# IRIS & ISOLDE: laser ion source

## Запаздывающее деление $^{188}$Bi. Исследование эволюции и сосуществования форм у ядер висмута. (ИРИС, ПИЯФ — ISOLDE, CERN)

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# ISOLDE

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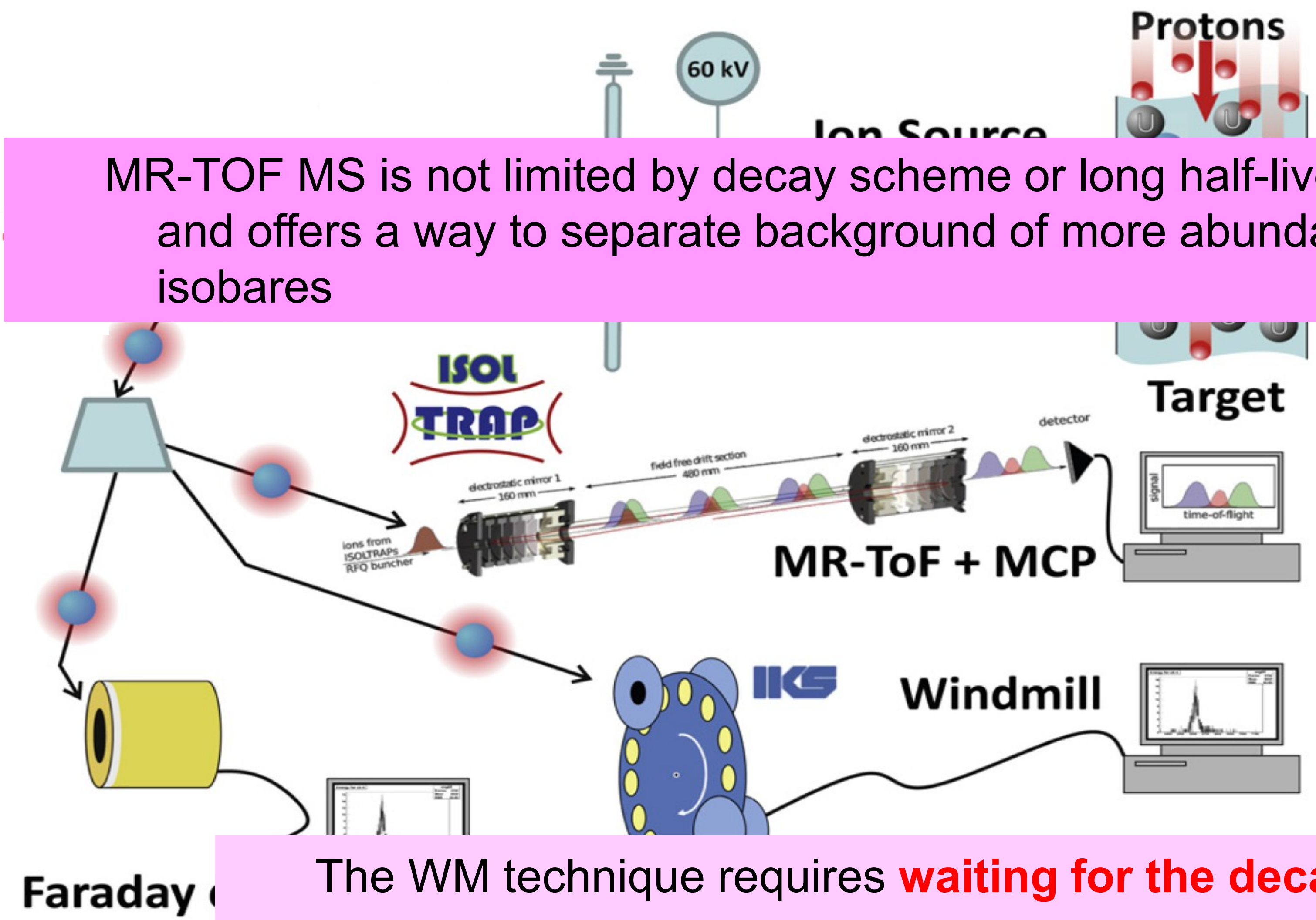
## IS 608:

Shape-coexistence and shape-evolution studies for Bi isotopes by in-source laser spectroscopy and beta-delayed fission in $^{188}$Bi

MR-TOF@ISOLTRAP collaboration
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

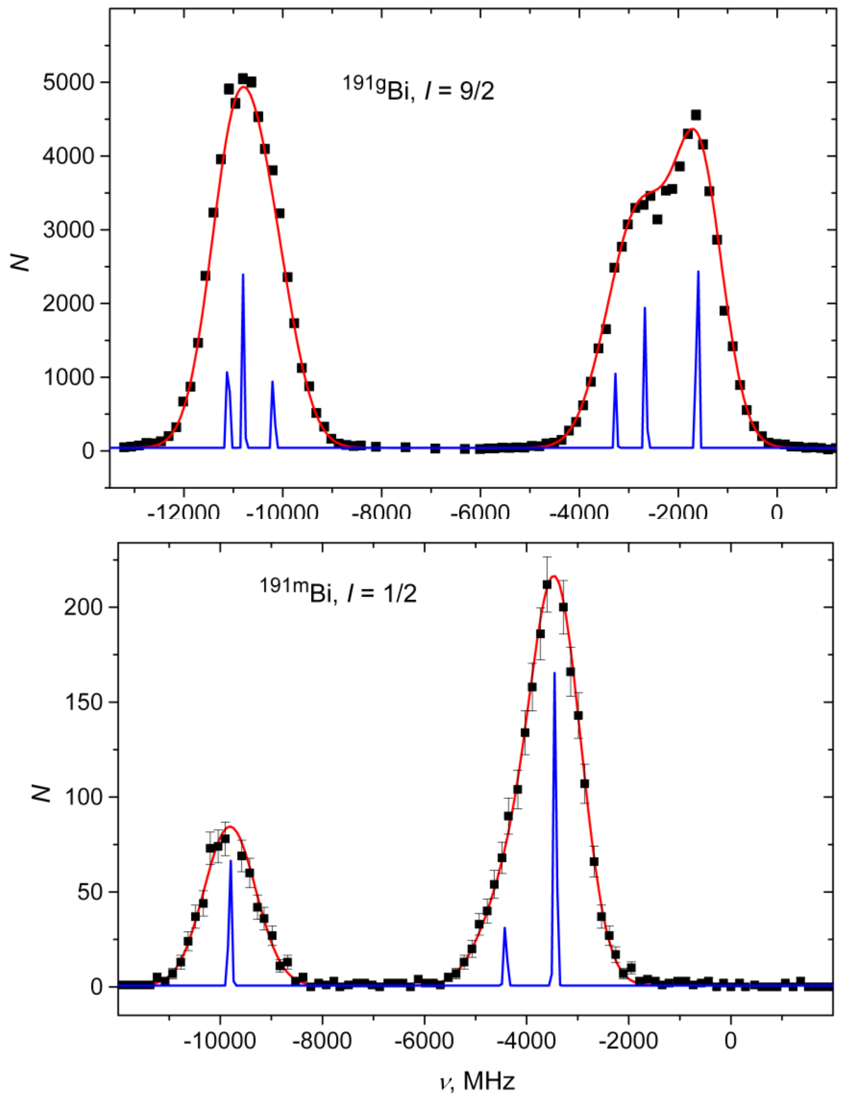
# ISOLDE: in-source spectroscopy

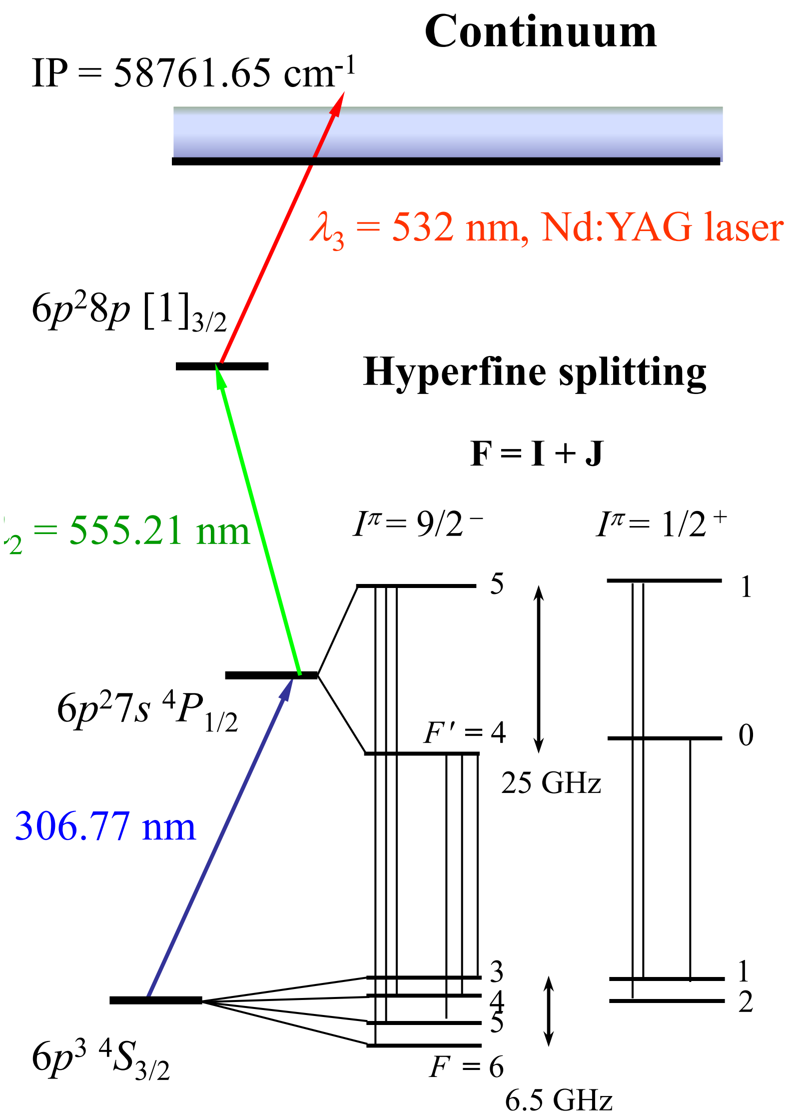



MR-TOF MS is not limited by decay scheme or long half-lives and offers a way to separate background of more abundant isobares

