Report to the ISOLDE and Neutron Time-of-Flight Committee

^{18}N: a challenge to the shell model and to ab initio models of the nuclear structure of light nuclei

[new title]

^{18}N: a challenge to the shell model and a part of the flow path to r-process element production in Type II supernovae

[old title]

A Matta [1], W N Catford [1], N K Timofeyuk [1], N L Achouri [1], F Delaunay [1], B Fernandez-Dominguez [3], F Flavigny [1], S J Freeman [4], J Gibelin [1], D G Jenkins [5], T Kroell [6], M Labiche [7], N Orr [1] with the T-REX and MINIBALL collaborations

“New” group for transfer experiments at ISOLDE, collaborating with T-Rex group

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[4] *The School of Physics and Astronomy, University of Manchester, Manchester, M13 9PL, UK*

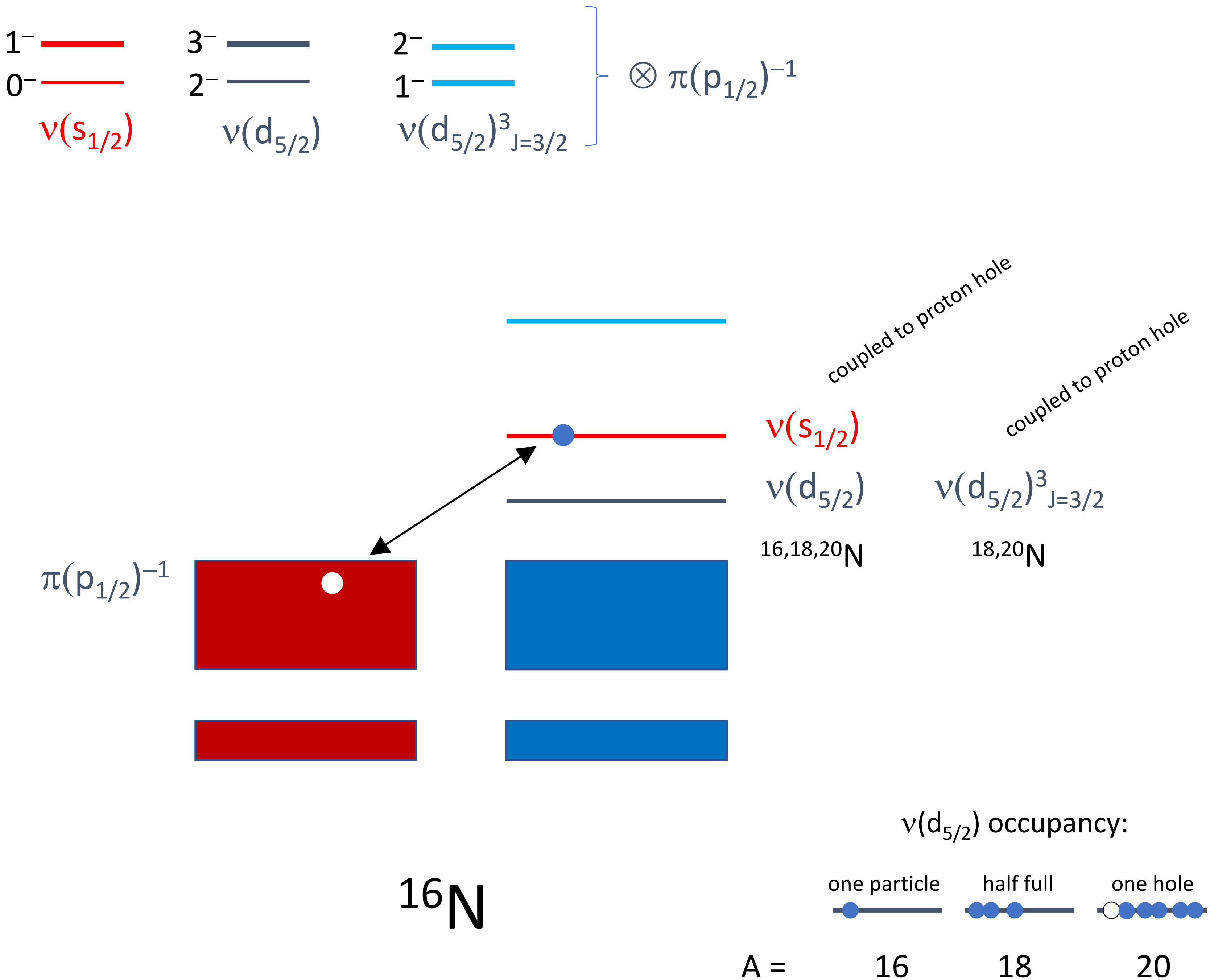
[5] *Department of Physics, University of York, York, YO10 5DD, UK*

[6] *Institut f?ur Kernphysik, Technische Universit?at Darmstadt, Darmstadt D-64289, Germany*

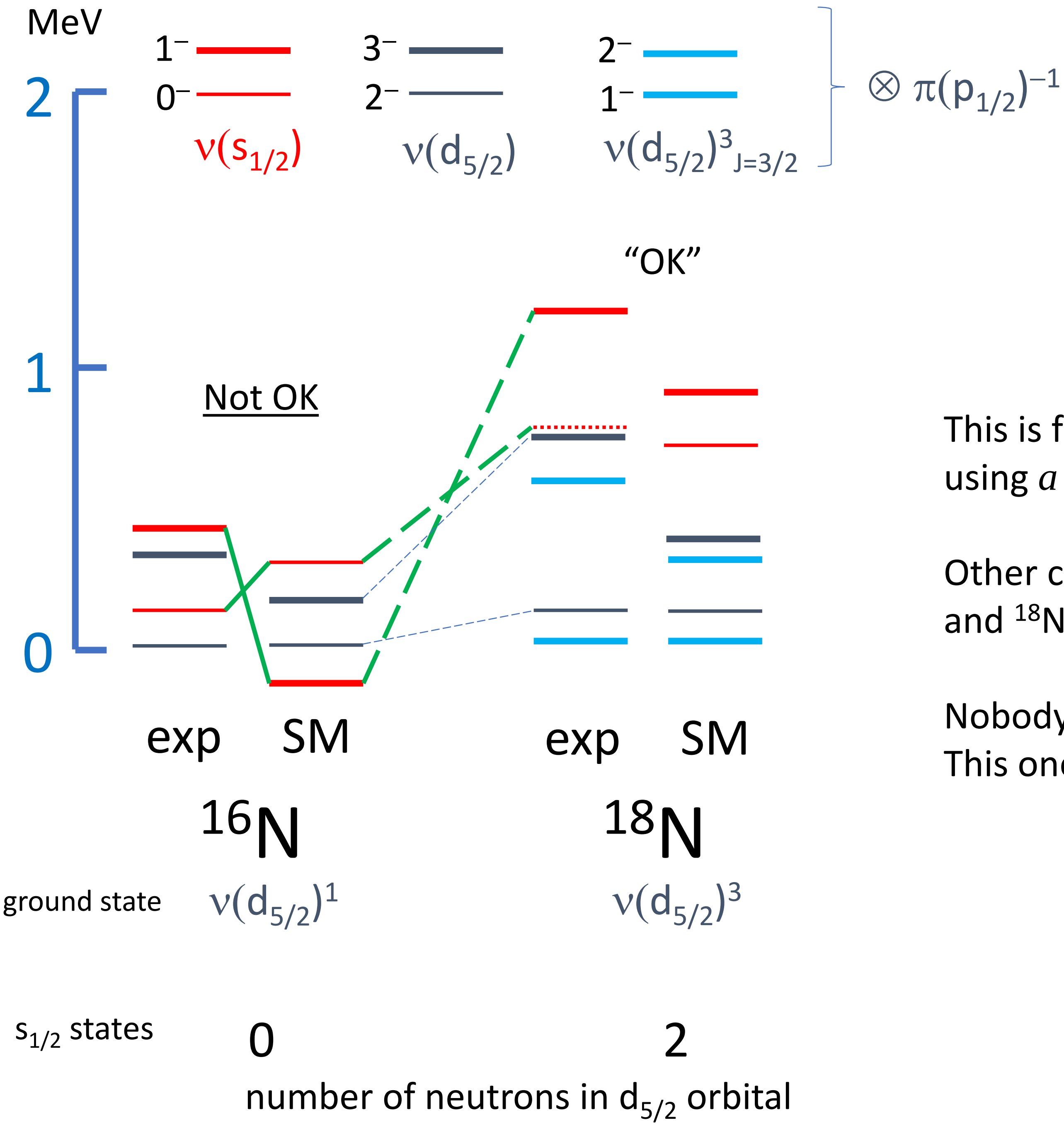
[7] *STFC Daresbury Laboratory, Daresbury, Warrington, Cheshire, WA4 4AD, UK*

Spokesperson(s): A Matta matta@lpccaen.in2p3.fr
and W N Catford w.catford@surrey.ac.uk

Originally proposed in 2013. No changes – this is still the experiment that we want to do.



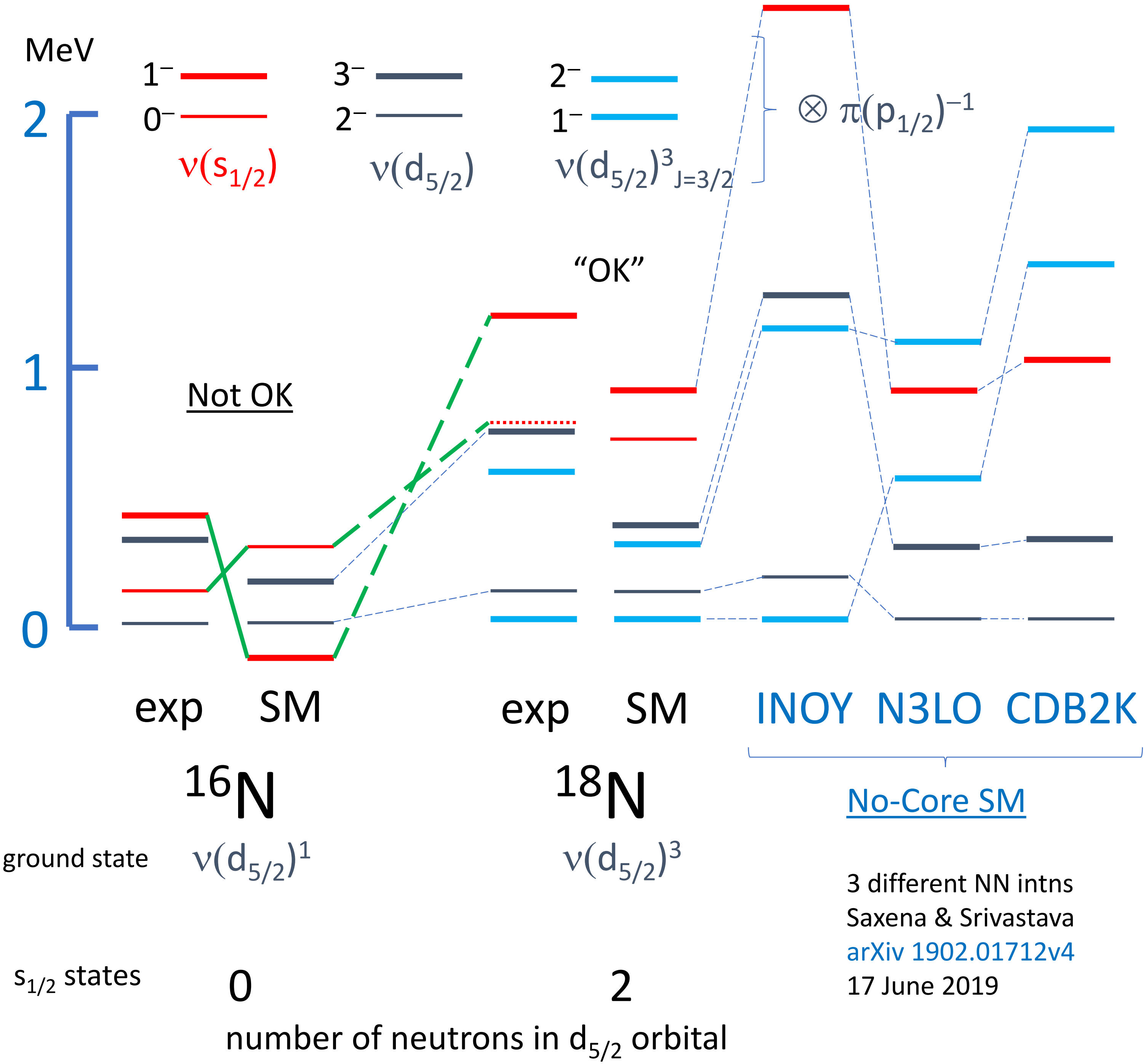
1^-
0^-
$\nu(s_{1/2})$
3^-
2^-
$\nu(d_{5/2})$
2^-
1^-
$\nu(d_{5/2})^3{}_{J=3/2}$
$\otimes\ \pi(p_{1/2})^{-1}$
coupled to proton hole
coupled to proton hole
$\nu(s_{1/2})$
$\nu(d_{5/2})$
$\nu(d_{5/2})^3{}_{J=3/2}$
$^{16,18,20}N$
$^{18,20}N$
$\pi(p_{1/2})^{-1}$
^{16}N
$\nu(d_{5/2})$ occupancy:
one particle
half full
one hole
A =
16
18
20



