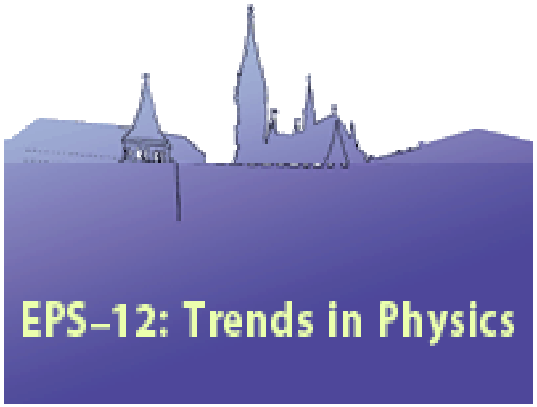
Multi-particle emission



Symposium on

Approaching the Drip-line for Unstable Nuclei

Budapest 29 August 2002

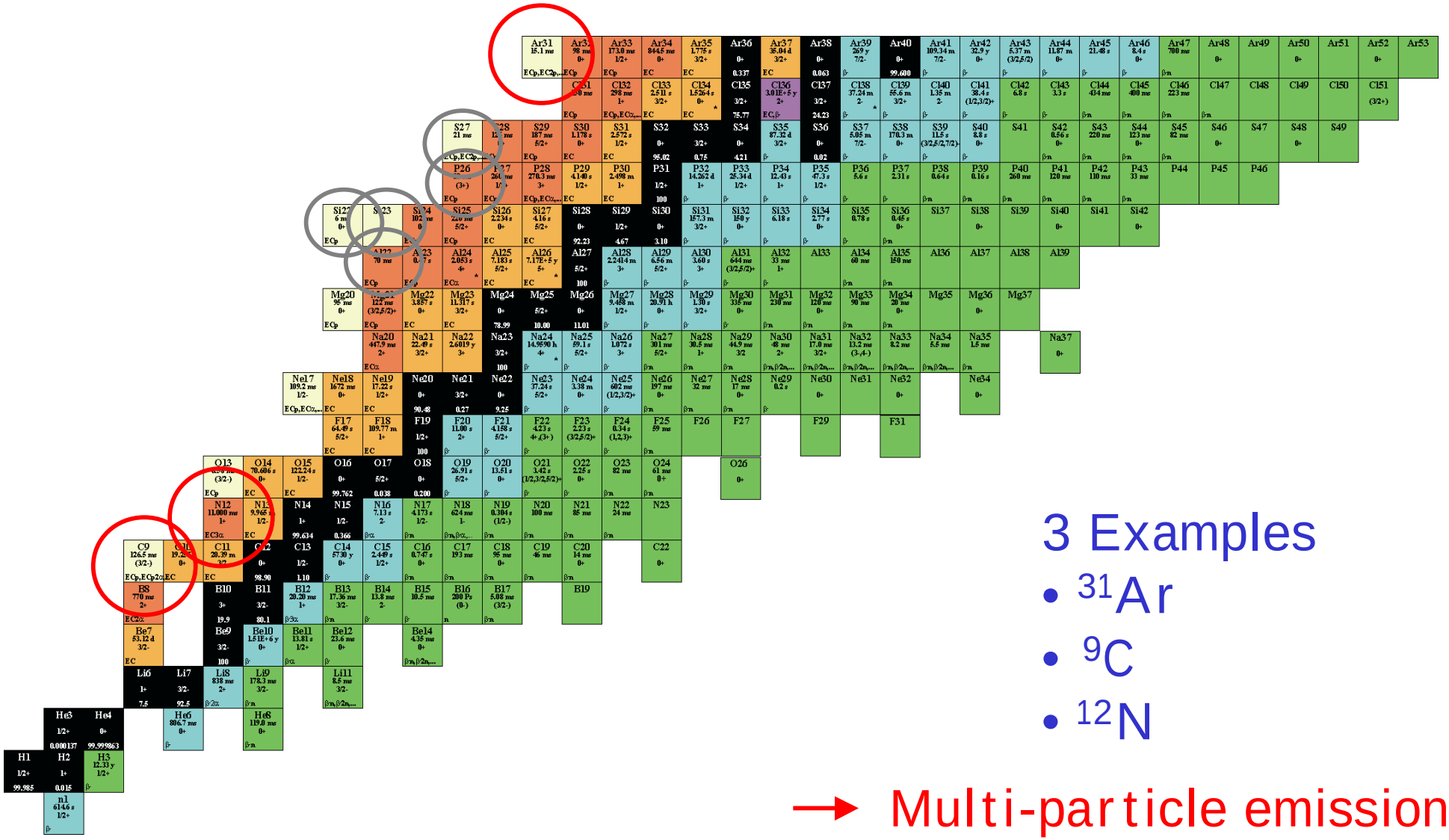
H.O.U. Fynbo

Department of Physics, University of Aarhus, Denmark

Århus-Göteborg-Madrid-Darmstadt collaboration

Decay Modes Near the Driplines

Decay Q-values increase and separation energies decrease



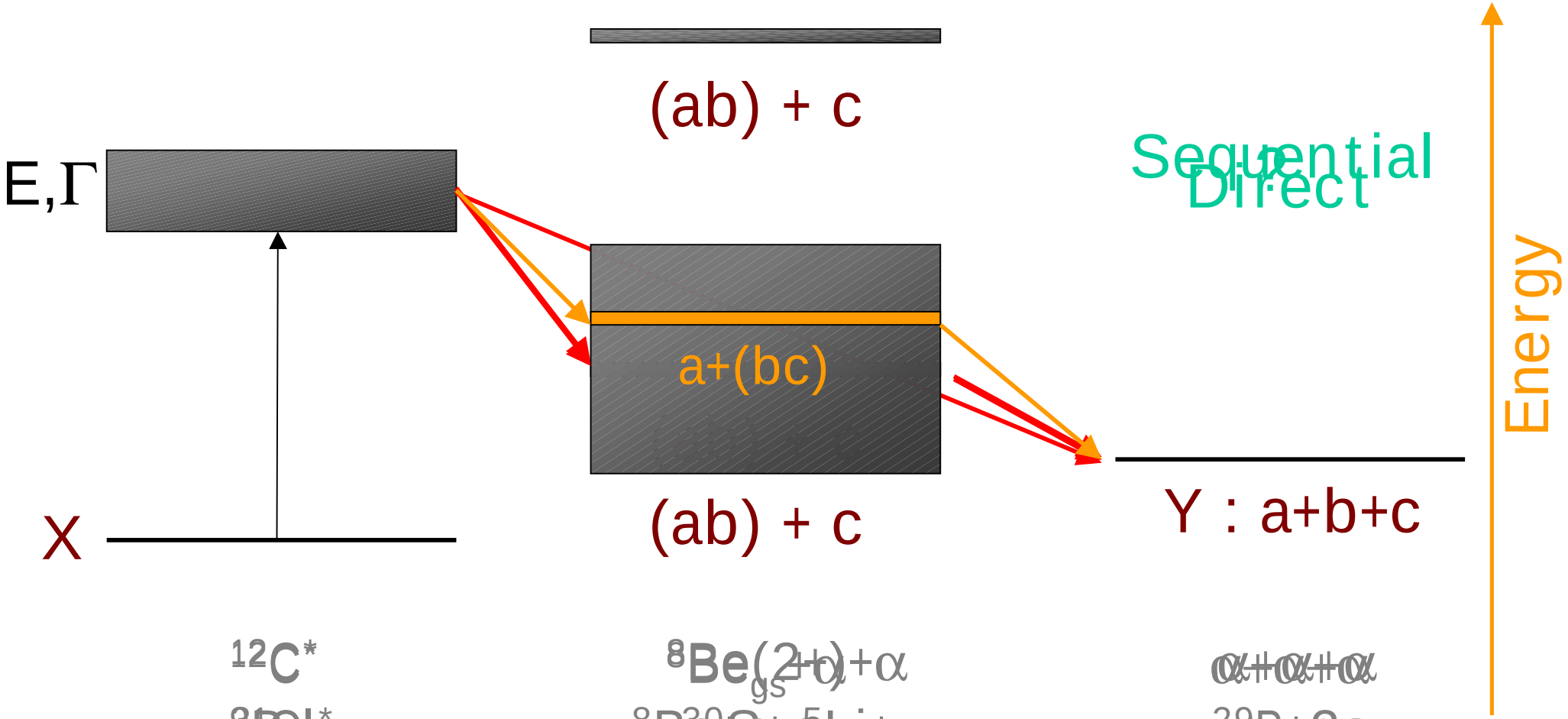
3 Examples

- ^{31}Ar
- ^{9}C
- ^{12}N

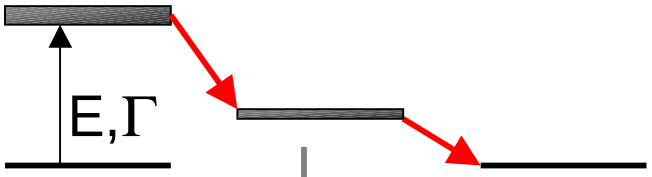
→ Multi-particle emission

Break-up to Multi-particle Final States

Initial state X	: Some (nuclear) state
Final state Y	: Three (or more) particles



