MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD

CSIC

R3B

^{13}Be studied by (p,2p) deep inelastic scattering reaction in complete kinematics.

O. Tengblad

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for the R^{3}B collaboration

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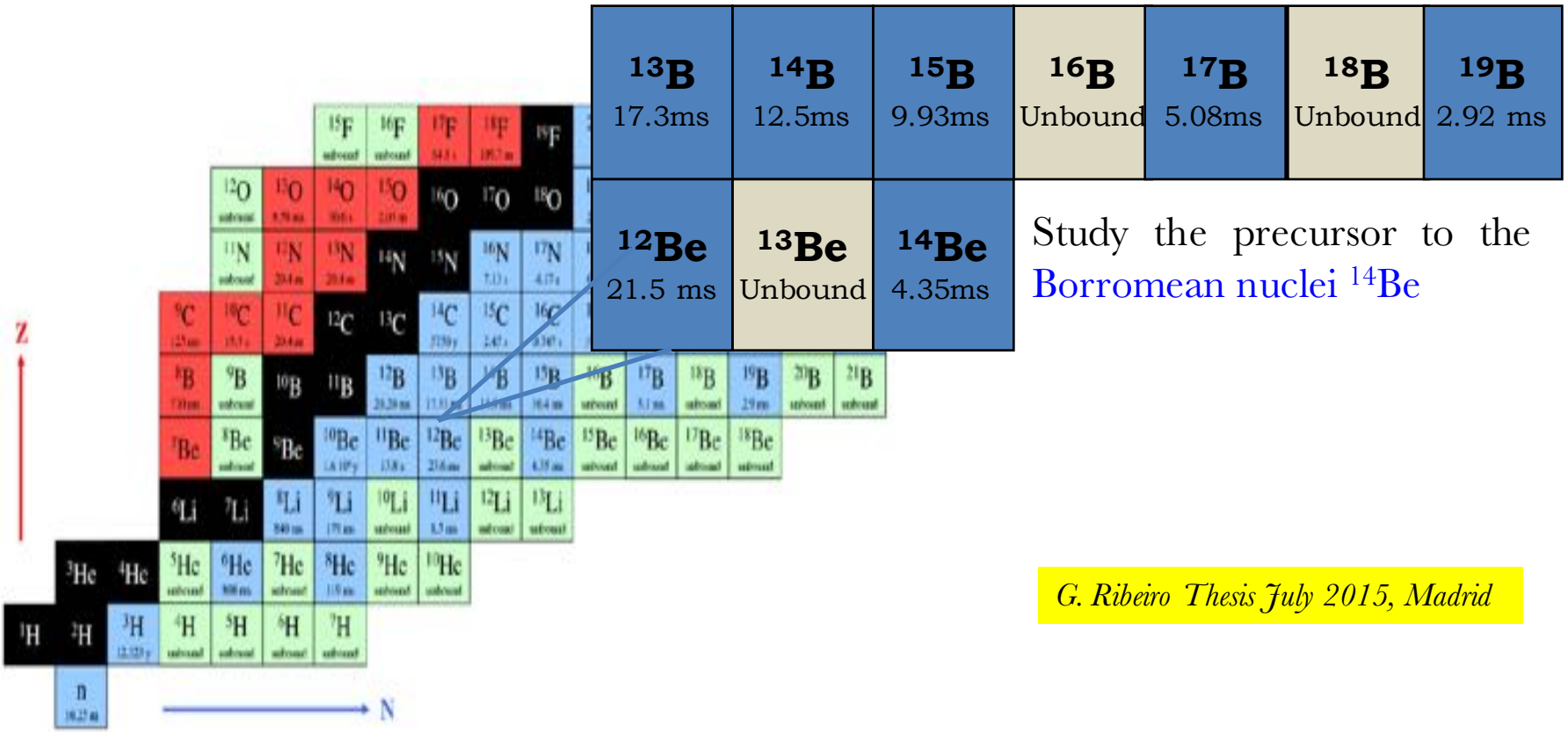
S393 experiment

Study of light neutro-rich nuclei (Be-Ne), using kinematically complete measurements in inverse kinematics @ GSI

quasi-free scattering: $^{14}B(p,2p)^{13}Be$



Study the precursor to the Borromean nuclei ^{14}Be

G. Ribeiro Thesis July 2015, Madrid

Quasi-Free Scattering: Knockout reaction

$^{14}B(p,2p)^{13}Be$

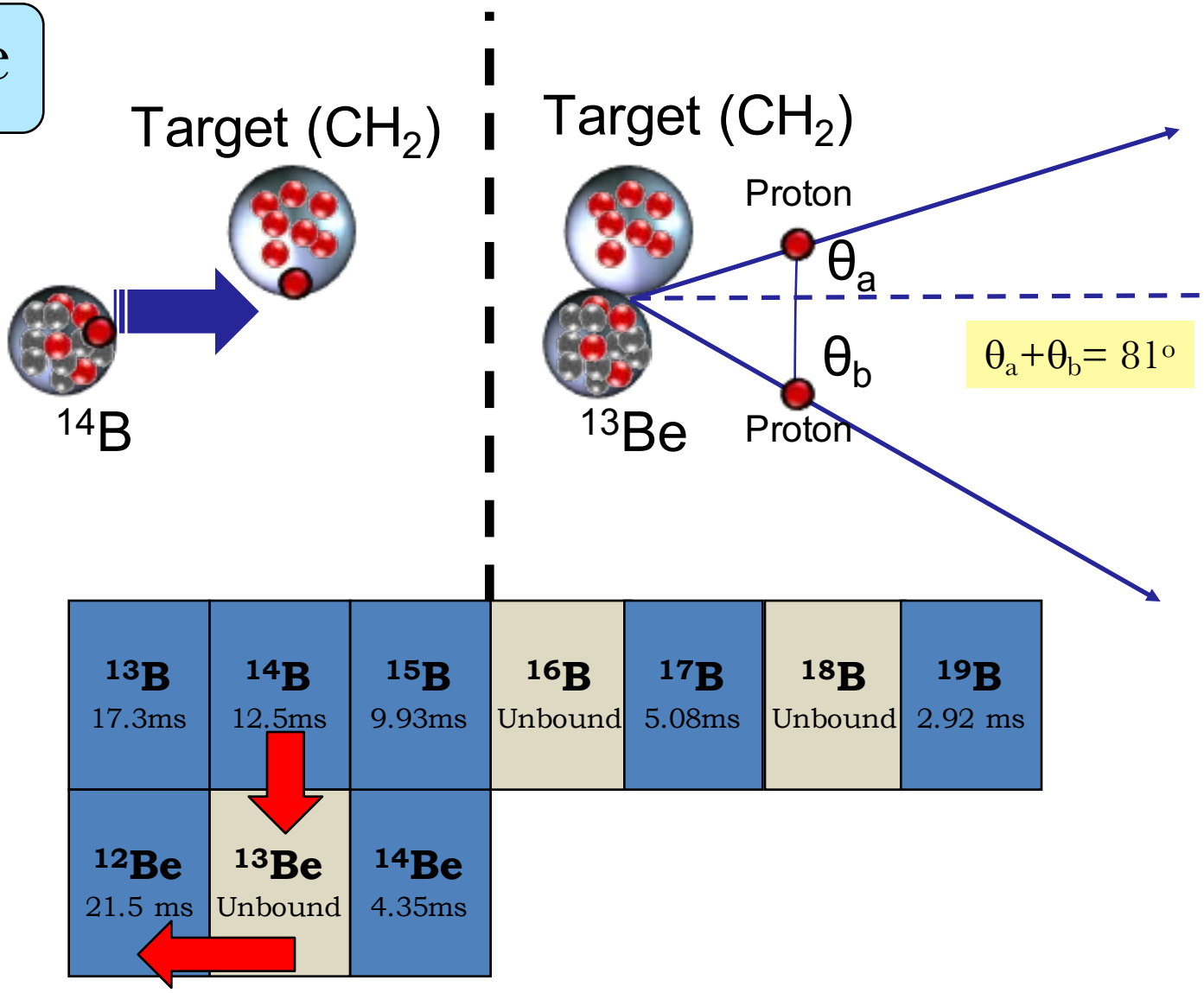
Direct Reaction:

(p,2p), (p,np)

from initial to final states without intermediate compound state.

