The 7th International Workshop on DRHBc Mass Table
2024-07-03

G16: Progress Report $132 \leq Z \leq 136$

Peng Guo [1], Sibo Wang [2], Xin-Hui Wu [3]

（郭鹏） （王锶博） （吴鑫辉）

[1] School of Physics, Peking University
[2] Department of Physics, Chongqing University
[3] Department of Physics, Fuzhou University

Naming rule of unknown elements

In the 6th international Workshop on DRHBc Mass Table, calculations of nuclei with $Z > 120$ have been added to the schedule.

Group	Nuclear region	Team	Principal investigator	Email
G-12*	Z = 121 to Z = 123	BNU	Jing Peng	jpeng@bnu.edu.cn
		NCEPU	Zhenhua Zhang Yuanyuan Wang	zhzhang@ncepu.edu.cn yywang1021@ncepu.edu.cn
		INPC, CAEP	Kaiyuan Zhang	zhangky@pku.edu.cn
G-13*	Z = 124 to Z = 126	JNU	Lang Liu	liulang@jiangnan.edu.cn
		AHNU	Cong Pan	cpan@ahnu.edu.cn
G-14*	Z = 127 to Z = 128	CIAE	Yingxun Zhang Zhanjiang Lian	zhyx@ciae.ac.cn lian180821@163.com
		ITP-CAS	Xiao Lu	luxiao@itp.ac.cn
G-15*	Z = 129 to Z = 131	HKU	To Chung Martin Yiu	yiutc@connect.hku.hk
		UTokyo	Haozhao Liang	hzliang@g.ecc.u-tokyo.ac.jp
		JLU	Jian Li	jianli@jlu.edu.cn
G-16*	Z = 132 to Z = 136	PKU	Peng Guo	2301110125@pku.edu.cn
		CQU	Sibo Wang	sbwang@cqu.edu.cn
		FZU	Xinhui Wu	wuxinhui@fzu.edu.cn

Summary of the 6th International Workshop on DRHBc Mass Table

- These unknown elements do not have official names yet.

Naming rule of unknown elements

Temporary naming rule for unknown elements with $101 \leq Z \leq 999$.

Recommended by the International Union of Pure and Applied Chemistry

1. The name is derived directly from the atomic number of the element using the following numerical roots:

0 = nil	3 = tri	6 = hex	9 = enn
1 = un	4 = quad	7 = sept	
2 = bi	5 = pent	8 = oct	

2. The roots are put together in the order of the digits which make up the atomic number and terminated by 'ium' to spell out the name. The final 'n' of 'enn' is elided when it occurs before 'nil', and the final 'i' of 'bi' and of 'tri' when it occurs before 'ium'.

3. The symbol of the element is composed of the initial letters of the numerical roots which make up the name.

4. The root 'un' is pronounced with a long 'u', to rhyme with 'moon'. In the element names each root is to be pronounced separately.

J. Chatt, Recommendations for the Naming of Elements of Atomic Numbers Greater than 100, Pure and Applied Chemistry, 51, 381 (1979)

Naming rule of unknown elements

Naming rule for the unknown elements with $101 \leq Z \leq 999$.

Digit	Root
0	nil
1	un
2	bi
3	tri
4	quad
5	pent
6	hex
7	sept
8	oct
9	enn

Naming Rule:

Atomic number: 100*a + 10*b + 1*c

a, b, c ∈ (0, 1, 2, … ,9)

Naming: root(a)+root(b)+root(c) + ium

Example for Z=136:

Atomic number: 1 3 6

Un tri hex ium

Naming: Untrihexium (Uth)

Z	132	133	134	135	136
Name	Untribium	Untritrium	Untriquadium	Untripentium	Untrihexium
abbr.	Utb	Utt	Utq	Utp	Uth

Progress Report $132 \leq Z \leq 136$

Numerical detail

Numerical detail for $101 \leq Z \leq 136$

- Code Version: Code_DRHBc_202401
- Box size: R_{box} = 20 fm
- Mesh size: Δr = 0.1 fm
- Energy cutoff: E_{cut} = 300 MeV
- Angular momentum cutoff: $J_{max} = 23/2\ \hbar$
- Legendre expansion order: λ_{max} = 10
- Relativistic density functional: PC-PK1
- Pairing strength: -325 MeV fm^3
- Blocking treatment: Automatic

DRHBc Mass Table Collaboration, Phys. Rev. C 106, 014316 (2022)
Suggested in the 58^{th} Skype meeting

Uth (Z = 136) isotopes

- ^{400}Uth as an example

Determining the ground state

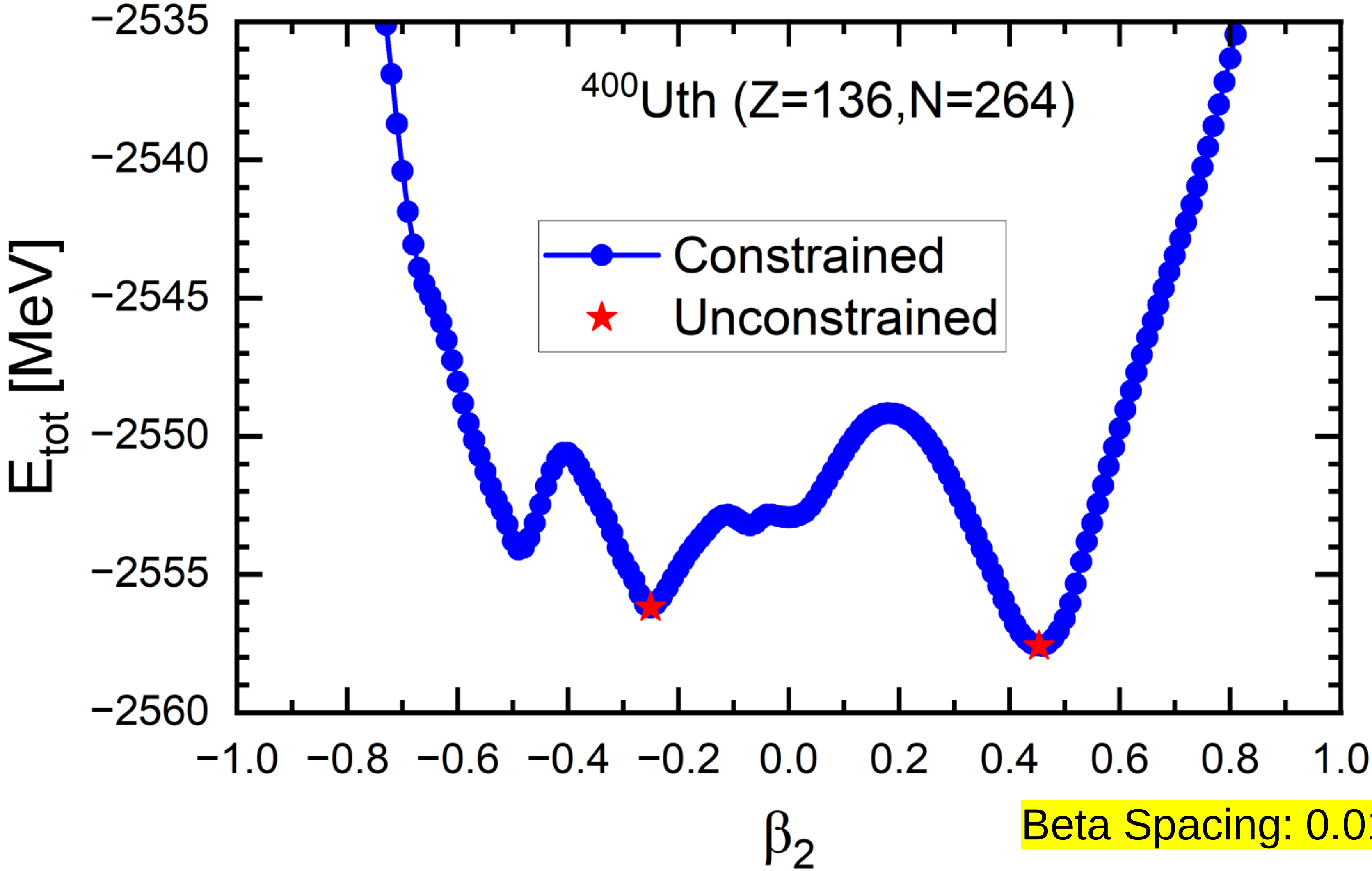
Results from different initial β_2 (unconstrained calculations)

Initial beta	E_{totcm} [MeV]	beta	steps	si
-0.4	-2556.195909	-0.250496	73	0.000085
-0.2	-2556.196121	-0.250495	71	0.000054
0.0	-2552.932569	0.000000	55	0.000036
0.2	-2552.299550	0.204900	101	1.027883
0.4	-2557.587229	0.453673	70	0.000080
0.6	-2557.587201	0.453675	69	0.000087

- Ground state is determined to be $\beta_2 = 0.4537, E_{\mathrm{totcm}} = -2557.587$ MeV

