DRHBc calculation result for odd-Z nuclei with Z=61,63 and 65

The 7th workshop on nuclear mass table with DRHBc theory

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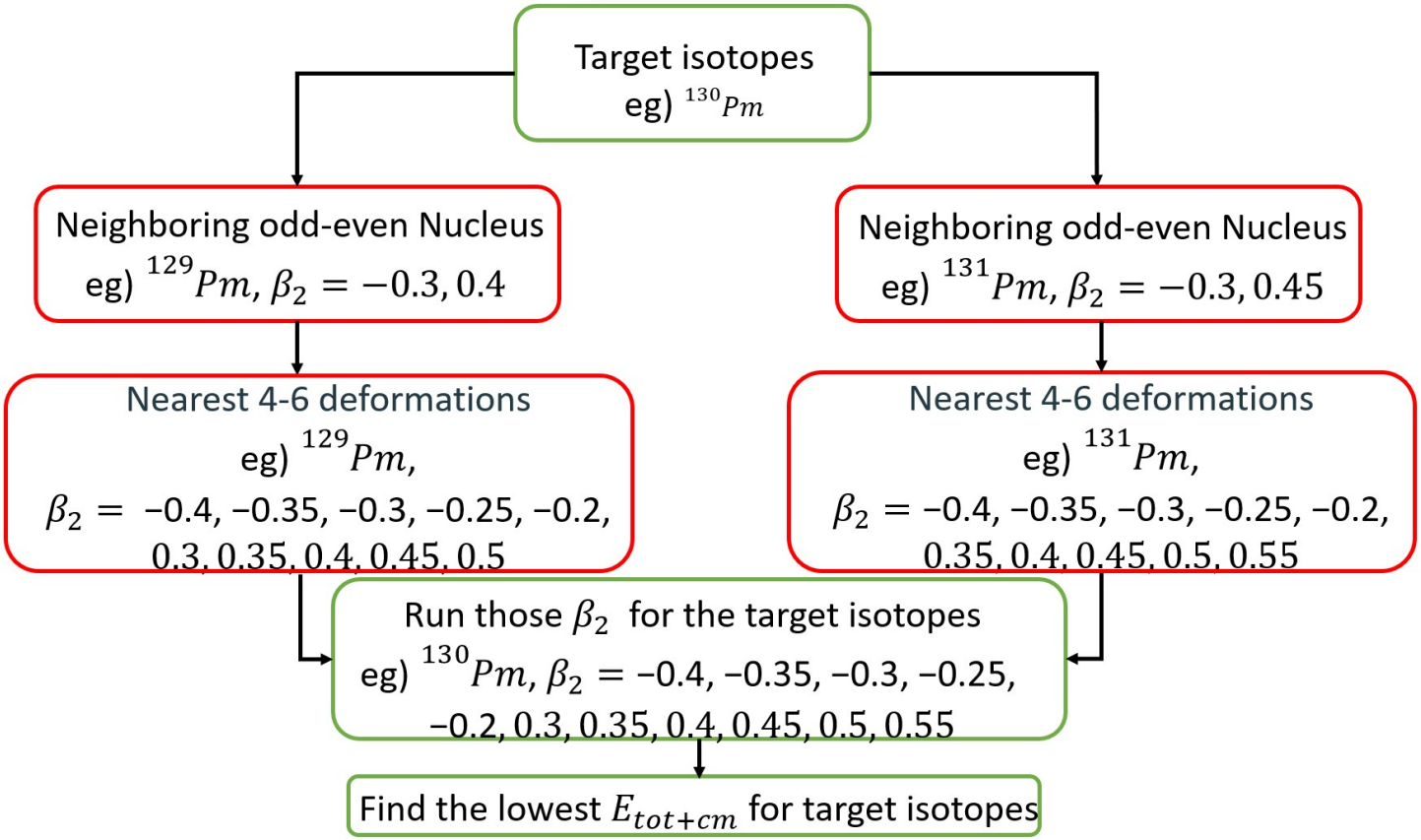
Odd-even nuclei ($Z = 61, 63, 65$)

- Constrained calculations for each isotope
  - Run each isotope with deformation from –0.40 to 0.55
    - β_2 =-0.40, -0.35, -0.30, ..., 0.50, 0.55
    - 20 β_2 per isotope
  - Figure out the β_2 of local minimum E_{tot+cm}
- Unconstrained calculations
  - Run 5 deformations with step sizes of 0.05 near β_2 above
  - Unconstrained calculation with lowest E_{tot+cm}
    $\Rightarrow$ ground state

Odd-odd nuclei ($Z = 61, 63, 65$)

- Follow the guideline from ManualforDRHBc_202112.pdf
- With results from odd-even nuclei
  - Progress is simplified
  - Do not need constrained calculation



Code version (odd-Z nuclei)

- Odd-even isotopes
  - All odd-even isotopes $61 \leq Z \leq 65$ are done (Code_DRHBc_202112)
- Odd-odd isotopes
  - All odd-odd isotopes $61 \leq Z \leq 65$ are done
  - All unconstained calculation: Code_DRHBc_202112
  - Constained calculation for Pm($Z = 61$): Code_DRHBc_202112
  - Constained calculation for Eu($Z = 63$) and Tb($Z = 65$): Code_DRHBc_202401

