

IRIS & ISOLDE: laser ion source

Исследование запаздывающего деления
и сосуществования форм
в области свинца (ядра висмута и астата)
(ИРИС, ПИЯФ — ISOLDE, CERN)

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П. Л. Молканов, Ф. В. Мороз, С. Ю. Орлов, В. Н. Пантелеев,
М. Д. Селиверстов, Д. В. Федоров, А. М. Филатова**

ISOLDE

A collage of logos for the ISOLDE project partners. The logos include: KATHOLIEKE UNIVERSITEIT LEUVEN, UNIVERSITY OF OULU (OULUN TIIDEPISTO), UNIVERSITY OF LIVERPOOL, ULB UNIVERSITÉ LIBRE DE BRUXELLES, and CENBG. There are also some smaller, less distinct logos and a circular graphic element.

IS 534:

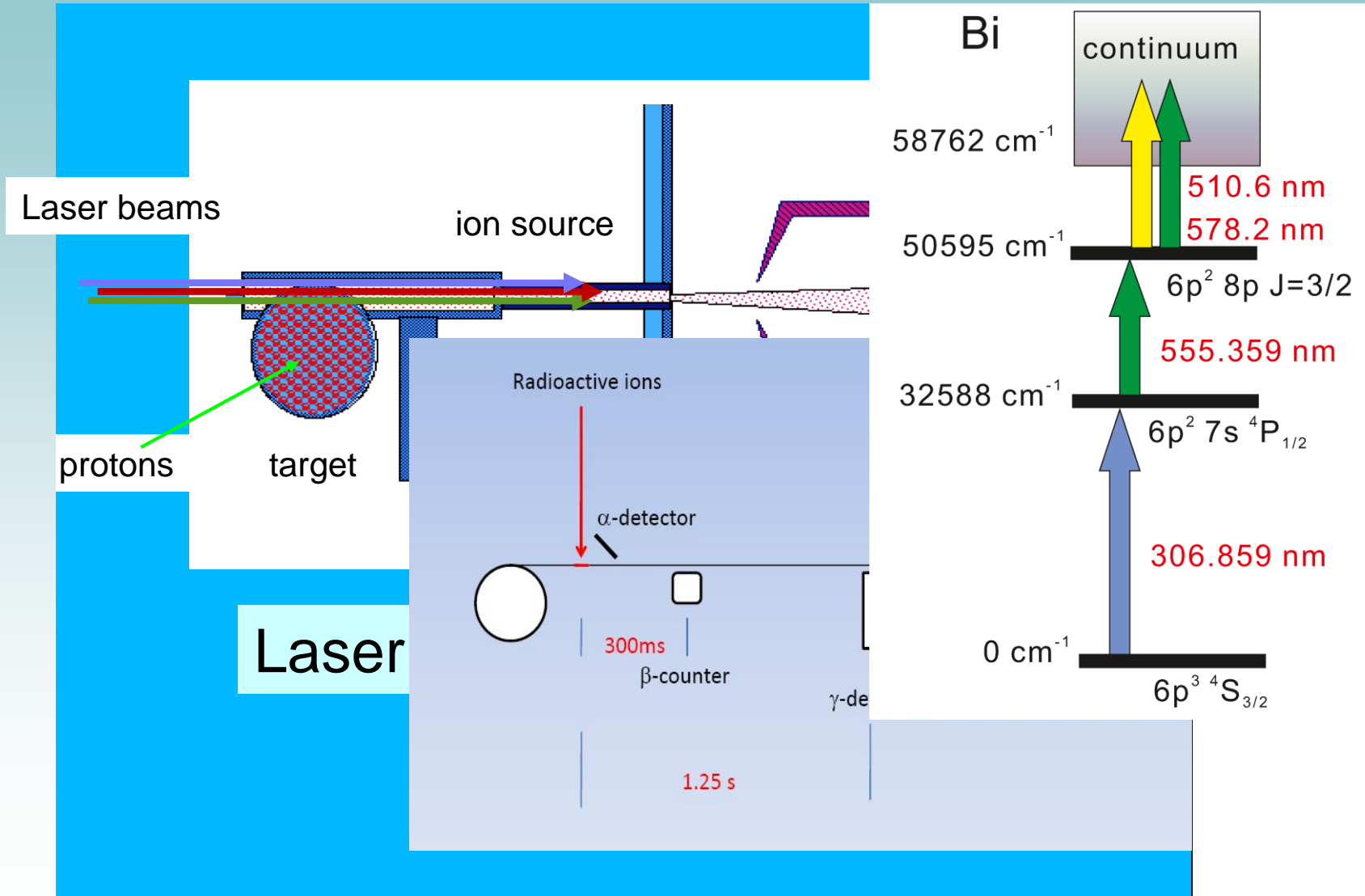
Beta-delayed fission, laser spectroscopy
and shape-coexistence studies
with radioactive ^{85}At beams

ИРИС

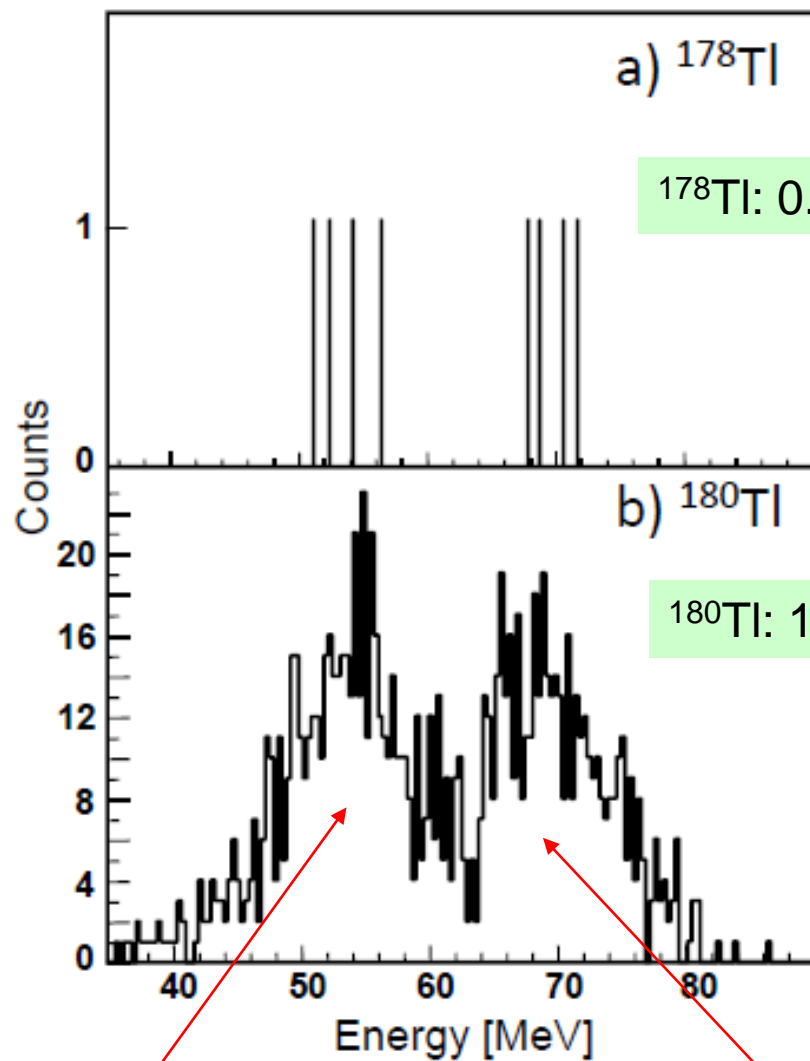
Исследование сосуществования форм в изотопах Bi :
изотопические изменения зарядовых радиусов и
электромагнитные моменты



IRIS: laser ion source



ISOLDE: beta-delayed fission (2010–2012)



^{178}Tl : 0.1 ions/ $\mu\text{C/s}$, 8 fission events

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

^{180}Tl : 1111 fission events

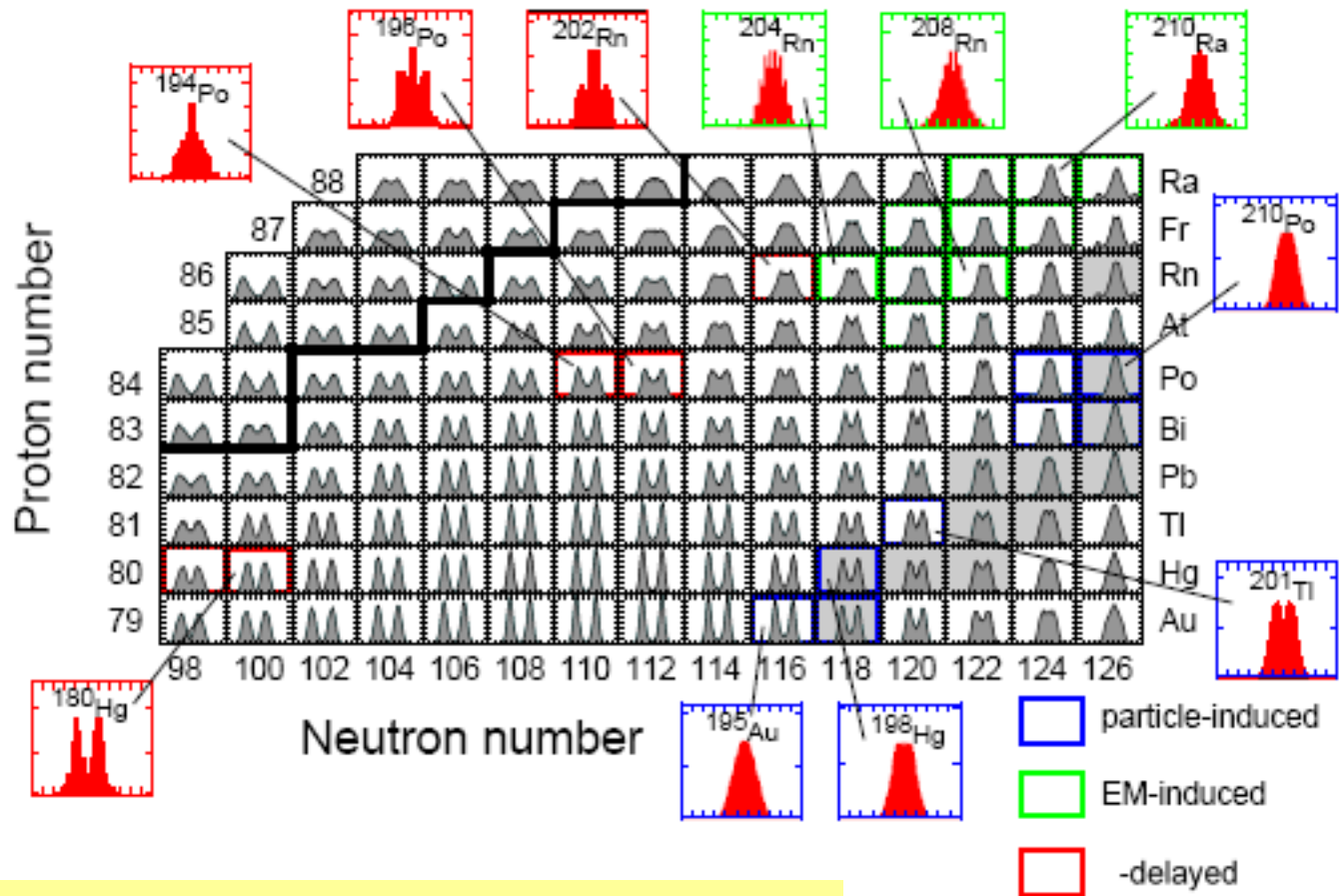
$P_{\beta DF} (^{180}\text{Tl}) = 3.2(2) \times 10^{-3}\%$

