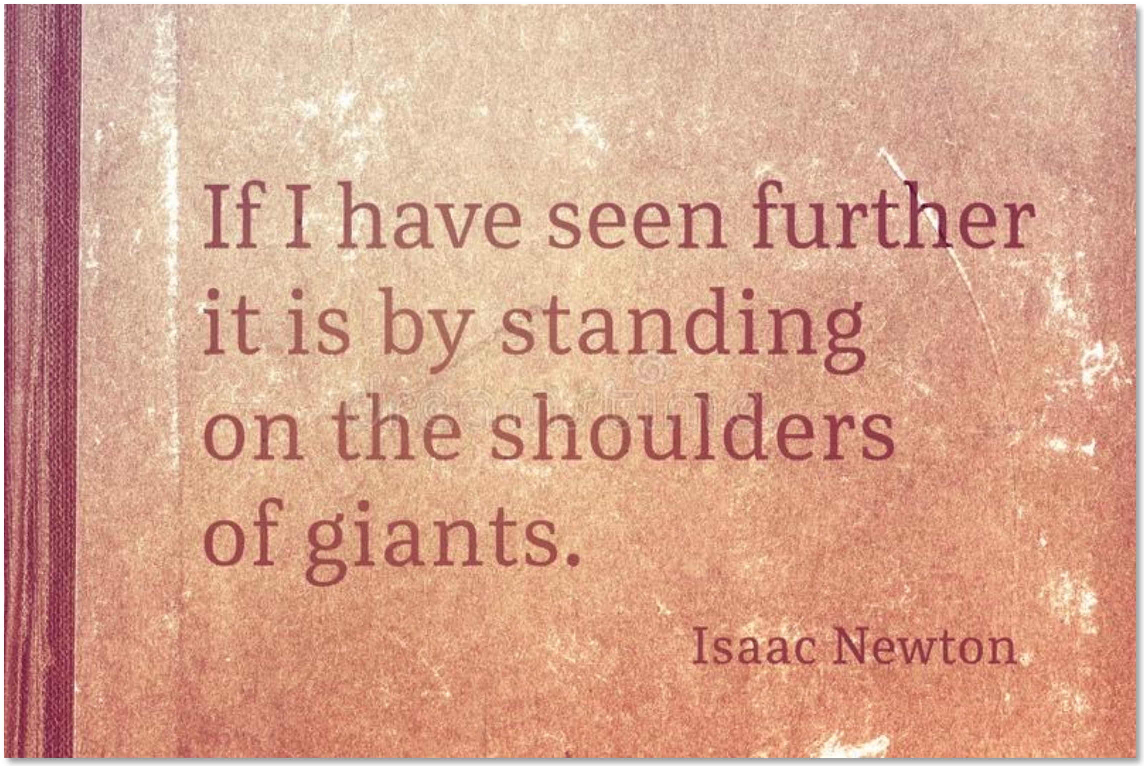
The Islands of Inversion from the Nilsson Perspective

A. O. Macchiavelli

Physics Division, Oak Ridge National Laboratory, USA

ESNT-DPhN Seminar

September 8th, 2023

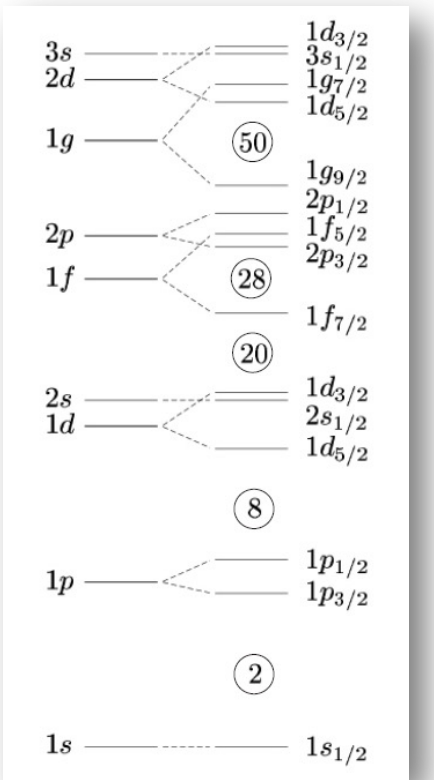

If I have seen further
it is by standing
on the shoulders
of giants.
Isaac Newton

Ricardo A. Broglia
1939-2022

John P. Schiffer
1930-2023

Thank you
You are sorely missed !

Evolution of Shell Structure and Collectivity



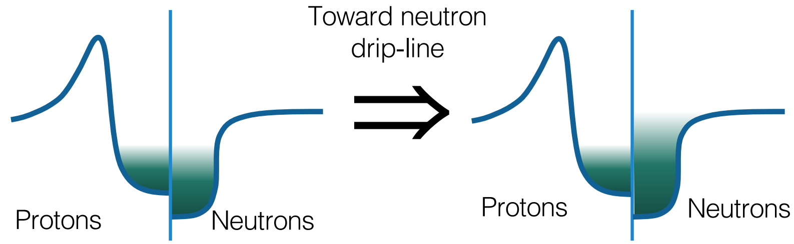
Near the valley of β stability

A driving question in nuclear physics:

Is the shell-model description static across the entire chart of nuclides?

Approaching the drip-lines

⇒ ?



"Classic" magic numbers are generally correct only for stable and near stable isotopes

Experimental studies of new exotic nuclei revealed that "Classic" magic numbers are generally correct only for stable and near stable isotopes

Changes in shell structure and collectivity, have provided insight on the important role played by the central, tensor, (and 3N) forces in these changes and its N/Z (Isospin) dependence

Role of weak binding and the continuum

9/7/2023, 6:42:32 AM

The Islands of Inversion, also known as the Inversion Islands, are a theoretical concept in physics and chemistry. They refer to a phenomenon that occurs in certain atomic nuclei, where the order of energy levels of the single-particle orbitals is inverted compared to what is normally expected.

In nuclear physics, the term "inversion" refers to the reversal of the normal order of energy levels. Normally, the energy levels of single-particle states increase with increasing energy, but in the case of the Islands of Inversion, this order is reversed, leading to unique and interesting nuclear properties.

The Islands of Inversion are typically observed in atomic nuclei with a high number of protons or neutrons, or both. In these nuclei, specific configurations of protons and neutrons result in the inversion of energy levels. This inversion can have a significant impact on the nuclear structure and behavior, leading to phenomena such as shape coexistence, enhanced collectivity, and exotic decay modes.

ChatGPT

The study of the Islands of Inversion is important for understanding the behavior of atomic nuclei and the limits of nuclear stability. It provides insights into the interplay between different nuclear forces and the emergence of new symmetries and structures.

It's worth noting that the Islands of Inversion are a theoretical concept and have not been observed in all atomic nuclei. However, experimental evidence from various isotopes suggests the existence of these islands, and ongoing research continues to explore and characterize this intriguing phenomenon.

9/7/2023, 6:42:32 AM

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and behavior, leading to phenomena such as shape coexistence, enhanced collectivity, and exotic decay modes.

ChatGPT

Evolution of shell structure in exotic nuclei

Takaharu Otsuka, Alexandra Gade, Olivier Sorlin, Toshio Suzuki, and Yutaka Utsuno

Rev. Mod. Phys. **92**, 015002 – Published 27 March 2020

The study of the Islands of Inversion is important for understanding the behavior of atomic nuclei and the limits of nuclear stability. It provides insights into the interplay between different nuclear forces and the emergence of new symmetries and structures.

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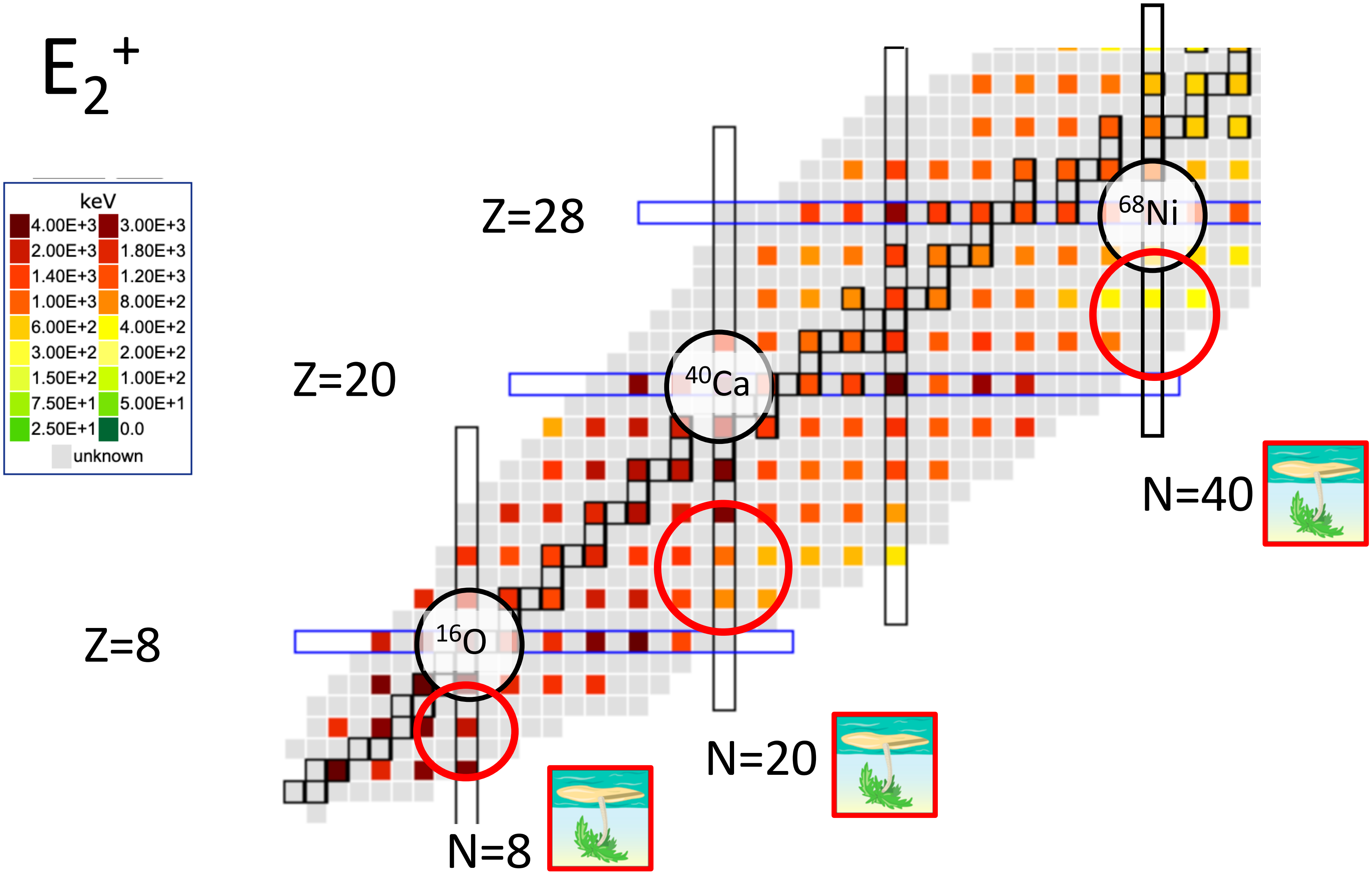
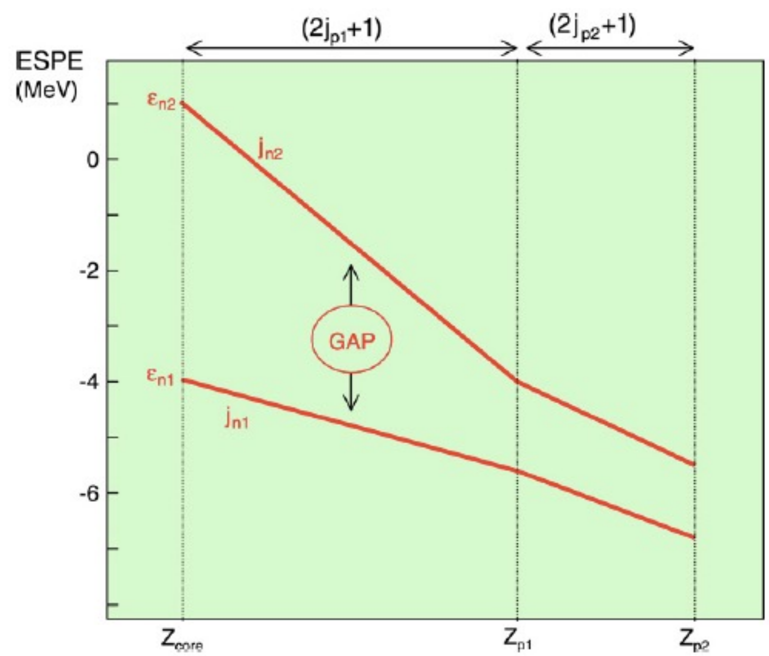


E2+
keV
4.00E+3
3.00E+3
2.00E+3
1.80E+3
1.40E+3
1.20E+3
1.00E+3
8.00E+2
6.00E+2
4.00E+2
3.00E+2
2.00E+2
1.50E+2
1.00E+2
7.50E+1
5.00E+1
2.50E+1
0.0
unknown
Z=28
Z=20
Z=8
68Ni
40Ca
16O
N=8
N=20
N=40

O. Sorlin, M.-G. Porquet / Progress in Particle and Nuclear Physics 61 (2008) 602–673



PRL 95, 232502 (2005) PHYSICAL REVIEW LETTERS week ending 2 DECEMBER 2005

Evolution of Nuclear Shells due to the Tensor Force

Takaharu Otsuka,[1,2,3,*] Toshio Suzuki,[4] Rintaro Fujimoto,[1] Hubert Grawe,[5] and Yoshinori Akaishi[6]

[1]*Department of Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[2]*Center for Nuclear Study, University of Tokyo, Hongo, Bunkyo-ku, Tokyo 113-0033, Japan*
[3]*RIKEN, Hirosawa, Wako-shi, Saitama 351-0198, Japan*
[4]*Department of Physics, Nihon University, Sakurajosui, Setagaya-ku, Tokyo 156-8550, Japan*
[5]*GSI, D-64291, Darmstadt, Germany*
[6]*KEK, Oho, Tsukuba-shi, Ibaraki 305-0801, Japan*

$$\Delta en(j) = \tfrac{1}{2}\{V_{j,j'}^{T=0} + V_{j,j'}^{T=1}\}\, n_p(j')$$

$$V_{j,j'}^{T} = \frac{\sum_J (2J+1)\langle jj'|V|jj'\rangle_{JT}}{\sum_J (2J+1)}$$

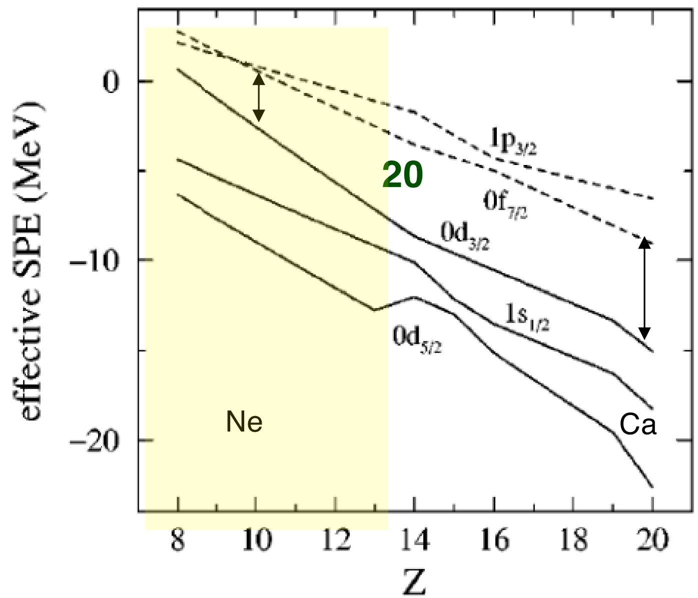
Monopole Average

$$V(r) = V_{Central} + V_{Tensor} + V_{SpinOrbit}$$

SO
SE
TO
TE

Migration of Effective Single-Particle Energies (ESPE)

Y.Utsuno et al PRC 60 (1999) 011301(R)

