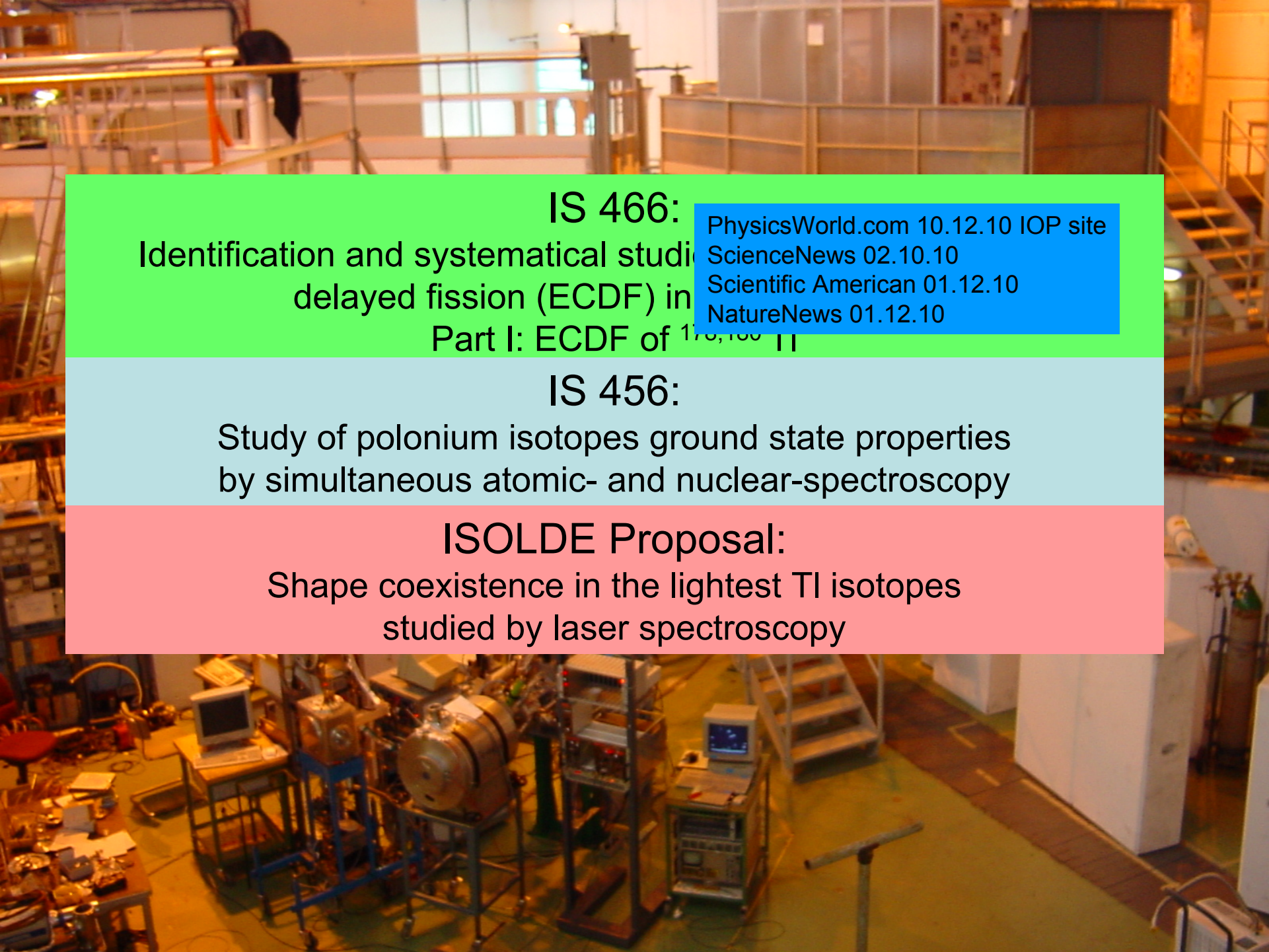


Исследование запаздывающего деления и
сосуществования форм
в экспериментах на ISOLDE
(изотопы Tl и Po)



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V.S. Ivanov, P.L. Molkanov,
M.D. Seliverstov, Yu.M. Volkov**



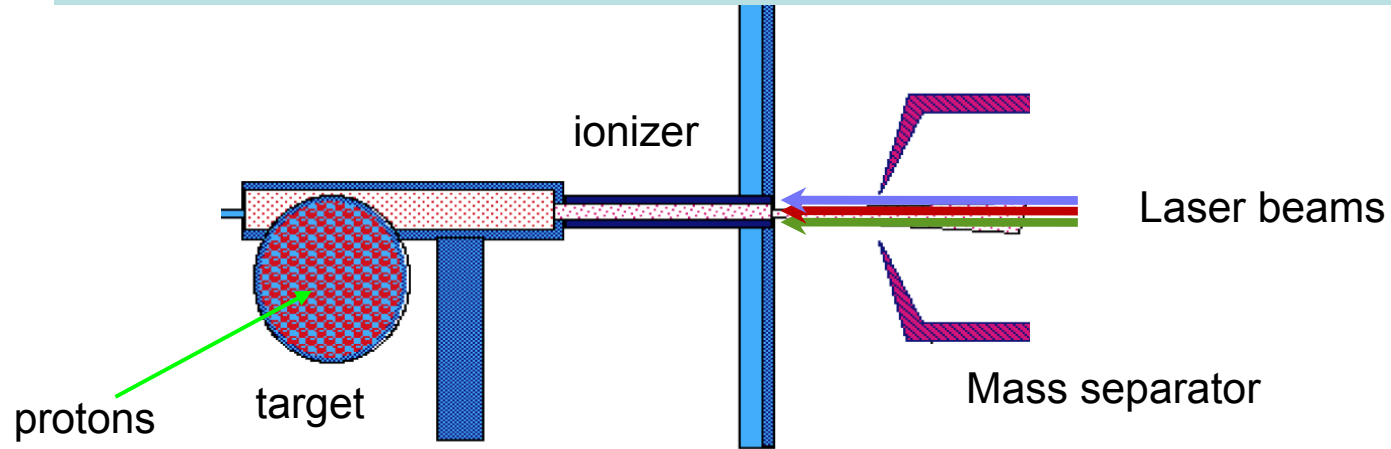
IS 466:
Identification and systematical study
of delayed fission (ECDF) in
Part I: ECDF of ^{187}Re II

PhysicsWorld.com 10.12.10 IOP site
ScienceNews 02.10.10
Scientific American 01.12.10
NatureNews 01.12.10

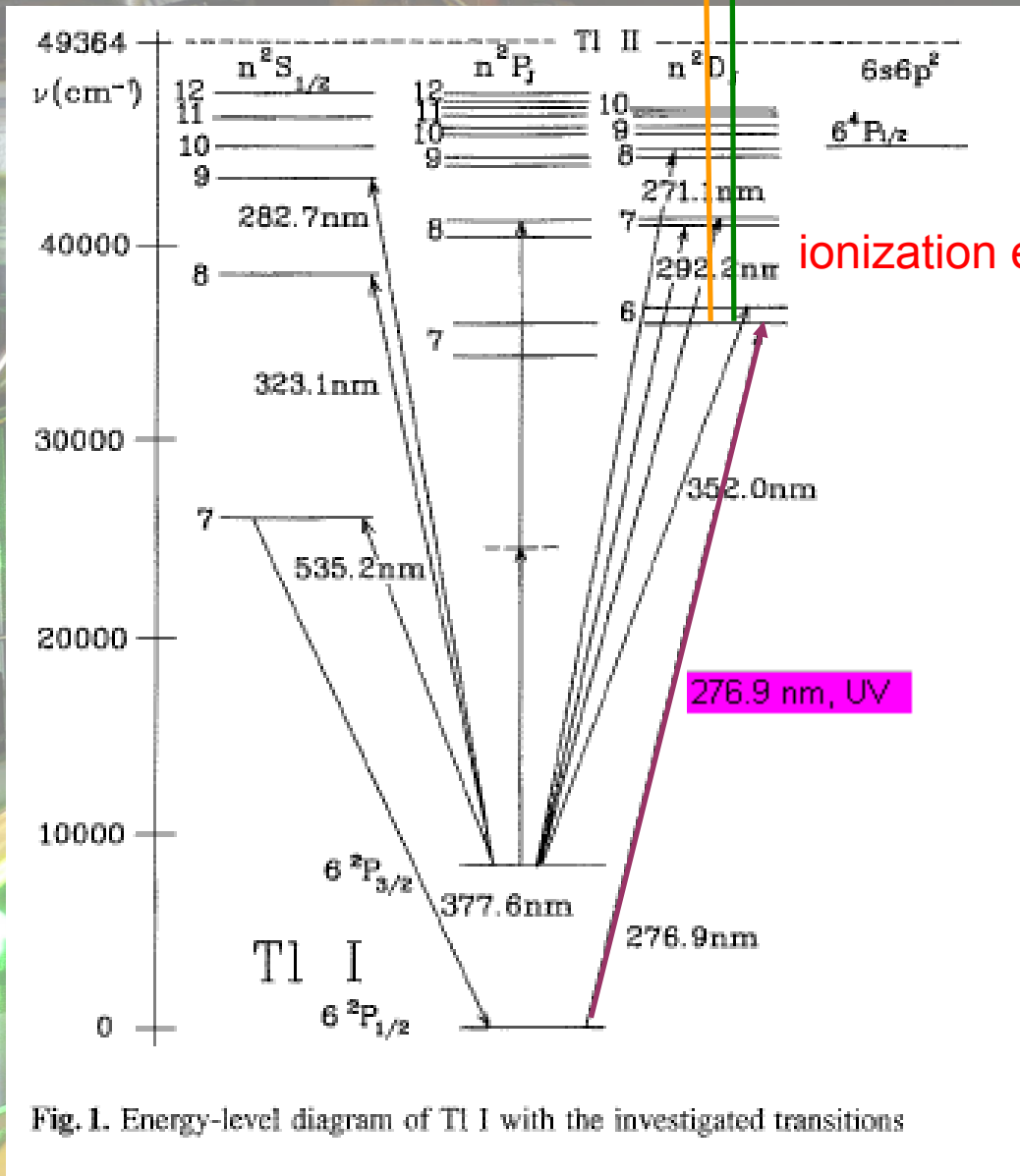
IS 456:
Study of polonium isotopes ground state properties
by simultaneous atomic- and nuclear-spectroscopy

ISOLDE Proposal:
Shape coexistence in the lightest TI isotopes
studied by laser spectroscopy

1. Delayed fission in light TI isotopes



Laser Ion Source (LIS)



