14th ITP/CAS–BLTP/JINR Joint Workshop on Physics of Strong Interacting Systems

Exotic structure and mirror symmetry breaking of dripline nuclei

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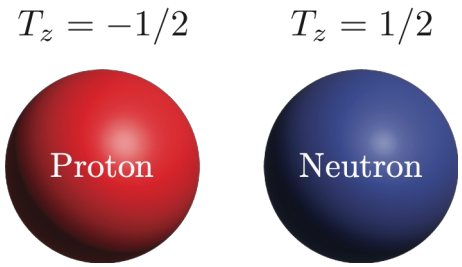
Collaborators:
S. M. Wang, H. Y. Shang, Y. G. Ma, H. Hua,
L. Ni…

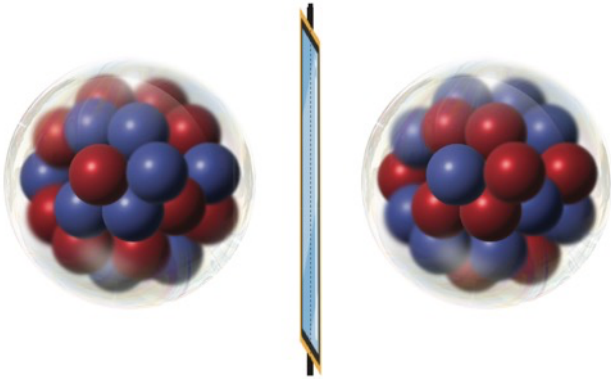


Outline

- Isospin symmetry and mirror symmetry breaking
- MSB with continuum coupling
- Ground-state mirror symmetry violation

Isospin symmetry and mirror nuclei



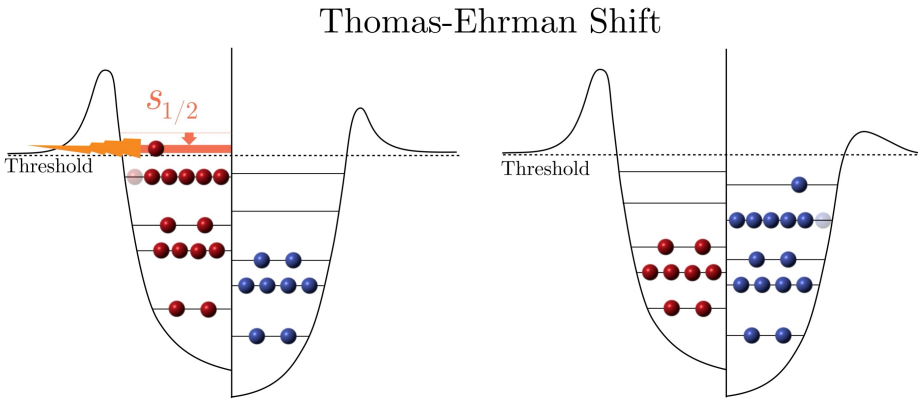


1. p-n mass difference:
   $m_p = 1.00782503\ u, m_n = 1.00866491u$
2. p-n charge difference:
   $e_p = e, e_n = (-4.3 \pm 7.1)\times 10^{-20} e$

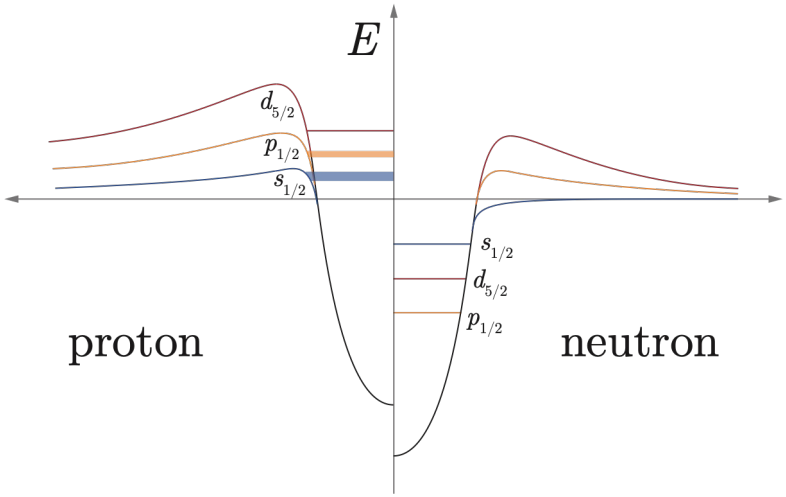
$V_{NN} \approx V_{PP} \approx V_{NP}$

- Isospin (Heisenberg, 1932): Symmetry between proton and neutron.
- Mirror nuclei near the β stability usually exhibit similar structures.
- Mirror symmetry breaking (MSB): *ZN* imbalance and/or near dripline.

