QUADRUPOLE AND OCTUPOLE STATES IN **ZIRCONIUM CHAIN** USING **TDHF & QRPA**

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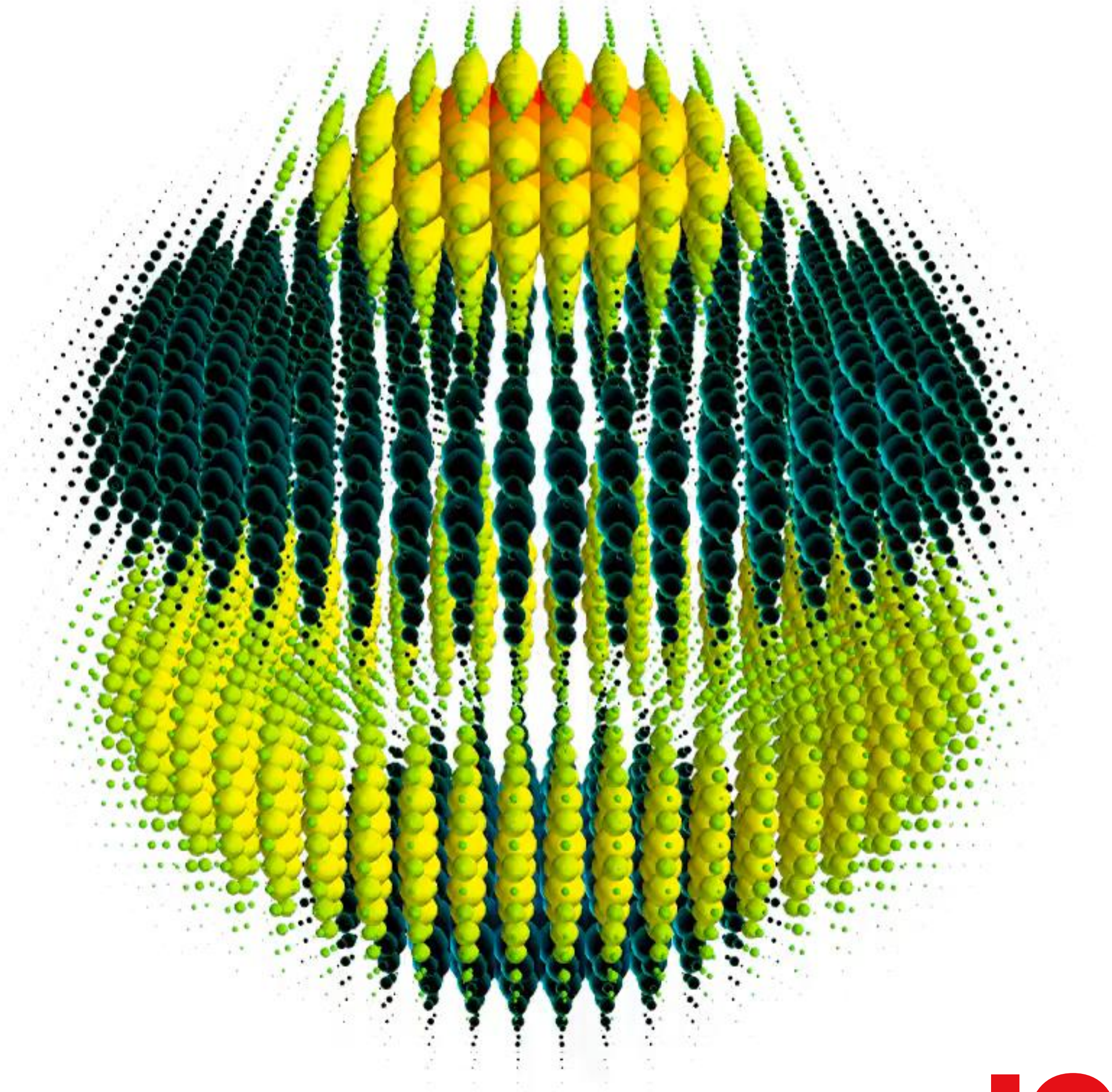

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OUTLINE

What is our Model (TDHF)

How it works

Comparison with QRPA

Results for Zr isotopes

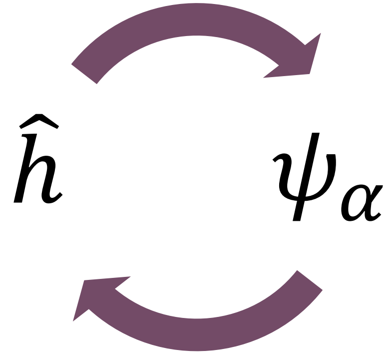
Conclusion

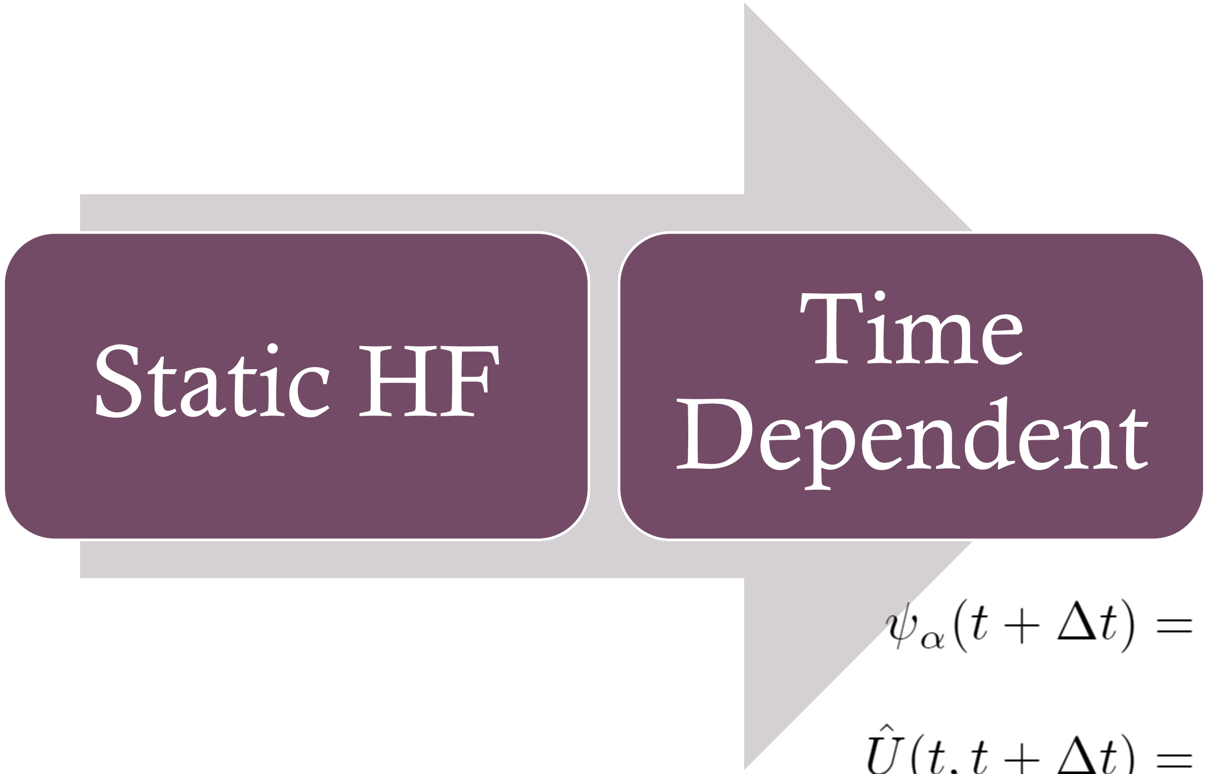
TIME DEPENDENT HARTREE FOCK (TDHF) MODEL

Density Dependent Mean Field

$$\hat{h}\psi_\alpha = \epsilon_\alpha \psi_\alpha$$

S.P. Wavefunctions





$$i\partial_t \psi_\alpha = \hat{h}\psi_\alpha$$

$$\psi_\alpha(t+\Delta t) = \hat{U}(t, t+\Delta t)\psi_\alpha(t)$$

$$\hat{U}(t, t+\Delta t) = \hat{\mathcal{T}} exp\left(\frac{-i}{\hbar}\int_t^{t+\Delta t} \hat{h}(t^{'})dt^{'}\right)$$

J Maruhn, P.-G. Reinhard, P. Stevenson, and A. Umar, Computer Physics Communications 185, 2195 (2014).