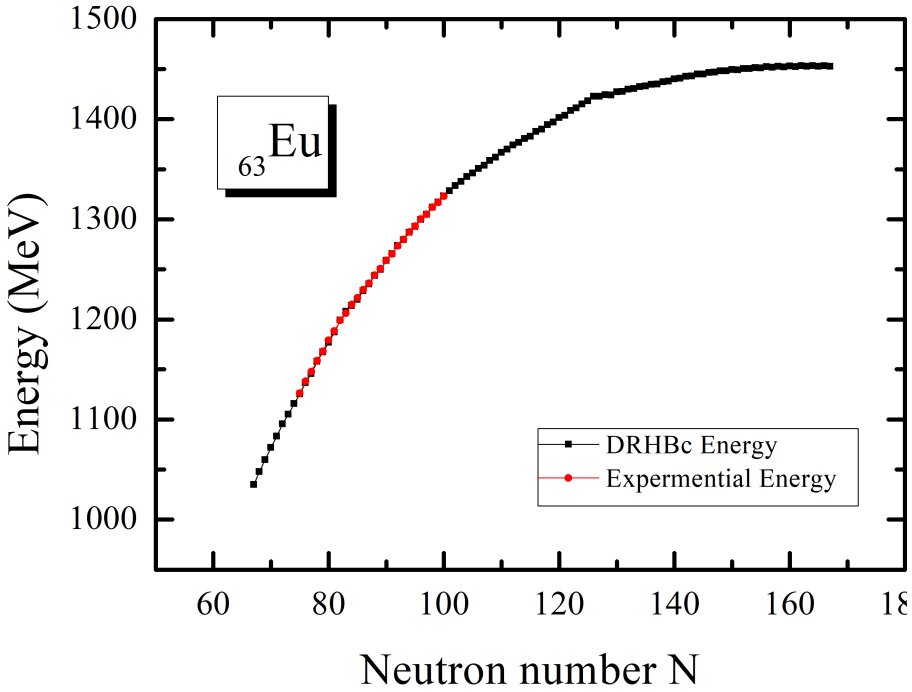
Table summary

N	A	Etot	E-cm	Etotcm	E-rot	Etotcmr	E_exp	beta n	beta p	beta t	radius	radius	radius	radius	lam n	lam p	pairin	pairin	pairin	S2n	S1n
66	128	-1014.833	-6.624	-1021.456	-2.847	-1024.303		0.385	0.404	0.395	4.854	4.895	4.874	4.960	-12.678	0.319	-3.590	-5.307	-8.897		
67	129	-1026.831	-6.612	-1033.444	-2.460	-1035.904		0.372	0.390	0.381	4.867	4.895	4.880	4.960	-12.528	-0.148	0.000	-6.537	-6.537		-11.988
68	130	-1039.414	-6.519	-1045.933	-2.803	-1048.736		0.366	0.383	0.374	4.884	4.900	4.891	4.965	-12.041	-0.585	-3.847	-7.143	-10.990	-24.477	-12.490
69	131	-1050.892	-6.547	-1057.439	-2.584	-1060.023		0.358	0.372	0.365	4.898	4.902	4.900	4.966	-11.679	-1.069	0.000	-8.418	-8.418	-23.995	-11.506
70	132	-1062.782	-6.547	-1069.328	-2.874	-1072.203		0.354	0.366	0.360	4.914	4.905	4.910	4.970	-11.196	-1.508	-0.265	-9.106	-9.371	-23.395	-11.890
71	133	-1073.537	-6.549	-1080.085	-2.685	-1082.770		0.399	0.408	0.403	4.954	4.934	4.944	4.998	-10.887	-1.768	0.000	-7.450	-7.450	-22.646	-10.757
72	134	-1085.219	-6.536	-1091.754	-2.757	-1094.512		0.438	0.443	0.440	4.993	4.962	4.979	5.026	-10.682	-1.991	0.000	-6.721	-6.721	-22.426	-11.669
73	135	-1094.464	-6.535	-1100.999	-2.494	-1103.493	-1103.98	0.402	0.408	0.405	4.991	4.952	4.973	5.016	-10.609	-2.359	0.000	-5.803	-5.803	-20.914	-9.245
74	136	-1105.665	-6.322	-1111.987	-2.585	-1114.572	-1116.00	0.233	0.255	0.243	4.936	4.889	4.915	4.954	-10.661	-2.405	-5.710	-11.034	-16.744	-20.233	-10.988
75	137	-1115.464	-6.389	-1121.854	-2.313	-1124.167	-1125.29	0.212	0.233	0.222	4.945	4.886	4.918	4.951	-10.646	-2.689	-0.668	-11.566	-12.235	-20.854	-9.867
76	138	-1126.563	-6.236	-1132.799	-2.663	-1135.463	-1136.83	0.185	0.208	0.195	4.956	4.886	4.925	4.951	-10.398	-2.862	-6.205	-12.746	-18.951	-20.812	-10.946
77	139	-1136.141	-6.223	-1142.364	-2.357	-1144.721	-1145.79	0.159	0.183	0.170	4.966	4.885	4.930	4.950	-10.485	-3.104	-3.278	-13.730	-17.008	-20.511	-9.565
78	140	-1147.267	-6.149	-1153.416	-2.345	-1155.761	-1156.93	0.127	0.149	0.137	4.976	4.884	4.935	4.949	-10.475	-3.390	-5.534	-14.967	-20.501	-20.617	-11.052
79	141	-1157.022	-6.224	-1163.246	-1.571	-1164.817	-1165.48	0.112	0.132	0.121	4.988	4.886	4.943	4.951	-10.115	-3.720	0.000	-15.125	-15.125	-20.881	-9.829
80	142	-1168.359	-6.104	-1174.463	0.000	-1174.463	-1176.61	0.000	0.000	0.000	4.994	4.880	4.945	4.945	-10.978	-3.991	-6.117	-15.684	-21.801	-21.047	-11.218
81	143	-1178.530	-6.193	-1184.723	0.000	-1184.723	-1185.21	0.041	0.049	0.044	5.008	4.885	4.955	4.950	-8.902	-4.317	0.000	-15.554	-15.554	-21.477	-10.259
82	144	-1190.090	-6.206	-1196.296	0.000	-1196.296	-1195.73	0.000	0.000	0.000	5.020	4.887	4.963	4.952	-8.749	-4.594	0.000	-15.690	-15.690	-21.832	-11.573
83	145	-1195.460	-6.195	-1201.656	0.000	-1201.656	-1202.49	-0.043	-0.051	-0.046	5.044	4.903	4.984	4.968	-8.635	-4.932	0.000	-15.196	-15.196	-16.933	-5.360
84	146	-1202.532	-6.028	-1208.561	0.000	-1208.561	-1210.90	0.000	0.000	0.000	5.064	4.911	5.000	4.975	-6.197	-5.209	-8.238	-15.522	-23.760	-12.265	-6.905
85	147	-1208.497	-6.160	-1214.657	-1.130	-1215.788	-1217.24	0.126	0.135	0.130	5.096	4.937	5.030	5.002	-7.319	-5.633	0.000	-14.047	-14.047	-13.001	-6.097
86	148	-1216.059	-6.060	-1222.119	-1.898	-1224.017	-1225.39	0.152	0.162	0.156	5.120	4.951	5.050	5.015	-7.109	-5.955	-4.223	-13.631	-17.854	-13.558	-7.462
87	149	-1222.735	-6.121	-1228.856	-1.557	-1230.413	-1231.26	0.186	0.201	0.192	5.146	4.971	5.074	5.035	-6.938	-6.292	0.000	-12.708	-12.708	-14.198	-6.736
88	150	-1230.371	-6.068	-1236.438	-1.890	-1238.328	-1239.24	0.215	0.232	0.222	5.172	4.987	5.096	5.051	-7.047	-6.593	-2.449	-11.266	-13.716	-14.319	-7.583
89	151	-1236.810	-6.163	-1242.972	-1.463	-1244.435	-1244.84	0.254	0.277	0.263	5.201	5.011	5.124	5.074	-7.156	-6.951	0.000	-7.596	-7.596	-14.117	-6.534
90	152	-1244.488	-6.125	-1250.612	-2.114	-1252.726	-1253.10	0.301	0.322	0.309	5.237	5.039	5.157	5.102	-7.225	-7.195	-4.591	-4.791	-9.382	-14.174	-7.640
91	153	-1251.243	-6.209	-1257.452	-1.874	-1259.326	-1258.97	0.314	0.332	0.321	5.258	5.052	5.176	5.115	-6.844	-7.428	0.000	-4.555	-4.555	-14.480	-6.840
92	154	-1258.585	-6.208	-1264.793	-2.126	-1266.919	-1266.93	0.339	0.353	0.345	5.286	5.070	5.200	5.133	-6.636	-7.666	-0.007	-4.574	-4.581	-14.181	-7.341
93	155	-1264.373	-6.161	-1270.534	-2.051	-1272.585	-1272.74	0.342	0.354	0.347	5.304	5.077	5.215	5.140	-6.548	-7.956	0.000	-4.698	-4.698	-13.082	-5.741
94	156	-1271.027	-6.048	-1277.076	-2.467	-1279.542	-1279.98	0.347	0.358	0.351	5.324	5.089	5.232	5.152	-6.126	-8.382	-5.851	-4.453	-10.304	-12.283	-6.542
95	157	-1276.382	-6.060	-1282.442	-2.371	-1284.813	-1285.37	0.352	0.360	0.355	5.343	5.100	5.248	5.162	-5.912	-8.761	-3.544	-4.360	-7.904	-11.908	-5.366
96	158	-1283.008	-5.988	-1288.996	-2.527	-1291.522	-1292.01	0.356	0.364	0.359	5.362	5.109	5.264	5.172	-5.934	-9.090	-6.529	-4.467	-10.996	-11.920	-6.554
97	159	-1288.202	-6.034	-1294.236	-2.112	-1296.349	-1297.04	0.358	0.364	0.360	5.379	5.118	5.279	5.180	-5.779	-9.452	-1.795	-4.471	-6.267	-11.794	-5.240
98	160	-1294.581	-5.970	-1300.551	-2.440	-1302.991	-1303.14	0.369	0.372	0.370	5.401	5.131	5.298	5.193	-5.696	-9.765	-4.929	-4.518	-9.446	-11.555	-6.315
99	161	-1299.837	-6.034	-1305.871	-2.055	-1307.926	-1307.65	0.376	0.378	0.377	5.420	5.142	5.315	5.204	-5.220	-10.101	0.000	-4.450	-4.450	-11.634	-5.320
100	162	-1305.612	-5.994	-1311.606	-2.040	-1313.646		0.379	0.380	0.380	5.441	5.151	5.332	5.213	-5.134	-10.368	-0.002	-4.589	-4.591	-11.055	-5.735
101	163	-1310.038	-5.997	-1316.036	-2.260	-1318.296		0.385	0.385	0.385	5.459	5.162	5.348	5.224	-5.010	-10.771	0.000	-4.445	-4.445	-10.165	-4.430
102	164	-1314.903	-5.880	-1320.783	-2.566	-1323.349		0.383	0.382	0.383	5.478	5.170	5.364	5.231	-4.444	-11.005	-5.130	-4.803	-9.932	-9.177	-4.747
103	165	-1318.752	-5.939	-1324.691	-2.306	-1326.997		0.455	0.434	0.447	5.536	5.210	5.416	5.271	-4.405	-11.027	0.000	-3.567	-3.567	-8.655	-3.908
104	166	-1323.551	-5.873	-1329.424	-2.536	-1331.961		0.450	0.430	0.442	5.550	5.216	5.427	5.277	-4.251	-11.362	-3.488	-3.729	-7.218	-8.641	-4.734
105	167	-1327.178	-5.888	-1333.066	-2.290	-1335.356		0.449	0.429	0.442	5.567	5.222	5.441	5.283	-4.083	-11.587	0.000	-3.998	-3.999	-8.375	-3.642

