Heavy-ion radiative capture

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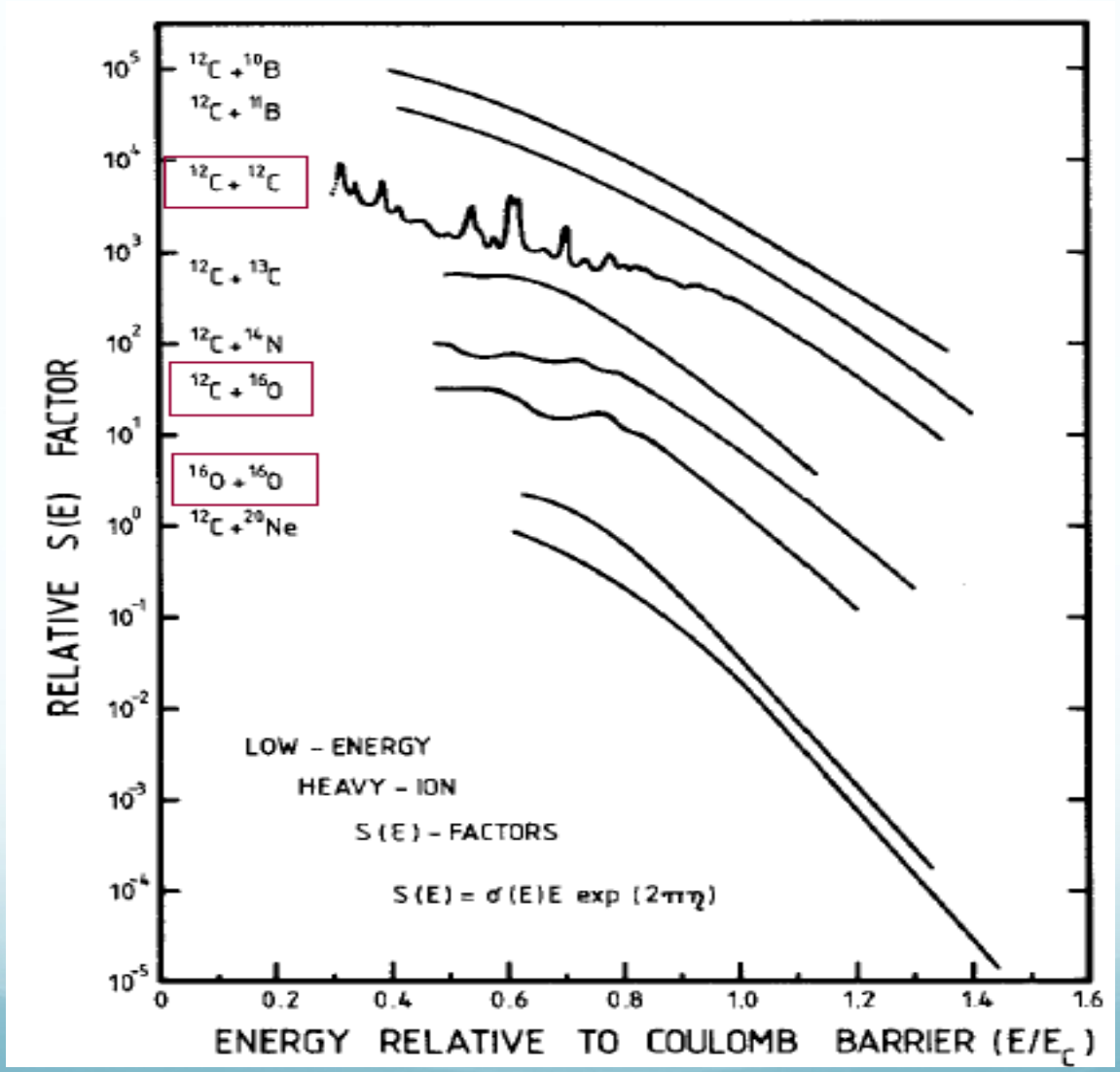
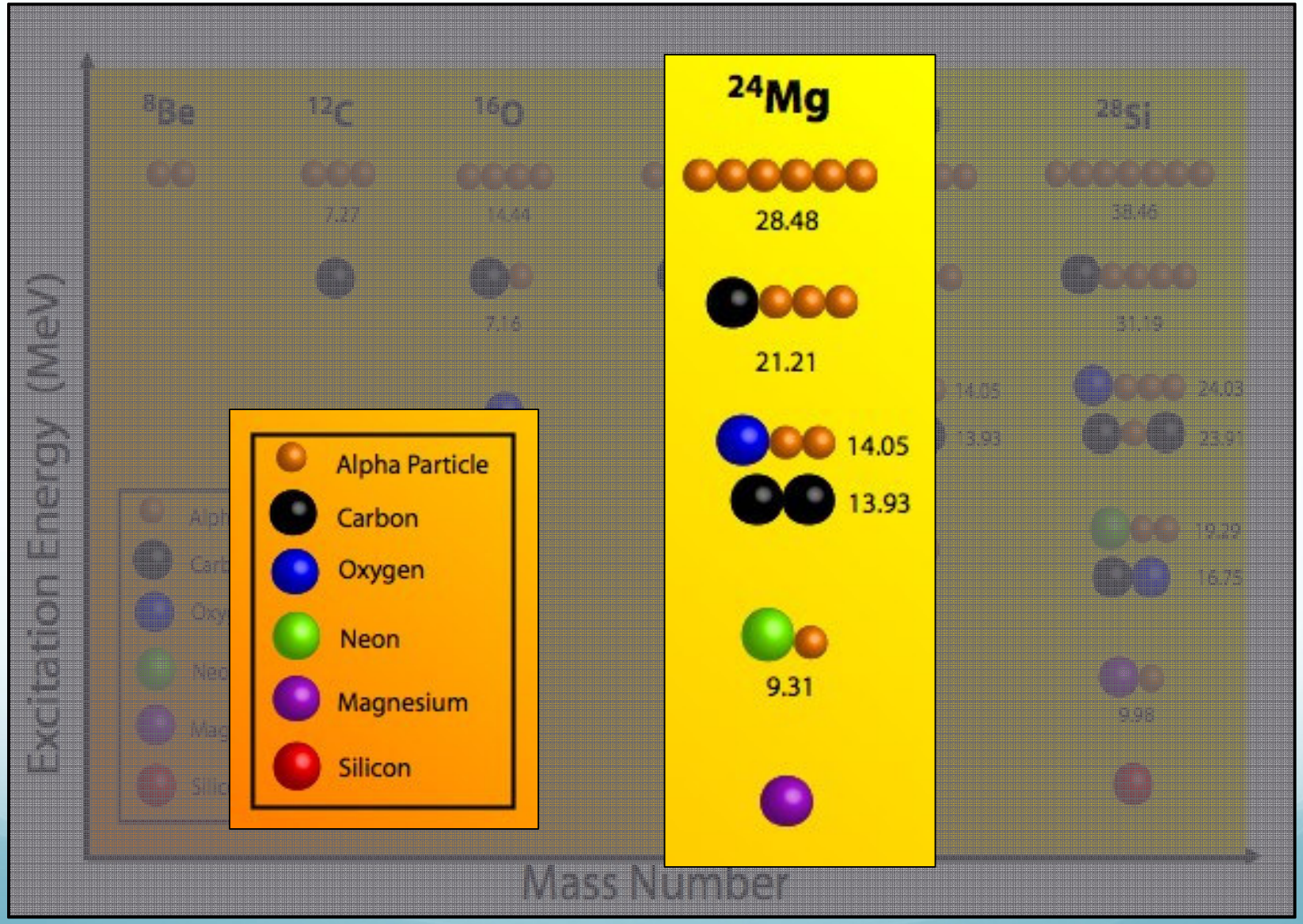
THE UNIVERSITY of York

The mystery of $^{12}C+^{12}C$



Ikeda Diagram



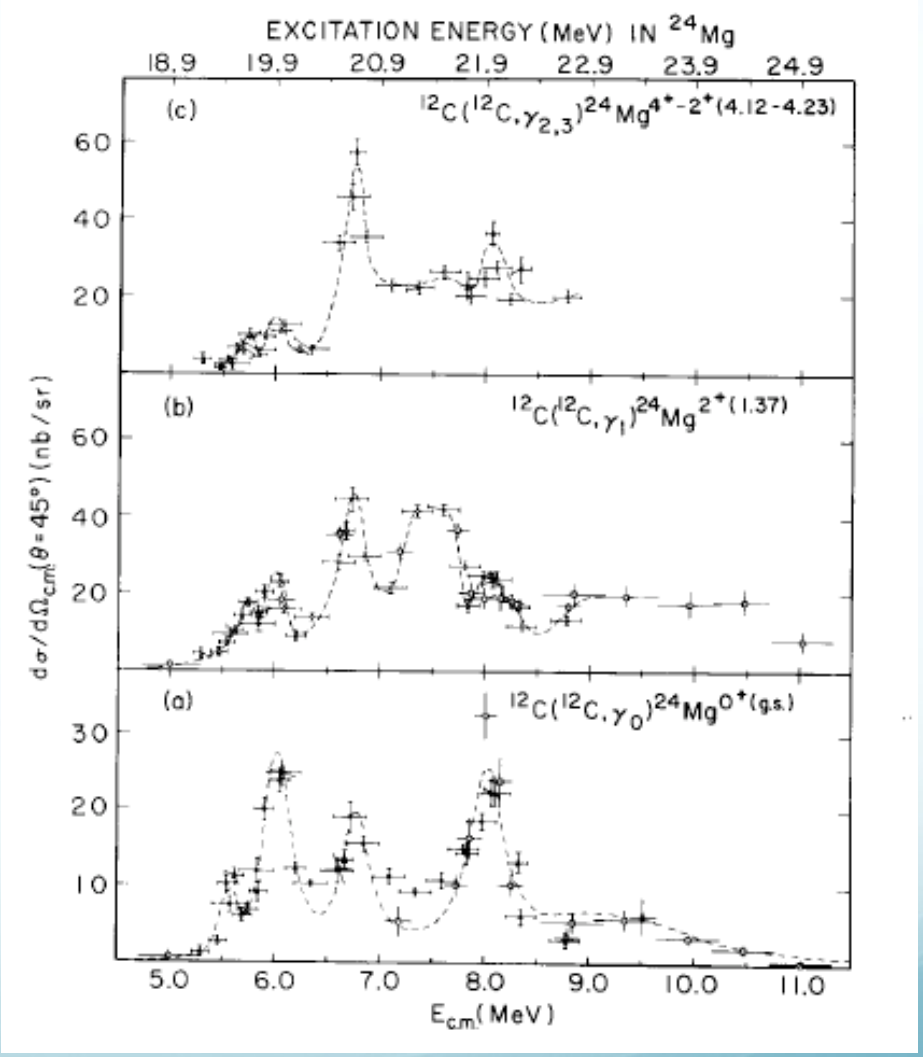
Heavy ion radiative capture

Direct connection between "molecular resonances" and low-lying structure of ^{24}Mg

Open questions:
What is the origin of the resonances?

