Эффект чередования форм у нейтроно-дефицитных изотопов ртути

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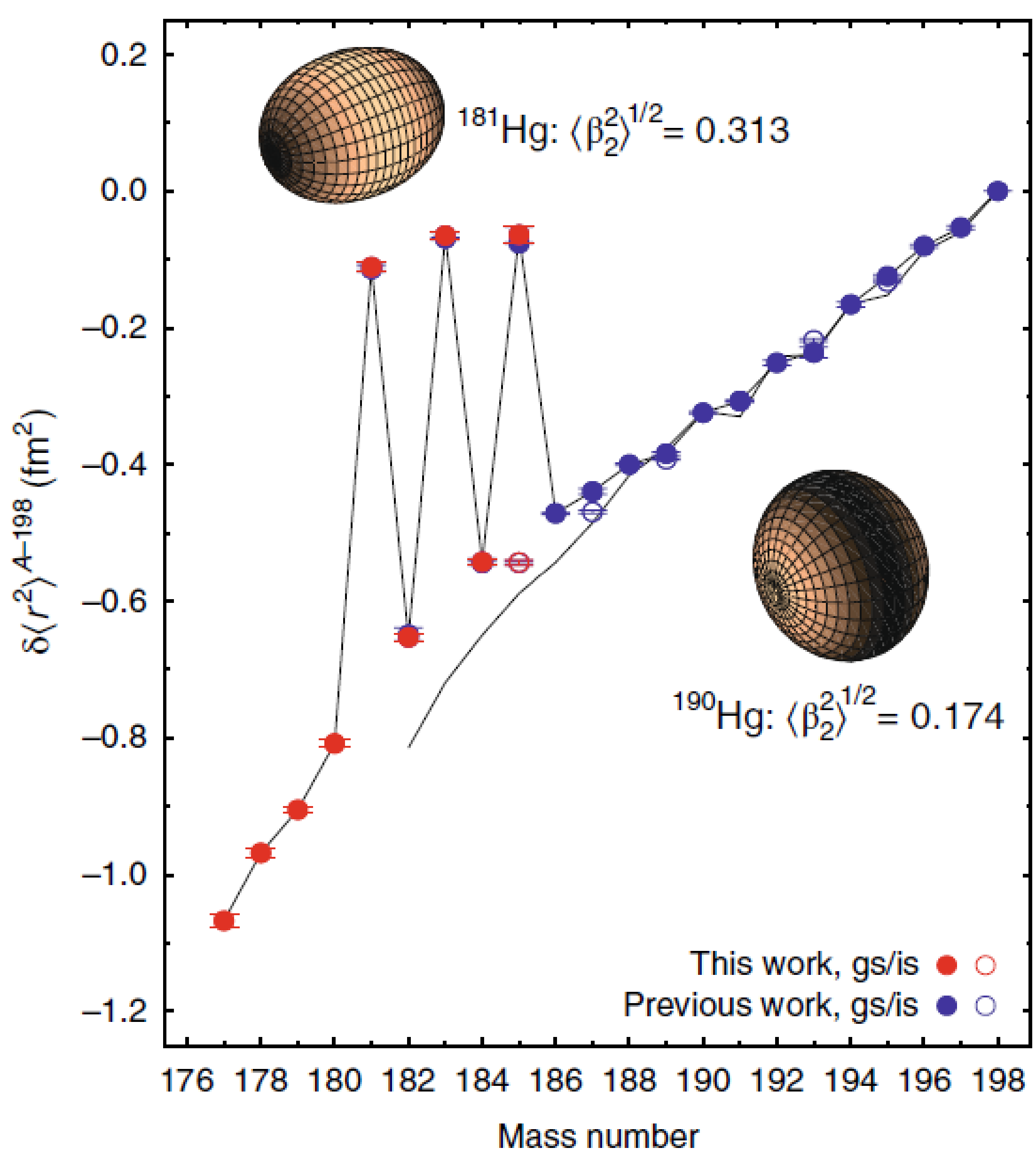
23.10.2018

Shape staggering in neutron deficient Hg isotopes



nature physics

LETTERS

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Characterization of the shape-staggering effect in mercury nuclei

B. A. Marsh[1*], T. Day Goodacre[1,2,18], S. Sels[3,18], Y. Tsunoda[4], B. Andel[5], A. N. Andreyev[6,7], N. A. Althubiti[2], D. Atanasov[8], A. E. Barzakh[9], J. Billowes[2], K. Blaum[8], T. E. Cocolios[2,3], J. G. Cubiss[6], J. Dobaczewski[6], G. J. Farooq-Smith[2,3], D. V. Fedorov[9], V. N. Fedosseev[1], K. T. Flanagan[2], L. P. Gaffney[3,10], L. Ghys[3], M. Huyse[3], S. Kreim[8], D. Lunney[11], K. M. Lynch[1], V. Manea[8], Y. Martinez Palenzuela[3], P. L. Molkanov[9], T. Otsuka[3,4,12,13,14], A. Pastore[6], M. Rosenbusch[13,15], R. E. Rossel[1], S. Rothe[1,2], L. Schweikhard[15], M. D. Seliverstov[9], P. Spagnoletti[10], C. Van Beveren[3], P. Van Duppen[3], M. Veinhard[1], E. Verstraelen[3], A. Welker[16], K. Wendt[17], F. Wienholtz[15], R. N. Wolf[8], A. Zadvornaya[3] and K. Zuber[16]

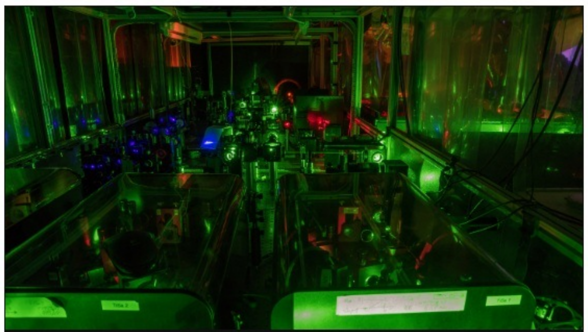
In rare cases, the removal of a single proton (Z) or neutron (N) from an atomic nucleus leads to a dramatic shape change. These instances are crucial for understanding the components of the nuclear interactions that drive deformation. The mercury isotopes (Z = 80) are a striking example[1,2]: their close

the minimum-energy configuration of the nucleus to deformation. Consequently, the ground states of most isotopes in the nuclear chart are non-spherical. Most commonly they are prolate (rugby-ball) shaped, although different shapes, corresponding to alternative nucleon configurations, can coexist within the same nucleus[3,4].

01.10.2018

ISOLDE reveals shape-shifting character of Mercury isotopes

Posted by Corinne Pralavorio on 1 Oct 2018. Last updated 1 Oct 2018, 19.34.
Voir en français



Lasers at ISOLDE. RILIS experiment (Image: Noemi Caraban/CERN)

An unprecedented combination of experimental nuclear physics and theoretical and computational modelling techniques has been brought together to reveal the full extent of the odd-even shape staggering of exotic

