$\nu 0p_{1/2} - \nu 0p_{3/2}$ spin-orbit splitting in ^{20}O

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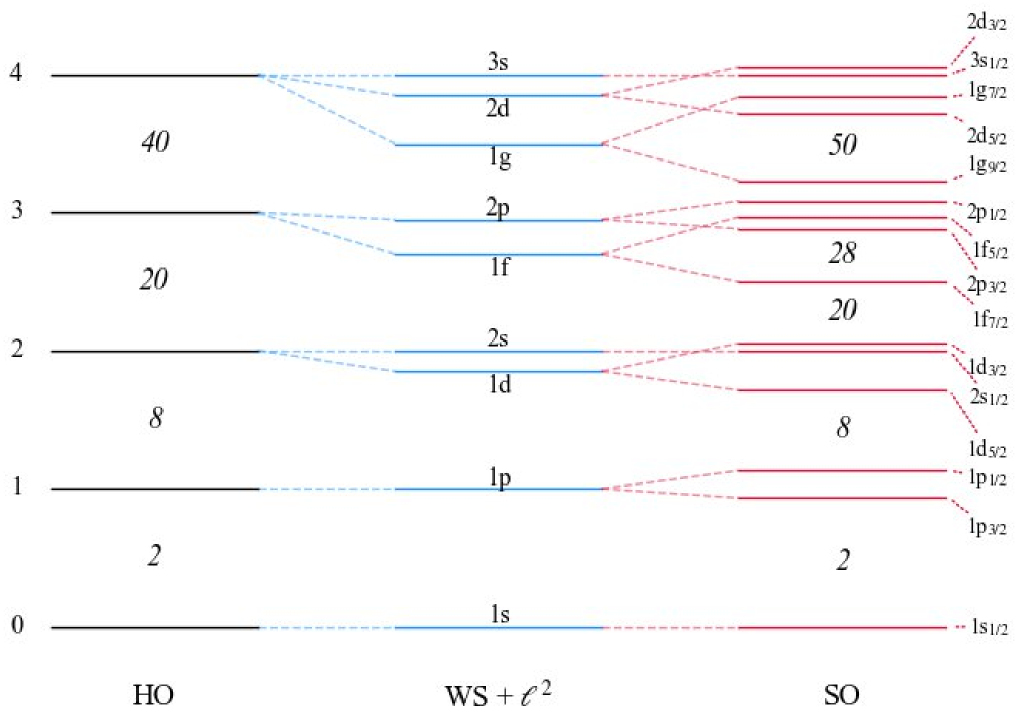
IGFAE-USC, GANIL and LPC-Caen

EuNPC 2025 - Caen

A recap on the SO splitting

Introduced by M. Goeppert-Mayer, reproduces magic numbers for stable nuclei.



SO splitting is mainly a surface effect:

$$V_{SO} = -\frac{1}{\hbar^2} V_{so} (\vec{l} \cdot \vec{s}) \left(\frac{1}{r} \frac{dV}{dr} \right)$$

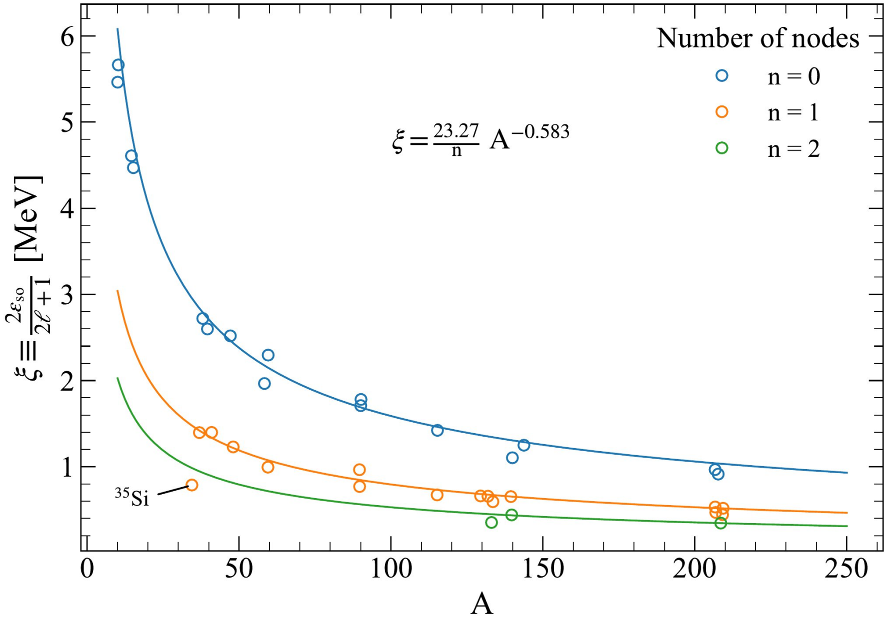
which yields a l-depending gap:

$$\Delta_{so} = \frac{\hbar^2}{2} (2\ell + 1)\xi$$

⇒ Expected to evolve towards more exotic nuclei, where surface blurs

A recap on the SO splitting

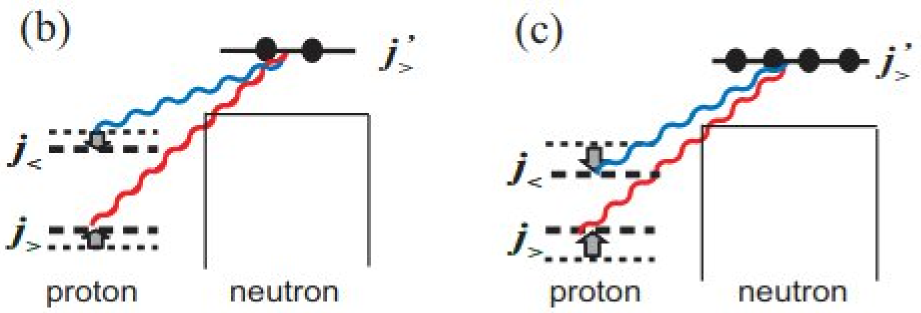
G .Mairle *et al.* (PLB 304 (1993)) found systematic trends easily parametrizable.