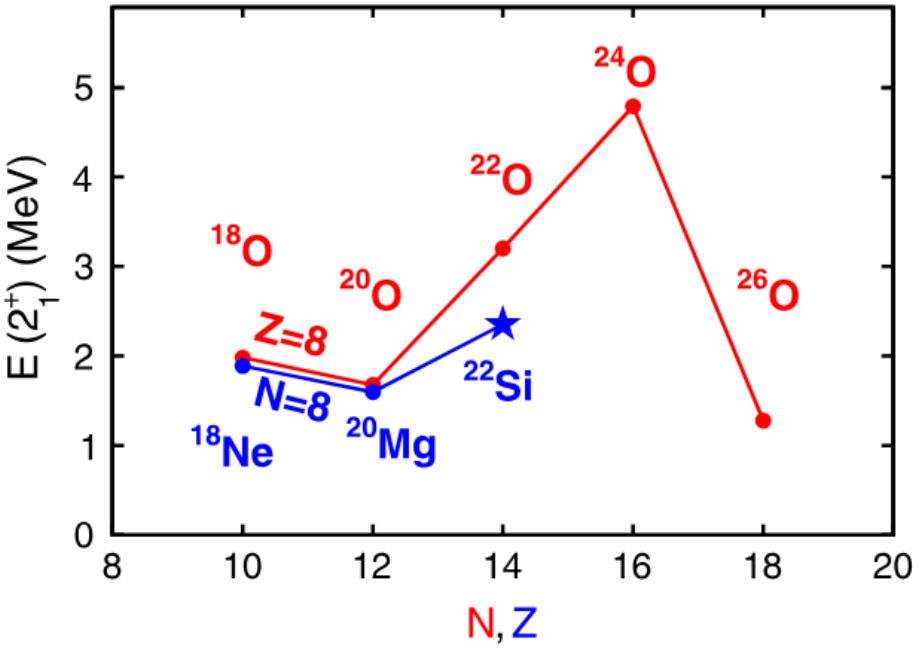
Mirror symmetry breaking near dripline



Coulomb and threshold effect



low-l: low centrifugal barrier
different behavior



- Threshold effect of the excited states
- Similar occupancy, different energy

R. G. Thomas, Phys. Rev. 88, 1109 (1952)
J. B. Ehrman,, Phys. Rev. 81, 412 (1951)
J. S. Phillips, *et al*. Phys. Rev. Lett. 135, 252501 (2025)

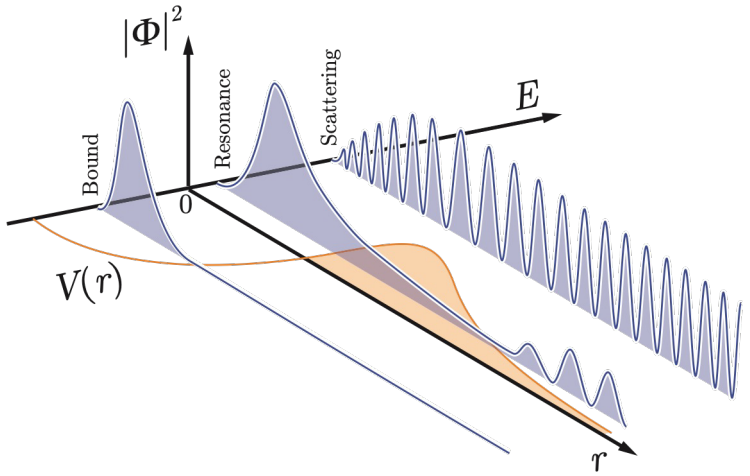
Mirror symmetry breaking near dripline

Beta decay MSB



	$^{22}\mathrm{Si} \rightarrow {}^{22}\mathrm{Al}$		$^{22}\mathrm{O} \rightarrow {}^{22}\mathrm{F}$	
	Experiment	Calculations	Experiment	Calculations
I_i^π	$\lvert M_{\mathrm{GT}}^{+}\rvert^2$	$\lvert M_{\mathrm{GT}}^{+}\rvert^2$	$\lvert M_{\mathrm{GT}}^{-}\rvert^2$	$\lvert M_{\mathrm{GT}}^{-}\rvert^2$
1_1^+	0.0310 (58)	0.0587 [0.1138]	0.096 (20)	0.1831 [0.1059]
1_2^+	0.563 (61)	0.7449 [0.7193]	0.60 (12)	0.7196 [0.7948]