578.2 nm Cu vapor laser

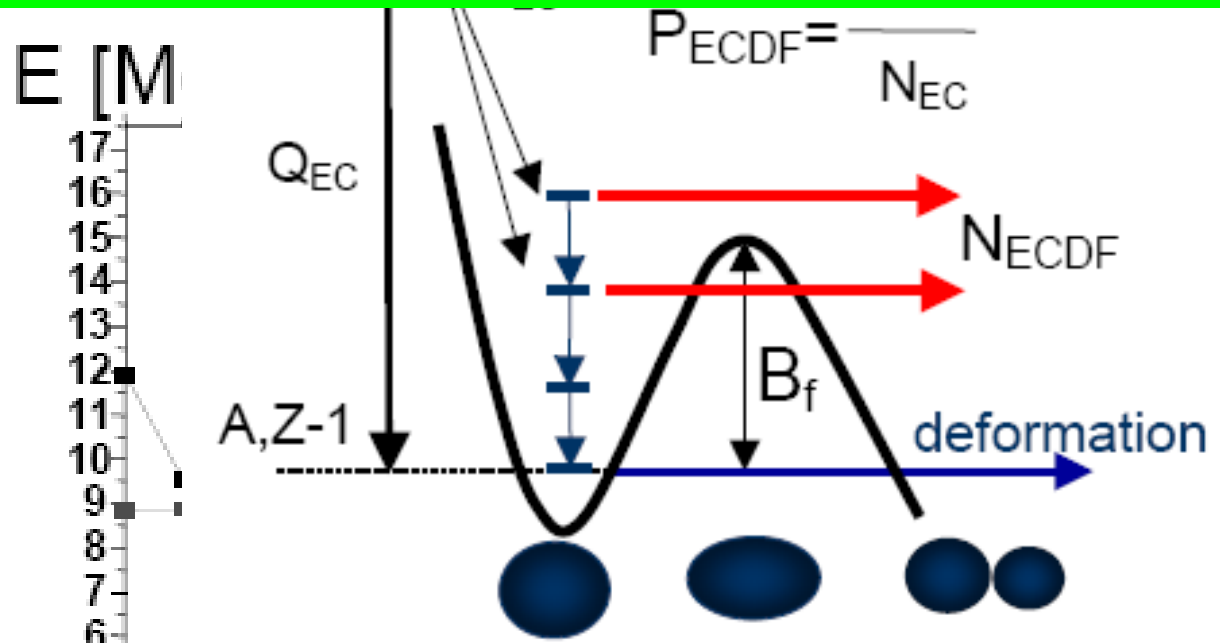
510.6 nm Cu vapor laser

ionization efficiency ~ 15%

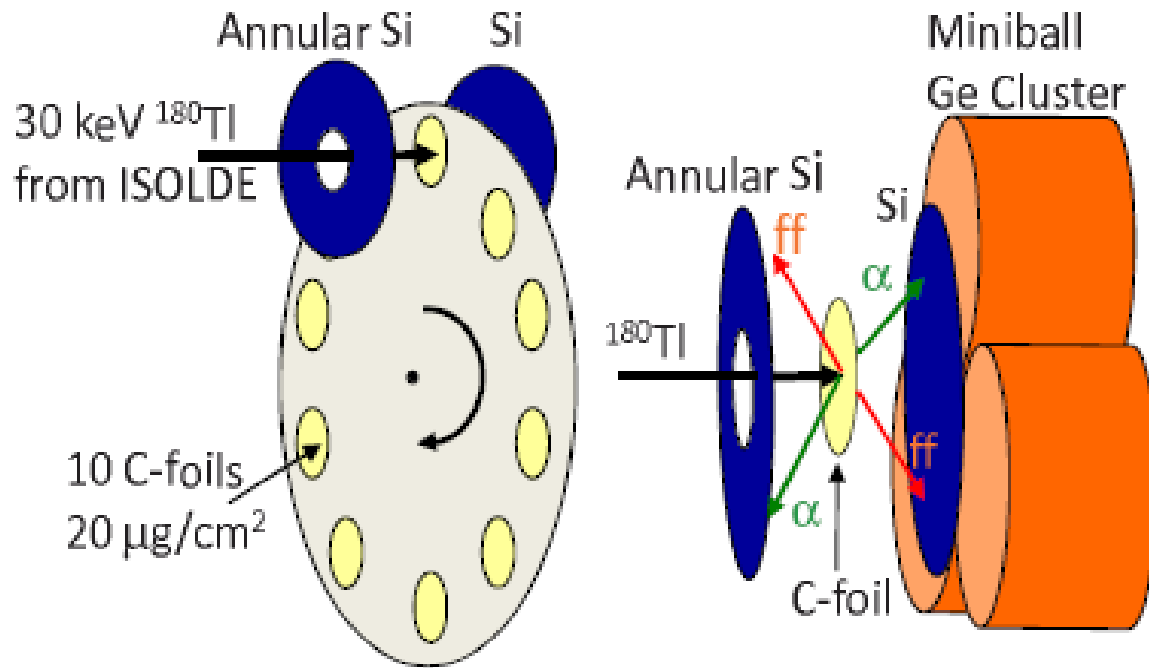
Fig. 1. Energy-level diagram of Tl I with the investigated transitions

Two areas in the nuclear chart were identified where DF is experimentally accessible: the U region and a region near the very neutron-deficient Pb isotopes.

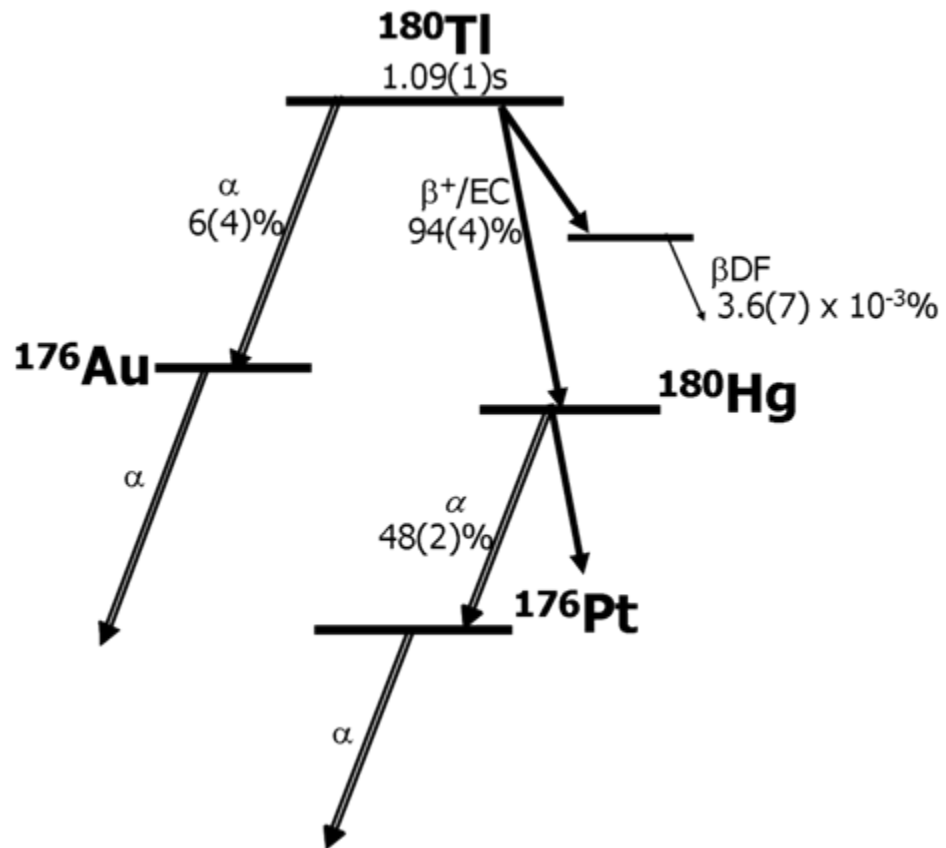
$N/Z = 1,25$ for ^{180}Hg ,
 in contrast to a typical ratio of $N/Z = 1,55-1,59$ in the U region.

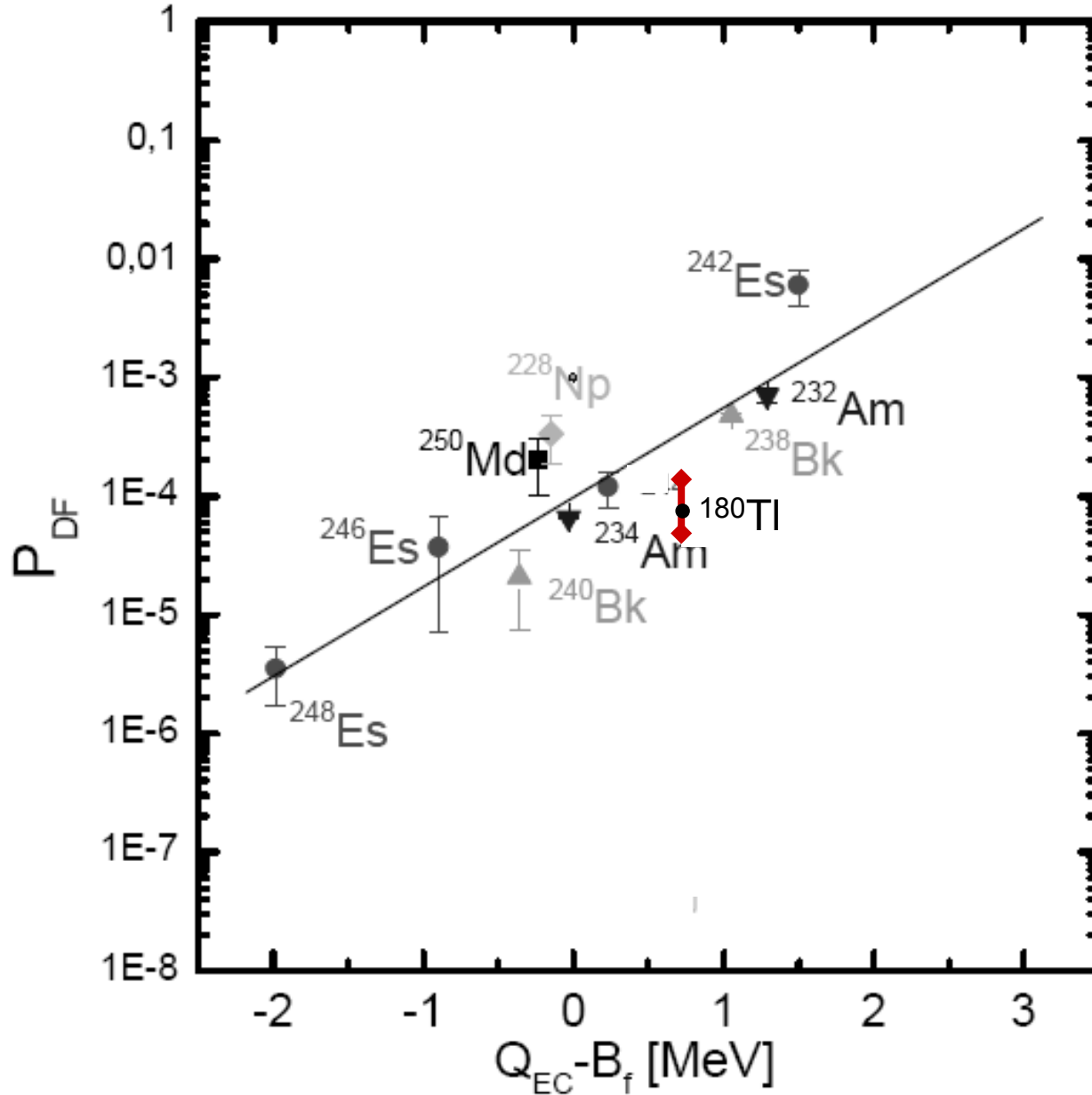


- $Q_{EC}(^{180}\text{Tl}) - B_f(^{180}\text{Hg}) = 0.6 \text{ MeV}$ (calculation) (? Dubna 1992)
- $Q_{EC}(^{178}\text{Tl}) - B_f(^{178}\text{Hg}) = 1.9 \text{ MeV}$ (calculation)
- $Q_{EC}(^{182}\text{Tl}) - B_f(^{182}\text{Hg}) = -0.5 \text{ MeV}$ (calculation)



In total, approximately ~ 1200 singles ECDF decays of ^{180}Tl were detected, ~ 350 of which being observed as double-fold fission-fission coincident events.