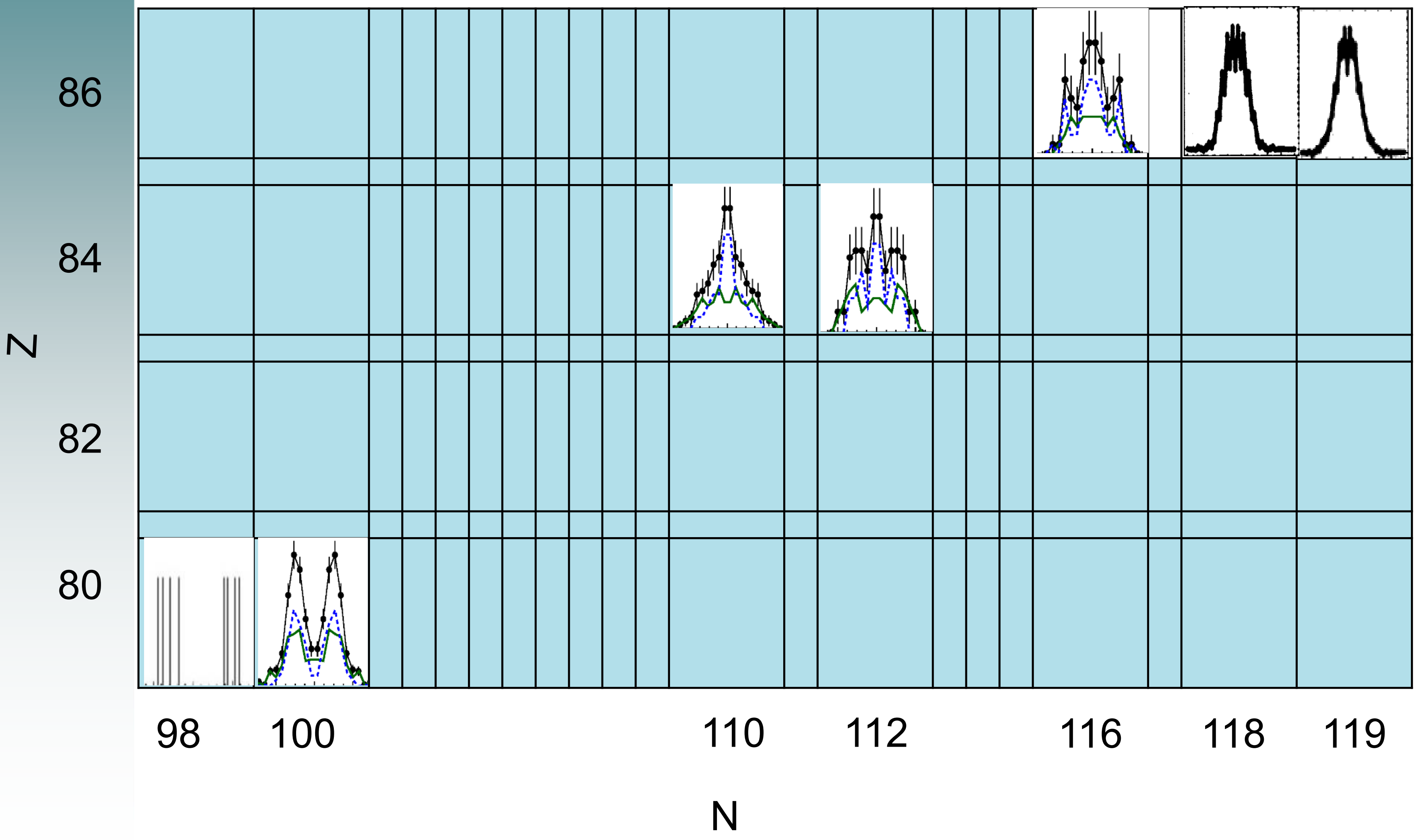
The WM technique requires **waiting for the decay** of the isotope (usually, α-decay). Not practical for long-lived or stable isotopes (or for β-decaying).