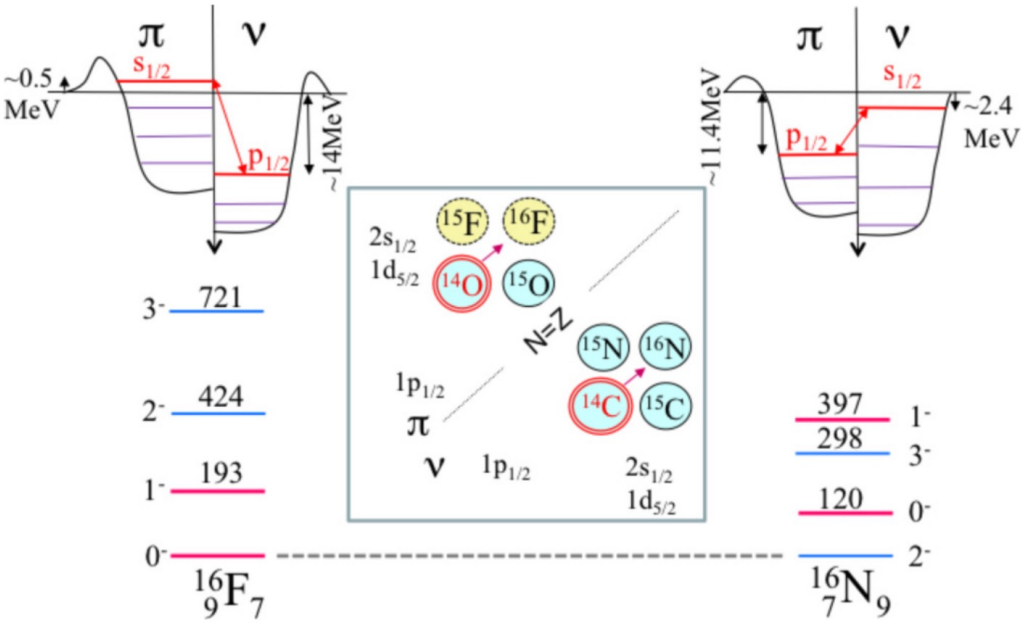
- MSB in both energy and GT transition
  - larger MED of two 1^+ states
  - Wave function changed in mirror nuclei
  - Gamow-Teller transition density



J. Lee, *et al*. Phys. Rev. Lett. 125, 192503 (2020)
ZX, *et al*. Phys. Rev. C 108, L031301 (2023)

Ground-state mirror symmetry violation

GMSV: Ground state spin in mirror nuclei are different



- Most exotic and rare MSB found recently
- First & only confirmed GMSV ^{16}F/^{16}N
  - Continuum coupling
  - single particle structure

I. Stefan, *et al.*, Phys. Rev. C 90, 014307 (2014)

First & only confirmed GMSV ^{16}F/^{16}N

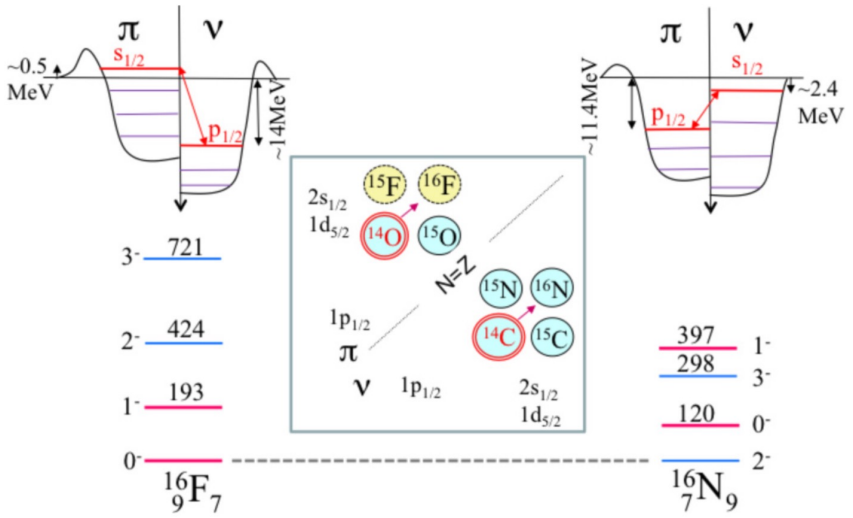
Mechanism: Thomas Ehrman Shift + single particle

$$\mathrm{BE}(^{16}\mathrm{N}_{\mathrm{free}}) = \mathrm{BE}(^{14}\mathrm{C})_{0^+} + \mathrm{BE}(\pi 1p_{1/2}) + \mathrm{BE}(\nu 2s_{1/2}),$$

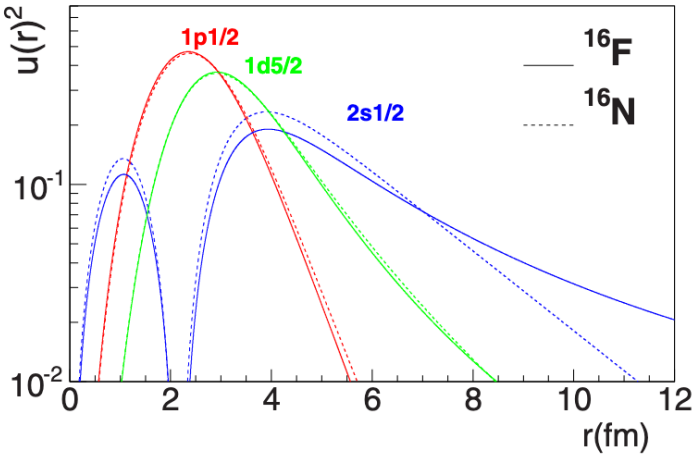
where

$$\mathrm{BE}(\pi 1p_{1/2}) = \mathrm{BE}(^{15}\mathrm{N})_{1/2^-} - \mathrm{BE}(^{14}\mathrm{C})_{0^+},$$