Determining the ground state

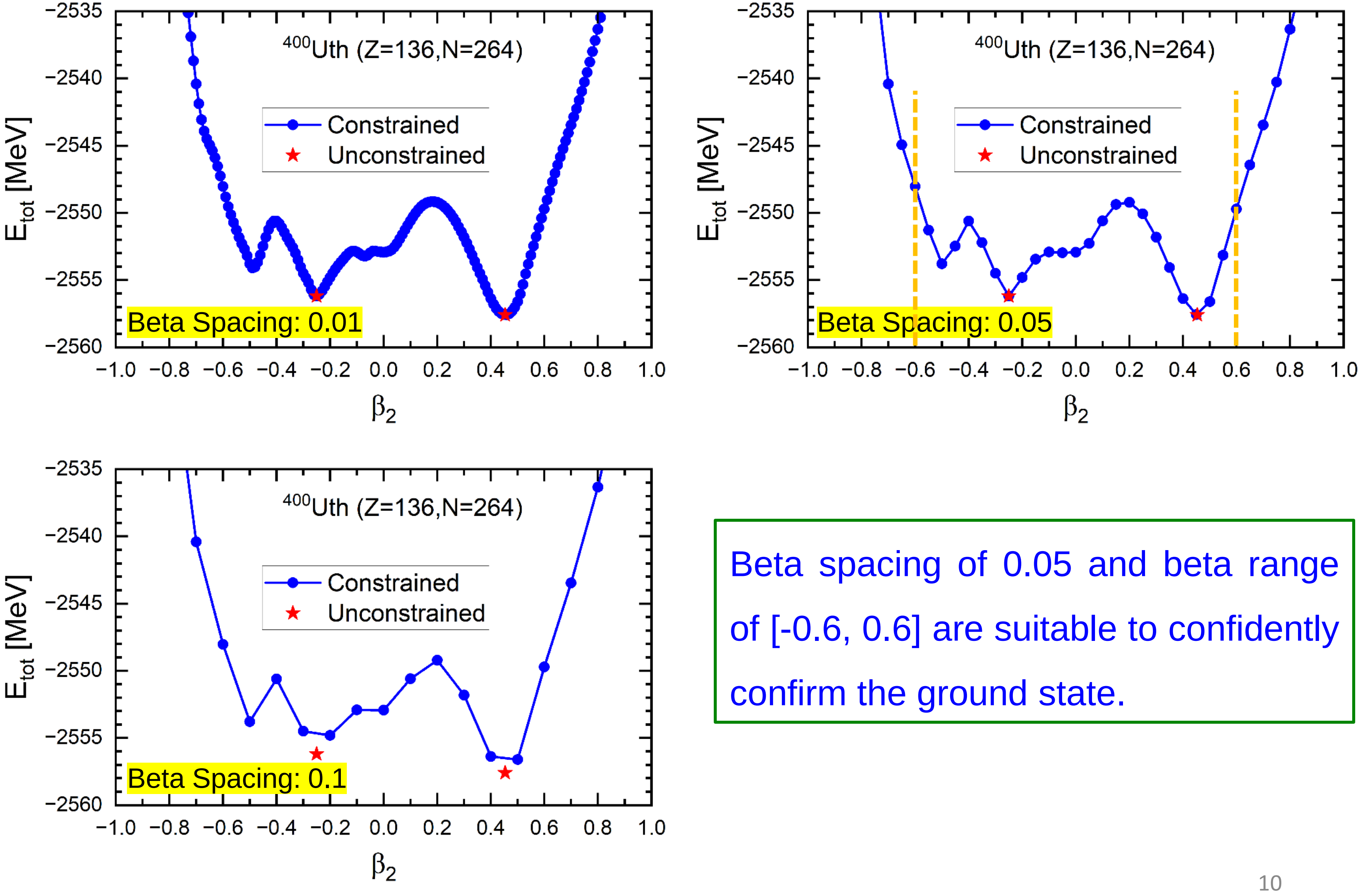
Potential energy curve (constrained calculations)



Beta Spacing: 0.01

- PEC confirms the determining ground state.

Beta spacing and range



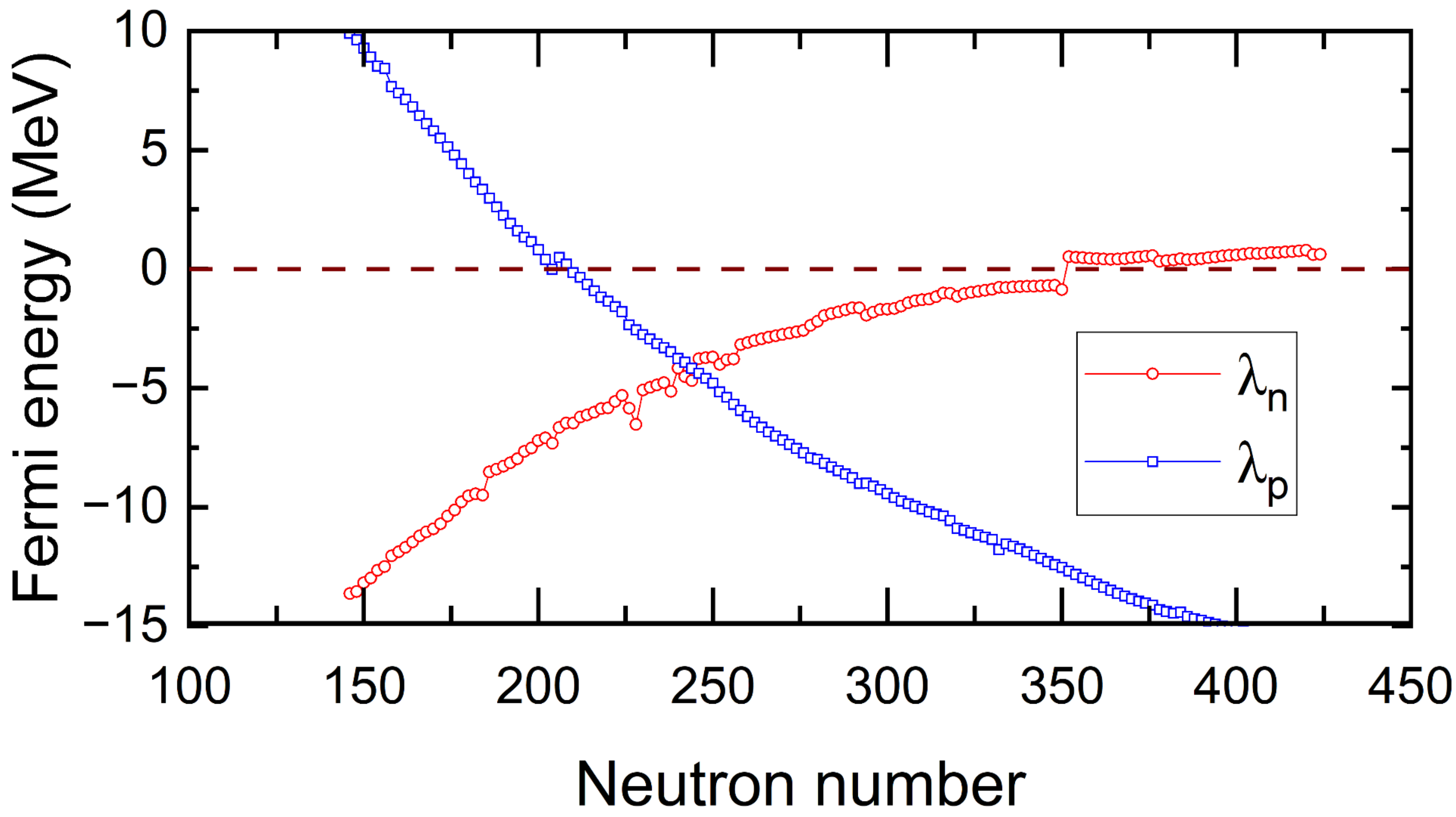
Beta spacing of 0.05 and beta range of [-0.6, 0.6] are suitable to confidently confirm the ground state.

