Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

A review of chemically selective ion sources for radioisotope production at ISOL facilities

Tom Day Goodacre

16th October 2017

Outline

1. What is a thick target ISOL facility?

2. What does this mean for ion source requirements?

3. Ion source types: challenges, development highlights and directions for the future
   - 3.1 Surface ion sources
   - 3.2 FEBIAD type ion sources
   - 3.3 RILIS
   - 3.4 Blurred boundaries

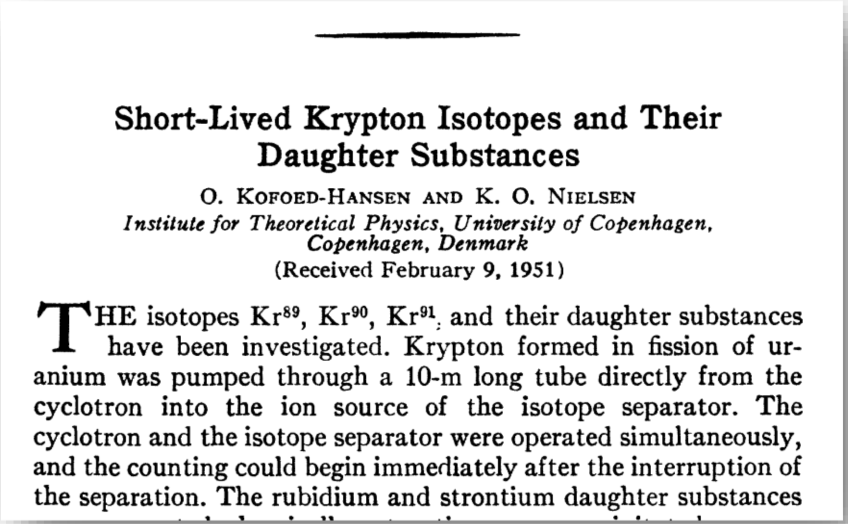
4. Summary

Outline

1. What is a thick target ISOL facility?

ISOL = Isotope Separator On-Line

1951


Short-Lived Krypton Isotopes and Their Daughter Substances

O. Kofoed-Hansen and K. O. Nielsen

Institute for Theoretical Physics, University of Copenhagen, Copenhagen, Denmark

(Received February 9, 1951)

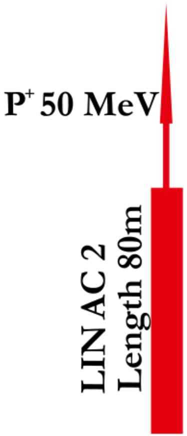
THE isotopes Kr^{89}, Kr^{90}, Kr^{91}, and their daughter substances have been investigated. Krypton formed in fission of uranium was pumped through a 10-m long tube directly from the cyclotron into the ion source of the isotope separator. The cyclotron and the isotope separator were operated simultaneously, and the counting could begin immediately after the interruption of the separation. The rubidium and strontium daughter substances

http://dx.doi.org/10.1103/PhysRev.82.96.2

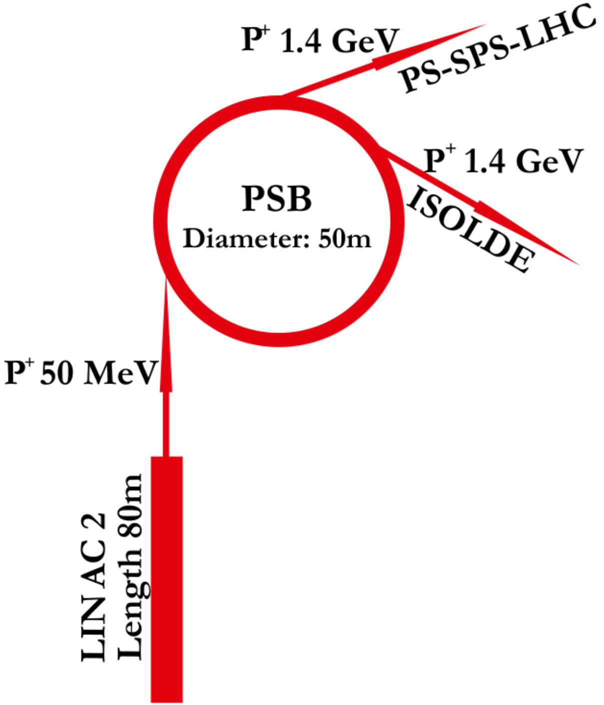
"…Krypton formed in fission of uranium was pumped through a 10-m long tube directly from the cyclotron into the ion source of the isotope separator. The cyclotron and the isotope separator were operated ***simultaneously****…"*

Combined production, release, ionization and study of radioactive isotopes

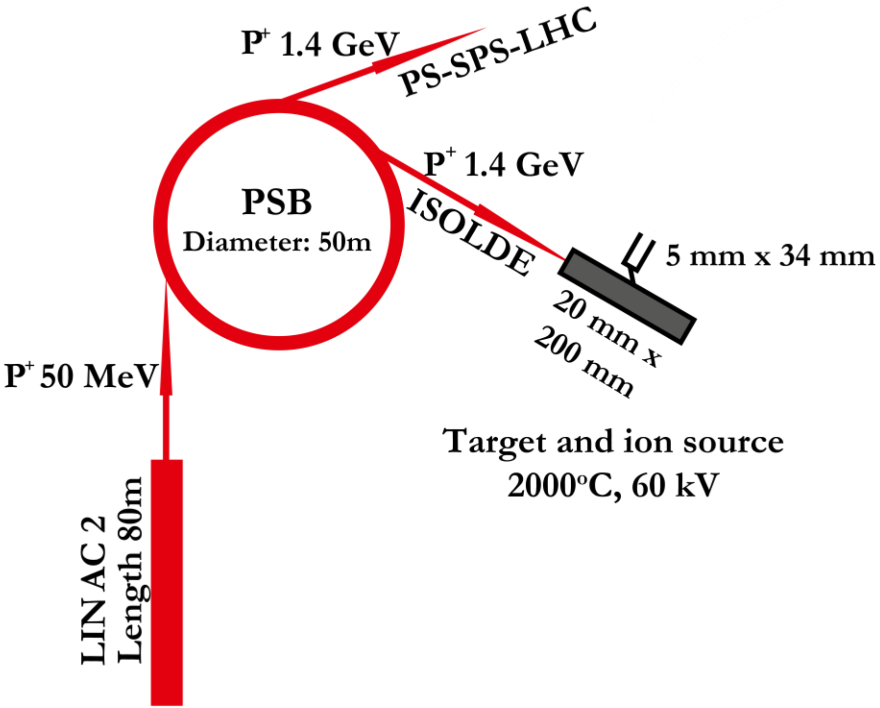
Combined production, release, ionization and study of radioactive isotopes



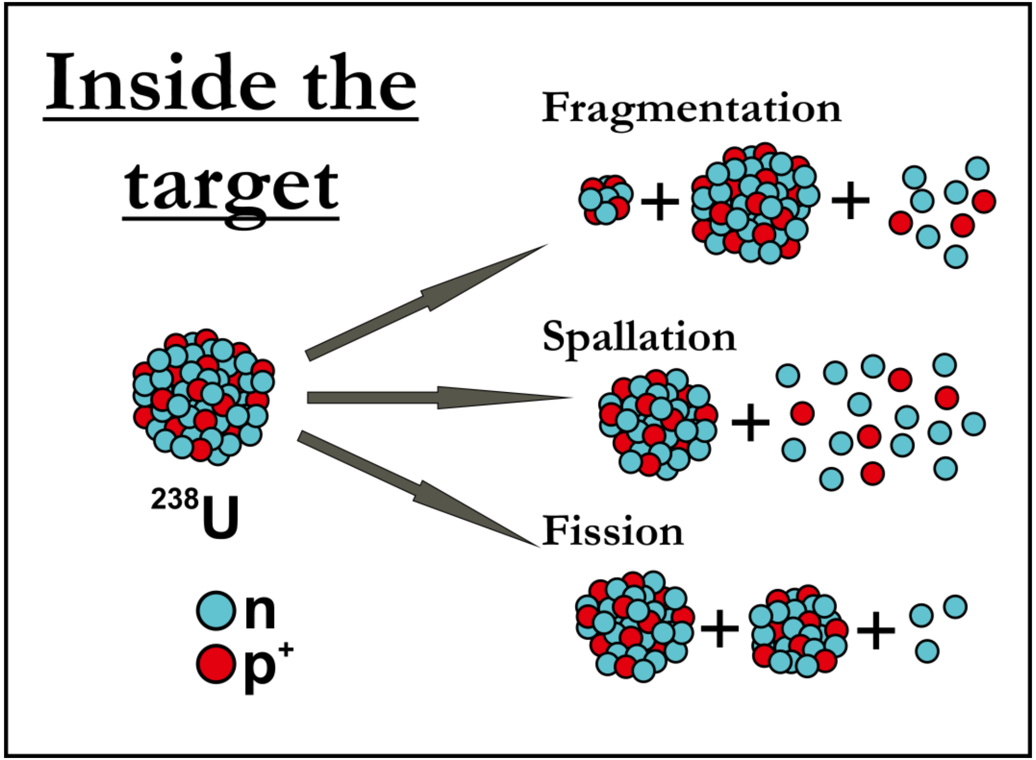
Combined production, release, ionization and study of radioactive isotopes



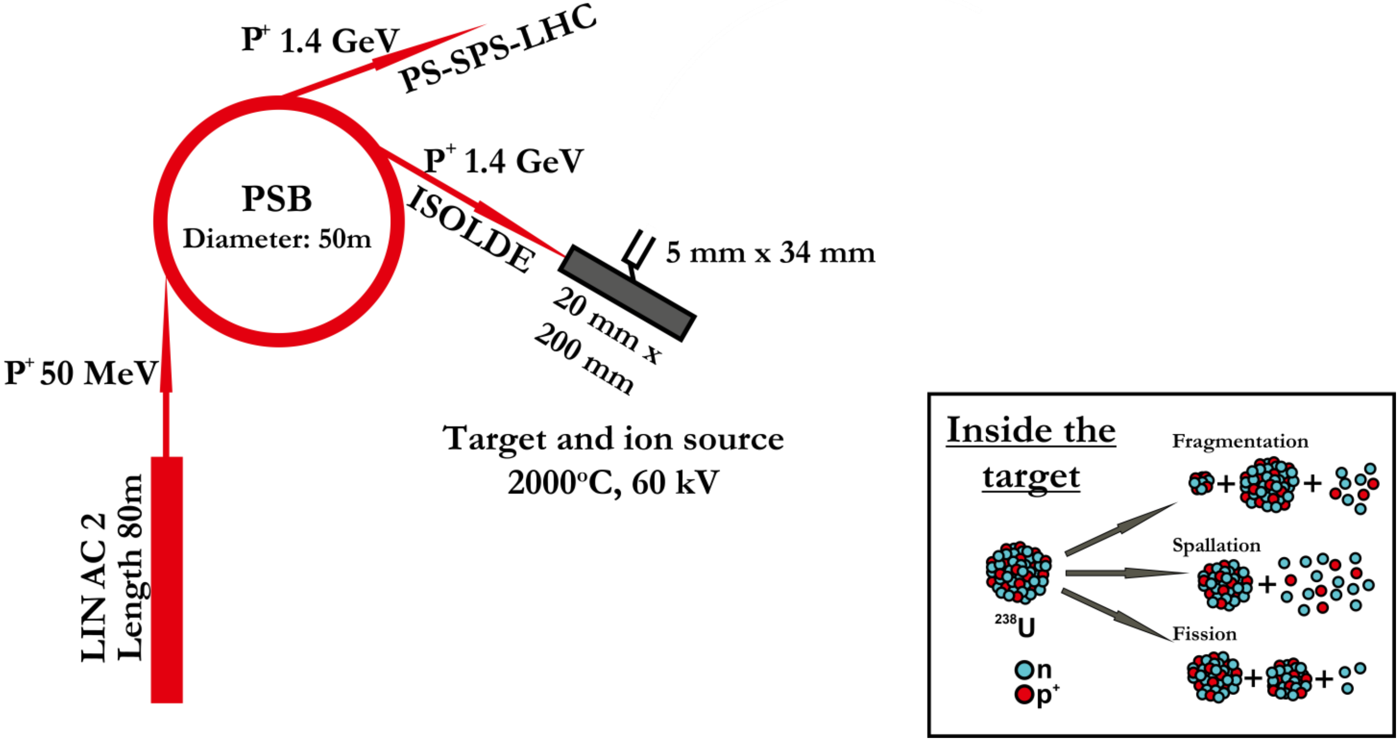
Combined production, release, ionization and study of radioactive isotopes



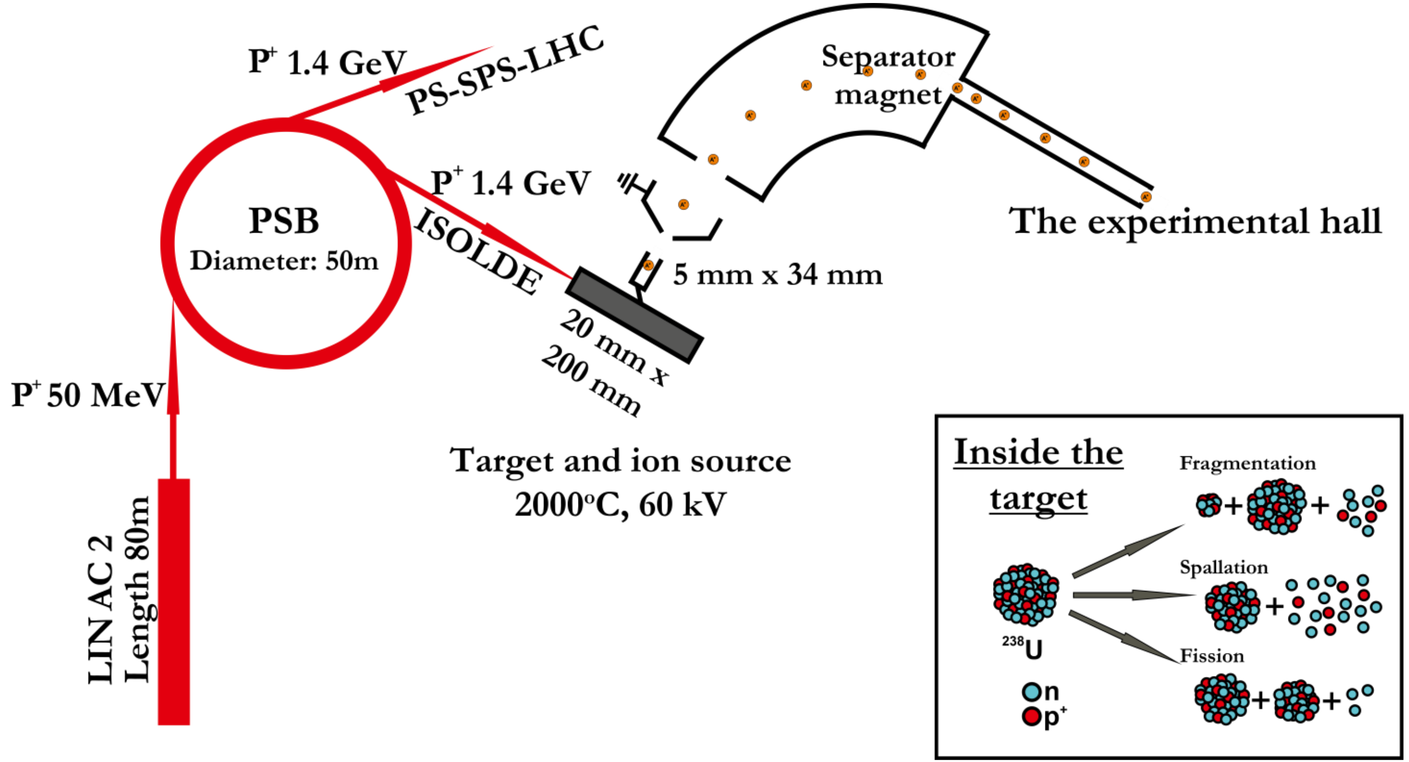
Combined production, release, ionization and study of radioactive isotopes



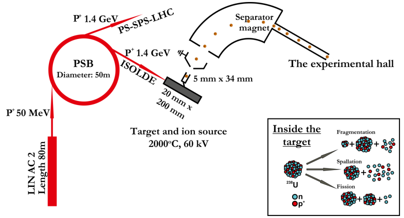
Combined production, release, ionization and study of radioactive isotopes



Combined production, release, ionization and study of radioactive isotopes

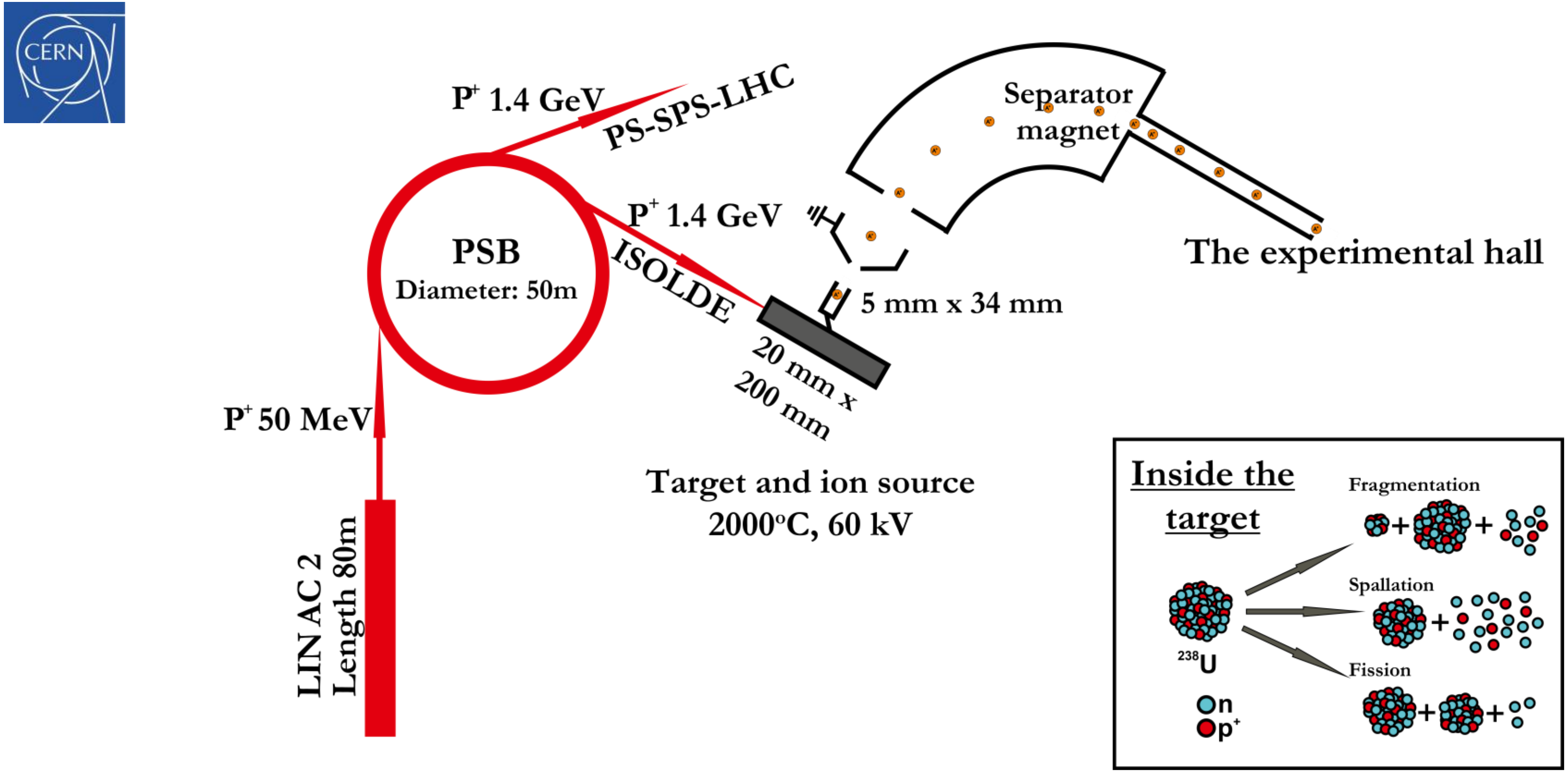


Happy Birthday ISOLDE!



