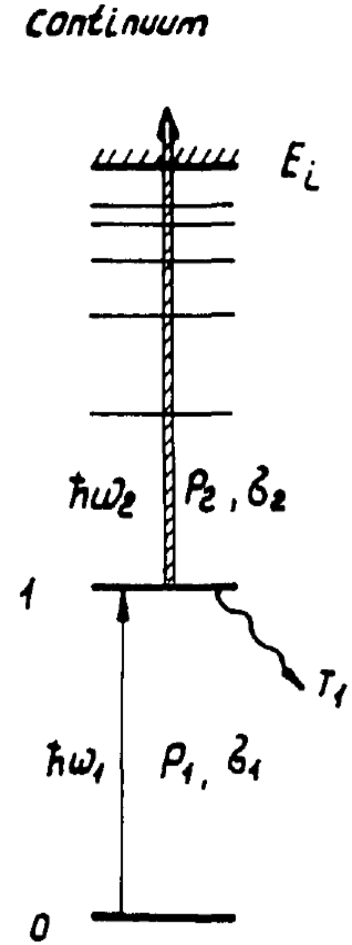
Лазерный ионный источник:

История, статус, перспективы



R. V. Ambartzumian, V. P. Kalinin, and V. S. Letokhov, ZhETF Pis. Red. 13, 305 (1971) [JETP Lett. 13, 217 (1971)].

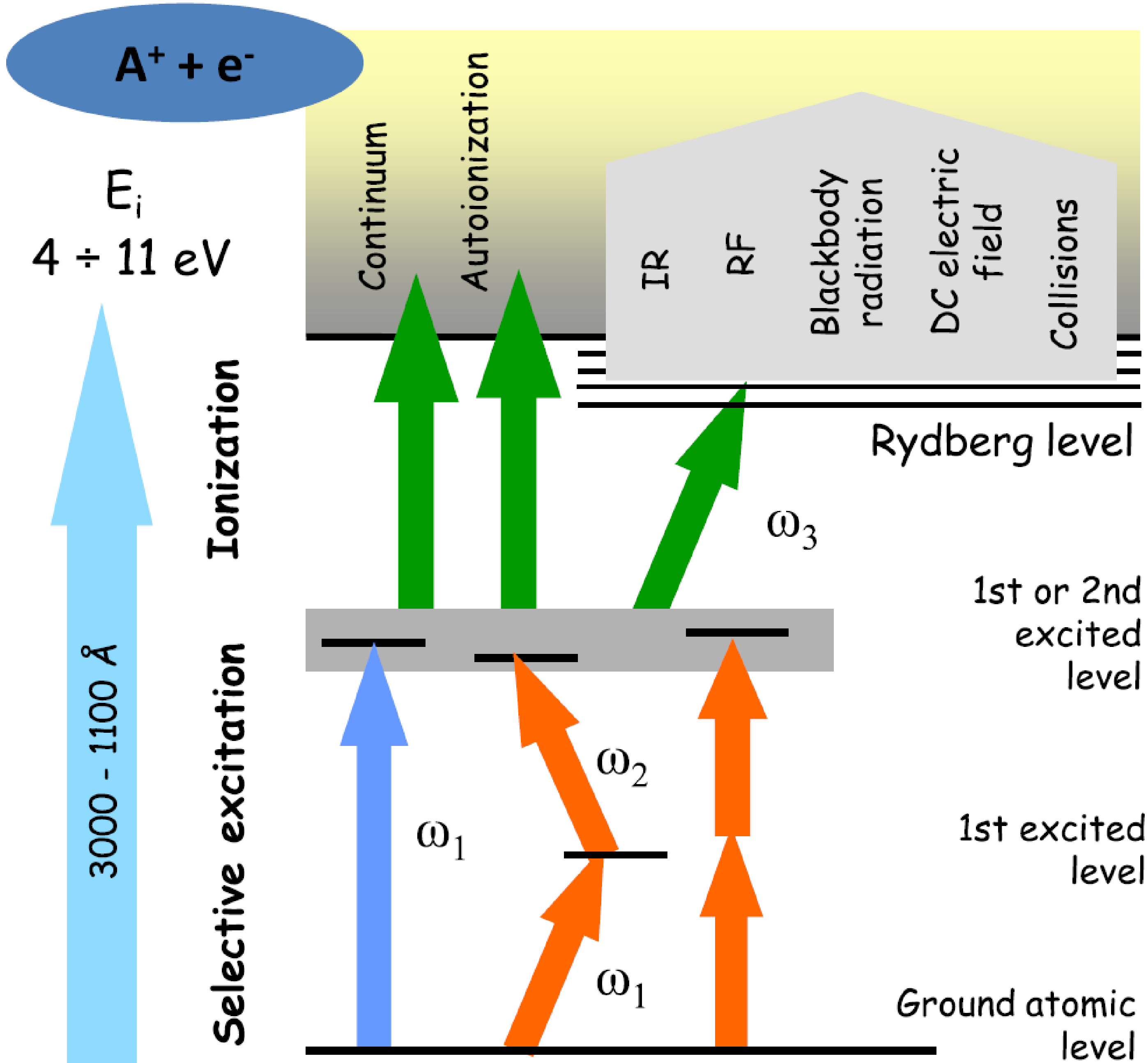
$$P_1 \simeq \frac{\hbar\omega_1}{\sigma_1 T_1}$$

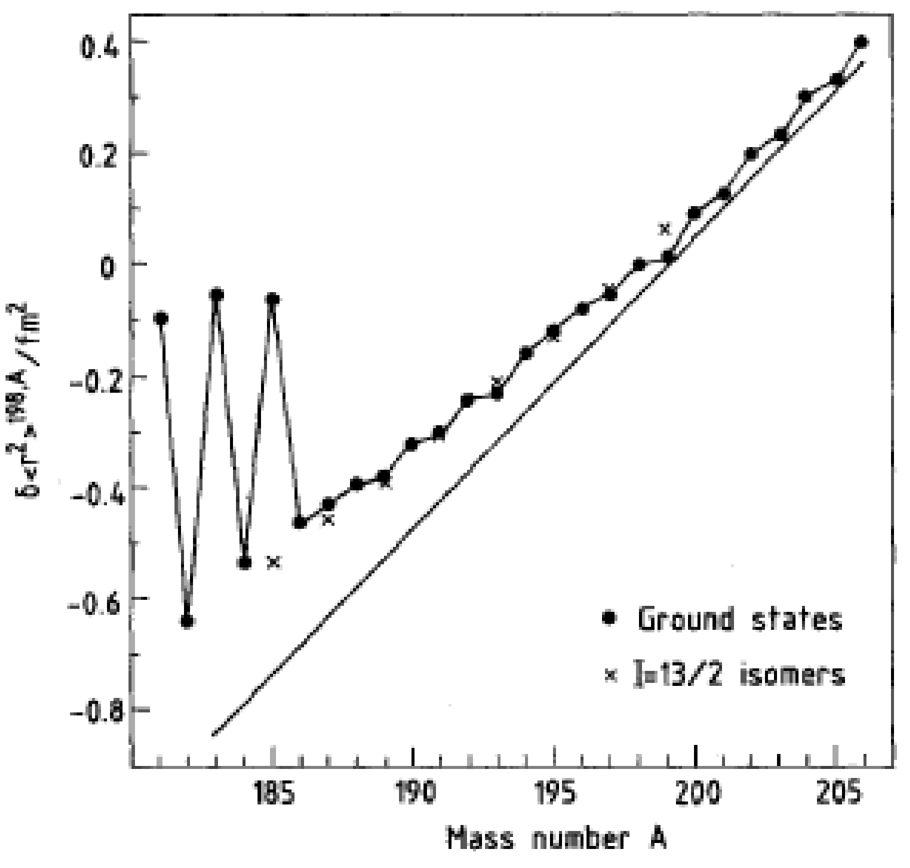
$$W_2 = \frac{\sigma_2 P_2}{\hbar\omega_2} \gtrsim \frac{1}{T_1}$$

$$\frac{P_2}{P_1} \gtrsim \frac{\sigma_1}{\sigma_2} \gg 1$$

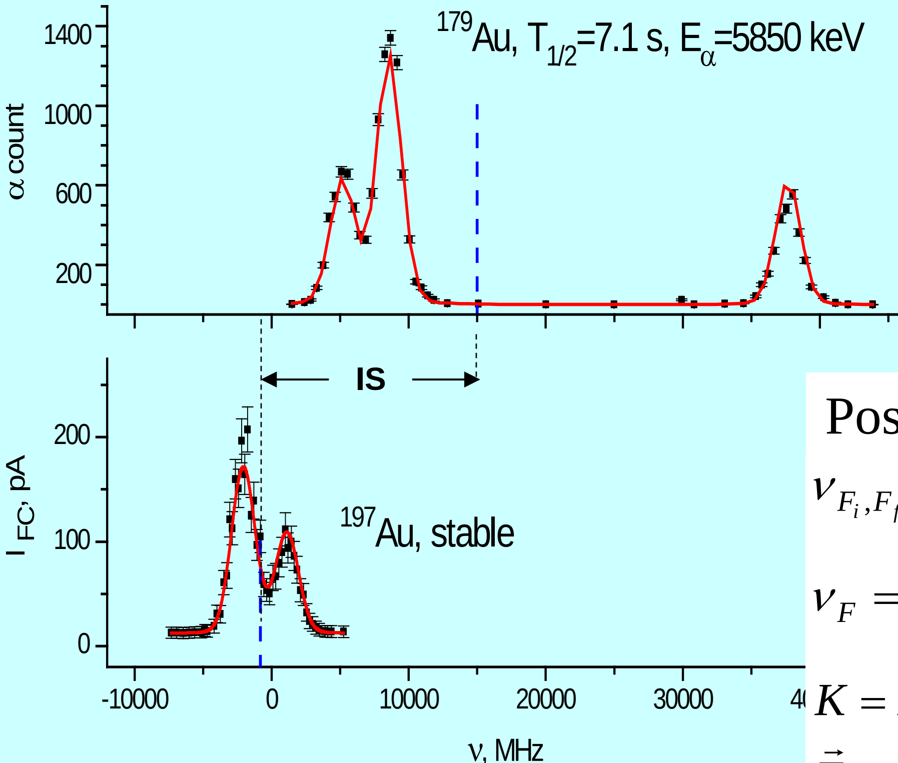
$$\sigma_1 \simeq 10^{-9} - 10^{-11}\ cm^2$$

$$\sigma_2 \simeq 10^{-18} - 10^{-19}\ cm^2$$


A+ + e-
Ei
4 ÷ 11 eV
3000 - 1100 Å
Ionization
Selective excitation
Continuum
Autoionization
IR
RF
Blackbody radiation
DC electric field
Collisions
Rydberg level
ω3
1st or 2nd excited level
ω2
ω1
1st excited level
ω1
Ground atomic level



J. Bonn, G. Huber, H.-J. Kluge and E. W. Otten., Z. Phys. A 276, 203 (1976)



Positions of the components:

$$\nu_{F_i,F_f} = \nu_0 + \nu_{F_f} - \nu_{F_i}$$

$$\nu_F = A \cdot \frac{K}{2} + B \cdot \frac{0.75 \cdot K \cdot (K+1) - I \cdot (I+1) \cdot J \cdot (J+1)}{2 \cdot (2I-1) \cdot (2J-1) \cdot I \cdot J}$$

$$K = F \cdot (F+1) - I \cdot (I+1) - J \cdot (J+1)$$

$$\vec{F} = \vec{I} + \vec{J}, \quad F = |I-J|, |I-J|+1, \ldots, I+J$$

$$A \propto \mu, \quad B \propto Q$$

Isotope shift $\delta\nu_{A,A'}$:

$$\delta\nu_{A,A'} = F \cdot \delta < r^2 >_{A,A'} + M \cdot \frac{A - A'}{A \cdot A'}$$

V. N. Fedoseyev, V. S. Lethokov, V. I. Mishin, G. D. Alkhazov, A. E. Barzakh, V. P. Denisov, A. G. Dernyatin, and V. S. Ivanov, *Opt. Commun.* **52**:24 (1984).

G. D. Alkhazov, A. E. Barzakh, E. I. Berlovich, V. P. Denisov, A. J. Dernyatin, V. S. Ivanov, A. N. Zherikhin, O. N. Kompanets, V. S. Letokhov, V. I. Mishin, and V. N. Fedoseyev, *JETP Lett.* **37**:274 (1983).

