CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Observation of γ-delayed 3α-break-up in ^{12}C

O. Tengblad

for the MAGISOL collaboration

Analysis & Transparencies by M. Alcorta

EURORIB 2010 6-11 June 2010 Village de Vacances de Lamoura

CSIC
Consejo Superior de Investigaciones Científicas

Outline

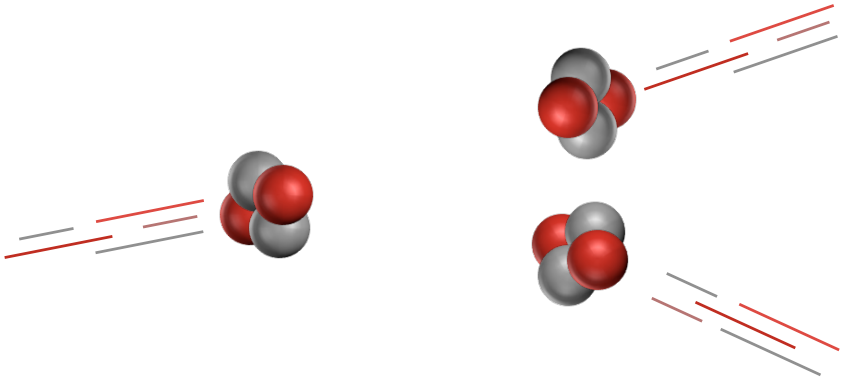
- Motivation
  - Nuclear structure
    - Current status/models
    - Decay mechanism
- Experiment
  - CMAM/setup
- Analysis
  - Branching ratios
  - Indirect detection of gamma-decay

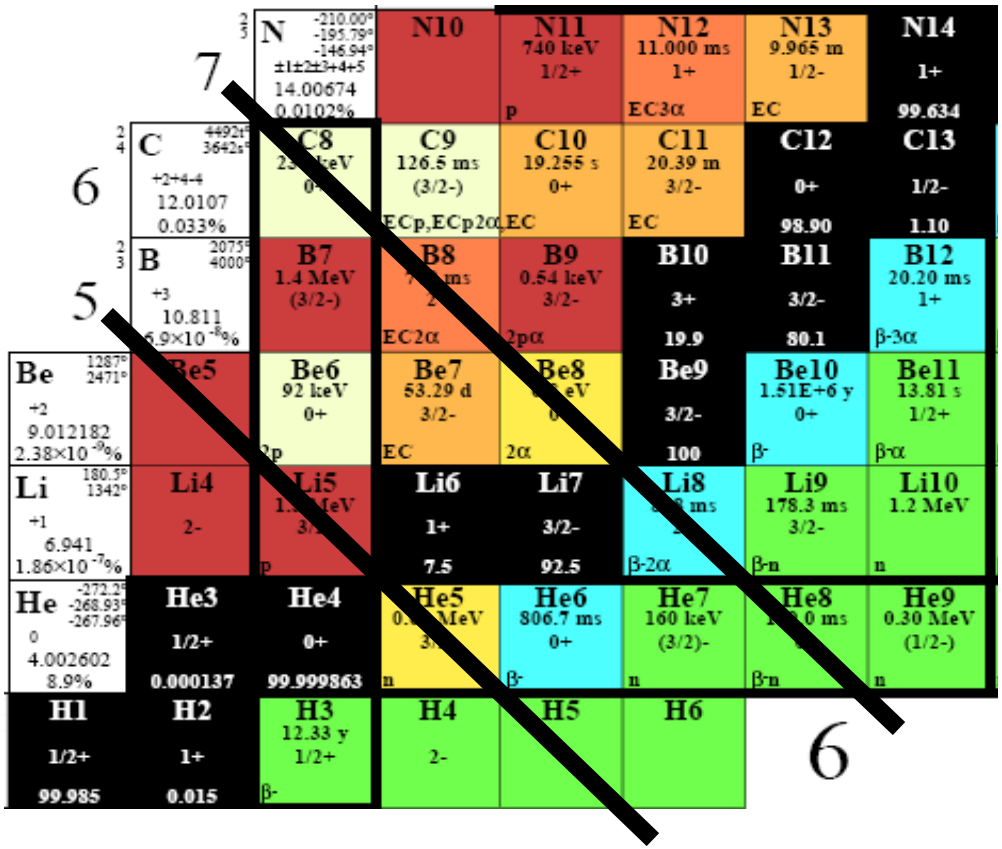
CSIC
Consejo Superior de Investigaciones Científicas

Nuclear Structure & Astrophysics

N6. A State in C^{12} Predicted from Astrophysical Evidence.* F. Hoyle, *Cambridge University* and D. N. F. Dunbar, W. A. Wenzel, and W. Whaling, *Kellogg Radiation Laboratory, California Institute of Technology.*—It is

Phys. Rev. 92:1095 (1953)

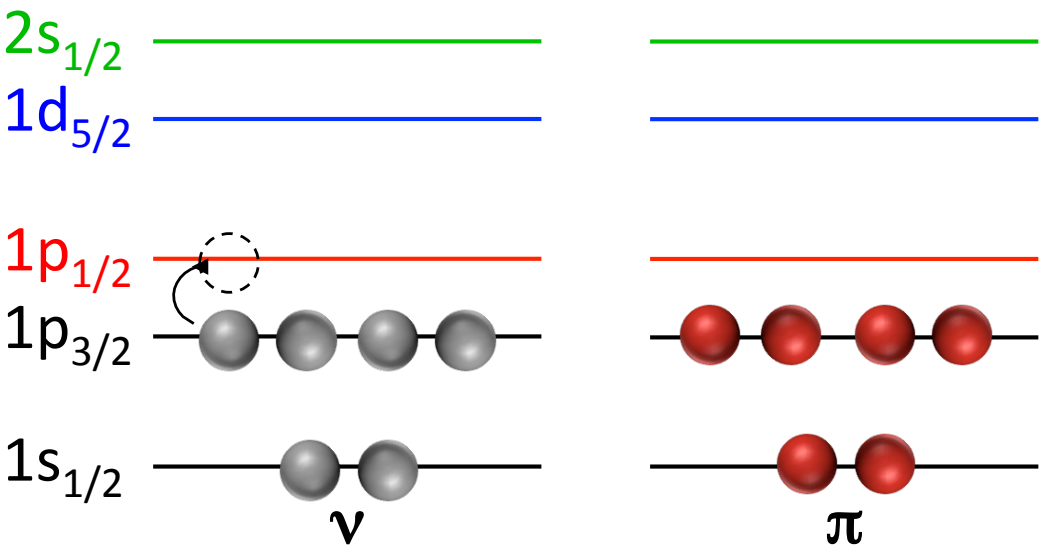




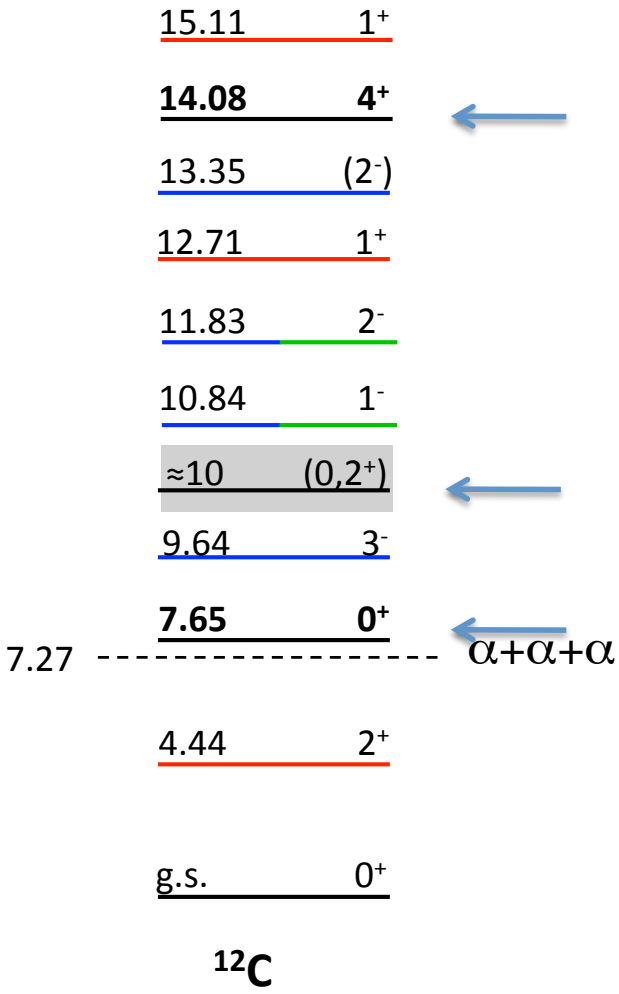
Excited states: Theory

- **Single-nucleon excitations to $1p_{1/2}$,$1d_{5/2}$ and $2s_{1/2}$:**

$1^+, 2^+$ $1^-, 2^-, 3^-, 4^-$ $1^-, 2^-$



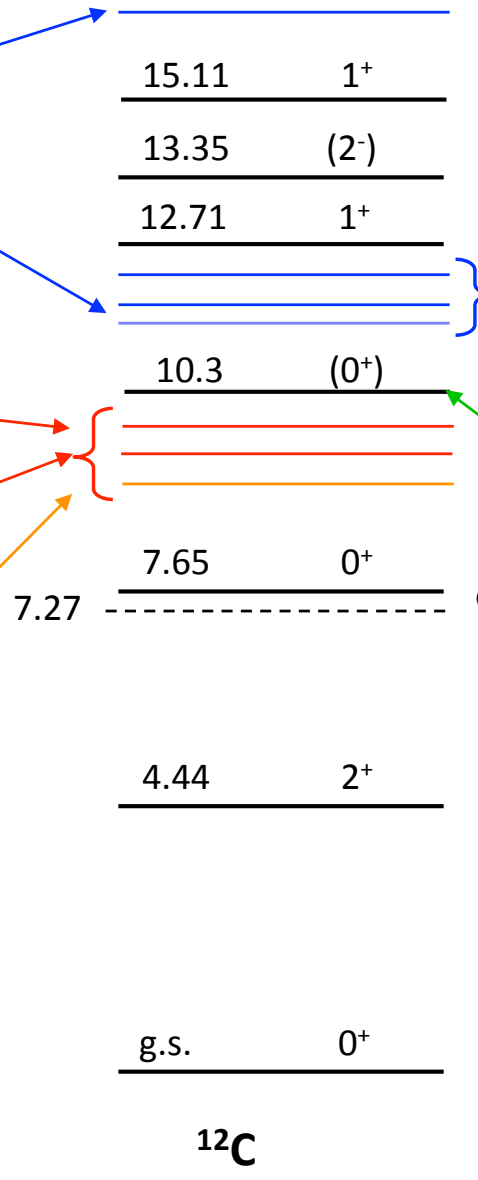
$^{12}C^*$



Recent theoretical papers discussing different cluster modules, that can reproduce rather well the states in ^{12}C:

- Bijker and Iachello, Ann. Phys. **298,** 334 (2002).
- Kanada En'yo, Prog. Theo. Phys. **117** (2007) 65

Excited states: Recent experiments



(2⁺) @ 11.2 and 15.4 MeV
TUNL compilation
Nucl. Phys. A, 506, 1, 1990

2⁺ @ 9.9(3) MeV
$^{12}C(\alpha,\alpha')^{12}C^*$
Nucl. Phys. A, 738, 268, 2004

2⁺ @ 9.6 MeV
$^{12}C(p,p')^{12}C^*$
Nucl. Phys. A, 834, 621c, 2010

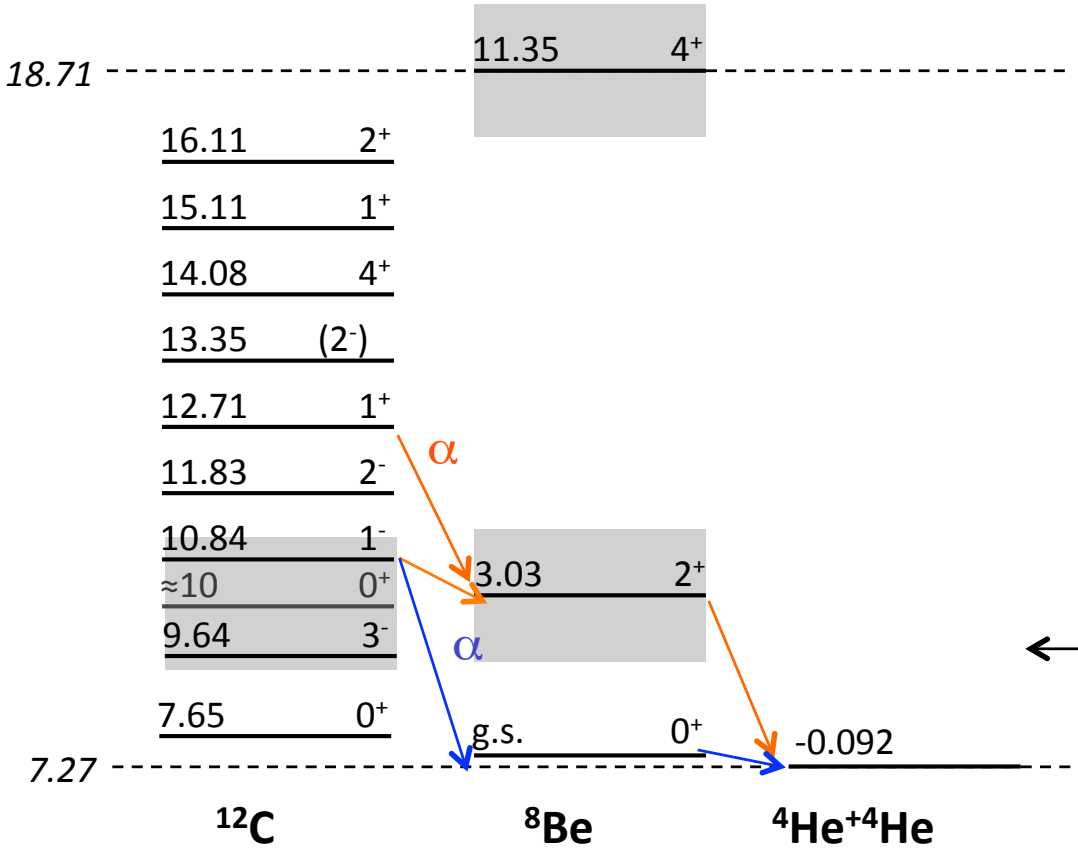
2⁺ @ 9.0 MeV
Included in the NACRE compilation (theory)
Nucl. Phys. A, 656,3,1999

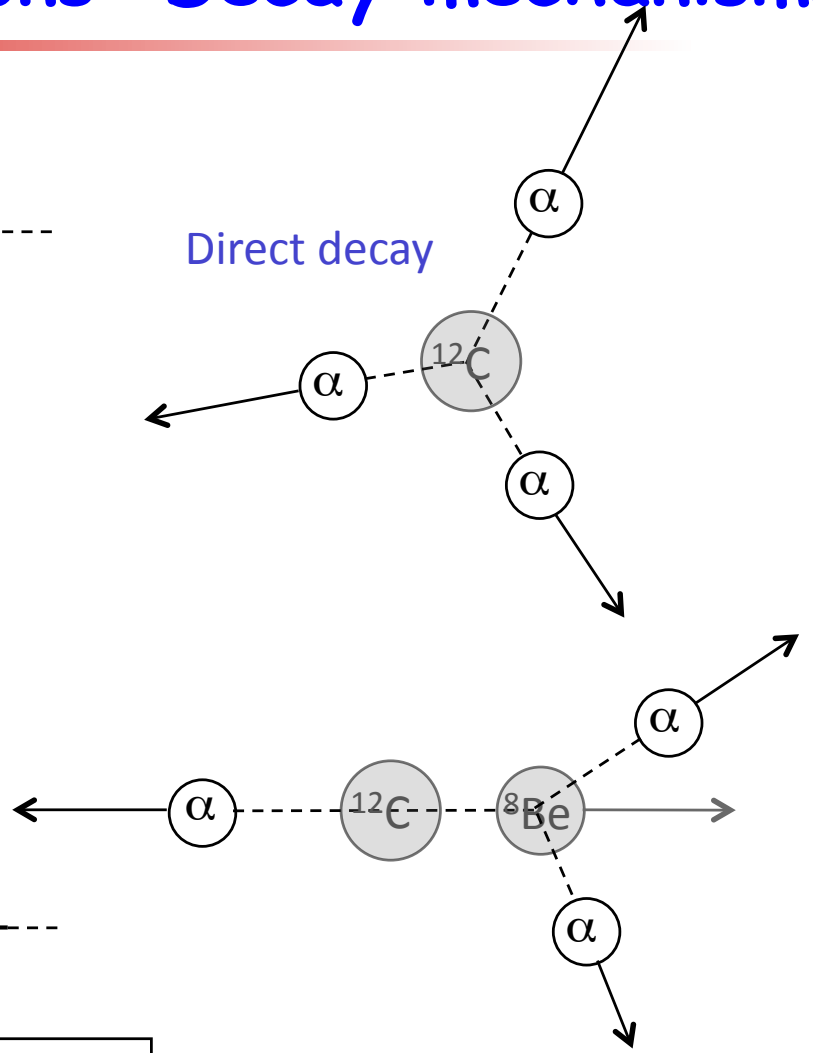
2⁺ @ 11.5 MeV
$^{12}C(\alpha,\alpha')^{12}C^*$
Phys. Rev. C 68, 014305, 2003

2⁺ @ 11.16 MeV
$^{12}C(^{12}C,3\alpha)$
Phys. Rev. C 76, 034320, 2007. (also new 1^-, 3^-)

2⁺ @ 11.1 MeV
0⁺ @ 11.2 MeV
β-decay ^{12}N,^{12}B
Phys. Rev. C 81, 024303, 2010.

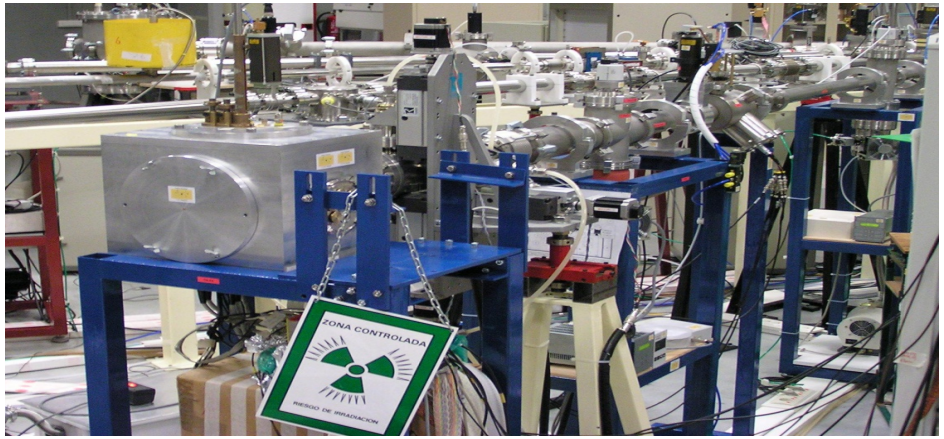
More questions: Decay mechanisms

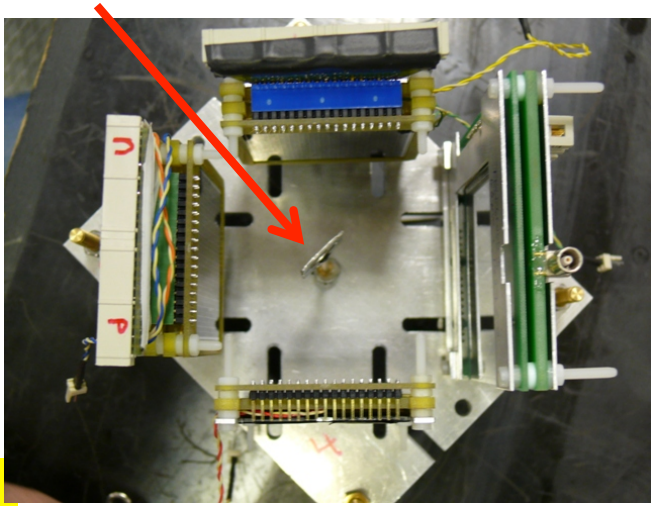




- How do the different states decay ?
- How is this related to the state structure ?