# Bi: hfs spectra

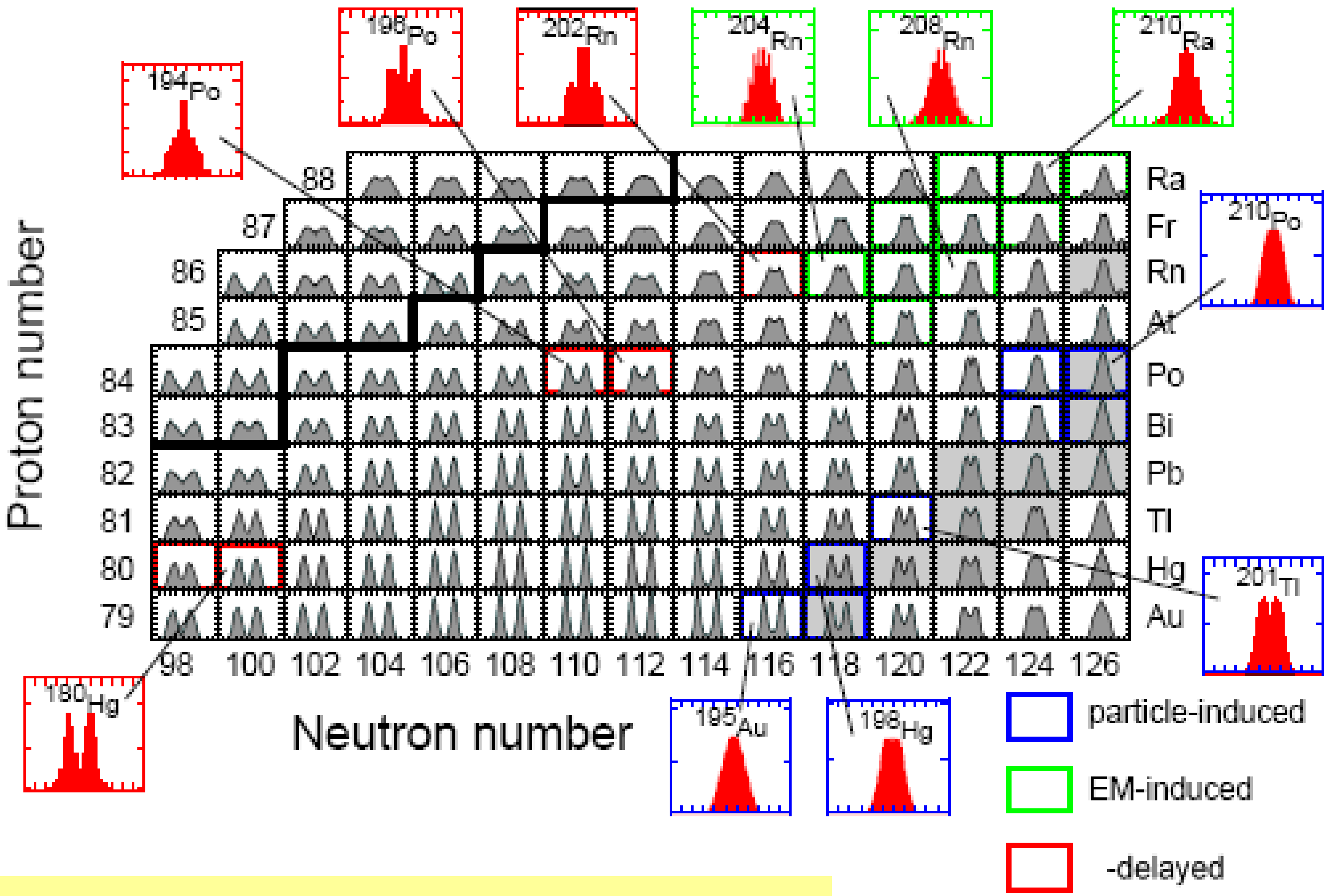


# Transition from asymmetric to symmetric fission



# Beta-delayed fission: theory

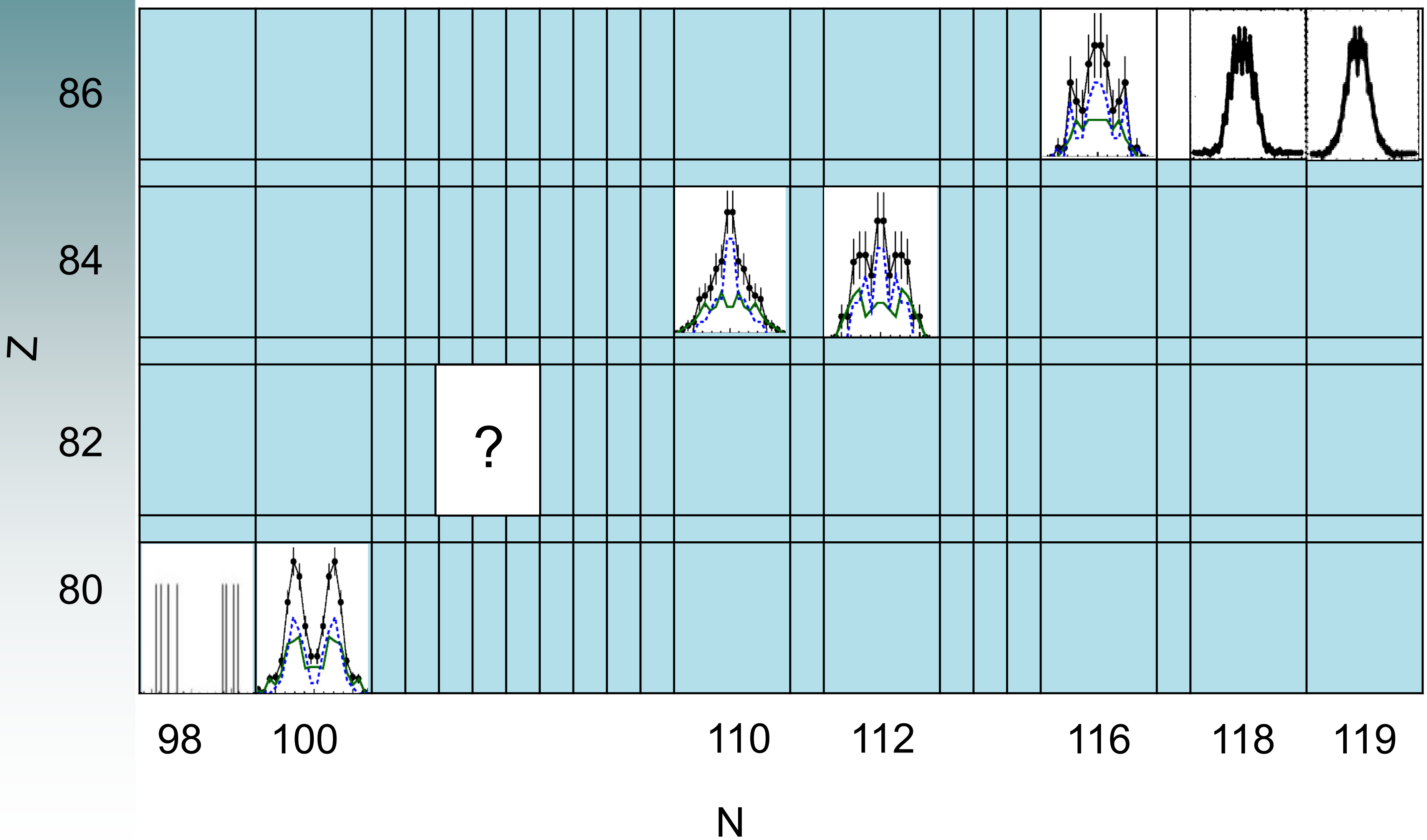



J. Randrup, P. Möller, Phys. Rev. C **88**, 064606 (2013).

P. Möller, J. Randrup, A. Sierk, Phys. Rev. C **85**, 024306 (2012)

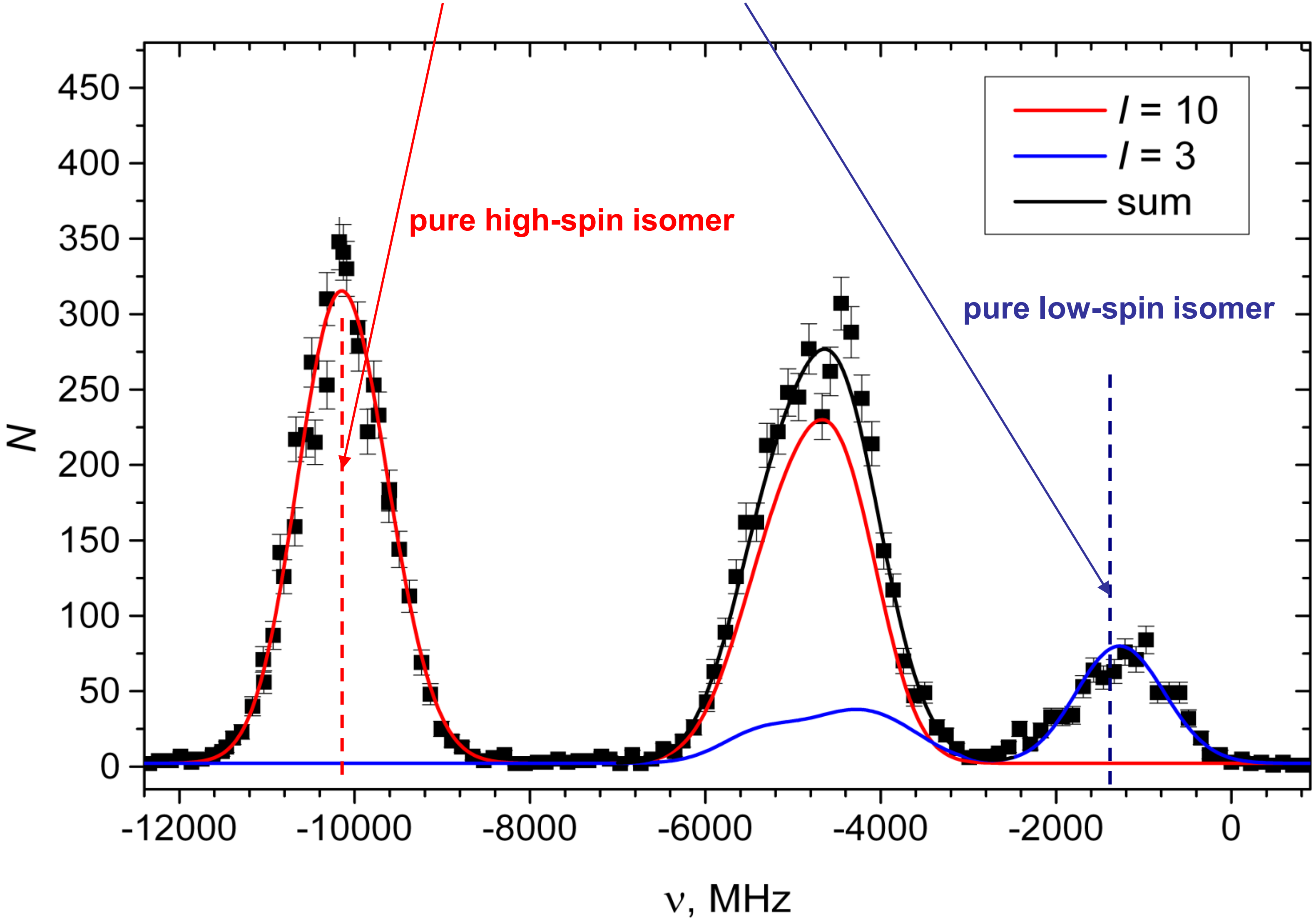
M. Veselsky *et al*. Phys. Rev. C **86**, 024308 (2012)

# Transition from asymmetric to symmetric fission

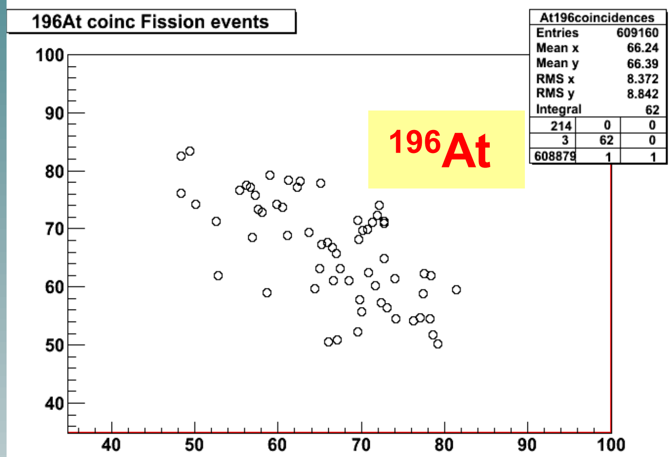


# $^{188}$Bi: Isomer selective beta delayed fission

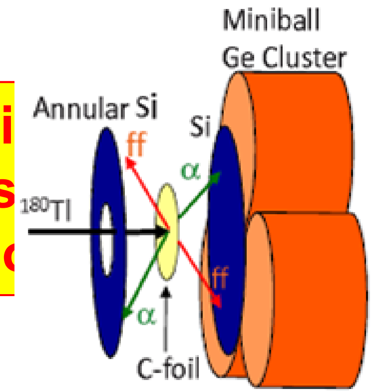
at these frequencies we obtain at the exit of the mass-separator…

