中山大學中法核工程与技术学院
Institut franco-chinois de l'énergie nucléaire université Sun Yat-sen

基于统一有效核力的壳模型研究初探

袁岑溪
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中山大學中法核工程与技术学院
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学院简介

2009年，中法签署《关于成立中山大学中法核工程与技术学院的合作协议》，首个两国总理见证的国际合作办学案例

2010年，中山大学与法国原子能与可替代委员会(CEA)、法国格勒诺布尔理工大学为首的民用核能工程师教学联盟合作组建中山大学中法核工程与技术学院，本硕联读6年约9000课时，工人-助理工程师-工程师三段式共9个月实习

2012年核能与核技术工程二级学科专业硕士点；2015年核科学与技术一级学科硕士点；2016年核工程力学二级学科博士点； 2021年核科学与技术一级学科博士点

结合法国工程师教育和中国高等教育资源，培养核能领域的一流工程师，通过法国工程师职衔委员会(CTI)认证和欧洲工程教育认证(EUR-ACE)，合格毕业生不出国门就能拿到欧洲认可的证书。

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中法核工程与技术学院培养模式

法国CTI认证证书

EUR-ACE 工程教育认证

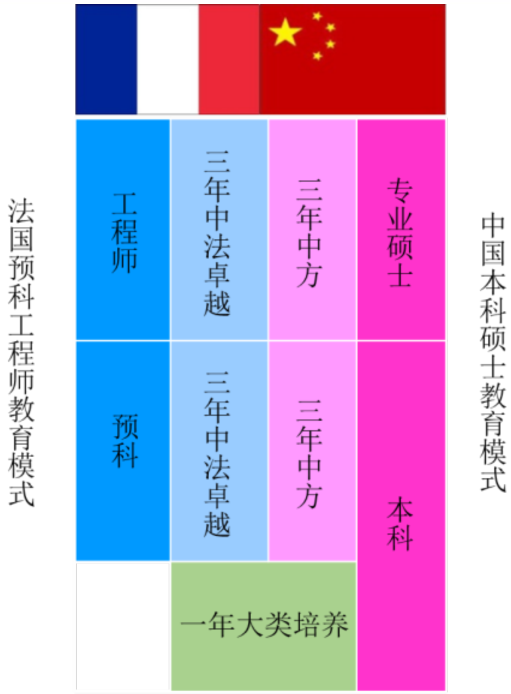
我国核领域率先获得国际工程教育认证

大类培养、中法融合
(法语第二外语)
1+3+3

- 1年本科**大类培养**
- 3年本科学院培养 **中法融合**
- 3年硕士 **增设核技术方向**

高推免率+高就业率+高国际交流率

国内外共建**20多个实习基地**

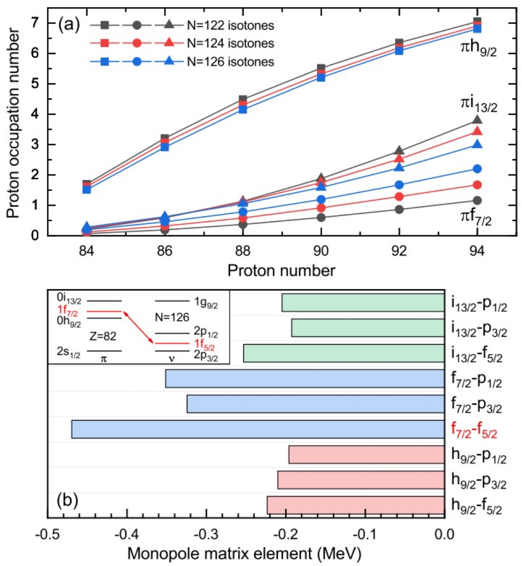


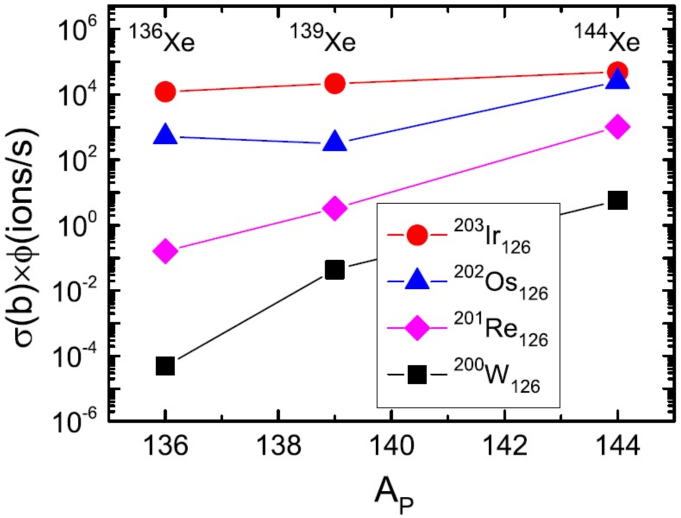
中法核学院1+3+3模式

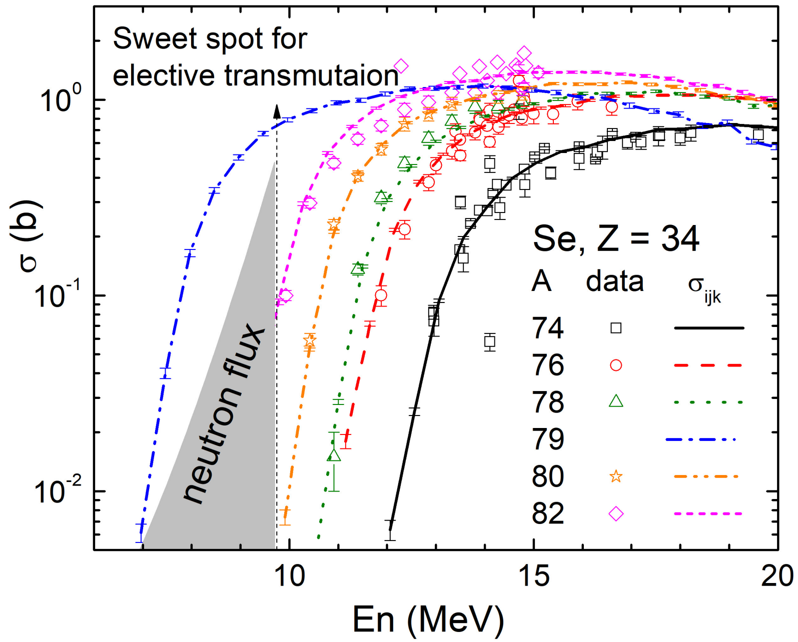
实习类型	实习时长
工人实习	1个月 大三结束后
助理工程师实习	2个月 研一结束后
工程师实习	6个月 研二上学期中

核物理与核数据团队

- 核物理与核数据学科现有成员11人，其中副教授9人，主要研究领域为核物理、核数据、中微子物理等。在新核素与新同核异能态合成及性质、奇特核结构、多核子与重离子反应、人工智能核数据、中微子测量等方向做出了一些代表性工作，研究方向：
  - 理论模型的发展与核数据预测
  - 核数据评估与预测相关算法的发展
  - 核数据与中微子测量及相关设备研发





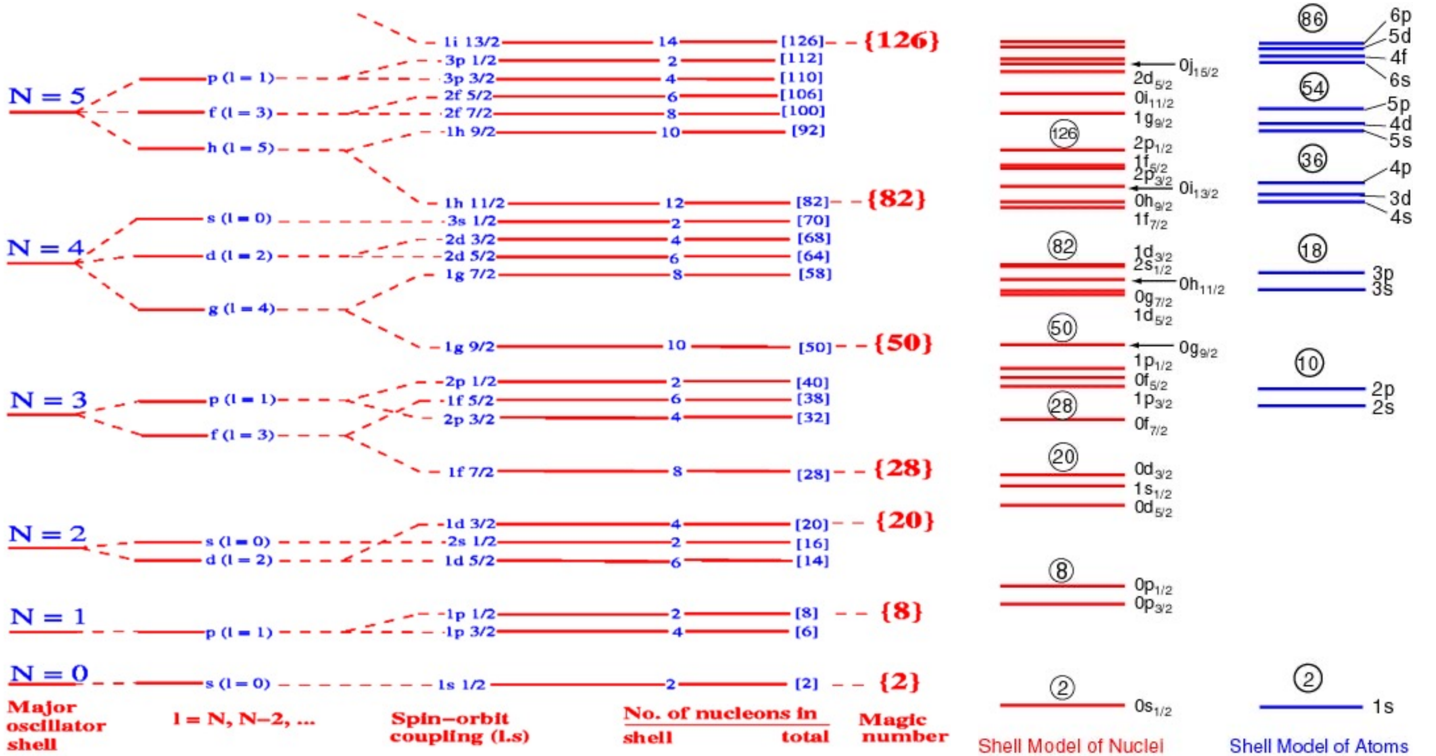


报告提纲

- 组态混合壳模型
- 轻核中的跨壳激发和镜像不对称性
- 中重核中的新核素和新同核异能态
- 统一描述中重核的相互作用初探
- 总结

组态混合壳模型

原子核的质子数(中子数)为2，8，20，28，50，82和中子数为126时，原子核特别稳定，这些数目叫做“幻数”。对确定数目的质子和中子，两者分别从低到高占据这些能级，一种占据称为一个单粒子组态，进一步可考虑多种组态间的组态混合



组态混合壳模型

单粒子基矢
(通常为谐振子基)

选择部分轨道
作为模型空间

构建基于此空间的有效
哈密顿量

$$H = \sum_i \epsilon_i n_i + \sum_{i,j,k,l} v_{ij,kl} a_i^\dagger a_j^\dagger a_l a_k,$$

列出模型空间内的所有
可能的组态混合波函数

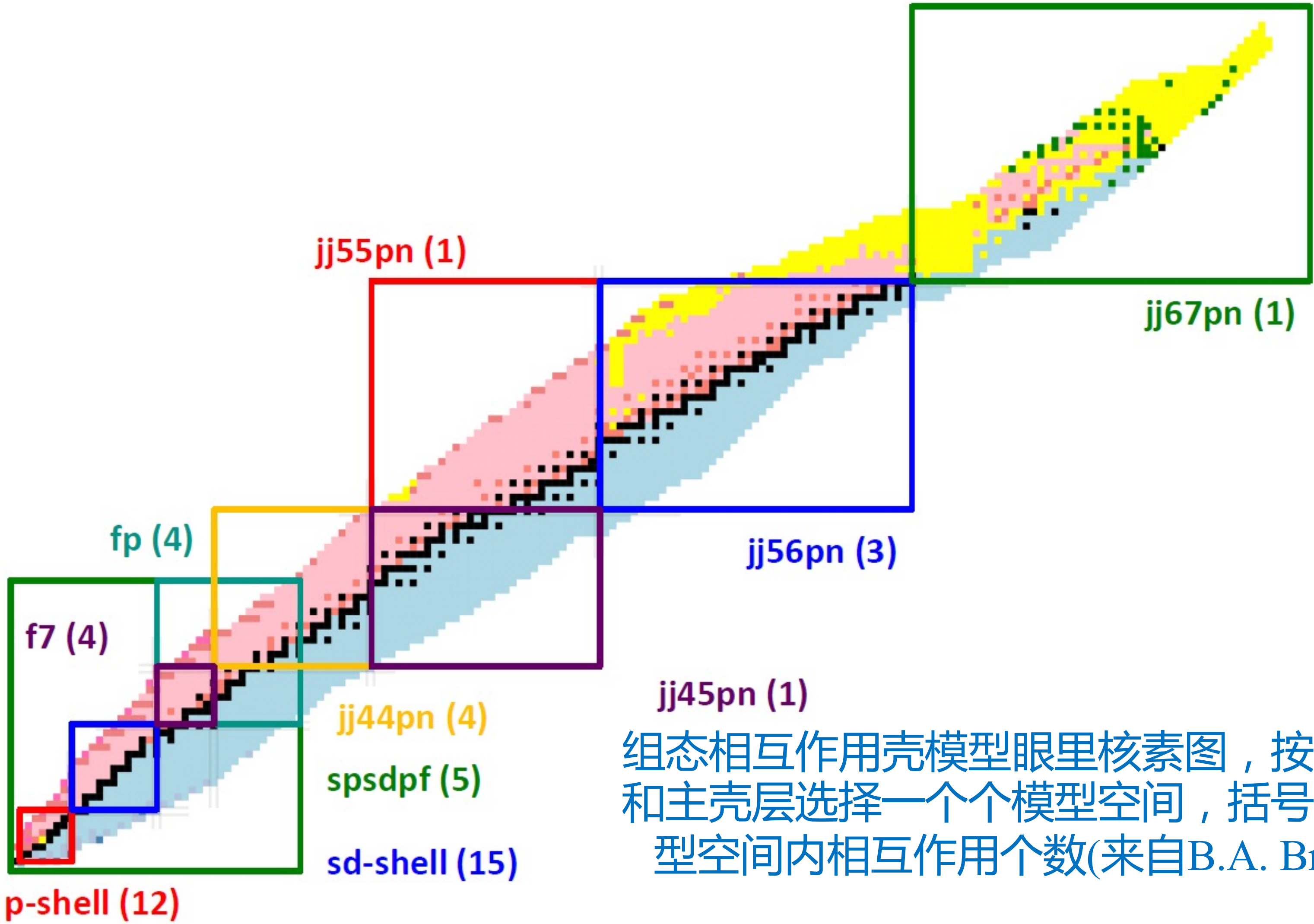
在模型空间内求解薛定谔方程
(各个态的能量和波函数)

$$\boldsymbol{H}\Psi = E\Psi \rightarrow \boldsymbol{H}_{\text{eff}}\Psi_{\text{eff}} = E\Psi_{\text{eff}}$$

基于波函数求解其他性质：电磁矩和跃迁、beta衰变、谱因子等等

组态相互作用壳模型的三要素：对一个核选择模型空间、构建有效哈密顿量、通过程序计算

模型空间



组态相互作用壳模型眼里核素图，按照幻数和主壳层选择一个个模型空间，括号内为模型空间内相互作用个数(来自B.A. Brown)

报告提纲

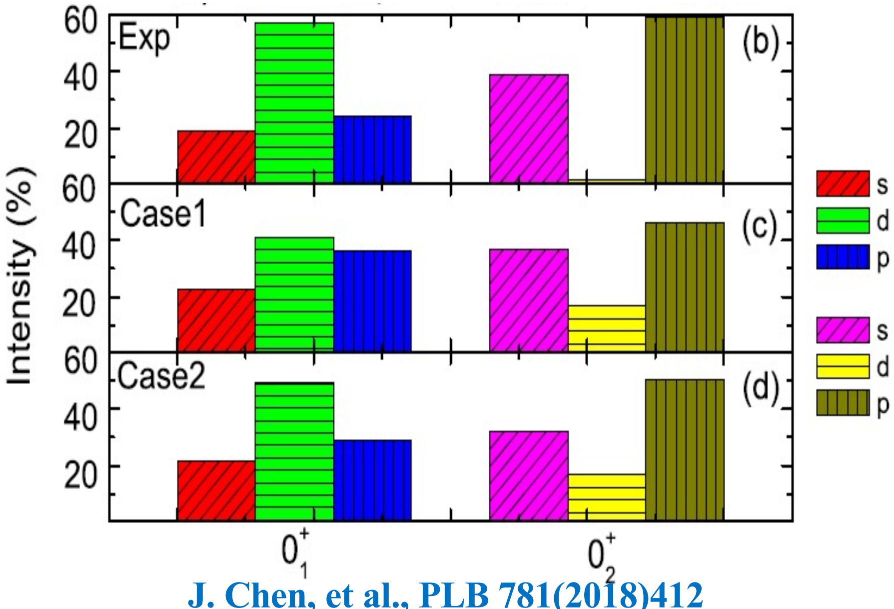
- 组态混合壳模型
- 轻核中的跨壳激发和镜像不对称性
- 中重核中的新核素和新同核异能态
- 统一描述中重核的相互作用初探
- 总结