$$\mathrm{BE}(\nu 2s_{1/2}) = \mathrm{BE}(^{15}\mathrm{C})_{1/2^+} - \mathrm{BE}(^{14}\mathrm{C})_{0^+}.$$

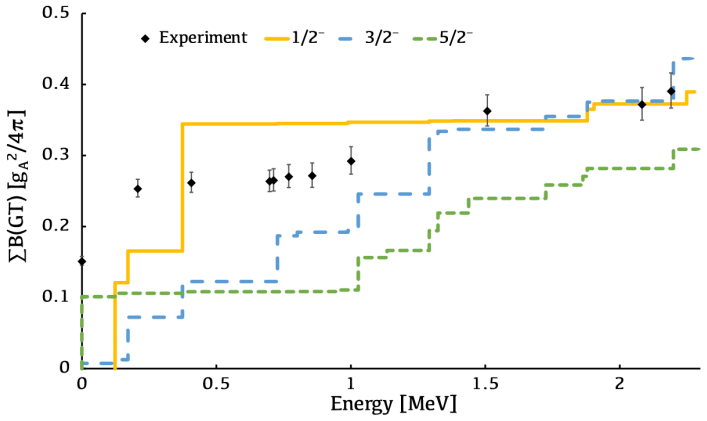


- Single particle sturcture:
  - 0^-, 1^- states: core + $0p_{1/2}$ + $1s_{1/2}$;
  - 2^-, 3^- states: core + $0p_{1/2}$ + $0d_{5/2}$.
- effective interactions differences in the mirror systems
  - 0^-, 1^- states: near 40%
  - 2^-, 3^- states: near 10%
- Continuum coupling of low-*l* orbit.



I. Stefan, *et al.*, Phys. Rev. C 90, 014307 (2014)

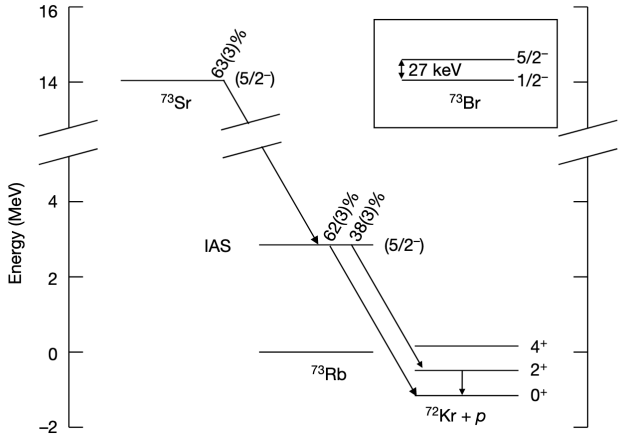
More GMSV candidates



^{71}Kr/^{71}Br

A. Algora, *et al*., Phys. Rev. Lett 134, 162502 (2025)

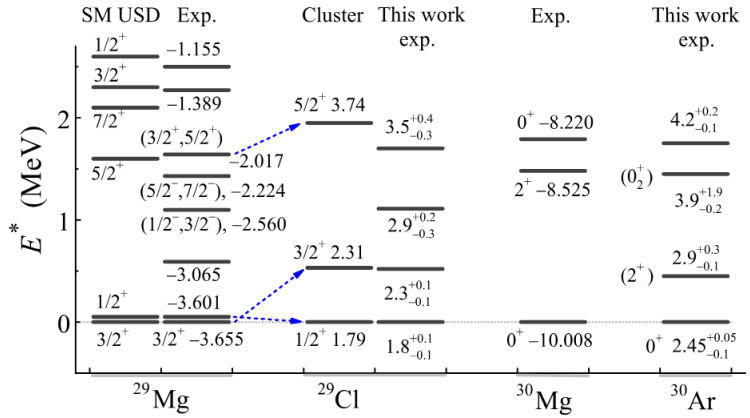
Deformation?



