Clustering in ^{18}O – absolute determination of branching ratios via high-resolution particle spectroscopy

S. Pirrie, C. Wheldon, Tz. Kokalova *et al.*

University of Birmingham, United Kingdom

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UNIVERSITY OF BIRMINGHAM

Overview

Alpha clustering

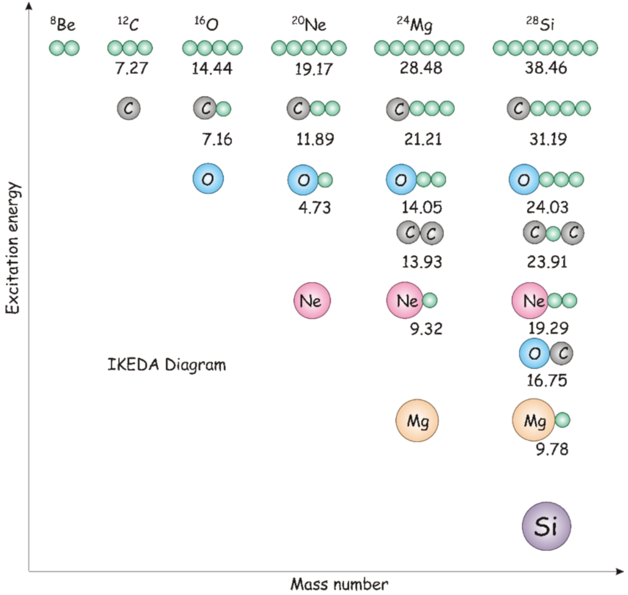

Figure produced by Tz. Kokalova, taken from M. Freer, W. von Oertzen, and Y. Kanada-Enyo.Physics Reports, 432(2):43113, 2006.

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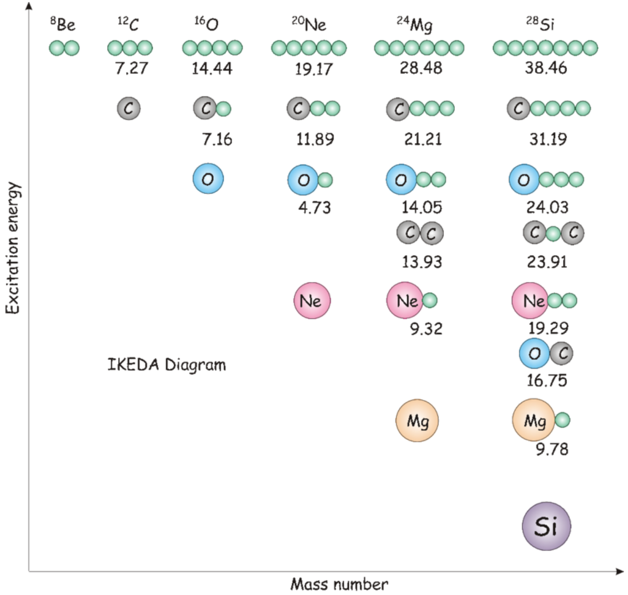

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- Alpha clustering in light, $N = Z$ nuclei is well-established (e.g. Hoyle state in ^{12}C).

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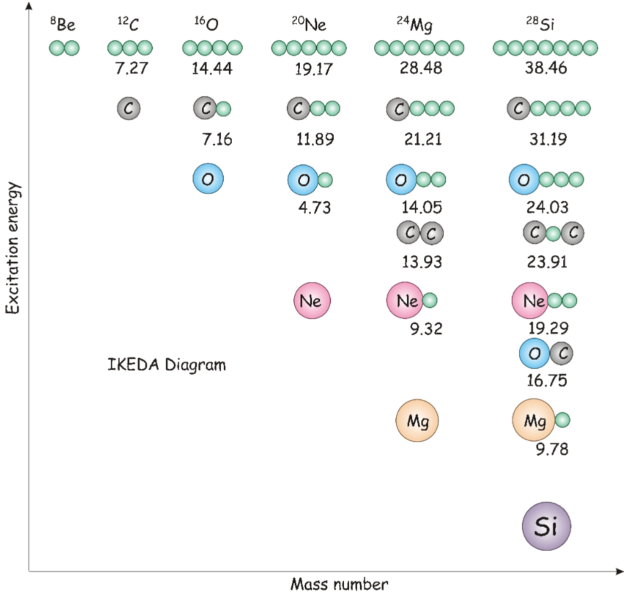

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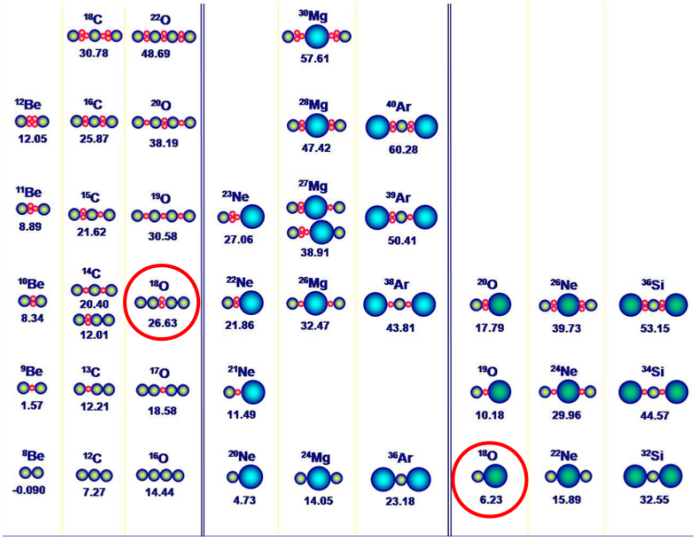
- Alpha clustering in light, $N = Z$ nuclei is well-established (e.g. Hoyle state in ^{12}C).
- Clustering provides a good test of theoretical models, and enables the computational modelling of many-nucleon systems.

Alpha clustering



W. von Oerzten 2001 Eur. Phys. J. A 11 403
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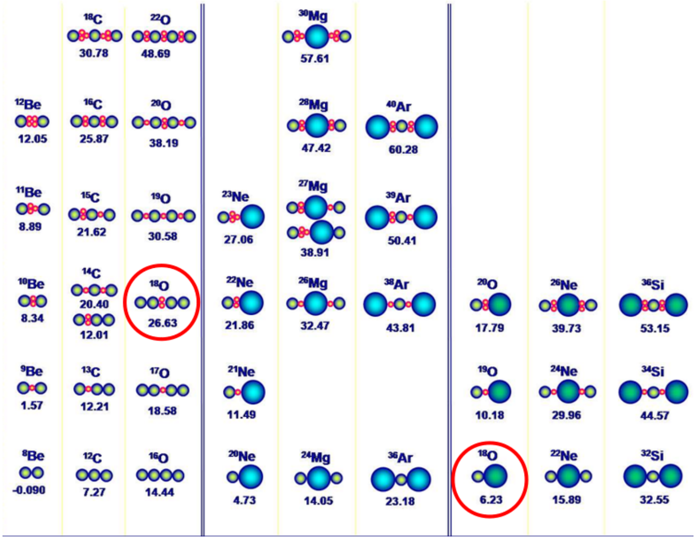

