# Исследование свойств ядер с помощью лазерной резонансной фотоионизационной спектоскопии в лазерном ионном источнике на установке ISOLDE (CERN)

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**Ядерный семинар ОФВЭ**

4 июня 2013 ПИЯФ

# Содержание (структура доклада?)

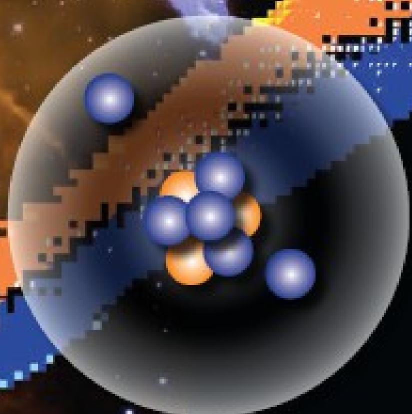
- **Ядерный комплекс ISOLDE**
- **Лазерный ионный источник RILIS (ISOLDE)**
- **Фотоионизационная лазерная спектроскопия с помощью RILIS**
  - Общее описание метода и экспериментальной установки
  - Развитие установки
- **Применение фотоионизационной спектроскопии на установке ISOLDE**
  - Поиск новых схем фотоионизации (Po, At) и измерение потенциала ионизации (At)
  - Разделение изомеров
  - Измерение изотопических сдвигов и сверхтонкой структуры атомных переходов (ядерные зарядовые радиусы и электромагнитные моменты)
- **Перспективы**

# Exploring *exotic nuclei at ISOLDE*

## Production
ISOLDE produces radioactive nuclei in reactions between protons at 1.4 GeV energy and nuclei in a variety of special targets. Several different types of reaction can take place, making a broad range of elements available. The targets are heated so that the new radioactive species diffuse out quickly before they decay. Scientists and engineers at ISOLDE have worked for decades to develop the best materials and designs for the targets.

## Selection
To produce a beam of a chosen exotic nucleus requires not only the right choice of target material, but also methods to extract the nuclei as ions (with fewer electrons than atoms) and to separate them electromagnetically from other species. ISOLDE has pioneered a very selective ionization technique that uses several wavelengths of laser light simultaneously to pick out specific elements. ISOLDE can deliver more than 700 different beams of isotopes from 70 chemical elements.

## Acceleration
To make the most of the nuclei produced at ISOLDE, the REX ISOLDE system provides an acceleration stage. Here the nuclei are trapped, bunched, stripped of additional electrons, selected according to mass, and finally fed into a linear accelerator to boost their energy to 3 MeV per nucleon.



## Nuclear mass surface
Ions that are confined almost at rest in devices called Penning traps can have their masses measured with very high precision. The large variety of nuclear species available at ISOLDE allows a comprehensive survey of the "nuclear mass surface" – in effect a map of the many nuclear masses. This gives important input for studies of fundamental symmetries, theoretical models of the atomic nucleus, and nuclear astrophysics.

## Fundamental symmetries
The nuclei produced at ISOLDE, with proton-to-neutron numbers varying over a wide range, provide an interesting microscopic laboratory for low-energy tests of the Standard Model of elementary particle physics. The high quality of the beams allows high-precision measurements of beta decay, particle correlations and atomic masses.

## Nuclear astrophysics
One of the most fundamental and challenging questions of the 21st century is how the elements from iron to uranium were created. Nuclear reactions occurring in explosive stellar environments, such as novae, supernovae and X-ray bursters, are believed to play an important role in the synthesis of these heavier elements. The pathways of the reactions leading to them involve short-lived radioactive exotic nuclei, which can be studied at ISOLDE and REX ISOLDE.

## Sizes and shapes
Nuclei come in a variety of sizes and shapes, from spherical to deformed shapes, which can be "prolate" (cigar-shaped) or "oblate" (like a discus). Experiments at ISOLDE can investigate the transitions between extremes, for example, the development of a neutron-halo structure in lithium-11, which makes this nucleus with only 11 nucleons (neutrons and protons) as big as a lead nucleus with 208 nucleons.

## Excited states
Nuclei are governed by the laws of quantum mechanics and exhibit "excited states" with well-defined energies and other properties predicted by theory. Radioactive decays and nuclear collisions can leave nuclei in excited states that decay to the ground state by emitting gamma rays. These can be detected by advanced germanium detectors cooled to liquid nitrogen temperature, as in the MINIBALL array. The properties of the gamma-rays (energy and angle) provide information on the excited states, which can be used to test theories.

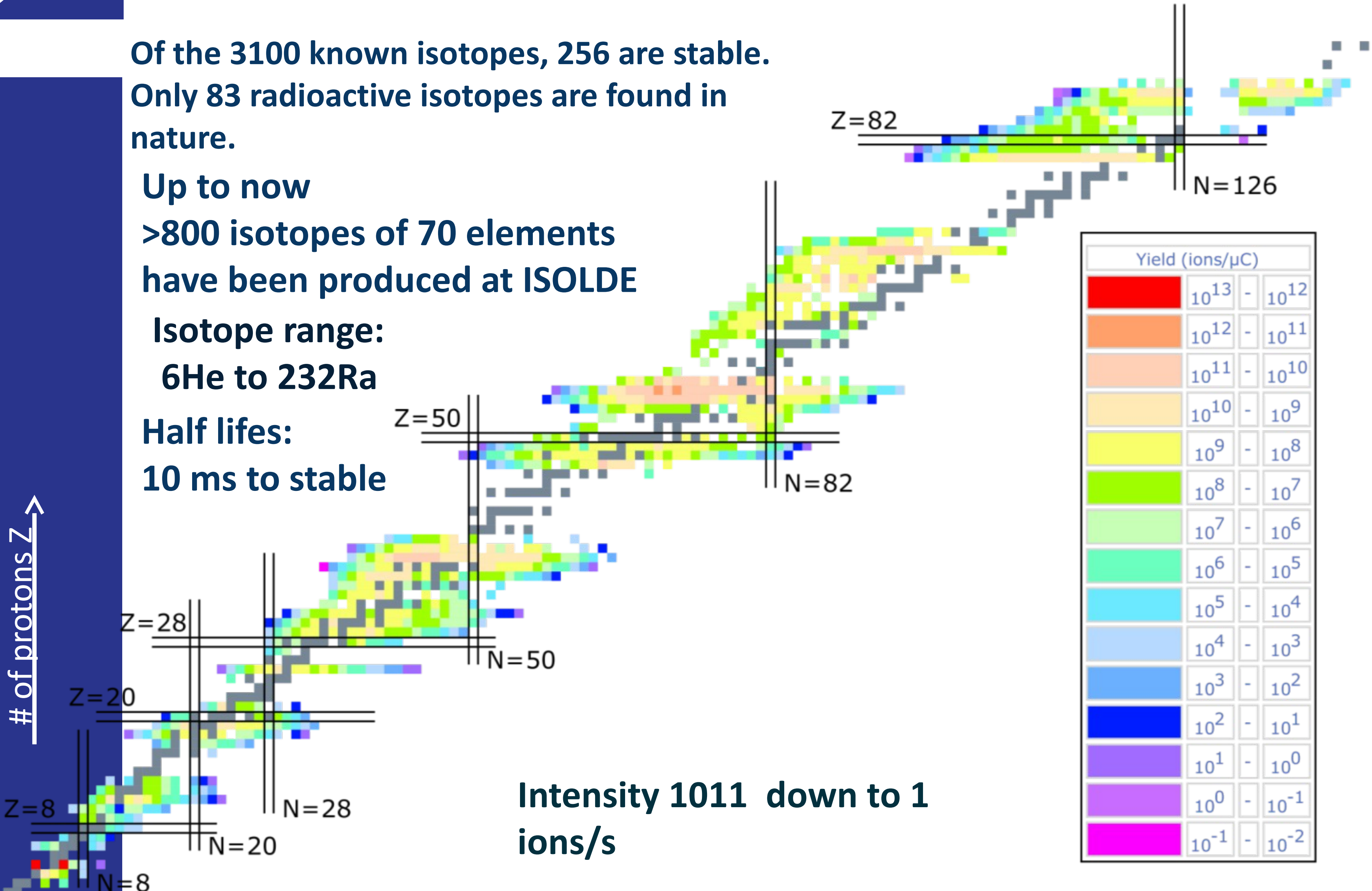
# ISOLDE – An Isotope Factory

**Of the 3100 known isotopes, 256 are stable. Only 83 radioactive isotopes are found in nature.**

**Up to now**
**>800 isotopes of 70 elements have been produced at ISOLDE**

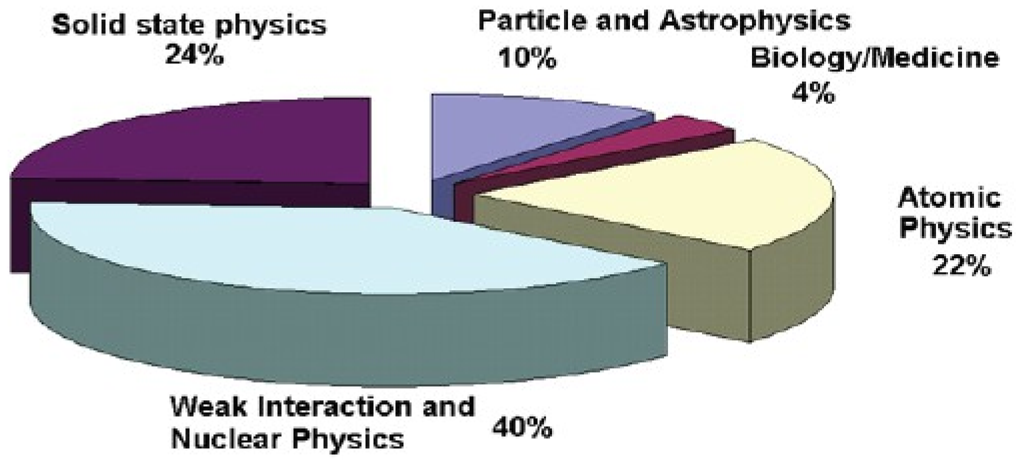
**Isotope range:**
**6He to 232Ra**

**Half lifes:**
**10 ms to stable**



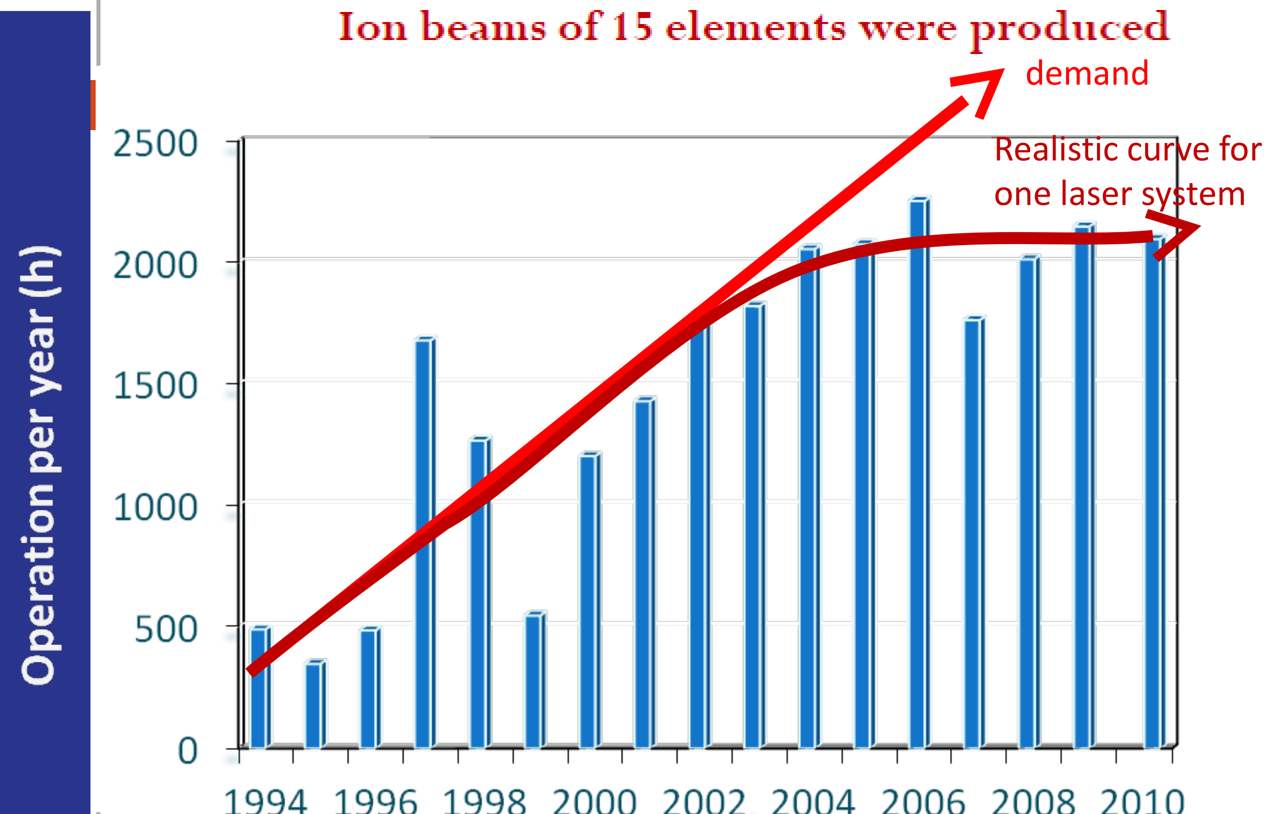

**Intensity 1011 down to 1 ions/s**

# ISOLDE physics program



# RILIS operation

Ion beams of 15 elements were produced




Laser ON time in 2011:

**2756 h – Total**

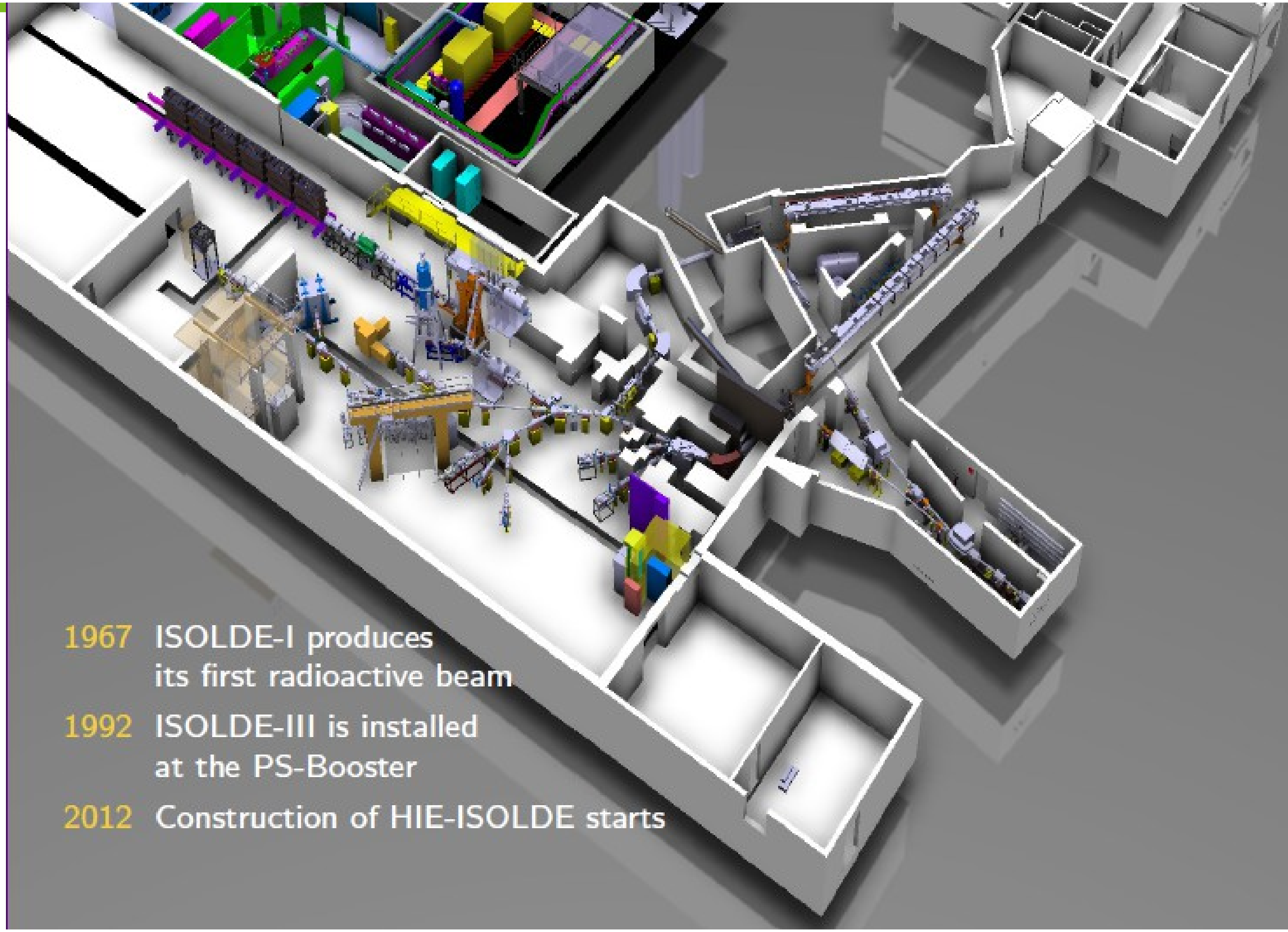
**2527 h – On-line**

> 50 % of the Total running time of ISOLDE facility

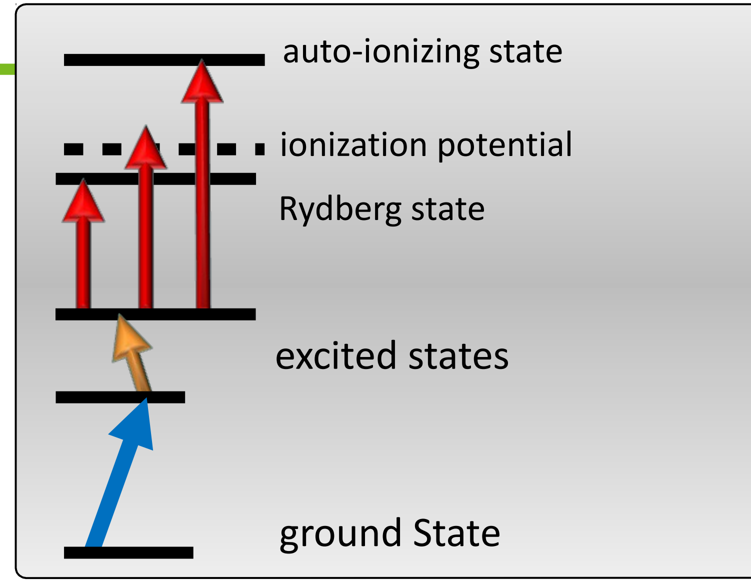
| Beam | Sm | Ga | Mg | At | Pb | Dy | Nd | Pr | Ag | Tl | Cd | Mn | Ni | Yb | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Planned | 80 | 104 | 256 | 160 | 184 | 64 | 136 | - | 112 | 208 | 288 | 120 | 272 | - | 376 |
| Real | 89 | 101 | 146 | 269 | 221 | 35 | 110 | 4 | 92 | 231 | 242 | 390 | 348 | 73 | 407 |

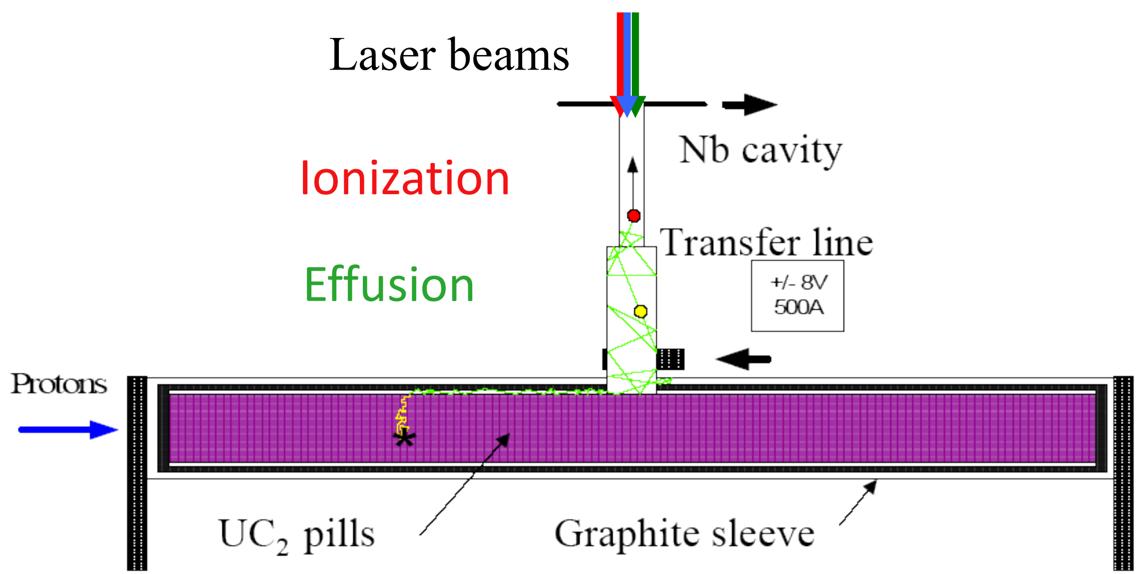
V. Fedosseev, B. Marsh

# ISOLDE

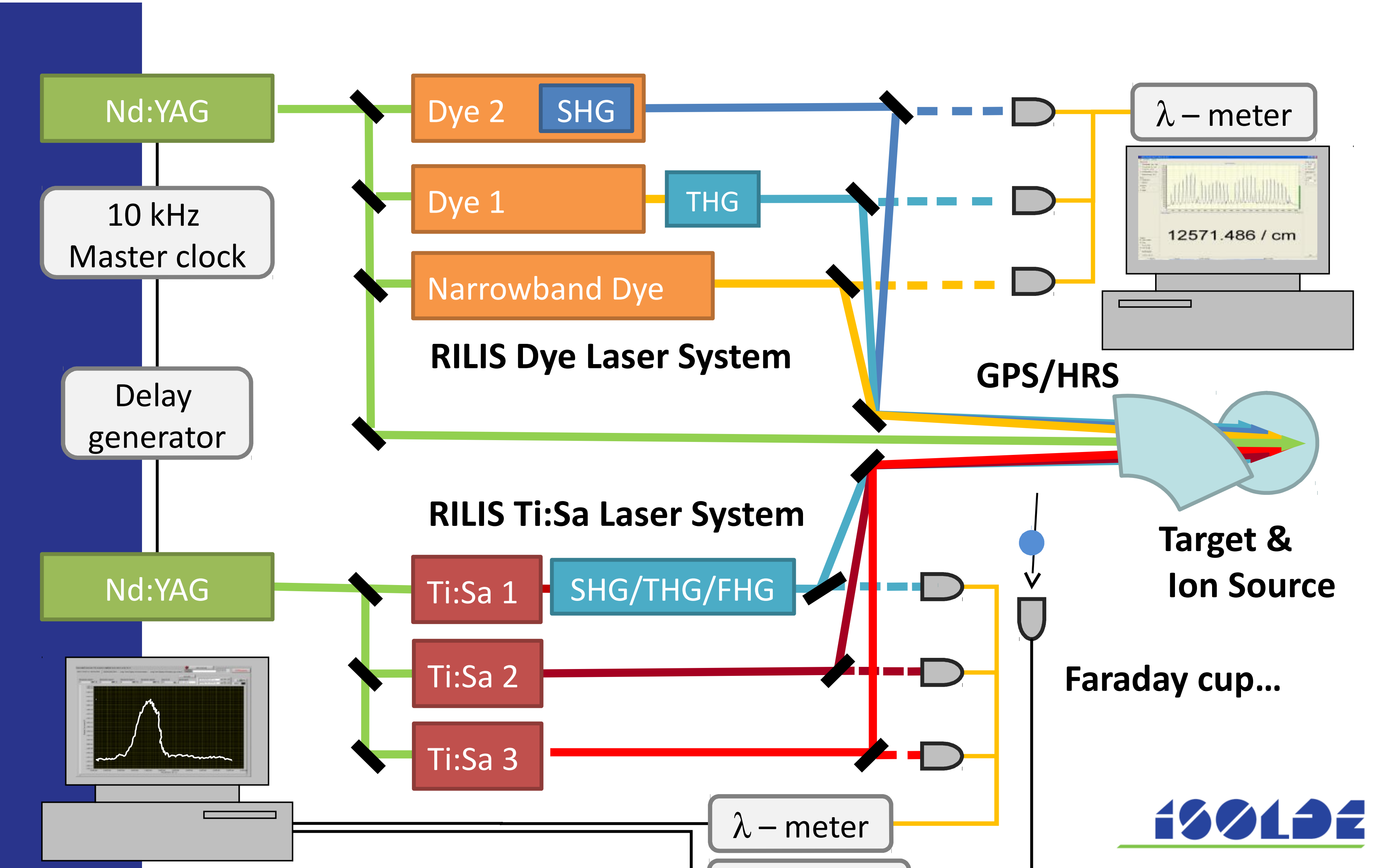

1967 ISOLDE-I produces its first radioactive beam
1992 ISOLDE-III is installed at the PS-Booster
2012 Construction of HIE-ISOLDE starts