Proton-neutron interactions drive **shell evolution**

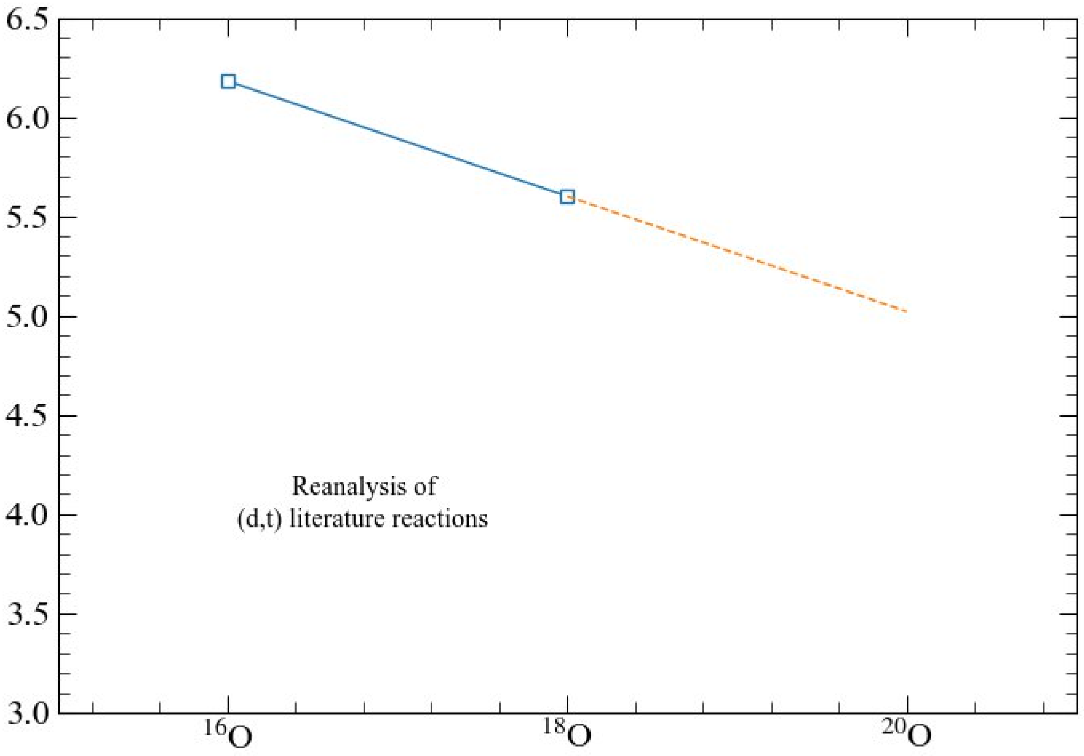
Deviations from the trend are found due to:

- Loosely bound orbitals
- Nuclear matter depletion (^{35}Si?)
- Role of **tensor force**



SO gap for Z = 8 isotopes

Evolution of the SO gap is plotted below for neutron-rich O isotopes.



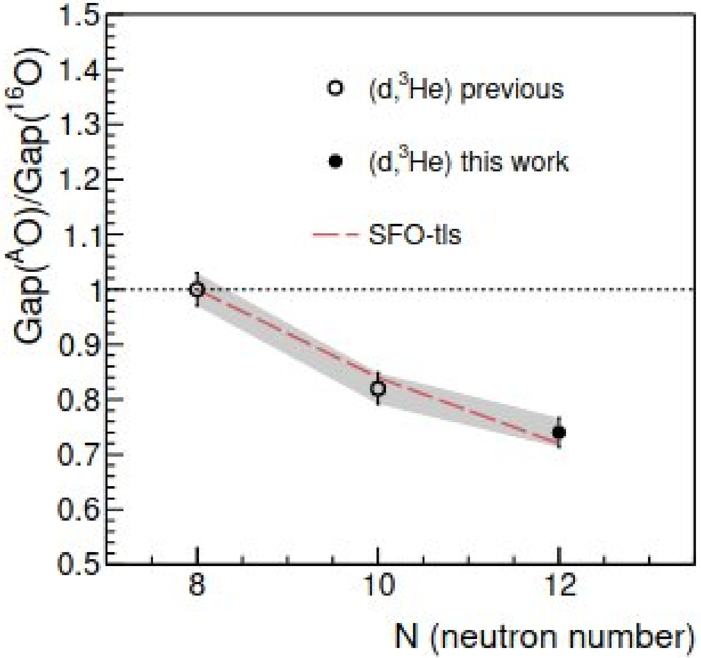
Will ^{20}O follow the trend?

Could be determine the *pn* tensor contribution?

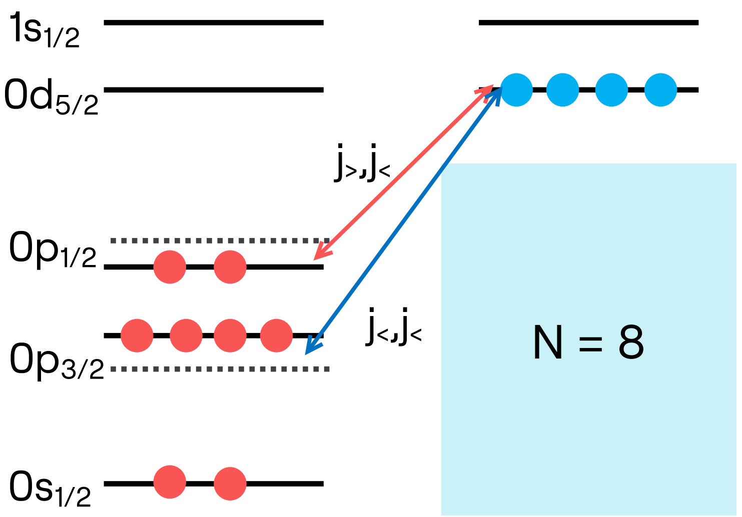
Physics case

E796 to measure **transfer** reactions probing single-particle occupancies in ^{20}O.

1. Proton removal $^{20}O(d,^3He)^{19}N$ to investigate persistence of Z = 6



J. Lois-Fuentes, PhD thesis (2023)



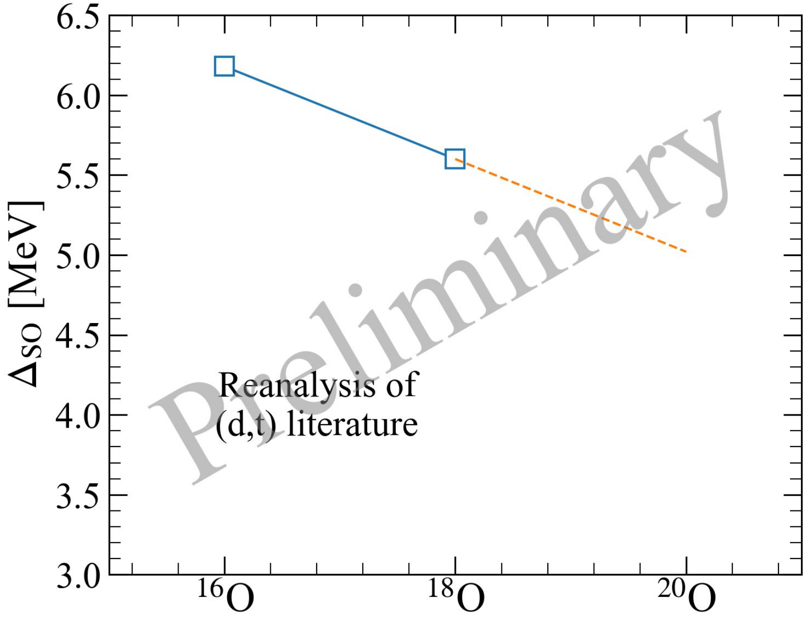
Schematic view of tensor interaction in ^{20}O