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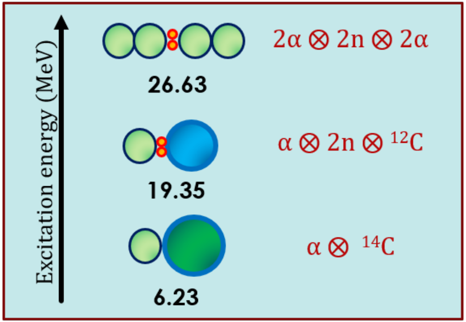
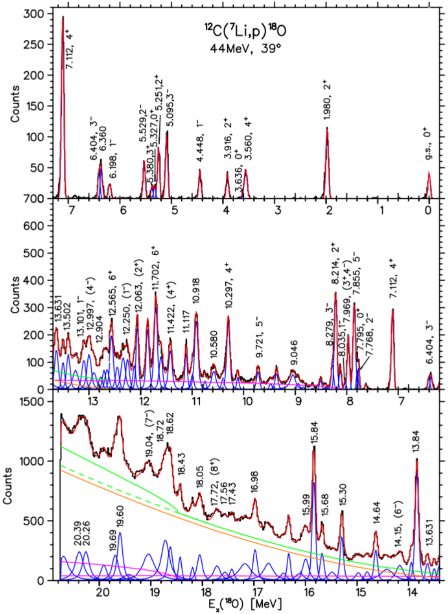
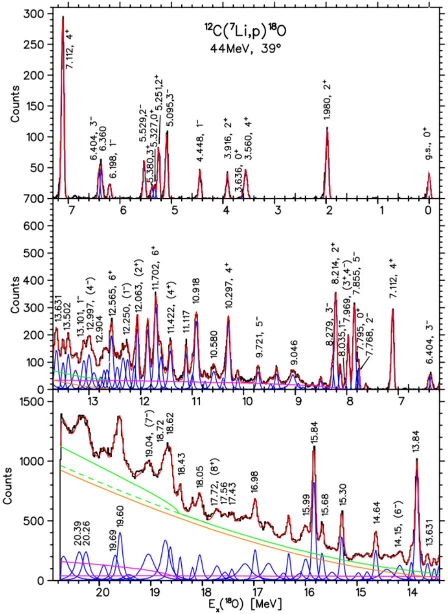


Motivations



W. von Oertzen et al. Eur. Phys. J. A 43, 1733 (2010)



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- An experiment was performed at the Maier-Leibnitz Laboratory (MLL) in Munich by W. von Oertzen *et al*, utilising the ^{12}C(^{7}Li,p)^{18}O* ($Q_0 = +8.401$ MeV) reaction.

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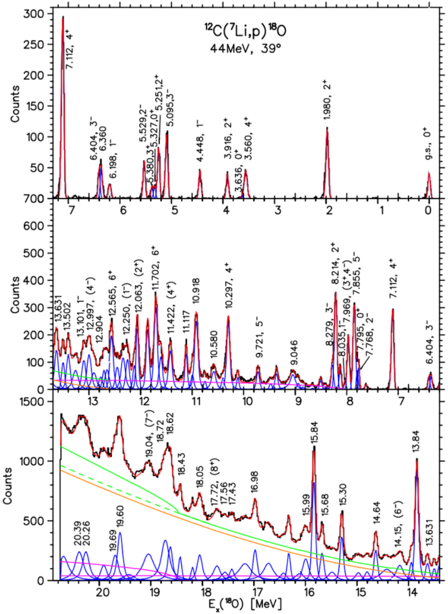

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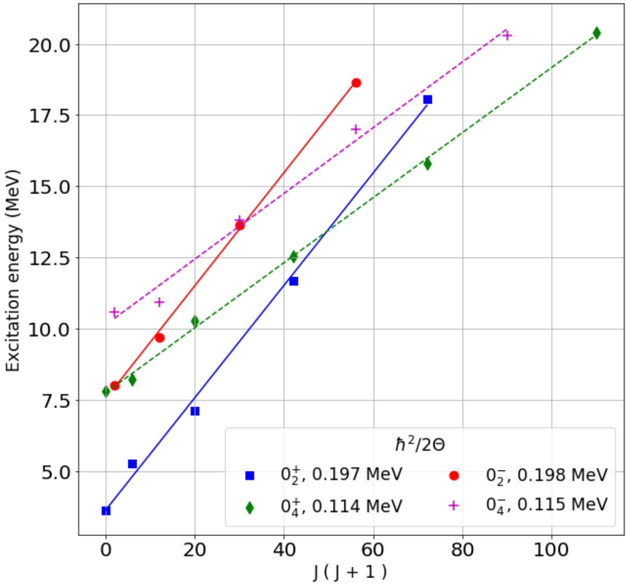
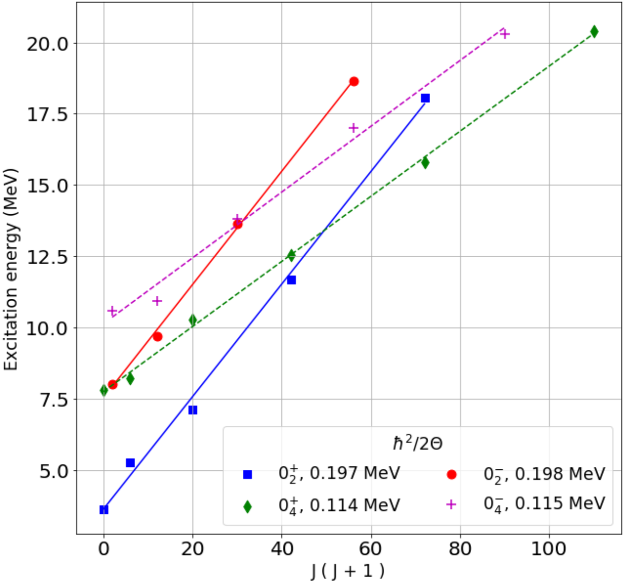
- Through use of the Q3D magnetic spectrograph, $\sim$30 new states in ^{18}O were discovered.

What is a rotational band?





- The excitation energy, E_x, of a nucleus can be related to its total angular momentum, J, through

$$E_x(J) = \frac{\hbar^2}{2\mathcal{I}}(J(J+1)) + E_0. \quad (1)$$

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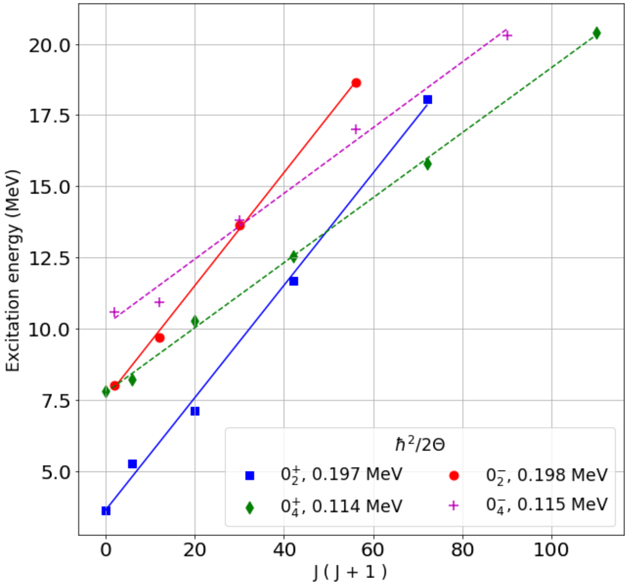

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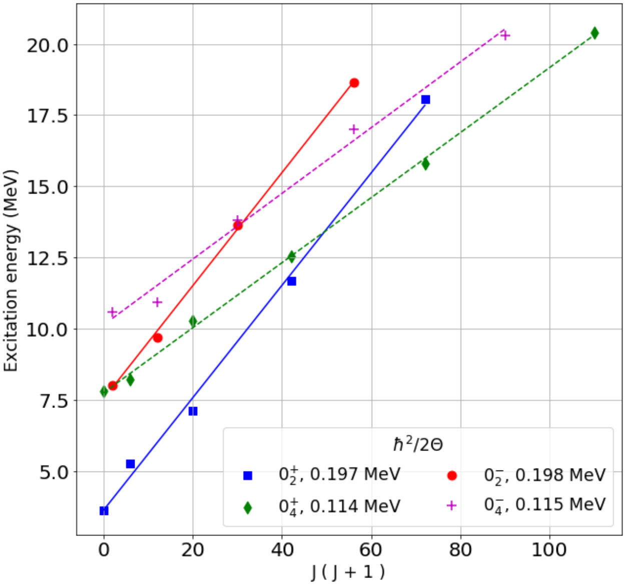

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- Nuclear configurations with identical structure will have the same moment of inertia, $\mathcal{I}$.
- Rotational bands can be split into positive and negative parities due to signature splitting.