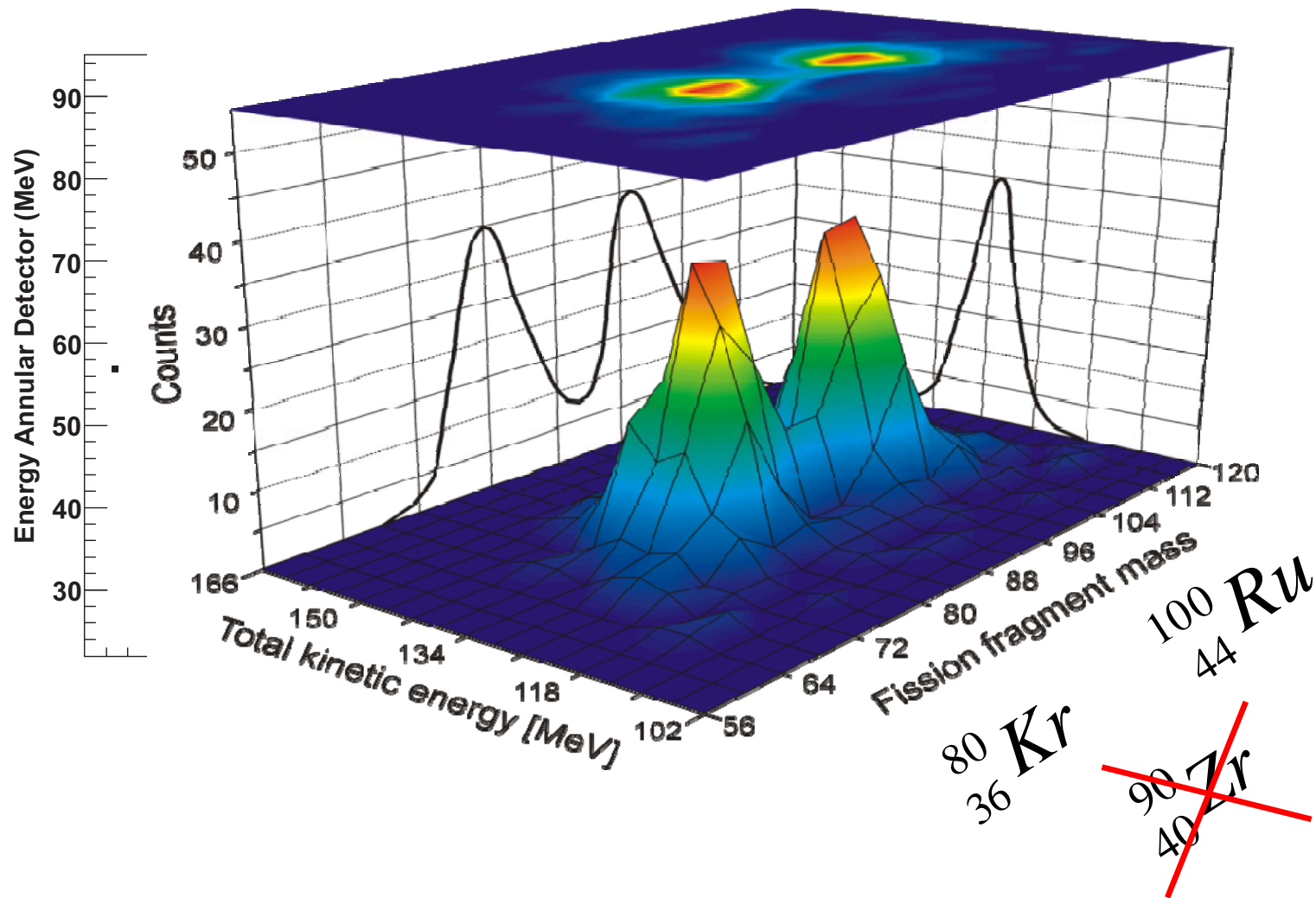




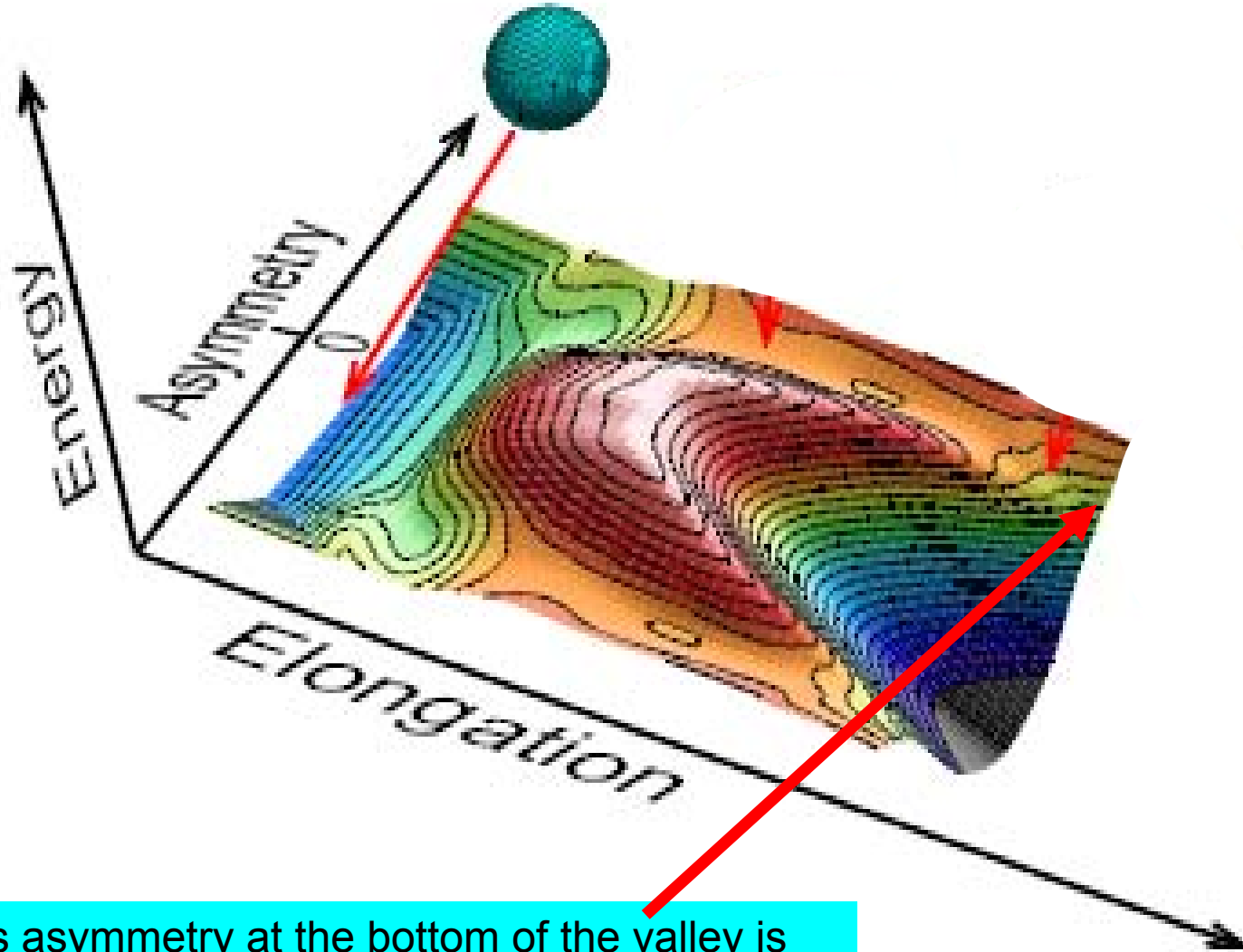
A new ECDF branching ratio of $P_{ECDF} = 3,6(7) \cdot 10^{-5}$ was deduced for the parent nucleus ^{180}Tl , which is much higher and much more precise than the previously estimated value of $P_{ECDF} \sim 10^{-(7 \pm 1)}$ (Dubna, 1992).

In low-energy fission (including β - or EC-delayed fission) for nuclei from Fm to U asymmetric fission dominate over symmetric fission due to influence of doubly magic ^{132}Sn .
Below Th (Th, At) only symmetric fission has been found.

For $^{180}_{80}\text{Hg}$ symmetrical split in two semi-magic $^{90}_{40}\text{Zr}$ nuclei was expected before the experiment.



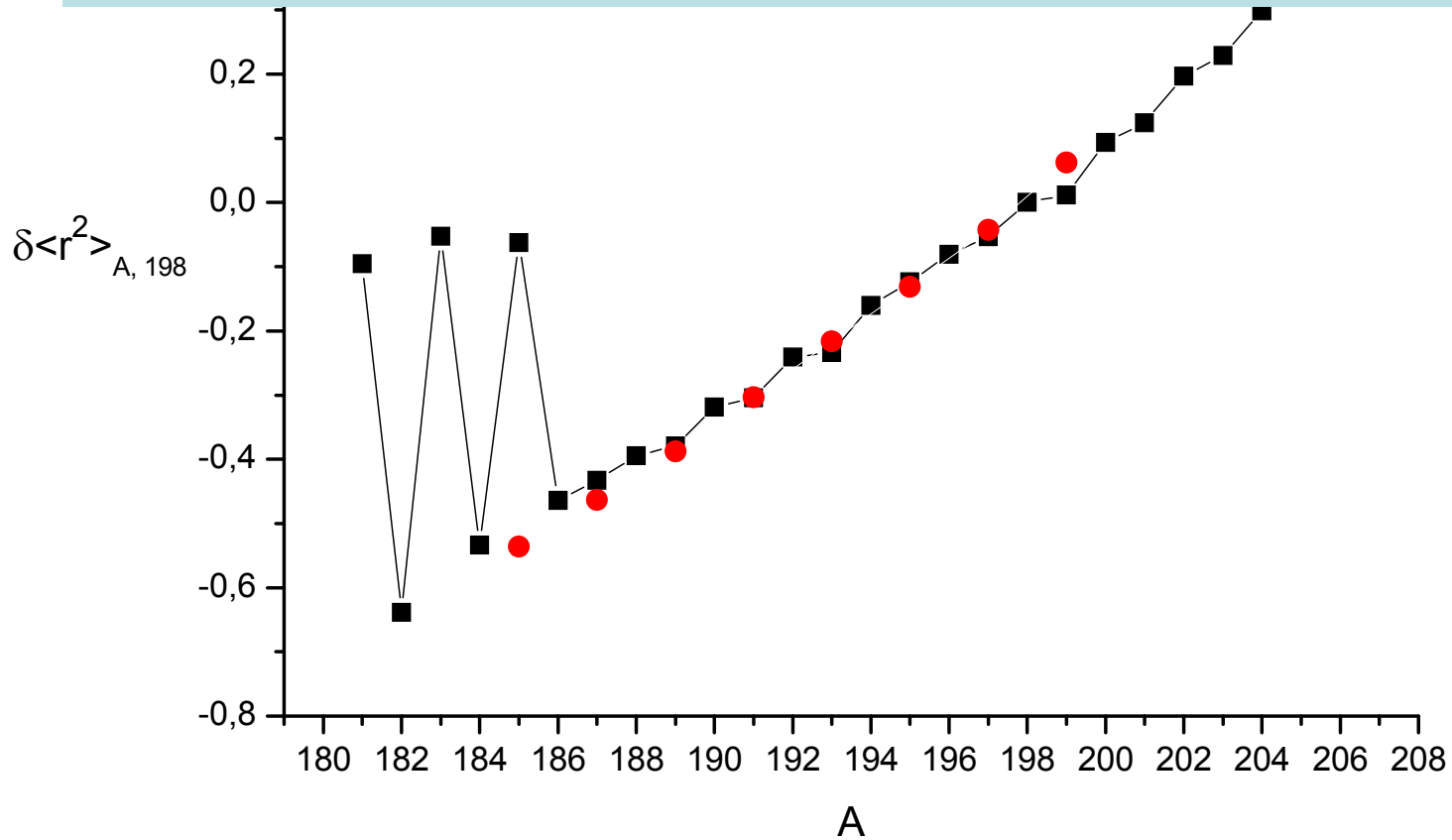
P. Möller's calculations (2D projection of the total 5D picture):

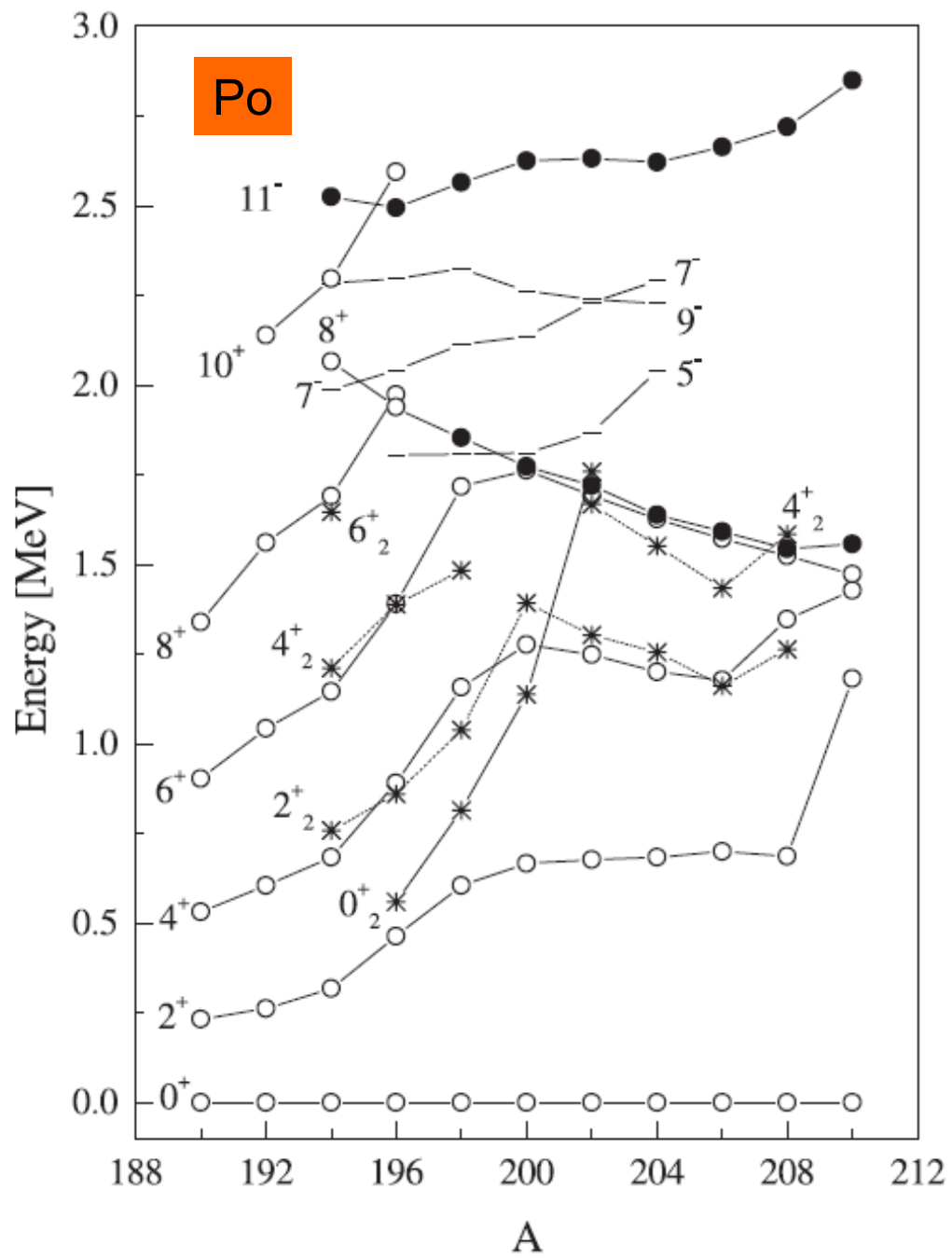
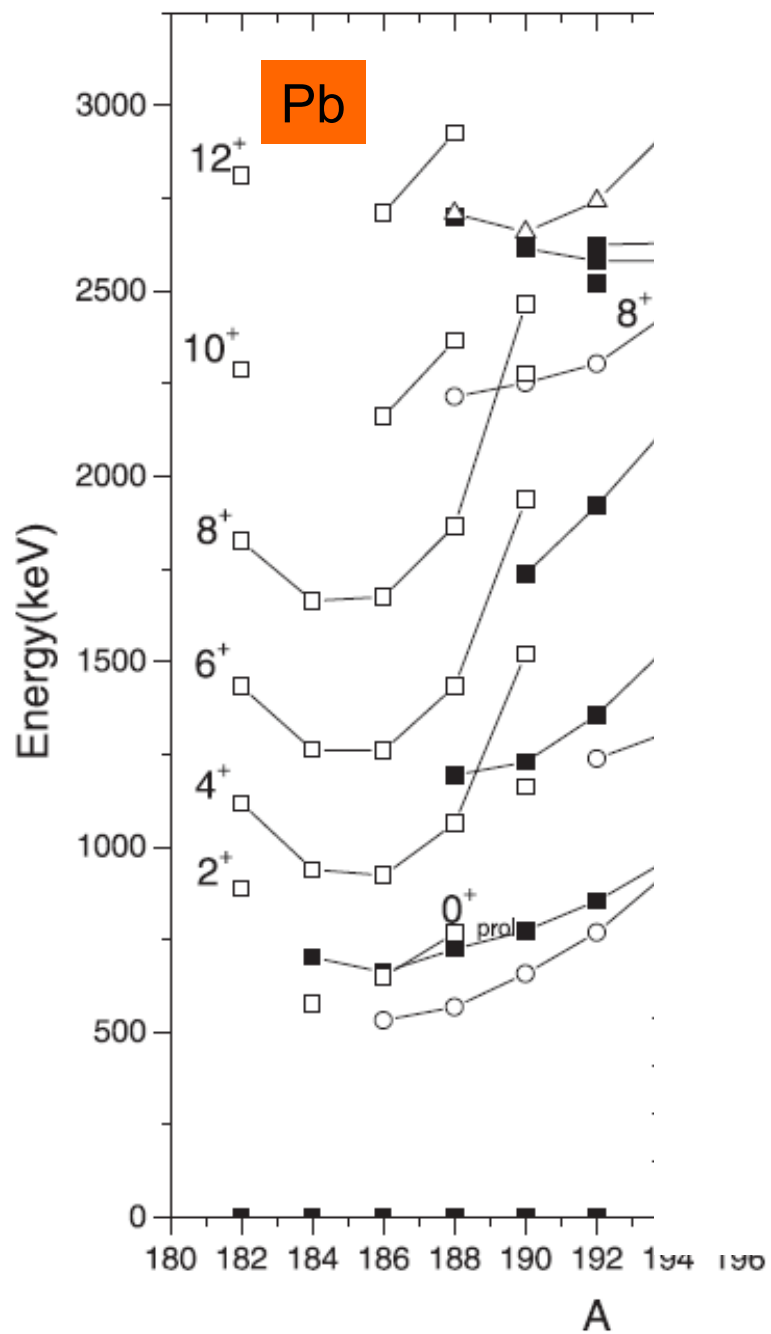


