

Addendum to IS534:

“Part I: Beta-delayed fission, laser spectroscopy and shape-coexistence studies with At beams

Part II: Delineating the island of deformation in the light Au isotopes by means of laser spectroscopy

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on behalf of “Astatine-Gold” Collaboration

Astatine-Gold collaboration

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MR-TOF@ISOLTRAP team (IS518): S. Kreim, V. Manea, +...

4th February 2010: LoI I086 "Development of Astatine ion beams with RILIS"

The Problem: Element At has no stable isotopes (longest $T_{1/2}=8\text{h}$)
Only ~68 mg of At present in the 1st mile of Earth' core
Must be produced/studied 'on-line' at an accelerator

Letter of Intent to the ISOLDE and N-ToF Experiments Committee (INTC)

Development of astatine ion beams with RILIS

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CERN-INTC-2010-010
INTC-I-086

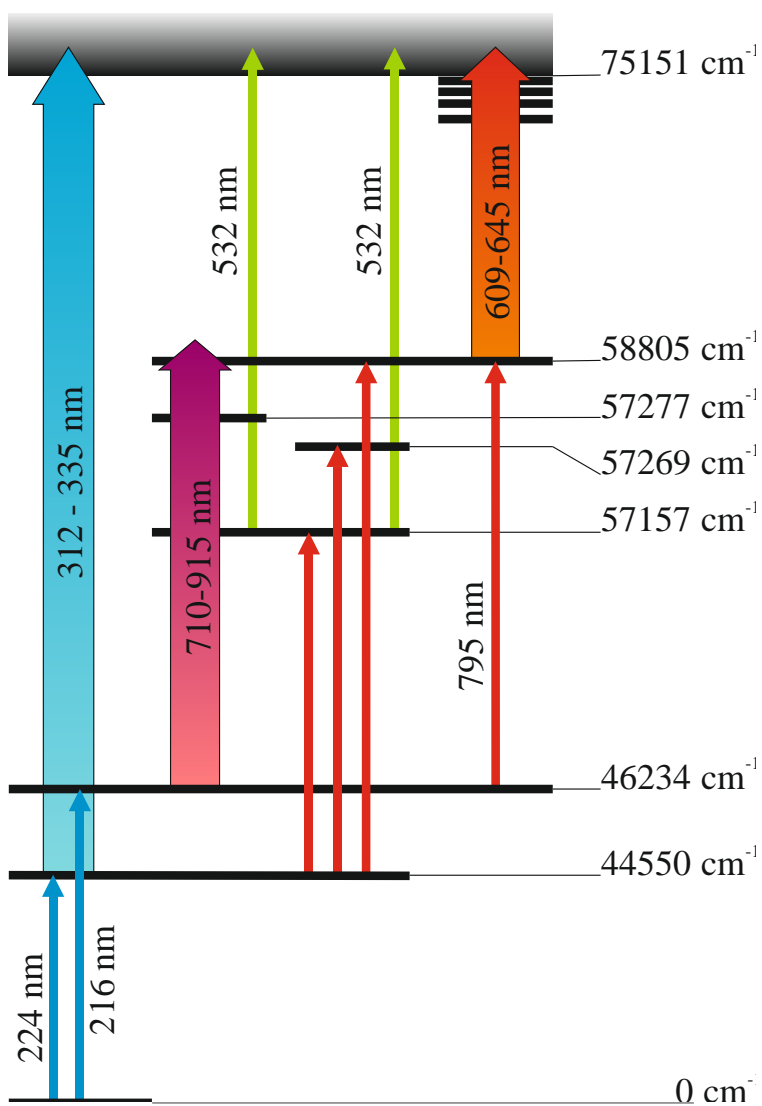
- 1: University of the West of Scotland, Paisley, UK
- 2: Comenius University, Bratislava, Slovakia
- 3: Royal Institute of Technology (KTH), Stockholm, Sweden
- 4: IKS, KU Leuven, Belgium
- 5: CERN, Geneva, Switzerland
- 6: Institut für Physik, Mainz University, Mainz, Germany
- 7: ILL, Grenoble, France
- 8: University of Warsaw, Poland
- 9: TRIUMF, Vancouver, Canada
10. Department of Nuclear and Particle Physics, Uppsala University, Sweden
- 11: The University of Manchester, Manchester, UK
- 12: University of Liverpool, UK

Spokespersons: A. Andreyev, V.N. Fedosseev
Contact person: S. Rothe

Five Physics Cases for LoI I086

- **Studies of the beta-delayed fission (β DF)** in At isotopes (Paisley-Leuven-Bratislava-Geneva-Gent-Liverpool-Los Alamos-Tokai- collaboration)
- **HFS, IS and charge radii measurements within the long chain of At isotopes**, from the very neutron-deficient side, across the N=126 neutron closure, up to the most neutron-rich isotopes (Paisley-Leuven-Bratislava-Liverpool - collaboration)
- **Shape coexistence in the lightest Po isotopes** (β^+ /EC -decay products of At), in particular the search for coexisting oblate, prolate and spherical 0^+ band-heads and corresponding excitations in the odd-A Po isotopes (Paisley-Leuven-Bratislava-Liverpool-JYFL-Warsaw - collaboration)
- **Search for octupole collectivity in the neutron-rich Rn isotopes** (beta-decay products of At) (Madrid, Oslo, Uppsala, Warsaw - collaboration)
- **Few-nucleon transfer reactions of At isotopes** to study single-particle around N=126 and multi-particle multi-hole structures in the neutron-deficient and neutron-rich isotopes. This would need beam energies from HIE ISOLDE.

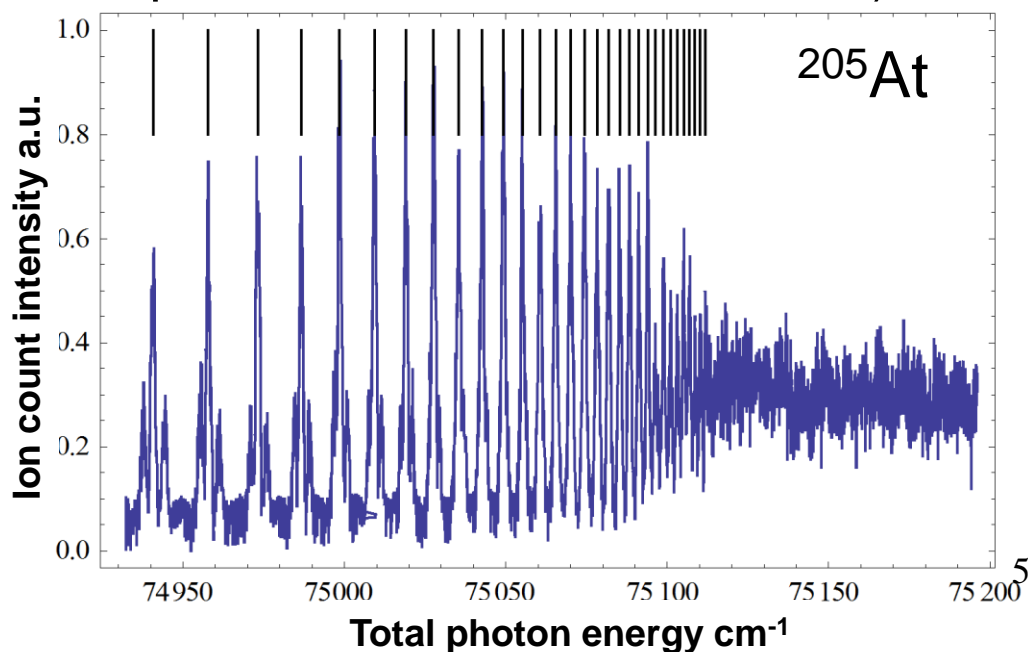
First determination of the Ionization Potential for the radioactive element At



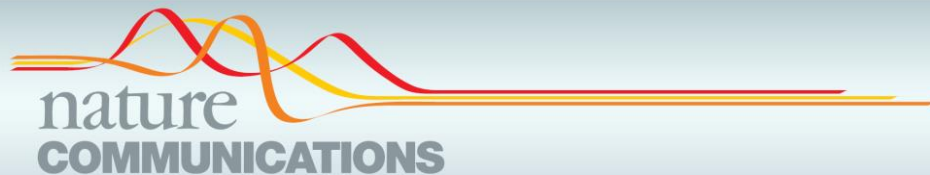
3 successful **on-line** development runs
ISOLDE (Nov. 2010, May 2011)
TRIUMF, Canada (Dec. 2010)

- Many new atomic levels found
- Transition strengths measured

• **Ionization potential measured** (scan of ionizing laser: converging Rydberg levels allow precise determination of the IP)