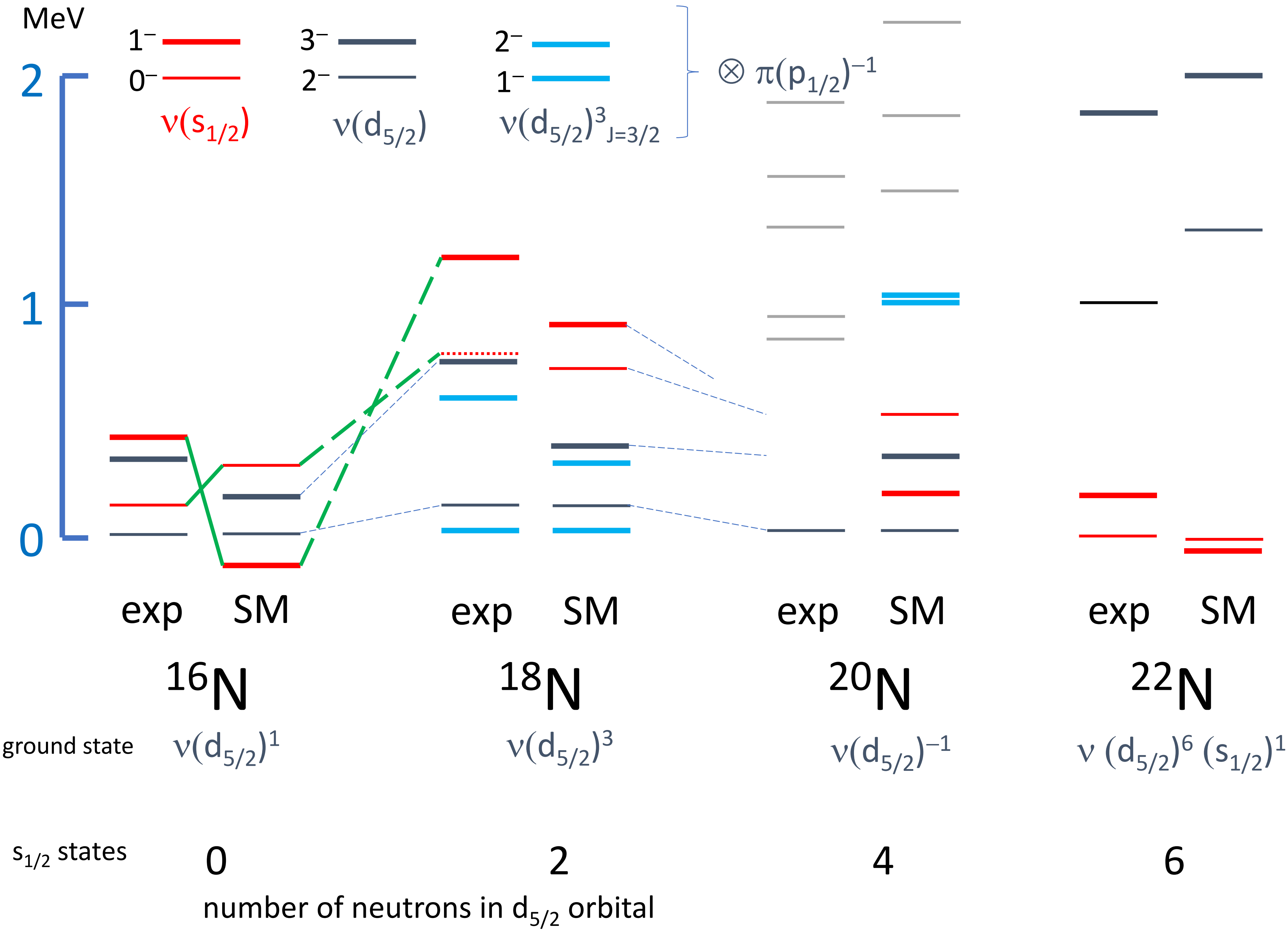
This is for the latest SM calculations using *a priori* interaction (Otsuka).

Other calculations get ^{16}N correct and ^{18}N incorrect.

Nobody can get <u>both</u> correct.
This one gets ^{18}N right, most get ^{16}N.

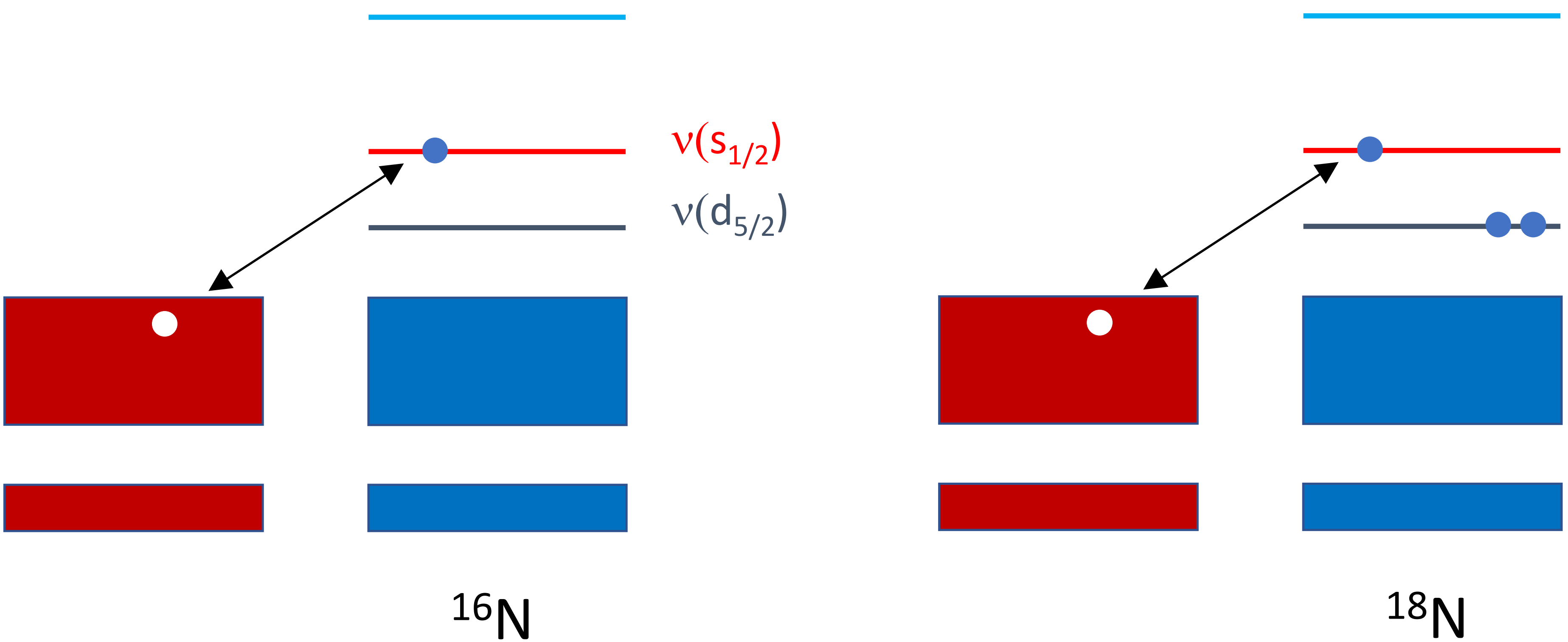


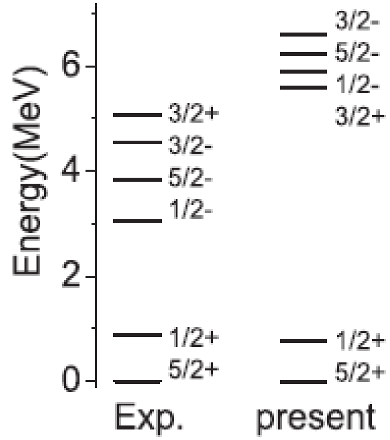
MeV
2
1
0
1⁻
0⁻
ν(s1/2)
3⁻
2⁻
ν(d5/2)
2⁻
1⁻
ν(d5/2)3 J=3/2
⊗ π(p1/2)−1
"OK"
Not OK
exp
SM
exp
SM
INOY
N3LO
CDB2K
No-Core SM
16N
18N
ground state
ν(d5/2)1
ν(d5/2)3
3 different NN intns
Saxena & Srivastava
arXiv 1902.01712v4
17 June 2019
s1/2 states
0
2
number of neutrons in d5/2 orbital



MeV
2
1
0
1⁻
0⁻
ν(s1/2)
3⁻
2⁻
ν(d5/2)
2⁻
1⁻
ν(d5/2)3J=3/2
⊗ π(p1/2)−1
exp
SM
exp
SM
exp
SM
exp
SM
16N
18N
20N
22N
ground state
ν(d5/2)1
ν(d5/2)3
ν(d5/2)−1
ν (d5/2)6 (s1/2)1
s1/2 states
0
2
4
6
number of neutrons in d5/2 orbital

Nobody can get <u>both</u> correct.
Why is this?