corresponds to $A=80(1)$

$\text{FWHM} \approx 9 \text{ amu}$

$A=100(1)$

Beta-delayed fission: theory

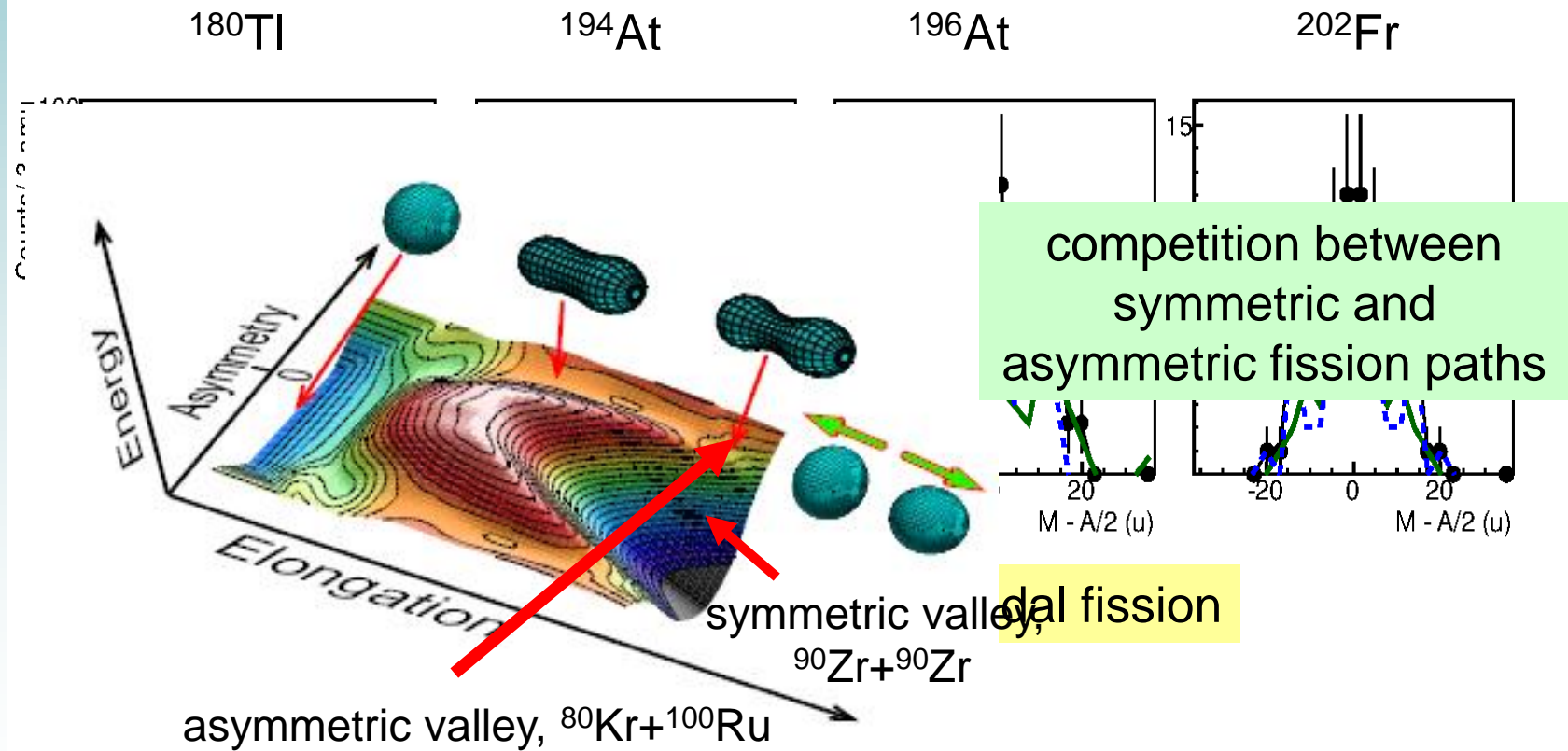


J. Randrup, P. Möller, Phys. Rev. C **88**, 064606 (2013).

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

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

ISOLDE: beta-delayed fission



IRIS & ISOLDE: shape coexistence study

K. Heyde and J.L. Wood, Shape coexistence in atomic nuclei, Rev. Mod. Phys. 83, 1467 (2011)

Understanding the occurrence of shape coexistence in atomic nuclei **is one of the greatest challenges** faced by theories of nuclear structure. We suggest that a major revolution is underway.

At present, no region of manifestation of coexistence has been thoroughly studied. Surprise occurrences continue to be discovered.

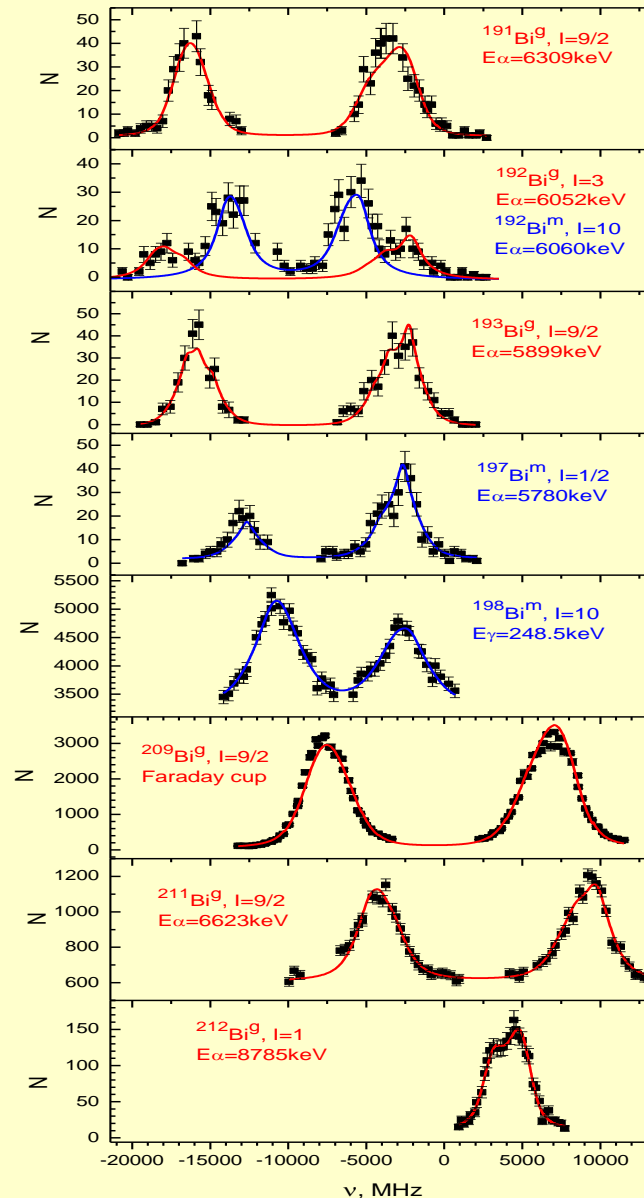
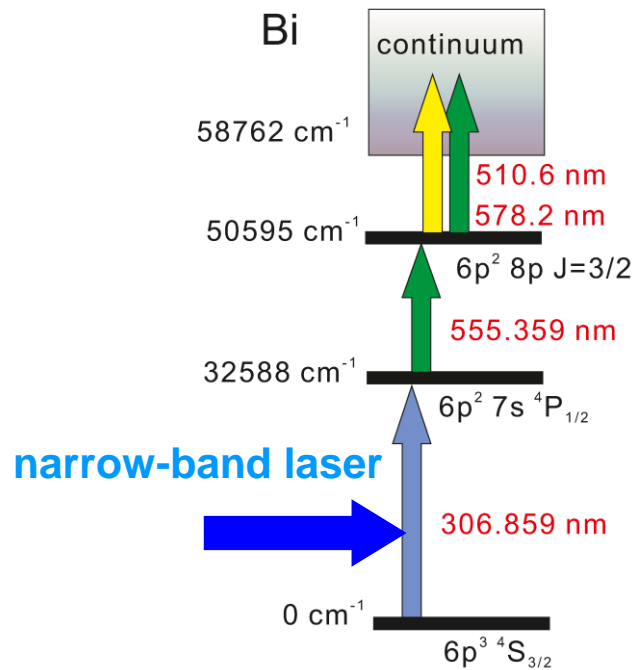
The neutron-deficient isotopes at and near $Z = 82$ exhibit the most extensive manifestation of shape coexistence known anywhere on the nuclear mass surface.

However, the study of this region has been challenging because it is centered on isotopes that lie far from stability. Consequently, experimental investigations demanded the use of some of the most extreme methods ever developed for far-from-stability nuclear structure study.

