Vijay Pandharipande & Few-Body Physics

J. Carlson, LANL

Some of Vijay's many contributions in Few-Nucleon Physics:

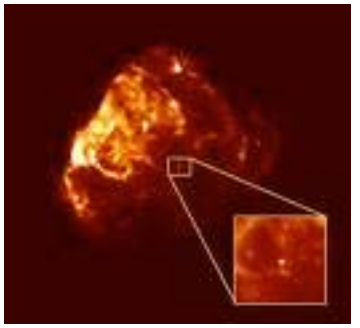
- Realistic 2-nucleon interactions
  amenable to accurate few- & many-body theory
- 3-nucleon interactions in nuclear physics
- Correlations in light (and heavy) nuclei
- Monte Carlo calculations of light nuclei
- Deuteron Structure (T20)
- Proton-Proton Capture
- Quark Models (Flux-Tube) of Hadrons

Graduate Students / Thesis Title

Robert Wiringa (1978)	A variational theory of nuclear matter
Kevin Edward Schmidt (1979)	Variational theory of quantum fluids
Isaac Lagaris (1981)	Nuclear matter with realistic Hamiltonians
Joseph Carlson (1983)	Few body problems in nuclear and particle physics
Efstratios Manousakis (1985)	On the microscopic theory of liquid 4He
Rocco Schiavilla (1987)	Monte Carlo studies of momentum distributions and longitudinal response functions of A=3 and 4 nuclei
Thomas J. Schlagel (1990)	Classical models of heavy-ion collisions
Aleksandar Belic (1992)	Deep inelastic scattering by quantum fluids
Brian Pudliner (1996)	Green's function Monte Carlo calculation of few nucleon systems
Roger Loucks (1996)	Electro-pion production from p, d, and 3He
Jun Forest (1998)	Relativistic Hamiltonians and short range structure of nuclei
Arya Akmal (1998)	Variational studies of nucleon matter with realistic potentials
Mark Paris (2000)	Quantum Monte Carlo calculations of 3 and 6-quark states
Shannon Cowell (2004)	Quenching of weak interactions in nucleon matter
Soon-Yong Chang (2006)	Study of the properties of the dilute Fermi gas in the strongly-interacting regime

Jaime Morales (UIUC)
Alex Gezerlis (UIUC/LANL)
Abhishek Mukherjee (UIUC)

Early work on Neutron Stars:
Pulsars discovered and identified
as neutron stars (1967)



Originally used LOCV: variational method constraining two-nucleon correlations to average interparticle spacing

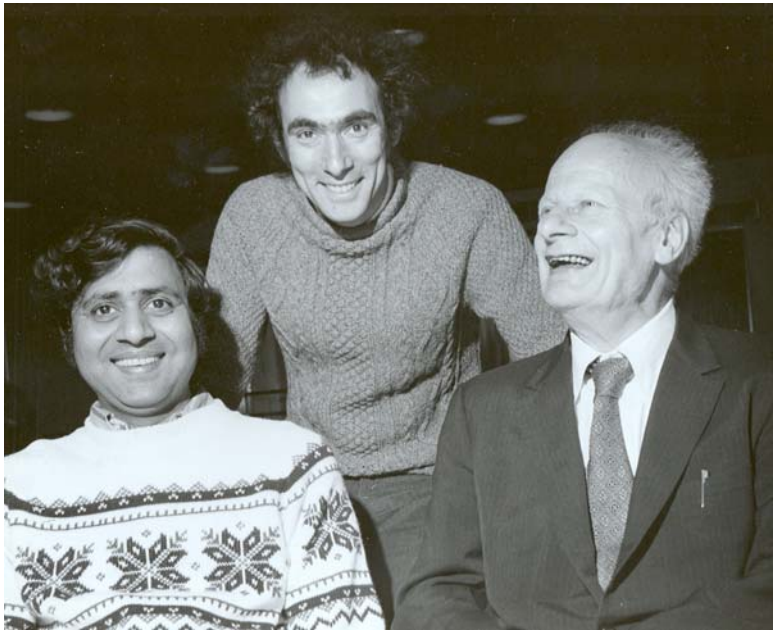
$$\Psi = [\prod F_{ij}] \Phi$$

Short-range correlations

Long-range Structure (Fermi Gas)

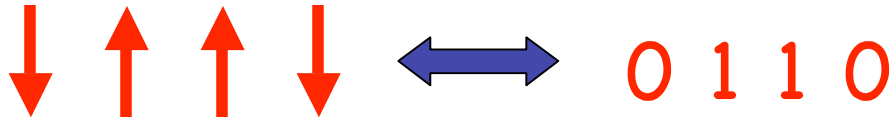
Essentially converted many-body problem to a two-body problem

Fairly accurate in many contexts, from neutron matter to cold atoms



Beginnings of Urbana Few-Body Theory

Vijay, Roger Smith, and Jorge Lomnitz-Adler
invented Monte Carlo methods for light nuclei
(Variational Monte Carlo)
Explicit sums over spin/isospin
Simple computer (matrix) algebra for different operators



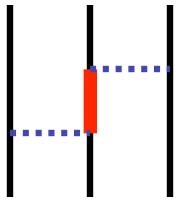
Spin-Spin dependence - bit operations on matrix indices
Variational Monte Carlo calculations with

$$\Psi = \left[\prod F_{ij}\right] \Phi$$

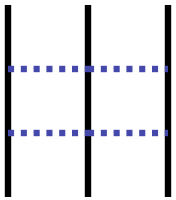
A simple and realistic triton wave function
J. Lomnitz-Adler and V. R. Pandharipande, Nucl. Phys. A342, 404 (1980)
Monte Carlo calculations of triton and 4He nuclei with the Reid potential
J. Lomnitz-Adler, V. R. Pandharipande, and R. A. Smith, Nucl. Phys. A361, 399 (1981)

Beginnings of Urbana Few-Body Theory (cont'd)