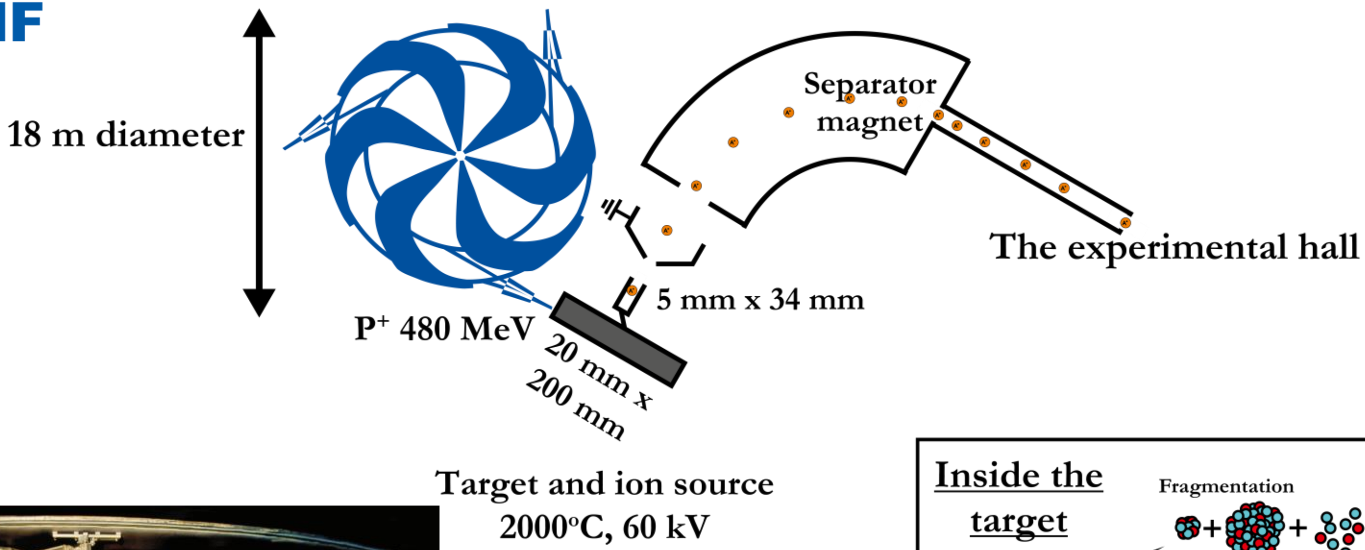
First radioactive ion beam 16th October 1967

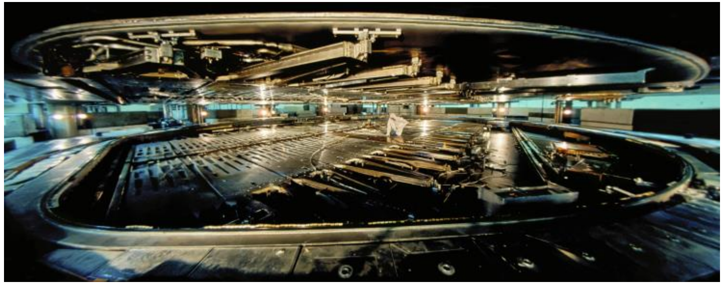
Combined production, release, ionization and study of radioactive isotopes

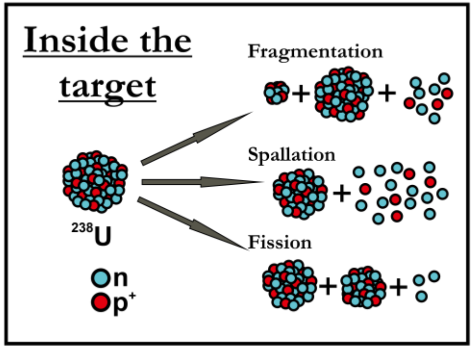


Combined production, release, ionization and study of radioactive isotopes

TRIUMF





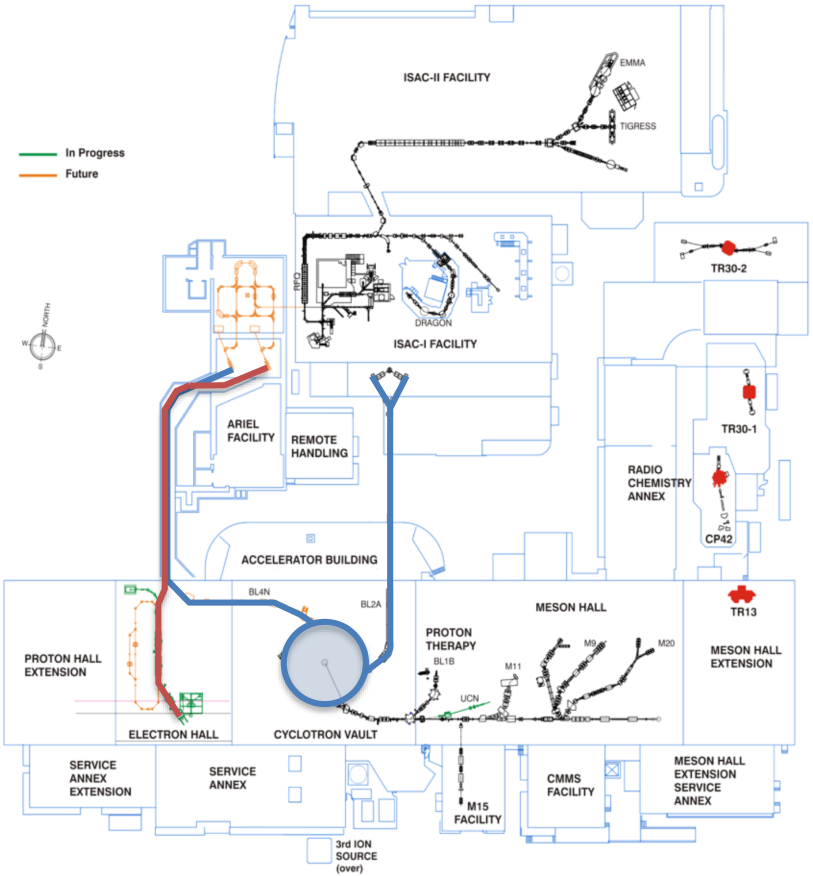


ISAC (currently):

- 480 MeV, ≤100 µA proton driver beam
- Two target stations (ITE, ITW), alternating operation

ARIEL (under construction):

- Two independent target stations
- 480 MeV, ≤100 µA proton driver beam
- ≤ 50 MeV, ≤10 mA electron driver beam
- RIB beam through beam transport and CANREB system to ISAC experiments
- 9000 hours of RIB available annually:
  Requires both reliability + new beams!



Outline

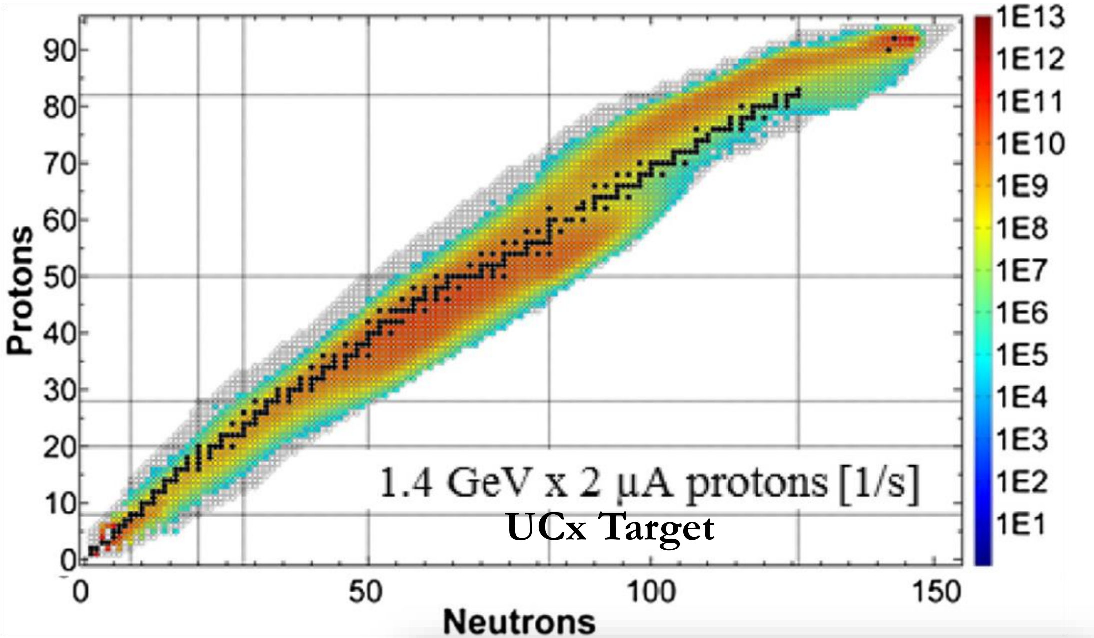
1. What is a thick target ISOL facility?

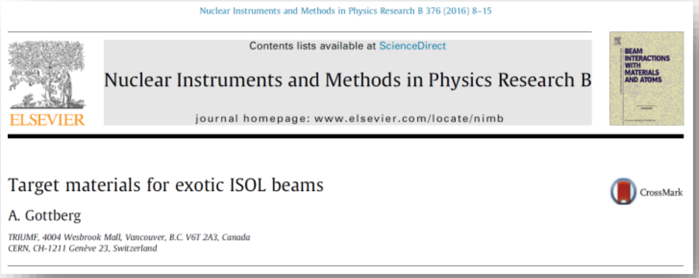
2. What does this mean for ion source requirements?

Ion source requirements @ thick target ISOL

1. Efficiency
2.
3.
4.

- A fixed amount of the isotope of interest
- The interest in an isotope is often inversely proportional to its production rate




Nuclear Instruments and Methods in Physics Research B 376 (2016) 8–15

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

ELSEVIER

Target materials for exotic ISOL beams

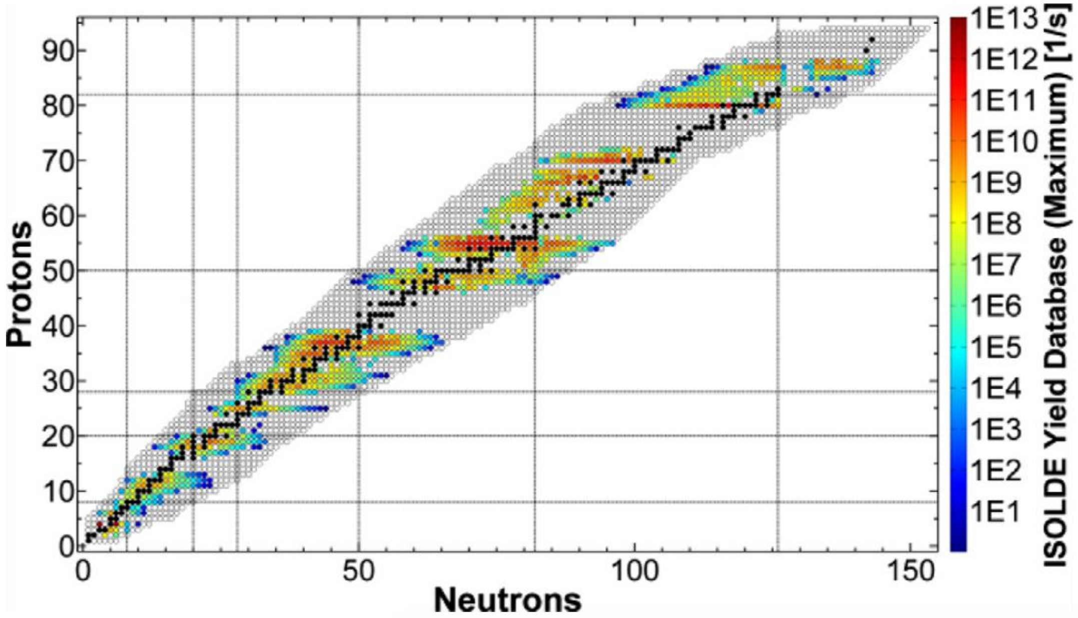
A. Gottberg

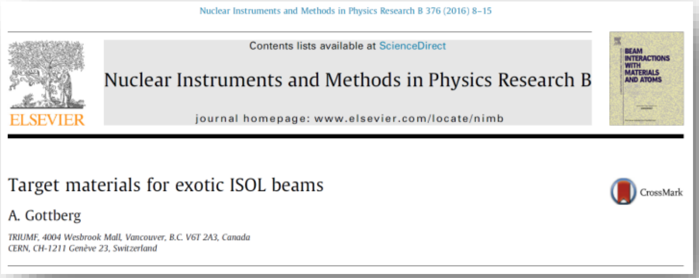
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada
CERN, CH-1211 Genève 23, Switzerland

Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
3.
4.

- The effects of chemical reactions and low volatility is apparent in the extracted yields
- For a $t_{1/2}$=5 ms isotope, a 100 ms delay is a loss factor of 10^6




Nuclear Instruments and Methods in Physics Research B 376 (2016) 8–15
Contents lists available at ScienceDirect
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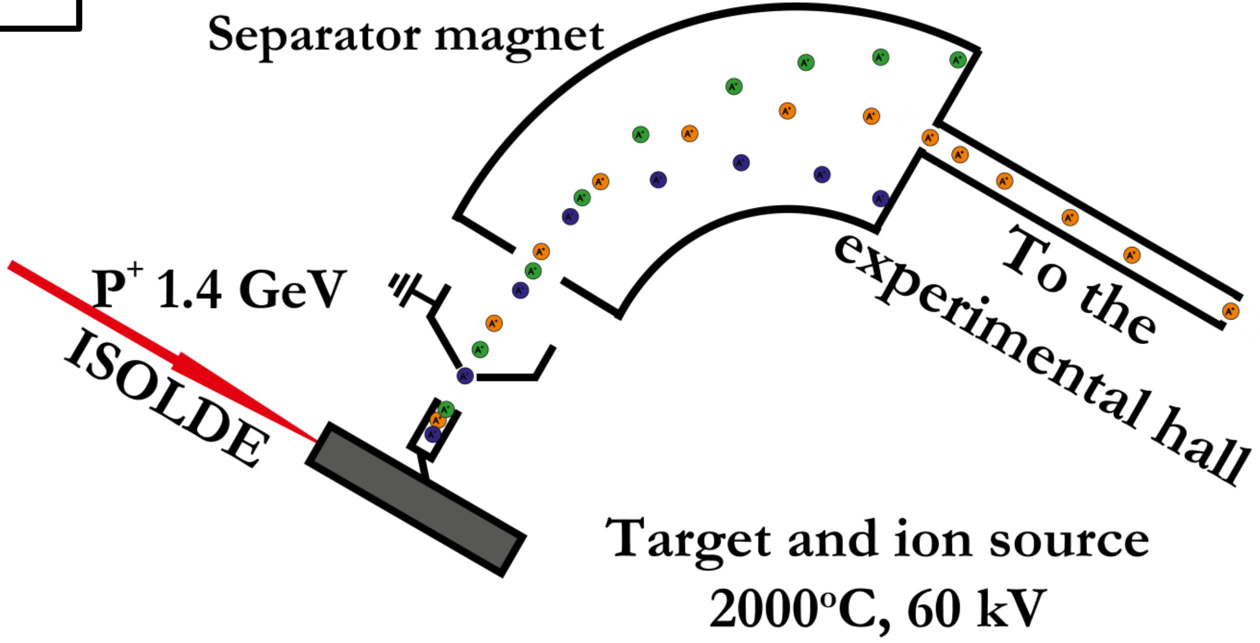
journal homepage: www.elsevier.com/locate/nimb
ELSEVIER
Target materials for exotic ISOL beams
A. Gottberg
TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3, Canada
CERN, CH-1211 Genève 23, Switzerland

Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
3. Ion beam "quality"
4.

$$\text{Bending radius} = \frac{\text{Mass x Velocity}}{\text{Charge x Magnetic field}}$$

The transverse emittance and the longitudinal energy spread affect the effectiveness of mass separation



Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
3. Ion beam "quality"
4.

Nuclear Instruments and Methods 186 (1981) 275–293
North-Holland Publishing Company

Part V. Ion sources techniques

PROGRESS IN ION SOURCE DEVELOPMENT FOR ON-LINE SEPARATORS

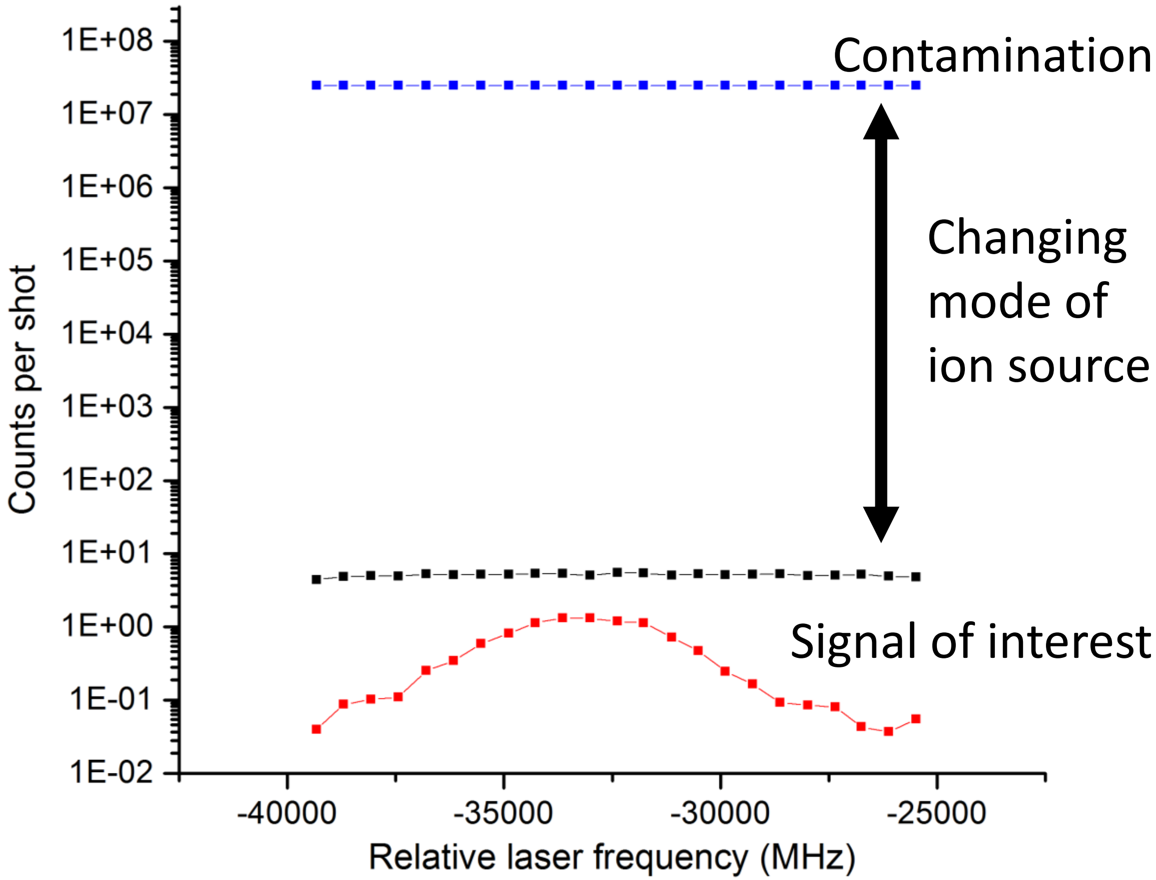
R. KIRCHNER
GSI Darmstadt, Postfach 110541, D-6100 Darmstadt 11, FRG

1981

"…the development of ion sources during the last decade has made most elements accessible to an effective *ionization* and consequently has led to the situation, where successful application to ISOL depends almost exclusively on the extent to which the release problems have been overcome."

Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
3. Ion beam “quality”
4. Chemical selectivity

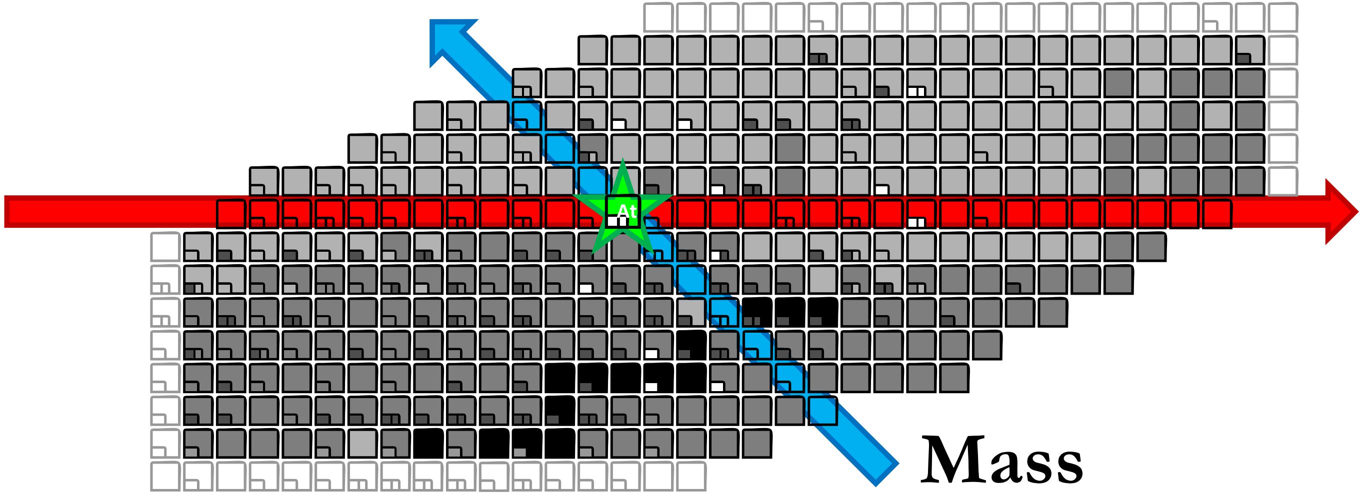


Chemical selectivity has been at the heart of ISOL ion source development over the last three decades

1. Efficiency
2. Extraction/ionization time
3. Ion beam “quality”
4. Chemical selectivity

Isotope specific purification

Element selectivity



Mass selectivity

Images by S. Rothe

1. What is a thick target ISOL facility?
2. What does this mean for ion source requirements?
3. Ion source types: challenges, development highlights and directions for the future

   3.1 Surface ion sources

1971

NUCLEAR INSTRUMENTS AND METHODS 96 (1971) 437–439; © NORTH-HOLLAND PUBLISHING CO.

A NEW METHOD FOR RARE-EARTH ISOTOPE SEPARATION

G. J. BEYER, E. HERRMANN, A. PIOTROWSKI, V. J. RAIKO and H. TYRROFF

Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, Dubna, USSR

1973

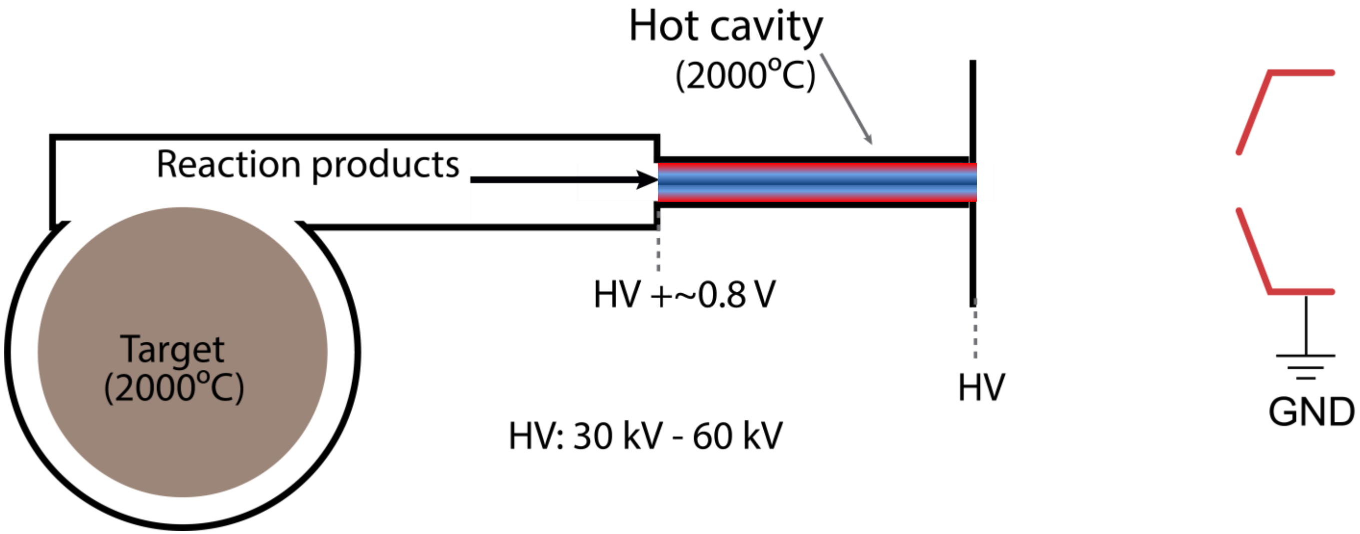
NUCLEAR INSTRUMENTS AND METHODS 106 (1973) 83–87; © NORTH-HOLLAND PUBLISHING CO.