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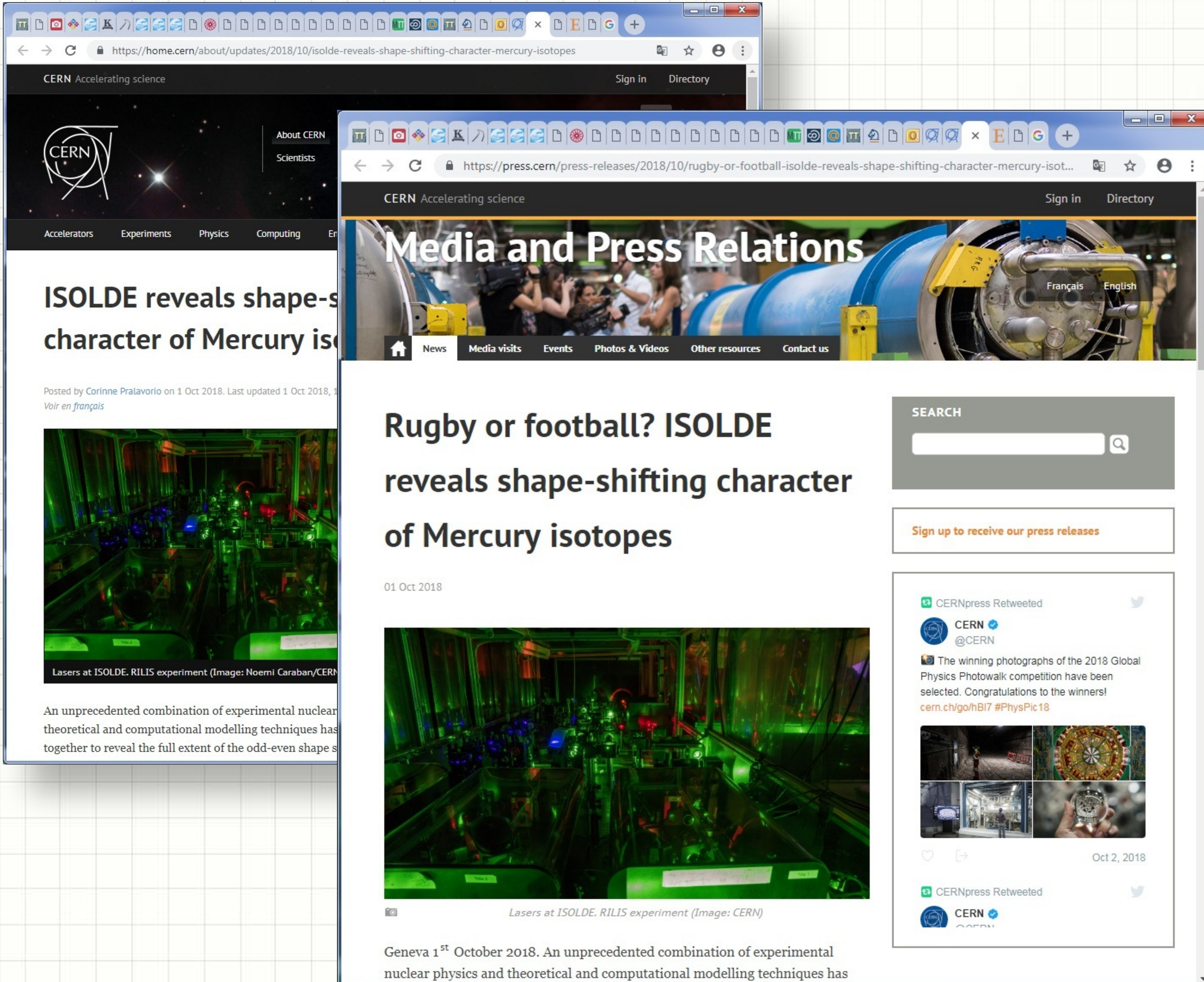
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An unprecedented combination of experimental nuclear
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Rugby or football? ISOLDE reveals shape-shifting character of Mercury isotopes
01 Oct 2018
Lasers at ISOLDE. RILIS experiment (Image: CERN)
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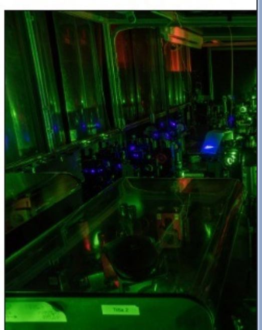

Lasers at ISOLDE. RILIS experiment (Im...

An unprecedented combination of... theoretical and computational mo... together to reveal the full extent of...

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РИАНАУКА

Физики из России выяснили, что заставляет атомы ртути превращаться в "яйца"

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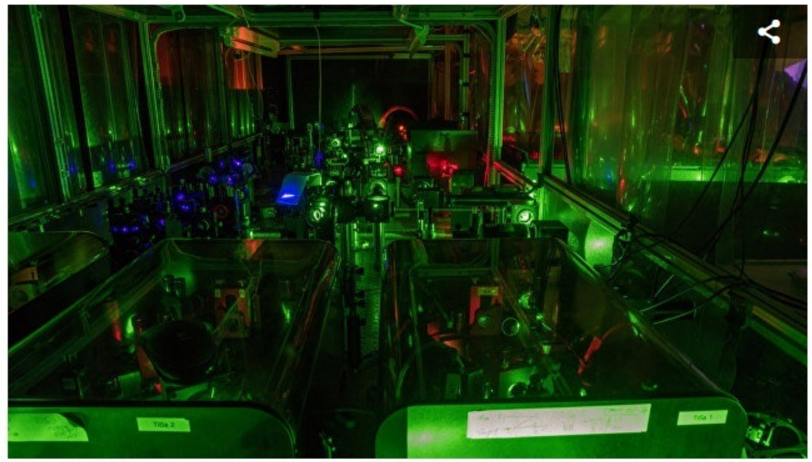

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МОСКВА, 1 окт – РИА Новости. Российские и зарубежные ученые, работающие в ЦЕРН, нашли объяснение того, почему атомы некоторых изотопов ртути могут резко растягиваться, превращаясь в "яйцо", если из них выбить всего один нейтрон. Их выводы были представлены в журнале Nature Physics.

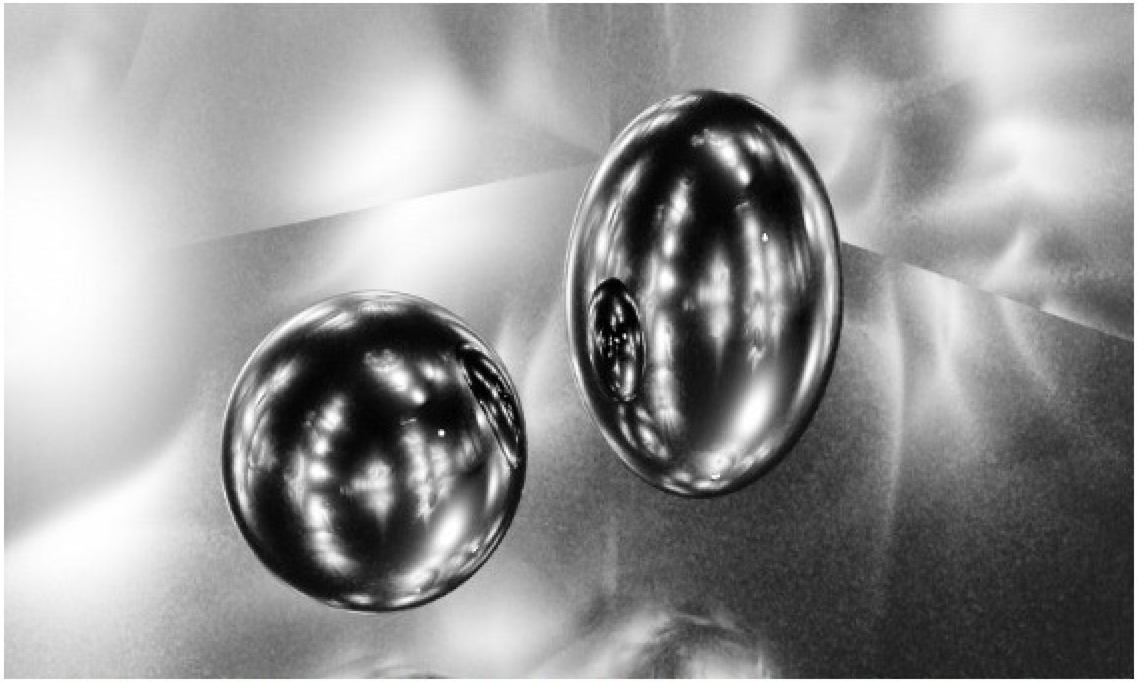
04-08_Sels-presen....pdf | droplets.png | Показать все

Lasers at ISOLDE. RILIS experiment (Image: CERN)

Geneva 1st October 2018. An unprecedented combination of experimental nuclear physics and theoretical and computational modelling techniques has

CERN

One of the earliest experiments in the ISOLDE facility observed dramatic nuclear shape staggering in the chain of mercury isotopes for the first time. That more than 40 year old result showed that although most of the isotopes with neutron numbers between 96 and 136 have spherical nuclei, those with 101, 103 and 105 neutrons have strongly elongated nuclei, the shape of rugby balls. That discovery has remained one of ISOLDE's flagship results, but it was so dramatic that it was difficult to believe.



