ISOLDE Workshop and Users Meeting 2015

CERN, 2-4 December 2015

Resonance photoionization spectroscopy of short-lived isotopes in the lead region using the ISOLDE RILIS

Bruce Marsh, *CERN EN-STI-LP*

On behalf of York-KU Leuven-Gatchina-Mainz-Manchester-Bratislava-Liverpool-ISOLDE collaboration

EN Engineering Department

New review article in this field

Progress in Particle and Nuclear Physics 86 (2016) 127–180

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

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

Review

Laser spectroscopy for nuclear structure physics

P. Campbell [a], I.D. Moore [b,*], M.R. Pearson [c]

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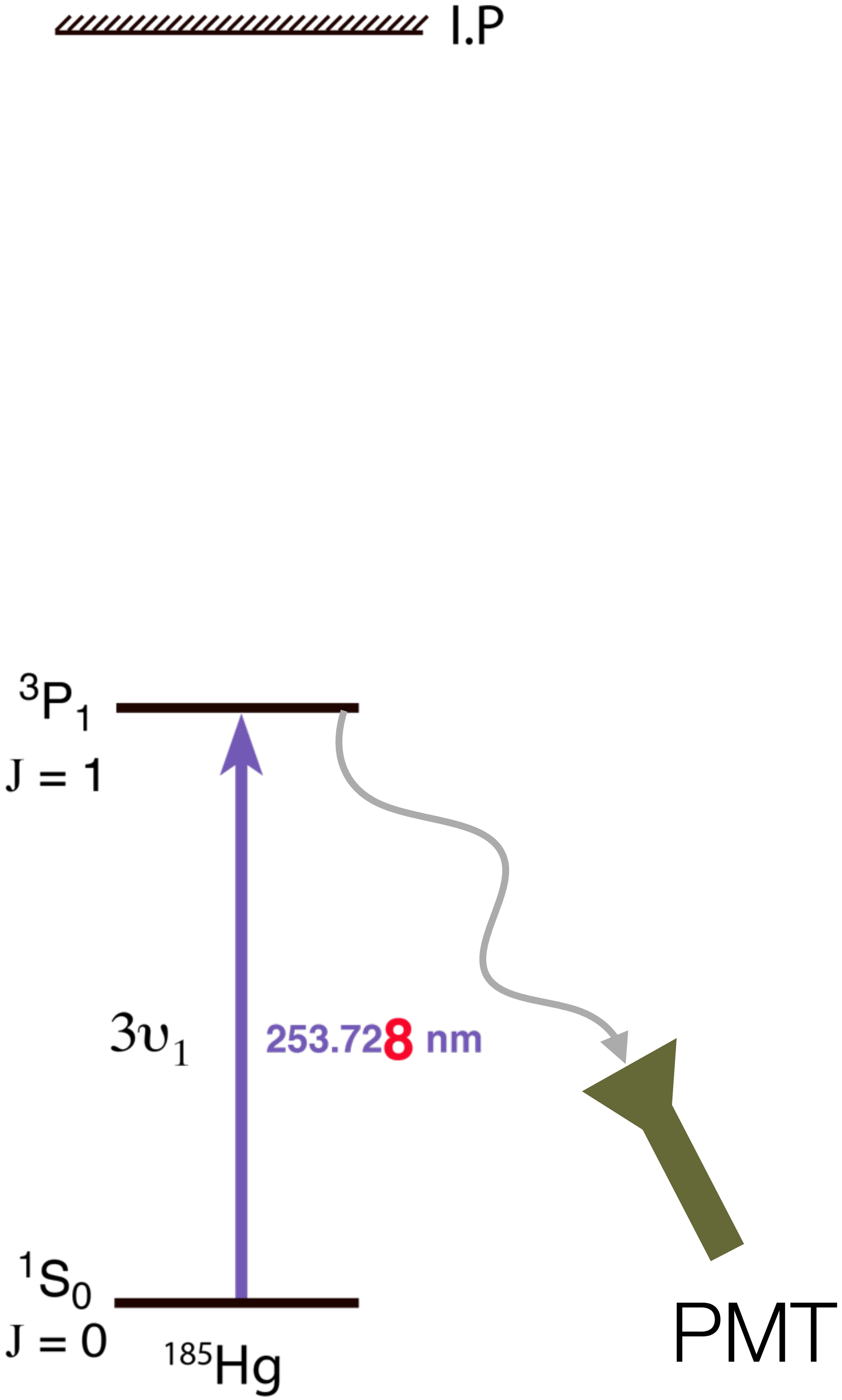
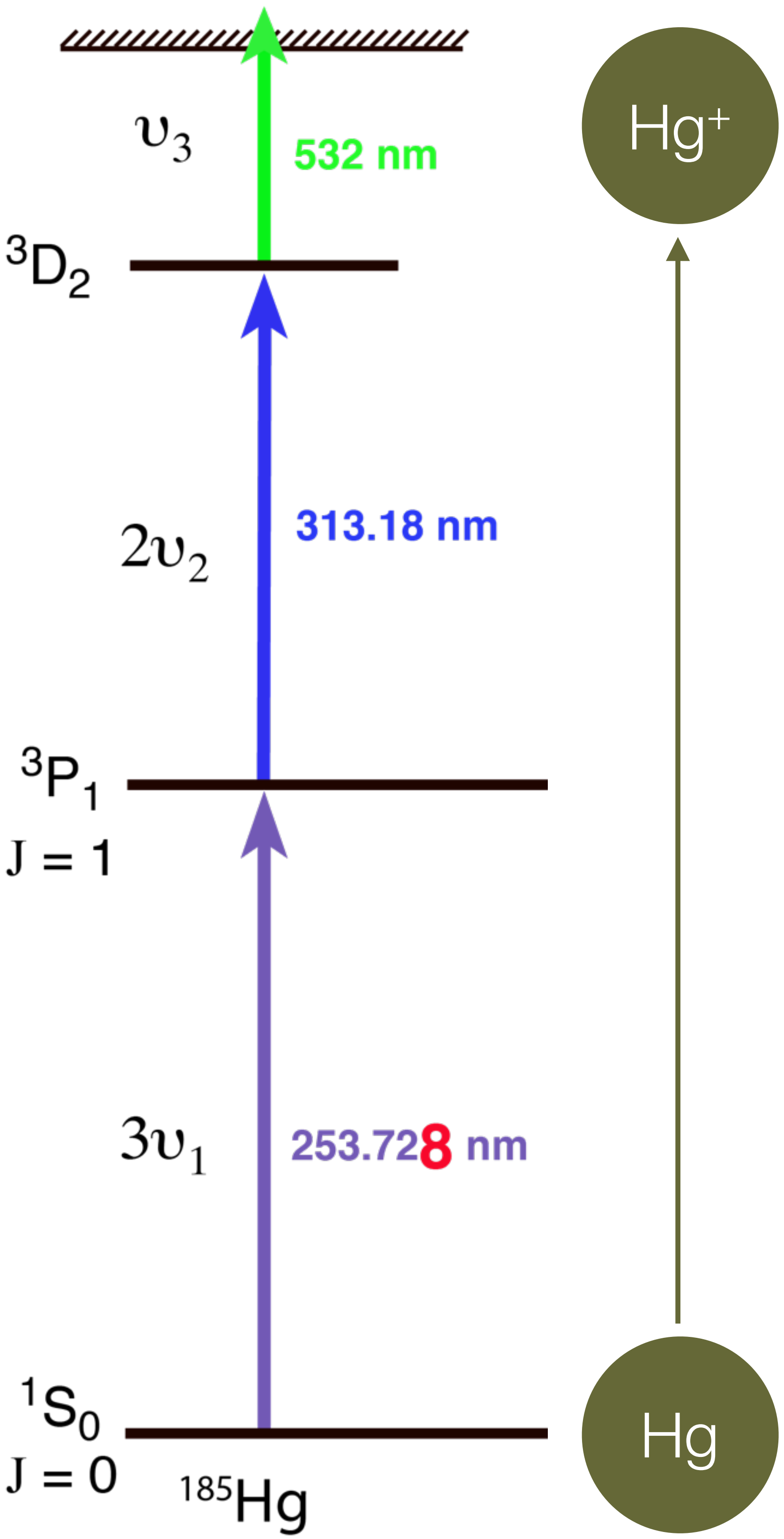
[b] *Department of Physics, University of Jyväskylä, Survontie 9, Jyväskylä, FI-40014, Finland*

[c] TRIUMF, *4004 Westbrook Mall, Vancouver BC, V6T 2A3, Canada*

Laser spectroscopy (mercury example)

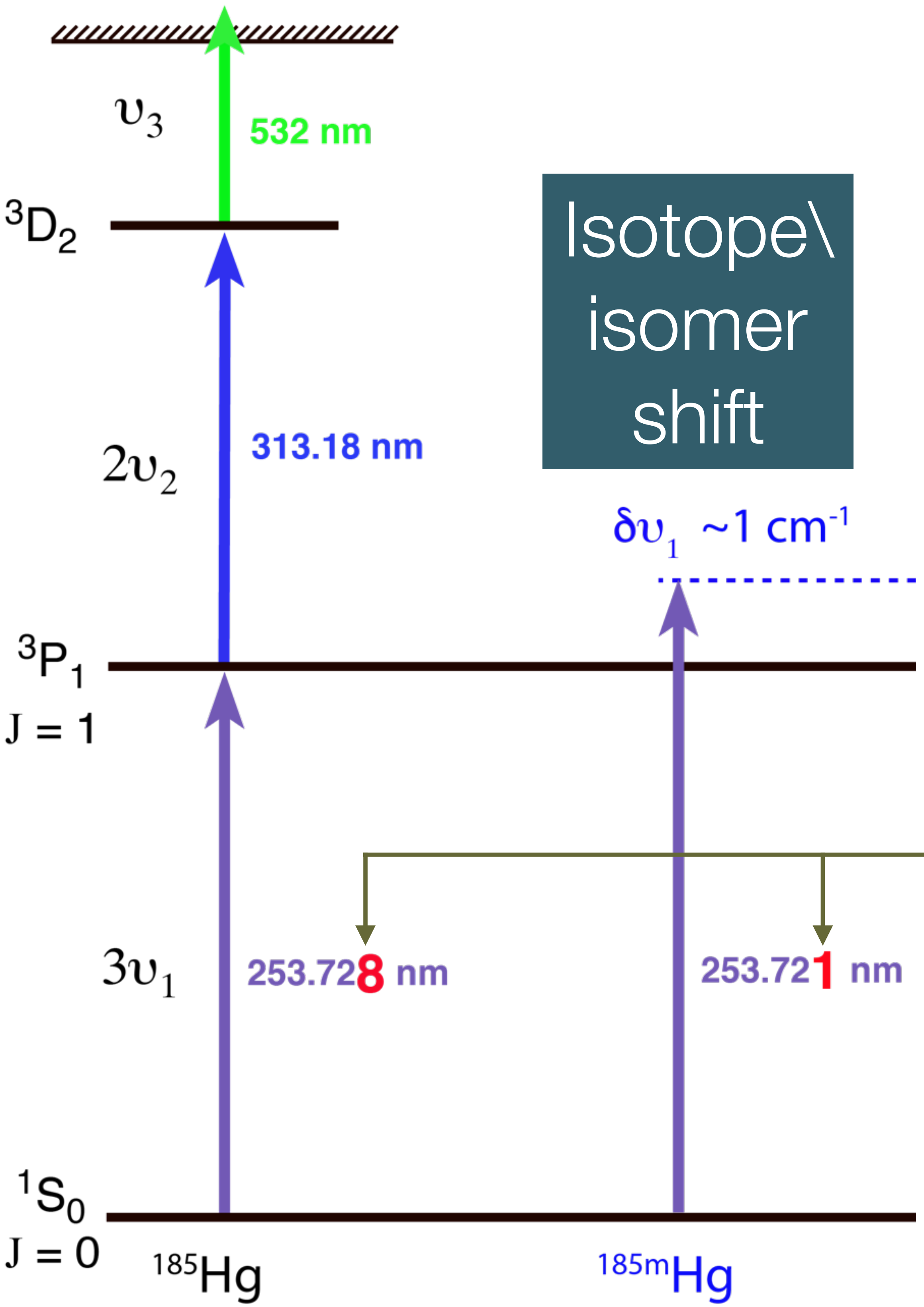


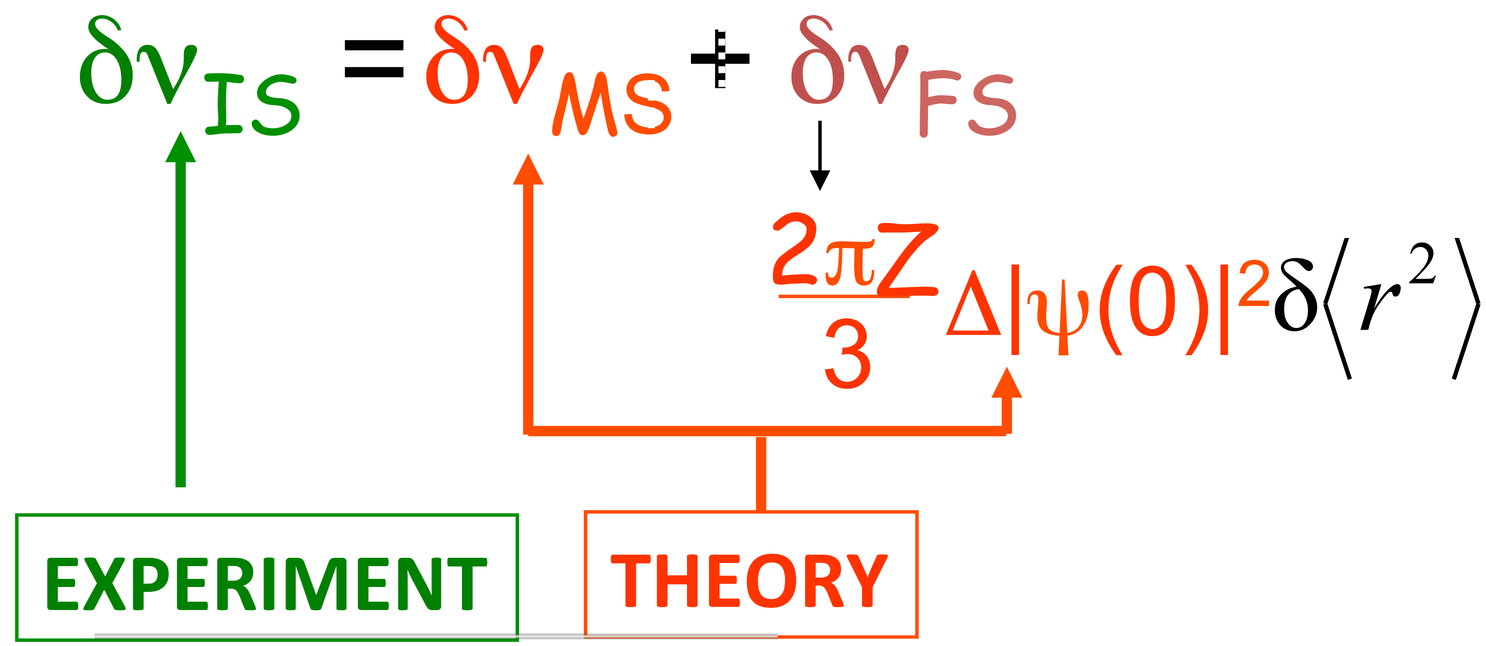
Laser spectroscopy (mercury example)