A HIGH TEMPERATURE ION SOURCE FOR ISOTOPE SEPARATORS*

P. G. JOHNSON, A. BOLSON and C. M. HENDERSON

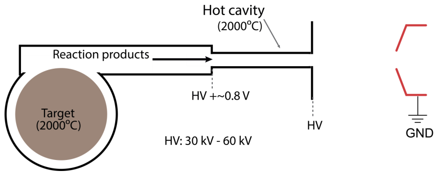
Lawrence Livermore Laboratory, University of California,
Livermore, California 94550, U.S.A.

Surface ion sources



Ionization on the surface of the hot cavity

$$\text{Efficiency} \approx \frac{\alpha}{1+\alpha}$$



R. Kirchner: On the thermoionization in hot cavities
https://doi.org/10.1016/0168-9002(90)90377-I

Atom-wall interactions

Work function

Effective ionization potential

$$\alpha = N\varepsilon e^{\left(\phi - IP/_{kT}\right)}$$

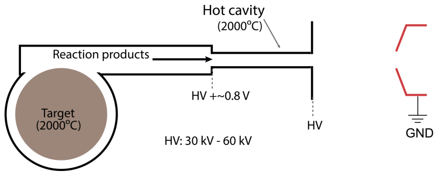
Ion survival probability

Boltzmann constant and temperature

The "hot cavity effect": a potential trough along the length of the cavity resulting from thermal electron emission has a multiplying effect

Ionization on the surface of the hot cavity

$$\text{Efficiency} \approx \frac{\alpha}{1+\alpha}$$



R. Kirchner: On the thermoionization in hot cavities
https://doi.org/10.1016/0168-9002(90)90377-I

Atom-wall interactions

Work function

Effective ionization potential

$$\alpha = N\varepsilon e^{\left(\phi - IP/kT\right)}$$

Ion survival probability

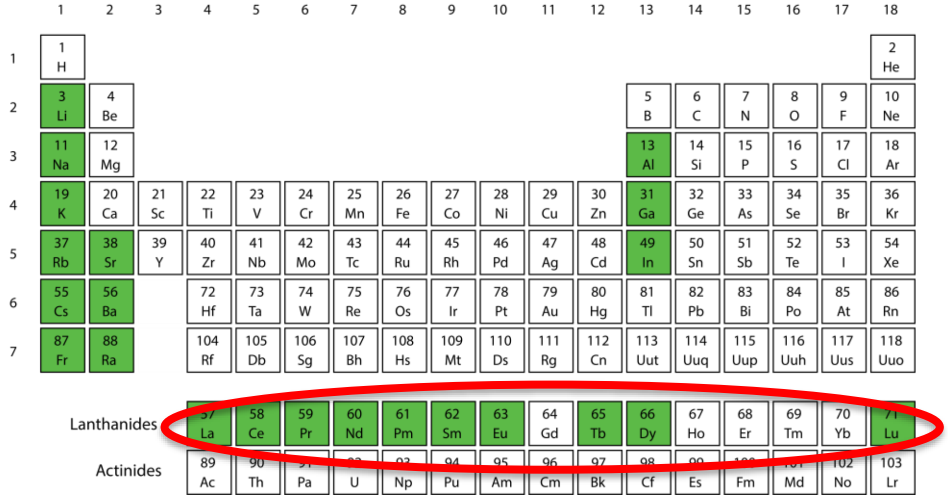
Boltzmann constant and temperature

Increasing the work function increases the ionization efficiency if $N\varepsilon$ are preserved:
Sufficient thermal electron emission must be maintained

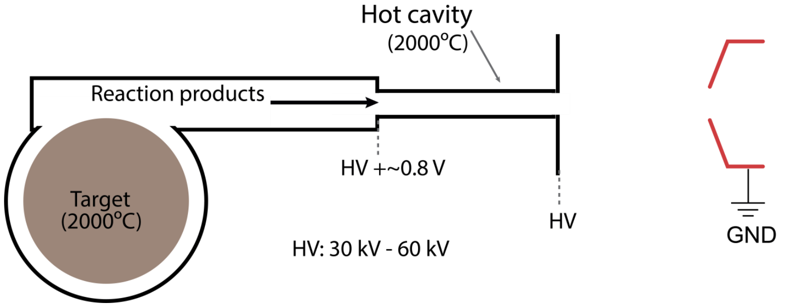
Surface ion sources

1. Efficiency: ionization potential and material dependent
2. Extraction/ionization time: ~100 μs (not considering sticking times)
3. Chemical selectivity: element dependent

Often applied for:

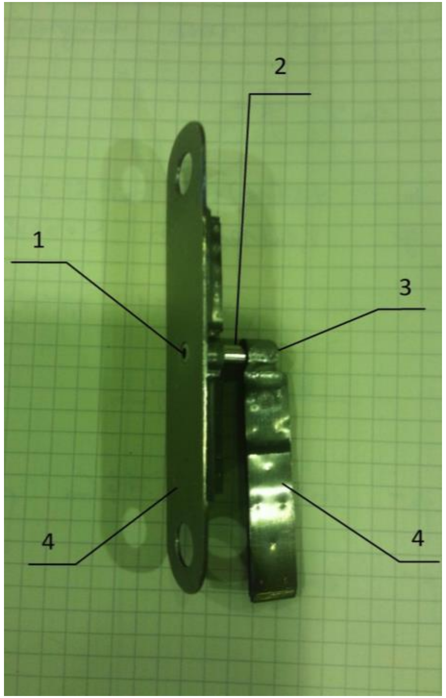


+ molecules



Surface ion sources: development highlight

PNPI



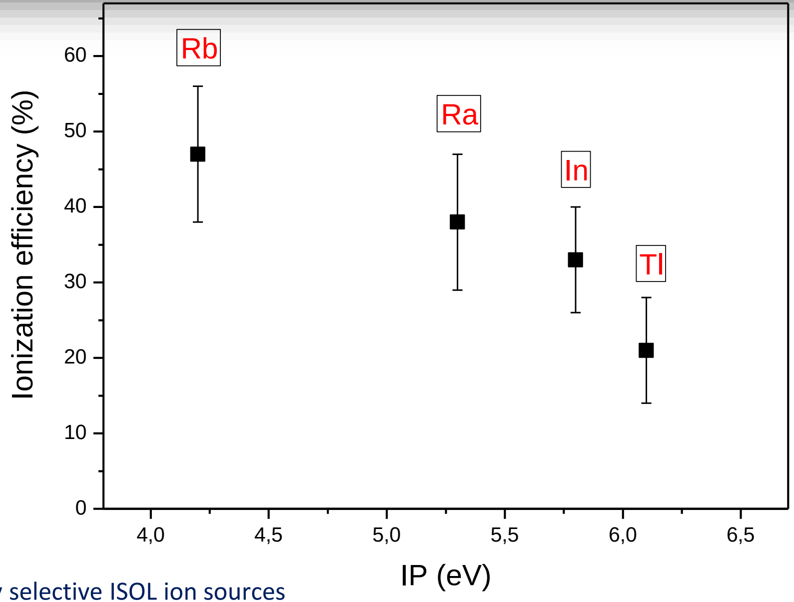
Single crystal tungsten cavity $\phi \approx 5$ eV

2400°C

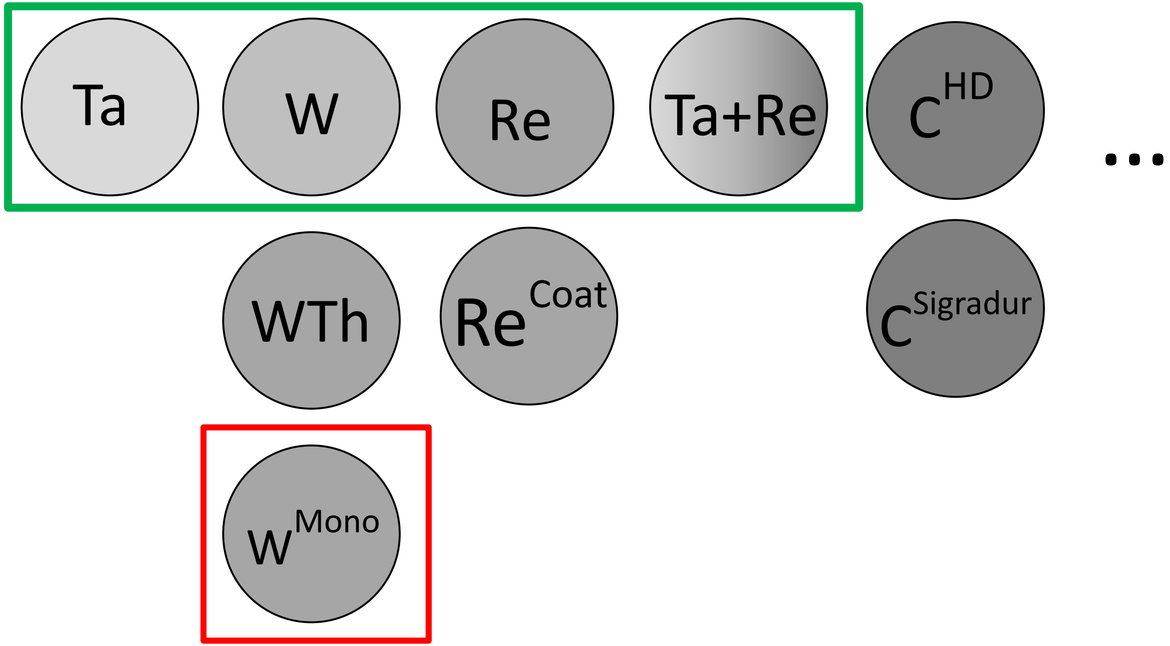
AIP Review of Scientific Instruments

The radioisotope complex project "RIC-80" at the Petersburg Nuclear Physics Institute

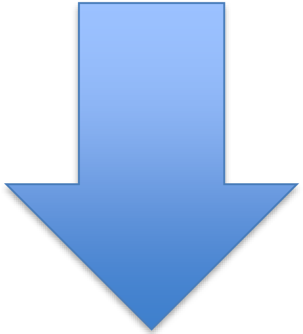
V. N. Panteleev, A. E. Barzakh, L. Kh. Batist, D. V. Fedorov, V. S. Ivanov, F. V. Moroz, P. L. Molkanov, S. Yu. Orlov, and Yu. M. Volkov



Development prospects: Materials!



Increased options



Additional element specific optimization opportunities

Outline

1. What is a thick target ISOL facility?

2. What does this mean for ion source requirements?

3. Ion source types: challenges, development highlights and directions for the future

    3.1 Surface ion sources

    3.2 FEBIAD type ion sources

FEBIAD-type ion sources: milestones

FEBIAD: Forced Electron Beam Induced Arc Discharge

1976 The first FEBAID

NUCLEAR INSTRUMENTS AND METHODS 139 (1976) 291–296; © NORTH-HOLLAND PUBLISHING CO.

A NOVEL ISOL ION SOURCE

R. KIRCHNER* and E. ROECKL

GSI Darmstadt, D-61 Darmstadt 1, Postfach 541, W. Germany

A new plasma ion source of Nielsen-type geometry is described permitting operation as normal arc discharge, forced electron beam induced arc discharge or as surface ionization source. Off-line and on-line performances with halogen, noble gas and alkali elements are discussed.

1992

Introduction of selectivity

Nuclear Instruments and Methods in Physics Research B70 (1992) 160–164
North-Holland

NIM B
Beam Interactions with Materials & Atoms

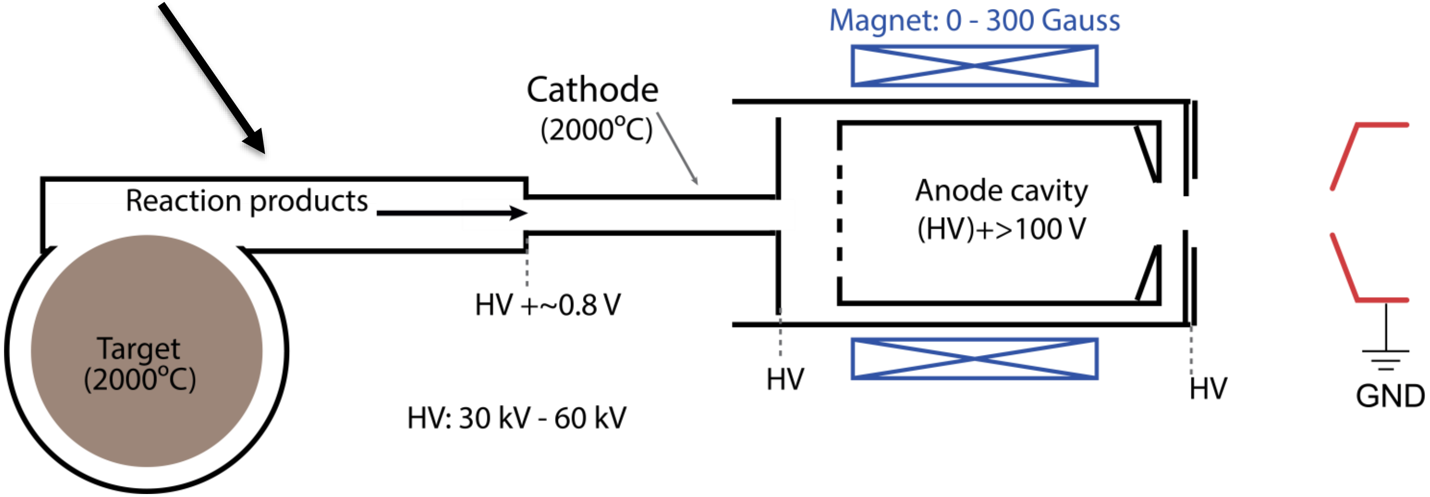
Ion source with combined cathode and transfer line heating

S. Sundell, H. Ravn and the ISOLDE Collaboration

CERN, CH-1211 Geneva 23, Switzerland

FEBIAD: Forced Electron Beam Induced Arc Discharge

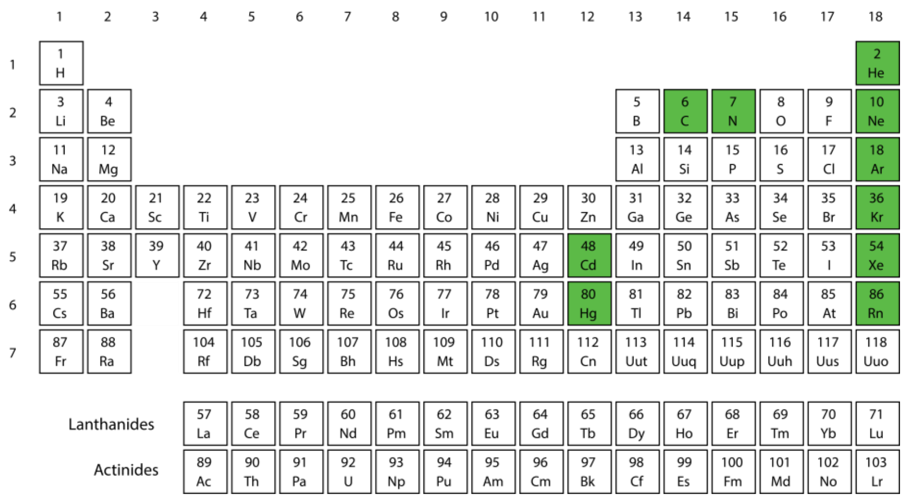
Selectivity introduced through temperature control of the transfer line



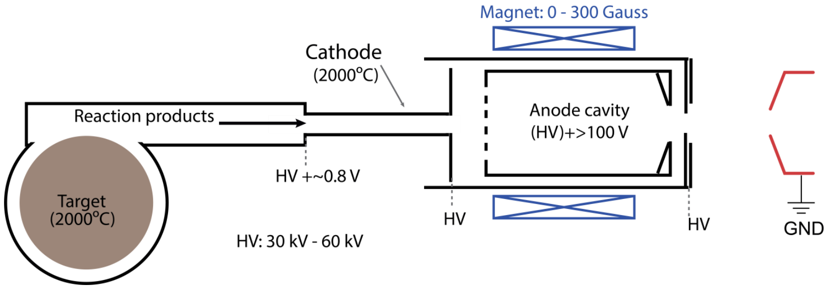
FEBIAD-type ion sources

1. Efficiency: ~universal typically 1-50 %
2. Extraction/ionization time: ~10-100 ms (neglecting sticking times)
3. Chemical selectivity: Introduced via transfer line development

Selective operation for:



Dedicated arc discharge ion source for ISOL: operation over a range of pressures down to 10^{-5} mbar



FEBIAD: Forced Electron Beam Induced Arc Discharge

2010

REVIEW OF SCIENTIFIC INSTRUMENTS **81**, 02A906 (2010)

Development of high efficiency Versatile Arc Discharge Ion Source at CERN ISOLDE[a)]

L. Penescu,[b)] R. Catherall, J. Lettry, and T. Stora
CERN, CH-1211, Geneva 23, Switzerland

(Presented 24 September 2009; received 21 September 2009; accepted 11 November 2009; published online 19 February 2010)

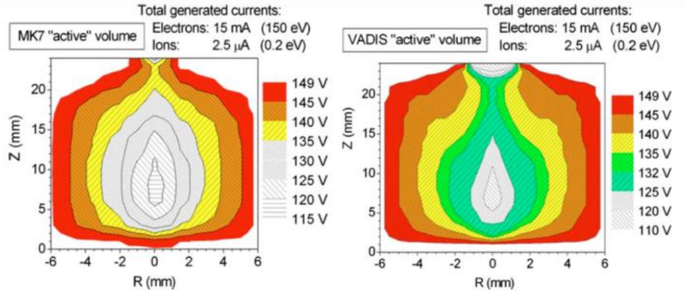
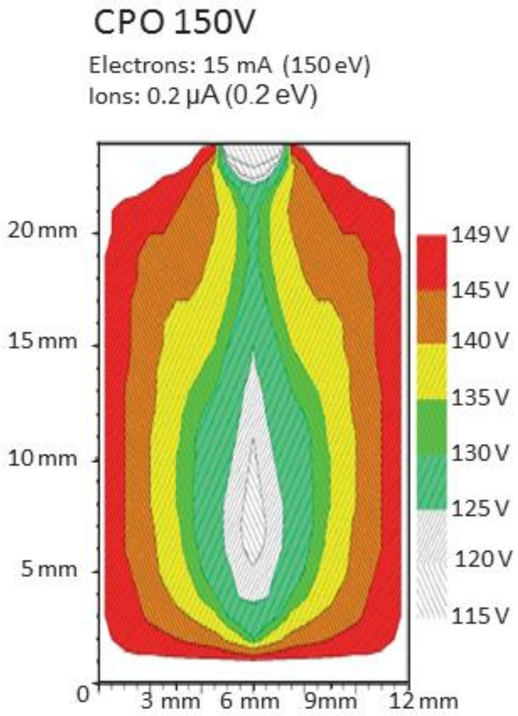


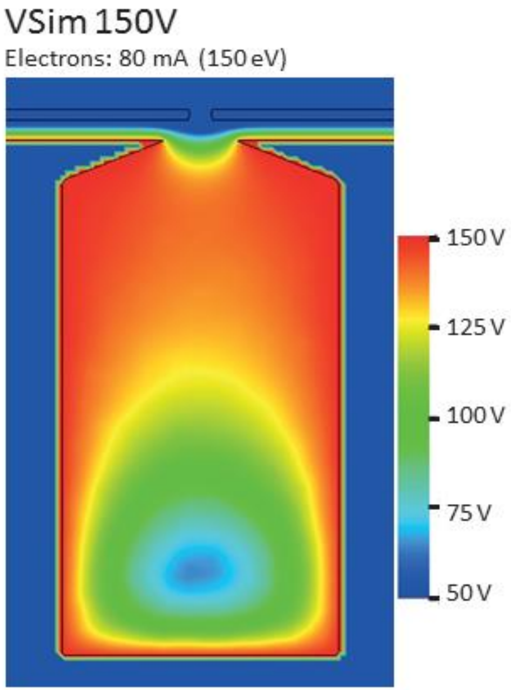
FIG. 3. (Color online) Potential contours inside MK7 (left) and MK5/VADIS (right) that can serve to estimate the active volumes and to justify

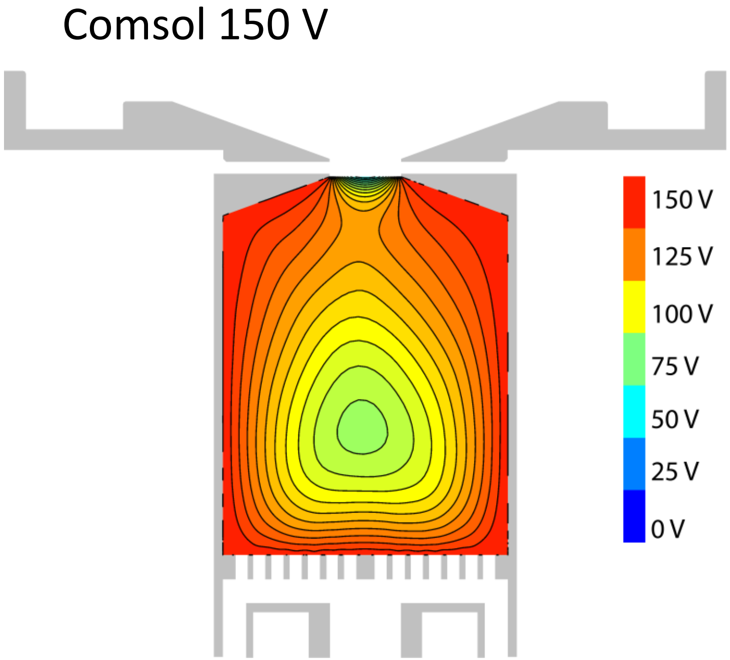
Simulations and testing improved understanding of FEBIAD anode geometries at ISOLDE, the Standardised source was renamed the VADIS

