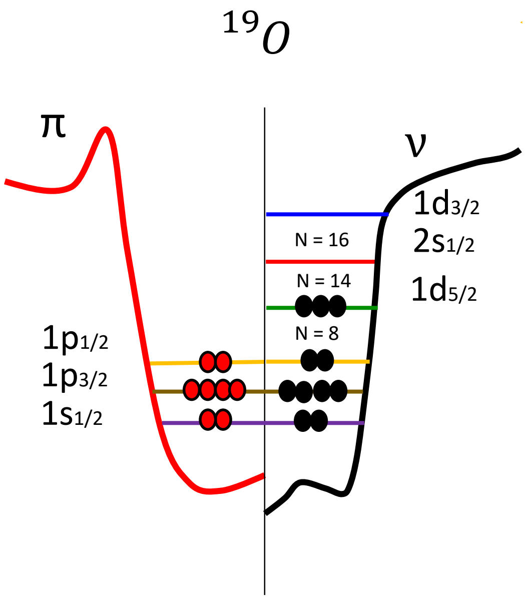
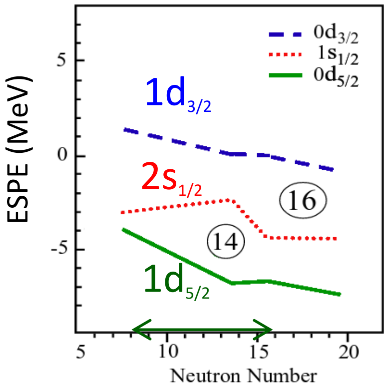
Location of the $\boldsymbol{\nu 1 d_{3/2}}$ strength in $\boldsymbol{^{17}C}$

J. Lois-Fuentes, X. Pereira-López, B. Fernández-Domínguez, F. Delaunay and the e628 collaboration

USC/IGFAE & LPC-Caen

The N=16 shell gap





WBT (USD) M. Stanoiu et al., PRC **78,** 034315 (2008)

n-rich Oxygen : N=14, 16 gaps

- High E_x of 2^+ state in ^{22}O and ^{24}O

  M. Stanoiu et al, PRC 69, 034312 (2004)
  C.R. Hoffman et al., PRL 109, 022501 (2012)

- Small β_2 parameter in ^{22}O and ^{24}O

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SM interactions reproduce well data : WBT, SFO

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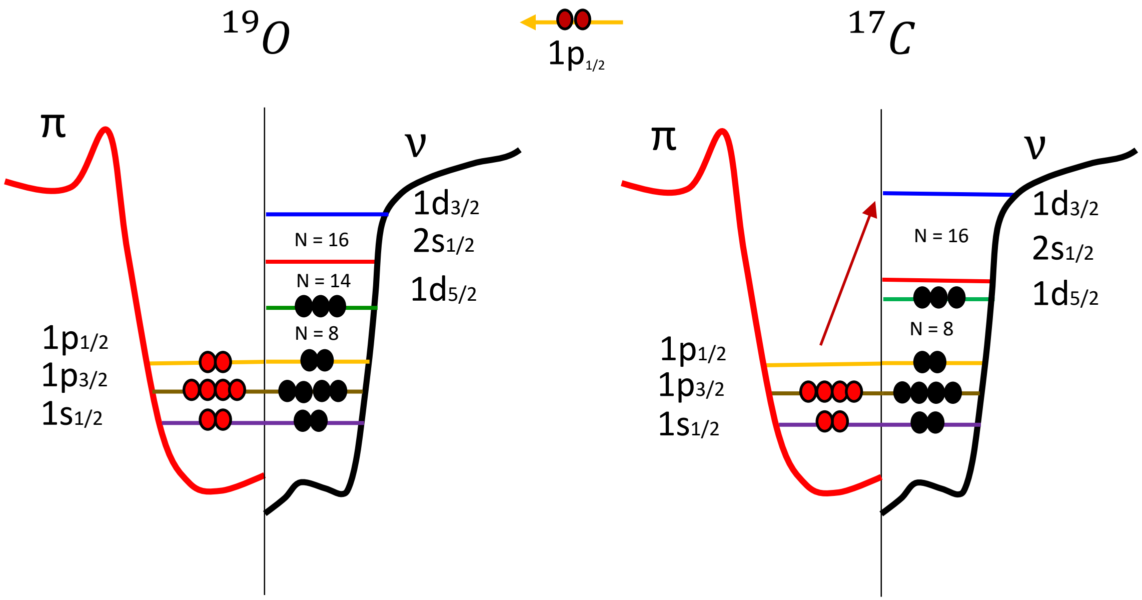

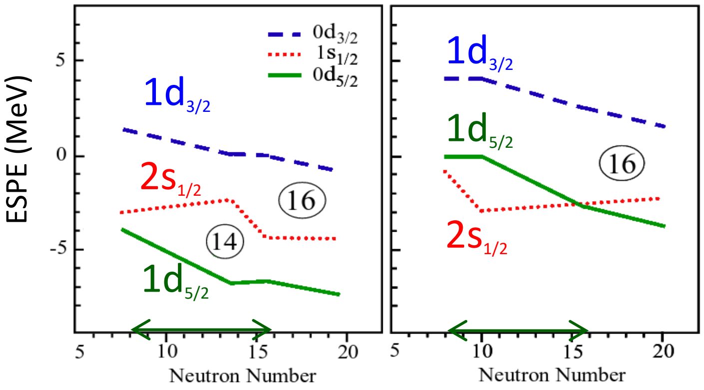

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  M. Petri et al., PRL 96, 012501 (2011)

Modification of SM interaction : WBT*, SFO-tls

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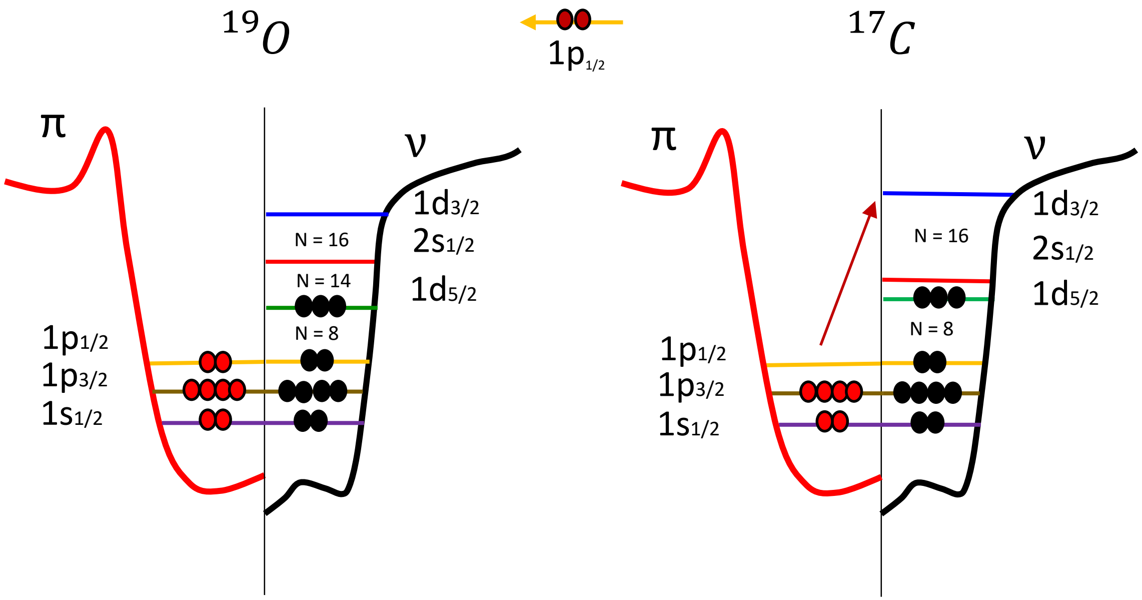