The experiment: highly segmented





Beam: ^{3}He @ 4.9 and 8.5 MeV from 5 MV Tandetron

Targets:

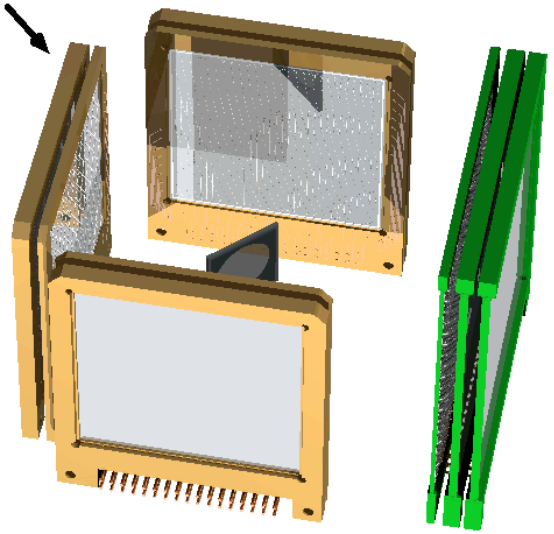
18.9 μg/cm^2 ^{10}B enriched (90%) on 4 μg/cm^2 C-backing

22.0 μg/cm^2 ^{11}B with 4 μg/cm^2 C-backing

Reactions: ^{10}B(^{3}He,p)ααα

^{11}B(^{3}He,d)ααα

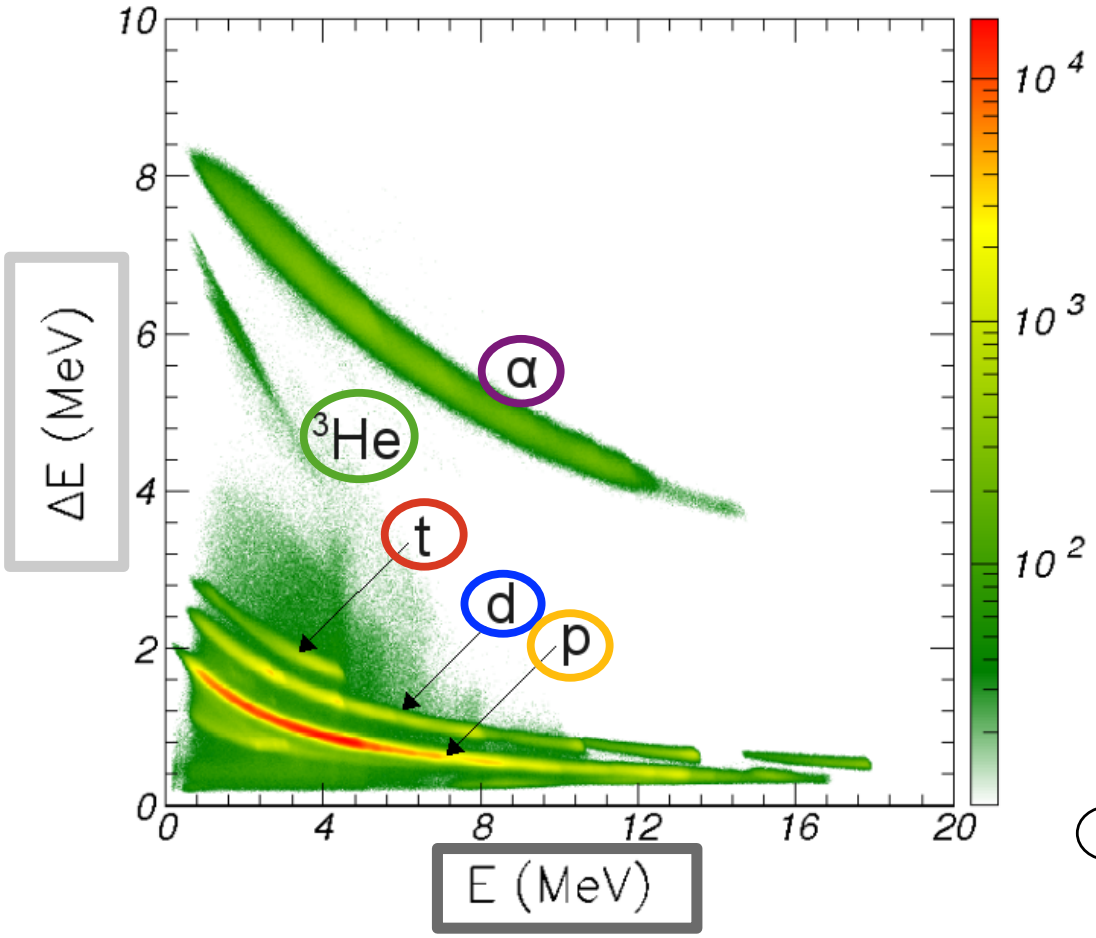
Ω = 38% of 4π



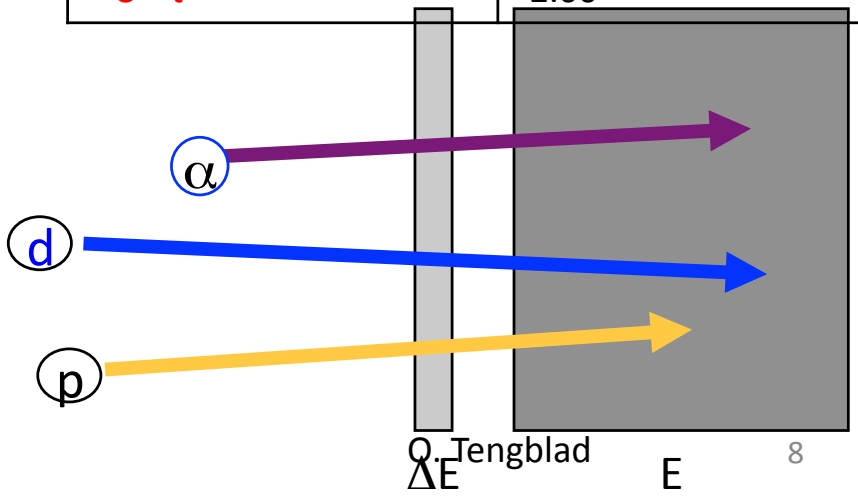
CSIC
Consejo Superior de Investigaciones Científicas

Particle Identification

$^{3}He + {}^{11}B \longrightarrow d + {}^{12}C^{*}$



Reaction products	Q-Value (MeV)
$^{14}N + \gamma$	20.74
$^{13}C + p$	13.19
$^{12}C + d$ ←	**10.46**
$^{10}B + \alpha$	9.12
$^{12}C + n + p$	8.24
$^{6}Li + 2\alpha$	4.66
$^{9}Be + p + \alpha$	2.54
$^{5}He + p + 2\alpha$	0.07
$^{11}B + {}^{3}He$	0.00
$^{11}C + t$	-2.00



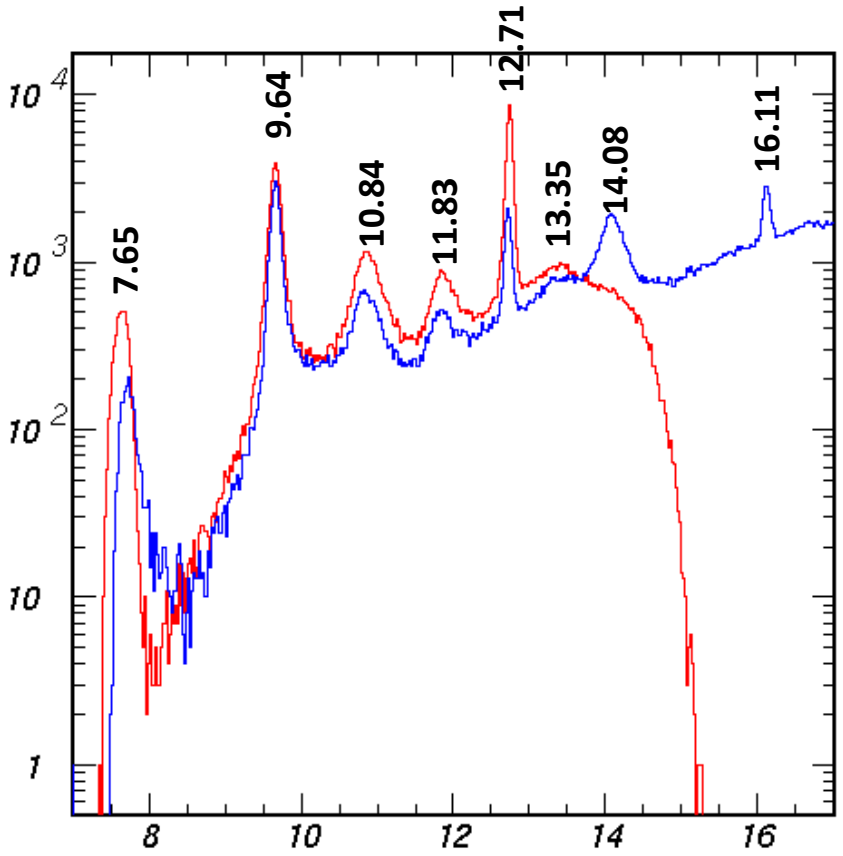
Identification of States in ^{12}C

$^{3}He + {}^{11}B \rightarrow d + {}^{12}C^{*}$ @ 8.5 MeV Q-value=10.46 MeV

$^{3}He + {}^{10}B \rightarrow p + {}^{12}C^{*}$ @ 4.9 MeV Q-value=19.69 MeV

16.11	2^+
15.11	1^+
14.08	4^+
13.35	(2^-)
12.71	1^+
11.83	2^-
10.84	1^-
≈10	0^+
9.64	3^-
7.65	0^+