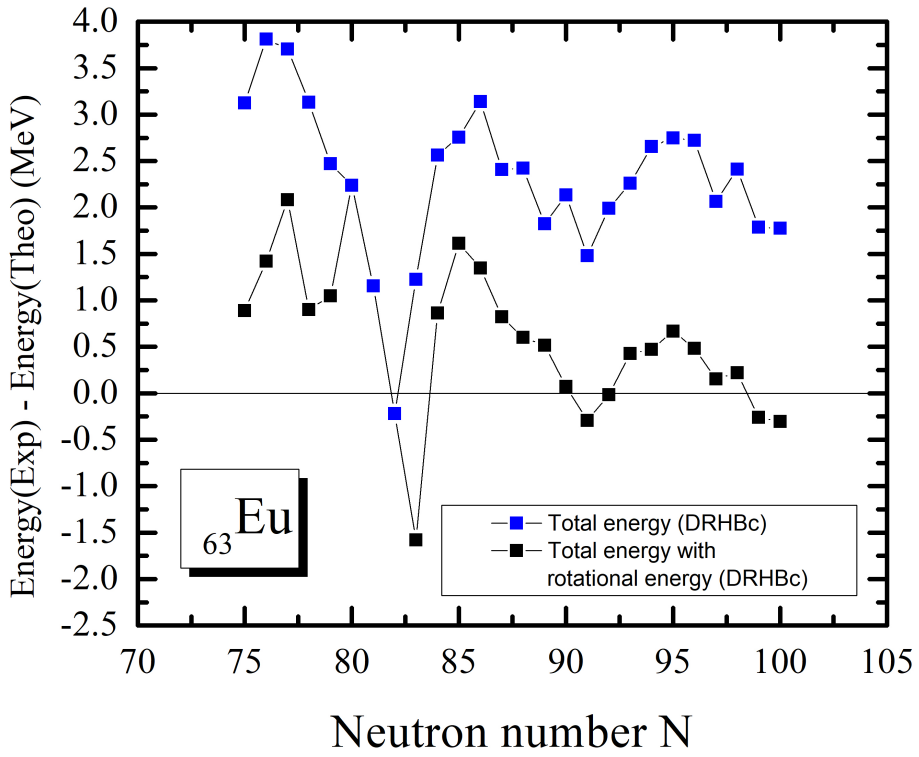
Results are being double-checked

Ground state energy: Eu ($Z = 63$)

Ground state energy for Eu ($Z = 63$)



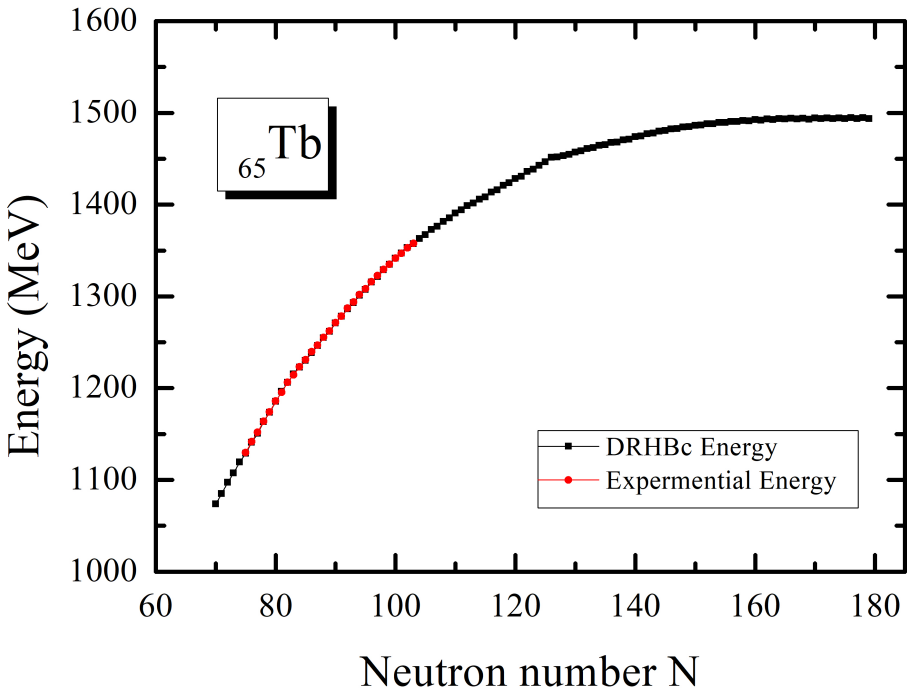
Difference between the experimental energy and DRHBc calculations from ^{137}Eu to ^{165}Eu



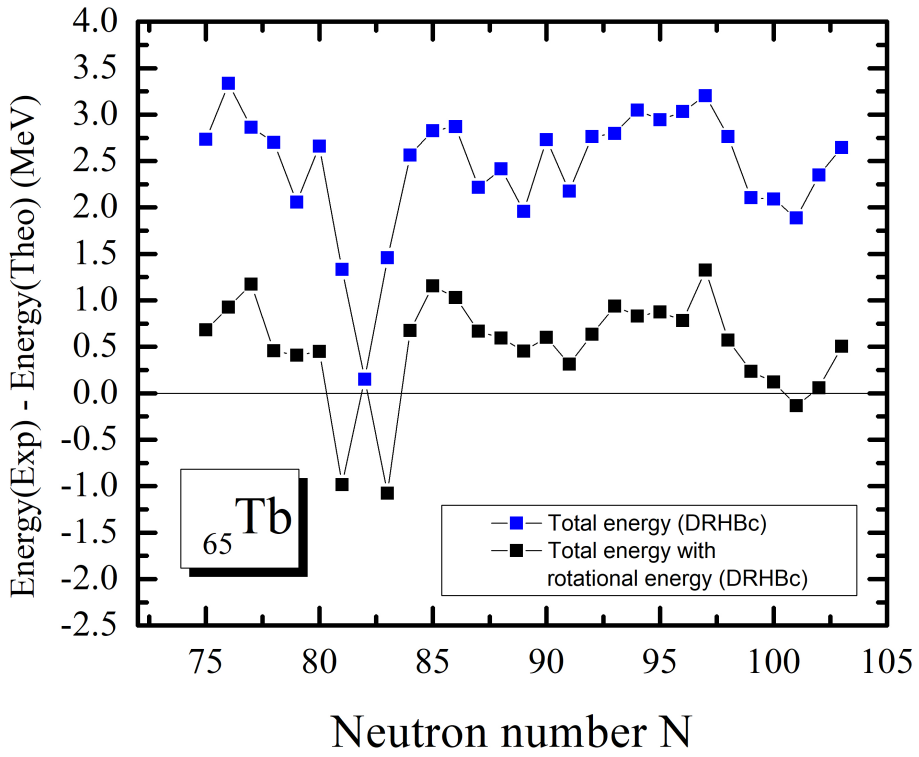
With rotational energy $\Rightarrow$ better prediction (Except ^{146}Eu)