YSOX, enlarged model space, 0-3hw compared with 0-1hw in WBT…

Cross-shell interaction is reconsidered

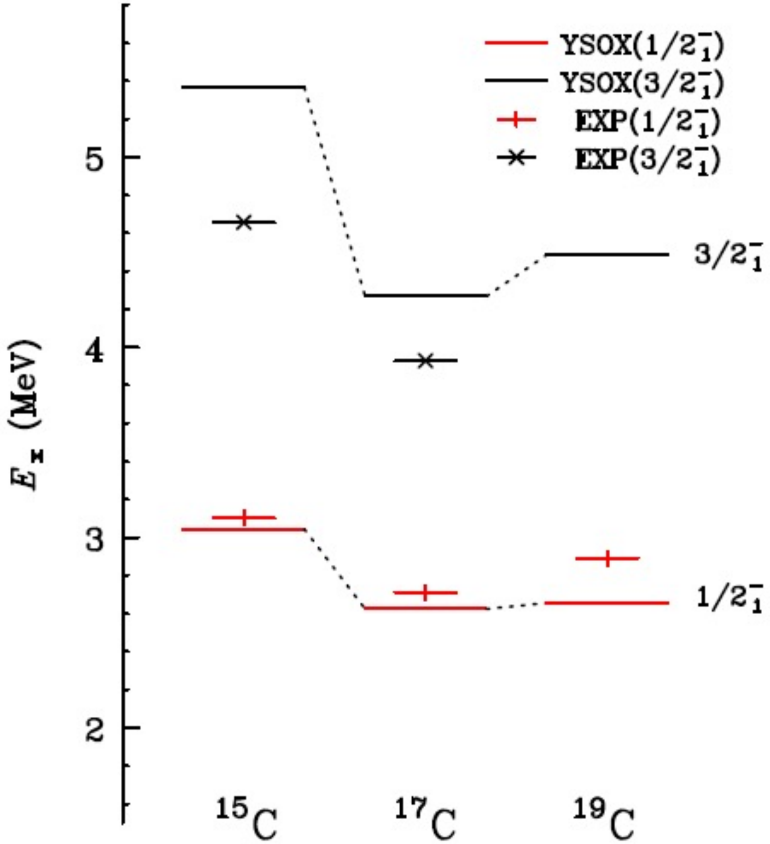
CXY, et al., PRC 85 (2012) 064324

sd component in ^{12}Be beyond N=8



J. Chen, et al., PLB 781(2018)412

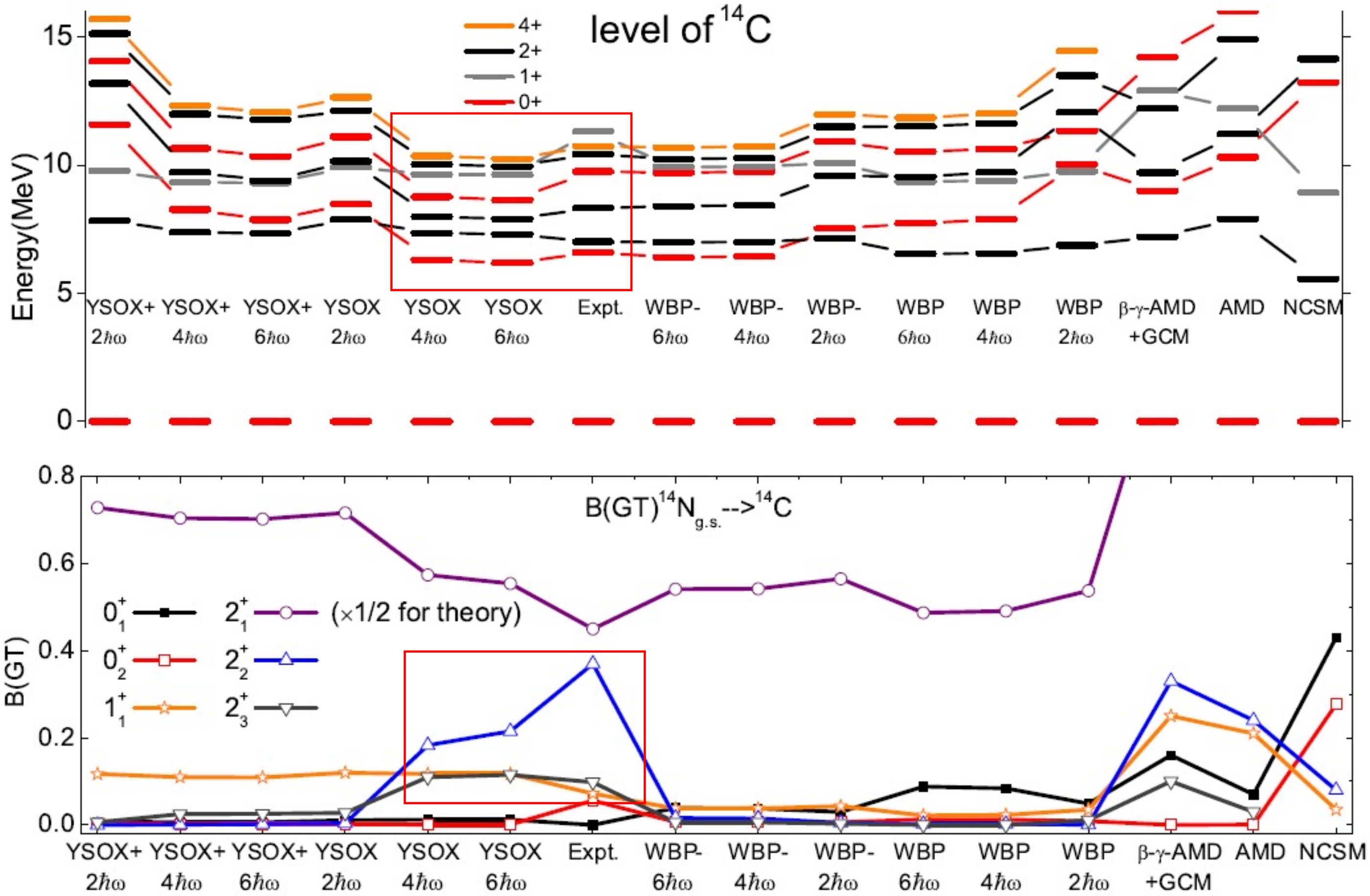
Negative states in ^{17}C and ^{19}C



J.W. Hwang, et al., PLB 769(2017)503

- Impact of 4hw model space and off-diagonal <pp|V|sdsd> (In YSOX and WBP-, reduced strength $\langle pp|V|sdsd\rangle_C$)
- Global optimization considering ^{11}Li, ^{12}Be, ^{13}B, and ^{14}C?

CXY, CPC, 41(10), 104102, (2017)

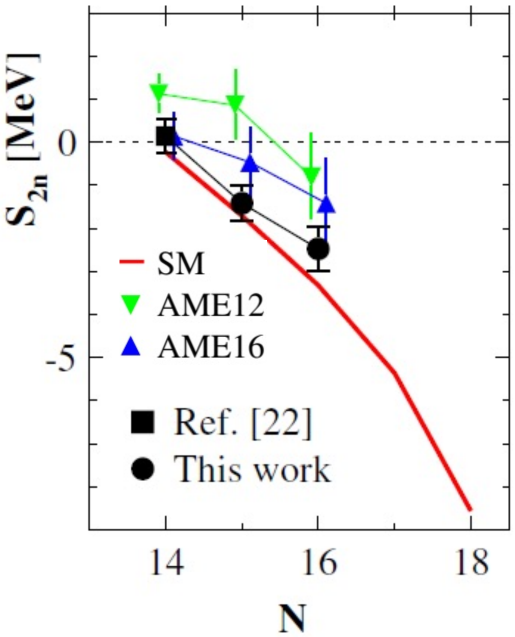


PHYSICAL REVIEW LETTERS **121,** 262502 (2018)

First Observation of ^{20}B and ^{21}B

S. Leblond,[1] F. M. Marqués,[1] J. Gibelin,[1] N. A. Orr,[1] Y. Kondo,[2] T. Nakamura,[2] J. Bonnard,[3] N. Michel,[4,5] N. L. Achouri,[1] T. Aumann,[6,7] H. Baba,[8] F. Delaunay,[1] Q. Deshayes,[1] P. Doornenbal,[8] N. Fukuda,[8] J. W. Hwang,[9] N. Inabe,[8] T. Isobe,[8] D. Kameda,[8] D. Kanno,[2] S. Kim,[9] N. Kobayashi,[2] T. Kobayashi,[10] T. Kubo,[8] J. Lee,[8] R. Minakata,[2] T. Motobayashi,[8] D. Murai,[11] T. Murakami,[12] K. Muto,[10] T. Nakashima,[2] N. Nakatsuka,[12] A. Navin,[13] S. Nishi,[2] S. Ogoshi,[2] H. Otsu,[8] H. Sato,[8] Y. Satou,[9] Y. Shimizu,[8] H. Suzuki,[8] K. Takahashi,[10] H. Takeda,[8] S. Takeuchi,[8] R. Tanaka,[2] Y. Togano,[2,7] A. G. Tuff,[14] M. Vandebrouck,[3] and K. Yoneda[8]

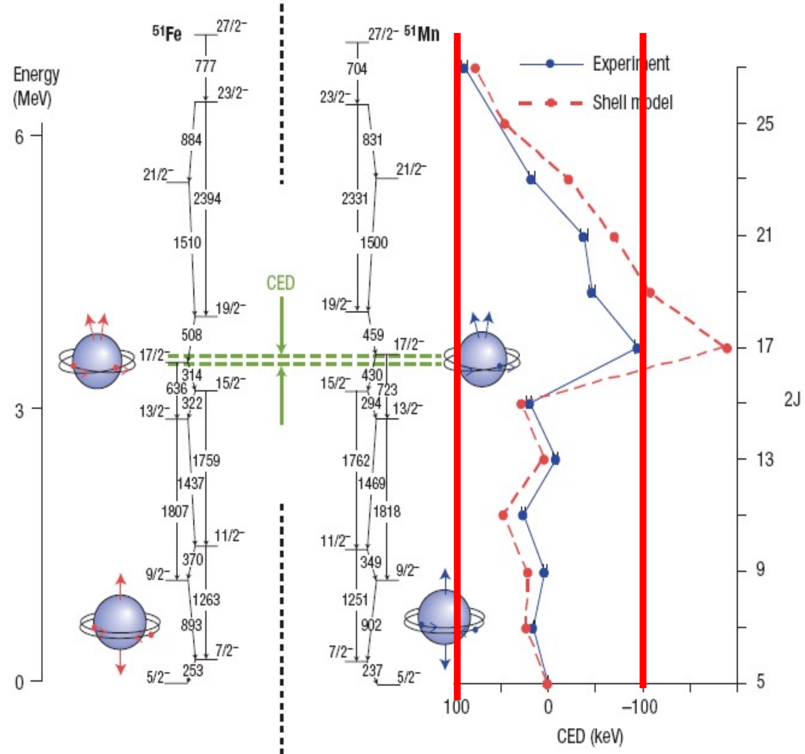
resonances which were detected through their decay into ^{19}B and one or two neutrons. Two-proton removal from ^{22}N populated a prominent resonancelike structure in ^{20}B at around 2.5 MeV above the one-neutron decay threshold, which is interpreted as arising from the closely spaced $1^-, 2^-$ ground-state doublet predicted by the shell model. In the case of proton removal from ^{22}C, the ^{19}B plus one- and two-neutron



(5.0 MeV). Given that the SM predicts the first excited state of ^{21}B to have a strength some 10 times less than the ground state in proton removal from ^{22}C, its nonobservation here is not surprising.

We wish to extend our thanks to the accelerator staff of the RIKEN Nishina Center for their efforts in delivering the intense ^{48}Ca beam, and to C. Yuan for the matrix elements of the YSOX interaction. N. L. A., F. D., J. G., F. M. M., and N. A. O. acknowledge partial support from the Franco-

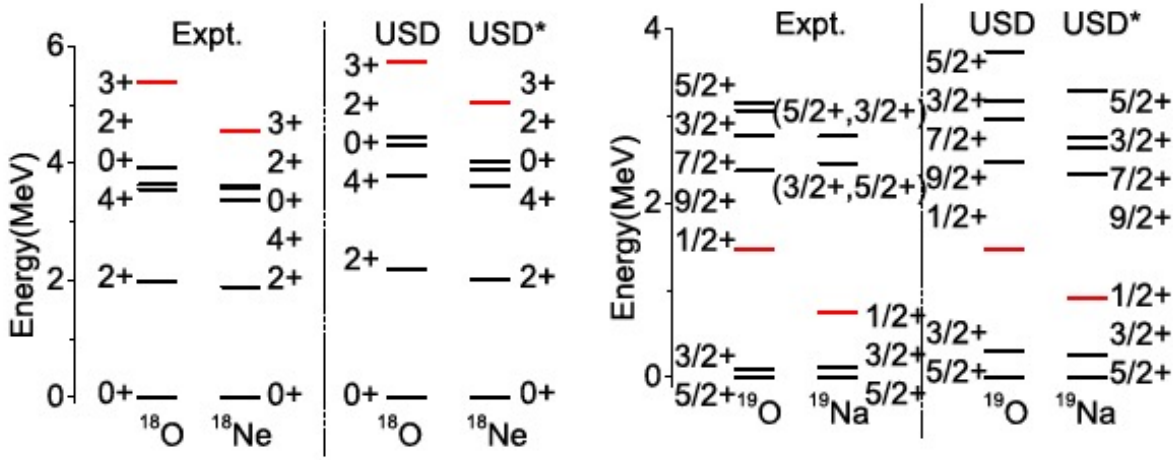
[32] C. Yuan, T. Suzuki, T. Otsuka, F. Xu, and N. Tsunoda, Phys. Rev. C **85**, 064324 (2012).



D. D. Warner, M. A. Bentley, and P. Van Isacker, Nat. Phys. 2, 311 (2006).

Mirror energy difference ~ 0.1MeV, isospin asymmetric

In weakly bound case, MED ~ 1MeV



CXY, C. Qi, F.R. Xu, T. Suzuki, T. Otsuka, PRC 89, 044327 (2014)

IAS of ^{22}Al, Expt. 8829 (406) keV, USD* 9020 keV

PLB766(2017)312

1, The shift of single particle energies

R. G. Thomas, Phys Rev. C 88, 1109 (1952). J. B. Ehrman, Phys Rev. C 81, 412 (1951).

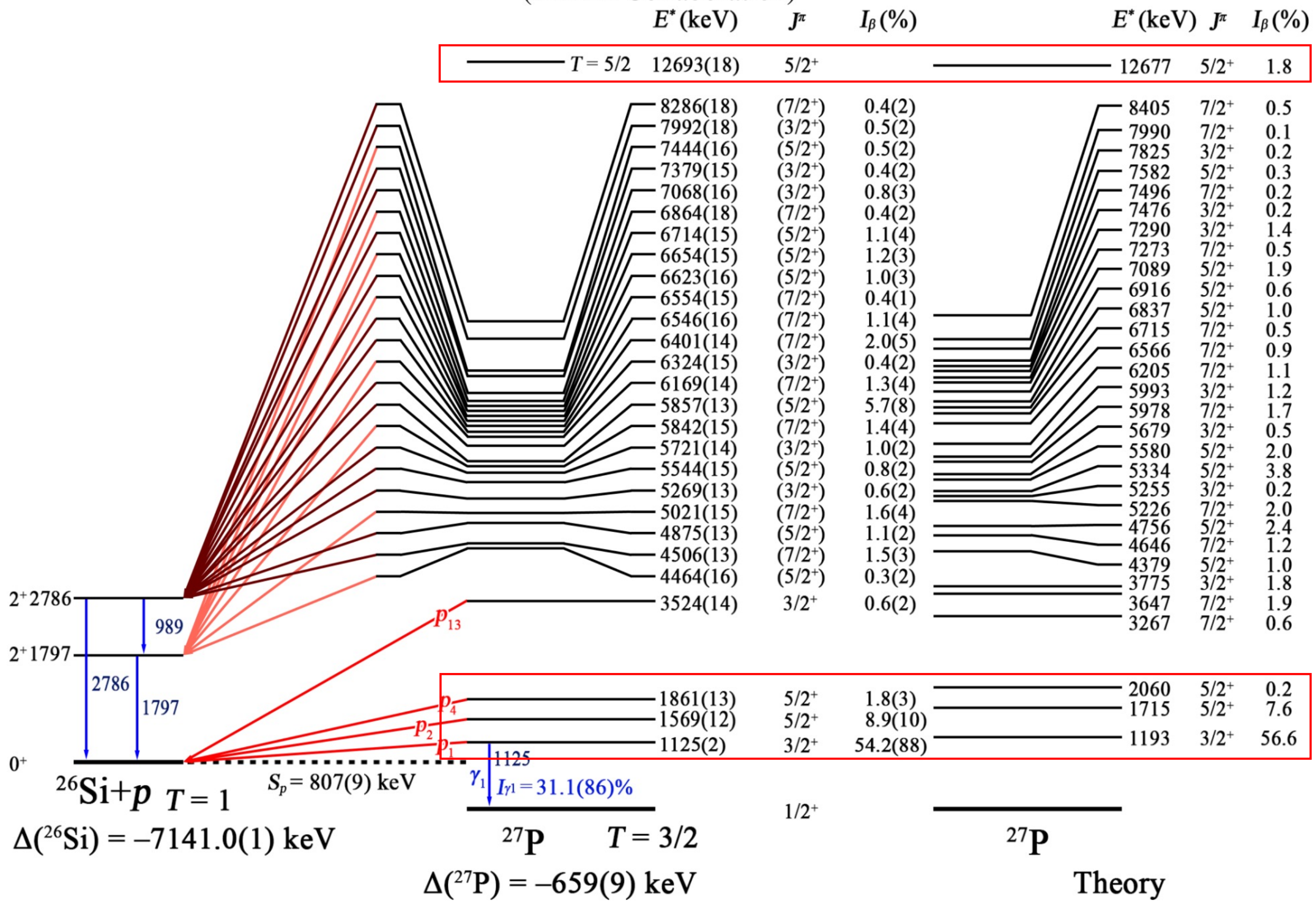
2, The modification of the residual interaction.