Uth (Z = 136) isotopes

- Even-even nuclei

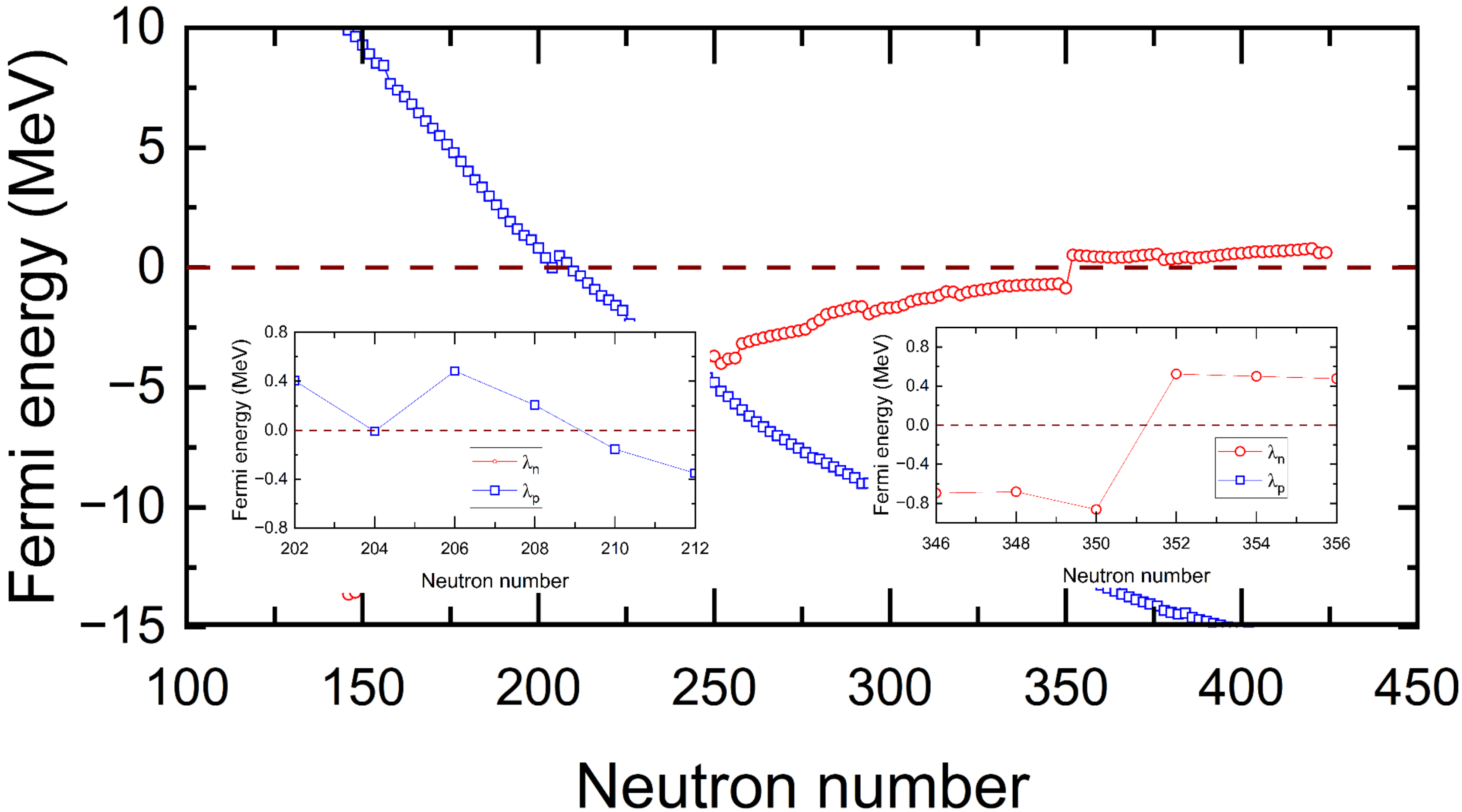
Fermi energy

- λ_n and λ_p to determine the range of bound nuclei



Fermi energy

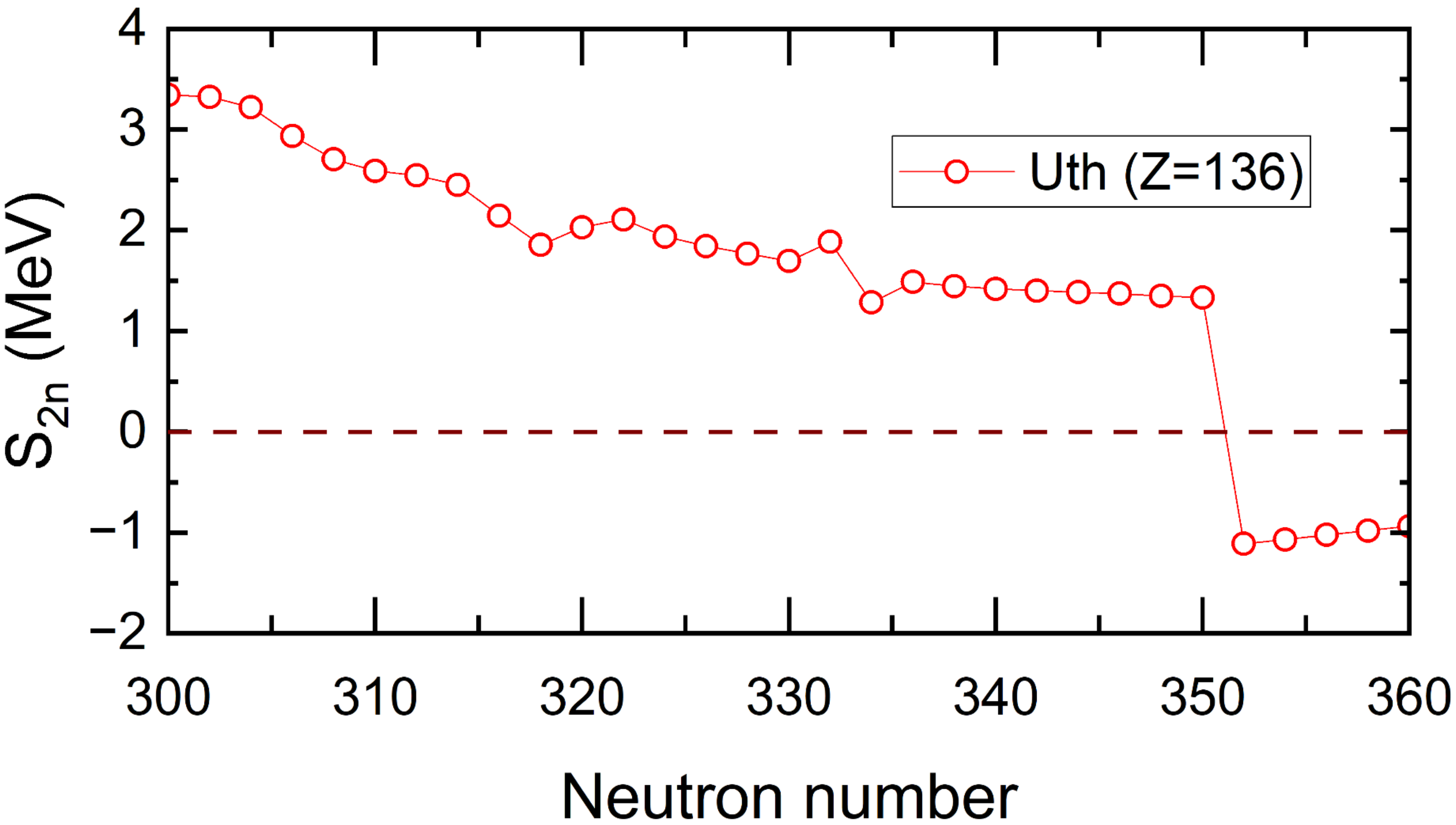
λ_n and λ_p to determine the range of bound nuclei



- The bound range determined by $\lambda_{n/p}$ is $204 \leq N \leq 350$

Separation energy

S_{2n} to determine the neutron drip nucleus



- The neutron-rich boundary determined by S_{2n} is $N = 350$

Uth: $204 \leq N \leq 350$

Progress of G-16

			calculate	analyze
Peng Guo	Utb Z = 132	even N		
		odd N		
	Utt Z = 133	even N		
		odd N		
Sibo Wang	Utq Z = 134	even N		
		odd N		
	Utp Z = 135	even N		
		odd N		
Xin-Hui Wu	Uth Z = 136	even N		
		odd N		

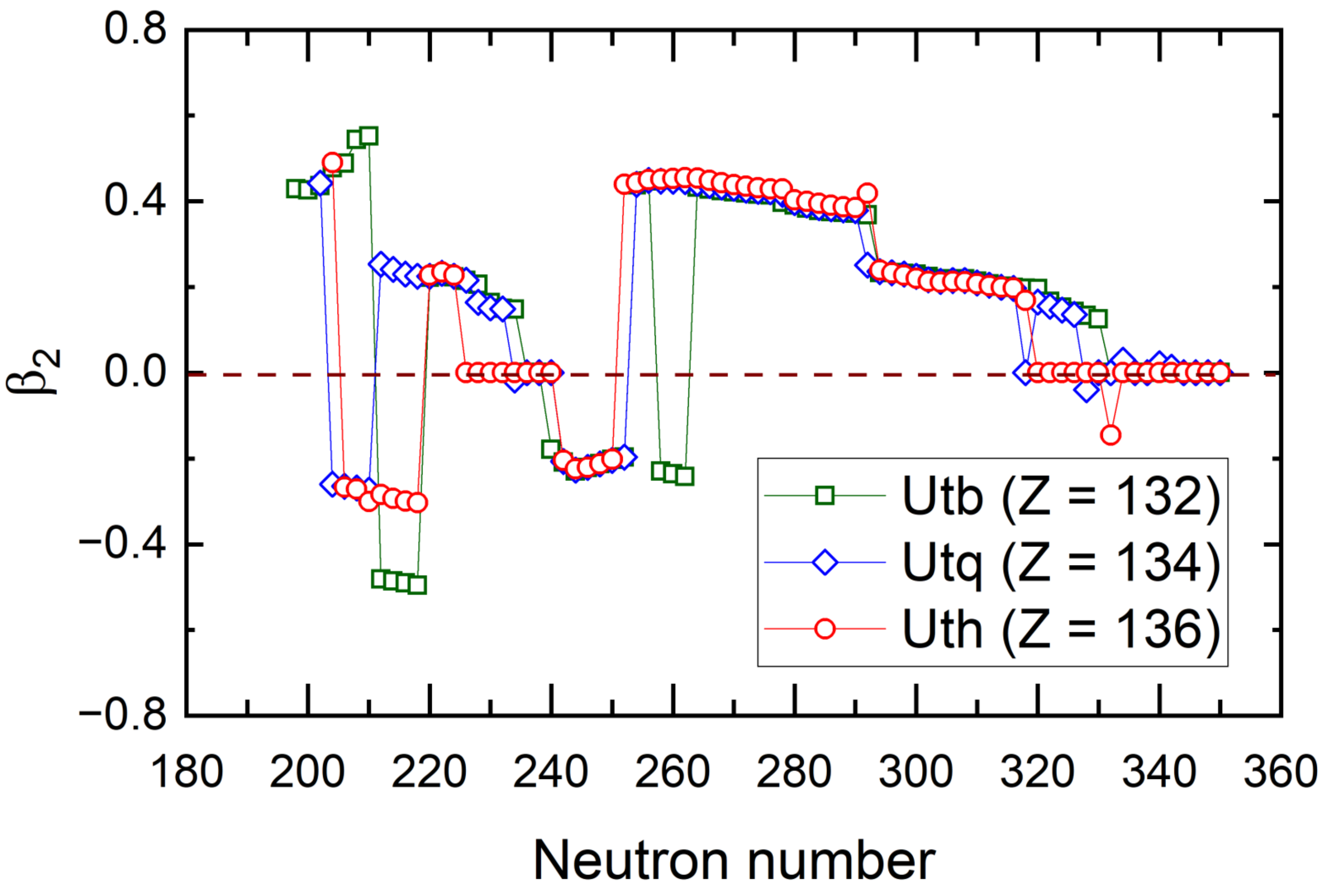
Even-even nuclei √

Results of even-even nuclei

- Z = 132, 134, 136

Quadrupole deformation

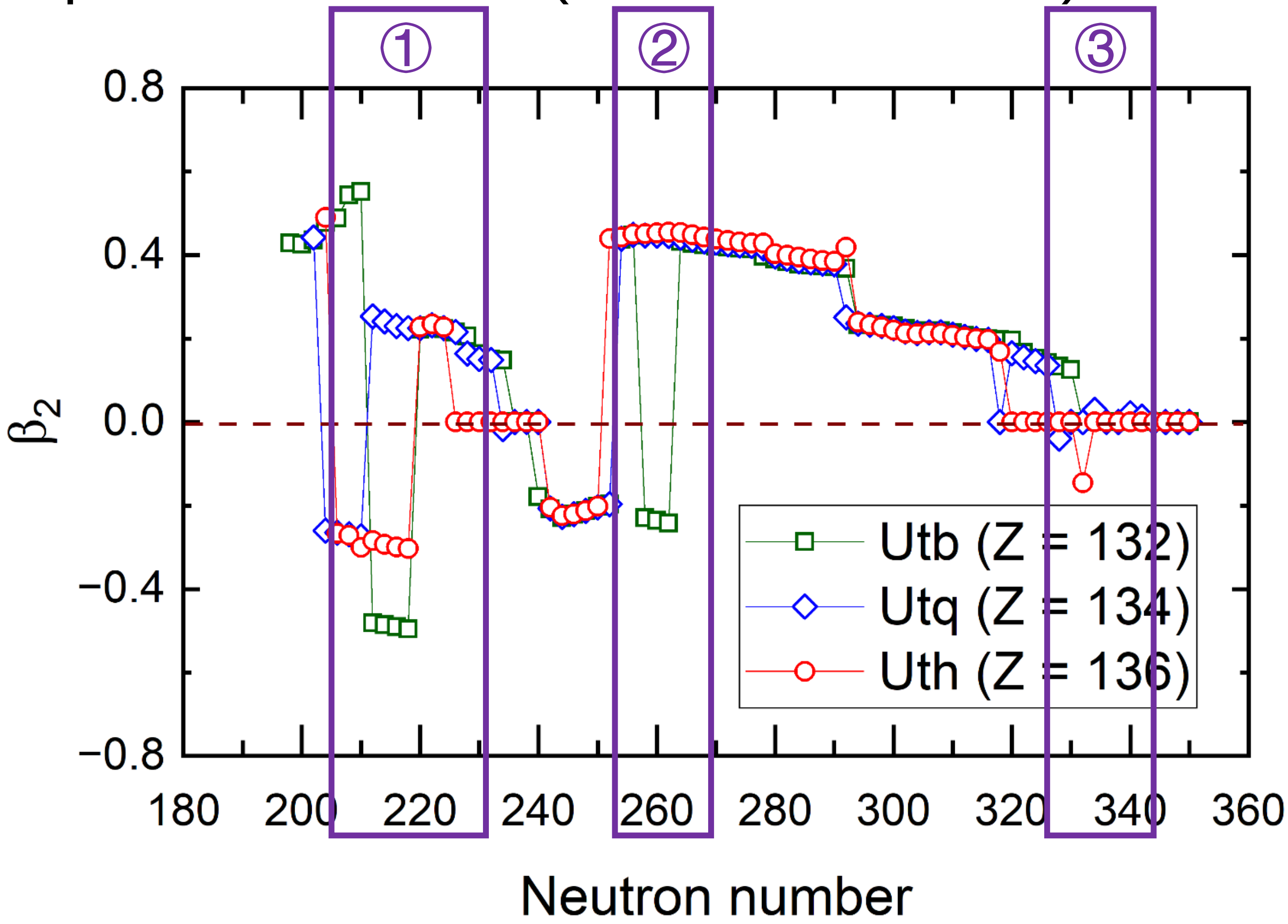
Quadrupole deformation (Z = 132, 134, 136)