First determination of the Ionization Potential for the radioactive element At



ARTICLE

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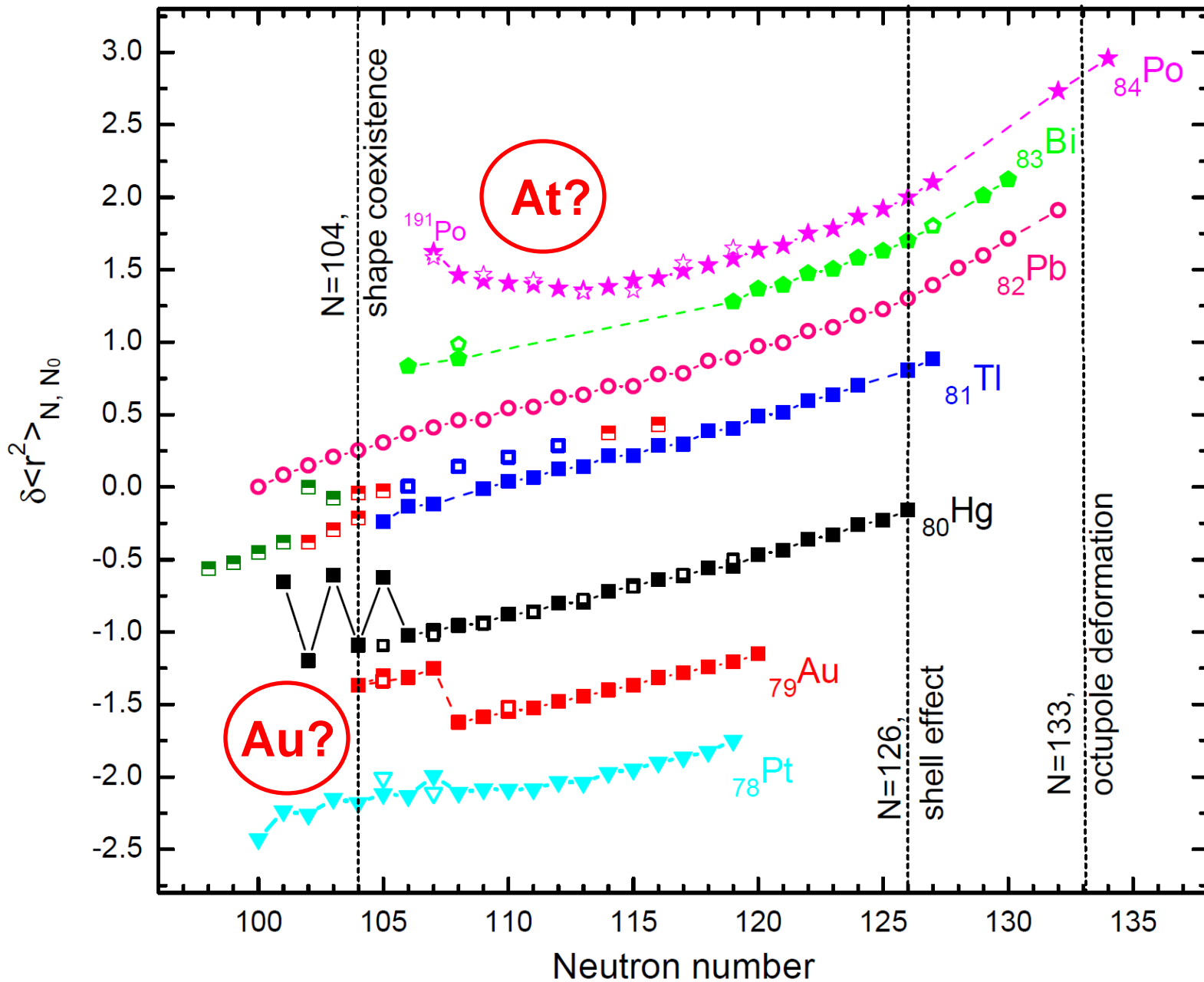
DOI: [10.1038/ncomms2819](https://doi.org/10.1038/ncomms2819)

OPEN

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

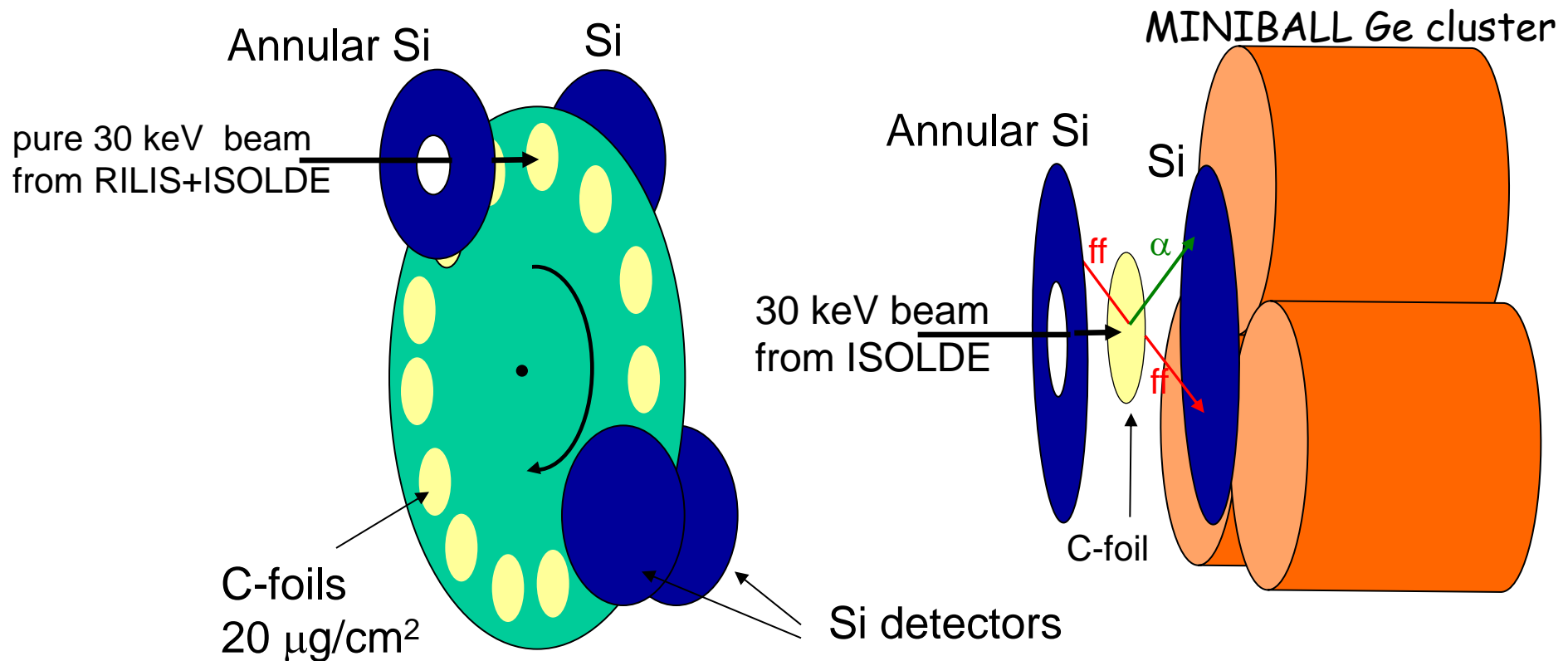
S. Rothe^{1,2}, A.N. Andreyev^{3,4,5,6}, S. Antalic⁷, A. Borschevsky^{8,9}, L. Capponi^{4,5}, T.E. Cocolios¹, H. De Witte¹⁰, E. Eliav¹¹, D.V. Fedorov¹², V.N. Fedosseev¹, D.A. Fink^{1,13}, S. Fritzsche^{14,15,†}, L. Ghys^{10,16}, M. Huyse¹⁰, N. Imai^{1,17}, U. Kaldor¹¹, Yuri Kudryavtsev¹⁰, U. Köster¹⁸, J.F.W. Lane^{4,5}, J. Lassen¹⁹, V. Liberati^{4,5}, K.M. Lynch^{1,20}, B.A. Marsh¹, K. Nishio⁶, D. Pauwels¹⁶, V. Pershina¹⁴, L. Popescu¹⁶, T.J. Procter²⁰, D. Radulov¹⁰, S. Raeder^{2,19}, M.M. Rajabali¹⁰, E. Rapisarda¹⁰, R.E. Rossel², K. Sandhu^{4,5}, M.D. Seliverstov^{1,4,5,12,10}, A.M. Sjödin¹, P. Van den Bergh¹⁰, P. Van Duppen¹⁰, M. Venhart²¹, Y. Wakabayashi⁶ & K.D.A. Wendt²