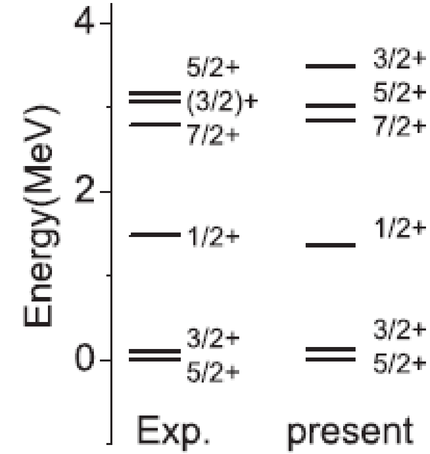




The respective isotones…

^{17}O

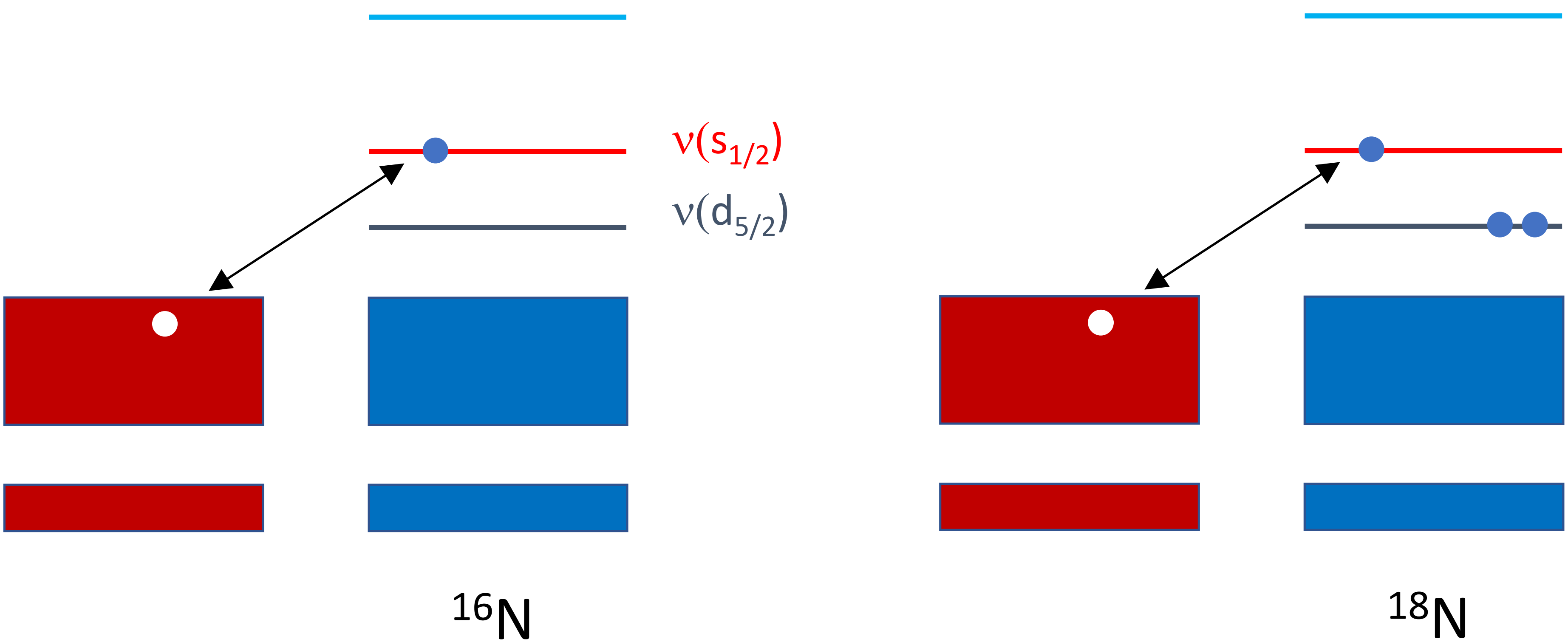
^{19}O



… are very well described in both cases

And what's more….

So are ^{15}C & ^{17}C even though the $\nu(s_{1/2})$ starts to intrude!

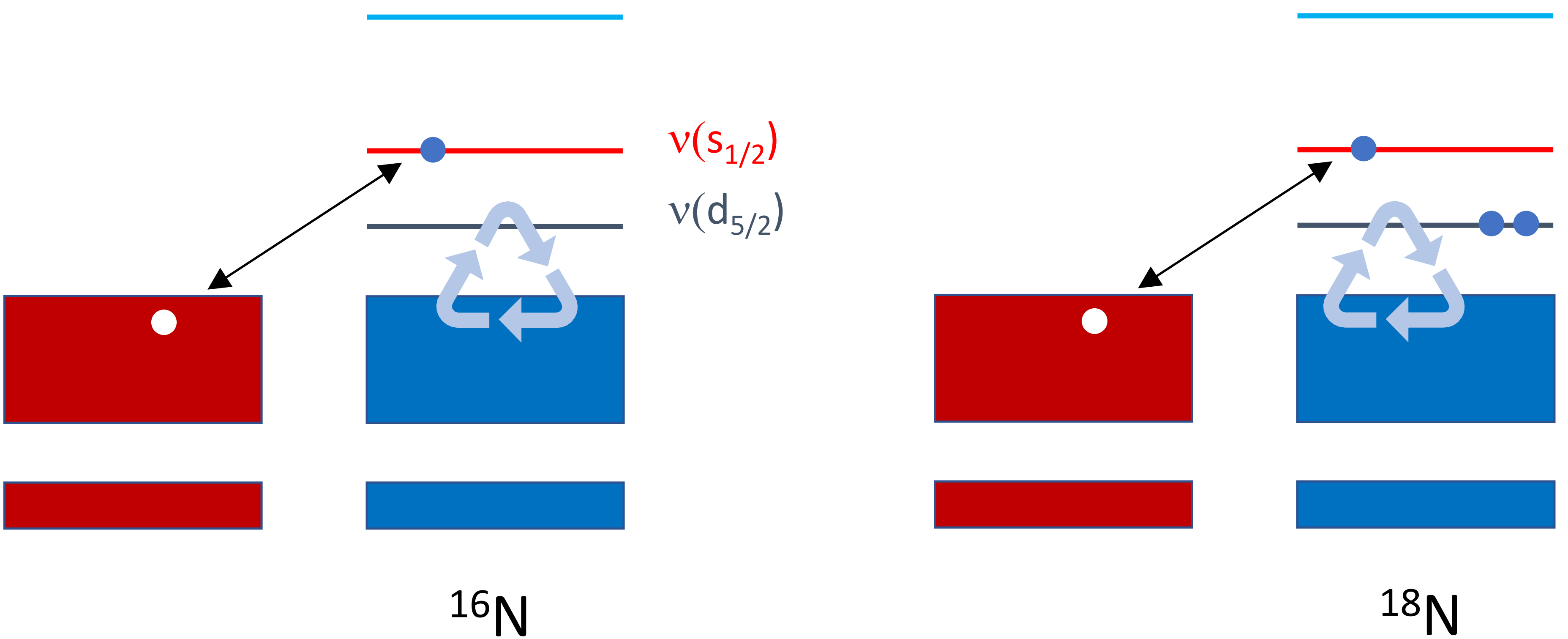


Why is nitrogen different?

Something seems to be happening, just for the nitrogen isotopes.

It could perhaps be cross-shell excitations giving additional neutron occupancy, which subtly affects the magnitude of the summed proton-neutron interactions…

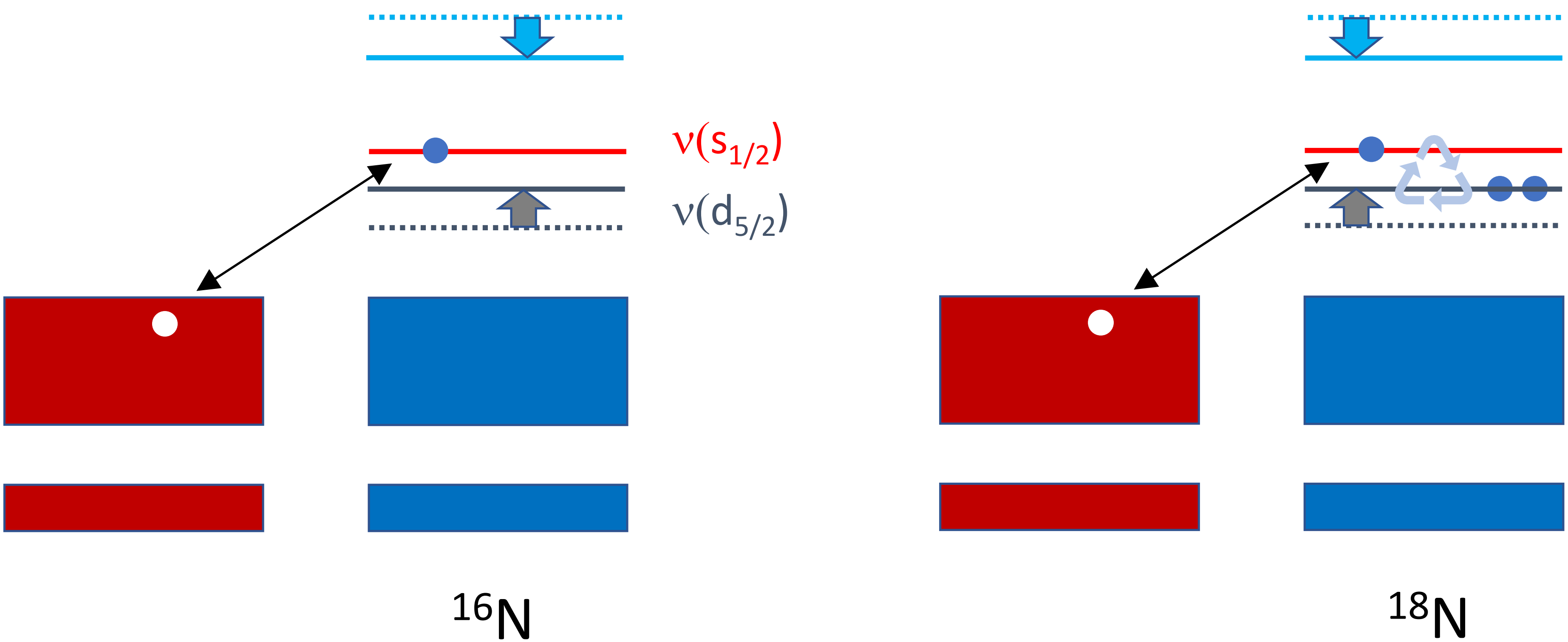
(this is something that better *ab initio* calculations should be able to address)