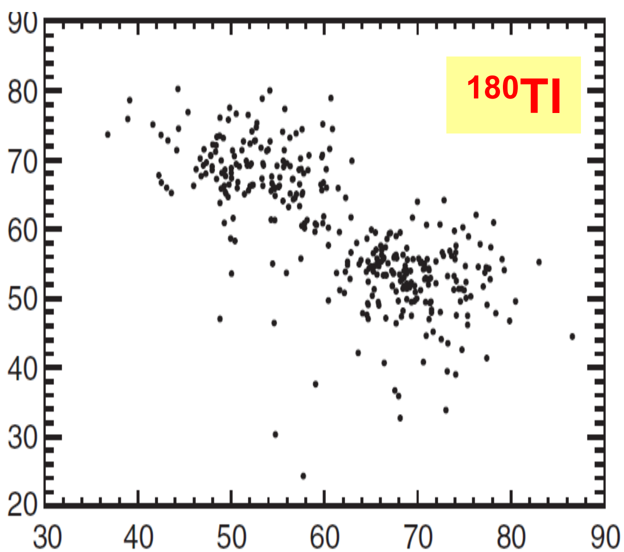


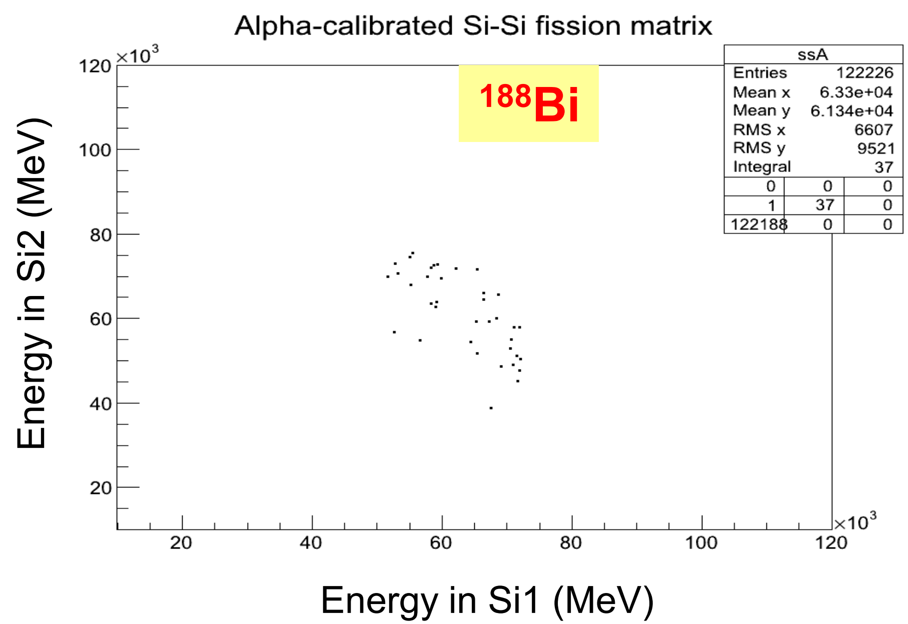
# ISOLDE: beta-delayed fission



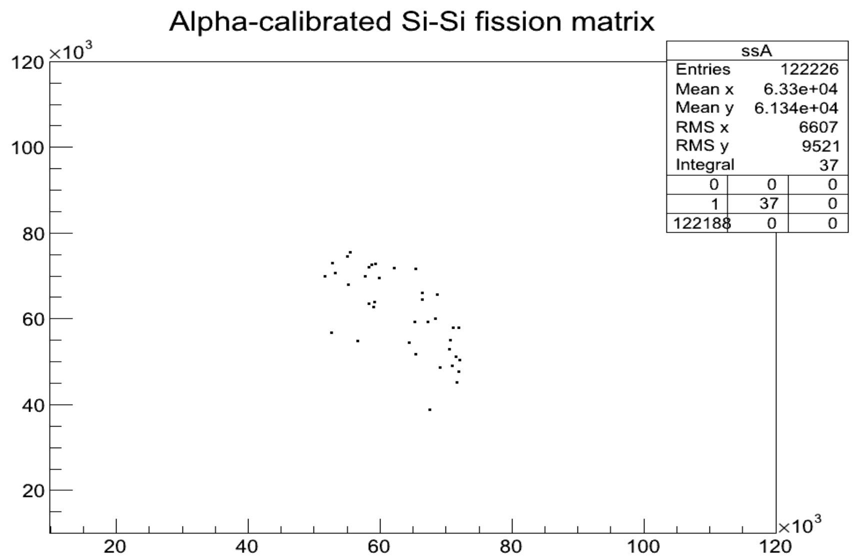

Clear di… mass … fissi… …rgy (thus, …etween …d $^{188}Pb$

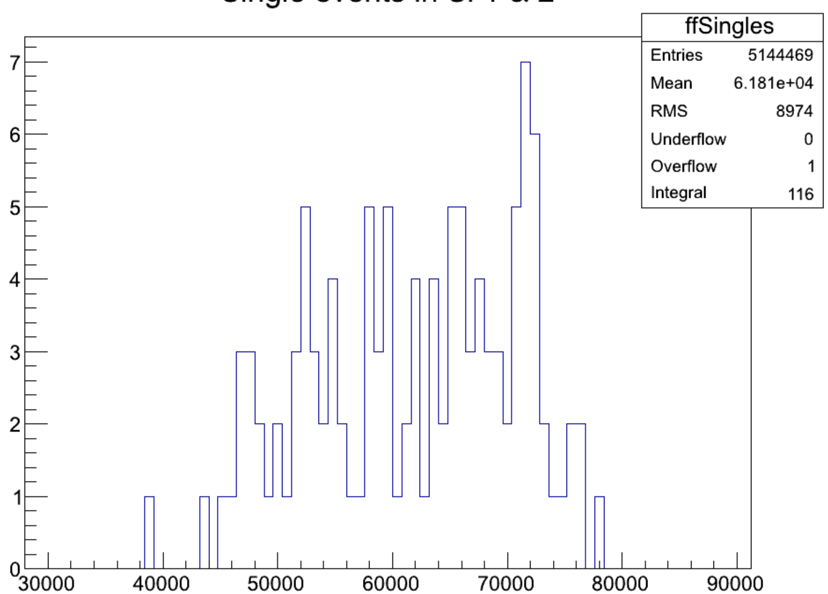


# $^{188}$Bi: Isomer selective beta delayed fission



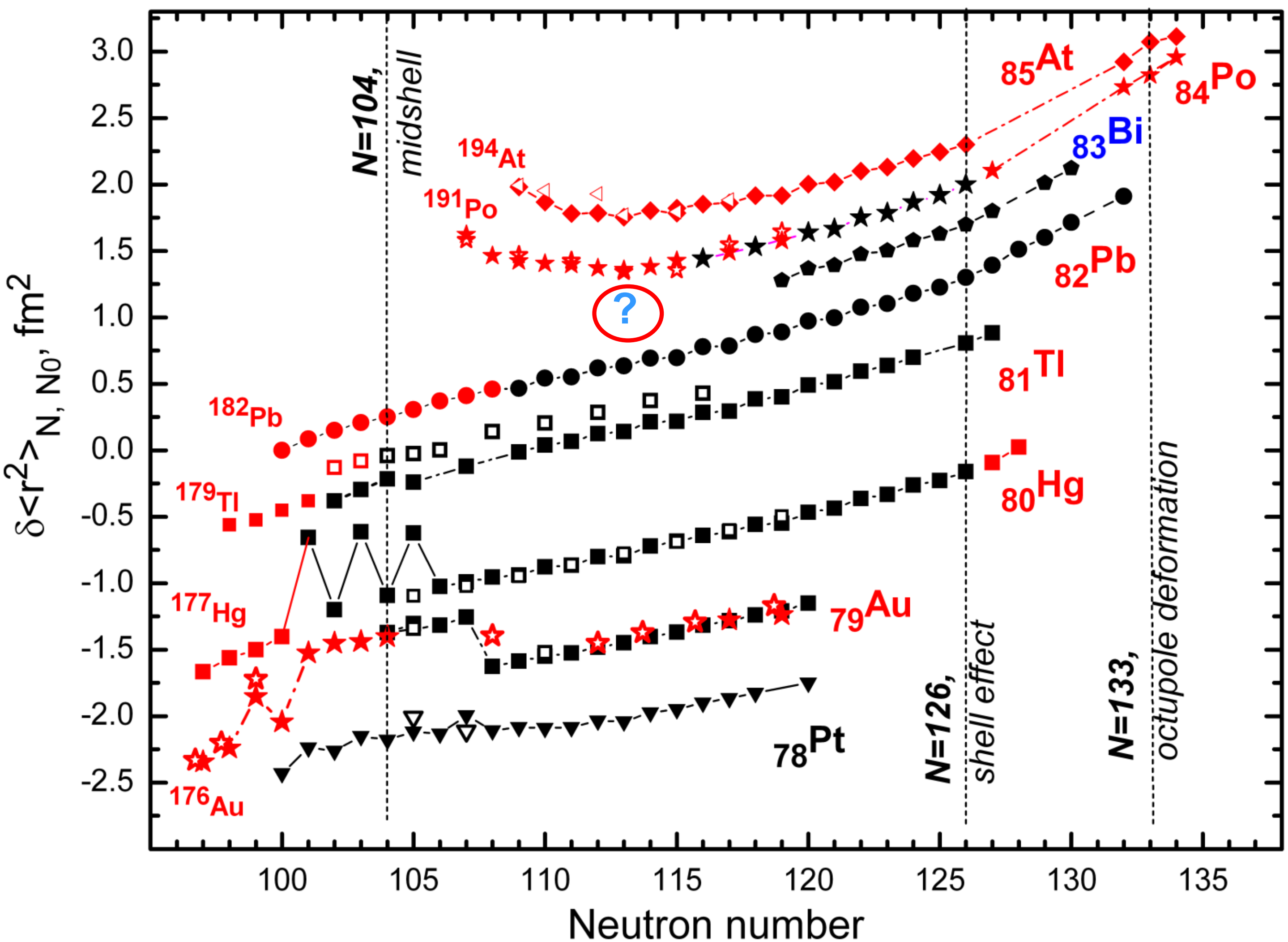




$P_{\beta DF}(^{188}\text{Bi}, I = 10) = 6.0(1.7)\cdot 10^{-4}$

Fission fragment mass distribution is similar to that for $^{196}$At where multimodal fission was found.

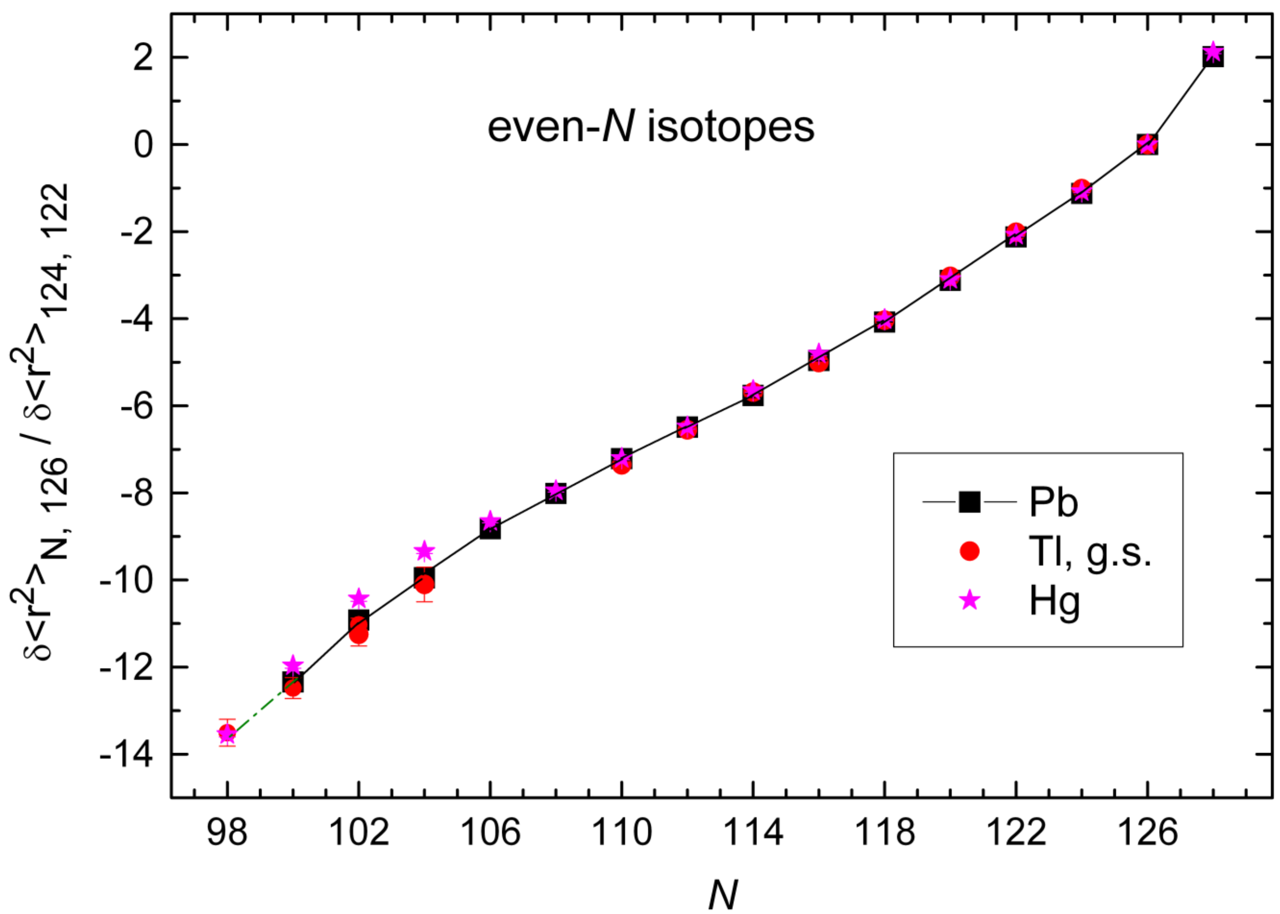
Strong spin dependence:
$P_{\beta DF}(^{188}\text{Bi}, I = 3) << P_{\beta DF}(^{188}\text{Bi}, I = 10)$

# Shape coexistence study in the Pb region



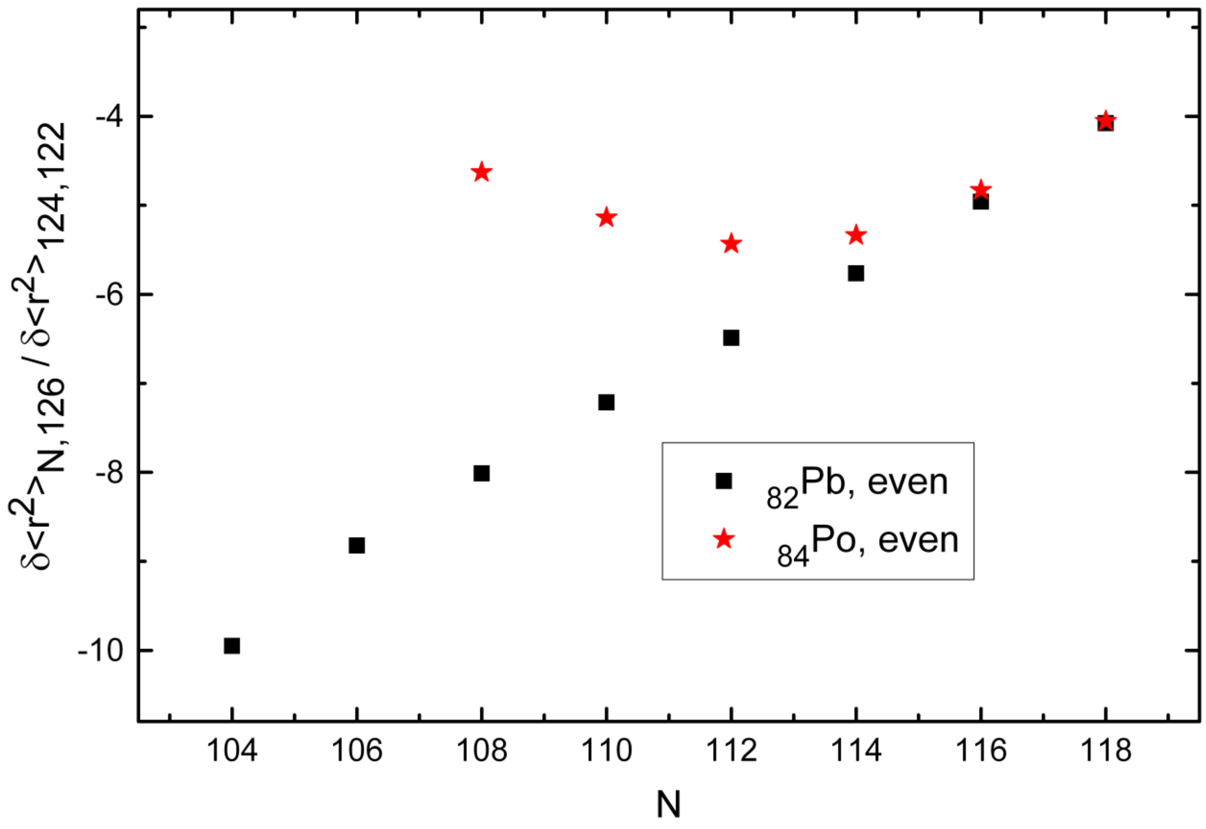
# Comparison of $_{81}$Tl and $_{80}$Hg with $_{82}$Pb