Tensor V_{pn} reduces Z = 6 gap as neutrons are added to $\nu 0d_{5/2}$

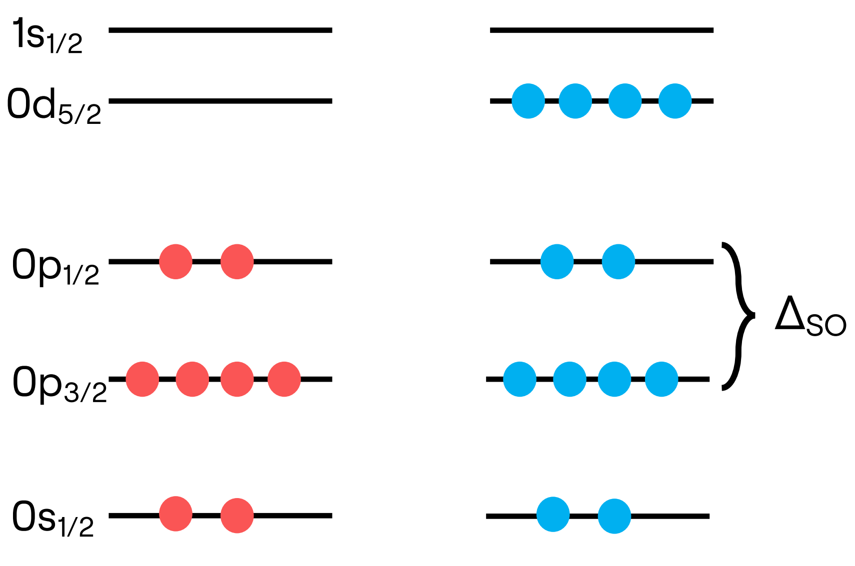
Physics case

E796 to measure **transfer** reactions probing single-particle occupancies in ^{20}O.

2. Neutron removal $^{20}O(d,t)^{19}O$ to extract N = 6 SO gap



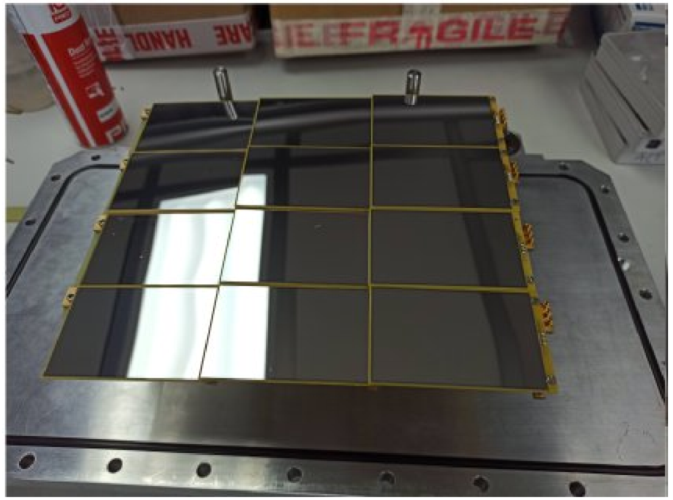
Reanalyis of previous data



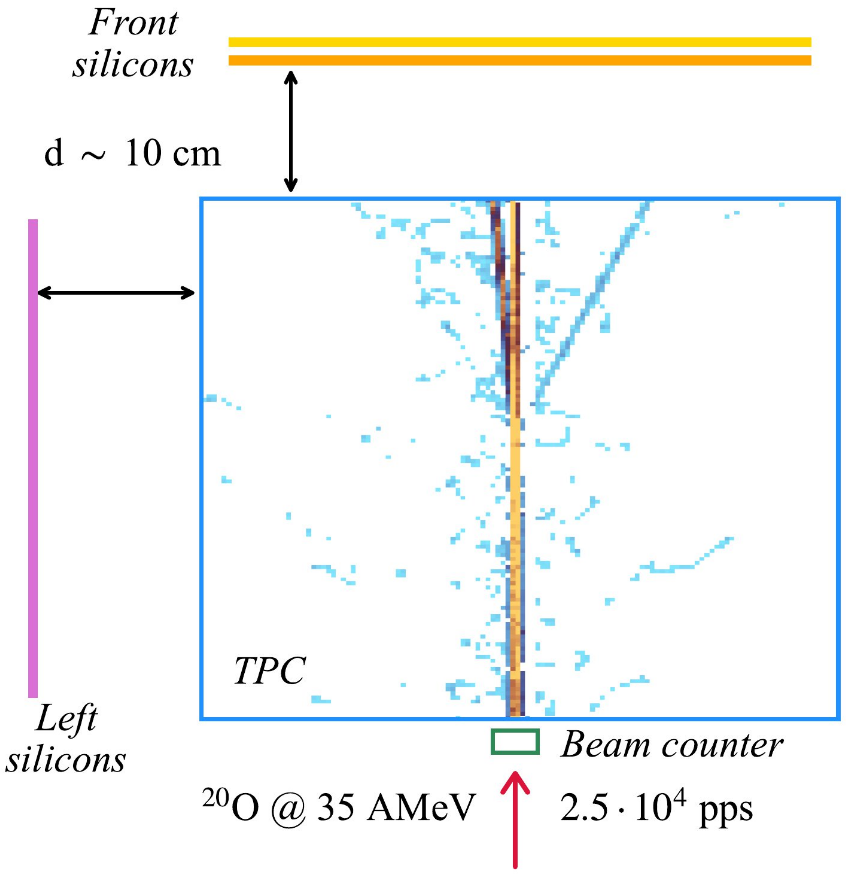
IPSM of ***^{20}O***

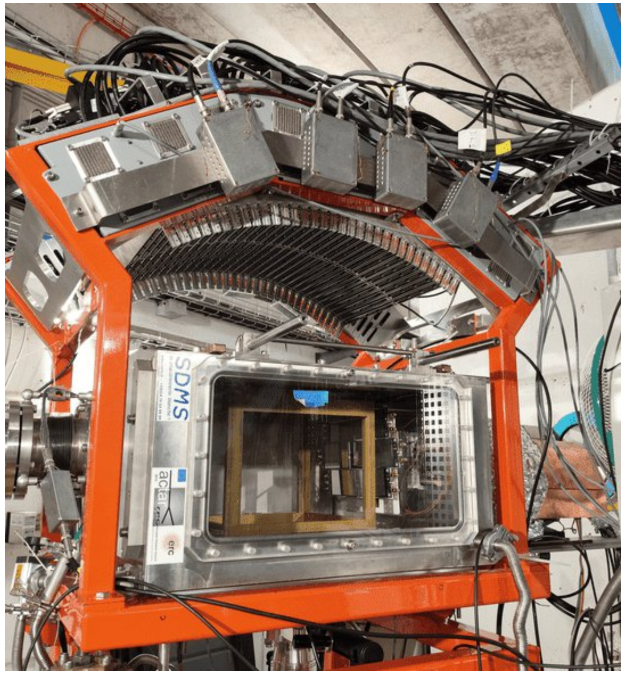
Experimental setup

E796 @ LISE in 2022. First transfer experiment with ACTAR TPC!