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COLLECTIVE EXCITATIONS

$$\hat{h}_q \rightarrow \hat{h}_q + \eta f(t) F_q(\vec{r})$$

$$F_q(\vec{r}) = \sqrt{2L+1} r^L Y_{LM}$$

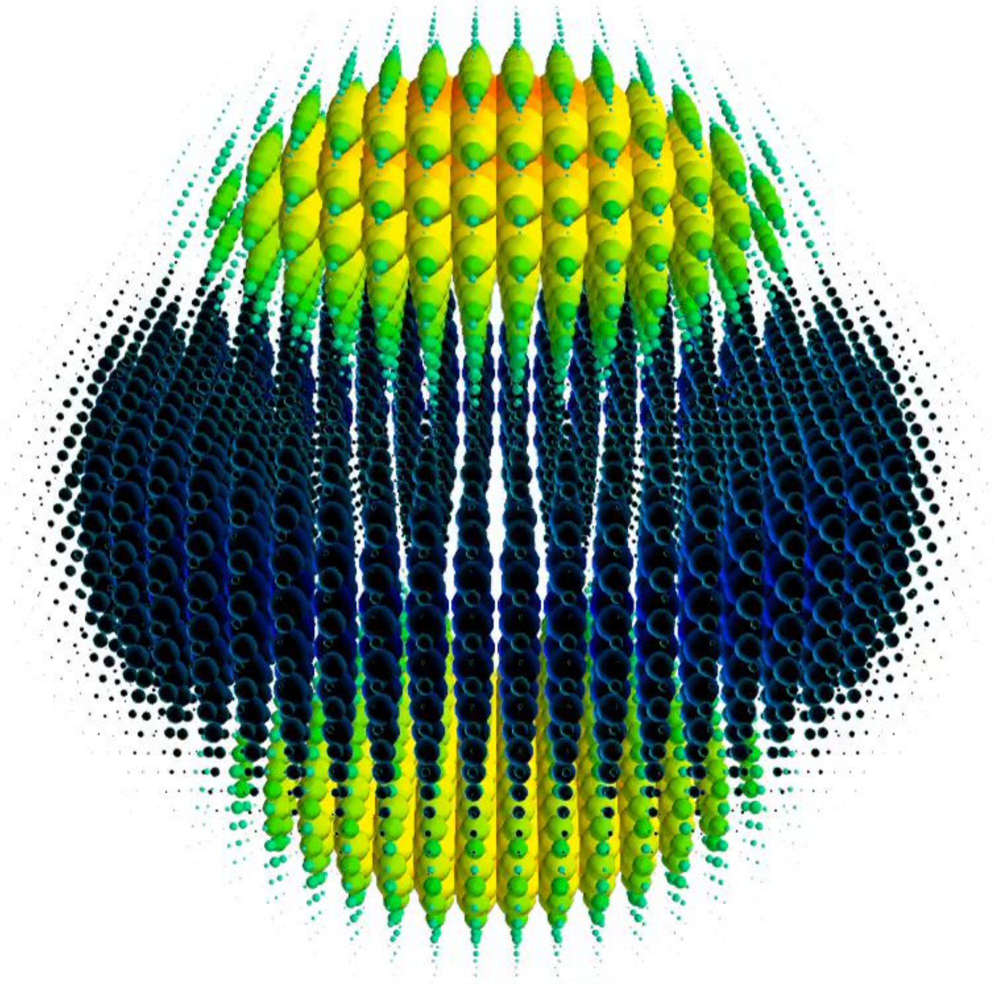
$$F_q(\vec{r}) \rightarrow \frac{F_q(\vec{r})}{1 + e^{(r-r0)/\Delta r}}$$

q denotes the isospin

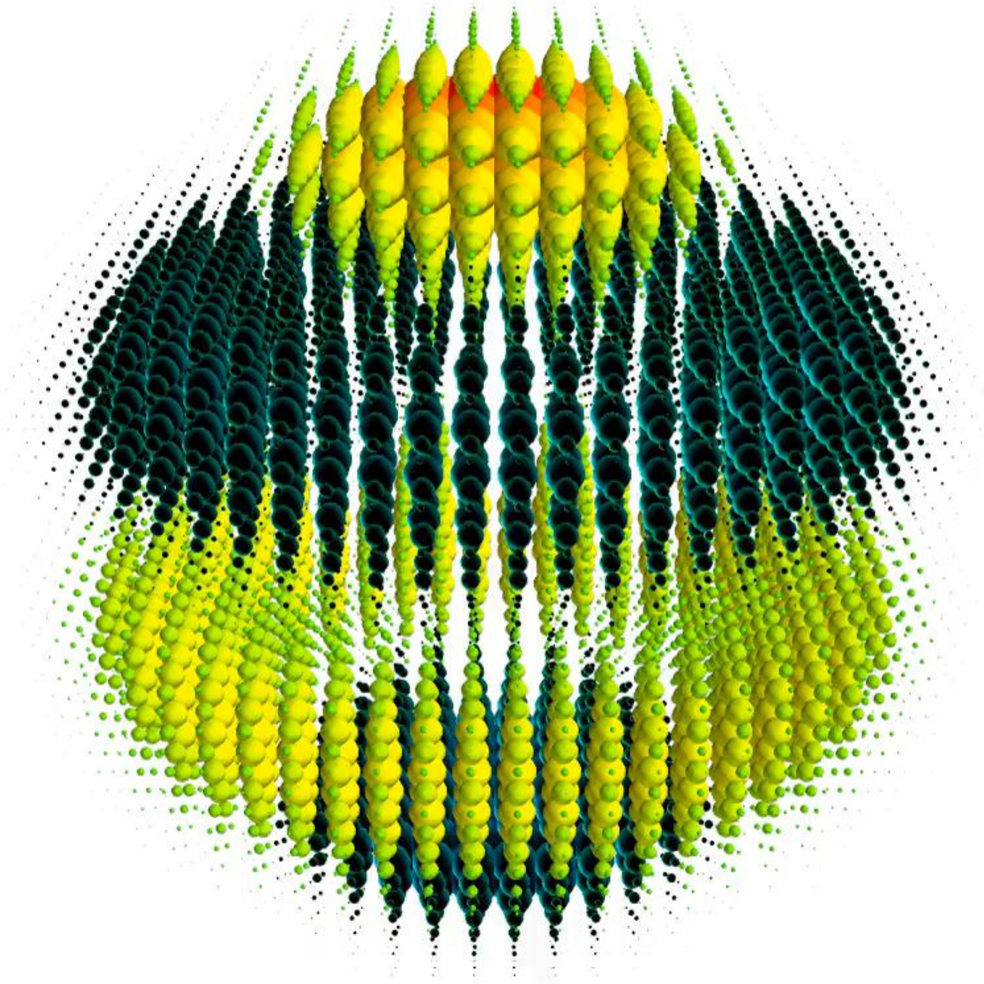
L=2 (Quadrupole)

L=3 (Octupole)

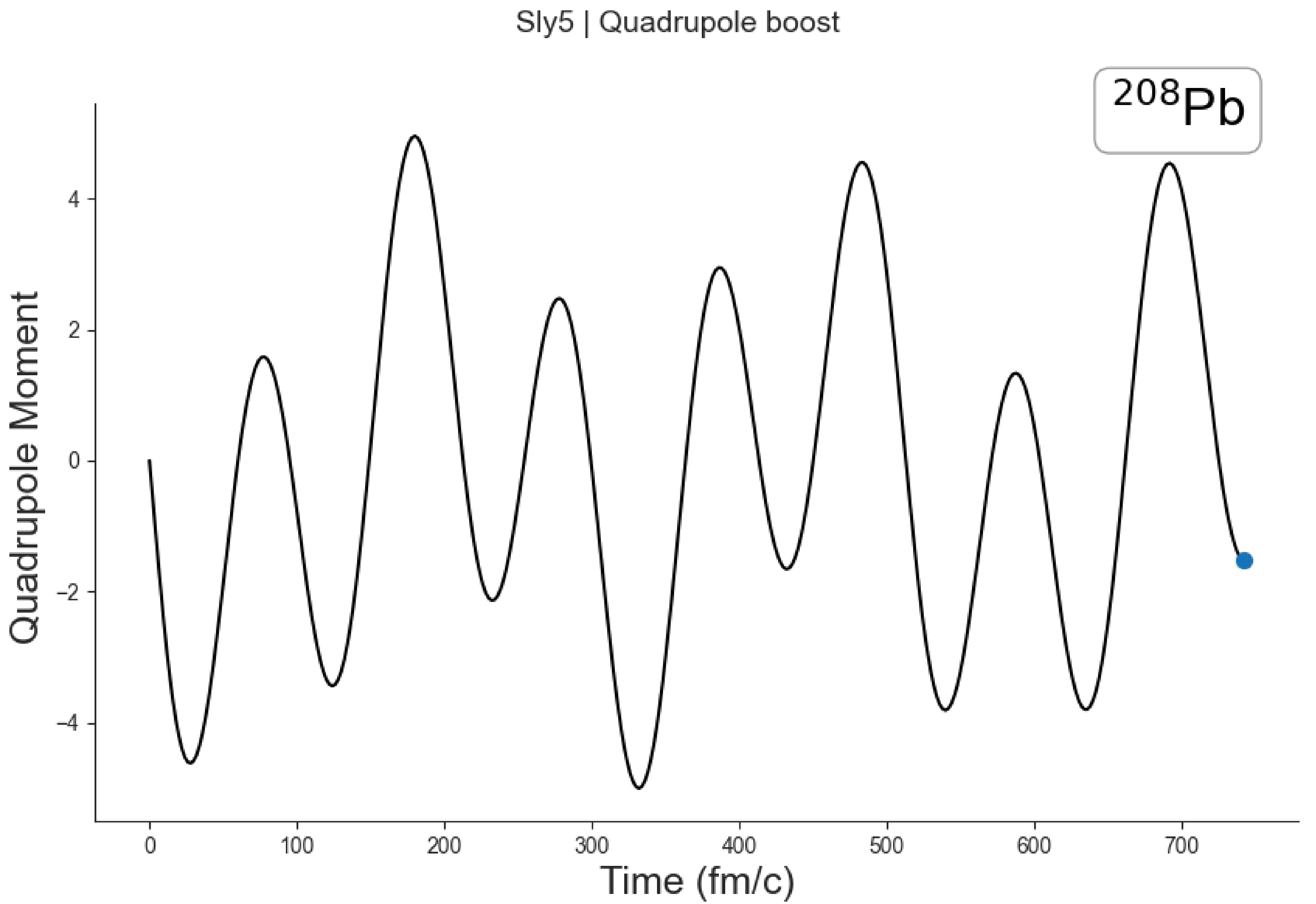
.J Maruhn, P.-G. Reinhard, P. Stevenson, and A. Umar, Computer Physics Communications 185, 2195 (2014).