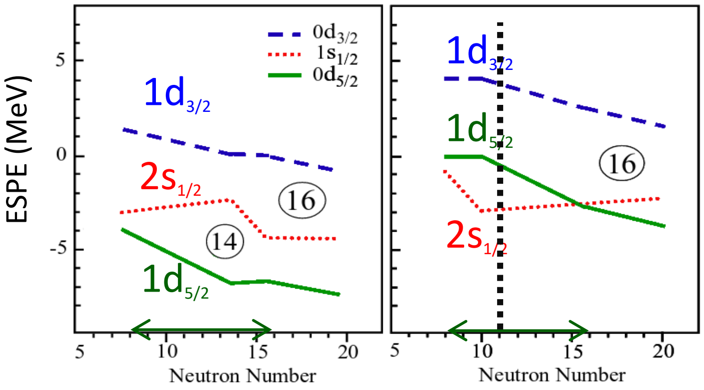

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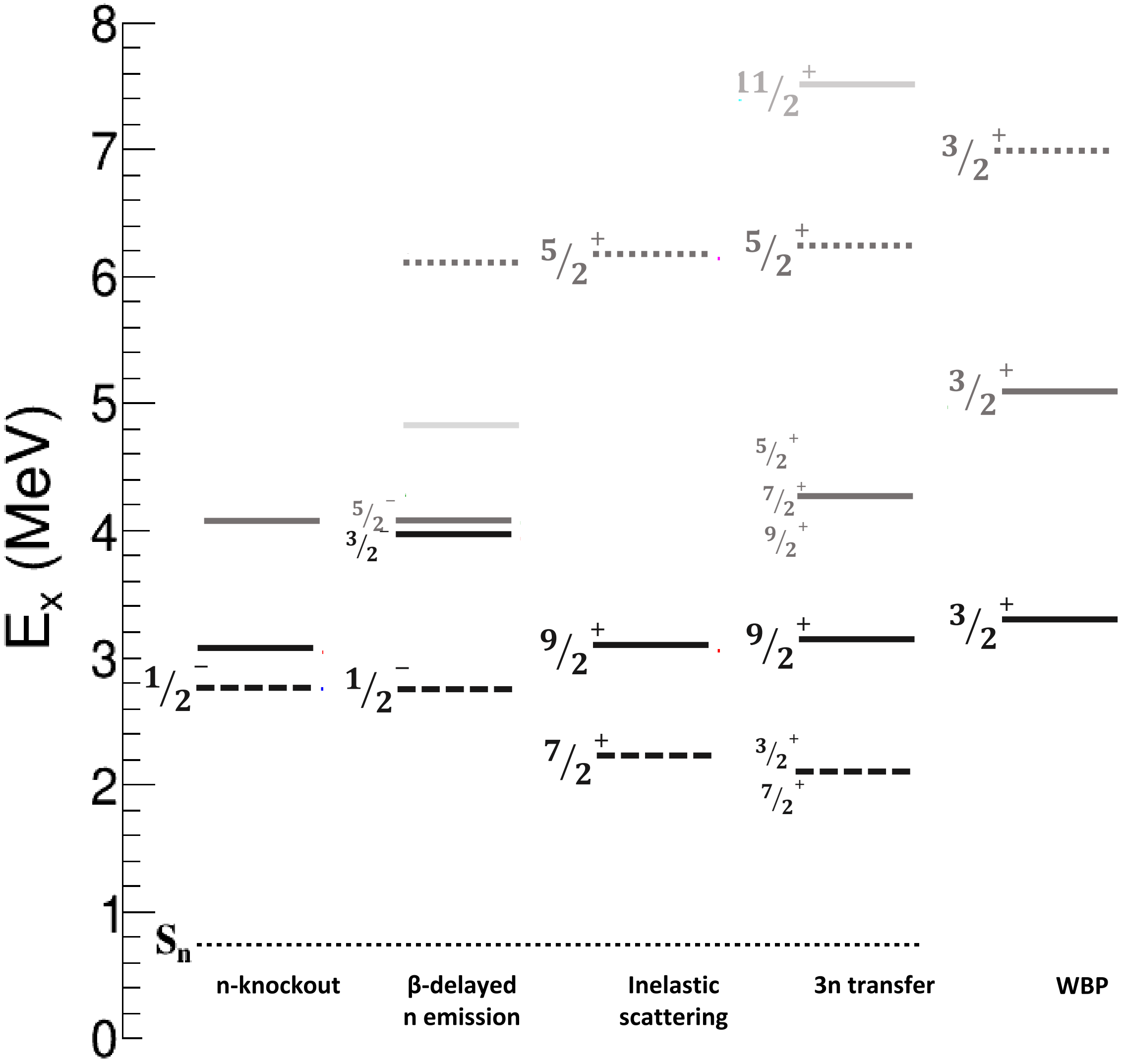
Modification of SM interaction : WBT*, SFO-tls

Locate the sp strength of the $\nu 1d_{3/2}$ involved in the N=16 shell gap in ^{17}C

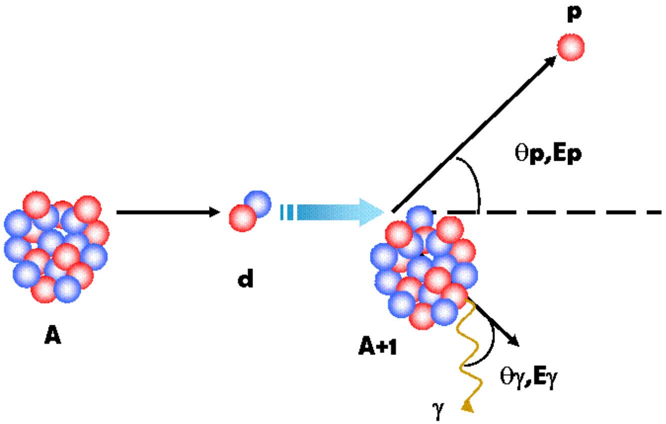
Previous spectroscopic experiments of ^{17}C



No evidence of $^{3}/_{2}^{+}$ single particle states!

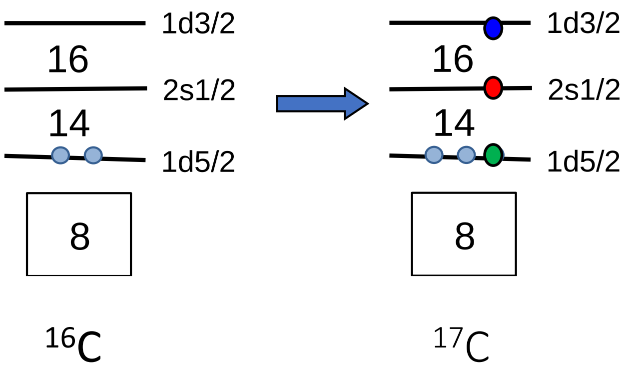
Single-neutron transfer

Spectroscopic tool : Transfer reactions in inverse kinematics : ^{16}C(d,p)^{17}C*



Spectroscopy of Bound-Unbound states

Ex,J, Spectroscopic Factors (SF)



