DSAM Measurement in ^{24}Ne – Ab-Initio test

E. Clément and anybody interested

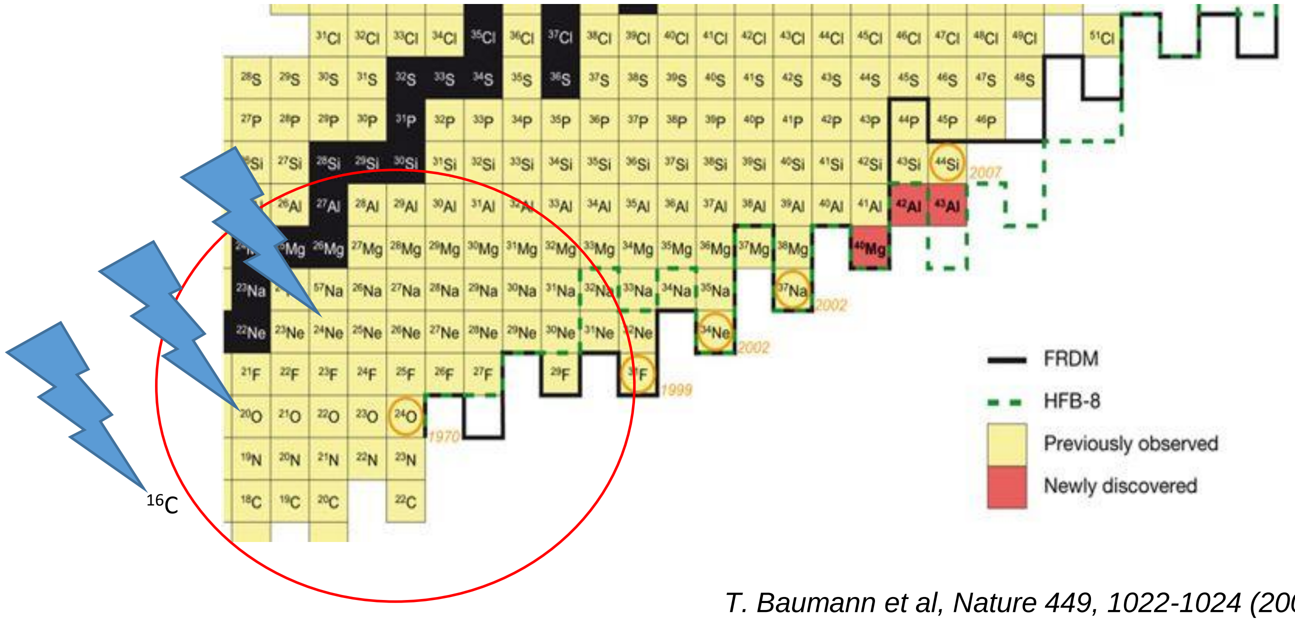
Motivations

- The limit of bound nuclei (drip-line) is a fundamental ingredient of our understanding of the nuclear interaction

- For neutron-rich nuclei, the neutron drip line evolves regularly from light to medium-mass nuclei except for a striking anomaly in the oxygen isotopes

- ^{24}O is the last bound isotopes

- This anomaly is not reproduced in shell model calculations derived from microscopic two-nucleon forces

