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Charge radii and β-decay properties of heavy Hg and Pt isotopes

Precision laser spectroscopy of the hyper-fine splitting spectra and beta-decay measurements at RIB facilities have made a great progress nowadays.

This calls for theoretical studies of different nuclear observables in a single self-consistent framework.

ICPPA, MEPhI, 22-25. 10. 2024

***Charge radii* and β–decay half-lives “ south-east” of 208Pb**

80Hg, 78Pt isotopes with one and 2 pairs of protons removed from Z=82 .

They are well suited for EDF studies of isotopic dependence of ***δ <r²> (N,N’) and beta-decay T1/2.***

Self-consistent Finite Fermi Systems theory (FFS) is used with the Fayans density functional (effective mass m=1). This EDF family describes exp. q-p levels near ε_{Fermi} .*

It will be shown that the ordering of neutron levels above N=126 is important for formation of the so-called “kink” in dms radii.

Also it is decisive for the competition between the Gamow-Teller (GT) and high-energy first-forbidden (FF) decays for nuclei “south-east “ of 208Pb.

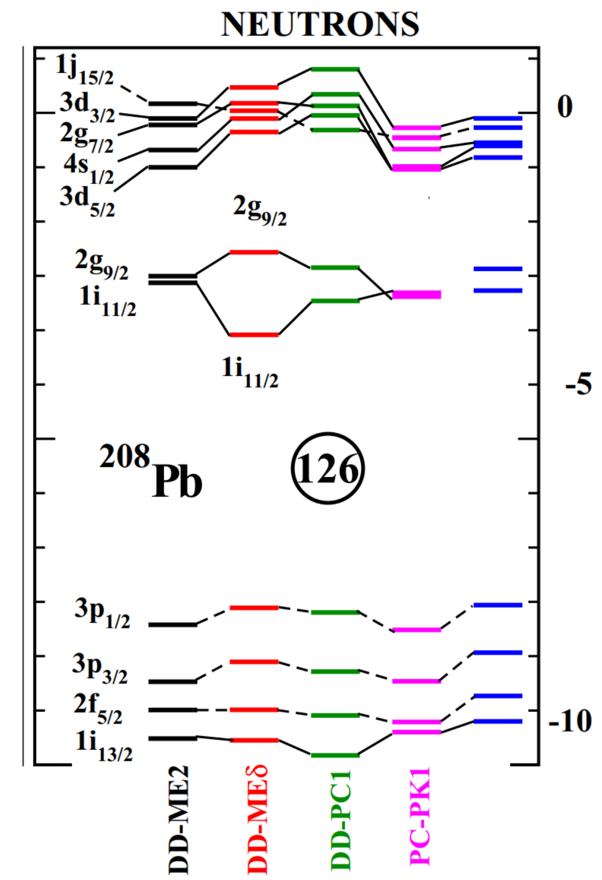
? Is it possible to simultaneously describe the radii and beta-decay half-lives in the RMF and FFS models (i.e. with and without the qp-levels inversion).

In RMF, the kink in charge radii at N=126 is due solely to inversion of n2g9/2 –n1i11/2 (which contradicts to the exp.data).

Exp.		DF3-a
-2.51	n 1j 15/2	-2.60
-3.16	n 1i 11/2	-3.12
-3.94	n 2g9/2	-3.66

Experiment :

$E(g_{9/2}) - E(i_{11/2}) = - 780$ keV



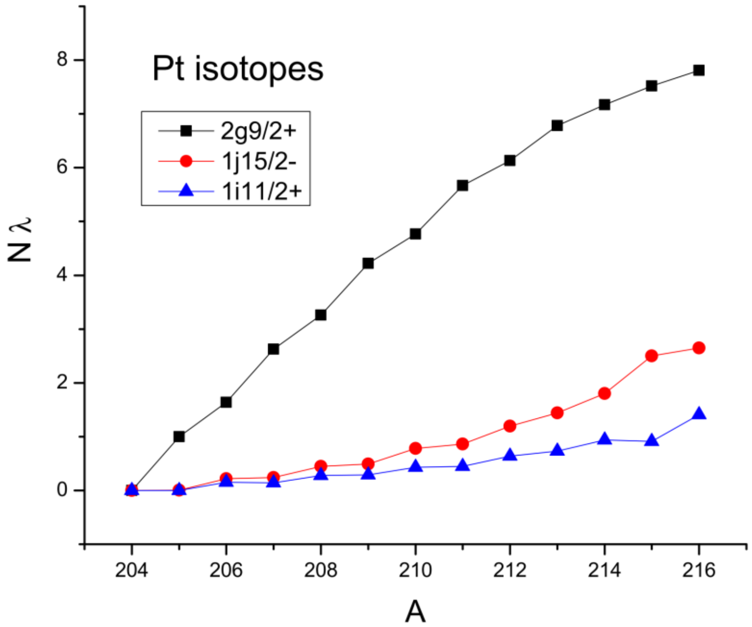
Using the RMF model with inverted g and i levels leads one to a conclusion that

