Structure of *spdf* Nuclei at High Spin and Isospin

Experimental Comparison with Shell Models

Ph.D. Graduates

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This Presentation

5.1.1 Selected direct reactions populating fully aligned states
S. L. Tabor, C. Wibisono, C. Benetti, Vandana Tripathi, and A. Volya

5.1.2 Experimental tests of ab-initio nucleon-nucleon interactions
S. L. Tabor, C. Wibisono, Vandana Tripathi, and A. Volya

Presented by Vandana Tripathi

5.1.3 High-spin γ-ray spectroscopy of nuclei approaching the second island of inversion
V. Tripathi, G.S., S. L. Tabor, I. Wiedenhöver, and P. C. Bender (Umass Lowell)

5.2.3 Beta-delayed neutron emission of extremely neutron-rich nuclei with Z = 14-18 using the FDSi at FRIB
Vandana Tripathi, M. Wheeler, S. Ajayi, S. L. Tabor, S. N. Liddick (FRIB), J.M. Allmond (ORNL), R. Grzywacz (UTK), R. Lubna (FRIB) and A. Volya

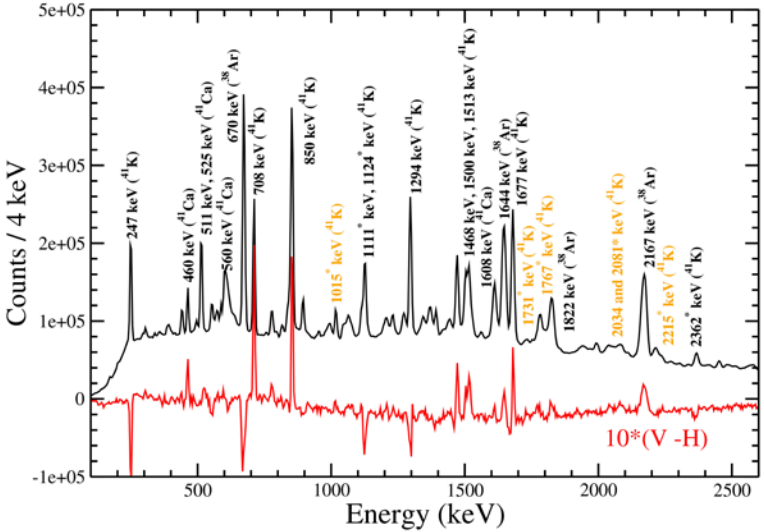
Elizabeth Rubino (now at LLNL)

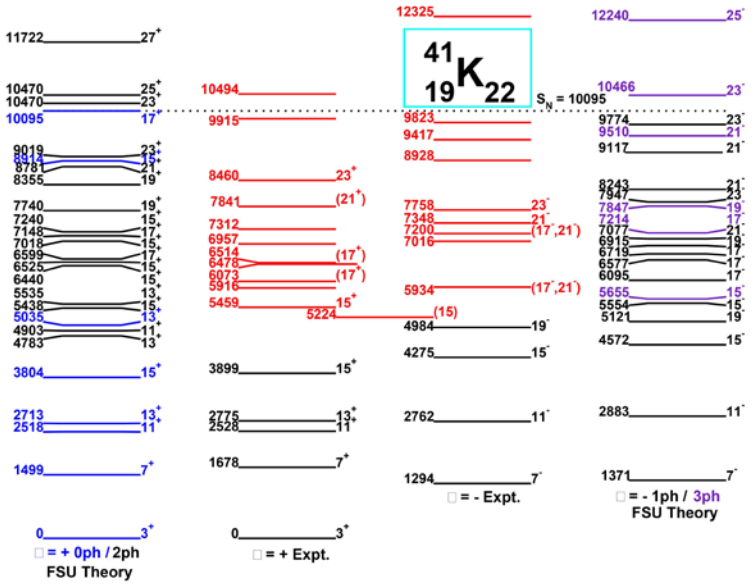
High-spin structure of ^{41}K using ^{26}Mg(^{18}O,p2nγ)^{41}K

Known structure extended up to likely 25/2$^-$

Excellent agreement with FSU interaction (of whose formulation Elizabeth was a participant)

Success of FSU interaction lies in excellent agreement with the 1ph and higher configurations.