mass asymmetry at the bottom of the valley is $108/72$ (rather close to the observed $100/80$ value)

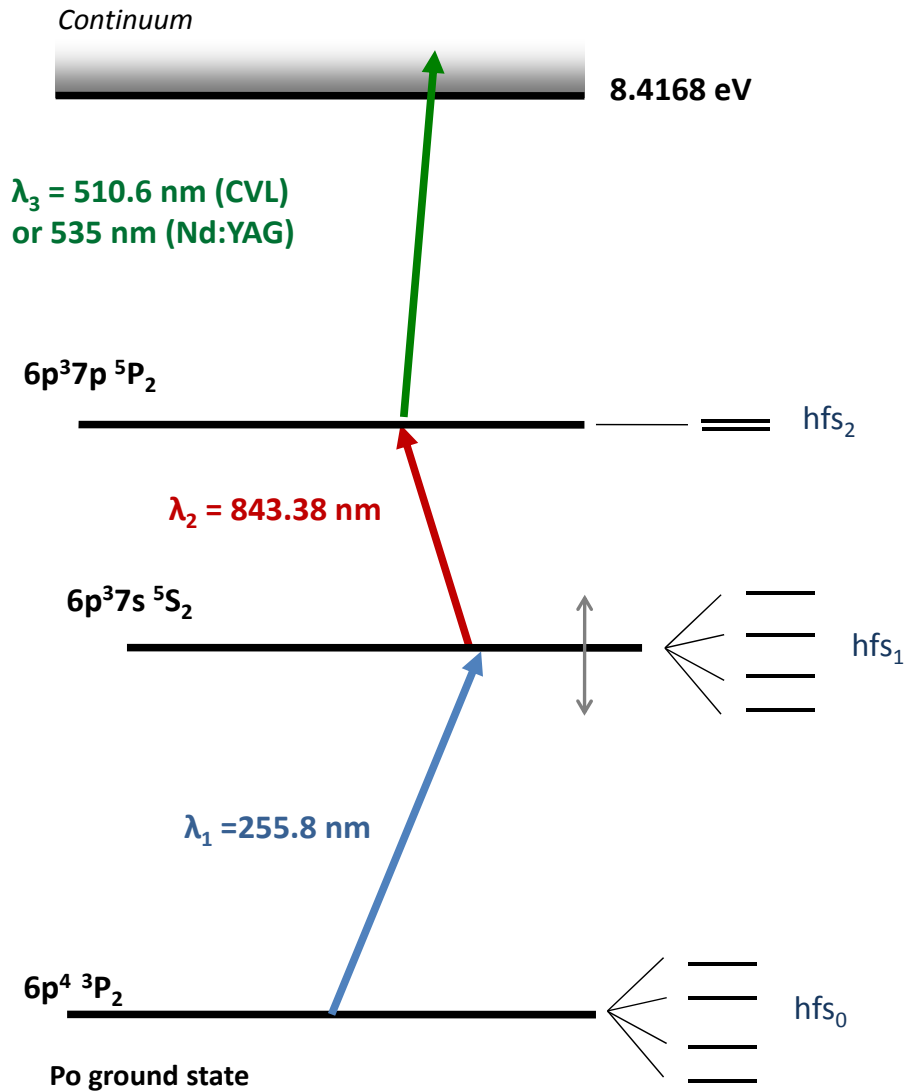
—■— Hg ground states

2. Shape coexistence in light Po isotopes





Photoionization scheme for Po



Detection:
Faraday Cup
 α -detection (Windmill)
 β -detection (tape-station)
 γ -detection (tape-station)

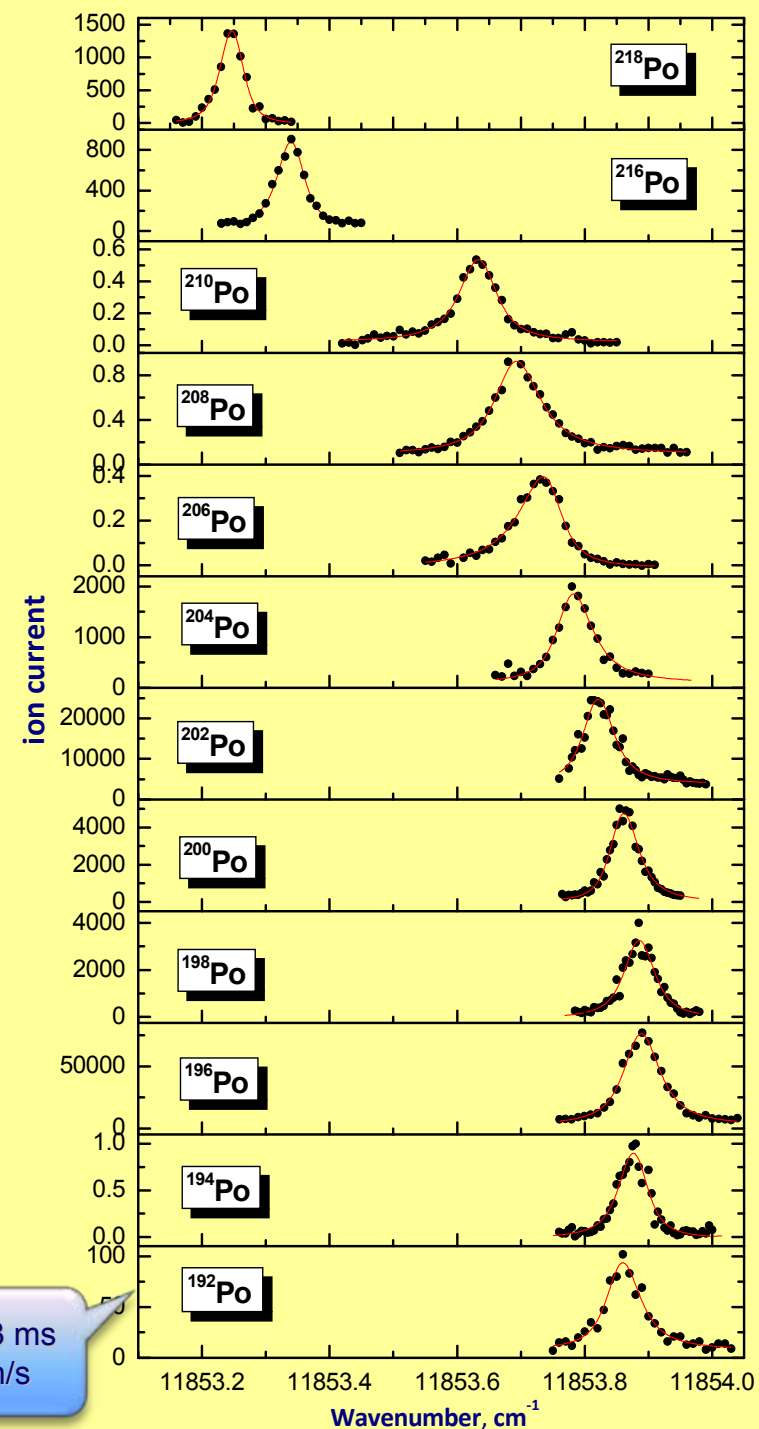
Isotope shift $\delta\nu_{A,A'}$:

$$\delta\nu_{A,A'} = F \cdot \lambda_{A,A'} + (NMS + SMS)_{A,A'}$$

$$(NMS + SMS)_{A,A'} = \frac{M \cdot (A - A')}{A \cdot A'}$$

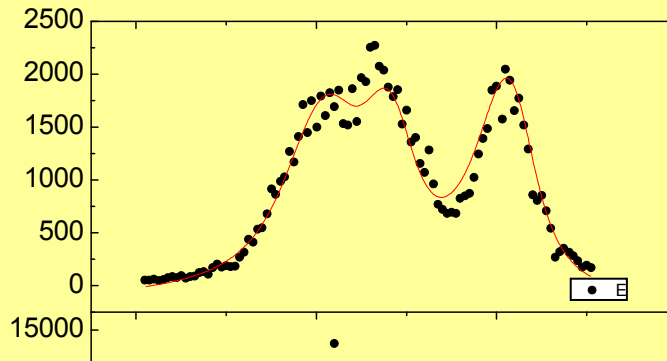
Changes in rms charge radius :

$$\lambda_{A,A'} = \delta\langle r^2 \rangle + C_2 \delta\langle r^4 \rangle + \dots \approx 0.93 \delta\langle r^2 \rangle$$

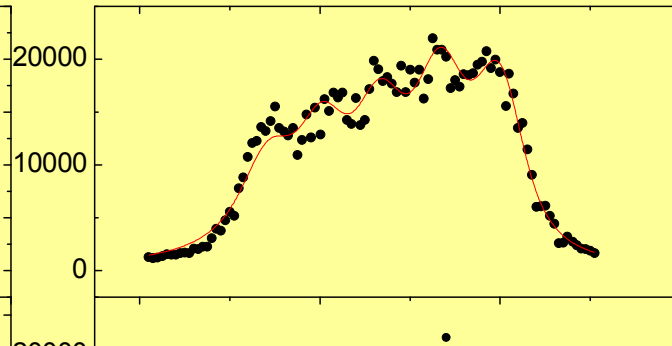


$T_{1/2} = 33 \text{ ms}$
 $< 1 \text{ ion/s}$

Low spin (3/2)



High spin spin (13/2)



¹⁹⁷Po

⁵Po

³Po

$$\nu = \nu_0 + A \cdot \frac{C}{2} + B \cdot \frac{\frac{3}{4} C \cdot (C + 1) - I \cdot (I + 1) \cdot J \cdot (J + 1)}{2 \cdot (2I - 1) \cdot (2J - 1) \cdot I \cdot J}$$

$$C = F \cdot (F + 1) - I \cdot (I + 1) - J \cdot (J + 1)$$

$$\vec{F} = \vec{I} + \vec{J}, \quad F = |I - J|, |I - J| + 1, \dots, I + J$$

$$A \propto \mu, \quad B \propto Q$$

$$\delta v_{A,A'} = F * \lambda_{A,A'} + (NMS+SMS)_{A,A'}$$

$$(NMS + SMS)_{A,A'} = \frac{M \cdot (A - A')}{A \cdot A'}$$

King plot: $\Delta\sigma^{A,A'} = \Delta v_{A,A'} / (A - A')$
 $\Delta\sigma_{\lambda 1}$ vs $\Delta\sigma_{\lambda 2}$

