Studies of neutron rich beryllium isotopes using transfer reactions.

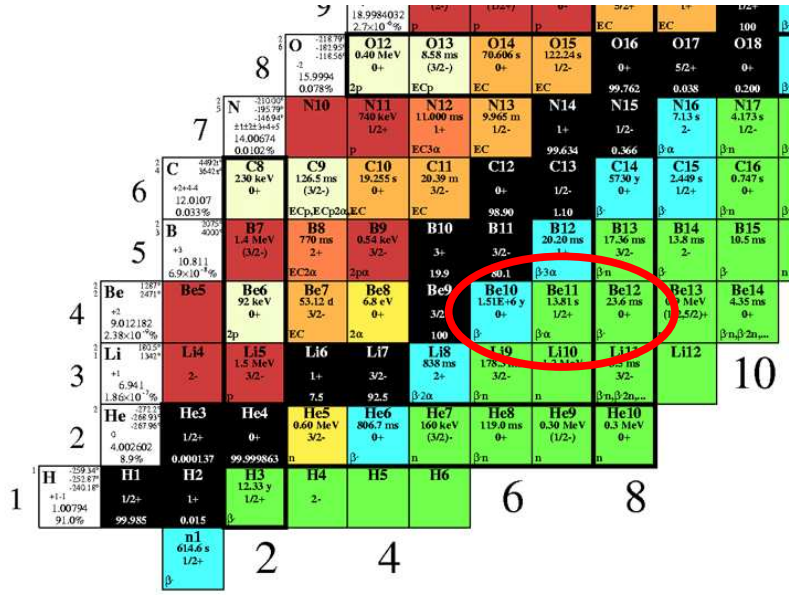
Jacob S. Johansen
Aarhus University

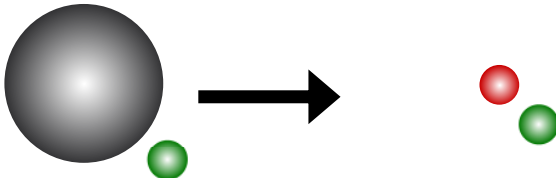
29. March 2012

Introduction

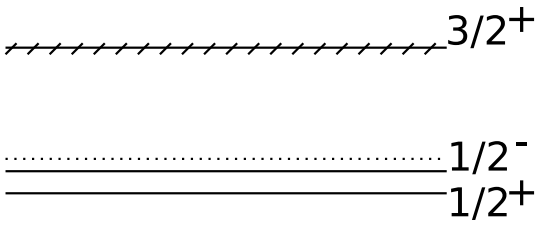
^{11}Be + d

- The experiment was performed at ISOLDE in 2010 using MINIBALL and 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.

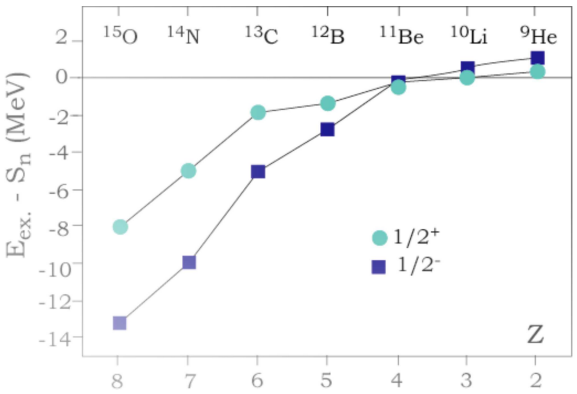




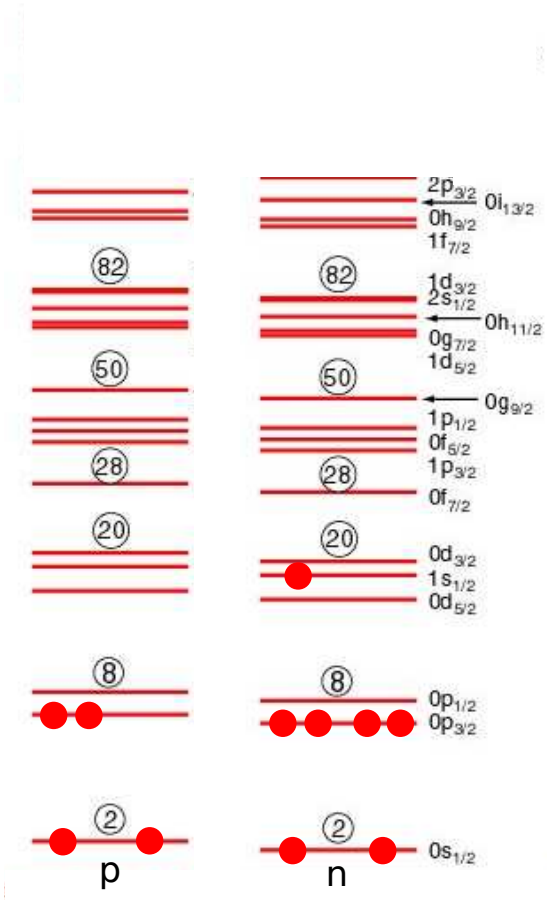
The physics case: The mixing of the 0p and the sd shells.



^{11}Be

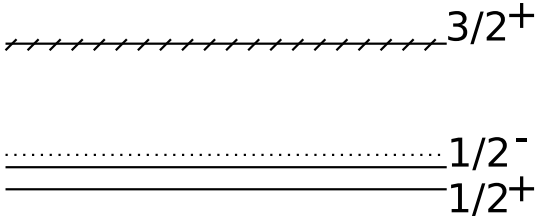


Shell evolution in N=7 nuclei.

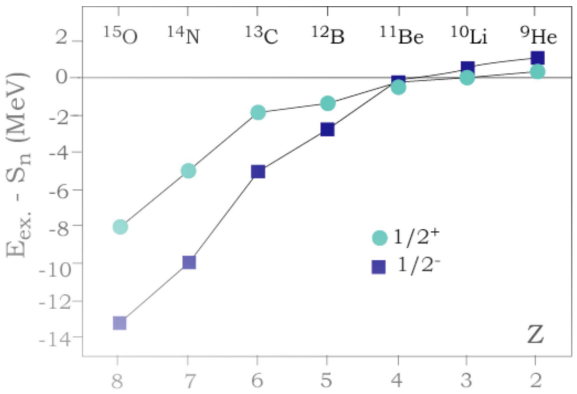


^{11}Be$_{gs}$

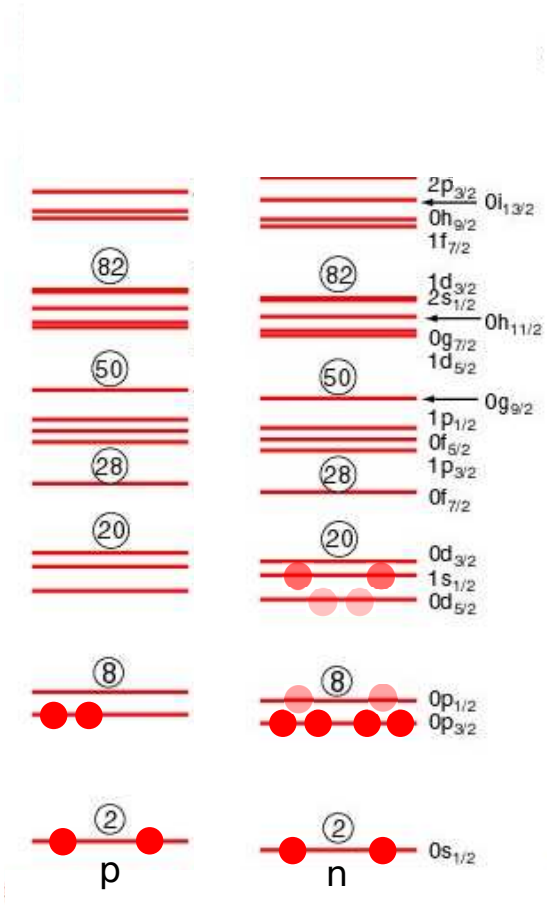
The physics case: The mixing of the 0p and the sd shells.



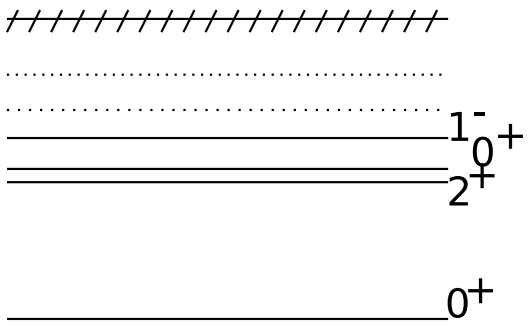
^{11}Be



Shell evolution in N=7 nuclei.



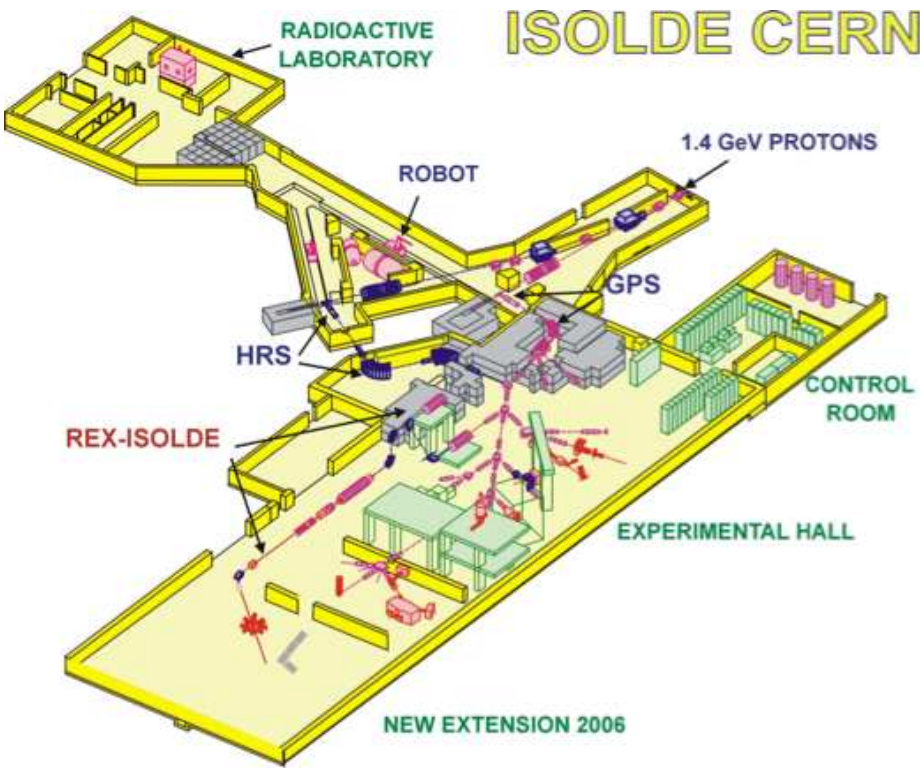
^{12}Be$_{gs}$



^{12}Be.

Spectroscopic factors.

The experiment.



