Study of the magicity of the ^{13}B nucleus and mixed configurations in ^{12}Be via QFS knockout reactions

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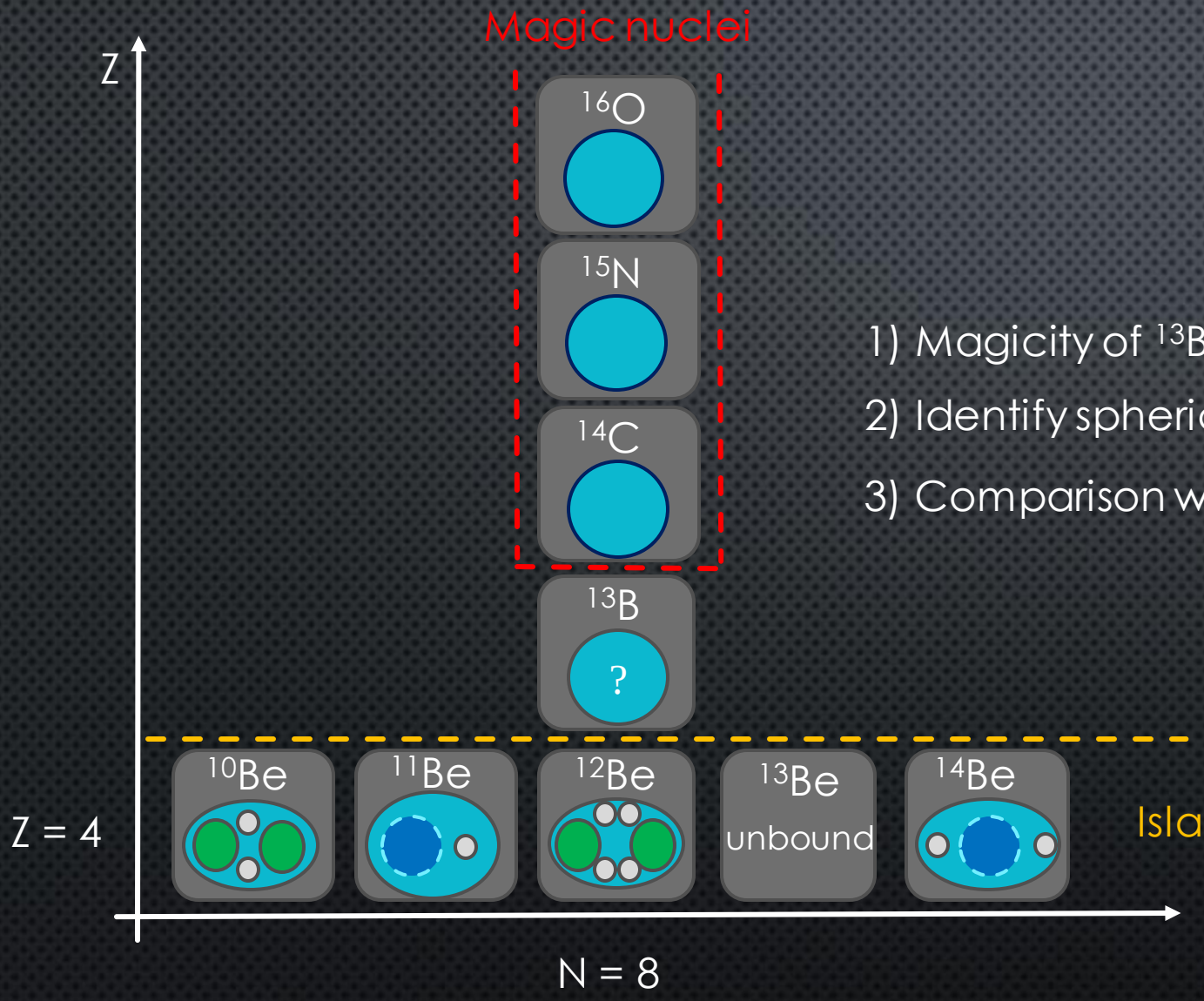
C. Caesar, M. Holl, V. Panin, M. Vandebrouck, F. Wamers, C.X. Yuan
and R^{3}B collaboration

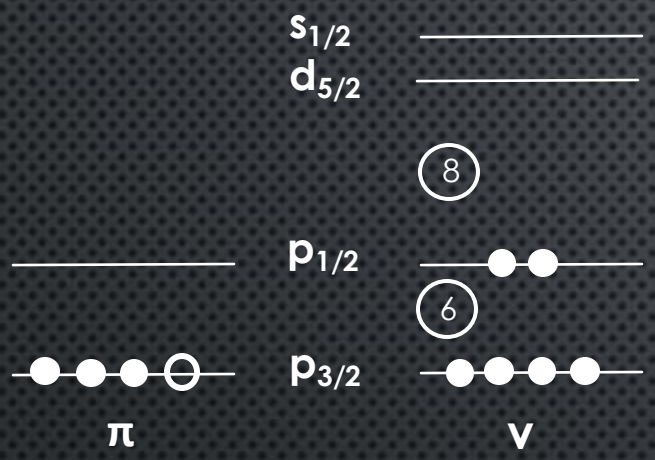
I) Outlines



1) Magicity of ^{13}B through ^{13}B(p,pn)^{12}B QFS reaction
2) Identify spherical states in ^{12}Be through (p,2p) QFS reaction
3) Comparison with other results and discussion

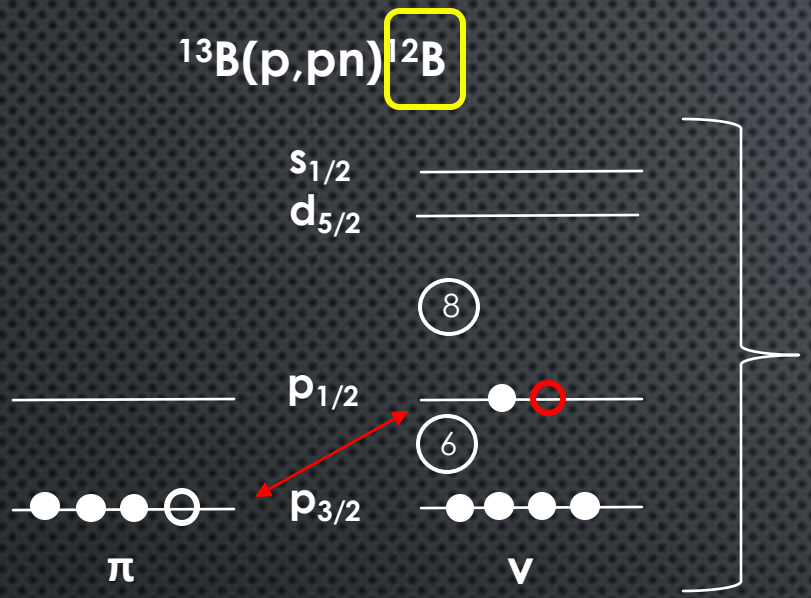
II) Magicity of ^{13}B

$^{13}B(p,pn)^{12}B$



Closed shell :
--> normal configuration

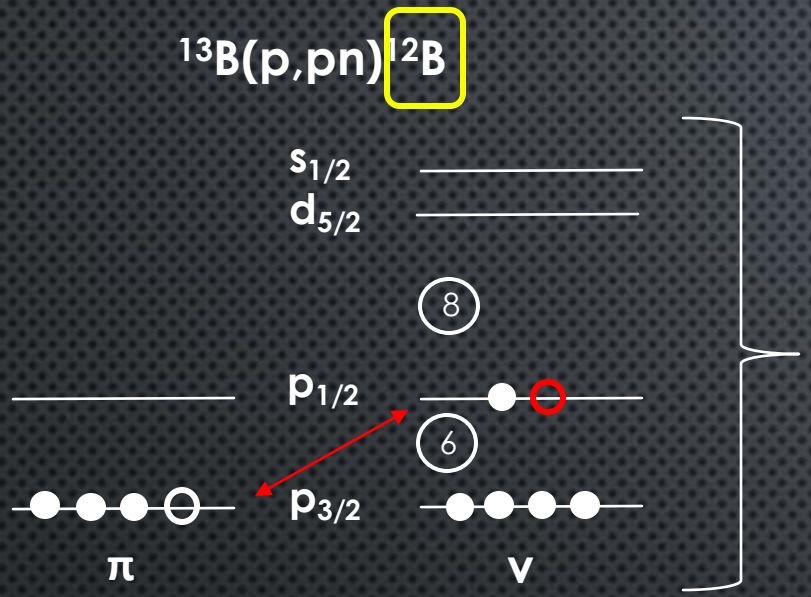
II) Magicity of ^{13}B



1^+ , 2^+
(bound states)

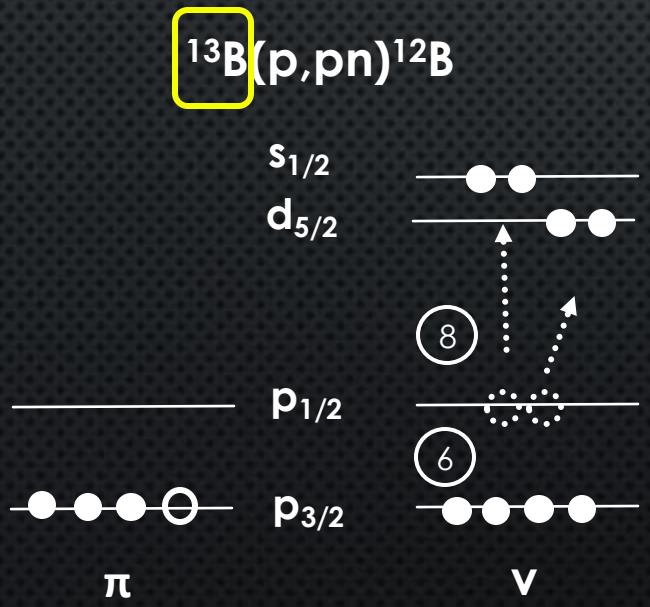
Closed shell :
Positive parity

II) Magicity of ^{13}B



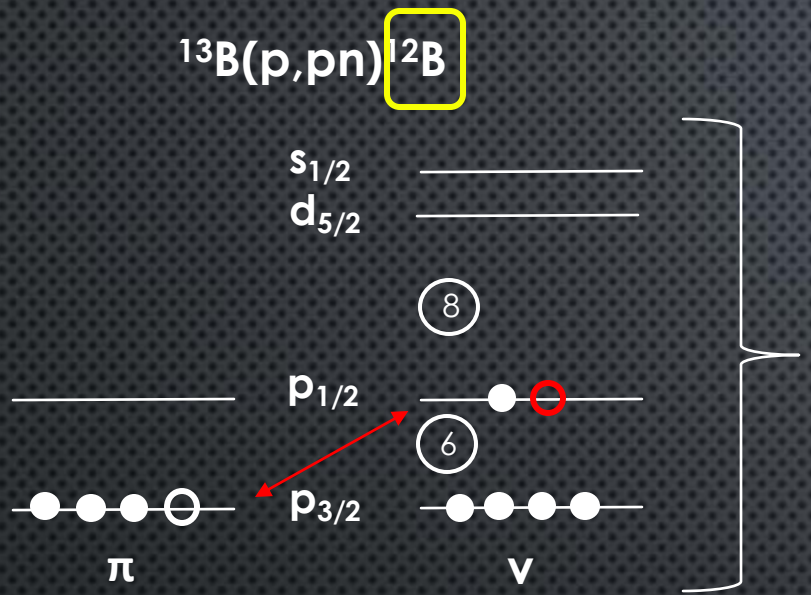
1^+ , 2^+
(bound states)

