第一届安徽省核物理研讨会

Kr and Sr isotopes with the deformed relativistic Hartree-Bogoliubov theory in

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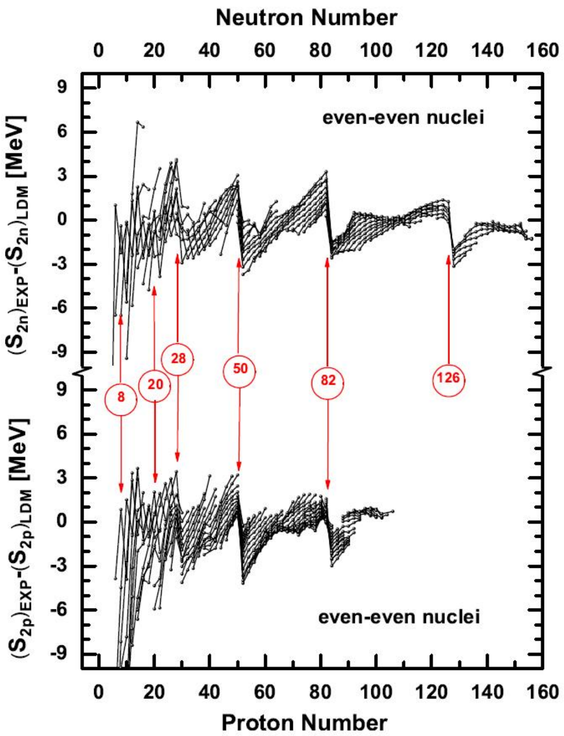
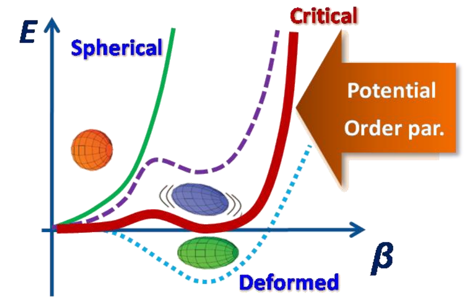
Introduction

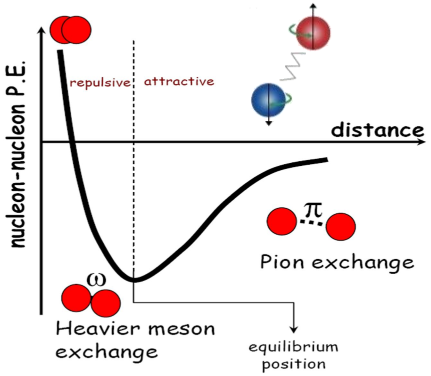
- Nuclear mass plays important roles not only in various aspects of nuclear physics, but also in other branches of physics, such as astrophysics and nuclear engineering. [Lunney2003RMP, Burbidge1957RMP]

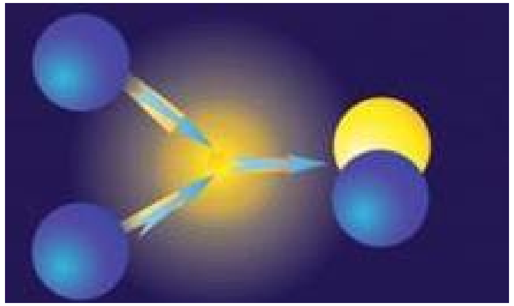
✓ Nuclear physics: it contains wealth of nuclear structure information such as magic number and shape transition, and it is widely used to extract nuclear effective interactions.

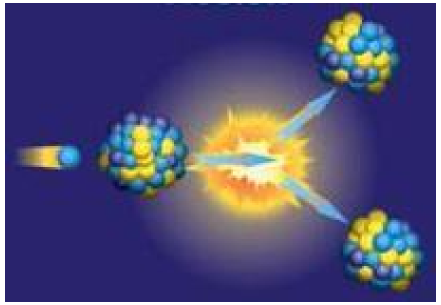
✓ Other branches: it is essential to determine nuclear reaction and decay energies, so it is important in astrophysics and nuclear engineering.