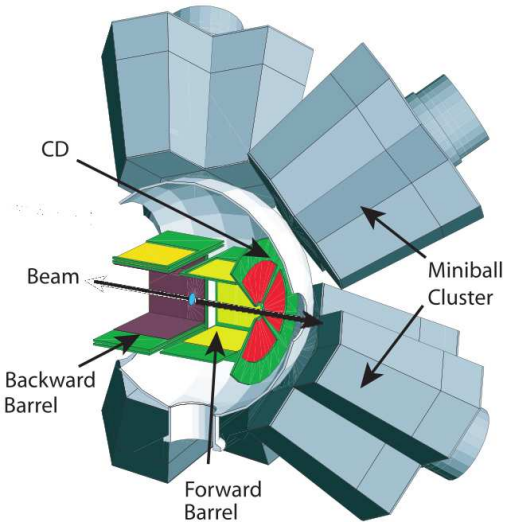
^{11}Be beam:

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

Targets:

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

The MINIBALL and T-REX setup

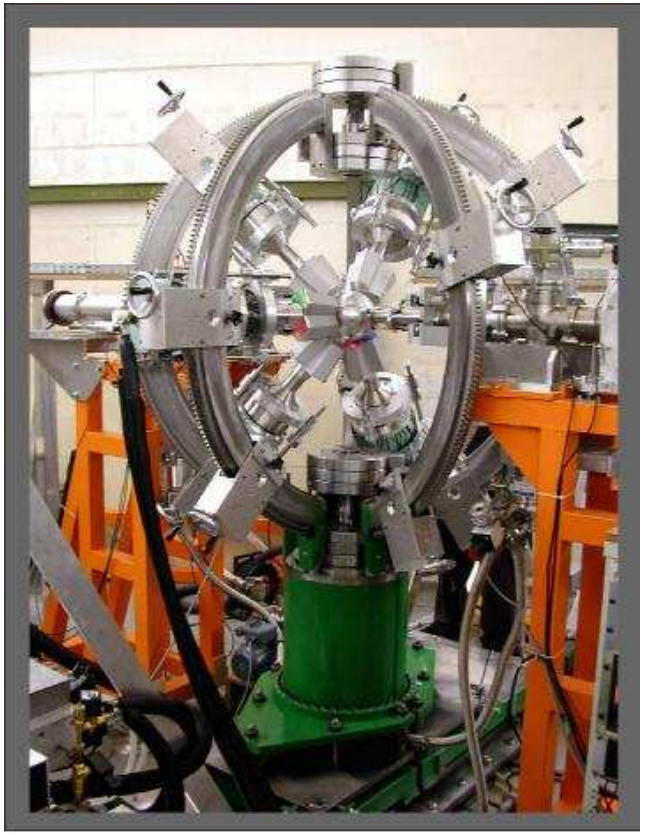


MINIBALL:

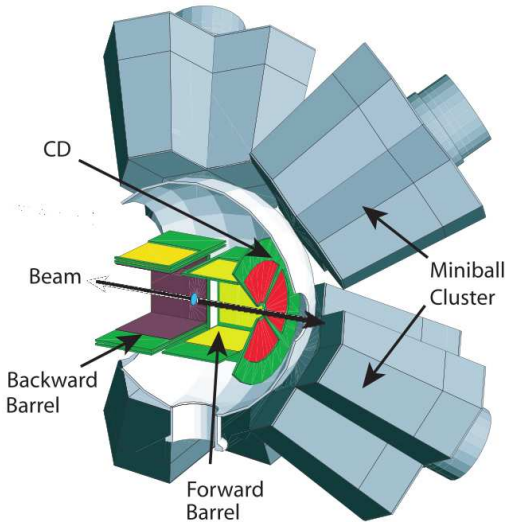
- 8 clusters.
- 3 detectors in each cluster.
- 6 segments in each detector.

T-REX:

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



The MINIBALL and T-REX setup

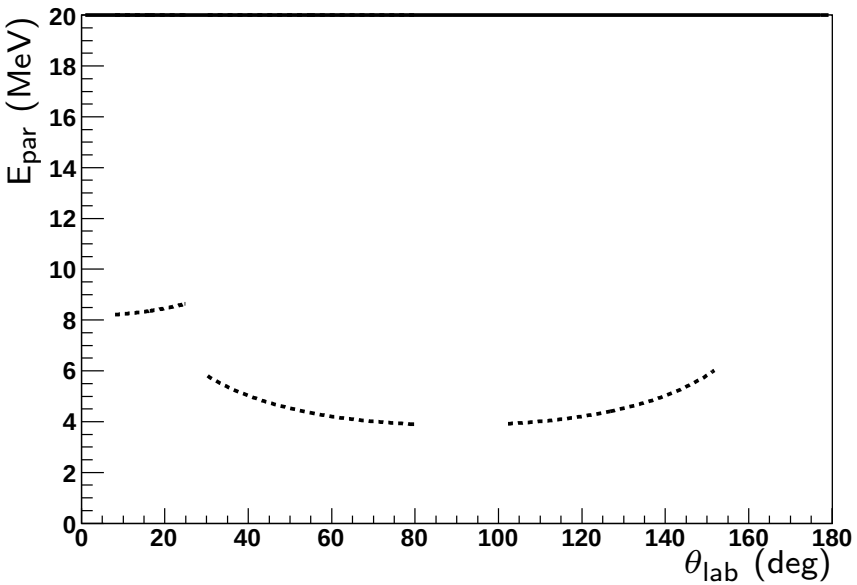


MINIBALL:

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

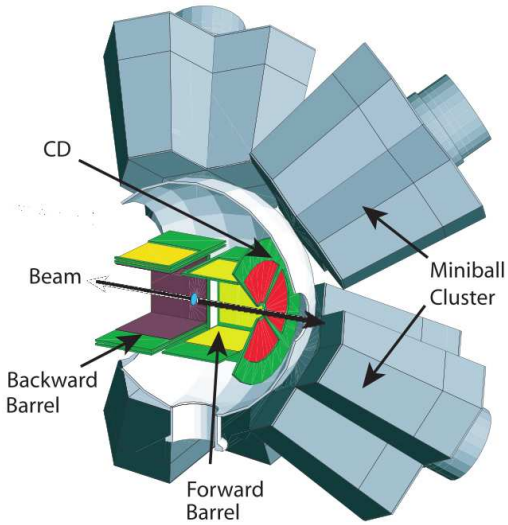
T-REX:

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



CD FB BB

The MINIBALL and T-REX setup



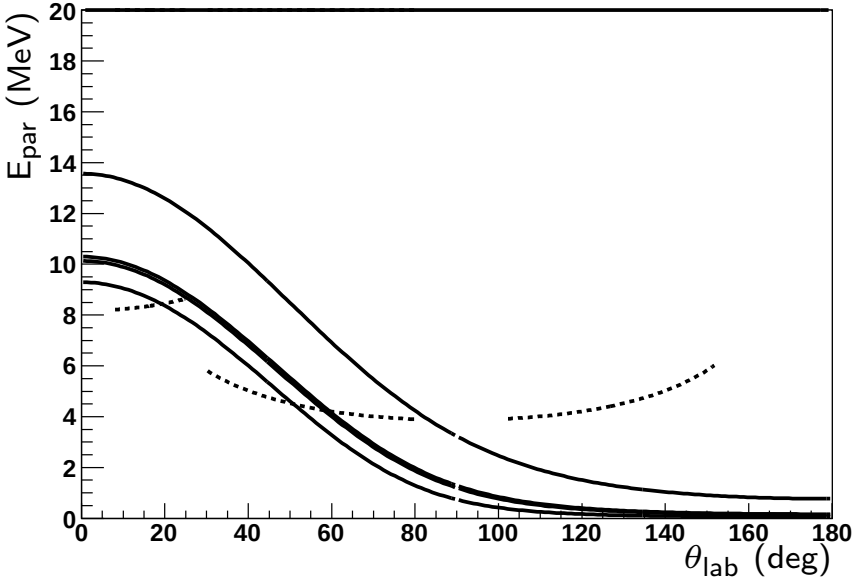
MINIBALL:

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

T-REX:

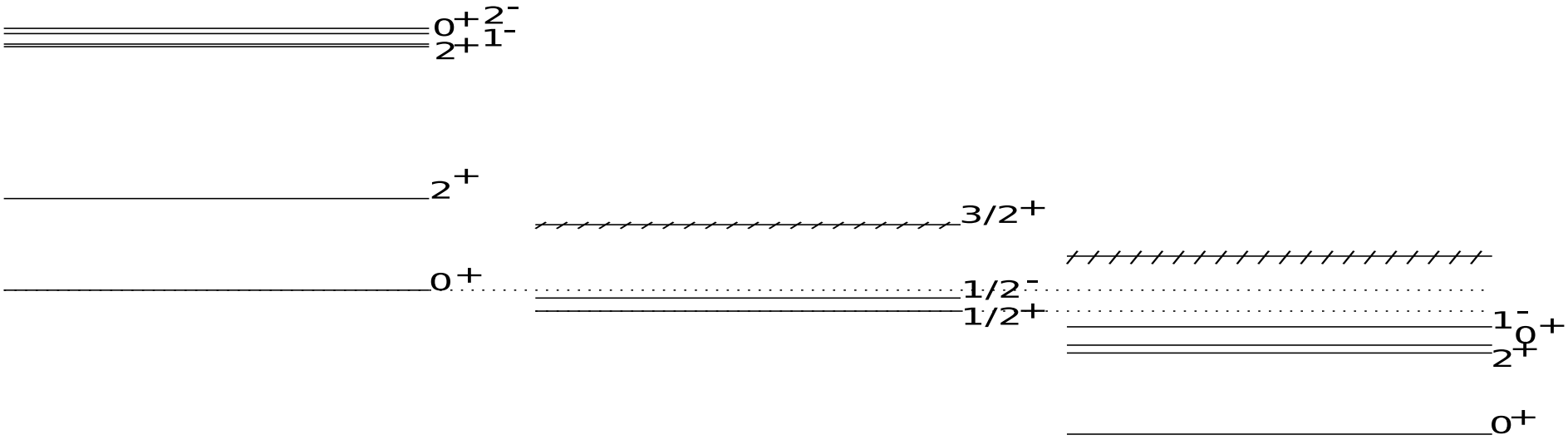
- 4 annular telescope detectors (500μm+500μm) (CD).
- 8 Pad telescope detectors (140μm+1000μm) (FB+BB).