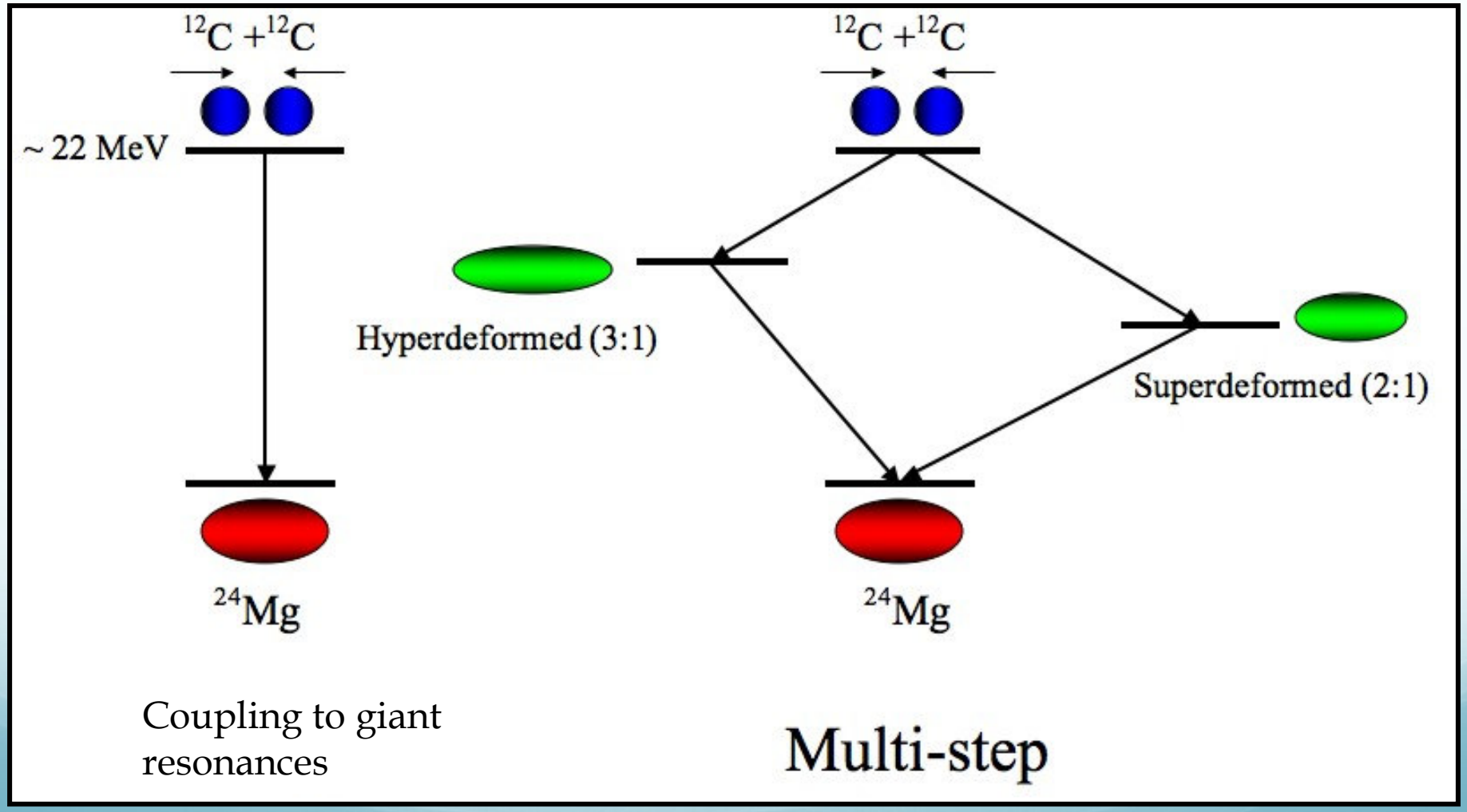
What is the relationship to "time-inverse" reactions e.g. electrofission and break-up?

Is the radiative capture process statistical or does it have structural dependence?

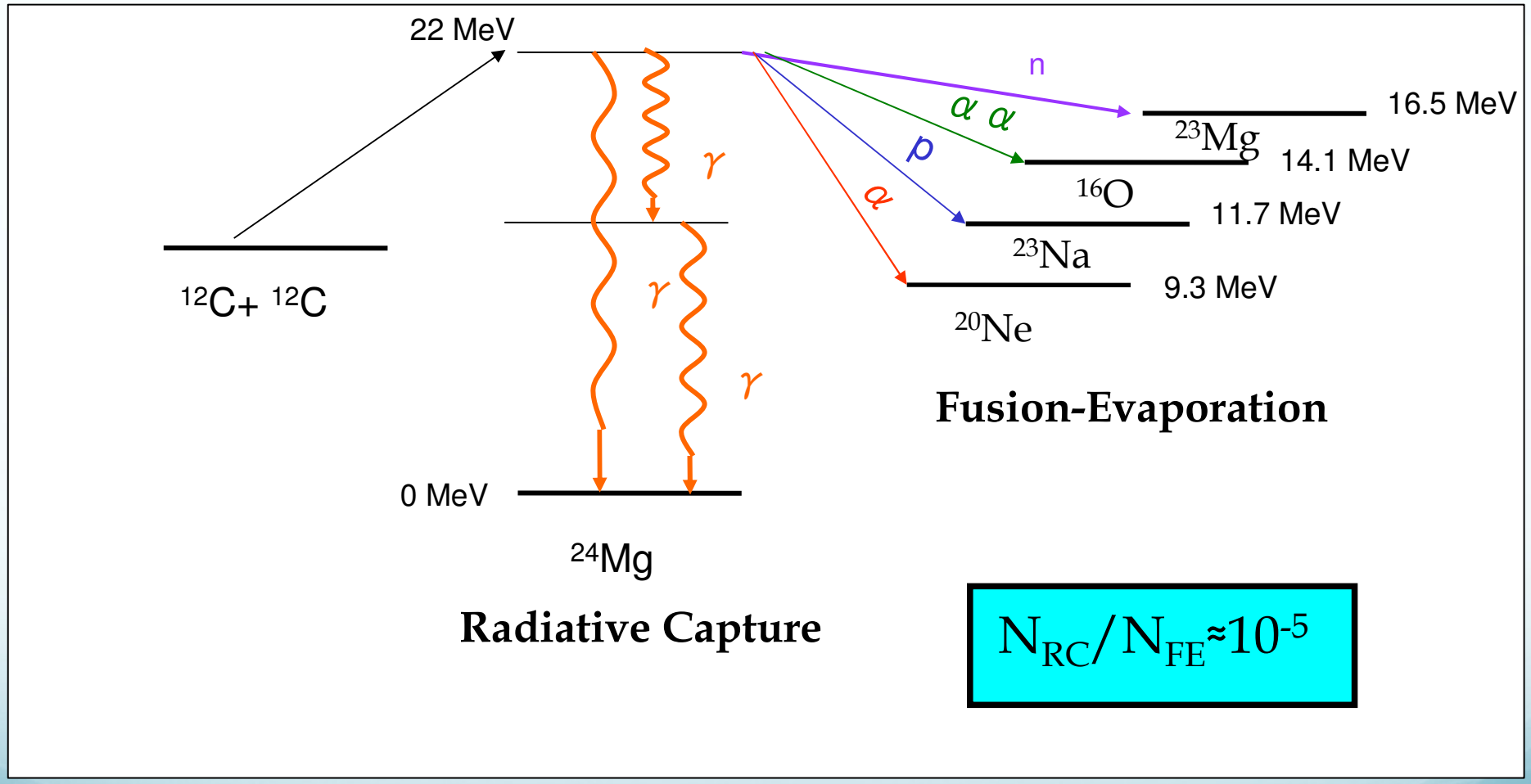


A.M. Nathan, A.M. Sandorfi and T.J. Bowles, Phys. Rev. C 24, 932 (1981)

Decay Pathways

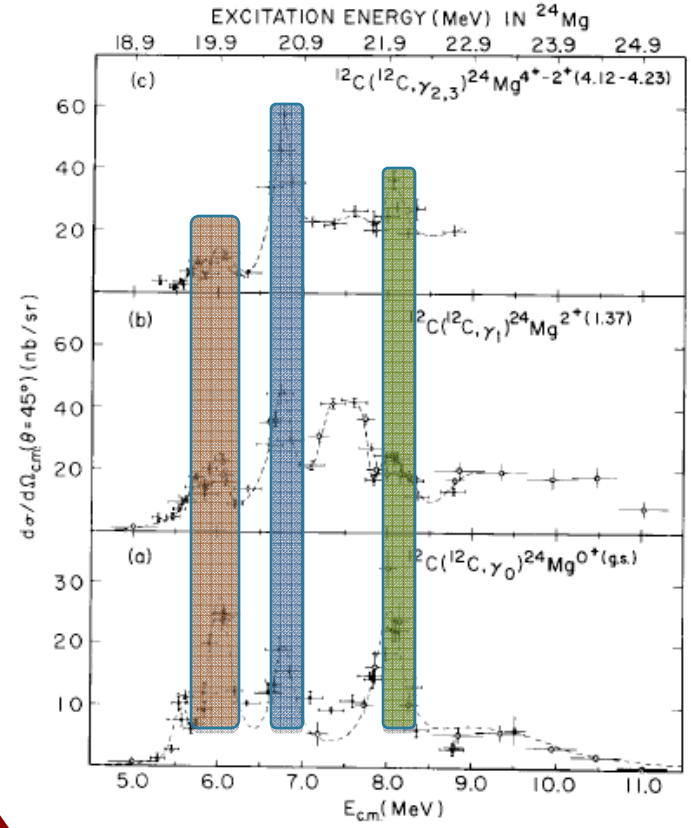


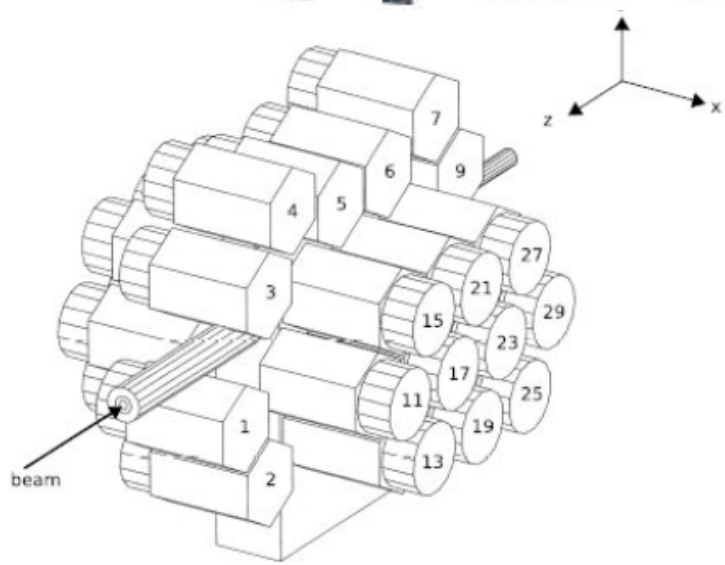
Radiative capture

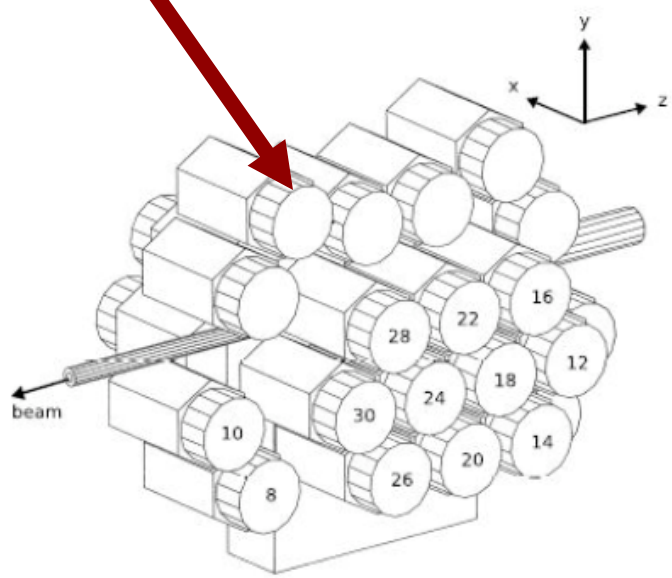


$N_{RC}/N_{FE} \approx 10^{-5}$

DRAGON
Detector of Recoils And
Gammas Of Nuclear reactions
Gas Target
Gamma Array
Magnetic Quads
Magnetic Dipole
Charge Slit Box
Magnetic Quads
Electrostatic Dipole
Mass Slit Box
Magnetic Dipole
Recoil Detectors
Final Focus Box
Magnetic Quads
Electrostatic Dipole
Quads
IC/PGAC Stop
MCP Start


