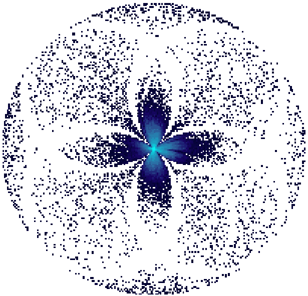
Transfer reaction studies of neutron rich Be isotopes.

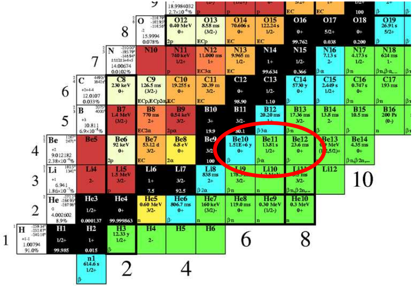
Jacob S. Johansen
Aarhus University

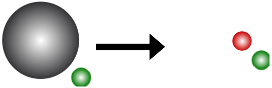
25. May 2012



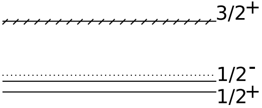
^{11}Be + d

- The experiment was performed at ISOLDE in 2010 using MINIBALL an T-REX.
- Inverse kinematics.
- ^{11}Be(d,p)^{12}Be (Primary reaction).
  - Study of single particle excitations
- ^{11}Be(d,t)^{10}Be.
- ^{11}Be(d,d')^{11}Be.

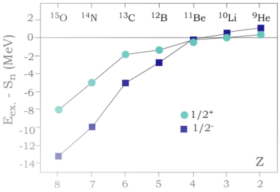




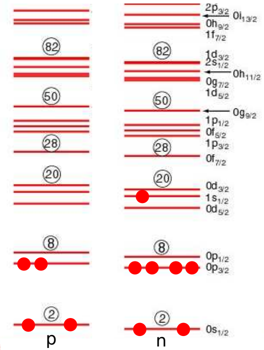
The physics case: The mixing of the 0p and the sd shells.



^{11}Be



Shell evolution in N=7 nuclei.



^{11}Be$_{gs}$

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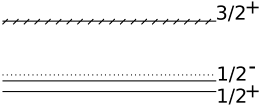
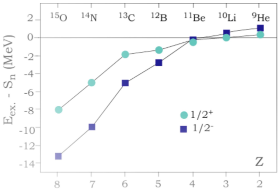


^{11}Be



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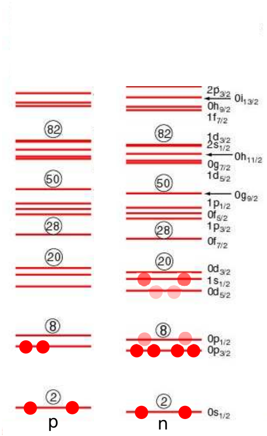
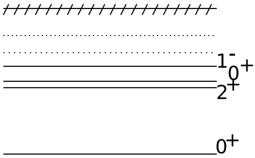


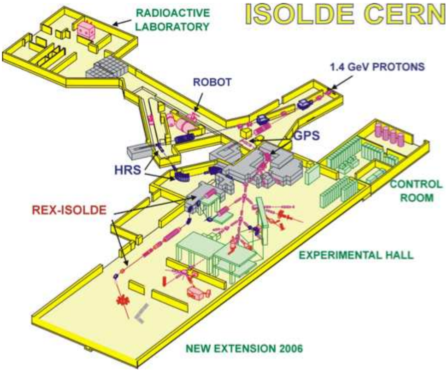
^{12}Be$_{gs}$



^{12}Be.

Want to determine spectroscopic factors.

The experiment.



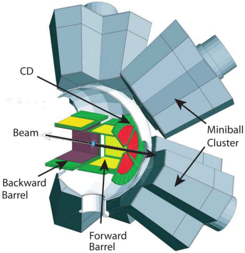
^{11}Be beam:

- $E_{beam} = 2.85$ MeV/u.
- $I_{beam} = 10^6$ /s.
- 4 days of beamtime.

