Status and Trends of on-line (ISOL-) Resonance Ionization Laser Ion Sources

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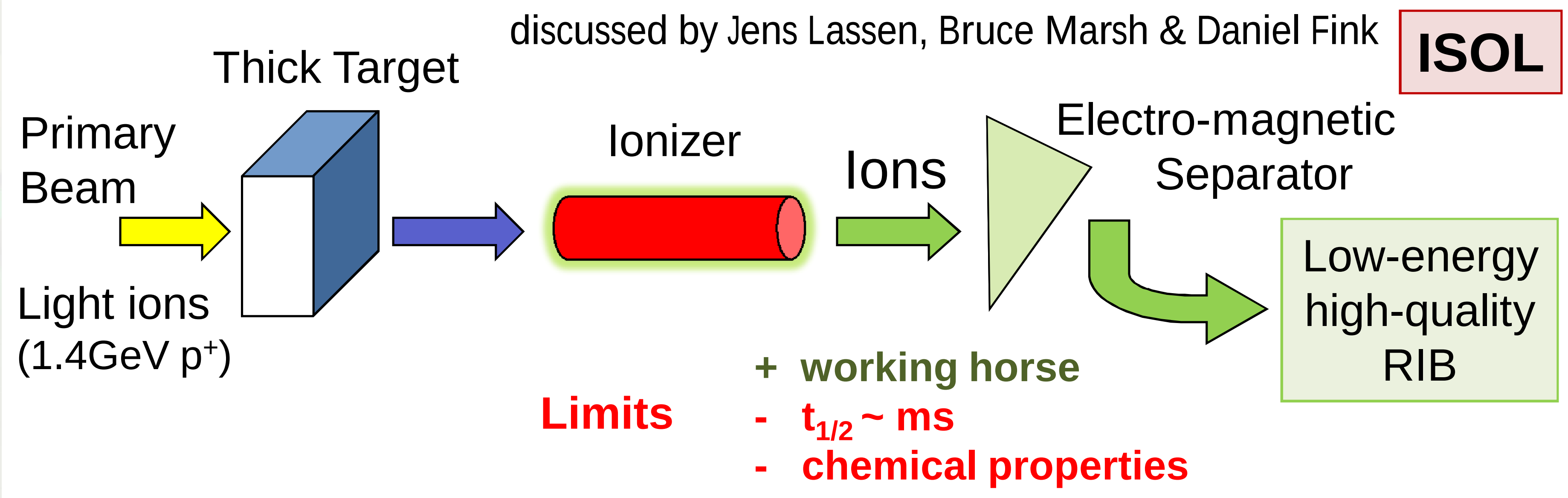
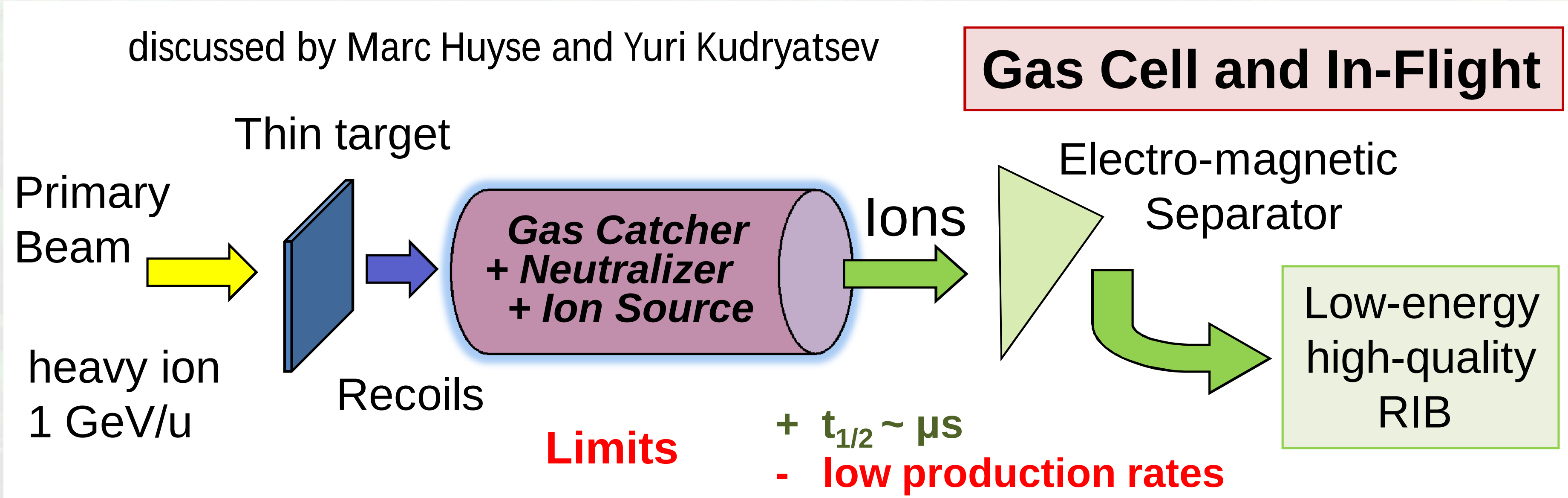
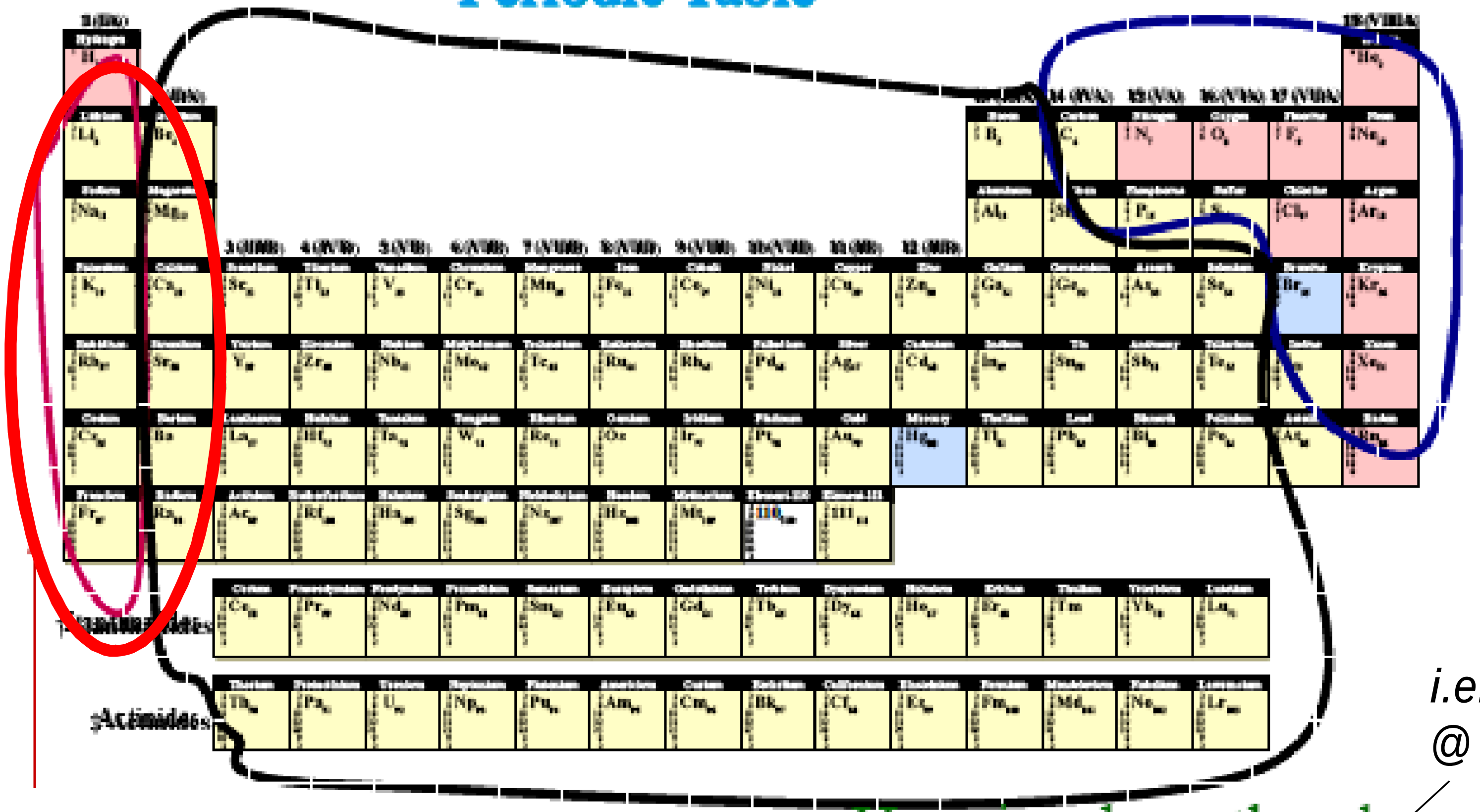
RIB Facilities: Hot Cavity versus Gas Cell





Ionization Processes for Exotic Isotopes

Periodic Table



Region of Efficient Negative Ion or ECR Production

i.e. > 2000 h/y @ ISOLDE

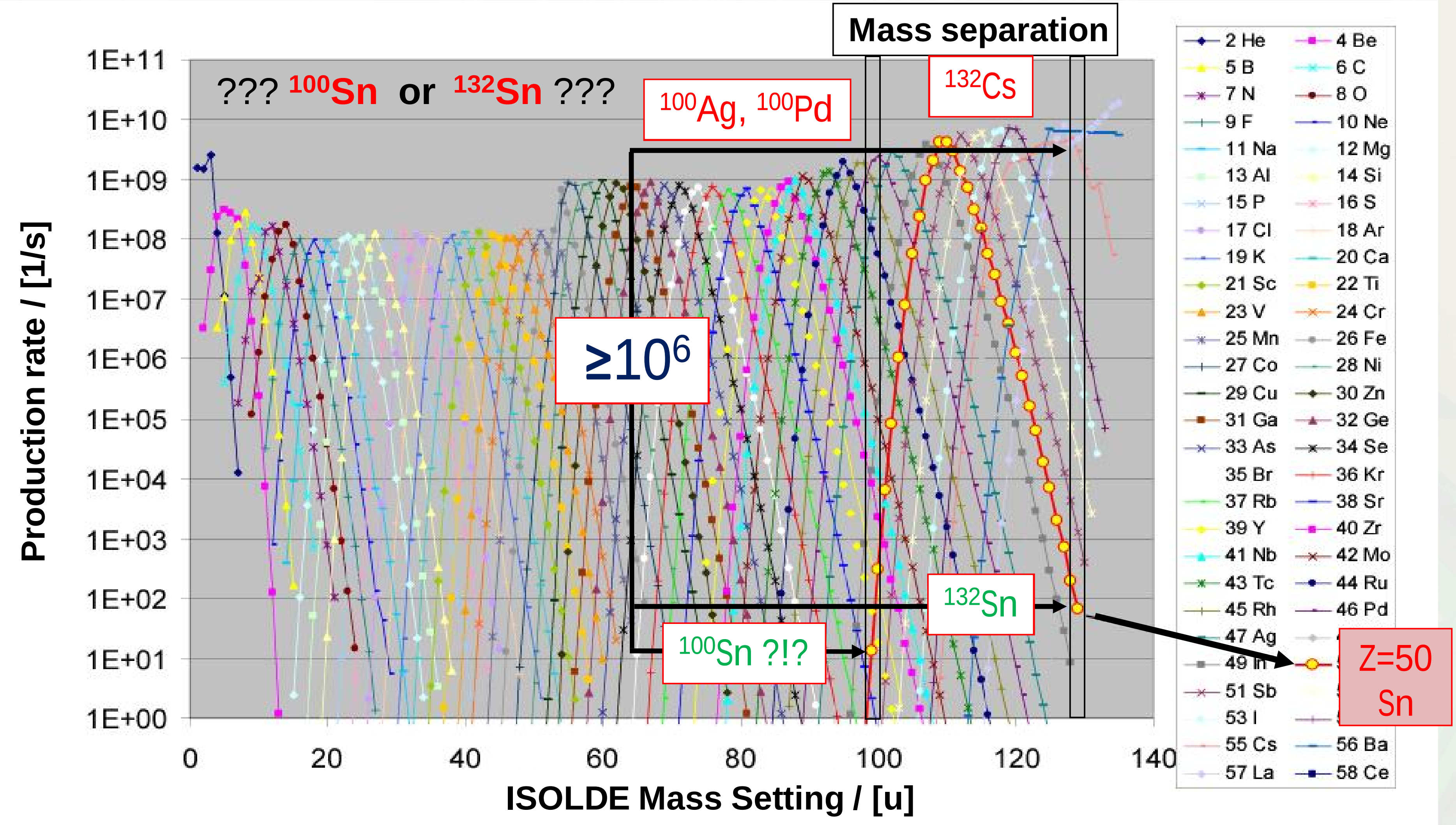
Hot surface ion source Works well here

Here is where the plasma and laser ion source are operating

Original slide stolen from **Pierre Bricault, Laser Ion Workshop, TRIUMF 2000**

Purity Requirements of ISOL Beams

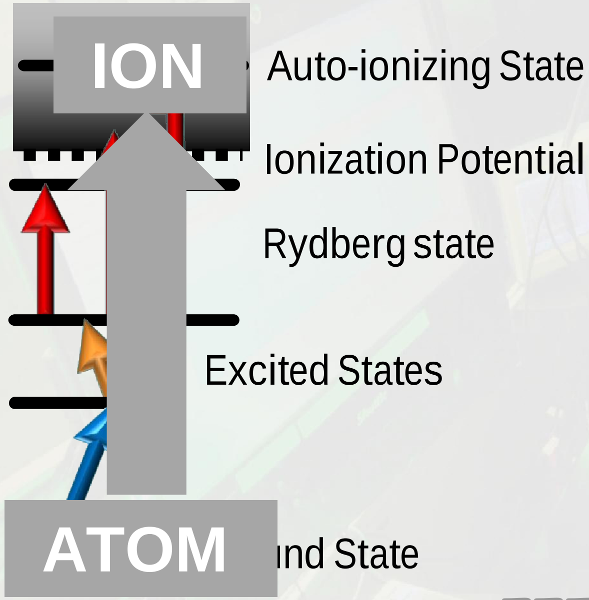
ISOLDE on-line yield (Theoretical prediction for1 GeV p^+ on La-target)

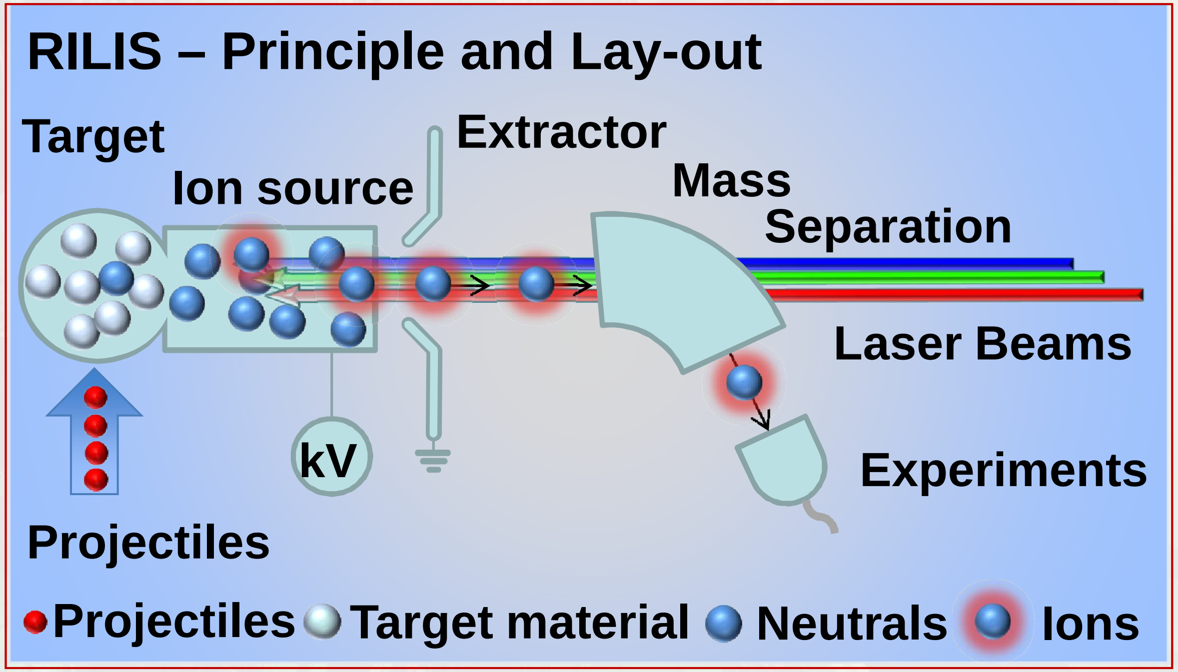


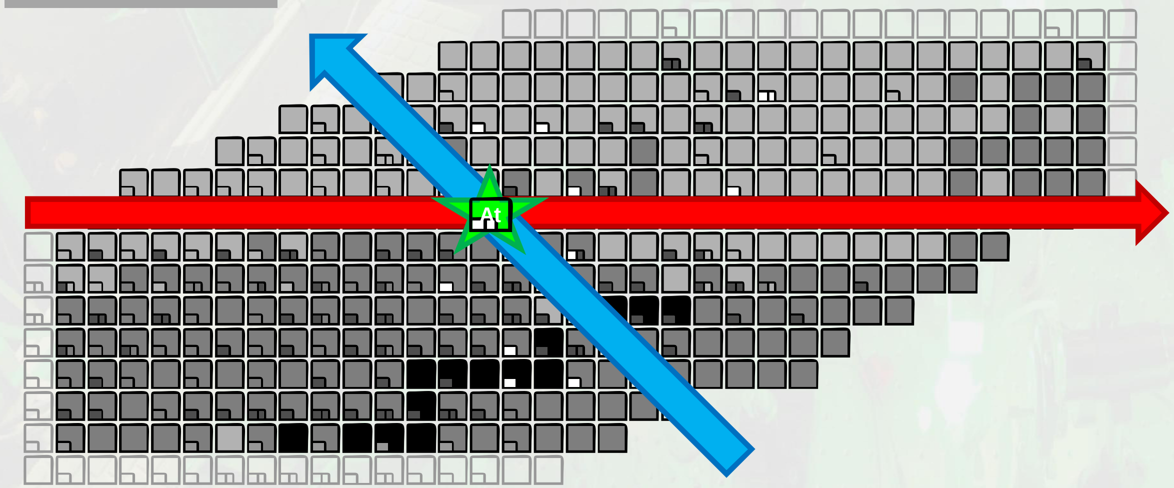
Element selective ion source is essential → Isobaric Purity – Reduction of Radioactivity