“ pairing is not that important for the kink “ .

Is that so ?

*U. C. Perera ,A. V. Afanasjev , and P. Ring. Charge radii in covariant density functional theory: A global view Phys.Rev. C **104**, 064313 (2021)*

Origin of kink in Pt chain at N>126: DF3-a



DF3-a produces no i –g inversion;
Pairing dependence on the
density gradient is important .

The occupancy N_λ of $2g_{9/2}$ is bigger than the N_λ for high-spin orbitals.

Pairing correlations change the particle numbers N_λ .

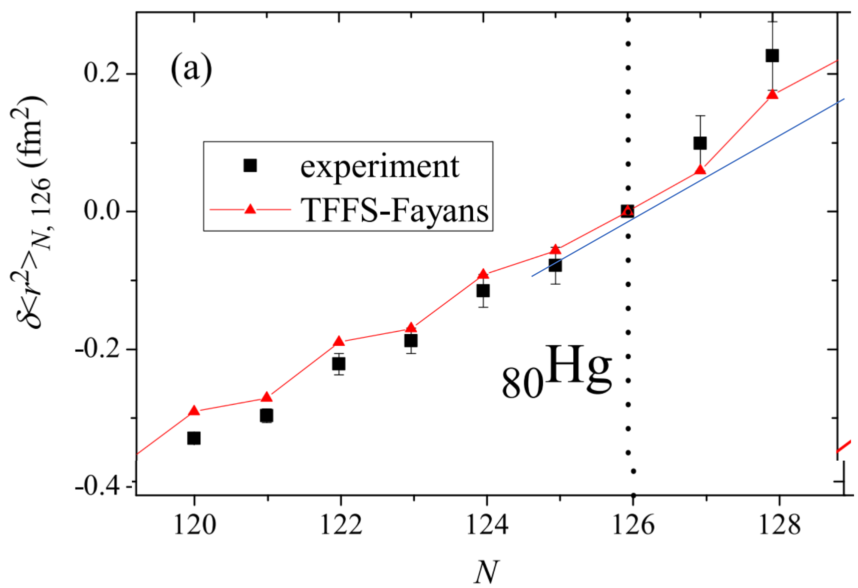
This affects both charge radii, as well as beta-decay strength functions.

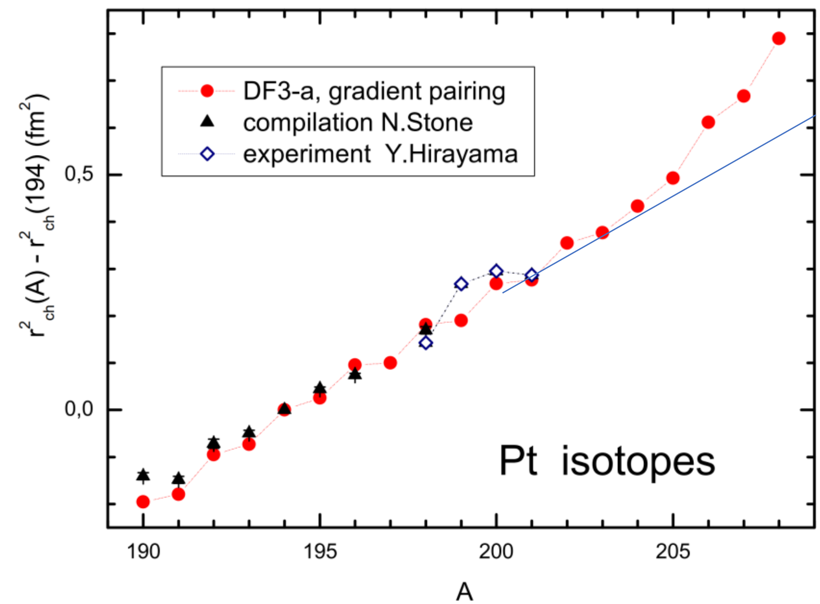
$$B(GT^-) \sim [\, n_\lambda^{(n)} - n_\lambda^{(p)} \,] * 8l\,(l+1) / (2l+1)\, |\langle p^{-1}|M|n\rangle|^2$$