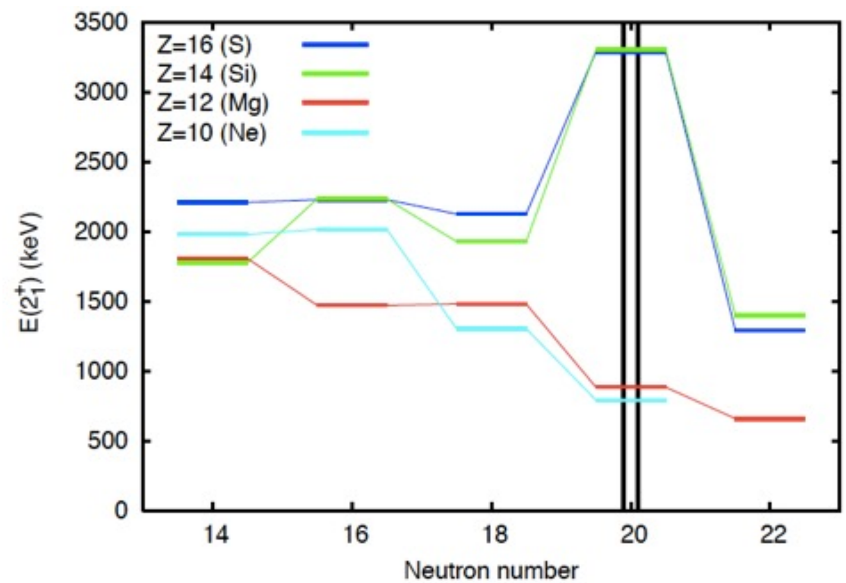


$d_{5/2}$ | $s_{1/2}$ | $d_{3/2}$

N=20 shell gap

Role of the π $d_{5/2}$- ν $d_{3/2}$ interaction

$\Delta\ell=\Delta j=2$
→ Quadrupole Correlations



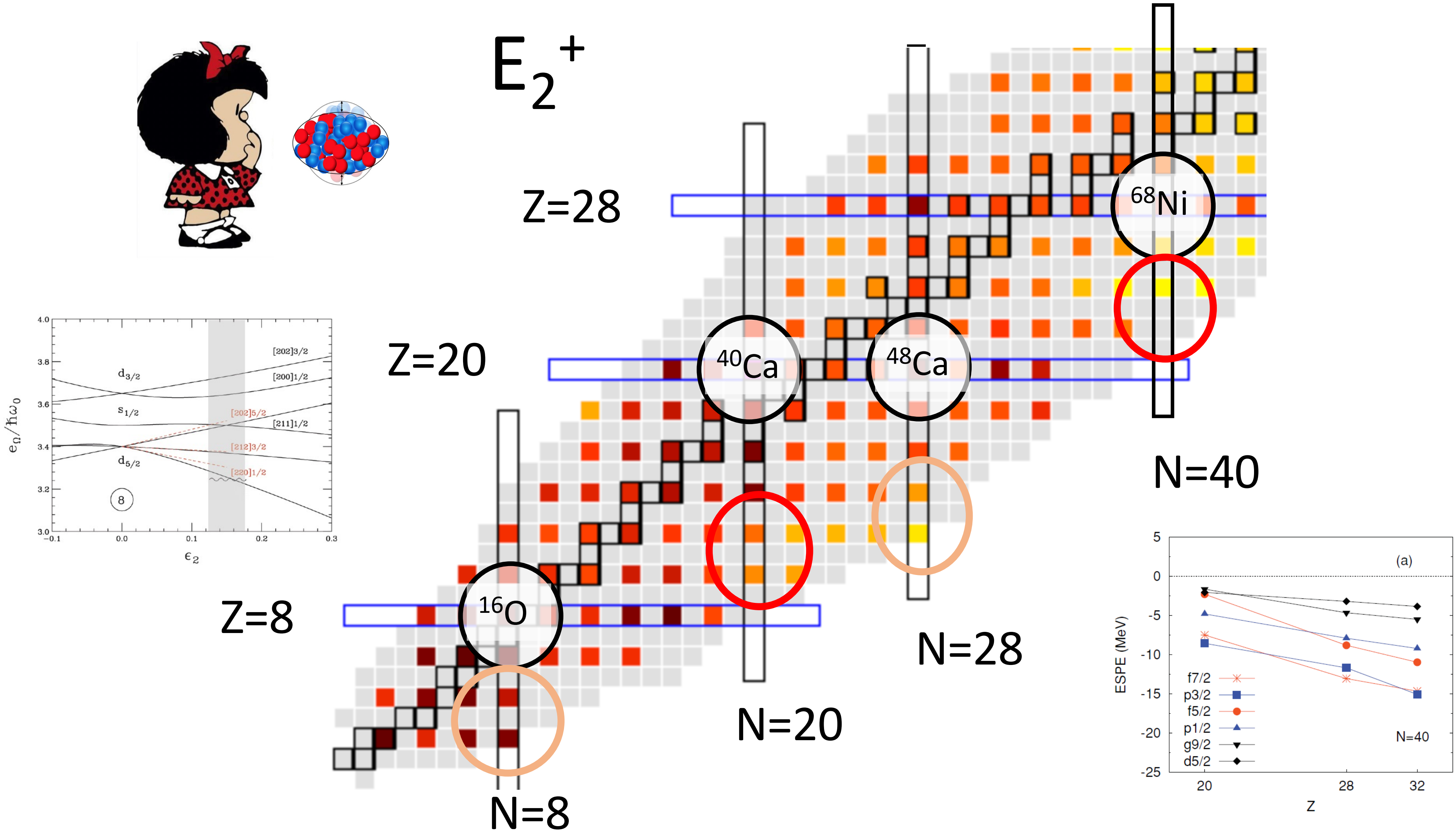
$$H = Esp + GP^{+}P + xQ.Q$$

A. Poves and J. Retamosa, Phys. Lett. B **184**, 311 (1987).
E. K. Warburton, J. A. Becker, and B. A. Brown, Phys. Rev. C**41**, 1147 (1990).

Since much evidence has been obtained for the existence of deformed ground states

⇩

How about the deformed shell model ?



E2+
Z=28
Z=20
Z=8
68Ni
40Ca
48Ca
16O
N=8
N=20
N=28
N=40
ESPE (MeV)
Z
(a)
N=40
f7/2
p3/2
f5/2
p1/2
g9/2
d5/2
d3/2
s1/2
d5/2
[202]3/2
[200]1/2
[202]5/2
[211]1/2
[212]3/2
[220]1/2

The Islands of Inversion from the Nilsson Perspective

A refresher on the Particle plus Rotor Model

Spectroscopic Factors in the Nilsson Strong Coupling Limit

N=20 Island of Inversion

Structure of ^{25}F and ^{29}F

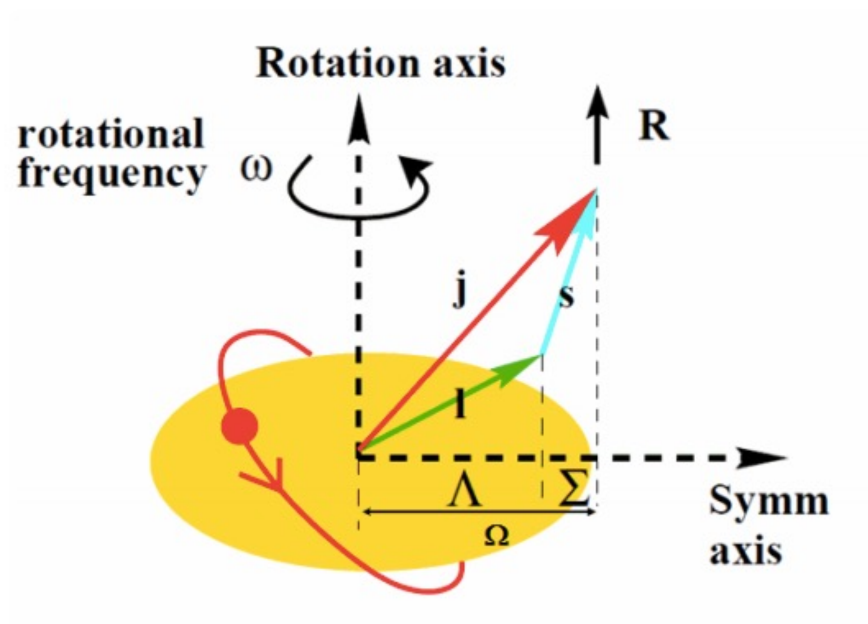
N=40 Island of Inversion

Structure of $^{63,65}Mn$

How light can you go?

$^{7,8,9}He$

Particle plus Rotor Model 101



PRM Hamiltonian

$$H = E_\Omega + \frac{\hbar^2}{2\mathscr{I}} I(I+1) + H_C \quad \longrightarrow \quad H_C = -\frac{\hbar^2}{2\mathscr{I}}(I_+ j_- + I_- j_+)$$

Particle (E_Ω)

Rotor ($\frac{\hbar^2}{2\mathscr{I}} I(I+1)$)

Coriolis coupling (H_C)

PRM
Hamiltonian

$$H = E_\Omega + \frac{\hbar^2}{2\mathscr{I}} I(I+1) + H_C \longrightarrow H_C = -\frac{\hbar^2}{2\mathscr{I}}(I_+ j_- + I_- j_+)$$

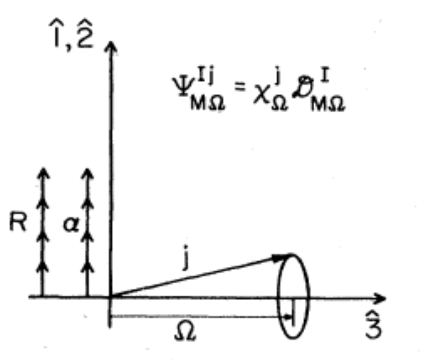
Particle

Rotor

Coriolis coupling

$H_c/\Delta E_K << 1$

Deformation aligned
Strongly coupled



$$E(K,I) = E_K + AI(I+1) + BI^2(I+1)^2 + \cdots$$

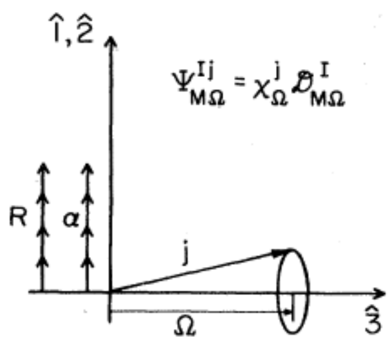
PRM Hamiltonian

$$H = E_\Omega + \frac{\hbar^2}{2\mathscr{I}} I(I+1) + H_C \rightarrow H_C = -\frac{\hbar^2}{2\mathscr{I}}(I_+ j_- + I_- j_+)$$

Particle — Rotor — Coriolis coupling

$H_c/\Delta E_K << 1$

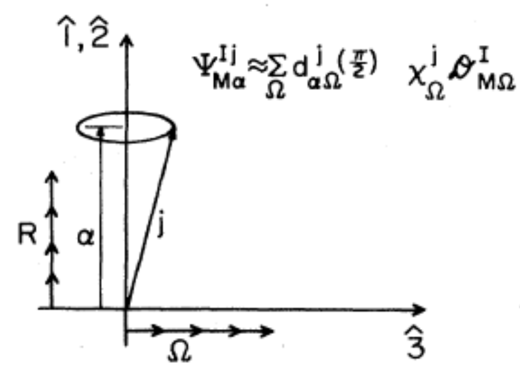
Deformation aligned
Strongly coupled



$$E(K,I) = E_K + AI(I+1) + BI^2(I+1)^2 + \cdots$$

$H_c/\Delta E_K >> 1$

Rotation aligned
Decoupled

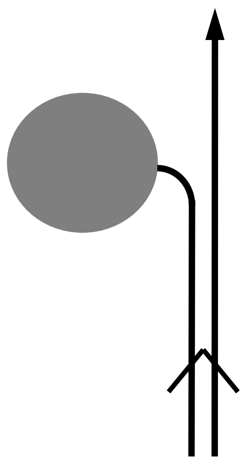


$$I = j,\ j+2,\ j+4,\ \ldots$$

$$E(I+2) - E(I) \approx E(R+2) - E(R).$$

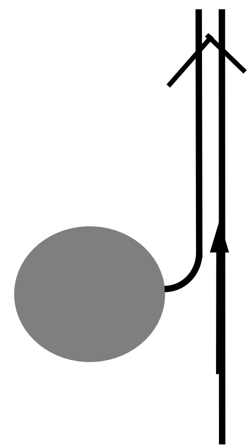
Direct reactions

Direct transfer reactions continue to play major role in our understanding of the nuclear elementary modes of excitation, particularly in the characterization of the single particle degrees of freedom and their correlations.



$$< A+1 \,|\, a^{+} \,|\, A >$$

(d,p) vacancies



$$< A-1 \,|\, a \,|\, A >$$

(p,d) particles

Direct reactions

$$d\sigma^{(-1)}(j;I_1\rightarrow I_2)=(2I_1+1)^{-1}\sum_{M_1M_2m}d\sigma^{(-1)}(jm;I_1M_1\rightarrow I_2M_2)$$
$$=(2j+1)^{-1}(2I_1+1)^{-1}\langle I_1\|a^\dagger(j)\|I_2\rangle^2\,d\sigma_{\rm sp}^{(-1)}(j)$$

$$d\sigma_{\rm sp}^{(-1)}(j)=\sum_m d\sigma_{\rm sp}^{(-1)}(jm)$$

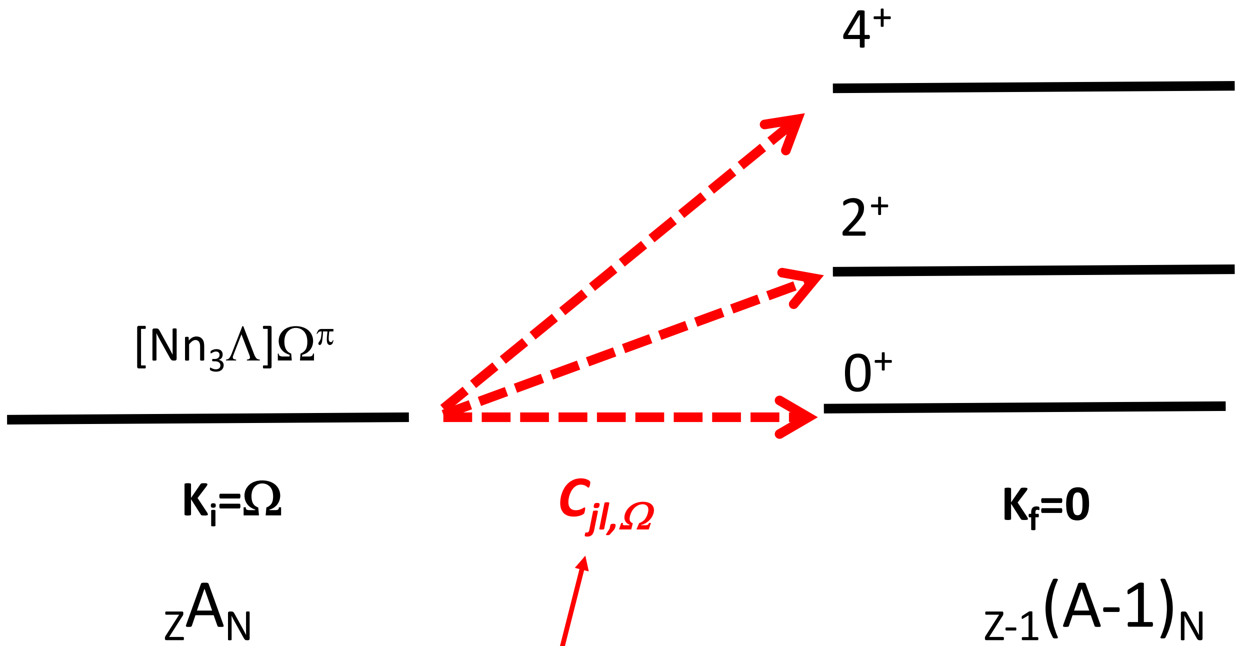
Structure

$$\mathscr{S}=(2I_2+1)^{-1}\langle I_2\|a^\dagger(j)\|I_1\rangle^2$$

Reaction
DWBA
Eikonal
DWIA

Macfarlane, M. H., and French, J. B. (1960), ***Rev. Mod. Phys.* 32,** 567.

(-1p) à la Nilsson



$$|[Nn_3\Lambda]\Omega^\pi> \; = \sum_{\alpha j \Omega} c^{(\nu)}_{\alpha j \Omega} \psi^{\alpha j}_{\Omega}, \qquad \alpha = N, l.$$

Nilsson Spectroscopic Factors

Single nucleon knockout

$$S_{i,f}(j\ell, K) = (g\langle I_i j \Omega_\nu K_i | I_f K_f \rangle C_{j,\ell} V_\nu \langle \phi_f | \phi_i \rangle)^2$$
$$= \theta_{i,f}(j\ell, K)^2$$

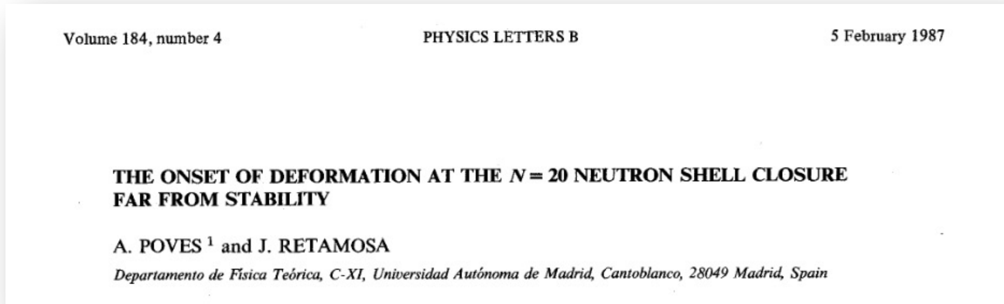
Nilsson amplitudes

BCS occupations

Core overlap

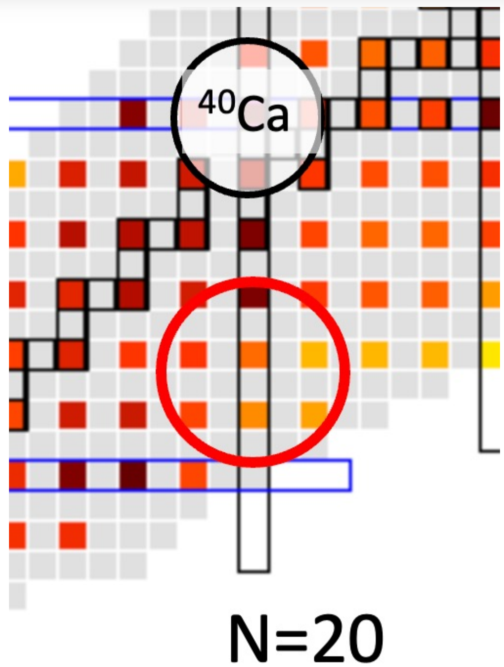
$$\frac{d\sigma}{d\Omega} = \sum_{j,\ell} S_{j,\ell} \times \sigma_\ell^{sp}$$

B. Elbek and P. Tjom,
Advances in Nucl. Phys. Vol 3, 259 (1969)


Volume 184, number 4 PHYSICS LETTERS B 5 February 1987

THE ONSET OF DEFORMATION AT THE $N = 20$ NEUTRON SHELL CLOSURE FAR FROM STABILITY

A. POVES [1] and J. RETAMOSA
Departamento de Física Teórica, C-XI, Universidad Autónoma de Madrid, Cantoblanco, 28049 Madrid, Spain