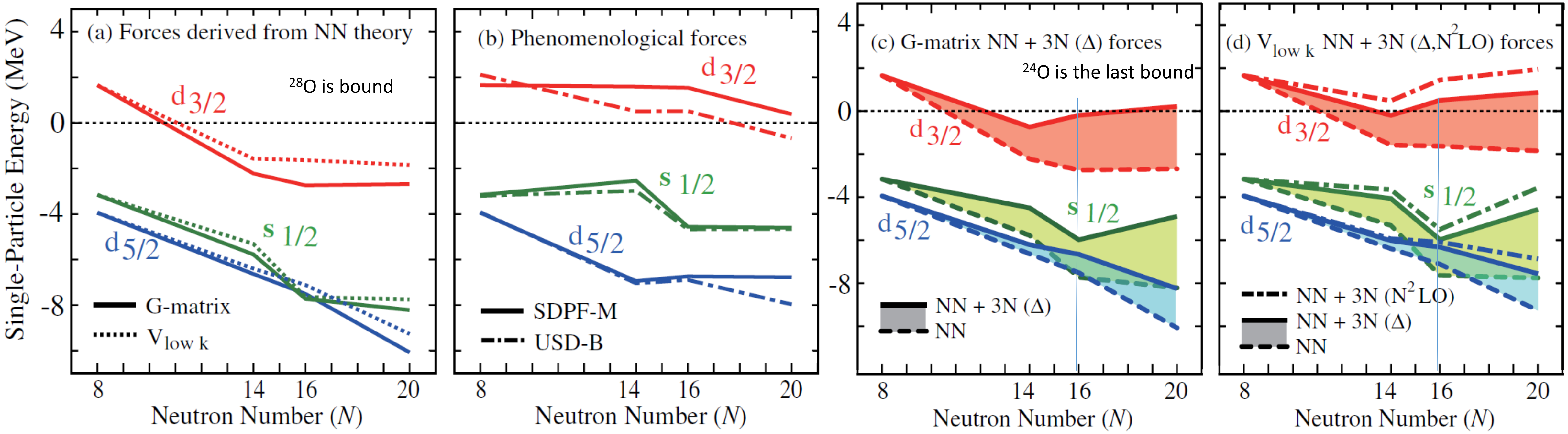


T. Baumann et al, Nature 449, 1022-1024 (2007)

A. Ozawa et al., Phys. Rev. Lett. 84, 5493 (2000)
C.R. Hoffman et al., Phys. Rev. Lett. 100, 152502 (2008)
R. Kanungo et al., Phys. Rev. Lett. 102, 152501 (2009)
R.V. F. Janssens, Nature (London) 459, 1069 (2009)