E. Rubino, *et al.*, EPJA **58**, 107 (2022)

Parity sensitivity from Compton scattering parallel (H) and perpendicular (V) to beam direction

"Clover" spectrometers with 4 HPGe crystals in a 4-leaf clover arrangement.

5.1.1 Selected direct reactions populating fully aligned states

S. L. Tabor, C. Wibisono, C. Benetti, Vandana Tripathi, and A. Volya

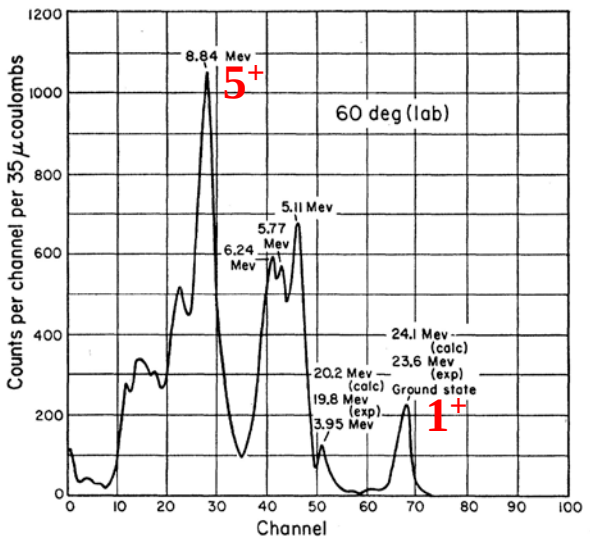
Unique selectivity of the (α,d) reaction to populate fully aligned states first reported for $^{12}C(\alpha,d)^{14}N$ by Harvey and Czerny in 1960 (same year as first FSU tandem accelerator)

Strongest peak is fully aligned ($\pi d_{5/2}$ x $\nu d_{5/2}$) 5^+

Deuteron itself is fully aligned in its 1+ g.s., so breakup of 0^+ α transfers fully aligned p-n pair to target

Considerable early interest in (α,d) reactions by Harvey and his students and later by other groups gradually faded due to lack of theory

Our heavy ion high-spin interests and theory collaboration led to comprehensive FSU cross-shell *s-p-d-f-p* interaction



B.G. Harvey and J. Czerny, Phys. Rev. **120**, 2162 (1960)

FSU interaction very successful in understanding high-spin states, even those involving pairs of particles promoted to the fp shell although only fitted to states with one particle promoted.