If both outgoing particles have the same masses, in the lab system:

$\theta_a+\theta_b= 81^o$

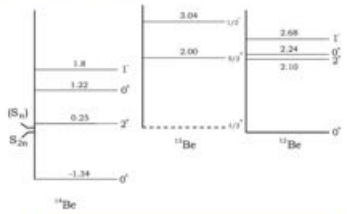


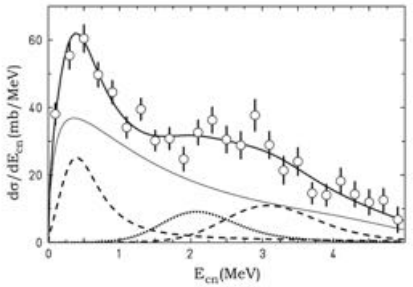
Previous studies

2007 GSI $^{14}Be(p,pn)^{13}Be$

H. Simon et al. / Nuclear Physics A 791 (2007) 267–302

^{13}Be state	Neutron, knocked out from ^{14}Be	Structure of the ^{13}Be state	Appearance in the n + ^{12}Be spectrum	Width (MeV)
		$0d_{5/2} \otimes 1^-$	0.36 MeV	
$1/2^-$	$0p_{1/2}$	$0p_{1/2} \otimes 0^+_1$	0.80 MeV	0.4
		$0p_{1/2} \otimes 0^+_2$	3.04 MeV	2.0
		$1s_{1/2} \otimes 1^-$	0.36 MeV	
$5/2^+$	$0d_{5/2}$	$0d_{5/2} \otimes 0^+_1$	2.00 MeV	0.3
		$1s_{1/2} \otimes 2^+$	low energy	narrow
$1/2^+$	$1s_{1/2}$	$1s_{1/2} \otimes 0^+_1$	low energy	broad
		$1s_{1/2} \otimes 0^+_2$	low energy	broad

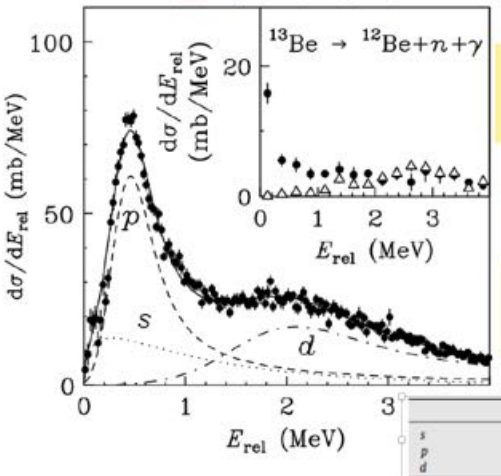




The ^{12}Be + n system reveals resonances with complicated structures.
Using the data obtained in other experiments, one may conclude that the s-wave interaction between the neutron and ^{12}Be fragment is much weaker than that in the ^{9}Li + n case. The Iπ = 1/2− assignment to the ^{13}Be state at 3.04(7) MeV was made from comparison with the neighbouring N = 9 isotones, and further confirmed by the measured ^{12}Be − n angular correlations.

2010 RIKEN $^{14}Be(p,pn)^{13}Be$

Kondo et.al. Phys. Lett. B, 690, (2010), 245–249



The relative energy spectra obtained in coincidence with the 2.1-MeV (filled circles) and 2.7-MeV (open triangles) γ rays are shown in the inset.

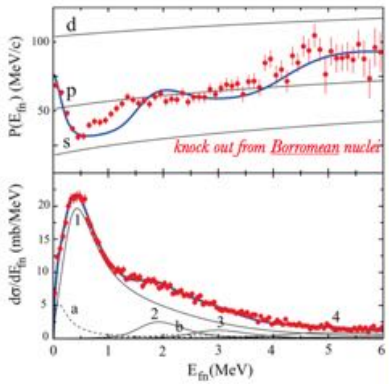
Concludes that the 0.5-MeV peak is the ground state of ^{13}Be.

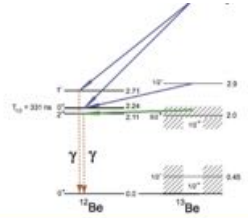
The *p*-wave nature of the 0.5-MeV resonance was shown by the transverse momentum distribution and the resonance width. This state was assigned to $J^\pi = 1/2^-$.

	a_s or E_r	Γ_γ
s	−3.4(6) fm	–
p	0.51(1) MeV	0.45(3) MeV
d	2.39(5) MeV	2.4(2) MeV

2013 GSI $^{14}Be(p,pn)^{13}Be$

Aksyutina, et.al. Phys. Rev. C, 87, 064316, (2013)
L.V. Chulkov, B. Jonson and M.V. Zhukov
Eur. Phys. J. A (2015) 51: 97





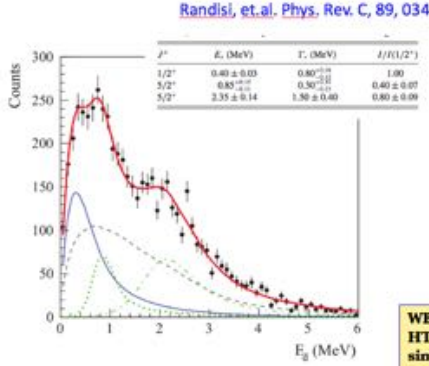
Momentum profile of the 12Be + n system after 1n knockout from ^{14}Be impinging on a H target at 304 MeV/u.

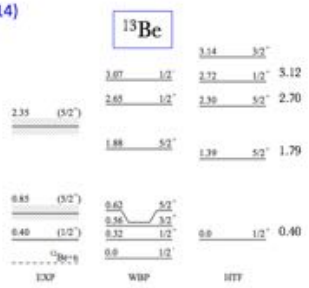
Upper panel: The solid line calculated profile function obtained from the fit to the ^{12}Be + n relative-energy spectrum.
Lower panel: ^{12}Be+n relative-energy spectrum from
The fit gave χ2/N = 0.91.