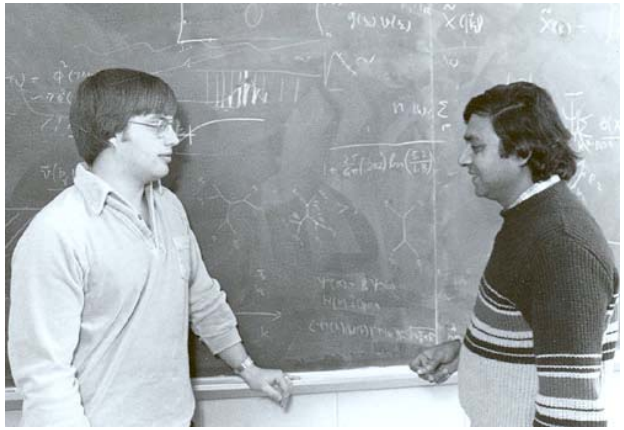
Early 3-nucleon interactions



2-pion TNI
(attraction)



Simple model
For repulsion



A study of three-nucleon interaction in three- and four-body nuclei

J. Carlson and V. R. Pandharipande, Nucl. Phys. A371, 301 (1981)

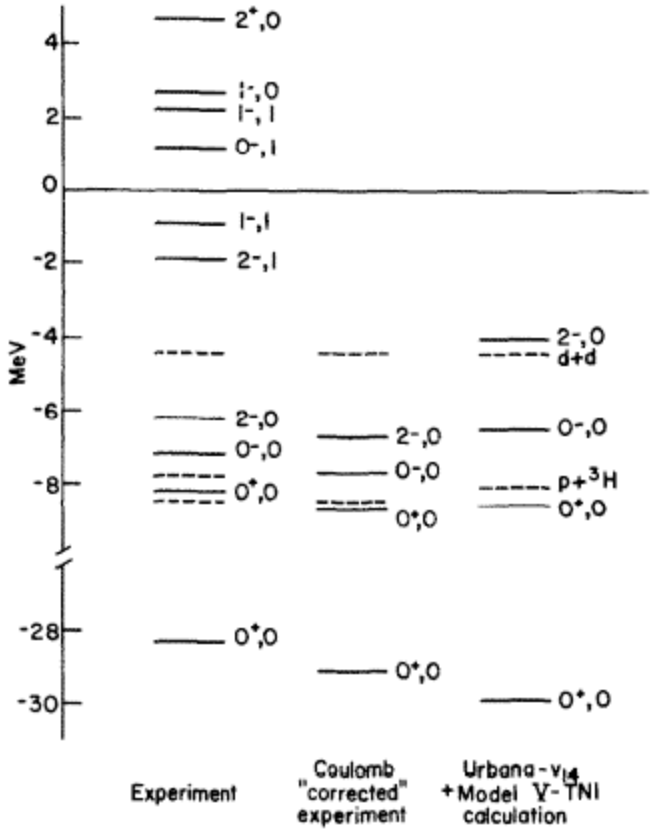
Three-nucleon interaction in 3-, 4-, and infinite-body systems

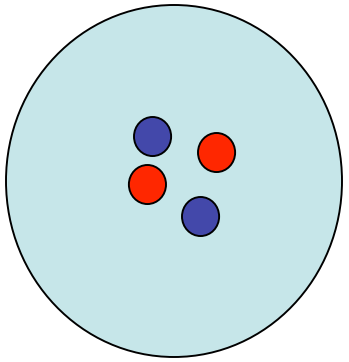
J. Carlson, V. R. Pandharipande, and R. B. Wiringa, Nucl. Phys. A401, 59 (1983)

Reconciling Light Nuclei with Nuclear/Neutron Matter

Scattering / Excited States:

Realistic treatment of 0^+ excitation in A=4

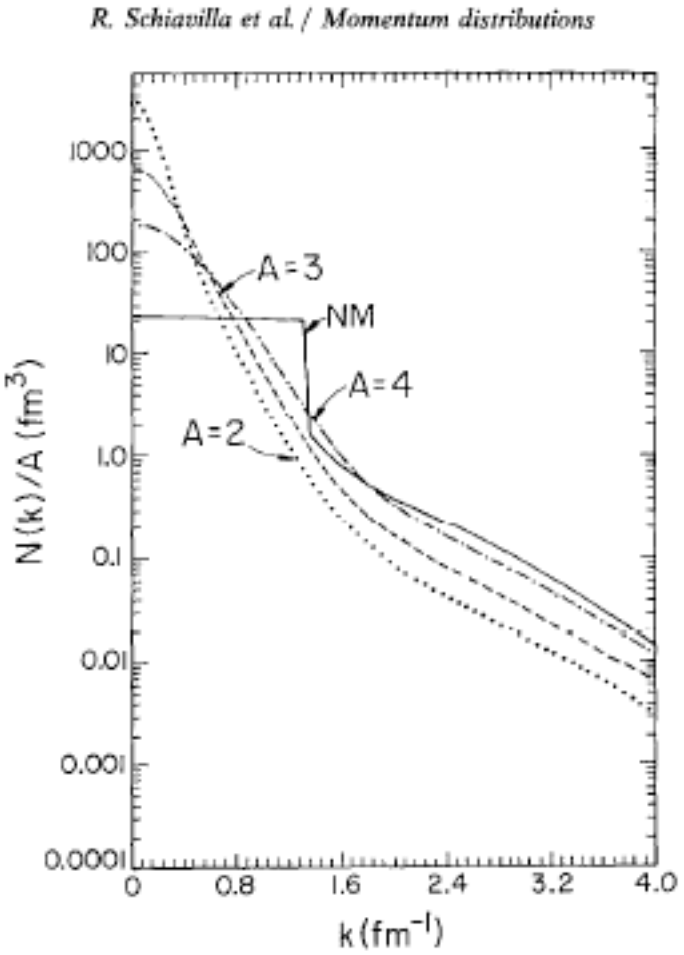




Variational calculations of resonant states in 4He

J. Carlson, V. R. Pandharipande, and R. B. Wiringa, Nucl. Phys. A424, 47 (1984)s

Momentum Distributions

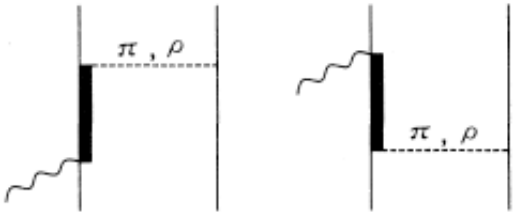


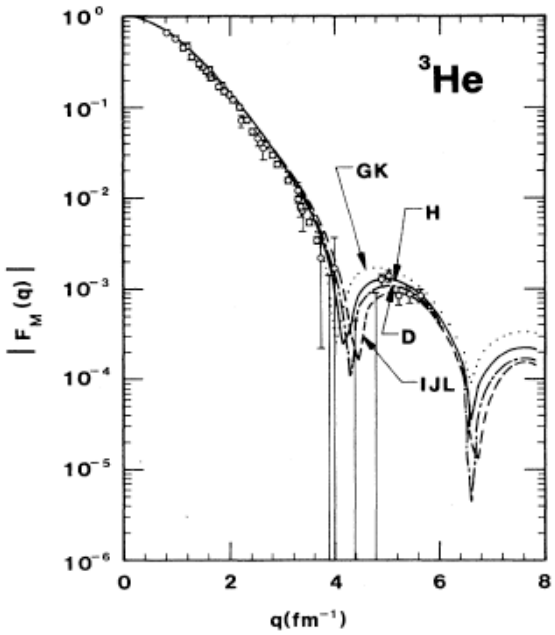
Importance of high-momentum Components in light nuclei: electron scattering, etc.

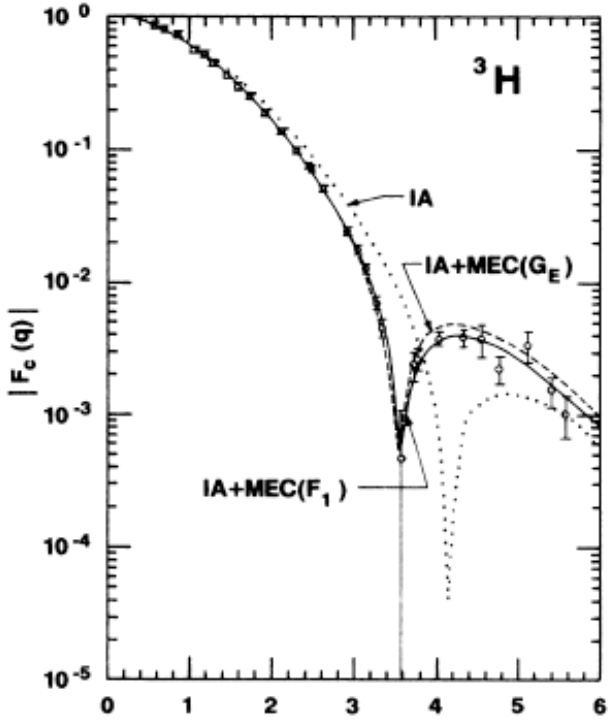
Momentum distributions in A = 3 and 4 nuclei

R. Schiavilla, V. R. Pandharipande, and R. B. Wiringa, Nucl. Phys. A449, 219 (1986)

Form Factors of Light Nuclei







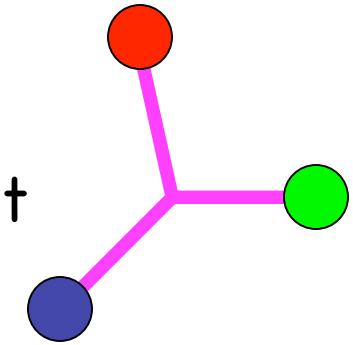
Magnetic Form Factors of the Trinucleons

R. Schiavilla, V. R. Pandharipande, and D. O. Riska, Phys. Rev. C40, 2294 (1989)

Charge Form Factors of the 3- and 4-body Nuclei

R. Schiavilla, V. R. Pandharipande, and D. O. Riska, Phys. Rev. C41, 309 (1990)

1-Nucleon Problem: Hadron Spectroscopy



Introduced flux-tube model for confinement
VMC calculations

Stressed: flux-tube confinement
strong correlations in N-Delta, etc.,
mass differences (di-quarks)

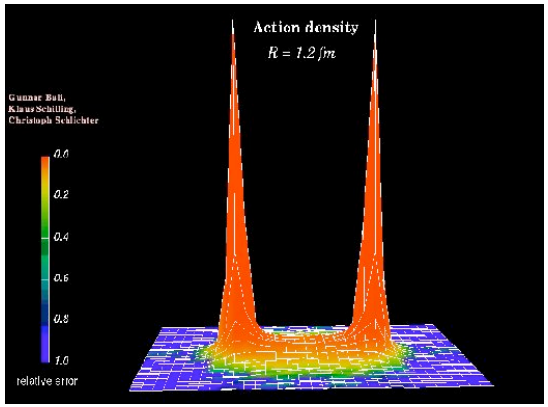


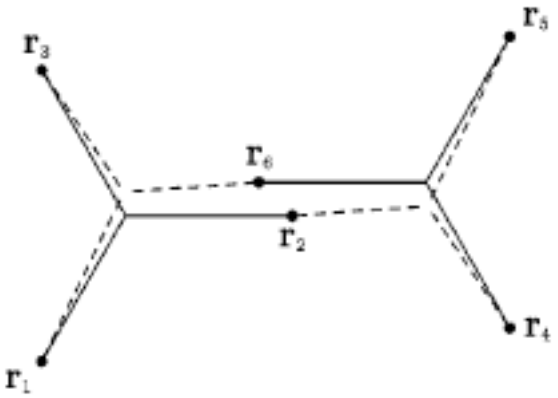
Image from Lucini, de Forcrand

Quark model for baryons based on quantum chromodynamics.
J. CARLSON; J. KOGUT, V. R. PANDHARIPANDE PRD 27, p.233 (1983).

