Multineutron systems ?

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I.P.H.C. Strasbourg, october 9, 2012

Collaboration with R. Lazauskas

INTRODUCTION

Several theoretical studies indicate that there is no reasonable chance for ^{3}n and ^{4}n to exist[1]

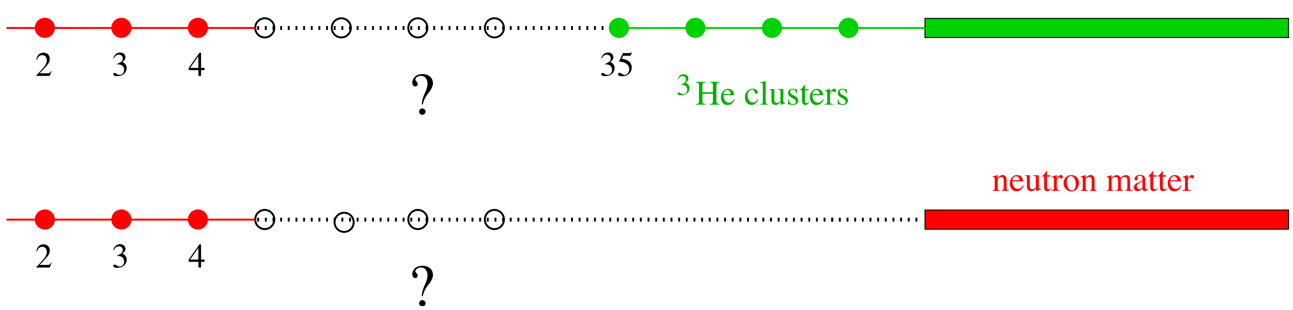
GANIL result[2] has not been confirmed

another experiment scanning the ^{4}n continuum[3] did not provide any clear signal yet

It is enlightenning to make a parallel with a similar – better known – fermion system and ask

Since "there are" small ^{3}He droplets[4] (N=35?)

should we expect n droplets ?



If YES where ?

If NOT why ?

(1) ^{2}n is still on debate !

(2) M. Marques et al

(3) D. Baumel et al d(^{8}He,^{6}Li)4n

(4) R. Guardiola, J. Navarro, Phys. Rev. Lett. 84 (2001) 1144

INTRODUCTION (II)

Answering this question requires a rigorous *"ab initio"* solution of the N-body problem

$$(E - H_0)\Psi = V\Psi \qquad V = \sum_{ij} V_{ij} + \sum_{ijk} V_{ijk} + \ldots$$

- Presumably for N>>1
- When bound state appears - if at all ! - it will be loosely bound
- The 3-n forces are out of control, although smaller than in normal nuclei

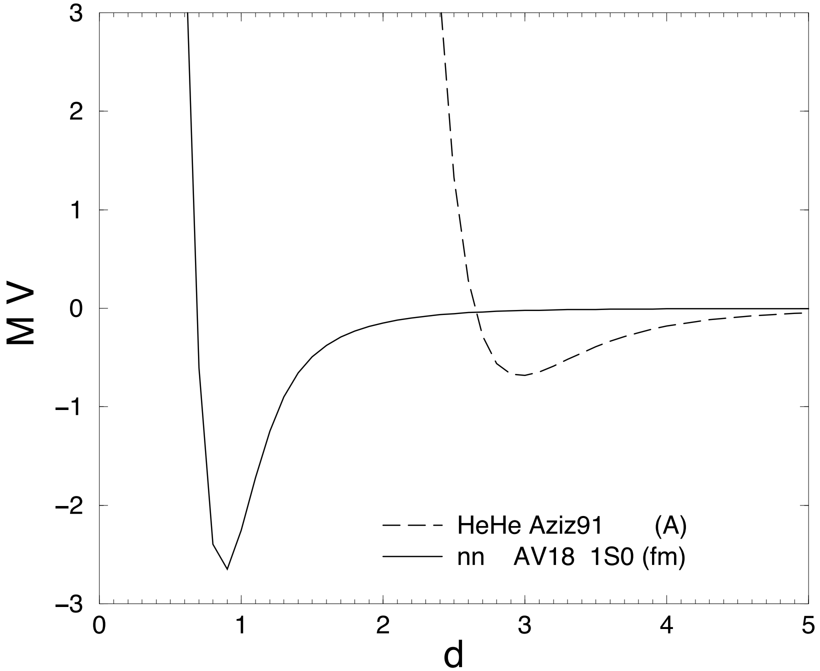
It is certainly too ambitious !