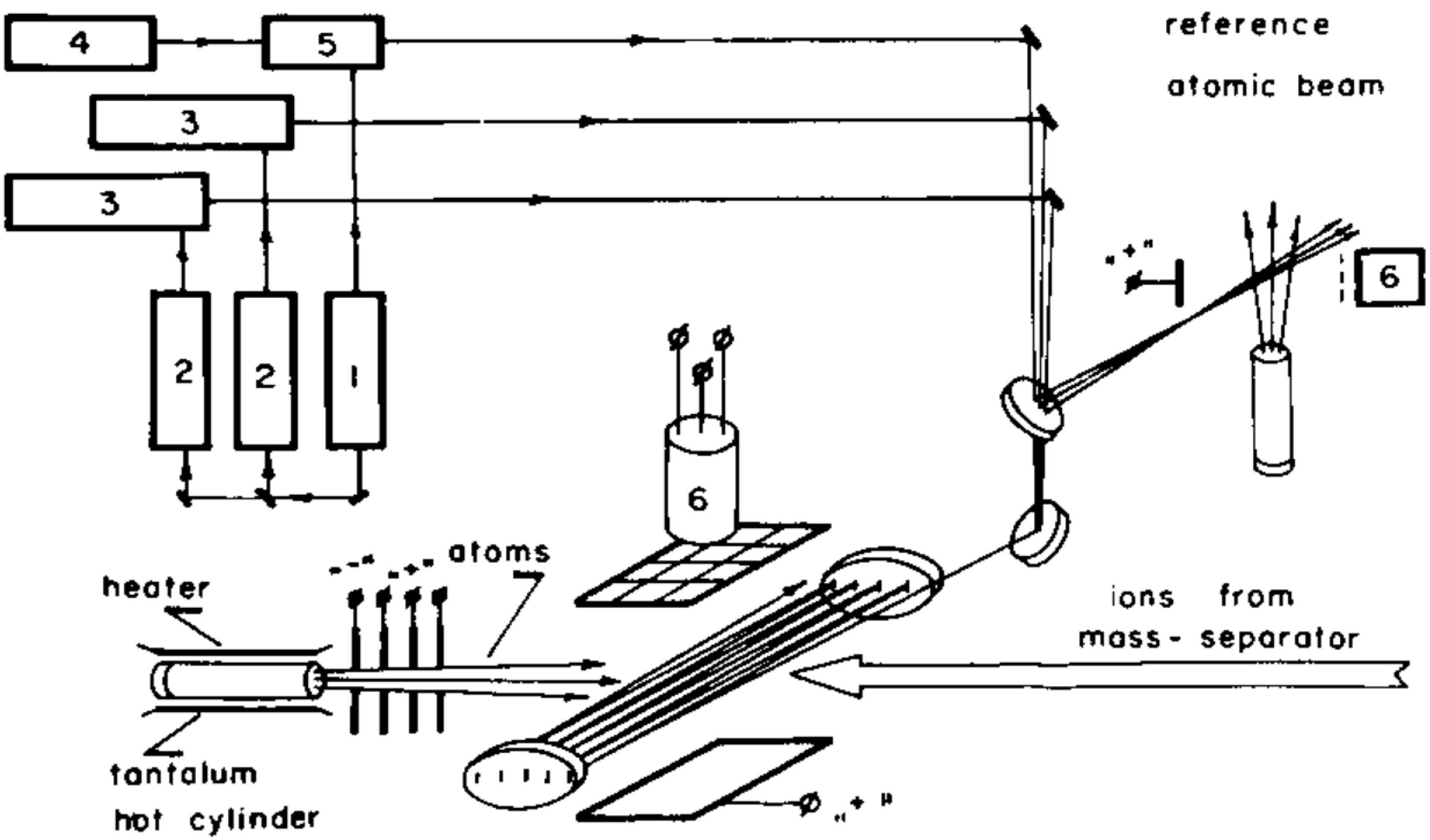
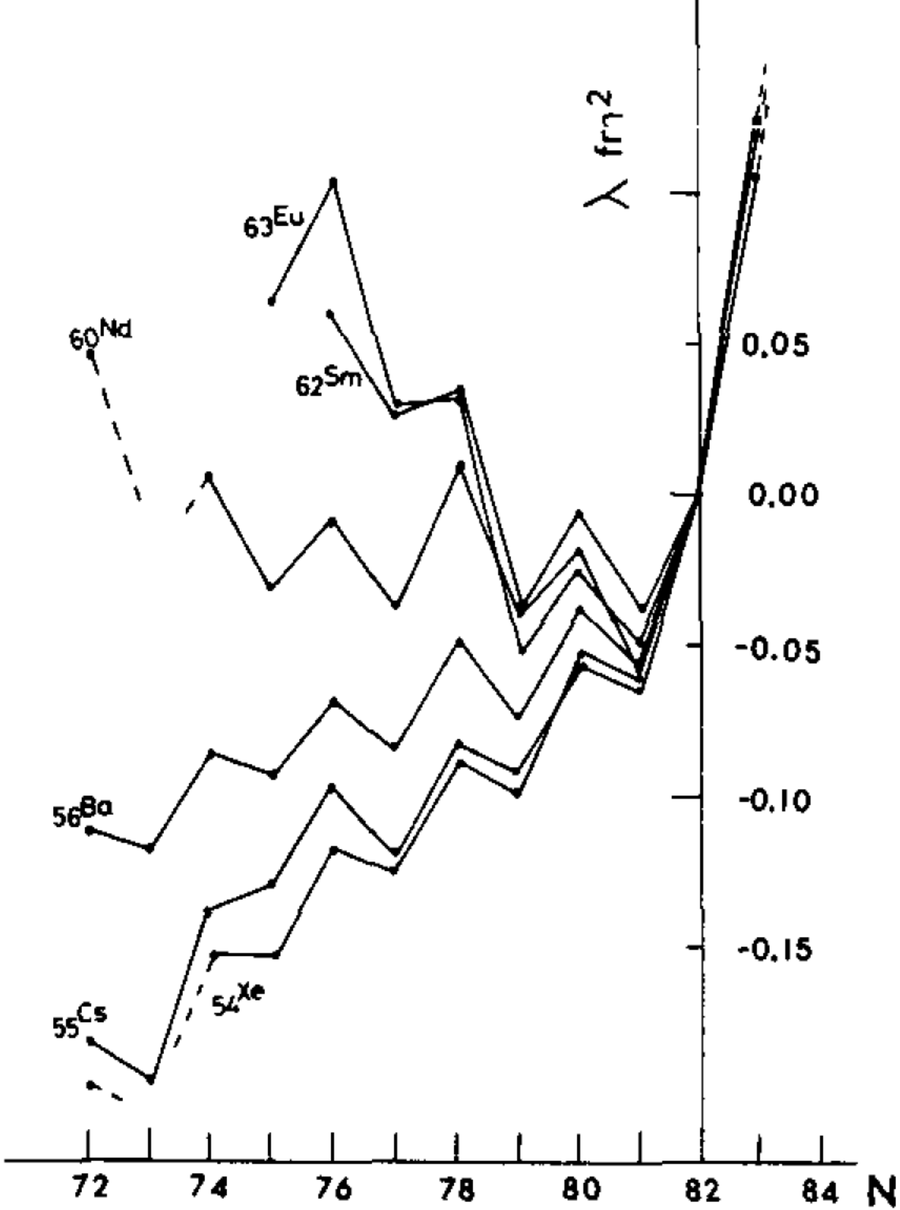


Figure 1. Scheme of the experimental set-up for the resonance ionization spectroscopy of radioactive atoms: 1, Cu vapour laser; 2, Cu vapour amplifiers; 3, pulsed dye lasers; 4, Ar-ion laser and cw single frequency dye laser; 5, pulsed dye laser amplifier; 6, multichannel electron multiplier.



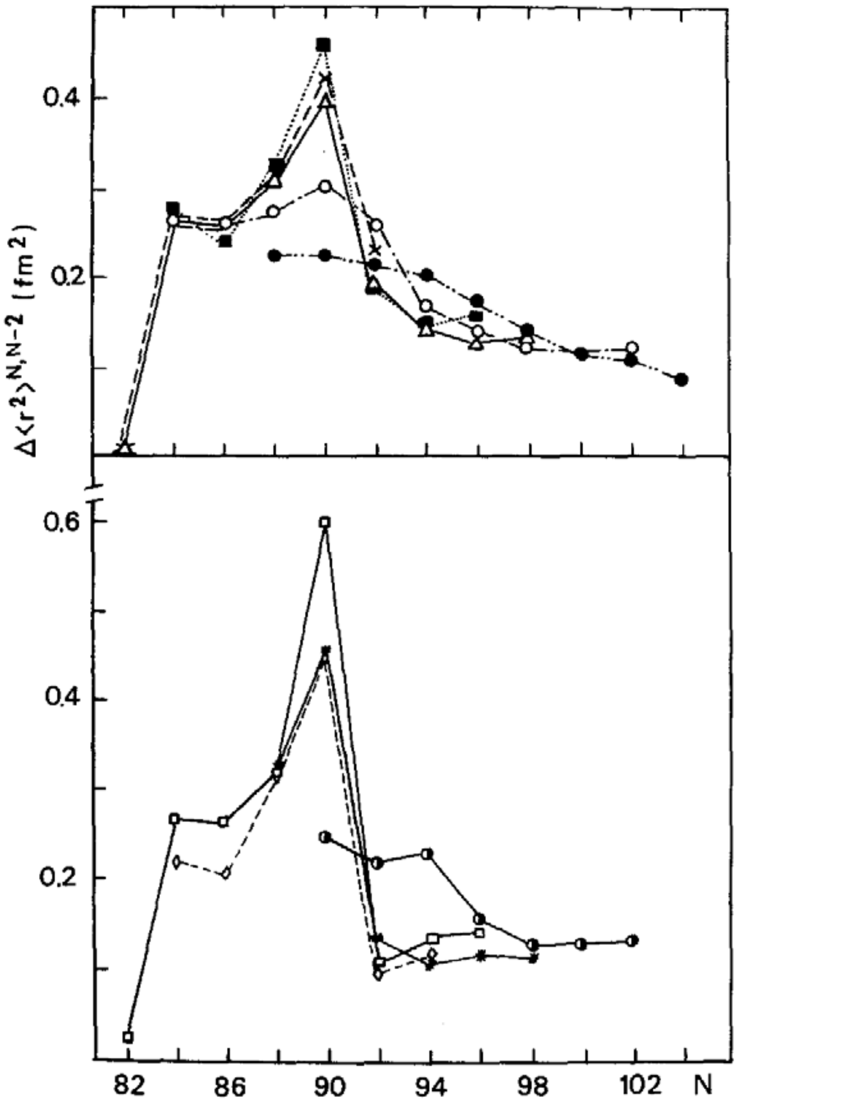
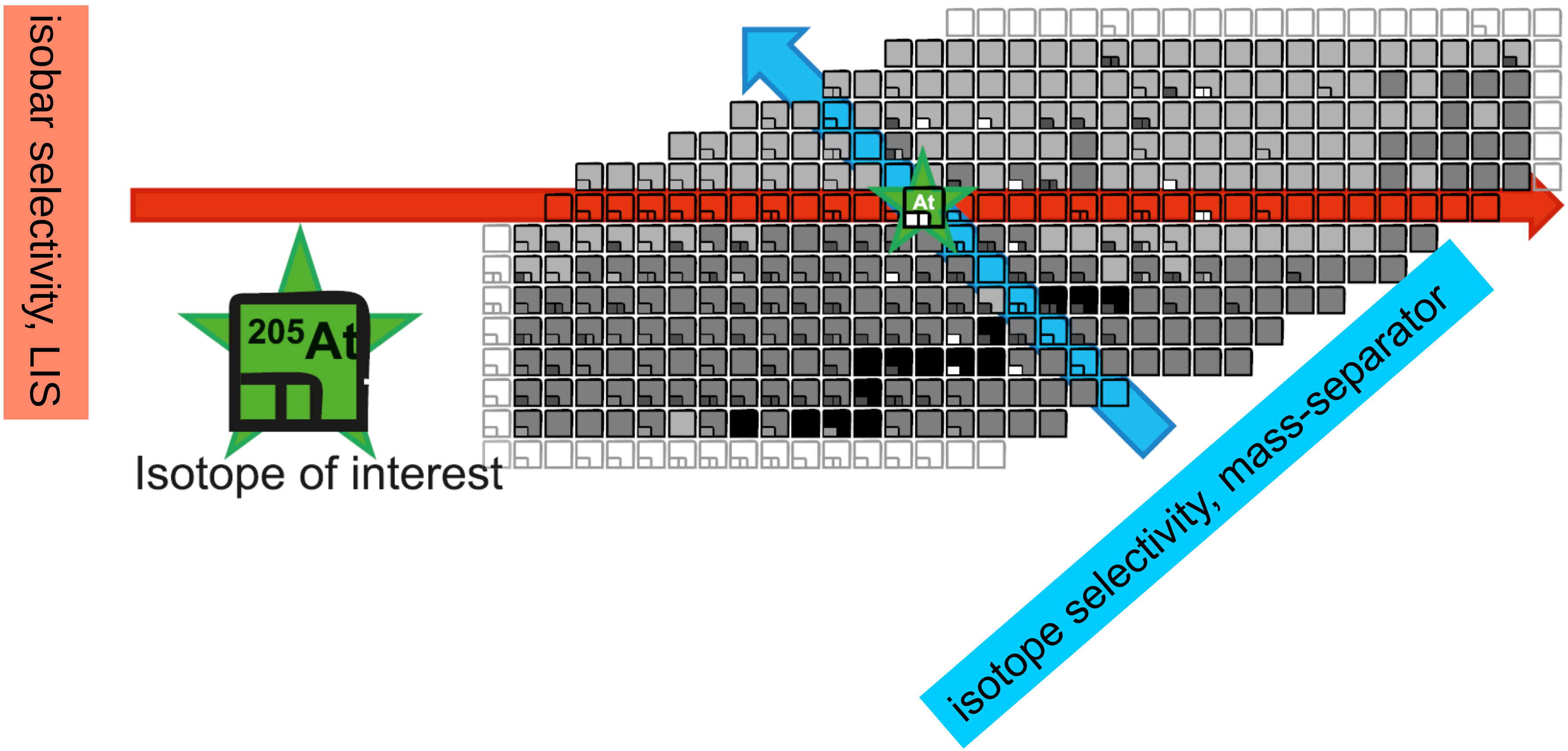


Fig. 2. Differential changes in the mean square charge radii for the nuclei with Z close to $Z=64$. Upper part: data for even-Z nuclei $_{70}$Yb (full circles), $_{68}$Er (open circles), $_{66}$Dy (triangles), $_{64}$Gd (full squares), $_{62}$Sm (crosses) [1, 8, 11]; Lower part: data for odd-Z nuclei $_{69}$Tm (semiopen circles), $_{67}$Ho (asterisks), $_{65}$Tb (rhombs), $_{63}$Eu (open squares) ([2, 3] and the present paper)

J. Phys. G: Nucl. Part. Phys. **18** (1992) 1177

Z. Phys. A 337, 36 (1990)



isobar selectivity, LIS
205At
Isotope of interest
At
isotope selectivity, mass-separator

С. Андреев, В. Мишин, С. Секацкий, ***Квант. Электроника 12, 611 (1985)***
S. Andreev, V. I. Mishin and V. S. Letokhov, ***Opt. Commun. 57, 317 (1986)***
S.V. Andreev, V.S. Letokhov, V.I. Mishin, ***Phys. Rev. Lett. 59, 1274 (1987)***

Fr: ε ~ 7·10^{-3}

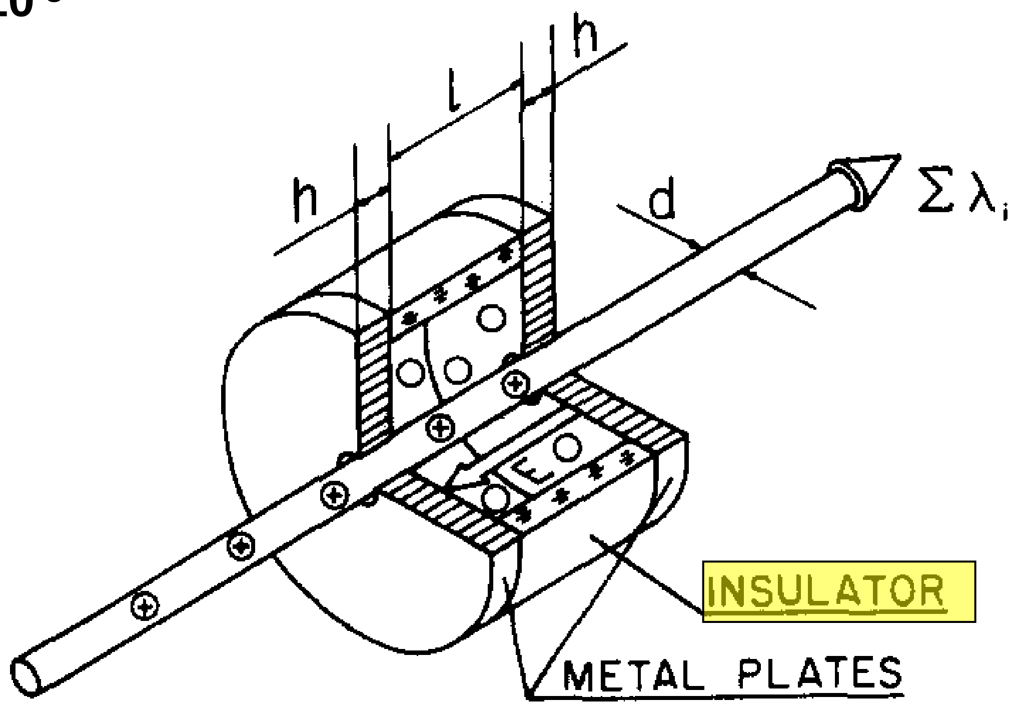
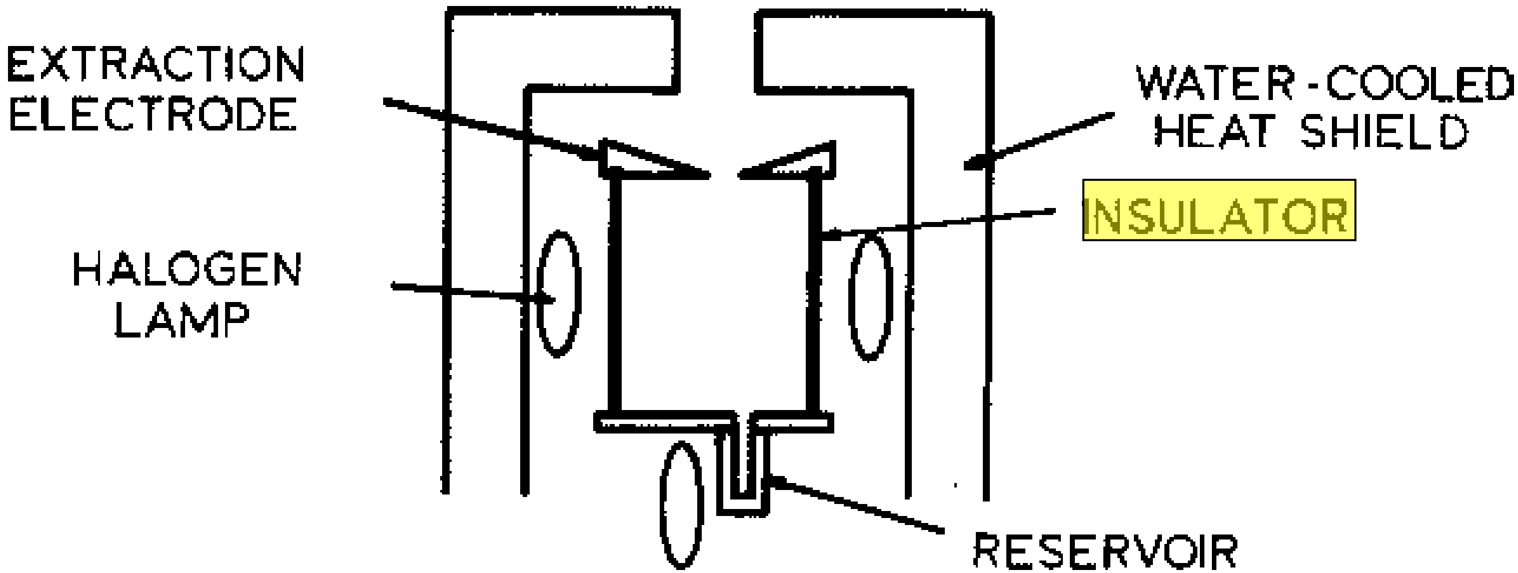