Resonance Ionization Laser Ion Source

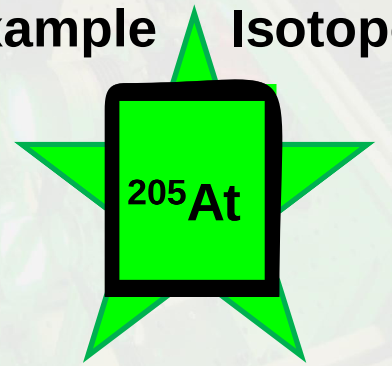
Element selective excitation scheme



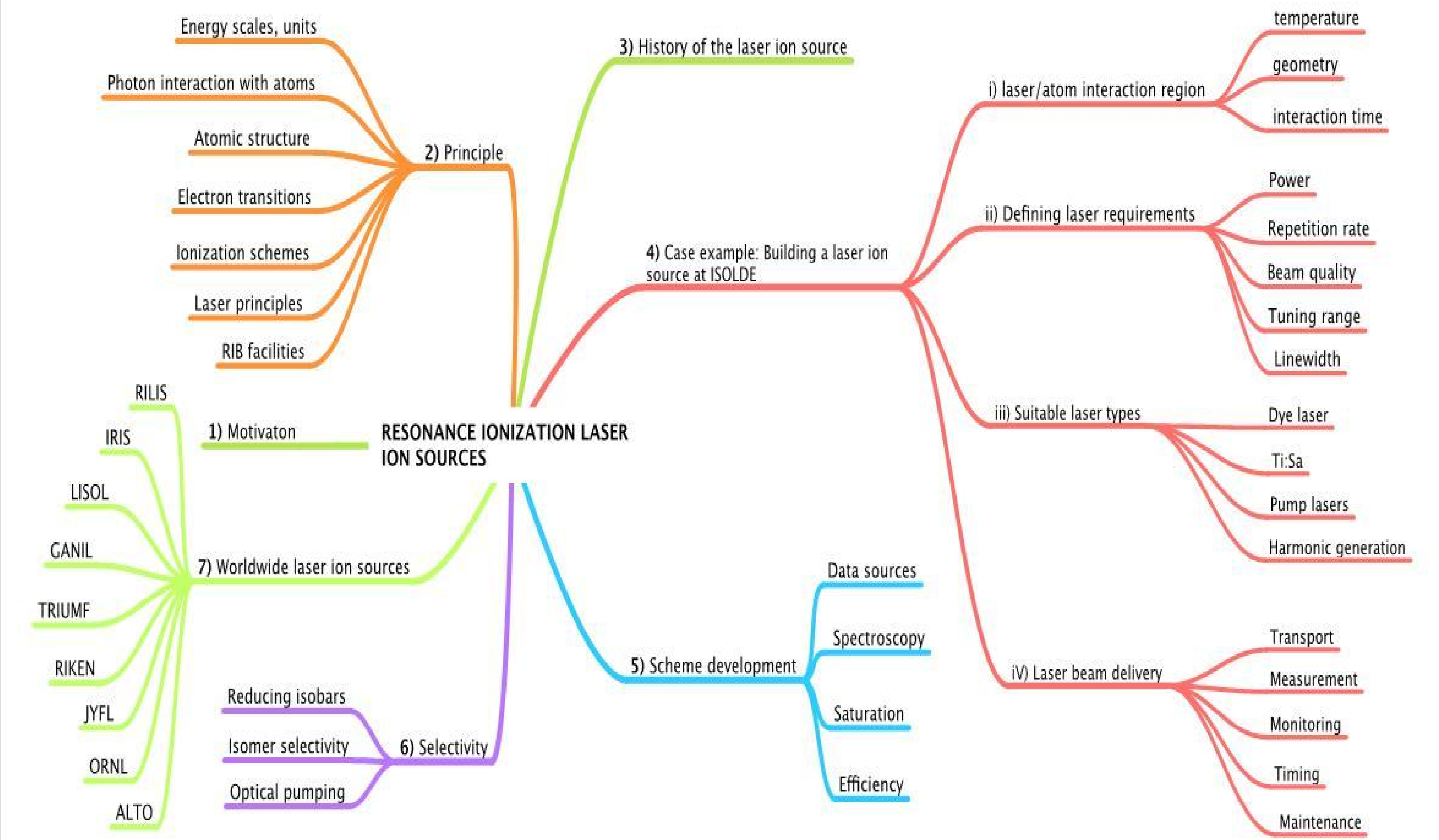




Example Isotope



Outline of the Talk



Slide: B. Marsh

First RILIS Proposal: V. Letokhov 1984

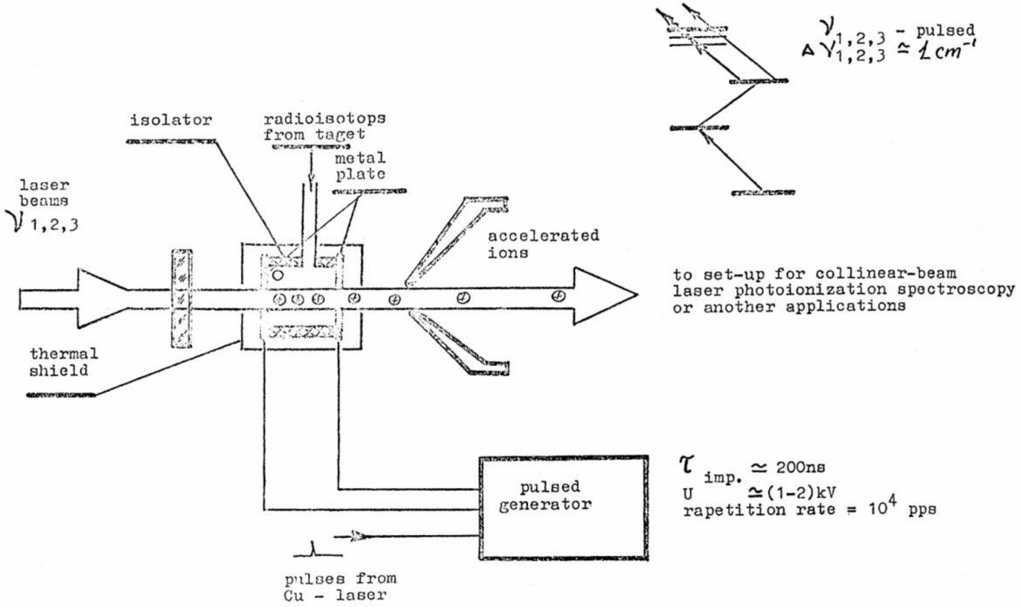
PROPOSAL

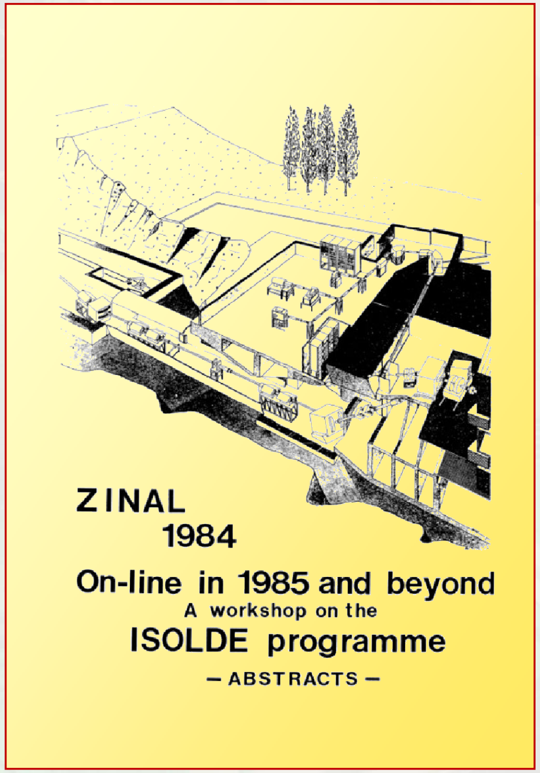
of the Institute of Spectroscopy, Acad.Sci. USSR
for experiments with ISOLDE-CERN Facility

(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.





Slide: B. Marsh

ISOLDE Implementation H.J. Kluge et. al 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.

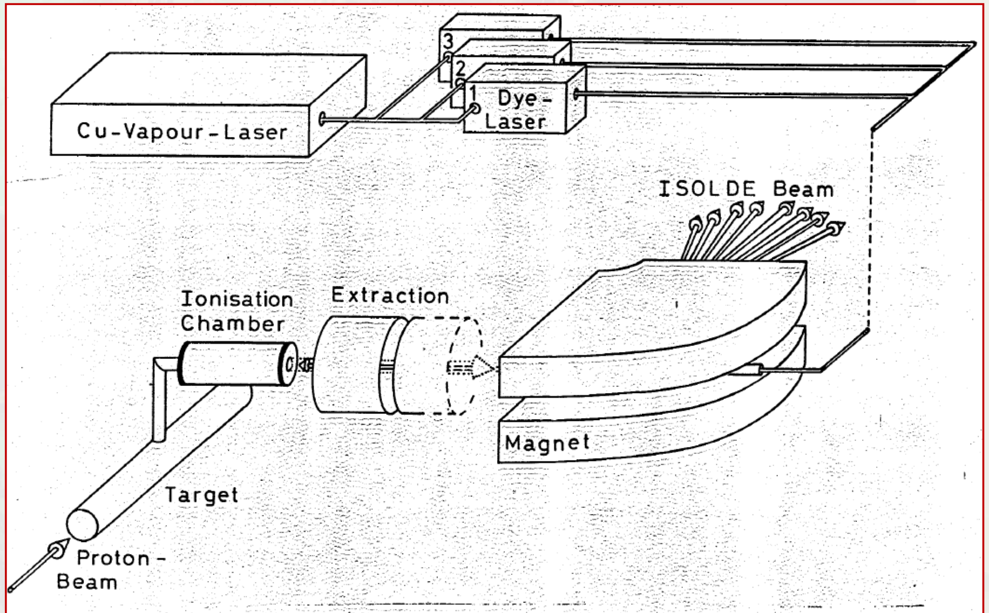
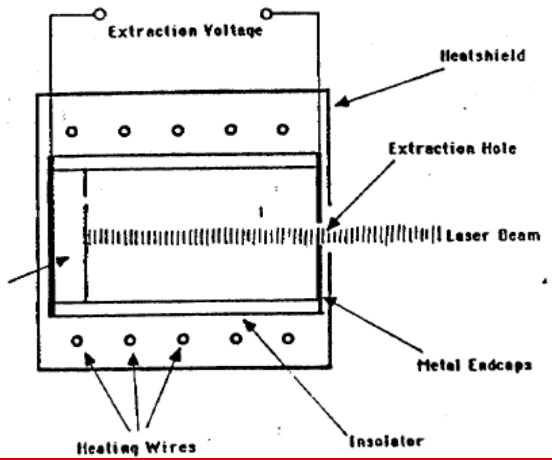


