Исследование запаздывающего деления и сосуществования форм в ядрах таллия, астата и золота (ИРИС, ПИЯФ — ISOLDE, CERN)

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ISOLDE

Iden

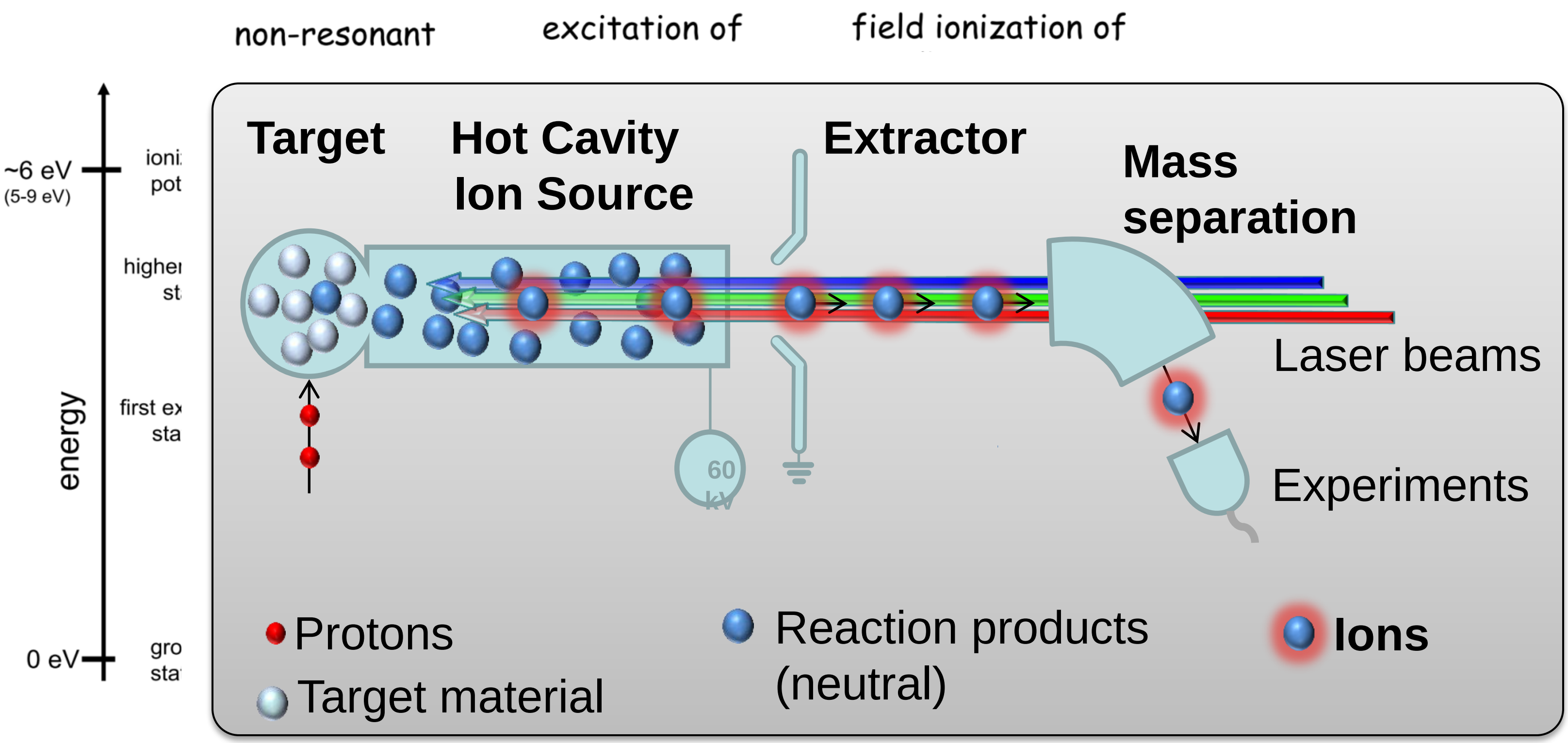
IS 534:
Beta-delayed fission, laser spectroscopy
and shape-coexistence studies
with radioactive $_{85}$At beams

IS 534 (addendum):
Laser spectroscopy
and shape-coexistence studies
with radioactive $_{79}$Au beams

ИРИС

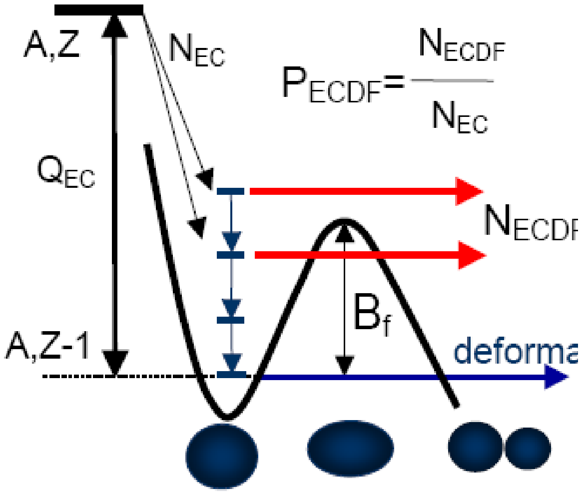
1. Изотопические изменения зарядовых радиусов и сосуществование форм в нейтронно-дефицитных изотопах Tl.
2. Аномалия сверхтонкой структуры у изотопов Tl и возможность изучения распределения ядерной намагниченности.
3. Ядерная спектроскопия ^{189}Tl и ^{189}Hg.

Laser Ion Source

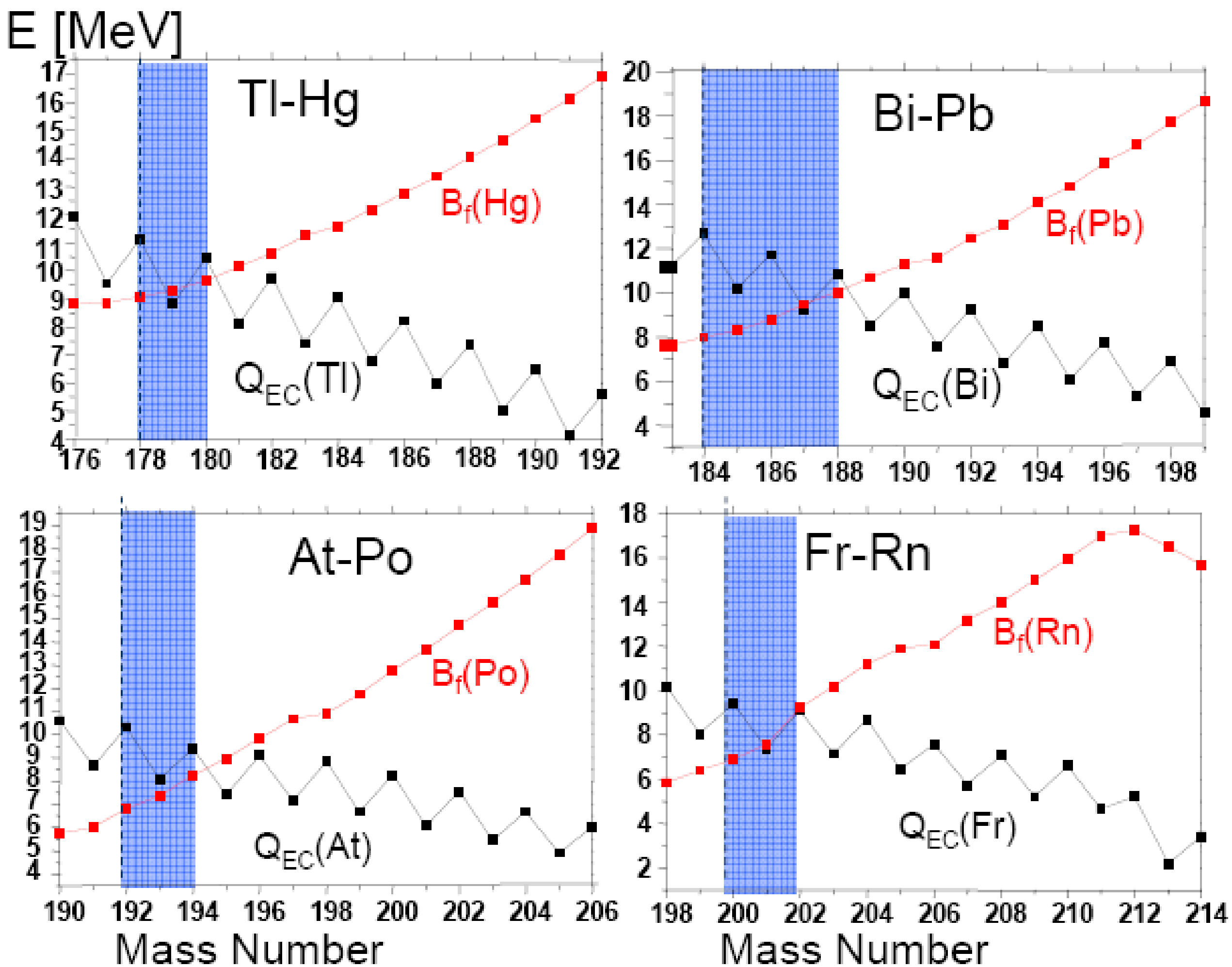


- **Scanning the laser frequency of the first/second step of the selective ionisation scheme for a particular isotope (or an isomer)**
- **Isotope shift (IS), hyperfine structure (HFS) measurements**
- **Measuring FC current, α/γ or ToF spectra while scanning the frequency**

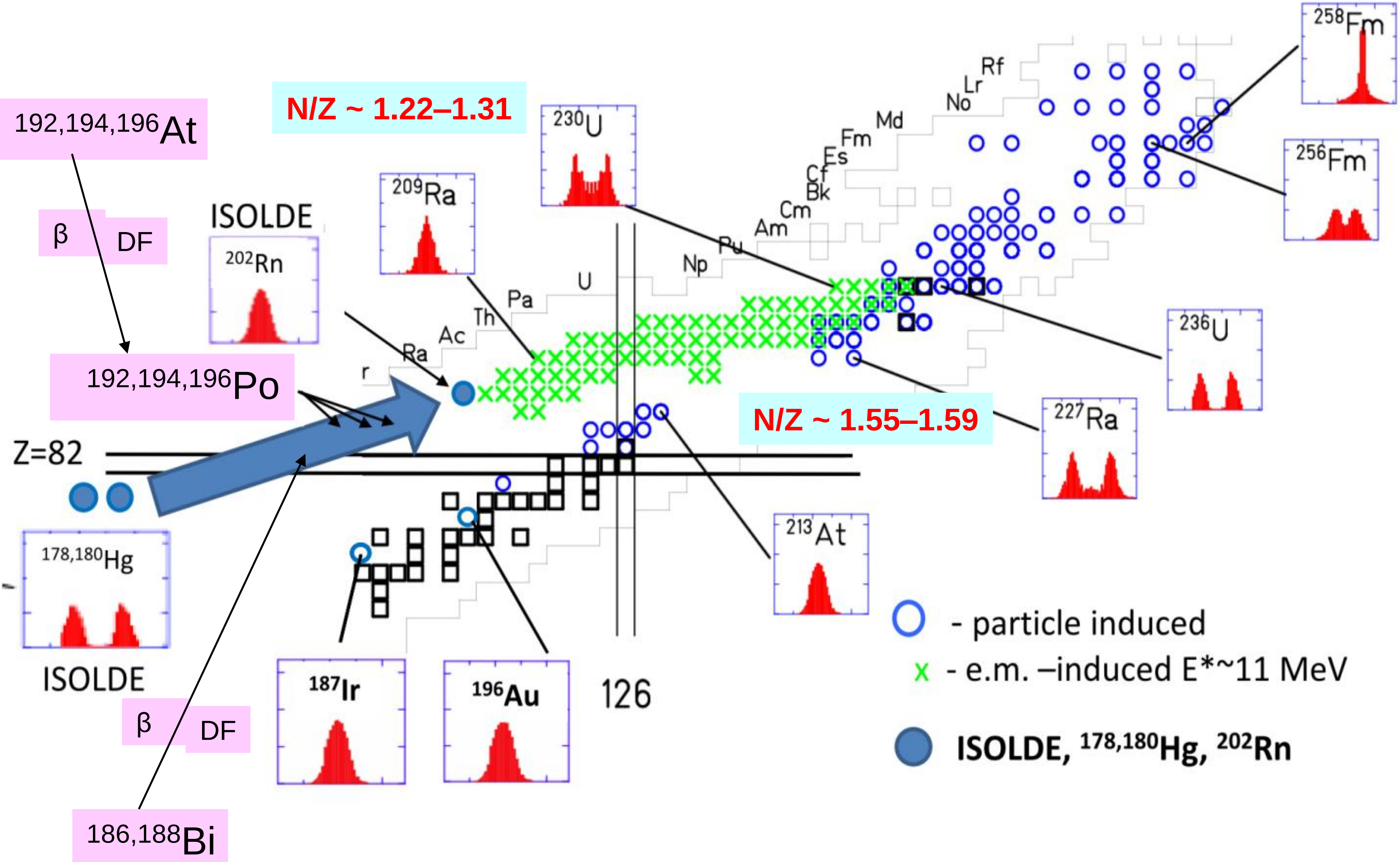
Beta-Delayed Fission



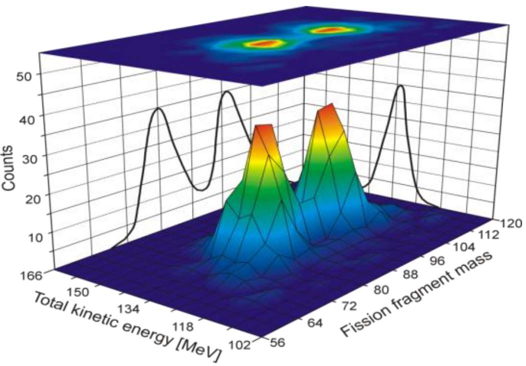
$$Q_{EC}(A, Z) \gtrsim B_f(A, Z\text{-}1)$$