The curves show the decomposition
14 Be ⇒ 1) 13 Be(1/2+) + n (l = 0), 2) 13Be(5/2+) + n(l = 2)
⇒ 12Be(g.s.) a) 13Be(5/2+) + n (l = 2)
⇒ 12Be(2+) 3) 13Be(1/2−) + n (l = 1)
⇒ 12Be(g.s.) b) 13Be(1/2+)+n(l=0)
⇒12Be(1−) 4)13Be(5/2+ or3/2+)+ n(l = 2)

2014 GANIL $C(^{14}B,^{12}Be+n)$

Randisi, et.al. Phys. Rev. C, 89, 034320, (2014)



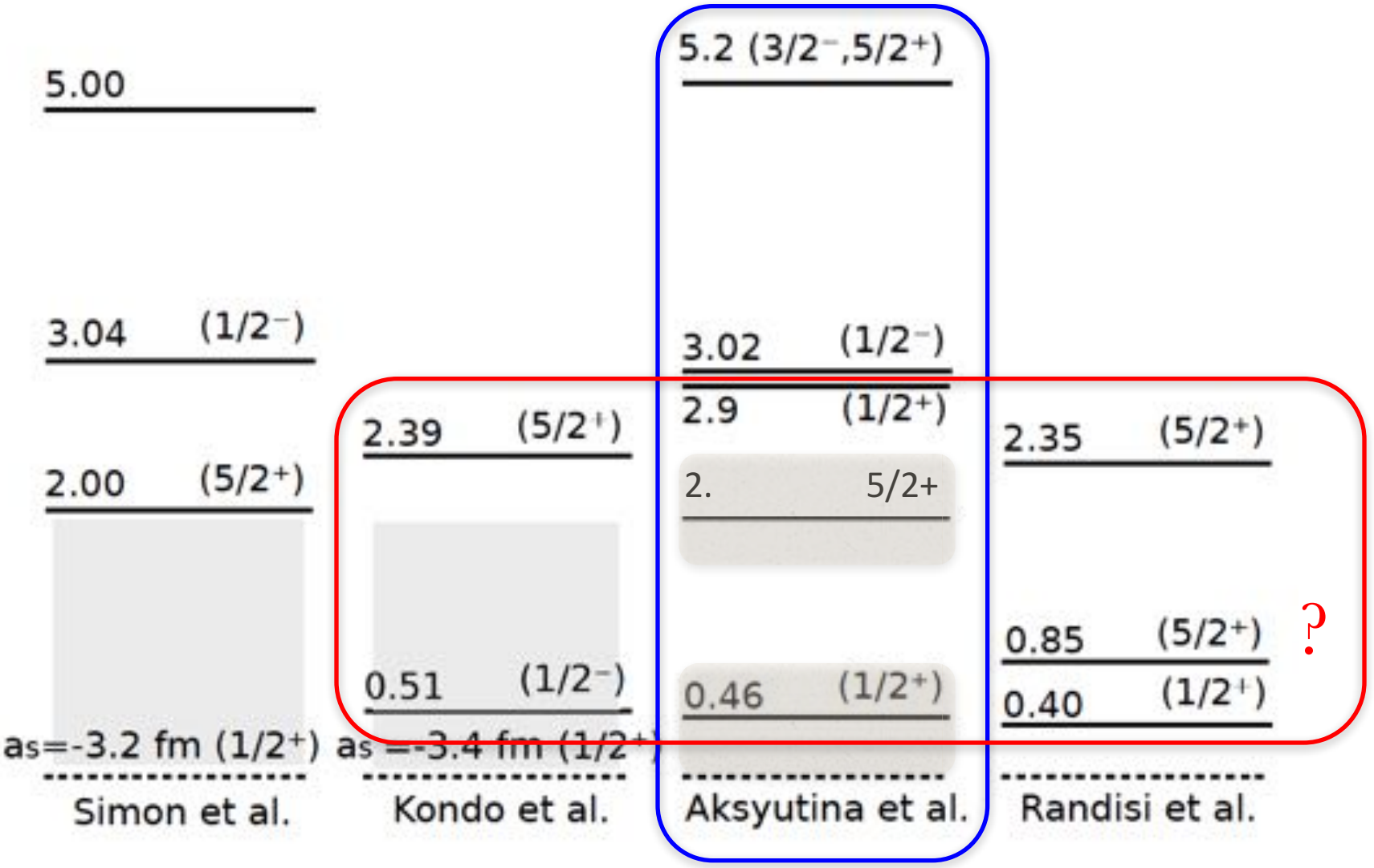


Reconstructed ^{12}Be + n decay energy for the C(^{14}B,^{12}Be + n) reaction compared to simulations incorporating an
s -wave virtual state
d -wave resonance
d -wave resonance
nonresonant continuum.

WBP - ω shell- model calculations
HTF estimated, for positive-parity states, within the simplified scheme of Fortune Phys. Rev. C **87**, 014305 (2013), where the lowest 1/2+ state is assumed to lie 0.4 MeV above threshold.

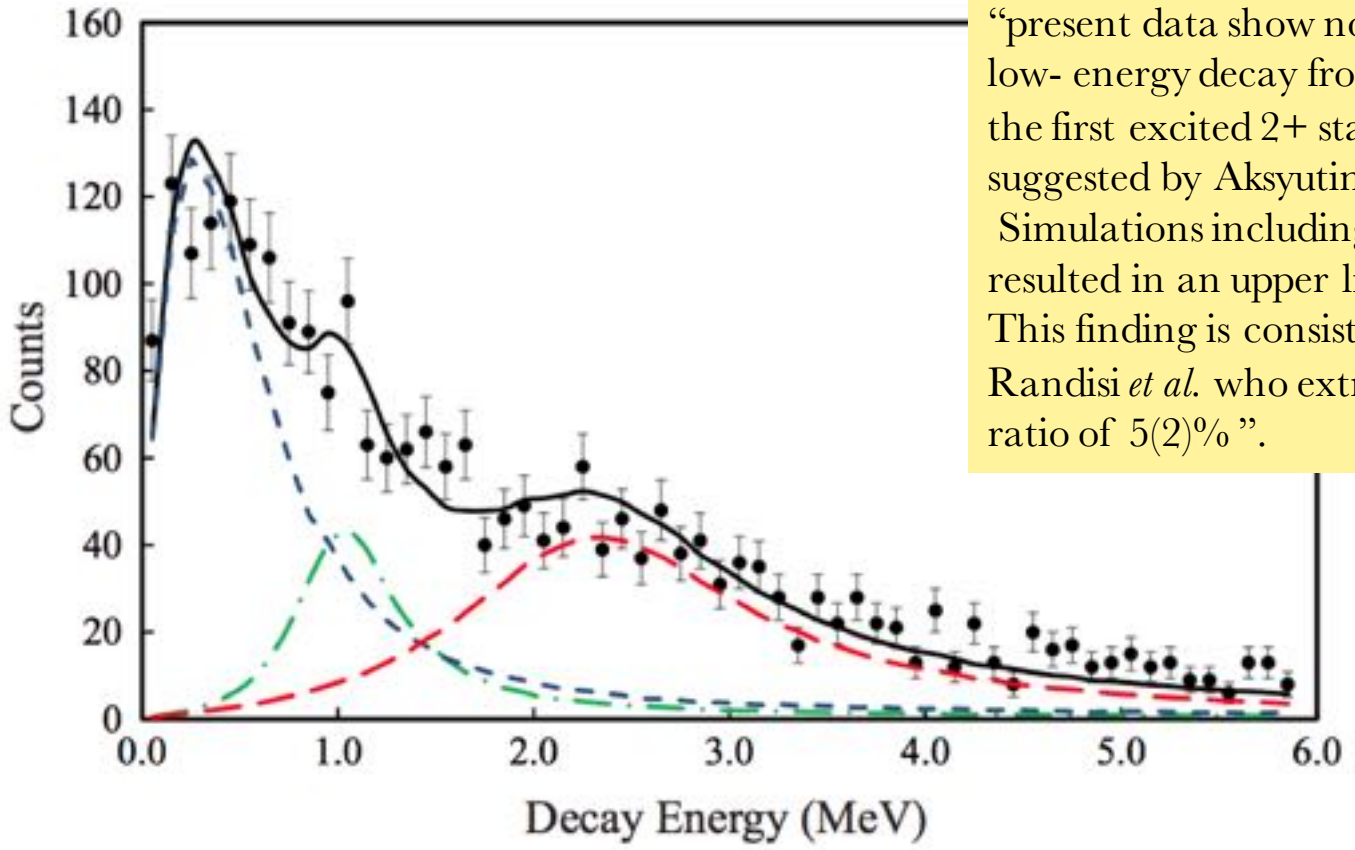
The Randisi results are shown (EXP), where the level 0.40 MeV above the ^{12}Be + n threshold is identified with the predicted 1/2+ state. Experimental energies are listed with respect to the ^{12}Be + n threshold.