$r^2 Y_2^0$



$r^3 Y_3^0$



Sly5 | Quadrupole boost
^{208}Pb
Quadrupole Moment
4
2
0
−2
−4
0
100
200
300
400
500
600
700
Time (fm/c)

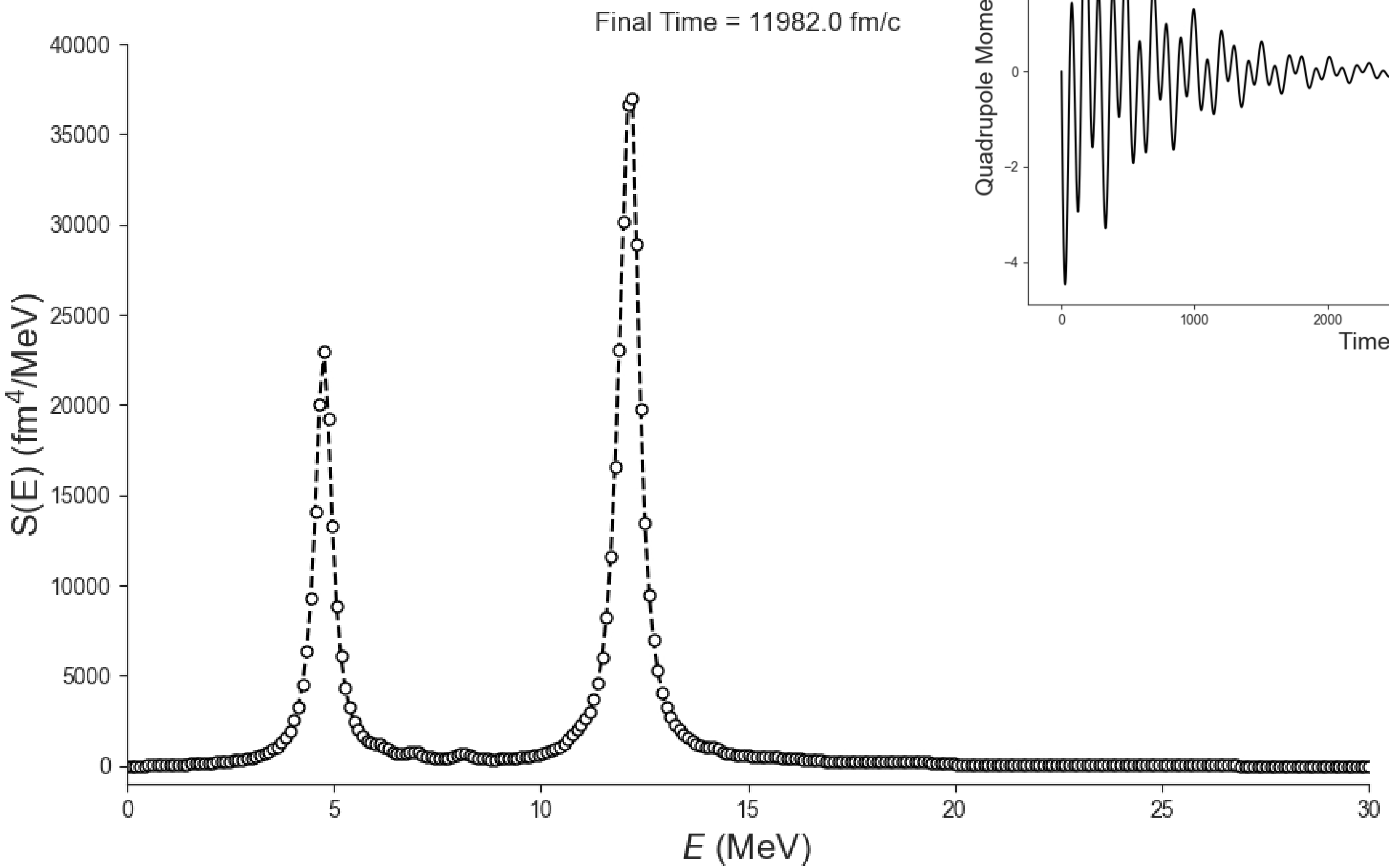
STRENGTH FUNCTION

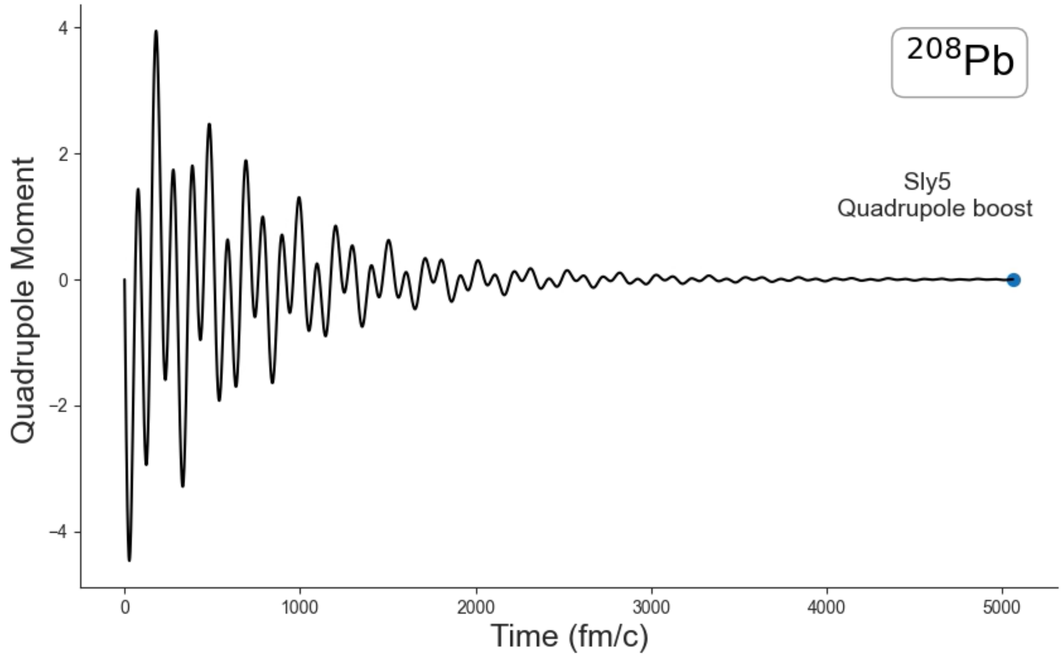
The boost gives some weight to all the system's excitation frequencies

$$\hat{F}_q(t) = \langle \Phi(t) | \hat{F}_q | \Phi(t) \rangle$$

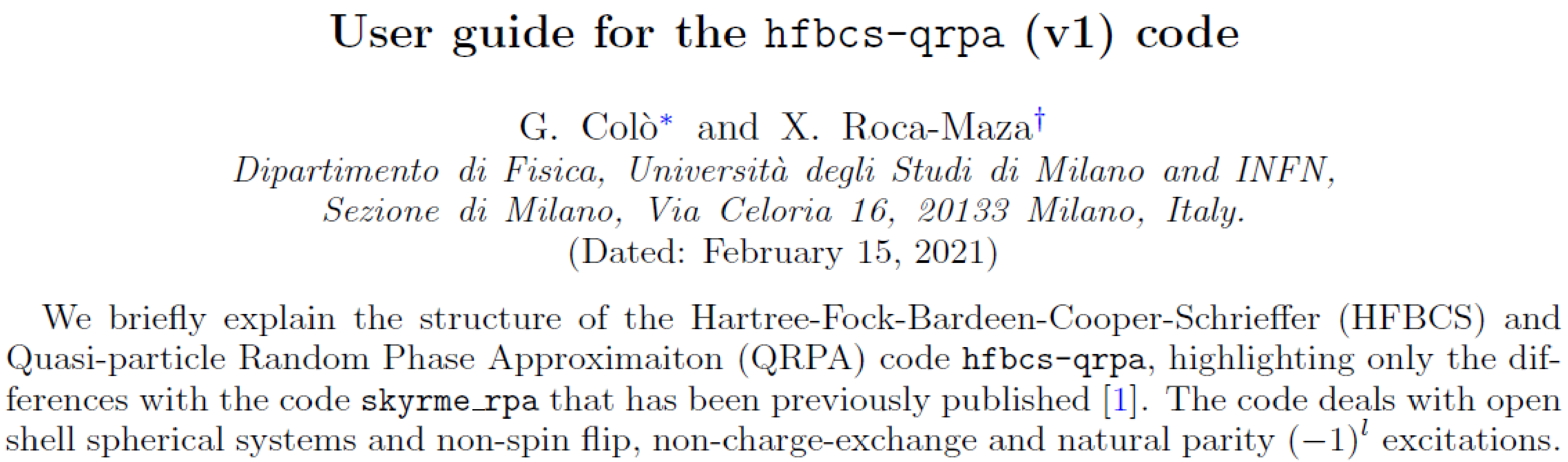
$$S(E) = \frac{1}{\eta \hbar \pi} \text{im}[\hat{F}_q(\omega)]$$

$$\hat{F}_q(t) \rightarrow \hat{F}_{q\,fil}(t) = \hat{F}_q(t) e^{\frac{-\Gamma t}{2\hbar}},$$


