Two-proton cluster states close to threshold and their decay modes in ^{15}F

Valérian

Alcindor

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Technische Universität Darmstadt

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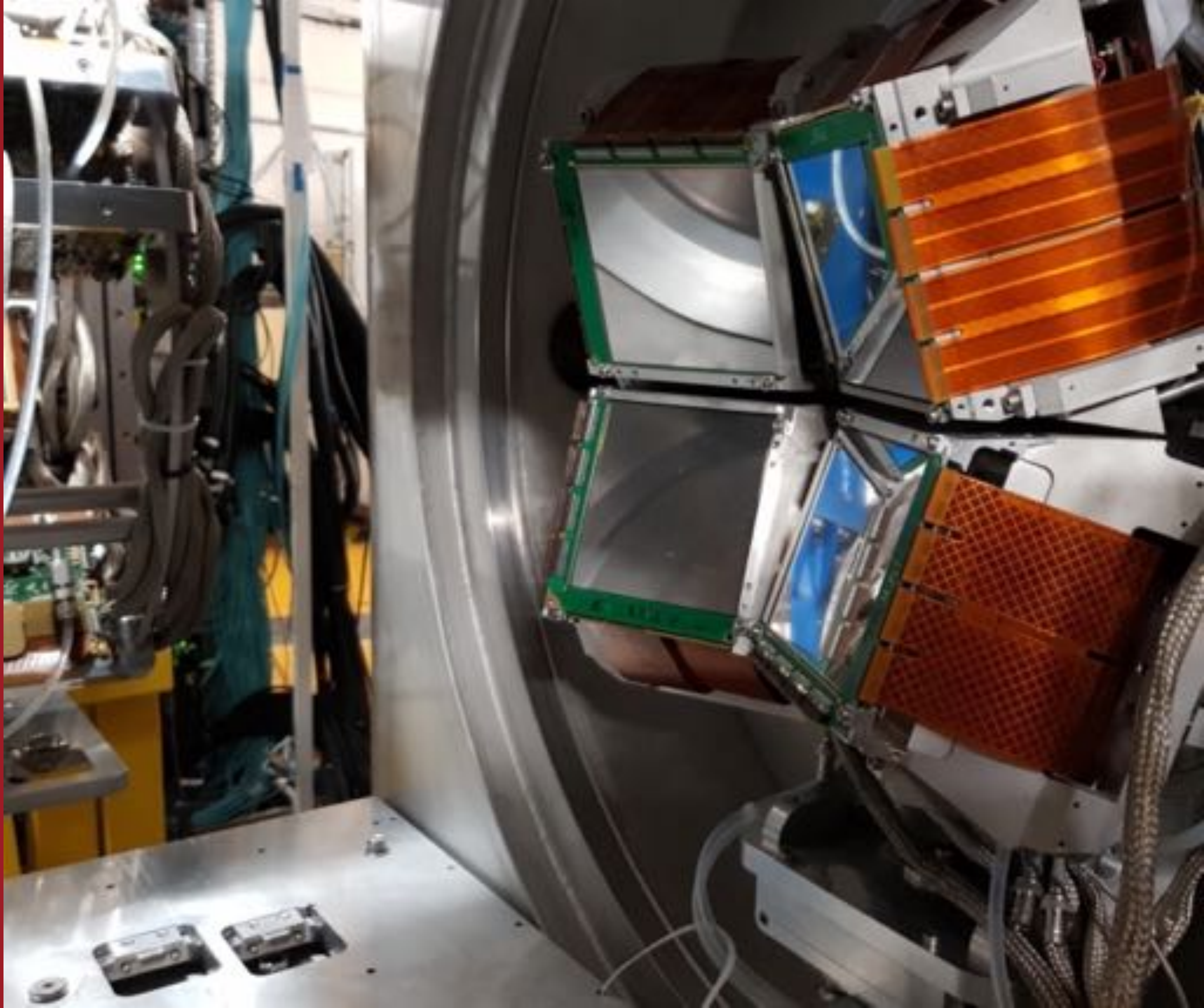
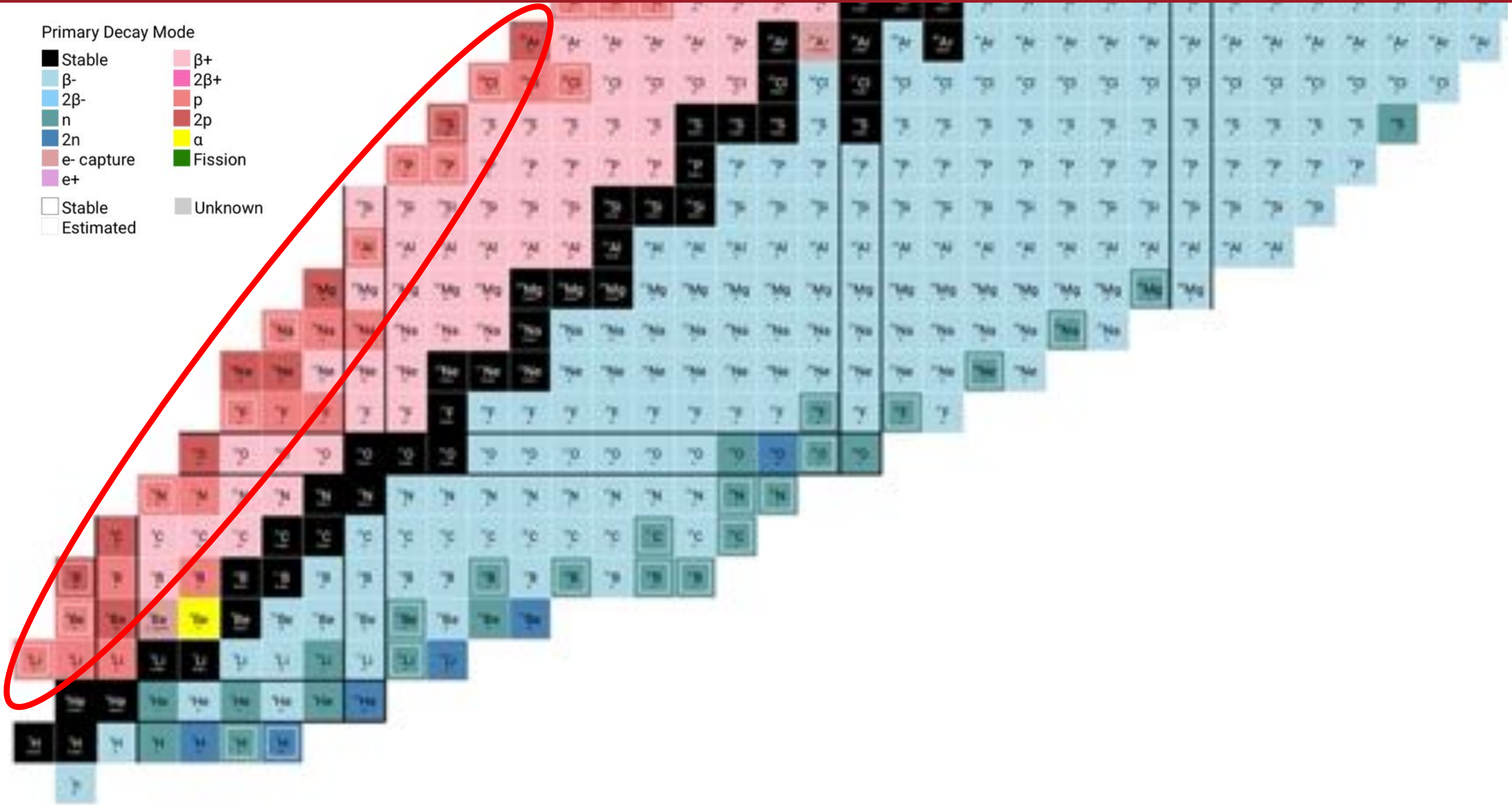


Physics at the drip line



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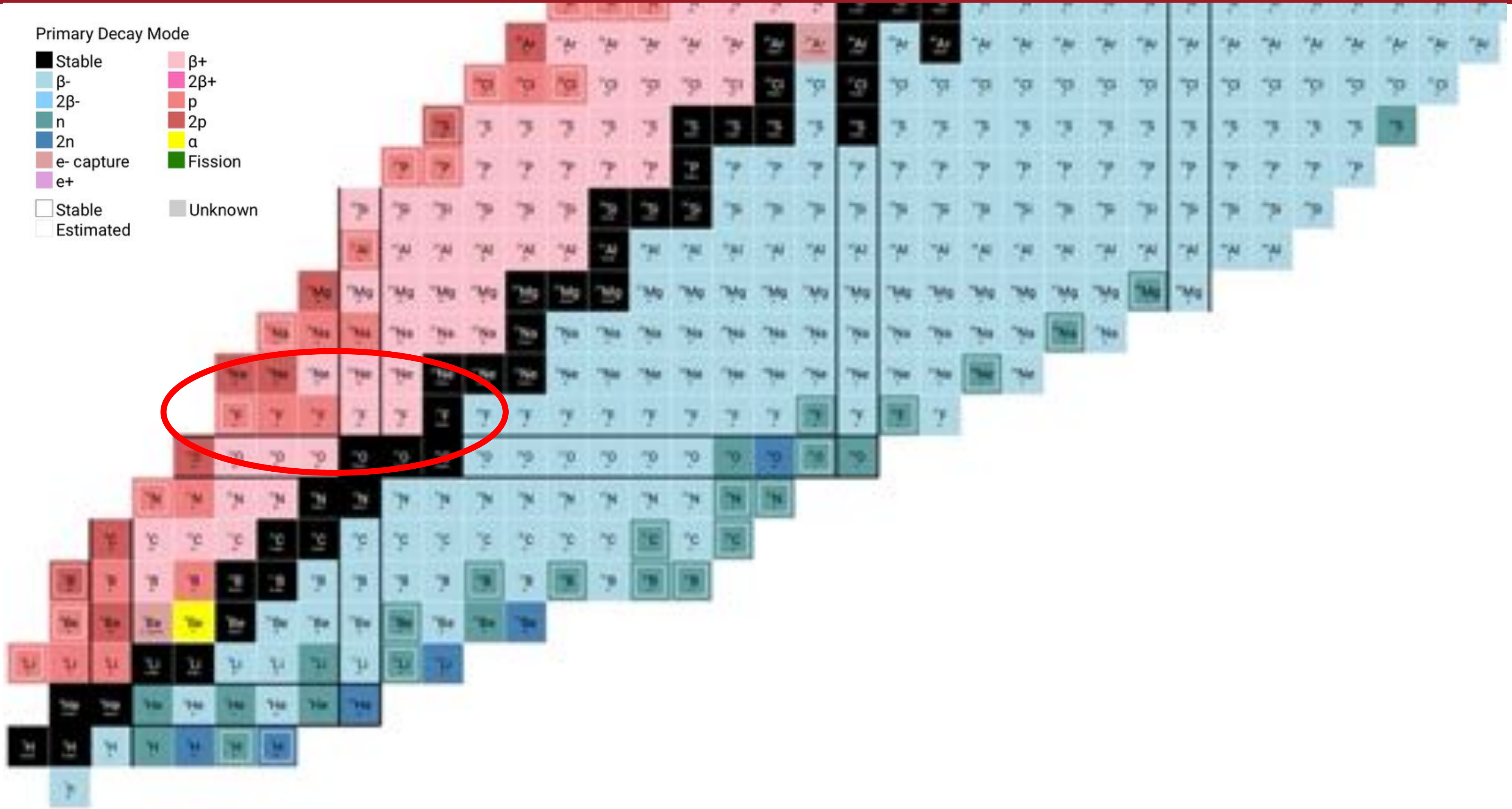

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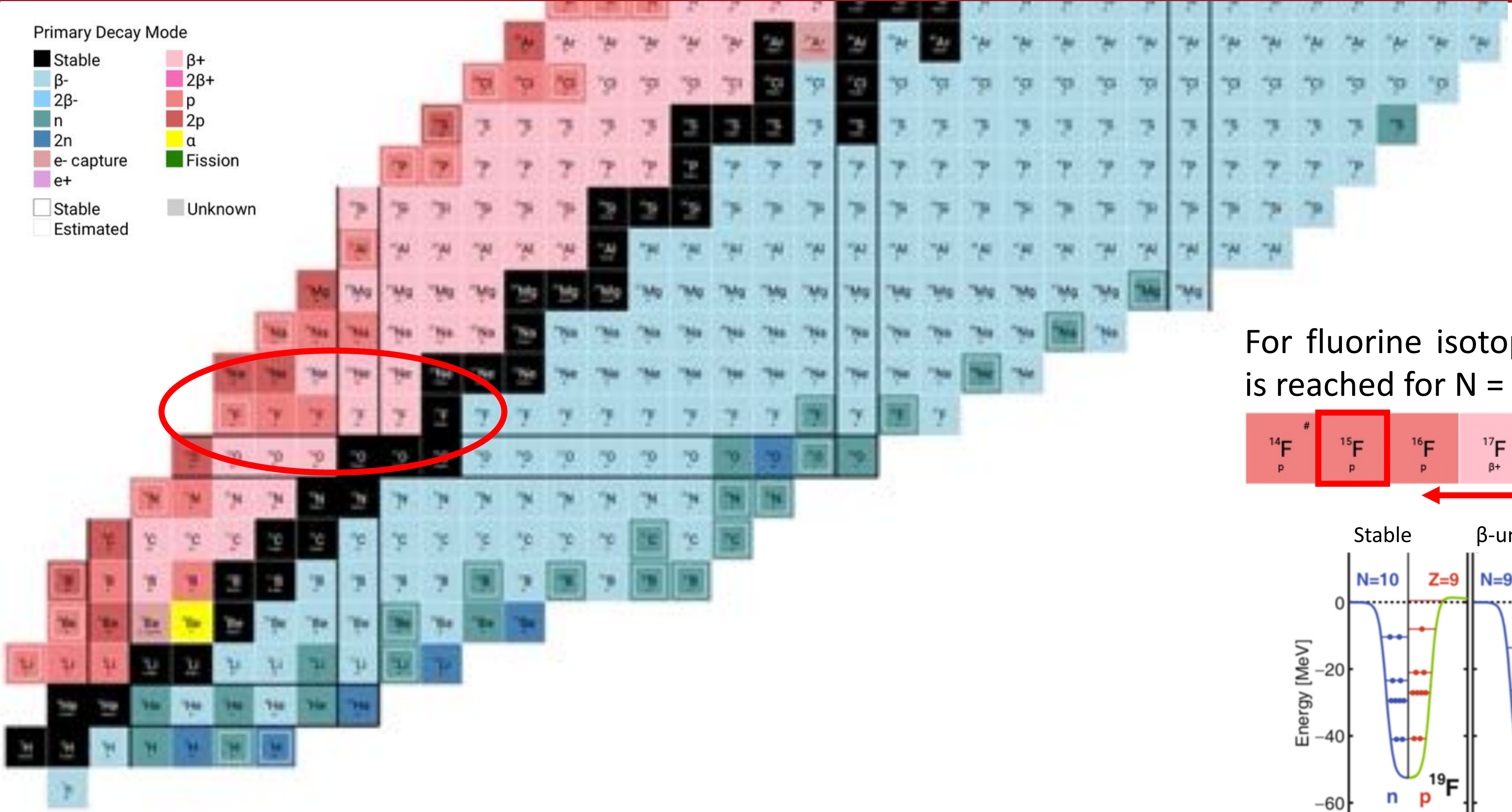
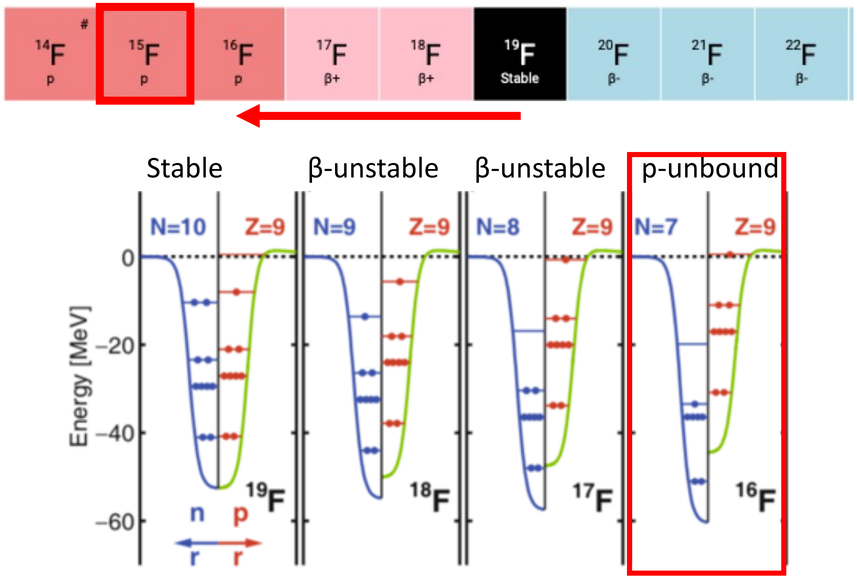


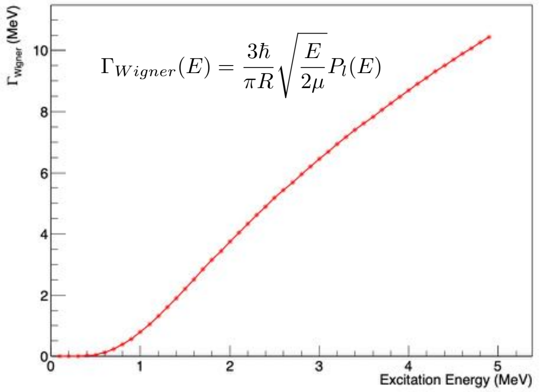
For fluorine isotopes the proton drip-line is reached for N = 7:



Charity, R.J. *Eur. Phys. J. Plus* **131**, 63 (2016)

The unbound nucleus ^{15}F

- Expected to be measured as a broad resonance
- Excited states with increased width as a function of excitation energy



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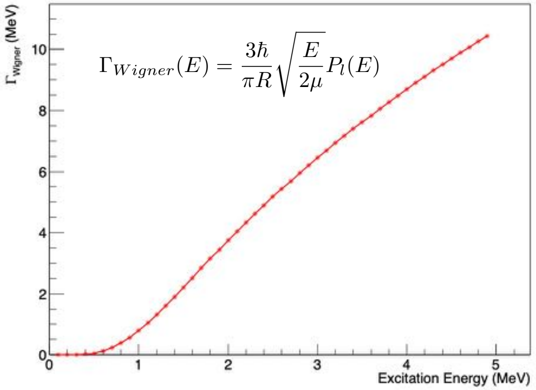

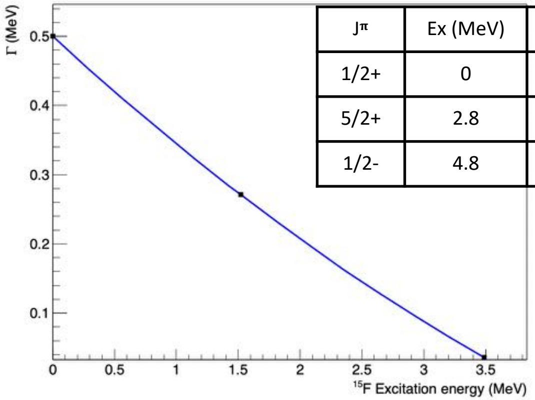

Jπ	Ex (MeV)	Γ (keV)
1/2+	0	500
5/2+	2.8	270
1/2-	4.8	40

1 order of magnitude narrower!