Summary Previous studies 2014



MSU: $^{13}B(-1p + 1n)$ nucleon exchange reaction on ^{9}Be @ 71 AMeV

B. R. Marks, et.al Phys Rev C 92, 054320 (2015)



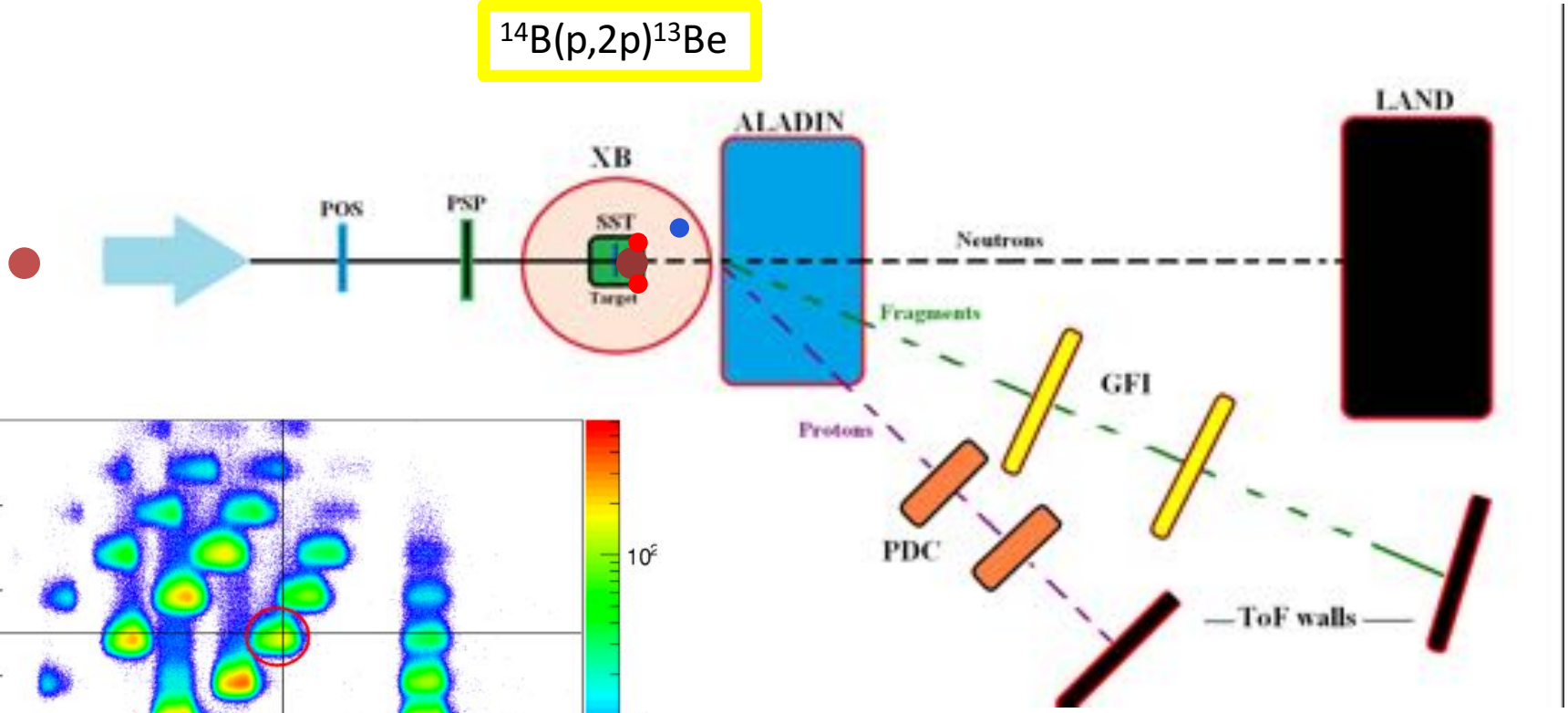
MSU conclusion

"present data show no evidence of any low- energy decay from the second d5/2 to the first excited 2+ state in ^{12}Be as was suggested by Aksyutina *et al.*.

Simulations including such a decay branch resulted in an upper limit of less than 10%. This finding is consistent with results by Randisi *et al.* who extracted a branching ratio of 5(2)% ".

Experiment: Cave C @ GSI

$^{14}B(p,2p)^{13}Be$



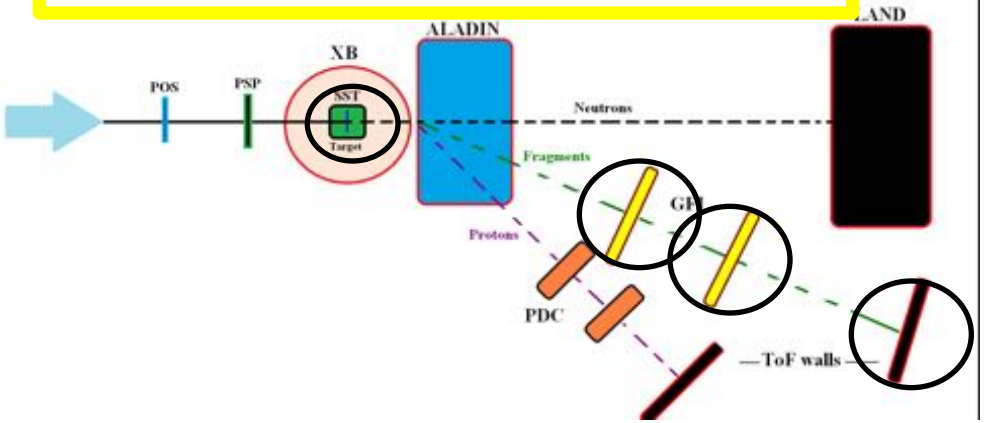
$$\frac{A}{Z} = K \cdot \frac{B\rho}{\beta\gamma}$$

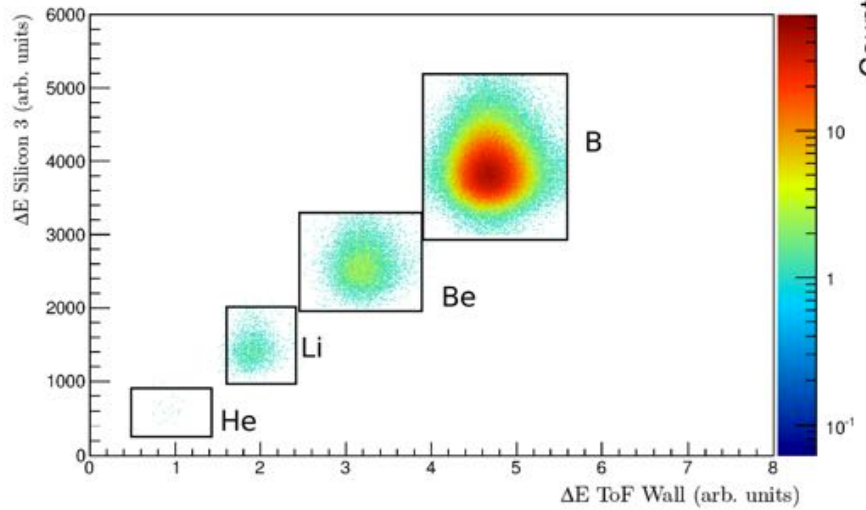
Primary beam	$^{40}Ar^{11+}$ @ 490 MeV/u
Intensity	$6 \cdot 10^{10}$ ions/spill.
Production target	Be 4 mg/cm^2
Reaction target	H, C, empty