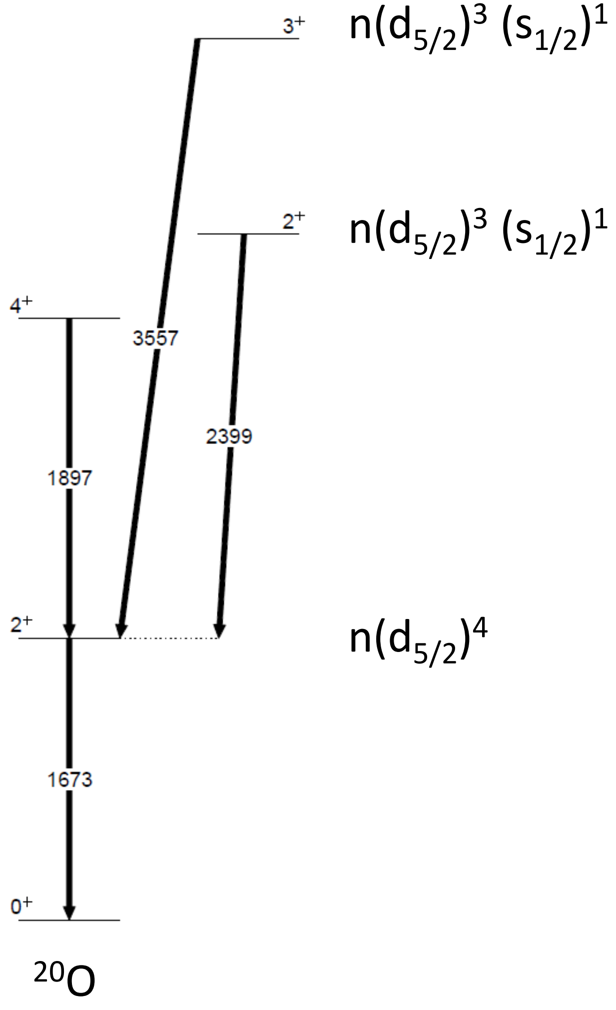
Motivations

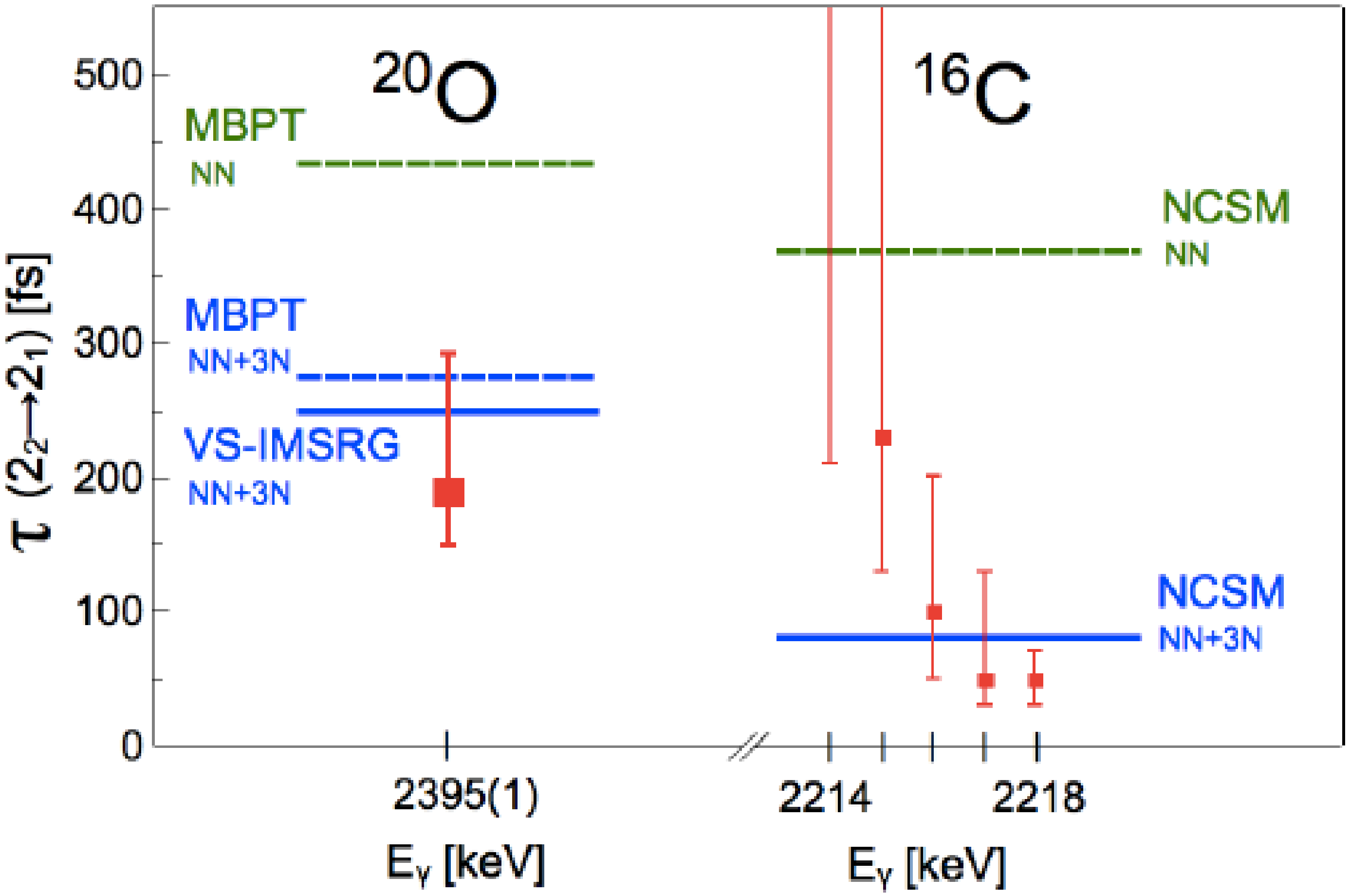
- A microscopic explanation of the oxygen anomaly is based on the introduction of a three-nucleon force contribution
- The 3-body interaction leads to repulsive contributions to the interactions with the neutrons number changing the location of the neutron drip line from ^{28}O to the experimentally observed ^{24}O ($s_{1/2}$ filled)
- Can we constrain the relative position of the s1/2 and d3/2 in neutron rich oxygen and hence probe the 3-body interaction contribution ?



T. Otsuka et al, PRL 104, 012501 (2010)

First measurement of the 2^+_2 state lifetime in ^{20}O

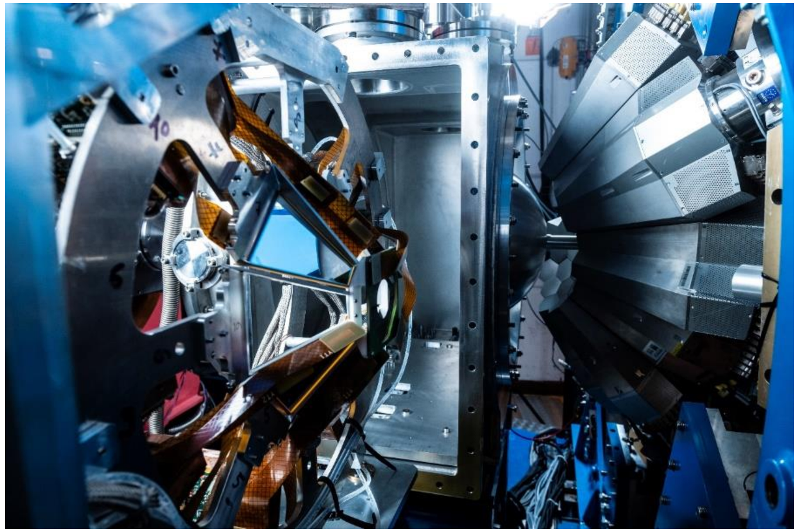




Pioneer work at AGATA-VAMOS-PARIS :
M. Ciemala et al , (PRC. C101, 021303(R) (2020))

E775s: Testing 3-body interactions from controlled lifetime measurement using a RIB beam