# Target –Ion Source unit

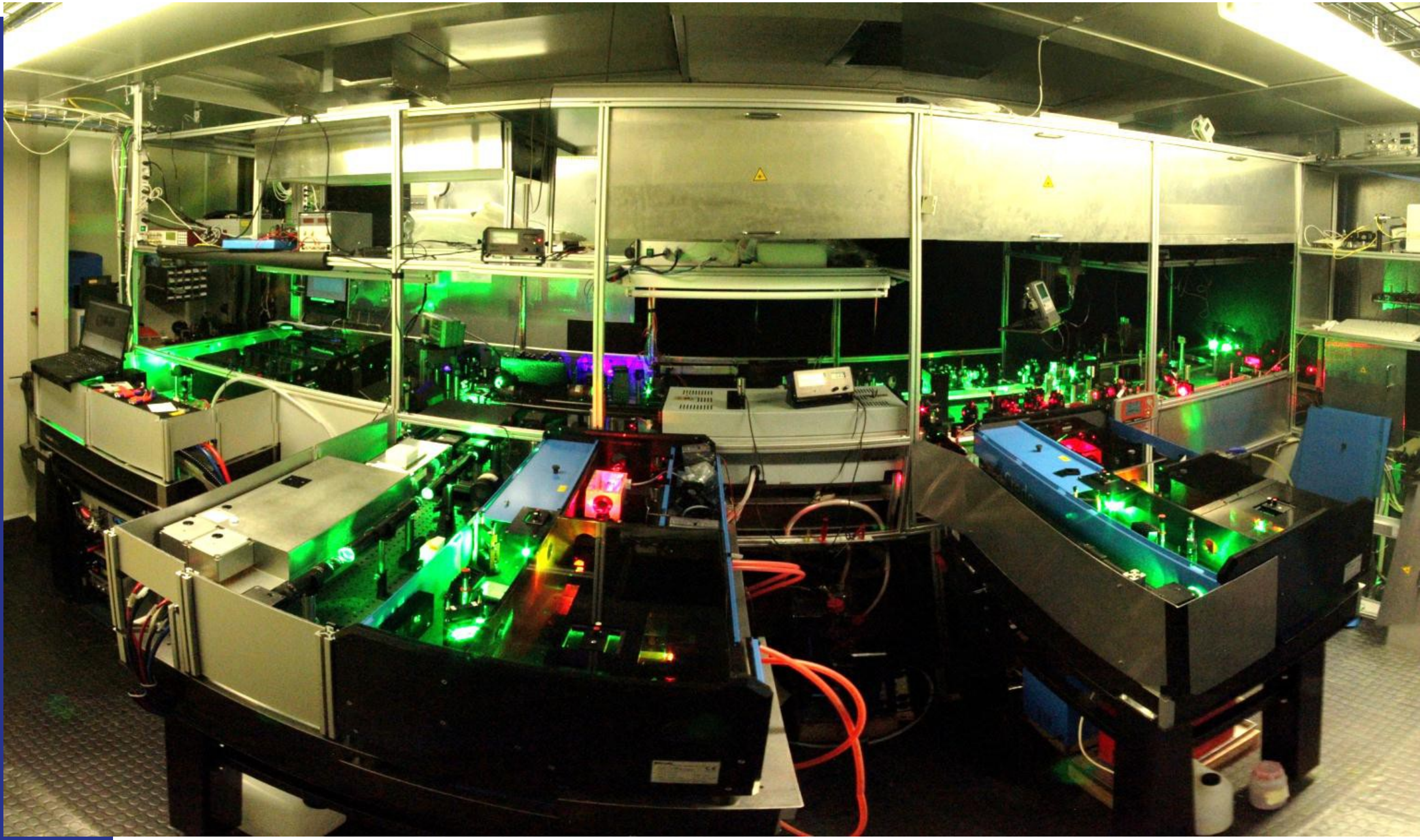


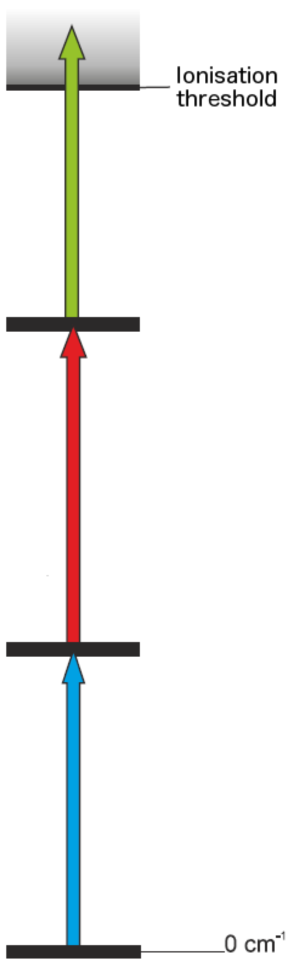
# RILIS laser system

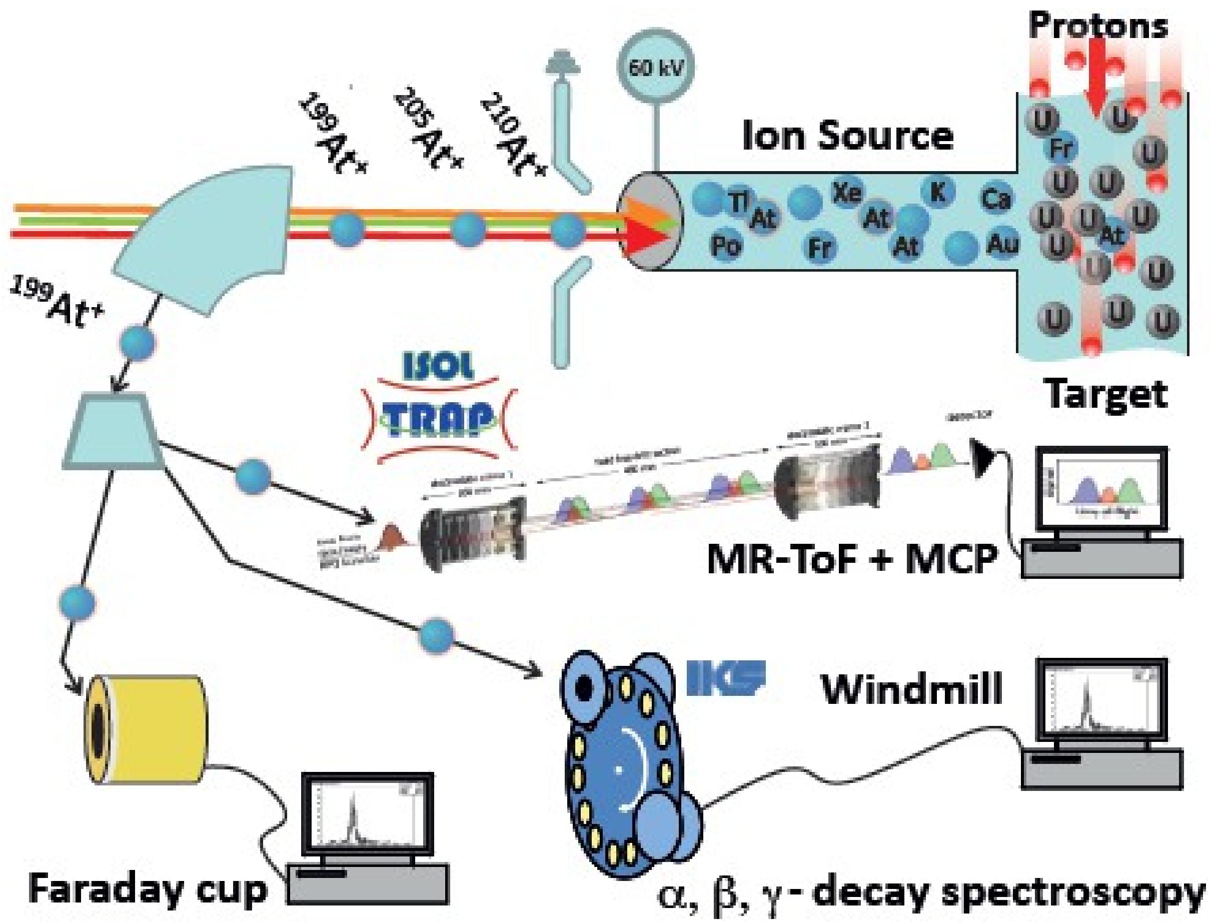


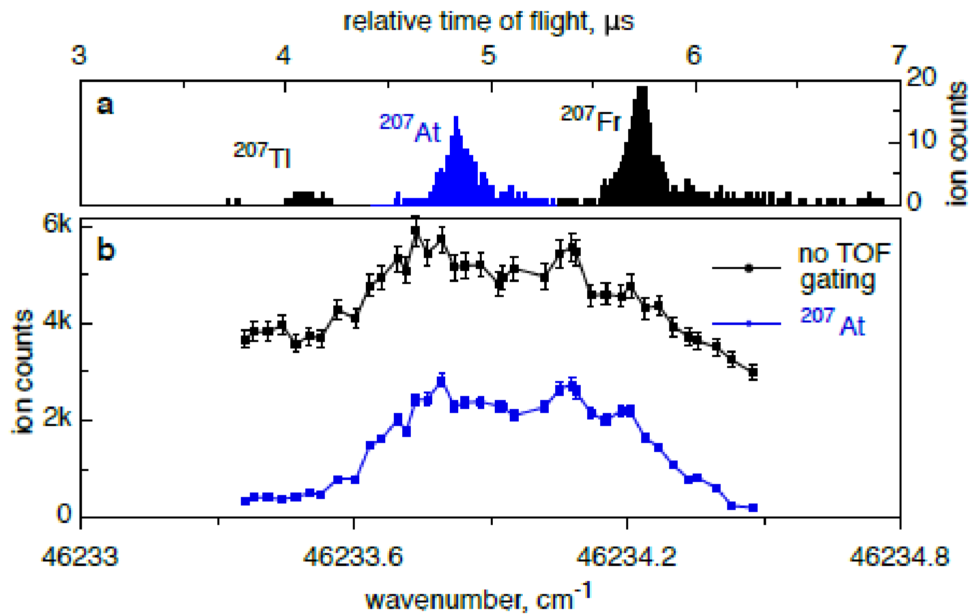
# RILIS lasers



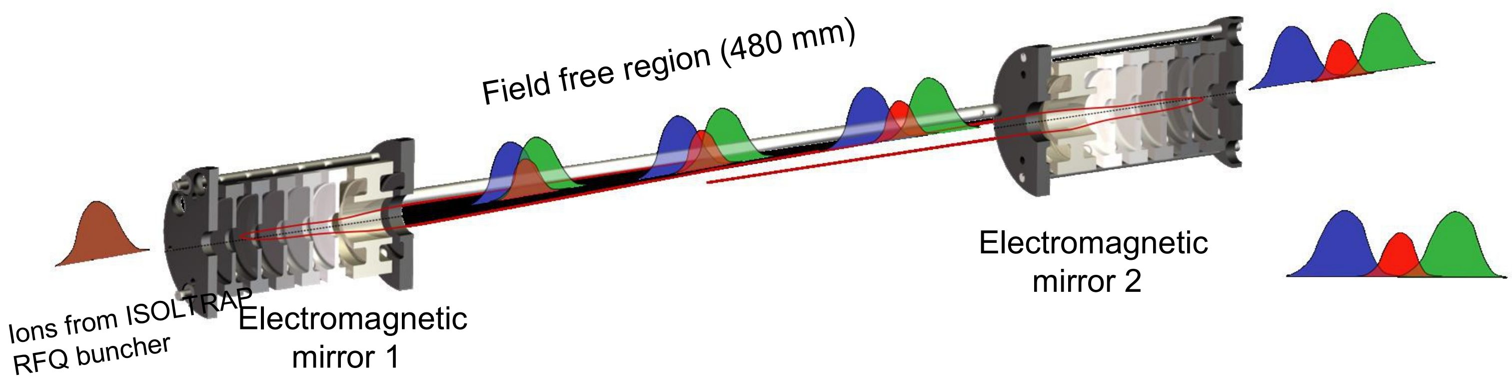

RILIS-screen 1
PHOTONICS INDUSTRIES


Ionisation threshold
0 cm-1

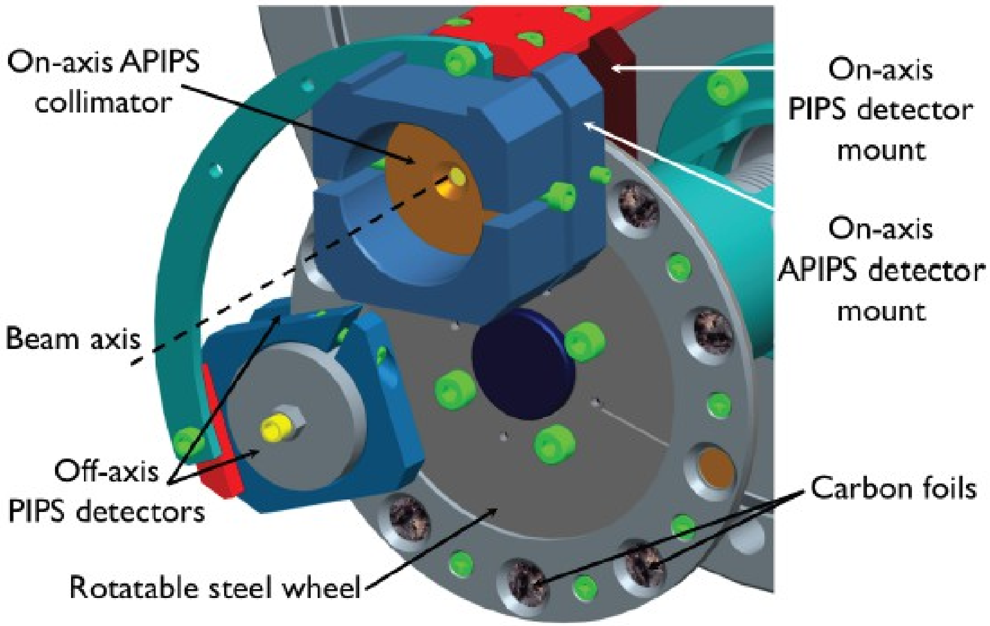

Protons
60 kV
Ion Source
199At+
205At+
210At+
Tl
At
Xe
K
Ca
Po
Fr
Au
U
Target
199At+
ISOL
TRAP
MR-ToF + MCP
Windmill
Faraday cup
α, β, γ - decay spectroscopy

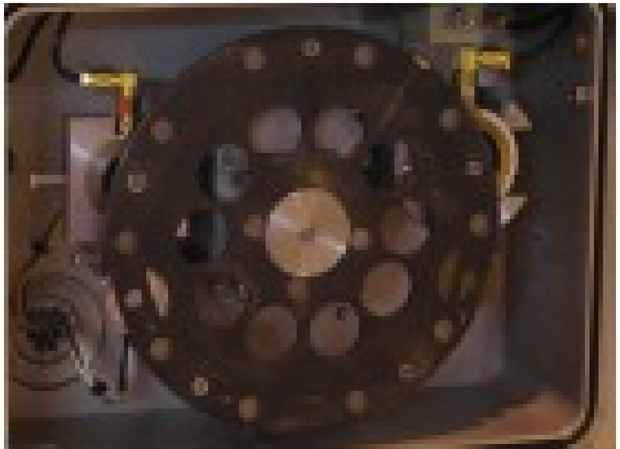


relative time of flight, µs
3
4
5
6
7
20
10
0
ion counts
a
207Tl
207At
207Fr
6k
4k
2k
0
ion counts
b
no TOF gating
207 At
46233
46233.6
46234.2
46234.8
wavenumber, cm-1

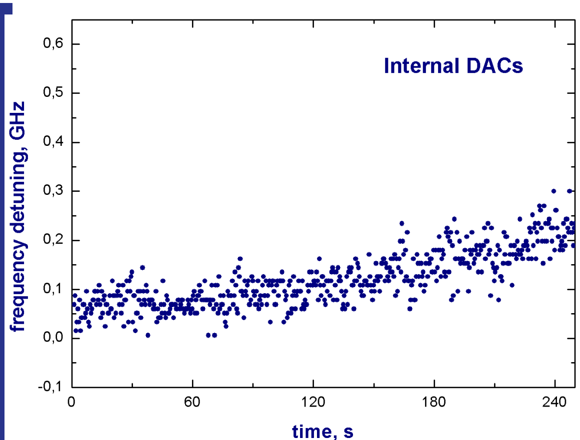



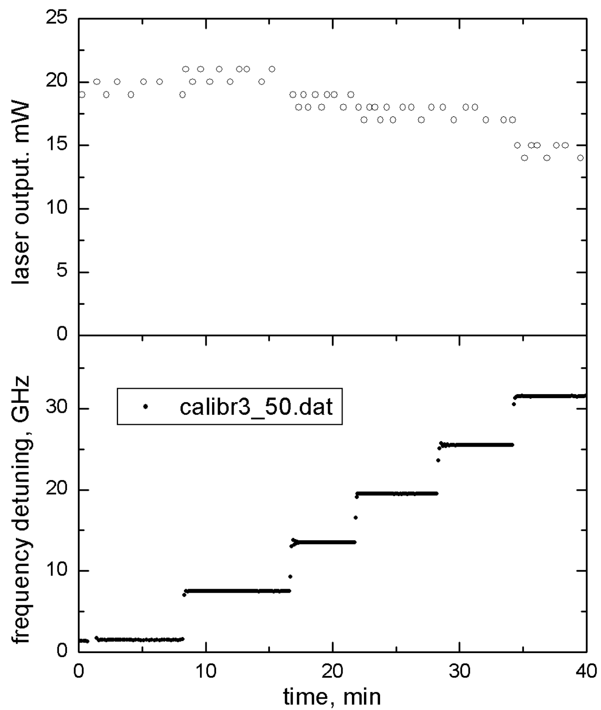
Field free region (480 mm)
Ions from ISOLTRAP RFQ buncher
Electromagnetic mirror 1
Electromagnetic mirror 2

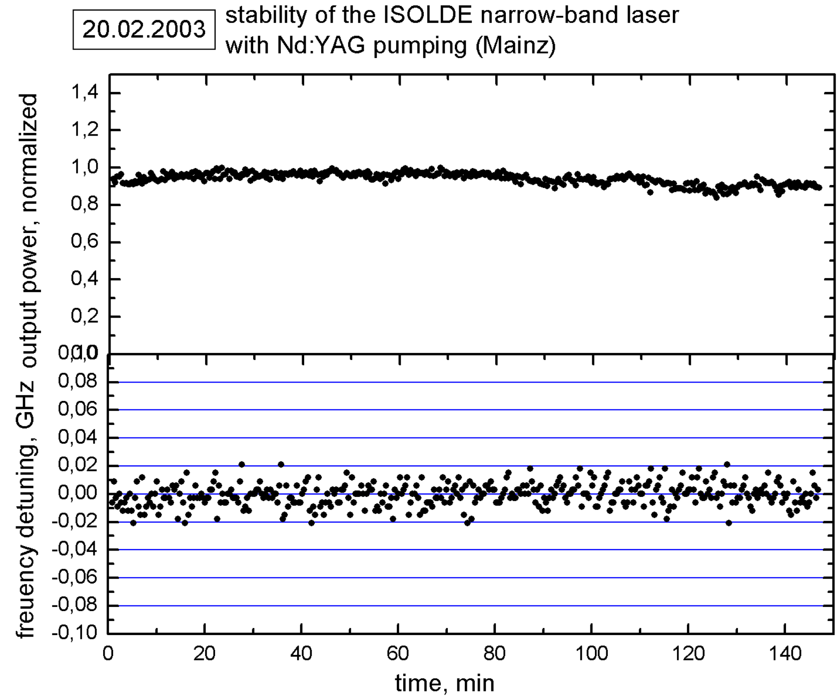

On-axis APIPS
collimator
On-axis
PIPS detector
mount
On-axis
APIPS detector
mount
Beam axis
Off-axis
PIPS detectors
Carbon foils
Rotatable steel wheel

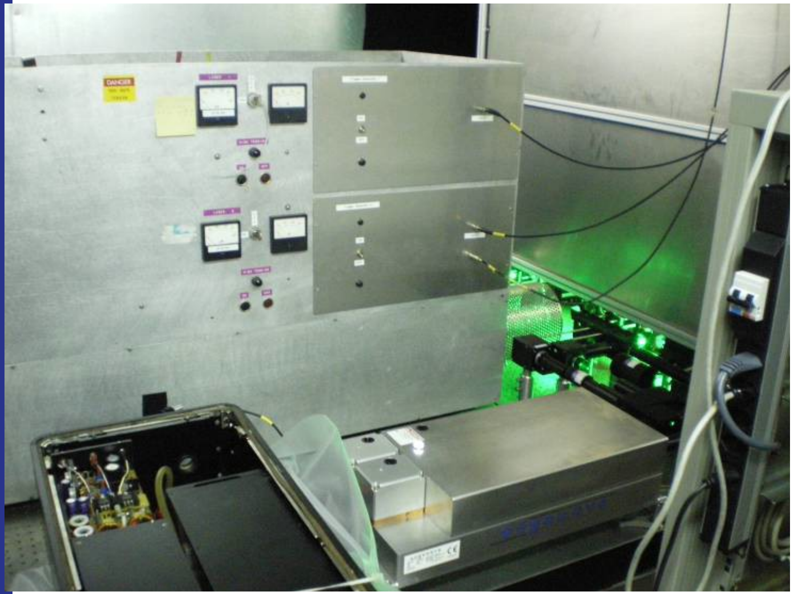


# RILIS upgrade


Internal DACs
frequency detuning, GHz
time, s
0,6
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
0
60
120
180
240


laser output. mW
frequency detuning, GHz
time, min
calibr3_50.dat
25
20
15
10
5
0
30
20
10
0
0
10
20
30
40


20.02.2003
stability of the ISOLDE narrow-band laser
with Nd:YAG pumping (Mainz)
output power, normalized
freuency detuning, GHz
time, min
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0,10
0,08
0,06
0,04
0,02
0,00
-0,02
-0,04
-0,06
-0,08
-0,10
0
20
40
60
80
100
120
140



Copper Vapor Lasers are replaced by Diode Pumped Solid State Nd:YAG Lasers
Total power > 100 W

Laser generates 3 beams at 10 kHz:

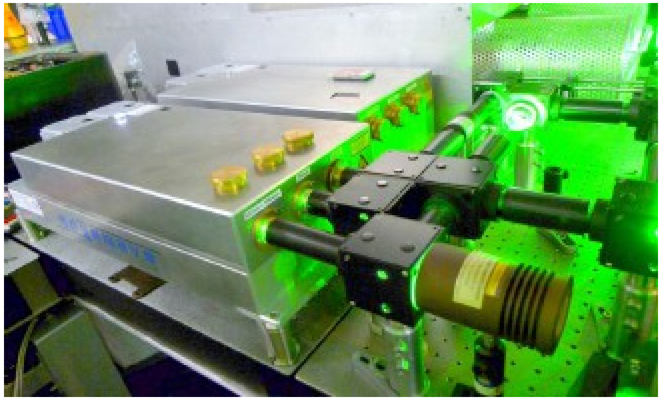
- Main green beam
  – 532nm, 70-80 W, 8 ns
- Residual green beam
  – 532 nm, 12-28 W, 9 ns
- UV beam
  - 355 nm, 18-20 W, 11 ns

**Advantages:**

- Better beam quality
- Stability of operation
- **No desynchronization problems!**

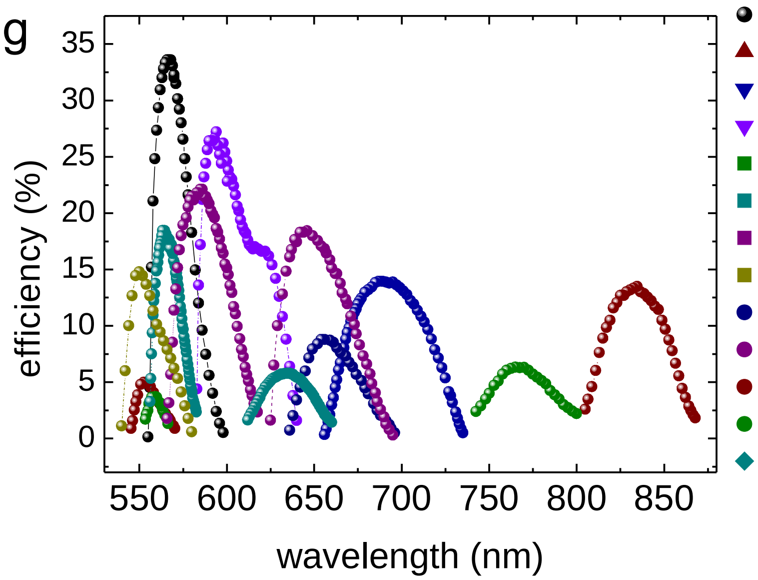
**Complications:**

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



# RILIS Dye Lasers

Optimized for Nd:YAG pumping (UV+Visible)
Higher power
Tunable and **SCANNING**




Pump laser: Nd:YAG (532 nm), Edgewave
Repetition rate: 10 kHz,
Pulse duration: 9 ns
Power: 100 W