Simulation validation

Off-line and on-line ion source tests ongoing







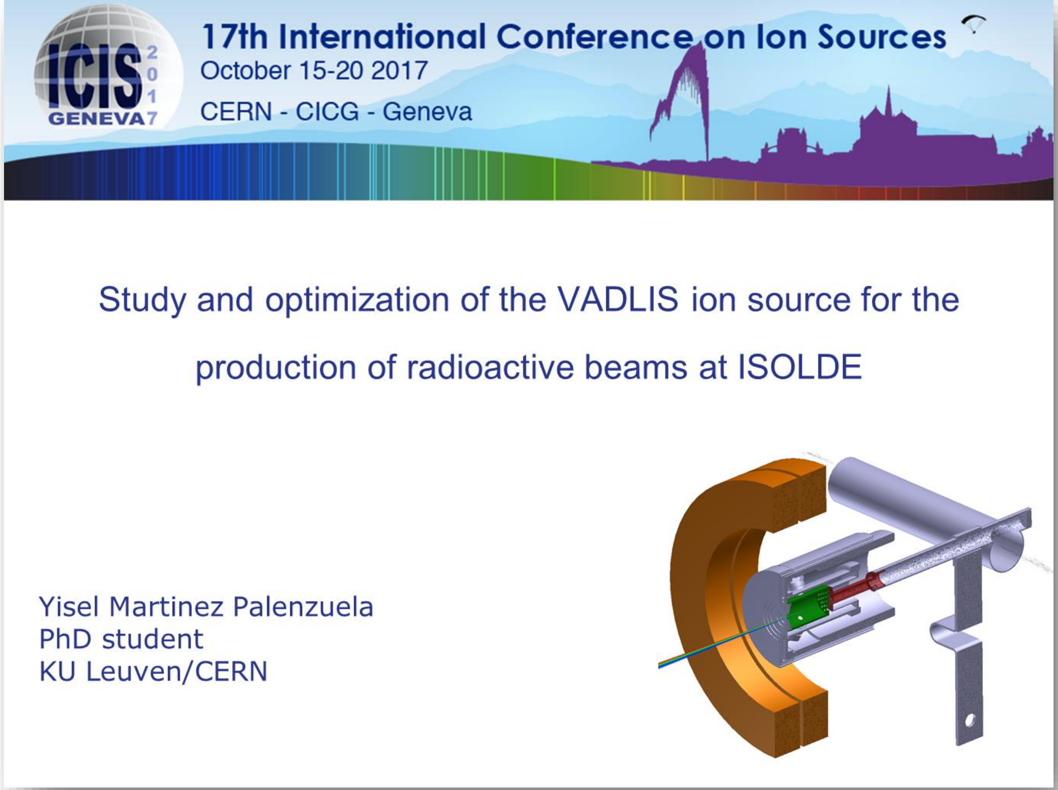
Simulation and characterization

ISOLDE

KU LEUVEN

Y. Martinez

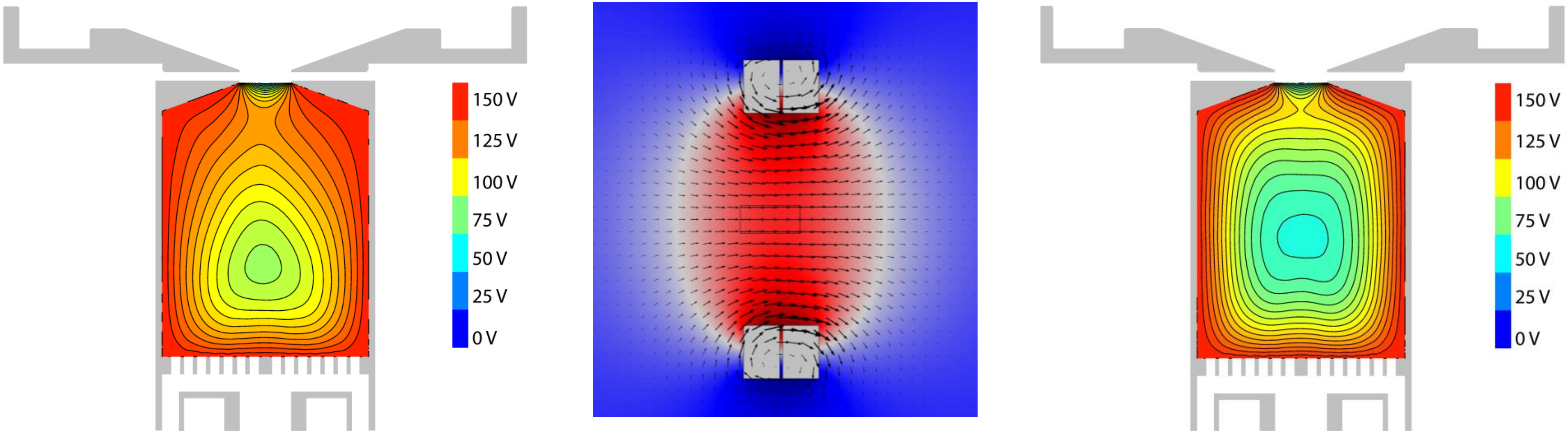
12:10 Wednesday



Simulation and characterization

TRIUMF

Influence of the magnetic field



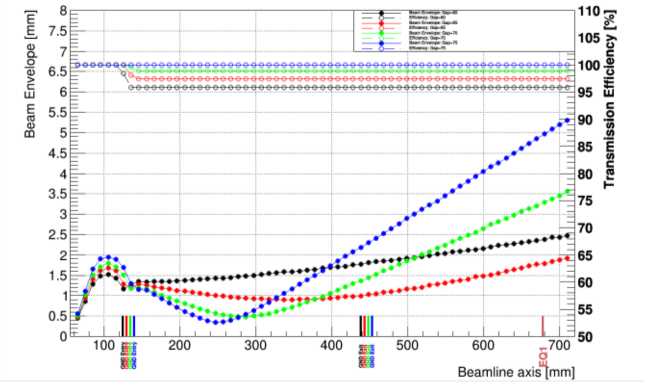
Comsol

PhD of F. Maldonado

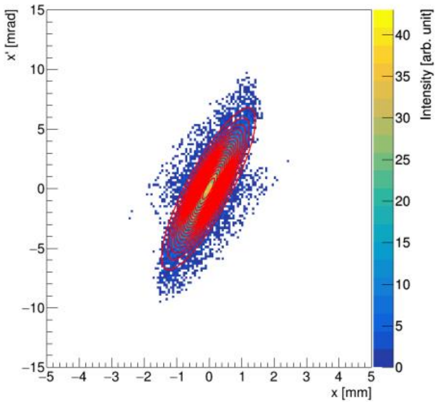
"Observable values" extracted for surface and FEBIAD ion sources

- Emittance
- Ion beam envelope

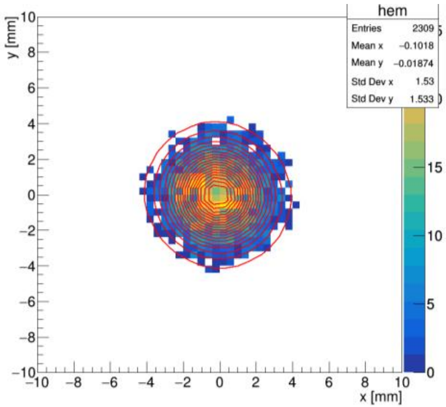
Simulation validation ongoing at the ISAC test stand



Ion beam envelope



Horizontal emittance



Ion beam profiles

PhD of F. Maldonado

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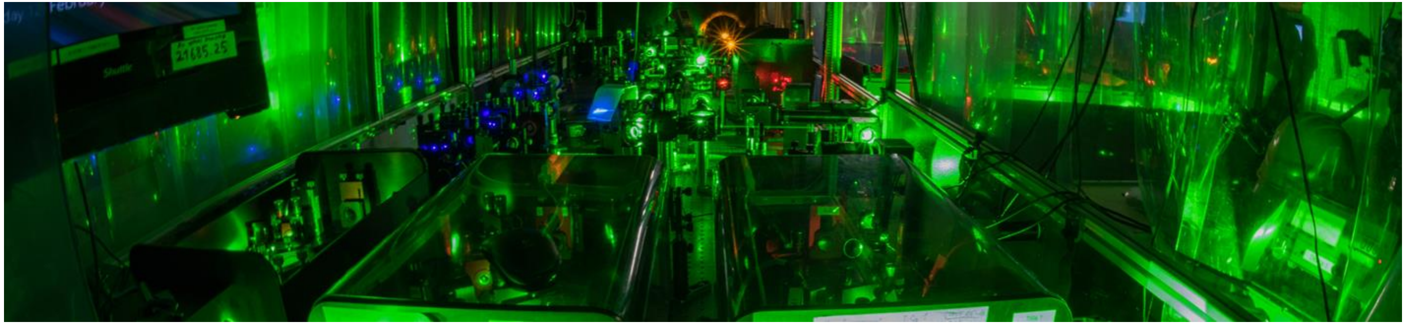
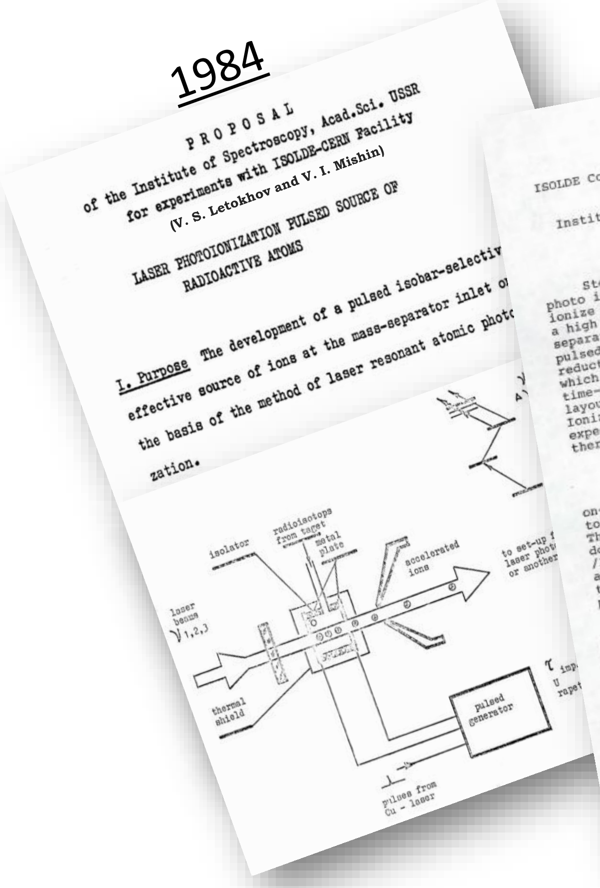
   3.2 FEBIAD type ion sources

   3.3 RILIS



RILIS (Resonance ionization laser ion source): origins

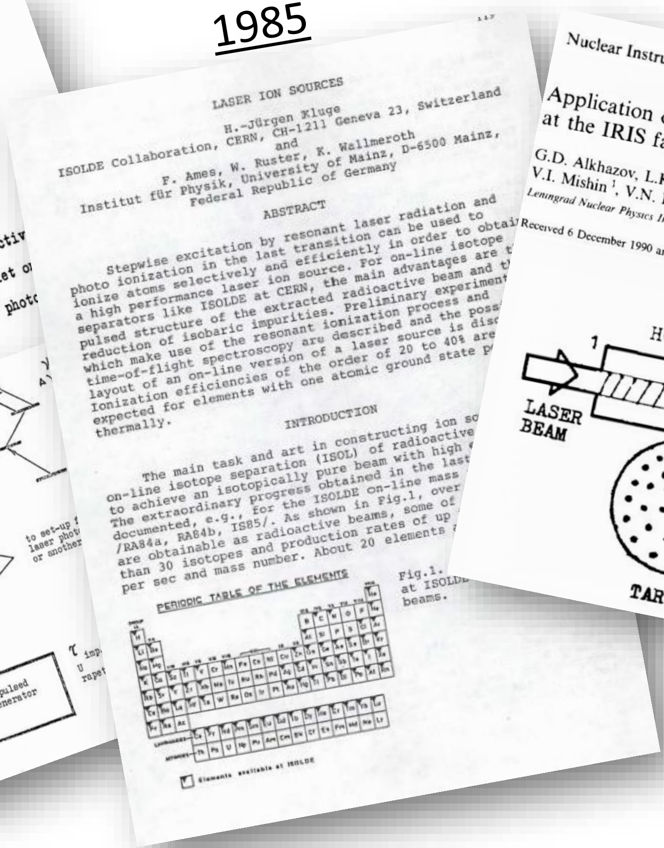
1984


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-selectiv
effective source of ions at the mass-separator inlet o
the basis of the method of laser resonant atomic photo
zation.

1985


LASER ION SOURCES

H.-Jürgen Kluge
ISOLDE Collaboration, CERN, CH-1211 Geneva 23, Switzerland
and
F. Ames, W. Ruster, K. Wallmeroth
Institut für Physik, University of Mainz, D-6500 Mainz,
Federal Republic of Germany

ABSTRACT

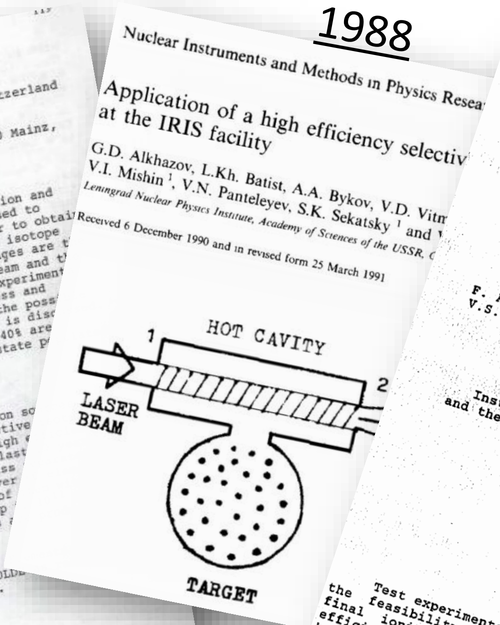
Stepwise excitation by resonant laser radiation and photo ionization in the last transition can be used to ionize atoms selectively and efficiently in order to obtai a high performance laser ion source. For on-line isotope separators like ISOLDE at CERN, the main advantages are t pulsed structure of the extracted radioactive beam and t reduction of isobaric impurities. Preliminary experiment which make use of the resonant ionization process and time-of-flight spectroscopy are described and the possi layout of an on-line version of a laser source is disc Ionization efficiencies of the order of 20 to 40% are expected for elements with one atomic ground state p thermally.

INTRODUCTION

The main task and art in constructing ion so on-line isotope separation (ISOL) of radioactive to achieve an isotopically pure beam with high e The extraordinary progress obtained in the last documented, e.g., for the ISOLDE on-line mass /RA84a, RA84b, IS85/. As shown in Fig.1, over are obtainable as radioactive beams, some of than 30 isotopes and production rates of up per sec and mass number. About 20 elements

Fig.1. at ISOLD beams.

1988

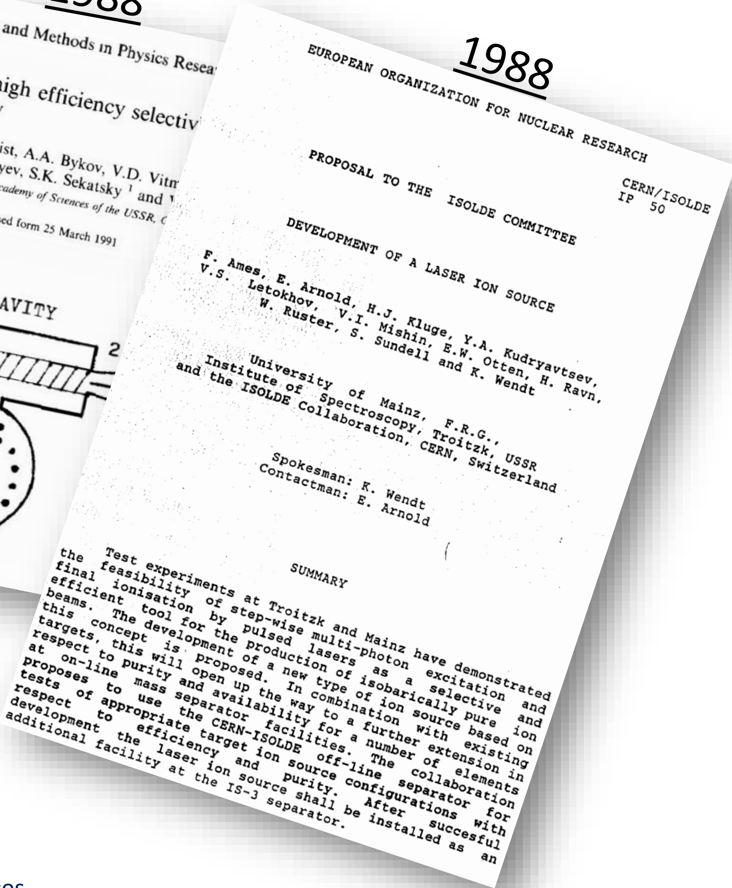

Nuclear Instruments and Methods in Physics Resea

Application of a high efficiency selectiv
at the IRIS facility

G.D. Alkhazov, L.Kh. Batist, A.A. Bykov, V.D. Vitm
V.I. Mishin [1], V.N. Panteleyev, S.K. Sekatsky [1] and
Leningrad Nuclear Physics Institute, Academy of Sciences of the USSR,

Received 6 December 1990 and in revised form 25 March 1991

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

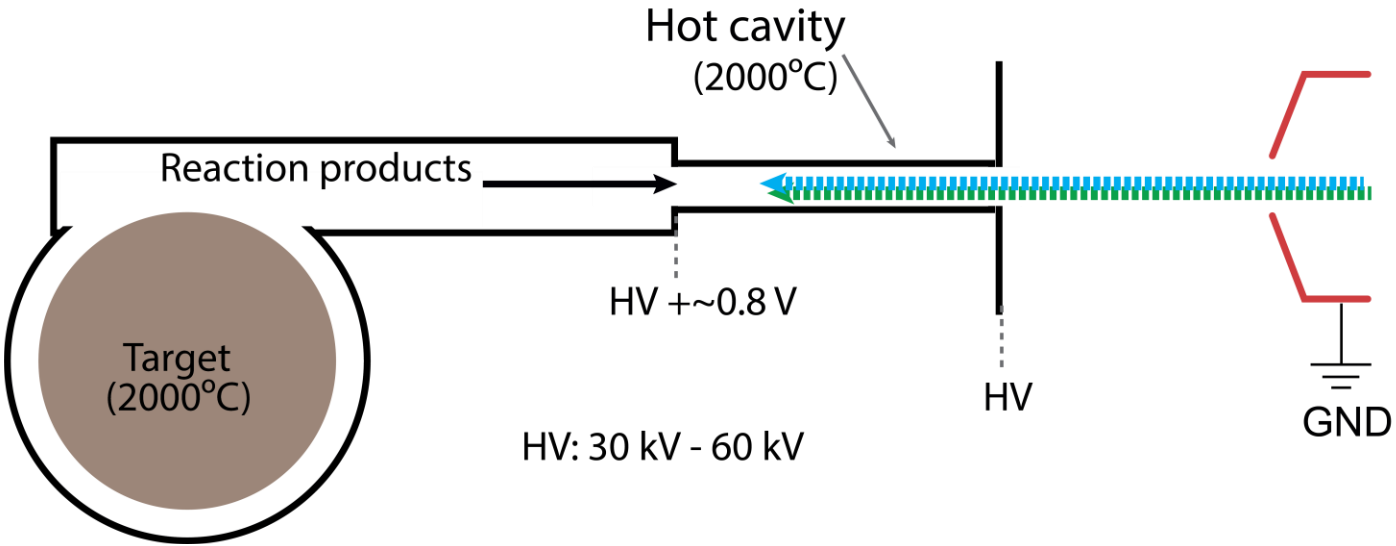
University of Mainz, F.R.G.,
Institute of Spectroscopy, Troitzk, USSR
and the ISOLDE Collaboration, CERN, Switzerland

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 successful development the laser ion source shall be installed as an additional facility at the IS-3 separator.