^{73}Sr/^{73}Br

D. E. M. Hoff, *et al*., Nature 580, 52-55 (2020)

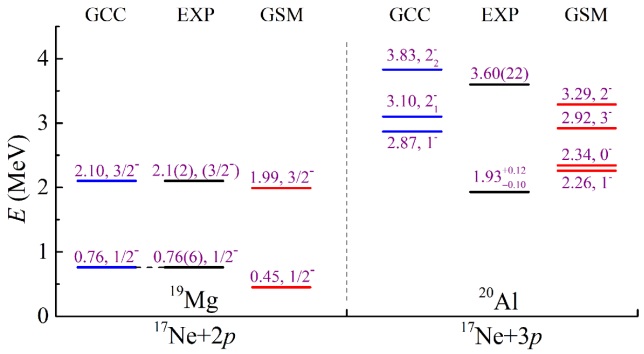
Proton-rich nuclei
Near dripline!



^{29}Cl/^{29}Mg

I. Mukha, *et al*., Phys. Rev. Lett 115, 202501 (2015)
X.-D. Xu, *et al*., Phys. Rev. C 97, 034305 (2018)

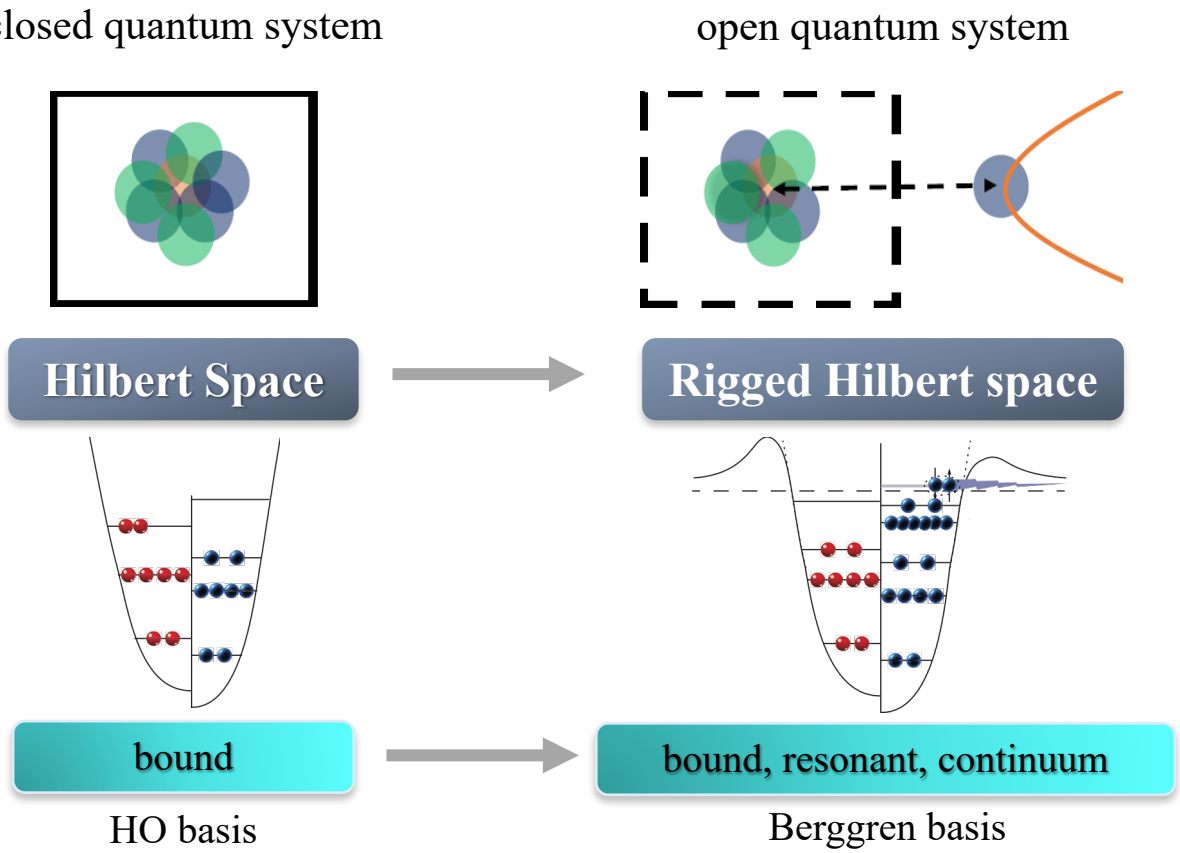
TES?