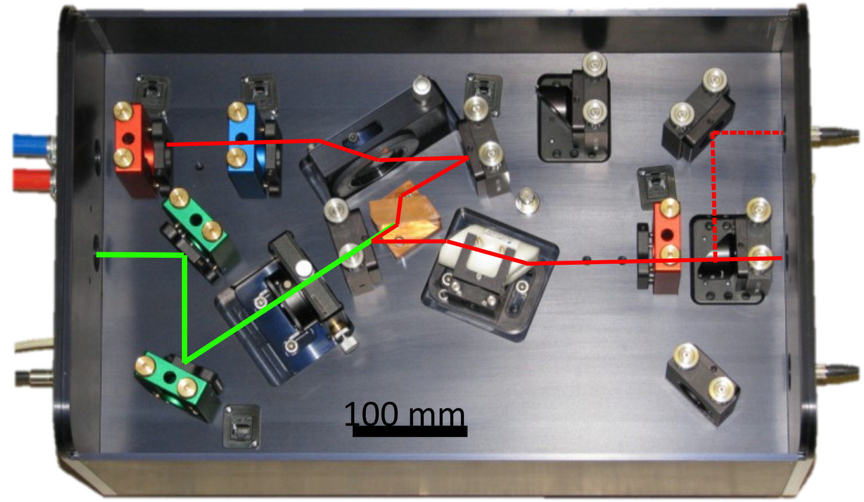
# RILIS Ti:Sa lasers

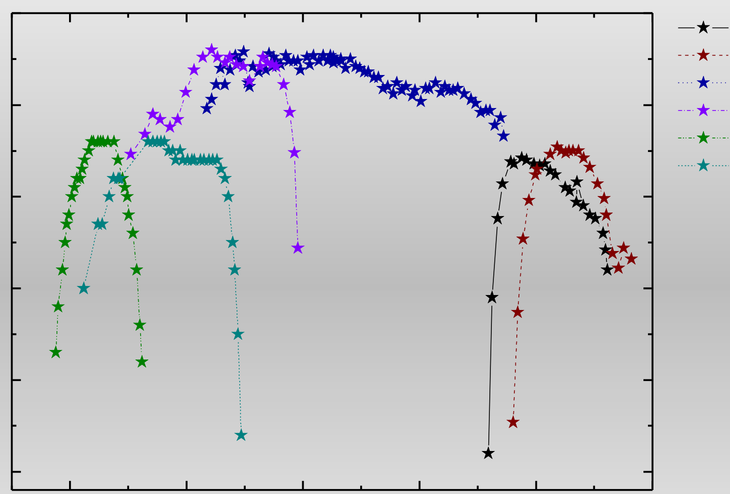
<u>Pump laser</u>: Nd:YAG (532 nm), Photonics

Repetition rate: 10 kHz

Pulse length: 180 ns

Power: 60 W

Design & Construction:
S. Rothe (Uni Mainz)

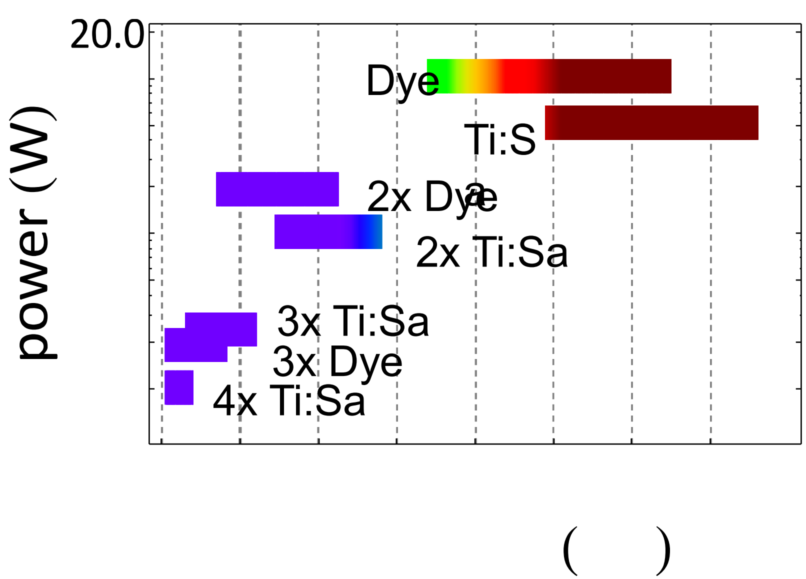
Wavelength tuning range:

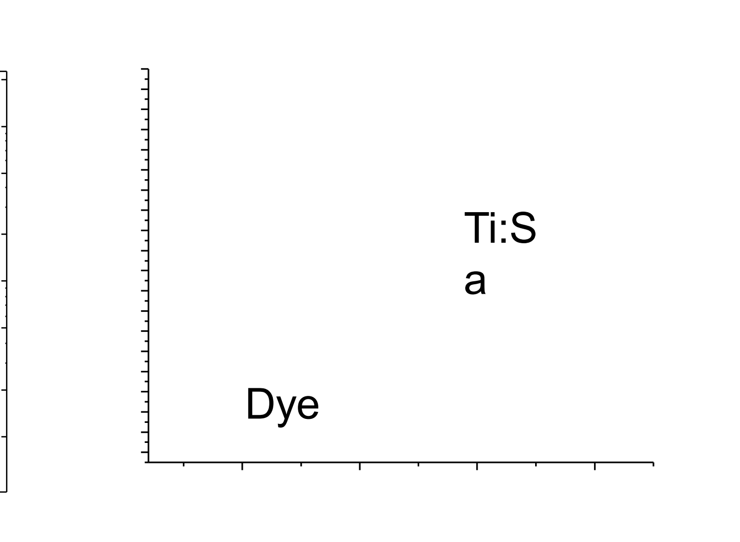
- Fundamental (ω) **690** **940** nm (5 W)
- 2nd harmonic (2ω) **345** **470** nm (1 W)
- 3rd harmonic (3ω) **230** **310** nm (150 mW)
- 4th harmonic (4ω) **205** - **235** nm (50 mW)

6 resonator mirror sets cover the Ti:Sa range

# Comparison dye vs. Ti:Sa system

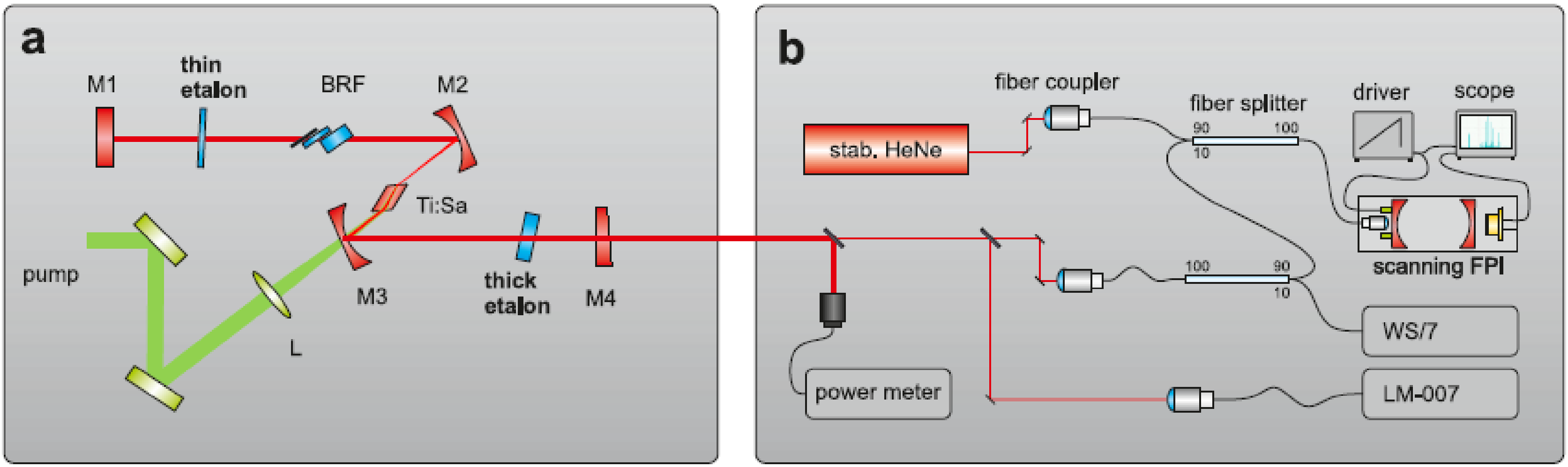
| | Dye | Ti:Sa |
|---|---|---|
| Active Medium | > 10 different dyes | =1 Ti:sapphire crystal |
| condition of aggregation | liquid (org. solvents) | solid-state |
| Tuning range | 540 – 850 nm | 680 – 980 nm |
| Power | < 12 W | < 5 W |
| Pulse duration | ~8 ns | ~50 ns |
| Synchronization | optical delay lines | q-switch, pump power |
| # of schemes developed | 47 | 37 |
| Maintenance | renew dye solutions | ~ none |

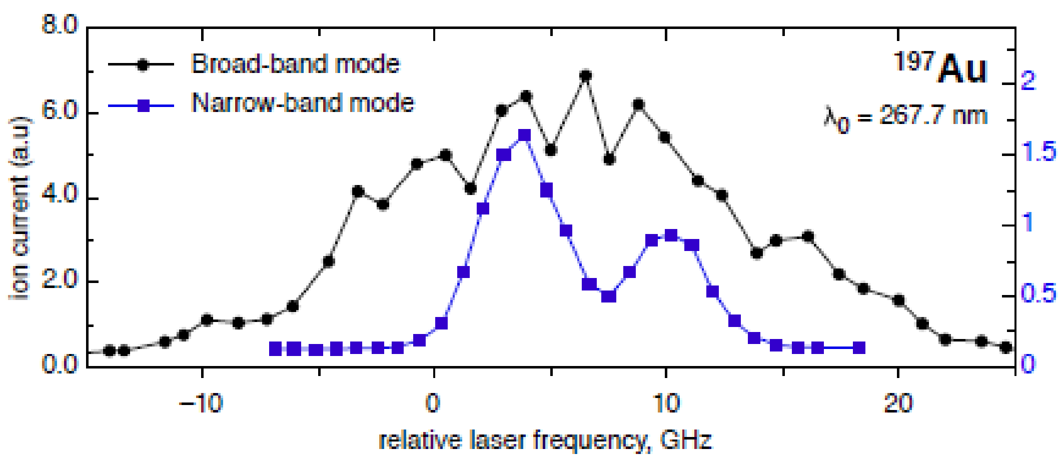



**Ti:Sa system is complementary**

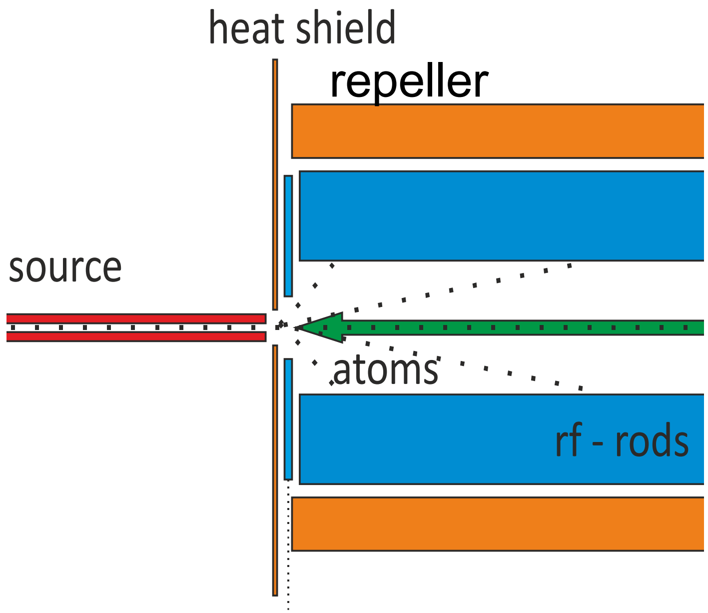
# Narrow-band scanning Ti:Sa laser

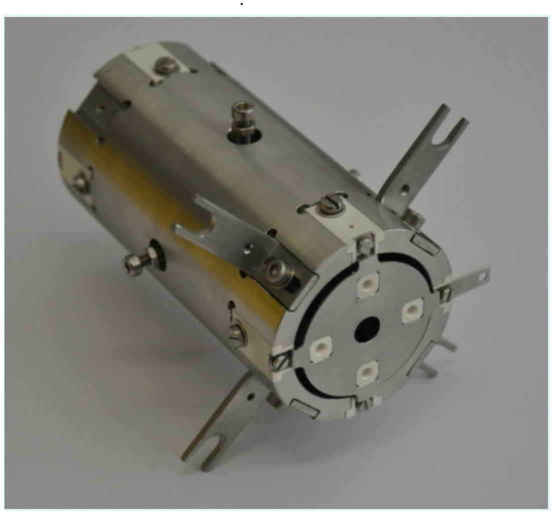


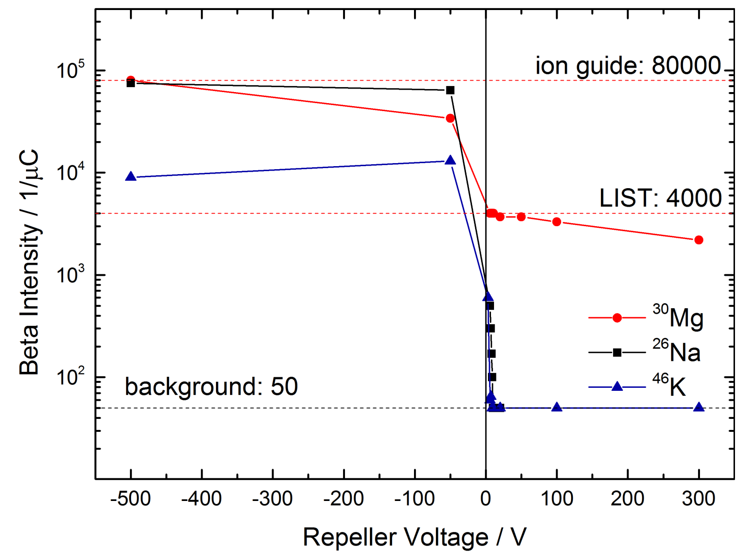



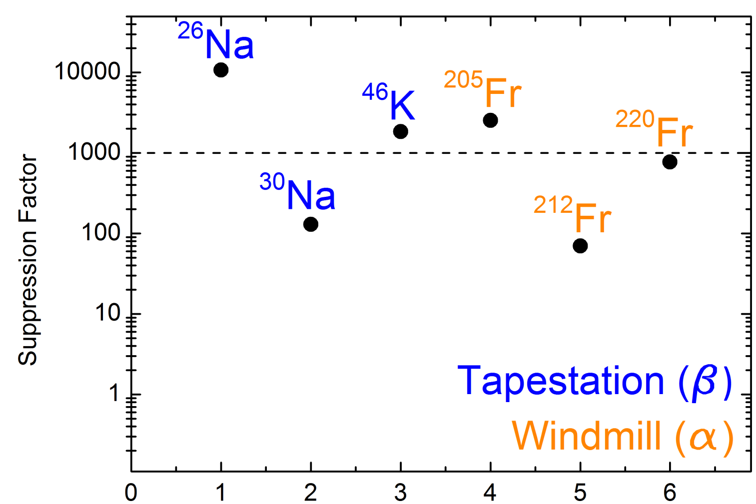

**2012**

# LIST: Laser Ion Source Trap

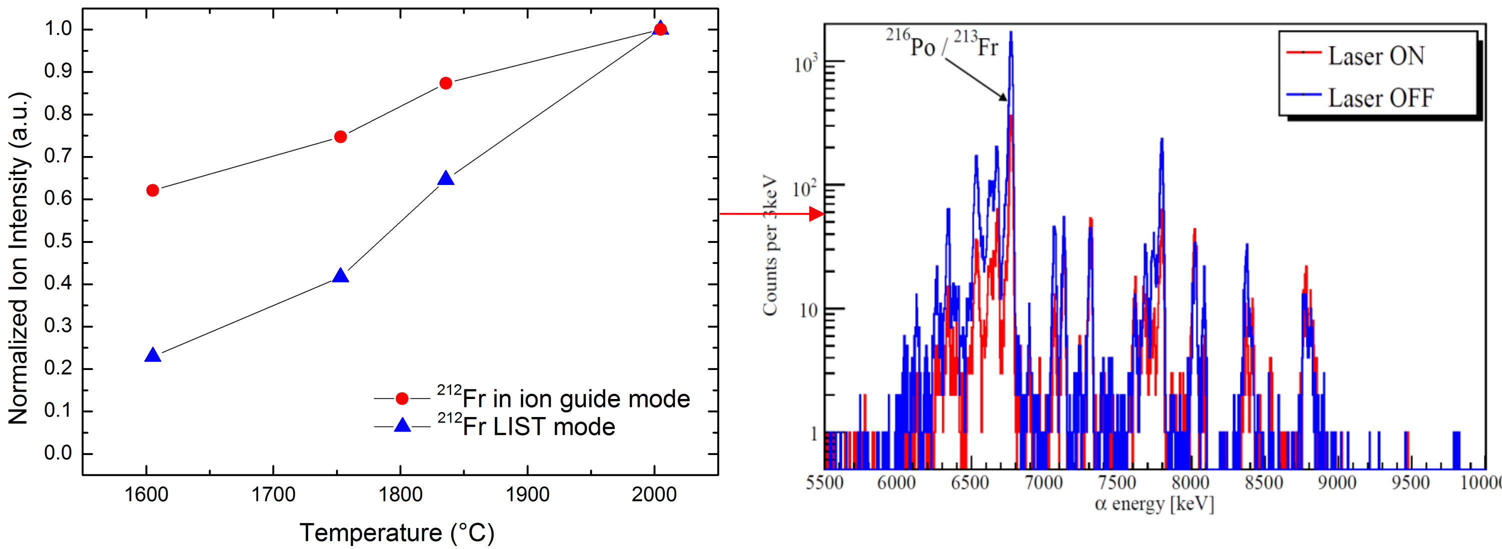




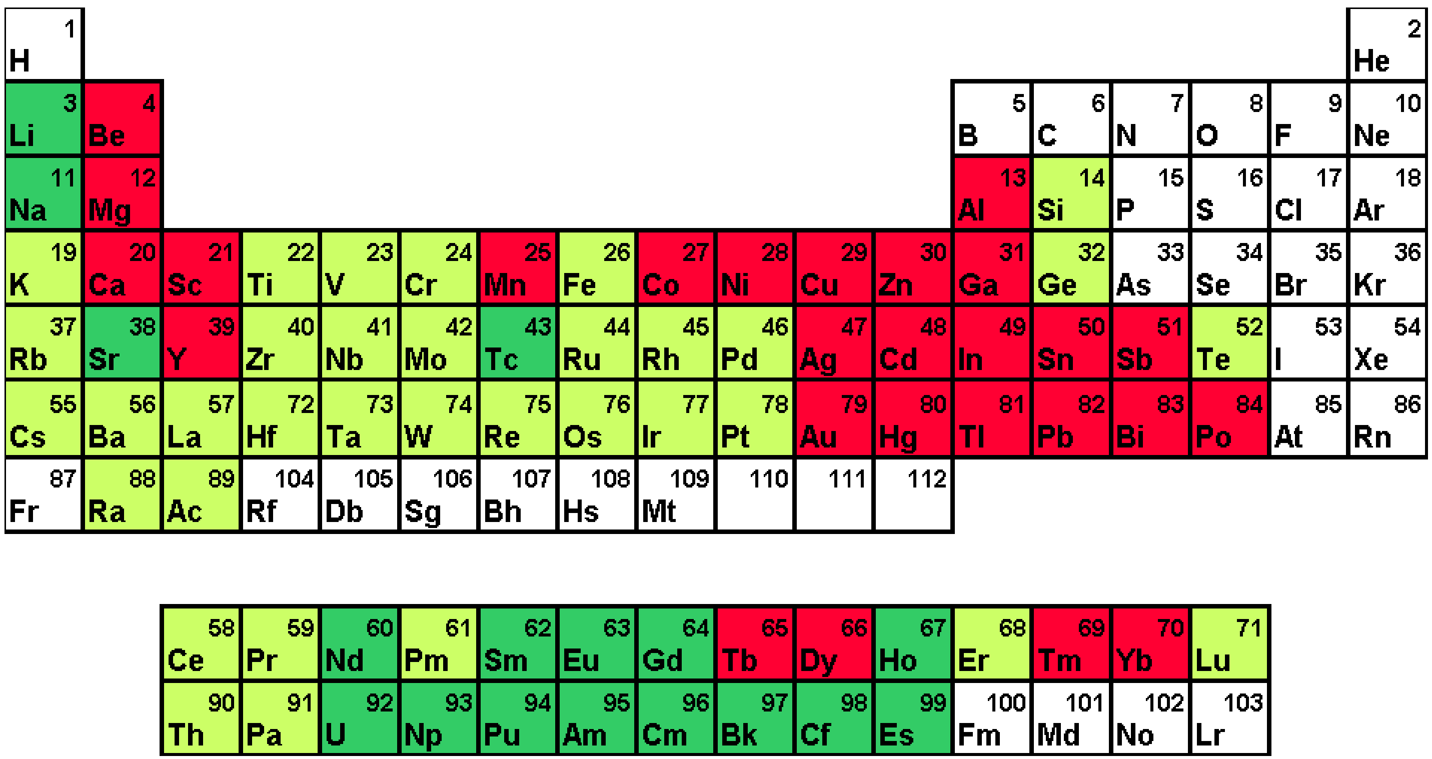



# LIST: Laser Spectroscopy of 217Po

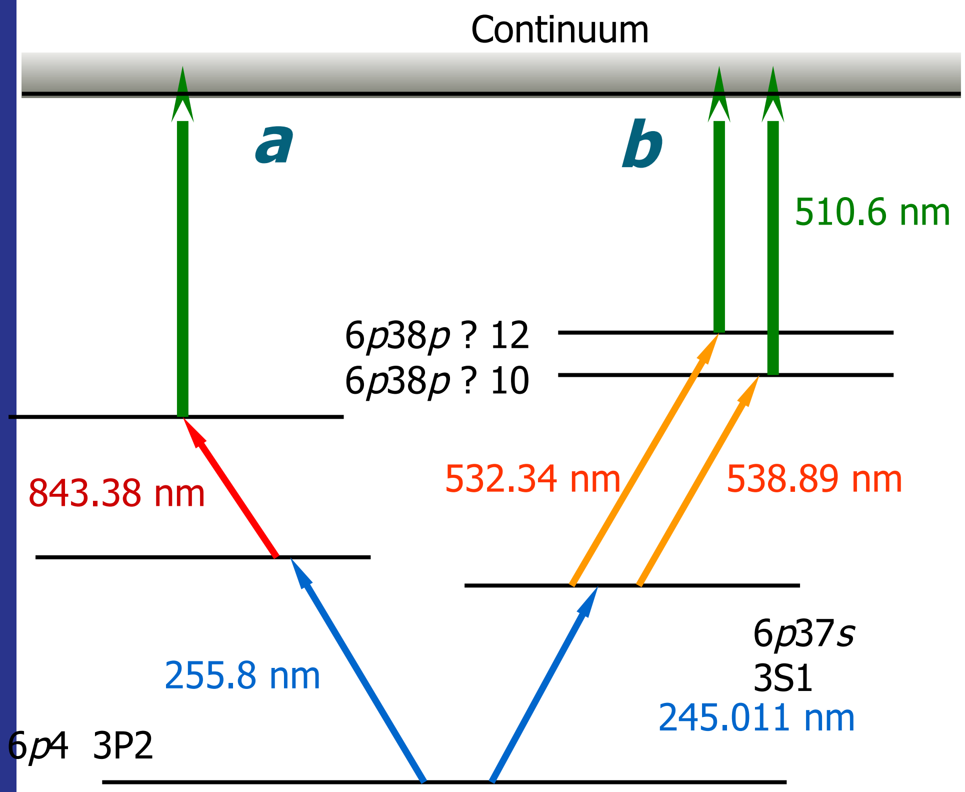


# RILIS elements

Currently available RILIS elements are highlighted in red.
Elements for which ionization schemes have been tested to some extent but not yet applied are highlighted in green.
Elements for which ionization is feasible at RILIS but has not been tested are highlighted in yellow.