Resonance ionization laser ion sources (RILIS)

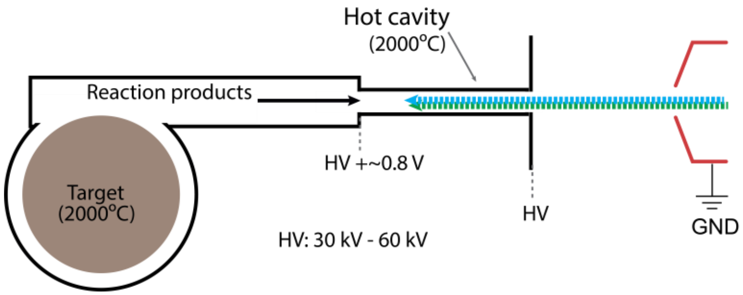


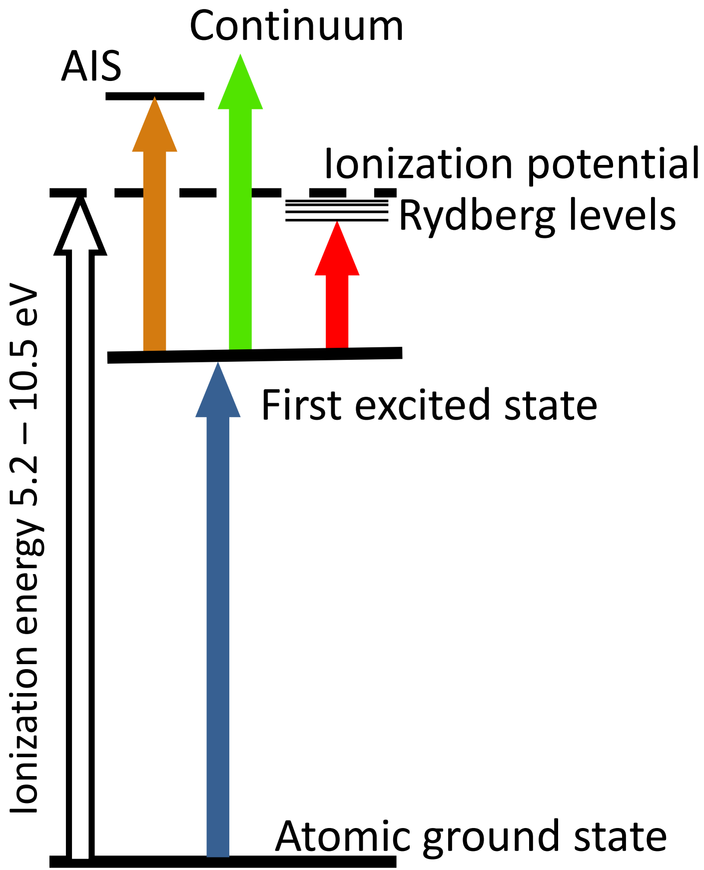
Stepwise resonance ionization

Multiple tuneable lasers target element unique atomic resonances

Ionizing step:

- Autoionizing state
- Ionization to the continuum
- Ionization via Rydberg levels





Stepwise resonance ionization

Multiple tuneable lasers target element unique atomic resonances

Ionizing step:
- Autoionizing state
- Ionization to the continuum
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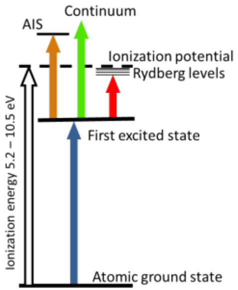
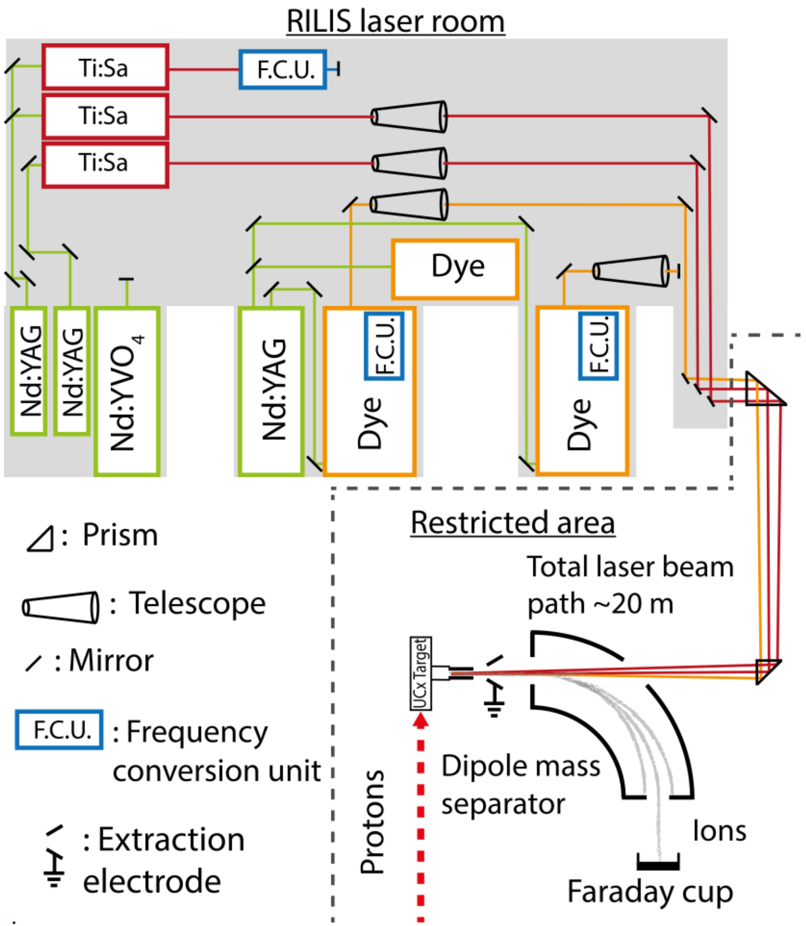
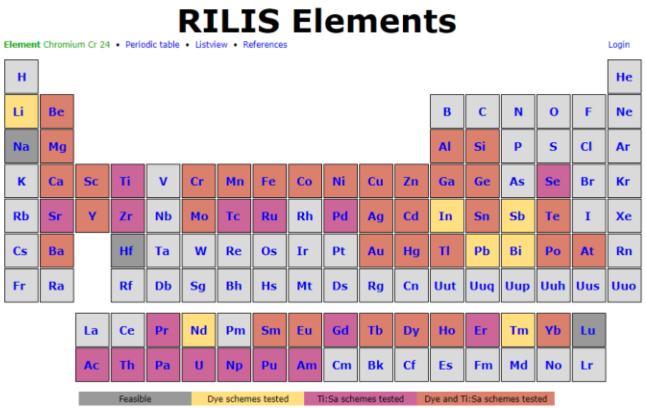


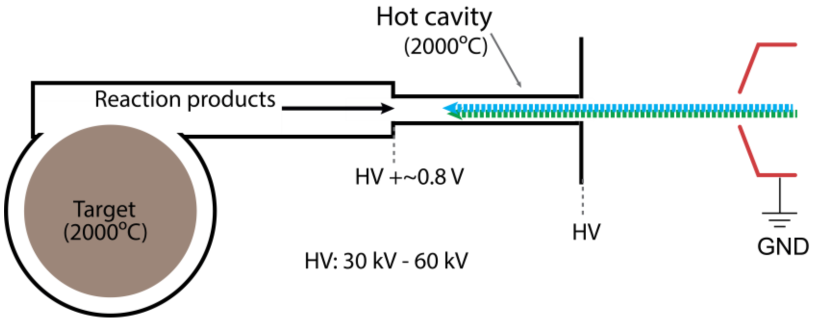
>75 % of ISOLDE physics each year
>60 % of TRIUMF physics each year



1. Efficiency: ~1-40%
2. Extraction/ionization time ~100 μs (not considering sticking times)
3. Chemical selectivity: process is selective, may not be the only ionization mechanism

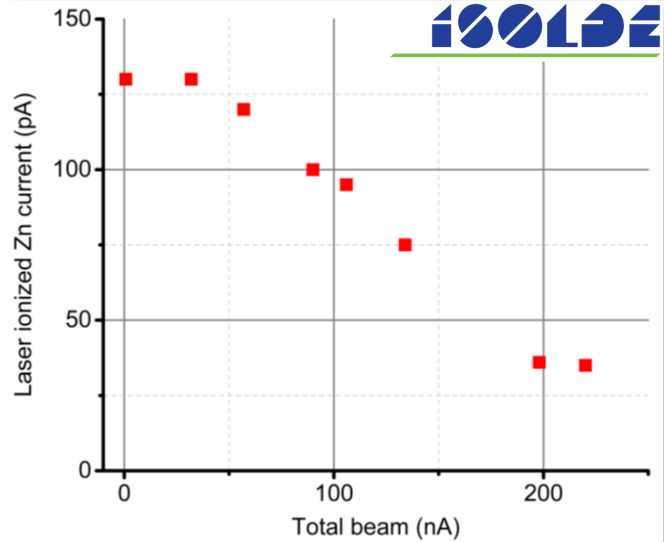
Element selective→ an ionization scheme must be developed for each element



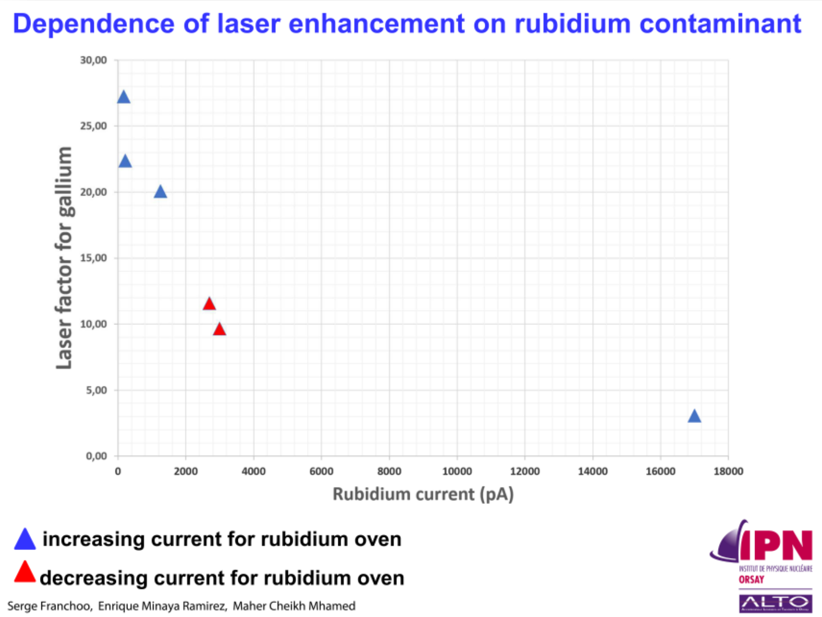


https://riliselements.web.cern.ch/riliselements/index.php

RILIS/general: upcoming challenges

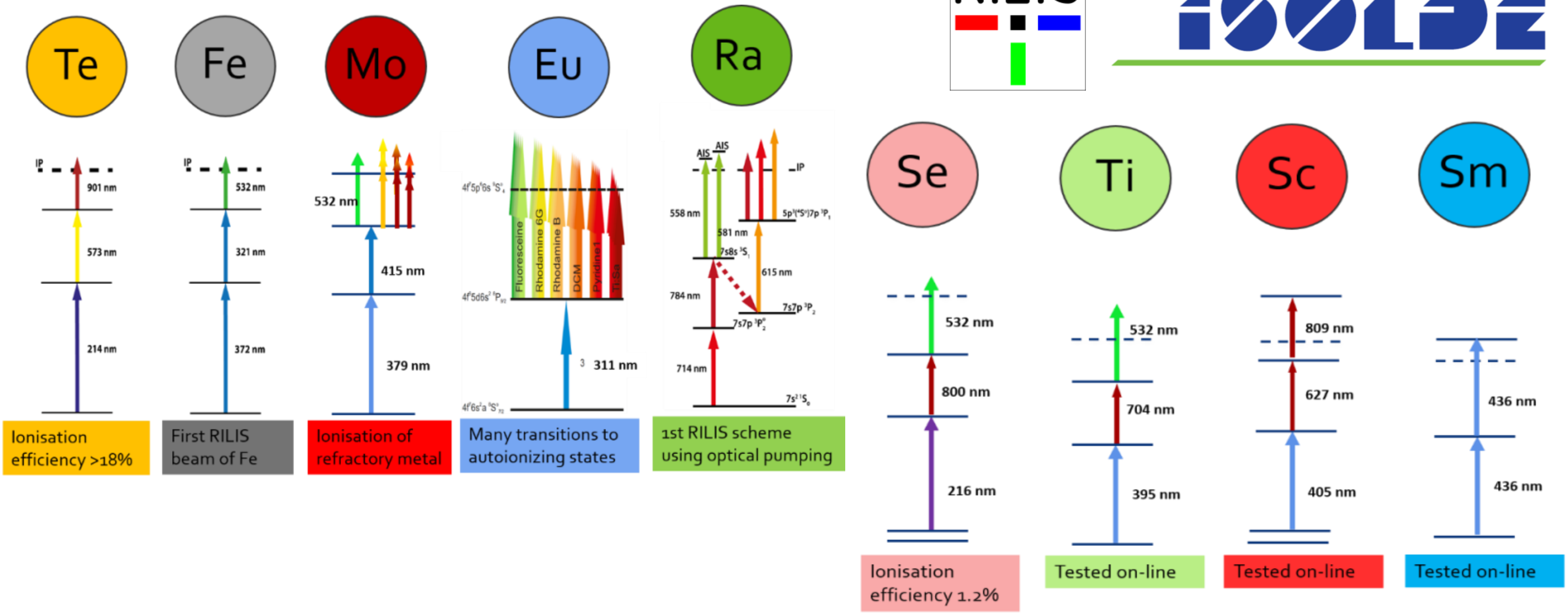


Decrease in laser ionized Zn observed while heating a Rb excess mass marker. Factor of ~4 reduction in laser ion extraction with a total beam of 200 nA.



The efficiency of the ion survival/extraction can be severely reduced by total ion currents >100 nA. Higher limit for FEBIADS though more universal ionization method. A potential issue for new target materials and "high power" facilities.

Ionization scheme development at the ISOLDE RILIS 2016-2017



ICIS 2017 Poster:

Resonant Ionization of Atomic Tellurium with Ti:Sapphire Lasers

Y. Liu[1], T. Kieck[2], D. W. Stracener[1], K. D. A. Wendt[2]

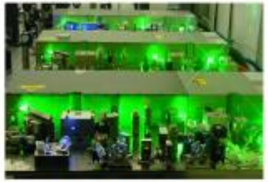
[1]Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[2]Institut für Physik, Johannes Gutenberg-Universität Mainz, D-55128 Mainz, Germany

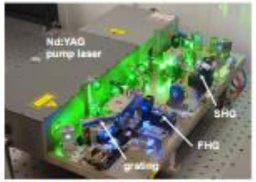
MOTIVATION

- Resonance ionization laser ion sources have become essential tools for the production of isobarically pure radioactive ion beams for nuclear research [1]
- Efficient resonant ionization of beams of atomic tellurium using a combination of Ti:Sapphire and dye lasers has been recently reported [2]. However, the ionization schemes are not applicable to laser ion sources equipped only with Ti:Sapphire lasers
- This study investigates potential resonant ionization schemes of tellurium using only Ti:Sapphire lasers

LASER SYSTEM

Three Ti:Sapphire lasers, three Q-switched, frequency-doubled Nd:YAG pump lasers, and frequency doubling (SHG), tripling (THG), and quadrupling (FHG) units





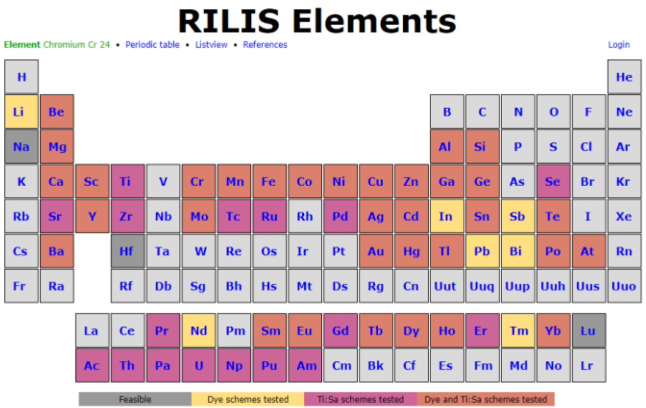
- Nd:YAG pump lasers: 18-20 W max. power
- Repetition rate: 10 kHz
- Ti:Sapphire laser pulse width: 25 to 30 ns

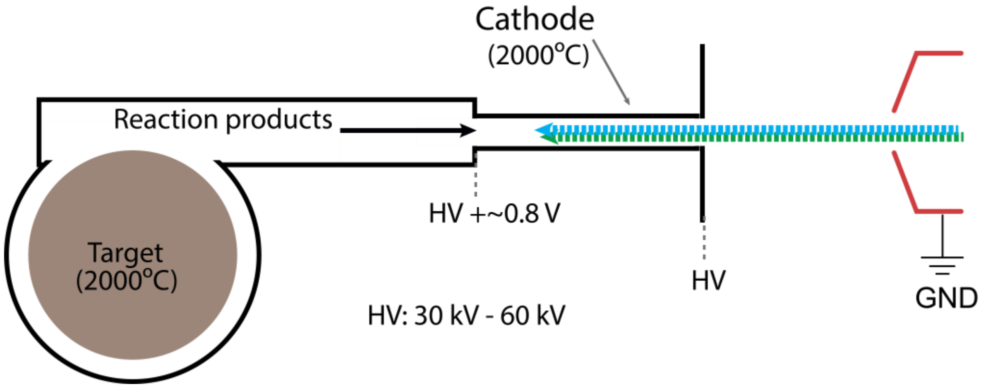
Figure 1. Photos of the Ti:Sapphire laser system for the RILIS at ORNL.

Tuesday #72 Y. Liu

1. Efficiency: ~1-40%
2. Extraction/ionization time ~100 μs (not considering sticking times)
3. Chemical selectivity: process is selective, may not be the only ionization mechanism

Element selective→ an ionization scheme must be developed for each element





https://riliselements.web.cern.ch/riliselements/index.php

RILIS developments: cavity investigations

2016

Nuclear Instruments and Methods in Physics Research A 830 (2016) 520–525

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Contents lists available at ScienceDirect

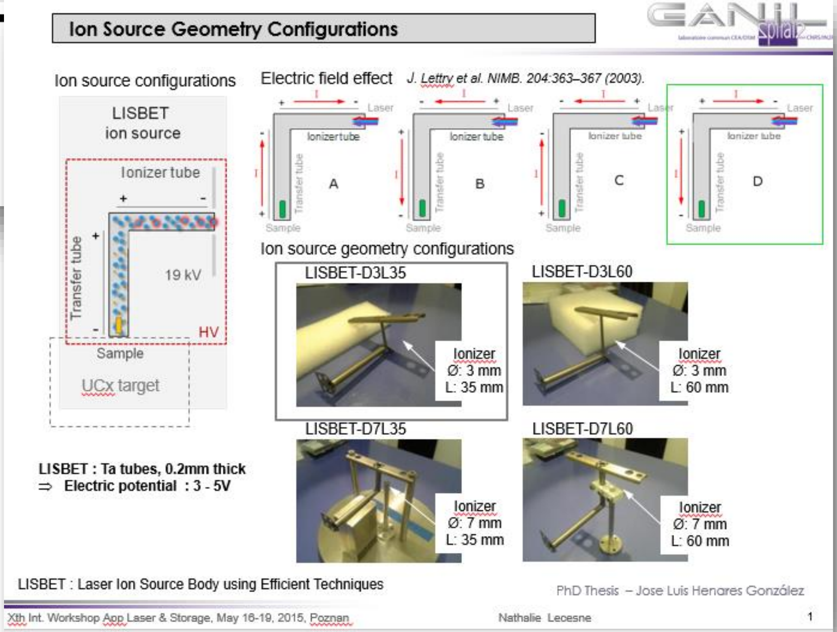
Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

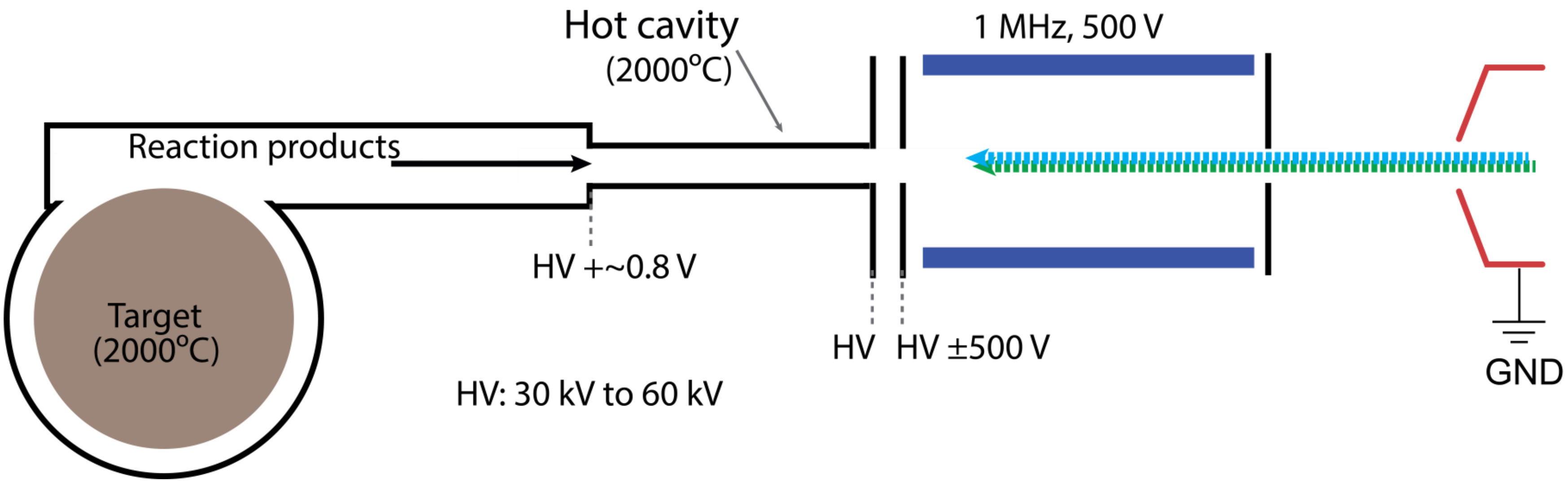
Hot-cavity studies for the Resonance Ionization Laser Ion Source

J.L. Henares [a,*], N. Lecesne [a], L. Hijazi [a], B. Bastin [a], T. Kron [b], J. Lassen [c], F. Le Blanc [d], R. Leroy [a], B. Osmond [a], S. Raeder [b,e], F. Schneider [b], K. Wendt [b]

GANIL spiral2 laboratoire commun CEA/DSM CNRS/IN2P3



RILIS developments: LIST/IG-LIS



2003

Available online at www.sciencedirect.com
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Nuclear Instruments and Methods in Physics Research B 204 (2003) 331–335
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

A novel scheme for a highly selective laser ion source

K. Blaum [a,*], C. Geppert [b], H.-J. Kluge [a], M. Mukherjee [a], S. Schwarz [c], K. Wendt [b]

[a] *GSI Darmstadt, Planckstraße 1, 64291 Darmstadt, Germany*
[b] *Inst. f. Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany*
[c] *NSCL, Michigan State University, East Lansing, MI 48824-1321, USA*

Laser Ion Source (LIST) and Trap/Ion Guide-Laser Ion Source (IG-LIS)

- Up to 10^6 in isobaric suppression
- 1-2 orders of magnitude of loss in the ion beam of interest
- Scope for increased efficiency

JG|U RILIS ISOLDE TRIUMF

2013

Nuclear Instruments and Methods in Physics Research B 317 (2013) 417–421
Contents lists available at SciVerse ScienceDirect
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Nuclear Instruments and Methods in Physics Research B
journal homepage: www.elsevier.com/locate/nimb
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

First application of the Laser Ion Source and Trap (LIST) for on-line experiments at ISOLDE

CrossMark

D.A. Fink [a,b,c,*,1], S.D. Richter [d], B. Bastin [e], K. Blaum [b], R. Catherall [a], T.E. Cocolios [a,f], D.V. Fedorov [g], V.N. Fedosseev [a], K.T. Flanagan [f], L. Ghys [h,i], A. Gottberg [a,j], N. Imai [k], T. Kron [d], N. Lecesne [e], K.M. Lynch [a,f], B.A. Marsh [a], T.M. Mendonca [a,l], D. Pauwels [h], E. Rapisarda [a], J.P. Ramos [a,m], R.E. Rossel [a,d], S. Rothe [a,d], M.D. Seliverstov [g,n], M. Sjödin [e], T. Stora [a], C. Van Beveren [h], K.D.A. Wendt [d]

2014

REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 033309 (2014)

CrossMark

An ion guide laser ion source for isobar-suppressed rare isotope beams

Sebastian Raeder,[1,a)] Henning Heggen,[1,2,b)] Jens Lassen,[1,3,c)] Friedhelm Ames,[1] Daryl Bishop,[1] Pierre Bricault,[1] Peter Kunz,[1] Anders Mjøs,[1] and Andrea Teigelhöfer[1,3]
[1]*TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada*
[2]*Institute of Applied Physics, TU Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany*
[3]*Department of Physics and Astronomy, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada*

Can we be more selective?