➢ Not true in ^{15}F

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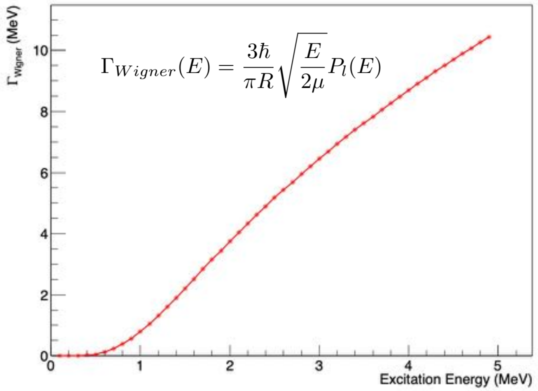

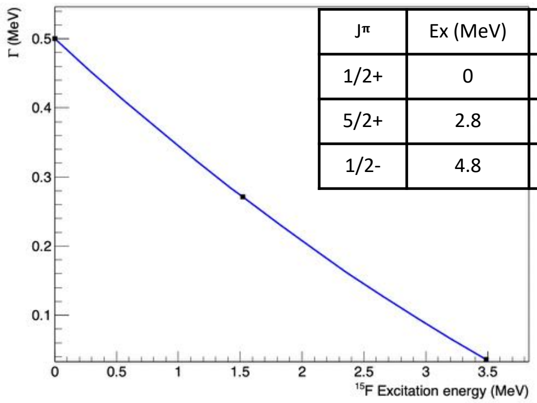

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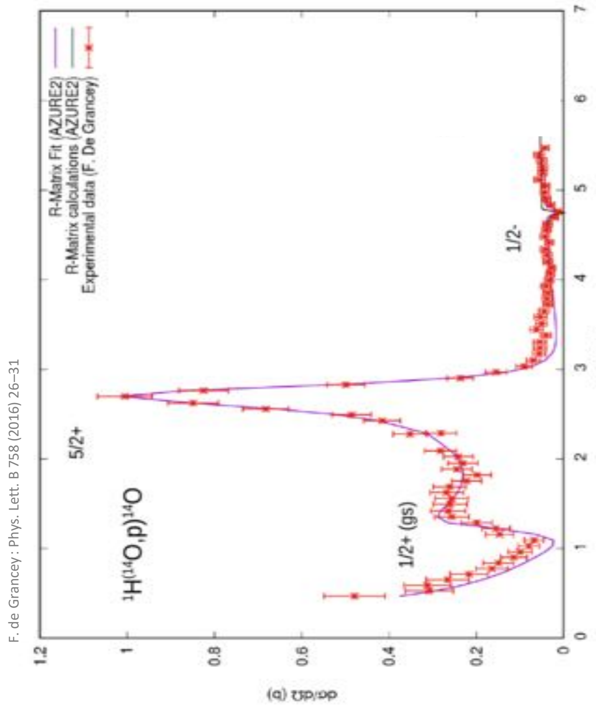

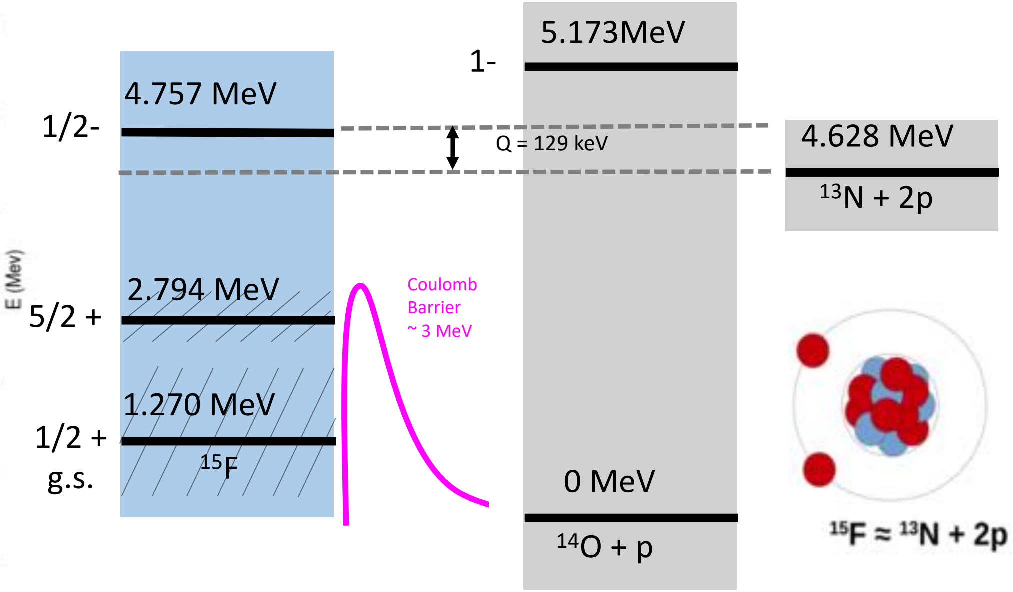

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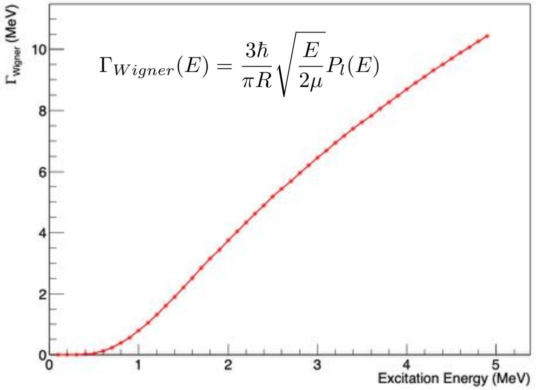

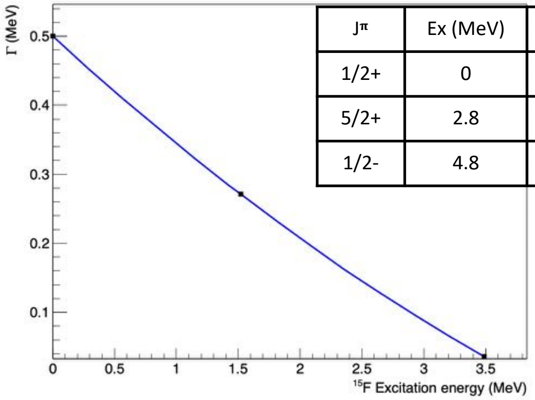

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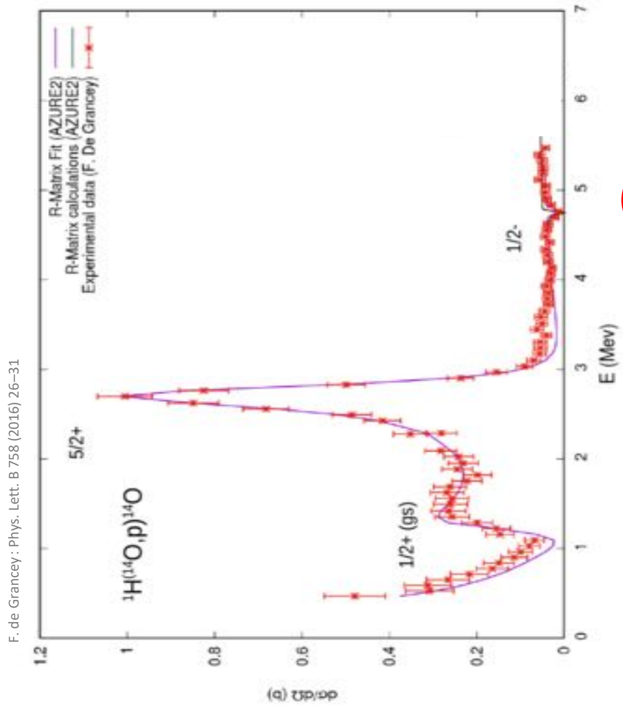

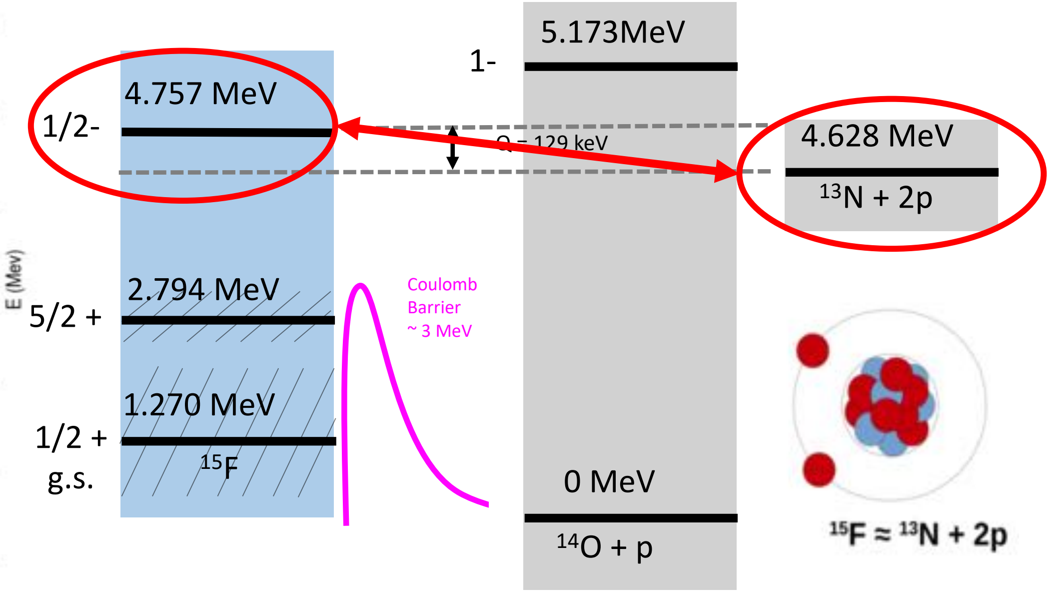

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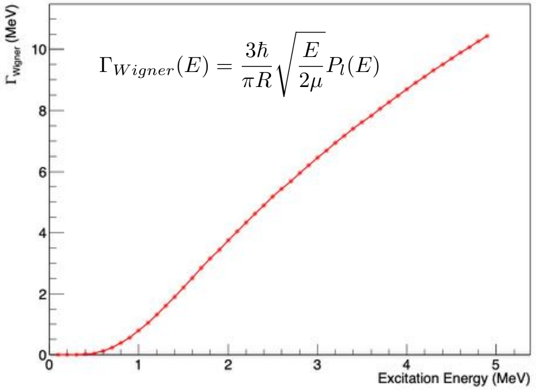

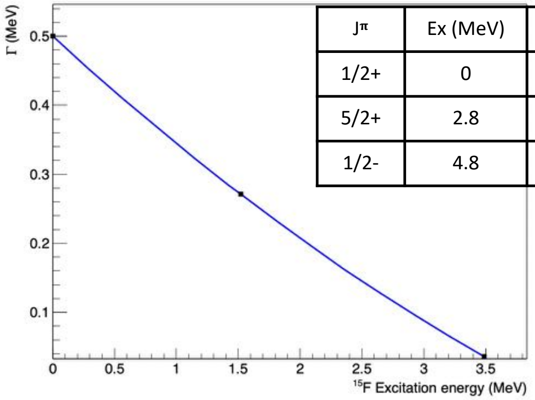

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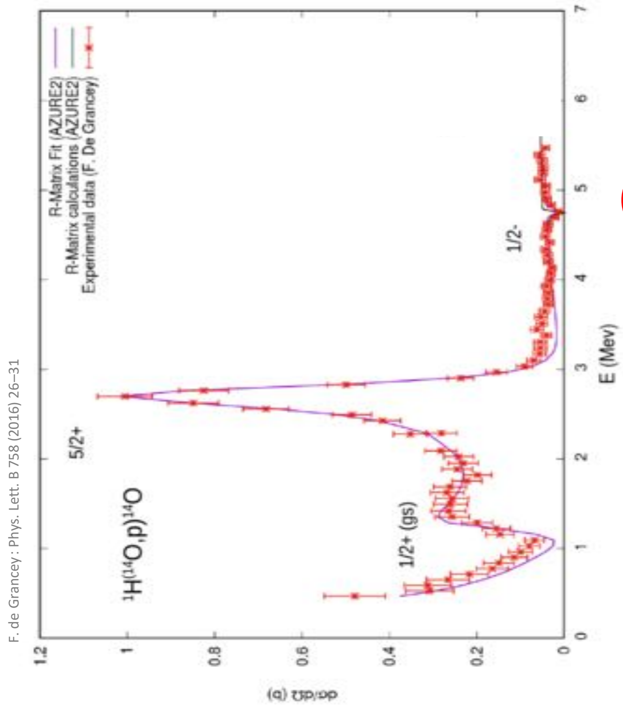
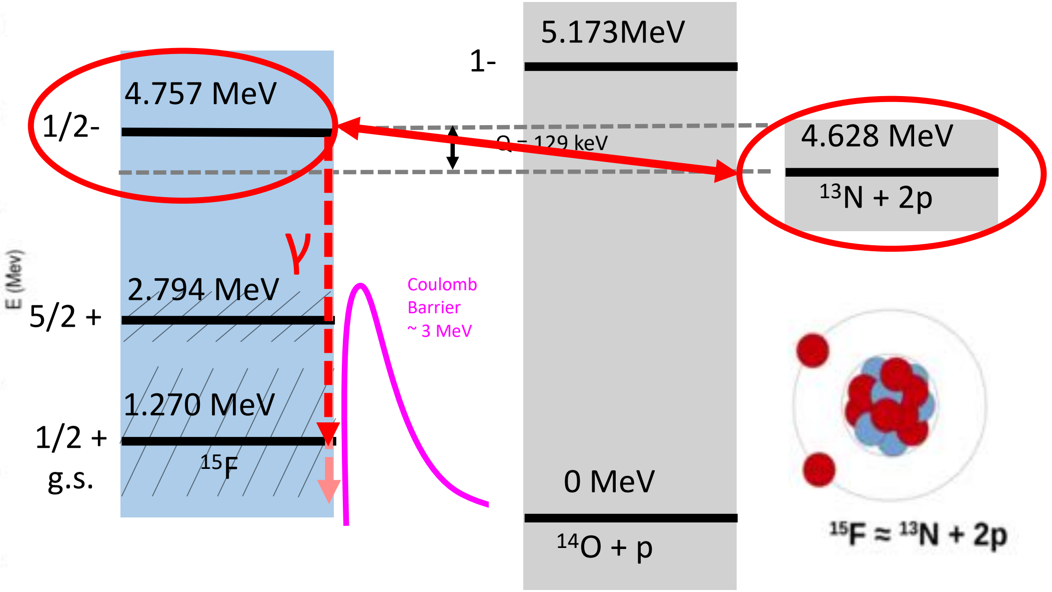
$$\tau \propto \frac{1}{\Gamma}$$

E (keV)	Γ (keV)	Jπ	T (s)
1270	500	1/2+	~10^{-21}
4757	40	1/2-	**~10^{-20}**



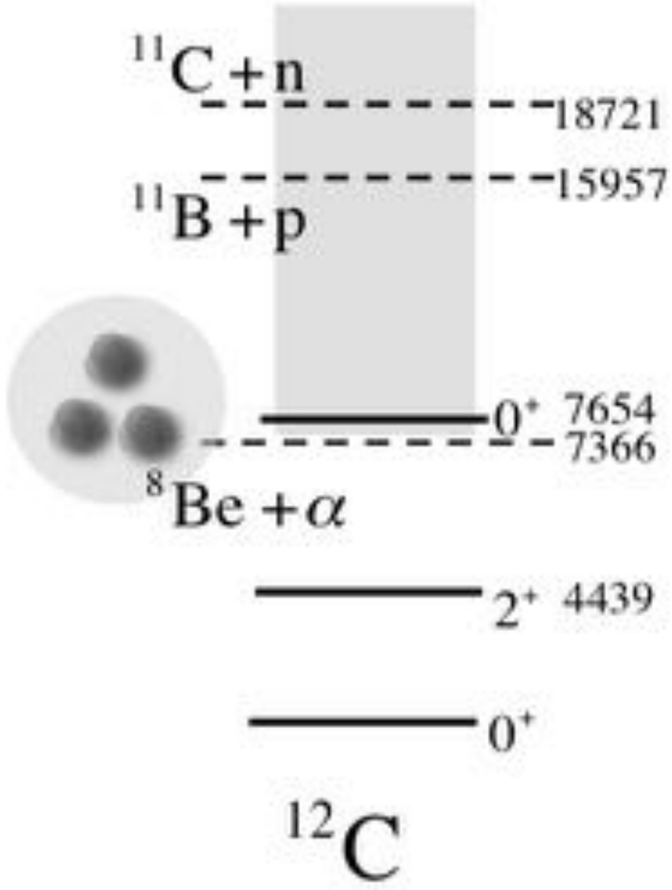


➢ The structure of this state changed by the nearby threshold: understood at 99% as a ^{13}N core + 2_p

➢ Can the longer half-life make the measurement of the gamma emission possible?

Near threshold clusterization

The Hoyle state:



Jacek Okołowicz et al. *Progress of Theoretical Physics Supplement*, Vol. 196, Oct. 2012

- Most "famous" nuclear state
- 3α-cluster

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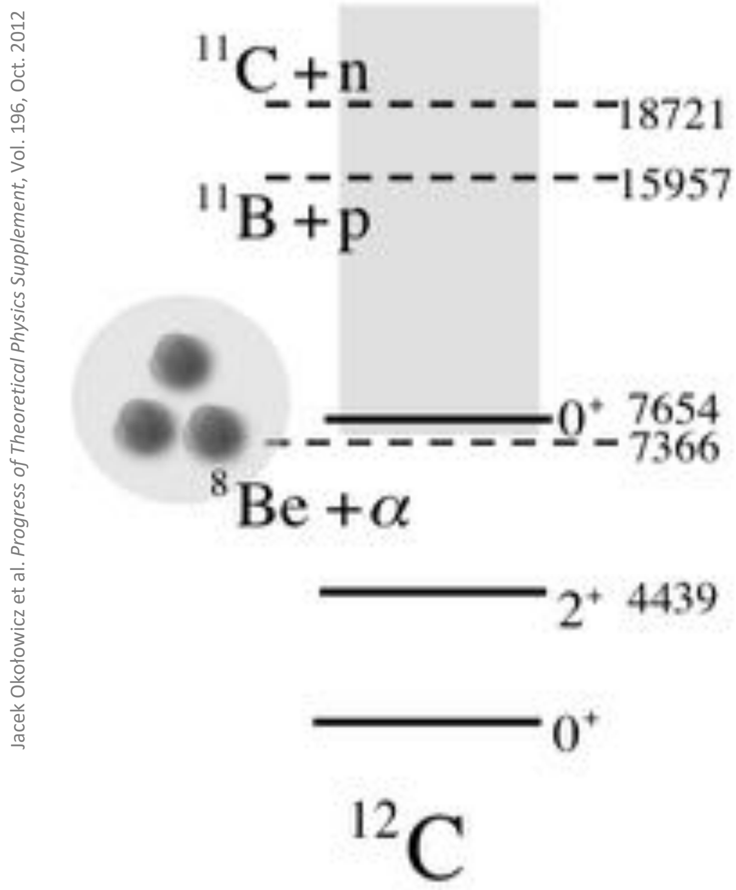

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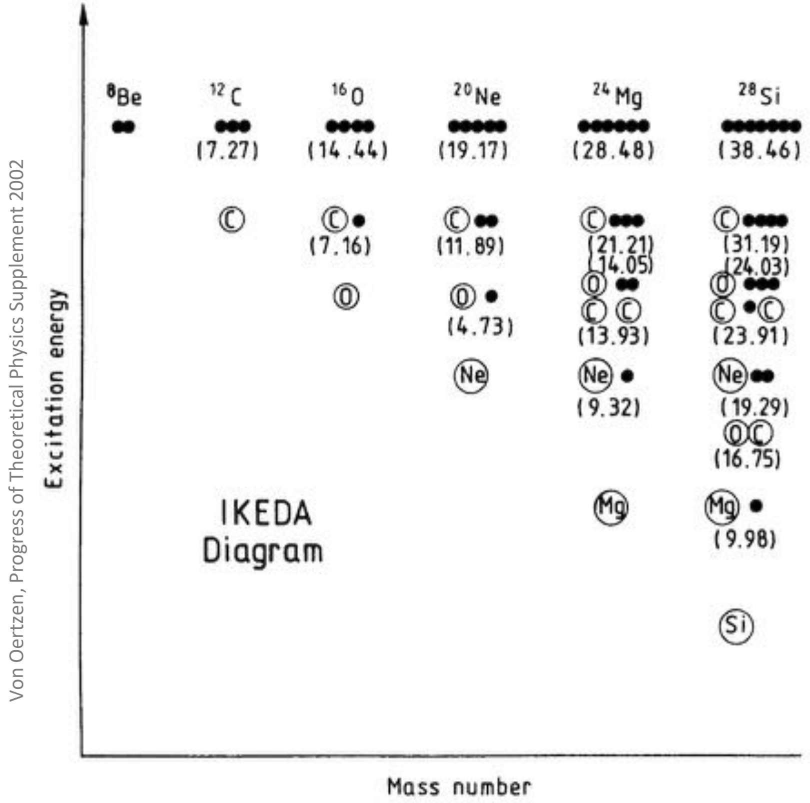
The Systematic Structure-Change into the Molecule-like Structures in the Self-Conjugate 4n Nuclei

Kiyomi IKEDA,*) Noboru TAKIGAWA and Hisashi HORIUCHI



- Ikeda conjecture: *the structure of states near their Nα decay thresholds should lead to the formation of Nα-cluster states.*

Near threshold clusterization

Generalization of Ikeda's conjecture

On the Origin of Nuclear Clustering

Jacek OKOŁOWICZ,[1,*] Marek PŁOSZAJCZAK[2,**] and Witold NAZAREWICZ[3,4,5,***]

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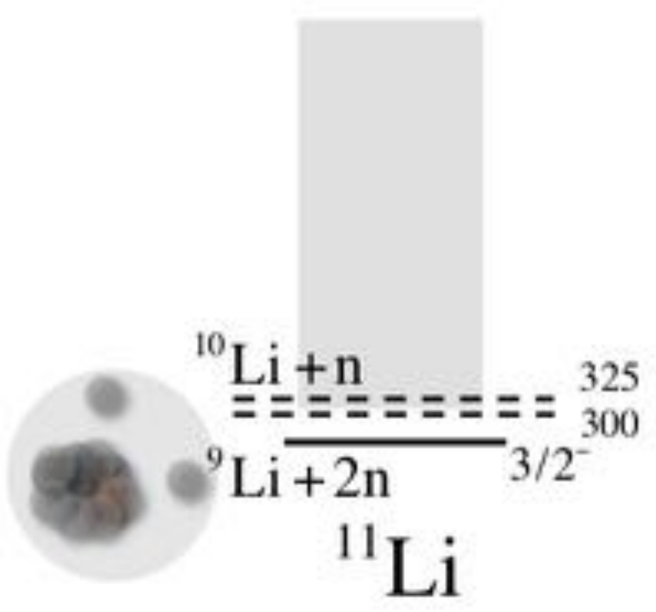