EXCITATION ENERGY (MeV) IN ^{24}Mg
18.9 19.9 20.9 21.9 22.9 23.9 24.9
(c) ^{12}C(^{12}C,$\gamma_{2,3}$)^{24}Mg$^{4^+-2^+}$(4.12-4.23)
(b) ^{12}C(^{12}C,γ_1)^{24}Mg$^{2^+}$(1.37)
(a) ^{12}C(^{12}C,γ_0)^{24}Mg$^{0^+}$(g.s.)
$d\sigma/d\Omega_{cm}(\theta=45°)$ (nb/sr)
E_{cm} (MeV)


beam
z
x

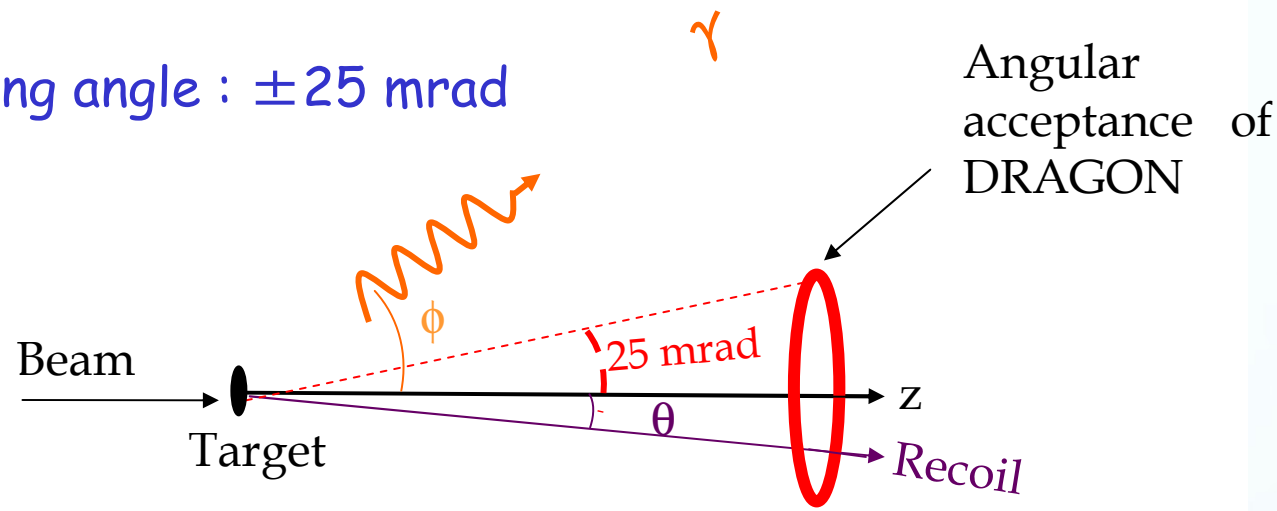

beam
x
y
z

Details of DRAGON experiments

Beam	^{12}C	^{16}O
Intensity	50 pnA	10 pnA
Targets	^{12}C (40 μ g/cm^2)	^{12}C (40 μ g/cm^2)
Bombarding energy	12 MeV : ON 12.8 MeV : OFF 13.6 MeV : ON 15 MeV : ON-OFF 16 MeV : ON	19.83 MeV : ON 20.53 MeV : OFF 21 MeV : ON
Réactions	$^{12}C(^{12}C,\gamma)^{24}Mg$	$^{12}C(^{16}O,\gamma)^{28}Si$

Finite acceptance of DRAGON

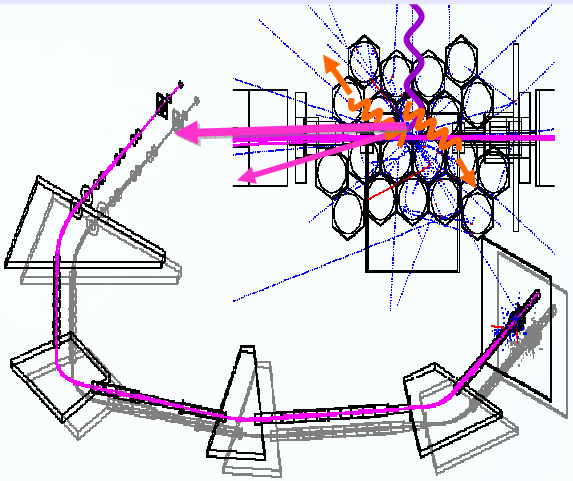
Opening angle : ±25 mrad



Recoil	^{24}Mg	^{28}Si
Range of angles	38,8 mrad	31,9 mrad
Range in energy	± 6,6%	± 7,6%

Simulations of Dragon+BGO System

Interdependence between the detection of the recoils and of the γ $\rightarrow$ need for simulations



•Entrance channel spins:

- spin distribution
- a unique j^{π}

•Branching ratios of the entrance states:

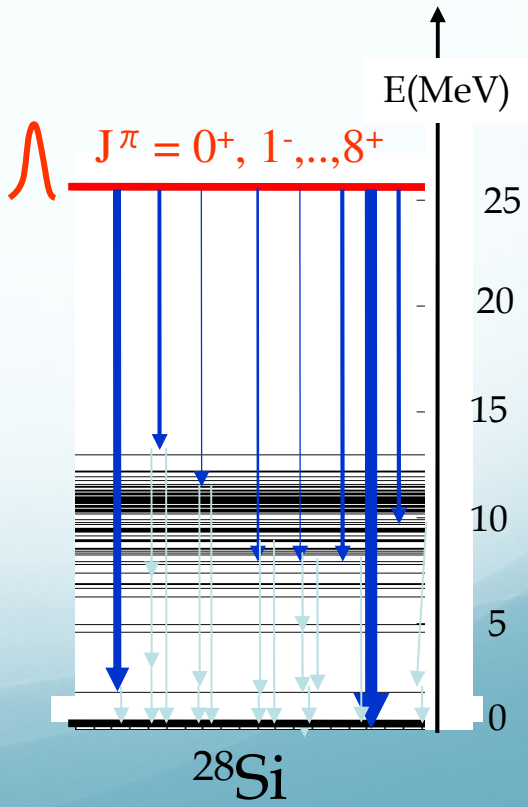
- Statistical:

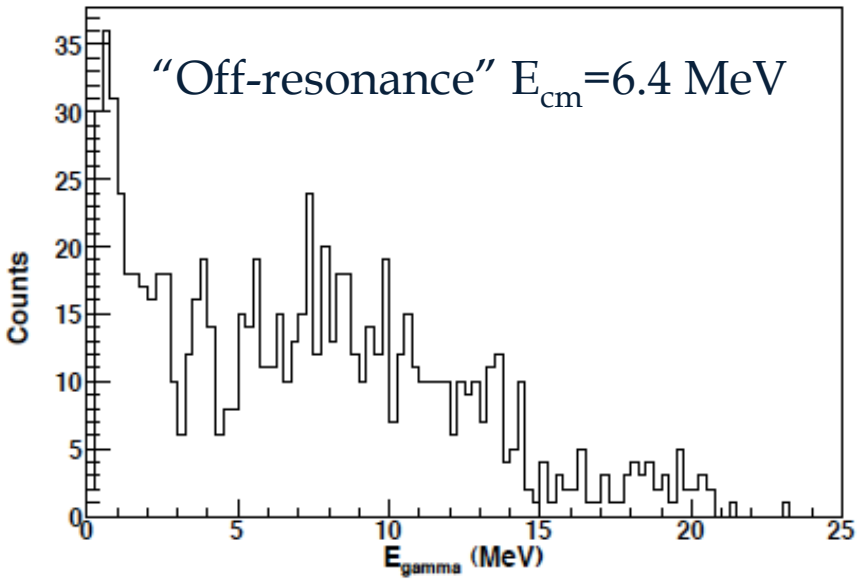
  69 bound or quasi bound states
  +Weisskopf widths + Mean widths

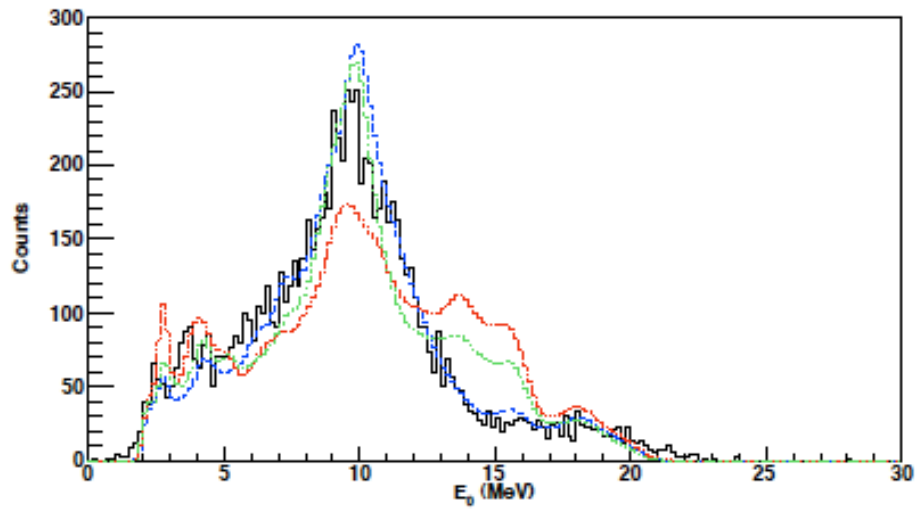
  $$\Gamma_{\gamma} = S * \Gamma_{w}$$

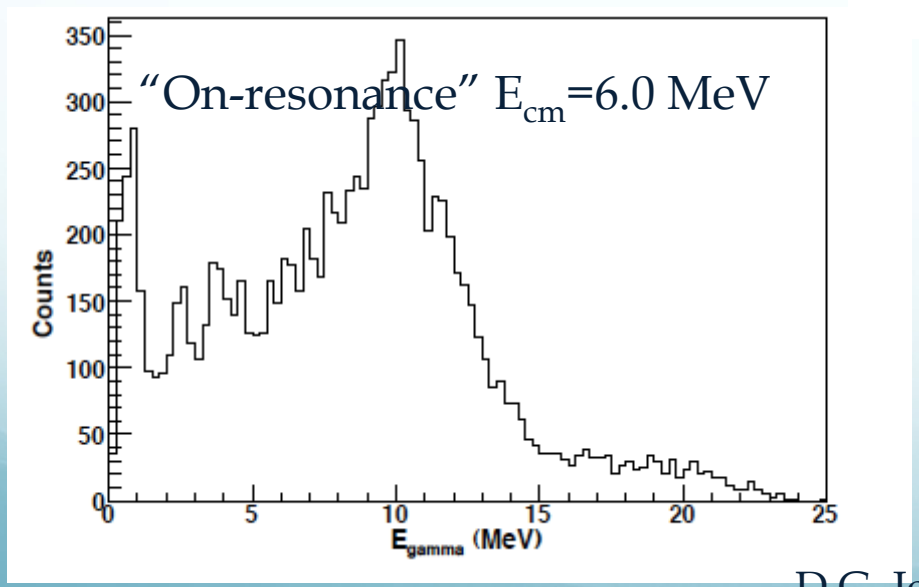
- Cluster model calculation (Debrecen group)