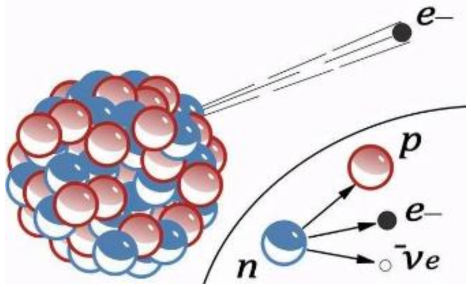


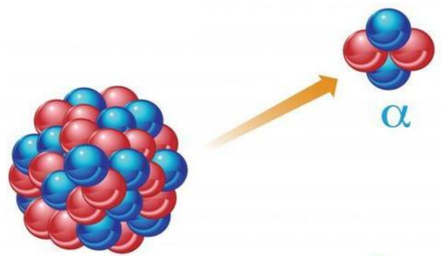






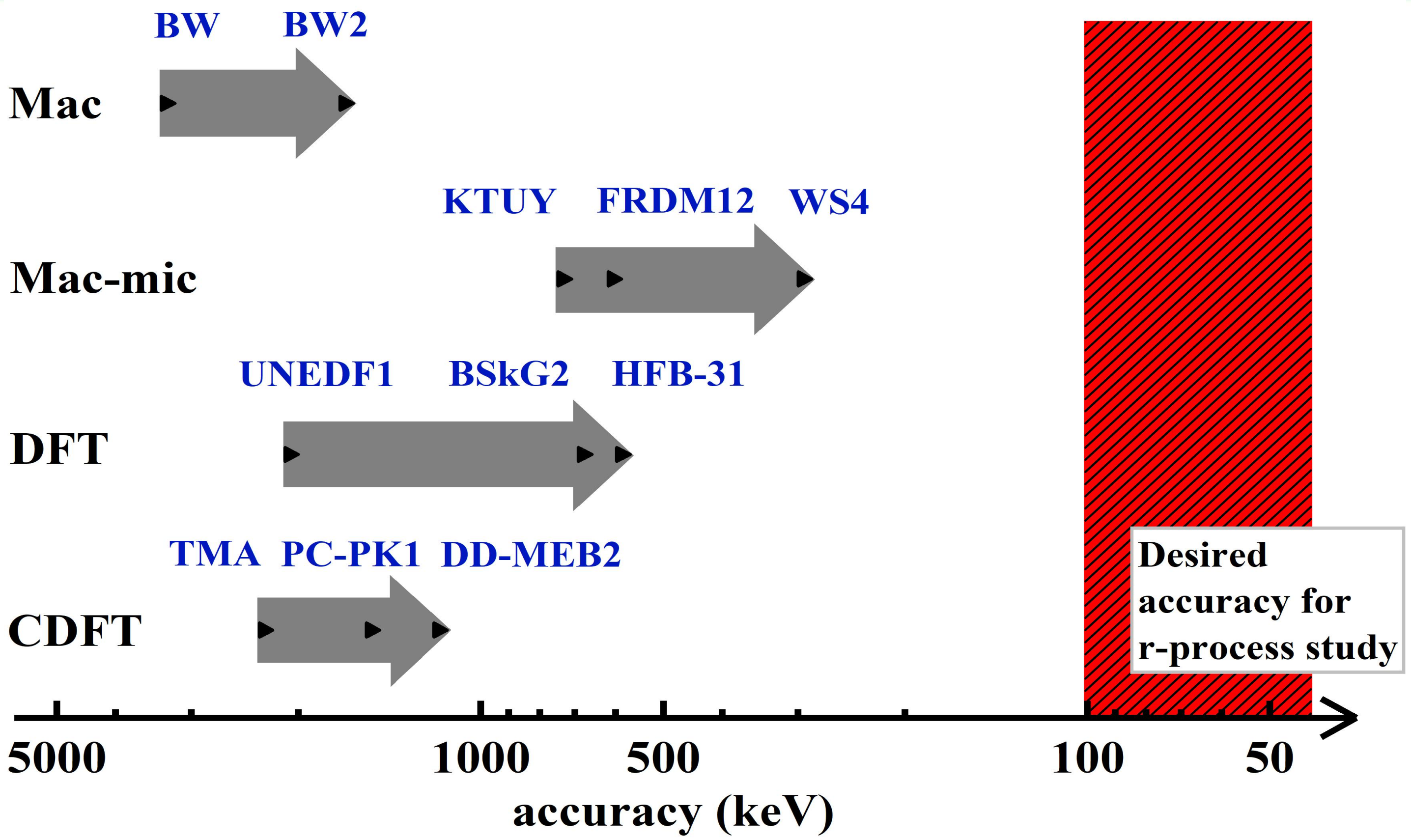






Nuclear mass models

- Macroscopic models: BW, BW2 [Weizsäcker1935ZP, Bethe1937RMP, Kirson2008NPA]
- Macro-microscopic models: KTUY, FRDM, WS4 [Koura2050PTP, Moller2012PRL, Wang2014PLB]
- Density functional theory: UNEDF1, BSkG2,HFB-31 [Kortelainen2014PRC, Scamps2021EPJA, Goriely2016PRC]
- Covariant density functional theory: TMA, PC-PK1, DD-MEB2[Geng2005PTP, Zhang2022ADNDT, Arteaga2016EPJA]



Deformed relativistic Hartree-Bogoliubov theory in continuum (DRHBc) +2DCH:

- Microscopic relativistic model including superfluidity, deformation, and continuum effects, which self-consistently describes g.s. and excited states for both stable and exotic nuclei [Zhou2010PRC, Zhang2020PRC, … …].
- Employ the two-dimensional collective Hamiltonian (2DCH) method to consider the beyond-mean-field dynamical correlation energies(DCEs) are essential for describing nuclei with different deformations, including (near) spherical nuclei.[Sun2022CPC]