Targets:

- CD_2 (Primary).
- CH_2, C (Background).
- Ag (Beam intensity).

The MINIBALL and T-REX setup

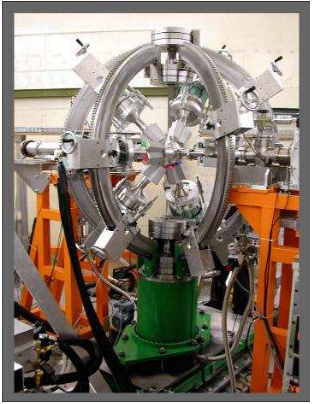


MINIBALL:

- 8 clusters.
- 3 detectors in each cluster.
- 6 segments in each detector.

T-REX:

- 4 annular telescope detectors (500μm+500μm) (CD).
- 8 Pad telescope detectors (140μm+1000μm) (FB+BB).



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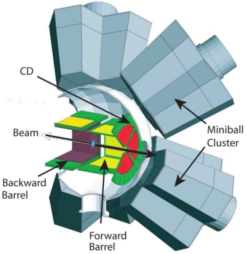

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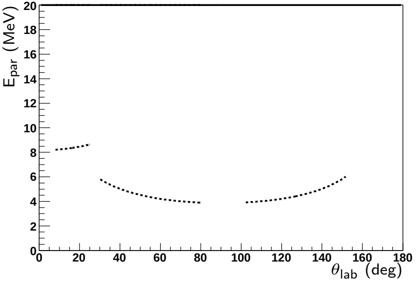
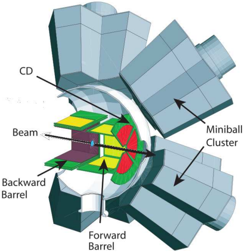


CD FB BB

The MINIBALL and T-REX setup



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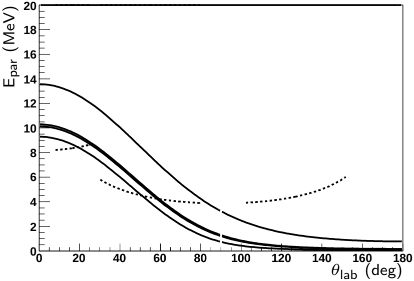
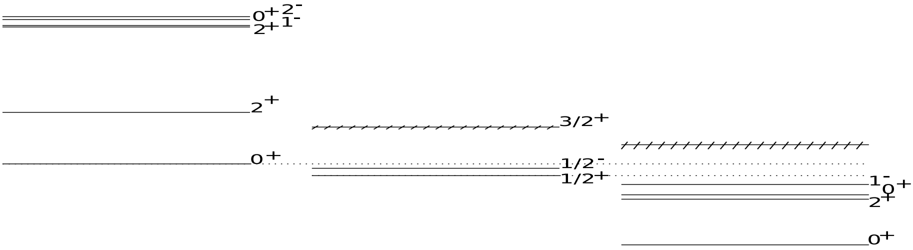
$d(^{11}Be,p)^{12}Be$

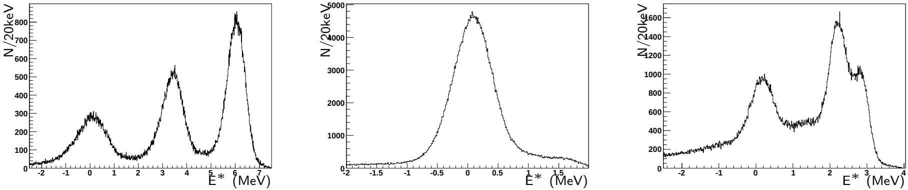


CD FB BB

ΔEE Identified particles

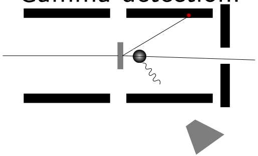


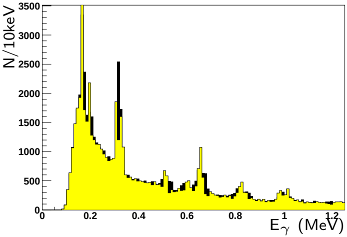
^{10}Be ^{11}Be ^{12}Be



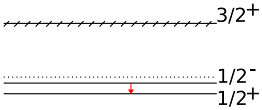
Good statistics, but gammas are needed to separate closely lying states.