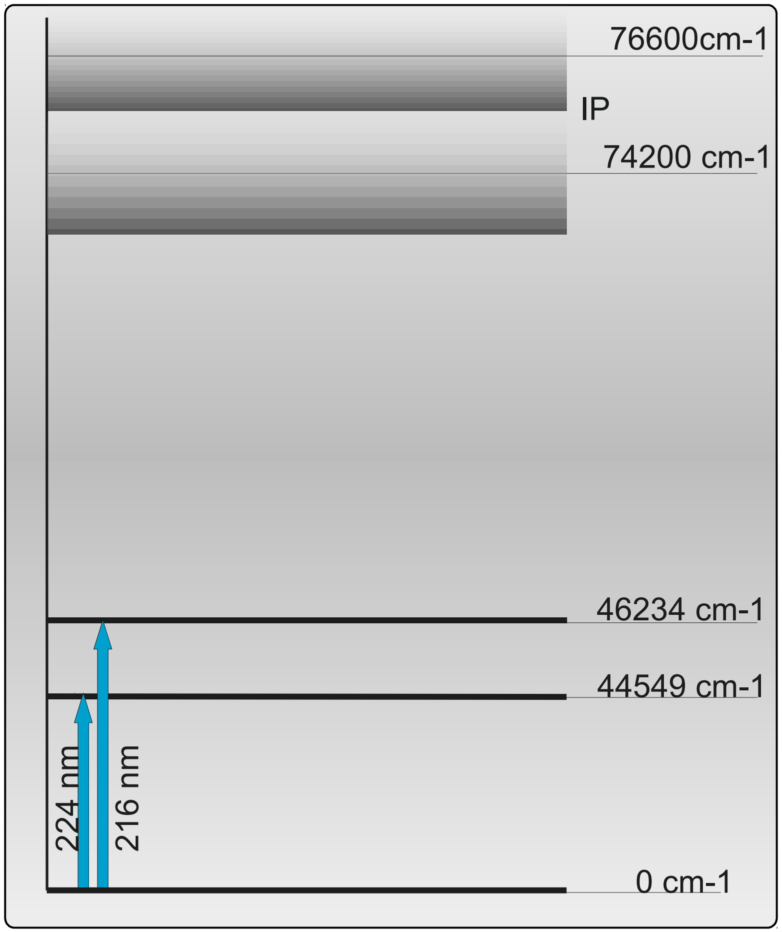
# New photoionization schemes: Po




**Po yields (scheme „a")**

| Isotope | Half life, s | Yield, Atoms/µC |
|---|---|---|
| **193gPo** | 0.42 | 7×101 |
| **193mPo** | 0.24 | 1×102 |
| **194Po** | 0.392 | 2.5×103 |
| **195gPo** | 4.64 | 2×104 |
| **195mPo** | 1.92 | 5×104 |
| **196Po** | 5.8 | 4.7×105 |
| **197gPo** | 53.6 | 2.5×105 |
| **197mPo** | 25.8 | 1.75×106 |
| **198Po** | 106.2 | 7×106 |

# At: Photoionization scheme and Ionization potential



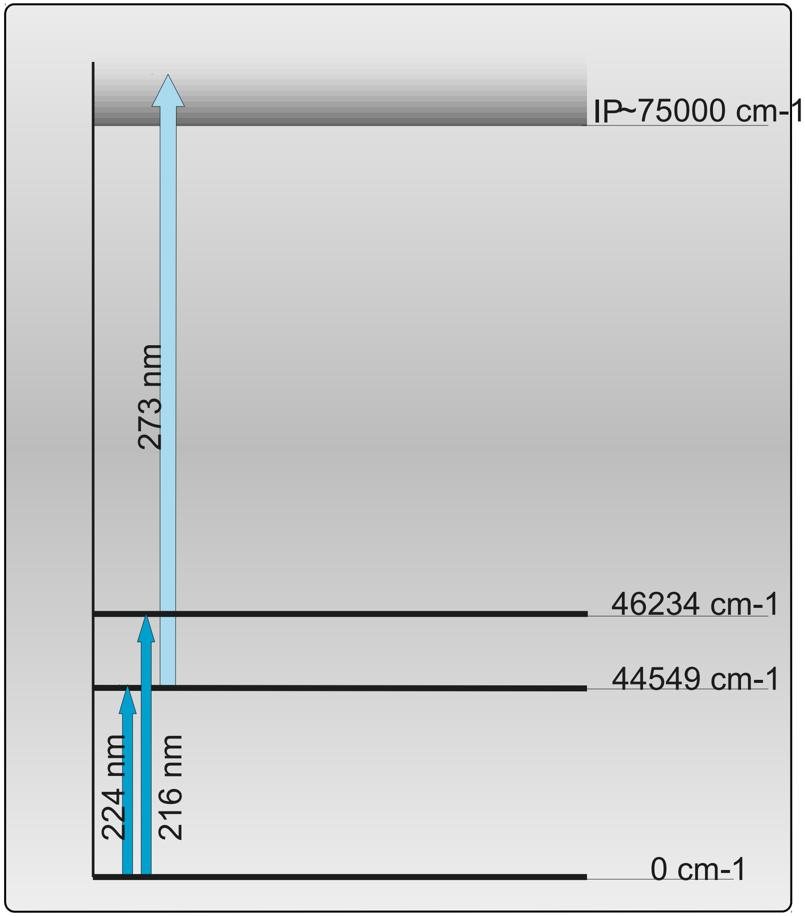

Recent interest in At and its IP:

- targeted a therapy for cancer treatment
- Benchmark for theoretical chemistry of astatine
- Benchmark for calculations for IP( 117Uus)
- At beam for ISOLDE users ($\beta$-delayed fission, laser spectroscopy)

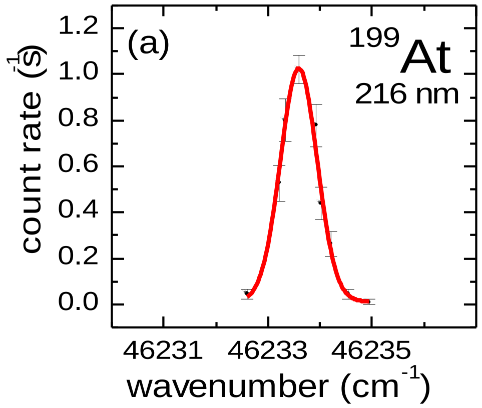
Theoretial predictions of IP(At)

| Reference | Year | IP (eV) | IP ($cm^{-1}$) |
|---|---|---|---|
| [Fin55] | 1955 | 9.2 ± 0.4 | 74 203 ± 6 500 |
| [Kis60] | 1960 | 9.5 | 76 623 |
| [Kue91] | 1991 | 9.4 | 75 816 |
| [Mit06] | 2006 | 9.24 | 74 526 |
| [Cha10] | 2010 | 9.35 ± 0.01 | 75 413 ± 160 |

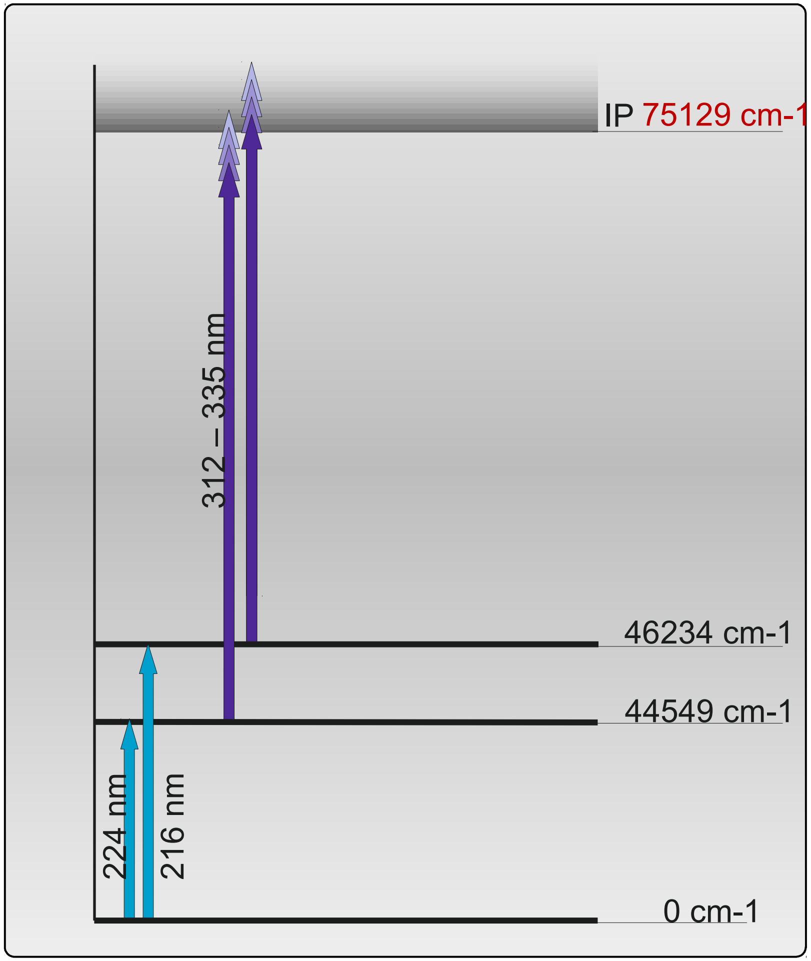
# At: Photoionization scheme and Ionization potential

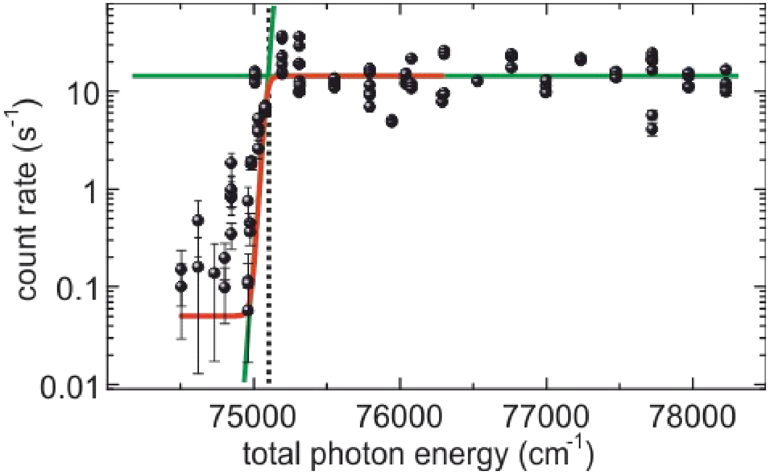



- ~2W @ 273 nm for non-resonant ionization
- Laser scans of 224 nm and 216 nm transitions
- Very low yields 1-10 s-1
- ~5 min per wavelength step



# At: Photoionization scheme and Ionization potential



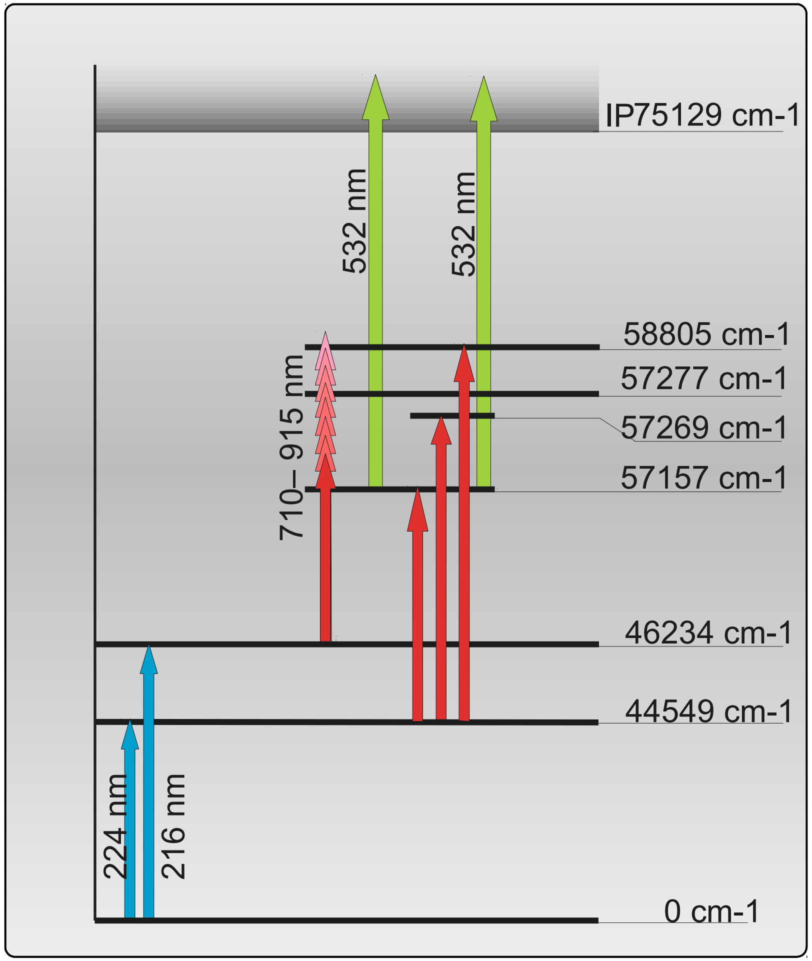




- Laser scan of second laser
- Low resolution
- Required ~6 h data taking

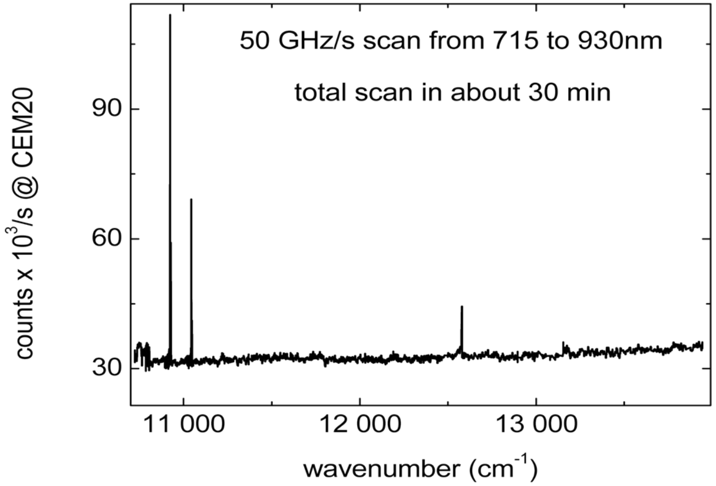
IPthreshold(At) = 75129(95) cm-1

- Higher resolution needed
- low yield due to low laser power in final step
- 3-color scheme allows use of 532 nm (50W)

# At: Photoionization scheme and Ionization potential

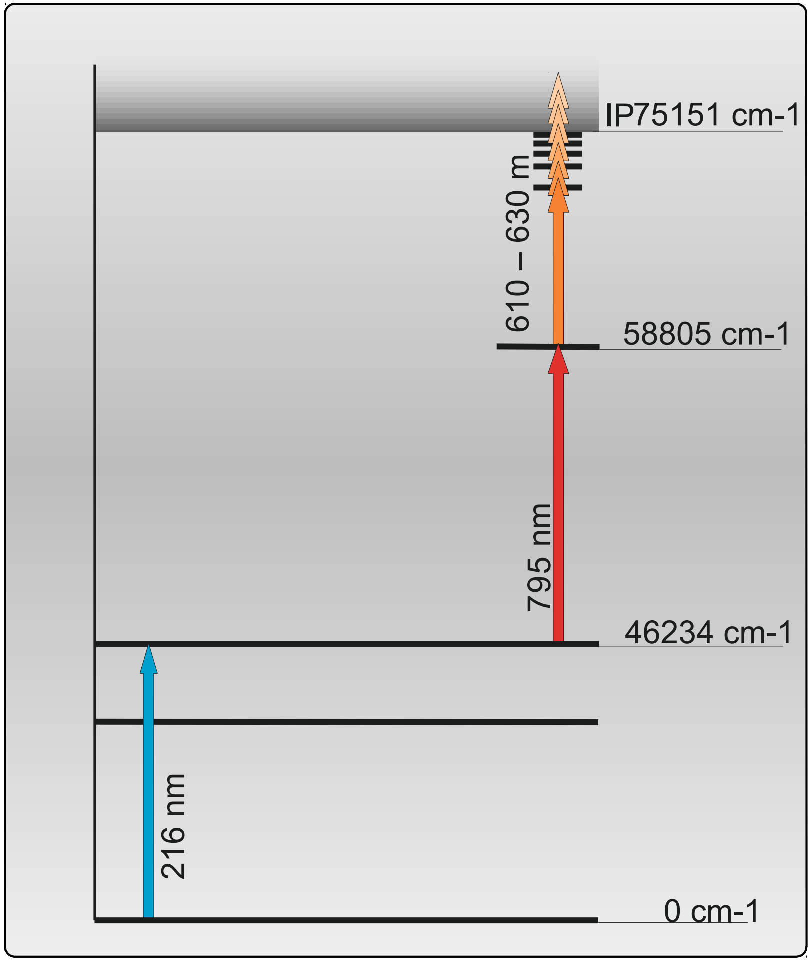



- Spectroscopy at ISAC/TRIUMF (199At)
- cw proton beam from cyclotron
- 200 nm scan: 3 new transitions
- Verified at ISOLDE/CERN (205At)

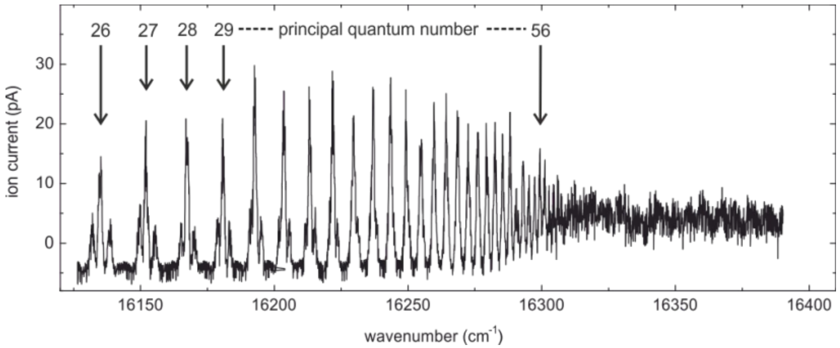


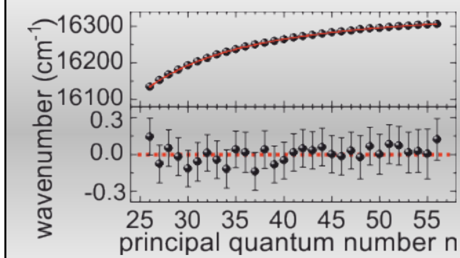

- 6 transitions, 4 new energy levels available
- Up to 150 pA of 205At
- Continuously measurable with Faraday cup

# At: Photoionization scheme and Ionization potential




## Spectroscopy of Rydberg levels




Rydberg-Ritz formula

$$\nu_n = \mathrm{IP} - \frac{\mathrm{R_M}}{(n-\delta)^2}$$

IPRydberg(At) = 75151(1) cm-1

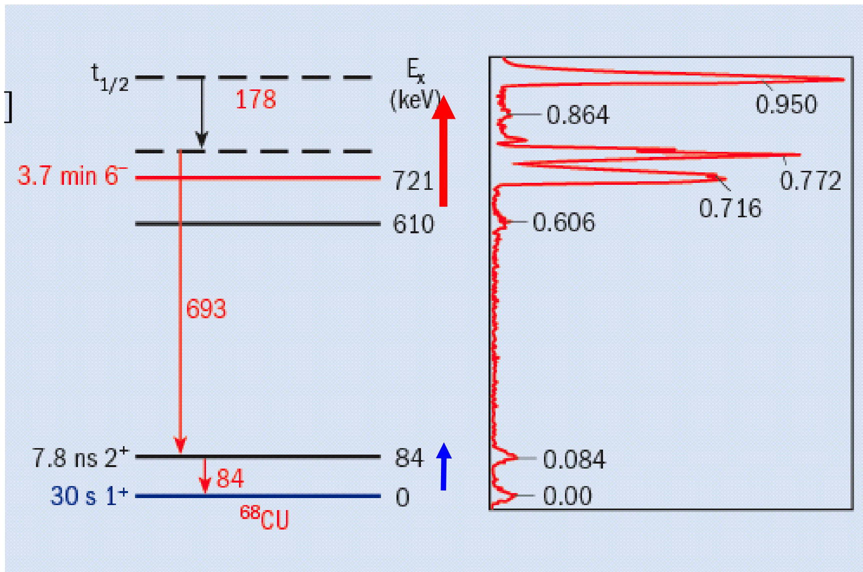
IPthreshold(At) = 75129(95) cm-1

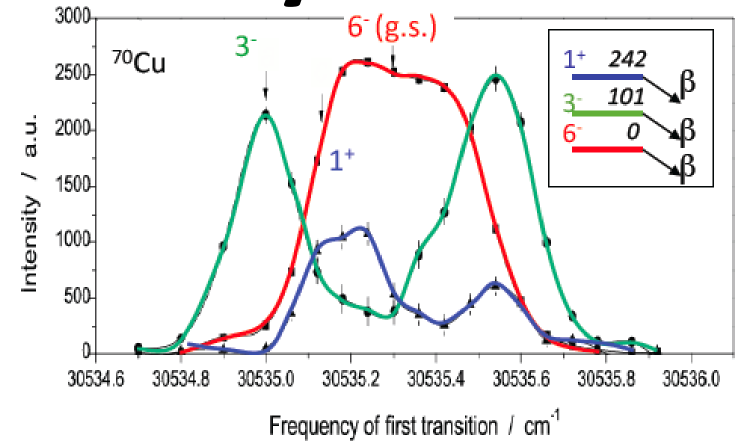
# Isomer selectivity

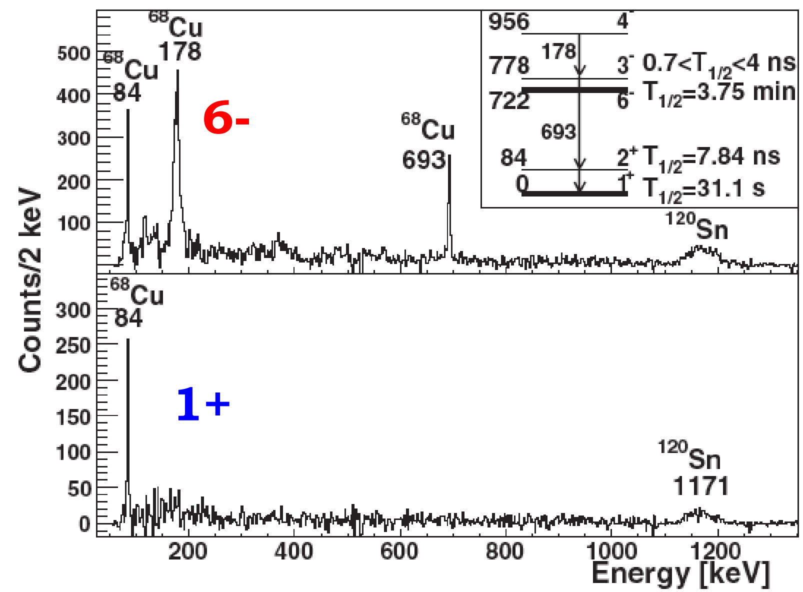
Laser-> Maximize different isomers

$[\pi\, 1p_{3/2} \nu\, 0g_{9/2}]$

$[\pi\, 1p_{3/2} \nu\, 1p_{1/2}]$

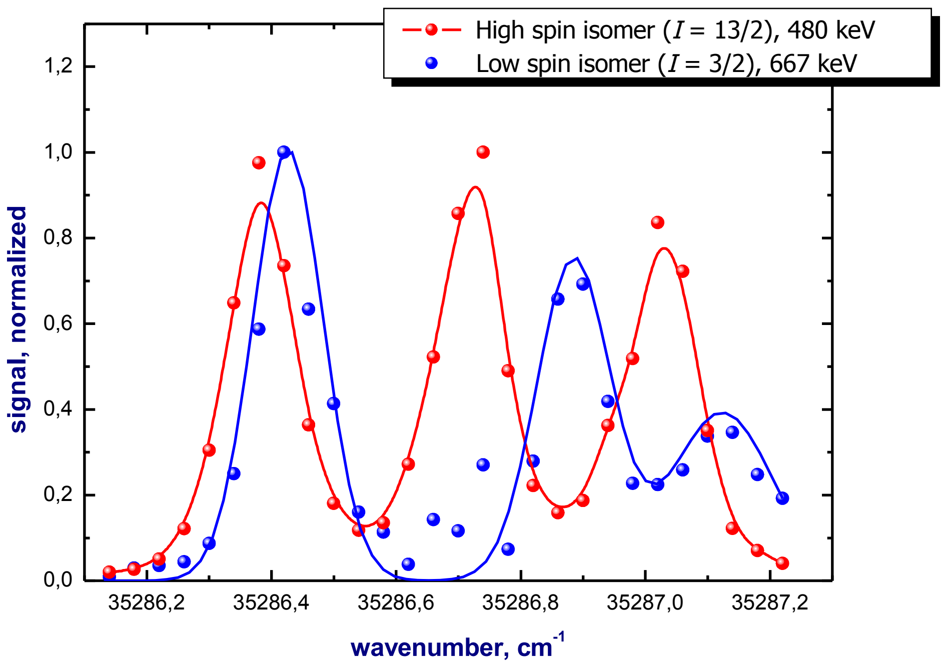


# Isomer selectivity

Laser-> Maximize different isomers

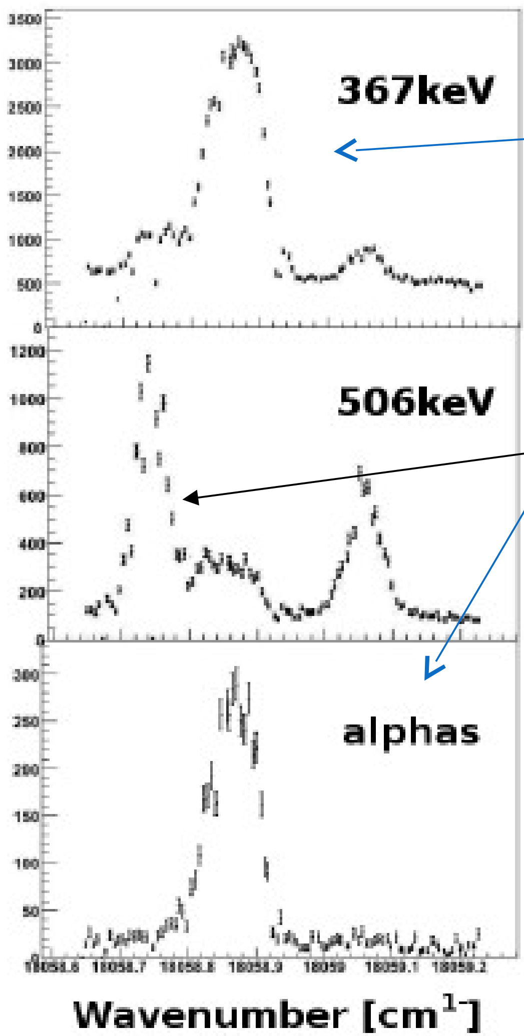



## 189Pb

A level scheme of the 189Tl nucleus has been established from the β+/EC decay study of the 189Pb isomers using both nuclear spectroscopy and in-source laser spectroscopy experiments.