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Numerical details

Deformed relativistic Hartree-Bogoliubov theory in continuum with a point-coupling functional: Examples of even-even Nd isotopes

Kaiyuan Zhang (张开元),[1] Myung-Ki Cheoun,[2] Yong-Beom Choi,[3] Pooi Seong Chong,[4] Jianmin Dong (董建敏),[5,6] Lisheng Geng (耿立升),[7] Eunja Ha,[2] Xiaotao He (贺晓涛),[8] Chan Heo,[4] Meng Chit Ho,[4] Eun Jin In,[9] Seonghyun Kim,[2] Youngman Kim,[10] Chang-Hwan Lee,[3] Jenny Lee,[4] Zhipan Li (李志攀),[11] Tianpeng Luo (骆天鹏),[1] Jie Meng (孟杰),[1,*] Myeong-Hwan Mun,[12] Zhongming Niu (牛中明),[13,14] Cong Pan (潘琮),[1] Panagiota Papakonstantinou,[15] Xinle Shang (尚新乐),[5,6] Caiwan Shen (沈彩万),[16] Guofang Shen (申国防),[7] Wei Sun (孙玮),[11] Xiang-Xiang Sun (孙向向),[17,18] Chi Kin Tam,[4] Thaivayongnou ,[7] Chen Wang (王晨),[8] Sau Hei Wong,[4] Xuewei Xia (夏学伟),[19] Yijun Yan (晏一珺),[5,6] Ryan Wai-Yen Yeung,[4] To Chung Yiu,[4] Shuangquan Zhang (张双全),[1] Wei Zhang (张炜),[20] and Shan-Gui Zhou (周善贵)[17,18,21,22]
(DRHBc Mass Table Collaboration)

- Nuclei: Even-even Kr to Zr (Z= 36-40) isotopes
- Version: Code_DRHBc_202112
- Density functional: PC-PK1
- Mesh size: Δr=0.1 fm; Box size: R_{box}=20 fm
- Angular momentum cutoff: J_{max}=23/2
- Energy cutoff: E_{cut} =300 MeV
- Pairing strength: V_0=-325.0 MeV fm^3
- Legendre expansion: λ_{max}=6 (8≤Z≤ 80)

