3 Nucleon Interactions Beyond A=4

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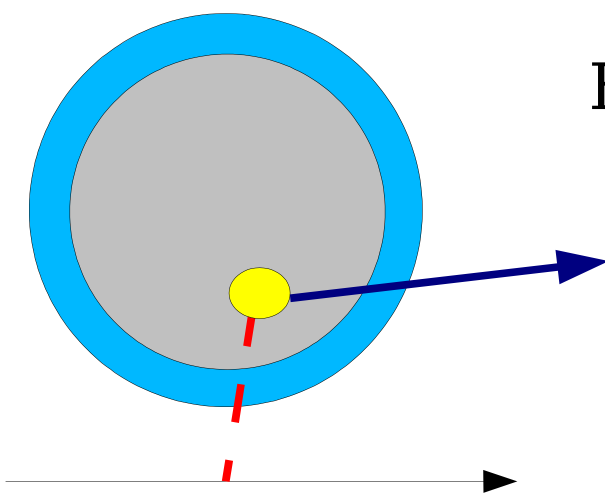
Goal: Understand Nuclear Properties & Reactions from 'Realistic' Interactions & Currents

Relative Momenta beyond 2 x Fermi Momenta
CM Energies up to ~ 100 MeV



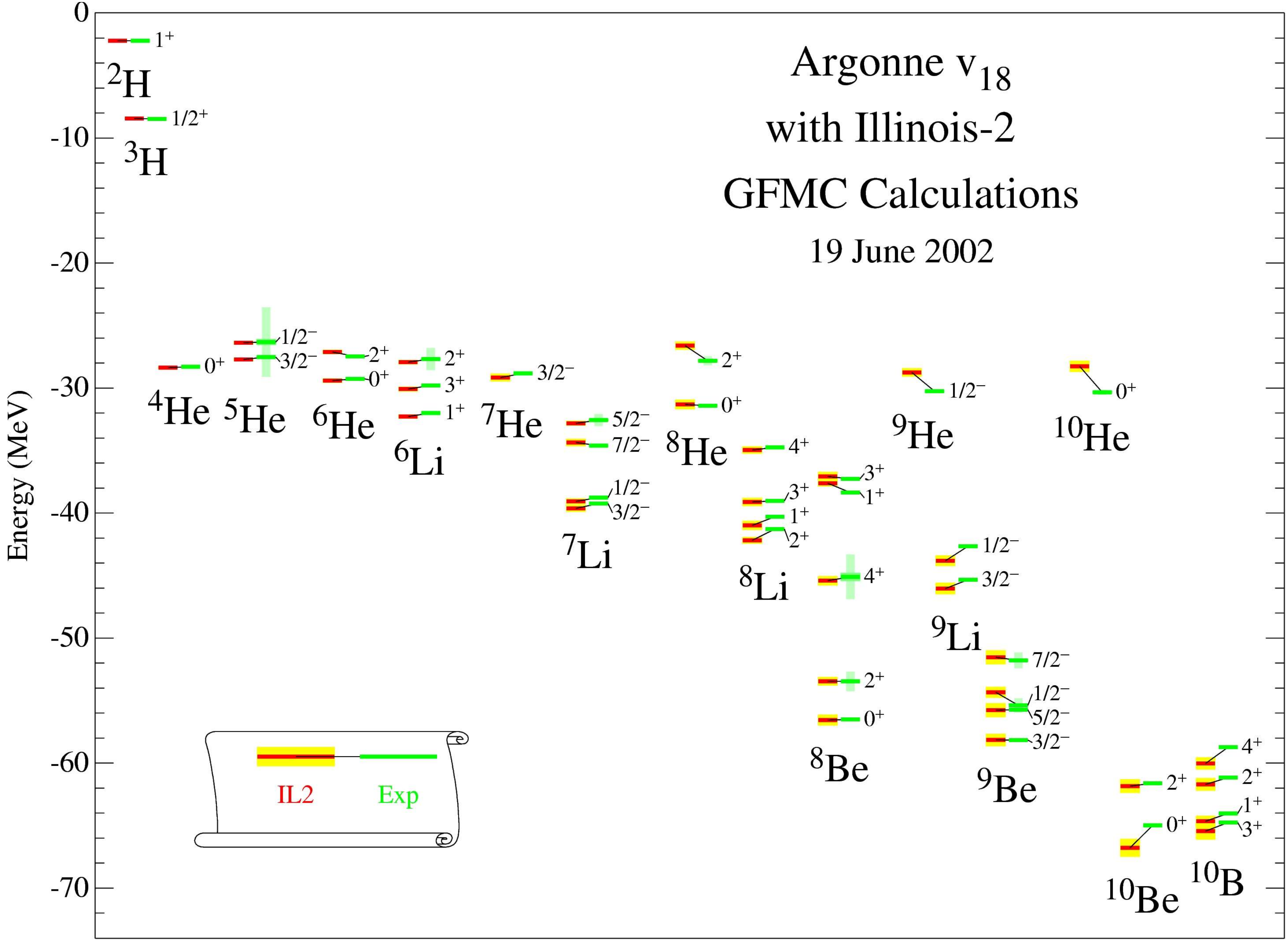
$E \sim k^2/2\mu \sim 100$ MeV

Concerns on EFT in many-body systems

Binding Energy Differences Small:
- E(6Li) - (E(4He) + E(D)) = 1.5 MeV
- E(7Li) – Eth = 2.4 MeV
- yielding concerns about counting schemes that require perturbation theory

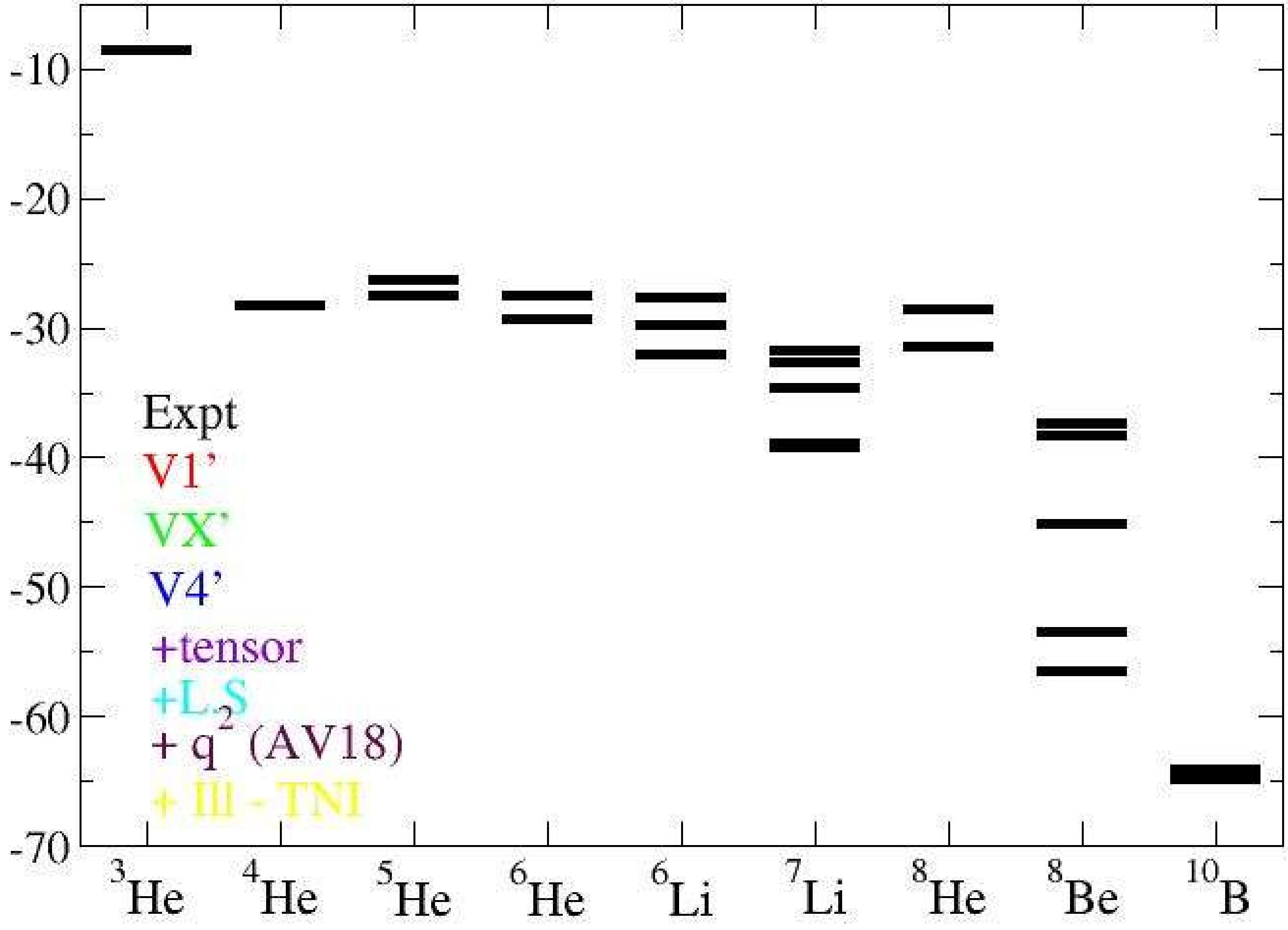
Interaction Terms in Many-Body systems can
- add coherently (L.S splittings) or
- cancel strongly (TNI in n-rich systems).