- Similar mostly
- Different in several regions

Quadrupole deformation

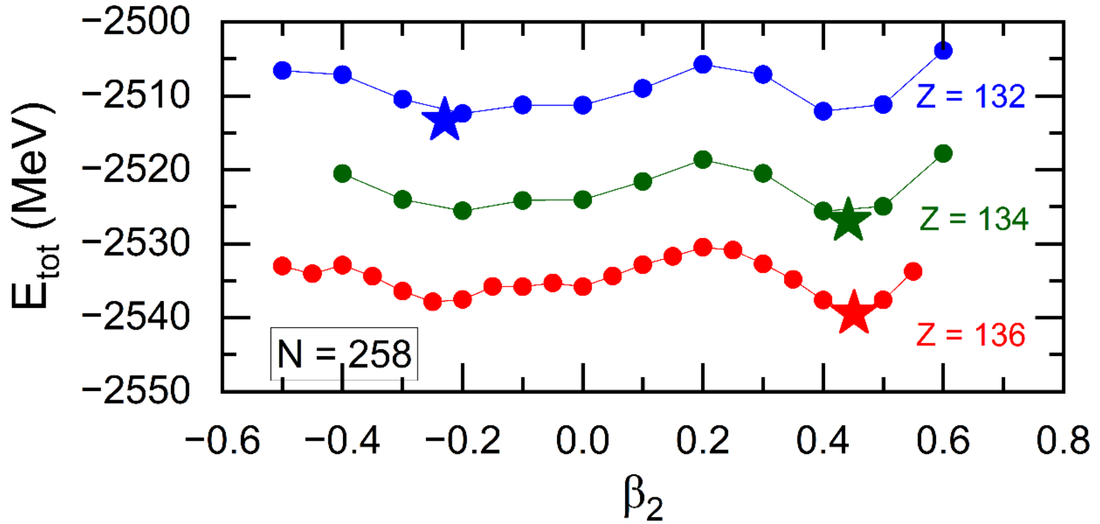
Quadrupole deformation (Z = 132, 134, 136)



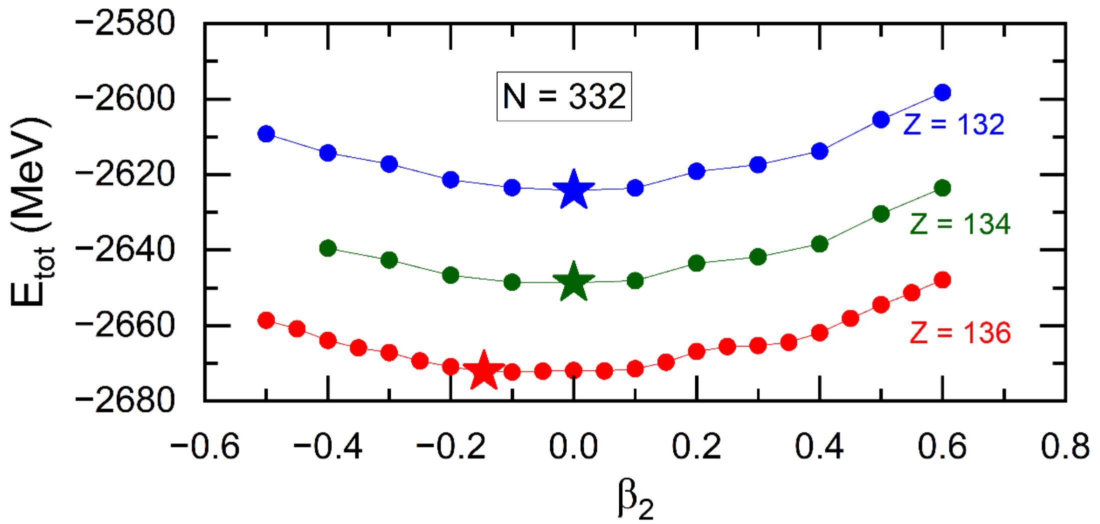
- Behaviors around ① and ② are caused by the competition of prolate and oblate deformations. (Further check is required)
- Behaviors around ③ are caused by the softness of PEC around $\beta = 0$.

Quadrupole deformation

- Competition of prolate and oblate deformations (①②)



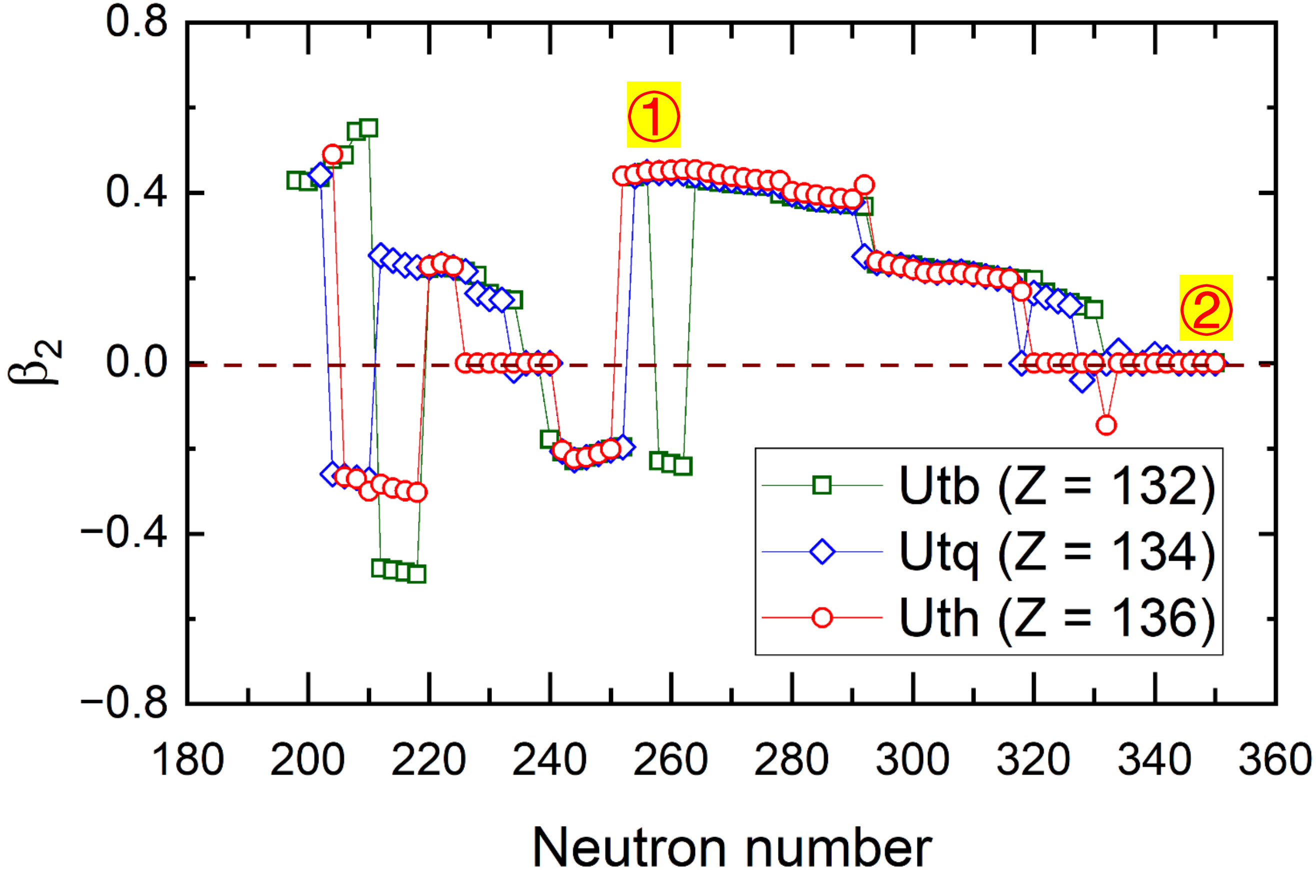
- Softness of PEC around $\beta = 0$ (③)



Quadrupole deformation

Two interesting points

Also in C. Pan's talk (G13)