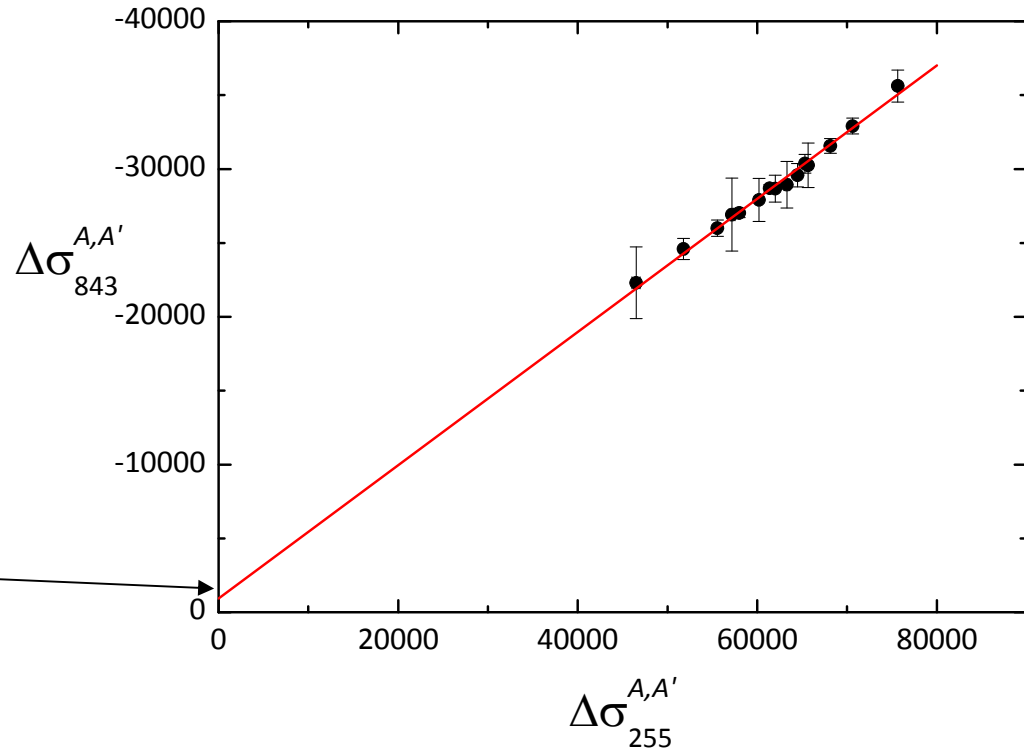
Calculations for Po:

$$F_{255} = 29140 \text{ MHz/fm}^2$$

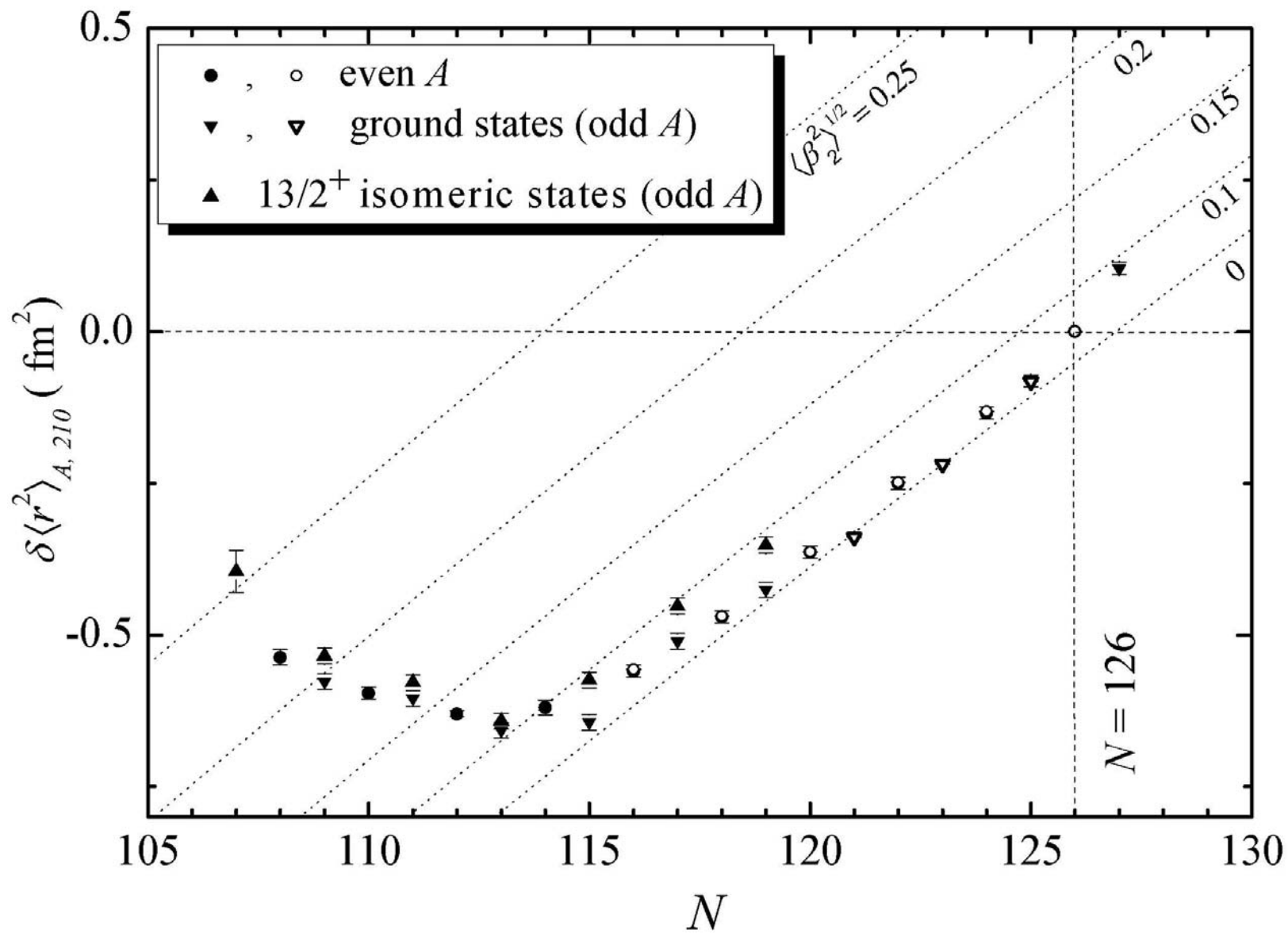
$$F_{843} = -12976 \text{ MHz/fm}^2$$

$$F_{843}/F_{255} = 0.44$$

Mass shifts sum

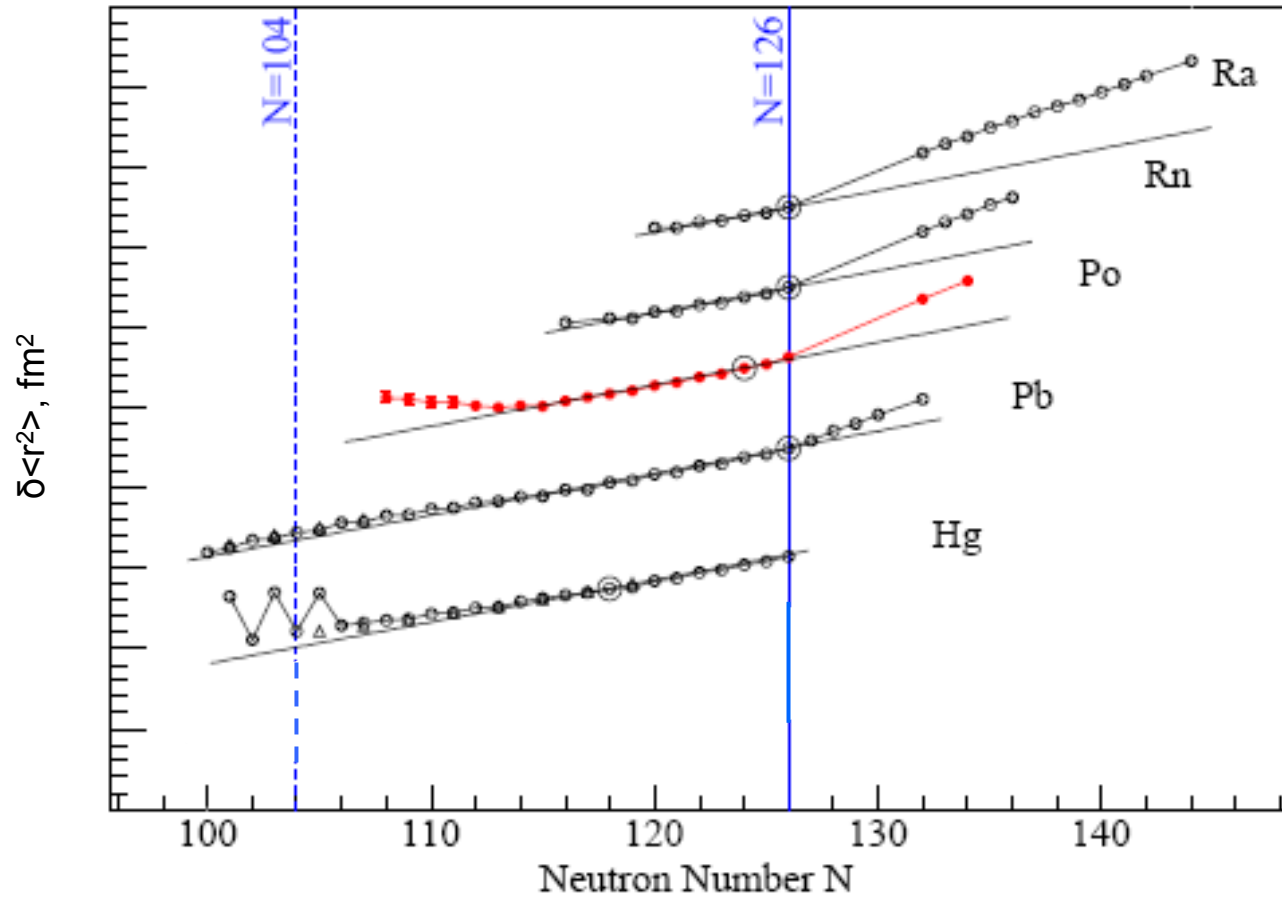


Slope gives F factors ratio:
 $F_{843}/F_{255} = 0.45(3)$ from King plot

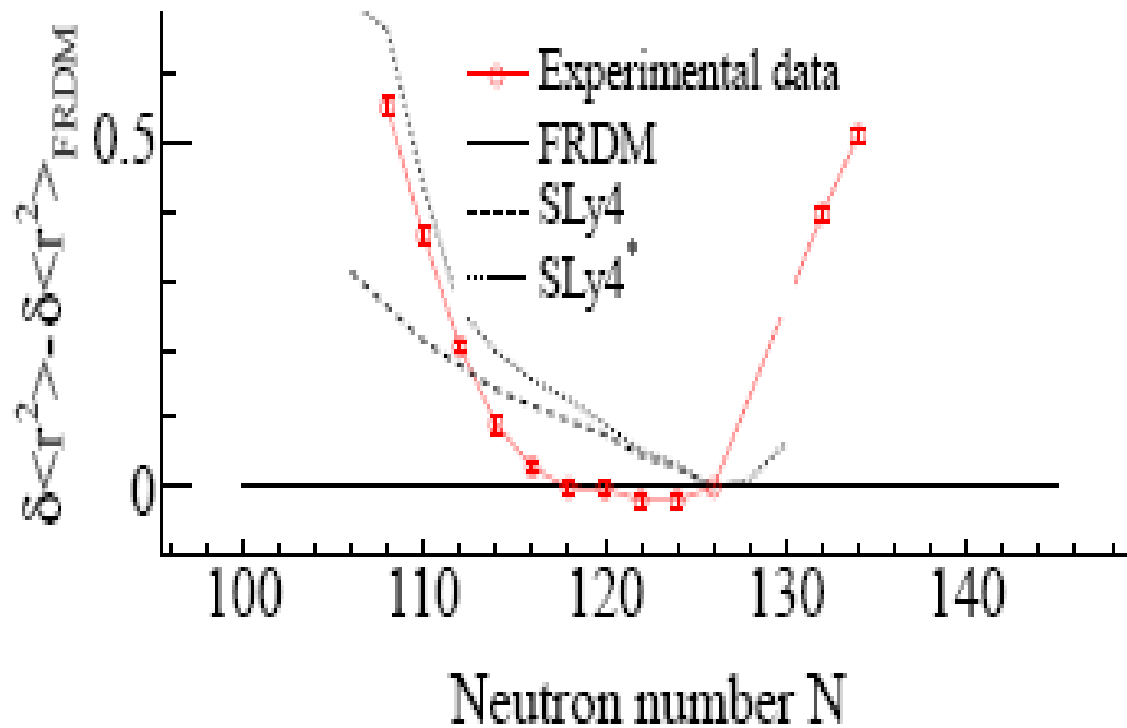


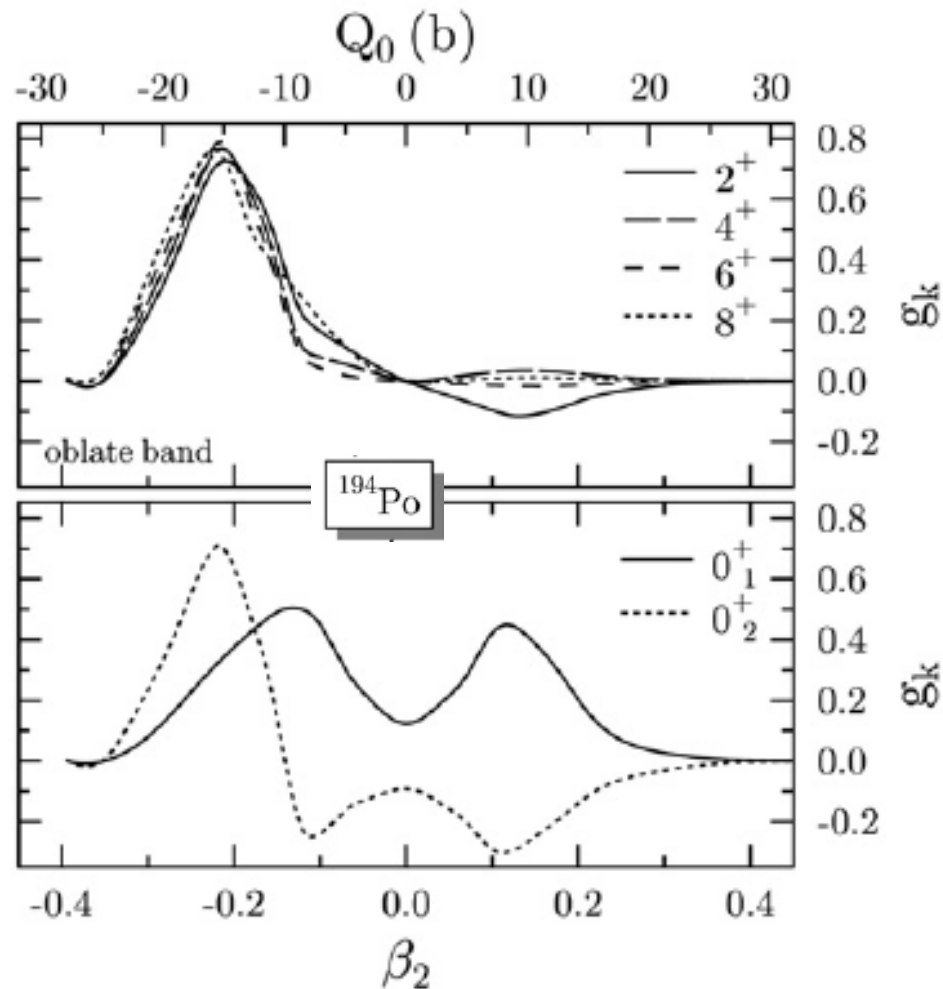
$$\langle r^2 \rangle = \langle r_{DM}^2 \rangle \cdot \left(1 + \frac{5}{4\pi} \langle \beta^2 \rangle \right)$$

even-even isotopes



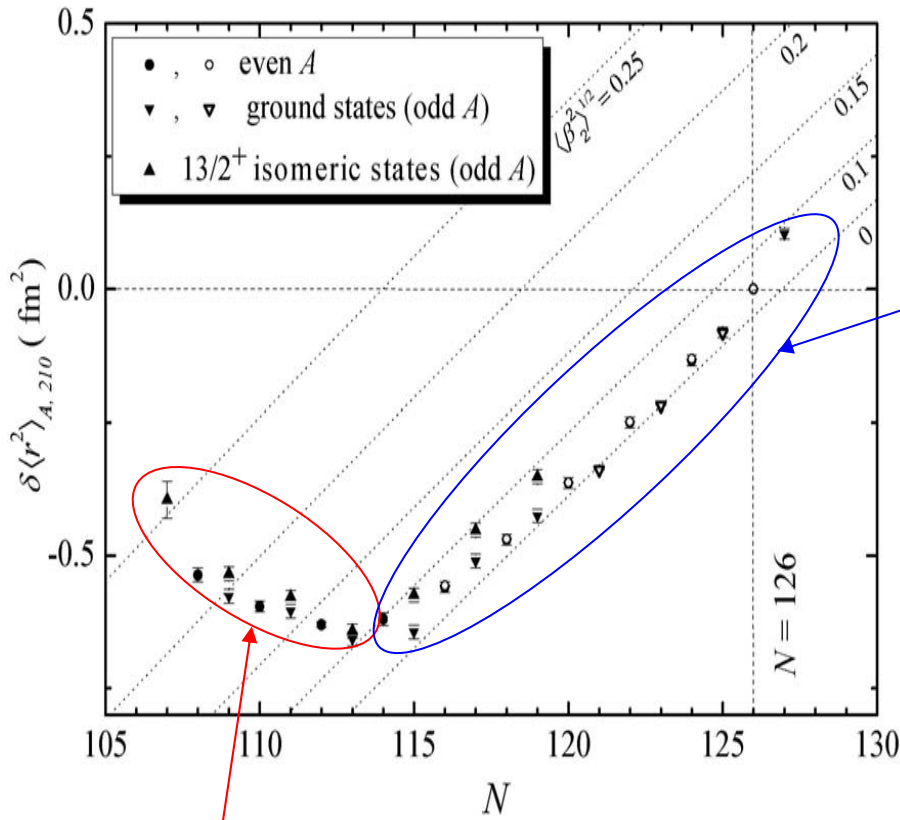
Angular-momentum projected configuration-mixing method starting with Skyrme interaction SLy4 in the mean-field channel and a density-dependent zero-range pairing force (discretized Hill-Wheeler equation without any additional parameters)





The increasing softness of the deformation energy surfaces, when going down from ^{210}Po to ^{194}Po , leads to collective ground-state wave functions of increasing spread over oblate, prolate and spherical shapes. For $^{192,190}\text{Po}$, the ground-state wave function becomes centered around an oblate minimum in the deformation energy surface.

odd isotopes



near spherical nuclei

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

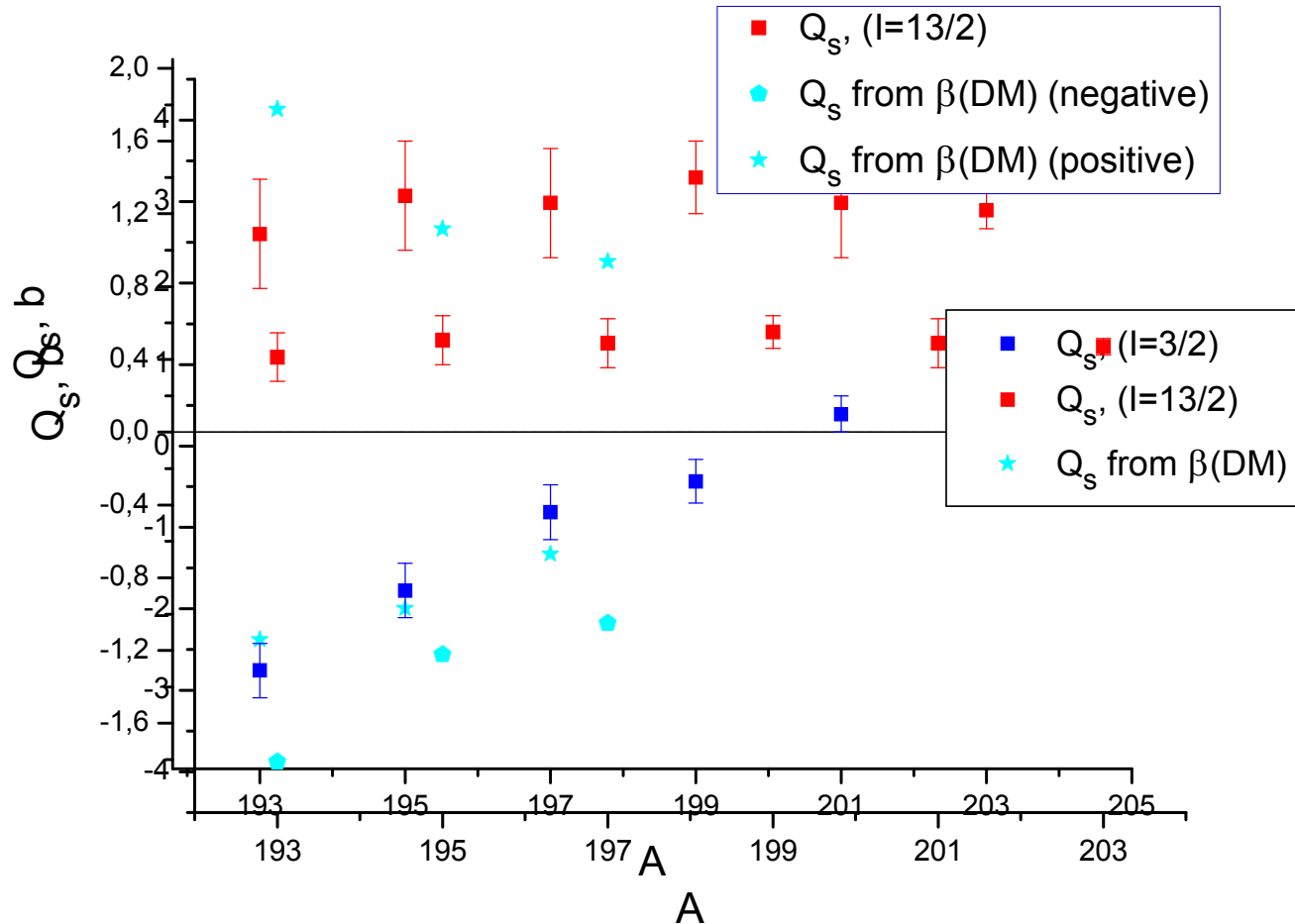
A	I	β(DM)
191	1,5	0,26
191m	4,5	0,25
193	1,5	0,19
193m	6,5	0,2
195	1,5	0,16
195m	6,5	0,13
197	1,5	0,11
197m	6,5	0,11

“deformed” nuclei

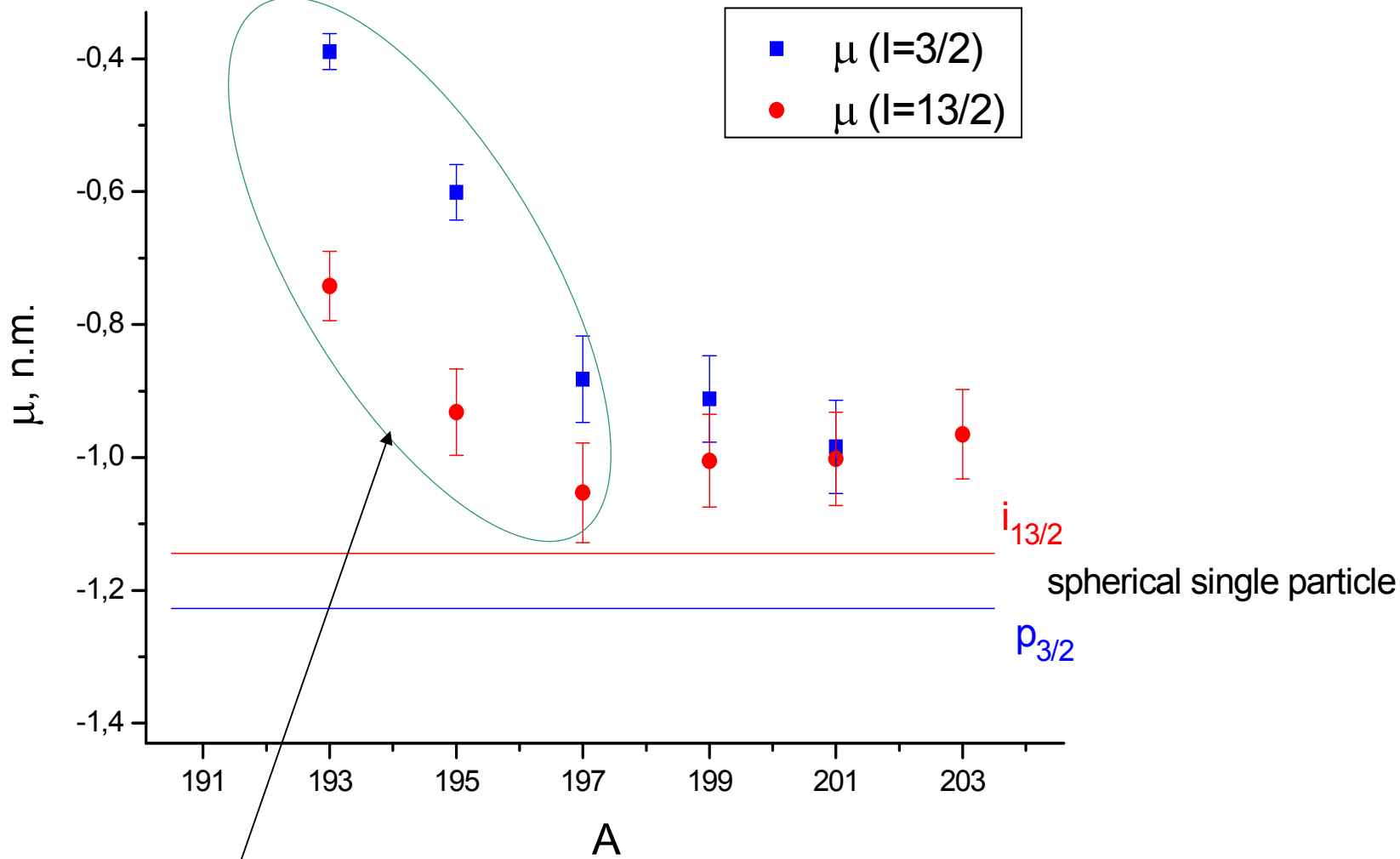
$$Q_s = \frac{3K^2 - I \cdot (I + 1)}{(I + 1) \cdot (2I + 3)} \cdot \frac{3e}{\sqrt{5\pi}} \cdot Z \cdot R_0^2 \cdot \beta \cdot (1 + 0,16 \cdot \beta + \dots)$$

strong coupling (at large deformation): $K=I$

$$Q_s = \frac{I \cdot (2I - 1)}{(I + 1) \cdot (2I + 3)} \cdot \frac{3e}{\sqrt{5\pi}} \cdot Z \cdot R_0^2 \cdot \beta \cdot (1 + 0,16 \cdot \beta + \dots)$$