Fig. 5: General layout of the experimental set-up at the off-line separator

Atomizer
Cavity
Lay-out
with
internal
potential
gradient



Slide: B. Marsh

First Results from RILIS, 20 years ago

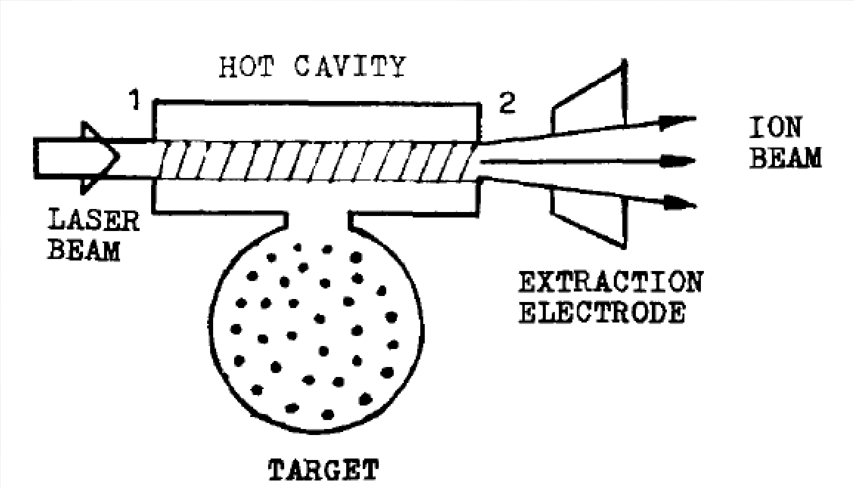
IRSI, Gatchina, 1991

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



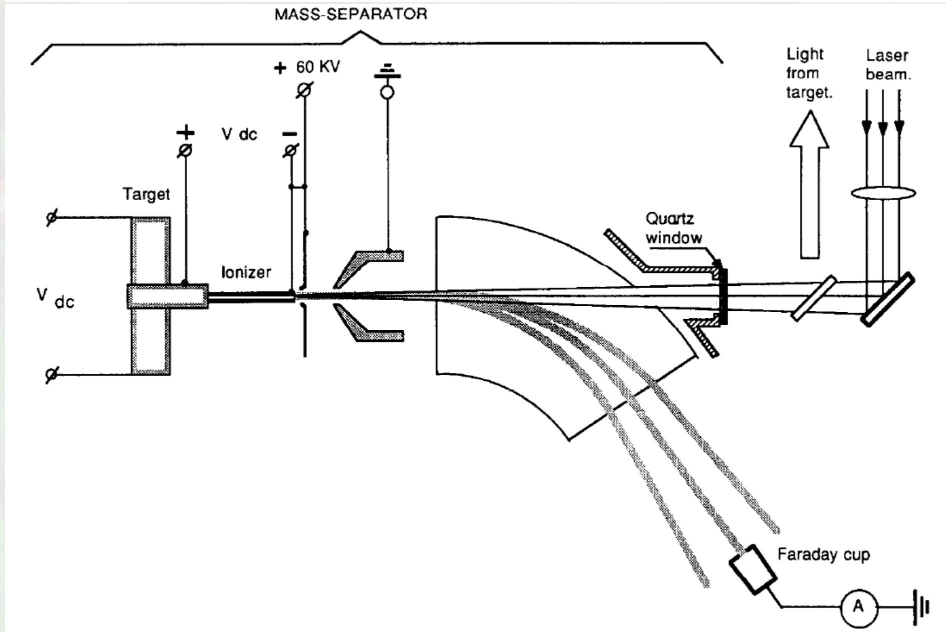
ISOLDE, CERN, 1993

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



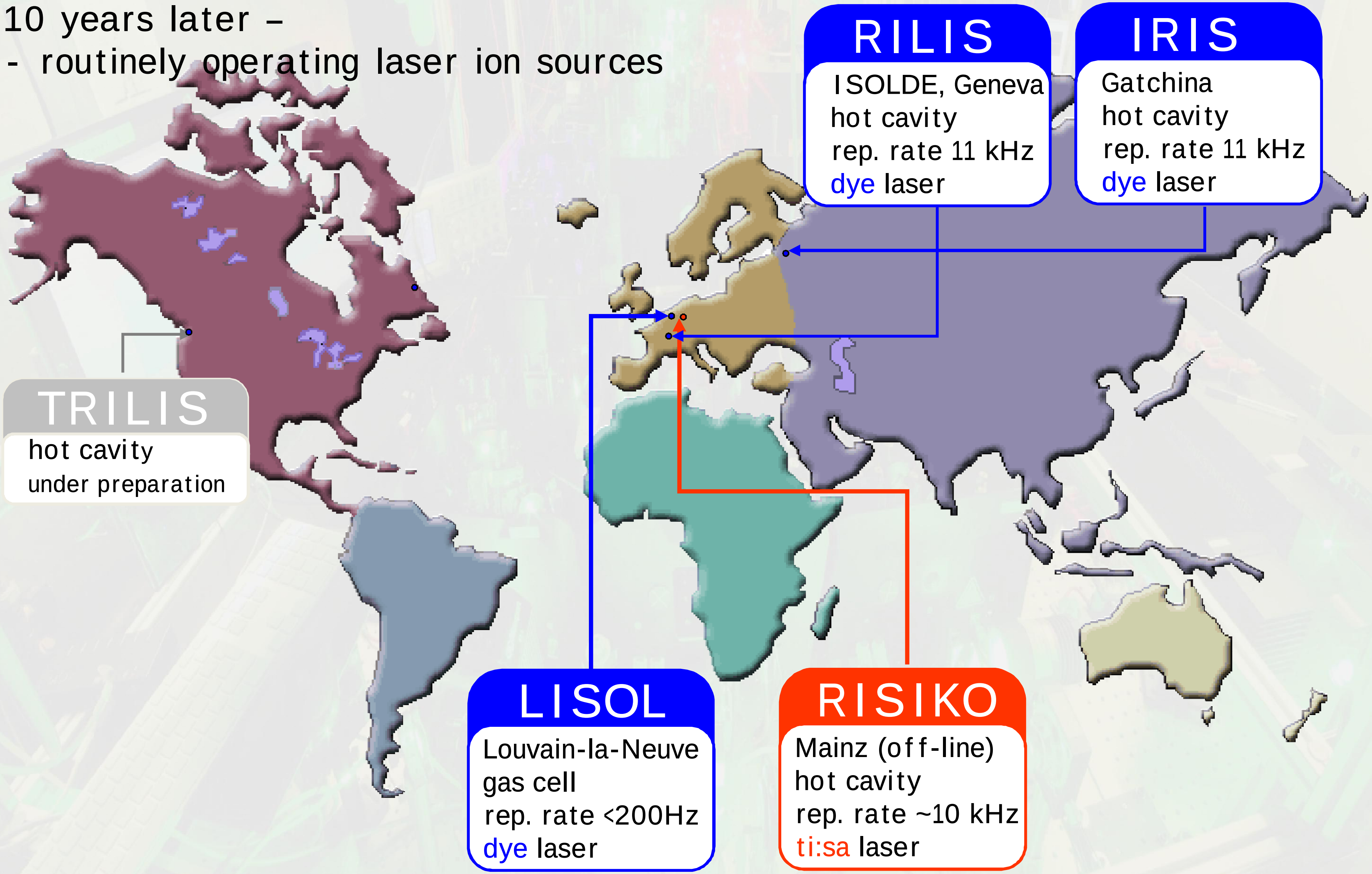
Demonstrated:

Yb, Nd, Ho	**- off-line**	**Yb, Tm, Sn, Li**	**- off-line**
Ho	**- on-line**	**Yb**	**- on-line**

Slide: B. Marsh

Laser Ion Sources 2002 (14. EMIS, Victoria)

10 years later –
- routinely operating laser ion sources



Slide: C. Geppert

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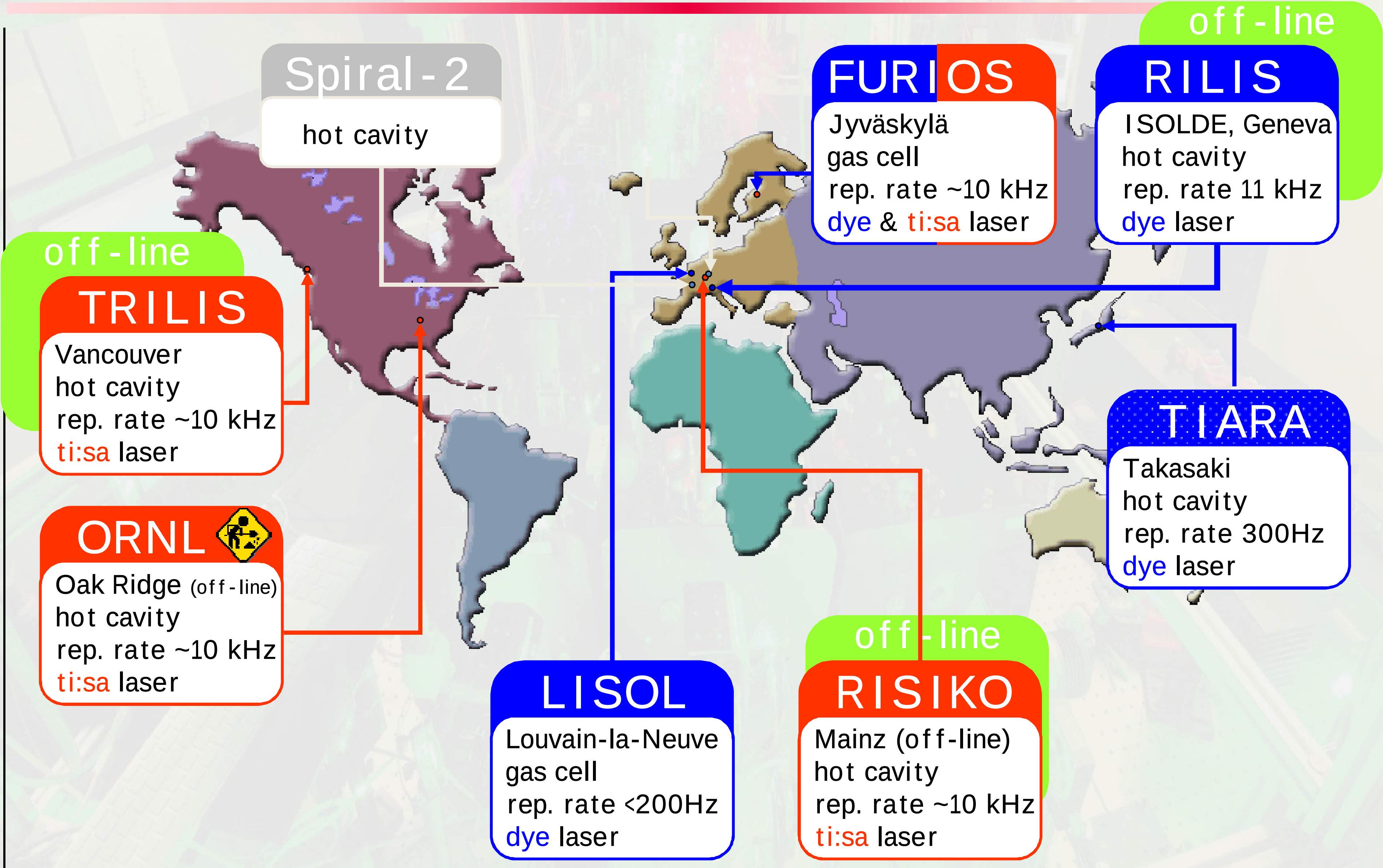
Laser Ion Sources 2007 *(15. EMIS, Deauville)*



Slide: C. Geppert, Inv.

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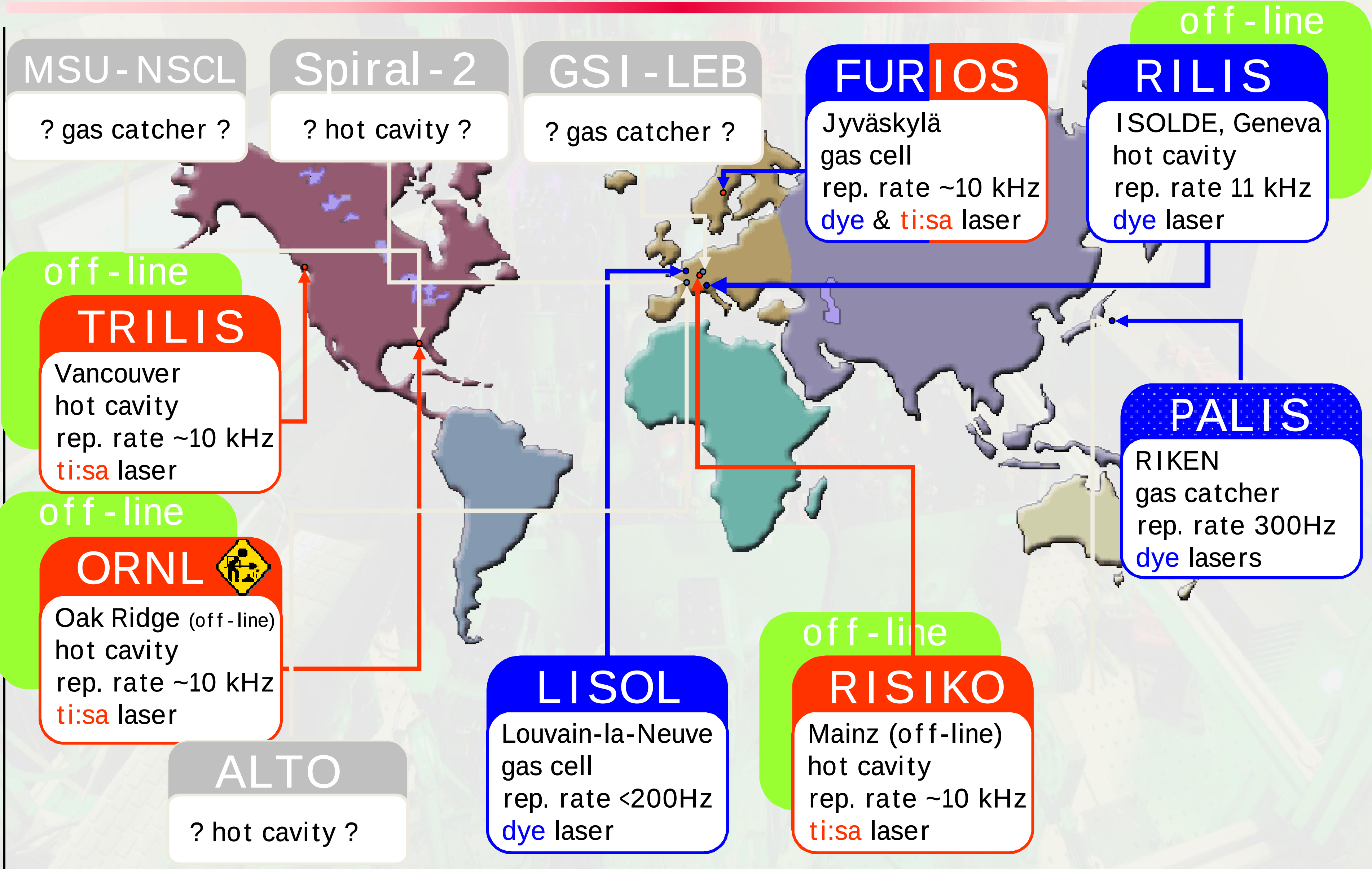
Laser Ion Sources ... 2010 and beyond



updated from C. Geppert, EMIS, Deauville, 2007

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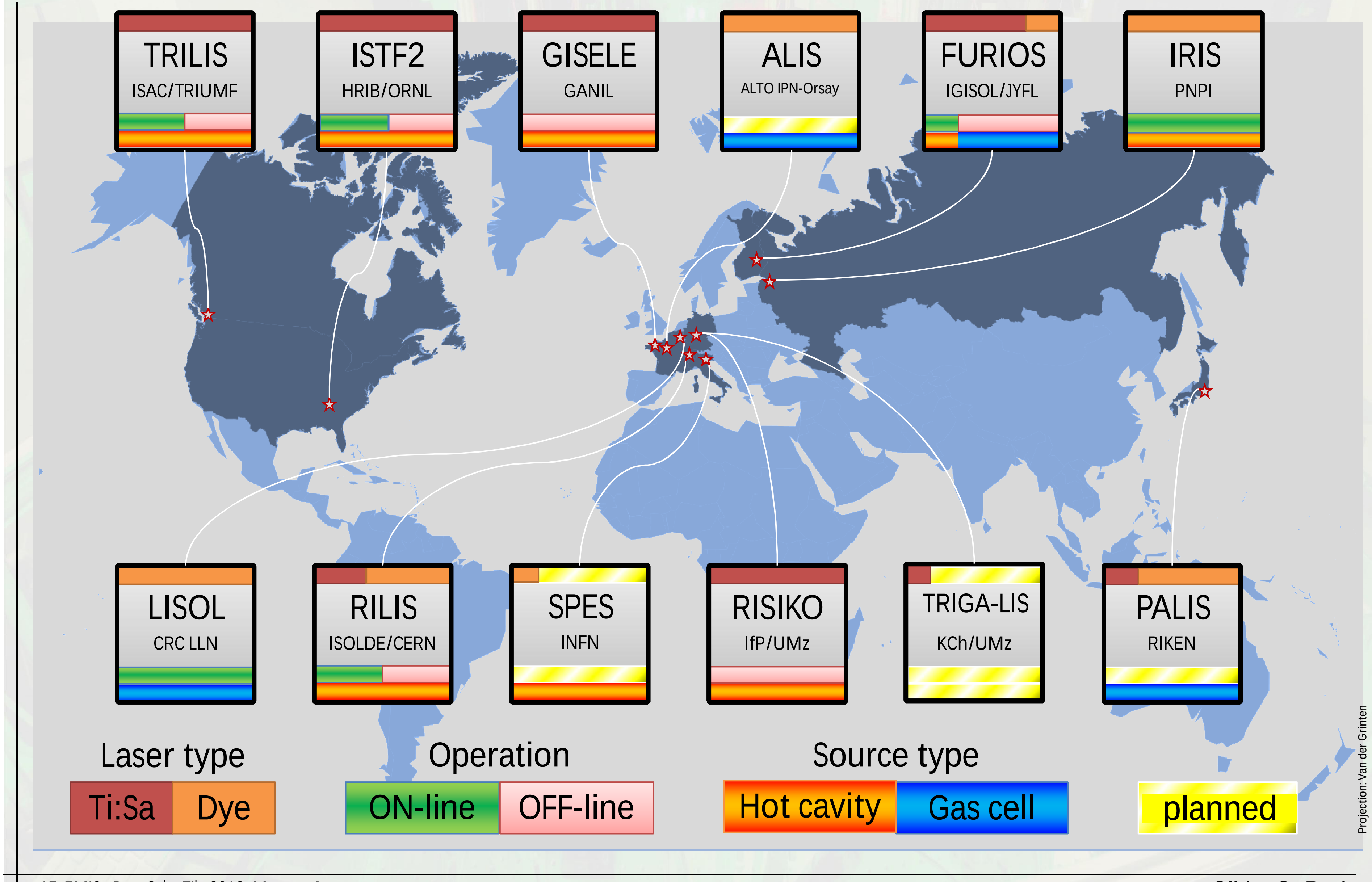
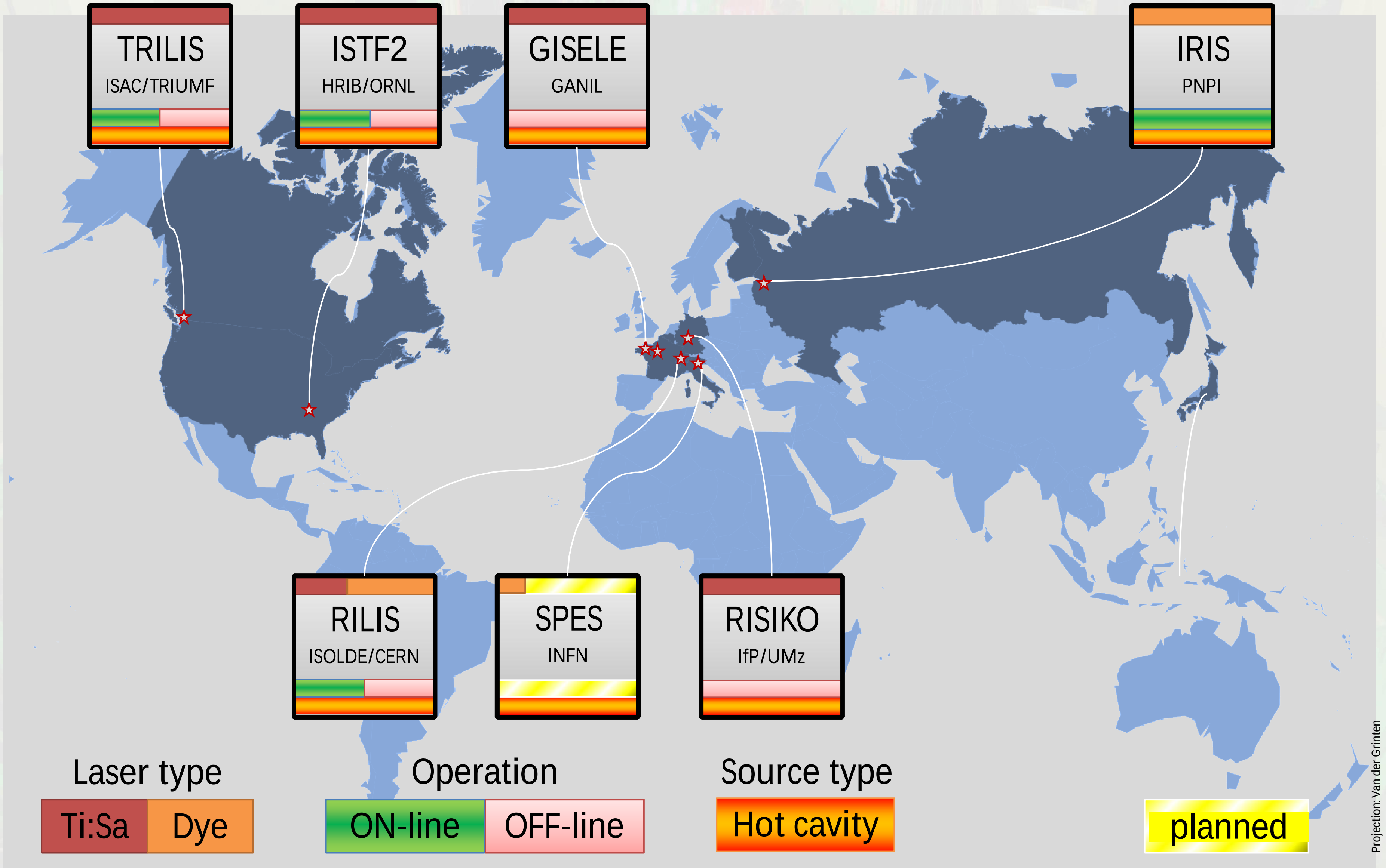
Laser Ion Sources Worldwide 2012 and beyond