Gamma detection:

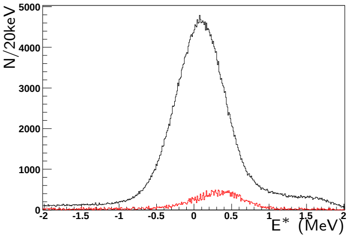




Yellow: Raw gamma spectrum.
Black: Doppler corrected spectrum.



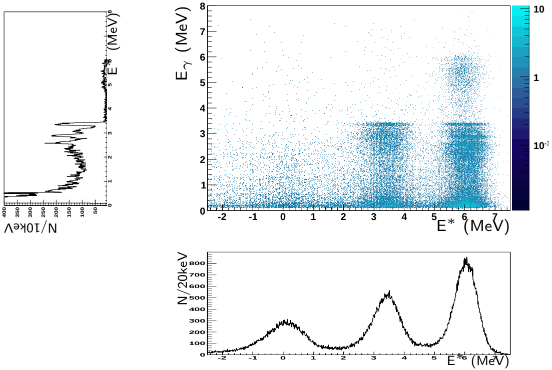
^{11}Be.

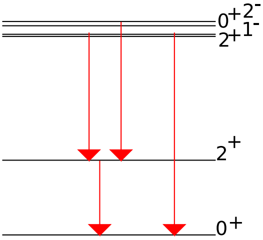


Black: Total Excitation spectrum.
Red: Gamma gated Excitation spectrum.

Elastic scattering dominates

E^* vs E_γ for the (d,t) reaction.

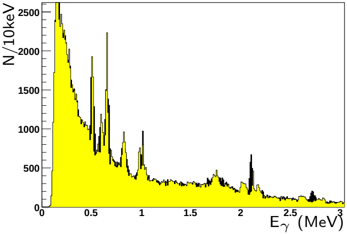




^{10}Be.

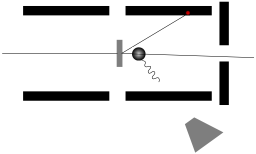
- Identified all but one bound state in ^{10}Be.
- Separated 1_1^- and 2_2^+ even though $\Delta E = 5keV$.

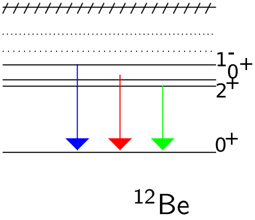
$d(^{11}Be,p)^{12}Be$



Yellow: Raw gamma spectrum.
Black: Doppler corrected spectrum.

2_1^+ to 0_1^+ and
1_1^- to 0_1^+ transition:





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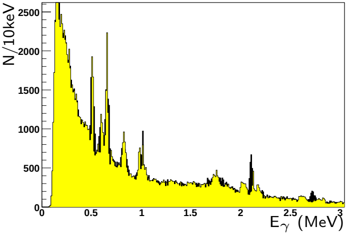

Yellow: Raw gamma spectrum.
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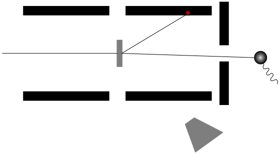
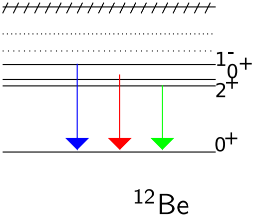
0_2^+ to 0_1^+ transition:
$\tau \approx 330$ns. $E_\gamma = 511$keV.