IS534: At and Au Charge Radii



Windmill System at ISOLDE

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

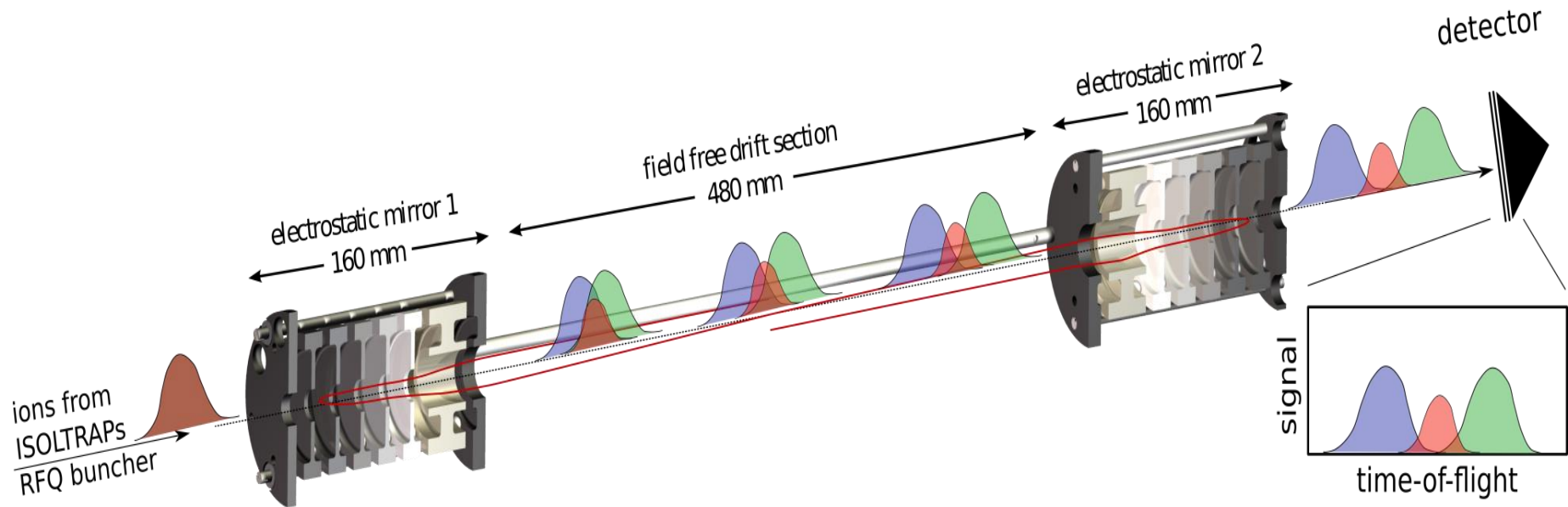


Setup: Si detectors from both sides of the C-foil

- Simple setup & DAQ: 4 PIPS (1 of them – annular)
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-gamma coincidences
- Digital electronics

Multi-Reflection Time-of-Flight (MR-ToF) Spectrometer for HFS studies

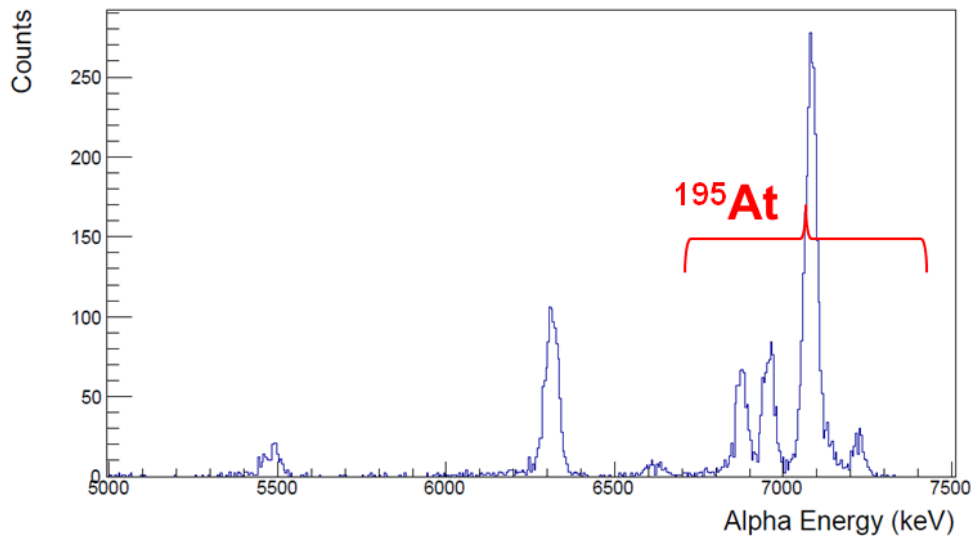
- The WM technique requires **waiting for the decay** of the isotope (usually, α -decay, to provide selectivity between isotopes/isomers). Not practical for long-lived or stable isotopes (or for β -decaying)
- Alternative – to **use 'counting' ions** (instead of waiting for decay)



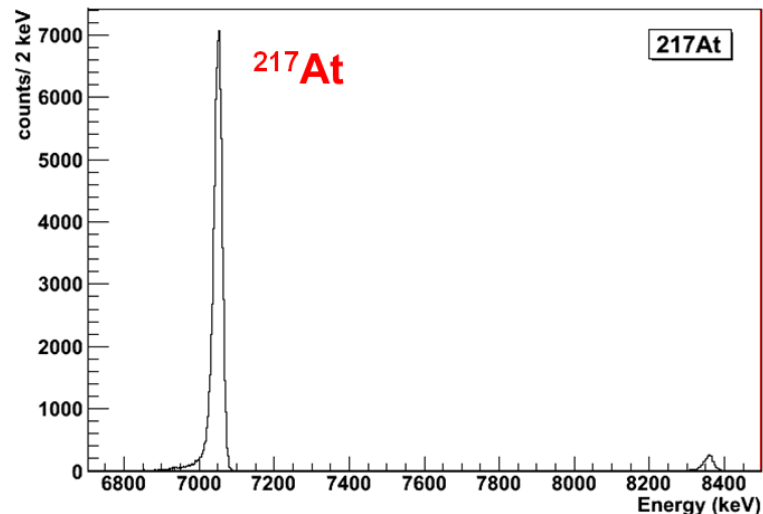
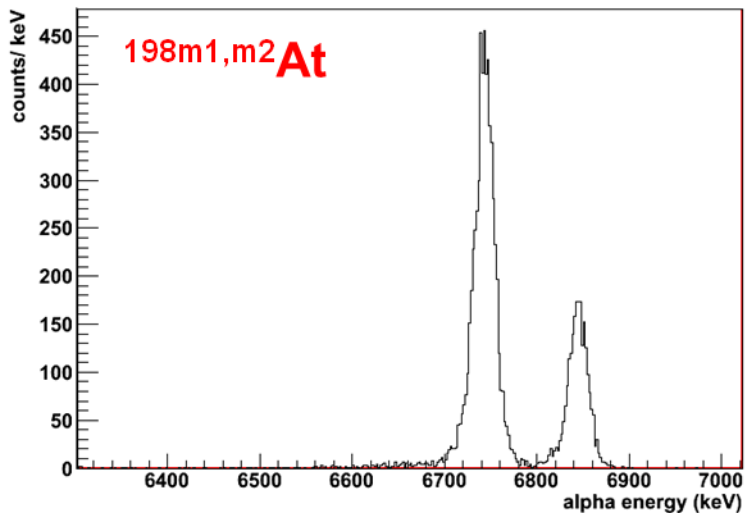
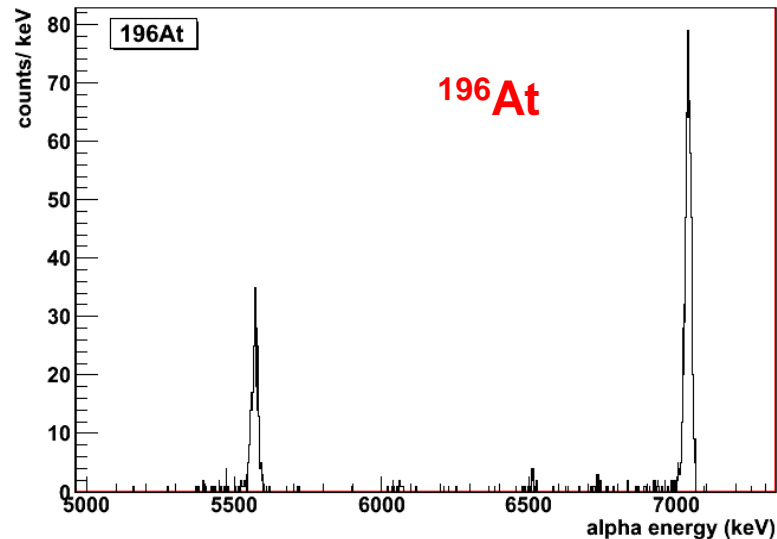
IS534, May/October 2012