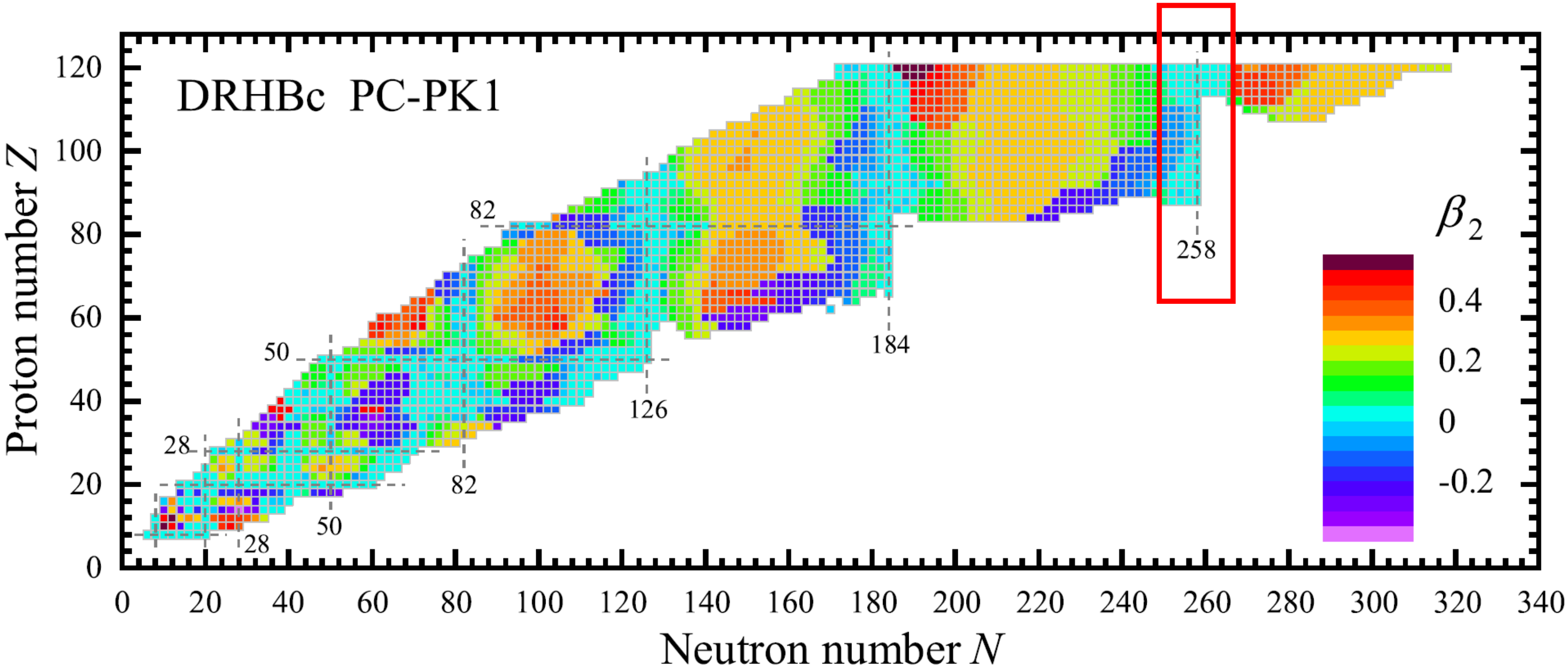


①: Nuclei around N = 258 are not spherical, different with $Z \leq 120$.

②: Drip line locates at N = 350, and nuclei around are spherical.

① Magic number N = 258 ?

N = 258 is predicted as a magic number by the DRHBc calculations for $Z \leq 120$.

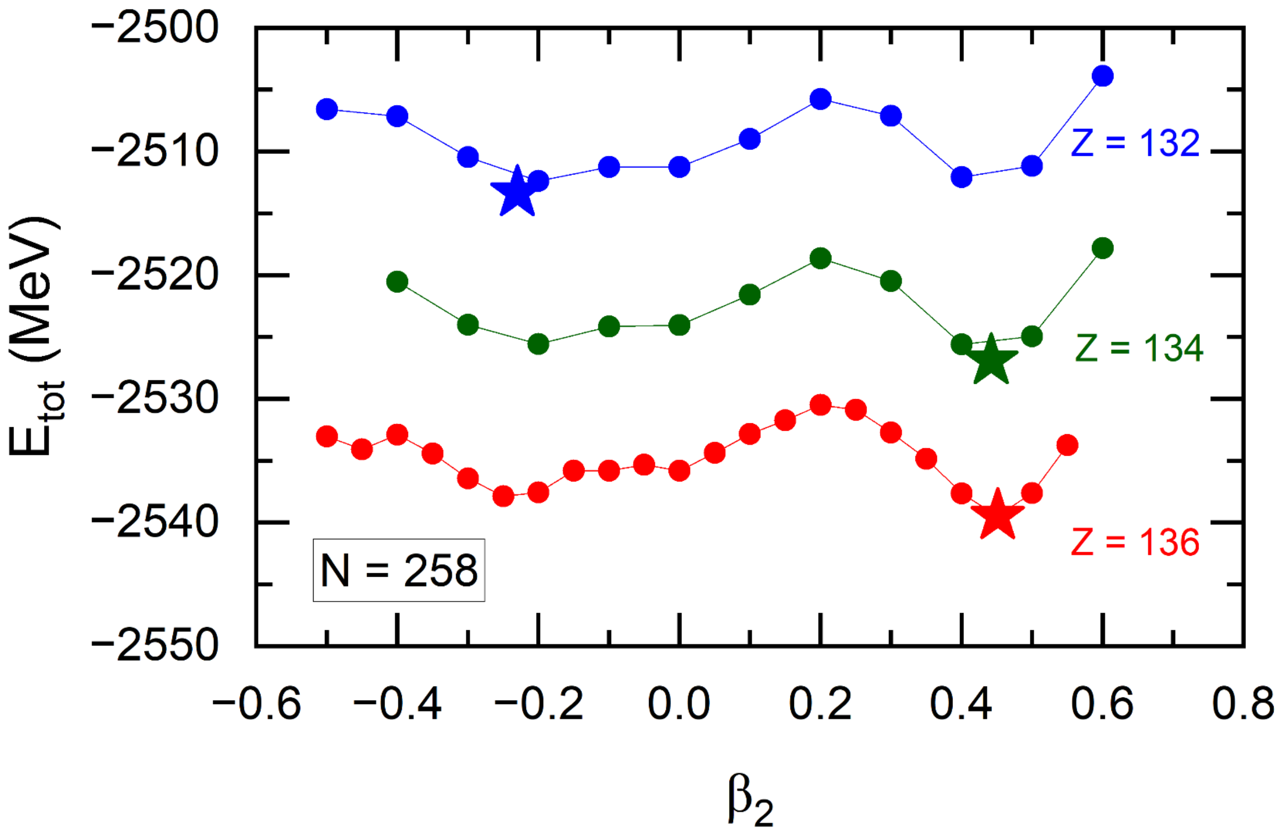


K. Y. Zhang et al., (DRHBc Mass Table Collaboration), Atom. Data Nucl. Data Tables 144, 101488 (2022)

- Nuclei around N = 258 are spherical nuclei (for $Z \leq 120$).

① Magic number N = 258 ?

Nuclei with N=258 and Z=132, 134, 136 are not spherical.

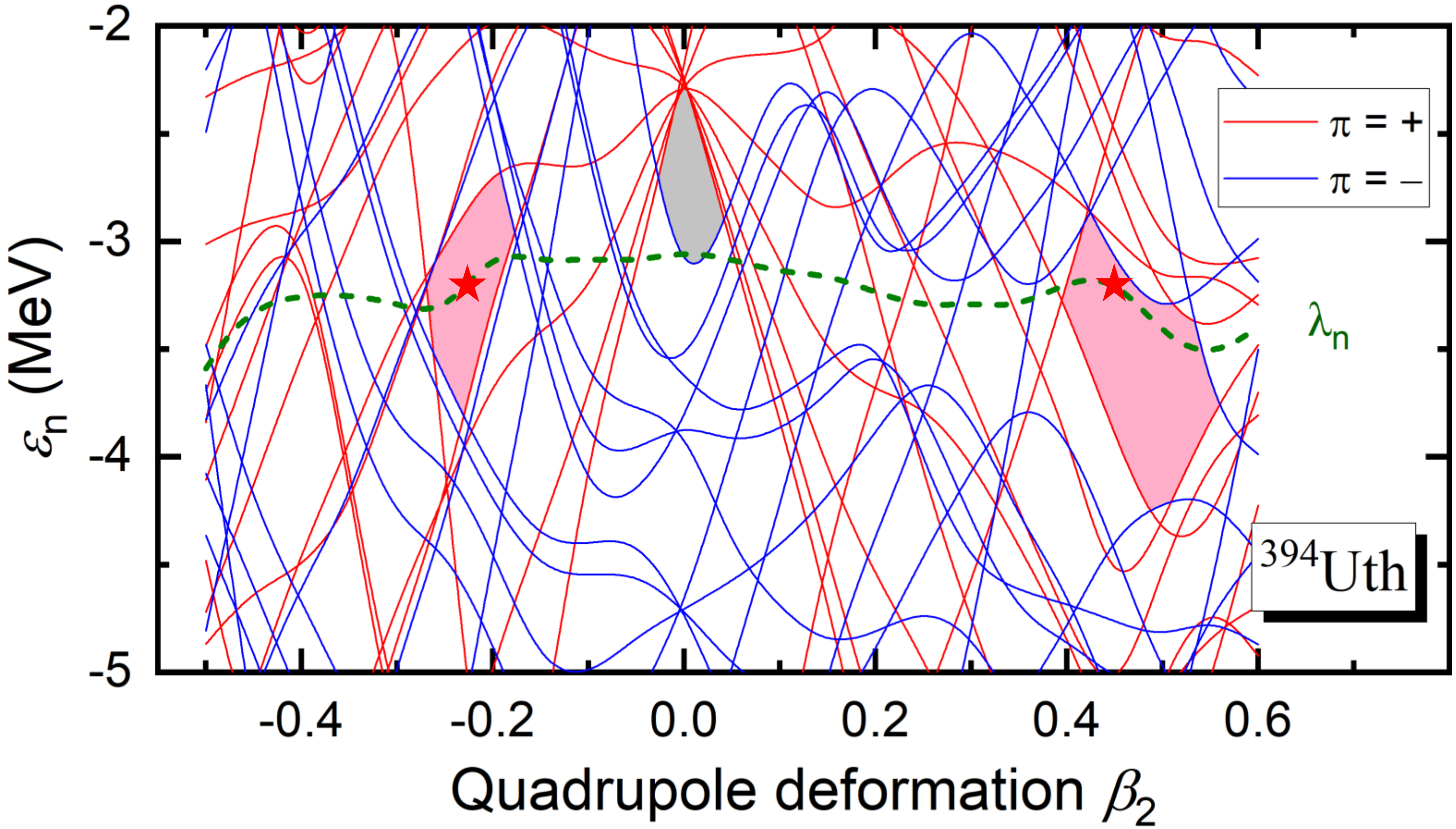


- The minima with prolate and oblate deformations are superior in energy than the spherical case.

Whether neutron magic number $N = 258$ exist in superheavy region or not?

① Magic number N = 258 ?