Silicon sizes:
80 x 50 x 0.5 mm^3

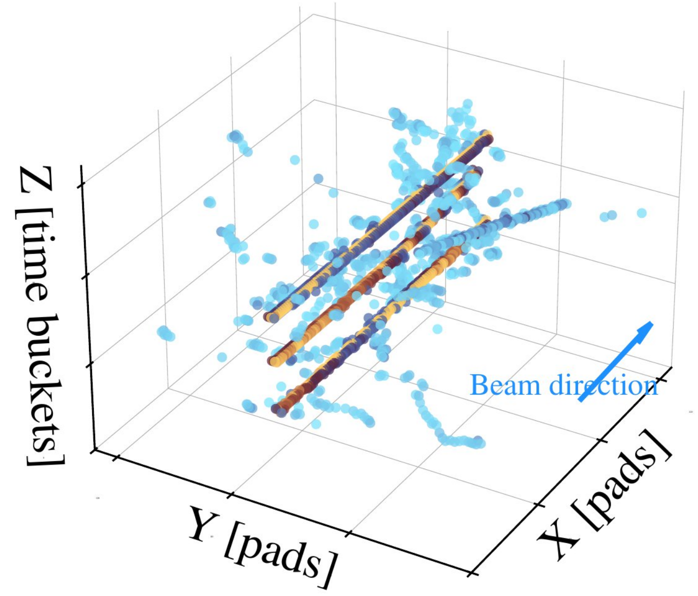


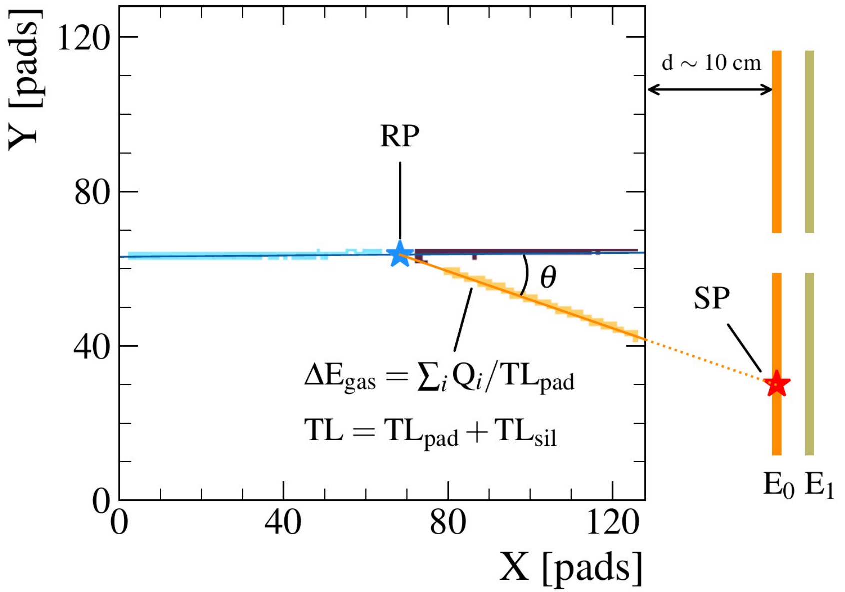


Gas mixture:
90% D_2 + 10 % iC_4H_{10}
at 952 mbar

A window to the analysis

Intricate analysis to extract reactions of interest out of noisy data.





Unique advantages from the TPC:

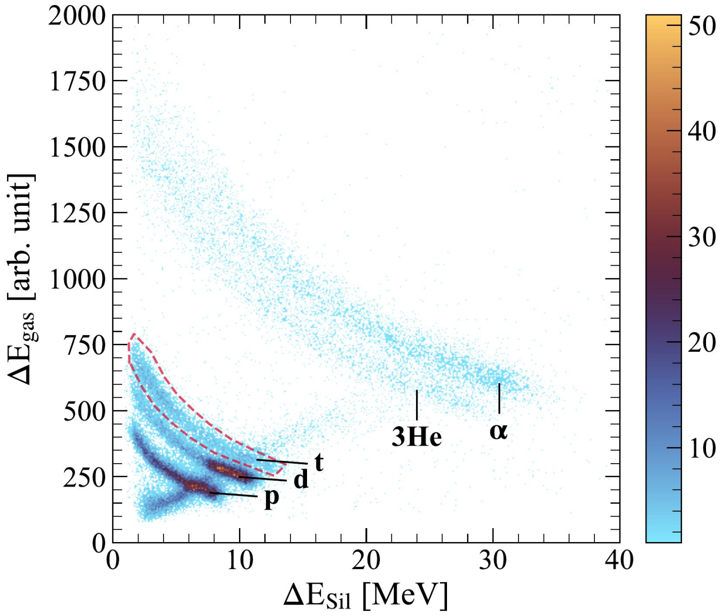
- Precise **vertex** determination
- Improved ΔE corrections

- Factor 10 in target number
- Implicit PID with ΔE_{gas}

A window to the analysis

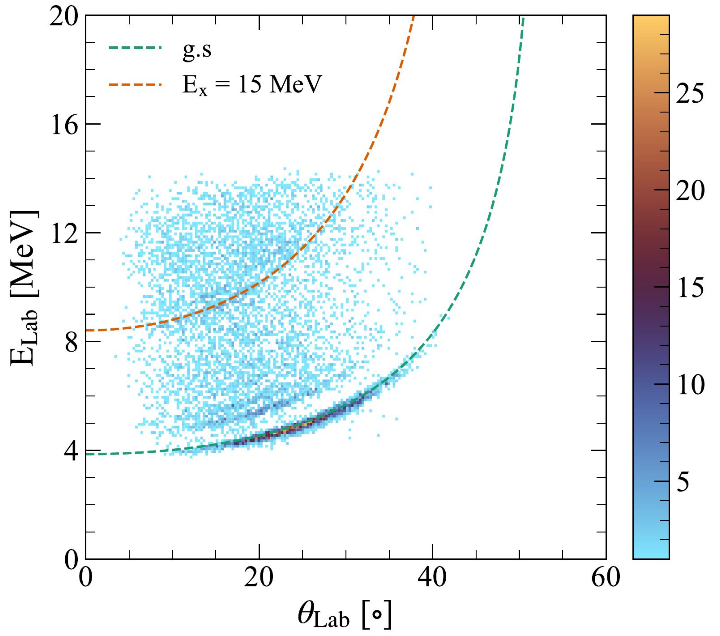
Two steps are needed after a binary reaction has been identified.