Aims

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- For states in the proposed rotational bands, use the absolute branching ratios to determine the reduced α-partial decay widths:

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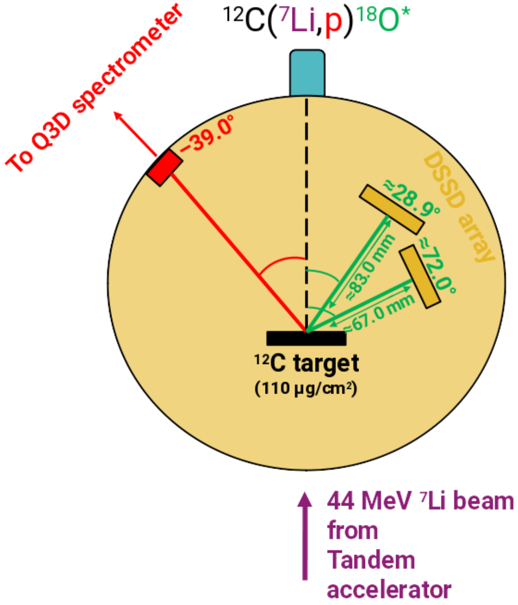
- For states in the proposed rotational bands, use the absolute branching ratios to determine the reduced α-partial decay widths:

$$\gamma_\alpha^2 = \frac{\Gamma_\alpha}{2P_l}. \tag{2}$$

- Compare γ_α^2 to the Wigner limit, γ_W^2, in order to determine tendency towards α-clustering for these states. The Wigner limit is defined by

$$\gamma_W^2 = \frac{3\hbar^2}{2\mu\alpha^2}. \tag{3}$$

Experimental set-up



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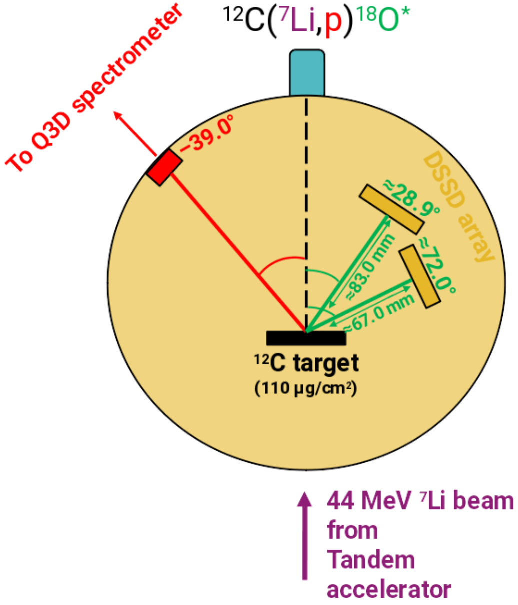
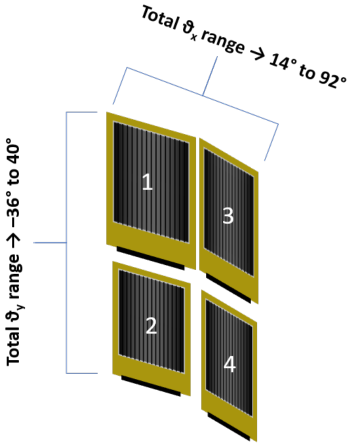
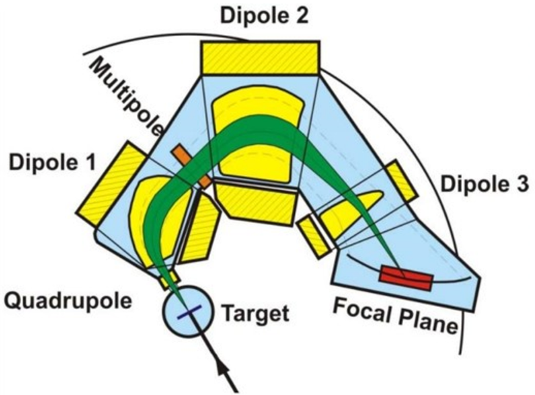
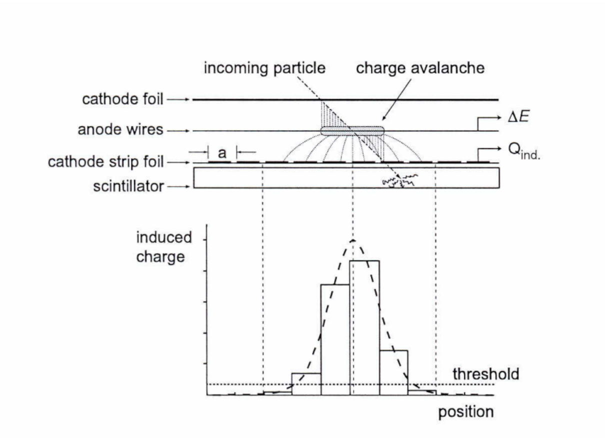




Q3D magnetic spectrograph

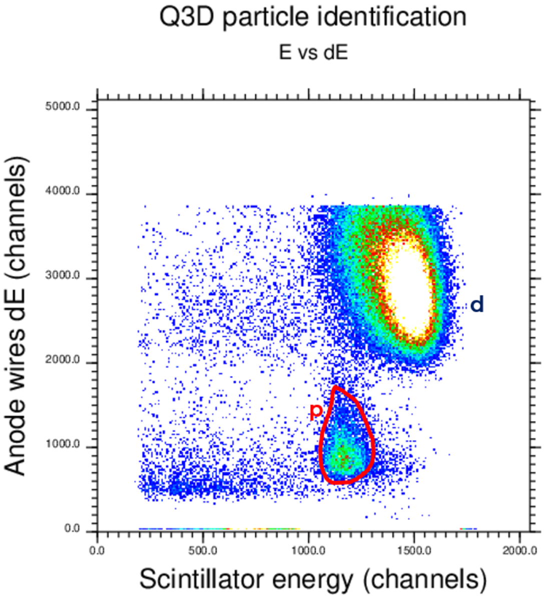


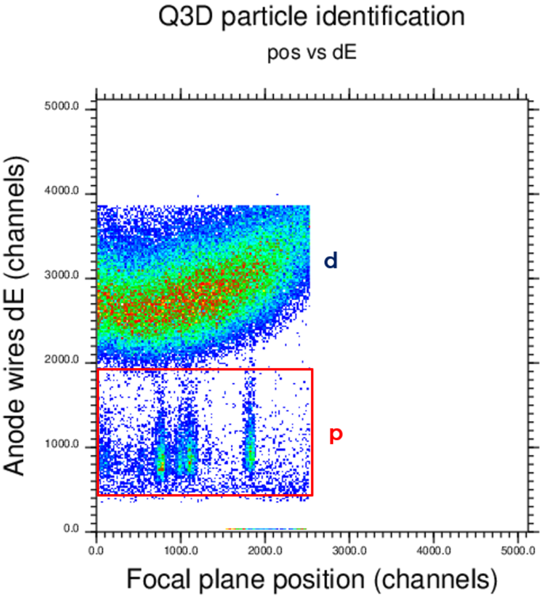
Private communication, R. Krücken



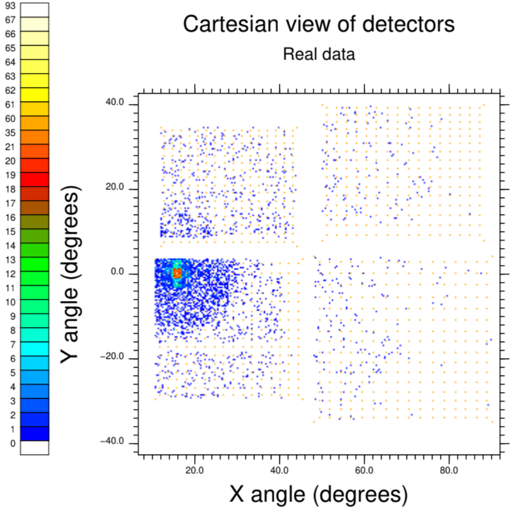
H.-F. Wirth, Ph.D. thesis, Technischen Universität, München, 2001

