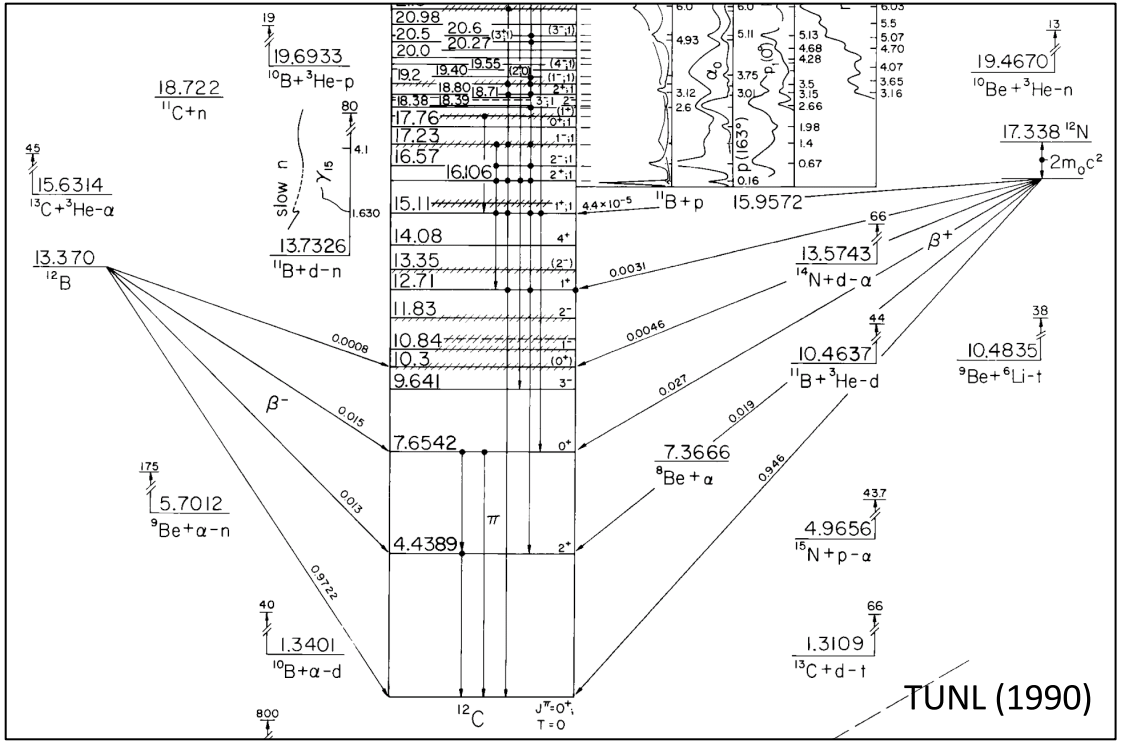
Using gamma decay to study low-lying resonances in ^{12}C

Oliver Kirsebom

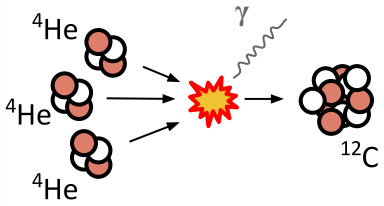
COMEX5, Krakow, 17/9/2015

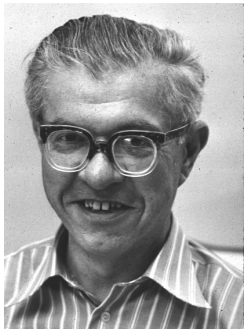
Motivation

Motivation

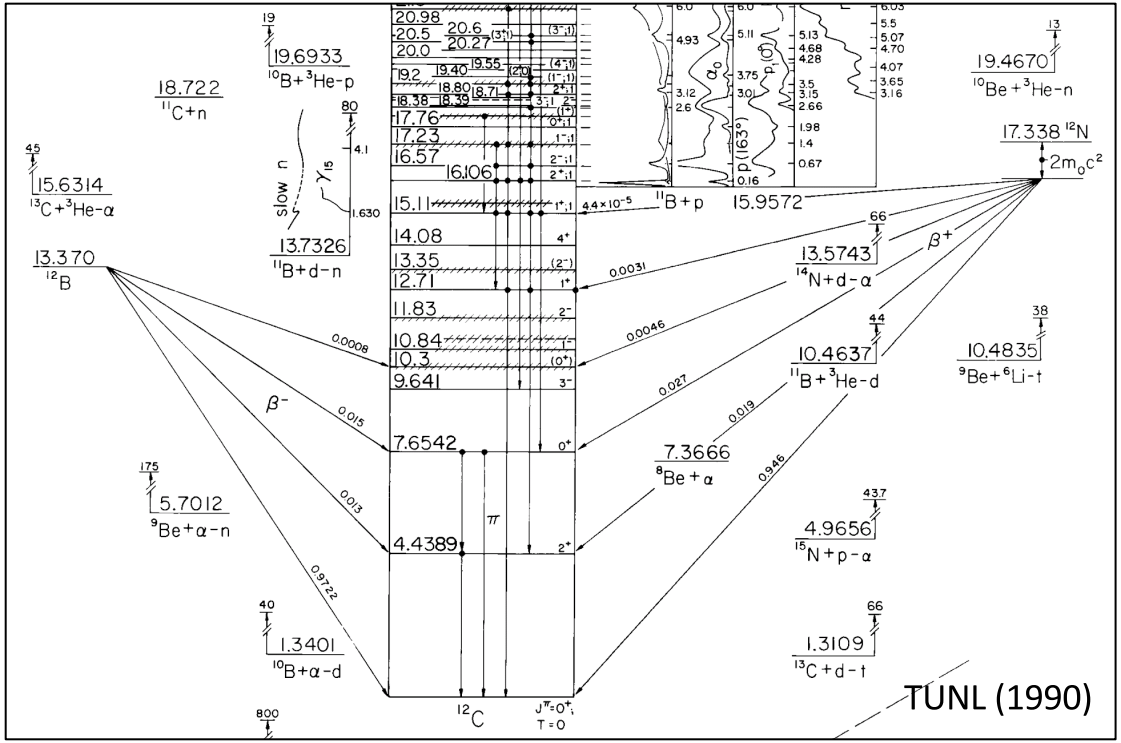

19.6933
^{10}B+^{3}He-p
18.722
^{11}C+n
15.6314
^{13}C+^{3}He-α
13.3700
^{12}B
13.7326
^{11}B+d-n
slow n
γ_{15}
1.630
4.1
80
20.98
20.5
20.6
20.27
20.0
19.55
19.2
19.40
18.80
18.71
18.38
18.39
17.76
17.23
16.57
16.106
15.11
14.08
13.35
12.71
11.83
10.84
10.3
9.641
7.6542
4.4389
^{12}C
$J^{\pi}=0^{+}$; T=0
^{11}B+p
15.9572
4.4×10^{-5}
19.4670
^{10}Be+^{3}He-n
17.338 ^{12}N
2m$_0$c^2
13.5743
^{14}N+d-α
10.4637
^{11}B+^{3}He-d
10.4835
^{9}Be+^{6}Li-t
7.3666
^{8}Be+α
4.9656
^{15}N+p-α
1.3109
^{13}C+d-t
5.7012
^{9}Be+α-n
1.3401
^{10}B+α-d
β$^-$
β$^+$
π
0.0008
0.015
0.013
0.9722
0.0031
0.0046
0.027
0.019
0.946
TUNL (1990)

Motivation

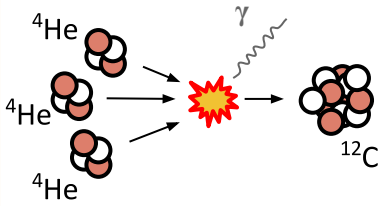


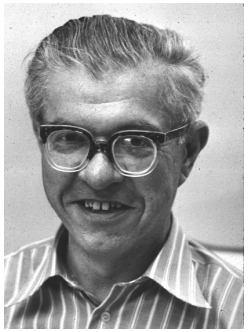


Fred Hoyle
(1953)



