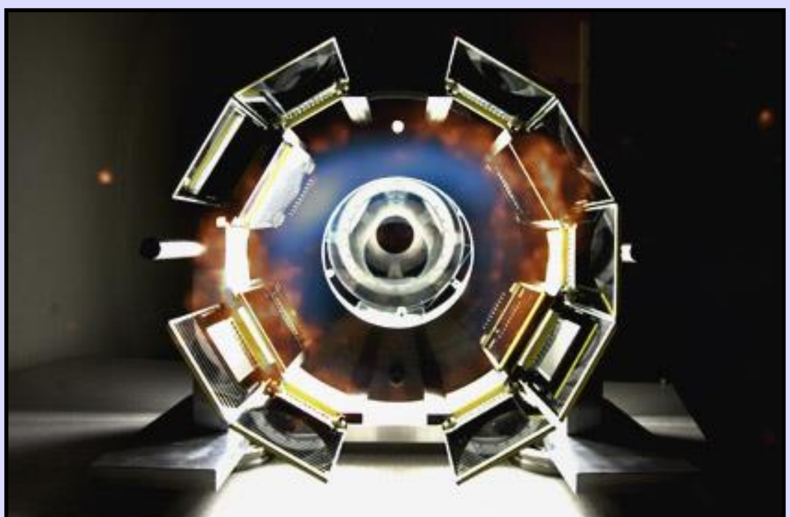
Measurement of the (d,p) reaction in inverse kinematics
An experimentalist's perspective

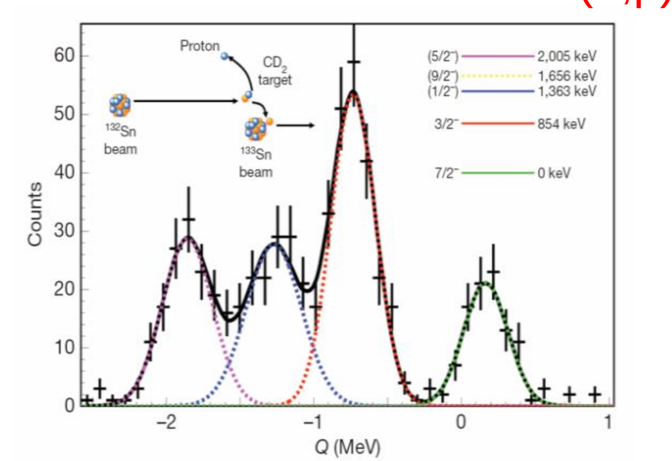
Steven D. Pain

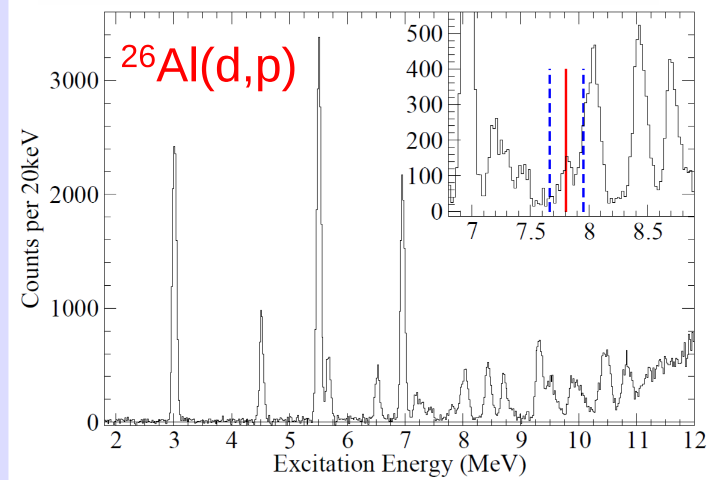
Oak Ridge National Laboratory

- Example measurements – ^{132}Sn(d,p) and ^{26}Al(d,p)
- Why are these so different?
- Why is the ^{26}Al a near-ideal measurement?
- What are the limiting factors to IK measurements?
- What quality of elastic scattering data can we expect?



^{132}Sn(d,p)



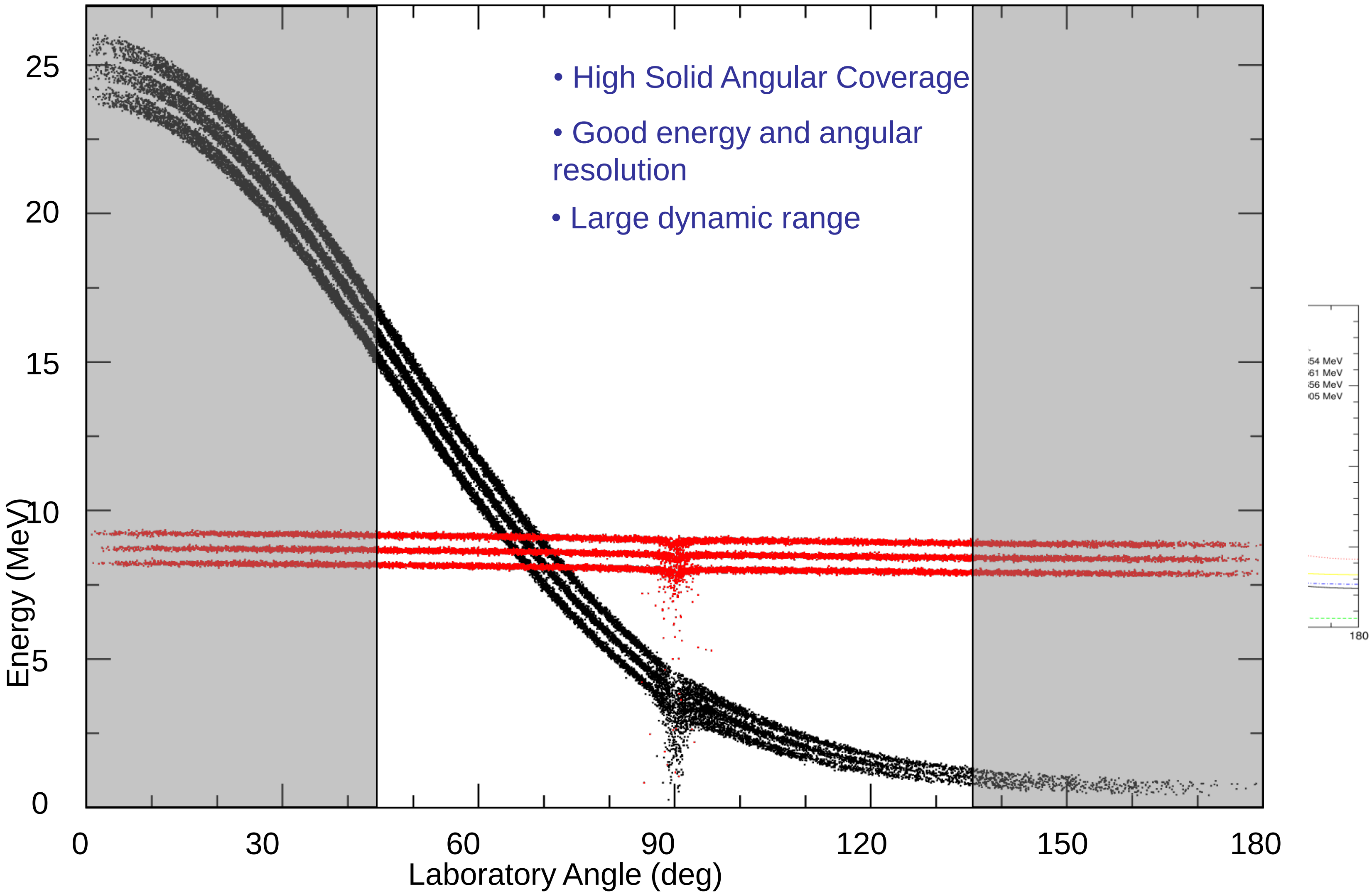


Deuteron-induced reactions workshop, MSU 2016

(d,p) Reactions

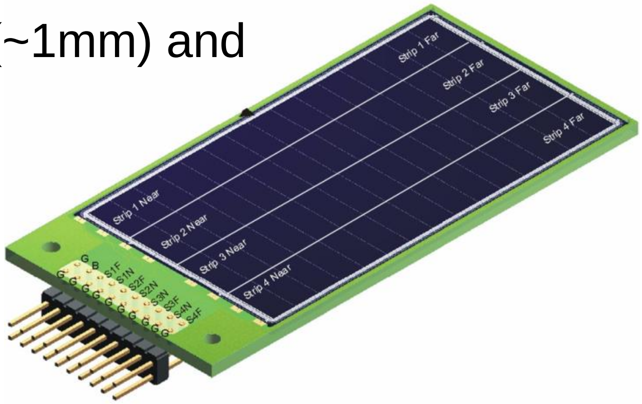
Proton Energy-Angle Systematics

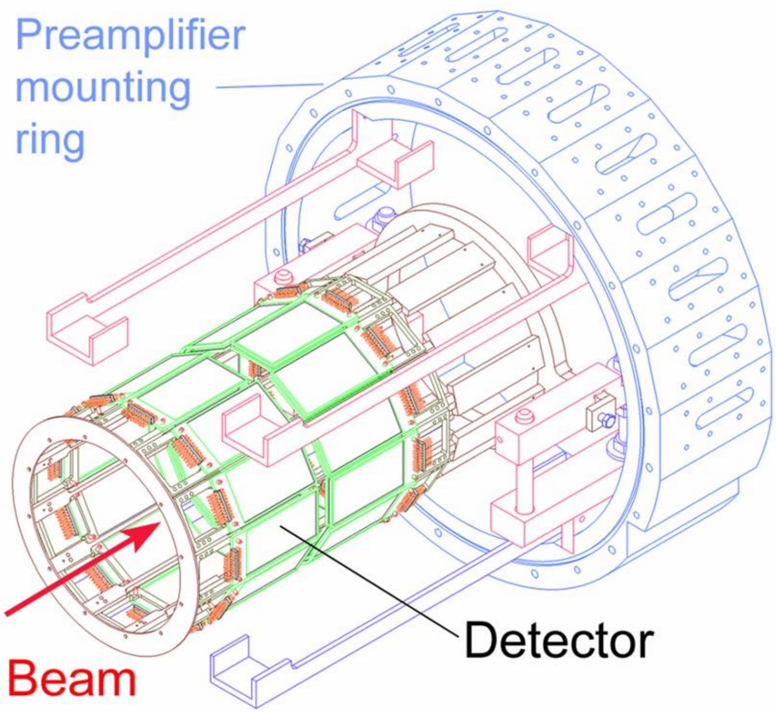
$^{132}Sn(d,p)$ @ 4.5 MeV/A

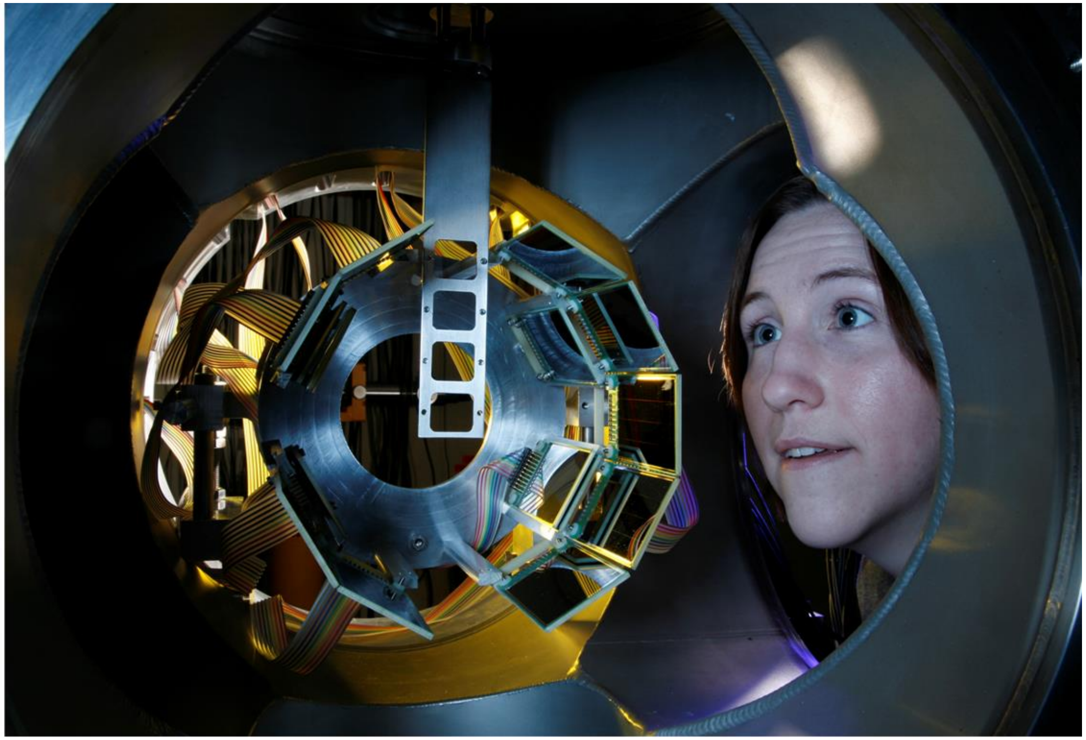


Oak Ridge Rutgers University Barrel Array

- Barrel array of ion-implanted silicon strip detectors
- Custom resistive design used to achieve good position (~1mm) and energy (80 keV)
- 2 rings – $\theta < 90°$: 12 telescopes (1000μm R + 65μm NR)
  - – $\theta > 90°$: 12 detectors (500μm R)
- ORRUBA gives ~80% ϕ coverage over $\theta = 45° \rightarrow 135°$
- 288 electronics channels







$^{132}Sn(d,p)$ – a far from ideal measurement

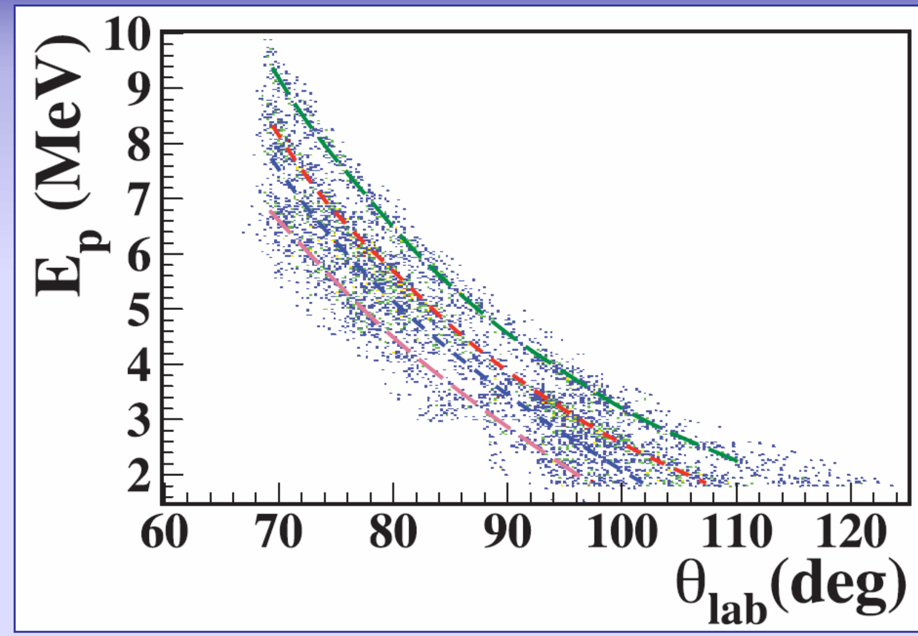
^{132}Sn(d,p)^{133}Sn Measurement at the HRIBF


nature Vol 465|27 May 2010|doi:10.1038/nature09048

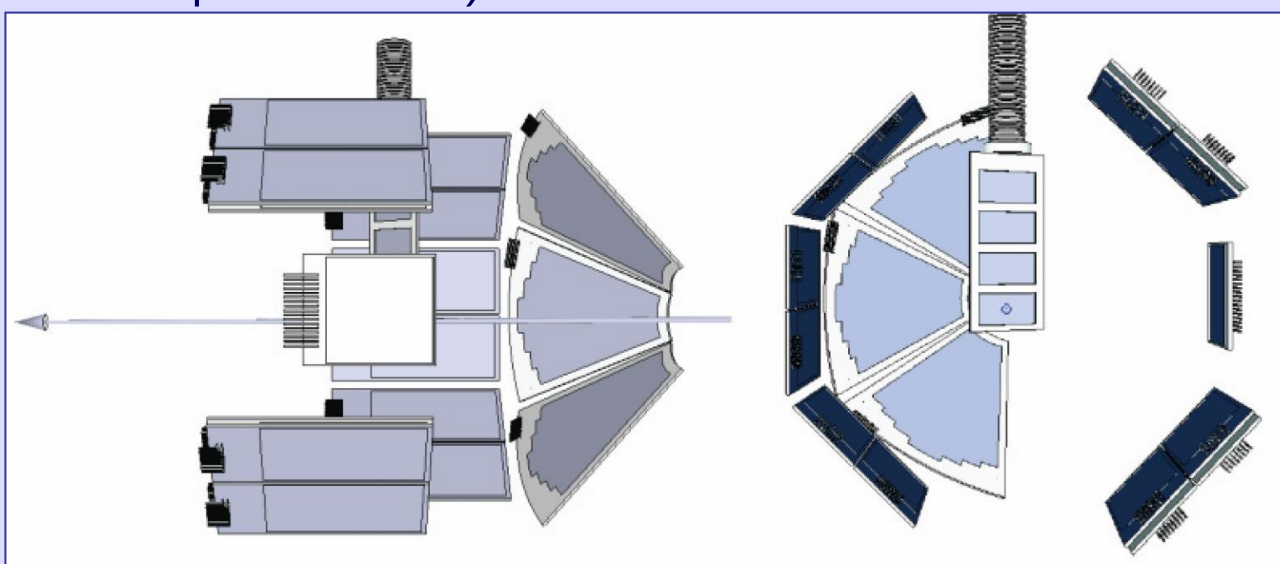
LETTERS

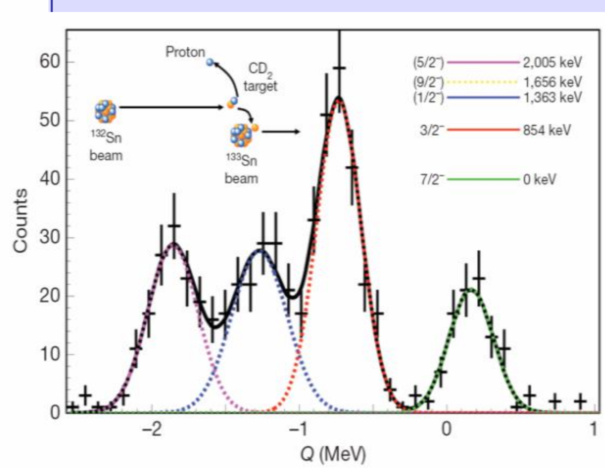
The magic nature of ^{132}Sn explored through the single-particle states of ^{133}Sn

K. L. Jones[1,2], A. S. Adekola[3], D. W. Bardayan[4], J. C. Blackmon[4], K. Y. Chae[1], K. A. Chipps[5], J. A. Cizewski[2], L. Erikson[5], C. Harlin[6], R. Hatarik[2], R. Kapler[1], R. L. Kozub[7], J. F. Liang[4], R. Livesay[5], Z. Ma[1], B. H. Moazen[1], C. D. Nesaraja[4], F. M. Nunes[8], S. D. Pain[2], N. P. Patterson[6], D. Shapira[4], J. F. Shriner Jr[7], M. S. Smith[4], T. P. Swan[2,6] & J. S. Thomas[6]



- Beam of ^{132}Sn at 630 MeV
- 160 μg/cm^2 CD_2 target (effective thickness) ROTATED
- 69 to 107 degree coverage (ORRUBA, 1st implementation)

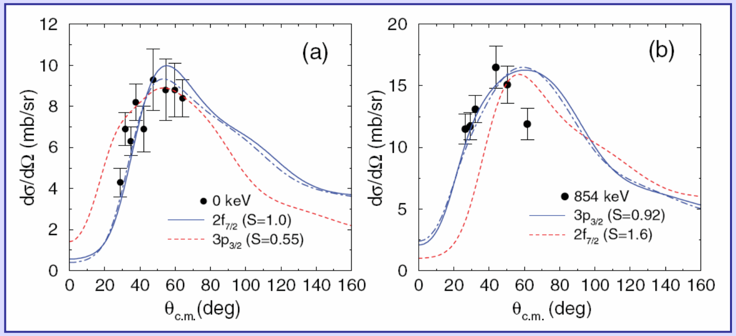


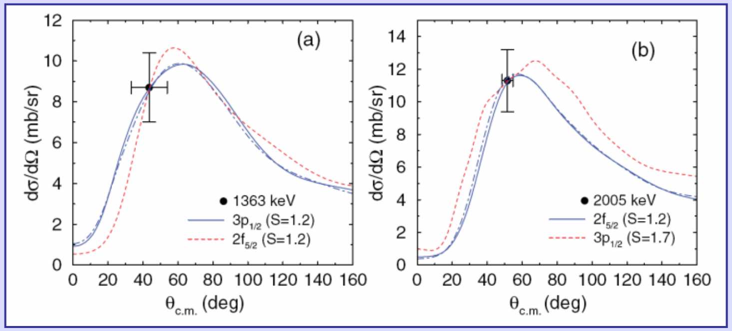


^{132}Sn(d,p)^{133}Sn Measurement – Spectroscopic information

TABLE I. Spectroscopic factors S of the four single-particle states populated by the ^{132}Sn(d,p)^{132}Sn reaction extracted using the DWBA [12] and ADWA formalisms. Error margins listed include only experimental uncertainties. Values extracted from the ADWA-CH are considered the most reliable and are listed in boldface.

		Spectroscopic factor		
E_x (keV)	nlj	DWBA	FR-ADWA-BG	**FR-ADWA-CH**
0	$2f_{7/2}$	0.86 ± 0.07	1.2 ± 0.1	**1.00 ± 0.08**
854	$3p_{3/2}$	0.92 ± 0.07	1.0 ± 0.1	**0.92 ± 0.07**
1363 ± 31	$(3p_{1/2})$	1.1 ± 0.2	1.2 ± 0.3	**1.2 ± 0.2**
2005	$(2f_{5/2})$	1.1 ± 0.2	1.3 ± 0.3	**1.2 ± 0.3**





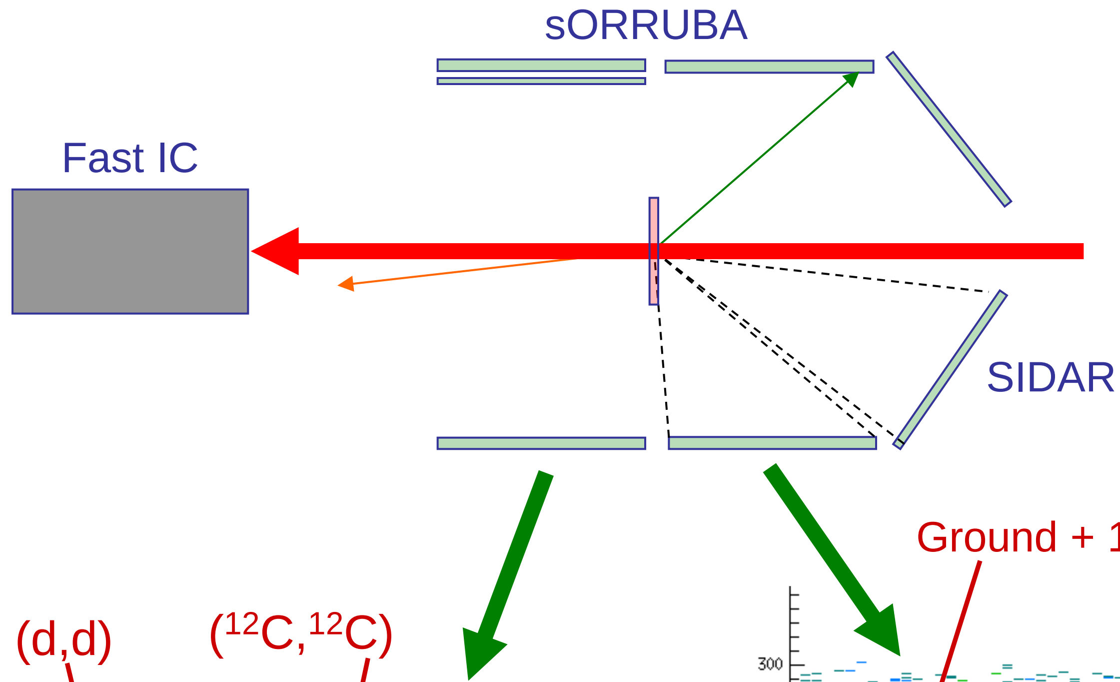
Finite Range ADWA calculations

TABLE II. Asymptotic normalization coefficients (ANCs) of the four single-particle states populated by the ^{132}Sn(d,p)^{132}Sn reaction. Listed error margins include only experimental uncertainties.