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Binding energy

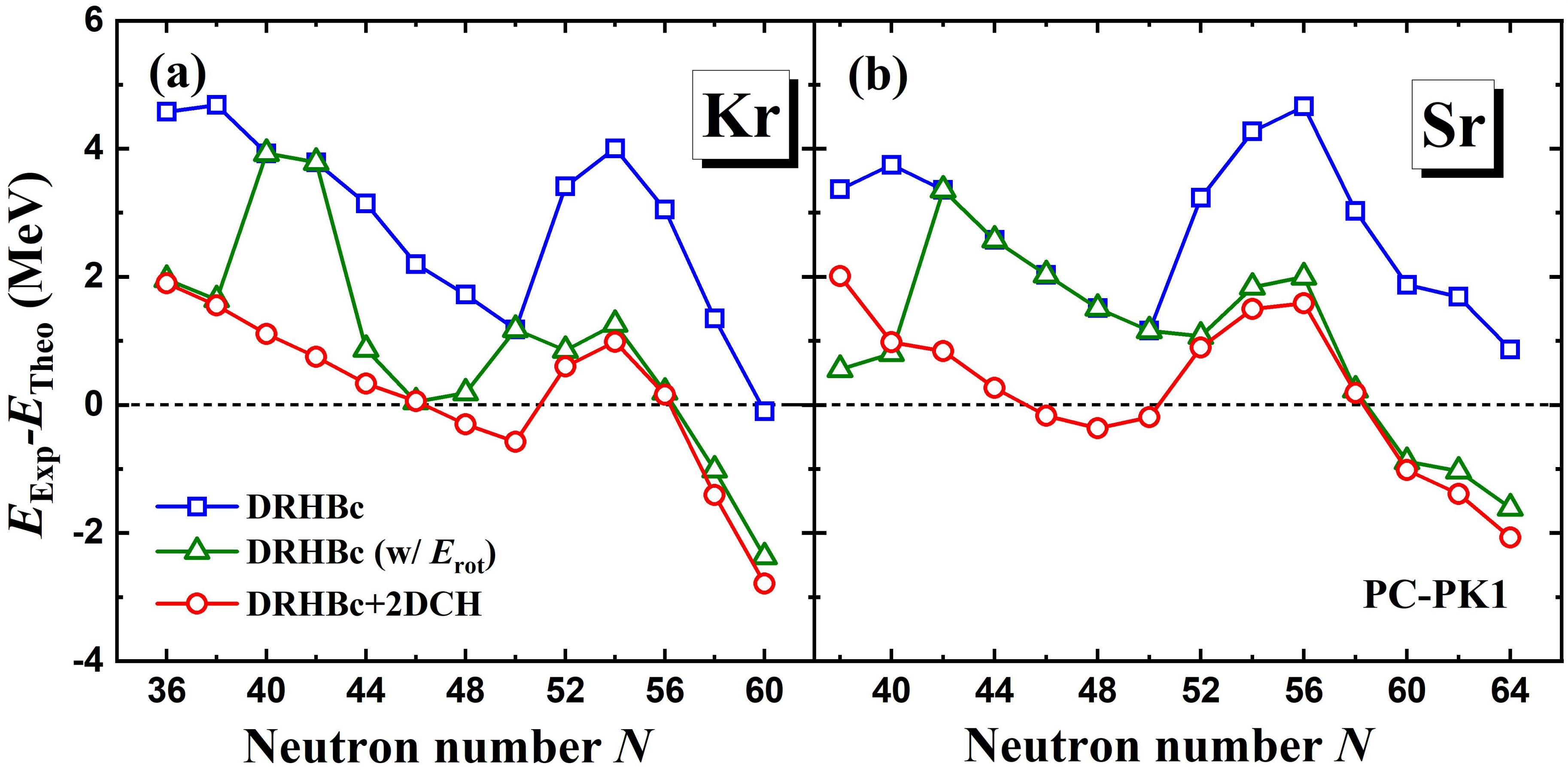
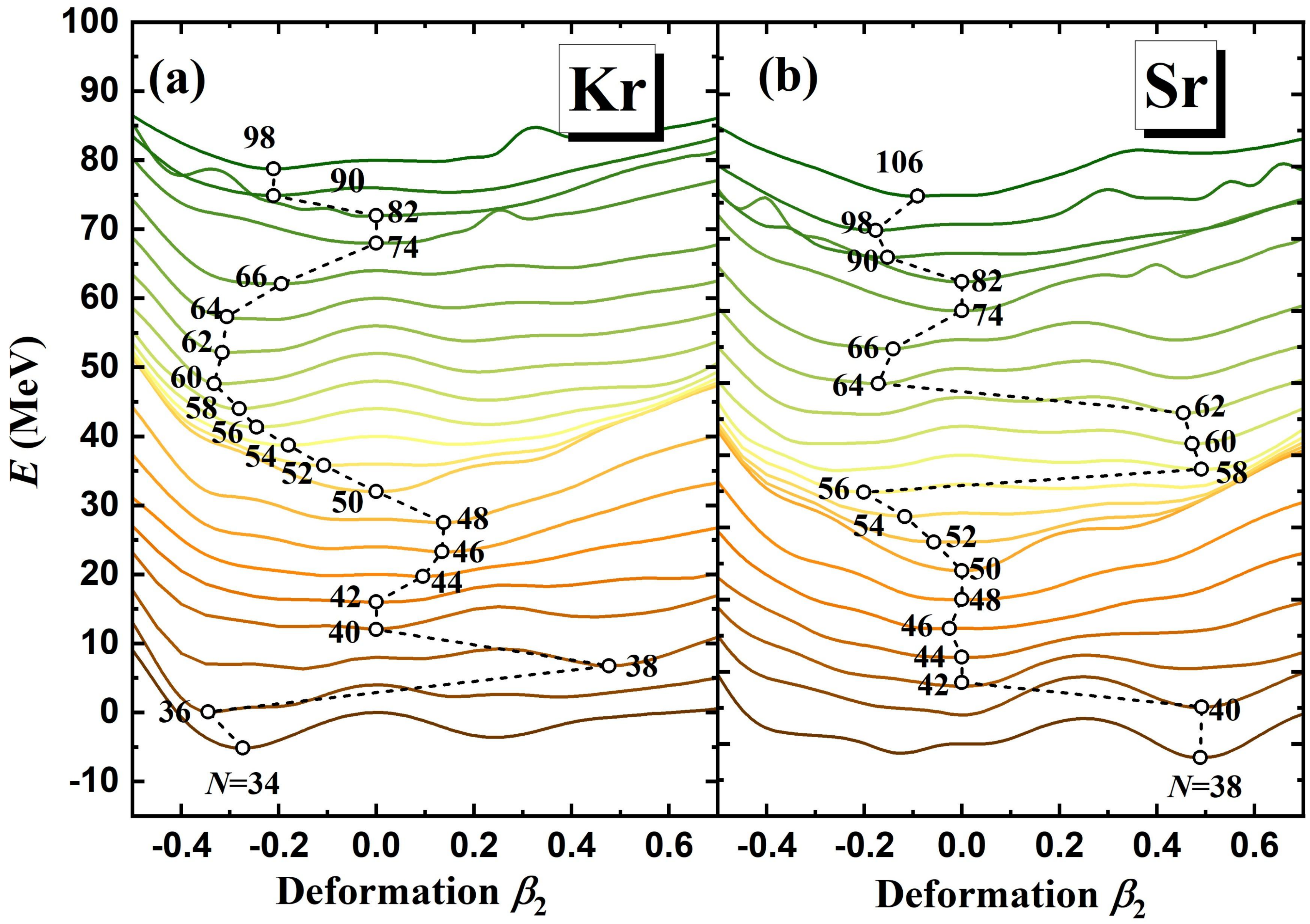


Fig. The differences between the experimental binding energies and the DRHBc results, the DRHBc results with E_{rot}, and the DRHBc+2DCH results.