• Known subsequent decay of the 69 states from the litterature





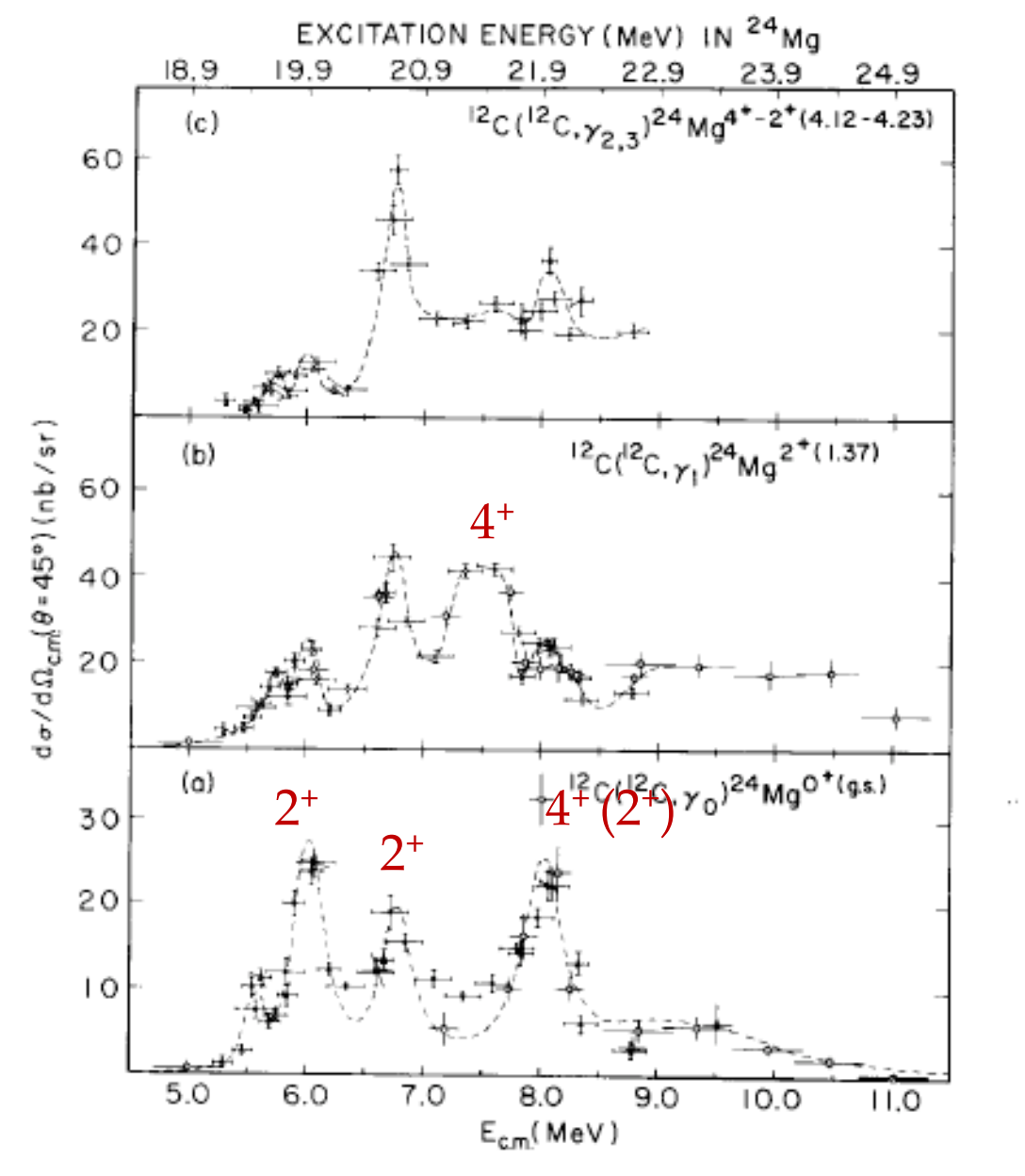




Data fitted to GEANT4 simulation of DRAGON (residue acceptance not 100%)

Important role of M1 $\Delta T=1$ transitions in explaining peak around 10 MeV

D.G. Jenkins et al., Phys.Rev. C 76, 044310 (2007)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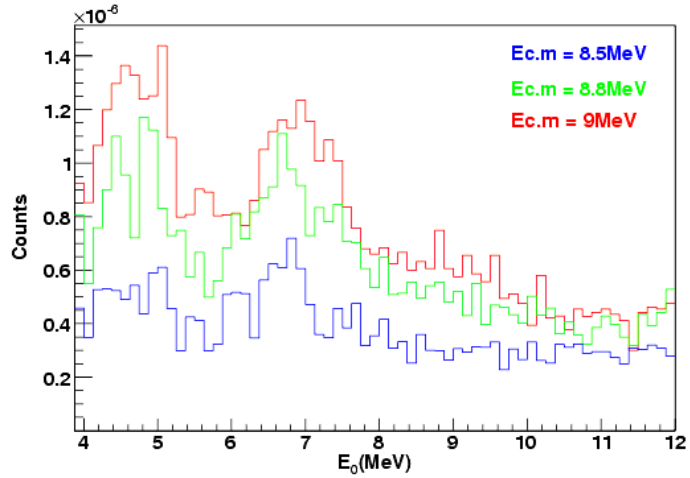
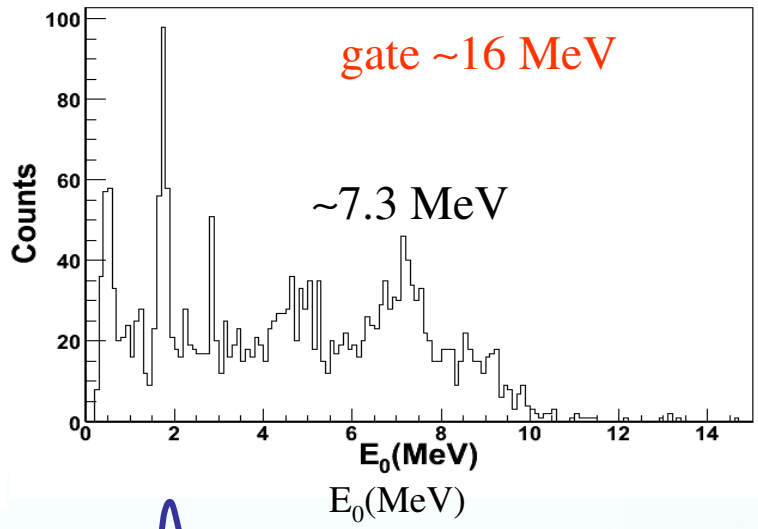
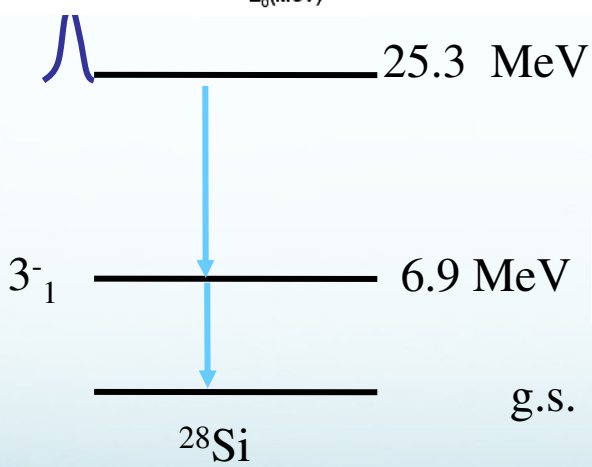
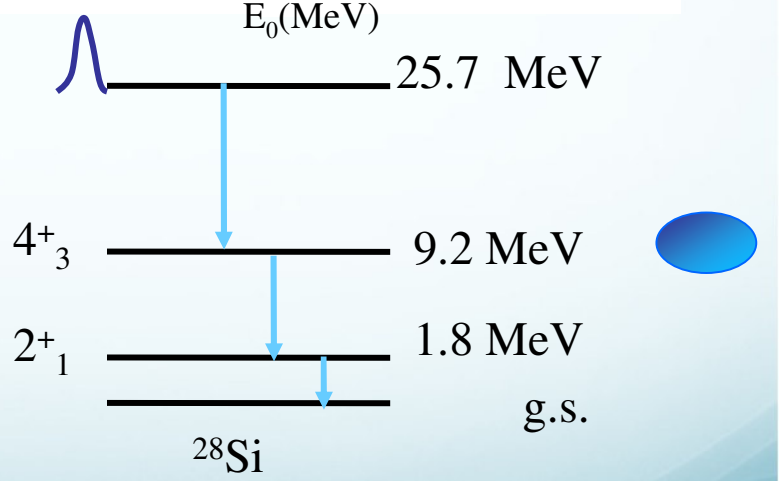
4+
(a)
^{12}C(^{12}C,γ_0)^{24}Mg$^{0^+}$(g.s.)
2+
2+
4+ (2+)
$d\sigma/d\Omega_{c.m.}(\theta=45°)$ (nb/sr)
$E_{c.m.}$ (MeV)

$^{12}C(^{16}O,\gamma)$







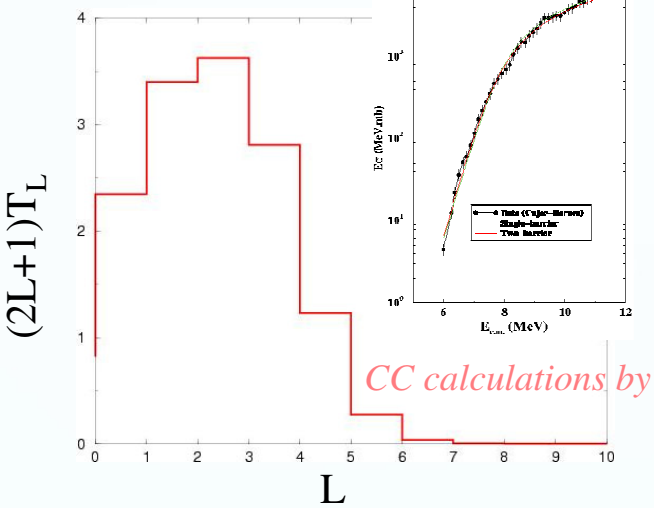


Direct feeding of the first 3^{-} state at 6.89 MeV

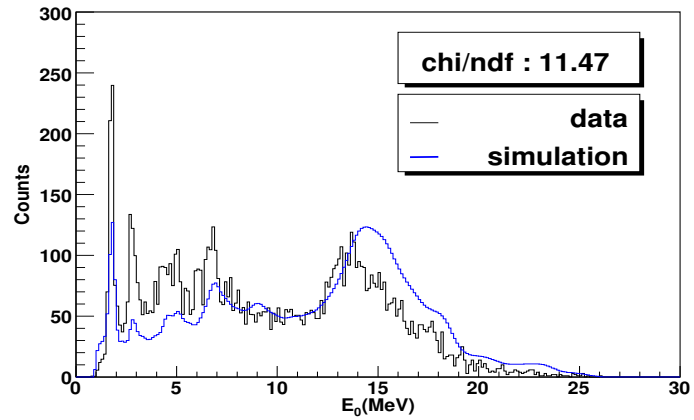
Direct feeding of the 4_3^+ (prolate) at 9.164 MeV