examples of alpha spectra from WM

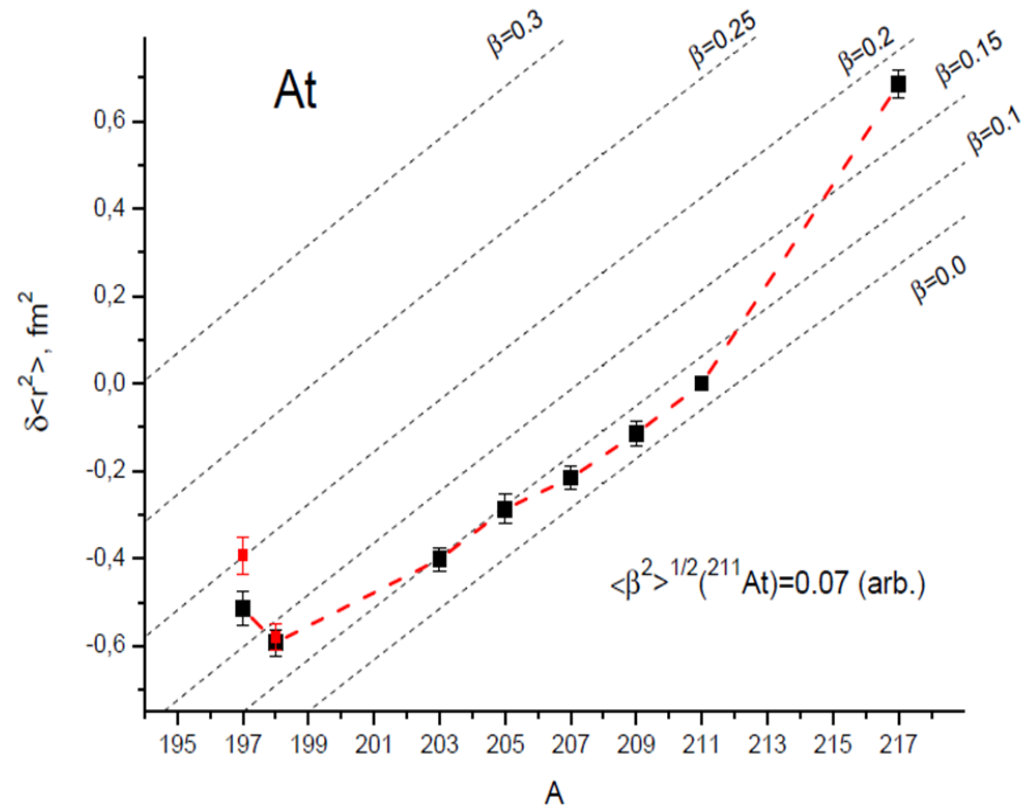
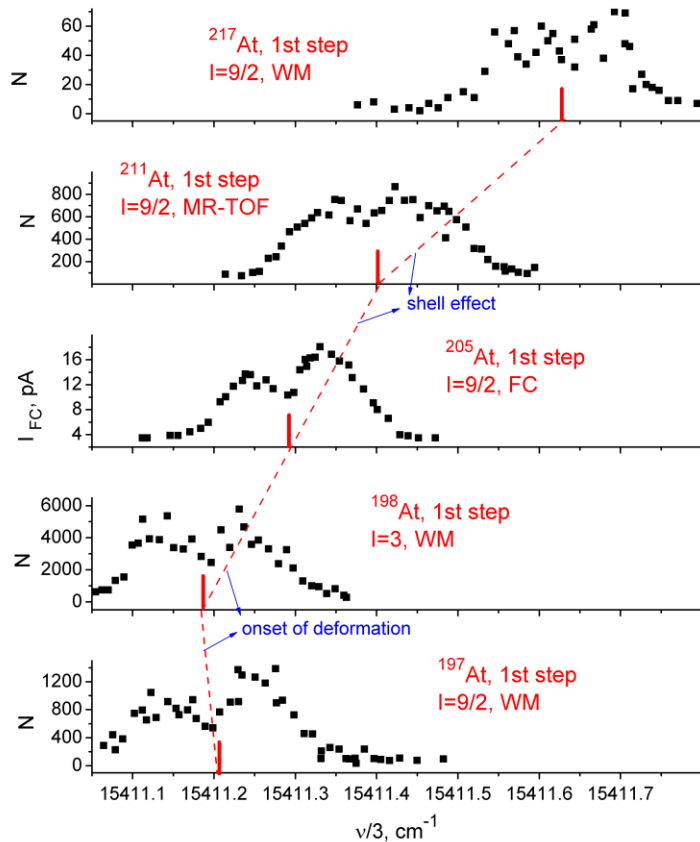
195At HRS S1



RILIS+SOLDE, IS534

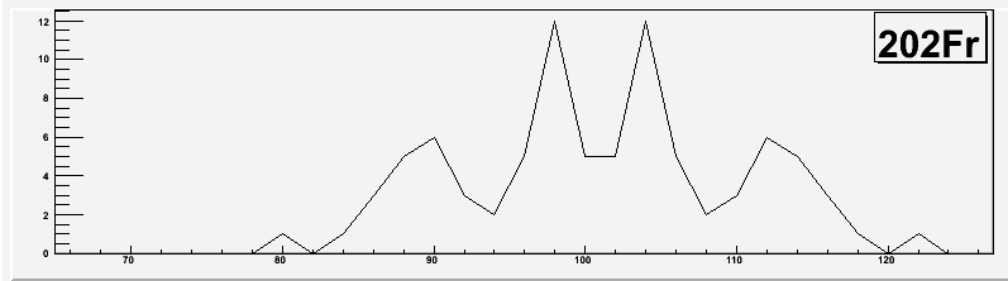
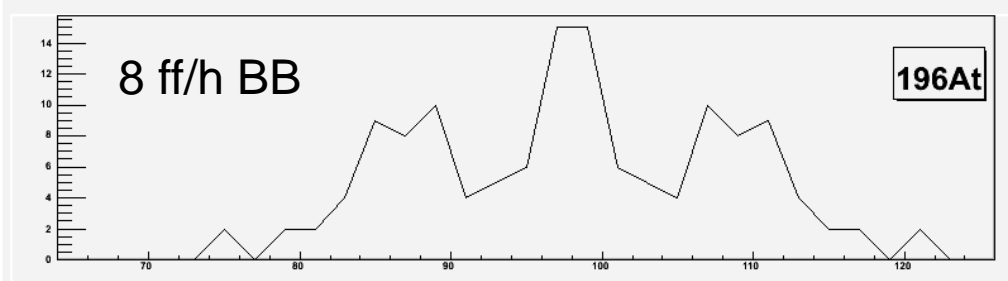
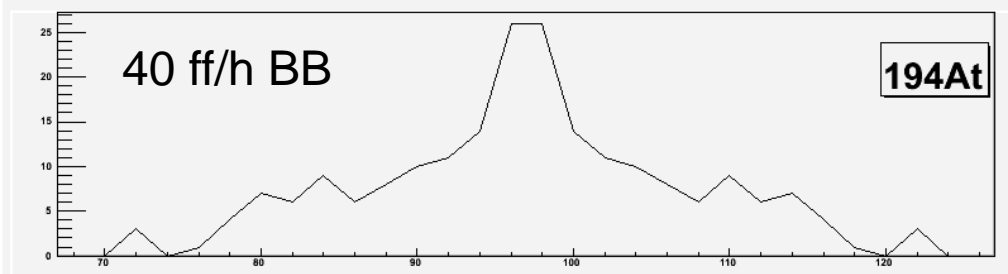
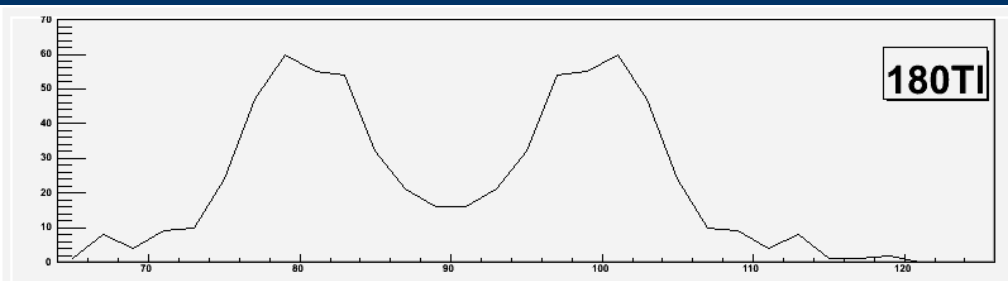


HFS spectra for At isotopes (WM/FC/MR-TOF)



- Need 'missing' isotopes, need more spectra for some of measured
- To complete the IS/HFS measurements we ask 10 shifts of 193-196,202,204,206,208,210,212,218,219 At beams (WM/FC/MR-TOF)

May and June 2012: Mass Distributions Measurements via β DF of $^{194,196}\text{At}$ and $^{200,202}\text{Fr}$