Reaction channel Idenitification

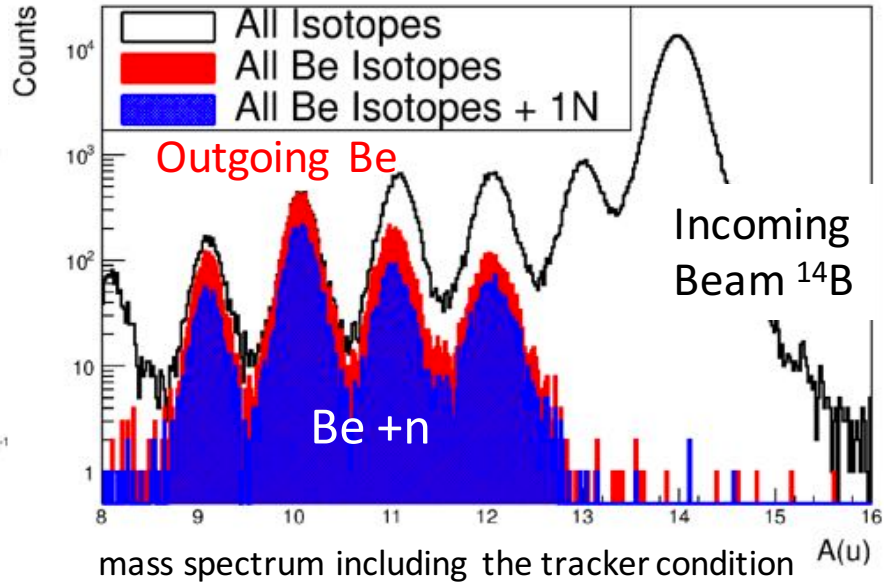
- Energy loss in the TFW & SST after the target: Identify the element after the reaction.
- Identify the isotope from the ALADIN position deviation and beta of the fragment.

^{14}B $(2p\gamma)$ $^{12}Be + n$



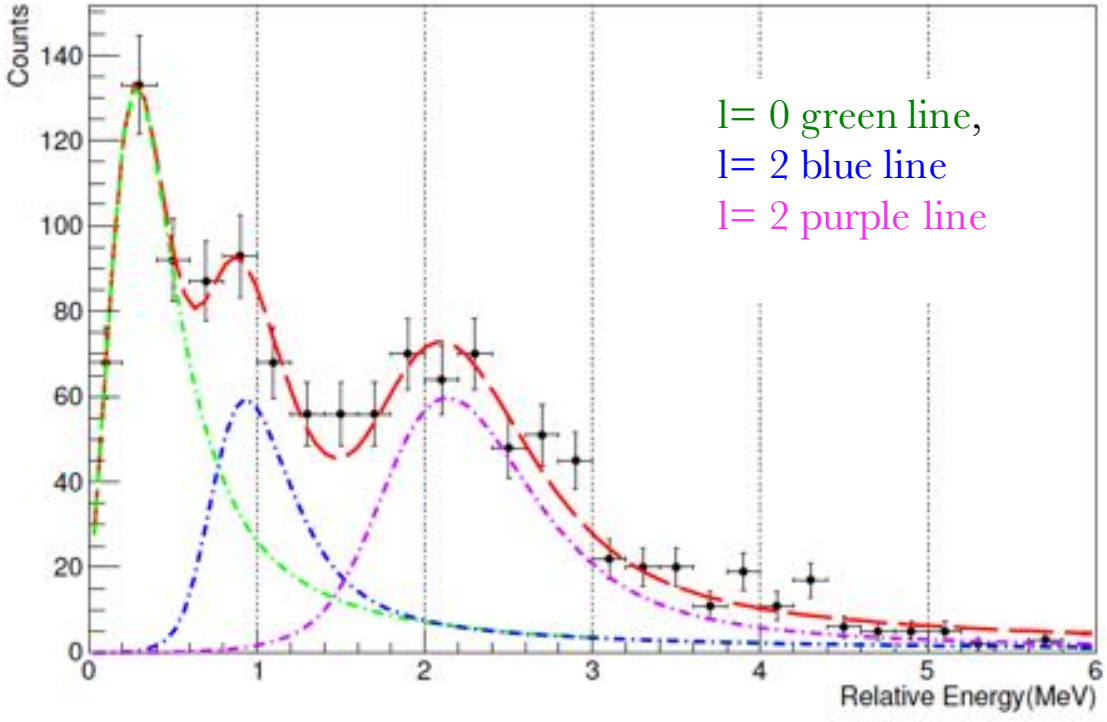


Charge identification plot



mass spectrum including the tracker condition

^{13}Be relative energy spectrum (^{12}Be+n)



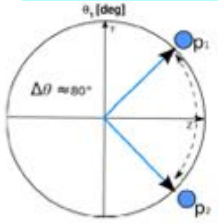
#	l	E_r(MeV)	Γ (MeV)
1	0	0.333±0.036	0.5196±0.0054
2	2	0.951±0.055	0.29±0.026
3	2	2.157±0.058	0.5845±0.0076
χ^2		29.9	
χ^2/N_{df}		1.57	

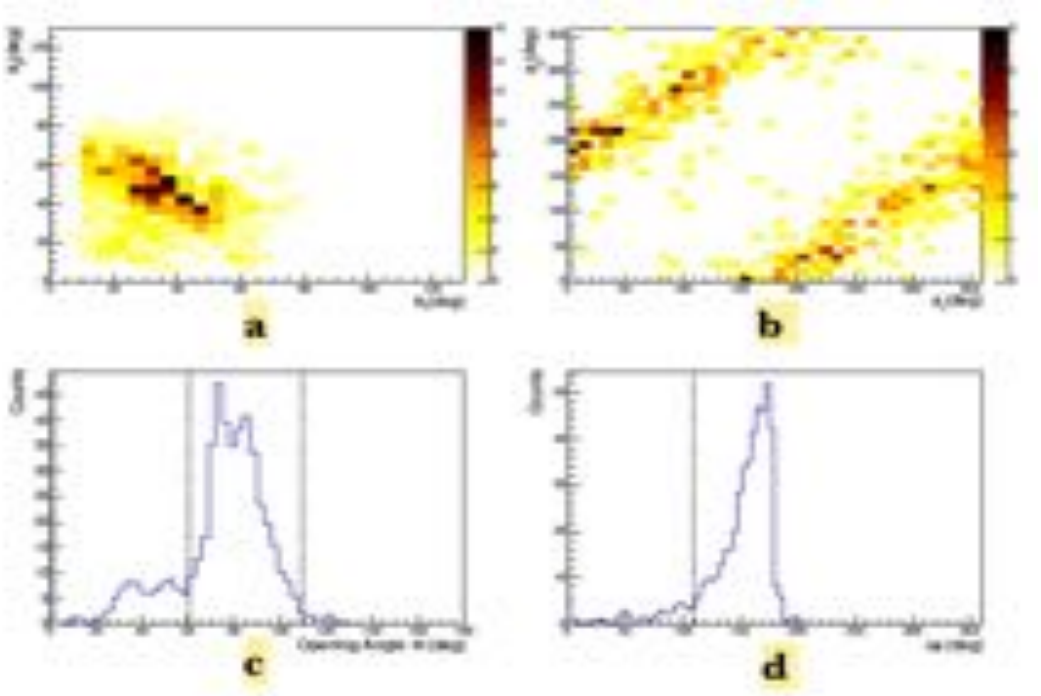
Relative energy spectrum ^{13}Be = ^{12}Be + n considering **three resonances**
Breit Wigner functions with
l= 0 for the green line, l= 2 for the blue line, l=2 for the purple line.
The global fit χ^2= 1.57 represented by the red line.