Final Time = 11982.0 fm/c
S(E) (fm^4/MeV)
E (MeV)
0
5000
10000
15000
20000
25000
30000
35000
40000
0
5
10
15
20
25
30


^{208}Pb
Sly5
Quadrupole boost
Quadrupole Moment
Time (fm/c)
4
2
0
-2
-4
0
1000
2000
3000
4000
5000

COMPARISON WITH QRPA


User guide for the hfbcs-qrpa (v1) code

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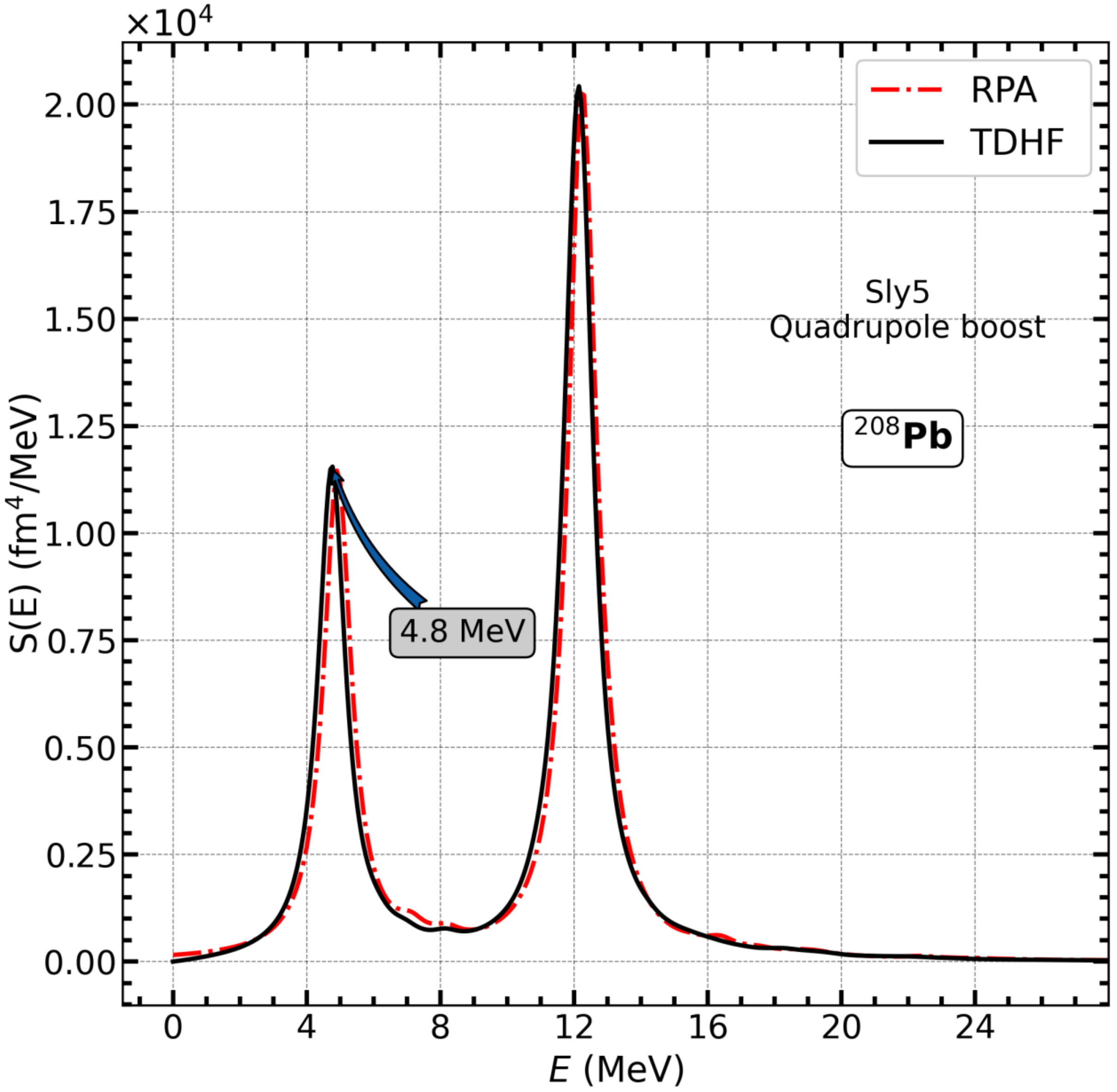
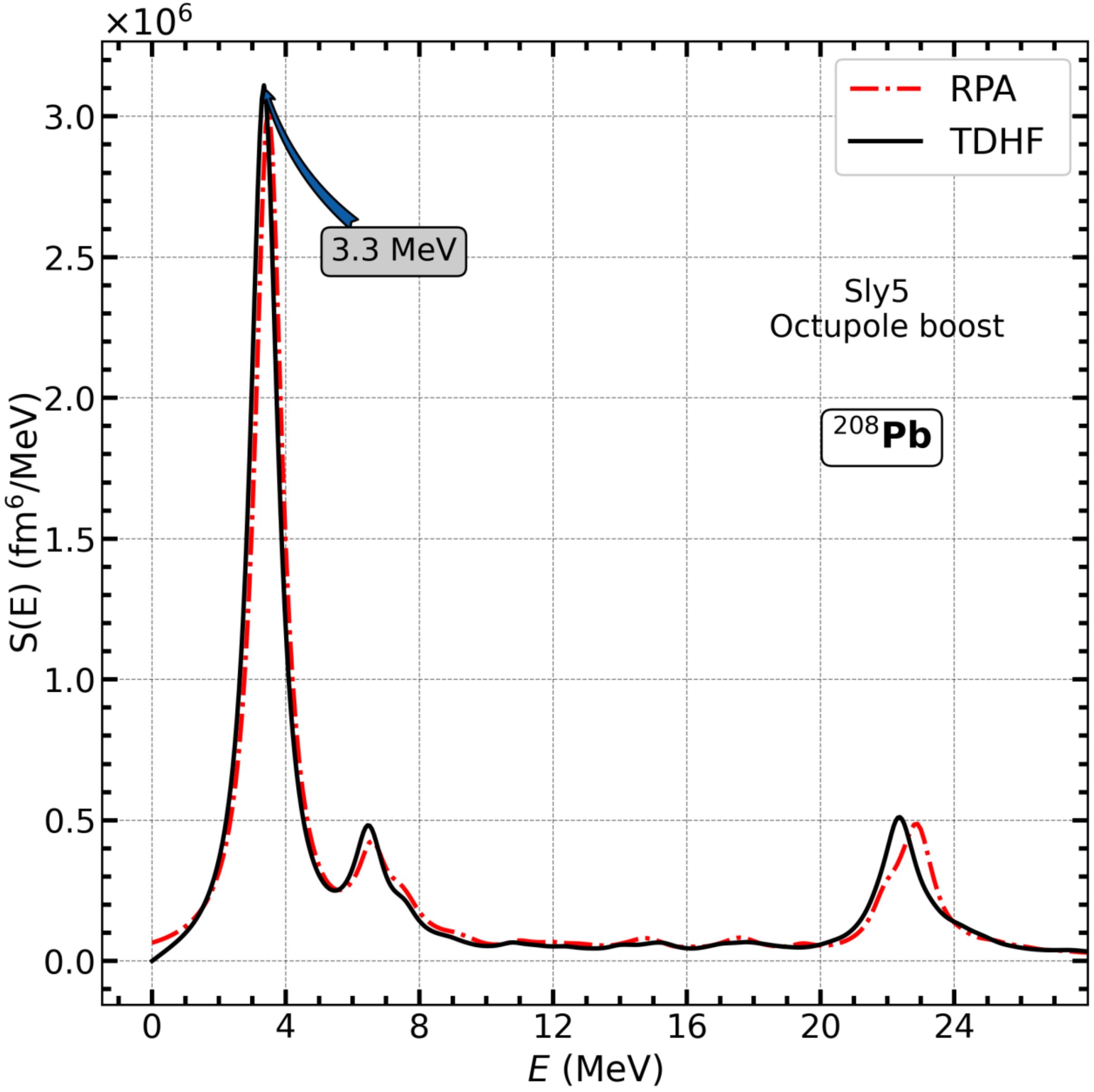
Sezione di Milano, Via Celoria 16, 20133 Milano, Italy.
(Dated: February 15, 2021)