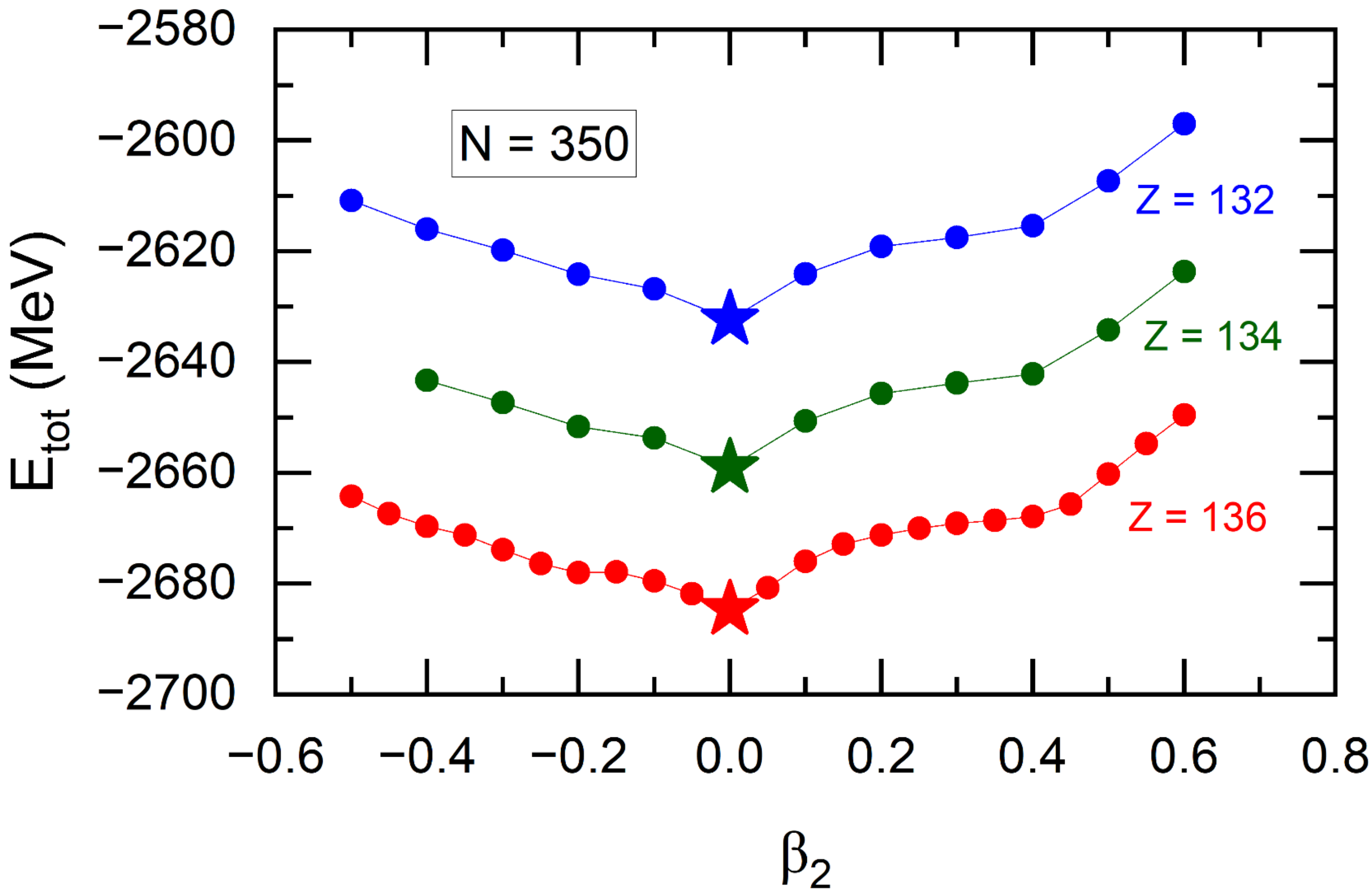
Evaluation of single particle levels with deformation



- The gap near the spherical region (gray) still exists, but not significant.
- The gaps in the prolate and oblate regions (pink) are larger.

② Magic number N = 350

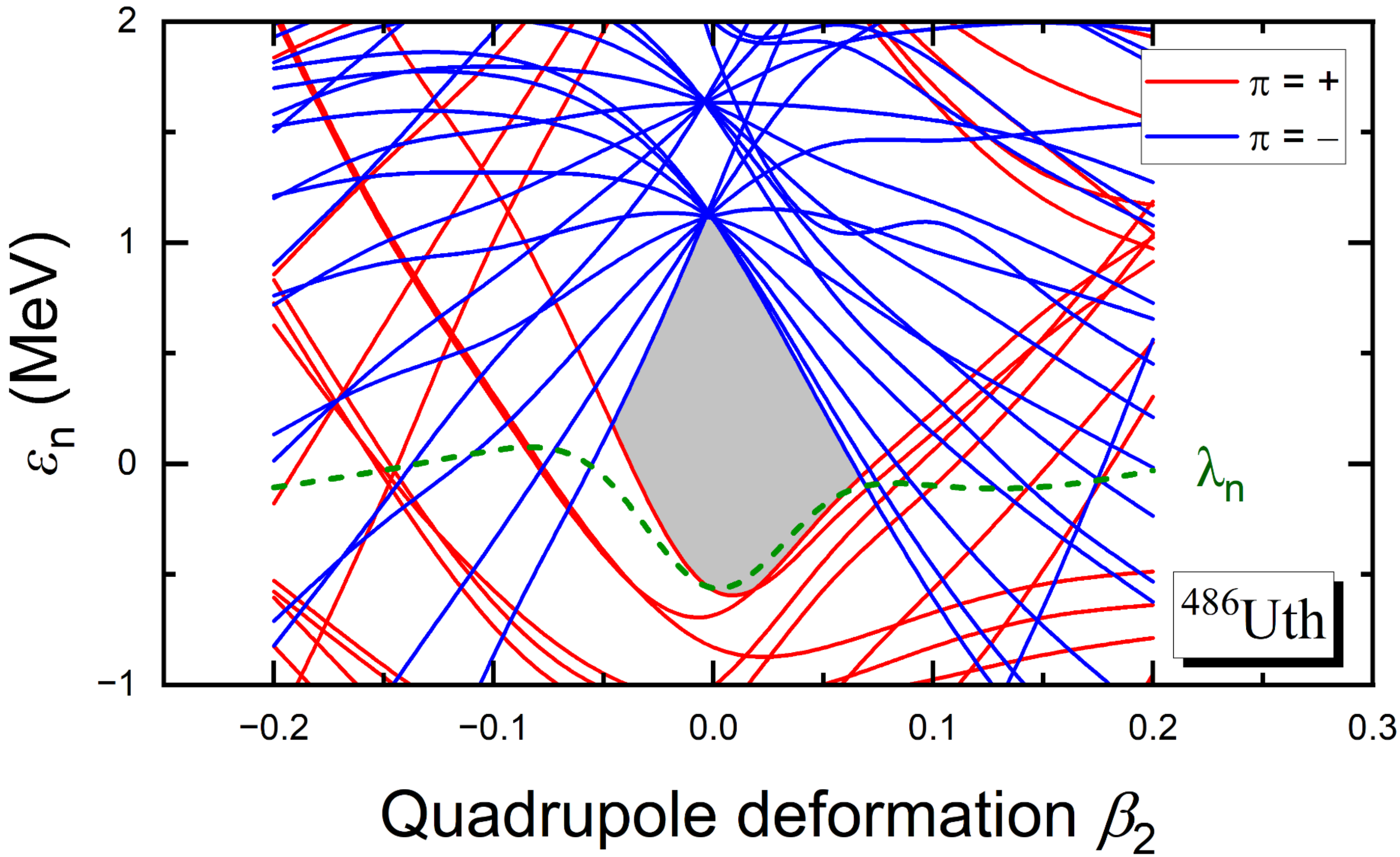
Nuclei with N=350 and Z=132, 134, 136 are spherical nuclei.



- Support the $N = 350$ to be a magic number.

② Magic number N = 350

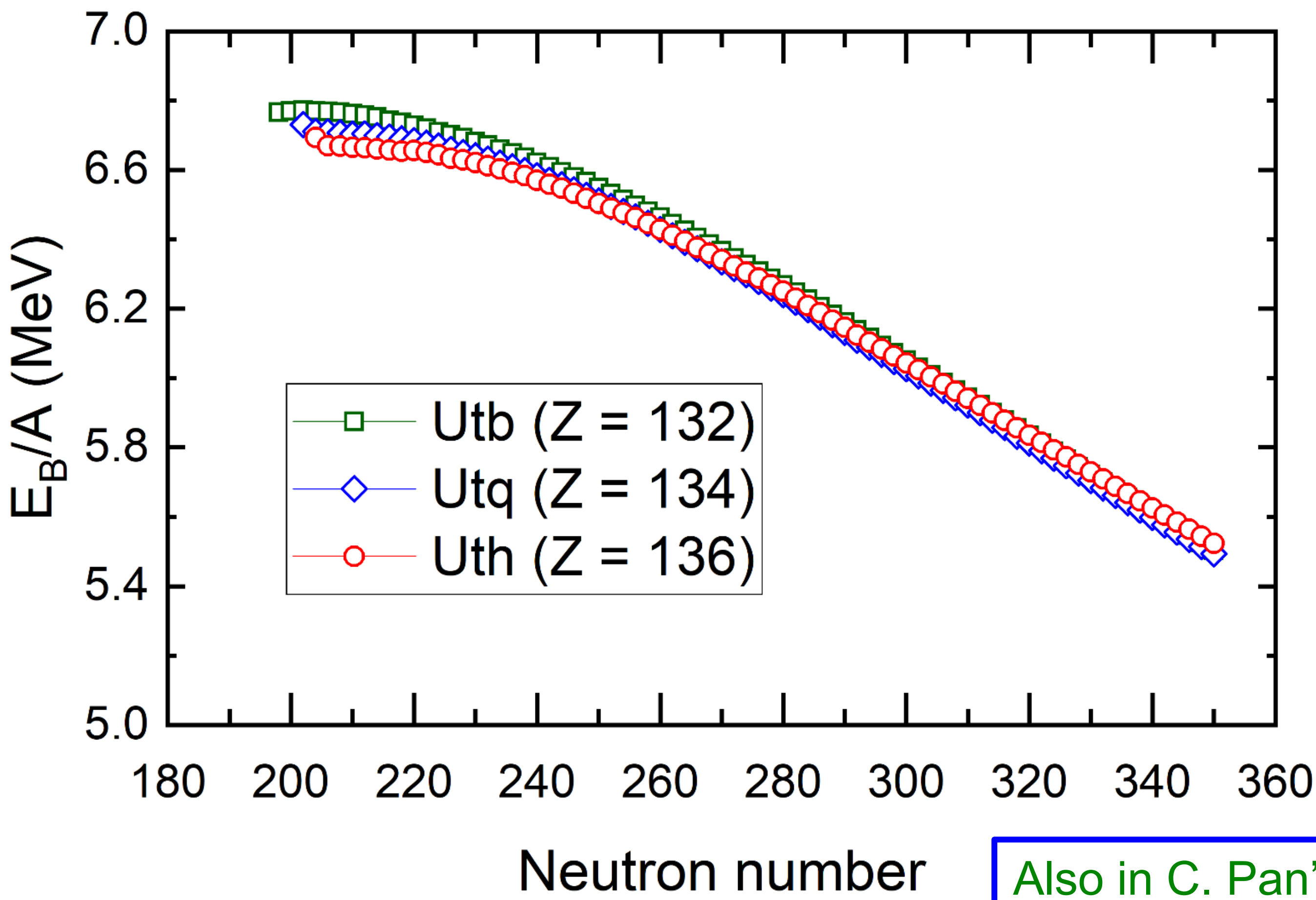
Evaluation of single particle levels with deformation



- The gap near the spherical region (gray) is large.