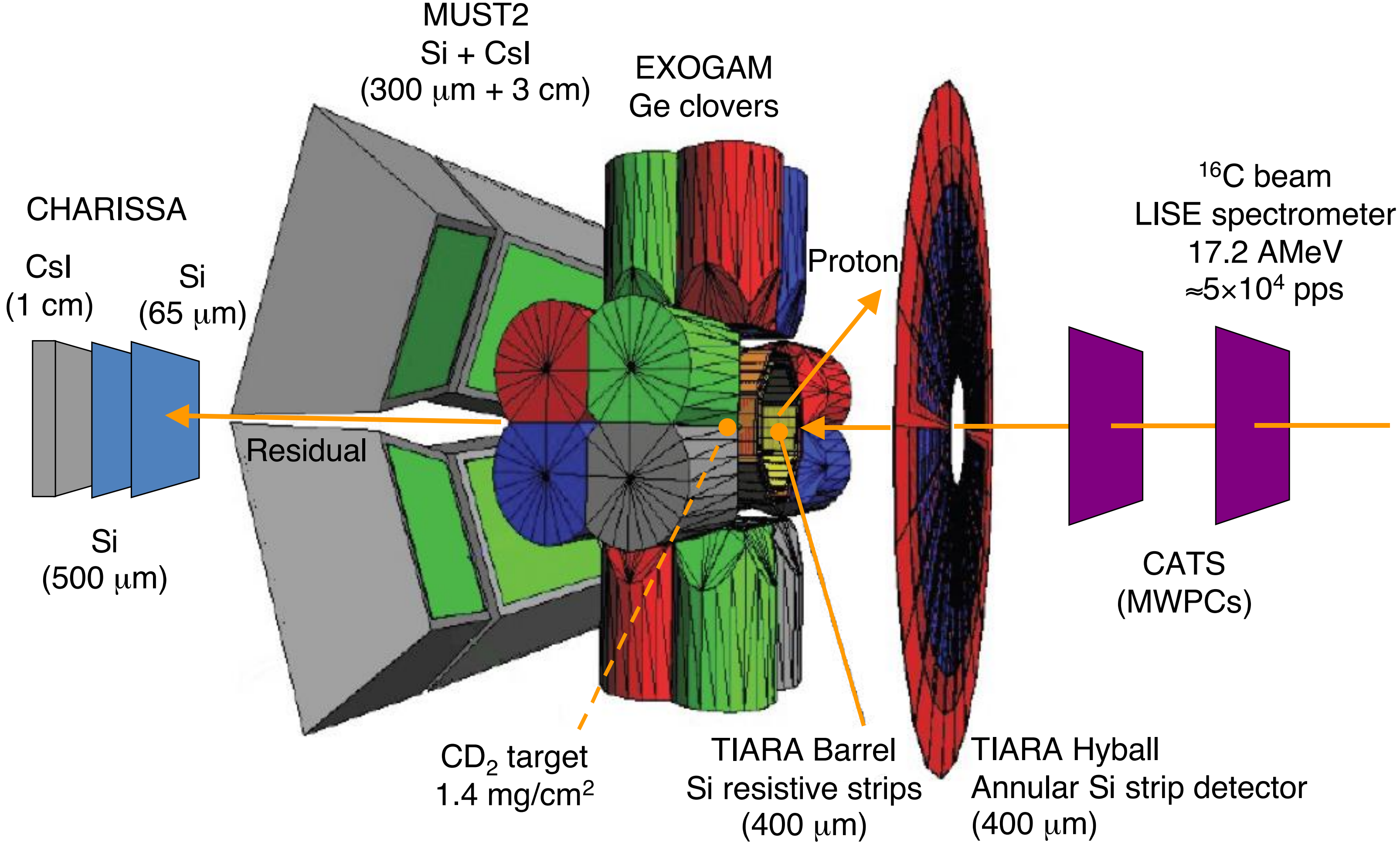
Measurements ⇒ Observables

$E_p, \theta \longrightarrow$ Ex

Natural width (Γ) $\longrightarrow$ C^{2}S, some l information

Selectively populates single-particle states in ^{17}C

Experimental set-up



MUST2
Si + CsI
(300 μm + 3 cm)

EXOGAM
Ge clovers

CHARISSA

CsI
(1 cm)

Si
(65 μm)

Proton

^{16}C beam
LISE spectrometer
17.2 AMeV
≈5×10^4 pps

Residual

Si
(500 μm)

CATS
(MWPCs)

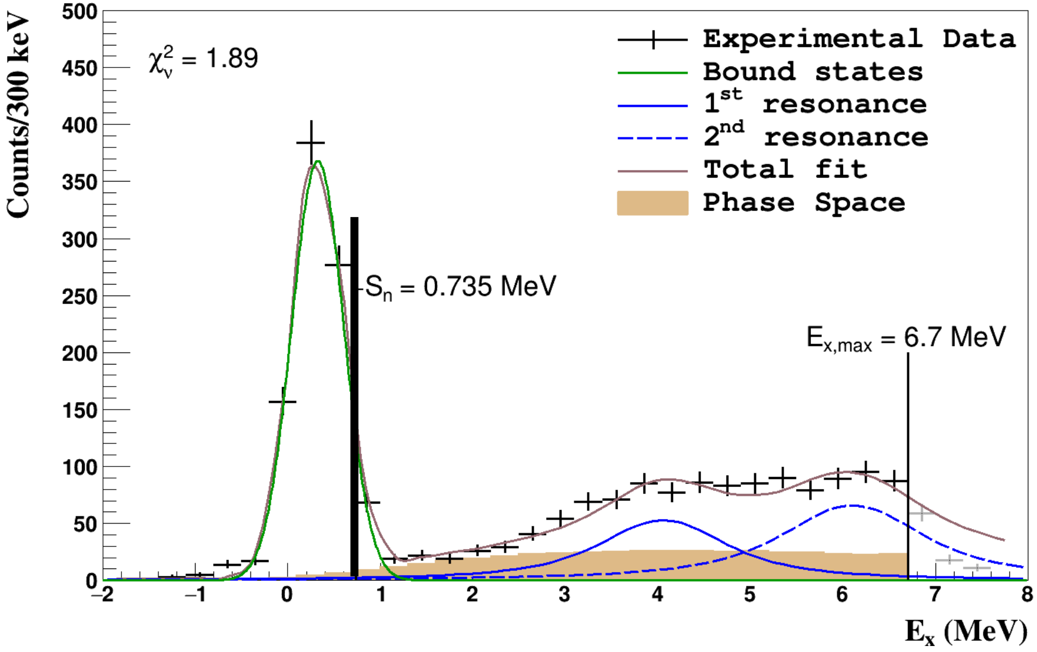
CD$_2$ target
1.4 mg/cm^2

TIARA Barrel
Si resistive strips
(400 μm)

TIARA Hyball
Annular Si strip detector
(400 μm)

^{17}C (dp-channel : bound states)

Preliminary



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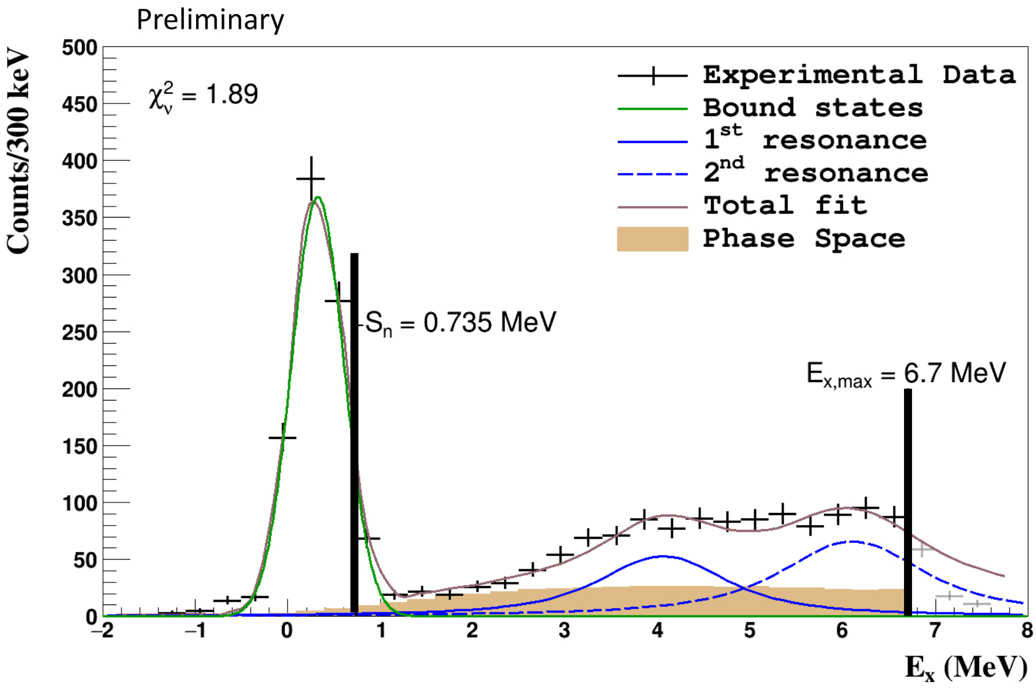
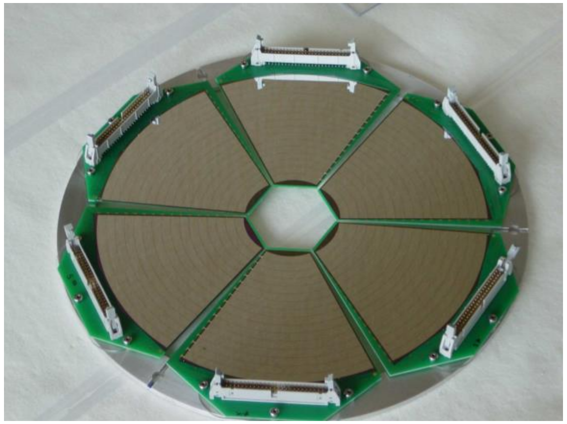


E_x limited by E > 0.5 MeV
Tiara Hyball threshold!