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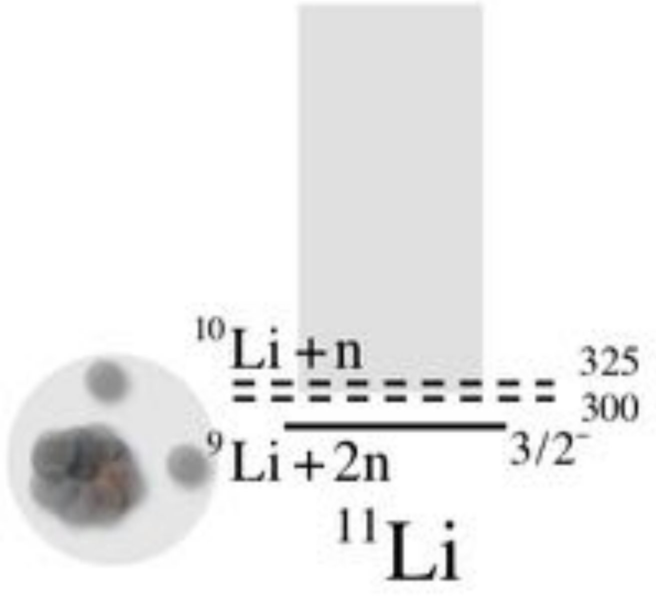
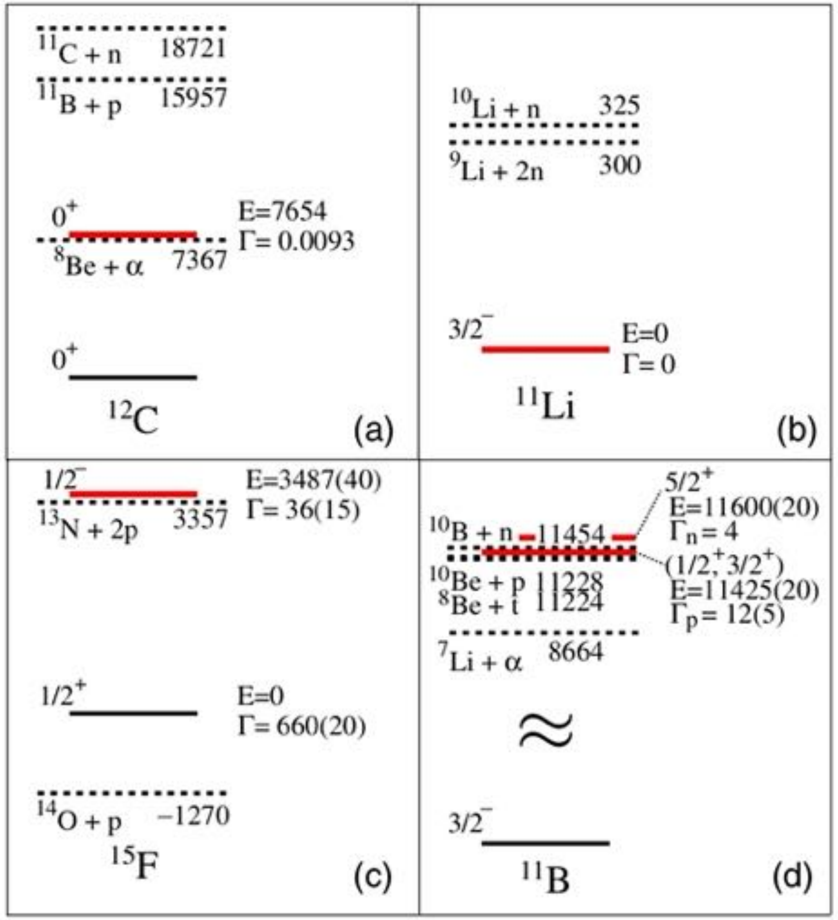


Convenient Location of a Near-Threshold Proton-Emitting Resonance in ^{11}B

J. Okołowicz,[1] M. Płoszajczak,[2] and W. Nazarewicz[3]



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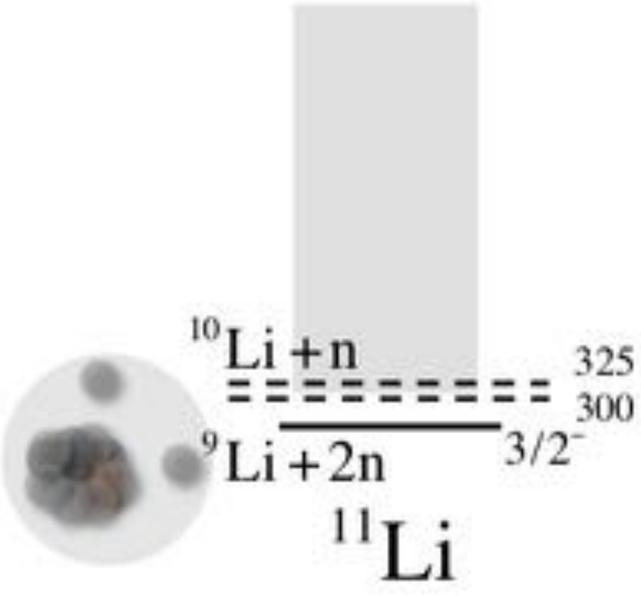

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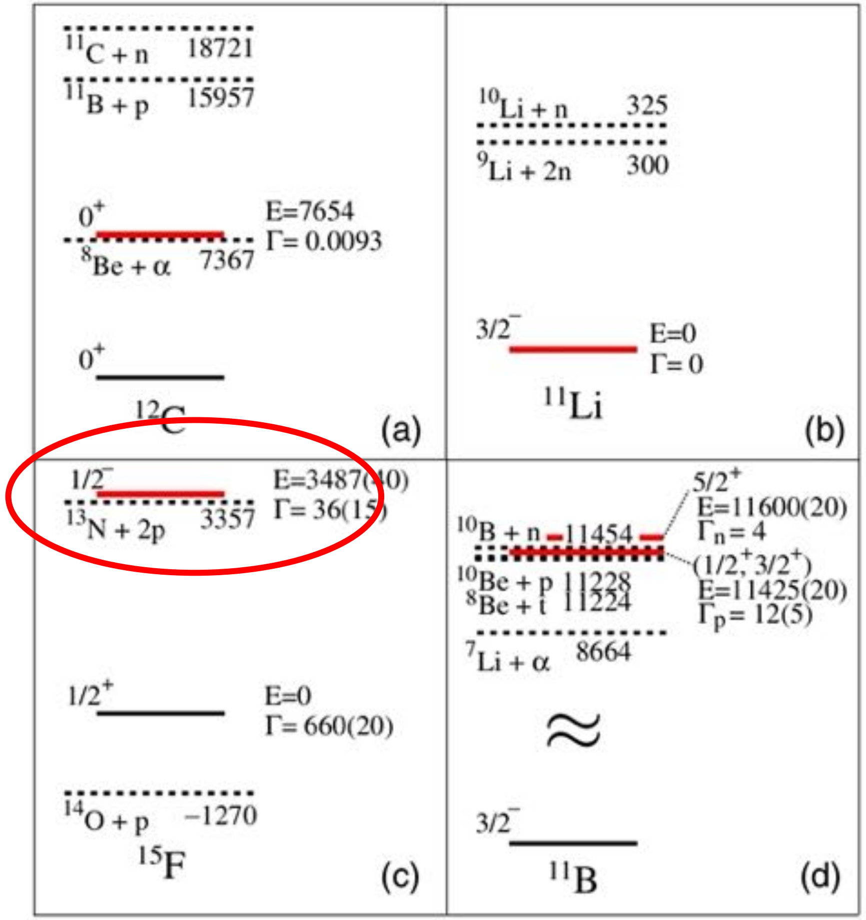
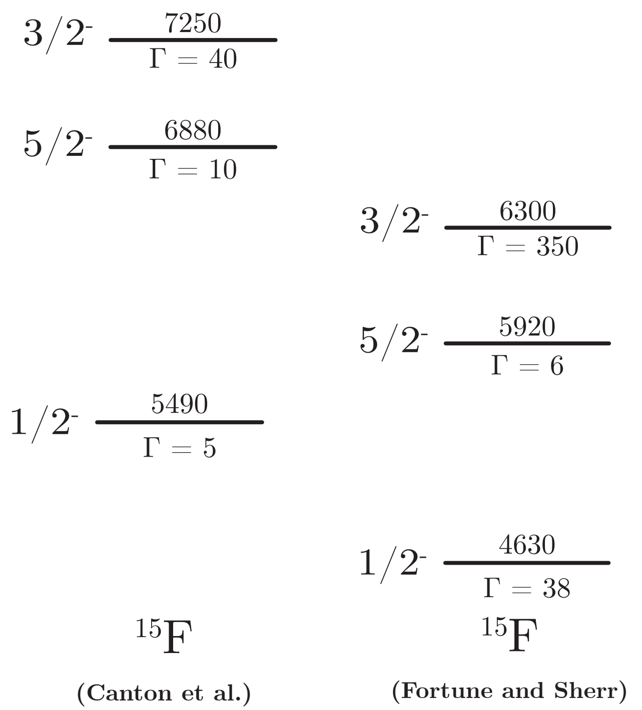


➢ Does Ikeda's conjecture hold for all near threshold states ?

Motivations

Predictions of other narrow states:



- Large differences for the width of the 3/2- state between Canton et al. and Fortune and Sherr.

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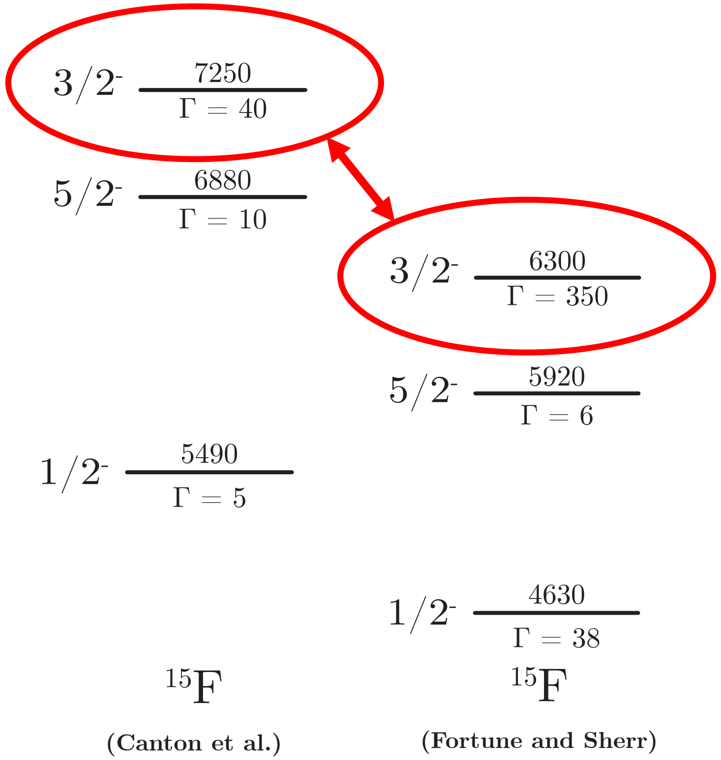

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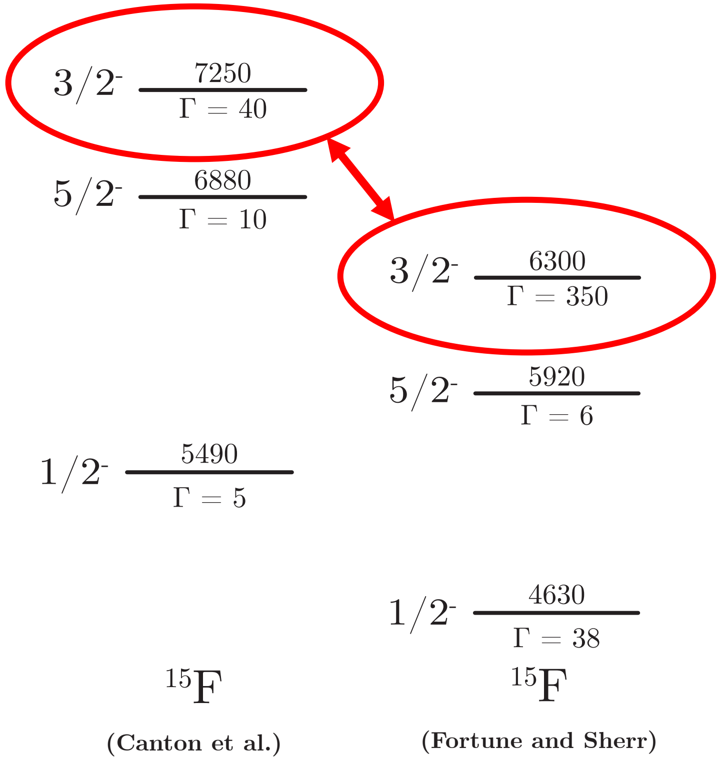

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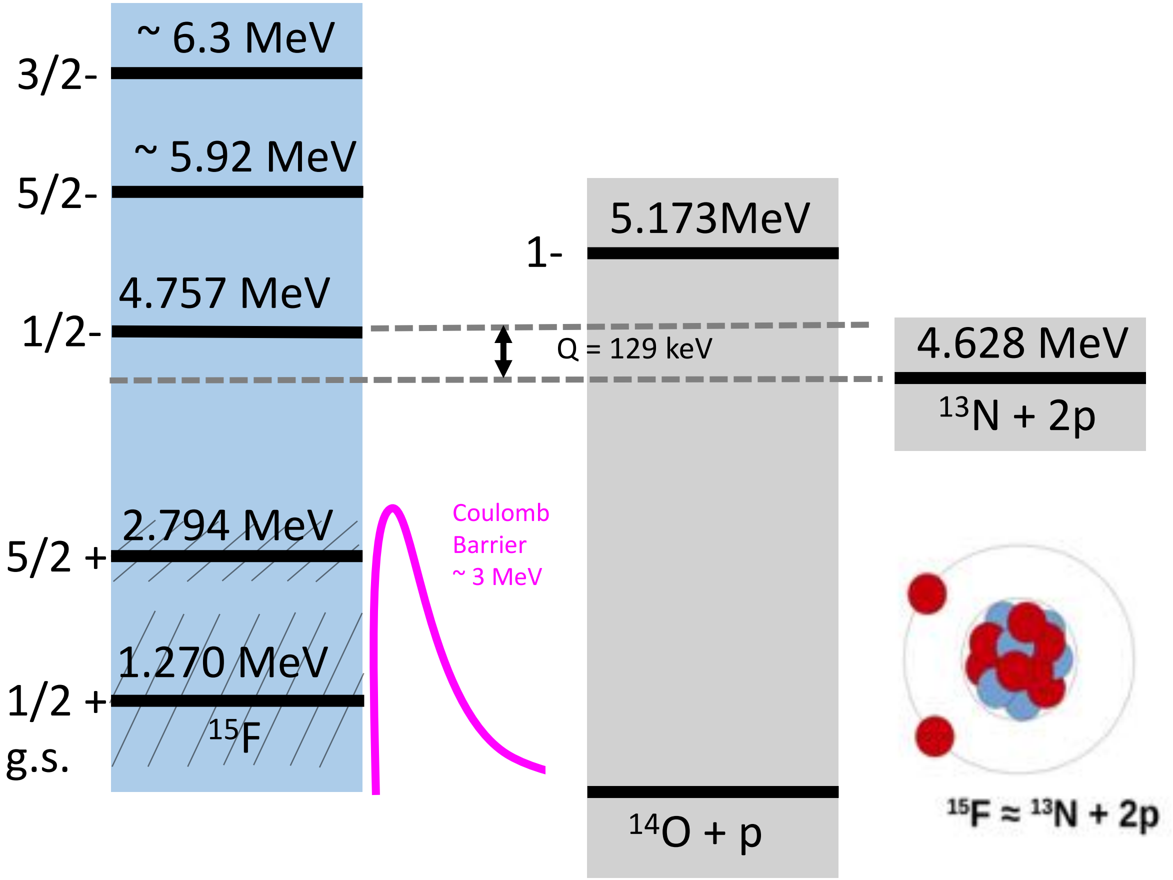

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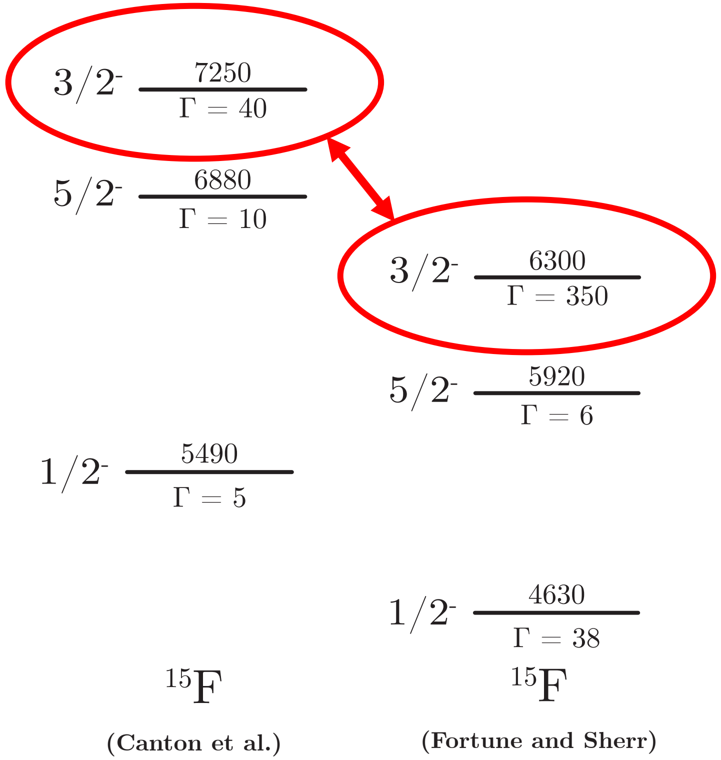

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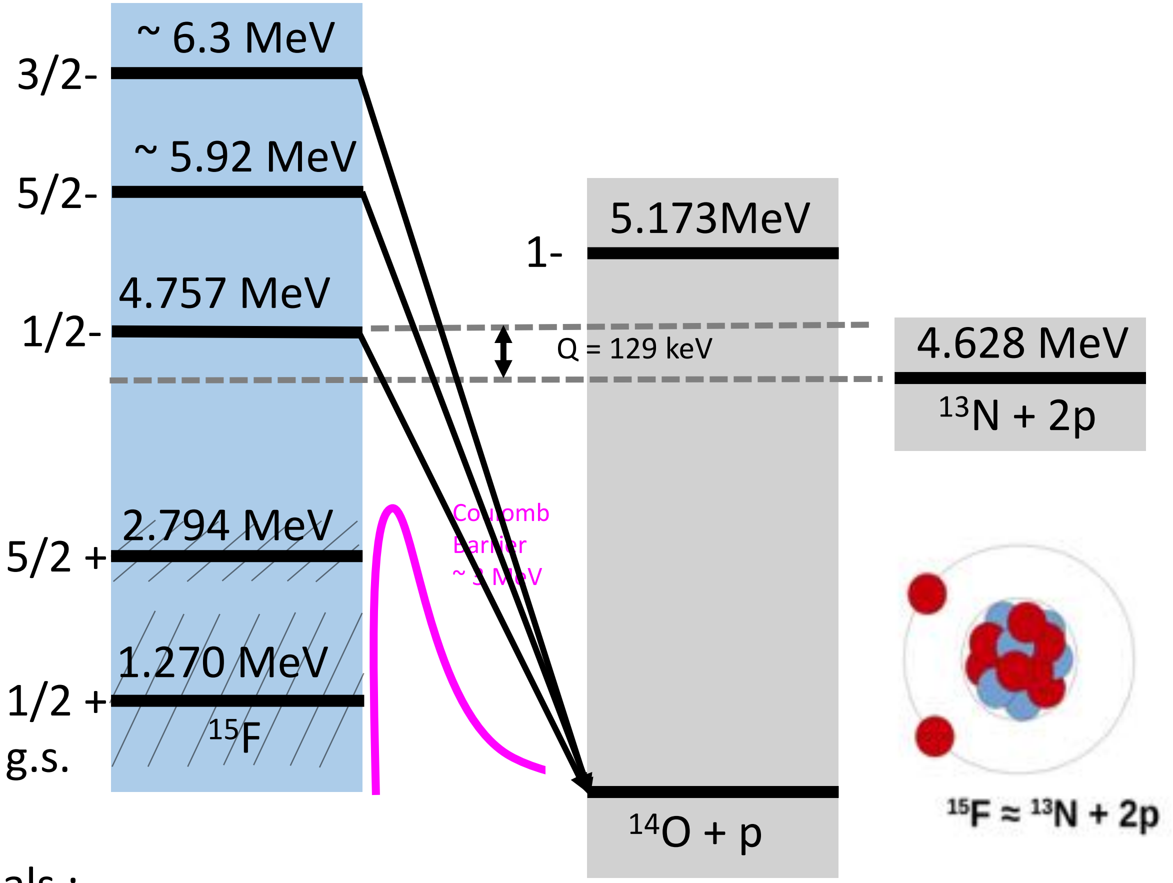

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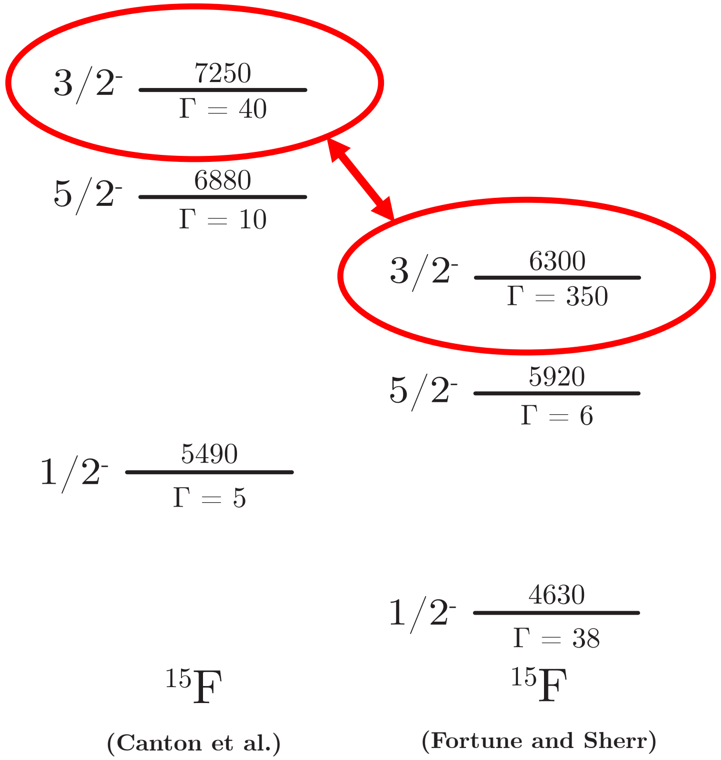