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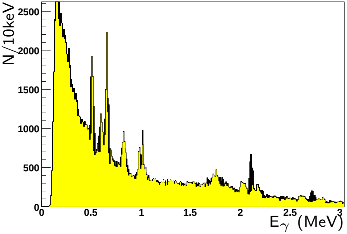

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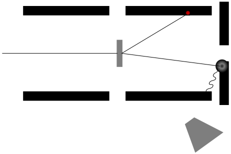
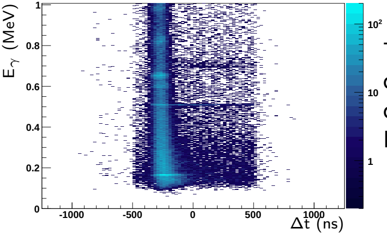
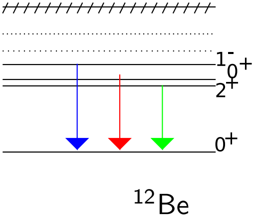
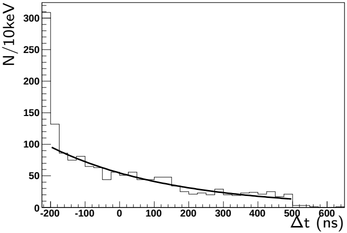




Time between detected particle and detected gamma vs. E_γ.





Lifetime measurement of $0_2^+ \rightarrow 0_1^+$:

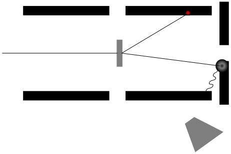
$\tau_{\text{fit}} = 353(22)$ns.

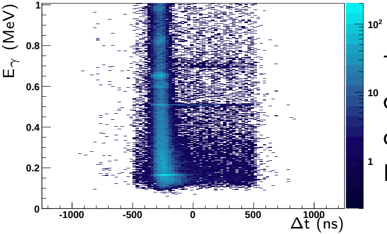
S. Shimoura et al:

$\tau = 331(12)$ns.

0_2^+ to 0_1^+ transition:

$\tau \approx 330$ns. $E_\gamma = 511$keV.





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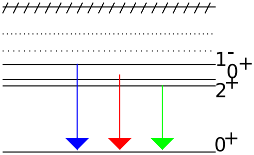
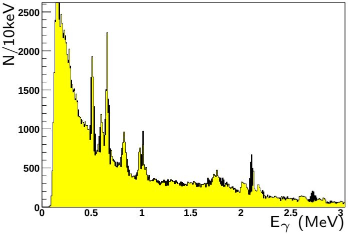


^{12}Be

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



Yellow: Raw gamma spectrum.
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0_2^+ to 0_1^+ transition:
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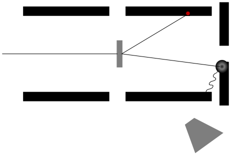
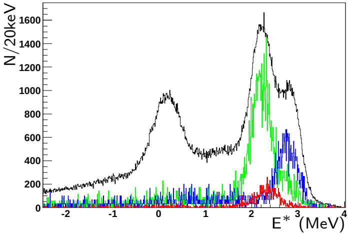
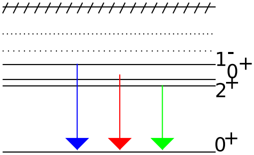
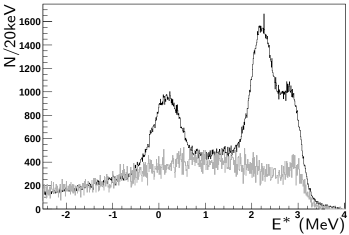




Total and γ-gated excitation sepctra of ^{12}Be.

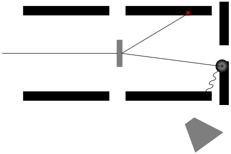


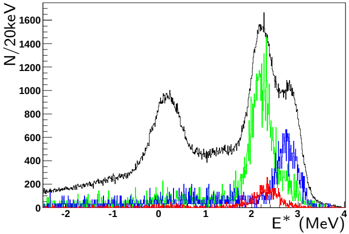
^{12}Be



Background from reactions of $^{12}C(^{11}Be,p)$, analyzed as $d(^{11}Be,p)$

0_2^+ to 0_1^+ transition: $\tau \approx 330\text{ns}$. $E_\gamma = 511\text{keV}$.