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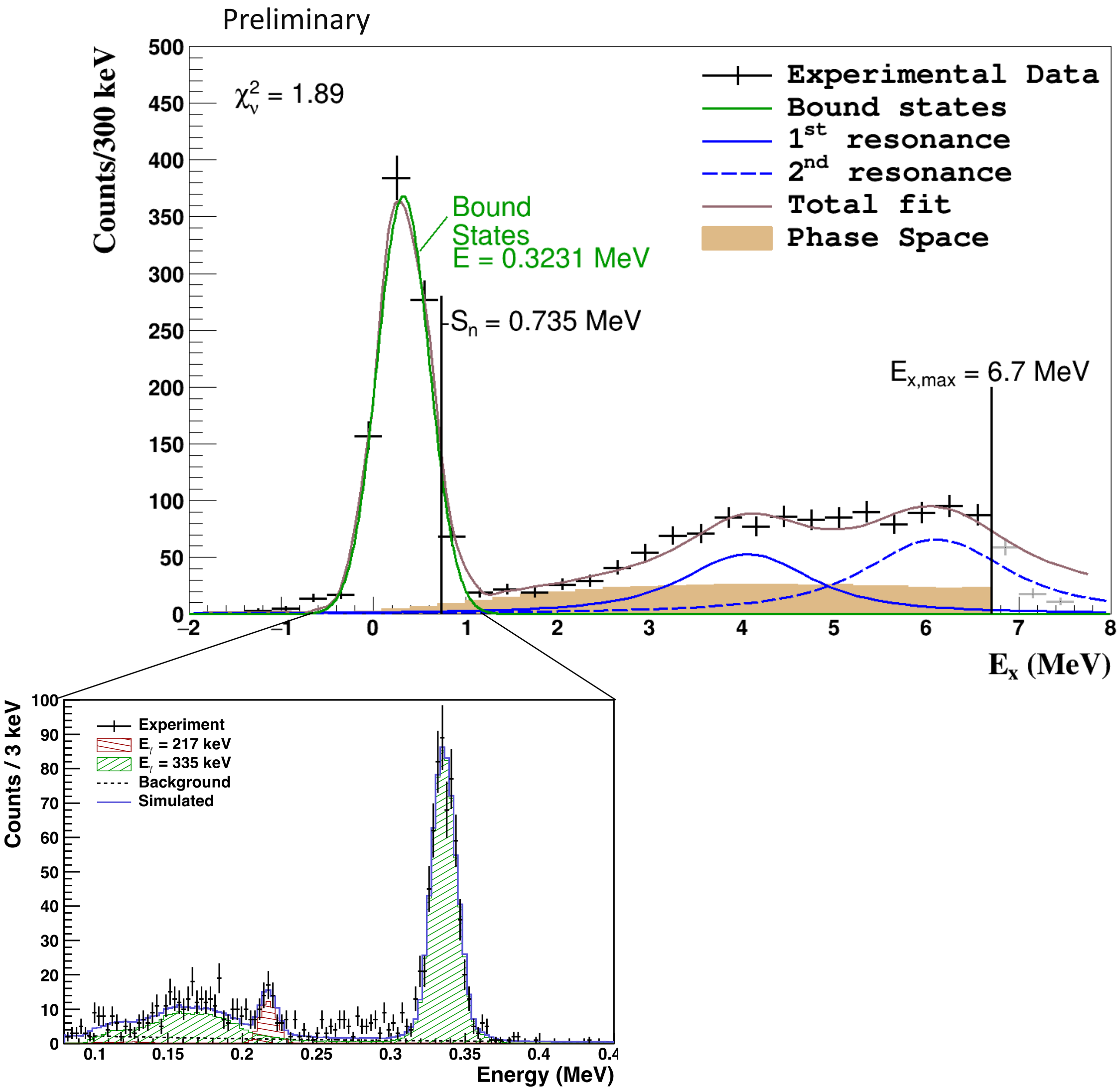
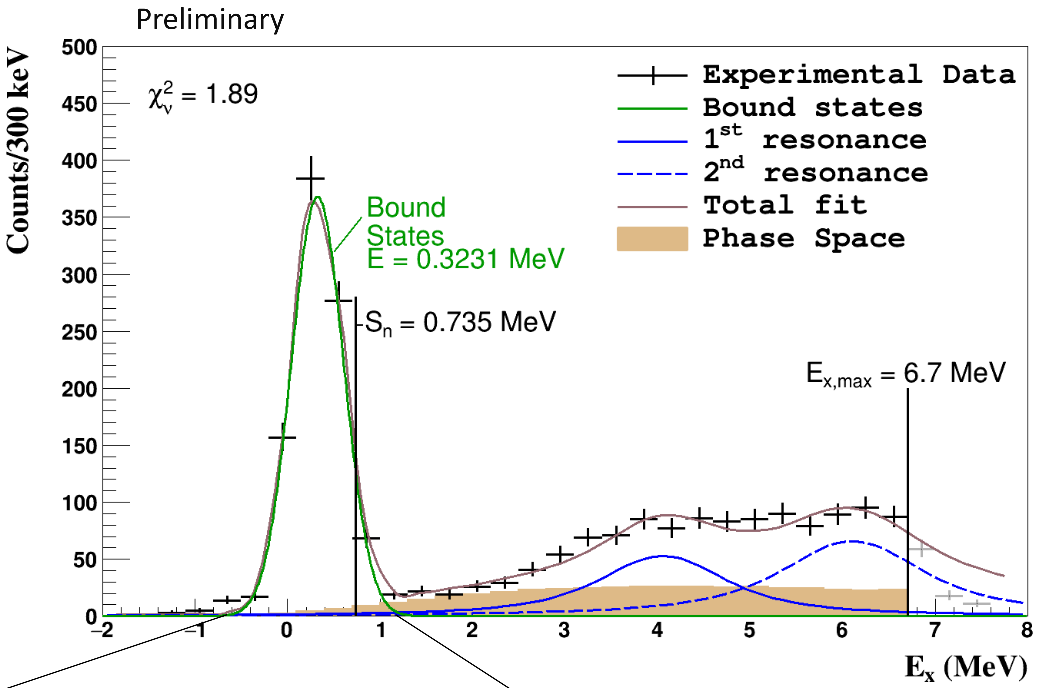
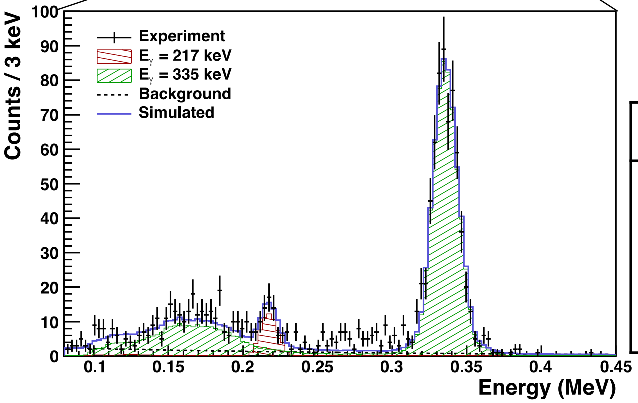


X. Pereira et al. Physics Letters B 811 (2020) 135939

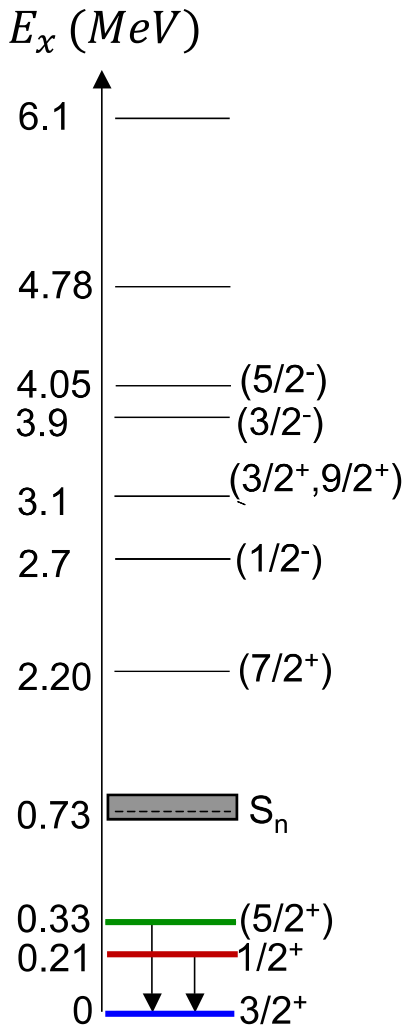
^{17}C (dp-channel : bound states)





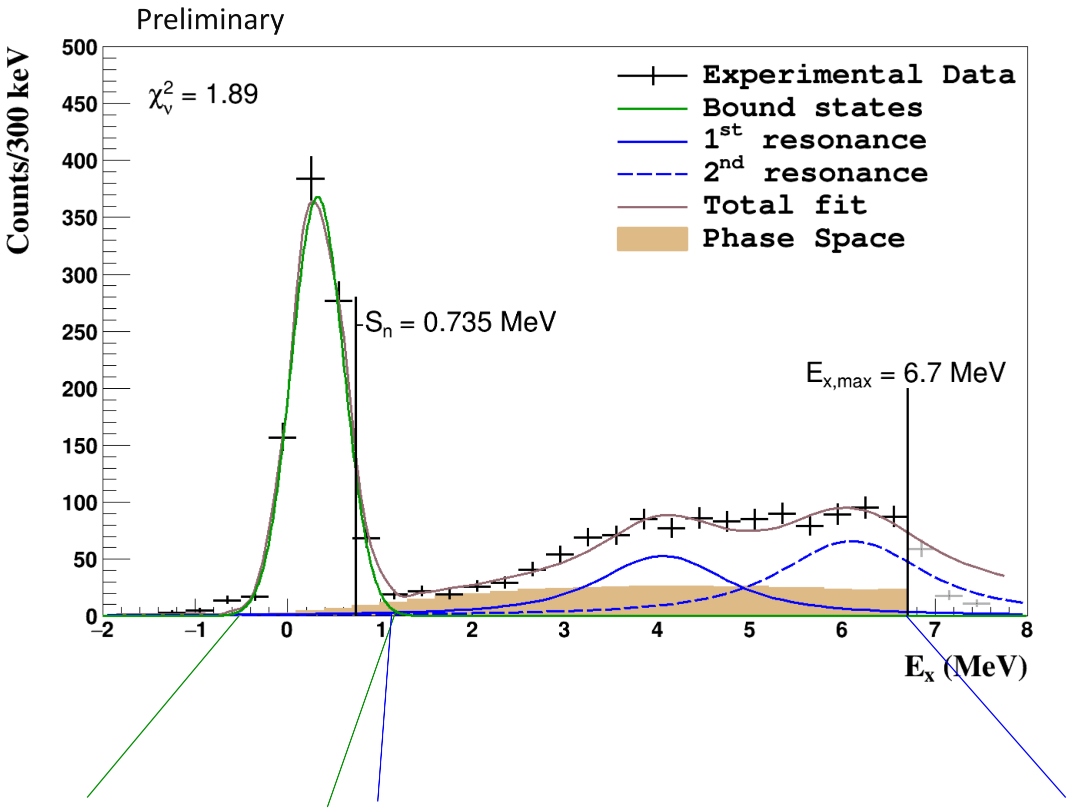
X. Pereira et al. Physics Letters B 811 (2020) 135939