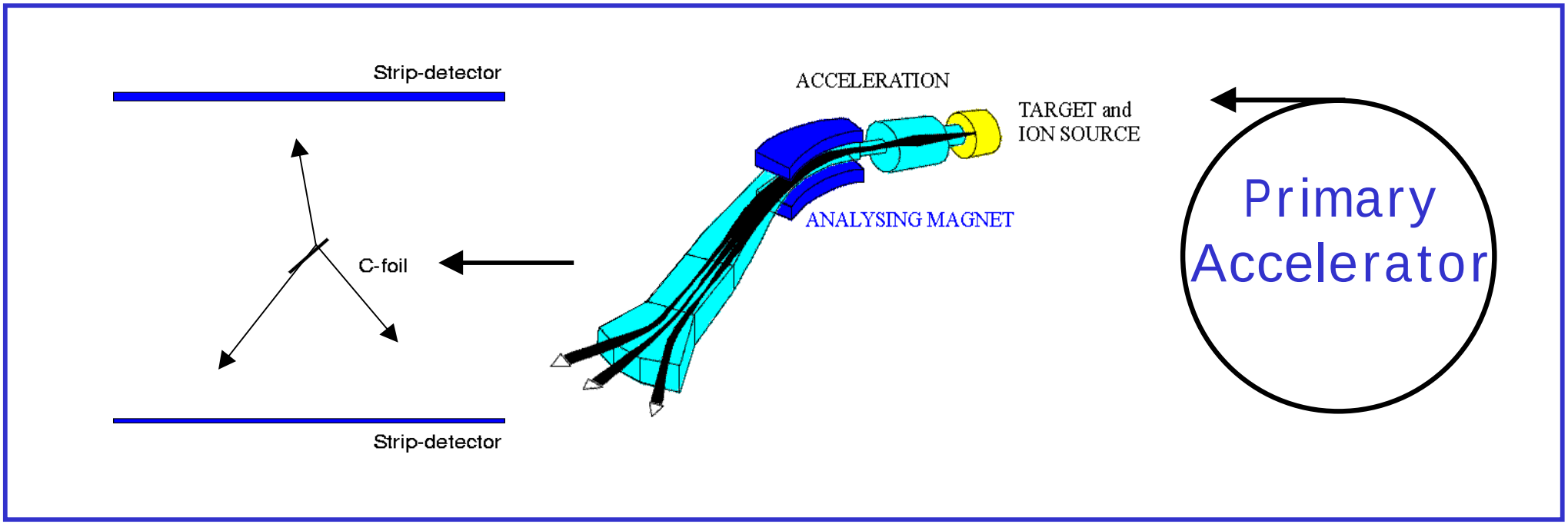
Questions



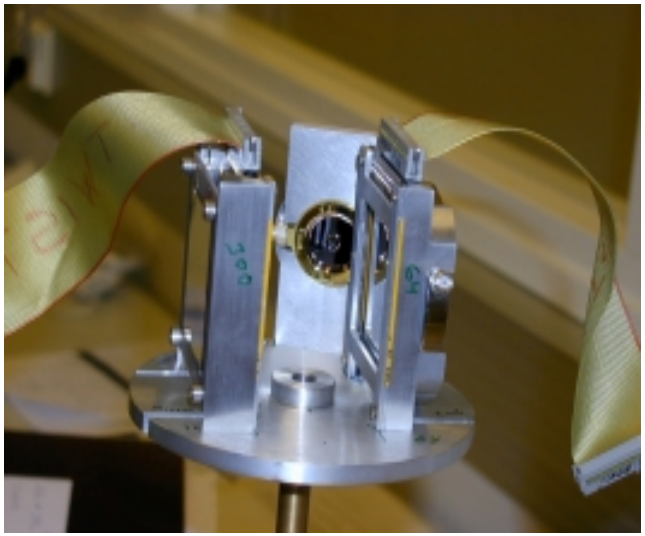
What is :

- E,Γ ?
  - -Often difficult to Measure
- Spin-parity?
  - - Selection rules
- The structure of the state?
  - -Cluster states
  - -Many-body states
- The mechanism of the break-up?
  - -Sequential or direct?
  - -Importance of different channels
- Relation to state structure
- Assymptotic Spectra
  - -Observable
  - -Energy and angular correlations

Experimental techniques



- ISOL method
- β-decay to populate state of interest
  - clean and selective
- Use DSSSDs for complete kinematics
  - Large solid angle (rare events)
  - High Segmentation (avoid summing)
  - Effective Readout