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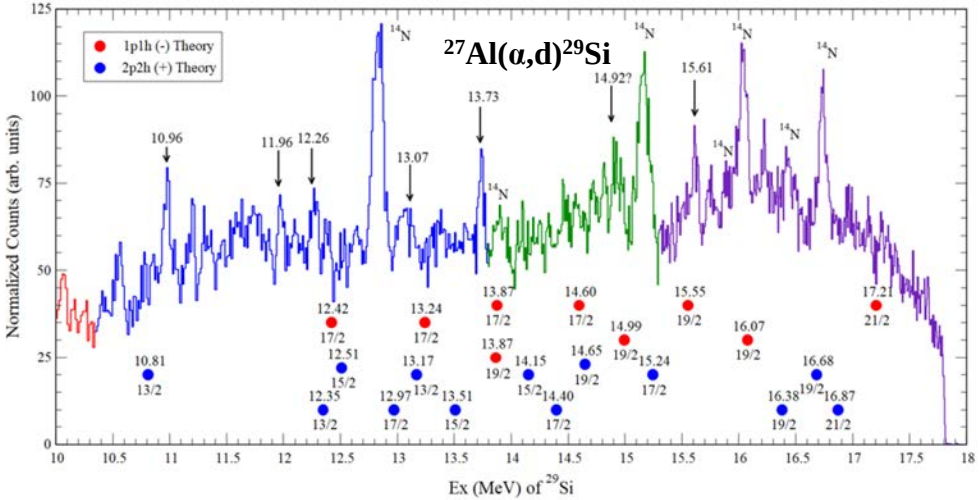
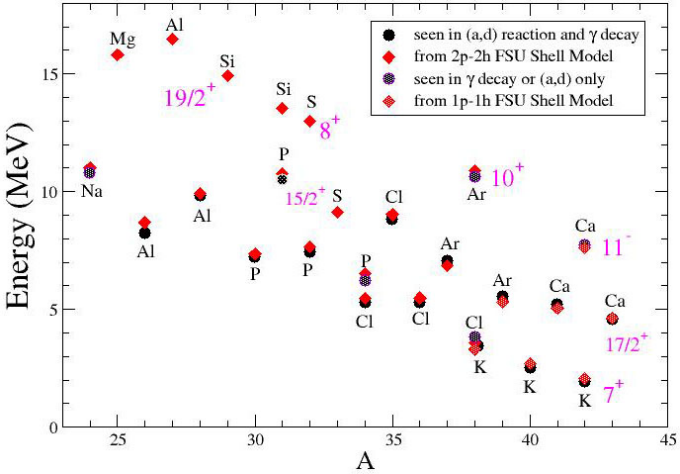
FSU interaction works well for 2ph "island of inversion" states and 2ph fully aligned states where experimental information available

High level density reduces confidence in identification of (α,d) states with theory ones and high-spin γ decay states

Example is ^{27}Al(α,d) spectrum in figure below.



C. Benetti, FSU Ph.D. dissertation 2023



R. Lubna, *et al*. Phys. Rev. Res. 2, 043342 (2020)

High-spin γ decay sequences in fusion-evaporation reactions pass through states with about same energy as ones seen in (α,d) reactions

but no γ coincidences reported yet with strong (α,d) peaks

5.1.1 Selected direct reactions populating fully aligned states

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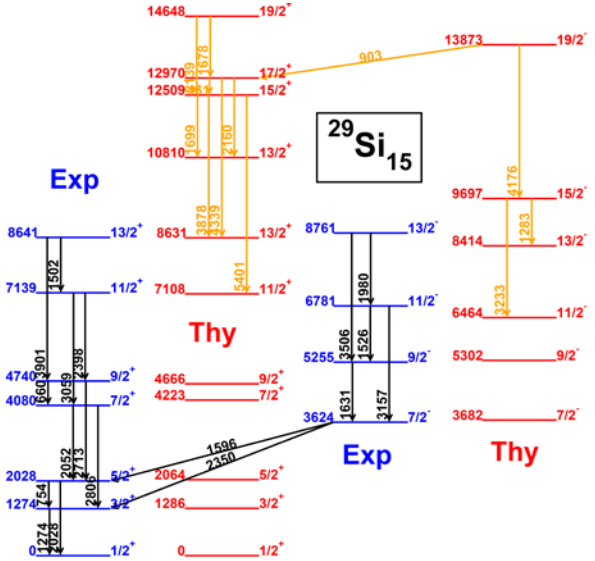
What would the γ decay of, fully aligned states look like??

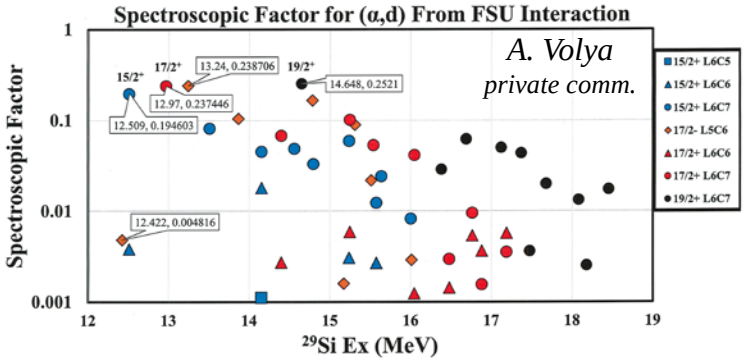
Example of likely decay of lowest fully aligned $19/2^+$ state in ^{29}Si

Hybrid experiment(blue)-theory(red) level and decay scheme.