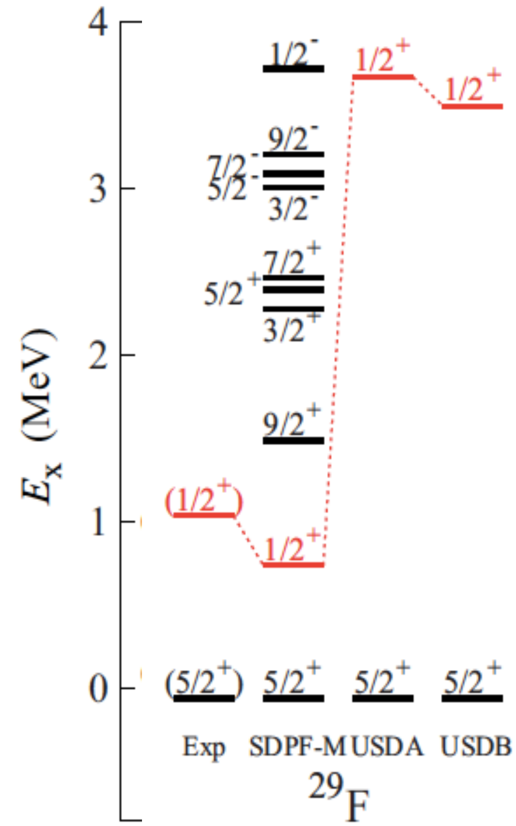
The case of ^{29}F

PHYSICAL REVIEW C **95**, 041301(R) (2017)

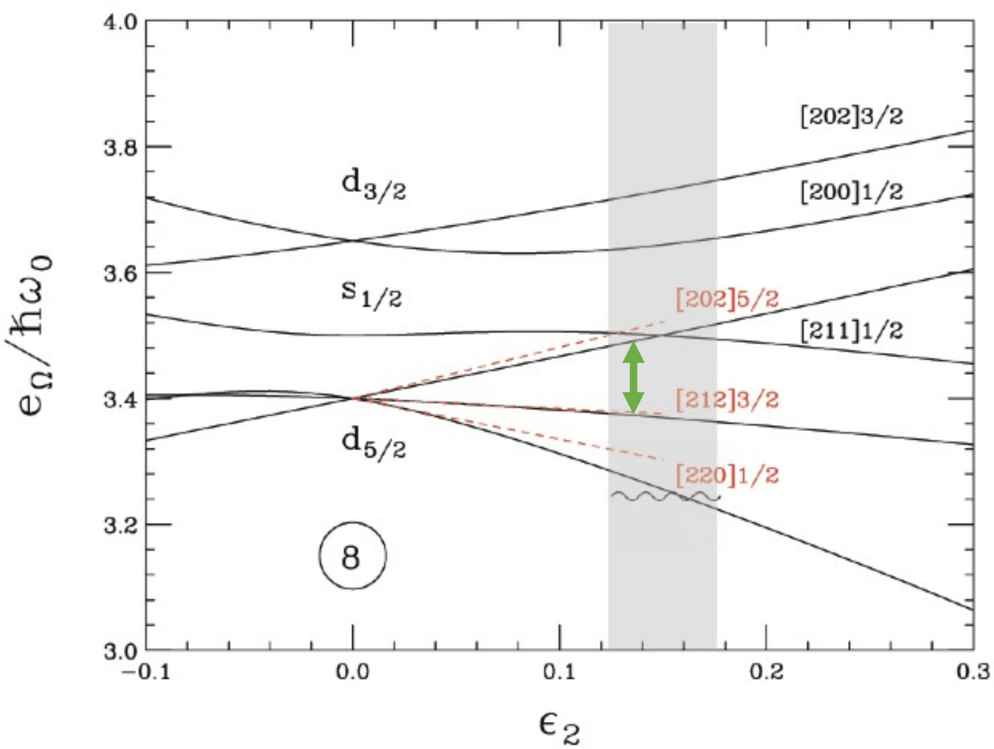
Low-Z shore of the "island of inversion" and the reduced neutron magicity toward ^{28}O

P. Doornenbal,[1,*] H. Scheit,[1,2,†] S. Takeuchi (武内 聡),[1,‡] Y. Utsuno (宇都野 穣),[3] N. Aoi (青井 考),[1,§] K. Li (李 闊昂),[1,2]
M. Matsushita (松下 昌史),[1,4,‖] D. Steppenbeck,[1] H. Wang (王 赫),[1,2] H. Baba (馬場 秀忠),[1] E. Ideguchi (井手口　栄治),[5,§]
N. Kobayashi (小林 信之),[6,§] Y. Kondo (近藤 洋介),[6] J. Lee (李曉菁),[1,¶] S. Michimasa (道正　新一郎),[5]
T. Motobayashi (本林 透),[1] T. Otsuka (大塚 孝治),[5,7] H. Sakurai (櫻井 博儀),[1] M. Takechi (武智 麻耶),[1,#]
Y. Togano (栂野 泰宏),[1,‡] and K. Yoneda (米田健一郎)[1]
[1]*RIKEN Nishina Center, Wako, Saitama 351-0198, Japan*
[2]*Peking University, Beijing 100871, People's Republic of China*
[3]*Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*
[4]*Department of Physics, Rikkyo University, Toshima, Tokyo 172-8501, Japan*
[5]*Center for Nuclear Study, University of Tokyo, RIKEN Campus, Wako, Saitama 351-0198, Japan*
[6]*Department of Physics, Tokyo Institute of Technology, Meguro, Tokyo 152-8551, Japan*
[7]*Department of Physics, University of Tokyo, Bunkyo, Tokyo 113-0033, Japan*
(Received 11 February 2015; revised manuscript received 20 February 2017; published 13 April 2017)

The two odd-even fluorine isotopes ^{27,29}F were studied via in-beam γ-ray spectroscopy at the RIKEN Radioactive Isotope Beam Factory. A secondary beam of ^{30}Ne was used to induce one-proton and one-proton–two-neutron removal reactions on carbon and polyethylene targets at midtarget energies of 228 MeV/u. Excited states were observed at 915(12) keV for ^{27}F and at 1080(18) keV for ^{29}F. Both were assigned a $1/2^+_1$ spin and parity. The low transition energy for ^{29}F largely disagrees with shell model predictions restricted to the sd model space. Calculations using effective interactions that include the neutron pf shell indicate that the $N = 20$ gap is quenched for ^{29}F, thus extending the "island of inversion" to isotopes with proton number $Z = 9$. Variations of the $N = 20$ gap further reveal a strong correlation to the $1/2^+_1$ level energy in ^{29}F and suggest a persistent reduced neutron gap for ^{28}O.



Nilsson levels



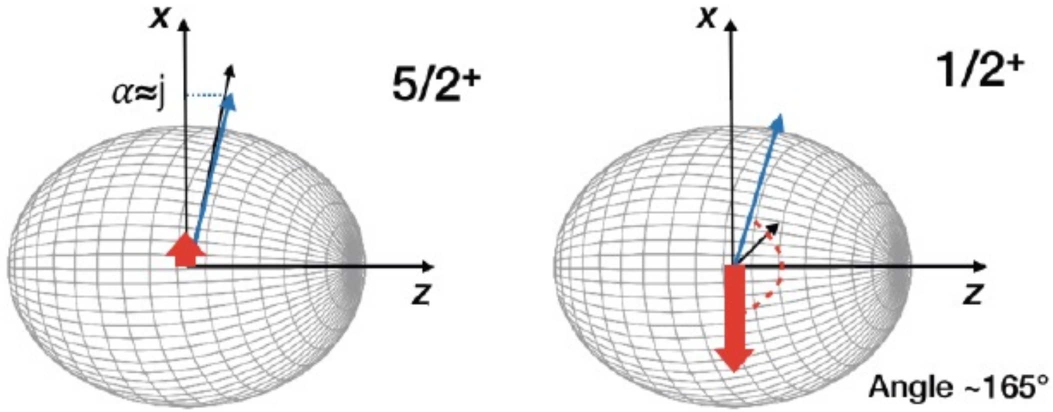
$\Delta E_K \sim \varepsilon_2 h\omega_0 \sim 1$ MeV

$H_c \sim j.\omega_{rot} \sim 3$ Mev

$H_c/\Delta E_K \sim 3 > 1$

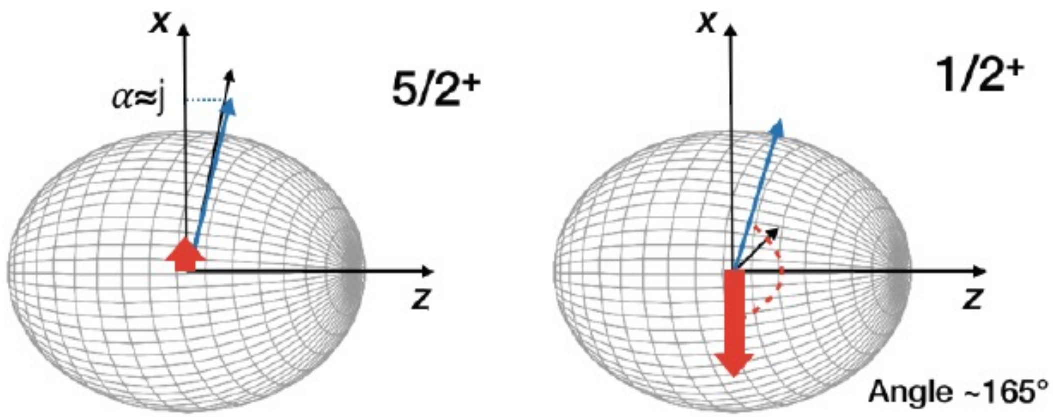
Decoupled band?

Structure of ^{29}F: Geometry



A.O. Macchiavelli, H. L. Crawford, *et al*. Physics Letters B 775 (2017) 160–162

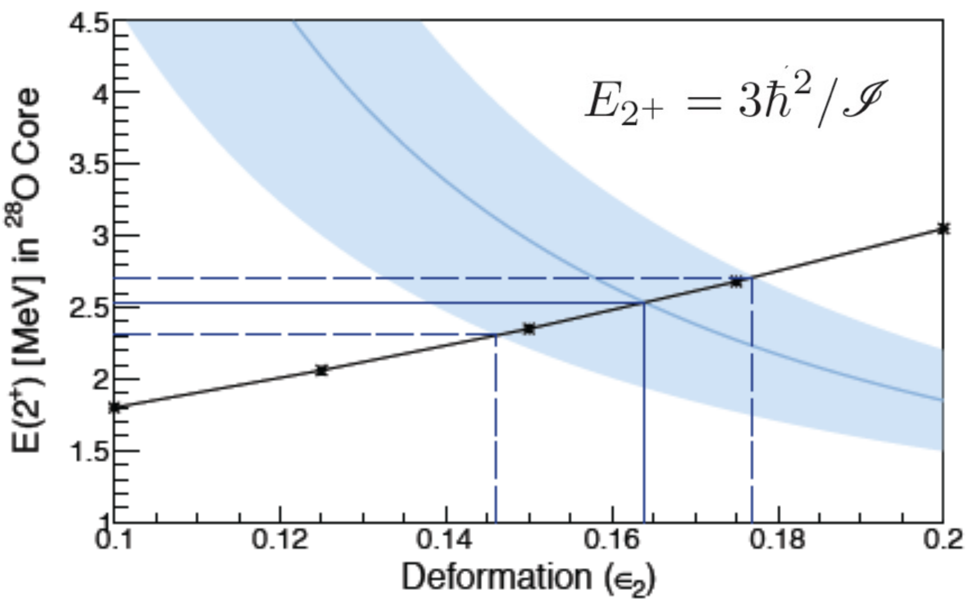
Structure of ^{29}F: Geometry



State	Energy [MeV]	$\langle R \rangle$	E_{rot} [MeV]	$\langle I_z \rangle$	$\langle \vec{I} \cdot \vec{j} \rangle / \lvert I \rvert$	$\langle \vec{R} \cdot \vec{j} \rangle / \lvert R \rvert$
$5/2^+$	0	0.53	0.34	0.11	2.78	−0.30
$1/2^+$	1.08	1.46	2.00	0.5	1.47	−2.14
$3/2^+$	2.2	2.01	2.54	−1.12	1.58	−2.18
$9/2^+$	2.6	2.18	2.91	0.04	2.65	1.76
$7/2^+$	3.2	2.09	2.71	0.60	2.27	0.12

A.O. Macchiavelli, H. L. Crawford, *et al*. Physics Letters B 775 (2017) 160–162

Structure of ^{29}F: PRM Solution

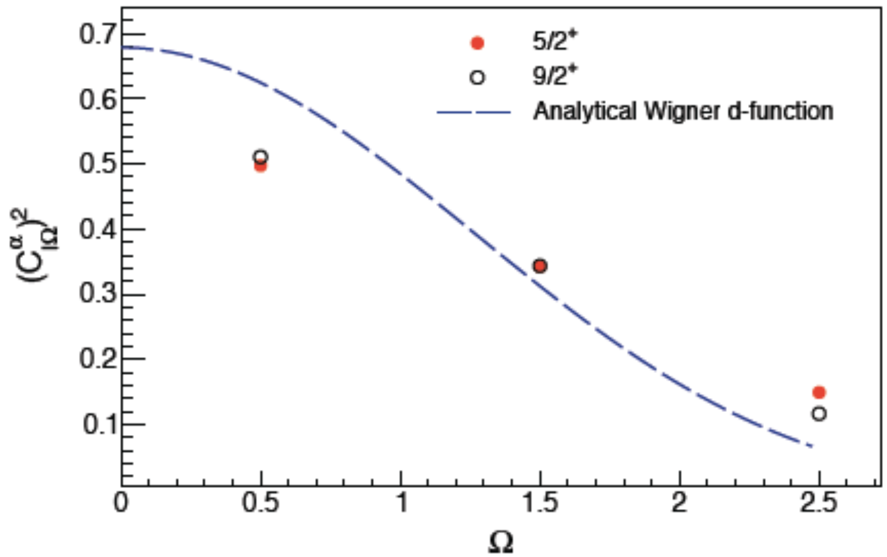


PRM

$$\mathscr{I} = \frac{\mathscr{I}_{rigid}}{(1 + (\frac{2\Delta}{\hbar\omega_0 \epsilon_2})^2)^{3/2}}$$

NP1712-RIBF164 (H.Crawford, Coulomb excitation of ^{29}F)

Structure of ^{29}F: Decoupled Band



$$|I,\alpha\rangle = \sum_{\Omega_p=1/2}^{5/2} C^{\alpha}_{I\Omega_p} |I,\Omega_p\rangle$$

$$C^{\alpha}_{I\Omega} \approx d^{j}_{\alpha,\Omega}(\pi/2)$$

Full *sd* PRM calculation

Pure decoupled $d_{5/2}$ band

Structure of ^{25}F and its effective ^{24}O core

PHYSICAL REVIEW LETTERS **124,** 212502 (2020)

How Different is the Core of ^{25}F from ^{24}O$_{g.s.}$?

T. L. Tang,[1,2,*] T. Uesaka,[2] S. Kawase,[1,†] D. Beaumel,[3] M. Dozono,[2] T. Fujii,[1] N. Fukuda,[2] T. Fukunaga,[4] A. Galindo-Uribarri,[5] S. H. Hwang,[6,‡] N. Inabe,[2] D. Kameda,[2] T. Kawahara,[7] W. Kim,[6] K. Kisamori,[1] M. Kobayashi,[1] T. Kubo,[2] Y. Kubota,[1,§] K. Kusaka,[2] C. S. Lee,[1] Y. Maeda,[8] H. Matsubara,[2,∥] S. Michimasa,[1] H. Miya,[1] T. Noro,[4] A. Obertelli,[2,9,§] K. Ogata,[10,11] S. Ota,[1] E. Padilla-Rodal,[12] S. Sakaguchi,[4] H. Sakai,[2] M. Sasano,[2] S. Shimoura,[1] S. S. Stepanyan,[6] H. Suzuki,[2] M. Takaki,[1] H. Takeda,[2] H. Tokieda,[1] T. Wakasa,[4] T. Wakui,[13,¶] K. Yako,[1] Y. Yanagisawa,[2] J. Yasuda,[4] R. Yokoyama,[1] K. Yoshida,[2] K. Yoshida,[10,**] and J. Zenihiro[2]

The structure of a neutron-rich ^{25}F nucleus is investigated by a quasifree $(p, 2p)$ knockout reaction at 270*A* MeV in inverse kinematics. The sum of spectroscopic factors of $\pi 0d_{5/2}$ orbital is found to be 1.0 ± 0.3. However, the spectroscopic factor with residual ^{24}O nucleus being in the ground state is found to be only 0.36 ± 0.13, while those in the excited state is 0.65 ± 0.25. The result shows that the ^{24}O core of ^{25}F nucleus significantly differs from a free ^{24}O nucleus, and the core consists of ~35% ^{24}O$_{g.s.}$. and ~65% excited ^{24}O. The result may infer that the addition of the $0d_{5/2}$ proton considerably changes neutron structure in ^{25}F from that in ^{24}O, which could be a possible mechanism responsible for the oxygen dripline anomaly.