Unlike any other element, the nuclei of Mercury isotopes can have two different shapes and after more than 40 years, ISOLDE has solved the mystery of how and why this happens. (©Krystof Dockx)

Volume 38B, number 5 PHYSICS LETTERS 6 March 1972

SUDDEN CHANGE IN THE NUCLEAR CHARGE DISTRIBUTION OF VERY LIGHT MERCURY ISOTOPES

J. BONN, G. HUBER, H.-J. KLUGE, L. KUGLER and E. W. OTTEN
CERN, Geneva, Switzerland
and I. Physikalisches Institut, University of Heidelberg, Germany

Received 29 November 1971

The following quantities have been determined by optical pumping with the spectral line 2537 Å: ^{183}Hg: $I = 1/2$, $\mu_I = 0.513(9)$ nm, isotopic shift (^{183}Hg - ^{204}Hg) = 18.9(8) GHz; ^{185}Hg: $I = 1/2$, $\mu_I = 0.449(4)$ nm, isotopic shift (^{185}Hg - ^{204}Hg) = 19.2(4) GHz. The siotopic shifts for ^{183,185}Hg deviate very strongly from an extrapolation from the heavier mercury isotopic (including ^{187}Hg). This indicates that a large increase in the effective nuclear volume of Hg occurs in going from $N = 107$ to $N = 105$.

Recently, an optical pumping experiment on the neutron-deficient isotope ^{187}Hg was reported

Doppler width, the spectral line of a ^{204}Hg light source is split by a magnetic field H_L into its

06.03.1972

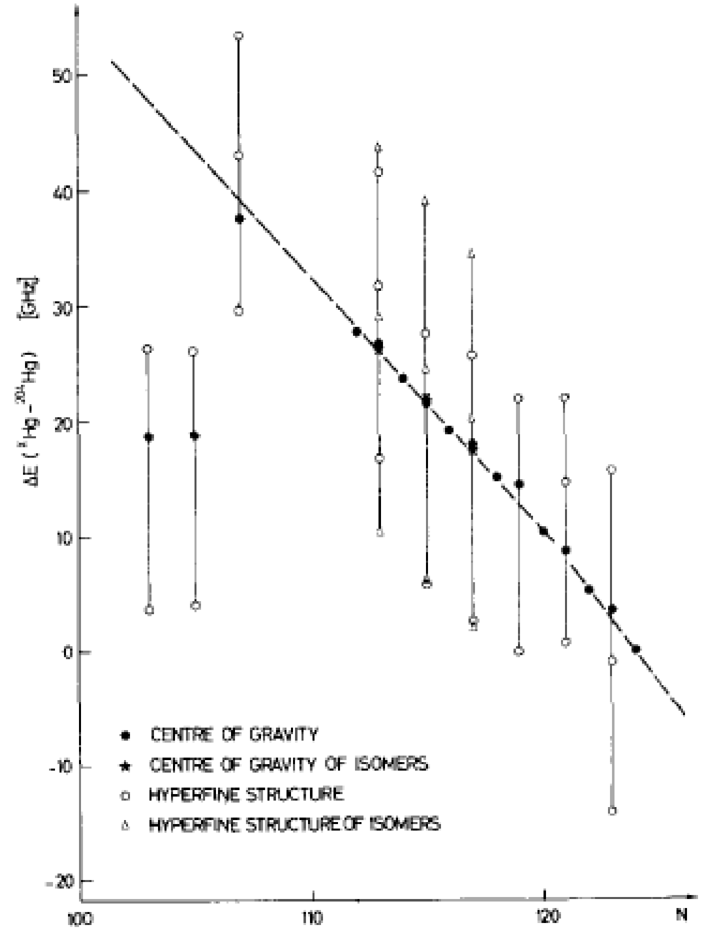
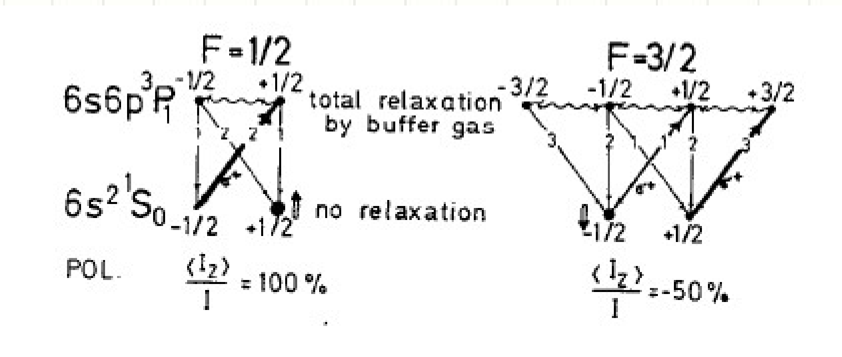


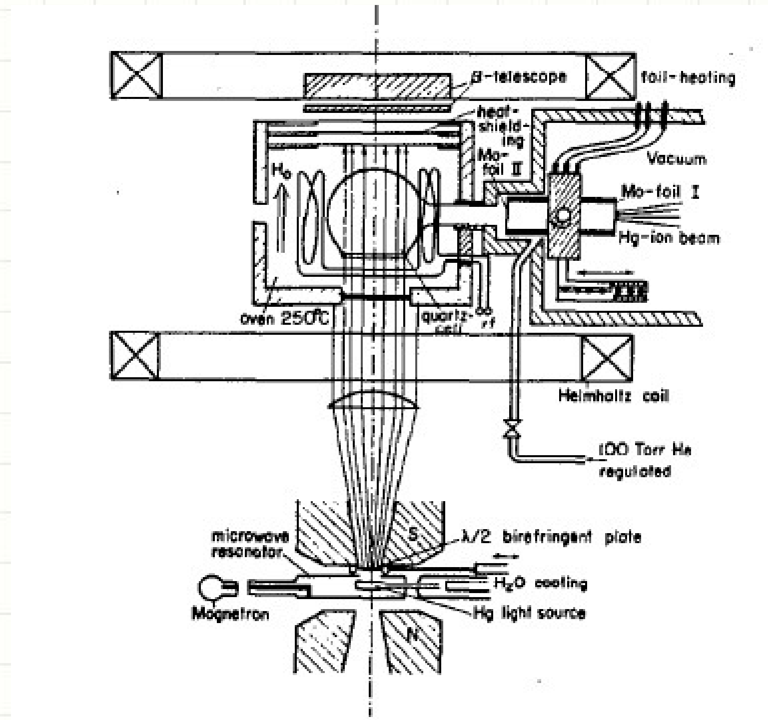
Fig.3: Hyperfine structure splitting and isotope shift relative to ^{204}Hg in the $^3P_1 - {}^1S_0$ 2537 Å line of the mercury spectrum. The dotted line represents the volume effect of the isotopic shift. The errors in the positions of the centres of gravity are of the order of or smaller than the diameter of the dots.

RADOP

Nuclear Radiation Detected Optical Pumping



Optical pumping cycle for Hg isotopes with I = 1/2 between states with J = 0 and J = 1