For comparison radii trend for different isotopic chains it is better to use relative $\delta\langle r^2\rangle$: $\delta\langle r^2\rangle_{N,126} / \delta\langle r^2\rangle_{124,122}$



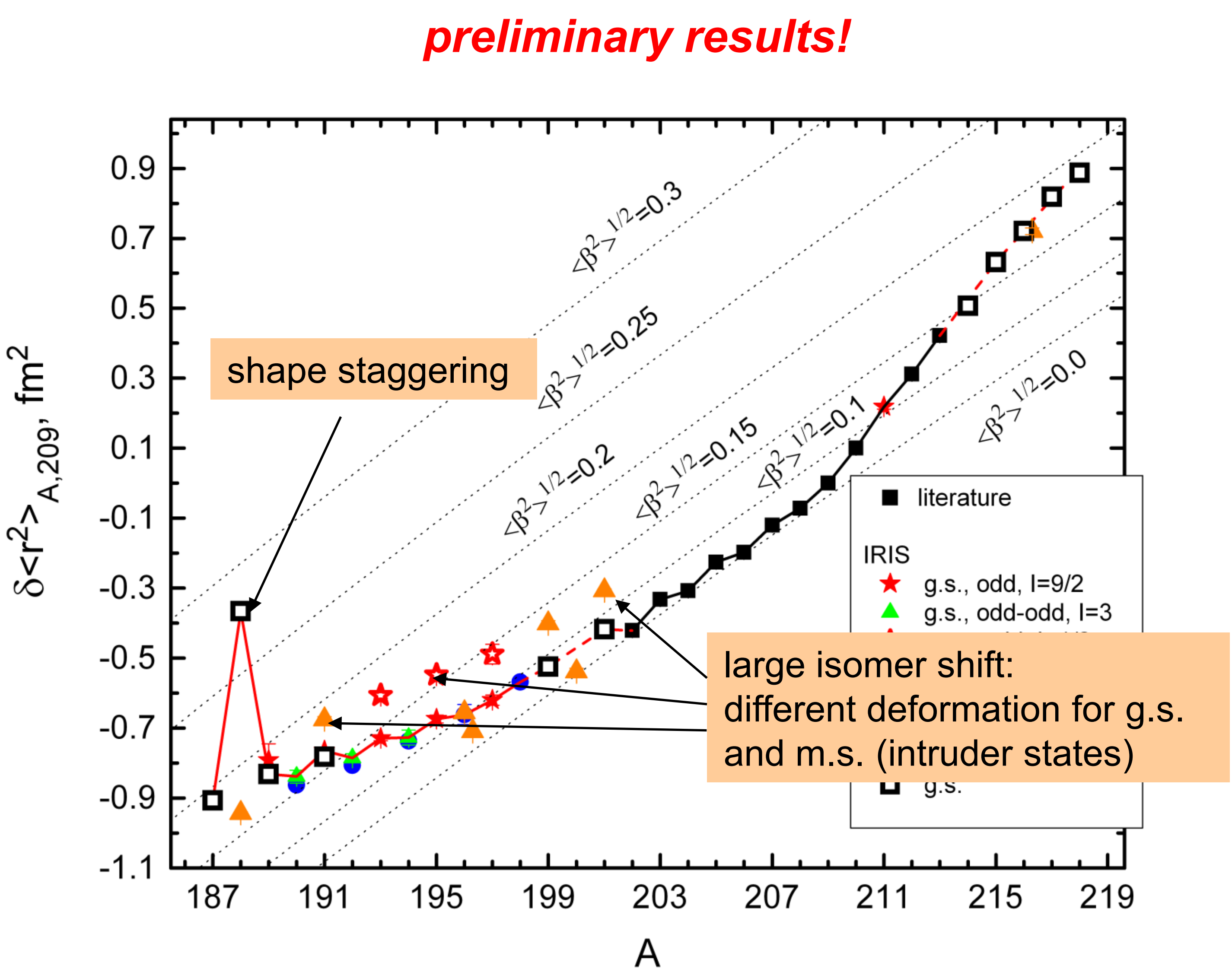

remarkable coincidence of the relative-radii trends for $Z$ = 80, 81, 82 at the extensive neutron range