Motivation





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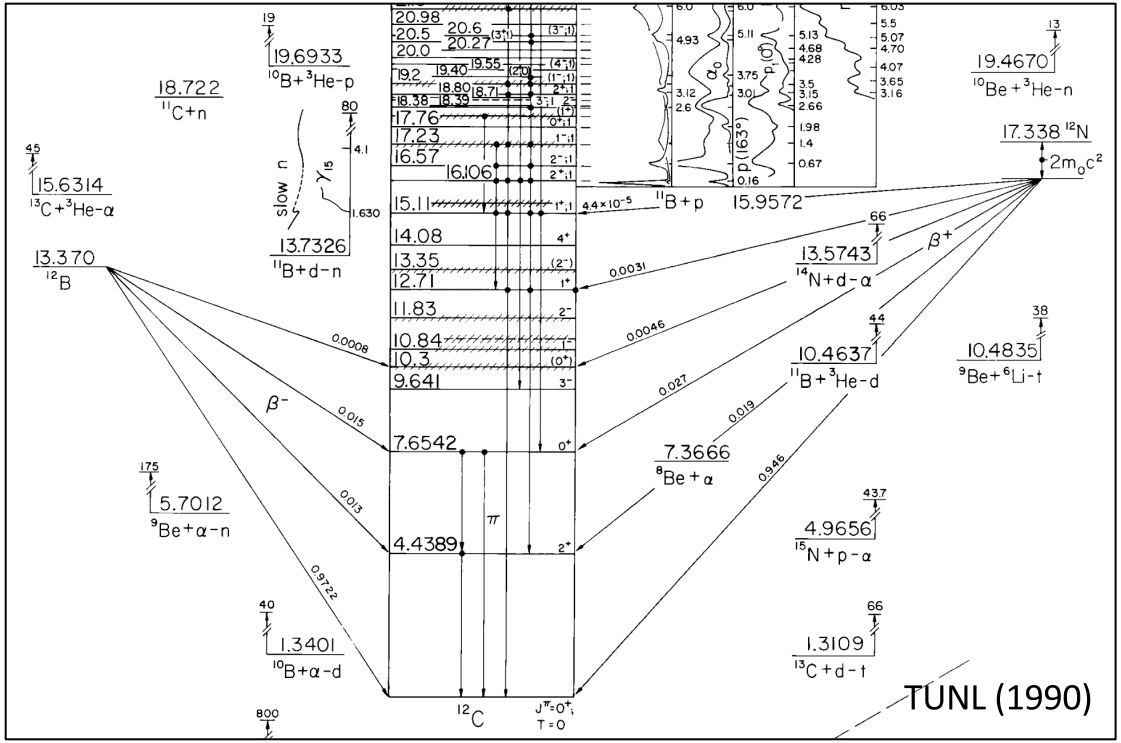
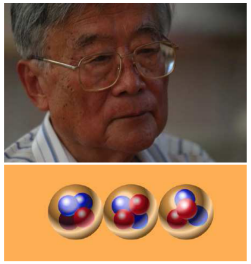
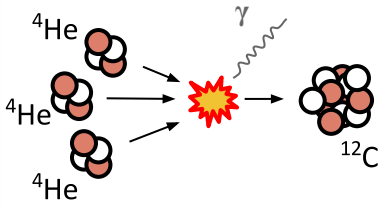
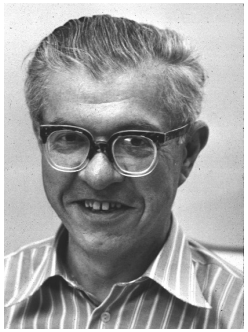




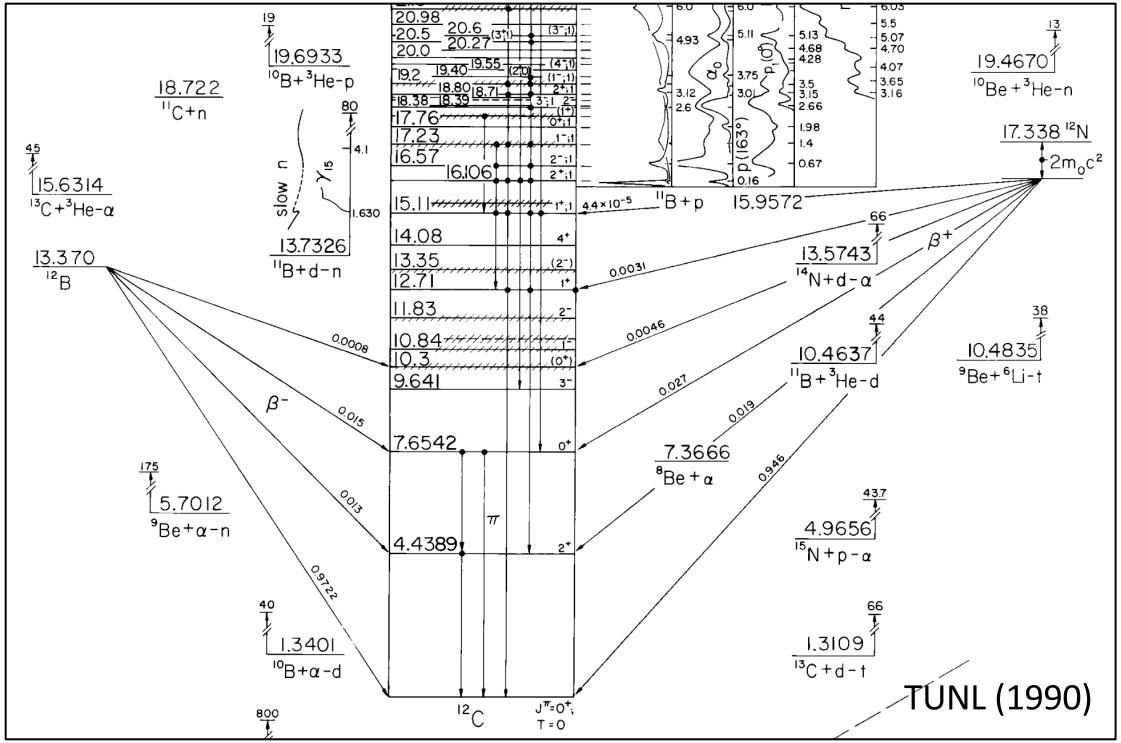
H. Morinaga
(1956)

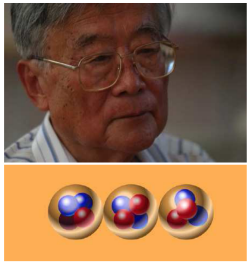
Motivation





Fred Hoyle
(1953)





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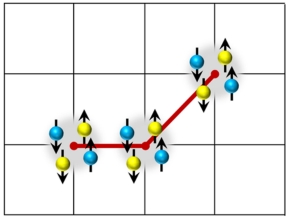
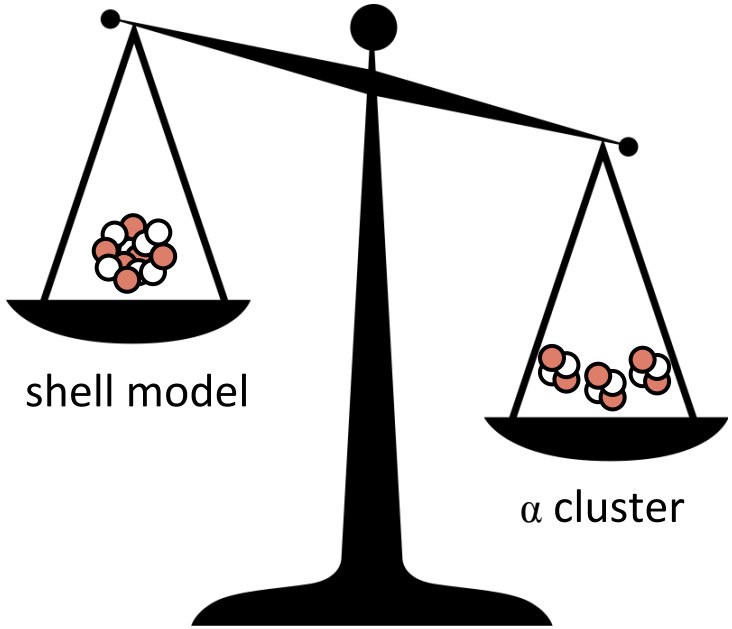
(1956)

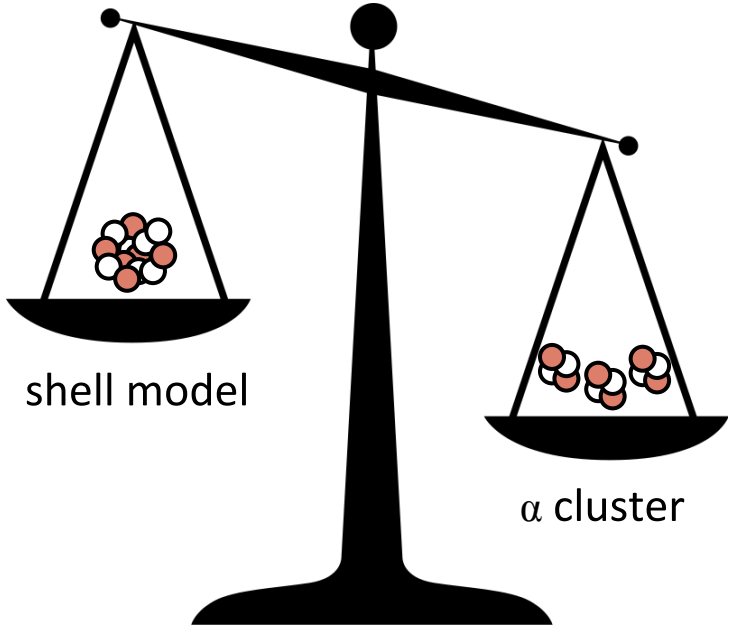


Epelbaum *et al.* PRL
109 (2012) 252501

Shell-model or α-cluster state ?



Shell-model or α-cluster state ?