B(GT) depends both on occupancies n_λ and orbital momentum l.
Thus, it is important which orbital has to be filled first: $2g_{9/2}$ or $1i_{11/2}$

The TFFS-DF3-a calculations of $\delta\langle r^2\rangle$(N,126) compared with the experiment for the 80Hg, 78Pt isotopes for N approaching N = 126 and above.

CHARGE RADII OF THALLIUM ISOTOPES NEAR …





PHYSICAL REVIEW C **110**, 034315 (2024)

Charge radii of thallium isotopes near the *N* = 126 shell closure

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(IDS Collaboration)

PHYSICAL REVIEW C **106**, 034326 (2022)

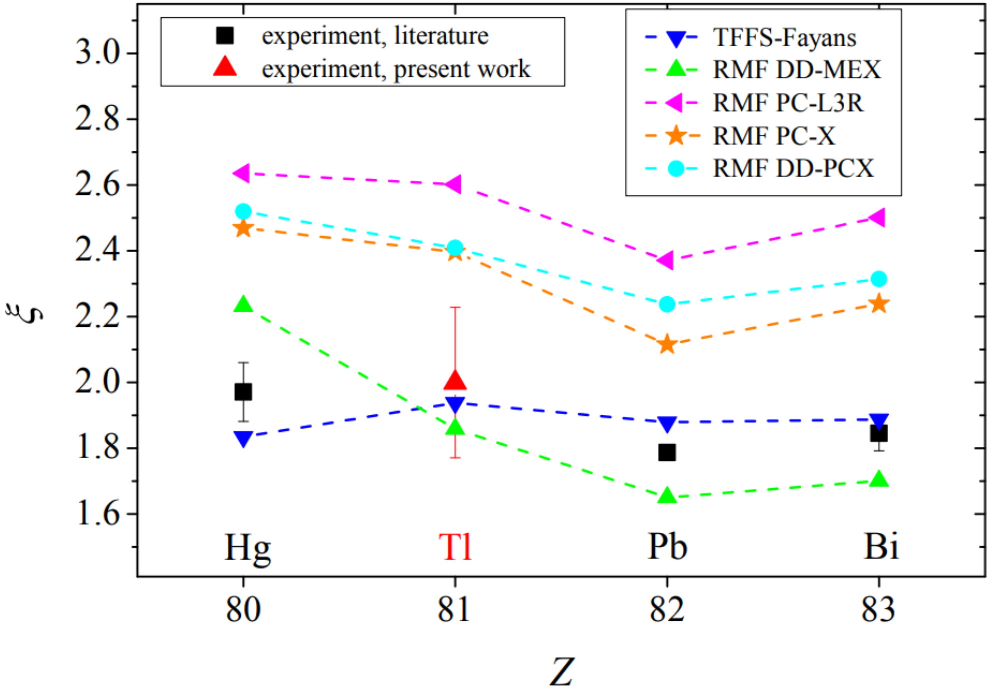
In-gas-cell laser resonance ionization spectroscopy of 200,201Pt

Y. Hirayama,[1,*] M. Mukai,[2] Y. X. Watanabe,[1]

et.al
(KISS Collaboration)

Kink indicators for Hg - Bi

$$\xi = \frac{\delta\langle r^2\rangle^{128,126}}{\delta\langle r^2\rangle^{126,124}}.$$



The TFFS (DF3-a) calculations reproduce the experimental rink ξ –indicators in Hg -Bi.

RMF-DD-MEX functional predicts a noticeable Z dependence of the kink indicator which is not observed experimentally.