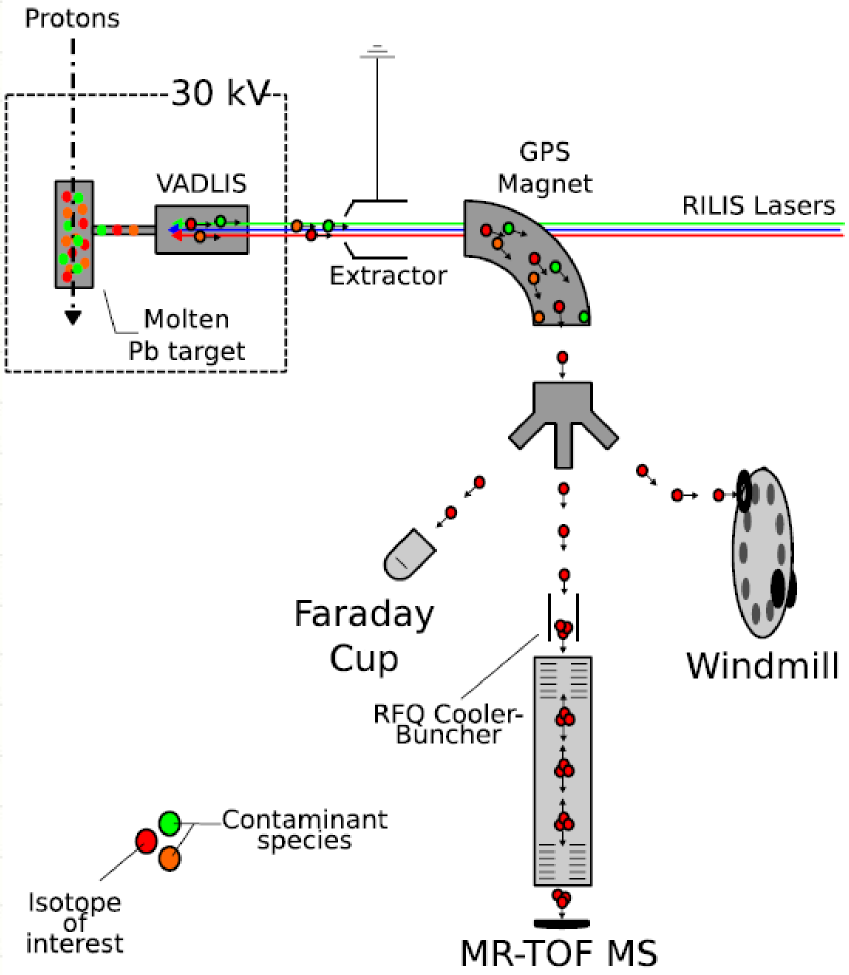


RADOP setup at ISOLDE

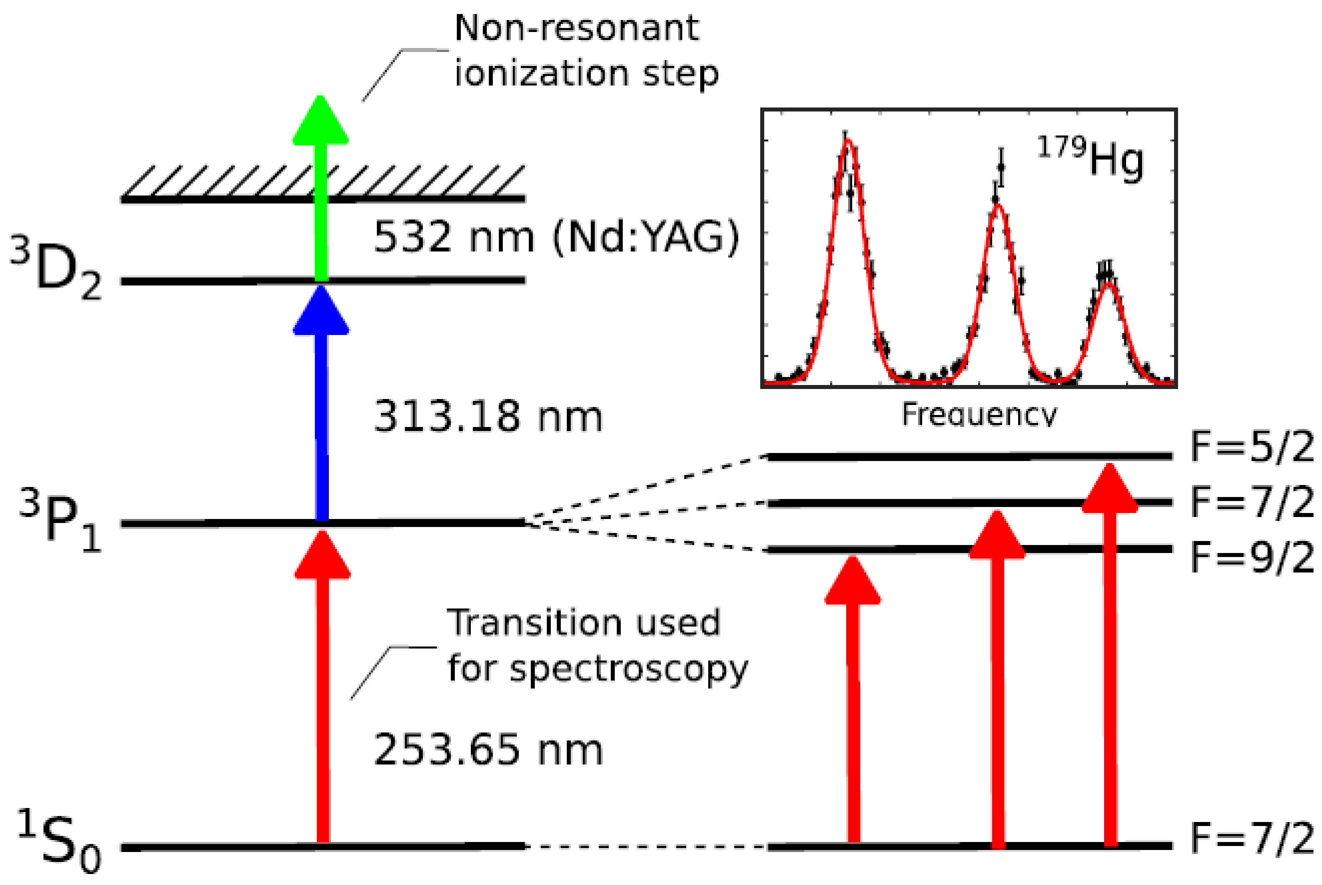
- Observation of the huge odd-even effect in charge radii led to discovery of nuclear shape coexistence
- Application of optical technique paved the way to experimental investigation of this striking effect of shape coexistence