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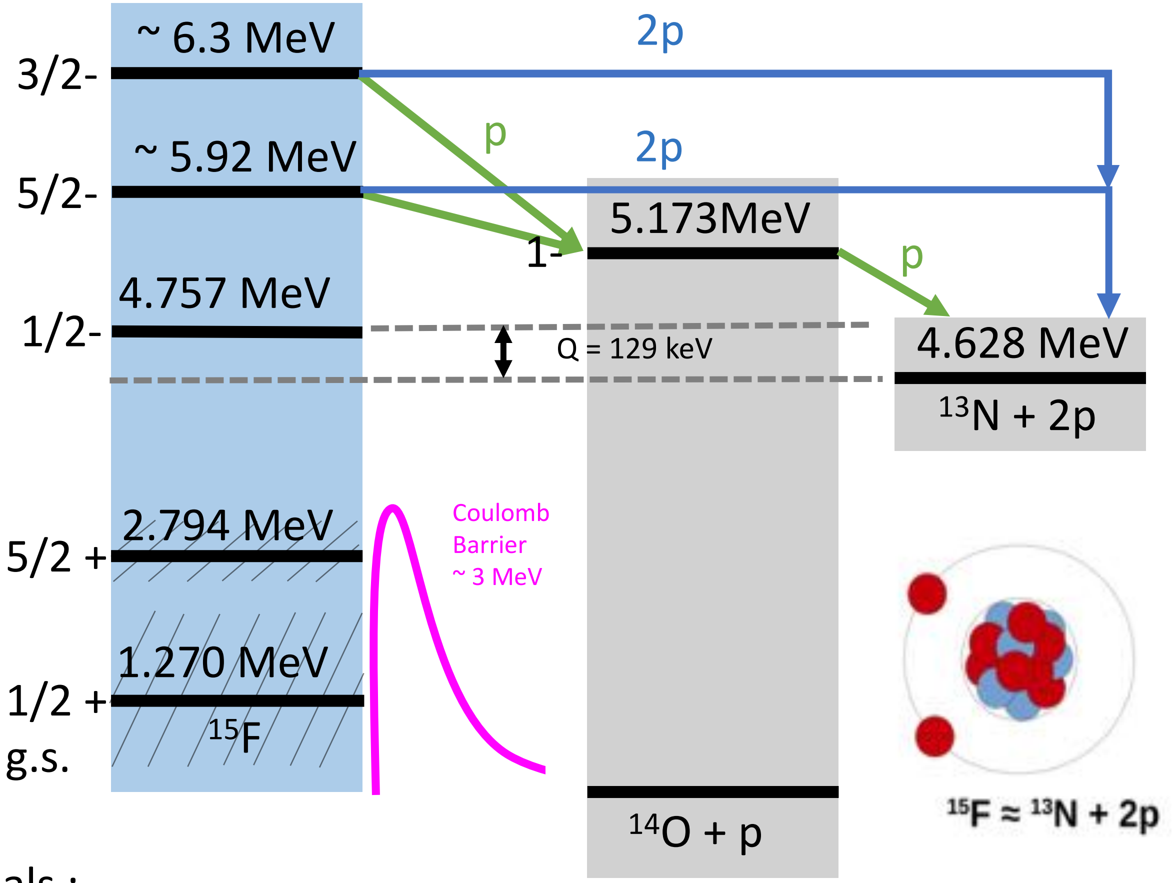

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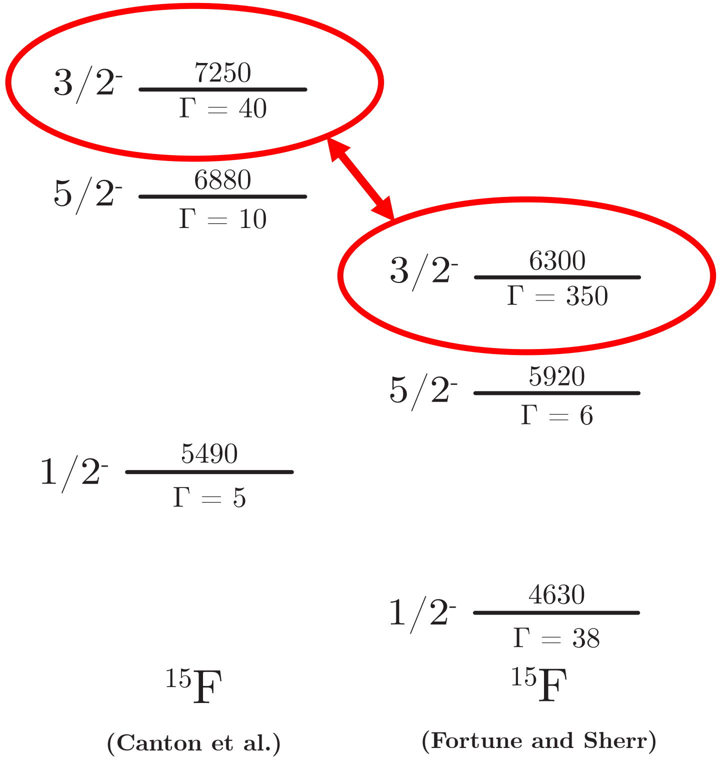

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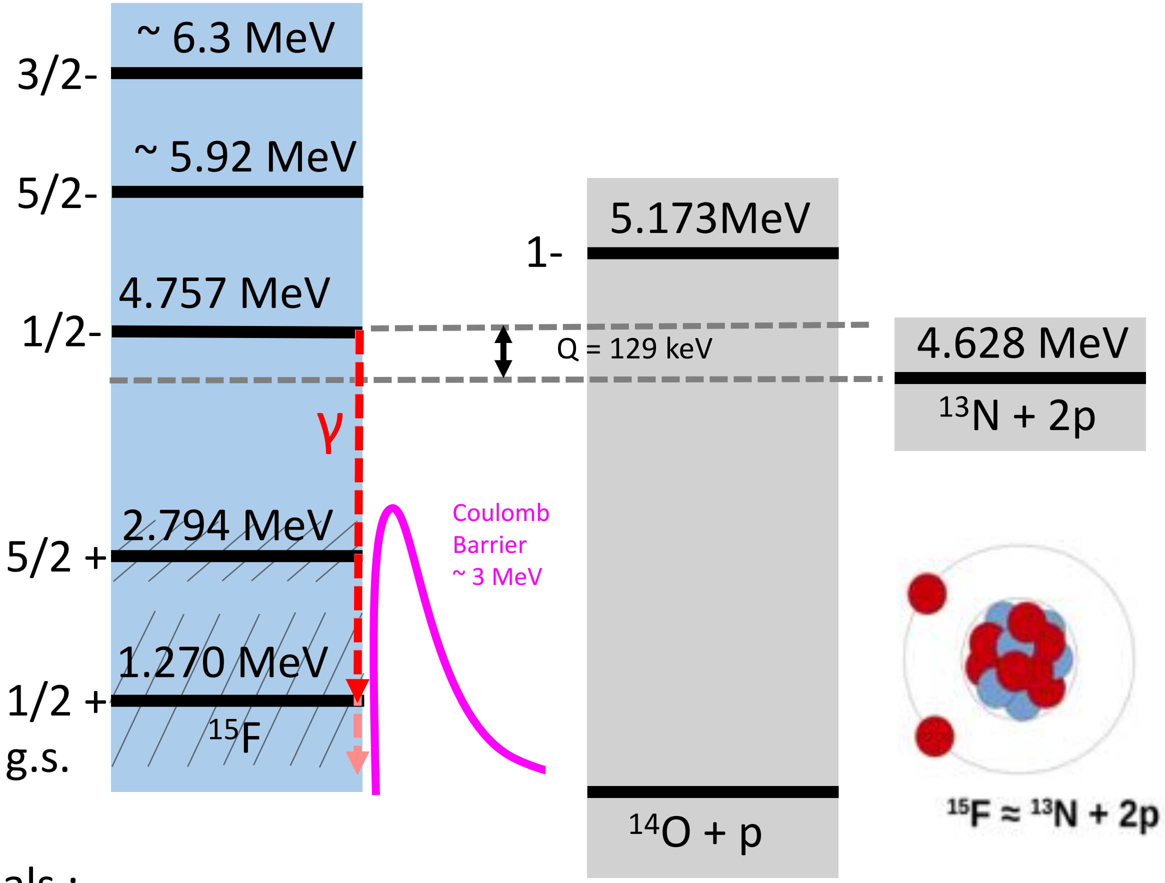

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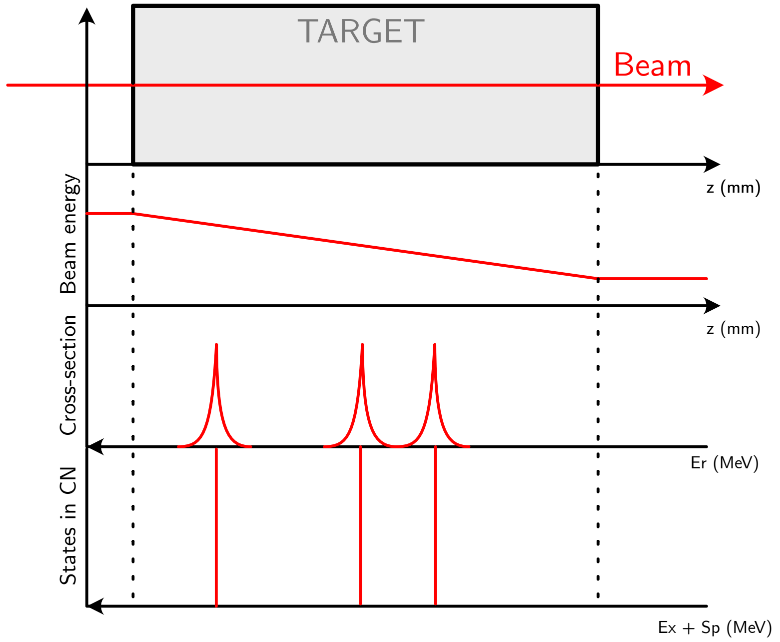
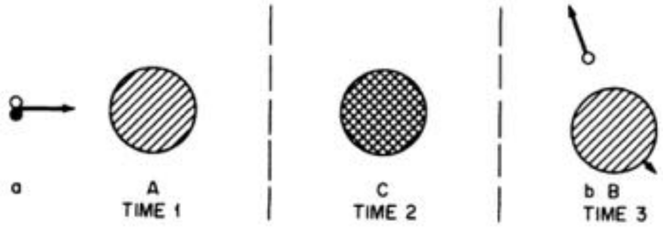
- ❑ **Observation of the gamma branching ratio: ^{1}H(^{14}O) ^{15}F$^{(*)}$(ɣ) ^{15}F(p) ^{14}O**

Experimental method

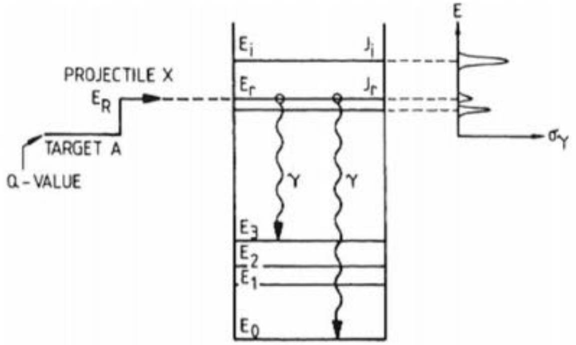
To fulfill those goals:

- The thick target technique was used

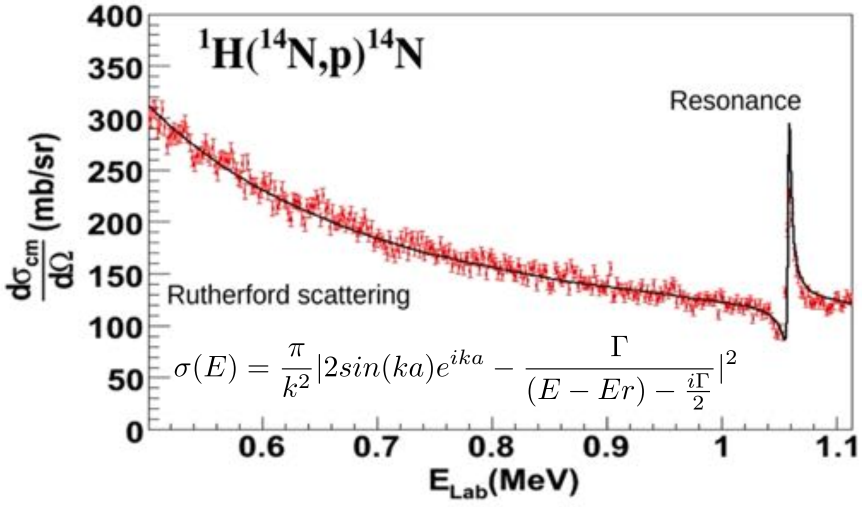




Satchler : Intro to nuclear reactions



C. E. Rolfs : Cauldrons in the cosmos



I. Stefan PhD thesis

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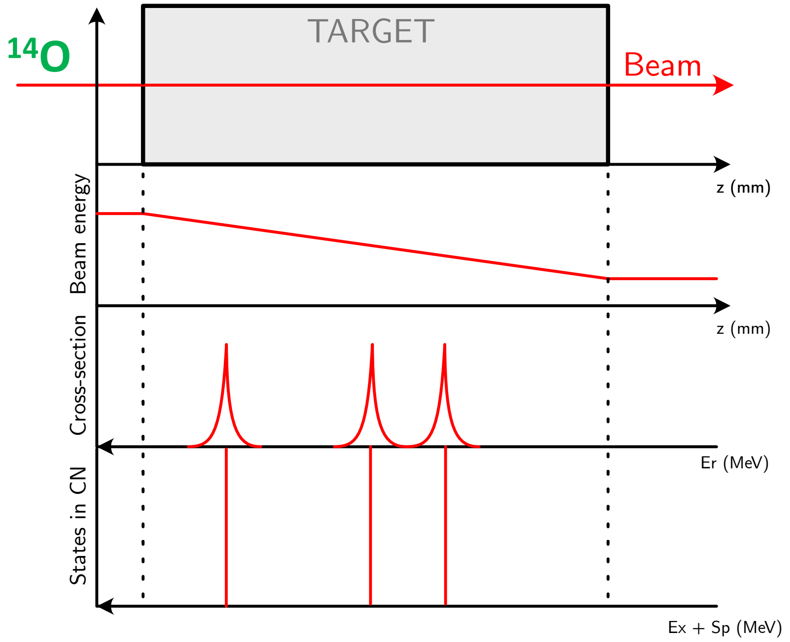

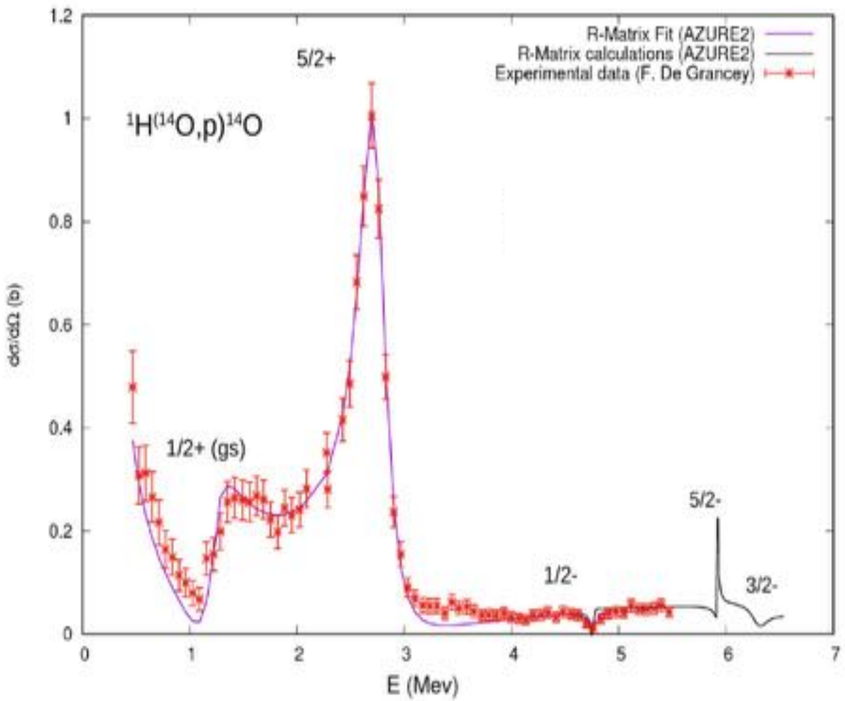

F. de Grancey : Phys. Lett. B 758 (2016) 26–31

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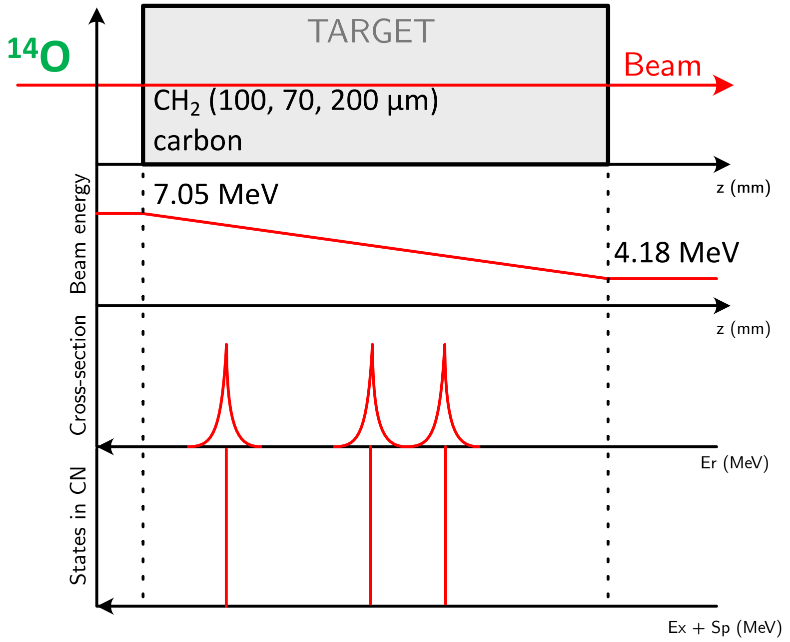

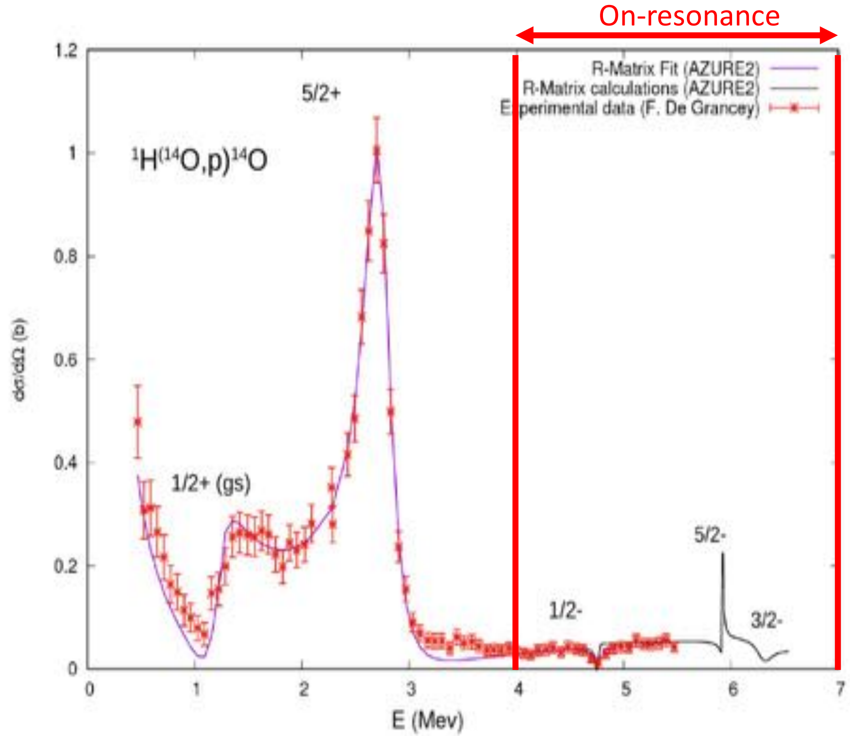

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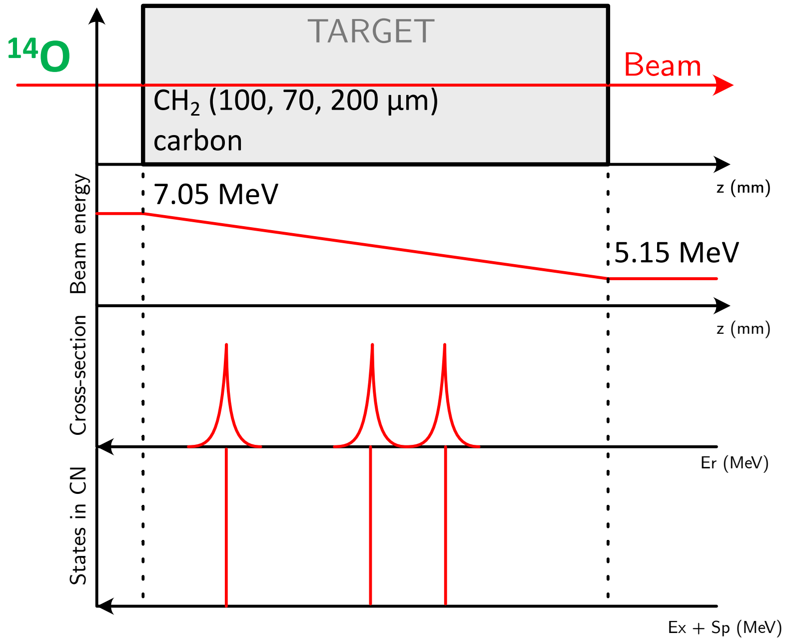