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

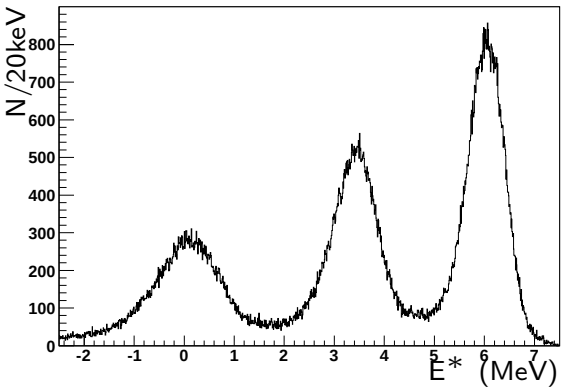


CD FB BB

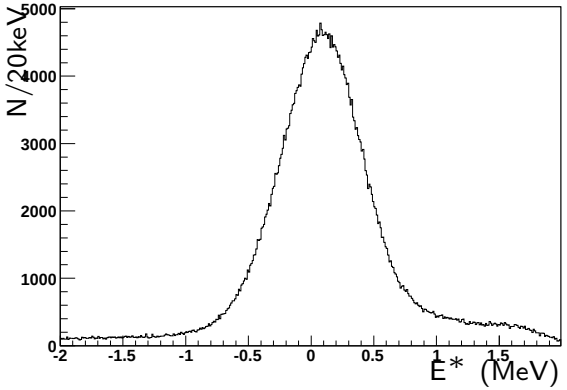
ΔEE Identified particles



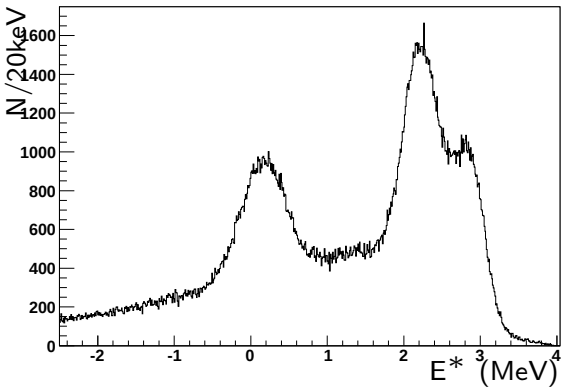
^{10}Be



^{11}Be



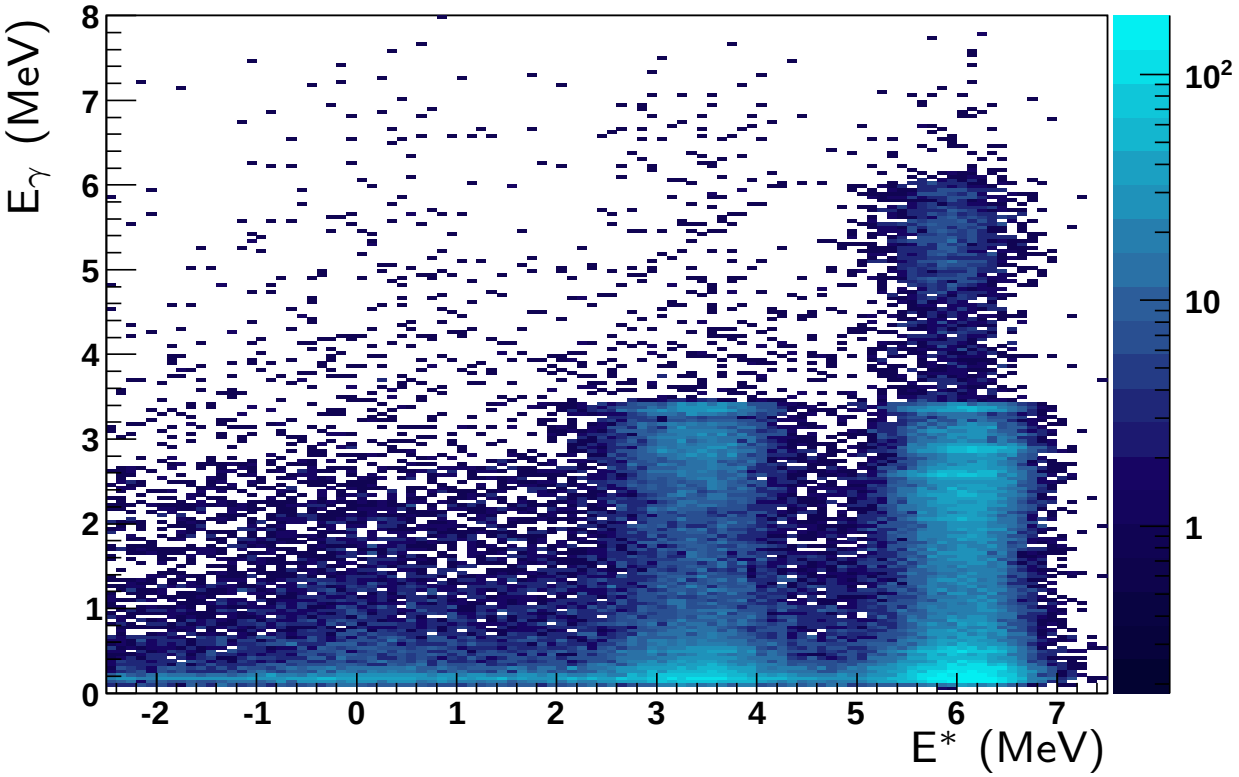
^{12}Be

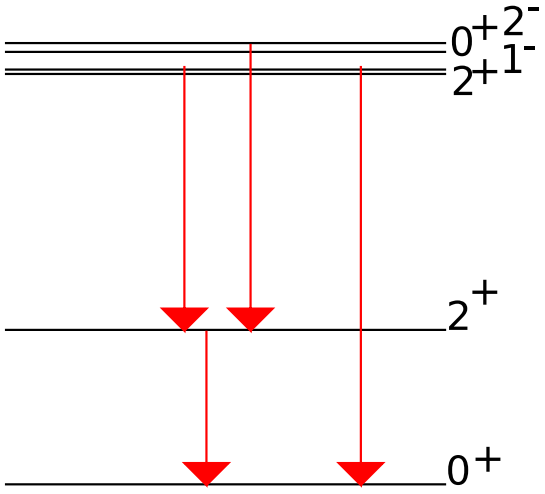


Good statistics, but gammas are needed to separate closely lying states.

Identified particles ^{10}Be

E^* vs E_γ for the (d,t) reaction.



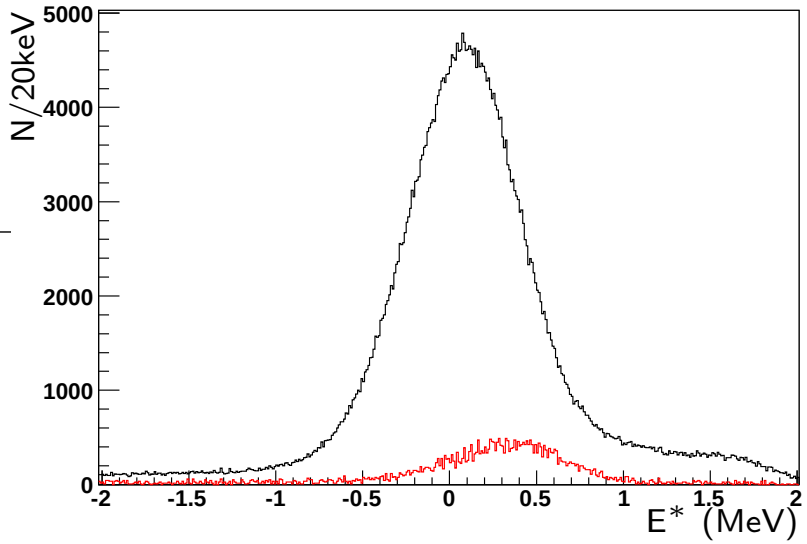


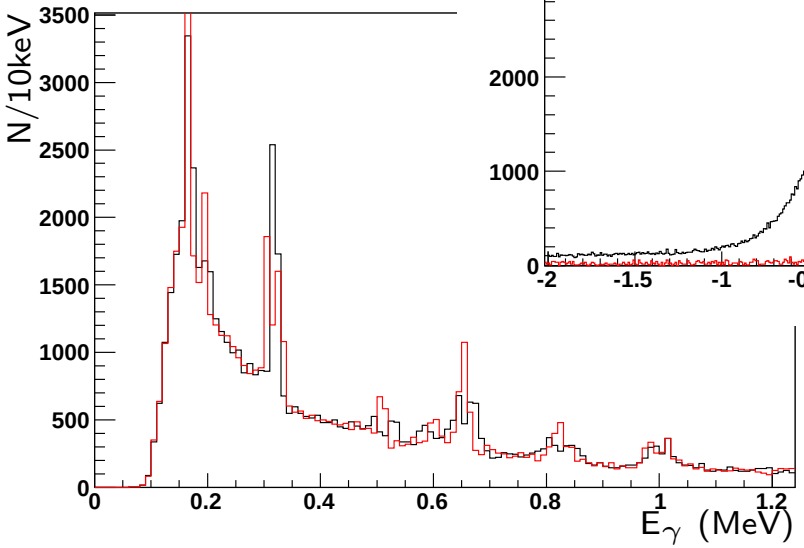
^{10}Be.

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

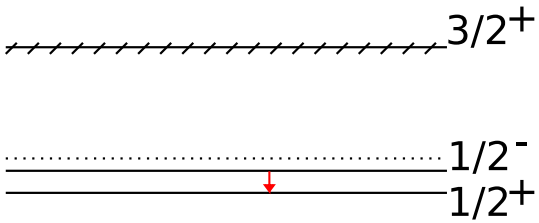
Identified particles ^{11}Be

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





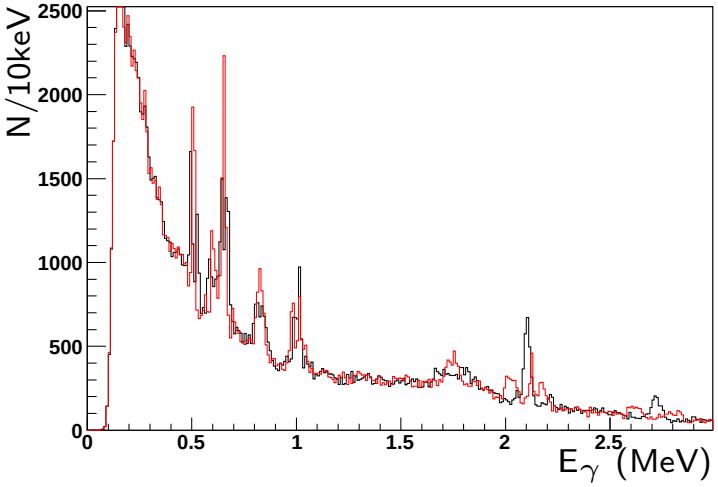
Red: Raw gamma spectrum.
Black: Doppler corrected spectrum.



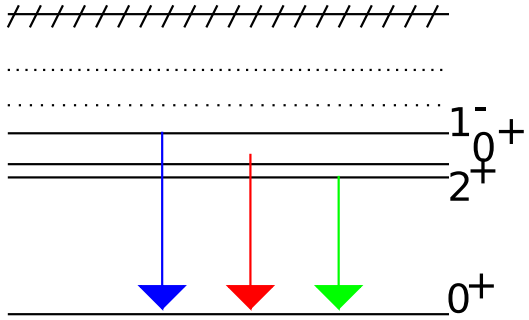
^{11}Be.

Elastic scattering dominates.

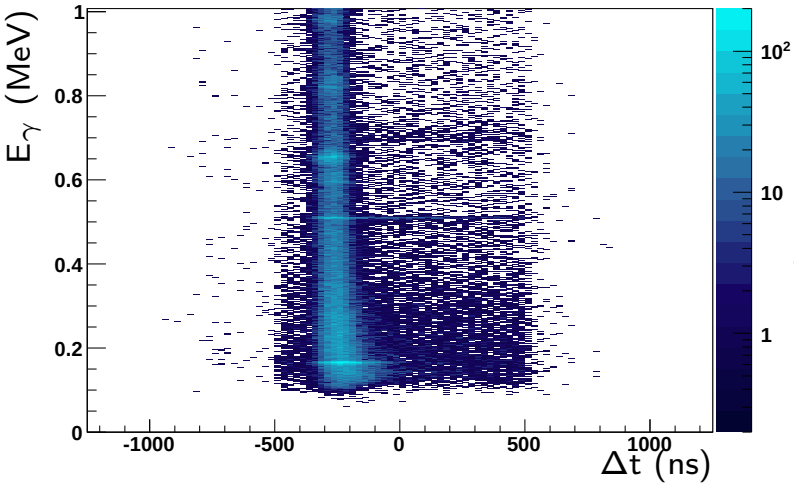
Identified particles ^{12}Be



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

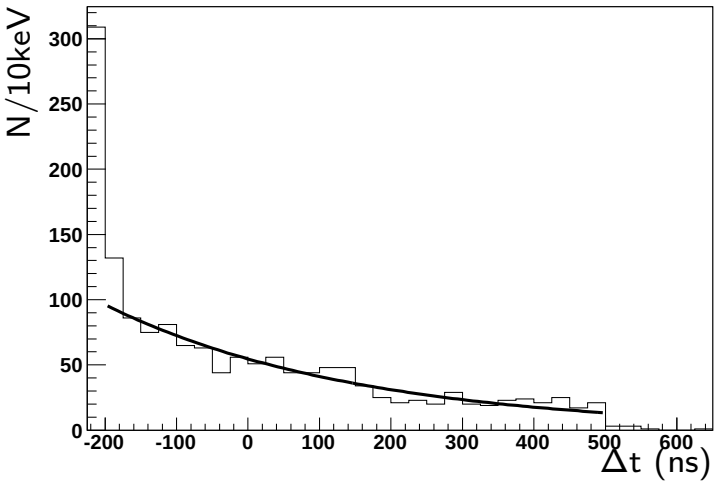


^{12}Be



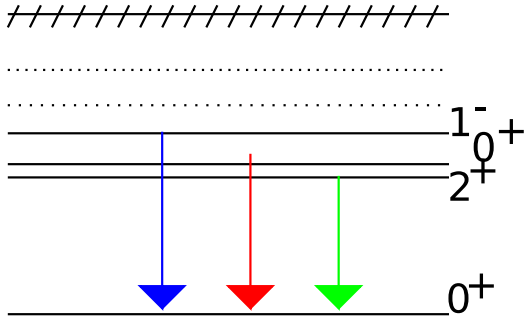
Time between detected particle and detected gamma vs. E_γ.