Ion or
radiation detection

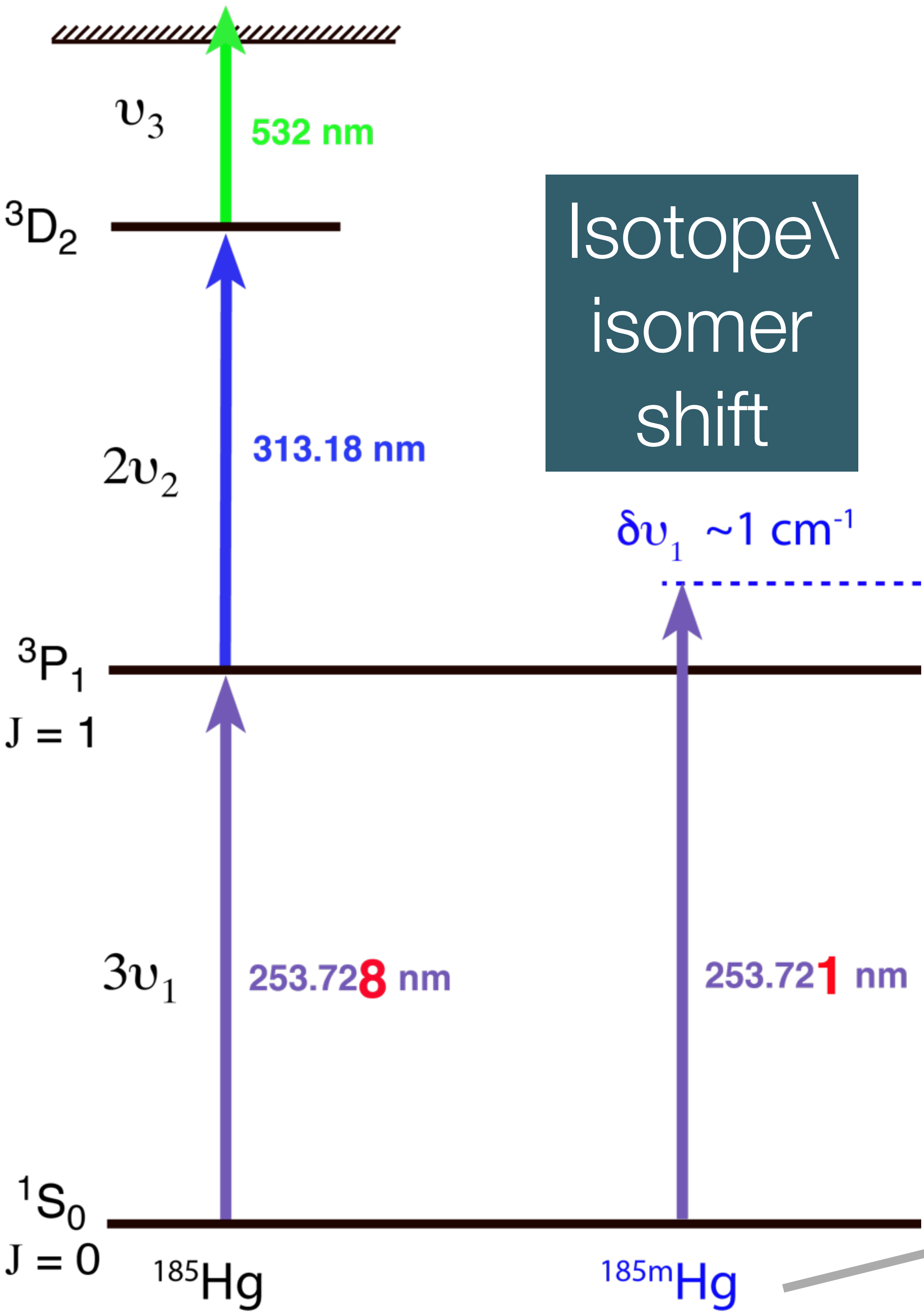
Laser spectroscopy (mercury example)





The isomer shift is seen as a minuscule change in resonance wavelength

Laser spectroscopy (mercury example)

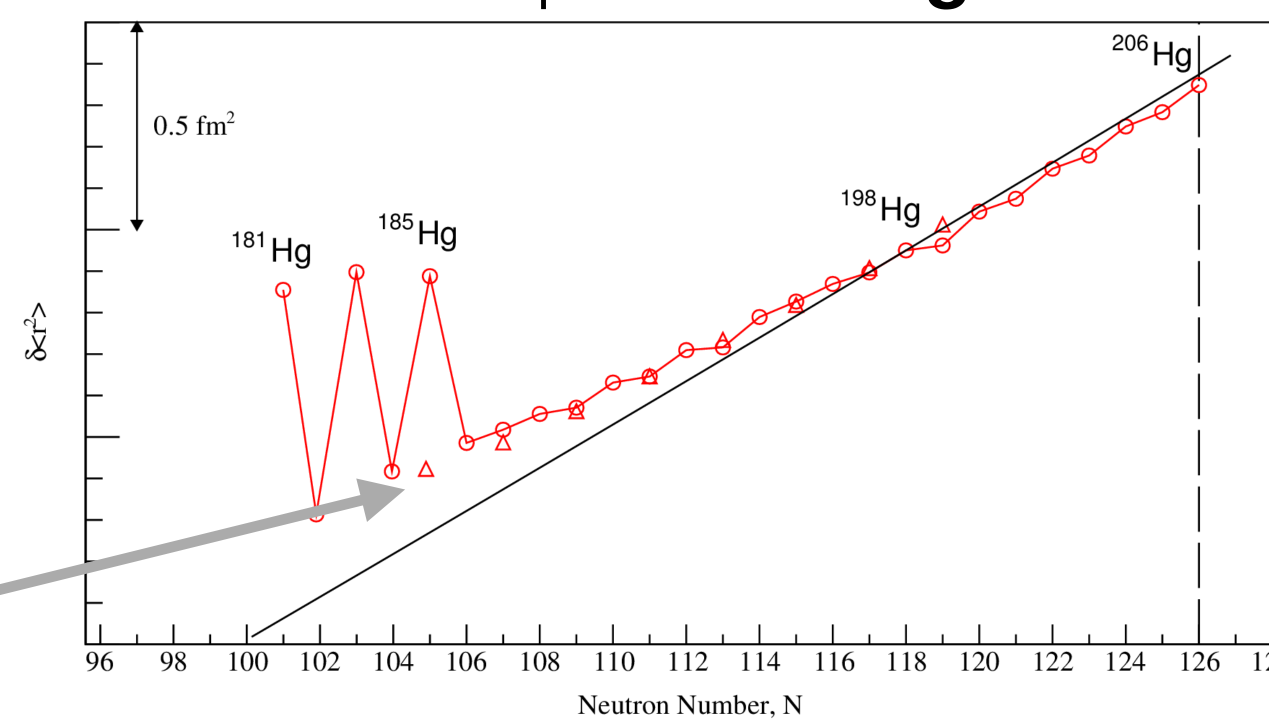


$$\delta\nu_{IS} = \delta\nu_{MS} + \delta\nu_{FS}$$

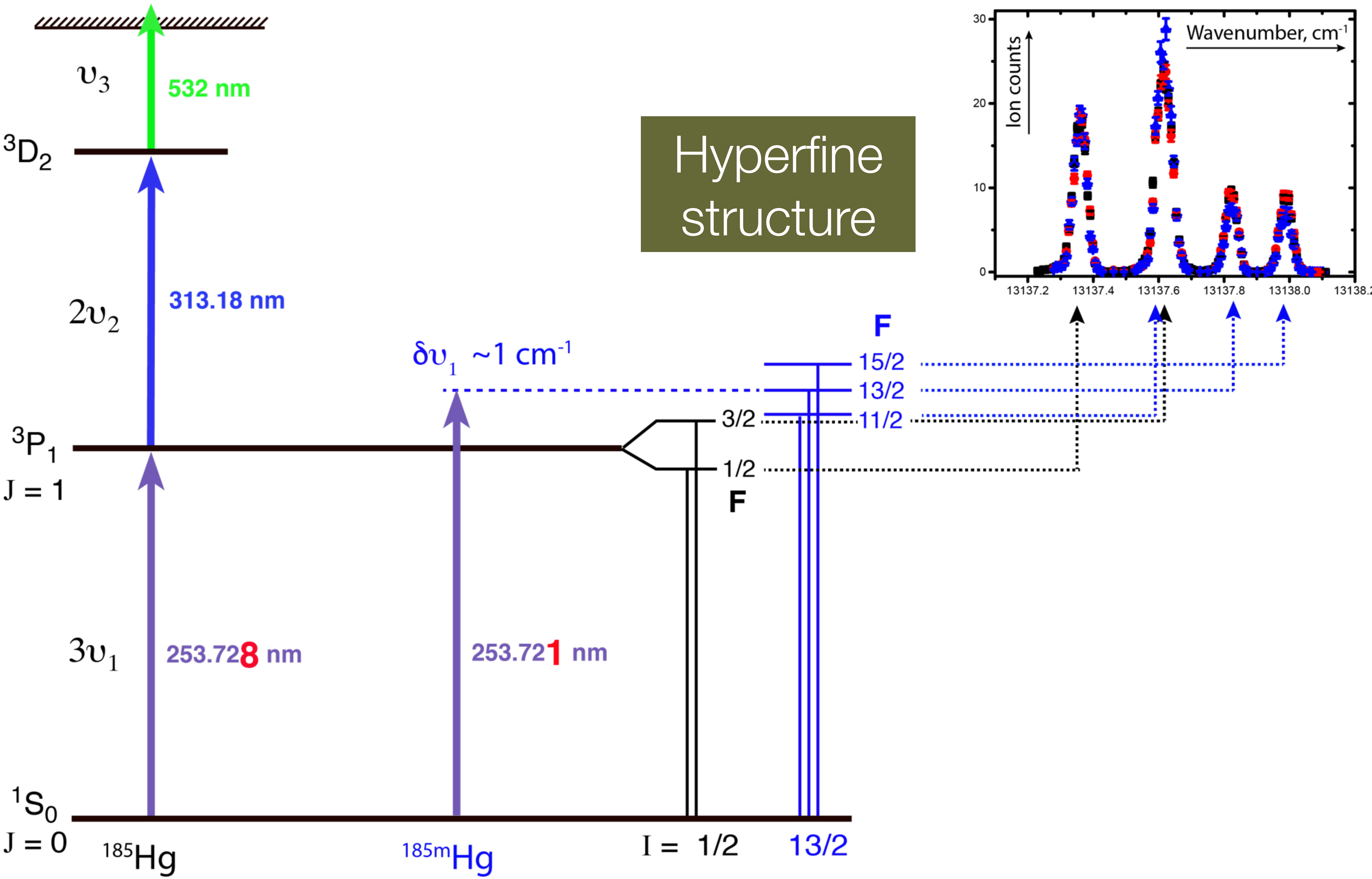
$$\delta\nu_{FS} = \frac{2\pi Z}{3}\Delta|\psi(0)|^2\delta\langle r^2\rangle$$

EXPERIMENT **THEORY**

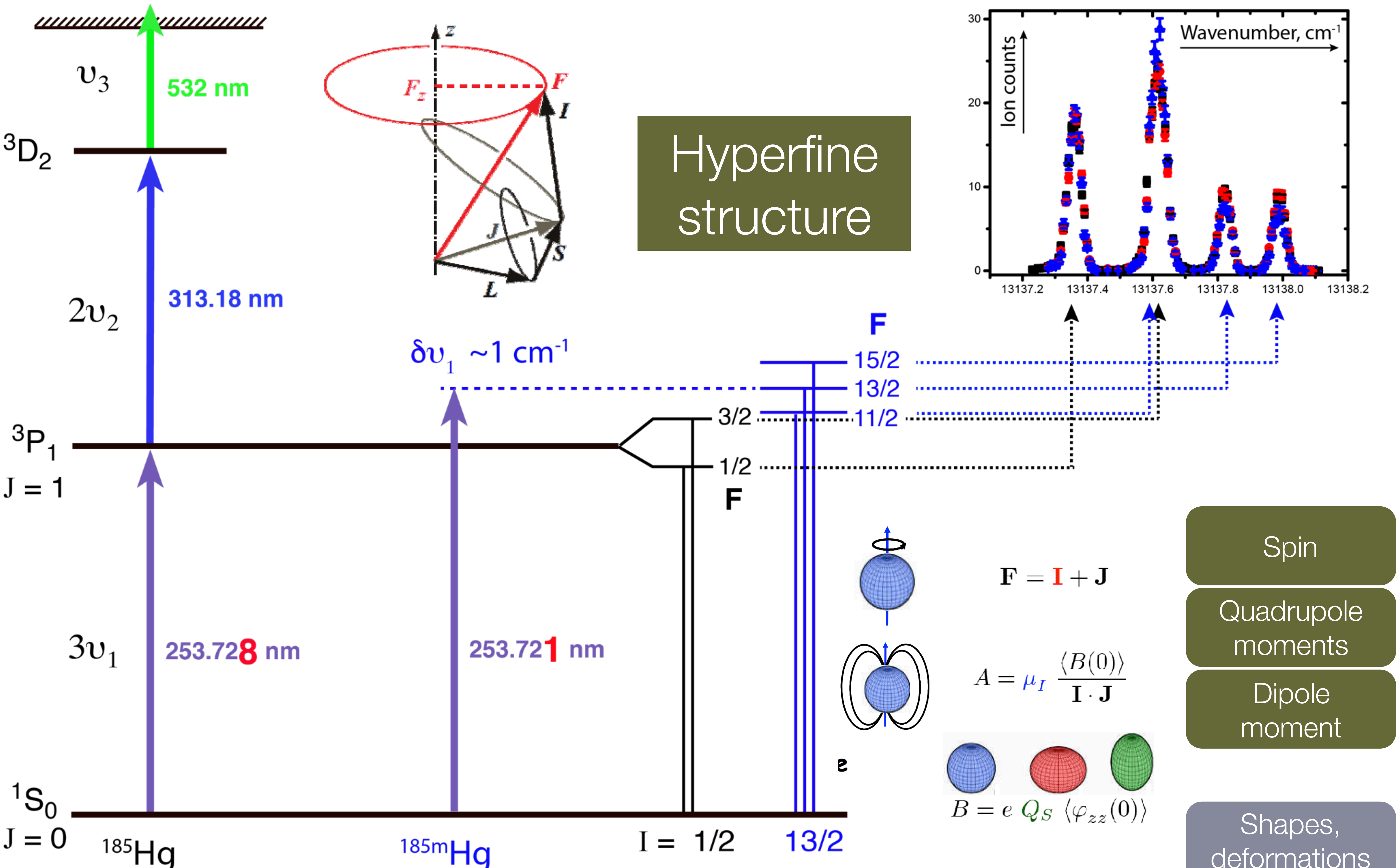
Change in nuclear mean-squared **charge radius**



Laser spectroscopy (mercury example)



Laser spectroscopy (mercury example)