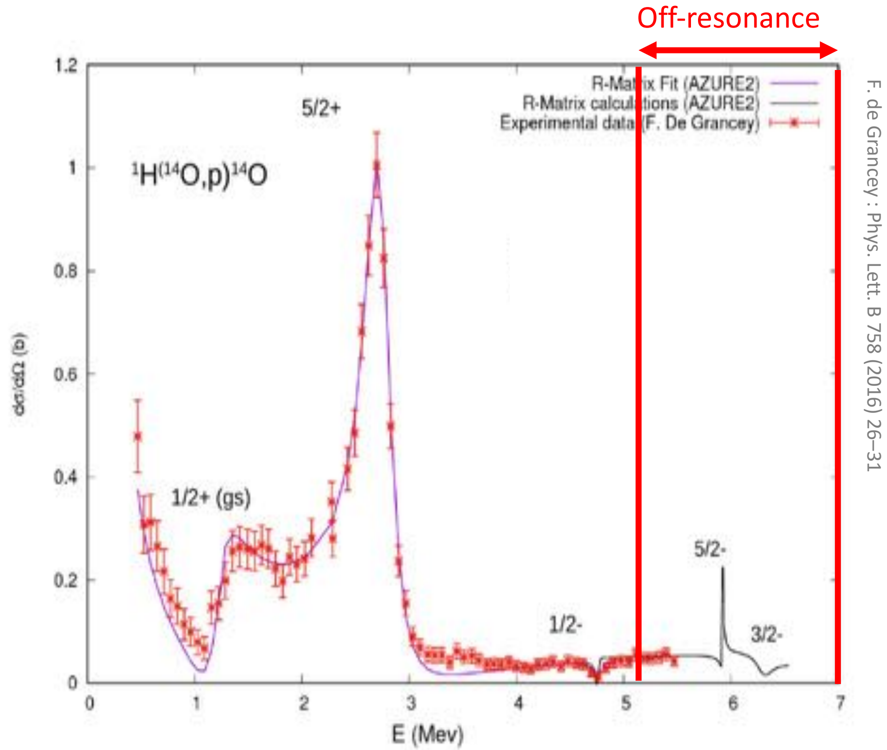

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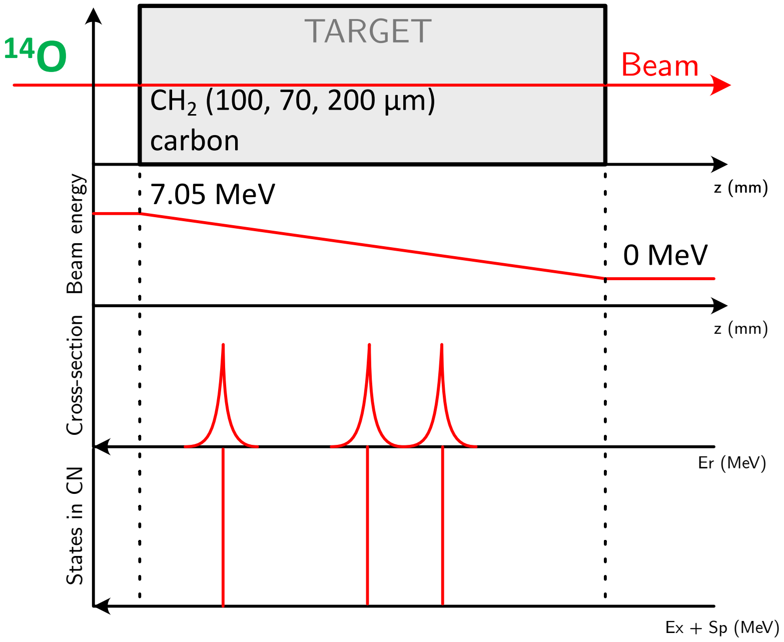

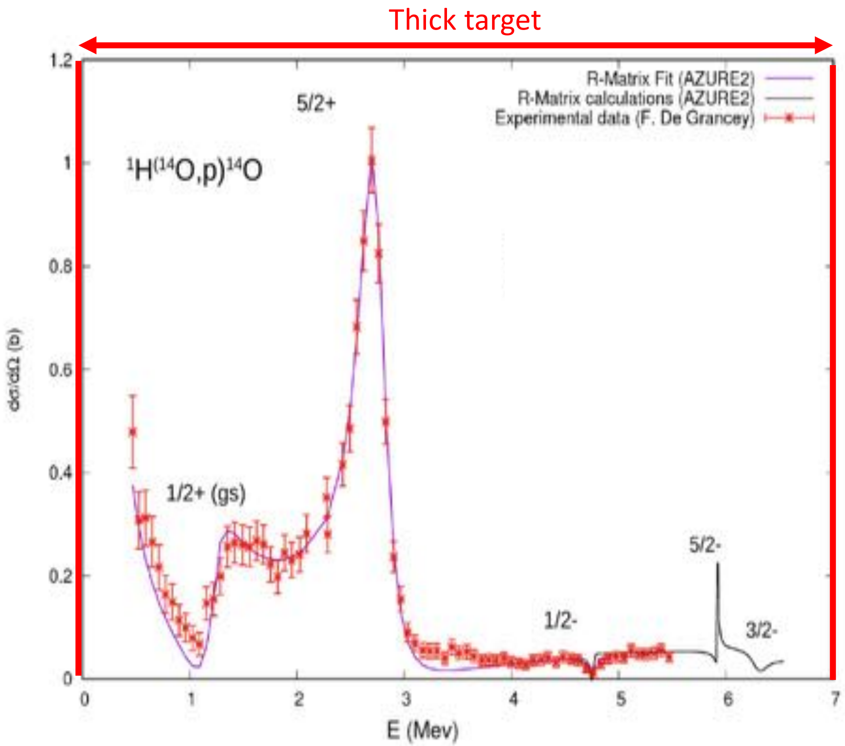

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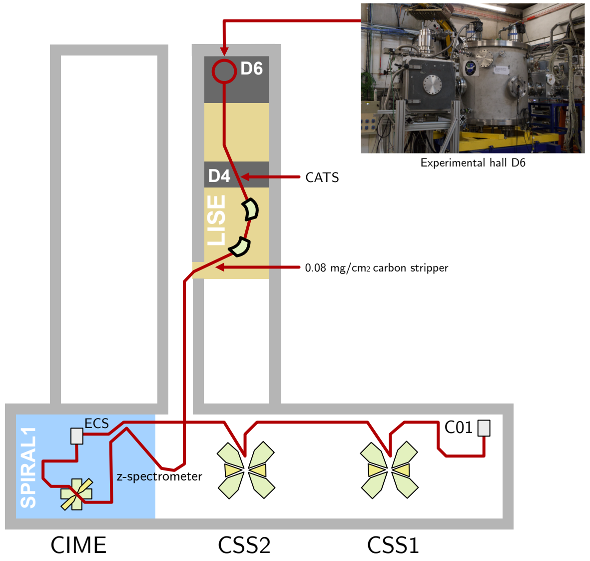
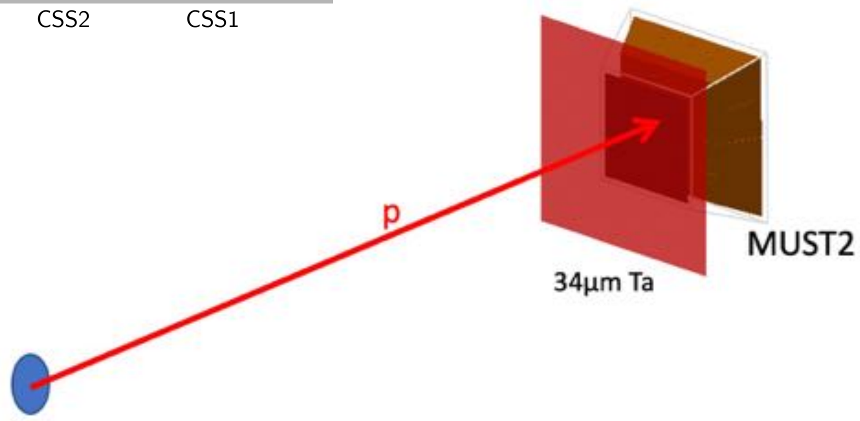
Experimental setup



First experiment (May 2018):

- At LISE
- Spiral1 7.46 MeV/u $^{14}O^{8+}$ RIB



➢ Measurement of the 1_p excitation function.

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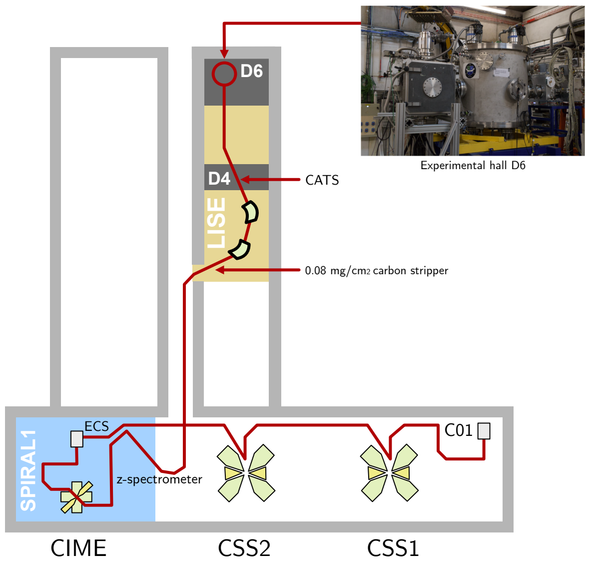
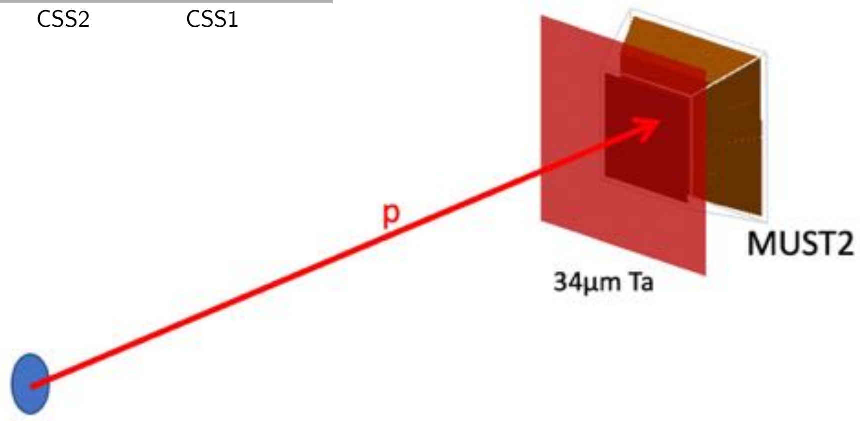
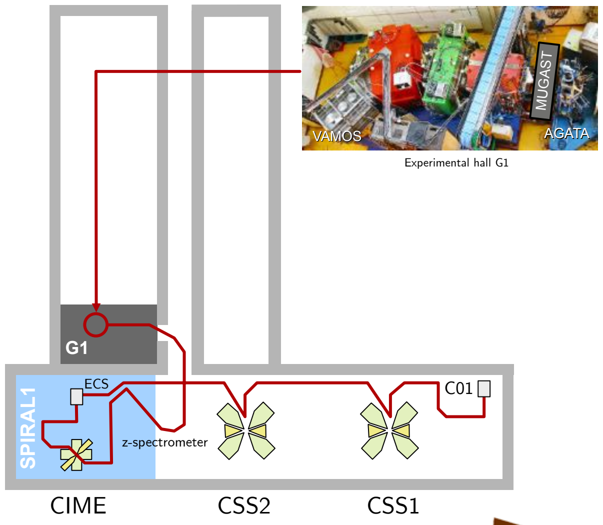


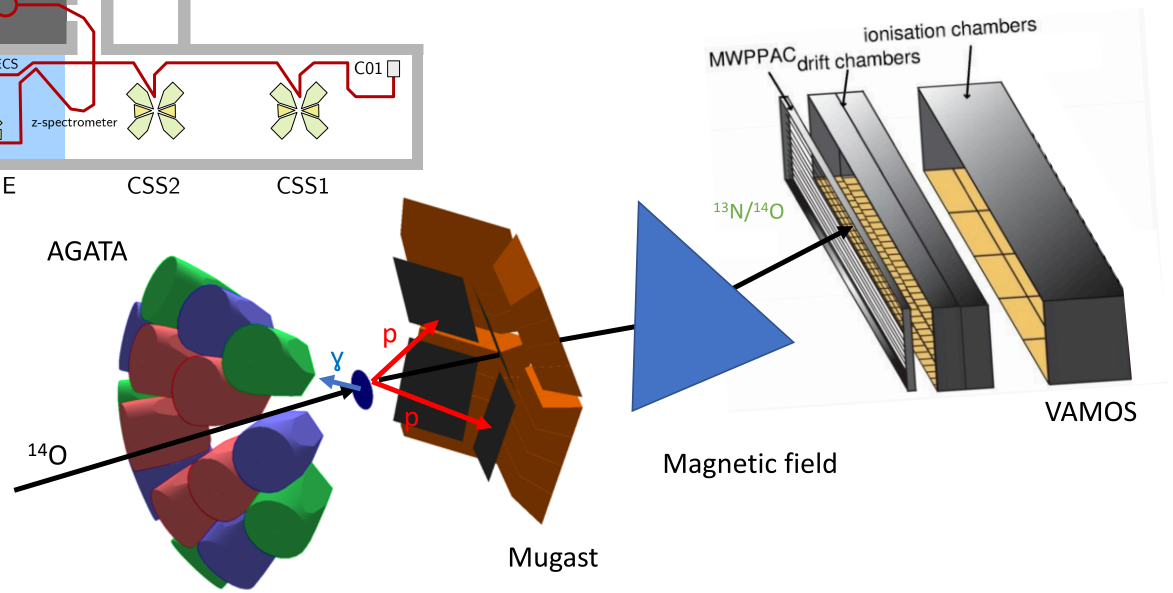


➢ Measurement of the 1_p excitation function.

Second experiment (April 2019):

- With MUGAST VAMOS and AGATA
- Spiral1 7.42 MeV/u $^{14}O^{8+}$ RIB

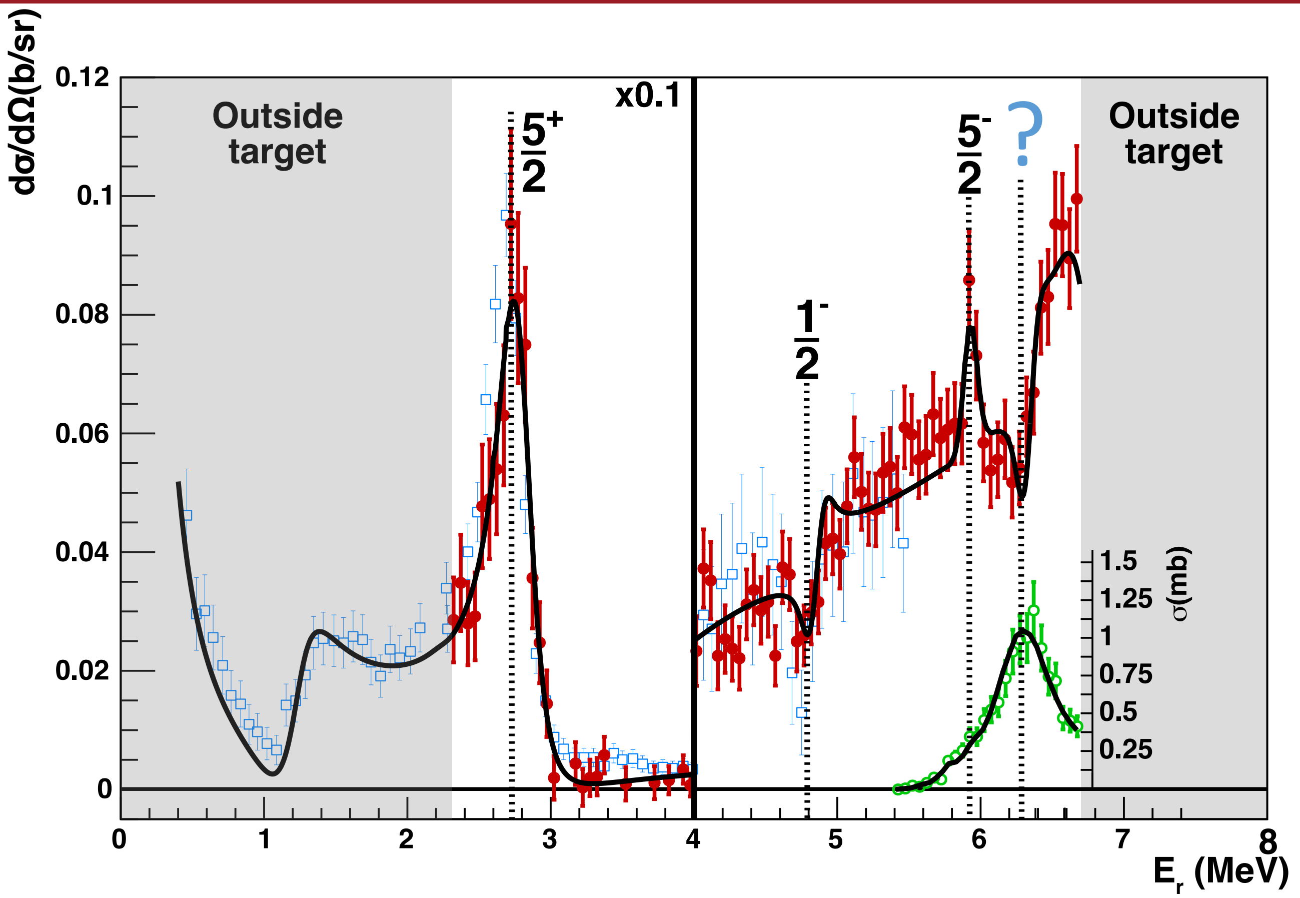




➢ 2_p excitation function and 2_p correlations measurement.

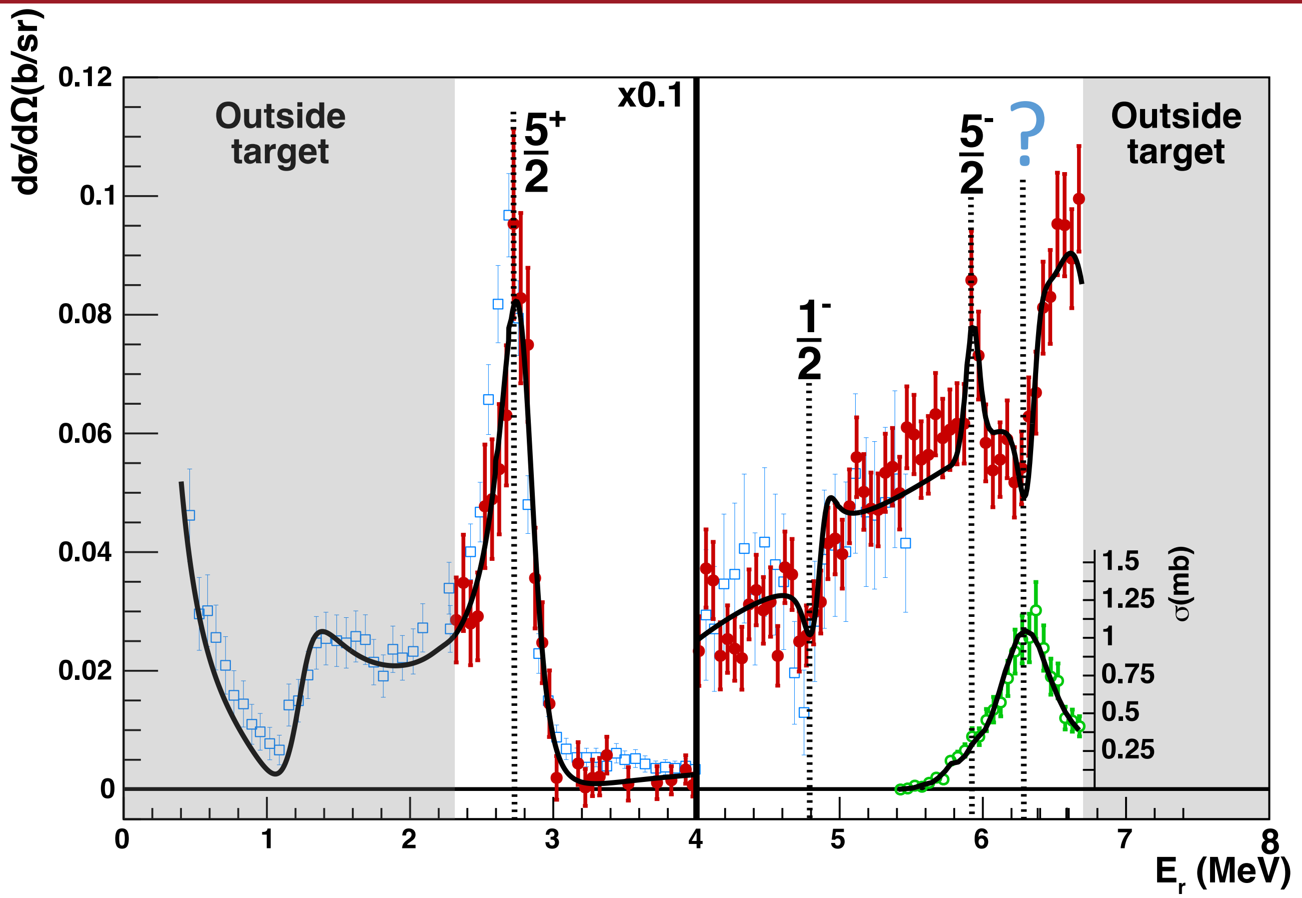
➢ γ-emission measurement

Results: $^{1}H(^{14}O,p)^{14}O$ and $^{1}H(^{14}O,2p)^{13}N$



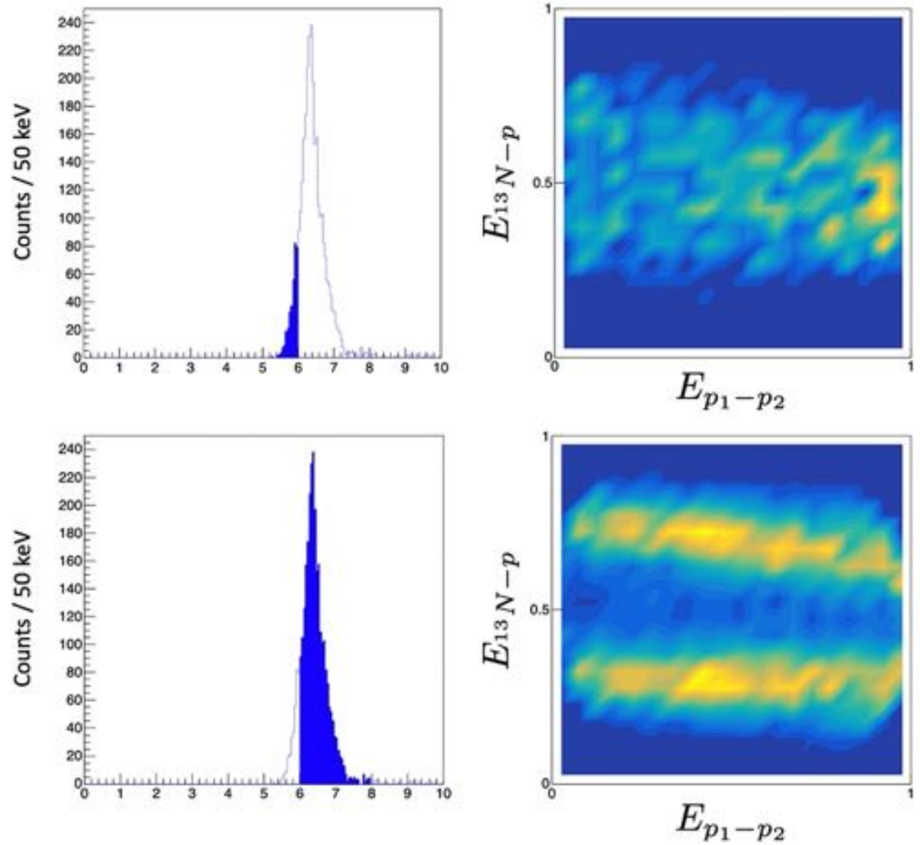
- State at Er ~ 6.3 MeV consistent with both a 3/2- and 1/2+ state