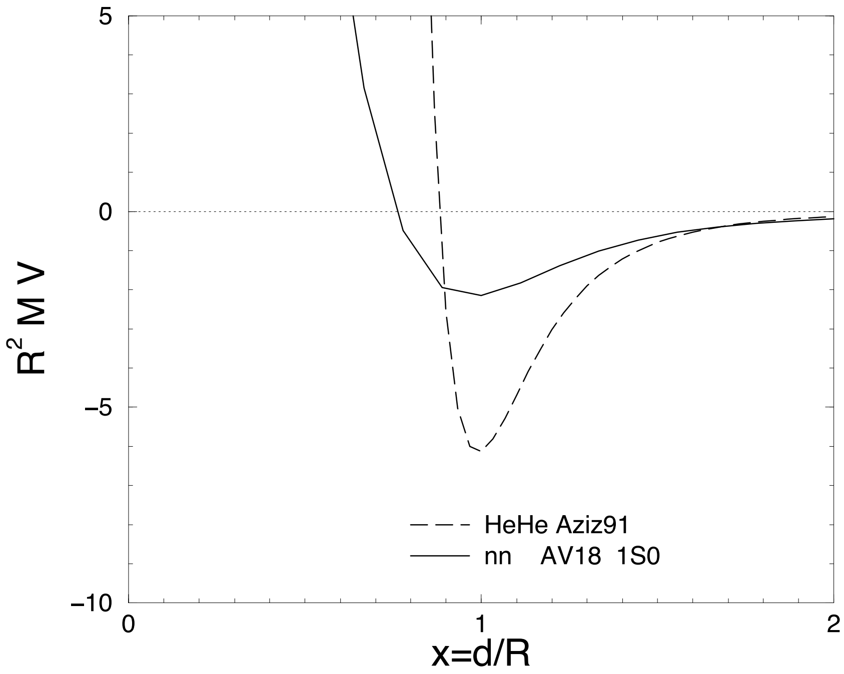
But one can guess the tendency …. If one proceeds step by step

Two-neutrons

We have considered 3 different Vnn : Argonne V18, Nijmegen Reid 93, CD-MT13 (!) and the ^3He-^3He from Aziz (1991)

I. They look very similar





Two-neutrons

II. Low energy parameters

	n-n (fm)				He-He ($\AA$)	
	V18	Reid	CD-MT13	Exp[5]	Aziz 91	Exp
a	-18.49	-17.54	-18.59	-18.59 ± 0.4	-7.24	?
r_0	1.04	2.85	2.94	2.75 ± 0.1	13.5	?

III. None of them supports a dimer (since a<0) but atomic ^{3}He seems less favorable !

IV. Forcing to bound: enhancement factor $V^{(\eta)}(r) = \eta V_{nn}(r)$

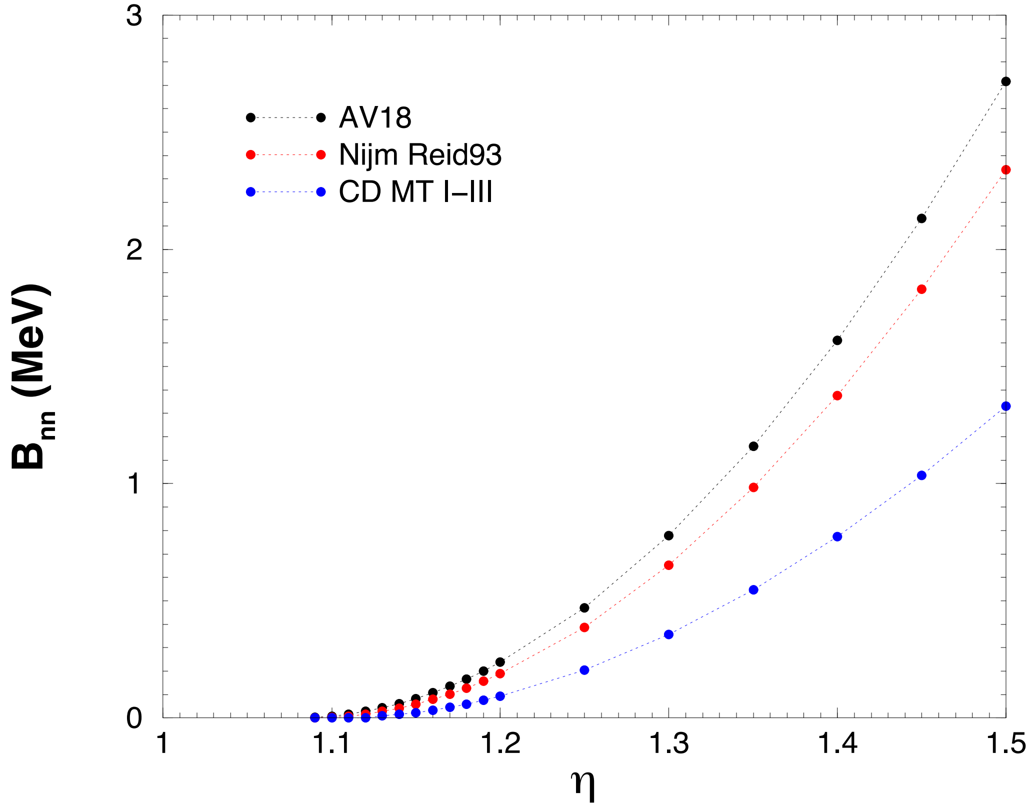
Critical η values, binding a dimer with B=0

CD MT13	1.1011	$\hbar^2/m$
Nijm II	1.0876	41.4425
Reid 93	1.0872	”
AV18	1.0799	”
Aziz	1.2989	16.08

Here again, ^{3}He is less promising than n to form bound states

III. Different B(η) behaviour between realistic and MT13 potentials

MT13 gives less binding (a “première” !)