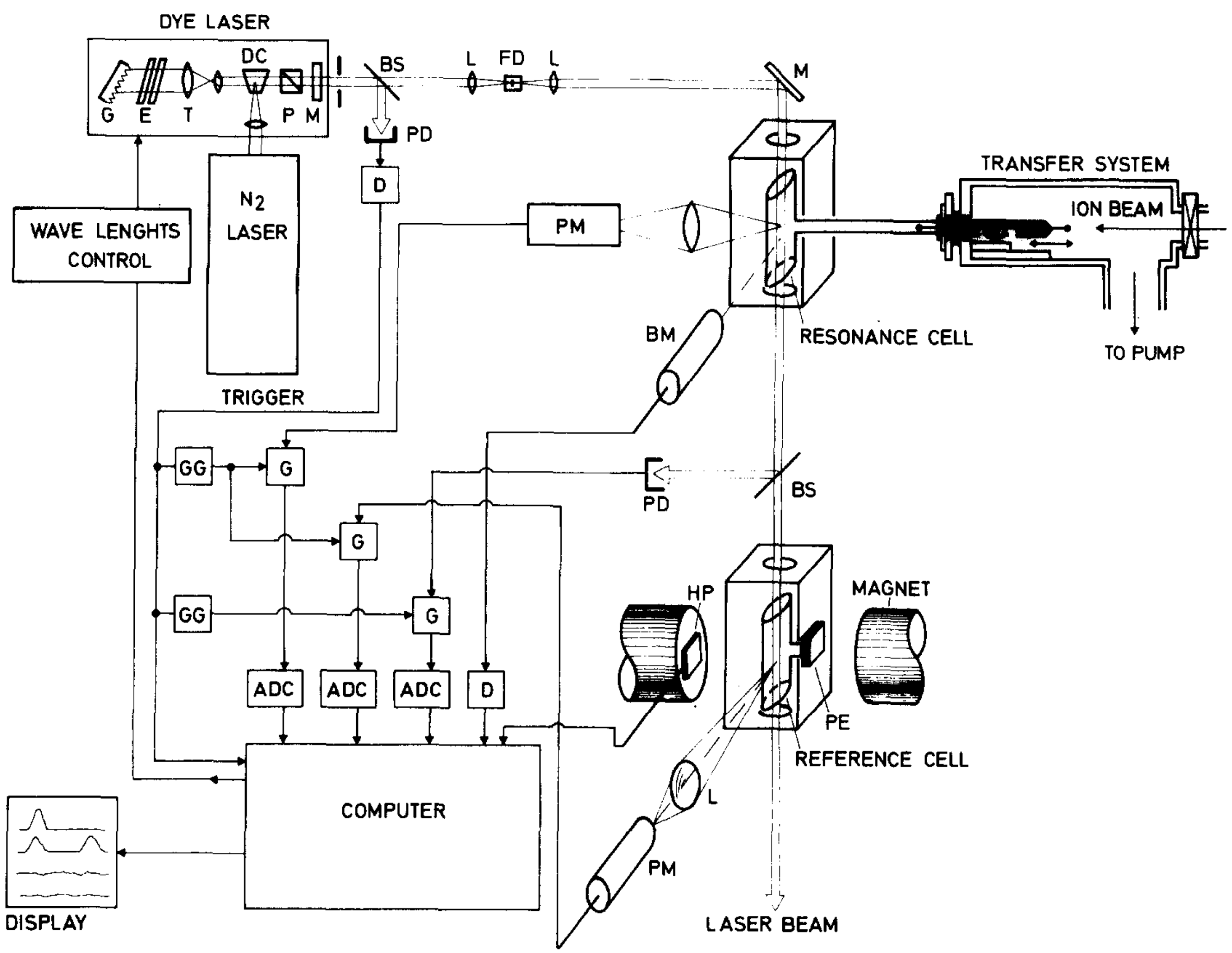
Year 1977

Pioneering early studies: $^{204-184}Hg$

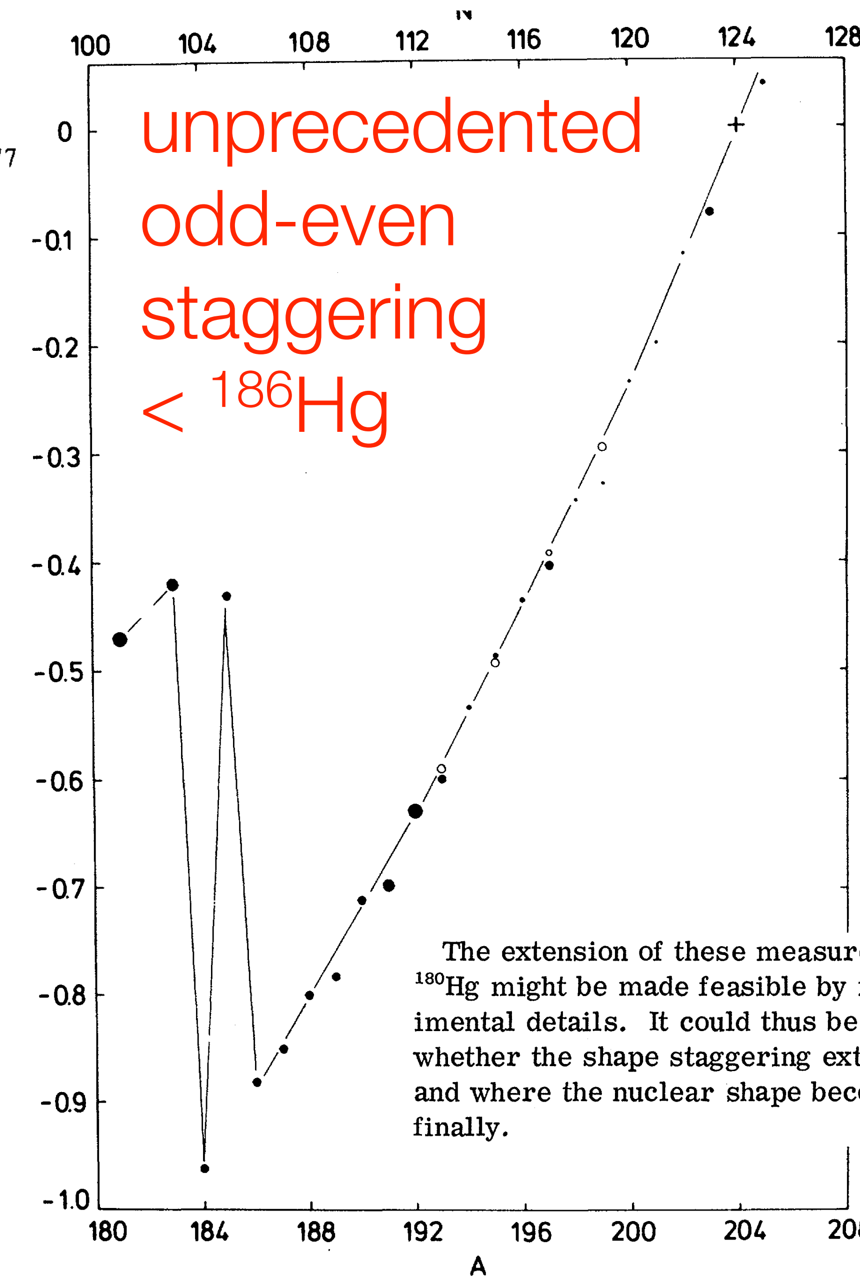
Nuclear Shape Staggering in Very Neutron-Deficient Hg Isotopes Detected by Laser Spectroscopy[a]

T. Kühl, P. Dabkiewicz, C. Duke,[b] H. Fischer, H.-J. Kluge, H. Kremmling, and E.-W. Otten
Institut für Physik, Universität Mainz, Mainz, Germany
(Received 1 April 1977)

Volume 60A, number 4 PHYSICS LETTERS 7 March 1977



Volume 39, Number 4 PHYSICAL REVIEW LETTERS 25 July 1977



The extension of these measurements down to ^{180}Hg might be made feasible by improving experimental details. It could thus be determined whether the shape staggering extends further, and where the nuclear shape becomes stabilized finally.

✗ Collection time limited by half-life

✗ Low sensitivity: photon detection

Year 1987

Pioneering early studies: $^{185\text{-}189}$Au

VOLUME 58, NUMBER 15 PHYSICAL REVIEW LETTERS 13 APRIL 1987

Sudden Change in the Nuclear Charge Distribution of Very Light Gold Isotopes

K. Wallmeroth, G. Bollen, A. Dohn,[a] P. Egelhof, J. Grüner, F. Lindenlauf, and U. Krönert
Institut für Physik, Universität Mainz, D-6500 Mainz, Federal Republic of Germany

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M. J. G. Borge and A. Venugopalan[b]
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J. L. Wood
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R. B. Moore
McGill University, Montreal, Canada H3A 2B2

and

H.-J. Kluge
Institut für Physik, Universität Mainz, D-6500 Mainz, Federal Republic of Germany, and ISOLDE Collaboration, CERN, CH-1211 Geneva, Switzerland
(Received 29 December 1986)

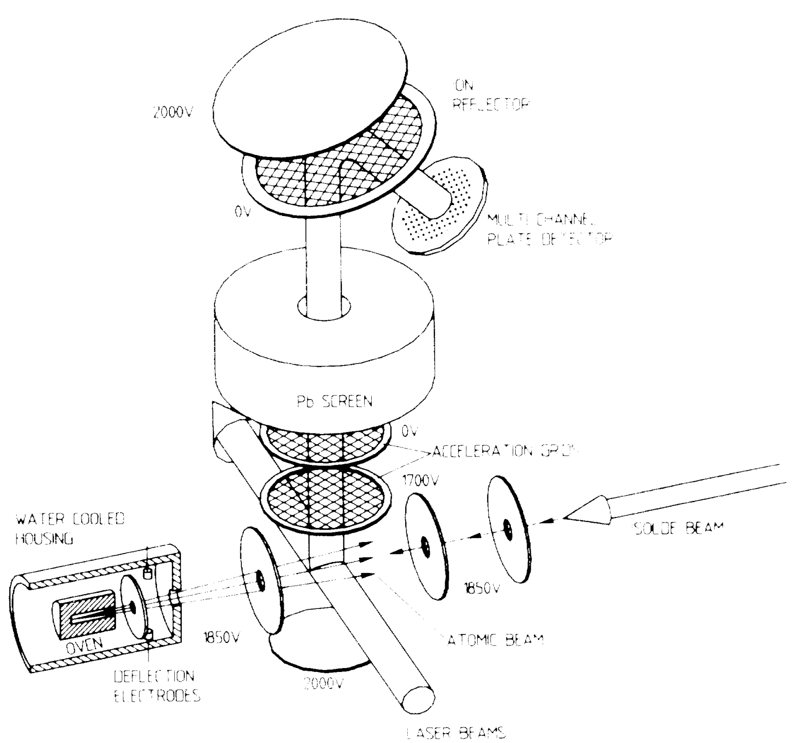
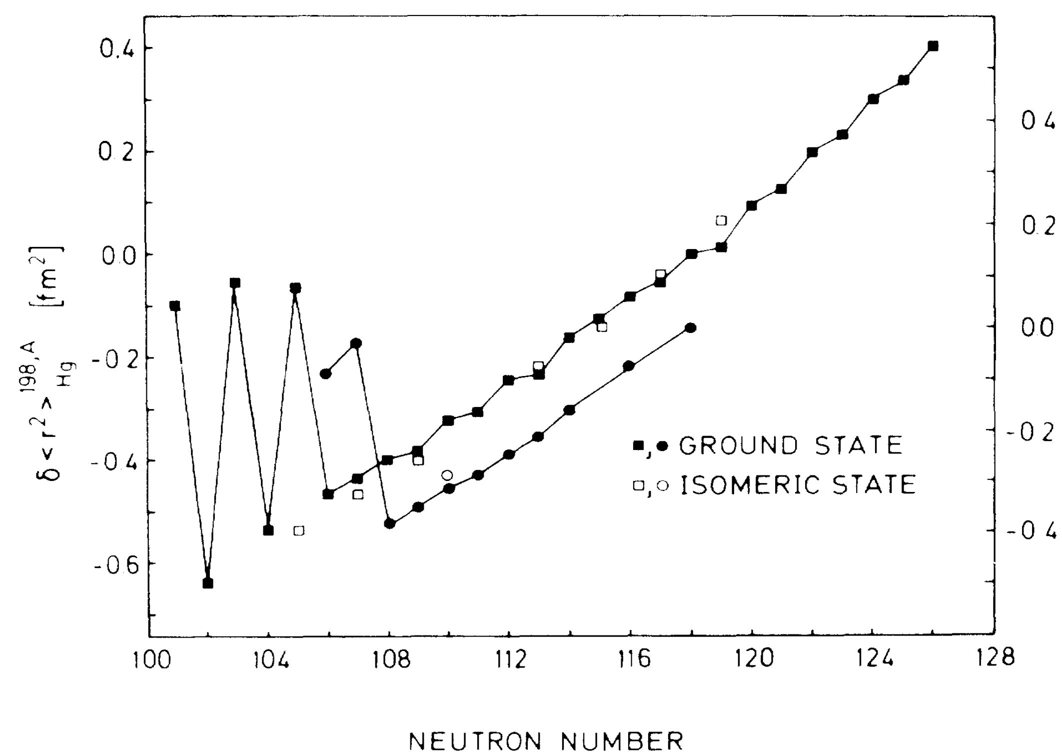


FIG. 1. Setup for on-line resonance ionization mass spectroscopy on short-lived Au isotopes.



Sudden onset of quadrupole deformation (β=0.25) at ^{186}Au

Does this persist beyond N=104?