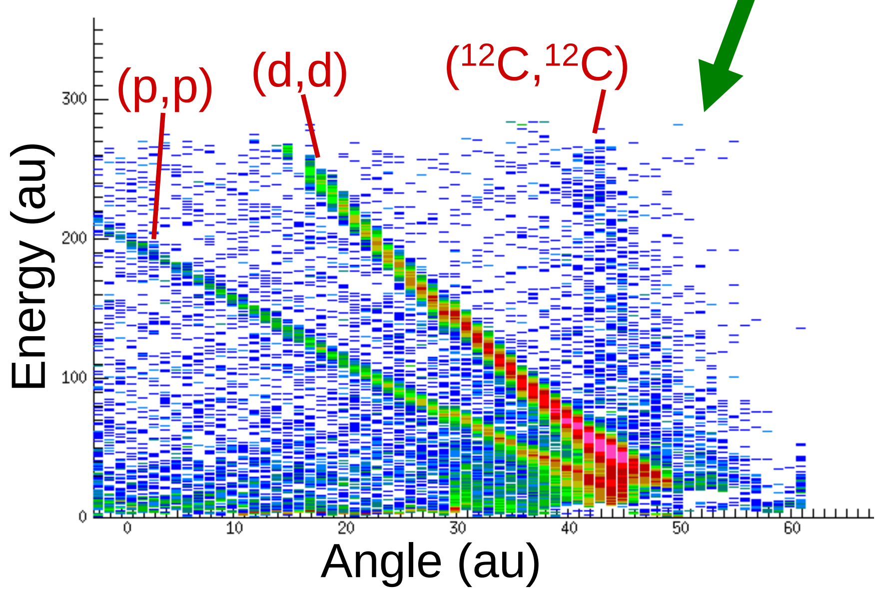
		C^2 (fm^{-1})	
E_x (keV)	nlj	DWBA	FR-ADWA-CH
0	2f7/2	0.64 ± 0.05	0.82 ± 0.07
854	3p3/2	5.6 ± 0.4	6.5 ± 0.5
1363 ± 31	(3p1/2)	2.6 ± 0.6	2.9 ± 0.6
2005	(2f5/2)	$(0.9 \pm 0.2) \times 10^{-3}$	$(1.2 \pm 0.3) \times 10^{-3}$

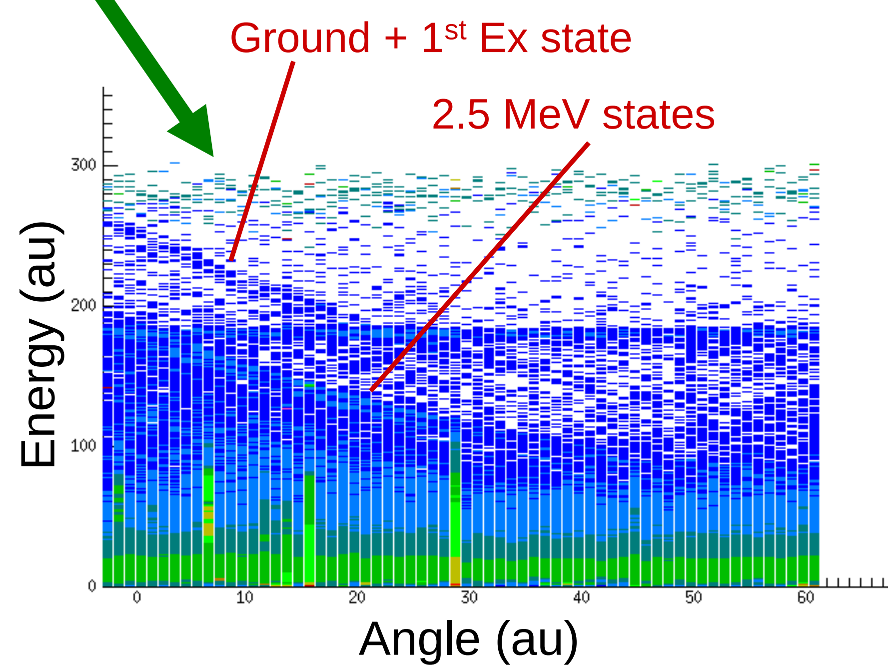
What ideally could have been better?

superORRUBA data – ^{130}Te(d,p)^{131}Te

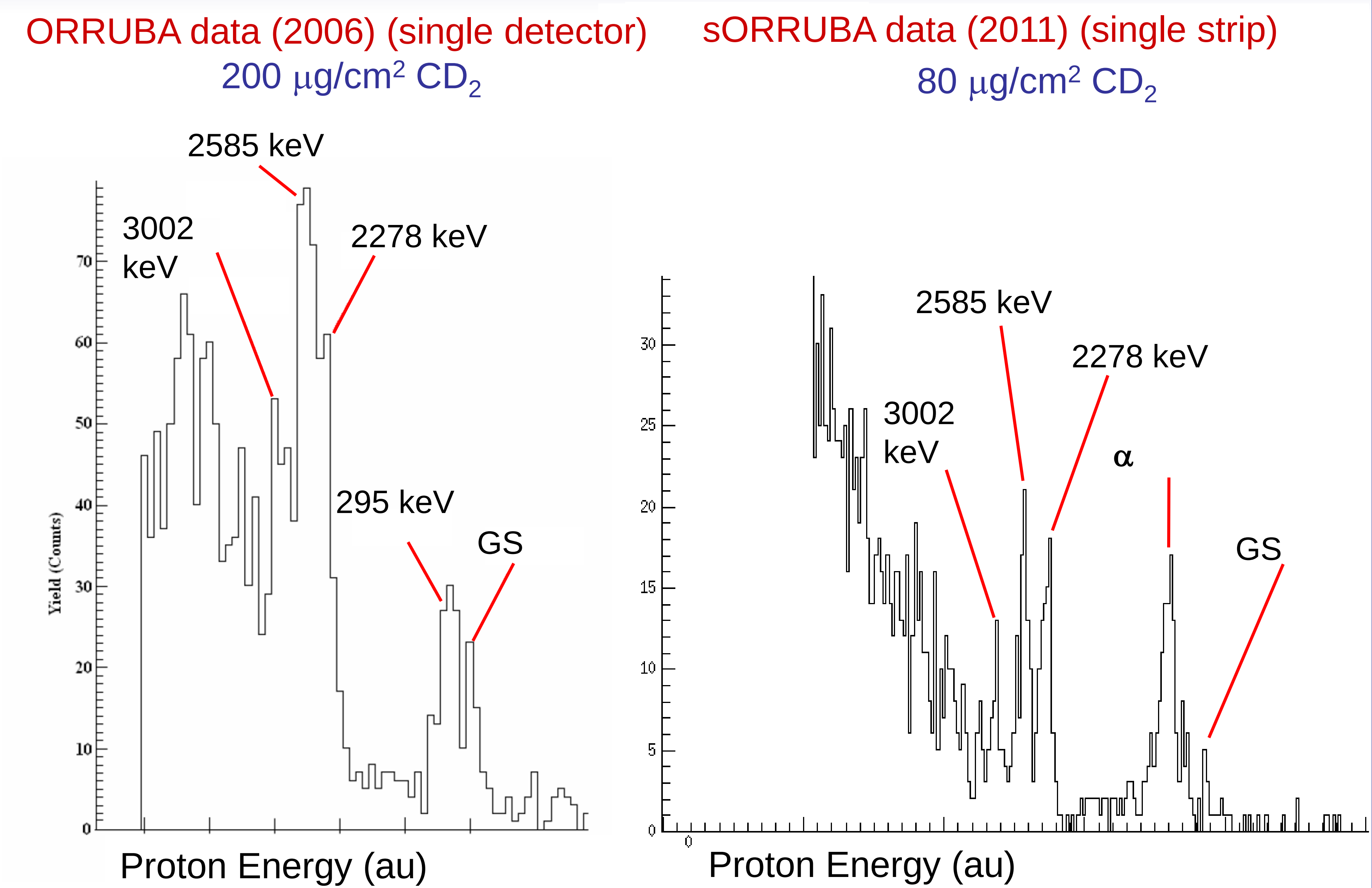


Performed as preparation and calibration for (d,p) on ^{126,128}Sn and ^{132}Te



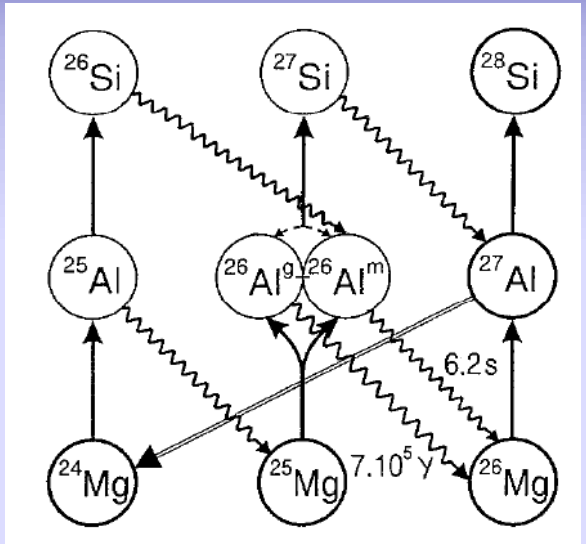


ORRUBA – sORRUBA comparison $^{130}Te(d,p)^{131}Te$



$^{26}Al(d,p)^{27}Al$ – a nearly ideal measurement

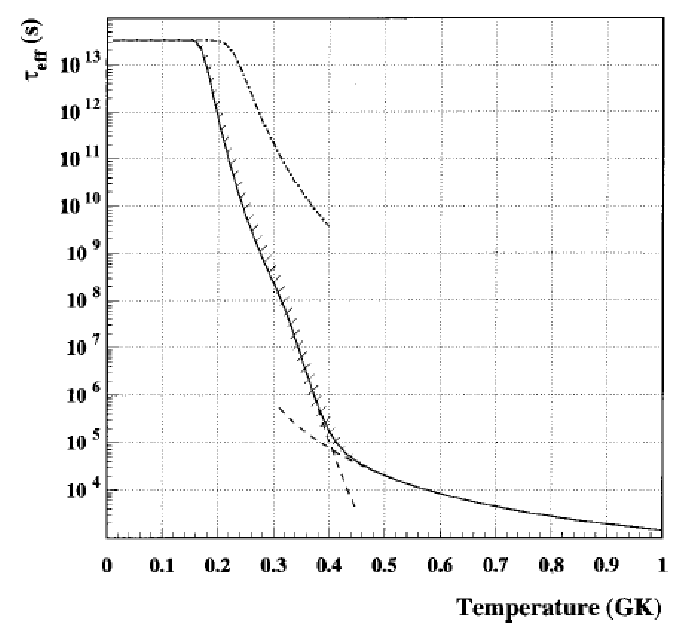
^{26}Al - Background



5^+ gs

0^+ isomeric state at 228 keV

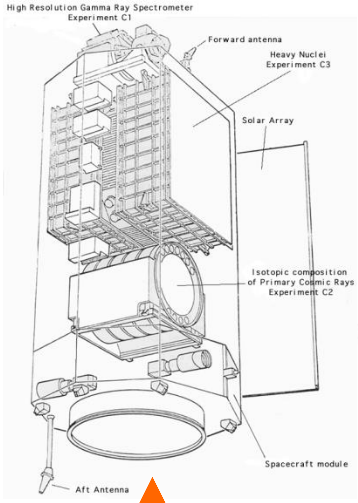
N. Prantzos, R. Diehl. **Physics Reports 267** 1-69 (1996)

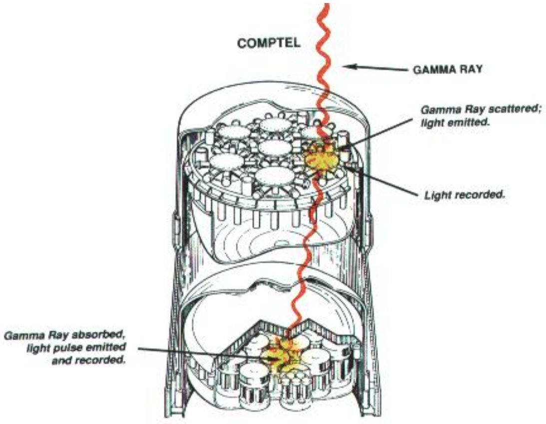


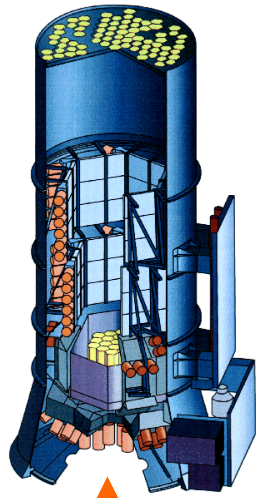
Coc, Porquet and Nowacki **PRC 015801** (1999)

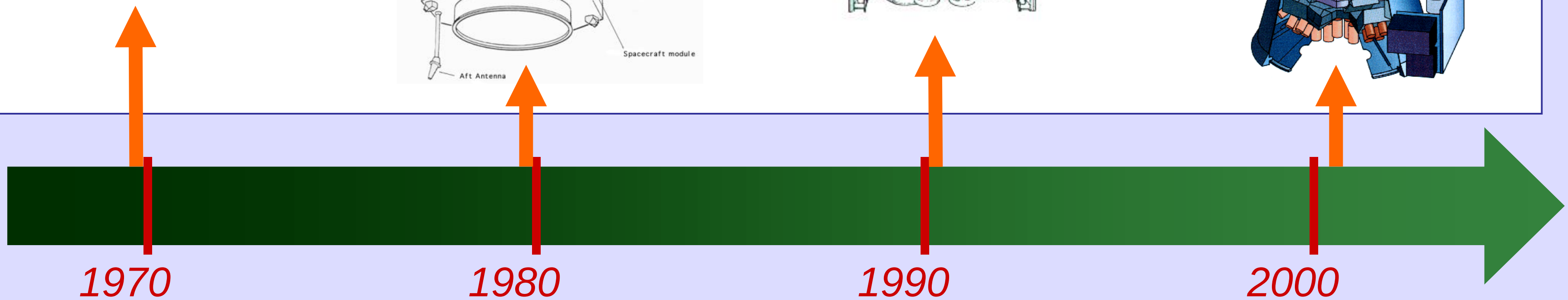
- ^{26}Al nucleus was the first radioisotope detected in the interstellar medium
- Half life of 7.2x10^5 years
- Observation of γ rays associated with its decay provides evidence of nucleosynthesis
- Temperatures 0.03 – 0.3 GK, the ^{26g}Al(p,γ)^{27}Si reaction is expected to contribute to the destruction of ^{26}Al

^{26}Al – Observation History

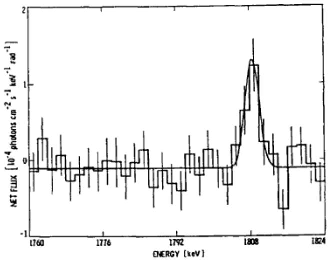




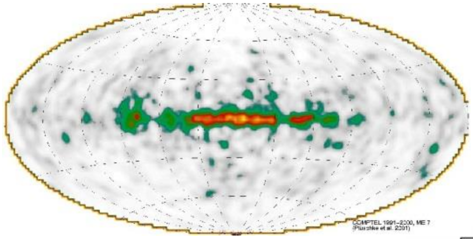




Meteoritic grains

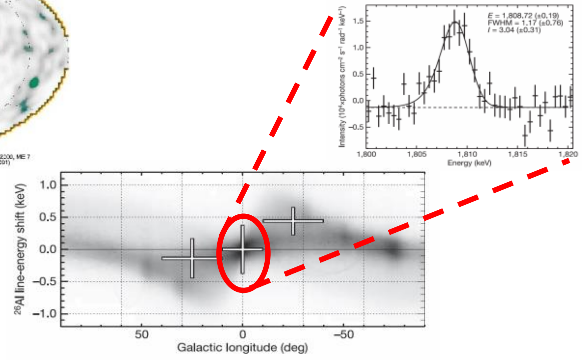


HEAO (High Energy Astronomy Observatory)

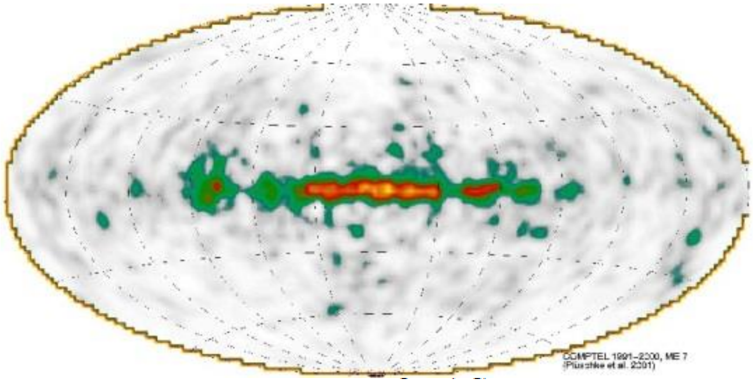


COMPTEL (CGRO)

INTEGRAL



Tracing ^{26}Al sources

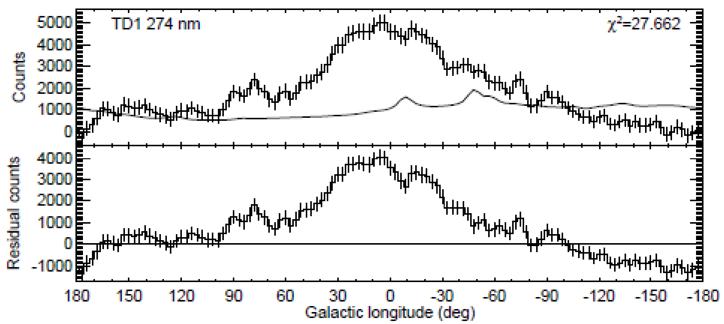


A multiwavelength comparison of COMPTEL 1.8 MeV ^{26}Al line data

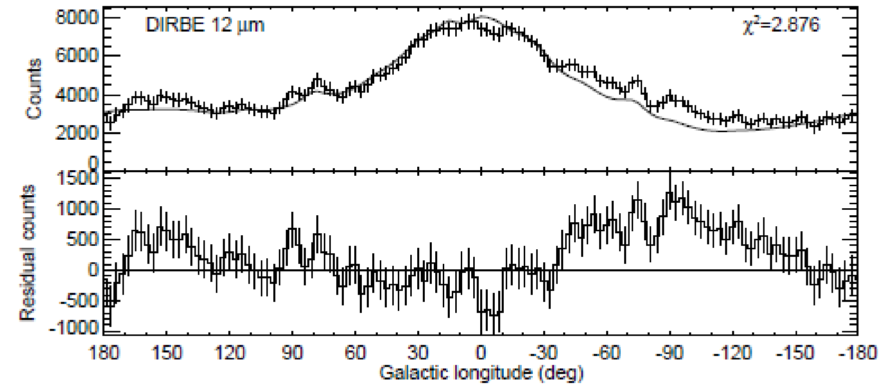
J. Knödlseder[1], K. Bennett[5], H. Bloemen[3], R. Diehl[2], W. Hermsen[3], U. Oberlack[6], J. Ryan[4], V. Schönfelder[2], and P. von Ballmoos[1]

Astron. Astrophys. 344, 68–82 (1999)

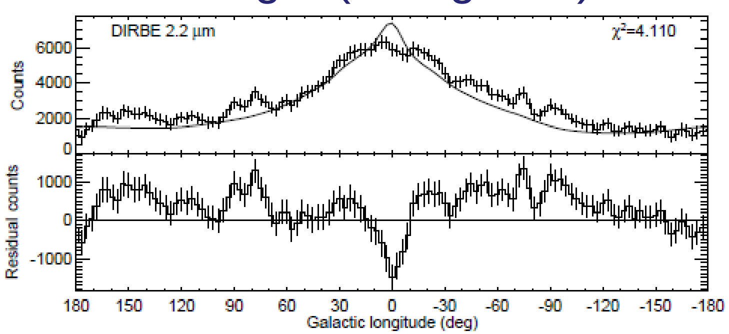
Starlight (nearby hot stars)



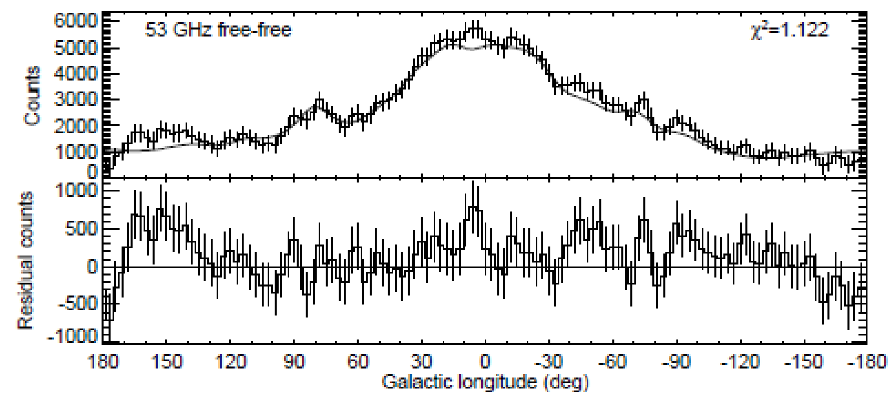
Thermal dust/AGB stars



Starlight (K/M giants)

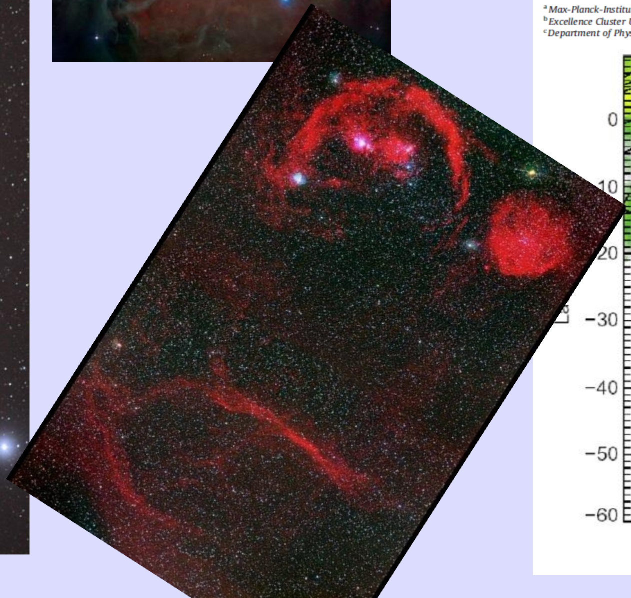


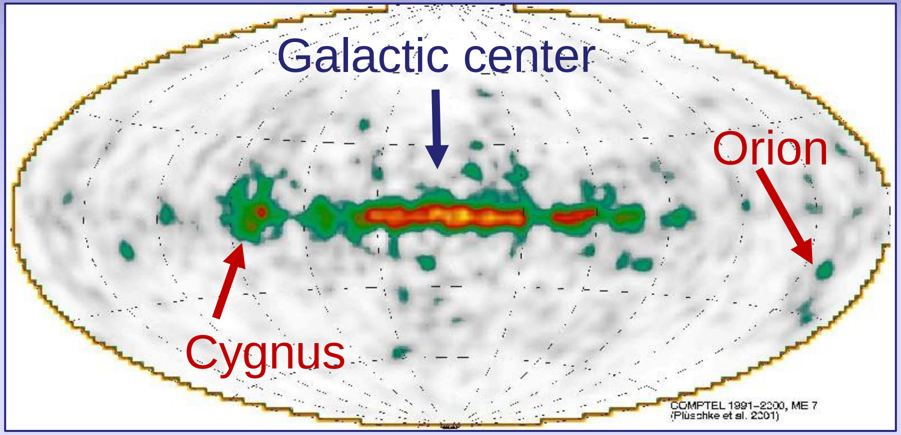
Ionized gas

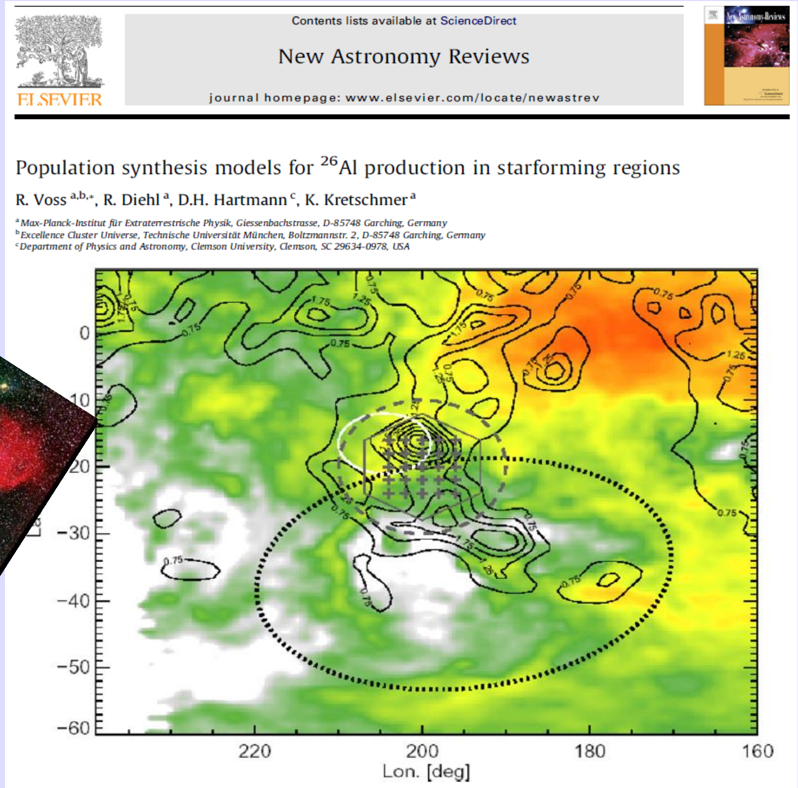


Orion region – tracing massive star ejecta

>30 $M_{\odot}$ stars – develop strong stellar winds blowing material into space







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journal homepage: www.elsevier.com/locate/newastrev