Physics Letters B 672 (2009) 17–21

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Evidence for a doubly magic ^{24}O

C.R. Hoffman[a,*], T. Baumann[b], D. Bazin[b], J. Brown[c], G. Christian[b,d], D.H. Denby[e], P.A. DeYoung[e], J.E. Finck[f], N. Frank[b,d,1], J. Hinnefeld[g], S. Mosby[h], W.A. Peters[b,d,2], W.F. Rogers[h], A. Schiller[b,3], A. Spyrou[b], M.J. Scott[f], S.L. Tabor[a], M. Thoennessen[b,d], P. Voss[f]

NSCL
MoNA

^{26}F 85 MeV/A

PRL **102,** 152501 (2009) PHYSICAL REVIEW LETTERS week ending 17 APRIL 2009

One-Neutron Removal Measurement Reveals ^{24}O as a New Doubly Magic Nucleus

R. Kanungo,[1,*] C. Nociforo,[2] A. Prochazka,[2,3] T. Aumann,[2] D. Boutin,[3] D. Cortina-Gil,[4] B. Davids,[5] M. Diakaki,[6] F. Farinon,[2,3] H. Geissel,[2] R. Gernhäuser,[7] J. Gerl,[2] R. Janik,[8] B. Jonson,[9] B. Kindler,[2] R. Knöbel,[2,3] R. Krücken,[7] M. Lantz,[9] H. Lenske,[3] Y. Litvinov,[2] B. Lommel,[2] K. Mahata,[2] P. Maierbeck,[7] A. Musumarra,[10,11] T. Nilsson,[9] T. Otsuka,[12] C. Perro,[1] C. Scheidenberger,[2] B. Sitar,[8] P. Strmen,[8] B. Sun,[2] I. Szarka,[8] I. Tanihata,[13] Y. Utsuno,[14] H. Weick,[2] and M. Winkler[2]

GSI FRS

^{24}O at 920 MeV/A

PRL **109,** 022501 (2012) PHYSICAL REVIEW LETTERS week ending 13 JULY 2012

$N = 16$ Spherical Shell Closure in ^{24}O

K. Tshoo,[1,*] Y. Satou,[1] H. Bhang,[1] S. Choi,[1] T. Nakamura,[2] Y. Kondo,[2] S. Deguchi,[2] Y. Kawada,[2] N. Kobayashi,[2] Y. Nakayama,[2] K. N. Tanaka,[2] N. Tanaka,[2] N. Aoi,[3] M. Ishihara,[3] T. Motobayashi,[3] H. Otsu,[3] H. Sakurai,[3] S. Takeuchi,[3] Y. Togano,[3] K. Yoneda,[3] Z. H. Li,[3] F. Delaunay,[4] J. Gibelin,[4] F. M. Marqués,[4] N. A. Orr,[4] T. Honda,[5] M. Matsushita,[5] T. Kobayashi,[6] Y. Miyashita,[7] T. Sumikama,[7] K. Yoshinaga,[7] S. Shimoura,[8] D. Sohler,[9] T. Zheng,[10] and Z. X. Cao[10]

RIKEN

^{24}O(p,p')

Structure of ^{25}F and its effective ^{24}O core

Channel	Mean [MeV]	Width [MeV]	σ_{exp} [μb]	σ_{th} [μb]	J^{π}_{th}	S_{exp}	S_{th}(USDB)	S_{th}(SFO)	S_{th}(SPDF-MU)
(^{25}F, ^{24}O)	−0.5(1.1)	4.8(1.3)	53(18)	149(24)	$5/2^+$	0.36(13)	1.01	0.90	0.95
(^{25}F, ^{23}O)	6.5(1.4)	6.3(9)	81(26)	125(26)	$5/2^+$	0.65(25)	0.01	0.07	0.05
(^{25}F, ^{22}O)	12.7(6)	7.6(6)	274(71)	80(24)	$1/2^-$	3.43(1.4)		2.19	

The $0d_{5/2}$ proton knockout from ^{25}F populates the ^{24}O ground state with a smaller probability than the ^{24}O excited states. This result indicates that the oxygen core of ^{25}F is considerably different from $^{24}O_{gs}$ and has a larger overlap with the excited states of ^{24}O. The change in the neutron-shell structure due to the $0d_{5/2}$ proton may be responsible for the small overlap between ^{25}F and $^{24}O_{gs}$

A comparison with the shell model calculations indicates that the USDB, SFO, and SFPD-MU interactions are insufficient to reproduce the present results. A stronger tensor force or other mechanism such as the 3N force effects, or both, might be needed to explain the experimental results. More experimental and theoretical studies are necessary to clarify the mechanism for the change in the core of neutron-rich fluorine from the ground state of oxygen isotopes.

PHYSICAL REVIEW LETTERS **124,** 212502 (2020)

How Different is the Core of ^{25}F from ^{24}O$_{g.s.}$?

T. L. Tang,[1,2,*] T. Uesaka,[2] S. Kawase,[1,†] D. Beaumel,[3] M. Dozono,[2] T. Fujii,[1] N. Fukuda,[2] T. Fukunaga,[4] A. Galindo-Uribarri,[5] S. H. Hwang,[6,‡] N. Inabe,[2] D. Kameda,[2] T. Kawahara,[7] W. Kim,[6] K. Kisamori,[1] M. Kobayashi,[1] T. Kubo,[2] Y. Kubota,[1,§] K. Kusaka,[2] C. S. Lee,[1] Y. Maeda,[8] H. Matsubara,[2,‖] S. Michimasa,[1] H. Miya,[1] T. Noro,[4] A. Obertelli,[2,9,§] K. Ogata,[10,11] S. Ota,[1] E. Padilla-Rodal,[12] S. Sakaguchi,[4] H. Sakai,[2] M. Sasano,[2] S. Shimoura,[1] S. S. Stepanyan,[6] H. Suzuki,[2] M. Takaki,[1] H. Takeda,[2] H. Tokieda,[1] T. Wakasa,[4] T. Wakui,[13,¶] K. Yako,[1] Y. Yanagisawa,[2] J. Yasuda,[4] R. Yokoyama,[1] K. Yoshida,[2] K. Yoshida,[10,**] and J. Zenihiro[2]

The structure of a neutron-rich ^{25}F nucleus is investigated by a quasifree $(p, 2p)$ knockout reaction at 270*A* MeV in inverse kinematics. The sum of spectroscopic factors of $\pi 0d_{5/2}$ orbital is found to be 1.0 ± 0.3. However, the spectroscopic factor with residual ^{24}O nucleus being in the ground state is found to be only 0.36 ± 0.13, while those in the excited state is 0.65 ± 0.25. The result shows that the ^{24}O core of ^{25}F nucleus significantly differs from a free ^{24}O nucleus, and the core consists of ~35% ^{24}O$_{g.s.}$ and ~65% excited ^{24}O. The result may infer that the addition of the $0d_{5/2}$ proton considerably changes neutron structure in ^{25}F from that in ^{24}O, which could be a possible mechanism responsible for the oxygen dripline anomaly.

Channel	Mean [MeV]	Width [MeV]	σ_{exp} [μb]	σ_{th} [μb]	J^{π}_{th}	S_{exp}	S_{th}(USDB)	S_{th}(SFO)	S_{th}(SPDF-MU)
(^{25}F, ^{24}O)	−0.5(1.1)	4.8(1.3)	53(18)	149(24)	$5/2^+$	0.36(13)	1.01	0.90	0.95
(^{25}F, ^{23}O)	6.5(1.4)	6.3(9)	81(26)	125(26)	$5/2^+$	0.65(25)	0.01	0.07	0.05
(^{25}F, ^{22}O)	12.7(6)	7.6(6)	274(71)	80(24)	$1/2^-$	3.43(1.4)		2.19	

Letter

Core of ^{25}F studied by the ^{25}F$(-p)$ proton-removal reaction

H. L. Crawford,[1,*] M. D. Jones,[1,2] A. O. Macchiavelli,[1,3] P. Fallon,[1] D. Bazin,[4] P. C. Bender,[4,†] B. A. Brown,[4,5]
C. M. Campbell,[1] R. M. Clark,[1] M. Cromaz,[1] B. Elman,[4,5] A. Gade,[4,5] J. D. Holt,[6] R. V. F. Janssens,[2] I. Y. Lee,[1]
B. Longfellow,[4,5,‡] S. Paschalis,[7] M. Petri,[7] A. L. Richard,[4,‡] M. Salathe,[1] J. A. Tostevin,[8] and D. Weisshaar[4]

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[2]*Department of Physics and Astronomy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina 27559-3255, USA and Triangle Universities Nuclear Laboratory, Duke University, Durham, North Carolina 27708-0308, USA*
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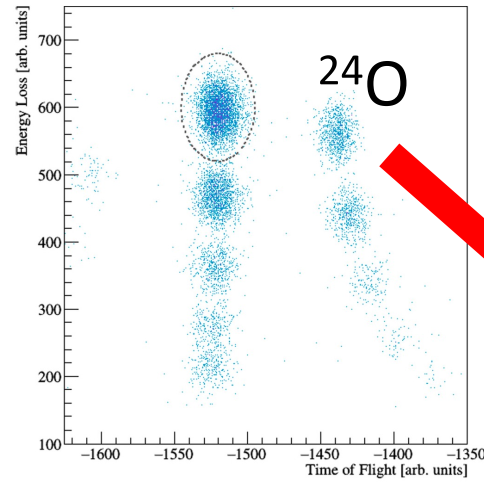
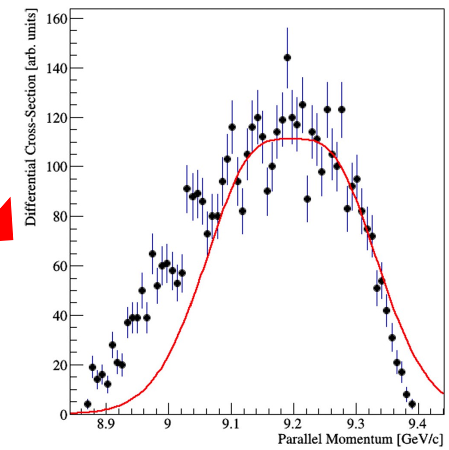
The ^{9}Be(^{25}F$(5/2^+)$, ^{24}O)X proton-removal reaction was studied at the NSCL using the S800 spectrometer. The experimental spectroscopic factor for the ground-state to ground-state transition indicates a substantial depletion of the proton $d_{5/2}$ strength compared to shell-model expectations, similar to the findings of an inverse-kinematics $(p, 2p)$ measurement performed at RIBF. The ^{25}F to ^{24}O ground-states overlap is considerably less than anticipated if the core nucleons behaved as rigid, doubly-magic ^{24}O within ^{25}F. We interpret the new results within the framework of the Particle-Vibration Coupling (PVC) model, of a $d_{5/2}$ proton coupled to a quadrupole phonon of an effective core. This approach provides a good description of the experimental data, requiring an effective ^{24}O* core with a phonon energy of $\hbar\omega_2 = 3.2$ MeV and a $B(E2) \approx 2.7$ W.u. – softer and more collective than a bare ^{24}O. Both the Nilsson deformed mean field and the PVC models appear to capture the properties of the effective core of ^{25}F, suggesting that the additional proton polarizes ^{24}O in such a way that it becomes either slightly deformed or a quadrupole vibrator.

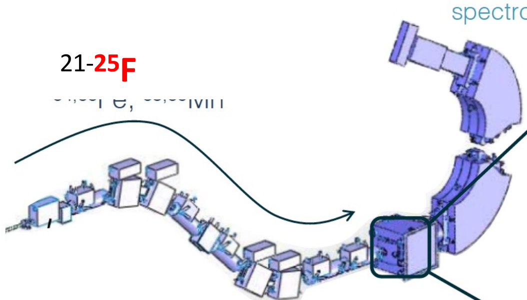
Proton Knockout at NSCL

^{20}Ne	^{21}Ne	^{22}Ne	^{23}Ne	^{24}Ne	^{25}Ne	^{26}Ne	^{27}Ne
^{19}F	^{20}F	^{21}F	^{22}F	^{23}F	^{24}F	^{25}F	^{26}F
^{18}O	^{19}O	^{20}O	^{21}O	^{22}O	^{23}O	^{24}O	^{25}O
^{17}N	^{18}N	^{19}N	^{20}N	^{21}N	^{22}N	^{23}N	^{24}N



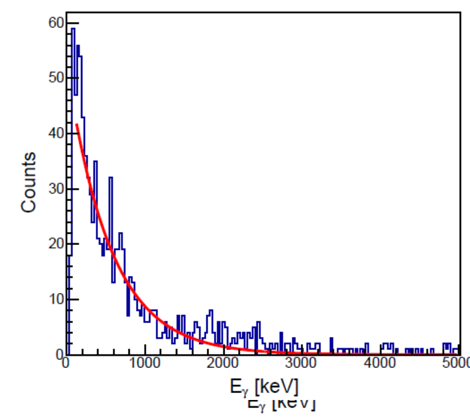
$\ell=2 \rightarrow d_{5/2}$

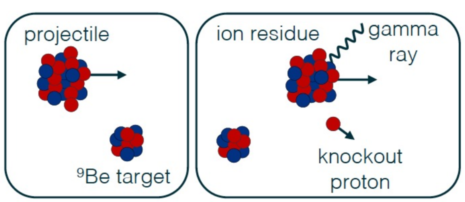




4 quads at 58°, 8 quads at 90°

https://people.nscl.msu.edu/~noji/gret_12det





- Paschalis *et al.*, NIM A 709 (2013) 44–55
- Bazin *et al.*, NIM B 204 (2003) 629–633

$\sigma = 4.3(6)\ mb$

$\sigma_{sp} = 15.7\ mb$

$S_{exp} = 0.27\ (4)$ **0.56(15)corrected**

PHYSICAL REVIEW C **102**, 041301(R) (2020)

Rapid Communications

Core of ^{25}F in the rotational model

A. O. Macchiavelli, R. M. Clark, H. L. Crawford, P. Fallon, I. Y. Lee, C. Morse, C. M. Campbell, M. Cromaz, and C. Santamaria

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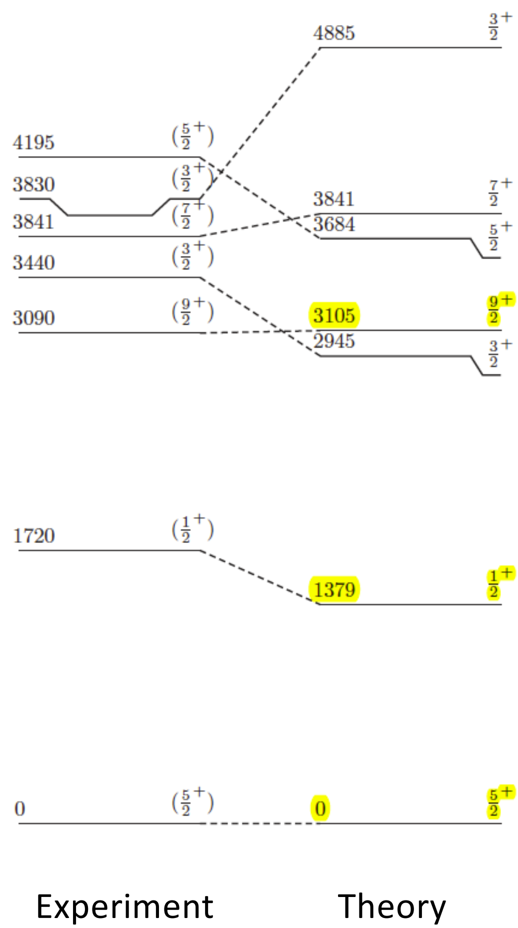
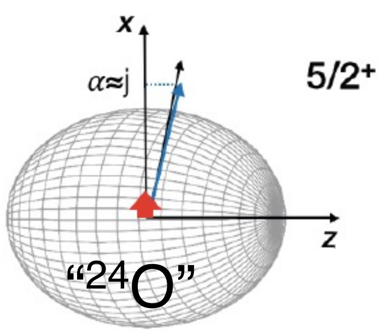
^{25}F in the PRM



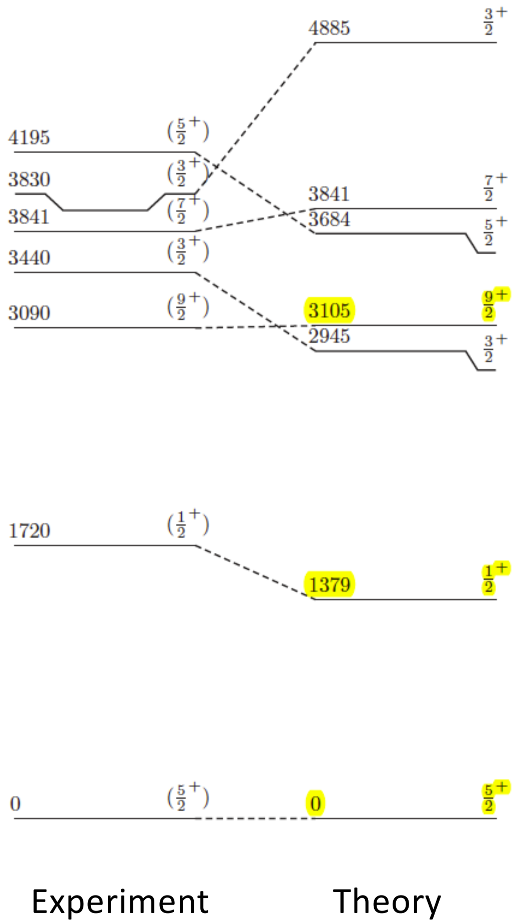
Zs. Vajta *et al*., Phys. Rev. C **89**, 054323 (2014).

The effective ^{24}O core in ^{25}F can be interpreted as a slightly deformed rotor with:

$E_{2^+}(\text{core}) \approx 3.2$ MeV and $\varepsilon_2 \approx 0.15$,



^{25}F in the PRM



Zs. Vajta *et al*., Phys. Rev. C **89**, 054323 (2014).

Furthermore, in ^{26}F * the 1^+ ground and 4^+ isomeric states can be associated with the antiparallel and parallel couplings of the odd neutron in the $d_{3/2}$ Nilsson multiplet to the structure of ^{25}F.

The former, favored by the Gallagher-Moszkowski rule gives 1^+ as the lowest state and the latter a 4^+ as the bandhead of a doubly decoupled band.

* A. Lepailleur *et al*., Phys. Rev. Lett. **110**, 082502 (2013)

Spectroscopic factors

PRM ➡ $\psi_I = \sum_K \mathcal{A}_K | IK\rangle.$ ➡ $S_{i,f}(j\ell) = \left(\sum_K \mathcal{A}_K \theta_{i,f}(j\ell, K)\right)^2,$

Final state in ^{24}O	S_{exp} Ref. [7]	S_{th} PRM1	PRM2	SDPF-MU
Ground	0.36(13)	0.85	0.56	0.95
Excited	0.65(25)	0.15	0.44	0.05

No Quenching

$\langle \phi_f | \phi_i \rangle \approx 0.81$

Following: T. Takemasa, M. Sakagami, and M. Sano, Phys. Rev. Lett. **29**, 133 (1979).
T. Takemasa, Comput. Phys. Commun. **36**, 79 (1985).

