Investigation of Single-Particle Structure in ^{26}Na using the new SHARC Array

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LPC

TRIUMF

THE UNIVERSITY of York

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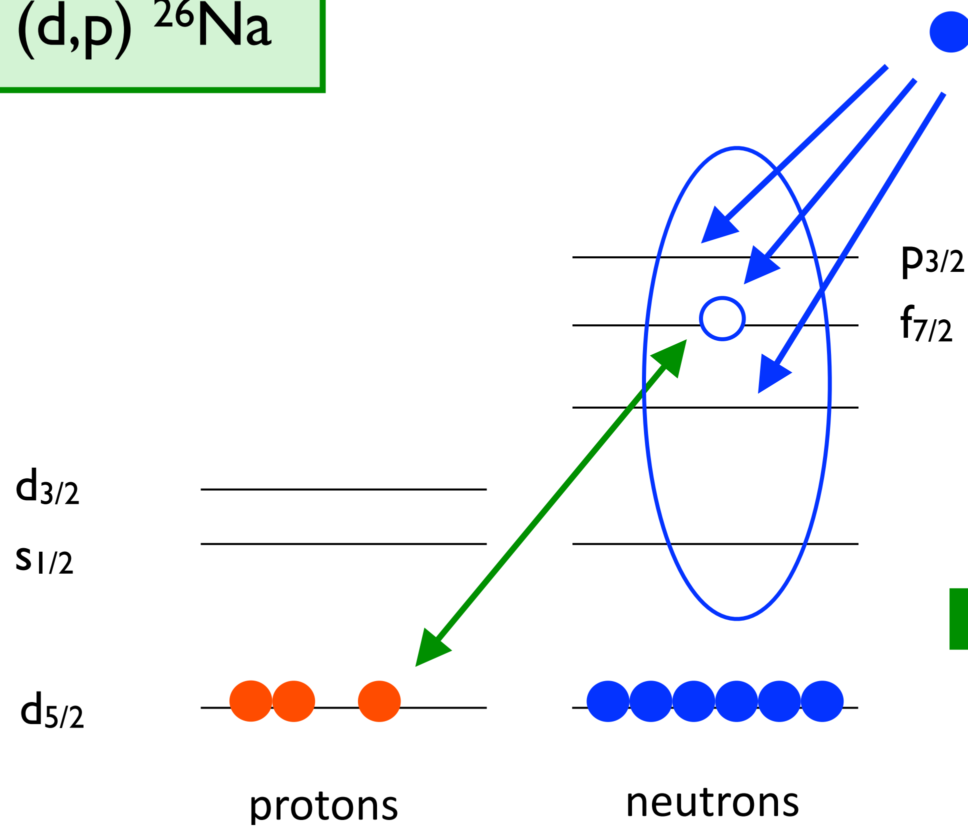
^{25}Na (d,p) ^{26}Na



Multiplets:

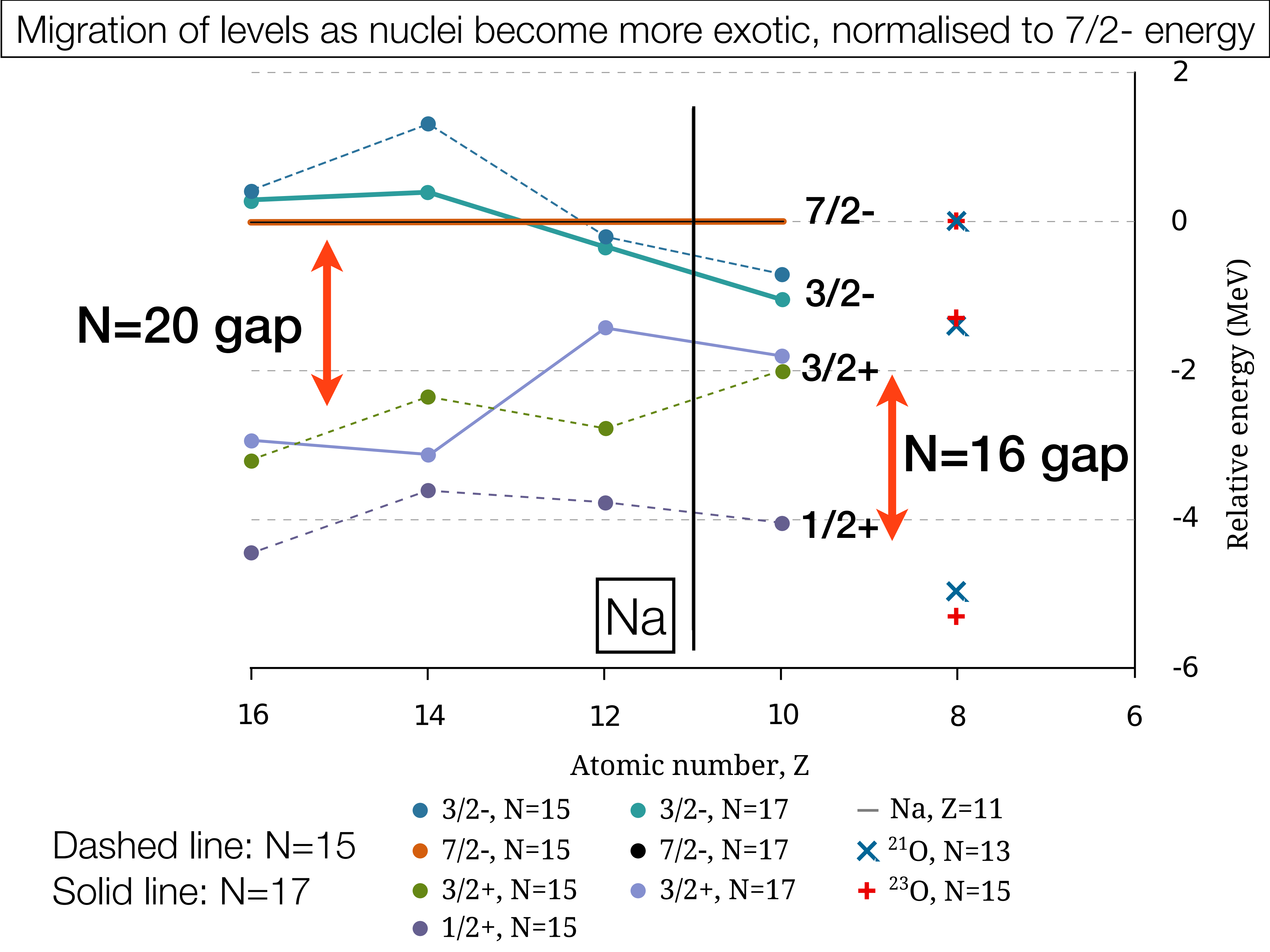
$\pi(d5/2) \otimes \upsilon(p3/2)$

$\longrightarrow (1,2,3,4)^-$

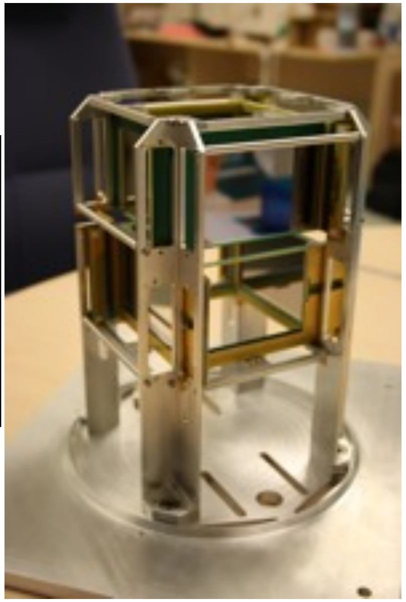
odd-odd final nucleus

High density of states

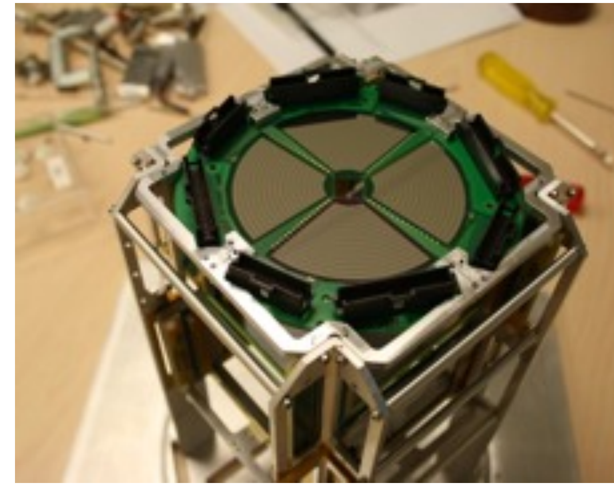
Gamma-gating needed


Migration of levels as nuclei become more exotic, normalised to 7/2- energy
N=20 gap
N=16 gap
7/2-
3/2-
3/2+
1/2+
Na
2
0
-2
-4
-6
Relative energy (MeV)
16
14
12
10
8
6
Atomic number, Z
Dashed line: N=15
Solid line: N=17
3/2-, N=15
7/2-, N=15
3/2+, N=15
1/2+, N=15
3/2-, N=17
7/2-, N=17
3/2+, N=17
Na, Z=11
21O, N=13
23O, N=15

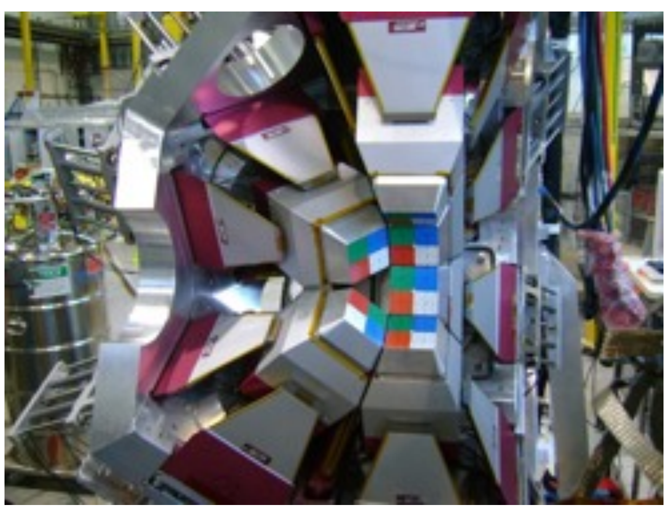
SHARC



- Upstream box of 4 DSSSDs
- Downstream box of up to 4 dE-E
- Upstream CD of 4 DSSSDs



- 4 clovers at 90°, 4 at 135°
- Full BGO suppression
- Each clover has 32-fold segmentation