Ground state energy: Tb ($Z = 65$)

Ground state energy for Tb ($Z = 65$)



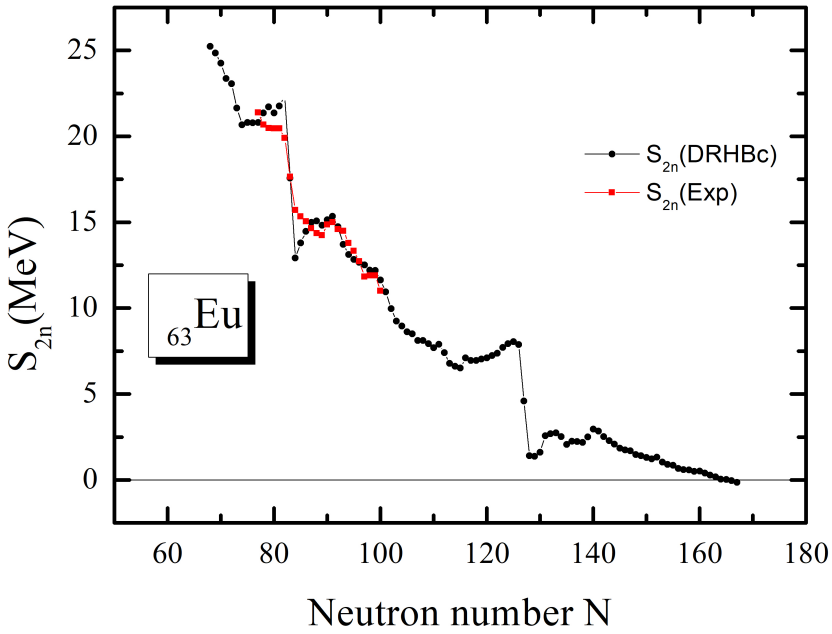
Difference between the experimental energy and DRHBc calculations from ^{141}Tb to ^{167}Tb



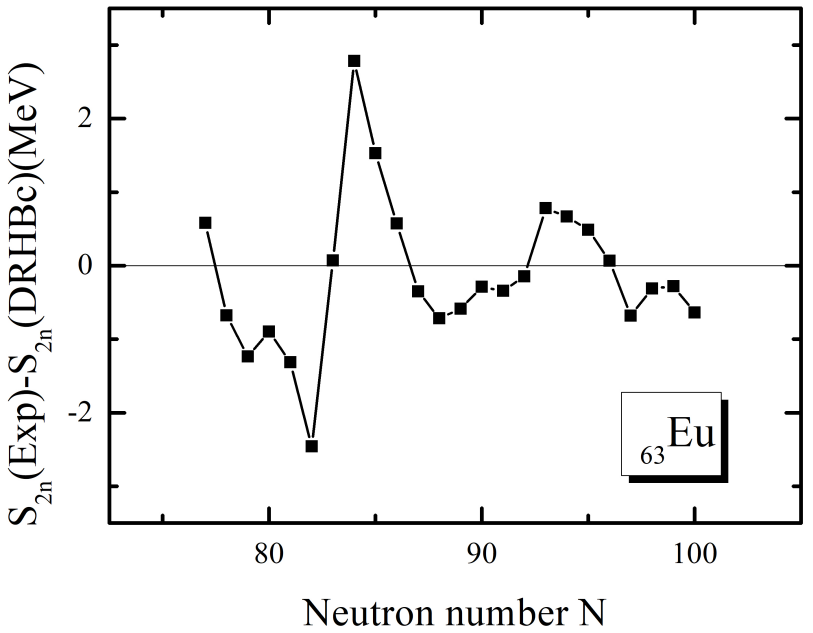
With rotational energy $\Rightarrow$ better prediction

2-neutron Separation Energy: Eu ($Z = 63$)

2-neutron separation Energy for Eu ($Z = 63$)



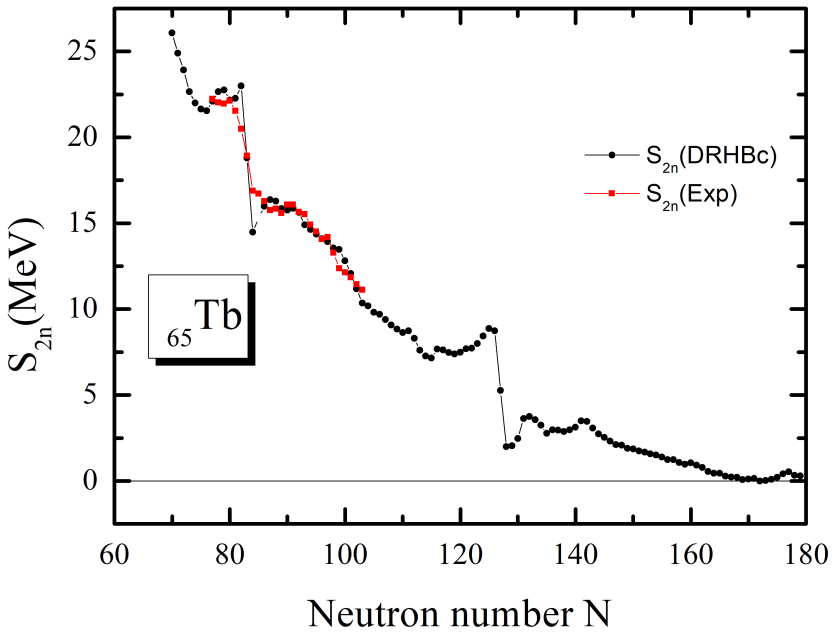
Difference between experimental S_{2n} and DRHBc S_{2n} from ^{139}Eu to ^{165}Eu



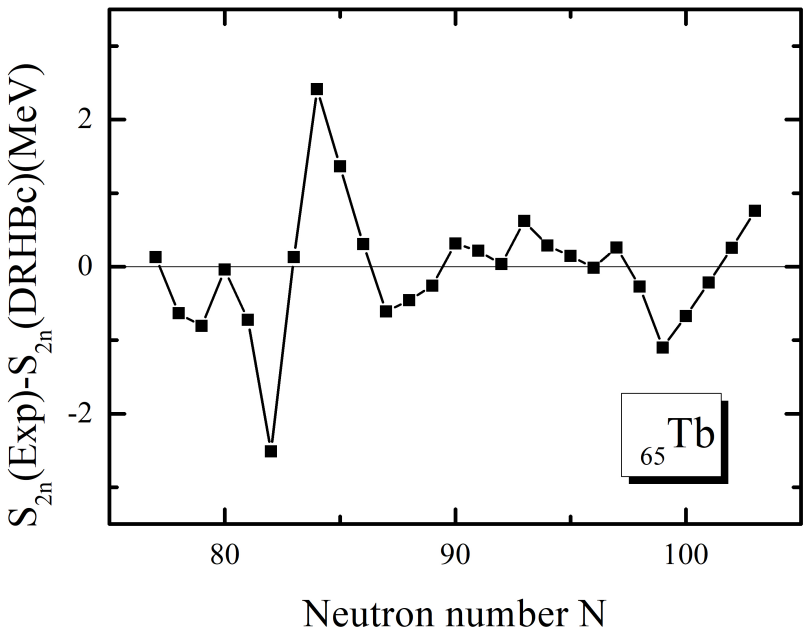
Agree with shell closure, but description needs improvement