K. Ogawa, H. Nakada, S. Hino, and R. Motegi, Phys. Lett. B464, 157 (1999).

PHYSICAL REVIEW C **99**, 064312 (2019)

β-decay spectroscopy of ^{27}S

(RIBLL Collaboration)



PHYSICAL REVIEW LETTERS **127,** 262502 (2021)

Editors' Suggestion | Featured in Physics

First Observation of the Four-Proton Unbound Nucleus ^{18}Mg

Y. Jin,[1,*] C. Y. Niu,[2,*] K. W. Brown,[2,3,†] Z. H. Li,[1,‡] H. Hua,[1,§] A. K. Anthony,[2,4] J. Barney,[2,4] R. J. Charity,[5] J. Crosby,[2,4] D. Dell'Aquila,[2] J. M. Elson,[5] J. Estee,[2,4] M. Ghazali,[2,4] G. Jhang,[2] J. G. Li,[1,6,7] W. G. Lynch,[2,4] N. Michel,[6,7] L. G. Sobotka,[5,8] S. Sweany,[2,4] F. C. E. Teh,[2,4] A. Thomas,[5] C. Y. Tsang,[2,4] M. B. Tsang,[2,4] S. M. Wang,[9,10] H. Y. Wu,[1] C. X. Yuan,[11] and K. Zhu[2,4]

[1]*School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, Chi*
[2]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
[3]*Department of Chemistry, Michigan State University, East Lansing, Michigan 48824, USA*
[4]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824, USA*
[5]*Department of Chemistry, Washington University, St. Louis, Missouri 63130, USA*
[6]*Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China*
[7]*School of Nuclear Science and Technology, University of Chinese Academy of Sciences, Beijing 100049, China*
[8]*Department of Physics, Washington University, St. Louis, Missouri 63130, USA*
[9]*Institute of Modern Physics, Fudan University, Shanghai 200433, China*
[10]*FRIB Laboratory, Michigan State University, East Lansing, Michigan 48824, USA*
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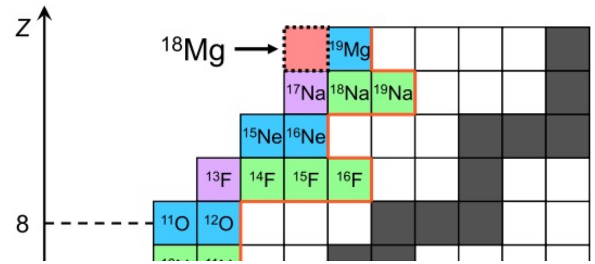
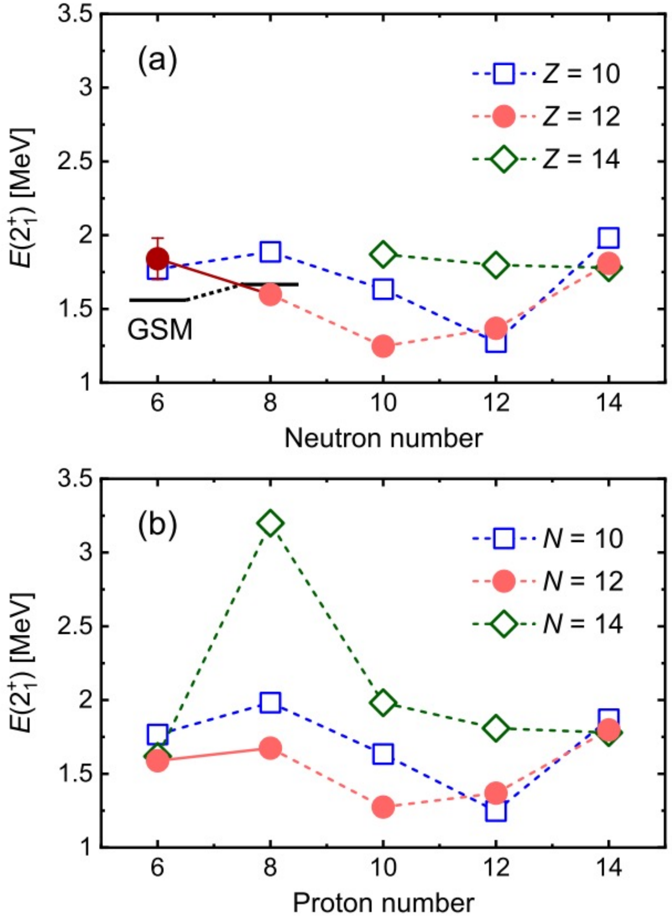
^{18}Mg was observed, for the first time, by the invariant-mass reconstruction of $^{14}\mathrm{O} + 4p$ events. The ground-state decay energy and width are $E_T = 4.865(34)$ MeV and $\Gamma = 115(100)$ keV, respectively. The observed momentum correlations between the five particles are consistent with two sequential steps of prompt $2p$ decay passing through the ground state of ^{16}Ne. The invariant-mass spectrum also provides evidence for an excited state at an excitation energy of 1.84(14) MeV, which is likely the first excited 2^+ state. As this energy exceeds that for the 2^+ state in ^{20}Mg, this observation provides an argument for the demise of the $N = 8$ shell closure in nuclei far from stability. However, in open systems this classical argument for shell strength is compromised by Thomas-Ehrman shifts.

DOI: 10.1103/PhysRevLett.127.262502





报告提纲

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- 轻核中的跨壳激发和镜像不对称性
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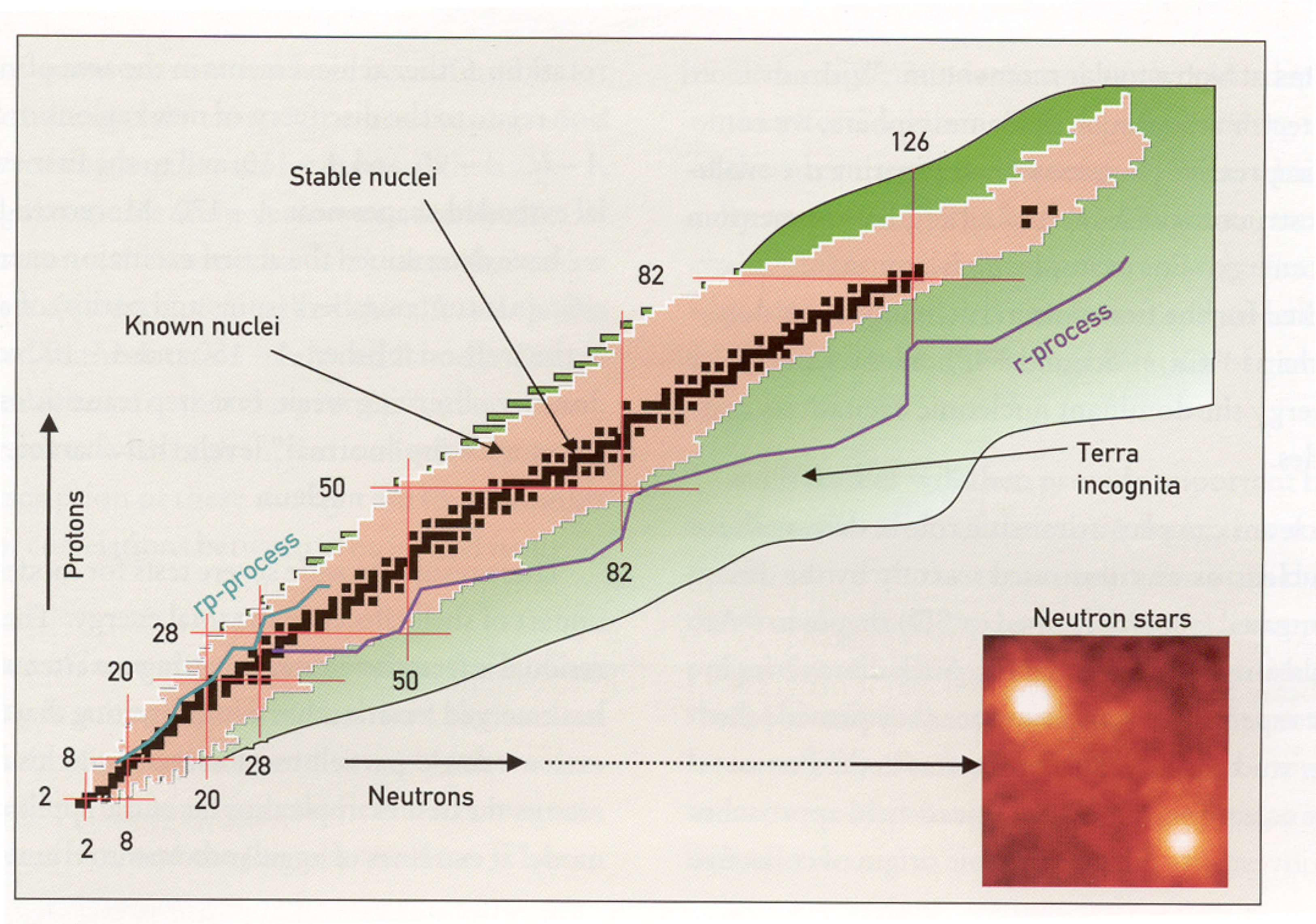

Stable nuclei
Known nuclei
126
82
50
28
20
8
2
2
8
20
28
50
82
rp-process
r-process
Terra incognita
Protons
Neutrons
Neutron stars

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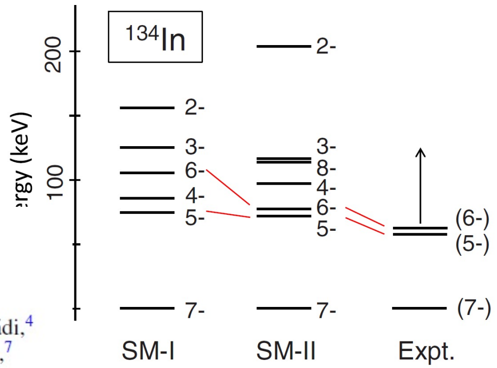
Nuclei	$J_i^\pi \to J_f^\pi$	E_i	ΔE	$B(E2)_{th}$	τ_{E2}	$B(E2)_{Expt}$	Configuration
^{134}Sn	$6^+ \to 4^+$	1.267	0.149	41.72	0.266	35(6)	$\nu(1f_{7/2})^2(96.3\%)$
^{135}Sn	$21/2^- \to 17/2^-$	2.288	0.147	93.96	0.127		$\nu(1f_{7/2})^2(0h_{9/2})(96.7\%)$
^{136}Sn	$6^+ \to 4^+$	1.388	0.222	15.43	0.098	24(4)	$\nu(1f_{7/2})^4(75.5\%)$
^{138}Sn	$6^+ \to 4^+$	1.544	0.183	12.80	0.311	19(4)	$\nu(1f_{7/2})^6(53.13\%)$
^{132}In	$5^- \to 7^-$	0.067	0.067	1.75	345.693		$\mu(0g_{9/2})^{-1}\nu(1f_{7/2})(99.0\%)$
^{133}In	$17/2^- \to 13/2^-$	0.972	0.257	48.36	0.015		$\mu(0g_{9/2})^{-1}\nu(1f_{7/2})^2(93.9\%)$
^{134}In	$5^- \to 7^-$	0.074	0.074	27.69	13.282		$\mu(0g_{9/2})^{-1}\nu(1f_{7/2})^3(72.5\%)$
^{130}Cd	$8^+ \to 6^+$	2.123	0.106	59.07	1.032	66(13)/50(10)	$\mu(0g_{9/2})^{-2}(100.0\%)$
^{131}Cd	$19/2^- \to 15/2^-$	1.789	0.139	100.03	0.157		$\mu(0g_{9/2})^{-2}\nu(1f_{7/2})(99.7\%)$
^{130}Ag	$5^- \to 7^-$	0.072	0.072	18.06	23.350		$\mu(0g_{9/2})^{-3}\nu(1f_{7/2})(74.1\%)$
^{128}Pd	$8^+ \to 6^+$	2.198	0.100	13.43	6.076	8.43(0.25)	$\mu(0g_{9/2})^{-4}(69.3\%)$
^{129}Pd	$19/2^- \to 15/2^-$	1.913	0.146	13.70	0.898		$\mu(0g_{9/2})^{-4}\nu(1f_{7/2})(72.7\%)$
^{130}Pd	$6^+ \to 4^+$	1.328	0.211	184.24	0.011		$\mu(0g_{9/2})^{-4}\nu(1f_{7/2})^2(53.5\%)$

Isomerism in the "south-east" of ^{132}Sn and a predicted neutron-decaying isomer in ^{129}Pd

Cenxi Yuan[a,*], Zhong Liu[b,*], Furong Xu[c,d], P.M. Walker[e], Zs. Podolyák[e], C. Xu[f], Z.Z. Ren[f], B. Ding[b], M.L. Liu[b], X.Y. Liu[b], H.S. Xu[b], Y.H. Zhang[b], X.H. Zhou[b], W. Zuo[b]

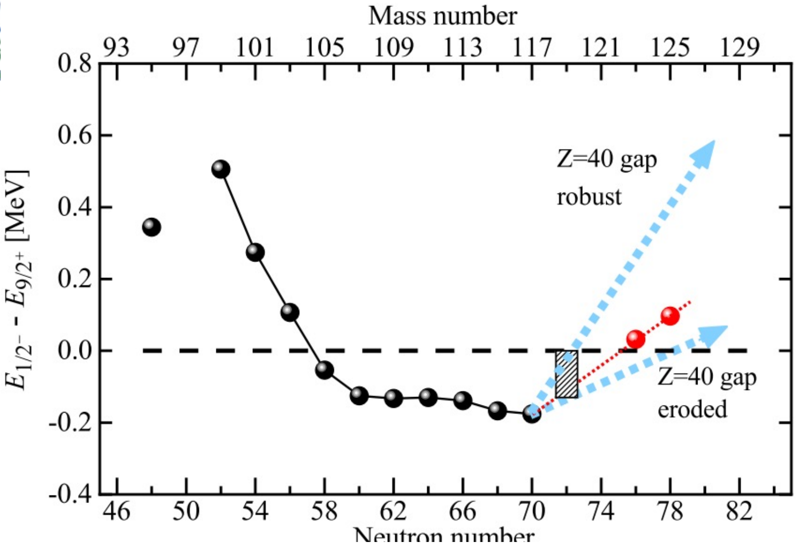
First spectroscopic information from even-even nuclei in the region "southeast" of ^{132}Sn: Neutron-excitation dominance of the 2_1^+ state in ^{132}Cd

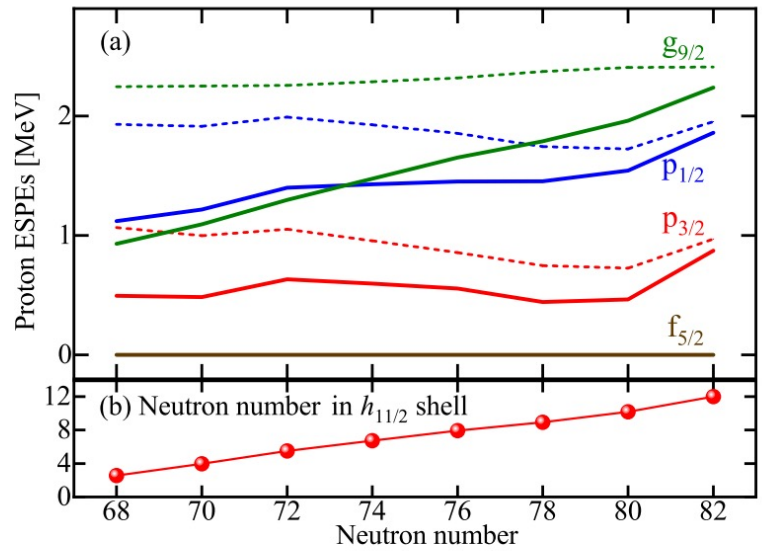
H. Wang,[1,*] N. Aoi,[2] S. Takeuchi,[1] M. Matsushita,[3] T. Motobayashi,[1] D. Steppenbeck,[1] K. Yoneda,[1] H. Baba,[1] Zs. Dombrádi,[4] K. Kobayashi,[5] Y. Kondo,[6] J. Lee,[1,†] H. Liu,[1,7] R. Minakata,[6] D. Nishimura,[8] H. Otsu,[1] H. Sakurai,[1,9] D. Sohler,[4] Y. Sun,[7] Z. Tian,[7] R. Tanaka,[6] Zs. Vajta,[4] Z. Yang,[7,‡] T. Yamamoto,[2] Y. Ye,[7] and R. Yokoyama[3]