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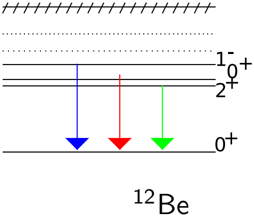
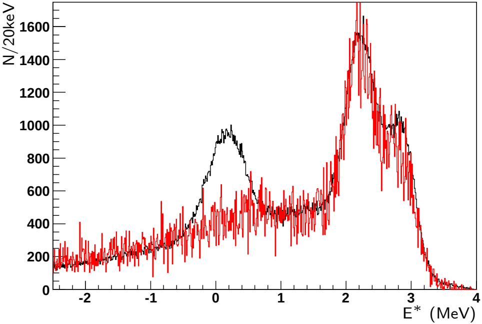
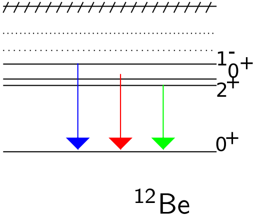




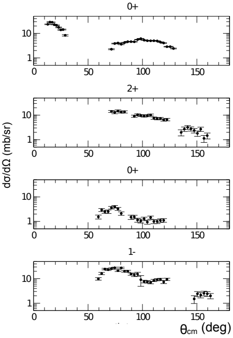


Black: Total excitation spectrum.
Red: Excitation spectrum from γ-gated and C-background spectra.

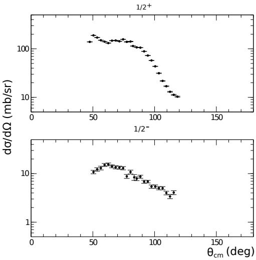
The background and the γ-gated spectra cover all except the ground state.

Differential cross sections

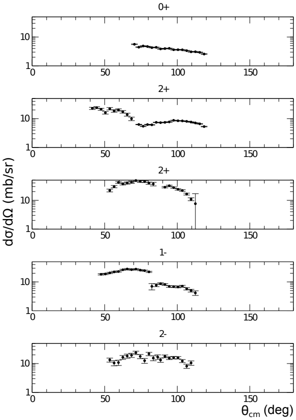
$^{11}Be(d,p)^{12}Be$



$^{11}Be(d,d)^{11}Be$



$^{11}Be(d,t)^{10}Be$



Differential cross sections

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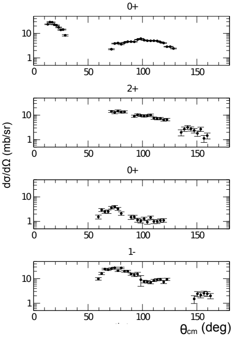

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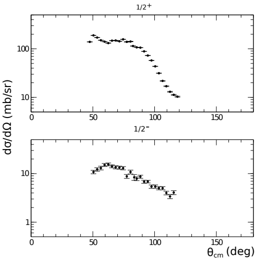
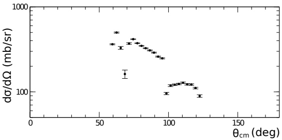


$^{11}Be(p,p)^{11}Be$



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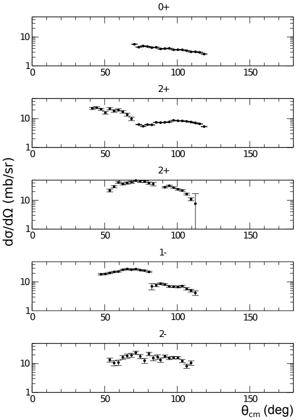
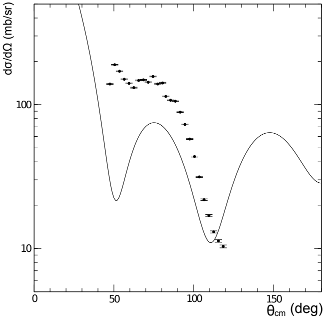


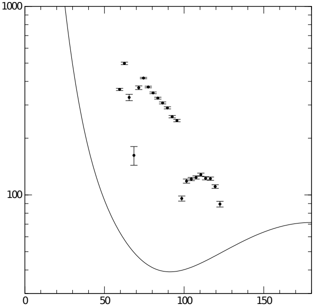
Optical model calculations

$^{11}Be(d,d)^{11}Be$.