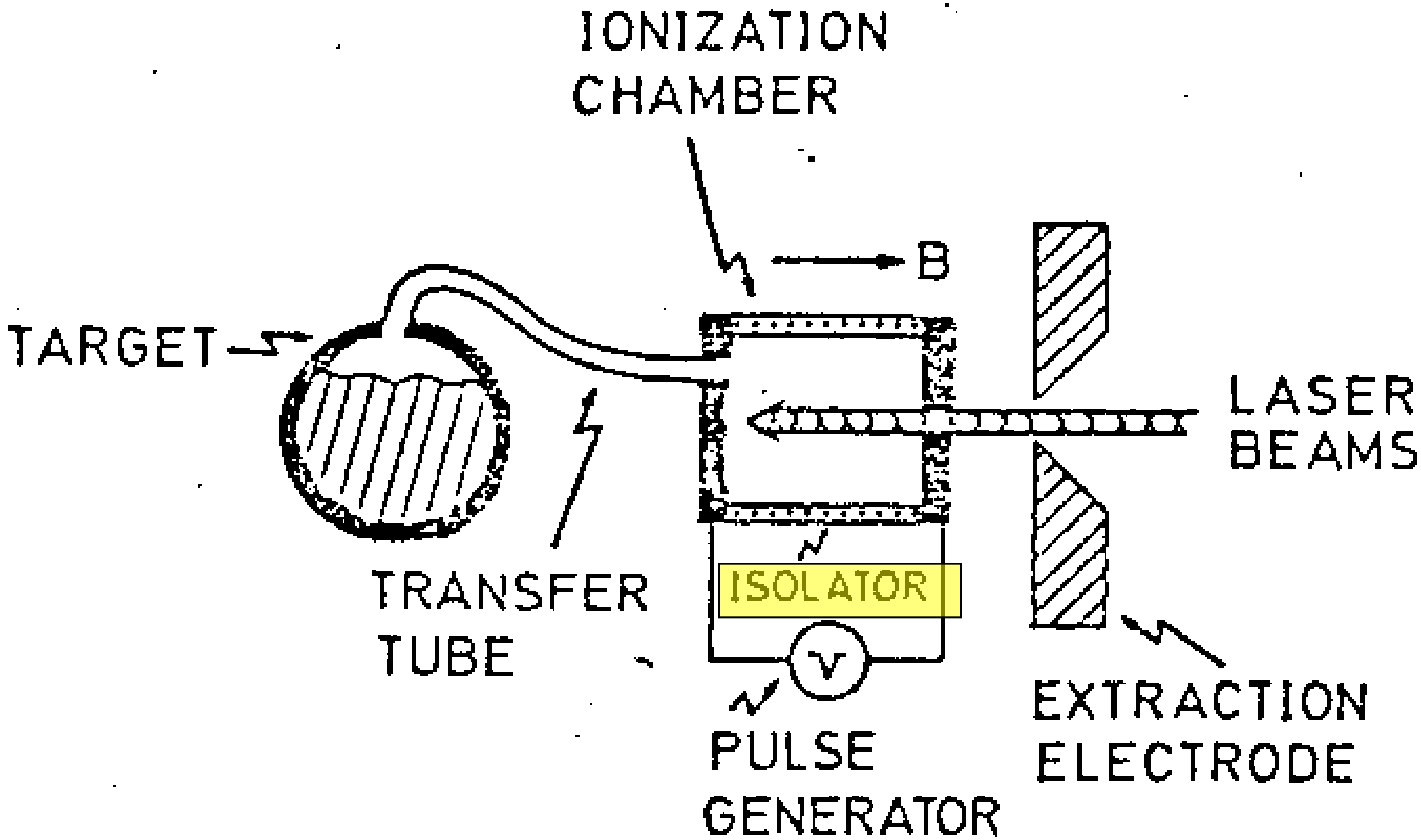
Fig. 1. Scheme of atomic photoionization in a hot cavity

H-J. Kluge, F. Ames, W. Ruster, K. Wallmeroth: ***Proceedings on Accelerated Radioactive Beams Workshop. Vancouver Island (1985), in L. Buchman, J.M. D'Auria (eds.), TRIUMF Proceedings TRI-85-1:119***

F. Ames, A. Becker, H-J. Kluge, H. Rimke, W. Ruster, N. Trautmann: *Fresenius* ***Z. Anal. Chem. 331, 133 (1988)***



V. Letokhov *et al.* In ***Abstracts from the workshop on the Isolde programme "on-line in 1985 and beyond" (1984).***
H.-J. Kluge *et al*. In ***Proceedings of the Accelerated Radioactive Beams Workshop (1985)***



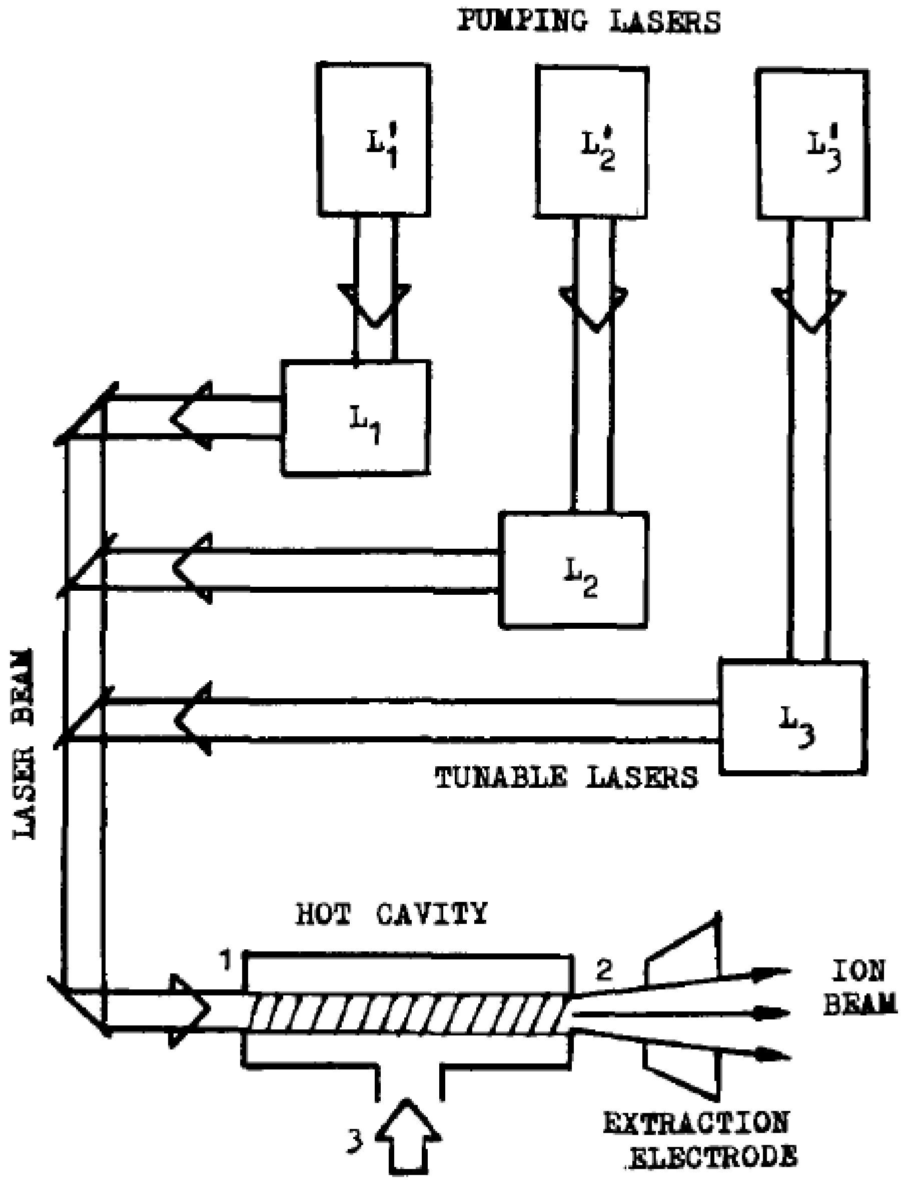


Fig. 1. Schematic drawing of the high-temperature resonant laser ion source. The dashed area is the region of ionization.

G. D . Alkhazov, E. Ye. Berlovich and V. N . Panteleyev, Pisma Zh. Tekn . Fiz. **14** (1988) 1109.

G. D. Alkhazov, E. Ye. Berlovich, V. N. Panteleev, *A new highly efficient selective laser ion source*, Nuclear Instruments and Methods A **280** (1989) 141

СОЮЗ СОВЕТСКИХ СОЦИАЛИСТИЧЕСКИХ РЕСПУБЛИК

ГОСУДАРСТВЕННЫЙ КОМИТЕТ СССР
ПО ДЕЛАМ ИЗОБРЕТЕНИЙ И ОТКРЫТИЙ

АВТОРСКОЕ СВИДЕТЕЛЬСТВО

№ 1316112

На основании полномочий, предоставленных Правительством СССР, Государственный комитет СССР по делам изобретений и открытий выдал настоящее авторское свидетельство на изобретение:
"Способ получения ионов изотопов элементов"

Автор (авторы): Алхазов Георгий Дмитриевич, Берлович Эммануил Ефремович и Пантелеев Владимир Николаевич

Заявитель: ЛЕНИНГРАДСКИЙ ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ ИМ.Б.П. КОНСТАНТИНОВА

Заявка № 3840526 Приоритет изобретения 16 января 1985г.

Зарегистрировано в Государственном реестре изобретений СССР

15 февраля 1987г.

Действие авторского свидетельства распространяется на всю территорию Союза ССР.

Председатель Комитета

Начальник отдела

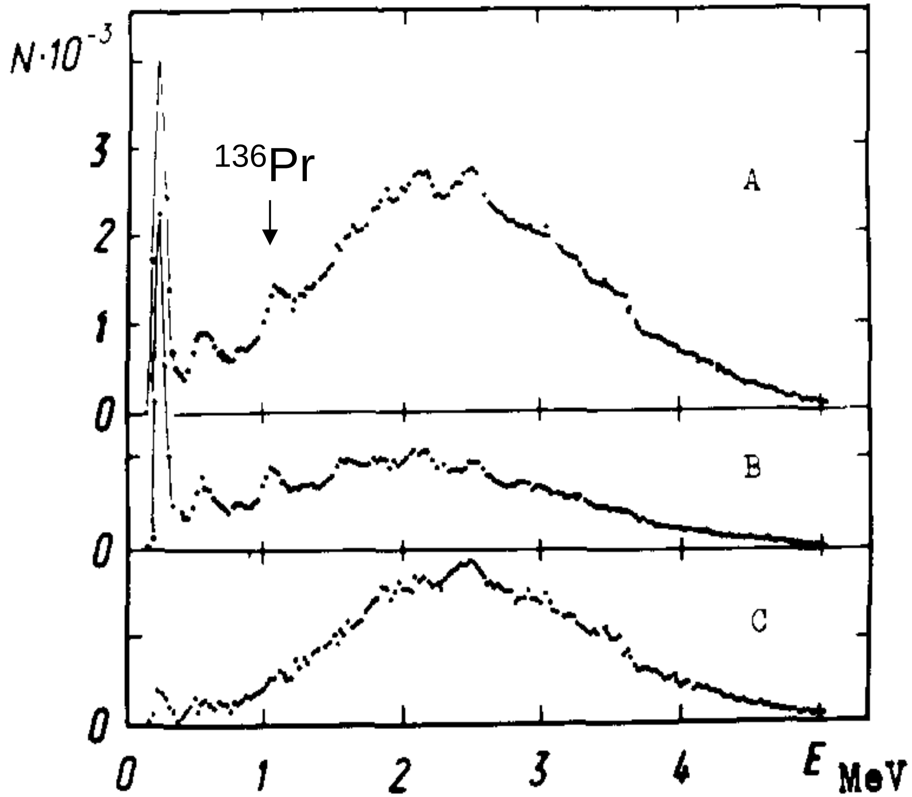


Fig. 3. Total absorption γ-spectra for decay of nuclei with $A = 152$: (A) with the lasers switched on; (B) with the lasers switched off, (C) the difference of spectra (A) and (B).