What are we sensitive to in light nuclear spectra?



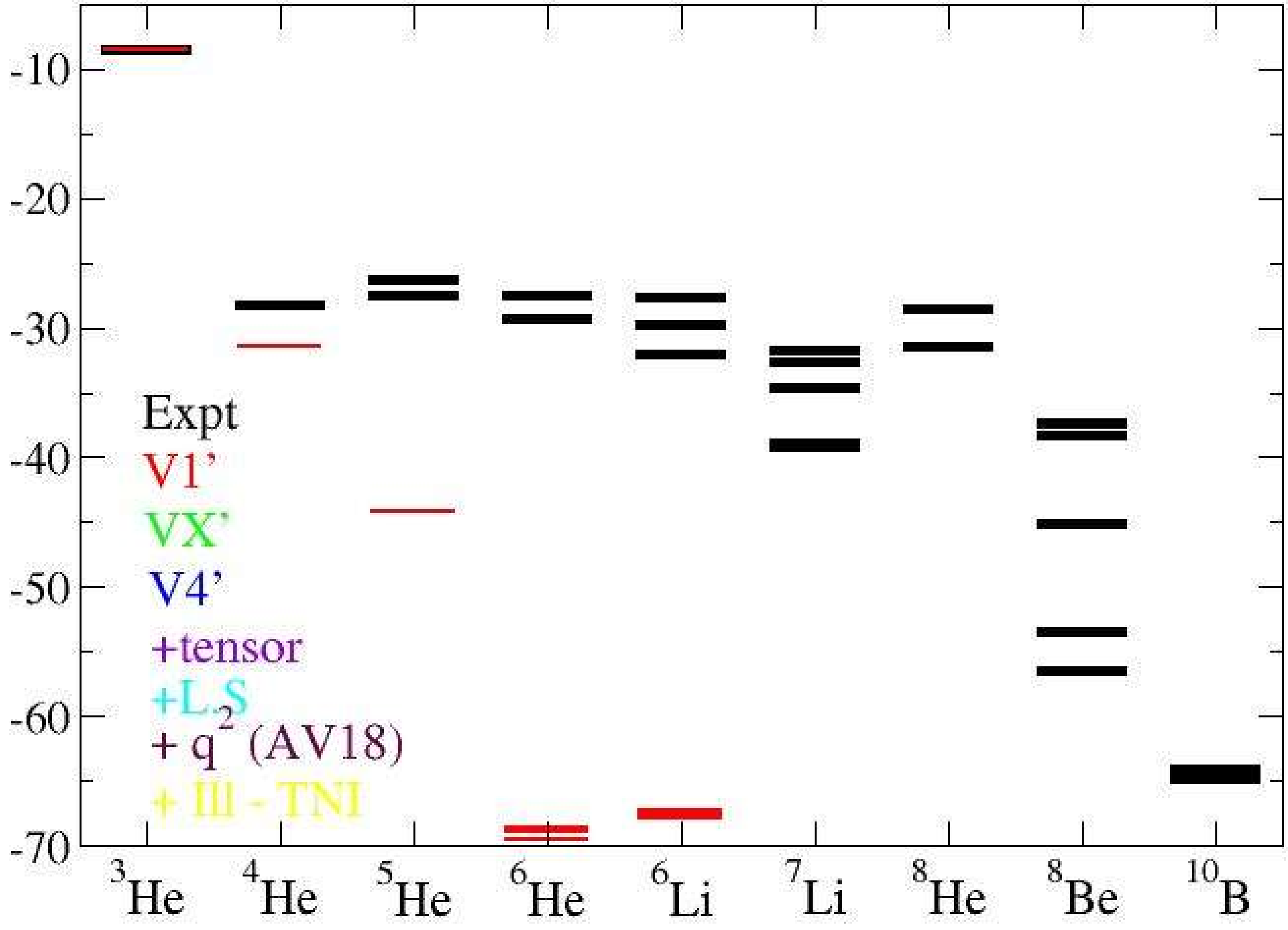
Pieper, Wiringa, & Varga

Can we understand forces from Spectra?

