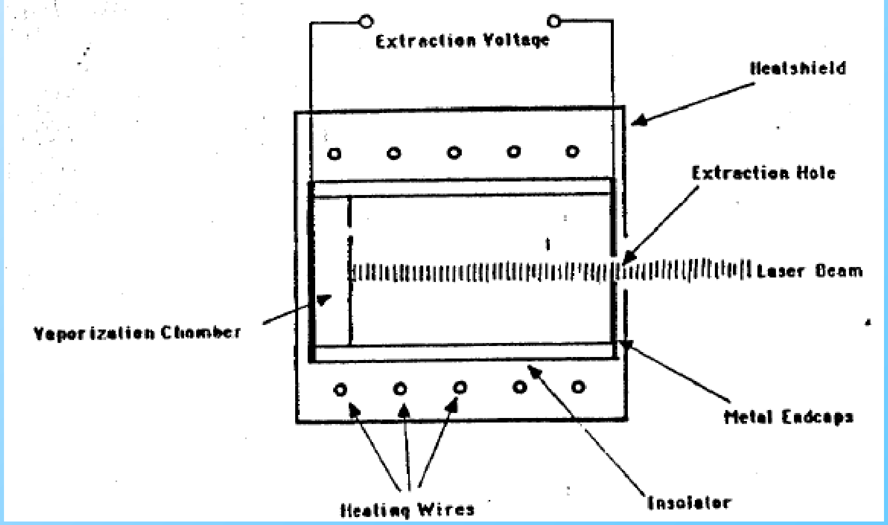



Fig. 5: General layout of the experimental set-up at the off-line separator



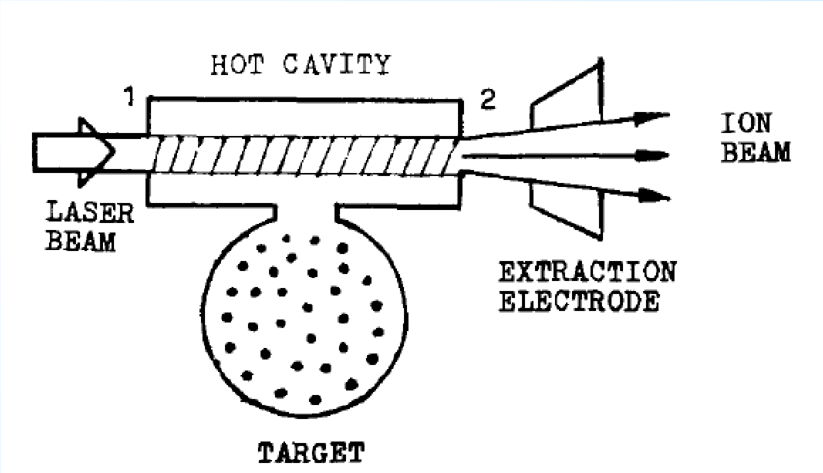
# Ionization in a hot metal cavity

Nuclear Instruments and Methods in Physics Research A306 (1991) 400–402

## Application of a high efficiency selective laser ion source at the IRIS facility

G.D. Alkhazov, L.Kh. Batist, A.A. Bykov, V.D. Vitman, V.S. Letokhov [1], V.I. Mishin [1], V.N. Panteleyev, S.K. Sekatsky [1] and V.N. Fedoseyev [1]
*Leningrad Nuclear Physics Institute, Academy of Sciences of the USSR, Gatchina, Leningrad district 188350, USSR*

Received 6 December 1990 and in revised form 25 March 1991




Demonstrated:

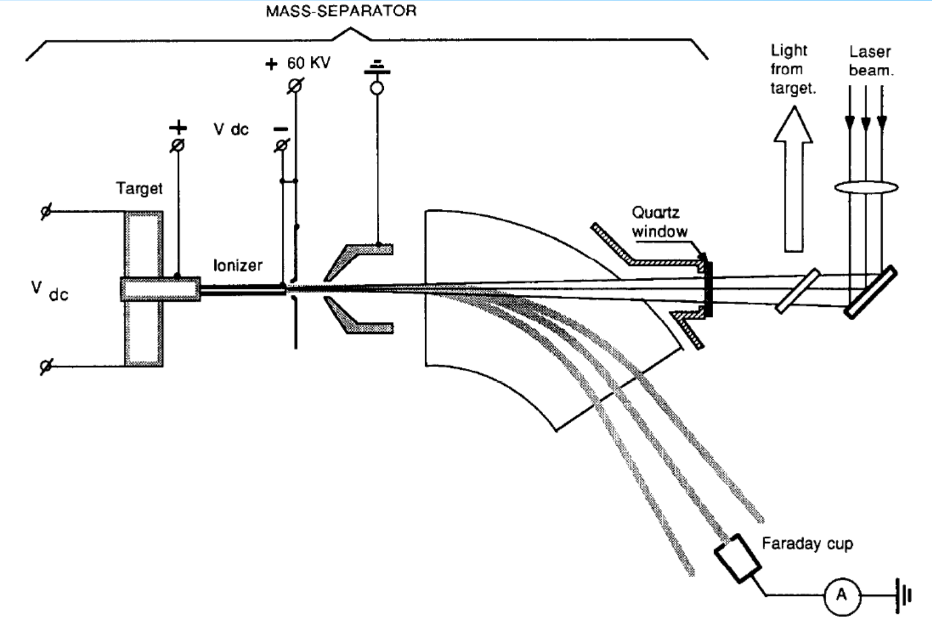
Yb, Nd, Ho - off-line
Ho - on-line

Nuclear Instruments and Methods in Physics Research B73 (1993) 550–560

## Chemically selective laser ion-source for the CERN–ISOLDE on-line mass separator facility

V.I. Mishin [1], V.N. Fedoseyev [1], H.-J. Kluge [2], V.S. Letokhov [1], H.L. Ravn [3], F. Scheerer [2], Y. Shirakabe [4], S. Sundell [3], O. Tengblad [3] and the ISOLDE Collaboration
*PPE Division, CERN, Geneva, Switzerland*

Received 26 November 1992




Yb, Tm, Sn, Li - off-line
Yb - on-line

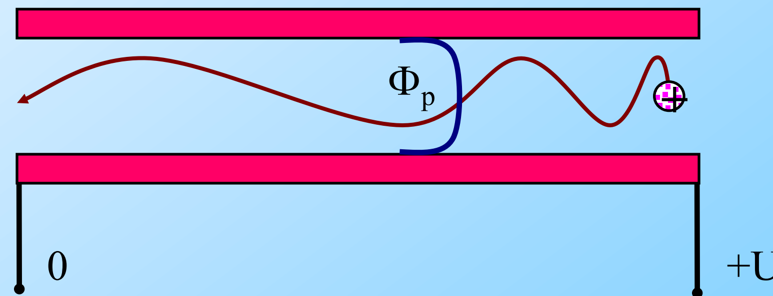
# Ions in a hot cavity

**Thermo electron emission**

$$n_{es} = 2\left(\frac{2\pi m k T}{h^2}\right)^{3/2} \exp\left(\frac{-\varphi}{kT}\right)$$ *(Richardson equation)*

**Plasma potential**

$$\Phi_p^{tde} = \frac{kT}{2e}\ln\left(\frac{n_{is}}{n_{es}}\right) \cong 2\ \text{eV}$$




| Material | Work function, eV | Surface temperature, K |
|---|---|---|
| W | 4.54 | 2500 |
| Ta | 4.25 | 2500 |
| Nb | 4.19 | 2200 |
| TaC | 3.14 | 1800 - 2100 |
| ZrC | 2.18 | < 2100 |
| $Ir_5Ce$ | 2.69 | < 2100 |

Typical values of U for L=30 mm, d=3 mm, t=1 mm

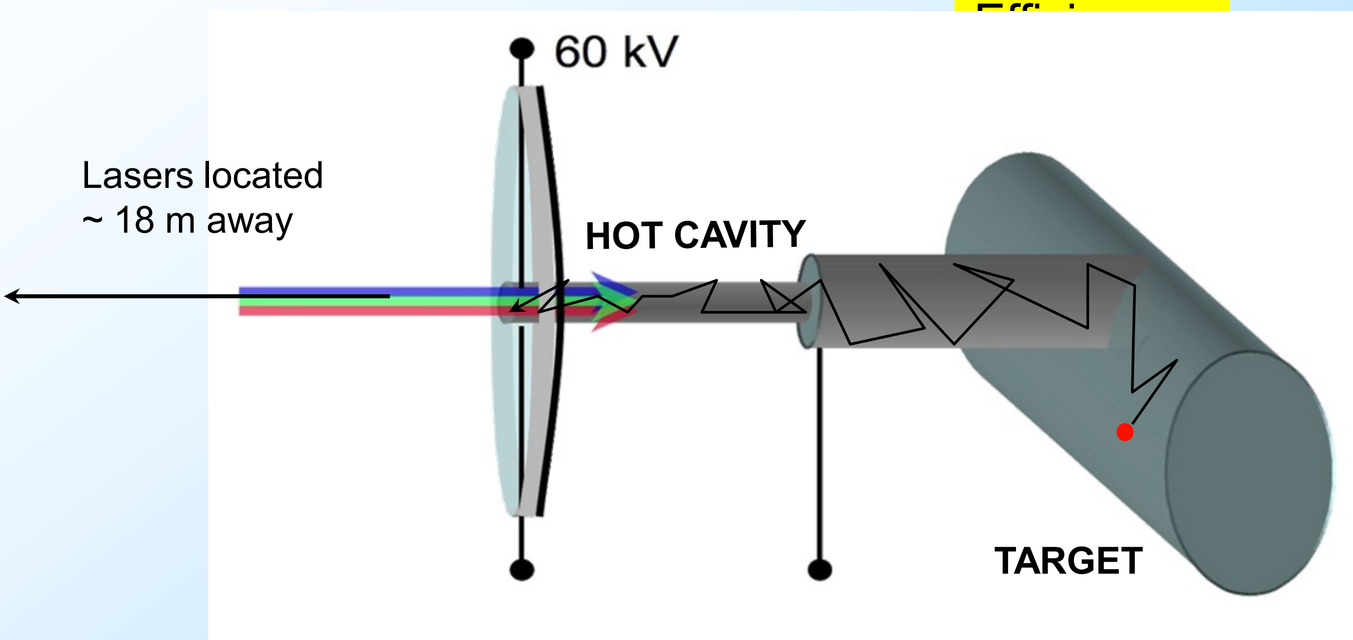
W - 1.5 V
Nb - 2 V, 4 V (t=0.5mm)
TaC - 3 V

**Lower φ** → **Higher plasma potential** → **Better extraction** → **Higher efficiency**

**Higher plasma potential** ↓ **Lower temperature** → **Lower thermal ionization** → **Higher selectivity**

# Hot Cavity Laser Ion Source

$$\varepsilon = \frac{P_{Ionisation}}{P_{Ionisation} + P_{Effusion}} = \frac{\nu_{rep}\,\varepsilon_{ion}}{\nu_{rep}\,\varepsilon_{ion} + \frac{2dv}{3L^2}}$$