G.D. Alkhazov, L.Kh. Batist, A.A. Bykov, V.D. Vitman, V.S. Letokhov, V.I . Mishin, V.N. Panteleyev, S.K. Sekatsky and V.N . Fedoseyev, Nuclear Instruments and Methods A **306** (1991) 400

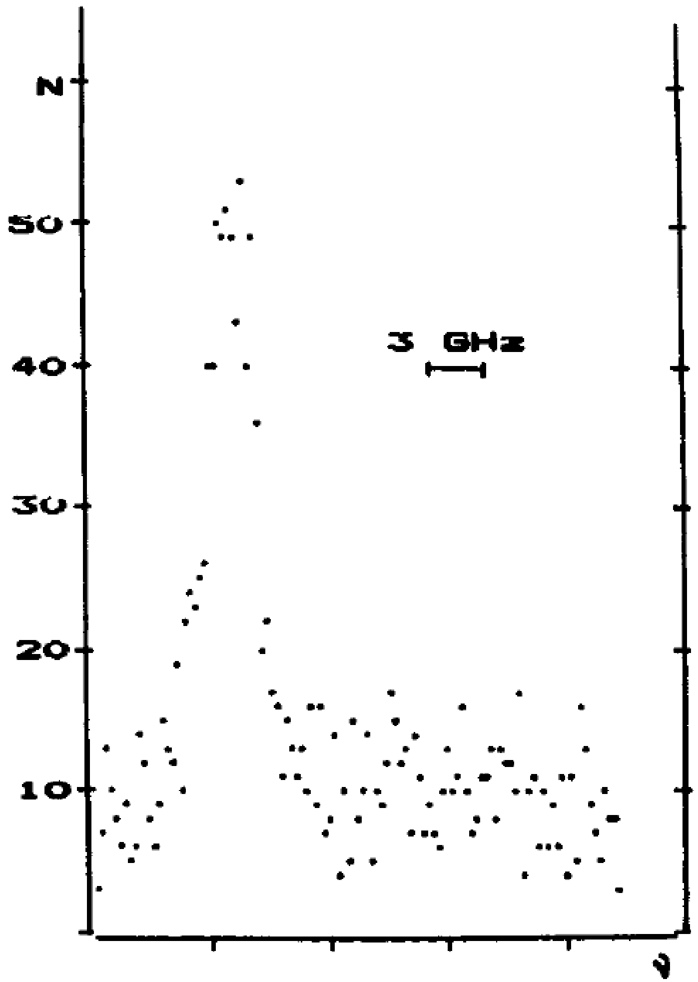
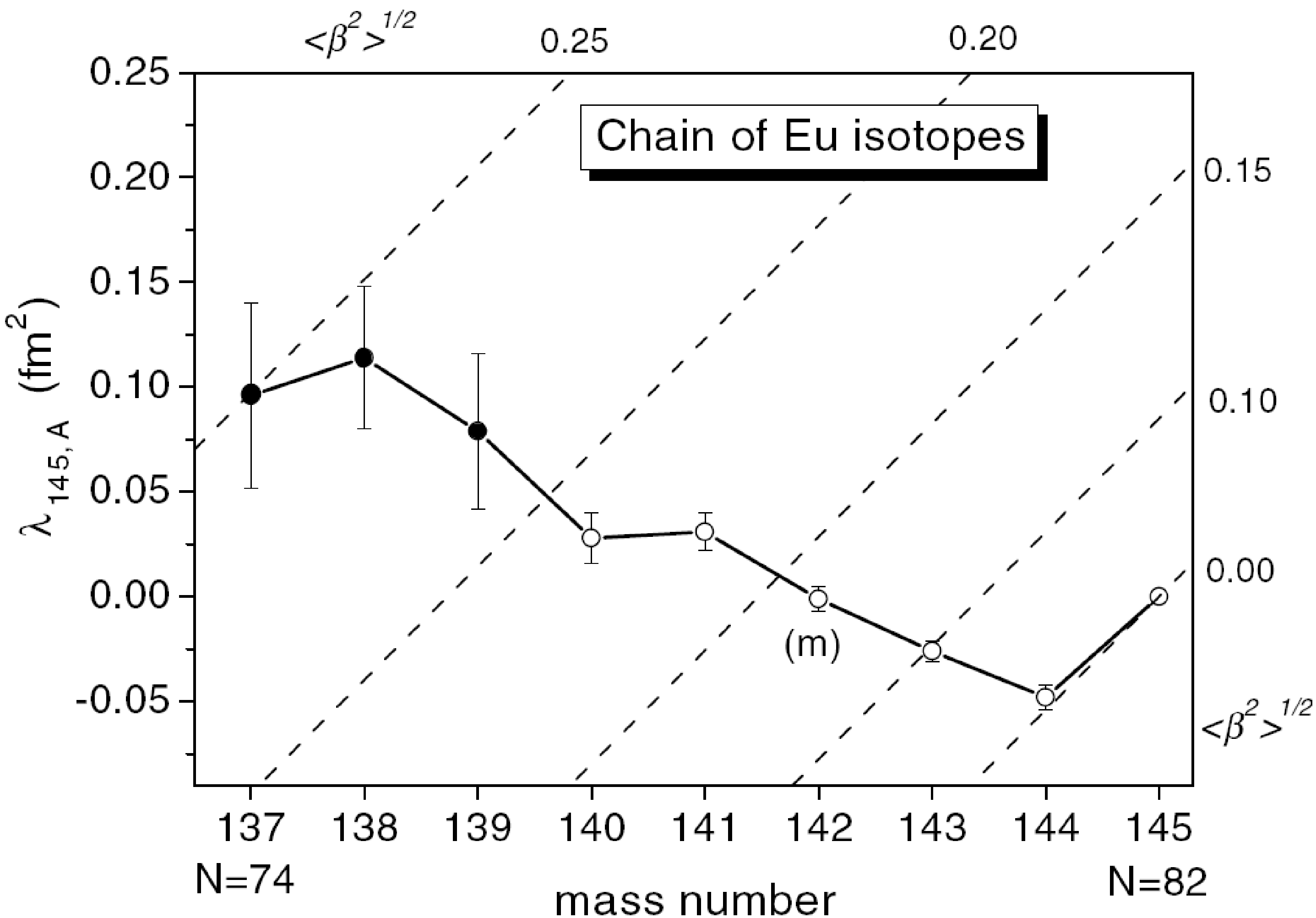
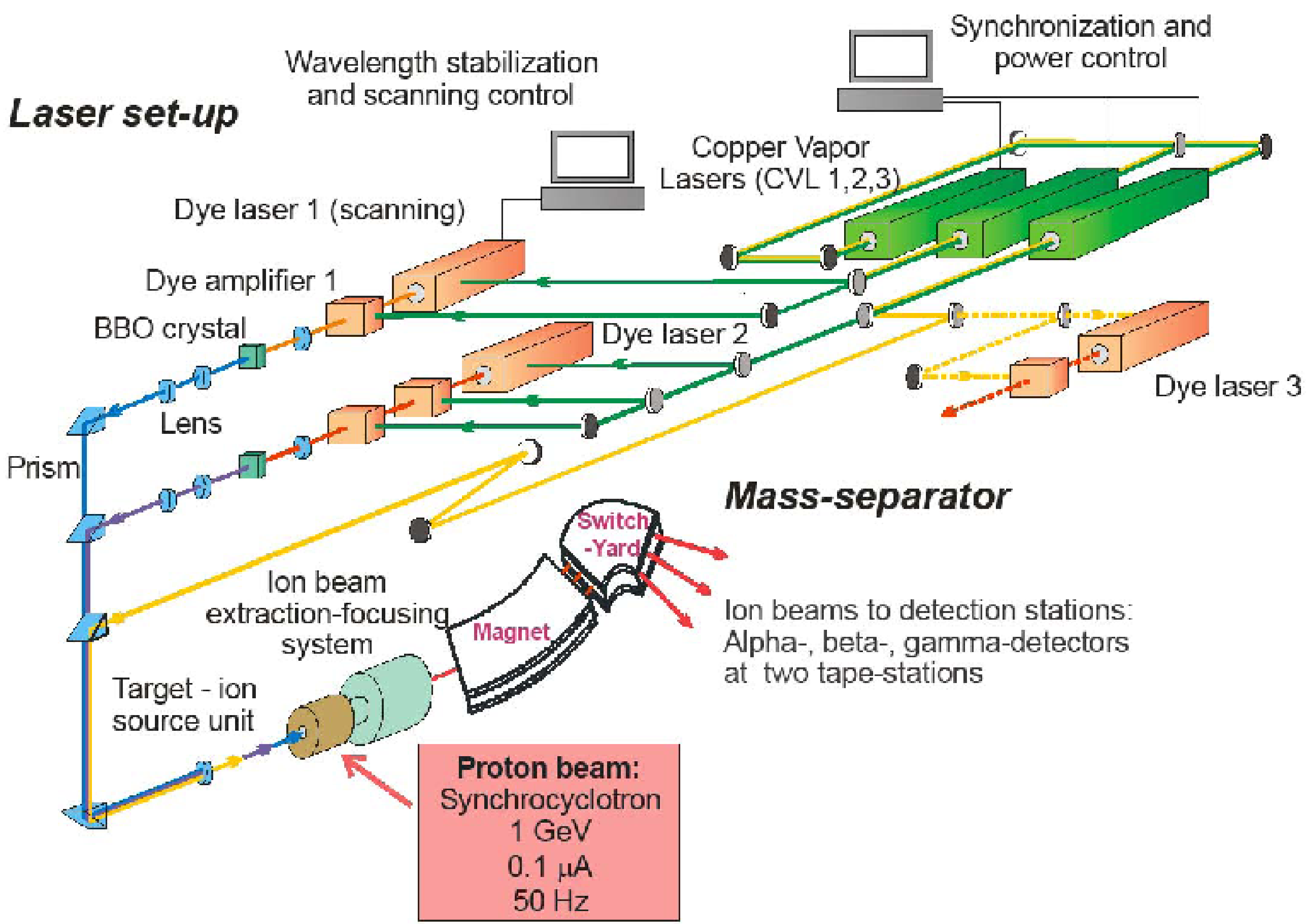


Fig. 3. Optical spectrum of ^{154}Yb.

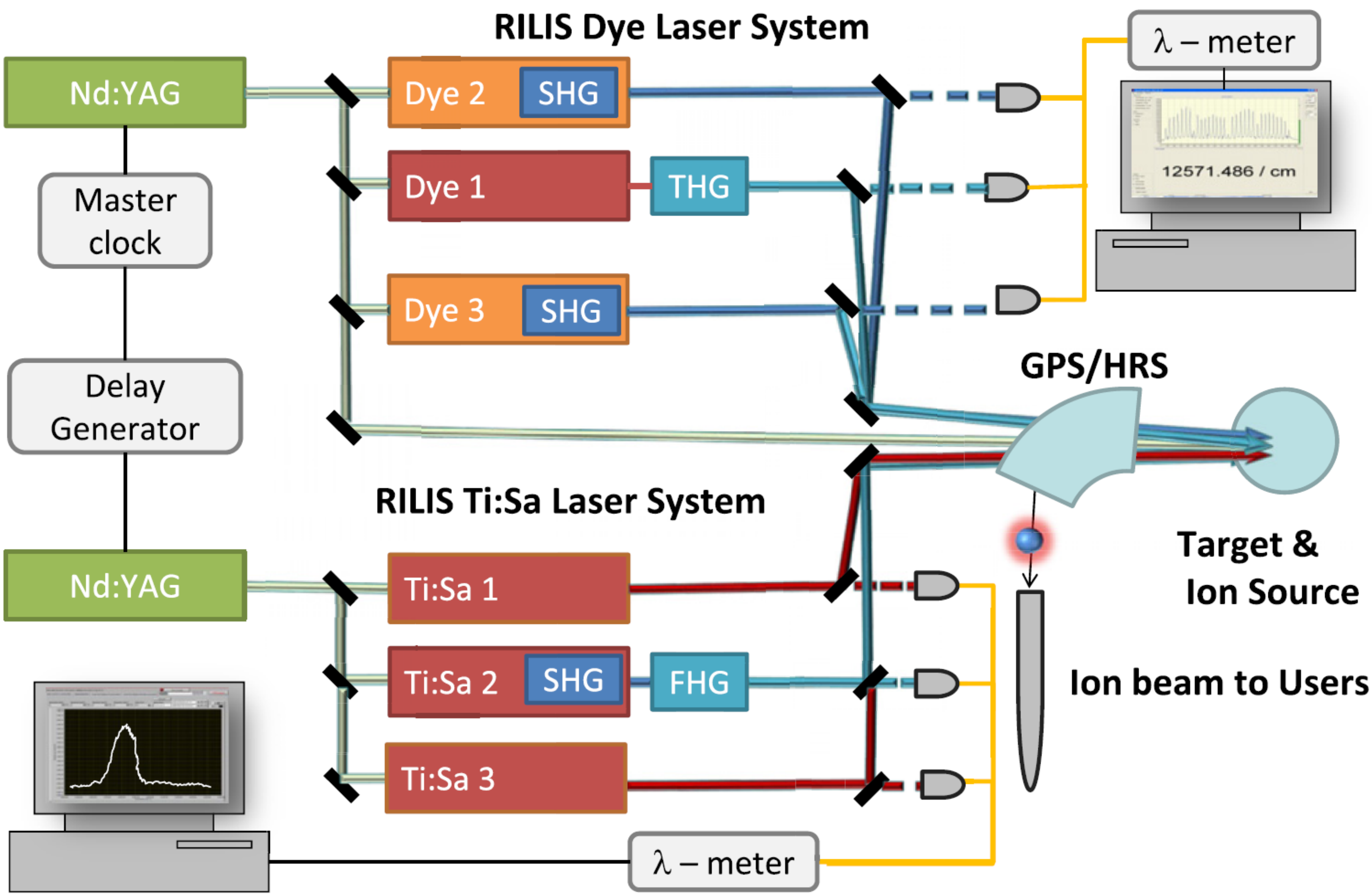
G.D. Alkhazov, A.E. Barzakh, V.P. Denisov, K.A. Mezilev, Yu.N. Novikov, V.N. Panteleyev, A. N. Popov, E.P. Sudentas, V.S. Letokhov, V.I. Mishin, V.N. Fedoseyev, S .V. Andreyev, D.S. Vedeneyev and A.D. Zyuzikov, ***A new highly efficient method of atomic spectroscopy for nuclides far from stability,*** Nuclear Instruments and Methods B **69** (1992) 517

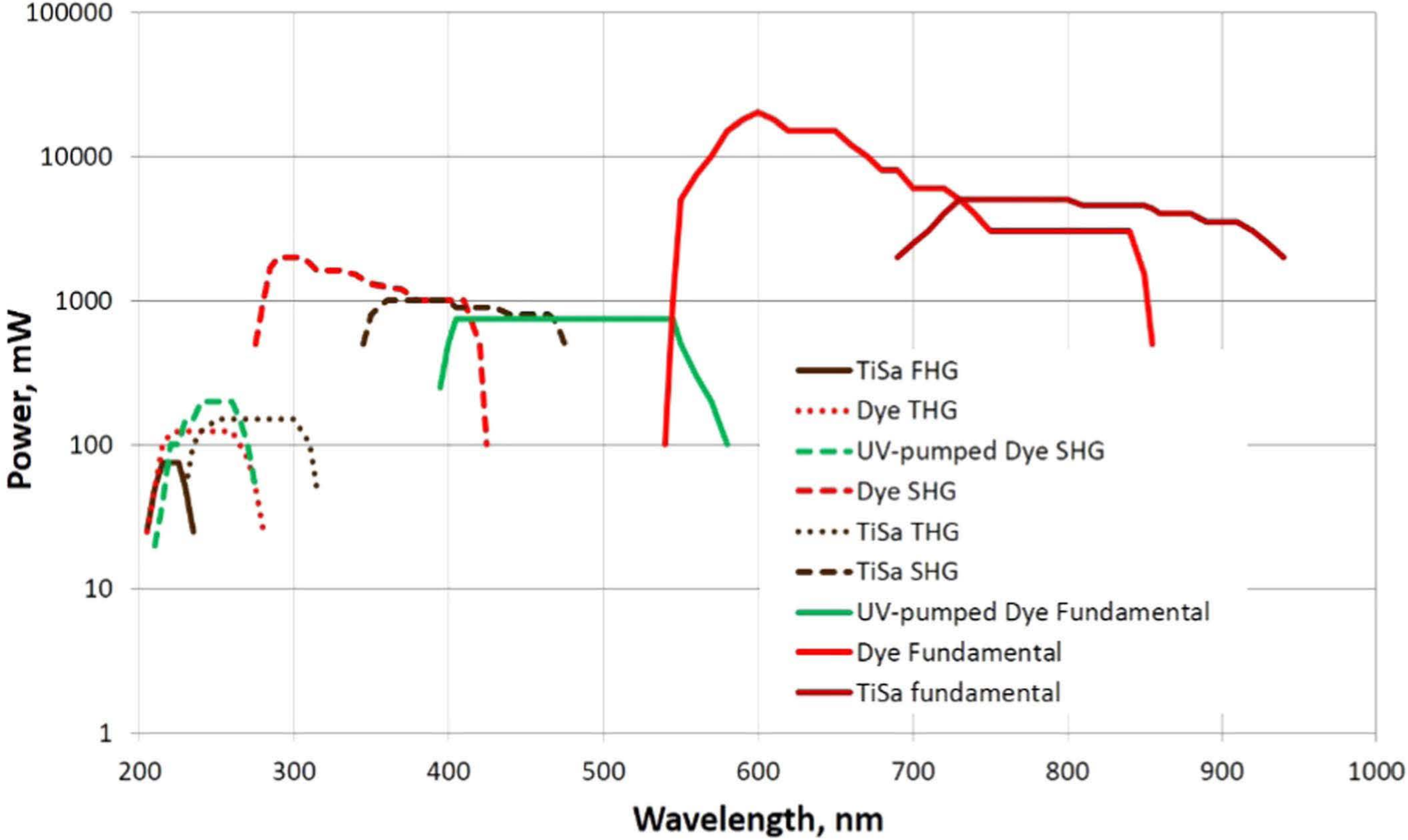
A.E. Barzakh, D.V. Fedorov, A.M. Ionan, V.S. Ivanov, F.V. Moroz, K.A. Mezilev, S.Yu. Orlov, V.N. Panteleev, and Yu.M. Volkov, ***Changes in the mean square charge radii of neutron-deficient Eu isotopes measured by the laser ion source resonance ionization spectroscopy***, Eur. Phys. J. A 22, 69 (2004)