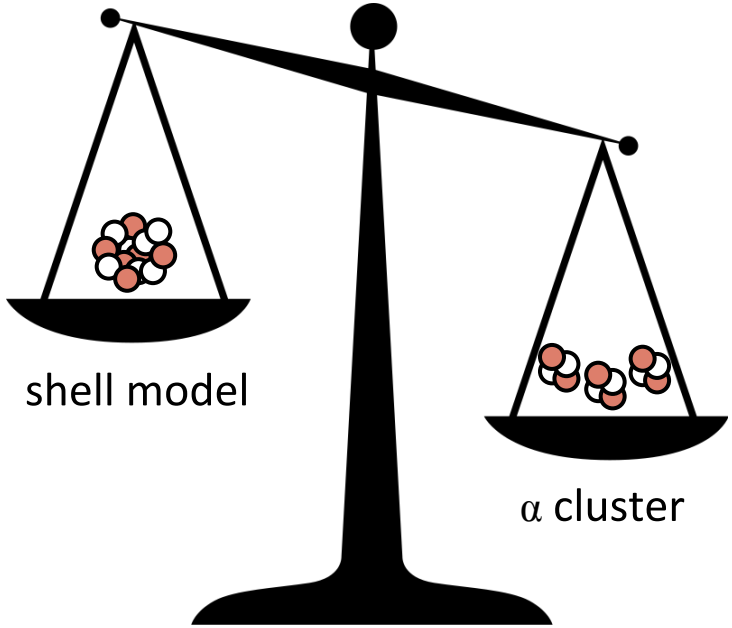


- Large reduced alpha width, $\theta_\alpha \approx 1.5$
- Large spatial extension, $r(0_2^+)/r(0_1^+) = 1.35–1.60$
- NCSM predicts too high excitation energy
- Well-described by microscopic α-cluster models (AMD, FMD)

Experimental evidence / Theoretical evidence

Shell-model or α-cluster state ?

- Appreciably excited in single-particle transfer reactions
- Sizeable M(E0), B(M1), B (E2), and B(GT) values
- FMD gives sizeable (30%) shell-model component



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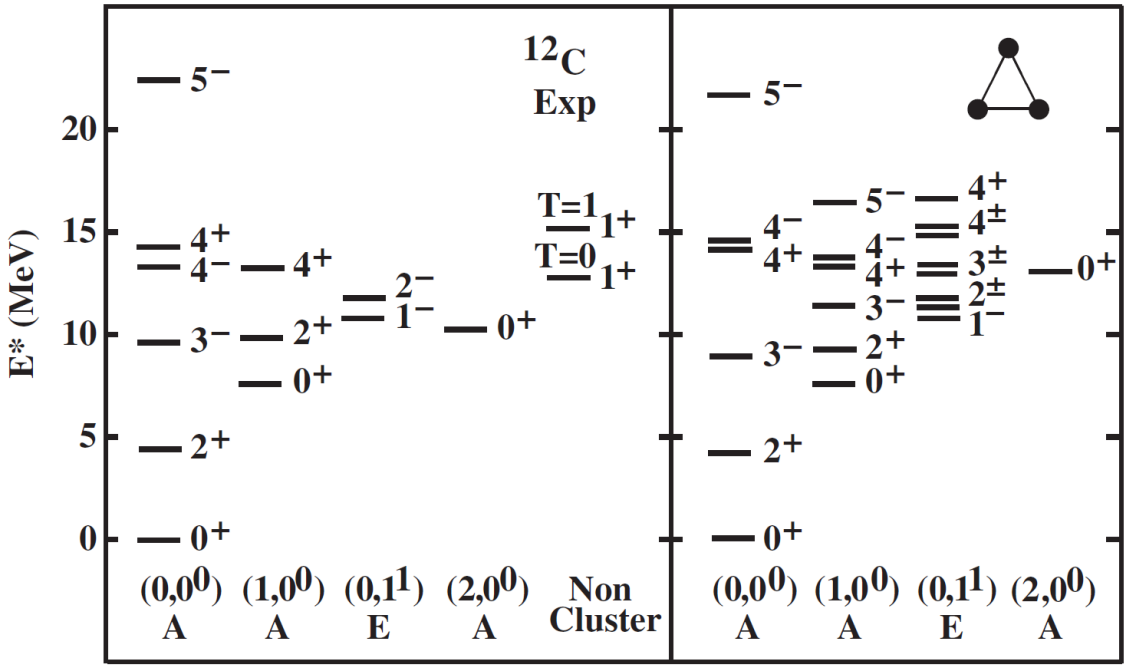
Experimental evidence / Theoretical evidence

Level structure

Marin-Lambarri *et al.* PRL **113** (2014) 012502



Experiment

Algebraic cluster model

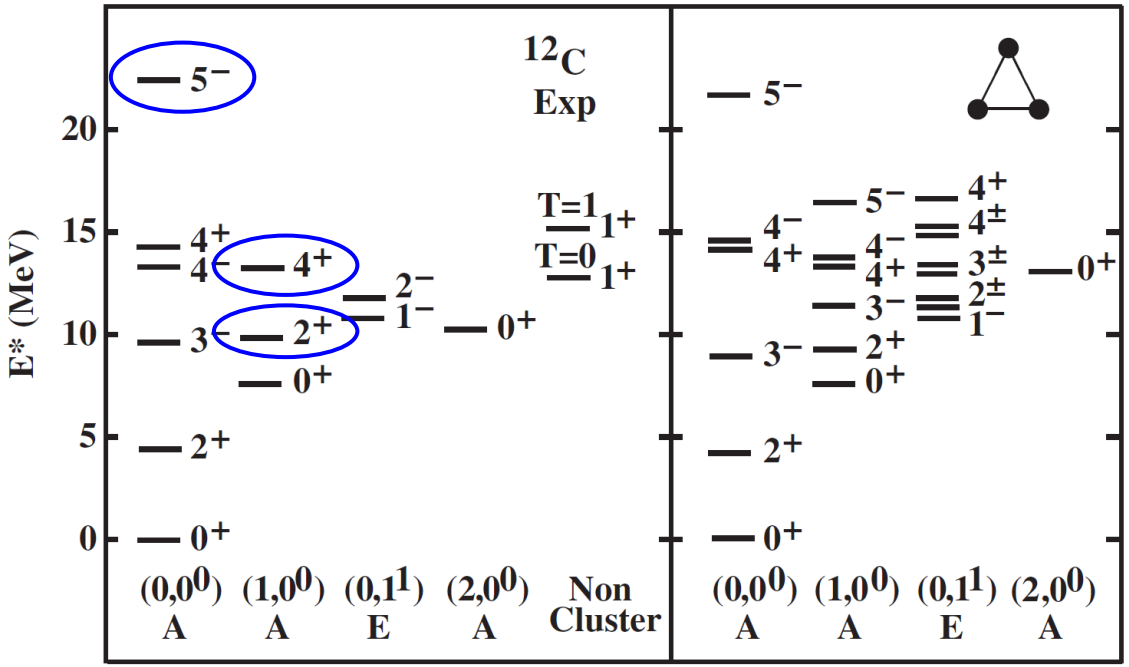
Level structure - experimental progress

Many new states found during past 10 years

Probes used:

(p,p')
(^{3}He,^{3}He')
(α,α')
(α,n)
(^{3}He,d)
(^{3}He,p)
(^{12}C,3α)
(γ,α)
(,βν)

Marin-Lambarri *et al.* PRL **113** (2014) 012502



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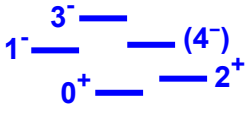
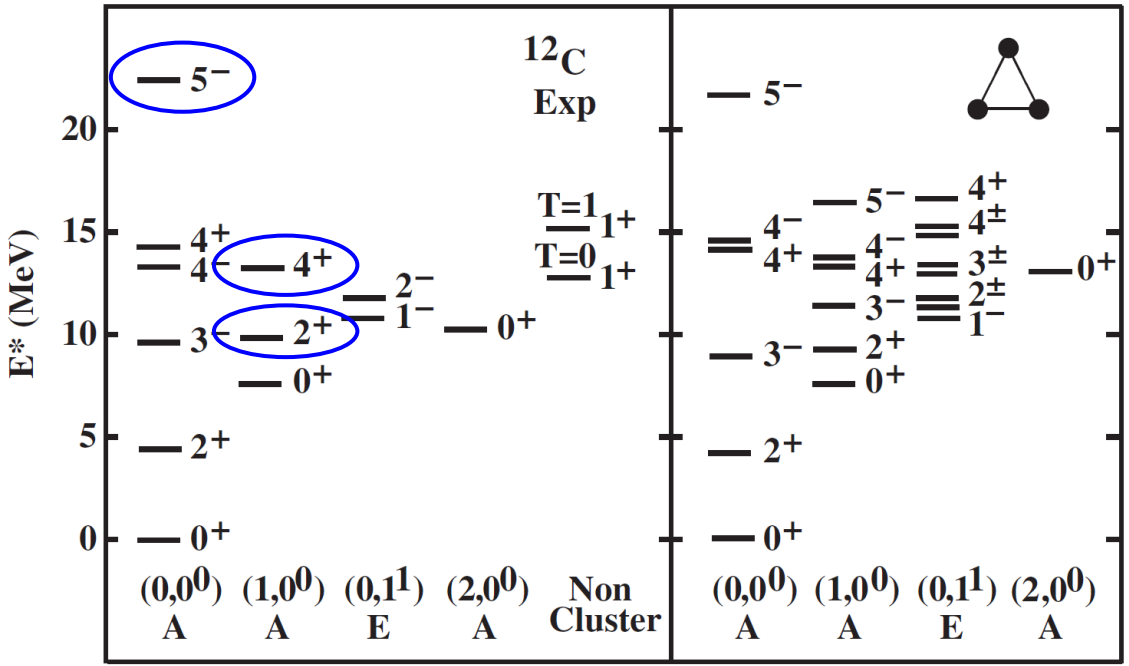