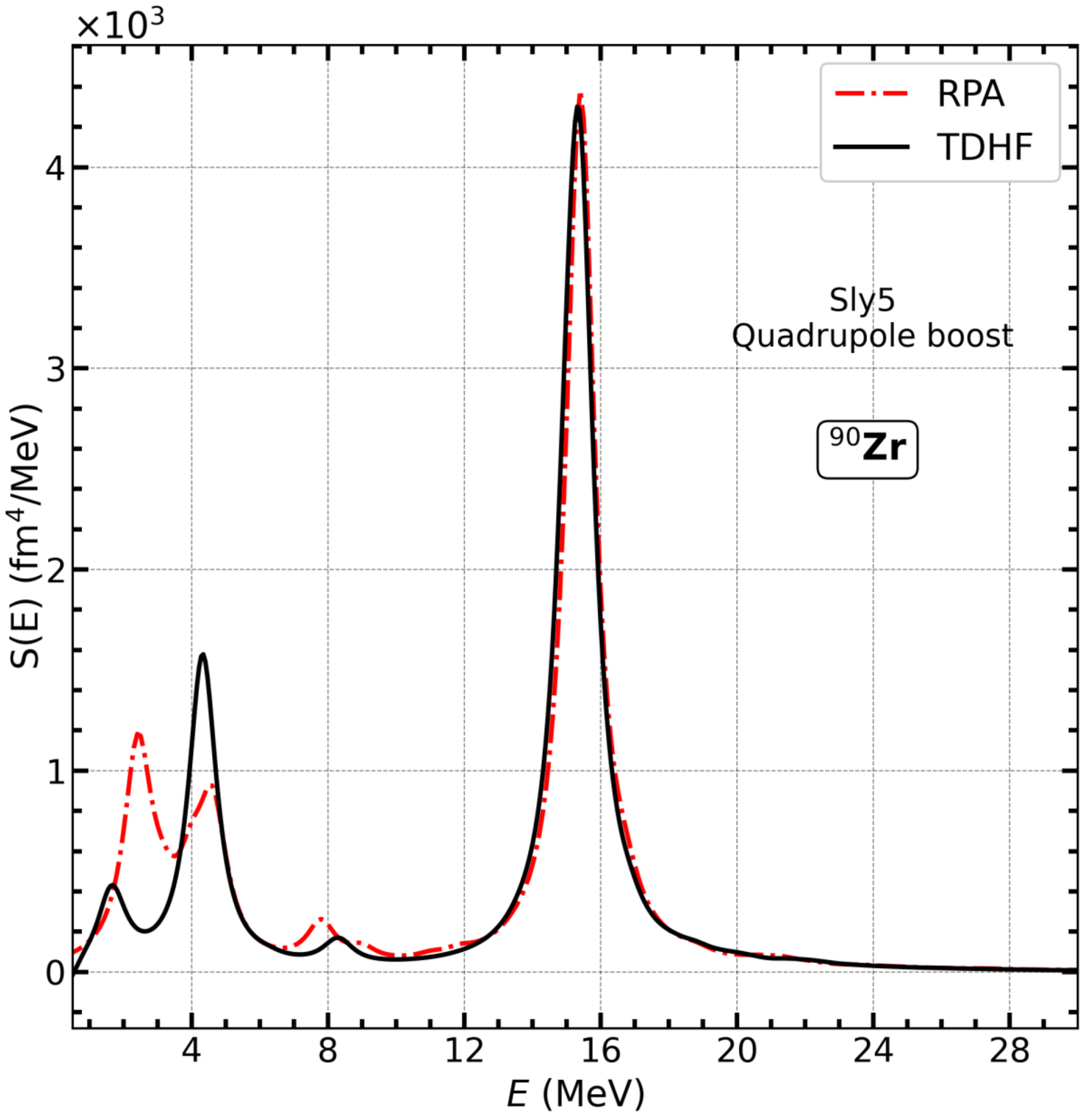
We briefly explain the structure of the Hartree-Fock-Bardeen-Cooper-Schrieffer (HFBCS) and Quasi-particle Random Phase Approximaiton (QRPA) code hfbcs-qrpa, highlighting only the differences with the code skyrme_rpa that has been previously published [1]. The code deals with open shell spherical systems and non-spin flip, non-charge-exchange and natural parity $(-1)^l$ excitations.



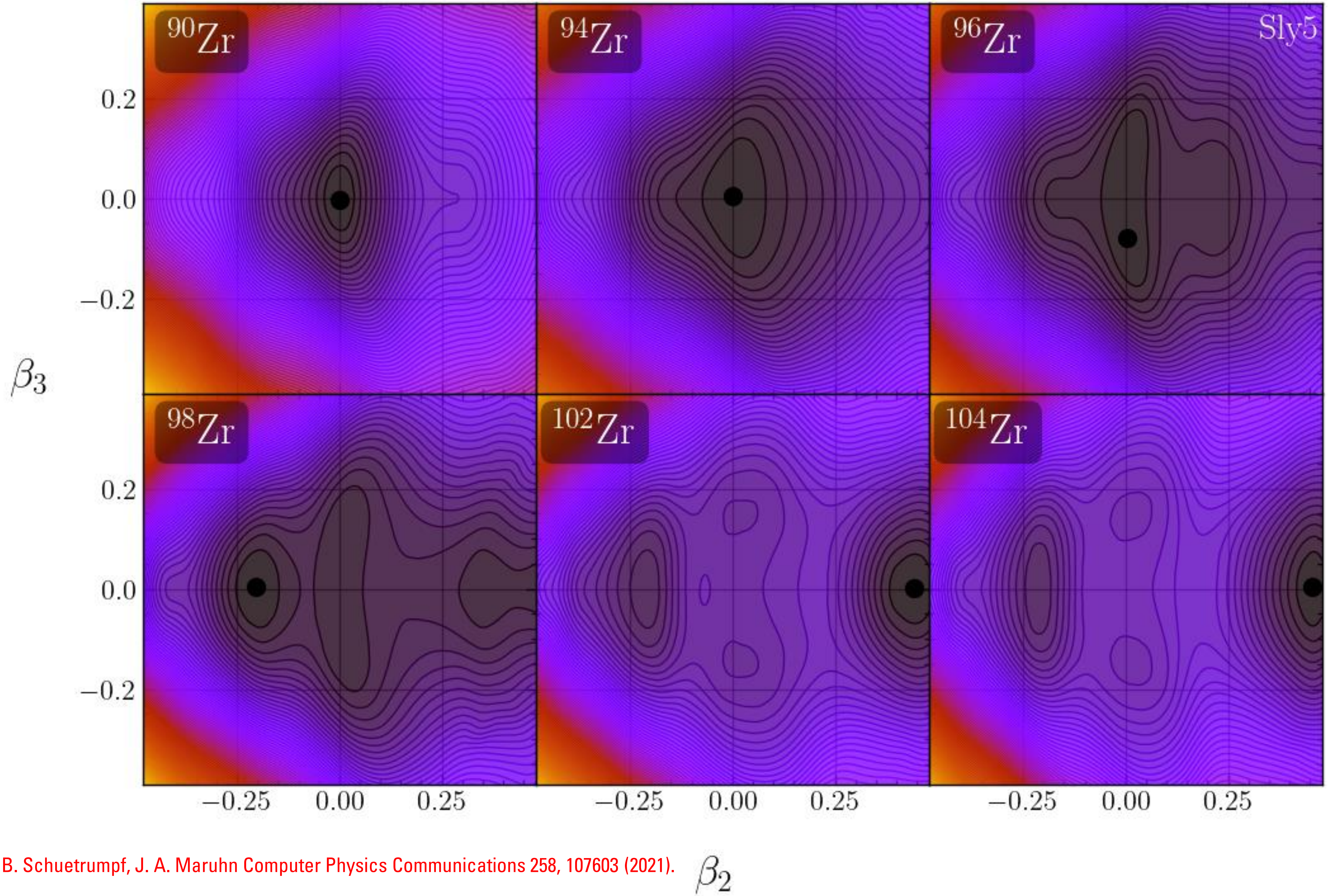


COMPARISON WITH QRPA

Zr

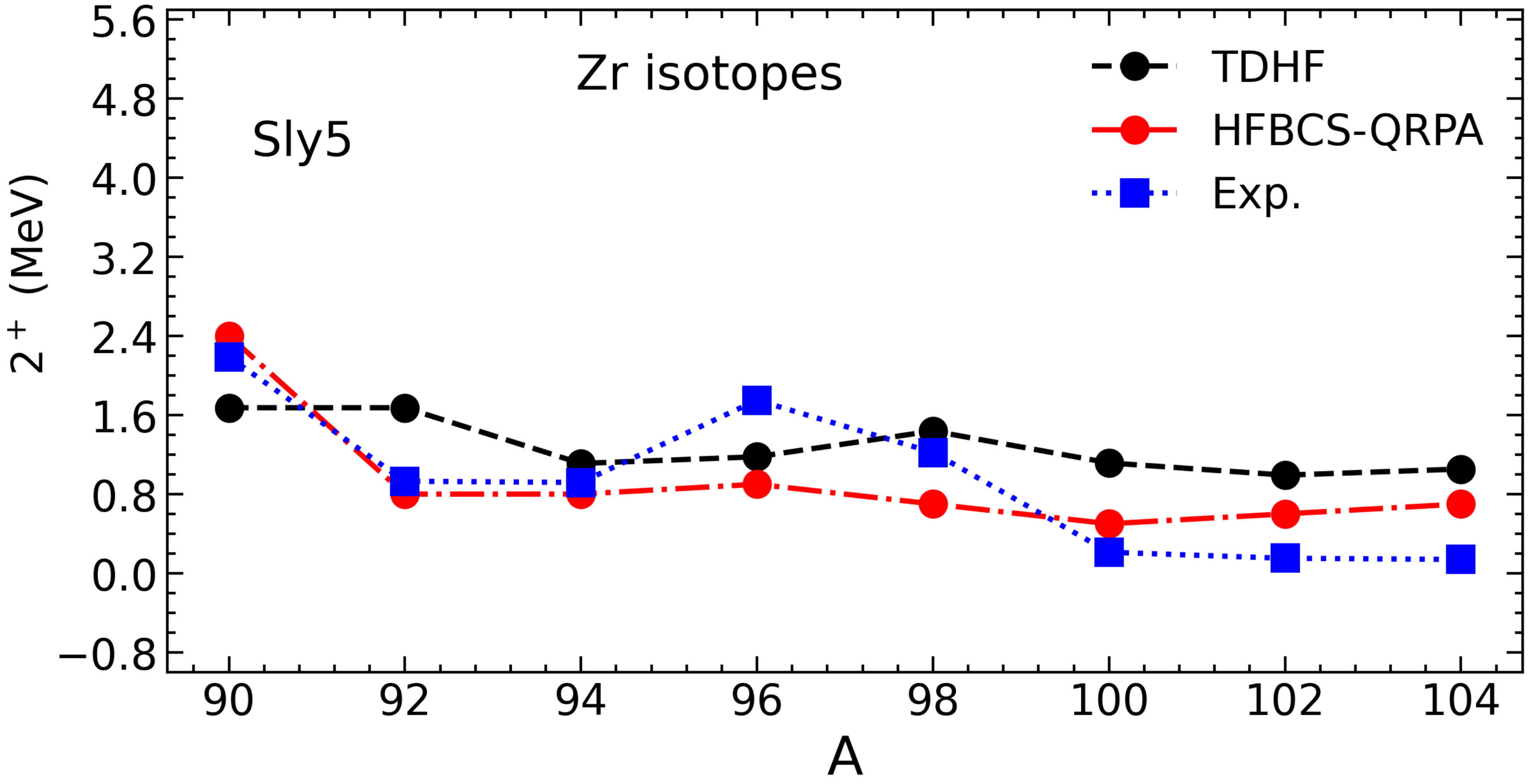


- Differences in lower energy peaks
- Experimental data available
- Comparison of first quadrupole and octupole energy peaks



P.-G. Reinhard, B. Schuetrumpf, J. A. Maruhn Computer Physics Communications 258, 107603 (2021).