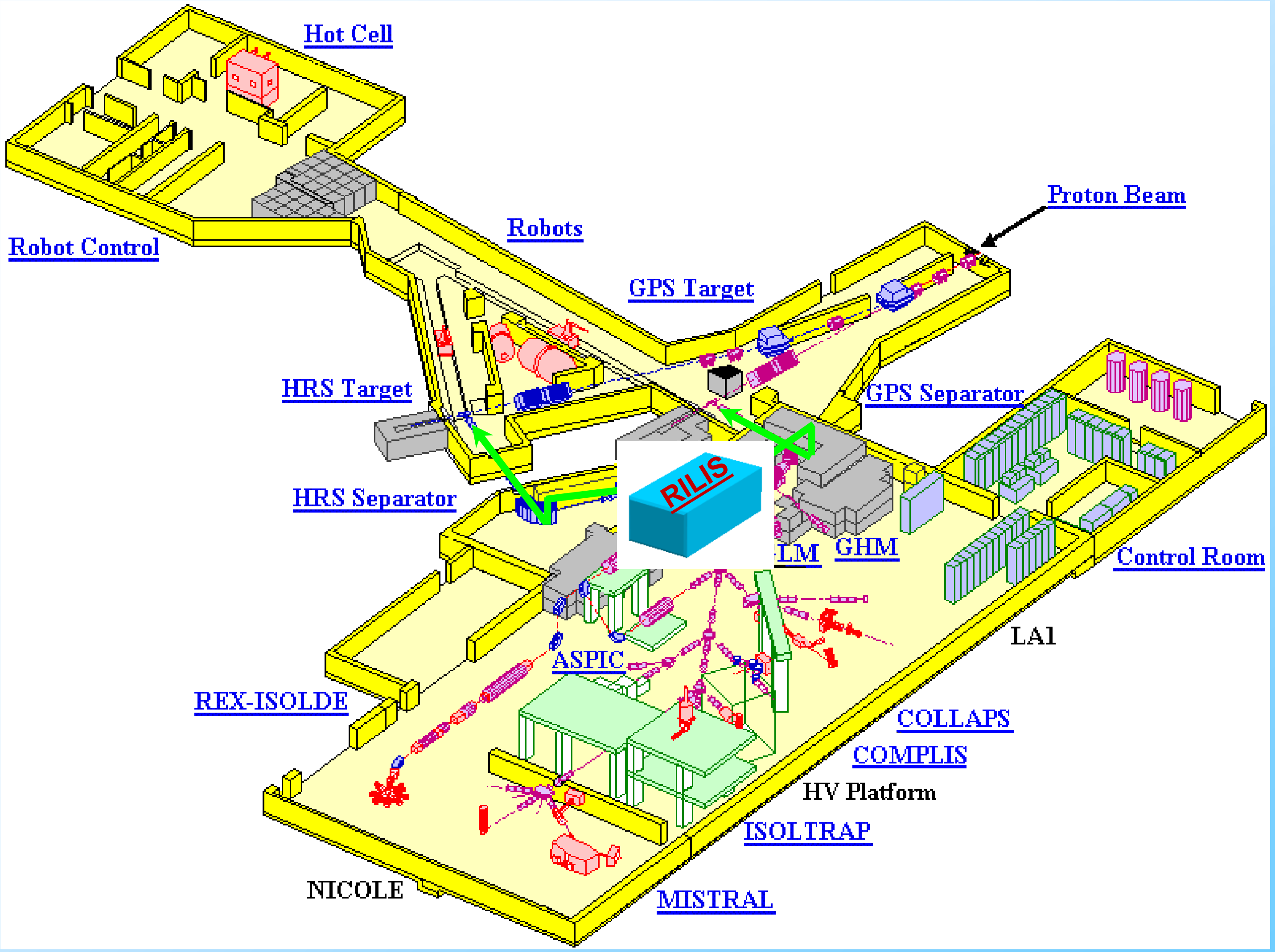

$\varepsilon_{laser}$ = 2% - 30%

Selectivity = $\frac{\text{Laser Ionization Efficiency}}{\text{Surface Ionization Efficiency}}$

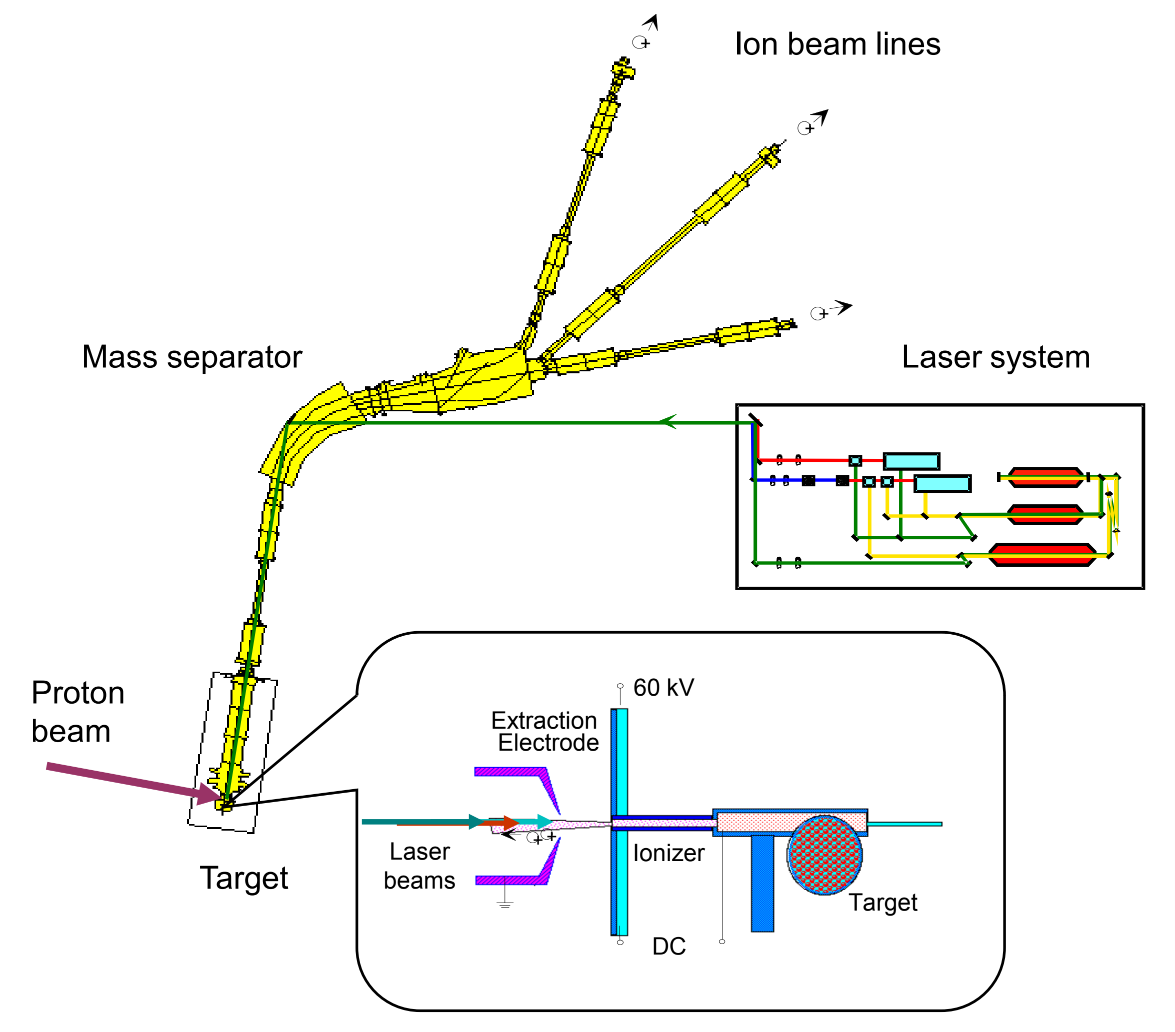
$\varepsilon_{surface}$
- > 5% - alkalies
- = 0.1% -2% - In, Ga, Ba, lanthanides
- < 0.1% - others

=> depends on the ionization potentials of isobar atoms

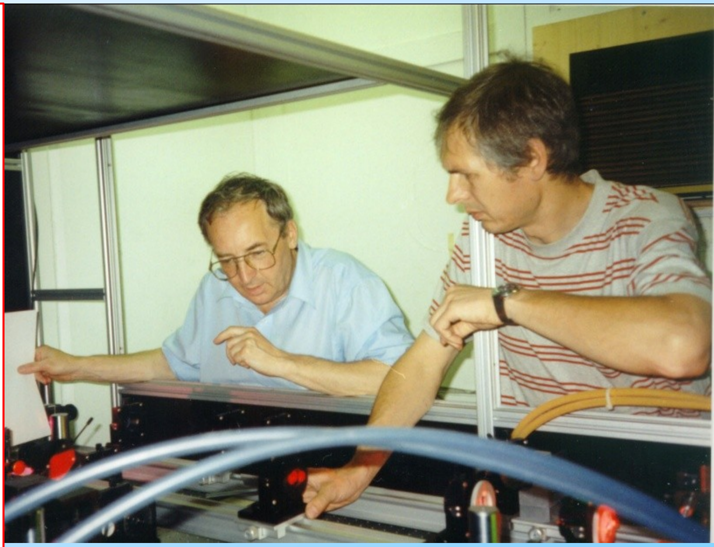
# RILIS at ISOLDE Facility



# RILIS at ISOLDE-PSB




Target - Ion Source Unit



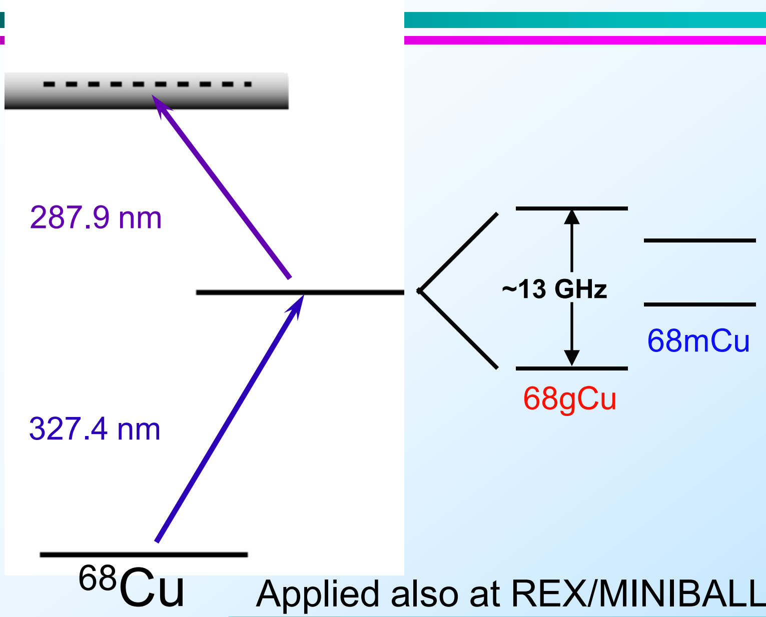
**CVL lasers:** $\nu_{rep}$=11.000 Hz
Oscillator + 2 amplifiers
2-3 dye lasers with amplifiers,
nonlinear crystals BBO:

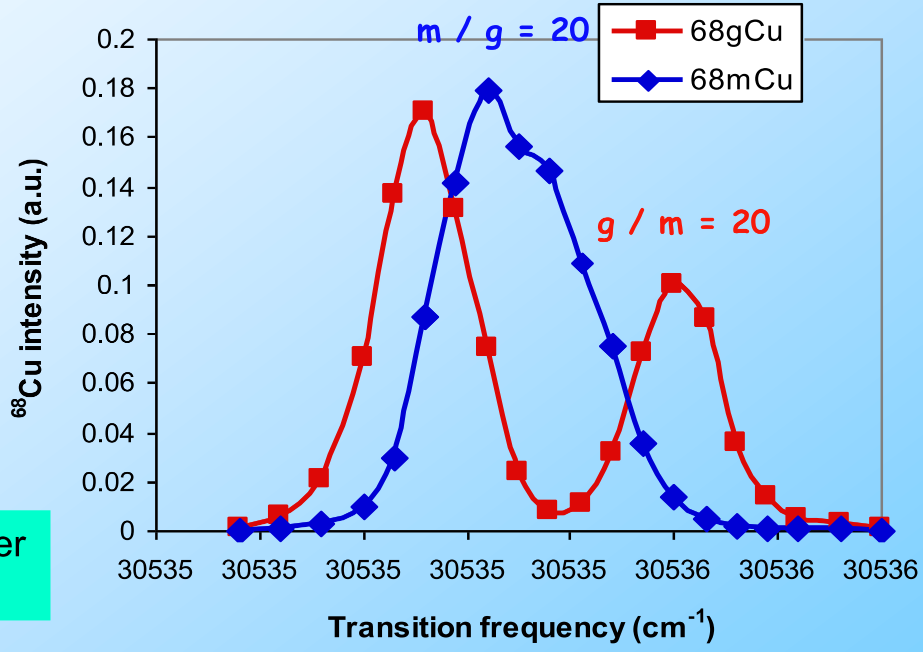
$P_{Cu}^{total} \leq 75\ W$

$P_{dye} \leq 8\ W$

$P_{2\omega} \leq 2\ W$ $P_{3\omega} \leq 0.2\ W$

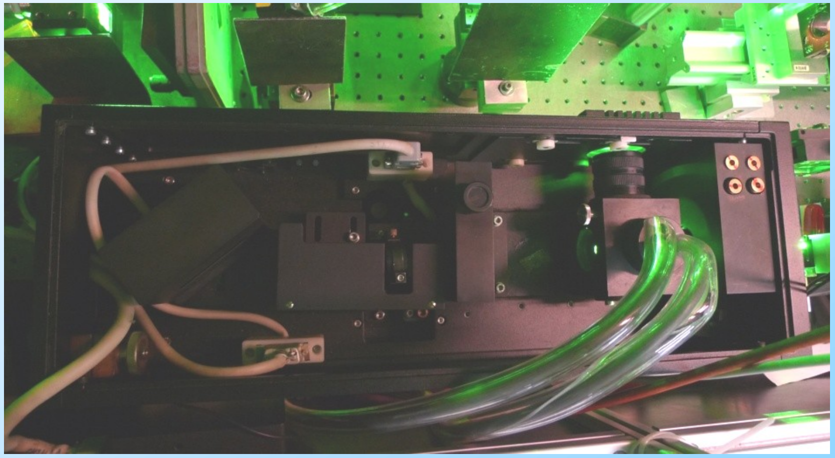
# Isomer selectivity with RILIS

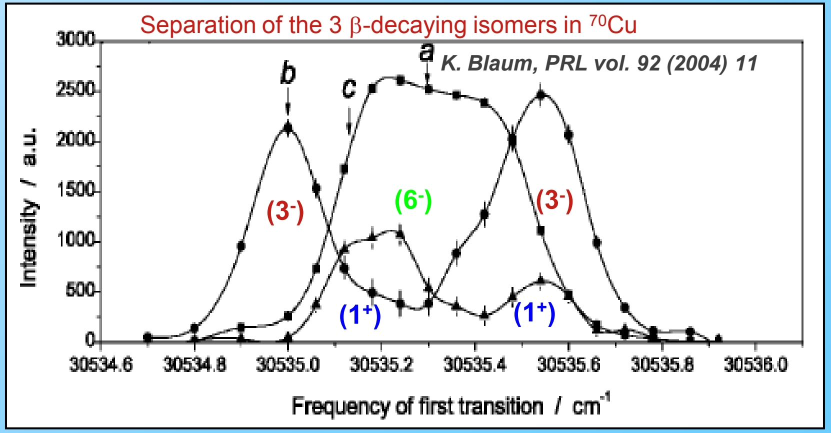


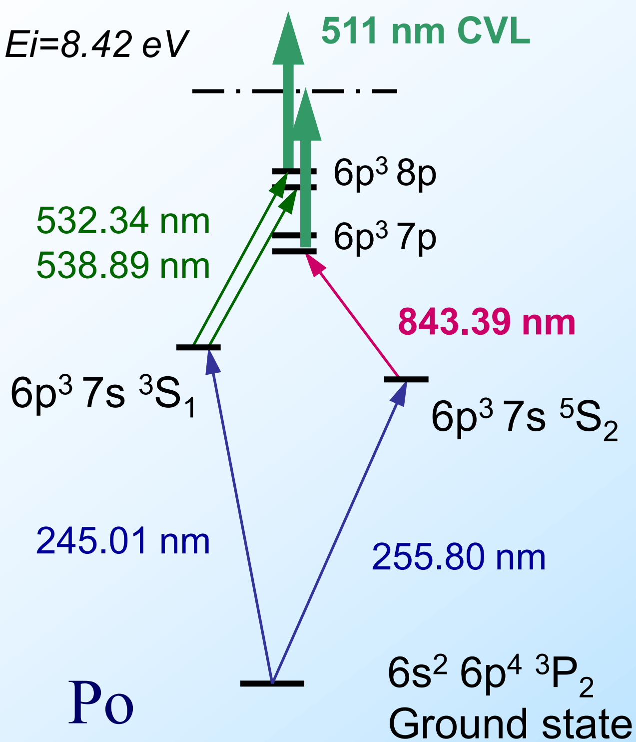

Applied also at REX/MINIBALL

Worlds first post accelerated isomer purified beams



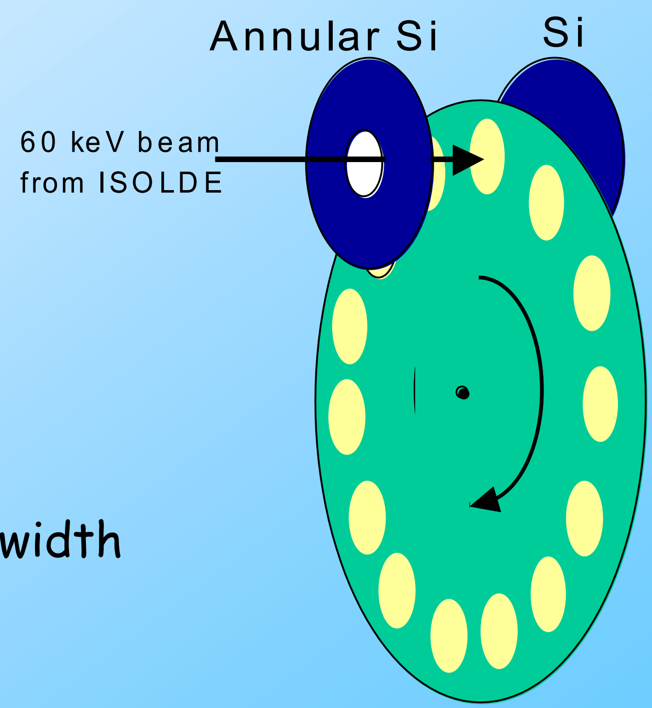


# In-source laser spectroscopy




Techniques used to detect Po ions:

- $\alpha$ – detector with energy resolution
- $\gamma$ – detectors
- $\beta$ – counter
- Faraday cap