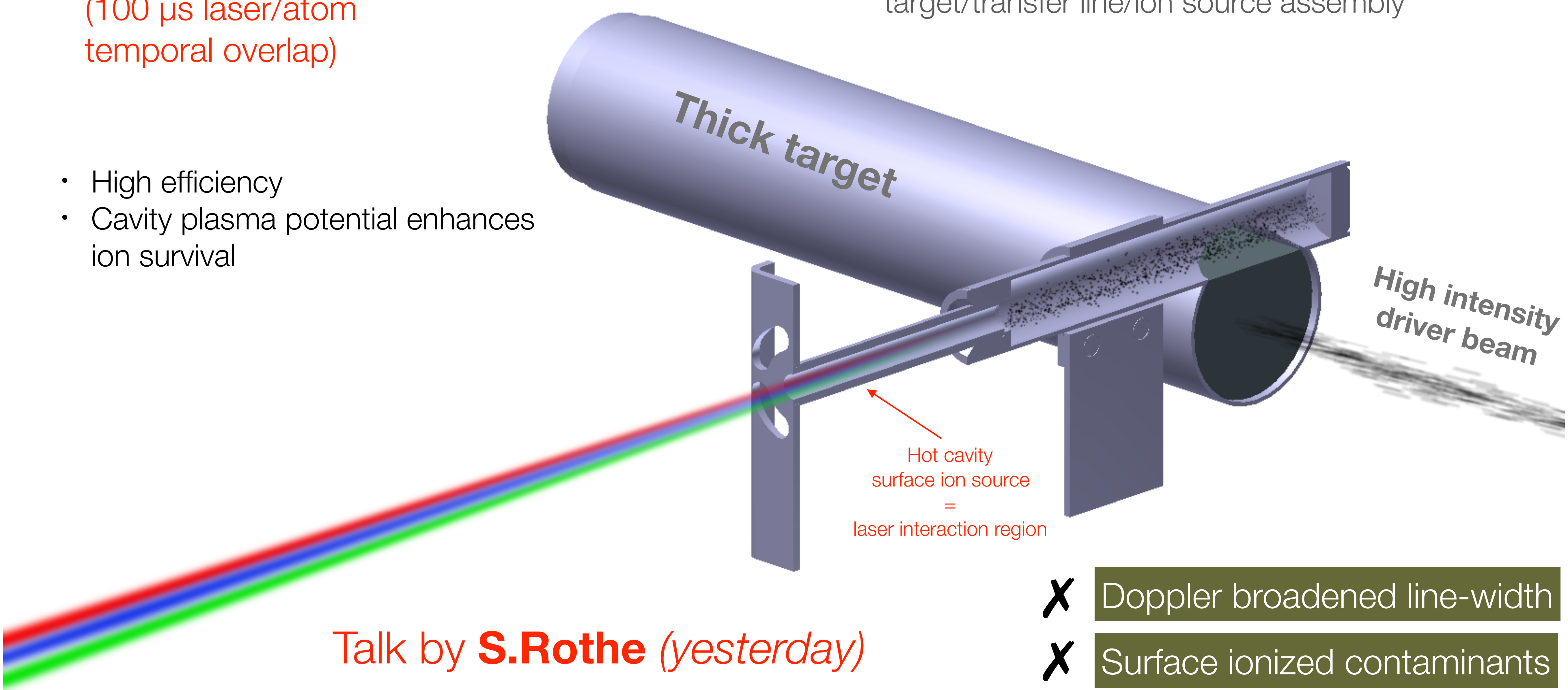
- ✗ Collection time limited by half-life
- ✗ Despite single ion detection, sensitivity limited by duty cycle losses

The ISOLDE RILIS - as a spectroscopy tool

36 RILIS ionized elements routinely available

Laser requirements:
>10 kHz rep rate
(100 μs laser/atom
temporal overlap)

- High efficiency
- Cavity plasma potential enhances ion survival

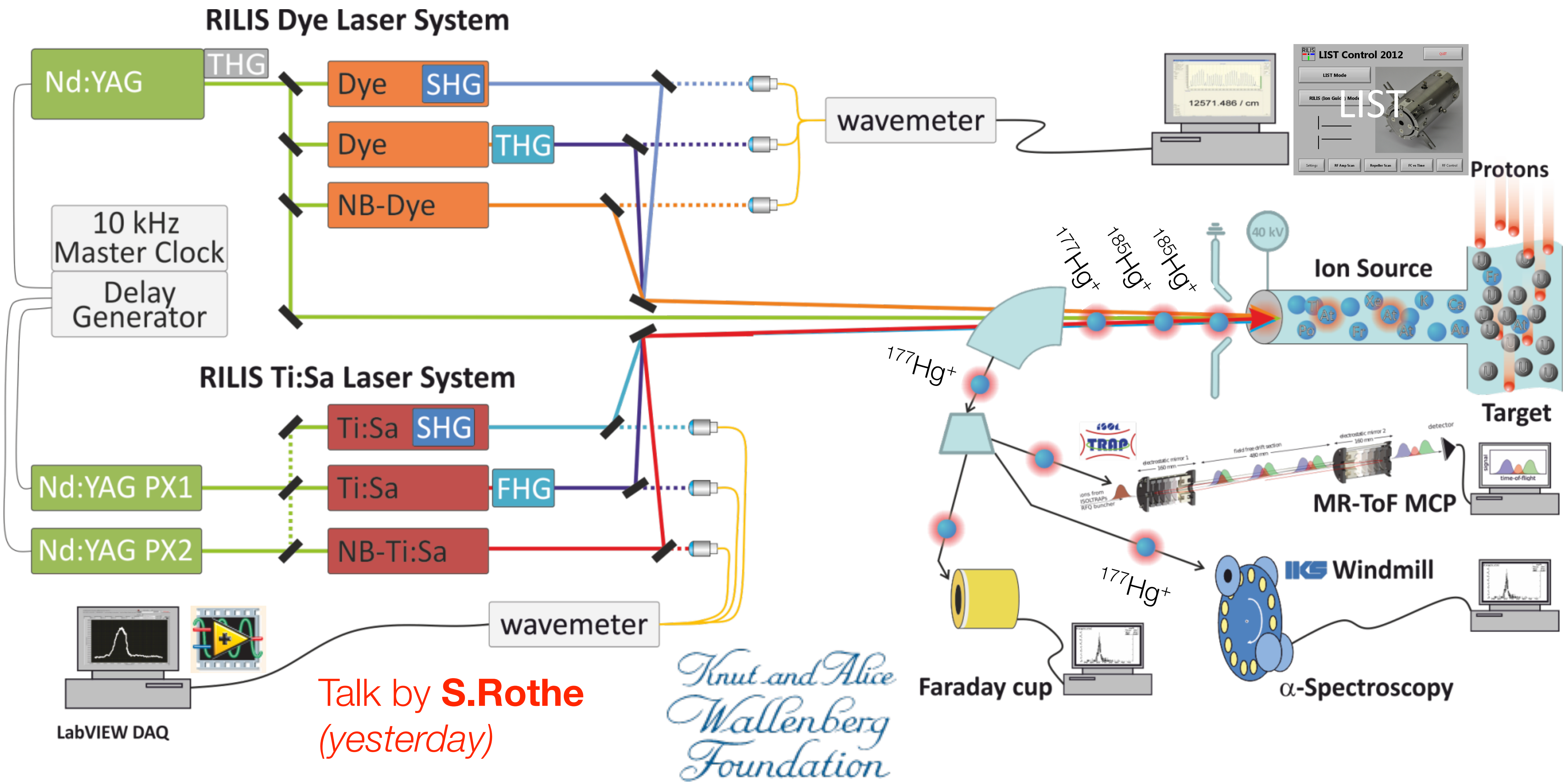


✗ Doppler broadened line-width

✗ Surface ionized contaminants

Talk by **S.Rothe** *(yesterday)*

The ISOLDE RILIS setup + detection methods



Talk by **S.Rothe**
(yesterday)

NB-TiSa

New DAQ and RILIS remote control

Laser Ion Source Trap

RILIS in FEBIAD ion source

ISOLTRAP MR-TOF MS synchronised with laser scanning

S.Rothe et al. EMIS 2015 Proceedings

The In-Source RIS collaboration at ISOLDE

Comenius University, Bratislava, Slovakia
GANIL, Caen, France
Helmholtz Institut Jena, Germany
ILL, Grenoble, France
Institut für Physik, Universität Mainz, Germany
IPN Orsay, France
JAEA, Tokai, Japan
KU Leuven, IKS, Belgium
PNPI, Gatchina, Russian Federation
RILIS and ISOLDE, CERN, Switzerland
SCK-CEN, Mol, Belgium
The University of Manchester, United Kingdom
The University of York, United Kingdom
University of Liverpool, United Kingdom
University of the West of Scotland, United Kingdom

>50 participants

14 institutes

RILIS

WINDMILL

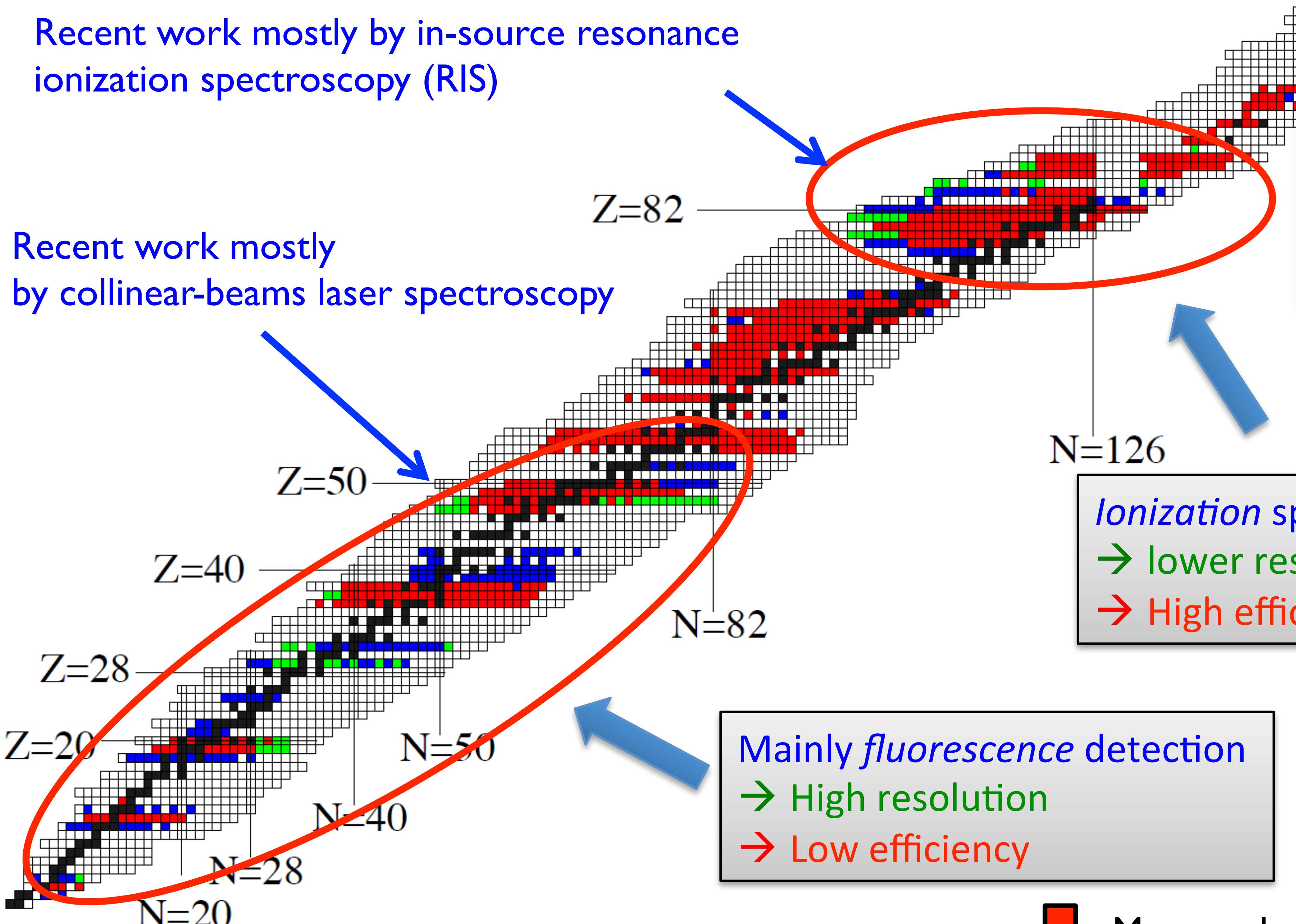
ISOLTRAP

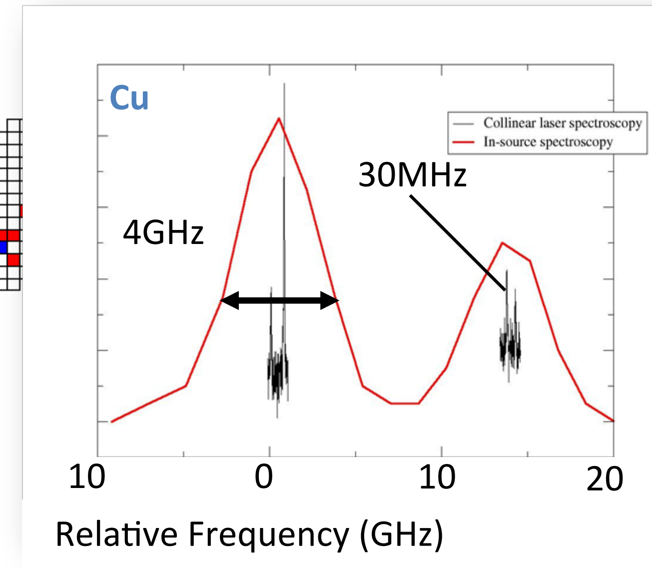
IS407 Pb, Bi	**IS456** Po	**IS511** Tl	**IS534** At, Au	**IS598** Hg	**IS???** Bi

The role of in-source RIS

Recent work mostly by in-source resonance ionization spectroscopy (RIS)

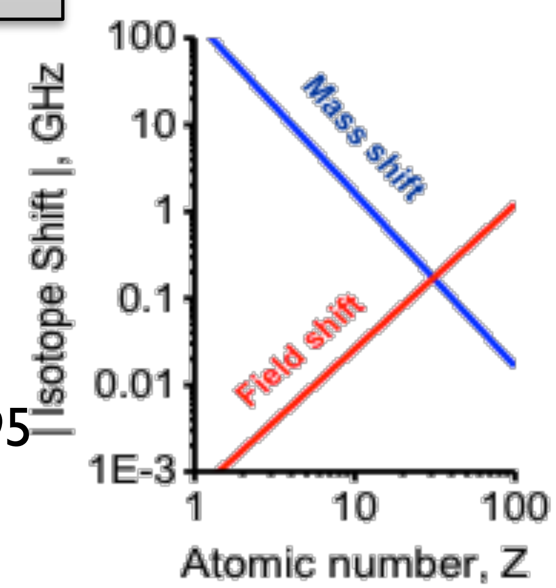
Recent work mostly by collinear-beams laser spectroscopy





Ionization spectroscopy
→ lower resolution
→ High efficiency

Mainly *fluorescence* detection
→ High resolution
→ Low efficiency

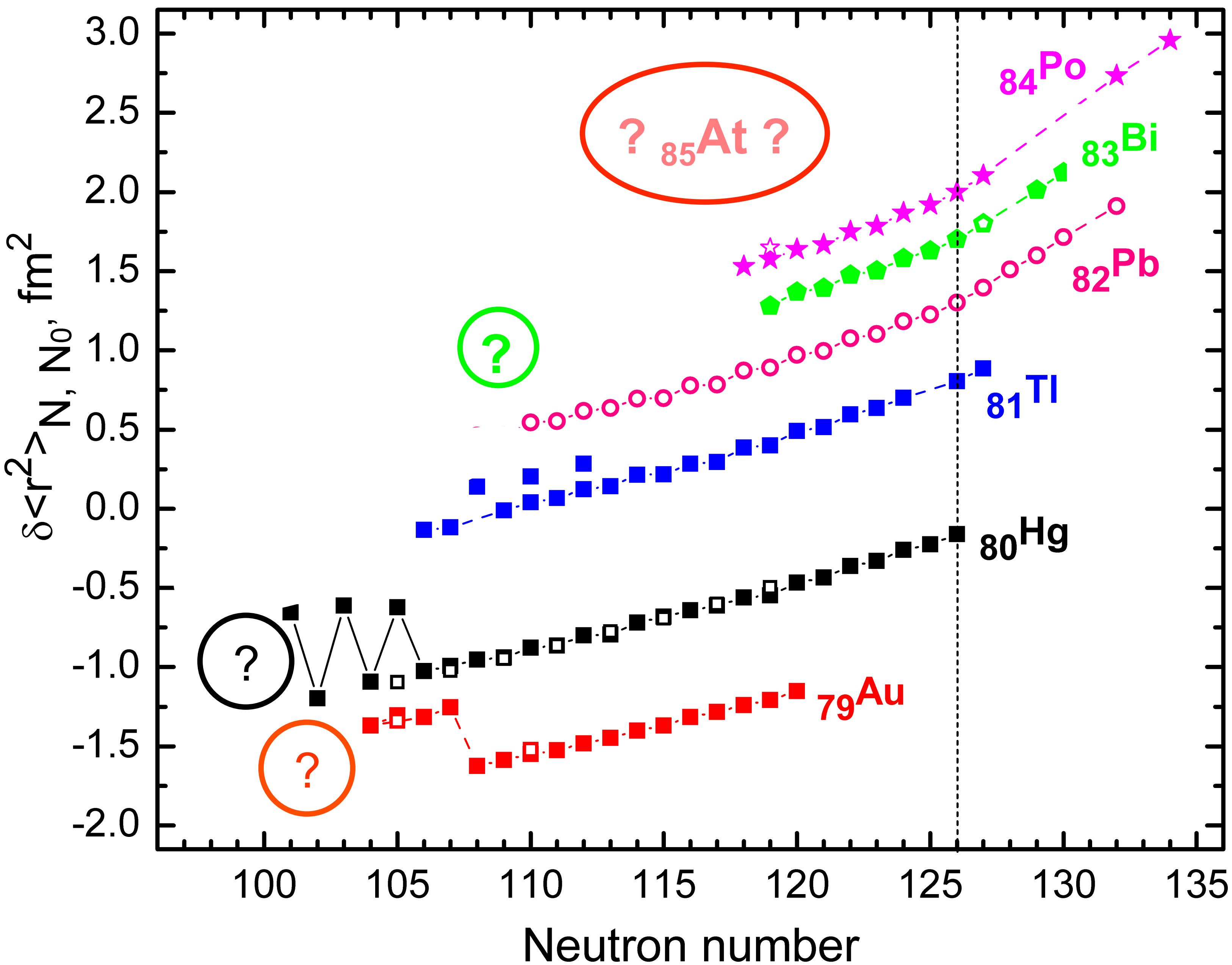


Measured prior to 1995
Measured 1995 - 2010
Measured since 2010

Updated plot provided by Bradley Cheal from 2010 review (B. Cheal & K.T. Flanagan J. Phys. G 37 (2010) 113101)