The other three RMF functionals overestimate the shell effect in radii

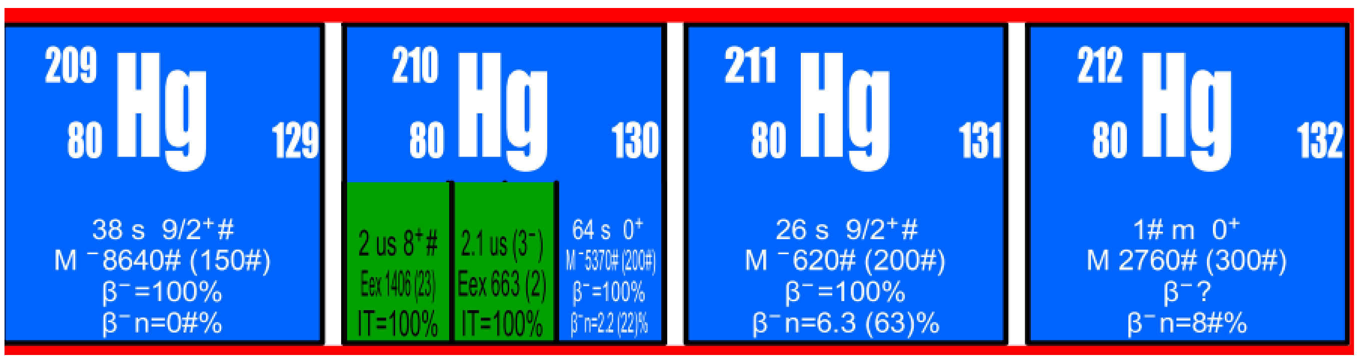
Z. Yue , A. E. Barzakh , A. N. Andreyev , I. N. Borzov , et.al.

*PHYSICAL REVIEW C **110**, 034315 (2024)*

CERN-INTC-2024-019 / INTC-P-698
10/01/2024

How well do we know the
beta-half-lives near N=126 ?

New exp. for
210-211 Hg
are planned
in 2024.
CERN

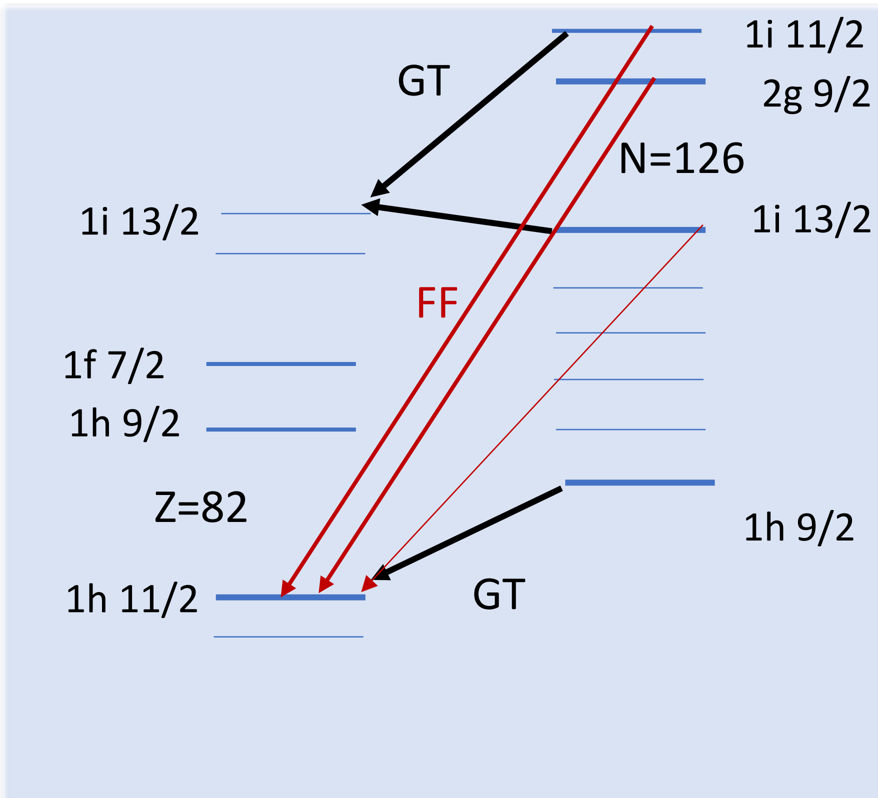


Beta-decay of nuclei near the neutron shell N=126
I.N. Borzov, Physics of Atomic Nuclei 74, 1435-1444 (2011).
76Os, 77Ir, 78Pt, 79Au