2-neutron Separation Energy: Tb ($Z = 65$)

2-neutron separation Energy for Tb ($Z = 65$)



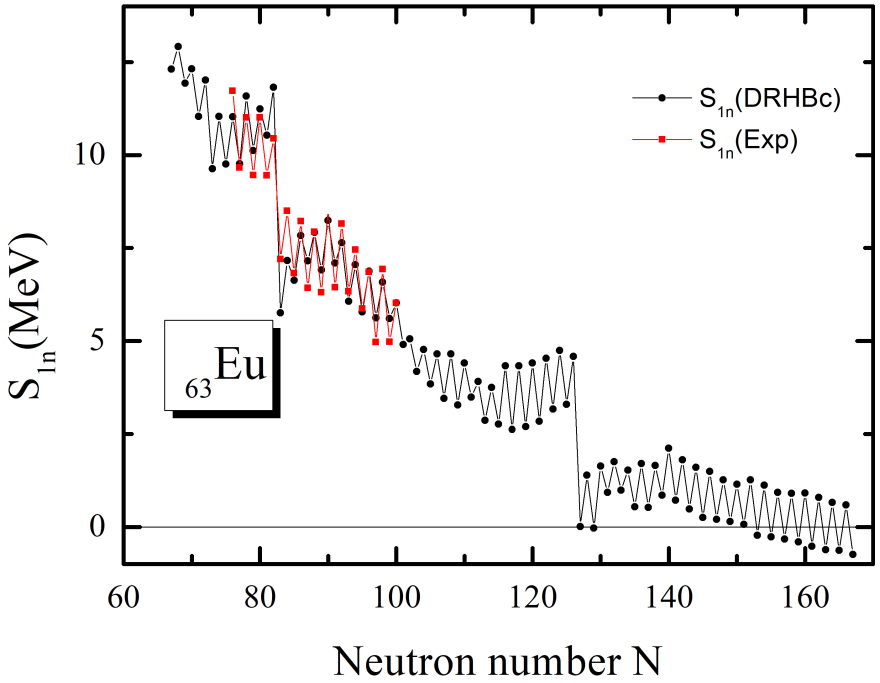
Difference between experimental S_{2n} and DRHBc S_{2n} from ^{143}Tb to ^{167}Tb



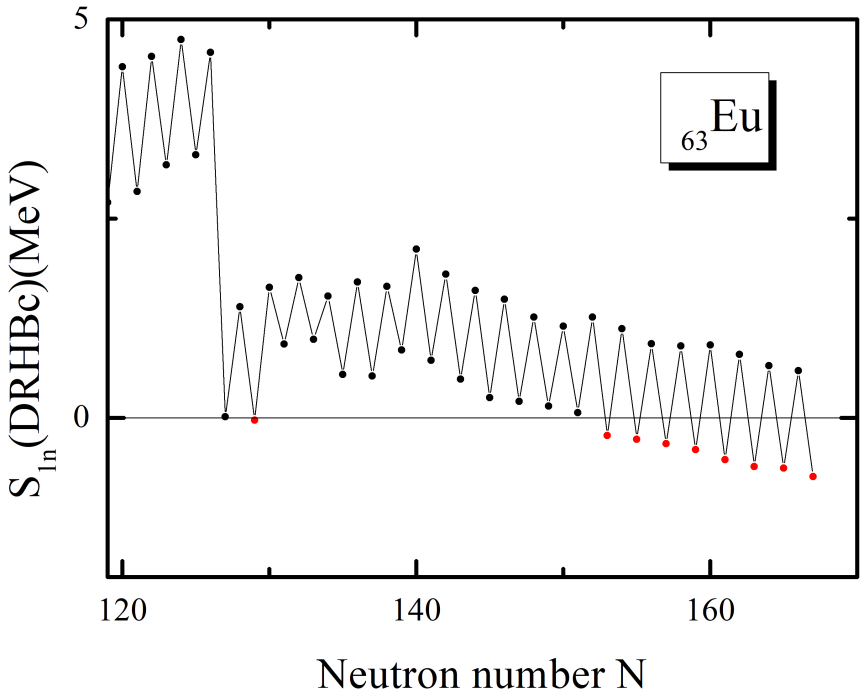
Same phenomenon can be concluded in Tb ($Z = 65$)

1-neutron Separation Energy: Eu ($Z = 63$)

Single neutron separation Energy for Eu ($Z = 63$)



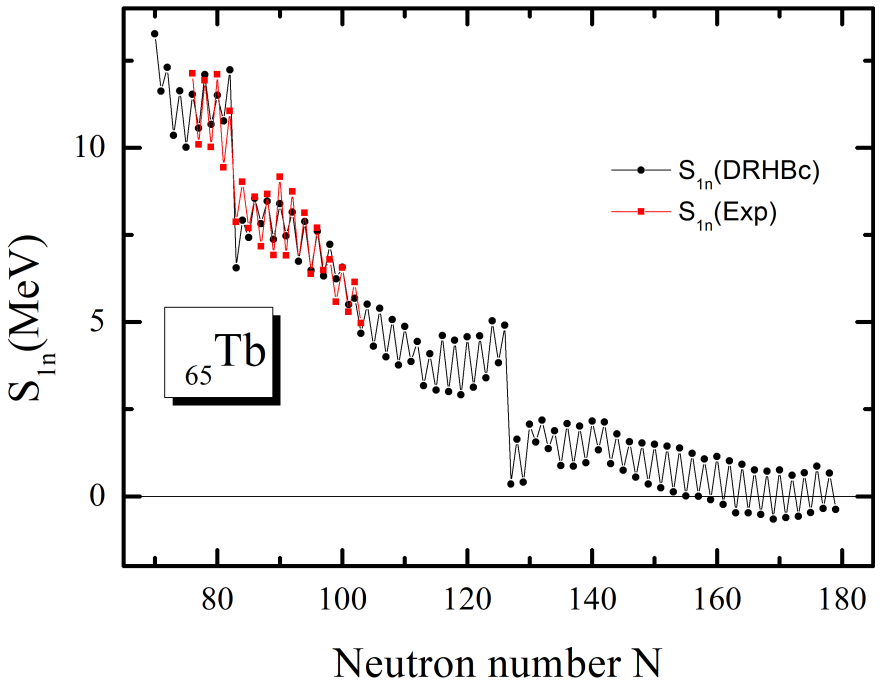
Single neutron separation Energy for Eu ($Z = 63$) from ^{183}Eu to ^{230}Eu