I. Zanon, E. Clément, A. Goasduff, et al Physical Review Letters, 2023, 131 (26), pp.262501

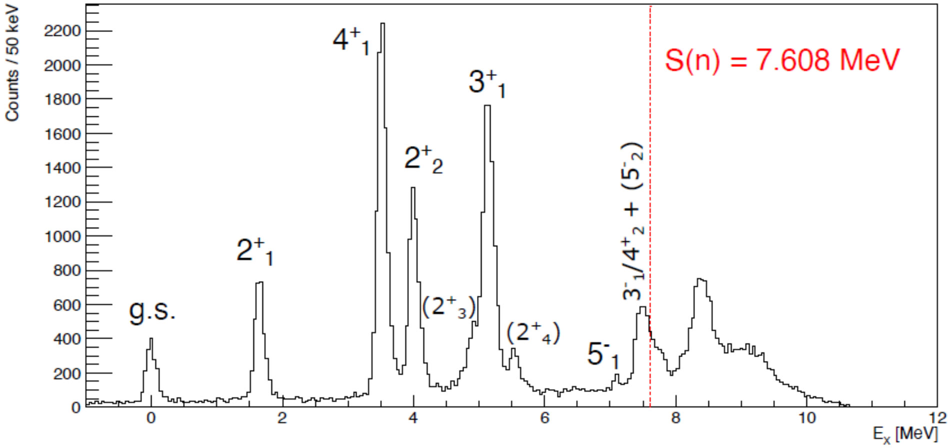


Probing the *ab-initio* 3-body interactions in neutron rich matter is a major challenge of the nuclear structure researches

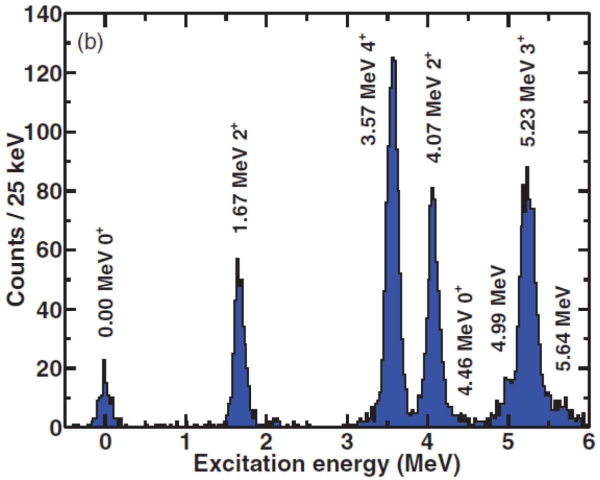
In the present experiment, the 2^+_2 and 3^+_1 state lifetime of ^{20}O are very sensitive the recently developed *ab-initio* 3-body interactions available on the market.

Method : **Controlled lifetime** measurement in the femto-sec. scale (DSAM method) using the direct reaction $^{19}O(d,p)^{20}O$ from a post-accelerated ^{19}O beam from the SPIRAL1 facility. (5 .10^5pps @ 8 MeV/A). **Unique at GANIL.**

Result : The entry point is well constrained by the measured excitation energy of ^{20}O using the sensitivity of the MUGAST array
The sensitivity of AGATA allows to measured the slowing down process to extract the nuclear lifetime of the 2^+_2 state at 2.4 MeV using a RIB



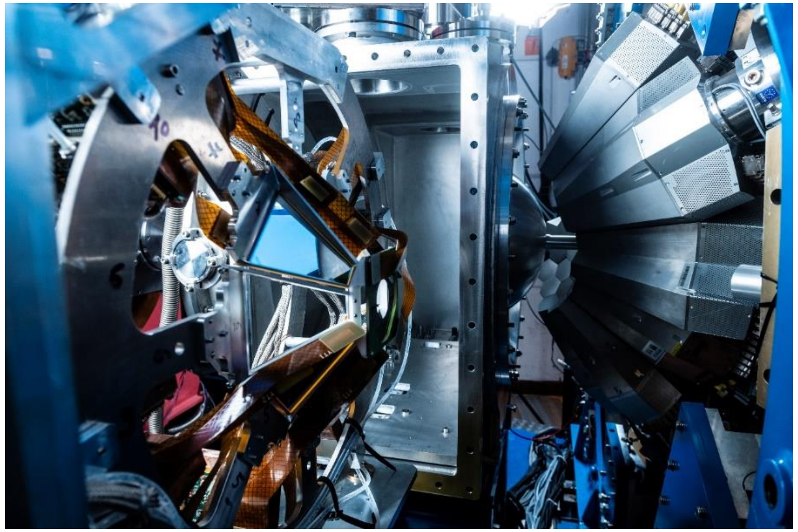
MUGAST



HELIOS

I. Zanon (PhD INFN/LNL defended)

E775s: Testing 3-body interactions from controlled lifetime measurement using a RIB beam



Motivation : A microscopic explanation of the oxygen drip-line anomaly is based on the introduction of a three-nucleon force contribution in the nuclear interaction.

Probing the *ab-initio* 3-body interactions in neutron rich matter is a major challenge of the nuclear structure researches

In the present experiment, the 2^+_2 and 3^+_1state lifetime of ^{20}O are very sensitive the recently developed *ab-initio* 3-body interactions available on the market.