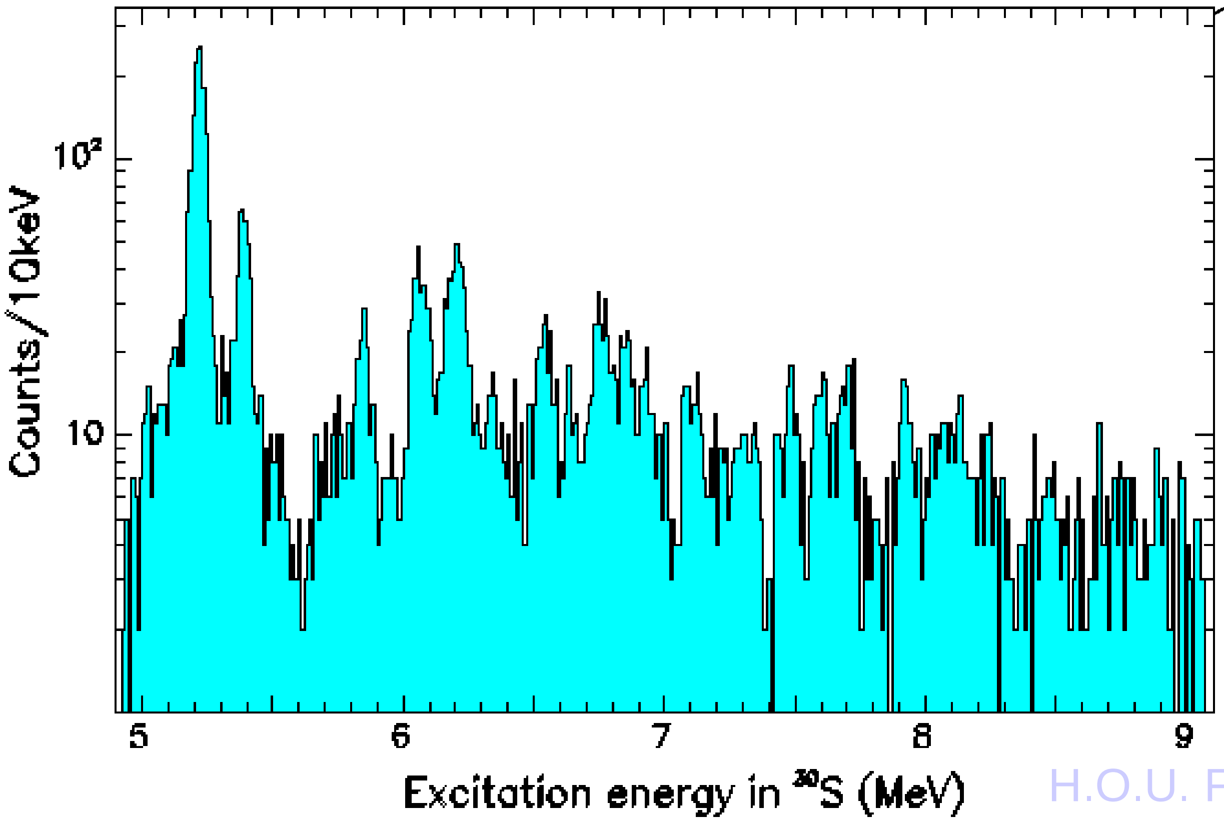


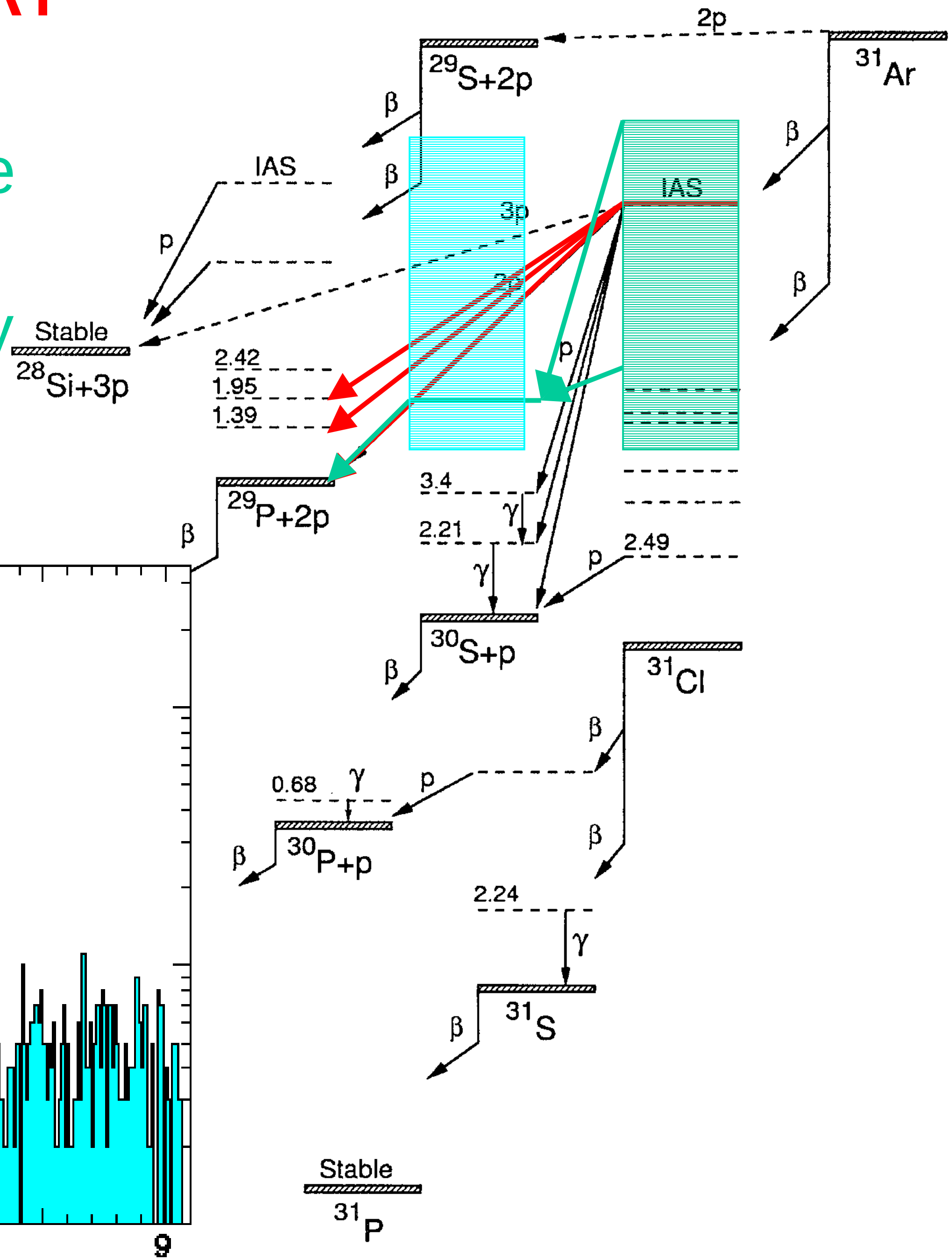
The decay of ^{31}Ar

From these diagonals we extract information on ^{30}S unbound states

Decay of IAS through 2p emission

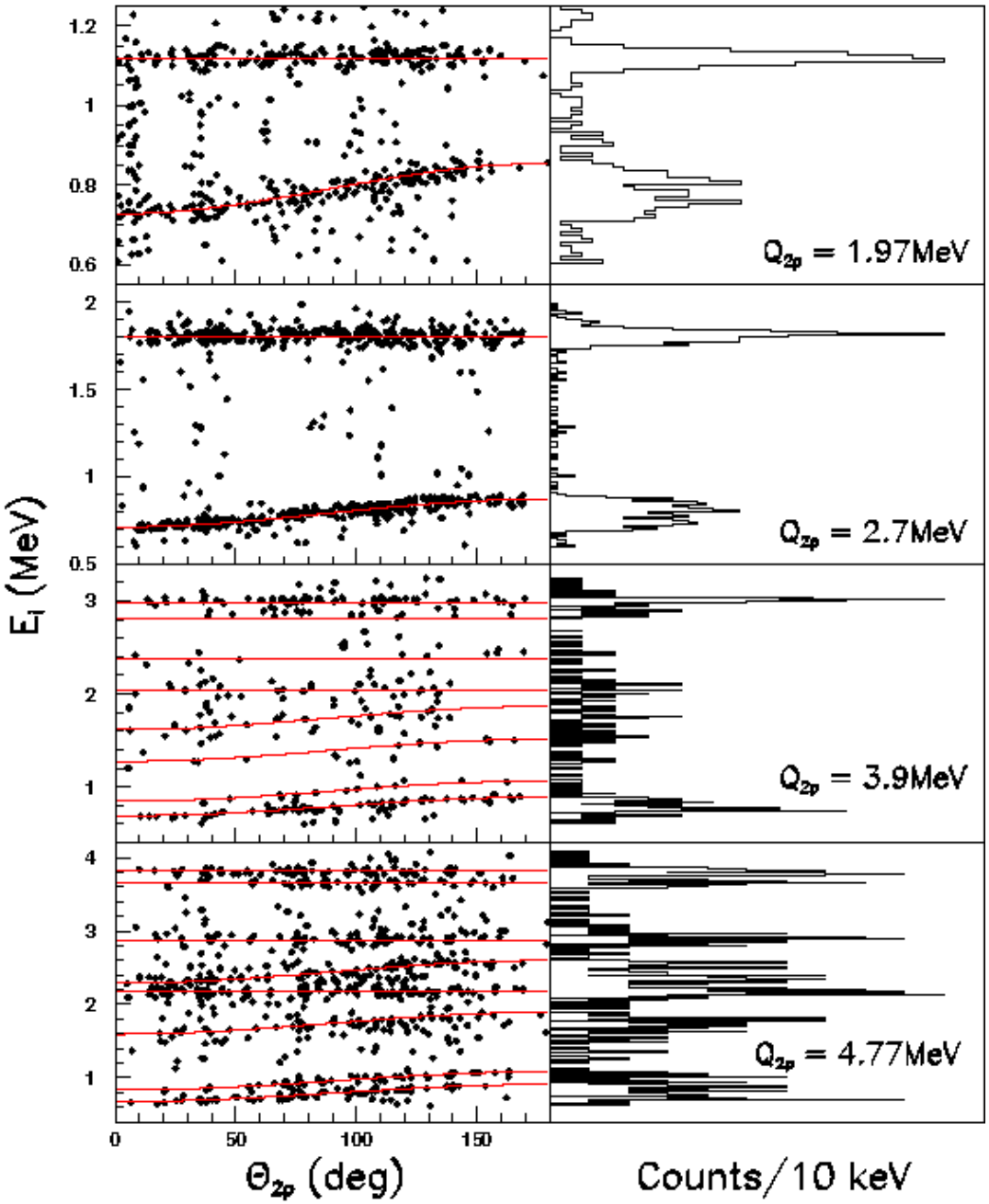
Diagonal from decay via single intermediate state from many initial states fed in beta-decay