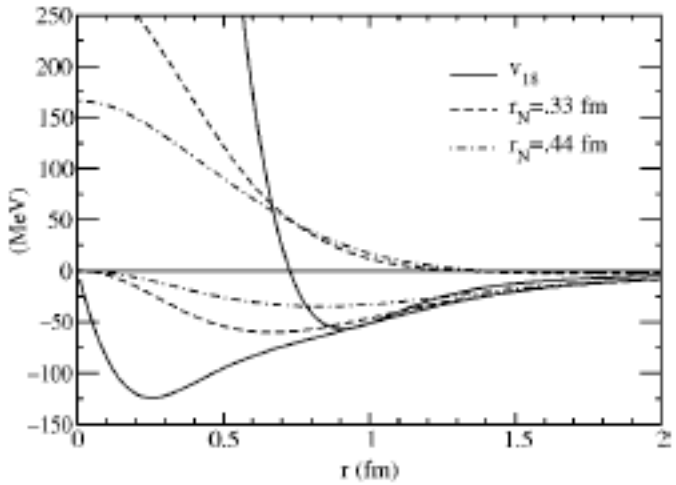
Hadron spectroscopy in a flux-tube quark model.
J. CARLSON, J.B. KOGUT, V. R. PANDHARIPANDE
PRD 28, vol.28, no.11, p.2807-17 (1983)

2-Nucleon Problem
Nuclear Interactions / Deuteron from QCD

Confinement in
6-quark sector



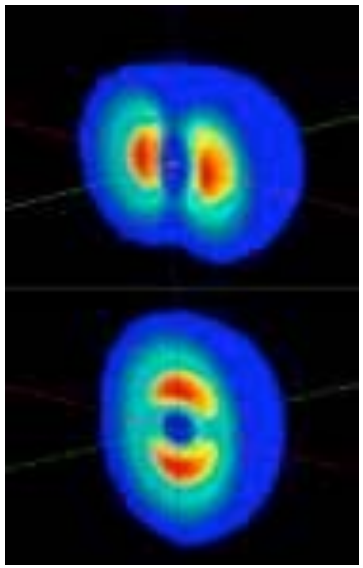
Nucleon-Nucleon
Interaction



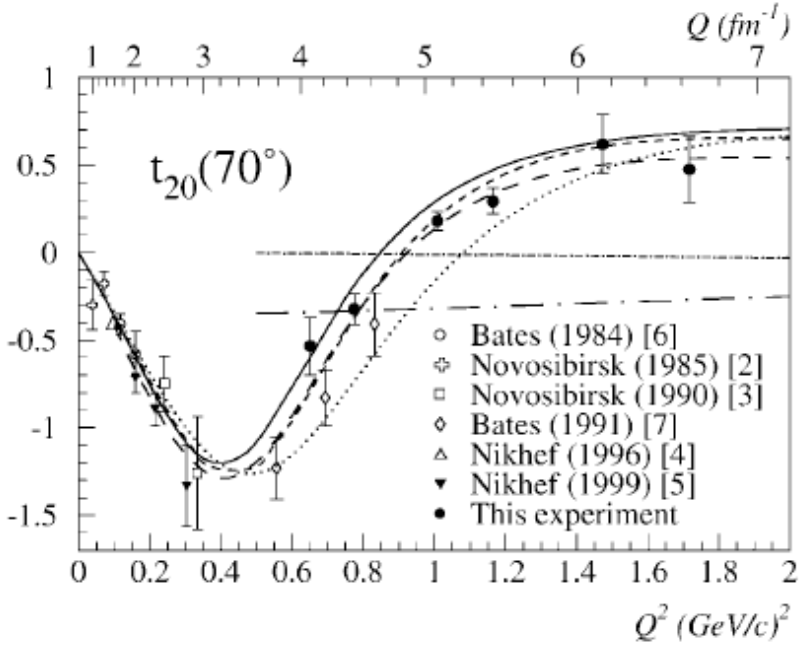
Quantum Monte Carlo Calculations of 6-Quark States.
M.W. Paris and V. R. Pandharipande, Phys. Rev. C62, 015201 (2000).

2-Nucleon problem

Developed w/ Lagaris, Wiringa, Schiavilla and others
realistic models of NN interaction and currents



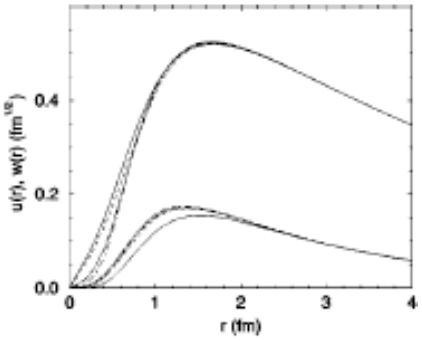
Importance of tensor correlations
Electron Scattering from the Deuteron



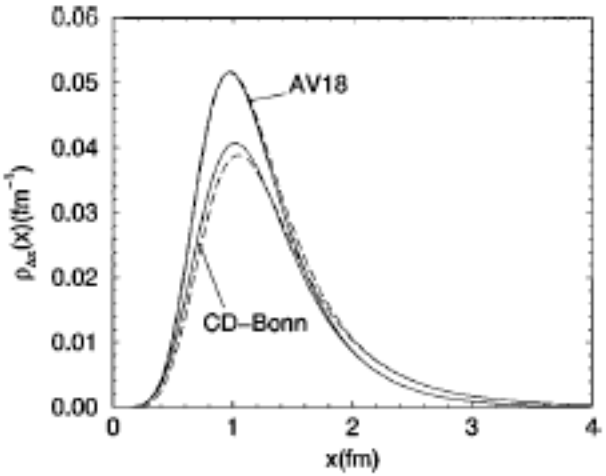
Femtometer toroidal structures in the Deuteron
Forest, JL; Pandharipande, VR; Pieper, SC; Wiringa, RB; Schiavilla, R; Arriaga, A
Physical Review C (Nuclear Physics); Aug. 1996; vol.54, no.2, p.646-67