Identified particles ^{12}Be

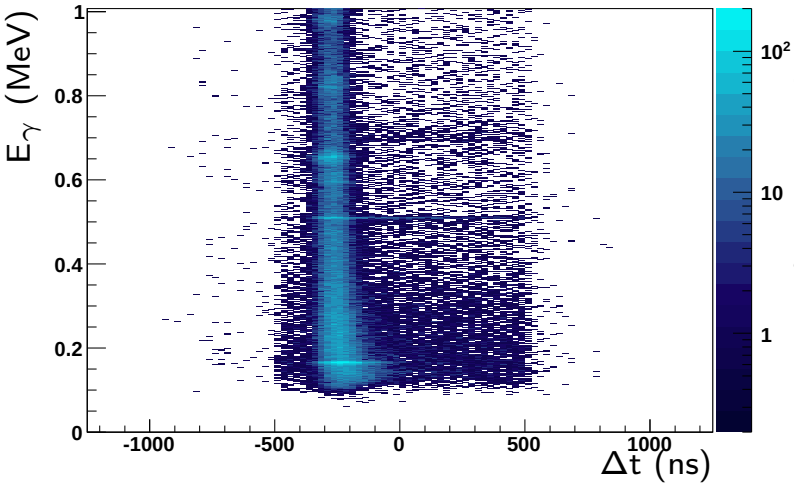


Lifetime measurement of $0_2^+ \rightarrow 0_1^+$:
$\tau_{\text{fit}} = 353(22)$ns.

S. Shimoura et al:
$\tau = 331(12)$ns.

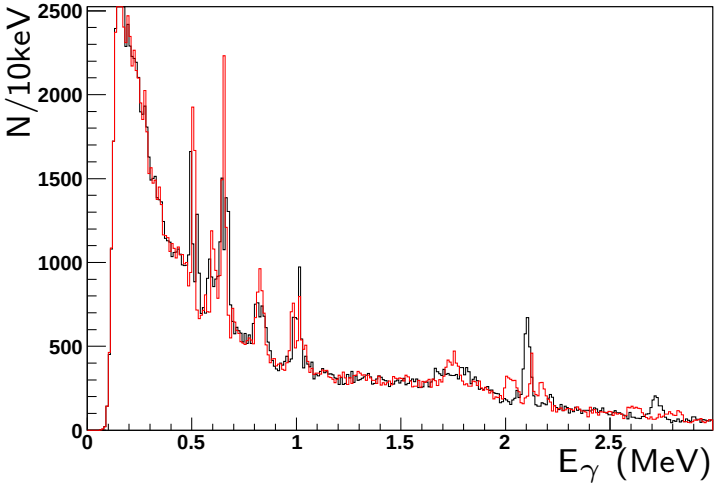


^{12}Be

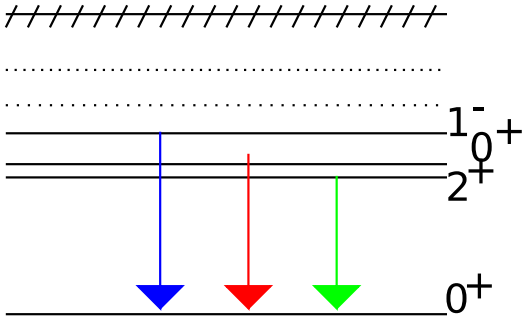


Time between detected particle and detected gamma vs. E_γ.

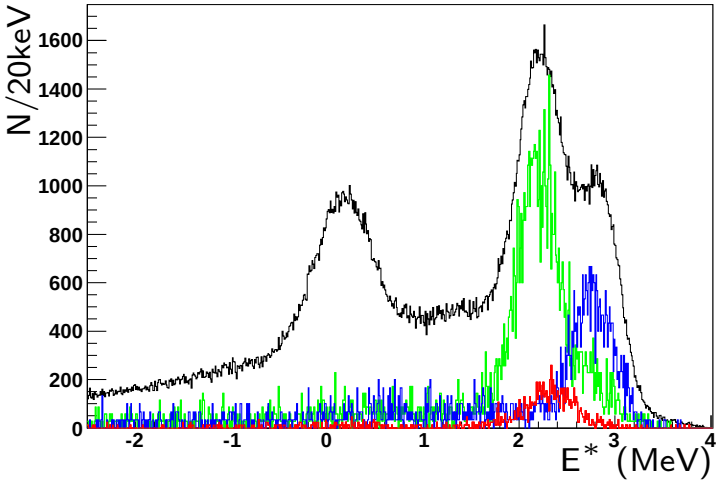
Identified particles ^{12}Be



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

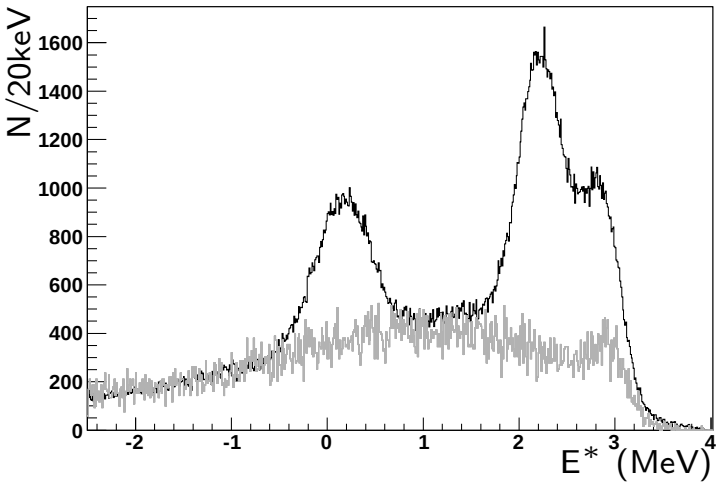


^{12}Be

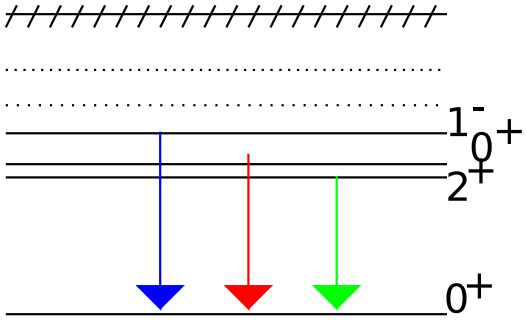


Total and γ-gated excitation sepctra of ^{12}Be.

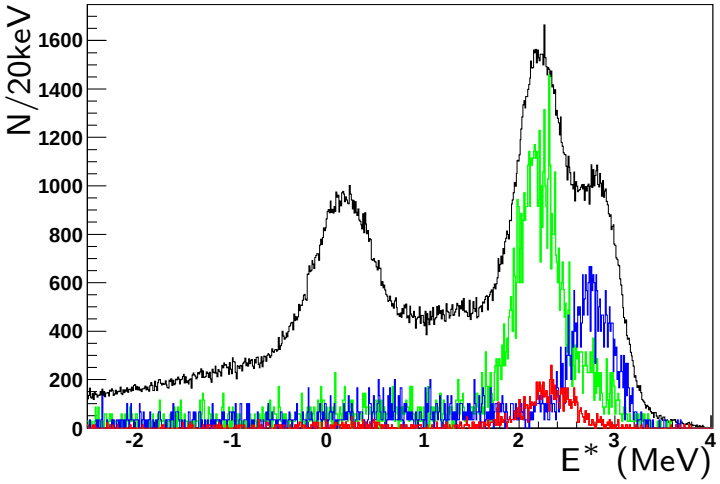
Identified particles ^{12}Be



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

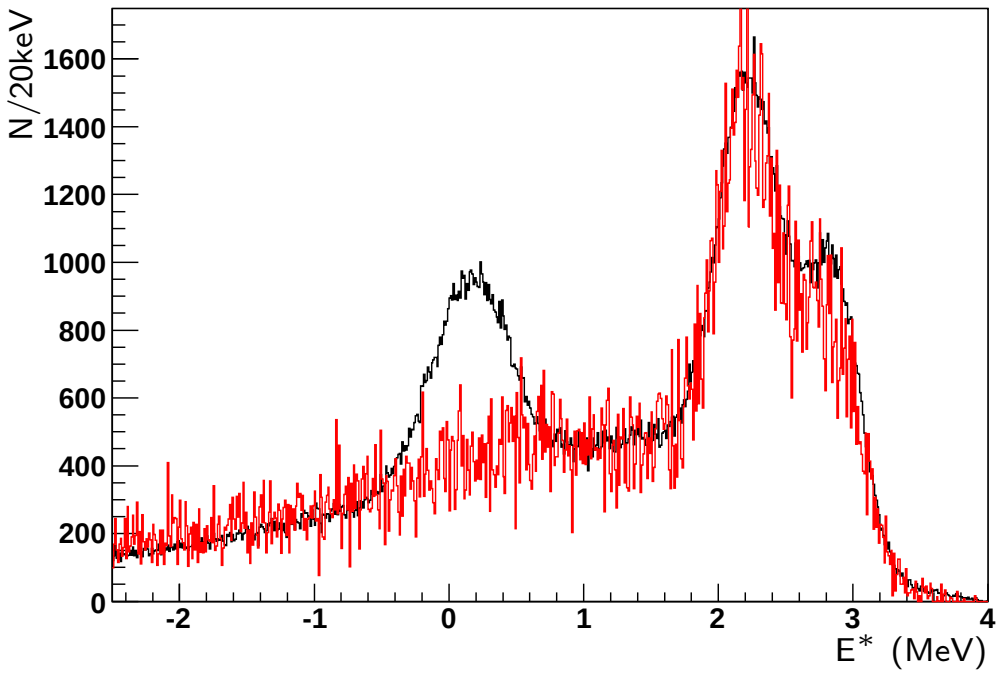


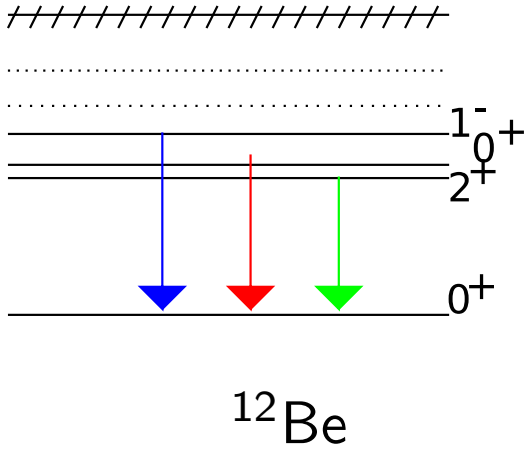
^{12}Be



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

Identified particles ^{12}Be





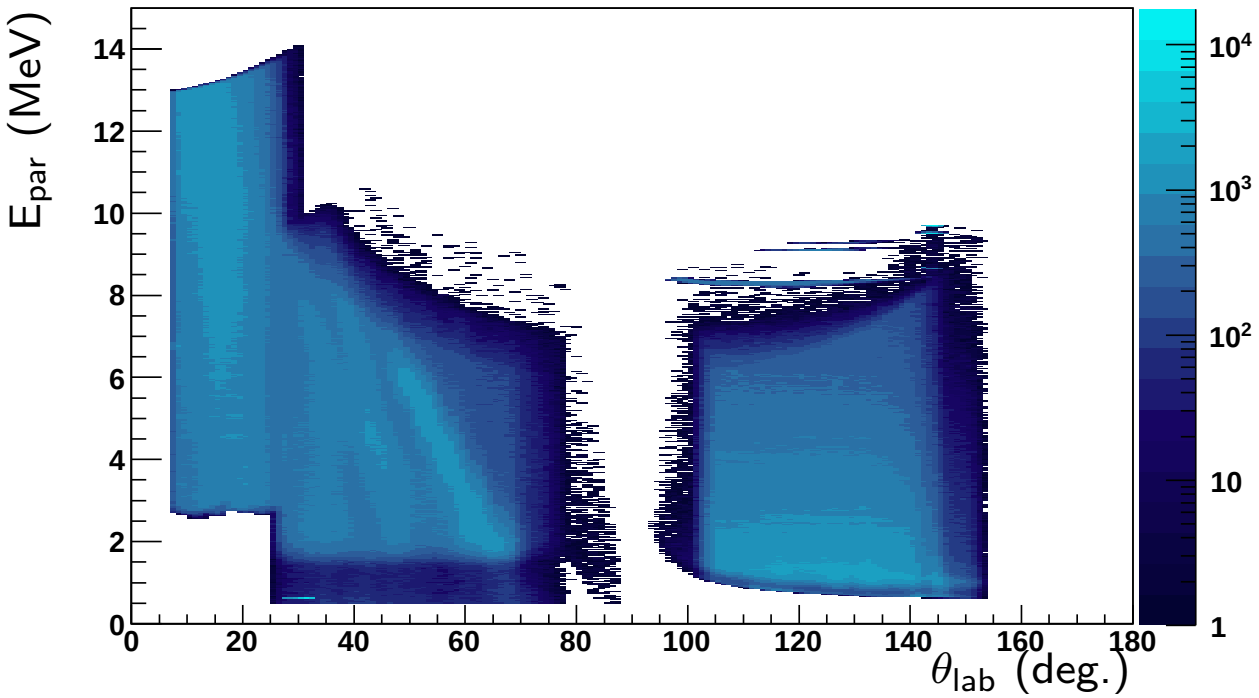
Black: Total excitation spectrum.