V_{nn} has never been "measured": it is extracted from pp + charge symetry or from A=3 (nd,nt,…)

Even the sign of the scattering length and consequently a bound dineutron is questioned

A recent paper (*) find its existence compatible with almost all nd data (if B<0.1 MeV).

Modifying few % V_{nn} has no dramatic consequences in spectroscopy: can be absorbed by V_{3N}

H. Witala, W. Gloeckle, Phys.Rev. C85 (2012) 064003

« A comparison to the available data for neutron-deuteron total cross sections and elastic scattering angular distributions cannot decisively exclude a possibility that the two neutrons can form $1S_0$ bound state. »

Beyond two-neutrons …

Despite de absence of dimers, “bosonic” n-trimers and n-tetramers do exists !

By solving Faddeev-Yakubowski equations we(*) found:

$$B_{n_3} \approx 1MeV \qquad B_{n_4} \approx 10MeV$$

These are the simplest “Borromean systems”

But they does not exist in case of ^{3}He !!

They disappear when impose an antisymmetric solution (Pauli principle)

… but could appear – as in ^{3}He – when adding more particles

The existence of small fermion clusters is thus a compromise between the attractive pairwise interactions and the (“repulsive”) Pauli principle

How to study something that does no exist ?

There are several ways…

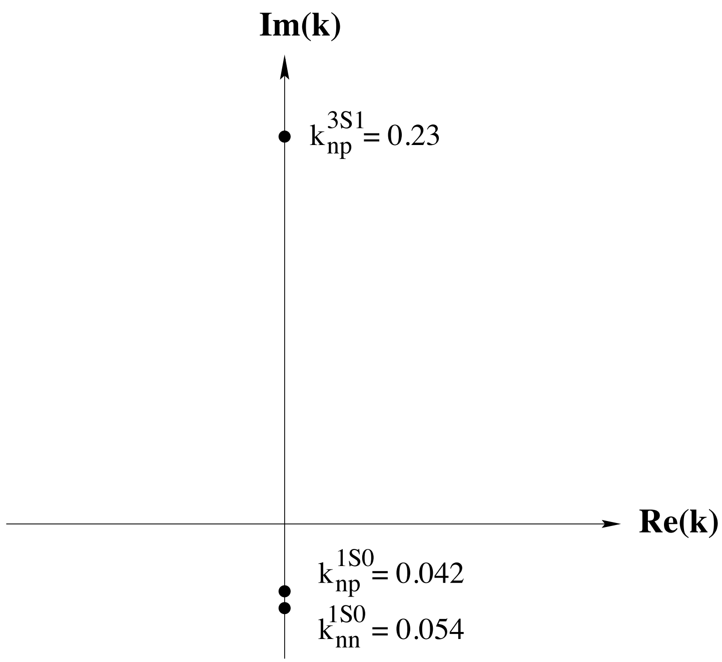
(*) R. Lazauskas, JC, Phys Rev. C

I. In Quantum Mechanics things always "exists"

… even if they do not belong to the physical world

They live in "another universe" (Second Riemann sheet): they can be found an studied

For instance the nn system "exists" as a pole of the NN scattering amplitude $f_{nn}(k)$ or $f_{nn}(E)$



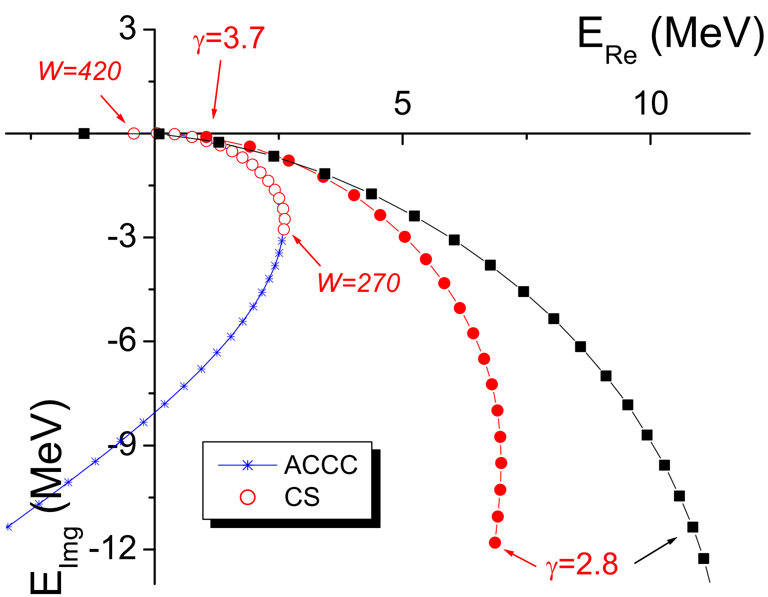
This is not a very easy task, specially for A>2 but we have done it for 3n and 4n