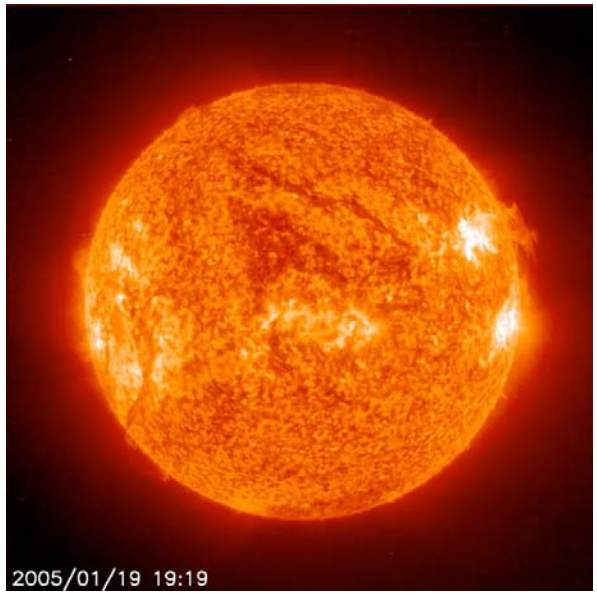
Weak proton-proton capture: Importance of experimental constraints on 2-nucleon currents

Deuteron



GT tritium & pp

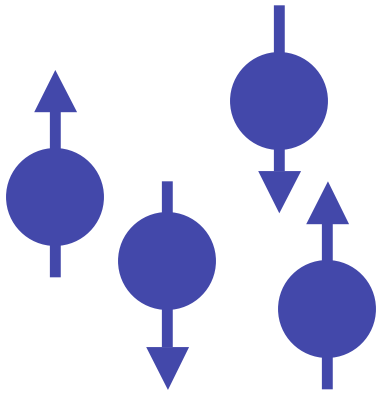




Weak capture of protons by protons.
Schiavilla, R; Stoks, VGJ; Glockle, W; Kamada, H; Nogga, A; Carlson, J; Machleidt, R; Pandharipande, VR; Wiringa, RB; Kievsky, A; et. al.
PRC; Aug. 1998; vol.58, no.2, p.1263-77

Healthy Skepticism

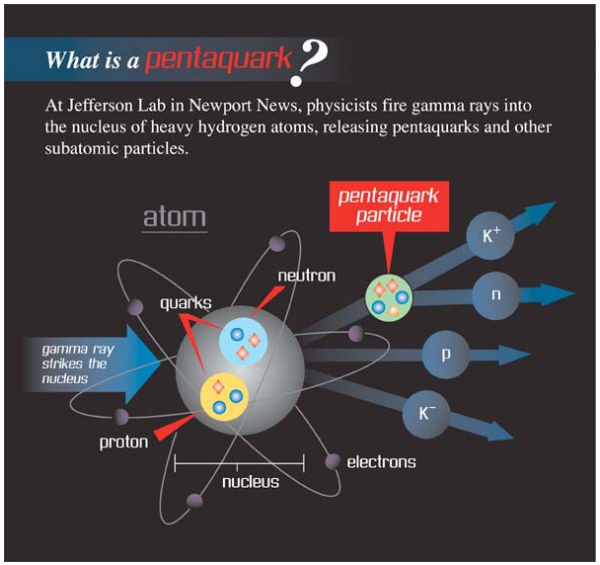
Tetra-neutron (Pieper)



Can Modern Nuclear Hamiltonians Tolerate a Bound Tetraneutron?,
S. C. Pieper, Phys. Rev. Lett. 90, 252501 (2003)

Pentaquark

Absence of Exotics in Flux-Tube Quark Models
J. Carlson and V. R. Pandharipande
Phys. Rev. D **43**, 1652-1658 (1991)



Structure of Light Nuclei

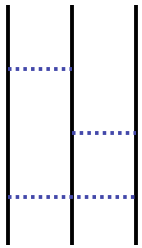
Vijay was awarded the 1999 Tom W. Bonner Prize in Nuclear Physics
"For fundamental contributions in determining the structure of light nuclei by solving the Schroedinger problem with more than three nucleons using realistic nucleon-nucleon interactions supplemented by three-body forces."

Quantum Monte Carlo calculations of A = 6 nuclei
B. S. Pudliner, V. R. Pandharipande, J. Carlson, and R. B. Wiringa,
Phys. Rev. Lett. 74, 4396 (1995)
Quantum Monte Carlo calculations of nuclei with A = 7
B. S. Pudliner, V. R. Pandharipande, J. Carlson, S. C. Pieper, and R. B. Wiringa,
Phys. Rev. C 56, 1720 (1997)