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

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

Low energy particles

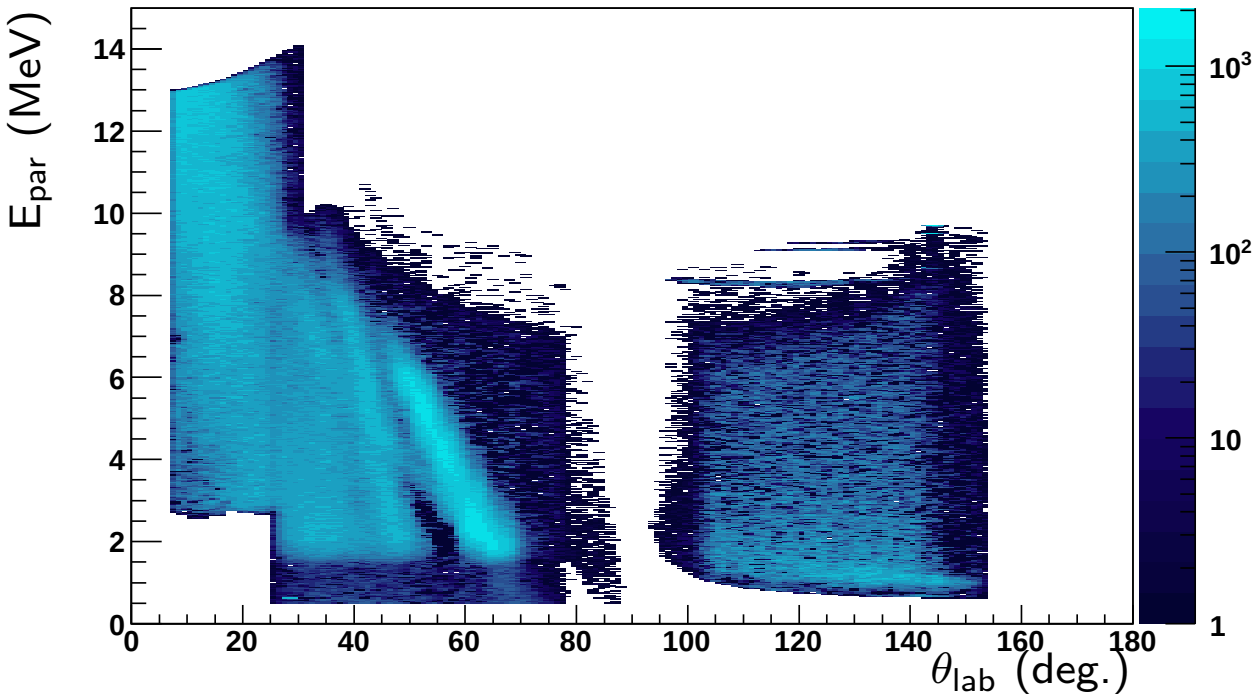
Particles stopped in the ΔE detector.



Low energy particles

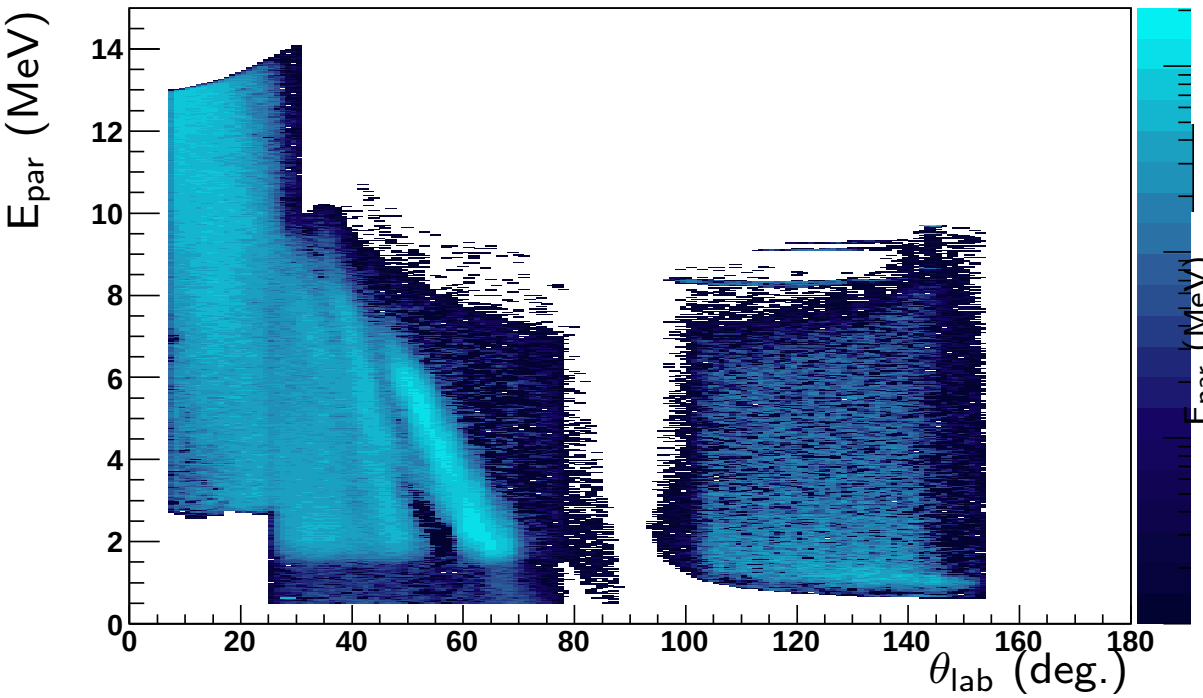
Particles stopped in the ΔE detector.
Subtracted background from reactions on C and H.

- (d,p) to $^{12}Be_{gs}$ is clearly seen in backward angles.
- Excited states still mixed.

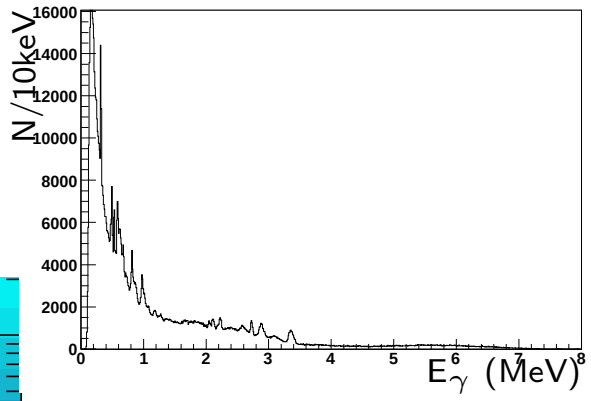


Low energy particles

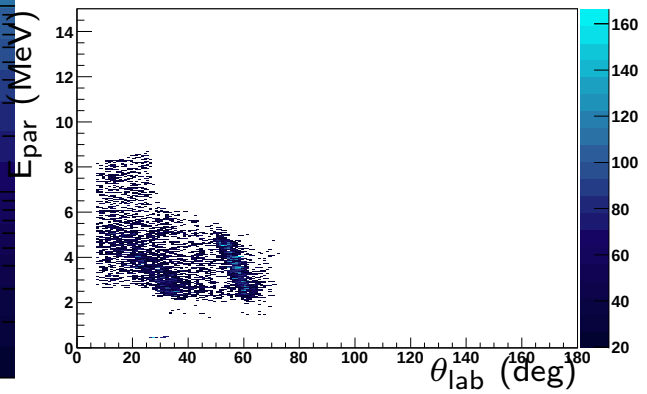
Particles stopped in the ΔE detector.
Subtracted background from reactions on C and H.



Doppler corrected gamma spectrum.

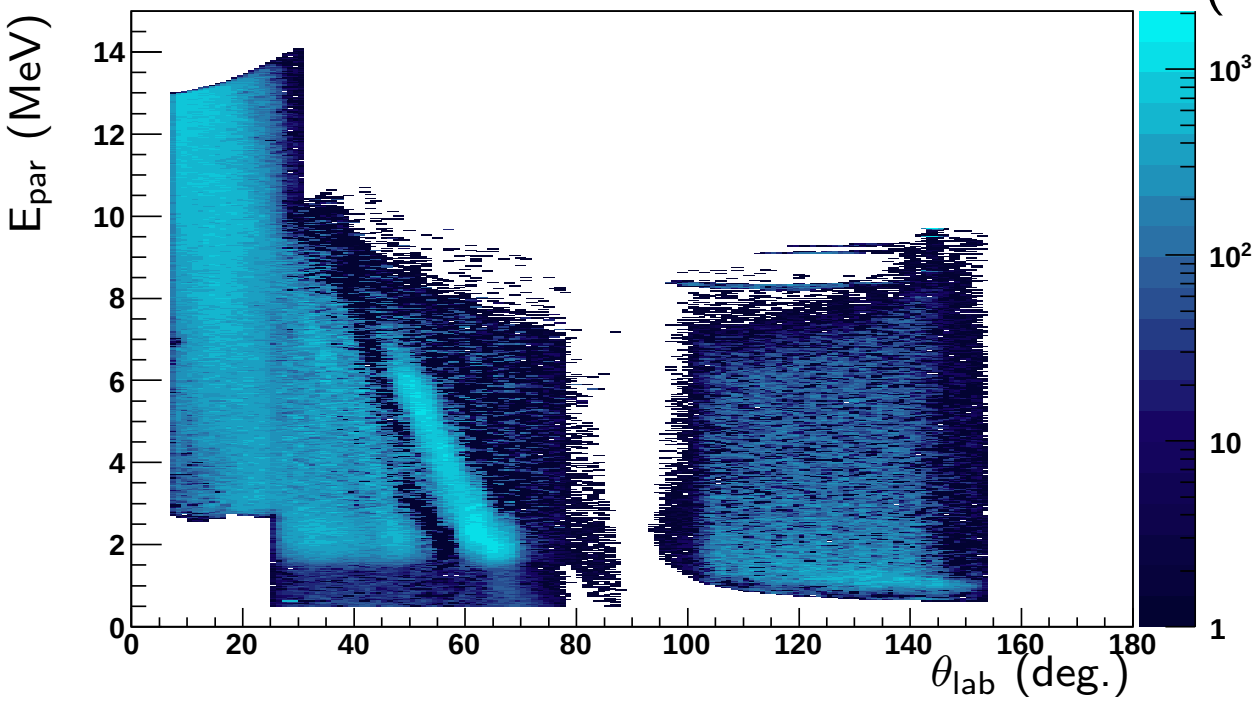


Gated on 320keV gamma.