40 gamma lines belonging to the β/EC decay of 189Pb have been identified: 386, 480, 700, 399....and 667keV are the main ones.

# Isomer selectivity




184Tl

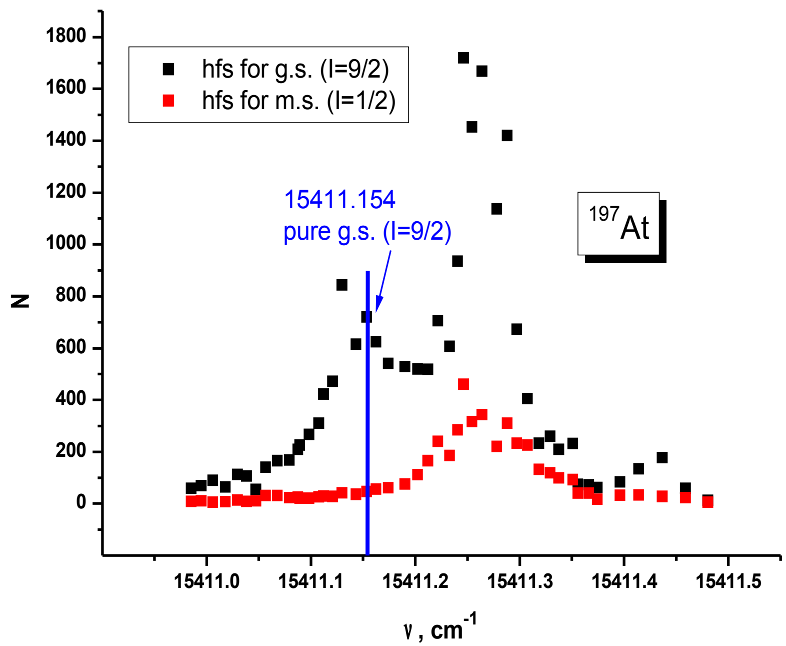
ground state hfs

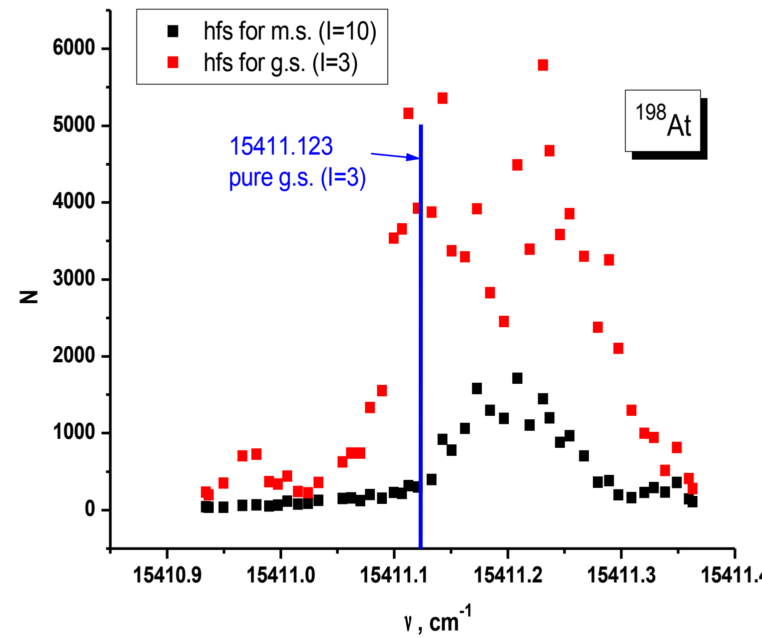
hfs of the previously unknown isomer (*I*=10)

Hyperfine structures observed for 184Tl with different detection modes

# Isomer selectivity

197,198At




Isomer selectivity enable us to measure masses of 197g,198gAt and receive nuclear spectroscopic information for pure g.s.

# Nuclear charge radii and electromagnetic moments

**Isotope shift $\delta\nu^{A,A'}$**

$$\delta\nu^{A,A'} = F\,\lambda^{A,A'} + MS$$

**Rms charge radius**

$$\lambda^{A,A'} = \delta\langle r^2\rangle^{A,A'} + C_2\,\delta\langle r^4\rangle^{A,A'} + \ldots = 0.93\,\delta\langle r^2\rangle^{A,A'}$$

**Relative line position → hyperfine constants *A* & *B* → *mI*, *QS***

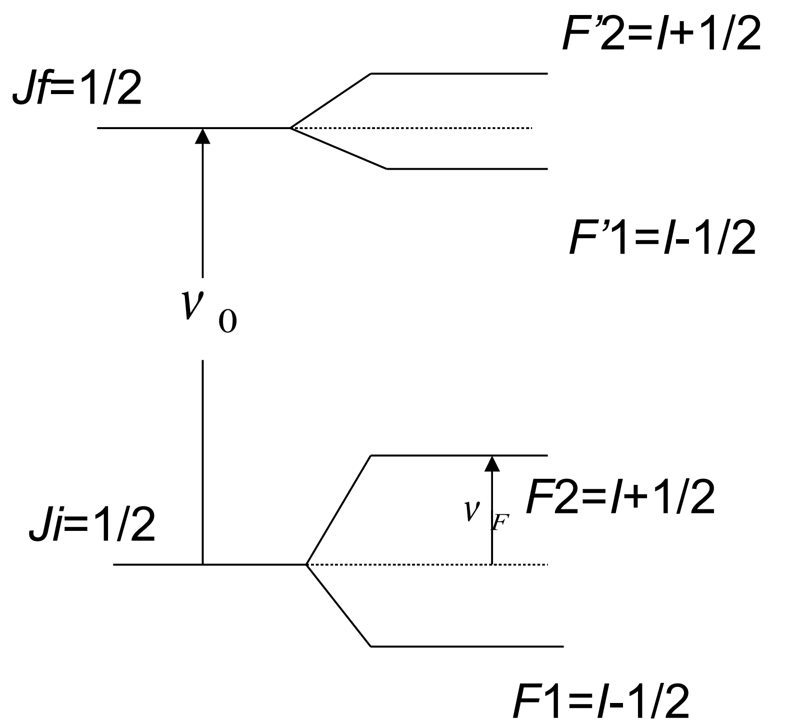
$$\nu_{F_i,F_f} = \nu_0 + \nu_{F_f} - \nu_{F_i}$$

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

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

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

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




Amplitudes of the components:

$$S(F_i \rightarrow F_f) = \frac{(2F_f+1)\times(2F_i+1)}{2I+1} \times \begin{Bmatrix} J_f & F_f & I \\ F_i & J_i & 1 \end{Bmatrix}^2$$

# Nuclear deformation

## Charge radii and deformation:

$$\langle r^2\rangle_A \approx \langle r^2\rangle_A^{sph}\left(1+\frac{5}{4\pi}\langle\beta_2^2\rangle_A\right)$$

$\langle r^2\rangle_A^{sph}$ is the mean square radius of a spherical nucleus with the same volume. Usually evaluated using droplet model

## Quadrupole moment and deformation:

$$Q_S = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)}Q_0,$$

*K* is the projection of the nuclear spin on the symmetry axis of the nucleus.

$$Q_0 \approx \frac{3}{\sqrt{5\pi}}eZR_0^2\left(\beta_2 + \frac{2}{7}\sqrt{\frac{5}{\pi}}\beta_2^2 + \ldots\right),$$

*R*o =1.2*A*1/3 fm.

# Hyperfine components intensities: rate equations

$$N_i(v) = C_1 \int N_0^G(v') P_i\left(I^{L'}(v - v')\right) dv' + C_0$$

To take into account the saturation of transitions, pumping processes between hyperfine structure (hfs) components and a population redistribution of the hfs levels the number of photoions *Nion* for each frequency step was calculated by solving the rate equations for the given photoionization scheme:

$$\begin{cases} \dfrac{dN_F}{dt} = \sum_k W_{F'_k F} N_{F'_k} - \sum_k W_{F F'_k} N_F - W_{F,ion} N_F \\ \vdots \\ \dfrac{dN_{ion}}{dt} = \sum_k W_{F'_k, ion} N_{F'_k} \end{cases}$$

$$W_{FF'} \sim S^*_{FF'} I(v + \Delta v^{FF'} - v'), \quad S^*_{FF'} = S_{FF'}/(2F+1)$$

At $t = 0$: $N_F^0 \sim 2F + 1$

# Hyperfine components intensities: rate equations

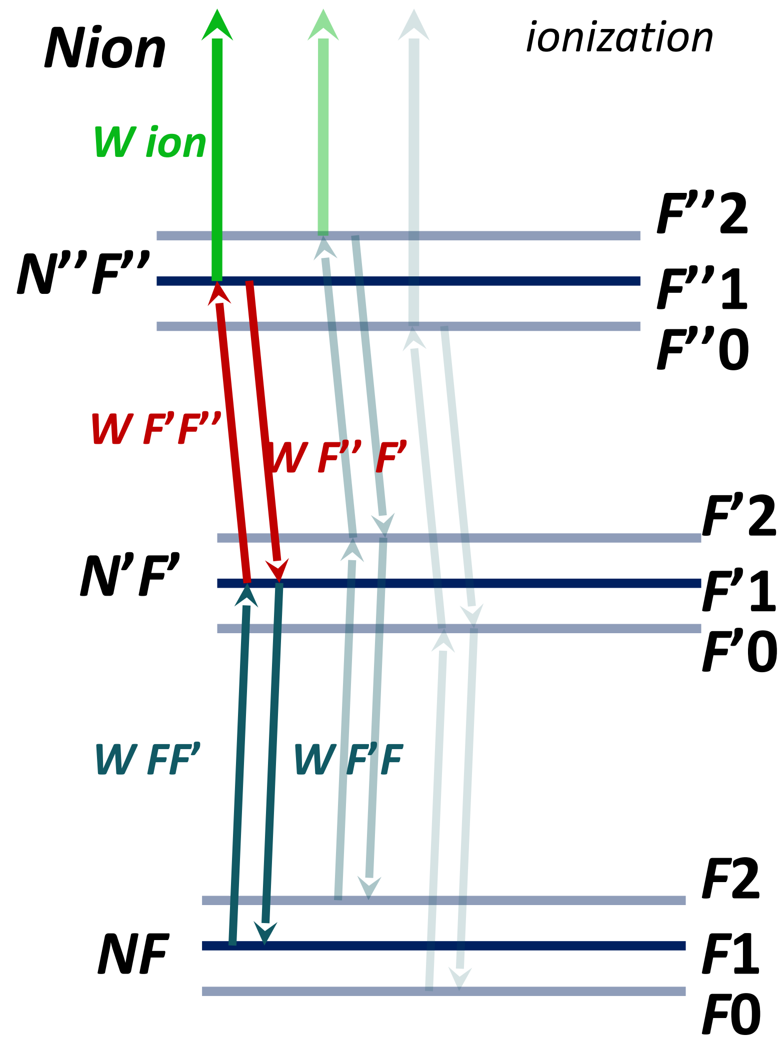
$$dN_{ion} = W_{ion} N''_{F''} dt + \ldots.$$

$$dN''_{F''} = -N''_{F''}(W_{ion} + W_{F''F'} + \ldots)dt + $$
$$+ N'_{F'} W_{F'F''} dt + \ldots$$

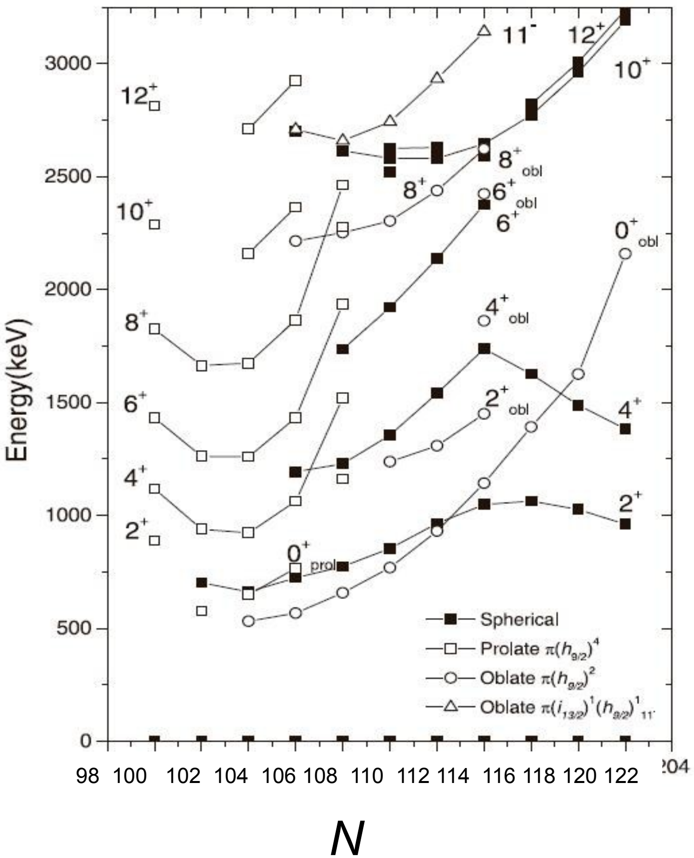
$$dN'_{F'} = -N'_{F'}(W_{F'F''} + W_{F'F} + \ldots)dt + $$
$$+ (N''_{F''} W_{F''F'} + N_F W_{FF'} + \ldots)dt$$

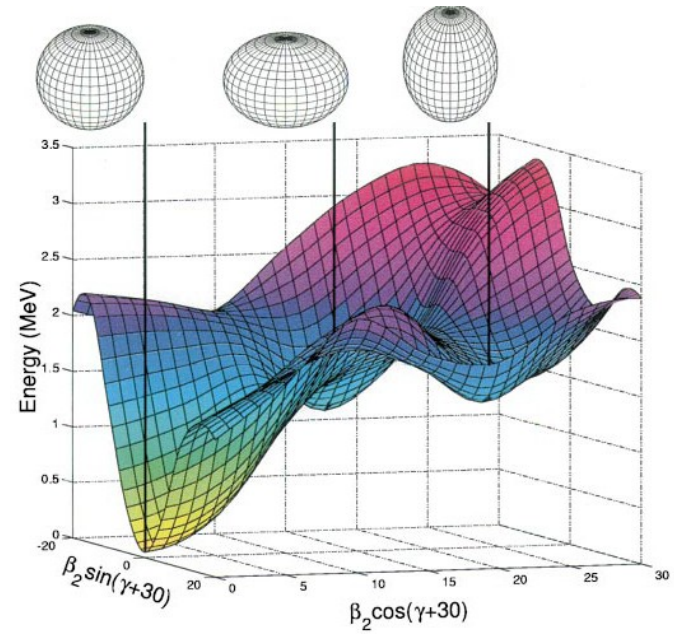
$$dN_F = -N_F(W_{FF'} + \ldots)dt + $$
$$+ (N'_{F'} W_{F'F} + \ldots)dt$$

$$\frac{W_{FF'}}{W_{F'F}} = \frac{2F'+1}{2F+1}$$



# Shape coexistence in Pb region

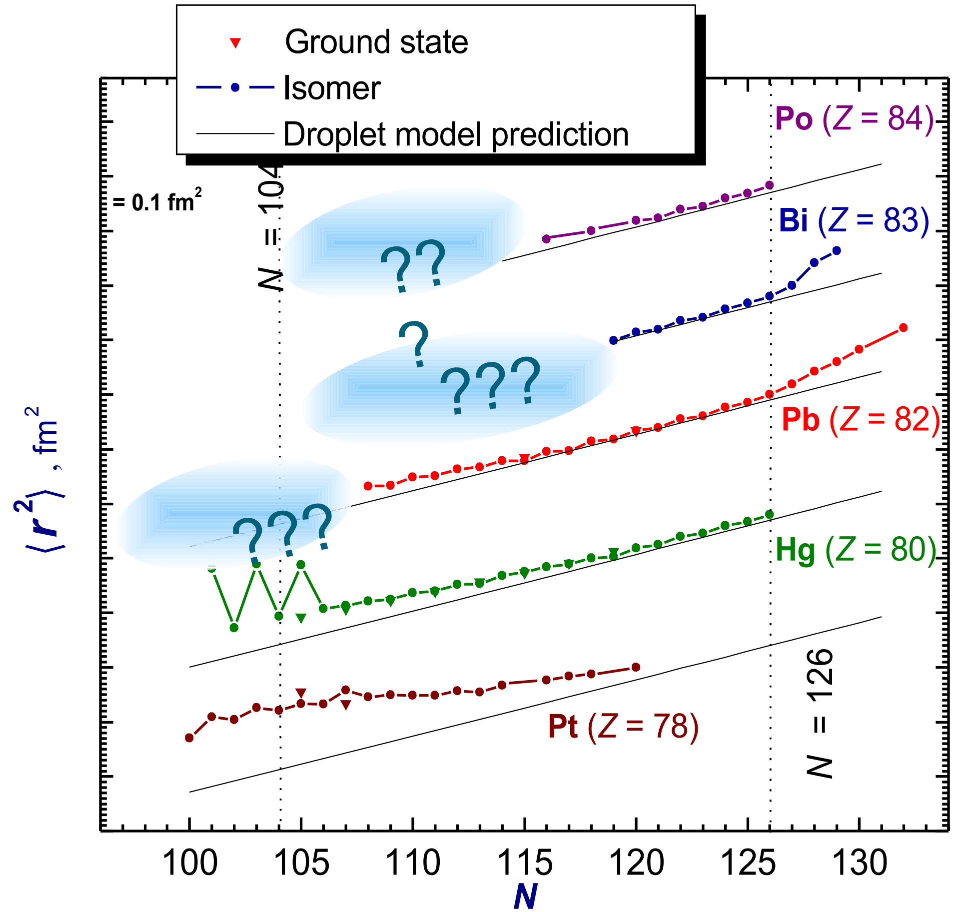



Level systematics for the neutron-deficient lead isotopes.

***R. Julin et al.,*** *J. Phys. G: Nucl. Part. Phys.* ***27*** *(2001)*

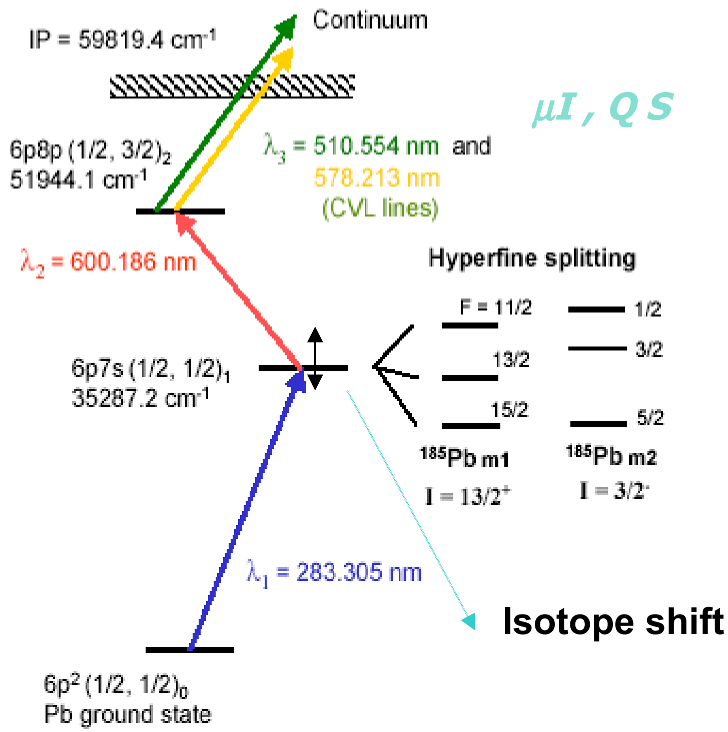
# Nuclear charge radii around *Z*=82




nuclear ground and isomeric state properties : $\delta \langle r^2 \rangle$

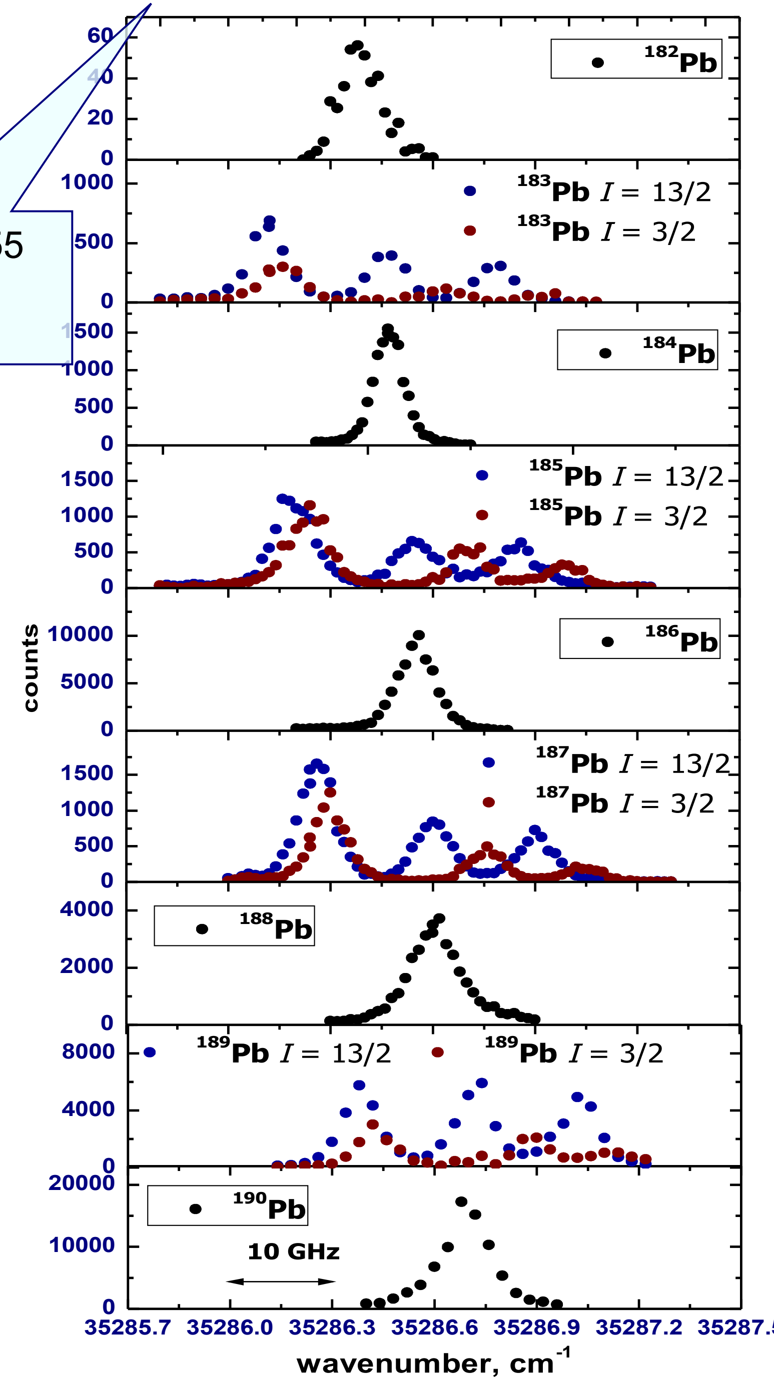
# Pb (Z= 82)