1. PID of tritons by plotting ΔE_{gas} vs ΔE_{Sil}

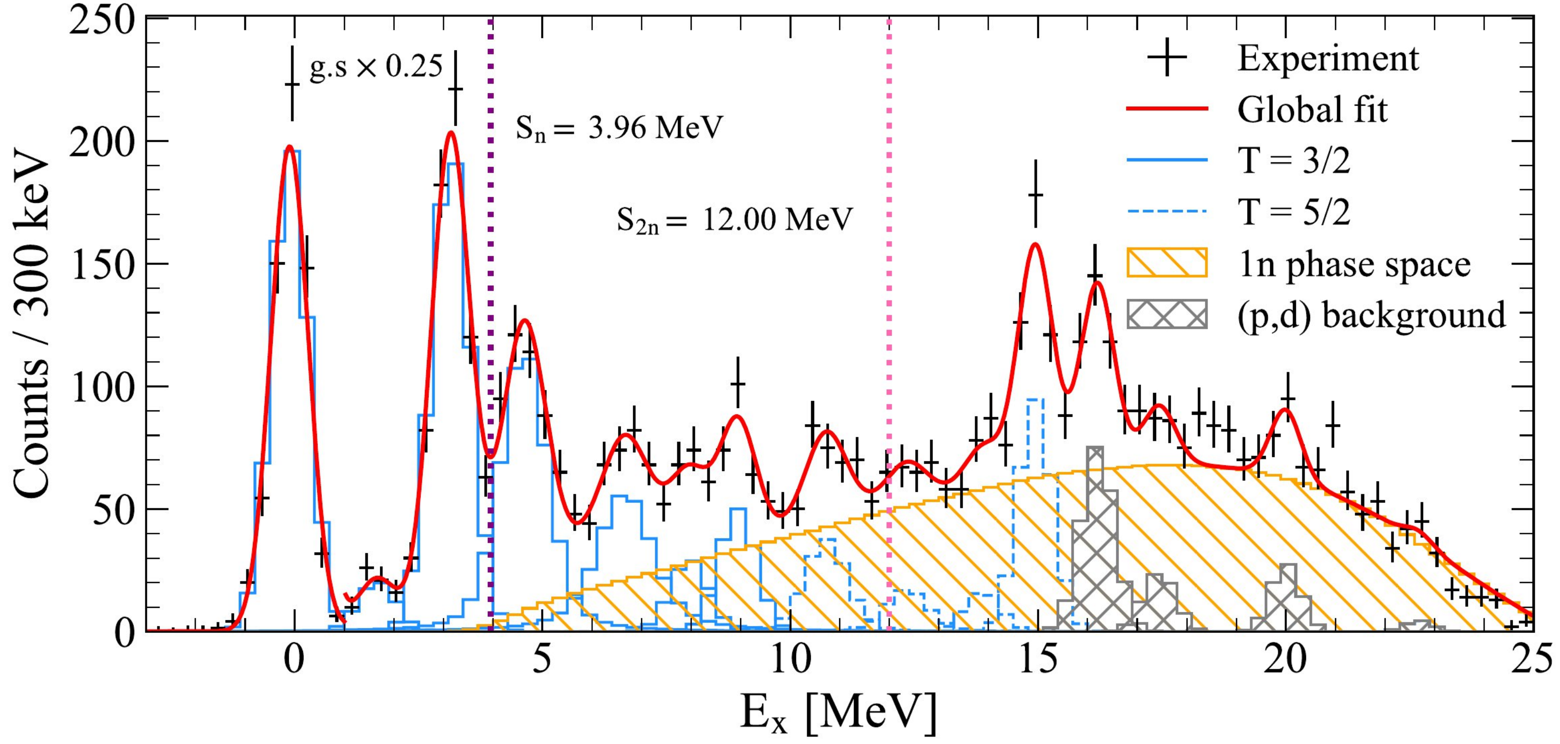


Masked punch-through to 2nd front layer

2. E_x reconstructed by the **missing-mass** technique



Results: E_x spectrum

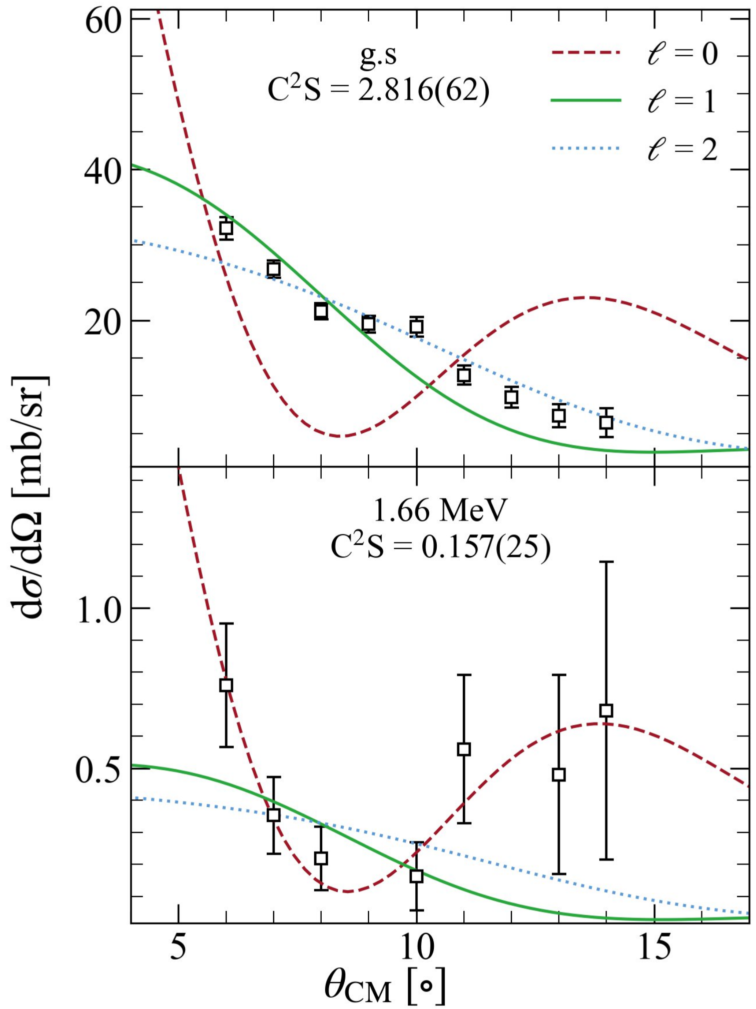


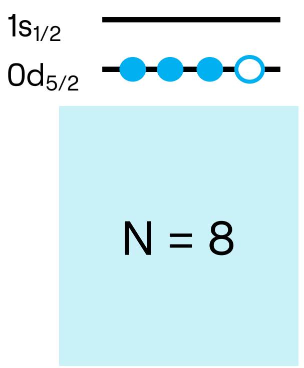
Negligible 2n phase space contribution

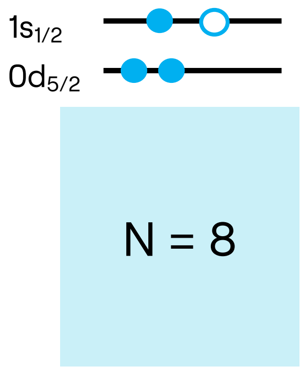
- 11 observed states
- At E_x > 15 MeV (p,d) contamination appears