Q3D magnetic spectrograph





Efficiency corrections



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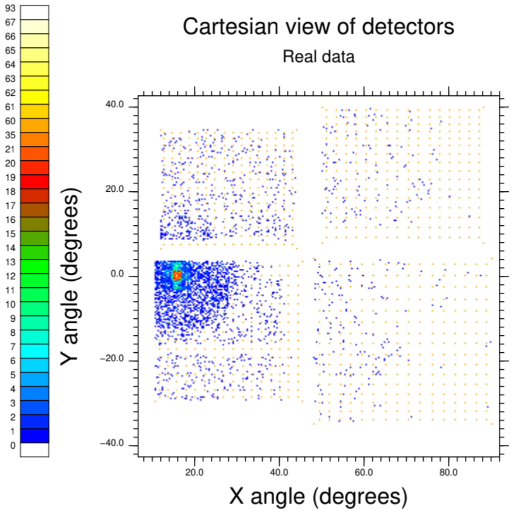
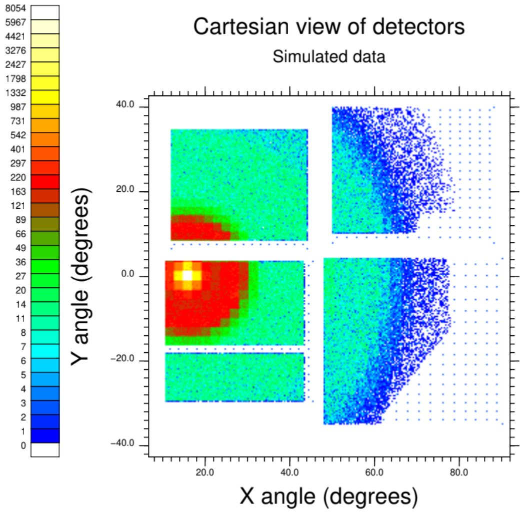
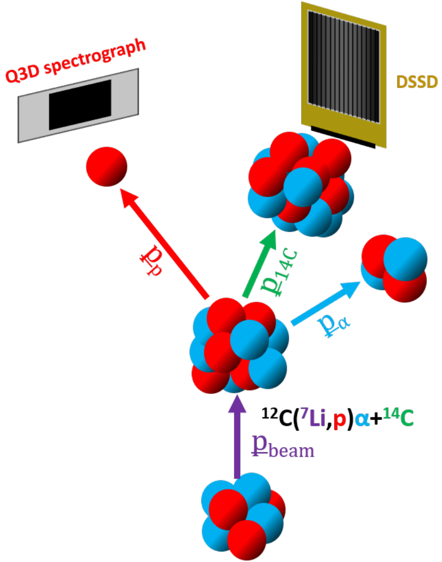


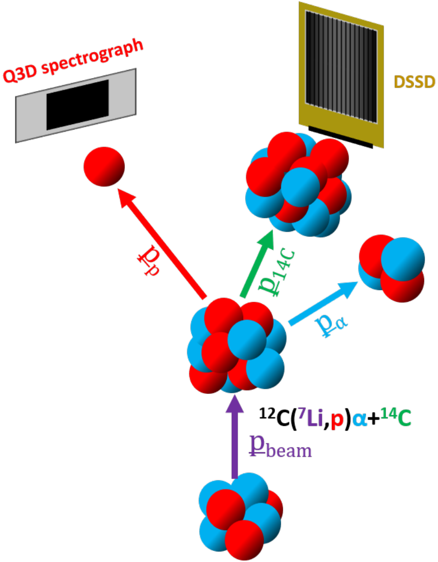


Catania plots



- The Q-value for the $^{12}C(^{7}Li,p)\alpha+^{14}C$ is given by

$$Q = E_C + E_\alpha + E_p - E_{beam}. \tag{4}$$



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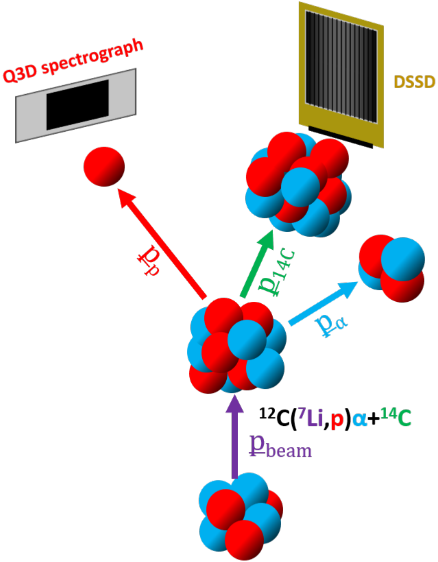
- Also, $E_\alpha = \frac{p_\alpha^2}{2m_\alpha}$.



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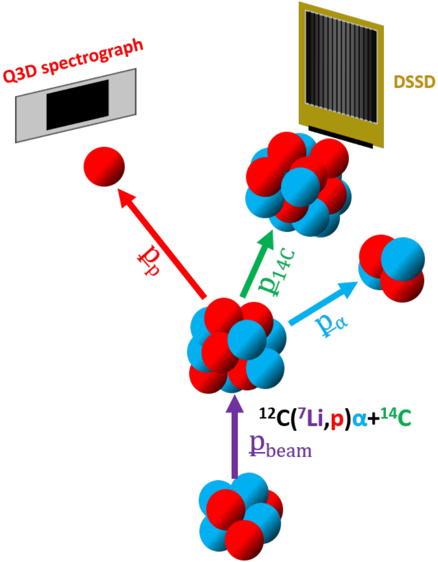
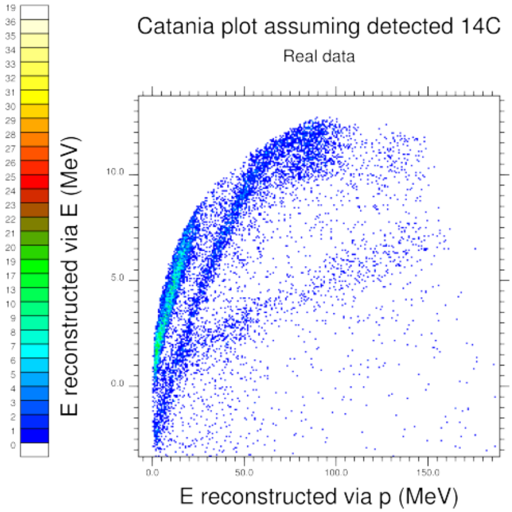
- Also, $E_\alpha = \frac{p_\alpha^2}{2m_\alpha}$.
- Through rearranging it can be shown that

$$E_{beam} - E_C - E_p = \frac{1}{m_\alpha}\frac{p_\alpha^2}{2} - Q. \qquad (5)$$



