SPINS AND DECAYS
in neutron-rich sodium isotopes

via (d,pγ) neutron transfer reactions

WILTON CATFORD

University of Surrey, UK

Experiments performed at TRIUMF, Vancouver, Canada

UNIVERSITY OF SURREY
Department of Physics

DREB2016
Direct Reactions with Exotic Beams
July 11-15, 2016
Halifax, Canada

SPINS AND DECAYS
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via (d,pγ) neutron transfer reactions

(a) motivation
(b) SHARC + TIGRESS + trifoil
(c) recently published d(^{25}Na,pγ)^{26}Na
(d) update on the d(^{25}Na,pγ)^{26}Na
(e) new results from d(^{24}Na,pγ)^{25}Na

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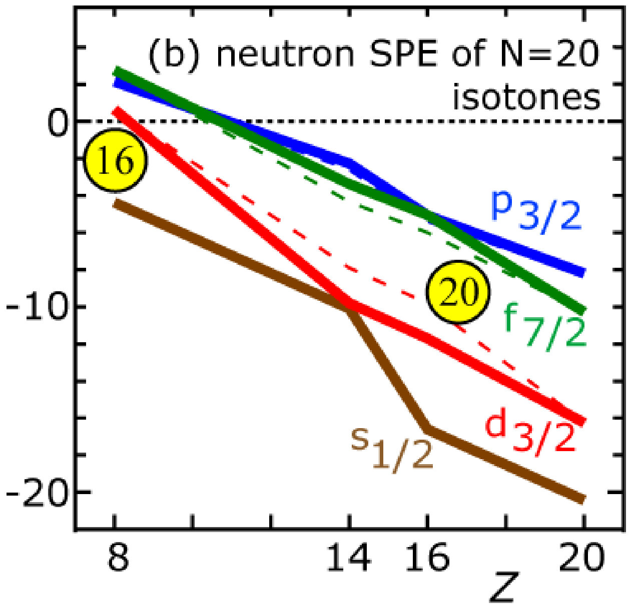
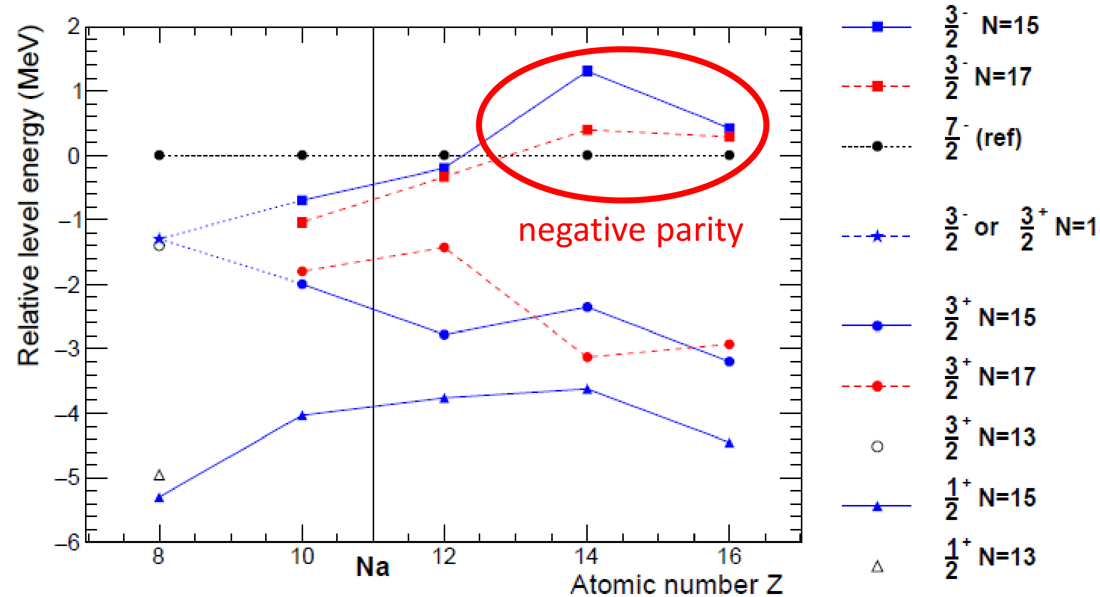
Theory: effective spe's

Experiment: energies of just the lowest levels



PRL **104,** 012501 (2010)

Otsuka et al.



PLB in press (2016) N=15 and 17 isotones

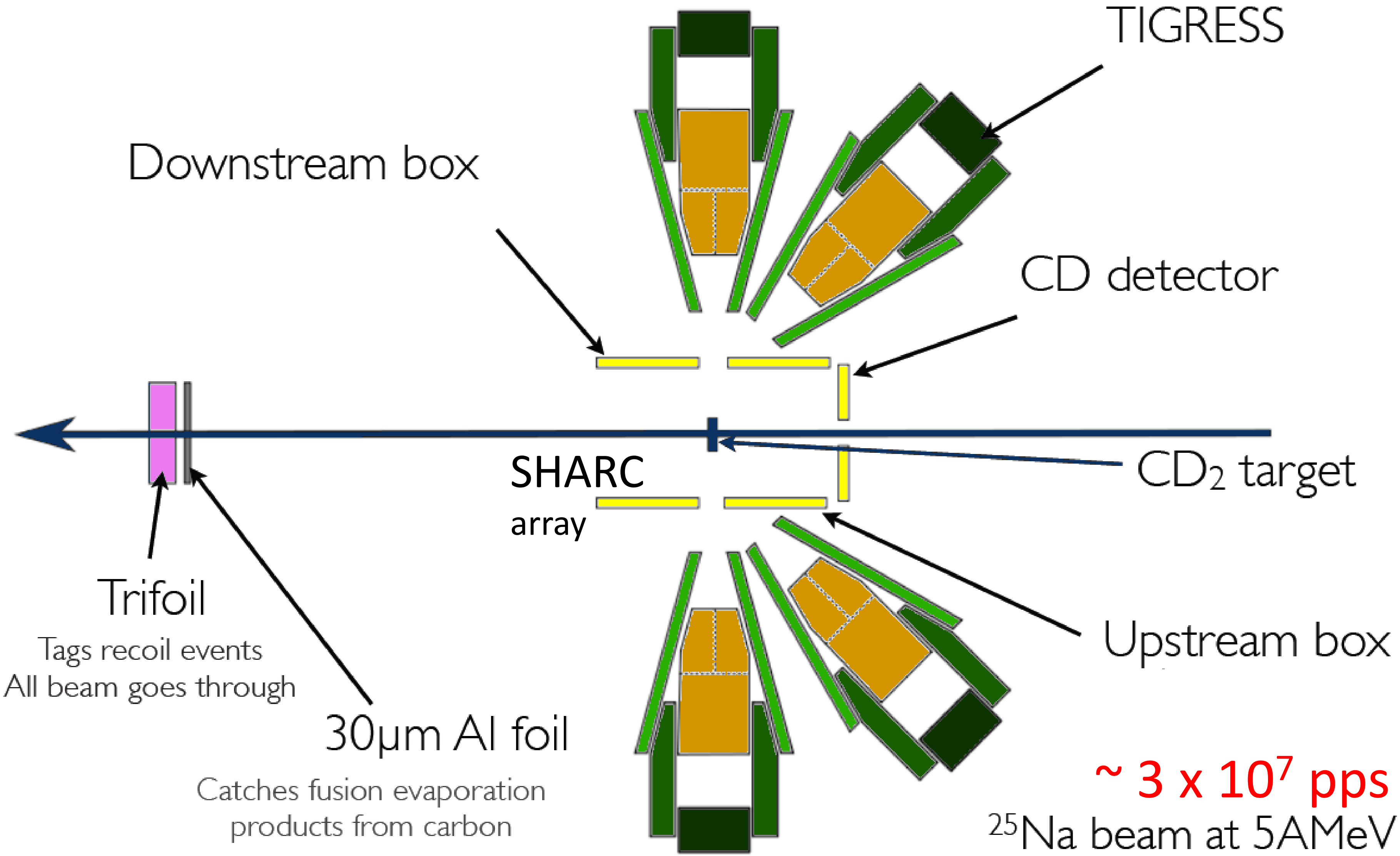
http://dx.doi.org/10.1016/j.physletb.2016.05.093

G.L. Wilson et al.