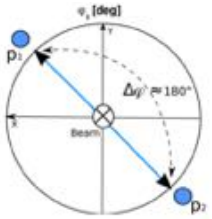
Quasifree scattering conditions (p,2p)

Both particles are emitted in the same plane, and as both have the same mass, with an opening angle of 90º in the laboratory frame.

The coplanar condition translates to 180º, whereas the high energies in inverse kinematics produce an opening angle of 80º, due to the mass increase of the incoming nucleon @ relativistic velocities ($\beta = 0.7$).





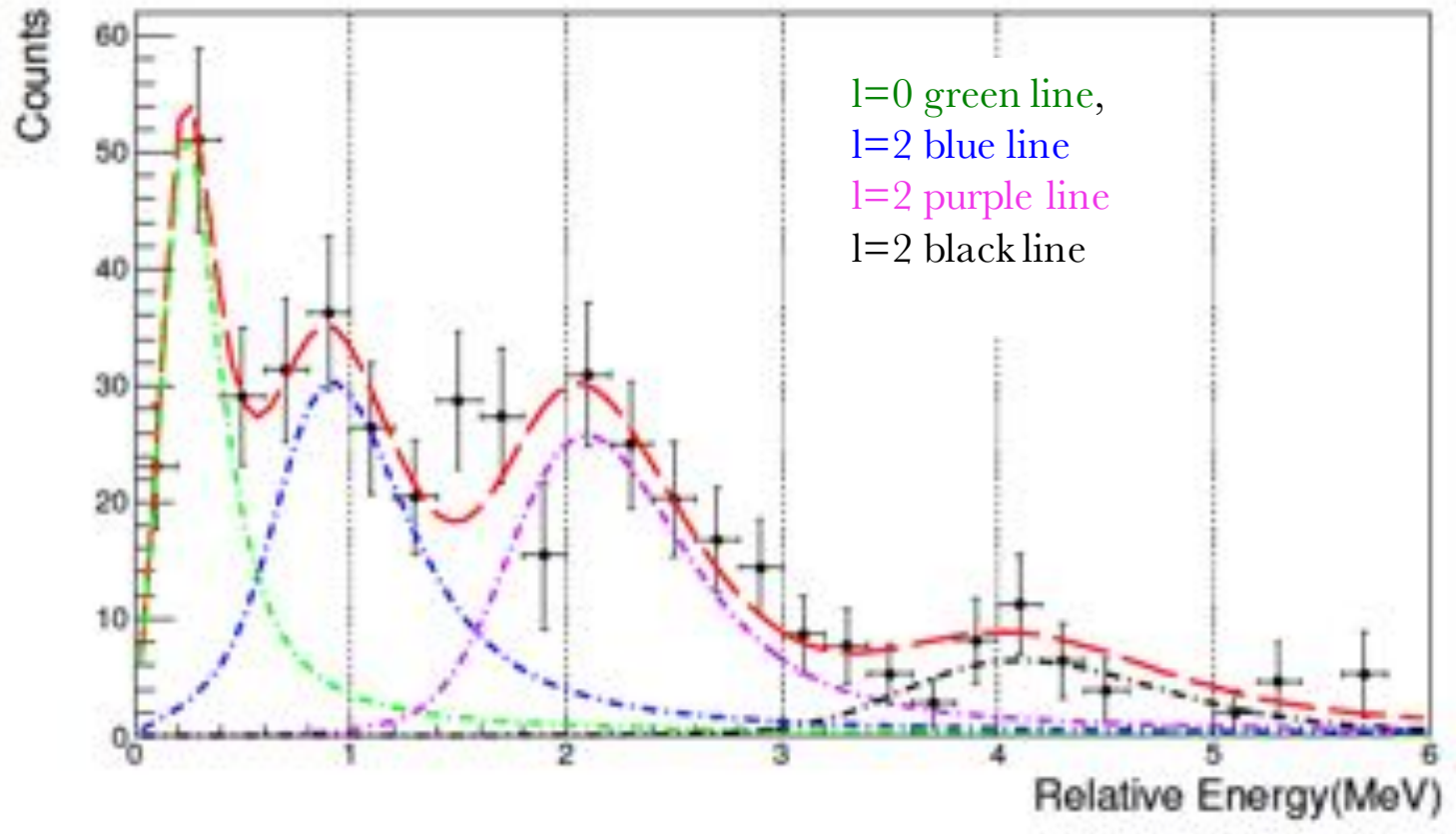


Angular distribution of the 2p in coincidence with ^{12}Be+n:

(**a**) Polar Angle correlation; (**b**) Azimuthal Angle correlation;
(**c**) Opening Angle, peaked at 82; (**d**) Azimuthal angle difference, peaked at 180.

The vertical dashed lines in (**c**) and (**d**) represent the limits for the QFS conditions.

Adding the Quasifree scattering conditions leads to less statistics, but clean data



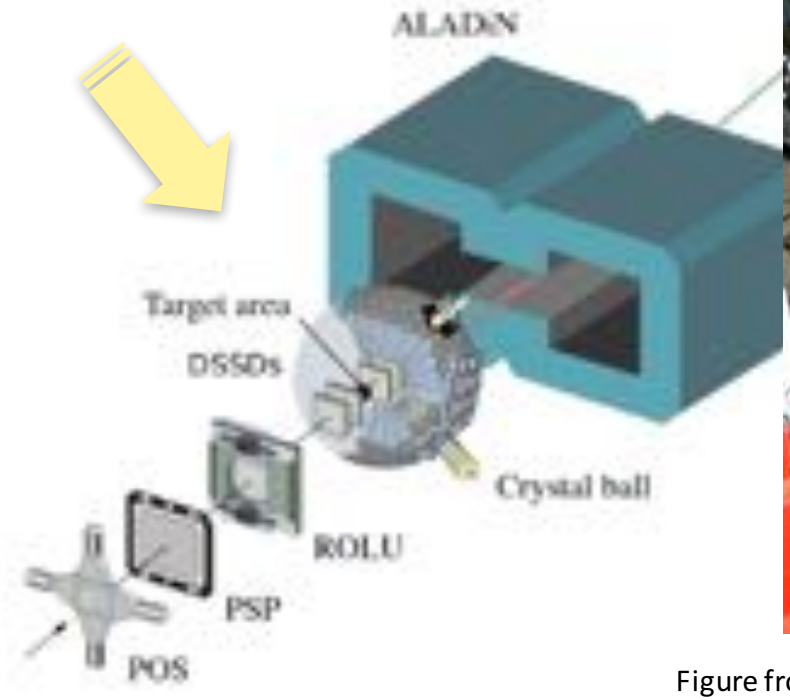
Relative energy spectrum $^{13}Be = {}^{12}Be + n$ considering **QFS conditions** the global fit to four Breit-Wigner resonances **fit χ^2= 1.3 red line.**

The R3B set-up @ GSI Cave C

What is New compared to previus experiments?