IRIS: examples of experimental hfs spectra

Shift of the centre of hfs gives isotopic shift

Distance between peaks gives magnetic moment



191

192g

192m

193

197m

198m

209

211

212

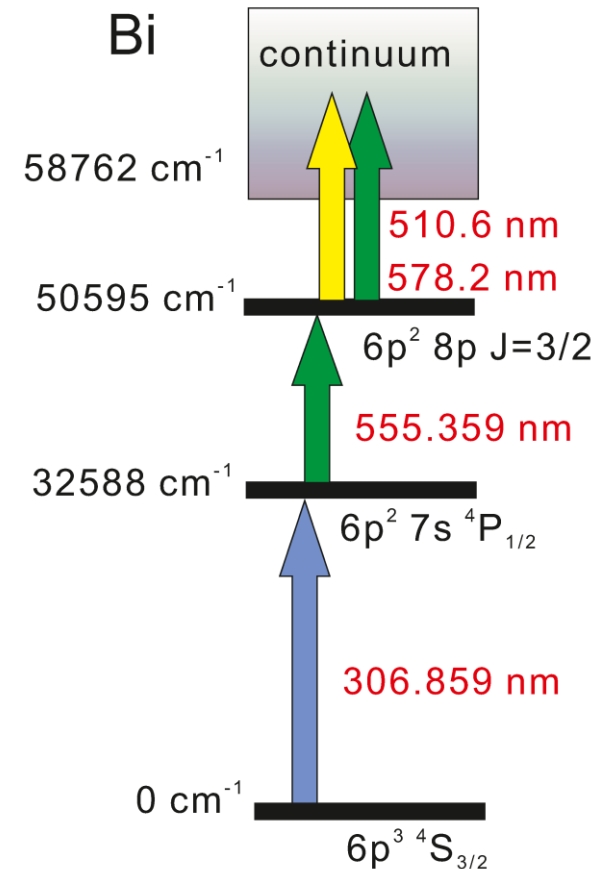
ISOLDE & IRIS: in-source spectroscopy

$$\delta\nu^{A,A'} = F \cdot \lambda^{A,A'} + (M_{NMS} + M_{SMS}) \cdot \frac{A - A'}{A \cdot A'}$$

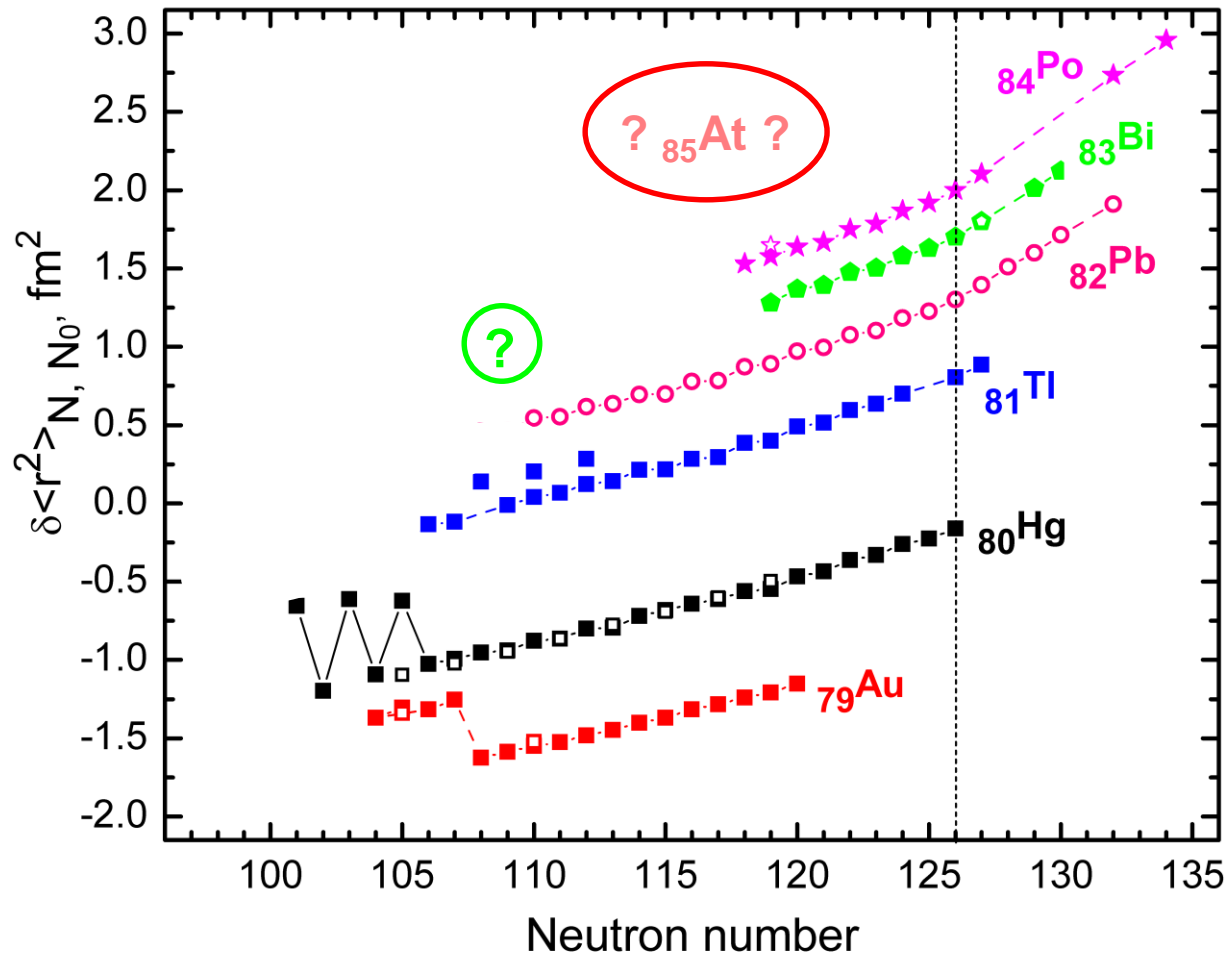
$$\lambda = K \cdot \delta \langle r^2 \rangle$$

$$\langle r^2 \rangle = \langle r^2 \rangle_{DM} \cdot \left(1 + \frac{5}{4\pi} \langle \beta^2 \rangle\right)$$

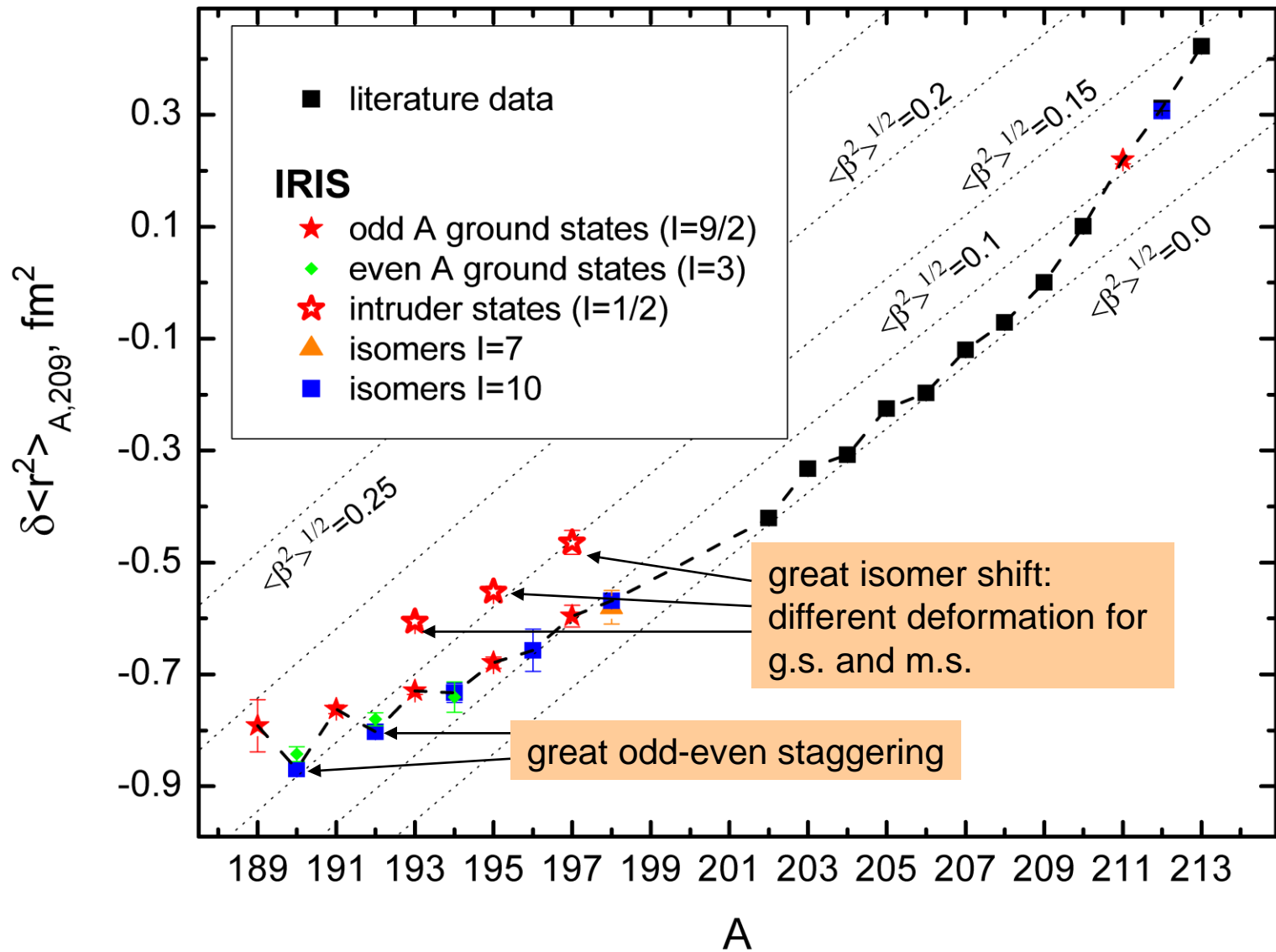
$$\delta \langle r^2 \rangle = \delta \langle r^2 \rangle_{DM} + \frac{5}{4\pi} \langle r^2 \rangle_{DM} \delta \langle \beta^2 \rangle$$