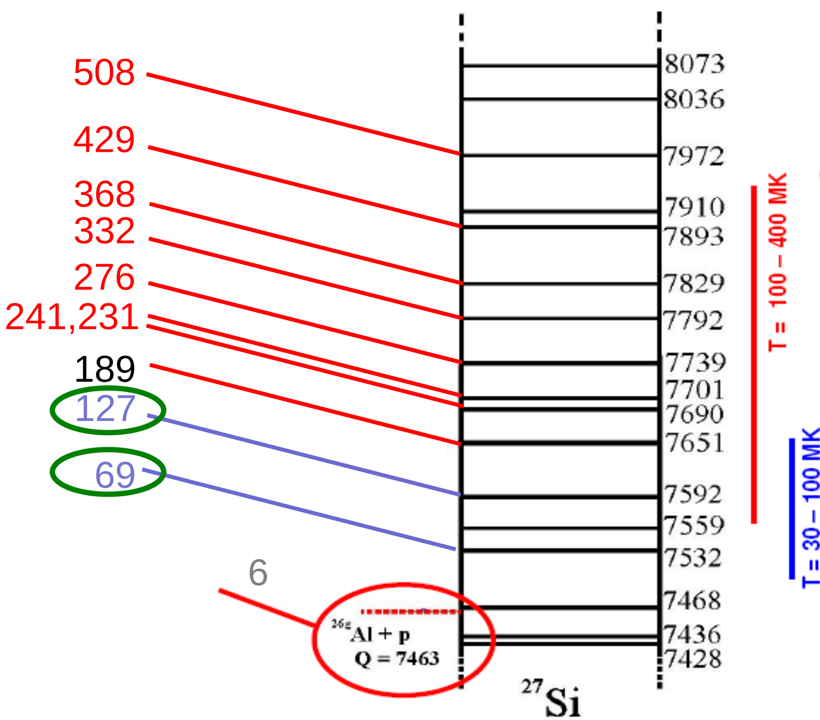
Population synthesis models for ^{26}Al production in starforming regions

R. Voss [a,b,*], R. Diehl [a], D.H. Hartmann [c], K. Kretschmer [a]

[a] Max-Planck-Institut für Extraterrestrische Physik, Giessenbachstrasse, D-85748 Garching, Germany
[b] Excellence Cluster Universe, Technische Universität München, Boltzmannstr. 2, D-85748 Garching, Germany
[c] Department of Physics and Astronomy, Clemson University, Clemson, SC 29634-0978, USA

$^{26}Al(p,\gamma)^{27}Si$ – states and mirrors

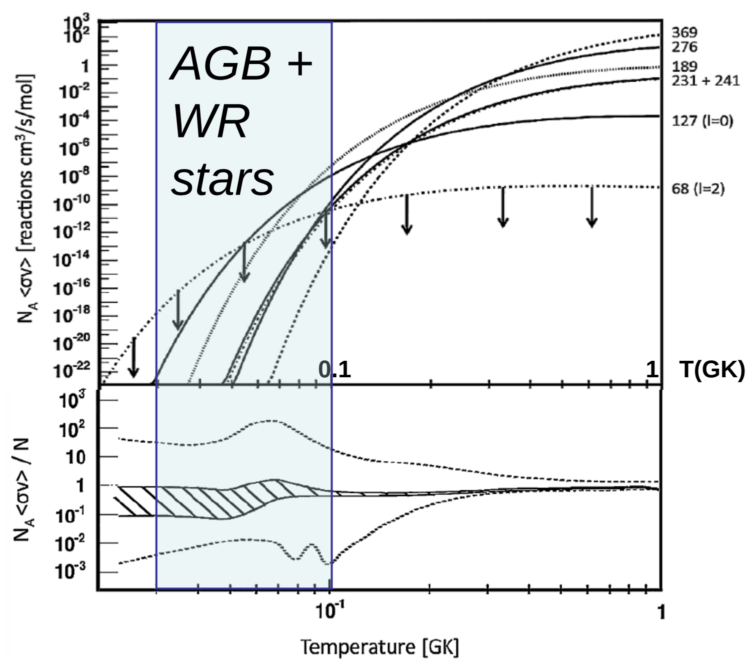
E_x (keV)	E_{res} (keV)		J^π		$\omega\gamma$ (meV)	^{27}Al E_x (keV)
7469	6		$(1/2, 5/2)^+$		$< 2.3 \times 10^{-66}$ [2][a]	7676
(7491)	(28)	Unmeasured	$(3/2^+)$		-	7799
7532	69	Unmeasured	$5/2^+$	ell=2	$< 2.3 \times 10^{-13}$ [2][a]	7790
(7557)[b]	(94)	Unmeasured	$(3/2^+)$		$< 1.9 \times 10^{-10}$ [2][a]	7858
7590	127	Unmeasured	$9/2^+$	ell=0	$< 5.9 \times 10^{-6}$ [3][c]	7807
7652	189	Measured	$11/2^+$		0.055(9) [4], 0.035(7) [5]	7950
7694	231	Measured	$5/2^+$		≤ 0.010 [4]	7722
7704	241	Measured	$7/2^-$		0.010(5) [4]	7900
7739	276	Measured	$9/2^+$		3.8(10) [6], 2.9(3) [4]	7998



ONe novae

AGB + WR stars

Strengths of 69 and 127 keV resonances major uncertainty



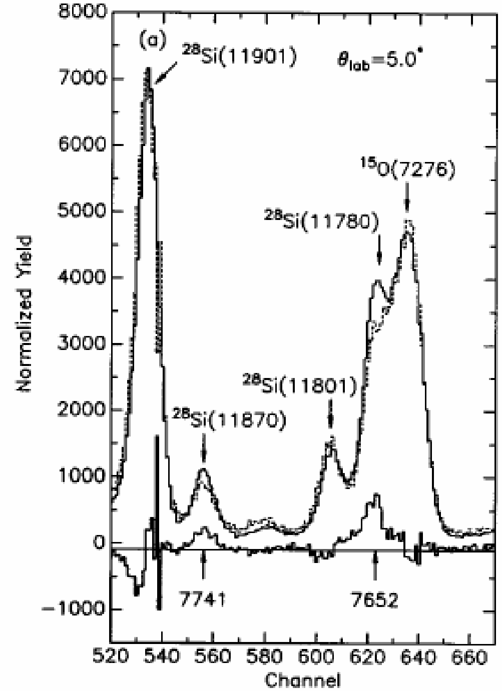
G. Lotay *et al*, **PRL 102** 162502 (2009)

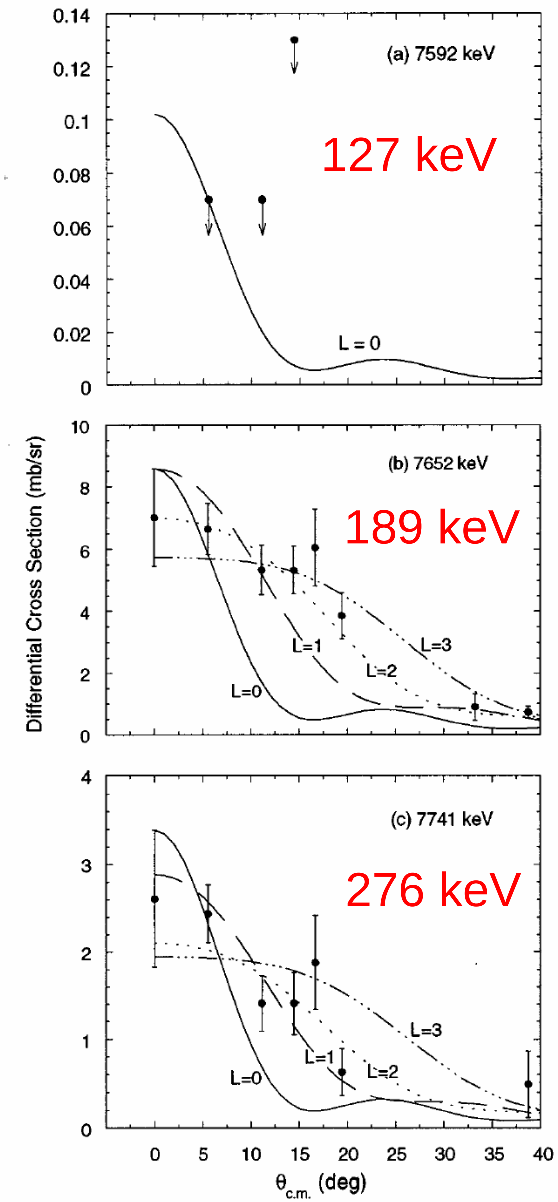
127 keV resonance strength from the $^{26}Al(^{3}He,d)^{27}Si$ reaction

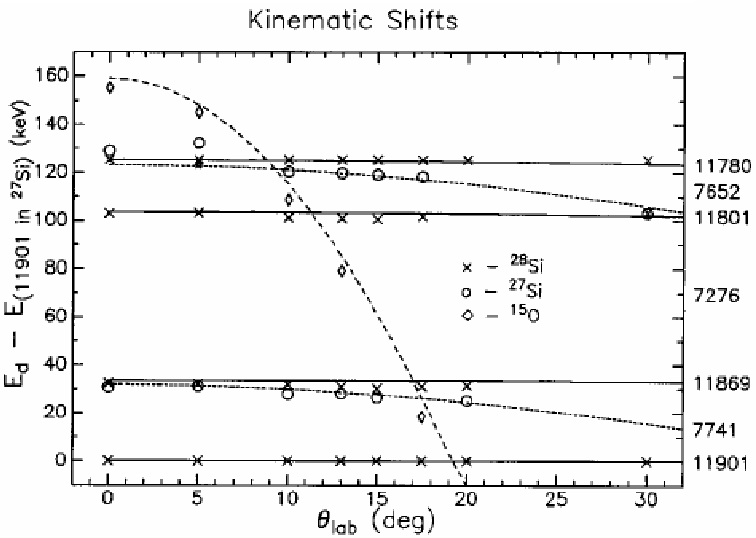
Vogelaar *et al*, **PRC 53** 1945 (1996)

$^{26}Al(^{3}He,d)^{27}Si$

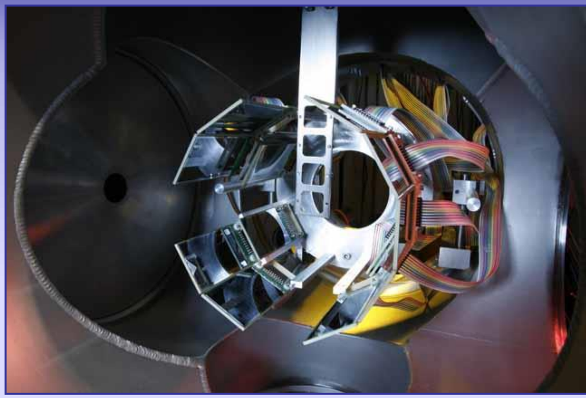
Isotopically enriched target (6.3% $^{26}Al/^{27}Al$)



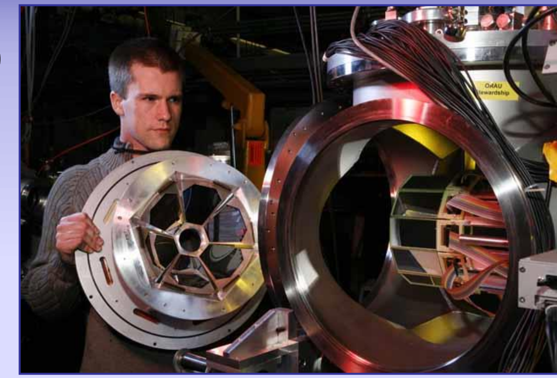


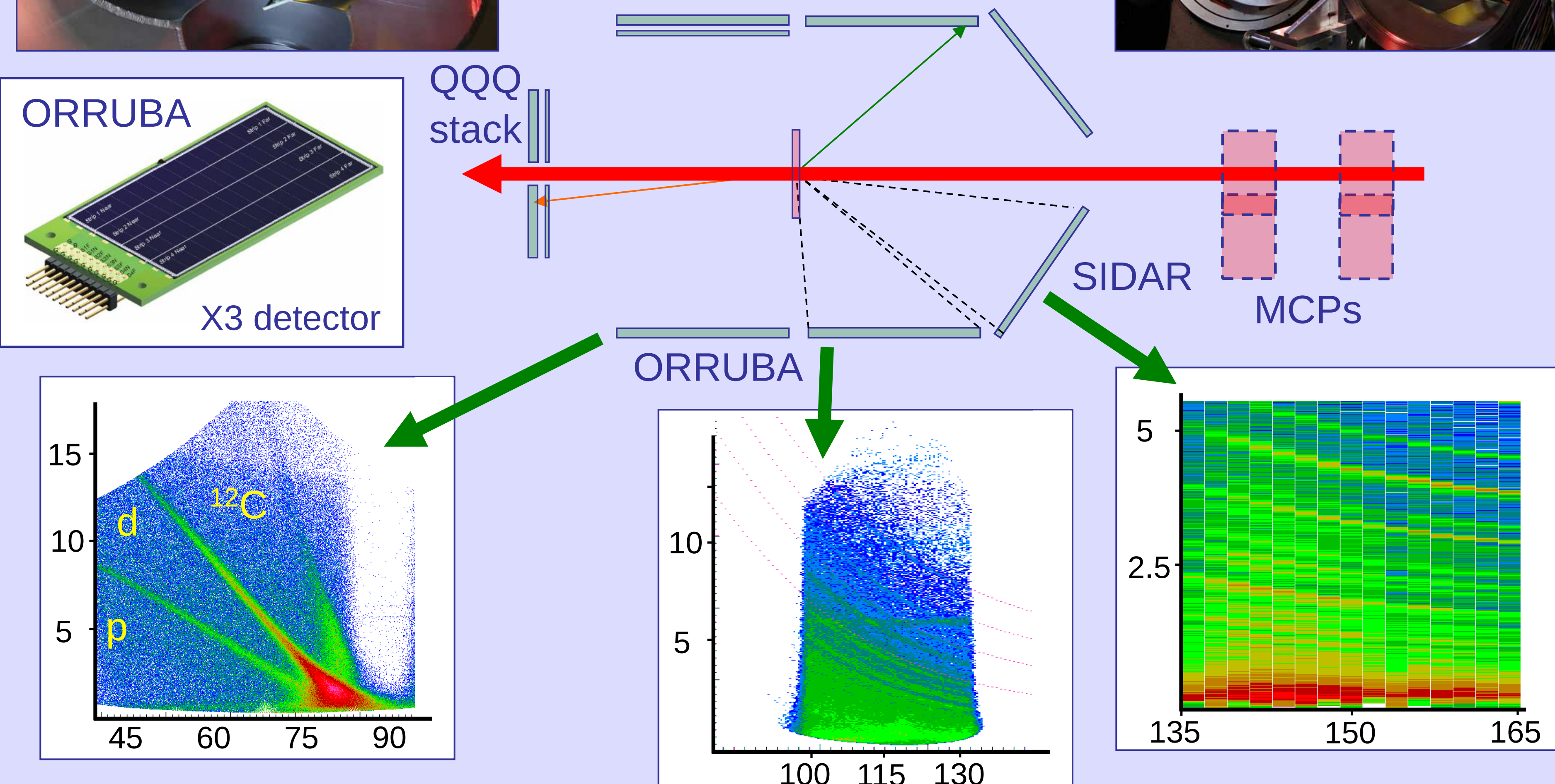


$^{26}Al(d,p)^{27}Al$ Experimental Details

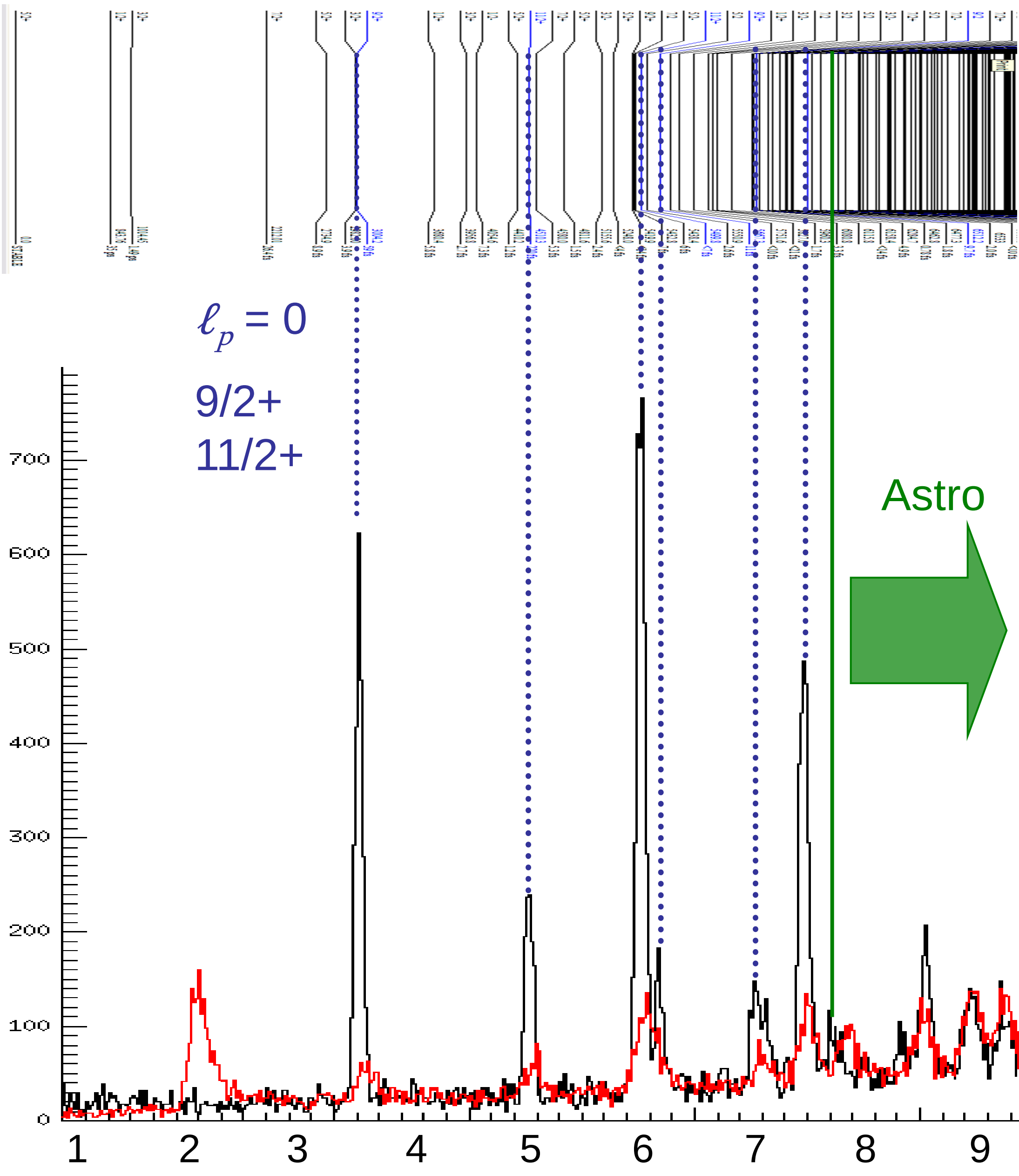


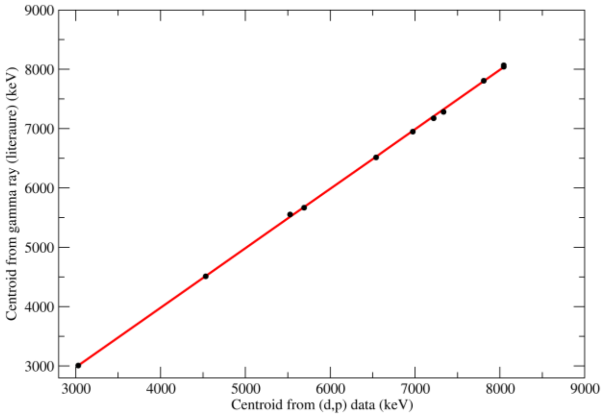
- 117 MeV ^{26}Al (Oak Ridge Tandem)
- 5×10^6 pps
- 150 $\mu g/cm^2$ CD_2
- MCP normalization (200 kHz)





$^{26}Al(d,p)^{27}Al$ – Internal energy calibration

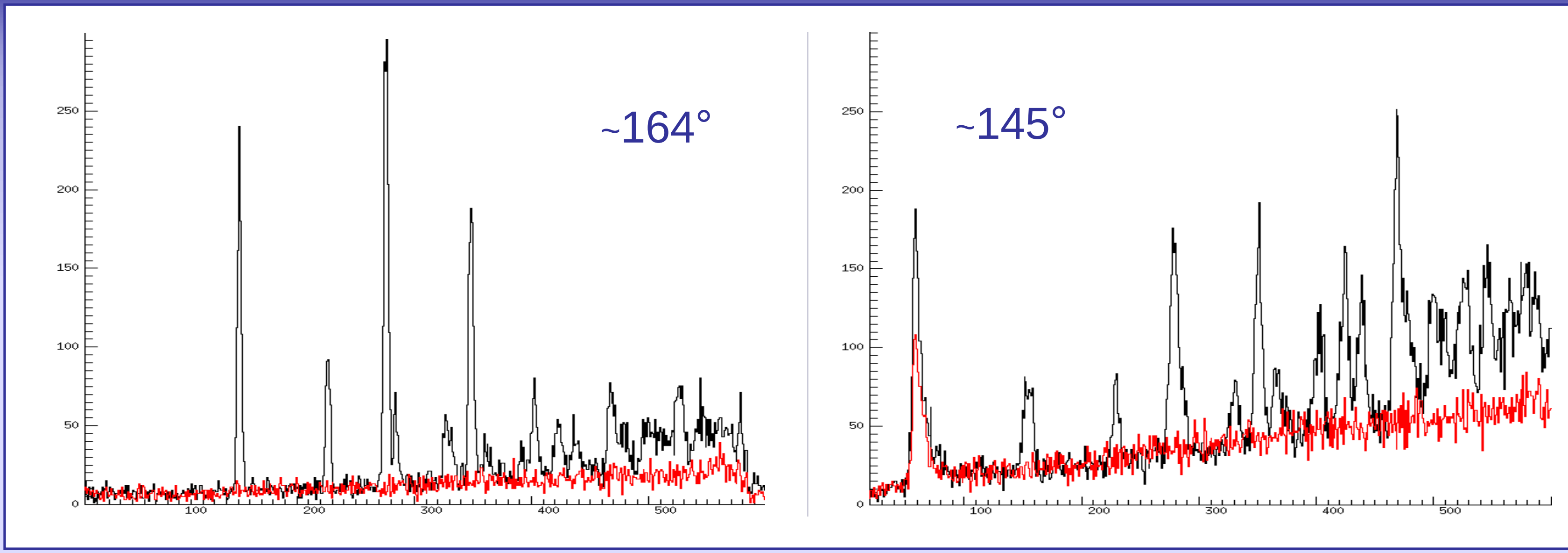




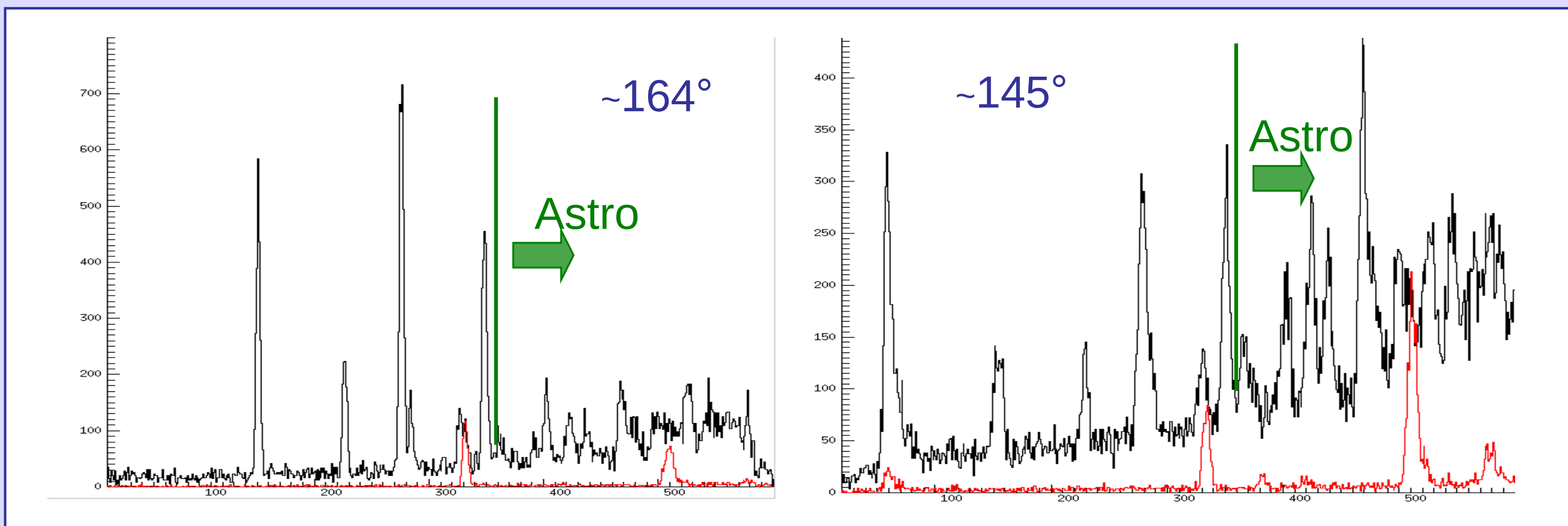
164 deg 75 keV (CoM)