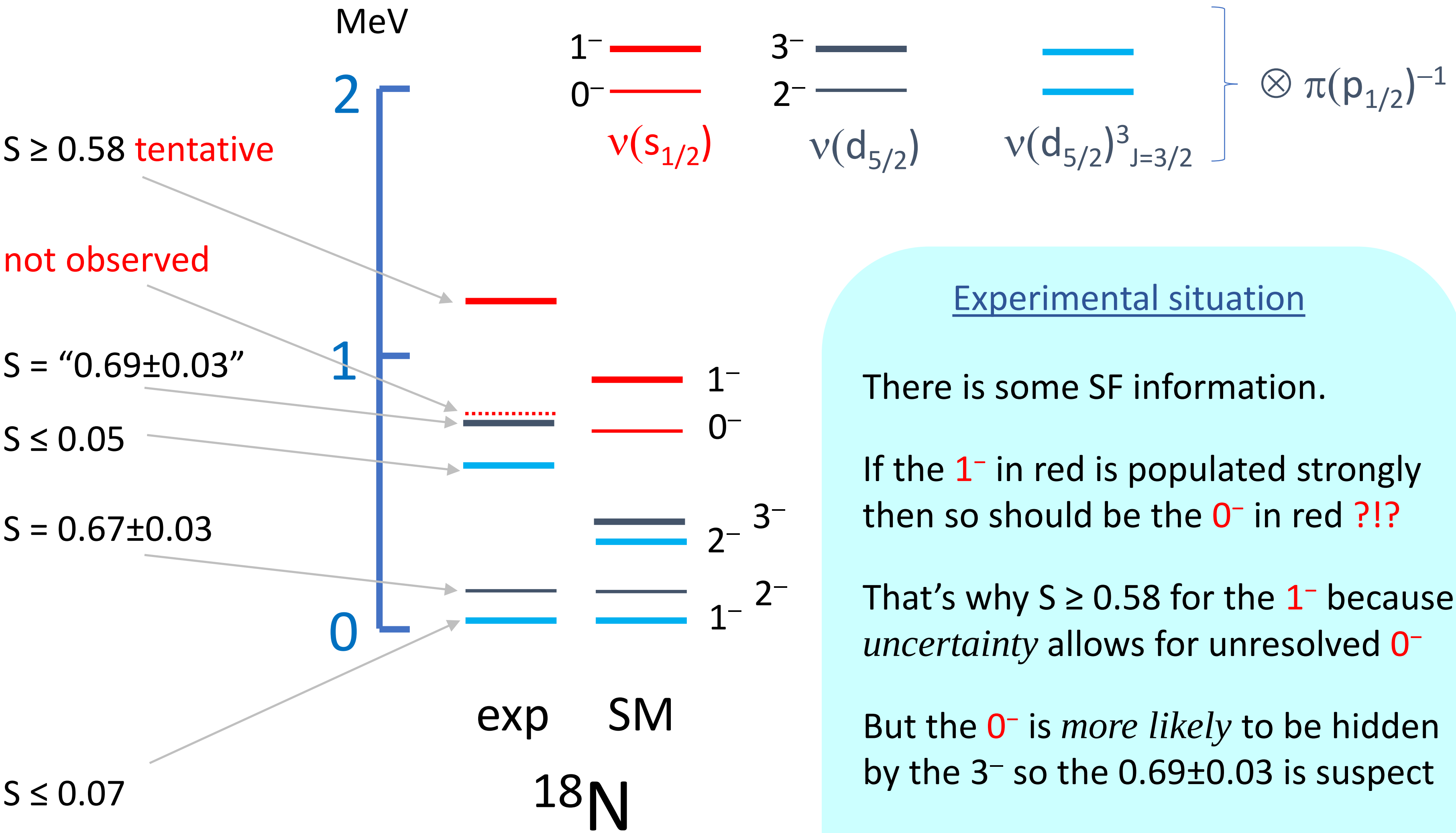


Something seems to be happening, just for the nitrogen isotopes.

OR it could perhaps be the monopole shift arising from the removal of the 0p1/2 proton, which affects the details of the neutron-neutron interactions…

(this is something that large basis SM calculations really should be able to get right)





Experimental situation

There is some SF information.

If the 1^- in red is populated strongly then so should be the 0^- in red ?!?

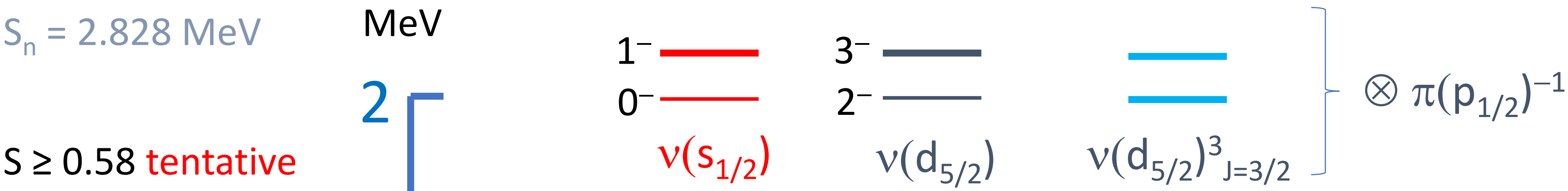
That’s why S ≥ 0.58 for the 1^- because *uncertainty* allows for unresolved 0^-

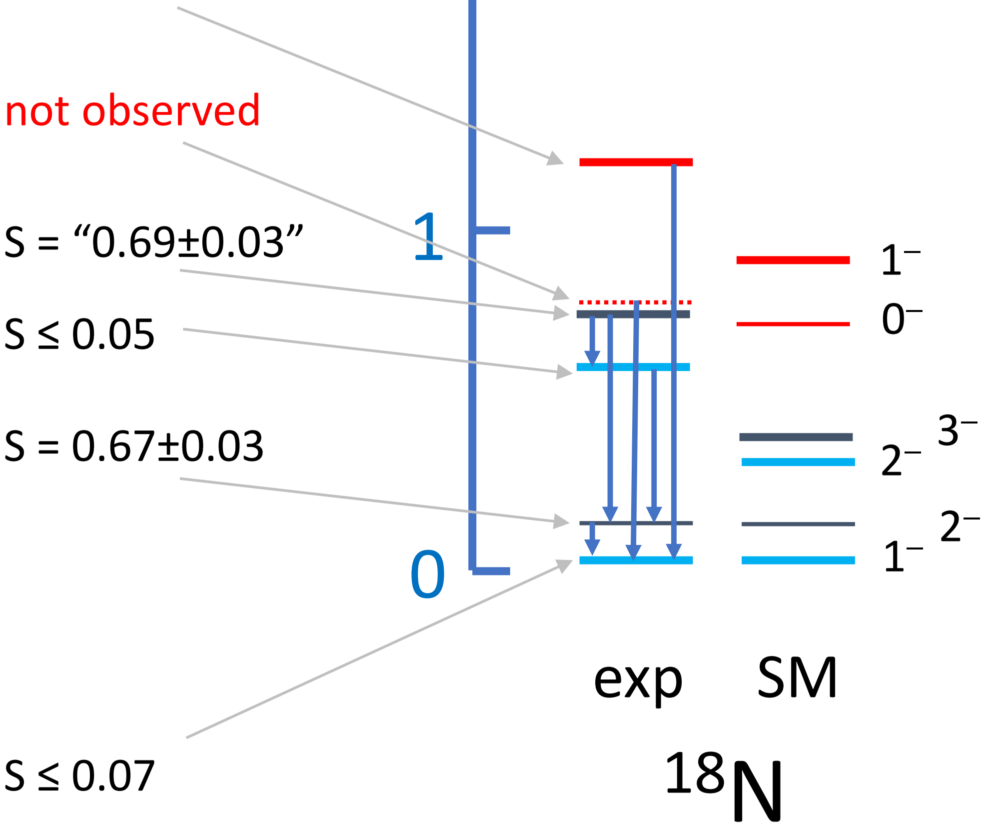
But the 0^- is *more likely* to be hidden by the 3^- so the 0.69±0.03 is suspect

Also the 1^- *assignment* is tentative

All of this can be greatly improved

Only previous (d,p) results:
C.R. Hoffman *et al.*, Phys. Rev. C88, 044317 (2013)





Gamma-Rays to the Rescue!

Eγ= 121, 155, 466, 621, 742, 1170 keV

… after Doppler correction

Resolution ≤ 25 keV, ΔEγ ≥ 121 keV

So states are easily RESOLVED
and also uniquely IDENTIFIED

(The weak 155 keV branch is not unique/essential but with ΔEγ=34 keV should also be resolved).

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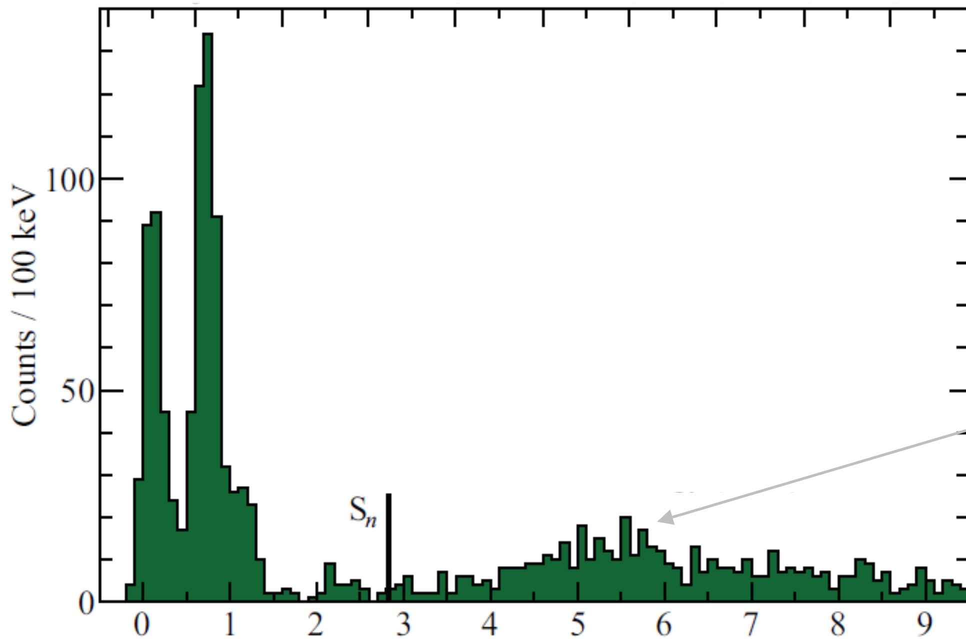
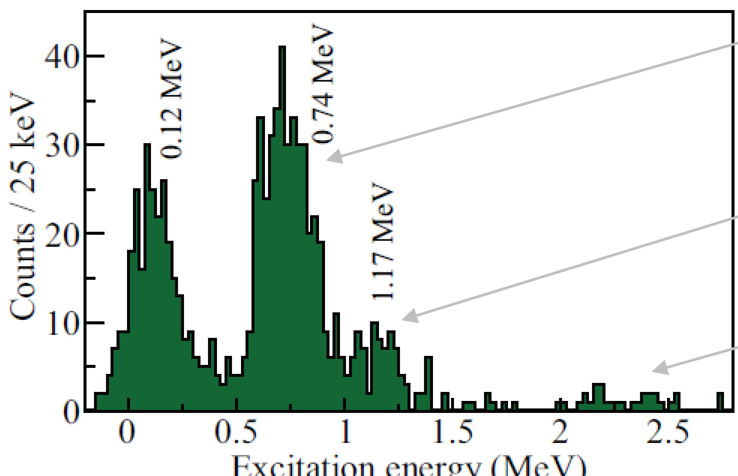
In many ways, the previous study at HELIOS raises more interesting questions than it answers…



BOUND

Unbound ^{18}N states that will probably decay into gamma-decaying ^{17}N states. These are likely $\pi = +$ and with astrophysical relevance in supernovae scenarios.