- Isospin T = 3/2 and 5/2
- Assigned based on $^{20}O(d,^{3}He)^{19}N$

Results: cross-sections





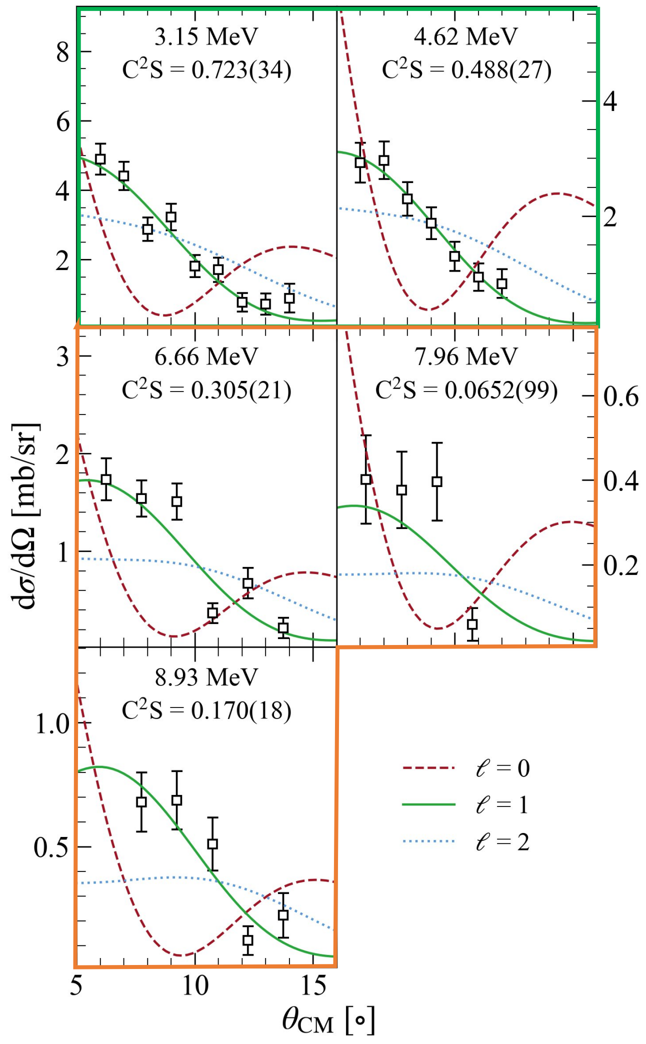


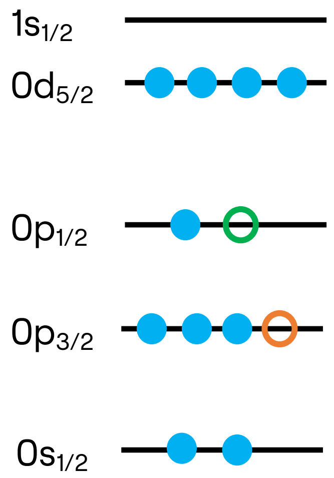
DBWA with Fresco

- OMP:
  - ^{20}O + d: Daehnick
  - ^{19}O + t: Pang
- ⟨ d | t ⟩ from ab-initio GFMC
- ⟨ ^{20}O | ^{19}O ⟩ from standard WS

- g.s: $5/2^+$, taking up 71% of the occupation
- 1^{st}: $1/2^+$, with 8% of $1s_{1/2}$ occupancy

Results: cross-sections





Based on shell-model calculations (see next slide):

- E_x = 3.1 and 4.6 MeV ⇒ $0p_{1/2}$
- E_x = 6.7, ..., 8.9 MeV ⇒ $0p_{3/2}$

T = 3/2 states:

- $0p_{1/2}$: 61 % of strength
- $0p_{3/2}$: just 14 % of occupancy!

Results: comparison with models

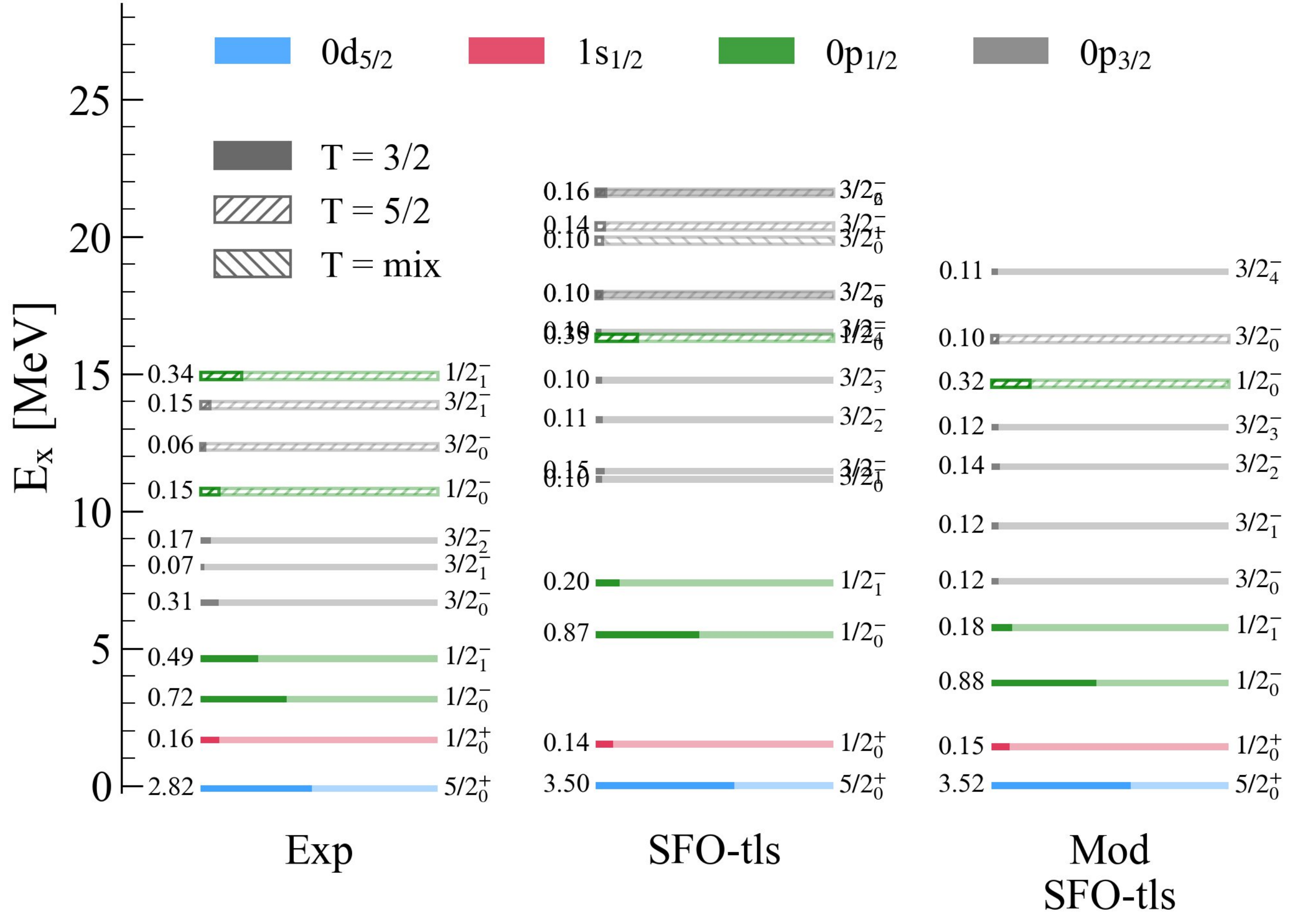
SFO-tls interaction

T. Suziki, T. Otsuka PRC 78 (2008)

- For *p-sd* neutron-rich nuclei
- *Modified:* reduced tensor $\nu\nu$ and $\nu\pi$ monopoles