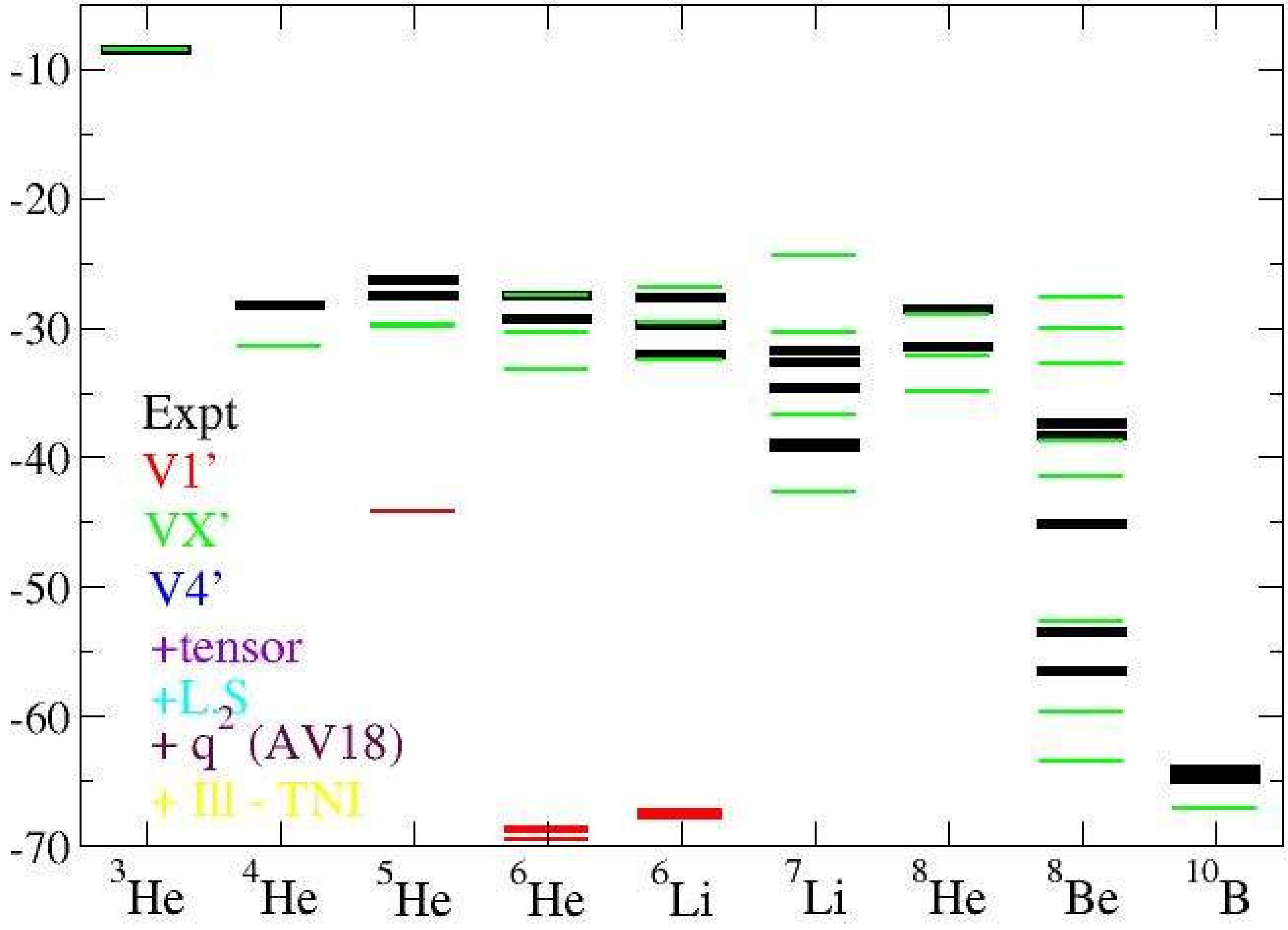


Pieper & Wiringa, PRL 2003

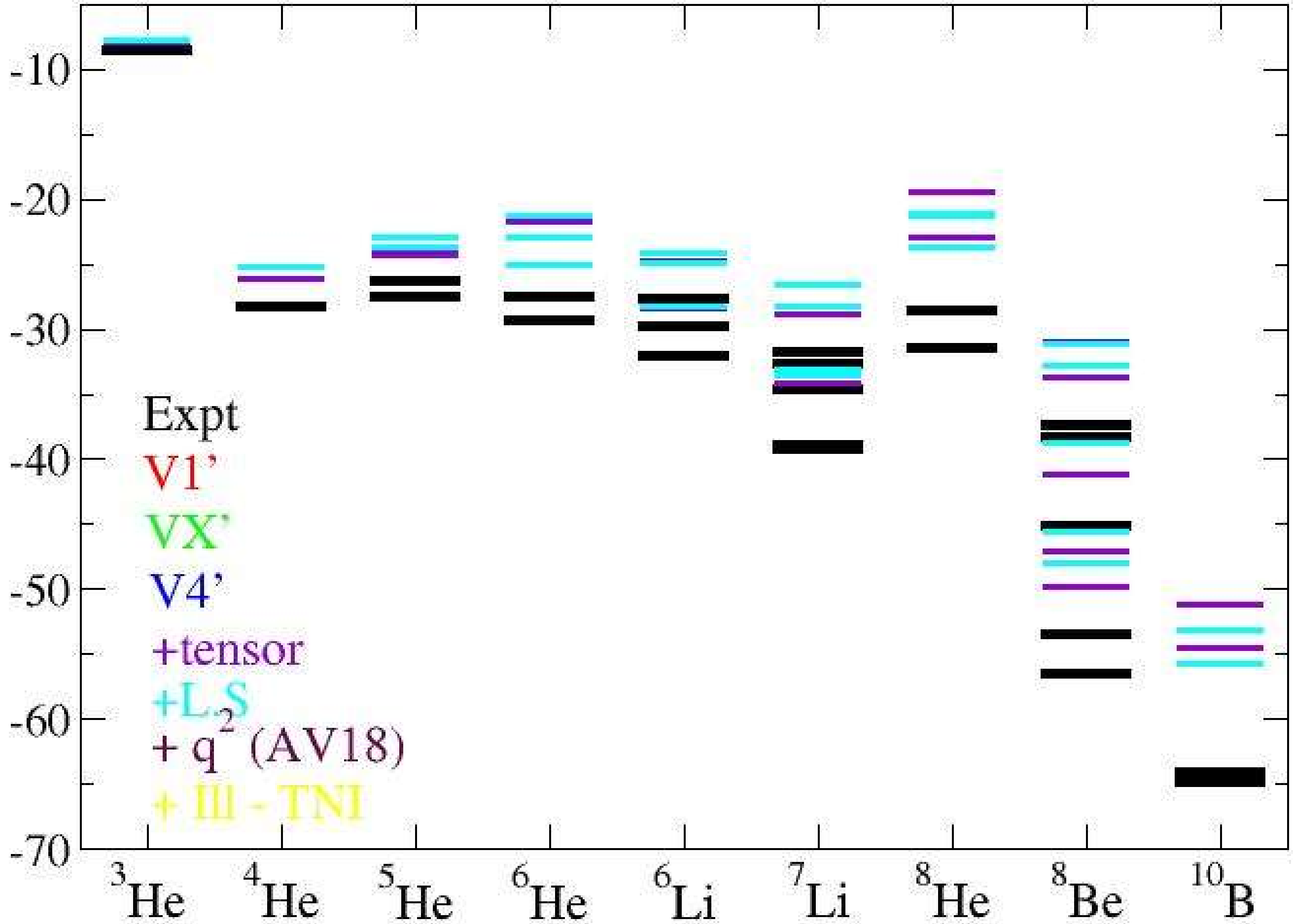
Central Interaction



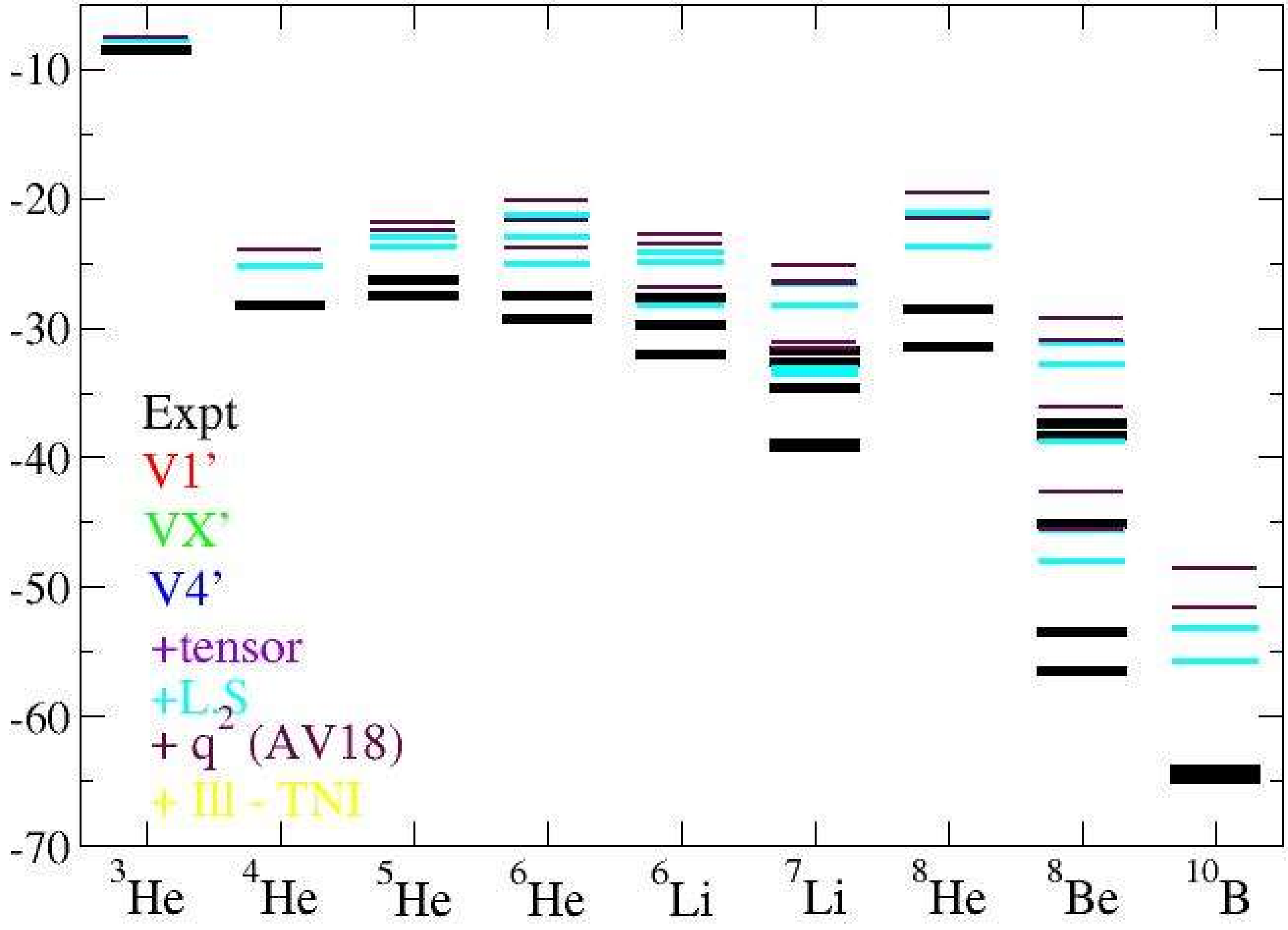
+ Space Exchange Interaction



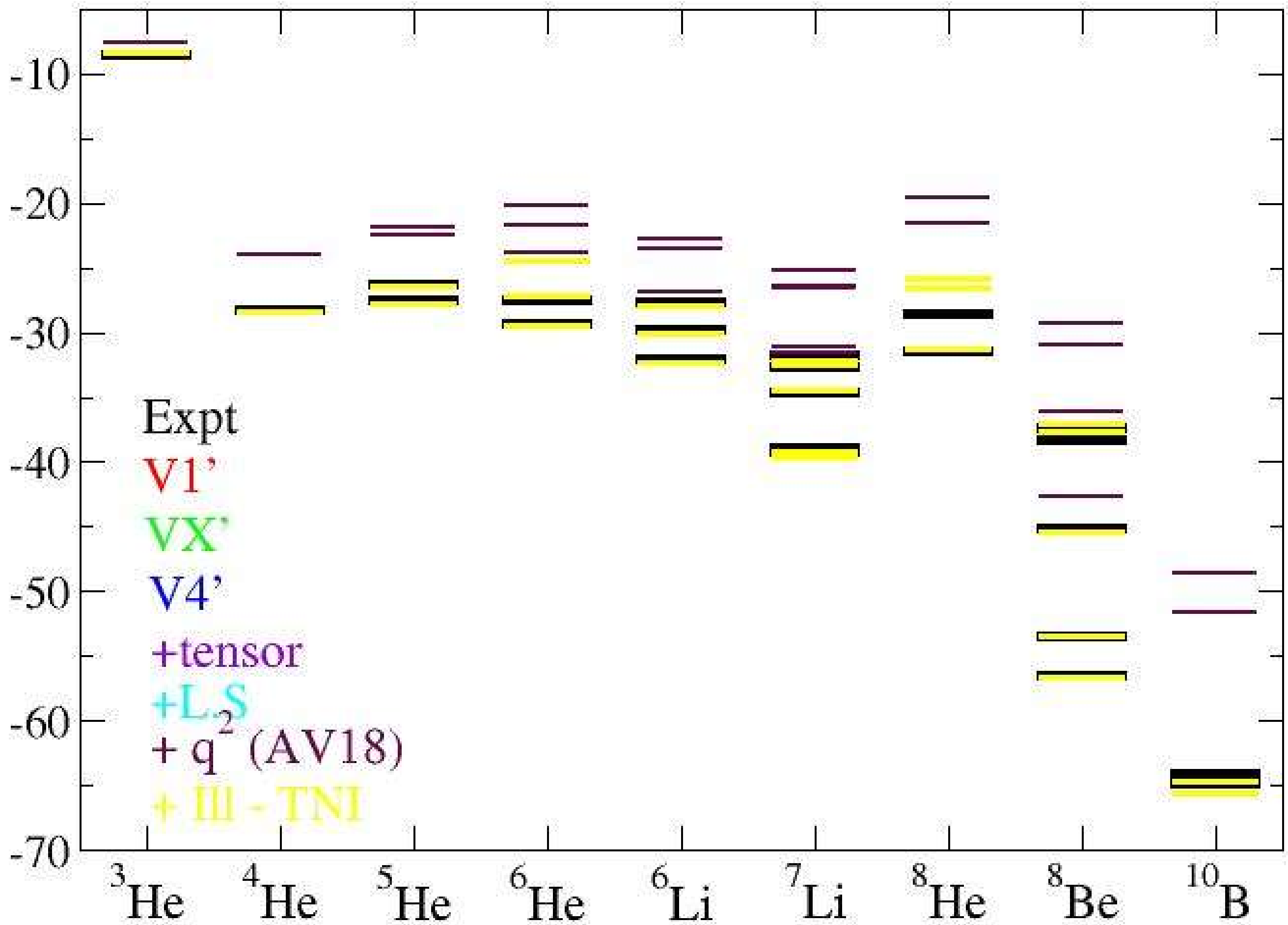
+ spin-spin, tensor, L.S



AV18 w/o TNI

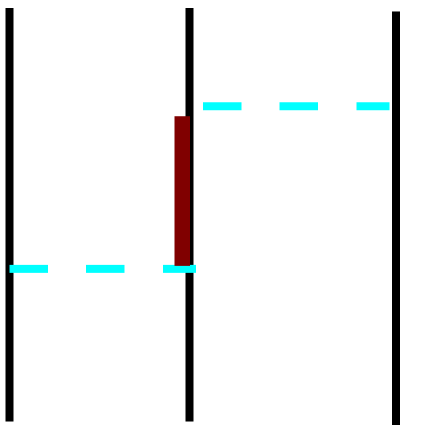

-10
-20
-30
-40
-50
-60
-70
Expt
V1'
VX'
V4'
+tensor
+L.S
+ q^2 (AV18)
+ III - TNI
^{3}He
^{4}He
^{5}He
^{6}He
^{6}Li
^{7}Li
^{8}He
^{8}Be
^{10}B

+ TNI



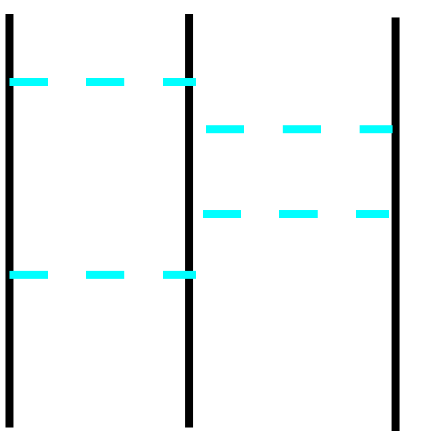
-10
-20
-30
-40
-50
-60
-70
Expt
V1'
VX'
V4'
+tensor
+L.S
+ q^2 (AV18)
+ III - TNI
3He
4He
5He
6He
6Li
7Li