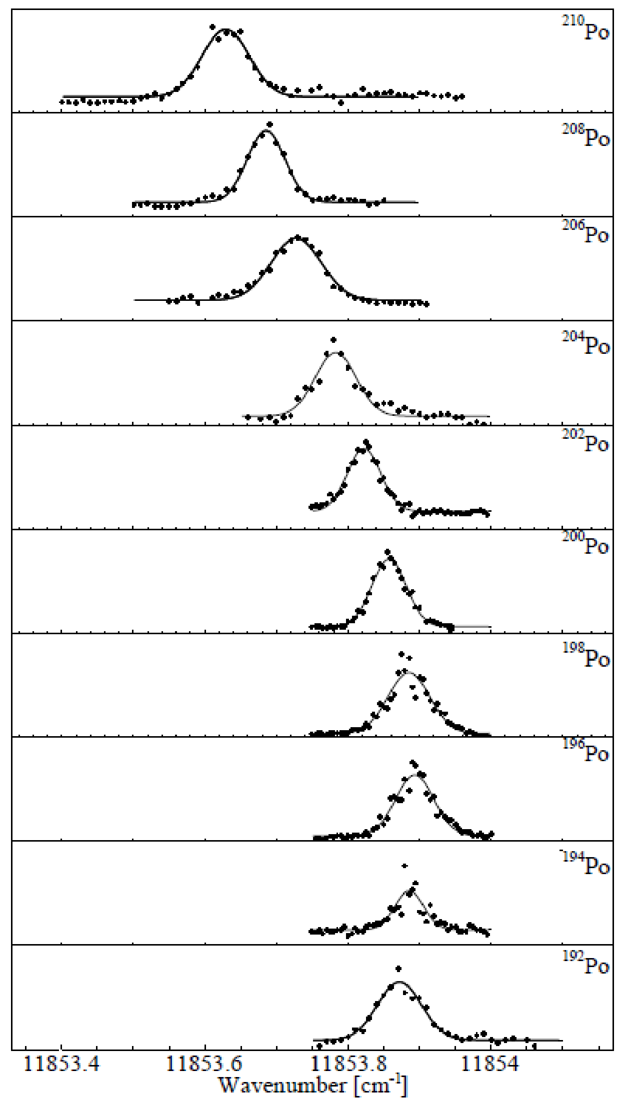



Spectral resolution is limited by Doppler width

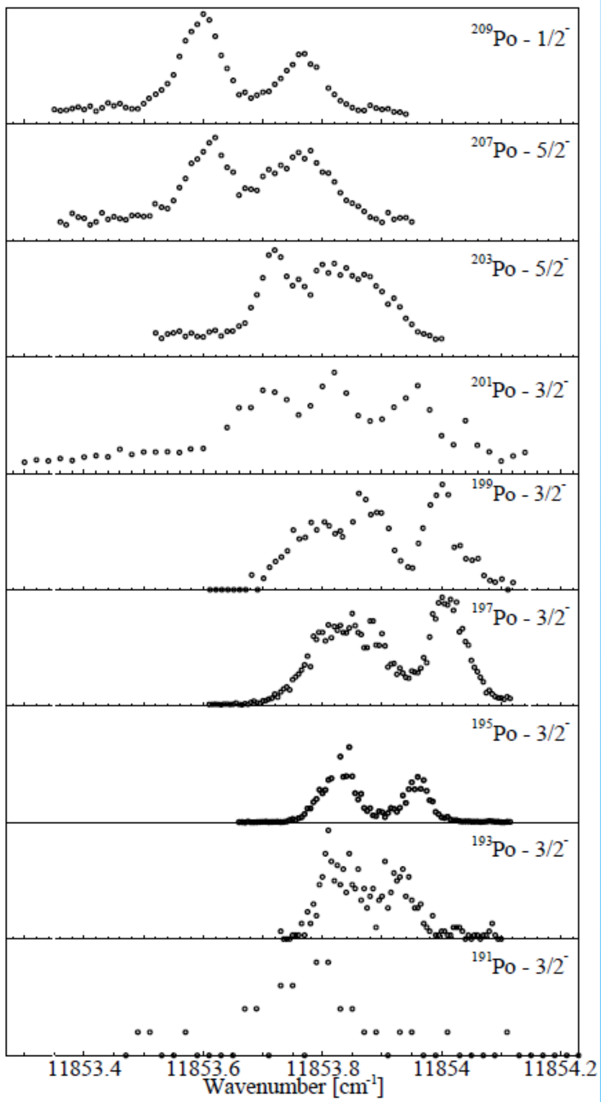
For transition at 843 nm $\Delta \nu_D = 0.8$ GHz

# IS and HFS spectra of Polonium

## Even isotopes




## Odd isotopes (low spin)



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# Latest achievement: At beam

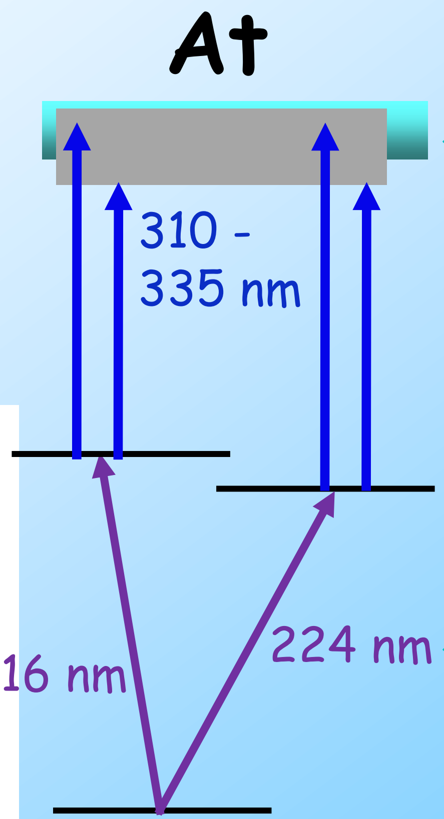
EN STI

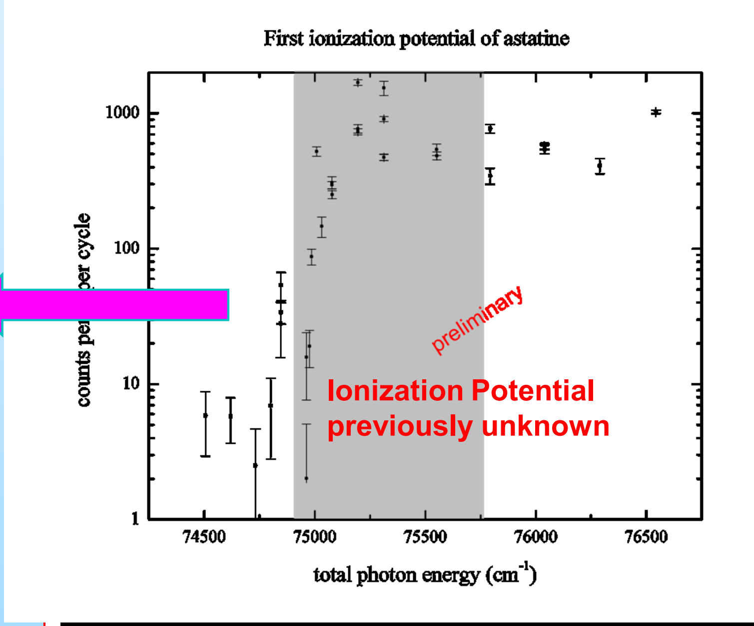
- Worlds 1st laser ionized astatine beam was generated in Nov 2010

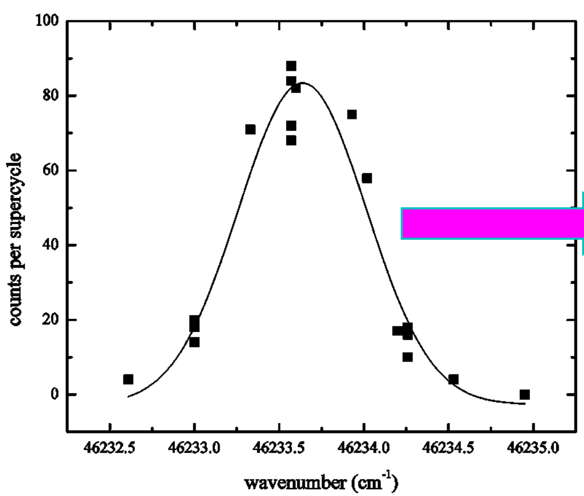
All measurements had to be made On-Line since there is no stable astatine isotope.

1) Two first step laser wavelengths were measured.

2) The ionization potential was determined by scanning the second laser.



# Upgrade of RILIS laser system

Replacement of CVL by SSL

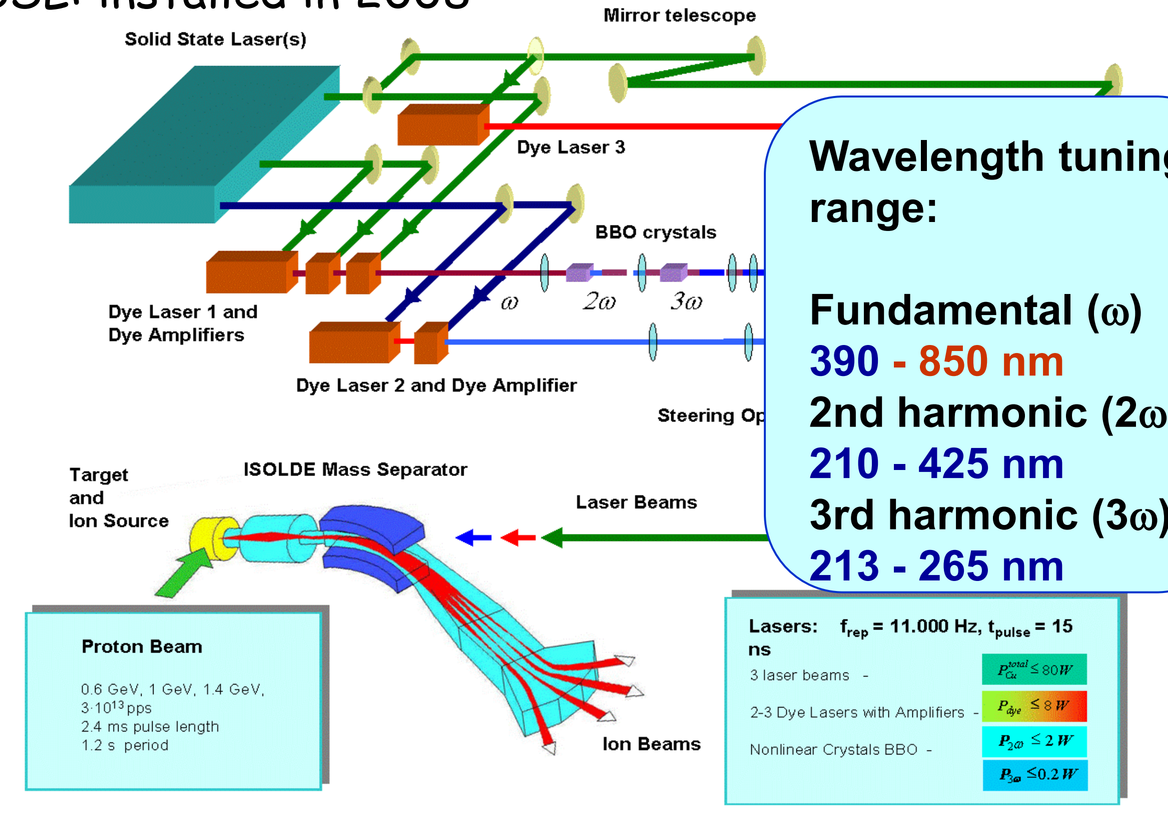
**Advantages:**

- Better beam quality
- Stability of operation
- Spectral coverage UV-NIR without gaps

**Complications:**

- New ionization schemes are needed (Mn, Au)
- Service by manufacturer only

SSL: installed in 2008




**Wavelength tuning range:**

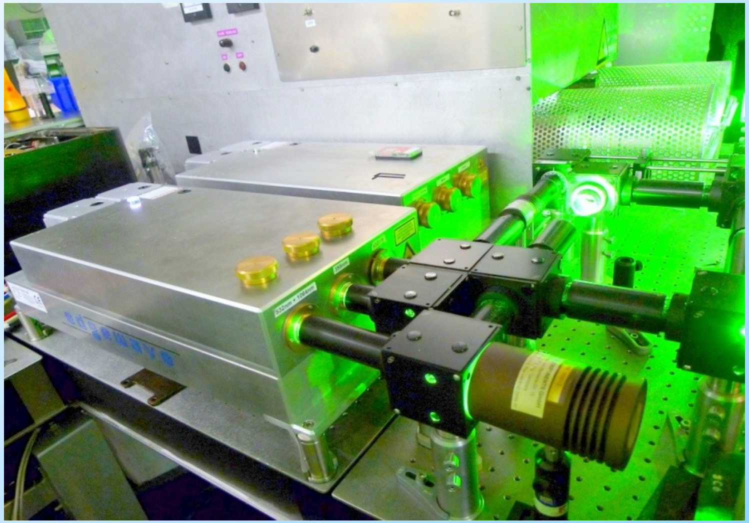
**Fundamental (ω)**
**390 - 850 nm**
**2nd harmonic (2ω)**
**210 - 425 nm**
**3rd harmonic (3ω)**
**213 - 265 nm**