Marin-Lambarri *et al.* PRL **113** (2014) 012502

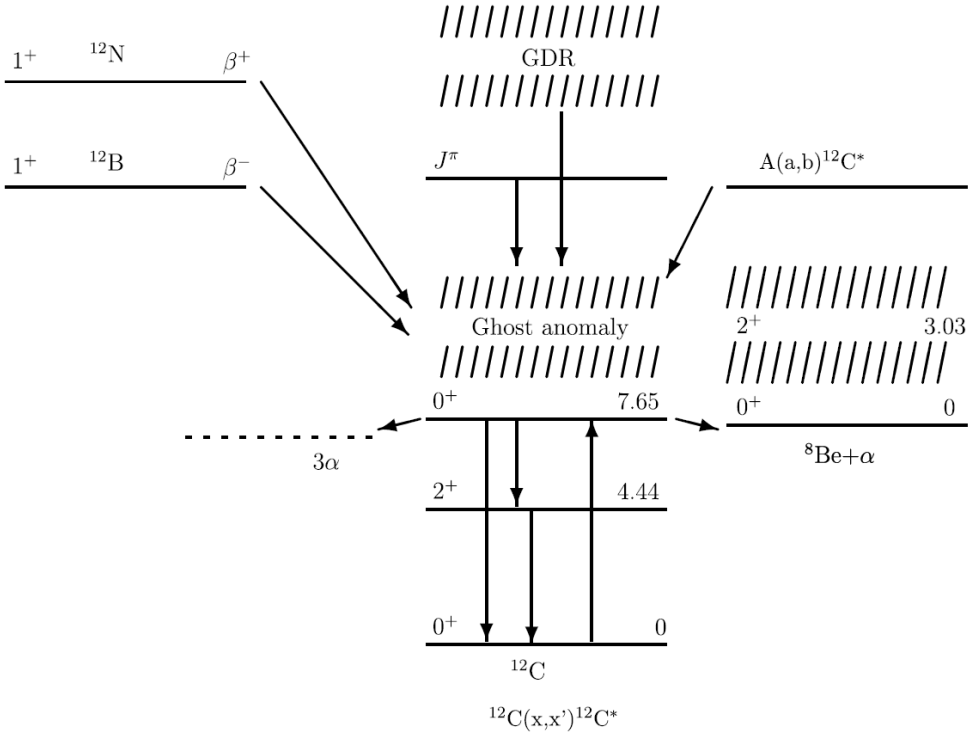


Experiment

Algebraic cluster model

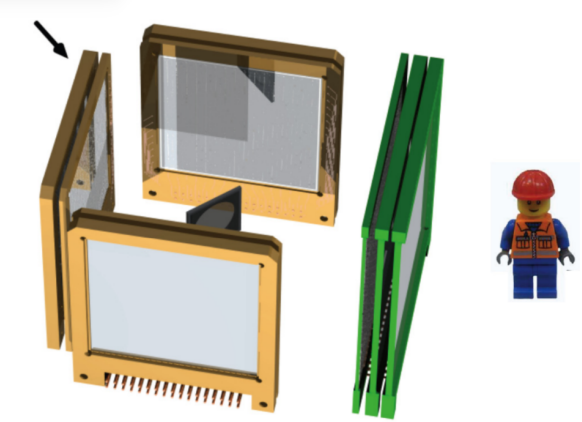
Experimental probes

M. Freer, H.O.U. Fynbo / Progress in Particle and Nuclear Physics 78 (2014) 1–23



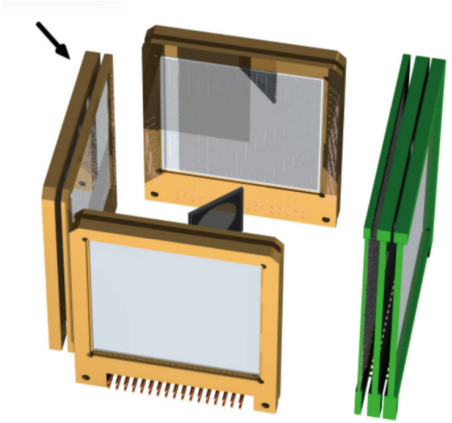
Gamma-decay experiments (indirect detection)

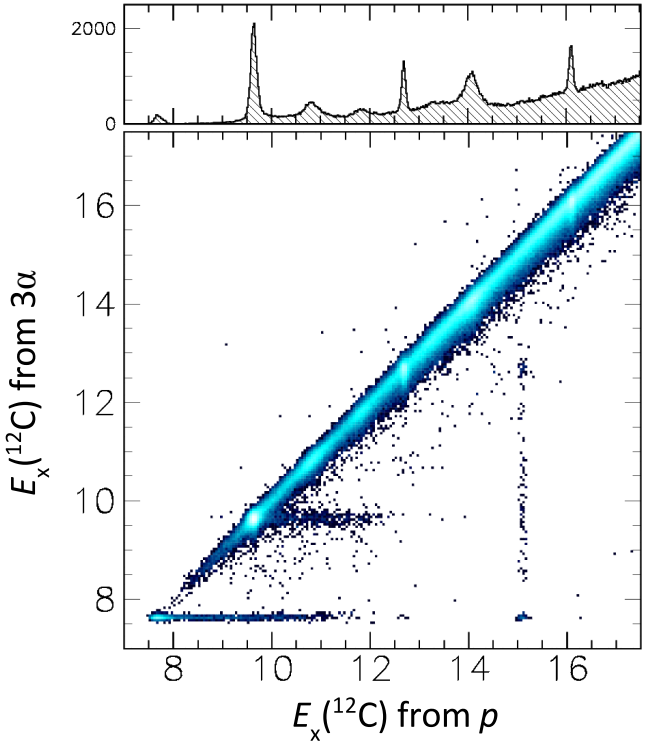
^{10}B(^{3}He,*p*) and ^{11}B(^{3}He,*d*)



Kirsebom *et al.* PLB **680** (2009) 44–49

^{10}B(^{3}He,*p*) and ^{11}B(^{3}He,*d*)





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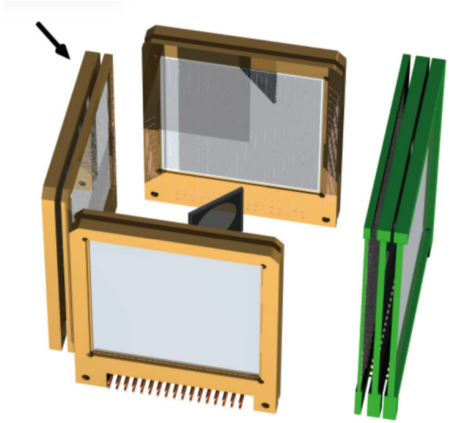

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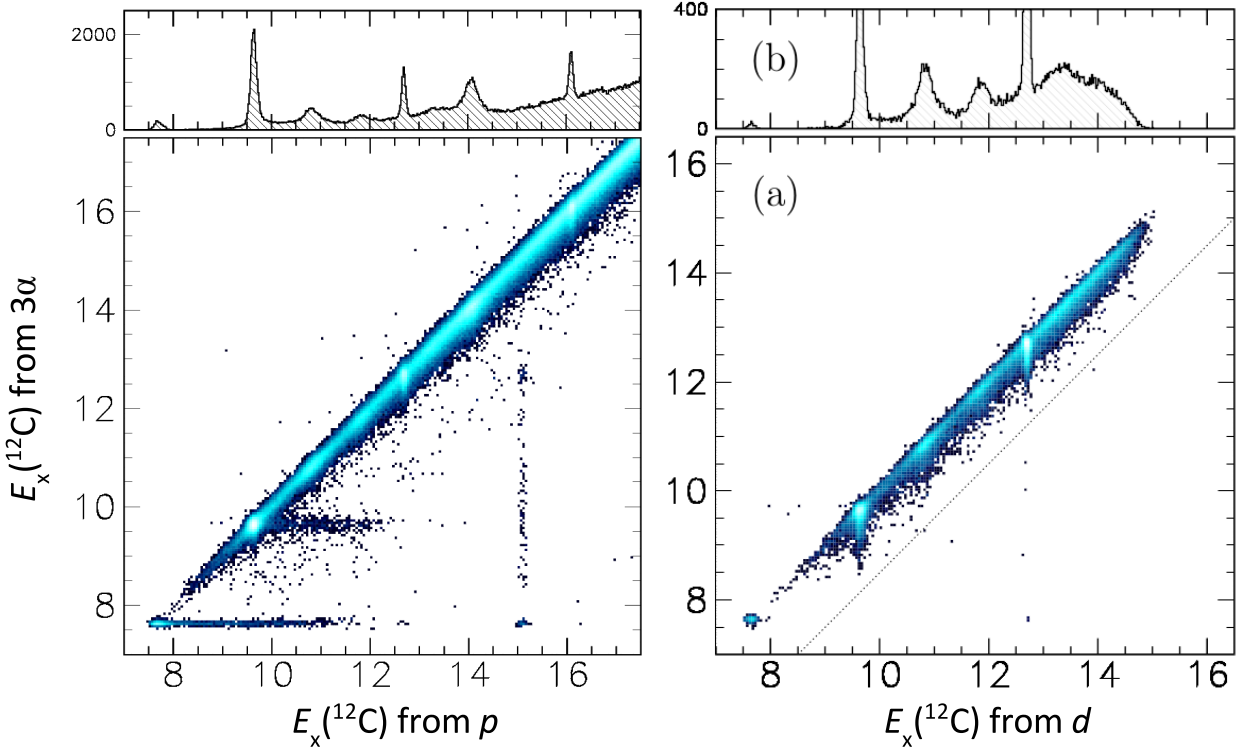