Closed shell :
Positive parity



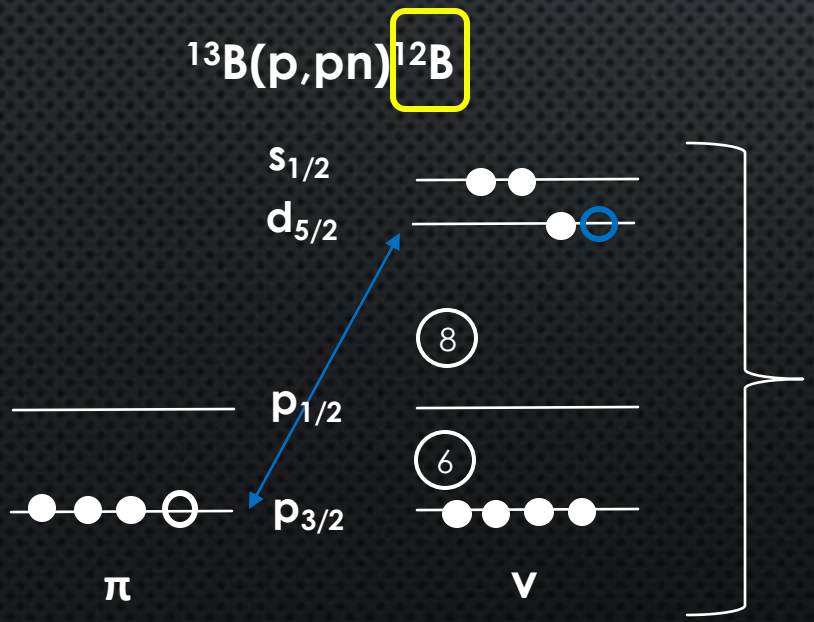
Unclosed shell not (2p2h)
--> intruder configurations

II) Magicity of ^{13}B



1^+ , 2^+
(bound states)

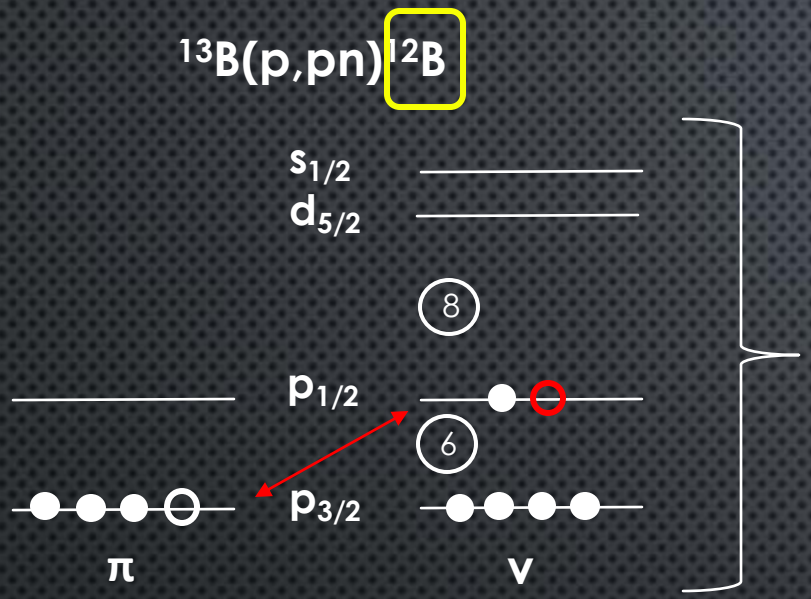
Closed shell :
Positive parity



1^- , 2^- , 3^- , 4^-
(unbound states)

Unclosed shell (2p2h) :
Negative parity

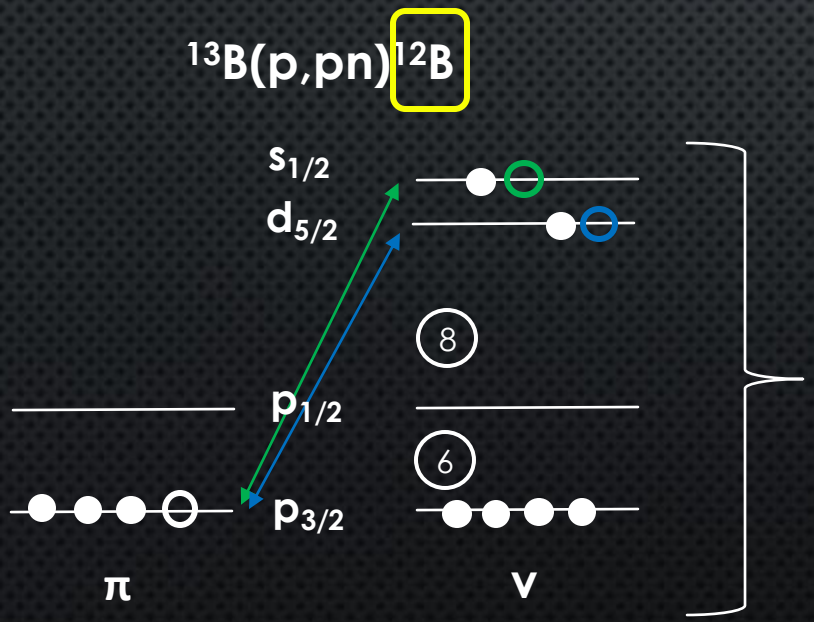
II) Magicity of ^{13}B



1^+ , 2^+
(bound states)

Closed shell :
Positive parity

All the states observed are already known



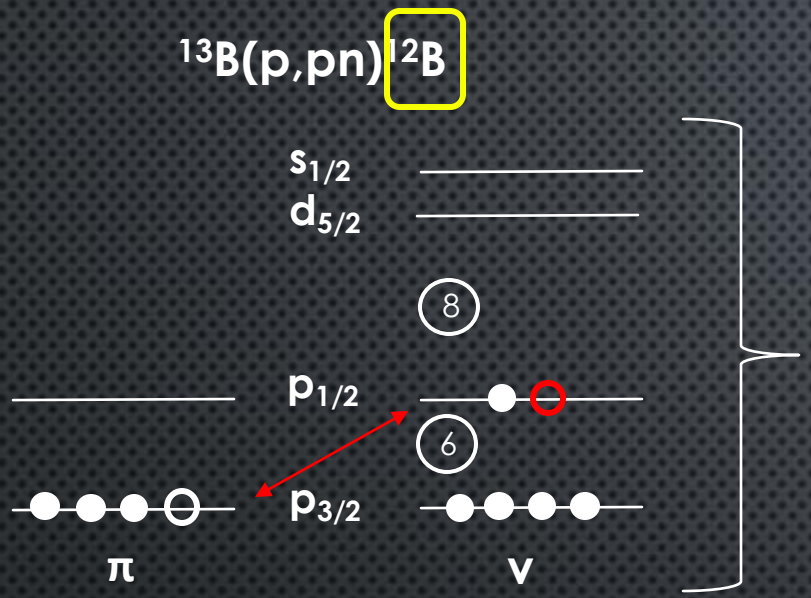
1^- , 2^-
(bound states)

or

1^- , 2^- , 3^- , 4^-
(unbound states)

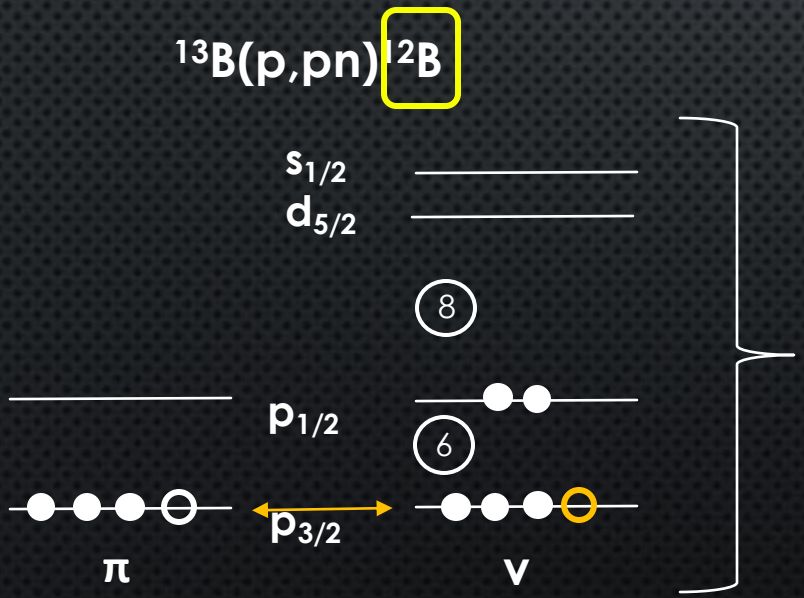
Unclosed shell (2p2h) :
Negative parity

II) Magicity of ^{13}B



1^+ , 2^+
(bound states)