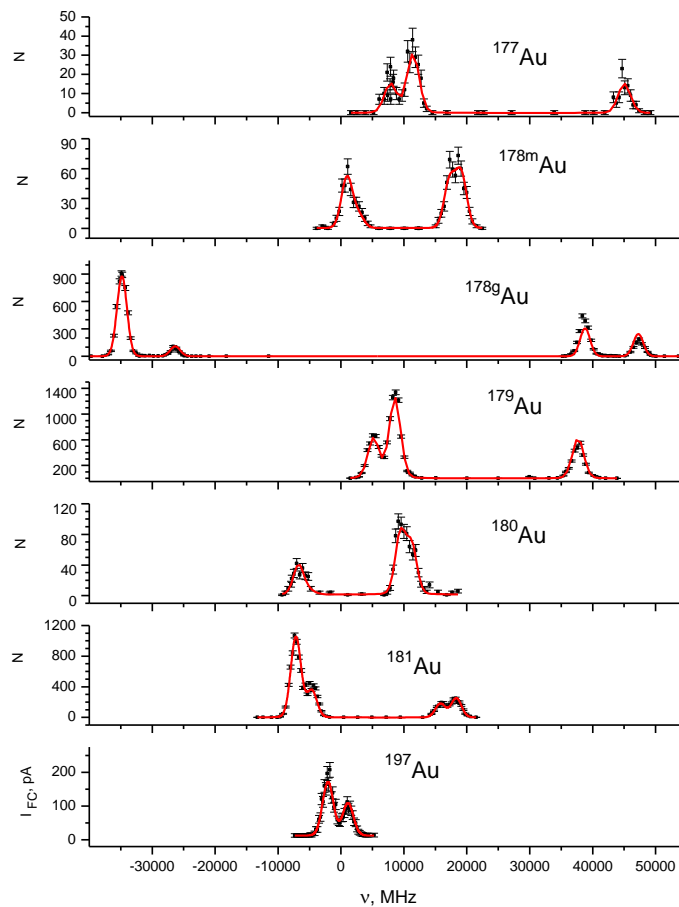
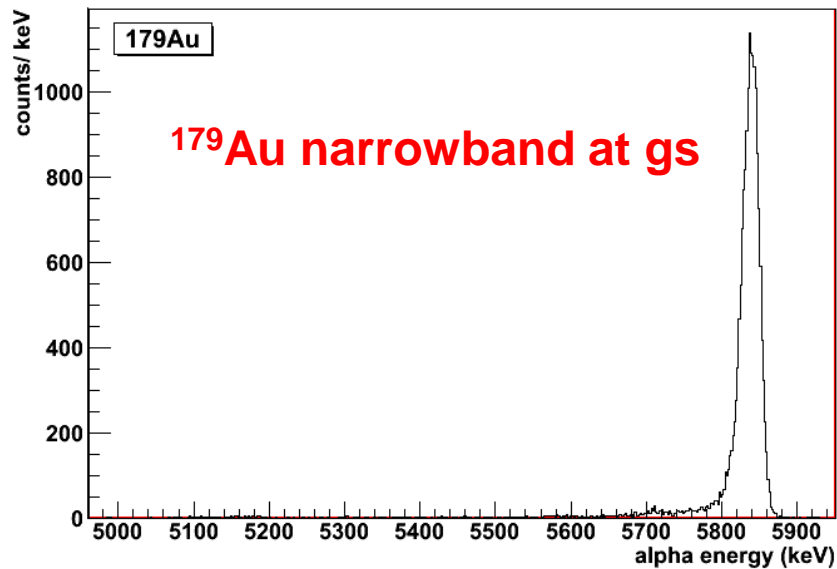
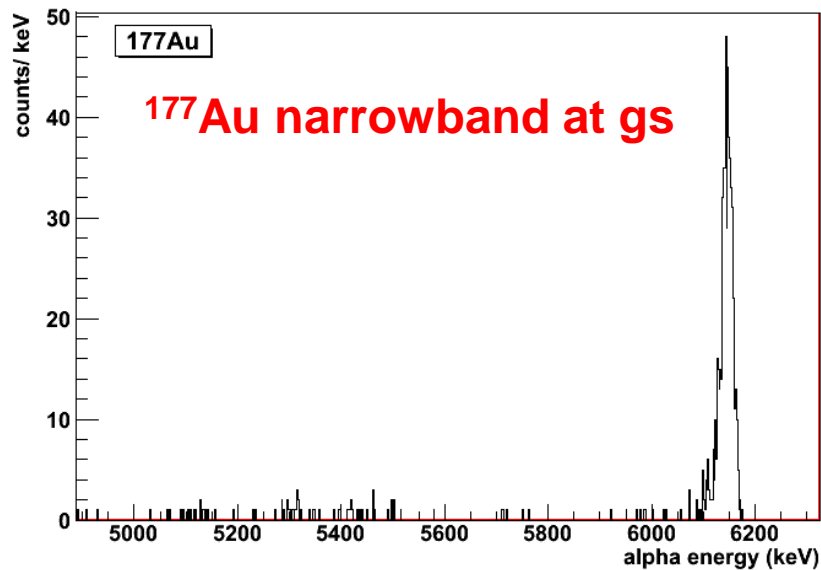
Fission Fragment Mass

Gradual transition from asymmetry in ^{180}Tl to a mixture of symmetric and asymmetric in $^{194,196}\text{At}$ and ^{202}Fr .

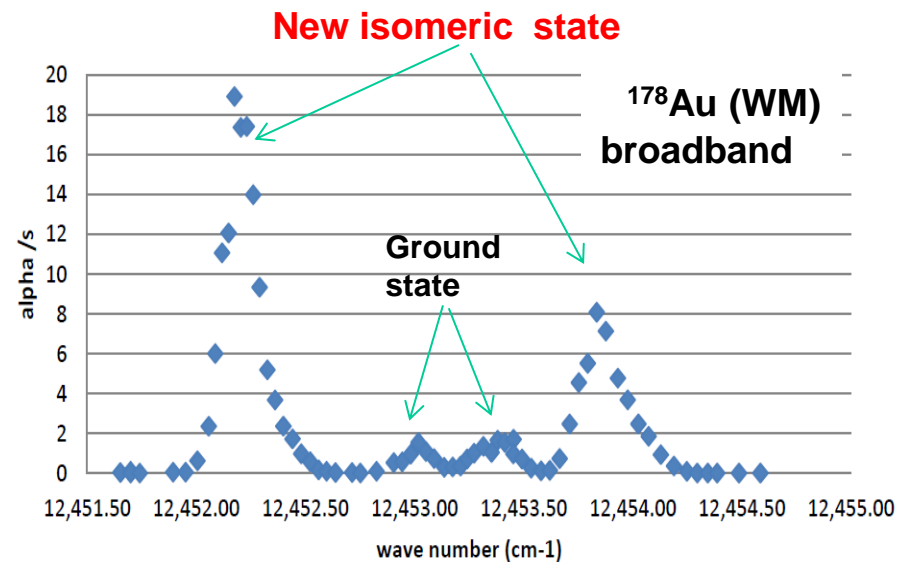
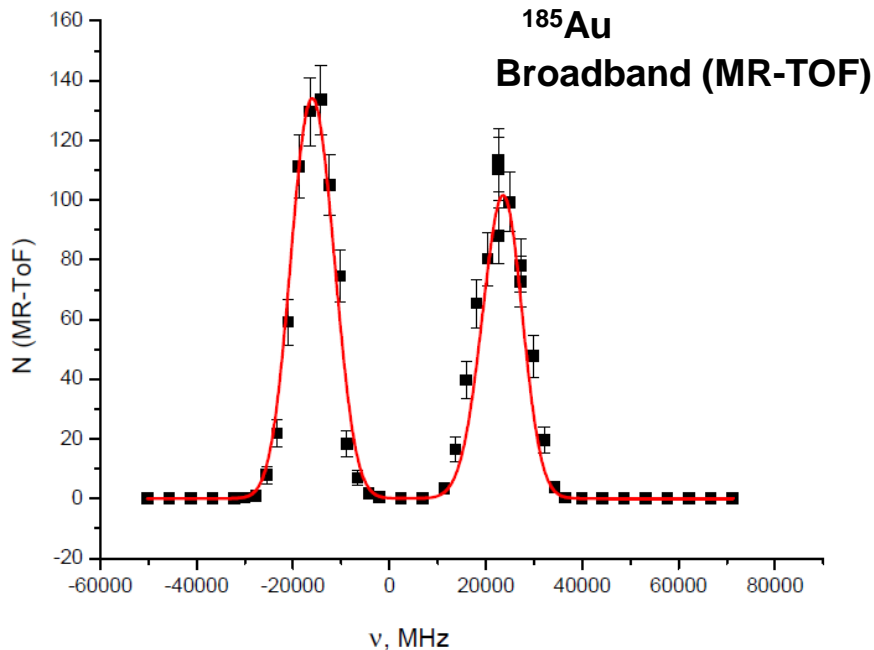
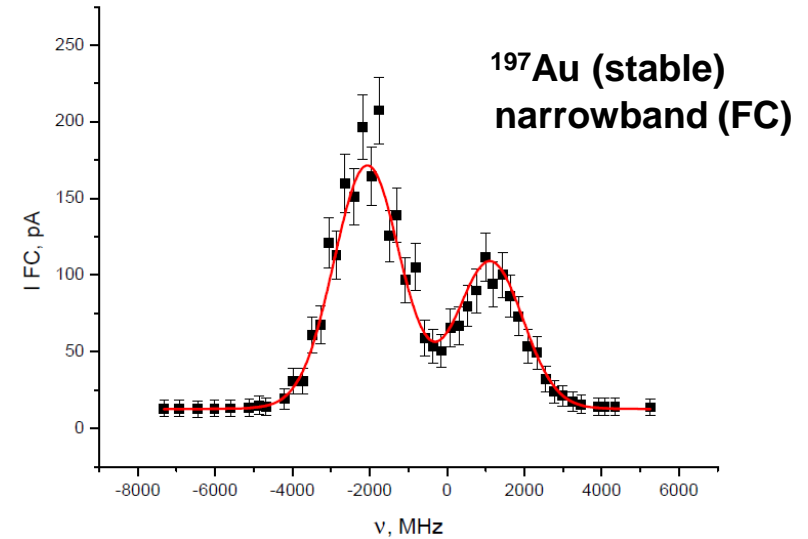
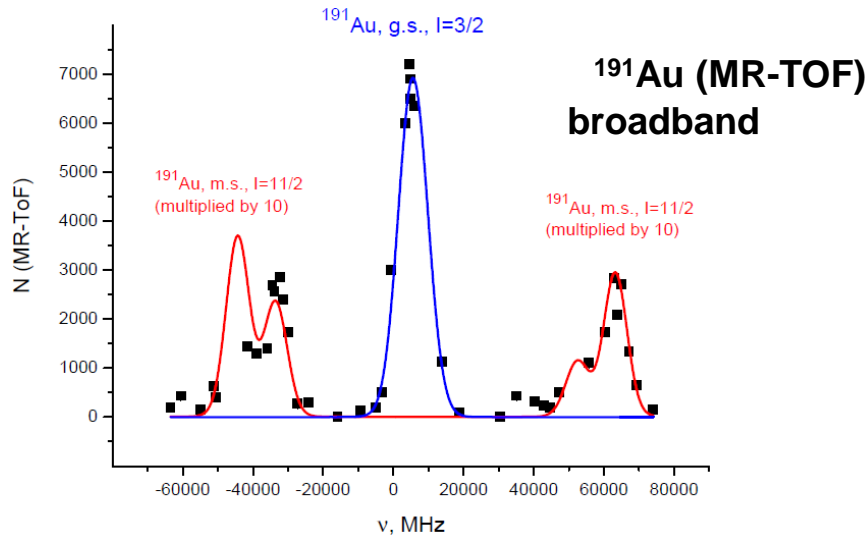
However: ^{194}At has 2 isomers, thus it's not clear yet if both or only one isomer fission?