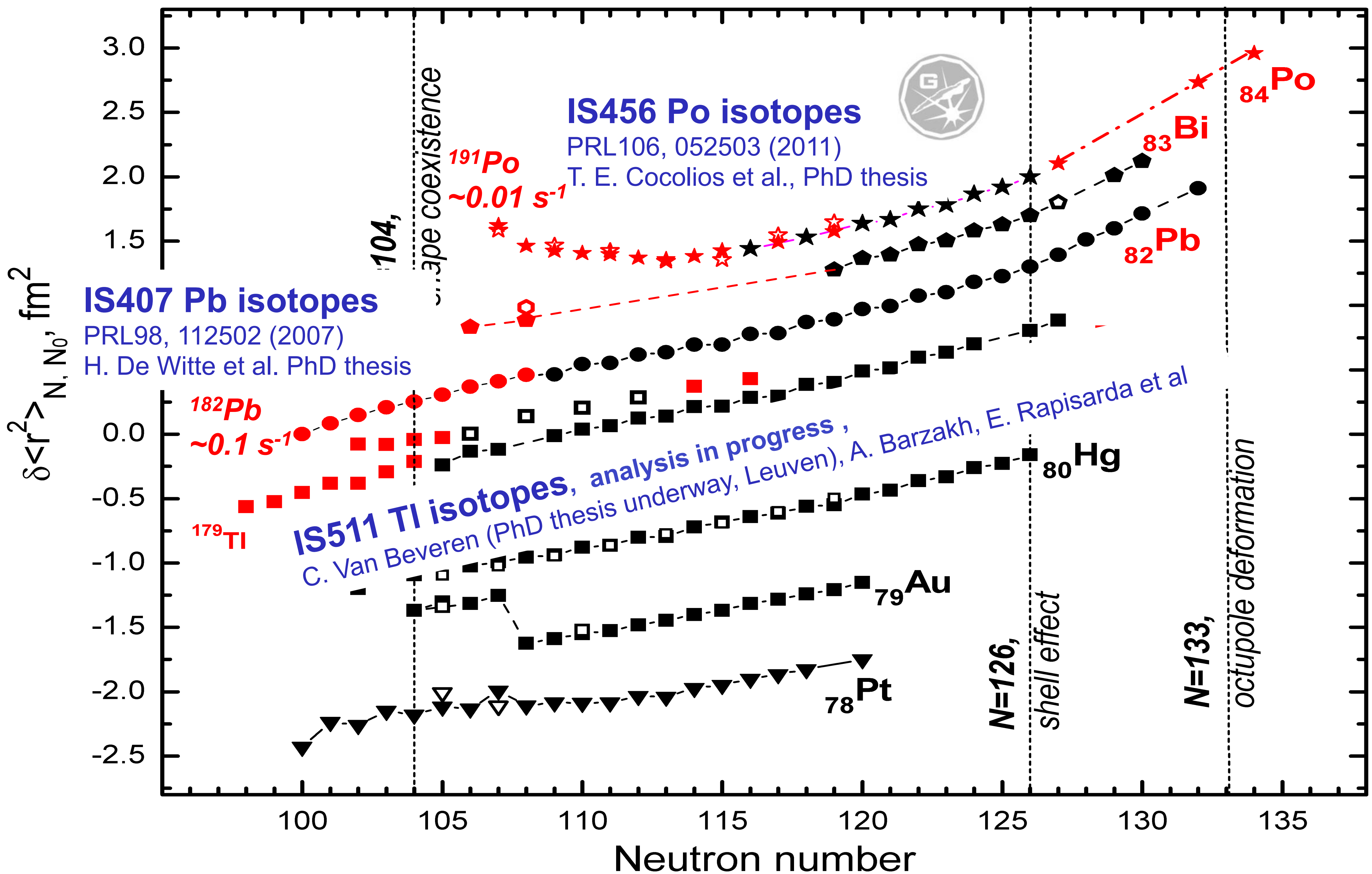
Pre 2002

Plots provided by A. Barzakh (PNPI)



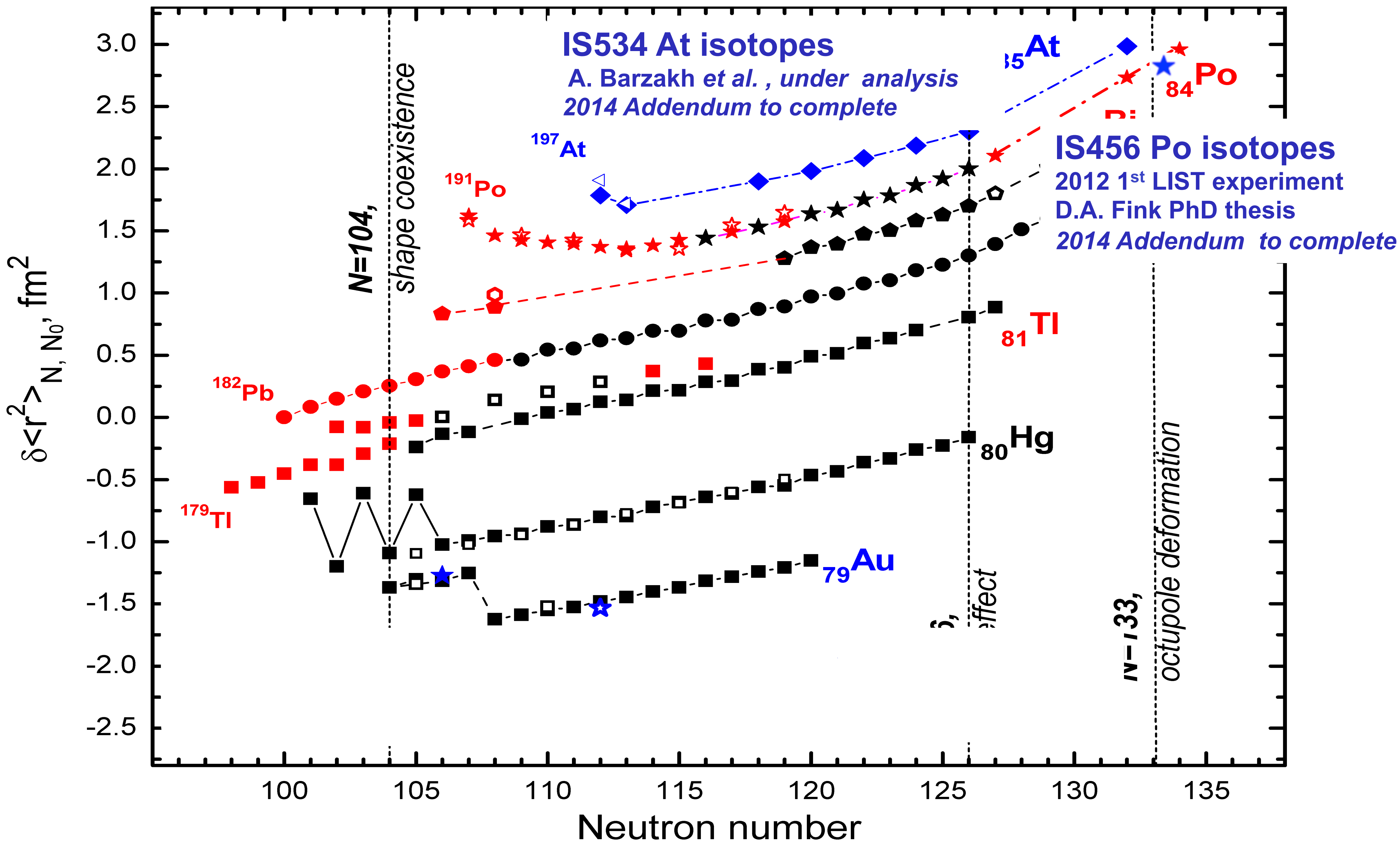
- Shape coexistence around N~104
- Sphericity around N=126, kink in radii, high-spin isomers
- Octupole effects around N~132, inverse odd-even radii staggering

2002-2011: Tl, Pb, Po, Bi



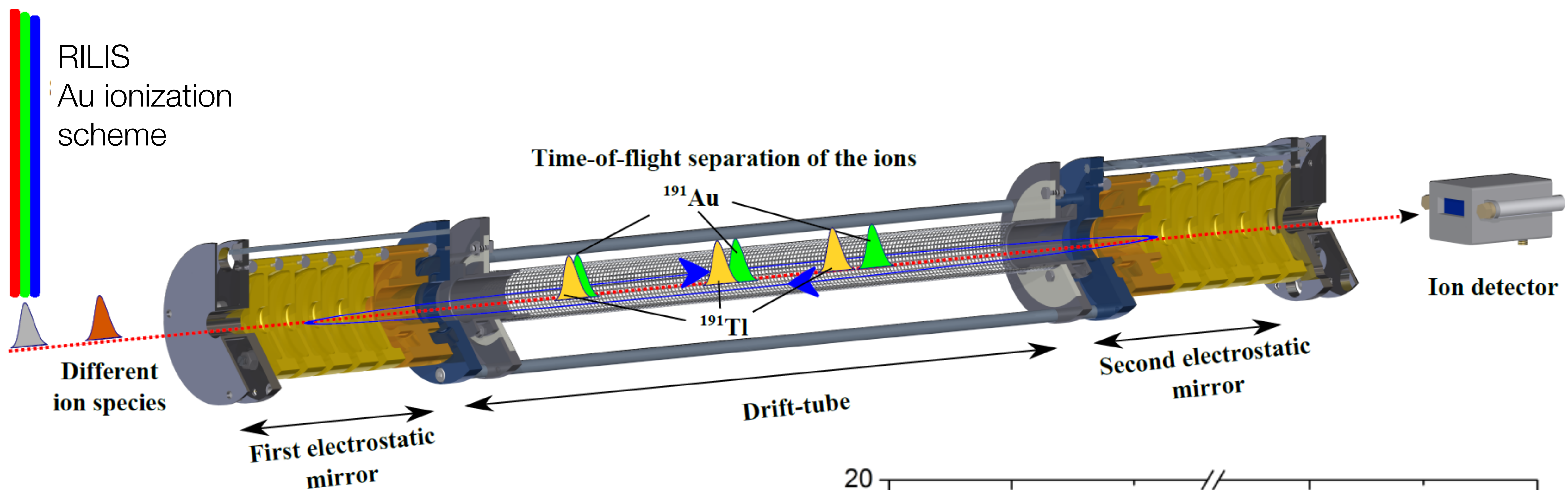
- 3 PhD theses: Pb: H. De Witte (KU Leuven); Bi: B.A. Marsh (Manchester); Po: T.E. Cocolios (KU Leuven)
- 2 PRL's, 1 PLB, + 5 papers