**182Pb**: *T*1/2= 55 ms
Yield: **~1 s-1**

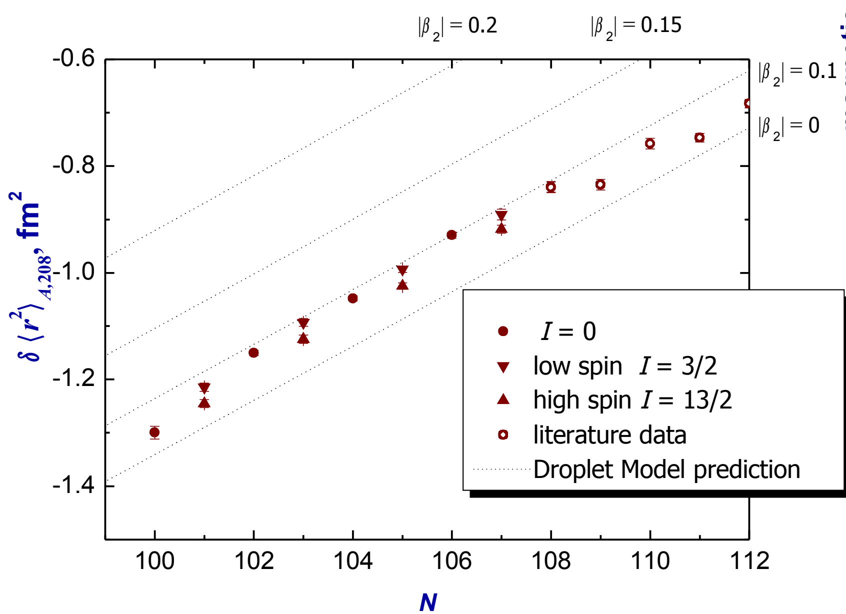


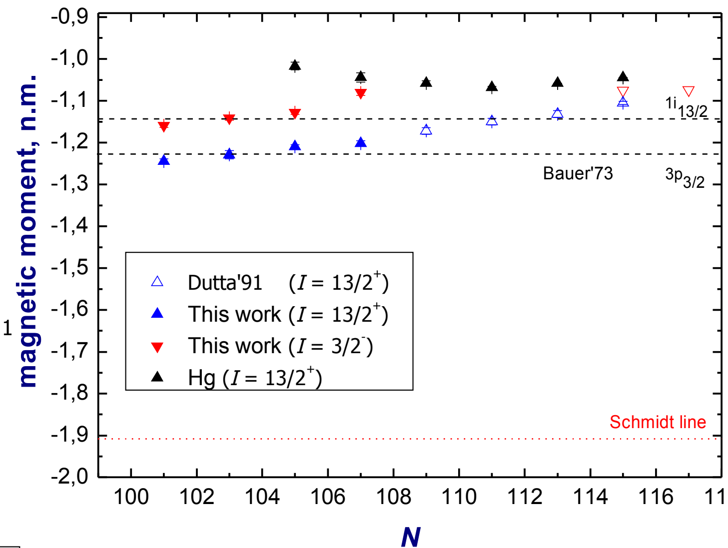

$\mu I, Q S$

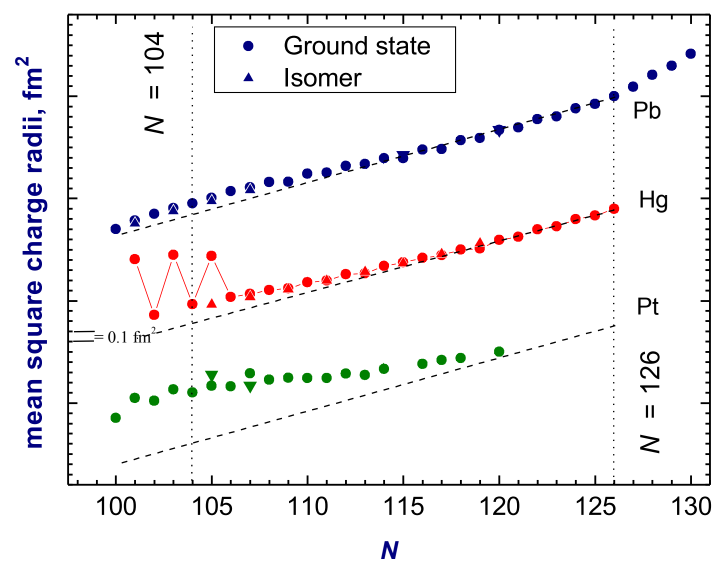
$\delta \langle r 2 \rangle$

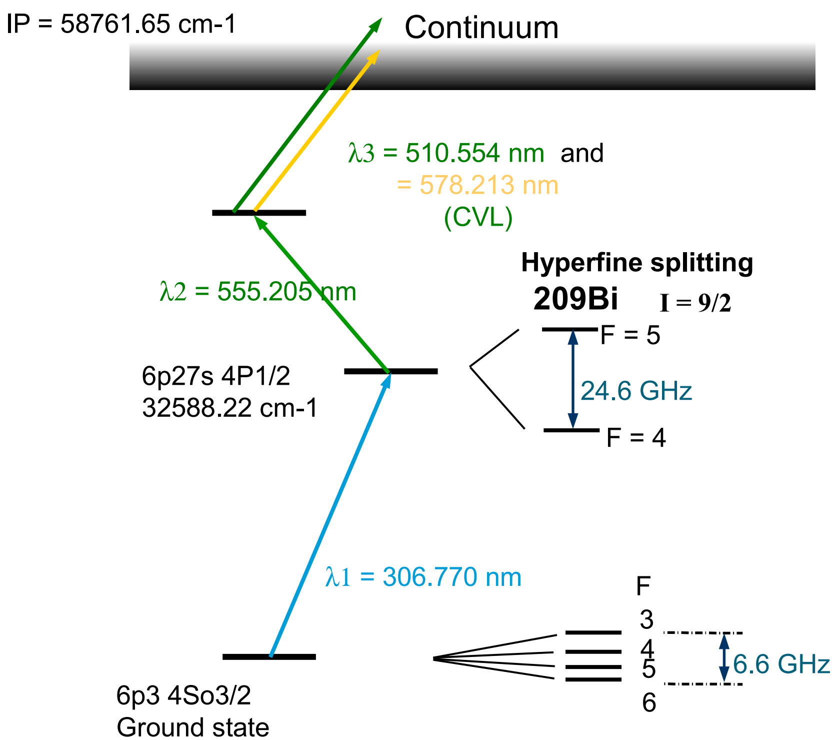


# Pb: charge radii and magnetic moments



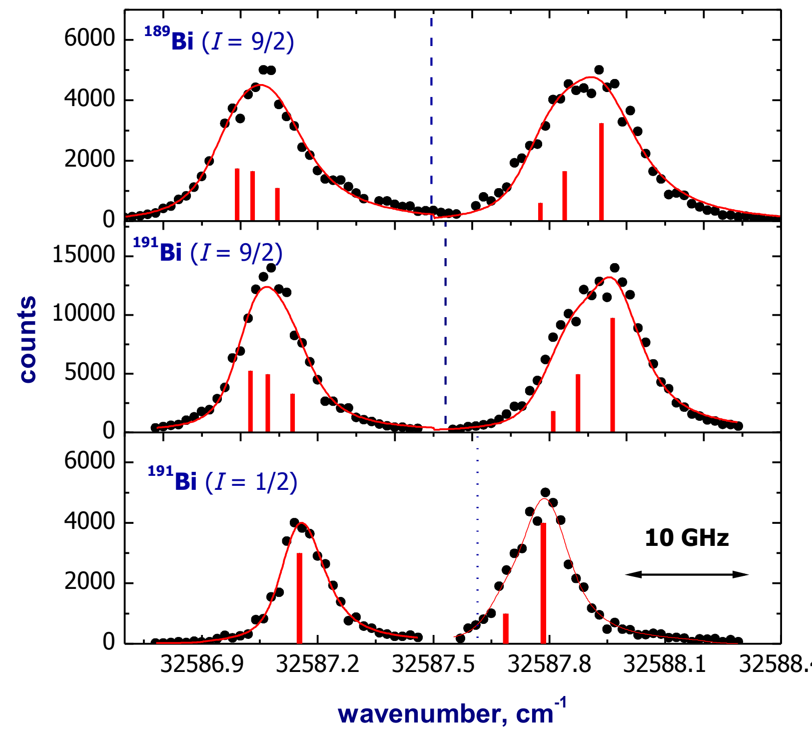





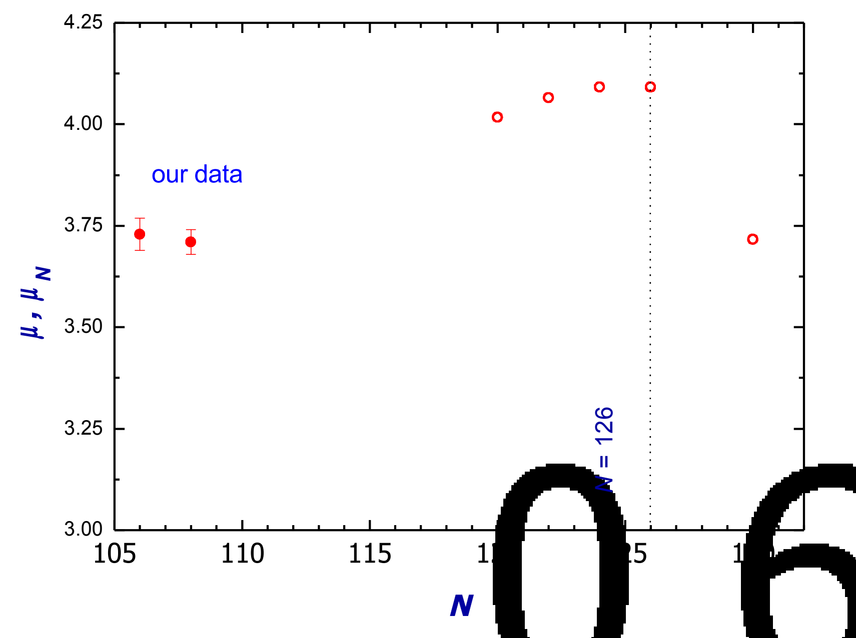
IP = 58761.65 cm-1
Continuum
λ3 = 510.554 nm and
= 578.213 nm
(CVL)
λ2 = 555.205 nm
Hyperfine splitting
209Bi I = 9/2
F = 5
24.6 GHz
F = 4
6p27s 4P1/2
32588.22 cm-1
λ1 = 306.770 nm
F
3
4
5
6
6.6 GHz
6p3 4So3/2
Ground state


Bi



189Bi (I = 9/2)
191Bi (I = 9/2)
191Bi (I = 1/2)
10 GHz
counts
wavenumber, cm-1
32586.9
32587.2
32587.5
32587.8
32588.1
32588.4

Magnetic moments



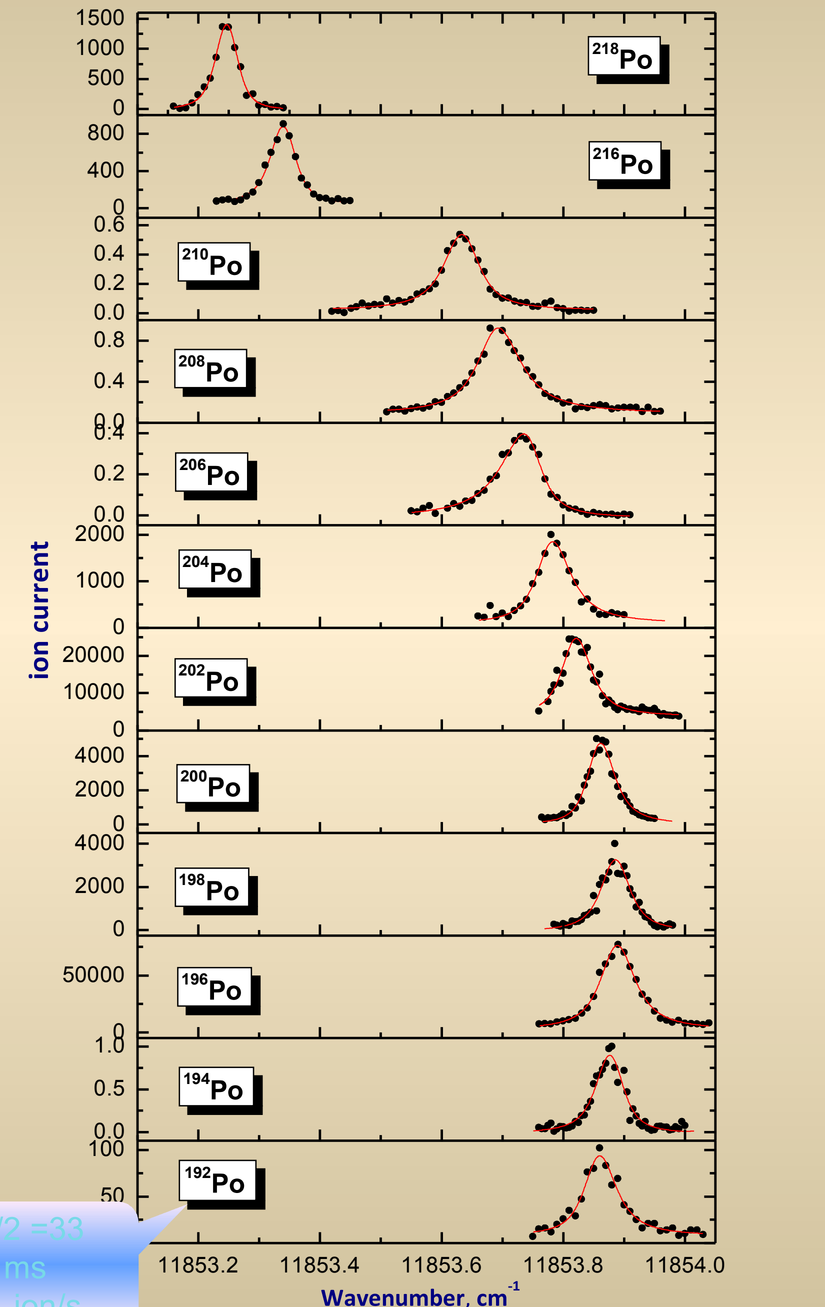

**No reliable values for electronic factor and specific mass shift constant :(**

From the comparison of isotopes shifts of Bi and Pb: ***F* = 27(3) GHz/fm2**

*P. Campbell et al., Phys. Lett. B* ***346*** *(1995) 21*

0,6

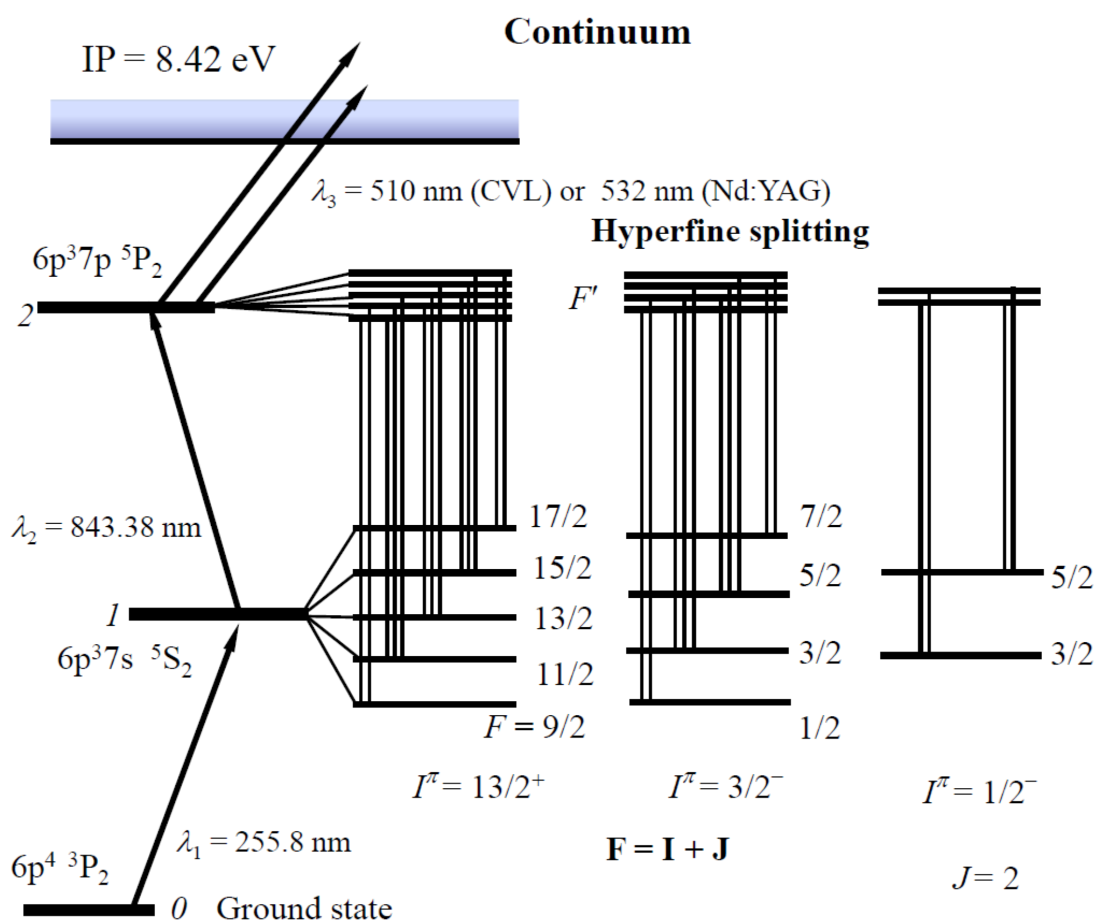
# Po (Z =84)

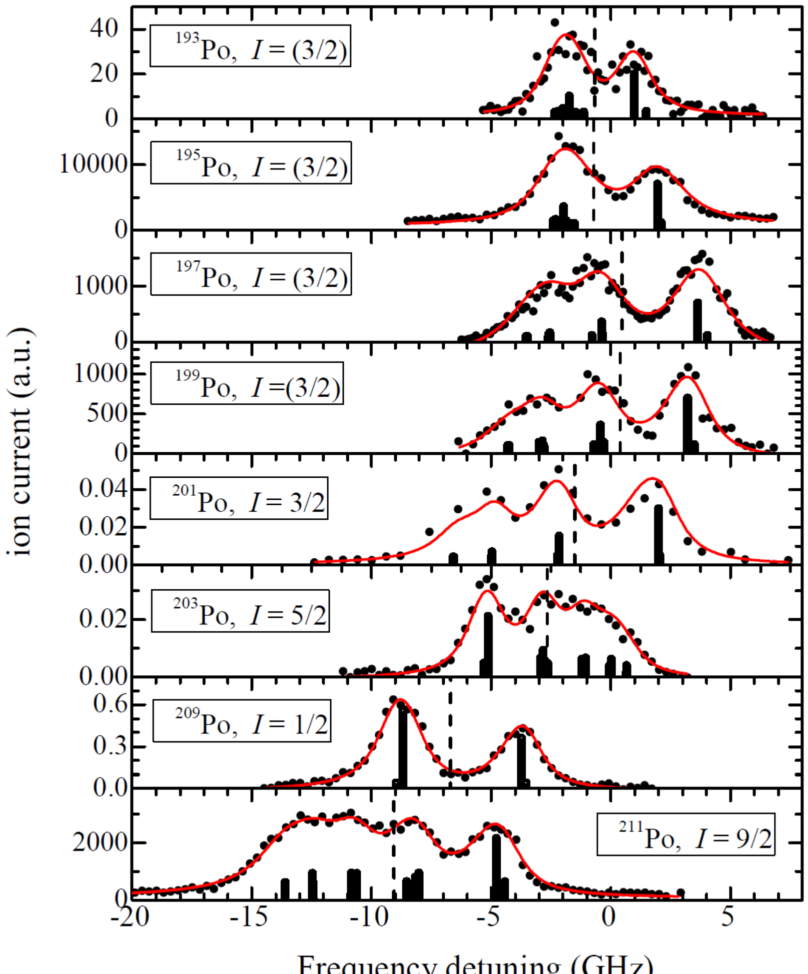


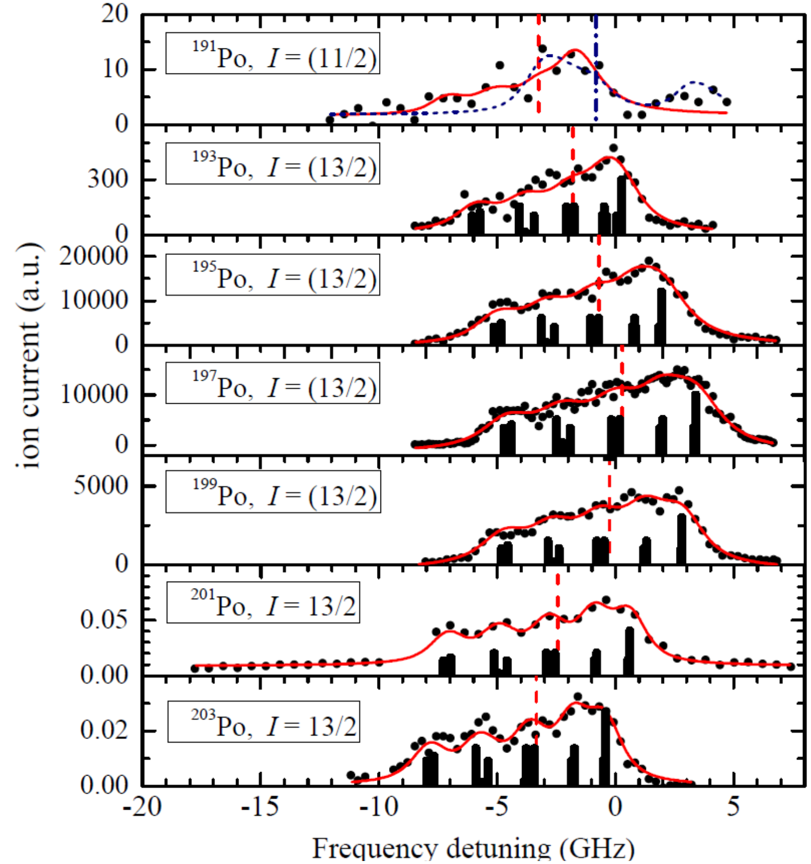

T1/2 =33 ms
<1 ion/s

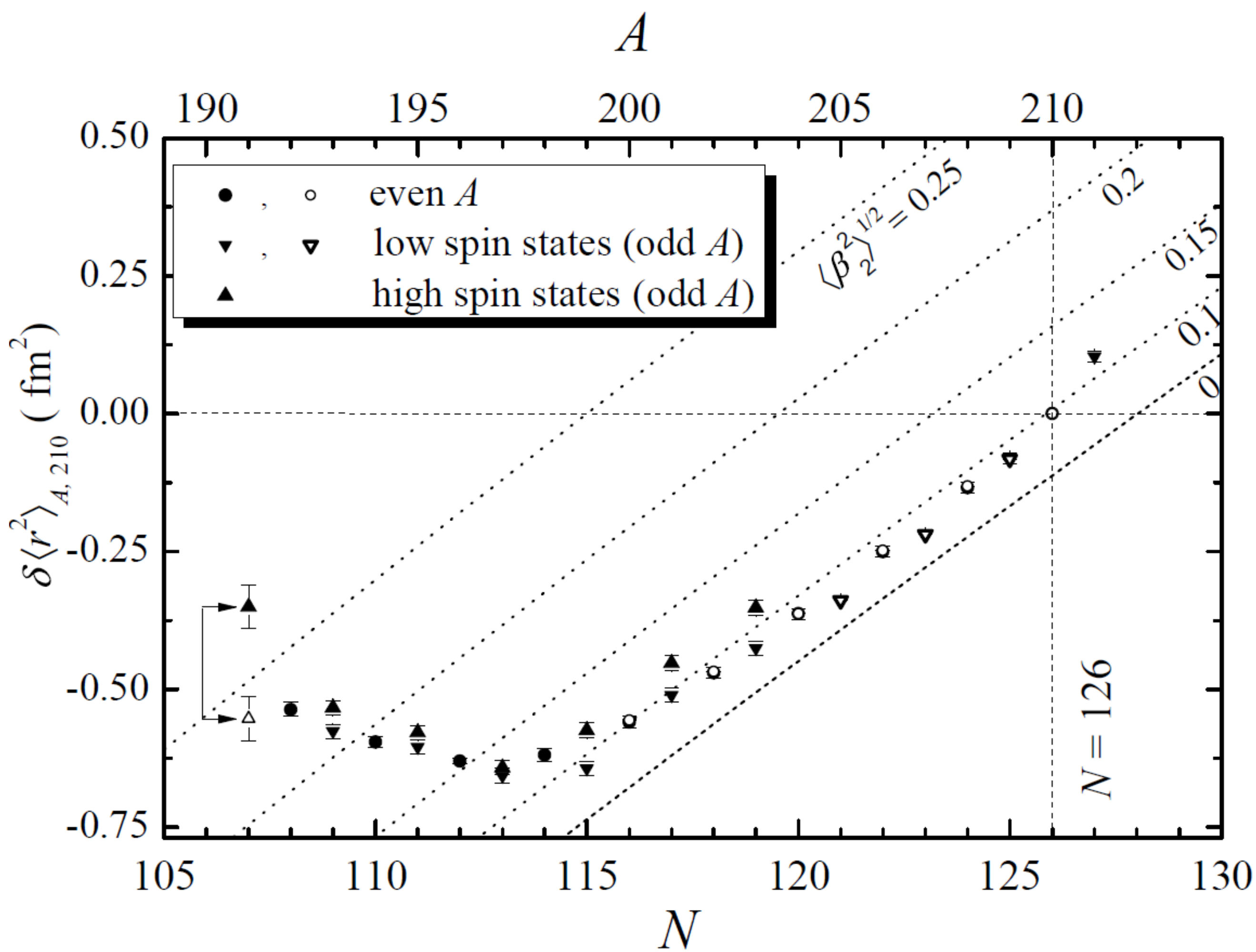
*

*This tranistion was already used for optical spectroscopy (Kowalewska *et al*, *Phys. Rev. A*, ***44*** *R1442, 1991.*)


Continuum
IP = 8.42 eV
λ3 = 510 nm (CVL) or 532 nm (Nd:YAG)
Hyperfine splitting
6p37p 5P2
2
F′
17/2
15/2
13/2
11/2
F = 9/2
7/2
5/2
3/2
1/2
5/2
3/2
λ2 = 843.38 nm
1
6p37s 5S2
Iπ = 13/2+
Iπ = 3/2−
Iπ = 1/2−
F = I + J
J = 2
λ1 = 255.8 nm
6p4 3P2
0
Ground state


40
20
0
$^{193}$Po, $I = (3/2)$
10000
0
$^{195}$Po, $I = (3/2)$
1000
0
$^{197}$Po, $I = (3/2)$
1000
500
0
$^{199}$Po, $I =(3/2)$
0.04
0.02
0.00
$^{201}$Po, $I = 3/2$
0.02
0.00
$^{203}$Po, $I = 5/2$
0.6
0.3
0.0
$^{209}$Po, $I = 1/2$
2000
0
$^{211}$Po, $I = 9/2$
-20
-15
-10
-5
0
5
ion current (a.u.)
Frequency detuning (GHz)