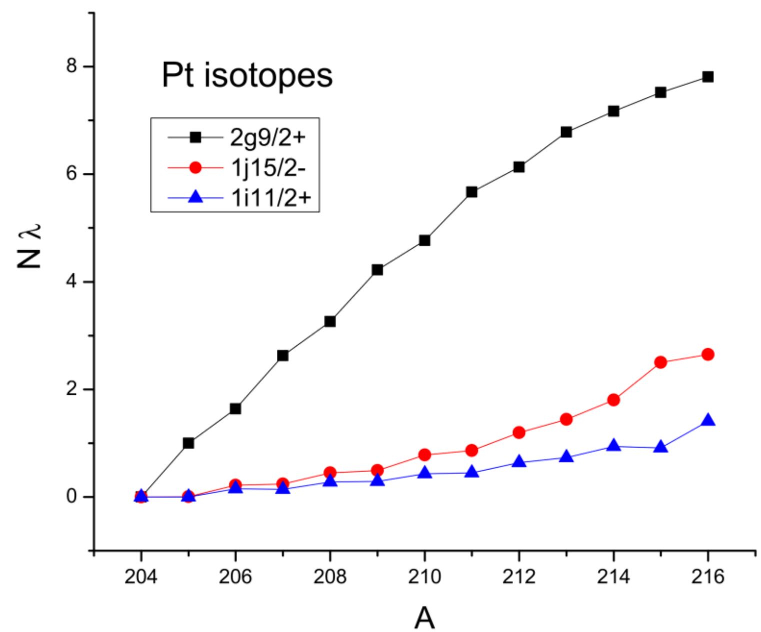
Gamow-Teller and ΔJ=0,1 (FF) beta-decay "south-east" of 208Pb.

For ^{78}**Pt,** ^{80}**Hg** at N>126, the β-decay rates are sensitive to the g – **i** orbitals ordering!

*At N<126, the GT decays - n1h 9/2 -> **p1h11/2**, and FF n1i13/2 → **p1h11/2**, are possible.*



*At N ≥126, **new GT and cross-shell FF** transitions are opened **due to pairing.***



At N>126 the main competing GT and FF transitions::
high-energy (cross-shell) FF n2g9//2; n1i11/2->p1h11/2
and lower energy GT transition n1i11/2->p1î13/2.

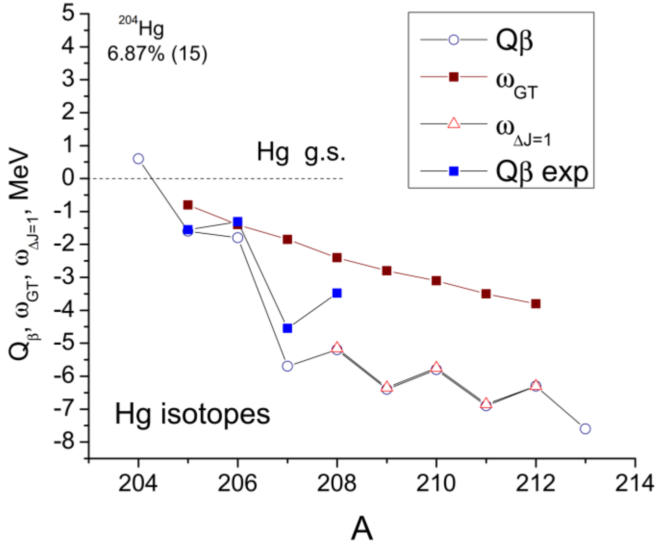
It is decisive which orbital is filled first: $2g_{9/2}$ *or* $1i_{11/2}$

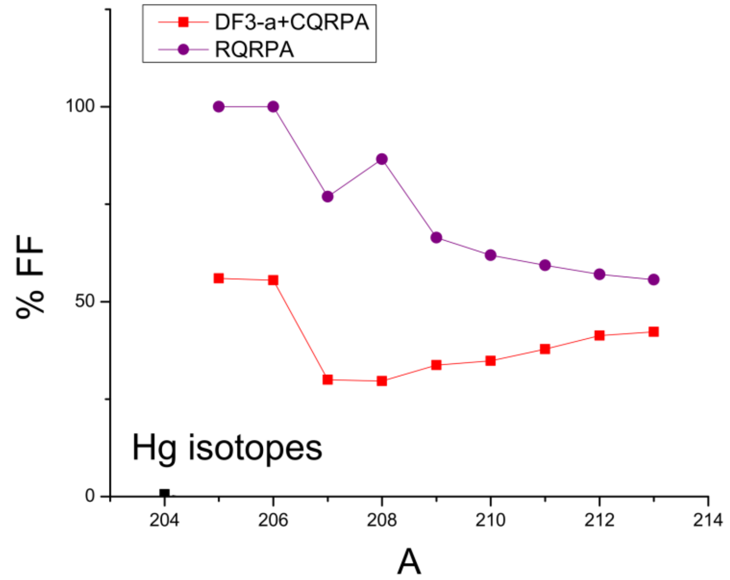
Energetics of 204-212Hg isotopes. % FF transitions.