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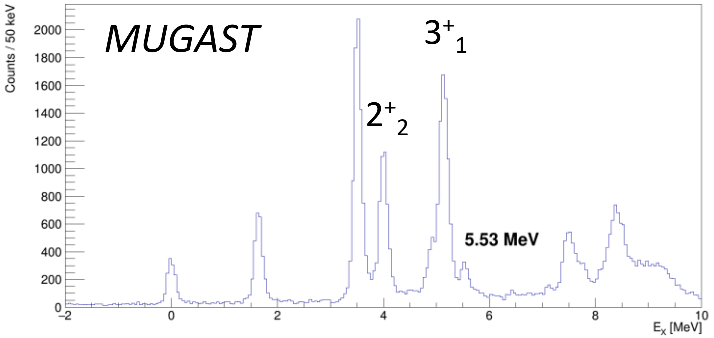
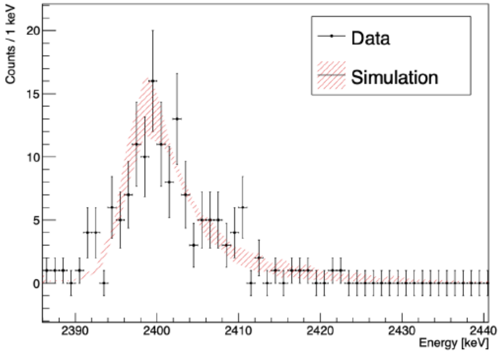
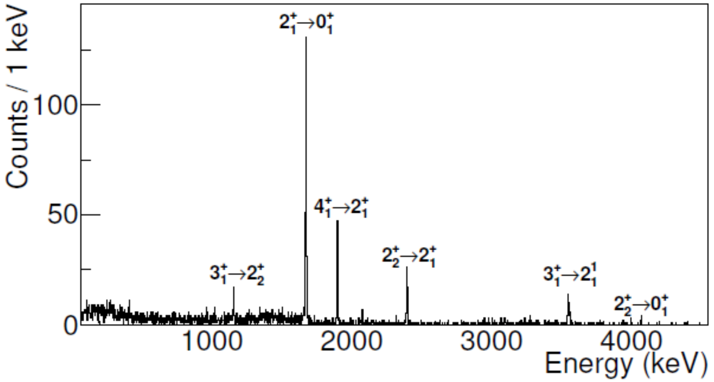


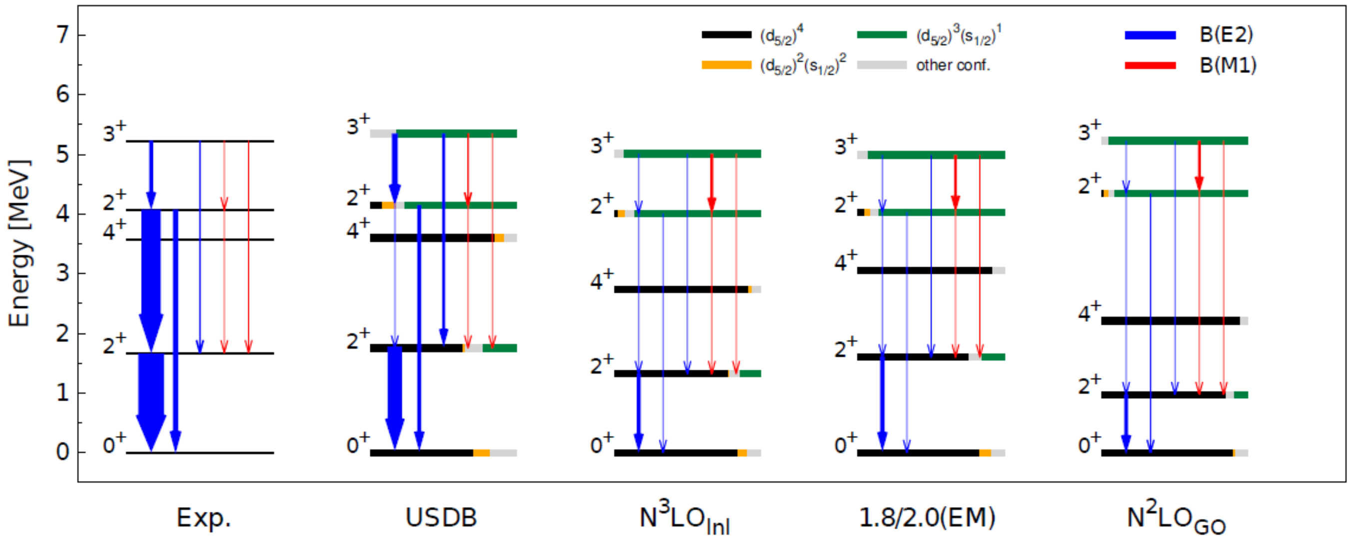
Result : The entry point is well constrained by the measured excitation energy of ^{20}O using the sensitivity of the MUGAST array
The sensitivity of AGATA allows to measured the slowing down process to extract the nuclear lifetime of the 2^+_2 state at 2.4 MeV
Confirm the short value only compatible with a 3-body contribution as in *M. Ciemala et al , (PRC. C101, 021303(R) (2020))*
The question is now the accuracy of the *ab-initio* calculations