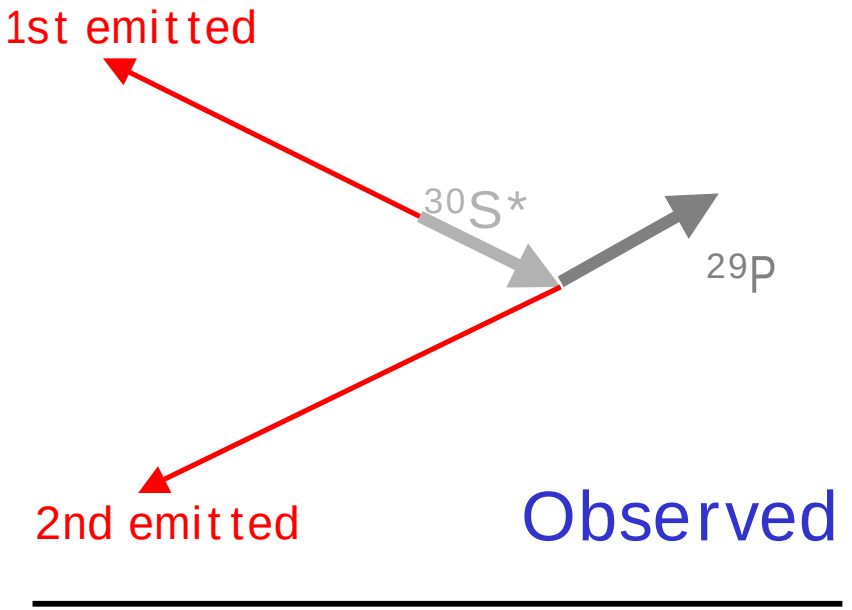


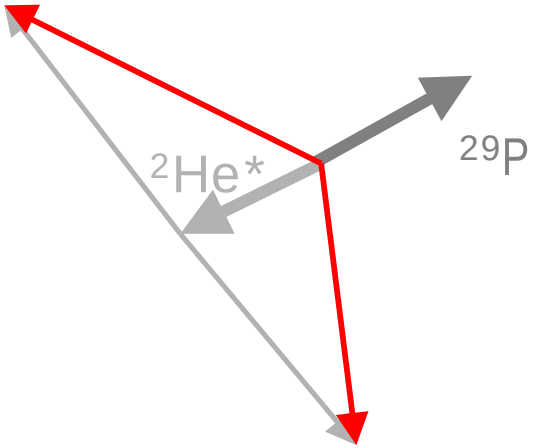


H.O.U. Fynbo *et al.* Nucl. Phys. **A677** (2000) 38

Kinematics of 2p-transition





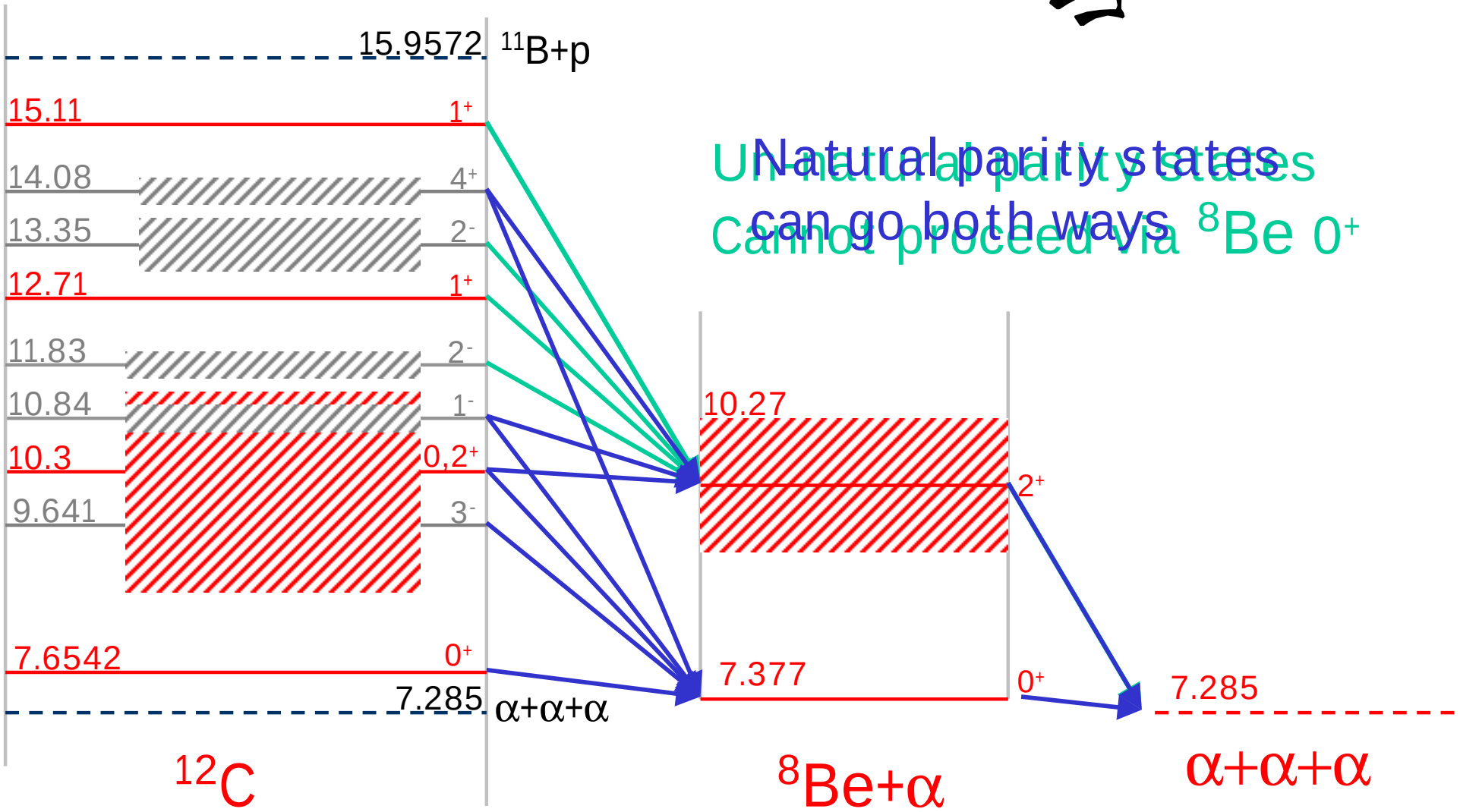


Not Observed

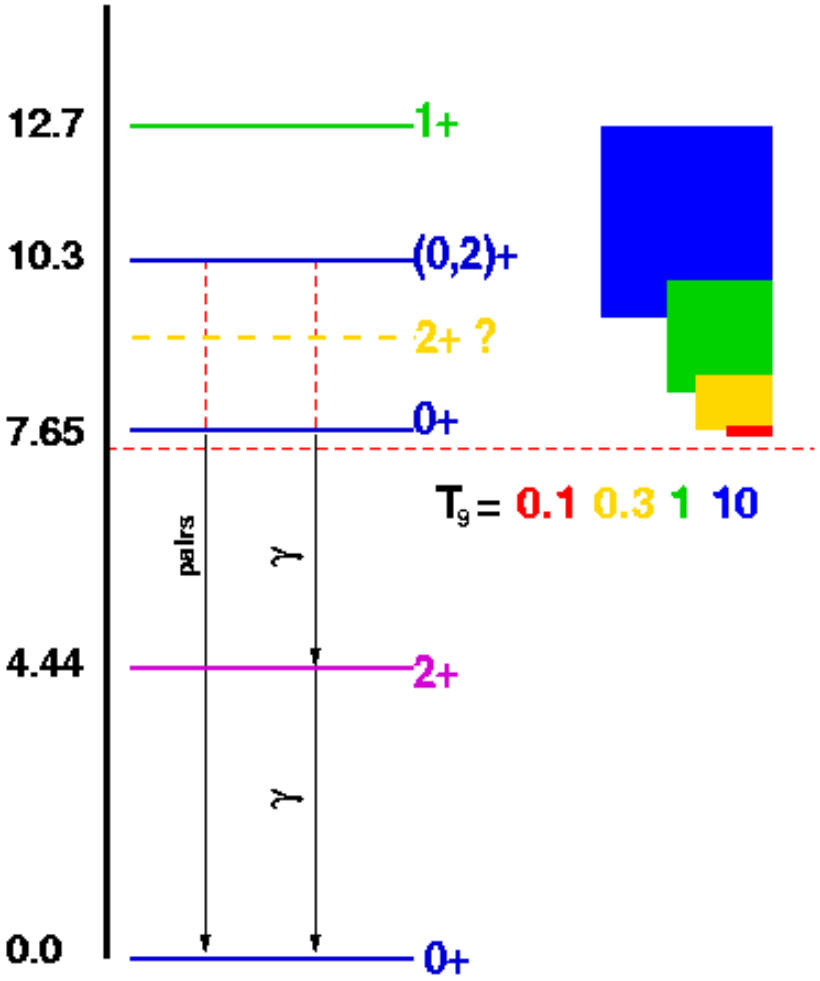
Properties of states in ^{12}C

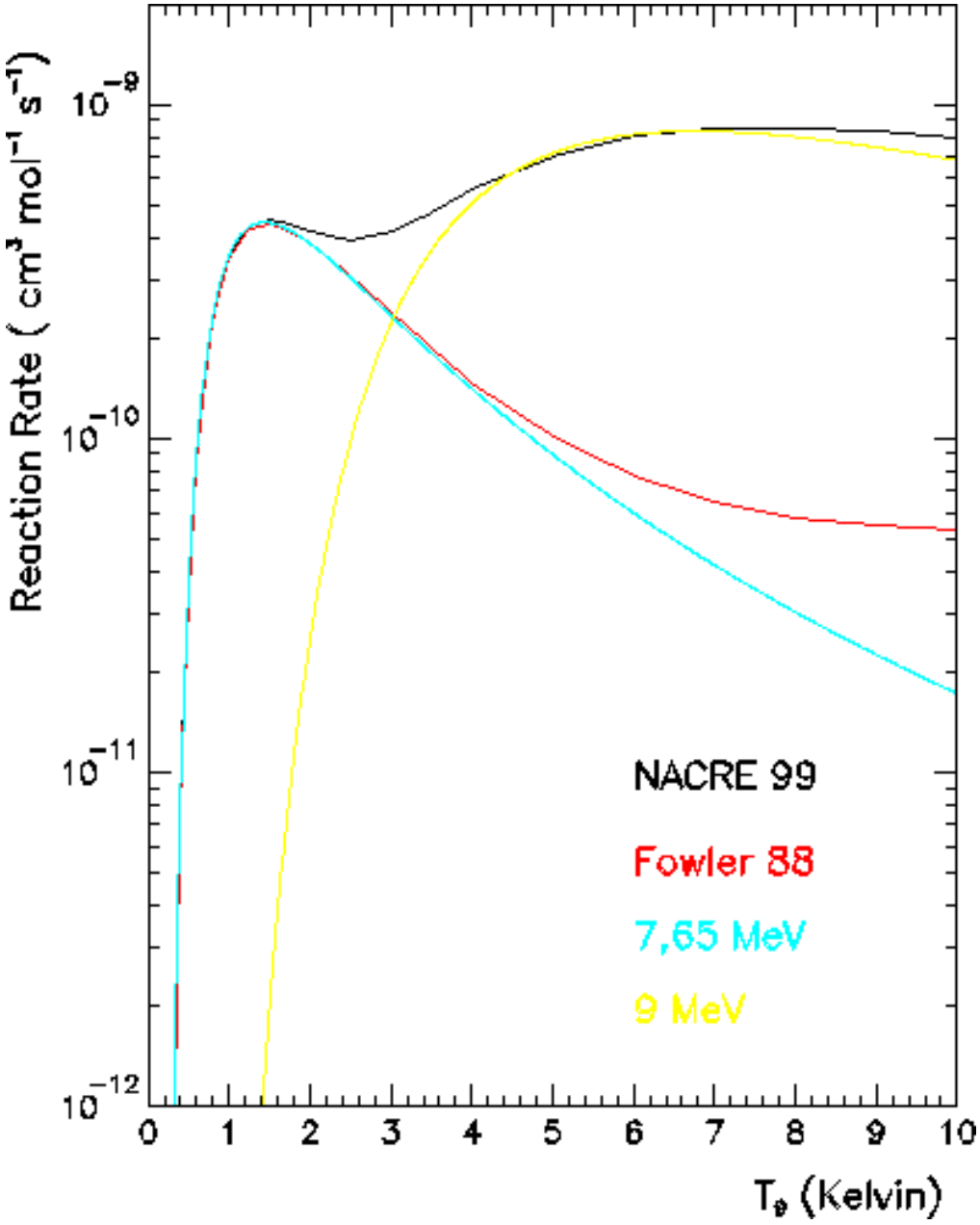
Width ↔ Decay ↔ Structure

Isn't it all Known ?



The triple-α reaction rate





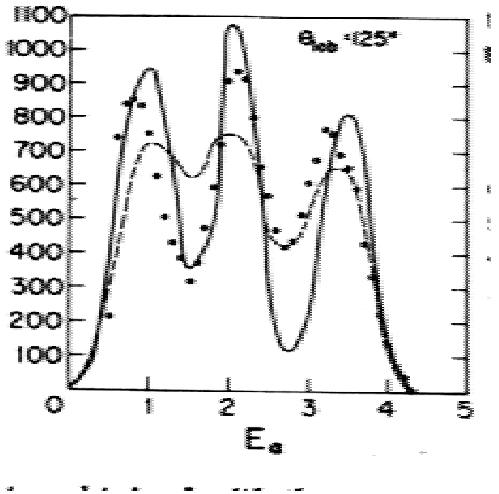
Known Break-up Properties

E_{level} / MeV	J^{π}	Γ_{level}	$^{8}Be\ (0^{+})$	$^{8}Be\ (2^{+})$
7.6542(15)	0^{+}	8.5(1.0) eV	>96%	<4%
9.641(5)	3^{-}	34(5) keV	>96%	<4%
10.3(3)	0^{+}	3.0(7) MeV	>90%	<10%
10.849(25)	1^{-}	315(25)keV	Strong	Yes