3n and 4n resonances

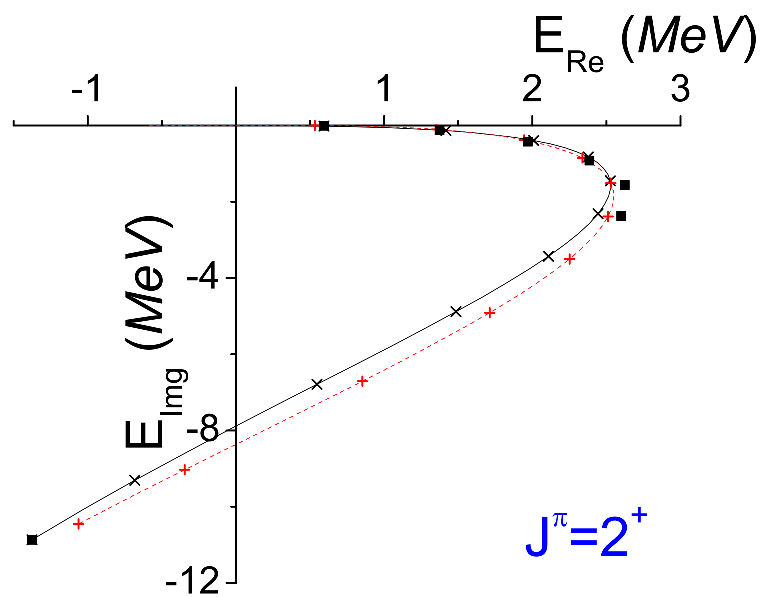
Maybe n_3 and n_4 are not bound …. but where are they ?

We computed 3 and 4-n resonances solving full FY in the complex plane

Phys. Rev. C71 (2005) 044004; nucl-th/0502037



Phys. Rev. C 72 (2005) 034003; nucl-th/0507022



We proved in this way that 3- and 4-n are not bound … because they are elsewhere !

This was a real « tour de force » difficult to extend beyond A=4

Other - more accessible - approaches consists in binding the system by « brut force »

II. Introducing the "enhancement" factor

If done at the two-body level it has the drawback of binding ^{2}n and open decay chanel $^{3}n \rightarrow n+^{2}n$

IV. Enhance only nn P-waves

Thus keeping ^{2}n unbound…but binding a P-wave states before ^{3}n

III. Introducing three-neutron forces (TnI)

Safer and numerically not very expensive if one takes hyper-radial dependence $V(\rho)$

VI. Confining the system in an OH trap

and look for the increasing of the n's binding energy as a funcion of N

One can also imagine more refined things like

V. Studying dimer-dimer scattering

To see whether or not they like to be together

We have explored all of them in the A=3,4 cases

None of them is fully satisfactory but they all can provide very useful indications

SOME RESULTS

VI. Confining the system in an OH trap

OH is the only external field in which "internal" and "center of mass" energies can be properly separated.

$$\frac{1}{2}m\omega^2 \sum_{i=1}^{N} r_i^2 = \frac{1}{2}\, m \, \left(\frac{\omega}{\sqrt{N}}\right)^2 \, \sum_{i<j}(\vec{r}_i - \vec{r}_j)^2 + \frac{1}{2}\, mN\, \omega^2\, R^2 \qquad (1)$$

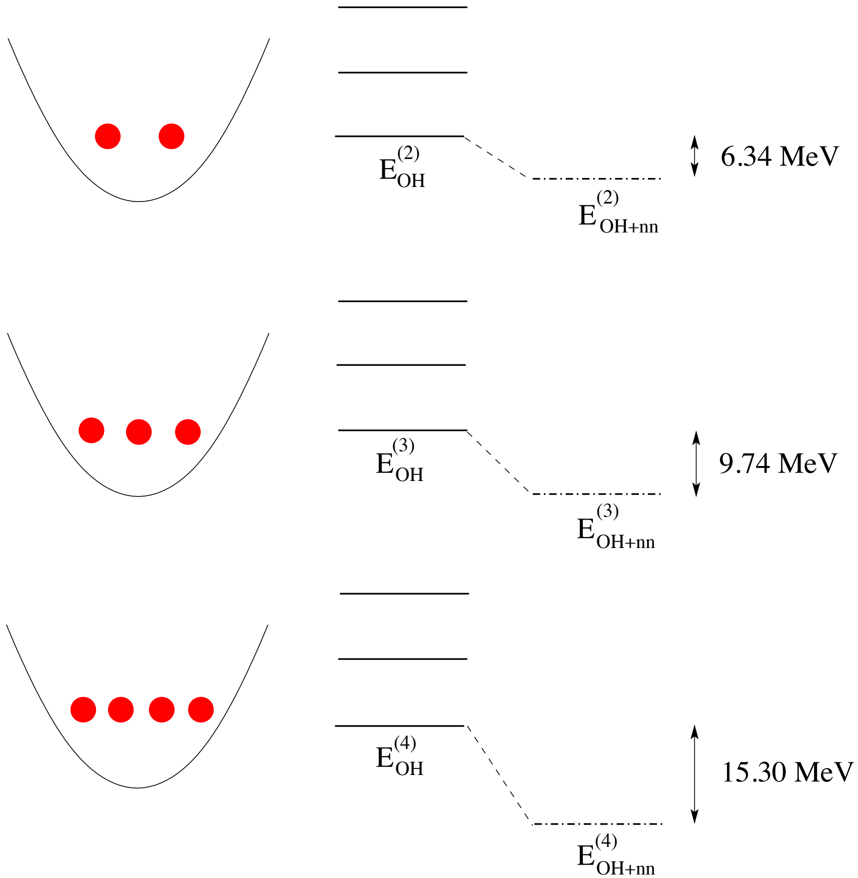
- In absence of n-n interaction the internal energies are simply