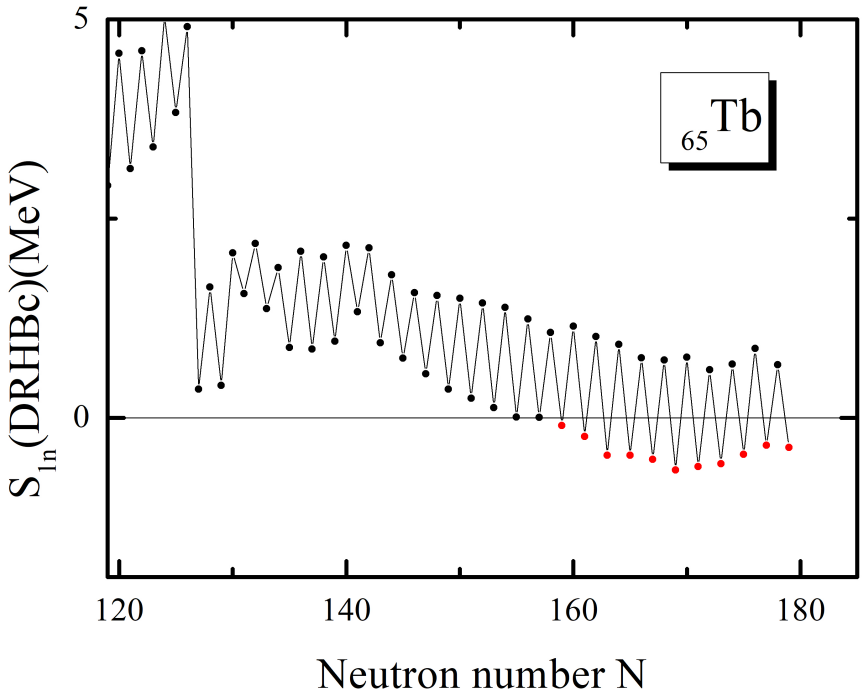
1 unbounded nuclei exist in ^{192}Eu

1-neutron Separation Energy: Tb ($Z = 65$)

Single neutron separation Energy for Tb ($Z = 65$)

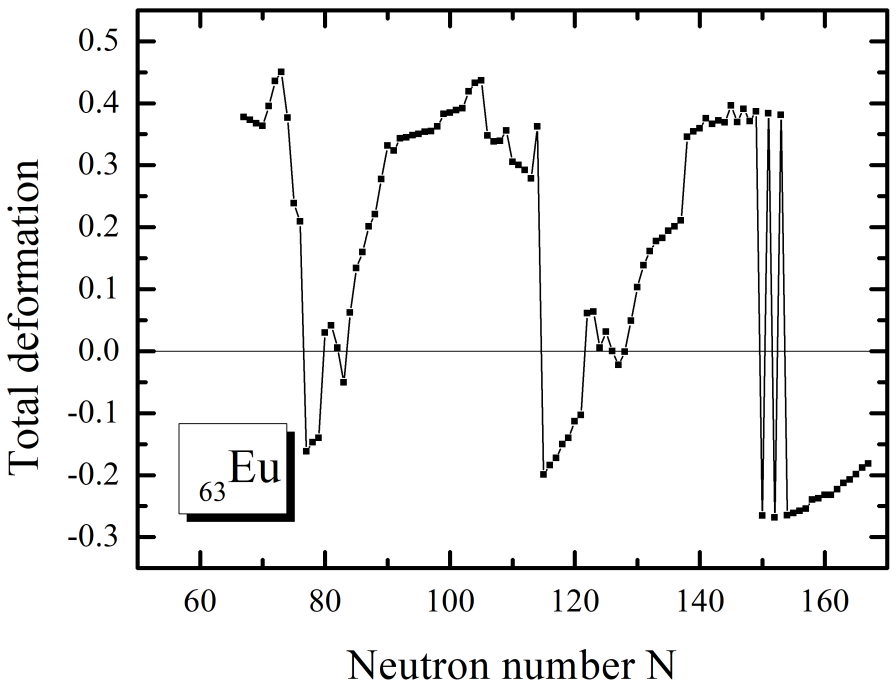


Single neutron separation Energy for Tb ($Z = 65$) from ^{185}Tb to ^{244}Tb

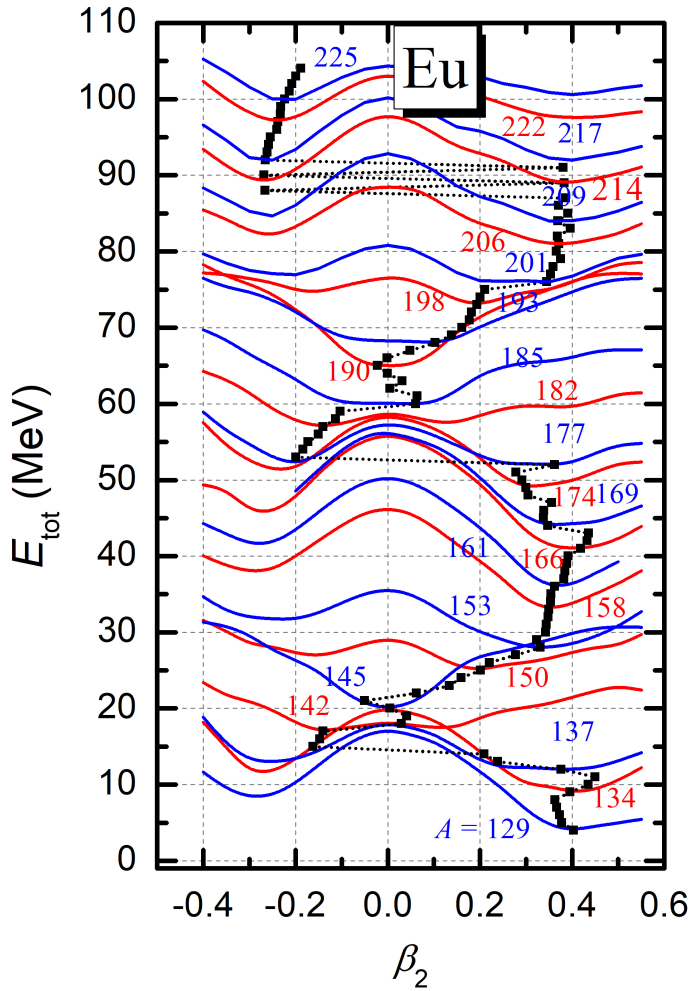


Deformation β_2 and potential energy curve: Eu

Deformation for Eu ($Z = 63$)