Closed shell :
Positive parity

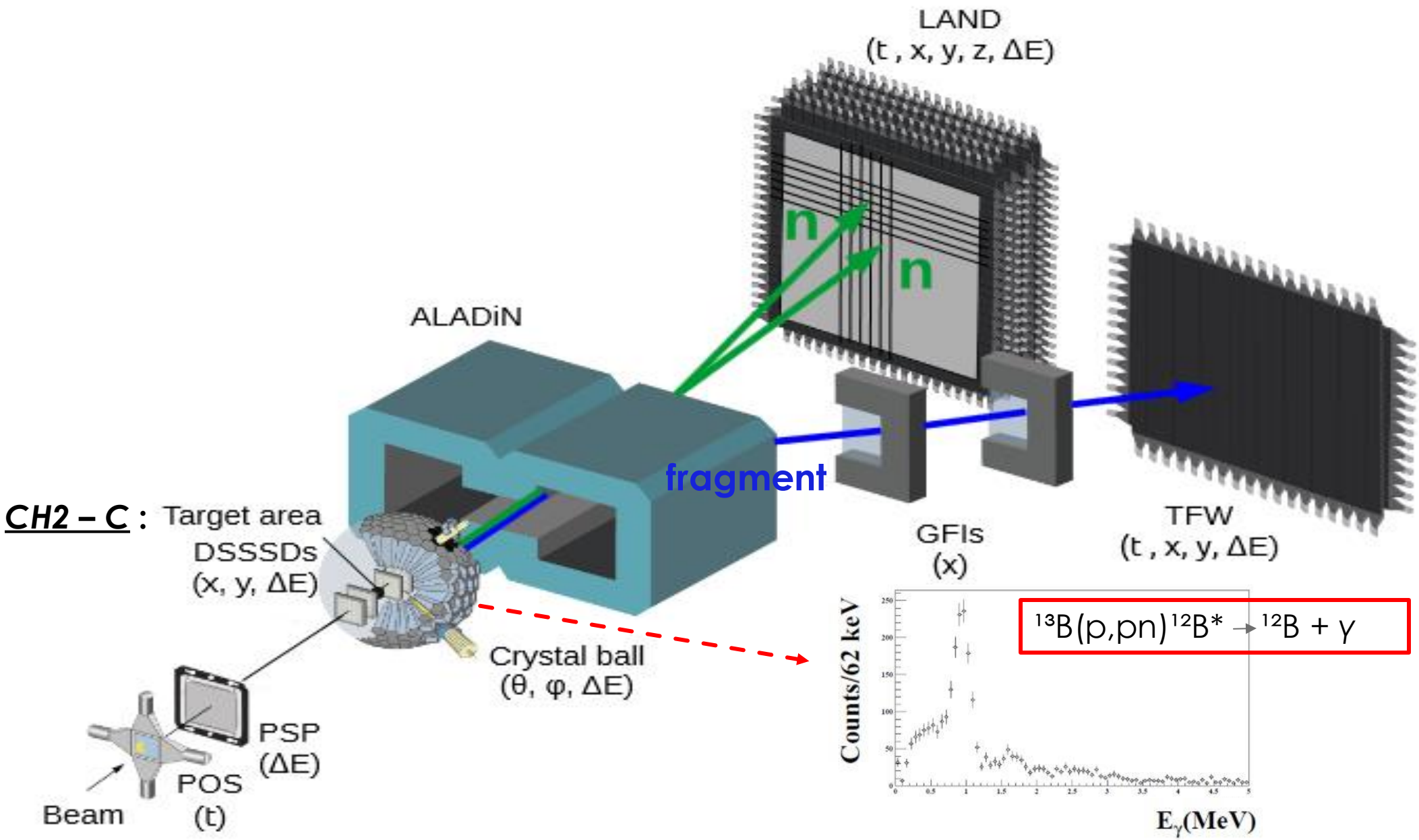


All the states observed are already known

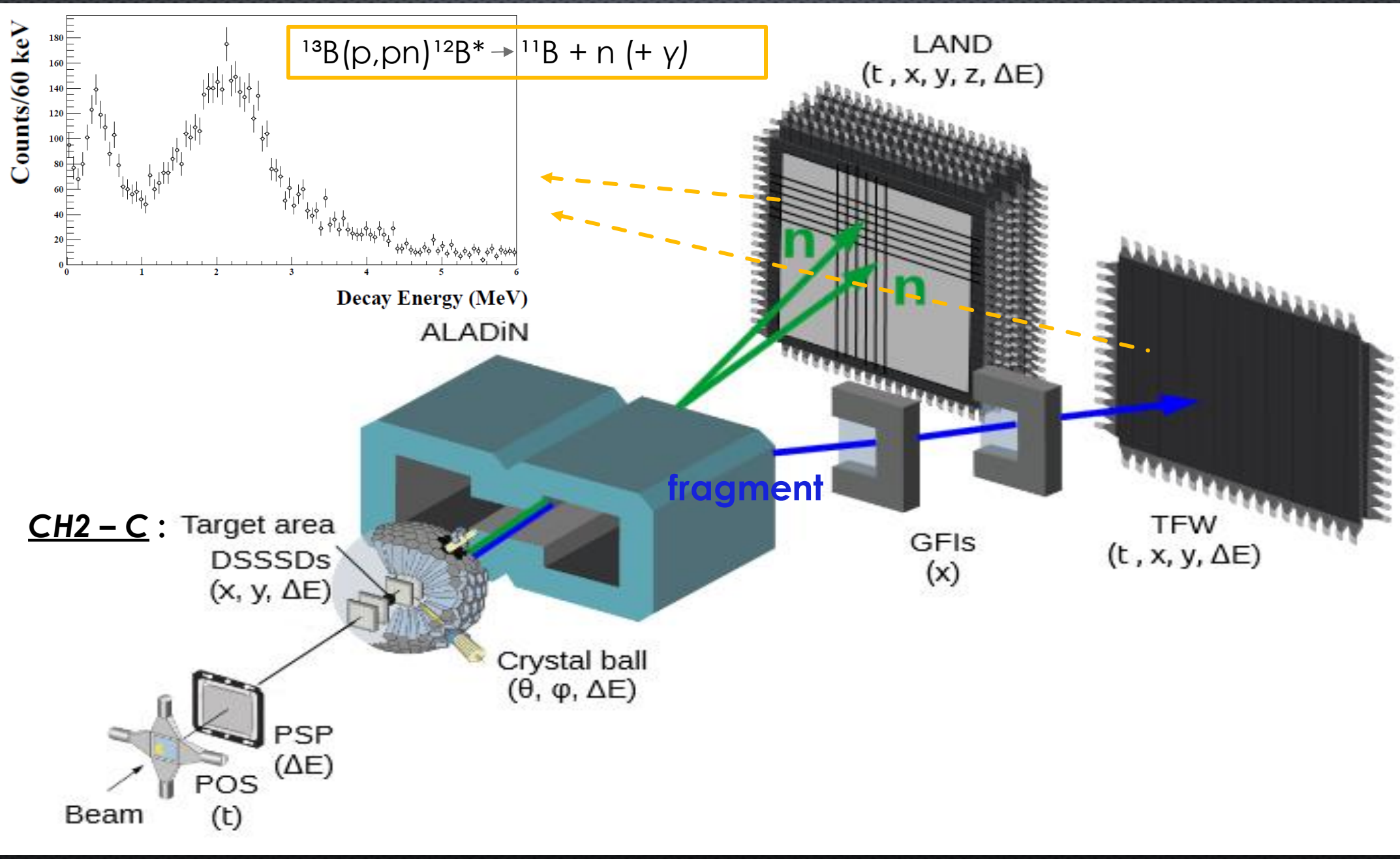
1^+ , 2^+ , 3^+ , 4^+
(bound and unbound states)

Knockout of a more deeply bound neutron

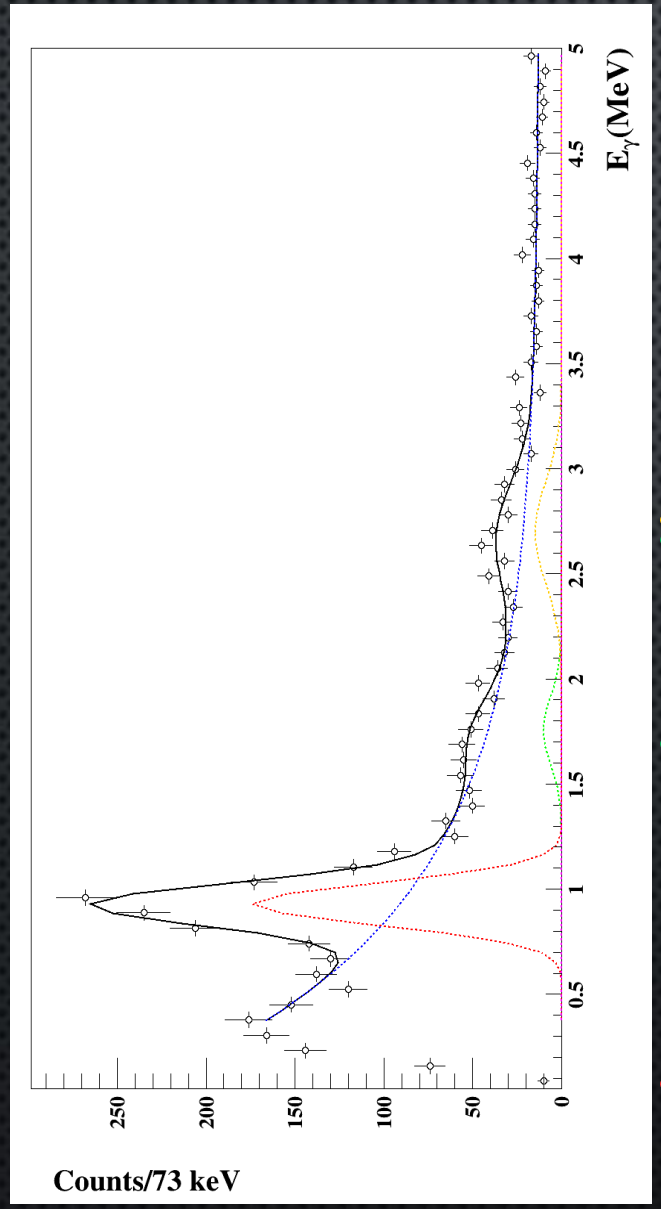
II) Populate bound and unbound states in ^{12}B using R^{3}B - LAND setup

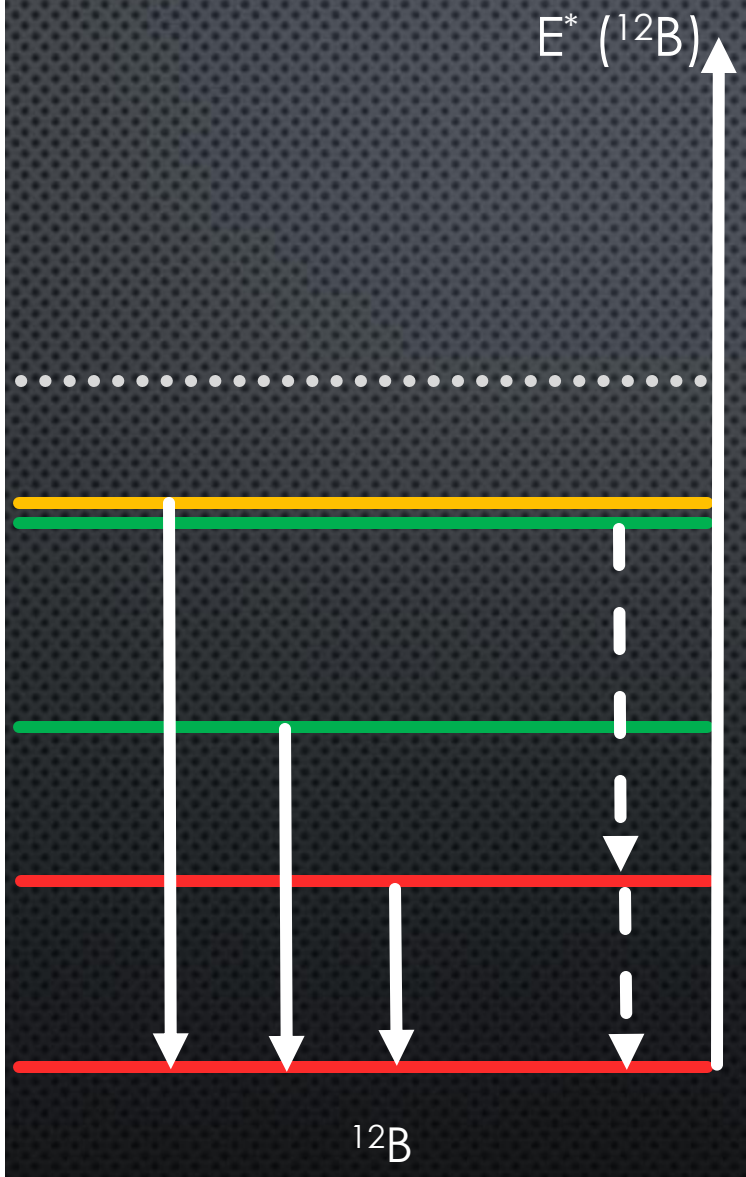


II) Populate bound and unbound states in ^{12}B using R^{3}B - LAND setup



II) Bound states in ^{12}B studied by gamma-ray emission





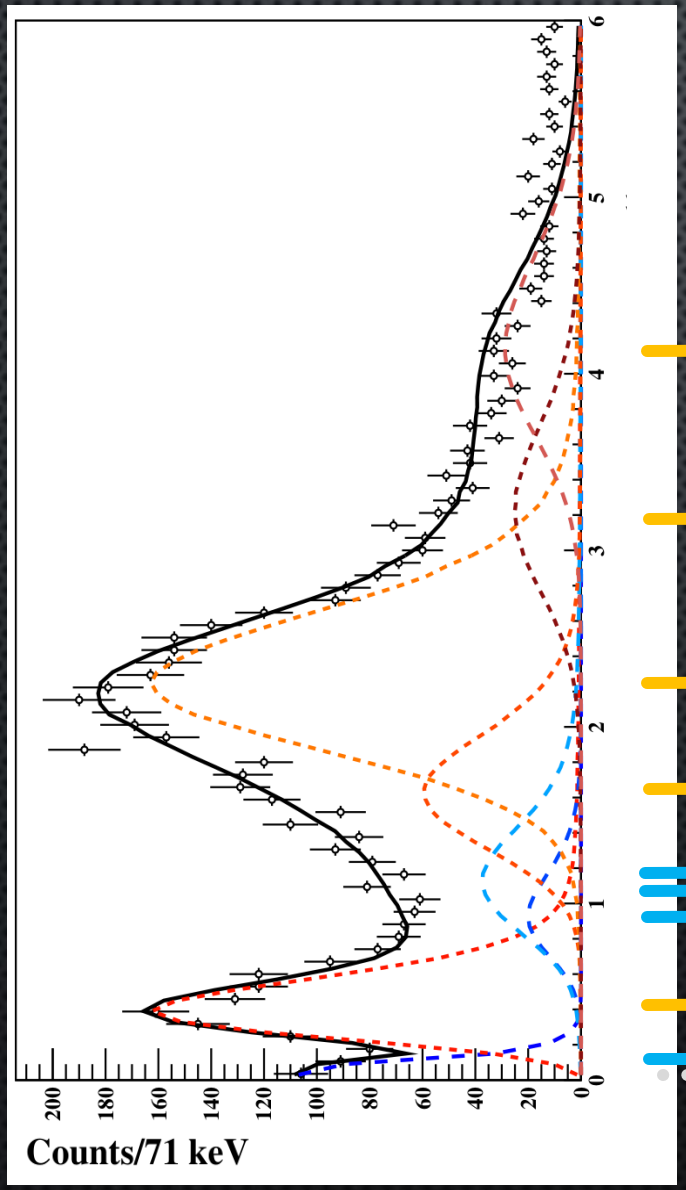
The main contribution for the bound states comes from the **$1p_{1/2}$** neutron orbital