Laser set-up
Wavelength stabilization and scanning control
Synchronization and power control
Copper Vapor Lasers (CVL 1,2,3)
Dye laser 1 (scanning)
Dye amplifier 1
BBO crystal
Dye laser 2
Dye laser 3
Lens
Prism
Mass-separator
Switch -Yard
Ion beam extraction-focusing system
Magnet
Ion beams to detection stations: Alpha-, beta-, gamma-detectors at two tape-stations
Target - ion source unit
Proton beam:
Synchrocyclotron
1 GeV
0.1 µA
50 Hz


RILIS Dye Laser System
Nd:YAG
Dye 2
SHG
Dye 1
THG
Dye 3
SHG
Master clock
Delay Generator
λ – meter
12571.486 / cm
GPS/HRS
Target & Ion Source
RILIS Ti:Sa Laser System
Nd:YAG
Ti:Sa 1
Ti:Sa 2
SHG
FHG
Ti:Sa 3
Ion beam to Users
λ – meter



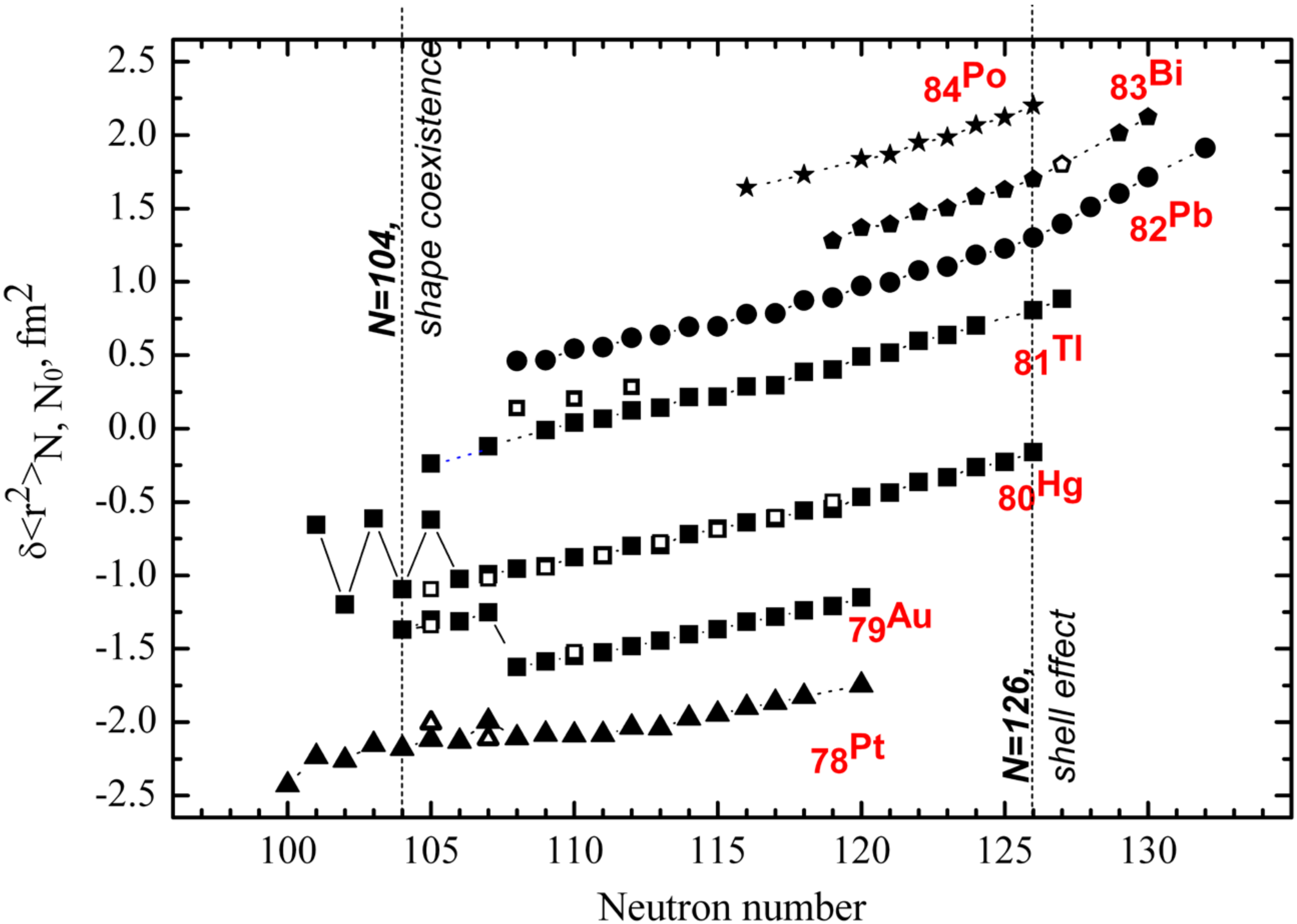
100000
10000
1000
100
10
1
Power, mW
200
300
400
500
600
700
800
900
1000
Wavelength, nm
TiSa FHG
Dye THG
UV-pumped Dye SHG
Dye SHG
TiSa THG
TiSa SHG
UV-pumped Dye Fundamental
Dye Fundamental
TiSa fundamental

RILIS @ ISOLDE ~ 40 elements

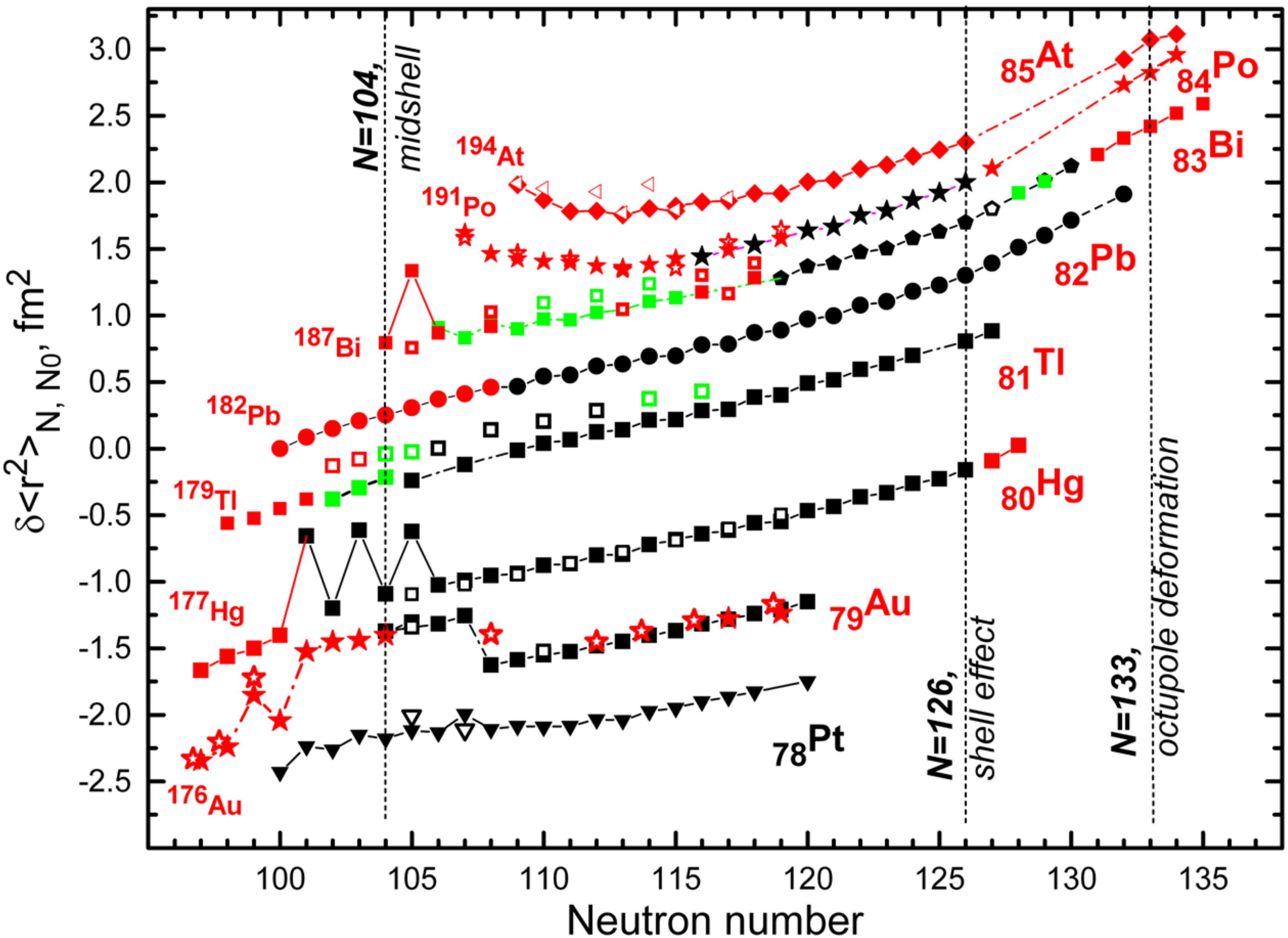
Element	Type of scheme[a]	λ_1 (vac) nm	λ_2 (vac) nm	λ_3 (vac) nm	Efficiency Abs. %	Efficiency Laser/surf.
Li	D	670.96	610.53	532		0.6
Be	H	234.93	297.41	—	>7	
Mg	I	285.30	552.99	510.69 & 578.37 532	10	
Al	A	308.30 & 309.37	510.69 & 578.37 532	—	>20	100
Ca	J	422.79	585.91	655.18		300
Sc	I	327.46	720.03	510.69	15	400
Cr	J	357.97	698.03	579.31	~20	2200
Mn	J	279.91	628.44	510.69 647.52	19	
Fe	L	372.10	321.26	532		10^5
Co	I	304.49	544.61	510.69 & 578.37	>4	
Ni	J	305.17	611.28	748.42	>6	8000
Cu[e]	I	327.49	793.53	510.69	6.6	
	H		287.98	—	>7	
Zn	I	213.92	636.41	510.69 532	5	
Ga	A	287.51	510.69 & 578.37	—	21	20–30
		287.51 & 294.50	532	—		>100
Ge	I	275.54	569.35	532	>2	
Y	I	408.49	582.07	582.07		16
		414.40	662.55	510.69		88
Mo	M	379.93	415.91	635.16		
Ag[e]	I	328.16	546.7	510.69 & 578.37 532	14	
	L	328.16	421.21	532		
Cd	I	228.87	644.02	510.69 532	10	

In[e]	A	304.02	510.69 & 578.37	—		7
		304.02 & 325.70	532			
Sn	I	303.50	607.08	607.08	0.2	
	J	301.00	811.40	823.68	9	
		286.30				
Sb	I	217.65	560.36	510.69	2.7	
				532		
Te	J	214.35	573.52	901.51	>18	
Ba	B	350.21	653.71	—		1
	A		532			
Ba^{+}	L	455.53	223.35	532	1.2[c]	
Pr	I	461.90	900.00	532		
Nd	D	588.95	597.10	597.10		15
Sm	E	600.58	675.34	676.37		6
Tb	E	579.72	551.80	618.43		>1.8
Dy	D	626.08	607.66	510.69	20	50
				532		
	I	418.80	776.22	532		12
Ho	I	405.50	623.43	532	>20	60
	J			838.36		45
Tm	E	589.73	571.40	575.67	>2	
Yb	E	555.80	581.23	581.23	15	20
	A	267.28	532	—		
Au[e]	M	267.67	306.63	674.08	>3	
Hg[e]	L	253.73	313.28	532	6	
Tl[e]	A	276.87	510.69 & 578.37	—	27	100
Bi[e]	I	306.86	555.36	510.69 & 578.37	6	
				532		
Po[e]	I	245.08	539.03	510.69		
			843.62			
		255.88	843.62	532		
	K	255.88	843.62	593.94		
At[e]	I	216.29	795.45	532		
			915.46	532		
	K		795.45	617.55		
Ra	E	714.32	784.03	557.65		3
	G			615.28		

IS and hfs: Lead region (before 2004)