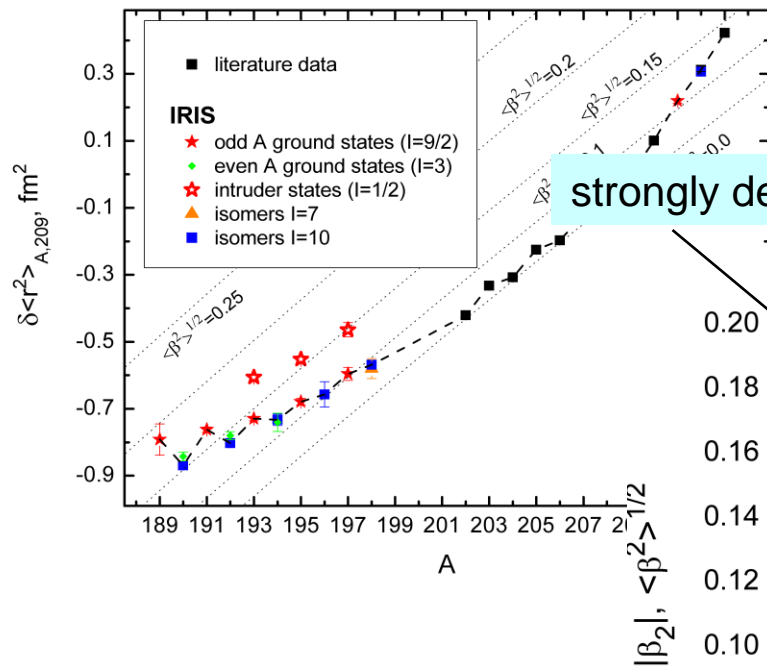
Lead region: shape coexistence study



IRIS, Bi isotopes: radii

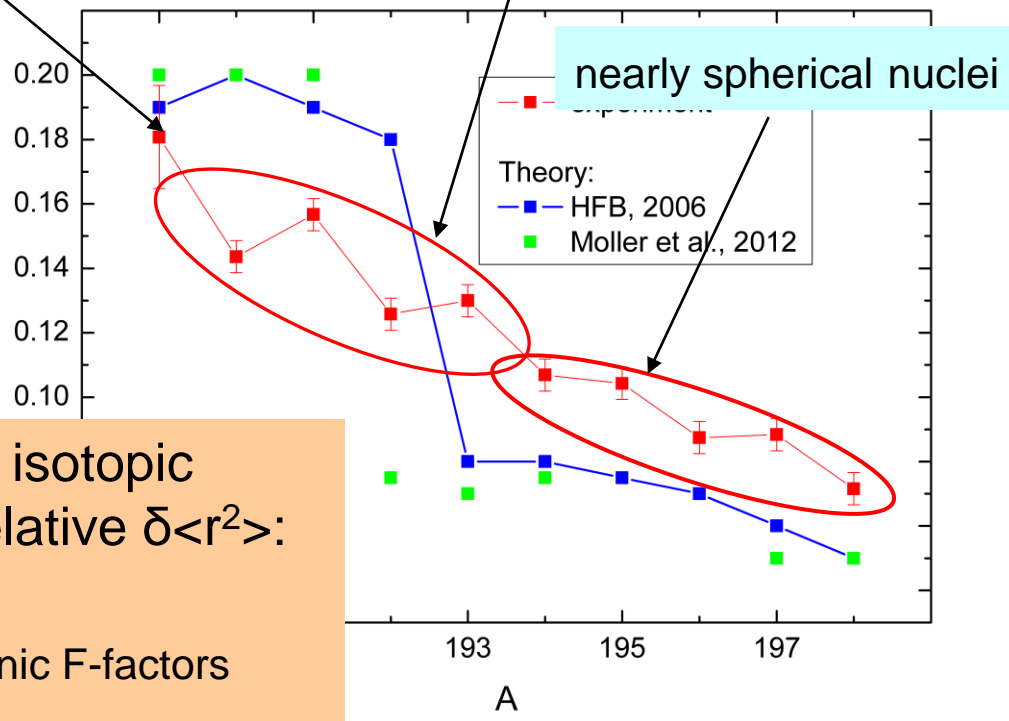


IRIS, Bi isotopes: deformation



mixture of nearly spherical and deformed configurations

strongly deformed nucleus



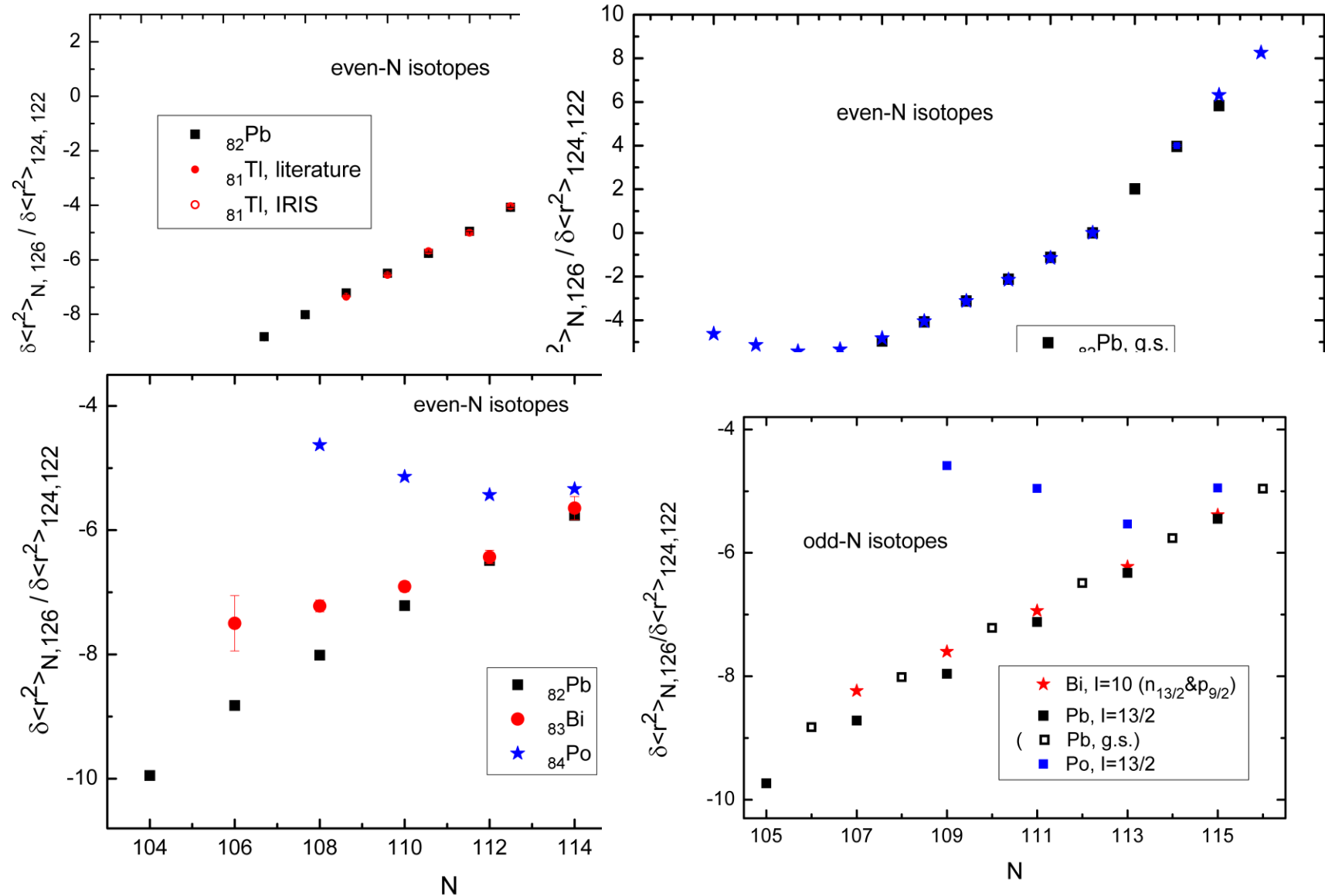
nearly spherical nuclei

For comparison with other isotopic chains it is better to use relative $\delta \langle r^2 \rangle$:
 $\delta \langle r^2 \rangle_{N,126} / \delta \langle r^2 \rangle_{124,122}$
 to avoid indeterminacy of electronic F-factors

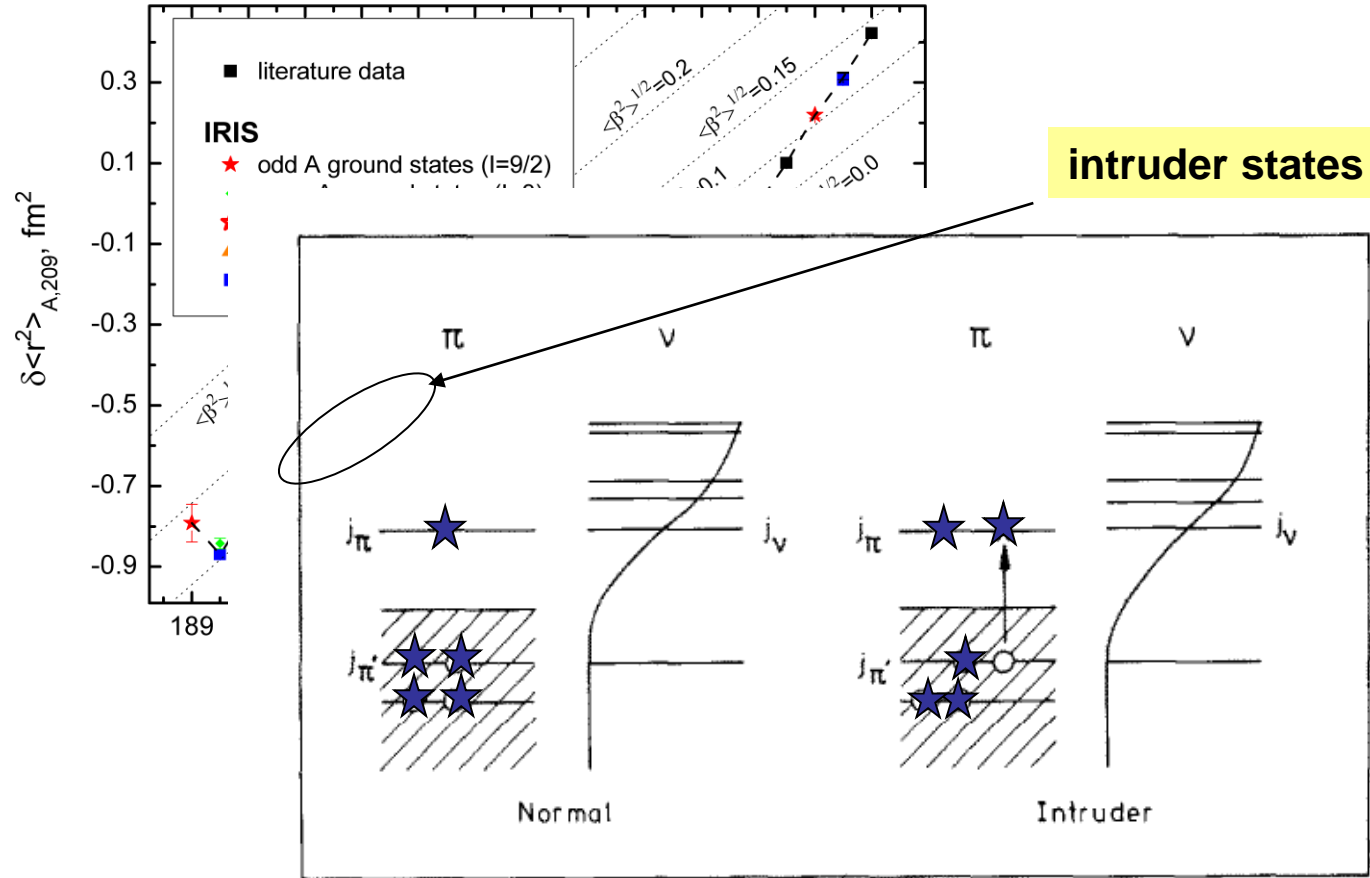
S.Hilaire, M.Girod,
http://www-phynu.cea.fr/science_en_ligne/carte_potentiels_microscopiques/carte_potentiel_nucleaire.htm