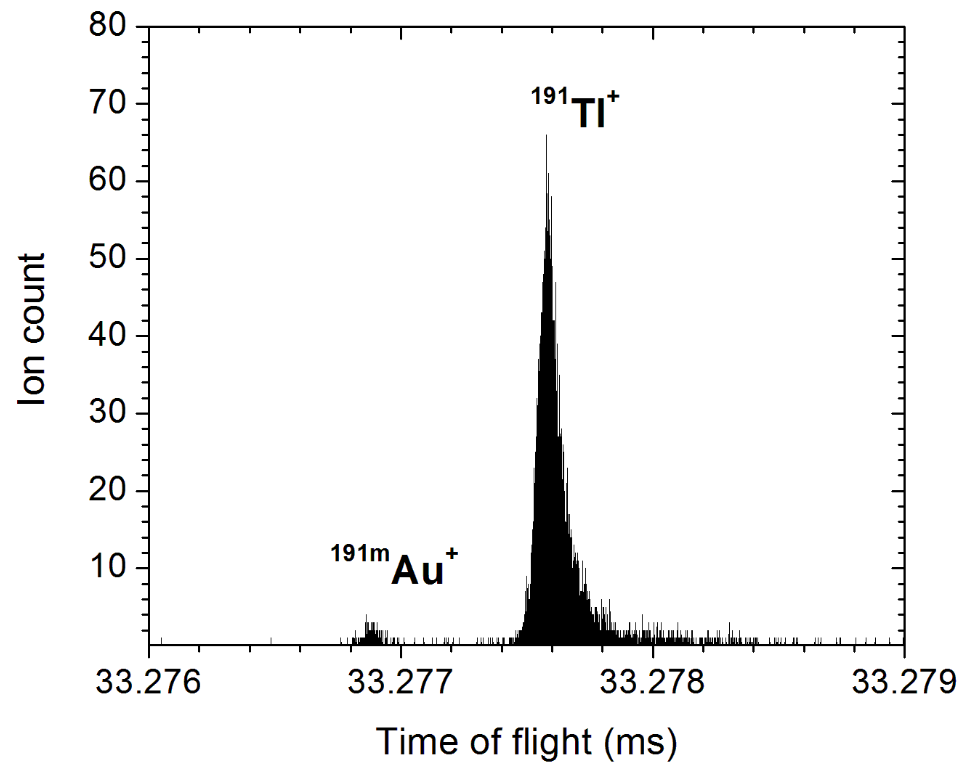
2011 - 2012: Po and At

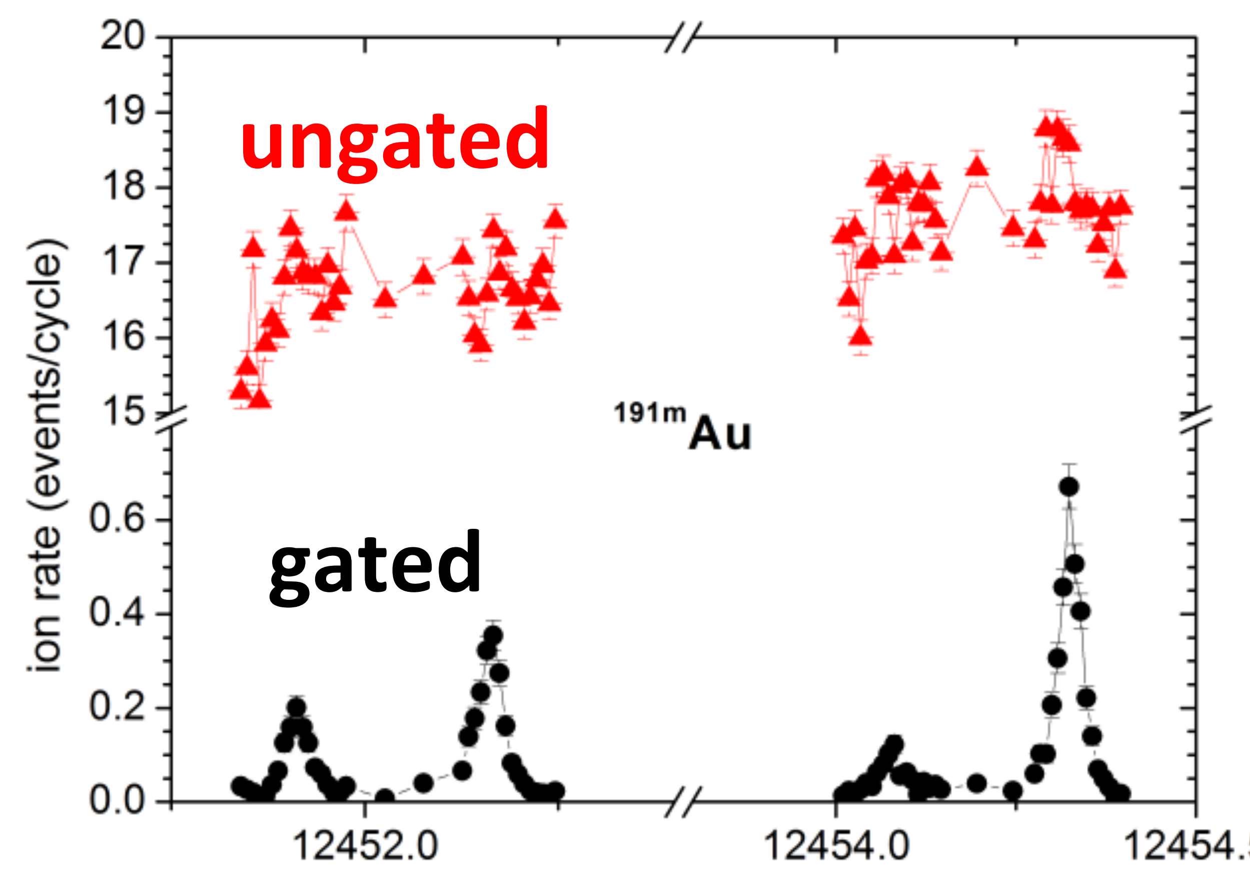


- **First measurement for At isotopes: ^{197,198,203,205,207,209,211,217}At**
- **First experiment with the LIST: ^{217}Po**

2014: Join forces with ISOLTRAP MRToF-MS



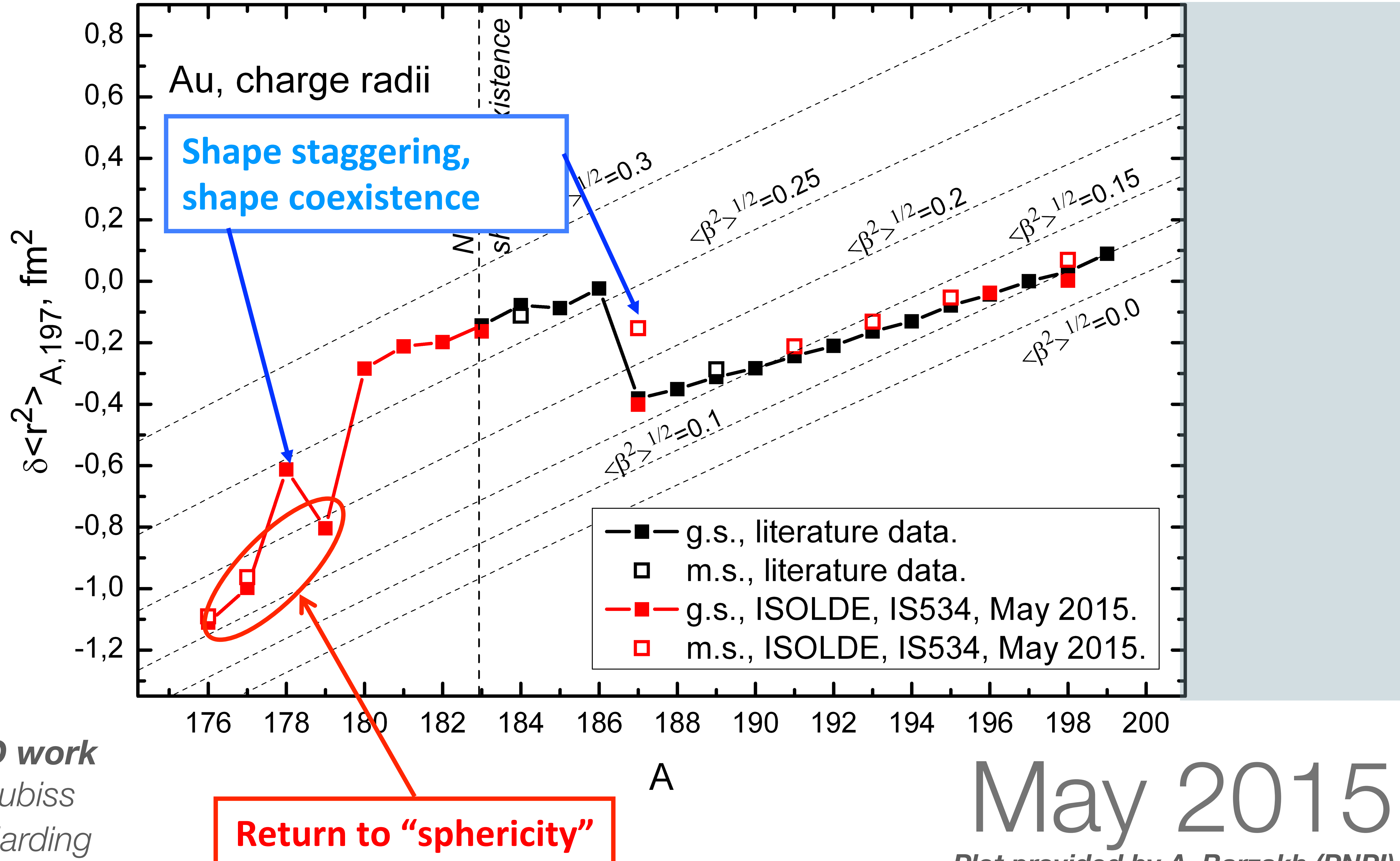




Slide:
V. Manea

28 years later……..