8He
8Be
10B

Urbana/ Illinois Models of TNI:



A(PW)

UIX: -0.0293
IL2: -0.037



'Short-range' Spin-Indep.

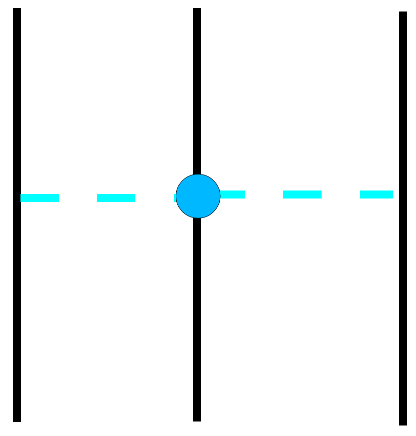
UIX: 0.00480 (0.00291)
IL2: 0.00705 (0.00493)

2-pion TNI terms in various interactions

	AC			C
	A'	B	C	D
Fujita-Miyazawa	0	-1.15	0	-0.29
TM	-1.03	-2.62	1.03	-0.60
Brazil	-1.05	-2.29	(1.05)	-0.77
UIX	0	-1.20	0	-0.30
Texas	-1.87	-3.82	0	-1.12
Ill-2	-1	-1.52	0	-0.38

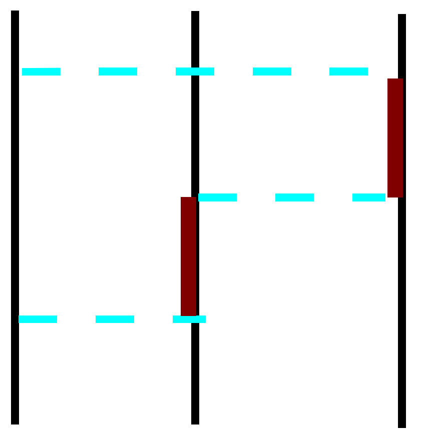
Huber, Friar, Nogga, Witala, van Kolck

Additional Terms in Illinois



S-wave Pion Term:

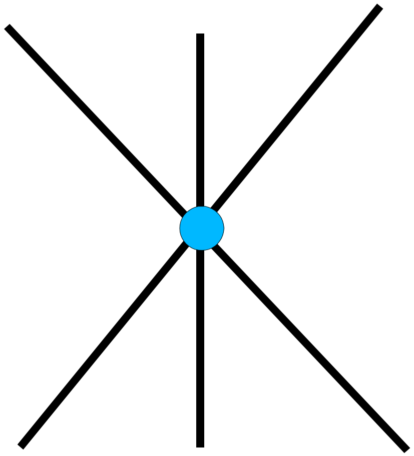
A(SW) [IL2] = -1.0
(as in chiral potentials)