The selectivity frontier: isotope/isomer specific ionization

The selectivity frontier: isotope/isomer specific ionization

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Gamma and fast-timing spectroscopy of the doubly magic ^{132}Sn and its one- and two-neutron particle/hole neighbours

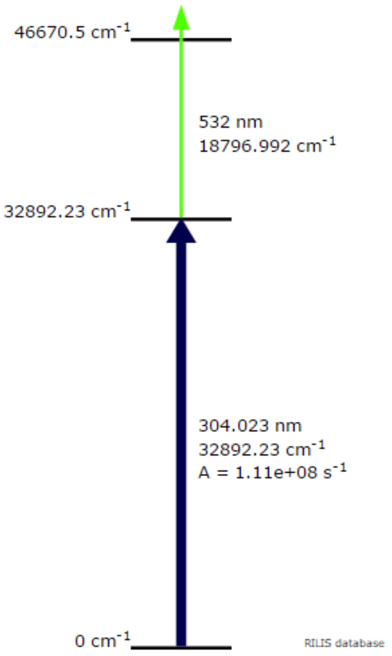
October 12, 2015

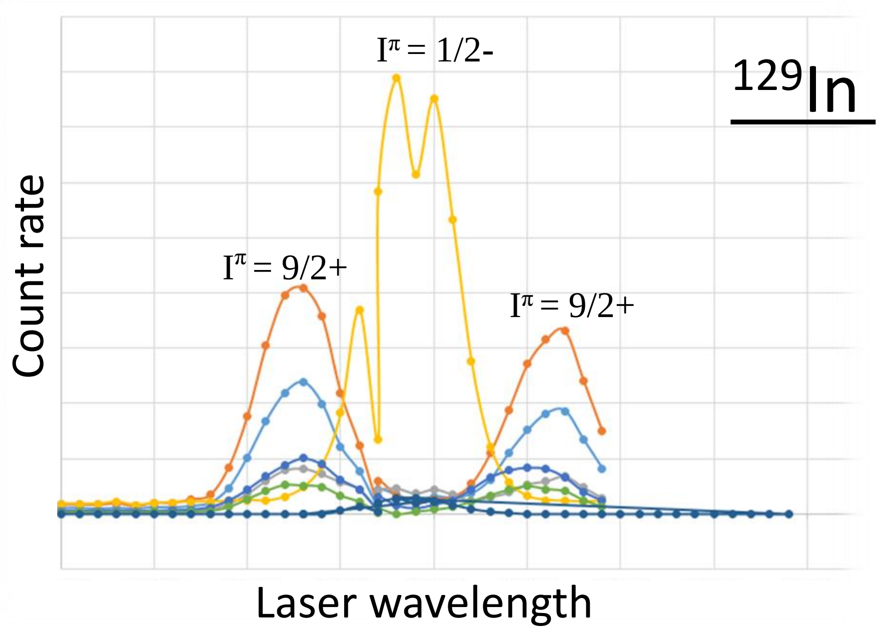
L.M. Fraile[1], A. Korgul[2], A. Gargano[3], A. Aprahamian[4], A. Algora[5], G. Benzoni[6], M.J.G. Borge[7], M. Carmona[1], C. Costache[8], A. Covello[9], H. Duckwitz[10], P. Van Duppen[11], V. Fedosseev[7], G. Fernández-Martínez[12], D. Ghiţă[8], T. Grahn[13,14], P.T. Greenlees[13,14], R. Grzywacz[15,16], C. Henrich[12], P. Hoff[17], M. Huyse[11], T. Ilieva[12], Z. Janas[2], A. Jokinen[13], J. Jolie[10], M. Karny[2], M. Kicińska-Habior[2], Th. Kröll[12], W. Kurcewicz[2], U. Köster[18], S. Lalkovski[19], R. Lică[7], M. Madurga[7], N. Mărginean[8], R. Mărginean[8], B. Marsh[7], C. Mazzocchi[2], C. Mihai[8], R.E. Mihai[8], A.I. Morales[6], K. Moschner[10], S. Nae[8], A. Negret[8], V. Paziy[1], M. Piersa[2], P. Rahkila[13,14], J. Pakarinen[13,14], J.-M. Régis[10], E. Ruchowska[20], K.P. Rykaczewski[16], G. Simpson[21], Ch. Sotty[8], M. Stanoiu[8], M. Stryjczyk[2], O. Tengblad[22], A. Turturica[8], J.M. Udías[1], V. Vedia[1], W.B. Walters[23], N. Warr[10], H. De Witte[11].

In

Isomer selective ionization!

RILIS





^{129}In

ISOLDE Decay Station

Can this be more widely applied?

ICIS 2017 Poster:

Towards Direct *High-Resolution Laser Spectroscopy at Hot Cavity Ion Sources*: Crossed Laser – Atom Beam Interaction in the Laser Ion Source and Trap LIST

JG|U LARISSA JOHANNES GUTENBERG-UNIVERSITÄT MAINZ

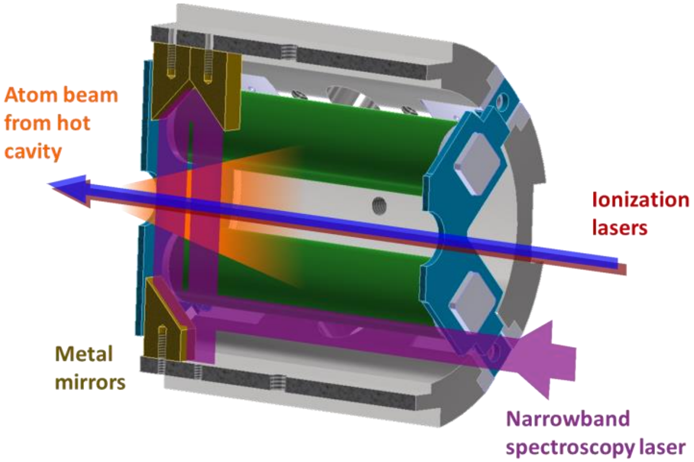
R. Heinke[1], K. Chrysalidis[1,2], V. Fedosseev[2], T. Kieck[1], T. Kron[1], B. Marsh[2], S. Raeder[3], S. Rothe[2], H. Tomita[4], M. Trümper[1] and K. Wendt[1]

ISOLDE

[1]Institute of Physics, Mainz University – [2]Engineering Department, CERN, Geneva – [3]GSI, Darmstadt – [4]Department of Quantum Engineering, Nagoya University

Tuesday #63

R. Heinke



The *Perpendicularly Illuminated Laser Ion Source & Trap* ***PI-LIST***

ICIS 2017 Poster:

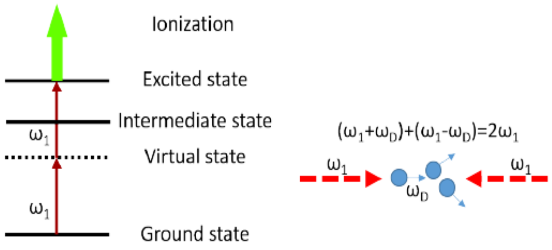
Tuesday #68
K. Chrysalidis

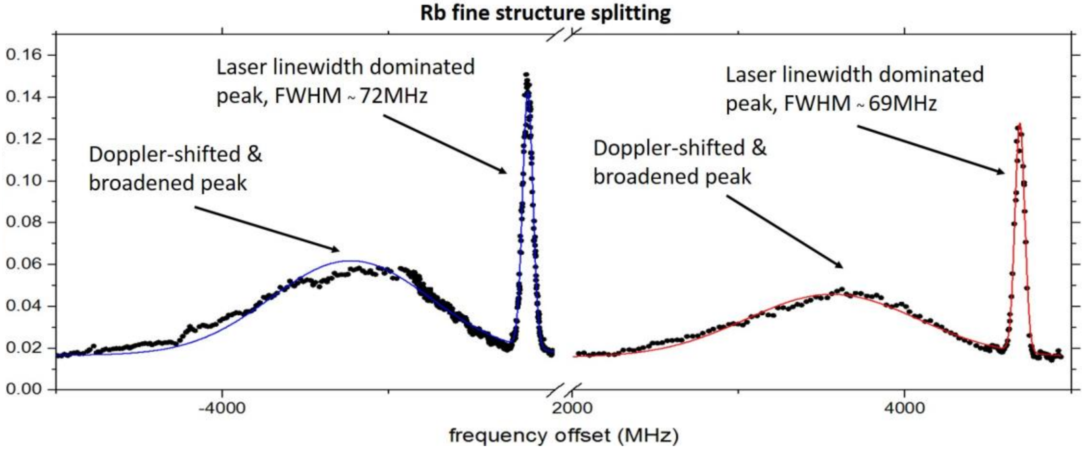
Laser Ion Source for High Resolution Doppler-Free Resonance Ionization Spectroscopy of Radioisotopes and Enhanced Isomer Selectivity

K. Chrysalidis [1,2], C. Granados [1], V. Fedosseev [1], R. Heinke [2], P. Larmonier [1], B. Marsh [1], S. Rothe [1], D. Studer [2], K. Wendt [2]

[1] CERN, Geneva, CH - [2] Johannes Gutenberg-Universität Mainz, DE

Doppler-free application scheme of two-photon excitation





Outline

1. What is a thick target ISOL facility?

2. What does this mean for ion source requirements?

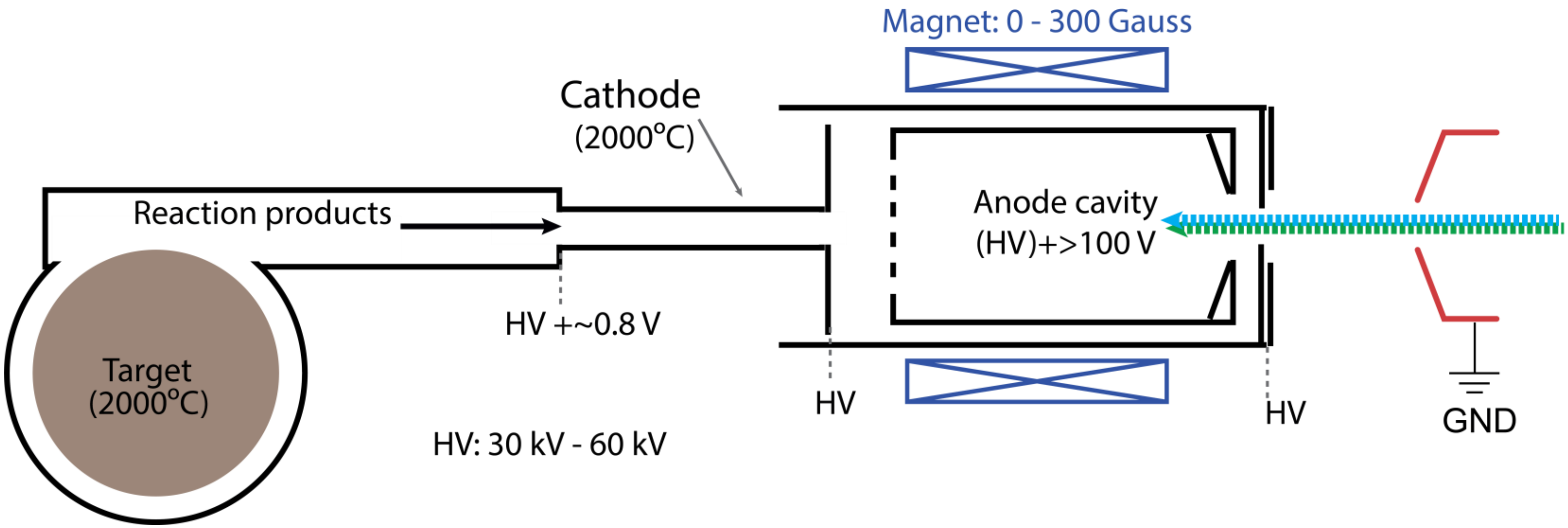
3. Ion source types: challenges, development highlights and directions for the future

   3.1 Surface ion sources

   3.2 FEBIAD type ion sources

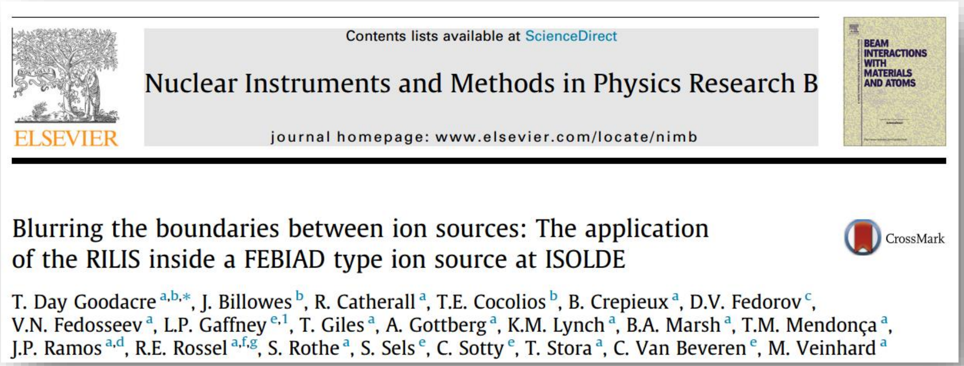
   3.3 RILIS

   3.4 Blurred boundaries



Magnet: 0 - 300 Gauss
Cathode
(2000°C)
Reaction products
Anode cavity
(HV)+>100 V
HV +~0.8 V
Target
(2000°C)
HV
HV
GND
HV: 30 kV - 60 kV

Versatile Arc Discharge and Laser Ion Source


Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

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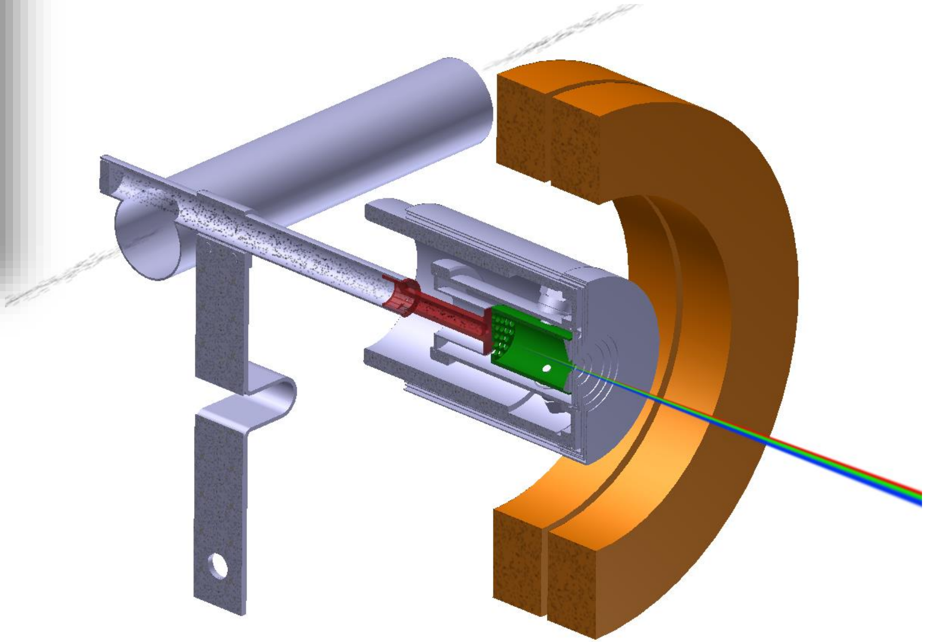
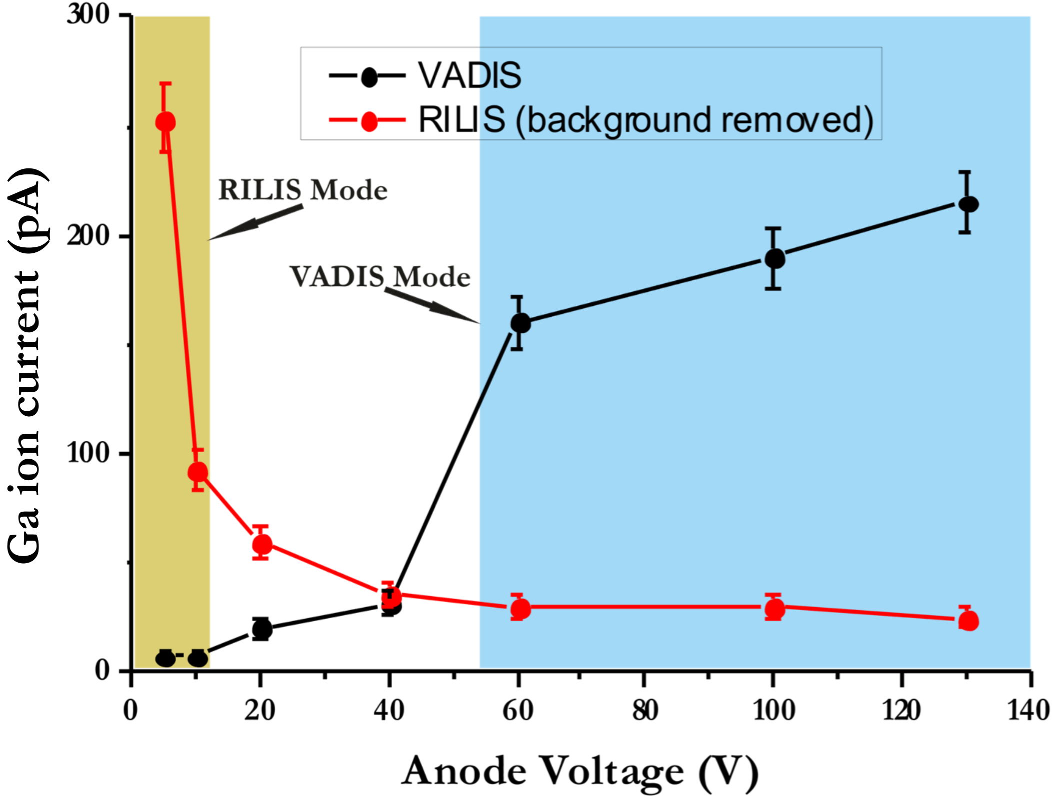
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Blurring the boundaries between ion sources: The application of the RILIS inside a FEBIAD type ion source at ISOLDE

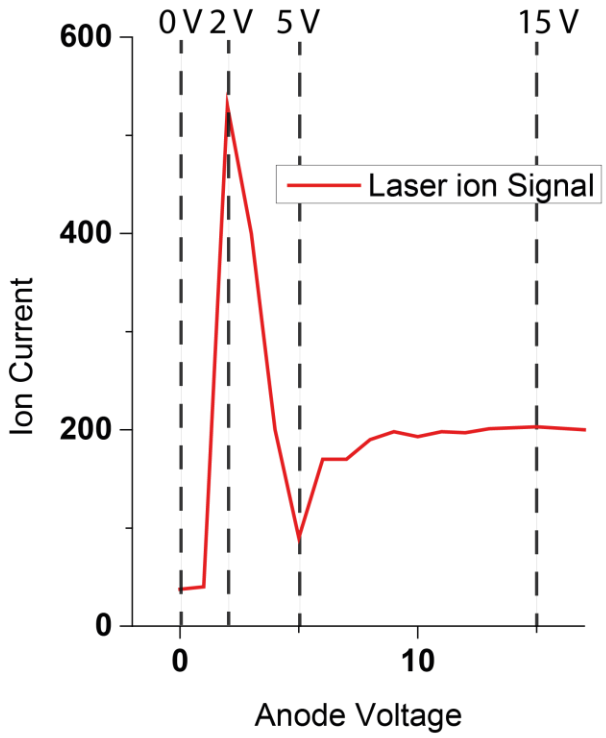
CrossMark

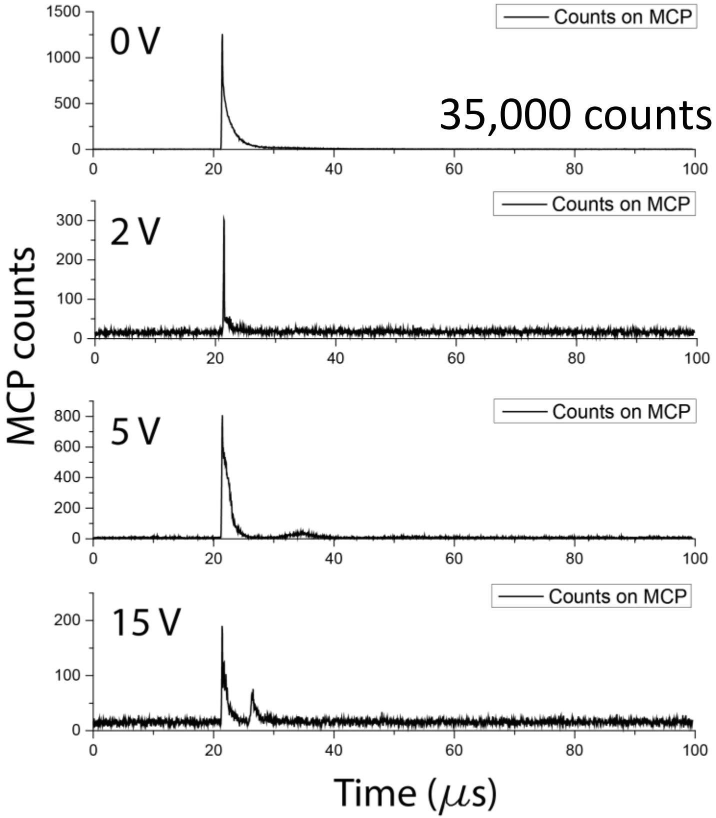
T. Day Goodacre [a,b,*], J. Billowes [b], R. Catherall [a], T.E. Cocolios [b], B. Crepieux [a], D.V. Fedorov [c], V.N. Fedosseev [a], L.P. Gaffney [e,1], T. Giles [a], A. Gottberg [a], K.M. Lynch [a], B.A. Marsh [a], T.M. Mendonça [a], J.P. Ramos [a,d], R.E. Rossel [a,f,g], S. Rothe [a], S. Sels [e], C. Sotty [e], T. Stora [a], C. Van Beveren [e], M. Veinhard [a]