Beta-Delayed Fission

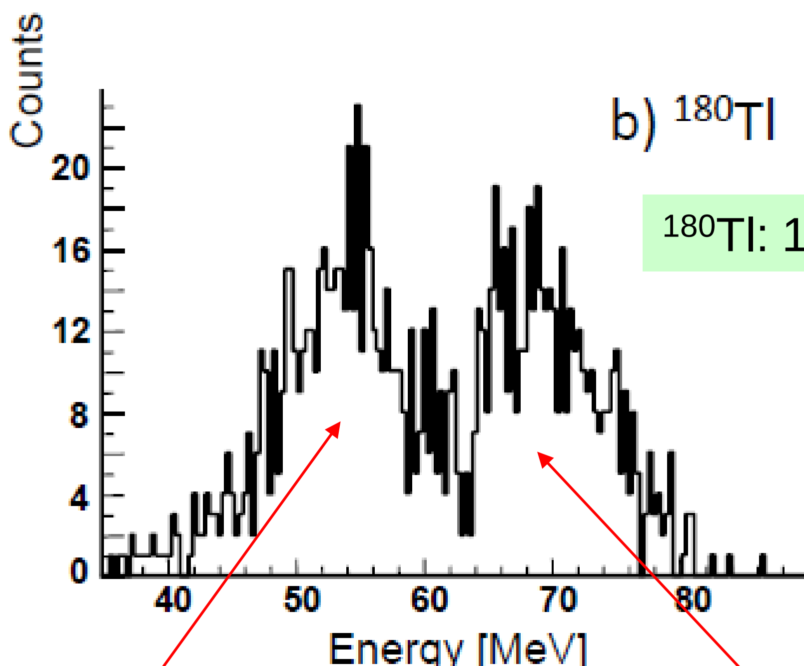


Fragment mass distribution in βDF of Tl isotopes (experiment)



. ions/μC/s, 8 fission events

$P_{\beta DF}$ (^{178}Tl)=0.15(6)%



^{180}Tl: 1111 fission events

$P_{\beta DF}$ (^{180}Tl)=3.2(2)×10^{-3}%

corresponds to A=80(1)

FWHM ≈ 9 amu

A=100(1)

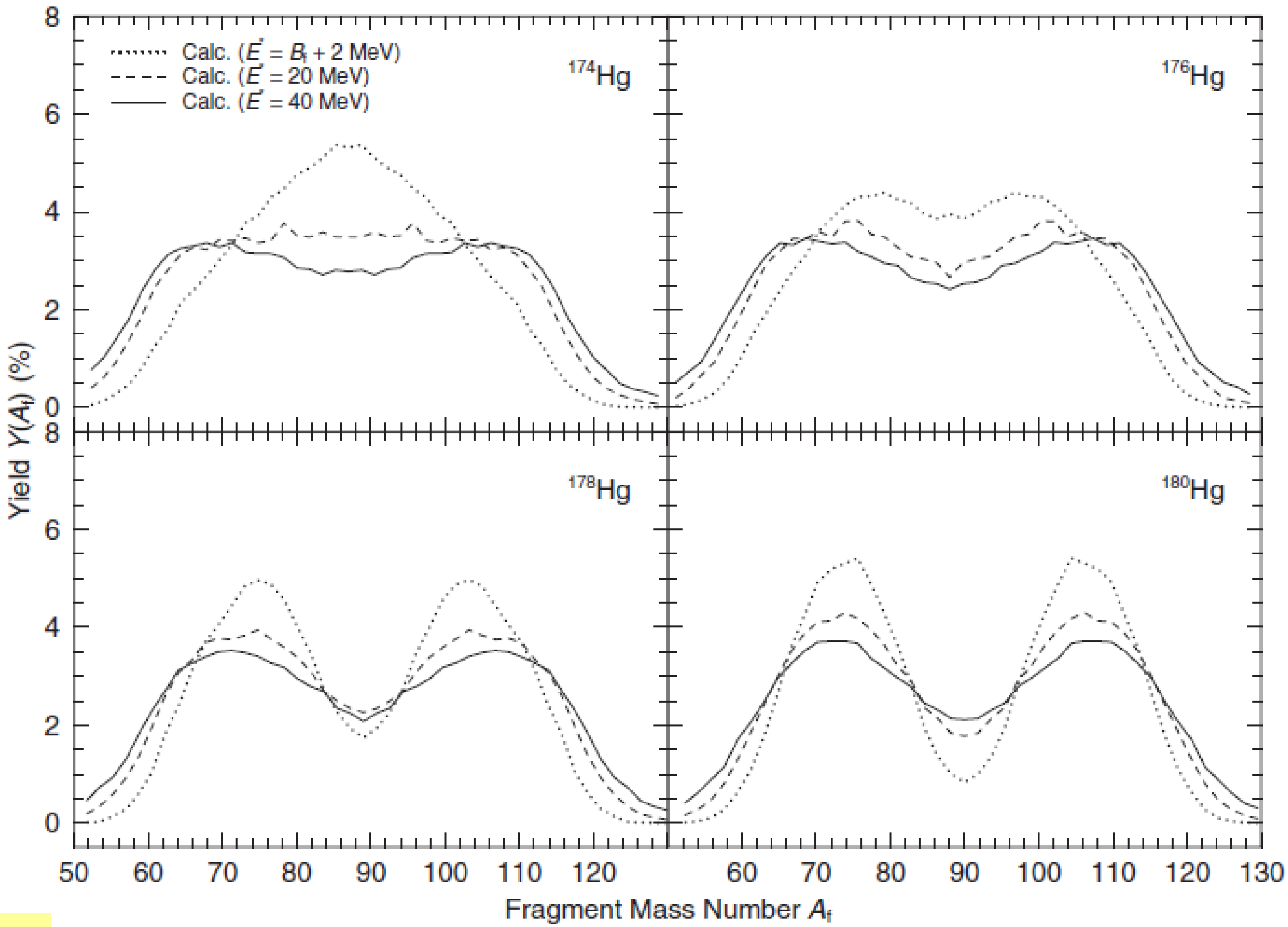
Fragment mass distribution in βDF of Tl isotopes and fission barriers for Hg isotopes (theory)

Model: BSM(M)

Brownian shape motion on five-dimensional (5D) potential energy surfaces in Metropolis random-walk approximation

	B_f, exp (model), MeV	B_f, theor MeV
^{180}Hg	7.5(1.5)	9.8
^{178}Hg	~ 7	9.3

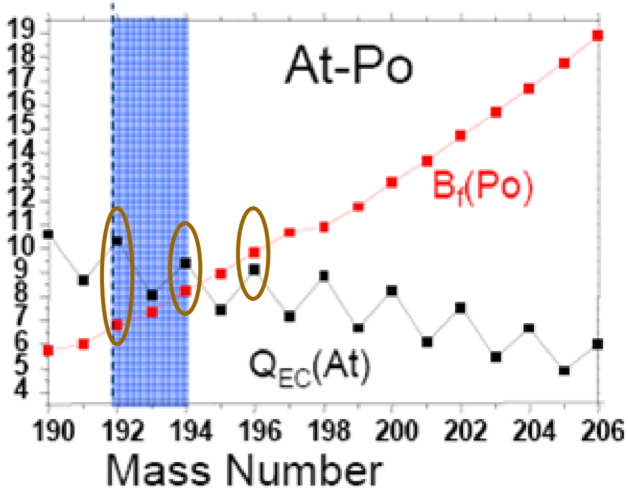
$P_{\beta DF}$ (^{180}Tl)$_{theor}$= 2×10^{-6}%
$P_{\beta DF}$ (^{180}Tl)$_{exp}$= 3.2(2)×10^{-3}%



Calculated yields for four Hg isotopes at three excitation energies. For the lighter isotopes the yields become more symmetric.

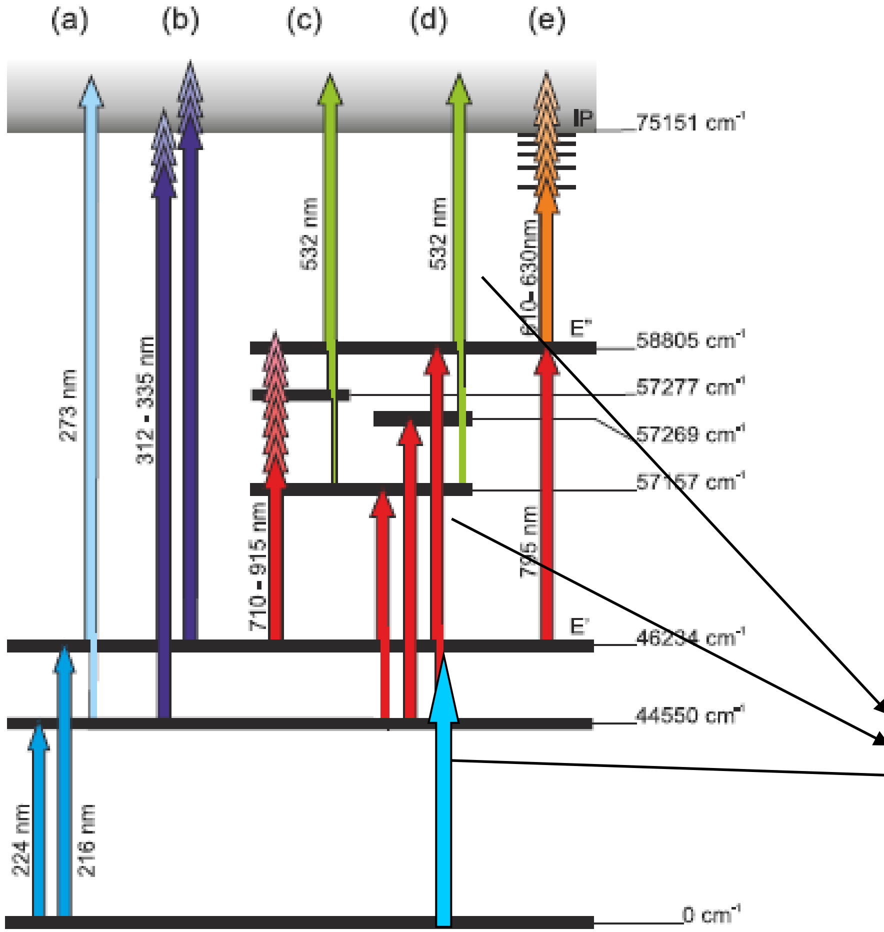
P. Möller, J. Randrup, A. Sierk, Phys. Rev. C **85**, 024306 (2012)   M. Veselsky *et al*. Phys. Rev. C **86**, 024308 (2012)

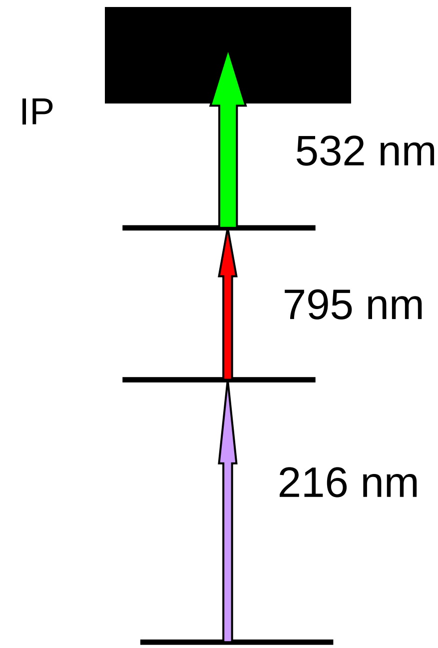
Development and use of laser-ionized At beams at ISOLDE



- **Determination of optical lines and efficient photoionization scheme. First measurement of the ionization potential of the element At**
- **Beta delayed fission of ^{194,196}At**
- **Charge radii measurement for At isotopes**

Photoionization scheme for the radioactive element At

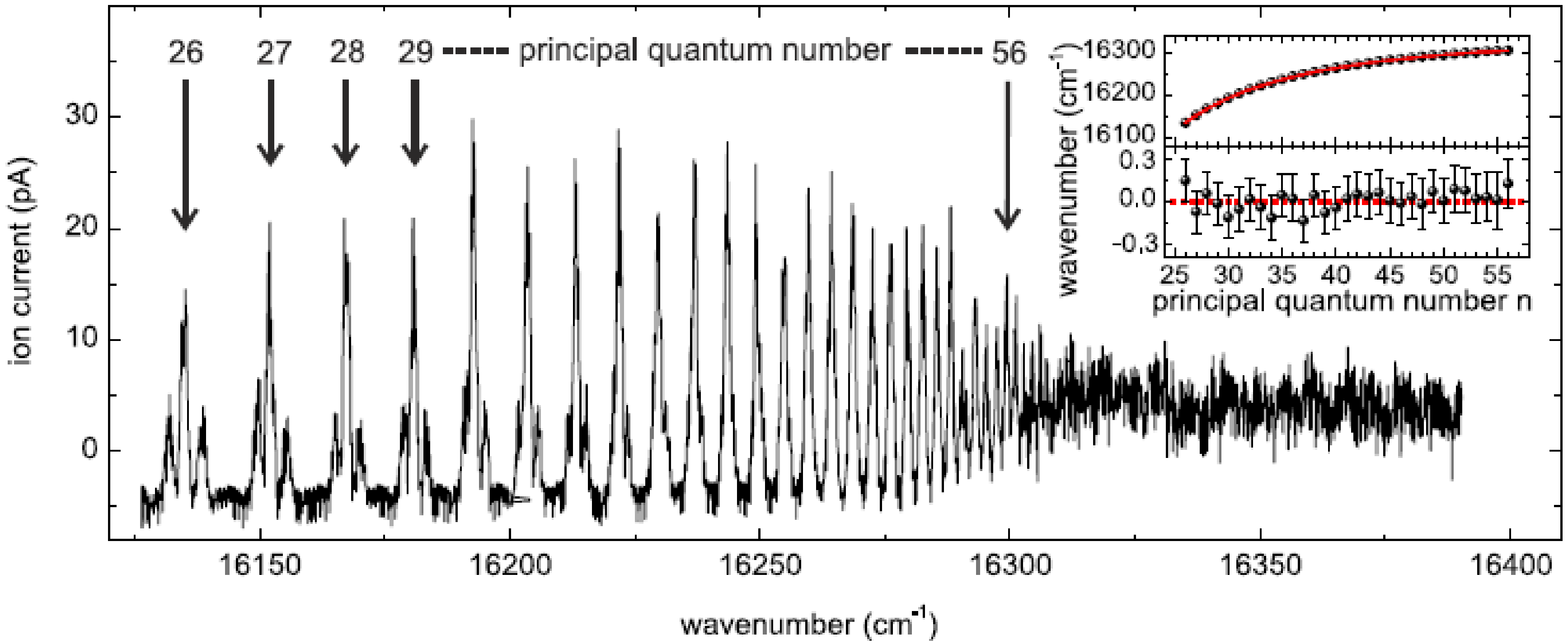




Optimal photoionization scheme.