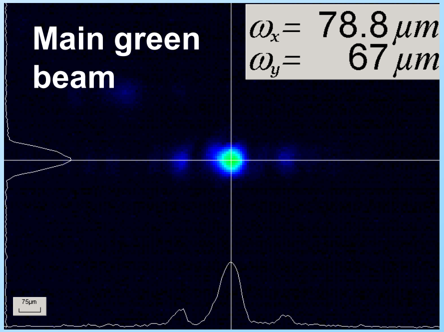
# New Nd:YAG lasers at ISOLDE RILIS

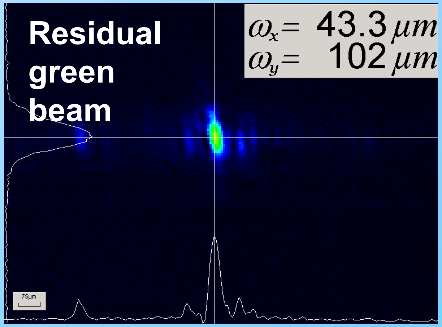


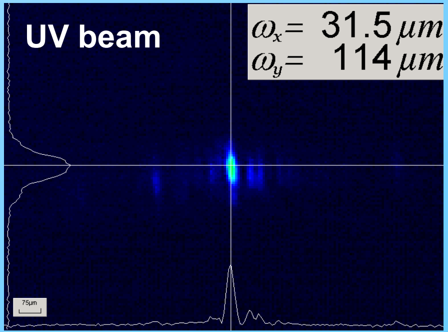
Copper Vapor Lasers are replaced by Diode Pumped Solid State Nd:YAG Lasers

- Two lasers are available:
- one in use, second as a backup





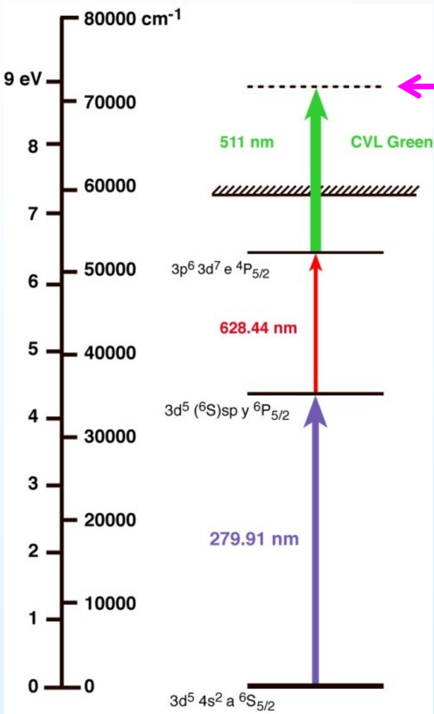



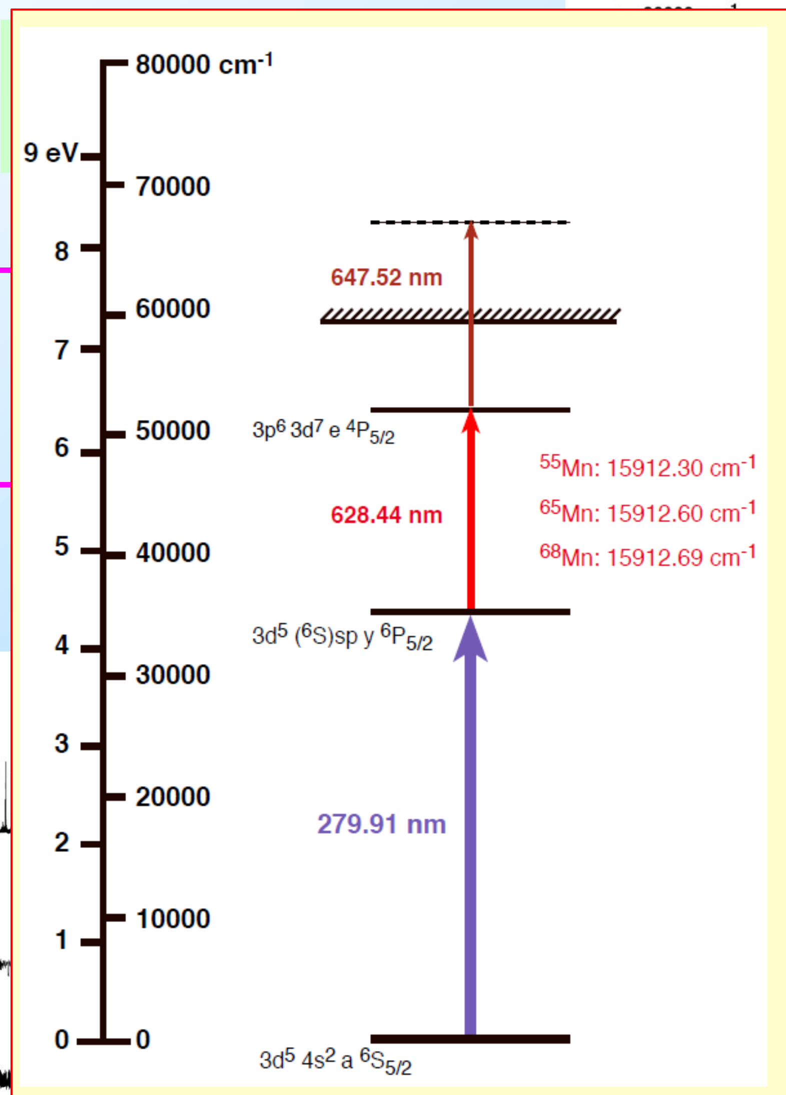



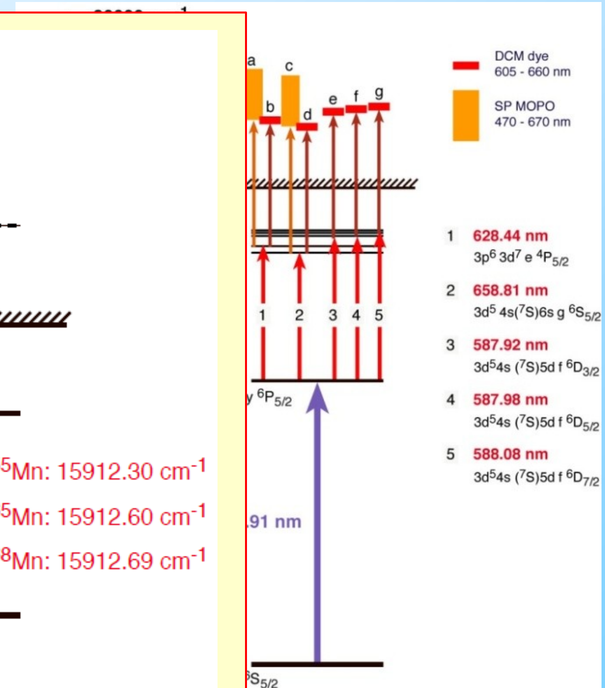

Laser generates 3 beams at 10 kHz:

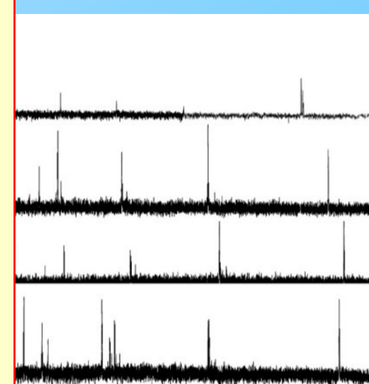
- Main green beam – 532nm, 60-90 W, 8 ns
- Residual green beam – 532 nm, 40-15 W, 9 ns
- UV beam - 355 nm, up to 20 W, 11 ns

# A new RILIS scheme for manganese - LARIS result



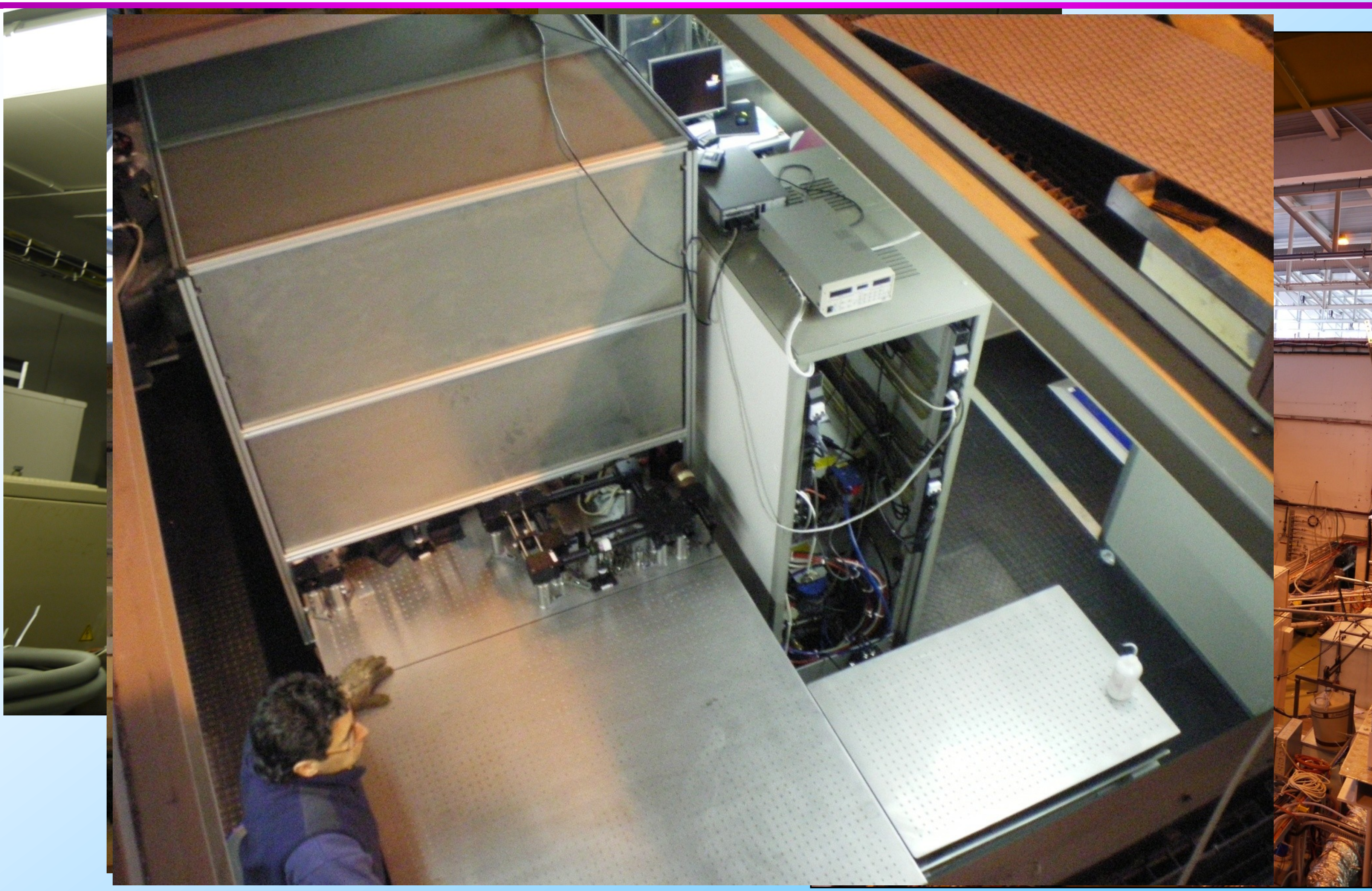
**Outcome of RIS study of Mn at LARIS:**