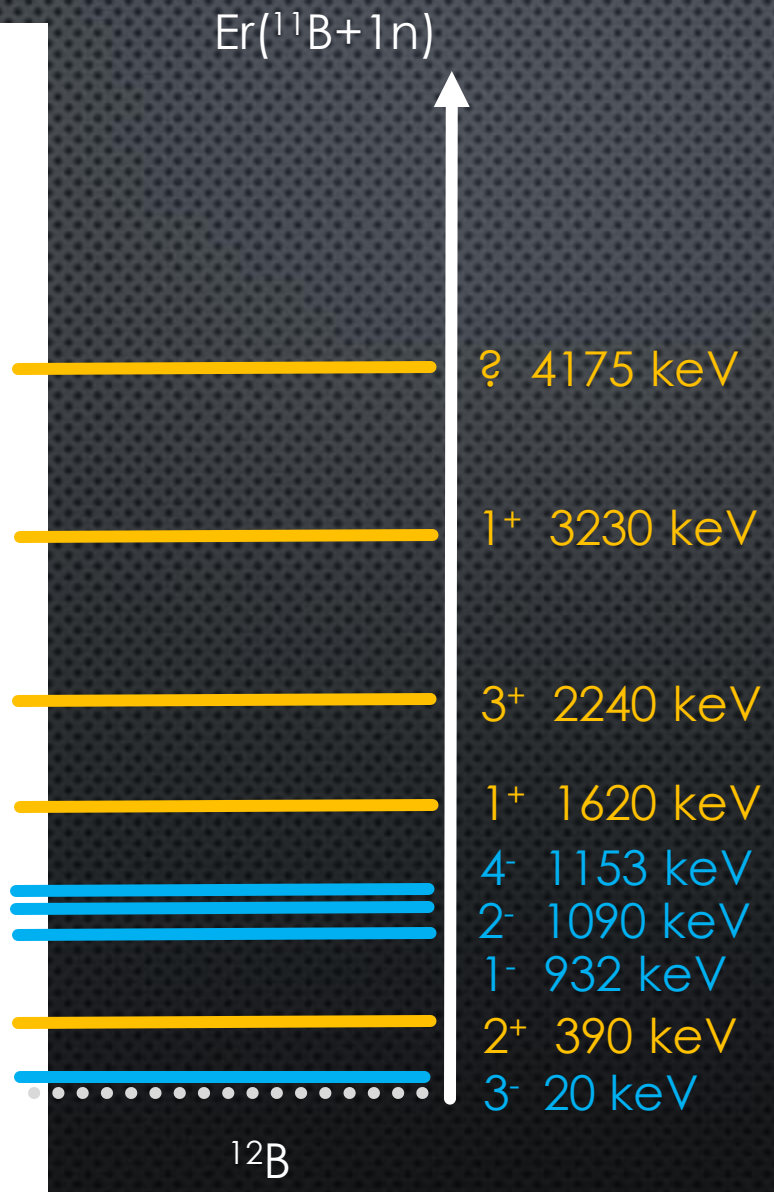
$\pi(1p_{3/2})\otimes\nu(1p_{3/2})$ -> $(0^+,1^+,2^+,3^+)$

$\pi(1p_{3/2})\otimes\nu(2s_{1/2})$ -> $(1^-,2^-)$

$\pi(1p_{3/2})\otimes\nu(1p_{1/2})$ -> $(1^+,2^+)$

II) Study of unbound states via neutron emission





Cross section of the multiplet coming from **$1d_{5/2}$** ~ 15% of the one from **$1p_{1/2}$**

Gammas detected in coincidence < 9% of the total neutron events

$\pi(1p_{3/2})\otimes\nu(1p_{3/2})$ -> $(0^+,1^+,2^+,3^+)$

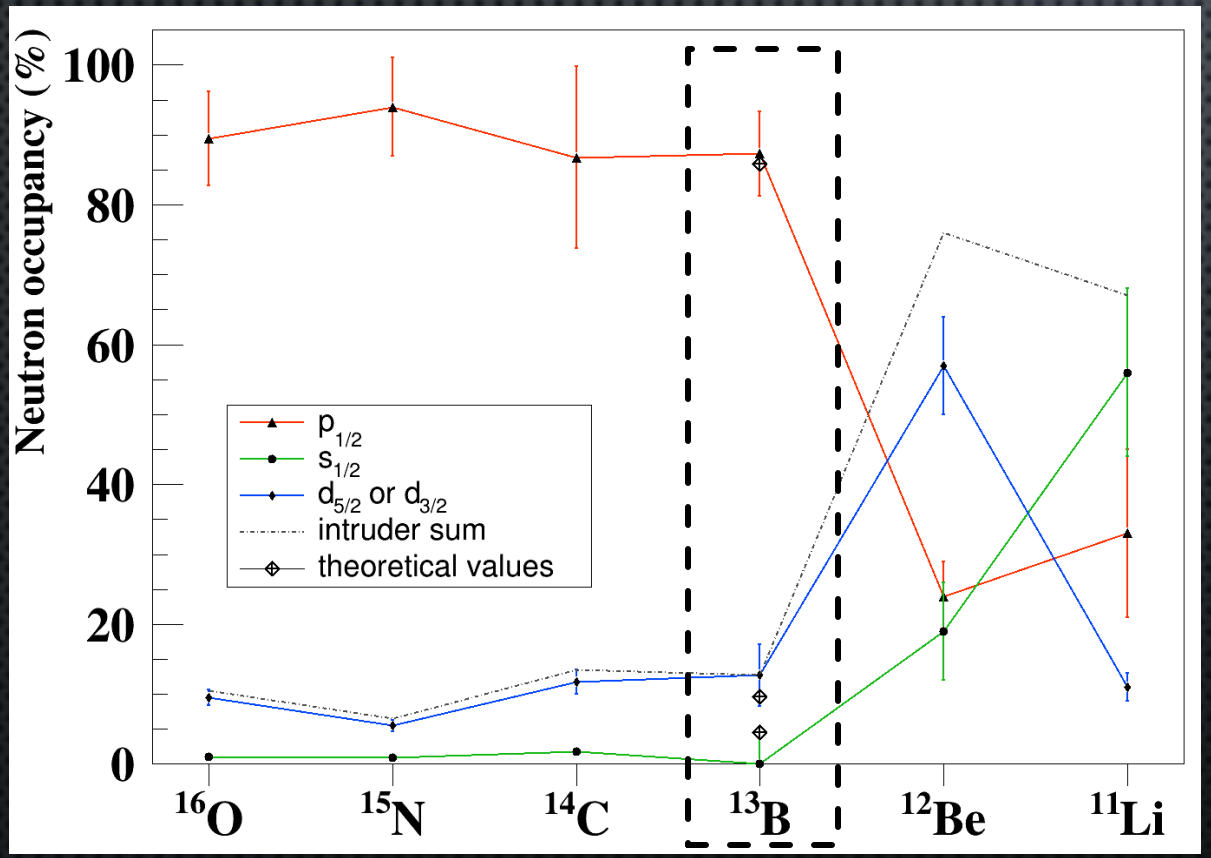
$\pi(1p_{3/2})\otimes\nu(1d_{5/2})$ -> $(1^-,2^-,3^-,4^-)$

II) Ground state of the ^{13}B nucleus

The Quasi Free Scattering approximation was used to calculate theoretical cross sections for a single particle (C.Bertulani).

$$C^2S_{exp} = \frac{\sigma_{exp}}{\sigma_{theo}}$$

These values are then compared to the experimental ones to determine the corresponding C^2S values.



$1p_{1/2}$: 88.1(59)%
$2s_{1/2}$: <4.6% (1 sigma)
$1d_{5/2}$: 11.9(45)%

The magicity of N=8 is strongly preserved in the ^{13}B nucleus

In good agreement with :

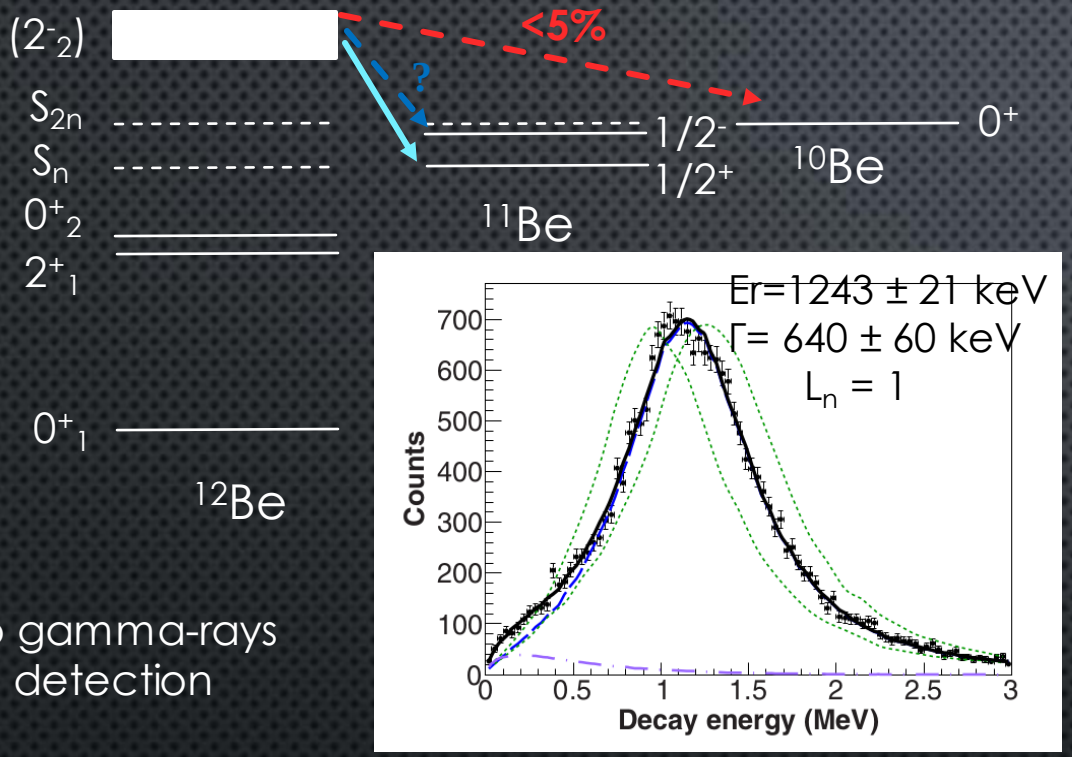
- Shell Model calculations of Cenxi Yuan;

- the experimental results from ^{13}B(p,d)^{12}B reaction (W. Liu *et al.* Phys. Rev. C 104, 064605 , 2021) :