Slide: S. Rothe

ISOL Hot-Cavity Laser Ion Sources



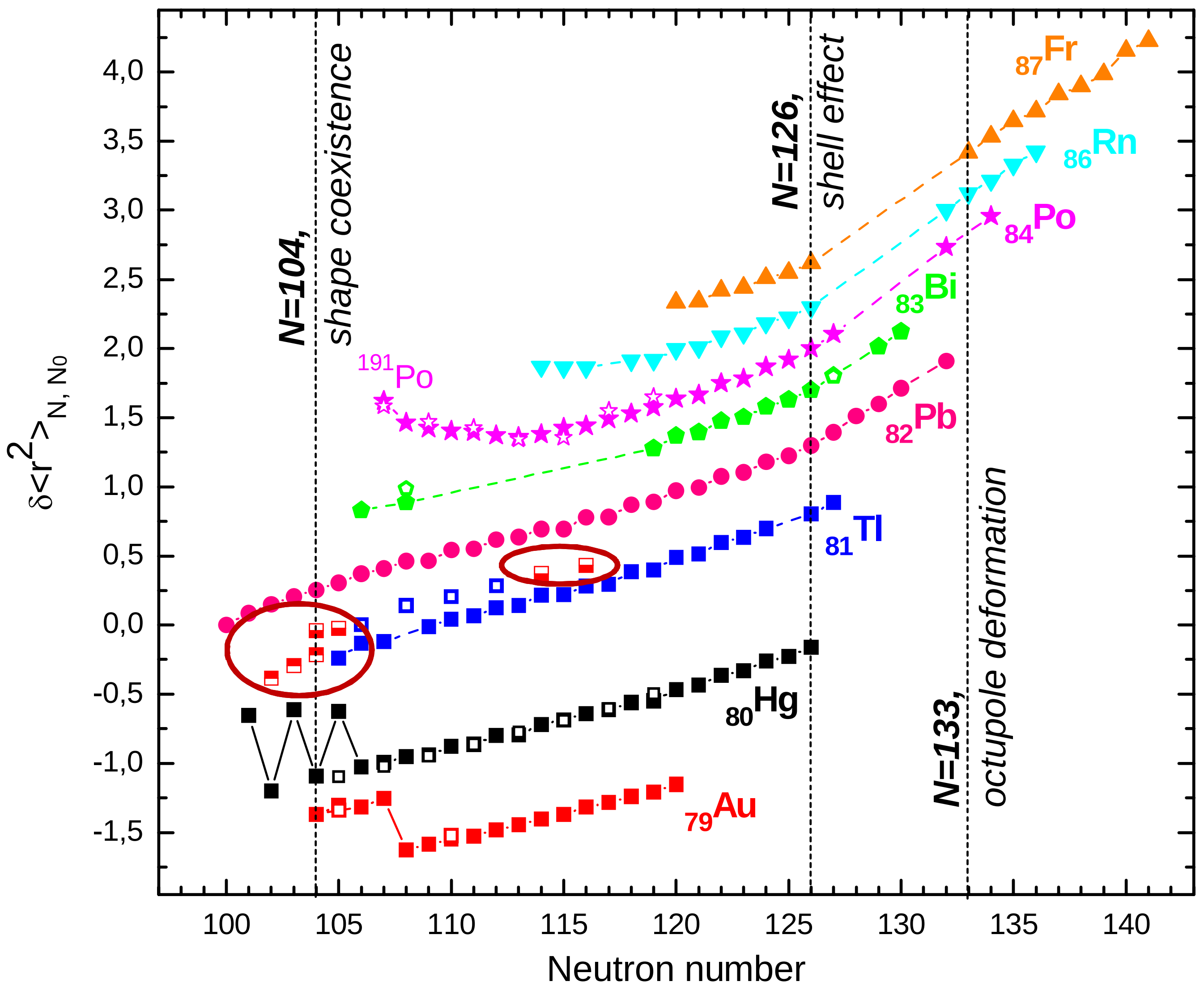
Petersburg Nuclear Physics Institute, Gatchina, Russia

New IRIS Laser Ion Source

PNPI IRIS Investigation of Radioactive Isotopes on Synchrocyclotron

Copper-v
CVL 1- ma
CVL 2,3 -
laser pow
waveleng
repetition
laser puls

nning control



Target and ion source

λ- meter

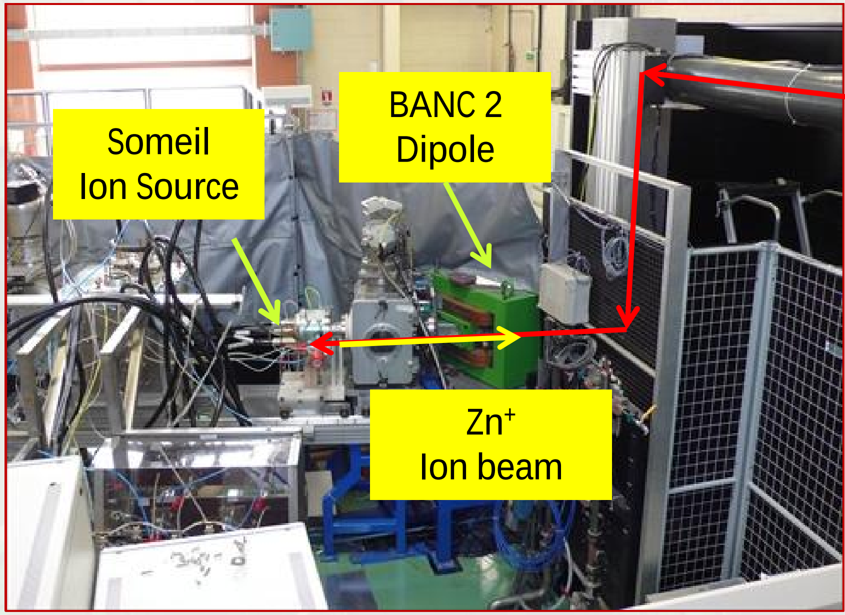
Proton beam:
Synchrocyclotron
1 GeV
0.1 µA
50 Hz

IS an

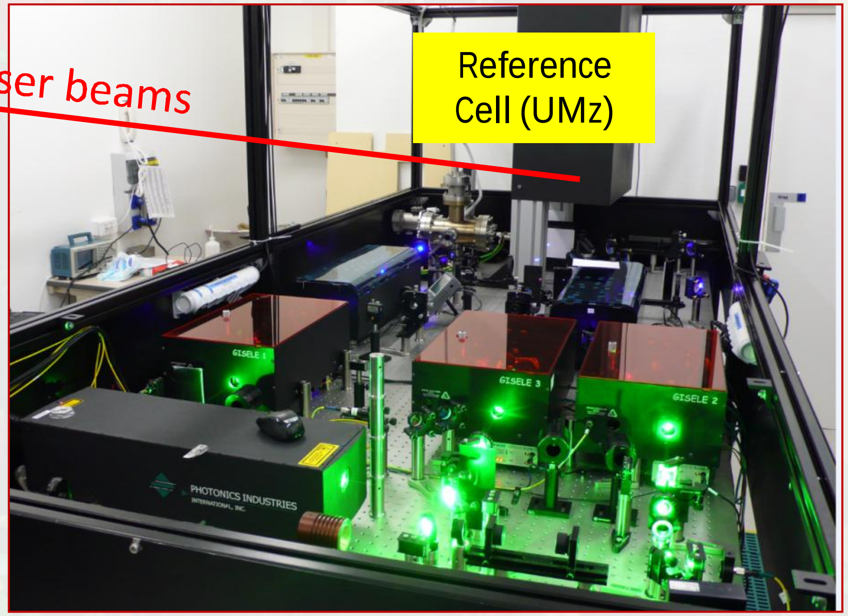
Pantel

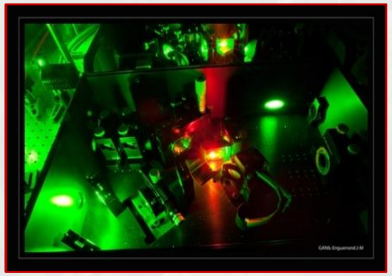
GISELE Laser Ion Source

BANC 2 Mass Separator & Someil Ion Source

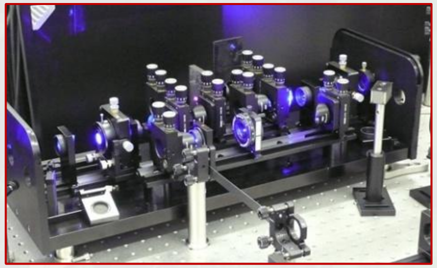


GISELE Laser System (GANIL - TRIUMF - UMz Coll.)

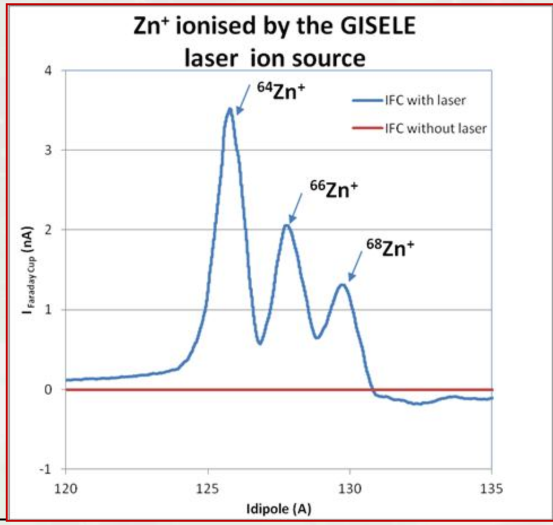




3 TiSa Cavities (TRIUMF)



2 Frequency Conversion Units (UMz)



July 2011: 1st Ga^+ beam

June-Nov 2012: Spect. of Zn^+

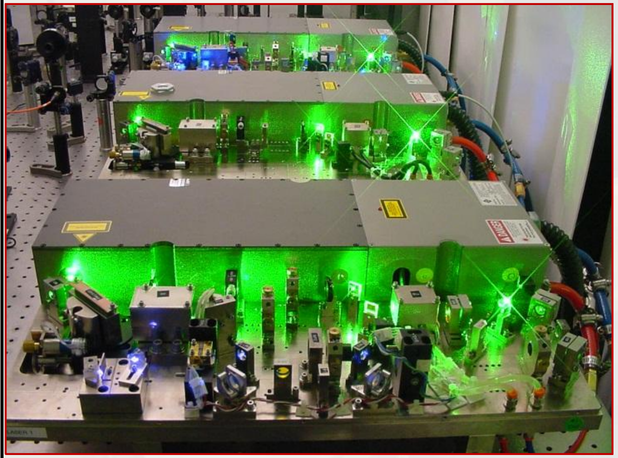
2013-2014: Sn, In, Y

(Day1 SPIRAL2 φ2)

Lecesne et al, RSI 81 (2010) 02A910
Sjödin et al, Hyperfine Interaction, in press

Hot-Cavity Laser Ion Source at HRIBF

Ti:Sapphire Laser System

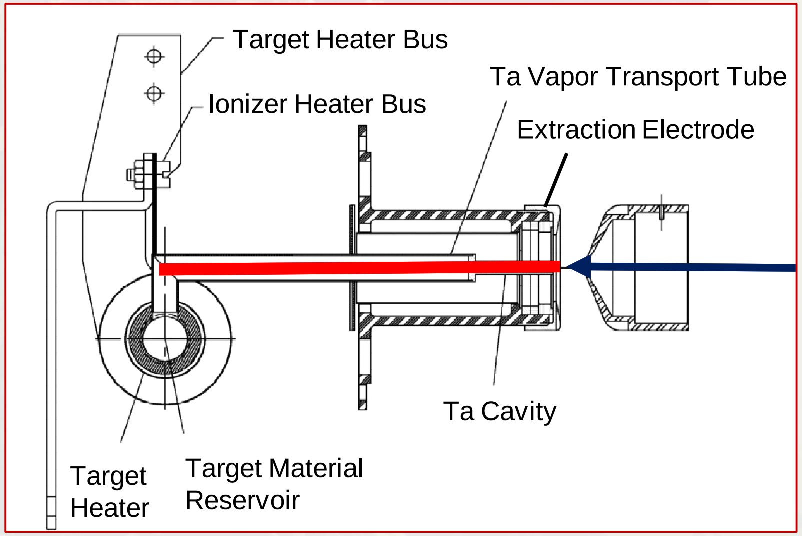


Pulse repetition rate: 10 kHz
Wavelength tuning range:

fundamental	715 - 960 nm
SHG	359 – 470 nm
THG	240 – 310 nm
FHG	208 – 230 nm

Peak laser power:
2.5 Watt (fundamental)
0.8 W (SHG)
0.12 W (THG)
30 mW (FHG @ 215nm)

Hot cavity ionizer



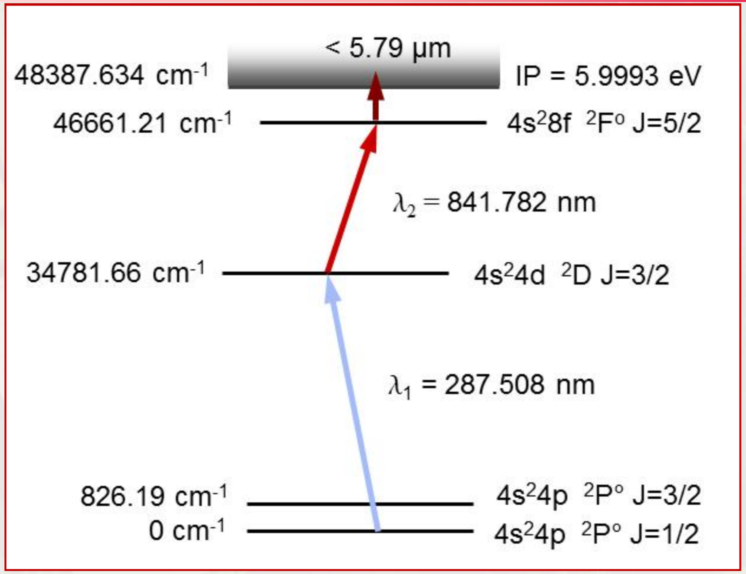
- Three Ti:Sa lasers with individual pump
  - Synchronizing the pump lasers
  - Eliminating the Pockels cells
- Continuous wavelength tuning
- Only one mirror set for full spectral range