Catania plot (example)



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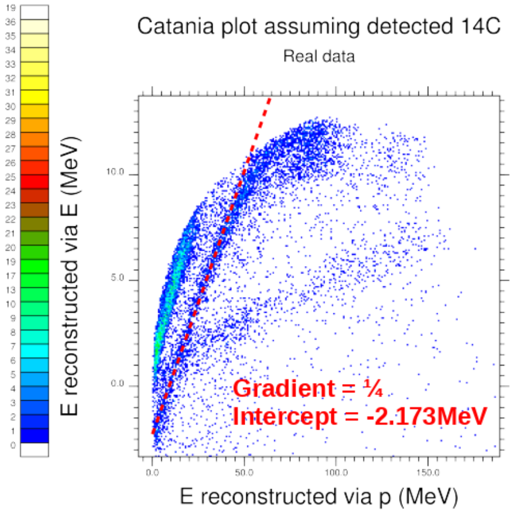

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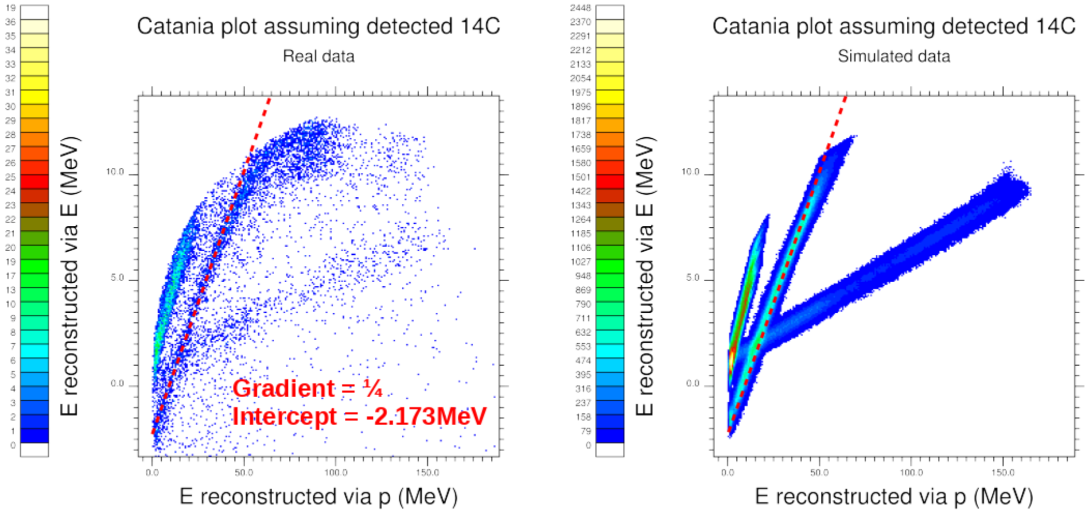

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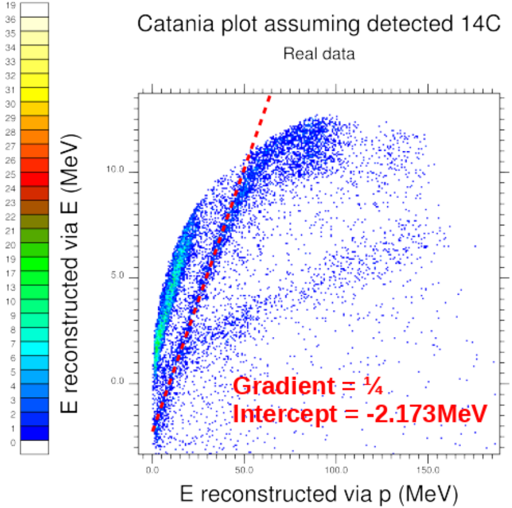

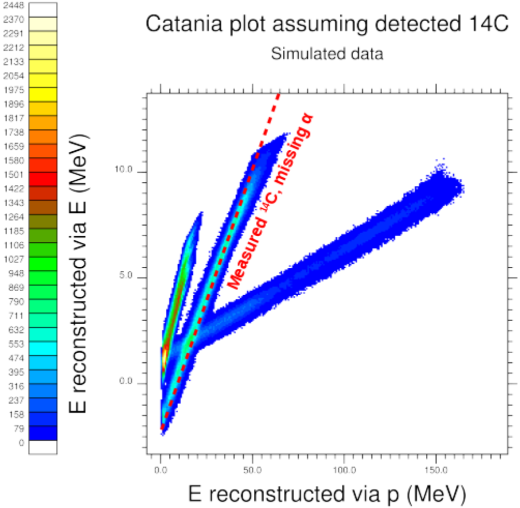

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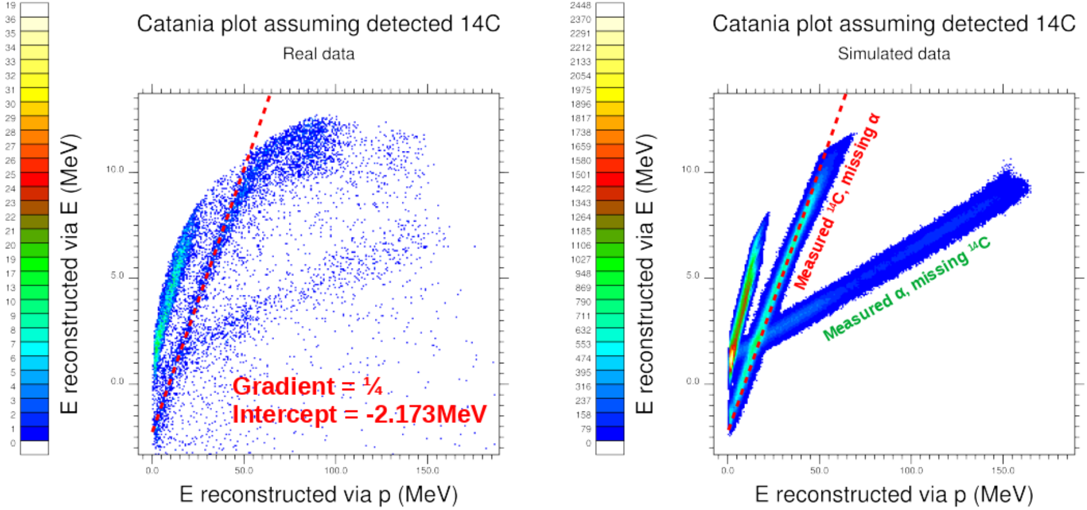
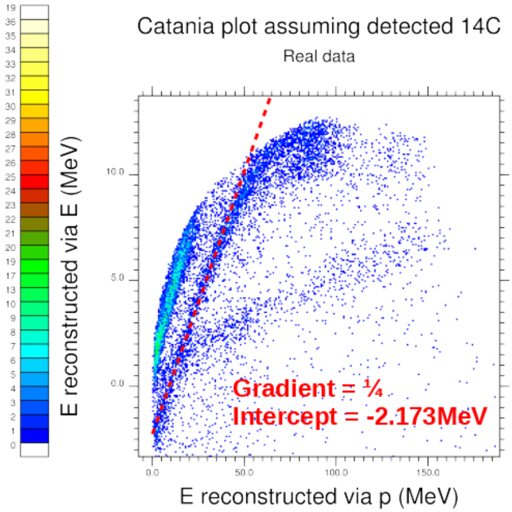
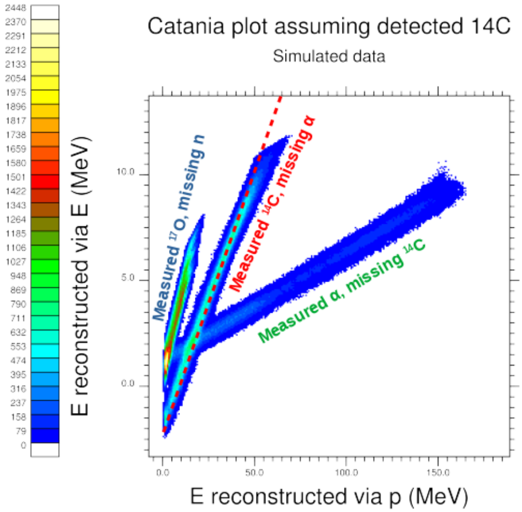
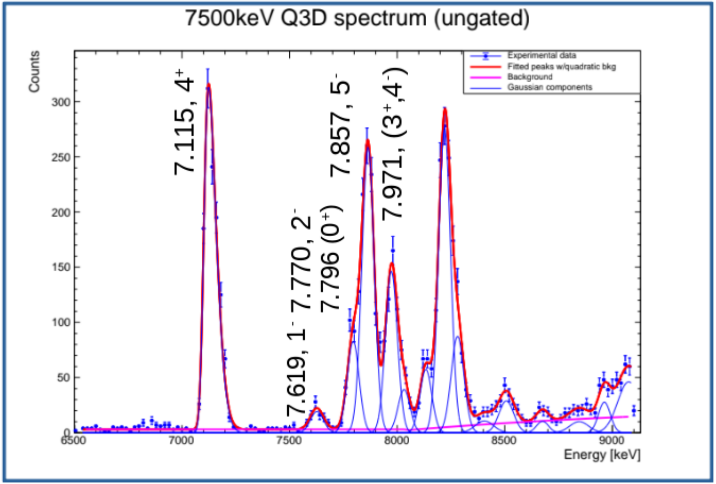