Easily identifiable cascade and help to pin down energies of fully aligned states



Agreement in energy of the calculated and measured state energies gives confidence in the predicted energies of higher-spin states.



Volya used the FSU interaction to calculate spectroscopic factors for the ^{27}Al(α,d)^{29}Si reaction

This technique provides a theoretical approach to predicting the selectivity of (α,d) reactions.

5.1.1 Selected direct reactions populating fully aligned states

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Propose to measure γ decays in coincidence with deuterons from (α,d) reactions using the high energy resolution of the Clarion2 γ detector array in conjunction with deuterons observed in the Trinity charged-particle detectors.

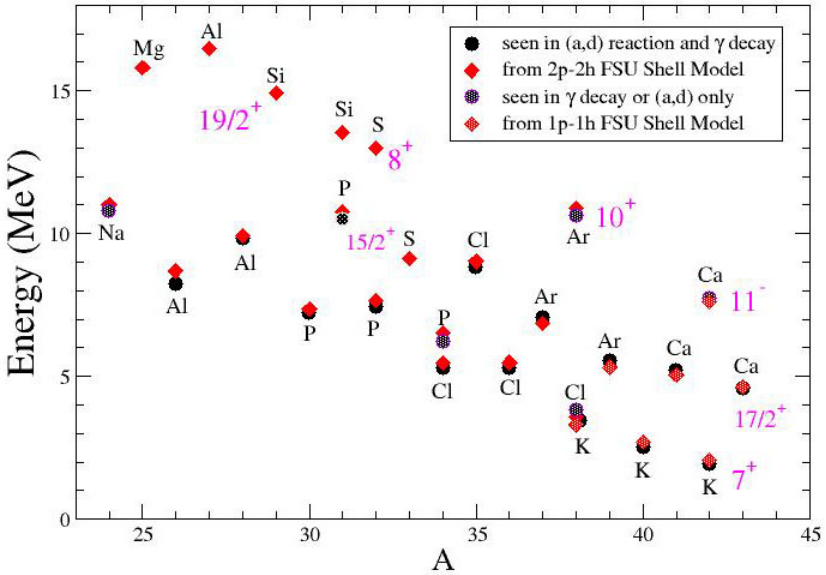
Pulse-shape discrimination between relatively high-energy p/d and α particles demonstrated* for GAGG scintillators in Trinity.

Use γ energies to discriminate between p and d final reaction products by the different γ lines in different final nuclei

Would start with $^{12}C(\alpha,d)^{14}N$ and $^{27}Al(\alpha,d)^{29}Si$ reactions with LINAC-boosted tandem α beams. Then $^{32}S(\alpha,d)^{34}Cl$ and $^{39}K(\alpha,d)^{41}Ca$

Goals are to conclusively identify strong (α,d) peaks with yrast high-spin states

Also explore use of direct (α,d) reaction as alternative to H.I. fusion-evaporation as tool for producing high-spin states