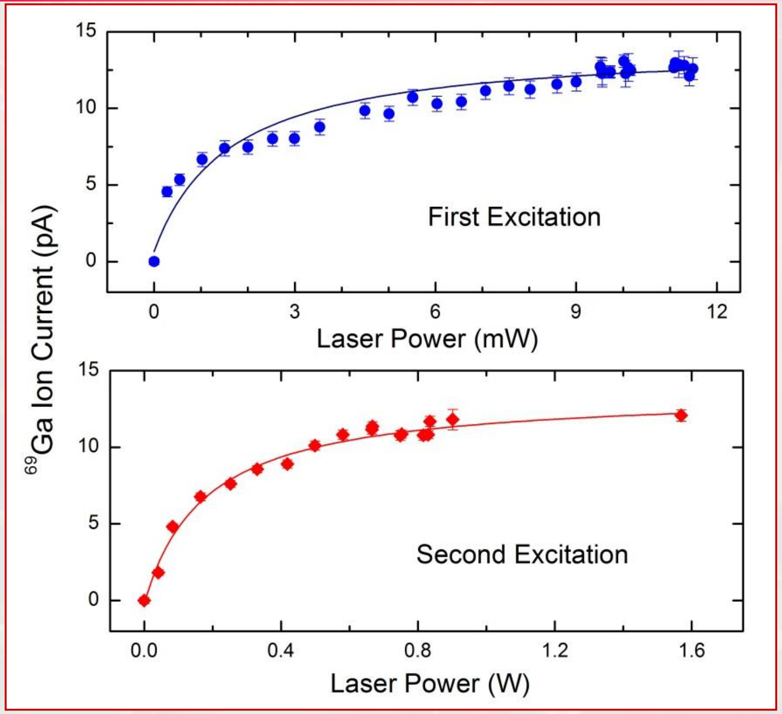
- Ionization schemes for 14 elements off-line
  Sn, Ni, Ge, Cu, Co, Ga, Sr,
  Mn, Fe, Al, Ho, Tb, Dy, Te
- Off-line Ionization efficiency for 8 elements

Element	Sn	Ni	Ge	Cu	Co	Ga	Mn	Ho
Efficiency (%)	22	2.7	3.3	2.4	>20	9	0.9	40

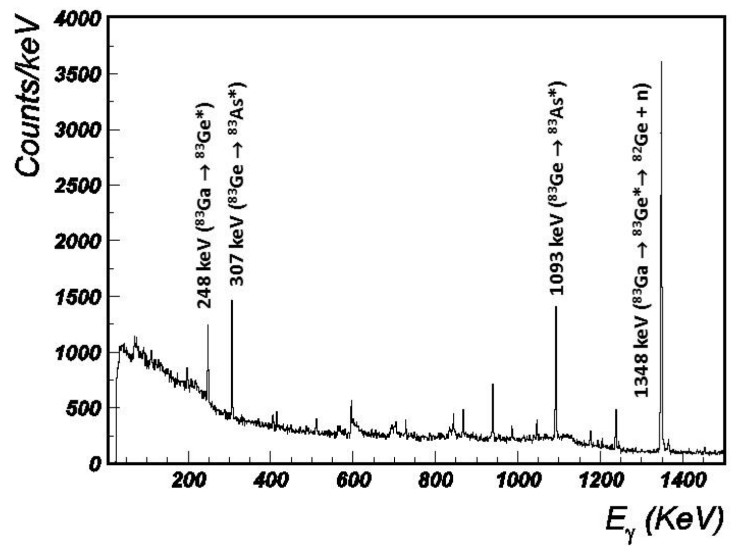
- The ORNL - LIS has gone on-line 2011 for production of RIBs in 2012

On-Line Production of Neutron-Rich $^{83-86}Ga$





Gated γ ray spectrum of the ^{83}Ga beam from the RILIS



- 15 mA, 50-MeV p^+ beam on UC_x target
- Pure beams of $^{83-86}Ga$ isotopes delivered for beta decay studies at rates of

~12000 pps **^{83}Ga**, 100 pps **^{85}Ga**, and 3 pps **^{86}Ga**

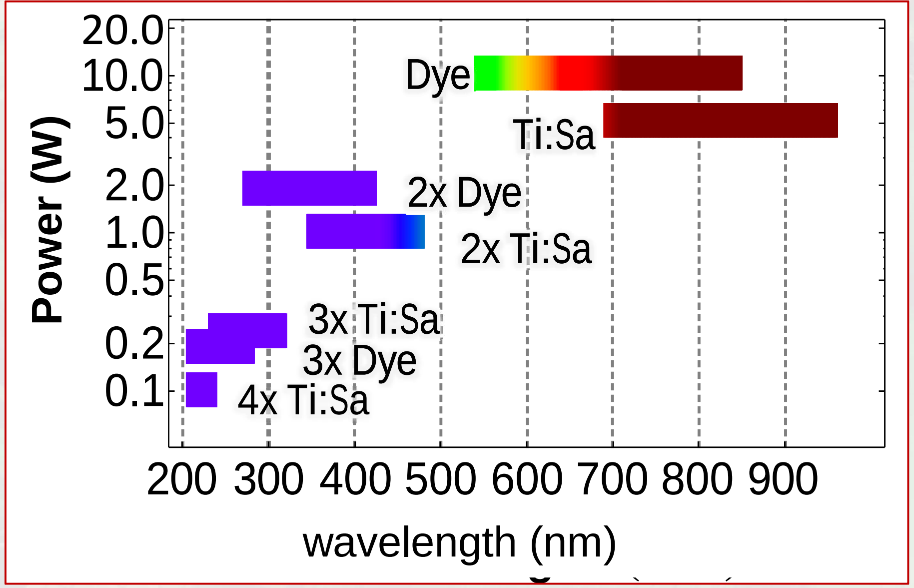
- On-line RILIS efficiency: 5-8%
- Enabled the first β-decay studies on very exotic nucleus **^{86}Ga**

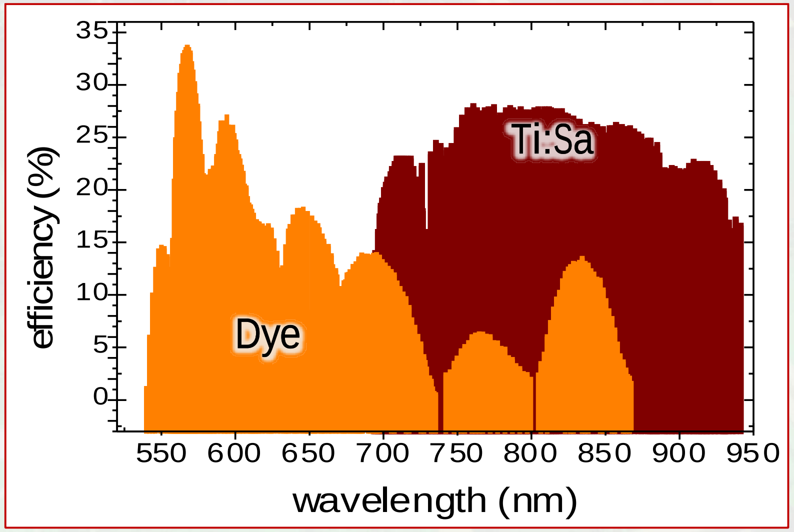
Y. Liu, et al., submitted to NIM B.

Slide: Y. Liu

Comparing Dye and Ti:sa Lasers

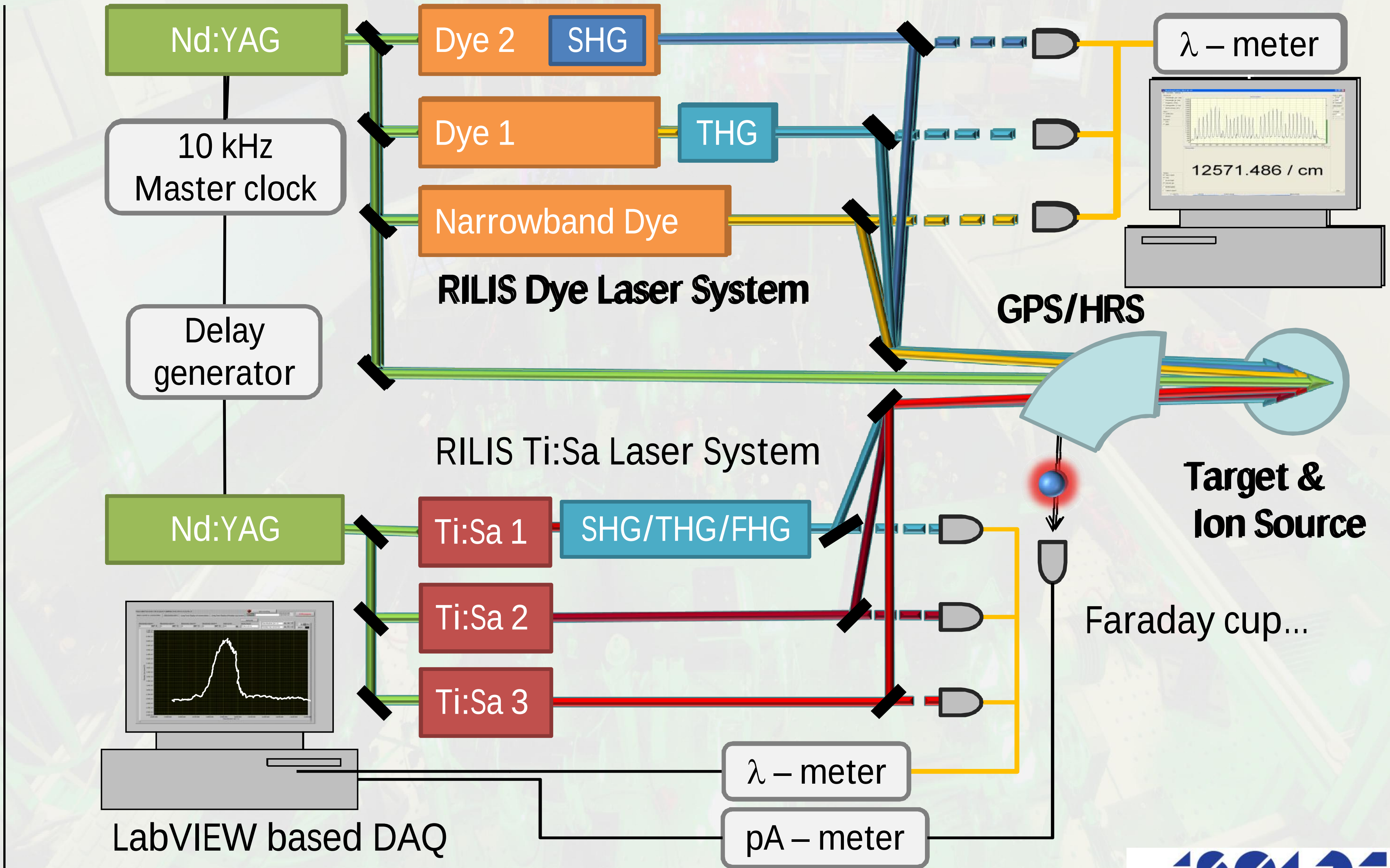
	Dye (apples)	Ti:sa (pears)
Gain Medium	> 10 different dyes liquid (org. solvents)	1 Ti:sapphire crystal solid-state
Tuning range	540 – 850 nm	680 – 980 nm
Power	< 12 W ☺	< 5 W
Pulse duration	~8 ns ☺	~50 ns
Spectral Width	1 GHz	5 GHz (600 MHz)
Synchronization	optical delay lines	q-switch, pump power
Number of schemes	47	37
Maintenance	renew dye solutions	~ none ☺





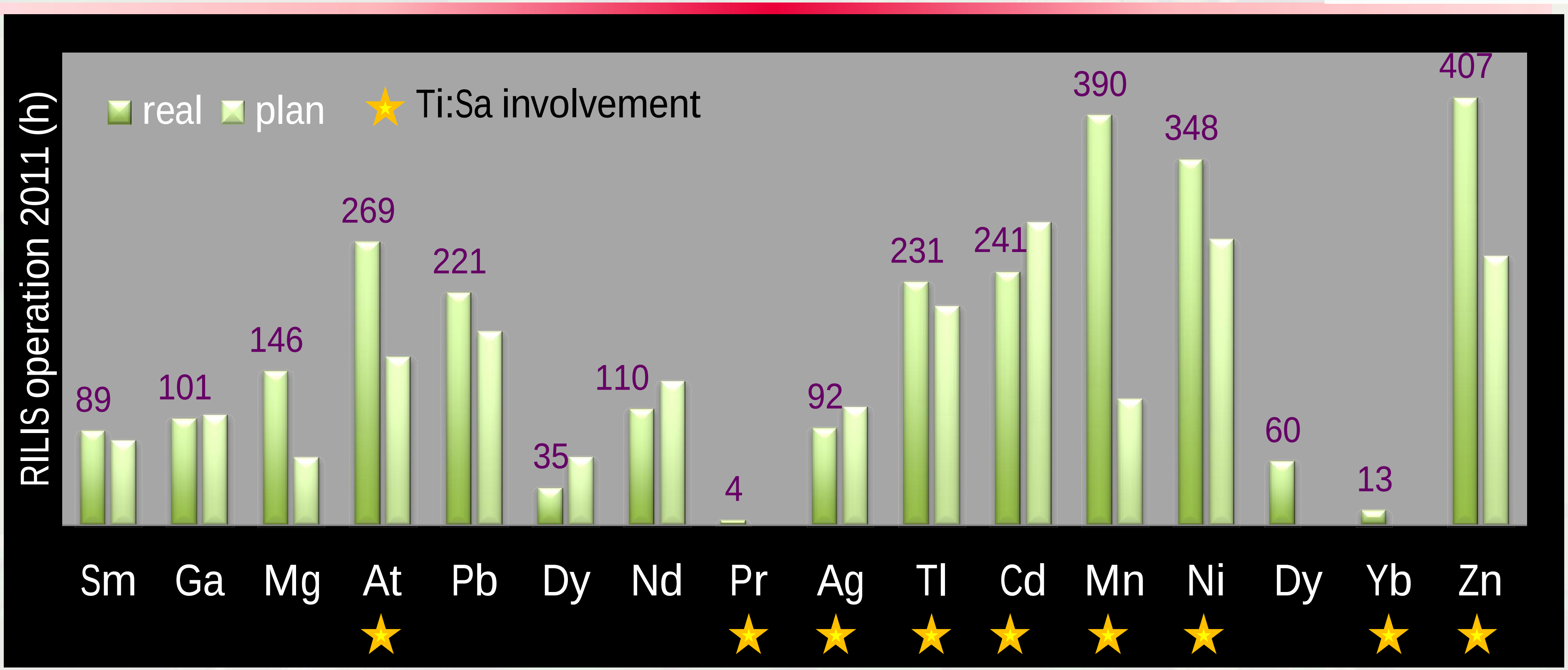
Dye and Ti:Sa systems are complementary !