$1p_{1/2}$: 83(6)% **$2s_{1/2}$: 5(2)%** **$1d_{5/2}$: 12(2)%**

III) Search for spherical and deformed 0^+ and 2^+ states in ^{12}Be

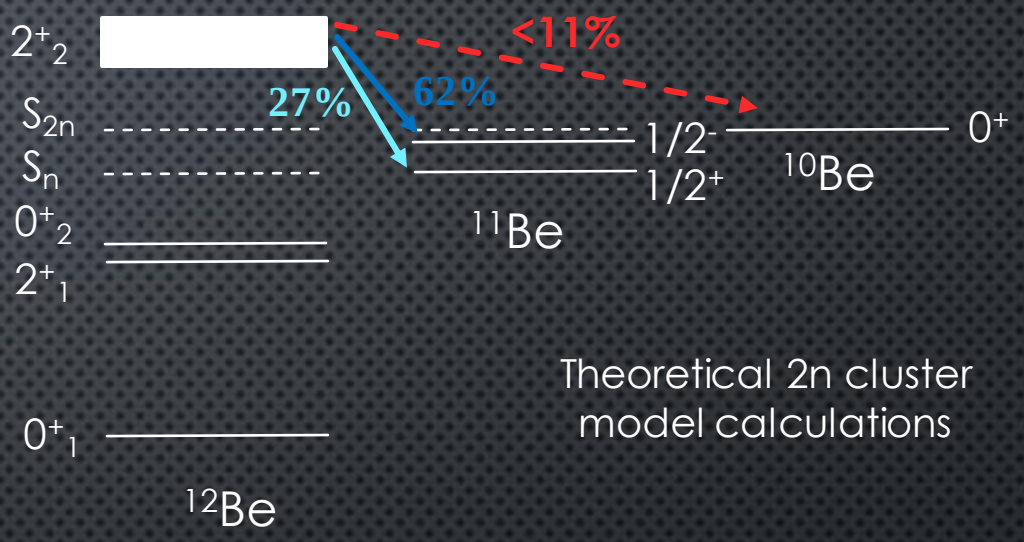
J.K.Smith *et al* , Phys. Rev. C **90**, 024309 (2014) : experiment



no gamma-rays detection

Er(^{11}Be + 1n)

H.T. Fortune, EPJ A **52**, 11 (2016) : theory

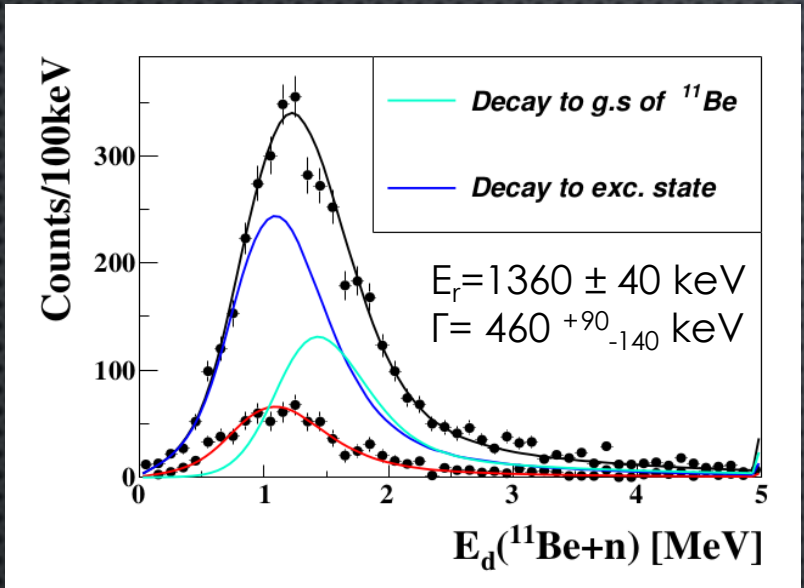


Theoretical 2n cluster model calculations

The ^{13}B(p,2p)^{12}Be reaction will feed 0^+_1 , 0^+_2 and 2^+_1 , 2^+_2

Spherical, deformed, mixing configuration ? -> use of Liu *et al* (2022) results combined with our work to answer

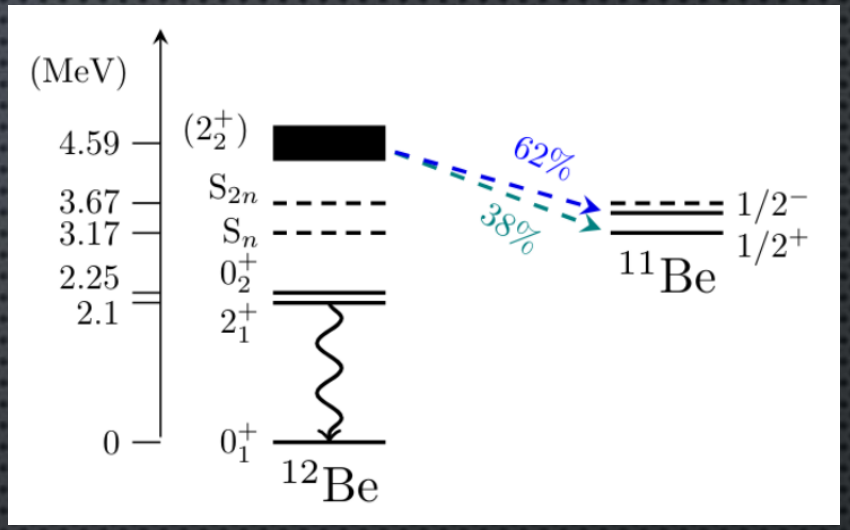
III) Results for neutrons (1n) spectroscopy

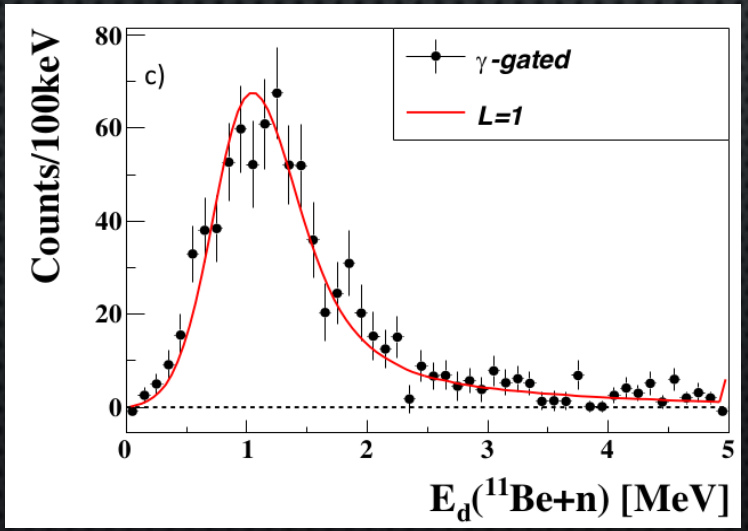


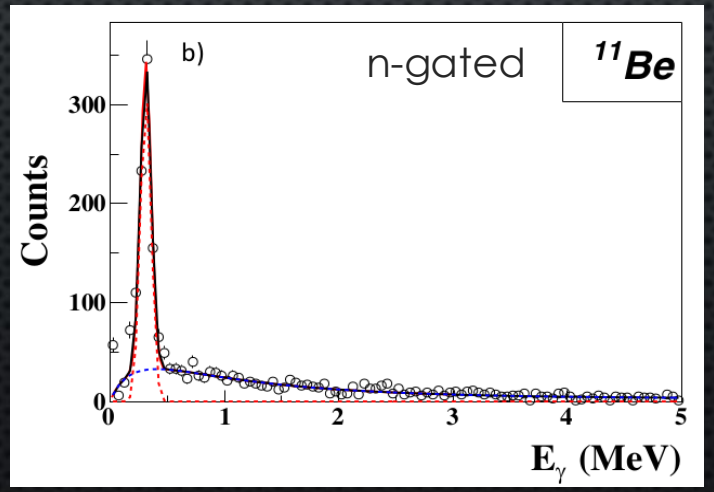
- Decay energy fitted by two BW separated by 320 keV

- The branching ratio to excited and GS is 62 ± 2 % and 38 ± 2 % : good agreement with H. Fortune

- Width smaller than before:
640 keV(Smith *et al*)
460 keV(this work)





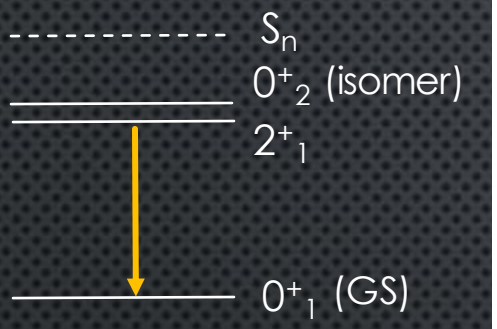


- Negative parity (L = 2 BW) excluded -> 2+ state

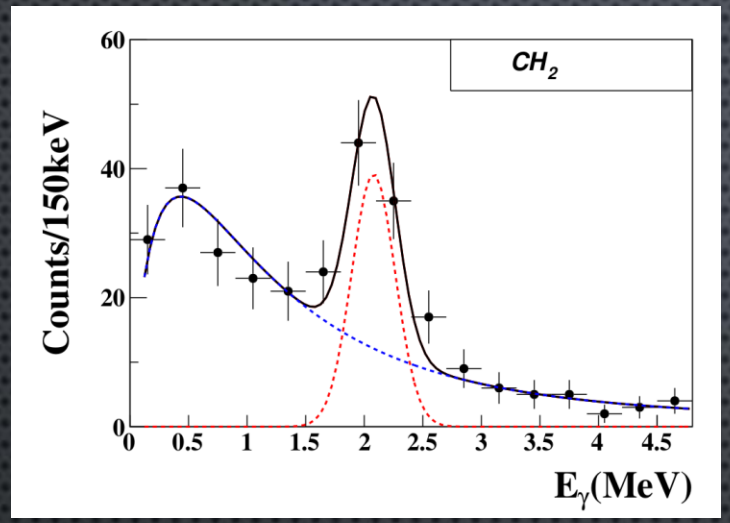
- $\sigma(2^+_2)/\sigma(2^+_1) \approx 6.6$
-> Large feeding of the 2^+_2 : spherical
-> Possible 2n emission ? $B_{2n}(2^+_2)$ = 4.0(5)%
In good agreement with Fortune and Smith

Gamma and decay energy spectra when we observe coincidences

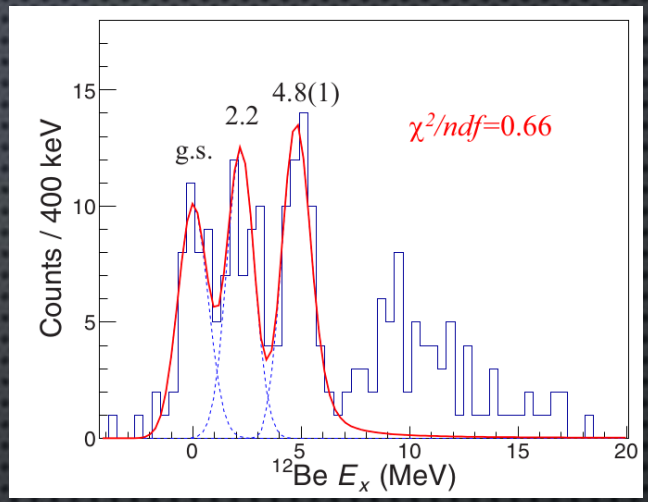
IV) Comparison of results



This work



Liu *et al* , Phys. Rev. C (2022)



C2S table	Lui *et al* (2022)	This work
0^+_1 + 0^+_2	X	0.636(74)
0^+_1	0.49(8)	X
0^+_2 + 2^+_1	0.60(11)	X
2^+_1	X	0.145(27)
2^+_2	1.49(20)	1.00(9)
Sum	2.58(24)	1.78(12)