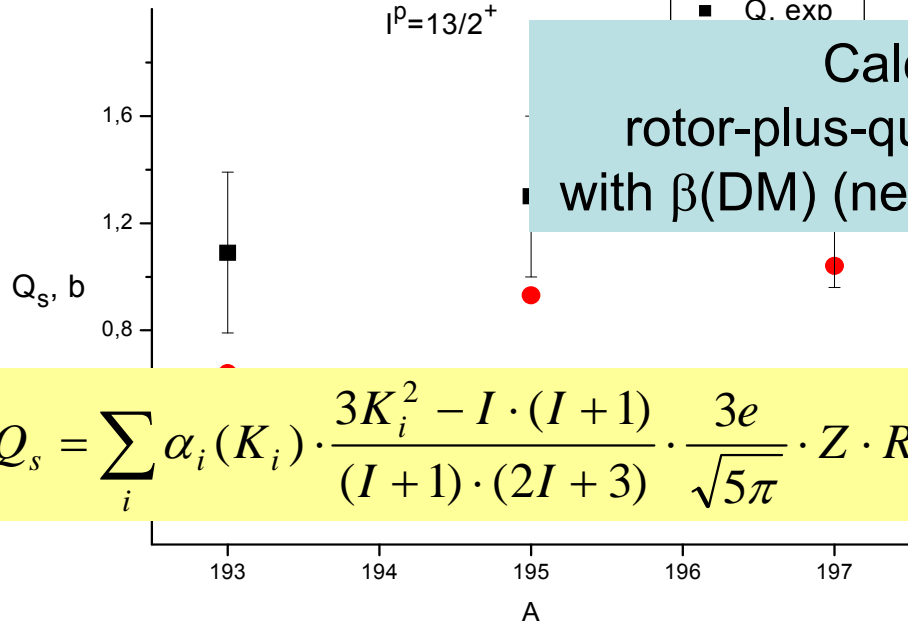
DM deformations fairly correspond to Q_s for $3/2^-$ Po isomers and completely disagree with Q_s for $13/2^+$ Po isomers



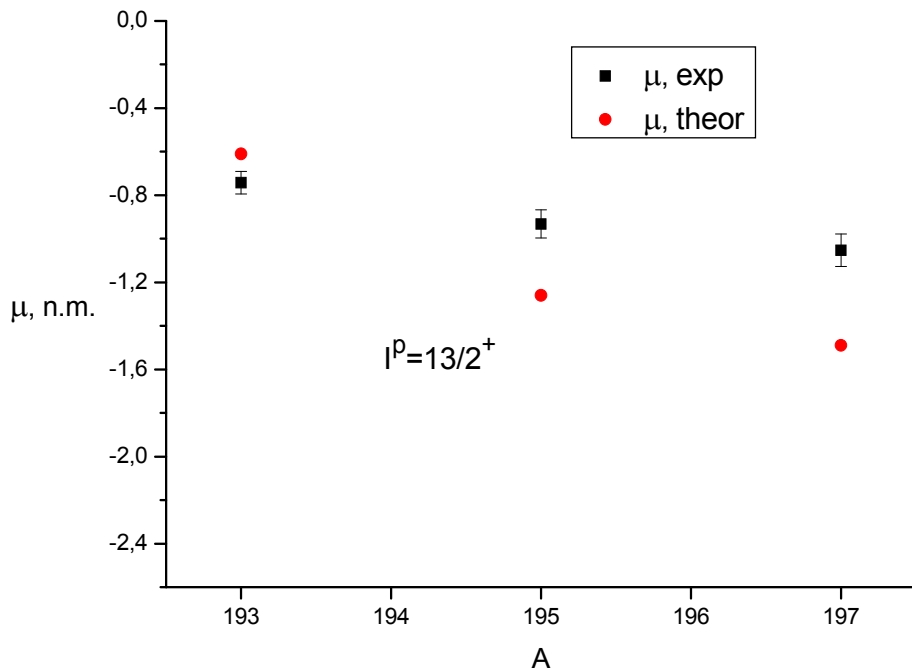
$I^p=13/2^+$

■ Q. exp

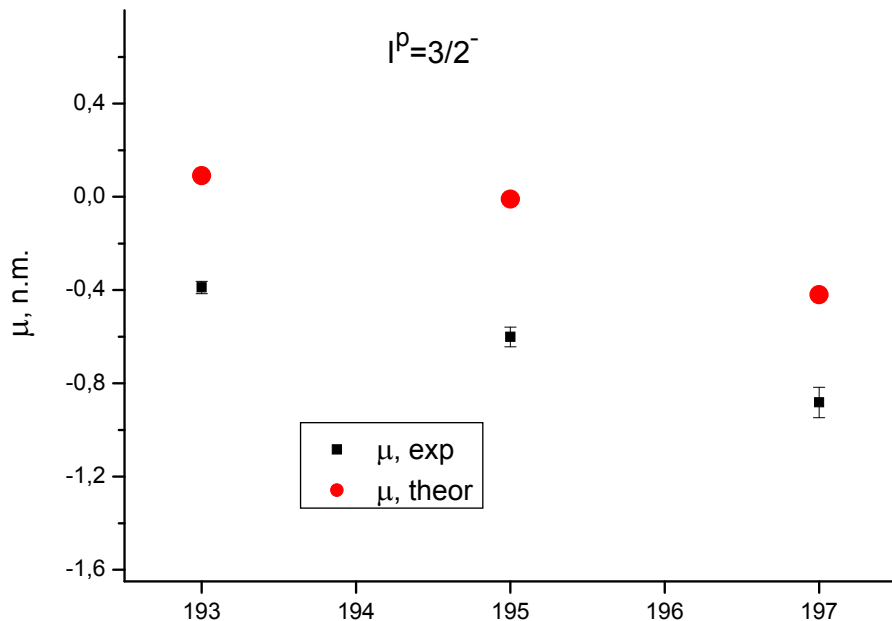
Calculations:
rotor-plus-quasiparticle model
with $\beta(\text{DM})$ (negative) deformations



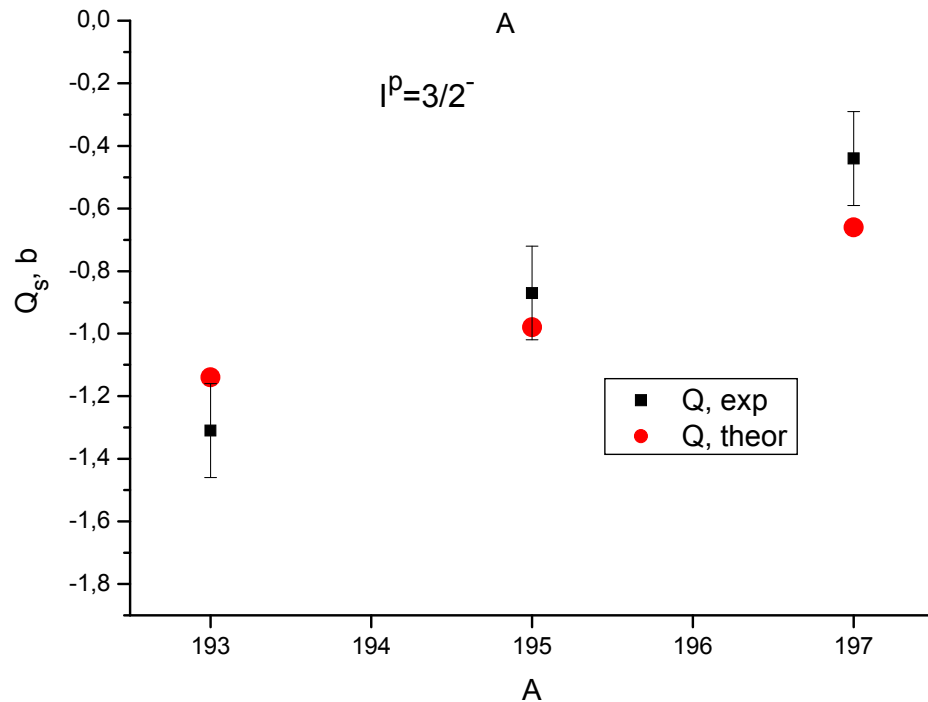
$$Q_s = \sum_i \alpha_i(K_i) \cdot \frac{3K_i^2 - I \cdot (I + 1)}{(I + 1) \cdot (2I + 3)} \cdot \frac{3e}{\sqrt{5\pi}} \cdot Z \cdot R_0^2 \cdot \beta \cdot (1 + 0,16 \cdot \beta + \dots), \quad K_i = I, I - 1, I - 2 \dots$$



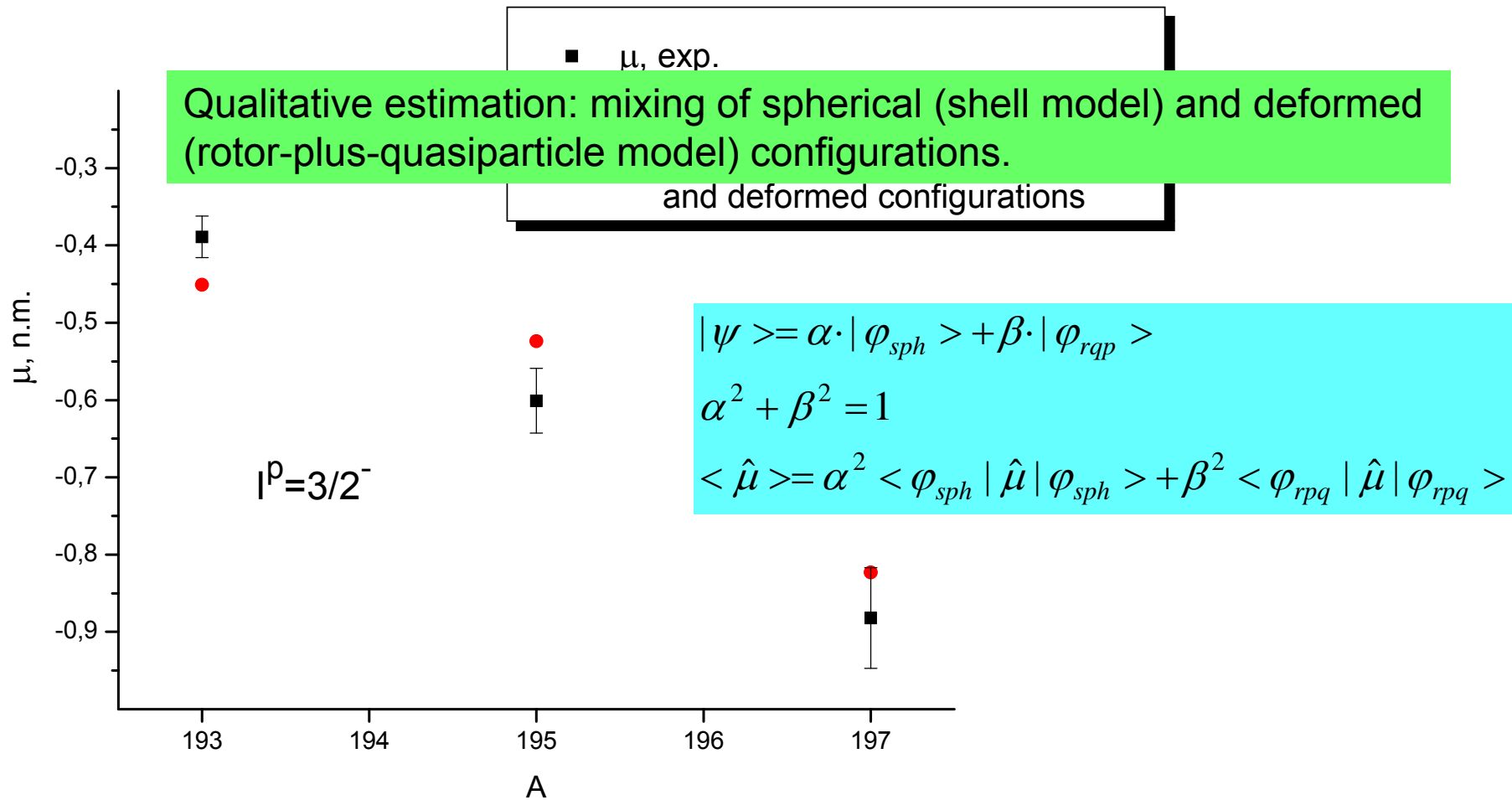
fair agreement!