RILIS @ ISOLDE

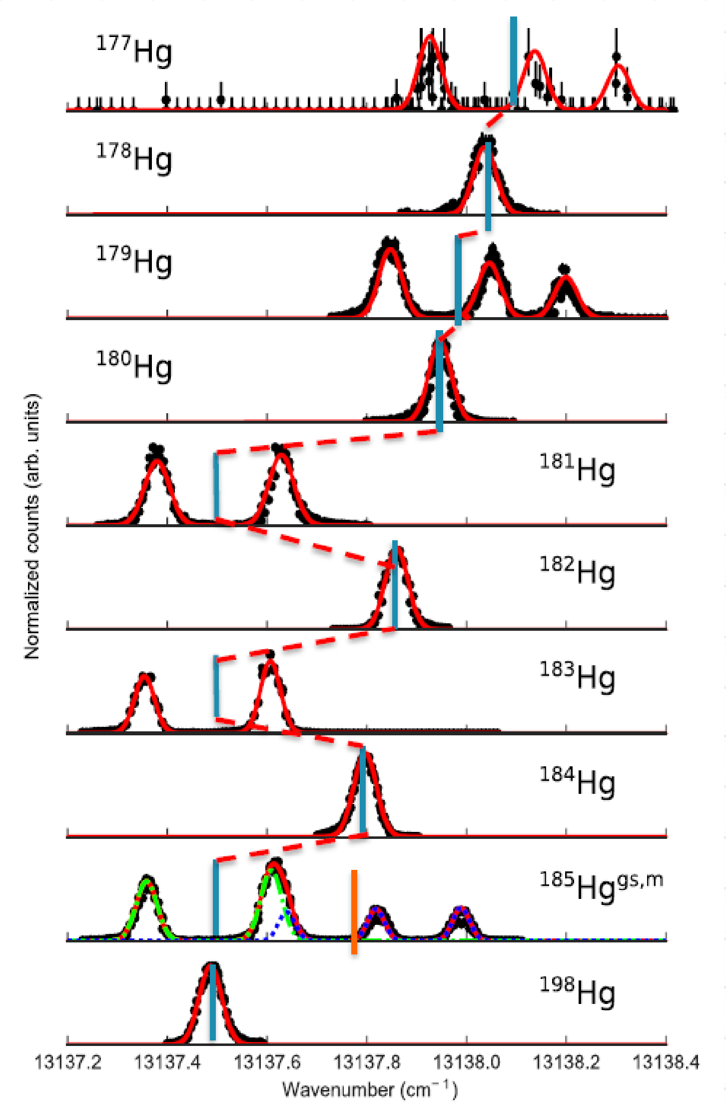
0.01 ions per second



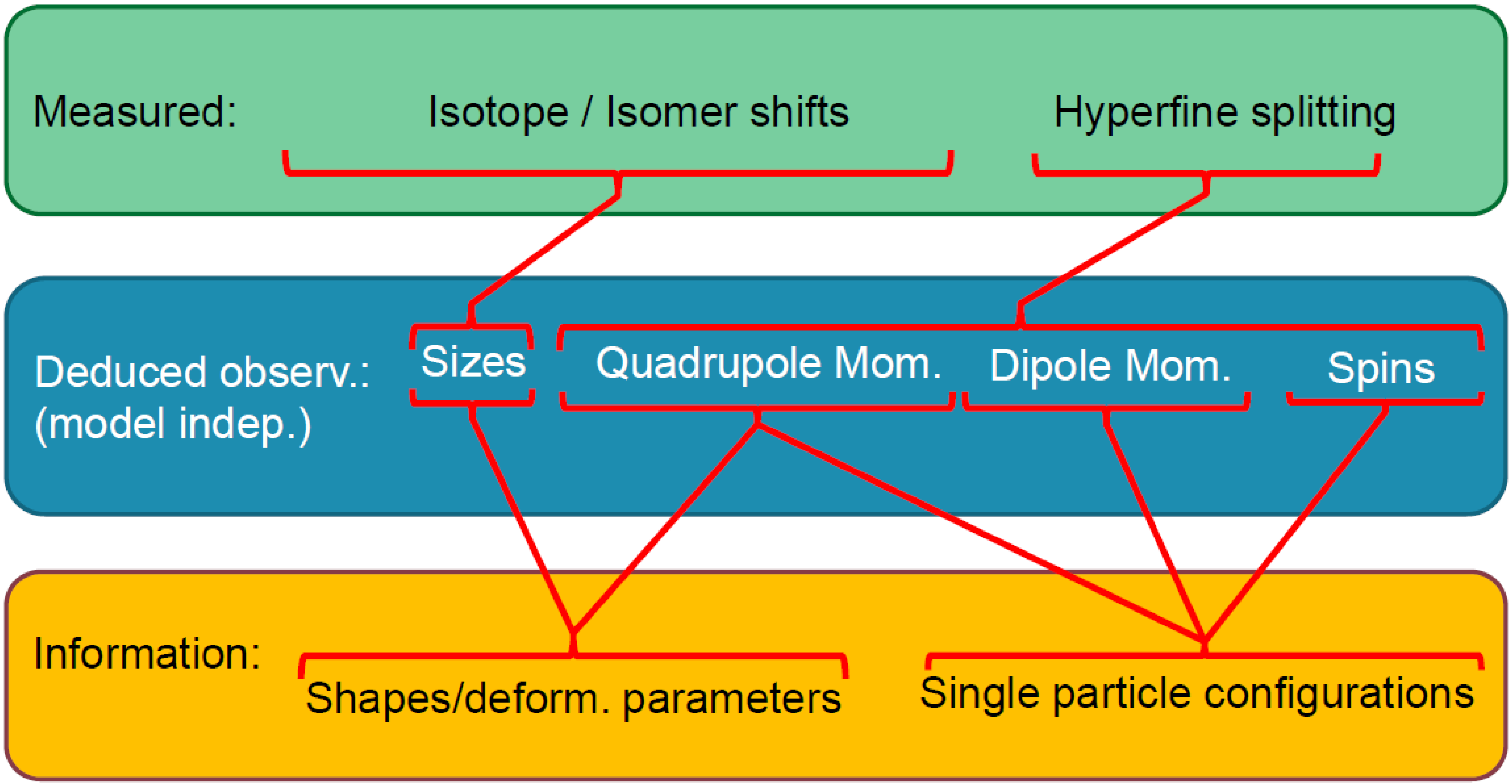
Laser spectroscopy



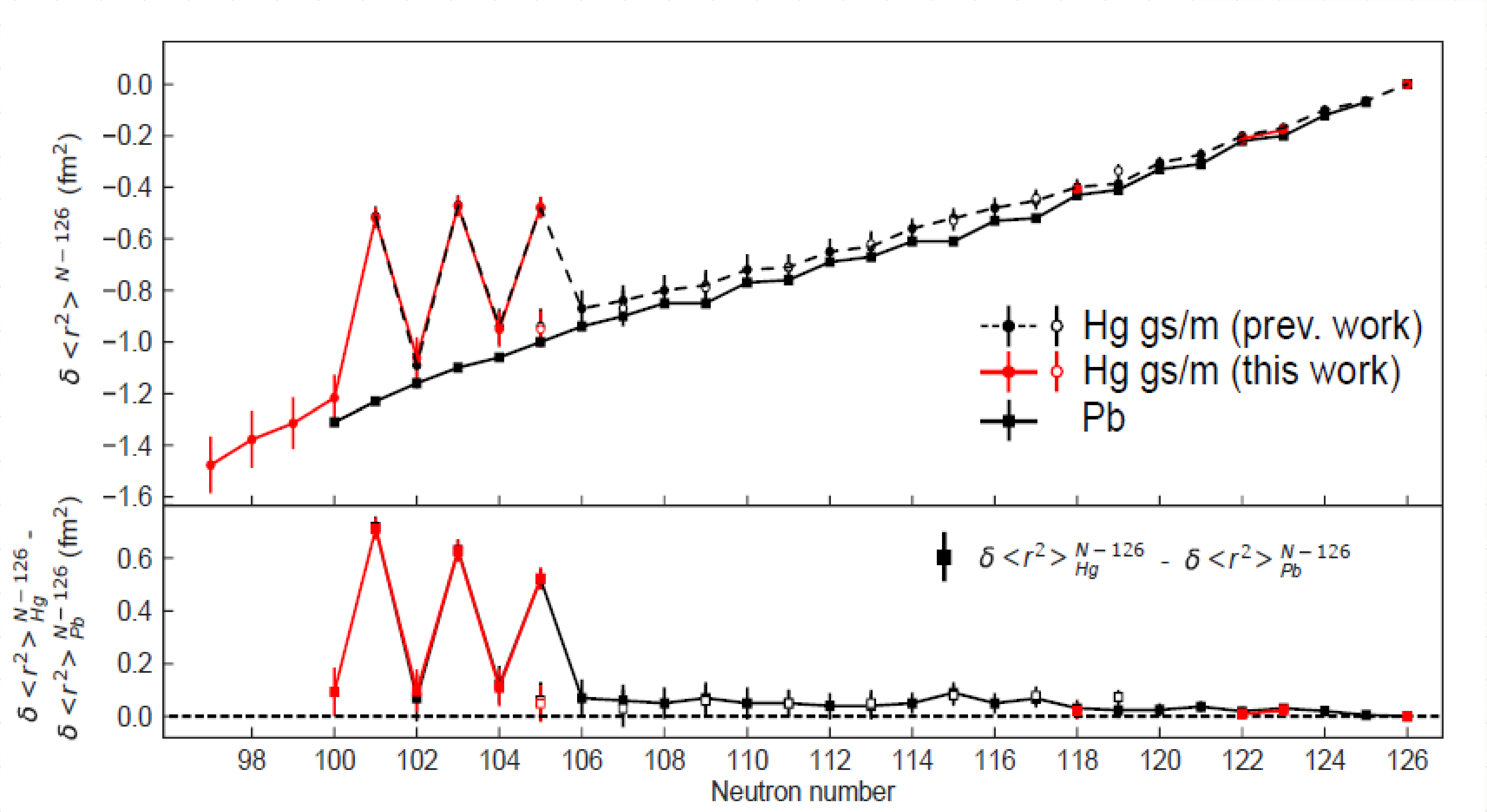
Hyperfine spectra



Laser spectroscopy variables



Results



Hg gs/m (prev. work)
Hg gs/m (this work)
Pb
$\delta < r^2 >^{N-126}$ (fm^2)
$\delta < r^2 >^{N-126}_{Hg}$ - $\delta < r^2 >^{N-126}_{Pb}$
$\delta < r^2 >^{N-126}_{Hg}$ - $\delta < r^2 >^{N-126}_{Pb}$ (fm^2)
Neutron number
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
−1.4
−1.6
0.6
0.4
0.2
0.0
98
100
102
104
106
108
110
112
114
116
118
120
122
124
126