The energies are given with respect to the parent g.s.

$$\lambda_{total} = \lambda_{GT} + \lambda_{FF}$$

$$\%FF = 100*\lambda_{FF} / \lambda_{total} = (T_{GT} - T_{total}) / T_{GT}$$





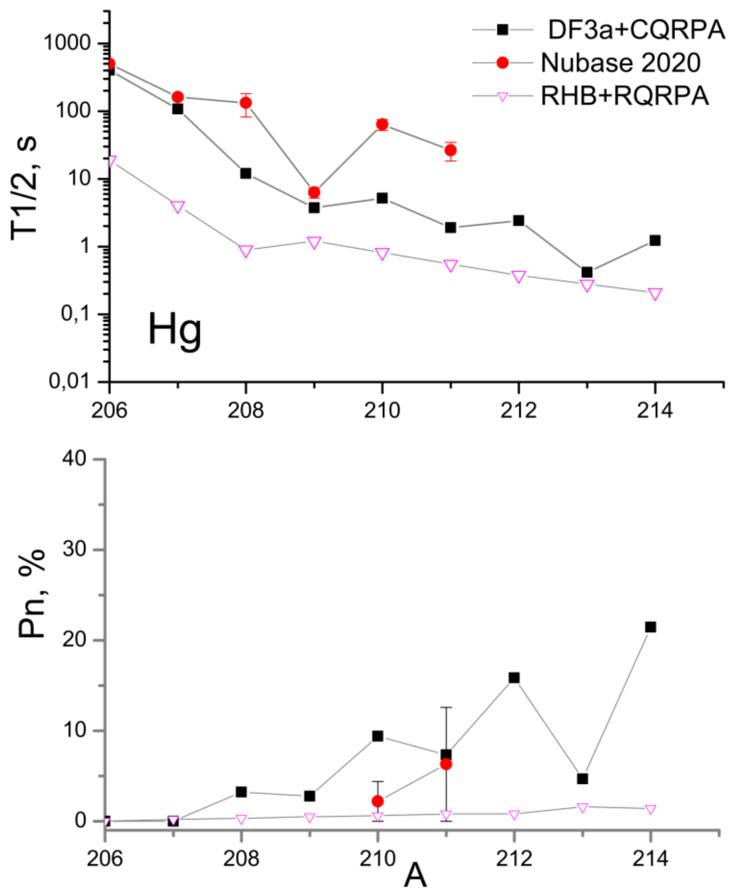
The energies of the high-energy FF (spin-dipole) transitions with ΔJ=1 and ΔJ=0 are close to the Qbeta-values. Thus, the phase-space factor amplifies their contribution to the T1/2.

In Hg isotopic chain the contribution of the FF decays to T1/2 is % FF(DF3-a) = 40-50 %.

A competition between low-energy GT-pygmy resonances and high-energy FF decays.

In the Relativistic QRPA (T. Marketin, et.al.. Phys. Rev. C 93, 025805 (2016).), the %FF is much higher.

Beta-decay half-lives and Pn-values for Hg isotopes.
DF3-a *(with no inversion)* vs. *RMF (with g-i inversion)*



For $^{206-211}$ Hg,
The DF3-a+CQRPA is closer to the exp. than RHB

Relativistic HB+RQRPA (DD-ME2 functional) underestimates T1/2 by the factor of 5 to 100 .
The delayed neutron emission Pn(N) ~ const.

T. Marketin, L. Huther, and G. Martínez-Pinedo. Phys. Rev. C 93, 025805 (2016).

FAM (not shown)– overestimate T1/2 (factor 2 to 100)

Qβ, Sn for RMF calculation…. not known …?
But the RMF qp-spectrum has g-i inversion.

New CERN-ISOLDE exp. run for 210-211 Hg in 2024

Irregularity of T1/2 for 209 Hg ?