Many new auto-ionizing states found

Various promising Nd:YAG based schemes tested

New scheme applied at RILIS
Efficiency > 8 %

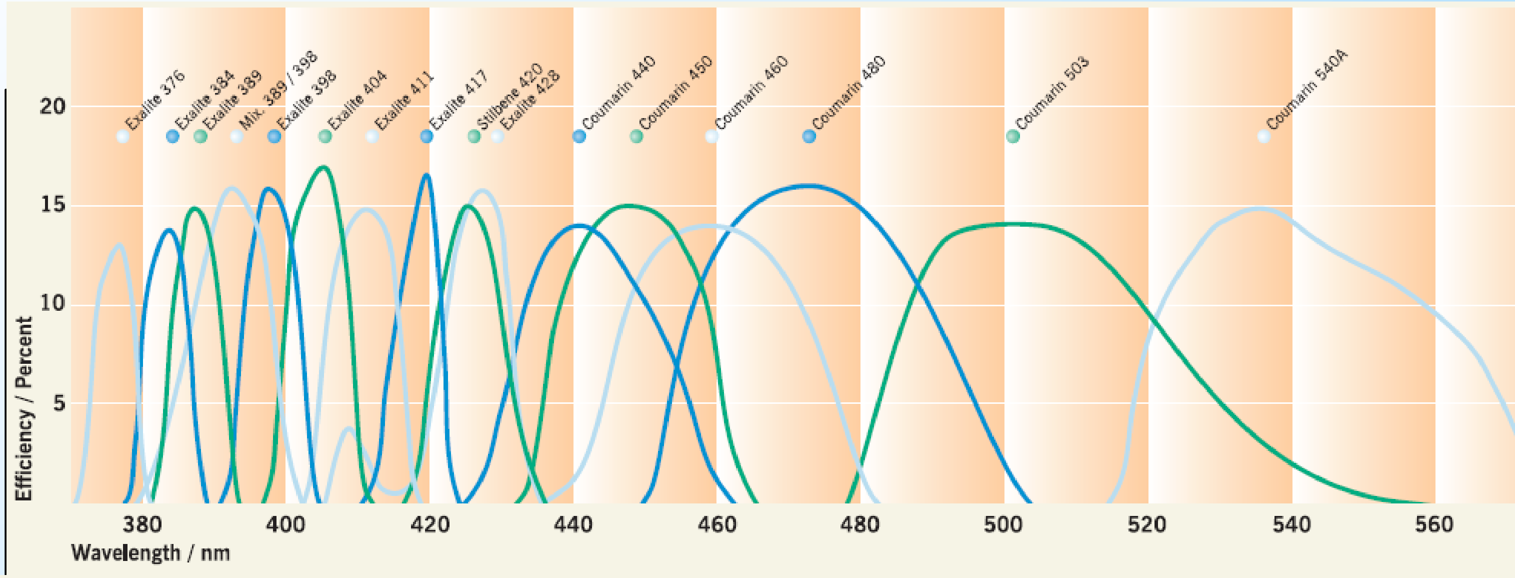
# Copper vapor lasers retired in 2010

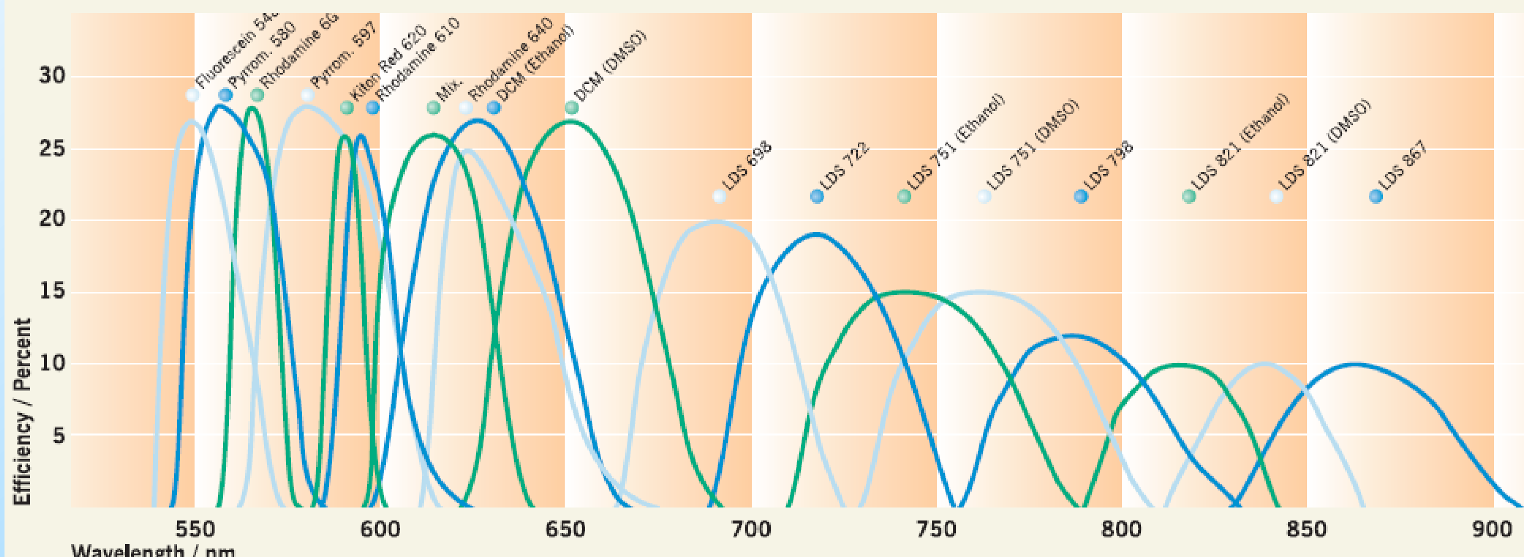


# New dye laser installed

**CREDO dye lasers made by Sirah GmbH**
installed in Feb/Mar 2010

- Optimized for 10 kHz EdgeWave pump
- Accept both 355 and 532 pumping beams
- Equipped with FCU (up to 2W of UV)