We ask 3 shifts to perform the isomer separation (narrowband) and measure β DF

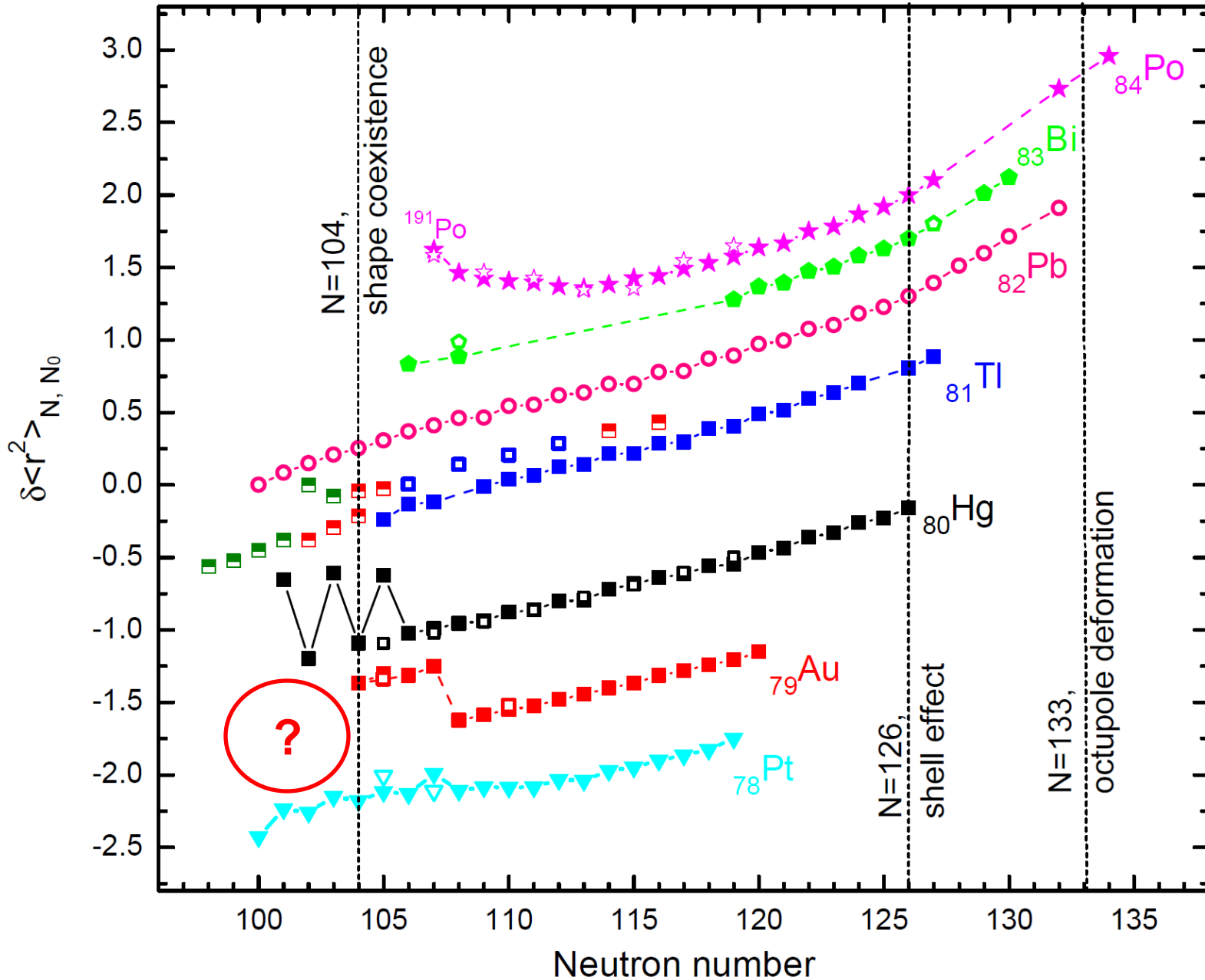
9-12 October 2012: Laser spectroscopy of Au isotopes



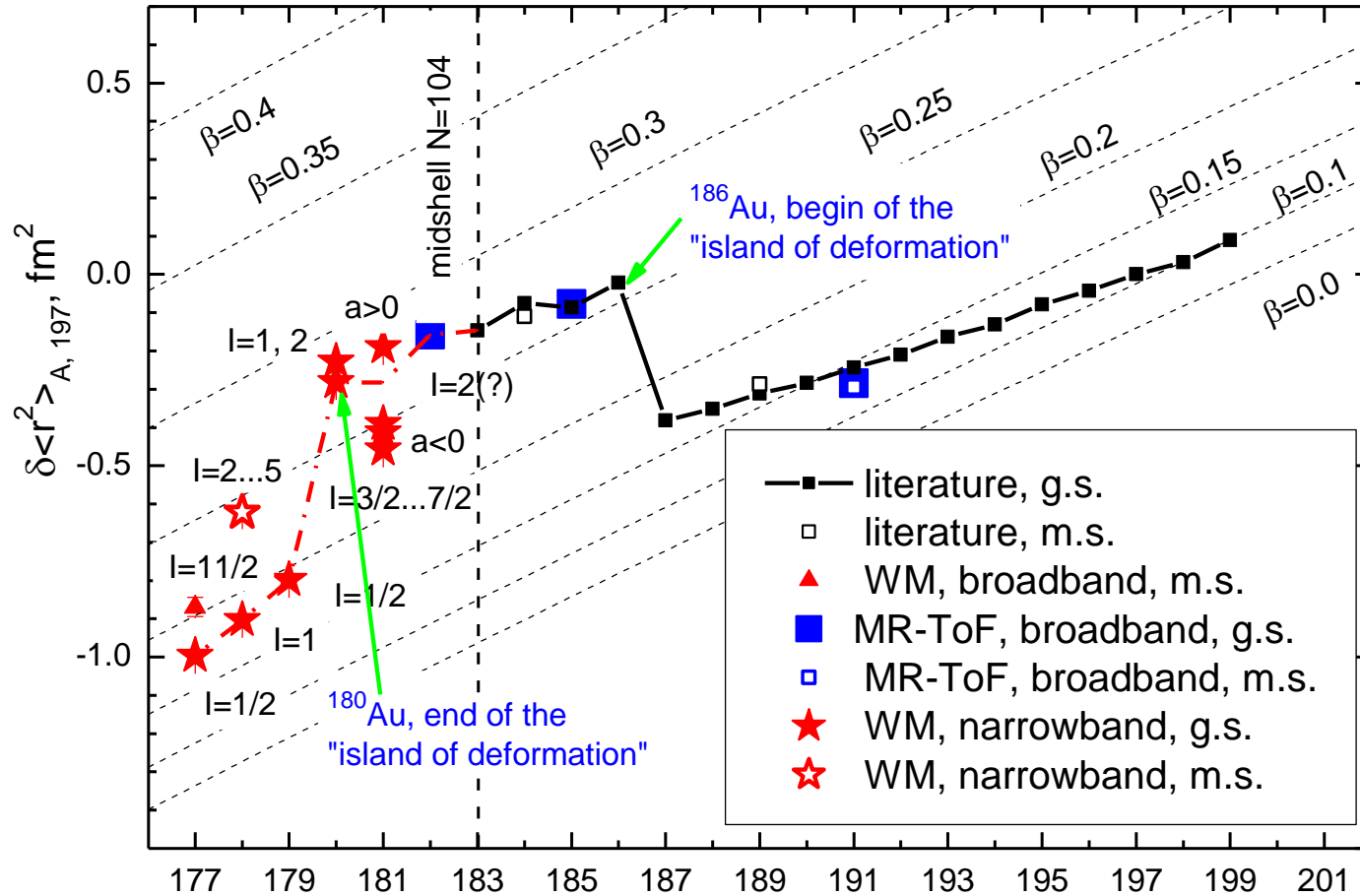
Hyperfine Splitting Scans for $^{178}, ^{185}, ^{191}, ^{197}\text{Au}$



Are the lightest Au isotopes deformed?