IS and hfs: Lead region (present status)



nature physics

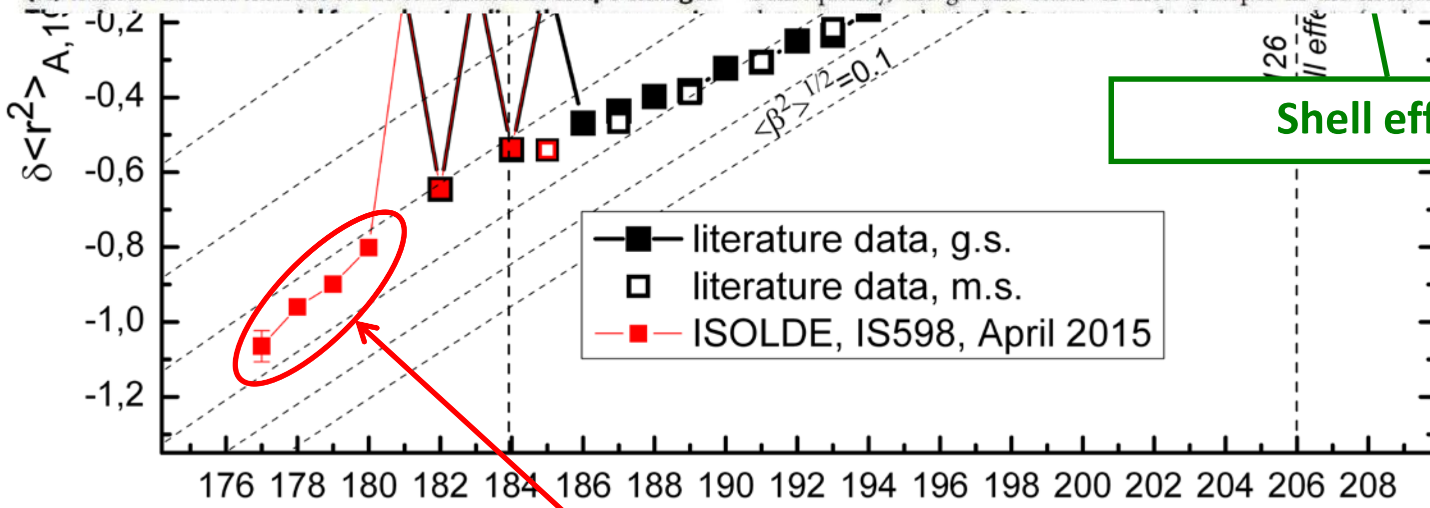
LETTERS

https://doi.org/10.1038/s41567-018-0292-8

Characterization of the shape-staggering effect in mercury nuclei

B. A. Marsh[1*], T. Day Goodacre[1,2,18], S. Sels[3,18], Y. Tsunoda[4], B. Andel[5], A. N. Andreyev[6,7], N. A. Althubiti[2], D. Atanasov[8], A. E. Barzakh[9], J. Billowes[2], K. Blaum[8], T. E. Cocolios[2,3], J. G. Cubiss[6], J. Dobaczewski[6], G. J. Farooq-Smith[2,3], D. V. Fedorov[9], V. N. Fedosseev[1], K. T. Flanagan[2], L. P. Gaffney[3,10], L. Ghys[3], M. Huyse[3], S. Kreim[8], D. Lunney[11], K. M. Lynch[1], V. Manea[8], Y. Martinez Palenzuela[3], P. L. Molkanov[9], T. Otsuka[3,4,12,13,14], A. Pastore[6], M. Rosenbusch[13,15], R. E. Rossel[1], S. Rothe[1,2], L. Schweikhard[15], M. D. Seliverstov[9], P. Spagnoletti[10], C. Van Beveren[3], P. Van Duppen[3], M. Veinhard[1], E. Verstraelen[3], A. Welker[16], K. Wendt[17], F. Wienholtz[15], R. N. Wolf[8], A. Zadvornaya[3] and K. Zuber[16]

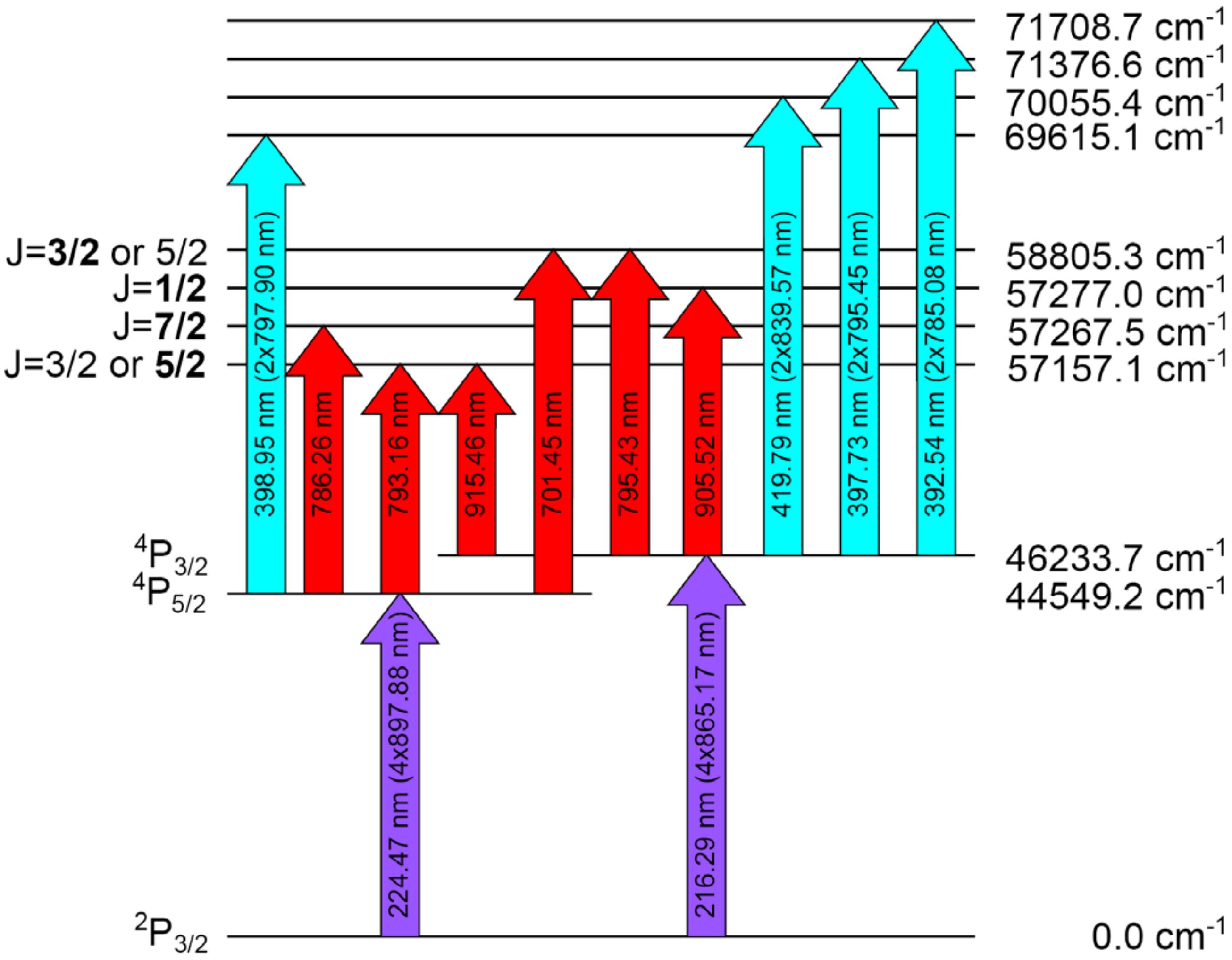
In rare cases, the removal of a single proton (Z) or neutron (N) from an atomic nucleus leads to a dramatic shape change. the minimum-energy configuration of the nucleus to deformation. Consequently, the ground states of most isotopes in the nuclear



Shell effect

Return to “sphericity”,
end of shape staggering

Astatine: Atomic spectroscopy



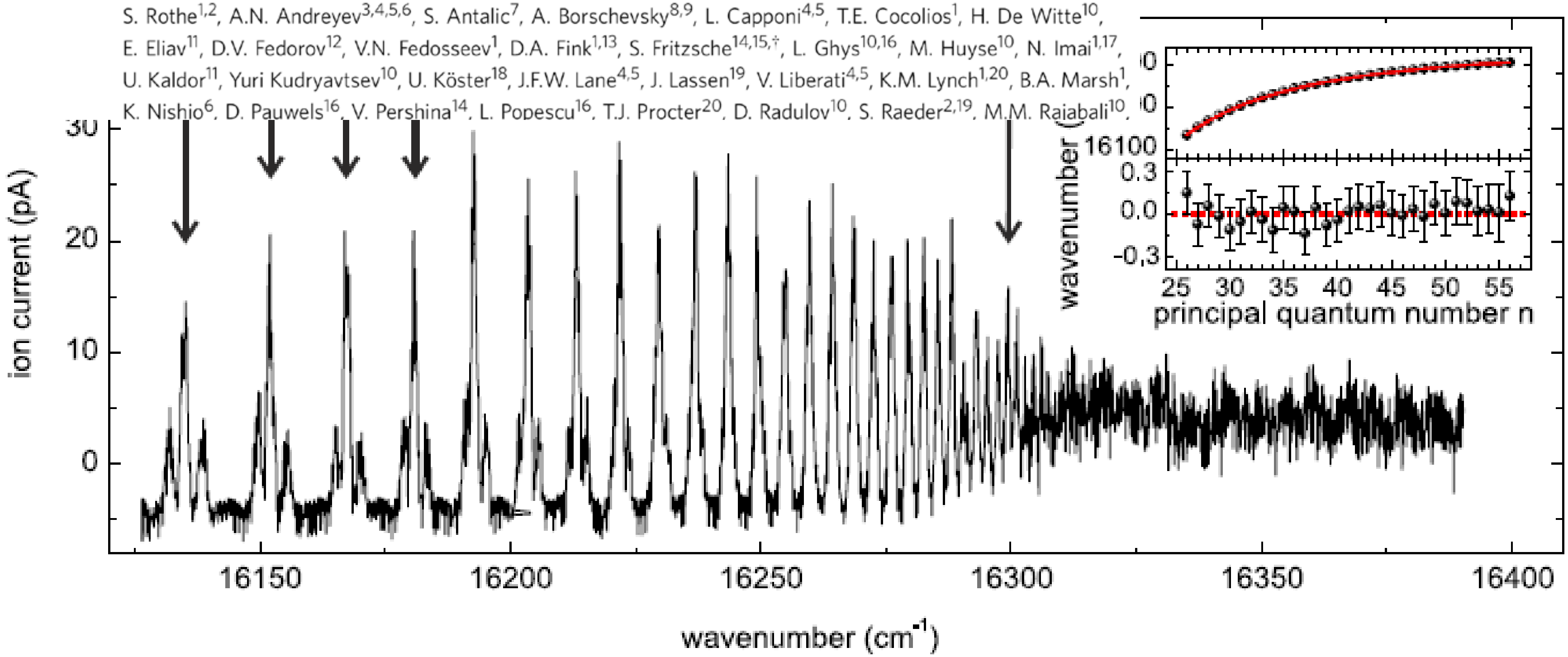
nature COMMUNICATIONS

ARTICLE

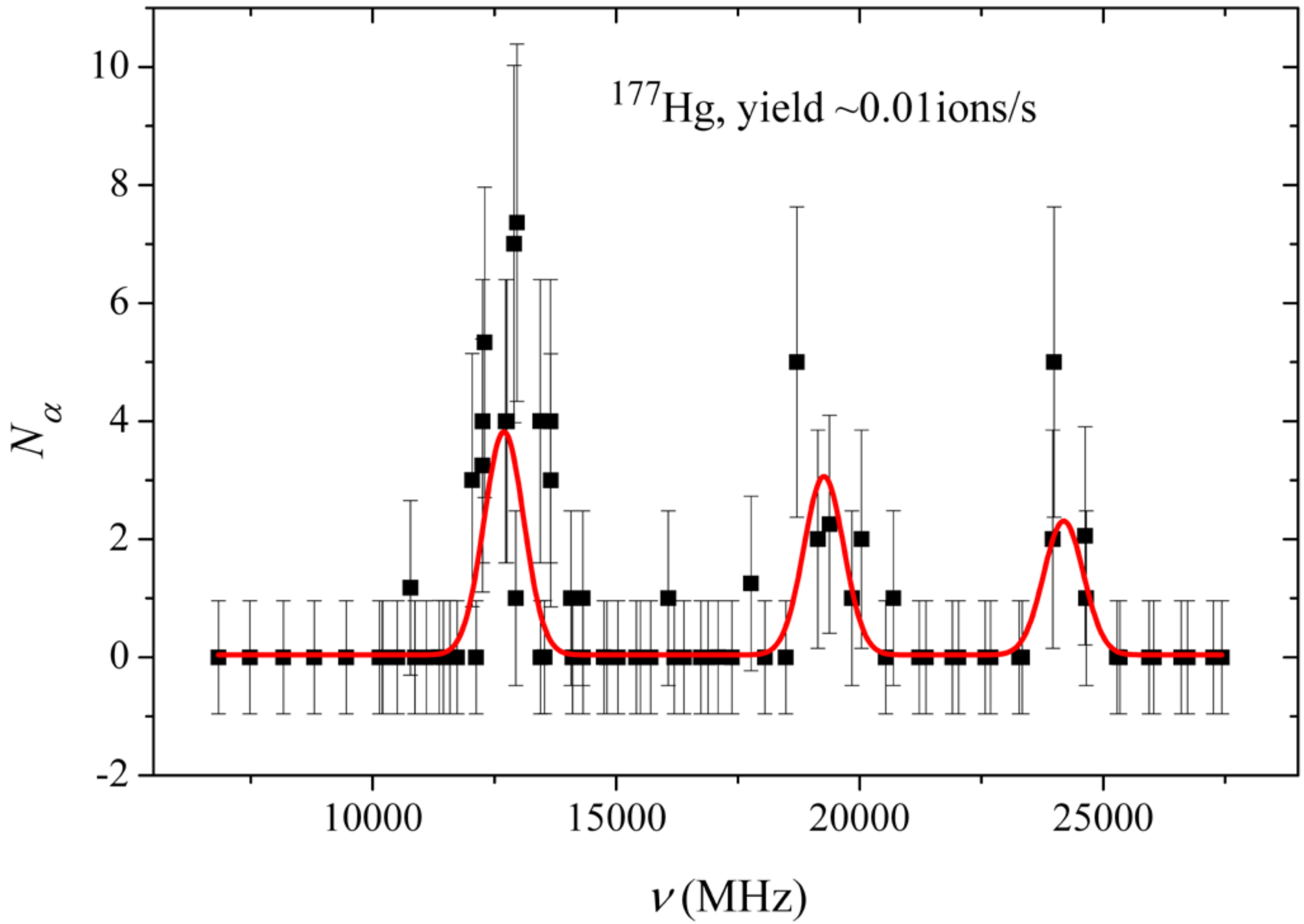
Received 21 Aug 2012 | Accepted 27 Mar 2013 | Published 14 May 2013 DOI: 10.1038/ncomms2819 OPEN

Measurement of the first ionization potential of astatine by laser ionization spectroscopy

S. Rothe[1,2], A.N. Andreyev[3,4,5,6], S. Antalic[7], A. Borschevsky[8,9], L. Capponi[4,5], T.E. Cocolios[1], H. De Witte[10], E. Eliav[11], D.V. Fedorov[12], V.N. Fedosseev[1], D.A. Fink[1,13], S. Fritzsche[14,15,†], L. Ghys[10,16], M. Huyse[10], N. Imai[1,17], U. Kaldor[11], Yuri Kudryavtsev[10], U. Köster[18], J.F.W. Lane[4,5], J. Lassen[19], V. Liberati[4,5], K.M. Lynch[1,20], B.A. Marsh[1], K. Nishio[6], D. Pauwels[16], V. Pershina[14], L. Popescu[16], T.J. Procter[20], D. Radulov[10], S. Raeder[2,19], M.M. Rajabali[10],



$$\nu_n = IP - E_2 - \frac{R_M}{(n-\delta)^2} \Rightarrow IP\ \text{(At)}=9.317510(84)\ \text{eV}$$



^{177}Hg, yield ~0.01ions/s
N_α
ν (MHz)
10
8
6
4
2
0
-2
10000
15000
20000
25000

RITU: H. Kettunen et al., EPJ A16, 457 (2003)