# RILIS ion beams

**Ion beams of 30 elements are produced at ISOLDE with RILIS**

elements available at ISOLDE LIS

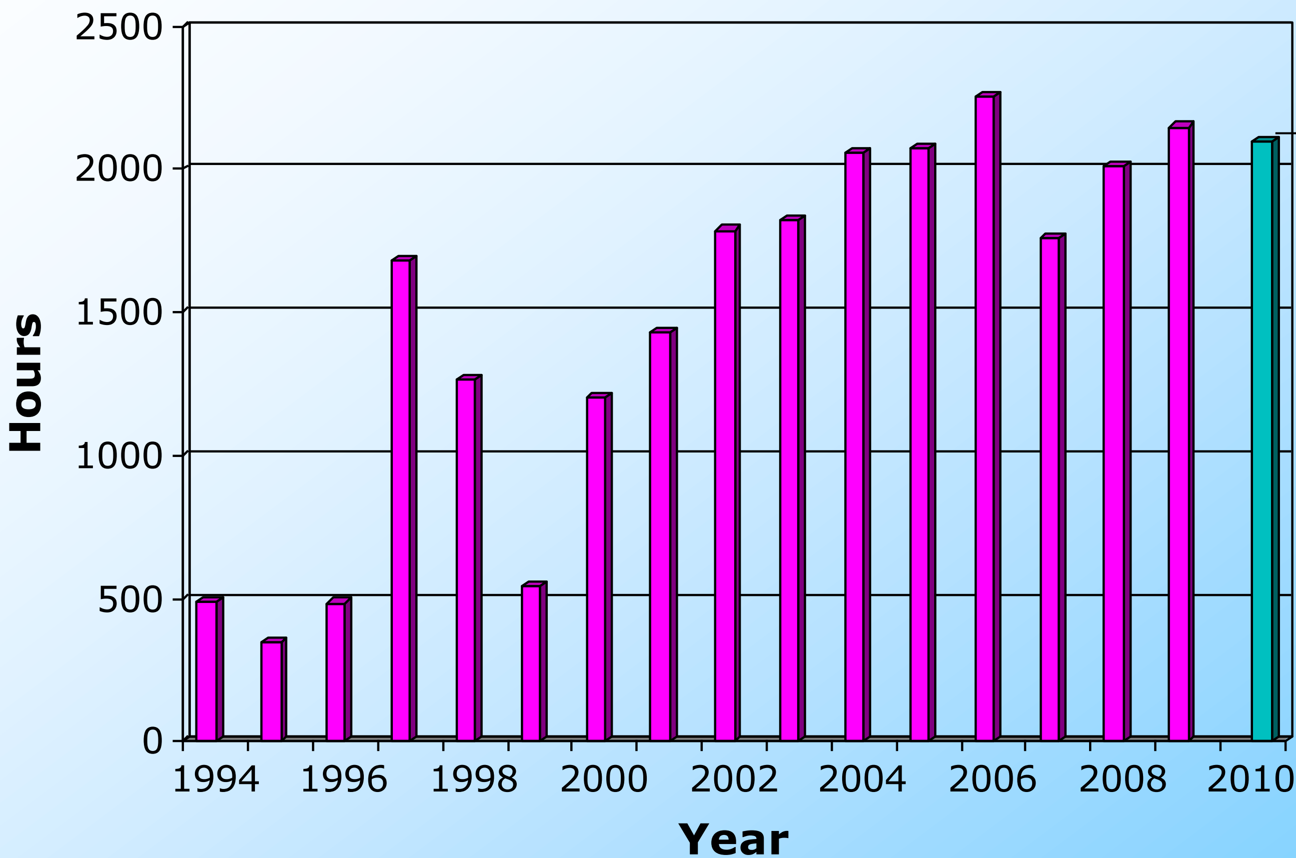
ionization scheme tested

ionization scheme untested

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 H | | | | | | | | | | | | | | | | | 2 He |
| 3 Li | 4 Be | | | | | | | | | | | 5 B | 6 C | 7 N | 8 O | 9 F | 10 Ne |
| 11 Na | 12 Mg | | | | | | | | | | | 13 Al | 14 Si | 15 P | 16 S | 17 Cl | 18 Ar |
| 19 K | 20 Ca | 21 Sc | 22 Ti | 23 V | 24 Cr | 25 Mn | 26 Fe | 27 Co | 28 Ni | 29 Cu | 30 Zn | 31 Ga | 32 Ge | 33 As | 34 Se | 35 Br | 36 Kr |
| 37 Rb | 38 Sr | 39 Y | 40 Zr | 41 Nb | 42 Mo | 43 Tc | 44 Ru | 45 Rh | 46 Pd | 47 Ag | 48 Cd | 49 In | 50 Sn | 51 Sb | 52 Te | 53 I | 54 Xe |
| 55 Cs | 56 Ba | 57 La | 72 Hf | 73 Ta | 74 W | 75 Re | 76 Os | 77 Ir | 78 Pt | 79 Au | 80 Hg | 81 Tl | 82 Pb | 83 Bi | 84 Po | 85 At | 86 Rn |
| 87 Fr | 88 Ra | 89 Ac | 104 Rf | 105 Ha | 106 Sg | 107 Ns | 108 Hs | 109 Mt | 110 | 111 | 112 | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy | 67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu | | |
| | | 90 Th | 91 Pa | 92 U | 93 Np | 94 Pu | 95 Am | 96 Cm | 97 Bk | 98 Cf | 99 Es | 100 Fm | 101 Md | 102 No | 103 Lr | | |

- RILIS web page: http://isolde-project-rilis.web.cern.ch/isolde-project-rilis/intro/principle.html

# RILIS operation in 1994-2010




Laser ON time in 2010:

- 2096 h – total
- 2000 h - on-line

**Laser time per beam for the operation year 2010**

| Sm | Mg | Cu | Ga | Tl | Be | Pb | Mn | Au | Be | Zn | Ag | At |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 52 | 154 | 183 | 52 | 184 | 54 | 123 | 228 | 114 | 344 | 299 | 140 | 74 |

# RILIS after CVL-YAG transition

- More laser power -> higher ionization efficiency
- High stability of SSL power -> ion current stability much better
- Time from cold start of SSL to nominal operation ~ 30 min.
- No electromagnetic noise to experimental hall from RILIS
- New ionization scheme of Mn is developed

    - SSL alignment and repair is possible only at EdgeWave
    - UV power is limited by the optical resistance of harmonics crystals
    - Efficiency of dye lasers is reduced due to shorter pump pulse
    - Lifetime of dyes is reduced
    - Operation of dye lasers and harmonics generators still requires continuous supervision by laser specialists

# Next step: addition of Ti:Sapphire lasers

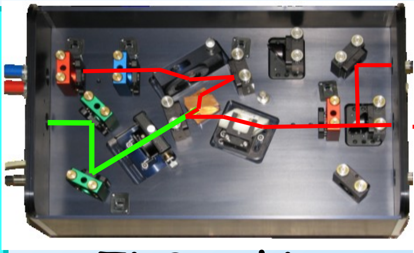
- **Nd:YAG pumped Ti:Sa system**
- **An additional independent fully solid state RILIS laser system**

- Reduction of the reliance on laser dyes.
- Better coverage of the IR and blue spectral ranges
- Dual RILIS system could enable simultaneous RILIS setup and operation.

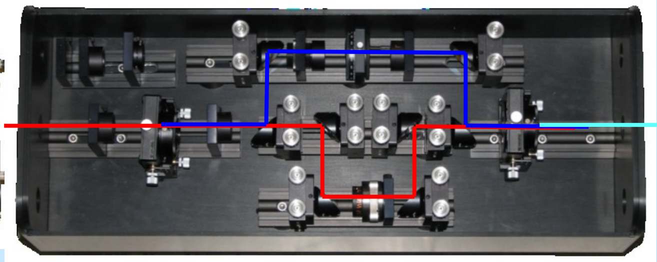
| | |
|---|---|
| **Pump laser:** | **2 commercial Nd:YAG, 532 nm, 60 W at 10 kHz** |
| **Tunable lasers:** | **3 single sided Uni-Mainz Ti:Sapphire lasers** |
| | **- frequency doubling, tripling and quadrupling** |
| | **- computerized temporal and spectral control, 3 GHz, 30 ns** |
| | **- specs: 3 - 5 W @ 690-980 nm** |
| | **1 W @ 350-470** |
| | **150 mW @ 200 – 315 nm** |

# New lasers for RILIS

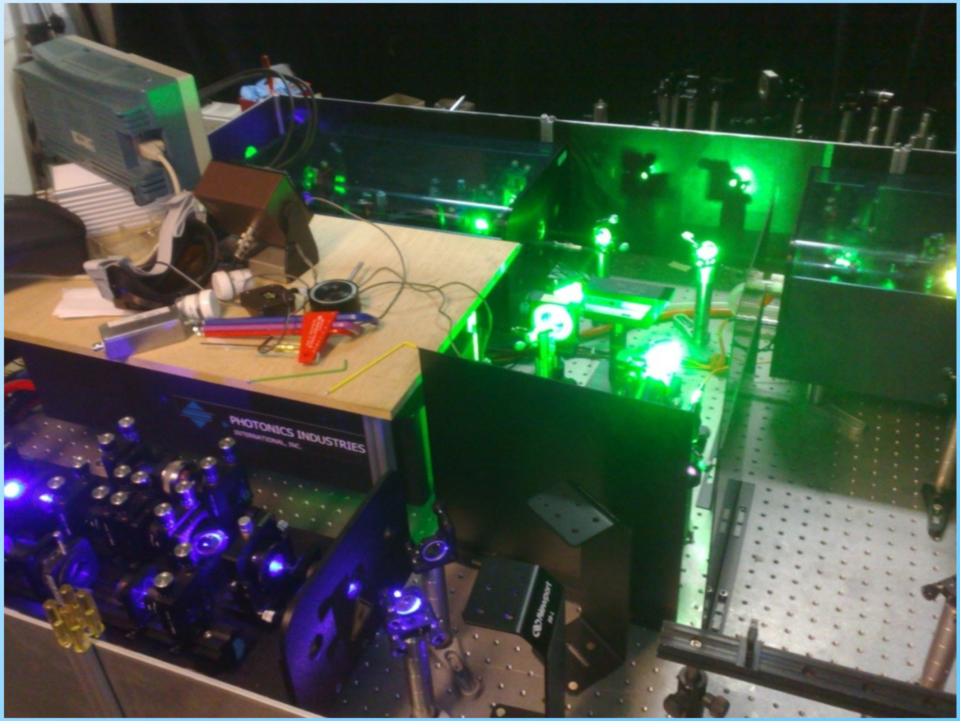
- Three Ti:sapphire laser units were constructed and tested (PhD student S.Rothe)
- Wavelengths in the near infra-red range 690 - 940 nm are obtained
- The Frequency Conversion Unit (FCU) allows generation of wavelengths in the blue and UV range
- Installed at the ISOLDE off-line mass separator for testing the Laser Ion Source Trap (LIST)
- To be installed at RILIS during the winter shut down