Results

Table 1 | Summary of resulting mean-square charge differences ($\delta\langle r^2\rangle^{A-198}$) and nuclear moments ($\mu$, Q) and their comparison to literature. $\delta\langle r^2\rangle$ (lit.) values were recalculated from the measured IS[19] with the same F and M_{SMS} factors as in the present work

Isotope	Spin I^π	$\delta\langle r^2\rangle^{A-198}$ (this work) (fm^2)	$\delta\langle r^2\rangle^{A-198}$ (lit.) (fm^2)	μ (this work) (μ_N)	μ (lit.) (μ_N)	Q_s (this work) (b)	Q_s (lit.) (b)
^{177}Hg	(7/2$^-$)	−1.067(8){78}	-	−1.027(53)	-	0.57(83)	-
^{178}Hg	0$^+$	−0.968(6){71}	-	-	-	-	-
^{179}Hg	(7/2$^-$)	−0.905(5){70}	-	−0.949(29)	-	0.77(28)	-
^{180}Hg	0$^+$	−0.808(5){60}	-	-	-	-	-
^{181}Hg	1/2$^-$	−0.111(6){11}	−0.114(4){10}	0.510(9)	0.5071(7)	-	-
^{182}Hg	0$^+$	−0.653(5){48}	−0.649(10){49}	-	-	-	-
^{183}Hg	1/2$^-$	−0.065(5){7}	−0.069(2){6}	0.516(11)	0.524(5)	-	-
^{184}Hg	0$^+$	−0.542(5){40}	−0.544(2){42}	-	-	-	-
^{185}Hg	1/2$^-$	−0.069(6){7}	−0.0764(6){63}	0.507(17)	0.509(4)	-	-
^{185m}Hg	13/2$^+$	−0.543(4){40}	−0.543(2){42}	−1.009(12)	−1.017(9)	−0.15(41)	0.19(32)

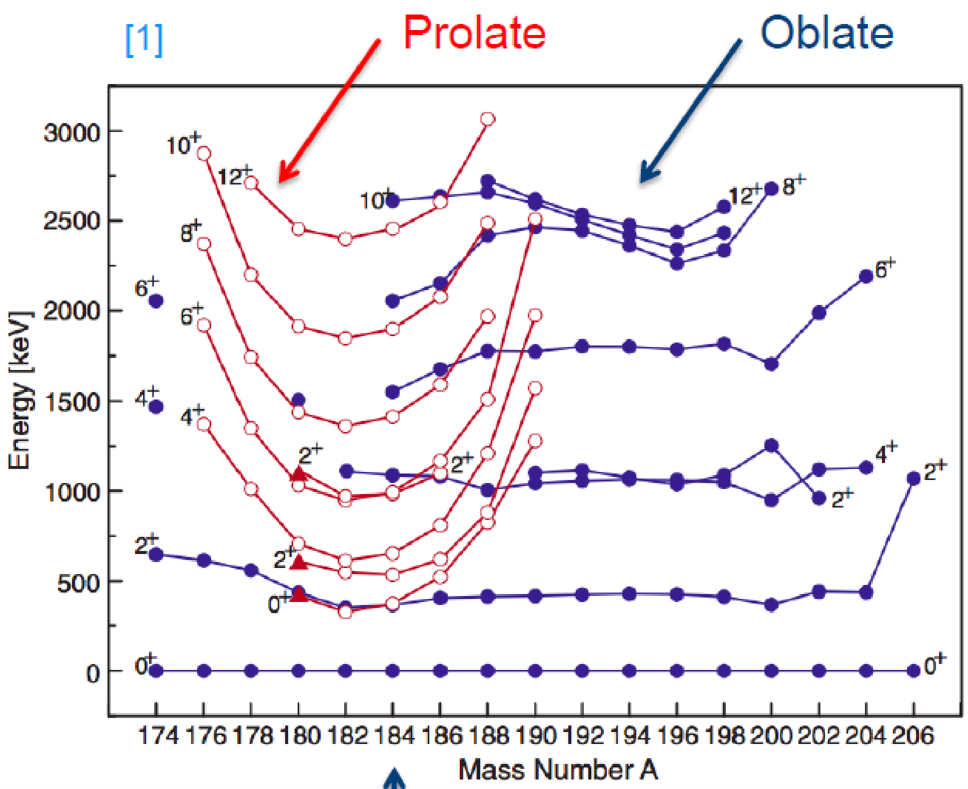
Statistical errors are given in parentheses. Systematic errors stemming from the indeterminacy of the F factor (7%, see ref. [19]) and M_{SMS} are shown in curly brackets. Reference values used to determine μ were: $\mu(^{199}\mathrm{Hg}^m) = -1.0147(8)$, with the hyperfne a parameter, $a(^{199}\mathrm{Hg}^m) = -2298.3(2)$ (ref. [20]) Reference values used to determine Q_s were: $Q_s(^{201}\mathrm{Hg}) = 0.387(6)$ (ref. [21]), with the hyperfine b parameter, $b(^{201}\mathrm{Hg}) = -280.107(5)$ (ref. [22]).

Moments

Magnetic: 177-179-185m Hg ≈ -1
181-183-185 Hg ≈ +0.5

Quadrupole: 177-179-185m Hg: small

Level systematics in even-even Hg



N = 104

Prolate intruder states come down in energy towards minimum around *N* = 104 midshell region

Studied by multitude of techniques:

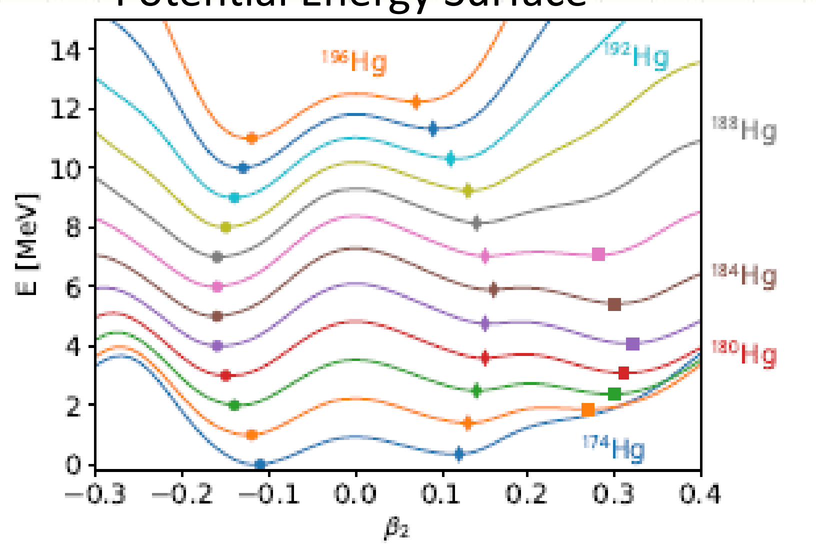
- Coulex
- Gamma spec.
- Decay spec.