Catania plot assuming detected 14C
Real data
E reconstructed via E (MeV)
E reconstructed via p (MeV)
Gradient = ¼
Intercept = -2.173MeV


Catania plot assuming detected 14C
Simulated data
E reconstructed via E (MeV)
E reconstructed via p (MeV)
Measured 17O, missing n
Measured 14C, missing α
Measured α, missing 14C

What about below the neutron threshold?



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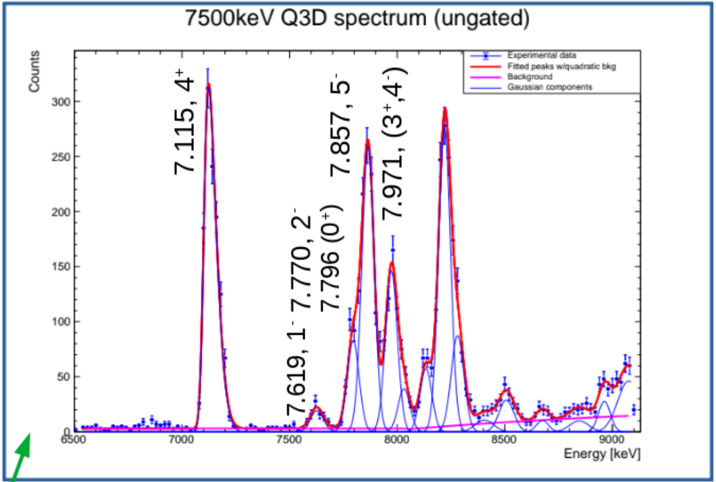

α-threshold:
6.227MeV

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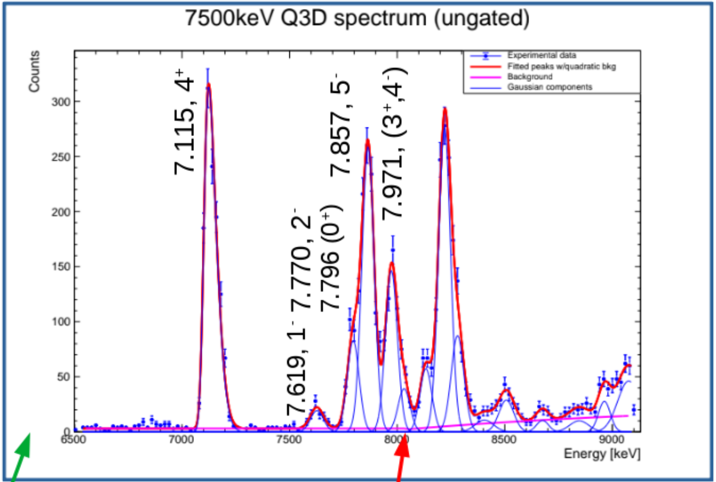

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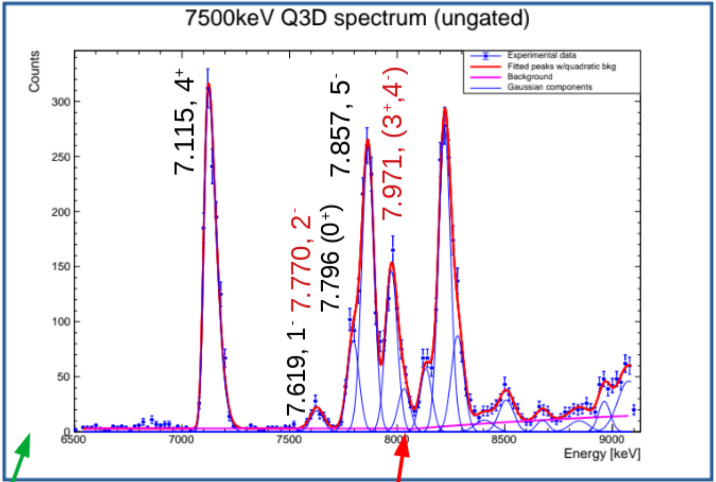

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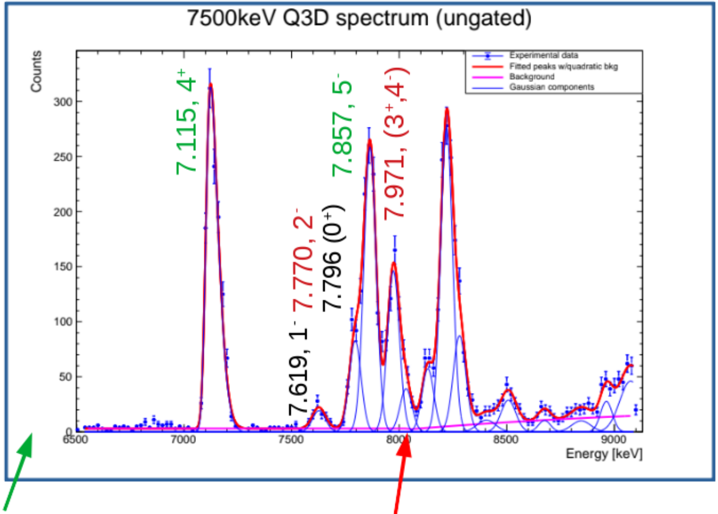