Binding energy

Binding energy per nucleon (Z = 132, 134, 136)



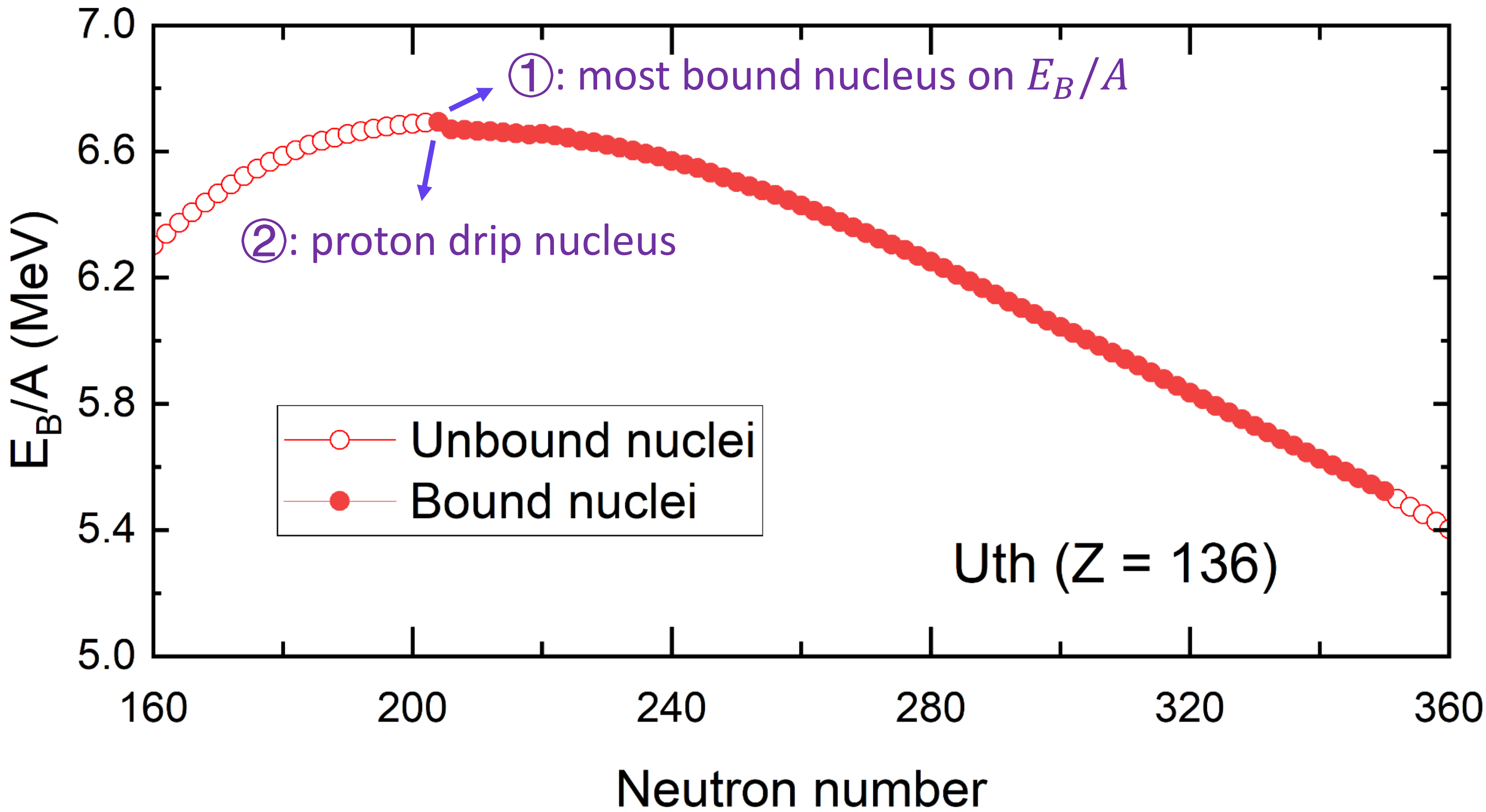
Also in C. Pan's talk (G13)

- E_B/A monotonically decrease with the increasing of neutron number.

It is expected to firstly increase and then decrease.

Binding energy

Binding energy per nucleon (Z = 132, 134, 136)

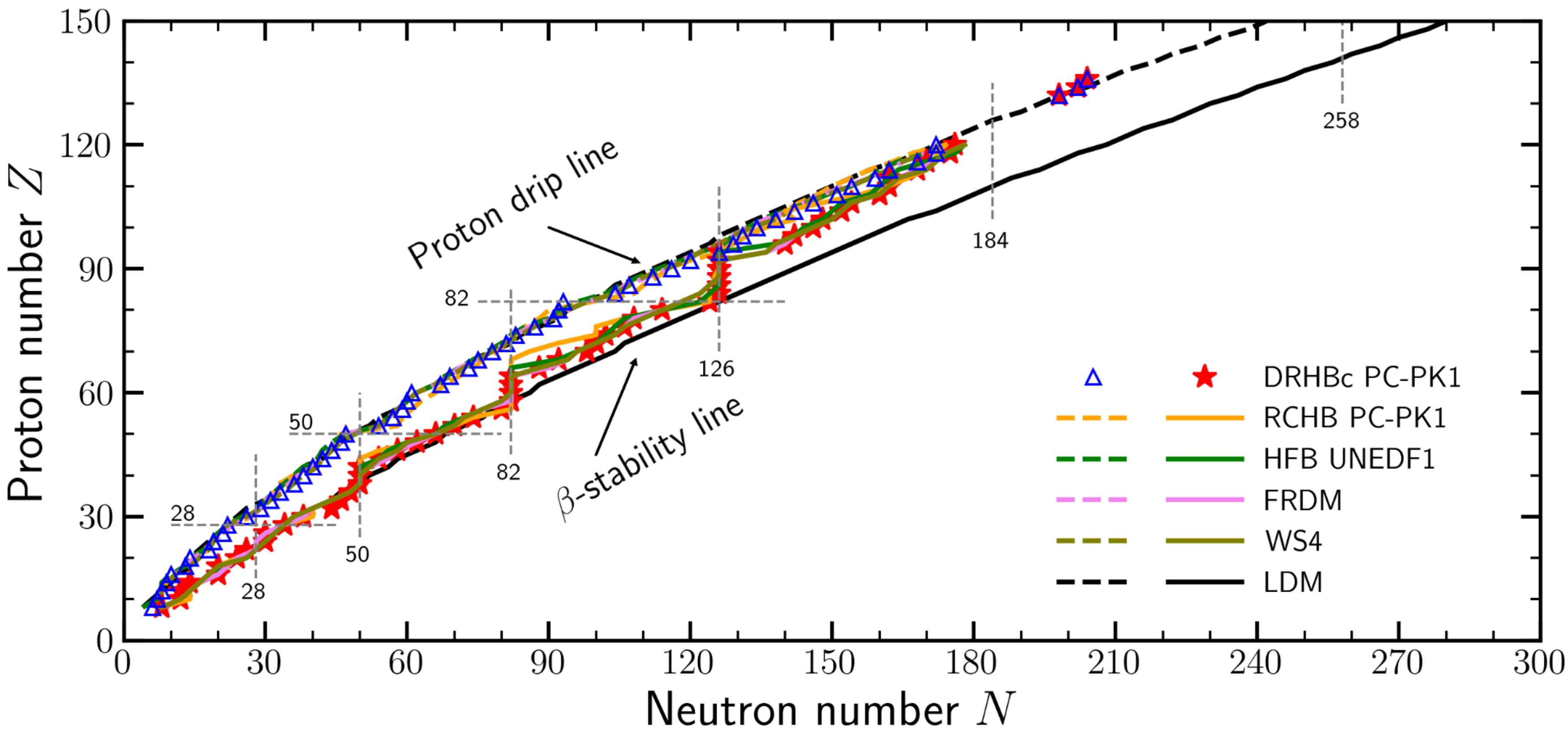


- ① and ② locate in the same place !

Most bound nucleus and proton drip nucleus are the same !

β-stability line and proton drip line

Relationship between β-stability line and proton drip line



β-stability line and proton drip line coincide with each other in superheavy region! Why?

Summary

Summary

Progress of G-16

Even-even nuclei √

		calculate	analyze
Z = 132	even N		
	odd N		
Z = 133	even N		
	odd N		
Z = 134	even N		
	odd N		
Z = 135	even N		
	odd N		
Z = 136	even N		
	odd N		

Next …

- Finish the calculations.
- Check the results carefully.

Some questions / notes / findings

- The shell gap dominated by the neutron magic number N = 258 is reduced in the superheavy region.

- N = 350 is predicted as a neutron magic number.

- β-stability line and proton drip line would coincide with each other in the superheavy region. Why?