VADIS
RILIS (background removed)
RILIS Mode
VADIS Mode
300
200
100
0
0
20
40
60
80
100
120
140
Ga ion current (pA)
Anode Voltage (V)

RILIS: developments:VADLIS

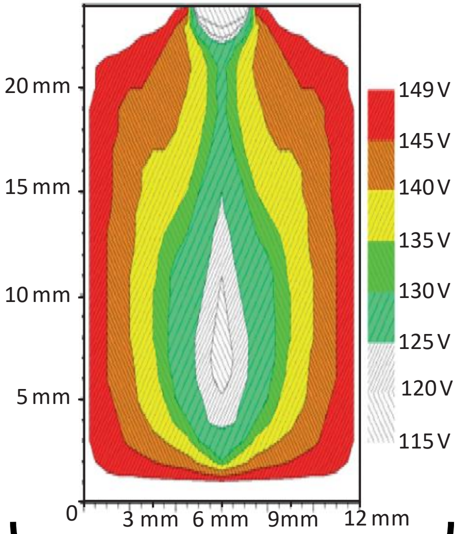




Ion survival was again found to be key to efficiency

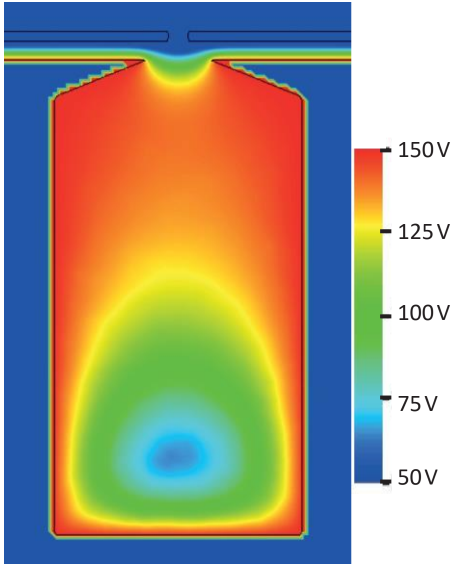
CPO 150V

Electrons: 15 mA (150 eV)
Ions: 0.2 µA (0.2 eV)

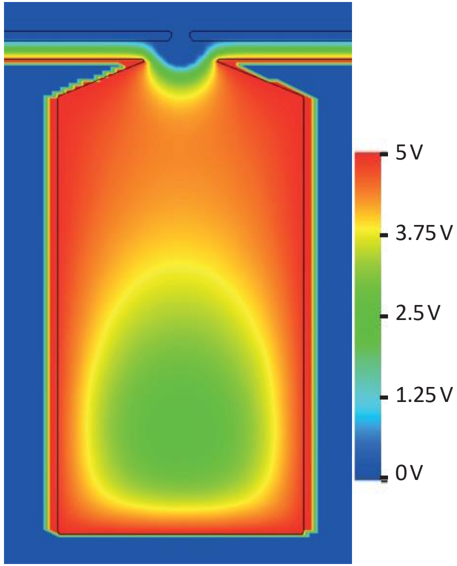


VSim 150V

Electrons: 80 mA (150 eV)



Anode voltage <10 V



Previous simulations using CPO

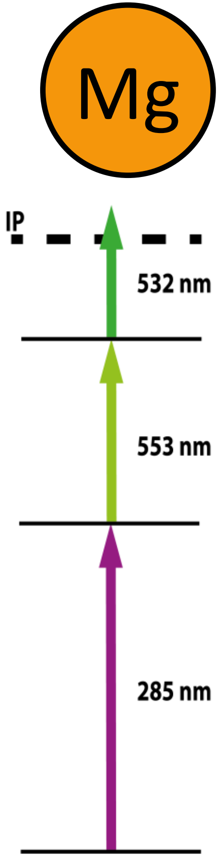
L. Penescu Rev. Sci. Inst. 2010

http://dx.doi.org/10.1063/1.3271245

New simulations using VSIM

See talk of Y. Martinez for latest developments

Why bother with ion source development?



Experiment requiring ion beams of Mg, Ne and Na!

Initial plan: only VADIS ionized beams

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

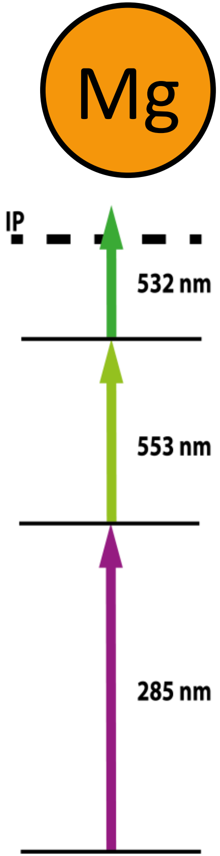
Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Q-values of Mirror Transitions for fundamental interaction studies

May 28th 2013

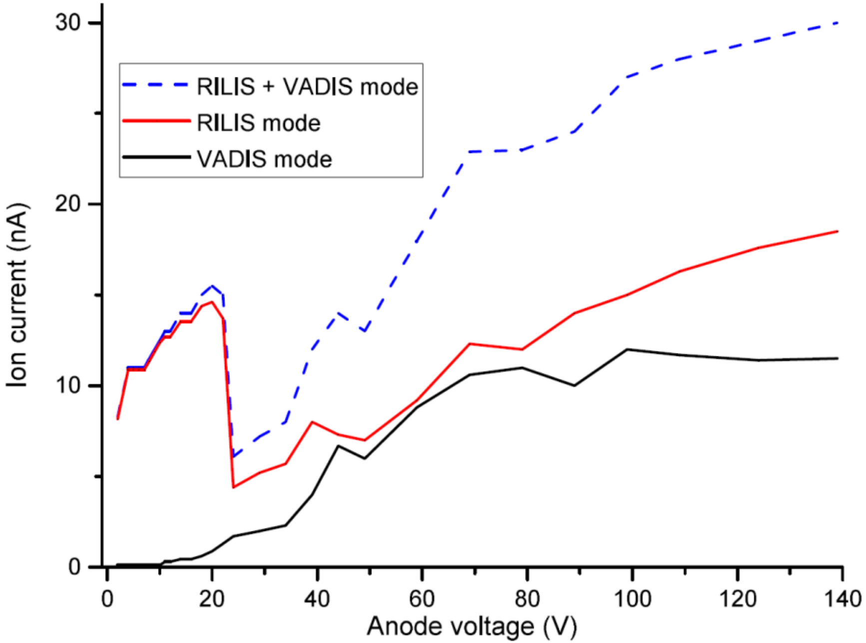
M. Breitenfeldt[1], D. Atanasov[2], K. Blaum[2], T. Eronen[2], P. Finlay[1], F. Herfurth[3], M. Kowalska[4], S. Kreim[4], Yu. Litvinov[3], D. Lunney[5], V. Manea[5], D. Neidherr[3], T. Porobic[1], M. Rosenbusch[6], L. Schweikhard[6], N. Severijns[1], F. Wienholtz[6], R.N. Wolf[6], K. Zuber[7]

Why bother with ion source development?



Experiment requiring ion beams of Mg, Ne and Na!

Initial plan: only VADIS ionized beams



Volatile Carbonyl Compounds for New Refractory Beams at ISOLDE

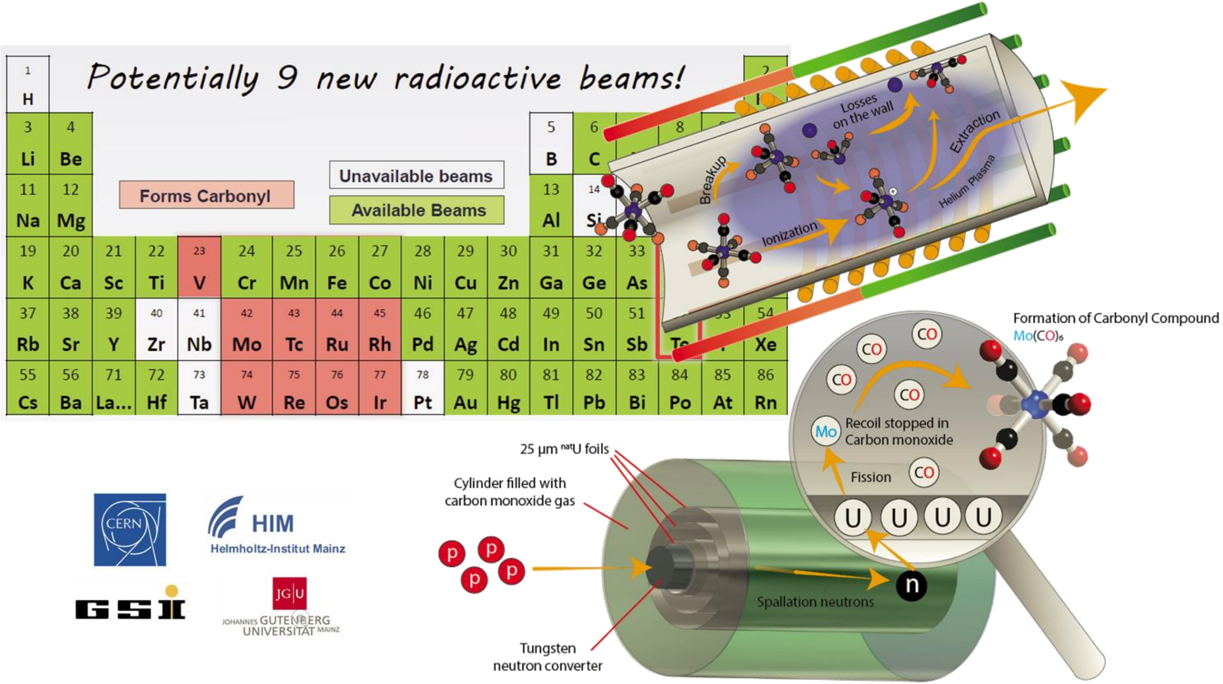
J. Ballof[1,2], C. Seiffert[1], Ch. E. Düllmann[2,3,4], J. P. Ramos[1], S. Rothe[1], T. Stora[1], A. Yakushev[3,4]

1) Johannes Gutenberg - Universität Mainz, Saarstr. 21, 55122 Mainz, Germany 2) CERN, Engineering Department, ISOLDE, 1211 Geneva 23, Switzerland
3) GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstr. 1, 64291 Darmstadt, Germany 4) Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, 55099 Mainz

ICIS 2017 Poster:

Tuesday #68

J. Ballof



CERN HIM Helmholtz-Institut Mainz GSI JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

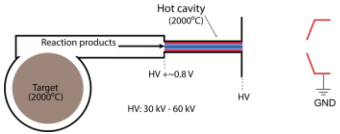
1. What is a thick target ISOL facility?

2. What does this mean for ion source requirements?

3. Ion source types: challenges, development highlights and directions for the future
   - 3.1 Surface ion sources
   - 3.2 FEBIAD type ion sources
   - 3.3 RILIS
   - 3.4 Blurred boundaries

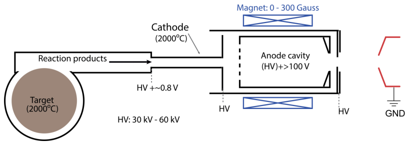
4. Summary

Summary



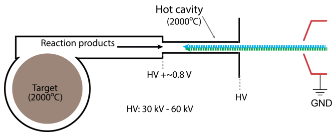
Surface ion source:

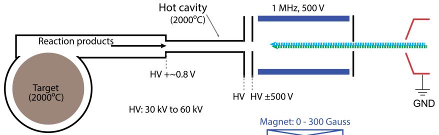
- Selectivity possible for certain elements
- Lots of scope for materials development

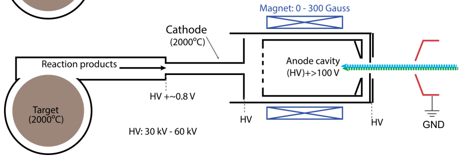


FEBIAD ion source:

- Selectivity possible with temperature controlled transfer lines
- Simulations for optimization ongoing







RILIS ion source:

- Ionization scheme development to further broaden the scope
- Laser atom interaction region development to reduce isobaric contamination and push the boundaries of selectivity

Acknowledgements

Many thanks to everyone who provided material for the presentation:

J. Ballof, K. Chrysalidis, D.V. Fedorov, V.N. Fedosseev, S. Franchoo, A. Gottberg, R. Heinke, N. Lecesne, J. Lassen, Y. Liu, F. Maldonado, B.A. Marsh, Y. Martinez.

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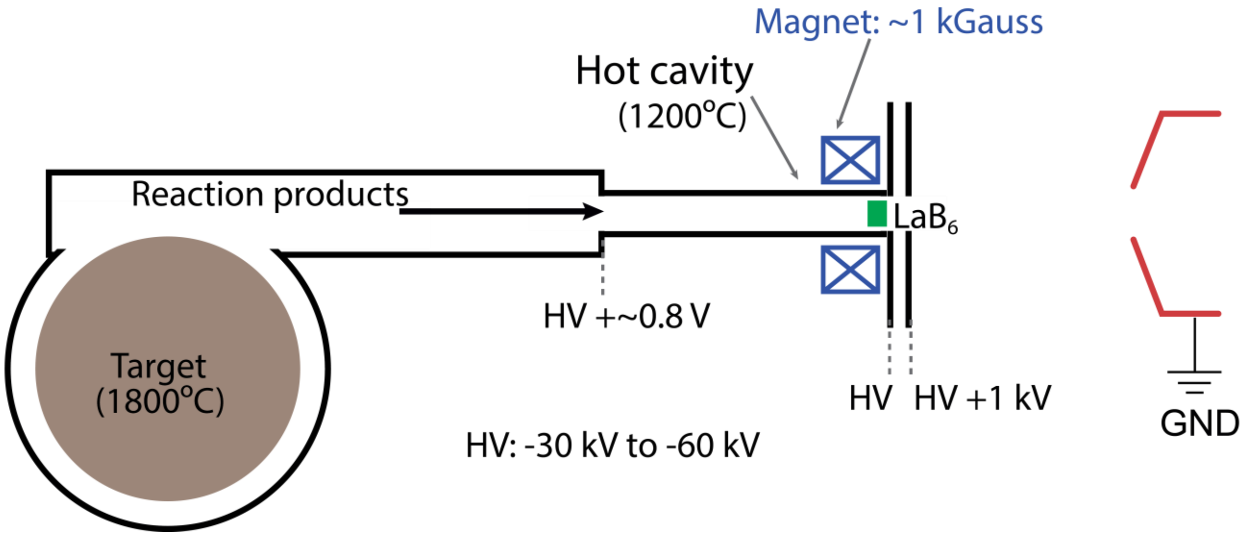
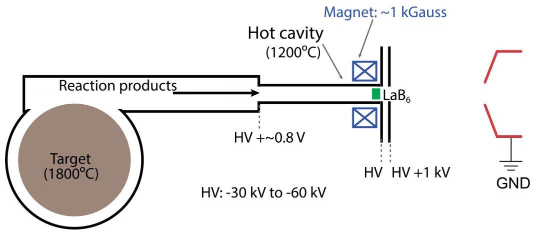
Surface ion sources (negative)



Negative surface ionization

$$\text{Efficiency} \approx \frac{\alpha}{1+\alpha}$$



Interaction probability

Atom-wall interactions

Electron affinity

Work function

$$\alpha = \cancel{N\varepsilon}Pe^{\left({EA-\phi}/{kT}\right)}$$

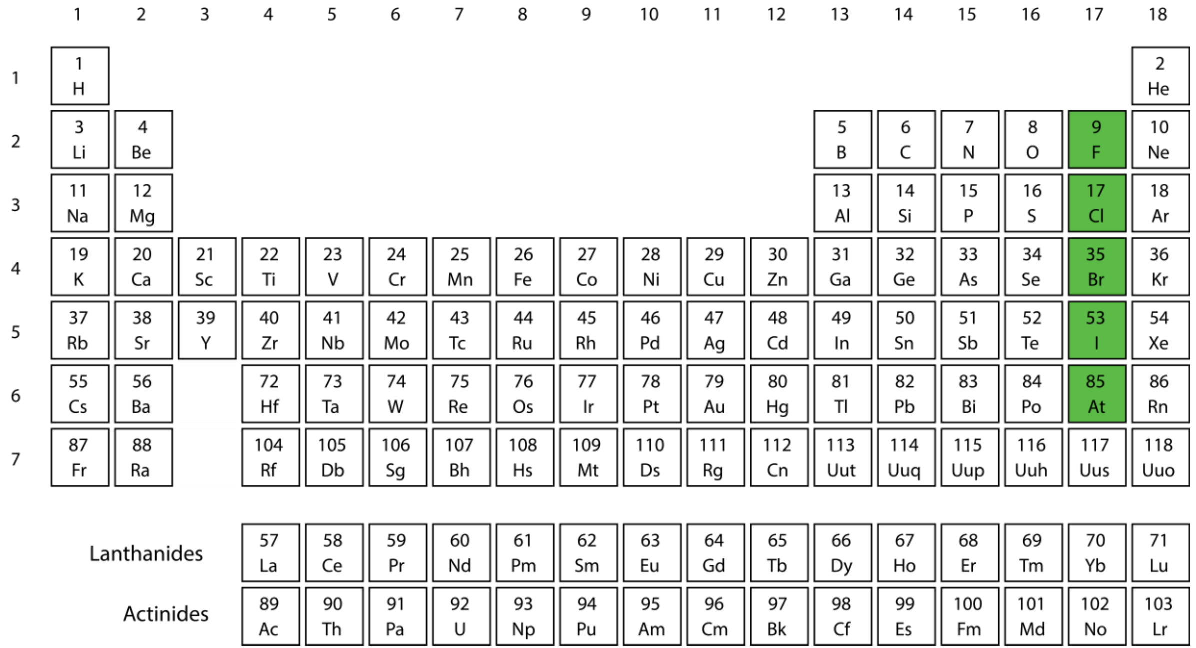
Ion survival probability

Boltzmann constant and temperature

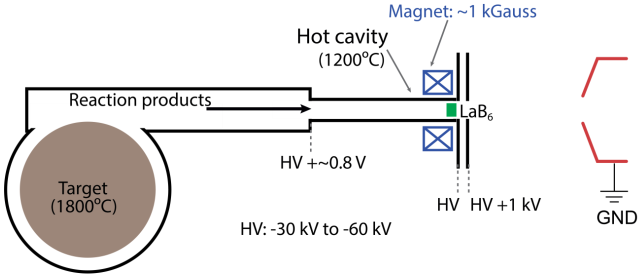
For negative surface ionization it is the electron affinity that must be considered, the work function should be minimized and the hot cavity effect is no-longer useful

Surface ion sources (negative)

1. Efficiency: electron affinity and cavity work function dependent
2. Extraction/ionization time ~100 µs (not considering sticking times)
3. Chemical selectivity: significant



- Particularly applicable for Halogens
- Scope for improvement in efficiency and lifetime…



ICIS 2017 Poster: David Leimbach

Towards Isobar-Free High-Resolution In-Source Spectroscopy On-Line: New Features of the Laser Ion Source & Trap LIST

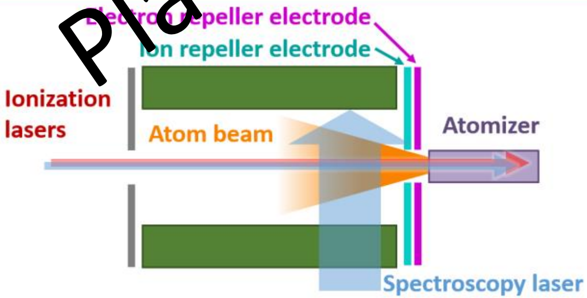
JG|U JOHANNES GUTENBERG-UNIVERSITÄT MAINZ LARISSA

R. Heinke[1], V. Fedosseev[2], T. Kron[1], B. Marsh[2], S. Raeder[3], T. Reich[4], S. Richter[1], S. Rothe[2,5], P. Schönberg[4], M. Trümper[1], C. Weichhold[1] and K. Wendt[1]

ISOLDE

[1]Institute of Physics, Mainz University – [2]EN Department, CERN, Geneva – [3]GSI, Darmstadt – [4]Institute of Nuclear Chemistry, Mainz University – [5]University of Manchester

High Resolution: PI-LIST



The *Perpendicularly Illuminated Laser Ion Source & Trap* ***PI-LIST***

ICIS 2017 Poster: Sebastian Rothe

Towards Isobar-Free High-Resolution In-Source Spectroscopy On-Line: New Features of the Laser Ion Source & Trap LIST