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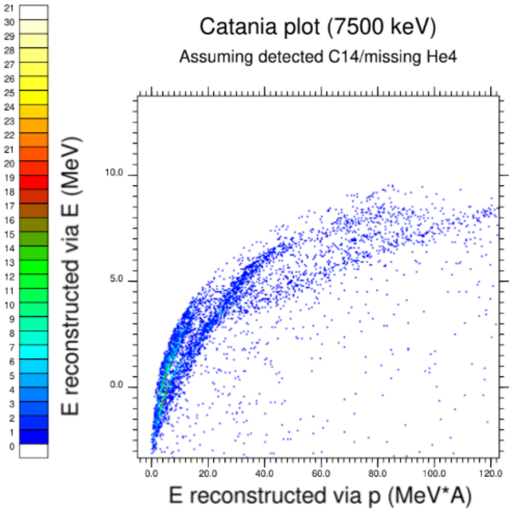
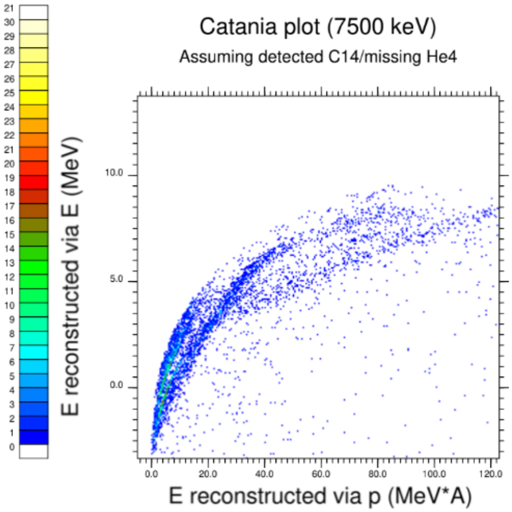

Catania plot (7500 keV)
Assuming detected C14/missing He4
E reconstructed via E (MeV)
E reconstructed via p (MeV*A)
10.0
5.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0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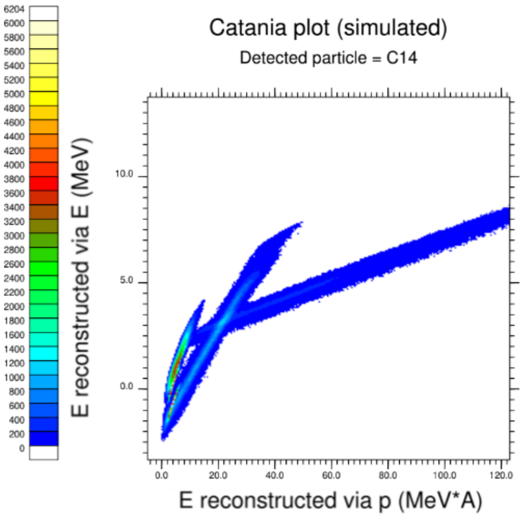
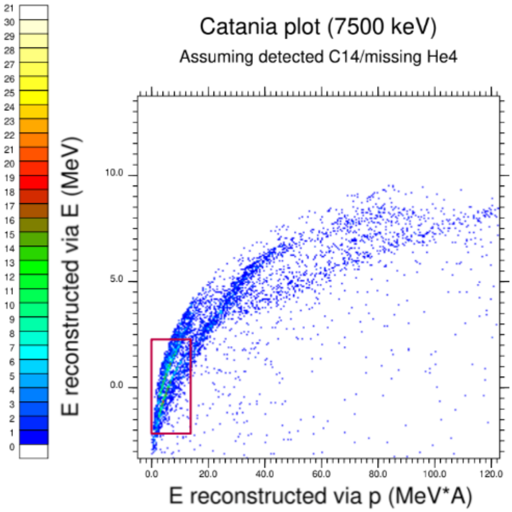

Catania plot (simulated)
Detected particle = C14
E reconstructed via E (MeV)
E reconstructed via p (MeV*A)



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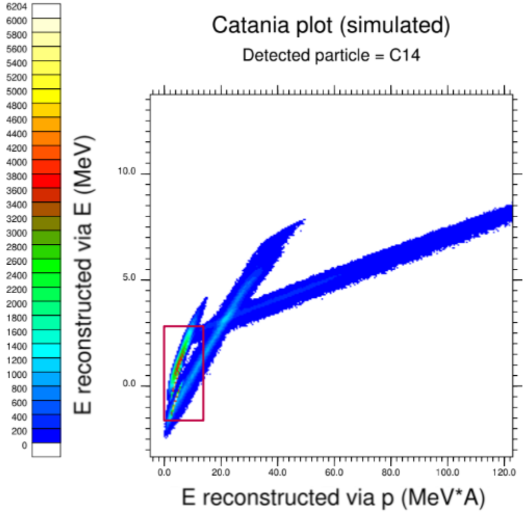

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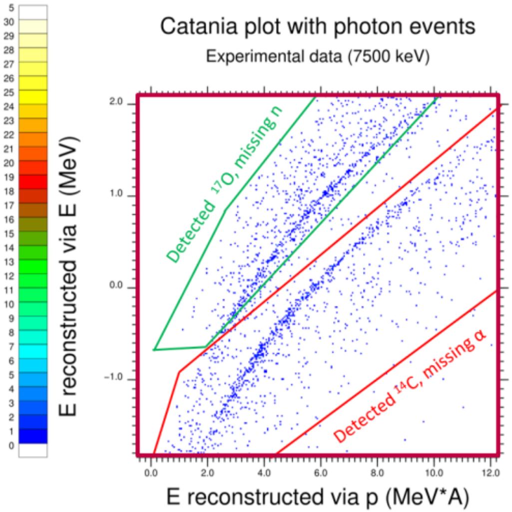
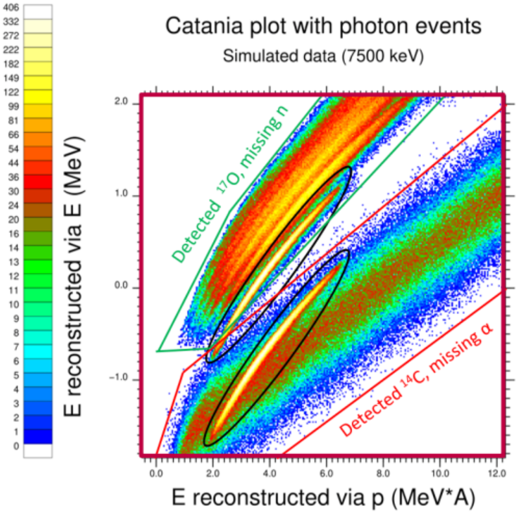

Catania plot with photon events
Experimental data (7500 keV)
Detected ^{17}O, missing n
Detected ^{14}C, missing α
E reconstructed via E (MeV)
E reconstructed via p (MeV*A)


Catania plot with photon events
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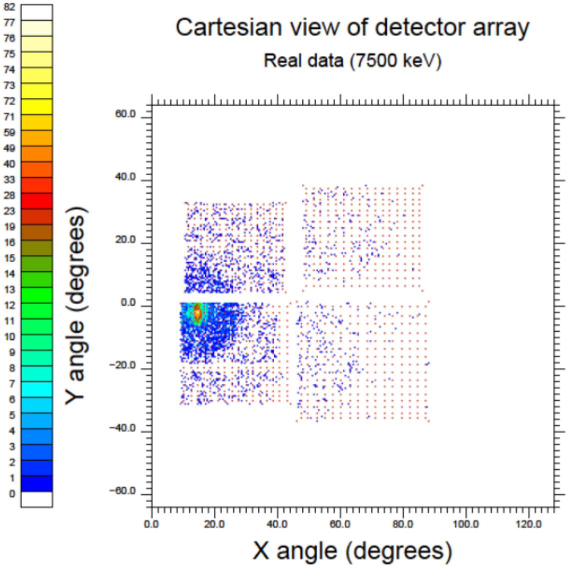
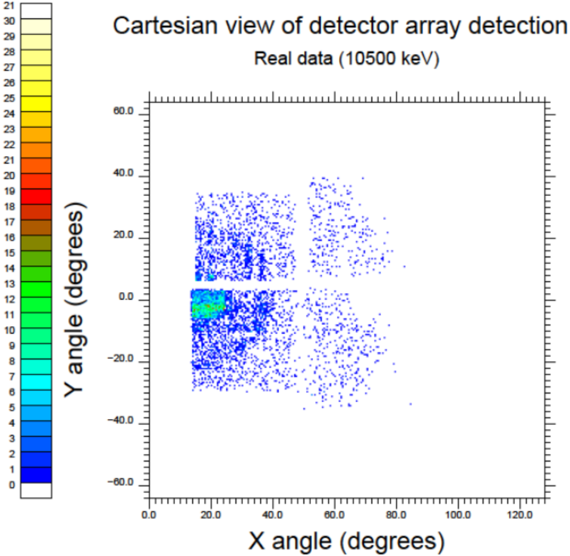
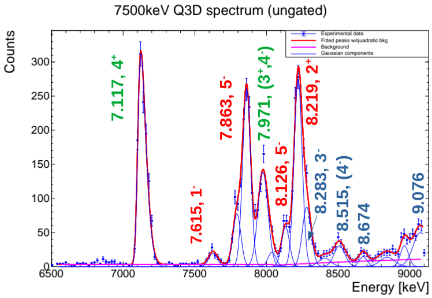
Detected ^{14}C, missing α
E reconstructed via E (MeV)
E reconstructed via p (MeV*A)