I. Zanon, E. Clément, A. Goasduff, et al Physical Review Letters, 2023, 131 (26), pp.262501

E775s: Testing 3-body interactions from controlled lifetime measurement using a RIB beam



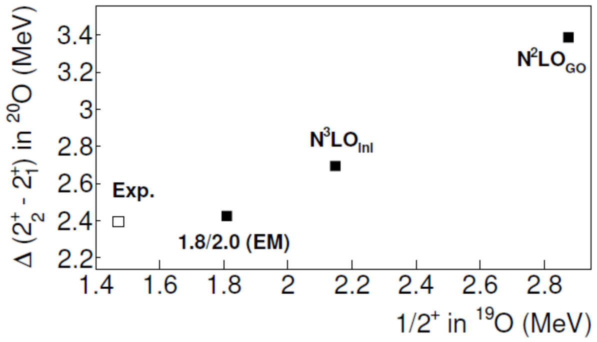


FIG. 6. Correlation between the excitation energy of the $1/2^+$ state in ^{19}O and the difference between the 2^+_1 and 2^+_2 states in ^{20}O for the three different Hamiltonian's and the experimental data.

	Exp.	USDB	N^3LO_{lnl}	1.8/2.0(EM)	N^2LO_{GO}
$B(E2;2^+_1\to0^+_1)$	5.9(2)	3.25	0.79	0.89	0.80
$B(E2;2^+_2\to0^+_1)$	1.3(2)	0.77	0.21	0.20	0.26
$B(E2;2^+_2\to2^+_1)$	4(2)	0.0005	0.089	0.070	0.18
$B(M1;2^+_2\to2^+_1)$	0.05(2)	0.019	0.014	0.017	0.012
$B(E2;3^+_1\to2^+_1)$	0.32(7)	0.57	0.16	0.17	0.17
$B(M1;3^+_1\to2^+_1)$	0.016(4)	0.029	0.023	0.028	0.0089
$B(E2;3^+_1\to2^+_2)$	0.7(2)	1.24	0.14	0.15	0.11
$B(M1;3^+_1\to2^+_2)$	0.19(4)	0.32	0.53	0.55	0.56
Binding energy	-23.74 [64]	-23.63	-19.67	-20.51	-22.71

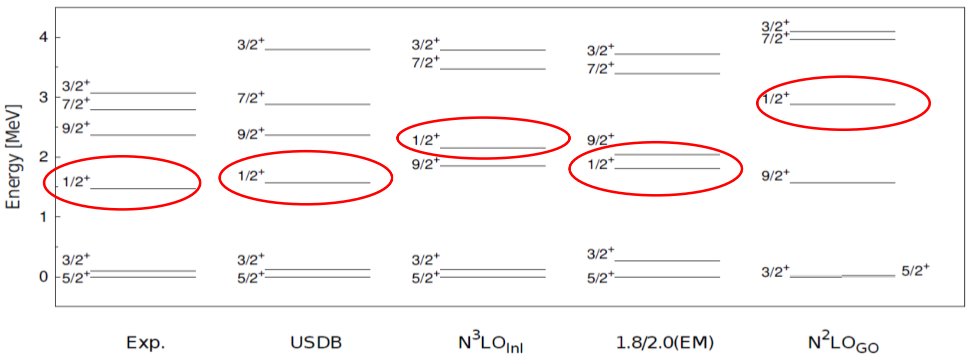
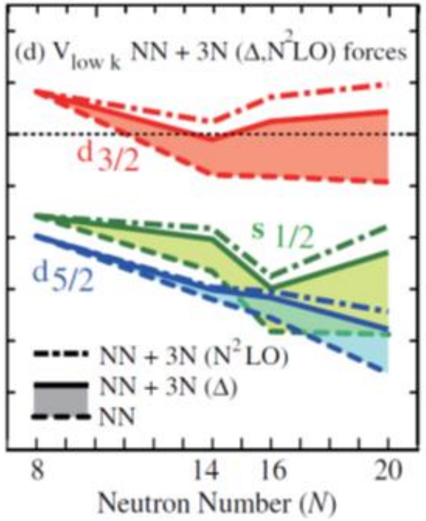


FIG. 7. Experimental ^{19}O excited states compared to theoretical USDB shell-model calculations and VS-IMSRG results obtained with three different Hamiltonians.