P. Moller et al. ADNDT 98 (2012) 149–300

ISOLDE & IRIS: comparison of Tl, Pb and Po

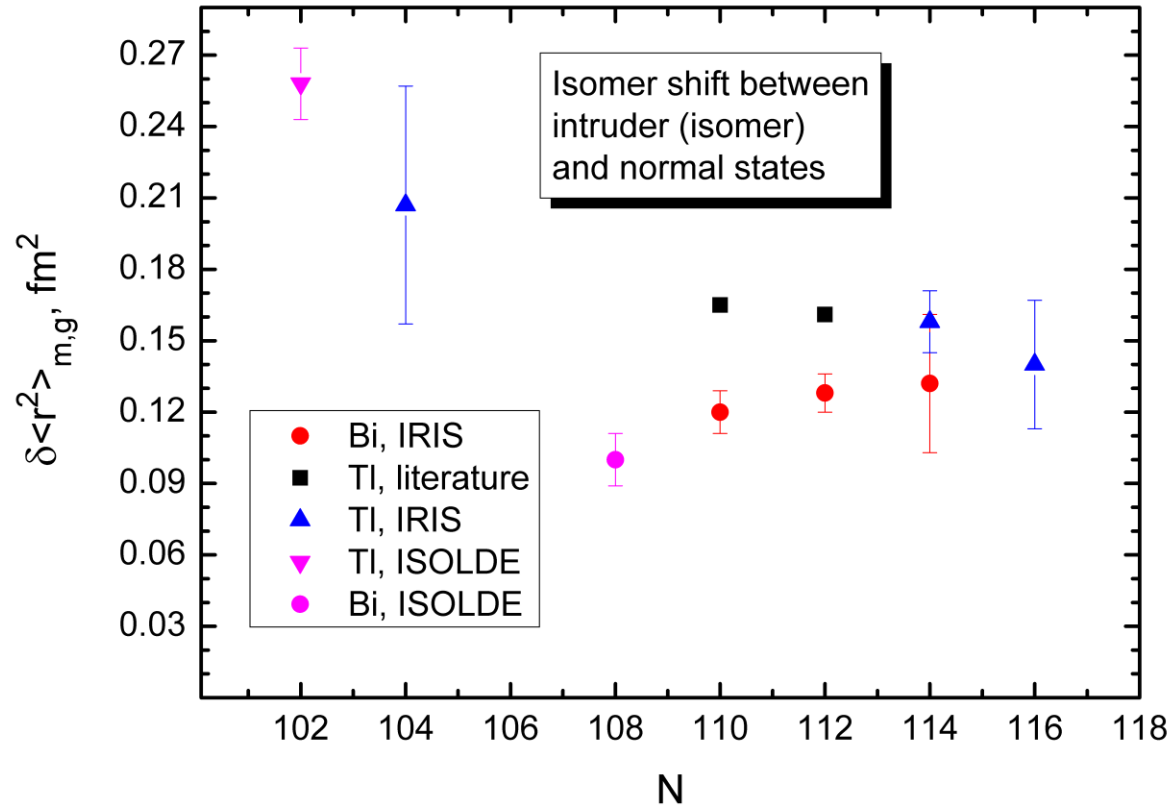


IRIS, Bi: intruder states (isomers $I^P=1/2^+$)

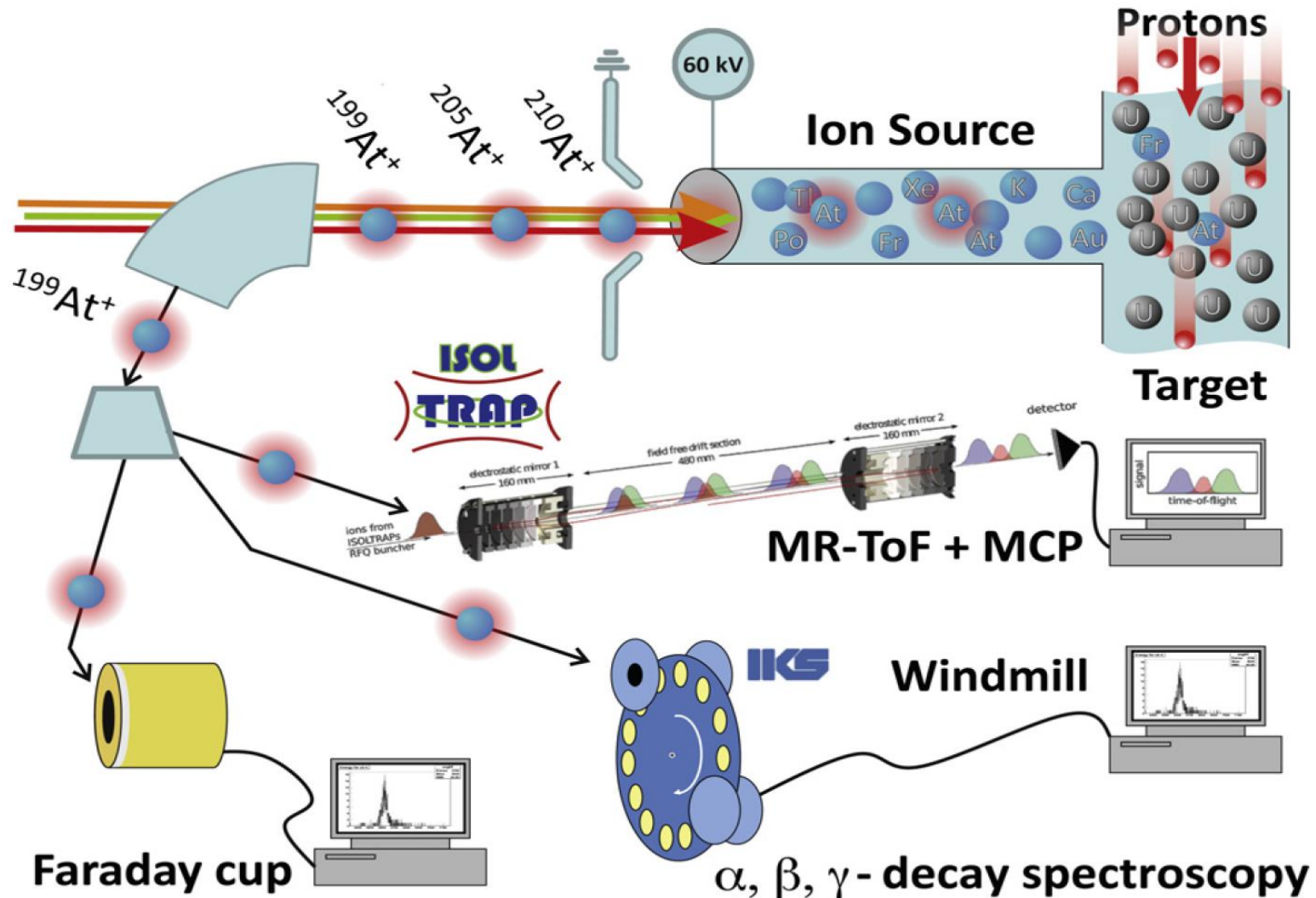


Schematic representation of a proton 2p1h intruder configuration (Bi)

IRIS, Bi: intruder states (isomers $I^{\pi}=1/2^{+}$)



ISOLDE: in-source spectroscopy

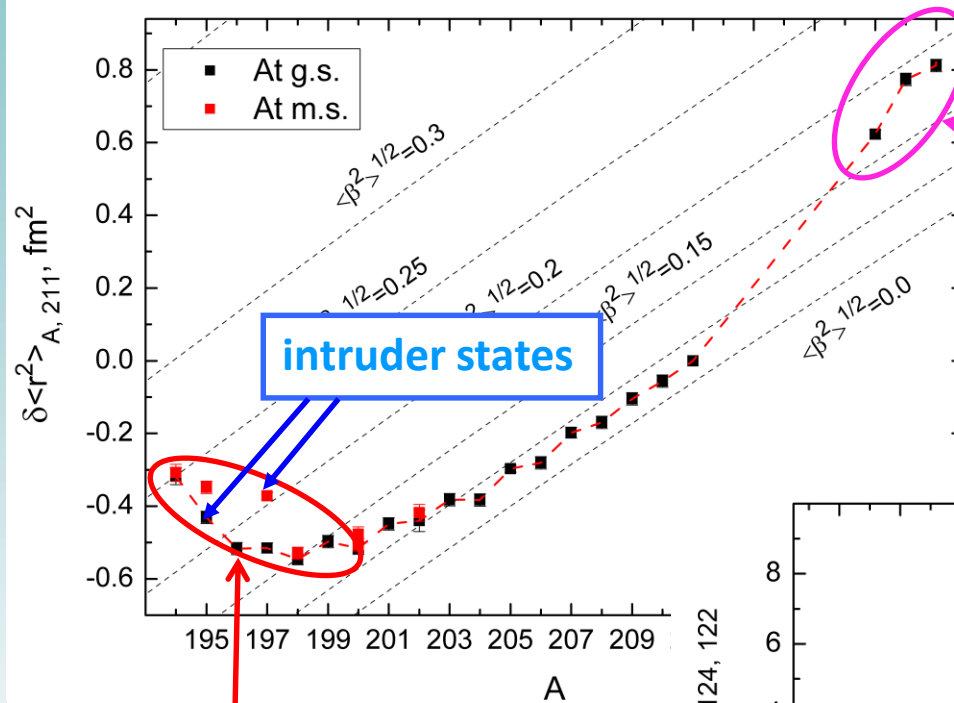


B. A. Marsh et al., 2013 EMIS conference, NIM B317, p.550 (2013)

WM: A.N. Andreyev et al, Phys. Rev. Lett 105, 252502 (2010)

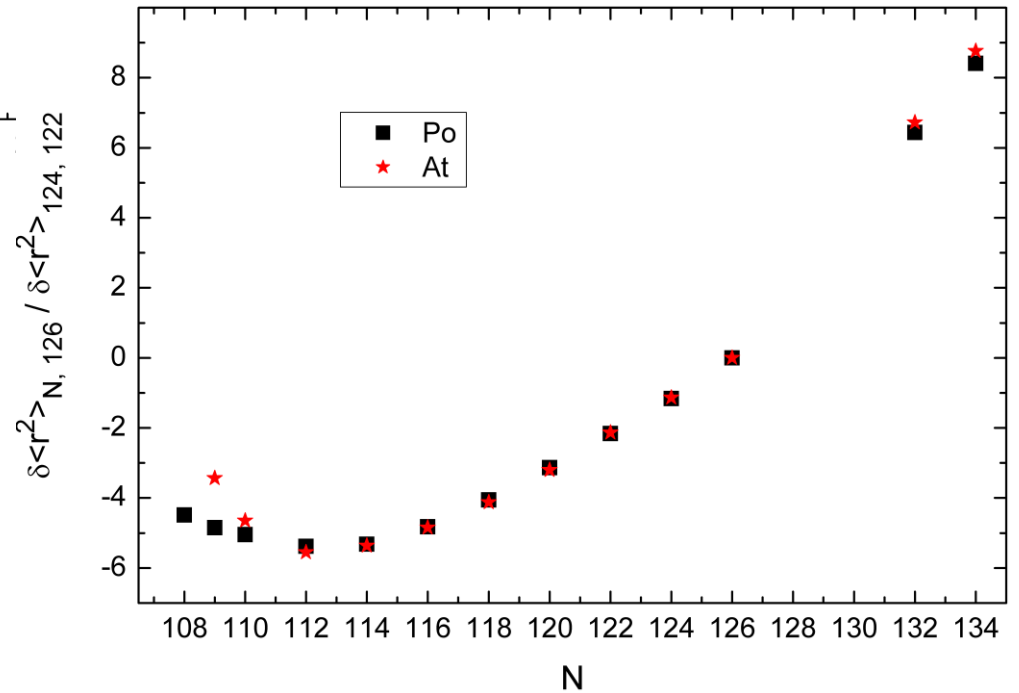
MR-ToF MS: R. N. Wolf et al, NIM, A686, 82 (2012)