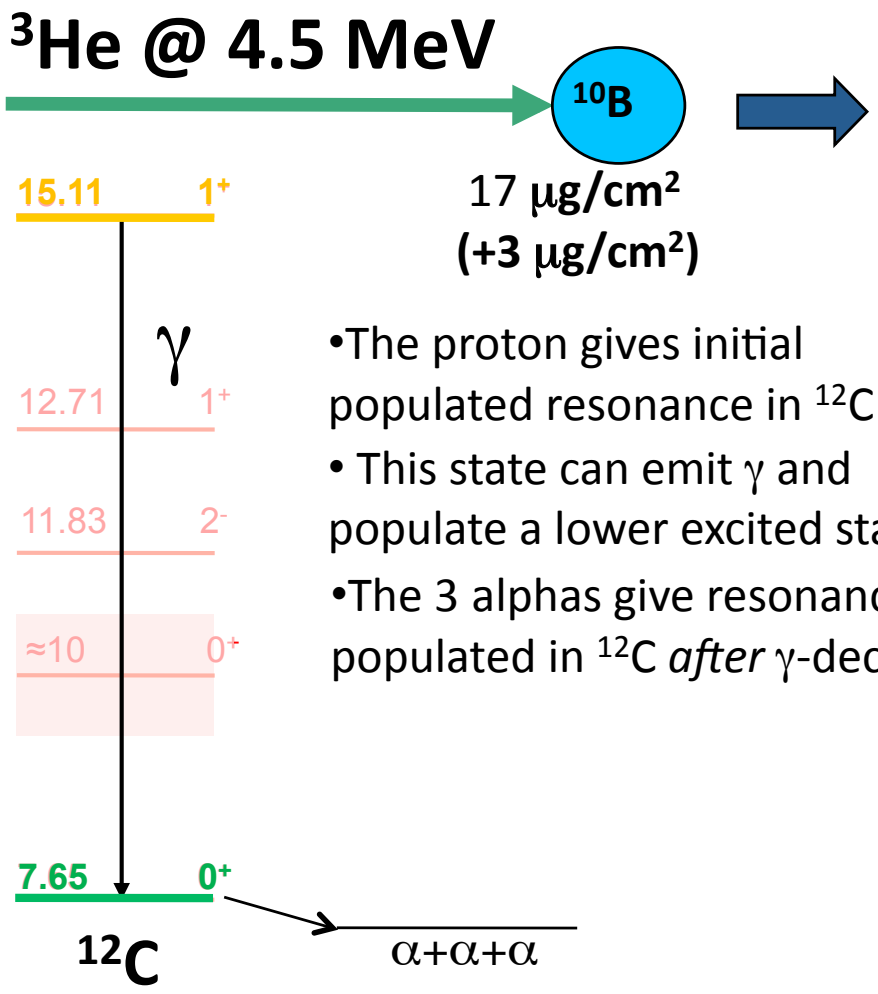
^{12}C



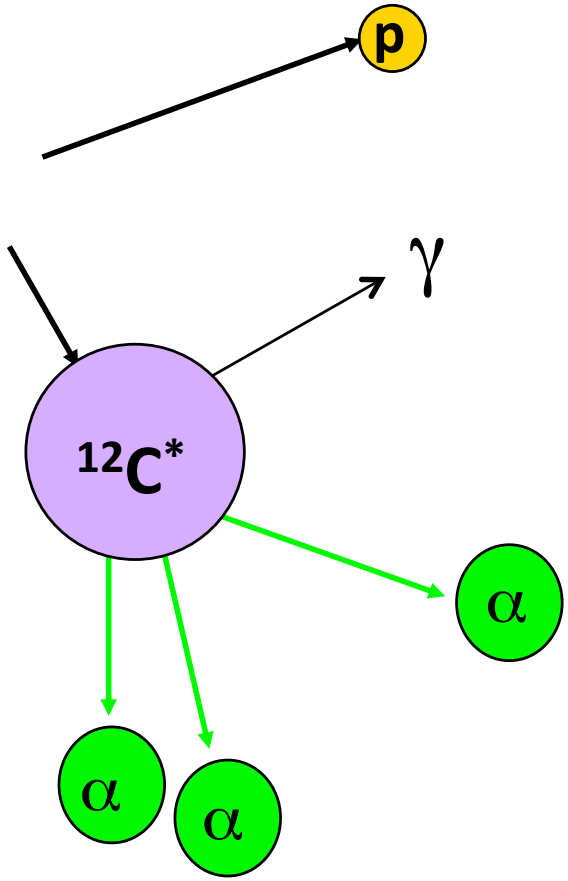
^{12}C Excitation Energy (MeV) (multiplicity 4)

- By selecting the **proton** or **deuteron**, we can calculate the ^{12}C excitation spectrum
- We also detect the decay fragments of ^{12}C (3α) to learn about the structure of the resonances in ^{12}C.

Indirect Detection of γ-decay

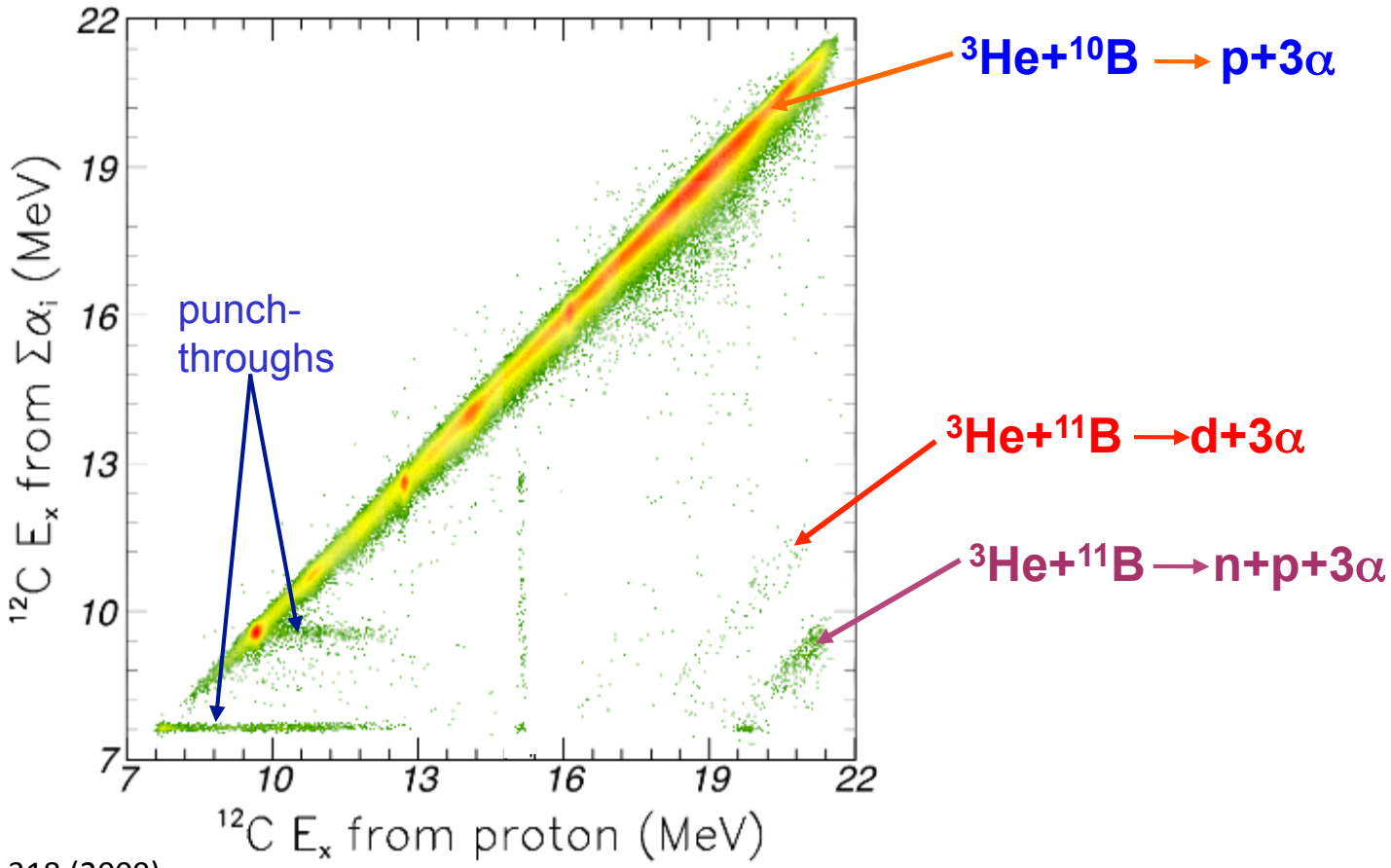


- The proton gives initial populated resonance in ^{12}C
- This state can emit γ and populate a lower excited state
- The 3 alphas give resonance populated in ^{12}C *after* γ-decay