Charge radii of the gold isotopes

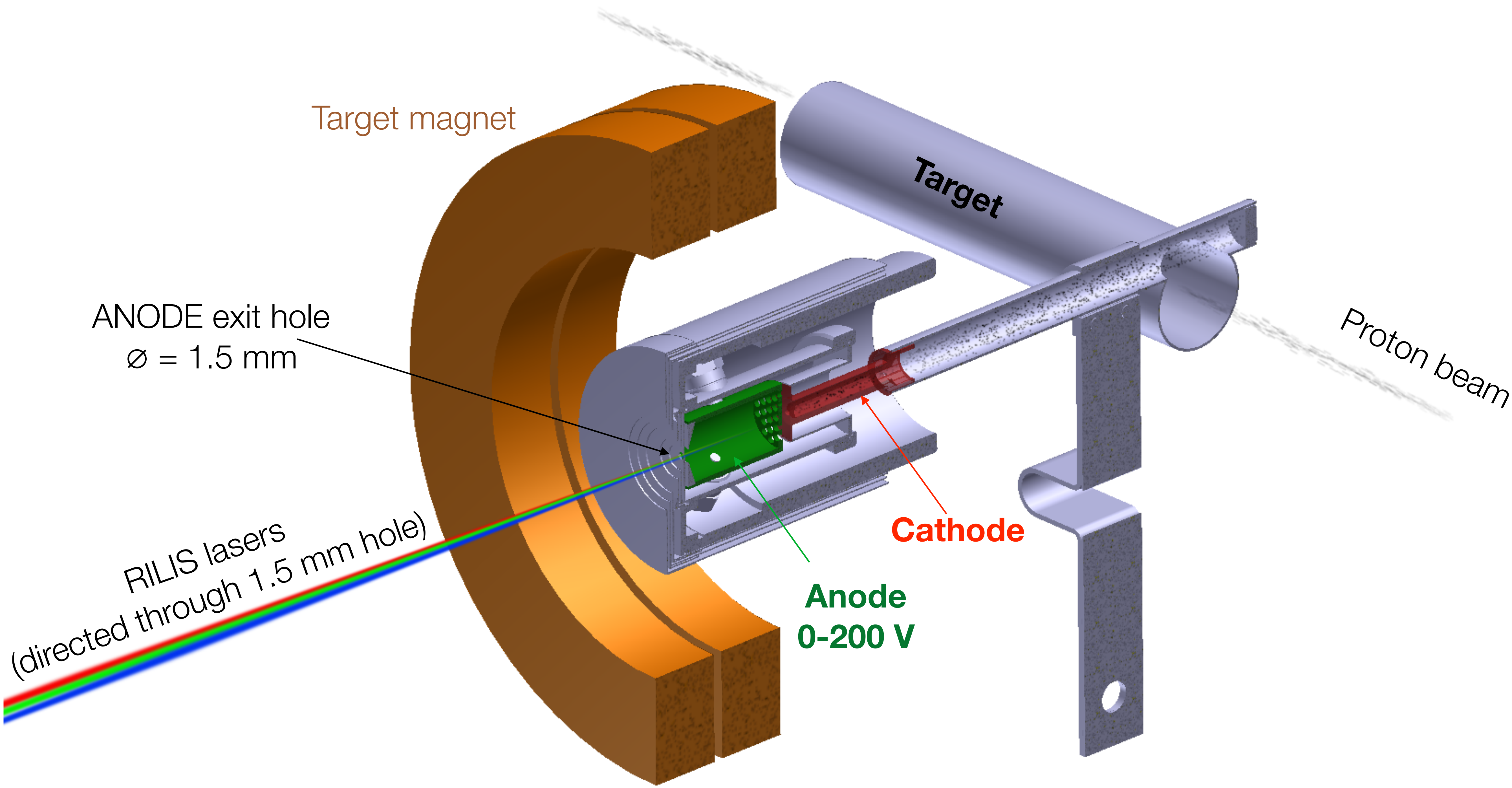


PhD work
J. Cubiss
R. Harding

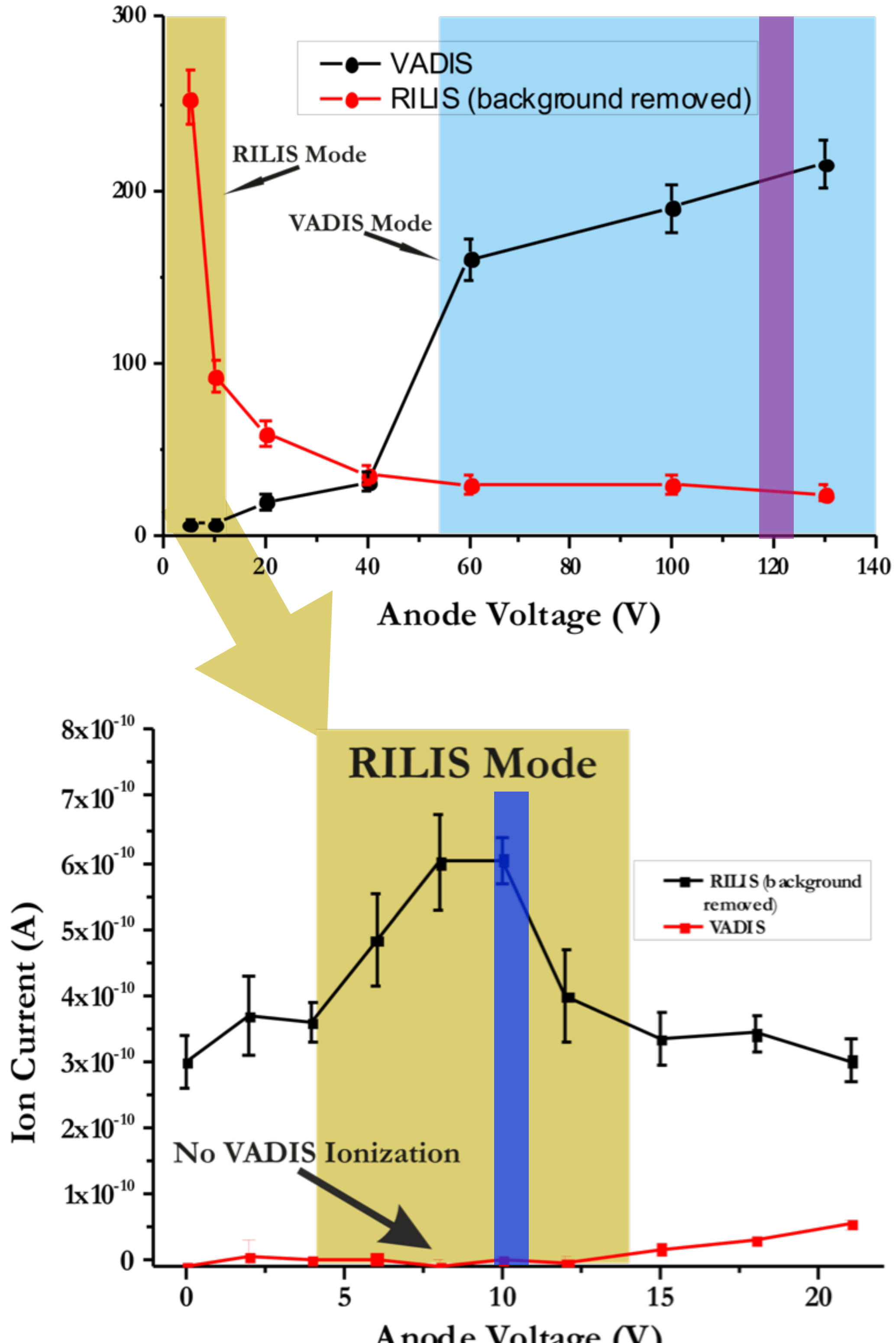
May 2015

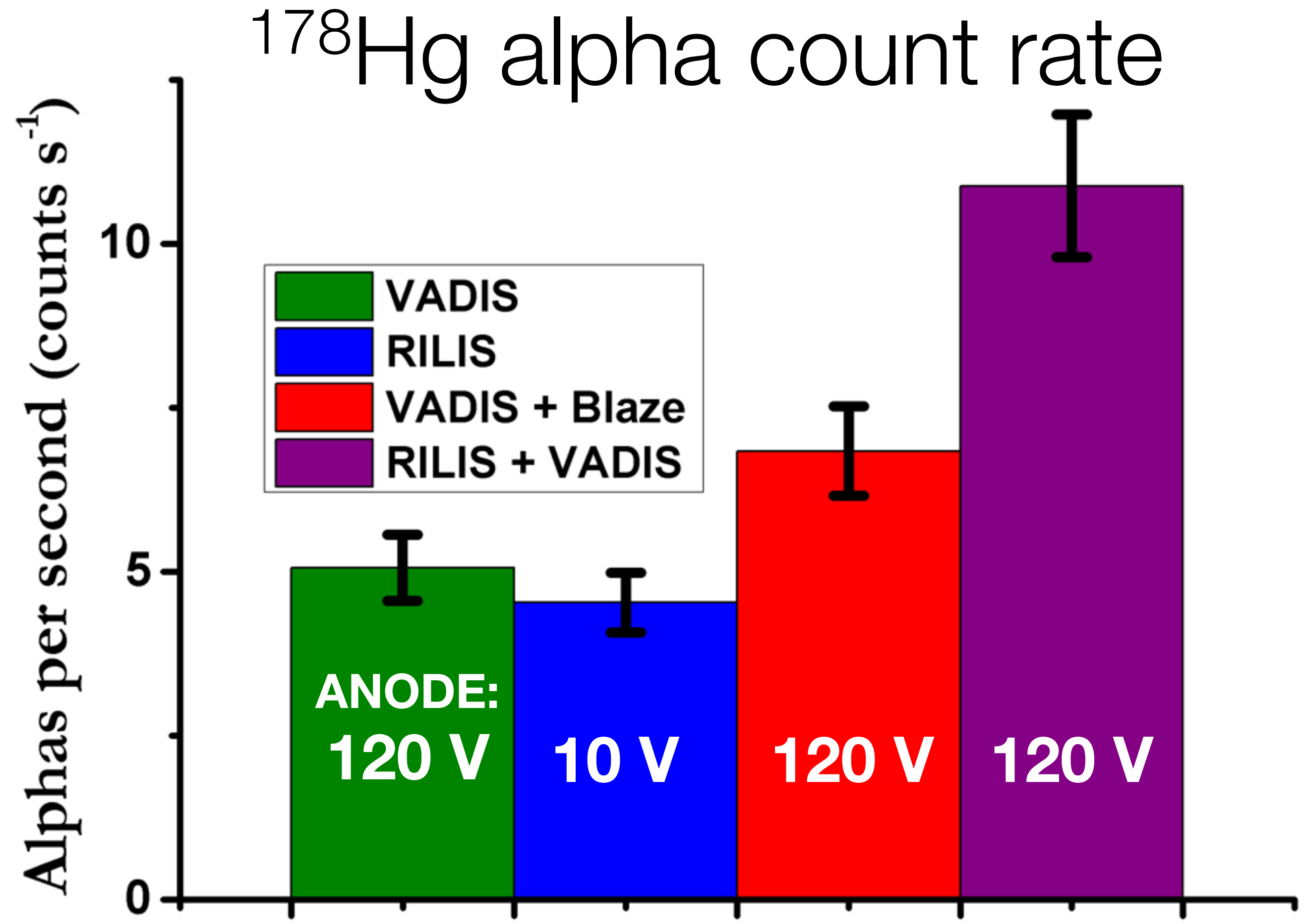
Plot provided by A. Barzakh (PNPI)

VADLIS: an alternative to hot-cavity RILIS



Establishing RILIS-mode FEBIAD operation





This enables RILIS to couple to a molten Pb target

Easy switching between highly selective RILIS mode and higher efficiency RILIS+FEBIAD mode

PhD work: *T. Day Goodacre*

Scope of the Hg study: April 2015

Measured Isotopes

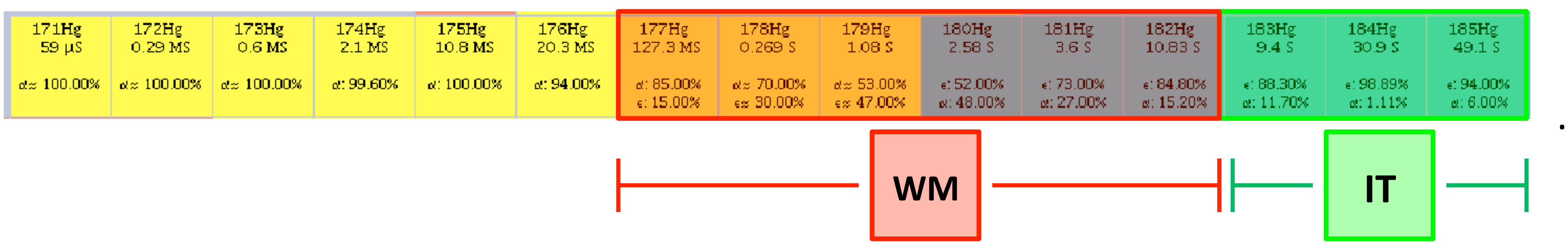
3 Different measurement techniques

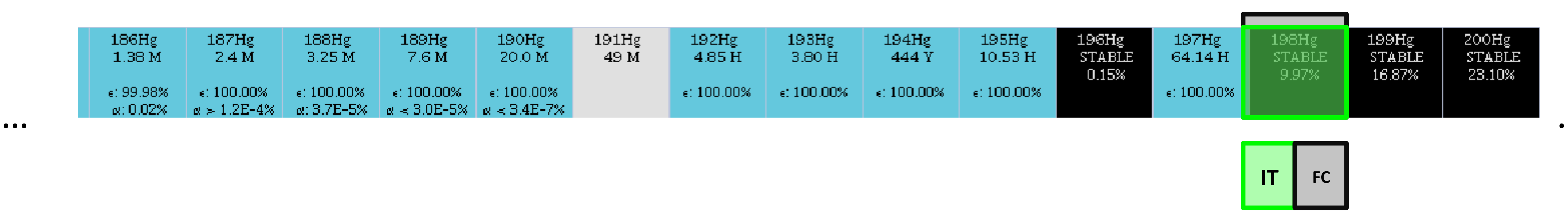
WM windmill | **IT** ISOLTRAP | **FC** Faraday cup