Spin distribution

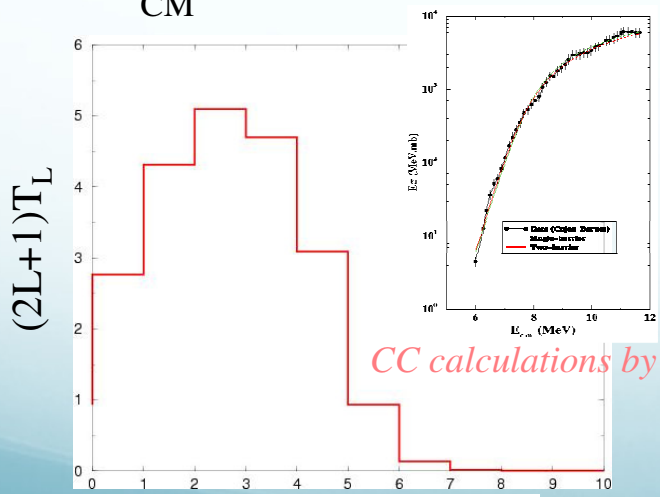
- E_{CM} = 8.5 MeV



CC calculations by N. Rowley



- E_{CM} = 9 MeV



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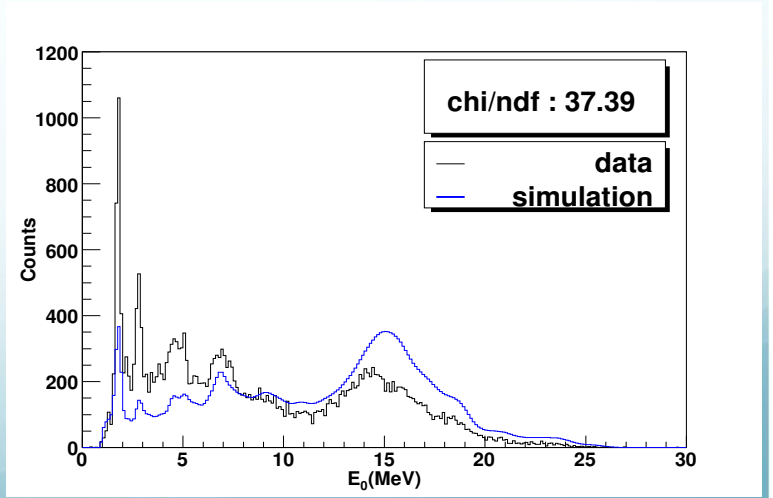
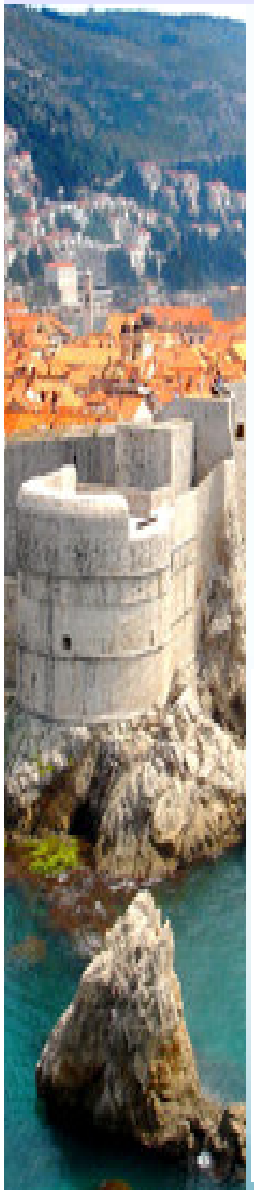
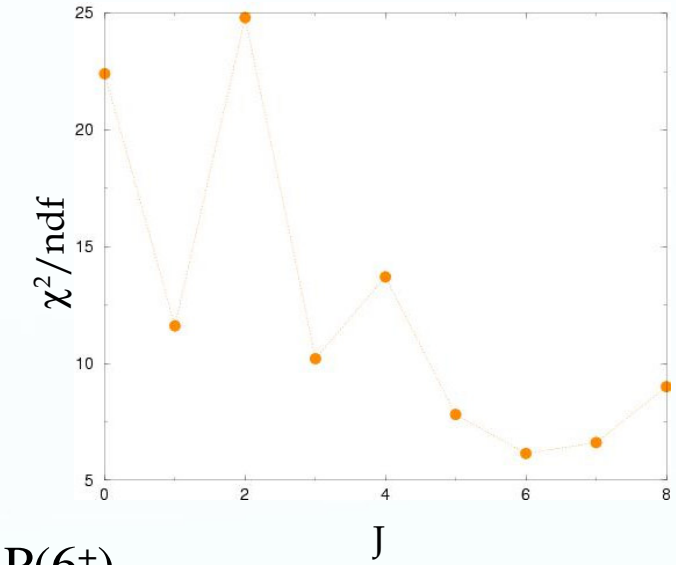


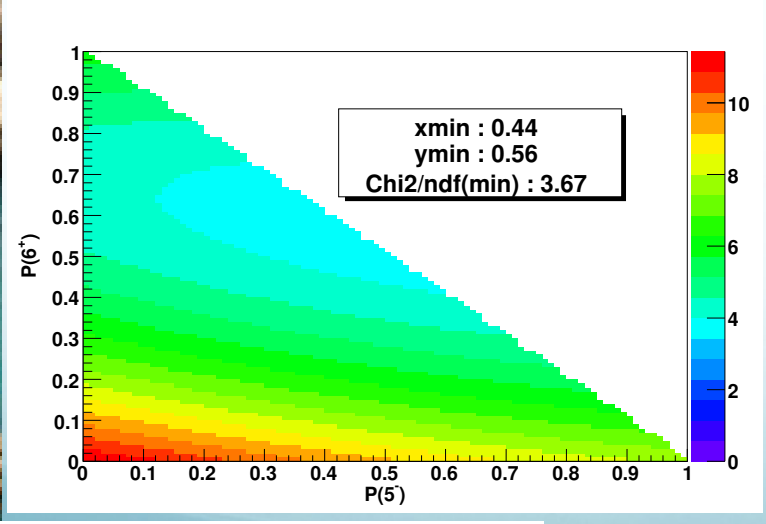
E_{CM} = 8.5 MeV

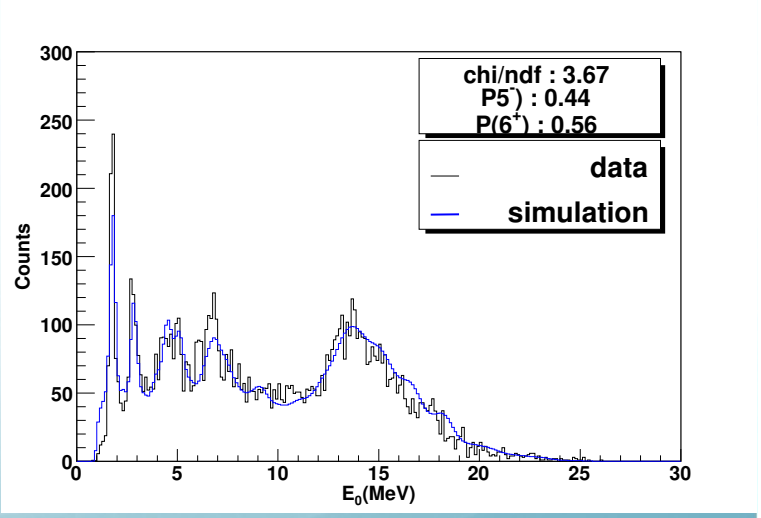


- unique J^{π}



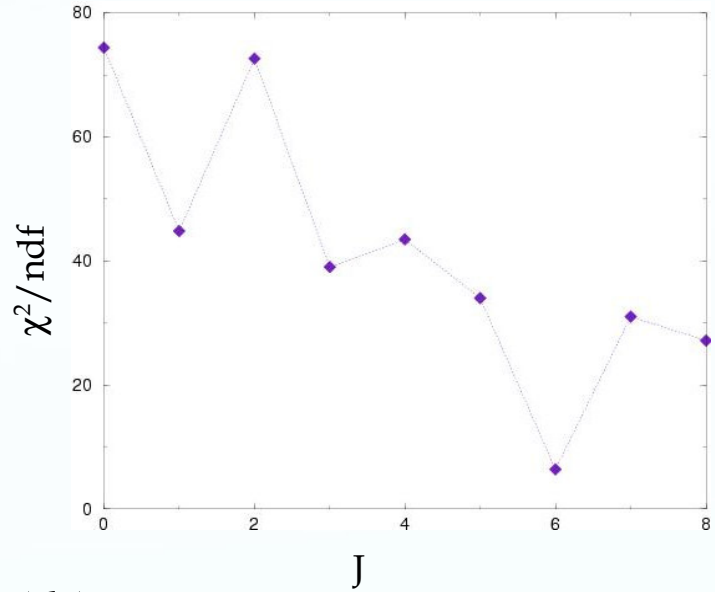
- Min χ^2 : $P(5^-)$, $P(6^+)$





$E_{CM} = 9$ MeV

- unique J^{π}



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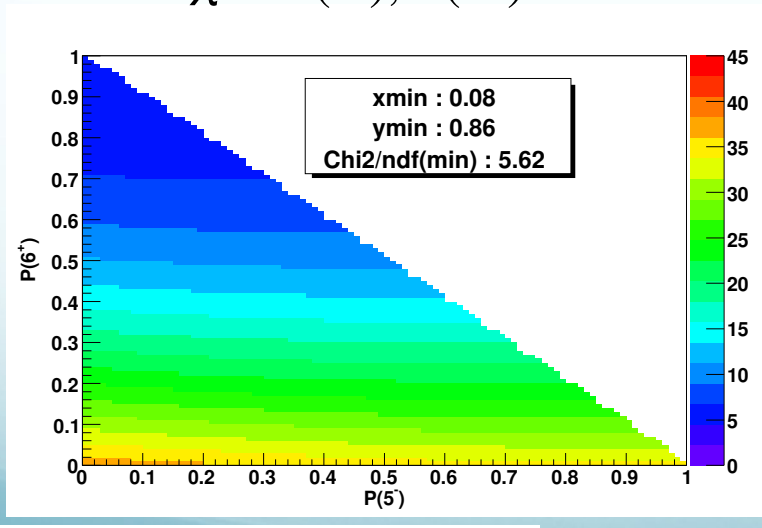
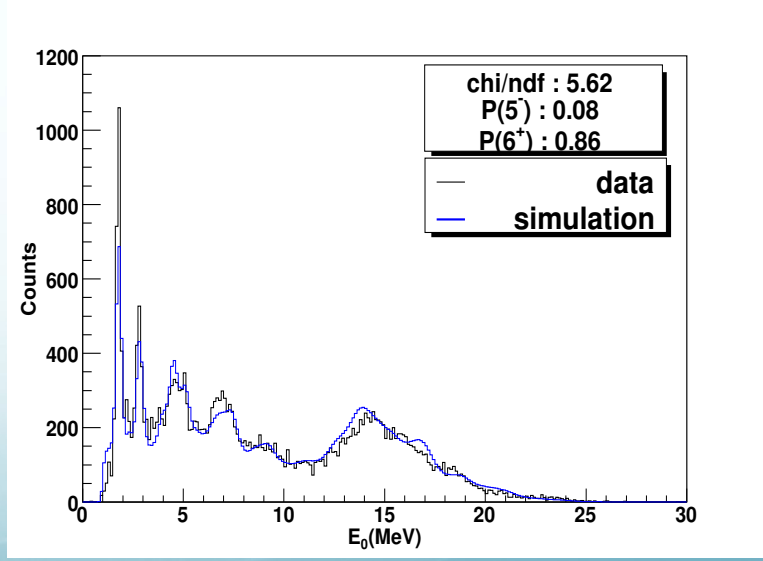