11.828(16)	2^{-}	260(25)keV	No	Yes
12.710(6)	1^{+}	18.1(2.8) eV	No	Yes
13.352(17)	2^{-}	375(40)keV	No	Yes
14.083(15)	4^{+}	258(15)keV	17(4)%	83(4)%
15.110(3)	1^{+}	43.6(1.3) eV	No	Yes

natural/un-natural parity

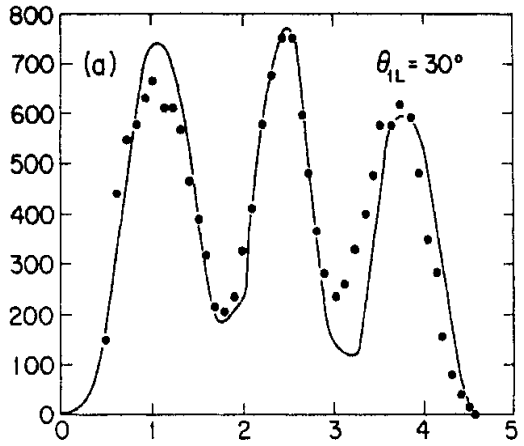
Breakup of the 12.71 MeV state in ^{12}C

Balamuth, Zurmuhle and
Tabor Phys. Rev. **C**10 (1974) 975



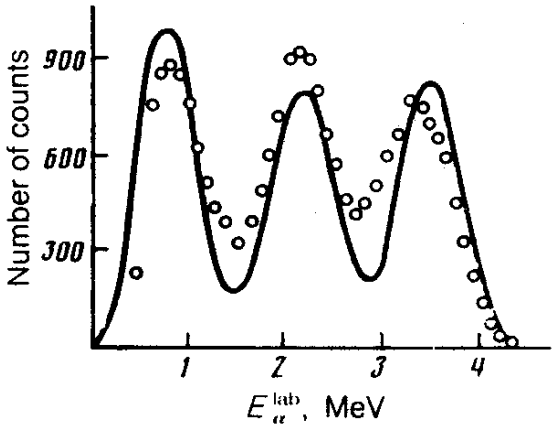
R-matrix based
sequential
break-up with
order-of-emission
interference

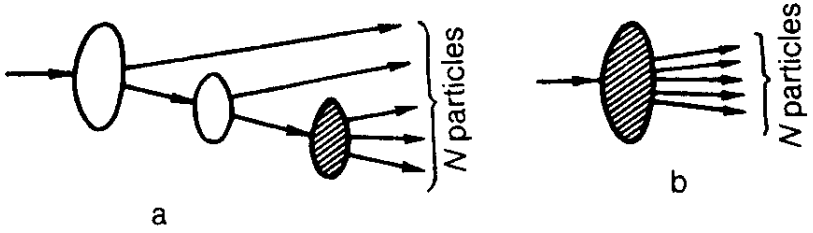
Tohru Takahashi
Phys. Rev. **C**16 (1977) 529



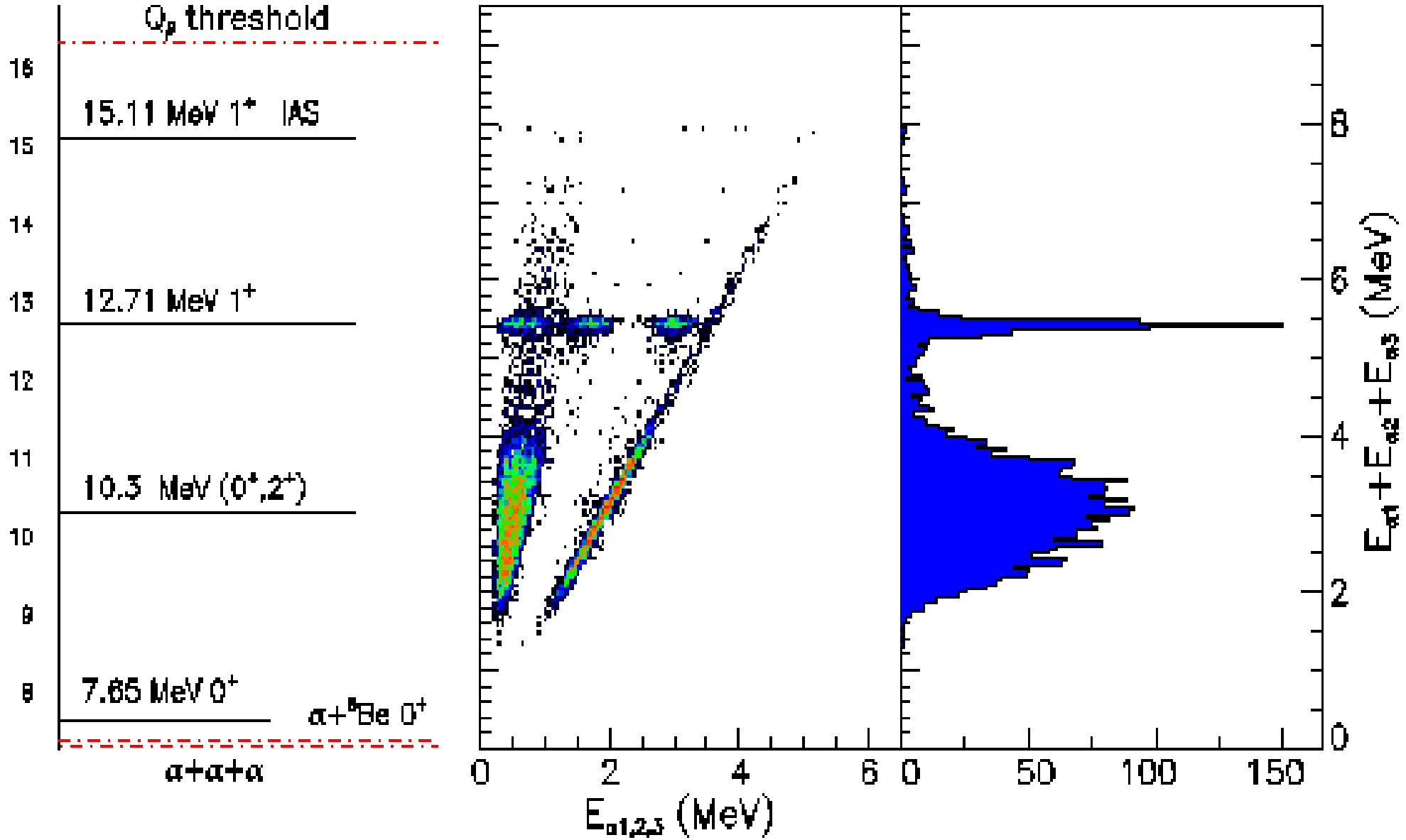
Faddeev equations
with a separable
Potential describing
the α–α interaction.