A first look at ^{28}F

PHYSICAL REVIEW LETTERS **124,** 152502 (2020)

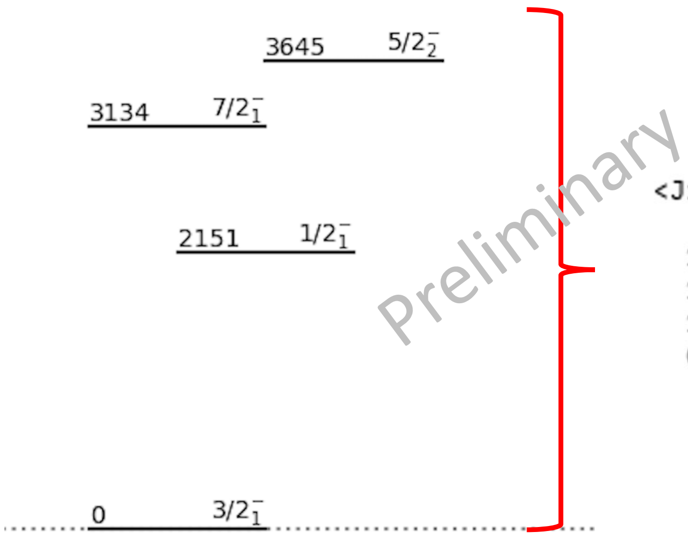
Extending the Southern Shore of the Island of Inversion to ^{28}F

A. Revel,[1,2] O. Sorlin,[1] F. M. Marqués,[2] Y. Kondo,[3] J. Kahlbow,[4,5] T. Nakamura,[3] N. A. Orr,[2] F. Nowacki,[6,7] J. A. Tostevin,[8] C. X. Yuan,[9] N. L. Achouri,[2] H. Al Falou,[10] L. Atar,[4] T. Aumann,[4,11] H. Baba,[5] K. Boretzky,[11] C. Caesar,[4,11] D. Calvet,[12] H. Chae,[13] N. Chiga,[5] A. Corsi,[12] H. L. Crawford,[14] F. Delaunay,[2] A. Delbart,[12] Q. Deshayes,[2] Z. Dombrádi,[15] C. A. Douma,[16] Z. Elekes,[15] P. Fallon,[14] I. Gašparić,[17,5] J.-M. Gheller,[12] J. Gibelin,[2] A. Gillibert,[12] M. N. Harakeh,[11,16] W. He,[5] A. Hirayama,[3] C. R. Hoffman,[18] M. Holl,[11] A. Horvat,[11] Á. Horváth,[19] J. W. Hwang,[20] T. Isobe,[5] N. Kalantar-Nayestanaki,[16] S. Kawase,[21] S. Kim,[20] K. Kisamori,[5] T. Kobayashi,[22] D. Körper,[11] S. Koyama,[23] I. Kuti,[15] V. Lapoux,[12] S. Lindberg,[24] S. Masuoka,[25] J. Mayer,[26] K. Miki,[27] T. Murakami,[28] M. Najafi,[16] K. Nakano,[21] N. Nakatsuka,[28] T. Nilsson,[24] A. Obertelli,[12] F. de Oliveira Santos,[1] H. Otsu,[5] T. Ozaki,[3] V. Panin,[5] S. Paschalis,[4] D. Rossi,[4] A. T. Saito,[3] T. Saito,[23] M. Sasano,[5] H. Sato,[5] Y. Satou,[20] H. Scheit,[4] F. Schindler,[4] P. Schrock,[25] M. Shikata,[3] Y. Shimizu,[5] H. Simon,[11] D. Sohler,[15] L. Stuhl,[5] S. Takeuchi,[3] M. Tanaka,[29] M. Thoennessen,[27] H. Törnqvist,[4] Y. Togano,[3] T. Tomai,[3] J. Tscheuschner,[4] J. Tsubota,[3] T. Uesaka,[5] Z. Yang,[5] M. Yasuda,[3] and K. Yoneda[5]

(SAMURAI21 collaboration)

Detailed spectroscopy of the neutron-unbound nucleus ^{28}F has been performed for the first time following proton/neutron removal from ^{29}Ne/^{29}F beams at energies around 230 MeV/nucleon. The invariant-mass spectra were reconstructed for both the $^{27}F^{(*)} + n$ and $^{26}F^{(*)} + 2n$ coincidences and revealed a series of well-defined resonances. A near-threshold state was observed in both reactions and is identified as the ^{28}F ground state, with $S_n(^{28}F) = -199(6)$ keV, while analysis of the $2n$ decay channel allowed a considerably improved $S_n(^{27}F) = 1620(60)$ keV to be deduced. Comparison with shell-model predictions and eikonal-model reaction calculations have allowed spin-parity assignments to be proposed for some of the lower-lying levels of ^{28}F. Importantly, in the case of the ground state, the reconstructed $^{27}F + n$ momentum distribution following neutron removal from ^{29}F indicates that it arises mainly from the $1p_{3/2}$ neutron intruder configuration. This demonstrates that the island of inversion around $N = 20$ includes ^{28}F, and most probably ^{29}F, and suggests that ^{28}O is not doubly magic.

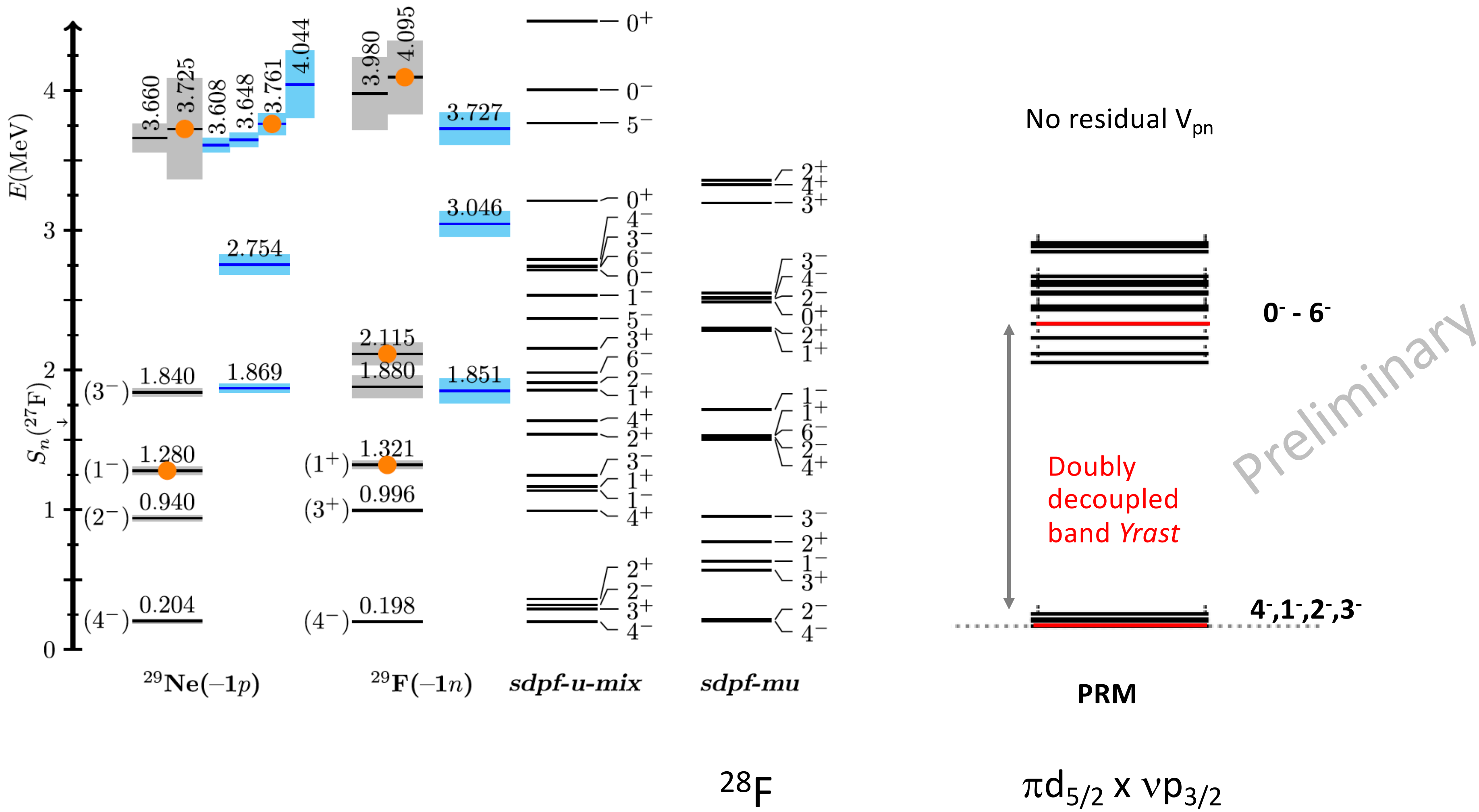
A first look at ^{28}F



Neutron plus ^{28}O*

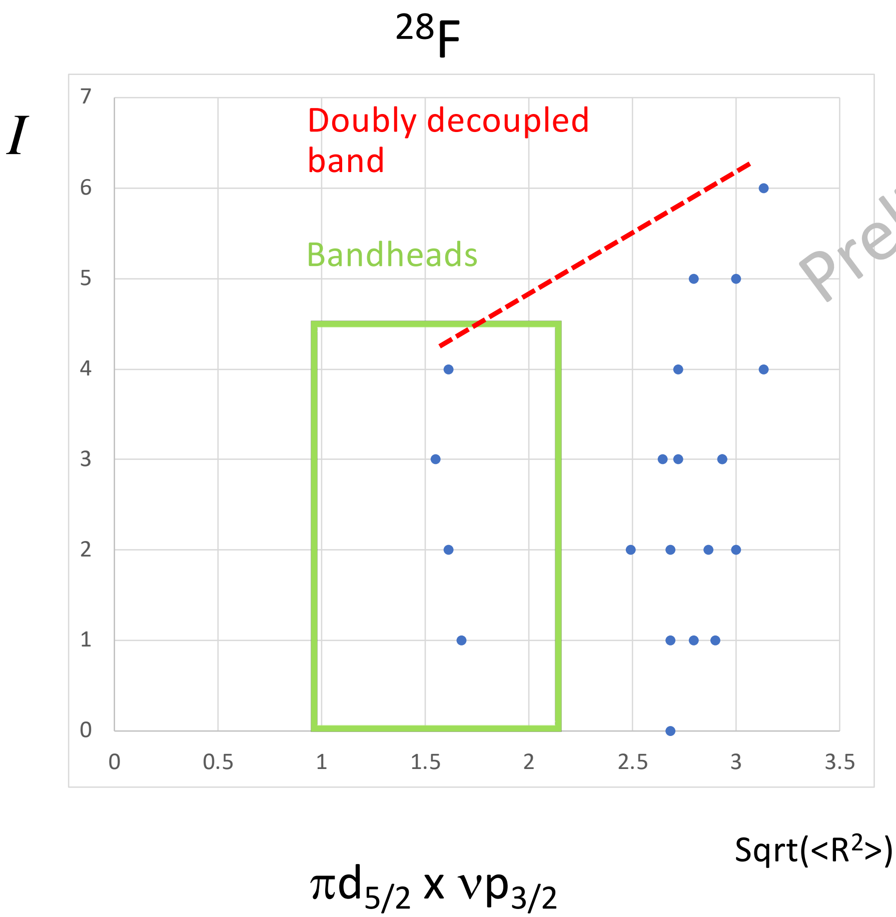
<Jx**2>	<Jy**2>	<Jz**2>	<I.j>/|I|	<Rx**2>	<Ry**2>	<Rz**2>	<R.j>/|R|
1.18	1.18	0.78	1.74	0.08	0.08	0.00	0.59
1.42	1.42	0.25	-0.80	2.61	2.61	0.00	-1.65
1.18	1.18	0.77	1.57	3.21	3.21	0.00	1.22
0.71	0.71	1.84	1.03	2.94	2.94	0.00	-0.08

→ $p_{3/2}$ decoupled band



E(MeV)
S_n(27F)
(4−) 0.204
(2−) 0.940
(1−) 1.280
(3−) 1.840
1.869
2.754
3.660
3.725
3.608
3.648
3.761
4.044
(4−) 0.198
(3+) 0.996
(1+) 1.321
1.880
2.115
3.980
4.095
1.851
3.046
3.727
29Ne(−1p)
29F(−1n)
sdpf-u-mix
sdpf-mu
28F
No residual V_pn
0- - 6-
4-,1-,2-,3-
Doubly decoupled band Yrast
Preliminary
PRM
πd5/2 x νp3/2

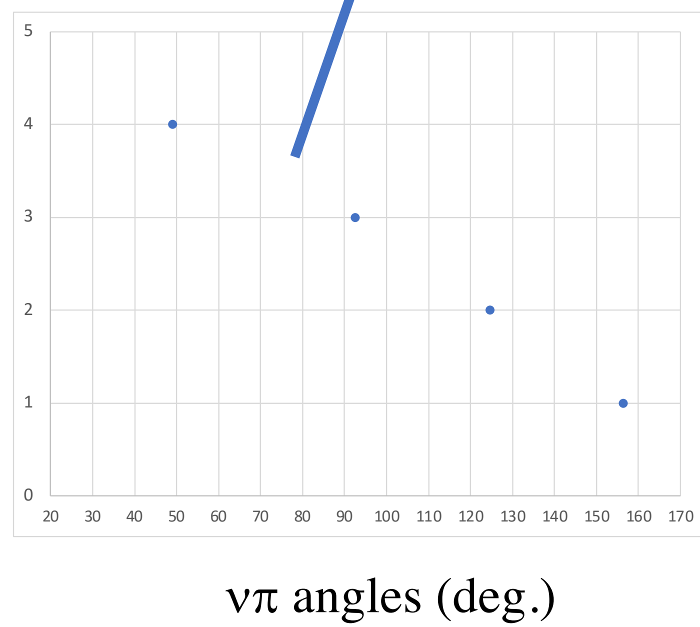
Angular momentum structure

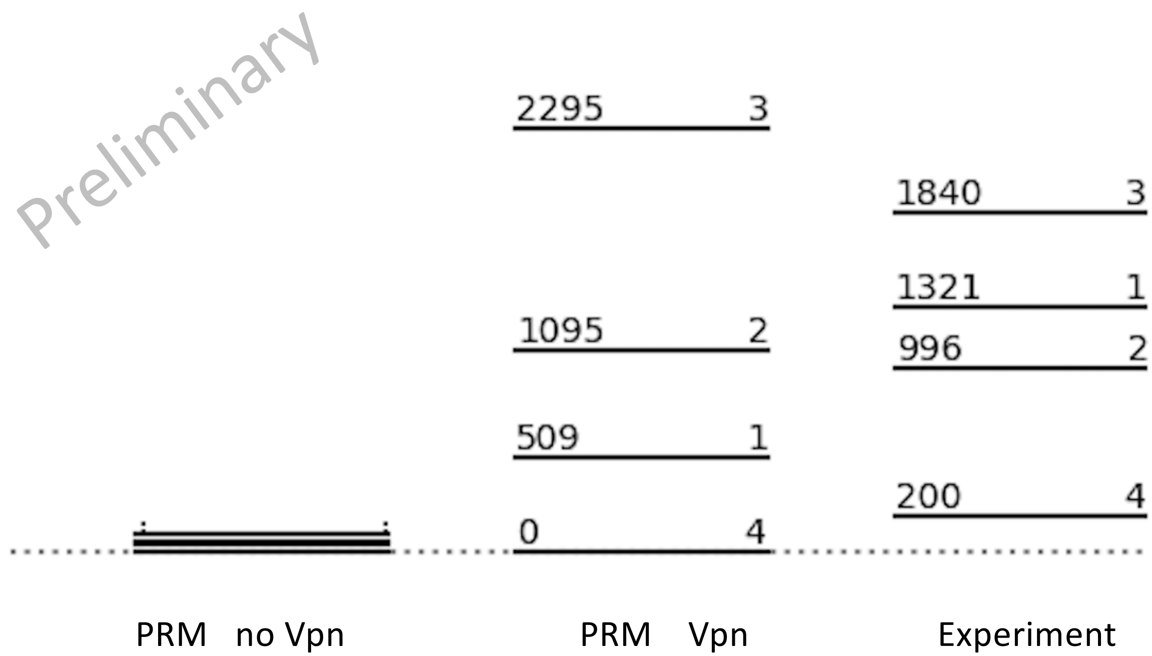


Preliminary

V_{pn} (angle)

A. Molinari, et al.
Nucl. Phys. A239, 45 (1975)





A. Molinari, et al. Nucl. Phys. A239, 45 (1975)
UNIVERSAL np FORCE

Summary

The low-lying structure of ^{25,29}F can be understood in terms of the rotation-aligned coupling limit of the PRM. Coriolis coupling on the $d_{5/2}$ proton Nilsson multiplet gives rise to a decoupled band with a $5/2^+$ bandhead.

Calculated proton spectroscopic factors for the ^{25}F($5/2^+$)($-1p$) ^{24}O reaction are in agreement with the experimental data. The observed fragmentation of the $d_{5/2}$ strength is due to both deformation and a core overlap.

The Nilsson plus PRM picture suggests that the extra proton with a dominant component in the down-sloping [220] ½ level polarizes ^{24,28}O and stabilizes its dynamic deformation. Thus, the effective core in ^{25}F (^{29}F) can be interpreted as a slightly deformed rotor with $E2+$ (core) ≈ 3.2 MeV (2.5MeV) and $\varepsilon_2 \approx 0.15$, compared to the real doubly magic ^{24}O (^{28}O) with $E2+$ ≈ 4.7 MeV (??) and weak vibrational quadrupole collectivity.