C2S table	Combinaison of both
0^+_1	0.49(8)
0^+_2	0.46(14)
2^+_1	0.22(4)
2^+_2	1.49(20)

mixing

-> deformed

-> spherical

Normalisation to be checked

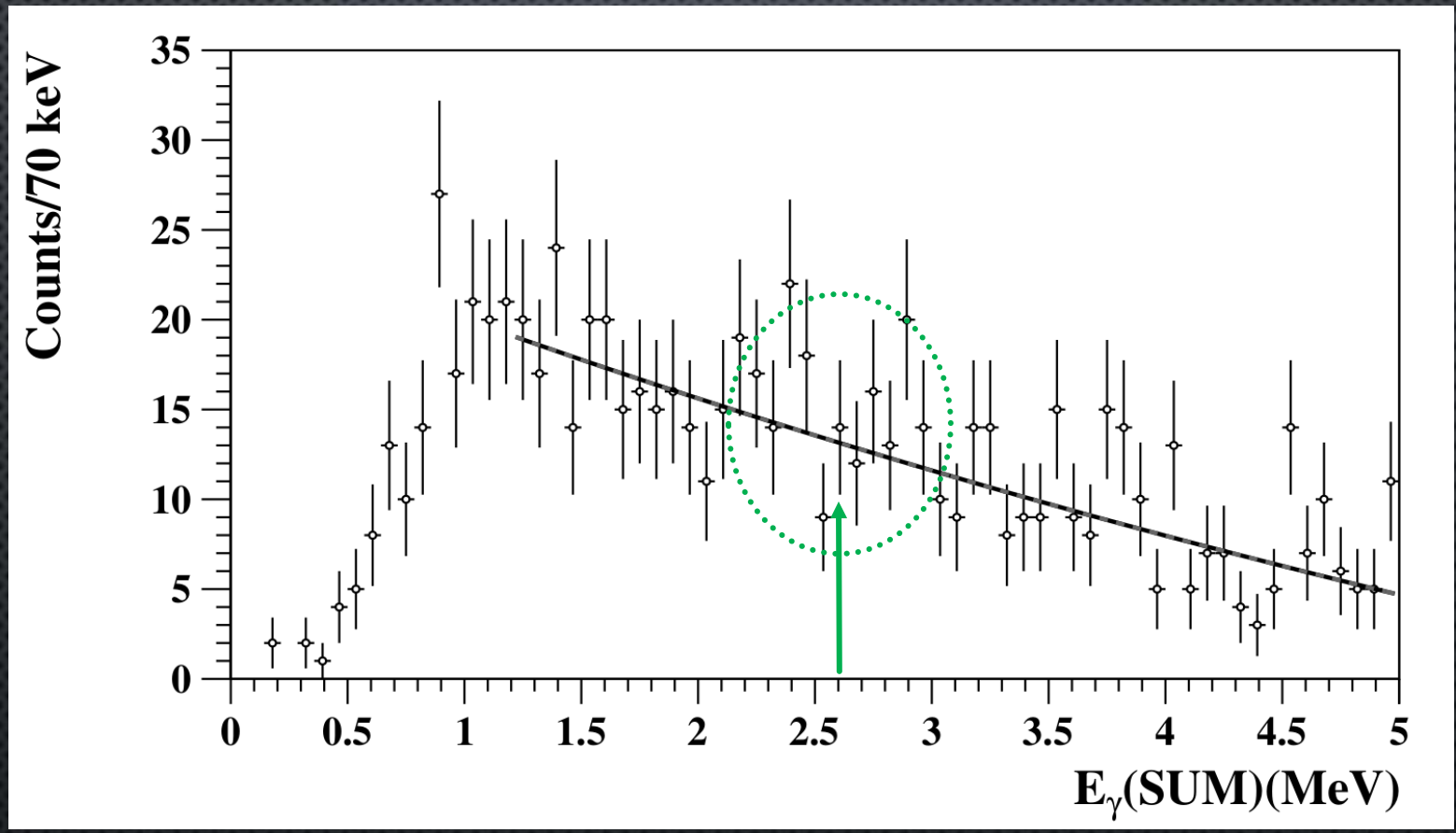
V) Conclusion

- Achievement of a combined analysis of the (p,pn) and (p,2p) reactions that demonstrates the sphericity of ^{13}B, thus favoring the feeding of spherical states in ^{12}Be.

- Analysis made up to states above the S_{2n} thanks to the complete kinematics measuments of these reactions, allowed by the LAND and Crystal ball detectors. The two 0^+ seem mixed contrary to the 2^+ which present a significant difference of cross section: the 2^+_2 being rather spherical.

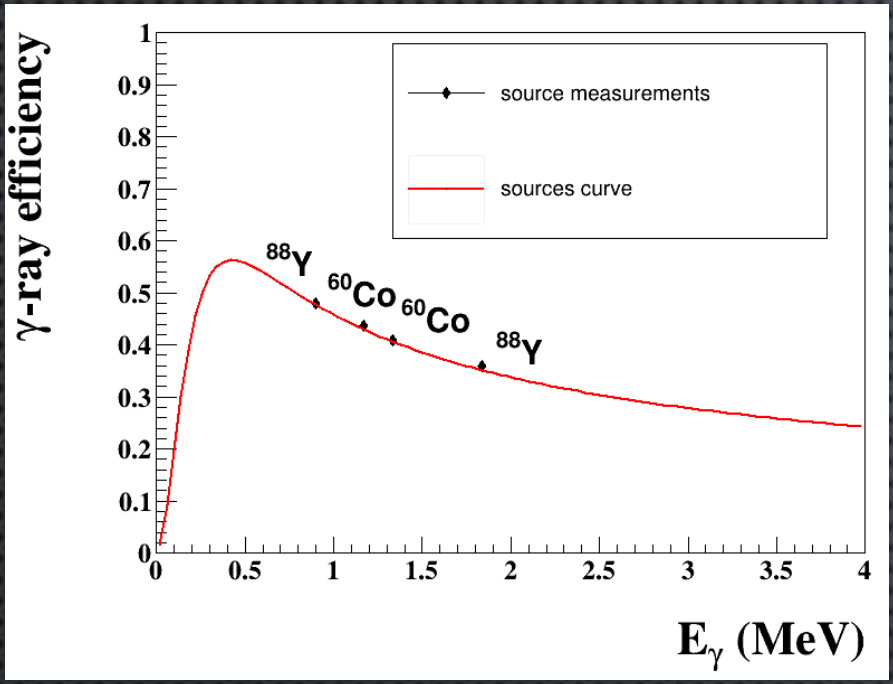
- Good agreement with the method using (p,d) and (d,^{3}He) transfer reactions performed by Liu *et al* and complementarity of these methods.

Thank you for your attention !

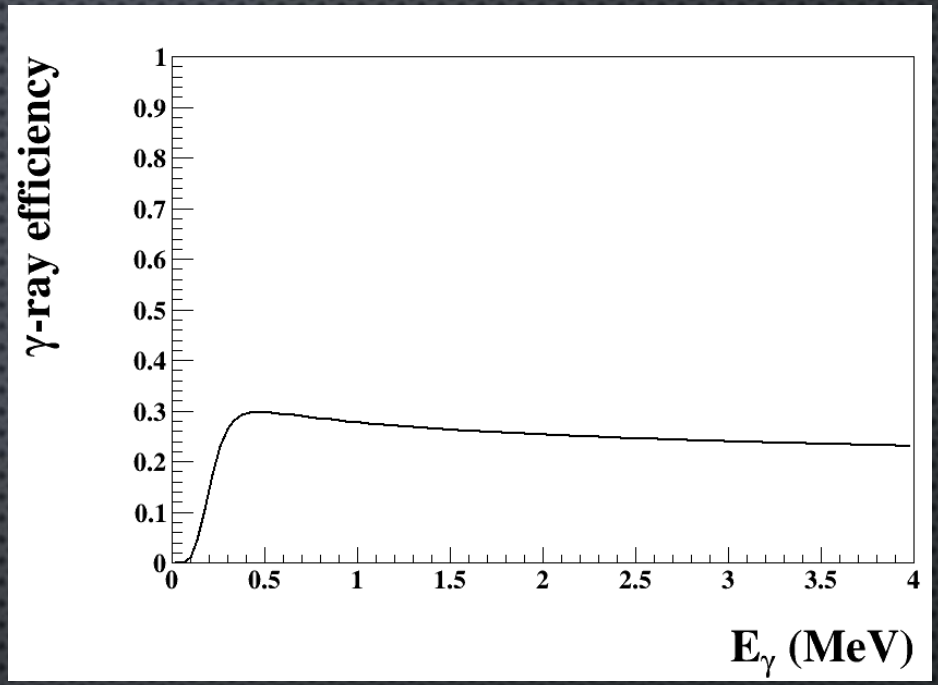


γ-energy sum spectrum for multiplicity = 2

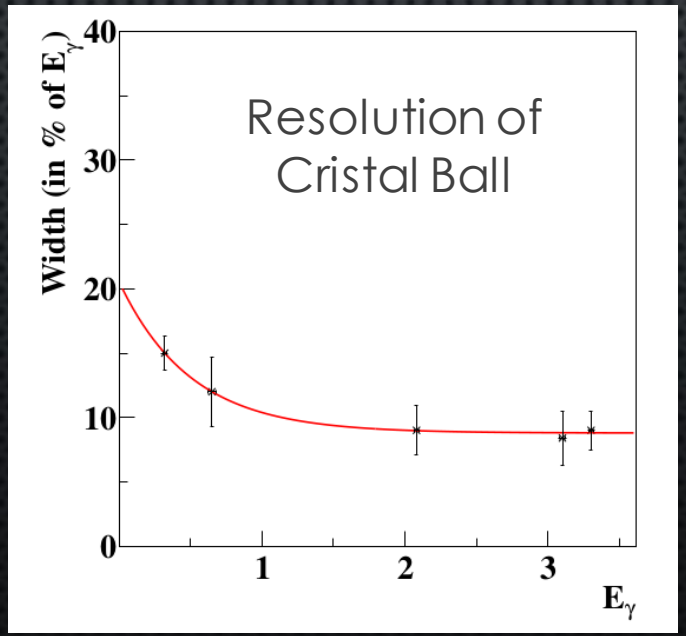
No peak sum indicating the presence of cascades → The contribution of 1^- state is negligible