# Comparison of $_{84}$Po with $_{82}$Pb



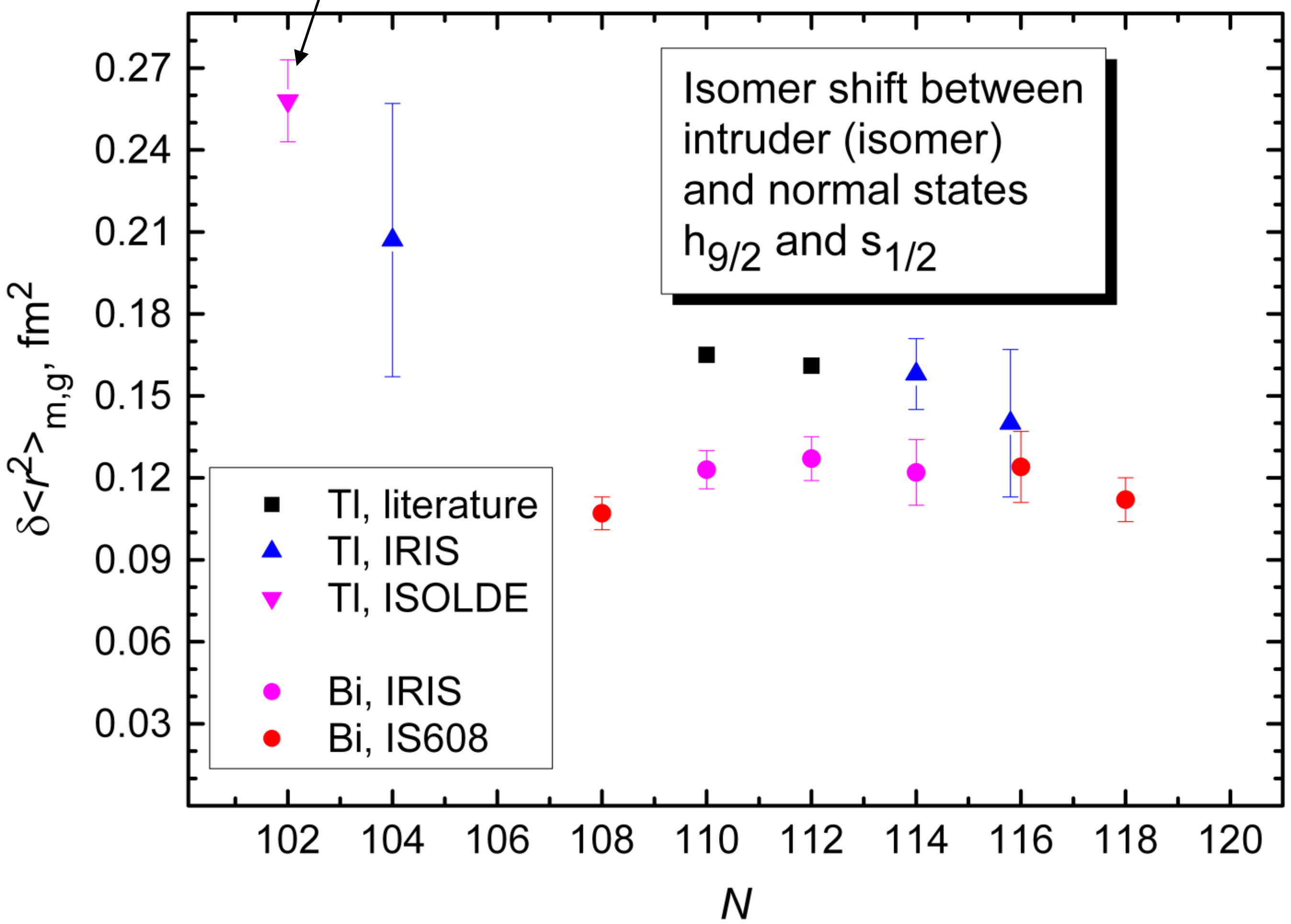

noticeable departure for Po — onset of deformation

# ISOLDE&IRIS, $_{83}$Bi isotopes: radii

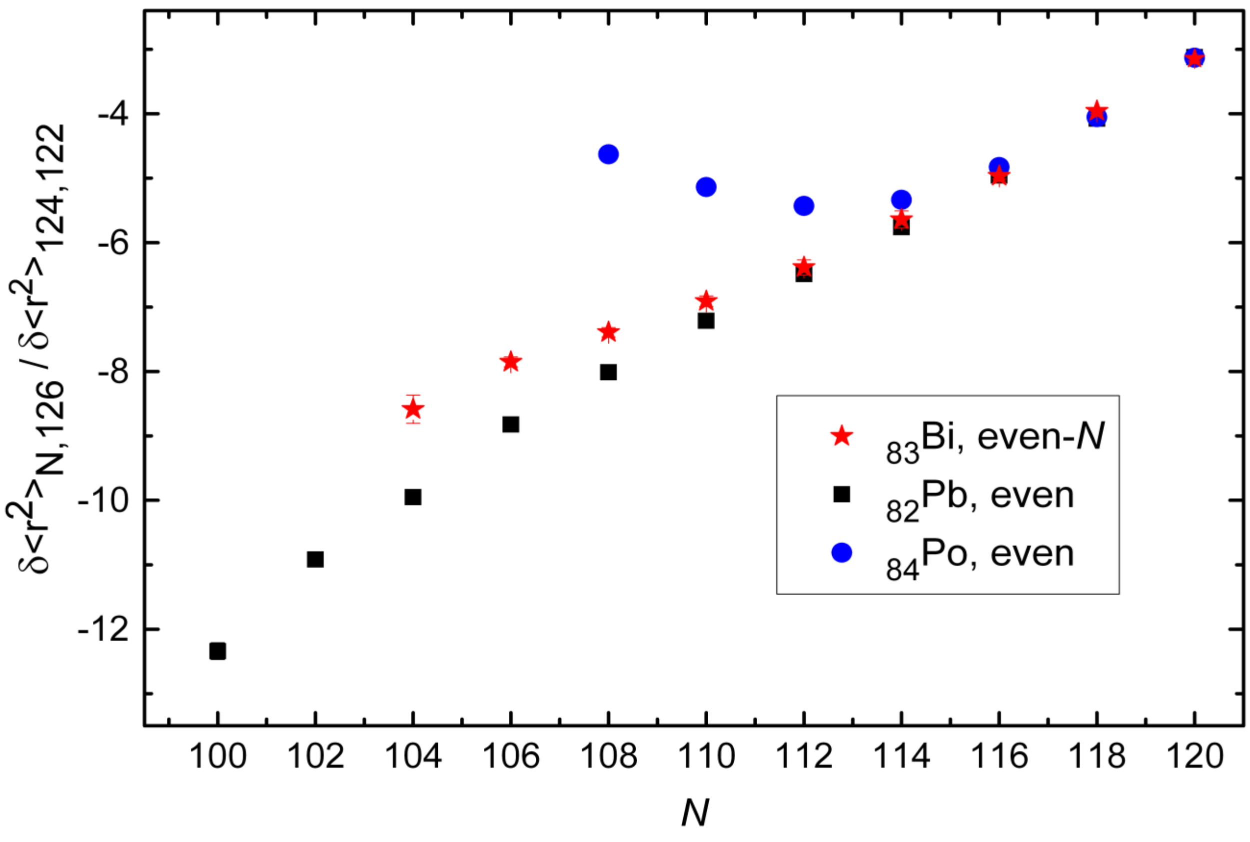


# $_{83}$Bi & $_{81}$Tl isotopes: intruder isomers

unexpected growth of the isomer shift points to the possible oblate-prolate mixture



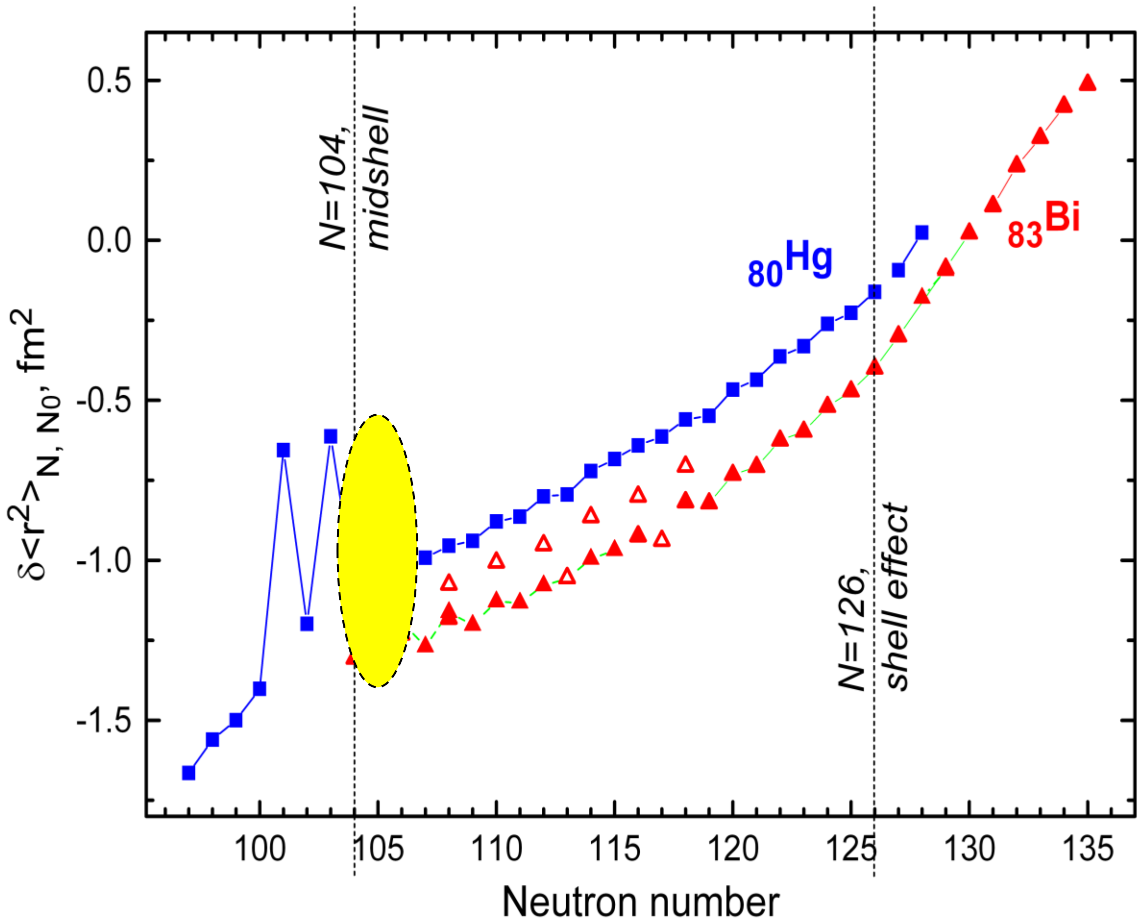
# Bi: relative radii




Even-*N* nuclei: shape evolution in the Bi and Tl isotopic chains markedly differs from each other, although these chains are "mirror" in respect to the filled proton shell (Z = 82)

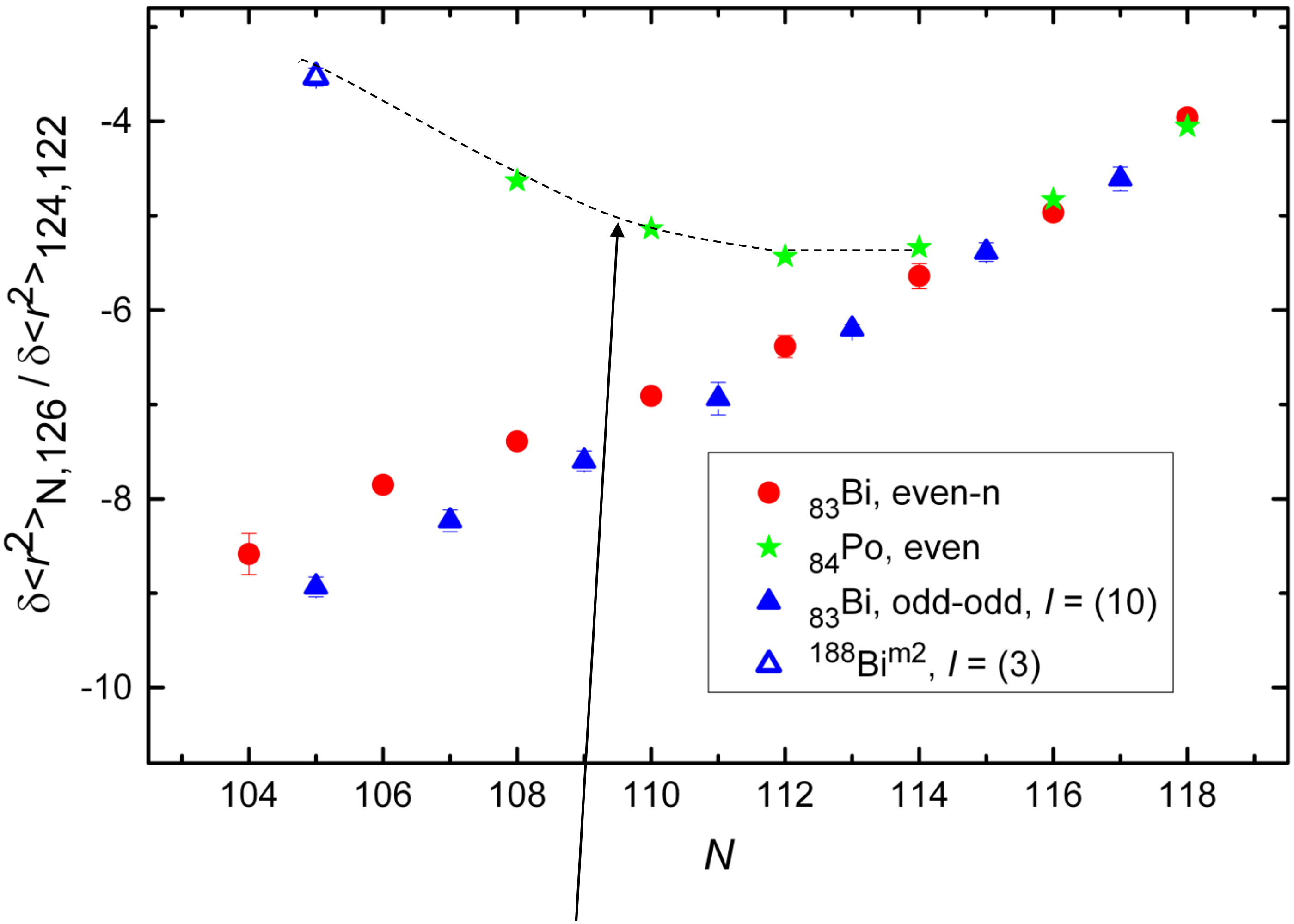
Radii trend for $_{83}$Bi is intermediate between "spherical" $_{82}$Pb trend and $_{84}$Po trend with the onset of deformation