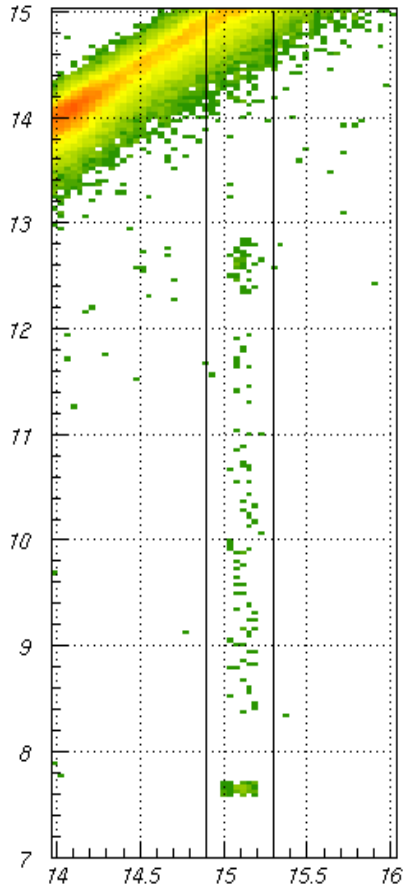
Indirect Detection of γ-decay

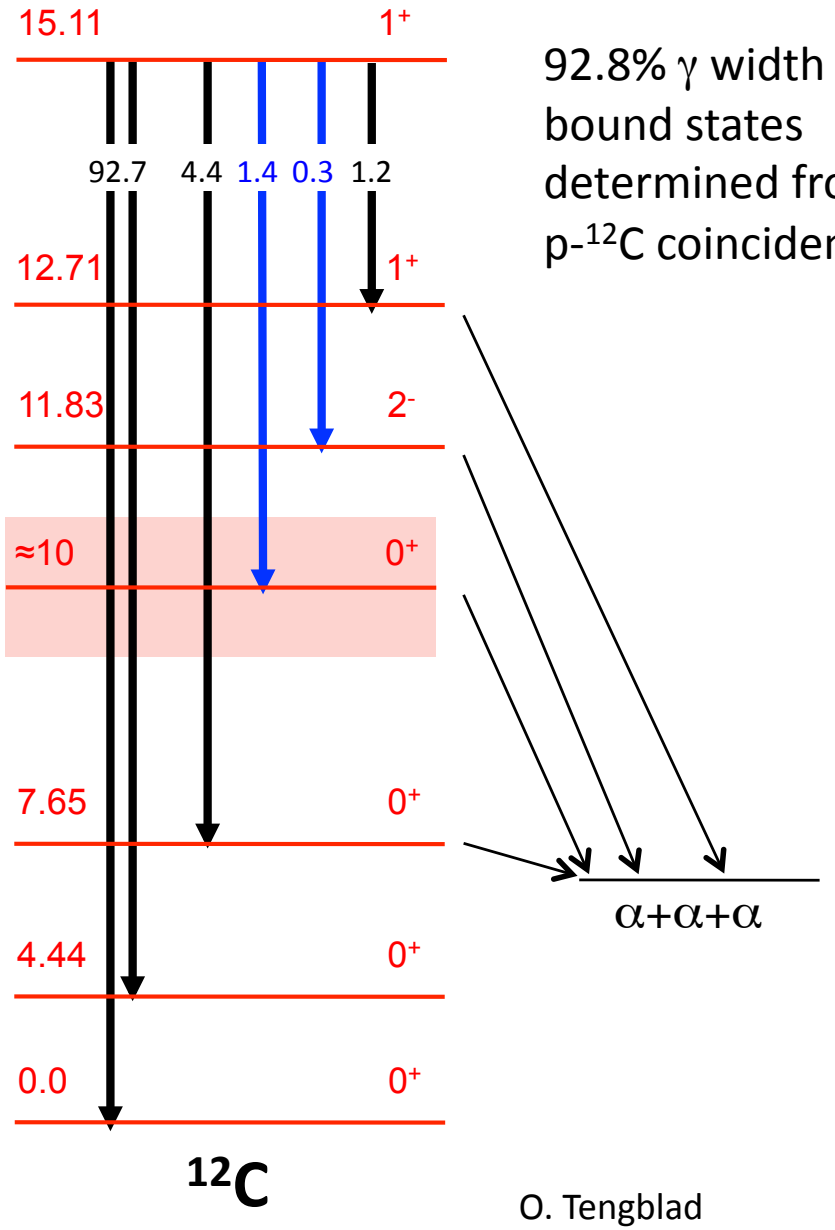
Excitation energy calculated from proton should be greater than that calculated form invariant mass of alphas



M. Alcorta *et al*, NIM **A605**, 318 (2009).

γ-decay of 15.11 MeV



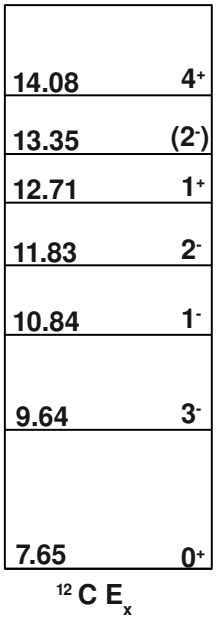


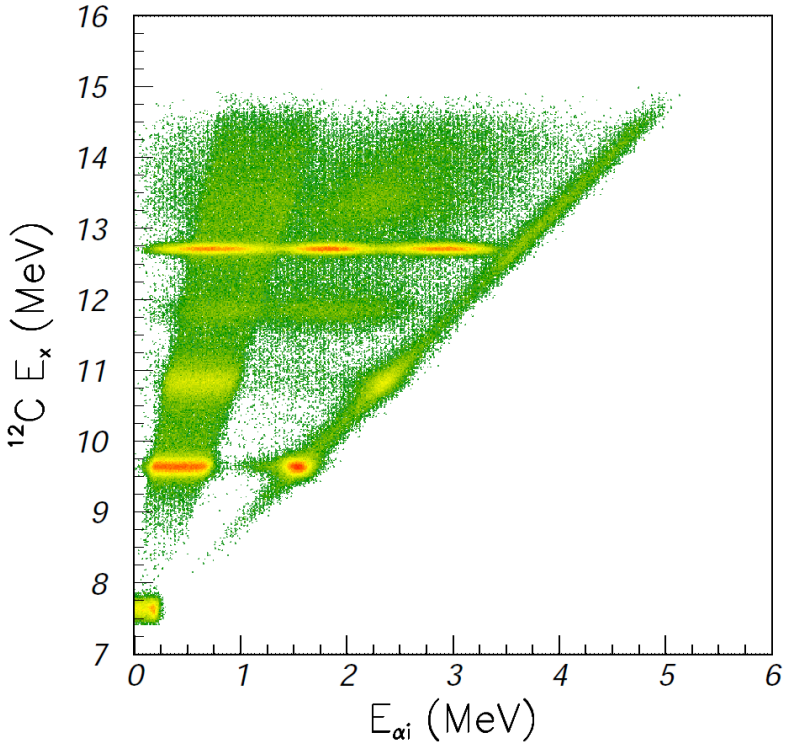
92.8% γ width to bound states determined from p-^{12}C coincidences

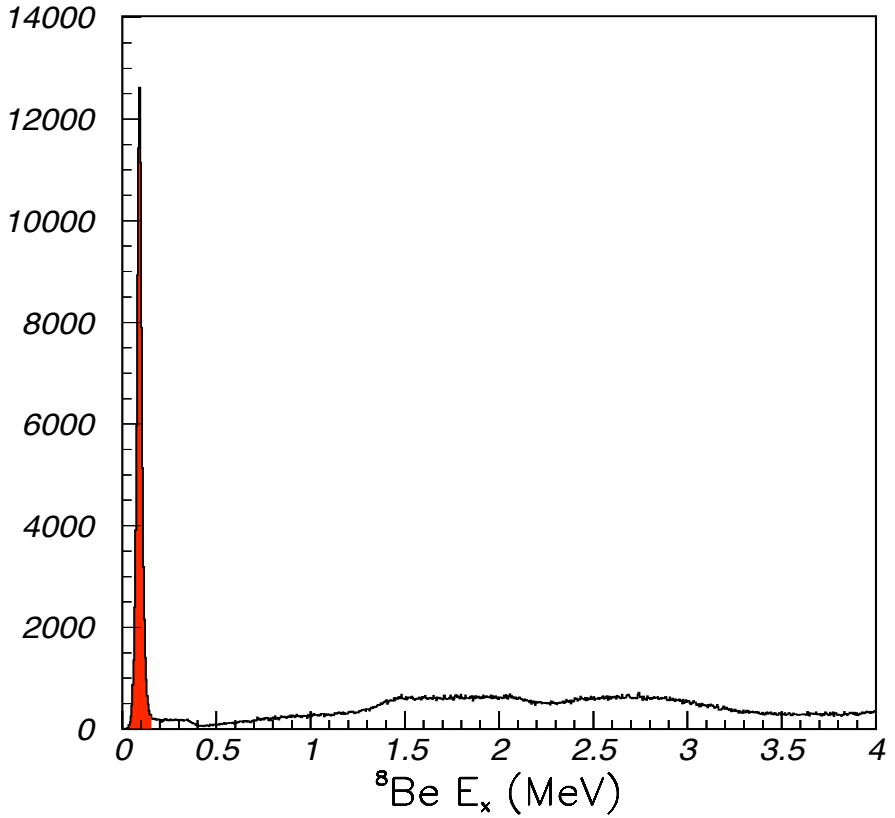
O. Kirsebom *et al*, PLB **680,** 44 (2009)

Partial branches

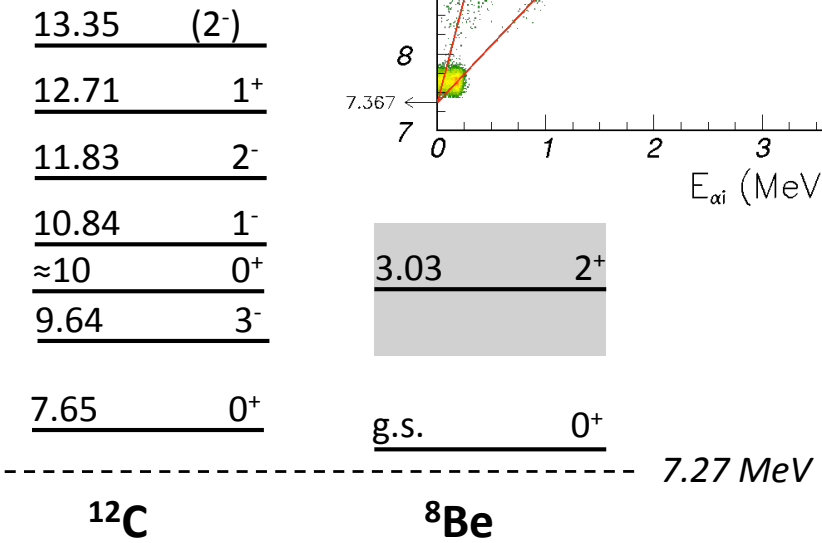
$$^{3}He + {}^{11}B \longrightarrow \mathbf{d} + {}^{12}C^{*} \longrightarrow \alpha+\alpha+\alpha$$