- σ_{rms} are 3.1, 1.8 and 1.2 MeV DRHBc, DRHBc w/ E_{rot} and DRHBc+2DCH.
- The DCEs are essential for describing nuclei with different deformations, including (near) spherical nuclei.

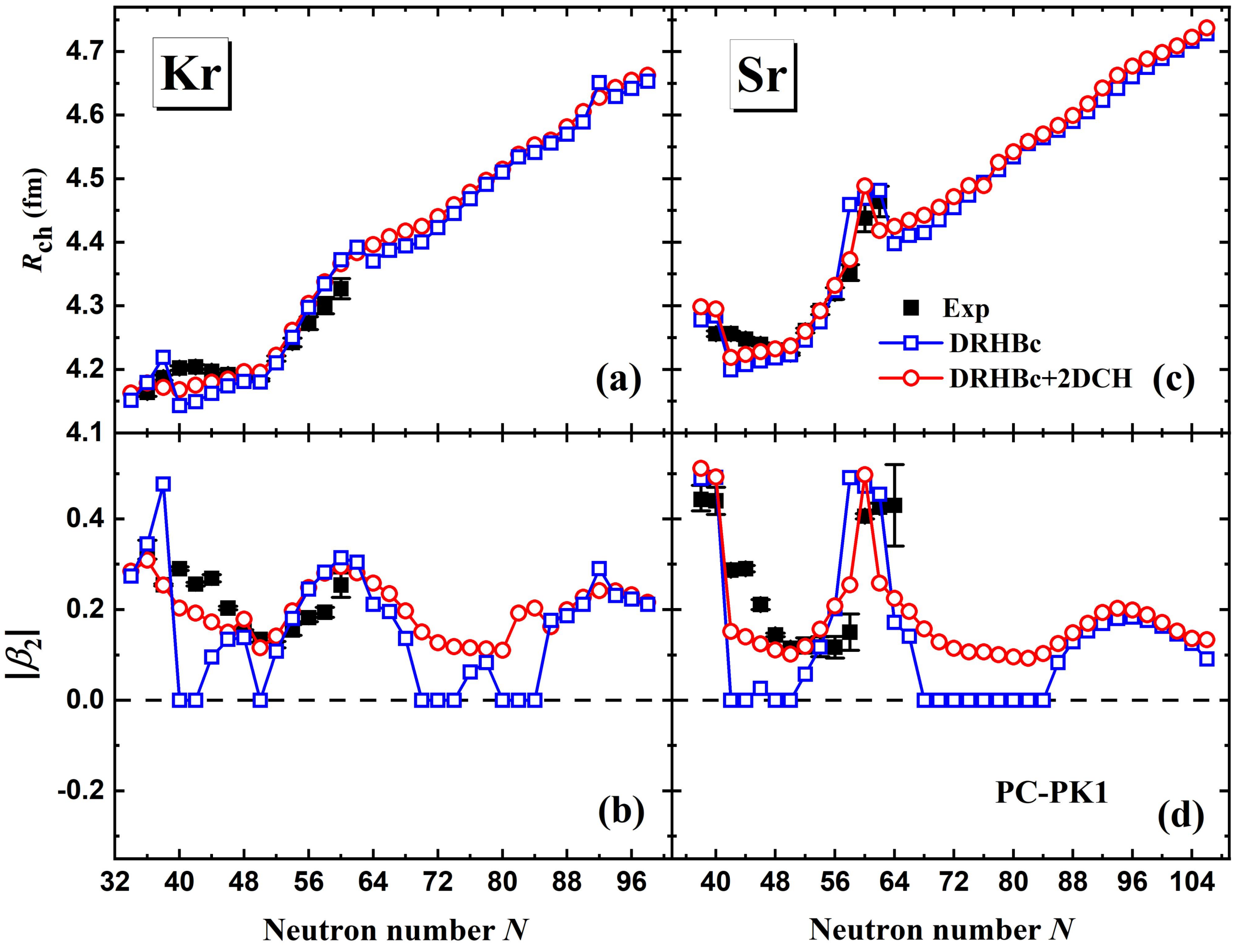
Binding energy



- The soft potentials around the global minima are found for nuclei with neutron number around magic number N = 50.
- possible candidates for shape coexistence: ^{74}Kr, ^{90}Kr and ^{92}Kr; ^{76}Sr, ^{78}Sr and ^{94}Sr

Fig. Evolution of the PECs for Kr (a) and Sr (b) isotopes from the constrained DRHBc calculations.