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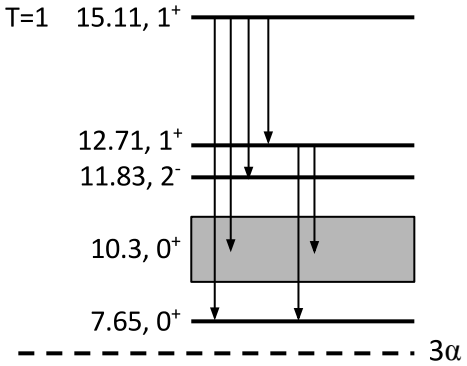
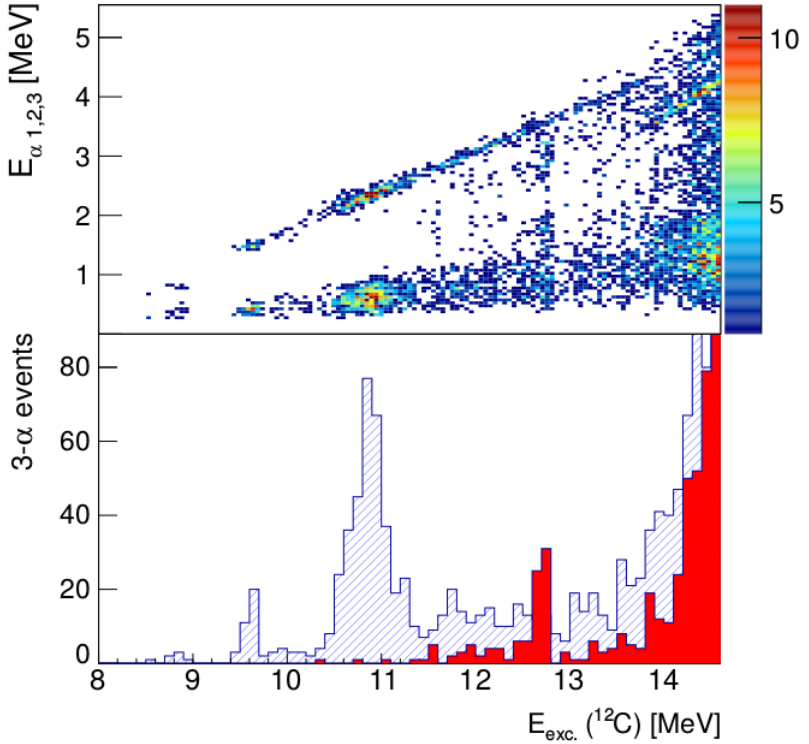
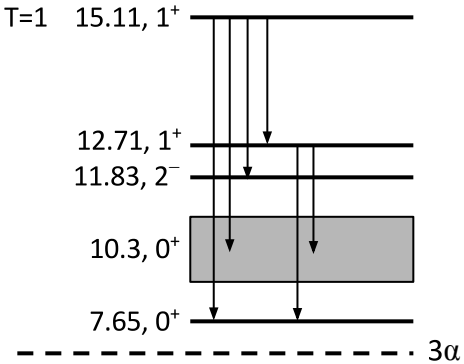
Kirsebom *et al.* PLB **680** (2009) 44–49



p+^{11}B @ 170 keV

Laursen *et al.* J. Phys. Conf. Ser. **569** (2014) 012073





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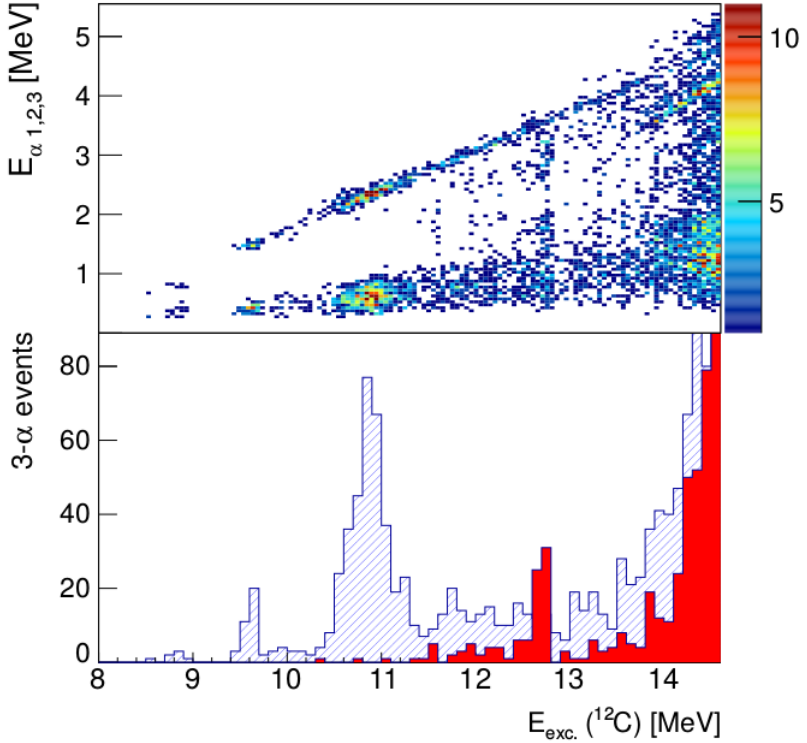
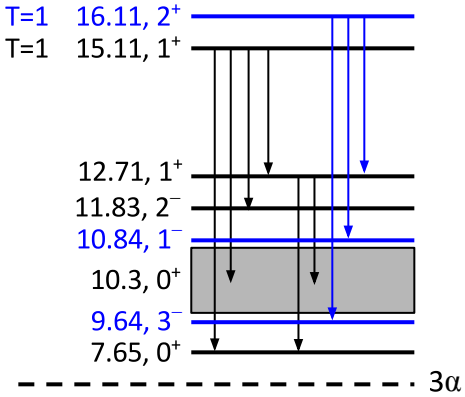
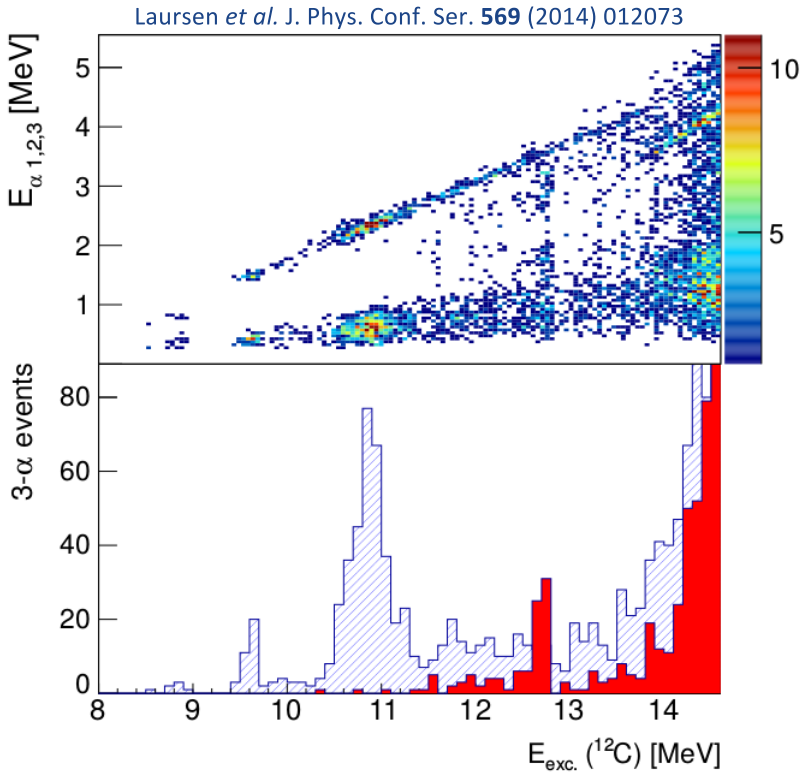
Laursen *et al.* J. Phys. Conf. Ser. **569** (2014) 012073