E_x (keV)	J^π	C^2S
0	**3/2 +**	**0.03** $\binom{+5}{-3}$
217	**1/2 +**	0.80 (22)
335	**5/2+**	0.62 (13)



Weak sp strength for the 1d3/2 !

^{17}C (dp-channel : unbound states)



Bound States

1st resonance

$$F(E) = A_G \cdot e^{\frac{1}{2}\left(\frac{E-E_0}{\sigma}\right)^2} + A_{R1} \cdot V(E, E_{R1}, \sigma_{R1}, \Gamma_{R1}) +$$

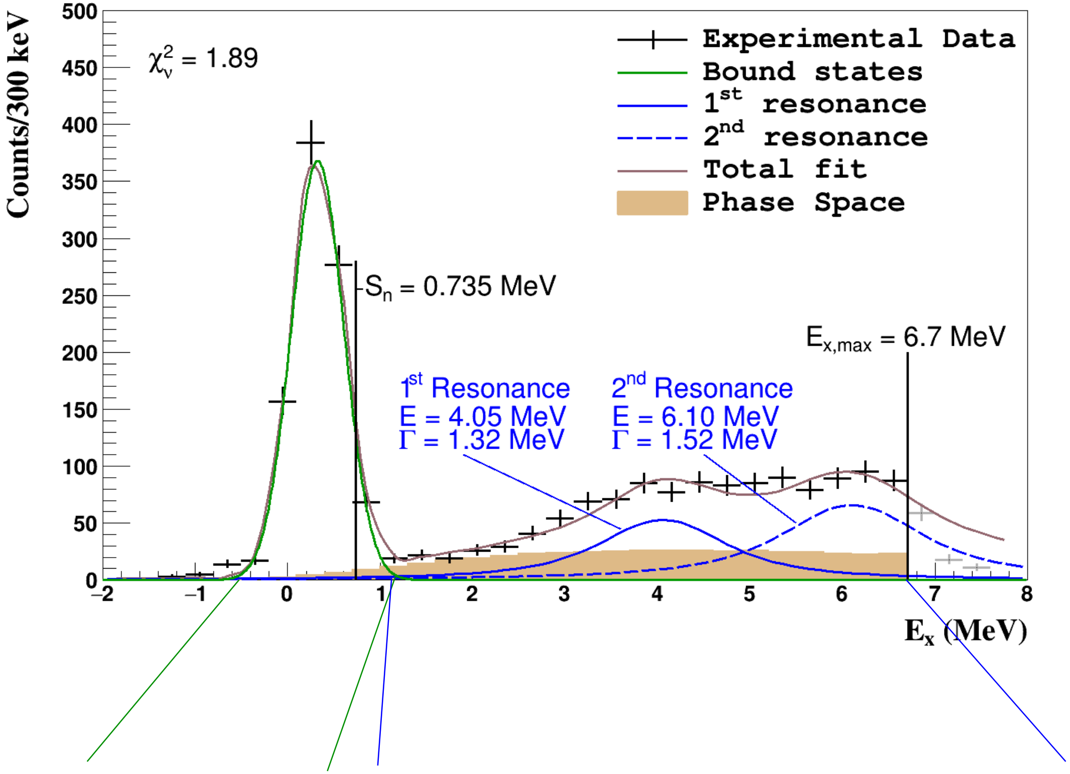
$$A_{R2} \cdot V(E, E_{R2}, \sigma_{R2}, \Gamma_{R2}) + A_{PS} \cdot S(E)$$

2nd resonance

Phase Space

^{17}C (dp-channel : unbound states)

Preliminary



Preliminary

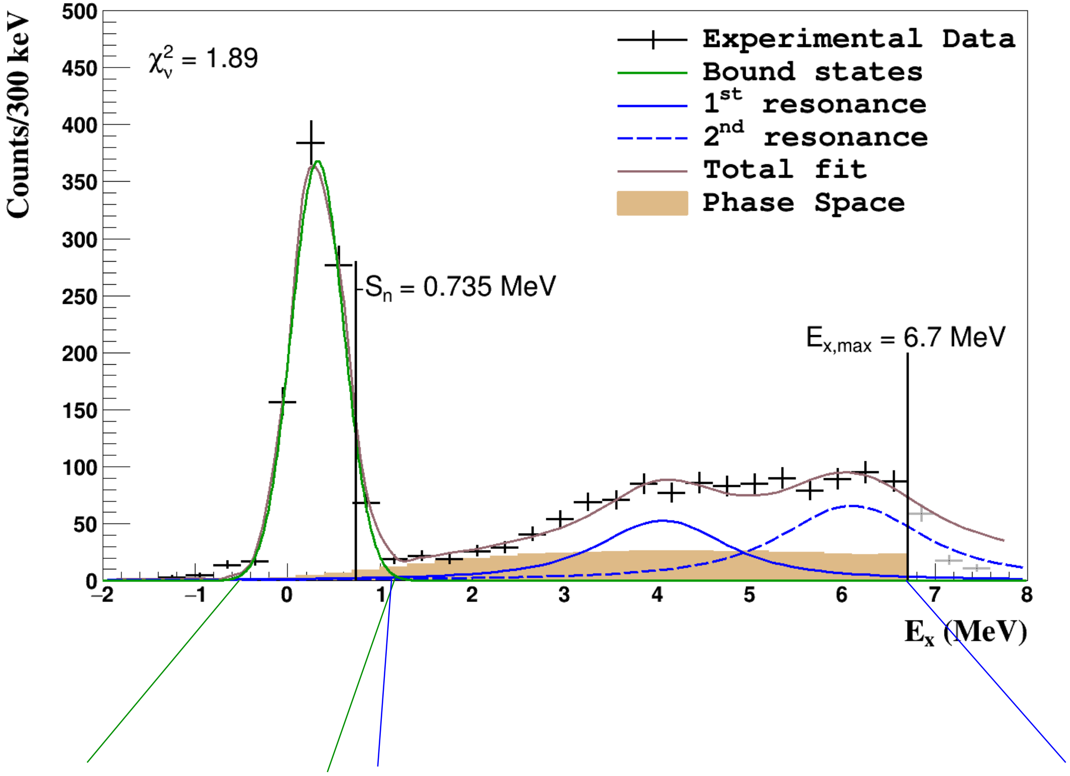
	R1	**R2**
E_x **(MeV)**	4.05(20)	6.10(17)
Γ **(MeV)**	1.32(33)	1.52(44)
$\Gamma_{sp}^{\nu 1d_{3/2}}$ **(MeV)**	2.07(41)	6.9(14)
$C^2S(0^+)$		

$$F(E) = \overbrace{A_G \cdot e^{\frac{1}{2}\left(\frac{E-E_0}{\sigma}\right)^2}}^{\text{Bound States}} + \overbrace{A_{R1} \cdot V(E, E_{R1}, \sigma_{R1}, \Gamma_{R1})}^{\text{1st resonance}} +$$

$$\underbrace{A_{R2} \cdot V(E, E_{R2}, \sigma_{R2}, \Gamma_{R2})}_{\text{2nd resonance}} + \underbrace{A_{PS} \cdot S(E)}_{\text{Phase Space}}$$

^{17}C (dp-channel : unbound states)

Preliminary



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$$C^2S = \Gamma_{exp} / \Gamma_{sp}$$