# Hg and Bi radii



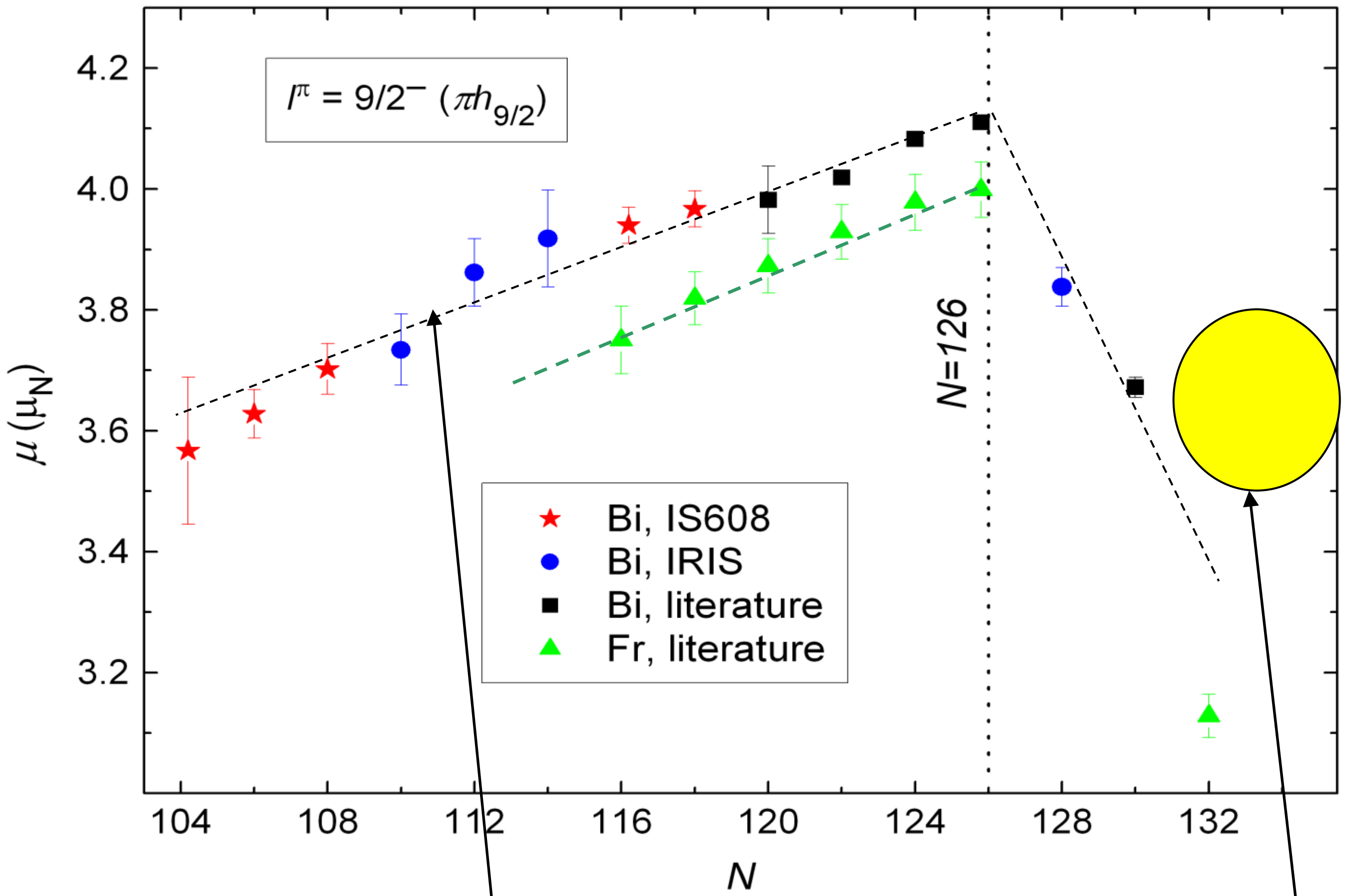

In Bi, shape staggering occurs at the same *N* as in Hg (*N* = 105), with the same amplitude and the same radii (deformation) difference between ground and $\nu i_{13/2}$ based isomeric states.

# Bi: relative radii




Radius of the strongly deformed $^{188}$Bi is found on the continuation of the Po-trend

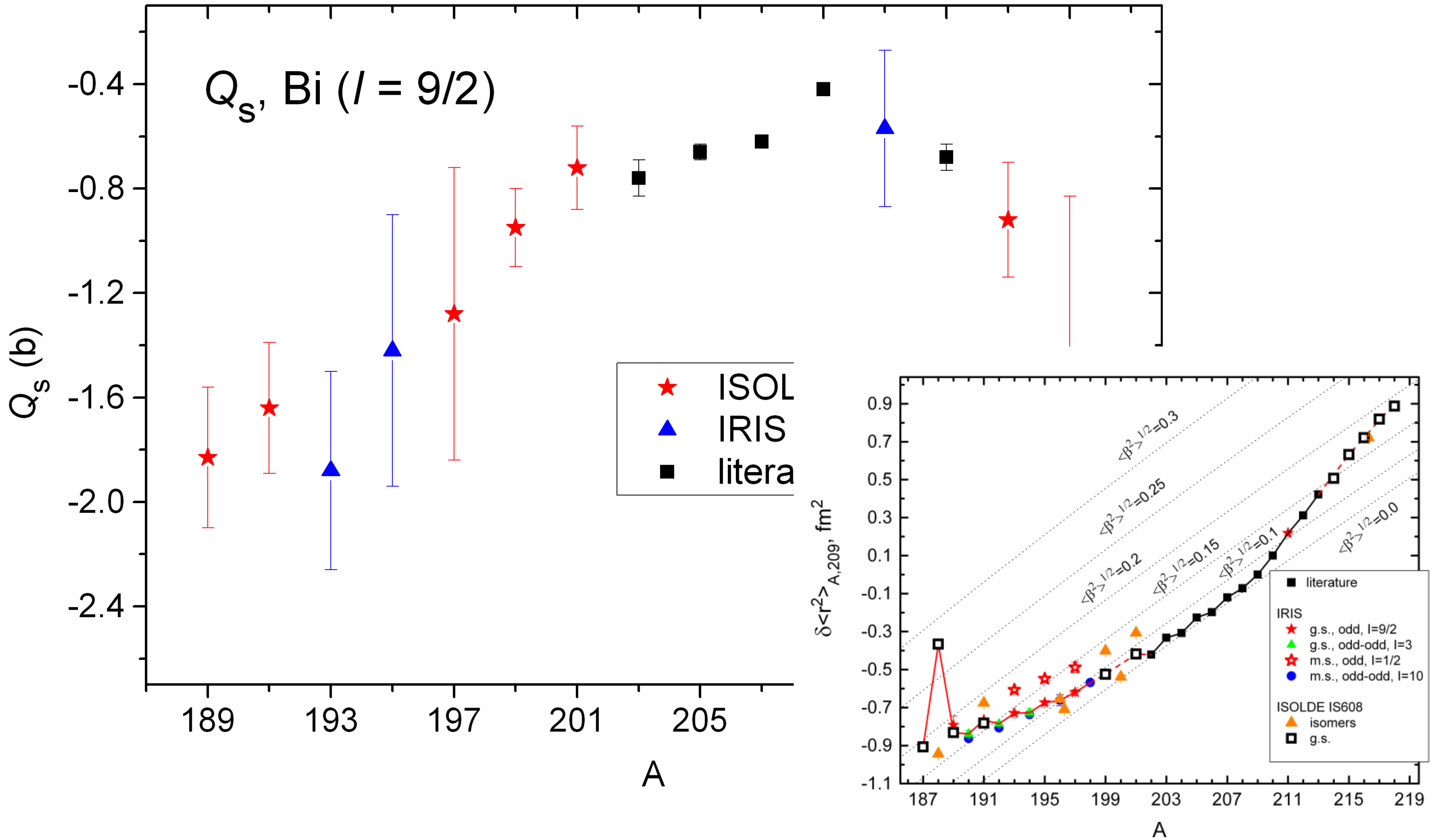
# Bi magnetic moments: qualitative considerations




linear N-dependence: first-order core-polarization correction?

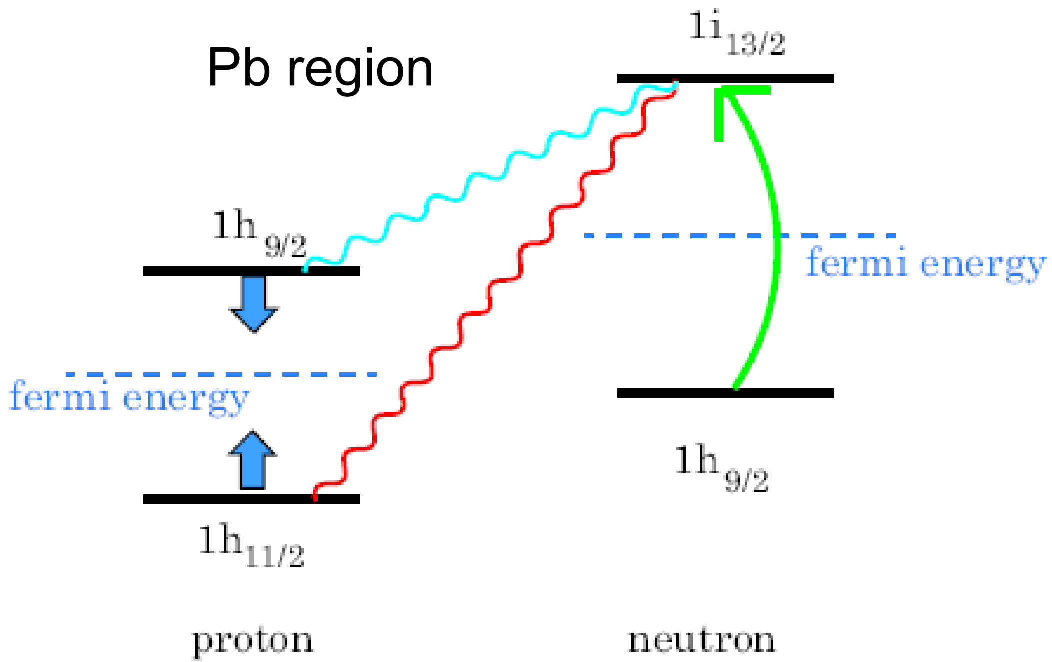
deviation from systematics: octupole degree of freedom influence?

# Bi: Quadrupole moments




Gradual increase of (oblate) deformation. $Q_s$ for $^{189}$Bi corresponds to $\beta$ = -0.13 (in the strong coupling scheme). Cf. $\beta_{DM}$ from IS: $|\beta_{DM}|$ ~ 0.16