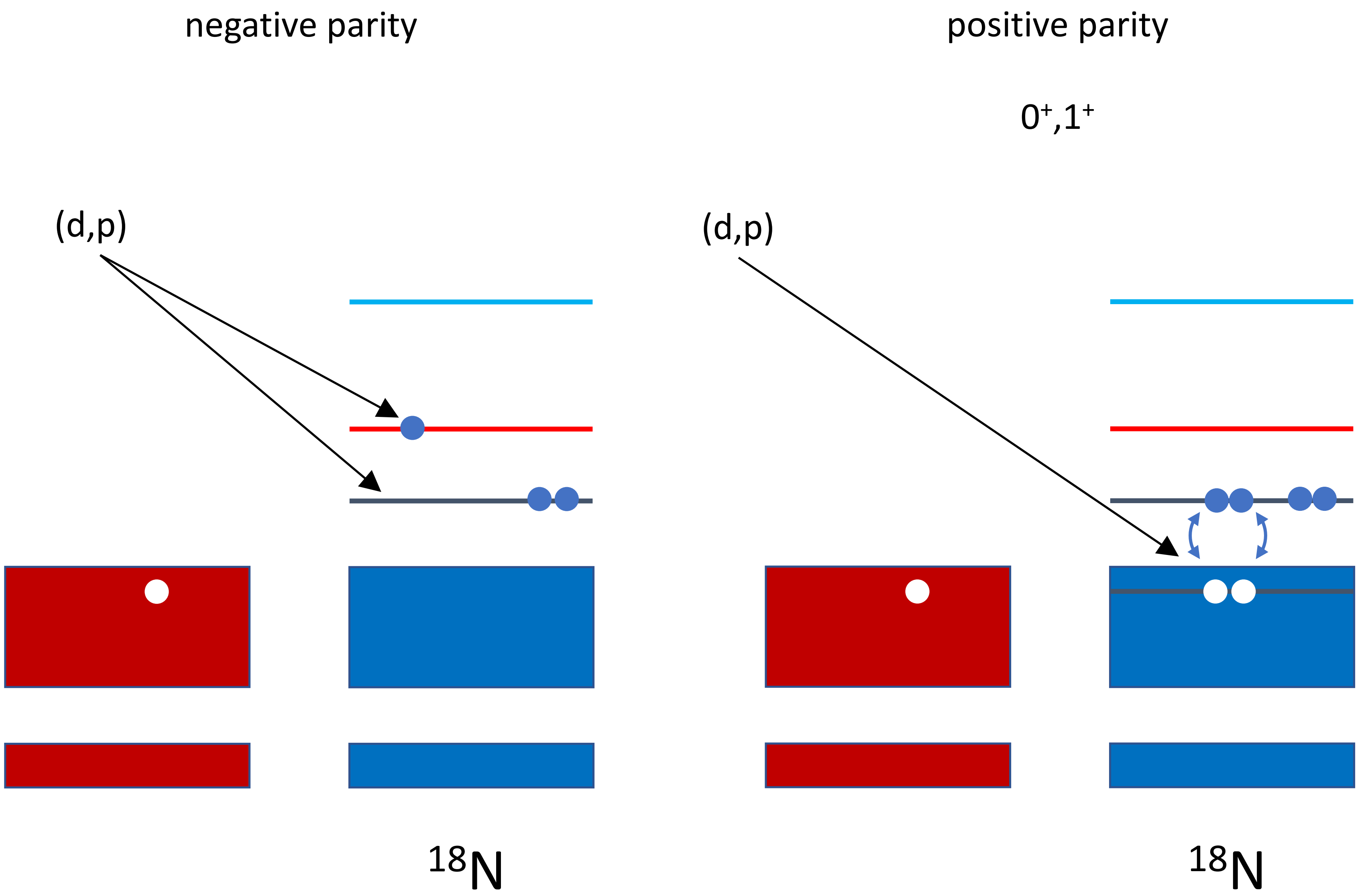
C.R. Hoffman *et al.*, Phys. Rev. C88, 044317 (2013)

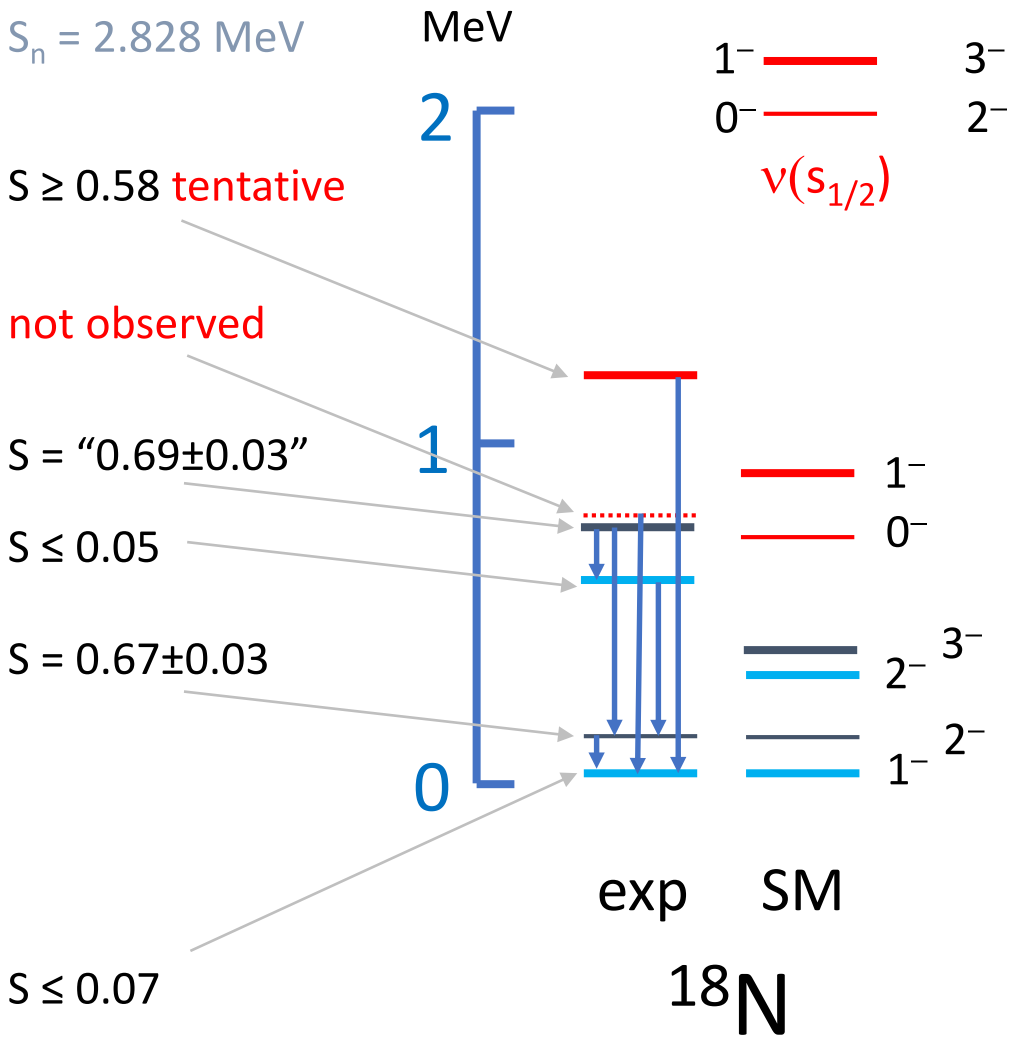
<u>UNRESOLVED</u>

2^- ,3^- ,0^- that we will resolve

tentative 1^- that we will confirm

States that will gamma-decay, and hence reveal their nature, possibly of $\nu(d_{5/2}{}^2\, d_{3/2})$ character or maybe $\pi = +$