- Our aim is to identify single-particle-like levels and determine their spin/parity
- We use the selective nature of (d,p) neutron transfer (with radioactive beams)
- We aim to track the evolution of these levels and compare to the shell model
- We use the large SF for theory/experimental states to associate them with each other
- Details of the precise numerical value of the SF don't affect this process
- Results will be shown here for Z=11 for N=14,15 respectively, **probing higher orbitals**

(for ^{29}Mg see Adrien Matta, on Friday)

Experimental Setup to Measure d(^{25}Na,p)^{26}Na at TRIUMF

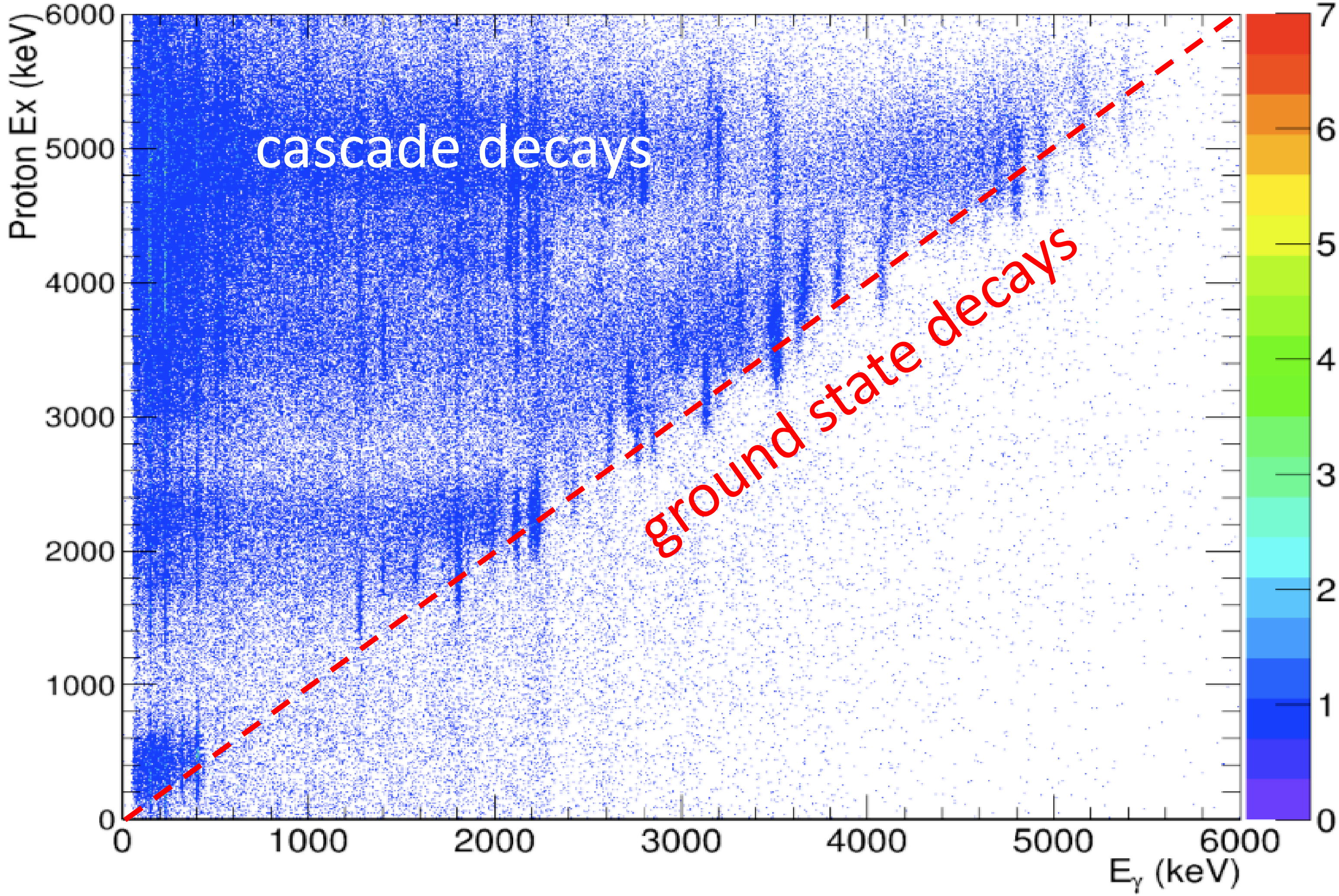


G.L. Wilson et al., Physics Letters B, in press

Data from d(^{25}Na,p)^{26}Na at 5 MeV/A using SHARC at ISAC2 at TRIUMF

Gemma Wilson, Surrey

Excitation energy deduced from proton energy and angle



Doppler corrected (β=0.10) gamma ray energy measured in TIGRESS

Experimental Results from studying d(^{25}Na,p)^{26}Na at TRIUMF

Negative parity states

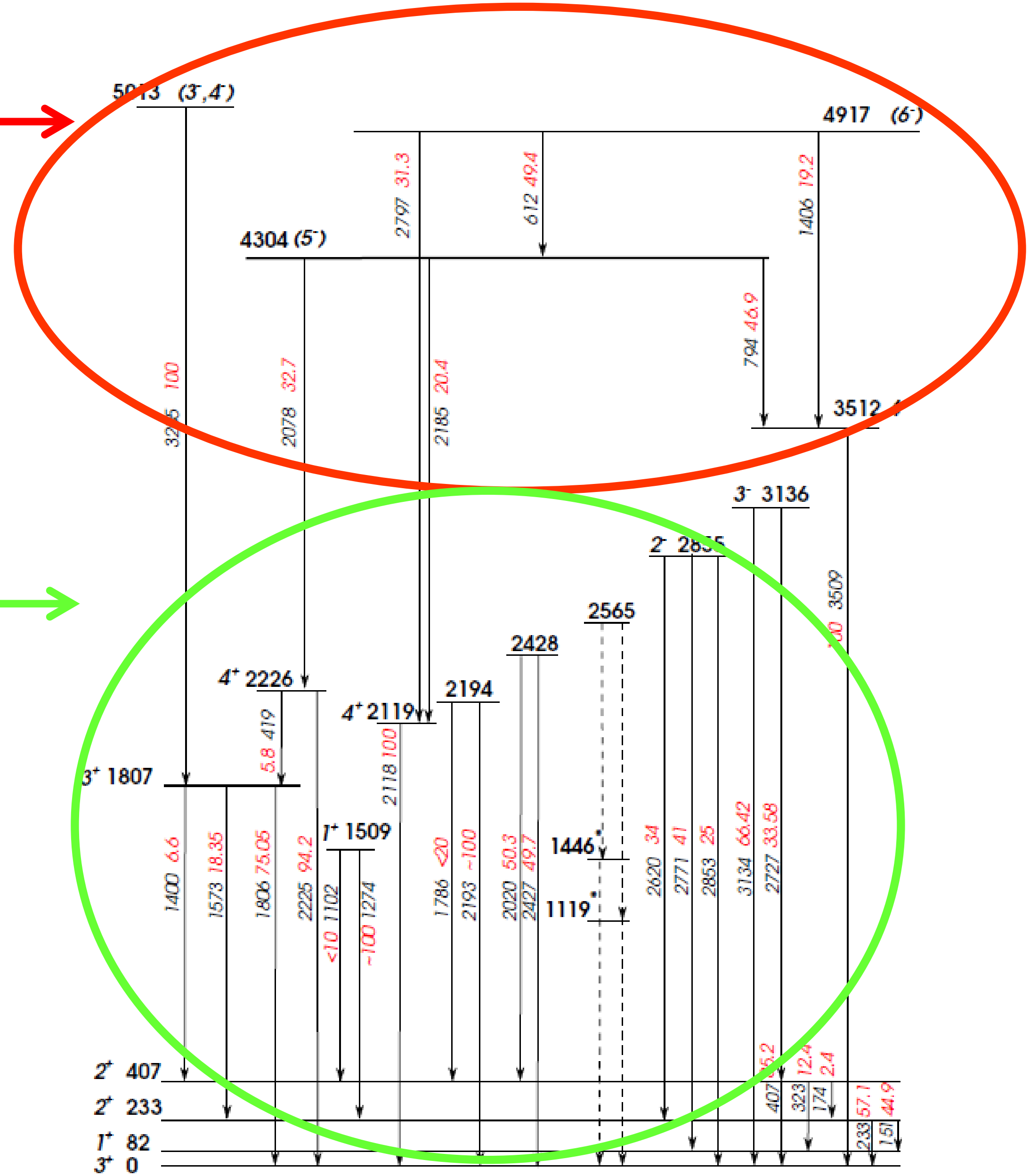
Levels never seen before, selected by (d,p)