The Crystal ball

The reaction target is surrounded by a sphere of
162 NaI scintillator crystal assembly
inner radius of 25 cm
crystal length of 20 cm



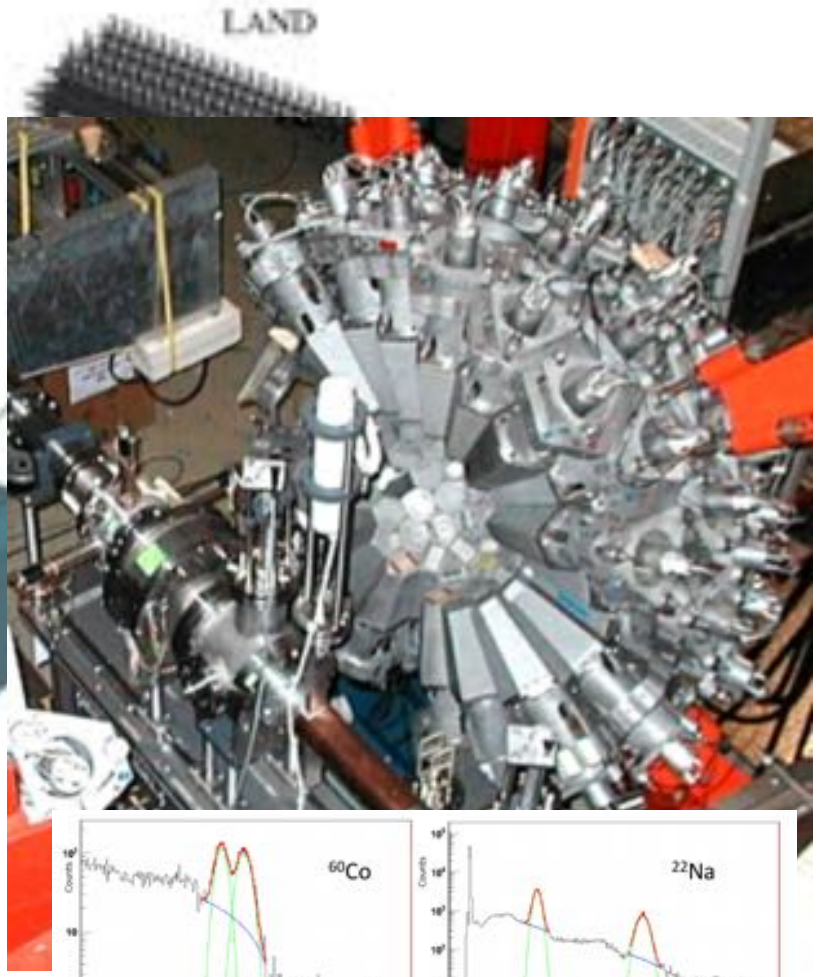
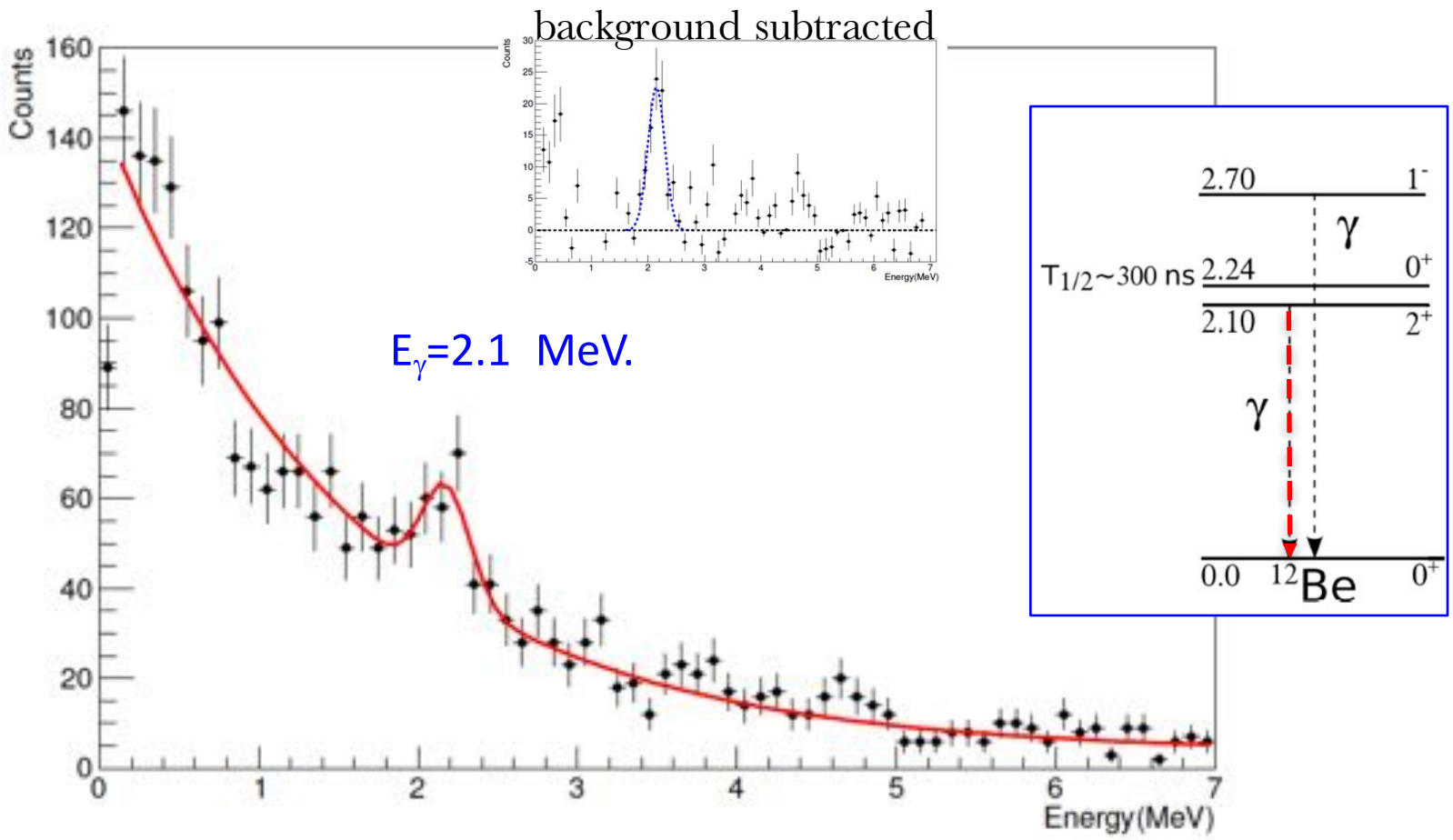


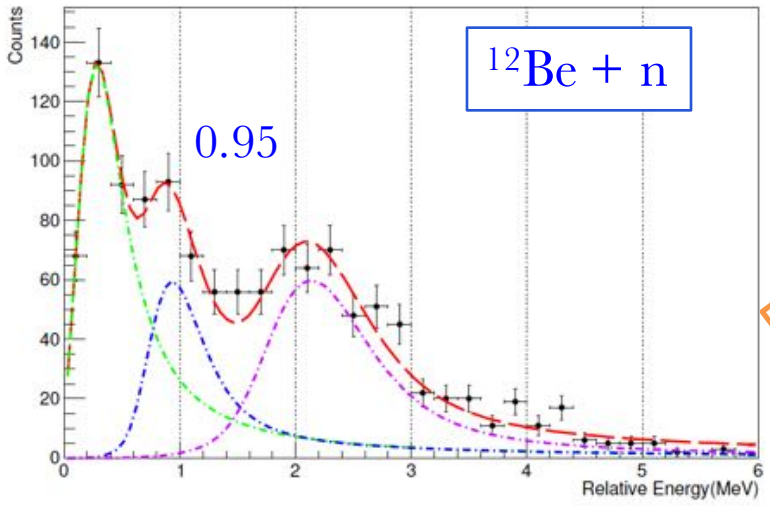
Figure from 14).

^{13}Be Doppler corrected Gamma spectrum detected by Crystal Ball in coincidence with ^{12}Be+n

^{13}Be Gamma spectrum detected by Crystal Ball in coincidence with ^{12}Be+n.
fitted to an exponential + Gaussian distribution in order to subtract the background.