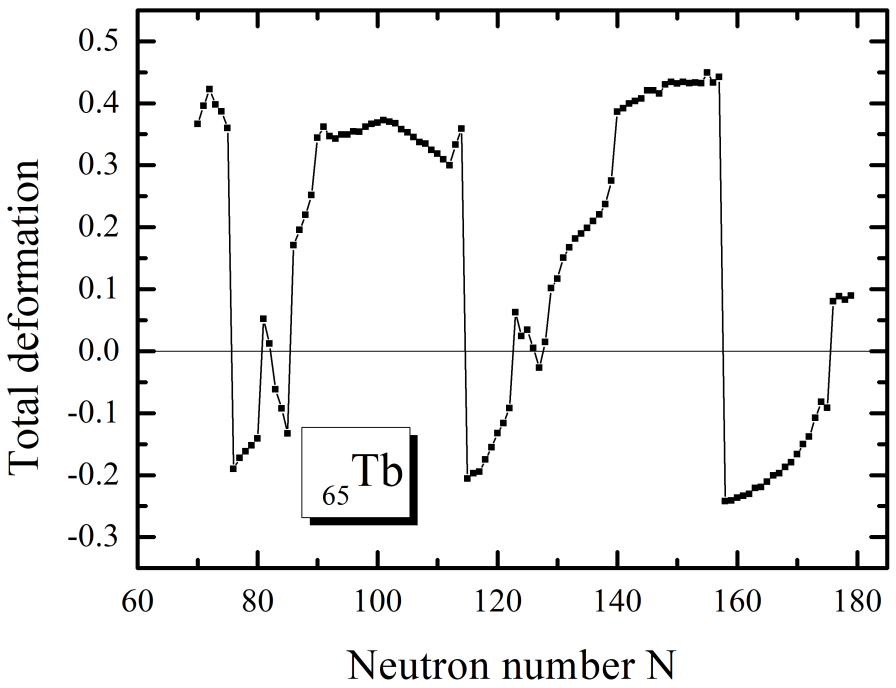


Evolution of potential energy

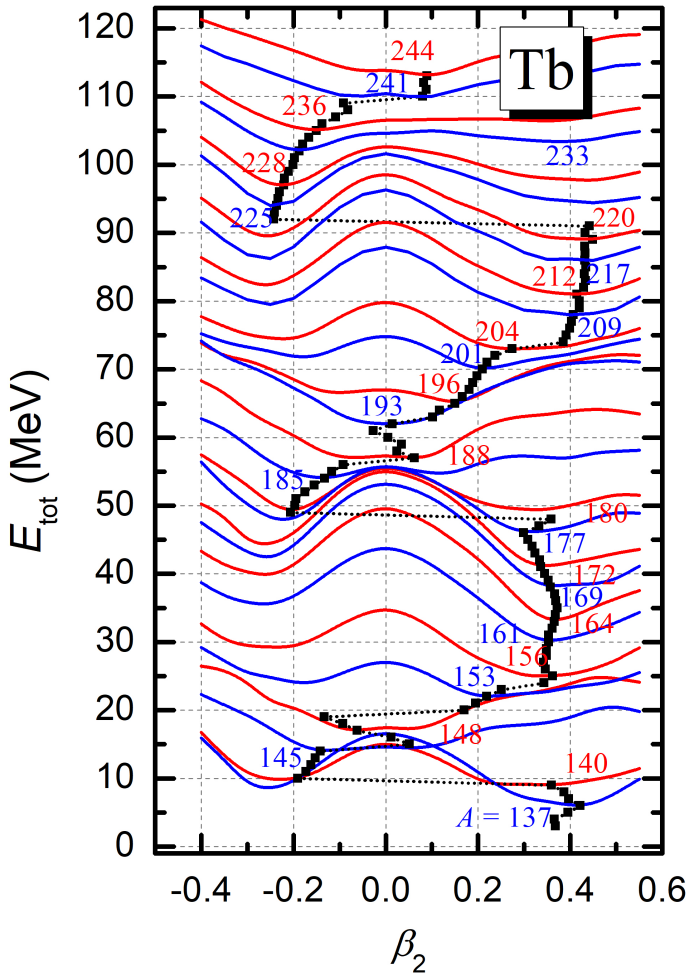


Deformation β_2 and potential energy curve: Tb

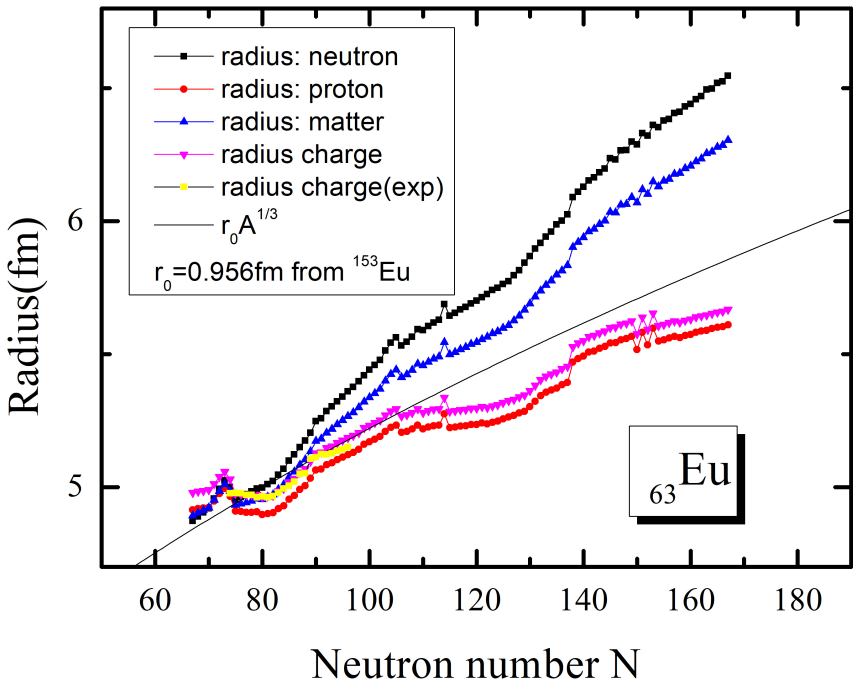
Deformation for Tb ($Z = 65$)

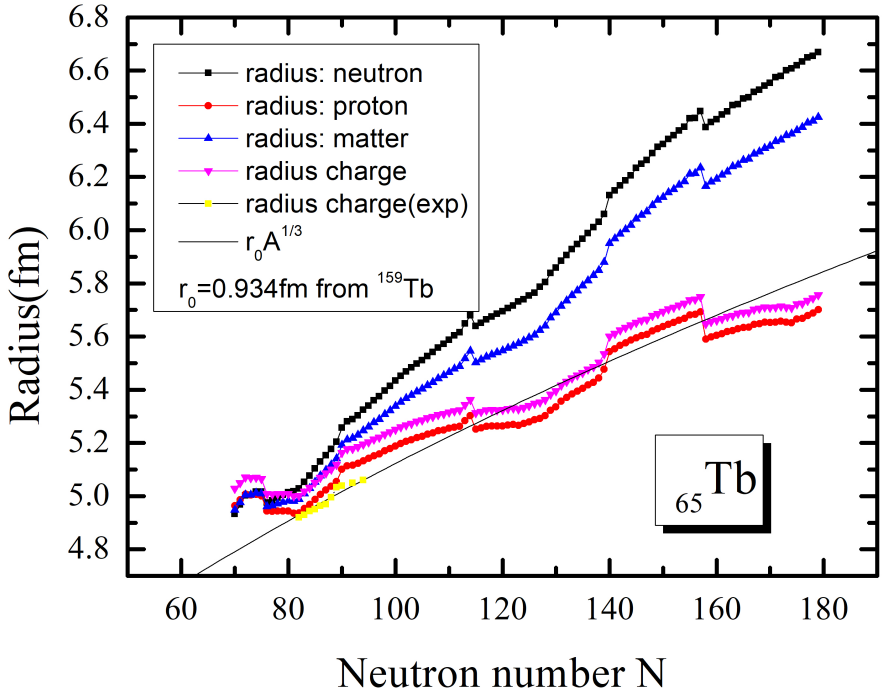


Evolution of potential energy



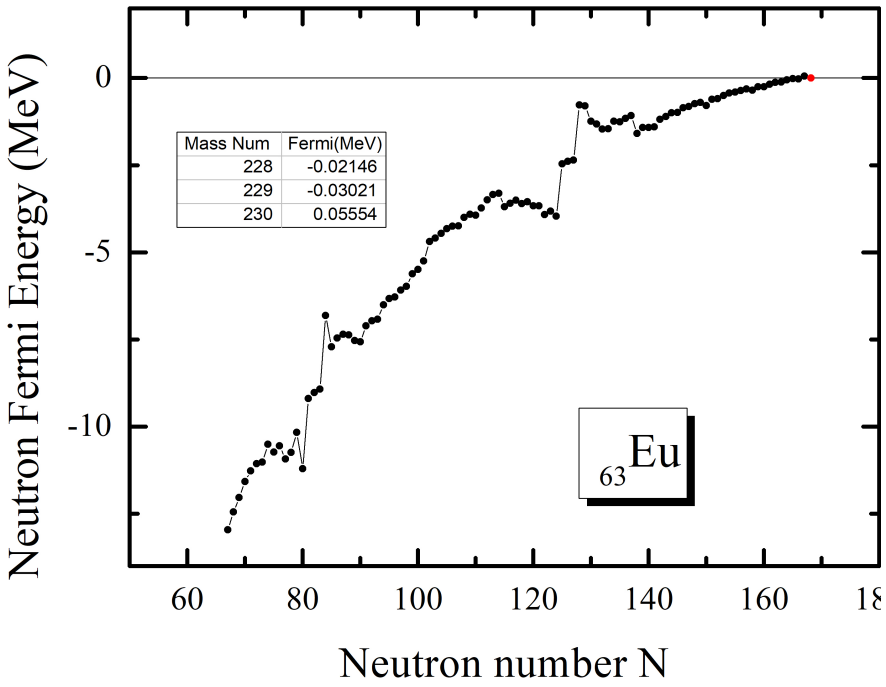
Radius: Eu ($Z = 63$) and Tb ($Z = 65$)