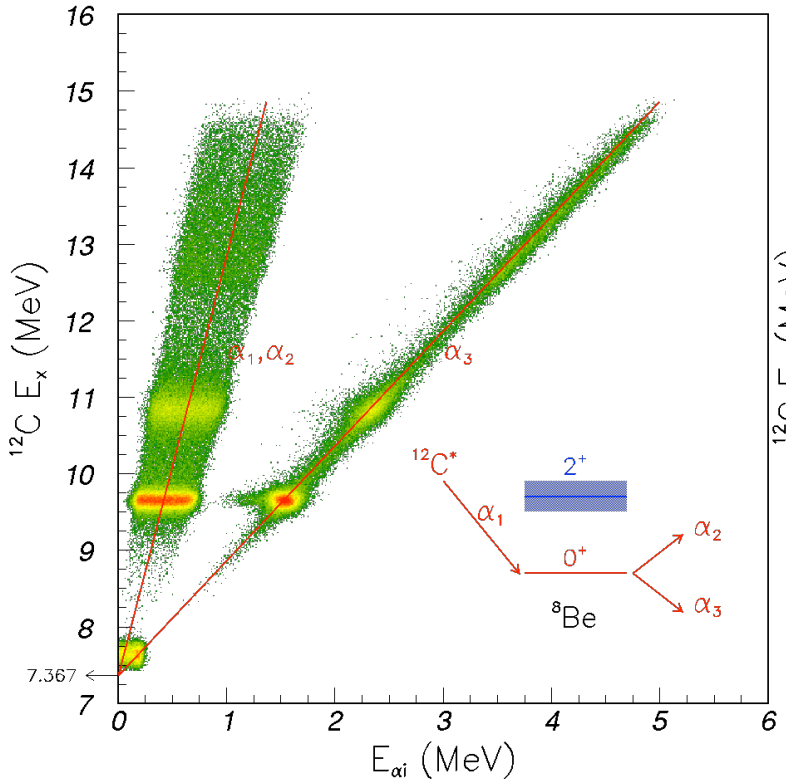


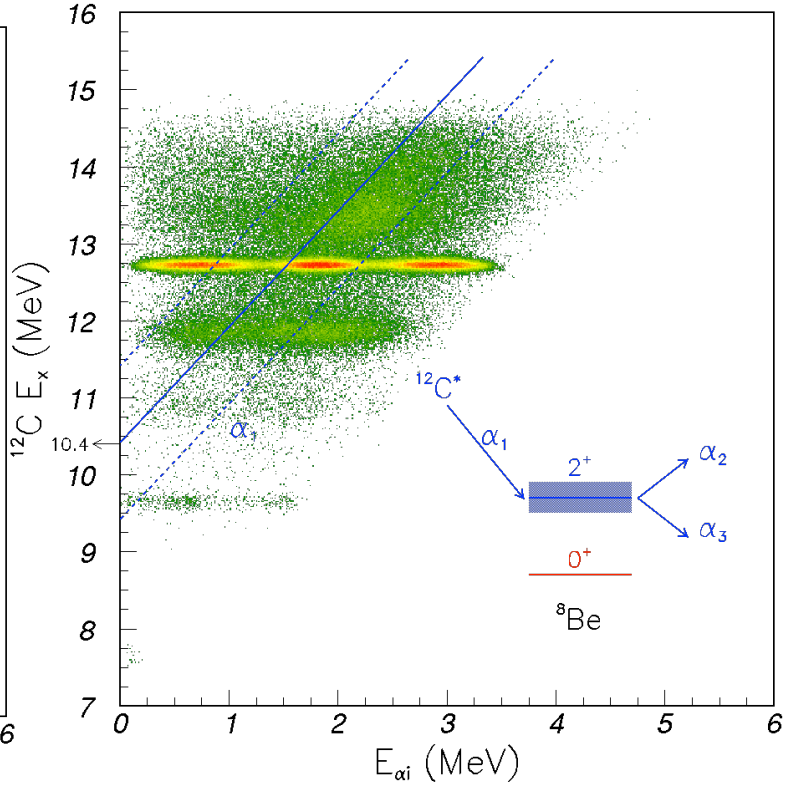




Partial branches





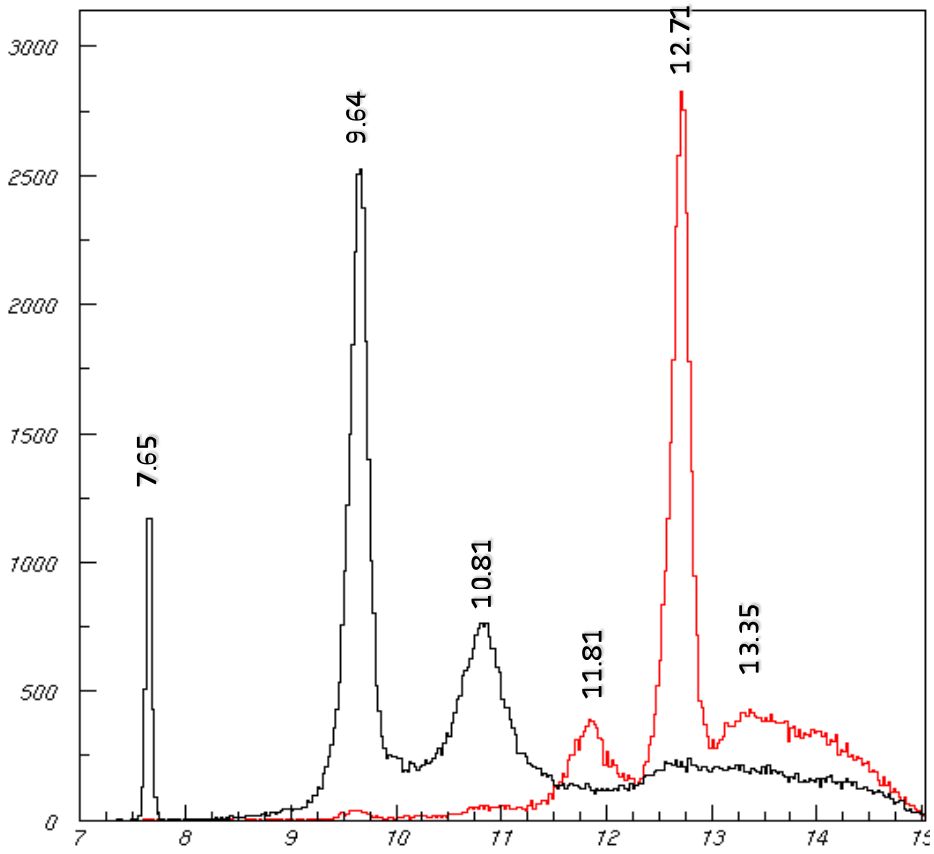


^{11}B(^{3}He,dααα) data

Partial branches

^{8}Be 2^{+} contribution

^{8}Be 0^{+} contribution

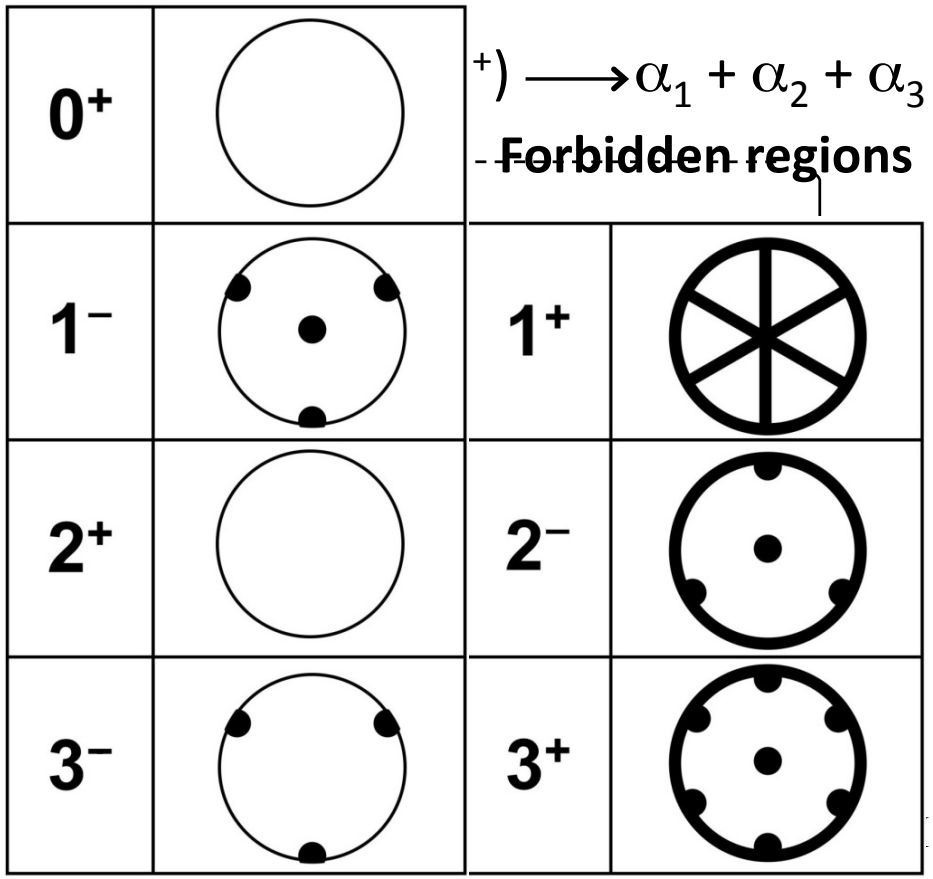


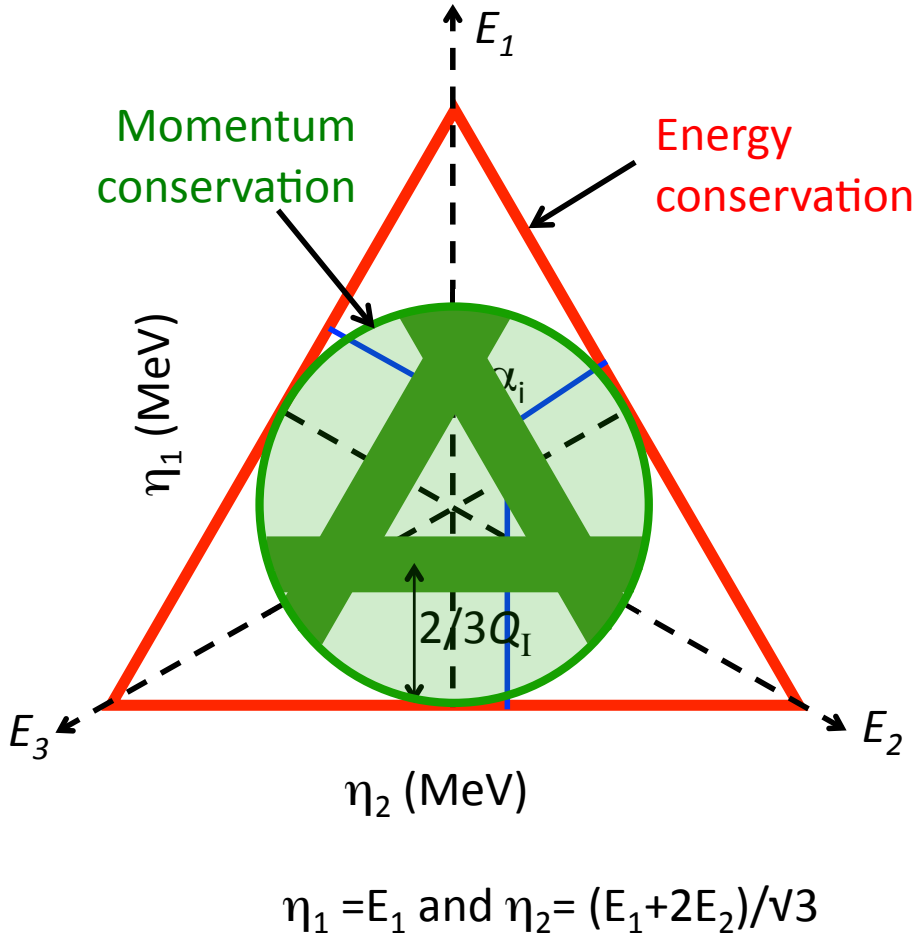
^{11}B(^{3}He,dααα) data

E^{x} ^{12}C (MeV)	J^{π}	BR (%)	BR (%) (corr.)	$\Gamma_{\alpha 0}$ (keV)
9.64	3^{-}	96.3(1)	99.5(6)	32(2)
10.84	1^{-}	94.7(5)	99.4(6)	249(2)
14.08	4^{+}	22.8(2)	24.2(2)	50(11)
16.11	2^{+}	5.6(1)	6.4(1)	0.3(1.0)