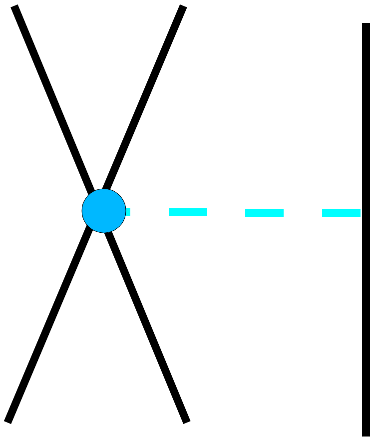
3-Pion Terms:

Quantum Numbers give large
T=3/2 contribution
Strength adjusted to A < 9

Additional Chiral TNI terms:



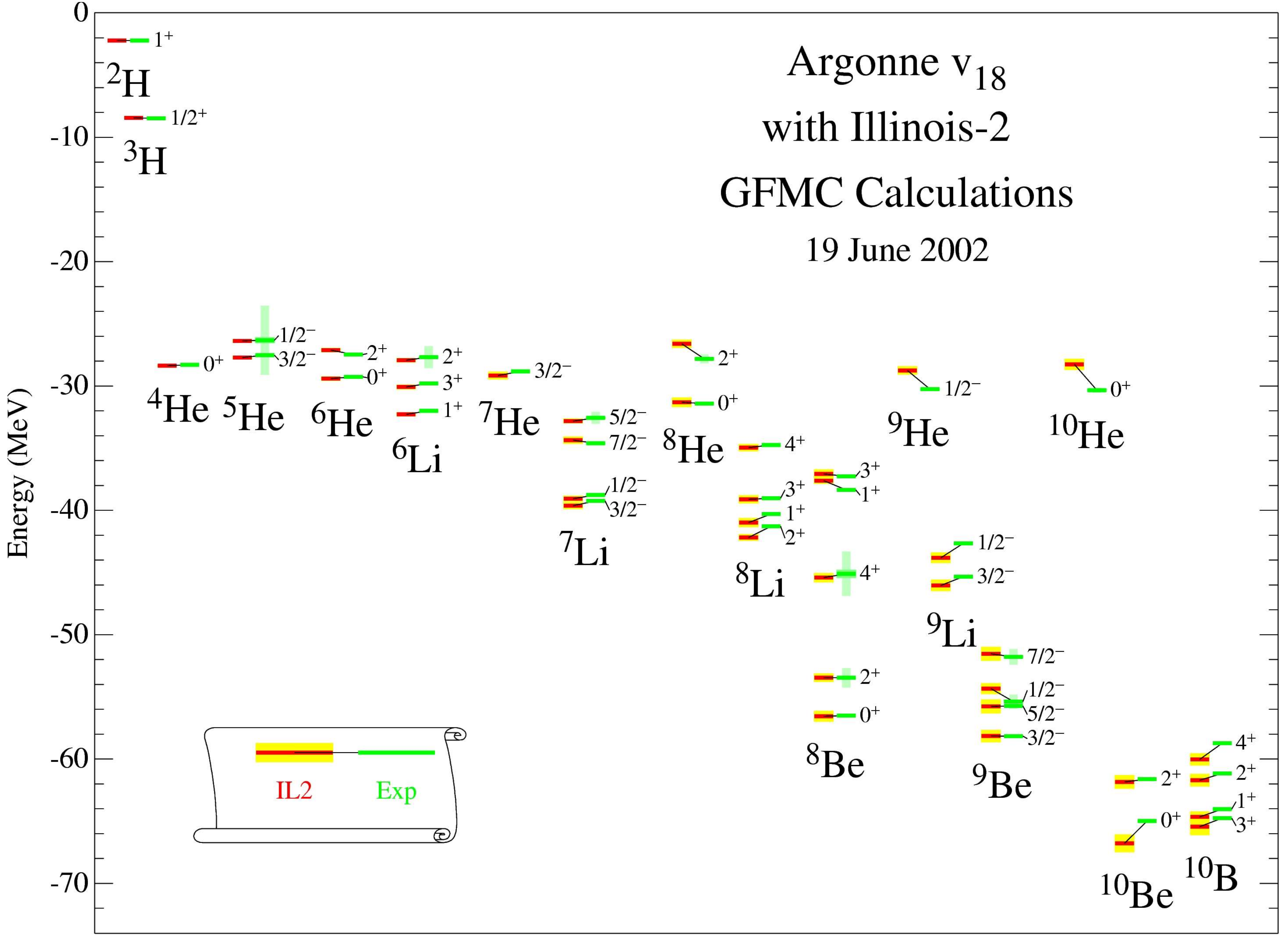
Contact term:
For short-range, acts only in T=1/2



Pion-range – short-range Term

$$
\begin{aligned}
V_4^{(1)} &= -\frac{d_2}{(2\pi)^6}\,\frac{g_A}{4f_\pi^2}\,\vec{\sigma}_1\times\vec{\sigma}_3\cdot\vec{Q}'\;\vec{\sigma}_2\cdot\vec{Q}'\;\frac{1}{Q'^2+m_\pi^2}\;\vec{\tau}_1\cdot\vec{\tau}_2\times\vec{\tau}_3 \\
&\quad -\frac{d_2}{(2\pi)^6}\,\frac{g_A}{4f_\pi^2}\,\vec{\sigma}_1\times\vec{\sigma}_2\cdot\vec{Q}\;\vec{\sigma}_3\cdot\vec{Q}\;\frac{1}{Q^2+m_\pi^2}\;\vec{\tau}_1\cdot\vec{\tau}_3\times\vec{\tau}_2
\end{aligned}
$$

Triple-product structure:
Acts only in T=1/2 (& S=1/2)



Argonne v18
with Illinois-2
GFMC Calculations
19 June 2002
Energy (MeV)
0
-10
-20
-30
-40
-50
-60
-70
2H
3H
4He
5He
6He
6Li
7He
7Li
8He
8Li
8Be
9He
9Li
9Be
10He
10Be
10B
1+
1/2+
0+
1/2−
3/2−
2+
3+
5/2−
7/2−
4+
7/2−
5/2−
IL2
Exp

Expectation Values:

Nucleus:	AV18/UIX	IL2	<TNI>/<VNN>
4He	-6.35(5)	-8.38(7)	0.06
7Li	-9.1(2)	-14.5(4)	0.07
8He	-8.0(2)	-16.3(5)	0.07
12C		-40.8(2.)	0.08

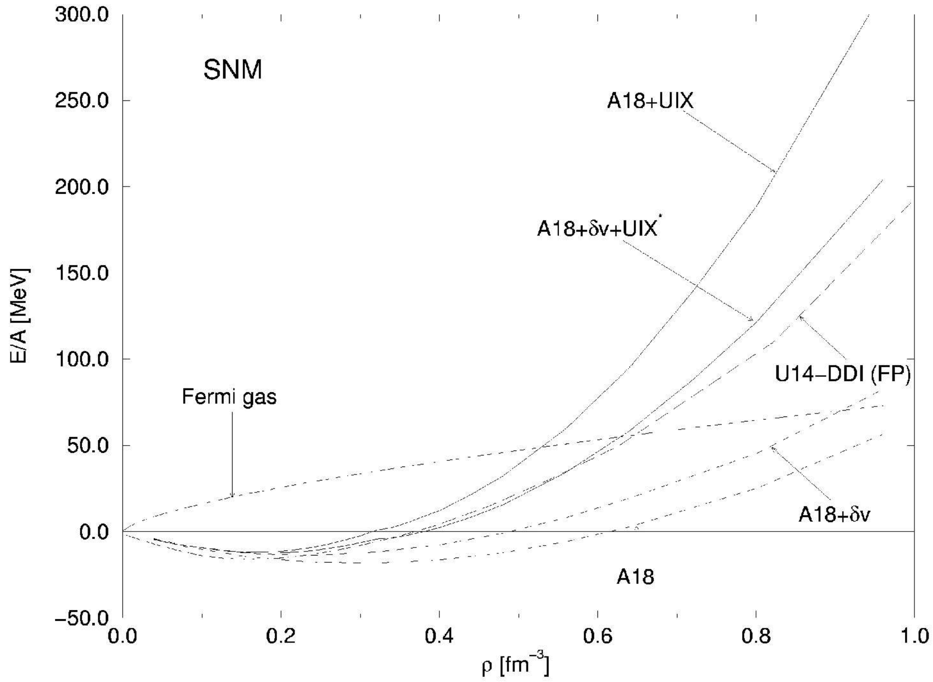
Nucleus:	2Pi(AC)	2Pi(C)	S-wv	VSR	3Pi(SS)	3Pi(AA)
12C	-40.	-24	-2	+30	-7	+2
8He	-16	-9	-1	+13	-5	+1
4He	-10	-6	-1	+7	0	+1