Gamma-ray <u>decay scheme</u>
Gamma-ray <u>branching ratios</u>

Positive parity states

<u>GATE on the gamma rays</u>, take advantage of 30 keV energy resolution

CHECK that this <u>does not</u> bias the proton distribution *(gamma angular efficiency)*

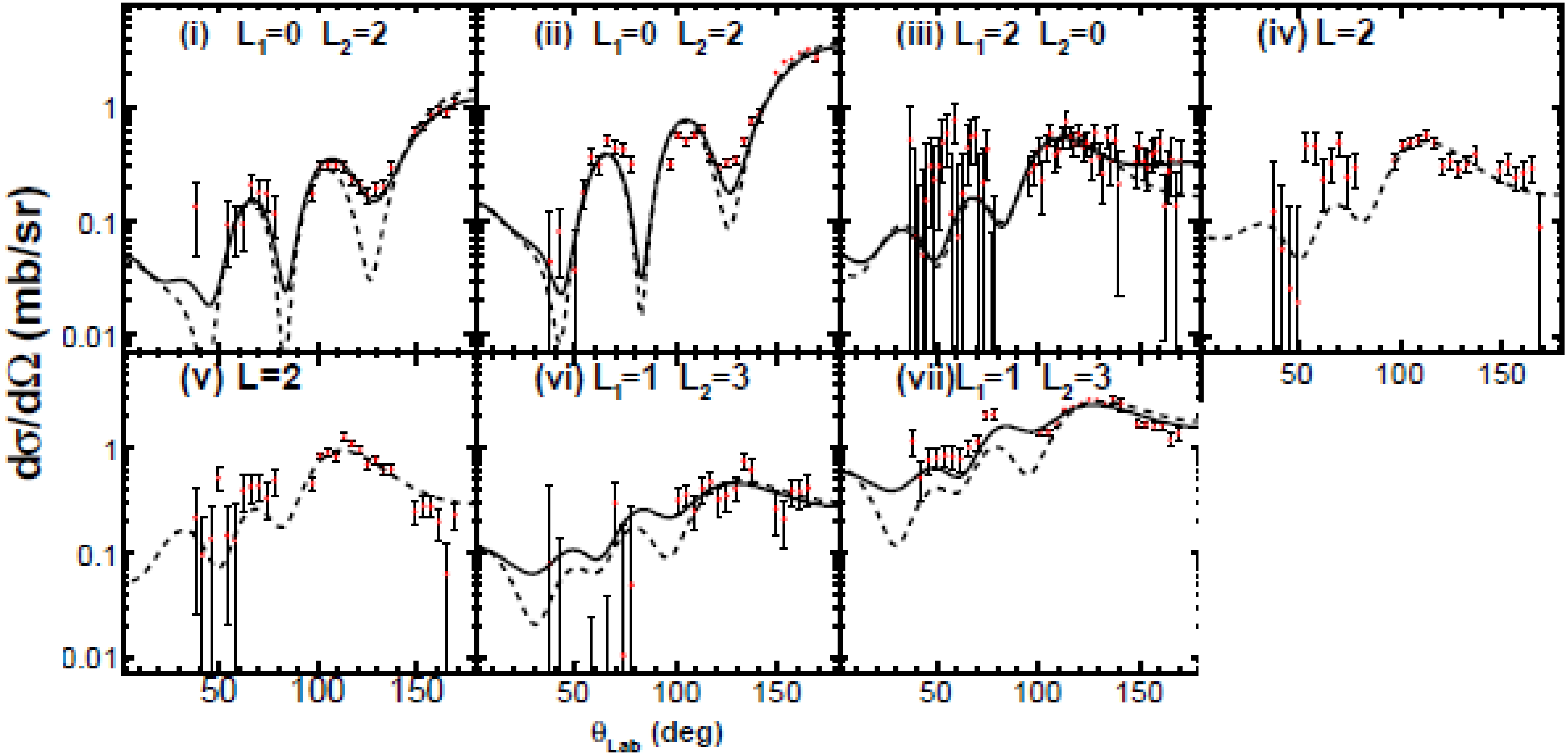


Differential cross sections and spectroscopic factors

First analysis of this type:

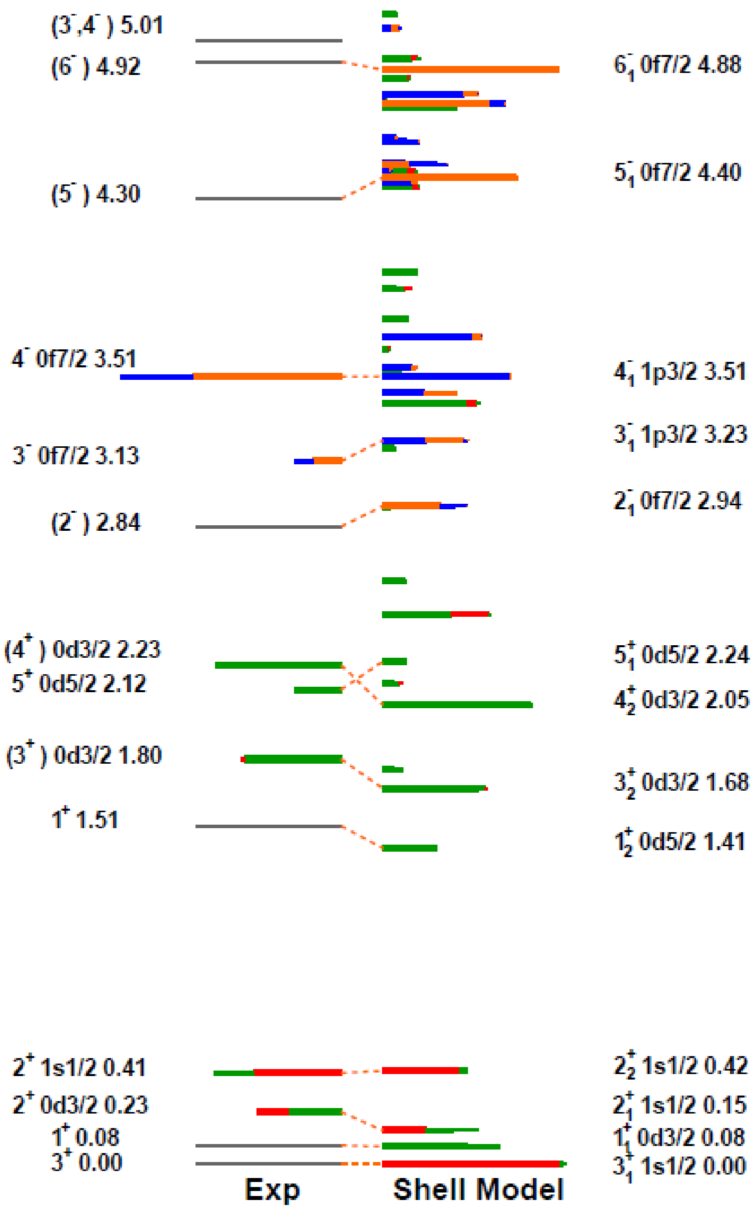
Each of these distributions is:

(a) gated on a gamma-ray peak
(b) background-subtracted
(c) corrected for gamma ray efficiency
(d) corrected for gamma ray branching ratio