- C^2S reduced wrt SFO-tls
- Great reproduction of low-lying states
- $0p_{3/2}$ less fragmented than predicted

- How to accommodate T = 5/2? Bc SFo-tls predicts it a much higher Ex!!



Results: centroids

***Modified* SFO-tls**:

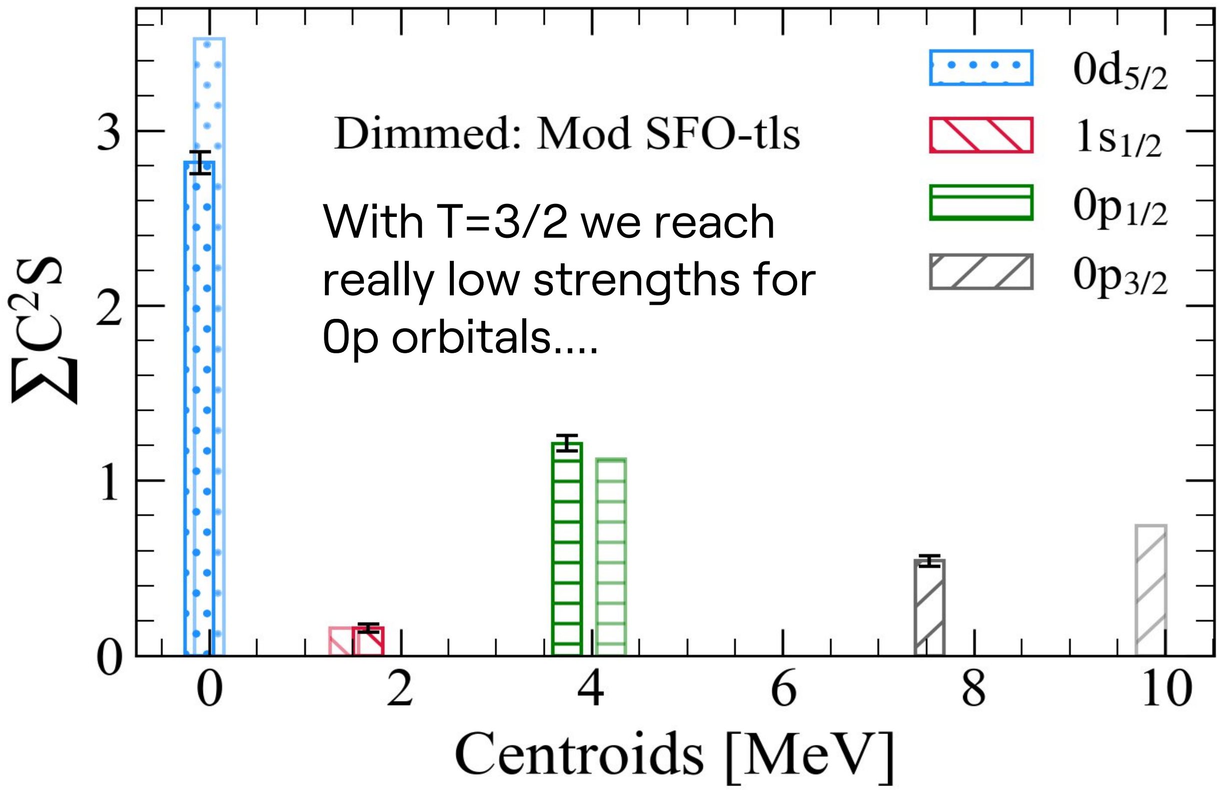
- Excellent agreement for $0d_{5/2}$, $1s_{1/2}$ and $0p_{1/2}$
- $0p_{3/2}$ shifted towards high E_x and overestimated $\sum C^2S$

$0p_{1/2}$ – $0p_{3/2}$ gap:

- Exp: 3.79(9) MeV
- Theo: 5.64 MeV

$\Rightarrow$ Gap is reduced by ~ 1.8 MeV!

No systematic errors on C2S have been included yet. Should we for the EuNPC? About 30% due to OMPs