Bound States

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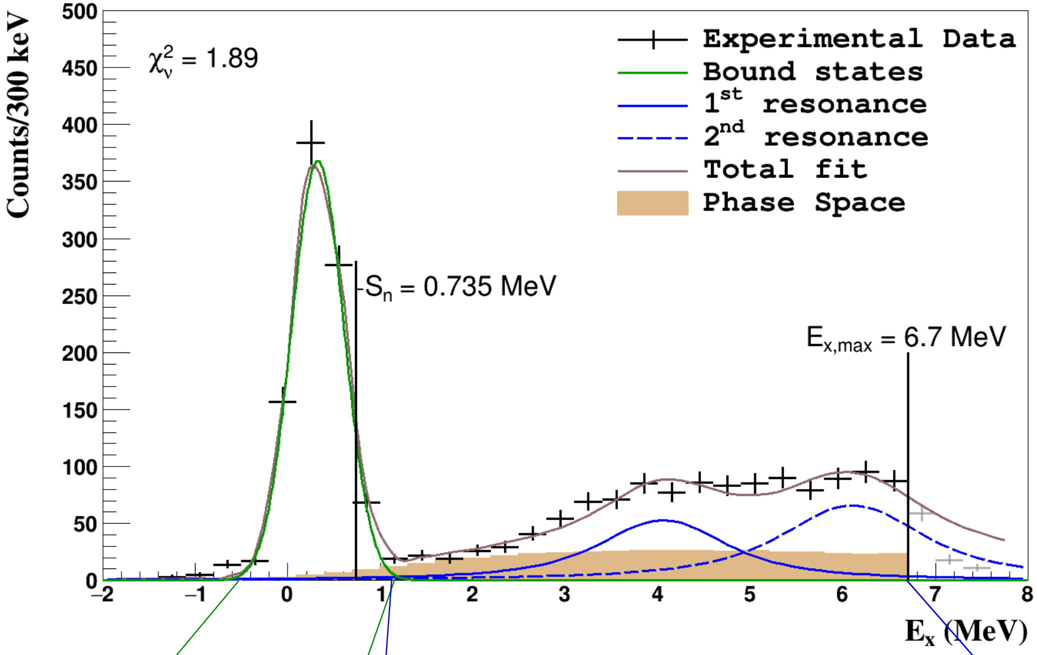
2nd resonance

Phase Space

^{17}C (dp-channel : unbound states)

Preliminary



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$$C^2S = \Gamma_{exp} / \Gamma_{sp}$$

l=1 The $\Gamma_{sp} \gg \Gamma_{exp}$

l=3 $\Gamma_{sp} \rightarrow 0$

l=2 $\frac{d\sigma}{d\Omega} \rightarrow$ coherent C^2S

Assigned to be l=2

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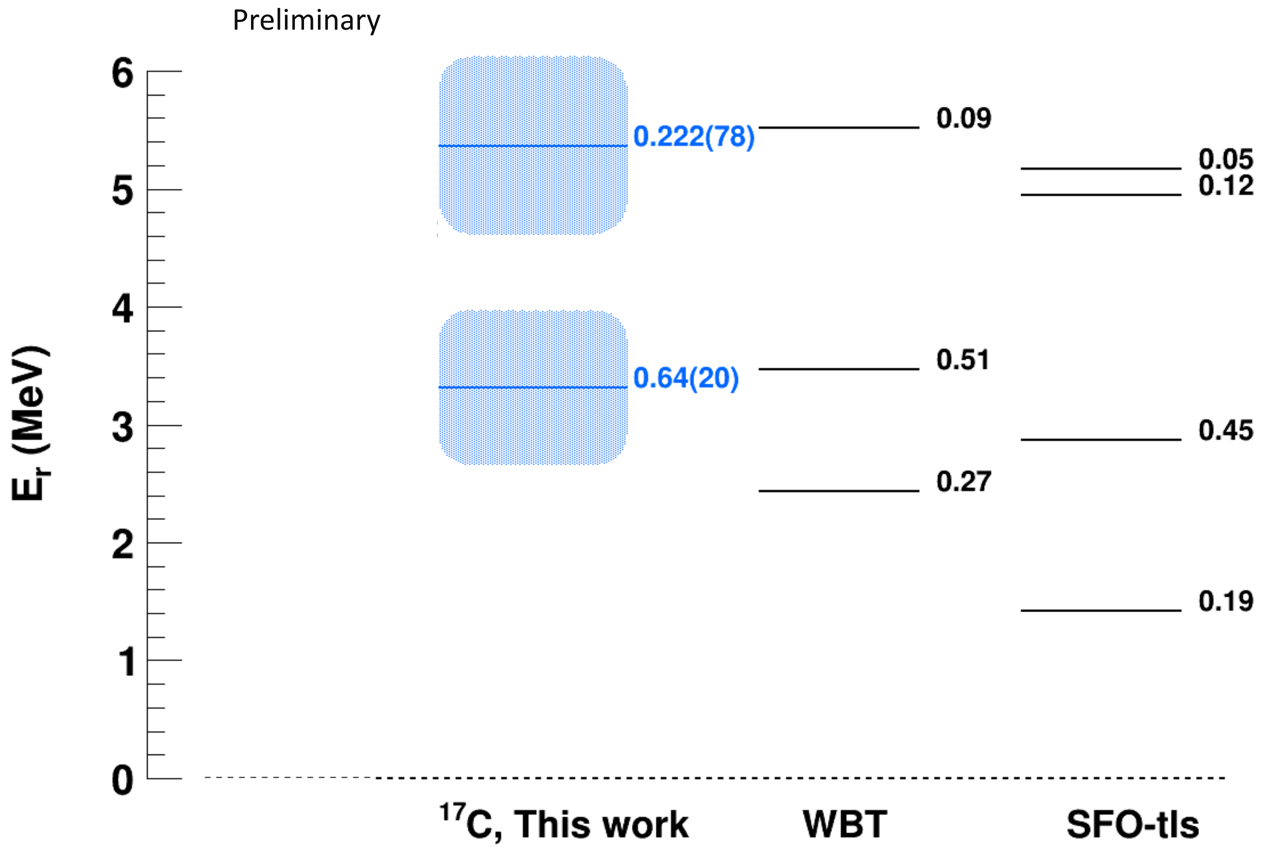
^{17}C (dp-channel : unbound states)

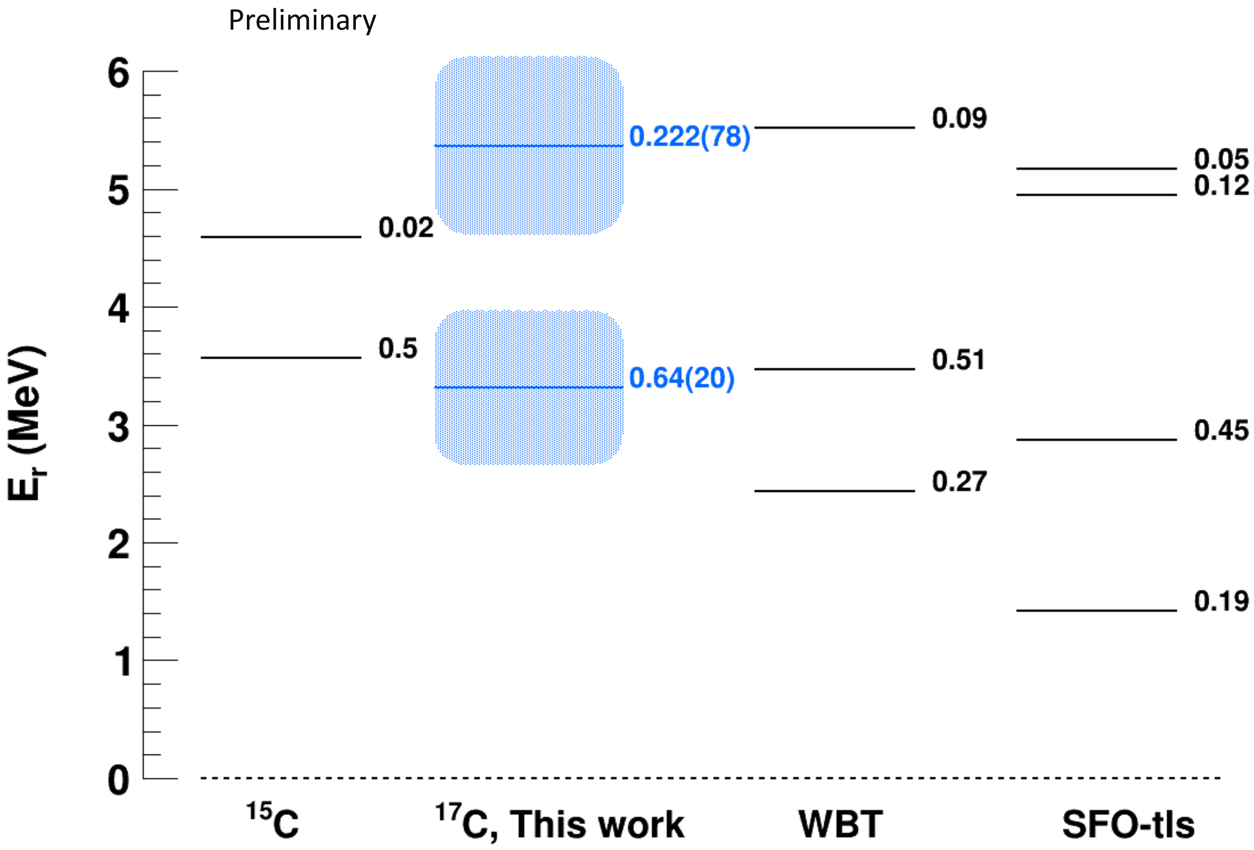


$$E_r = E_{x,R} - S_n$$

The energy and strength of the unbound states found is similar to the 2nd and 3d resonances predicted by the SM.