G.L. Wilson et al., Physics Letters B, in press

Experimental Results from studying d(^{25}Na,p)^{26}Na at TRIUMF



comparison between revised shell model energies and SFs

the results are somewhat subtle

evidence for stronger influence of the 1p3/2 orbital in the low-lying negative parity states, compared to the less exotic isotone ^{28}Al

this is evidence for the 1p3/2 orbital becoming lower, relative to the 0f7/2 orbital which is clear, in ^{27}Ne and ^{29}Mg

the shell model
works surprisingly well
wbc spsdpf 0+1$\hbar\omega$

Experimental Results from studying d(^{25}Na,p)^{26}Na at TRIUMF

					single L analysis				two L analysis (where applicable)							
No.	E_x a)	E_x^{SM} b)	J^{π} c)	J^{π}_{SM}	L	nlj	S	S^{SM}	L_1	$n_1l_1j_1$	S_1	S_1^{SM}	L_2	$n_2l_2j_2$	S_2	S_2^{SM}
	0	0	3^+	3^+_1	*	$1s_{1/2}$		0.61	*	$1s_{1/2}$		0.61	*	$0d_{3/2}$		0.01
														$0d_{5/2}$		0.01
	0.082$^{d)}$	0.077	1^+	1^+_1	*	$0d_{3/2}$		0.29								
						$0d_{5/2}$		0.11								
(i)	0.232	0.149	2^+	2^+_1	0	$1s_{1/2}$	0.13	0.15	0	$1s_{1/2}$	0.10	0.15	2	$0d_{3/2}$	0.19†	0.10
														$0d_{5/2}$		0.09
(ii)	0.405	0.416	2^+	2^+_2	0	$1s_{1/2}$	0.33	0.27	0	$1s_{1/2}$	0.30	0.27	2	$0d_{5/2}$	0.13†	0.03
														$0d_{3/2}$		0.03
	1.507	1.409	1^+	1^+_2	*	$0d_{3/2}$		0.09								
						$0d_{5/2}$		0.10								
(iii)	1.805	1.676	(3^+)	3^+_2	2	$0d_{3/2}$	0.37	0.33	2	$0d_{3/2}$	0.33†	0.33	0	$1s_{1/2}$	0.01‡	0.00
						$0d_{5/2}$		0.02	2	$0d_{5/2}$		0.02				
(iv)	2.116	2.241	5^+	5^+_1	2	$0d_{5/2}$	0.16	0.08								
(v)	2.225	2.048	(4^+)	4^+_2	2	$0d_{3/2}$	0.43	0.51								
						$0d_{5/2}$		0.01								
	2.843	2.936	(2^-)	2^-_1	*	$0f_{7/2}$		0.20	*	$0f_{7/2}$		0.20	*	$1p_{3/2}$		0.05
						$0f_{5/2}$		0.00		$0f_{5/2}$		0.00		$1p_{1/2}$		0.04
(vi)	3.135	3.228	3^-	3^-_1	1	$1p_{3/2}$	0.07†	0.15	1	$1p_{3/2}$	0.06†	0.15	3	$0f_{7/2}$	0.10‡	0.13
						$1p_{1/2}$		0.02		$1p_{1/2}$		0.02		$0f_{5/2}$		0.00
(vii)	3.511	3.513	4^-	4^-_1	1	$1p_{3/2}$	0.30	0.44	1	$1p_{3/2}$	0.25	0.44	3	$0f_{7/2}$	0.51†	0.00
														$0f_{5/2}$		0.00
	4.305	4.401	(5^-)	5^-_1	*	$0f_{7/2}$		0.46								
						$0f_{5/2}$		0.00								
	4.917	4.881	(6^-)	6^-_1	*	$0f_{7/2}$		0.61								
	5.009		$(3^-,4^-)$		*											