^{20}Al/^{20}N

X. D. Xu, *et al*., Phys. Rev. Lett 135, 022502 (2025)

Continuum-coupled frameworks



Gamow Shell Model

N. Michel *et al*, Phys. Rev. Lett. 89, 042502 (2002)

Gamow Coupled-Channel

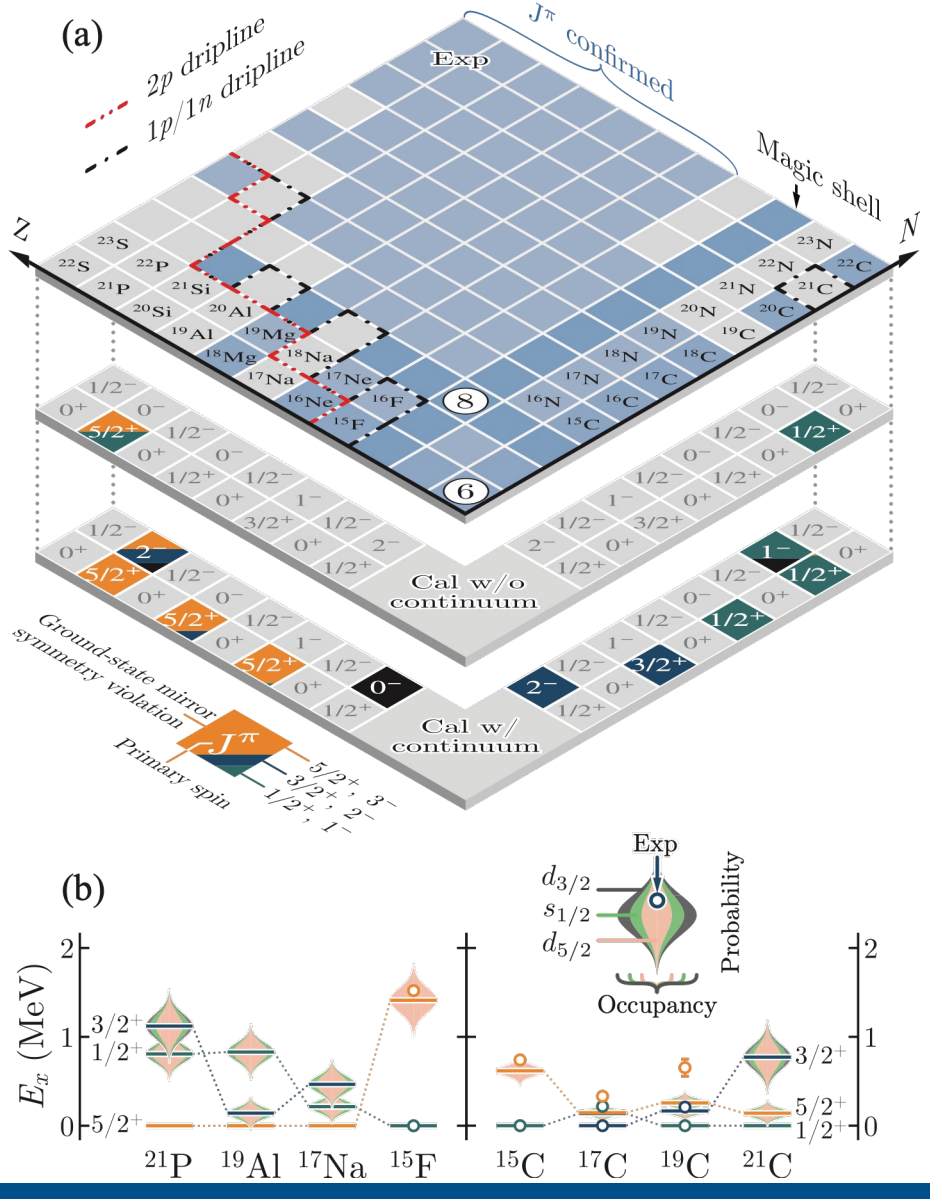
S. Wang *et al*, Phys. Rev. C. 96, 044307 (2017)

Gel'fand I M *et al*, Generalized Functions vol 4 (1961)
T. Berggren, Nucl. Phys. A 109, 265 (1968)