"Back to sphericity" in Au isotopes



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

To complete Gold IS/HFS measurements for $^{175-184}\text{Au}$: 15 shifts

Beamtime request

Astatine isotopes (13 shifts in total):

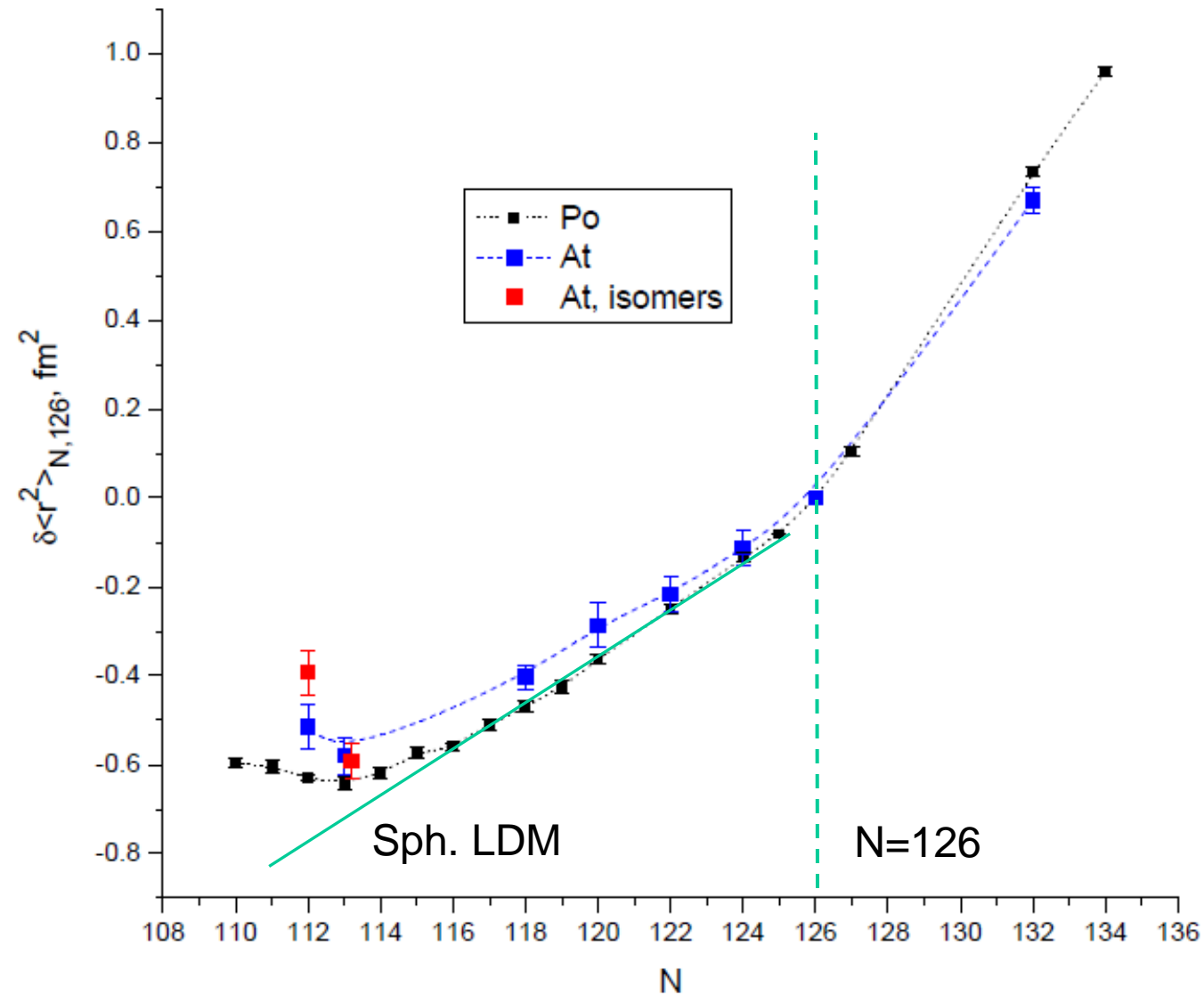
- 10 shifts to complete IS/HFS measurements for $^{193-196,202,204,206,208,210,212,218,219}\text{At}$ (WM/FC/MR-TOF)
- 3 shifts for βDF of ^{194}At @WM (isomer separation with RILIS)

Gold isotopes (18 shifts in total)

- 10 shifts for HFS measurements of $^{175-181}\text{Au}$ with WM
- 2 shifts for HFS measurements of $^{182,183}\text{Au}$ with MR-TOF
- 3 shifts for HFS measurements of isomeric states in $^{187,191,193,195}\text{Au}$ using ISOLTRAP's MR-TOF MS
- 3 shifts for mass measurements of isomeric states
- In total: 31 shifts of At and Au beams (most probably divided in 2 runs)

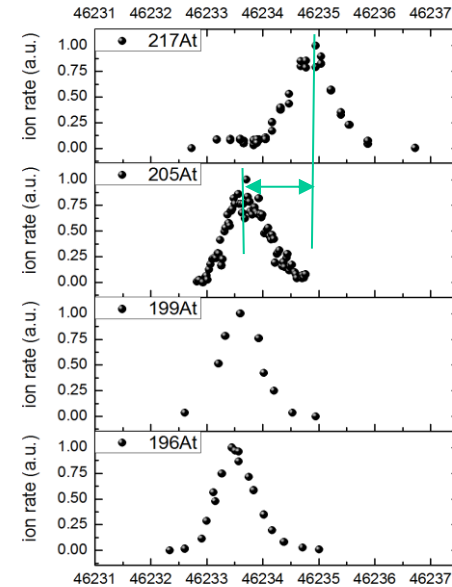
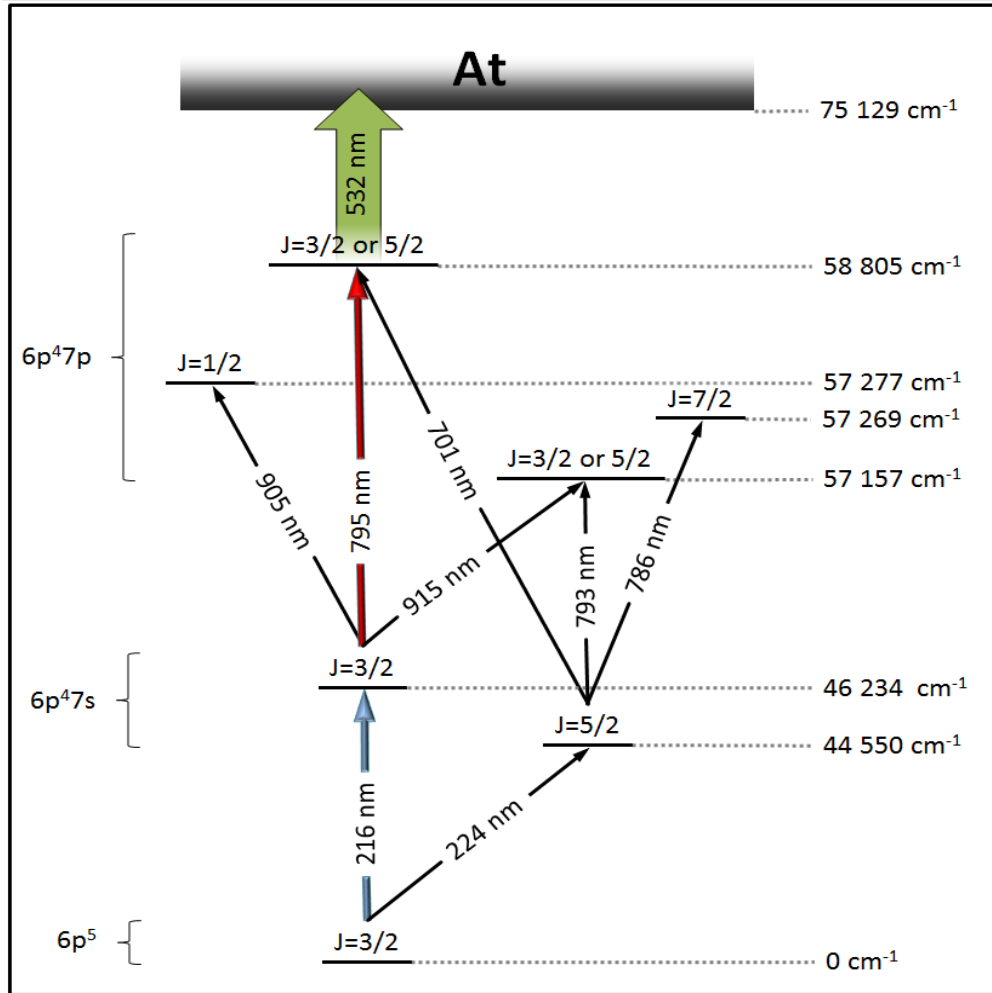
Thank you!