Results: $^1H(^{14}O,p)^{14}O$ and $^1H(^{14}O,2p)^{13}N$



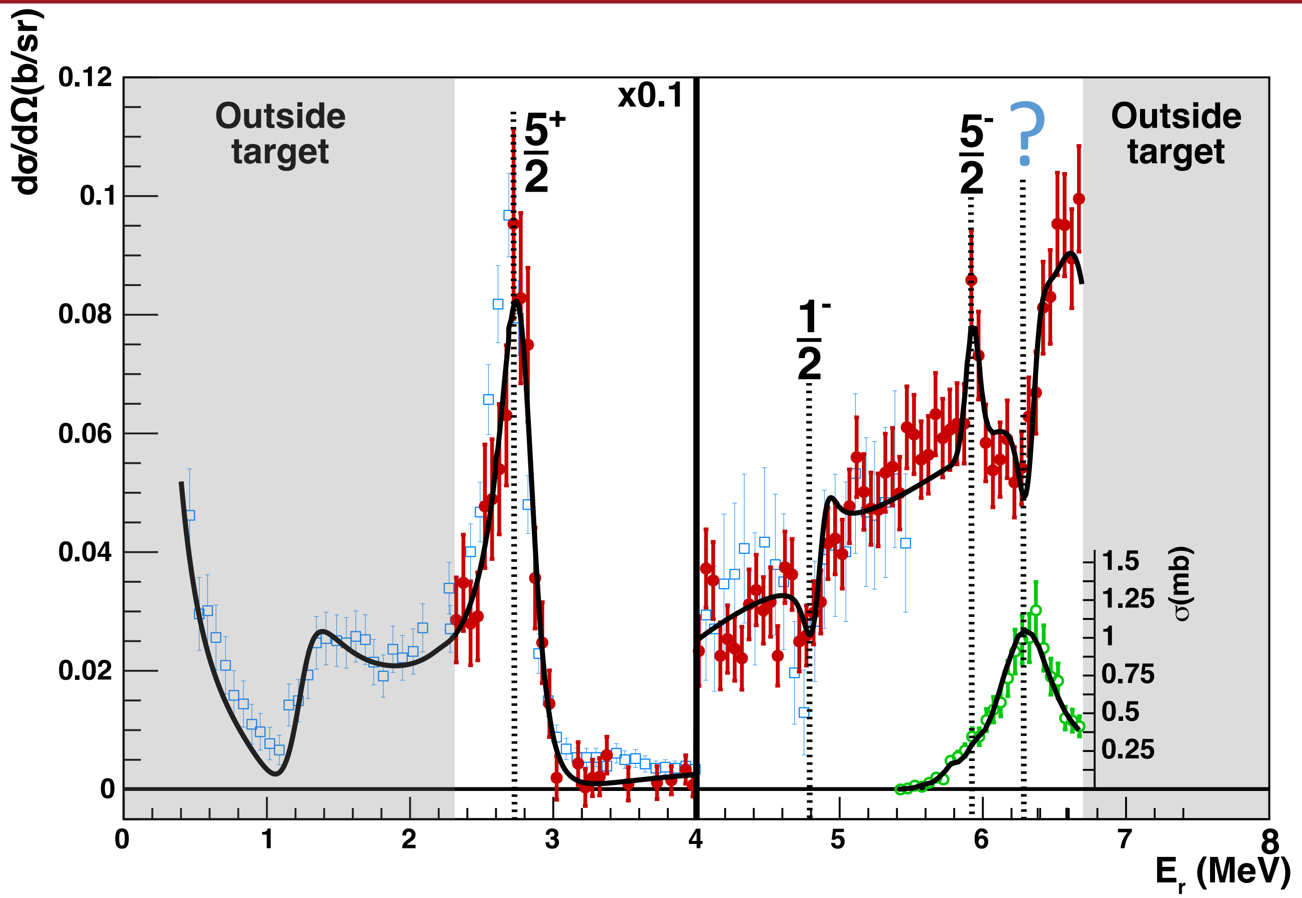
- State at Er ~ 6.3 MeV consistent with both a 3/2- and 1/2+ state

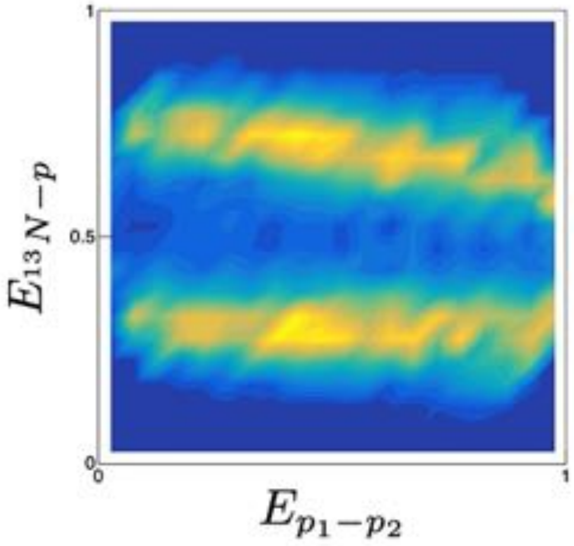
Dalitz plot:



- The two states above 6 MeV are both decaying sequentially by 2_p emission

Results: $^1H(^{14}O,p)^{14}O$ and $^1H(^{14}O,2p)^{13}N$





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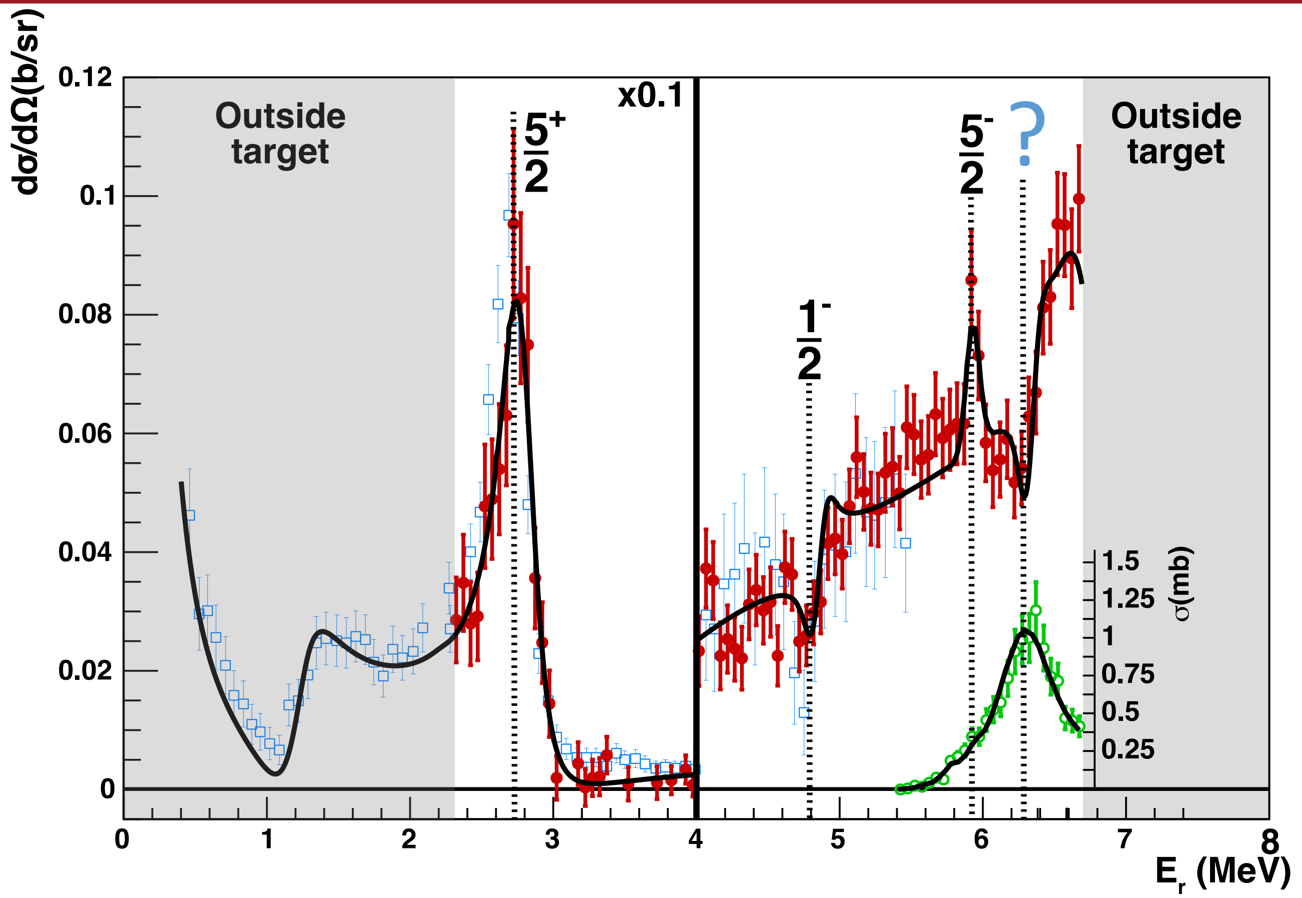

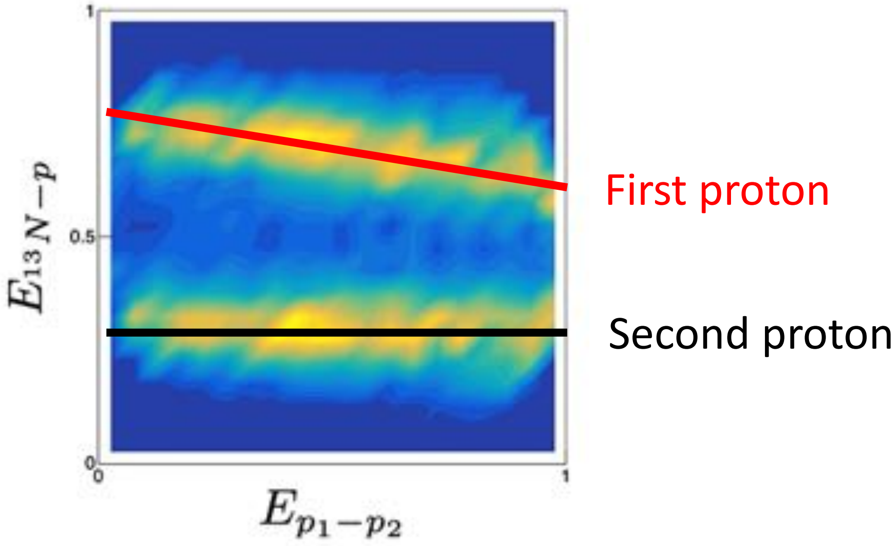

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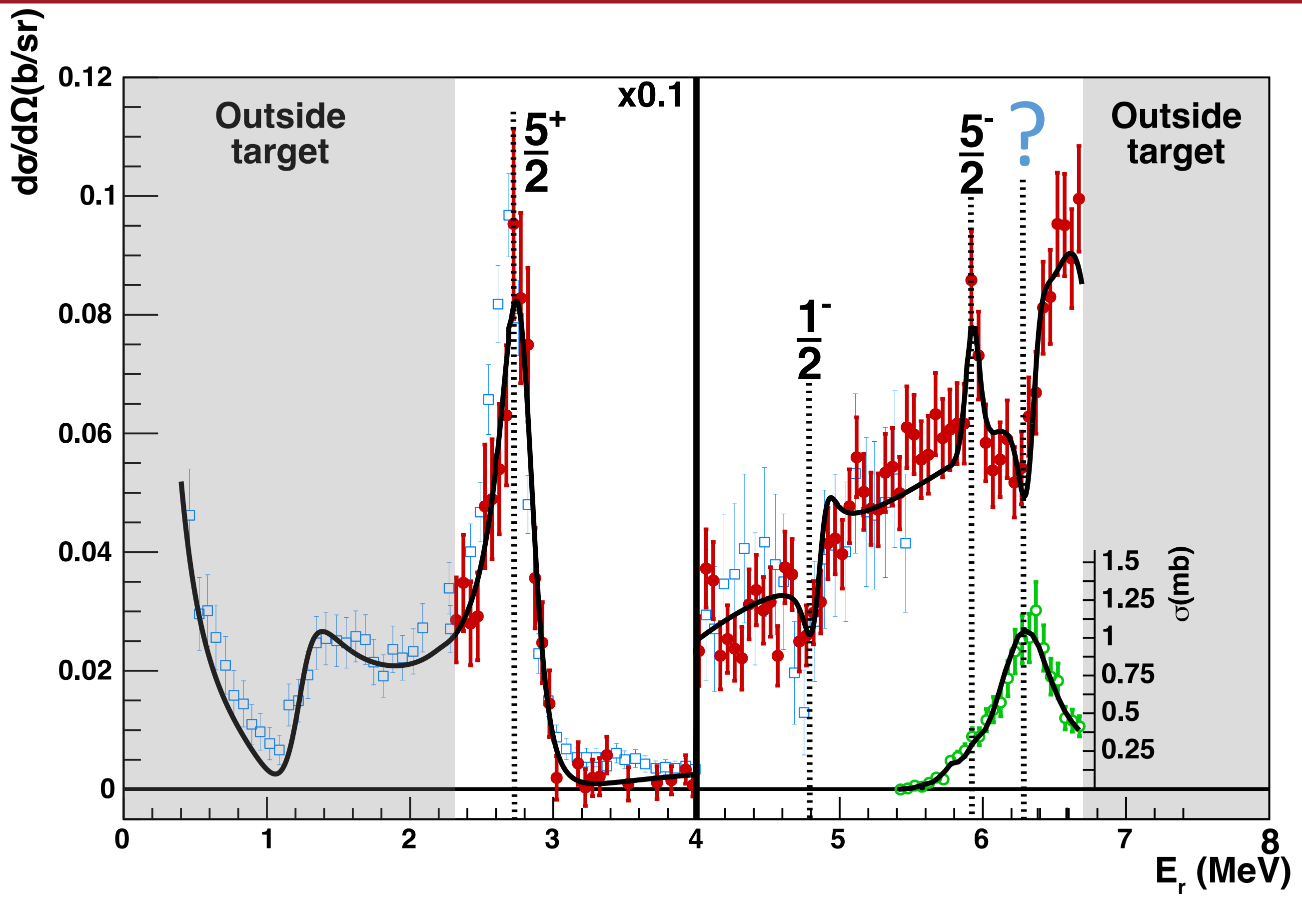
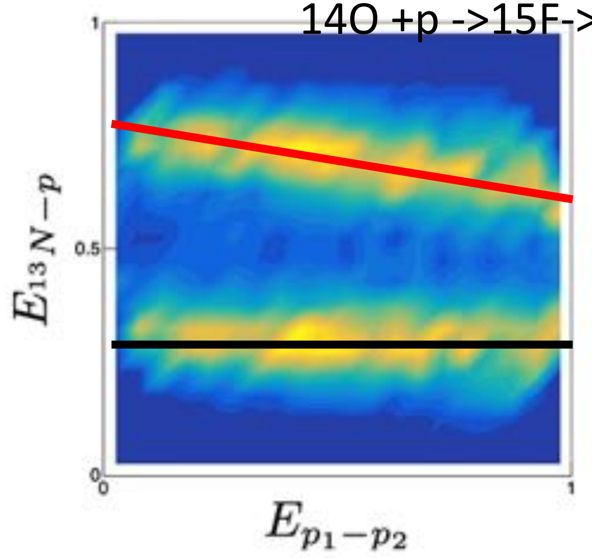
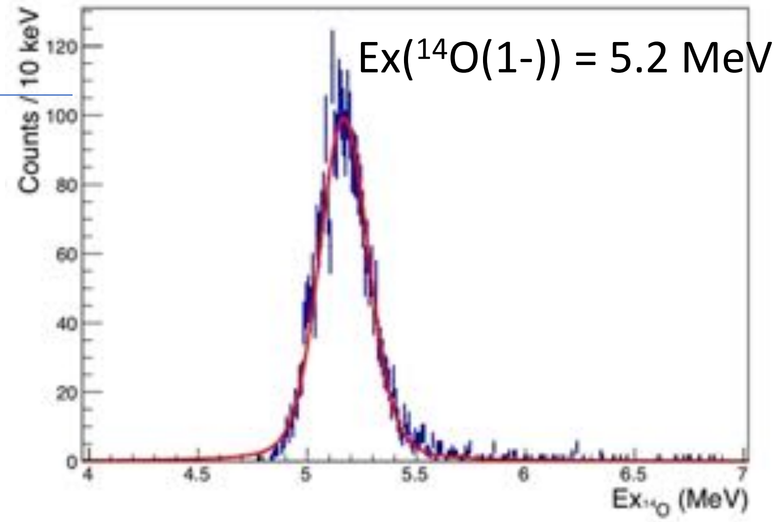


- State at Er ~ 6.3 MeV consistent with both a 3/2- and 1/2+ state

14O +p ->15F->14O(1-) +p -> 13N + p + p



Reconstructed $^{14}O(1-)$



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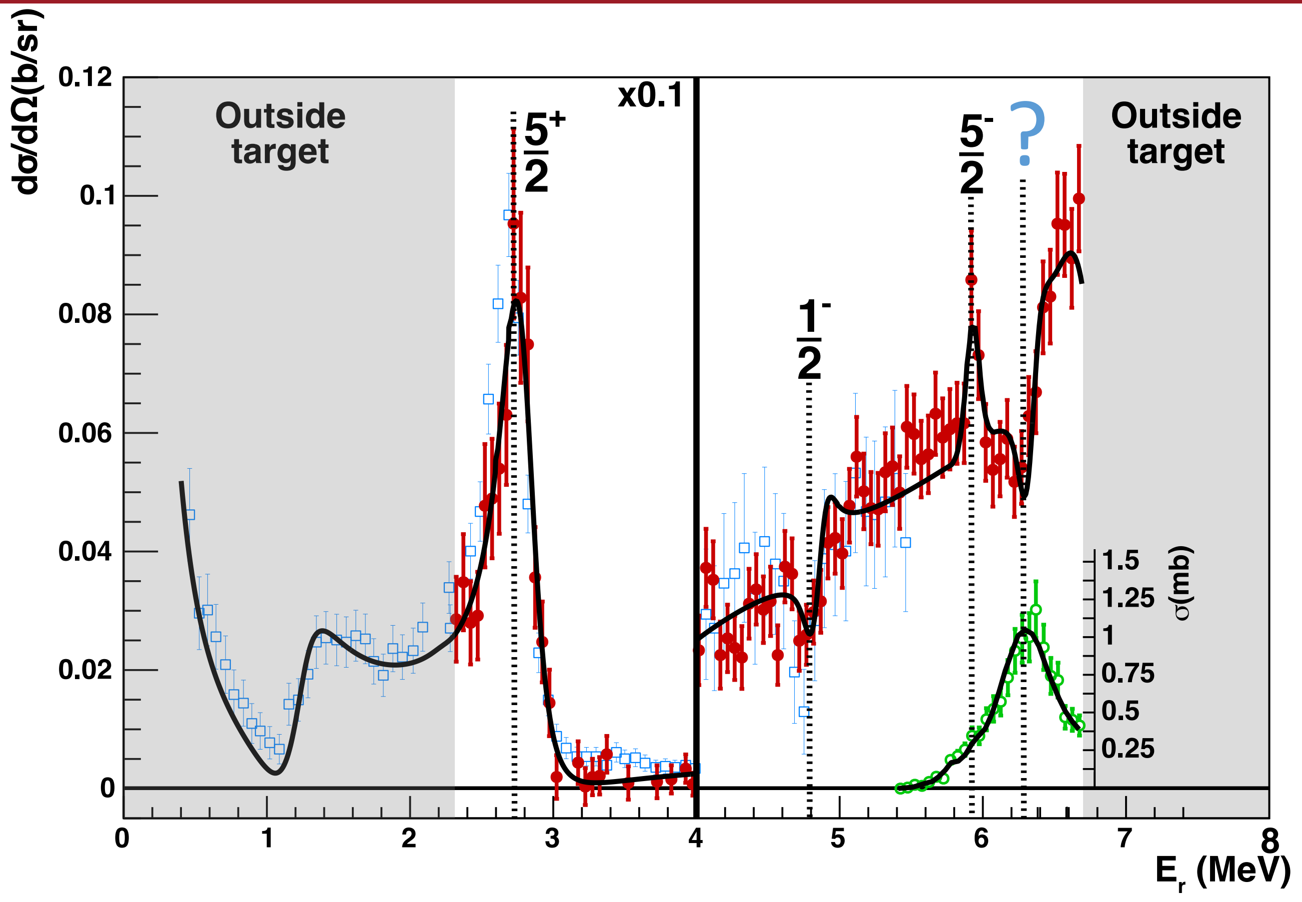
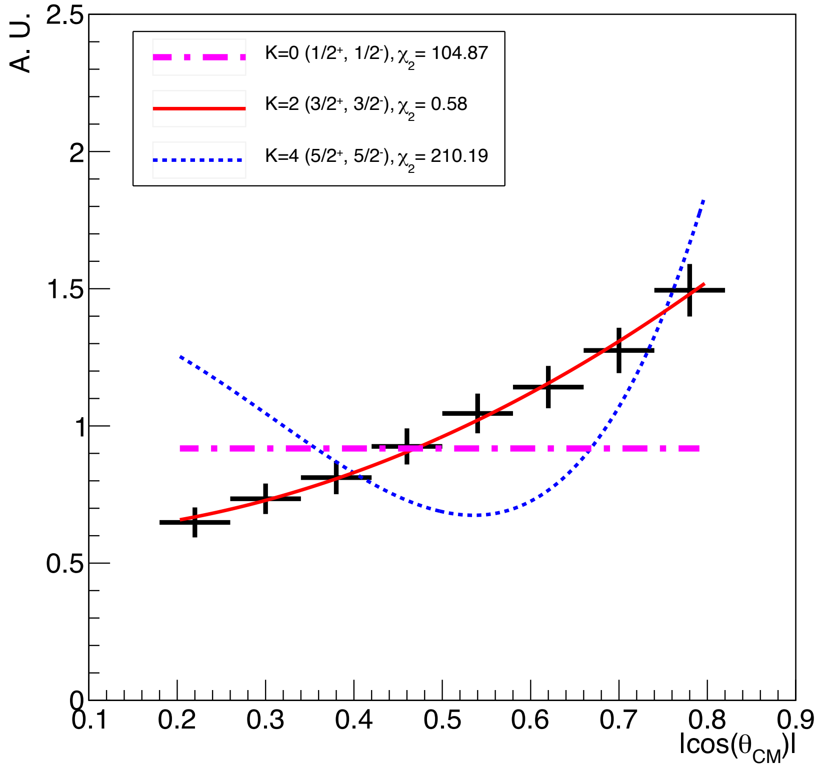