Deformation and charge radius



- The calculated deformations with the DRHBc+2DCH better agree with the experimental deformation data.
- The charge radius is closely related to the deformation.

Fig. The Charge radii and deformations with the DRHBc and the DRHBc+2DCH results.

Binding energy

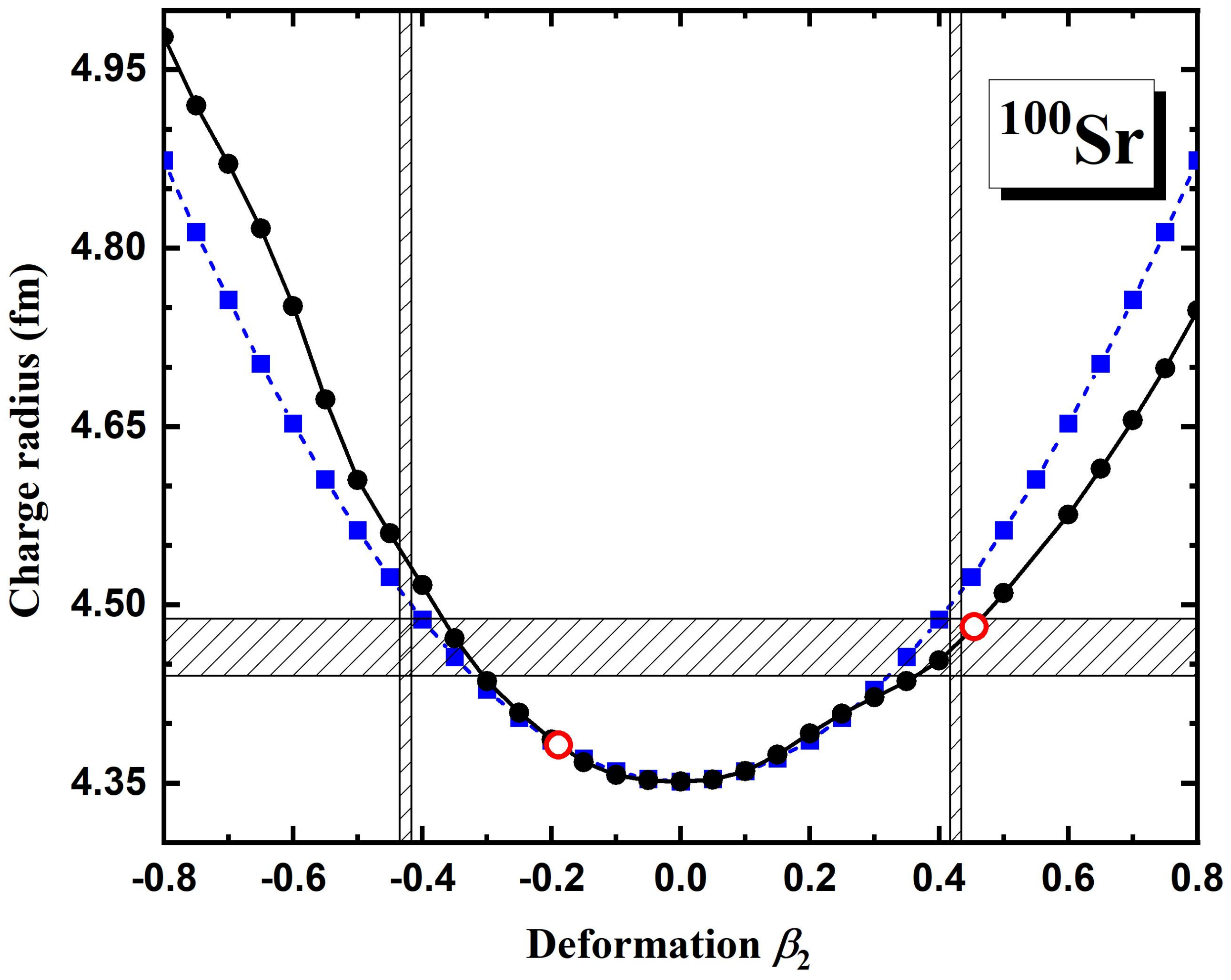


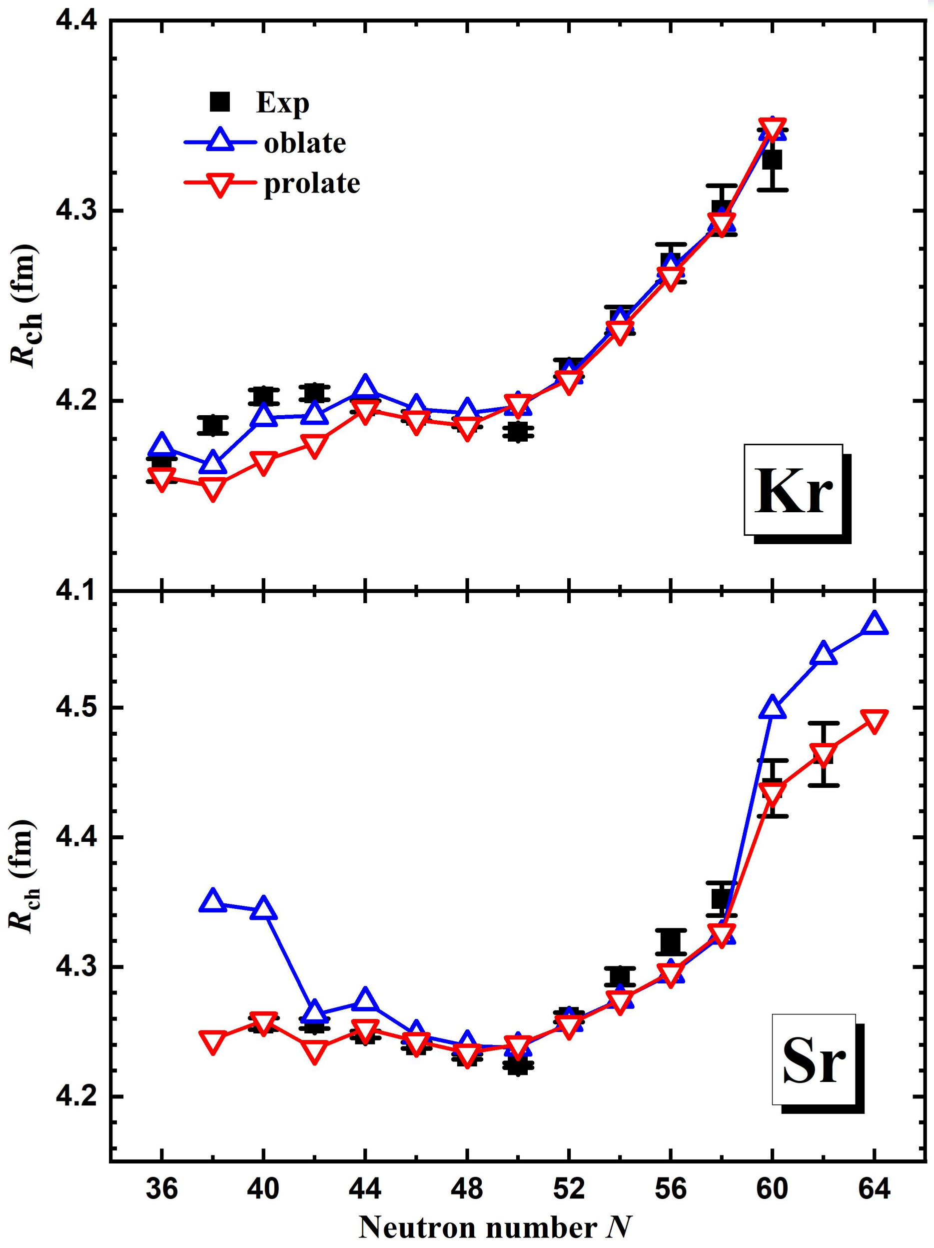
Fig. Charge radius as a function of deformation for ^{100}Sr.

- The empirical formula shows that the charge radius is independent of the sign of the deformation:

$$R_{\mathrm{ch}} = R_{\mathrm{ch0}}\left(1+\frac{5}{4\pi}\beta_2^2\right)$$

- The DRHBc also predict a prolate minimum at this region, which agree well with the experimental charge radius and deformation.
- The charge radius increases more rapidly along the oblate.

Binding energy



- At least one charge radius from the constrained DRHBc calculation can reproduce the experimental value.
- The correlation between charge radius and deformation can help to determine the oblate or prolate shape of a nucleus.

Fig. Charge radii from the constrained DRHBc calculations for Kr and Sr isotopes.

Contents

Summary and prospect

Summary:

- The calculated deformations with the DRHBc+2DCH better agree with the experimental deformation data.
- The constrained DRHBc calculations are helpful to distinguish the oblate or prolate shape for the nuclei with deformation $\beta_2 \geq 0.3$ by combining with the experimental charge radii and absolute values of deformations.

Perspectives:

- Large-scale calculations for even-even nuclei using DRHBc+2DCH are underway.