138 deg 180 keV (CoM)

^{26}Al(d,p)^{27}Al – background runs



Run on carbon foil to determine form of background from reactions on carbon



Run with ^{26}Mg beam (5+) to determine background peaks from reactions ^{26}Mg(d,p)

$^{26}Al(d,p)^{27}Al$ – Astrophysically important states

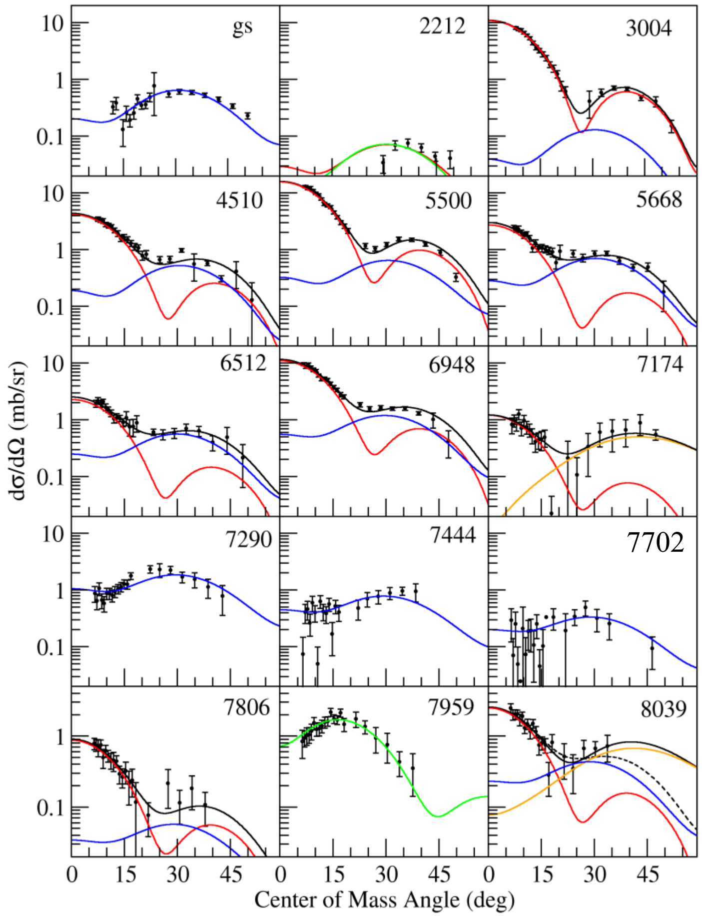
ADWA calculations

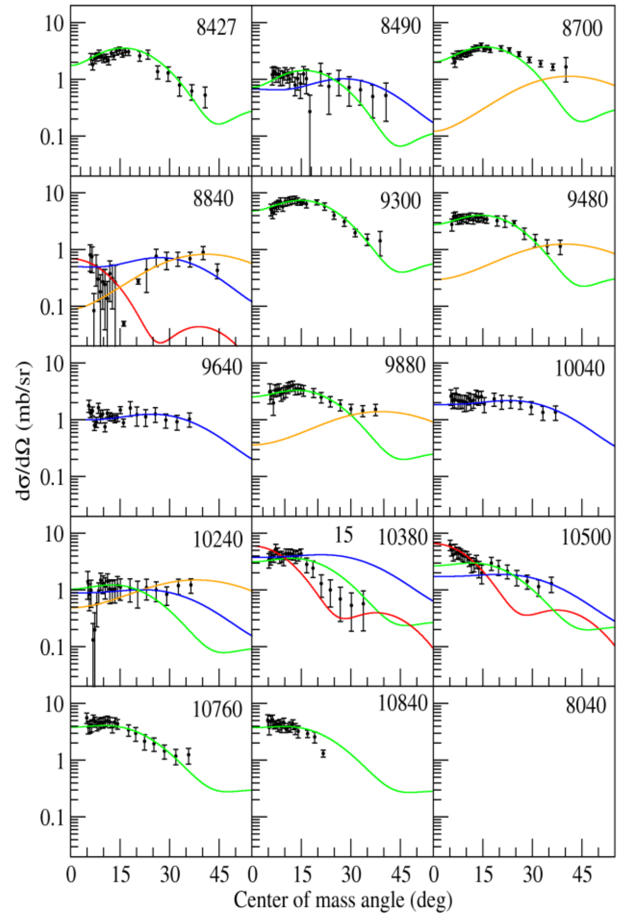
– ℓ = 0

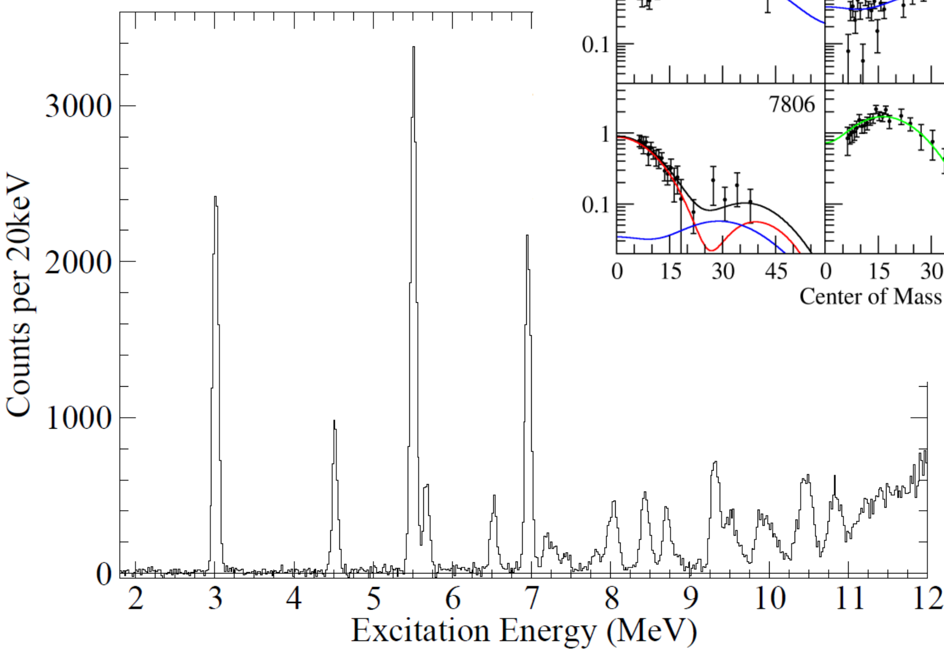
– ℓ = 1

– ℓ = 2

– ℓ = 3







FWHM = 72 keV (CoM)

$^{26}Al(d,p)^{27}Al$ – Astrophysically important states

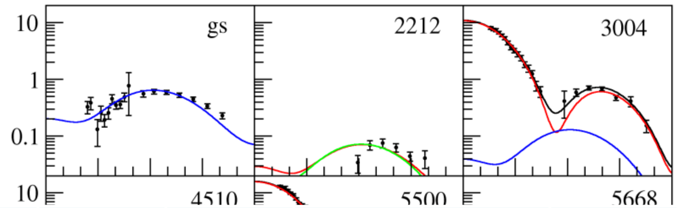
ADWA calculations

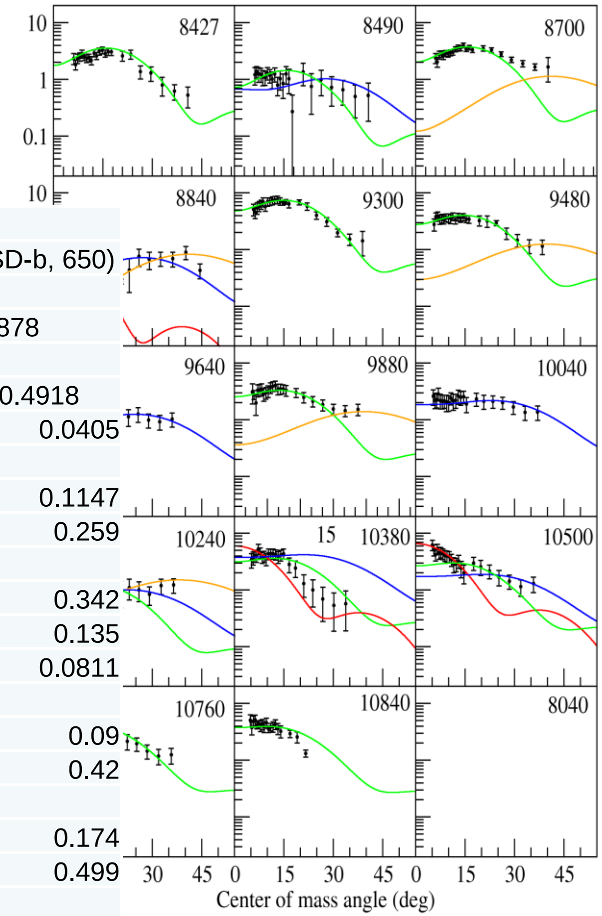
– ℓ = 0

– ℓ = 1

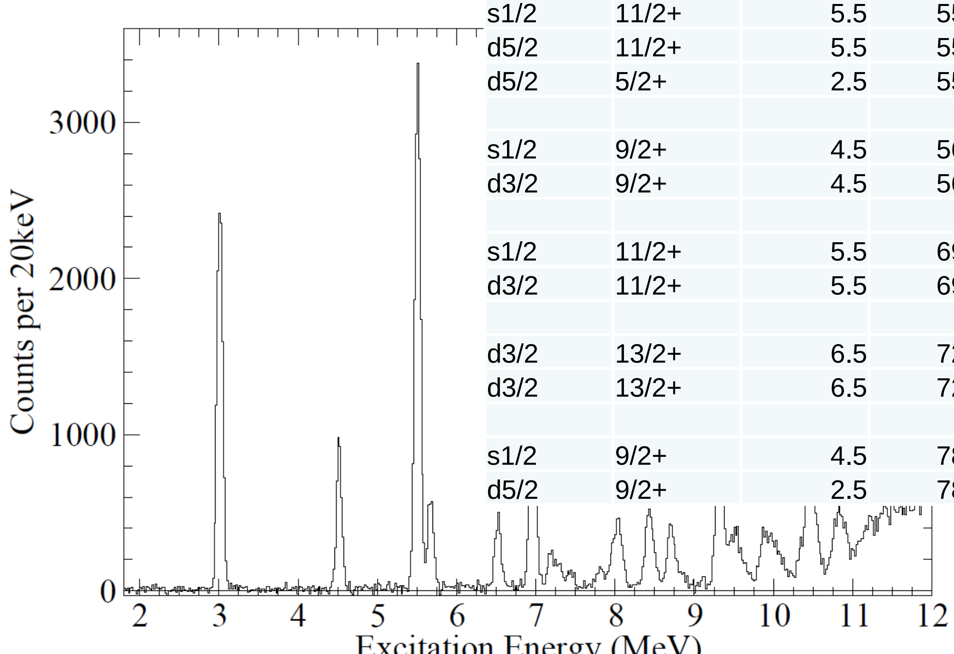
– ℓ = 2

– ℓ = 3





			Peak	ell	SF (exp)	SF (USD-b, 650)
d/5/2	5/2+	2.5	0	2	1.12	1.0878
s1/2	9/2+	4.5	3004	0	0.31	0.4918
	9/2+	4.5	3004	2	0.126	0.0405
s1/2	11/2+	5.5	4510	0	0.115	0.1147
d3/2	11/2+	5.5	4510	2	0.339	0.259
s1/2	11/2+	5.5	5500	0	0.227	0.342
d5/2	11/2+	5.5	5500	2	0.263	0.135
d5/2	5/2+	2.5	5551	2	0.522	0.0811
s1/2	9/2+	4.5	5668	0	0.045	0.09
d3/2	9/2+	4.5	5668	2	0.484	0.42
s1/2	11/2+	5.5	6948	0	0.123	0.174
d3/2	11/2+	5.5	6948	2	0.491	0.499
d3/2	13/2+	6.5	7292	0		
d3/2	13/2+	6.5	7292	2	1.063	
s1/2	9/2+	4.5	7806	0	0.01015	0.011
d5/2	9/2+	2.5	7806	2	0.0184	0.0107

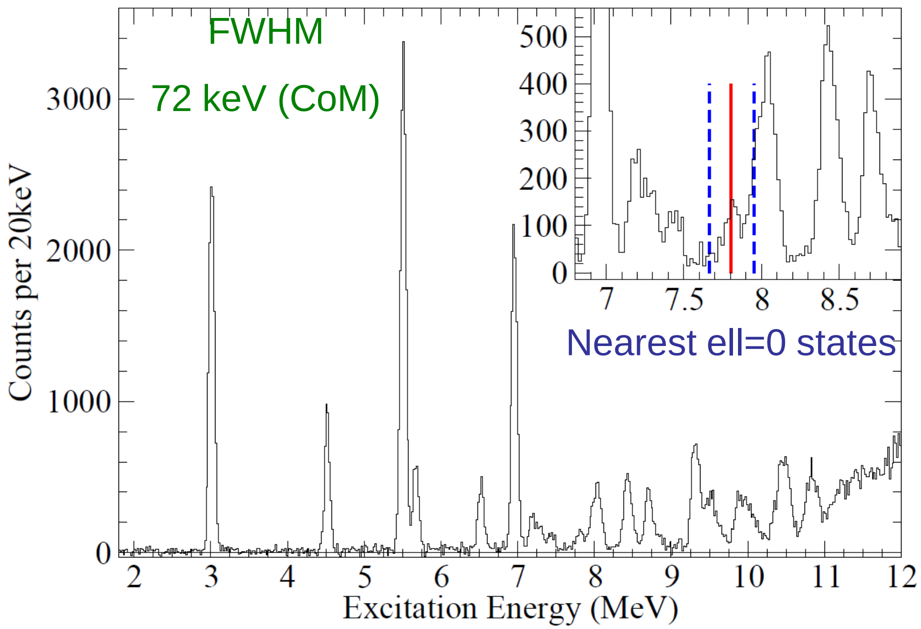


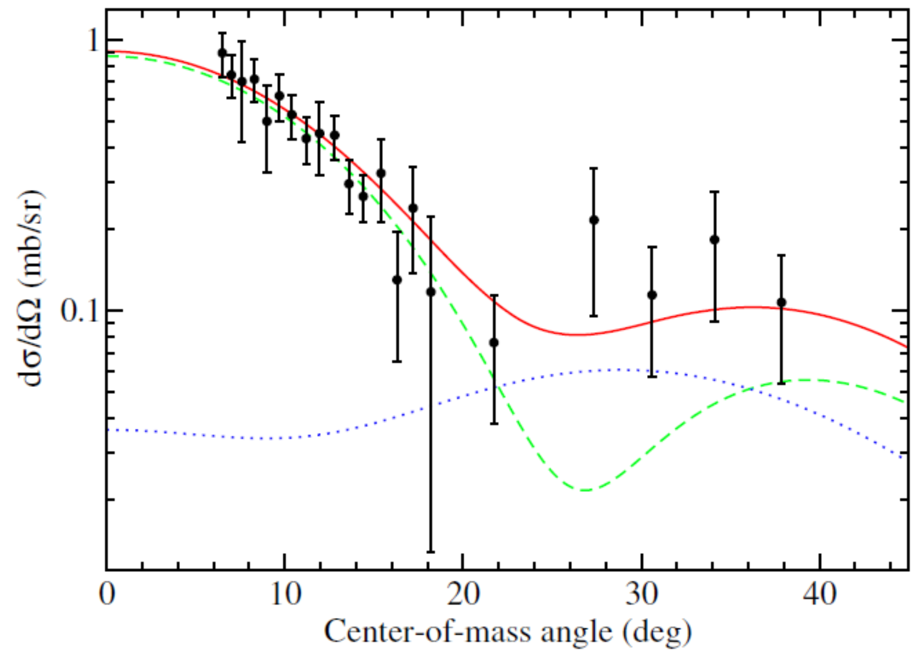
FWHM = 72 keV (CoM)

Constraint of the Astrophysical $^{26g}\text{Al}(p,\gamma)^{27}\text{Si}$ Destruction Rate at Stellar Temperatures

S. D. Pain,[1,*] D. W. Bardayan,[1,2] J. C. Blackmon,[3] S. M. Brown,[4] K. Y. Chae,[5,6] K. A. Chipps,[7] J. A. Cizewski,[7] K. L. Jones,[5] R. L. Kozub,[8] J. F. Liang,[1] C. Matei,[9] M. Matos,[3] B. H. Moazen,[5] C. D. Nesaraja,[1] J. Okołowicz,[10] P. D. O'Malley,[7] W. A. Peters,[9] S. T. Pittman,[5] M. Płoszajczak,[11] K. T. Schmitt,[5] J. F. Shriner, Jr.,[8] D. Shapira,[1] M. S. Smith,[1]

7805(12) keV (127-keV mirror)



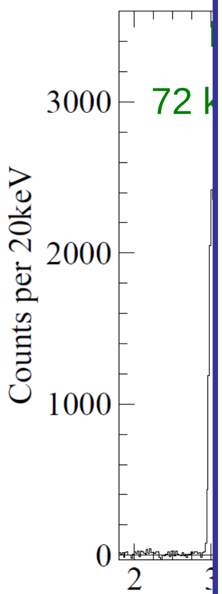


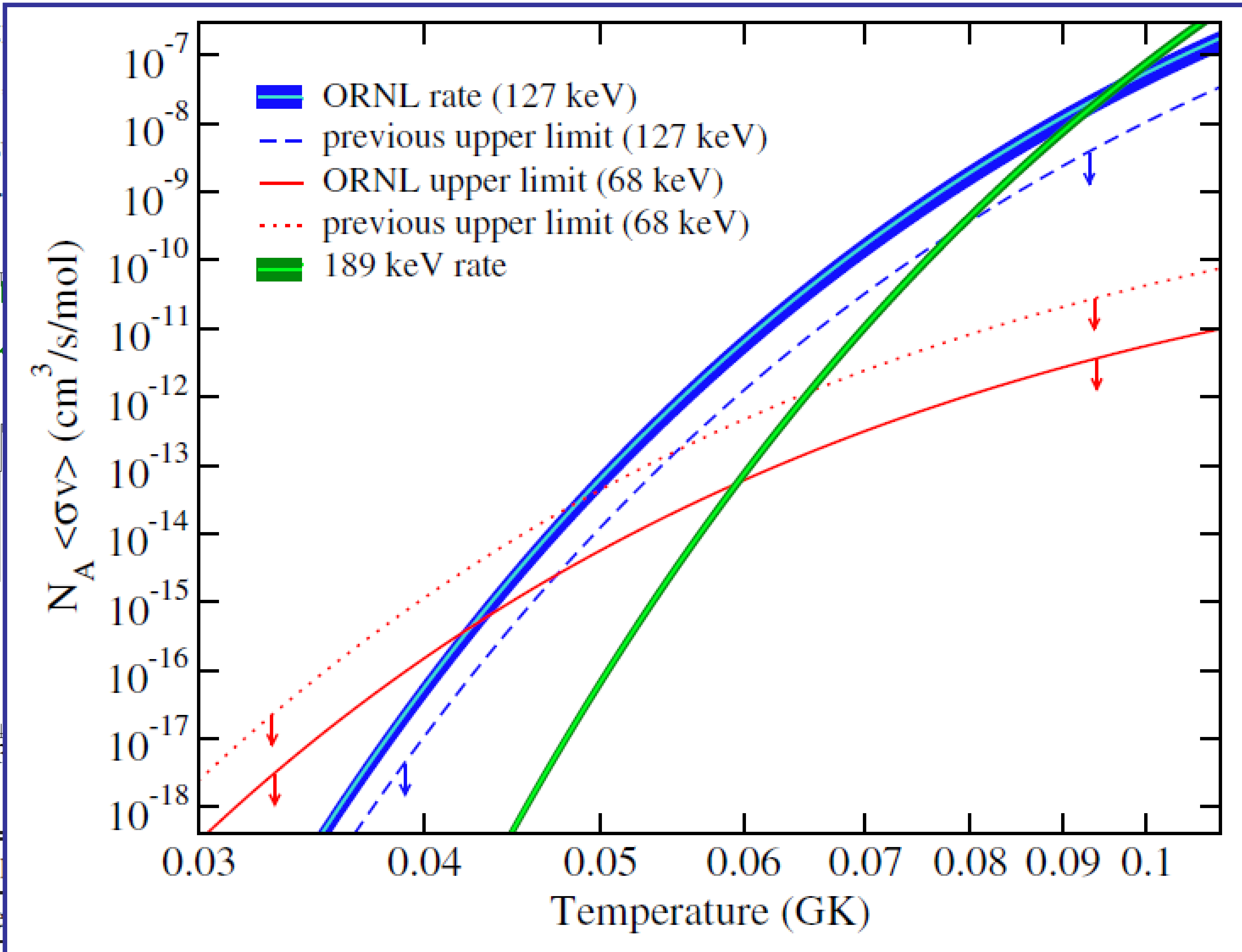
	^{27}Al	^{27}Al	^{27}Al[a]	^{27}Si[a]	^{27}Si	Γ_{sp}	Γ_p	$\omega\gamma$
J^π	E_x (keV)	$C^2S_\nu^{exp}$	$C^2S_\nu^{th}$	$C^2S_\pi^{th}$	C^2S_π	(meV)	(meV)	(meV)
$9/2^+$	7807	0.0102 ± 0.0021	$0.0112^{-0.0002}_{+0.0007}$	$0.0094^{+0.0016}_{-0.0024}$	$0.0085^{+0.0024}_{-0.0031}$	6.70×10^{-3}	$5.7^{+1.6}_{-2.1} \times 10^{-5}$	$2.6^{+0.7}_{-0.9} \times 10^{-5}$
$5/2^+$	7790	≤ 0.061	$0.0100^{+0.0006}_{-0.0002}$	$0.0088^{+0.0010}_{-0.0022}$	≤ 0.054	2.06×10^{-10}	$\leq 1.1 \times 10^{-11}$	$\leq 3.0 \times 10^{-12}$

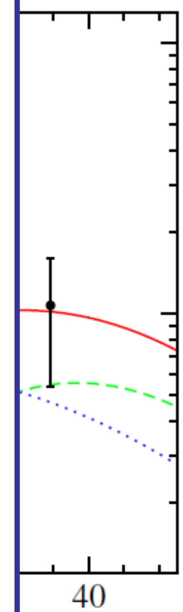
[a]From SMEC calculations using the USD-b effective interaction, using a continuum coupling constant of -650 MeV fm^3.

Const ... tures

S. D. Pain,[1,] ... K. L. Jones,[5]
R. L. Koz ... O'Malley,[7]
W. A. ... mith,[1]







^{27}Al								$\omega\gamma$
J^π	E_x (ke							(meV)
$9/2^+$	7807	0.0102 ± 0.0021	$0.0112_{+0.0007}$	$0.0094_{-0.0024}$	$0.0085_{-0.0031}$	6.70×10 [illegible]	$5.7_{-2.1} \times 10$ [illegible]	$2.6^{+0.7}_{-0.9} \times 10^{-5}$
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[a]From SMEC calculations using the USD-b effective interaction, using a continuum coupling constant of −650 MeV fm^3.