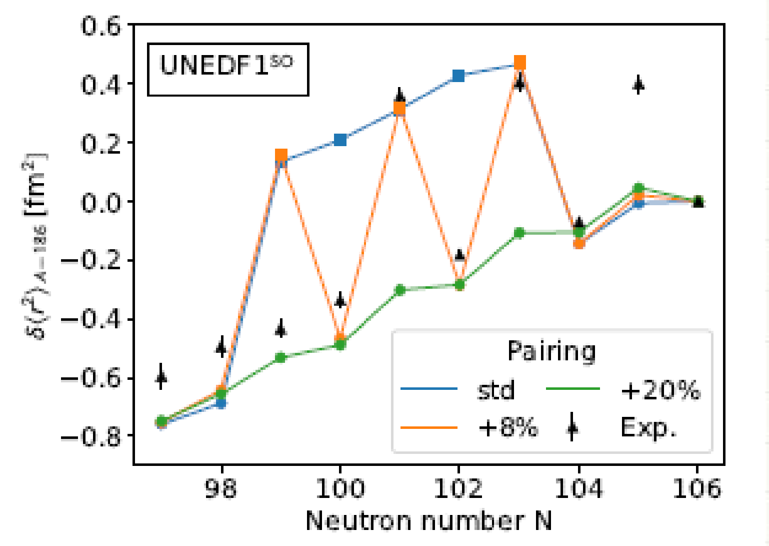
But direct measurements of ground state charge radii differences and electromagnetic moments missing below N = 101

Shape staggering comparison to HF calculations

Nuclear Density Functional Theory (DFT)

Potential Energy Surface



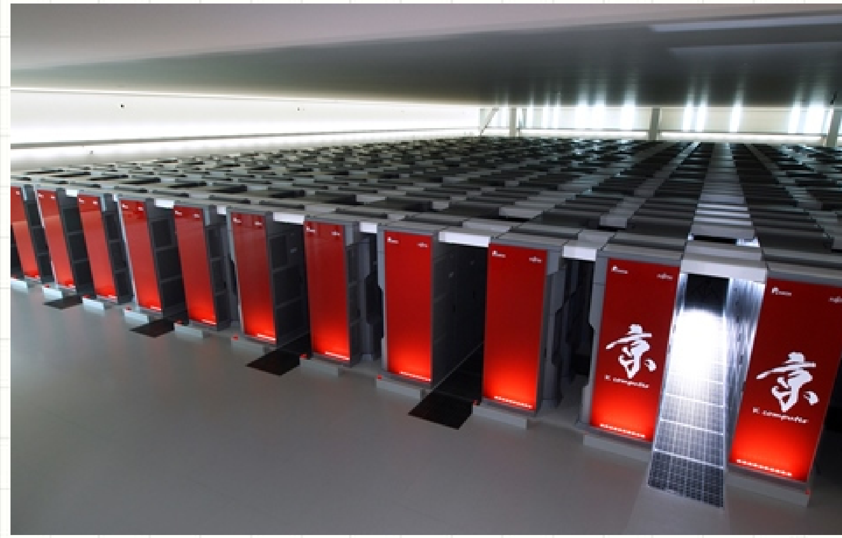


Circles: oblate, diamonds : weekly prolate,
Squares: strongly prolate minima

Skyrme functional UNEDF1^{SO}:
Adjusted to global properties of nuclear chart
Fine tuned SO and pairing to reproduce No spectroscopy

Configuration Interaction (CI) Monte Carlo Shell Modell (MCSM)

T. Otsuka, Y. Tsunoda *et al.*

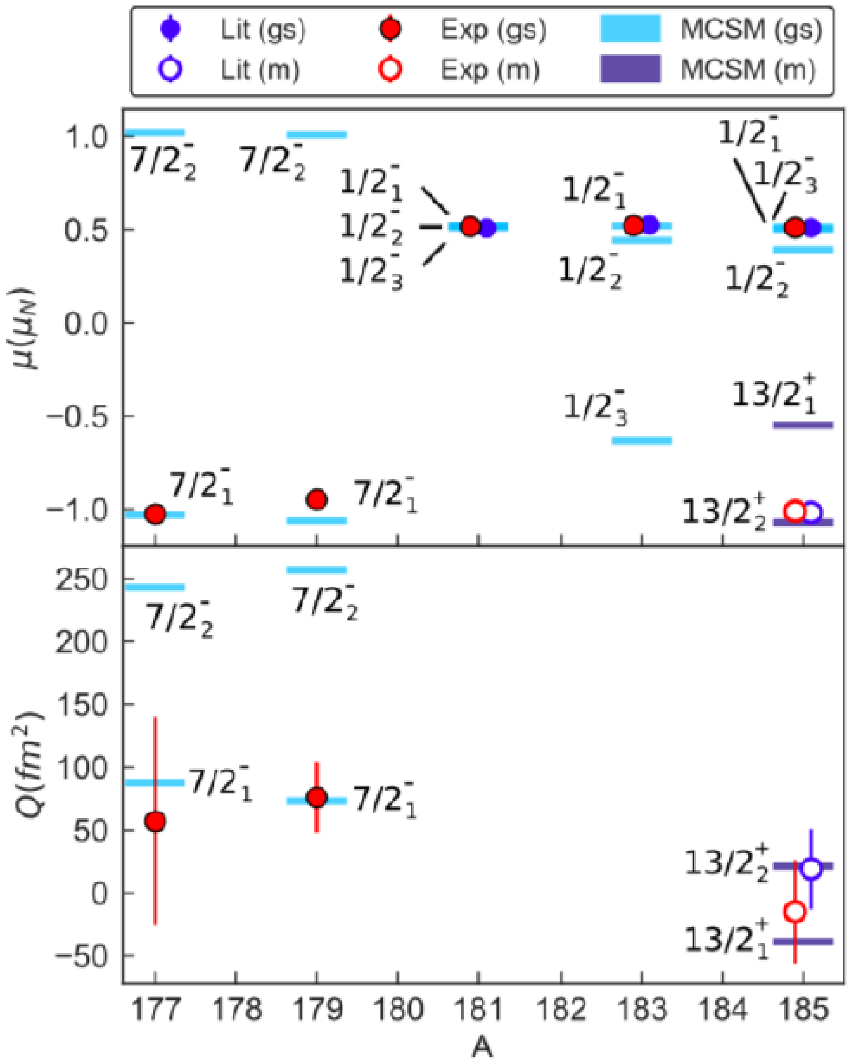


^{132}Sn as fixed core

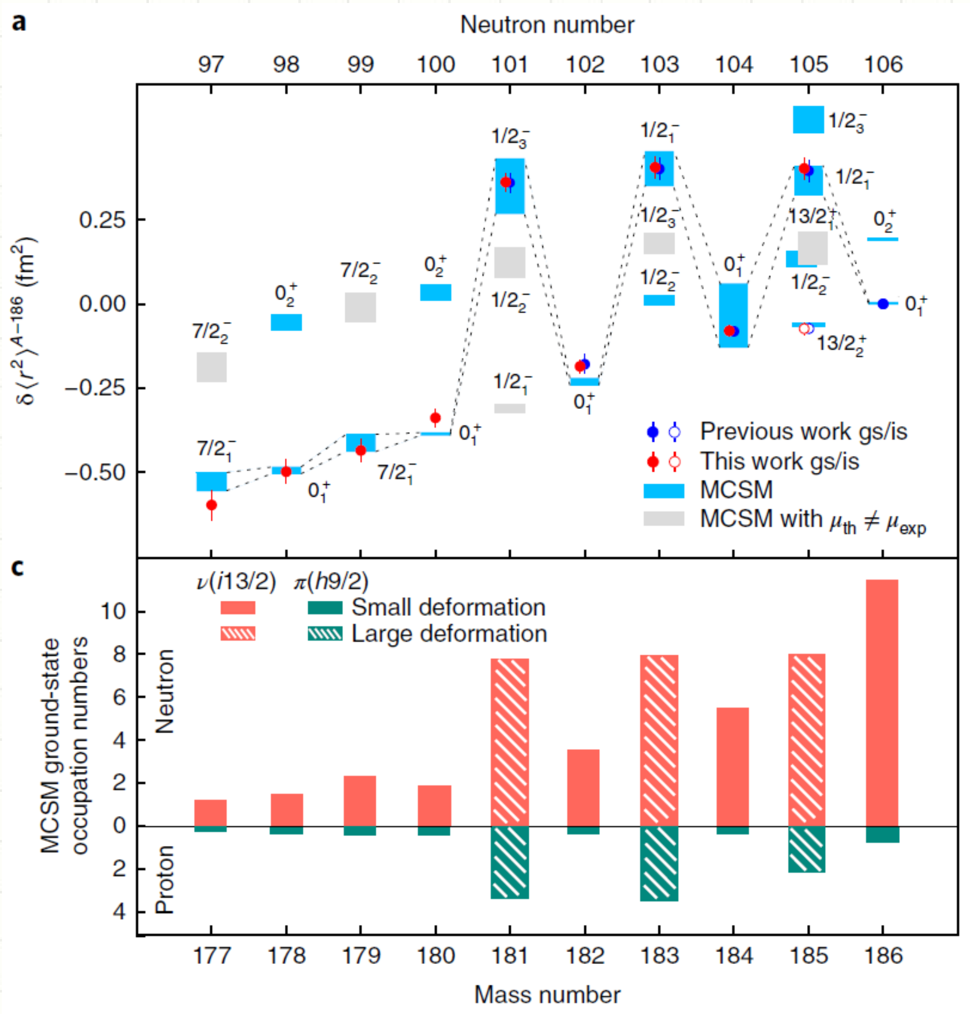
30 protons an 17-24 neutrons all interacting *NN*, *PP*, *PN*