  $$\left(N_1 + \frac{3}{2}\right)\hbar\omega + \left(N_1 + \frac{3}{2}\right)\hbar\omega + \ldots + \left(N_N + \frac{3}{2}\right)\hbar\omega - \left(N_R + \frac{3}{2}\right)\hbar\omega$$

  but can be obtained as well by solving the "internal" problem, i.e. pairwise OH with frequency $\left(\frac{\omega}{\sqrt{N}}\right)$

- By switching on V_{nn} we solve the internal problem with

  $$V_{ij} = \frac{1}{2}\, m \, \left(\frac{\omega}{\sqrt{N}}\right)^2 \, r_{ij}^2 + V_{nn}(r_{ij})$$

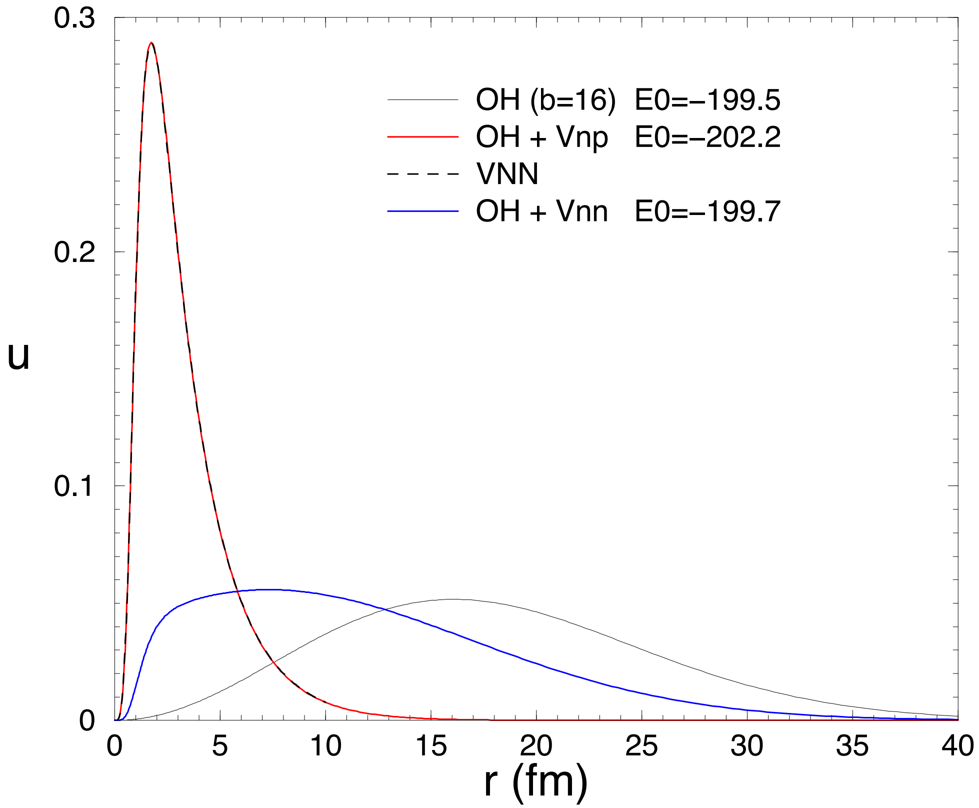


Clear indication that n's like to be together,
… once recovered form the N=3 "crisis"
B/N(N=4) > B/N(N=2) ... > B/N(N=2) pairing !
$B_4 > 2B_2$

N		E_0	B	$\frac{B}{N}$	$\frac{B}{E_0}$	E_0	B	$\frac{B}{N}$	$\frac{B}{E_0}$	E_i	B	$\frac{B}{N}$	$\frac{B}{E_0}$
		$b = 2$				$b = 3$				$b = 4$			
2	0^+	15.55	6.34	3.17	0.41	6.91	3.13	1.56	0.45	3.89	1.81	0.93	0.47
3	$\frac{3}{2}^-$	41.47	9.74	3.25	0.23	18.43	4.41	1.47	0.24	10.36	2.55	0.85	0.25
4	0^+	67.39	15.30	3.58	0.23	29.95	7.40	1.69	0.25	16.82	4.31	1.08	0.26