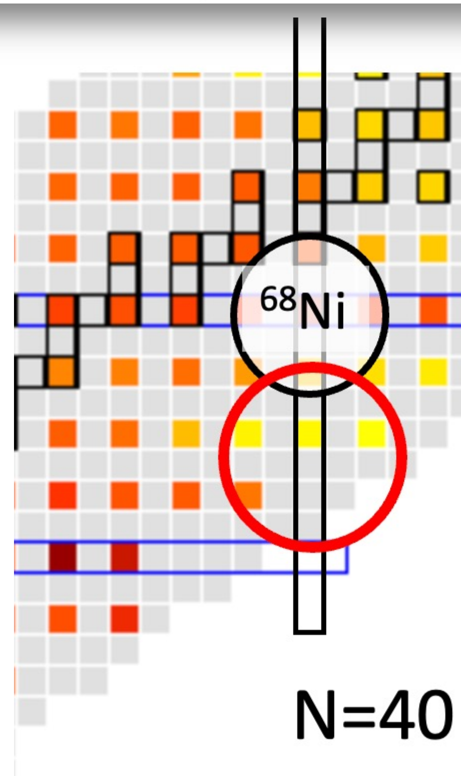
Electromagnetic observables for the three lowest experimental levels, obtained in the PRM, suggest that Coulomb excitation experiments will shed further light on the validity of our interpretation.

Two-qp plus rotor model calculations of ^{28,30}F are in progress.

PHYSICAL REVIEW C **82**, 054301 (2010)

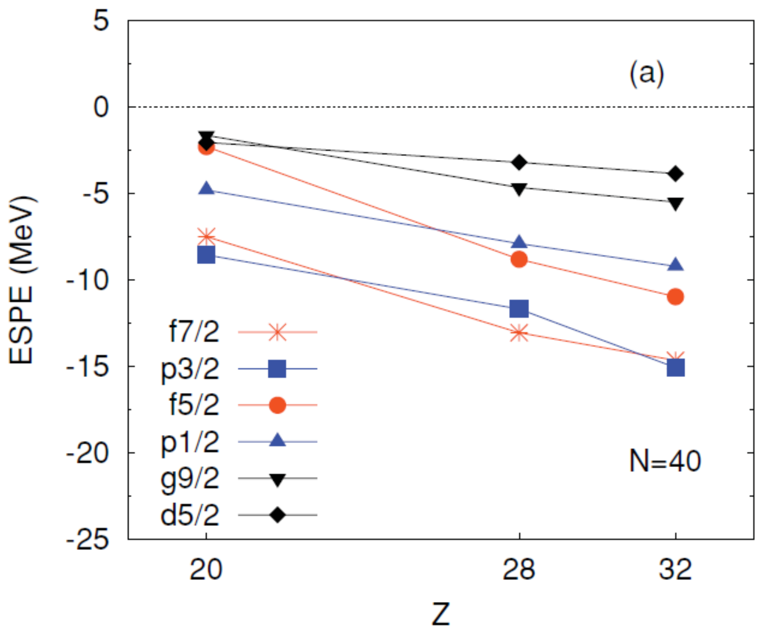
Island of inversion around ^{64}Cr

S. M. Lenzi,[1] F. Nowacki,[2] A. Poves,[3] and K. Sieja[2,*]
[1]*Dipartimento di Fisica dell'Università and INFN, Sezione di Padova, I-35131 Padova, Italy*
[2]*IPHC, IN2P3-CNRS et Université de Strasbourg, F-67037 Strasbourg, France*
[3]*Departamento de Física Teórica e IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain*



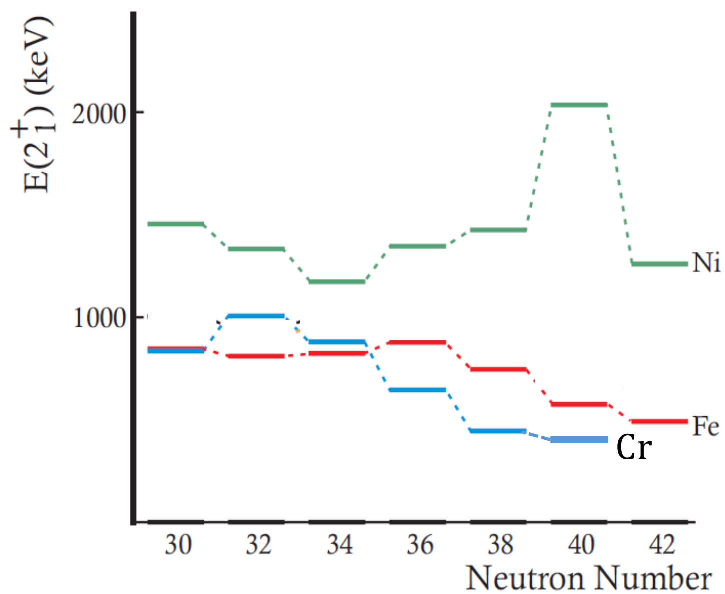
N=40 shell gap

Role of the π $f_{7/2}$- ν $f_{5/2}$ interaction



$f_{7/2}$ | $p_{3/2}$

$\Delta\ell = \Delta j = 2$



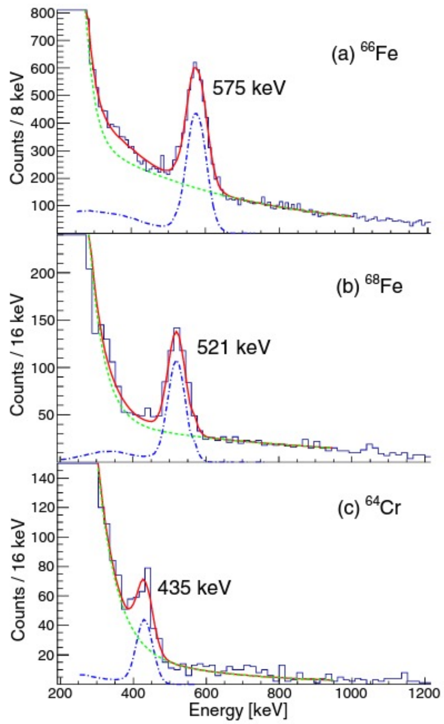
$$H = Esp + GP^{+}P + xQ.Q$$

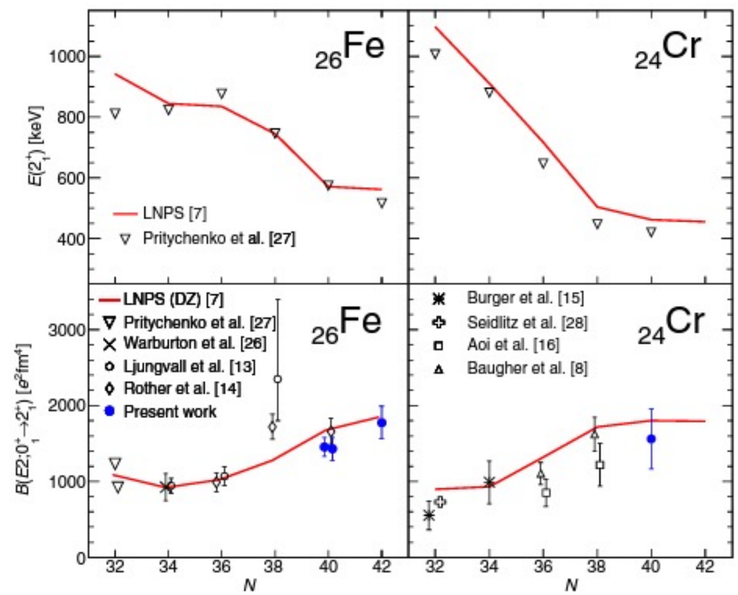
S. Lenzi *et al.*, PRC 82, 054301 (2010).

PRL **110,** 242701 (2013) PHYSICAL REVIEW LETTERS week ending 14 JUNE 2013

Quadrupole Collectivity in Neutron-Rich Fe and Cr Isotopes

H. L. Crawford,[1] R. M. Clark,[1] P. Fallon,[1] A. O. Macchiavelli,[1] T. Baugher,[2,3] D. Bazin,[2] C. W. Beausang,[4] J. S. Berryman,[2] D. L. Bleuel,[5] C. M. Campbell,[1] M. Cromaz,[1] G. de Angelis,[6] A. Gade,[2,3] R. O. Hughes,[4] I. Y. Lee,[1] S. M. Lenzi,[7] F. Nowacki,[8] S. Paschalis,[1] M. Petri,[1] A. Poves,[9] A. Ratkiewicz,[2,3] T. J. Ross,[4] E. Sahin,[6] D. Weisshaar,[2] K. Wimmer,[2,10] and R. Winkler[2]





The cases of $^{63,65}Mn$

Physics Letters B 784 (2018) 392–396

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Physics Letters B

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Spectroscopy of $^{65,67}_{25}$Mn: Strong coupling in the $N = 40$ “island of inversion”

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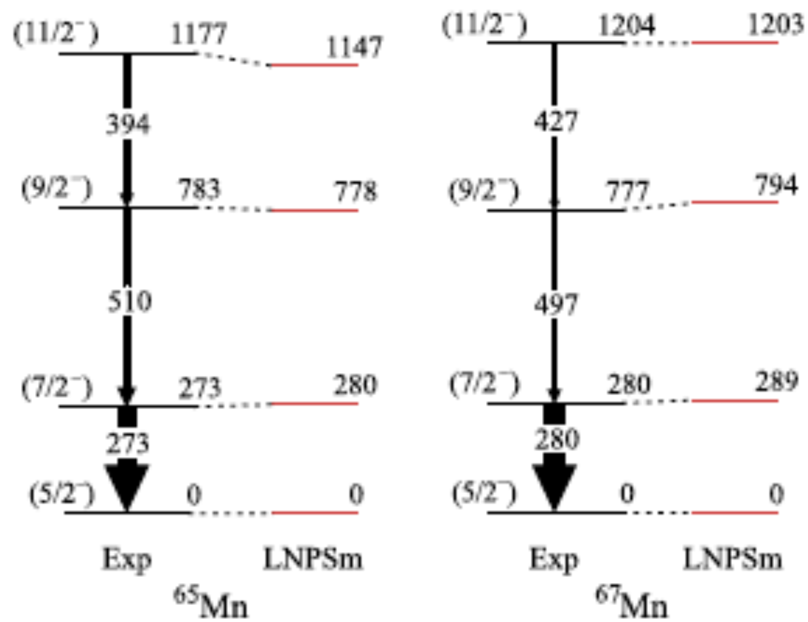
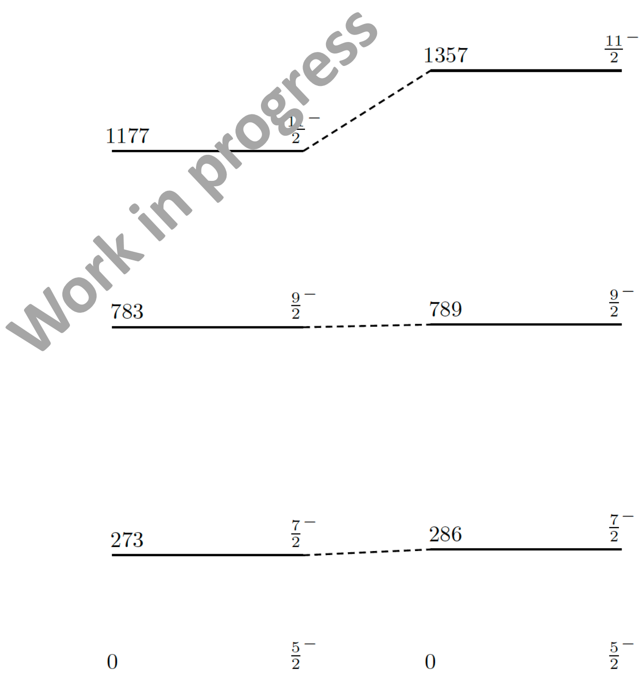
DETAILS

Large Scale Shell Model



Particle Rotor Model



^{65}Mn

[312]5/2

Strong coupling

Core properties from Migdal Analysis of even-even nuclei

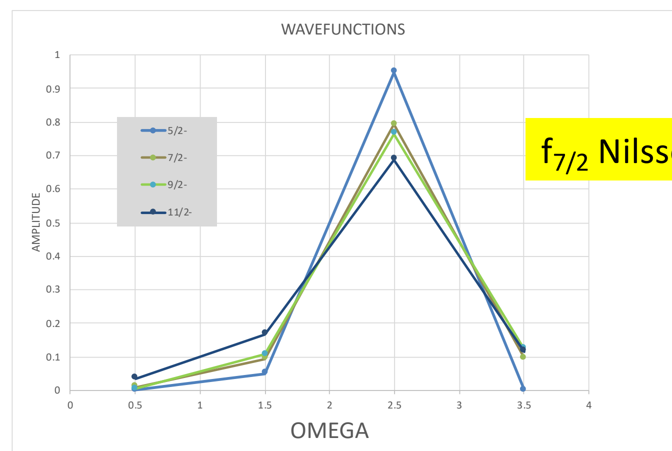
E_{2+}, B(E2), and pairing gaps suggests $\varepsilon_2 = 0.25$

Leading Order Fits of ^{65}Mn Energies

$$E(K,I) = E_K + AI(I+1) + BI^2(I+1)^2 + \cdots$$

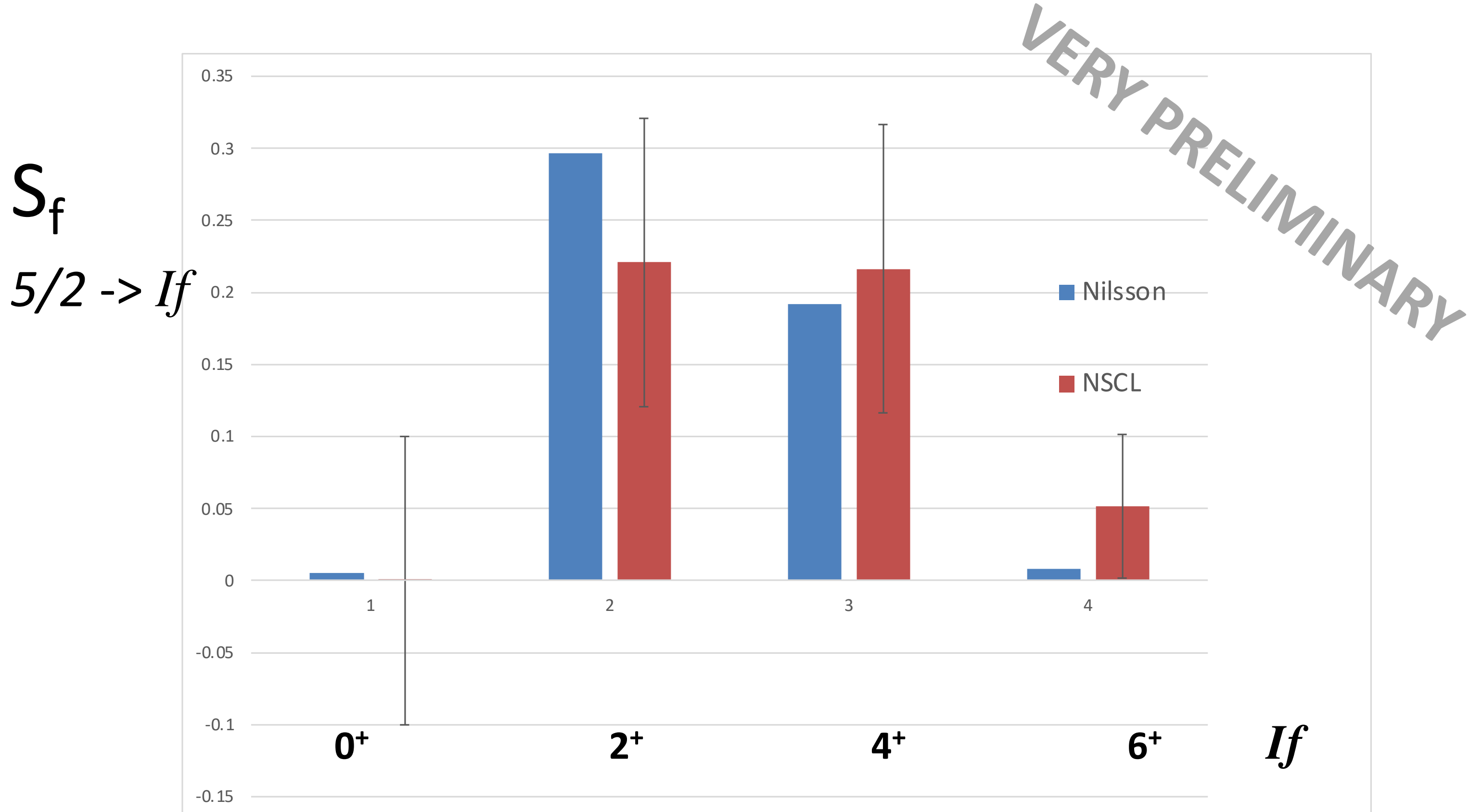
A small staggering term A_5 is determined from the fit the data

$$\Delta E_{rot} = (-1)^{I+K} A_{2K} \frac{(I+K)!}{(I-K)!}$$



$f_{7/2}$ Nilsson multiplet

^{63}Mn –> ^{62}Cr: Spectroscopic factors in the strong coupling limit



LSSM calculations are being performed by S. Lenzi and A. Poves

C. Porzio, H.L. Crawford, *et al.*

Merci 1 !