The (*almost*) ultimate RILIS Setup



Slide: S. Rothe

Recent RILIS operation @ ISOLDE



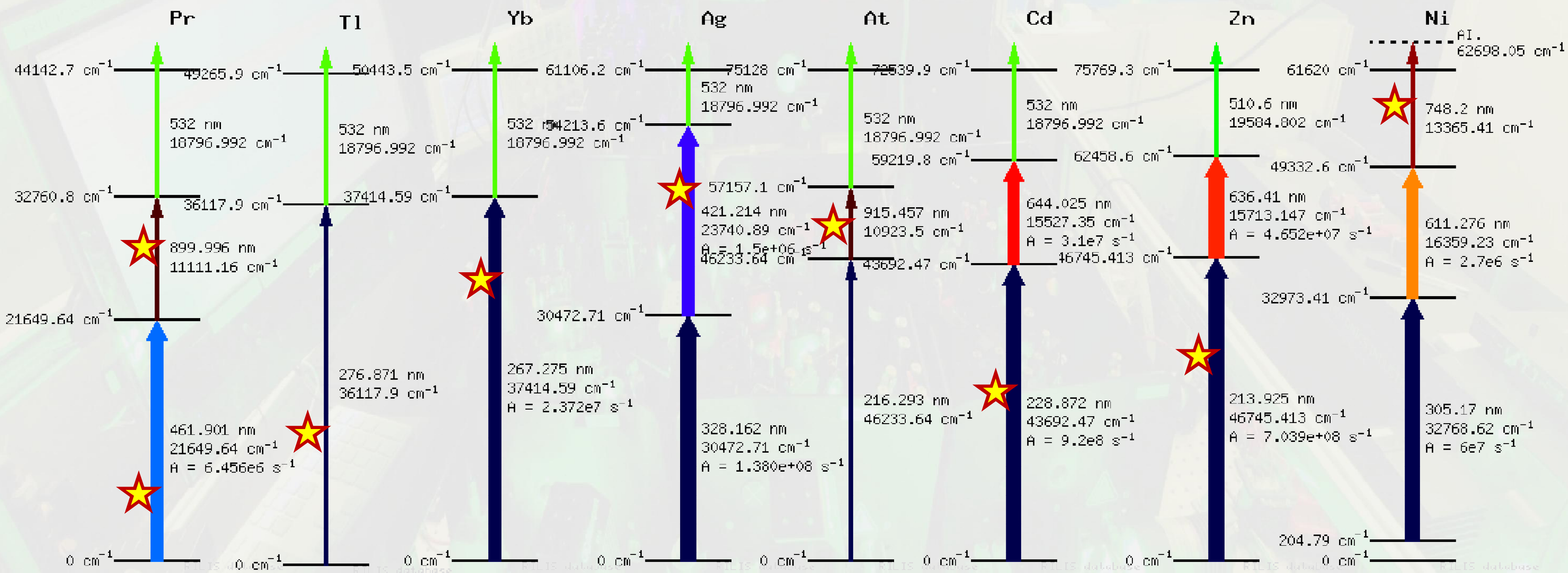
- **2573 h for on-line experiments in 2011, more than 3000 in 2012**
- **Access to two independent laser system**

  provides new chances for RIB production

Modes of RILIS Operation

Dual RILIS

Ti:Sa only mode 50 W Nd:YAG laser available for non-resonant ionization	Mixed mode Combination of dye and Ti:Sa	Backup mode dye and Ti:Sa are exchangeable



- Increased efficiency due to higher laser power or optimum scheme
- Improved reliability due to redundancy / backup
- More elements accessible due to enlarged tuning range
- RILIS excitation scheme database under preparation

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RILIS Efficiencies

CERN

Efficiency measured with stable isotopes off-line

ISOLDE CERN

averaged efficiency of >10 %

1 H																	2 He
3 Li	4 Be 7											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg 10											13 Al 20	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca 5	21 Sc 15	22 Ti	23 V	24 Cr	25 Mn 19	26 Fe	27 Co 4	28 Ni 6	29 Cu 7	30 Zn 4.9	31 Ga 21	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 14	48 Cd 10.4	49 In	50 Sn 9	51 Sb 3	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 3	80 Hg	81 Tl 27	82 Pb 3	83 Bi 6	84 Po	85 At	86 Rn
87 Fr	88 Ra	89 Ac	104 Rf	105 Ha	106	107	108	109	110	111	112	113					

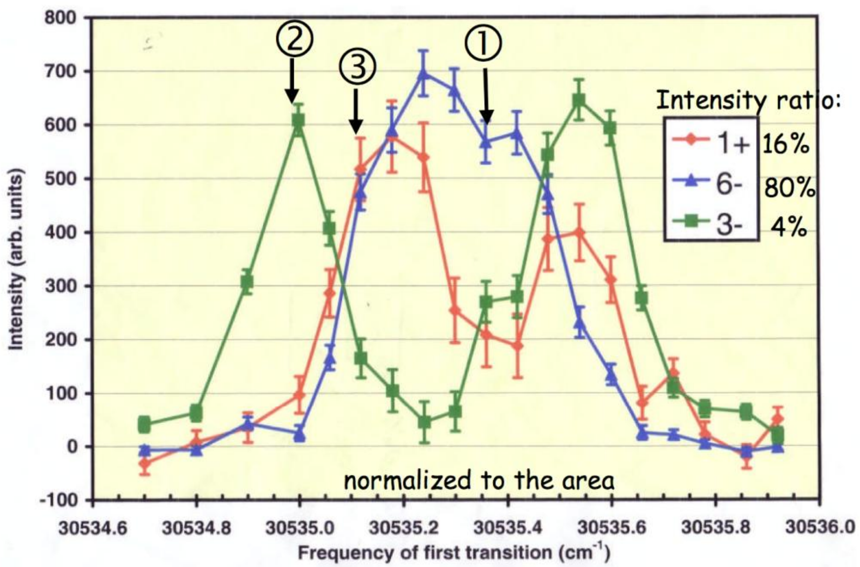
in units of %

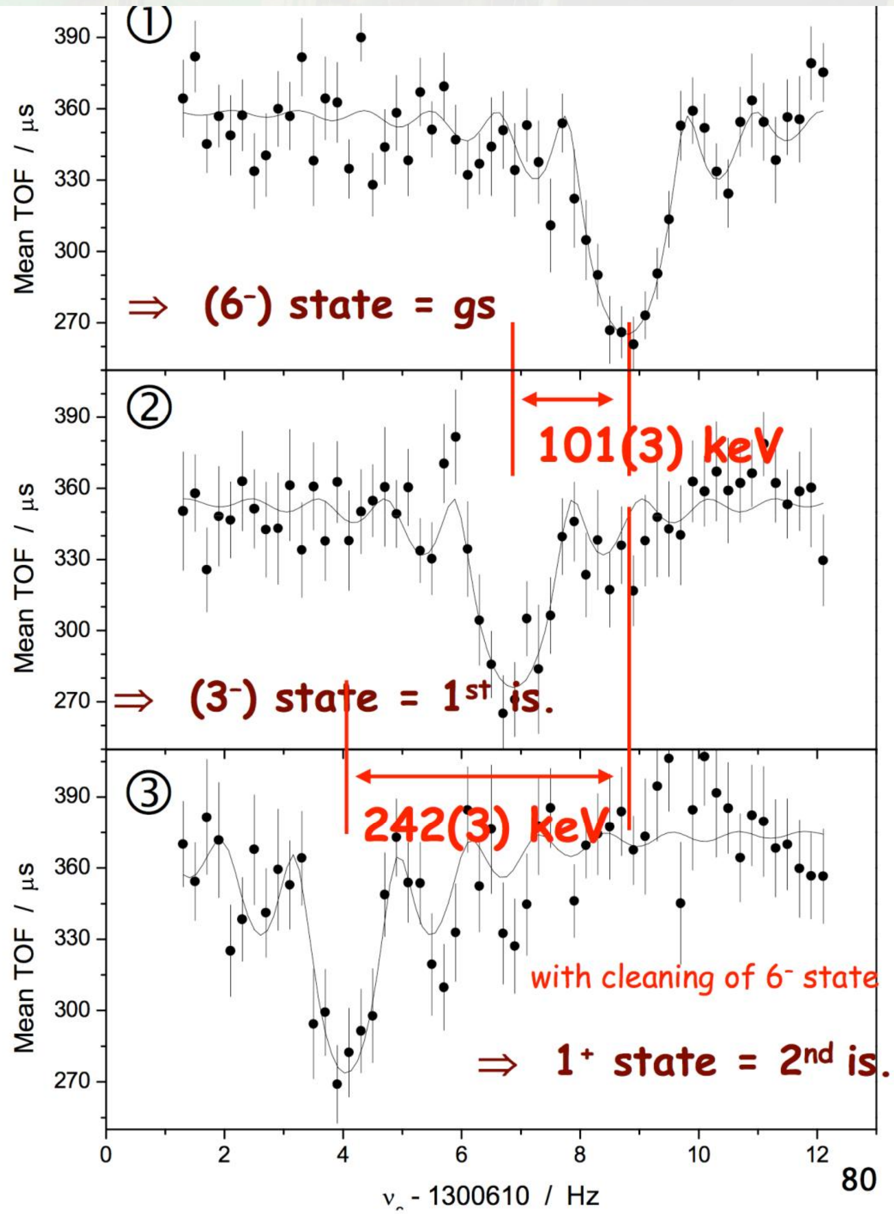
58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy 20	67 Ho	68 Er	69 Tm	70 Yb 15	71 Lu
90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Fc	99 Es	100 Fm	101 Md	102 No	103 Lr

Striking universality with all efficiencies beyond most conventional ion sources !

numbers taken from Bruce Marsh, EURONS meeting, April 11-15, 2007

Isomer selection using RILIS





$$\omega_c = \frac{q}{m} \cdot B$$

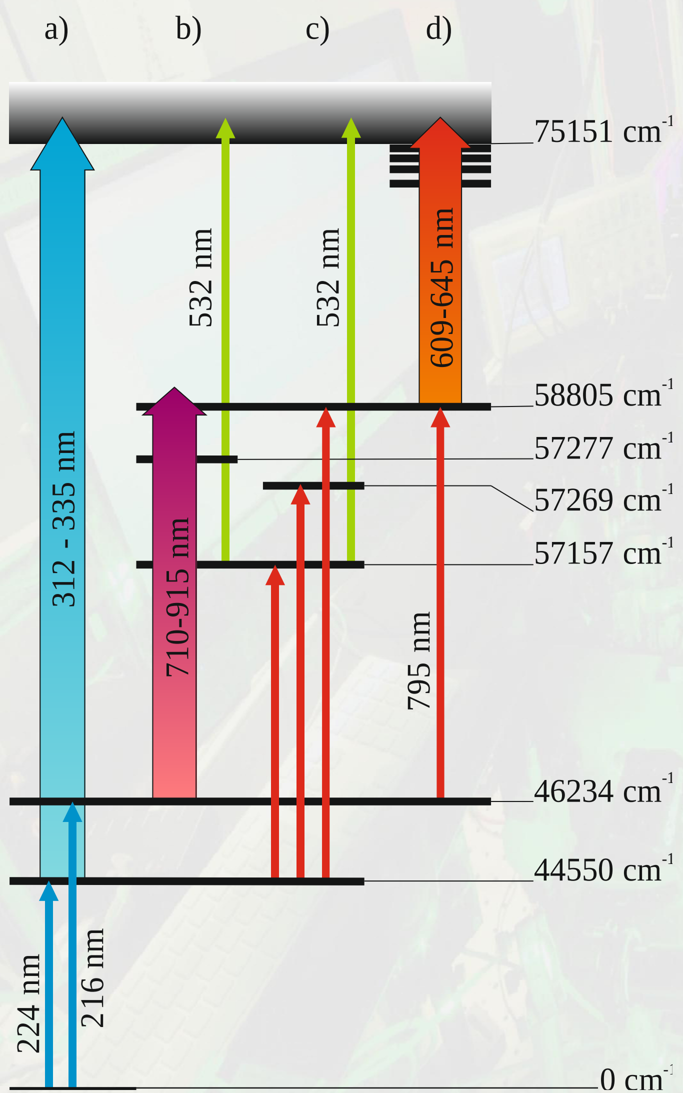
Unambiguous state assignment!

ME of ground state is 240 keV higher than literature value!

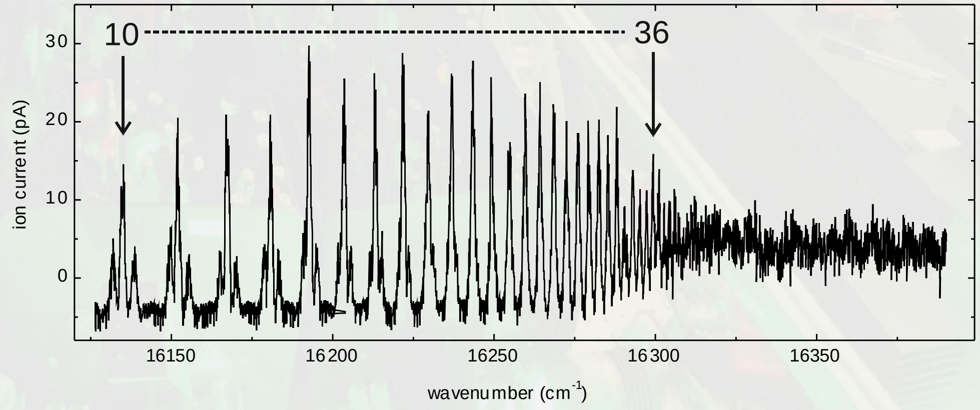
$R \approx 1 \cdot 10^7,\ \delta m/m \approx 4 \cdot 10^{-8}$

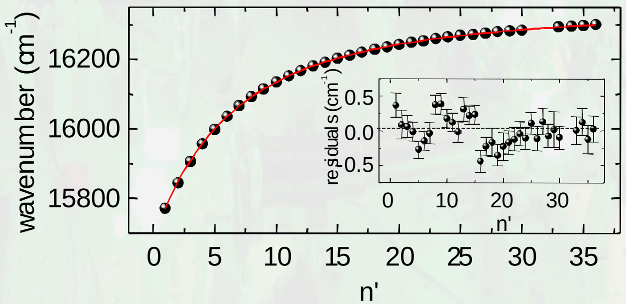
J. Van Roosbroeck et al., Phys. Rev. Lett. 92, 112501 (2004).

In-source Spectroscopy on Astatine



- Scans at ISOLDE/RILIS and TRIUMF/TRILIS
- Verification of levels, yield measurements using various detector systems
- Advanced atomic physics evaluation of the IP





$E_{IP}(At) =$

75151(1) cm^{-1}

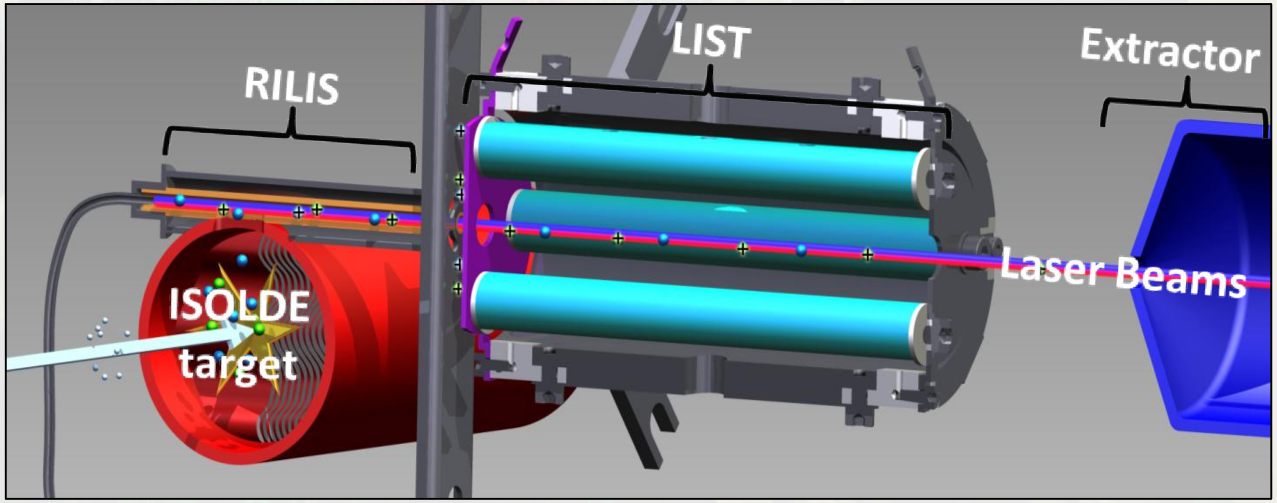
S. Rothe et al., Nature Comm. in press

Laser Ion Source & Trap (LIST)