Dalitz Plots

- Only two energies are needed to describe a 3-body decay
- Structures may arise from **final state interactions** or symmetries

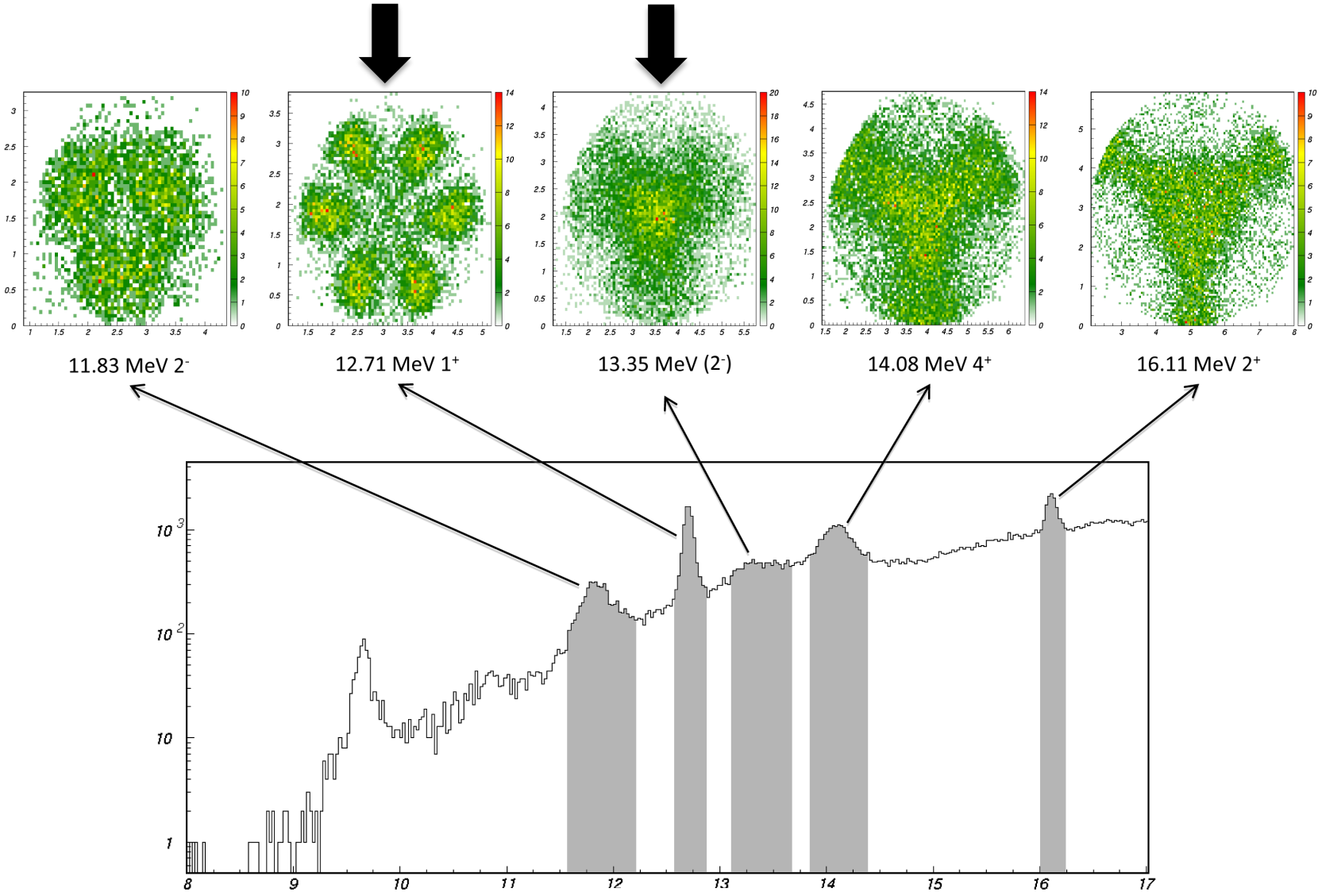




$\eta_1 = E_1$ and $\eta_2 = (E_1 + 2E_2)/\sqrt{3}$

C. Zemach, Phys Rev. **133** (1964) 1201 : Decay to 3π
R.H. Dalitz, Philos. Mag. **44**, 1068 (1953).

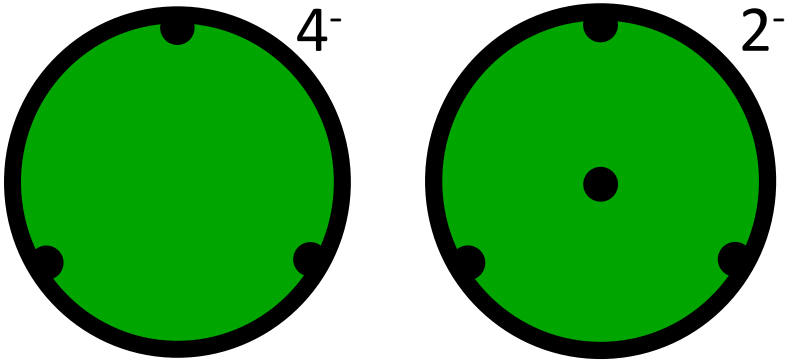
^{12}C Spectrum: Dalitz

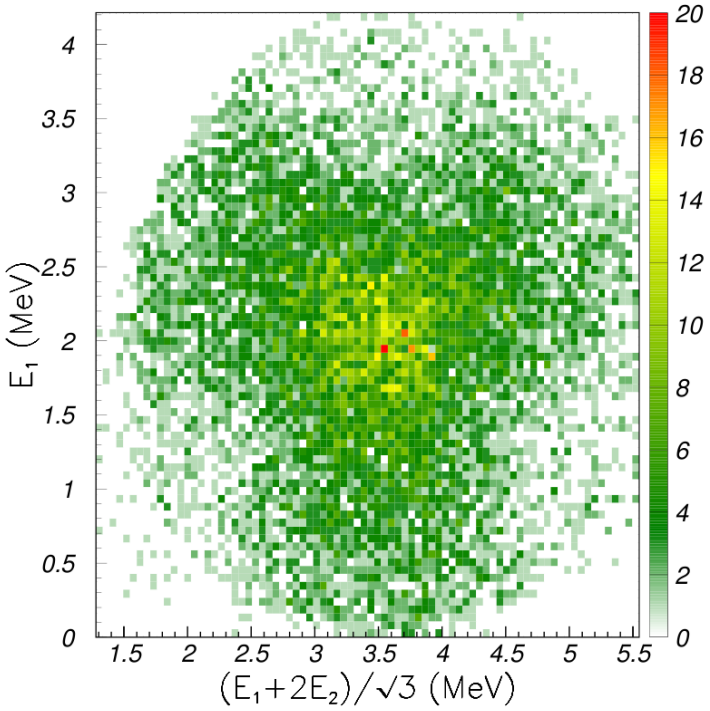


$^{10}B(^{3}He,p\alpha\alpha\alpha)$ multiplicity 4 data

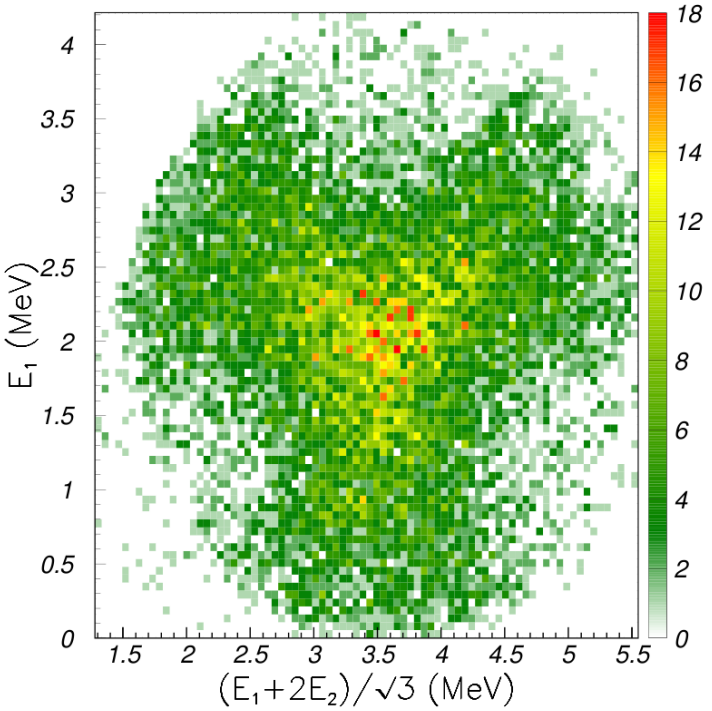
13.35 MeV: 2^- or 4^-?

Which is the J^π of the 13.35 MeV state?