ISOLDE, At isotopes: radii

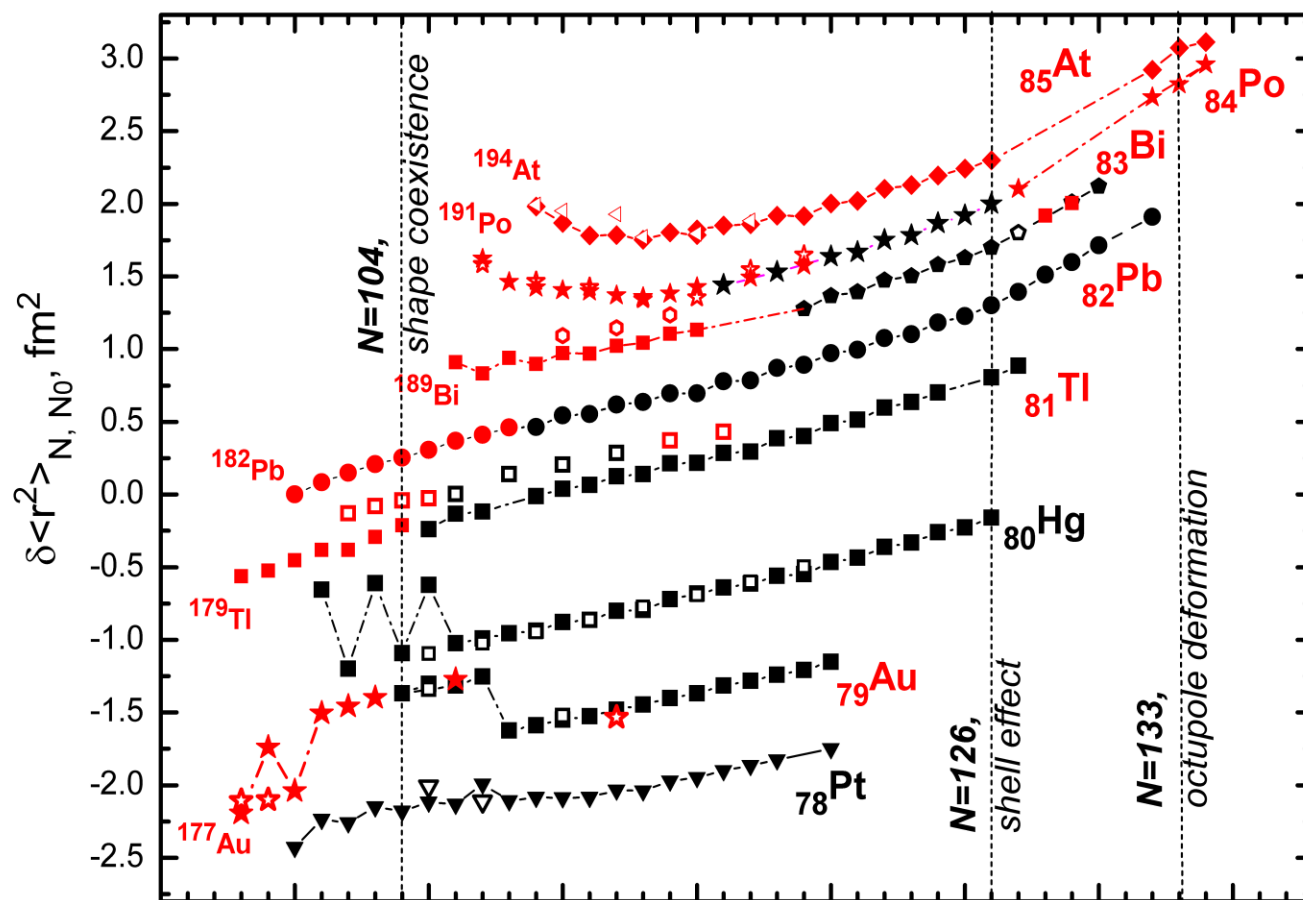


Possible octupole deformation?
(inverse odd-even effect)

Onset of quadrupole deformation



IRIS & ISOLDE: shape coexistence study

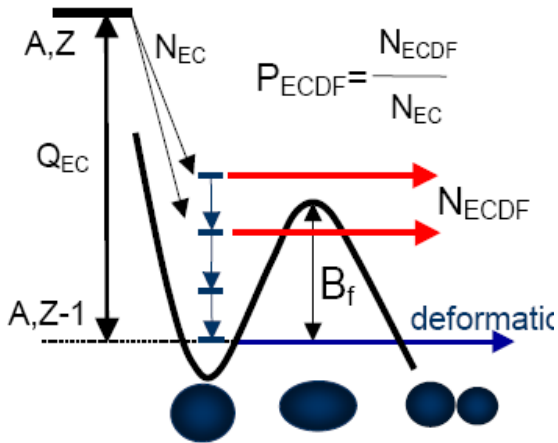


- IS/charge radii for 29 At and 20 Bi nuclei were measured
- Magnetic/quadrupole moments were deduced
- Large amount of by-product nuclear spectroscopic information on At and daughter products

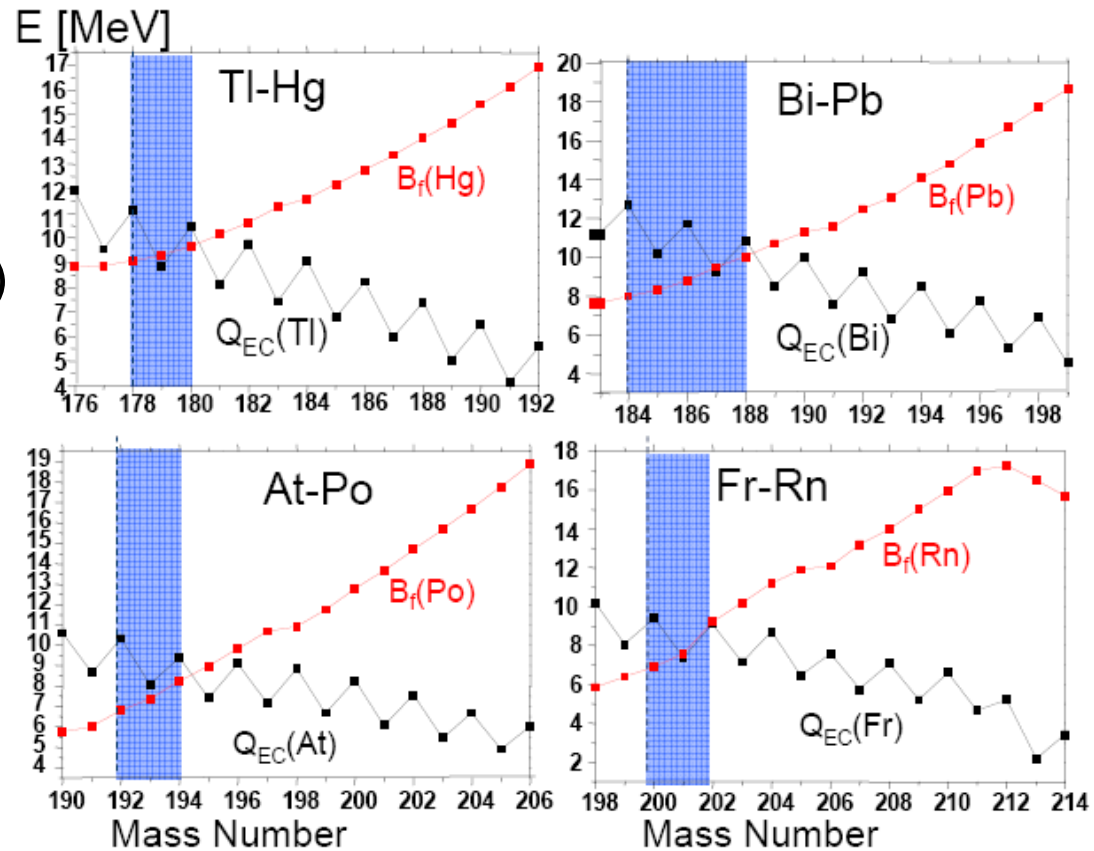
IRIS & ISOLDE: laser ion source — conclusions

1. Измерено массовое распределение осколков в запаздывающем делении $^{194,196}\text{At}$ и ^{202}Fr . Установлено, что переход от асимметричного к симметричному делению осуществляется через область мультимодального деления.
2. Измерены изотопические сдвиги и сверхтонкое расщепление (μ , Q , $\delta\langle r^2 \rangle$) для 29 изотопов (изомеров) At на двух переходах, 216 nm и 795 nm. Показано, что эффект «раннего возникновения деформации», обнаруженный ранее для Po, сохраняется и для At, причем, в отличие от Po, при $N < 111$ у ядер At происходит переход к режиму сильной деформации.
3. Измерены изотопические сдвиги и сверхтонкое расщепление (μ , Q , $\delta\langle r^2 \rangle$) для 20 изотопов (изомеров) ^{83}Bi на переходе 306.77 nm. Обнаружен «промежуточный» (по отношению к ^{82}Pb и ^{84}Po) характер изменения деформации у четно-нейтронных изотопов Bi. При этом ход радиусов для нечетно-нейтронных изотопов Bi не отклоняется от соответствующего хода для Pb.
4. Доказана деформированность интродер-состояний ($^{197m,195m,193m}\text{Bi}$, $^{195,197m,199m}\text{At}$); обнаружено различное поведение изомерных сдвигов для этих состояний в различных изотопических цепочках.