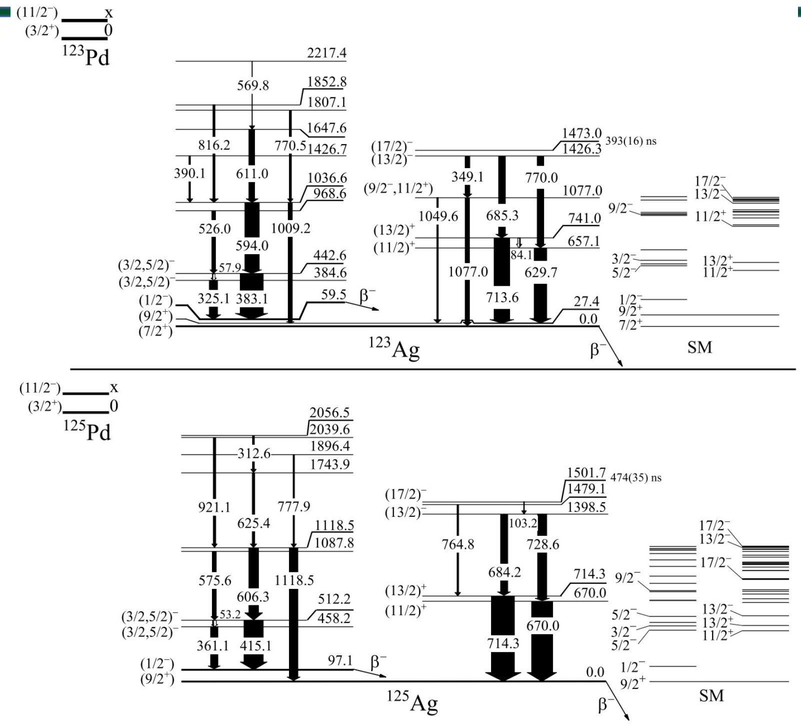


Phong et al., PRC 100, 011302(R) (2019)

2^+ state of ^{132}Cd: Our 708 keV, observed 618(8) keV

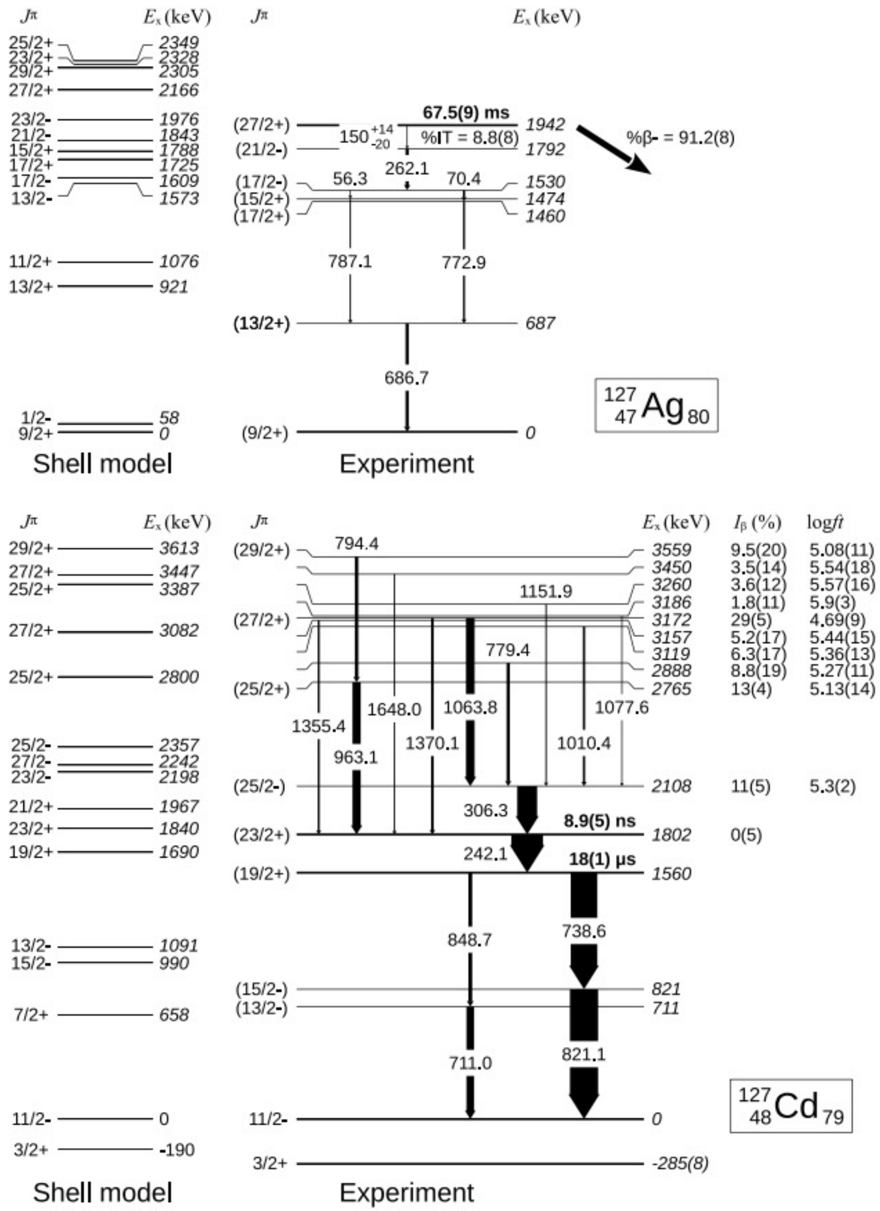


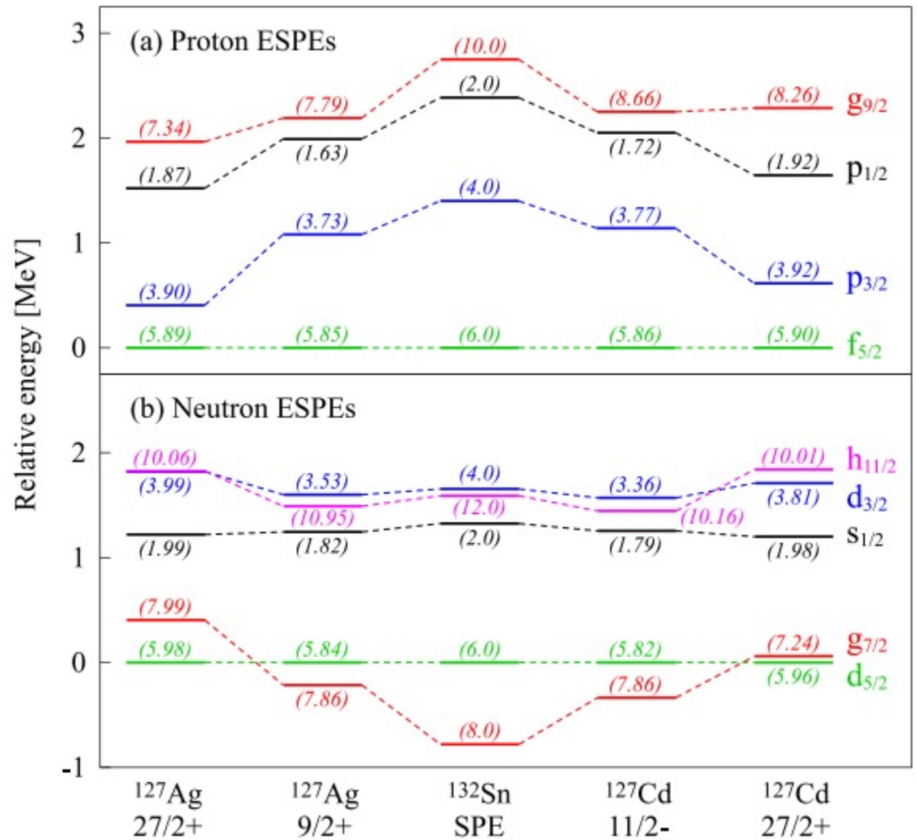




Such simple nuclear force give both nice description on levels, ESPE, and the mechanism of shell evolution

ZQ Chen, et al., PRL, 122, 212502 (2019)

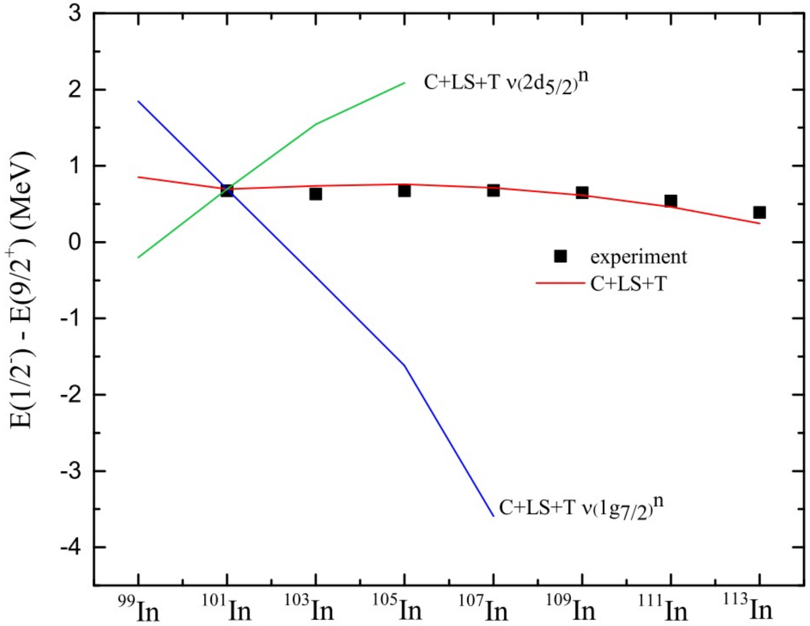


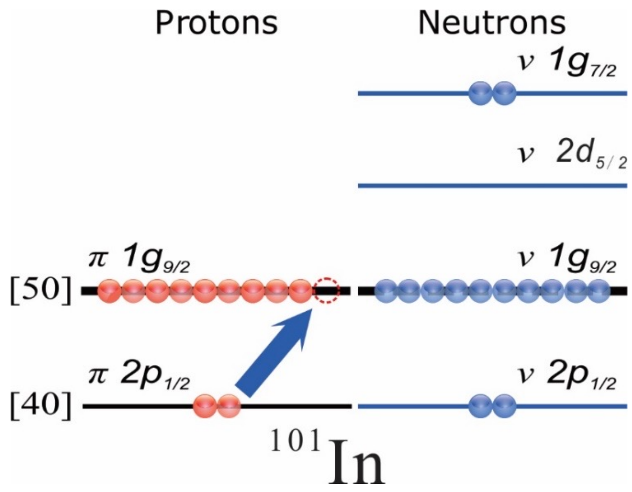


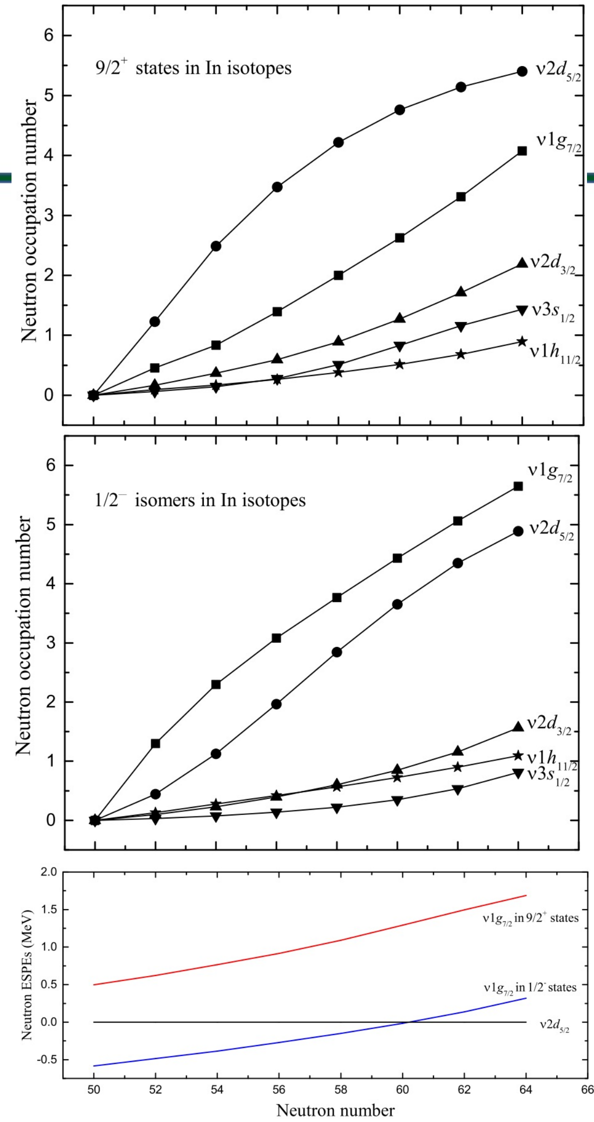
Transition	$B(\mathrm{GT})^{\mathrm{ex}}$	$B(\mathrm{GT})^{\mathrm{th}}$
$^{127}\mathrm{Ag}(27/2^+) \rightarrow {}^{127}\mathrm{Cd}(27/2^+)$	0.078(16)	0.088
$^{127}\mathrm{Ag}(27/2^+) \rightarrow {}^{127}\mathrm{Cd}(29/2^+)$	0.032(8)	0.024
$^{127}\mathrm{Ag}(27/2^+) \rightarrow {}^{127}\mathrm{Cd}(25/2^+)$	0.028(9)	0.014

Type II shell evolution

H. Watanabe, CXY, et al., PLB, 823, 136766 (2021)







Neutron-deficient, odd In isotopes
single proton-hole excitation induced considerable neutron s.p. changes

Xu et al., PRC 100, 051303(R) (2019)

Editors' Suggest

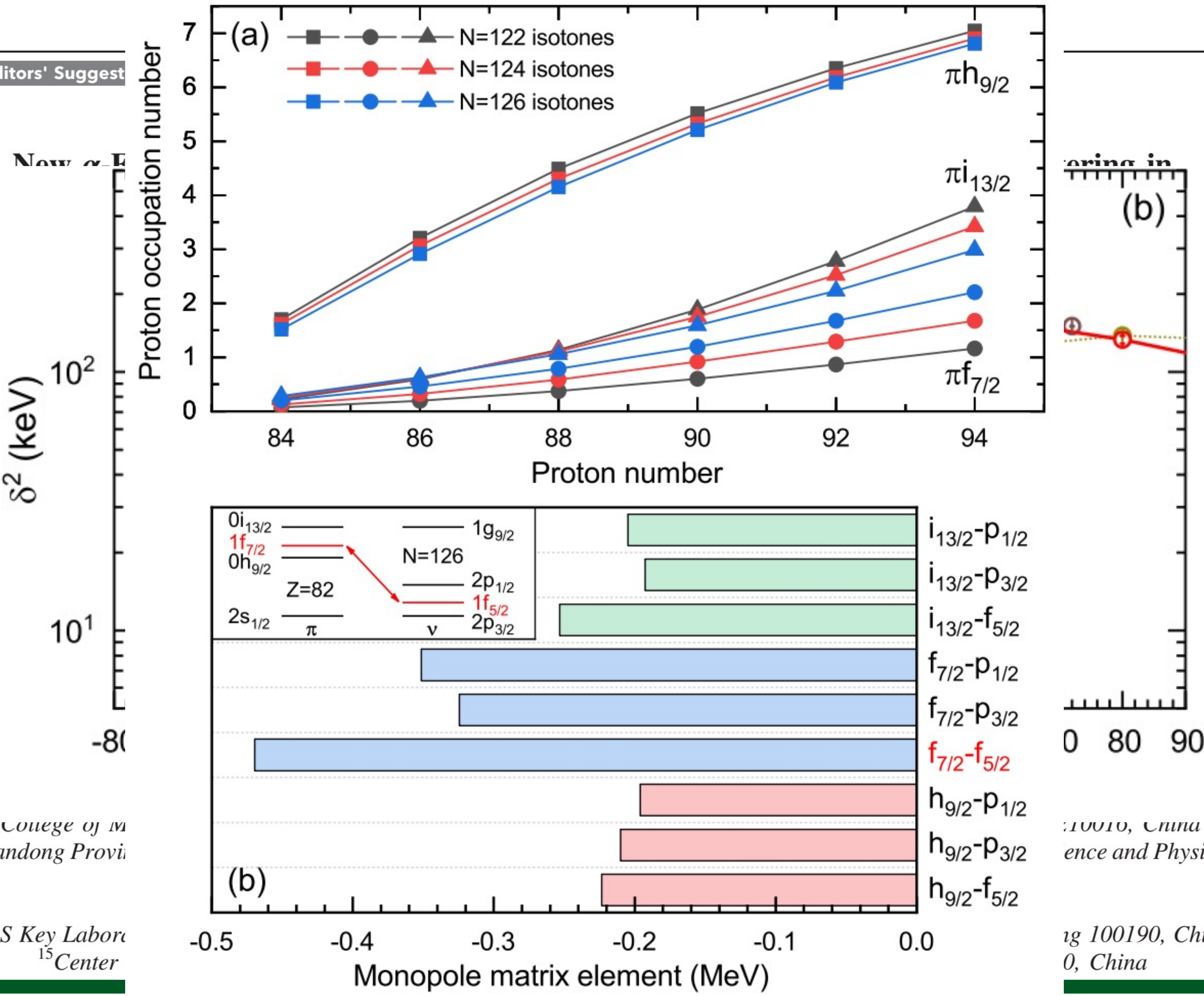
New α-... ering in

Z. ...

C. ...

L ...