No evidence of the 1st resonance.

^{17}C (dp-channel : unbound states)



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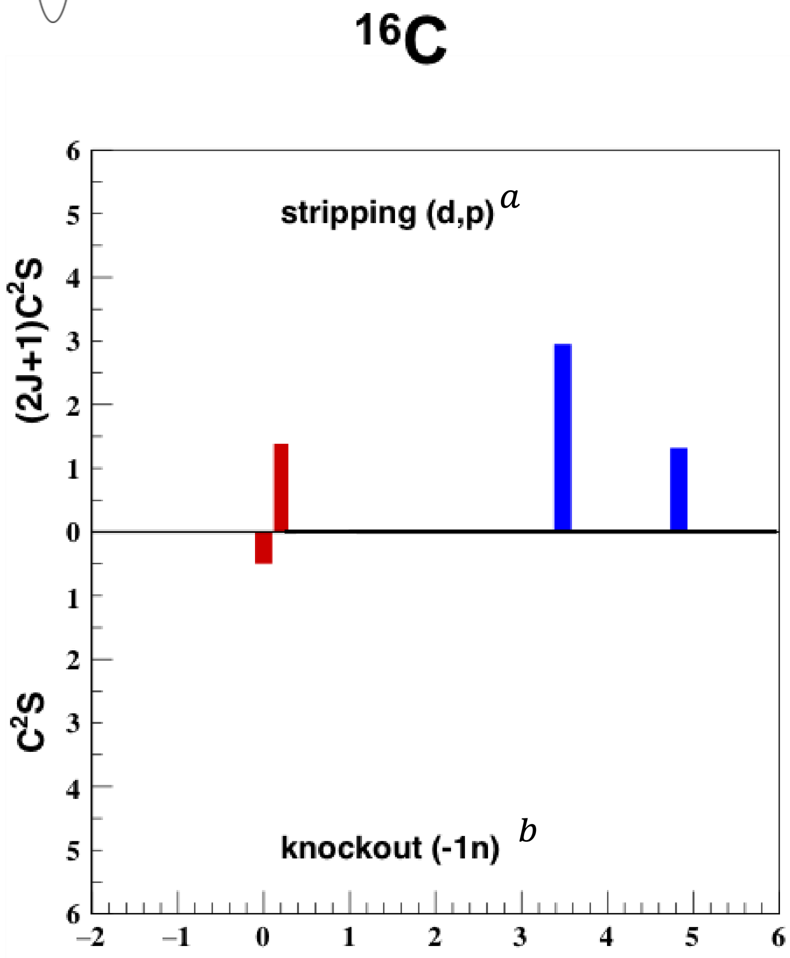
In the unbound ${}^{3}/_{2}{}^{+}$ states in ^{15}C most of the strength is also carried by the resonance that lays at lower energy.

Effective single-particle energy of the $\nu 1d_{3/2}$



$$\Delta_{N=16} = \epsilon_{\nu 1d_{3/2}} - \epsilon_{\nu 2s_{1/2}}$$

$2s_{1/2}$ = 2.16(45)

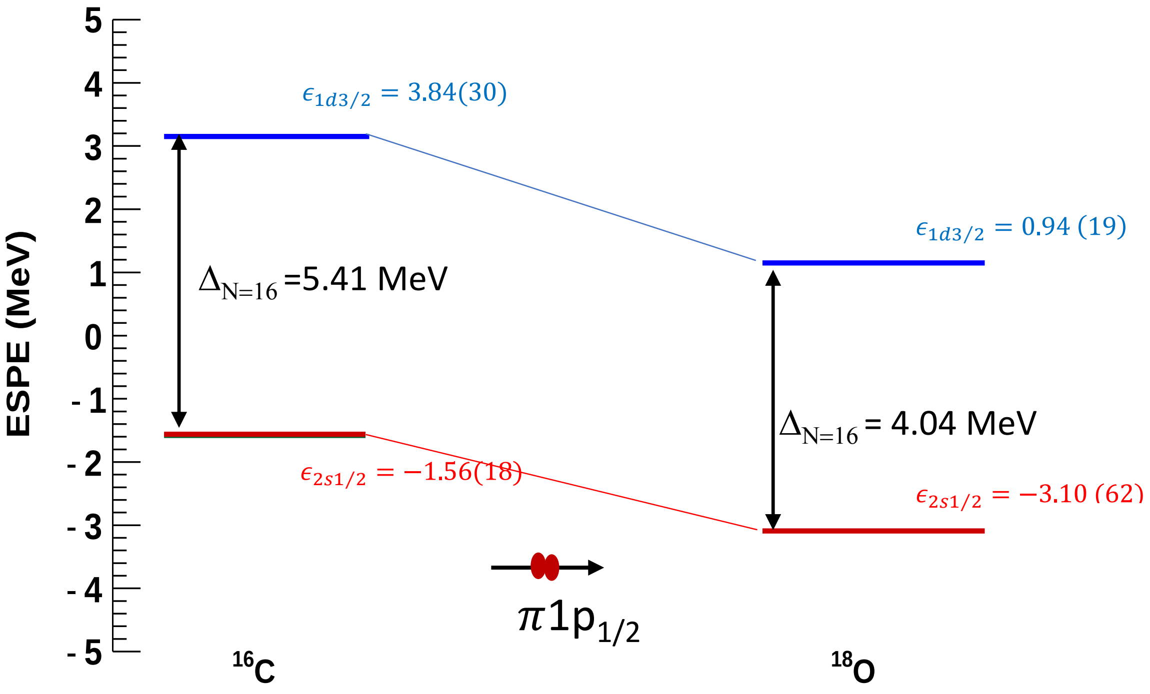
$1d_{3/2}$ = 3.45(86)

$$\epsilon = \frac{\sum_{f=0}^{n-}(E_0 - E_f^-)C^2S_f^- + (2J_f+1)\sum_{f=0}^{n+}(E_f^+ - E_0)C^2S_f^+}{\sum_{f=0}^{n-}C^2S_f^- + (2J_f+1)\sum_{f=0}^{n+}C^2S_f^+} \quad ^{c}$$

$\epsilon_{\nu 1d_{3/2}}$ = 3.84 (30) MeV

a -> X. Pereira et al. Physics Letters B 811 (2020) 135939 (bound states)
b -> V. Maddalena et al. PRC 72, 011302(R) (2014)
c-> M. Baranger et al. NPA 149, 225 (1970)

Shell evolution N=16 shell gaps



$\Delta_{N=16}$ (^{16}C) = $\varepsilon 1d_{3/2}$ - $\varepsilon 2s_{1/2}$ = 5.41(34) MeV bigger than ~ $\Delta_{N=16}$ (^{18}O) = 4.24 MeV