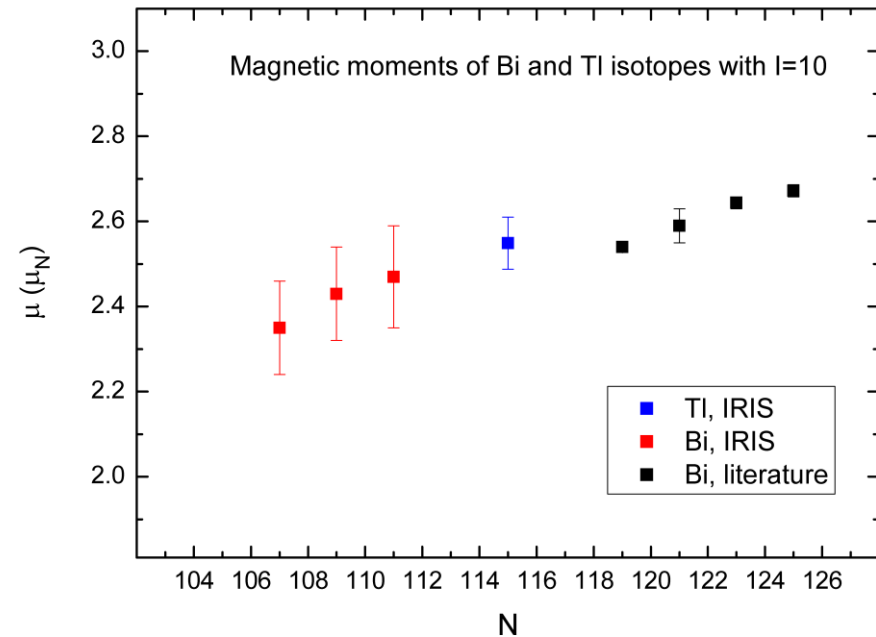
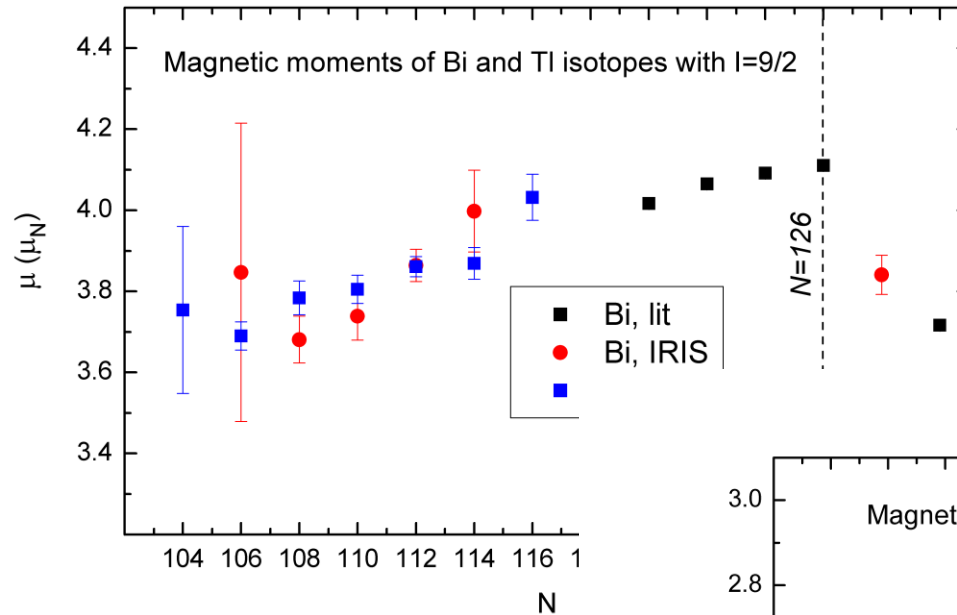
Beta-delayed fission