Eur. Phys. J. A (2015) **51**: 91
DOI 10.1140/epja/i2015-15091-2

THE EUROPEAN PHYSICAL JOURNAL A

Review

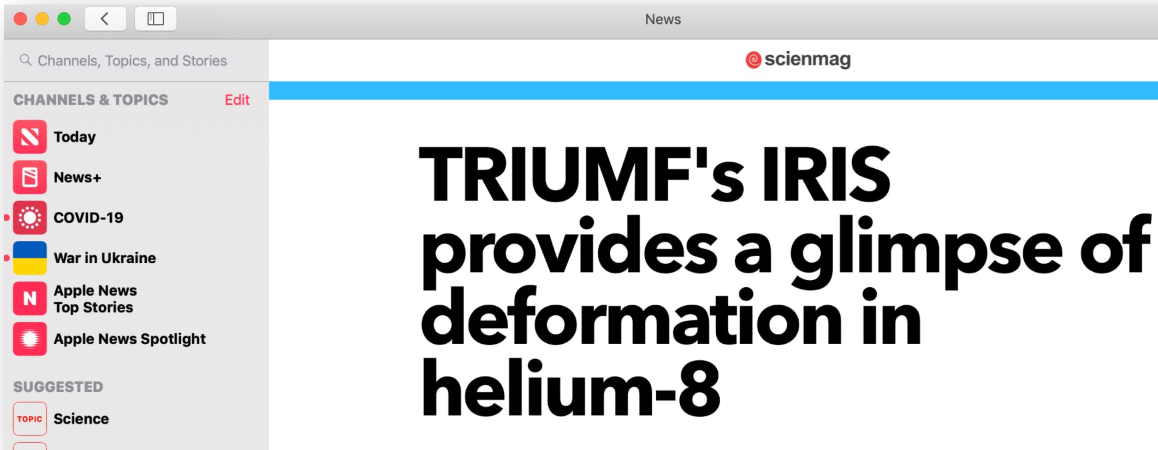
Weakly bound Borromean structures of the exotic ^{6,8}He nuclei through direct reactions on proton

Valérie Lapoux[a] and Nicolas Alamanos

CEA, Centre de Saclay, IRFU, Service de Physique Nucléaire, F-91191 Gif-sur-Yvette, France

Hello …

I feel completely inadequate here, would you please send the [IN]Security Team for help?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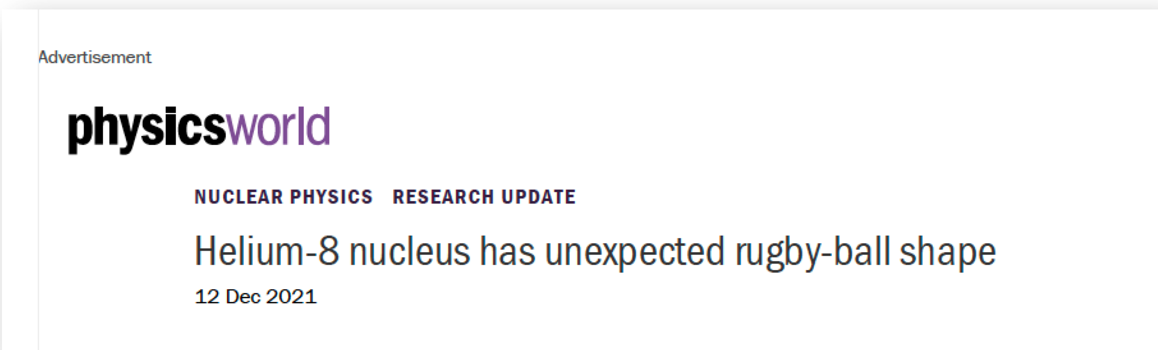
TRIUMF's IRIS provides a glimpse of deformation in helium-8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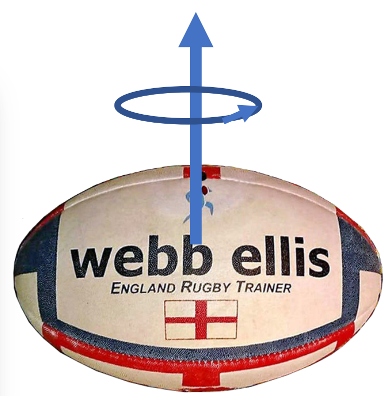
Helium-8 nucleus has unexpected rugby-ball shape
12 Dec 2021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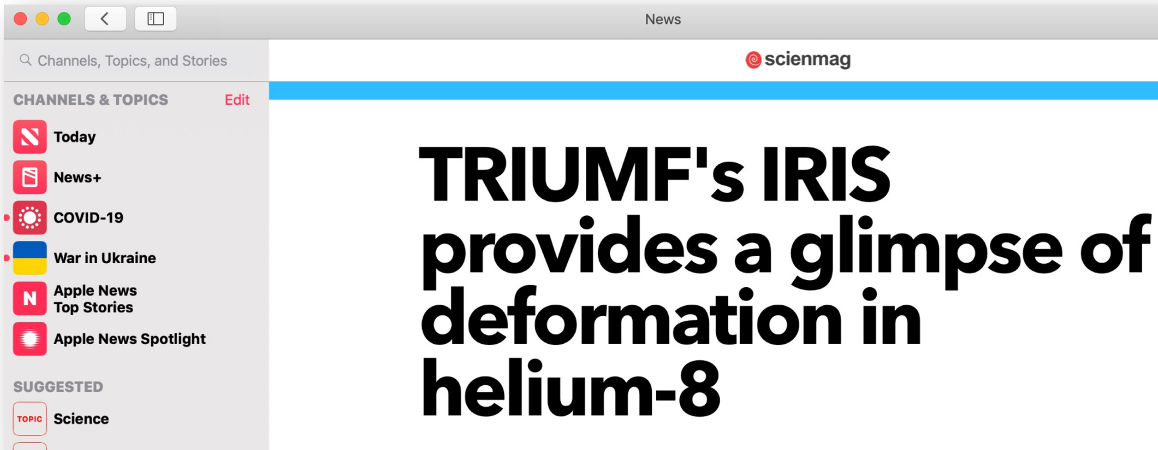
ENGLAND RUGBY TRAINER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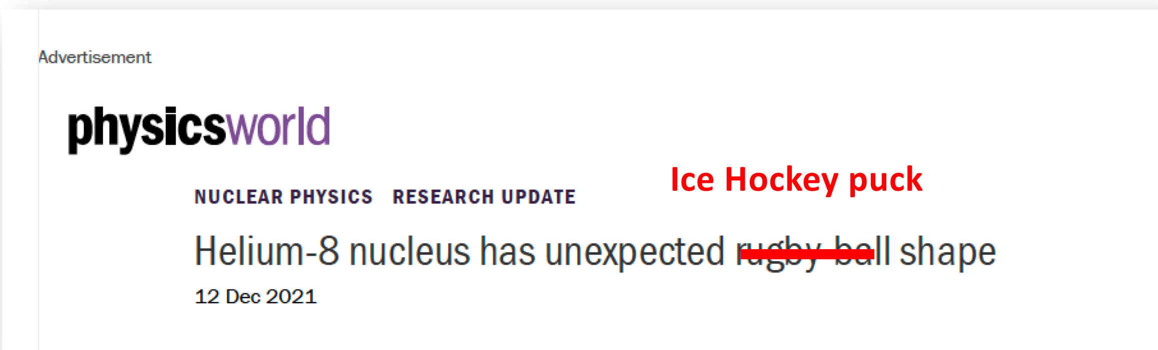
TRIUMF's IRIS provides a glimpse of deformation in helium-8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Ice Hockey puck
Helium-8 nucleus has unexpected ~~rugby ball~~ shape
12 Dec 2021

Physics Letters B 822 (2021) 136710

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Physics Letters B

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Proton inelastic scattering reveals deformation in ^{8}He

M. Holl [a,b], R. Kanungo [a,b,*], Z.H. Sun [c,d], G. Hagen [c,d], J.A. Lay [e,f], A.M. Moro [e,f], P. Navrátil [b], T. Papenbrock [c,d], M. Alcorta [b], D. Connolly [b], B. Davids [b], A. Diaz Varela [g], M. Gennari [b], G. Hackman [b], J. Henderson [b], S. Ishimoto [h], A.I. Kilic [g], R. Krücken [b], A. Lennarz [b,i], J. Liang [i], J. Measures [j], W. Mittig [k,l], O. Paetkau [b], A. Psaltis [i], S. Quaglioni [m], J.S. Randhawa [a], J. Smallcombe [b], I.J. Thompson [m], M. Vorabbi [b,n], M. Williams [b,o]

Proton inelastic scattering of ^{8}He at 8.25 MeV/A, carried out at TRIUMF

Analysis of the measured differential cross section using a phenomenological collective excitation form factor and microscopic coupled reaction channels framework, consistently yields a quadrupole deformation β_2=0.40(3), consistent with no-core shell model predictions.

The BM Phenomenon

Frequency illusion

From Wikipedia, the free encyclopedia

Frequency illusion, also known as the **Baader–Meinhof phenomenon** or **frequency bias**, is a cognitive bias in which, after noticing something for the first time, there is a tendency to notice it more often, leading someone to believe that it has an increased frequency of occurrence.[1][2][3] It occurs when increased awareness of something creates the illusion that it is appearing more often.[4] Put plainly, the frequency illusion occurs when "a concept or thing you just found out about suddenly seems to pop up everywhere."[5]

With a little grain of salt ...

Here we study the structure of $^{7,8,9}He$ in the framework of the Nilsson and Particle-Rotor Models

S. G. Nilsson, Mat. Fys. Medd. Dan. Vid. Selsk. 29, no. 16 (1955).
S. G. Nilsson and I. Ragnarsson, Shapes and Shells in Nuclear Structure, Cambridge University Press, 1995

PHYSICAL REVIEW C **88**, 034301 (2013)

Structure of unbound neutron-rich ^{9}He studied using single-neutron transfer

T. Al Kalanee,[1,2] J. Gibelin,[1,2,*] P. Roussel-Chomaz,[2] N. Keeley,[3] D. Beaumel,[4] Y. Blumenfeld,[4] B. Fernández-Domínguez,[2] C. Force,[2] L. Gaudefroy,[2] A. Gillibert,[5] J. Guillot,[4] H. Iwasaki,[4] S. Krupko,[6] V. Lapoux,[5] W. Mittig,[2] X. Mougeot,[5] L. Nalpas,[5] E. Pollacco,[5] K. Rusek,[3,7] T. Roger,[2] H. Savajols,[2] N. de Séréville,[4] S. Sidorchuk,[6] D. Suzuki,[4] I. Strojek,[3] and N. A. Orr[1]
[1]*LPC Caen, ENSICAEN, Université de Caen, CNRS/IN2P3, F-14050 CAEN Cedex, France*
[2]*GANIL, CEA/DSM-CNRS/IN2P3, BP55027, F-14076 Caen Cedex 5, France*
[3]*National Centre for Nuclear Research, ul. Andrzeja Sołtana 7, 05-400 Otwock, Poland*
[4]*IPN Orsay, IN2P3-CNRS, Université Paris Sud, F-91406 Orsay, France*
[5]*CEA-Saclay, DSM/IRFU SPhN, F-91191 Gif-sur-Yvette Cedex, France*
[6]*Flerov Laboratory of Nuclear Reactions, JINR, Dubna, RU-141980 Russia*
[7]*Heavy Ion Laboratory, University of Warsaw, ul. Pasteura 5A, PL-02-093 Warsaw, Poland*

The ^{8}He(d, p) reaction was studied in inverse kinematics at 15.4A MeV using the MUST2 Si-CsI array in order to shed light on the level structure of ^{9}He. The well known ^{16}O$(d, p)^{17}$O reaction, performed here in reverse kinematics, was used as a test to validate the experimental methods. The ^{9}He missing mass spectrum was deduced from the kinetic energies and emission angles of the recoiling protons. Several structures were observed above the neutron-emission threshold and the angular distributions were used to deduce the multipolarity of the transitions. This work confirms that the ground state of ^{9}He is located very close to the neutron threshold of ^{8}He and supports the occurrence of parity inversion in ^{9}He.

^9He

T. AL KALANEE *et al.* PHYSICAL REVIEW C **88**, 034301 (2013)

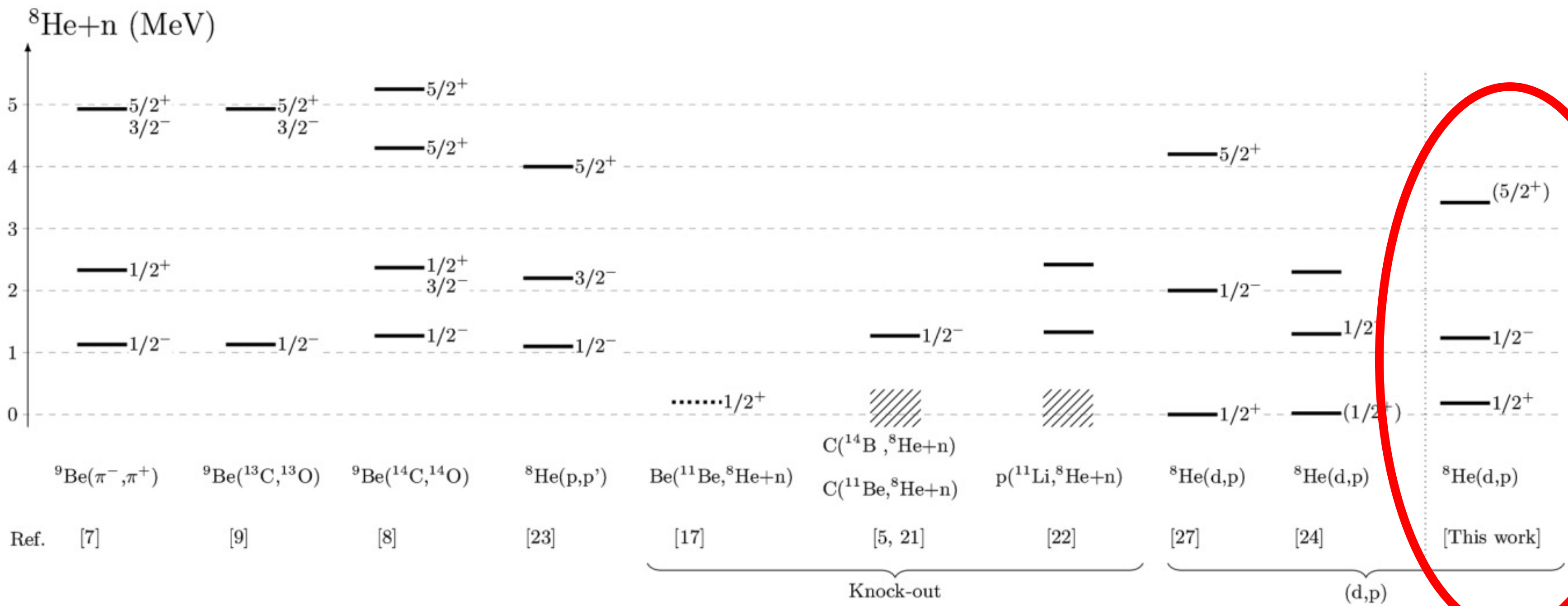


FIG. 5. Summary of all experimental results for ^9He, up to 5 MeV excitation energy. Solid lines represent states with well defined resonance. Dashed lines or hashed areas represent low-lying structures described by virtual s-wave states (see text for details).

PHYSICAL REVIEW C **97**, 034314 (2018)

Structure of the exotic ^{9}He nucleus from the no-core shell model with continuum

Matteo Vorabbi,* Angelo Calci, and Petr Navrátil†
TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia V6T 2A3, Canada

Michael K. G. Kruse and Sofia Quaglioni
Lawrence Livermore National Laboratory, P.O. Box 808, L-414, Livermore, California 94551, USA

Guillaume Hupin
Institut de Physique Nucléaire, CNRS/IN2P3, Université Paris-Sud, Université Paris-Saclay, F-91406, Orsay, France

experimental values.

Our analysis identified two resonances corresponding to spin-parity states of $1/2^-$ and $3/2^-$ respectively. The former is identified as the ground state of ^{9}He, while the latter is built on the 2^+ state of ^{8}He and represents the first excited state of ^{9}He. In particular, we did not find any resonance corresponding to a $1/2^+$ state; according to our calculations ^{9}He breaks the parity inversion observed in ^{11}Be and in ^{10}Li.

THE ^{8}HE CORE

A. B. Migdal, Nucl. Phys. 13 655, (1959)

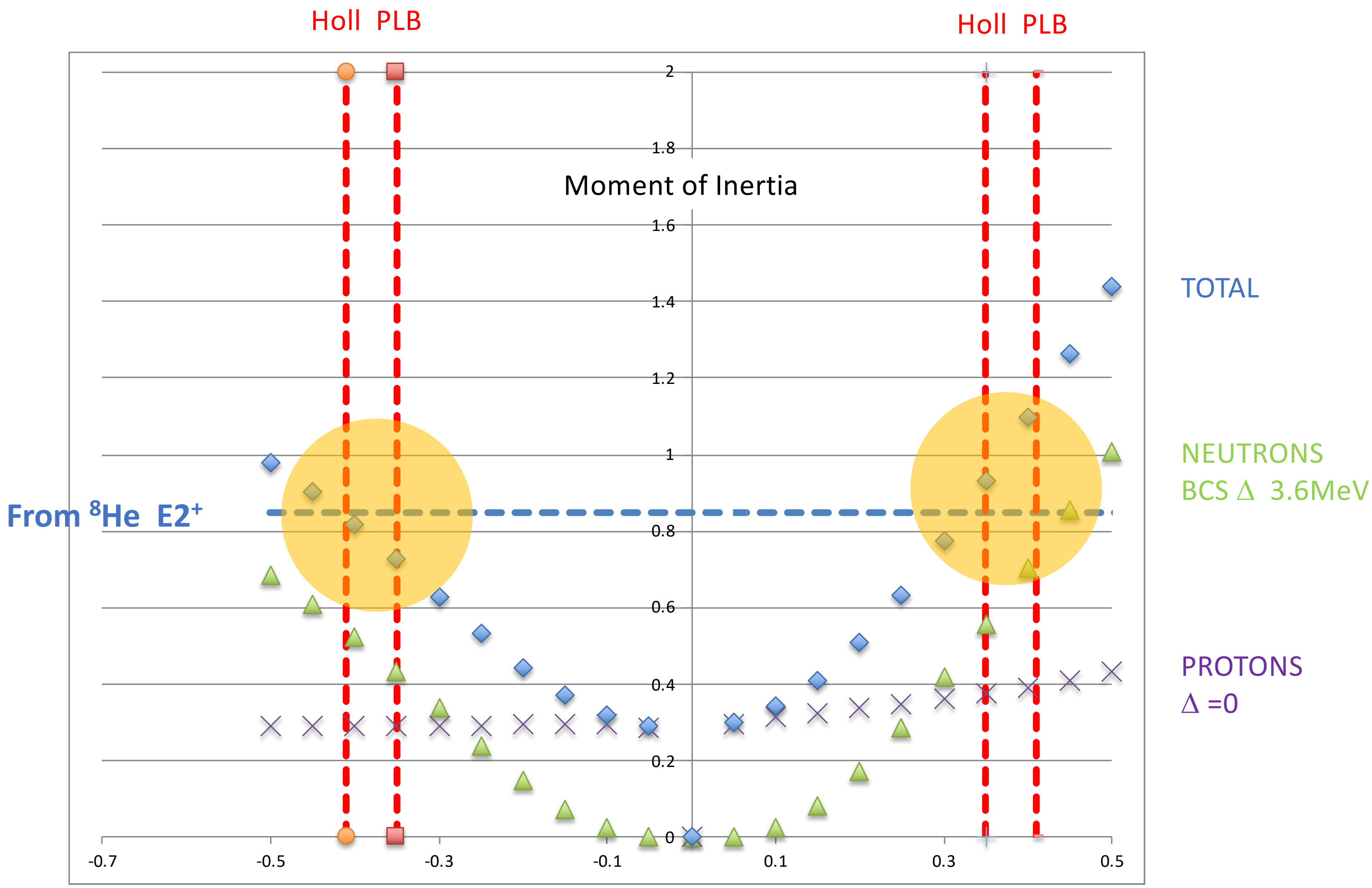
$$\mathscr{I}_{Migdal} = \mathscr{I}_{rigid}\left(\frac{1}{1+\mathscr{X}^2}\right)^{3/2} = \mathscr{I}_{rigid}\phi(\mathscr{X})$$

$$\mathscr{X} = \frac{2\Delta}{\hbar\omega_0\epsilon_2}$$

$$\frac{\mathscr{I}}{\mathscr{I}_{rigid}} = \frac{N}{A}\phi(\mathscr{X}_n) + \frac{Z}{A}\phi(\mathscr{X}_p)$$