D. Lebhertz
NSD09, May 4 - 8, 2009, Dubrovnik

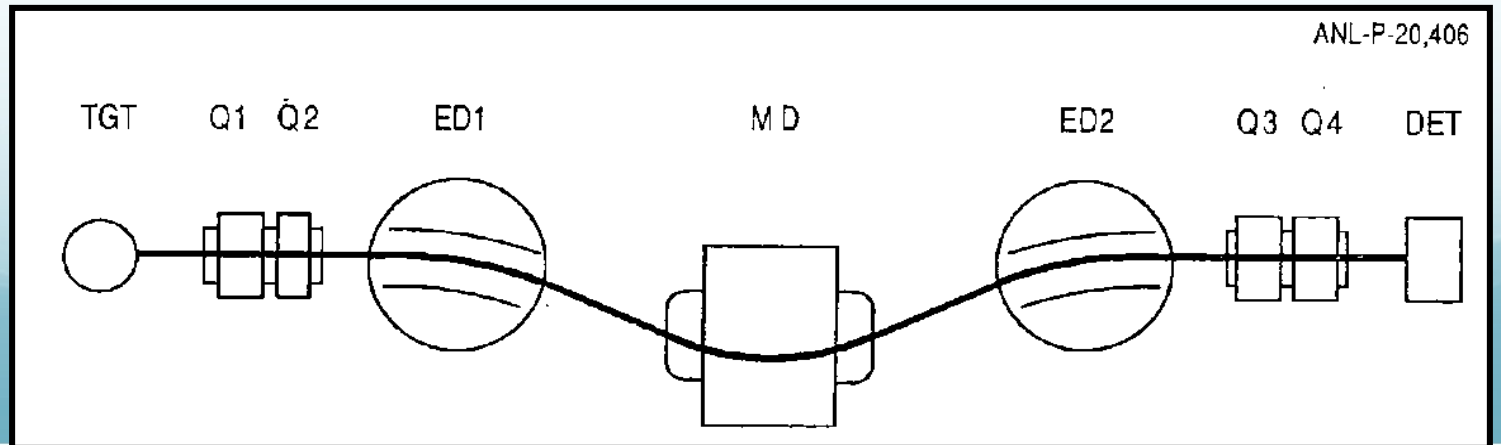
Argonne experiment

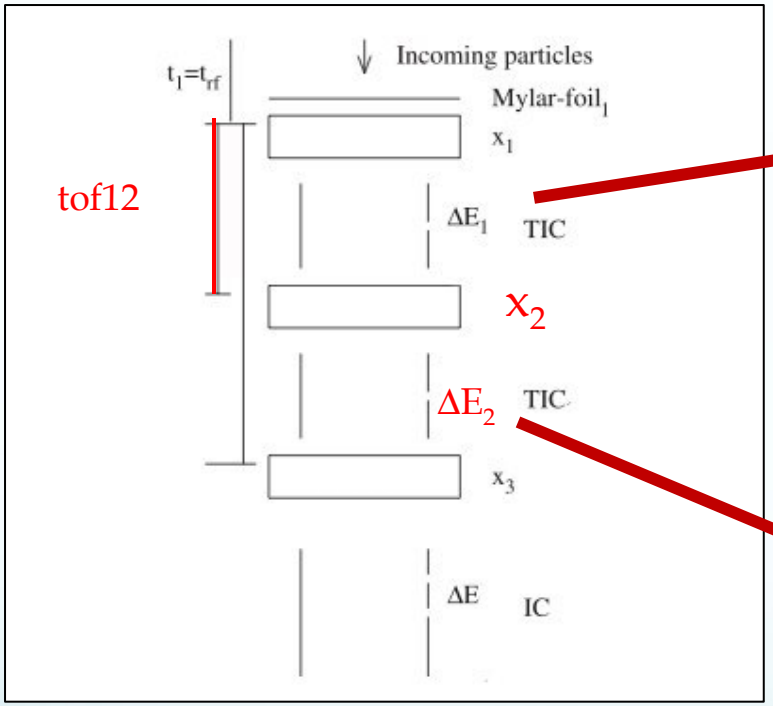
Gammasphere

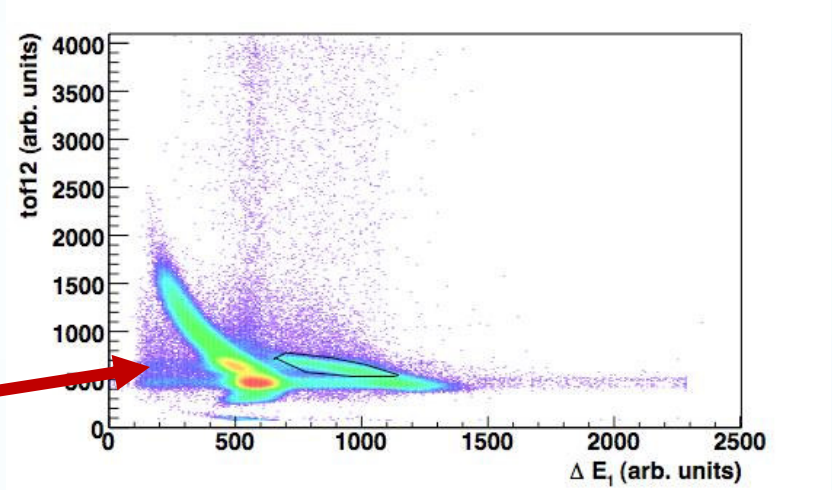
- 4π Germanium array of 110 detectors
- Full-read out of energy deposited in germanium and BGO shields

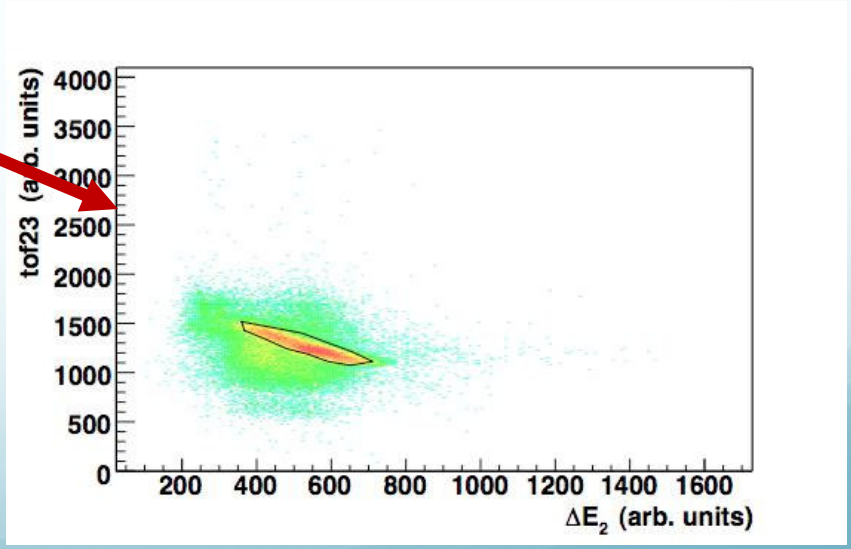
FMA

- Vacuum-mode recoil separator
- Disperse by A/q at the focal plane.