ZR ISOTOPES



Zr isotopes
Sly5
TDHF
HFBCS-QRPA
Exp.
2⁺ (MeV)
A
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
−0.8
90
92
94
96
98
100
102
104

QRPA COLLAPSE

Octupole deformation instability in atomic nuclei

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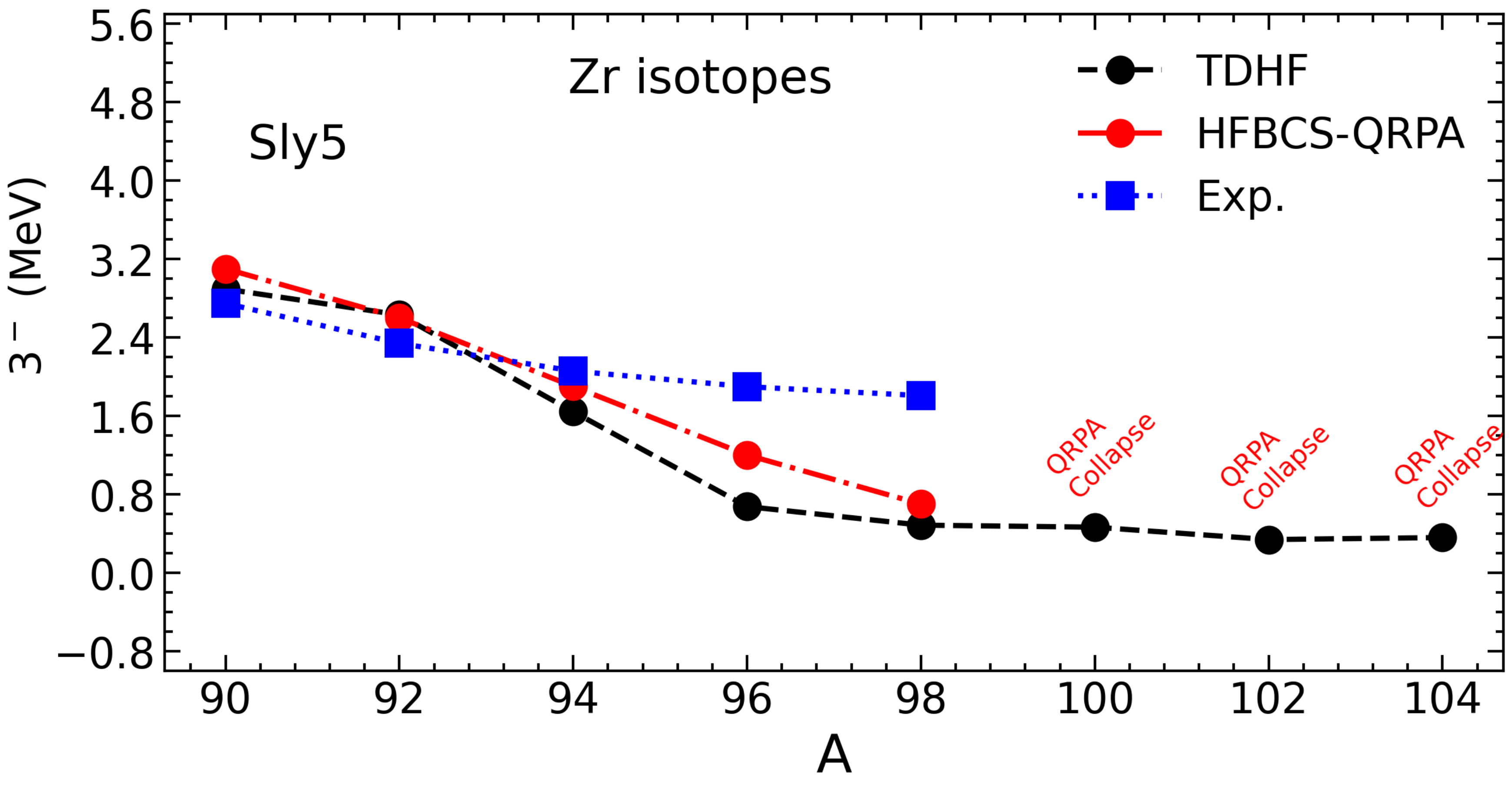
(Dated: March 21, 2023)

Recent high-energy heavy-ion collision experiments have revealed that some atomic nuclei exhibit unusual softness and significant shape fluctuations. In this Letter, we use the fully self-consistent mean-field theory to identify all even-even nuclei that are unstable or soft against octupole deformation. All exceptional cases of enhanced octupole transition strengths in stable even-even nuclei throughout the nuclide chart are resolved. These results represent a significant advance in our understanding of the underlying mechanisms of nuclear octupole deformation and have implications for further experimental and theoretical studies.

TABLE I. The HFBCS-QRPA result
contrast to the results of ^{96}Ru. The
and α are in MeV, W.u., and W.u./

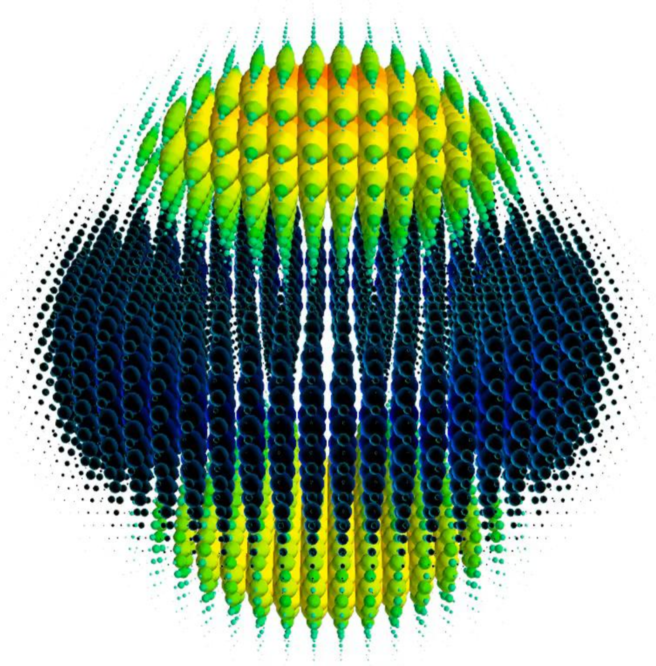
Force	^{96}Zr		
	$E(3_1^-)$	$B(E3)$	α
SIII	collapse		
SkM*	collapse		
SLy4	0.961	96.4	12.6
SLy5	1.698	51.9	4.0
Exp.	1.897	53	

ZR ISOTOPES



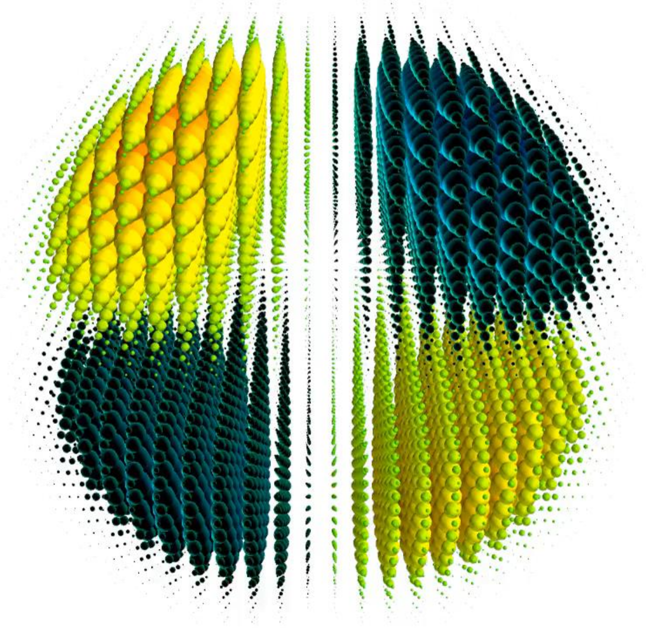
Zr isotopes
Sly5
TDHF
HFBCS-QRPA
Exp.
QRPA Collapse
QRPA Collapse
QRPA Collapse
3⁻ (MeV)
A
5.6
4.8
4.0
3.2
2.4
1.6
0.8
0.0
−0.8
90
92
94
96
98
100
102
104