JG|U LARISSA JOHANNES GUTENBERG-UNIVERSITÄT MAINZ

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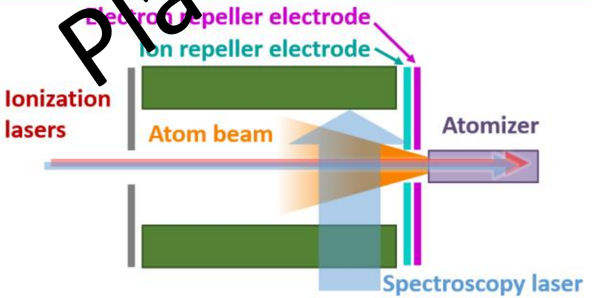
High Resolution: PI-LIST



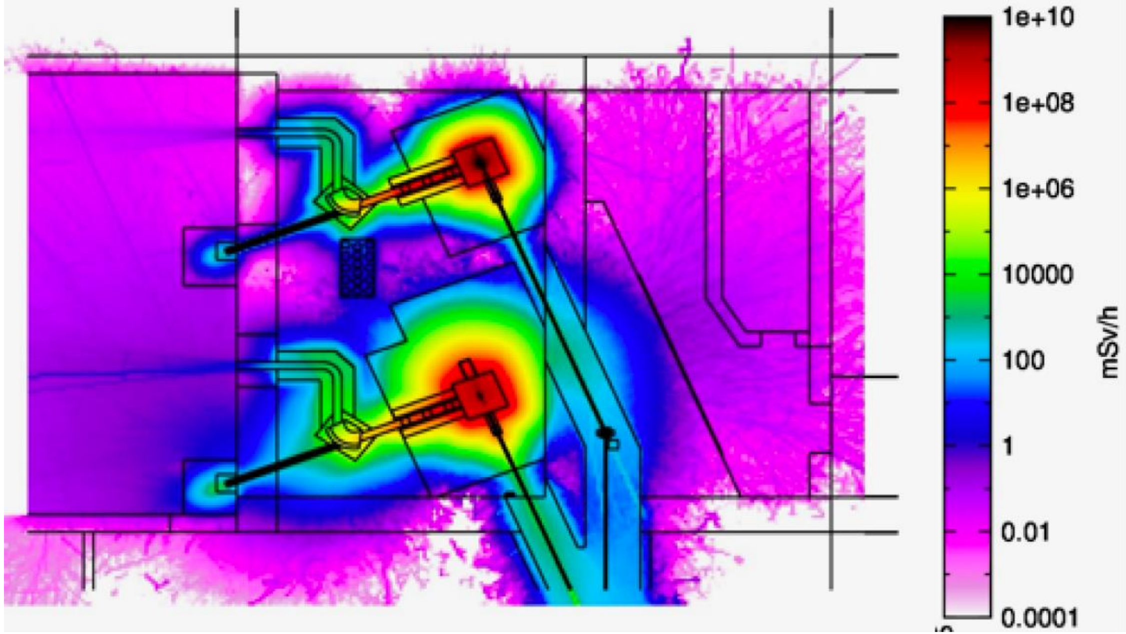
The *Perpendicularly Illuminated Laser Ion Source & Trap* ***PI-LIST***

Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
3. Ion beam quality
4. Chemical selectivity
5. Survival

- Extreme radiation fields
- Temperatures up to 2300°C
- Thermal cycling
- Inaccessibility

Expected dose rates @ARIEL target level



A. Gottberg

Ion source requirements @ thick target ISOL

1. Efficiency
2. Extraction/ionization time
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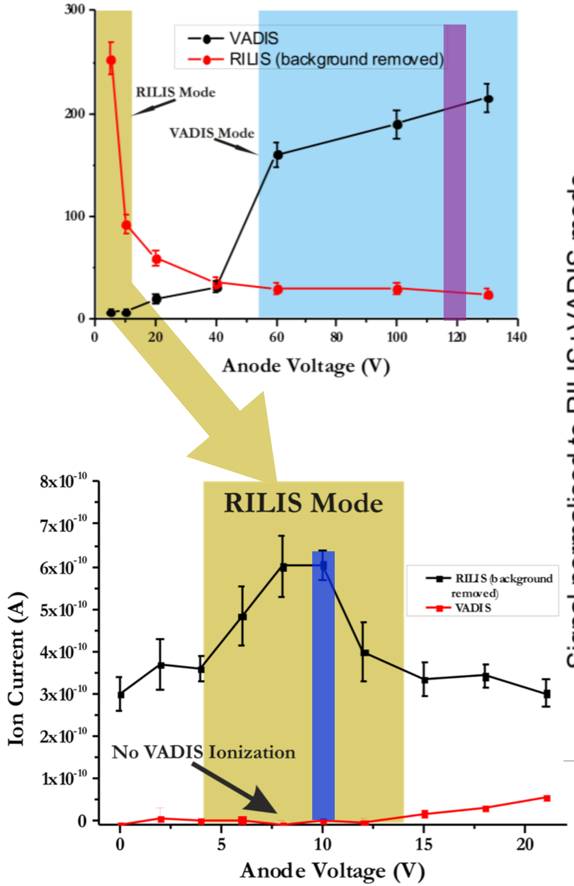
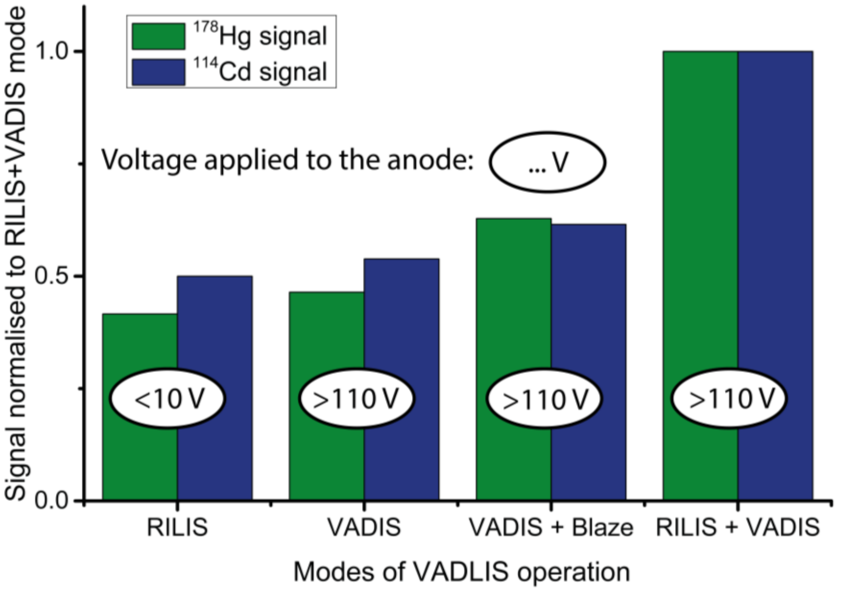
- Extreme radiation fields
- Temperatures up to 2300°C
- Thermal cycling
- Inaccessibility

ISAC target off-line acceptance tests

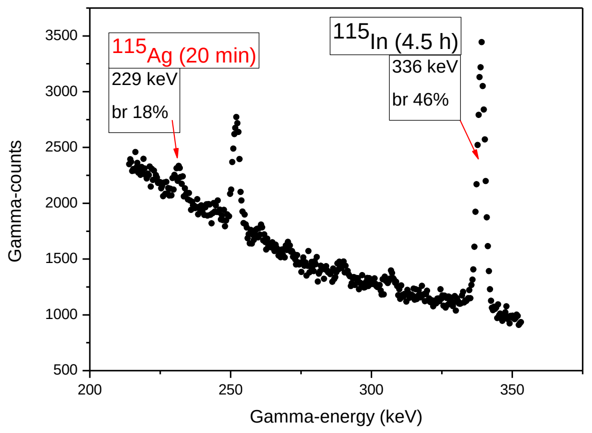
A. Schmidt

RILIS: developments:VADLIS





Blurred boundaries: developments



Compatibility with RILIS systems

Contents lists available at ScienceDirect
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journal homepage: www.elsevier.com/locate/nimb
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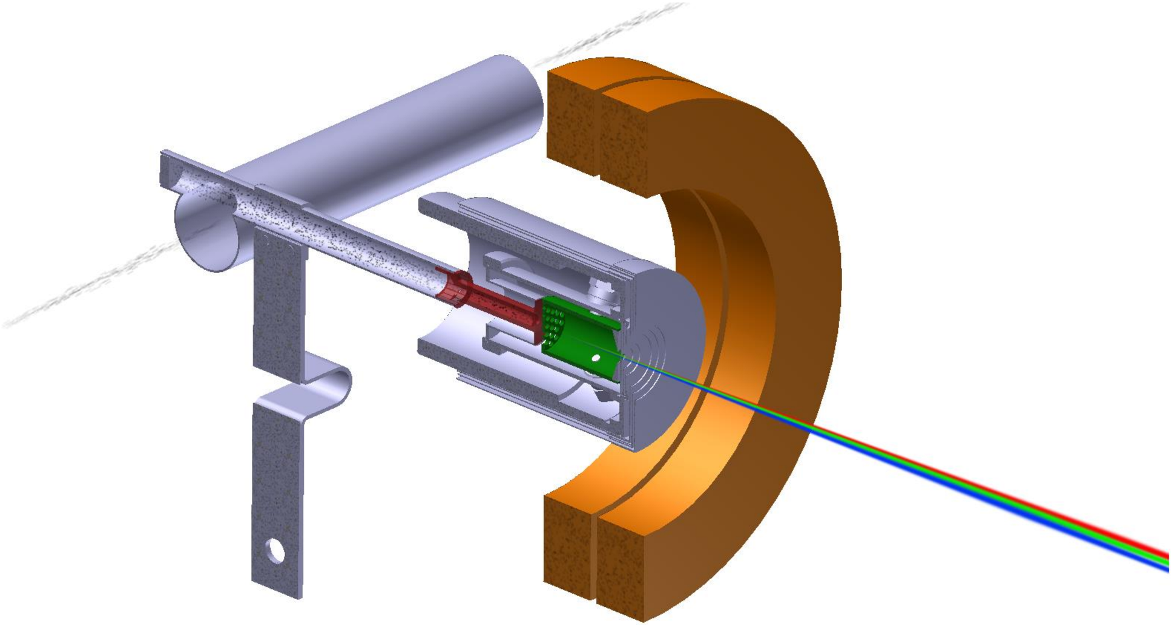
BEAM INTERACTIONS WITH MATERIALS AND ATOMS

Blurring the boundaries between ion sources: The application of the RILIS inside a FEBIAD type ion source at ISOLDE

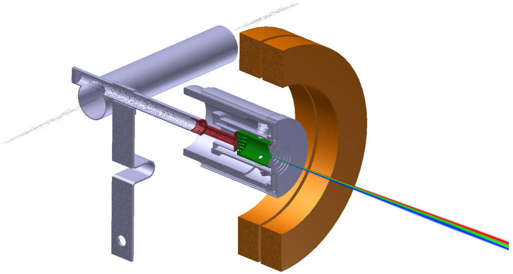
CrossMark

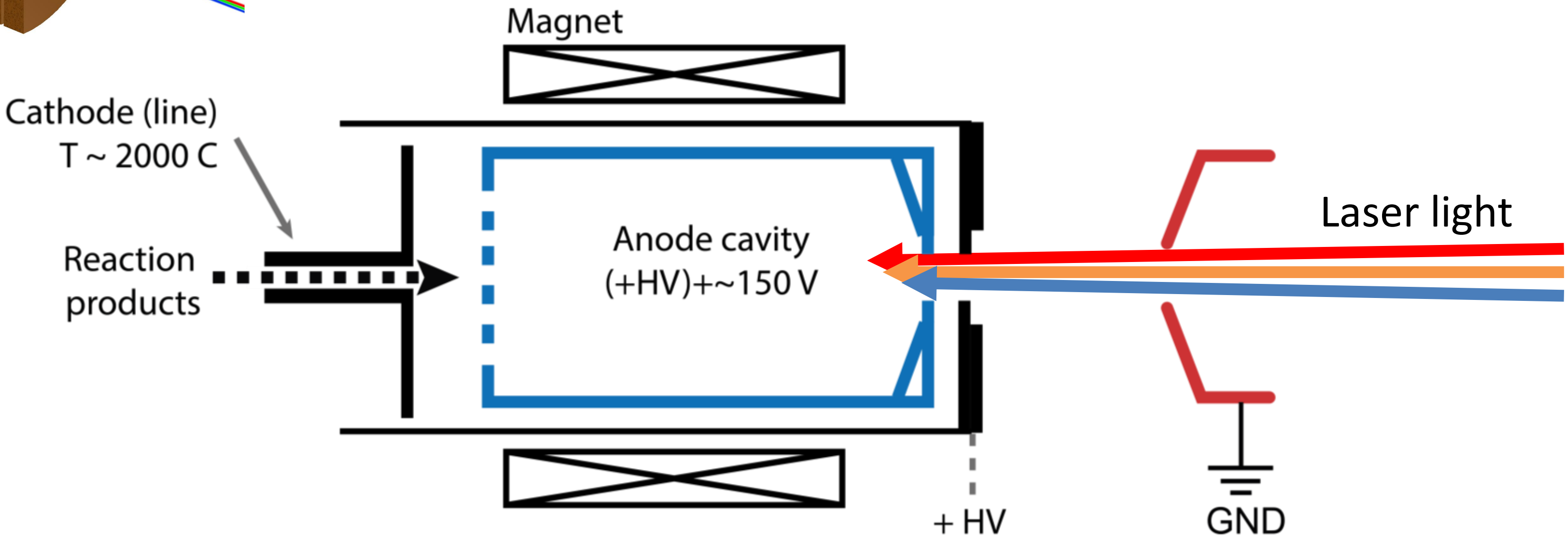
T. Day Goodacre [a,b,*], J. Billowes [b], R. Catherall [a], T.E. Cocolios [b], B. Crepieux [a], D.V. Fedorov [c], V.N. Fedosseev [a], L.P. Gaffney [e,1], T. Giles [a], A. Gottberg [a], K.M. Lynch [a], B.A. Marsh [a], T.M. Mendonça [a], J.P. Ramos [a,d], R.E. Rossel [a,f,g], S. Rothe [a], S. Sels [e], C. Sotty [e], T. Stora [a], C. Van Beveren [e], M. Veinhard [a]

What can developments bring?

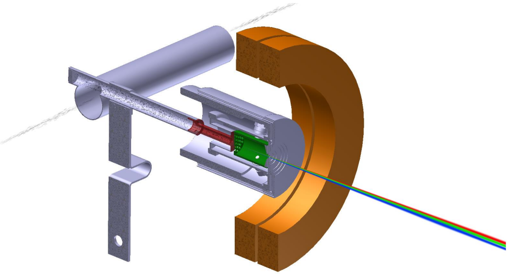


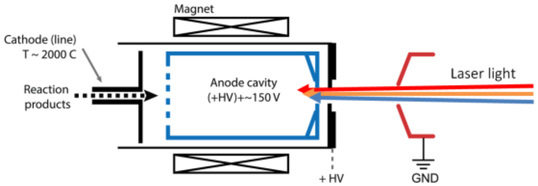
What can developments bring?

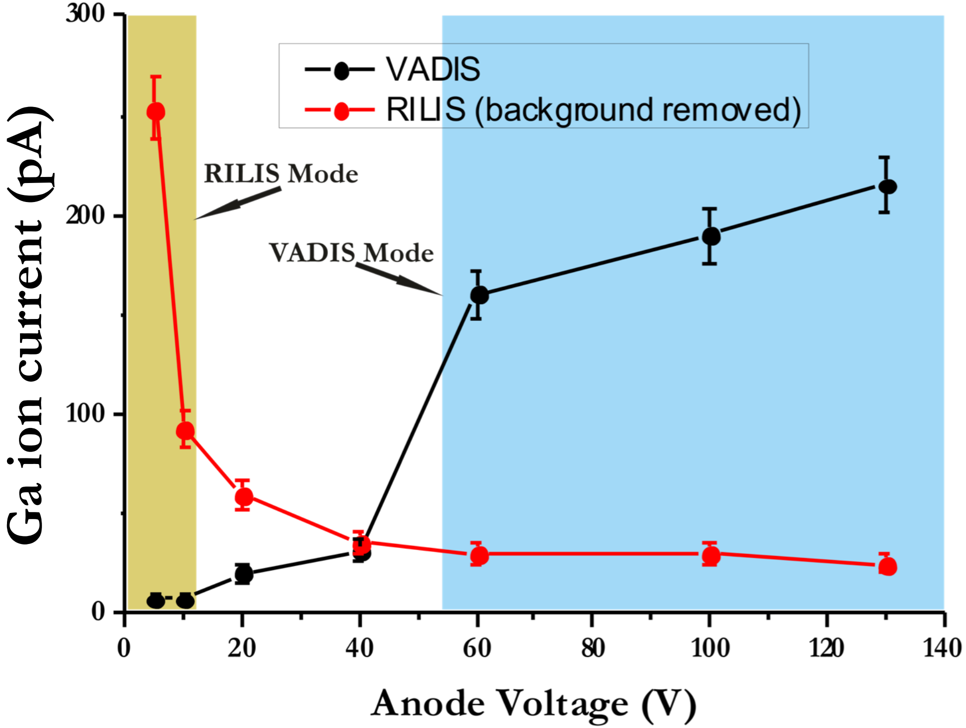




What can developments bring?







Where and how?

ISOL = Isotope Separator On-Line

1949

PHYSICAL REVIEW VOLUME 76, NUMBER 2 JULY 15, 1949

Measurements on Radioactive Krypton Isotopes from Fission after Mass-Spectrographic Separation

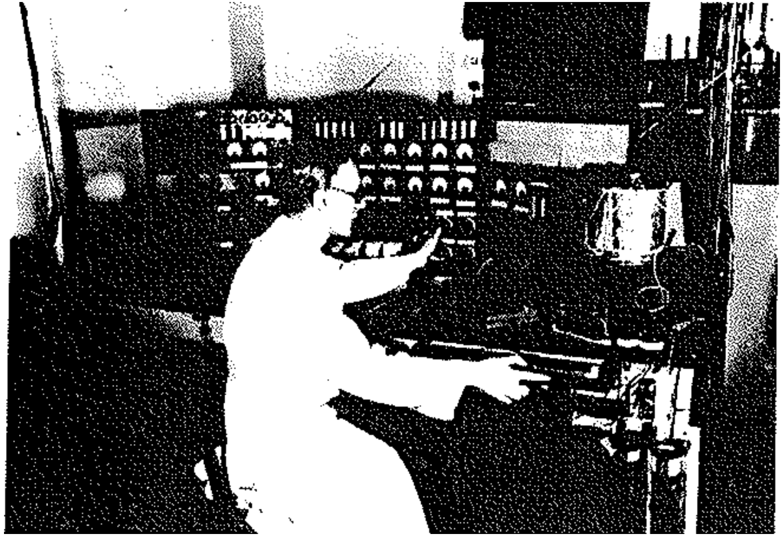
J. Koch, O. Kofoed-Hansen, P. Kristensen, and W. Drost-Hansen
Institute for Theoretical Physics, University of Copenhagen, Denmark
(Received April 4, 1949)

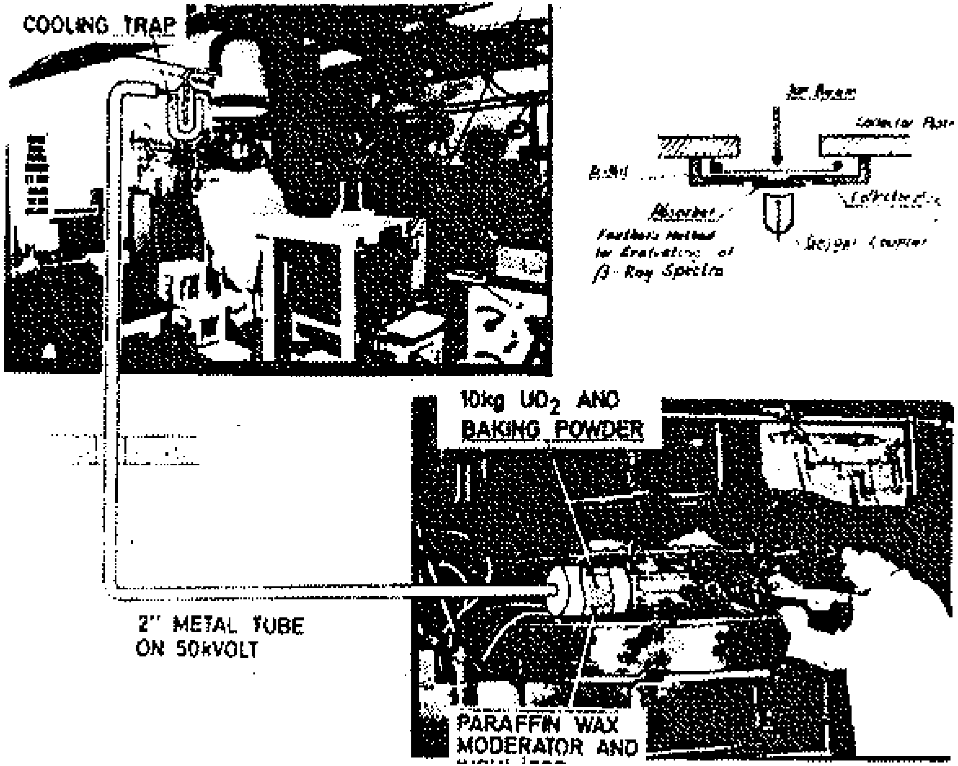
Radioactive isotopes of krypton resulting from fission of uranium have been separated in a mass-spectrograph. The half-lives and the relative fission yields of the isotopes Kr^{85}, Kr^{87}, and Kr^{88} have been measured. The maximum energies of the β-particles from Kr^{85} and Kr^{87} have been checked by absorption. It has been shown that Kr^{88} emits soft β-particles and an intense γ-radiation. This result combined with other measurements indicates that the β-spectrum of Kr^{88} is complex.

https://doi.org/10.1103/PhysRev.76.279

"Ten kilograms of powdered uranium oxide, mixed with a small portion of ammonium carbonate, were placed in a glass container which was surrounded by a few centimetres of paraffin… The uranium container was inserted between the coils of the cyclotron magnet… and then heavily irradiated for about three hours…"

The Birth of ISOL





Otto Kofoed-Hansen and Karl Ove Nielsen
Sitting in "ISOLDE 0 Control Room"
Niels Bohr Institute 1951