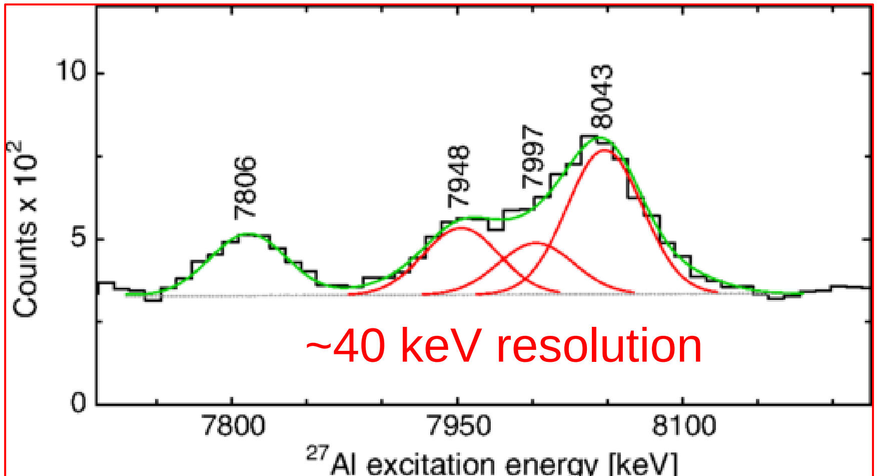
^{26}Al(d,p)^{27}Al Experiment at TRUIMF

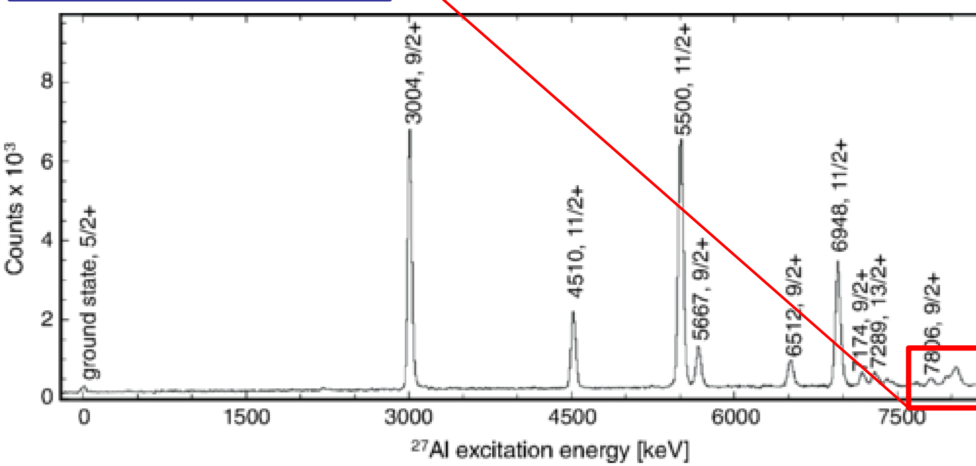
PRL 115, 062701 (2015) PHYSICAL REVIEW LETTERS week ending 7 AUGUST 2015

Inverse Kinematic Study of the ^{26g}Al$(d,p)^{27}$Al Reaction and Implications for Destruction of ^{26}Al in Wolf-Rayet and Asymptotic Giant Branch Stars

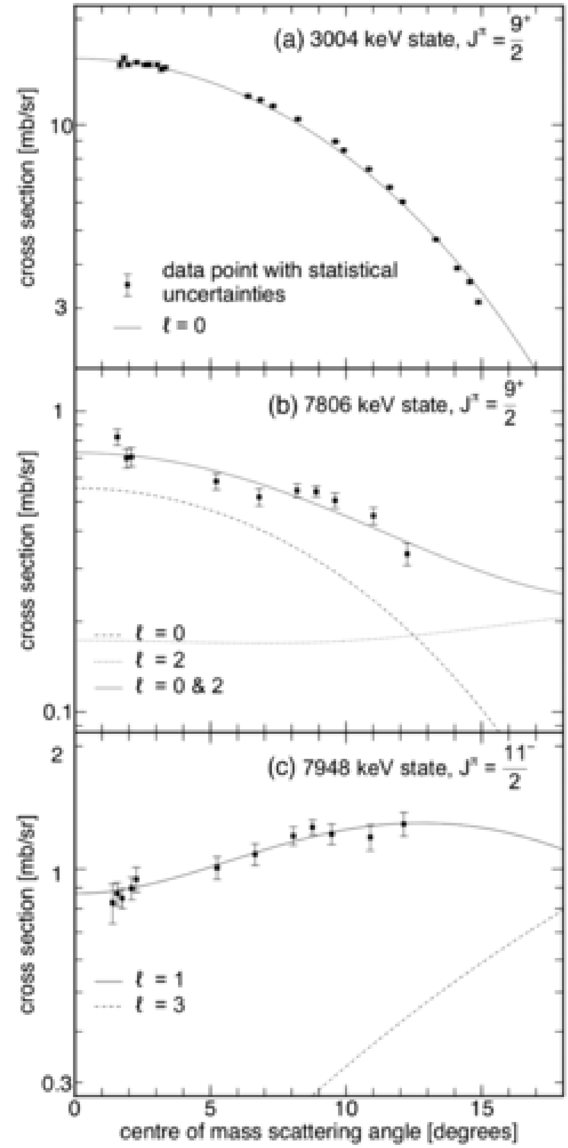
V. Margerin,[1] G. Lotay,[1,2,3,*] P. J. Woods,[1] M. Aliotta,[1] G. Christian,[4] B. Davids,[4] T. Davinson,[1] D. T. Doherty,[1,†] J. Fallis,[4] D. Howell,[4] O. S. Kirsebom,[4,‡] D. J. Mountford,[1] A. Rojas,[4] C. Ruiz,[4] and J. A. Tostevin[2]

- 1 pnA ^{26}Al
- 6 MeV/u
- ~50 µg CD_2
- Detectors 21 and 75 cm upstream





Smaller angular range



Comparison of HRIBF and TRIUMF results

PRL 114, 212501 (2015) PHYSICAL REVIEW LETTERS week ending 29 MAY 2015

Constraint of the Astrophysical $^{26g}Al(p,\gamma)^{27}Si$ Destruction Rate at Stellar Temperatures

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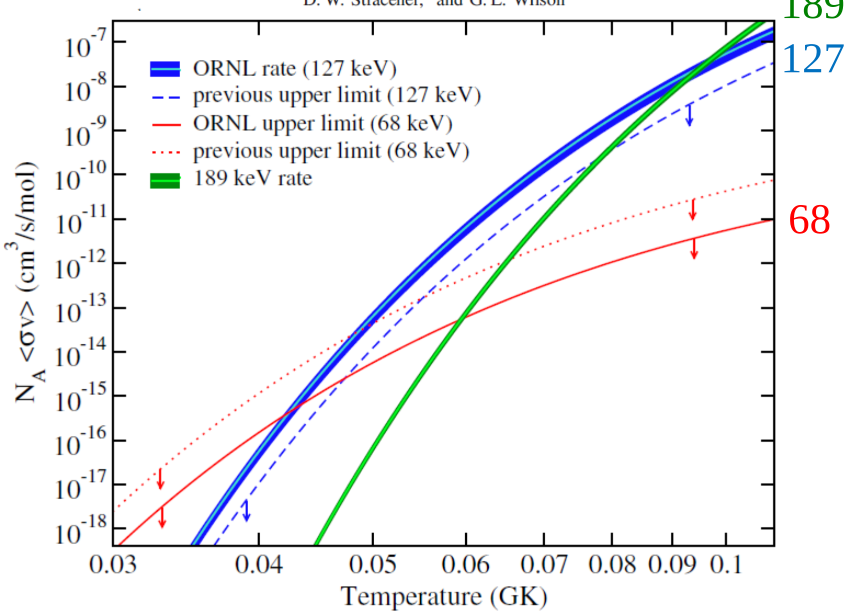

PRL 115, 062701 (2015) PHYSICAL REVIEW LETTERS week ending 7 AUGUST 2015

Inverse Kinematic Study of the $^{26g}Al(d,p)^{27}Al$ Reaction and Implications for Destruction of ^{26}Al in Wolf-Rayet and Asymptotic Giant Branch Stars

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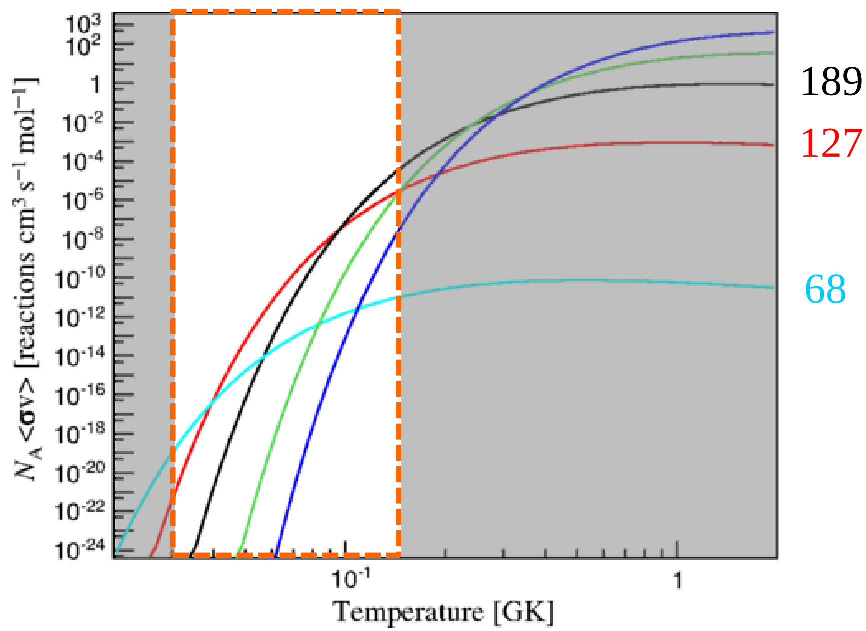
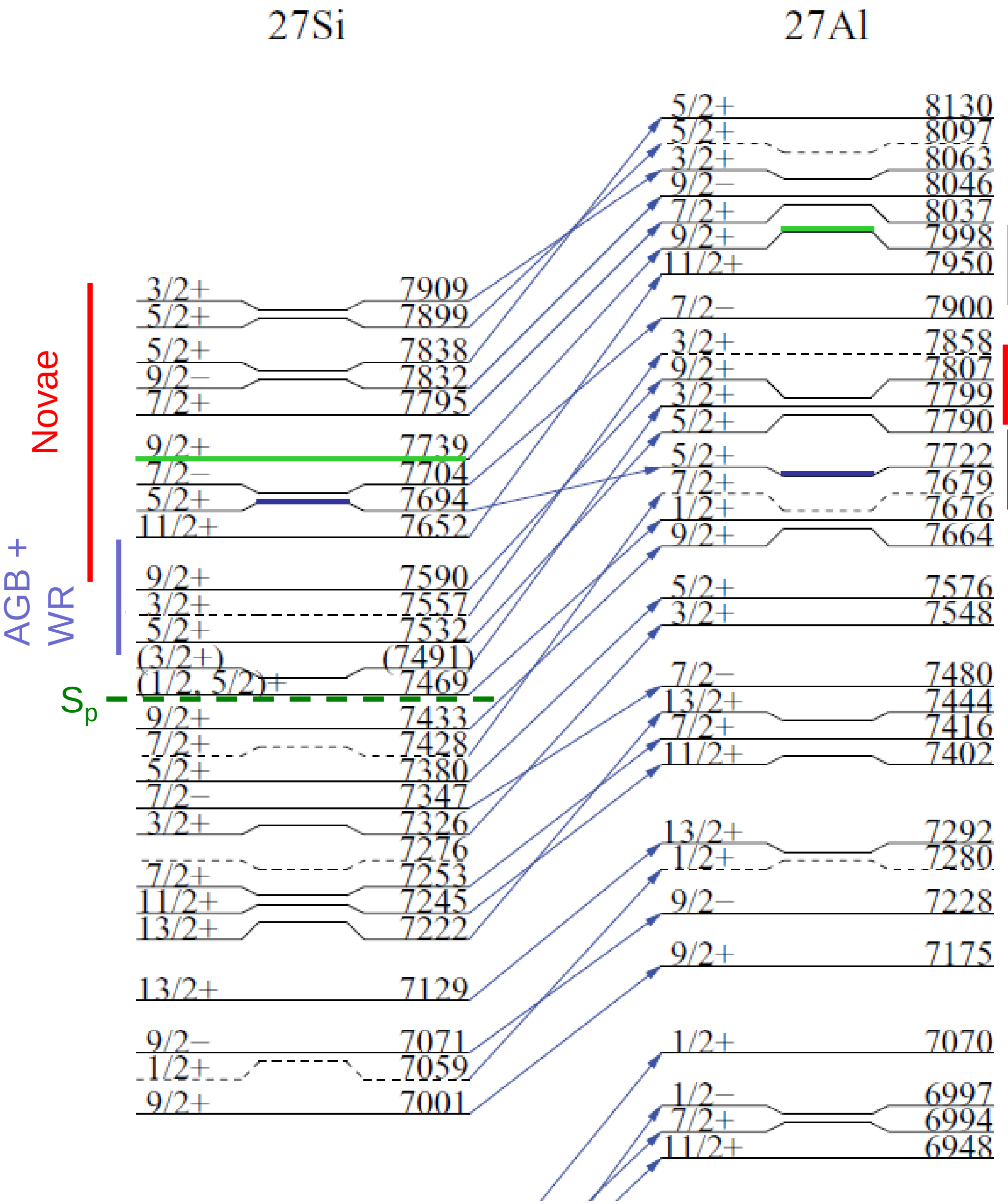


	C^2S	ωγ (μeV)	C^2S	ωγ (μeV)
68-keV	< 0.053	< 3.1e-9	< 0.016 *	< 0.8e-9
127-keV	0.0085(30)	0.026(7)	0.0093(19)	0.025(5)

* 0.068(14) 20% mirror uncertainty

Cross checks on other resonances – 231 keV and 189 keV



189 keV resonance

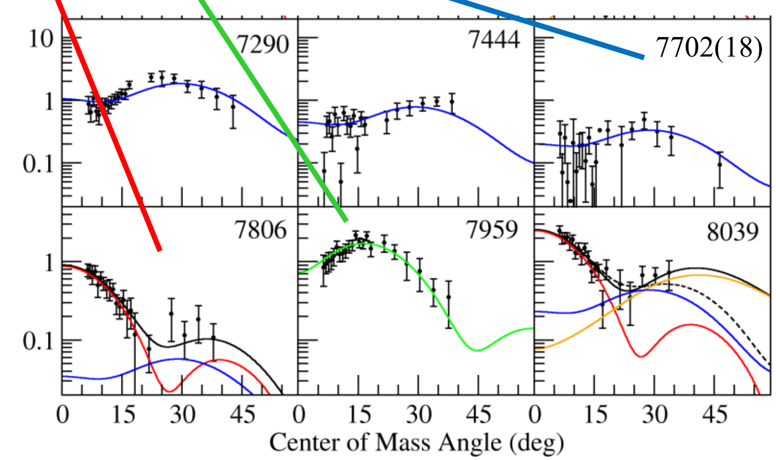
Direct measurement (p,γ):
ωγ = 0.055(9), 0.035(7) meV

Current data (d,p): C^2S = 0.056(5) ($2p_{3/2}$)
ωγ = 0.040(10) meV

231 keV resonance

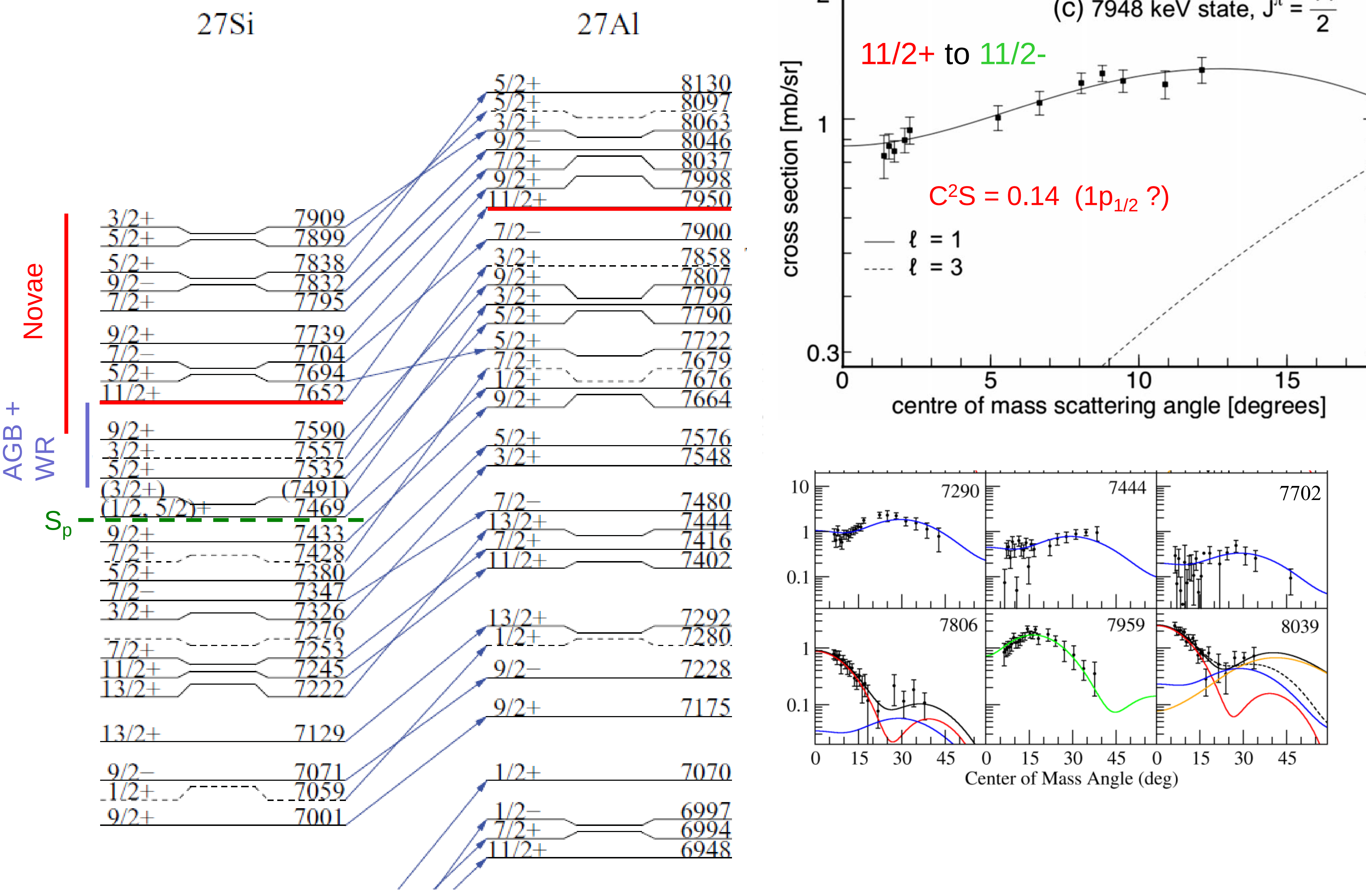
Direct measurement (p,γ):
ωγ < 0.040 (calorimetry), < 0.010 (branching ratio assumption) meV [*Vogelaar thesis*]

Current data (d,p): C^2S = 0.17(5) ($1d_{3/2}$)
ωγ = 0.019(6)



Other astrophysically-interesting states – parity of 189 keV resonance

G. Lotay *et al*, **PRC 34** 035802 (2011)

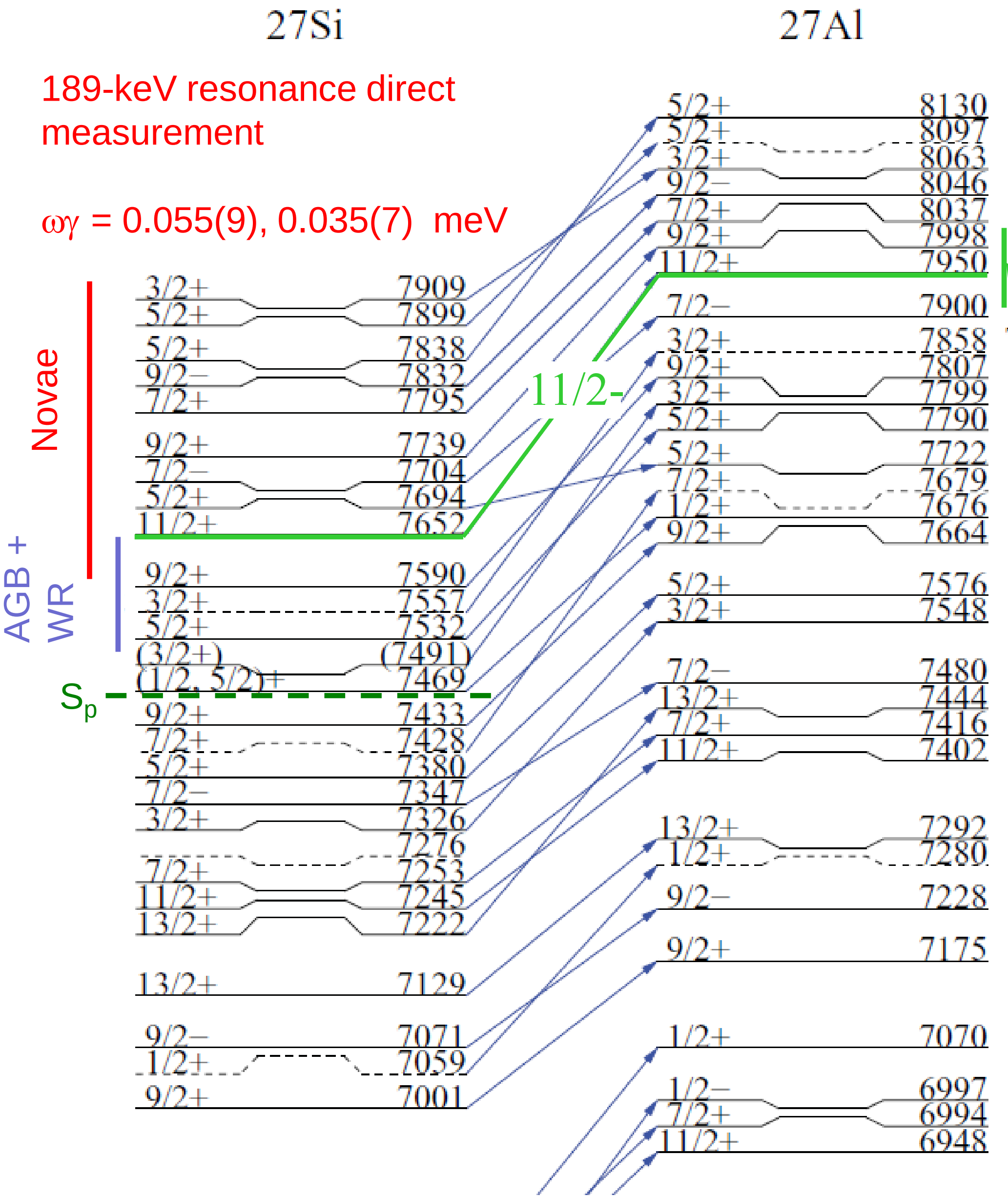


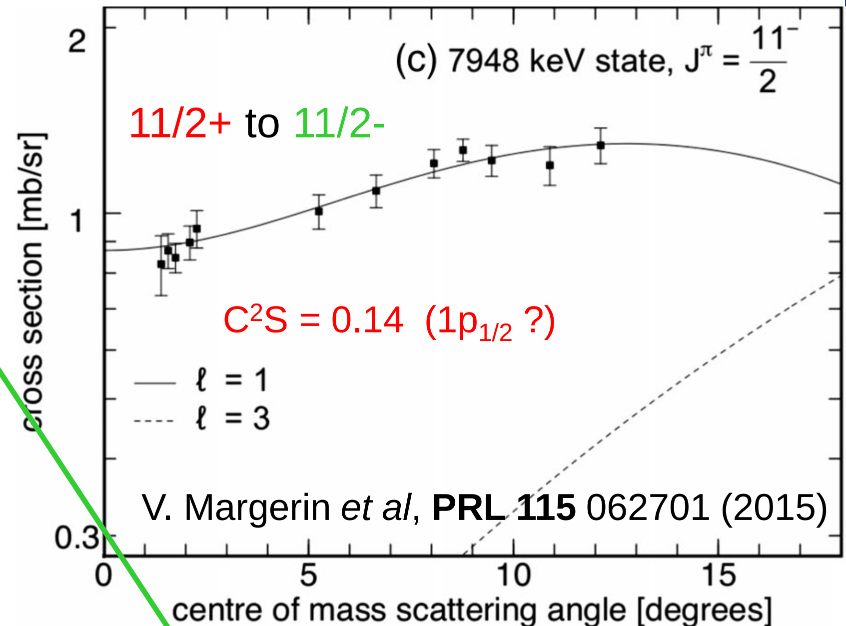
Other astrophysically-interesting states – parity of 189 keV resonance