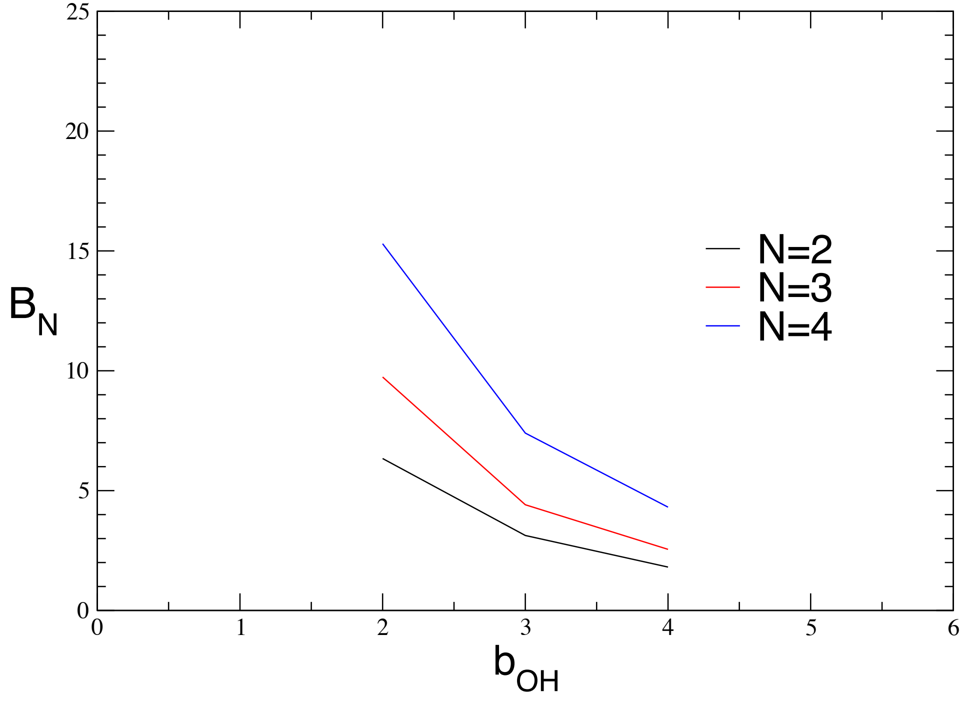
That's very nice, but how to decide when n's are bound by the V_{nn} and not by V_{OH} ?

One way is to look at the wave function (density)



If n's are bound by themselves their wf has $r \ll b_{OH}$ ($\omega^{-1/2}$)

Another one is the B(b)



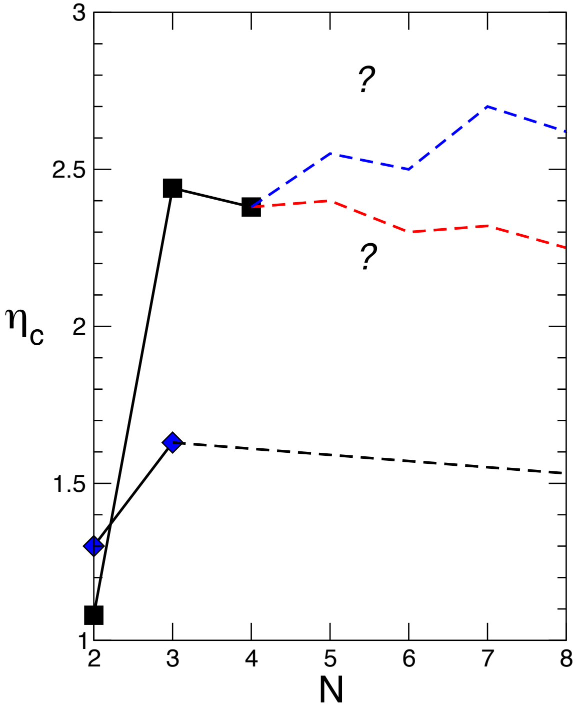
If n's are bound by themselves should be independent b_{OH} ($\omega^{-1/2}$)

II. Enhancement factor

Makes a big jump when moving from N=2 to N=3

Specially for ^{3}He that becomes favoured (due to P-waves !!!)