Low energy particles

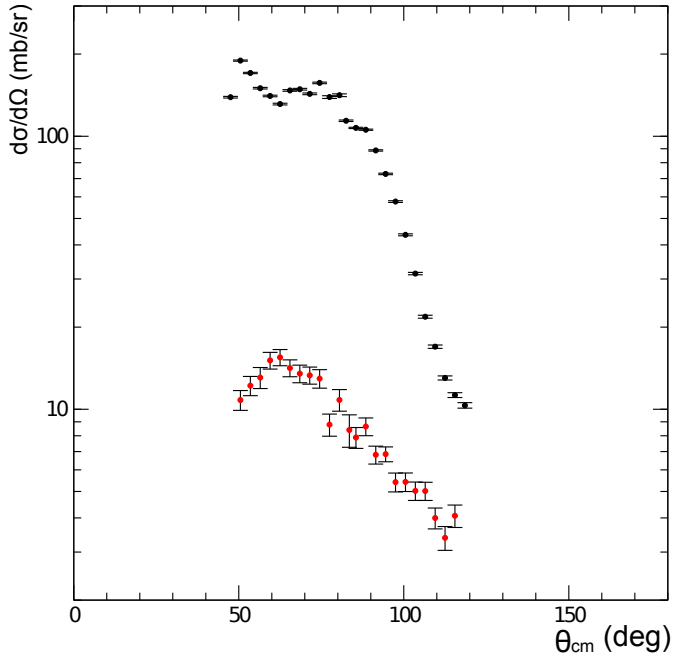
Particles stopped in the ΔE detector.
Subtracted background from reactions on C and H.
Subtracted excited states via gamma gates.



- The elastic channel is now very clean.
- Still a lot of heavy fragments in forward angles (^{10}Be, ^{7}Li etc.)

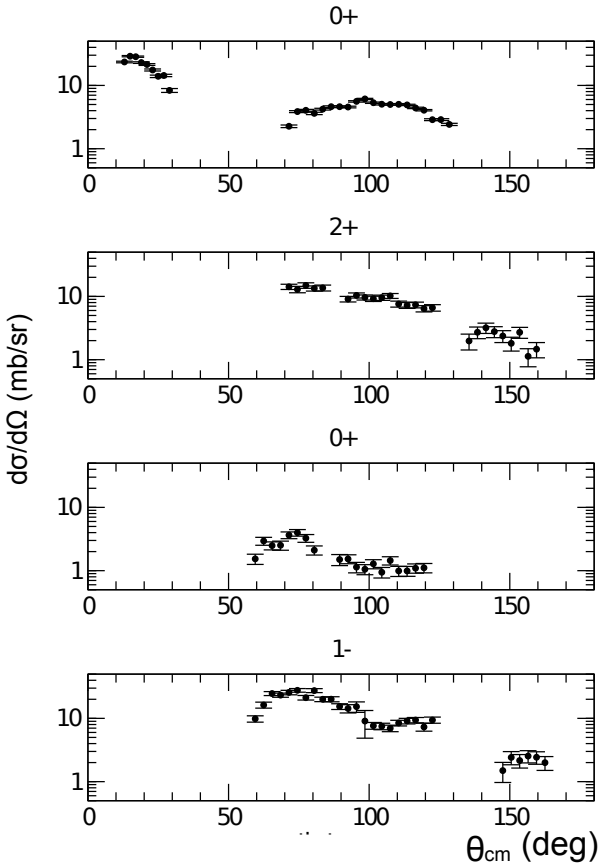
Differential cross sections

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



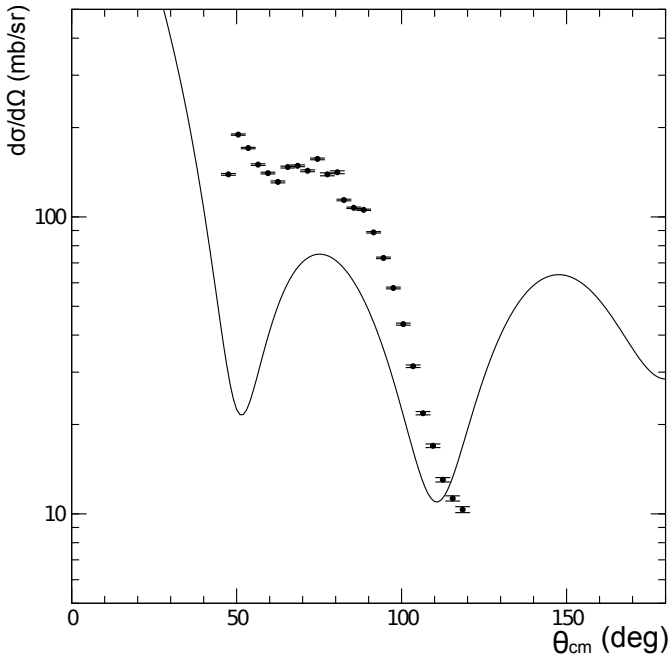
Black dots: Elastic scattering.
Red dots: Inelastic scattering.

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



Differential cross sections

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

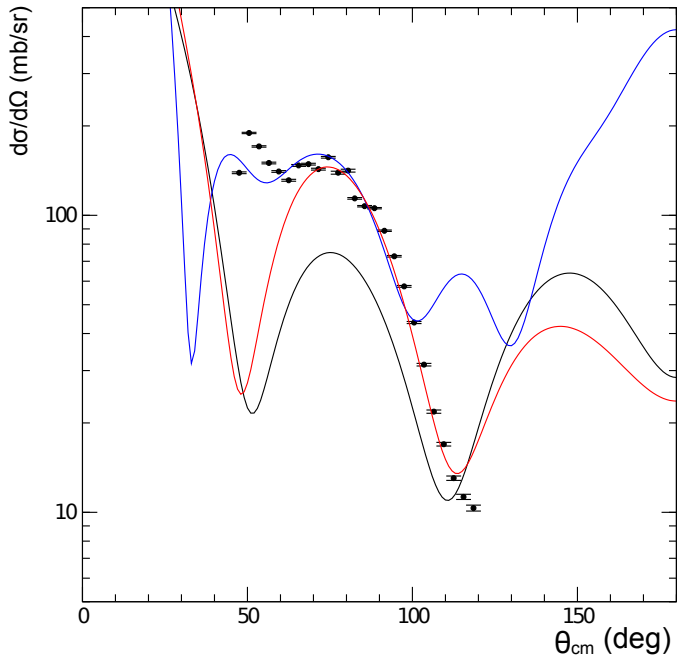


Black dots: Elastic scattering.
Black line: Satchler et al. Nucl. Phys 85 273

	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

Differential cross sections

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

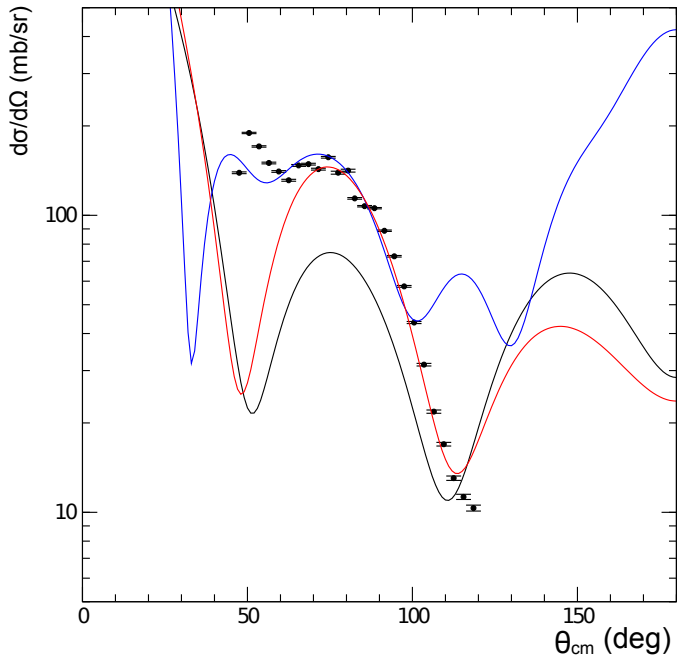


	Satchler	Fit 1	Fit 2
V	124.7	151.2	70.44
r	0.9	1.	2.28
a	0.9	1.65	0.25
W	4.38	4.8	2.9
r_i	2.275	2.5	2.1
a_i	0.264	0.454	0.45

Black dots: Elastic scattering.
Black line: Satchler et al. Nucl. Phys 85 273
Blue line: Fit 1.
Red line: Fit 2.

Differential cross sections

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



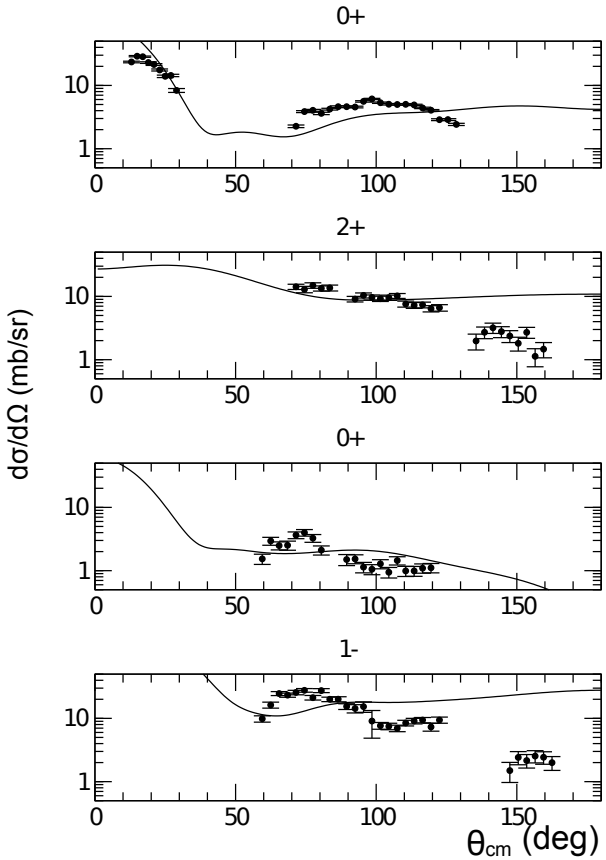
Black dots: Elastic scattering.
Black line: Satchler et al. Nucl. Phys 85 273
Blue line: Fit 1.
Red line: Fit 2.

	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

Next step: CDCC calculations.
Compound reactions?

Differential cross sections 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.

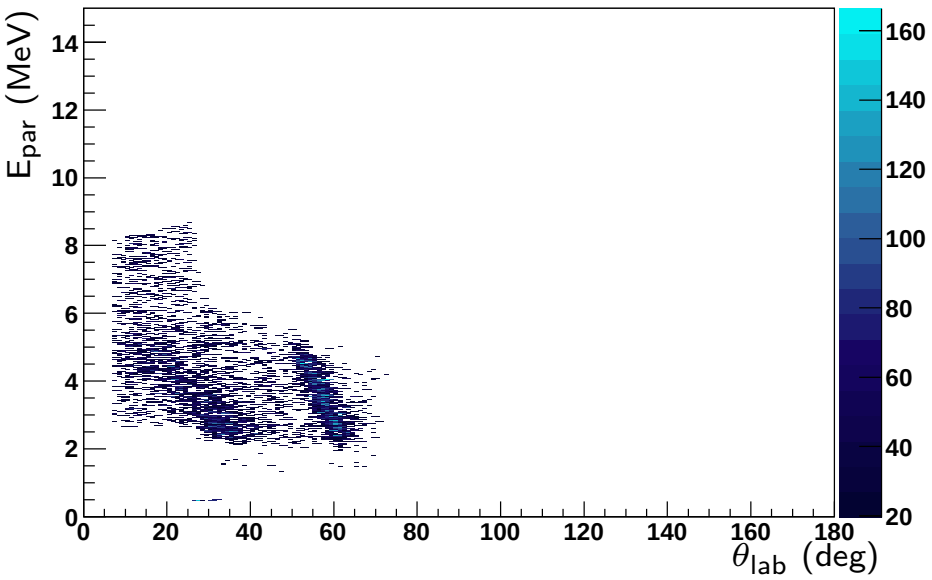
PRELIMINARY: Spectroscopic factors:

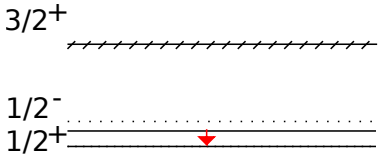
	^{11}Be$_{gs}$ $\otimes$	Exp	Shell model.
0_1^+	$1s_{1/2}$	0.4	0.78
2_1^+	$0d_{5/2}$	0.35	0.52
0_2^+	$1s_{1/2}$	0.55	0.37
1_1^-	$0p_{1/2}$	1.	