Calculations:
rotor-plus-quasiparticle model
with β (DM) (negative) deformations



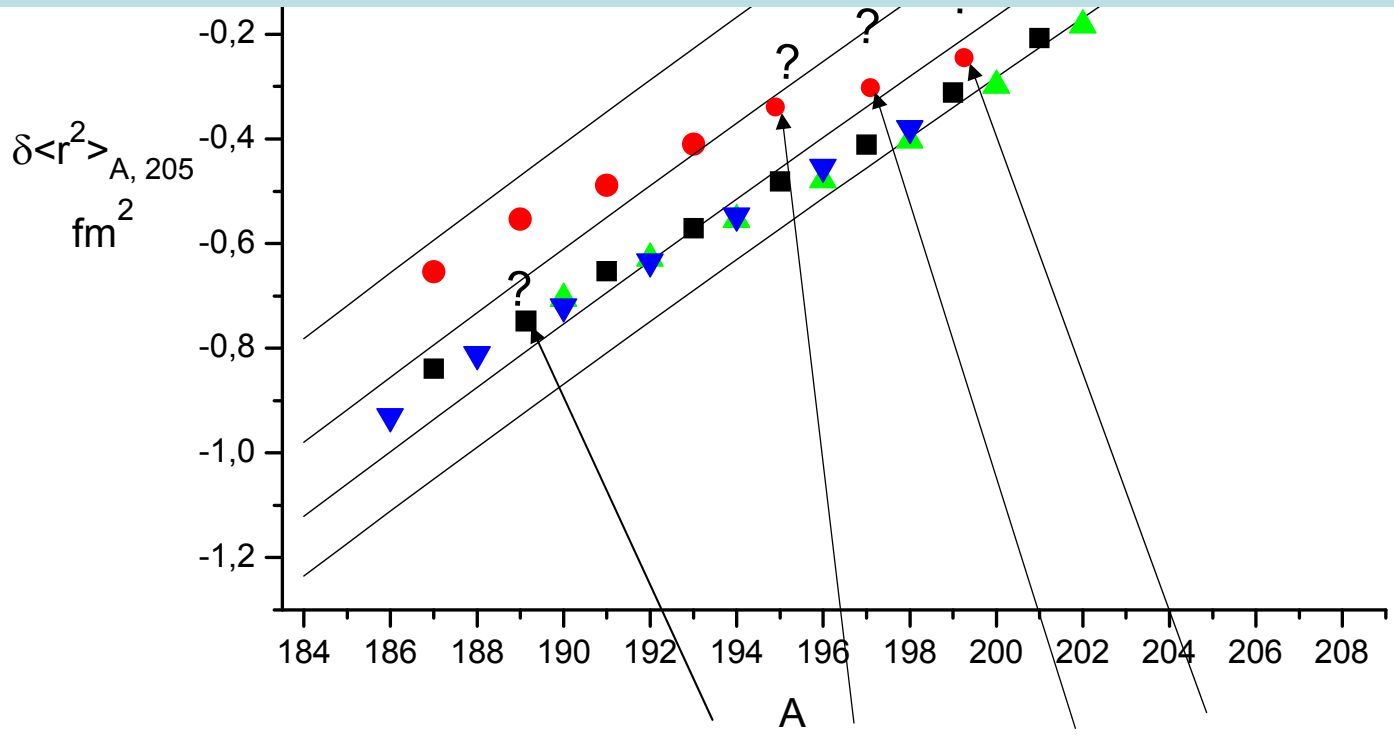
fair agreement for Q's
but great overestimation for μ 's



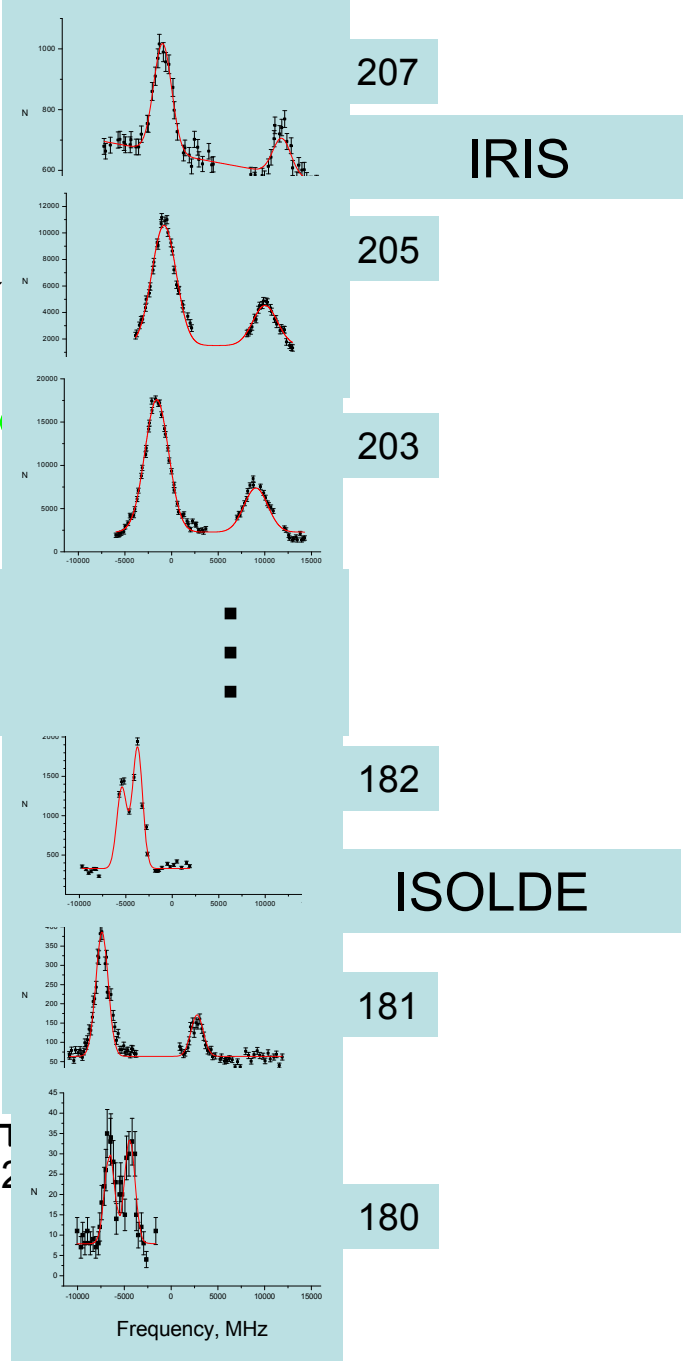
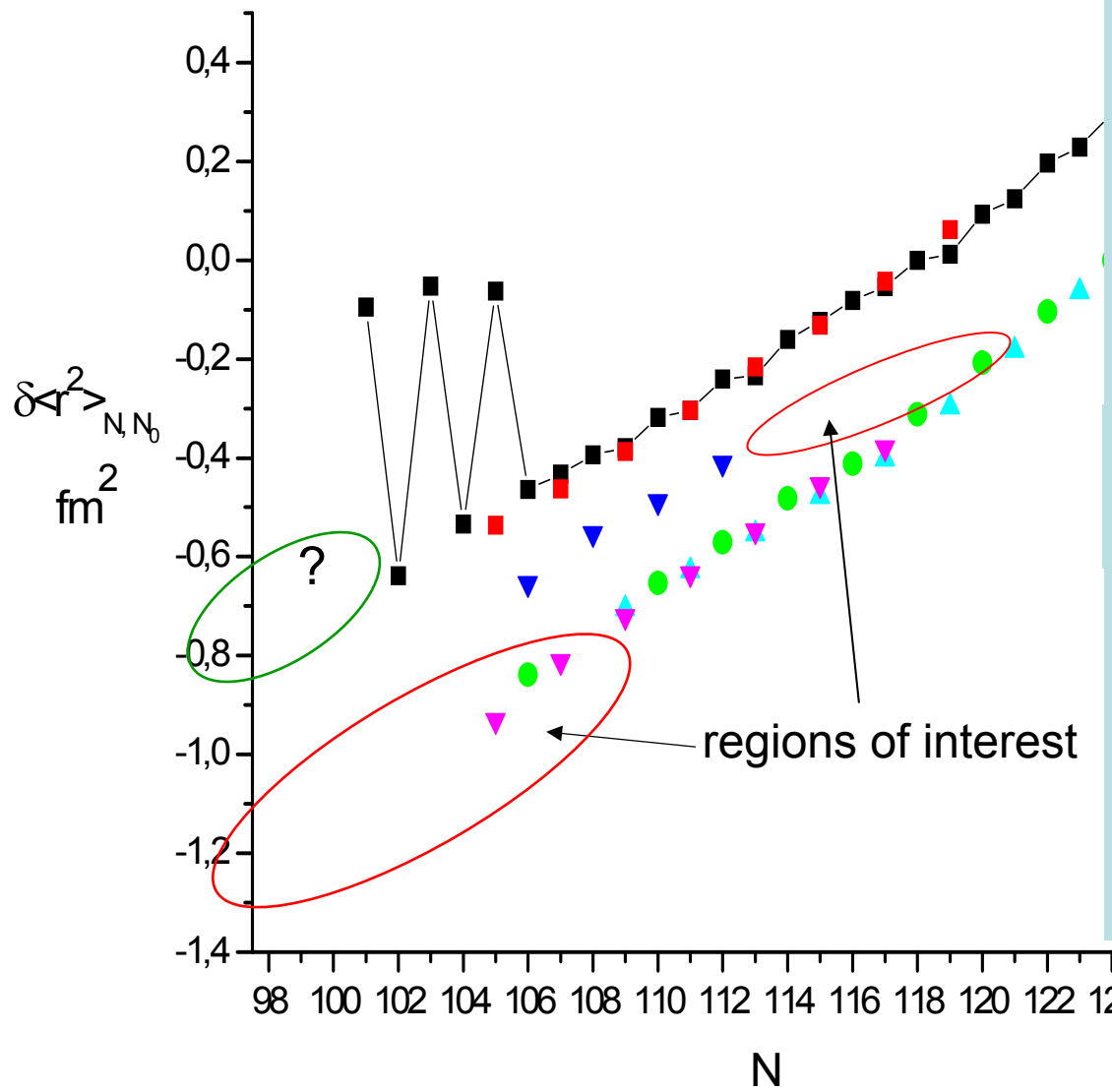
■ $I=1/2$
 ● $I=9/2$

$\langle \beta^2 \rangle^{1/2} = 0,15$
 $\langle \beta^2 \rangle^{1/2} = 0,1$

3. Shape coexistence in light Tl isotopes (proposal)





Does great isomer shift for $I=1/2, 9/2$ pair (i.e. different forms) preserve or vanish for $A > 193$?





Выводы

1. Продолжено исследование области сосуществования форм вблизи $Z=82$. Результаты, полученные для цепочки ядер Po , свидетельствуют, в частности, о значительном смешивании сферических и деформированных конфигураций в основных состояниях удаленных изотопов Po , что требует для описания этих состояний выхода за рамки метода Хартри-Фока.
Удалось согласовать данные по электромагнитным моментам и изотопическим сдвигам нечетных изотопов Po с использованием модели ротор-плюс-квазичастица и качественным учетом смешивания сферических и деформированных конфигураций.
 2. Подтверждено существование у ^{180}Tl ветки запаздывающего деления (ECDF), определена вероятность такого распада ($P_{ECDF}=3,6(7) \cdot 10^{-5}$) – впервые для ядер со столь малым N/Z . Обнаружено новое, неожиданное явление – асимметричное деление ^{180}Hg , не связанное, как в трансурановой области, с влиянием магии осколков. Для описания данного феномена требуется развитие микроскопической динамической модели деления.
- 



3. В развитие изучения сосуществования форм вблизи $Z=82$, а также для уточнения характеристик ядра ^{180}Tl , необходимых для детального понимания его асимметричного запаздывающего деления, предложено провести лазерно-спектроскопические исследования цепочки изотопов Tl, причем измерения для $A=184\text{--}207$ целесообразно проводить на ИРИС, а для $A=178\text{--}183$ – на ISOLDE. Предварительные эксперименты (как на ИРИС, так и на ISOLDE) свидетельствуют об осуществимости данного проекта).

4. Начато лазерно-спектроскопическое исследование At: поиск схемы ионизации элемента без стабильных изотопов. Нейтроно-дефицитные изотопы At – первоочередные кандидаты как для поиска и изучения запаздывающего деления, так и для продолжения исследований сосуществования форм.