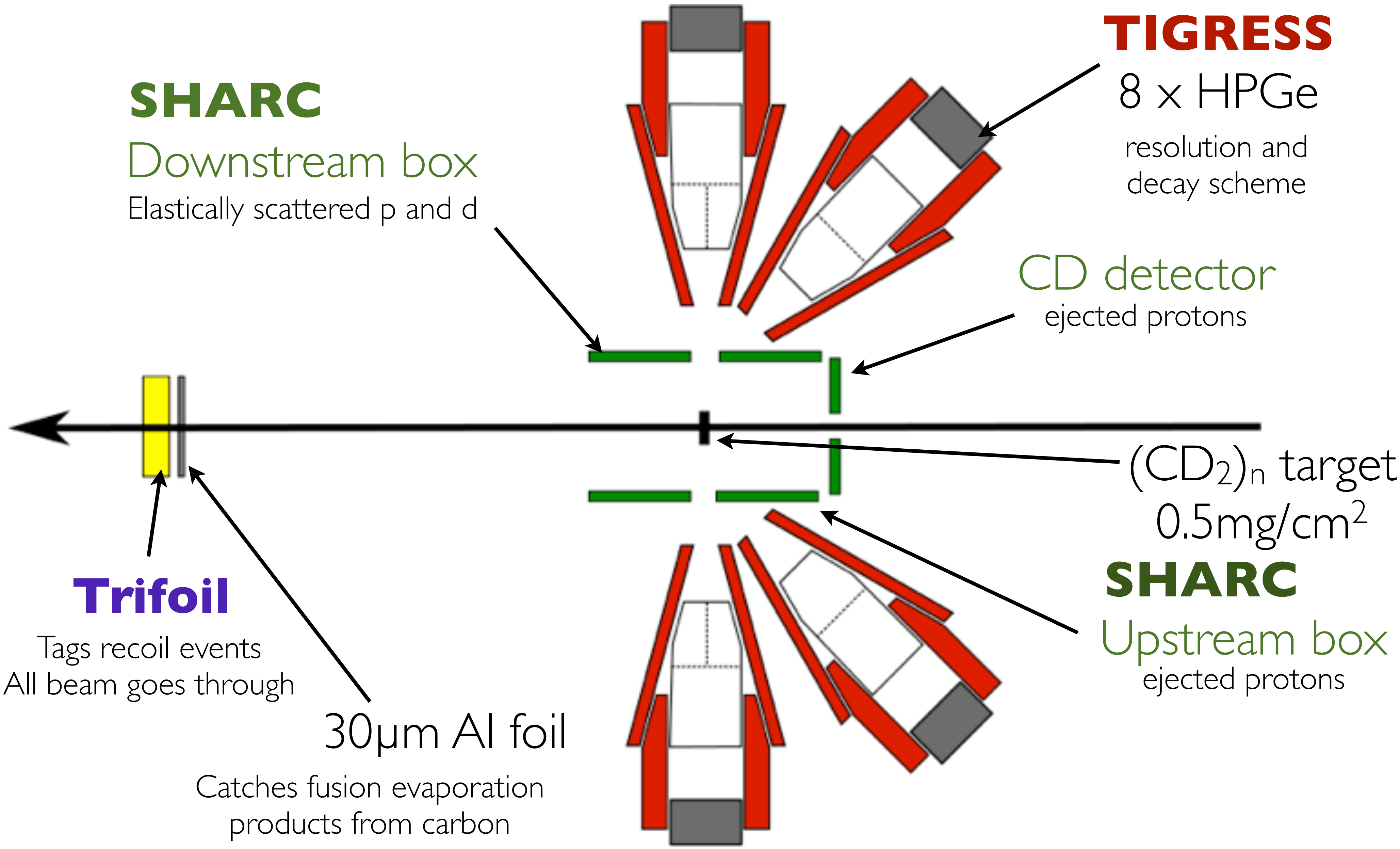
TIGRESS

Trifoil

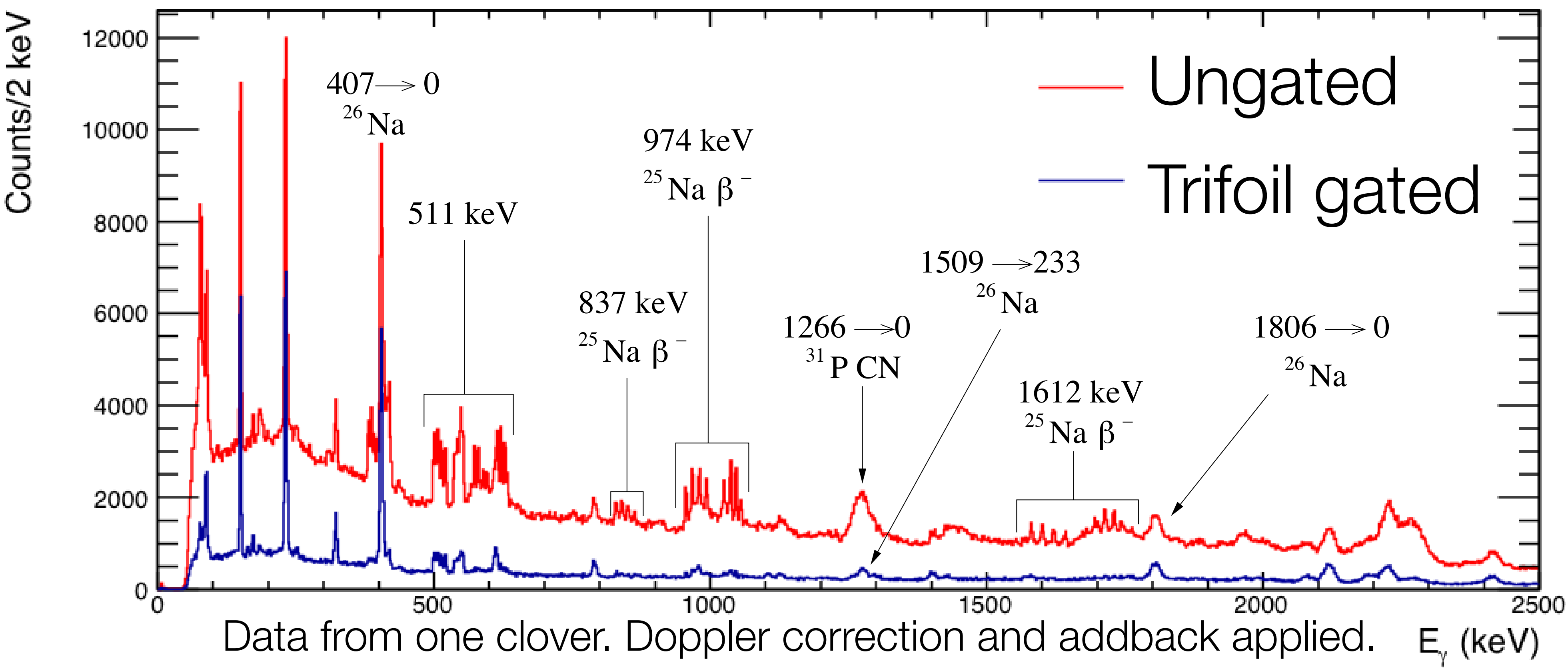
- Downstream of SHARC
- 10μm scintillation foil with active area of 40mm x 40mm
- Mounted with 30μm Al foil to stop fusion evaporation products