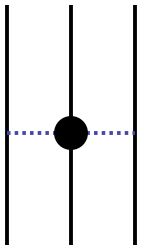
New 3-nucleon interactions

Neutron-rich nuclei improved with TNI (UIX) but still underbound

Spin-orbit splittings improved, but still too small

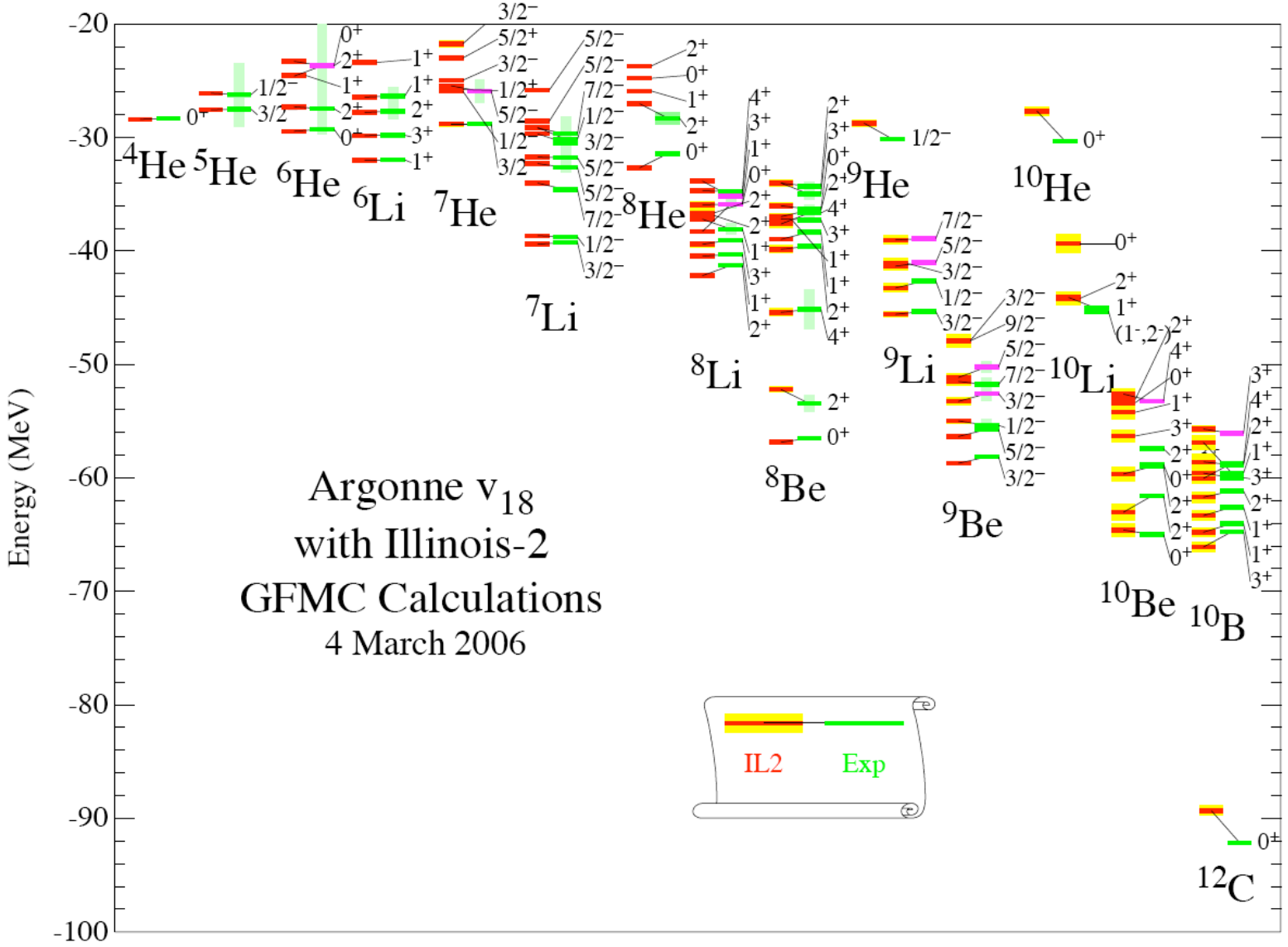


3 pion terms
Quantum #s from Delta model

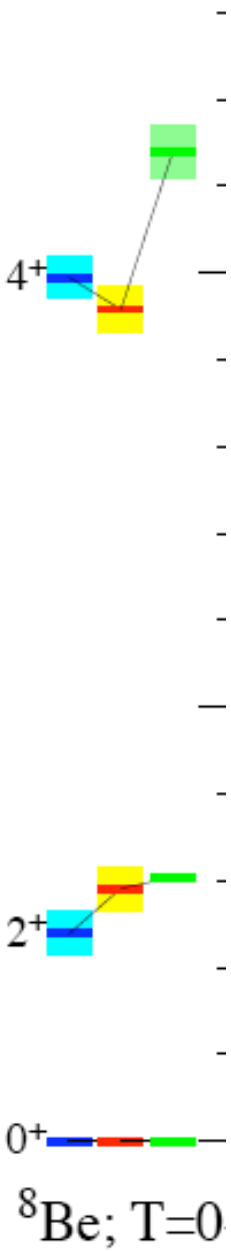


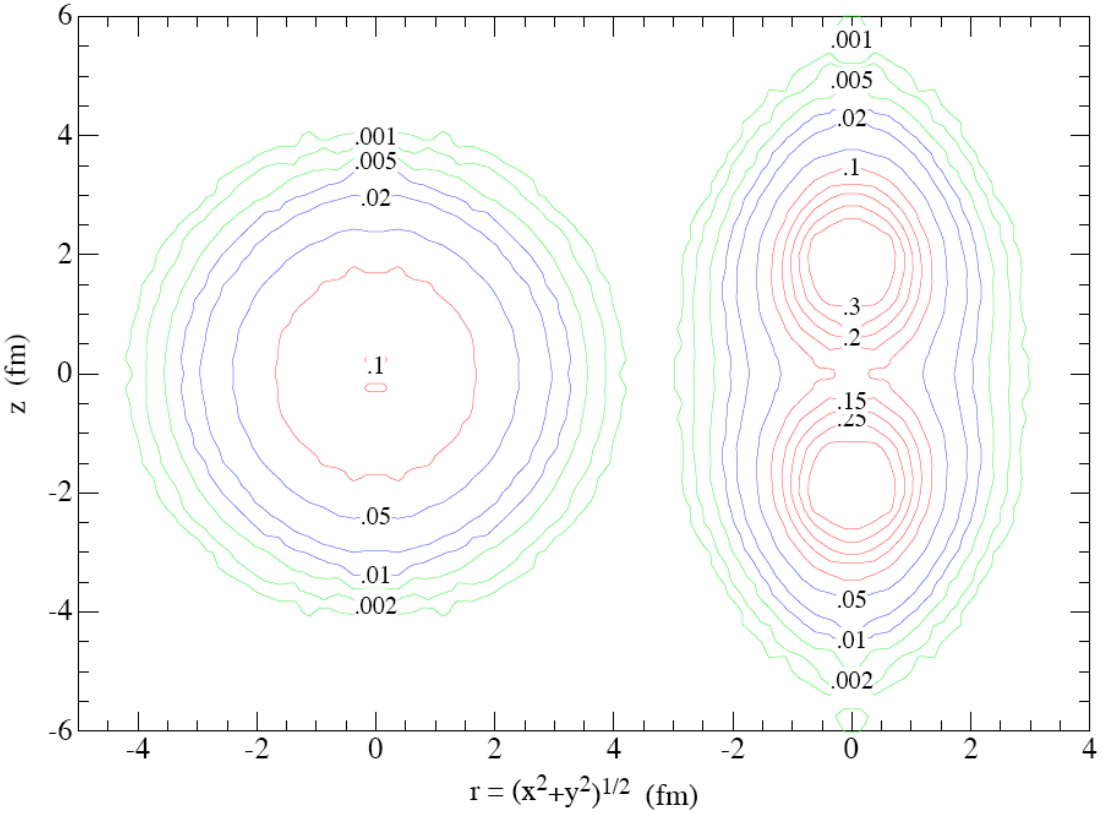
S-wave pion term
Strength from EFT

Strength constants fit up to A = 8


Energy (MeV)
-20
-30
-40
-50
-60
-70
-80
-90
-100
Argonne v18
with Illinois-2
GFMC Calculations
4 March 2006
IL2
Exp
4He
5He
6He
6Li
7He
7Li
8He
8Li
8Be
9He
9Li
9Be
10He
10Li
10Be
10B
12C