1. ISOLDE Target:
Production of exotic nuclei

2. RILIS:
Element selective ionization

3. LIST:
Full Isobar Suppression



On-line Figures of Merit

$^{21}_{11}Na_{10}$
22,49 s
$\beta^+ = 100\ \%$

$^{27}_{12}Mg_{15}$
9,458 m
$\beta^- = 100\ \%$

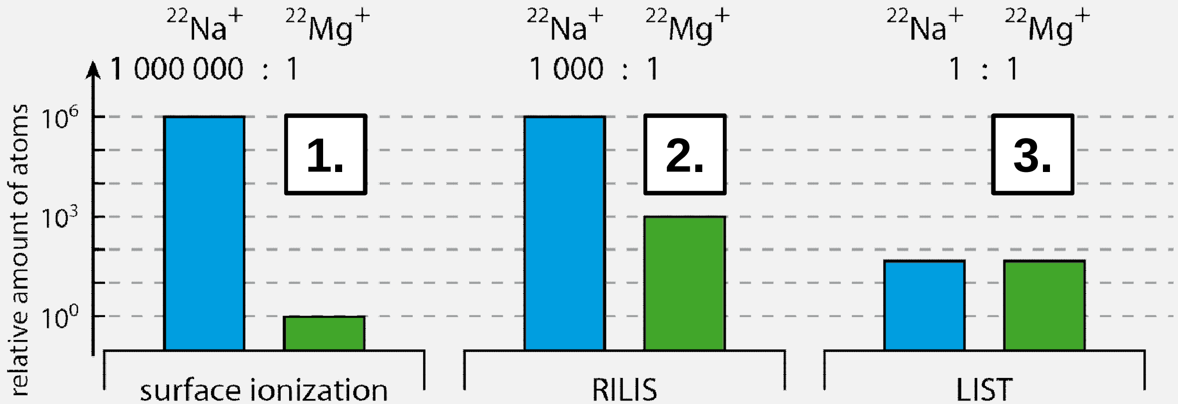
Selectivity

$$\Rightarrow S \geq 1\,600$$

Losses

$$\Rightarrow \beta \leq 50$$

Selectivity Gain for ^{22}Mg / ^{22}Na ratio

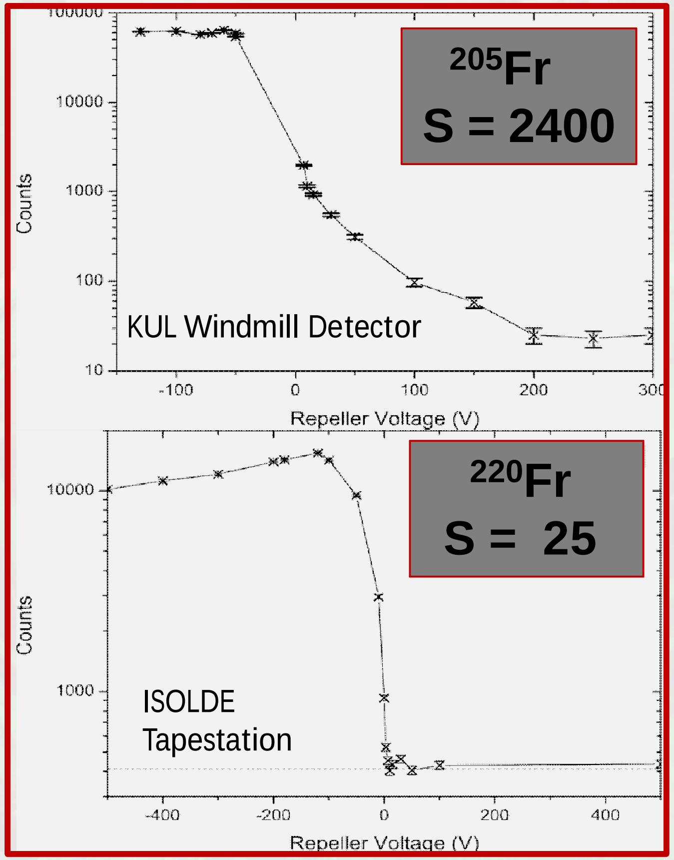


LIST on-line for Po Selection versus Fr

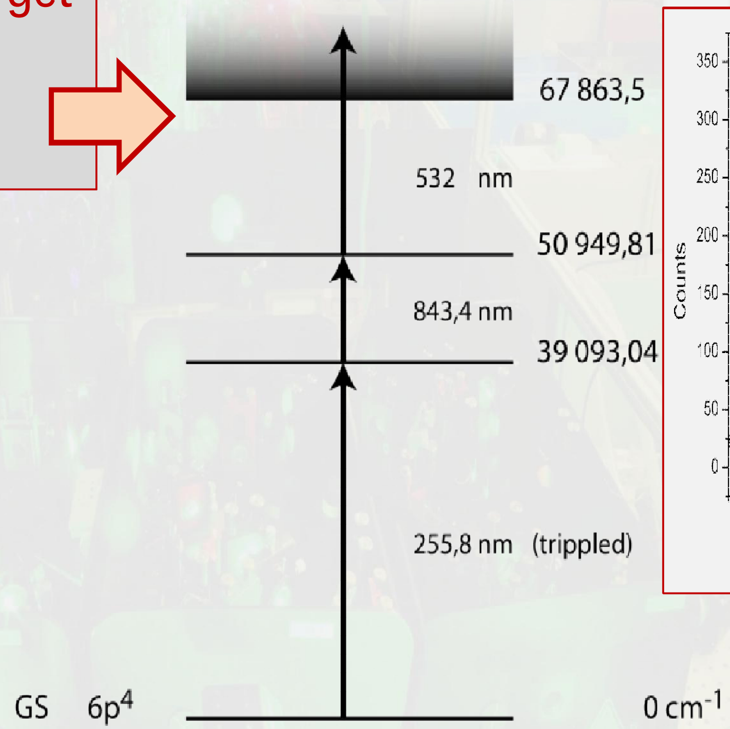
Proof of LIST operation @ UC_n target

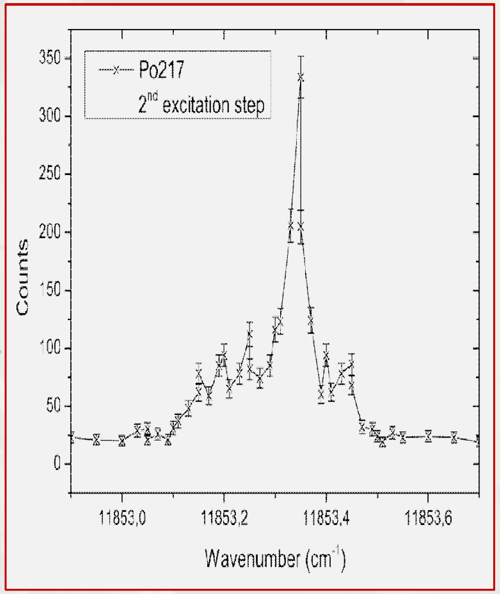
First studies of ^{217}Po with LIST

and KUL Windmill α-Detector



RILIS TiSa Laser Excitation Scheme





^{217}Po Signal

- LIST isobar suppression of Fr isotopes

  Selectivity depends strongly on individual isotope – more LIST development to be done

- Production of unexpected isotopes ^{216}At, ^{217}Rn

Improvements of the RILIS Performance

1. Complete suppression of unselective ionization of isobars, stemming e.g. from hot metal surfaces
2. Optical resolution increase for direct in-source spectroscopy
3. Further increase of the ionization efficiency towards 100 %

Possible solutions, e.g. for aspect 1. – A. reduce surface ionization

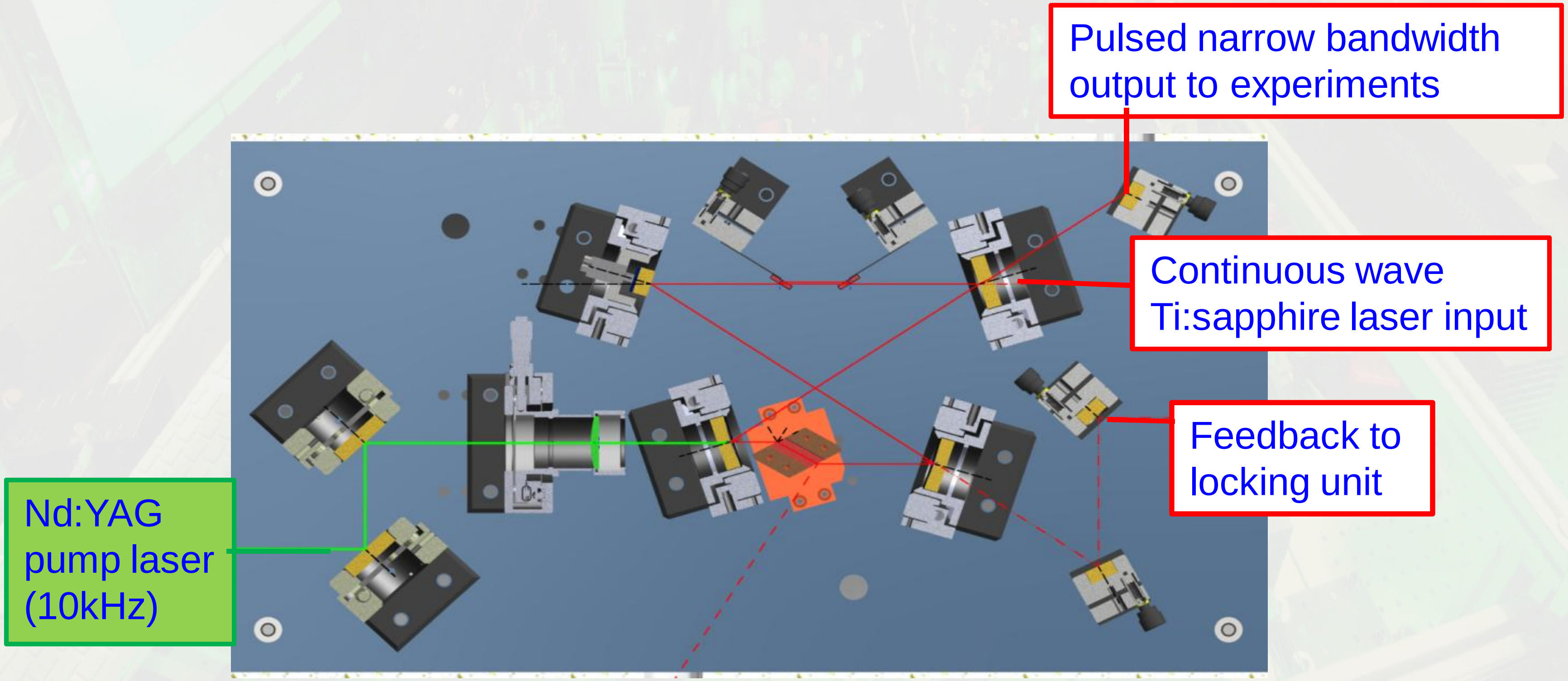
- Develop and use new atomizer, e.g. low work function materials
- Reduce atomizer temperature
- Trap unwanted elements between production target and atomizer cavity (add chemical selectivity to the effusion process)

– B. separate surface ions from laser ions

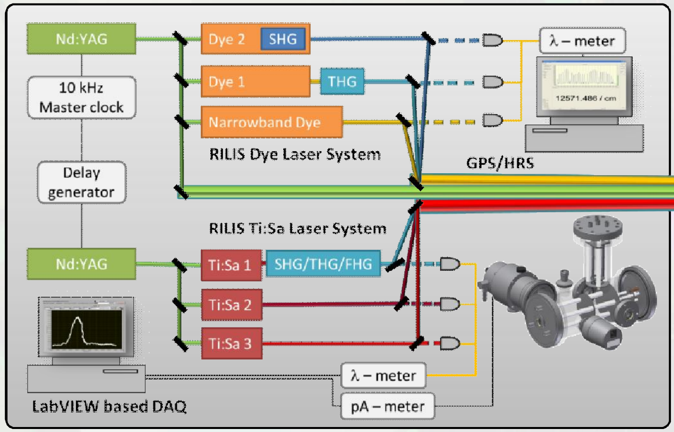
- Spatially separate and select laser from surface ions → LIST
- Temporally distinguish laser from surface ions → pulsed & time-of-flight operation of the mass separator

Optical Resolution for In-Source Spectroscopy

- Narrow Bandwidth Operation of a dye laser or
  double-etalon operation of aTi:sa laser (2012) → ~600 MHz (Poster 131, Rothe)
- Injection-locking of a pulsed Ti:sapphire (2013) → ~ 20 MHz (Poster 75, Sakamoto)
- Pulsed dye laser amplification of cw Laser (2012) → ~ 20 MHz (Talk Kudryatsev)



Reference Cell for In-Source Spectroscopy

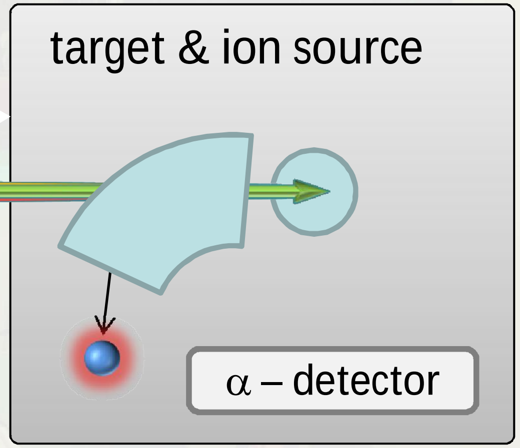


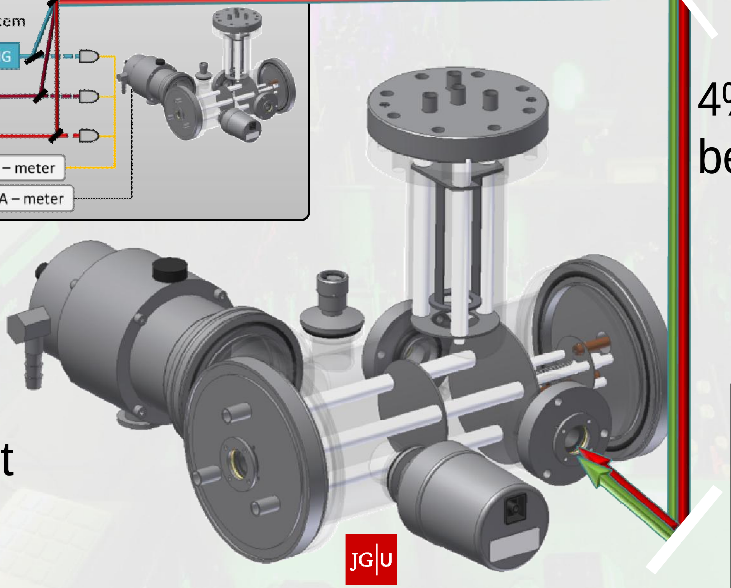
Under installation at RILIS, GISELE, ALTO, ...

~20 m

quartz plate

4% reflected beams



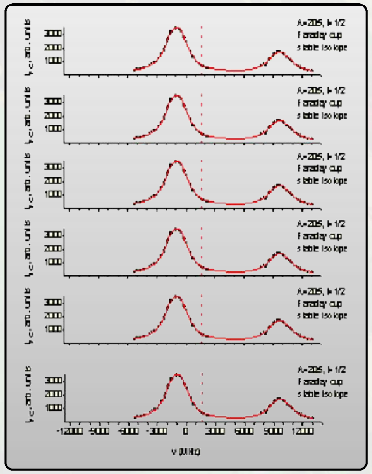


Reference cell

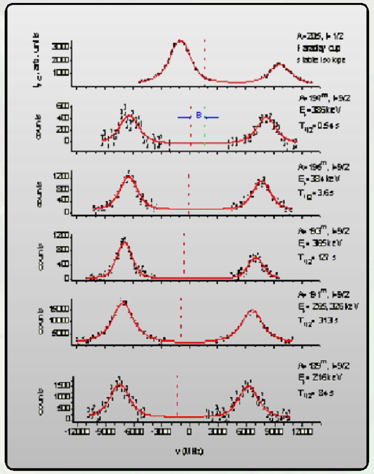
- small & portable atomic beam unit
- tested at GISELE

Installation at RILIS in 2012

- to measure reference spectra of stable isotopes for *In-Source laser spectroscopy*
- Reduces down-time and time for data taking
- Increases precision
- Application for on-line RILIS monitoring

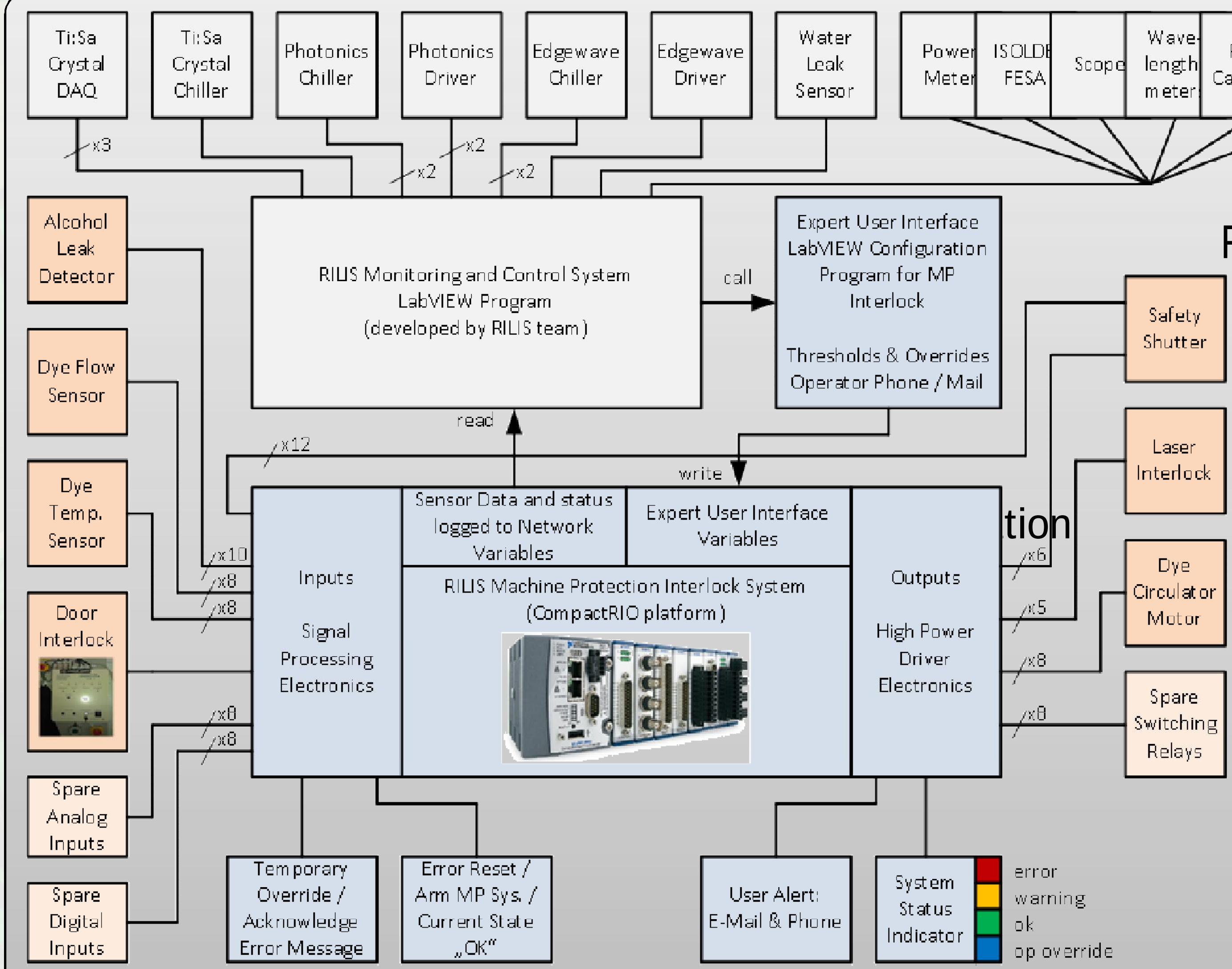


Stable isotope HFS from reference cell



HFS of radioisotopes by α decay detection

Laser System Automatization



...