Experimental Results from studying d(^{25}Na,p)^{26}Na at TRIUMF

UPDATE

8 new states plus 4 new ℓ values

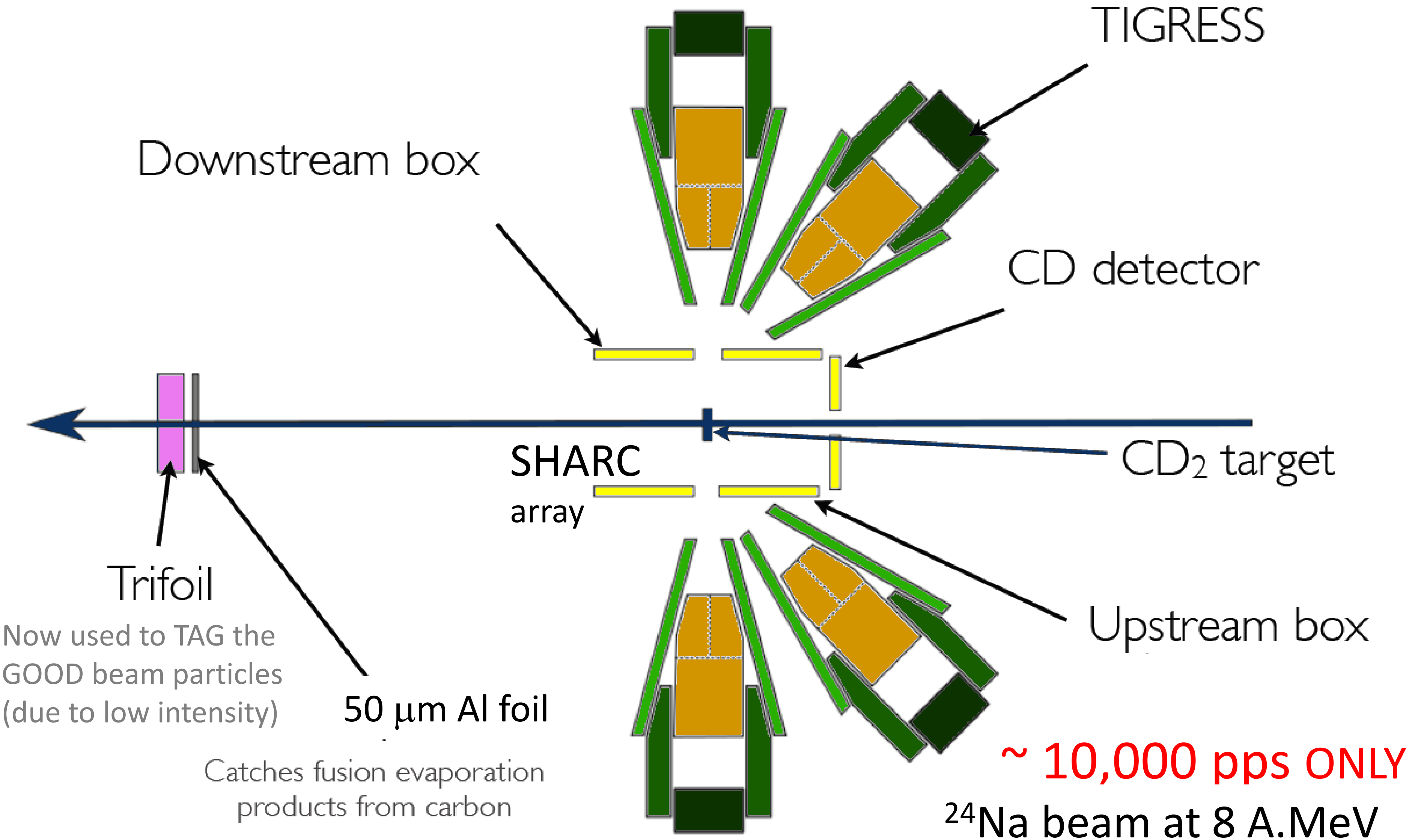
IMPROVED background subtraction

NEW gamma-ray angular correlations

I.C. Celik PhD thesis Surrey 2015

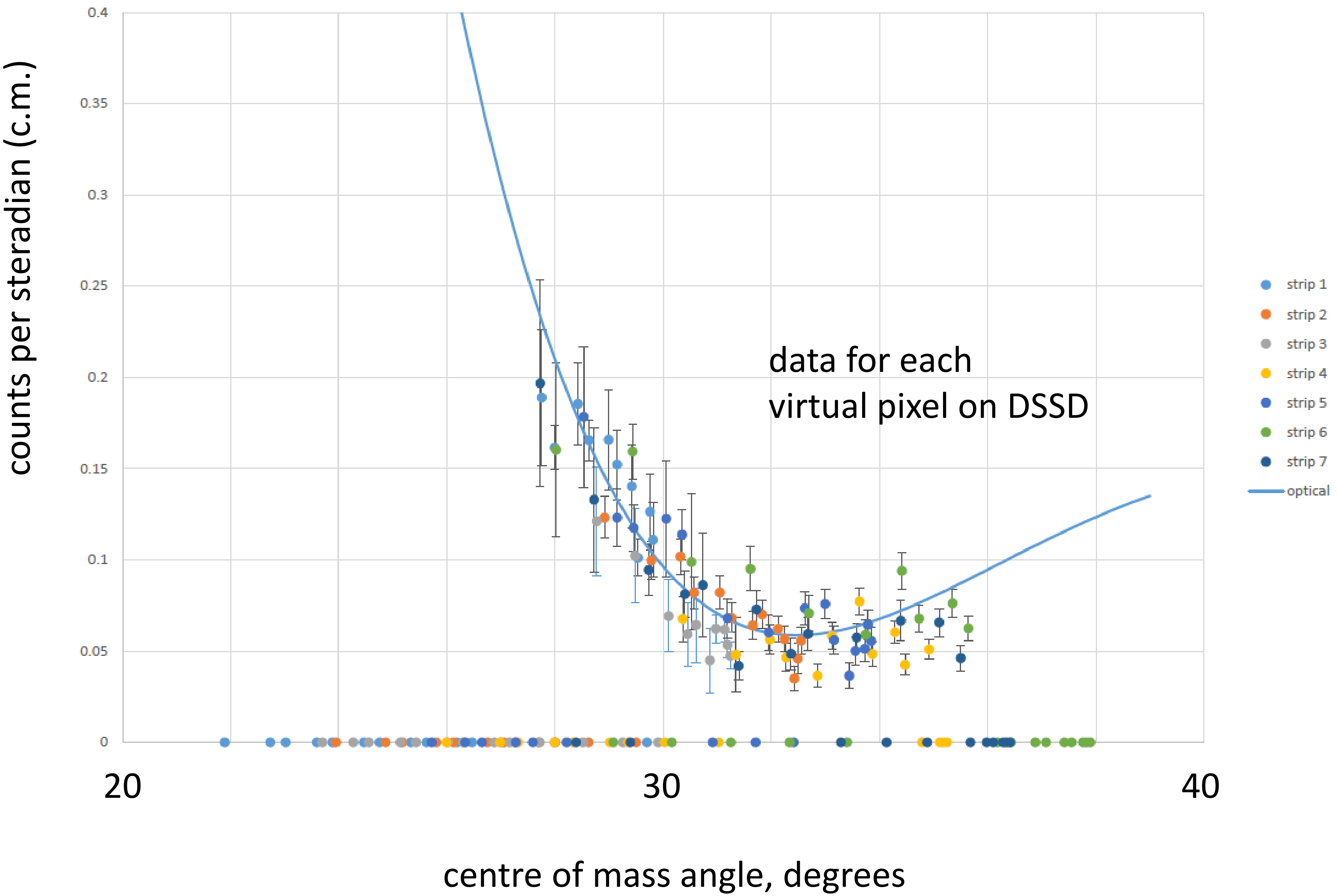
					single L analysis				two L analysis (where applicable)							
No.	E_x [a)]	E_x^{SM} [b)]	J^π [c)]	J^π_{SM}	L	nlj	S	S^{SM}	L_1	$n_1l_1j_1$	S_1	S_1^{SM}	L_2	$n_2l_2j_2$	S_2	S_2^{SM}
	0	0	3^+	3^+_1	*	$1s_{1/2}$		0.61	*	$1s_{1/2}$		0.61	*	$0d_{3/2}$		0.01
														$0d_{5/2}$		0.01
	0.082[d)]	0.077	1^+	1^+_1	*	$0d_{3/2}$		0.29								
						$0d_{5/2}$		0.11								
	0.232	0.149	2^+	2^+_1	0	$1s_{1/2}$	0.13	0.15	0	$1s_{1/2}$	0.10	0.15	2	$0d_{3/2}$	0.19†	0.10
														$0d_{5/2}$		0.09
	0.405	0.416	2^+	2^+_2	0	$1s_{1/2}$	0.33	0.27	0	$1s_{1/2}$	0.30	0.27	2	$0d_{5/2}$	0.13†	0.03
														$0d_{3/2}$		0.03
	1.507	1.409	1^+	1^+_2	2	$0d_{3/2}$	0.39	0.09								
						$0d_{5/2}$		0.10								
	1.805	1.676	(3^+)	3^+_2	2	$0d_{3/2}$	0.37	0.33	2	$0d_{3/2}$	0.33†	0.33	0	$1s_{1/2}$	0.01‡	0.00
						$0d_{5/2}$		0.02	2	$0d_{5/2}$		0.02				
	1.992	1.758	4^+	4^+_1	2	$0d_{3/2}$	0.07	0.07								
	2.116	2.241	5^+	5^+_1	2	$0d_{5/2}$	0.16	0.08								
	2.195	2.142	2^+	2^+_3	2	$0d_{3/2}$	0.49	0.06								
	2.225	2.048	(4^+)	4^+_2	2	$0d_{3/2}$	0.43	0.51								
						$0d_{5/2}$		0.01								
	2.423	2.452	2^+	2^+_4					0	$1s_{1/2}$	0.00	0.13	2	$0d_{3/2}$	0.14	0.23
	2.843	2.936	(2^-)	2^-_1	3	$1p_{3/2}$		0.20	3	$0f_{7/2}$	1.10	0.20	1	$1p_{3/2}$	0.10	0.05
						$0f_{5/2}$		0.00		$0f_{5/2}$		0.00		$1p_{1/2}$		0.04
	3.135	3.228	3^-	3^-_1	1	$1p_{3/2}$	0.07†	0.15	1	$1p_{3/2}$	0.06†	0.15	3	$0f_{7/2}$	0.10‡	0.13
						$1p_{1/2}$		0.02		$1p_{1/2}$		0.02		$0f_{5/2}$		0.00
	3.511	3.513	4^-	4^-_1	1	$1p_{3/2}$	0.30	0.44	1	$1p_{3/2}$	0.25	0.44	3	$0f_{7/2}$	0.51†	0.00
														$0f_{5/2}$		0.00
	4.087	3.690	2^-	2^-_2	3				1	$1p_{3/2}$	0.34	0.31	3	$0f_{7/2}$	0.78	0.03
	4.239	3.975	4^+	4^+_5	2	$0d_{3/2}$	0.12	0.12								
	4.305	4.401	(5^-)	5^-_1	3				1	$1p_{3/2}$	0.01	0.00	3	$0f_{7/2}$	0.25	0.46
	4.597	4.460	3^-	3^-_2	3	$0f_{7/2}$			1	$1p_{3/2}$	0.02	0.10	3	$0f_{7/2}$	0.76	0.10
	4.800	4.730	4^-	4^-_2	3	$0f_{7/2}$			1	$1p_{3/2}$	0.00	0.05	3	$0f_{7/2}$	0.62	0.37
	4.917	4.881	(6^-)	6^-_1	3	$0f_{7/2}$	0.51	0.61								
	4.932	4.770	3^-	3^-_4	3	$0f_{7/2}$			1	$1p_{3/2}$	0.00	0.28	3	$0f_{7/2}$	0.63	0.05
	5.009		$(3^-,4^-)$		*											