Experimental Setup

$d(^{25}Na,p)^{26}Na$ at TRIUMF
Beam: 3×10^7 pps,
5 AMeV ^{25}Na from ISAC II

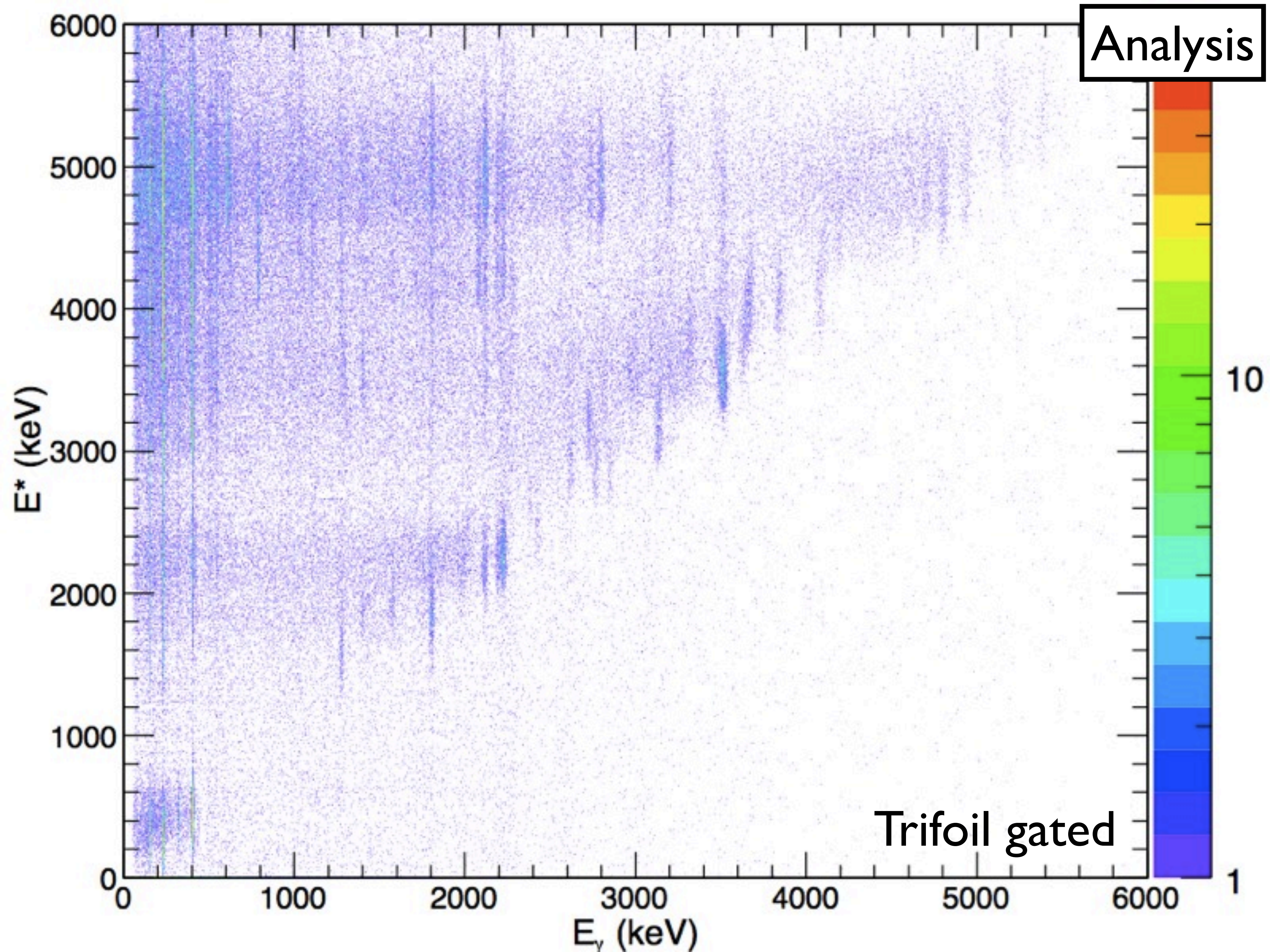


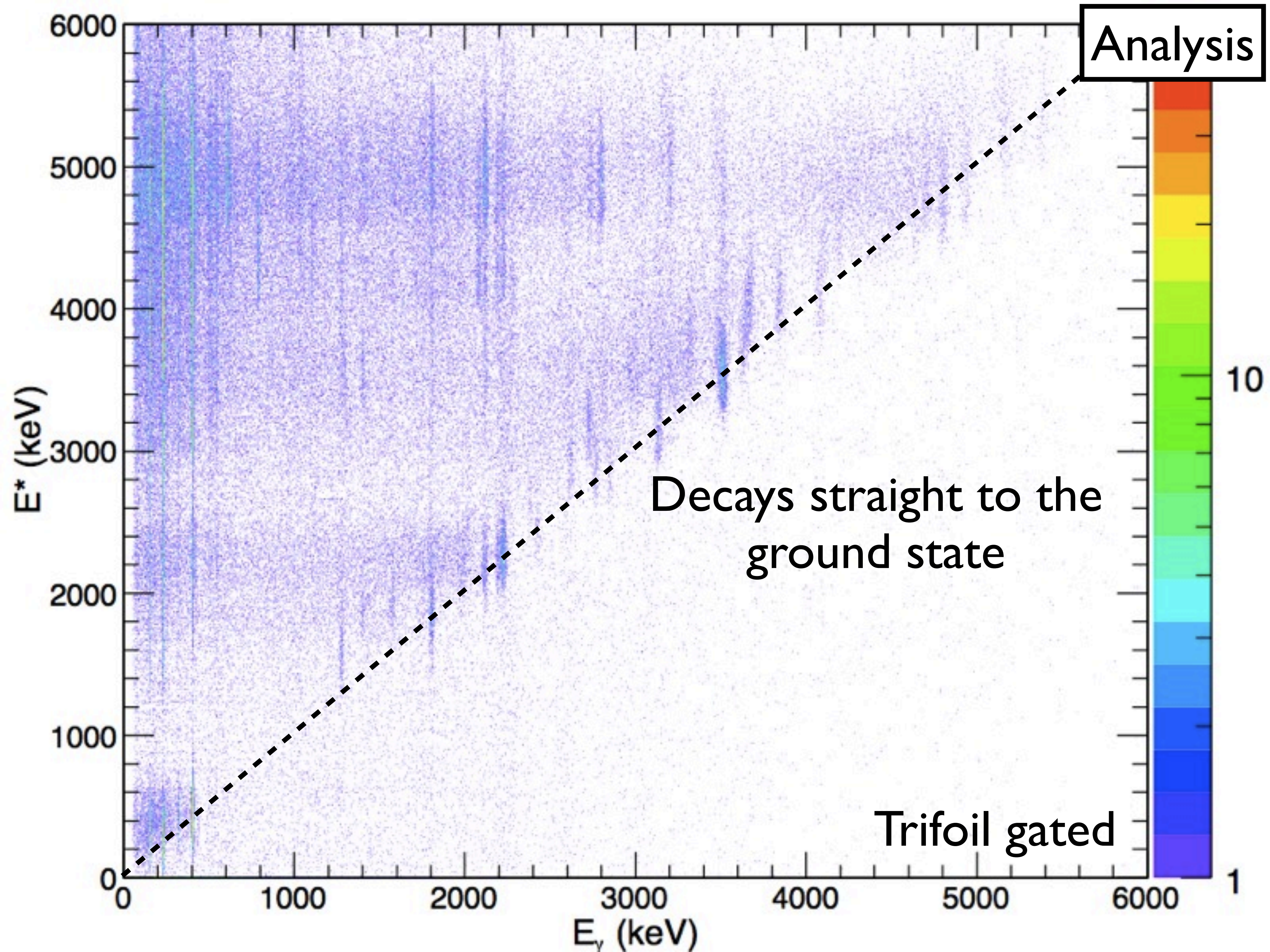
Use of Trifoil for vetoing γ rays



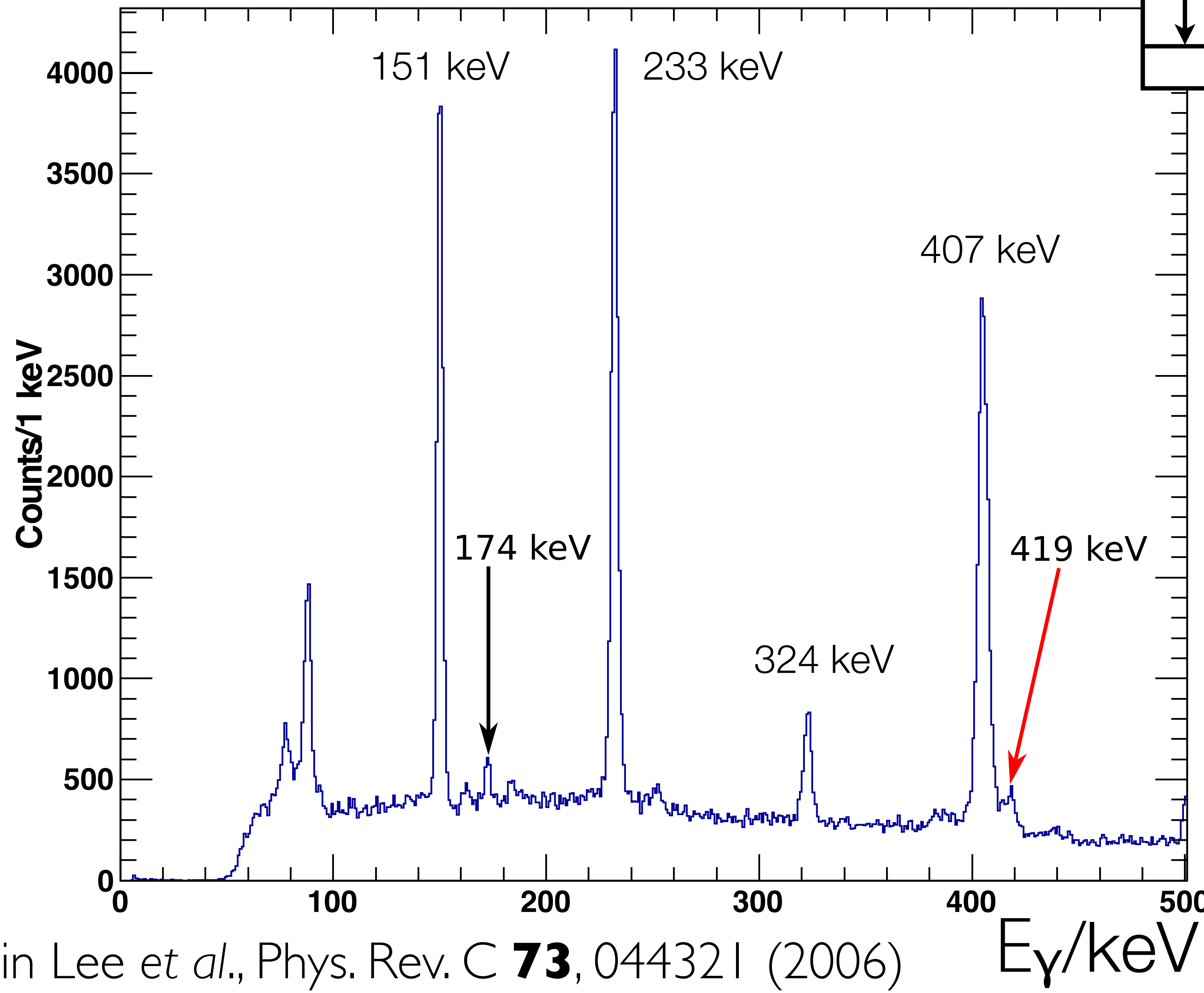
- signal to background ratio improved by a factor of 10
- 67% detection efficiency of γ rays from ^{26}Na[1]

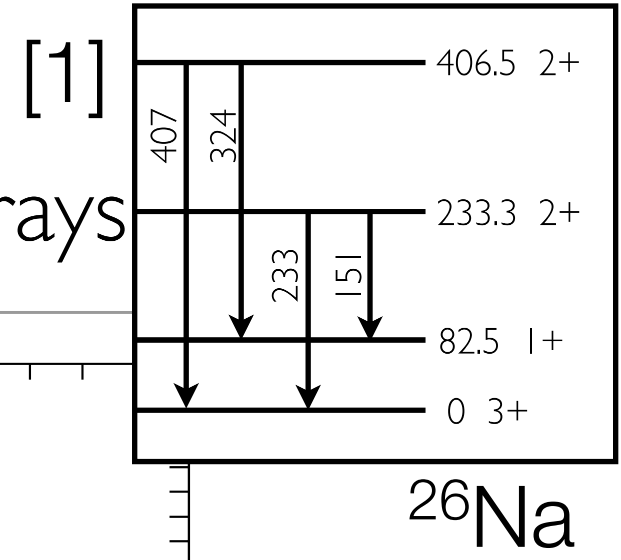
[1] G.W. *et al.*, J. Phys. Conf. Ser. **381**, 012097 (2012)


Analysis
Trifoil gated
E* (keV)
E$_\gamma$ (keV)
0
1000
2000
3000
4000
5000
6000
0
1000
2000
3000
4000
5000
6000
1
10


Analysis
Decays straight to the ground state
Trifoil gated
E* (keV)
Eγ (keV)
0
1000
2000
3000
4000
5000
6000
10
1

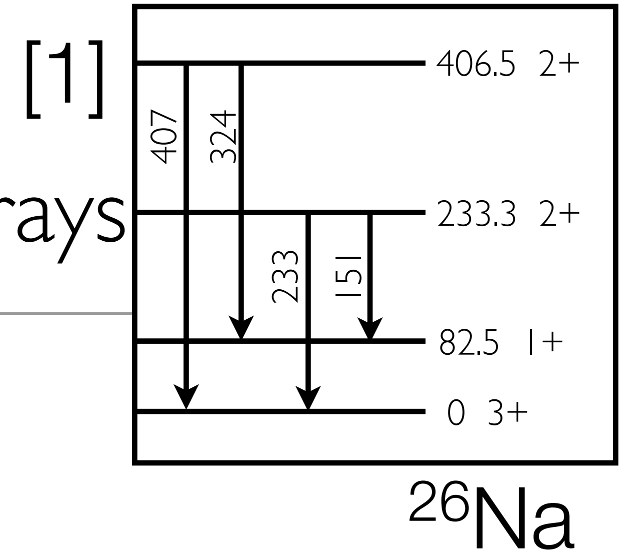
Using the Ex vs Eγ plot to identify γ rays

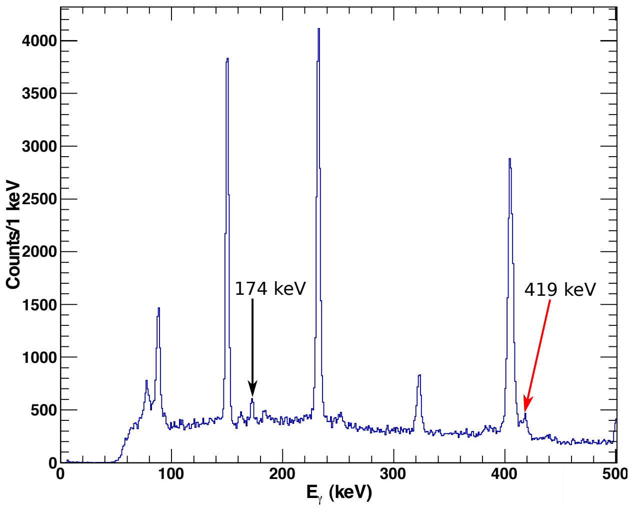


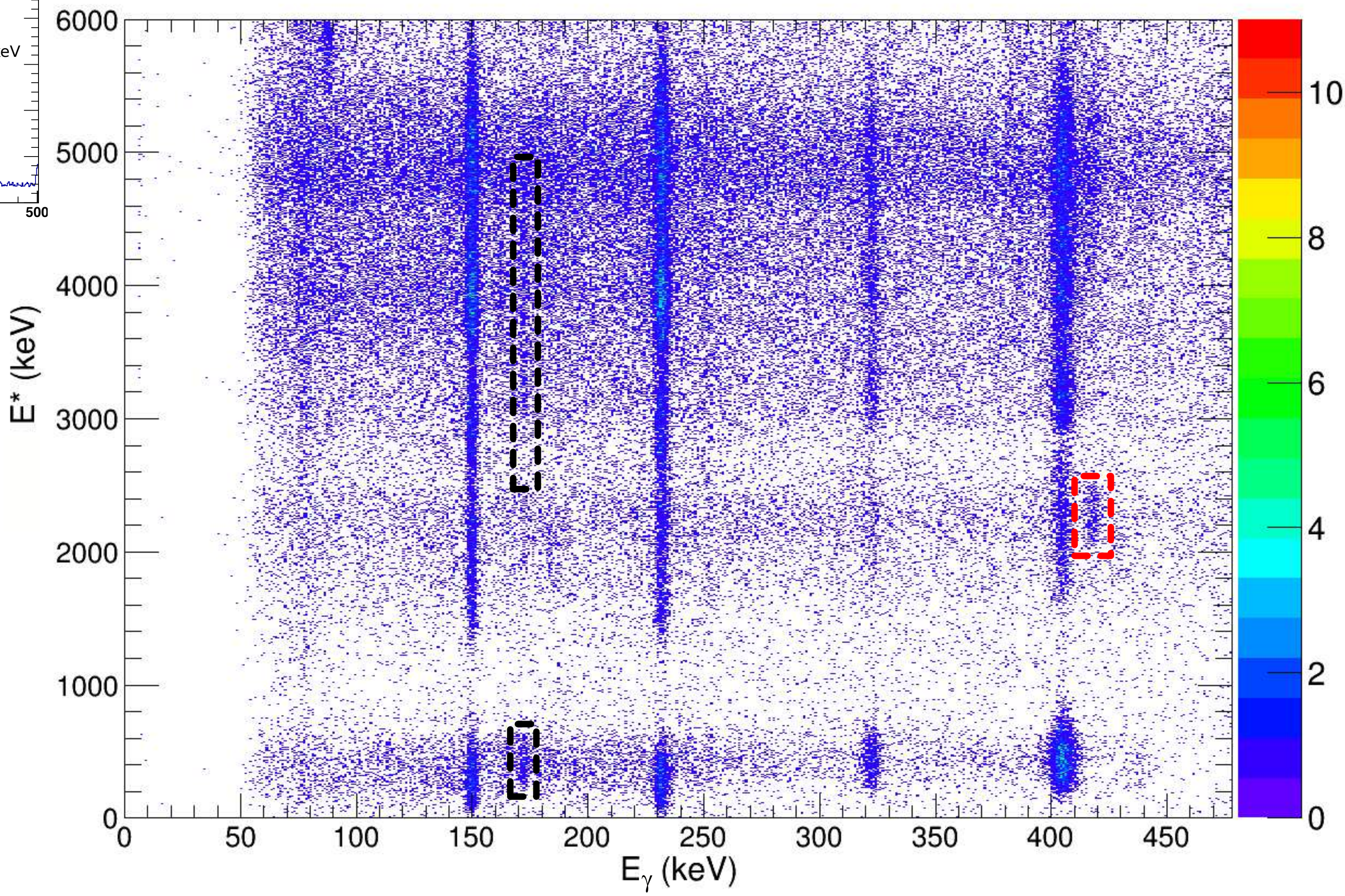


[1] Sangjin Lee *et al.*, Phys. Rev. C **73**, 044321 (2006)