A.A. Korshenninikov Sov. J. Nucl. Phys. **52** (1990) 827

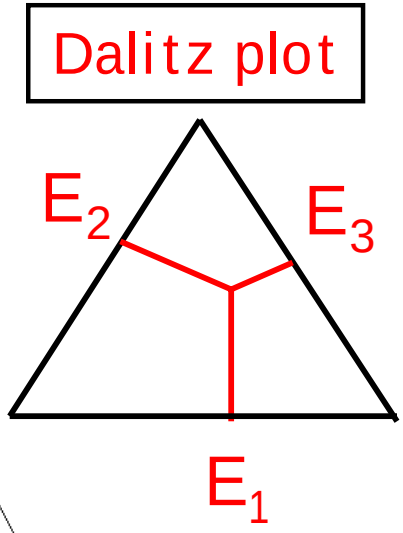


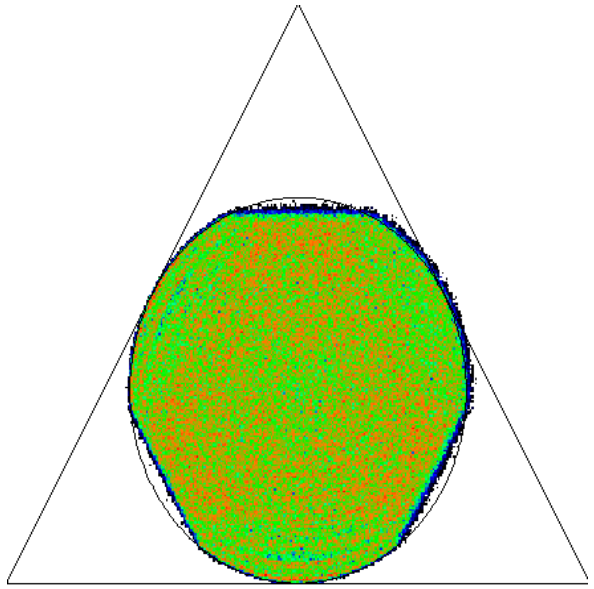


Hyperspherical Harmonics expansion.
Simultaneous emission.

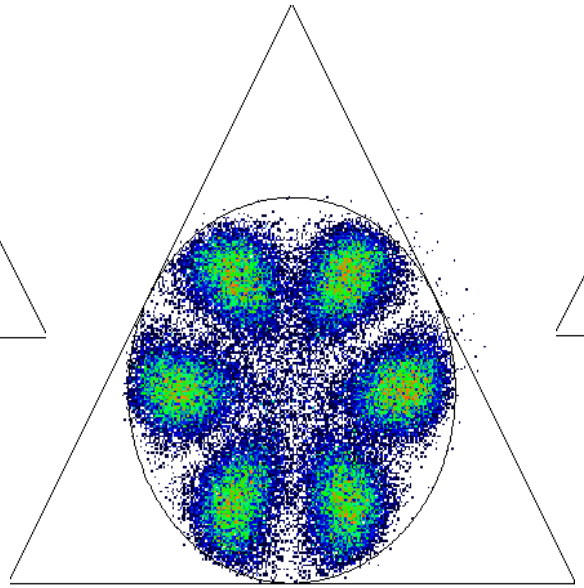

Multiplicity=3 data – Analysis June 2002
Q_p threshold
15.11 MeV 1⁺ IAS
12.71 MeV 1⁺
10.3 MeV (0⁺,2⁺)
7.65 MeV 0⁺
α+⁸Be 0⁺
α+α+α
16
15
14
13
12
11
10
9
8
0
2
4
6
$E_{\alpha 1,2,3}$ (MeV)
0
50
100
150
$E_{\alpha 1}+E_{\alpha 2}+E_{\alpha 3}$ (MeV)
8
6
4
2
0