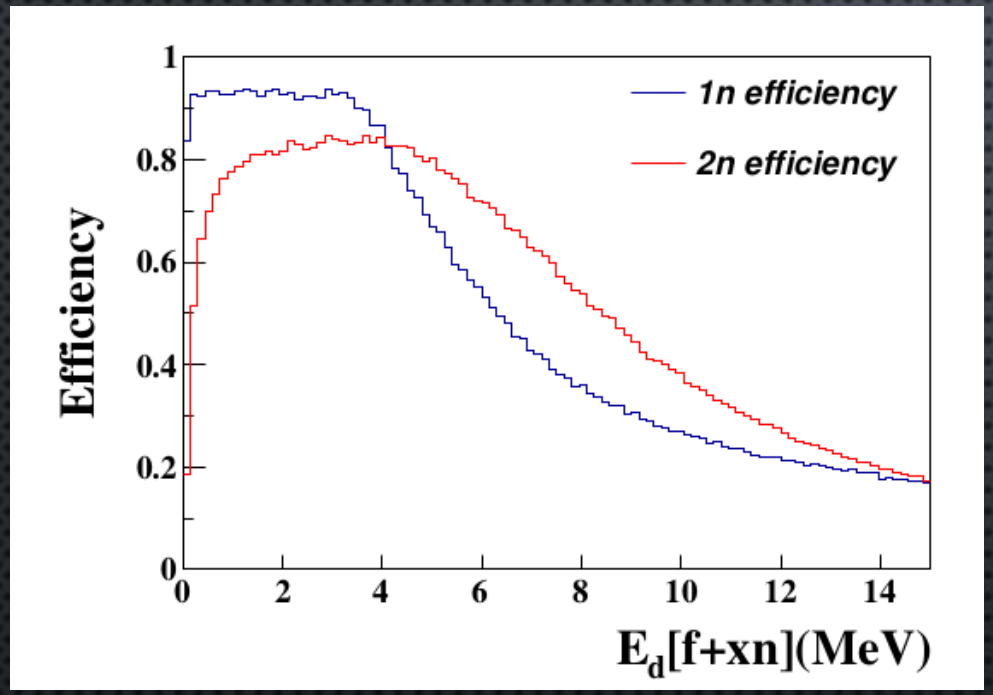


Photopeak efficiency for source validated by measurements

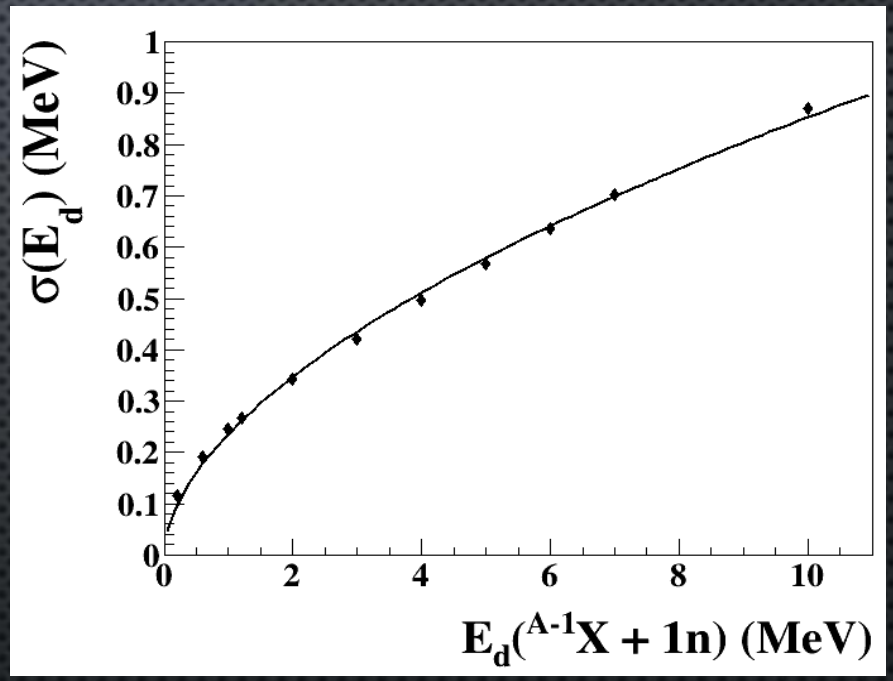


Photopeak efficiency for gamma emitted in flight

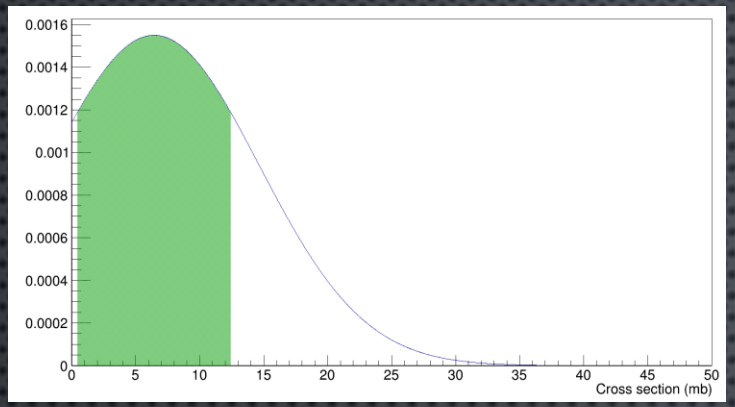




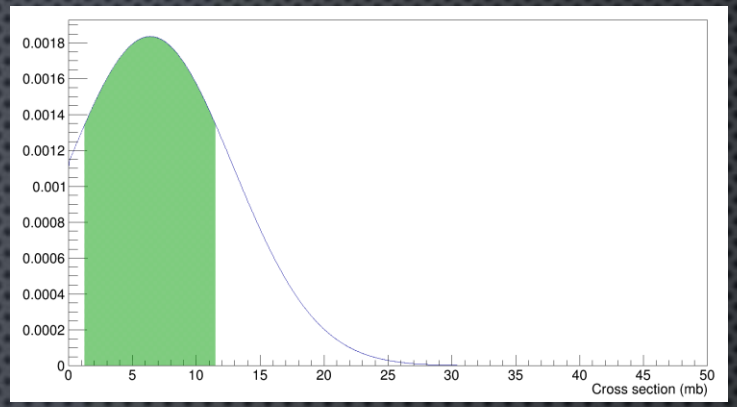
Efficiency of LAND



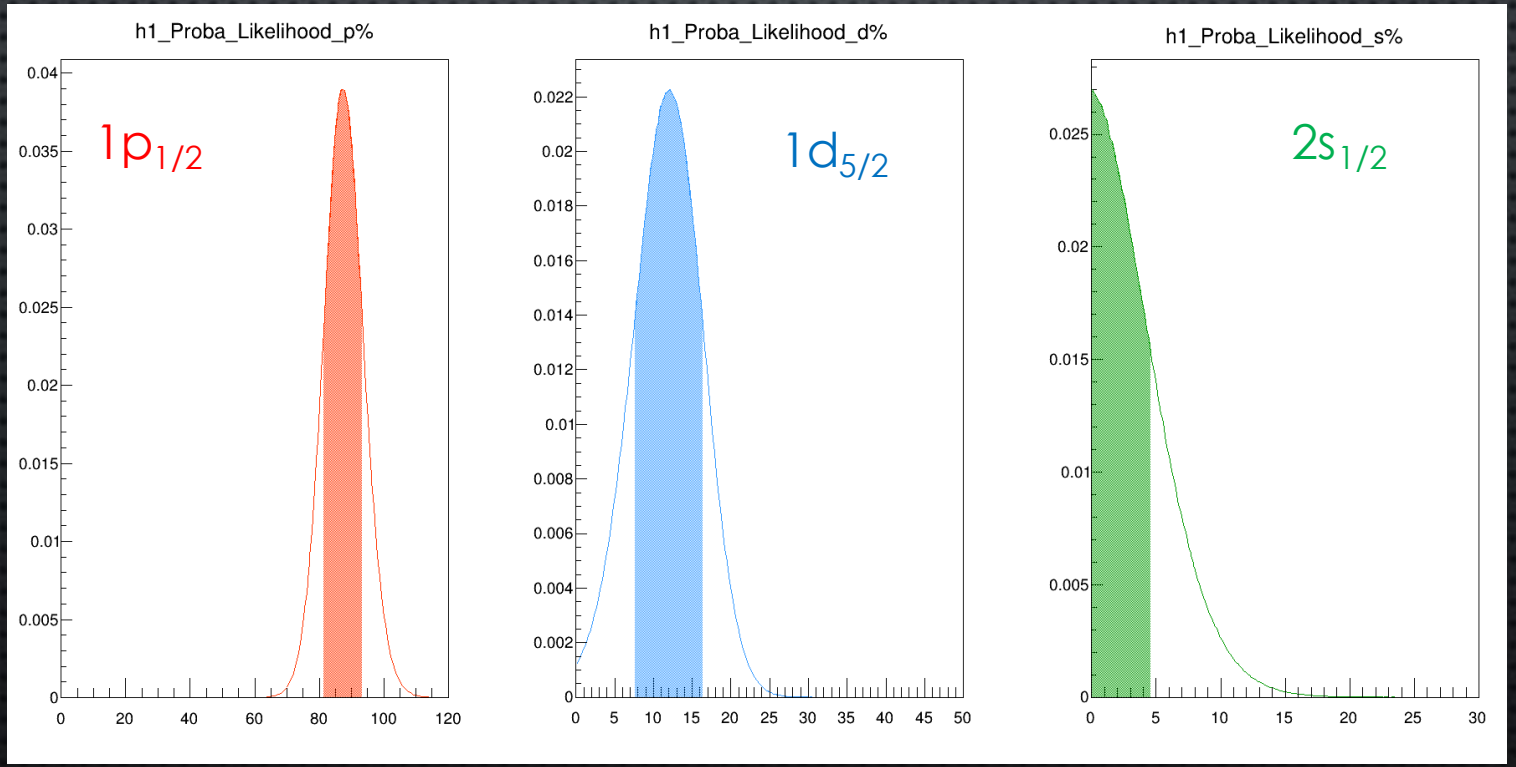
Resolution of LAND



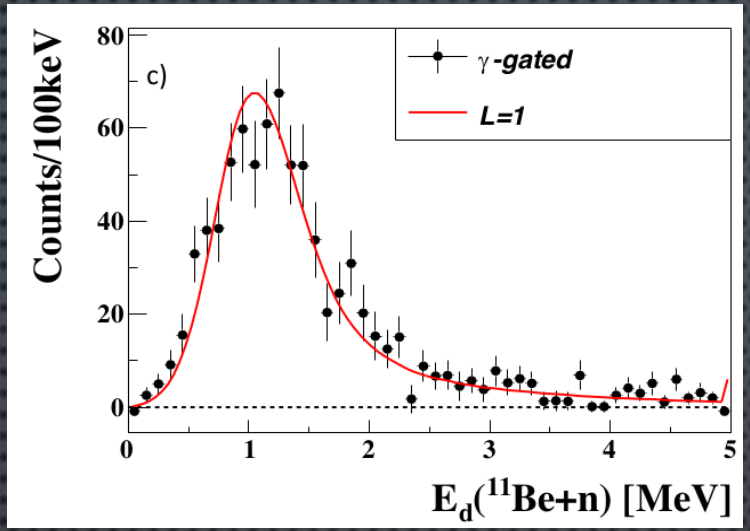
Cross section distribution for CH2 target



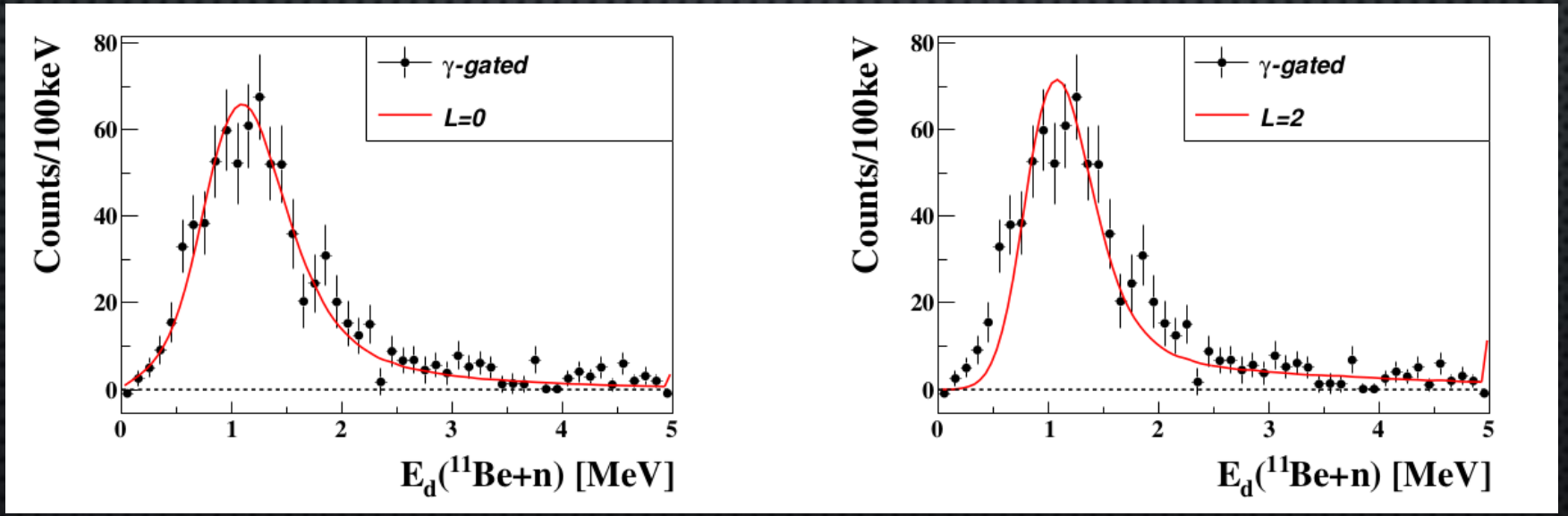
Cross section distribution for C target



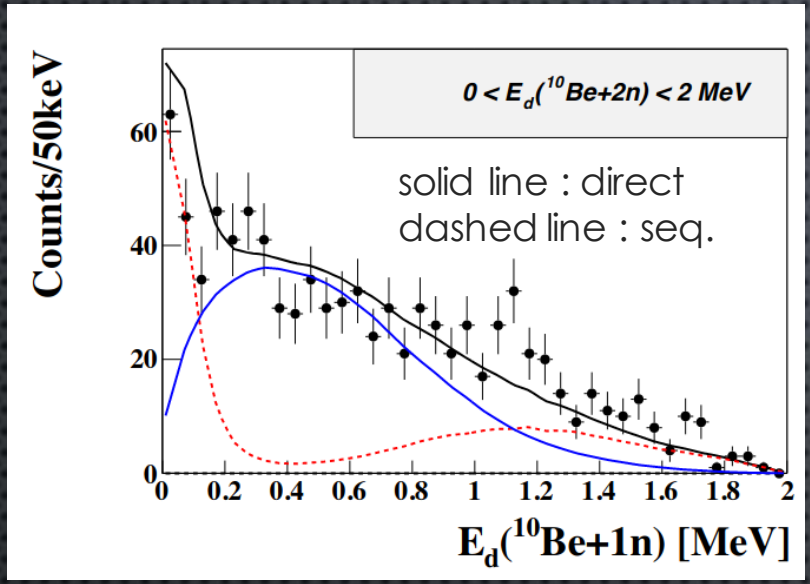
Distributions of the neutron occupancy in *psd* orbital