First for such a heavy system:
K-Supercomputer (Japan) which became the first computer to top 10 petaflops
In 2012 it was world’s fastest computer, now ˝K” is the eighth-fastest computer

MCSM: results



MCSM: results



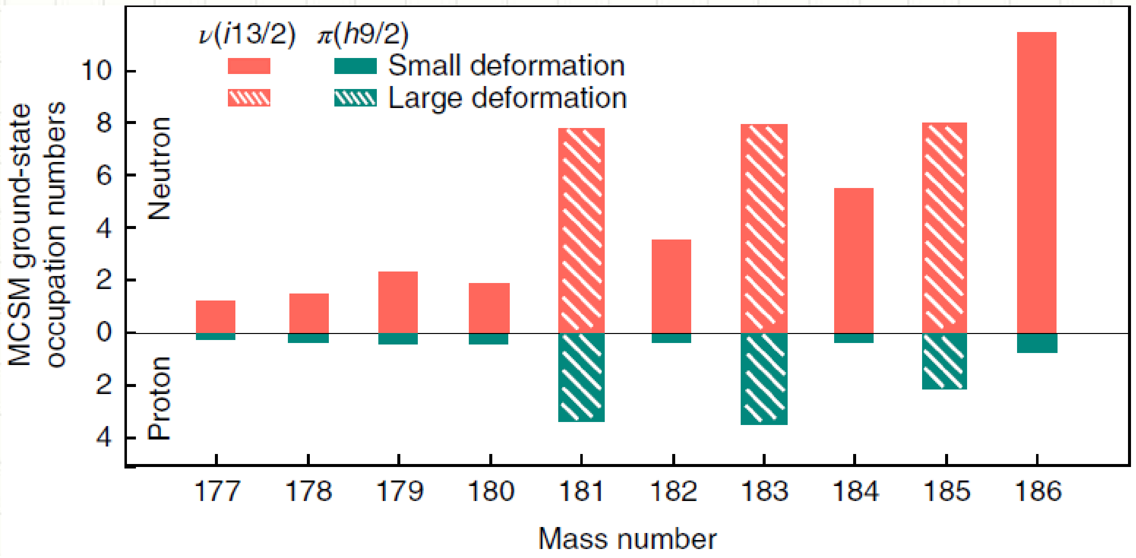
Shape staggering mechanism

Combined action of **monopole energy**, which for $n(\mathrm{i}_{13/2})$ and $p(\mathrm{h}_{9/2})$ stands out compared to others and due to:

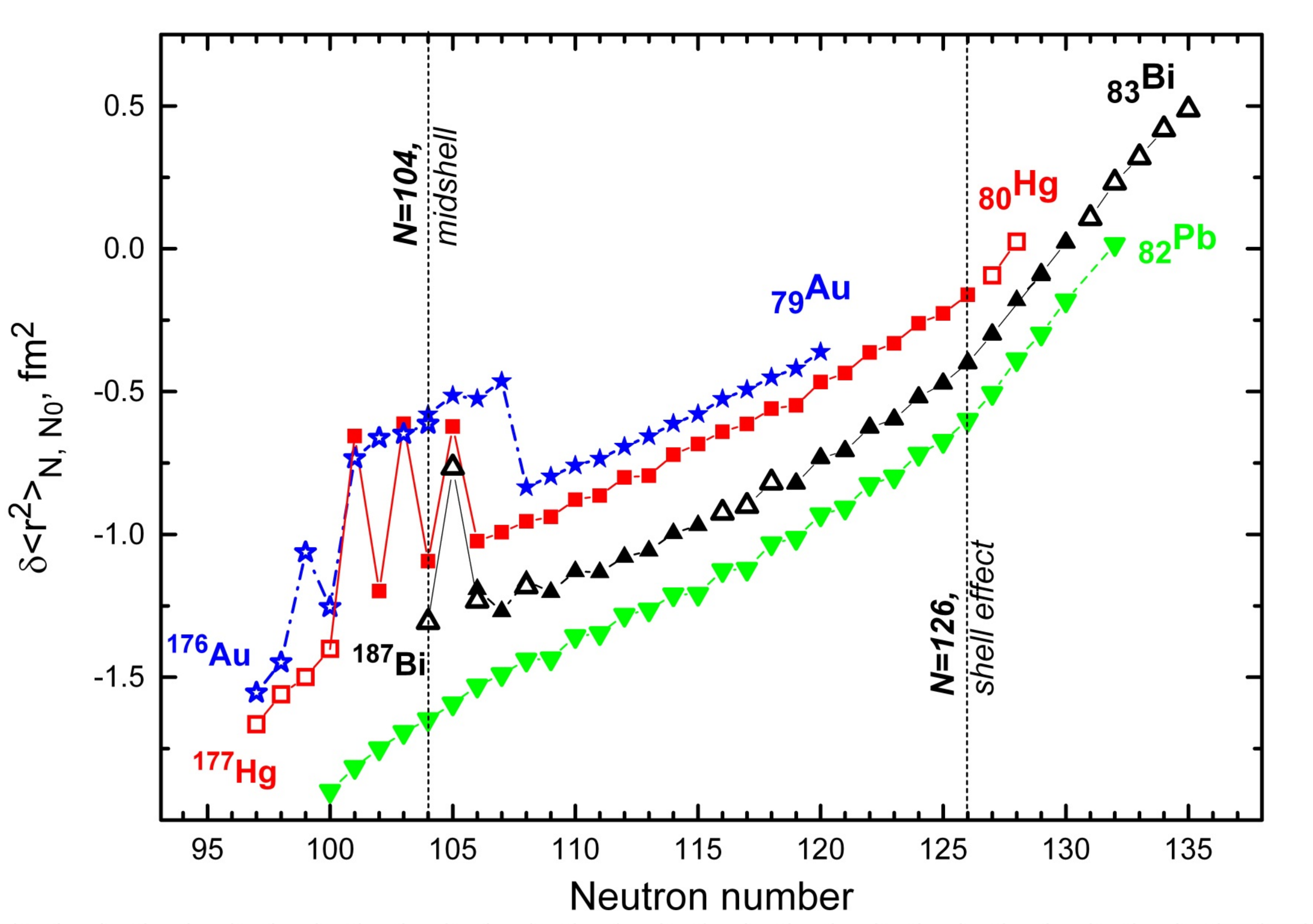
- Large overlap of wavefunctions

$$E_{\mathrm{mon}} = f(j_p, j_n) n_\pi(j_p) n_\nu(j_n)$$

and **quadrupole interaction** bringing down the *deformed* state in energy to near-degeneracy with *spherical* state



Outlook



δ<r²>_{N, N0}, fm²
Neutron number
0.5
0.0
-0.5
-1.0
-1.5
95
100
105
110
115
120
125
130
135
N=104, midshell
N=126, shell effect
83Bi
80Hg
82Pb
79Au
176Au
187Bi
177Hg

Изотопический сдвиг

$$\Delta\nu = \Delta\nu^{MS} + \Delta\nu^{FS}$$

Массовый сдвиг:

$$\Delta\nu^{MS} = \Delta\nu^{NMS} + \Delta\nu^{SMS}$$

Полевой сдвиг:

$$\Delta\nu^{FS} \approx F\delta\langle r^2\rangle$$

Сверхтонкое расщепление

$$\nu_{FF'} = \nu_0 + \Delta E_F - \Delta E_{F'}$$

$$\Delta E_F = A\,\frac{K}{2} + B\,\frac{0.75\,K\,(K+1) - I(I+1)J(J+1)}{2IJ(2I-1)(2J-1)}$$

$\mathbf{F} = \mathbf{I} + \mathbf{J}$ $\quad K = F(F+1) - I(I+1) - J(J+1)$

$A \sim \mu$ $\quad B \sim Q_S$