Spectra & Intrinsic Shapes in 8Be





Quantum Monte Carlo calculations of A = 8 nuclei

R. B. Wiringa, S. C. Pieper, J. Carlson, and V. R. Pandharipande, Phys. Rev. C 62, 014001 (2000)

+ Many More Things in Light Nuclei

Elastic / Transition Form Factors in Light Nuclei

Sum Rules & EW response

Low-Energy Astrophysical Reactions

Electron Scattering: (e,e') and (e,e'p)

Variational Cluster calculations of 16O

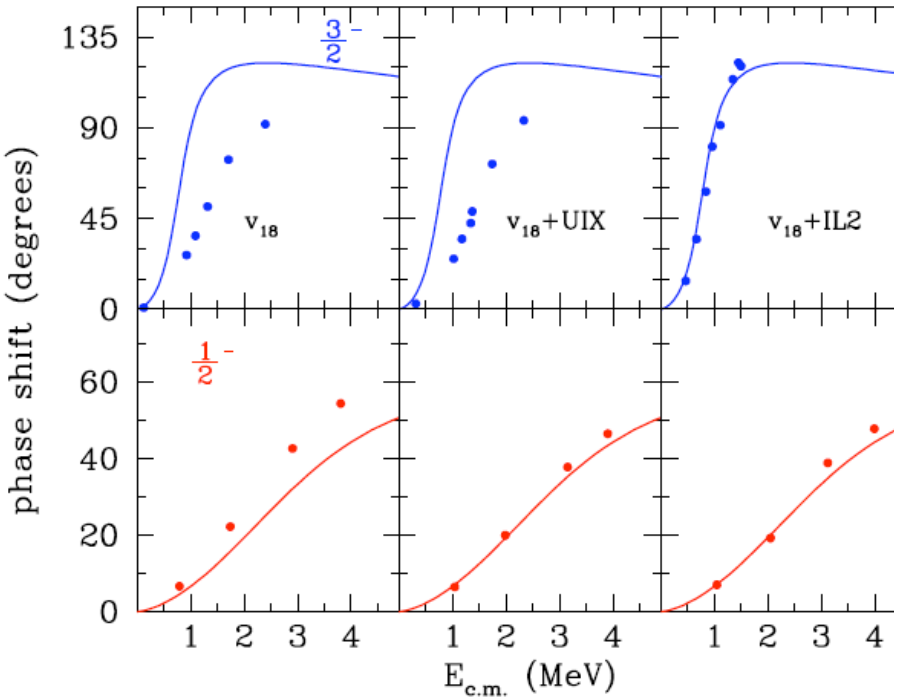
Spectral function, overlaps, …

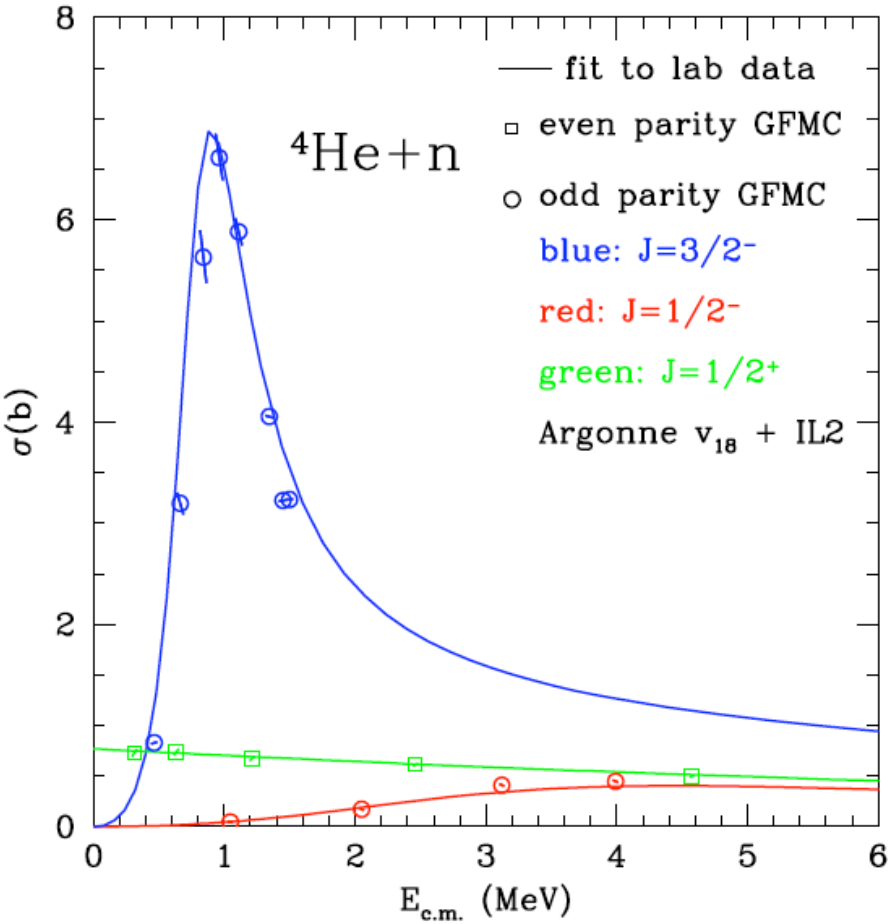
….