G. Lotay *et al*, **PRC 34** 035802 (2011)

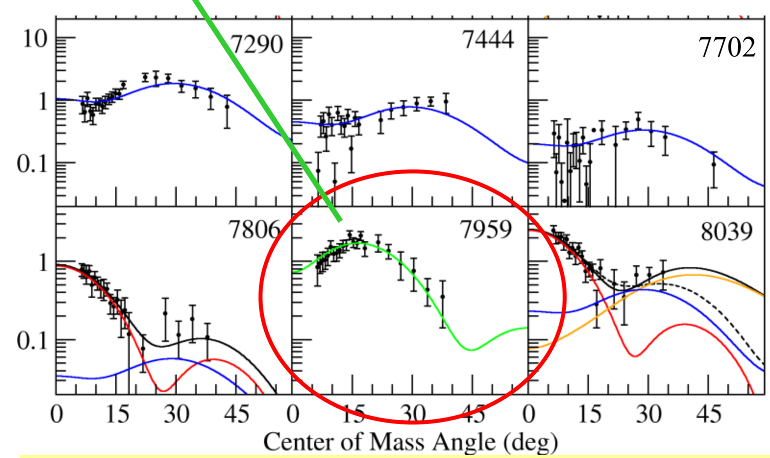
189-keV resonance direct measurement

$\omega\gamma$ = 0.055(9), 0.035(7) meV





V. Margerin *et al*, **PRL 115** 062701 (2015)

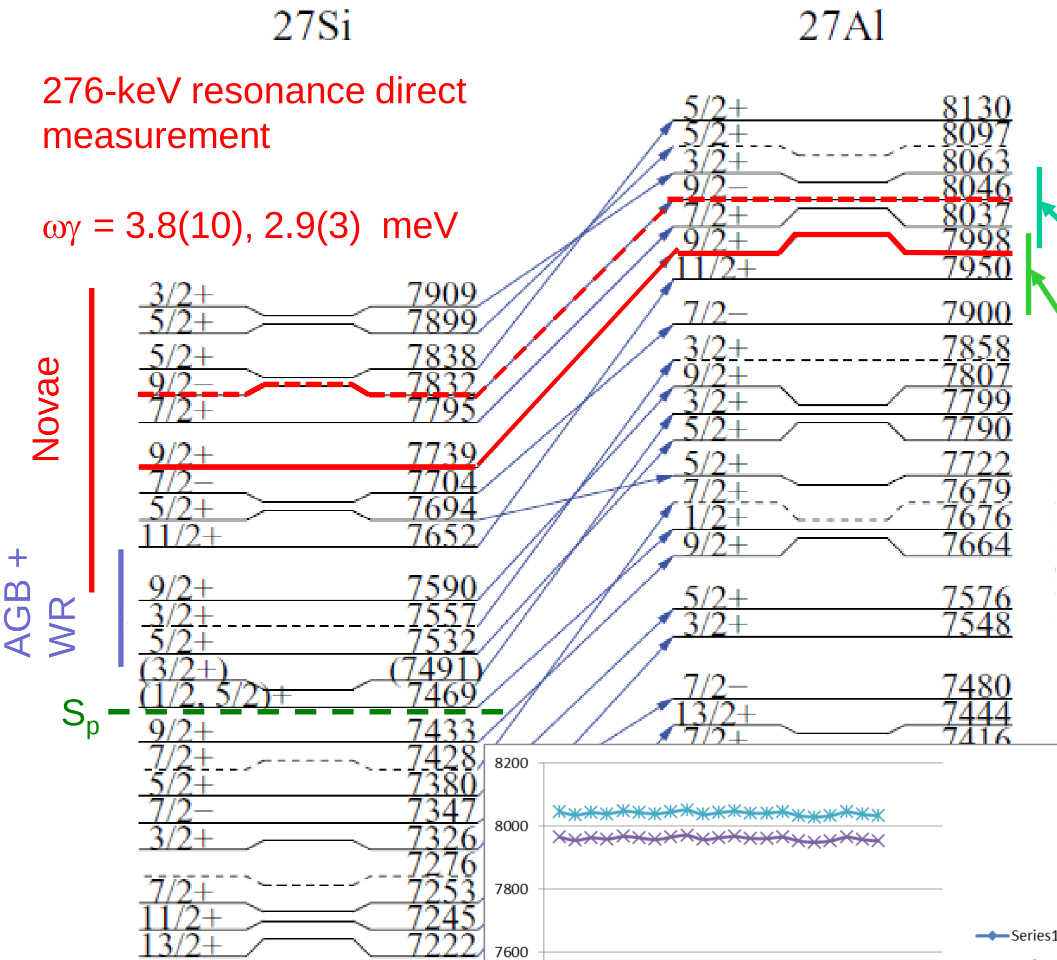


C^2S = 0.056 ($2p_{3/2}$) **$\omega\gamma$ = 0.040(10) meV**

Or C^2S = 0.166 ($1p_{1/2}$) $\omega\gamma$ = 0.114(30) meV

(preliminary) Speculation on 276 keV resonance

G. Lotay *et al*, **PRC 34** 035802 (2011)



A. Kankainen *et al*., **Eur. Phys. J. A 52** (2016) 6

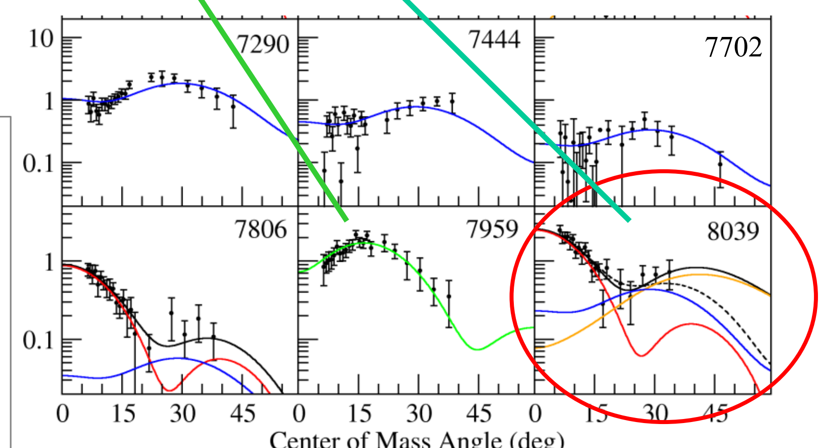
Could the 9/2+ be 9/2-?

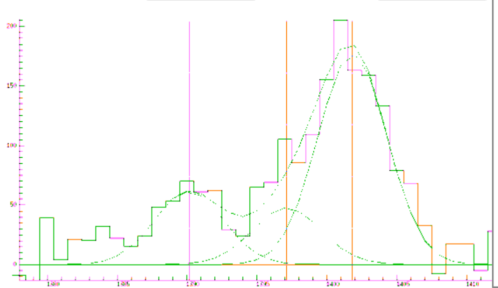
Argument based on integrated ^{26}Al(d,n) cross section and SM predictions (s=d)

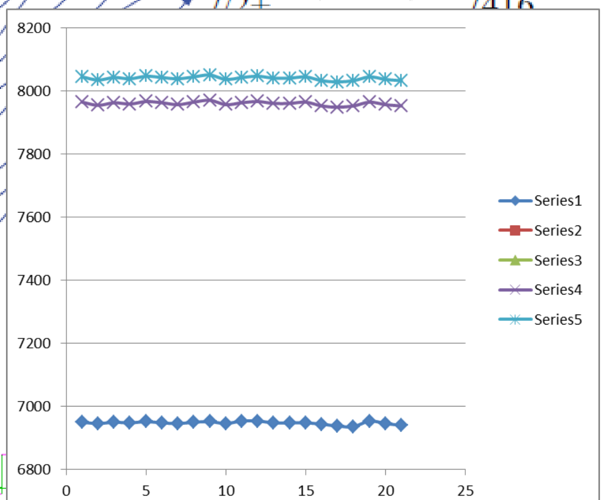
Data require: $C^2S = 0.02$ ($2s_{1/2}$)

$C^2S = 0.1$ ($1d_{3/2}$)

And could the 9/2- be a 9/2+?







$C^2S = 0.030$ ($2s_{1/2}$) **ωγ = 5.3(15) meV**

$C^2S = 0.177$ ($1d_{3/2}$)

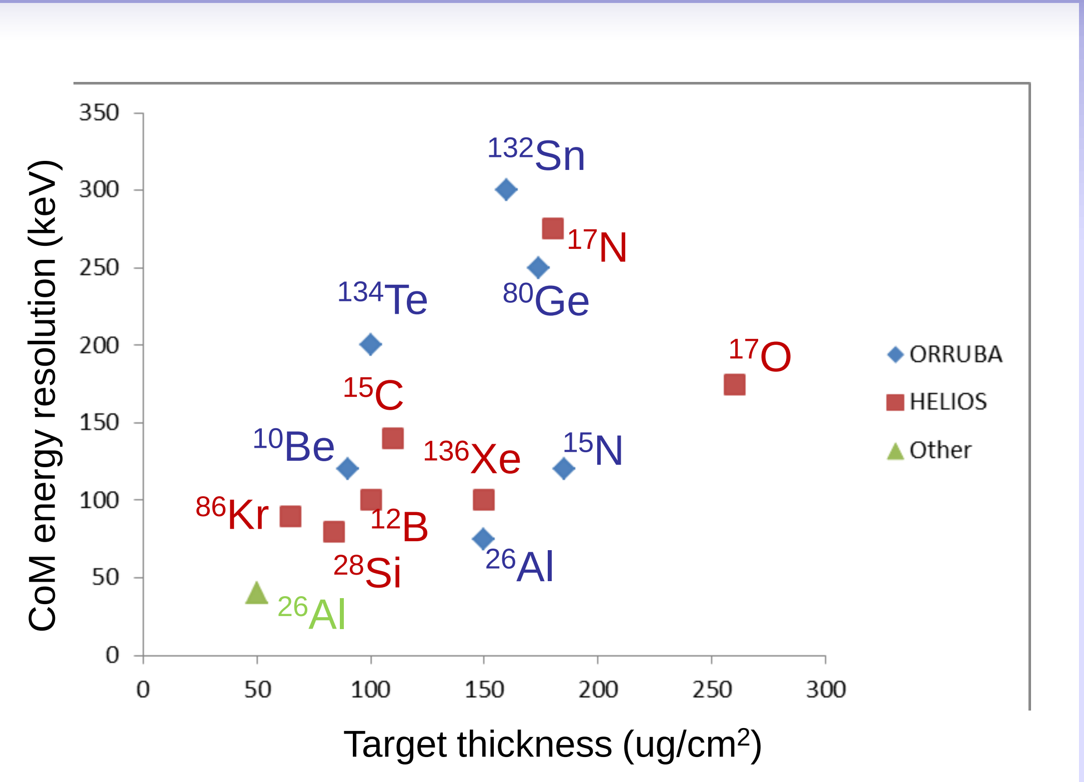
Summary

- ^{26}Al extremely well-studied astronomical signature (first detected radioisotope, first Galactic map)
- Low lying resonances for the ^{26}Al(p,γ)^{27}Si destruction mechanism (massive stars) poorly constrained
- Measured single-particle SFs of mirror levels via ^{26}Al(d,p) for constraining stellar reaction rate
  - 127-keV resonance strength constrained, ~4 times stronger than previously adopted upper limit
  - First experimentally-derived upper limit for 68 keV resonance (order of magnitude reduction)
  - 127-keV resonance dominates at temperatures for massive stars
  - Excellent agreement with Edinburgh/TRIUMF result
  - Support the reassignment of 189 keV resonance to negative parity
  - Evidence that 276 keV resonance maintains 9/2+ assignment (or mis-assignment of 7832 (^{27}Si) and 8046 (^{27}Al) keV pair
- Really want gamma rays in (d,p) measurement

What factors really affect a (d,p) measurement?

Issues affecting transfer measurements in inverse kinematics

- Resolution
  - Detector
    - Energy resolution
    - Position resolution
  - Target
    - Thickness
  - Beam
    - Emittance
    - Energy resolution
    - Energy (particle energy, KCF)
    - Mass (kinematic compression)
  - Physics
    - Q value (kinematic compression)



Plot doesn't imply that target thickness (or any other factor) is directly dominant, but carries with it a number of correlated factors (eg some rad beams have worse emittance, but also are weaker, so need thicker targets)

In some cases, kinematic compression dominates, but not always

Kinematic compression

Inverse kinematics results in a transformation between CoM and Lab systems, affecting the apparent separation of states in the lab system

Define Kinematic Compression Factor (KCF)

The separation in laboratory energy, at 180 deg in the lab (0 deg CoM), between two states that are separated by 1 MeV in the CoM system

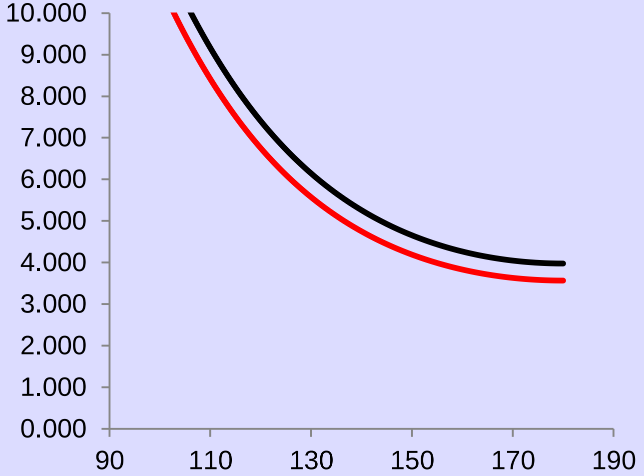
(Does change with angle)

Essentially the multiplicative factor telling you how your *detector* resolution will appear in the CoM

- Larger than 1 ☹
- Less than 1 ☺

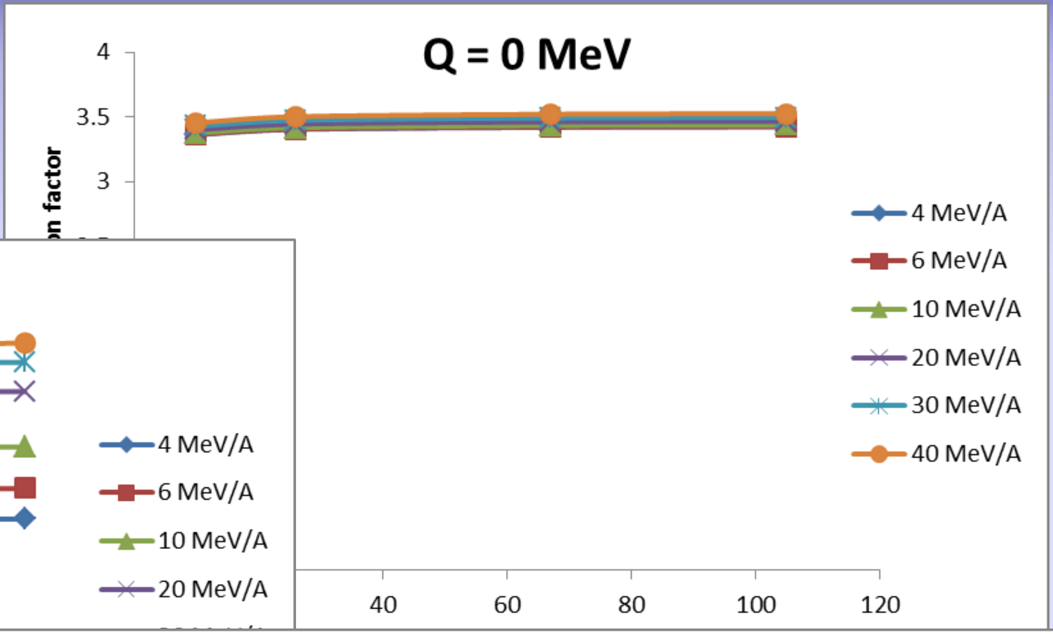
For (d,p) reactions in inverse kinematics, typically ~3

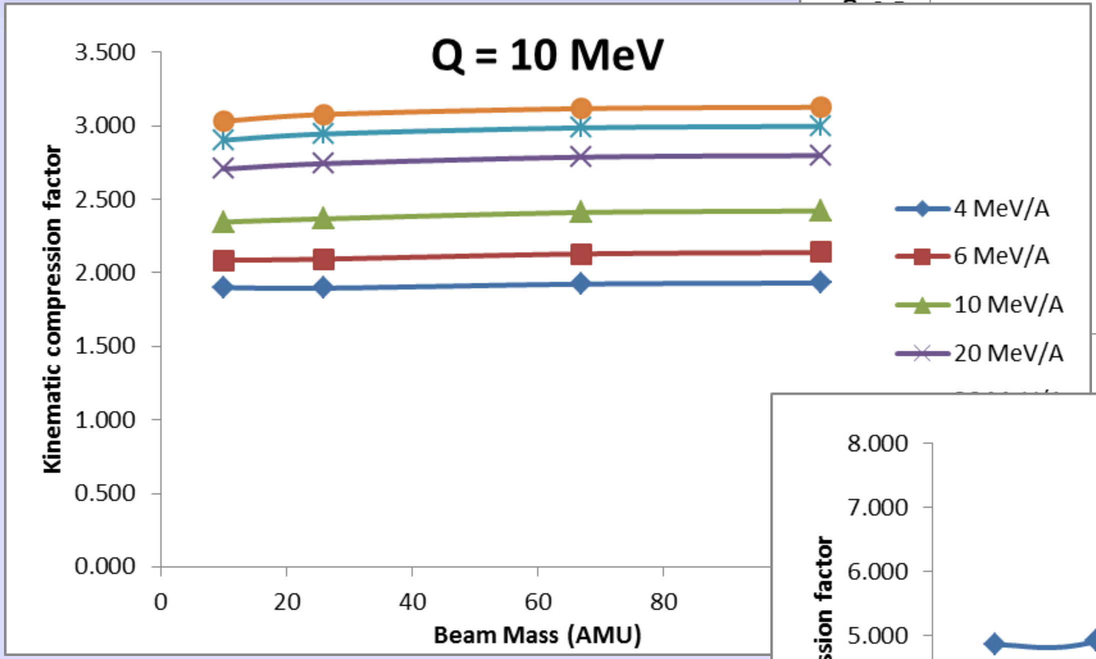
What does it depend on, and how strongly?

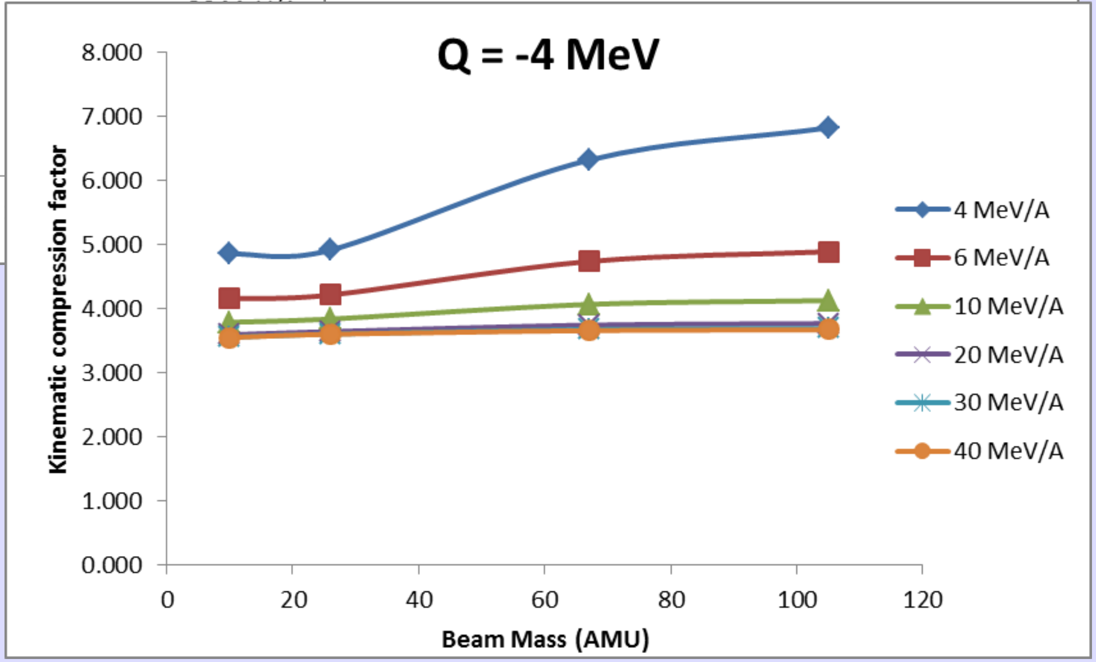


Kinematic compression

Mass?