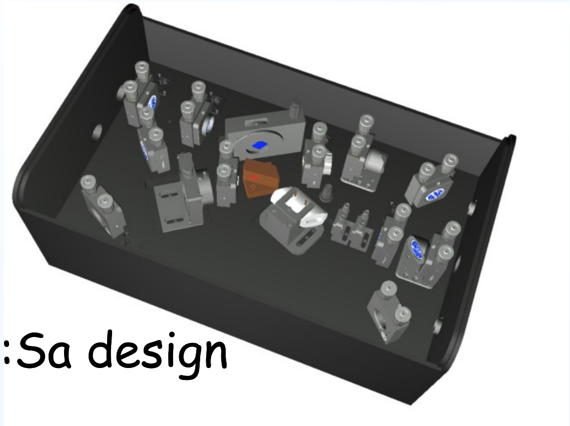
Ti:Sapphire laser



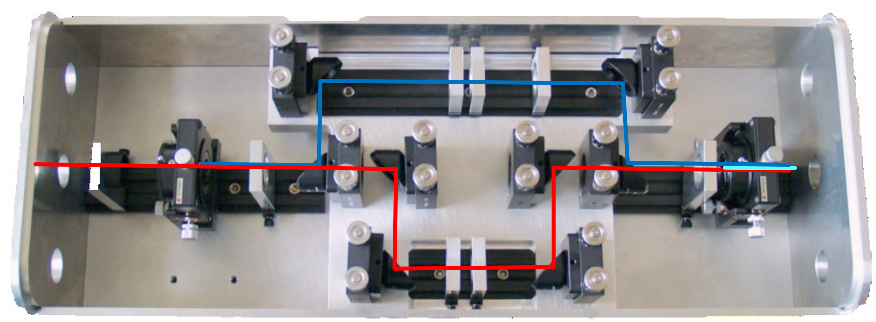
Frequency Conversion Unit



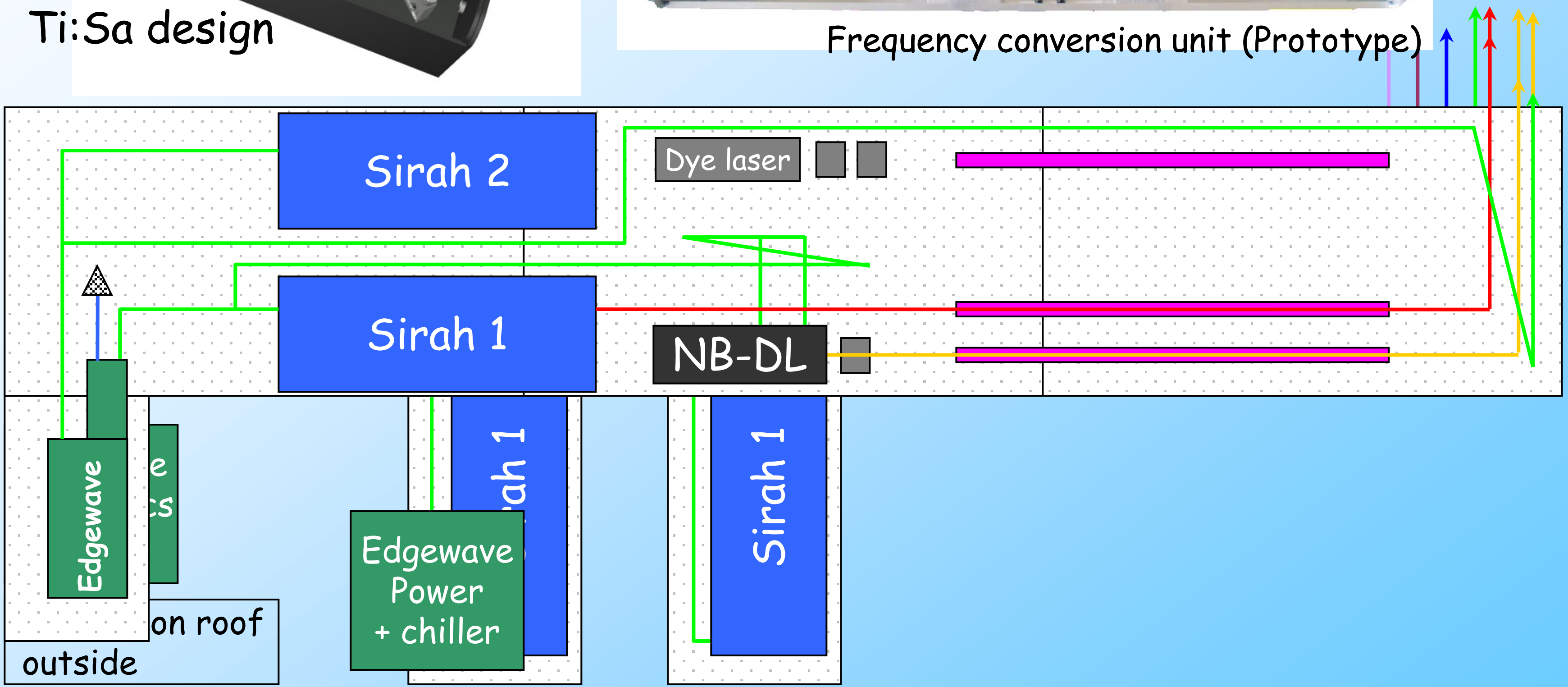
# RILIS Ti:Sa + dye laser system



Ti:Sa design



Frequency conversion unit (Prototype)



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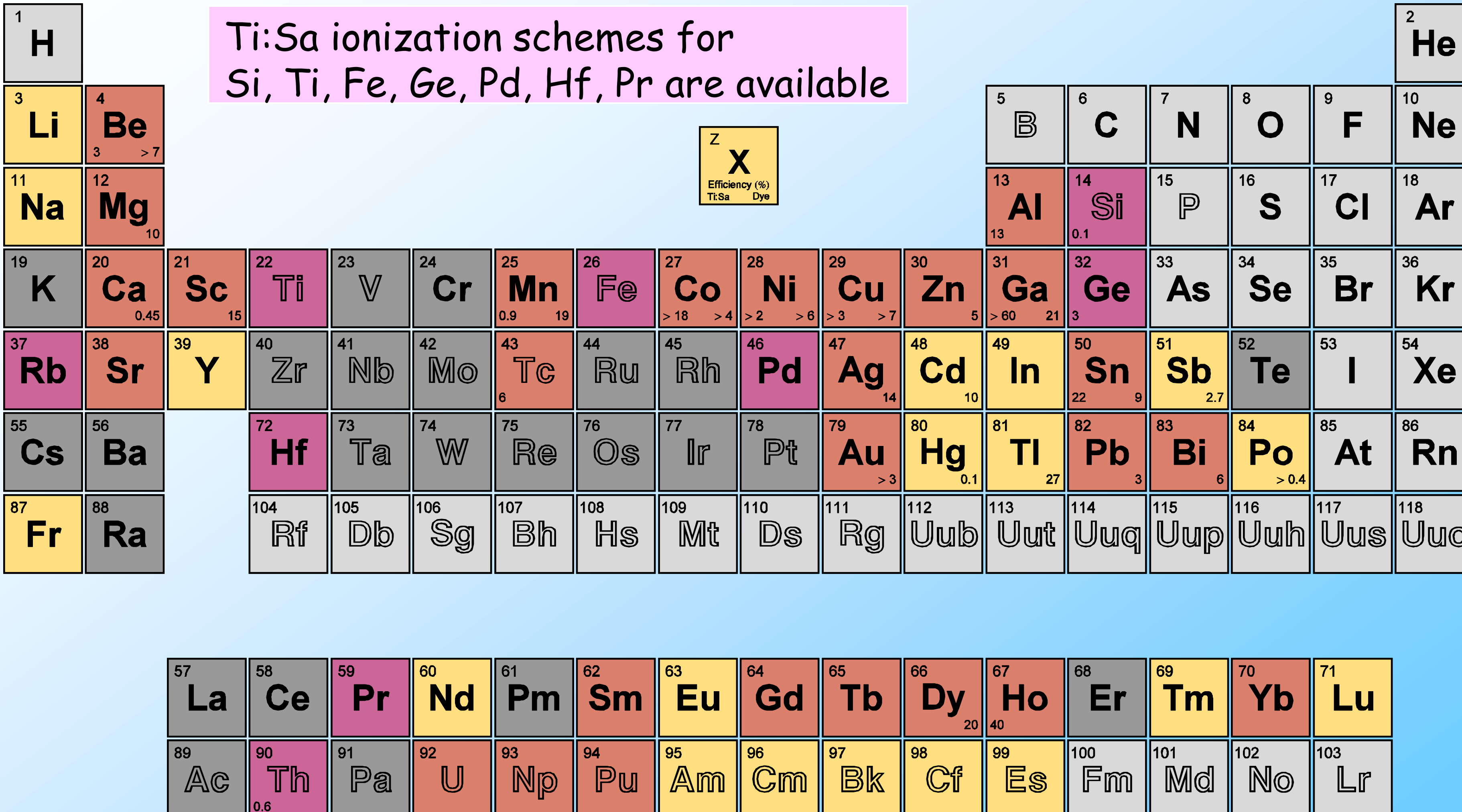
# Dye + Ti:Sa range

Ti:Sa ionization schemes for
Si, Ti, Fe, Ge, Pd, Hf, Pr are available



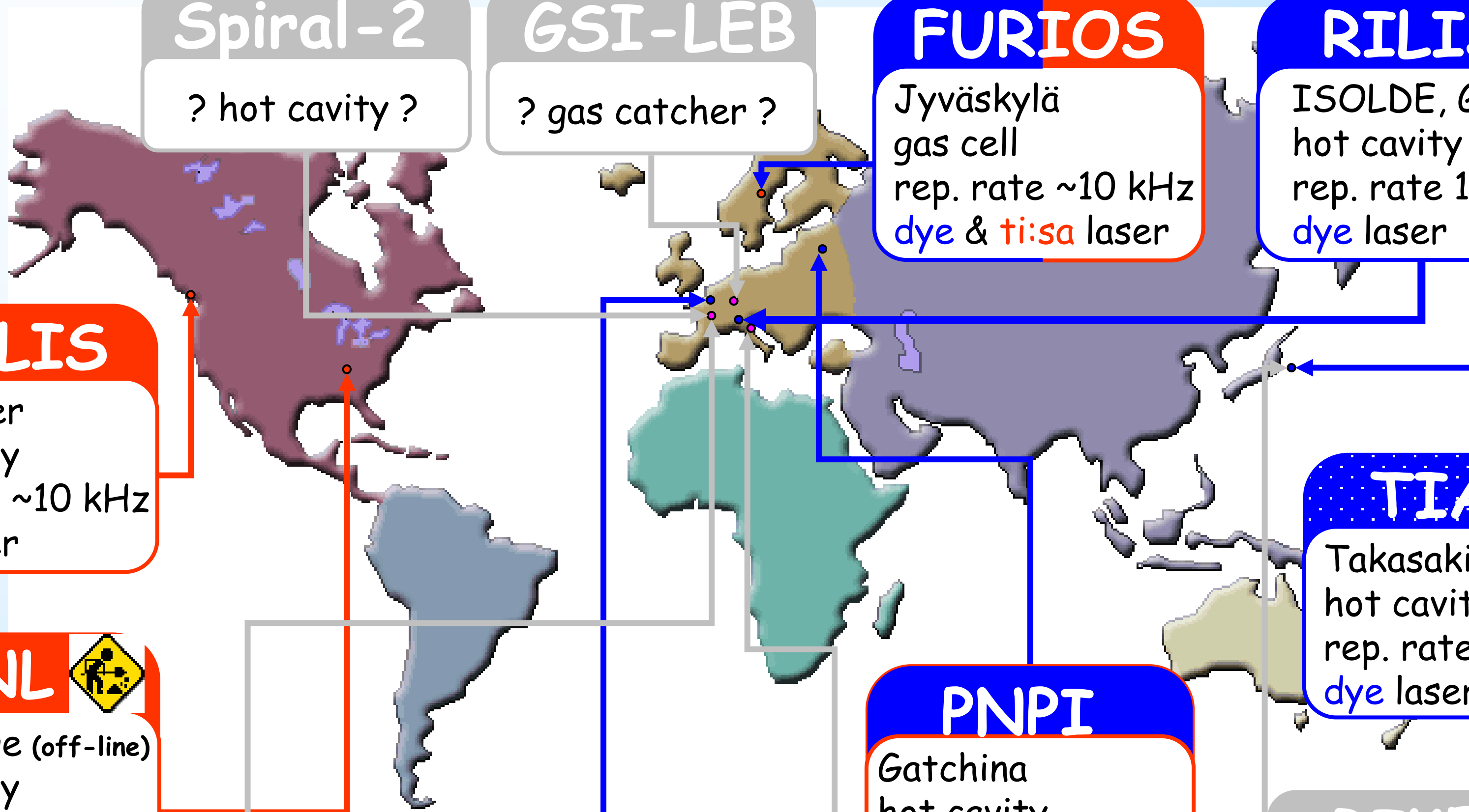

- Dye scheme tested
- Ti:Sa scheme tested
- Ti:Sa and Dye schemes tested
- Feasible

**Released** / Not released from ISOLDE target

# Resonance laser ion sources worldwide

ISOLDE CERN

EN STI



**Spiral-2**
? hot cavity ?

**GSI-LEB**
? gas catcher ?

**FURIOS**
Jyväskylä
gas cell
rep. rate ~10 kHz
dye & ti:sa laser

**RILIS**
ISOLDE, Geneva
hot cavity
rep. rate 10 kHz
dye laser

**TRILIS**
Vancouver
hot cavity
rep. rate ~10 kHz
ti:sa laser

**ORNL**
Oak Ridge (off-line)
hot cavity
rep. rate ~10 kHz
ti:sa laser

**TIARA**
Takasaki
hot cavity
rep. rate 300Hz
dye laser

**PNPI**
Gatchina
hot cavity
rep. rate ~10 kHz
dye laser

**RIKEN**
? gas catcher ?

**LISOL**
Louvain-la-Neuve
gas cell
rep. rate <200Hz
dye laser

**ALTO**
? hot cavity ?

**SPES**
? hot cavity ?

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