For N=4 both start decreasing



The only question is to know, whether or not $\eta_c(N) \rightarrow 1$ at large N

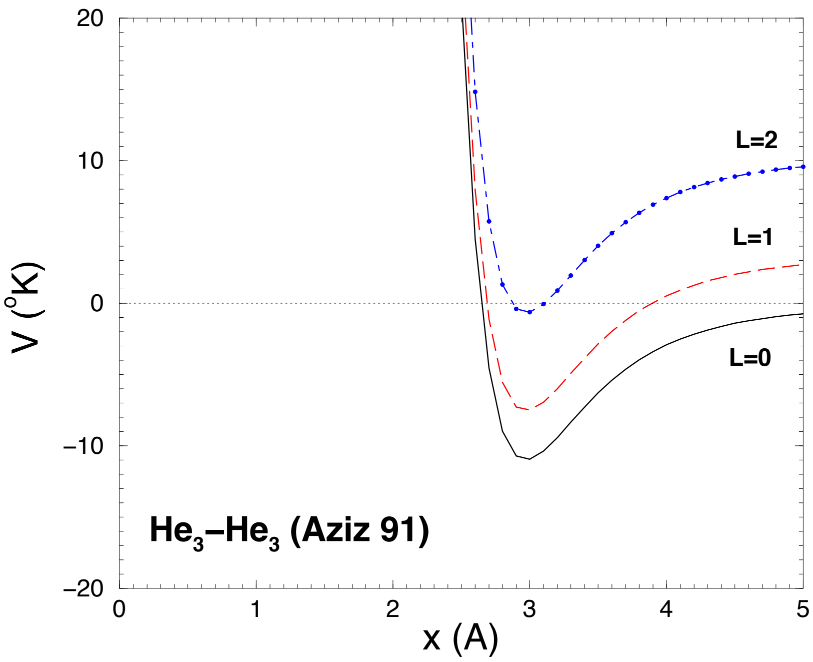
NCSM should be able to treat N=6,8,10, … using V_{nn} or W(ρ)

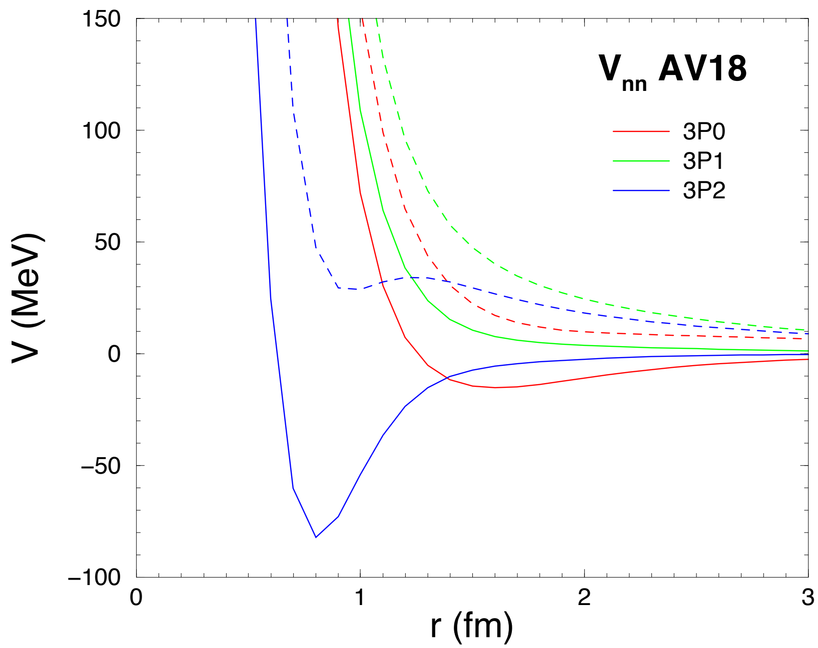
It may be enough to guess the result

The attractive pocket in ^{3}He-^{3}He potential is much more periferal

The centrifugal term is smaller and P-wave effective potentials remain attractive

They represent a 40% of the binding energy in He's but only 3% in n's N=4 (in OH)

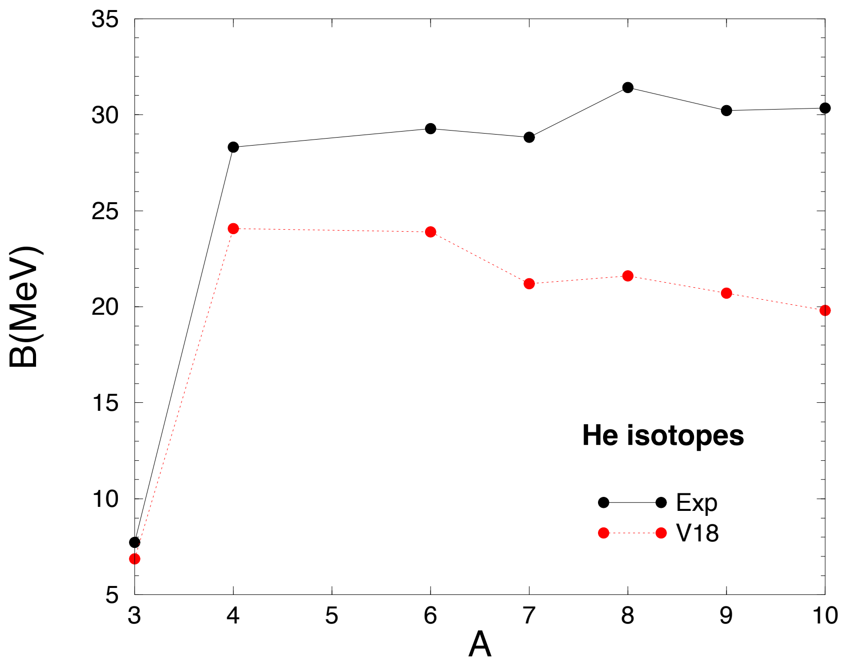




Conclusion (I)