S. ...



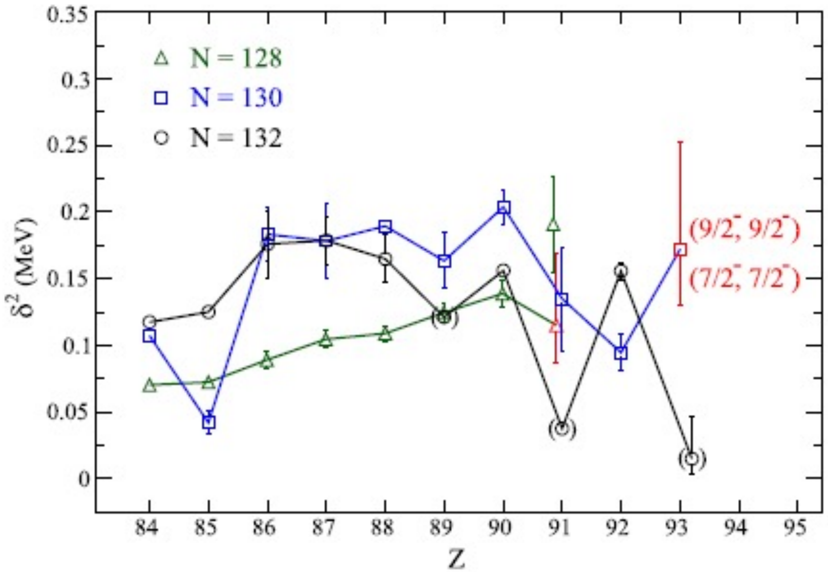
College of M... 10016, China

[12] Shandong Provi... ence and Physics,

[14] CAS Key Labor... ng 100190, China

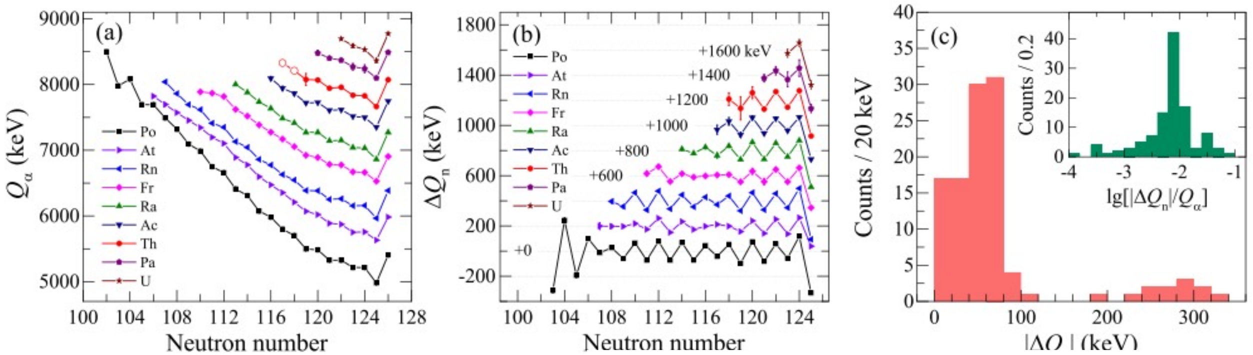
[15] Center ... 0, China

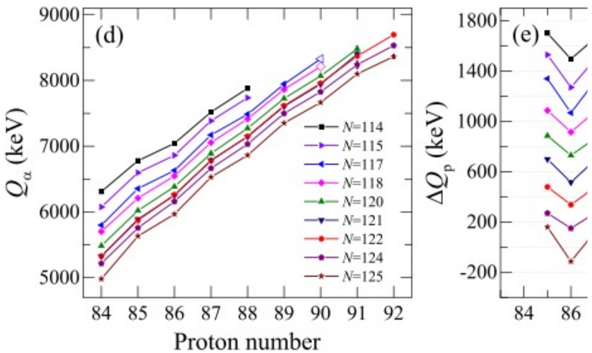
Ground state spin parity of ^{223}Np compared with alpha decay results

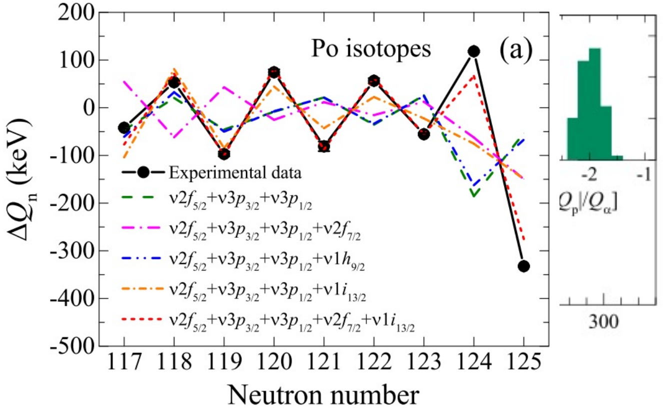


$Z = 92$ subshell closure. The spin and parity of ^{223}Np are proposed to be $9/2^-$ by combining the reduced α-decay width and large-scale shell-model calculations in truncated model space, negating

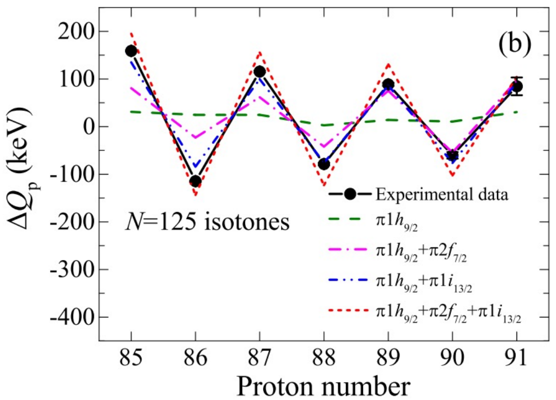
M.D. Sun *et al.* PLB771(2017)303





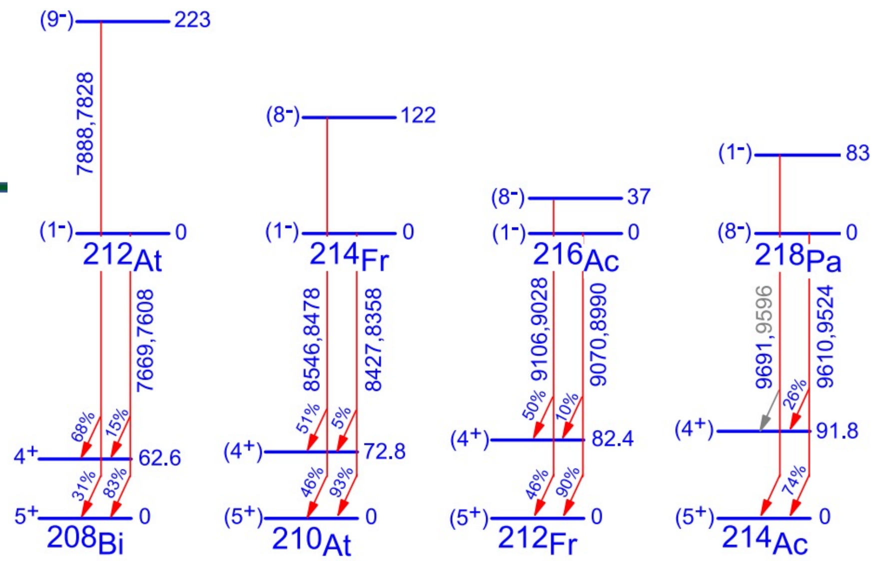


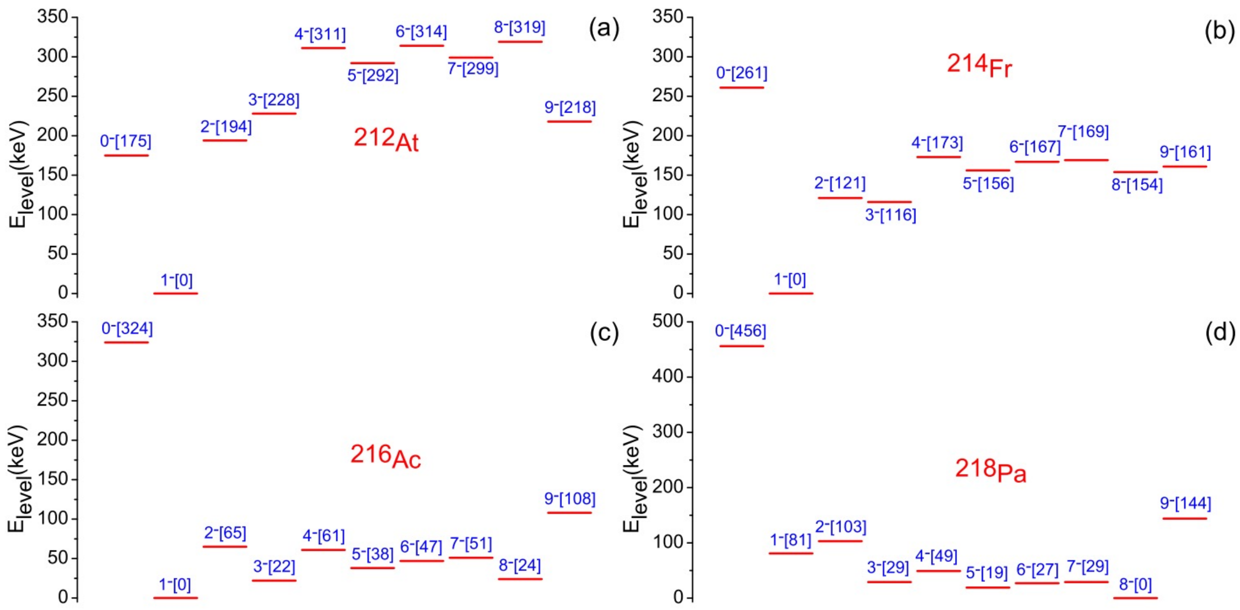
New element ^{207}Th
New OES relationship
HB Yang *et al.*
PRC105(2022)L051302



- **Inversion of ground state spin parity in ^{218}Pa**

Zhang et al., PLB 800, 135102 (2020).

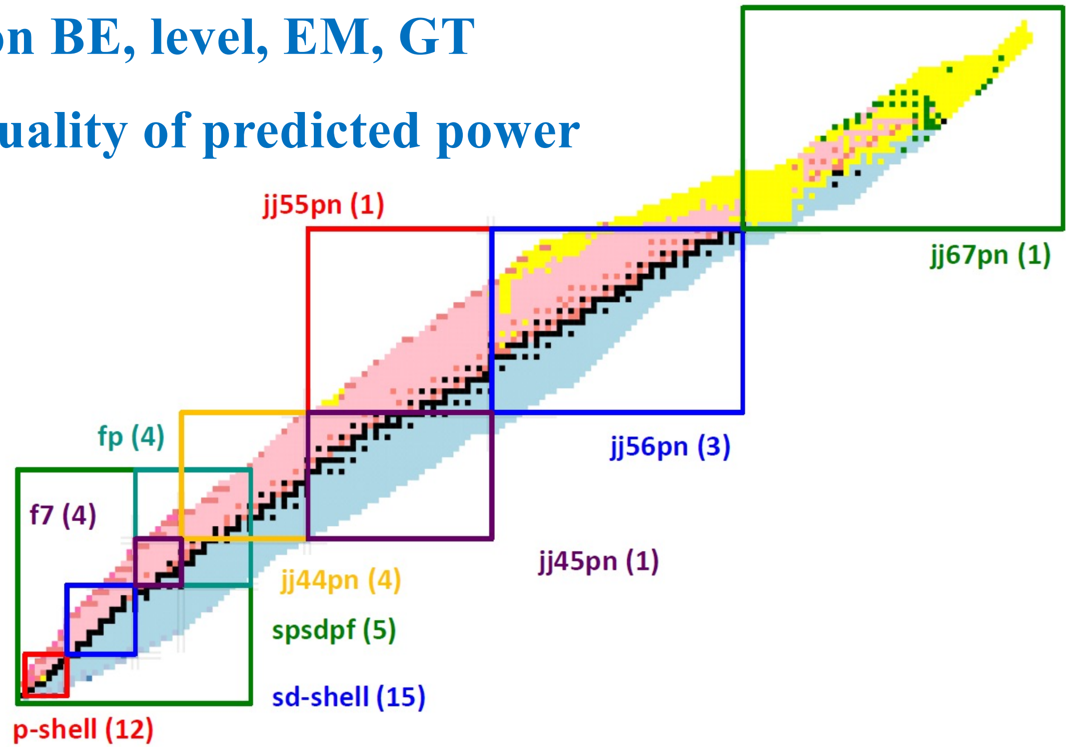




报告提纲

- 组态混合壳模型
- 轻核中的跨壳激发和镜像不对称性
- 中重核中的新核素和新同核异能态
- 统一描述中重核的相互作用初探
- 总结

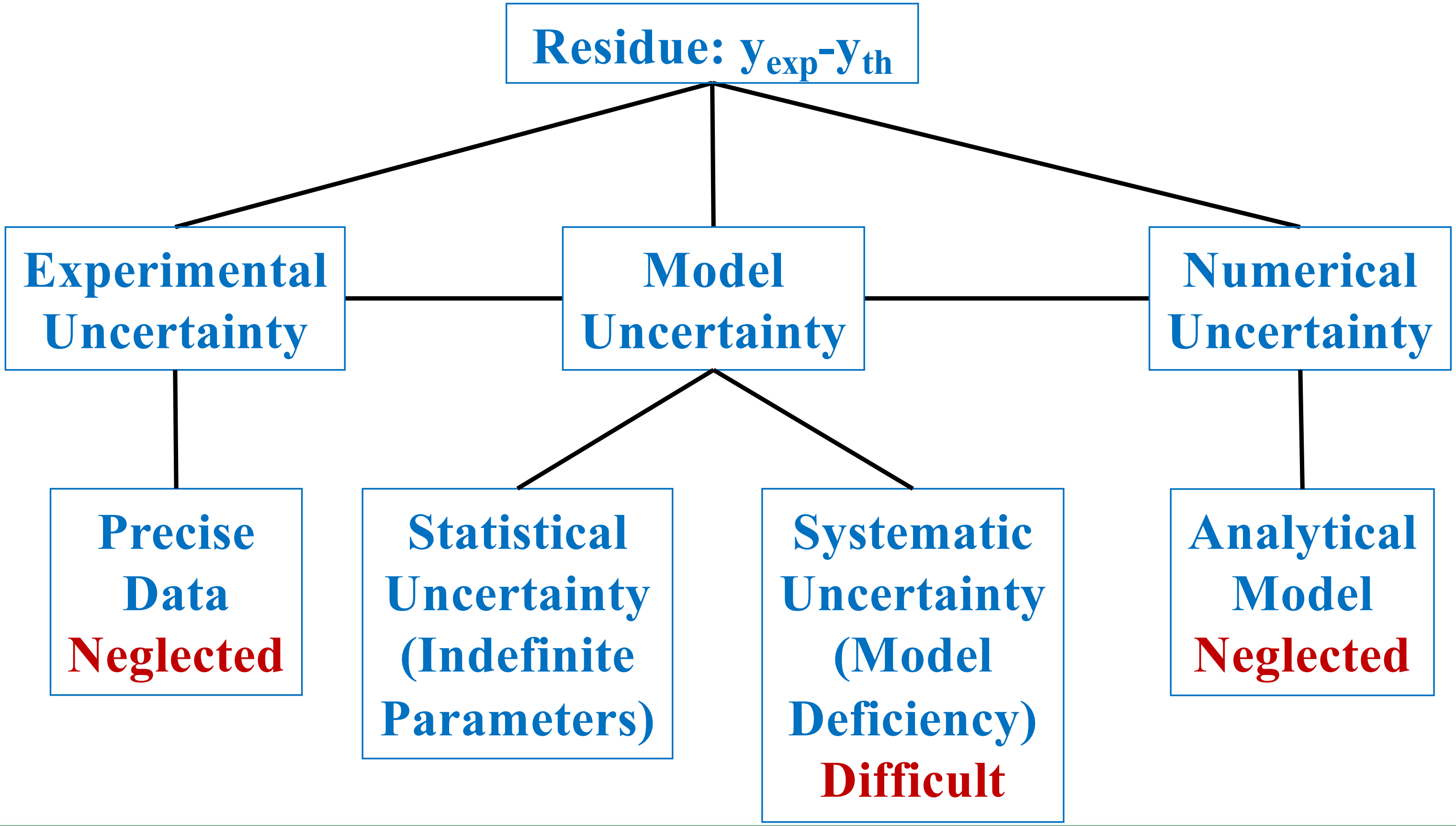
- **Confidence:** nice results on BE, level, EM, GT
- **Confusion:** different H, quality of predicted power



- Uncertainty **MUST** be included in shell model to evaluate predictions
- **One effective force** for all possible nuclei (RMS for BE, level, EM. GT)