Experimental Setup to Measure d(^{24}Na,p)^{25}Na at TRIUMF



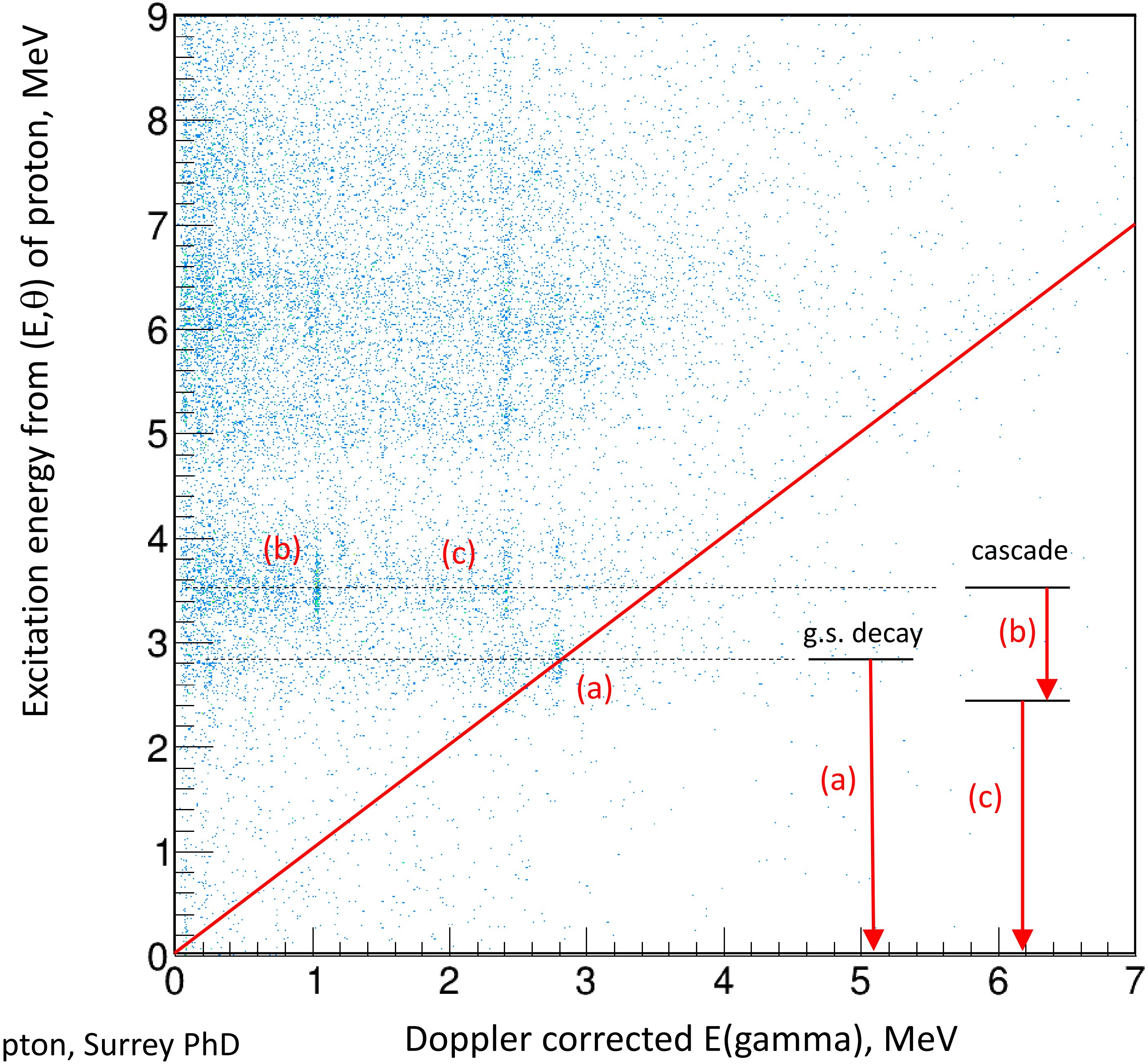
Andy Knapton, Surrey PhD (writing up)

In-built normalisation from d(^{24}Na,d)^{24}Na near 70° (lab)