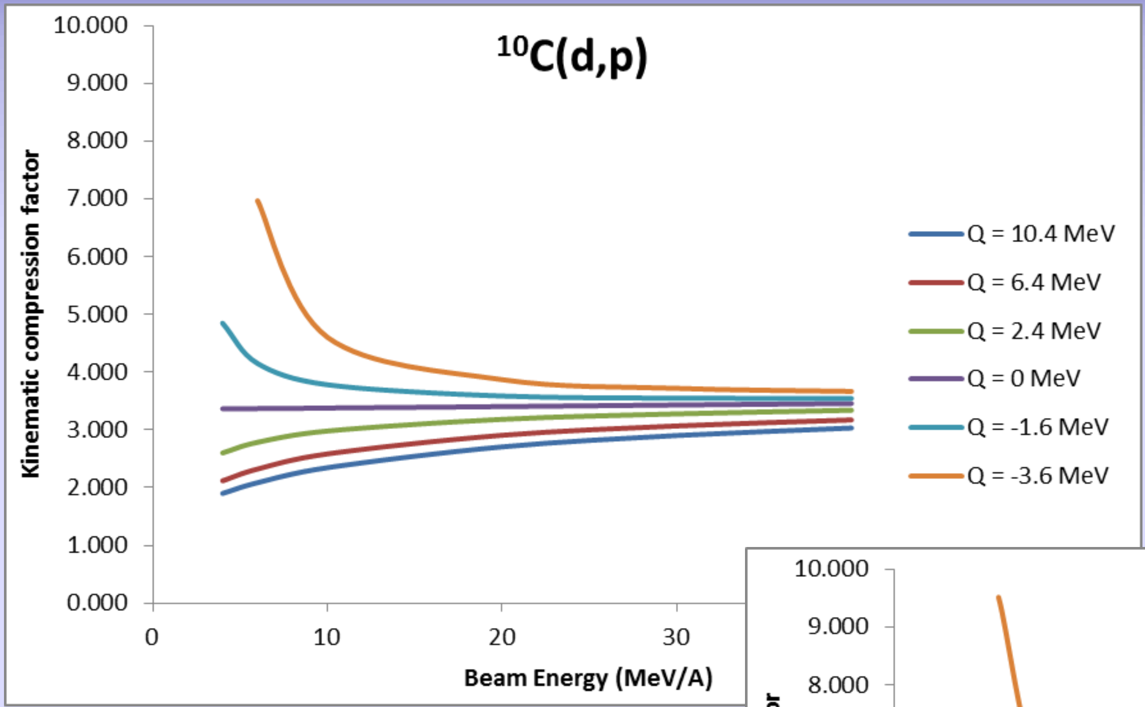




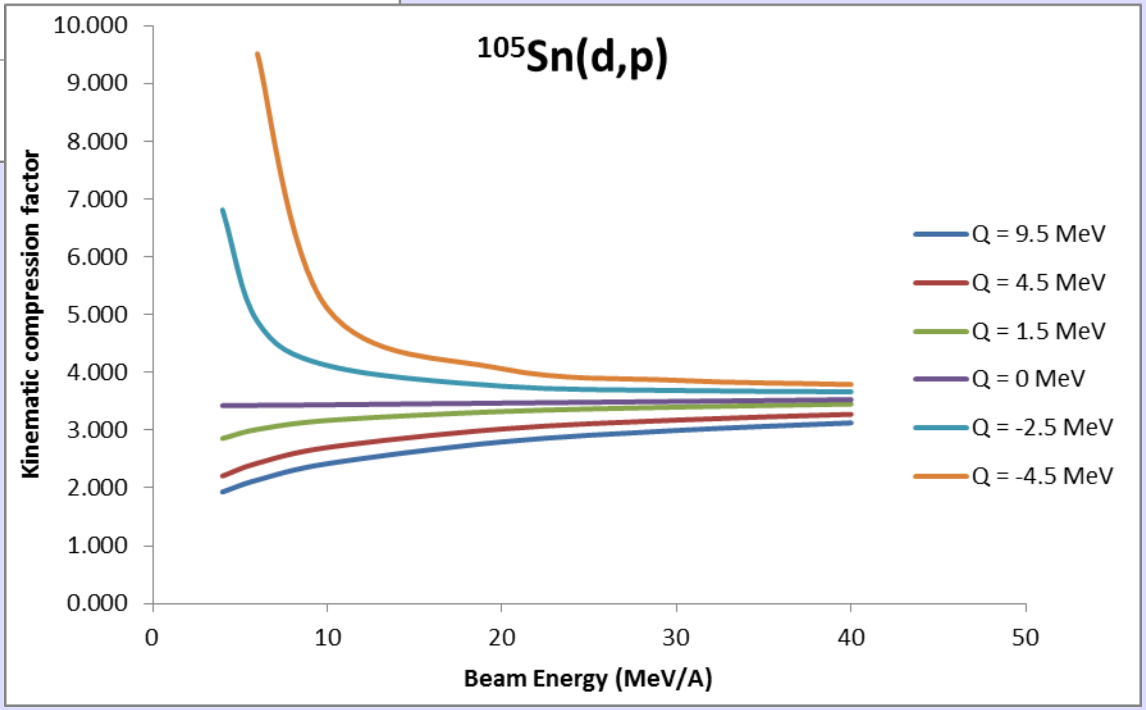


- Not directly (unless at low energy)
- Indirectly, via Q value, however…

Kinematic compression

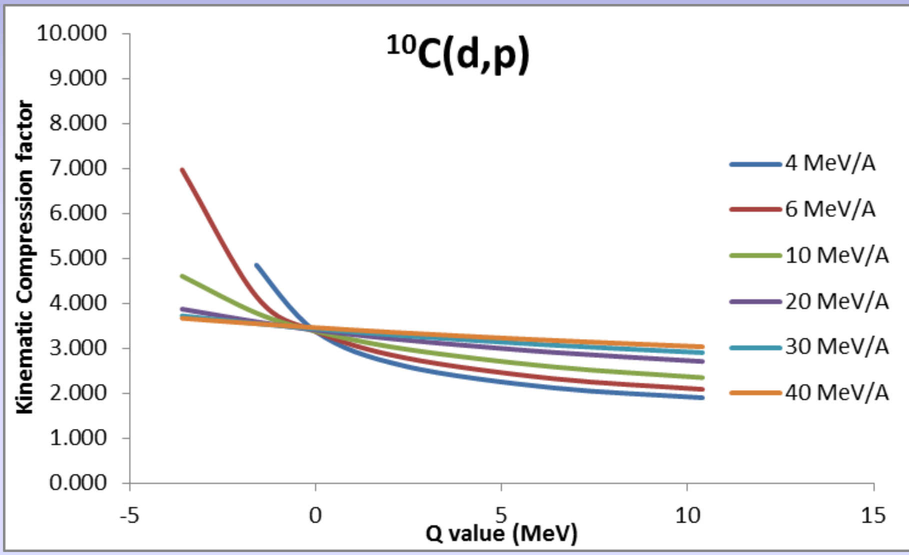


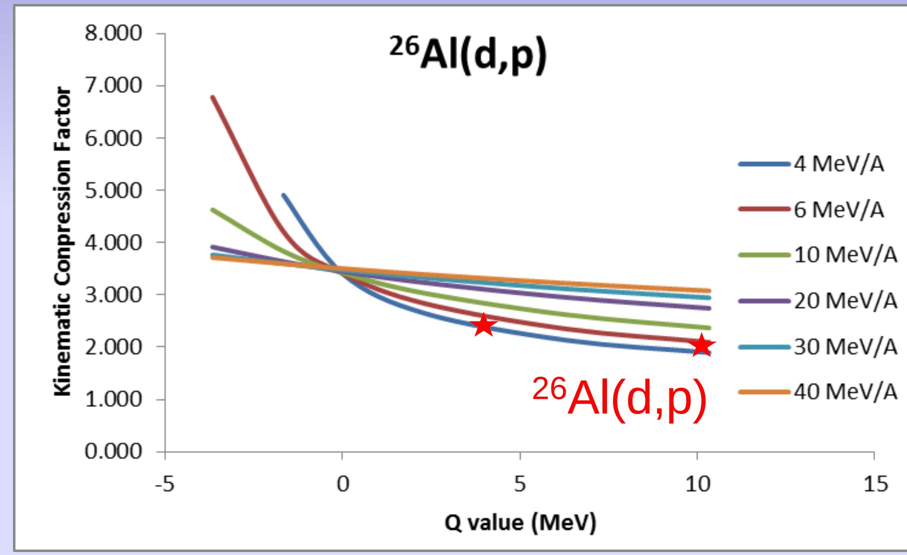
Beam energy and Q value

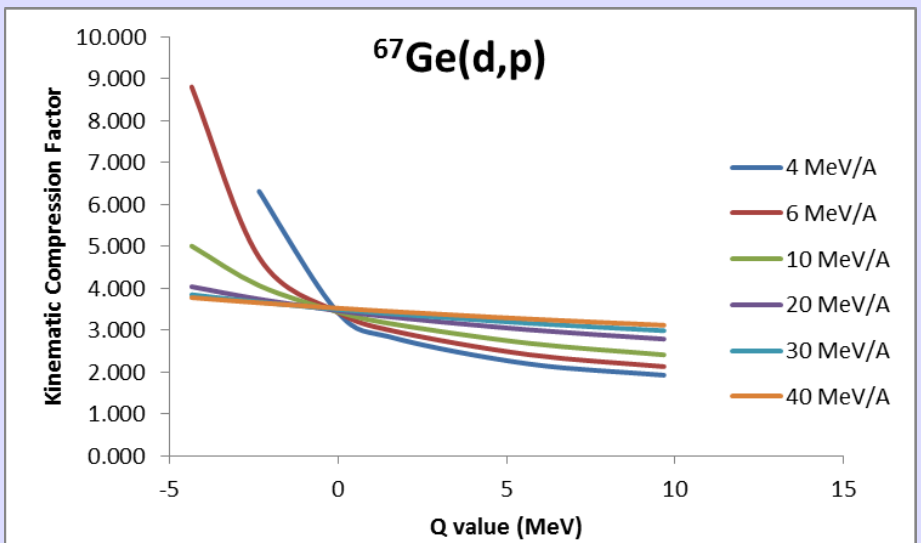


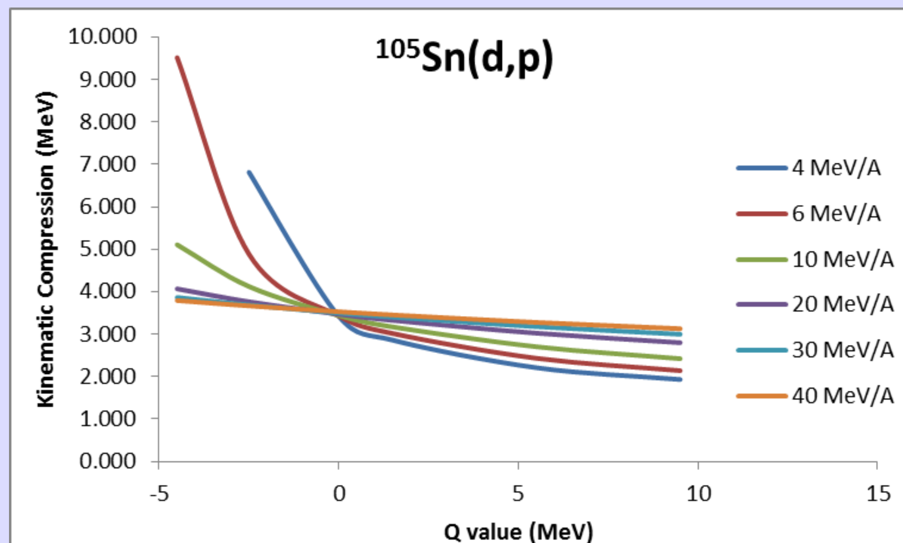
- Increasing beam energy results in a convergence (reduction in the dependence on Q value)

Kinematic compression

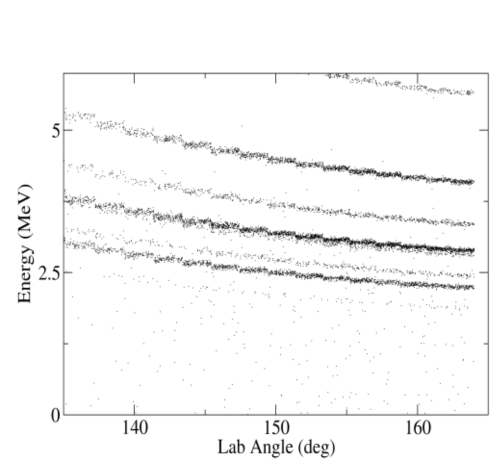


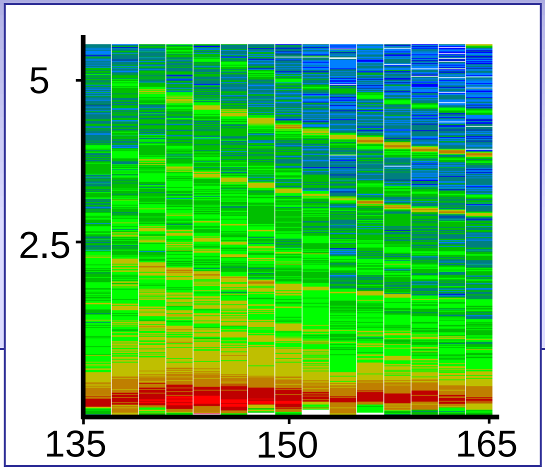


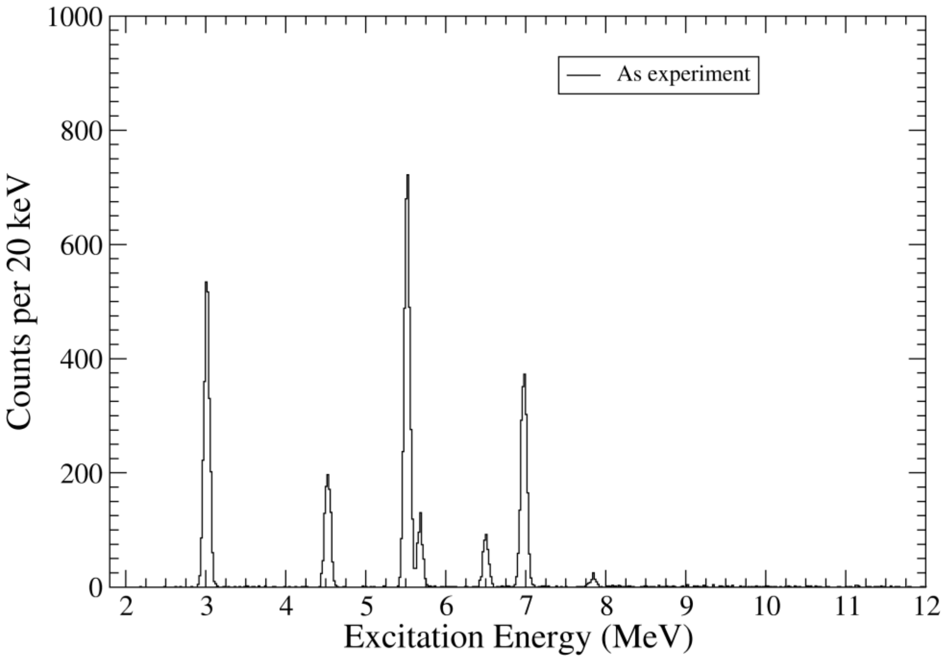


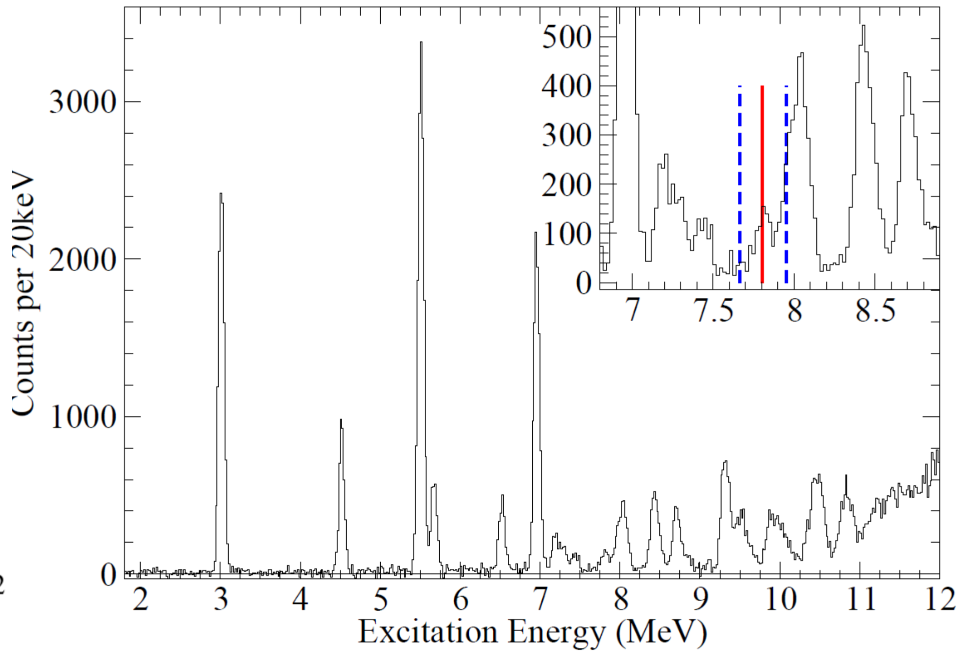


Factors affecting $^{26}Al(d,p)^{27}Al$ resolution









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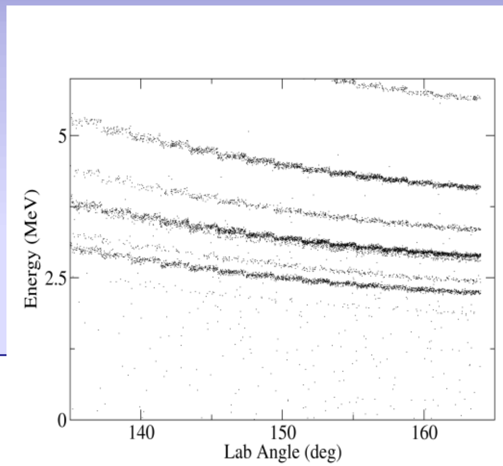

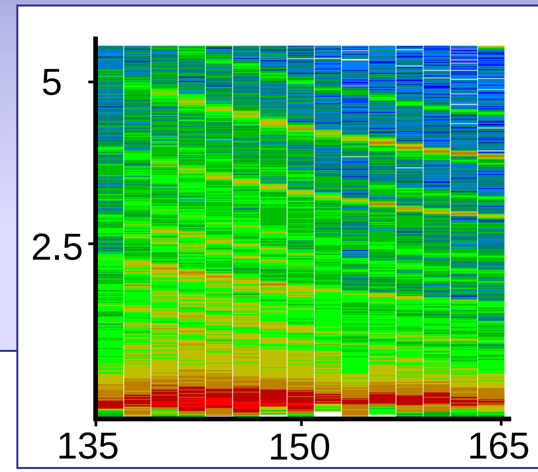

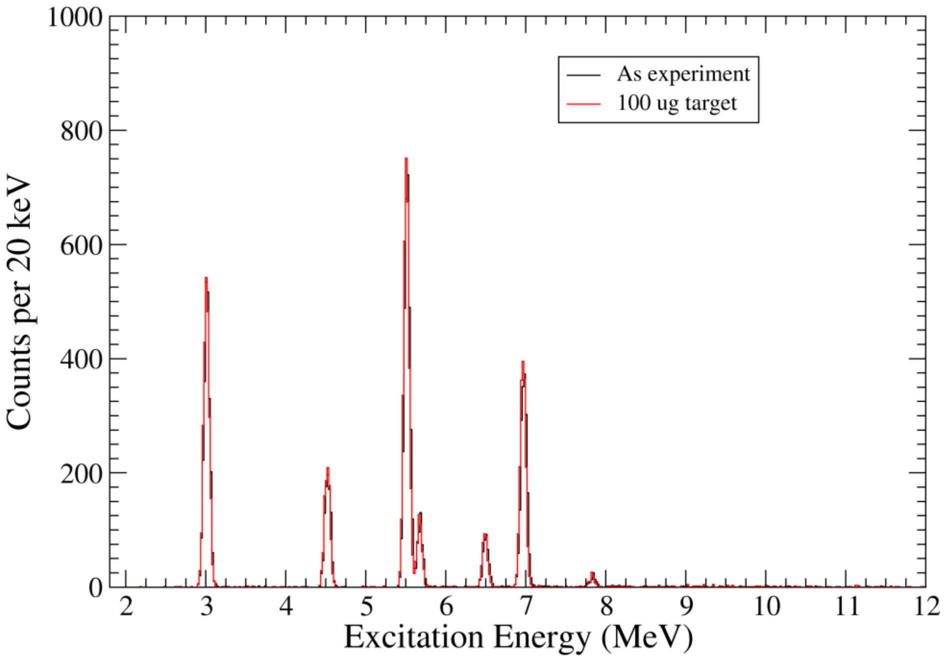

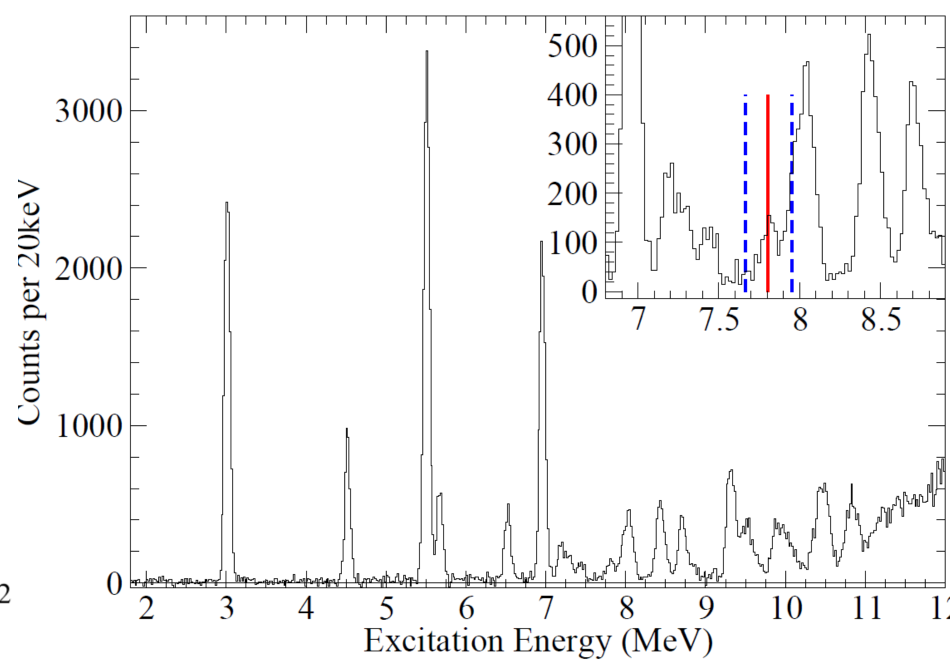

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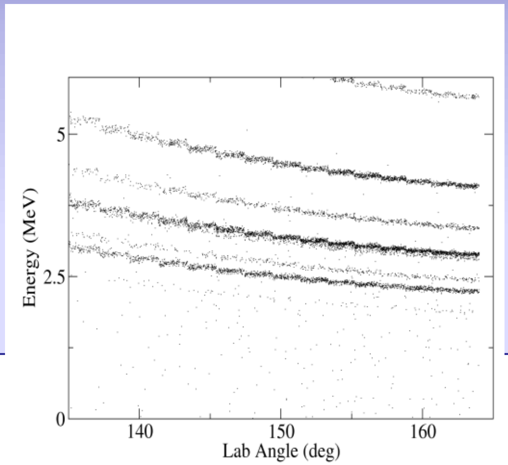