RILIS Process Control

Machine protection

- Dye flow
- Ethanol detectors
- Water leak
- Safety shut down

Monitoring

- Intensity
- Spectral
- Spatial
- Temporal

Remote Control

- User interface

On-line RILIS – State of the Art 2012

Status 2012:

Ion beams of > 60 elements are produced with Laser Ion Sources

34 elements ionized on-line with RILIS

26 ionization scheme tested off-line

25 RILIS ionization feasible

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

Conclusion and Outlook

- Tremendous Progress in on-line Laser Ion Sources

  both for Hot-Cavity and Gas-Cell Application

  (quantitatively but primarily qualitatively)

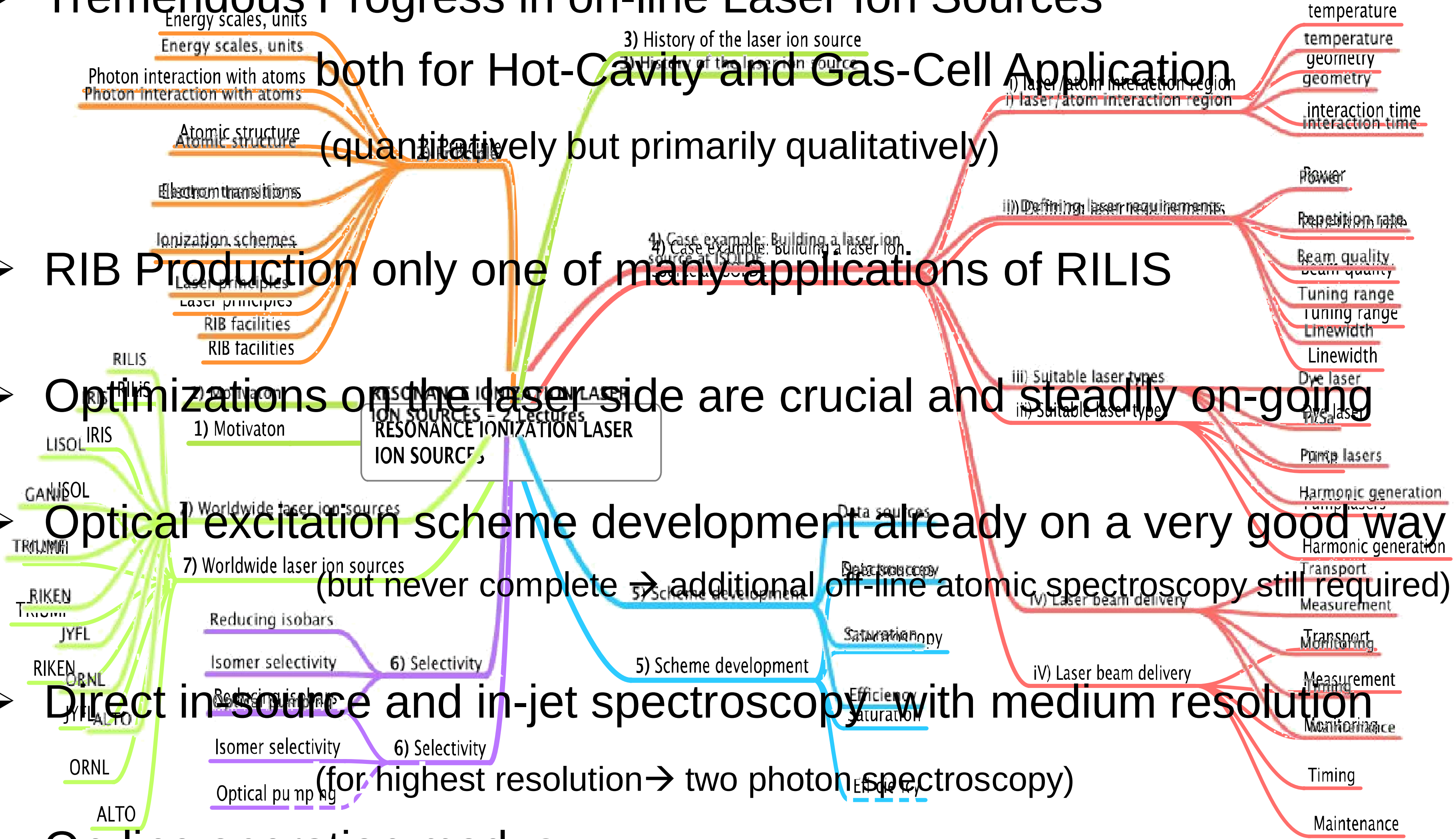
- RIB Production only one of many applications of RILIS
- Optimizations on the laser side are crucial and steadily on-going
- Optical excitation scheme development already on a very good way

  (but never complete → additional off-line atomic spectroscopy still required)

- Direct in-source and in-jet spectroscopy with medium resolution

  (for highest resolution→ two photon spectroscopy)

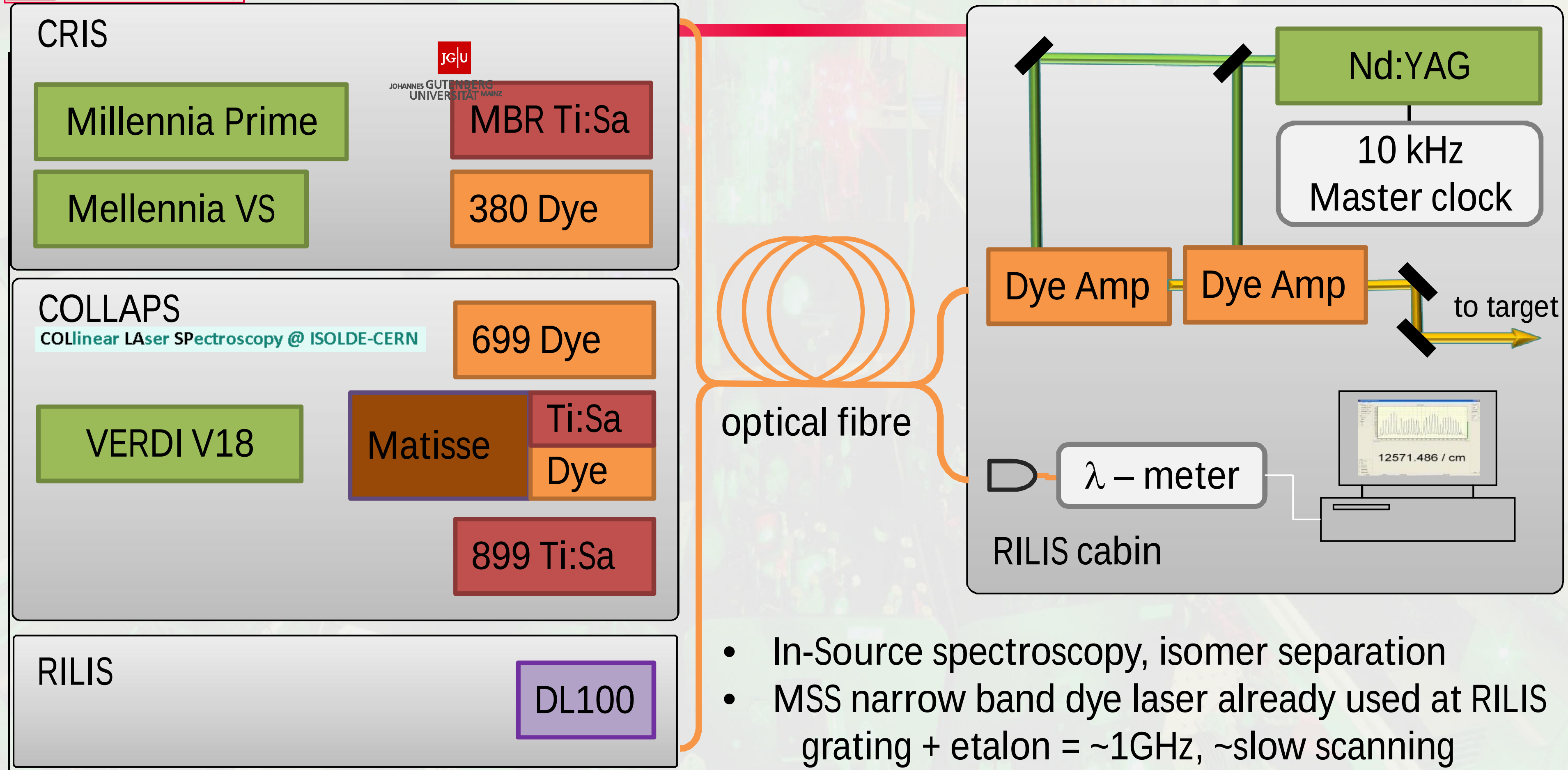
- On-line operation modus



Acknowledgements

Thanks for your Contributions...

Narrow bandwidth @ RILIS



Available kHz line width cw laser systems from different experiments at ISOLDE

- In-Source spectroscopy, isomer separation
- MSS narrow band dye laser already used at RILIS
  grating + etalon = ~1GHz, ~slow scanning
- Pulsed dye amplification of cw dye or Ti:Sa, Fourier limited, promising results from IKS
- Ti:Sa seeding
- Locked cw lasers as frequency reference

Materials to work with

1. Lap 2012
2. DPG 2012 Rudi invited
3. Dubna 2011
4. ISOLDE Workshop 2011 Rudi

Research Acitivities:

Ion Beam Generation
Isobar Suppression
Isomer Selection
In-Source Spectroscopy
Beam Manipulation

Content of the presentation:

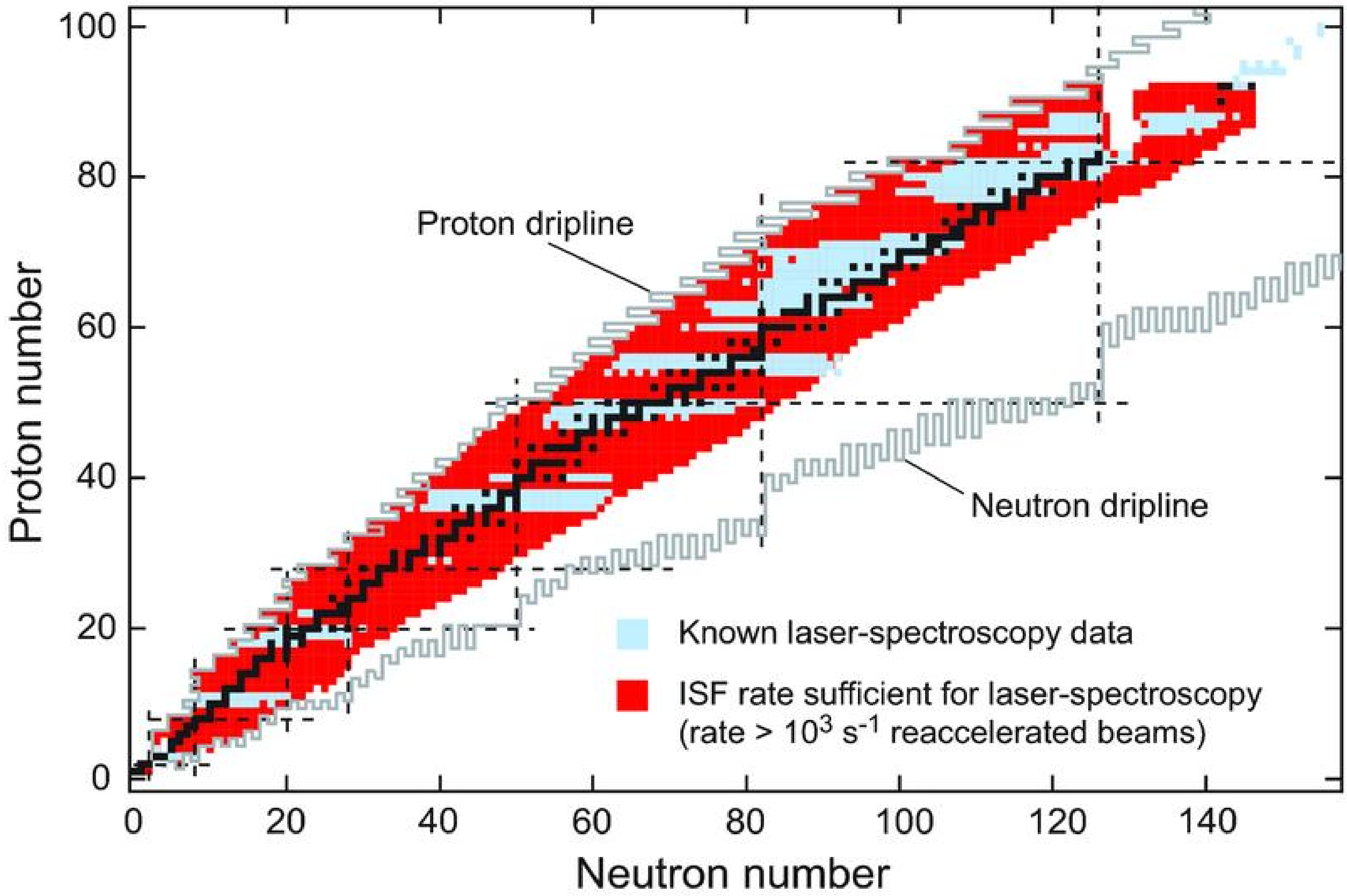
Status of RILIS
Two fundamentally different approaches hot cavity ← → gas cell

Hot cavity: removal of all complexity from the frontend to the outer world, automation of operation
laser optimization (new media, new resonators, higher pump rate, narrower line width, temporal control ISST)
scheme optimization for new elements and higher efficiency, , extended wavelength
hot cavity material improvement
laser use for beam preparation optical pumping
negative ions,
molecular sidebands , selective laser dissociation
double development dye + Tisa
use of 3. resonant step for ionization
broad band tunability
narrowing of line width → 2 etalon concept → 600 MHz, injection locking concept → 20 MHz

Twp competing laser systems → combined for complemetary operation Double, Dual and more

In source spectroscopy two photn, time structure, delayed ionization, ICE, In LIST Spectroscopy

Gas cell: shadow gas cell, in Jet spectroscopyl



Proton dripline
Neutron dripline
Known laser-spectroscopy data
ISF rate sufficient for laser-spectroscopy
(rate > 10^3 s^-1 reaccelerated beams)
Proton number
Neutron number

Optimizing the hot cavity materials or transfer line:

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Study of low work function materials for hot cavity resonance ionization laser ion sources

F. Schwellnus [a,*], R. Catherall [c], B. Crepieux [c], V.N. Fedosseev [c], B.A. Marsh [c], Ch. Mattolat [a], M. Menna [c], F.K. Österdahl [b,1], S. Raeder [a], T. Stora [c], K. Wendt [a]

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Beam purification by selective trapping in the transfer line of an ISOL target unit
E. Bouquerel, , R. Catherall, M. Eller, J. Lettry, S. Marzari, T. Stora, The ISOLDE Collaboration
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