At vs Po charge radii



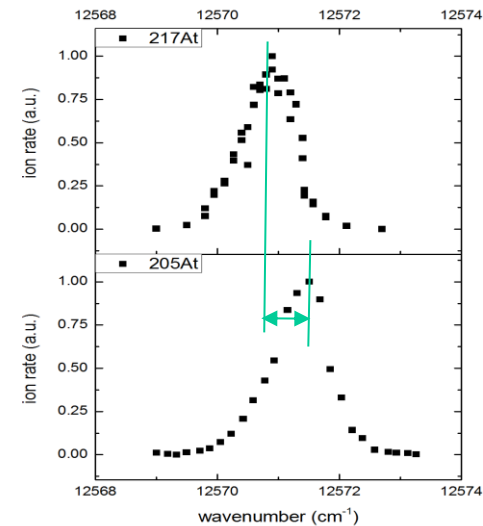
LoI I086: At Laser Spectroscopy in **Broadband** Mode

Plots: courtesy S. Rothe



216 nm

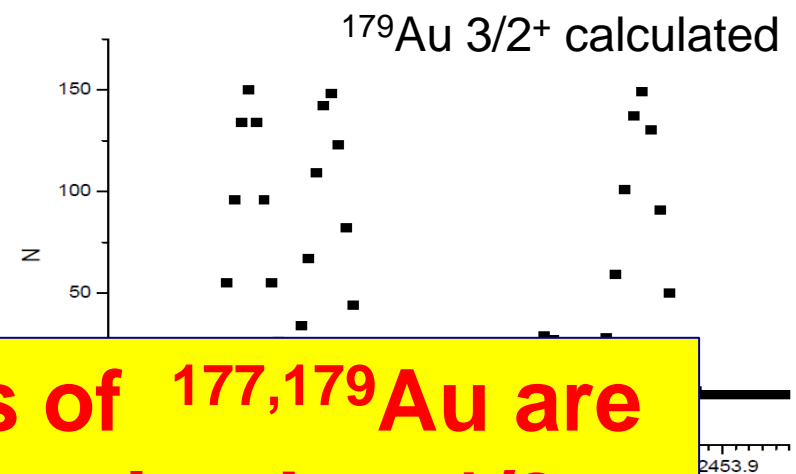
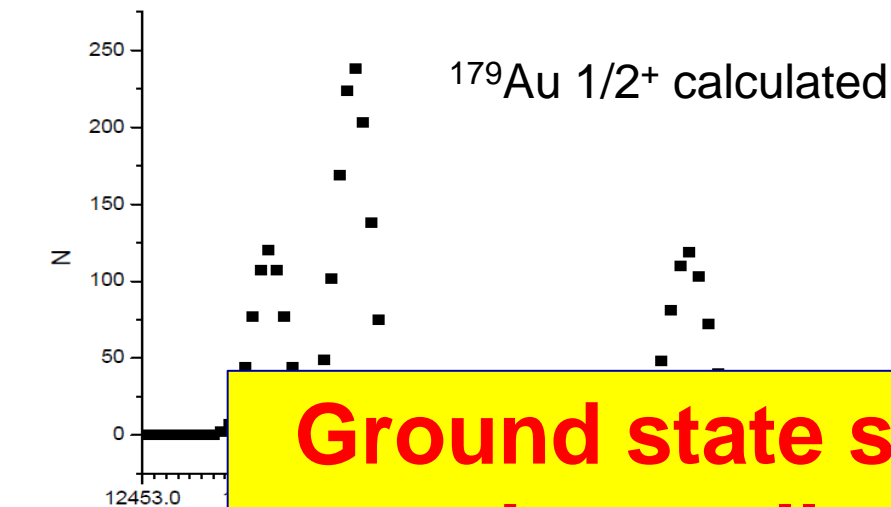
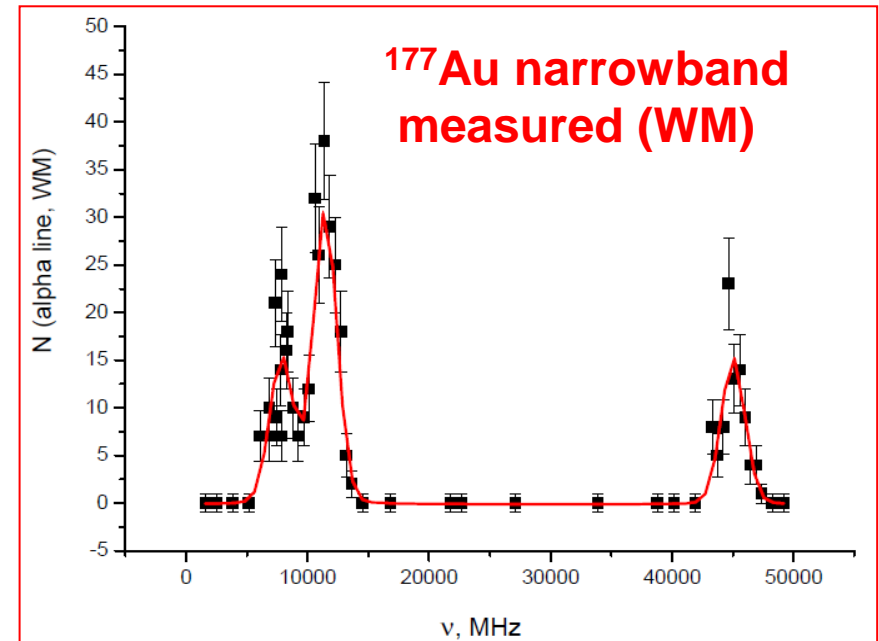
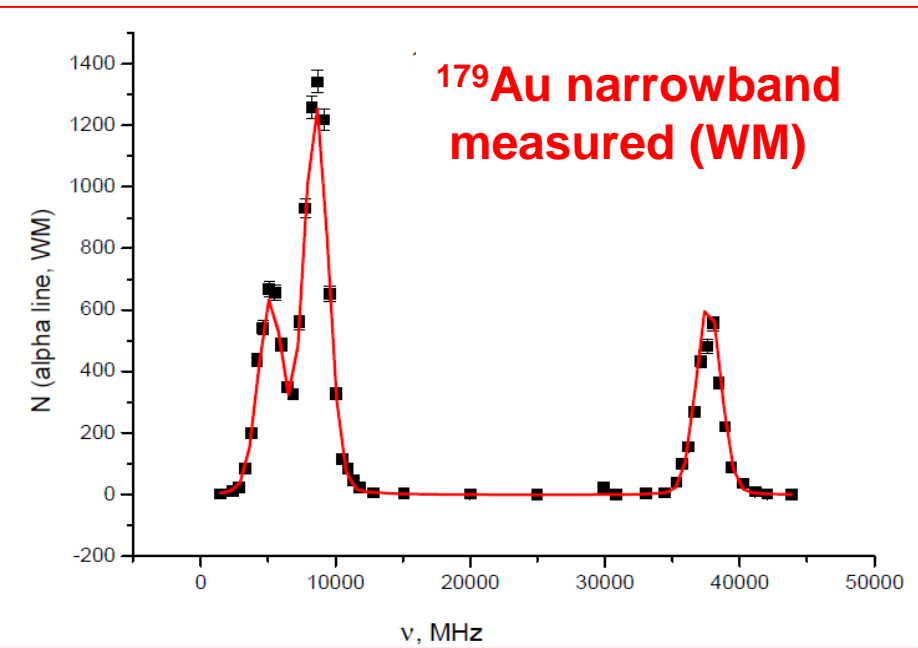
$IS_{217,205} =$
 $\sim 40 \text{ GHz}$
 1.3 cm^{-1}



795 nm

$IS_{217,205} =$
 $\sim 20 \text{ GHz}$
 0.7 cm^{-1}

IS534: Hyperfine Splitting Scans (HFS) for $^{177,179}\text{Au}$



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