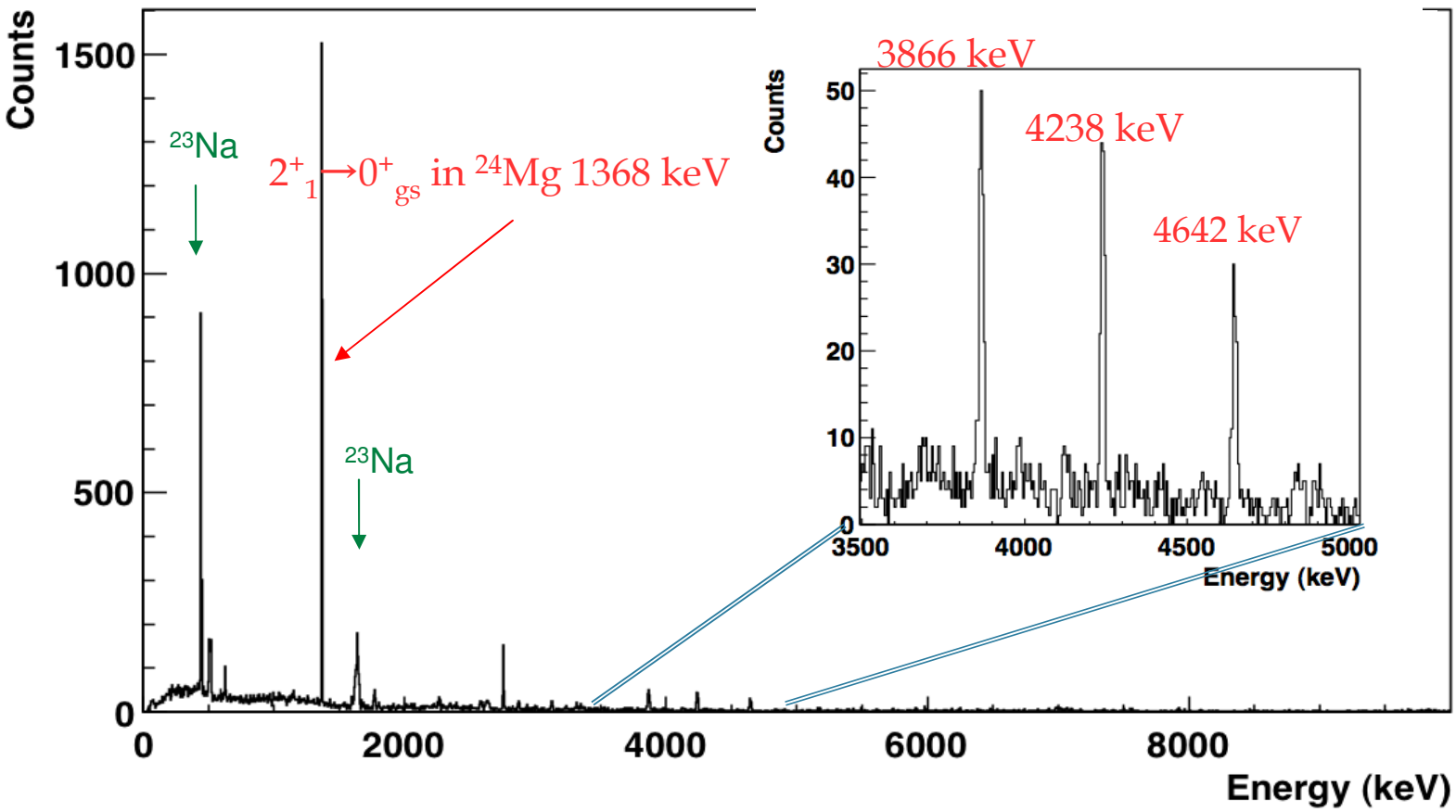




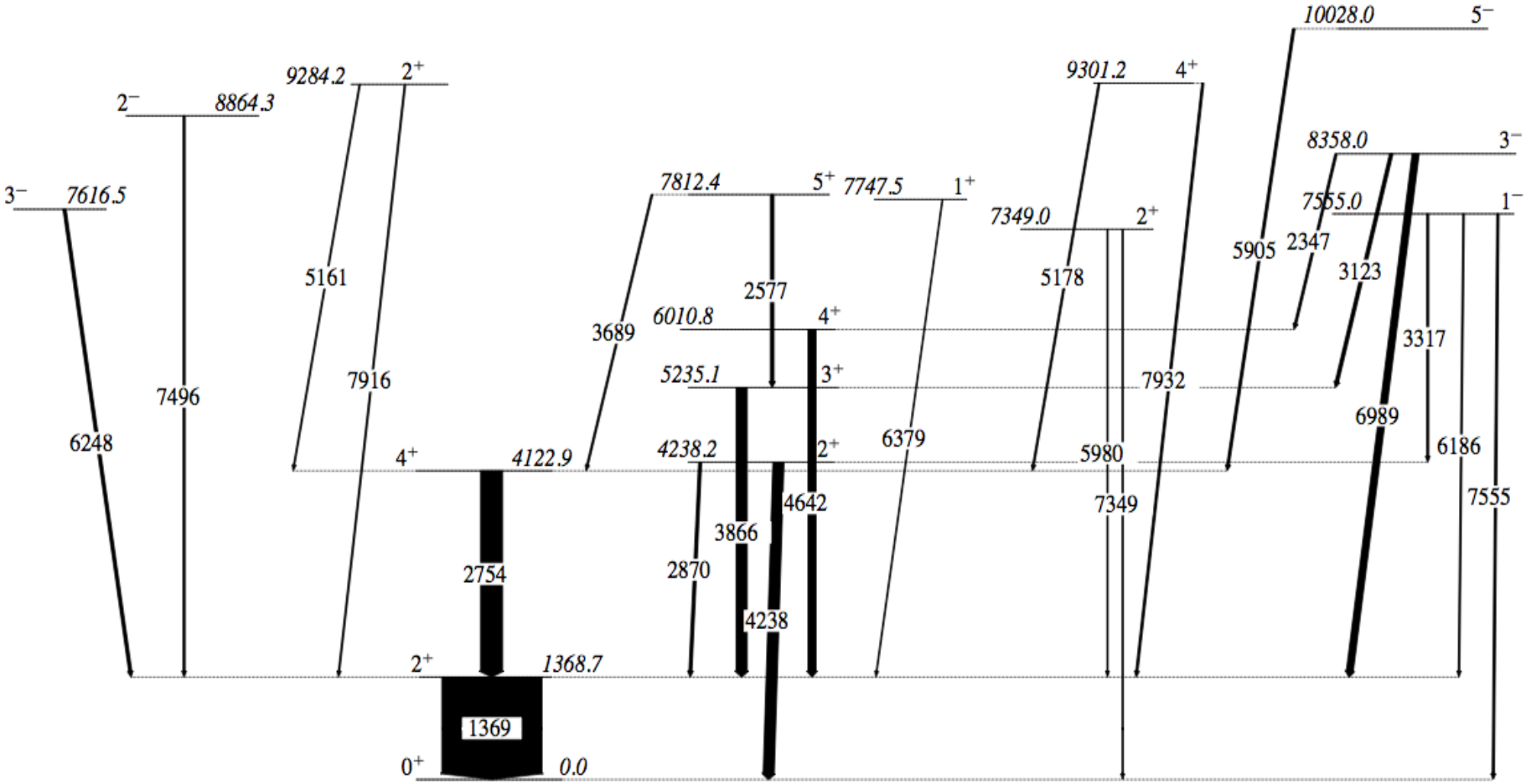


Multiple PPAC/ion chamber system used to rigorously identify ^{24}Mg residues

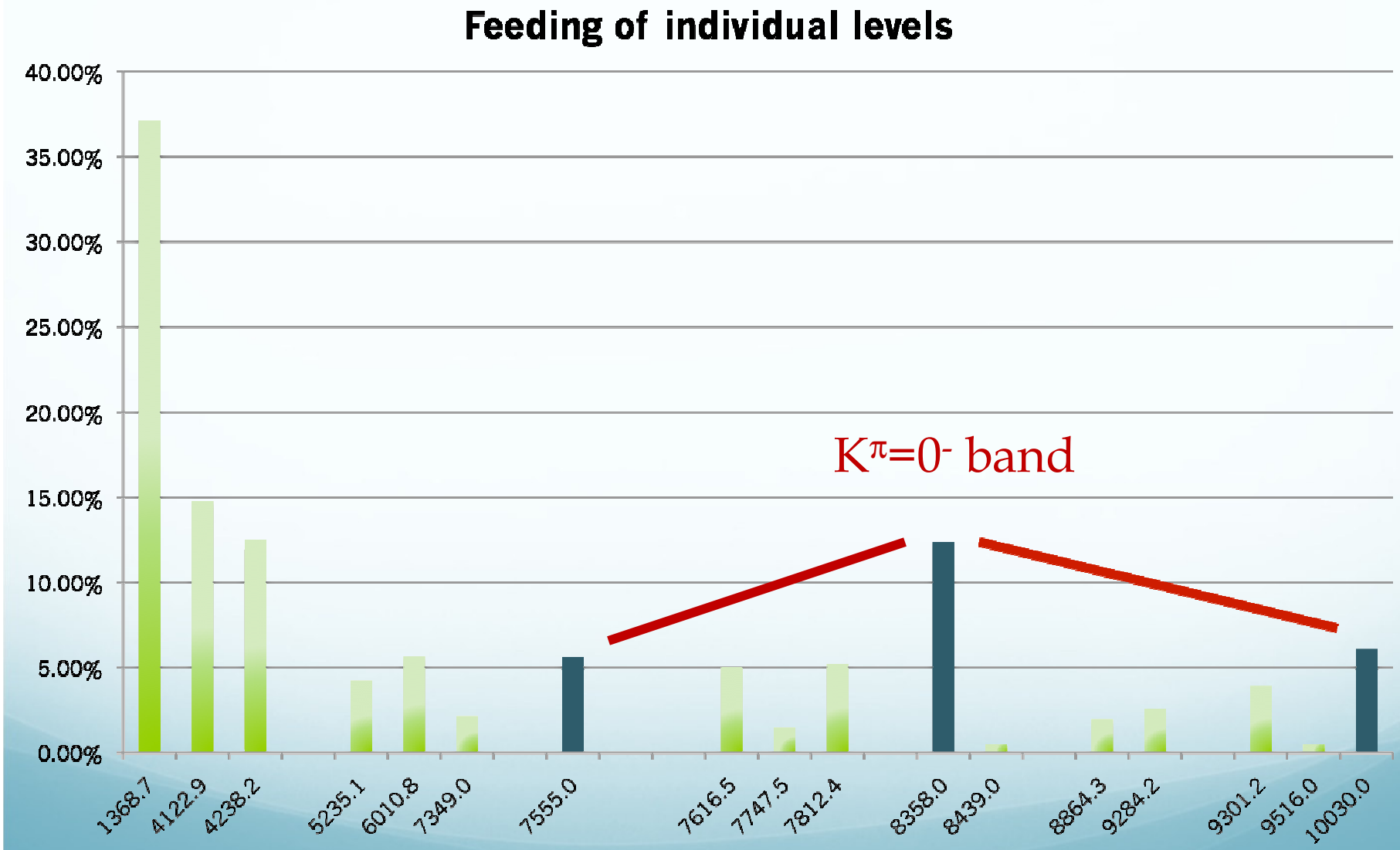
Singles spectrum in coincidence with radiative capture residues