chiral EFT nuclear forces + Gamow-MBPT + GSM

B. Hu *et al*, Phys. Lett. B 802, 135206 (2020)
S. Zhang *et al*, Phys. Rev. C. 108, 064316 (2023)

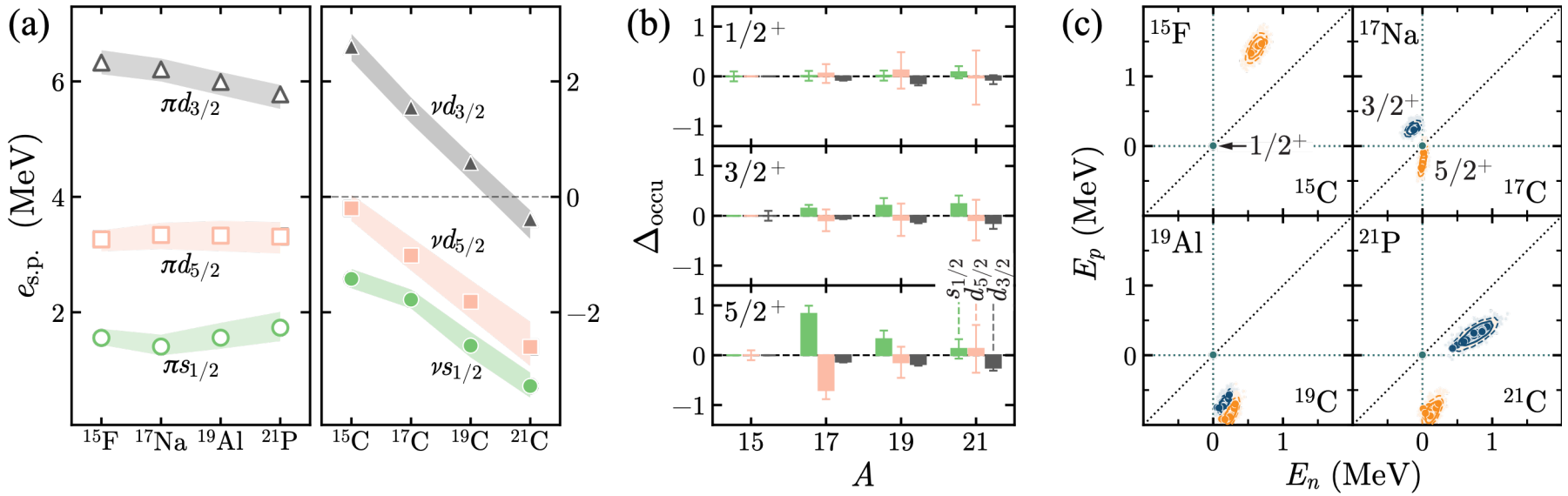
GMSV beyond the dripline



- GMSV cases (colorful cells) with Uncertainty Quantification (UQ)
  - Highly possible GMSV cases:
    - **^{16}F/^{16}N**, **^{17}Na/^{17}C**, ^{19}Al/^{19}C, ^{21}P/^{21}C
  - One candidates:
    - ^{22}P/^{22}N
- Experimental known ground states (blue cells)
- Neutron rich:
  - reproduced well with or without continuum
- proton rich:
  - spins changed with continuum
- *N*, *Z* = 6 odd nuclei Spectra with UQ

ZX, H. Y. Shang, S. M. Wang, Y. G. Ma. submitted to PRL

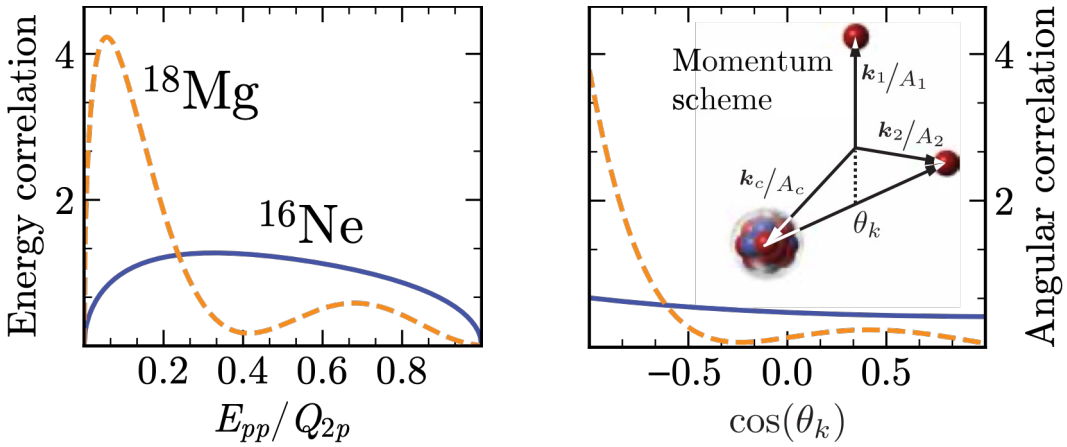
GMSV mechanism



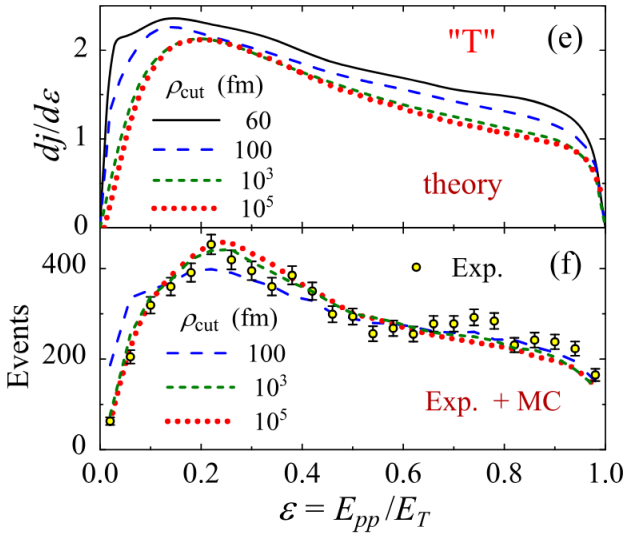
- Reverse $d_{5/2}$ and $s_{1/2}$ orbit found in ^{15}F/^{15}C mirror pair
- The shell gap is small in carbon chains
- The threshold effect shift the $s_{1/2}$ down in $N = 6$ nuclei
- The many-body correlations shown in ground-state spin, ESPEs, and occupancy differences