Narrow band lasers for 1st and 2nd transitions

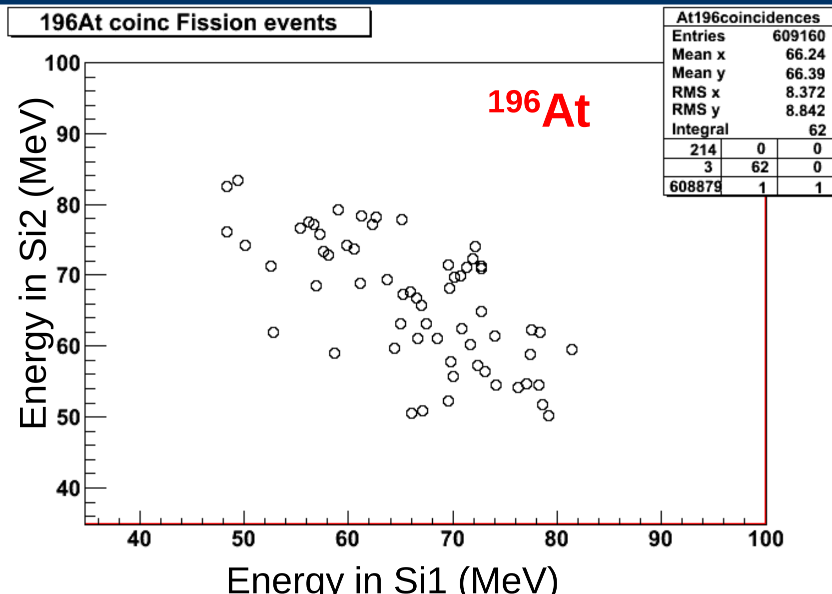
Precise determination of the Ionization Potential for the radioactive element At



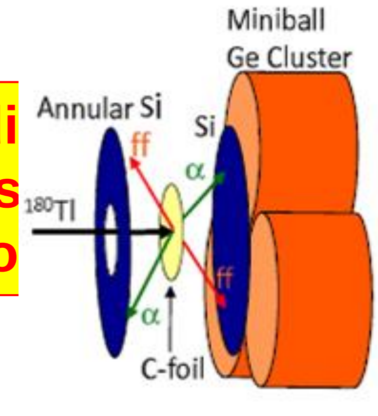
$$\nu_n = IP - E_2 - \frac{R_M}{(n-\delta)^2}$$

⇒ *IP* (At)=9.317510(84) eV

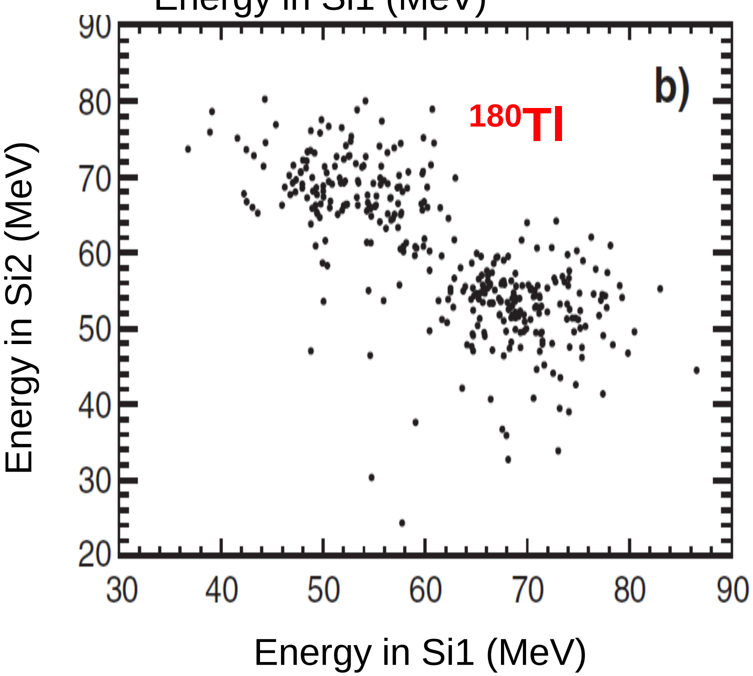
IS534, May 2012: Mass Distributions Measurements for βDF of $^{194,196}At$

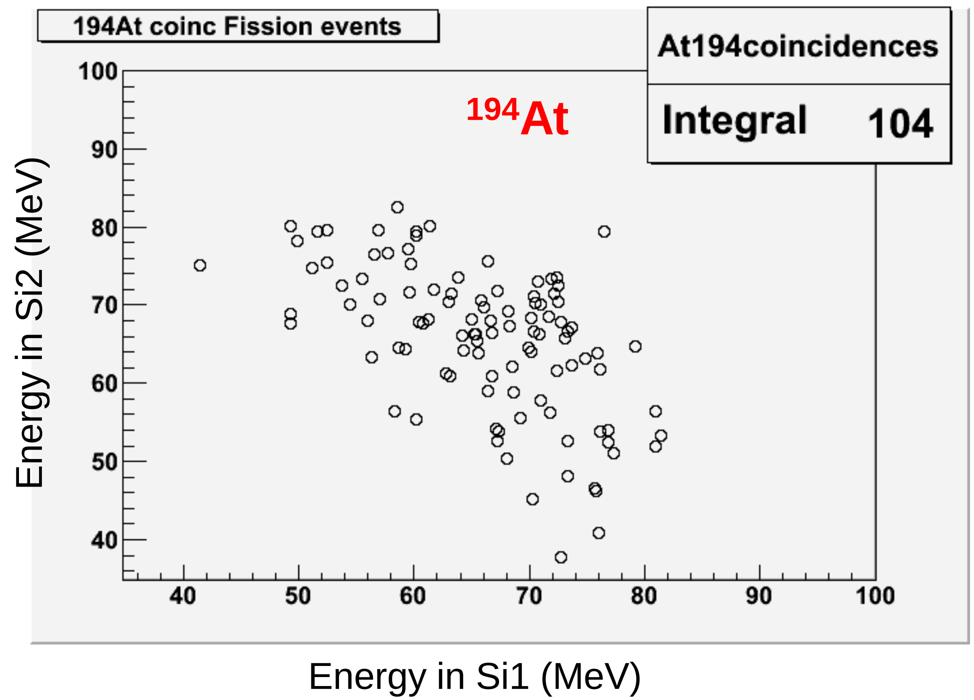


Clear di… mass… fissio…

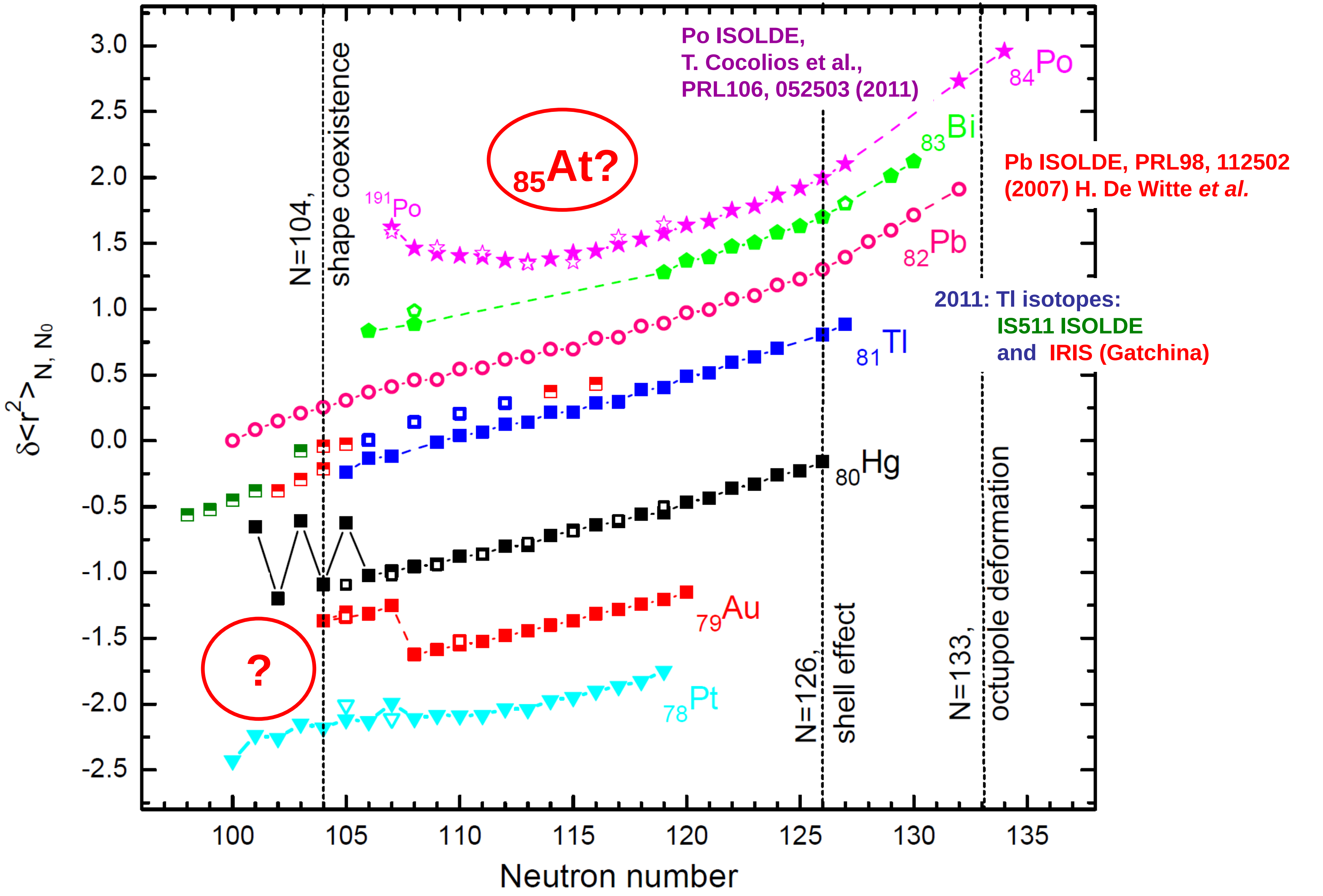


…rgy (thus, …etween …194,196Po

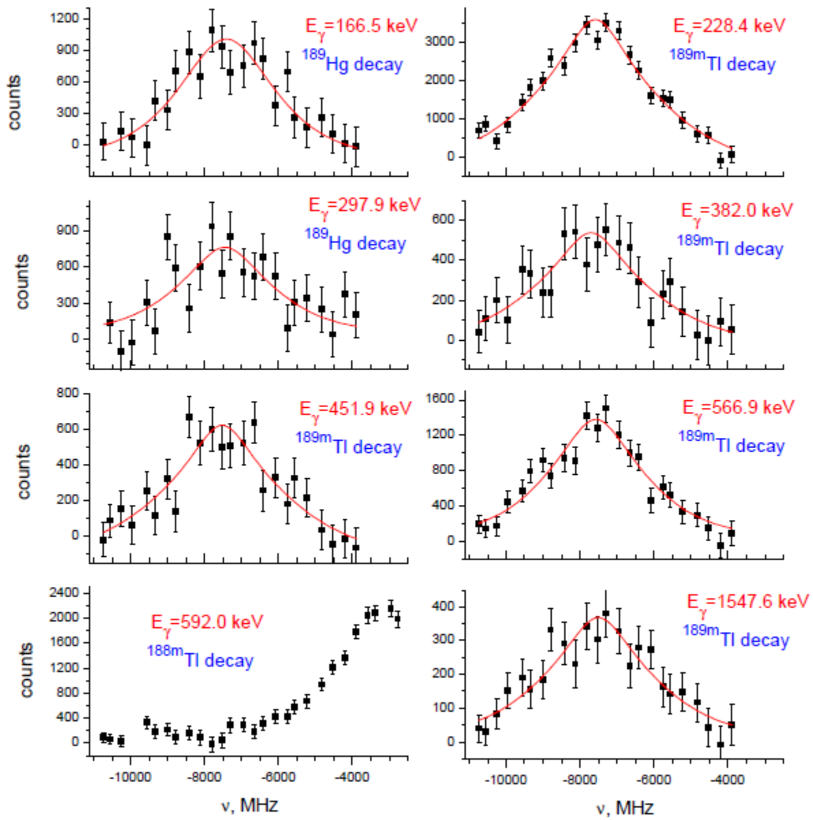




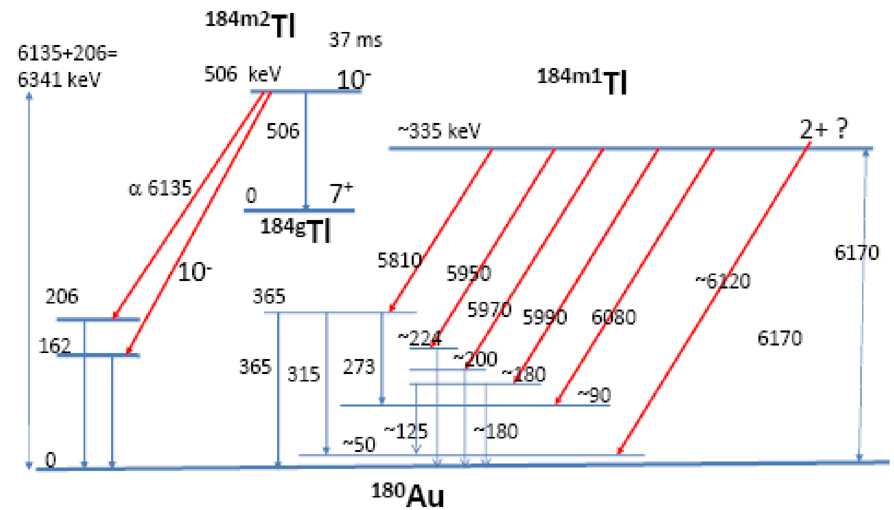
Shape coexistence and charge radii in Pb region