Black dots: Elastic scattering.
Black line: Satchler et al. Nucl. Phys 85 273

$^{11}Be(p,p)^{11}Be$.



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Optical model calculations

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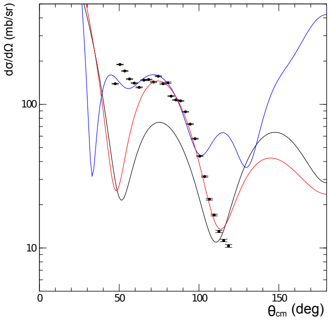


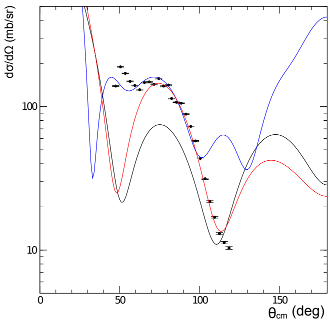
Black dots: Elastic scattering.
Black line: Satchler et al. Nucl. Phys 85 273
Blue line: Fit 1.

Red line: Fit 2.

	Satchler	Fit 1	Fit 2
V	124.7	151.2	70.44
r	0.9	1.	2.28
a	0.9	1.65	0.25
W	4.38	4.8	2.9
r_i	2.275	2.5	2.1
a_i	0.264	0.454	0.45

Optical model calculations

^{11}Be(d,d)^{11}Be.



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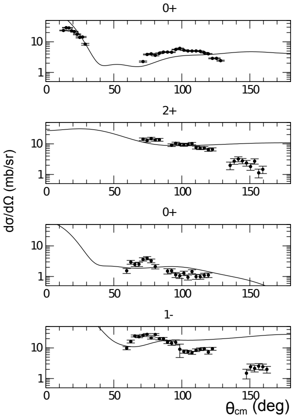
Next step: CDCC calculations.
Compound reactions?

DWBA calculations PRELIMINARY!

^{11}Be(d,p)^{12}Be.



Generalized optical potentials are used:

^{11}Be+d: Satchler et al. Nucl. Phys 85 273.

^{11,12}Be+p: Watson et al. Phys Rev. 182 977.

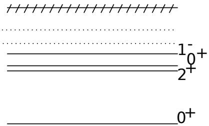
PRELIMINARY: Spectroscopic factors:

	$^{11}\mathrm{Be}_{gs}\otimes$	Exp	Shell model.
0_1^+	$1s_{1/2}$	0.4	0.78
2_1^+	$0d_{5/2}$	0.35	0.52
0_2^+	$1s_{1/2}$	0.55	0.37
1_1^-	$0p_{1/2}$	1.	

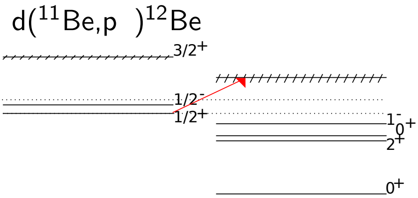
Shell model: Fortune et al. Phys Rev 83 044313

A low lying resonance in ^{12}Be

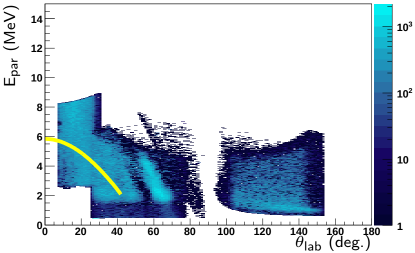
^{12}Be



A low lying resonance in ^{12}Be



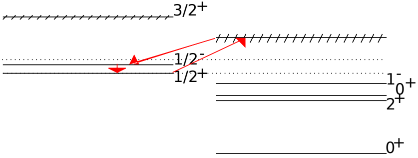
Kinetic curve of d(^{11}Be,p)^{12}Be,
$E^* = 4.5$MeV.