* **T.J. Gray, et al., Nucl. Instrum. Meth. A1041 (2022) 167392**

5.1.2 Experimental tests of ab-initio nucleon-nucleon interactions

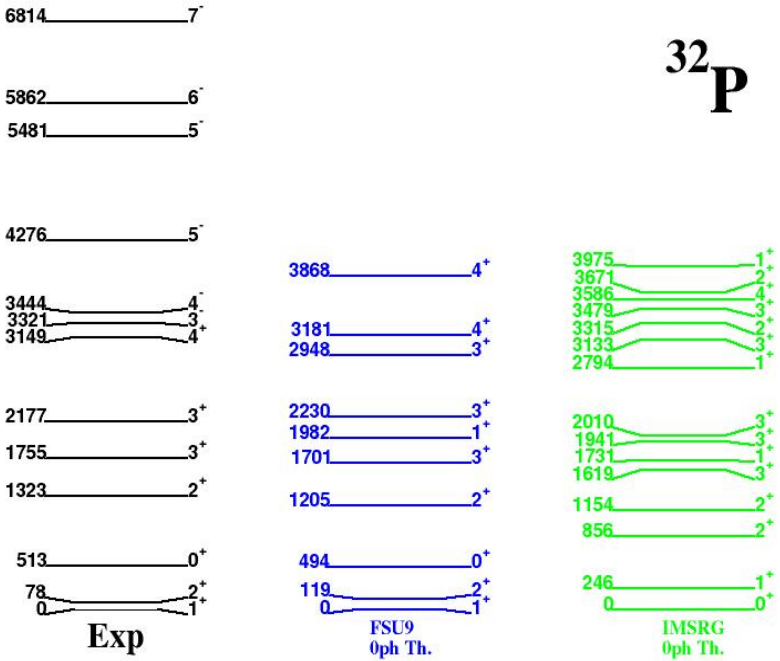
S. L. Tabor, C. Wibisono, Vandana Tripathi, and A. Volya

Apply in-medium similarity renormalization group (IMSRG) ab-initio interaction* to *sdpf*-shell nuclei.

Have calculated lowest 4 MeV of the predicted excitation spectrum of ^{32}P for comparison with experiment and with predictions of the FSU9 effective interaction.

Predictions of IMSRG ab-initio interaction differ significantly more (χ^2 = 418 keV) from experiment than those of the FSU interaction (χ^2 = 57 keV).

Perhaps more surprising is general similarity of the spectrum predicted by IMSRG to experiment.



*K. Tsukiyama, S.K. Bogner, and A. Schwenk, PRL **106**, 222502 (2011)

5.1.2 Experimental tests of ab-initio nucleon-nucleon interactions

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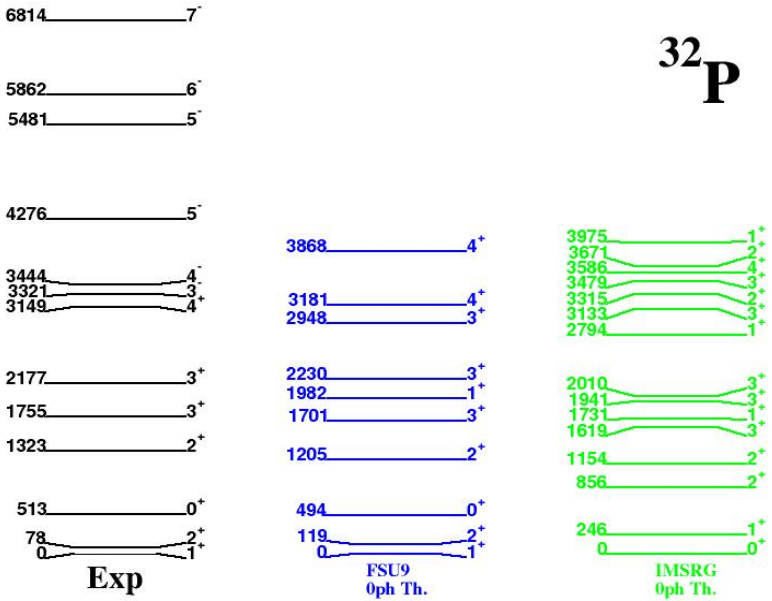
Ab-initio interactions offer more predictive promise than effective ones, especially farther from stability

However, they currently can't capture the subtleties of nuclear structure adequately.

We propose to study experimentally the structure of heavier, more neutron-rich nuclei at higher spin using fusion-evaporation reactions and Clarion2-Trinity to further explore the strengths and weaknesses of ab-initio approaches like IMSRG.

We would start with a measurement of the $^{18}O(^{14}C,2p)^{30}Mg$ reaction using the FSU ^{14}C beam.



In collaboration with FSU theorists we would also use the IMSRG interaction as a starting point for a new fit to *sdpf* nuclei to compare to the FSU9 interaction whose starting point came from the Brueckner G matrix approach.