Detected ^{18}O





Example gated Q3D spectra



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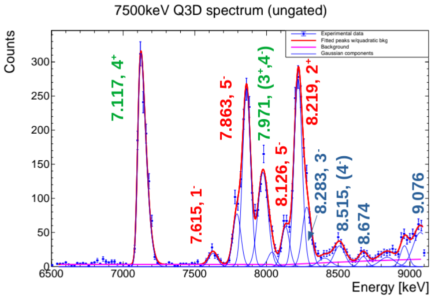
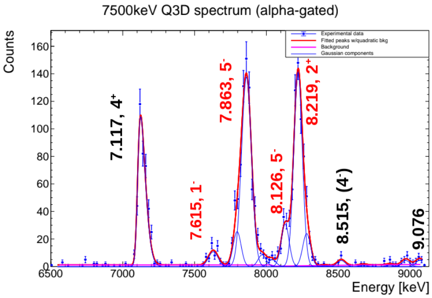
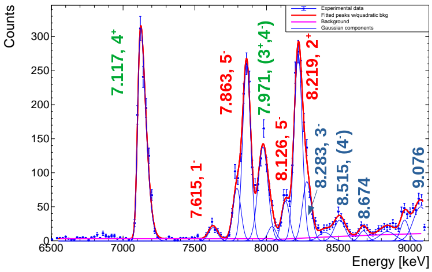


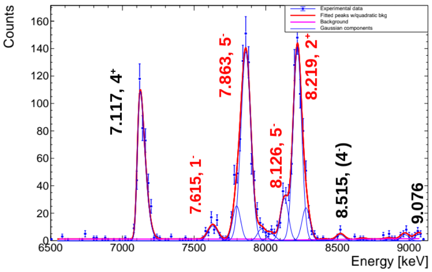


Example gated Q3D spectra

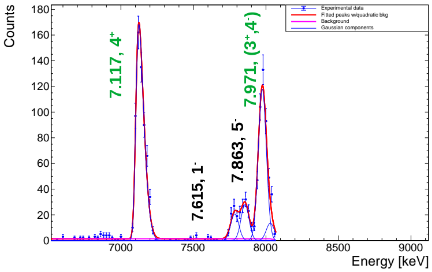
7500keV Q3D spectrum (ungated)



7500keV Q3D spectrum (alpha-gated)



7500keV Q3D spectrum (gamma-gated)



Example gated Q3D spectra

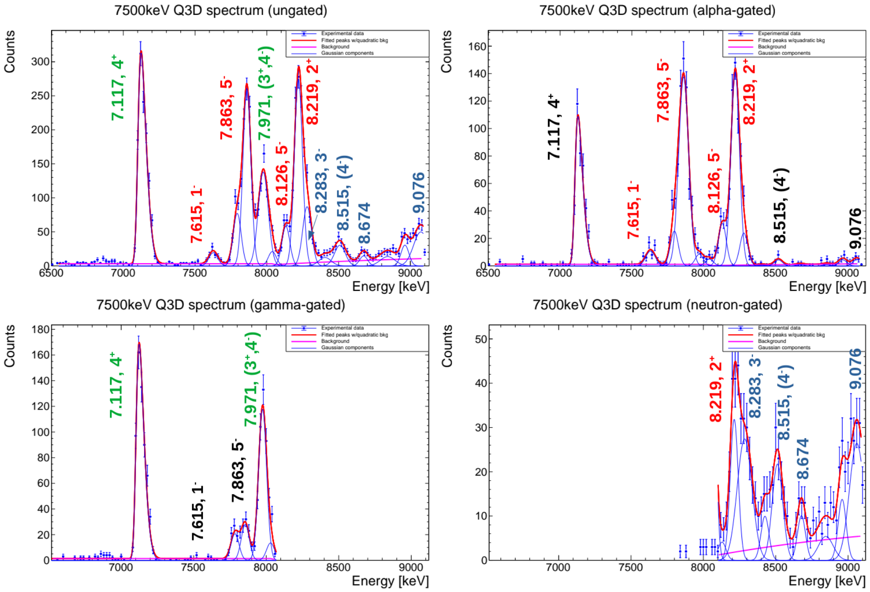


Table of results

Energy (keV)	Γ_{tot} (keV)	$\frac{\Gamma_\alpha}{\Gamma_{tot}}$	$\frac{\gamma_\alpha^2}{\gamma_W^2}$	E_{lit} (keV)	Γ_{lit} (keV)	J^π_{lit}
7117(2)	<16	0.48(2)	<0.09	7116.9(12)	<0.00024	4^+
7615(2)	<35	1.01(9)	-	7615.9(7)	<2.5	1^-
7795(2)*	<9	0.64(6)	<0.06 *	7796(5)*	<50*	0^+
7863(1)	<11	0.92(3)	-	7864(5)	-	5^-
7971(2)	<12	0.03(3)	-	7977(4)	-	$(3^+,4^-)$
8032(3)	<19	0.29(10)	<0.005	8037.8(7)	<2.5	1^-
8126(3)	<15	0.90(3)	<54	8125(2)	-	5^-
8219(1)	<15	0.88(3)	<0.007	8213(4)	1(8)	2^+
8283(4)	<28	0.39(7)	<0.12	8282(3)	8(1)	3^-
8409(10)	<56	0.07(8)	-	8410(8)	8(6)	(2^-)
8515(5)	<22	0.17(5)	-	8521(6)	5	(4^-)
8674(9)	<16	0.10(8)	-	8660(6)	8	-
8843(14)	80(30)	0.16(8)	-	8817(12)	70(12)	(1^+)
8963(5)	<33	0.21(6)	-	8955(4)	43(3)	-
9076(6)*	90(20)	0.24(7)	-	9053(6)*	100	-
9238(16)	<14	0.86(25)	-	9270(20)	-	$(0,1,2)^-$
9359(9)	47(20)	0.44(8)	-	9361(6)	27(15)	2^+

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- Comparison of the reduced α-partial widths, calculated using the absolute α-branching ratio, to the Wigner limit.

Collaborators

C. Wheldon, Tz. Kokalova, J. Bishop, N. Curtis, S. Bailey, R. Smith, D. Torresi, A. Turner

University of Birmingham

R. Hertenberger, H.-F. Wirth

Ludwig-Maximilians Universität München

Th. Faestermann

Technische Universität München

D. Mengoni

Università degli Studi di Padova

D. Dell'Aquila

Università degli Studi di Napoli Fedorico II