Additional Information (Beyond A=3,4)

- Nuclear / Neutron Matter
- Neutron Drops
- Scattering Processes

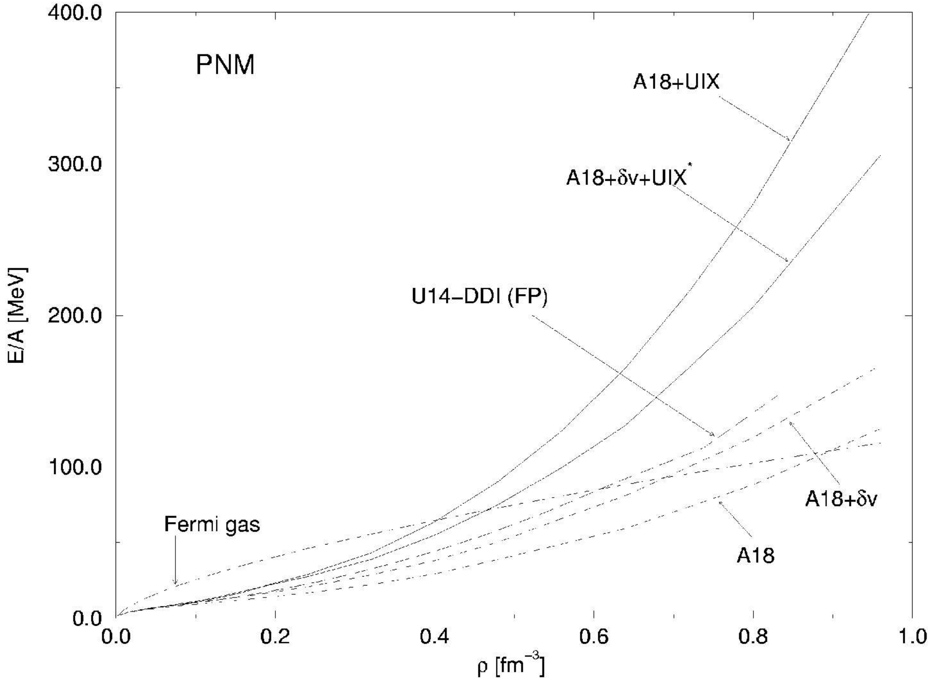
Symmetric Nuclear Matter
AV18 + UIX
Akmal, Pandharipande

Variational Method using Integral Eqn Techniques



"Simple" Wavefunction, cluster expansion
slowly convergent w/ IL2

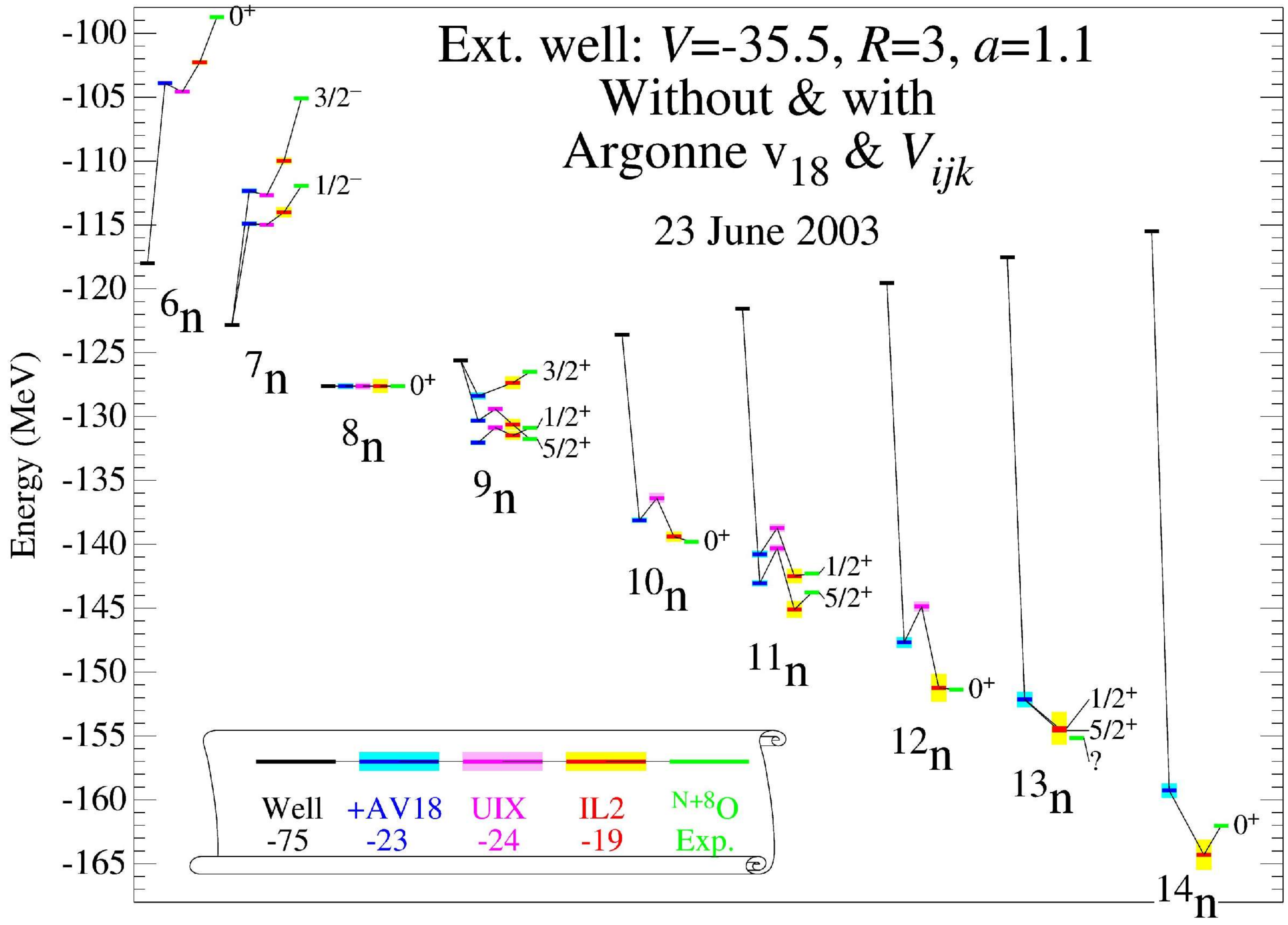
Neutron Matter (AV18 + UIX)