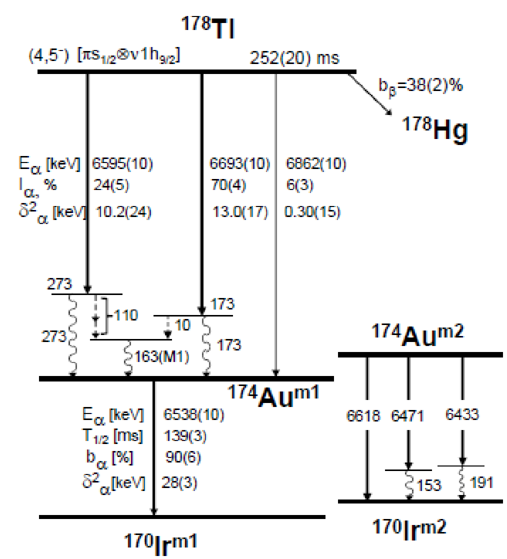


2012: Additional nuclear spectroscopic information from Tl isotopes decay



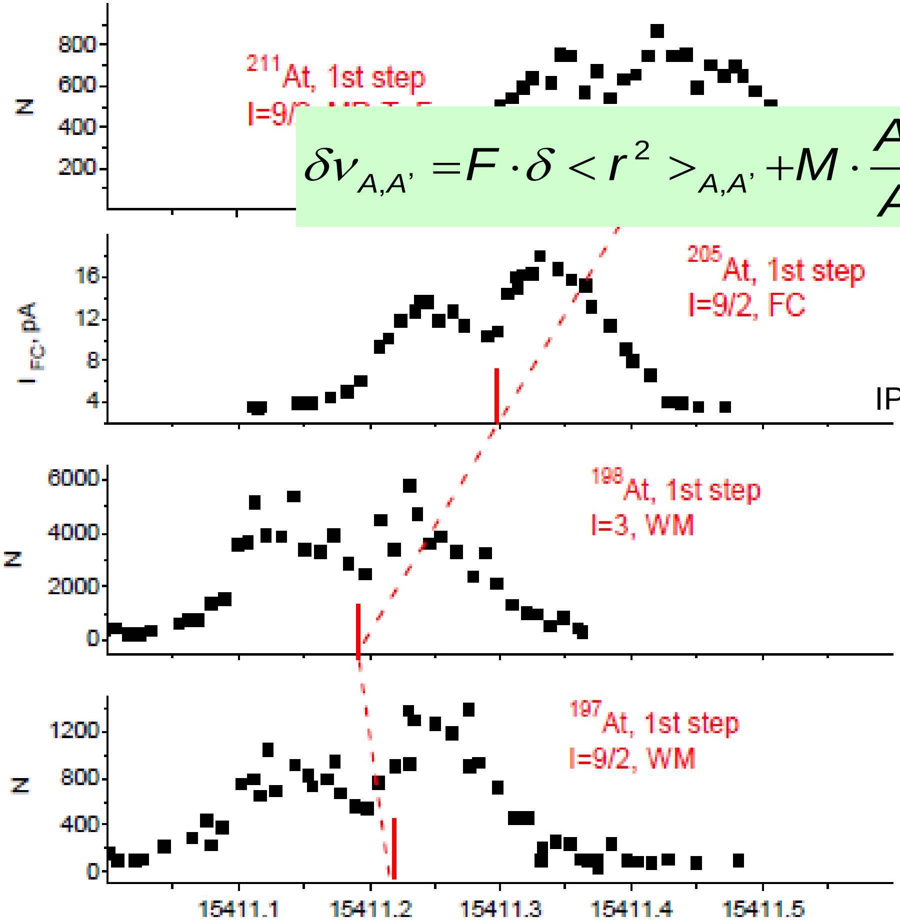
IRIS: 30 new ^{189}Hg γ-lines from ^{189m}Tl decay are unambiguously identified and their relative intensities are determined



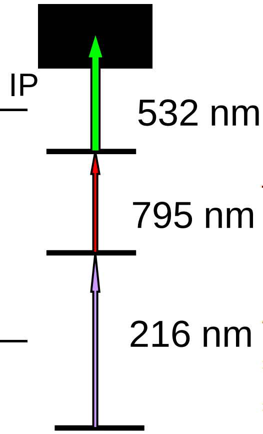


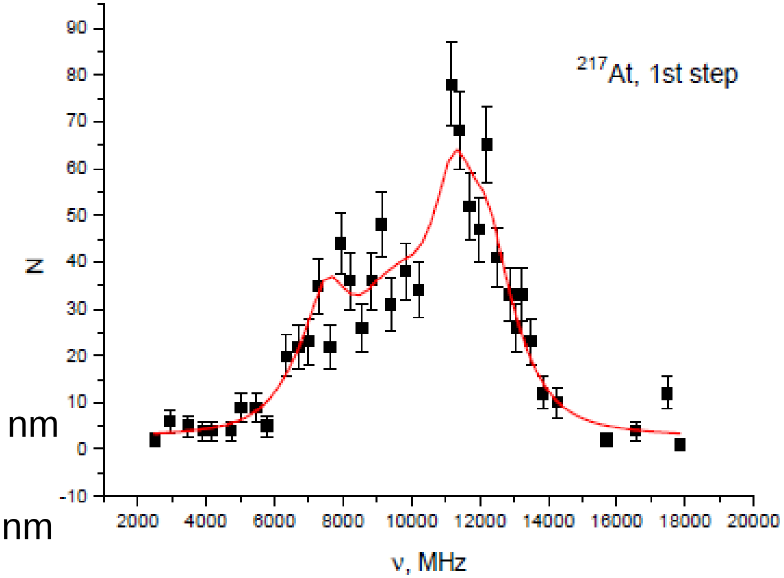
ISOLDE: decay schemes for some Tl isotopes are determined

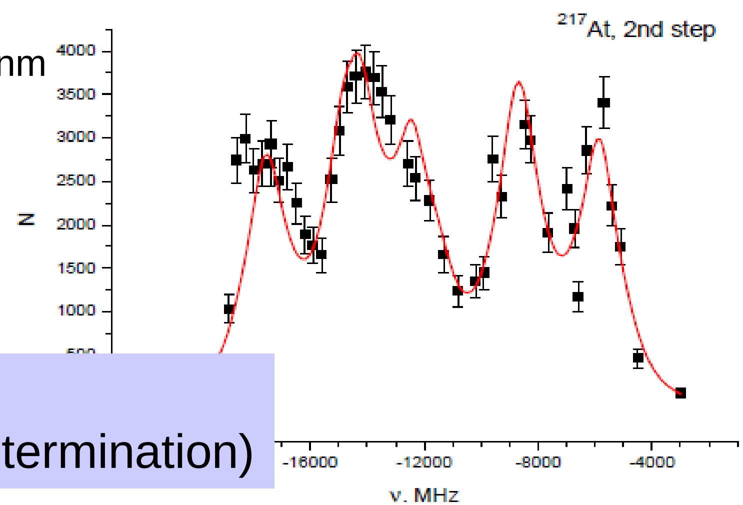
Astatine HFS spectra



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

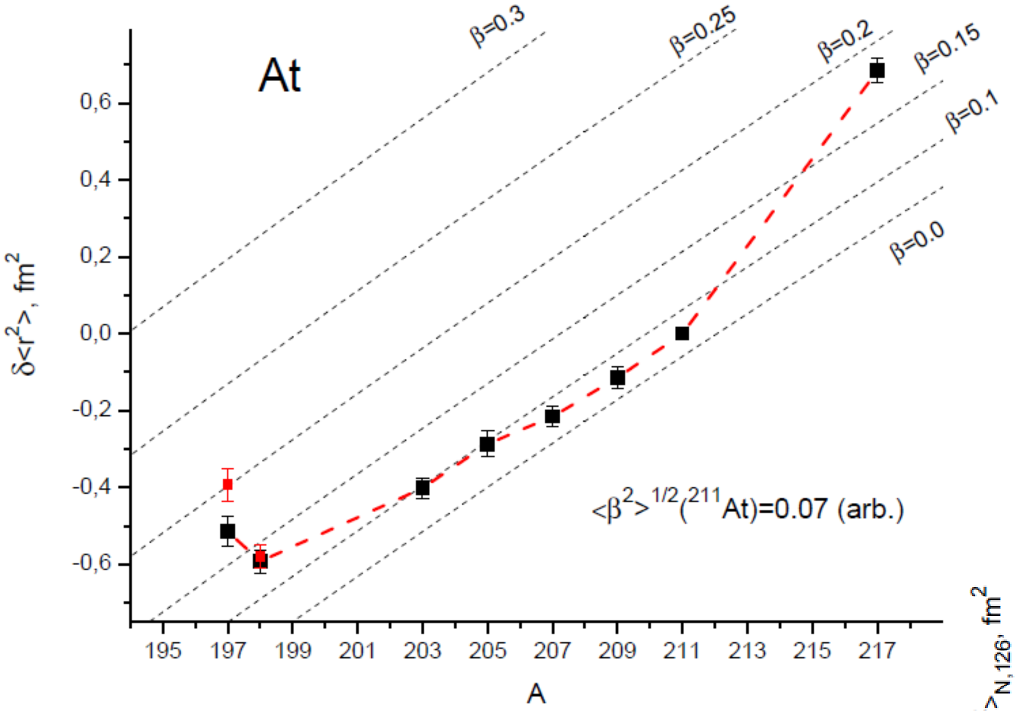


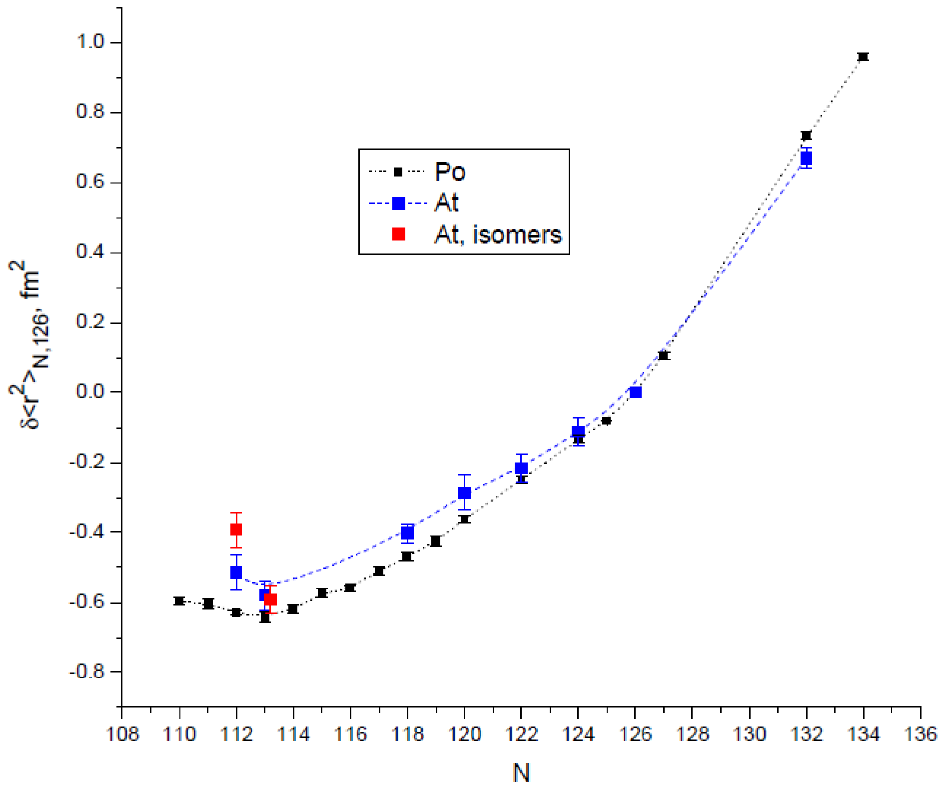




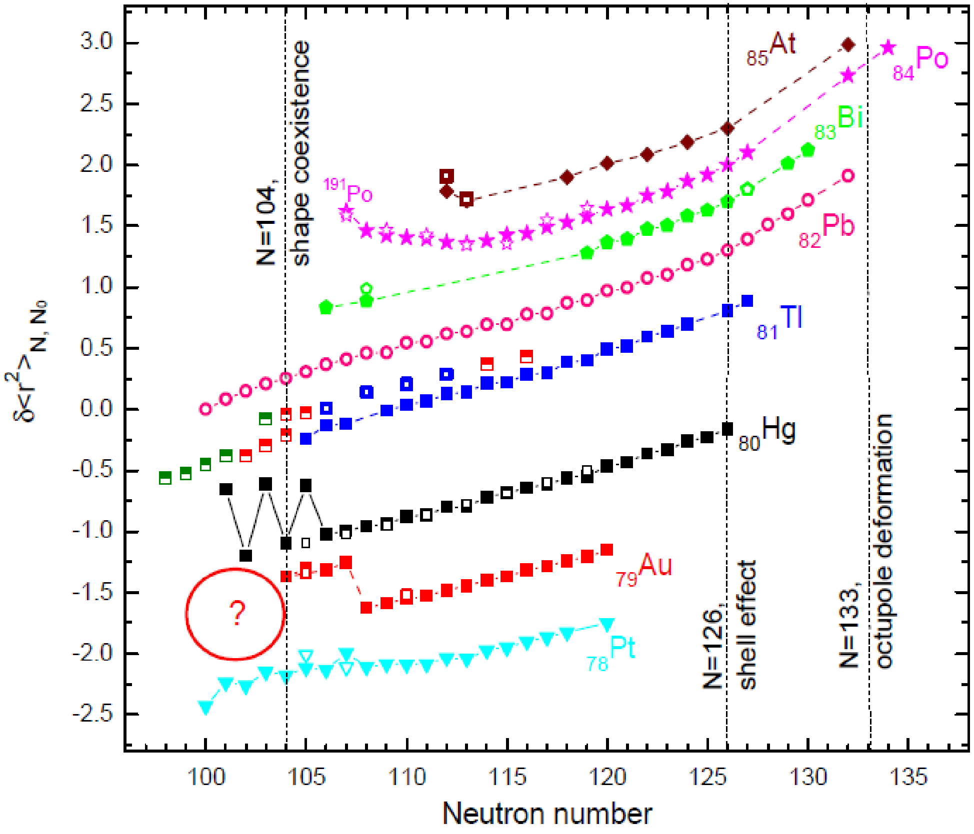
1st step is better for $\Delta\langle r^2 \rangle$ extraction
2nd step is better for hfs resolution (Q and μ determination)