➢ State at Er ~ 6.3 MeV consistent with both a 3/2- and 1/2+ state

Legendre polynomials fit of the centre of mass angular distribution of the first sequentially emitted proton in the $^{1}H(^{14}O, 2p)^{13}N$:



➢ Consistent with the mirror nuclei ^{15}C

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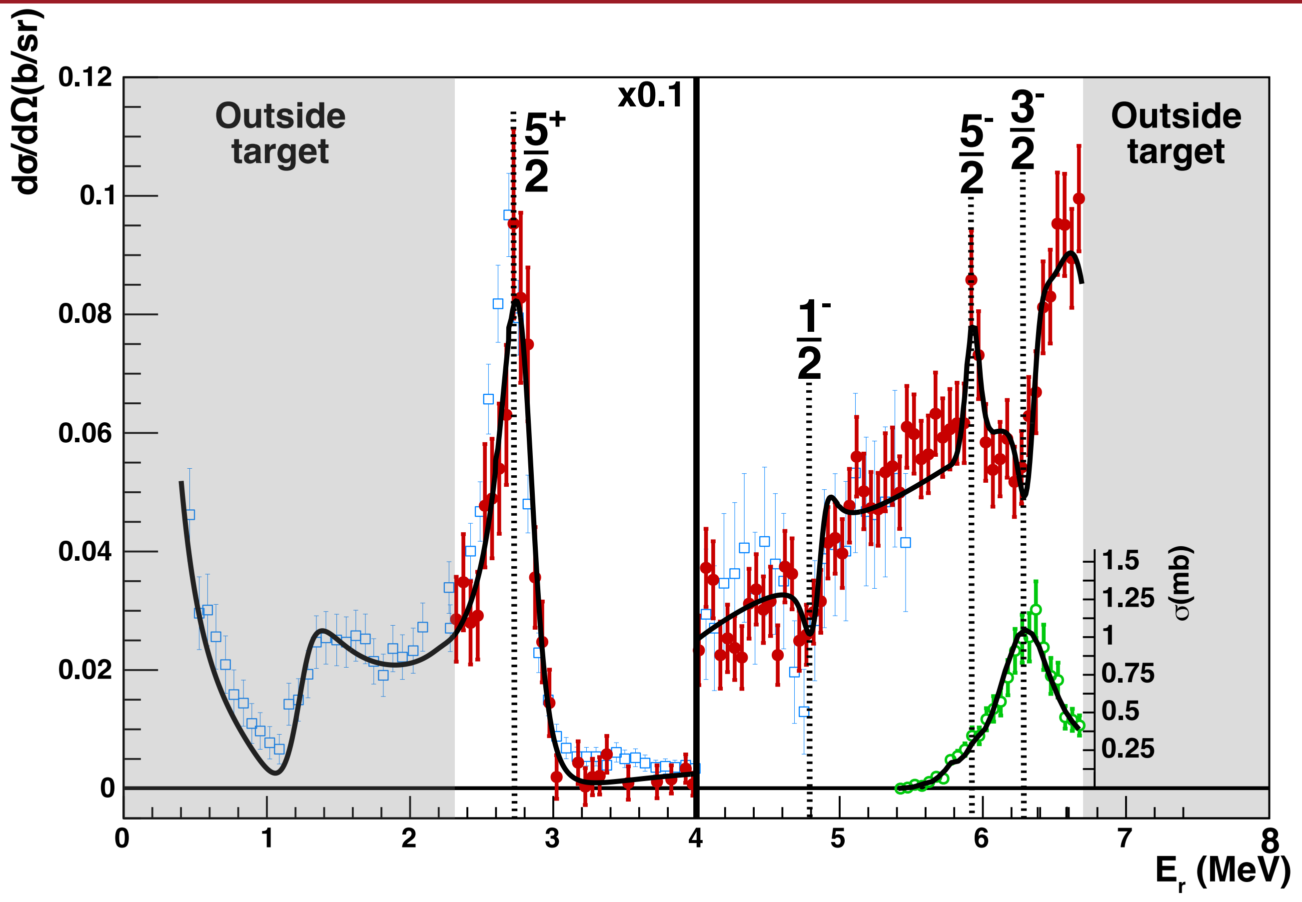

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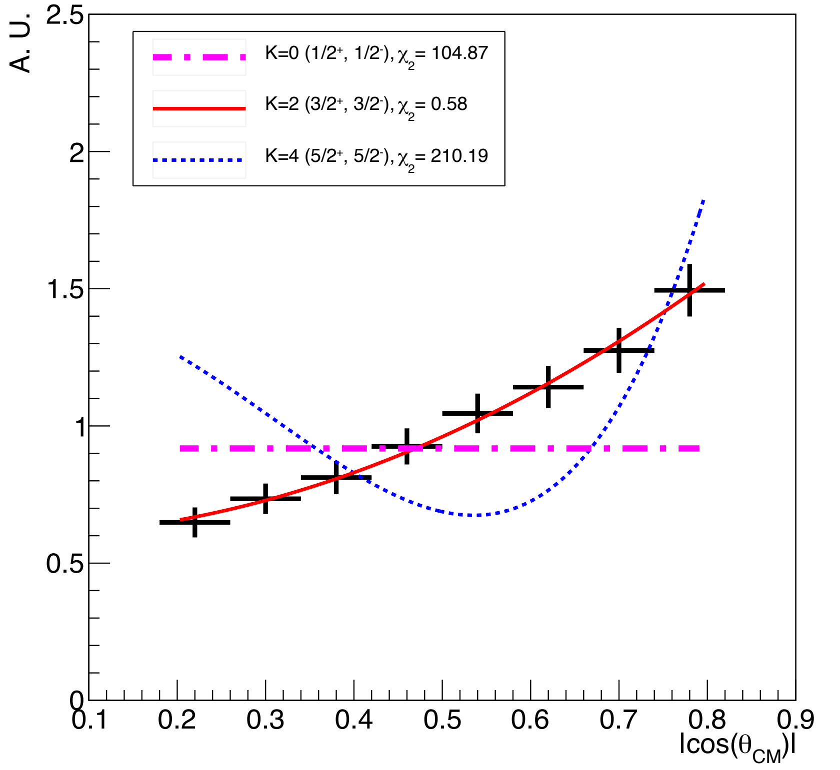

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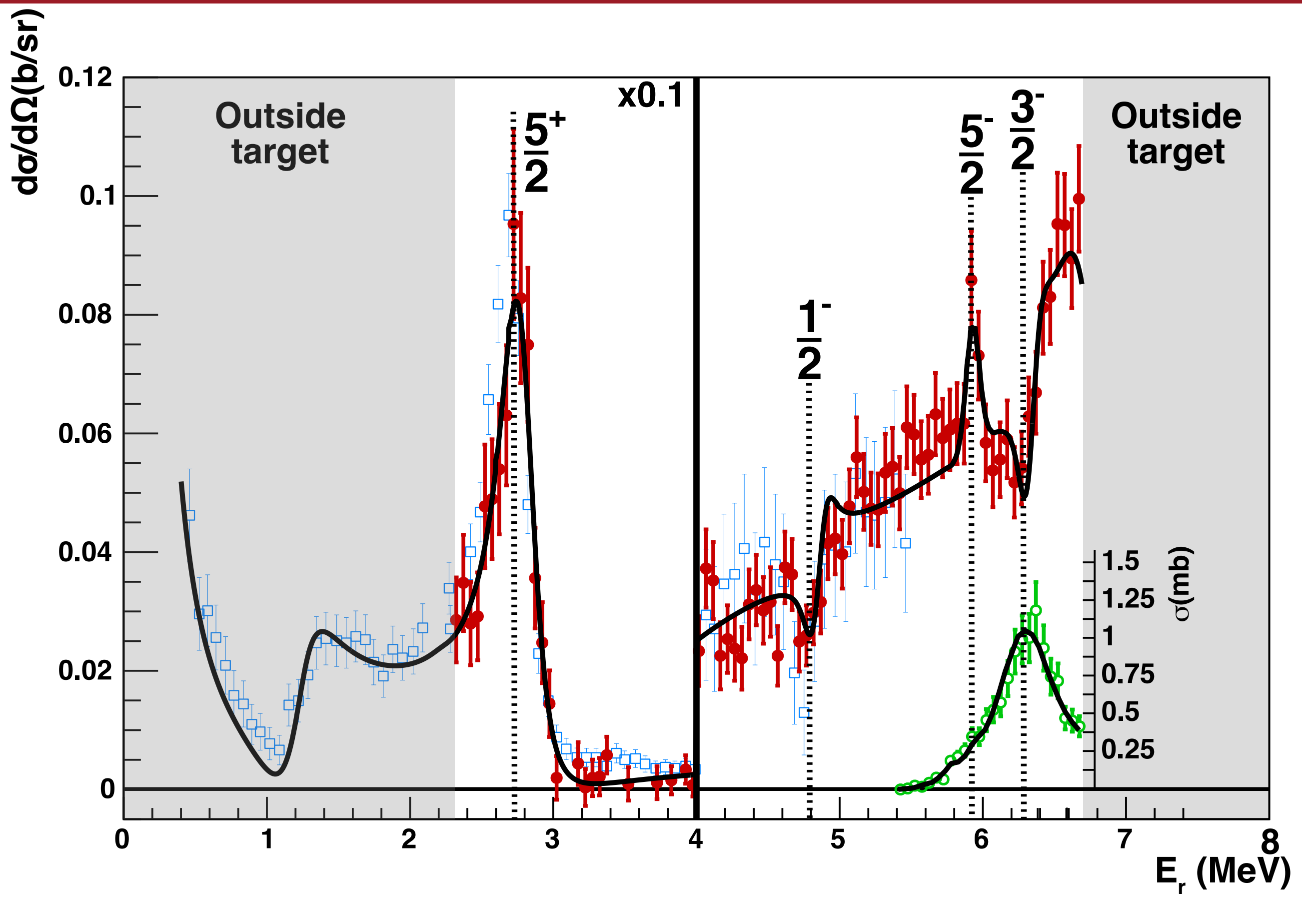
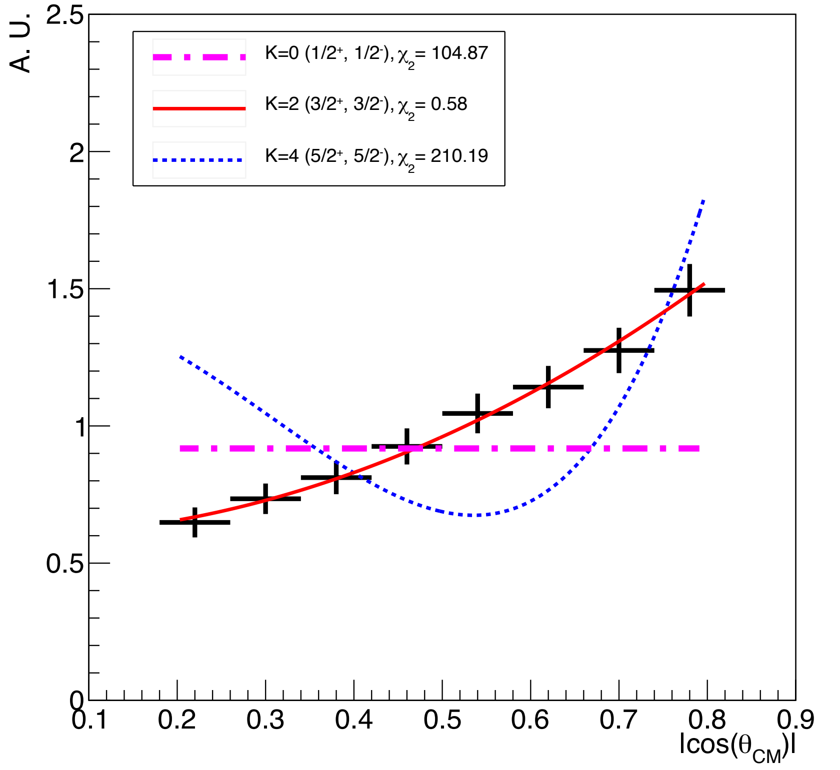


Previous work			This work			
J^π	E_r (MeV)	Γ_{1p} (keV)	J^π	E_r (MeV)	Γ_{1p} (keV)	Γ_{2p} (keV)
1/2+	1.270 (20)	~500				
5/2+	2.794 (16)	300 (16)	**5/2+**	**2.81 (12)**	**251 (26)**	
1/2-	4.757 (16)	36 (19)	**1/2-**	**4.88 (21)**	**30 (15)**	
			5/2-	**5.93 (10)**	**3 (2)**	0.04 (2)
5/2- or 3/2-	6.4 (2)	200 (200)	**3/2-**	**6.33 (13)**	**28 (13)**	0.33 (8)

Legendre polynomials fit of the centre of mass angular distribution of the first sequentially emitted proton in the $^1H(^{14}O, 2p)^{13}N$:



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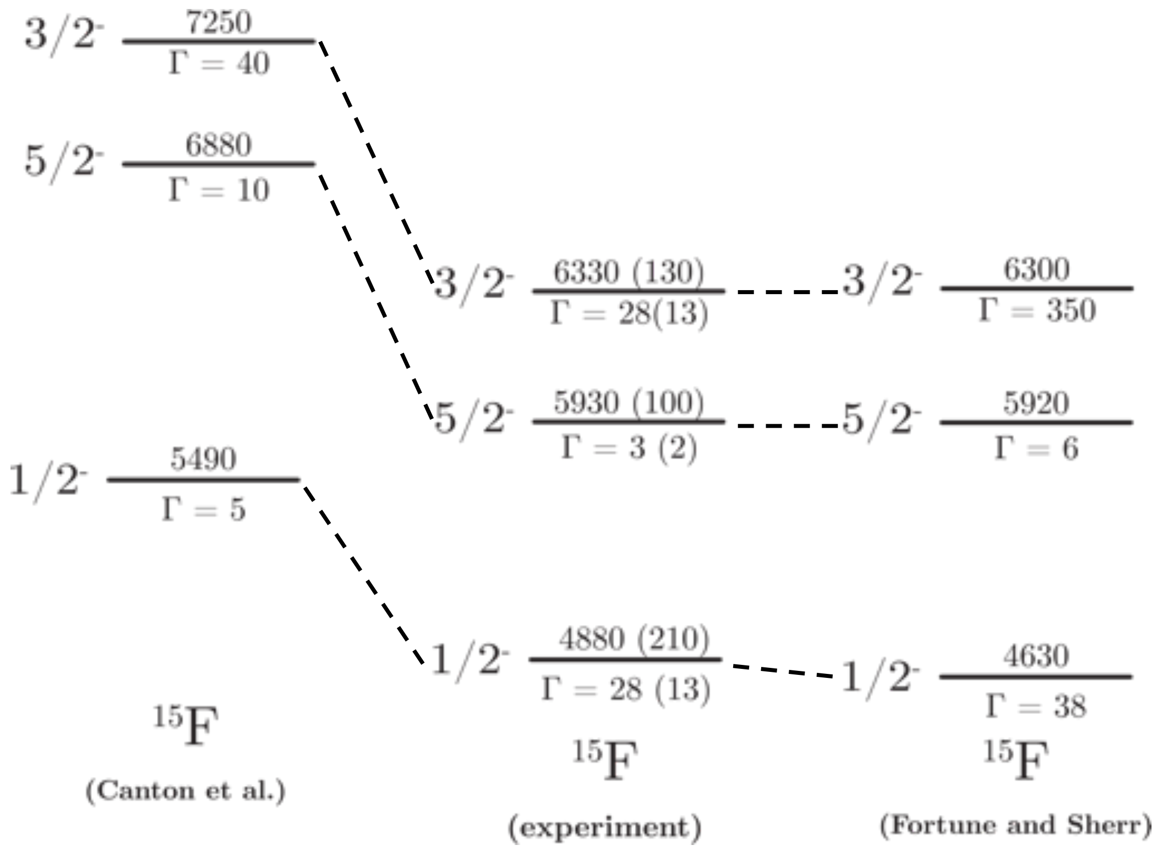

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- The 3/2- state is one order of magnitude narrower than Fortune and Sherr prediction, similar to Canton et al.