The 12.71MeV state: Dalitz plots for M2

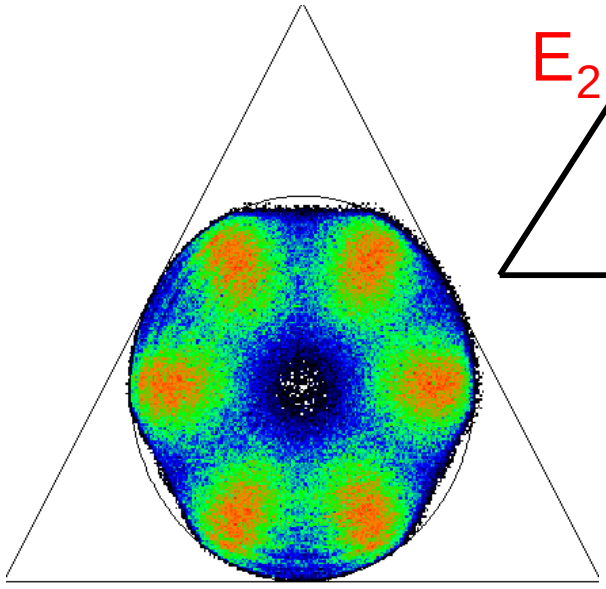




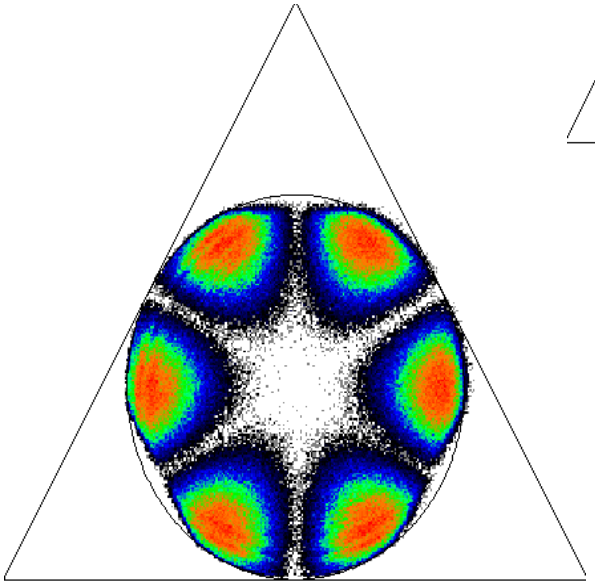
Phase space



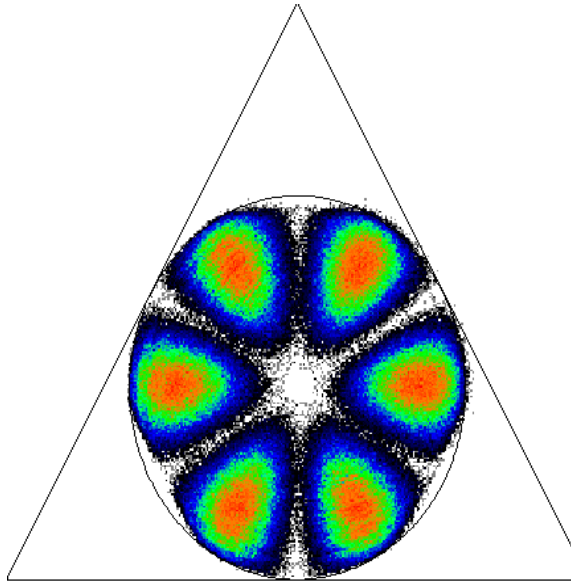
Data



R-matrix

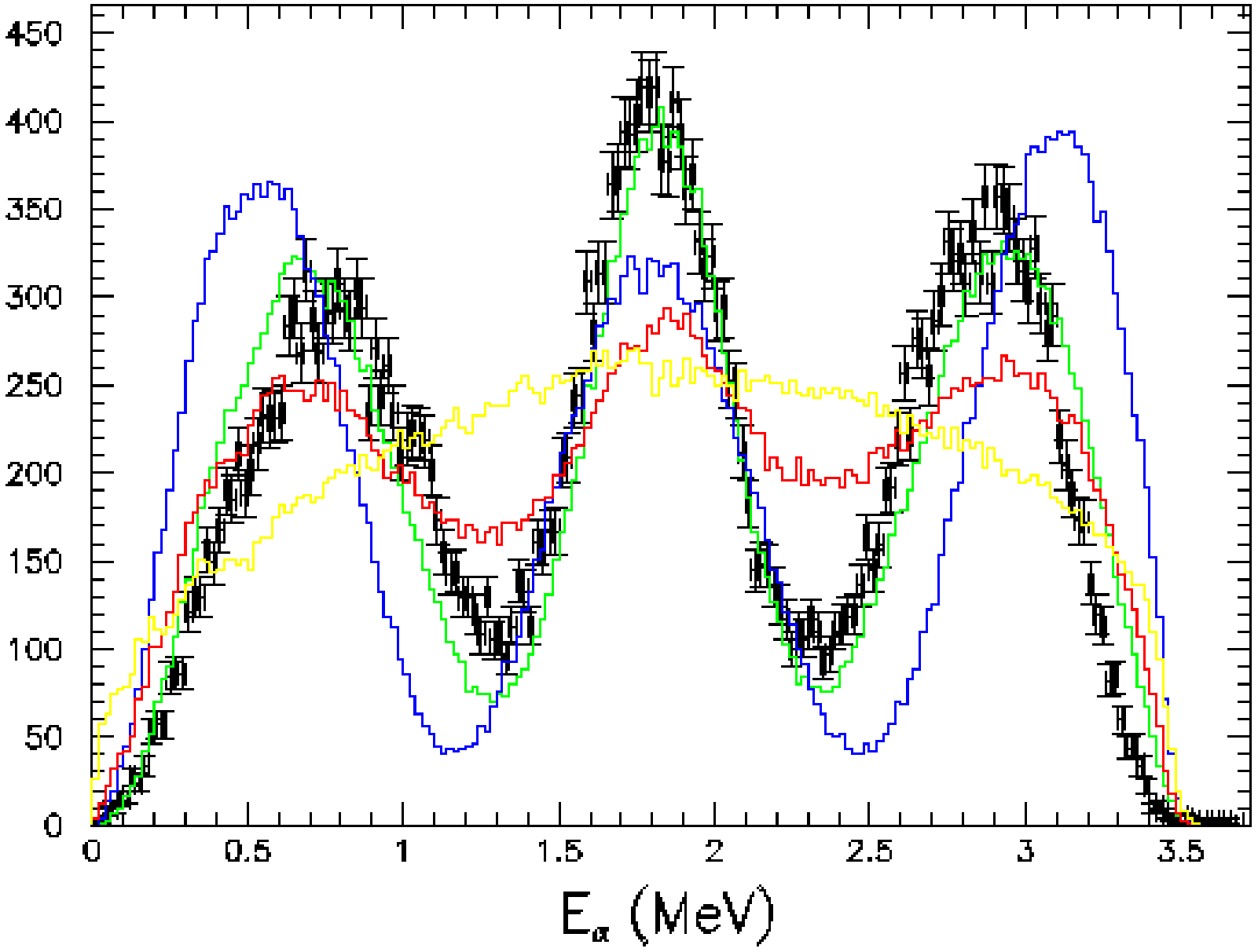


Democratic



R-matrix+interference

The 12.71MeV state: Individual energies for M2



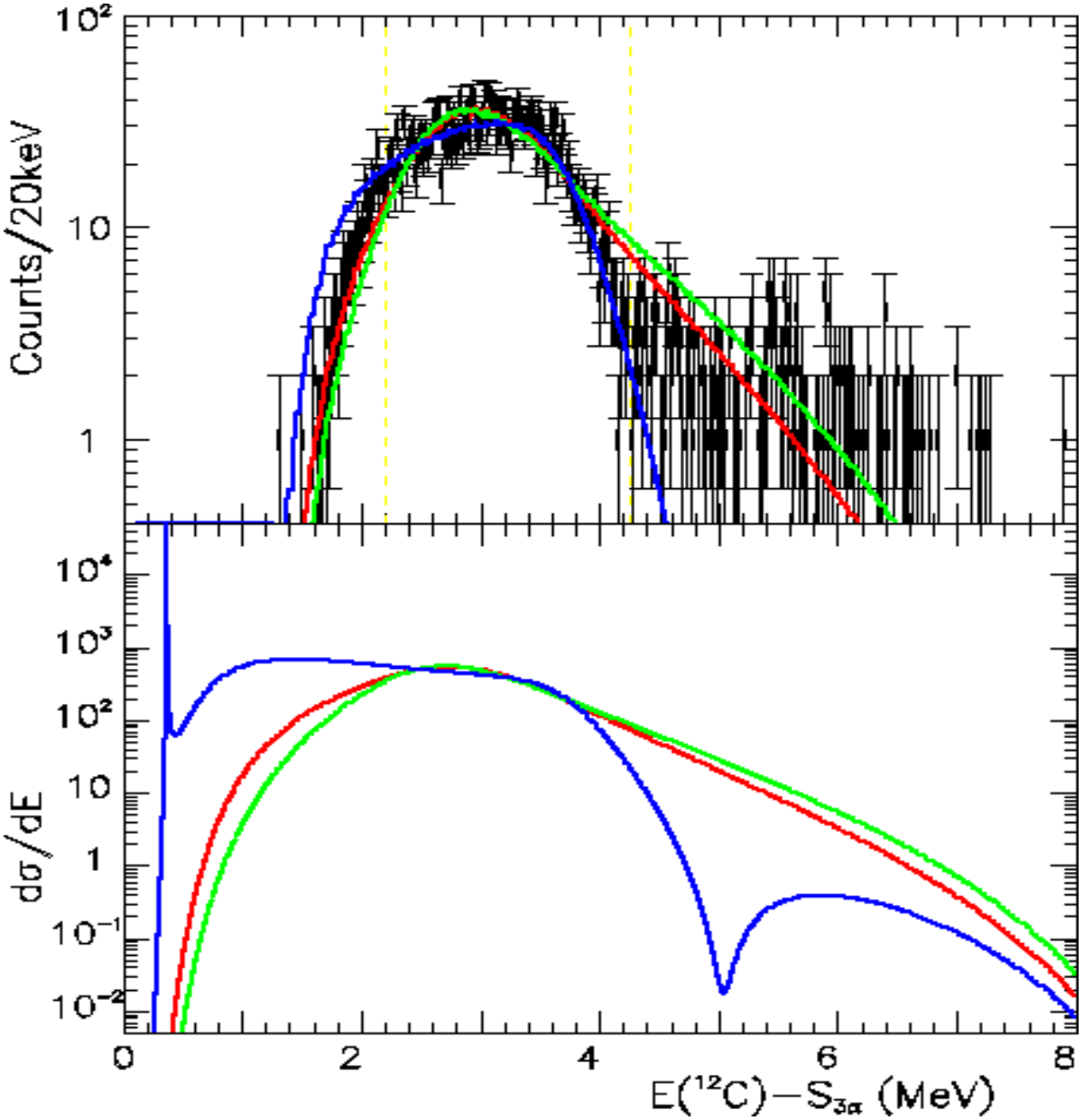
Phase space

R-matrix + interference

R-matrix

Democratic

The Nature of the “10Mev” State



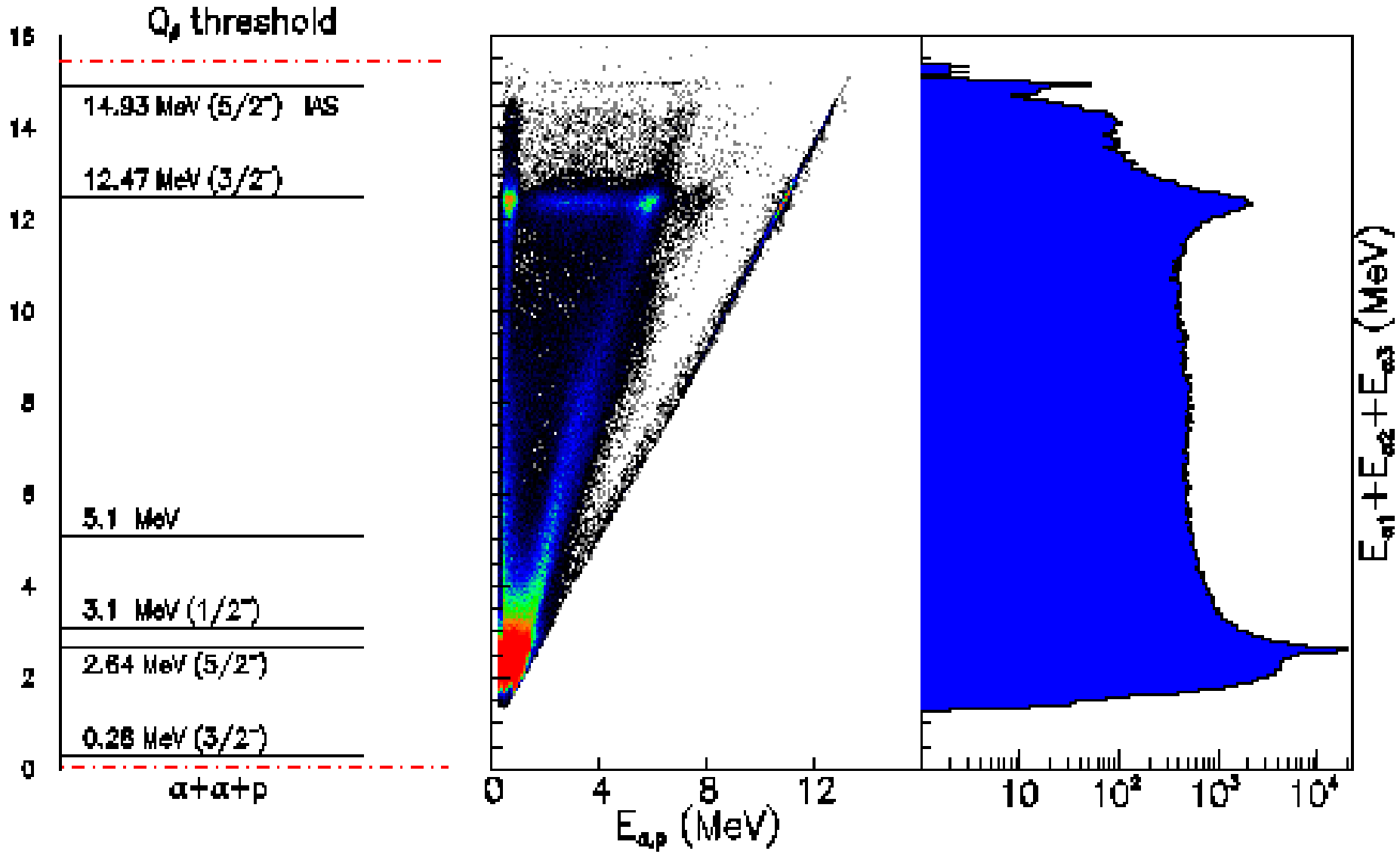
0^+ state

2^+ state

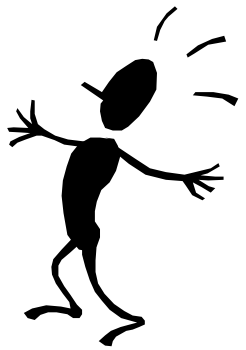