IS534 October 2012: Charge radii of At isotopes



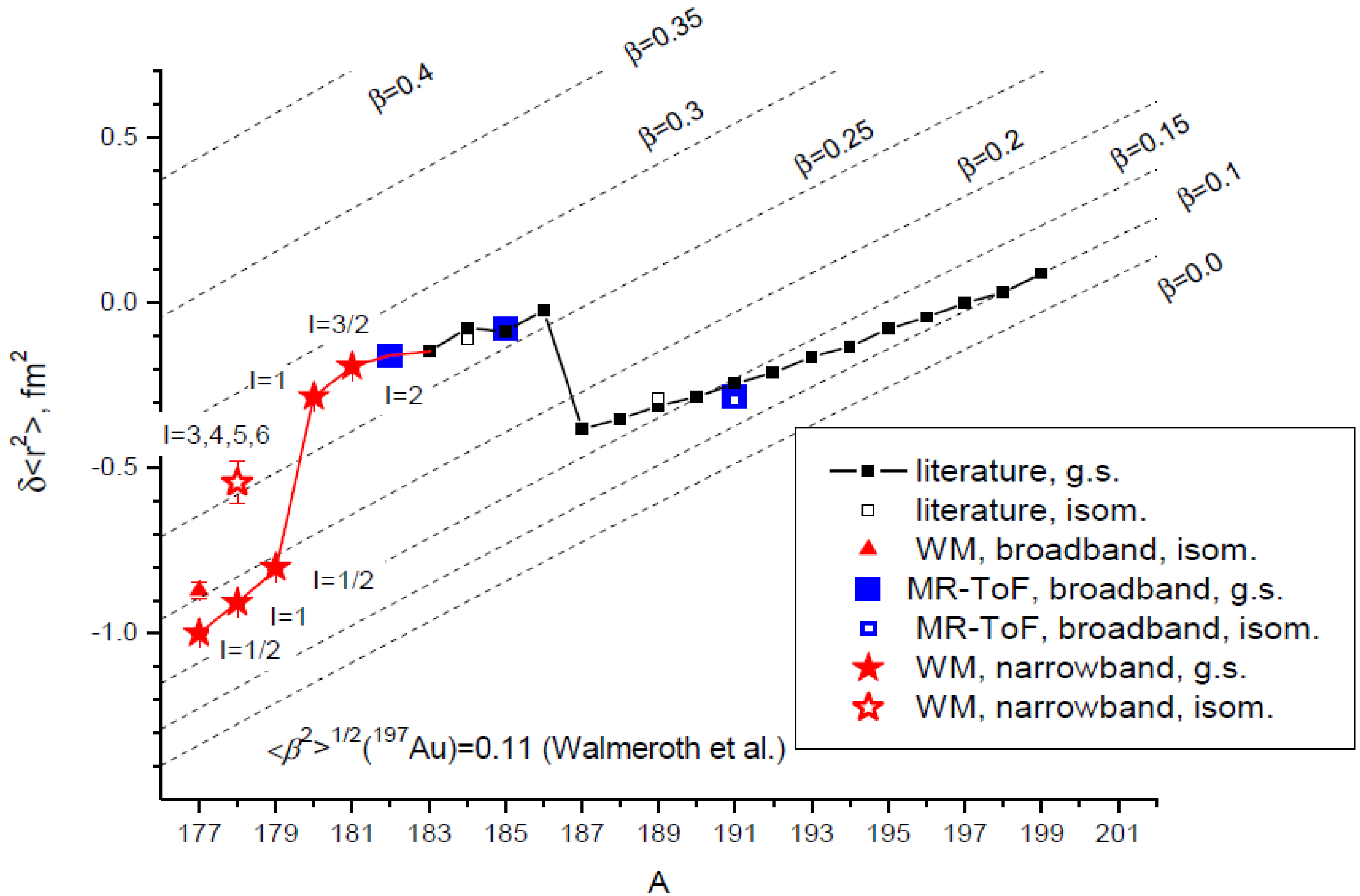


October 2012: IS534 experiment at ISOLDE - Au isotopes



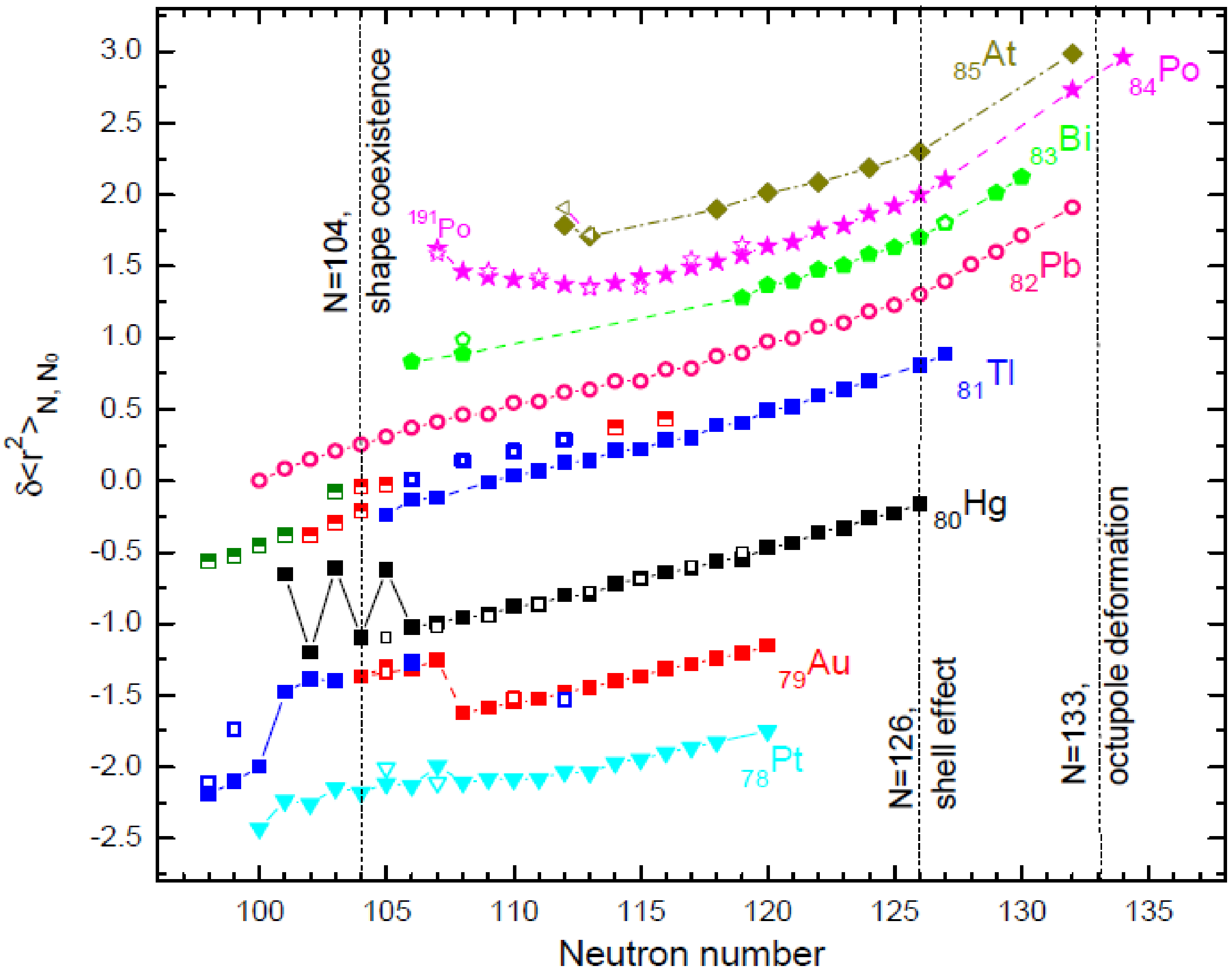
- Are the light Au isotopes deformed?
- What are the spins of ground and isomeric states?

IS534: Charge Radii of Au isotopes



- **Deformation jump toward less deformed shapes in the light Au isotopes**
- **Shape staggering in ^{178}Au (large deformation difference between 2 states)**

Summary: Charge Radii in Pb region



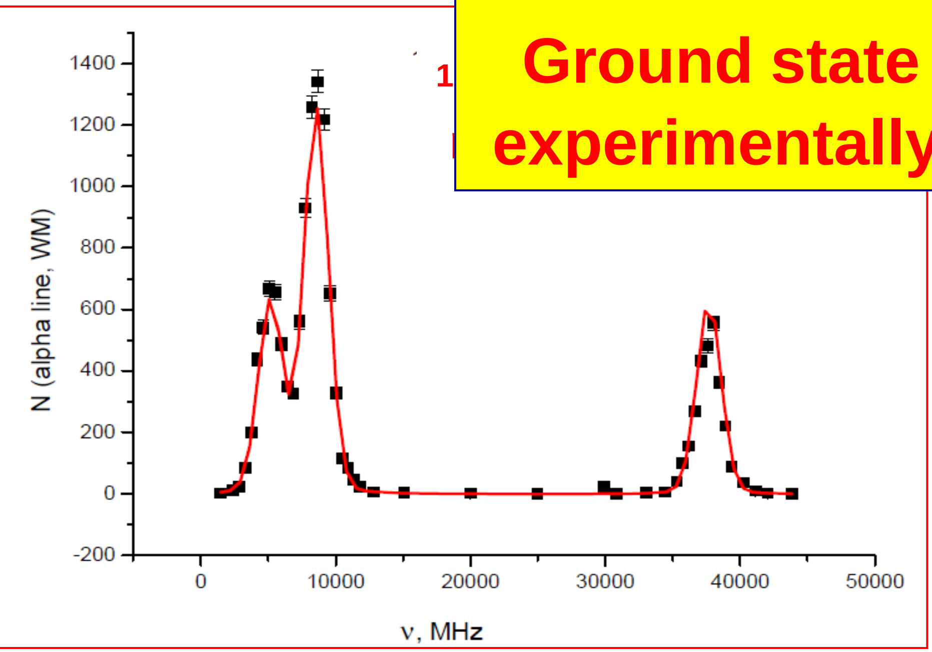
- IS/charge radii for 10 At nuclei were measured
- “Back to sphericity” in the lightest Au isotopes
- Magnetic/quadrupole moments will be deduced
- Large amount of by-product nuclear spectroscopic information on At and Au and their daughter products

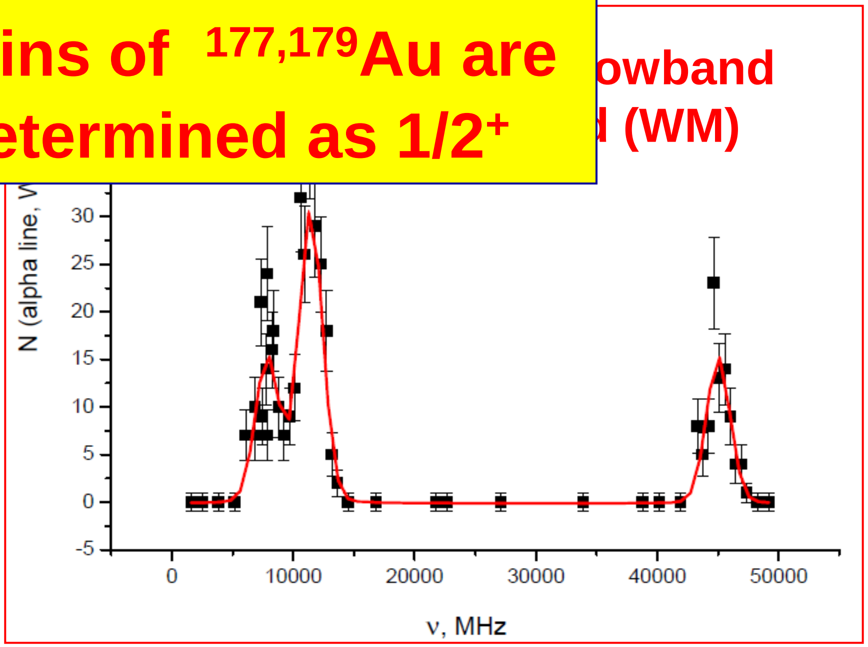
Заключение

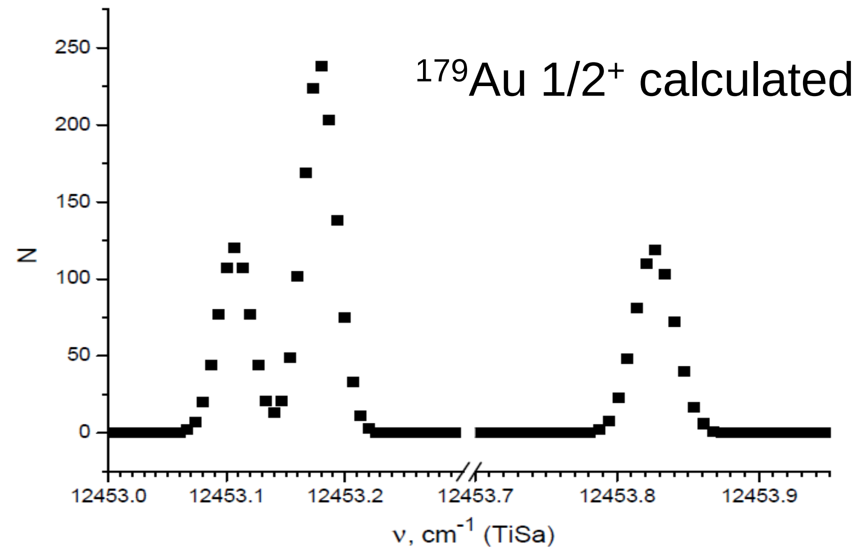
1. Измерено асимметричное массовое распределение осколков запаздывающего деления ^{178}Tl и определена вероятность такого распада. Получены значения барьеров деления для $^{178,180}Hg$.
2. Для исследования ядер At найдена эффективная схема фотоионизации, обнаружено около 20 ранее не известных атомных переходов, впервые определен потенциал ионизации At.
3. Обнаружено запаздывающее деление $^{196,194}At$. Предварительный анализ свидетельствует о его симметричном характере.
4. Измерены изотопические сдвиги и сверхтонкое расщепление для 10 изотопов (изомеров) At на двух переходах, 216 nm и 795 nm, что позволит получить новые данные о μ, Q, $\delta\langle r^2\rangle$ и деформации этих изотопов (изомеров).
5. Измерены изотопические сдвиги и сверхтонкое расщепление (μ, $\delta\langle r^2\rangle$) для 9 изотопов (изомеров) Au на переходе 267.6 nm. Впервые обнаружен «обратный скачок деформации» — возвращение к сферичности ядер с $N<101$. Обнаружены два изомера с существенно разной деформацией в ядре ^{178}Au.