Supports 1.8 Solar mass neutron star

Cluster Expansion much more difficult for Illinois models of TNI

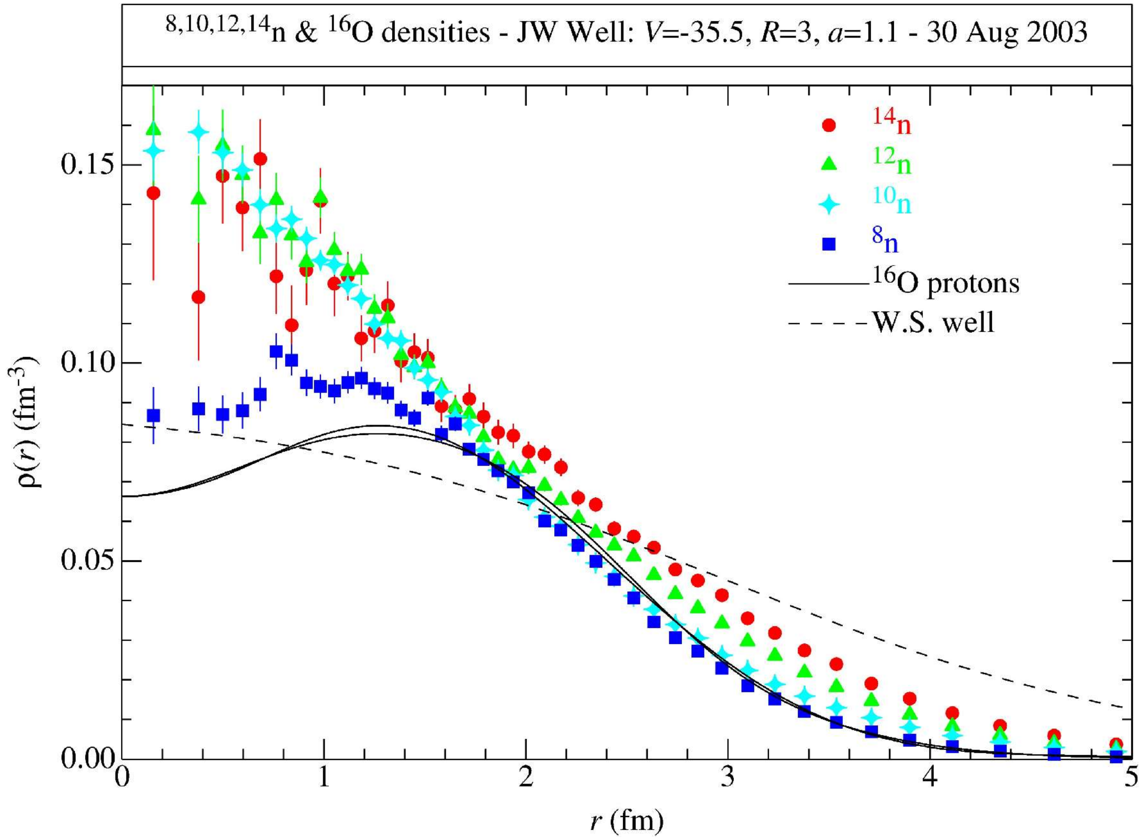
Neutron Drops
(N>8; mimicks Oxygen Isotopes)



Preliminary

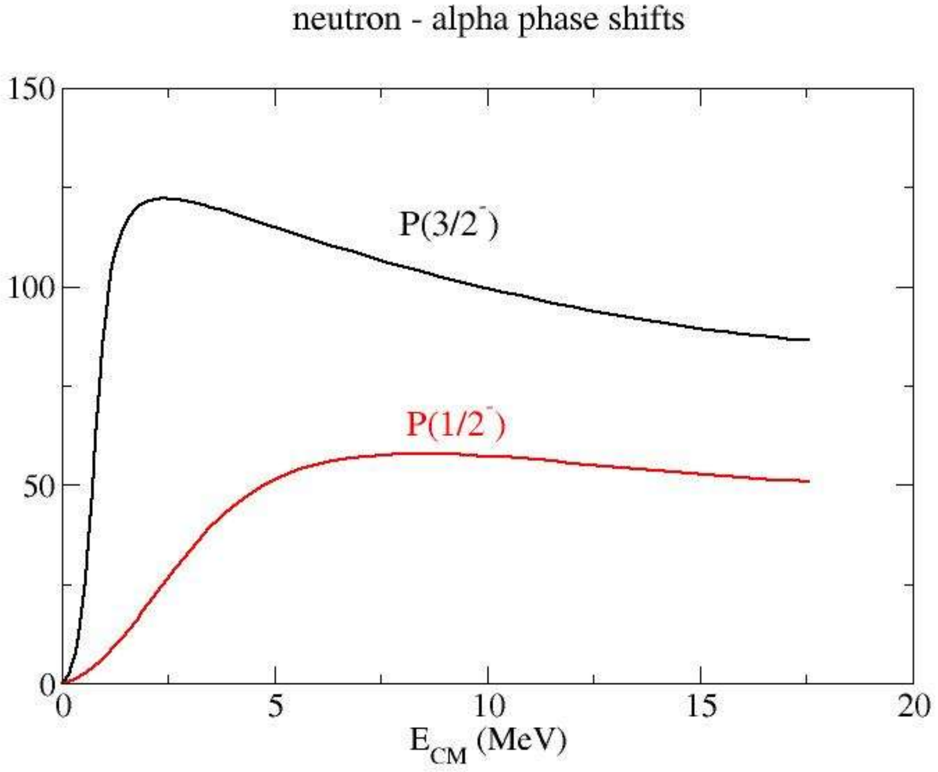
Expectation Values in Neutron Drops

	V1	VNN	VSR	V-2pi	V-sw	V-3pi	<TNI/VNN>
n=8	-173	-88	4	-0.	0.2	-10	7%
n=14	-260	-176	9	0.	0.5	-25	9%