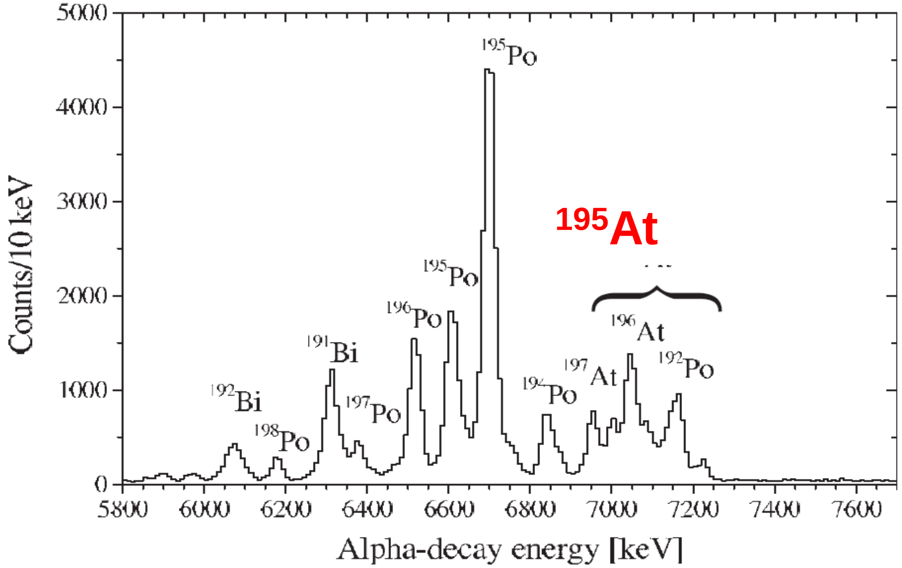
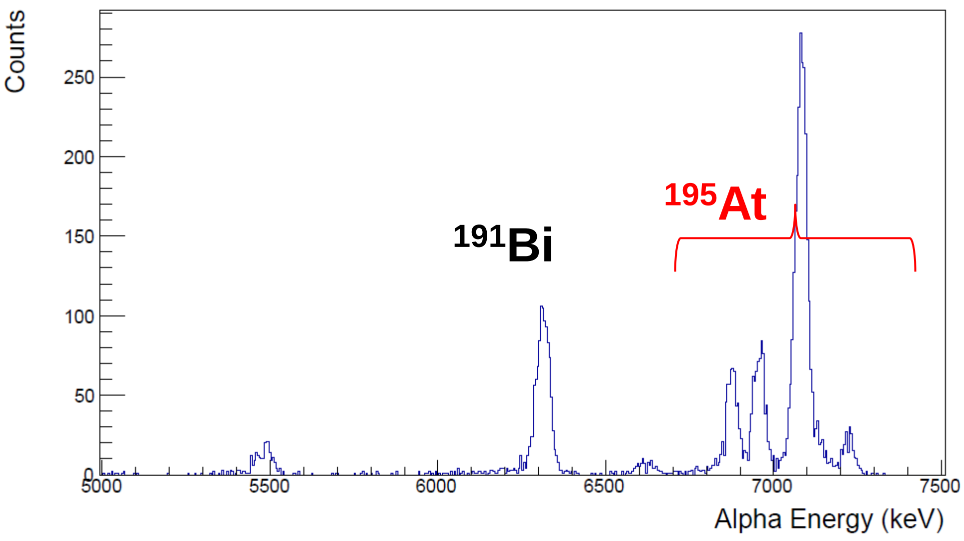
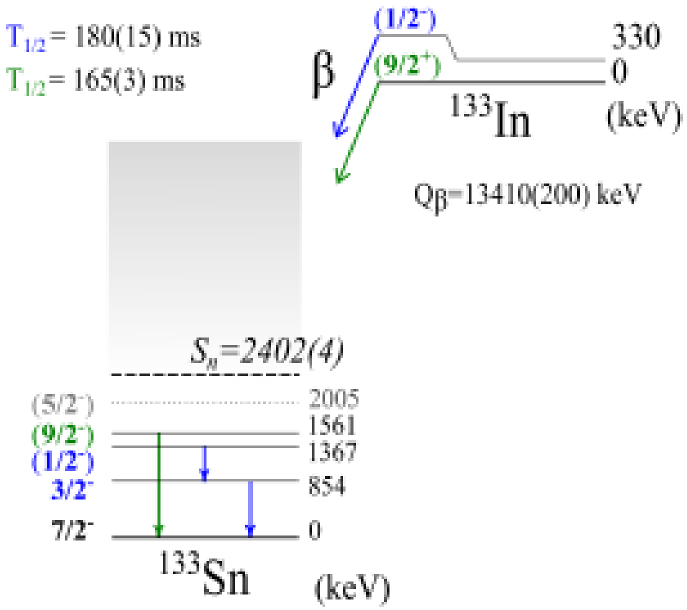


Fig. 1. Energy spectrum of alpha-decays from the reaction $^{56}Fe + ^{142}Nd$ measured in the silicon detector and vetoed with the gas counter.

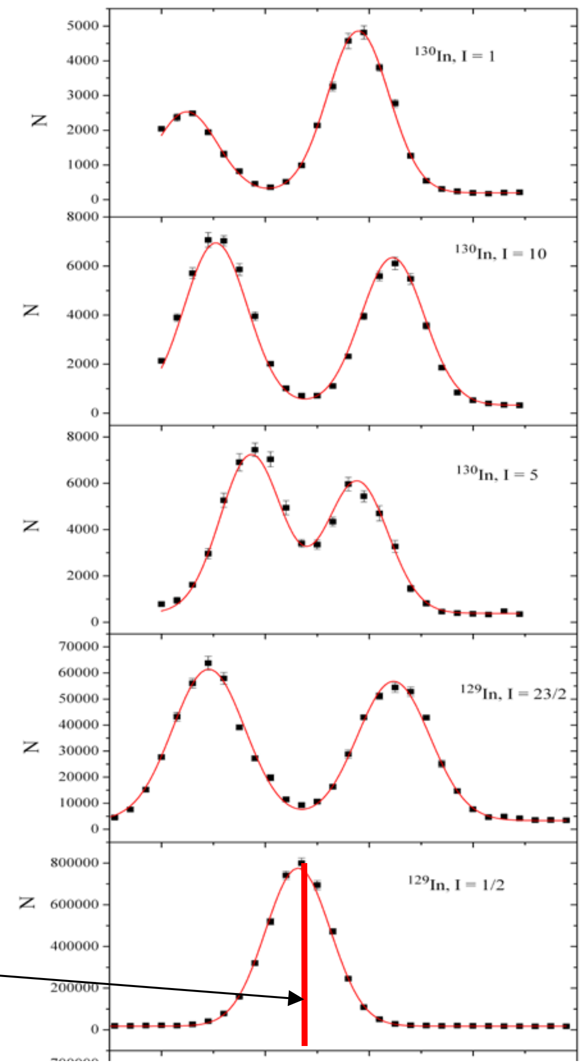
RILIS+SOLDE, IS534



M. Piersa *et al*., Phys. Rev. C **99**, 024304 (2019)

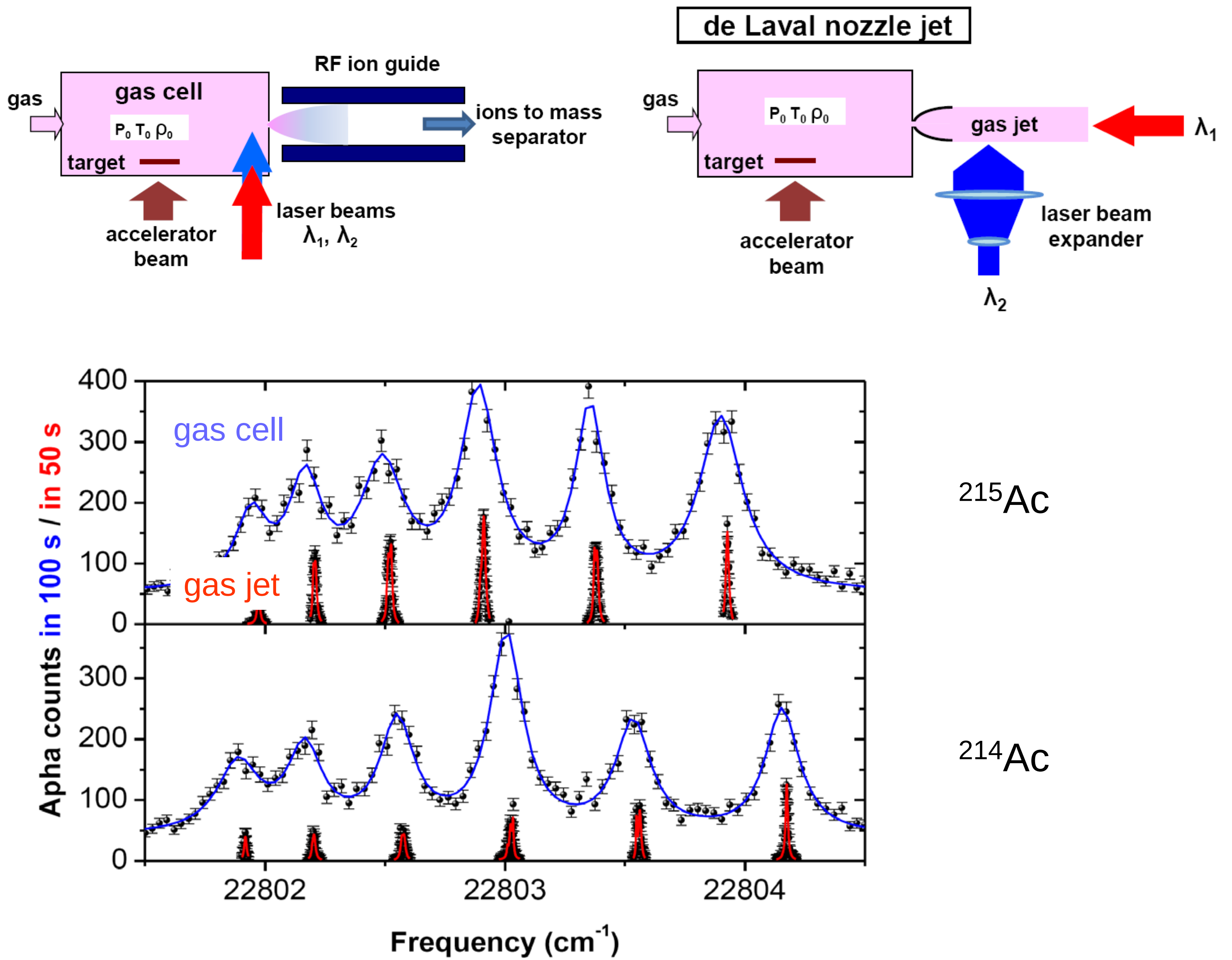


Low-lying states in ^{133}Sn

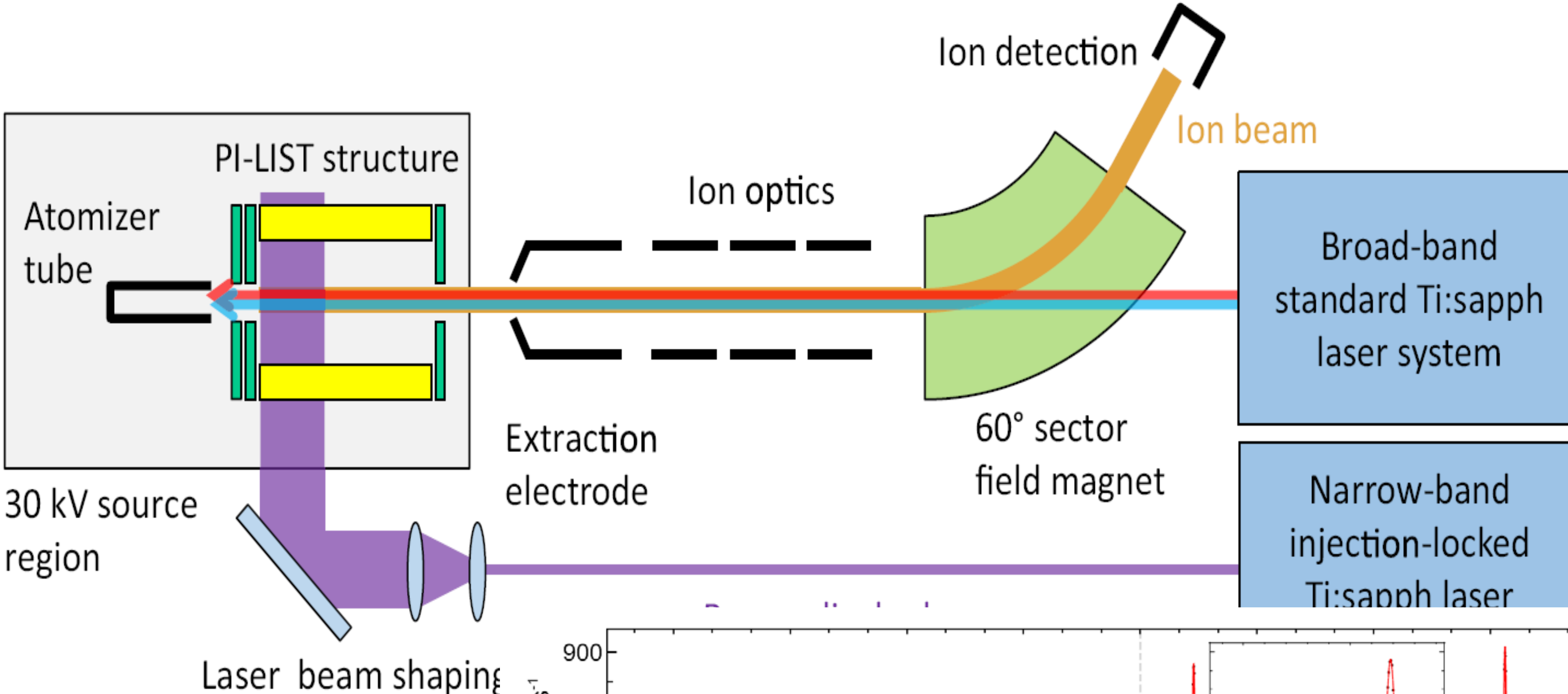


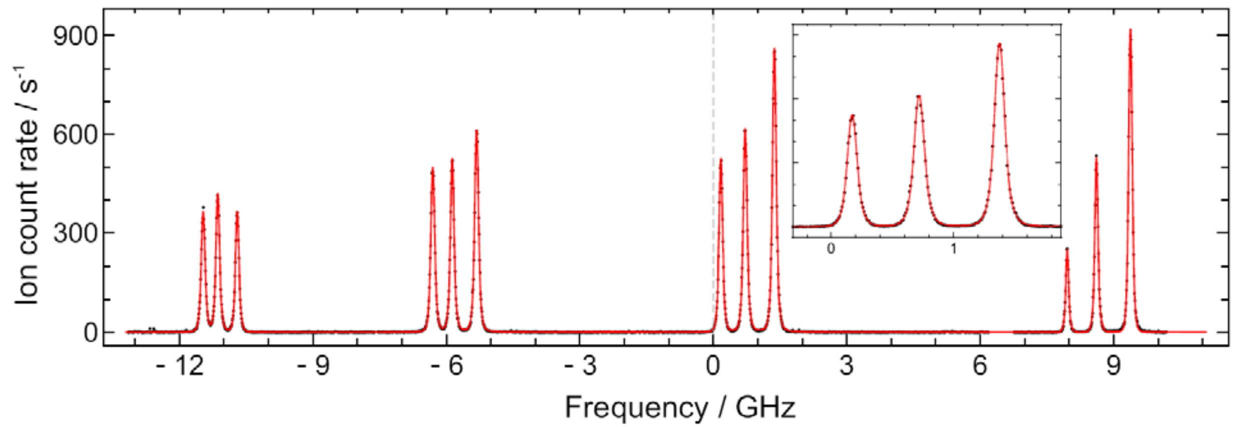
pure *I* = 1/2 isomer

V. I. Mishin, S. K. Sekatskii, V. N. Fedoseev, N. B. Buyanov, V. S. Letokhov, A. E. Barzakh, V. P. Denisov, A. G. Dernyatin, V. S. Ivanov, I. Ya. Chubukov and G. D. Alkhazov, ***Resonance photoionization spectroscopy and laser separation of ^{141}Sm and ^{164}Tm nuclear isomers*** Optics Communications, Volume 61, Issue 6 (1987) 383



de Laval nozzle jet
gas
gas cell
P_0 T_0 ρ_0
target
RF ion guide
ions to mass separator
accelerator beam
laser beams λ_1, λ_2
gas
P_0 T_0 ρ_0
target
gas jet
λ_1
accelerator beam
laser beam expander
λ_2
gas cell
gas jet
Apha counts in 100 s / in 50 s
Frequency (cm^{-1})
22802
22803
22804
^{215}Ac
^{214}Ac