Conclusion $^{14}Be(p,2p)^{13}Be$



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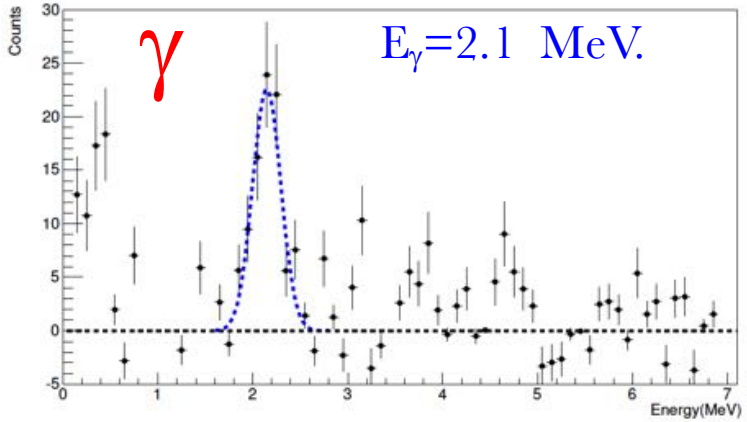
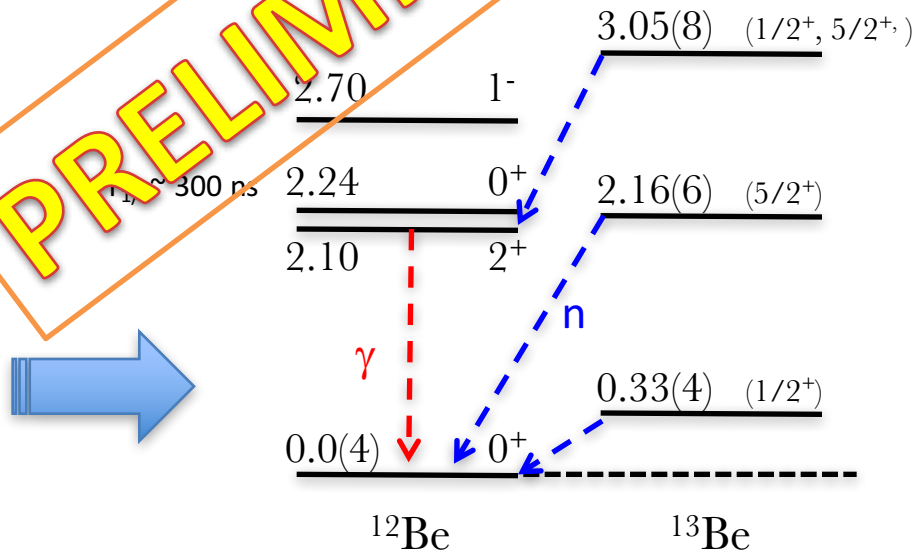


PRELIMINARY

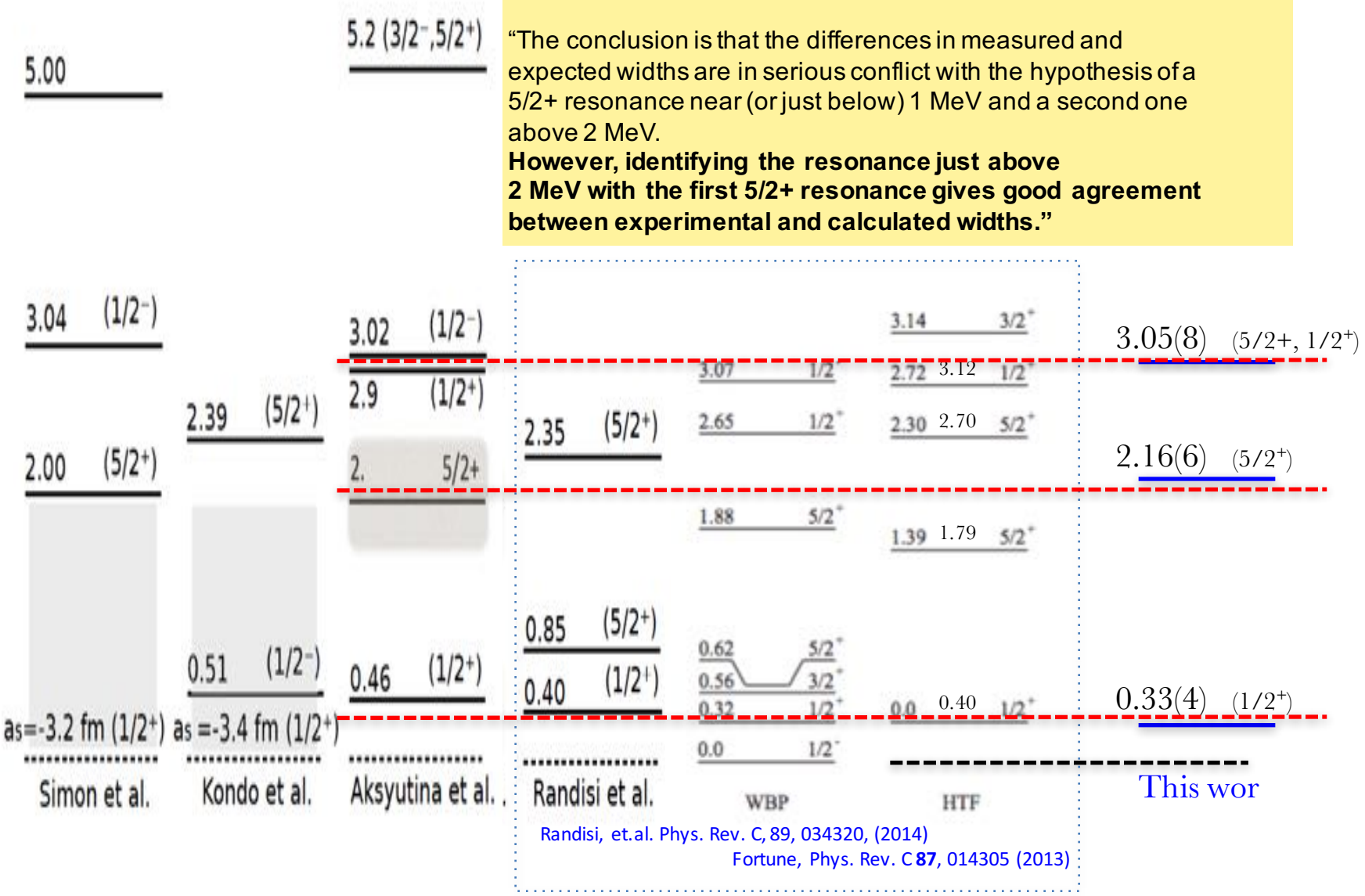


2.10 + 0.95(8) = 3.05(8)

Conclusion on ^{13}Be

H.T. Fortune Phys. Rev C93, 5, 31 May 2016, Article number 054327

"The conclusion is that the differences in measured and expected widths are in serious conflict with the hypothesis of a 5/2+ resonance near (or just below) 1 MeV and a second one above 2 MeV.
However, identifying the resonance just above 2 MeV with the first 5/2+ resonance gives good agreement between experimental and calculated widths."



Randisi, et.al. Phys. Rev. C, 89, 034320, (2014)
Fortune, Phys. Rev. C **87**, 014305 (2013)

In summary: I have discussed the

- Discussed the previous experimental knowledge of the un-bound nucleus ^{13}Be
- We have measured and discussed the gamma emission in coincidence with ^{13}Be i.e. with the ^{12}Be+n system
- This gamma coincidence moves the excitation level in ^{13}Be from 0.9 MeV to 3 MeV

Thanks for your attention!