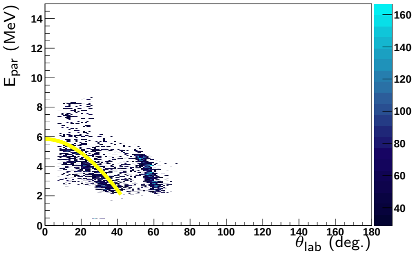
To much background to see anything.

A low lying resonance in ^{12}Be

$d(^{11}Be,p\gamma)^{12}Be$



Low energy particles gated on $E_\gamma = 320$keV.



The reaction is clearly seen.

A low lying resonance in ^{12}Be

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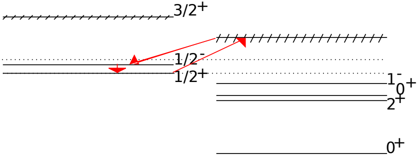

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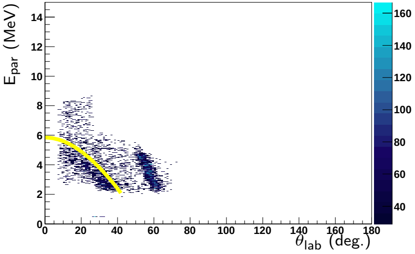

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A simple assumption

$|^{11}Be; 1/2^+\rangle = |^{10}Be; 0^+\rangle\, |n; 1s_{1/2}\rangle$

$\Downarrow +n$

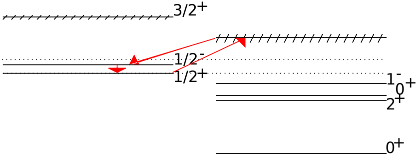
$|^{12}Be; ?\rangle = |^{10}Be; 0^+\rangle\, |n; 1s_{1/2}\rangle\, |n; ?\rangle$

$\Downarrow -n$

$|^{11}Be; 1/2^-\rangle = |^{10}Be; 0^+\rangle\, |n; 0p_{1/2}\rangle$

A low lying resonance in ^{12}Be

$d(^{11}Be,p\gamma)^{12}Be$



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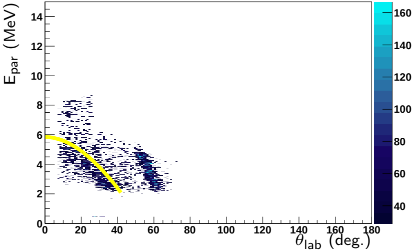

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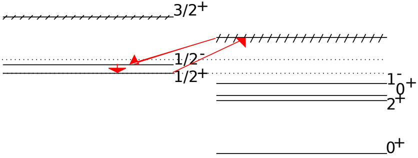

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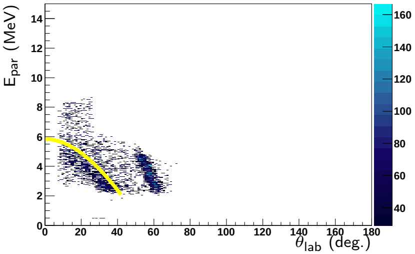

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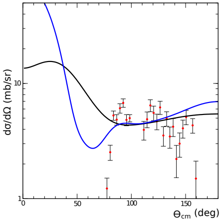
Preliminary three body calculations (E. Garrido) and ^{10}Be(t,p) reactions indicates a 1^- rather than a 0^-.

Differential cross section (PRELIMINARY):



Dots: Experiment. Black: 2^+. Blue: 1^-.

Summary

- ^{10,11,12}Be have been studied through transfer reactions and scattering.
- Gamma detection using the MINIBALL enabled identification of all but one bound states.
- Differential cross sections have been determined experimentally, and some are compared to theoretically calculated.
- A new quantum number (1^-) has been suggested for the lowest resonance in ^{12}Be.

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Thanks to:

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A. S. Jensen, E. Garrido and A. Moro for theoretical assistance.