Using the Ex vs Eγ plot to identify γ rays

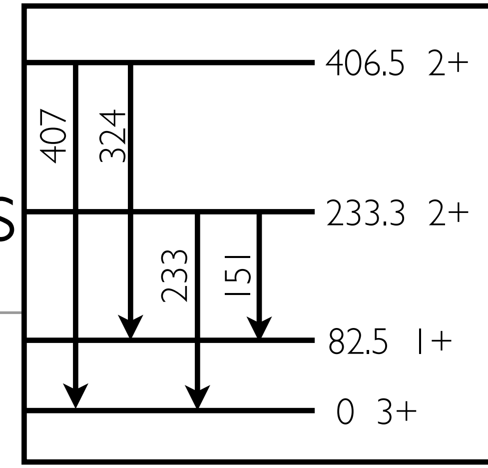




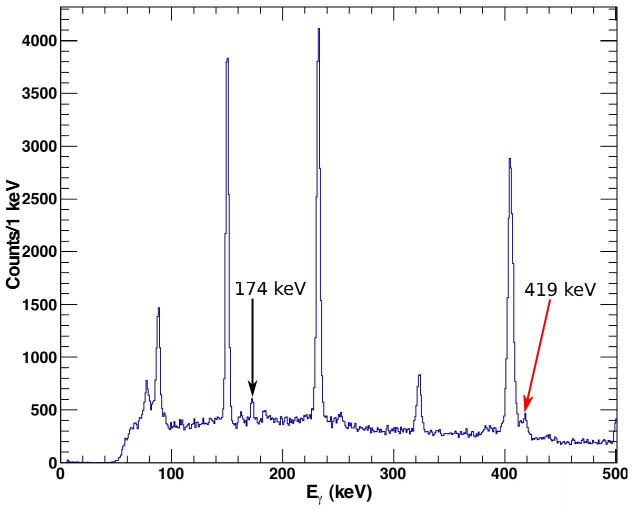


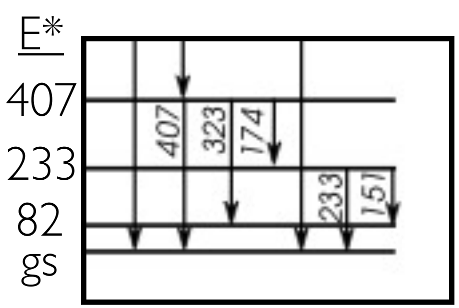
Using the Ex vs Eγ plot to identify γ rays

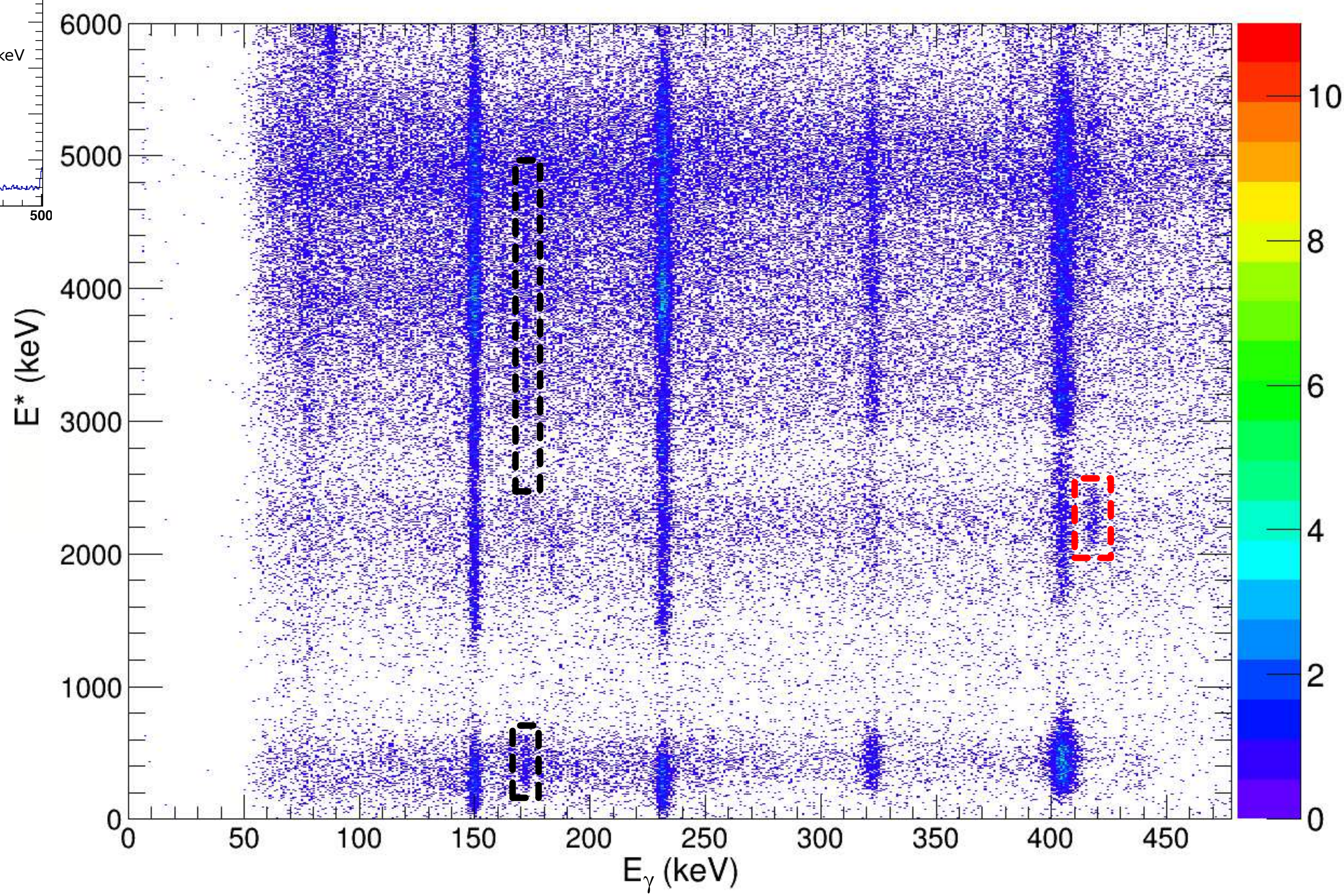
[1]



^{26}Na

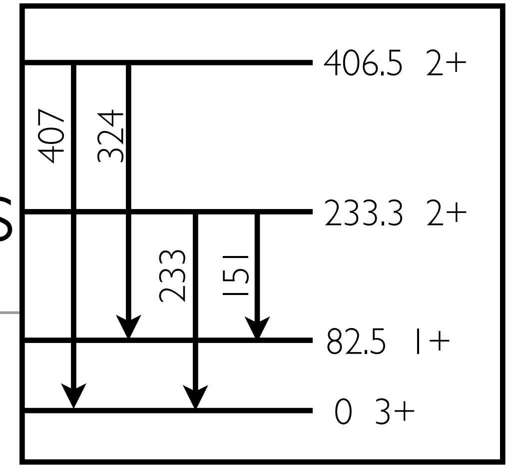




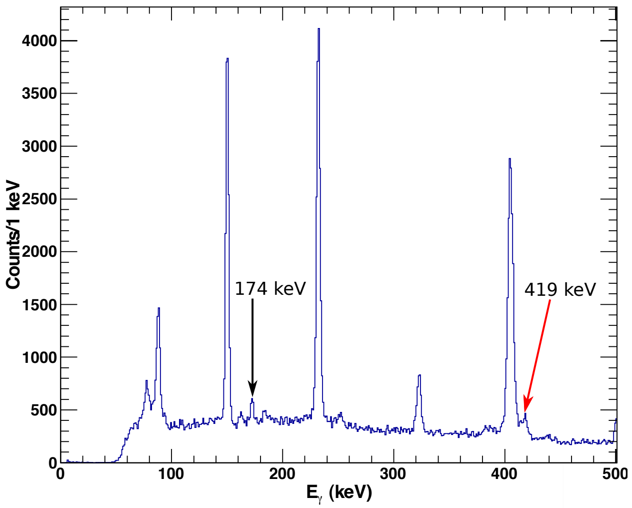


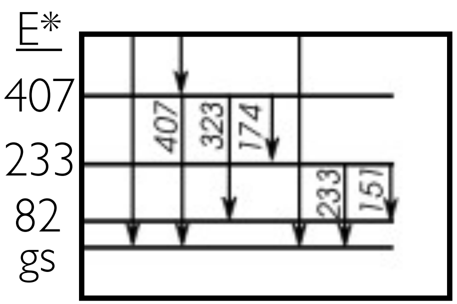
[1]

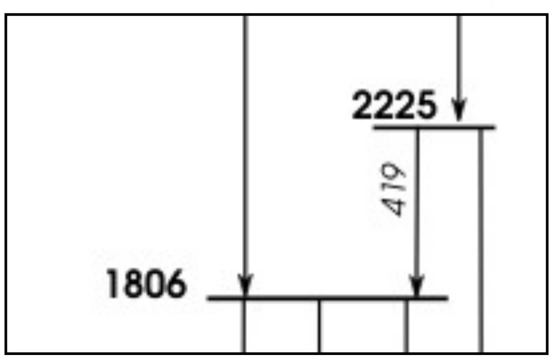
Using the Ex vs Eγ plot to identify γ rays