negative parity
positive parity
0+,1+
(d,p)
(d,p)
18N
18N



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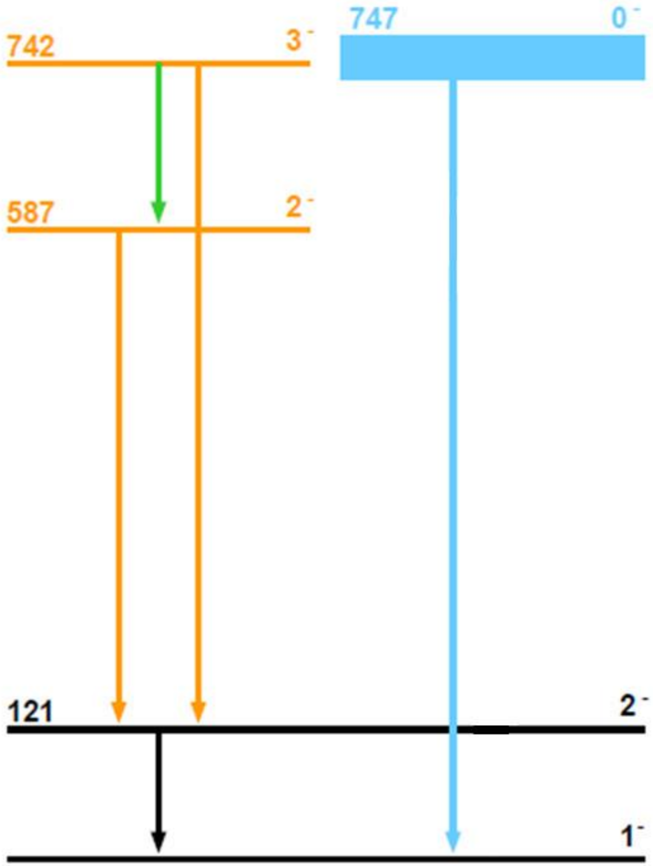
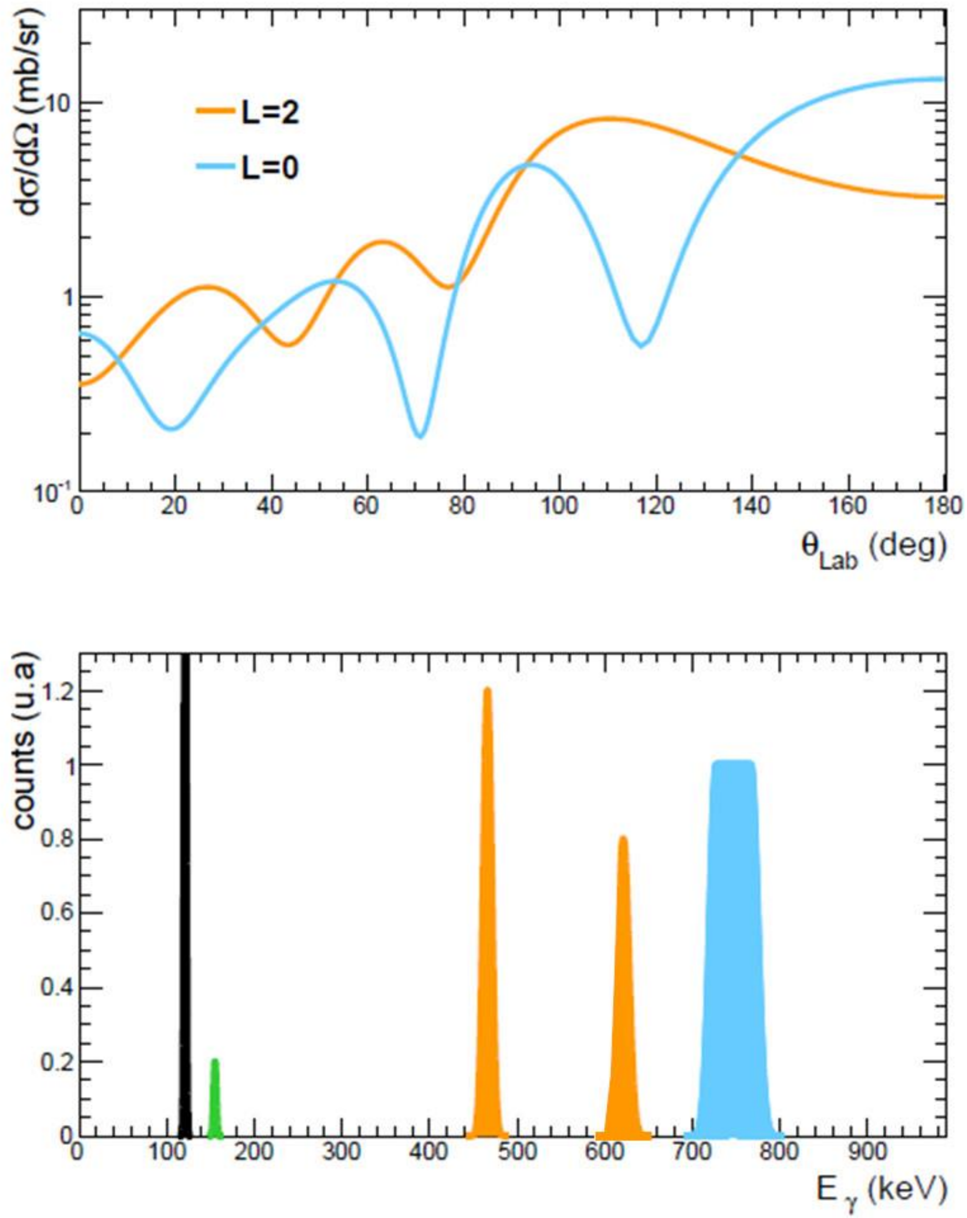
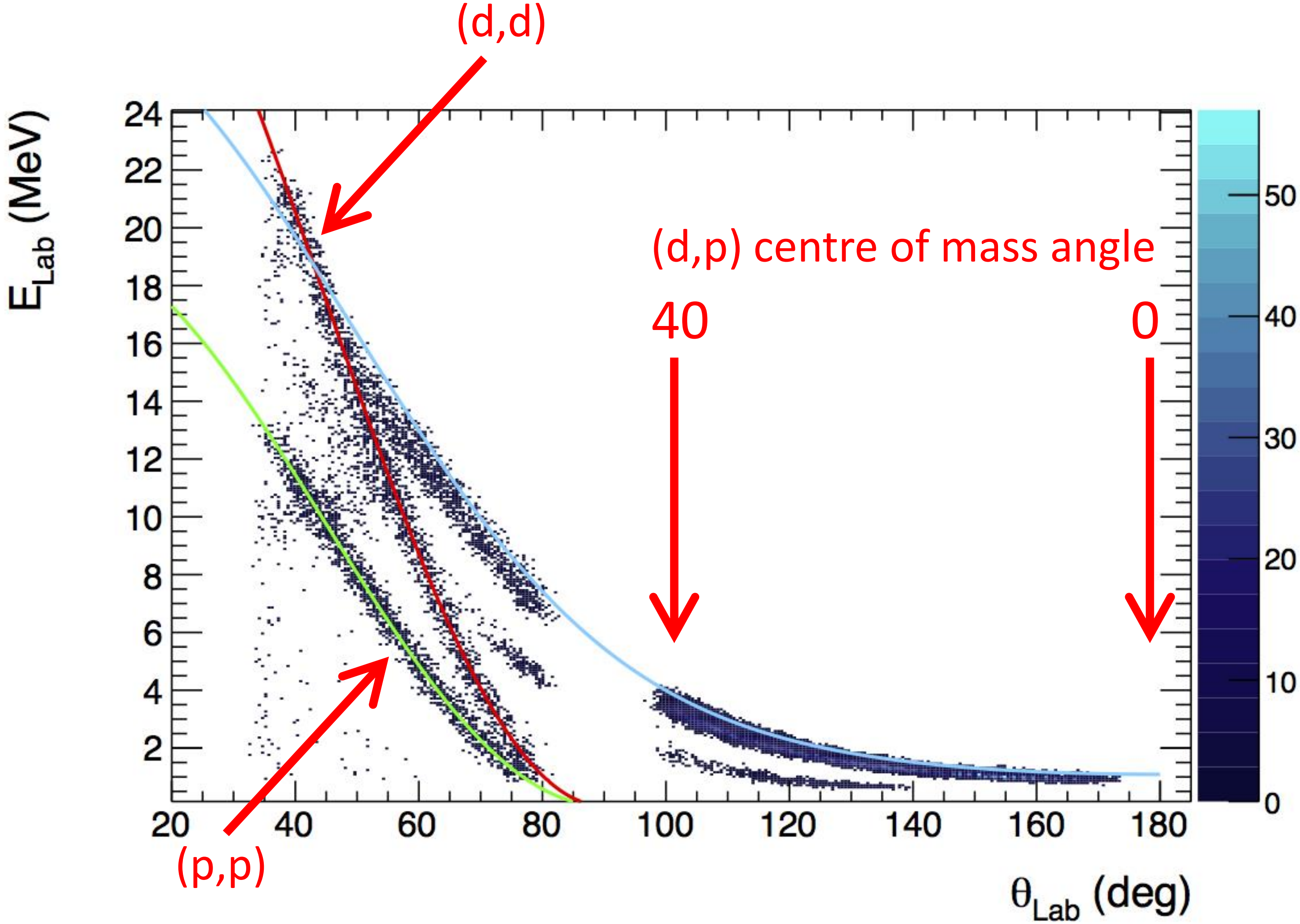
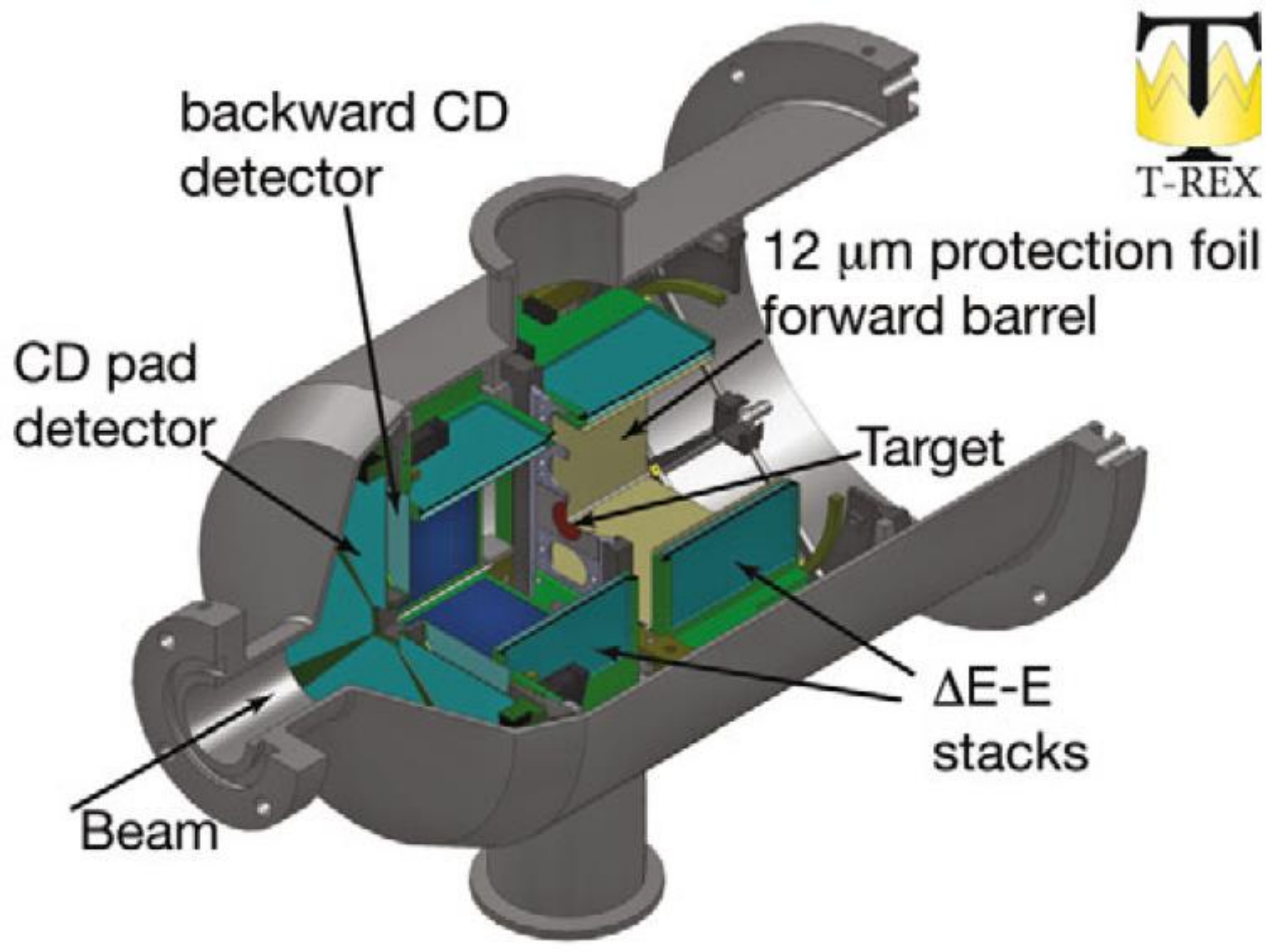

742
3-
747
0-
587
2-
121
2-
1-

^{18}N exp.

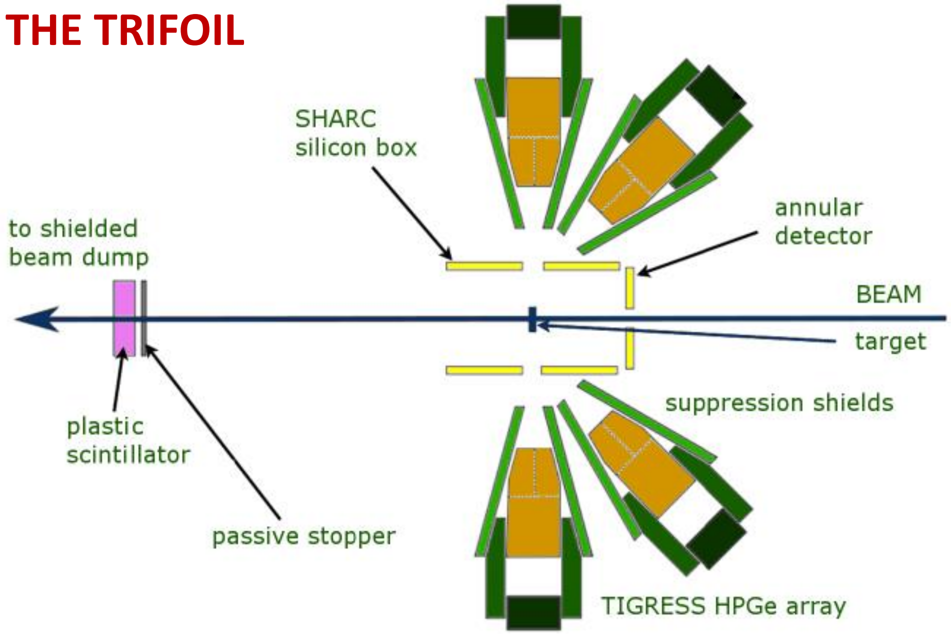

dσ/dΩ (mb/sr)
L=2
L=0
10
1
10^-1
0
20
40
60
80
100
120
140
160
180
θLab (deg)
counts (u.a)
1.2
1
0.8
0.6
0.4
0.2
0
0
100
200
300
400
500
600
700
800
900
E γ (keV)

WHAT WE SHOULD OBSERVE WHEN WE PLOT THE T-REX ENERGY AGAINST LAB ANGLE

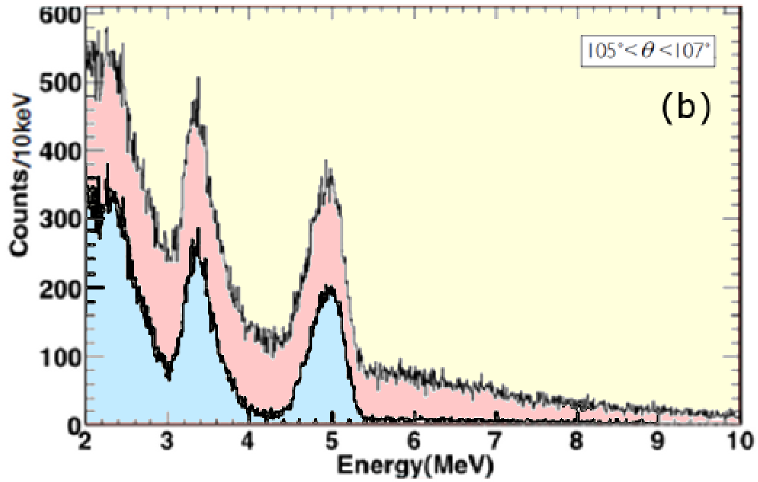



backward CD
detector
T-REX
12 μm protection foil
forward barrel
CD pad
detector
Target
ΔE-E
stacks
Beam