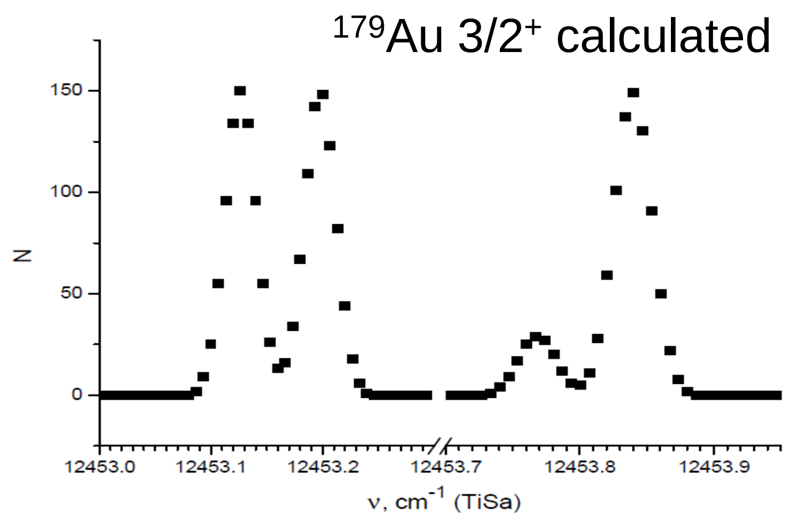
IS534: Hyperfine Structure Scans for ^{177,179}Au

Ground state spins of ^{177,179}Au are experimentally determined as $1/2^+$

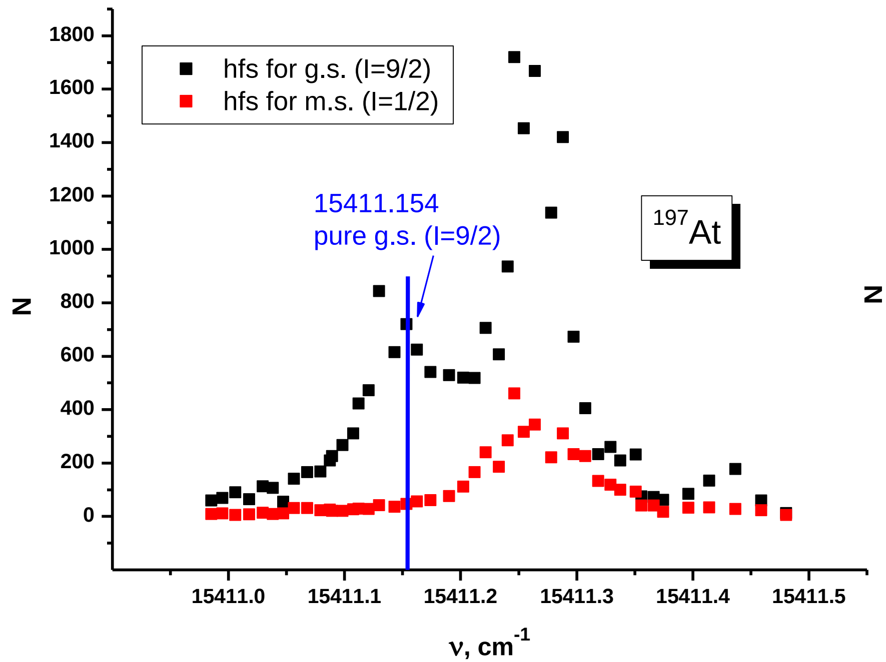


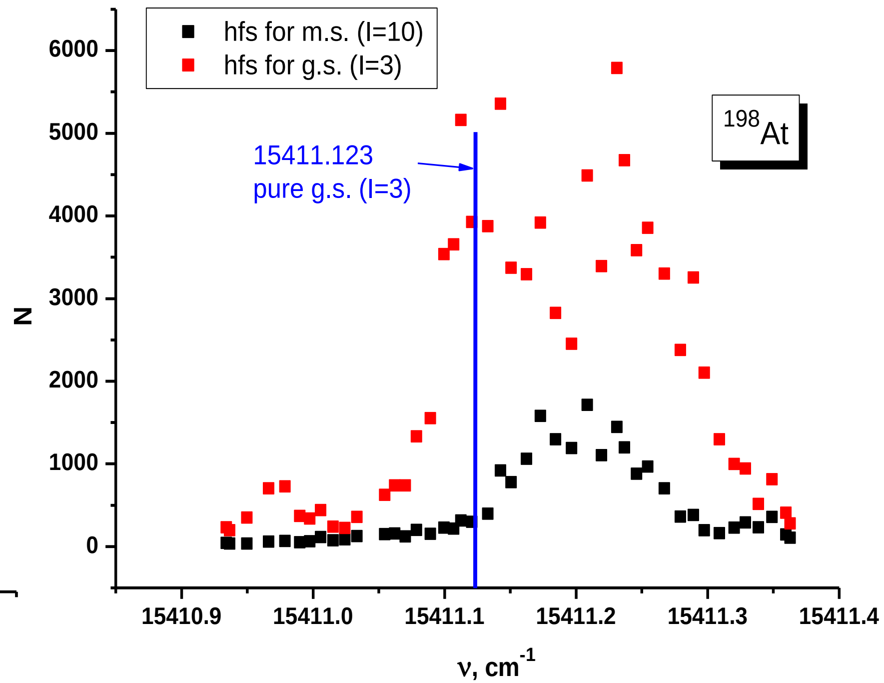






Isomer selectivity for $^{197,198}At$

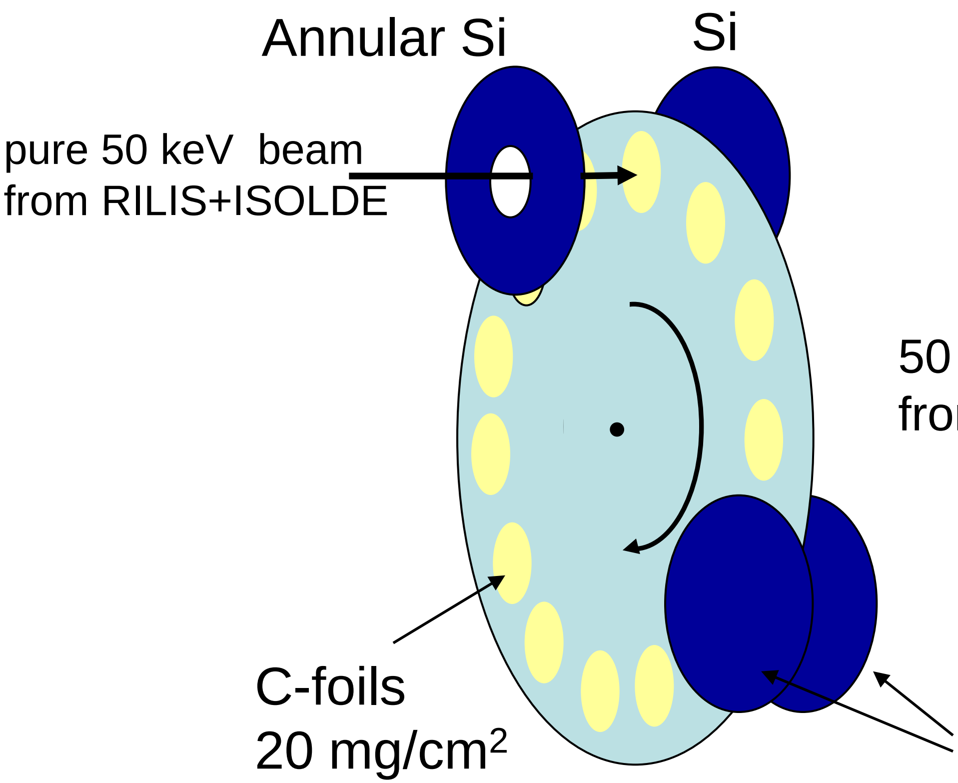


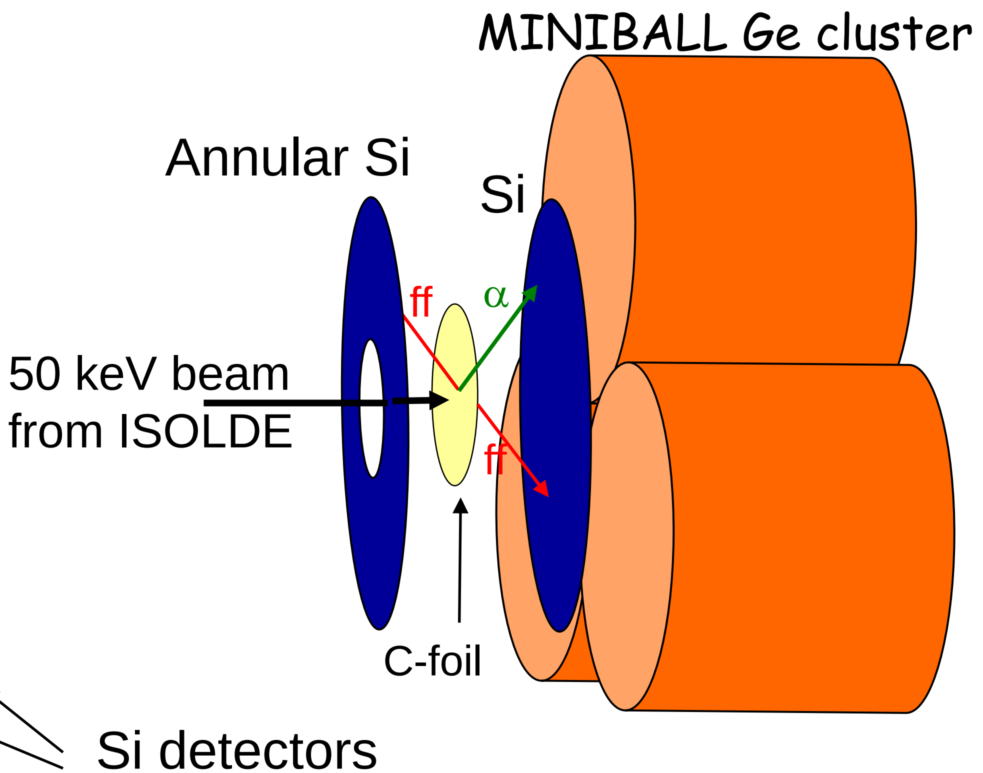


Isomer selectivity enables us to measure masses of $^{197g,198g}At$ and receive nuclear spectroscopic information for pure g.s.

Windmill System at ISOLDE

A. Andreyev et al., PRL 105, 252502 (2010)



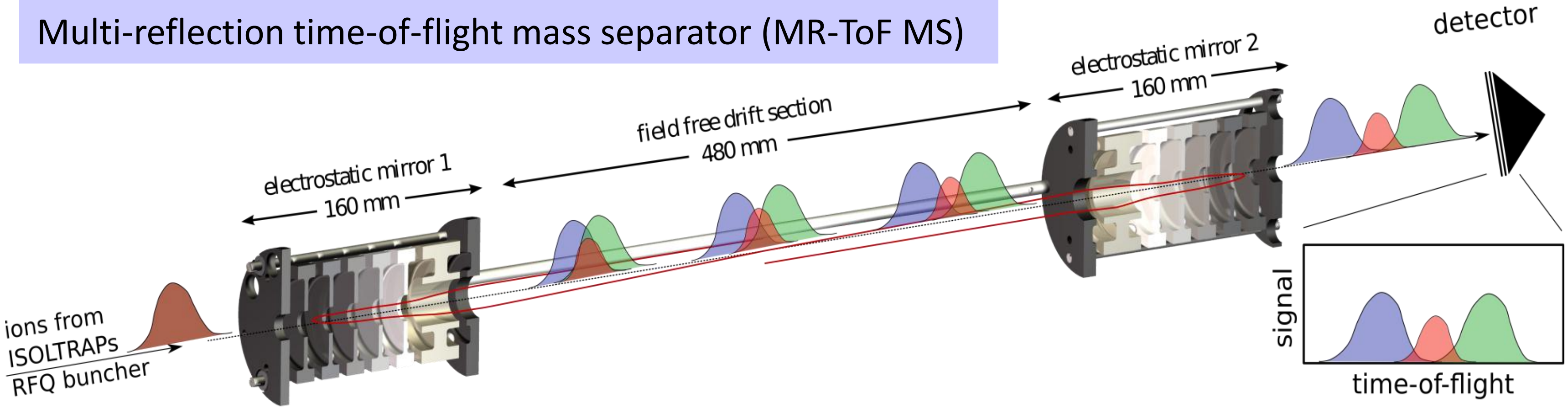


Setup: Si detectors from both sides of the C-foil

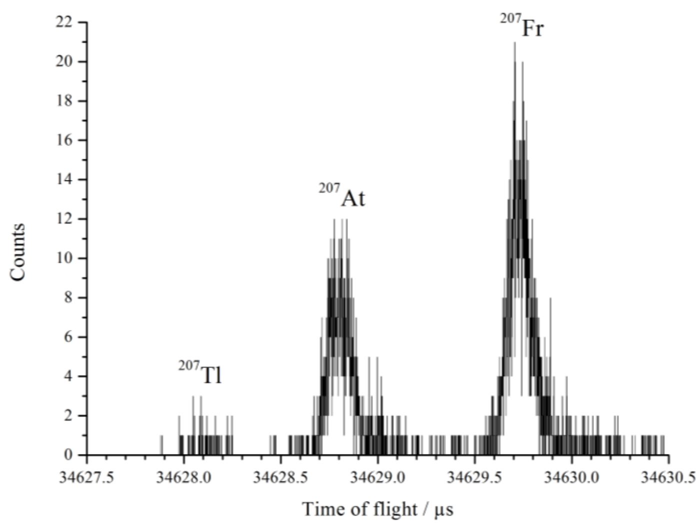
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-γ, γ-α, γ-γ, etc coincidences

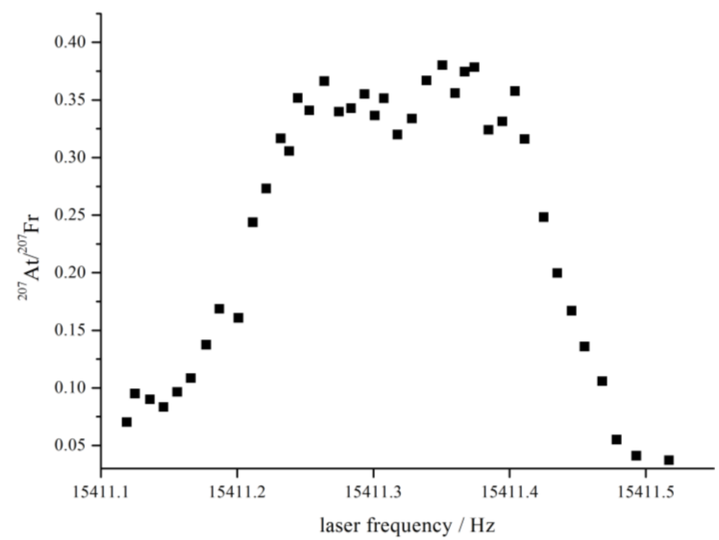
In-Source Spectroscopy with MR-ToF MS

Multi-reflection time-of-flight mass separator (MR-ToF MS)