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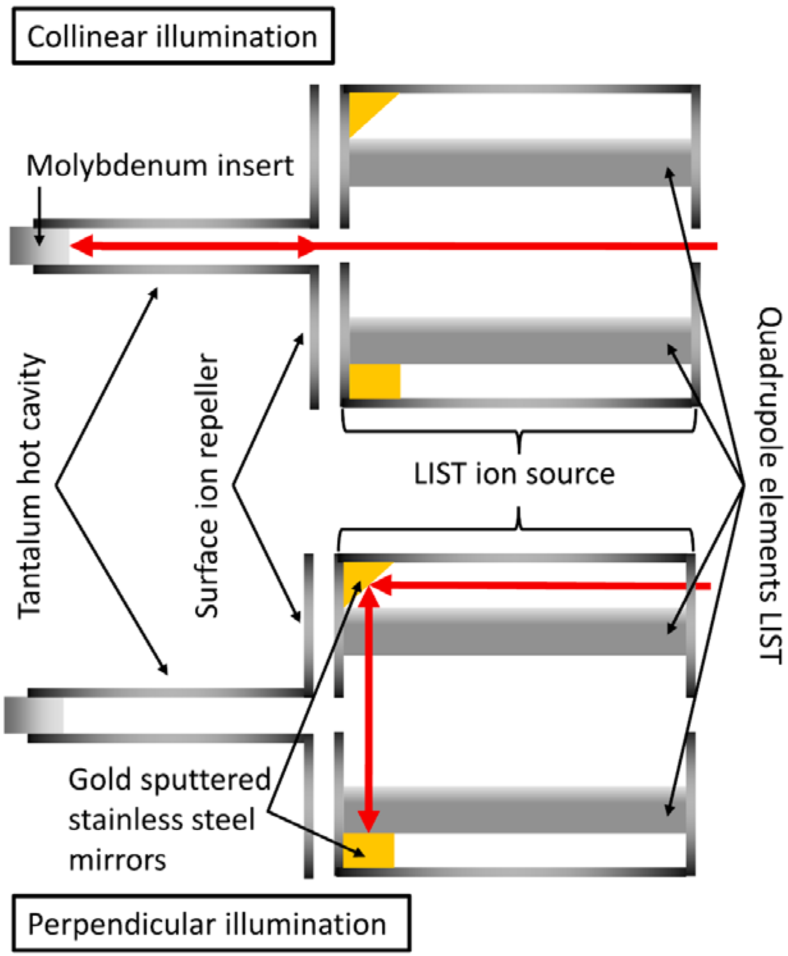

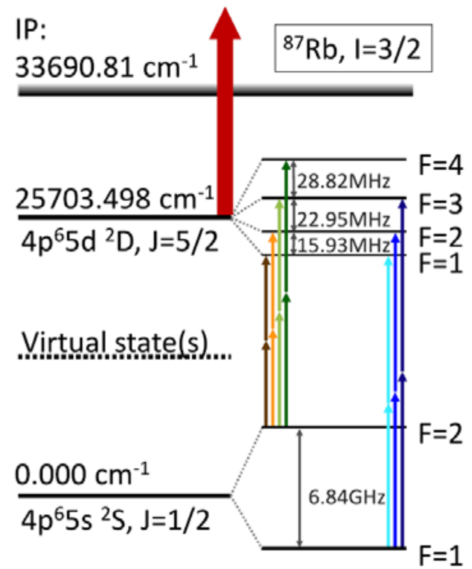

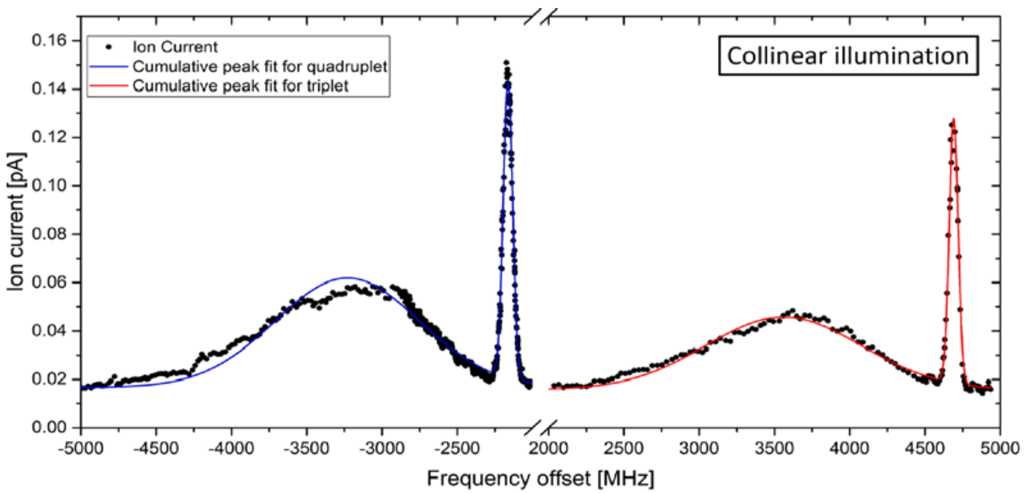

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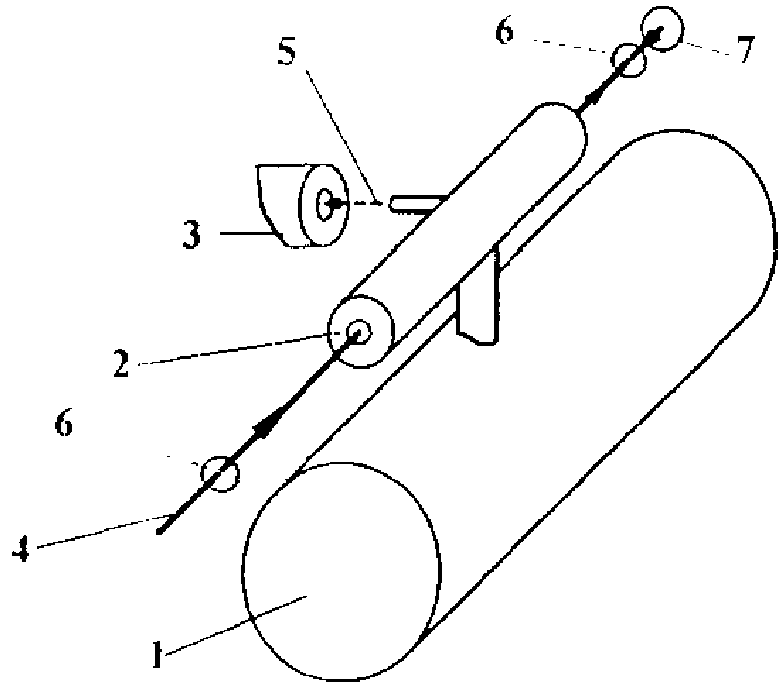
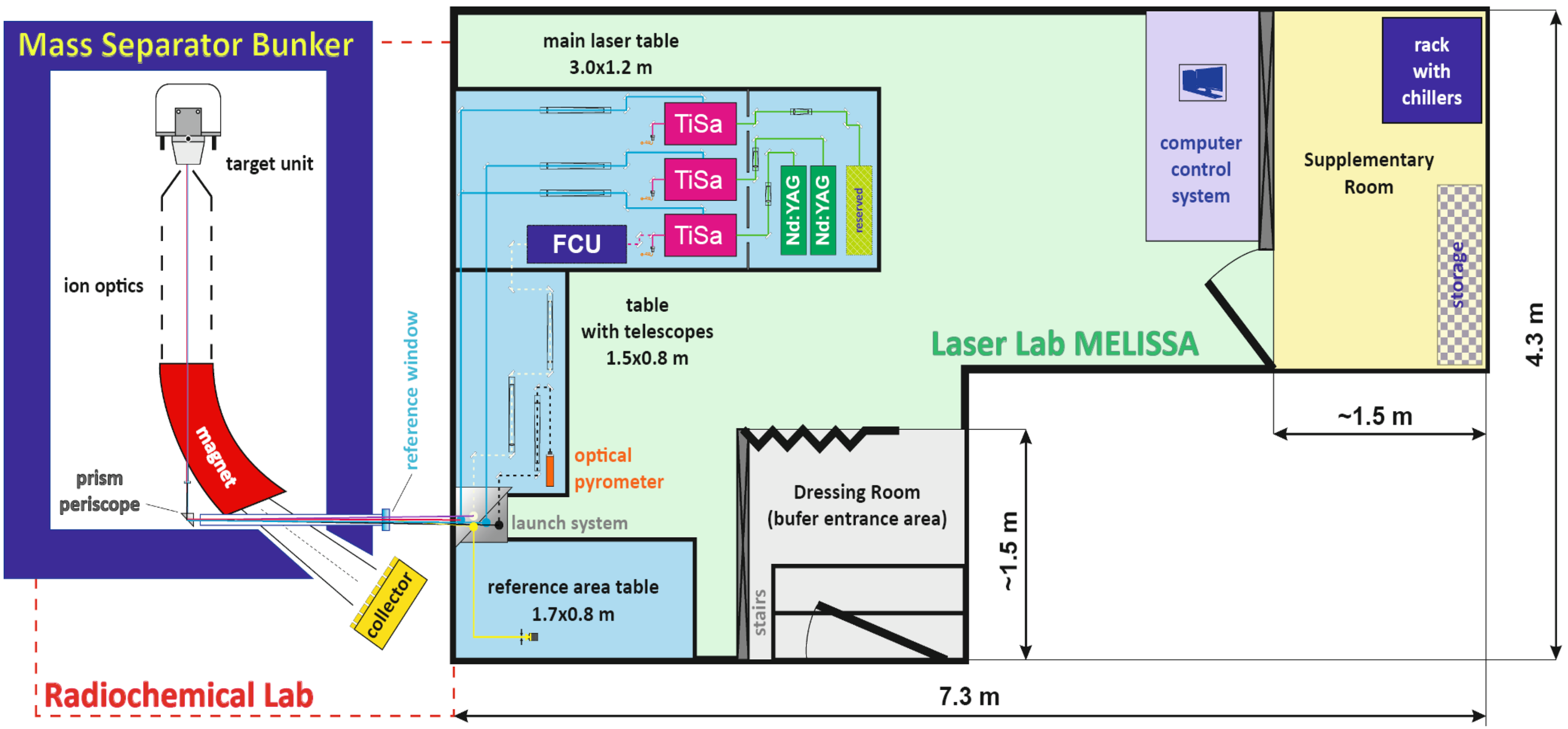
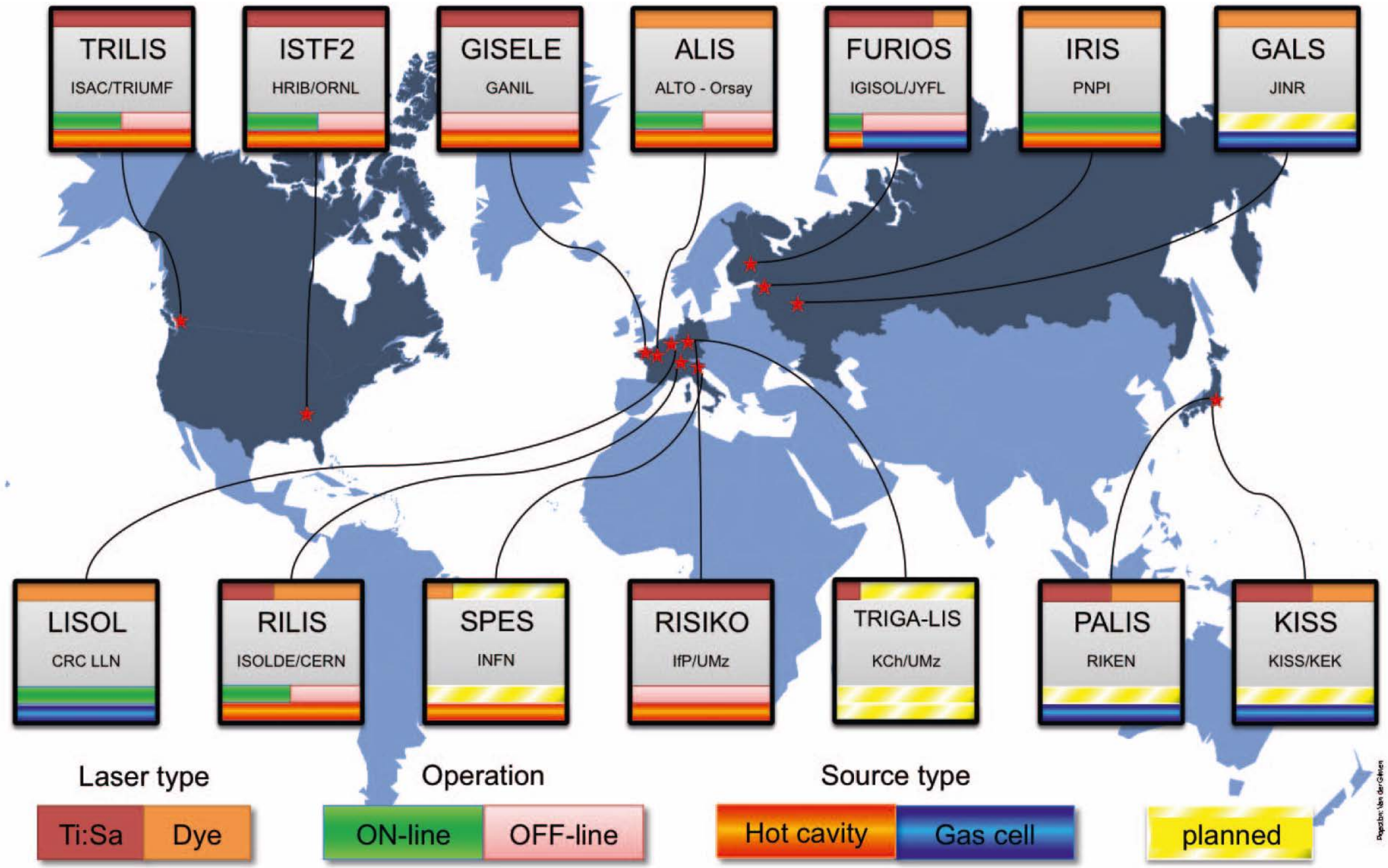


Fig. 4. New design of laser ion source. 1: target; 2: laser ion source; 3: extraction electrod; 4: laser beam; 5: ion beam; 6: vacuum chamber windows; 7: mirror.

The CERN-MEDICIS radioactive ion beam facility for the production of innovative medical radioisotopes




TRILIS
ISAC/TRIUMF
ISTF2
HRIB/ORNL
GISELE
GANIL
ALIS
ALTO - Orsay
FURIOS
IGISOL/JYFL
IRIS
PNPI
GALS
JINR
LISOL
CRC LLN
RILIS
ISOLDE/CERN
SPES
INFN
RISIKO
IfP/UMz
TRIGA-LIS
KCh/UMz
PALIS
RIKEN
KISS
KISS/KEK
Laser type
Ti:Sa
Dye
Operation
ON-line
OFF-line
Source type
Hot cavity
Gas cell
planned