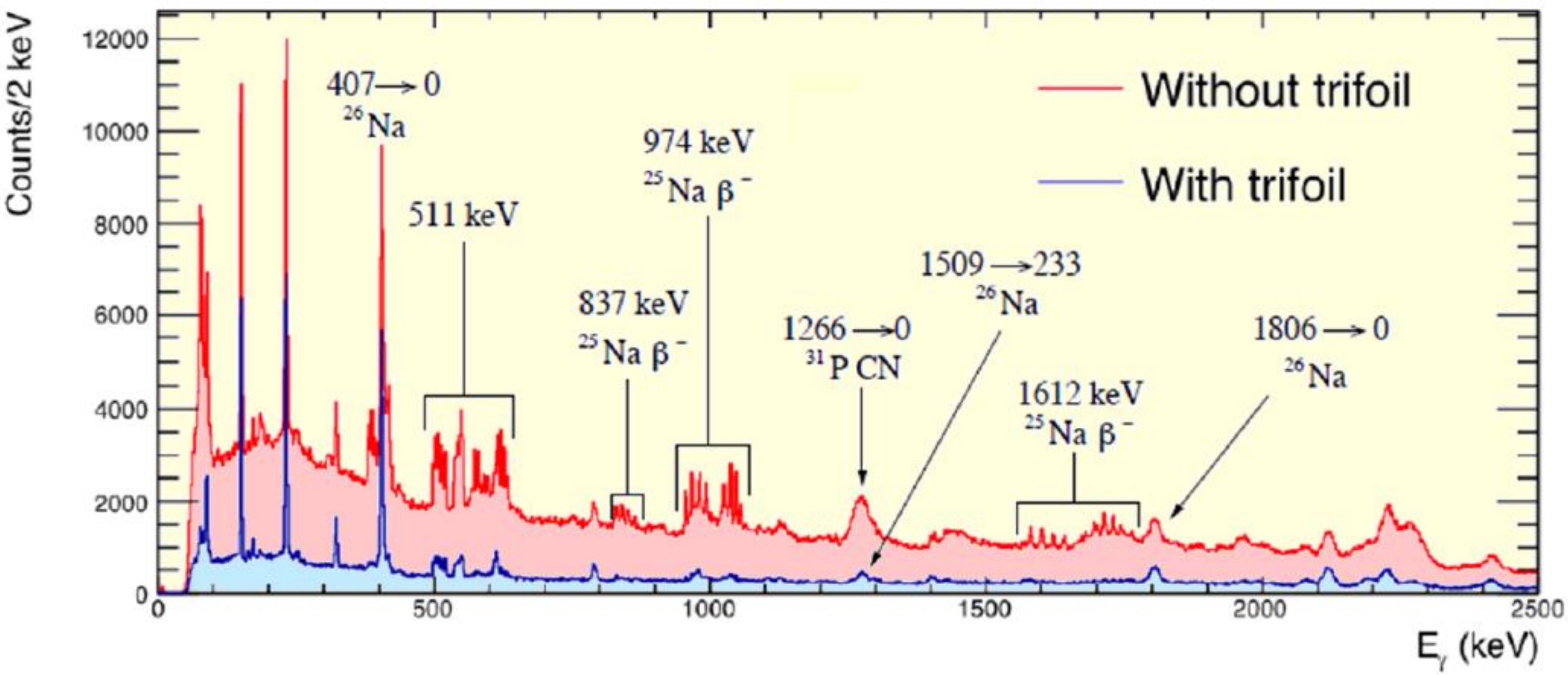
THE TRIFOIL



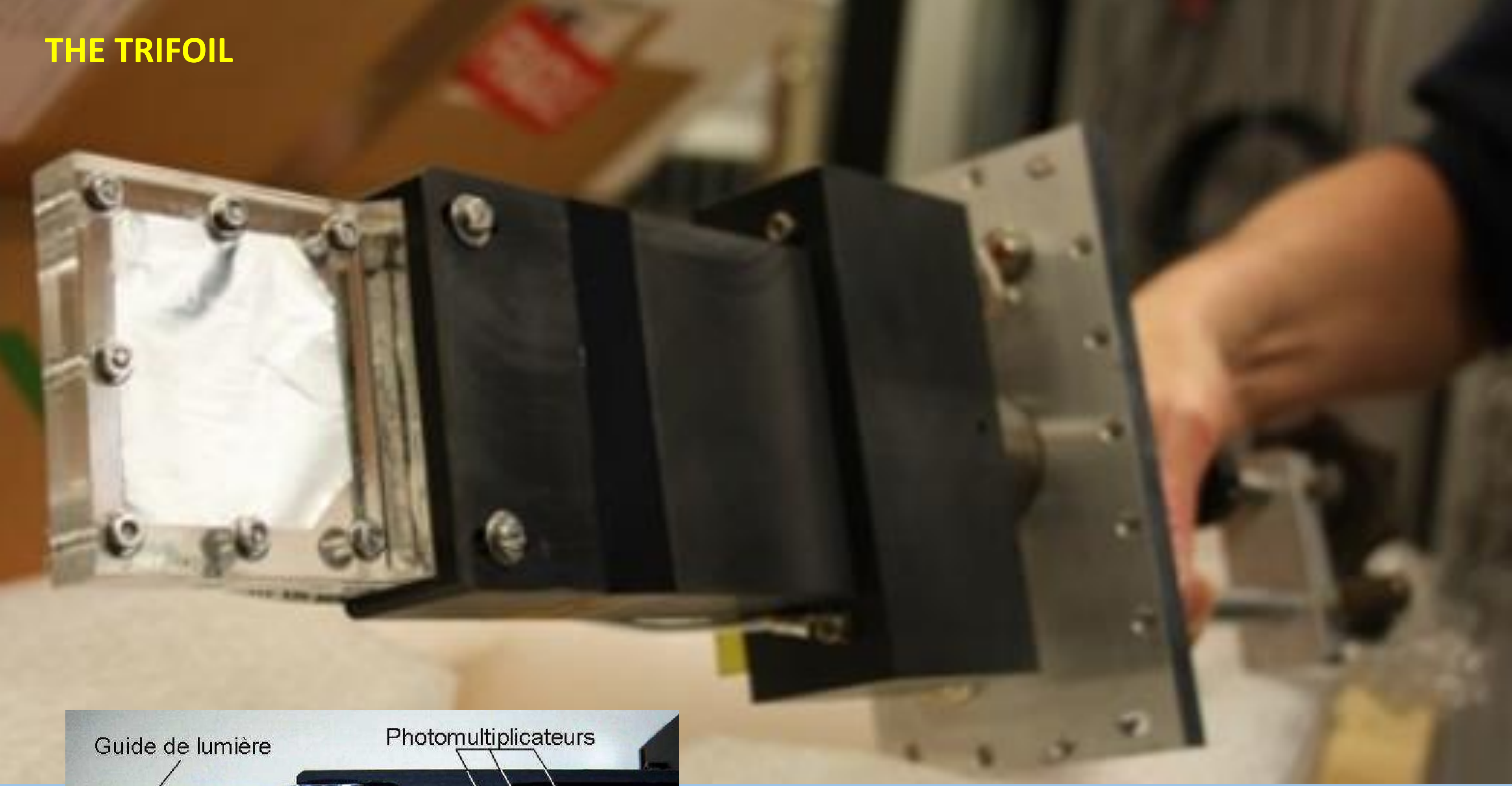
PARTICLES

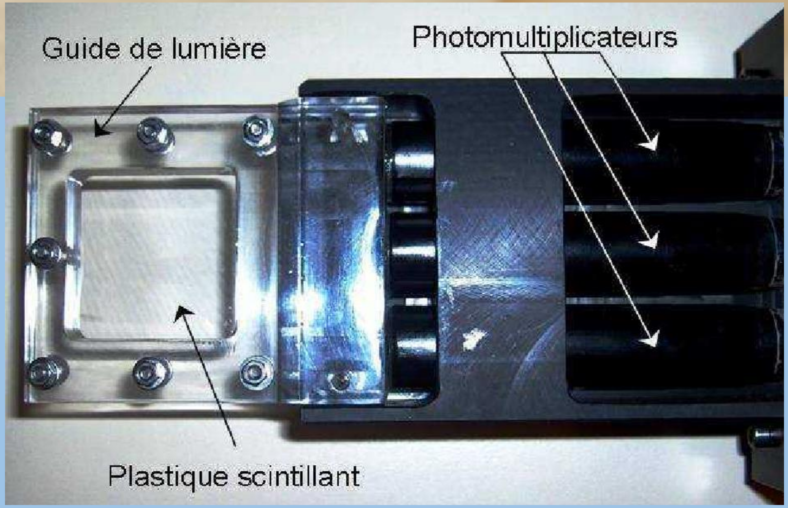


GAMMA-RAYS



THE TRIFOIL



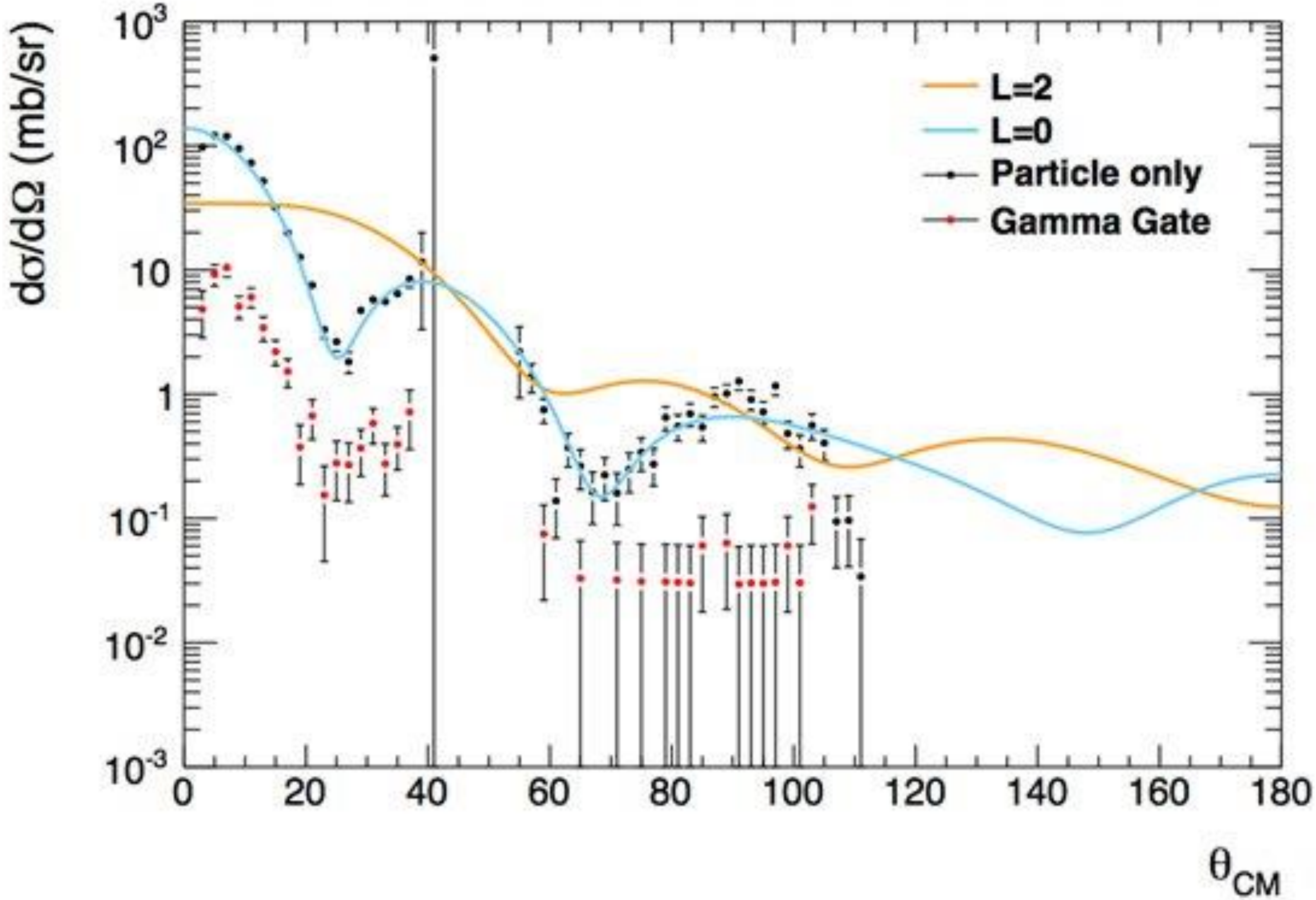


TRIFOIL DETECTOR

LPC Caen

SIMULATION OF THE DIFFERENTIAL CROSS SECTION FOR ONE OF THE $0^-/1^-$ s-WAVE STATES

Actual predicted statistics for one week of running with 0.5 mg/cm^2 target



Angle bins: 2 degrees in c.m.