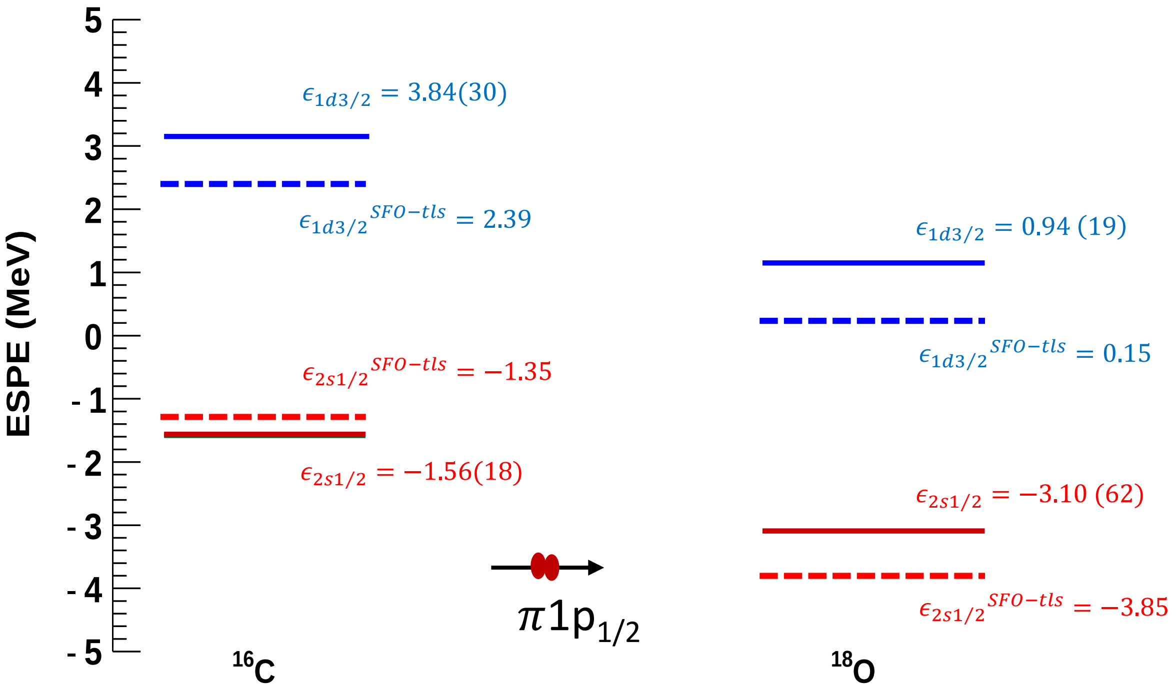
The **N=16 Shell gap survives** in n-rich Carbon isotopes

Preliminary

	^{16}C	^{18}O
$\Delta_{N=16}$ Exp (MeV)	5.41(34)	4.04(65)
$\Delta_{N=16}\ SM\ WBT^1$ (MeV)	4.45	3.91
$\Delta_{N=16}\ SM\ SFO-tls^2$ (MeV)	3.77	3.35

1. WBT (USD) M. Stanoiu et al., PRC 78, 034315 (2008)
2. SFO-tls T.Suzuki and T. Otsuka, PRC 78, 061301 (2008)

Shell evolution N=16 shell gaps



Preliminary

	^{16}C	^{18}O
$\epsilon_{2s1/2}(MeV)$	-1.56	-3.10
$\epsilon_{2s1/2}{}^{SFO-tls}\ (MeV)$	-1.35	-3.85
$\epsilon_{1d3/2}\ (MeV)$	3.84	0.94
$\epsilon_{1d3/2}{}^{SFO-tls}(MeV)$	2.39	0.15

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The **N=16 Shell gap survives** in n-rich Carbon isotopes

The $\nu 1d_{3/2}$ is less bounded than the predictions.

Conclusions

Preliminary

- 1. Two resonances have been found at E_x = 4.05(20) and 6.10(17) MeV and associated widths were deduced to be Γ=1.32(33) and 1.52(44) MeV respectively.

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$$\Delta_{N=16} = \epsilon_{\nu 1d_{3/2}} - \epsilon_{\nu 2s_{1/2}} = \textbf{5.41(39) MeV}$$

- 6. We observe that the $\nu 1d_{3/2}$ is less bound that what is expected in the n-rich C isotopes.

Future work

- 1. Apply the Gamow Shell model to take into account the radial extension of the wave function in the unbound states.
- 2. Estimate the contribution of the 2^+ in ^{16}C.
- 3. Combine the location of the $\nu 1d_{3/2}$ with previous results of the energy of the $\nu 1d_{5/2}$ to study the spin-orbit splitting.

E628 Collaboration

J. Lois-Fuentes b, X. Pereira-López a,b,c,d, B. Fernandez-Domínguez b, F. Delaunay a, N.L. Achouri a, N.A. Orr a, W.N. Catford e, M. Assie f, S. Bailey g, B. Bastin h, Y. Blumenfeld f, R. Borcea i, M. Caamano b, L. Caceres h, E. Clement h, A. Corsi i, N. Curtis g, Q. Deshayes, F. Farget h, M. Fisichella j, G. de France h, S. Franchoo, M.Freer, J. Gibelin a, A. Gillibert i, G.F. Grinyer h, F. Hammache f, O. Kamalou h, A. Knapton e, T. Kokalova g, V. Lapoux i, J. A. Lay k, B. Le Crom f, S. Leblond a, F.M. Marques a, A. Matta e, P. Morfouace f, A.M. Moro k, T. Otsuka l, J. Pancin, L. Perrot h, E. Pollacco i, D. Ramosb, C. Rodrıguez-Tajes b,h, T. Roger h, F. Rotaru m, M. Senoville i, N. de Seeere ville f, R. Smithg, O. Sorlin h, M. Stanoiu m, I. Stefan f, D. Suzuki f, T. Suzuki l, J.C. Thomas h, N. Timofeyuk e, M. Vandebrouck h, J. Walshe g, C. Wheldon g

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g) School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UK
h) GANIL, BP 55027, 14076 Caen Cedex 5, France
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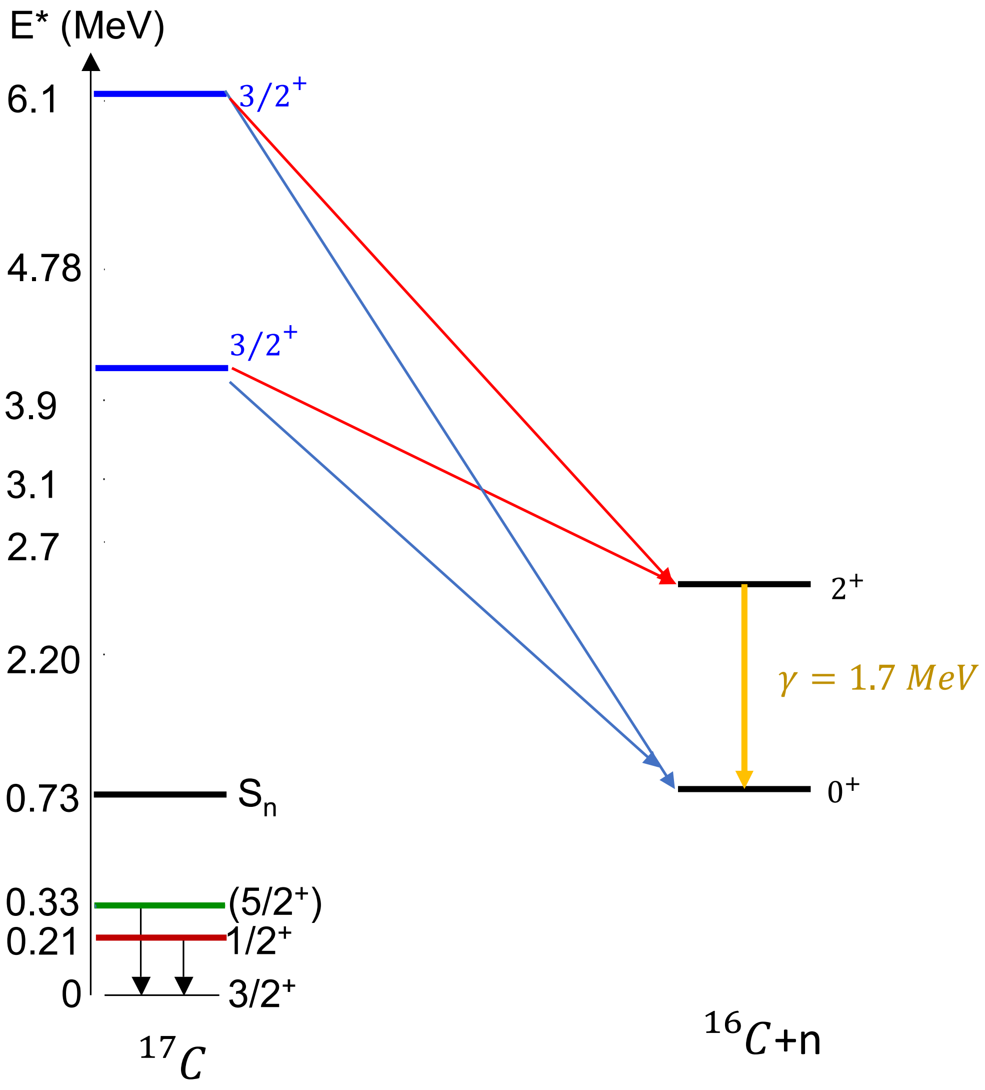
NO PART OF THE TALK

^{17}C (dp-channel : unbound states)



In this first analysis we're assuming that all the C^2S is going to the GS $^{16}C(0^+)$!

We're still workig on gating with the γ to determine how much of the unbounds decays to the excited 2^+ state.

In this stage our results of the C^2S are just upper limits!