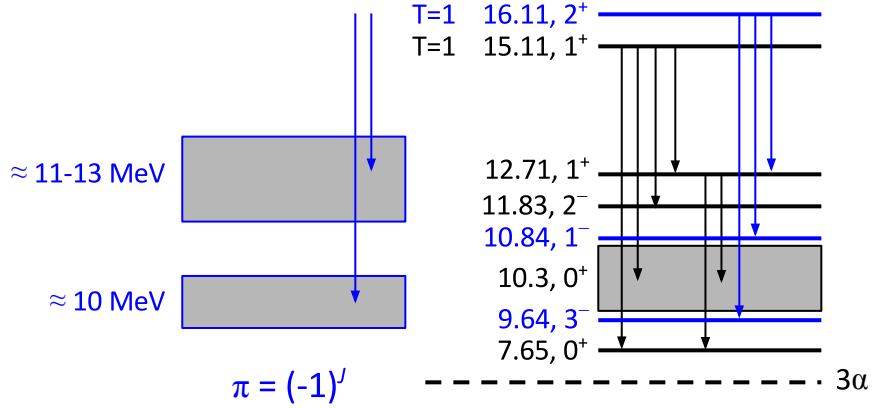




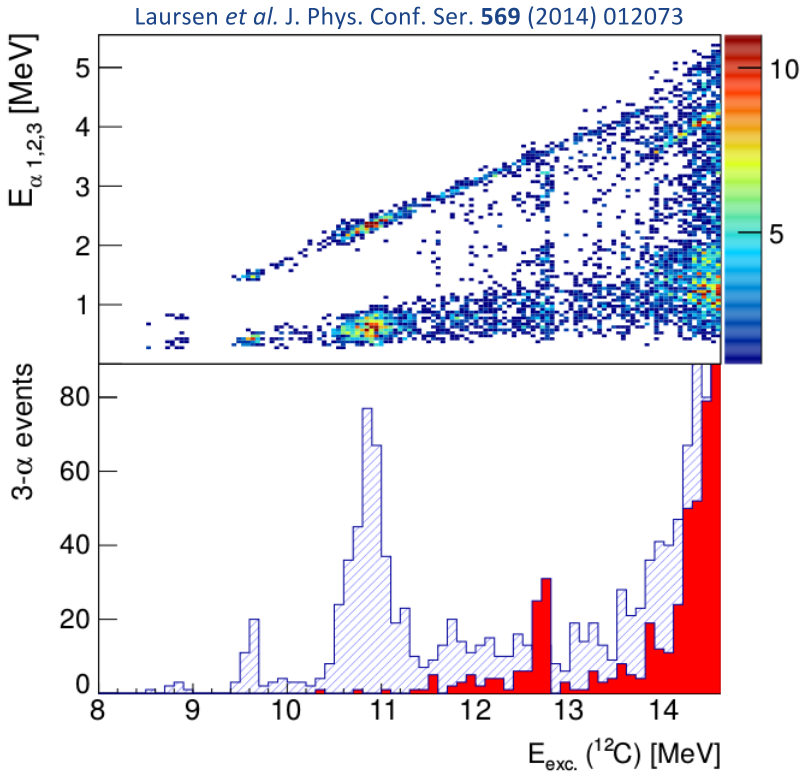
p+^{11}B @ 170 keV



El/Ml	16.11 MeV, 2^+
E1	$1^-, 2^-, 3^-$
M1	$1^+, 2^+, 3^+$
E2	$0^+, 1^+, 2^+, 3^+, 4^+$



p+^{11}B @ 170 keV



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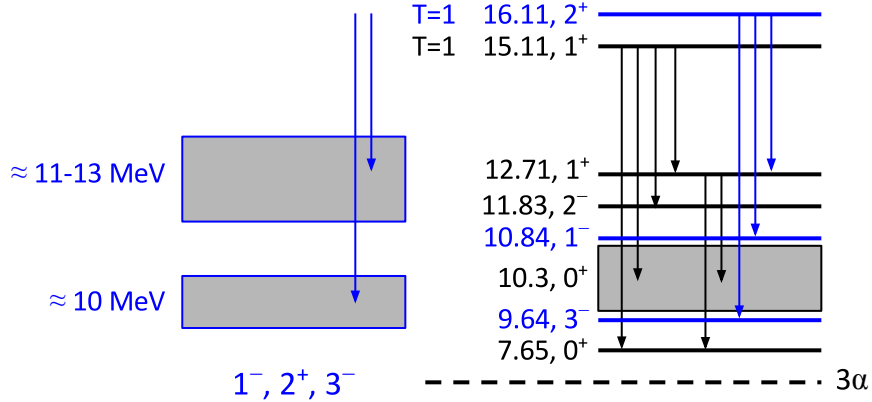
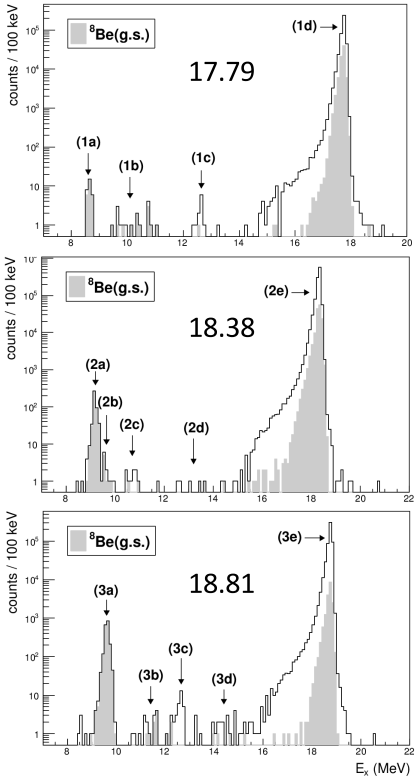
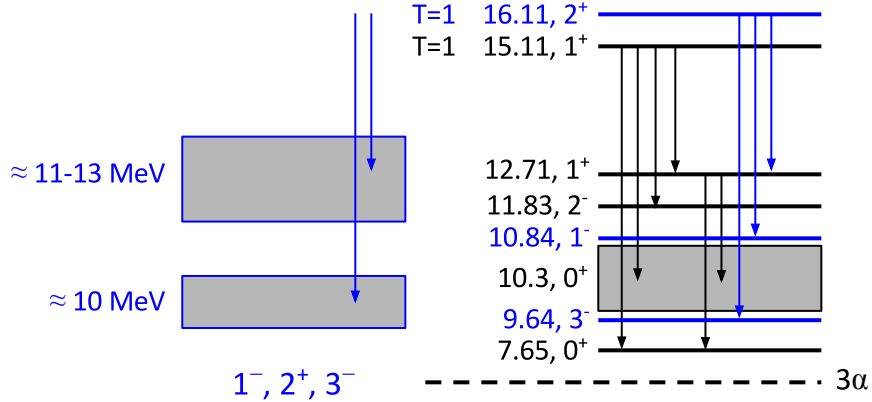


p+^{11}B @ 2.00, 2.63, 3.12 MeV

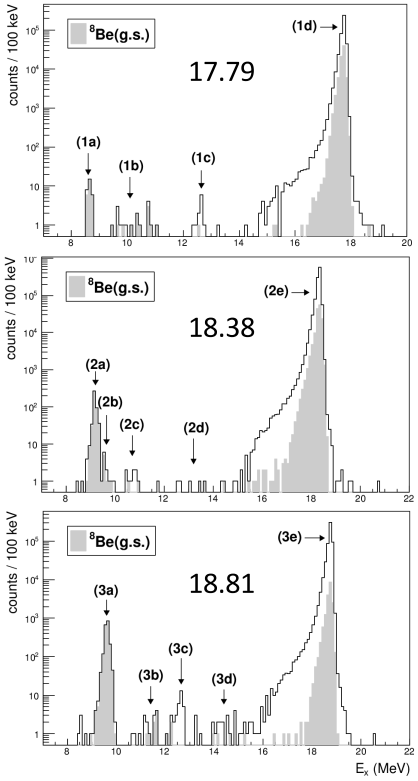


	17.79, 0^+	18.38, 3^-	18.81, 2^+
E1	1^-	2^+, 3^+, 4^+	1^-, 2^-, 3^-
M1	1^+	2^-, 3^-, 4^-	1^+, 2^+, 3^+
E2	1^+, 2^+	1^-, . . . , 5^-	0^+, . . . , 4^+