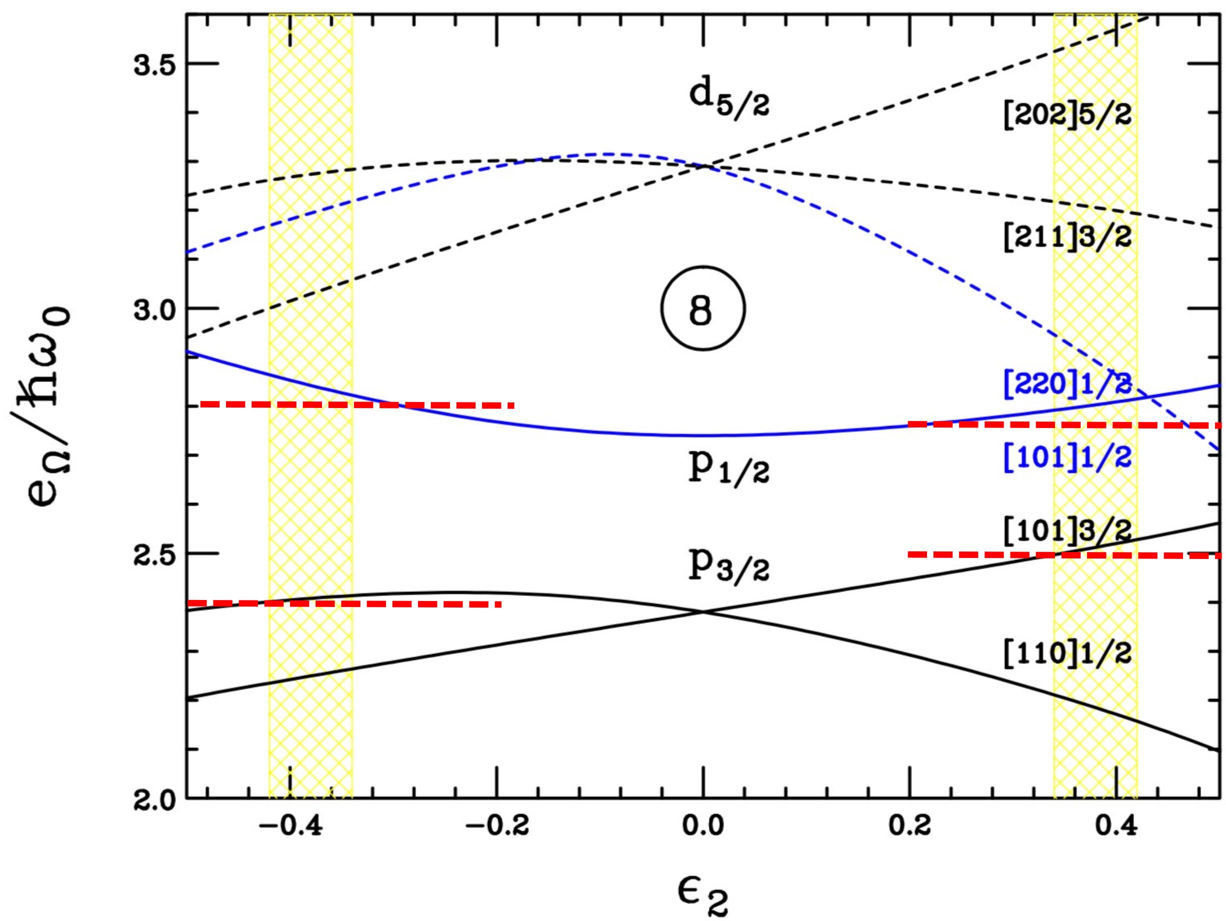
Moment of Inertia of a rigid ellipsoid

$$\mathscr{I}_{rigid} = \frac{2}{3}AM < r^2 > \frac{(1+(c/a)^2)}{(c/a)^{2/3}}$$



Holl PLB
Holl PLB
Moment of Inertia
TOTAL
NEUTRONS
BCS Δ 3.6MeV
PROTONS
Δ =0
From ^{8}He E2^{+}
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.7
-0.5
-0.3
-0.1
0.1
0.3
0.5

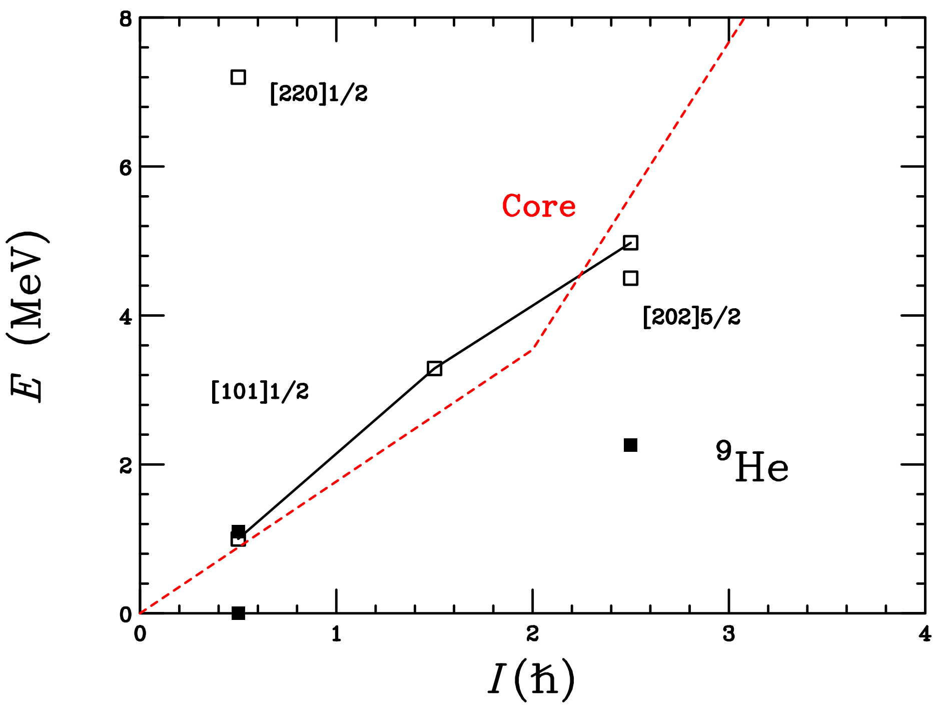
Nilsson Levels



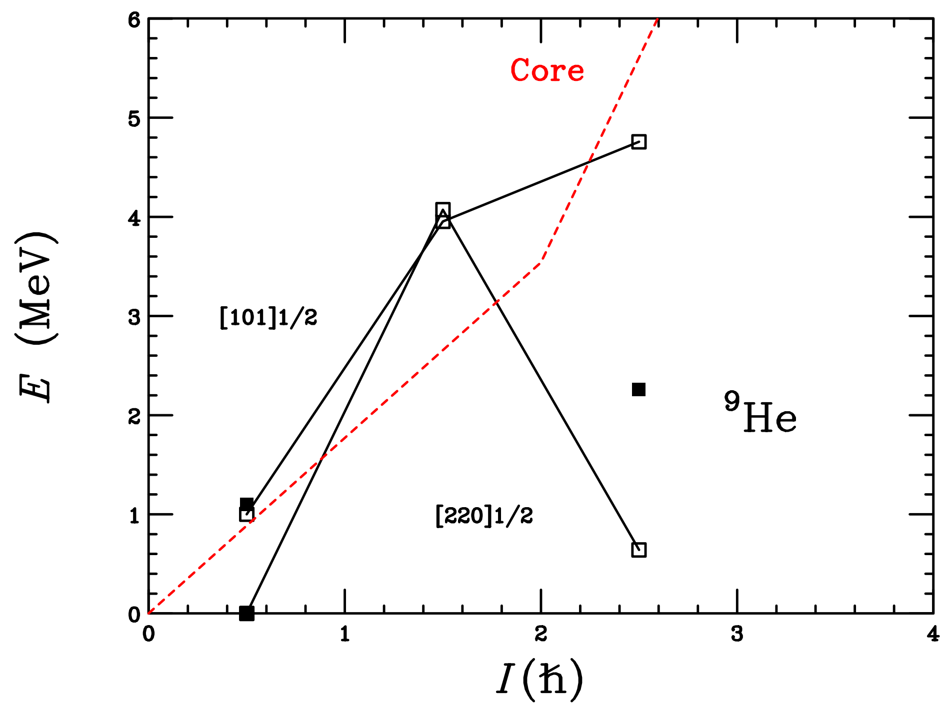
^{7,9}He BCS Fermi levels

^{9}He

Oblate

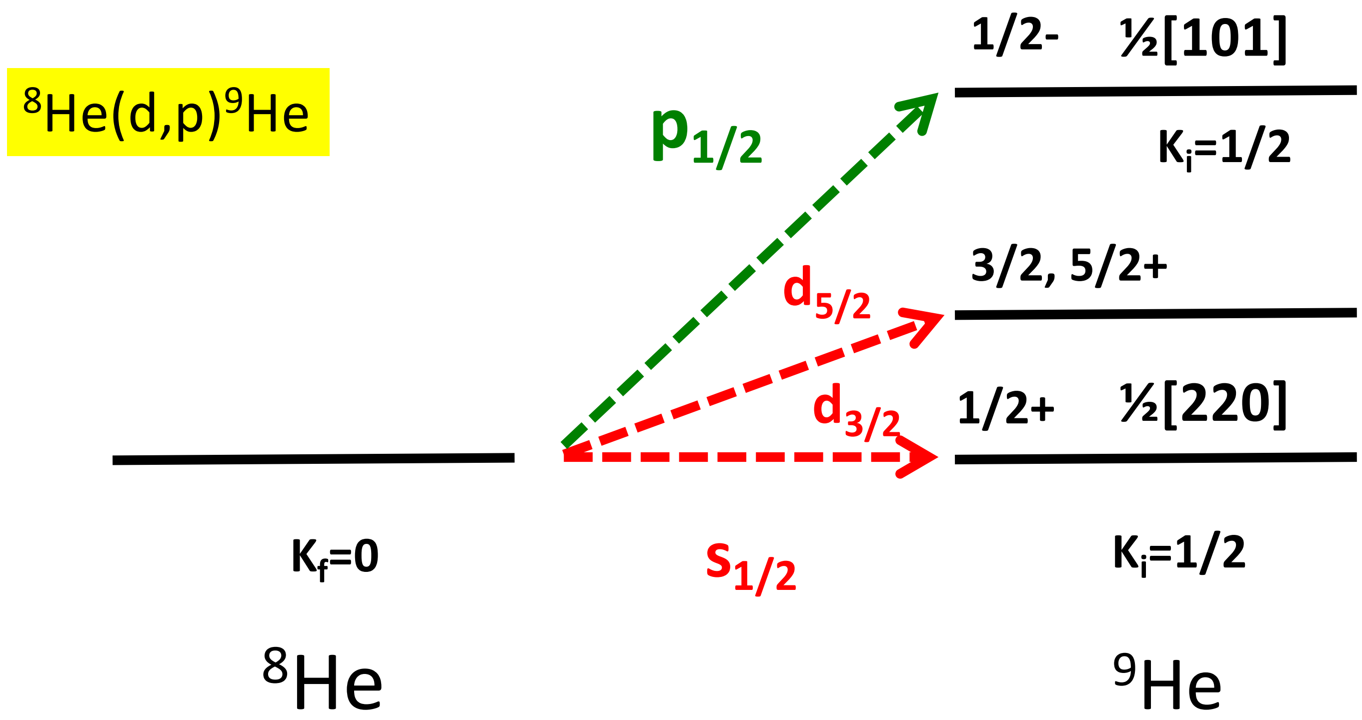


Prolate



Particle Rotor Model wavefunctions → Strong coupling limit

Spectroscopic Factors



$$\left|\tfrac{1}{2}[220]\right\rangle = C_{1/2,0}|s_{1/2}\rangle + C_{3/2,2}|d_{3/2}\rangle + C_{5/2,2}|d_{5/2}\rangle$$
$$\left|\tfrac{1}{2}[101]\right\rangle = C_{1/2,1}|p_{1/2}\rangle + C_{3/2,1}|p_{3/2}\rangle,$$

Spectroscopic Factors

T. Al Kalanee, *et al.* , Phys. Rev. **C88,** 034301 (2013)

$^{8}\mathbf{He}(d,p)^{9}\mathbf{He}$

^{9}He Levels

E(level)	J^{π}	Γ	L	C^2S	Comments
0	$1/2^+$	0.18 MeV *16*	0	≈0.13	C^2S: upper limit. E(level): from E_{res}=180 keV *85*.
1.06×10^3 *15*	$(1/2^-)$	0.13 MeV *+17−13*	(1)	≈0.06	L: $\sigma(\theta)$ data also consistent with L=2. E(level): from E_{res}=1.235 MeV *115*, using E_{res}=180 keV *85* for g.s.
3.24×10^3 *78*	$(5/2^+)$	2.90 MeV *39*	2	≤0.05	E(level): from E_{res}=3.42 MeV *78*, using E_{res}=180 keV *85* for g.s.

I_f	Experiment	Oblate	Prolate
$1/2^-$	0.06 (0.1)*	0.5	0.8
$1/2^+$	0.13 (0.2)*	0.35	0.65
$5/2^+$	< 0.05 (0.08)*	0.2	0.1

* Corrected by quenching

Spectroscopic Factors

In a more general approach (shape coexistence)

$|^{8}He\rangle = A|O\rangle + B|P\rangle$

$|^{9}He\rangle_{1/2-} = a\,[101]_{1/2} x|O\rangle + b[101]_{1/2} x|P\rangle$

$|^{9}He\rangle_{1/2+} = a'\,[220]_{1/2} x|O\rangle + b'[220]_{1/2} x|P\rangle$

$|^{7}He\rangle_{3/2-} = a''[110]_{1/2} x|O\rangle + b''[101]_{3/2} x|P\rangle$

When comparing with the data, consistent solution(s) are obtained

Spectroscopic Factors

$|^{8}He> \sim 0.87|O> + 0.5|P>$

$|^{9}He>_{1/2-} \sim 0.29\ [101]_{1/2} x|O> + 0.96[101]_{1/2} x|P>$

$|^{9}He>_{1/2+} \sim 0.05[220]_{1/2} x|O> + 0.999[220]_{1/2} x|P>$

$|^{7}He>_{3/2-} \sim 1\ [110]_{1/2} x|O> + 0\ [101]_{3/2} x|P>$

The appearance of quadrupole deformation and rotational motion in light nuclei is well established and has been extensively discussed in the literature

A. Bohr and B. R. Mottelson, Mat. Fys. Medd. Dan. Vid. Selsk. 27, no. 16 (1953)
J. P. Elliott, Proc. R. Soc. A 245 128 (1958) I
Ingemar Ragnarsson, et al., Phys. Scr. 24 215 (1981)

For example, and relevant to this work, are the Be isotopes. The strong α clustering in ^{8}Be naturally suggests that deformation degrees of freedom play a role in the structure of these nuclei

W. Von Oertzen, M. Freer, and Y. Kanada-Enyo, Physics Reports 432, 43 (2006)

The sudden drop of the $E(2^+)$ energy in ^{12}Be relative to the neighboring even-even isotopes and the change of the ground state of ^{11}Be from the expected $1/2^-$ to the observed positive parity $1/2^+$ state, support this conclusion. Energy levels and available electromagnetic and single-nucleon transfer reactions data on ^{11}Be and ^{12}Be can be explained in terms of single-particle motion in a deformed potential

I. Hamamoto and S. Shimoura J. Phys. G: Nucl. Part. Phys. 34, 2715 (2007)
A.O.Macchiavelli, H.L.Crawford, P.Fallon, et al. Physical Review C97, 011302(R), (2018)
A. O. Macchiavelli, H. L. Crawford , R. M. Clark, et al. Phys. Rev. C 103, 034307 (2021)

Summary

Inspired by the recent results of Holl et al. showing strong evidence for a deformed ^{8}He nucleus, we have studied the structure of the odd-A ^{7}He and ^{9}He isotopes in the rotational model

Comparison of the Migdal moment of inertia at $\varepsilon_2 \approx 0.38$ is in good agreement to that derived from the experimental 2^+ energy at both prolate and oblate deformations

The Nilsson levels arising from the *p* and *sd* spherical shells appear to provide a simple explanation of the low-lying structure of these nuclei as originating from strongly coupled rotational bands built on the: [101] 3/2 , [101] 1/2, and [220] 1/2 neutron orbits.

Spectroscopic factors for the $^{8}He(p, d)^{7}He$ and $^{8}He(d, p)^{9}He$ reactions suggest the presence of shape coexistence.

Revisiting (the analysis of) these reactions, in light of the above, will be interest

Merci 2 !