0^+ state including interference with ghost anomaly

fit region

Unbound states in ^{9}B from ^{9}C β-decay

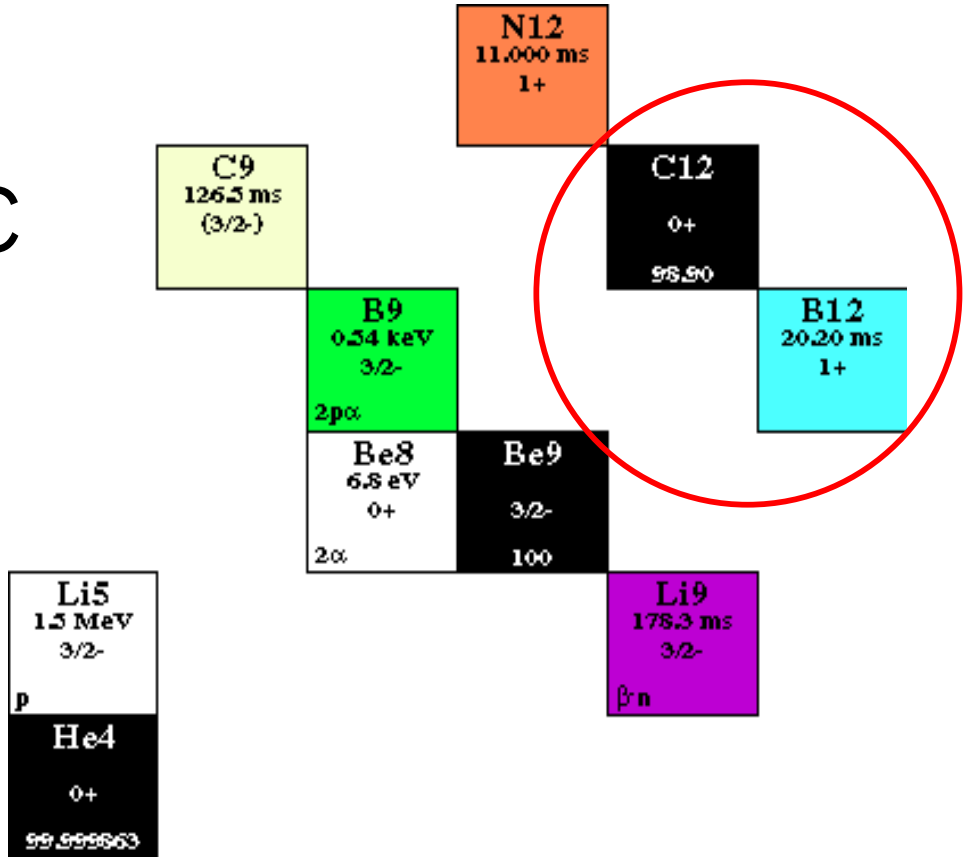


The future: ^{12}B



- Dedicated measurement of the β-decay of ^{12}B for the question of 0^+ and 2^+ states in ^{12}C

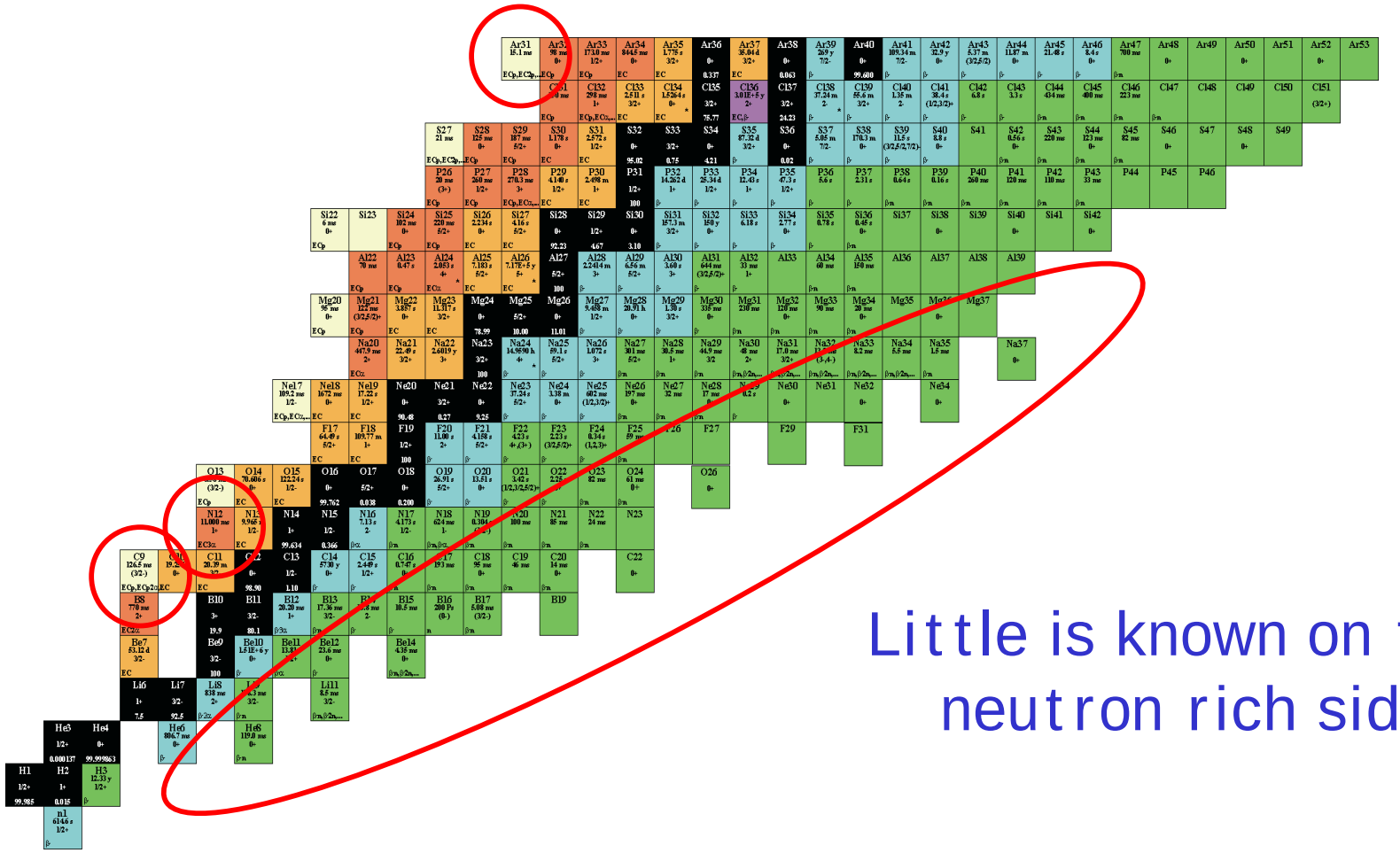
  - ^{12}B can be produced indirectly via ^{12}Be
  - Very high yield



IS404 October 2002

Summary and Outlook

- Far from β-stability exotic decay modes become dominating
- β-decay a natural way to reach unbound states



Little is known on the neutron rich side