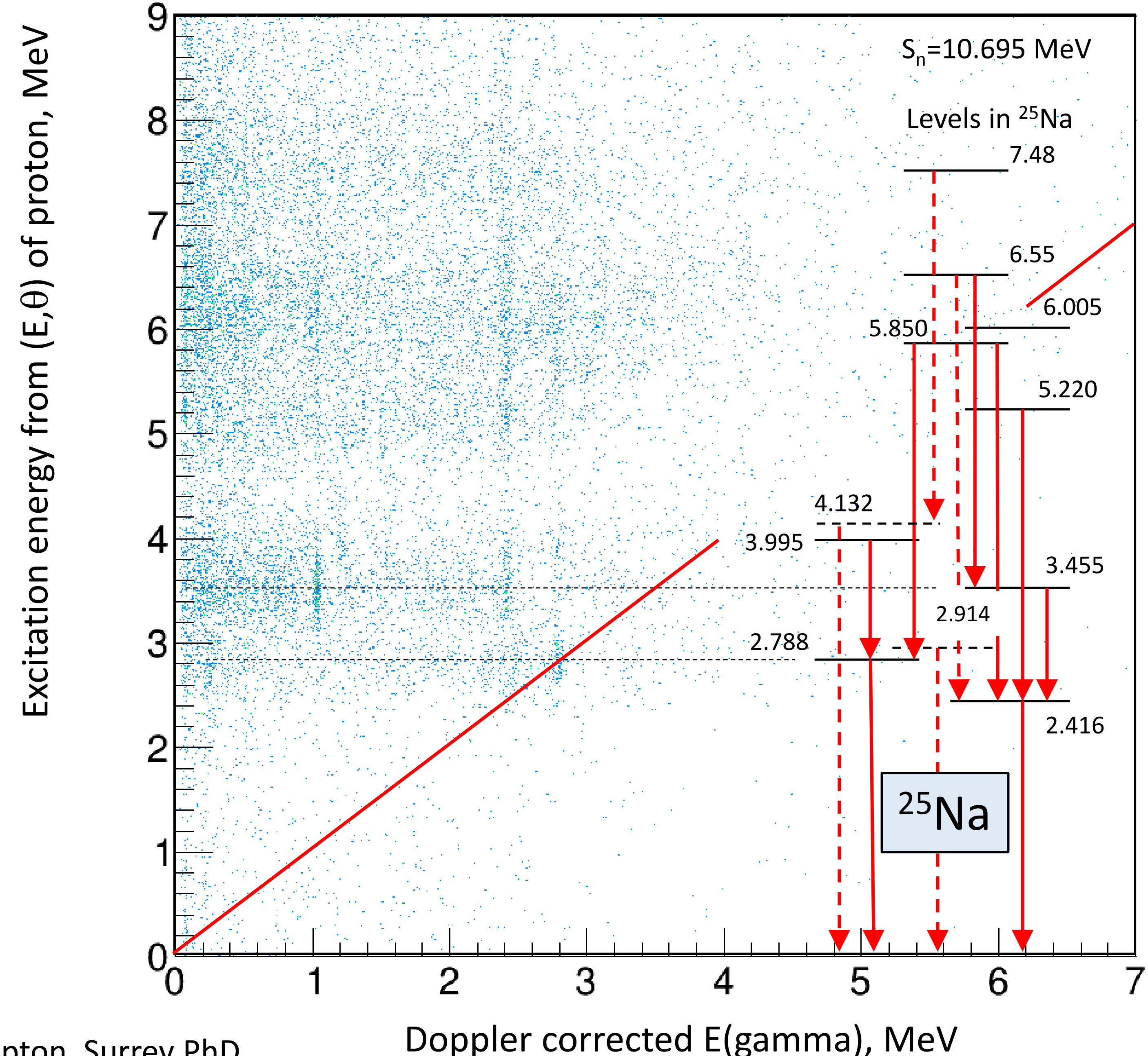
Andy Knapton, Surrey PhD

d(^{24}Na,p)^{25}Na at 8.0 MeV/u with 10,000 pps



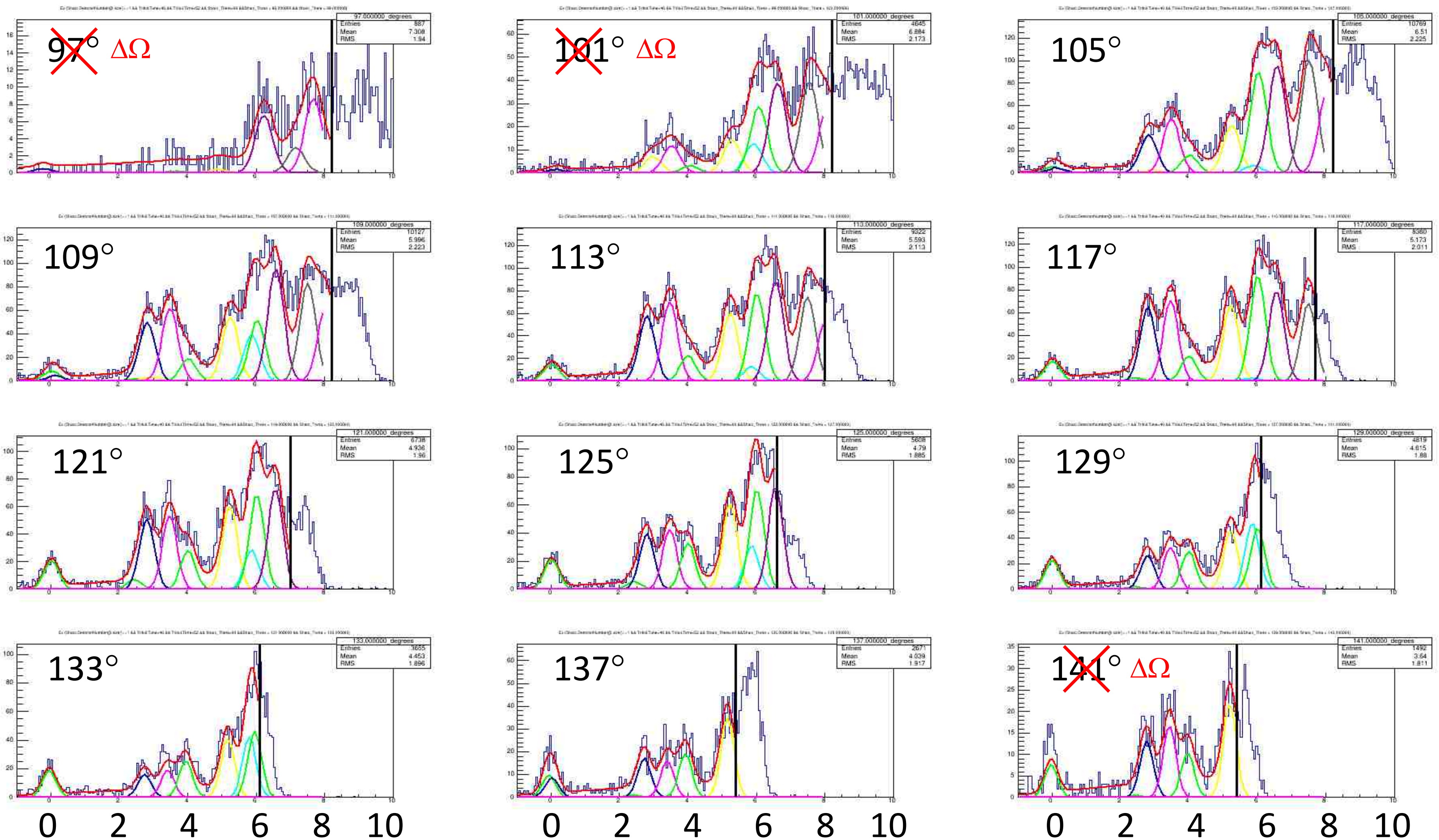
Andy Knapton, Surrey PhD

d(^{24}Na,p)^{25}Na at 8.0 MeV/u with 10,000 pps



Andy Knapton, Surrey PhD

d(^{24}Na,p)^{25}Na – fits to excitation energy spectrum at each angle

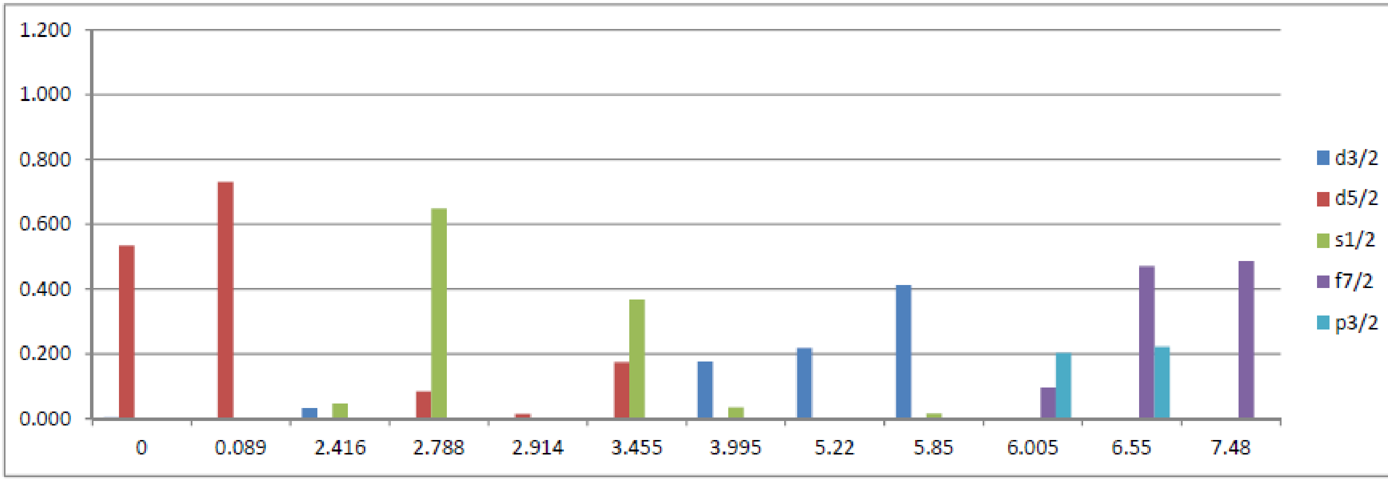


Excitation Energy in ^{25}Na (MeV)

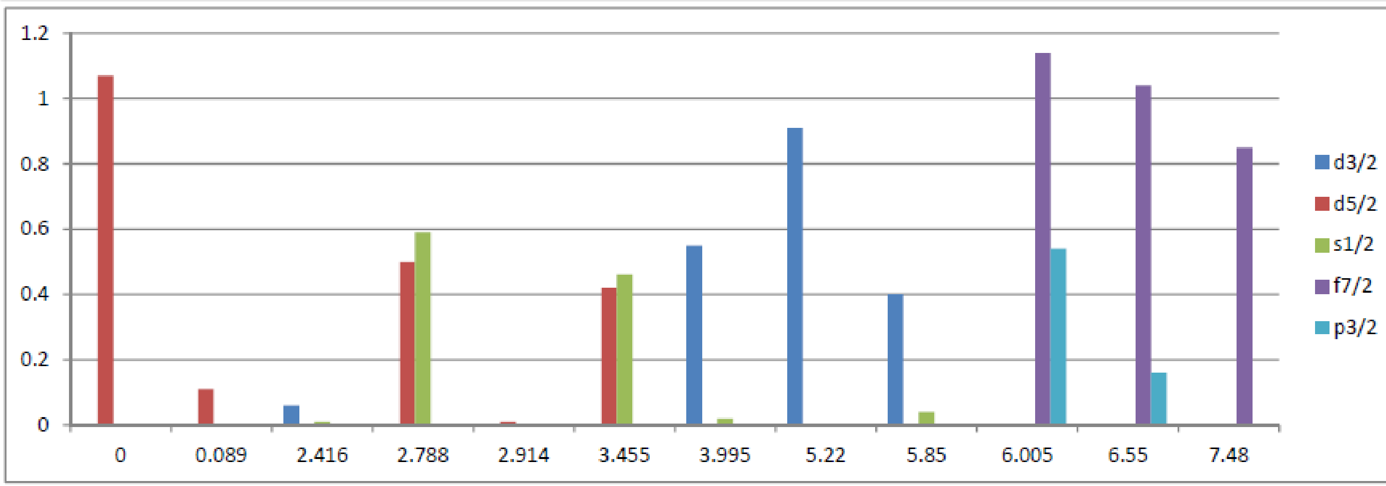
Andy Knapton, Surrey PhD

d(^{24}Na,p)^{25}Na – spectroscopic factors in ^{25}Na compared to theory

wbc
nushellx
(0+1)$\hbar\omega$



this work
ADWA
std geom

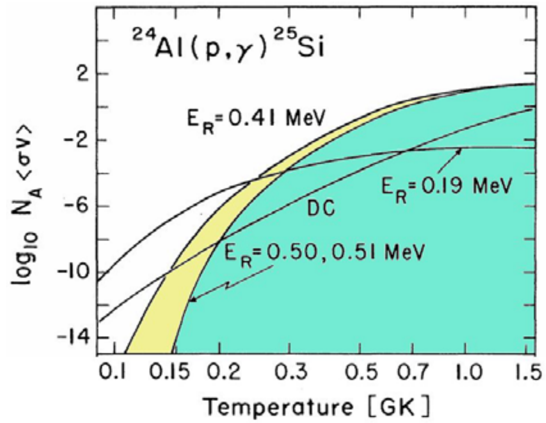


Excitation Energy in ^{25}Na (MeV)

present work	5/2+	3/2+	9/2+	7/2+	5/2+	9/2+	9/2+	11/2+	7/2+	7/2–	11/2–	13/2–
literature	5/2+	3/2+	?	3/2	5/2+	3/2+?	1/2–	?	?	(1/2, 3/2)–	?	?