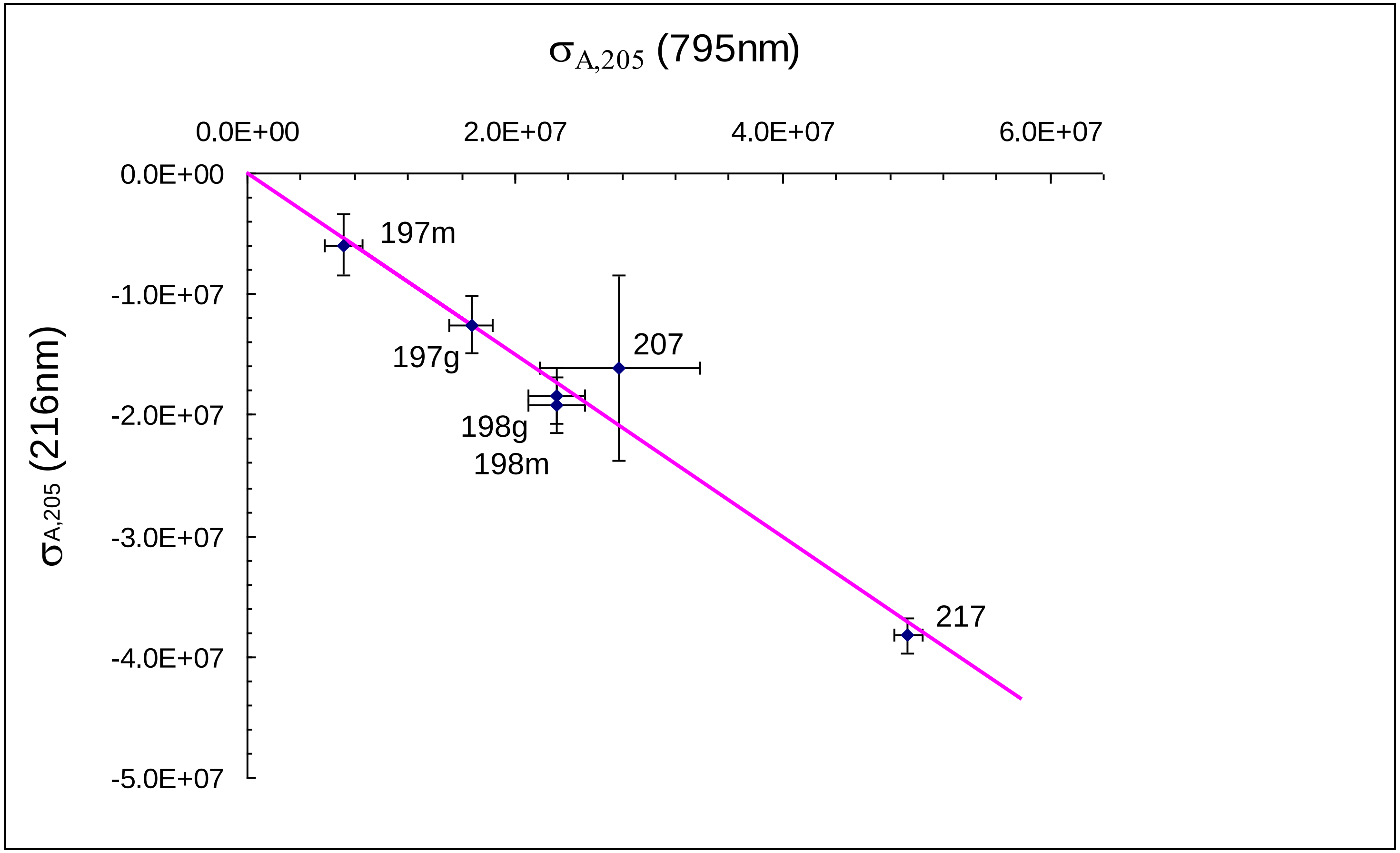
~1000 revolutions, ~35 ms, m/Δm ~ 10^5





R. N. Wolf *et al*., Nucl. Instr. and Meth. A 686, 82-90 (2012), S. Kreim *et al.,* INTC-P-299, IS 518 (2011)

King plot for 216 nm and 795 nm lines in At



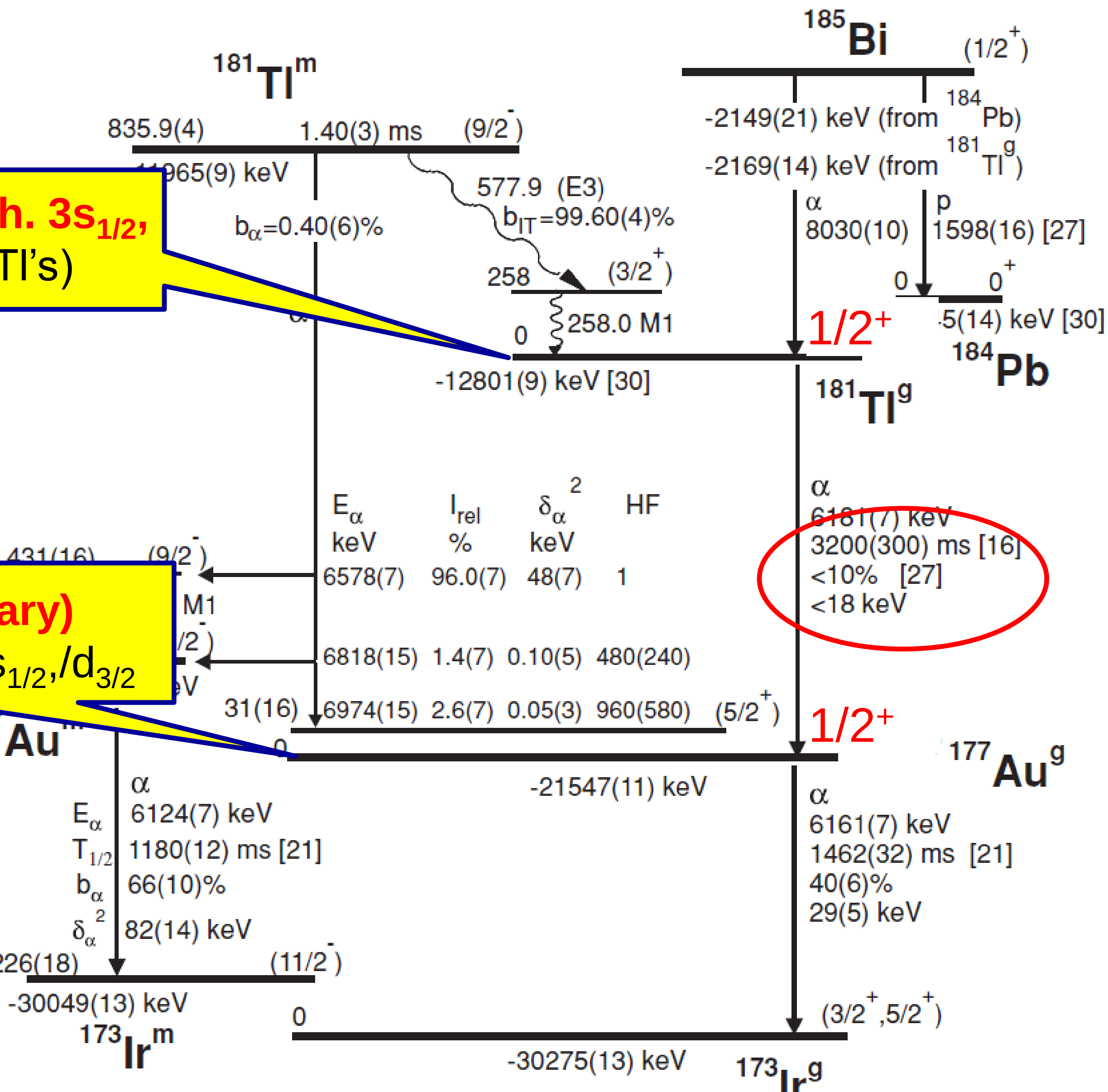
Isotope shift $\delta\ \nu_{A,A'}$:

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

$$\Delta\sigma_{A,A'} = \Delta\nu_{A,A'} \cdot \frac{A \cdot A'}{(A - A')}$$

Δσ for different transitions should lie on the straight line with a slope $F_{\lambda 1}/ F_{\lambda 2}$

Why is 1/2⁺→1/2⁺ ¹⁸¹Tl→¹⁷⁷Au α decay hindered?



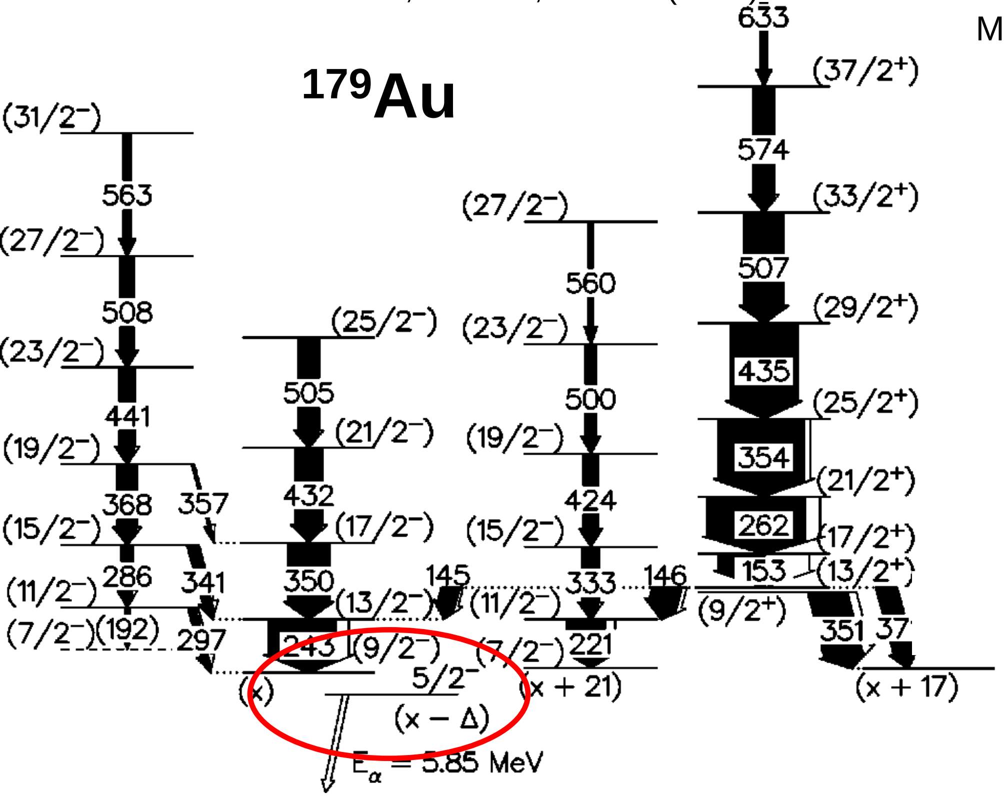
$\mu \sim 1.6\mu_N$, **pure sph. $3s_{1/2}$,**
(as in the heavier Tl's)

$\mu \sim 1.1\mu_N$, **(preliminary)**
mixed/def/triaxial $3s_{1/2}$,/$d_{3/2}$

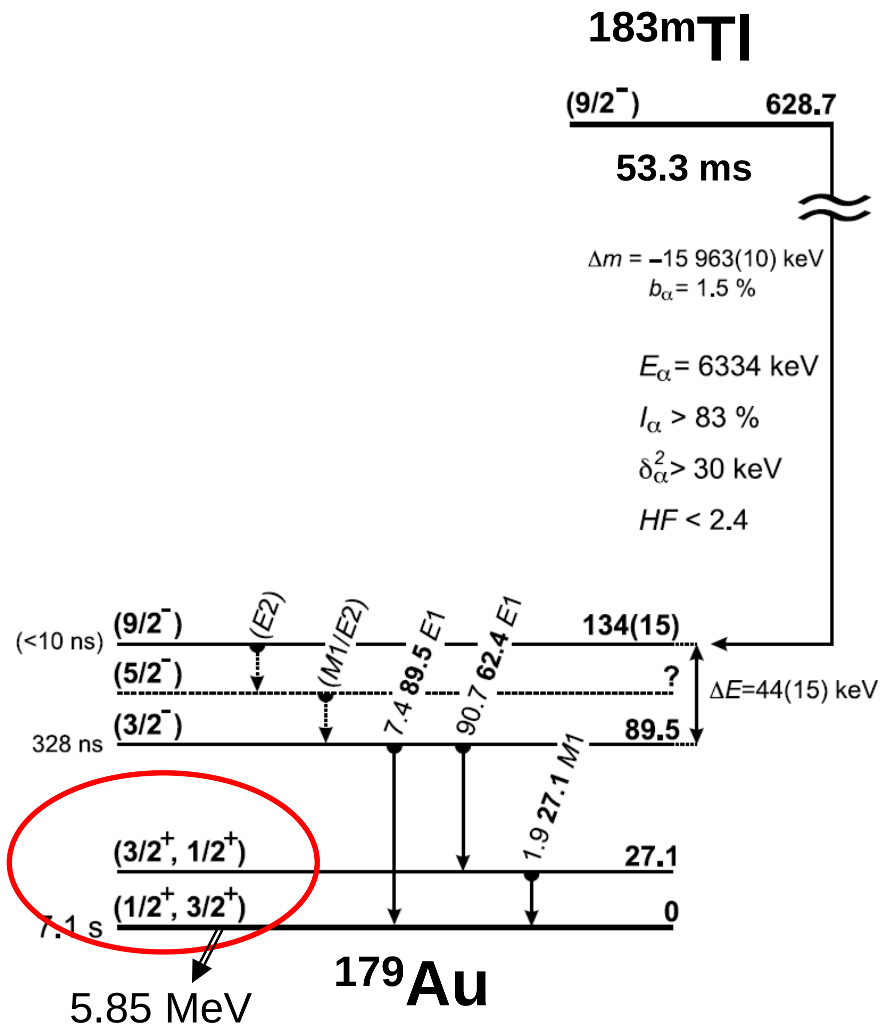
Plot from A.Andreyev et al., PRC 80, 024302 (2009)

What is the ground state spin of ^{179}Au: $1/2^+$, $3/2^+$ or $5/2^-$?