PROBING ASYMMETRY (QUADRUPOLE)



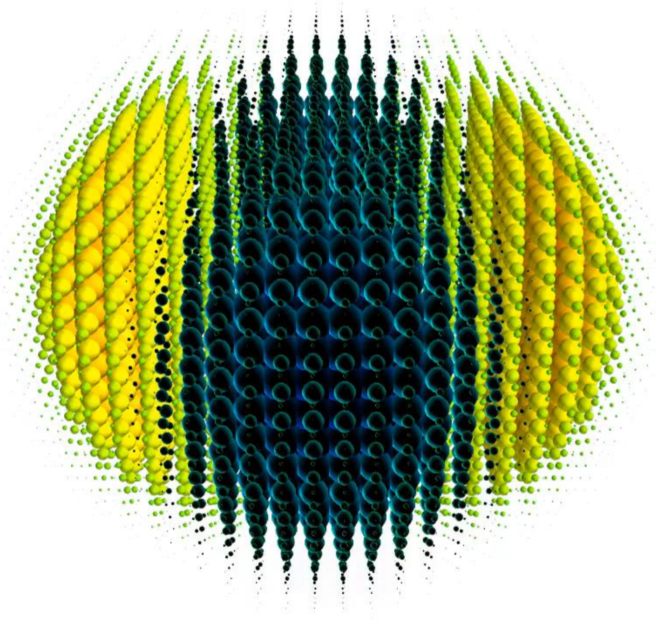
$r^2 Y_2^0$

K = 0



$r^2 Y_2^1$

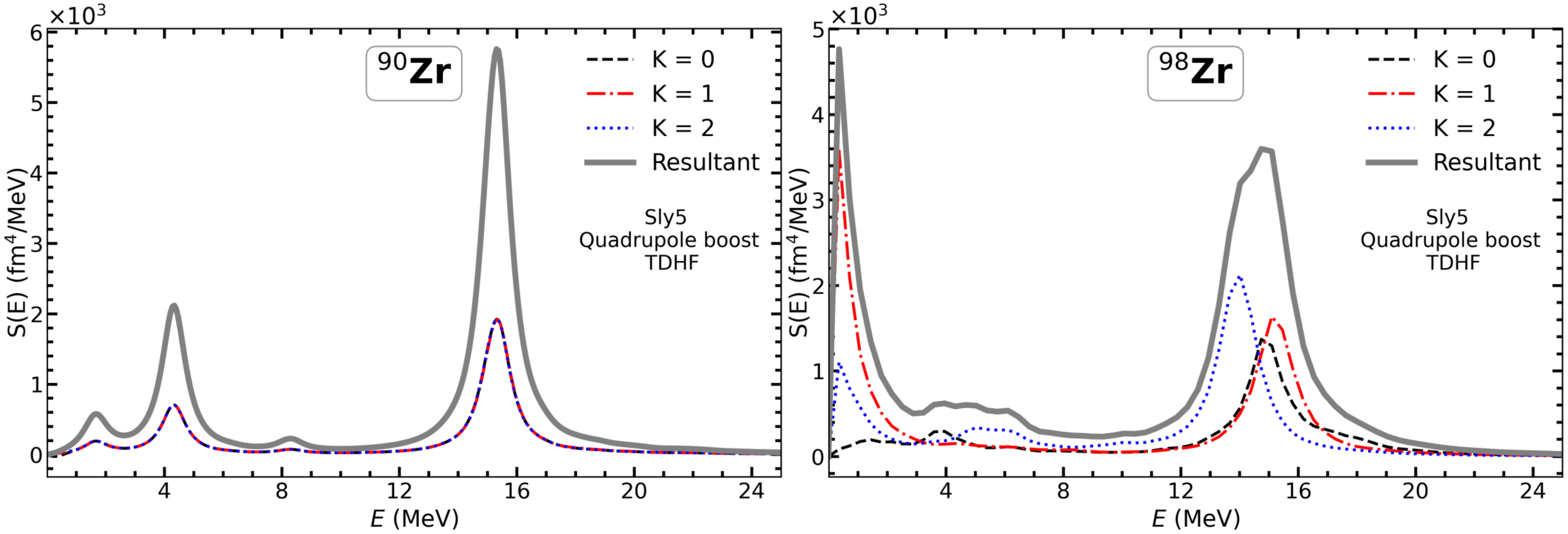
K = 1



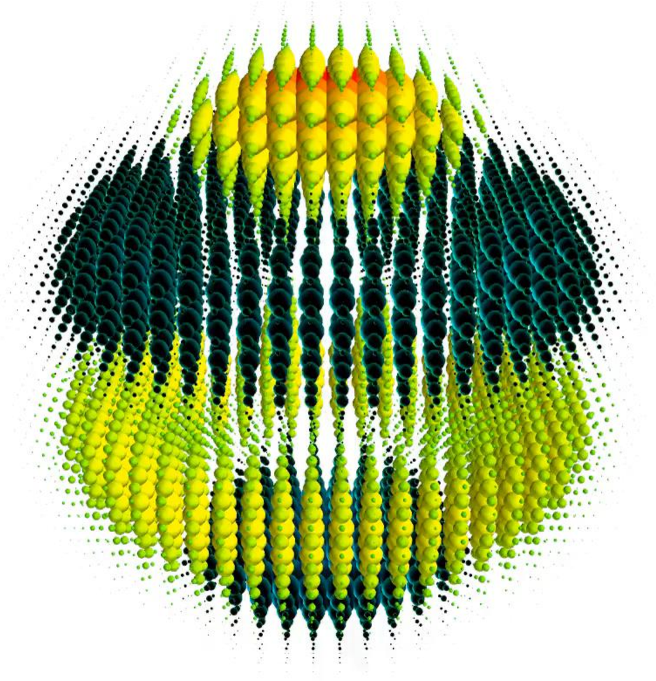
$r^2 Y_2^2$

K = 2

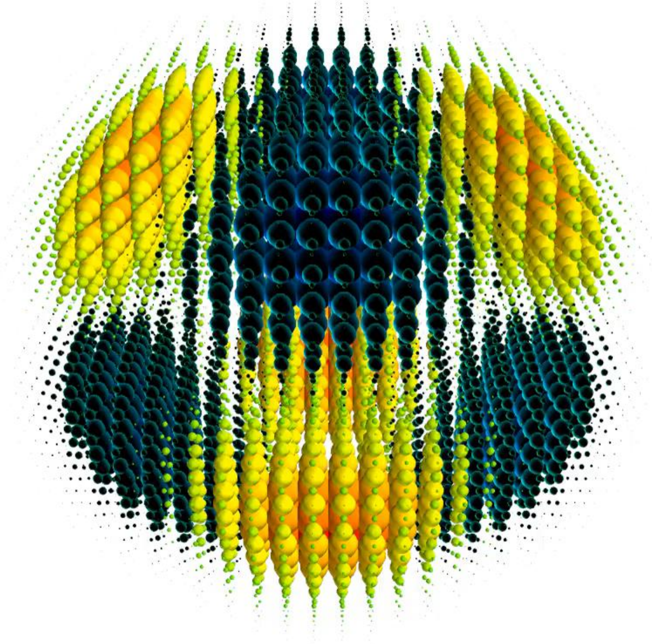
PROBING ASYMMETRY (QUADRUPOLE BOOST)



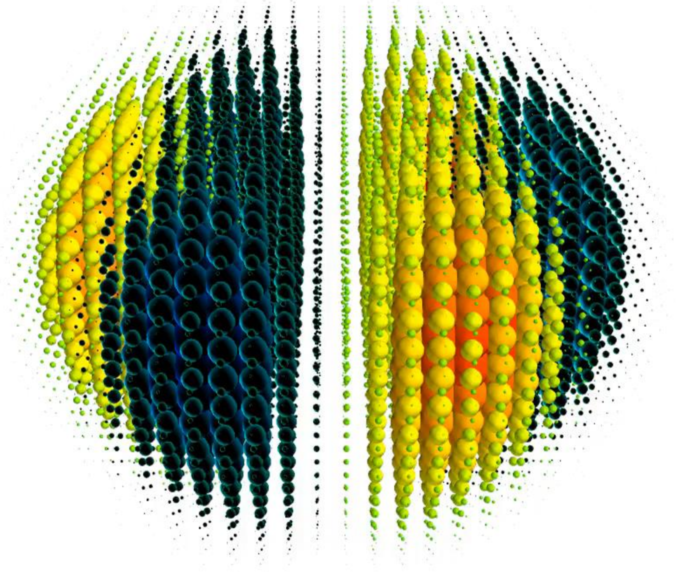
PROBING ASYMMETRY (OCTUPOLE)