I. Zanon, E. Clément, A. Goasduff, et al Physical Review Letters, 2023, 131 (26), pp.262501



GANIL

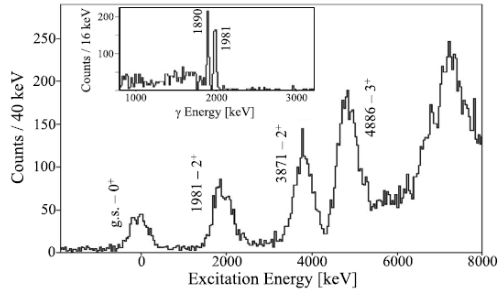
(d,p)

^{23}Ne ^{24}Ne

Δ = 100 keV

{2^+_2 (3867 keV), (3^+_1) } :

{0^+_1, 2^+_1, 4^+_1} : [π (d5/2)^2 ν$(d_{5/2})^6$ $(s_{1/2})^{x\,?}$]



G. Lotay, J. Henderson, W.N. Catford et al. Physics Letters B 833 (2022) 137361

Solid p p-shell core
G. Mairle and G. J. Wagner,
Nucl. Phys. A253, 253(1975).

(d,p)

^{19}O ^{20}O

{2^+_2, 3^+_1} : [ν$(d_{5/2})^3$ $(s_{1/2})^1$]

{0^+_1, 2^+_1, 4^+_1} : [ν$(d_{5/2})^4$]

M. Ciemala et al , (PRC. C101, 021303(R) (2020))

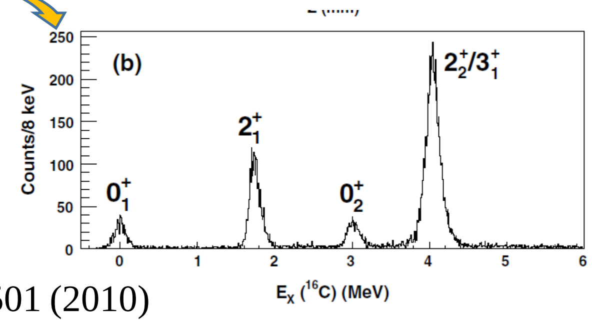
(d,p)

^{15}C ^{16}C

Δ = 100 keV

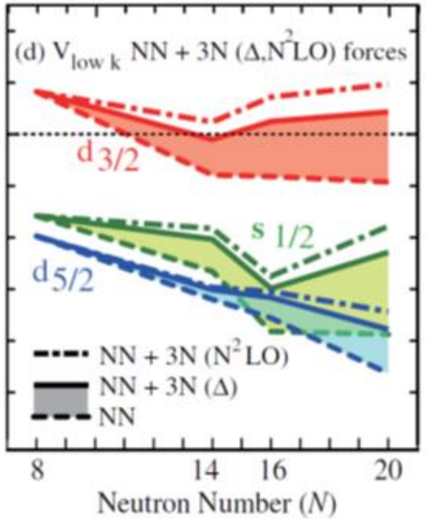
{2^+_2, 3^+_1} : [not clear in HELIOS data but all strongly mixed]

{0^+_1, 2^+_1} : [ν$(d_{5/2})^2$ ⊛ ν$(s_{1/2})^2$ ⊛ ν$(d_{5/2})^1$ $(s_{1/2})^1$] (mixed)



A. H. Wuosmaa PRL 105, 132501 (2010)

GANIL



(d,p)

^{23}Ne ^{24}Ne

$\{0^+_1, 2^+_1$

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$T_{1/2}$ for the 2^+_2 < 120 fs

Solid p p-shell core

G. Mairle and G. J. Wagner, Nucl. Phys. A253, 253(1975).

(d,p)

^{19}O ^{20}O

$\{2^+_2$

$\{0^+_1, 2^+_1, 4^+_1\}$

New results from AGATA GANIL

M. Ciemala et al , (PRC. C101, 021303(R) (2020))

(d,p)

^{15}C ^{16}C

$\{2^+_2, 3^+_1$

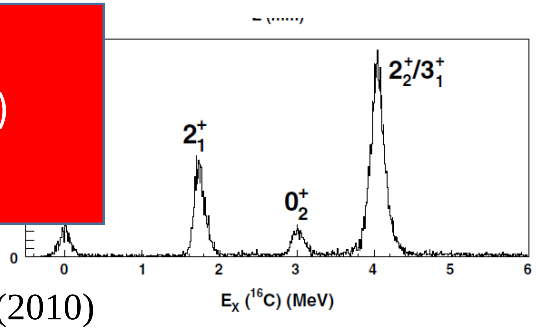
$\{0^+_1, 2^+_1\} : [\nu(d_{5/2}$

2^+_2 and 3^+_1 SF not clear

τ of the 2^+_1 still controvertial (from 18(4) to 77(33) ps)

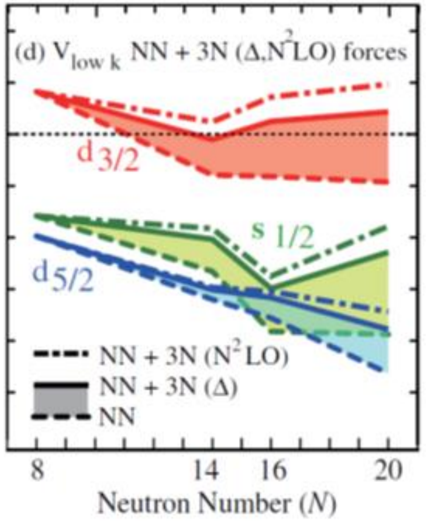
τ of the 2^+_2 still not yet accurate

Δ = 100 keV



A. H. Wuosmaa PRL 105, 132501 (2010)

Next measurements



Solid p p-shell core
G. Mairle and G. J. Wagner,
Nucl. Phys. A253, 253(1975).