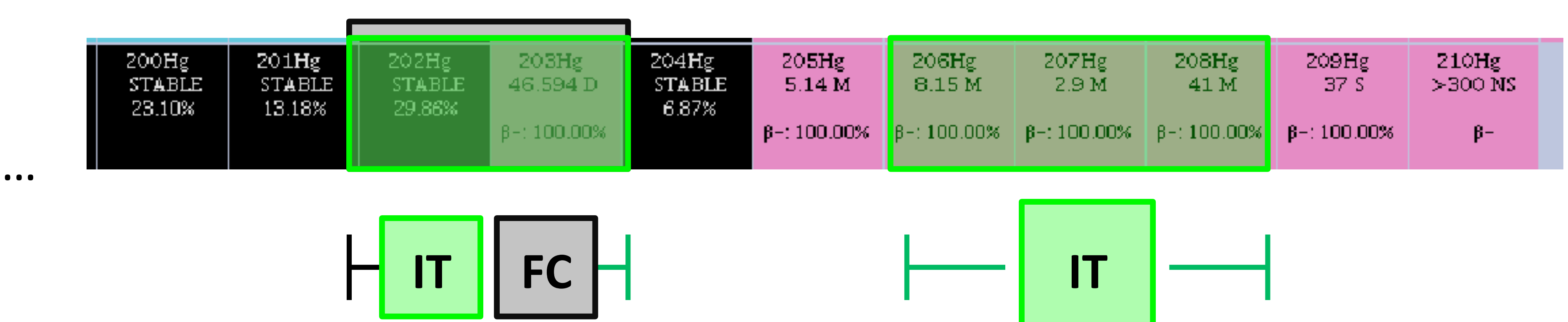
IS598 – APRIL 2015

15 Different Hg isotopes: 177,178,179,180,181,182,183,184,185,198,202,203,206,207,208

,198,202,203,







Slide: S. Sels

Windmill + MRToF-MS assisted laser scans

^{177}Hg

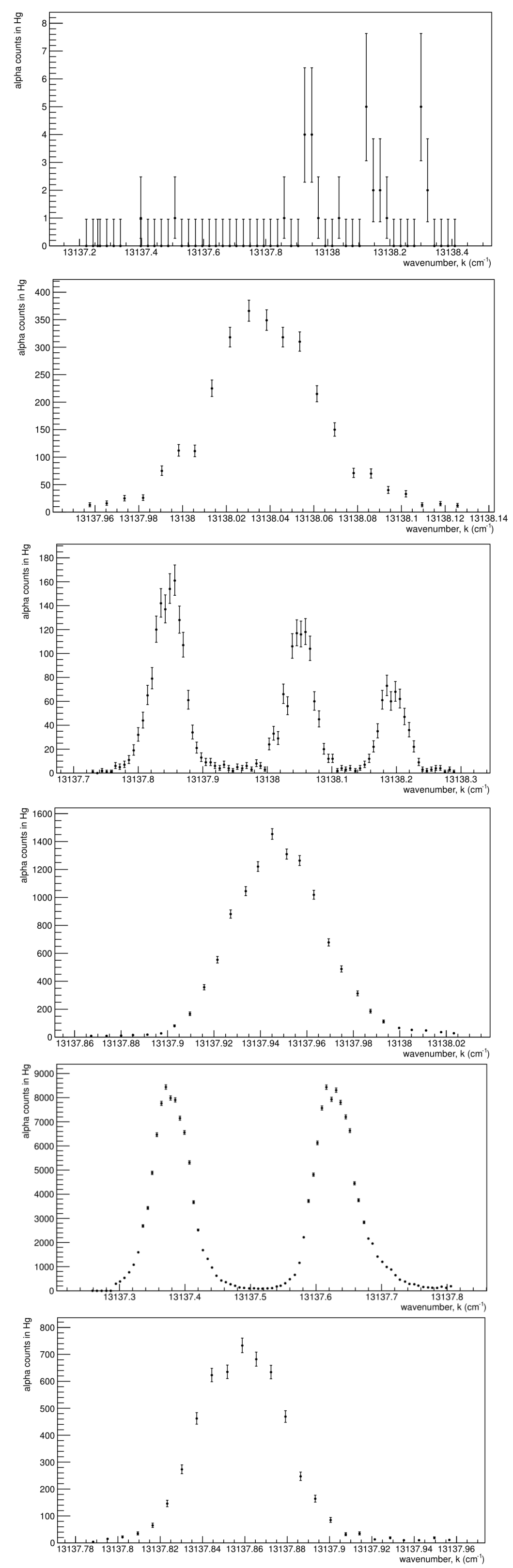
^{178}Hg

^{179}Hg

^{180}Hg

^{181}Hg

^{182}Hg



^{208}Hg

^{207}Hg

^{206}Hg

^{203}Hg

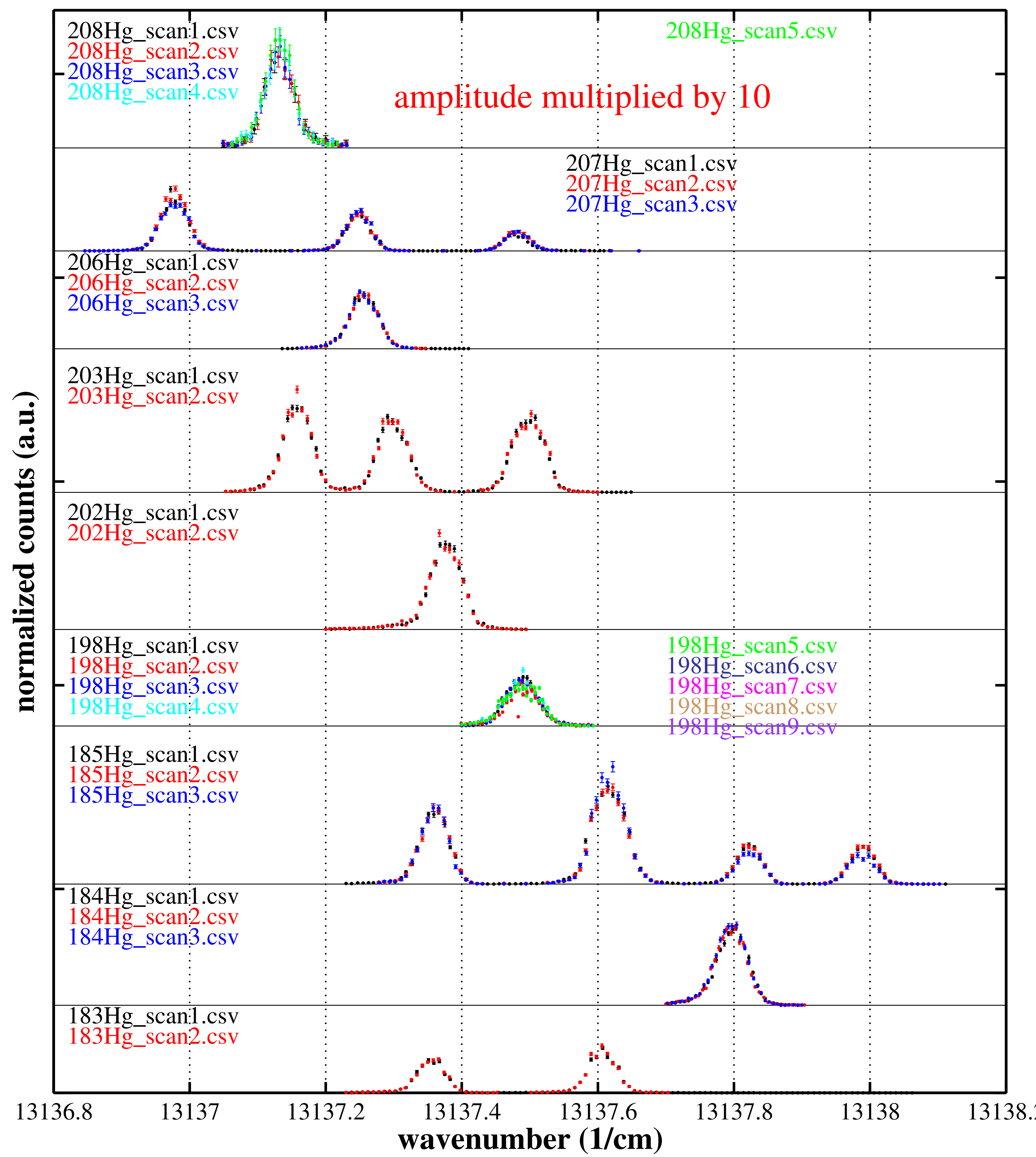
^{202}Hg

^{198}Hg

^{185}Hg

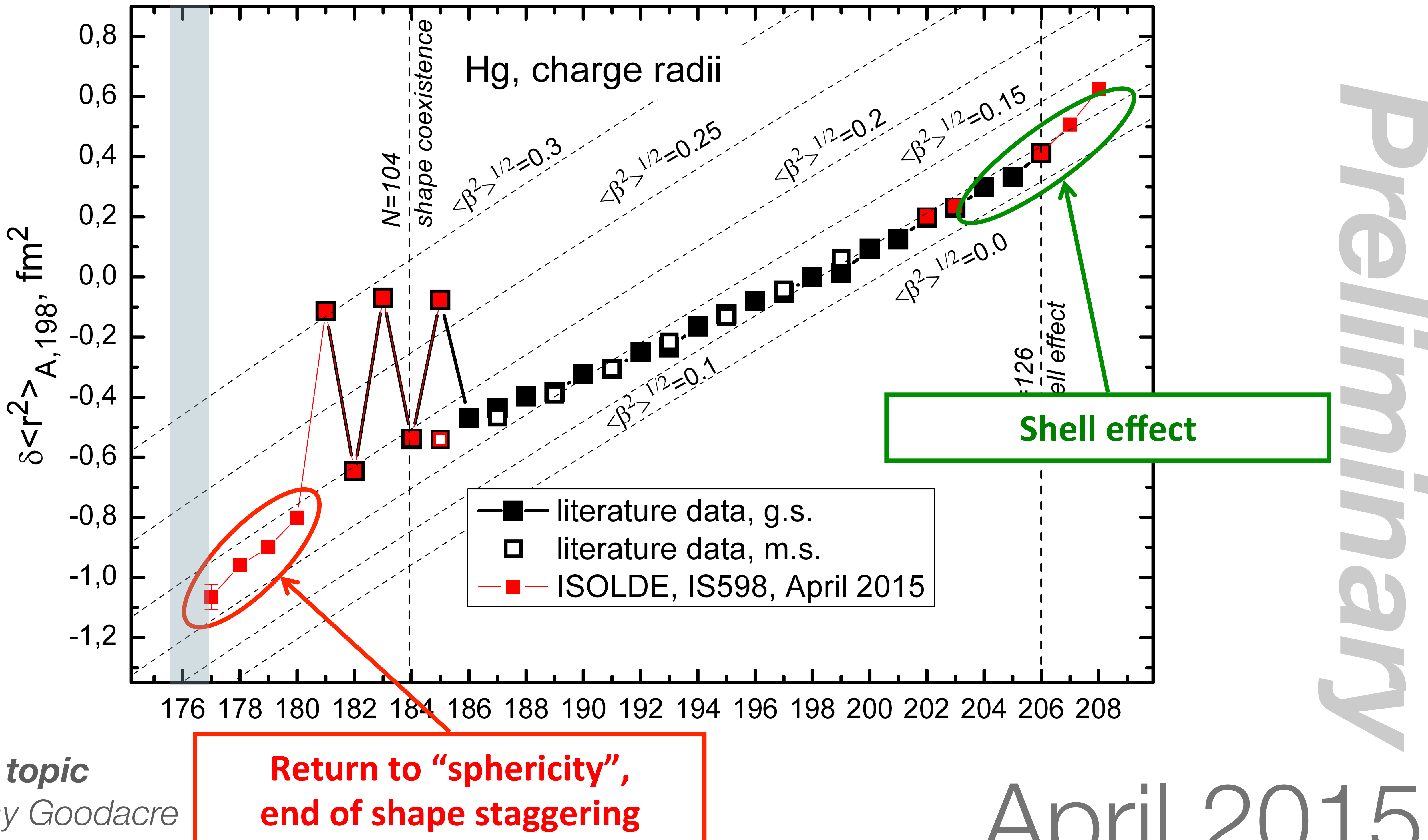
^{184}Hg

^{183}Hg



38 years later…….

Charge radii of the mercury isotopes

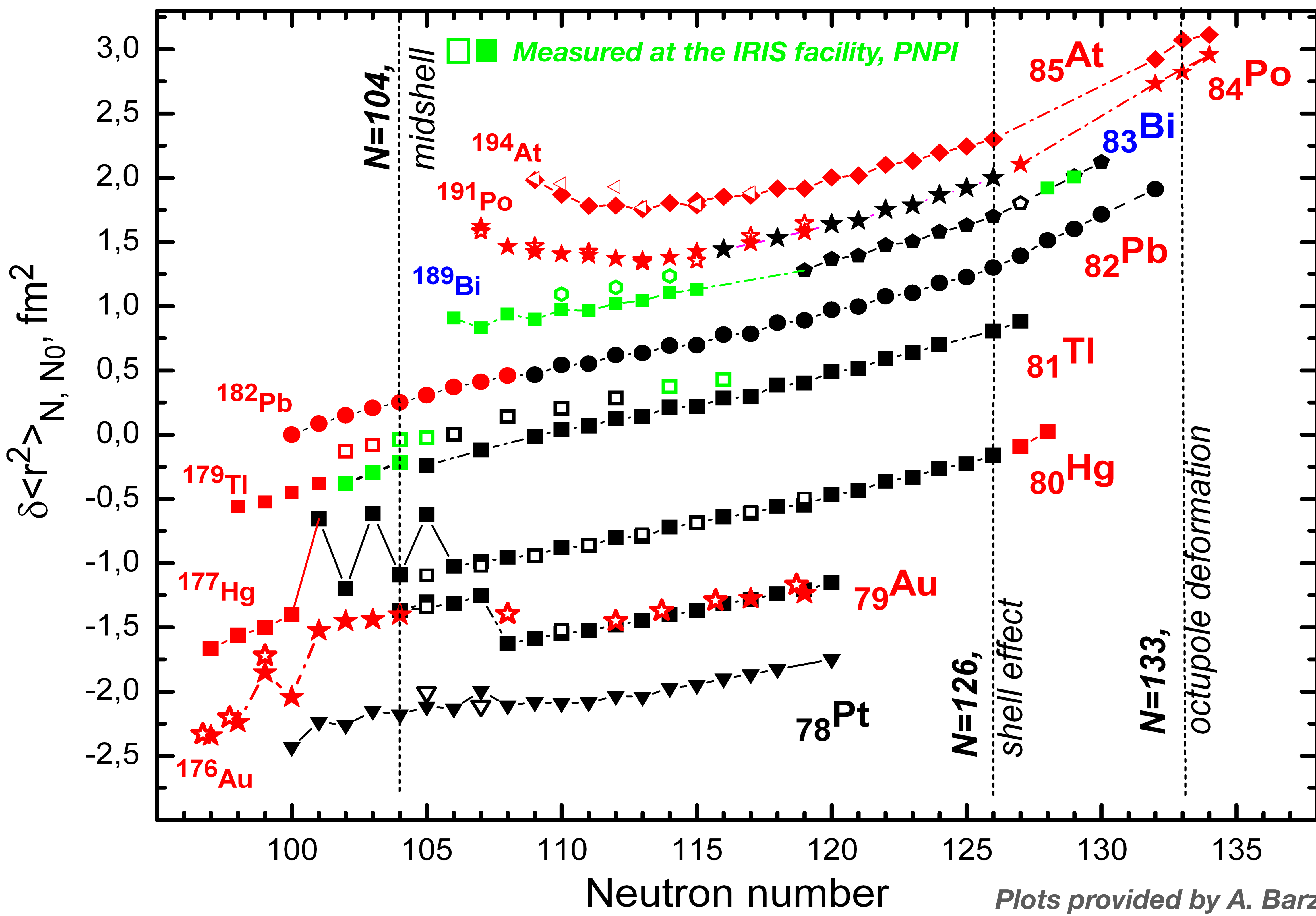


PhD topic
T. Day Goodacre
S. Sels

April 2015

Plot provided by A. Barzakh (PNPI)

Compilation of in-source RIS work



Plots provided by A. Barzakh (PNPI)

Extending in-source RIS in the Z=82 region

Selectivity

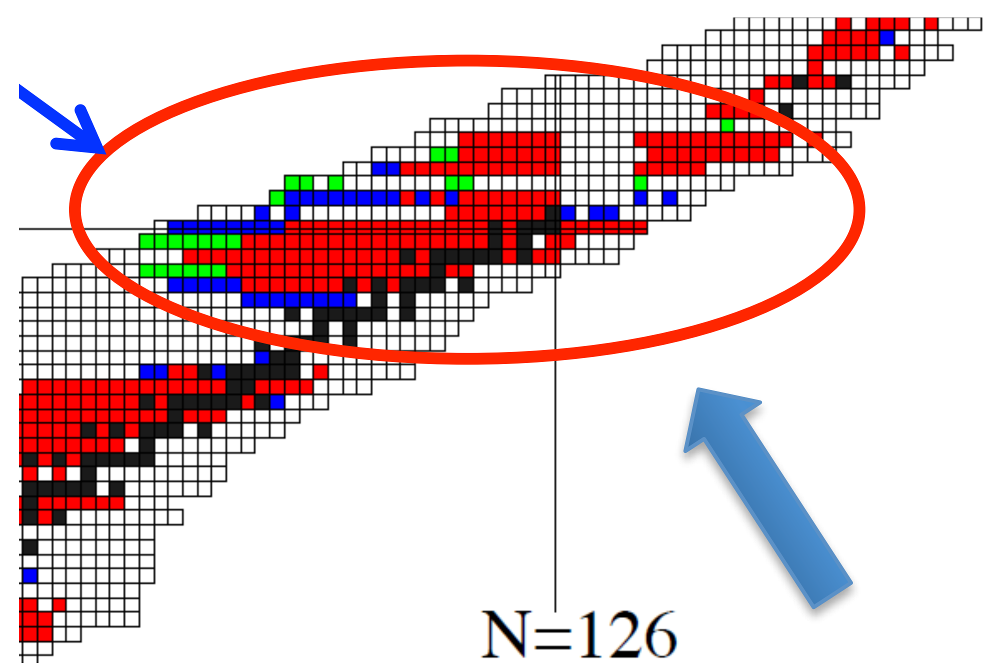
- Extending the already measured chains in the Z=82, dealing with isobaric contamination (Fr).
- Access to Low IP elements: **Ra** (*in conjunction with CRIS?*), Fr

Address thick-target / RILIS limitations

- Access to refractory metals: Os, Ir, Pt, Ac, Th, Pa
- Access to non-metals: **Rn *(feasibility is doubtful)***

Precision

- Improving resolution for HFA studies (Au, Bi)
- Better extraction of quadrupole moments from HFS



Extending in-source RIS below the Z=82 region

Toward high precision: Develop Doppler-free methods

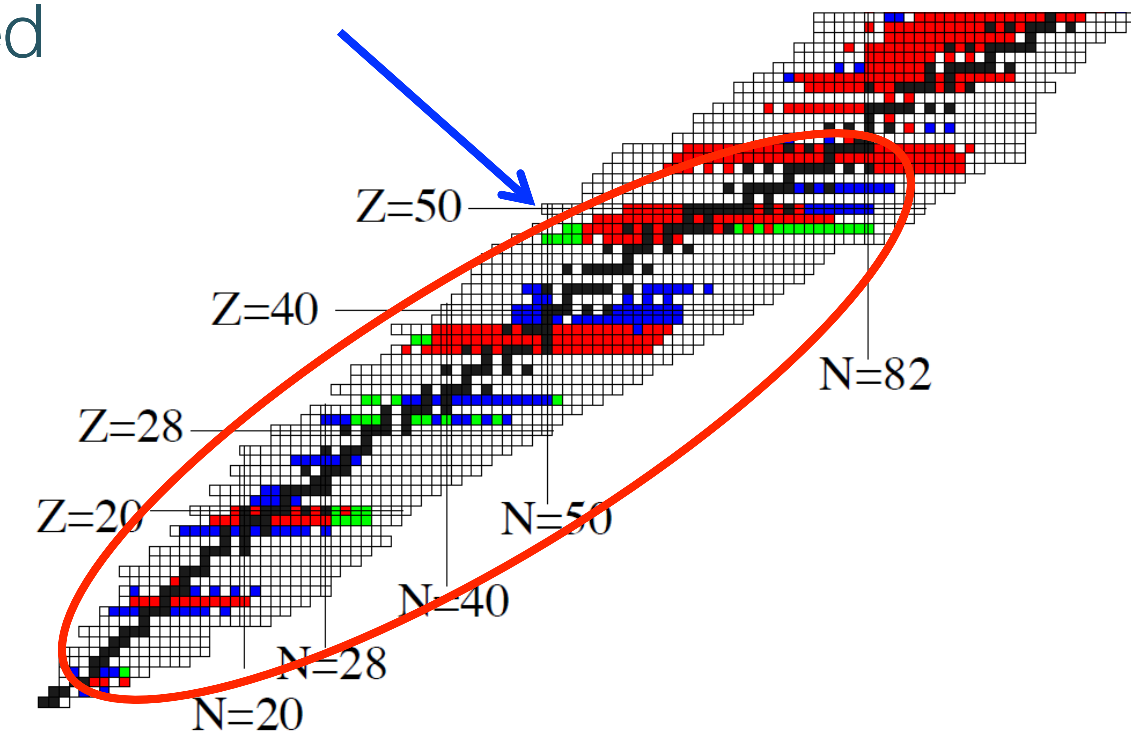
- Ion source developments
- Laser developments

Extend chains of isotopes already measured by fluorescence: Ca, Mn, Ni, Sn, Mg

Ac, plus BdF studies

Pm - smaller HFS expected, octupole deformation interest, IP measurement

Au - use J=3/2 level for Q determination



Thanks for your attention

The ISOLDE RILIS team

V. Fedosseev, A. Barzakh, T. Day Goodacre, D. Fedorov, B.Marsh,
P. Molkanov, R. Rossel, S. Rothe, M. Seliverstov, M. Veinhard.
New members: C. Seiffert, K. Chrysalidis

Knut and Alice Wallenberg Foundation

The In-Source RIS collaboration

L. P. Gaffney[1], T. Day Goodacre[2,3], A. N. Andreyev[4], M. Seliverstov[5,2], N. Althubiti[3], B. Andel[11], S. Antalic[11], D. Atanasov[10], A. E. Barzakh[5], K. Blaum[10], J. Billowes[3], T. E. Cocolios[3], J. Cubiss[4], G. Farooq-Smith[3], D. V. Fedorov[5], V. N. Fedosseev[2], R. Ferrer[1], K. T. Flanagan[3], L. Ghys[1,12], C. Granados[1], A. Gottberg[2], F. Herfurth[8], M. Huyse[1], D. G. Jenkins[4], D. Kisler[10], S. Kreim[10,2], T. Kron[7], Yu. Kudryavtsev[1], D. Lunney[13], K. M. Lynch[1,2], B. A. Marsh[2], V. Manea[10], T. M. Mendonca[2], P. L. Molkanov[5], D. Neidherr[8], R. Raabe[1], J. P. Ramos[2], S. Raeder[1], E. Rapisarda[2], M. Rosenbusch[9], R. E. Rossel[2,7], S. Rothe[2], L. Schweikhard[9], S. Sels[1], T. Stora[2], I. Tsekhanovich[6], C. Van Beveren[1], P. Van Duppen[1], M. Veinhard[2], R. Wadsworth[4], A. Welker[14], F. Wienholtz[9], K. Wendt[7], G. L. Wilson[4], S. Witkins[3], R. Wolf[10], K. Zuber[14]

[1] *KU Leuven, Belgium*; [2] *CERN-ISOLDE, CH*; [3] *The University of Manchester, UK*; [4] *The University of York, UK*; [5] *PNPI, Gatchina, Russia*; [6] *CENBG, Bordeaux, France*; [7] *Johannes Gutenberg University of Mainz, Germany*; [8] *GSI, Darmstadt, Germany*; [9] *Ernst-Moritz-Arndt Universität Greifswald, Germany*; [10] *Max-Planck-Institut für Kernphysik, Heidelberg, Germany*; [11] *Comenius University, Bratislava, Slovakia*; [12] *SCK•CEN, Mol, Belgium*; [13] *CSNSM-IN2P3-CNRS, Orsay, France*; [14] *Technische Universität Dresden, Germany*;

THE UNIVERSITY *of York*

Petersburg Nuclear Physics Institute

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ISOL TRAP