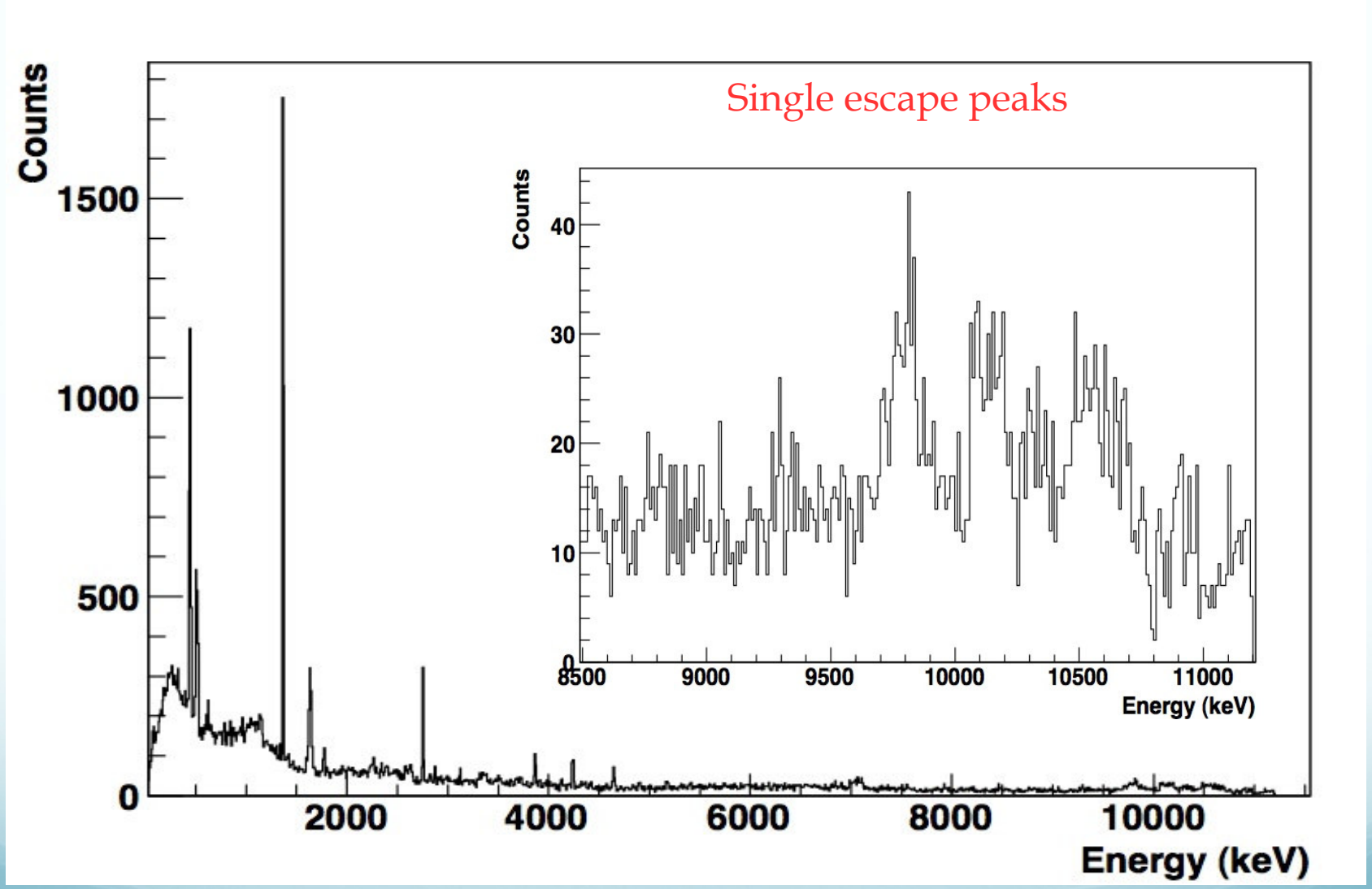
^{24}Mg level scheme



Feeding pattern



High energy gammas - “module” spectrum

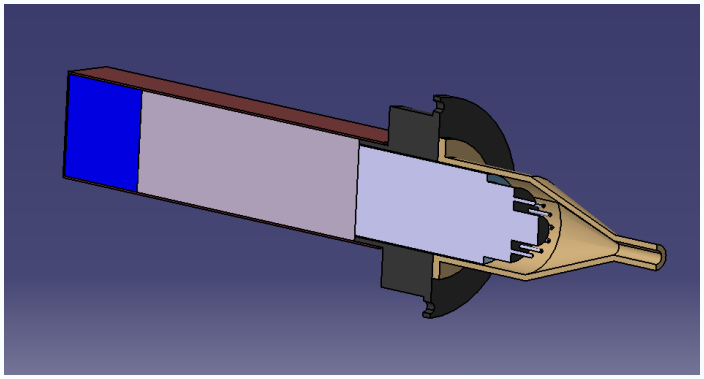


Summary

- DRAGON experiments
  - Low resolution gamma-ray spectra for several resonances
  - Decay pattern inferred from heavy reliance on simulation
  - Tentative spin assignments for the resonances
- FMA experiment
  - Very detailed spectroscopy at one resonance energy
  - Strong population of the $K^{\pi}=0^{-}$ band observed especially 3^{-} at 8358 keV
  - Origin of high energy (10 MeV) gammas not yet established

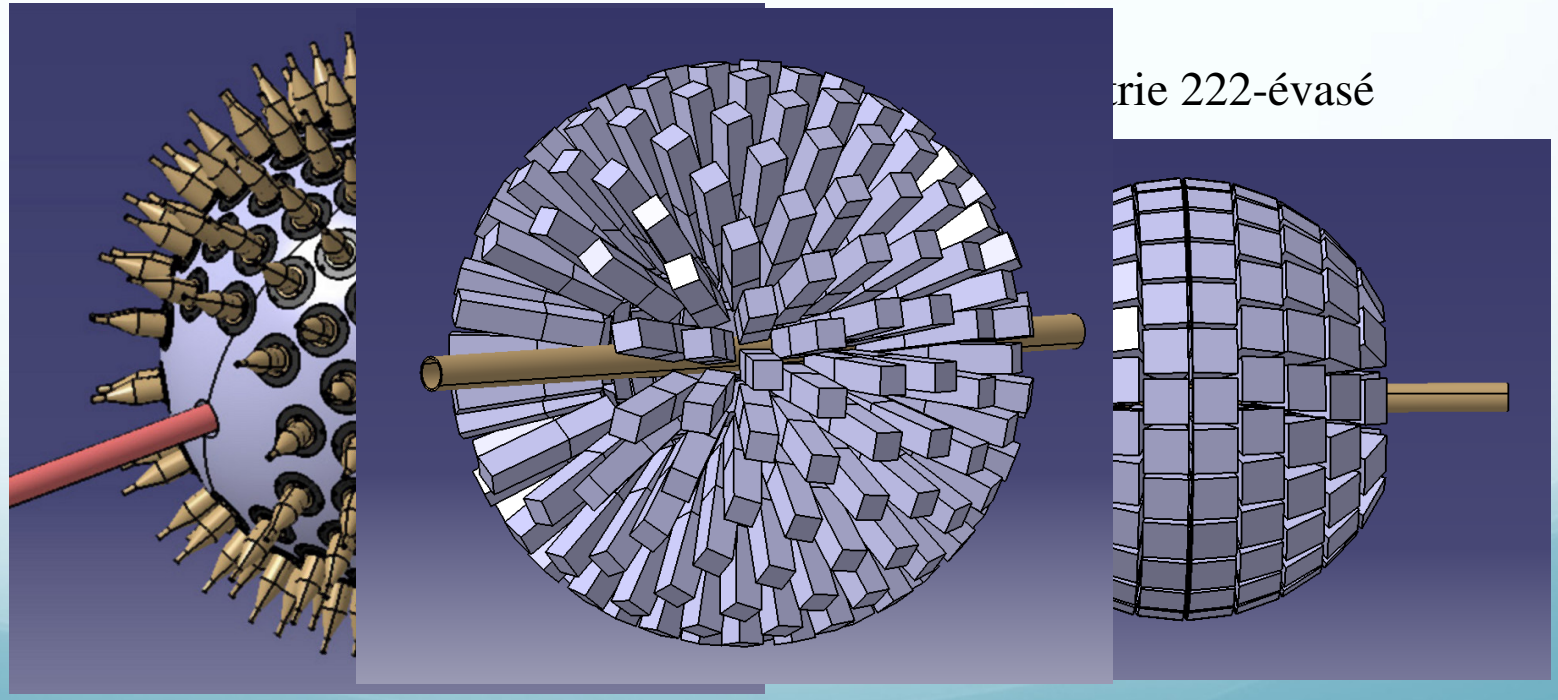
PARIS simulations

3 geometries considered
comprising LaBr-CsI
« phoswich »



Géométrie 222-226

Géométrie 224-226



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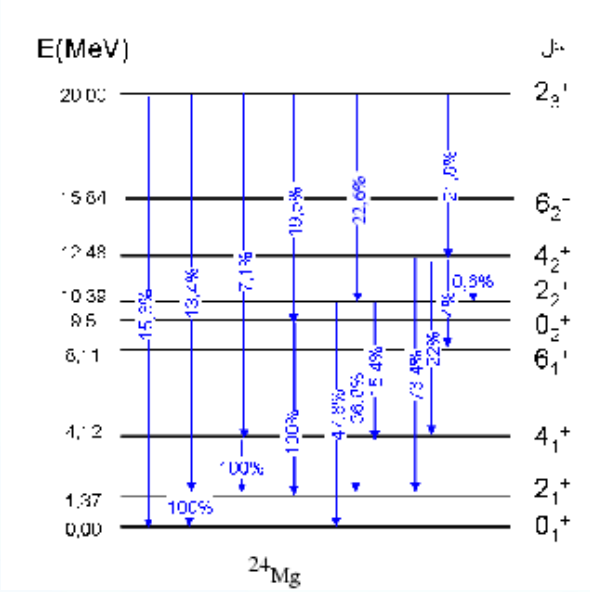
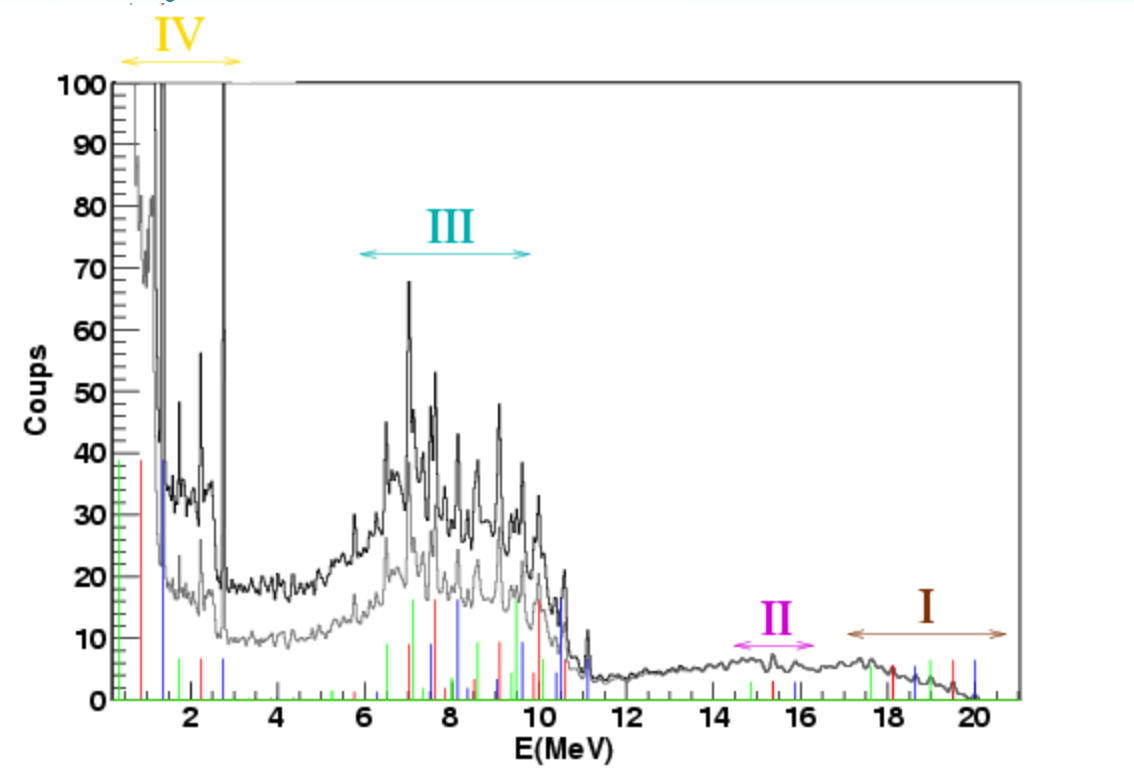
$^{12}C(^{12}C,\gamma)$ simulations





- Individual peaks can be resolved
- Calorimetric efficiency (ΣE_γ>15 MeV) :
  > 15 %

Collaborators

D.G. Jenkins, P.L. Marley, A. Robinson, R. Wadsworth
(University of York, UK)

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(IReS Strasbourg, France)

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(Argonne National Laboratory, US)

D.A. Hutcheon, C. Davis et al.
(TRIUMF, Canada)

THE UNIVERSITY of York

Argonne NATIONAL LABORATORY

iReS Institut de Recherches Subatomiques STRASBOURG

Finis

Experimental Details

Beam	^{12}C
Targets	2x ^{12}C (60 μ g/cm^2) 1x ^{13}C (90 μ g/cm^2)
Beam energy range	16.25 MeV
Reaction	$^{12}C(^{12}C, \gamma)^{24}Mg$

- Beam from ATLAS accelerator
- GAMMASPHERE + FMA

Overview

- Radiative capture
  - Mechanism
  - Role in investigation of clustering and nuclear molecules
- Experiment at Argonne National Laboratory (ANL)
  - Experimental setup
  - Analysis and level scheme
- Future analysis