SUMMARY of REQUEST

We are requesting **27 shifts of ^{17}N beam** at 5.5 MeV/A

With this, we will **perform (d,p) with the ^{17}N beam**, and study all populated states in ^{18}N, using gamma-rays to select and identify the closely spaced levels.

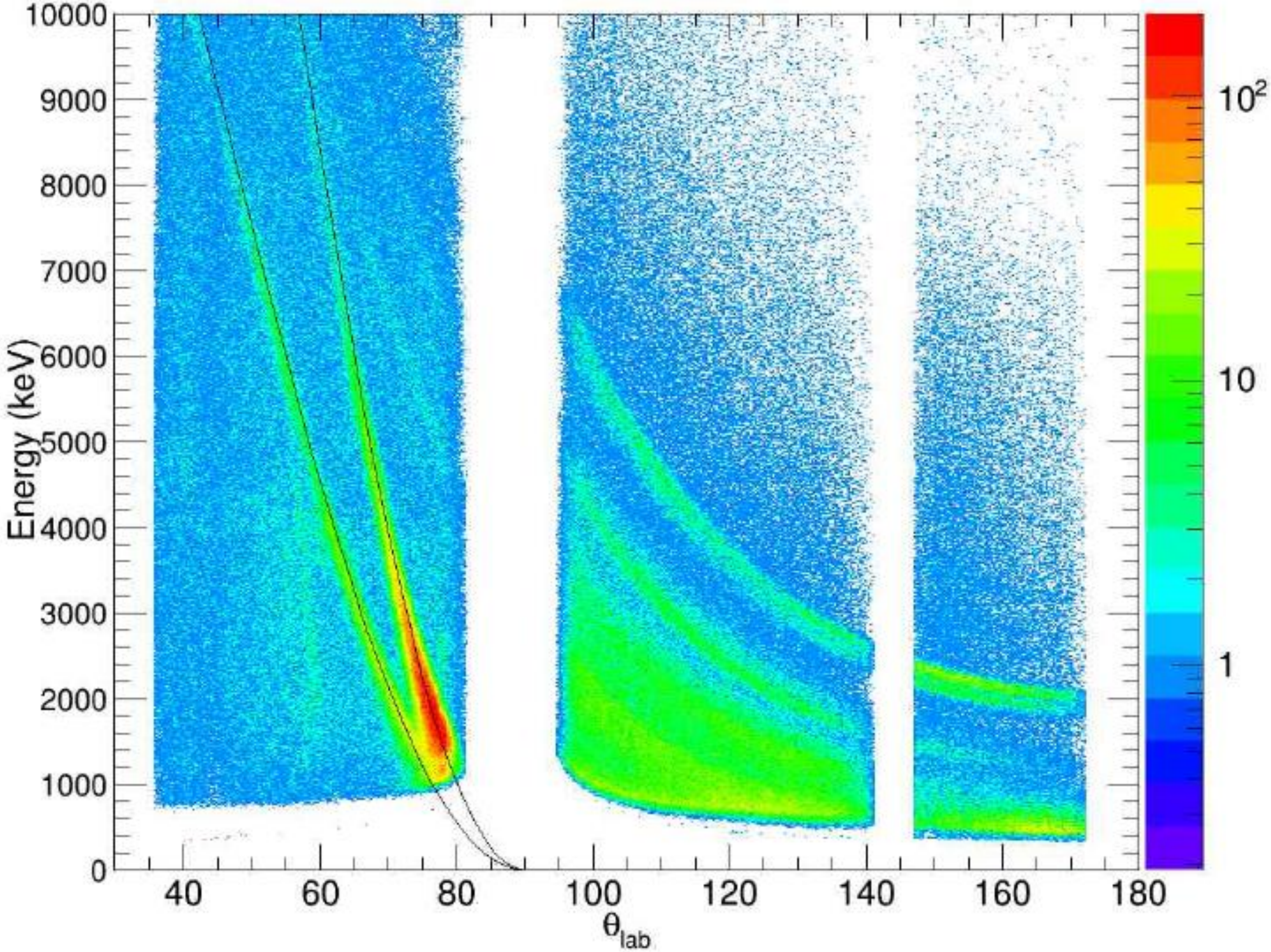
Of this, **21 shifts** are required in order to perform the **(d,p) measurement.**
We believe that we can save time by not running on a carbon target.
We would run on a carbon target (target contaminant) if time permits.

We have allowed **6 shifts** for optimising the charge state to accelerate (to minimise contaminants) (extraction will use NO^+ from nanoCaO+O_2, + plasma) and stripping methodology (what foils, and where) to eliminate ^{17}O.

We are requesting **3 shifts** for setting up with a stable **pilot beam**, to ensure that detectors and electronics are set up correctly

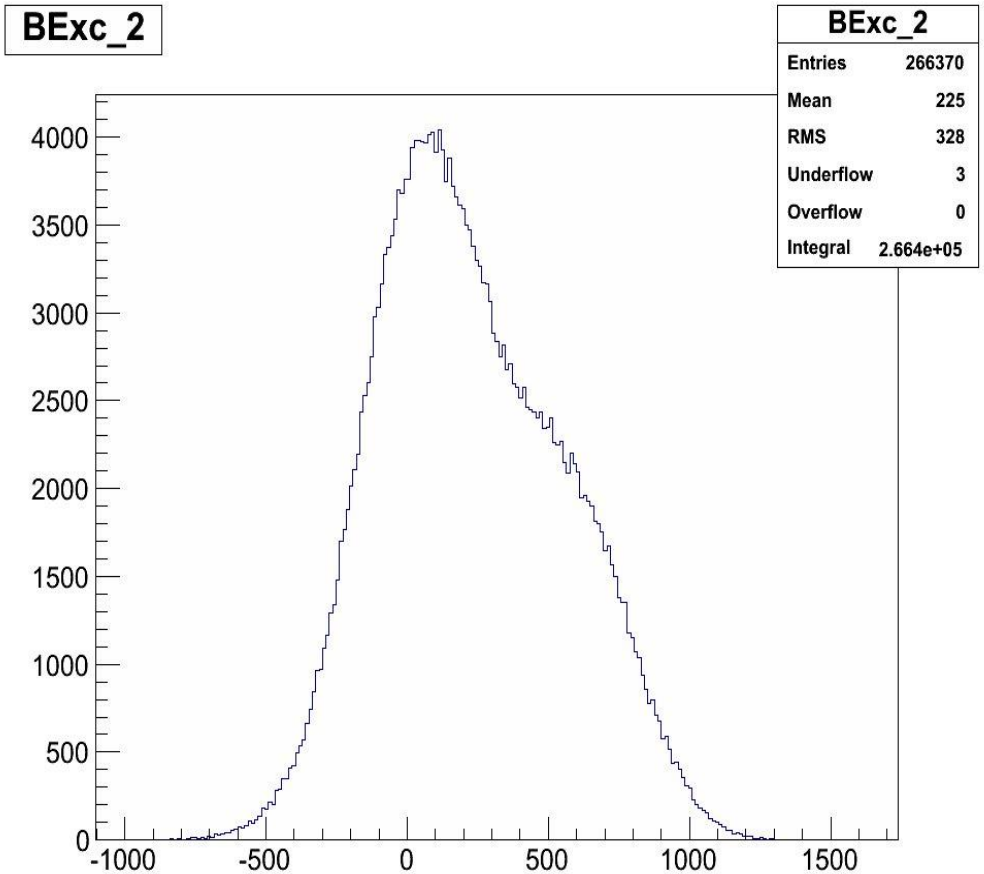
We **request 10^4 pps** for the ^{17}N beam, on the reaction target.
The beam should be delivered at the **T-REX + Miniball** setup.

We have allowed for a 5mm diameter beam spot on target (dominates the resolution).

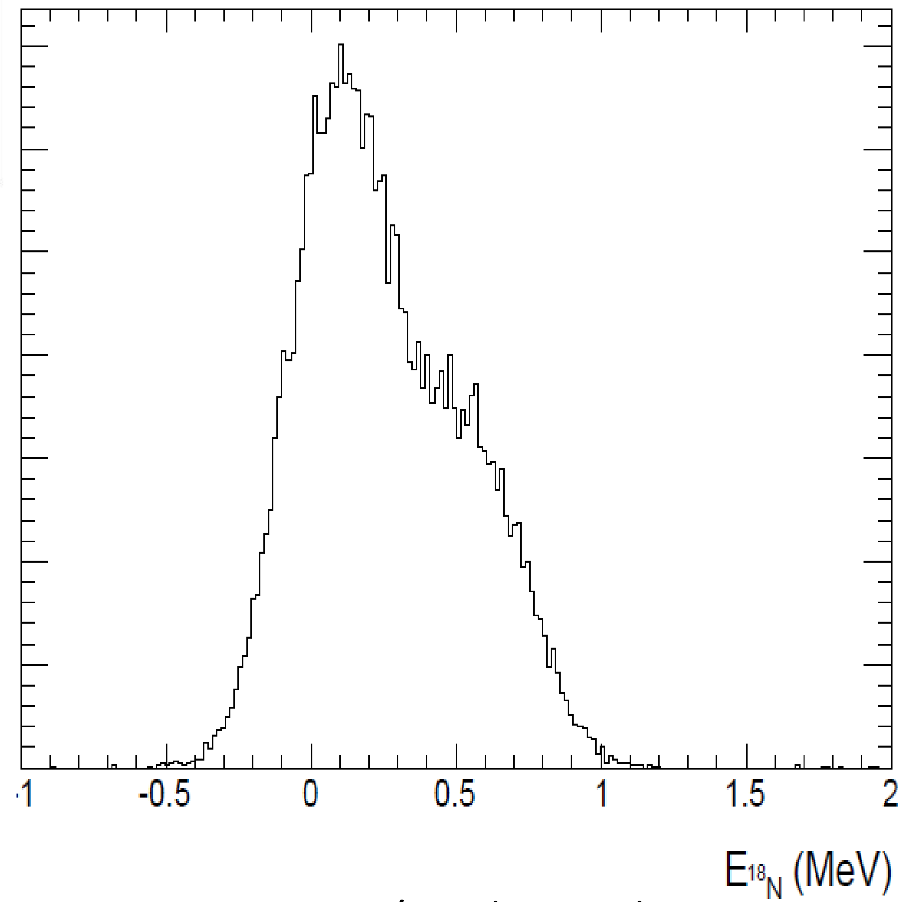


10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Energy (keV)
40
60
80
100
120
140
160
180
θ_{lab}
10^2
10
1

Reconstructed excitation energy for lowest four known states, assuming isotropic production



Klupp/Muecher @ Munich



Matta @ Surrey/LPC (approx)