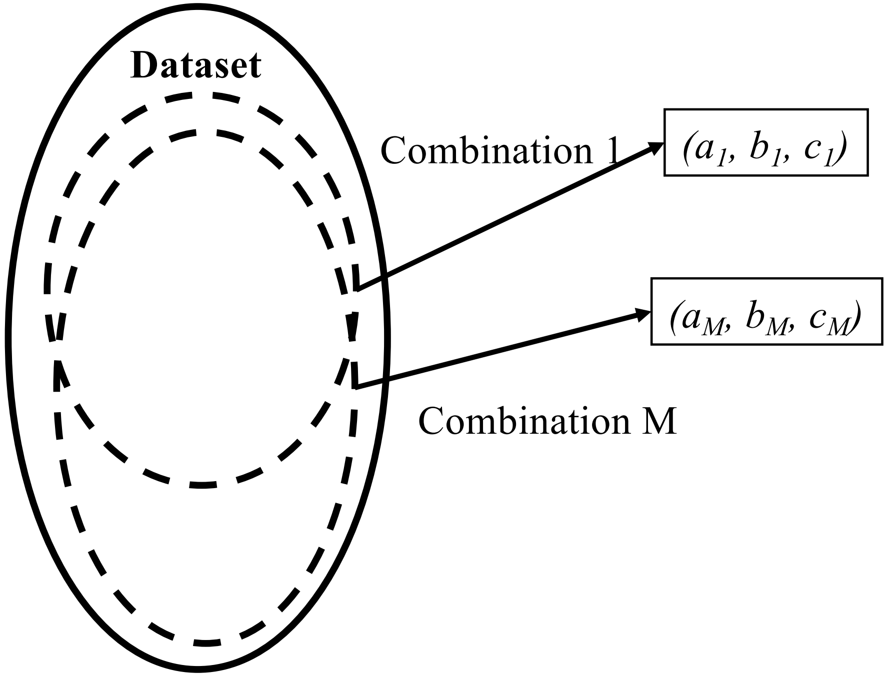
Theoretical model: $y_{th}=f(x_1, x_2\dots\ p_1,p_2\dots)$

y_{th}: unknown, f(): model, x_1,x_2 : known, p_1,p_2: parameters



Cai, Chen, Xu, CXY, *et al.*, PRC 101, 054304 (2020)

• Non-parametric Bootstrap Method



$$\sigma^2_{total}\left(Nu_k\right) = \frac{1}{N}\sum_{i=1}^{N} r^2\left(Nu_k, BS_i\right)$$

$$\hat{\sigma}^2_{total} = \frac{1}{M}\sum_{k=1}^{M}\hat{\sigma}^2_{total}\left(Nu_k\right)$$

$$\hat{\sigma}^2_{stat}\left(Nu_k\right) = \mathbf{Sd}\left(r\left(Nu_k, BS_i\right)\right)$$

$$\hat{\sigma}^2_{stat} = \frac{N-1}{NM}\sum_{k=1}^{M}\hat{\sigma}^2_{stat}\left(Nu_k\right)$$

$$\hat{\sigma}_{sys}\left(Nu_k\right) = \left|\frac{1}{N}\sum_{i=1}^{N} r\left(Nu_k, BS_i\right)\right|$$

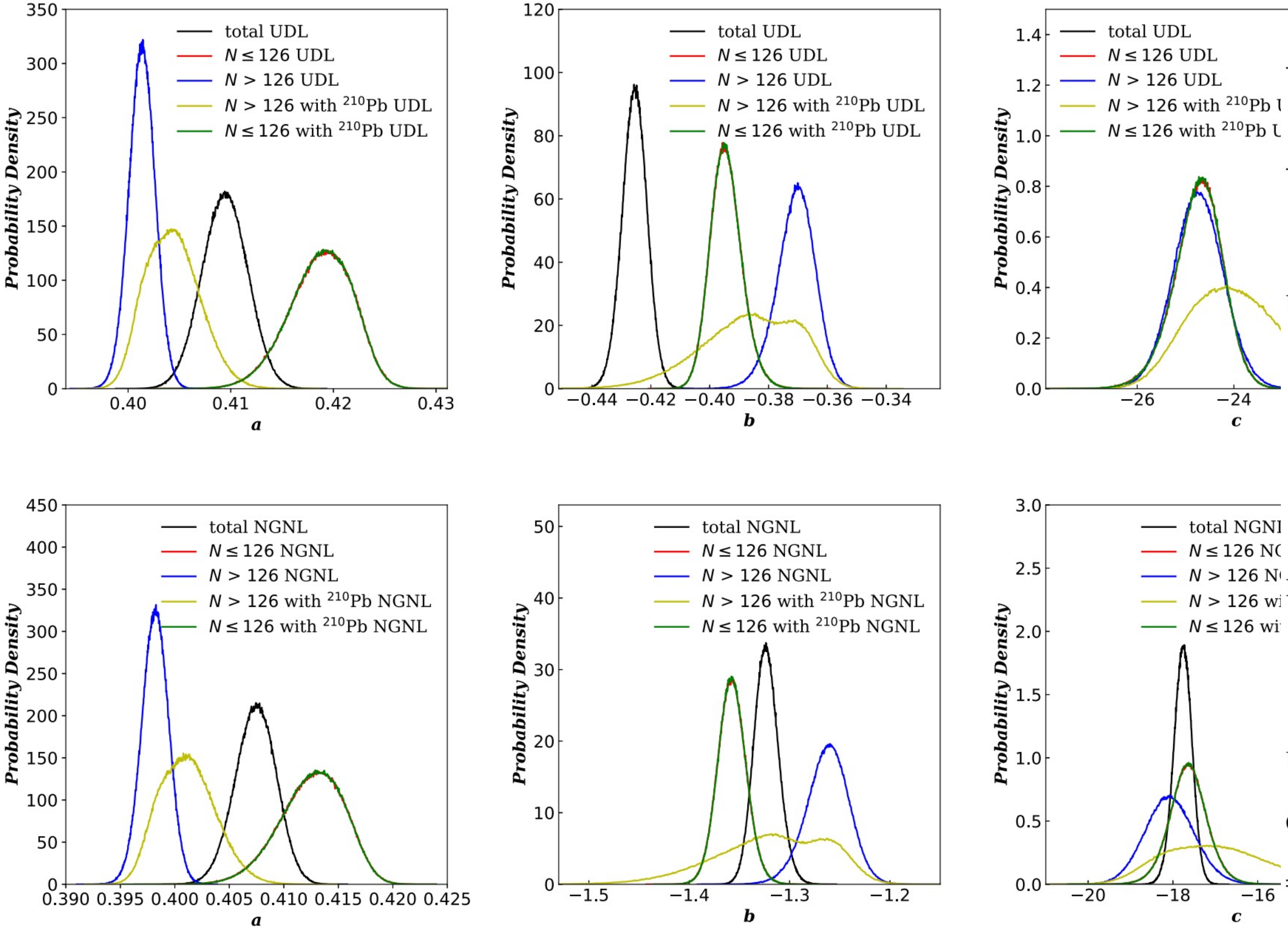
$$\hat{\sigma}^2_{sys} = \sigma^2_{total} - \sigma^2_{stat}$$

Universal Decay Law (by Qi *et al.* in 2009):

$$\log T_{1/2} = aZ_cZ_d\sqrt{\frac{\mu}{Q}} + b\sqrt{\mu Z_cZ_d\left(A_c^{1/3} + A_d^{1/3}\right)} + c$$

New Geiger-Nuttall Law (by Ren *et al.* in 2012):

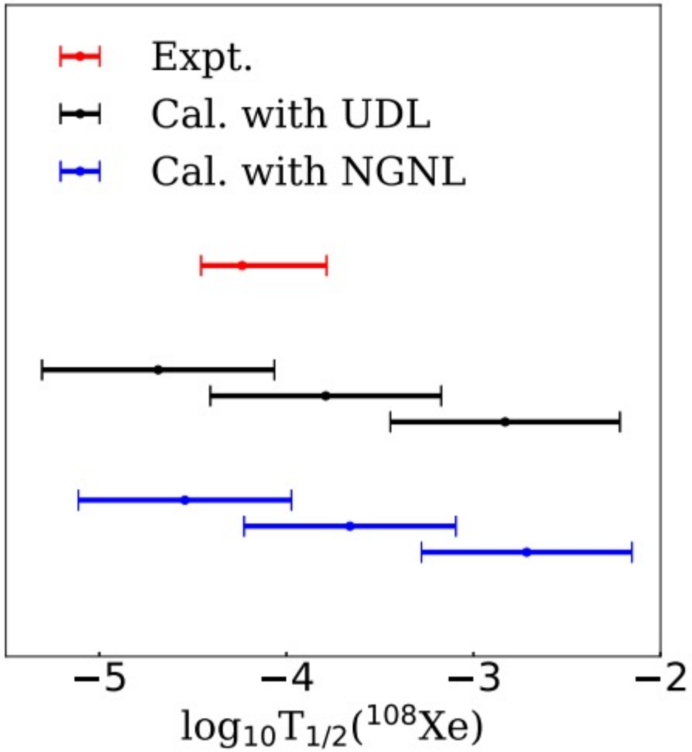
$$\log T_{1/2} = aZ_cZ_d\sqrt{\frac{\mu}{Q}} + b\sqrt{\mu Z_cZ_d} + c + S + Pl(l+1)$$

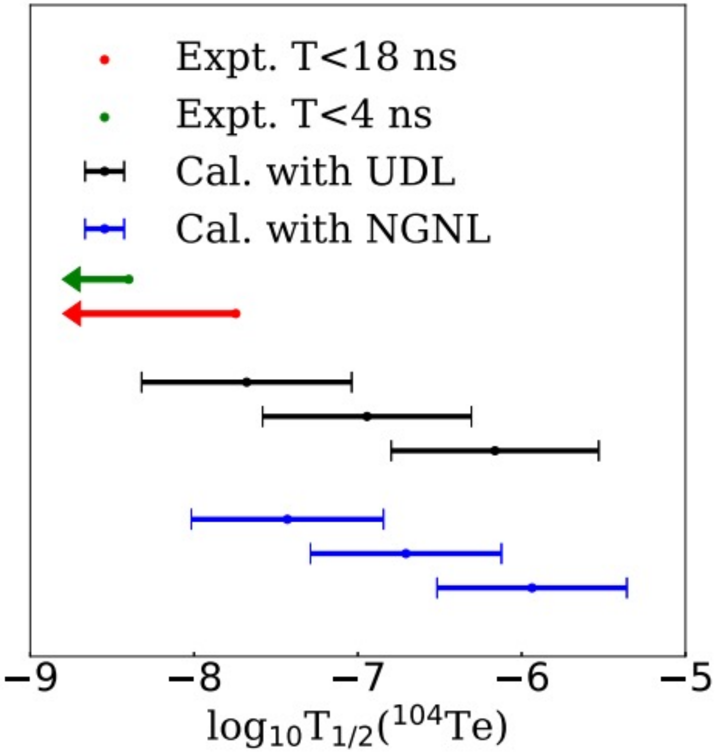


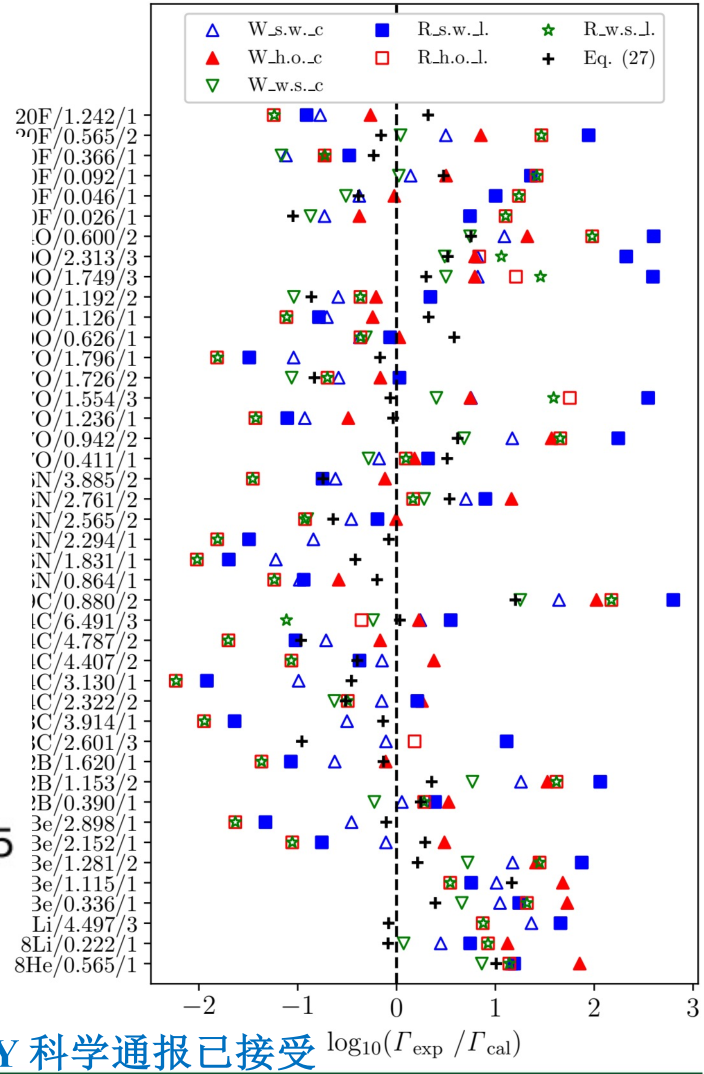
		Residuals	Uncertainty		
		Mean	Total	Stat	Sys
UDL	(Gs-Gs)	–	0.3442	0.0503	0.3405
	(Gs-Gs)[b]	–	0.3444	0.0513	0.3406
	(Gs-Gs)[c]	–	0.3443	0.0506	0.3405
	(Gs-Gs)[d]	–	0.3479	0.0506	0.3442
	$N \leqslant 126$	–	0.2922	0.0626	0.2854
	$N \leqslant 126$[d]	–	0.2915	0.0631	0.2846
	$N > 126$	–	0.1737	0.0356	0.1700
	$N > 126$[d]	–	0.2424	0.0686	0.2325
	$N > 126$[a]	−0.6619	0.7330	0.0939	0.7270
NGNL	(Gs-Gs)	–	0.2658	0.0407	0.2626
	(Gs-Gs)[b]	–	0.2661	0.0421	0.2627
	(Gs-Gs)[c]	–	0.2658	0.0410	0.2626
	(Gs-Gs)[d]	–	0.2807	0.0428	0.2774
	$N \leqslant 126$	–	0.2736	0.0577	0.2674
	$N \leqslant 126$[d]	–	0.2724	0.0582	0.2661
	$N > 126$	–	0.1720	0.0344	0.1686
	$N > 126$[d]	–	0.2454	0.0694	0.2354
	$N > 126$[a]	0.1093	0.3079	0.0814	0.2970
Uncorrected [Eq. (12)]	(Gs-Gs)		0.3939	0.0594	0.3894
Corrected [Eq. (18)]	(Gs-Gs)		0.2657	0.0466	0.2616

Cai, Chen, Xu, CXY, *et al.*, PRC 101, 054304 (2020)

$$\log_{10}\Gamma = c + bA^{1/3}\sqrt{\mu E_d} + \alpha\log_{10}A_o$$







Cai, Chen, Xu, CXY, *et al.*, PRC 101, 054304 (2020)

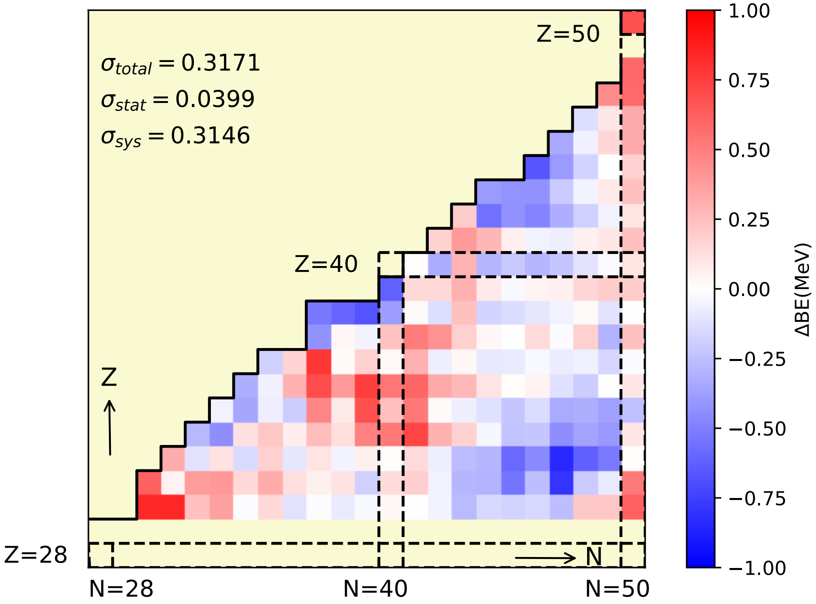
Cai, CXY 科学通报已接受

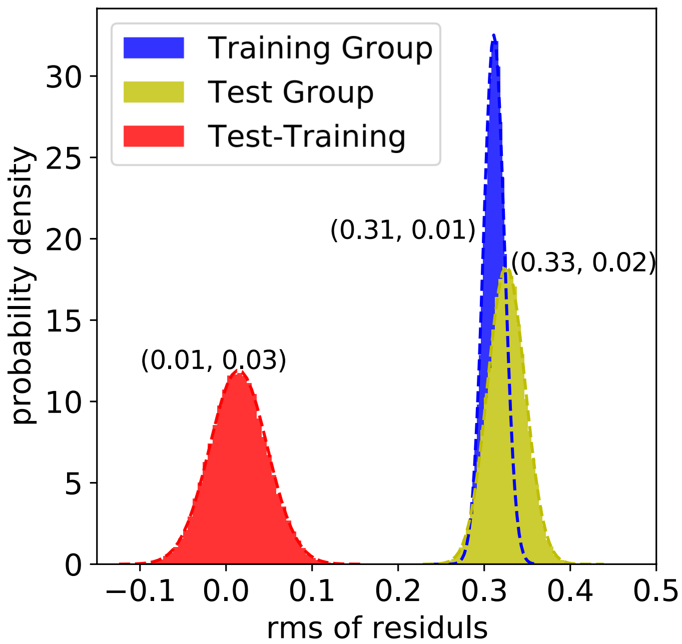
Cai, Chen, CXY, *et al.*, CPC accepted

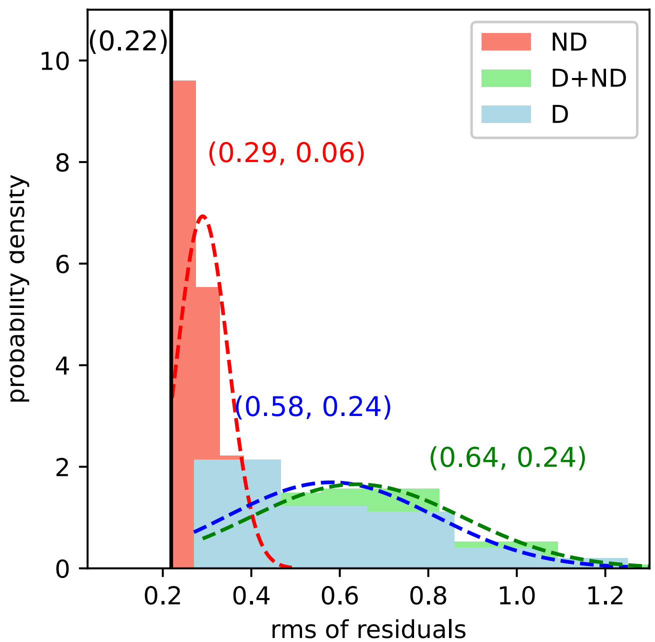
$$E_{BE}(Z,N) = E_{BE,SM}(Z,N) + \boxed{E_{BE}(^{56}\mathrm{Ni})} + \boxed{a(Z-28) + b(Z-28)^2 + c(Z-30)(Z-2N+50)}$$