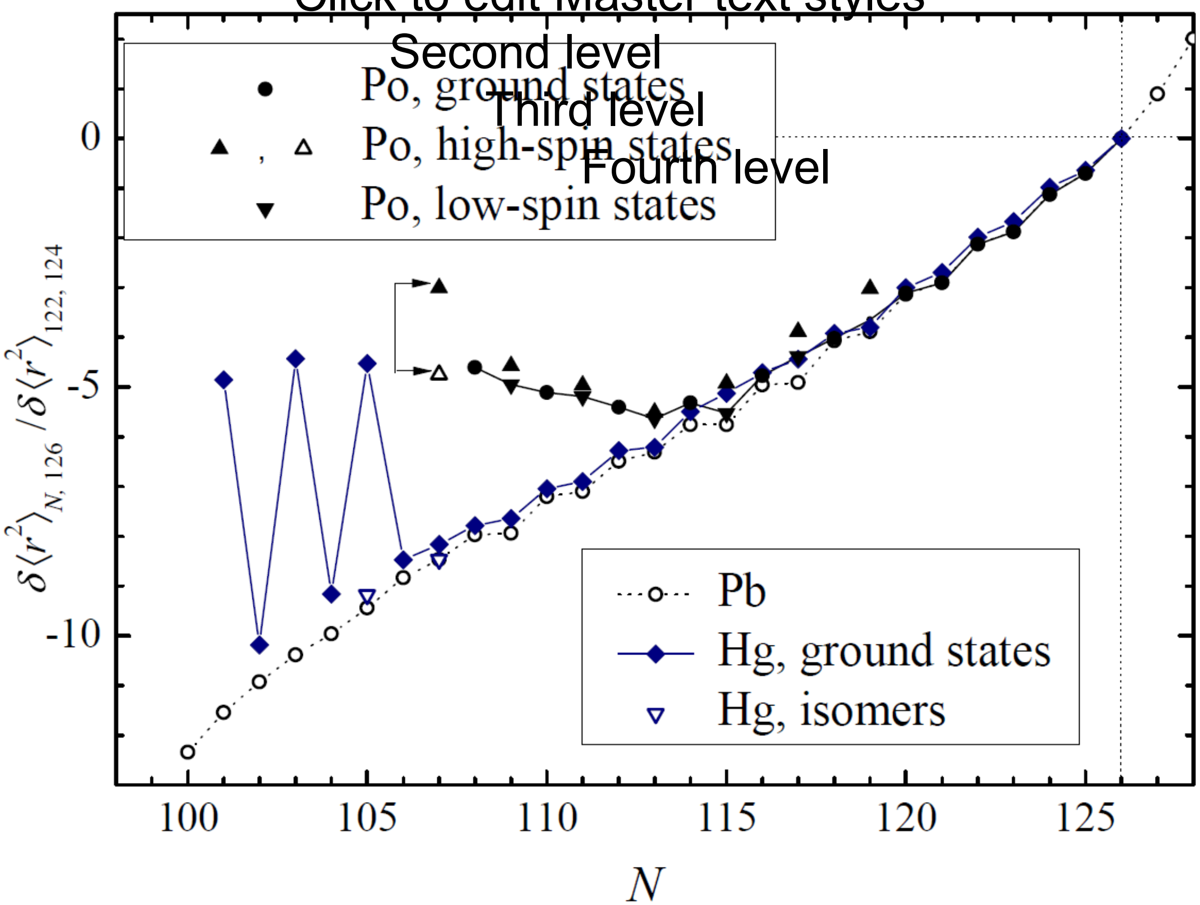

20
10
0
$^{191}$Po, $I = (11/2)$
300
0
$^{193}$Po, $I = (13/2)$
20000
10000
0
$^{195}$Po, $I = (13/2)$
10000
0
$^{197}$Po, $I = (13/2)$
5000
0
$^{199}$Po, $I = (13/2)$
0.05
0.00
$^{201}$Po, $I = 13/2$
0.02
0.00
$^{203}$Po, $I = 13/2$
-20
-15
-10
-5
0
5
ion current (a.u.)
Frequency detuning (GHz)



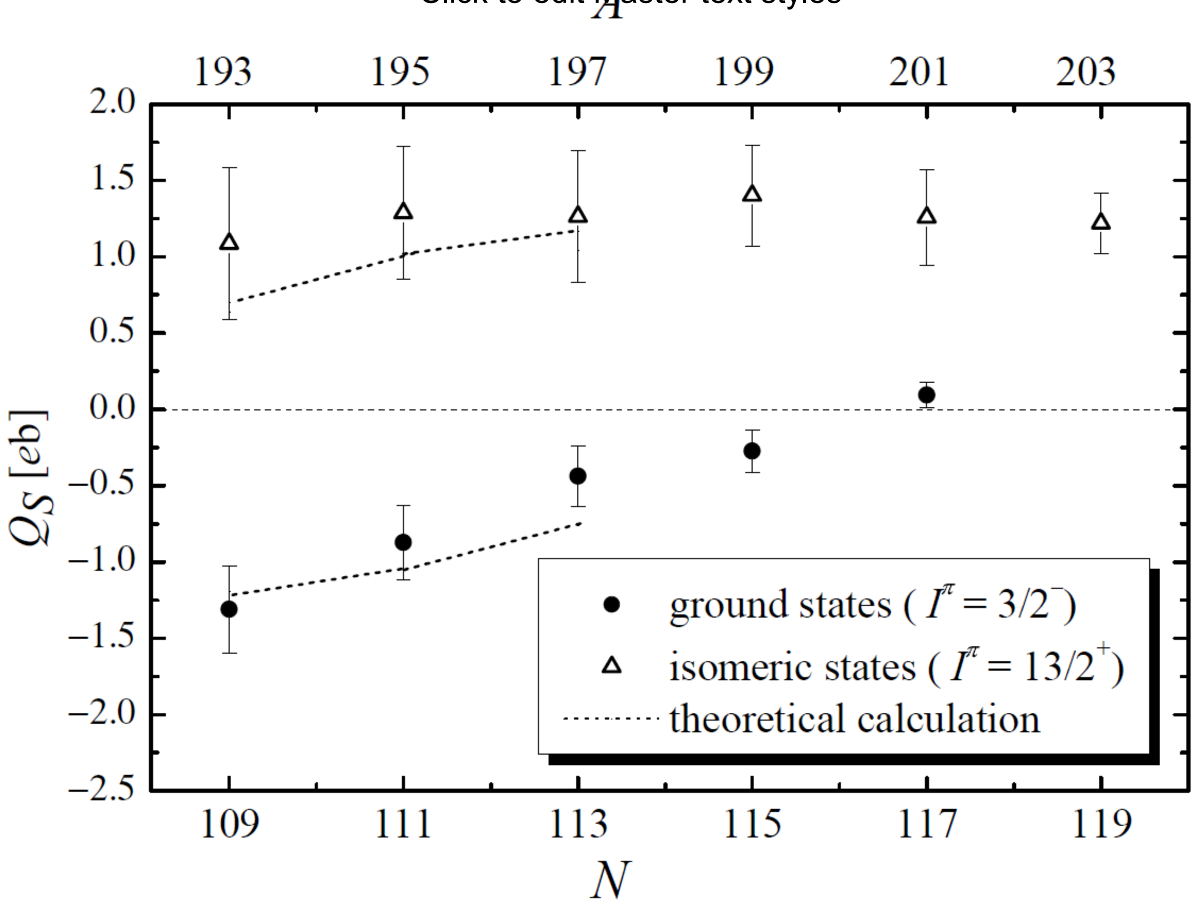
A
190
195
200
205
210
0.50
0.25
0.00
-0.25
-0.50
-0.75
even A
low spin states (odd A)
high spin states (odd A)
⟨β₂²⟩^1/2 = 0.25
0.2
0.15
0.1
0
N = 126
δ⟨r²⟩A, 210 ( fm²)
105
110
115
120
125
130
N

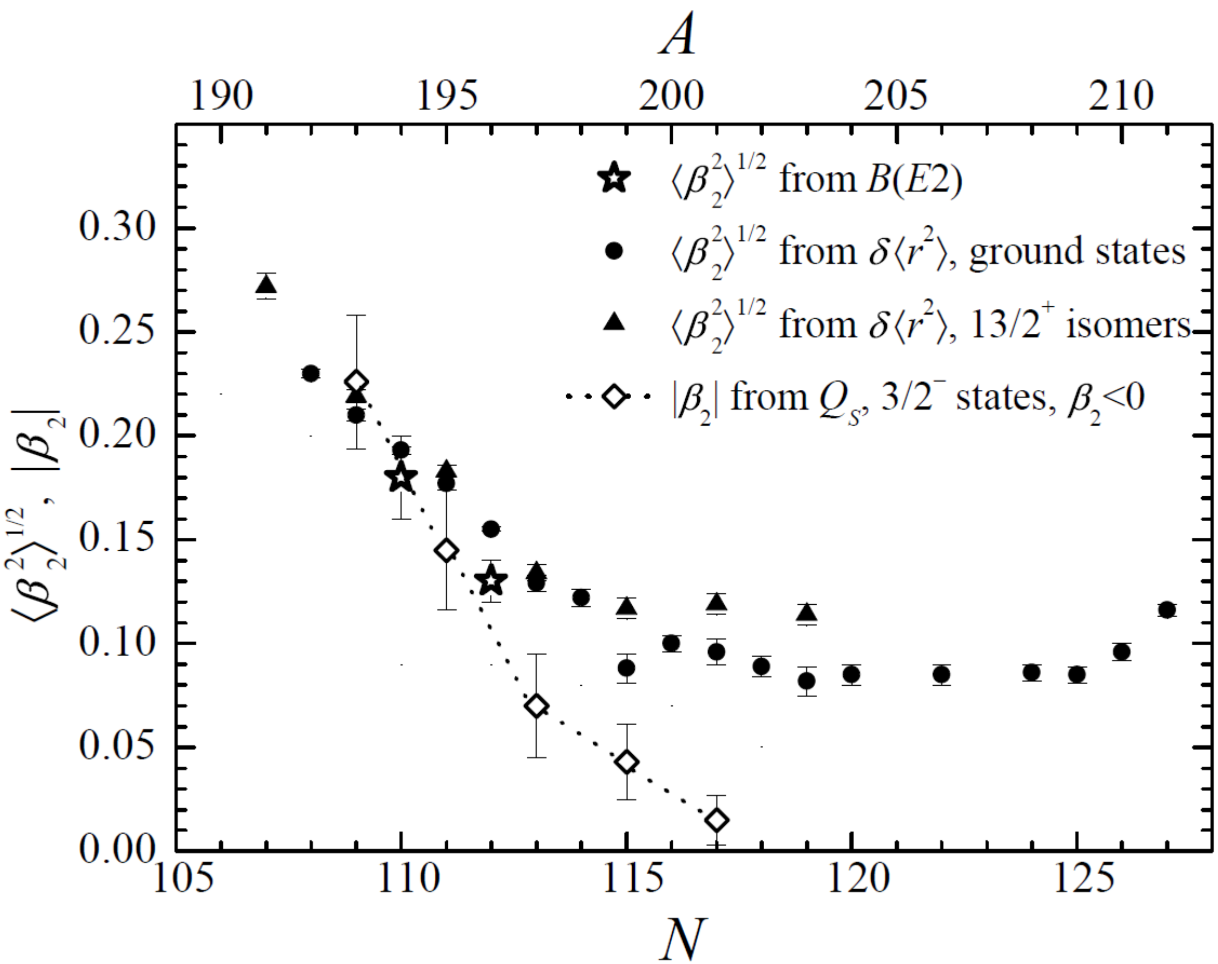
Click to edit Master text styles

- Second level
  - Third level
    - Fourth level

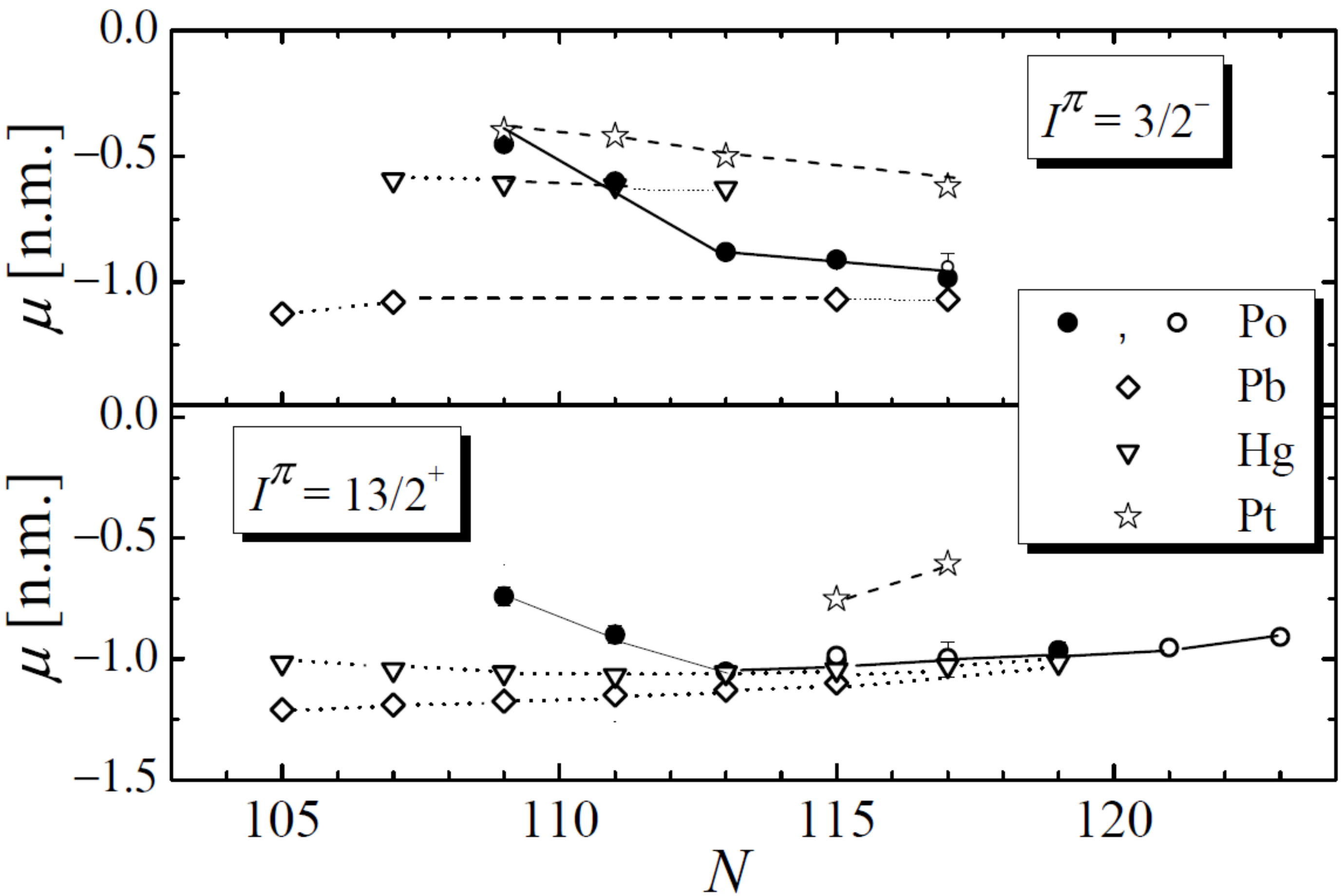


Click to edit Master text styles



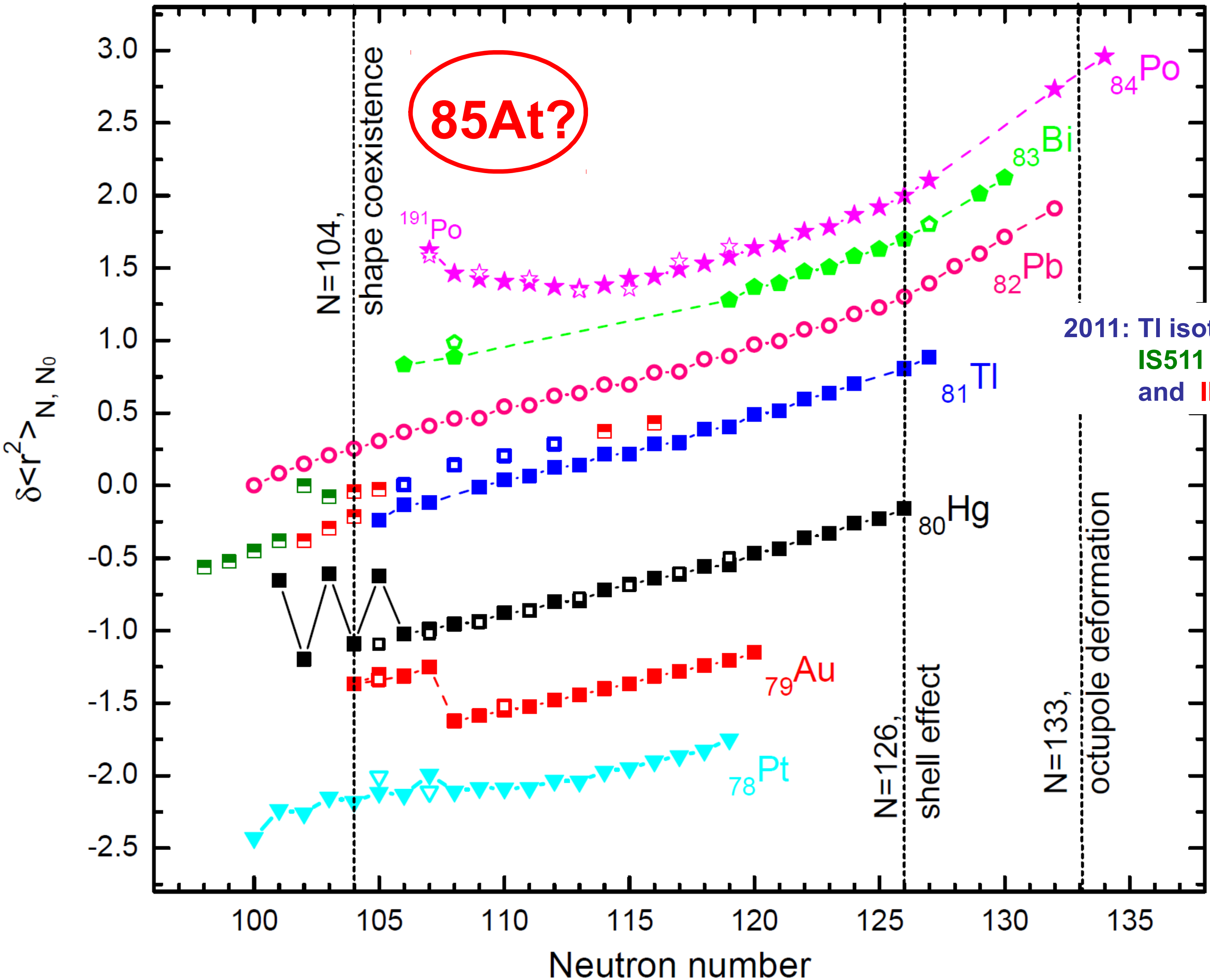


A
190
195
200
205
210
$\langle\beta_2^2\rangle^{1/2}$ from $B(E2)$
$\langle\beta_2^2\rangle^{1/2}$ from $\delta\langle r^2\rangle$, ground states
$\langle\beta_2^2\rangle^{1/2}$ from $\delta\langle r^2\rangle$, $13/2^+$ isomers
$|\beta_2|$ from $Q_S$, $3/2^-$ states, $\beta_2<0$
$\langle\beta_2^2\rangle^{1/2}$, $|\beta_2|$
0.30
0.25
0.20
0.15
0.10
0.05
0.00
105
110
115
120
125
N



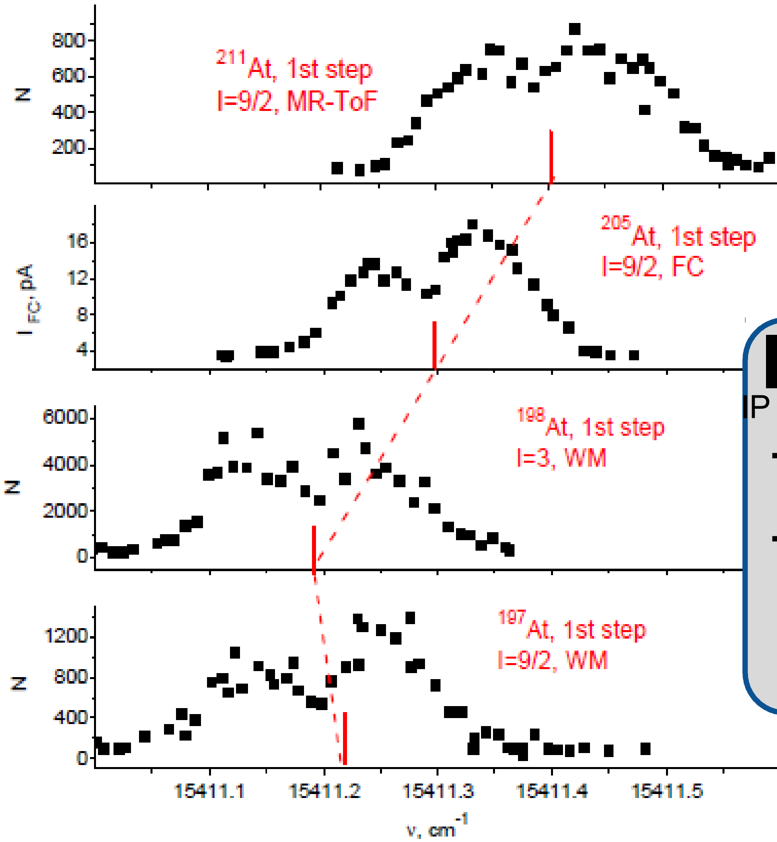
0.0
−0.5
−1.0
0.0
−0.5
−1.0
−1.5
μ [n.m.]
μ [n.m.]
$I^{\pi} = 3/2^{-}$
$I^{\pi} = 13/2^{+}$
Po
Pb
Hg
Pt
105
110
115
120
N