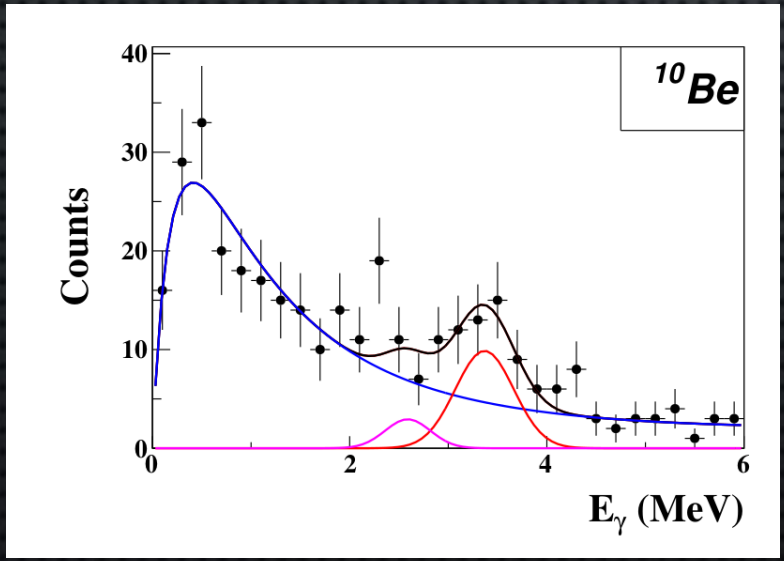


Final fit of the decay energy



Other fits of the decay energy using L = 0 and L = 2



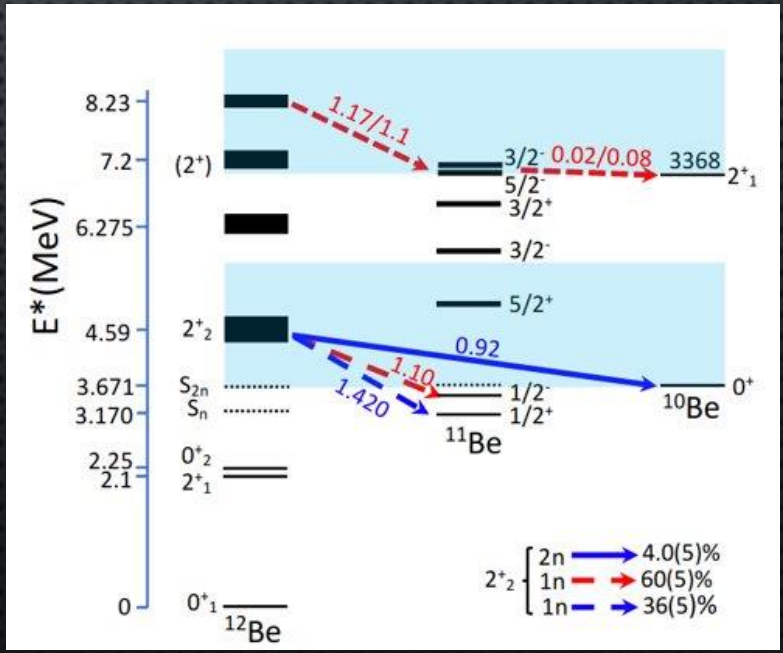


Gammas in coincidence with 2 neutrons in LAND

Fit for Er(^{10}Be + 2n) < 2 MeV :

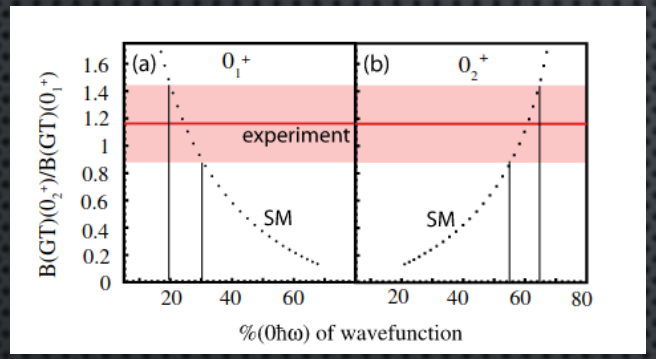
- 1 sequential transition identified
*W. A. Peters, Phys. Rev. C **83**, 057304 (2011)*

- Direct decay from the 2^+_2 to ^{10}Be(GS)



Charge exchange $^{12}B(^{7}Li,^{7}Be)^{12}Be$ and comparison with shell model calculations

R. Meharchand et al., Phys. Rev. Lett 108 (2012) 122501



$\%p_{1/2}(0^+_1) = 24 \pm 5$

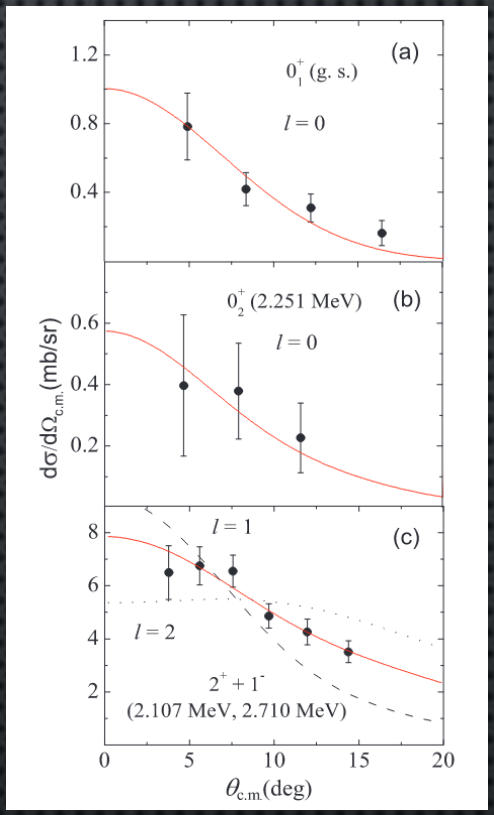
$\%p_{1/2}(0^+_2) = 59 \pm 5$

Transfert reaction $^{11}Be(d,p)^{12}Be$

J. Chen et al., Phys. Rev. C 98 (2018) 014616

$\%s_{1/2}(0^+_1) = 19 \pm 7$
$\%d_{5/2}(0^+_1) = 57 \pm 7$

$\%s_{1/2}(0^+_2) = 39 \pm 2$
$\%d_{5/2}(0^+_2) = 2 \pm 2$



Cross section for $^{13}B(p,2p)^{12}Be$ reaction

$$\sigma(0_i^+) \propto |\langle 0_i^+ | a_\nu^- | 3/2_{GS}^- \rangle|^2$$

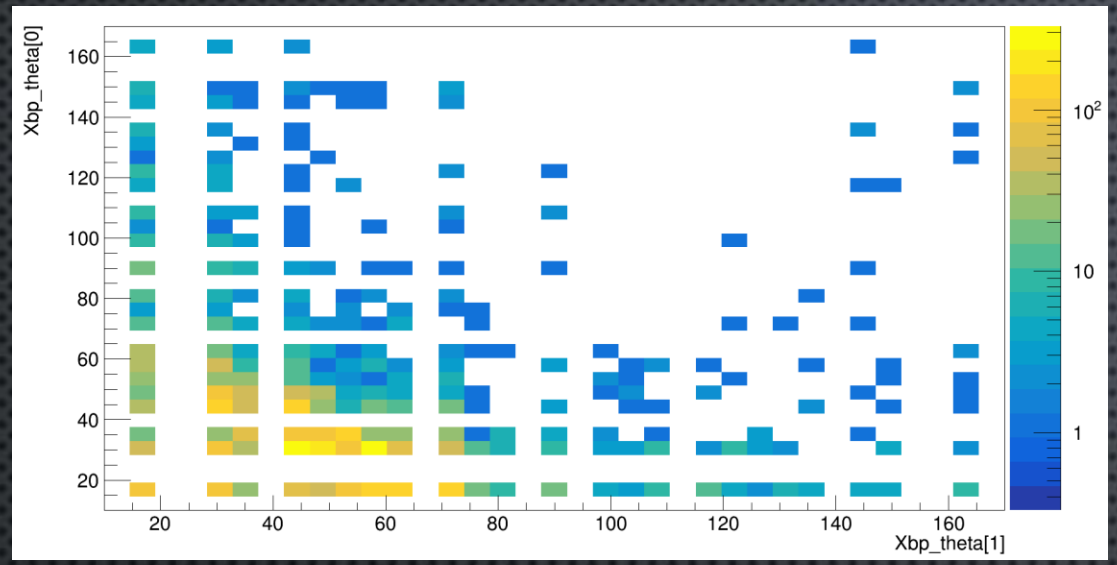
Assuming a similar value given by the removal operator in both cases

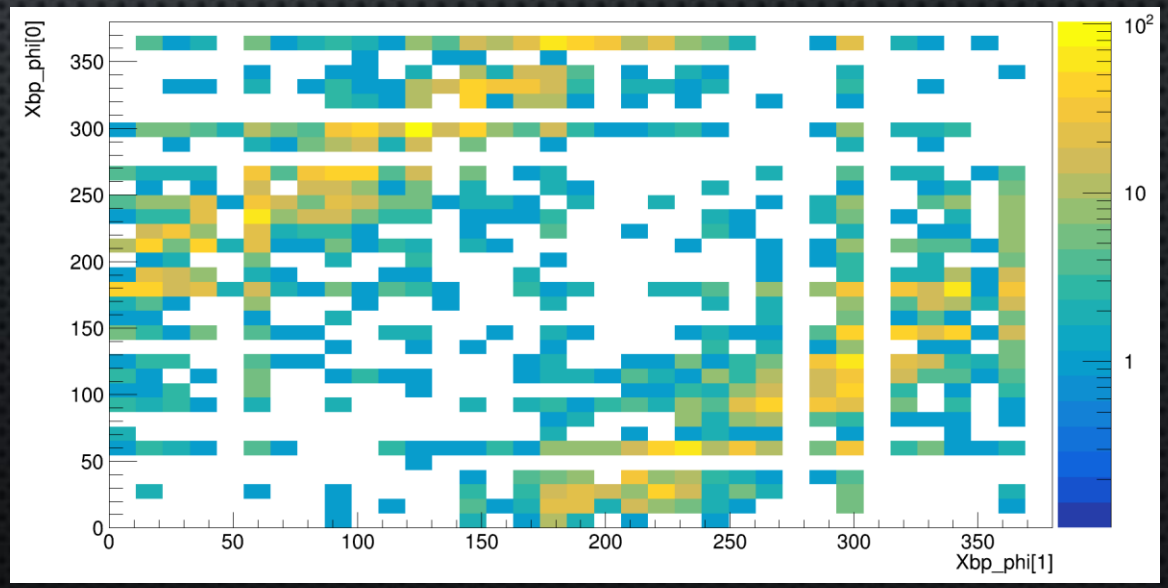
$C^2S(\text{isomer})/C^2S(\text{GS}) = 1.20(24)$

$C^2S(0^+(\text{GS})) = 0.411(67)$ mb

$C^2S(0^+(\text{isomer})) = 0.532(79)$ mb

Good agreement with previous values



theta(1) vs theta(2)

phi(1) vs phi(2)