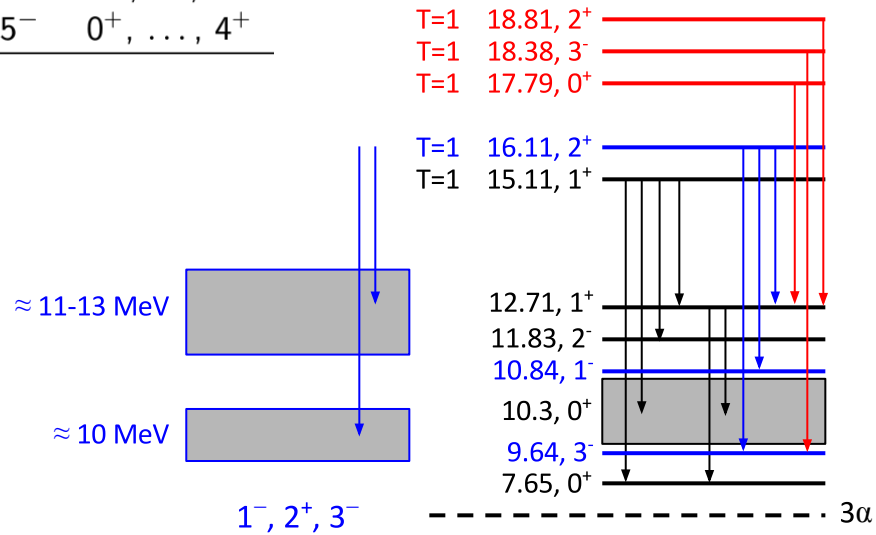


Kirsebom *et al.* J. Phys. Conf. Ser. **569** (2014) 012013

p+^{11}B @ 2.00, 2.63, 3.12 MeV



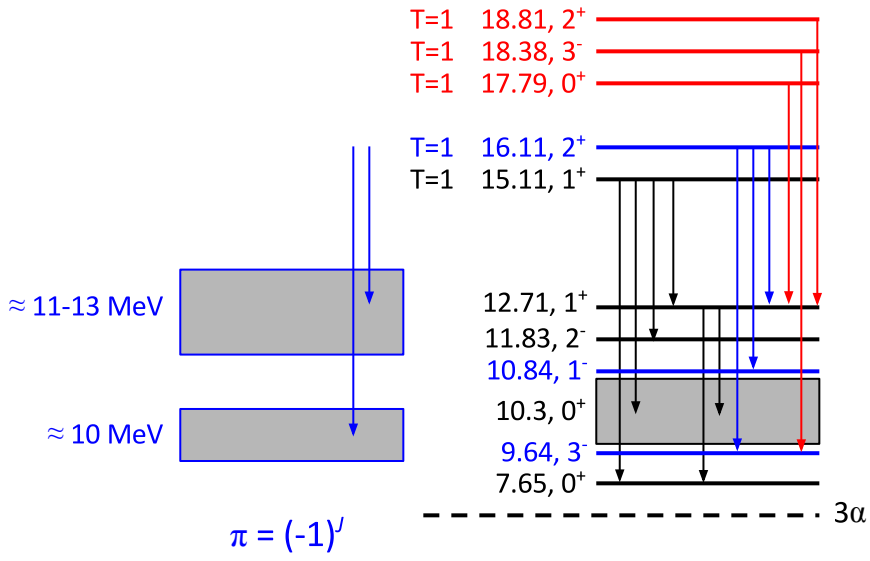
	17.79, 0^+	18.38, 3^-	18.81, 2^+
E1	1^-	2^+, 3^+, 4^+	1^-, 2^-, 3^-
M1	1^+	2^-, 3^-, 4^-	1^+, 2^+, 3^+
E2	1^+, 2^+	1^-, . . . , 5^-	0^+, . . . , 4^+



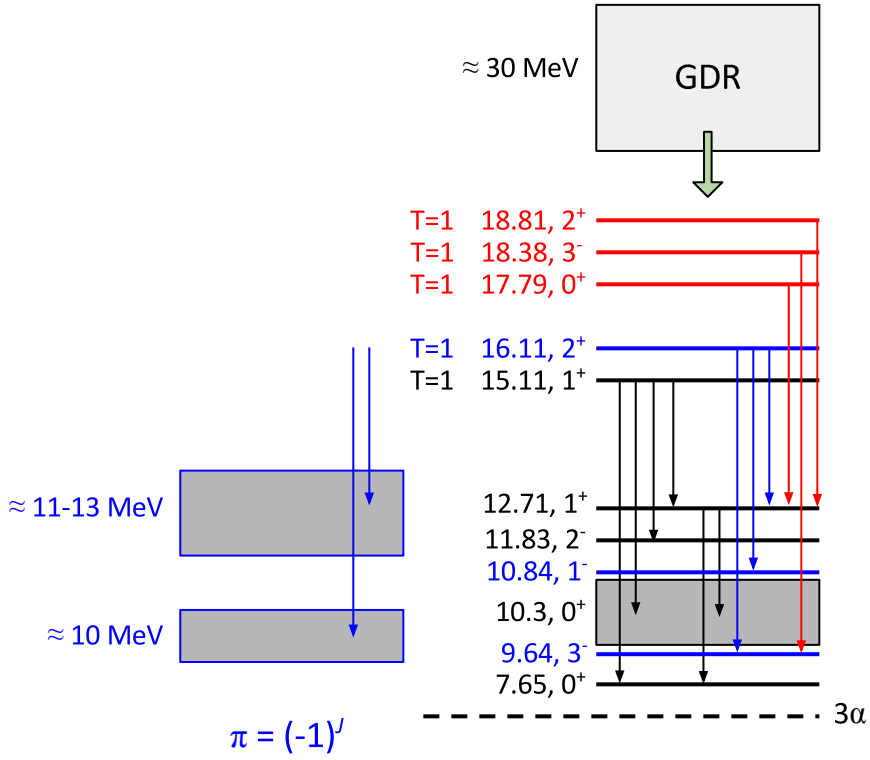
Kirsebom *et al.* J. Phys. Conf. Ser. **569** (2014) 012013

New projects

How about the giant dipole resonance (GDR) ?

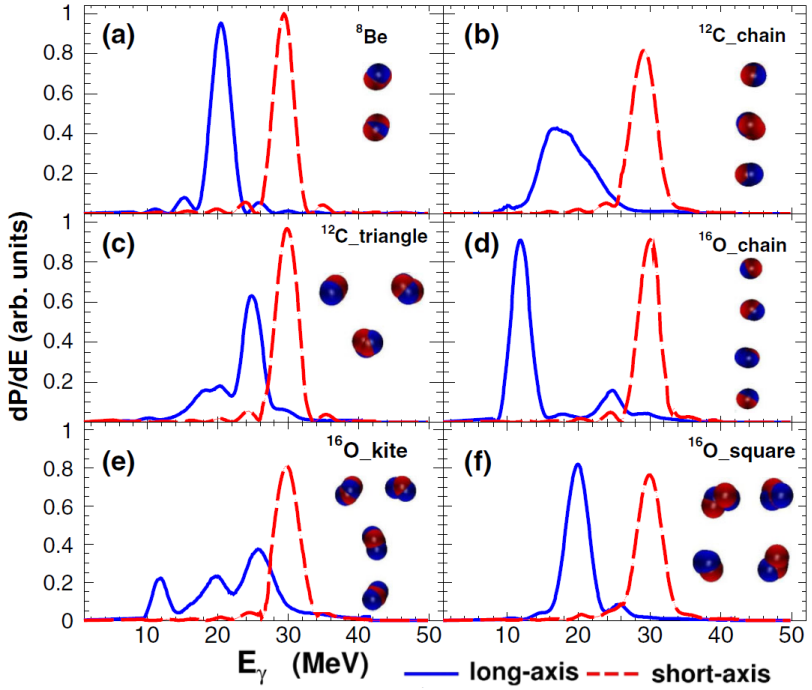


How about the giant dipole resonance (GDR) ?



How about the giant dipole resonance (GDR) ?

He *et al.*, PRL **113** (2014) 032506



QMD calculation

≈ 30 MeV GDR

≈ 11-13 MeV

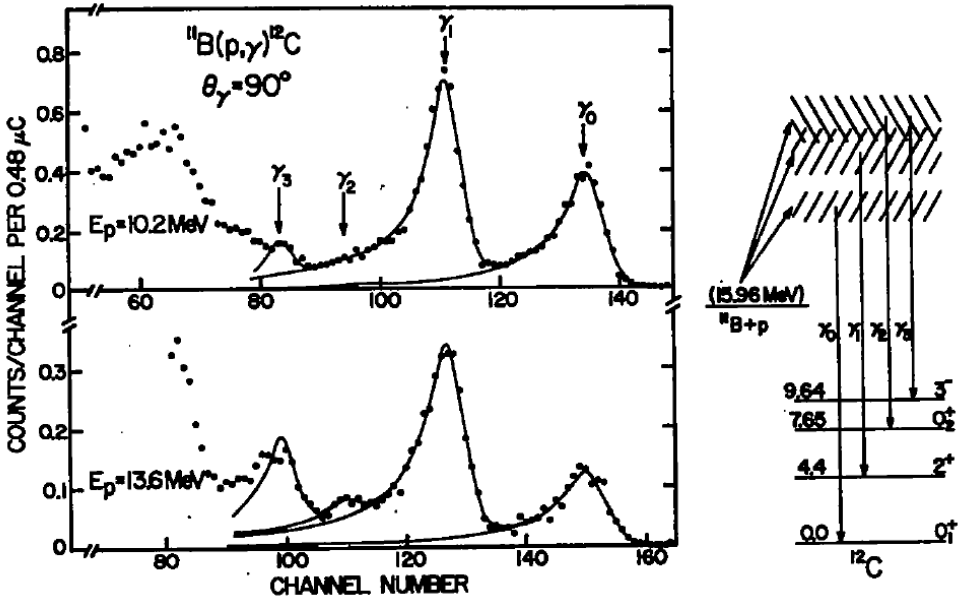
≈ 10 MeV

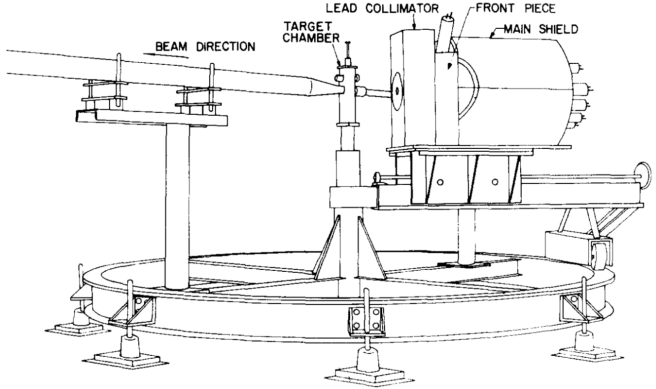
$\pi = (-1)^J$

T=1 18.81, 2^+
T=1 18.38, 3^-
T=1 17.79, 0^+
T=1 16.11, 2^+
T=1 15.11, 1^+
12.71, 1^+
11.83, 2^-
10.84, 1^-
10.3, 0^+
9.64, 3^-
7.65, 0^+
3α