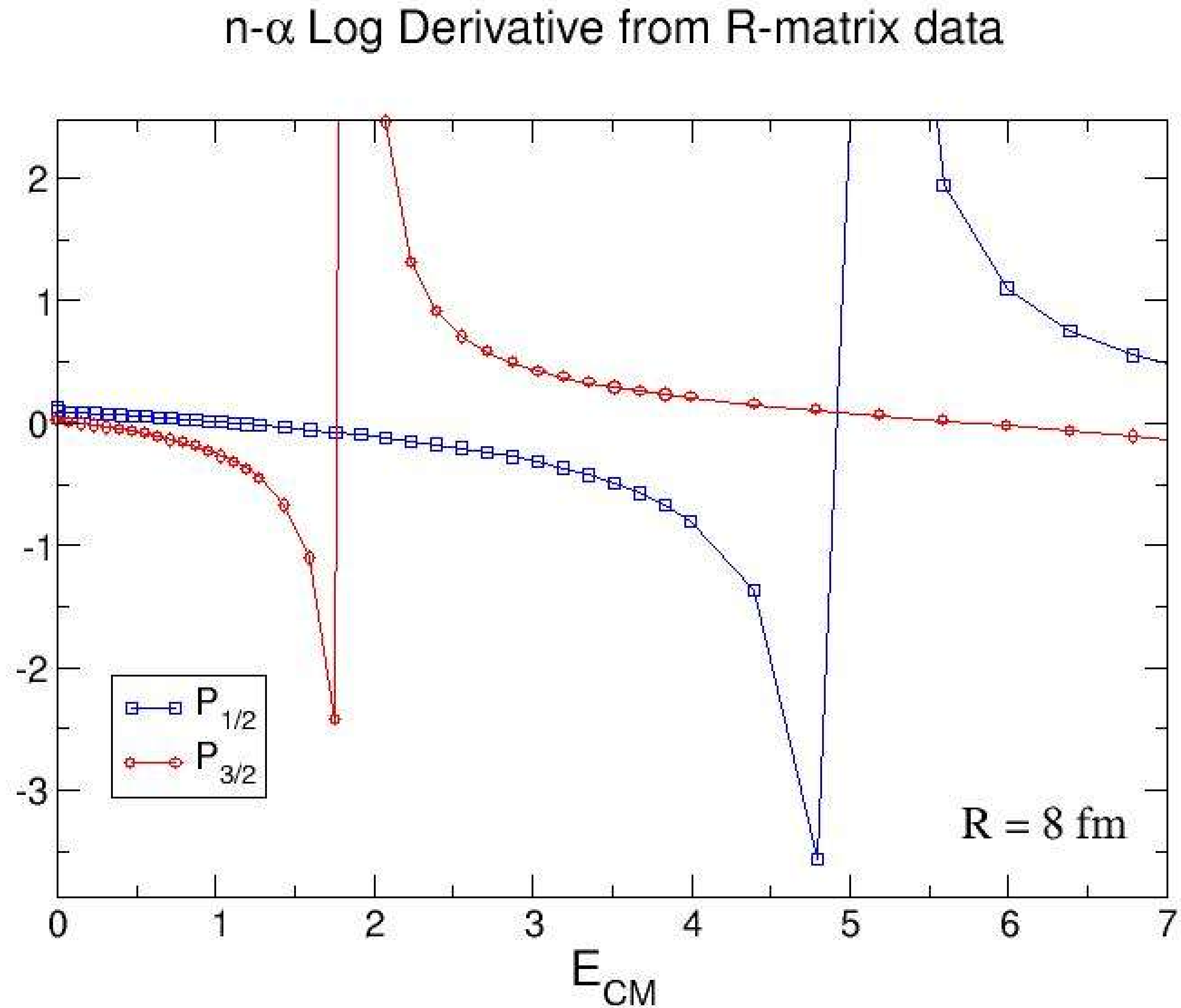


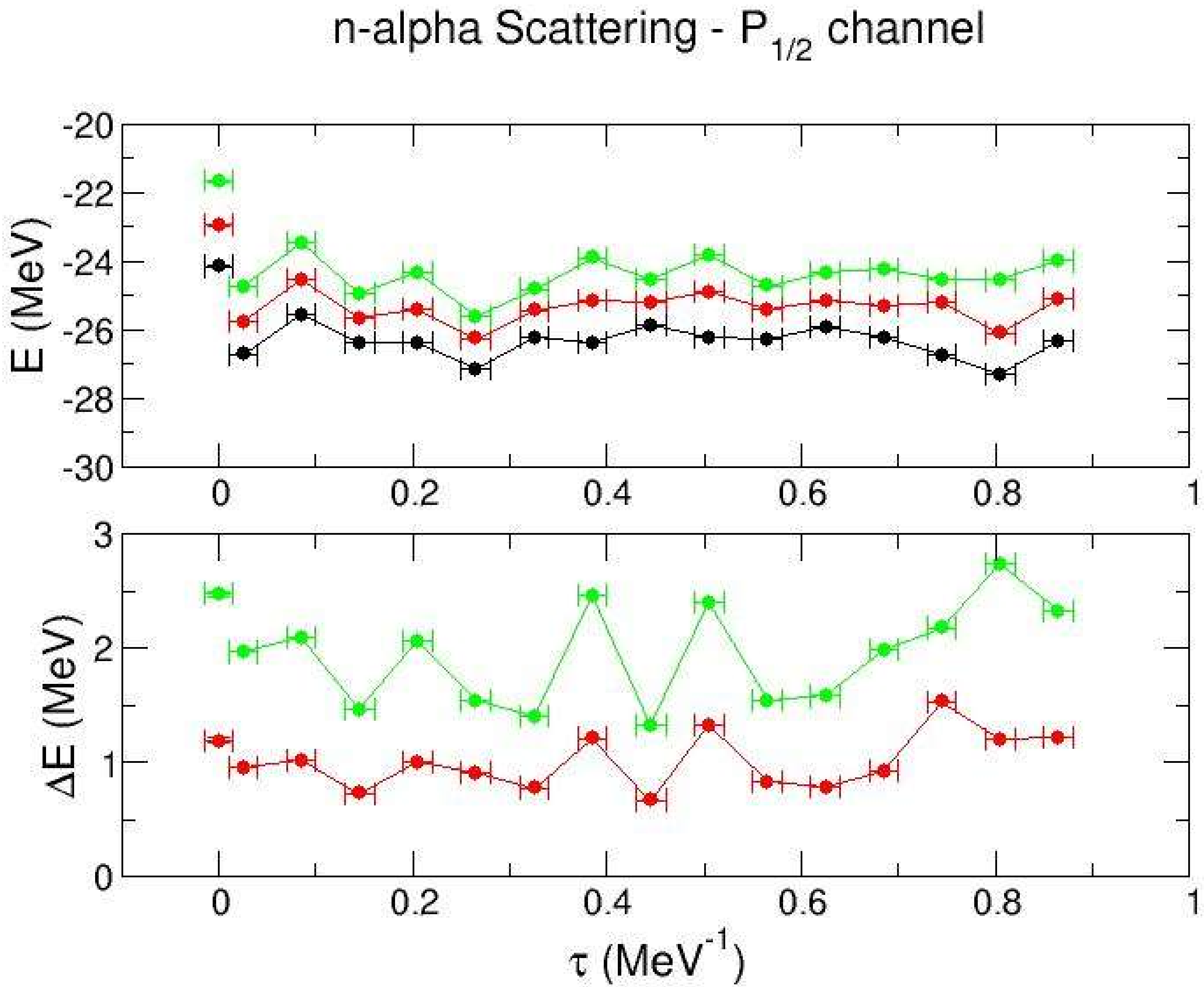
A great deal of additional data in low-energy scattering:

Example: n-alpha scattering



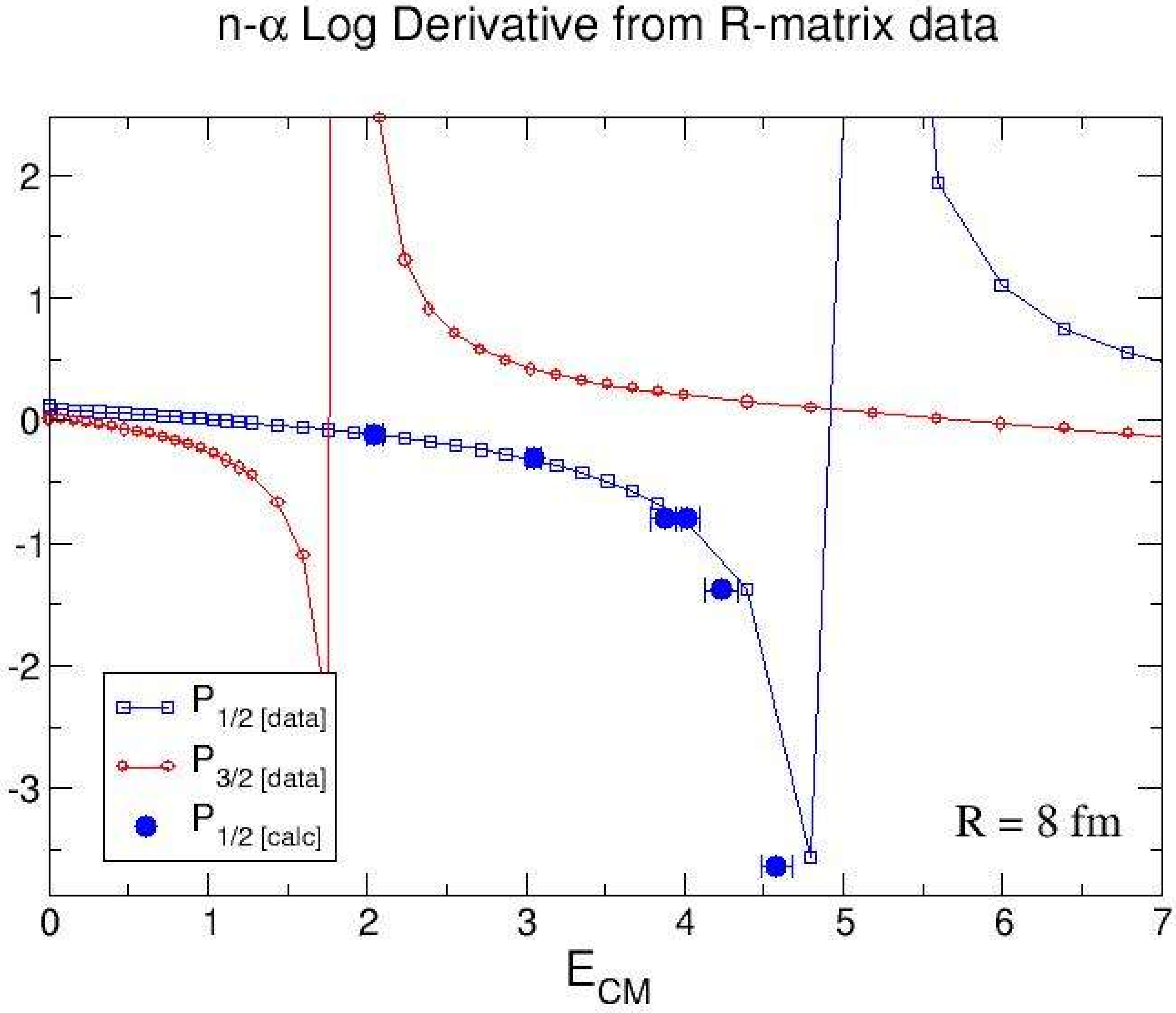
Same information can be represented as E vs. log derivative


n-α Log Derivative from R-matrix data
2
1
0
-1
-2
-3
0
1
2
3
4
5
6
7
E_{CM}
$P_{1/2}$
$P_{3/2}$
R = 8 fm



Strong Correlations – Energy Differences Preliminary

1/2(-) p-wave results --- AV18 + UIX



3/2(-) results will be worse

PRELIMINARY

Conclusions:

Nuclear spectra provide a valuable,
if limited, set of constraints on
nuclear interactions.

Additional Information can be provided by
- neutron-rich systems
- nuclear/neutron matter (potentially)
- scattering