Conclusions

- *For Pt, Hg isotopes **near and above N=126**, the self-consistent DF3-a and CQRPA calculations are done for **geometric (R_charge), energetics (Q_β), as well as magnetization and beta-decay properties (T1/2, Pn).***

- *For Pt and Hg isotopes, the charge **radii kink indices at** crossing N=126 magic shell*
- ***are well enough described from DF3-a. The accuracy, is the same, as in our previous calculations in the Tl to Bi isotopes (Z=81-83).***

*Z. Yue , A. E. Barzakh , A. N. Andreyev , I. N. Borzov , et.al. PHYSICAL REVIEW C **110**, 034315 (2024).*

The half-lives for the Pt, Hg isotopes are compared with the IAEA compilation (2017) and NUBASE 2020. It is concluded that:

- ***In the TFFS + Fayans one can simultaneously describe** the experimental s.p spectra, as well as the charge radii, (magnetic moments) and **beta-decay characteristics**.*

- ***In the relativistic RHB+RQRPA** calculations (Afanasjev et al.) that is not possible mainly due to inversion of the 2ng9/2 and 1ni11/2 levels.*

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A.N. Andreev, A.E. Barzakh for collaboration and info on their experiments in CERN.

S.V. Tolokonnikov for fruitful discussions .

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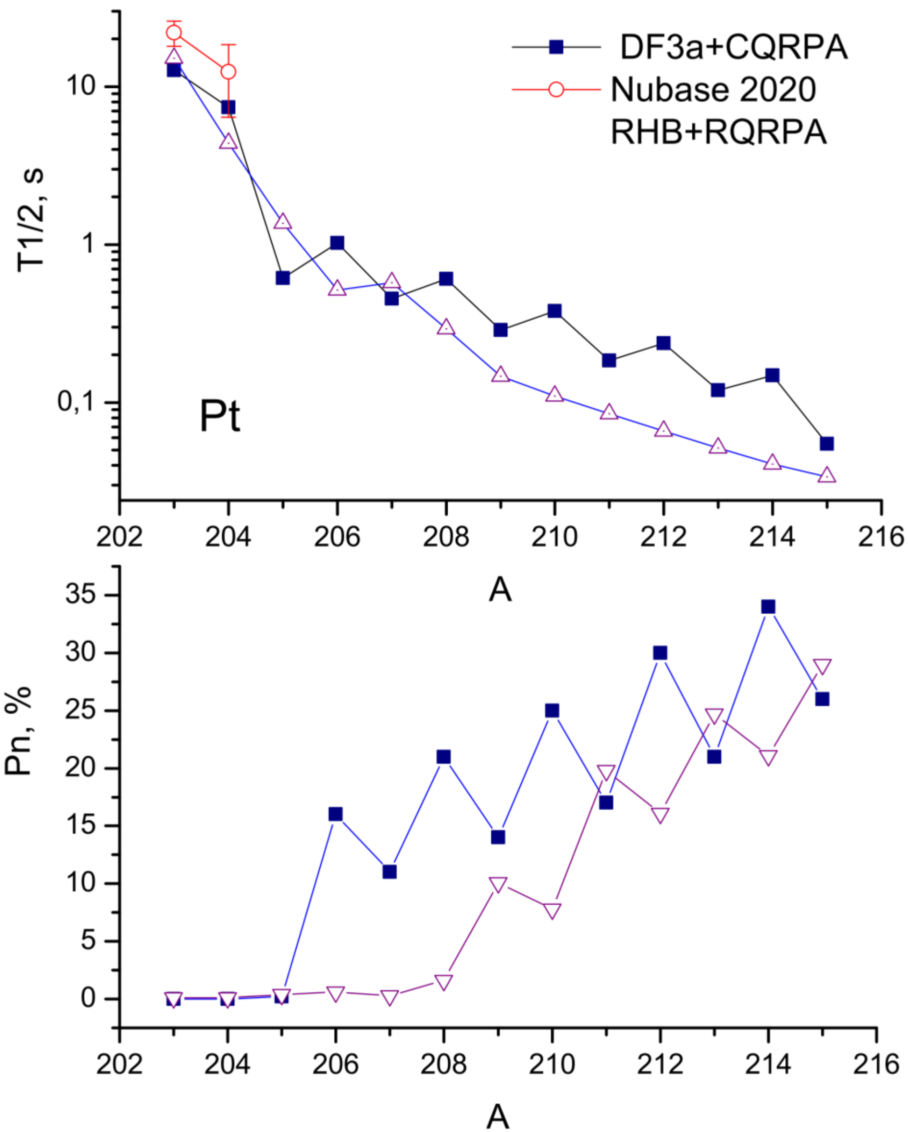
Beta-decay half-lives and Pn-values for Pt isotopes