(d,p)

^{23}Ne → ^{24}Ne

{0$^+_1$, 2$^+_1$ ...

SPIRAL1 ^{23}Ne(d,p)^{24}Ne
DSAM on the 2$^+_2$

(d,p)

^{19}O → ^{20}O

{2$^+_2$, 3$^+_1$} : [ν(d$_{5/2}$)^3 (s$_{1/2}$)^1]

{0$^+_1$, 2$^+_1$, 4$^+_1$} : [ν(d$_{5/2}$)^4]

M. Ciemala et al , (PRC. C101, 021303(R) (2020)) ★

(d,p)

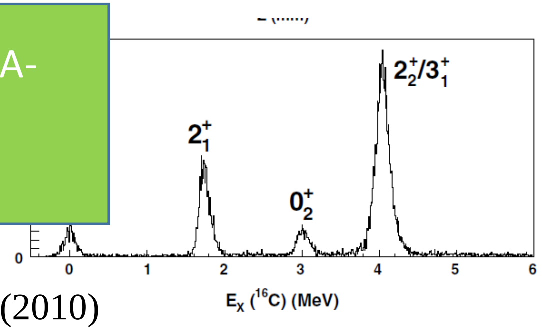
^{15}C → ^{16}C

{2$^+_2$, 3$^+_1$ ...

{0$^+_1$, 2$^+_1$} : [ν(d$_{5/2}$ ...

^{15}C(d,p)^{16}C DSAM experiment done at ANL with GRETINA-GODDESS July 2021.
I. Zanon, E. Clément, M. Siciliano et al.

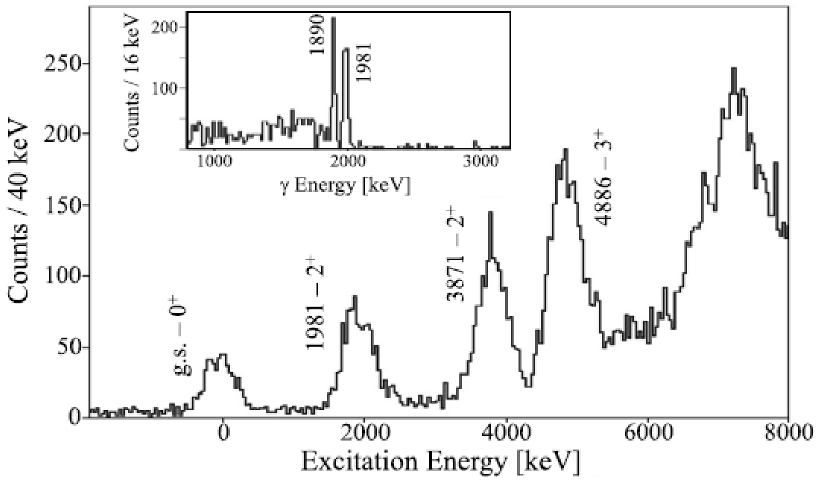
Δ = 100 keV



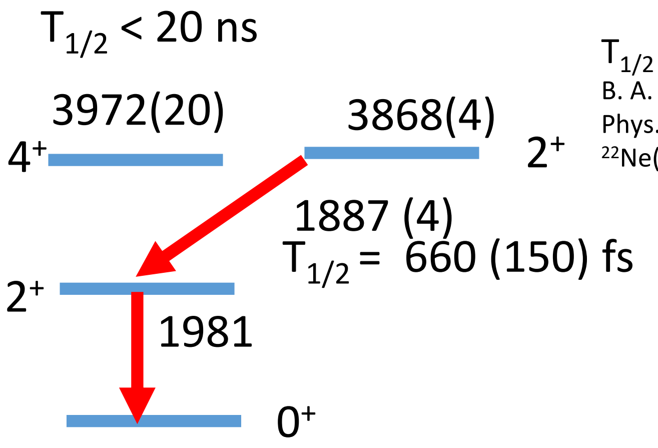
A. H. Wuosmaa PRL 105, 132501 (2010)

Proposed experiment

G. Lotay, J. Henderson, W.N. Catford et al. Physics Letters B 833 (2022) 137361



30 UT with ^{23}Ne RIB
300 (300) counts in CD2-Only(+Au)
+ (3UT) using the ^{21}Ne(d,p)^{22}Ne :
4^+ state at 3.3 MeV (T1/2= 225(4) fs).



$T_{1/2}$ < 70fs
B. A. Watson, et al
Phys. Rev. C 9, 1200 (1974)
^{22}Ne(t,p)