Shell model: Fortune et al. Phys Rev 83 044313

Low lying resonance in ^{12}Be

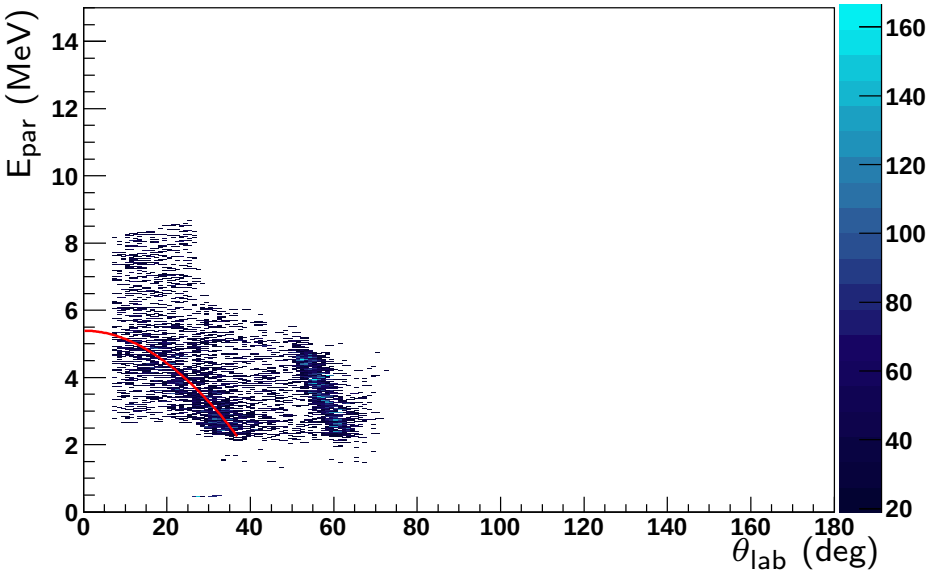
Particles gated on 320keV gamma.

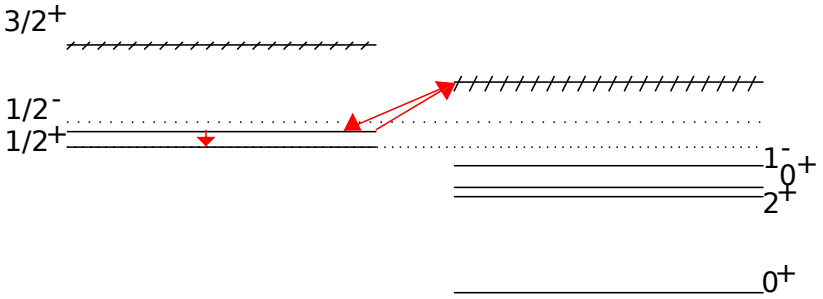




Low lying resonance in ^{12}Be

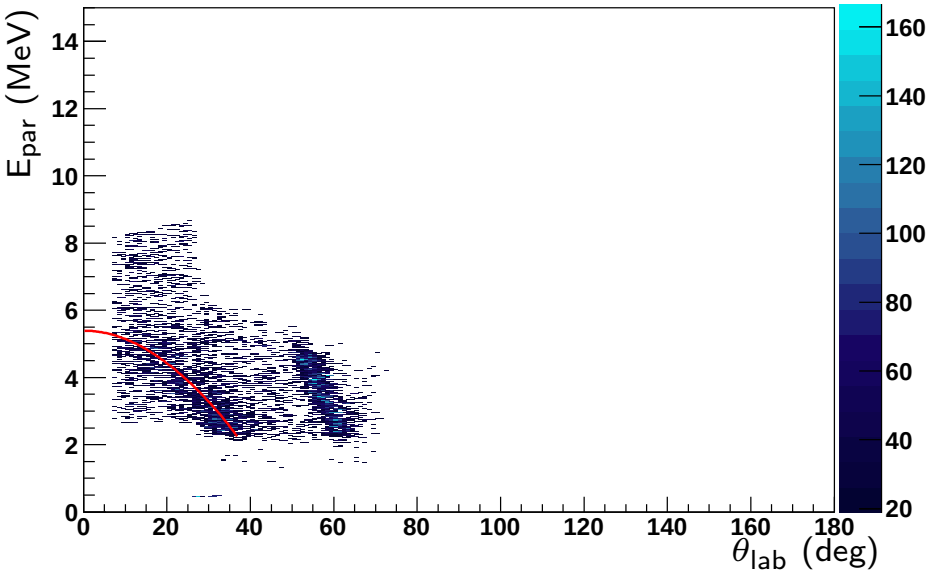
Particles gated on 320keV gamma.
^{11}Be(d,p)^{12}Be(E* = 4.5MeV)

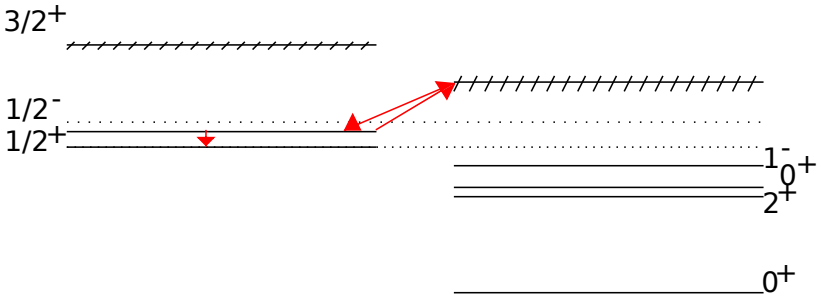




Low lying resonance in ^{12}Be

Particles gated on 320keV gamma.
^{11}Be(d,p)^{12}Be(E* = 4.5MeV)

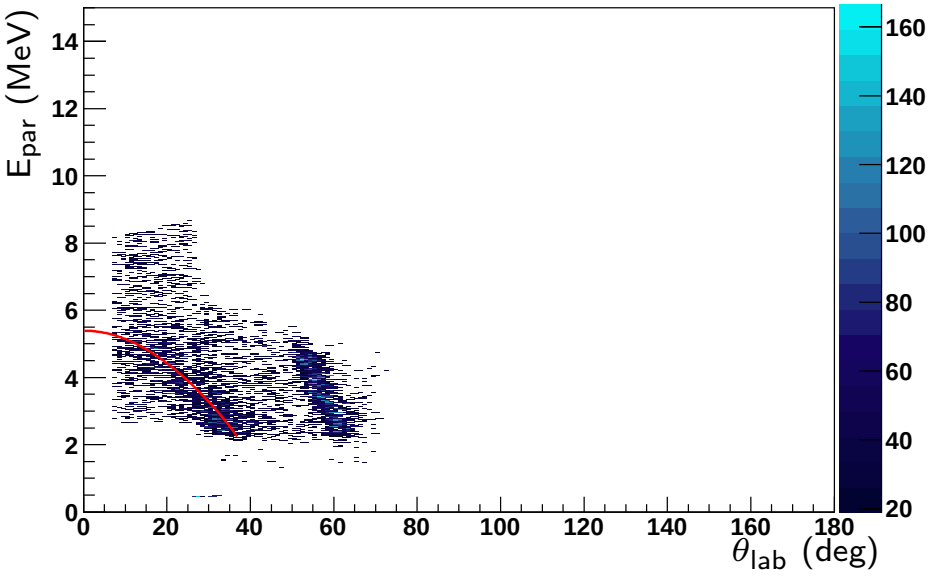


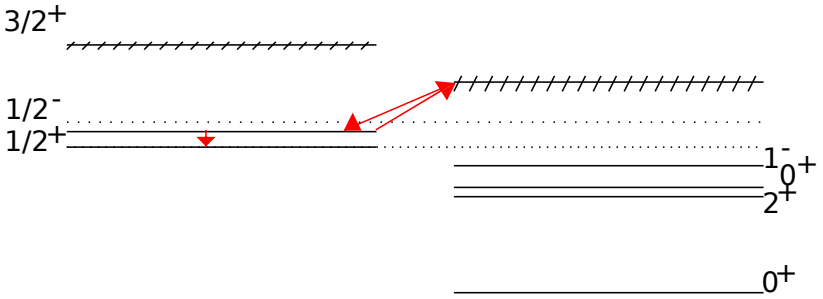


$$|^{11}\mathrm{Be}; 1/2^+\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle$$
$$\Downarrow +n$$
$$|^{12}\mathrm{Be}; ?\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle\, |n; ?\rangle$$
$$\Downarrow -n$$
$$|^{11}\mathrm{Be}; 1/2^-\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 0p_{1/2}\rangle$$

Low lying resonance in ^{12}Be

Particles gated on 320keV gamma.
^{11}Be(d,p)^{12}Be(E* = 4.5MeV)

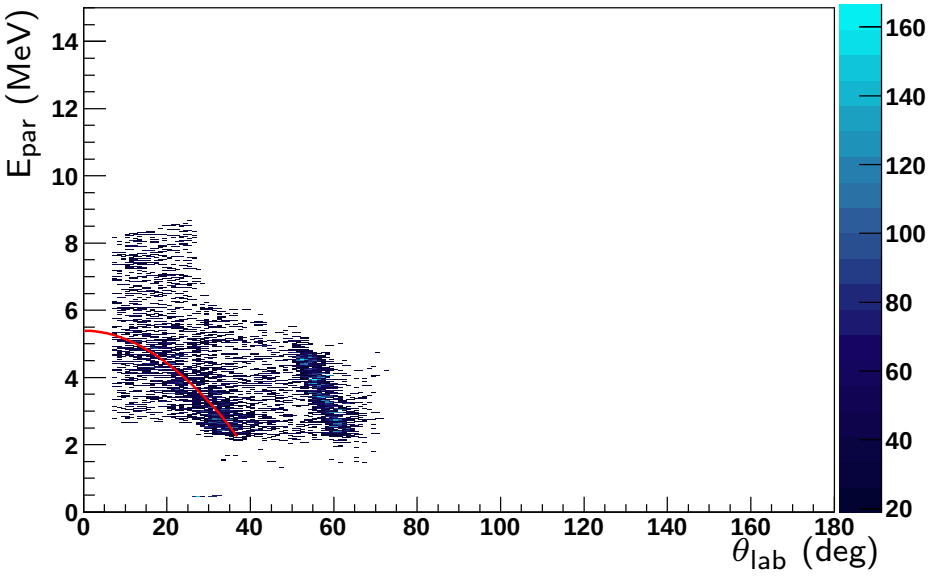


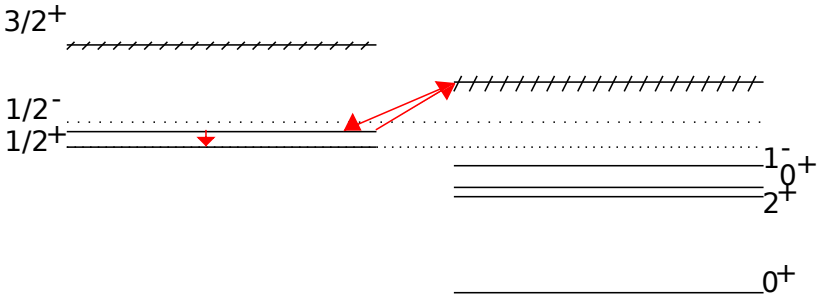


$$|^{11}\mathrm{Be}; 1/2^+\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle$$
$$\Downarrow +n$$
$$|^{12}\mathrm{Be}; (0,1)^-\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle\, |n; 0p_{1/2}\rangle$$
$$\Downarrow -n$$
$$|^{11}\mathrm{Be}; 1/2^-\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 0p_{1/2}\rangle$$

Low lying resonance in ^{12}Be

Particles gated on 320keV gamma.
^{11}Be(d,p)^{12}Be(E* = 4.5MeV)





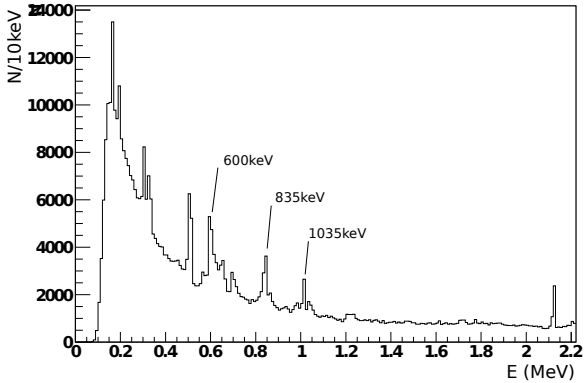
$$|^{11}\mathrm{Be}; 1/2^+\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle$$
$$\Downarrow +n$$
$$|^{12}\mathrm{Be}; 1^-\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 1s_{1/2}\rangle\, |n; 0p_{1/2}\rangle$$
$$\Downarrow -n$$
$$|^{11}\mathrm{Be}; 1/2^-\rangle = |^{10}\mathrm{Be}; 0^+\rangle\, |n; 0p_{1/2}\rangle$$

Preliminary three body calculations (E. Garrido) and ^{10}Be(t,p) reactions (H. Fortune et al, phys. rev. C50 (1994) 1355-1359) indicates a 1^- rather than a 0^-.