Collaborators：

Anhui University： Zhongming Niu (牛中明)

Sichuan Normal University： Xuewei Xia (夏学伟)

Southwest University： Zhipan Li (李志攀)、Wei Sun (孙玮)

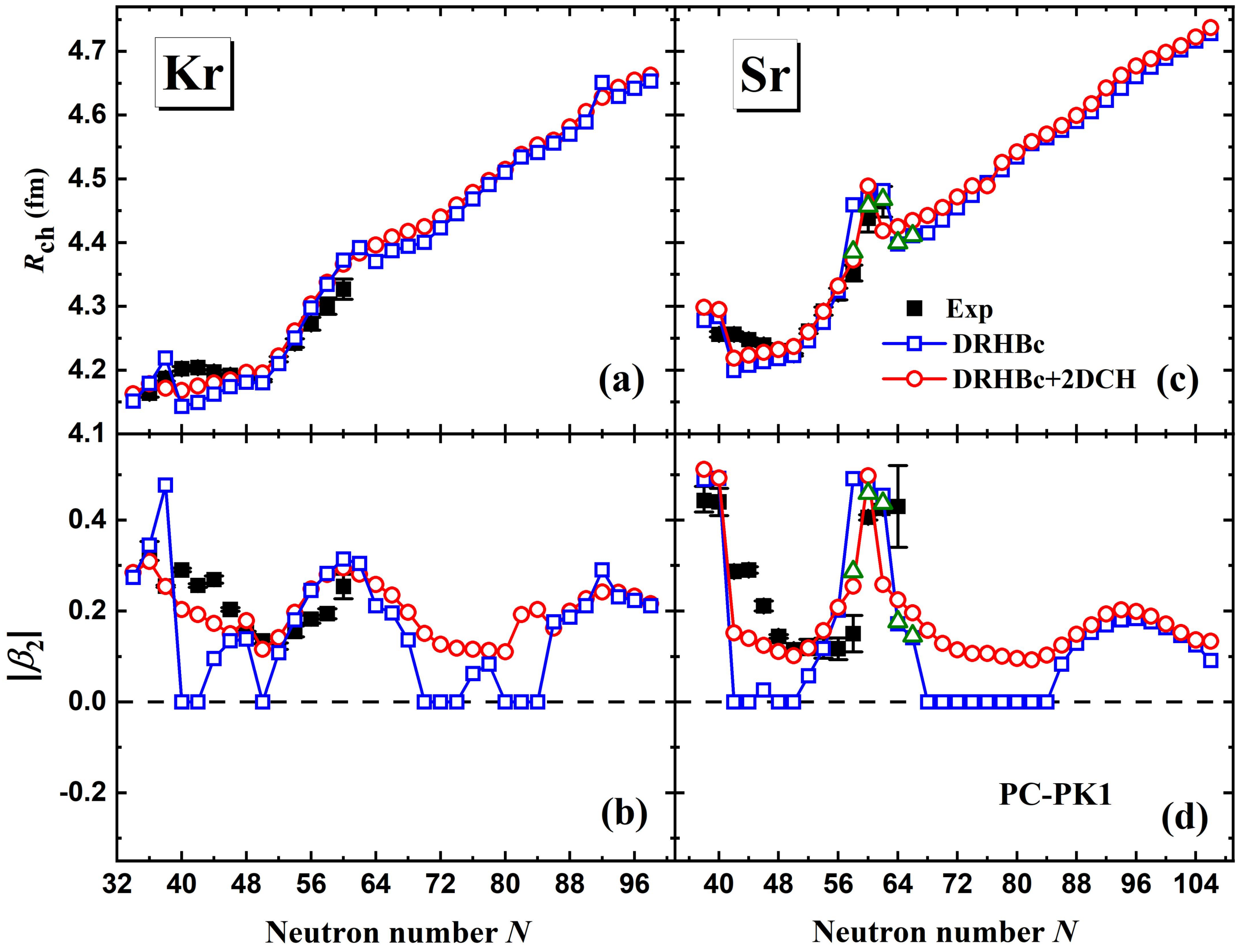
Thank you!

The 2DCH collective Hamiltonian is

$$
\begin{aligned}
\hat{H}_{\text{coll}} &= \hat{T}_{\text{vib}} + \hat{T}_{\text{rot}} + V_{\text{coll}} \\
&= -\frac{\hbar^2}{2}\frac{1}{\sqrt{\mathcal{I}B_{\beta\beta}}}\frac{\partial}{\partial\beta}\sqrt{\frac{\mathcal{I}}{B_{\beta\beta}}}\frac{\partial}{\partial\beta} + \frac{\hat{J}^2}{2\mathcal{I}} + V_{\text{coll}}
\end{aligned}
$$

The 5DCH

Nuclear excitations determined by quadrupole vibrational and rotational degrees of freedom can be treated simultaneously by considering five quadrupole collective coordinates to describe the surface of a deformed nucleus.


Kr
Sr
R_{ch} (fm)
4.7
4.6
4.5
4.4
4.3
4.2
4.1
(a)
(c)
Exp
DRHBc
DRHBc+2DCH
$|\beta_2|$
0.4
0.2
0.0
-0.2
(b)
(d)
PC-PK1
32
40
48
56
64
72
80
88
96
104
Neutron number N
Neutron number N