Factor of 3 - 5 difference in T1/2 at N>126

New exp. for A> 205 are planned

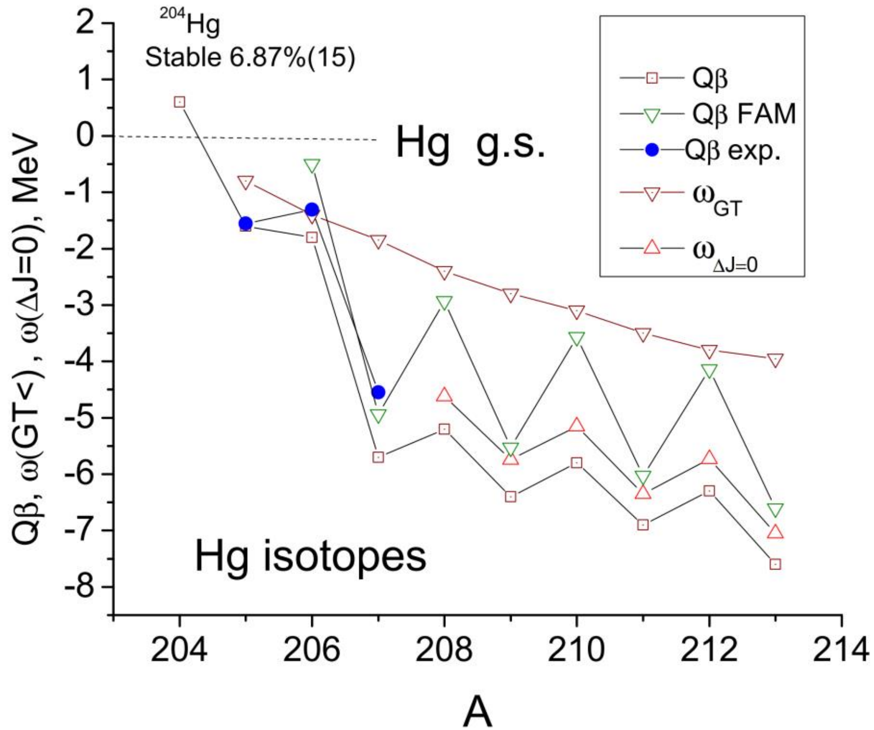
Y. Hirayama for KISS Collaboration.

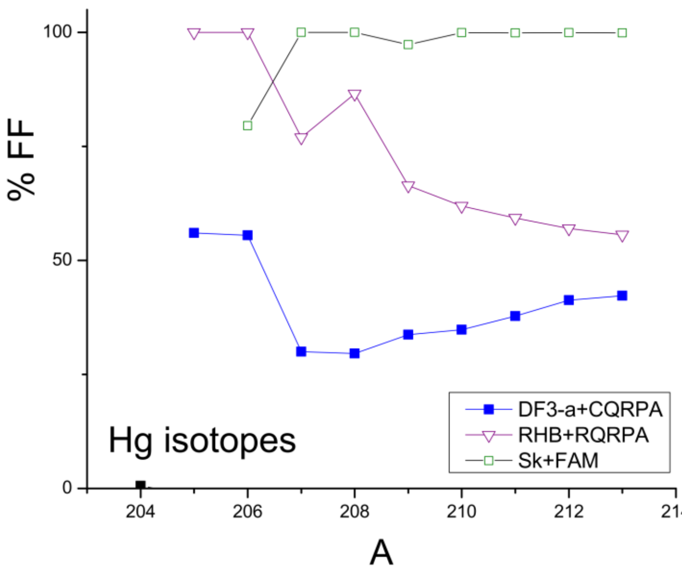
*Phys.Rev. C **106**, 034326 (2022);*

Eur. Phys. J. Spec. Top. 233, 1209 (2024).

Energetics of 205-212Hg isotopes and %FF

The energies are given with respect to the parent g.s.





The DF3-a calculations well describes Q_β for 204Hg (stable isotope, exp. abundance 6.87%).

The GT pygmy-resonance enters the window at A=205 ($|Q_\beta|$= 1.5 MeV).
The energies of the FF (spin-dipole) transitions with ΔJ=1 and ΔJ=0 are close to the Qbeta-values.

For RHB the calculated Qbeta-values are not published, for FAM – the odd-even effect is too strong.