Future: Light Nuclei

Low - Energy Scattering / Capture Reactions

N-alpha scattering w/ Illinois-2

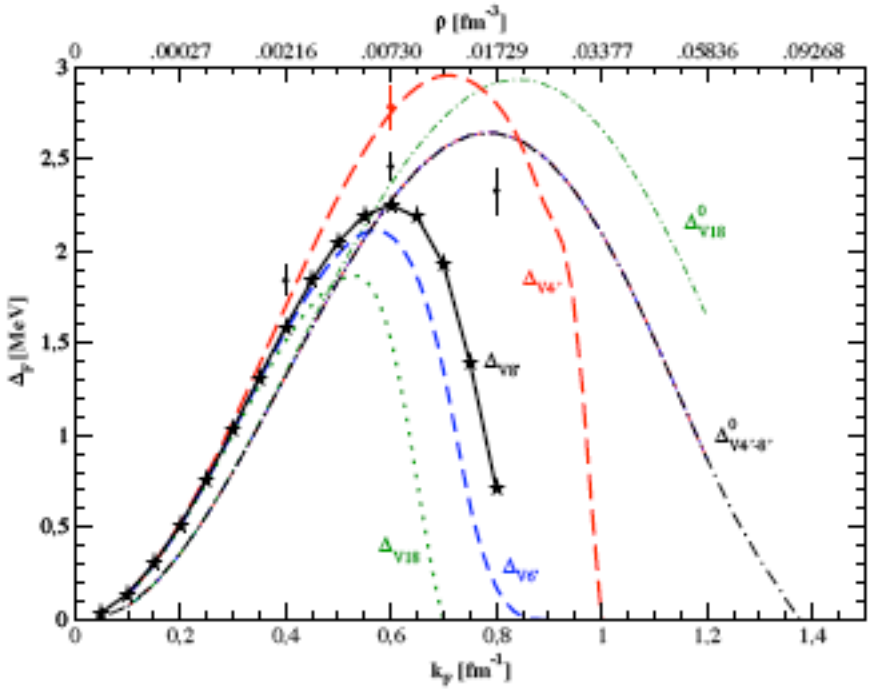


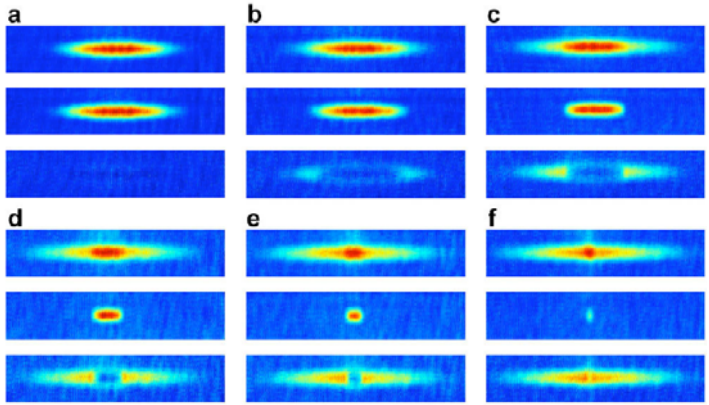


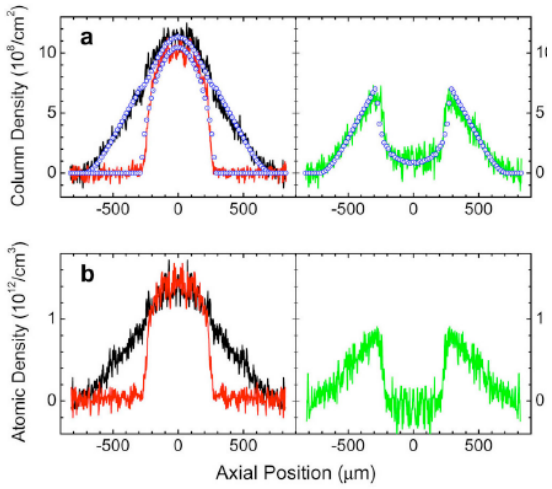
Future: Larger Nuclei/Matter

AFDMC Schmidt Fantoni, AFMC w/ constrained path: S. Zhang

Pairing in Nuclei / Neutron Star Matter / Atomic Gases





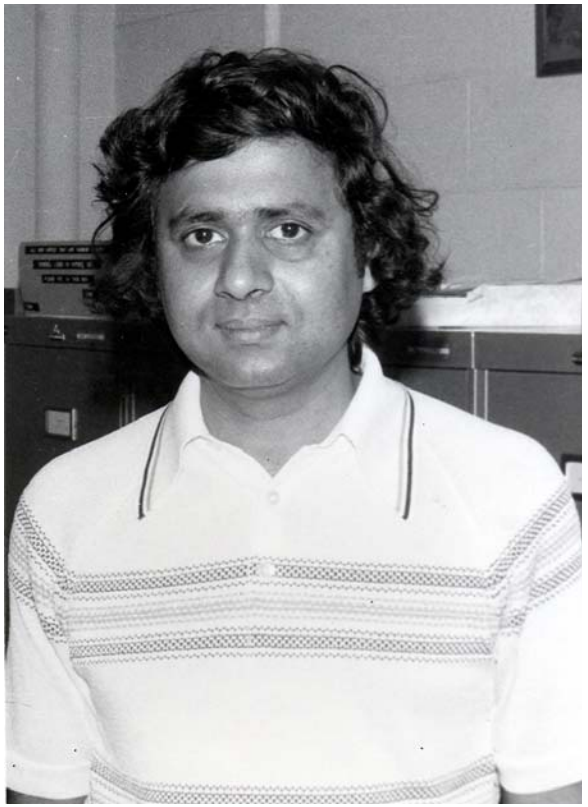


Larger Nuclei / Nucleonic Matter

Relations to Cold Atom Physics

Paper w/ 2nd student (1st cond matt. - Kevin Schmidt) and last (S.-Y. Chang)

Beautiful strong-interaction physics of the unitary regime



Thanks to:

Celia Elliott for photos of Vijay from the Urbana archives

All of Vijay's friends, family and collaborators