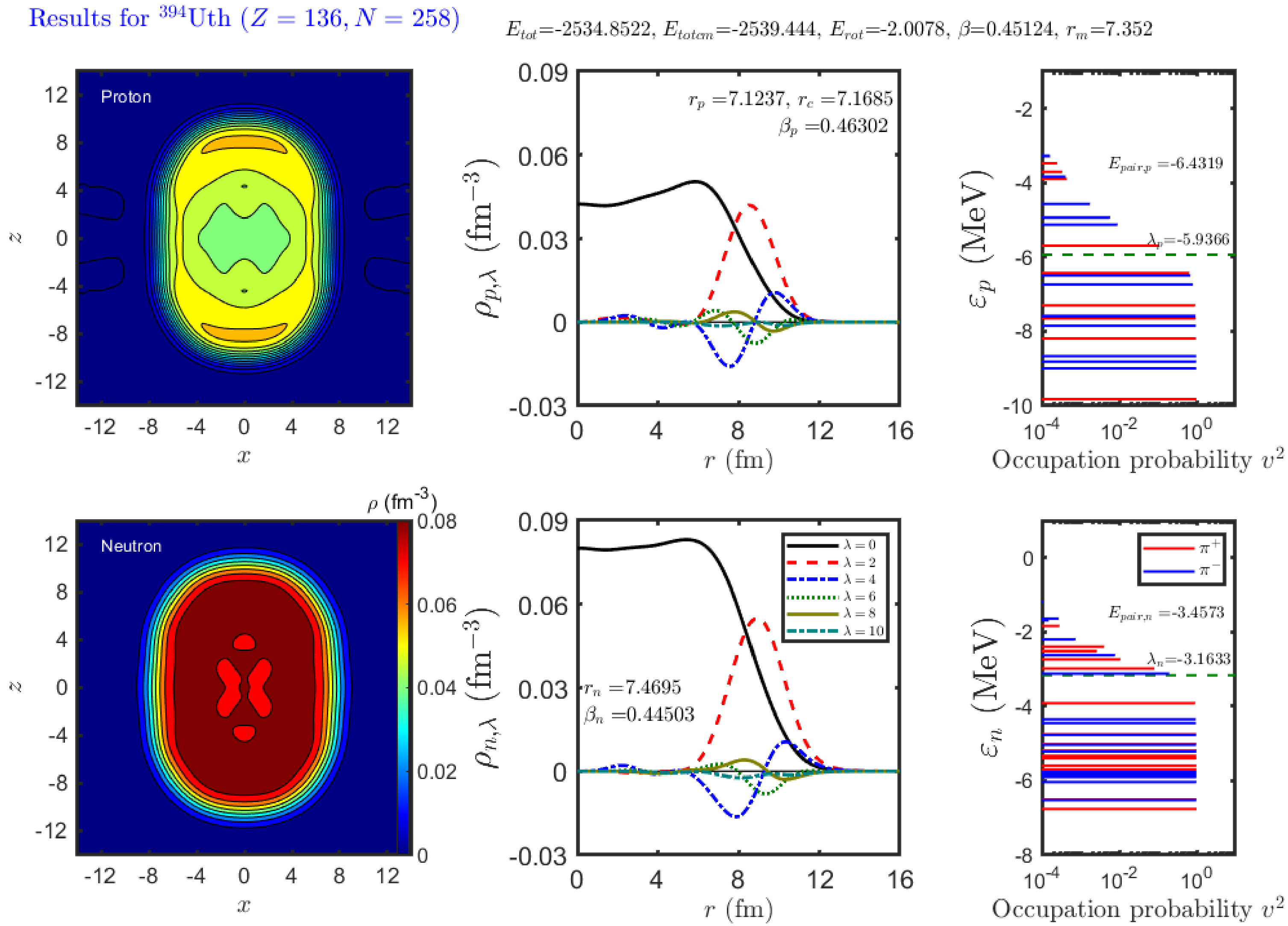
The end

Thanks

appendix

Visualization of DRHBc results via matlab script

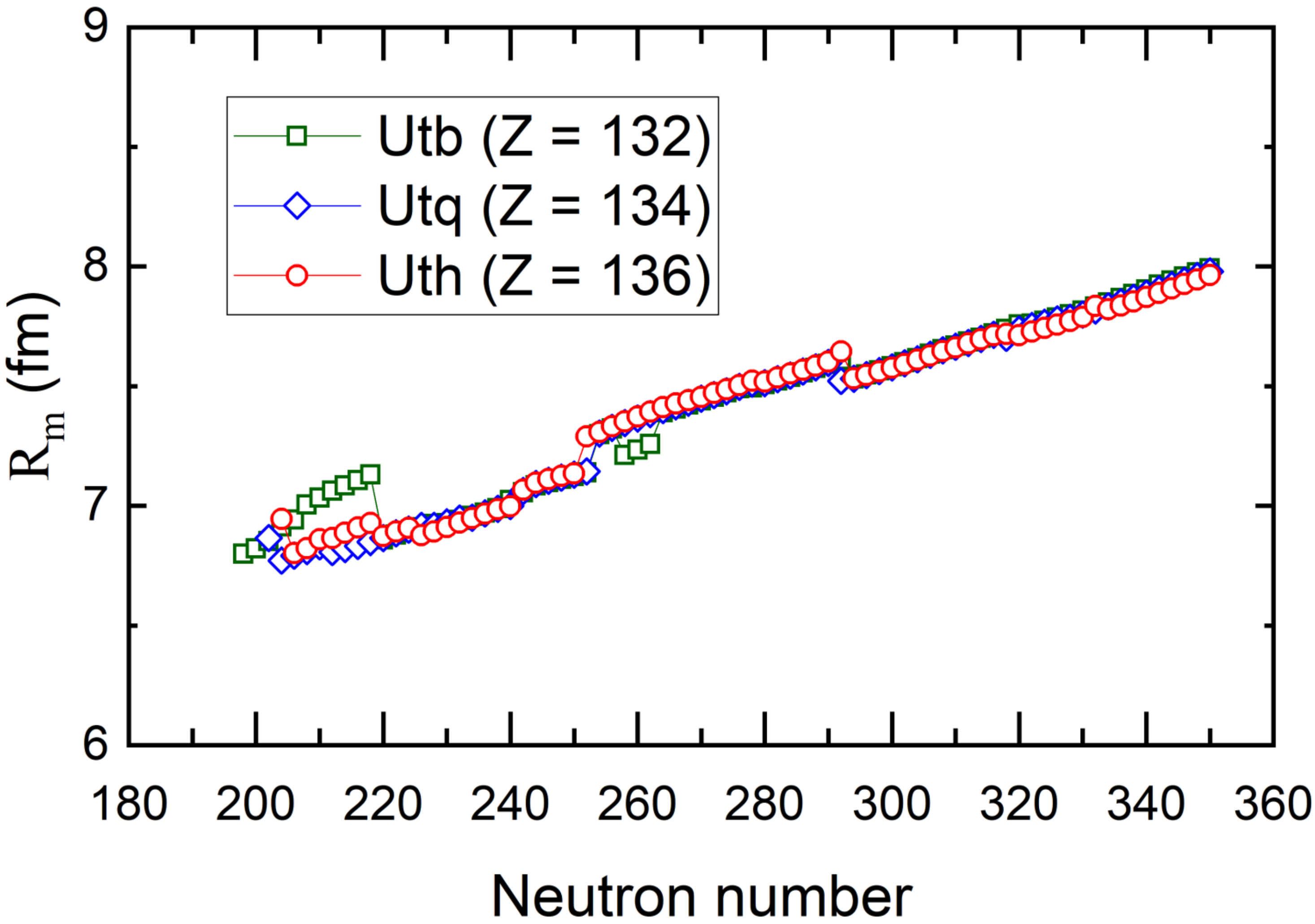
dir.out + one click, you will get:



- Contact me to get the script. (wuxinhui@fzu.edu.cn)

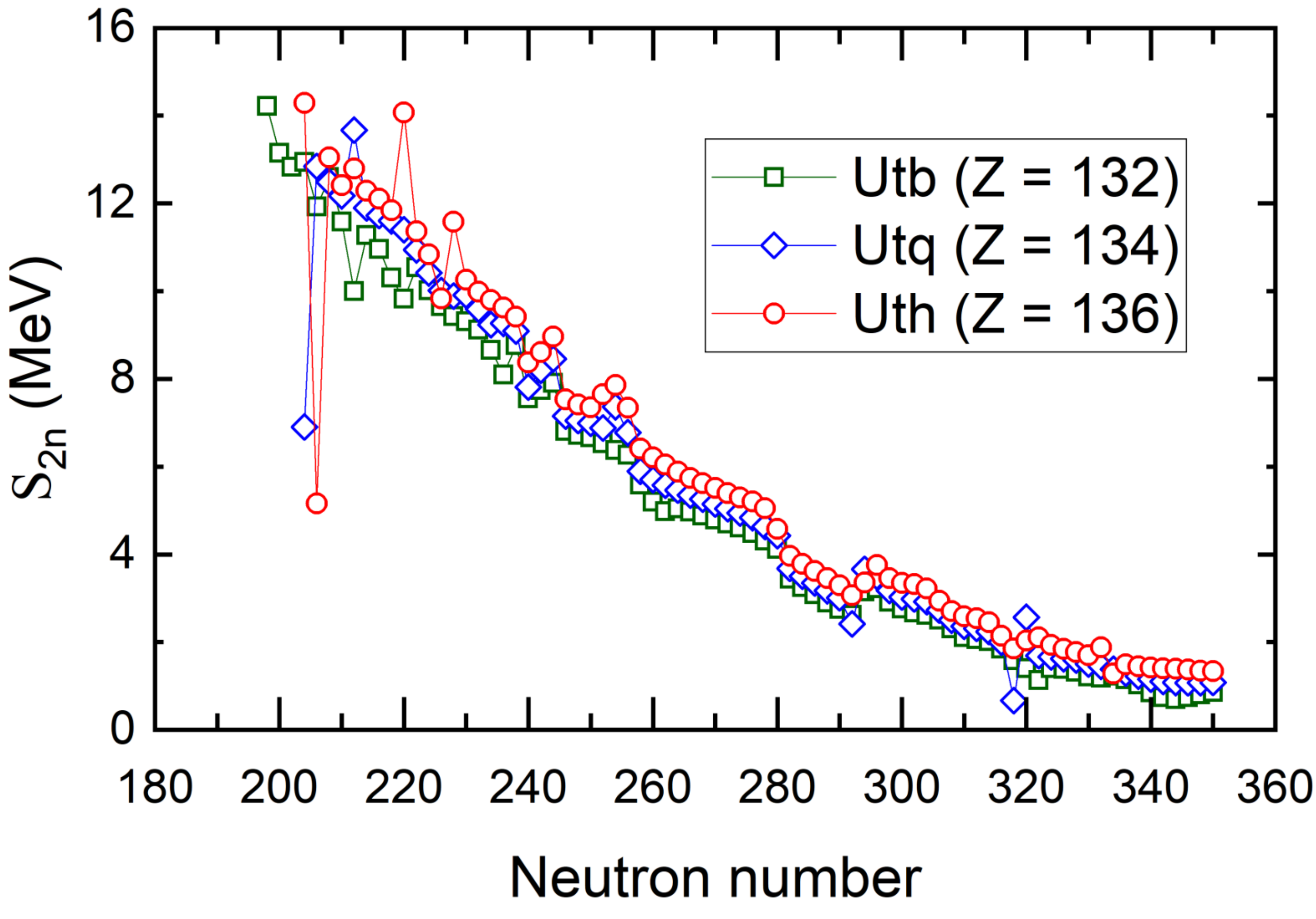
Radius

- R_{m}



Separation energy

- S_{2n}



Pairing energy

- Pairing energy