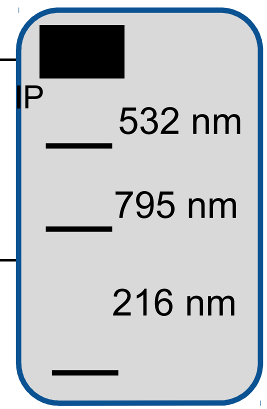
# Next step:  At

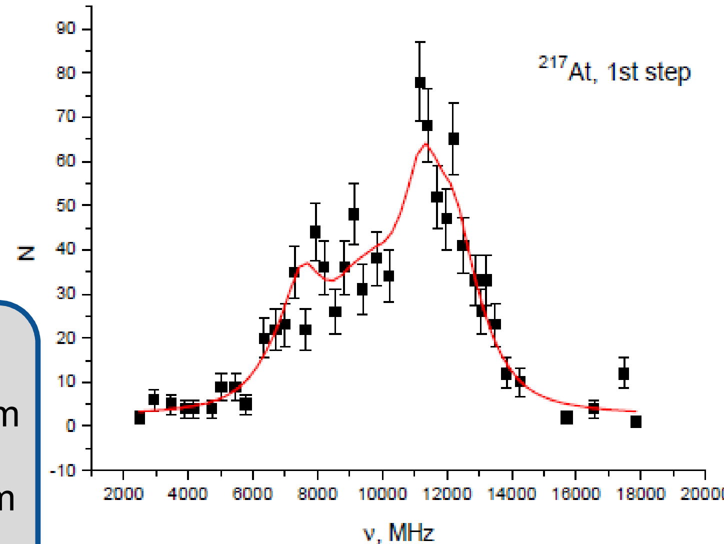


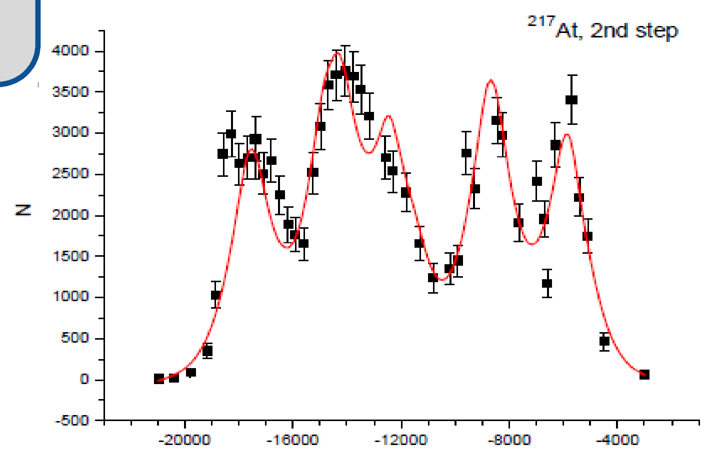

**2011: Tl isotopes:**
**IS511 ISOLDE**
**and IRIS (Gatchina)**

# At (Z=85)



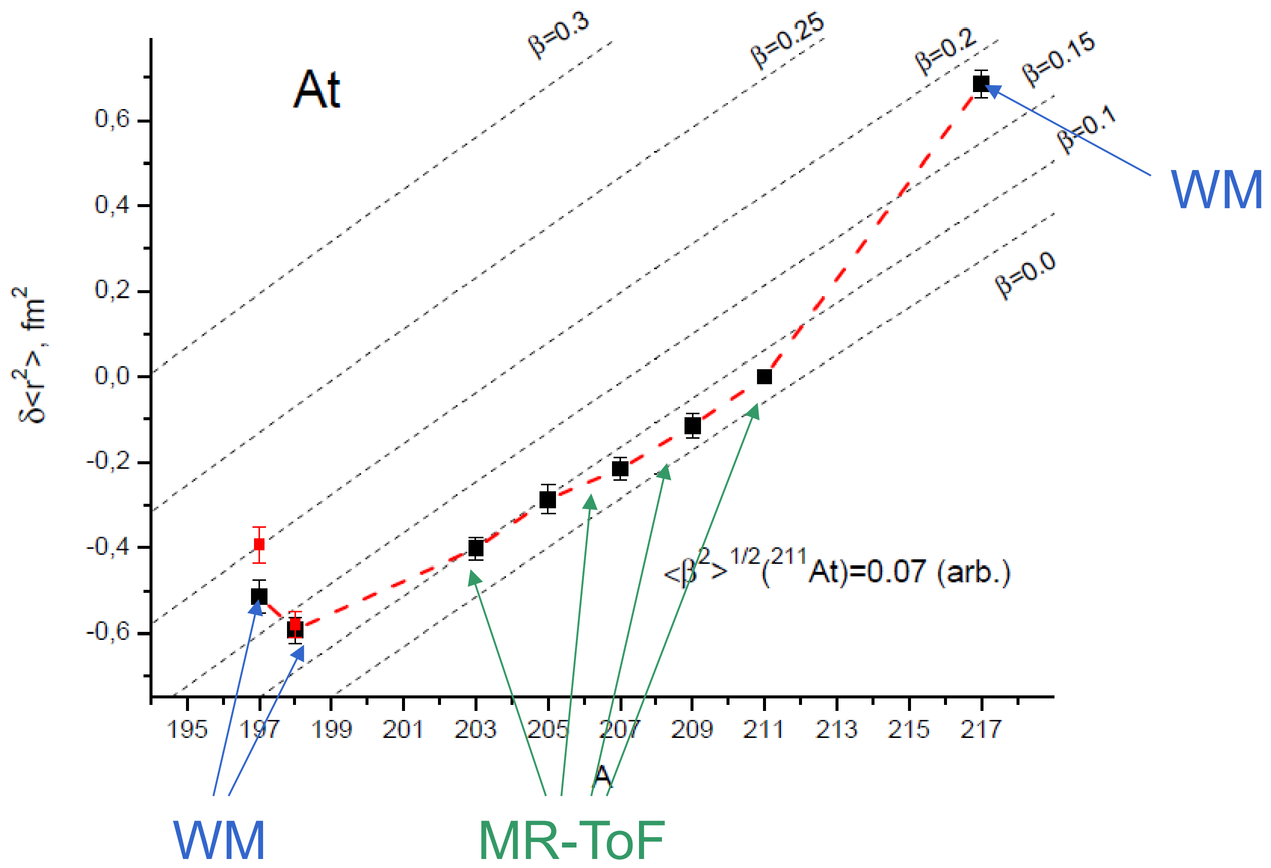



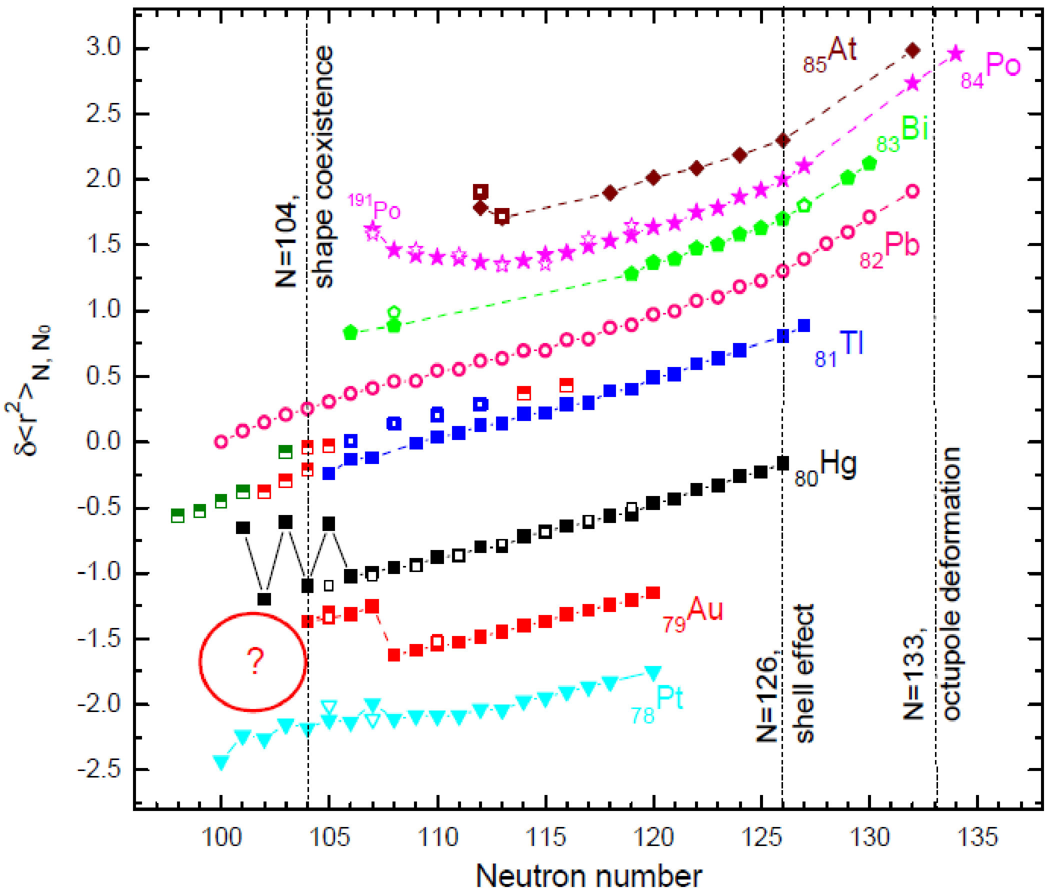




1st step scanning is better for Δ<*r*2> extraction
2nd step scanning is better for hfs resolution
(*Q* and *μ* determination)

# At: charge radii



# Next step: Au



$\delta\langle r^2\rangle_{N,N_0}$
Neutron number
N=104, shape coexistence
N=126, shell effect
N=133, octupole deformation
$_{85}$At
$_{84}$Po
$^{191}$Po
$_{83}$Bi
$_{82}$Pb
$_{81}$Tl
$_{80}$Hg
$_{79}$Au
$_{78}$Pt
?

# Au (Z=79)

Au ionization scheme

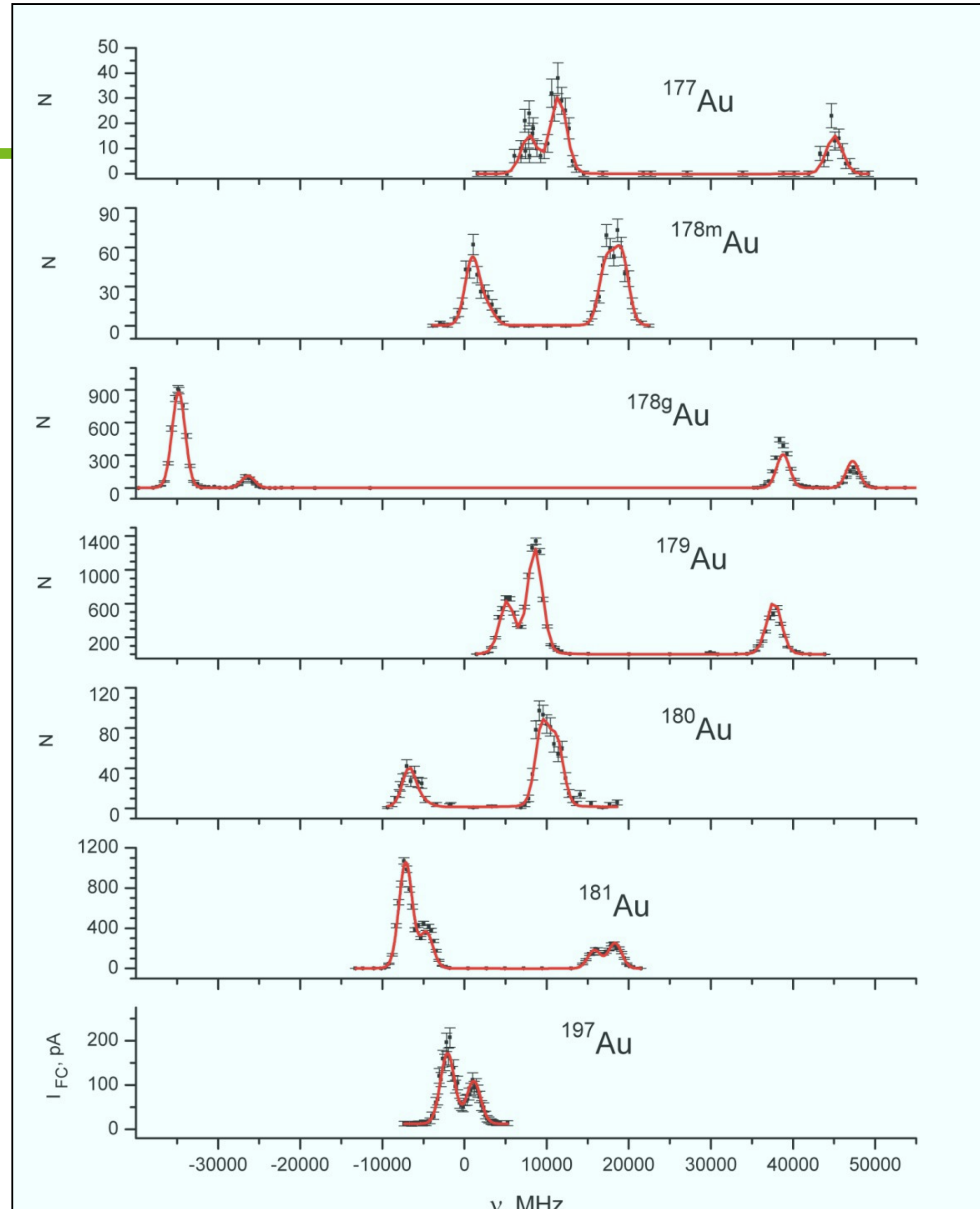
autoionizing state

IP

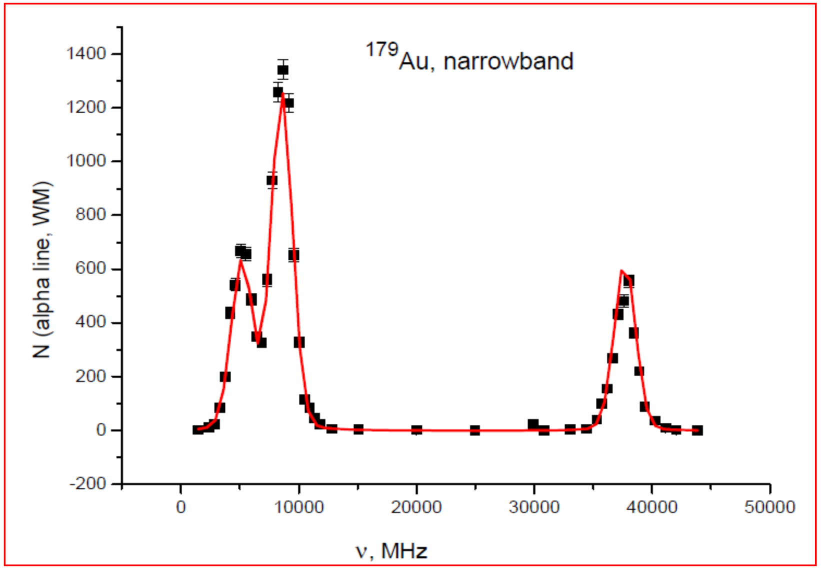
674.1 nm

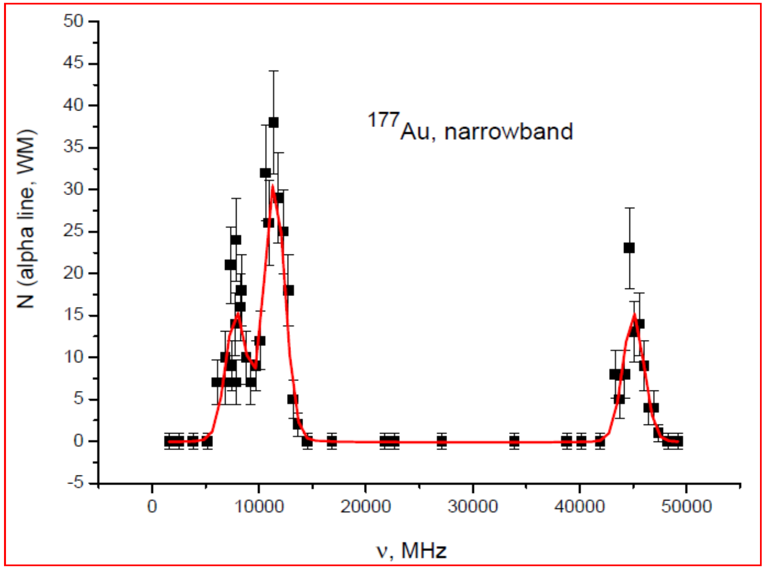
306.6 nm

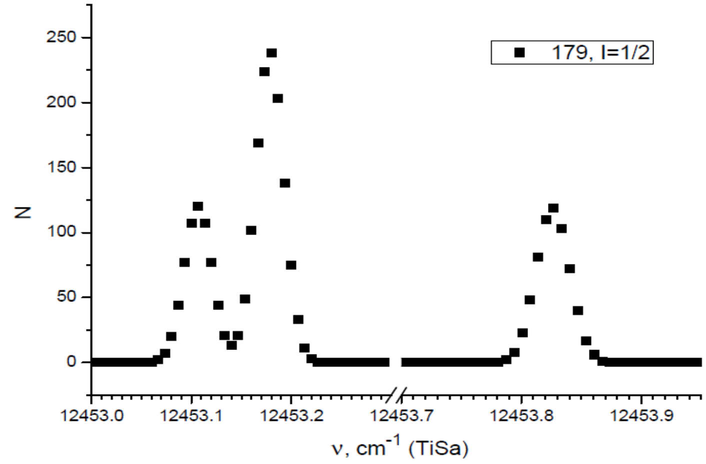
267.7 nm

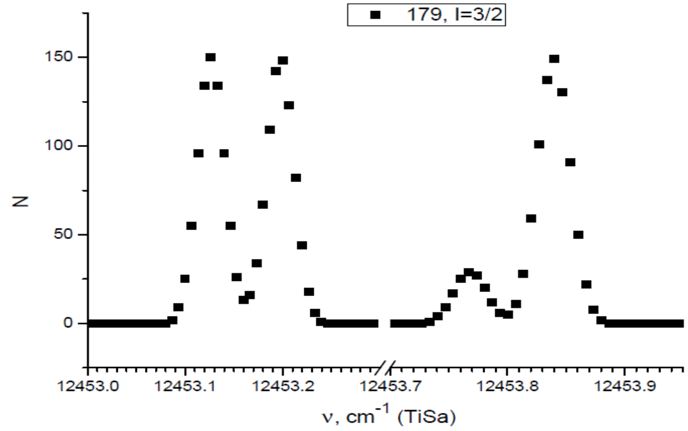


# Spins of 177g,179gAu

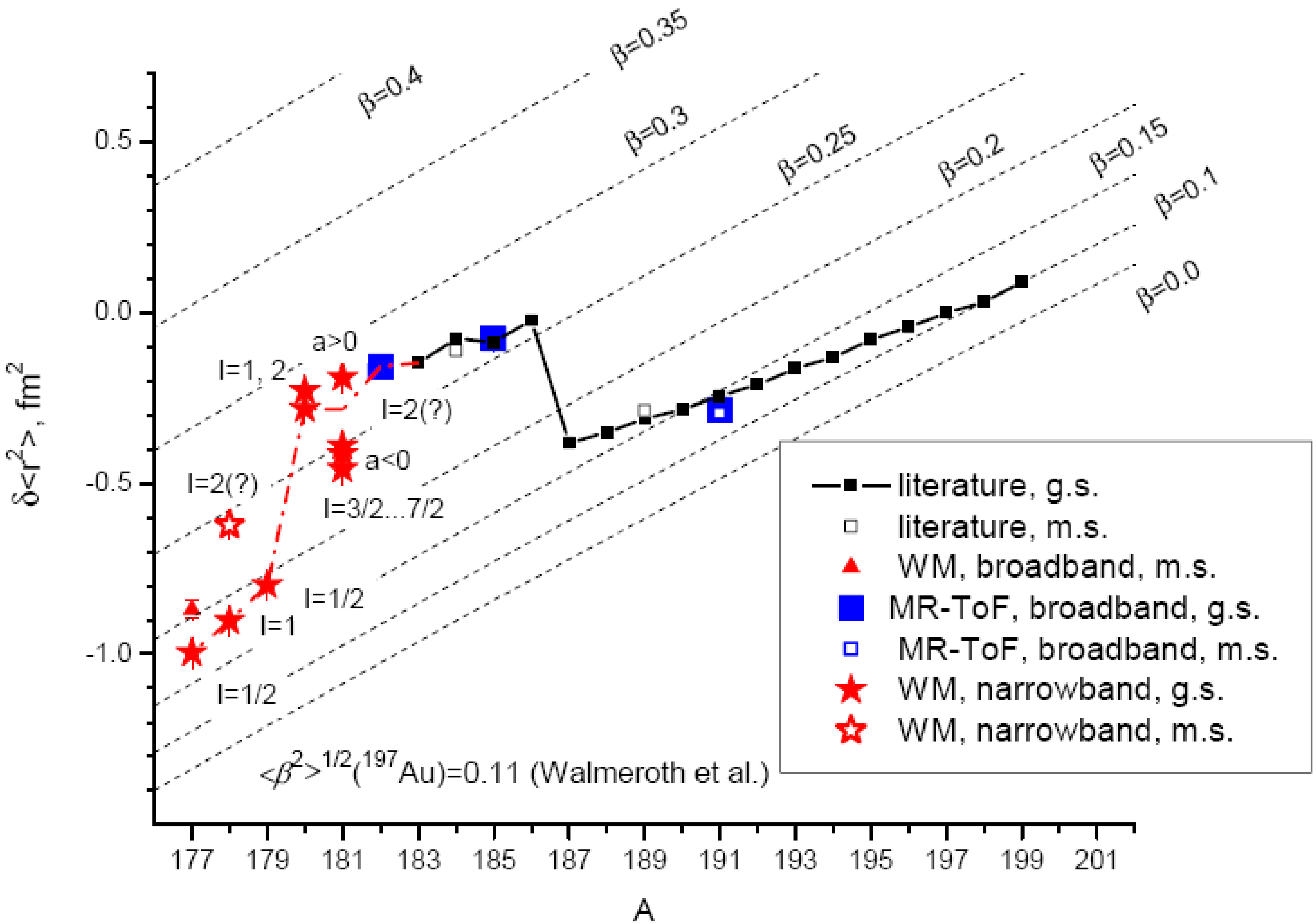


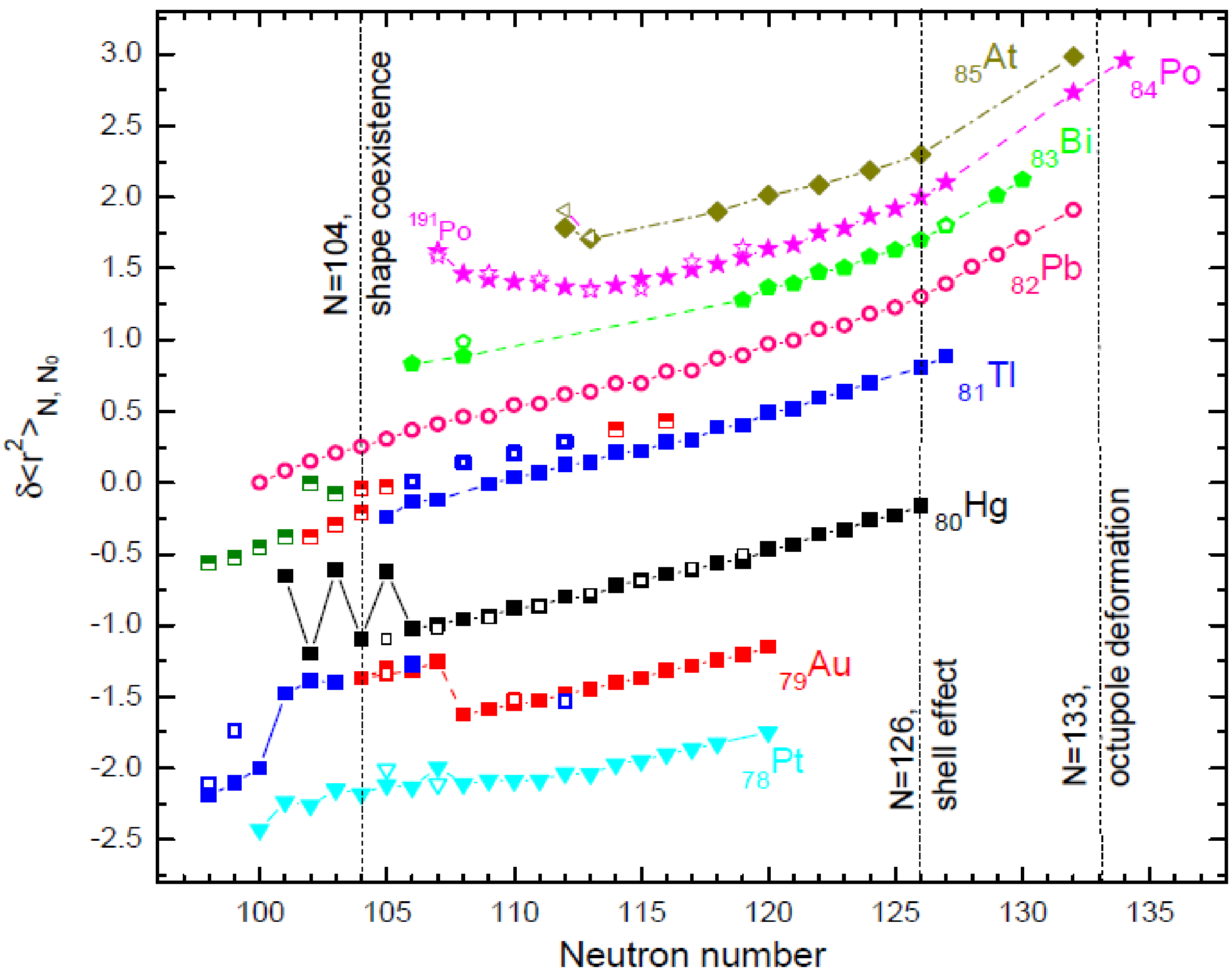



# Au: charge radii



# Charge radii in Pb region



# Charge radii: summary

- **Pb:** 182, 183, 183m, 184, 185, 185m, 186, 187, 187m, 188, 189, 189m - *published*
- **Bi:** 189, 191, 191m published *(IS and electromagnetic moments)*
- **Po:** 191, 192, 193, 193m, 194, 195, 195m, 196, 197, 197m, 198, 199, 199m, 201, 201m, 203, 203m, 211, 216, 217, 218 *partly published*
- **Tl:** 179, 180, 181, 182, 183, 183m, 184, 184m
- **At:** 197, 197m, 198, 203, 205, 207, 209, 211, 217
- **Au:** 177, 178, 178m, 179, 180, 181

At and Au: proposal submitted
Hg: proposal in preparation

# Collaboration

- ПИЯФ:  А.Е. Барзах, Д.В. Фёдоров, П.Л. Молканов, Ю.М. Волков …
- ISOLDE (CERN): В.Н. Федосеев, B. Marsh, S. Rothe, R.E. Rossel, D. Fink …
- KU Leuven: P. van Duppen, M. Huyse, A. Andreyev, H. de Witte, T.E. Cocolios …
- Mainz University

**Рабочая группа по сотрудничеству с ЦЕРН**

Расходование средств
на содержание российских специалистов на 20.09.2012
(в долларах США)

| Эксперимент | Координатор | Распределение 2012 года | Истрачено по проектам | Процент истрачено | Новое распред. |
|---|---|---|---|---|---|
| ATLAS | А.М. Зайцев | 817 000 | 538 685 | 65,9 | 915 000 |
| CMS | В.А. Матвеев<br>О.Ю. Лукина (FP) | 817 000 | 562 553<br>+ 20 177 | 71,3 | 915 000 |
| ALICE | В.И. Манько | 570 000 | 424 848 | 74,5 | 640 000 |
| LHCb | А.И. Голутвин | 466 000 | 362 970 | 77,9 | 520 000 |
| MUCAP | А.А. Воробьев | 32 000 | 18 924 | 59,1 | 36 000 |
| LHC-MA | Ю.М. Иванов | 70 000 | 31 846 | 45,5 | 80 000 |
| LCG | В.А. Ильин | 70 000 | 31 314 | 44,7 | 80 000 |
| COMPASS | С.В. Донсков | 92 000 | 56 939 | 61,9 | 105 000 |
| DIRAC | Л.Л. Немёнов | 32 000 | 31 888 | 99,7 | 42 000 |
| NA61 | А.Б. Курепин | 32 000 | 18 143 | 56,7 | 36 000 |
| NA62 | В.Ф. Образцов | 26 000 | 16 234 | 62,4 | 36 000 |
| ICARUS | В.А. Матвеев | 5 500 | 2 037 | 37,0 | 6 000 |
| CAST | В.А. Матвеев | 7 500 | 2 540 | 33,9 | 8 500 |
| ISOLDE | Д.В. Фёдоров | 6 500 | 5 044 | 77,6 | 7 000 |
| RD50 | А.Г. Залужный<br>Е.М. Вербицкая | 14 000 | 0 | 0 | 8 000<br>8 000 |
| MEG | Ю.А. Тихонов | 13 000 | 7 718 | 59,4 | 15 000 |
| AEGIS | В.А. Матвеев | 18 500 | 13 625 | 73,6 | 22 000 |
| ADM+RES | В.И. Саврин | 123 093 | 55 653 | 45,2 | 153 343 |
| ИТОГО: | | 3 212 093 | 2 201 138 | 68,5 | 3 632 843 |