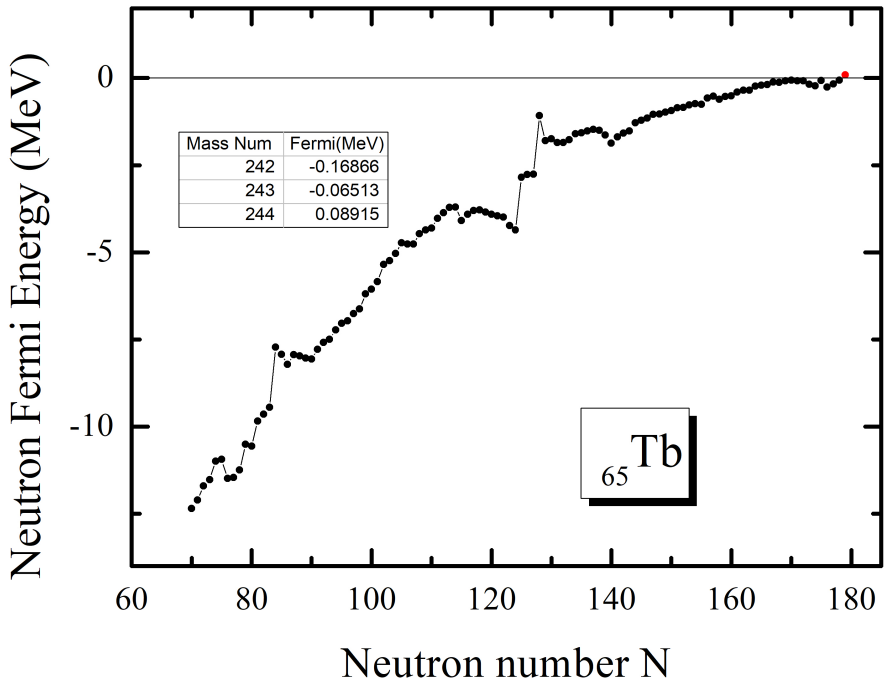




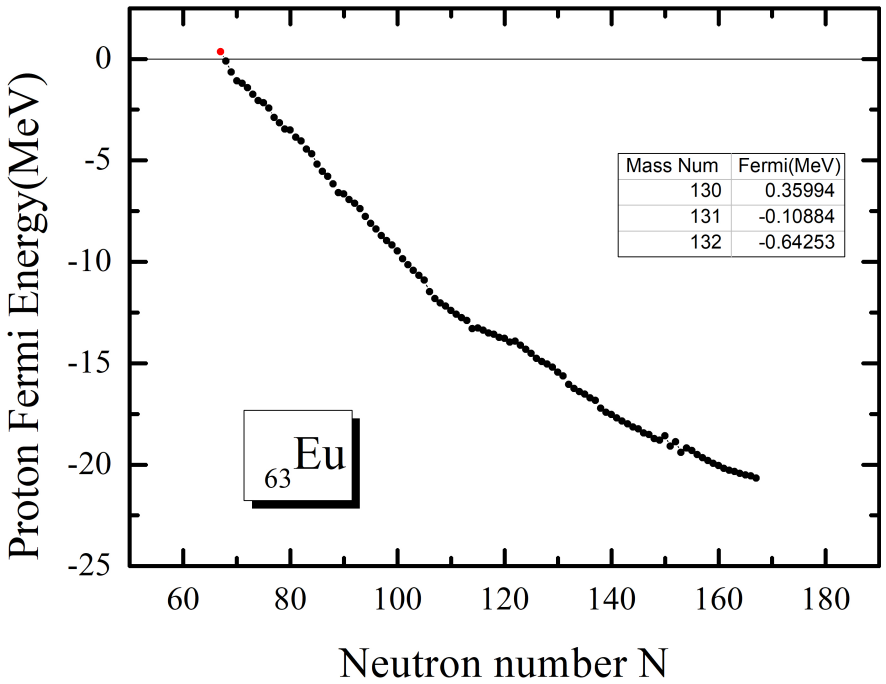
DRHBc overestimates radius for Tb ($Z = 65$)

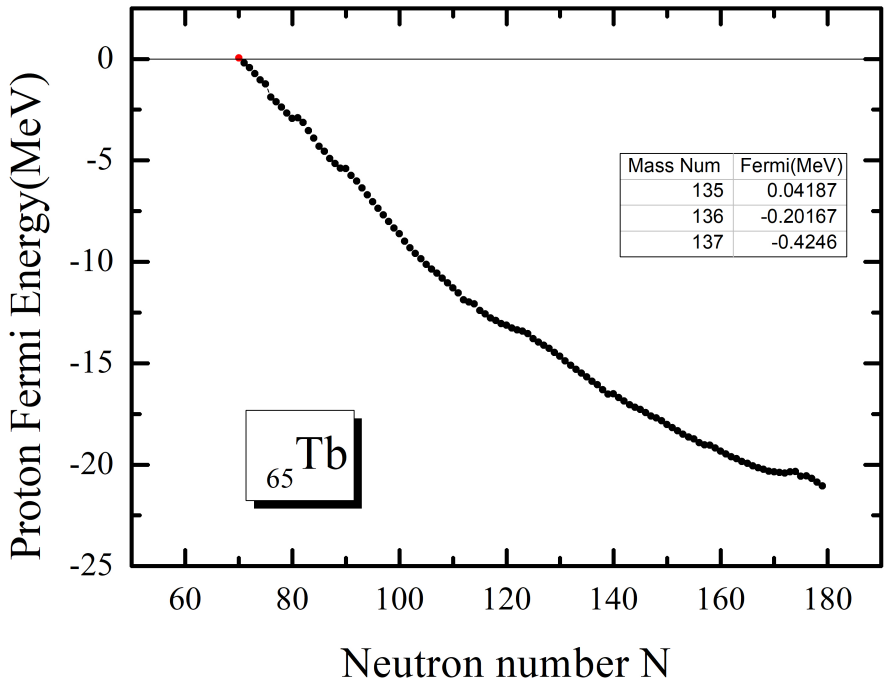
Neutron Fermi Energy: Eu and Tb





Proton Fermi Energy: Eu and Tb





Extend the proton drip line from ^{137}Tb to ^{136}Tb

Summary and Future plan

- Calculations completed (Odd-even isotopes)
  - All isotopes completed
- Calculations completed (Odd-odd isotopes)
  - All isotopes completed
- Future calculations
  - Constrained and unconstrained calculation for Z=129

Physics conclusion

- Nuclei mass prediction can be improved by including rotational correction
- Large difference between experimental and DRHBc S_{2n} near magic number (N=82)
- There exist bounded odd-odd and odd-even nuclei beyond one-neutron drip line (for Eu)
- Deformation matches with the evolution of potential energy
- DRHBc overestimates radius for Tb
- Odd-odd nuclei can extend the proton (for Tb) drip line