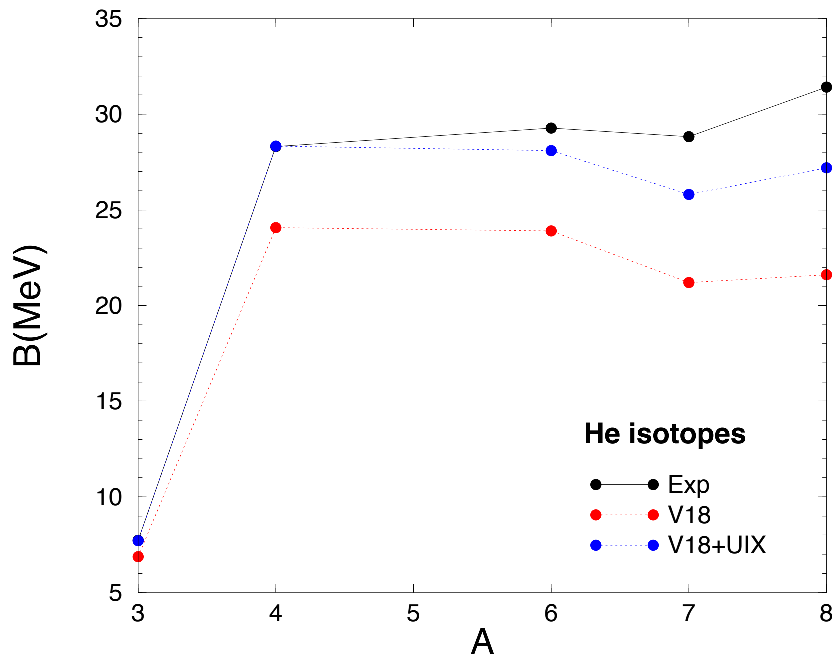
If the existence of bound 3n and 4 is excluded, the possibility larger bound neutron systems remains an open problem

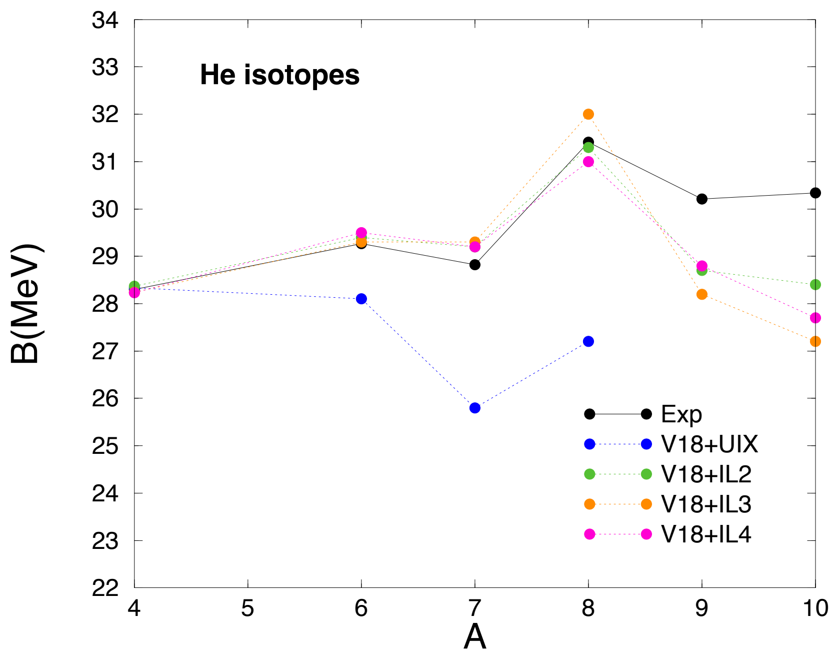
The most serious objection against larger clusters comes from the unbound n-matter
However N+NNN models suffers from a lack of predictivity in n-rich nuclei
For instance in He isotopes



Conclusion (II)

Traditional 3N forces suffer from “Sisyphe” effect…





What is the reliability in the limit $N \rightarrow \infty$?
Better to approach the problem “from below” !

Here EFT can be of great help (if parameters can be fixed !)

Conclusion (II)

I could have some interest to study **η_c(N)** dependence beyond A=4
NCSM seems the more apropiate technique

The study must be done in parallel with He, for which we know the answer

André, Etienne, Alfredo
thanks for all your numerous works, and for this kind invitation to come here

Still an effort ???