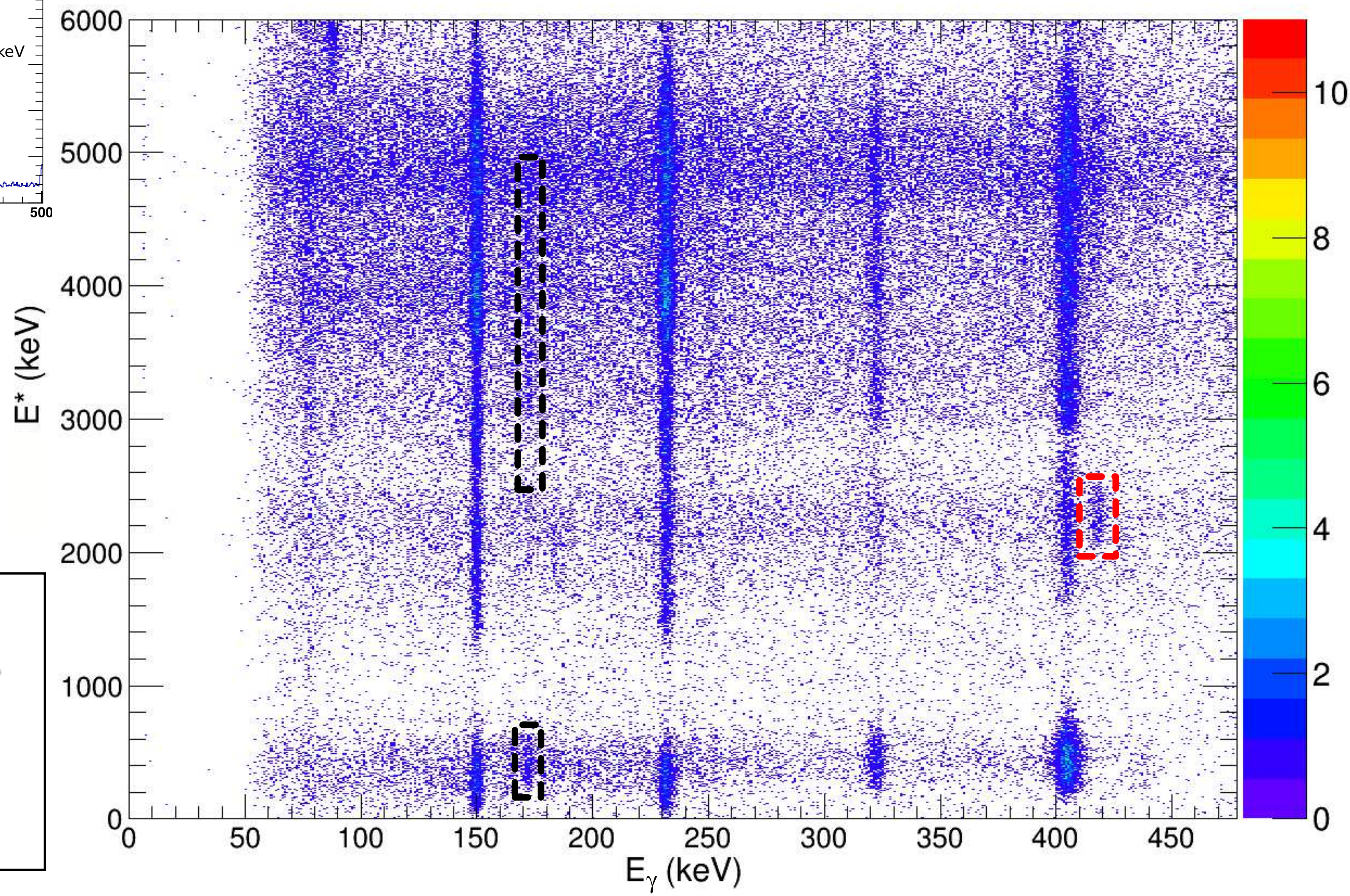


^{26}Na







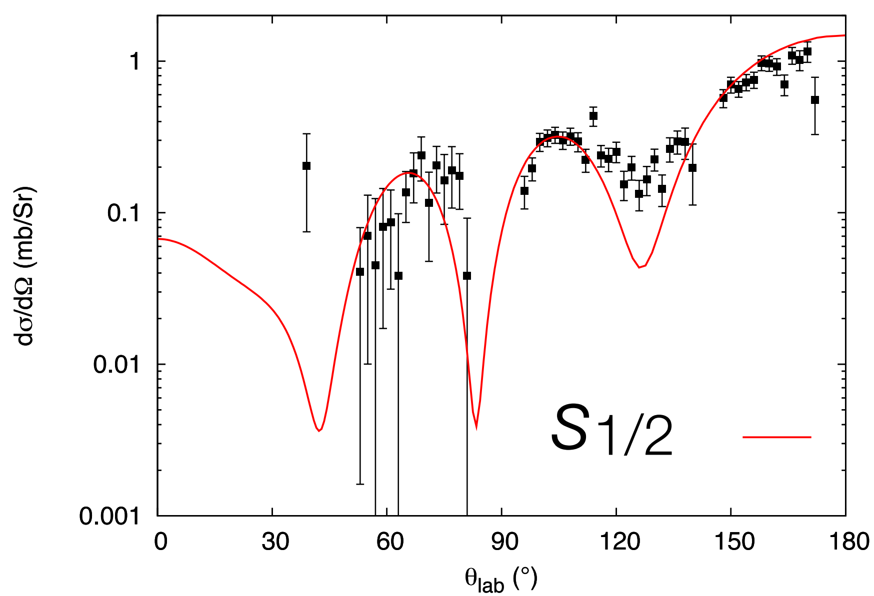


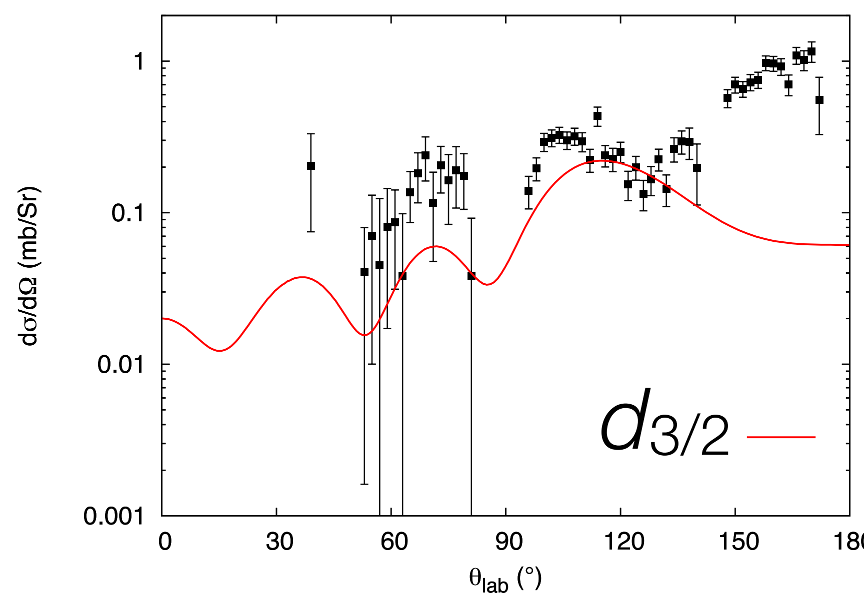
Angular distributions

- 7 states in ^{26}Na with a ground-state decay branch analysed
- Proton angular distributions extracted from γ-ray gating
- ℓ -transfer deduced from proton angular distributions

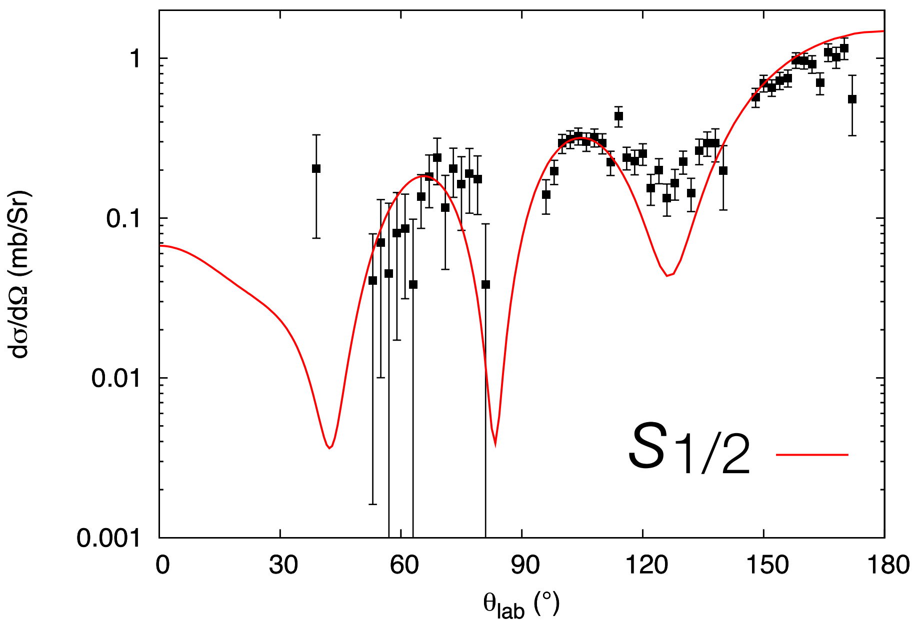
- Theoretical cross-sections calculated using ADWA Johnson-Soper method (R.C. Johnson and P.J.R. Soper, Phys. Rev. C. **1**, 976 (1970))
- For states with no angular distribution extracted, J^{π} assignments inferred from the N=15 isotone, ^{28}Al

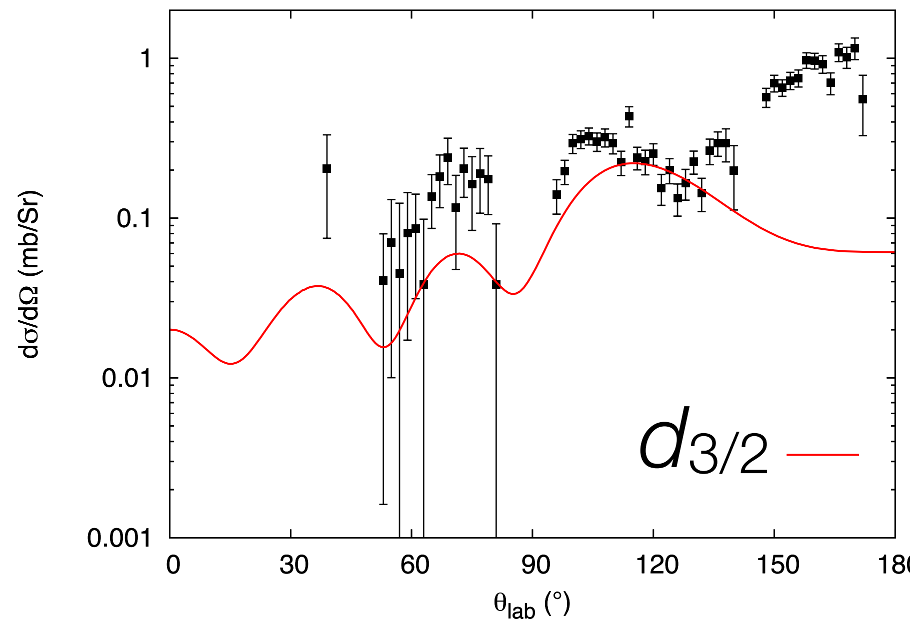
233-keV state:



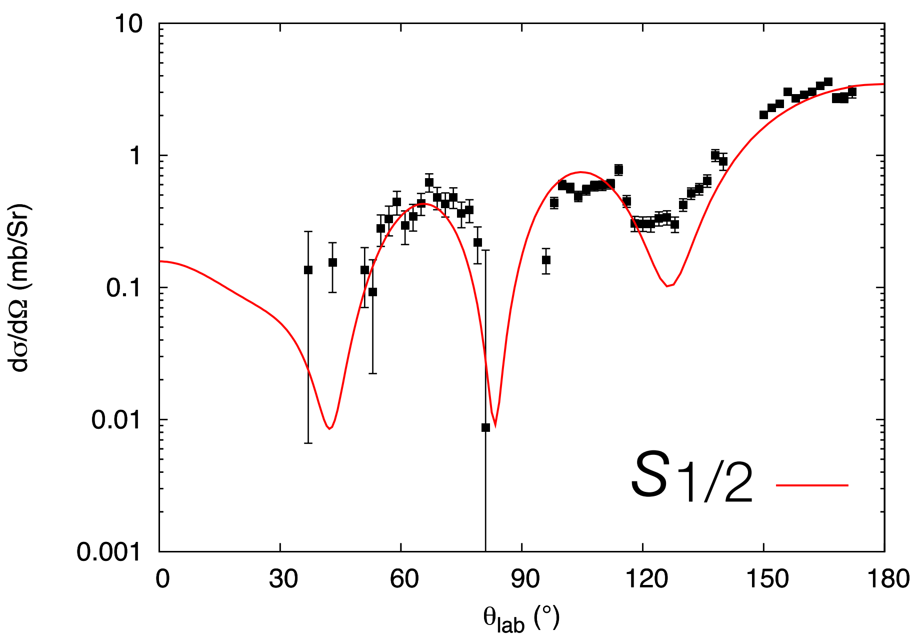


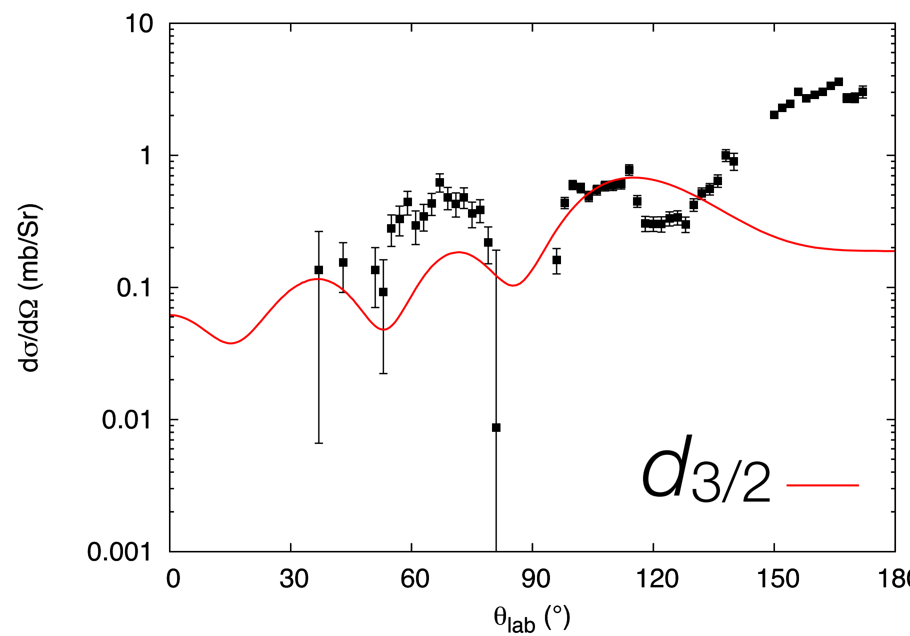
233-keV state:



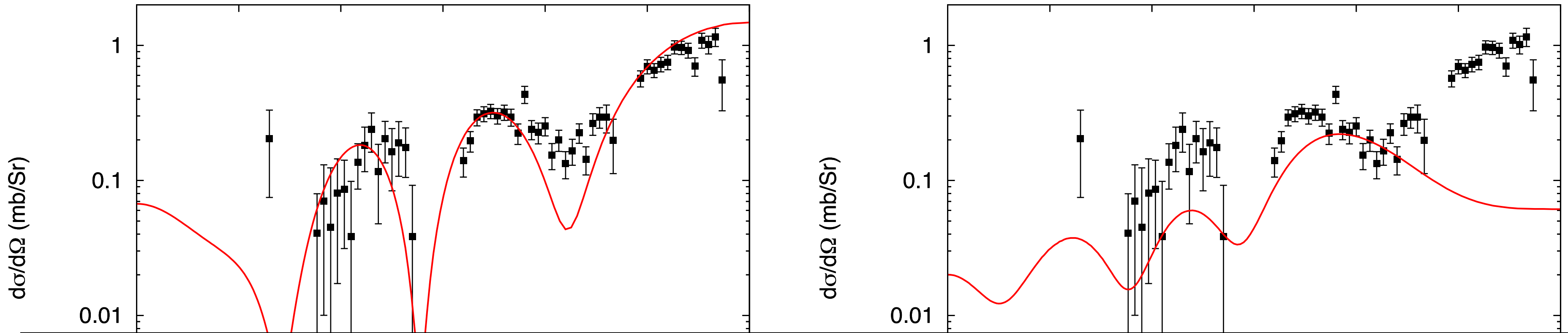


407-keV state:



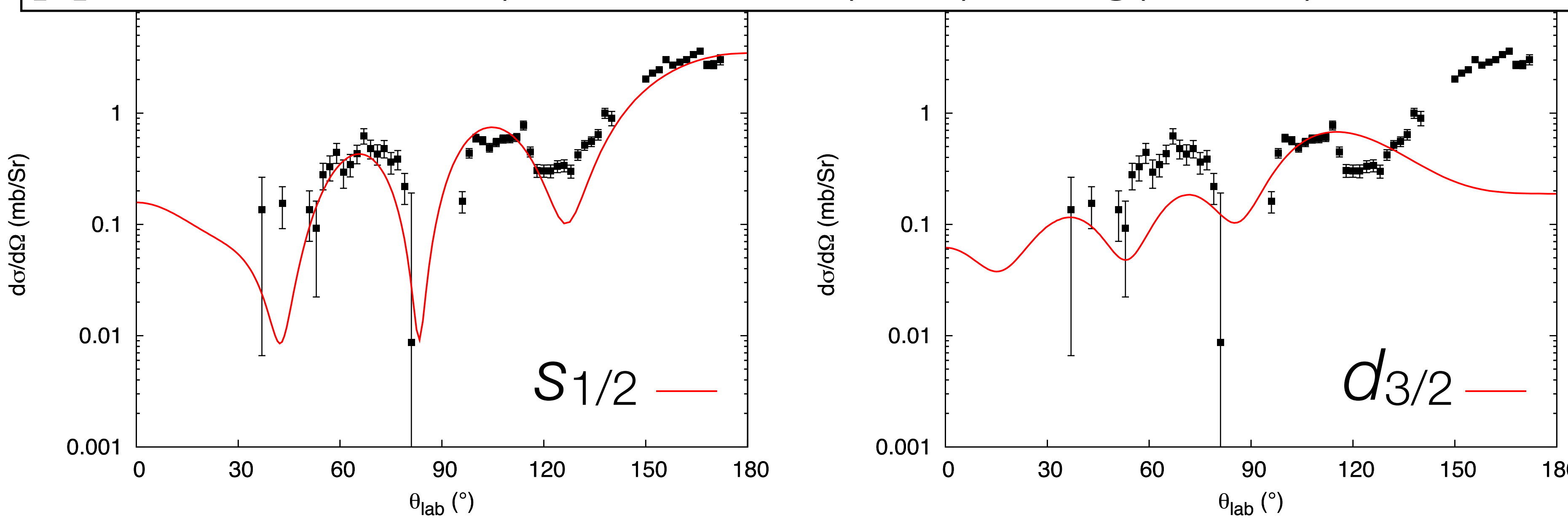


233-keV state:

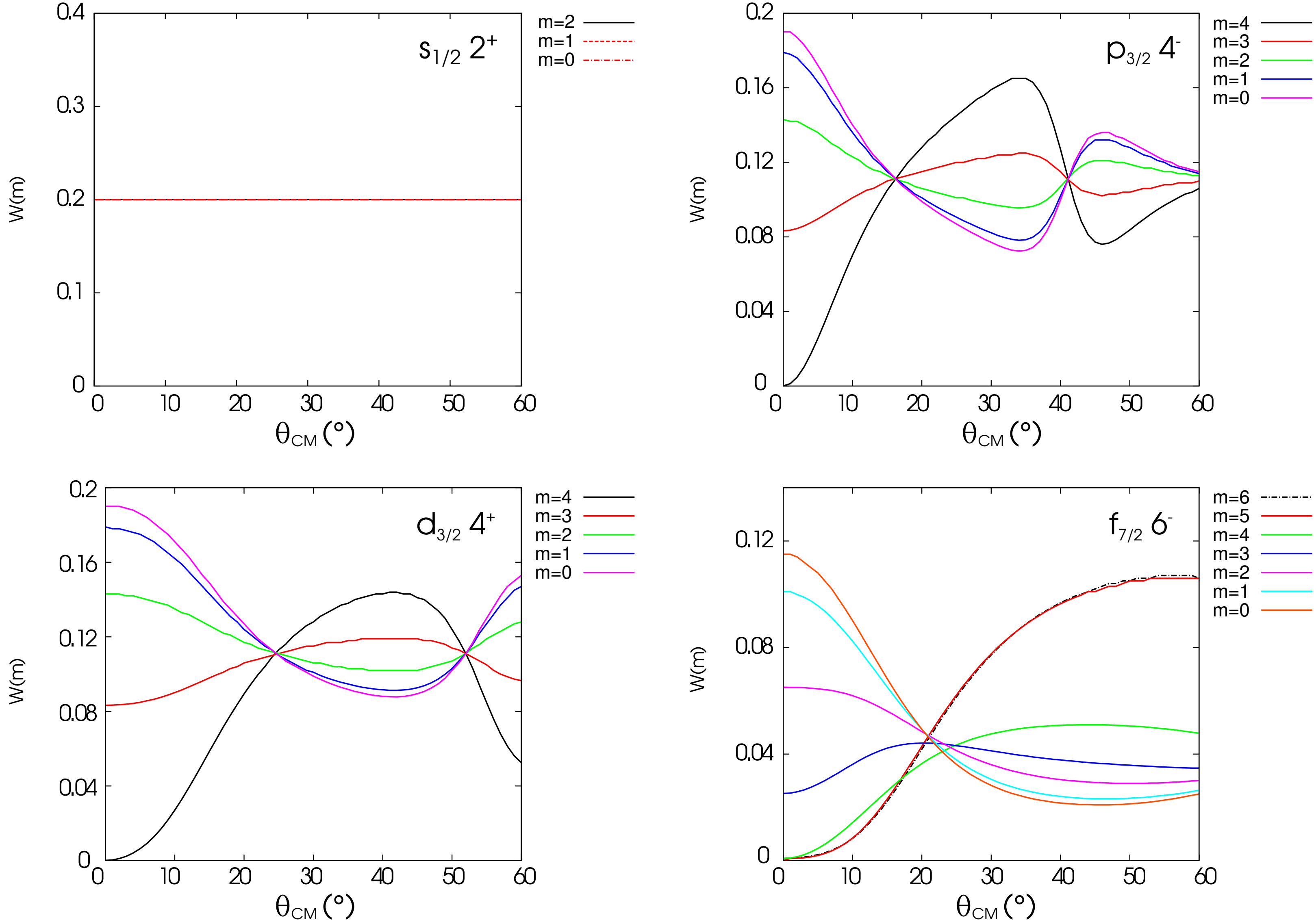


There have been no previous direct measurements of the 233- or 407-keV states; they have only been previously deduced to be 2^+ [1,2]

[1] Sangjin Lee *et al*., Phys. Rev. C **73**, 044321 (2006) - $^{14}C(^{14}C,d)$
[2] K.I. Pearce *et al*., Phys. Rev C **35**, 5 (1987) - $^{26}Mg(^{3}H, ^{3}He)^{26}Na$

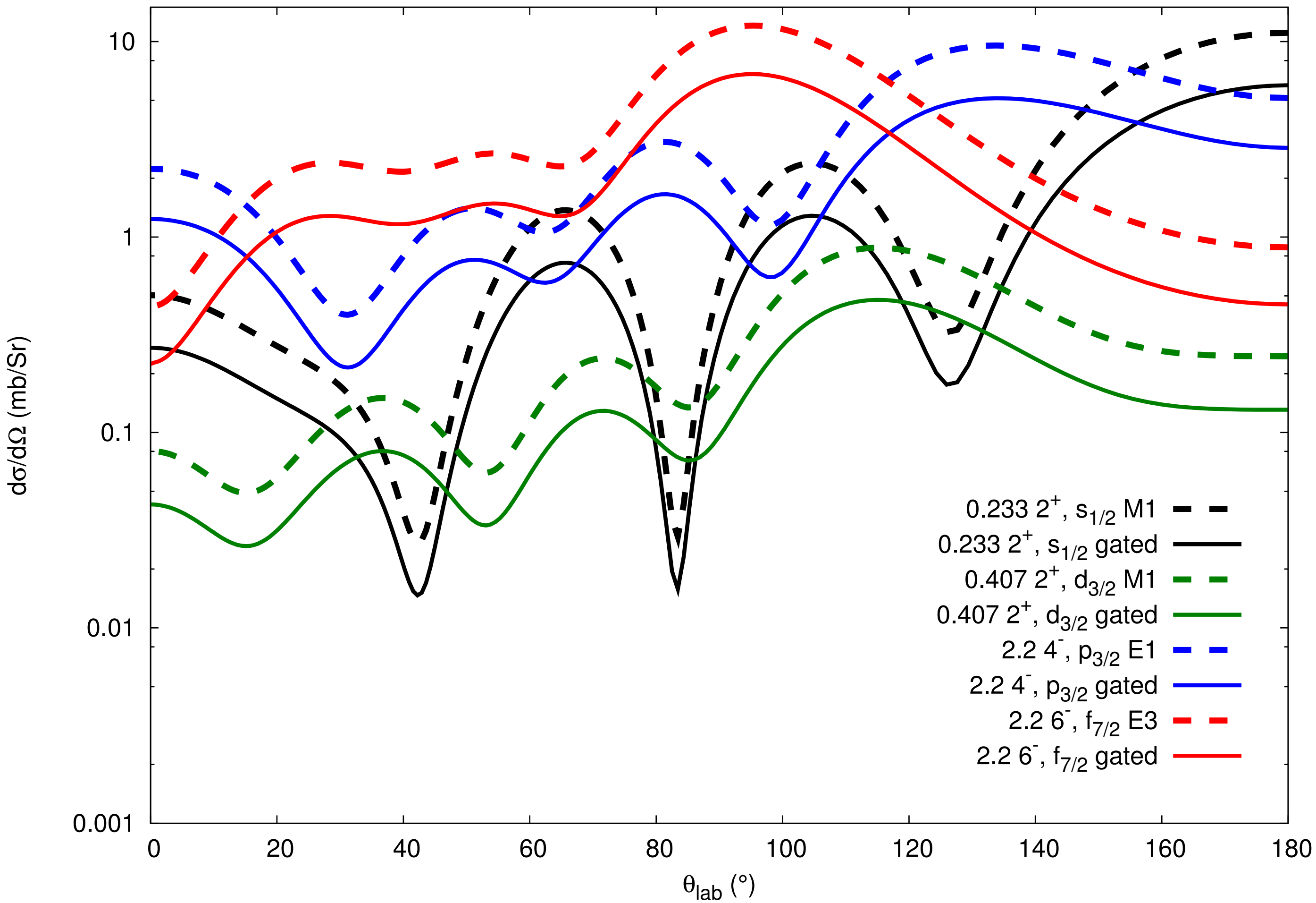


Substate populations over proton CM angle for a 2.2 MeV state in ^{26}Na



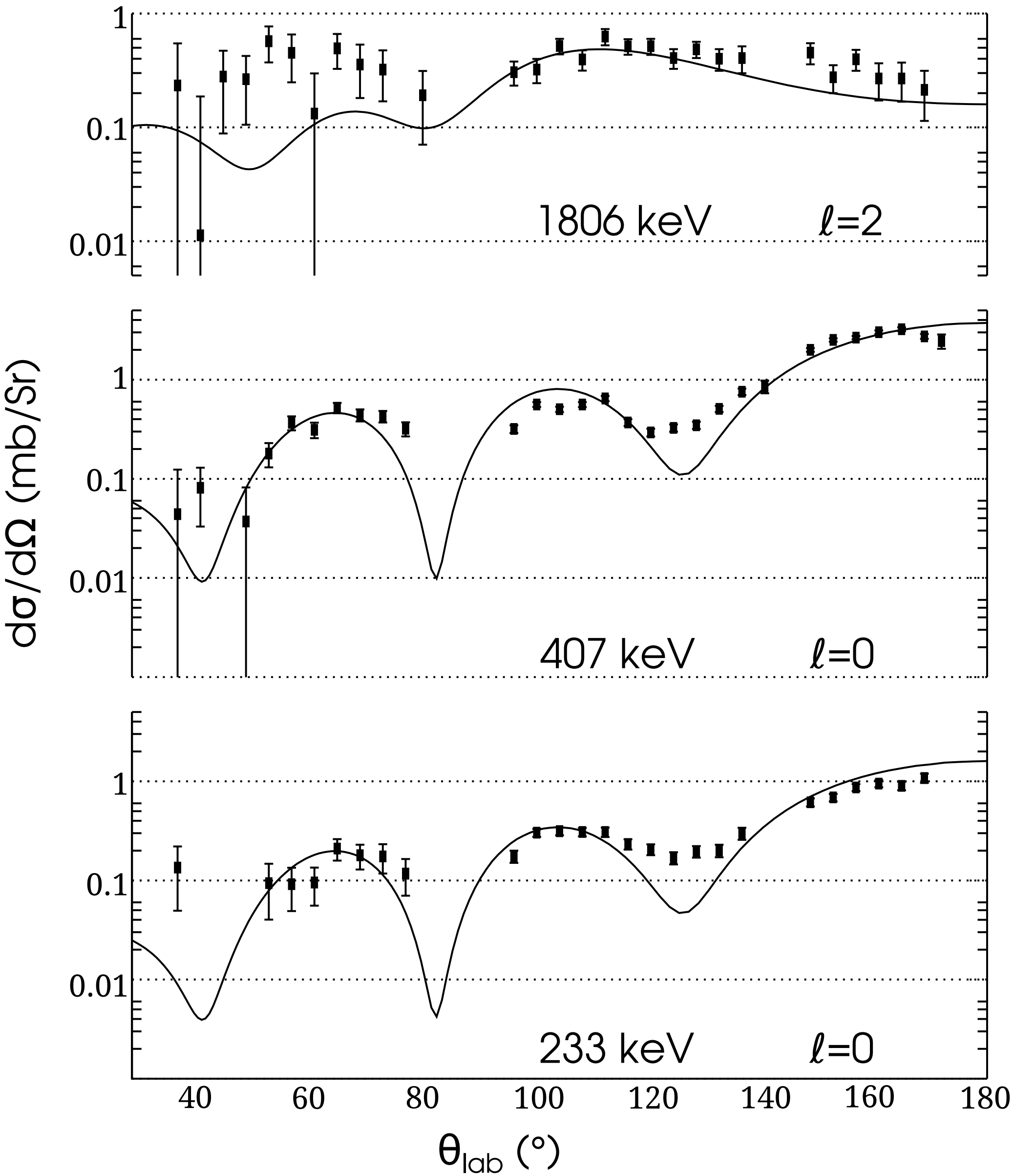
The γ-ray angular distribution varies as a function of proton angle, so proton angular distributions are distorted if extracted with the requirement of a γ ray. The effect is calculated by integrating the calculated γ-ray angular distribution for each proton angle over the range of the TIGRESS detectors.