# Pb region: Quantum Phase Transition



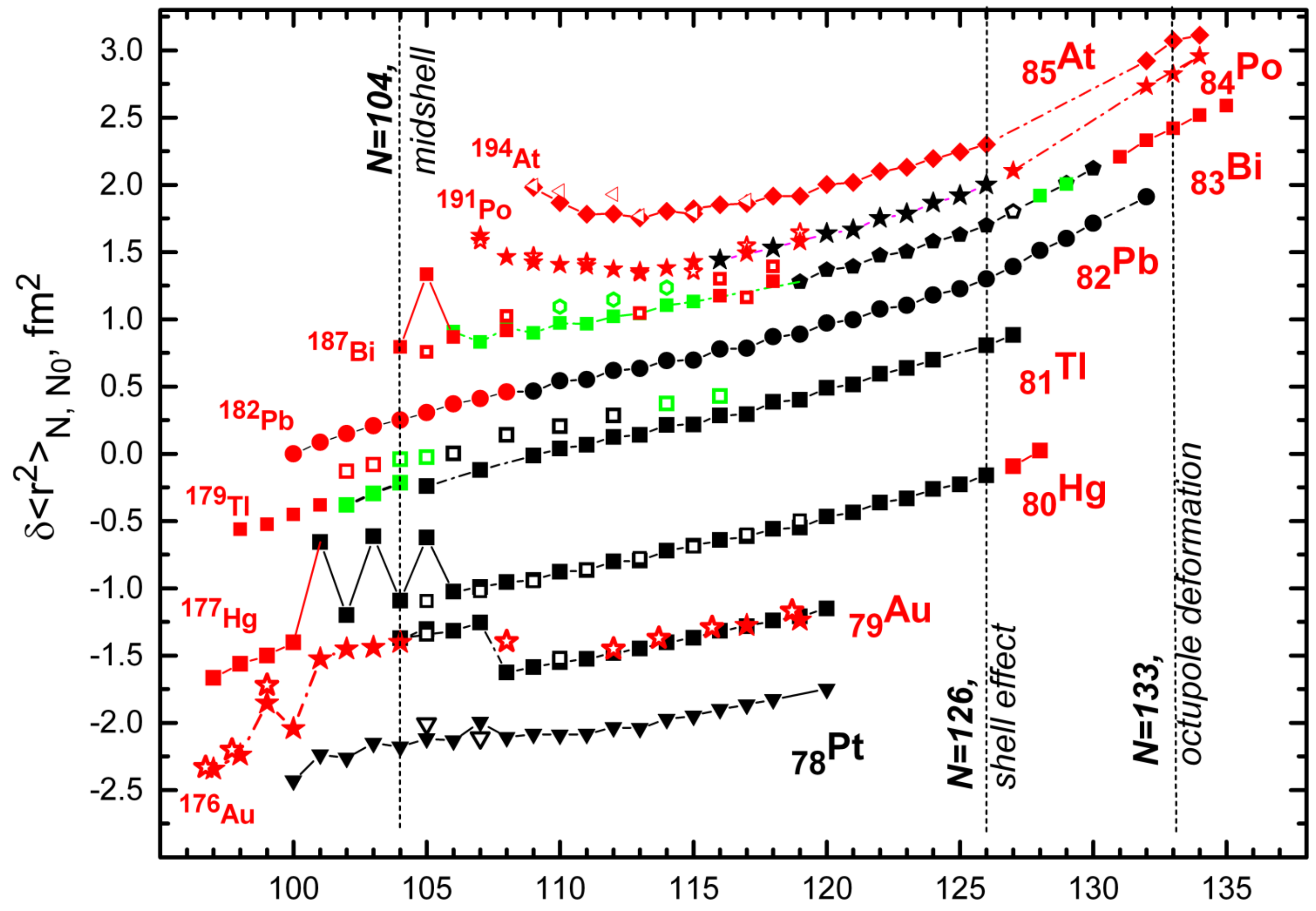

change of spin-orbit splitting (shell gap) due to the tensor force

T. Otsuka, and Y. Tsunoda, The role of shell evolution in shape coexistence, J. Phys. G: Nucl. Part. Phys. 43 (2016) 024009

# Bi: main results

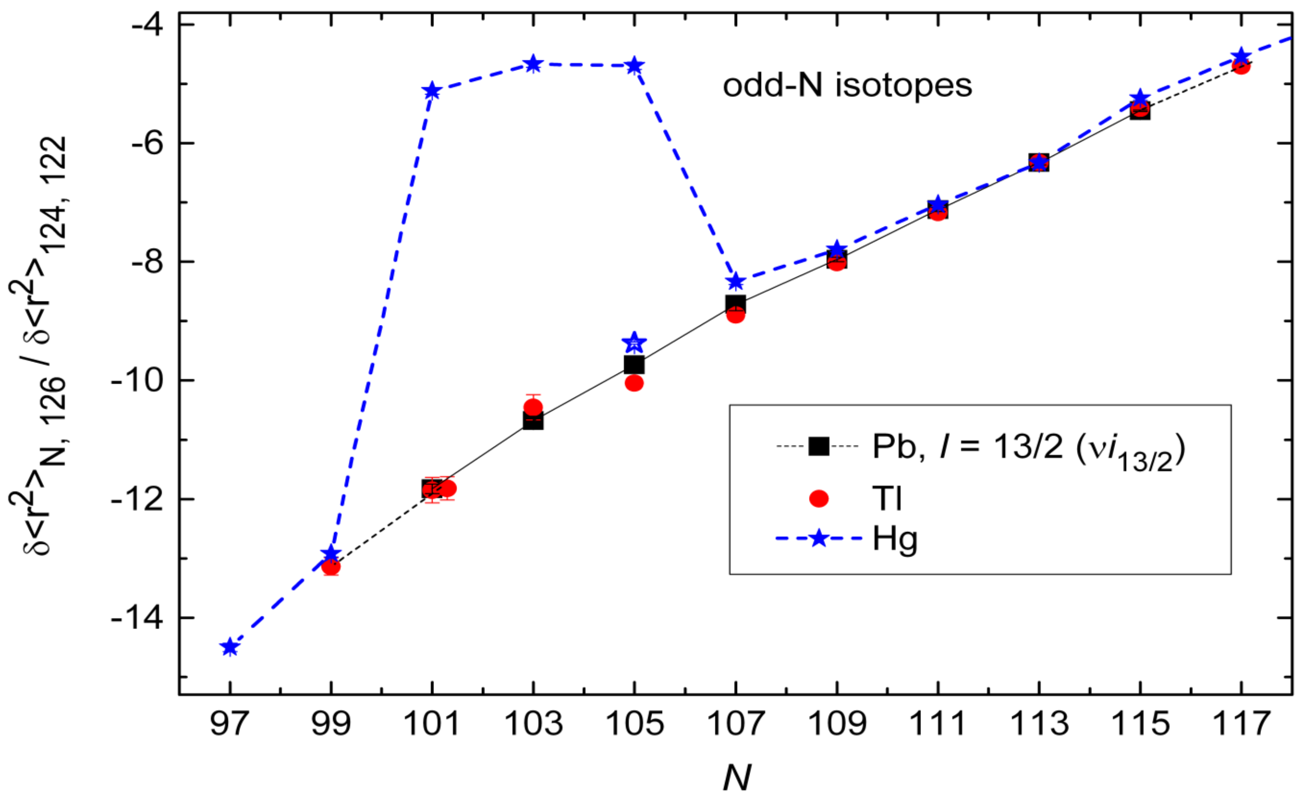
1. $\delta<r^2>$, $\mu$, $Q_s$ for 25 Bi isotopes/isomers
2. Marked deviation of Bi $\delta<r^2>$ trend from (spherical) Pb & Tl trend at $N < 109$, onset of small oblate deformation (?)
3. Large isomer shift (shape coexistence) for intruder isomers
4. Large shape staggering at $A = 188$ ($N = 105$)
5. Systematic behaviour of $I^\pi = 9/2^-$ ($\pi h_{9/2}$) and $I^\pi = 10^-$ ($\pi h_{9/2}$, $\nu i_{13/2}$) magnetic moments, deviation for $A = 215, 217$
6. First isomer selective βDF study ($^{188}$Bi). Spin dependence of βDF

# Shape coexistence study in the Pb region



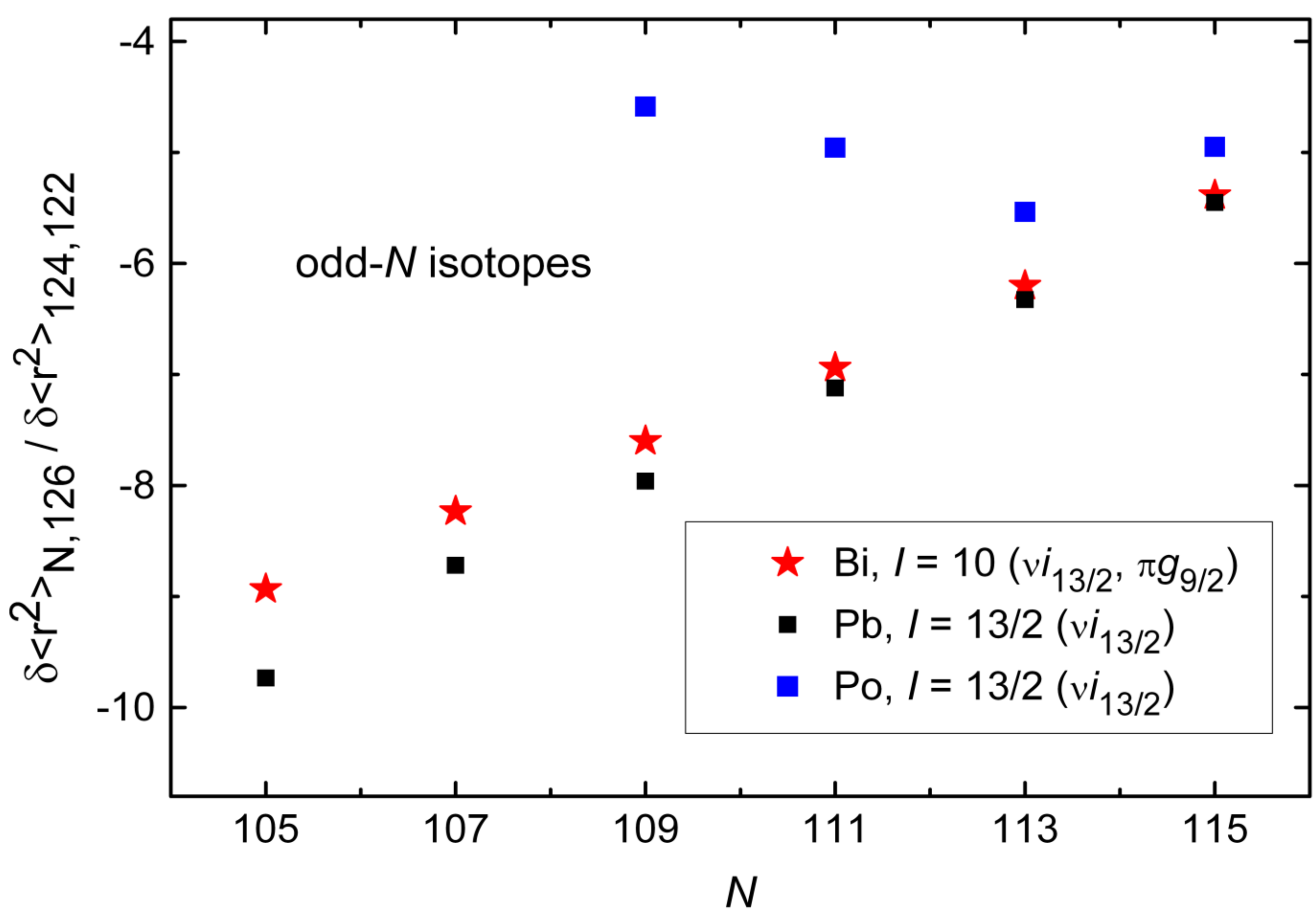

more than 120 isotopes/isomers were studied

# Comparison of $_{81}$Tl and $_{80}$Hg with $_{82}$Pb




Large prolate deformation for $^{181,\,183,\,185}$Hg. Return to “sphericity”: to the same Pb-Tl trend

# Bi: relative radii




Odd-*N* nuclei: radii trend for $_{83}$Bi is intermediate between "spherical" $_{82}$Pb trend and $_{84}$Po trend with the onset of deformation (although in a lesser extent than for even-*N* nuclei)