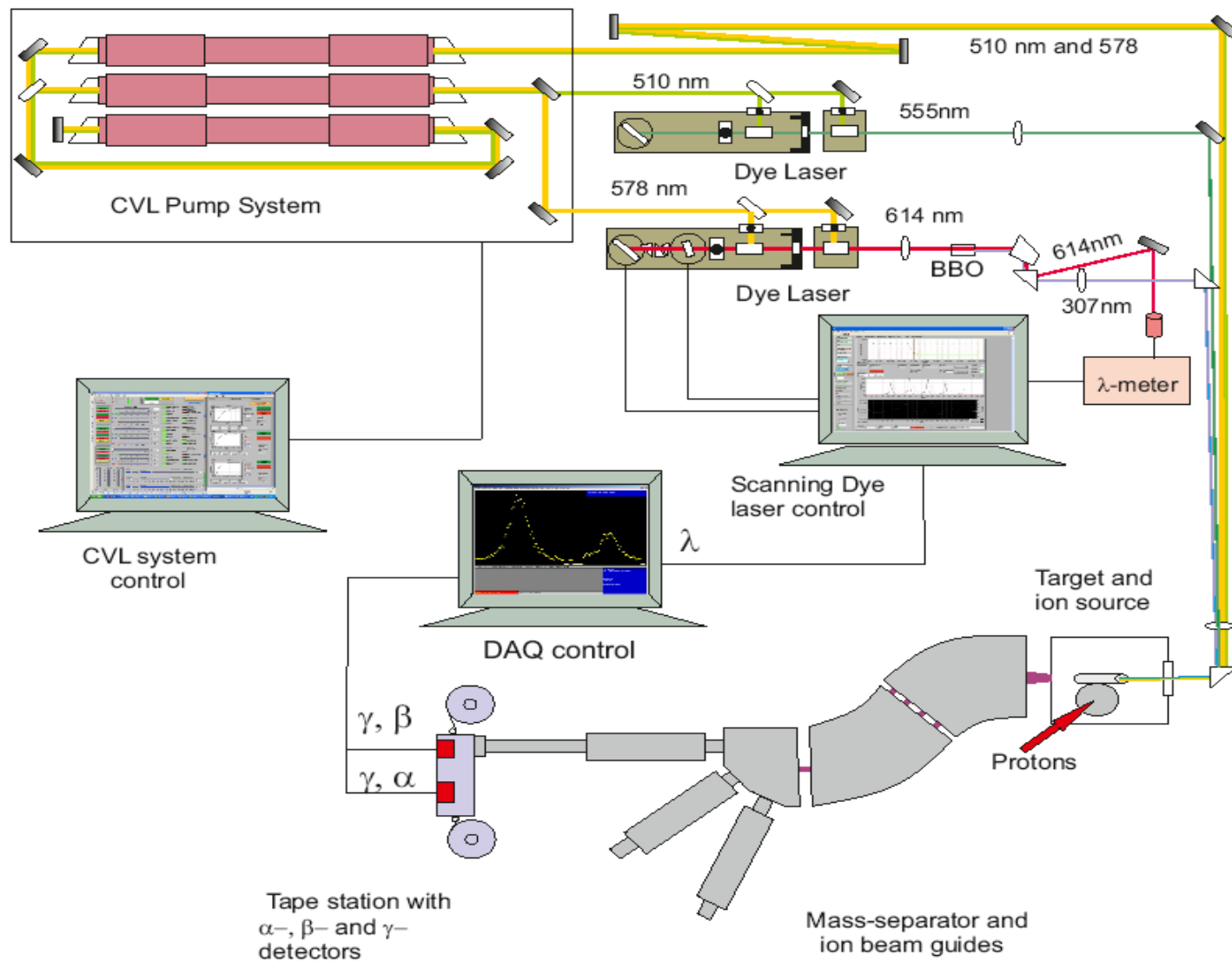
$$Q_{EC}(A, Z) \gtrsim B_f(A, Z-1)$$



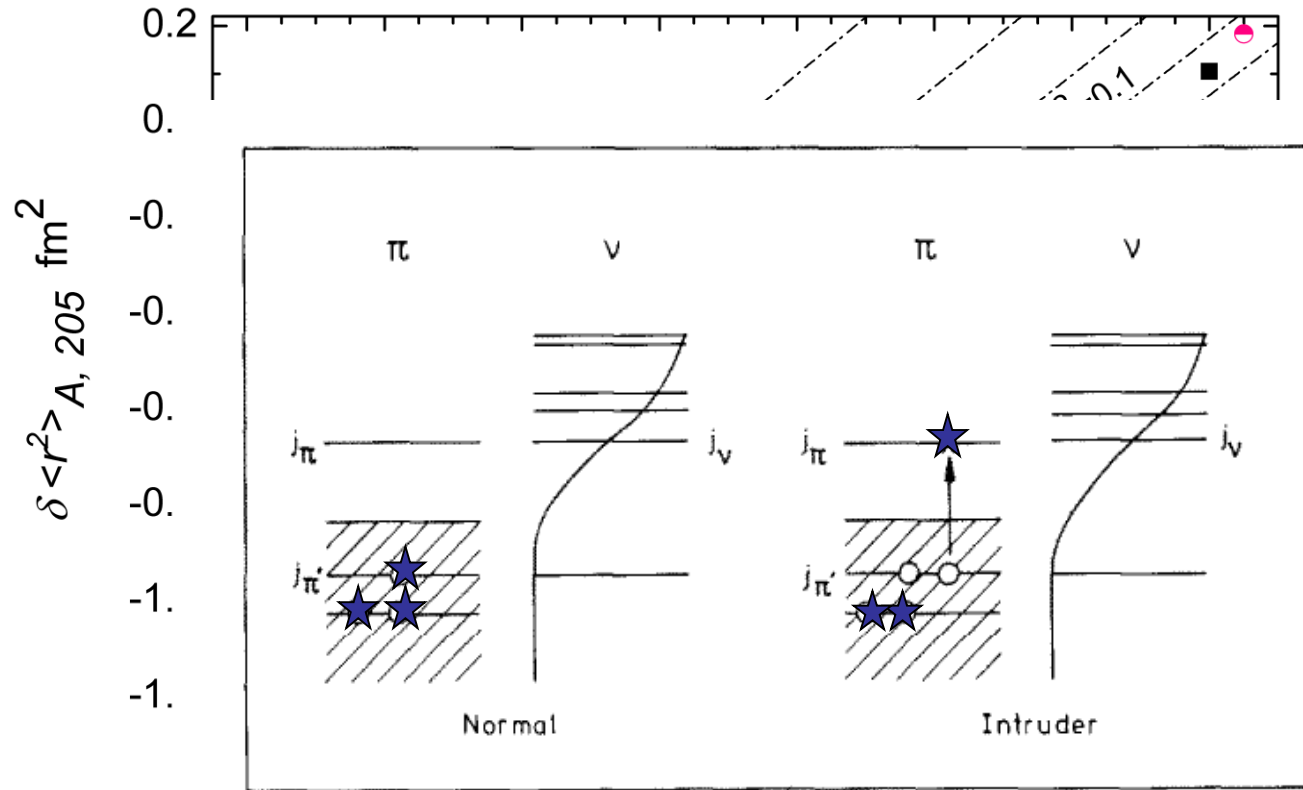
IRIS, Bi: magnetic moments



IRIS: laser ion source



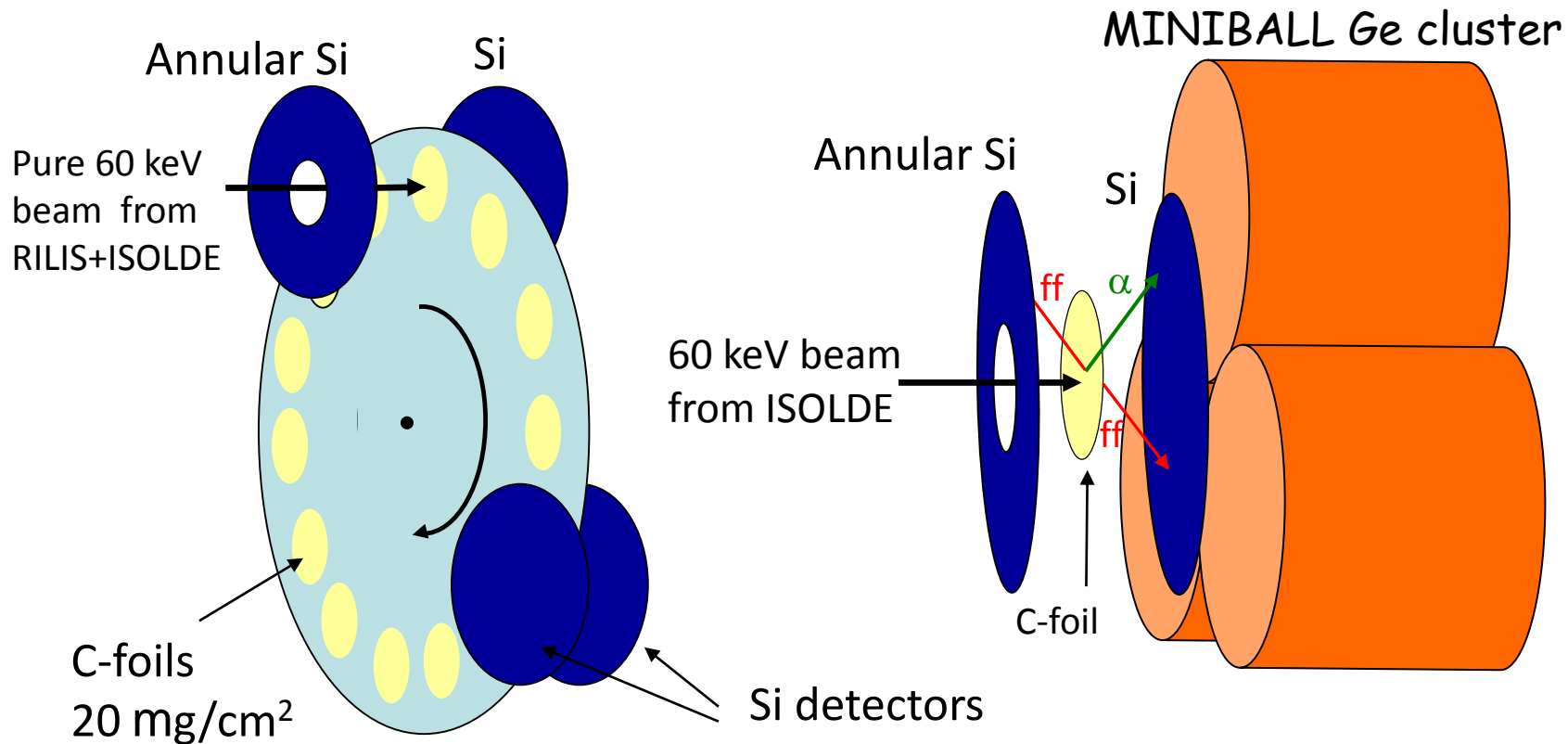
IRIS, Tl: intruder states (isomers $I^P=9/2^-$)



A

Schematic representation of a proton 1p2h intruder configuration (TI)

Windmill system at ISOLDE

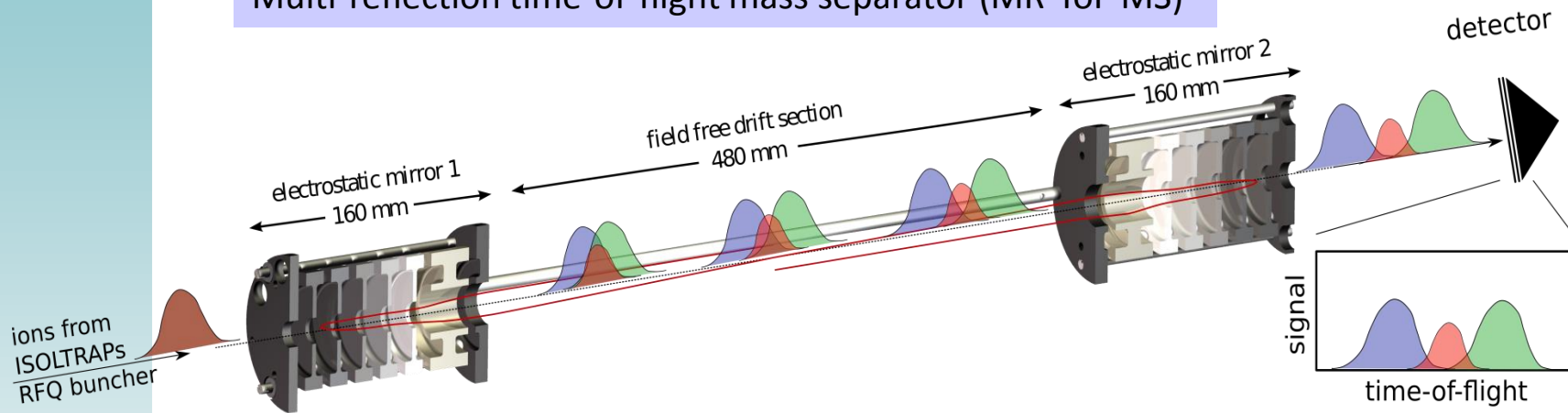


Setup: Si detectors both sides of the C-foil

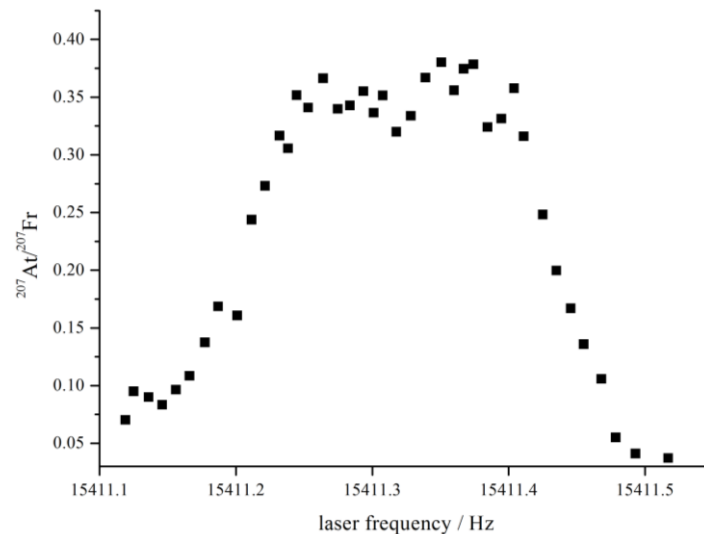
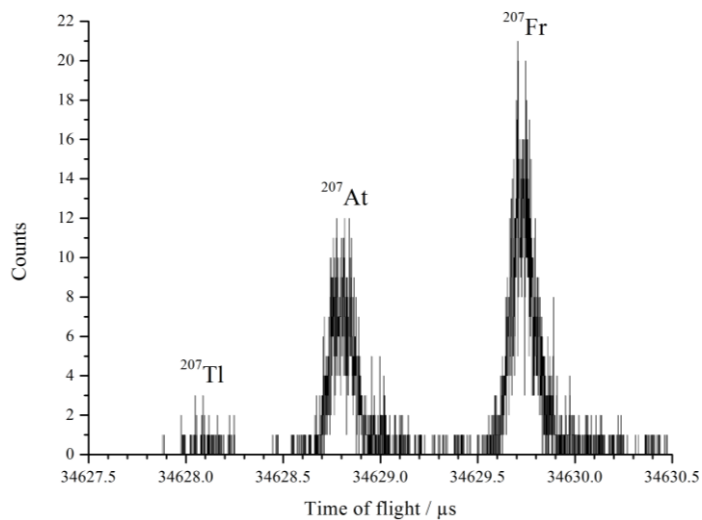
- Simple setup & DAQ: 4 PIPS (1 of them – annular)
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-gamma coincidences
- Digital electronics

MR-ToF at ISOLDE

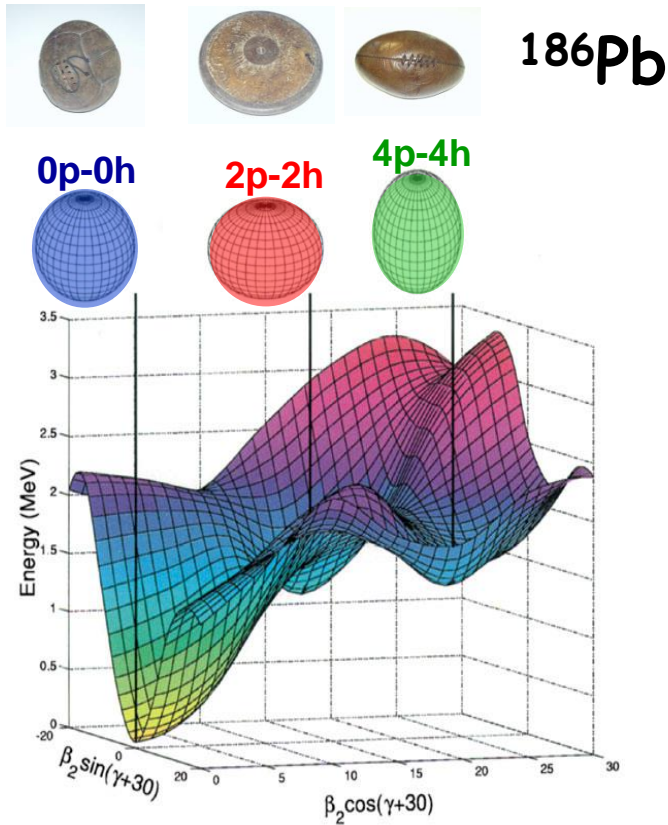
Multi-reflection time-of-flight mass separator (MR-ToF MS)



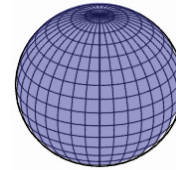
~ 1000 revolutions, ~ 35 ms, $m/\Delta m \sim 10^5$



Shape Coexistence in the Pb region

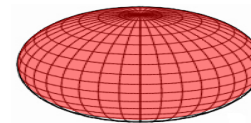


•Pb (Z=82) g.s.: $\pi(0p-0h)$ – spherical

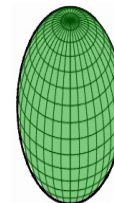


Proton pair excitations across Z=82 shell gap (neutrons are spectators):

•1 pair excitation: $\pi(2p-2h)$ -oblate



•2 pair excitation: $\pi(4p-4h)$ -prolate



Potential Energy Surface for ¹⁸⁶Pb

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

K. Heyde et al., Phys. Rep. 102 (1983) 291
 J.L. Wood et al., Phys. Rep. 215 (1992) 101
 A. Andreyev et al., Nature 405 (2000) 430
 K. Heyde and J. Wood, Review of Modern Physics, 2012