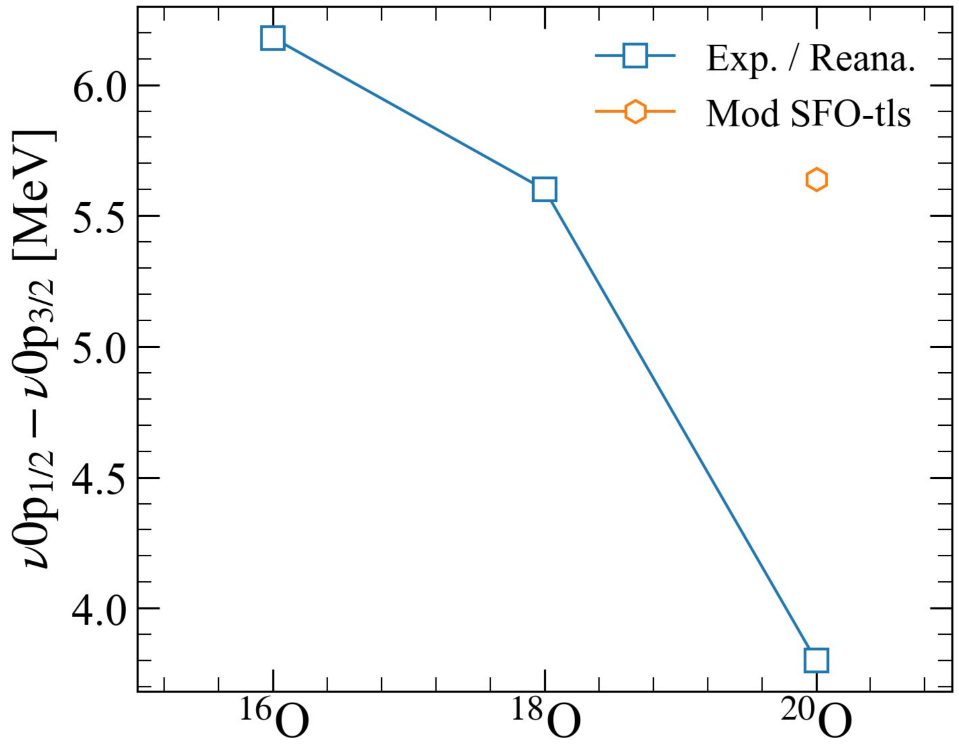


No 0p vacancies were observed through $^{20}O(d,p)^{21}O$

B. Fernández-Domínguez et al. PRC 84 (2011)

Results: gap evolution

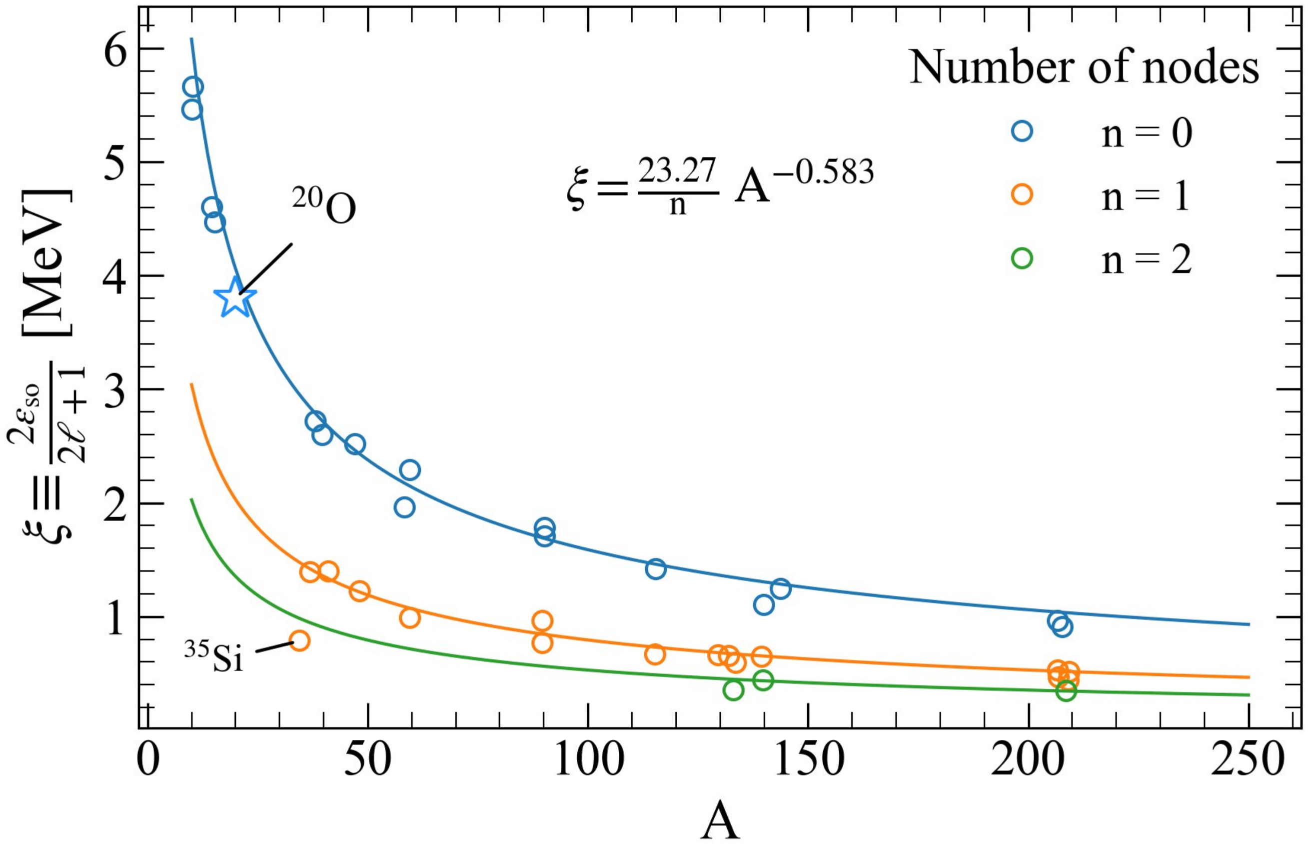
- ^{16}O(d,t): *K. H. Purser et al. NPA 132 (1969)*. No need to reanalyze xs bc there is only one state per nlj; just take the Ex
- ^{16}O(d,p): Alleged state 3/2- is not *single-particle* but j-forbidden stripping. See *K. Hosono JPSP 25 (1968)* Table II. This state is neutron $0d_{5/2}$ + proton $0p_{1/2}^{-1}0d_{5/2}^{1}$ as I understood from it
- ^{18}O(d,t): *G. Mairle et al. NPA 280 (1977)*. Reanalysis of xs with our OMPs and Fresco. Major discrepancies with their paper
- ^{20}O(d,t): this experiment



We are lacking theo calculations for 16O and 18O

Conclusions

- To be determined



Acknowledgements

GANIL

T. Roger
J. Pancin
F. Saillant
G. Wittwer
V. Morel
A. Cassisa
J.C. Thomas
O. Sorlin
L. Cáceres
C. Stodel
F. de Oliveira
C. Nicole

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J. Lois-Fuentes
B. Fernández-Domínguez
M. Caamaño
D. Fernández
D. Regueira
C. Cabo
H. Álvarez-Pol
Y. Ayyad
G. Mantovani

lpc Caen

F. Delaunay
L. Achouri

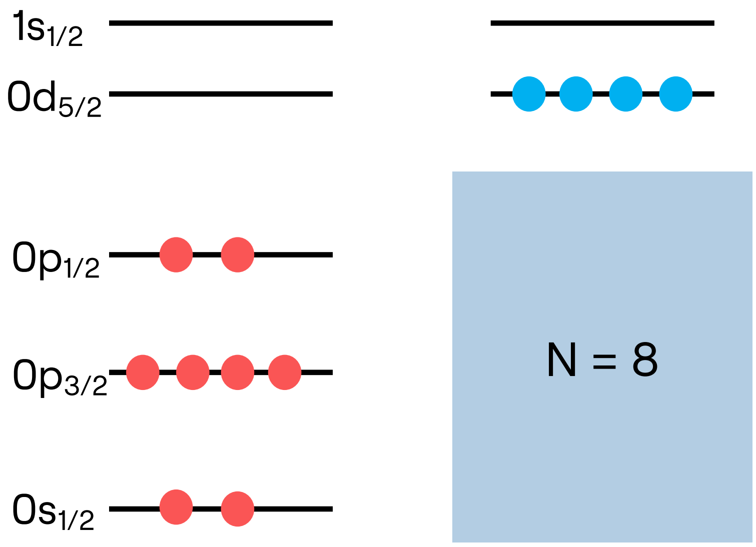
LP2i Bordeaux

J. Giovinnazzo
A. Ortega-Moral
S. Grevy
Q. Delignac
T. Kurtikian

Others pending of adding

Extra slides

A window to the analysis



Grazas!