Core energy

Single particle energy deviation and Coulomb correction

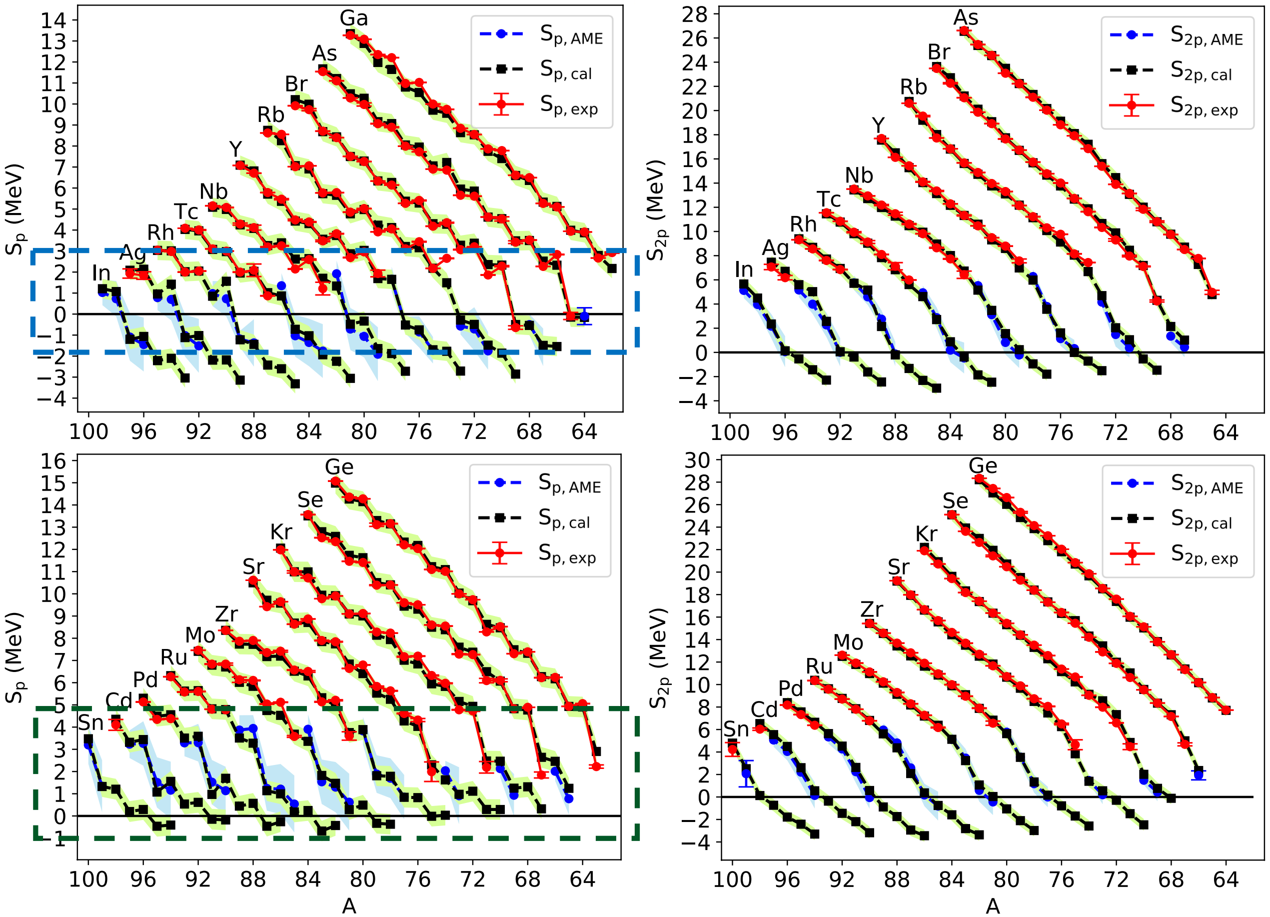






中山大學中法核工程与技术学院

Institut franco-chinois de l'énergie nucléaire université Sun Yat-sen



Nucl.	l_p	S_p (MeV)	$P(S_p<0)$	$\log_{10} T_{cal}$	$\log_{10} T_{exp}$	l_{2p}	S_{2p} (MeV)	$P(S_{2p}<0)$	$\log_{10} T_{cal}$
^{64}As	1	-0.157	75%	$8.6_{-18.2}$					
^{66}Br	1	-1.545	100%	$-15.8^{+2.4}_{-1.5}$					
^{67}Br$^{\#}$	1	-1.491	100%	$-15.6^{+2.6}_{-1.6}$			1.019	0%	
^{68}Br$^{\#}$	1	-0.540	99%	$-7.3^{+33.9}_{-5.6}$	-7.3 [62]		2.142	0%	
^{69}Rb	3	-2.856	100%	$-16.9^{+0.9}_{-0.7}$		2	-1.468	100%	$2.7^{+9.1}_{-5.2}$
^{70}Rb	1	-1.859	100%	$-15.5^{+1.8}_{-1.3}$		2	-0.539	98%	$26.6^{+319.2}_{-17.5}$
^{71}Rb$^{\#}$	3	-1.479	100%	$-13.1^{+2.7}_{-1.7}$			1.047	0%	
^{72}Rb	1	-0.491	98%	$-5.2^{+70.1}_{-6.6}$	$-7.0^{+0.08}_{-0.1}$ [59]		2.038	0%	
^{73}Rb	1	-0.285	89%	$2.1_{-11.7}$	<-7.1 [59]		4.695	0%	
^{70}Sr		0.290	10%			0	-2.477	100%	$-5.7^{+3.7}_{-2.6}$
^{71}Sr		0.294	10%			0	-1.485	100%	$2.8^{+9.1}_{-5.3}$
^{72}Sr		1.115	0%			0	-0.290	87%	$50.2_{-34.3}$
^{73}Y	4	-2.712	100%	$-14.9^{+1.0}_{-0.8}$		3	-1.511	100%	$4.4^{+9.1}_{-5.3}$
^{74}Y	2	-1.771	100%	$-15.0^{+2.1}_{-1.4}$		1	-0.717	100%	$20.7^{+51.7}_{-13.3}$
^{75}Y	2	-1.698	100%	$-14.7^{+2.3}_{-1.5}$			-0.003	51%	
^{76}Y$^{\#}$	0	-0.752	100%	$-9.2^{+12.0}_{-4.2}$			1.613	0%	
^{77}Y	2	-0.520	99%	$-4.1^{+46.1}_{-6.5}$			3.568	0%	
^{74}Zr		0.033	44%			0	-2.580	100%	$-5.1^{+3.6}_{-2.6}$
^{75}Zr		-0.014	52%			2	-1.693	100%	$2.5^{+7.6}_{-4.7}$
^{76}Zr		0.825	0%			0	-0.790	100%	$19.2^{+39.6}_{-12.2}$
^{77}Nb	2	-2.720	100%	$-17.2^{+1.1}_{-0.8}$		0	-1.798	100%	$1.6^{+7.0}_{-4.4}$
^{78}Nb	1	-1.878	100%	$-15.6^{+2.0}_{-1.4}$		1	-0.948	100%	$15.7^{+25.4}_{-10.0}$
^{79}Nb	1	-1.643	100%	$-14.7^{+2.5}_{-1.6}$			0.225	20%	
^{80}Nb	1	-0.332	93%	$2.5_{-11.1}$			1.553	0%	
^{81}Nb	1	-0.480	98%	$-2.8^{+101.3}_{-7.5}$	<-7.4 [63]		3.475	0%	
^{78}Mo	2	-0.372	95%	$2.19_{-10.1}$		0	-2.982	100%	$-6.1^{+3.0}_{-2.3}$
^{79}Mo	2	-0.330	92%	$4.1_{-11.4}$		1	-2.105	100%	$-0.3^{+5.4}_{-3.7}$
^{80}Mo		0.489	2%			0	-1.059	100%	$13.9^{+20.2}_{-9.1}$
^{81}Tc	1	-3.059	100%	$-18.2^{+0.9}_{-0.7}$		2	-2.462	100%	$-2.0^{+4.2}_{-3.1}$
^{82}Tc	2	-2.246	100%	$-15.7^{+1.5}_{-1.1}$		3	-1.861	100%	$3.5^{+6.9}_{-4.5}$
^{83}Tc	1	-1.936	100%	$-15.4^{+2.0}_{-1.4}$		2	-0.373	92%	$50.1_{-30.4}$
^{84}Tc$^{\#}$	2	-1.031	100%	$-9.7^{+6.5}_{-3.2}$			0.879	0%	
^{85}Tc$^{\#}$	1	-0.724	100%	$-6.7^{+14.7}_{-4.9}$	<-7.4 [63]		2.714	0%	
^{82}Ru	1	-0.429	97%	$0.6_{-9.1}$		0	-3.367	100%	$-6.8^{+2.6}_{-2.1}$
^{83}Ru	4	-0.679	100%	$-2.5^{+18.1}_{-5.4}$		2	-2.812	100%	$-3.6^{+3.5}_{-2.6}$
^{84}Ru		0.244	14%			0	-1.586	100%	$6.5^{+9.5}_{-5.7}$
^{89}Rh$^{\#}$	4	-1.223	100%	$-4.6^{+4.8}_{-2.7}$	<-6.9 [58]		2.143	0%	
^{93}Ag$^{\#}$	4	-1.119	100%	$-6.9^{+6.0}_{-3.1}$	$-6.6^{+0.03}_{-0.03}$ [58]		2.568	0%	

Cai, Chen, CXY, *et al.*, CPC accepted

$$EN(BU) = \sum_{i=1}^{n} a_i \frac{E_{2i-1}}{E_{2i}} + c$$

$$\frac{dN_k(\mathbf{r},t)}{dt} = -\beta_k(\mathbf{r},t)N_k(\mathbf{r},t) - \lambda_k N_k(\mathbf{r},t) + \sum_{m\neq k}\beta_{k\leftarrow m}(\mathbf{r},t)N_m(\mathbf{r},t) + \sum_{m\neq k}\lambda_{k\leftarrow m}N_m(\mathbf{r},t) \qquad (1)$$

$$\frac{dN_{235}}{dBU} = -\sigma_{a,5}N_{235}A \qquad (2a)$$

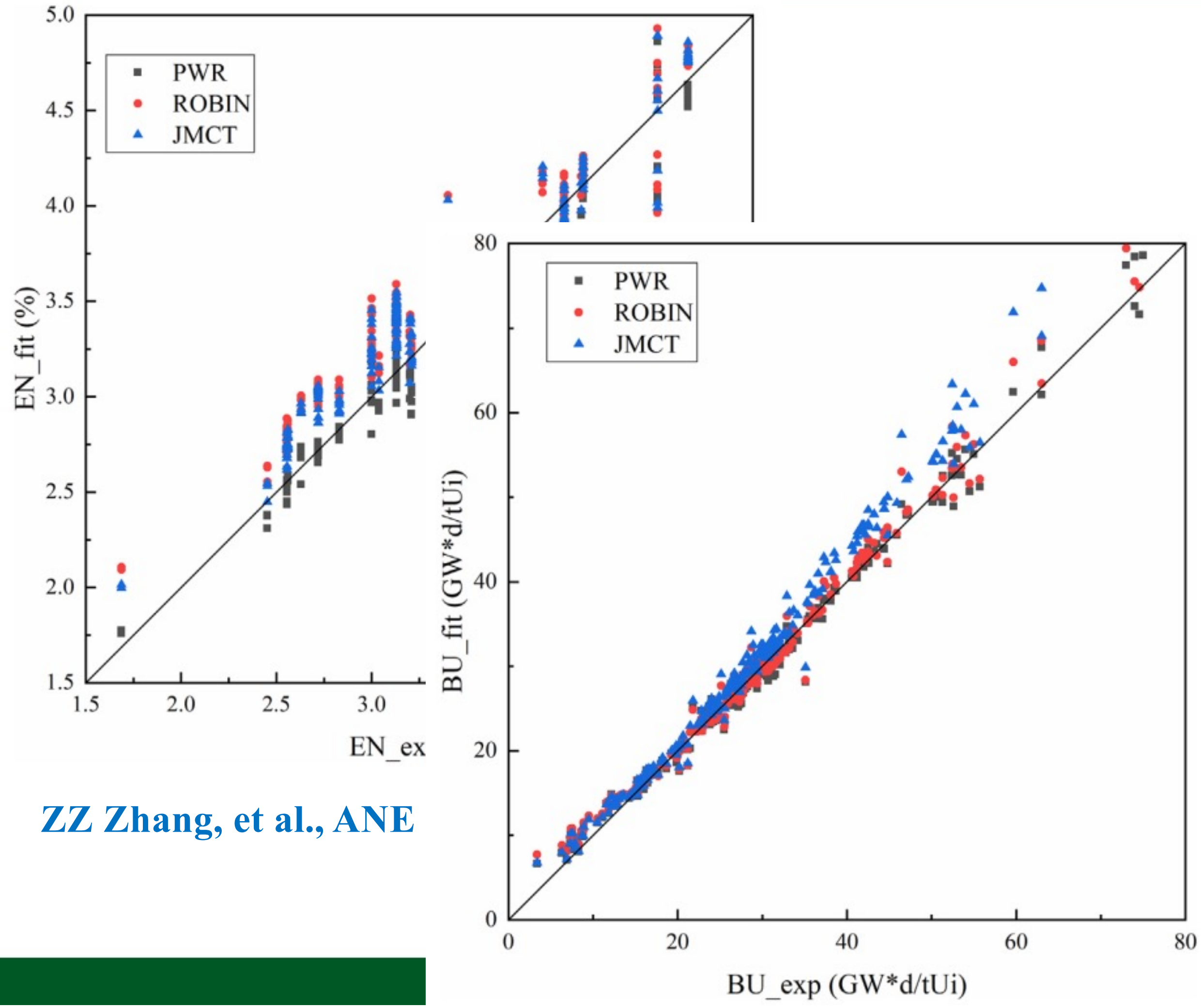
$$\frac{dN_{238}}{dBU} = -\sigma_{a,8}N_{238}A \qquad (2b)$$

$$\frac{dN_{236}}{dBU} = -\sigma_{a,6}N_{236}A + \sigma_{c,5}N_{235}A \qquad (2c)$$

$$\frac{dN_j}{dBU} = -\sigma_{a,j}N_jA + \sigma_{c,j-1}N_{j-1}A \qquad (2d)$$

$$\frac{N_{236}}{N_{238}} = c\left(\frac{N_{235,0}}{N_{238,0}} - \frac{N_{235}}{N_{238}}\right)$$

$$\frac{\beta\rho_U c_4}{(1-c_4)QN_{238,0}}BU = \frac{c_3-c_4}{1-c_4}\frac{N_{239}}{N_{238}} + \frac{c_2-c_4}{1-c_4}\frac{N_{240}}{N_{238}} + \frac{c_1-c_4}{1-c_4} \times \frac{N_{241}}{N_{238}} + \frac{N_{242}}{N_{238}} + \frac{\sigma_{f,5}c_4}{\sigma_{a,5}c(1-c_4)}\frac{N_{236}}{N_{238}}$$



ZZ Zhang, et al., ANE

Configuration mixing

Semi magic T=1

C10+C11+LS+T

Uncertainty of C10 and C11

The effective interaction between nucleons deduced from nuclear spectra*

John P. Schiffer

Argonne National Laboratory, Argonne, Illinois 60439
and University of Chicago, Chicago, Illinois 60637