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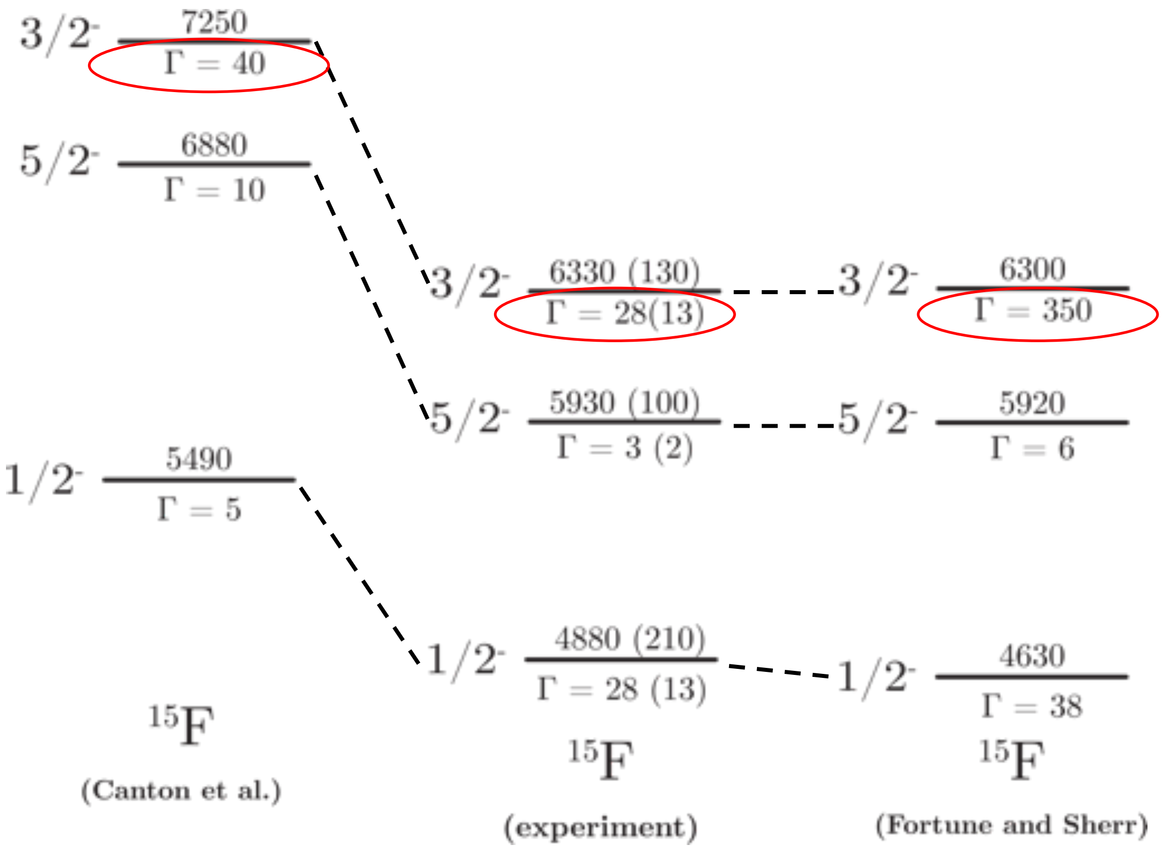

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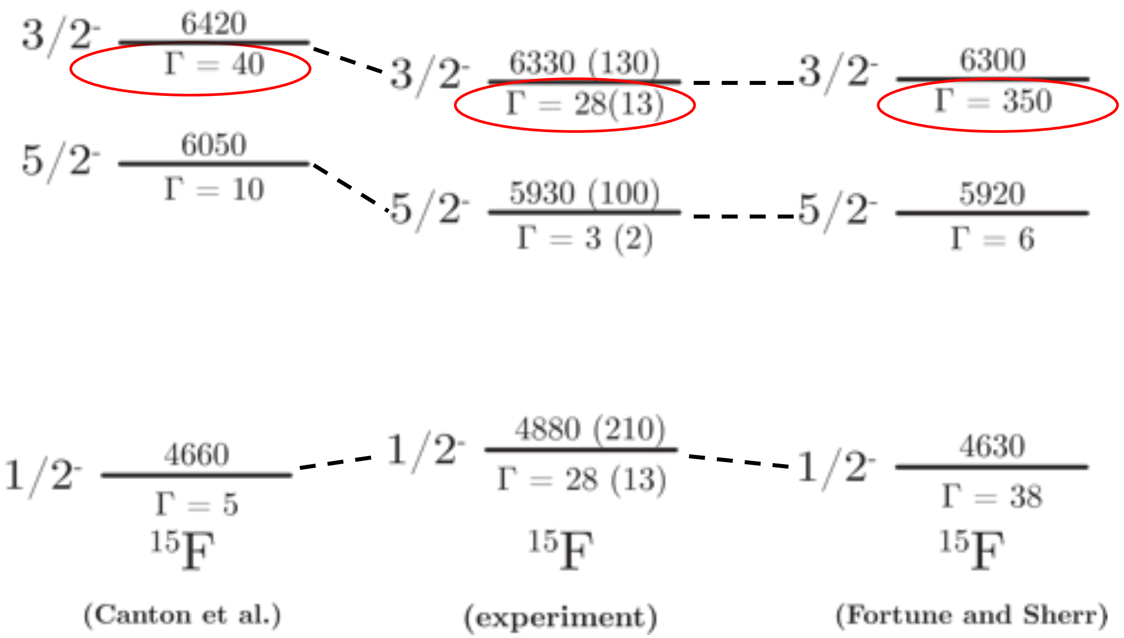
Scaling down by ~ 830 keV



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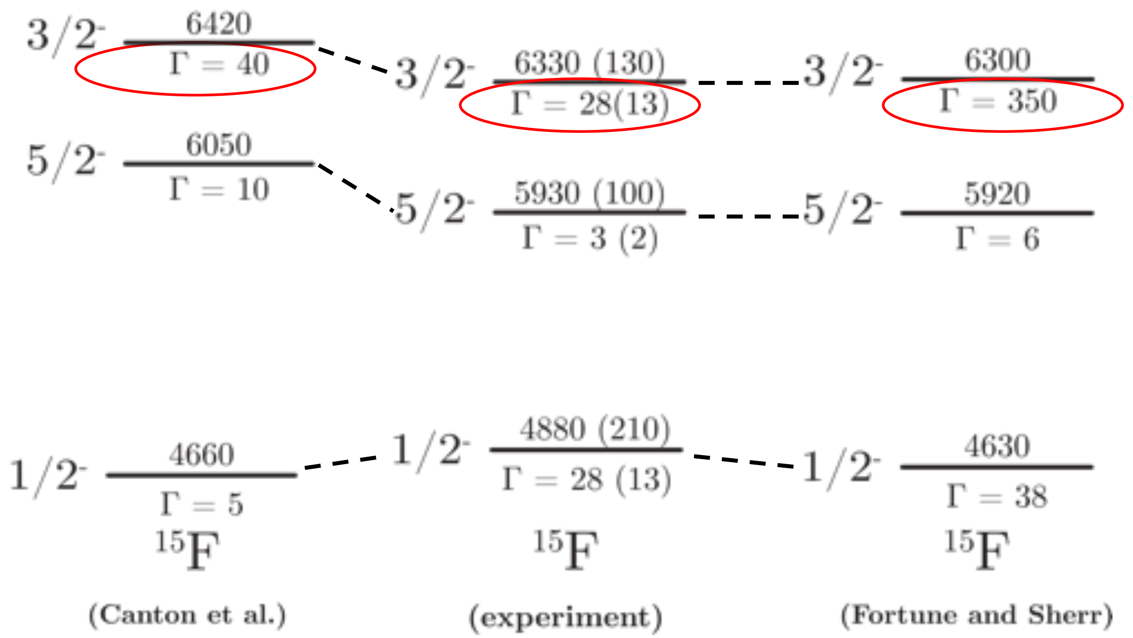

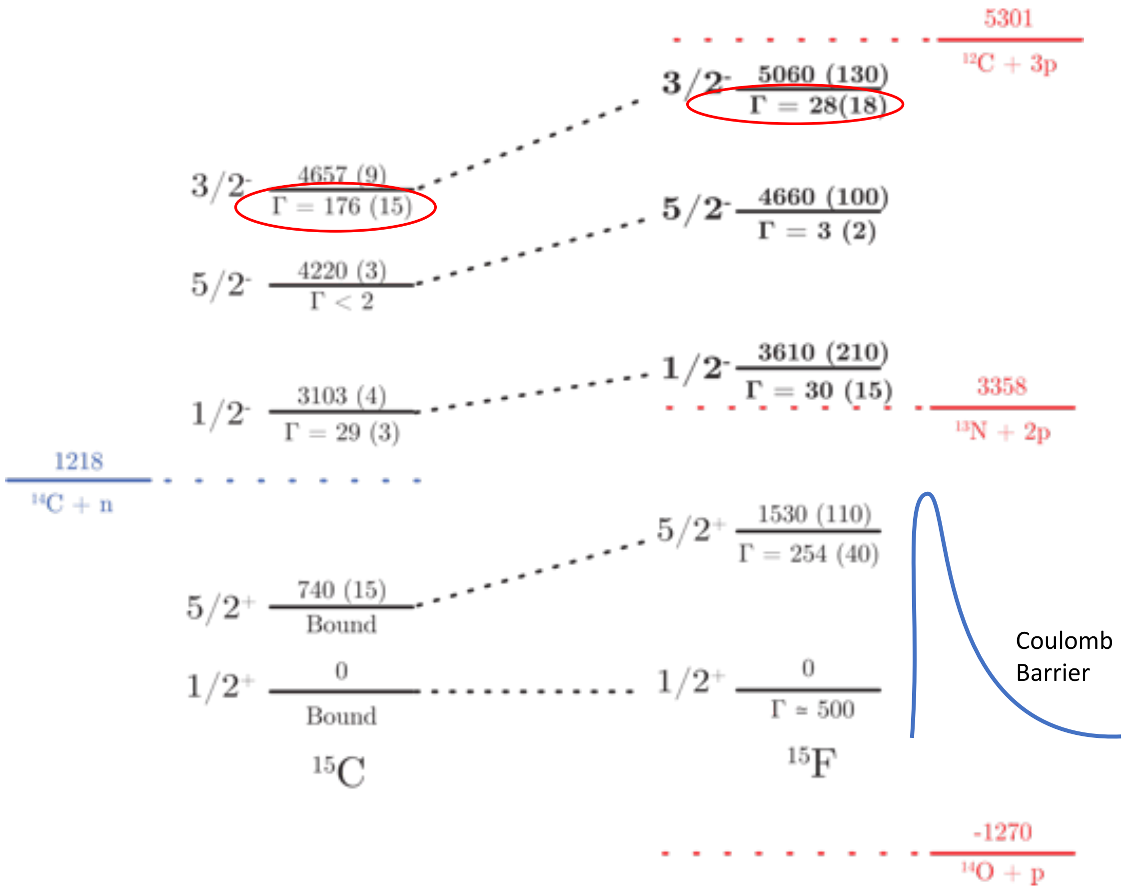

- Very good agreement with the energies predicted by Fortune and Sherr
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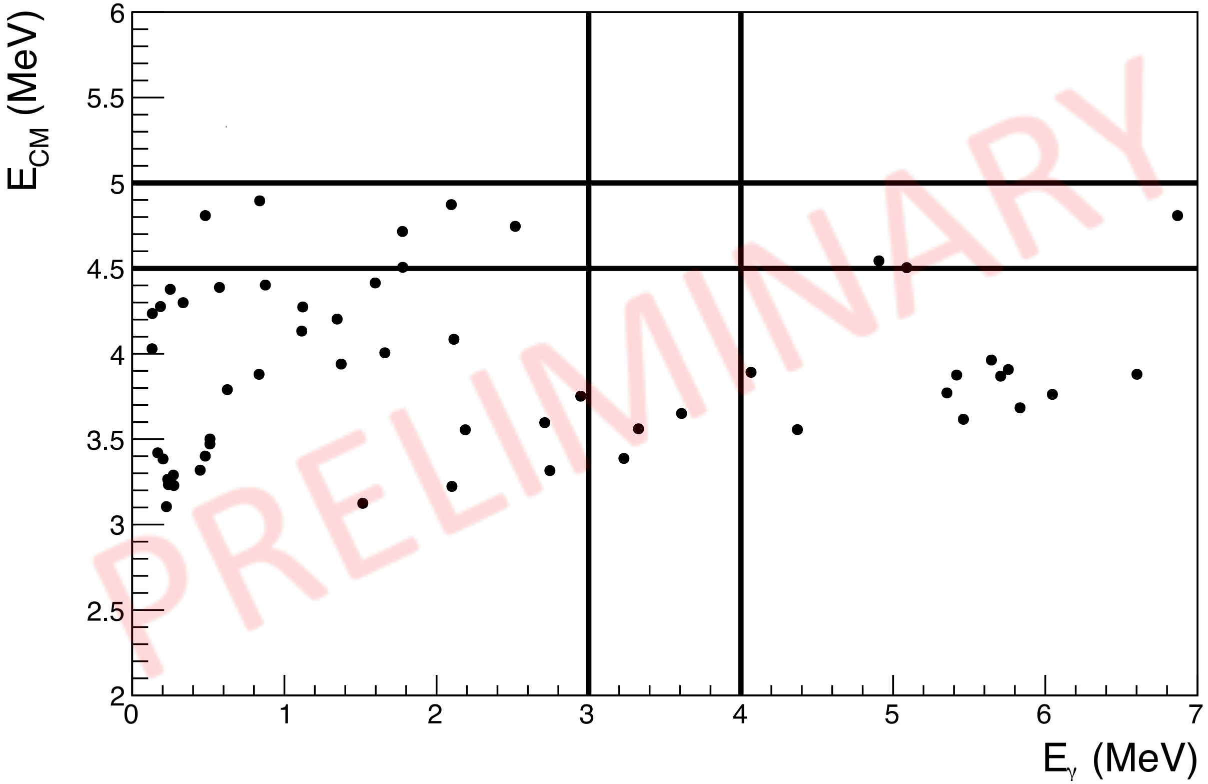
- 3/2- is ~ 4 times narrower than the mirror state in 15C!
- Many nearby thresholds: GSM and GSM-CC calculation on the way (A. Mercenne, N. Michel and M. Ploszajczak)

Results: γ-decay between unbound states?



- **No events compatible with the expected gamma transition**
- **Γɣ < 4.4 (1.5) eV -> BR < 0.019 (10) %**

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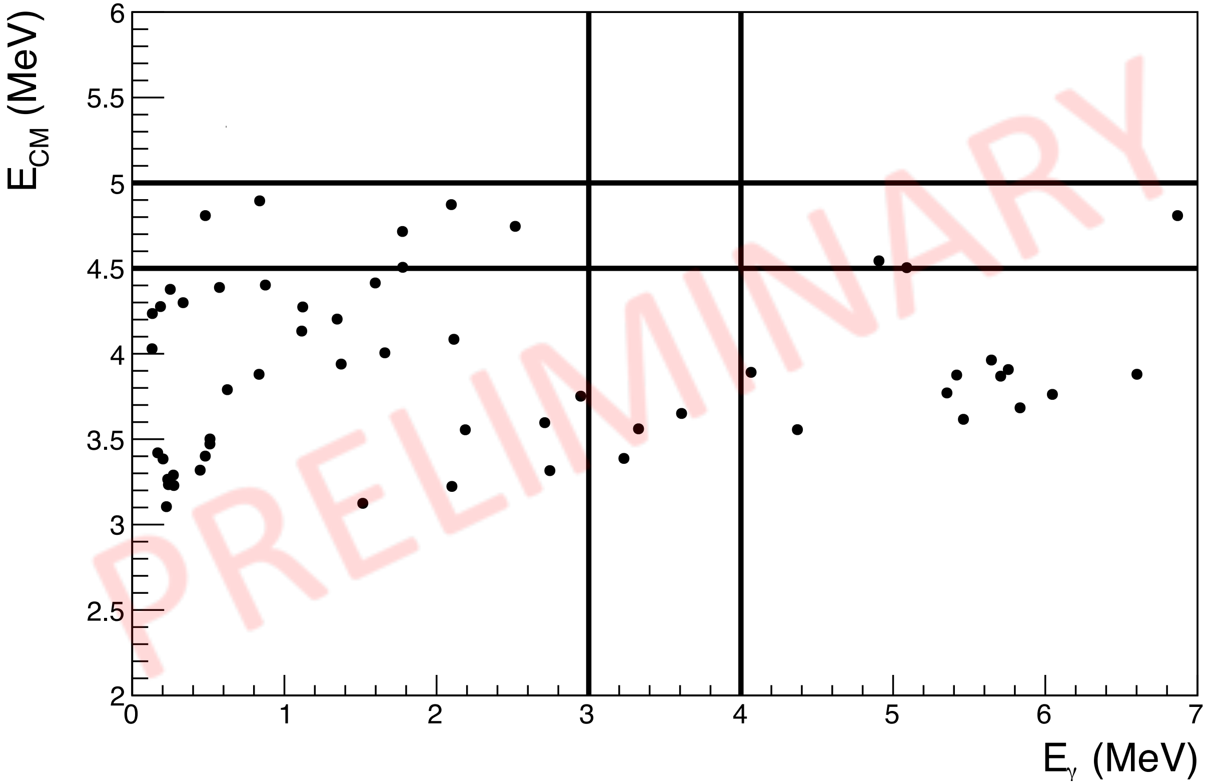

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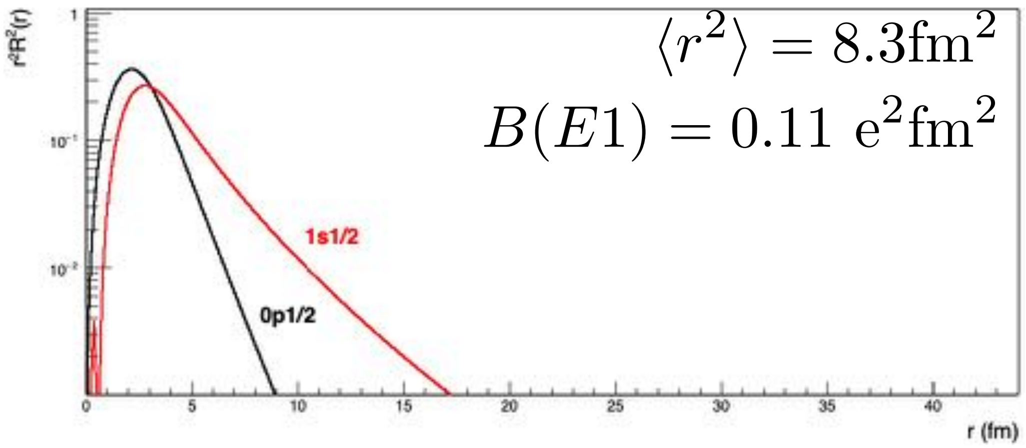
Calculation of the reduced transition probability:

$$B(E1) = \frac{6}{4\pi} \times \left(\frac{\tilde{e}}{e}\right)^2 \times \frac{1}{6} \times \langle r^l \rangle^2$$



$$\langle r^2 \rangle = 8.3\mathrm{fm}^2$$

$$B(E1) = 0.11\ \mathrm{e}^2\mathrm{fm}^2$$

$$\Gamma_\gamma^{calc} = 3.25eV \equiv \Gamma_\gamma^{exp} < 4.4(1.5)eV$$

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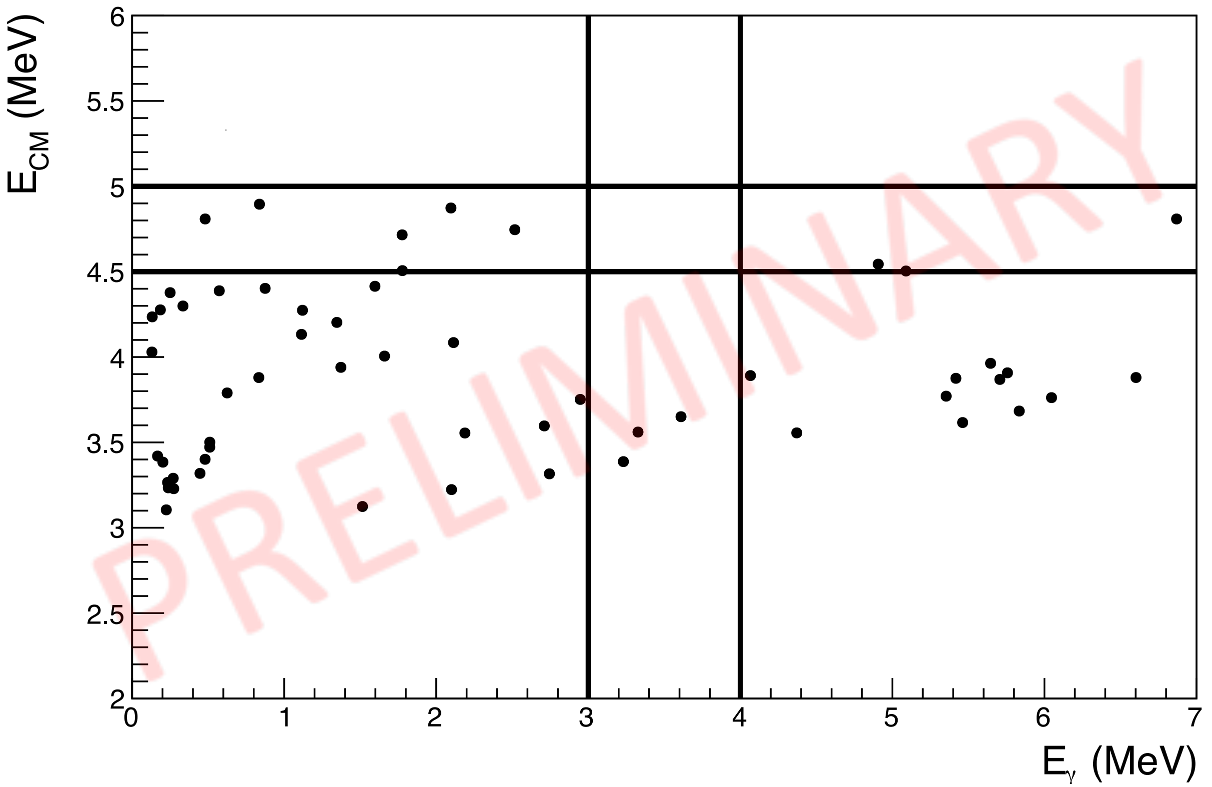

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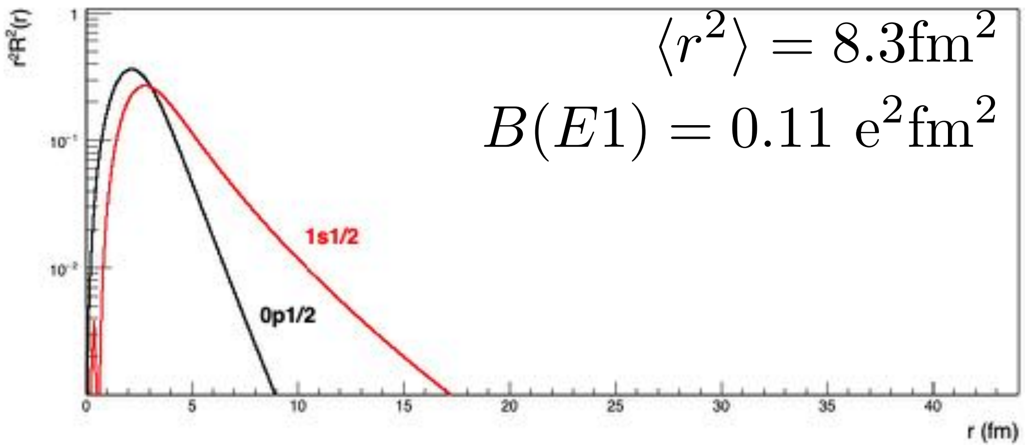

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Conclusion

- **Measurement of the excitation function of the $^{1}H(^{14}O,p)^{14}O$ in the first experiment:**
  - Confirmed the properties of the 5/2+ and 1/2- states
  - Precise measurement of the **new 5/2- and 3/2- states** found to be very **narrow** despite being **3 MeV above the Coulomb Barrier**

- **Interpretation of the structure of the measured states:**
  - The coupling to the nearby thresholds might explain the narrow width of the 3/2-

- **Measurement of the two-proton decay in the second experiment $^{1}H(^{14}O,p)^{14}O^{(*)}(p)^{13}N$:**
  - Two-proton decay correlations deduced from the use of Dalitz plot showed that **the 5/2- and 3/2- states decayed sequentially** through ^{14}O first excited state

- **Gamma branching ratio:**
  - Determination of an upper limit
  - The experimental upper limit is compatible with the calculated gamma width
  - Insight on what makes a good candidate for gamma transition between unbound states

Conclusion

Thank you for your attention!