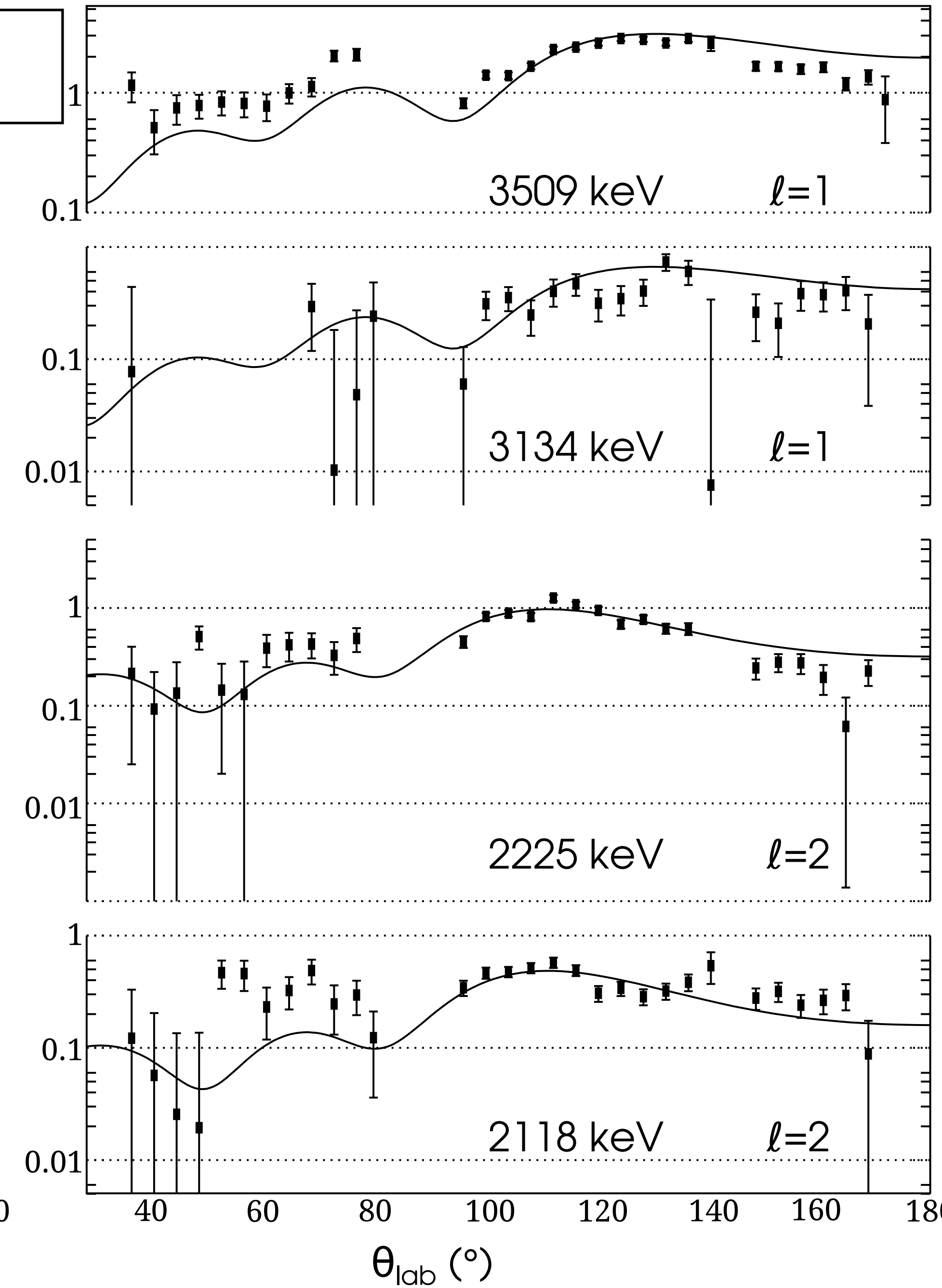
Comparison of proton angular distributions with and without a γ-ray gate



Gating does not affect the shape of the angular distribution, but the size of the cross section. The spectroscopic factor is recovered by correcting for the measured γ-ray efficiency.

Proton angular distributions



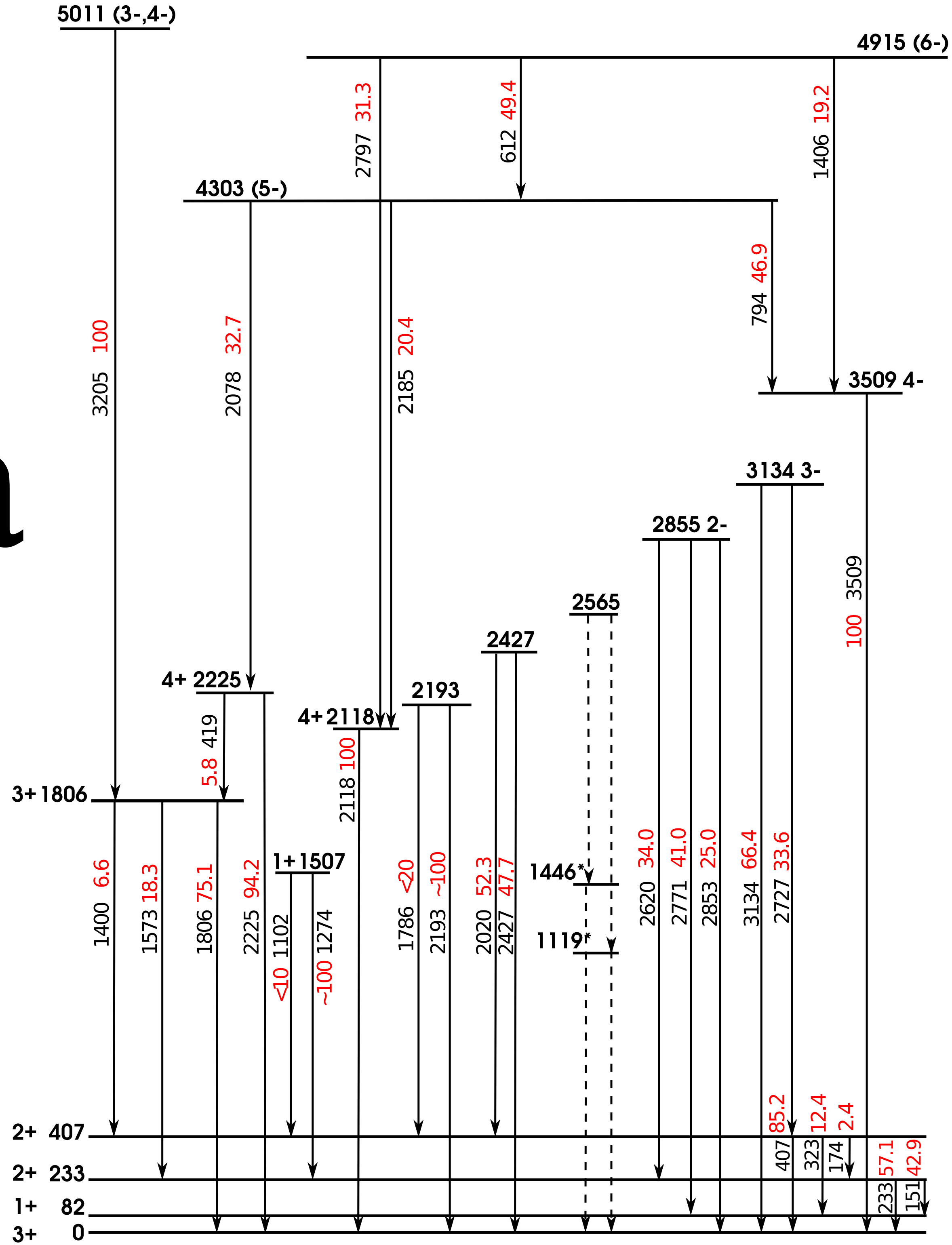


Theoretical cross-sections calculated using TWOFNR, using the zero-range ADWA method[1].

[1] R.C. Johnson and P.J.R. Soper, Phys. Rev. C **1**, 976 (1970)

^{26}Na

This work

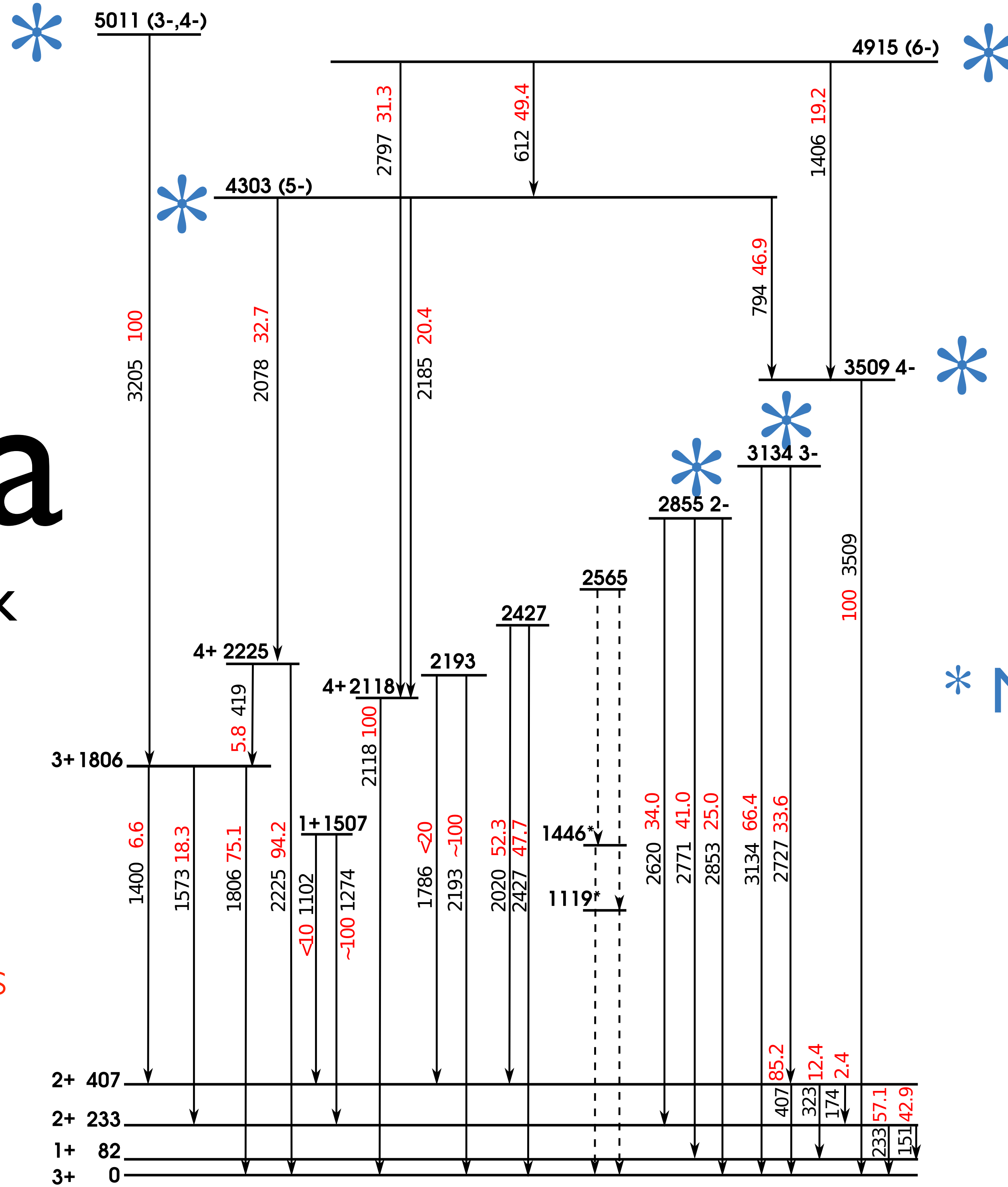


Energies in keV

Branching ratios in red

^{26}Na

This work



Energies in keV

Branching ratios in red

* Negative parity states

Final Spectroscopic Factors

This work				*sdpf* model space with 0.7 MeV reduction between the *sd*- and *pf*-shells			
E* (MeV)	coupling	S.F. ± ~20%	J^{π}	E* (MeV)	coupling	S.F. ± ~20%	J^{π}
3.512	$p_{3/2}$	0.54	4^-	3.613	$p_{3/2}$	0.43	4^-
3.136	$p_{3/2}$	0.10	3^-	3.377*	$p_{3/2}$	0.15	3^-
2.226	$d_{3/2}$	0.43	4^+	1.648	$d_{3/2}$	0.59	4^+
2.119	$d_{3/2}$	0.22	4^+				
1.807	$d_{3/2}$	0.22	3^+	1.247	$d_{3/2}$	0.32	3^+
0.407	$s_{1/2}$	0.34	2^+	0.231	$s_{1/2}$	0.19	2^+
0.233	$s_{1/2}$	0.14	2^+	0.05	$s_{1/2}$	0.22	2^+