M. Stanoiu, *et al.*, Phys. Rev. C 78, 034315 (2008)
D. Sohler, *et al.*, Phys. Rev. C 77, 044303 (2008)
M. J. Strongman, *et al.*, Phys. Rev. C 80, 021302(R) (2009)
ZX, H. Y. Shang, S. M. Wang, Y. G. Ma. submitted to PRL

Experimental signature of shell structure



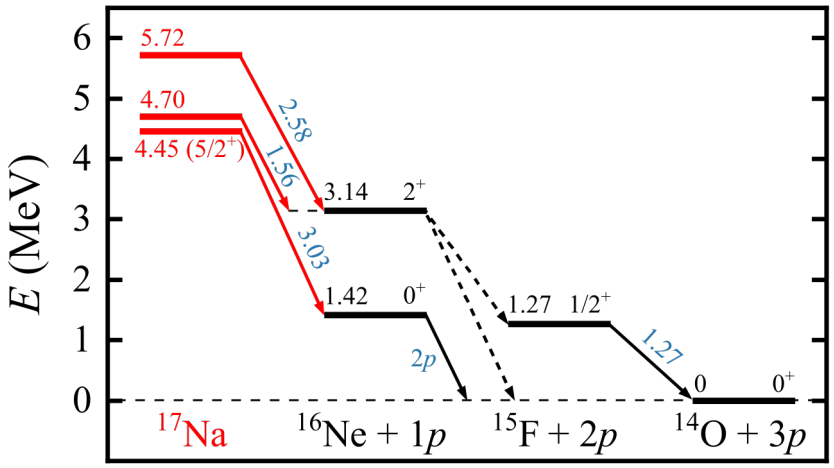
$$^{18}\mathrm{Mg}: (d_{5/2})^2$$
$$^{16}\mathrm{Ne}: (s_{1/2})^2$$

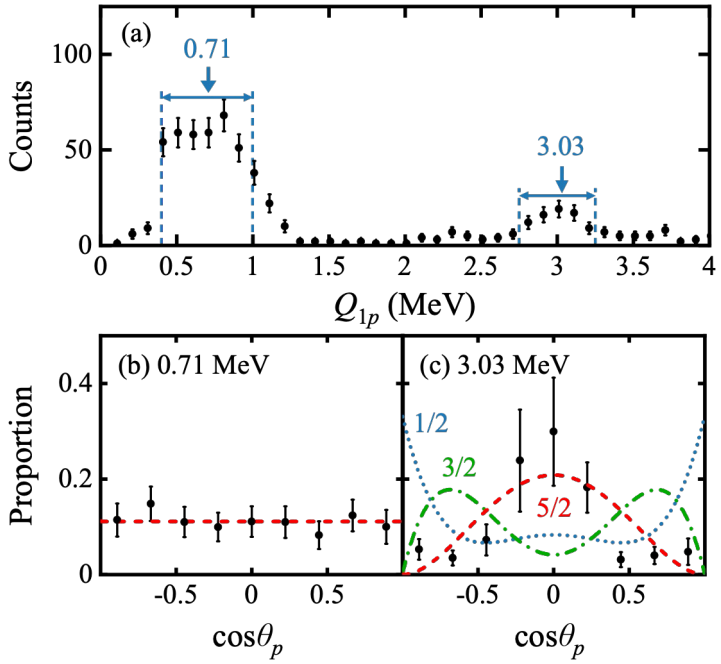


- Emitted 2*p* energy and angular correlations calculated with constraint
- The different 2*p* structures in ^{18}Mg and ^{16}Ne lead very different correlations
- The correlations in ^{16}Ne well reproduced experimental data
- The spectroscopic factors, two-nucleon amplitudes, and correlations **are probes**

I. Mukha, *et al*., Phys. Rev. C 77, 061303(R) (2008)
K. W. Brown, *et al*., Phys. Rev. Lett. 113, 232501 (2014)
ZX, H. Y. Shang, S. M. Wang, Y. G. Ma. submitted to PRL

^{17}Na/^{17}C GMSV in recent experiment





- Angular distribution of the emitted proton: ground state of ^{17}Na as $5/2^+$
- Ground state of ^{17}C is $3/2^+$, ^{17}Na/^{17}C GMSV was found
- Consistent between experiment and theory

L. Ni, **ZX**, Y. Jin *et al.*, Phys. Rev. Lett. 137, 102501 (2026)

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Thank you for your attention!

Summary

- Mirror symmetry breaking near dripline.
- GMSV beyond dripline.
- Both the continuum-driven single-particle shift and many-body correlations are essential.
- The shell structure can be directly tested in future measurements.



Acknowledgements

- S. M. Wang
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- …
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- L. Ni
- W. Nazarewicz
- …