Old experiment of Snover *et al.*

Snover *et al.* Nucl. Phys. A **285** (1977) 189197





Diener *et al.* Nucl. Instr. Meth. **83** (I970) 115-123

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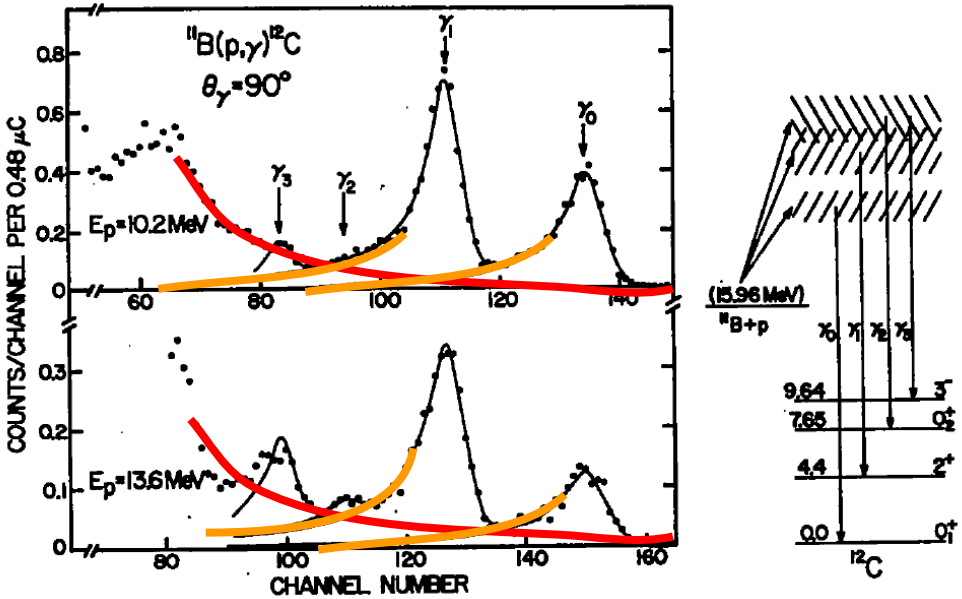
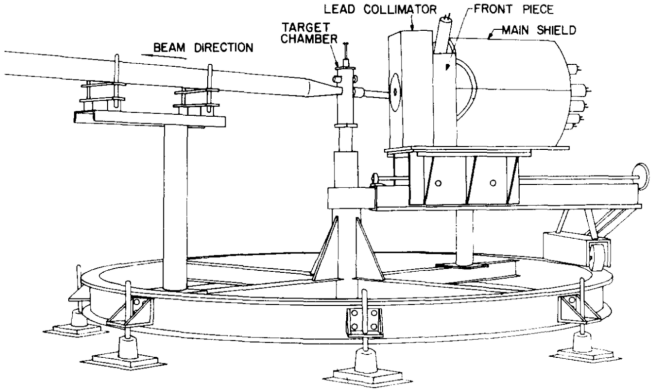
Snover *et al.* Nucl. Phys. A **285** (1977) 189197



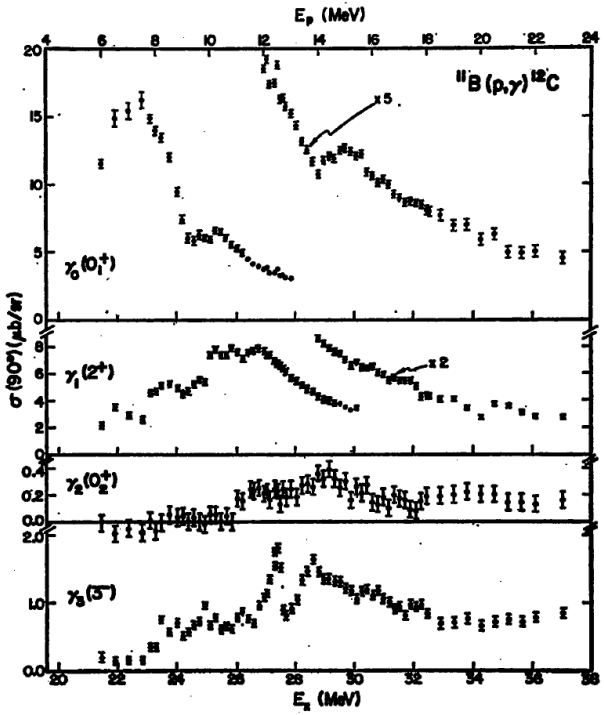


Diener *et al.* Nucl. Instr. Meth. **83** (I970) 115-123

Limited in terms of **statistics** and **background**/**response tails**

Old experiment of Snover *et al.*

Snover *et al.* Nucl. Phys. A **285** (1977) 189197



Old experiment of Snover *et al.*

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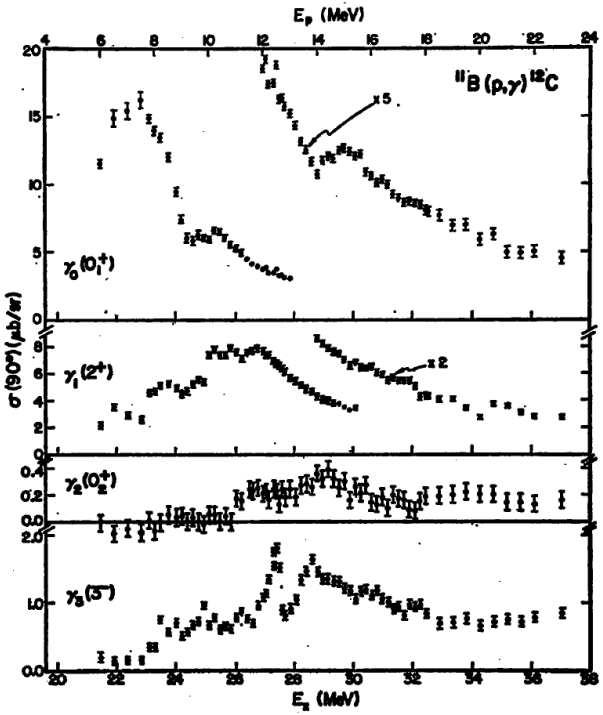


Why is the $\gamma_2(0^+_2)$ cross section so small ?

- The coupling to p+^{11}B channel is weak due to the α-cluster structure of the Hoyle state ?
- The strength is shifted to lower energy due to the large spatial extension of the Hoyle state ? (as seen in halo nuclei)

We need improved data to determine the correct answer!

Approved proposal at IPN Orsay

Proposal to the ALTO IPN-Orsay PAC

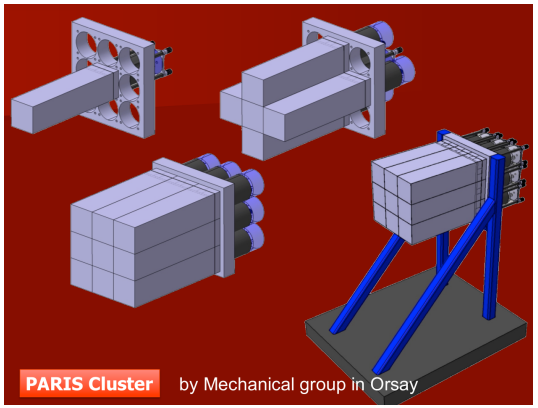
A new probe of α-cluster structure in ^{12}C

O. S. Kirsebom[1)], S. Courtin[2)3)], H. O. U. Fynbo[1)], D. G. Jenkins[4)], D Montanari[2)] and the PARIS collaboration.

Spokesperson: O. S. Kirsebom

PARIS

A high efficiency phoswich array ($LaBr_3$+NaI) for medium-resolution spectroscopy and calorimetry of high-energy gamma-rays.



courtesy Adam Maj

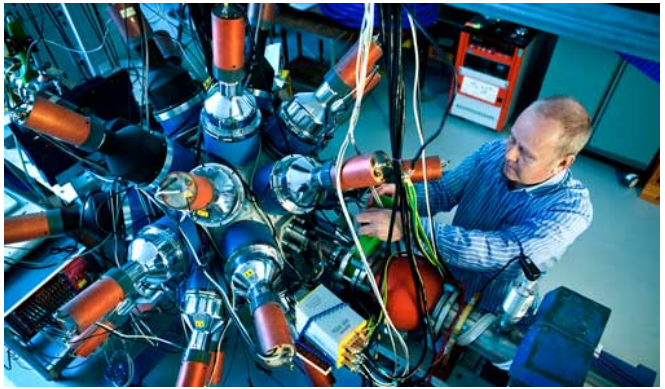
Advantages:

- Increased solid angle
- Segmentation allows for higher rate
- Improved pile-up rejection
- Angular distribution
- $\gamma\gamma$ coincidences

Alternatives to p+^{11}B ?

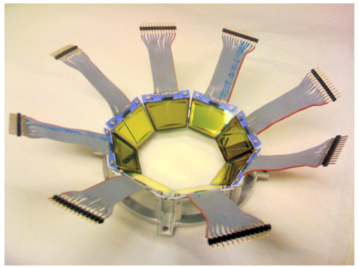
^{12}C(p,p')

OCL (Oslo Cyclotron Laboratory)



NaI/$LaBr_3$ array

Si array



Collaborators

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University of York
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Also thanks to:

VILLUM FONDEN

Thank you for your attention!