William W. True

University of California, Davis, California 95616

Two-body matrix elements of the residual nucleon–nucleon interaction are extracted from experimental data throughout the periodic table and are used to determine the ranges and well depths of various components of a local interaction. The $T=1$ even and odd components of the central interaction both definitely require two wells with different ranges; a shorter-range attractive well with a longer-range repulsive one. The need for a tensor interaction and a two-body spin–orbit interaction is also explored and their inclusion improves the fit slightly.

$$V_{\mathrm{CEN}} = U_{\mathrm{SO}}(r)P^{\mathrm{SO}} + U_{\mathrm{SE}}(r)P^{\mathrm{SE}} + U_{\mathrm{TO}}(r)P^{\mathrm{TO}} + U_{\mathrm{TE}}(r)P^{\mathrm{TE}},$$

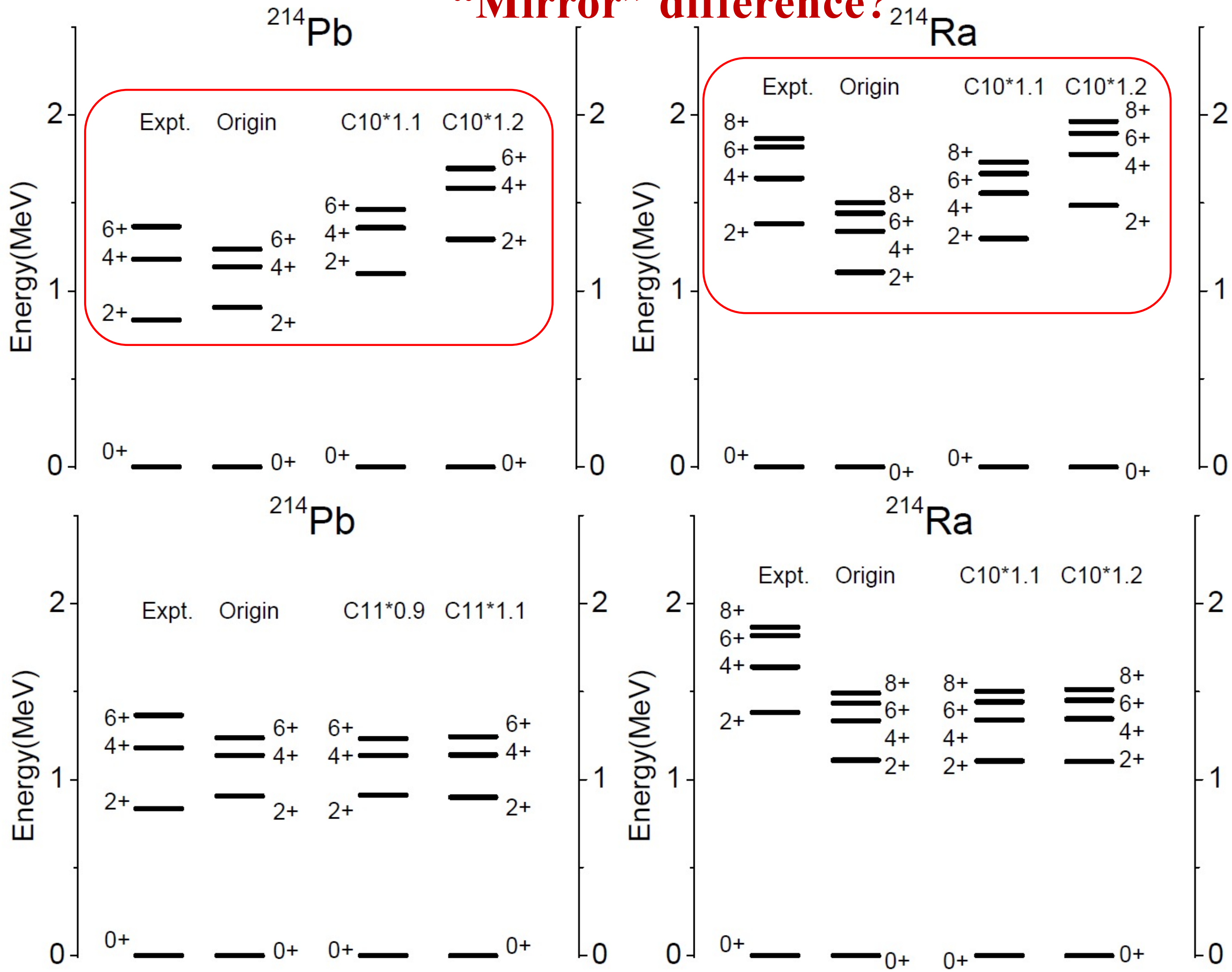
$$V_{\mathrm{LS}} = U_{\mathrm{LS}}(r)\vec{L}\cdot\vec{S}$$

$$V_{\mathrm{Tensor}} = U_{\mathrm{Tensor}}(r)\left[\frac{3(\vec{\sigma}_1\cdot\vec{r})(\vec{\sigma}_2\cdot\vec{r})-r^2(\vec{\sigma}_1\cdot\vec{\sigma}_2)}{r^2}\right]$$

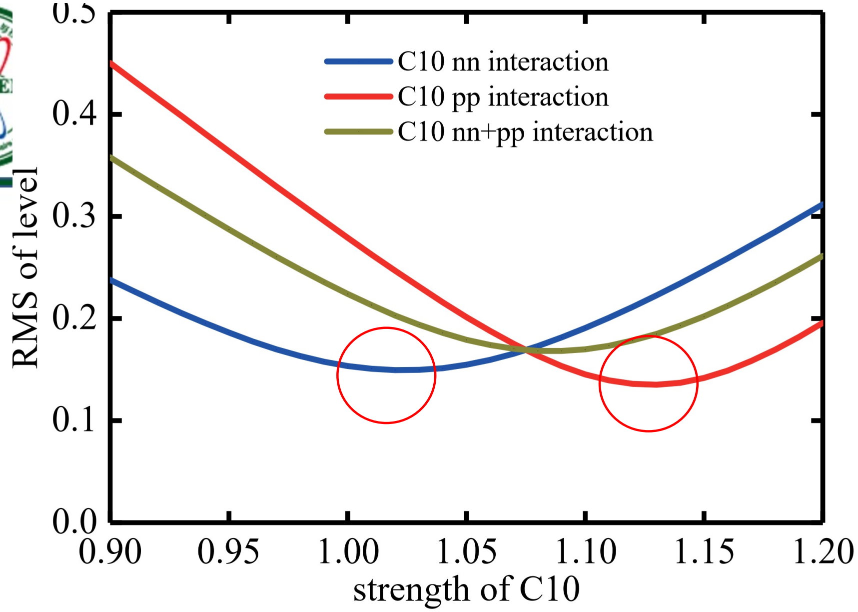
TABLE XV. Typical errors in the interaction strengths in MeV with $r_1=1.415$ fm and $r_2=2.0$ fm for a 1% change in χ^2.

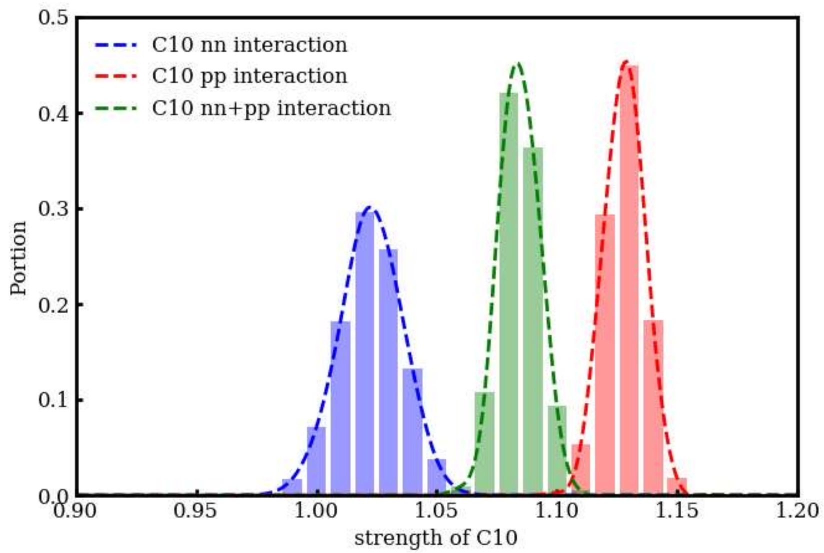
$T=0$ S. O.$_A$	S. O.$_B$	Tr. E.$_A$	Tr. E.$_B$	Tens. E.	LS. E.
3.7 ± 9	122 ± 73	−56 ± 2	−63 ± 20	−43 ± 10	−0.4 ± 2
$T=1$ S. E.$_A$	S. E.$_B$	Tr. O.$_A$	Tr. O.$_B$	Tens. O.	LS. O.
−13.5 ± 1.2	−36 ± 13	15.2 ± 1.1	−171 ± 12	−6.1 ± 1.4	3.4 ± 0.8

“Mirror” difference?



CXY, TX Du, NPR35.4(2018)537





RMS from nuclei around ^{208}Pb and ^{132}Sn
nn: 101 levels in Pb and Sn isotopes, $^{201\text{-}214}$Pb, $^{125\text{-}138}$Sn
pp: 97 levels in N=126 and N=82 isotones, ^{204}Pt-^{214}Ra, ^{128}Pd-^{139}La

Uncertainty of strength of C10 from bootstrap method

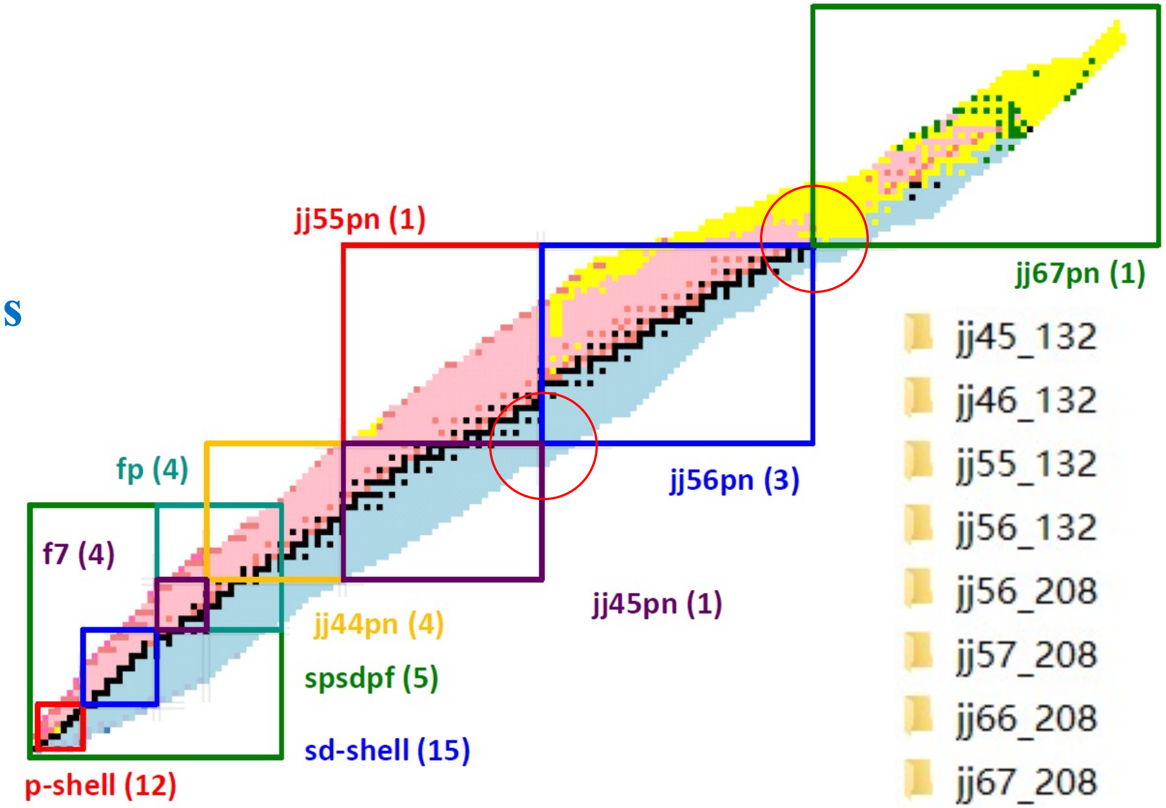
CXY, et al., ND2019 proceedings
EPJ Web of Conf. 239, 04002 (2020)

Comparing with 88 levels in 15 nuclei, the RMS of levels are 0.17, 0.27, and 0.47 for V_{MU}+LS, jj45pnm, and jj45pna, respectively. Simple nuclear force V_{MU}+LS gives

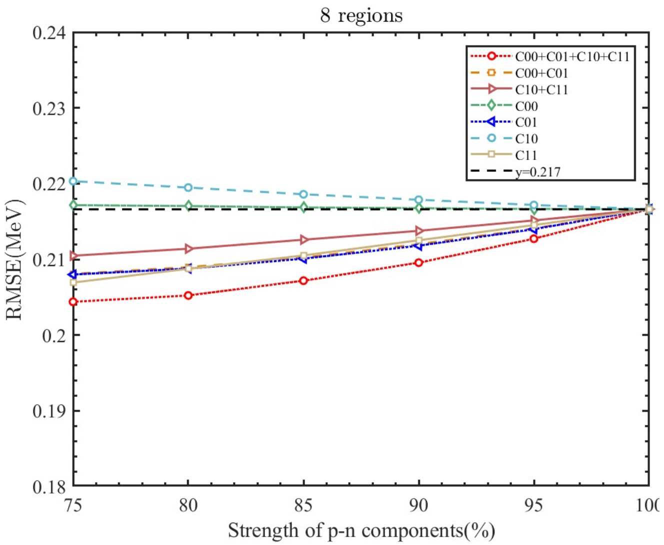
nucleus	$J\pi$	Expt.	V_{MU}+LS	jj45pnm	jj45pna
RMS			0.17	0.27	0.47

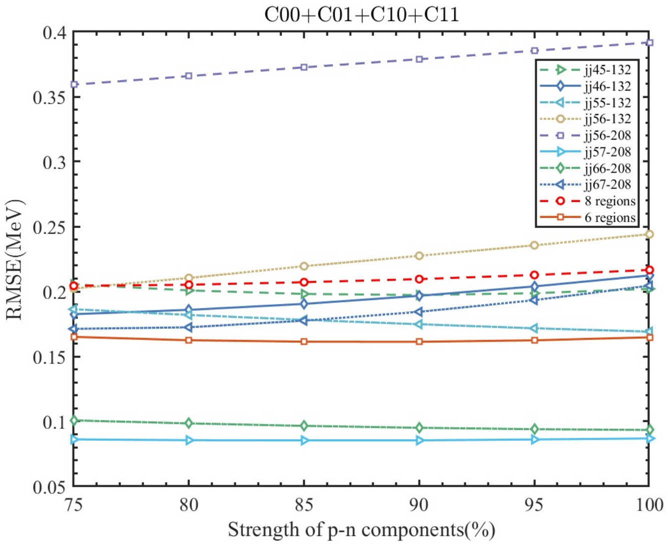
Use one effective nuclear force to deduce Hamiltonians for 8 model spaces around ^{132}Sn and ^{208}Pb;
At present, describe 825 levels in 154 nuclei

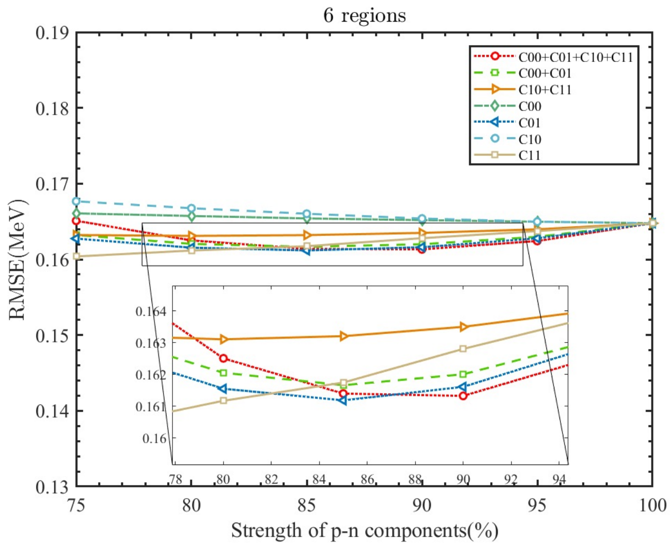
CXY, Liu, Ge, et al.,
In preparation



No. Nuclei	154	116	38 (semi-magic)
No. States	825	605	220
RMS (MeV)	0.203	0.217	0.158
Mean (MeV)	-0.078	-0.102	-0.015


8 regions
C00+C01+C10+C11
C00+C01
C10+C11
C00
C01
C10
C11
y=0.217
RMSE(MeV)
Strength of p-n components(%)


C00+C01+C10+C11
jj45-132
jj46-132
jj55-132
jj56-132
jj56-208
jj57-208
jj66-208
jj67-208
8 regions
6 regions
RMSE(MeV)
Strength of p-n components(%)


6 regions
C00+C01+C10+C11
C00+C01
C10+C11
C00
C01
C10
C11
RMSE(MeV)
Strength of p-n components(%)

报告提纲

- 组态混合壳模型
- 轻核中的跨壳激发和镜像不对称性
- 中重核中的新核素和新同核异能态
- 统一描述中重核的相互作用初探
- 总结

- **Summary and perspective**
  - **Systematic study from light to heavy nuclei**
  - **More data and more computational power! Uncertainty of shell model from more than 1000 nuclei and more than 10000 spectroscopic properties, BE, levels, EM, GT and FF**

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感谢！