$r^3 Y_3^0$
K = 0

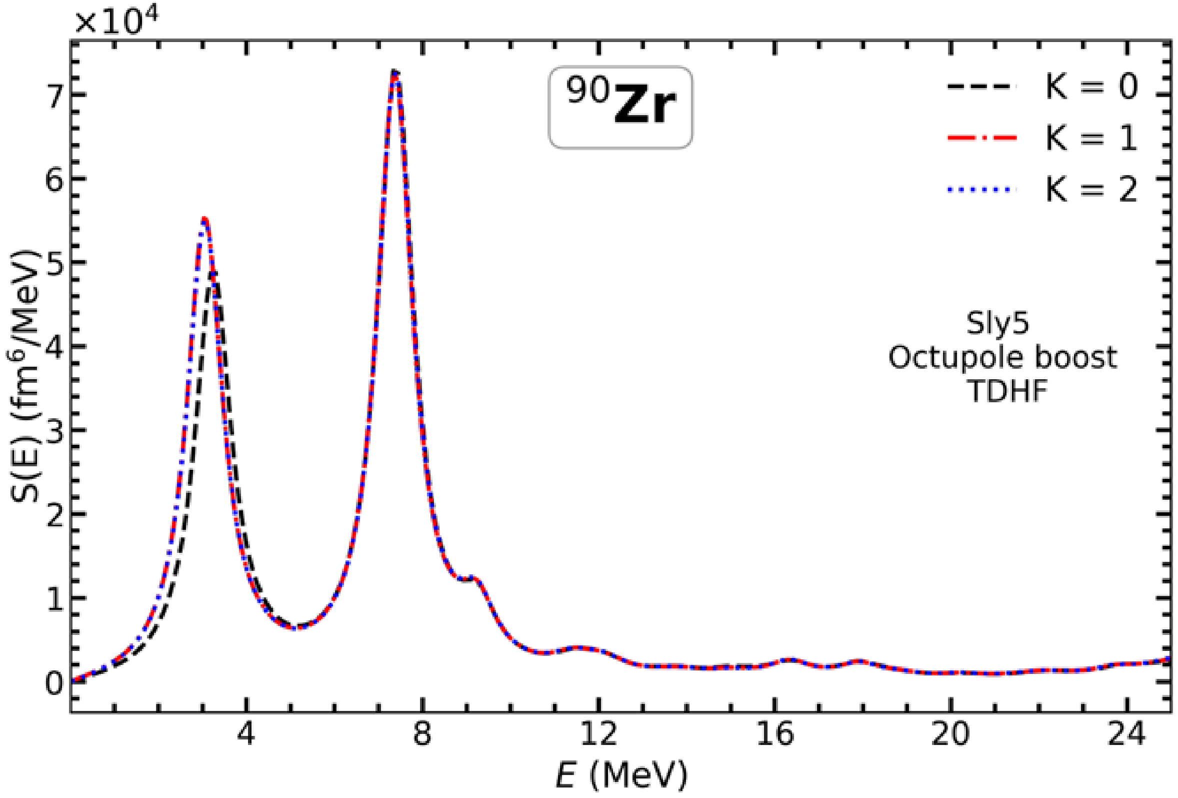


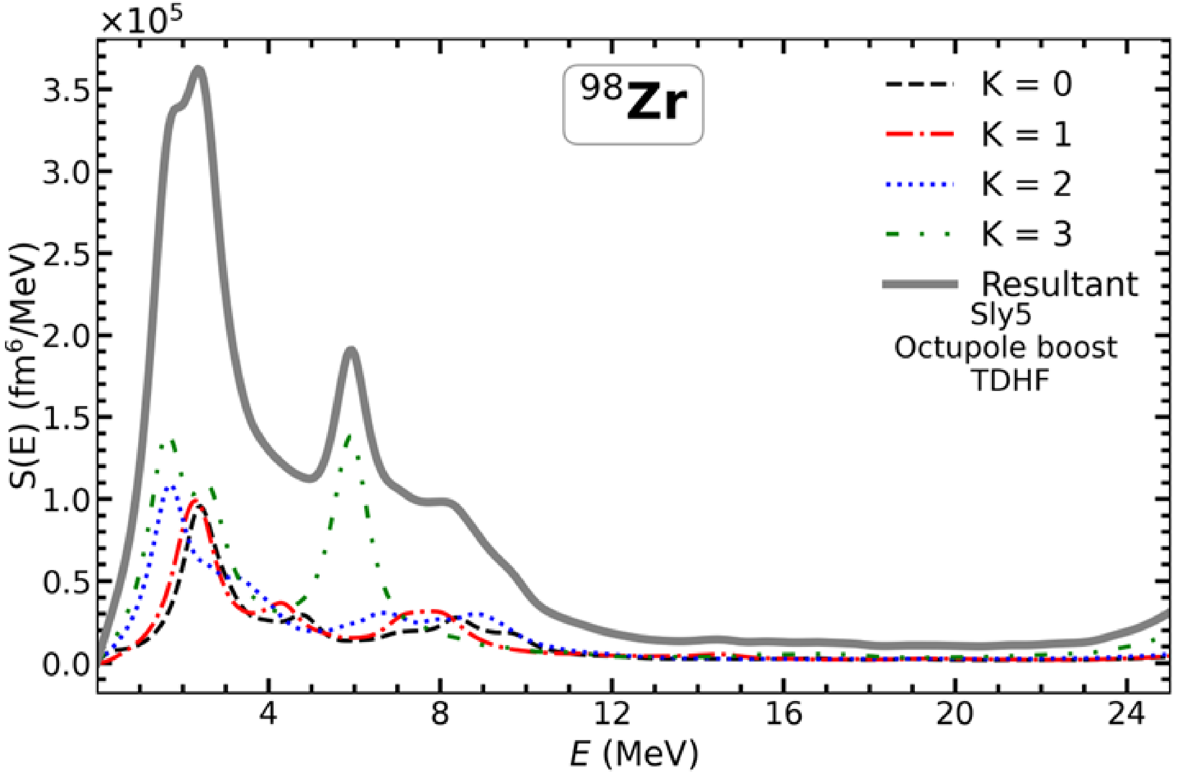
$r^3 Y_3^2$
K = 2



$r^3 Y_3^3$
K = 3

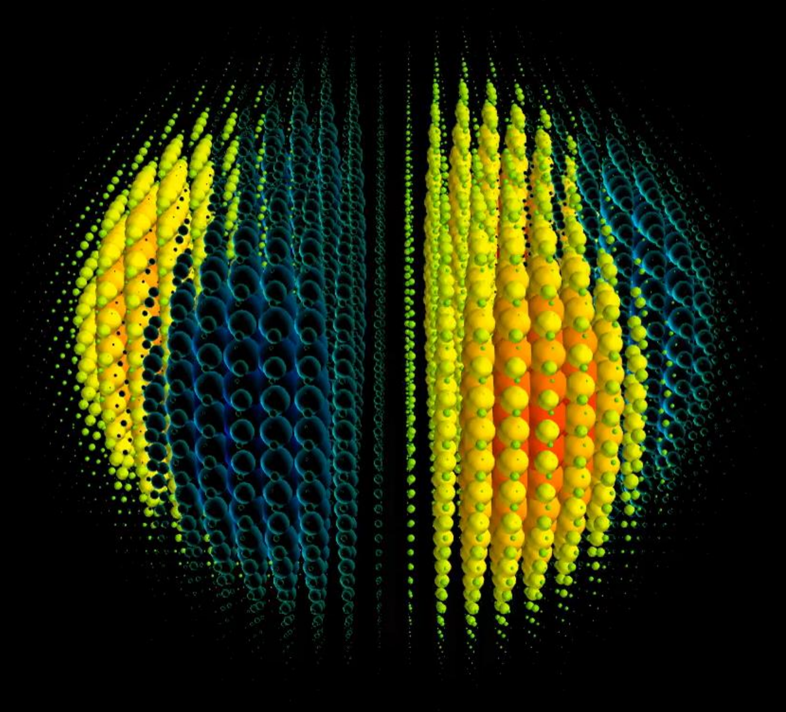
PROBING ASYMMETRY (OCTUPOLE BOOST)

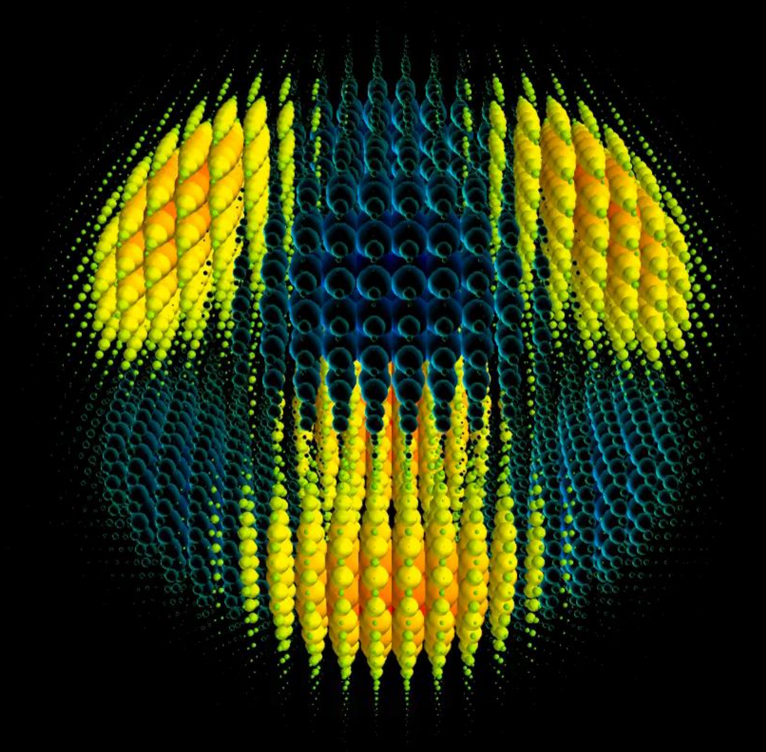




CONCLUSIONS

- Good Agreement within the two models in a doubly magic nucleus (Pb).
- Differences when there is softness along quadrupole and octupole degrees of freedom.
- TDHF can be a viable tool in extremely soft nuclei like Zr isotopes.
- Extreme softness leads to collapse of QRPA but not in TDHF.





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