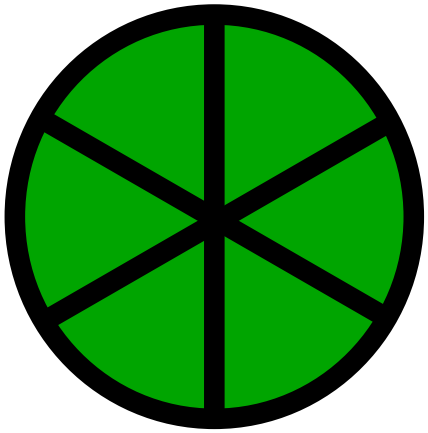
^{10}B(^{3}He,pααα) data

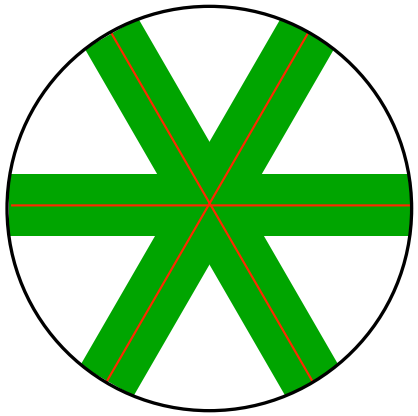


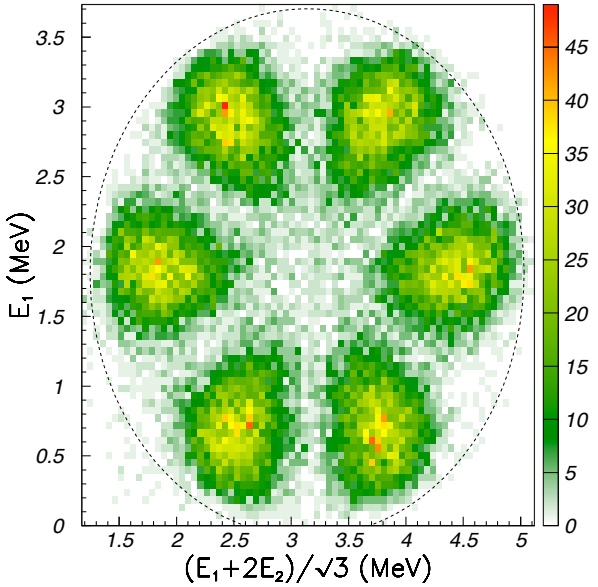
^{11}B(^{3}He,dααα) data

12.71 MeV 1^+ : Decay Mechanism

1. A.A. Korsheninnikov, Sov. J. Nucl. Phys. **52**, 827 (1990)- Democratic
2. R.Alvarez-Rodriguez et al., PRL **99** 072503 (2007)- 3-body Cluster model
3. D.P Balamuth et al., PRC **10** 975 (1974)- Sequential w/ interference

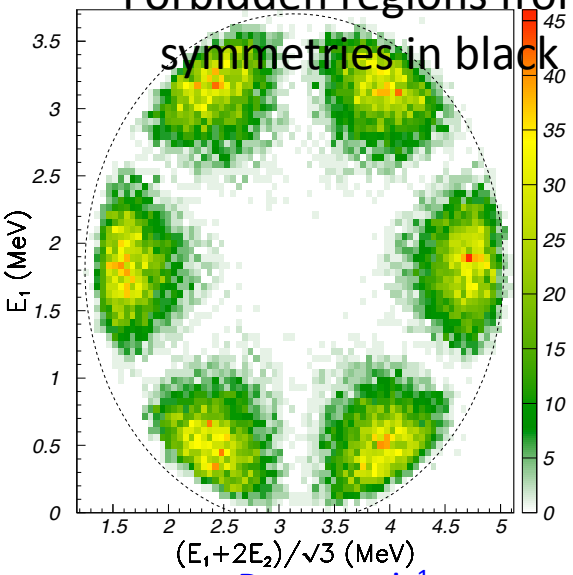






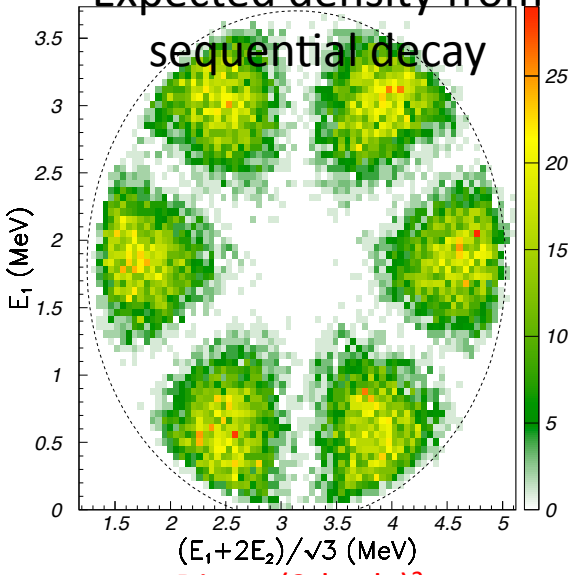
Data

Forbidden regions from symmetries in black

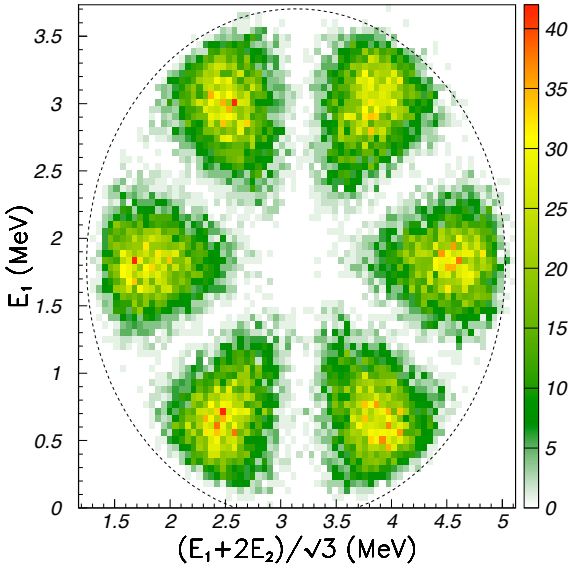


Democratic[1]

Expected density from sequential decay

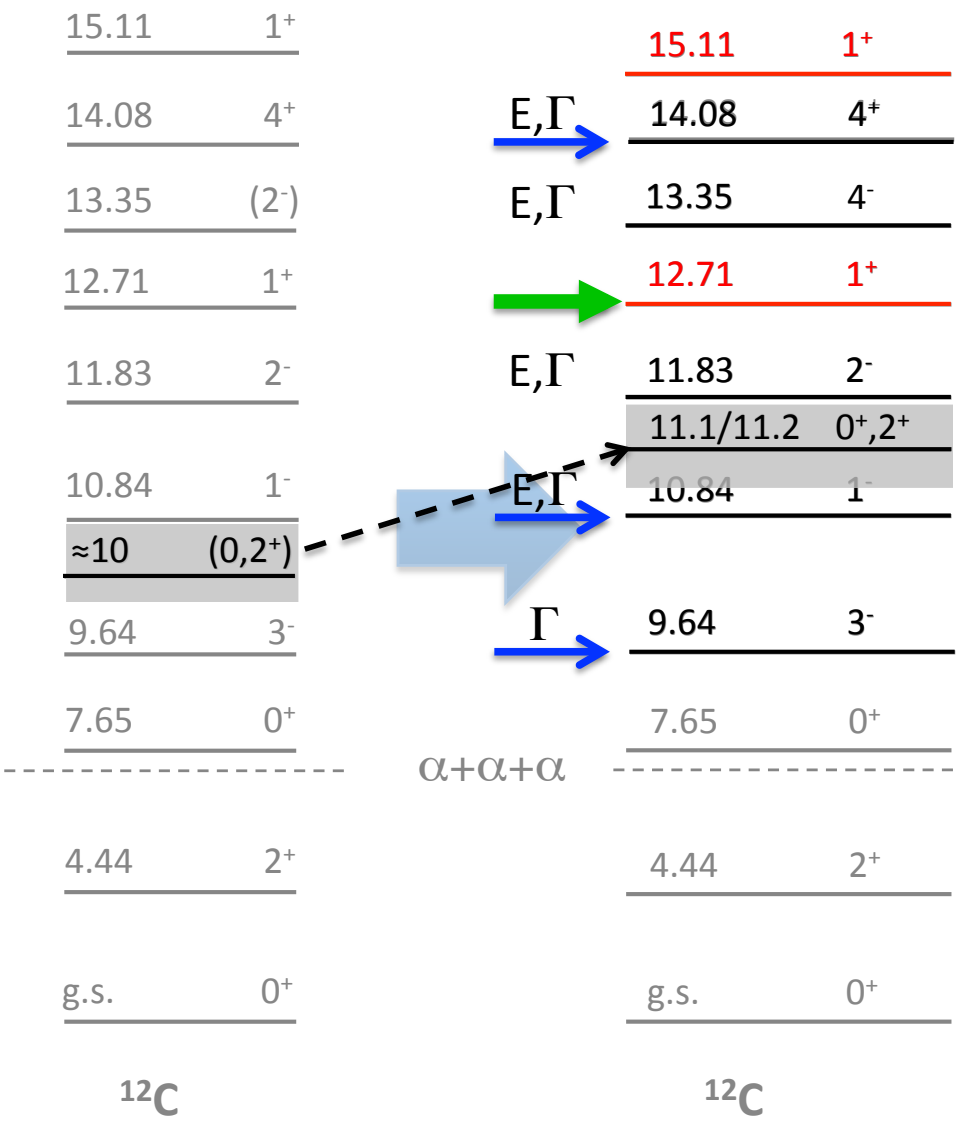


Direct (3-body)[2]



Sequential (R-matrix)[3]

Summary: what have we learned



1. Observation of γ-decay and α-decay of T=1 15.11 MeV state
2. γ-decay of T=0 12.71 MeV state observed to Hoyle state and to the broad 10 MeV state
3. Improved measurements of energy and widths for known states
4. Branching ratios of decay through the ^{8}Be(gs) were measured for natural parity states
5. Studied the decay mechanism of the 12.71 MeV resonance using Dalitz plots
6. Dalitz plots used to determine J^{π} of 13.35 MeV resonance

CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

Collaborators

- H.O.U. Fynbo, **O. Kirsebom**, S. Hyldegaard, K. Riisager
  Department of Physics and Astronomy, Århus University, Denmark

- **M. Alcorta**, M.J.G. Borge, M. Cubero, M. Madurga, A. Perea, O. Tengblad,
  Instituto Estructura de la Materia, CSIC, Madrid, Spain

- B. Jonson, T. Nilsson, G. Nyman
  Fundamental Physics, Chalmers Univ. of Technology, Göteborg, Sweden

- B. R. Fulton, C. Aa Diget
  University of York, United Kingdom.