GS+FMA: W.F. Muller et al, PRC 69, 064315 (2004)



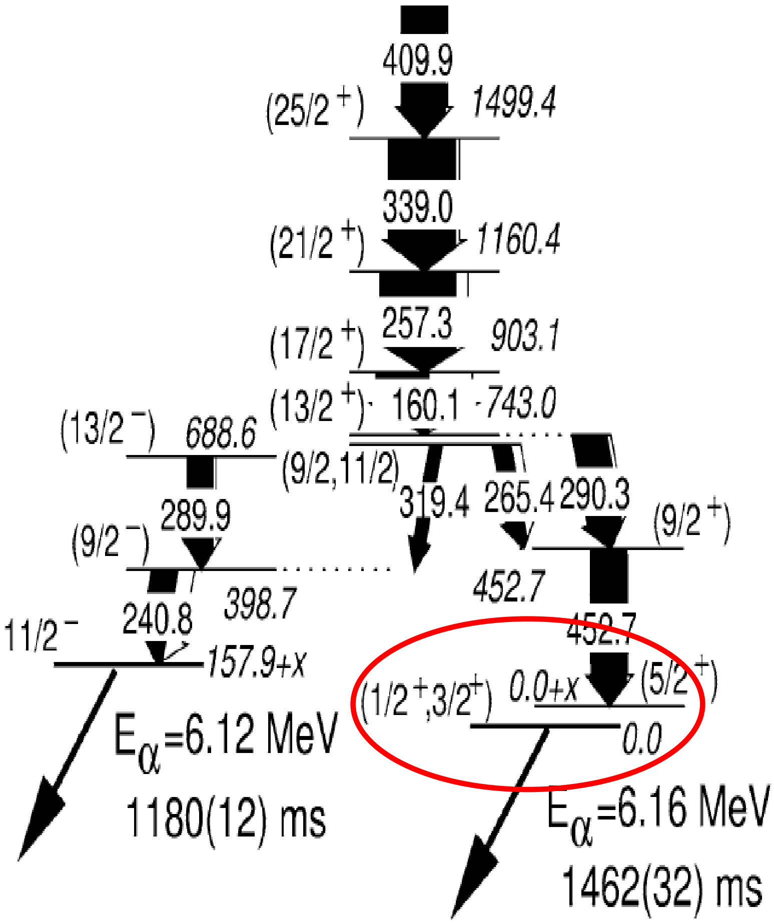
RITU: A. Andreyev et al., R35 experiment (+ISOLDE data)
M. Venhart et al, PLB 695, 82 (2011)



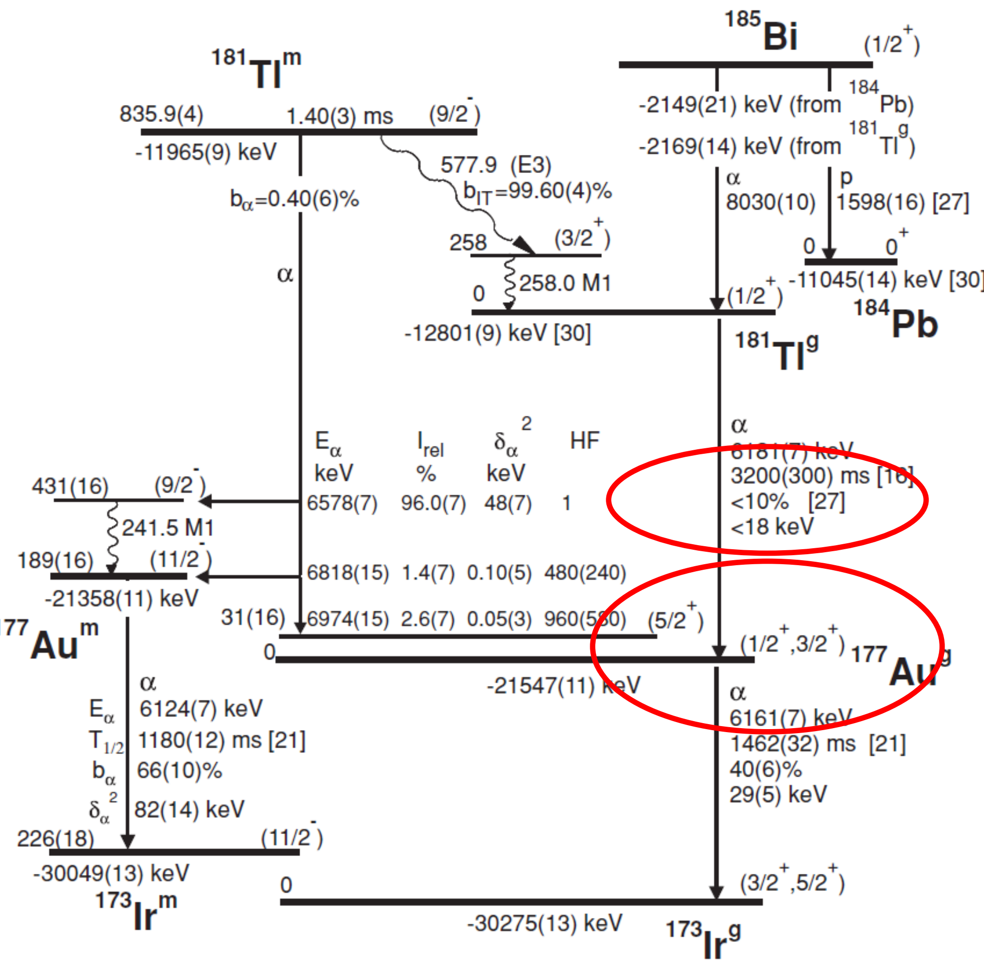
Extensive ISOLDE data for g.s. of ^{183}Tl are available, analysis underway

What is the ground state spin of ^{177}Au: $1/2^+$ or $3/2^+$?

GS+FMA: F.G. Kondev et al., PLB 512, 268 (2001)



SHIP: A.Andreyev et al., PRC 80, 024302 (2009)

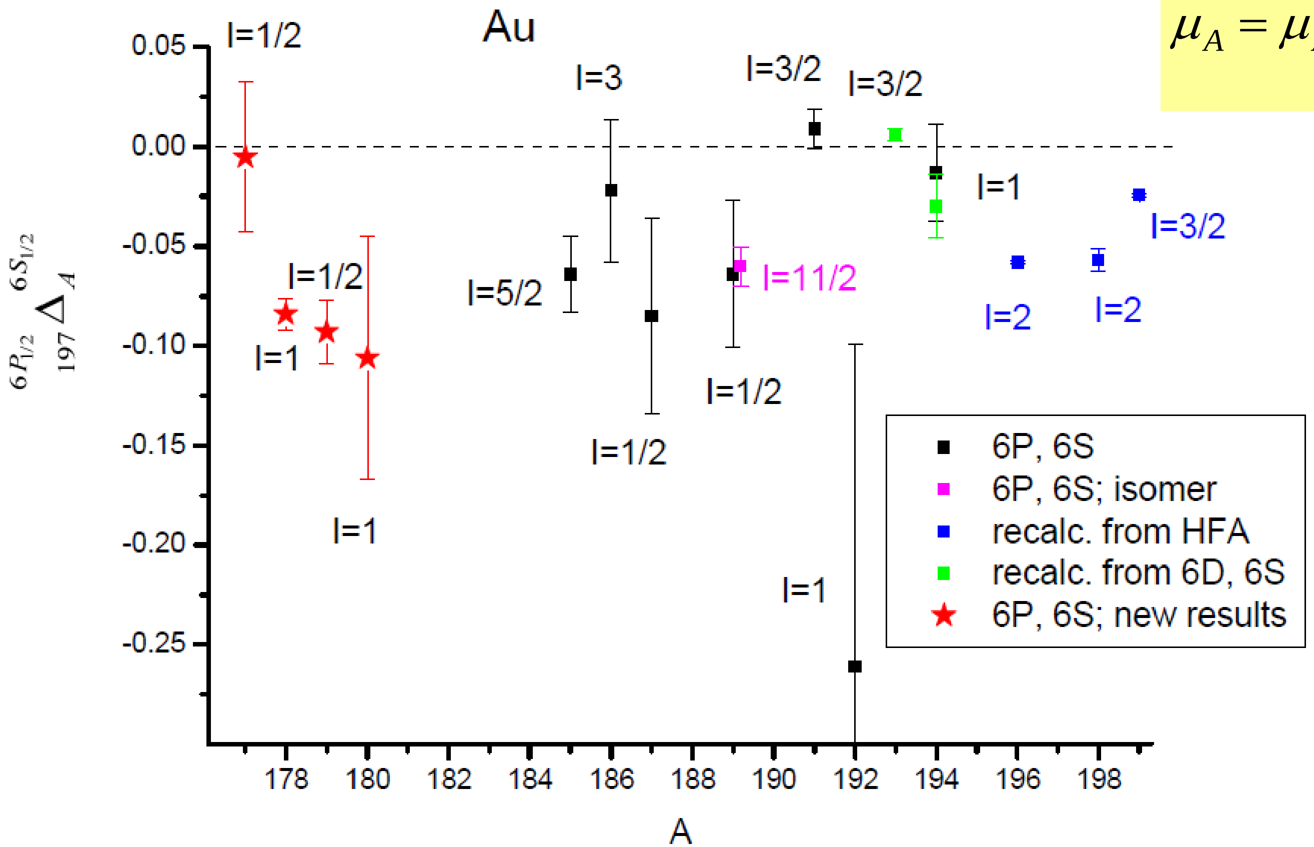


Why is α decay of $1/2^+$ gs of ^{181}Tl hindered, HF>3?

Extensive ISOLDE data for g.s. of ^{181}Tl are available, analysis underway

Hyperfine structure anomaly for Au isotopes

$$\mu_A = \mu_{A_0} \cdot \frac{I_A}{I_{A_0}} \cdot \frac{a_A(nl)}{a_{A_0}(nl)} \cdot (1 + {}^{A_0}\Delta^A_{nl})$$

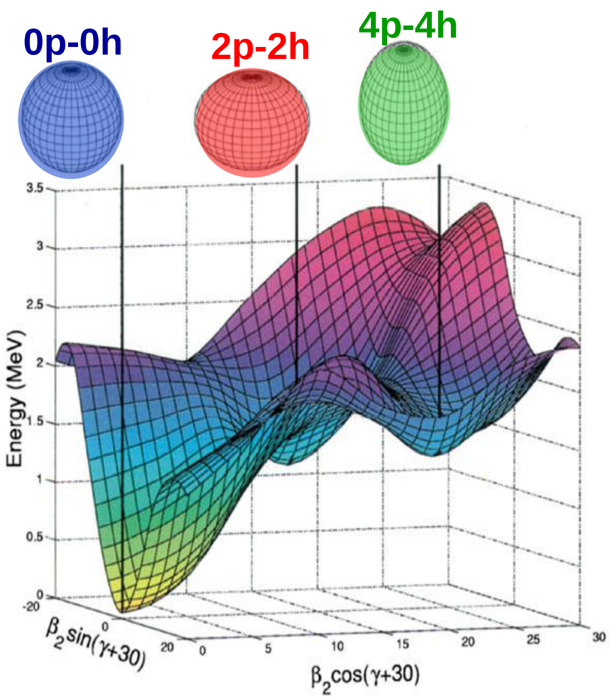


$$\rho^A_{n_1 l_1, n_2 l_2} = \frac{a^A_{n_1 l_1}}{a^A_{n_2 l_2}},$$

$$^{n_1 l_1}_{A_1}\Delta^{n_2 l_2}_{A_2} = \frac{\rho^{A_1}_{n_1 l_1, n_2 l_2}}{\rho^{A_2}_{n_1 l_1, n_2 l_2}} - 1 = {}^{A_1}\Delta^{A_2}(n_1 l_1) - {}^{A_1}\Delta^{A_2}(n_2 l_2)$$

Shape Coexistence in the Pb region

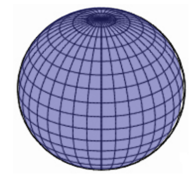
^{186}Pb



Potential Energy Surface for ^{186}Pb

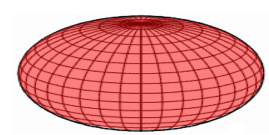
A.Andreyev et al. Nature, 405, 430 (2000)

- Pb (Z=82) g.s.: π(0p-0h) – spherical

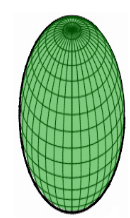


Proton pair excitations across Z=82 shell gap (neutrons are spectators):

- 1 pair excitation: π(2p-2h) -oblate



- 2 pair excitation: π(4p-4h) -prolate



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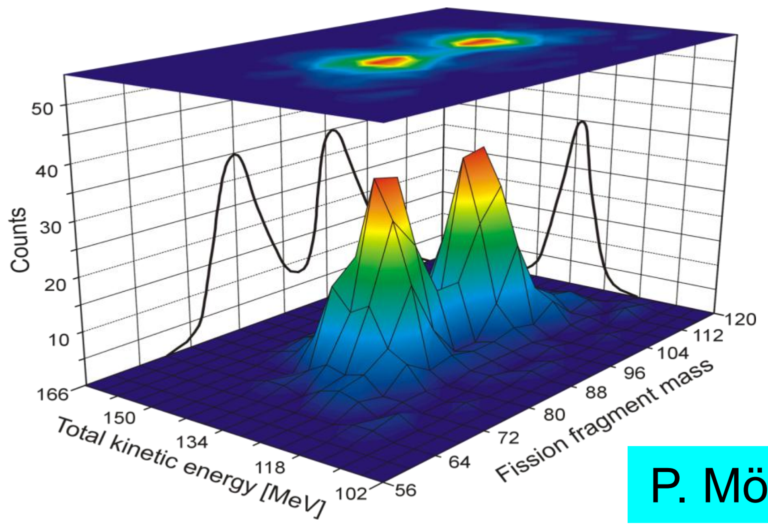

P. Möller’s calculations (2D projection of the total 5D picture):