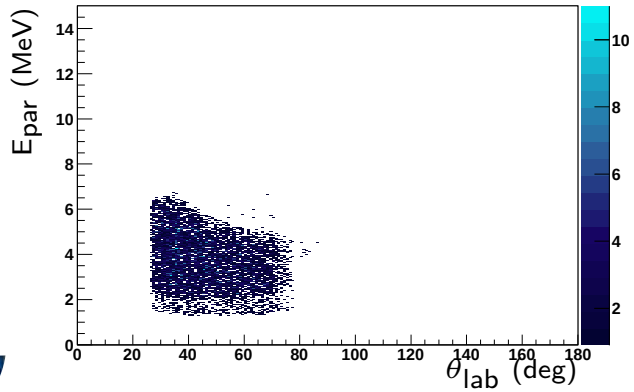
Neutron detection PRELIMINARY!

Neutron detected through Ge(n,n')Ge reactions in the Germanium detectors. (Chasman C. et al. NIM 37 (1965) 1)

Gammas from Ge(n,n')Ge



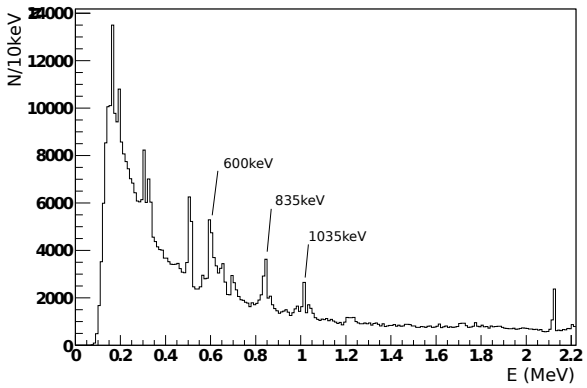
Single neutron events.



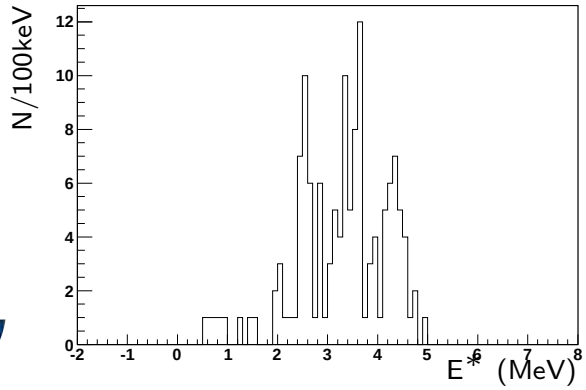
Neutron detection PRELIMINARY!

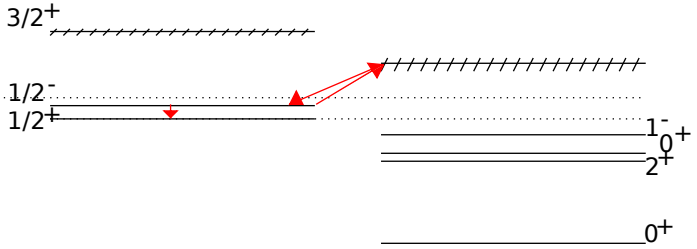
Neutron detected through Ge(n,n')Ge reactions in the Germanium detectors. (Chasman C. et al. NIM 37 (1965) 1)

Gammas from Ge(n,n')Ge



Single neutron + 320keV gamma.

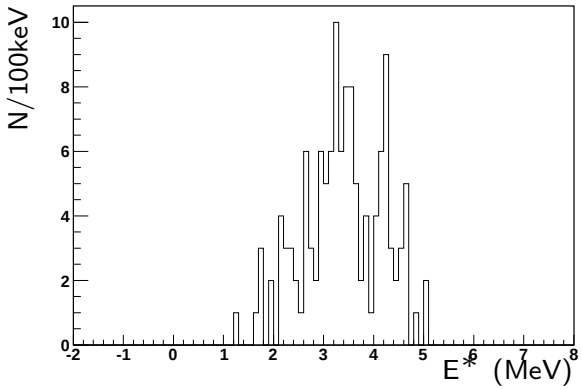


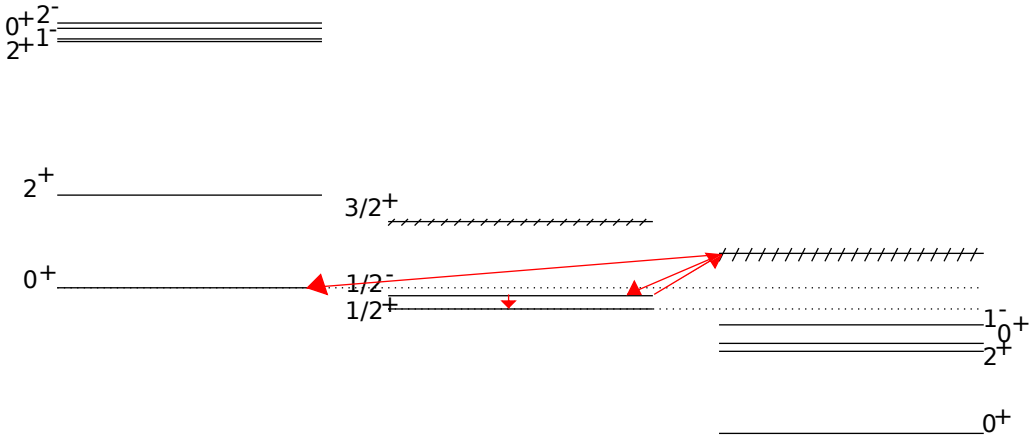


Neutron detection PRELIMINARY!

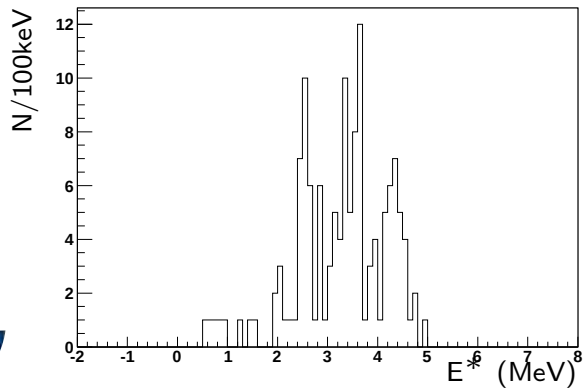
Neutron detected through Ge(n,n')Ge reactions in the Germanium detectors. (Chasman C. et al. NIM 37 (1965) 1)

Two neutron events





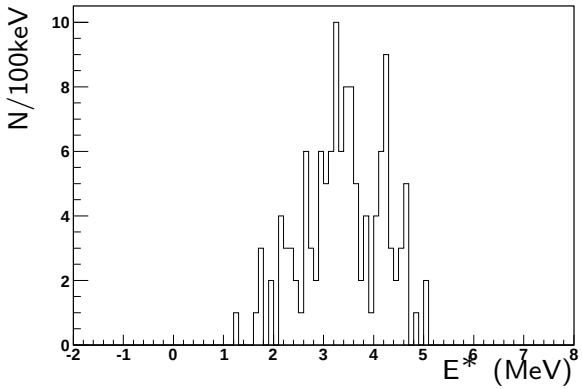
Single neutron + 320keV gamma.



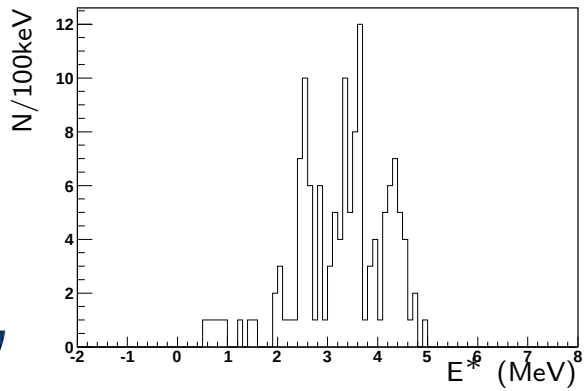
Neutron detection PRELIMINARY!

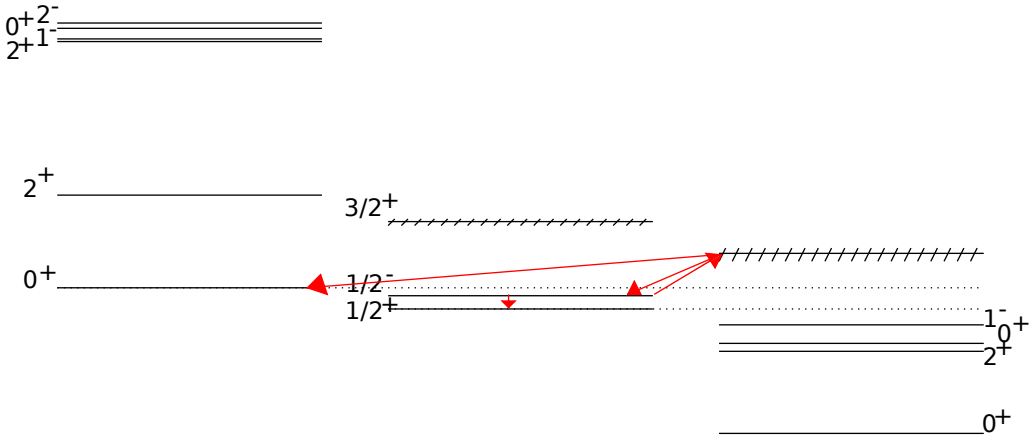
Neutron detected through Ge(n,n')Ge reactions in the Germanium detectors. (Chasman C. et al. NIM 37 (1965) 1)

Two neutron events



Single neutron + 320keV gamma.





$I_{nn} = 34$ counts. $I_{\gamma n} = 35$ counts.
$b_{nn} \approx b_{\gamma n}$.

Summary

- ^{10,11,12}Be have been studied through transfer reactions and scattering.
- Gamma detection using the MINIBALL enabled identification of all bound states.
- Differential cross sections have been determined experimentally, and some are compared to theoretically calculated.

NOTE: ^{11}Be(d,t), (p,p) and (p,d) cross sections have also been calculated.

- A new quantum number has been suggested for the lowest resonance in ^{12}Be.
- The MINIBALL has been used to detect neutrons.

Thanks to:

The MINIBALL and the IS430 collaborations.
A. S. Jensen, E. Garrido and A. Moro for theoretical assistance.