Andy Knapton, Surrey PhD

Using the ^{25}Na SFs to calculate ^{24}Al(p,γ)^{25}Si widths and $\omega\gamma$'s for novae



Wiescher, Brown PRC52, 1078 (1995)
revised the rate for ^{24}Al(p,γ) upwards $\times$ 100

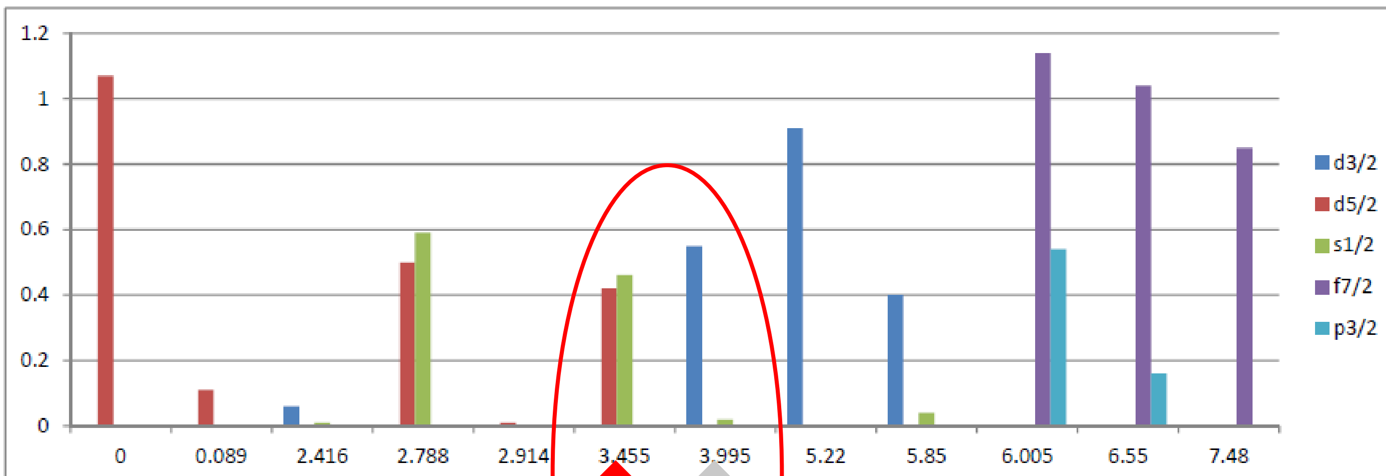
0.41 = 3.995 in ^{25}Na

resonance states in ^{25}Si

0.02 = 3.455 in ^{25}Na
(omitted due to misidentification)

^{24}Al + p

this work
ADWA
std geom



Excitation Energy in ^{25}Na (MeV)

present work	5/2+	3/2+	9/2+	7/2+	5/2+	9/2+	9/2+	11/2+	7/2+	7/2–	11/2–	13/2–
literature	5/2+	3/2+	?	3/2	5/2+	3/2+?	1/2–	?	?	(1/2, 3/2)–	?	?

bound states in mirror ^{25}Na

THE OXFORD MDM-2 MAGNETIC SPECTROMETER

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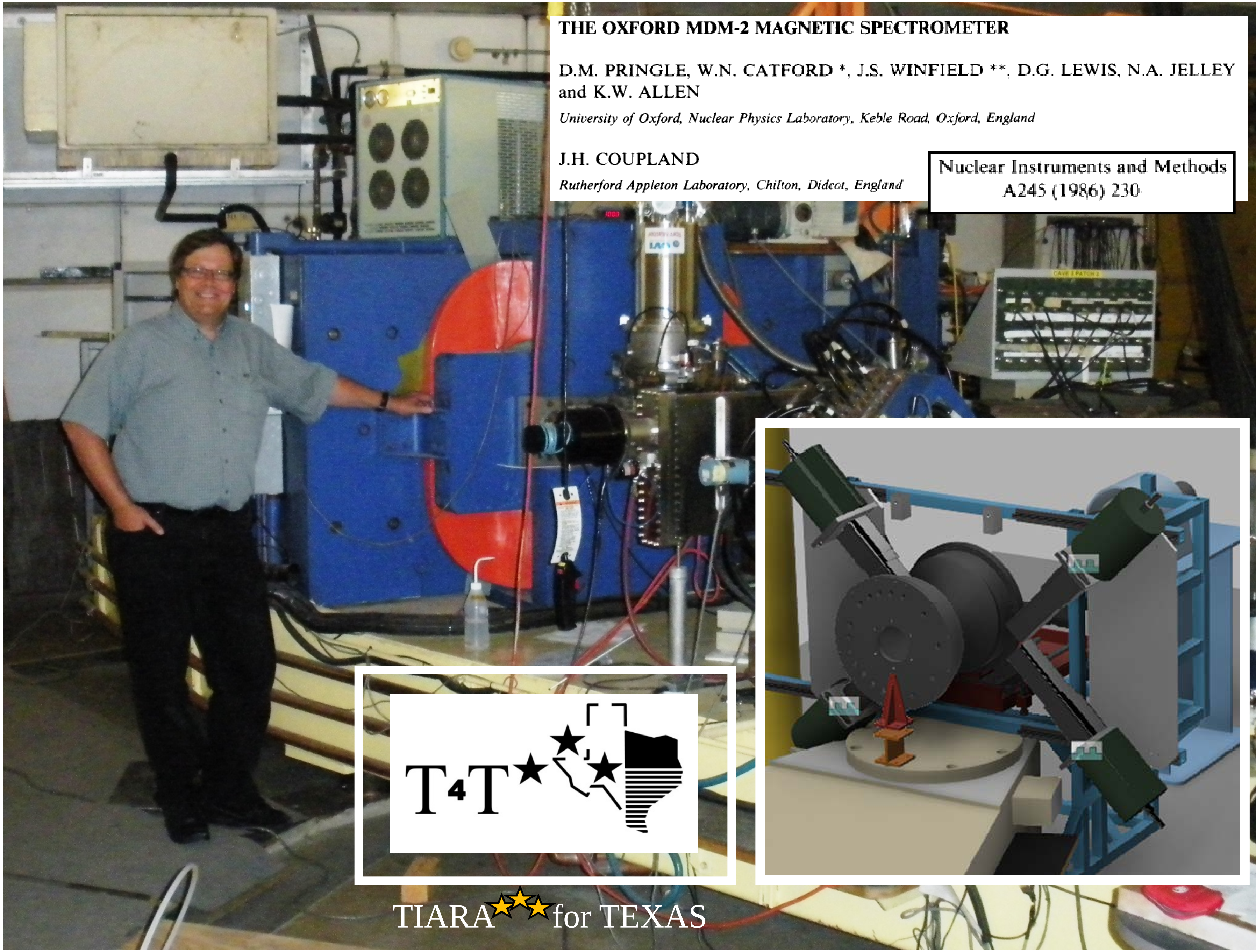
Nuclear Instruments and Methods
A245 (1986) 230



T4T

TIARA for TEXAS

UNIVERSITY OF SURREY
Department of Physics

Summary

- We found that just outside the borders of the island of inversion, the shell model that was adapted for the island (i.e. USD-A, wbc) seems to work reasonably well
- Even in some less exotic nuclei, the selectivity of (d,p) has been shown to be hugely powerful in identifying the most interesting states
- The new technique of gating on the coincident gamma rays to separate states that are not otherwise resolved has worked well
- We are moving back towards the island to test the shell model further and improve it – Friday: Adrien Matta and ^{29}Mg

  Otsuka (this afternoon)

  Tsunoda (Tuesday afternoon)
- We are preparing for new availability of beams at Texas A&M (also HIE-ISOLDE and MUGAST at GANIL)

  Daniele Mengoni (Thursday)

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