*This state also has an $f_{7/2}$ component, S.F. = 0.17

Findings - calculations

- Identified key states in ^{26}Na for comparison with the shell model. In this region, the shell model is having to reproduce negative-parity states at relatively low energies, and with the $\nu(d_{3/2})$ orbital giving states lower than the 7/2.
- SPDF-M calculations previously failed in this region (^{27}Ne), which motivated WBP. WBP-M found good agreement for positive and negative parity levels, and it predicts the multiplet spitting for the proton-neutron coupling well. Spectroscopic factors are well produced. WBP-M also worked for ^{25}Ne[1] and ^{27}Ne[2] with a 0.7 MeV shift.
- Full $1\hbar\omega$ *s-p-sd-pf* WBP-M calculations now being finalised for ^{26}Na, as presented for ^{27}Ne. We are finding that the SF comparisons are unaffected, and the shift of 0.7 MeV is appropriate again.
- Calculations also done for the isotone ^{28}Al, and a shift was also needed.

The states identified in ^{26}Na are key for shell-model comparisons

[1] W.N. Catford, et al. Phys. Rev. Lett. **104**, 192501 (2010)

[2] S.M. Brown, et al. Phys. Rev. C **85**, 011302 (2012)

Findings - future work

- Technique of gating on a γ ray to extract proton angular distributions works well. Subsequent analysis showing that large angular coverage for γ rays is proving to be effective at giving negligible distortion of the proton differential cross-sections.
- Future: Complete ^{26}Na analysis with further SF analysis for cascade decays of states and to extract the weaker states. Extend to ^{29}Mg (N=17) to measure SFs for lowest levels and identify further single-particle strength that is predicted to be found higher in energy (approved at TRIUMF)

Collaborators

W.N. Catford, S.M. Brown, A. Matta

N.A. Orr, N.L. Achouri

G. Hackman, A.B. Garnsworthy, S.J. Williams, C. Pearson, R. Churchman, M. Djongolov, C. Unsworth and the TIGRESS collaboration

C.Aa. Diget, B.R. Fulton, S.P. Fox, R. Wadsworth

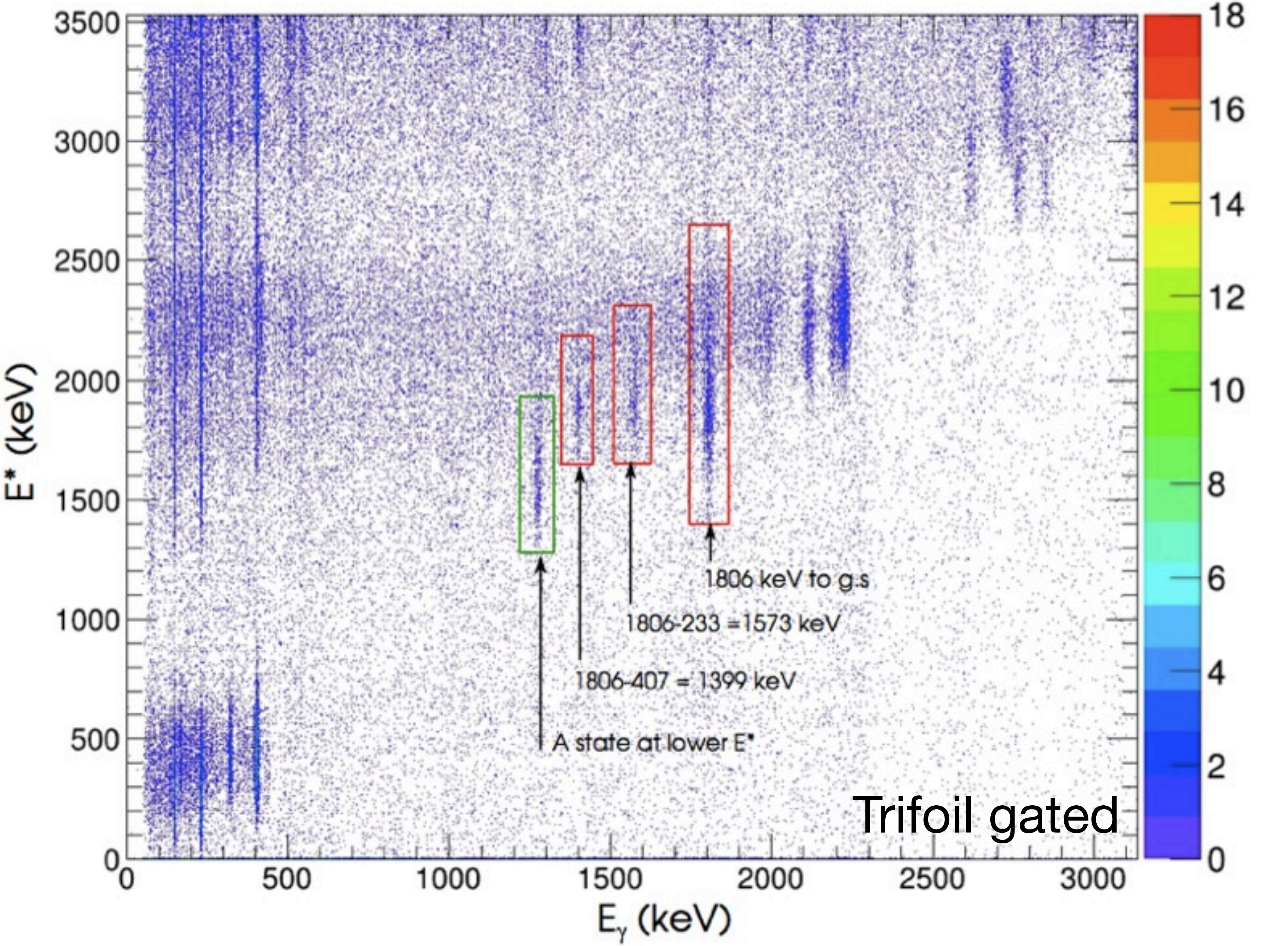
H.C. Boston, A.J. Boston, L. Harkness, R. Ashley

F. Sarazin

C. Svensson

J.C. Blackmon

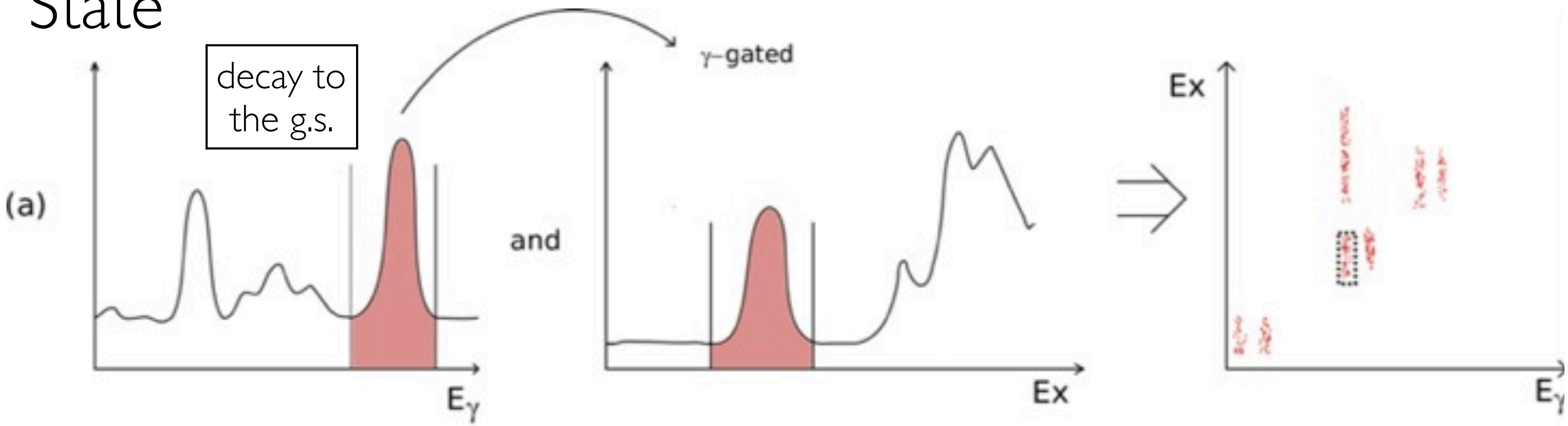
R.A.E. Austin



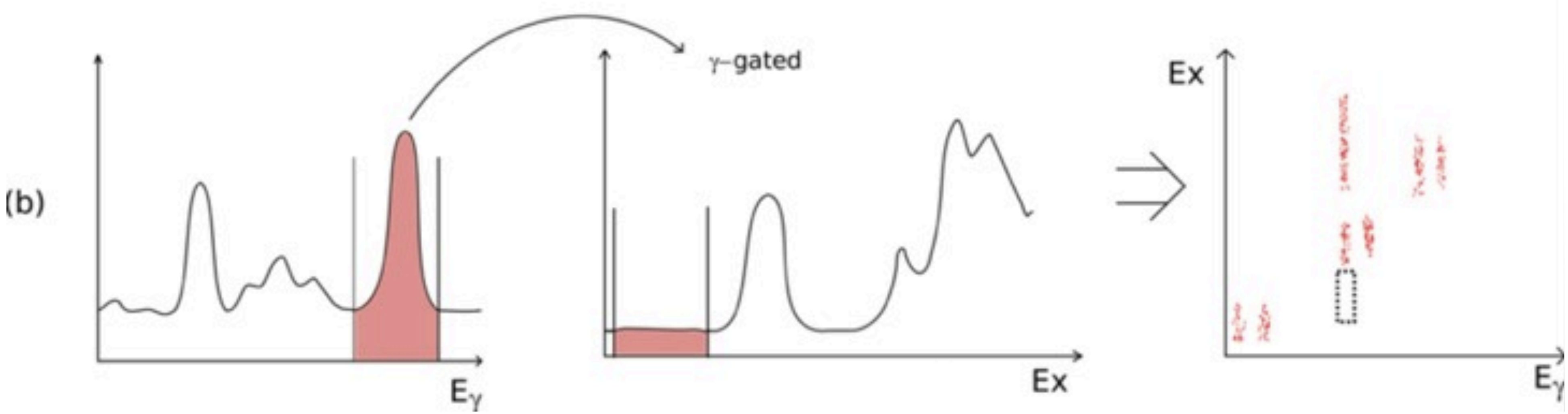
1806 keV to g.s
1806-233 =1573 keV
1806-407 = 1399 keV
A state at lower E*
Trifoil gated
E* (keV)
E$_\gamma$ (keV)

Gating technique

State



Background - general case



Findings

The energies of the negative parity states in ^{26}Na agree with predictions, to within ~100 keV when the gap between the *sd*- and *pf*-shells was reduced by 0.7 MeV relative to WBP in the *s-p-sd-pf* calculation

This systematic lowering of the shell gap was also applicable in the study of ^{25}Ne[1] and ^{27}Ne[2]

As previously seen in ^{25}Ne [1], we see the $\nu(d_{3/2})$ states ~0.5 MeV higher than predicted than WBP (which uses USD in the sd-shell)

These findings should motivate improvements to the shell model interactions to remove the need for ad hoc adjustments of single particle levels

[1] W.N. Catford, *et al*. Phys. Rev. Lett. **104**, 192501 (2010)

[2] S.M. Brown, *et al*. Phys. Rev. C **85**, 011302 (2012)