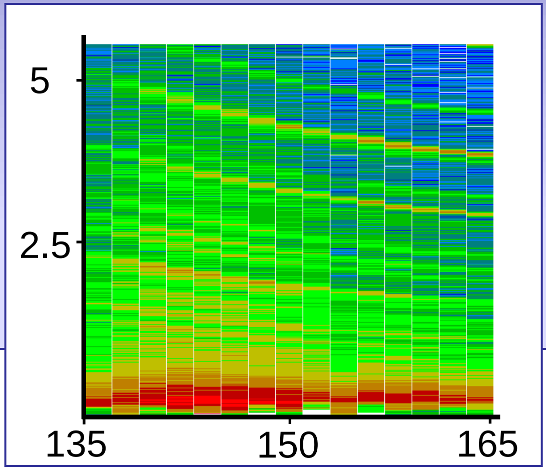

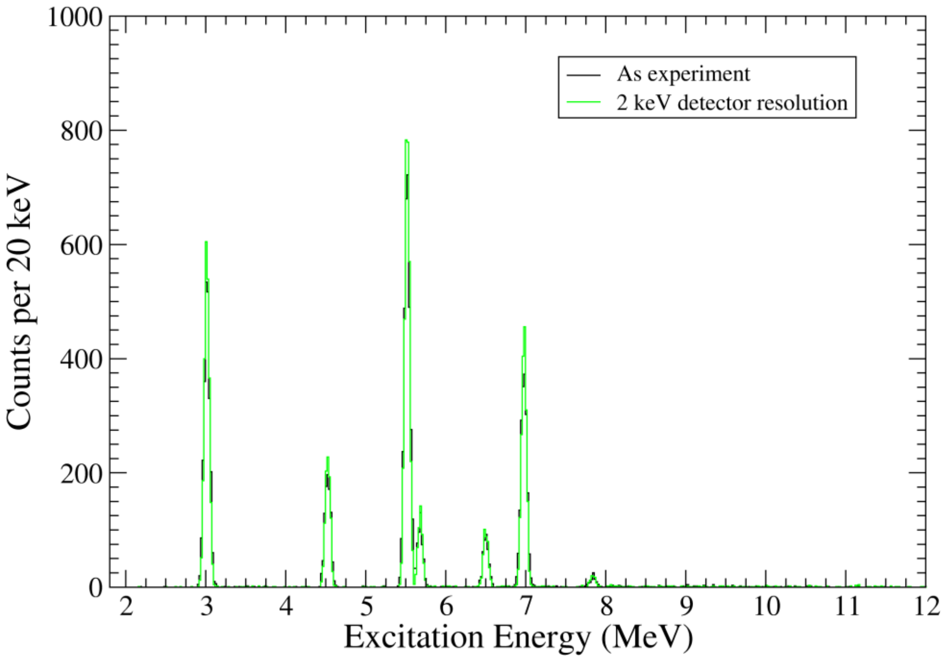

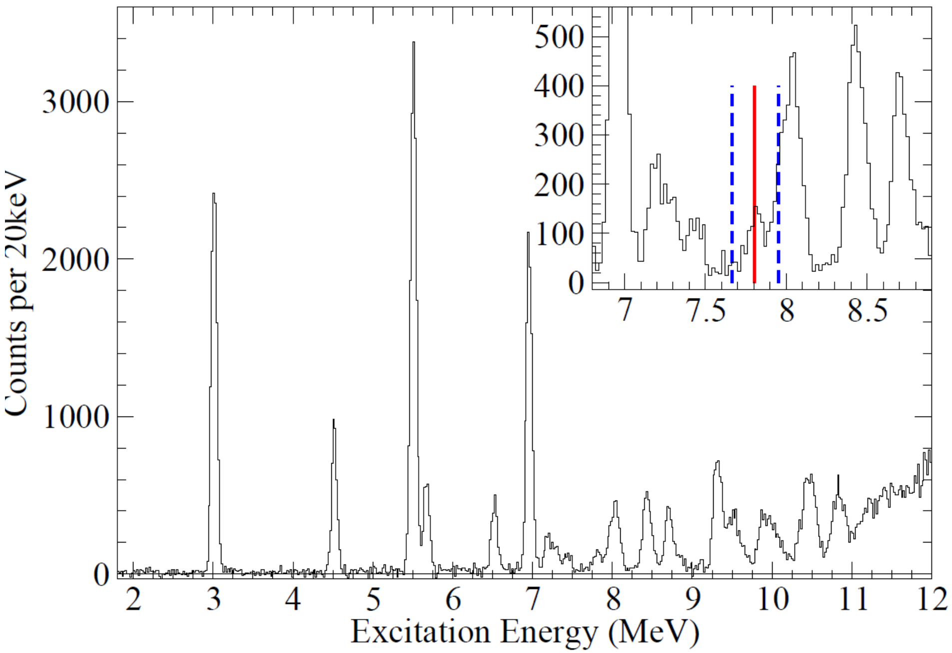

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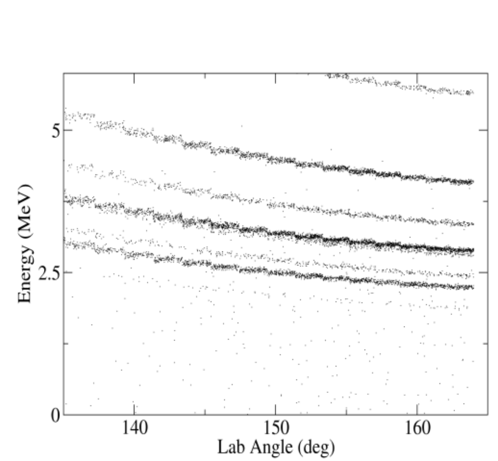
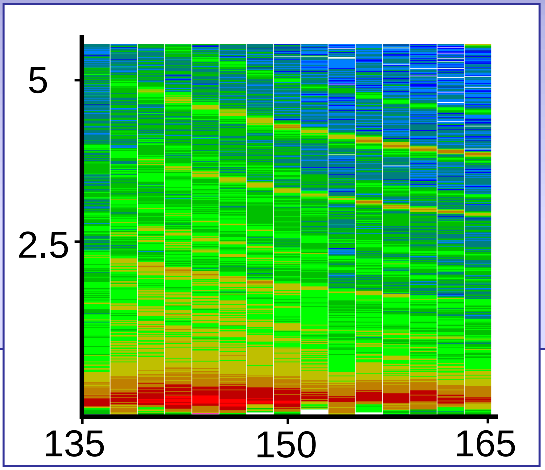
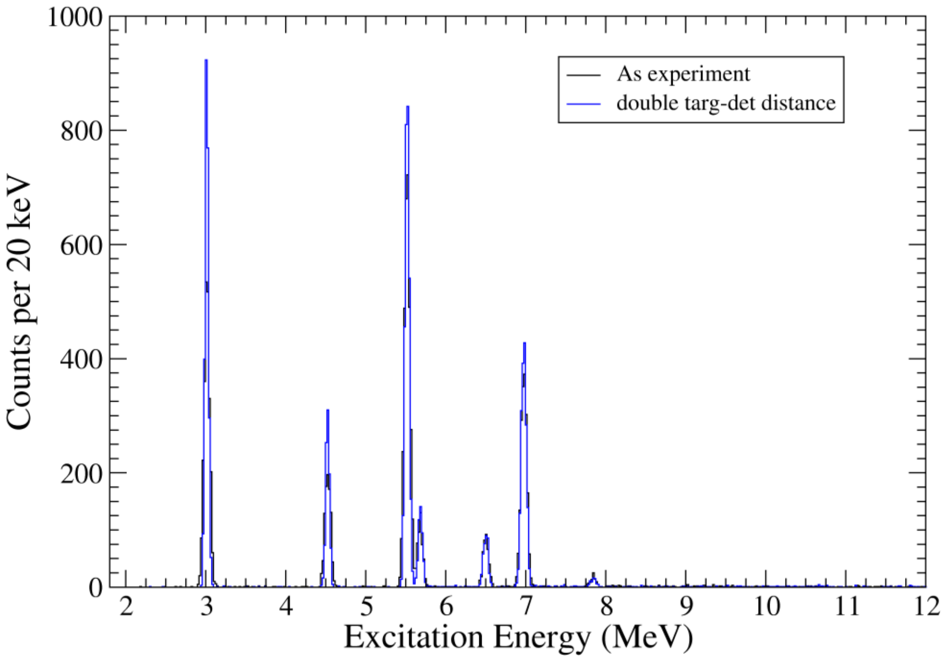
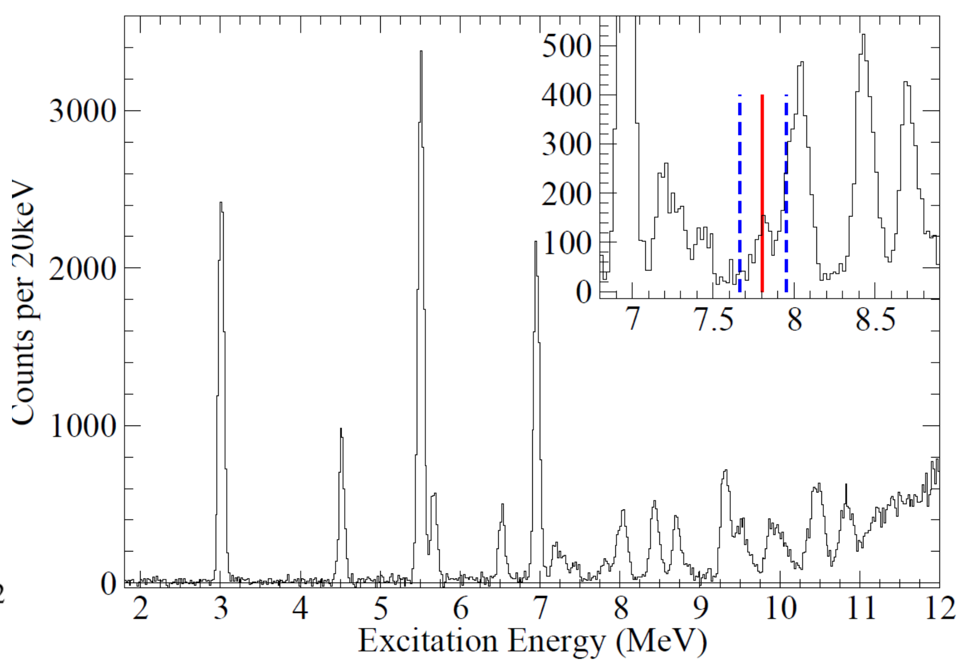
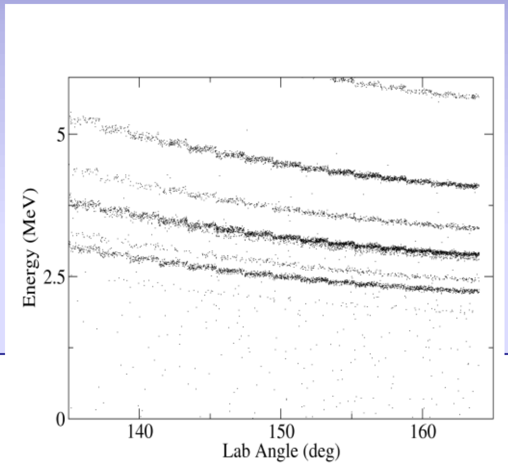


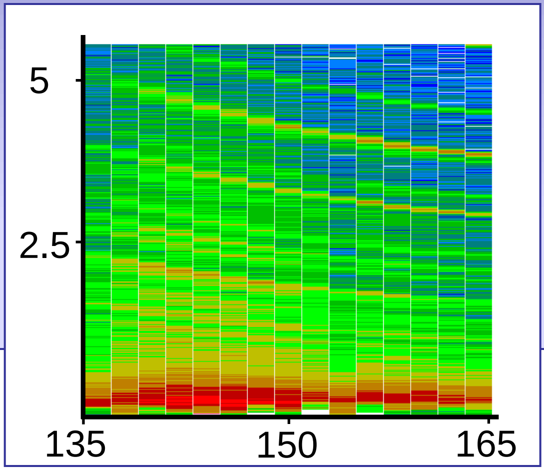


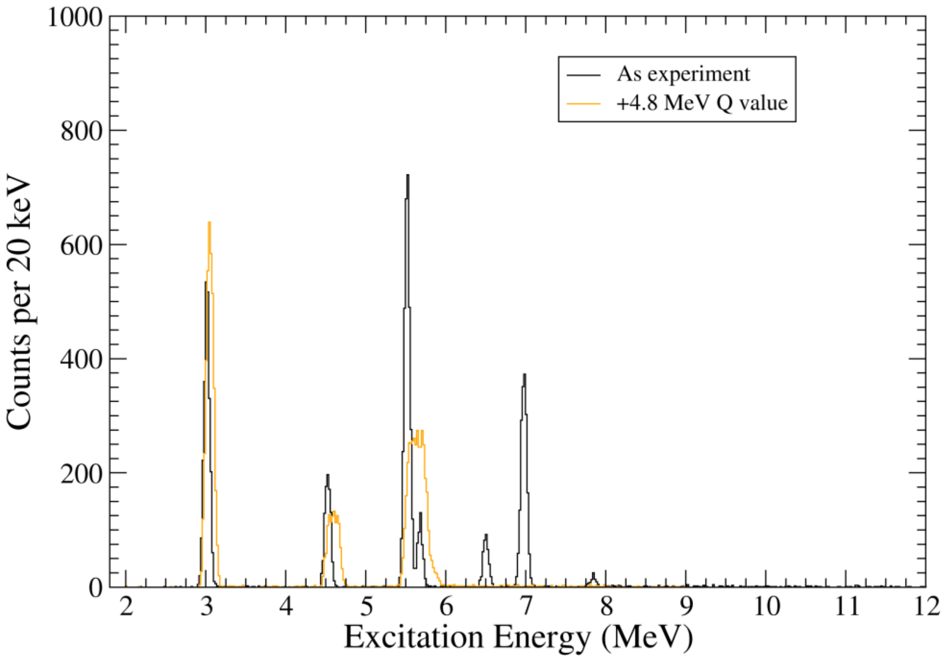


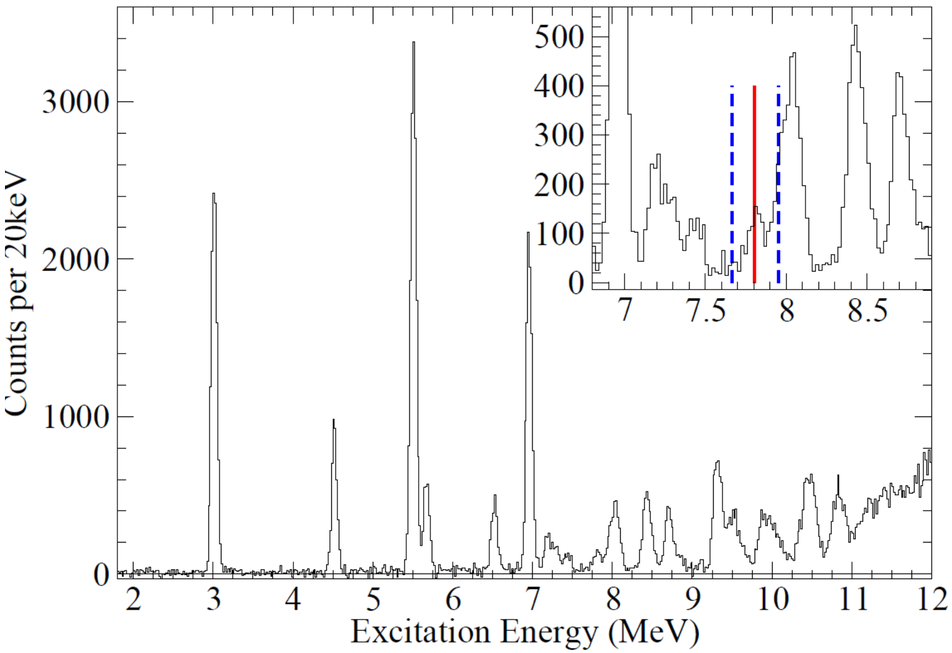


Factors affecting $^{26}Al(d,p)^{27}Al$ resolution

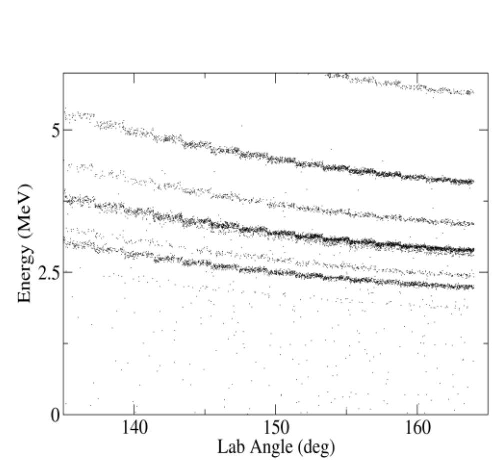


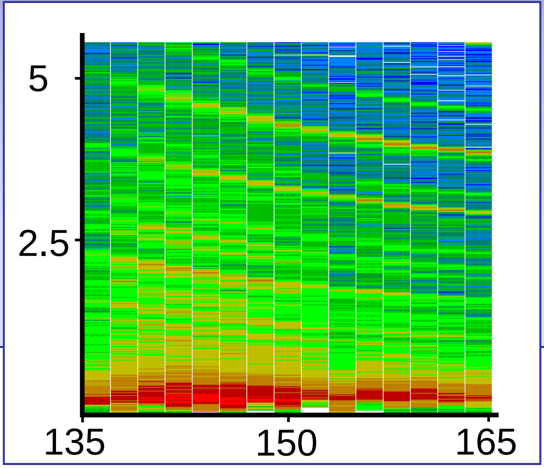


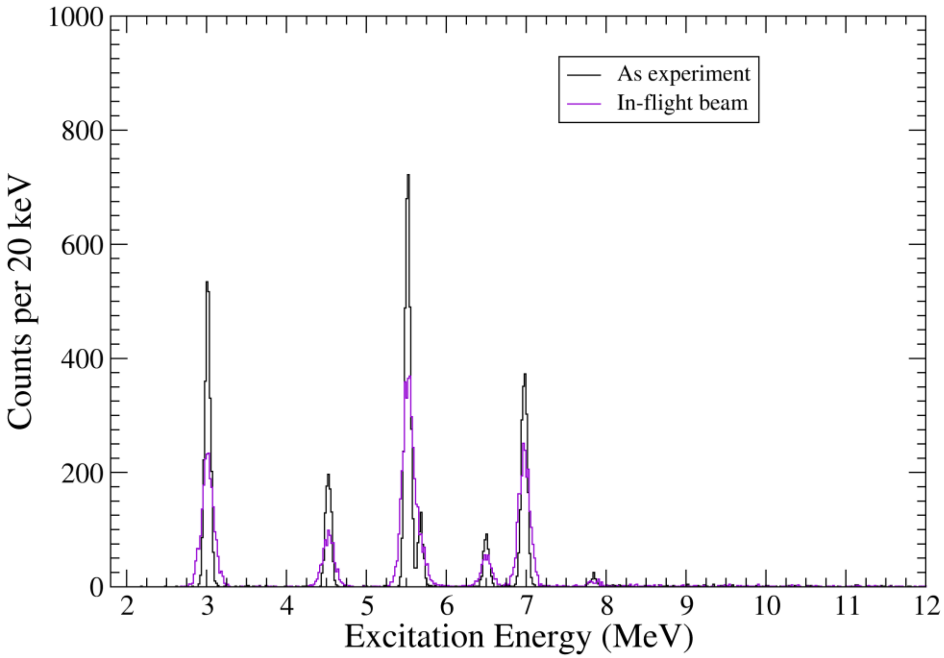


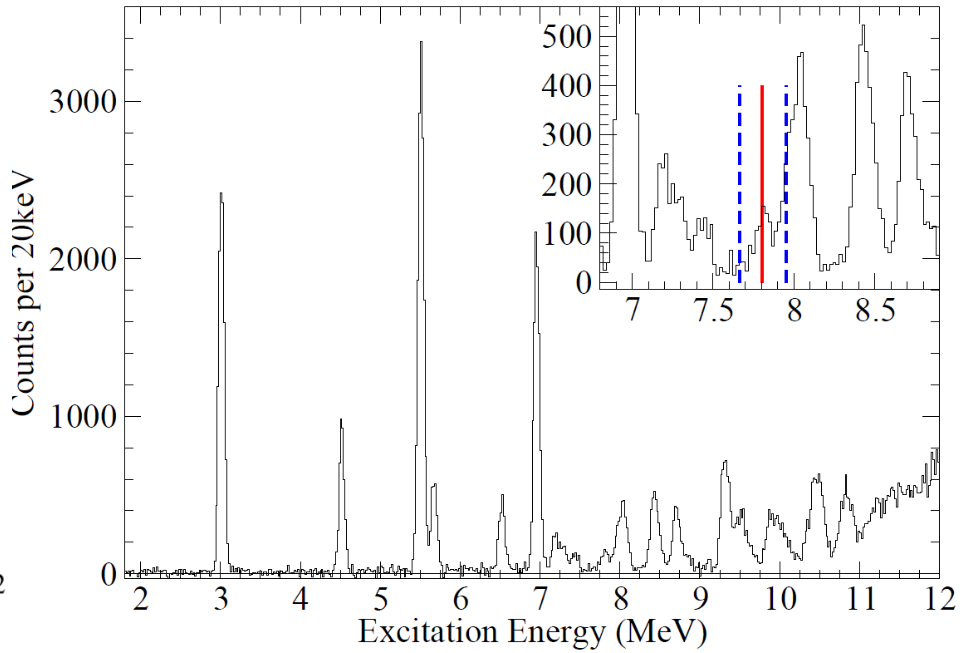


Factors affecting $^{26}Al(d,p)^{27}Al$ resolution



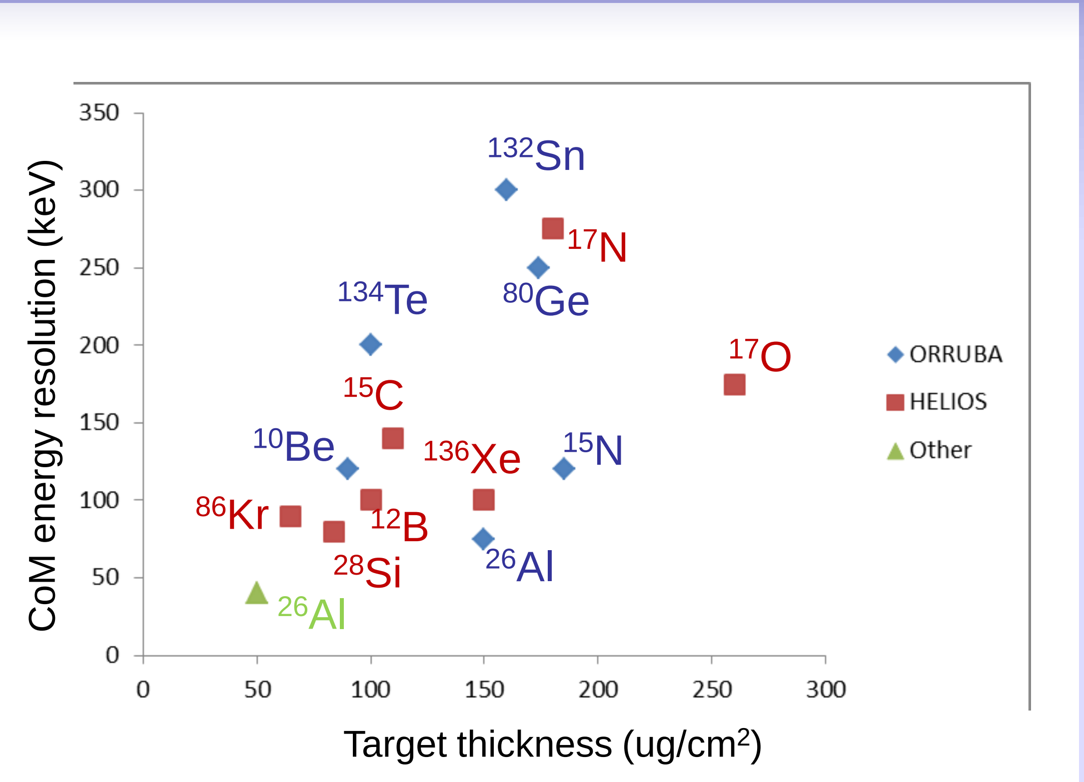






Issues affecting transfer measurements in inverse kinematics

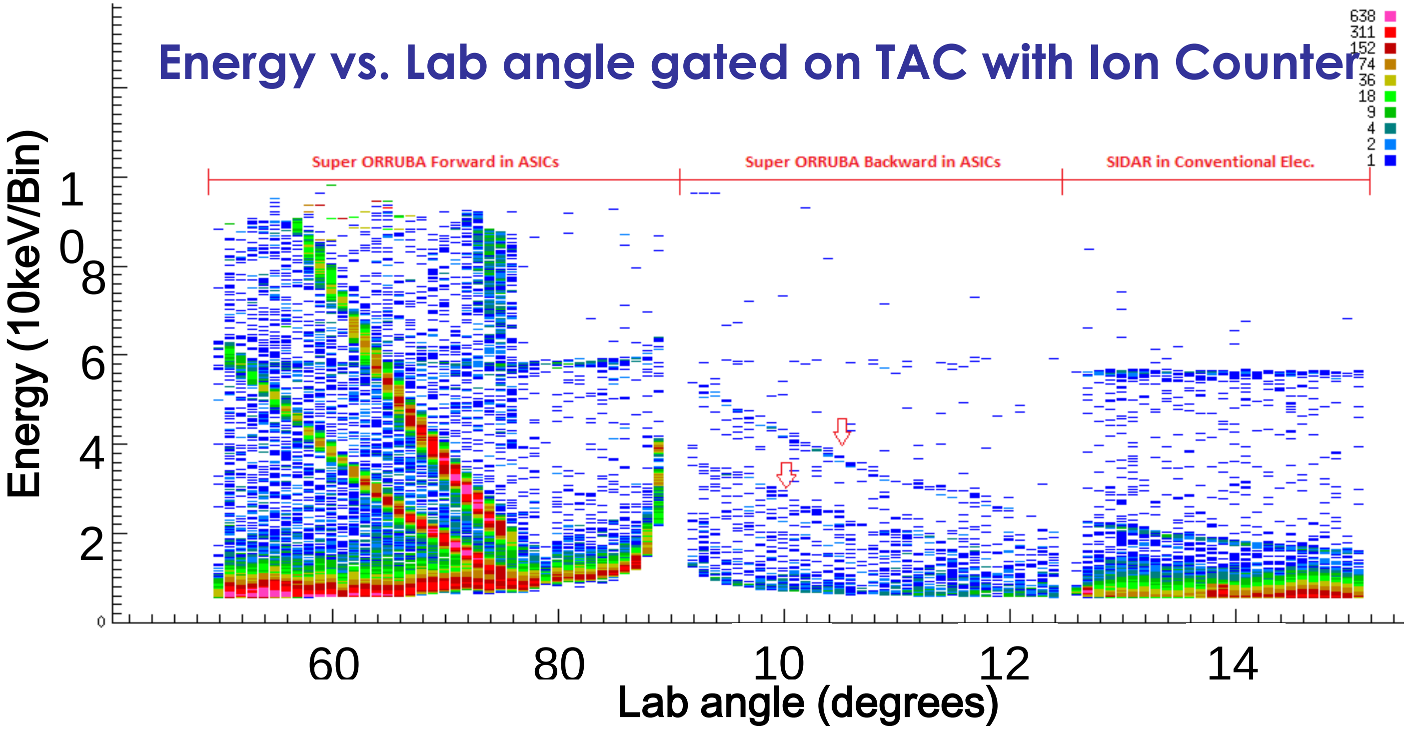
- Resolution
  - Detector
    - Energy resolution
    - Position resolution
  - Target
    - Thickness
  - Beam
    - Emittance
    - Energy resolution
    - Energy (particle energy, KCF)
    - Mass (kinematic compression)
  - Physics
    - Q value (kinematic compression)
- Statistics
  - Beam intensity
  - Target thickness
  - Detector efficiency
- Signal:background
  - Beam purity
  - Target purity
  - Detector performance
  - Physics



Plot doesn't imply that target thickness is directly the factor, but carries with it a number of correlated factors (eg rad beams have worse emittance, but also are weaker, so need thicker targets)

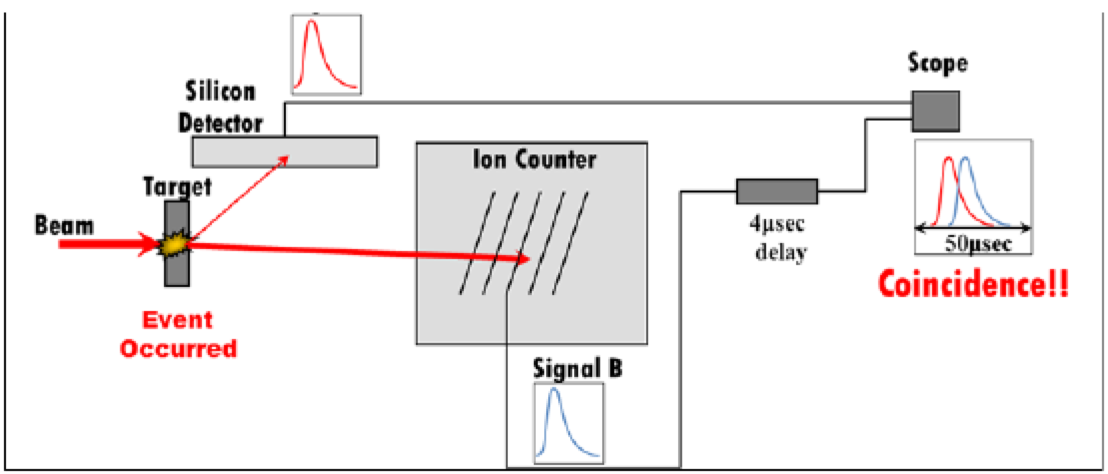
What about the beam?

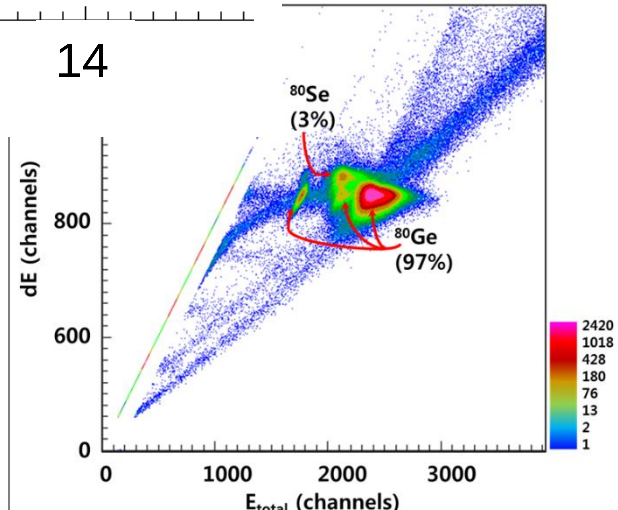
Mixed beams and tagging



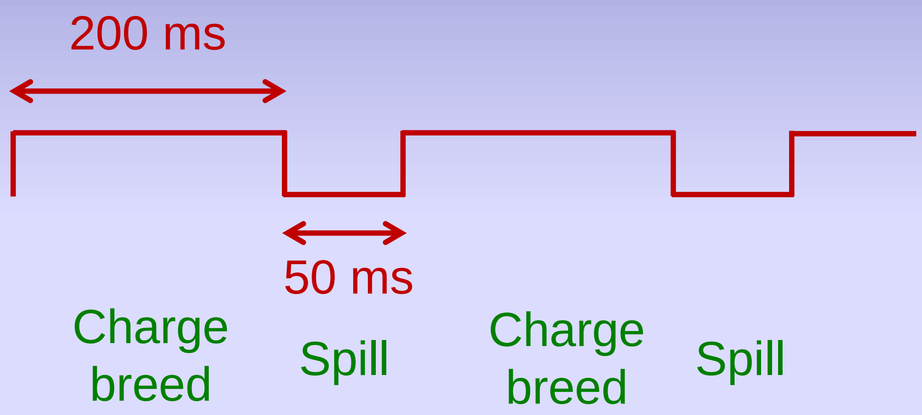
Beams are very often not pure

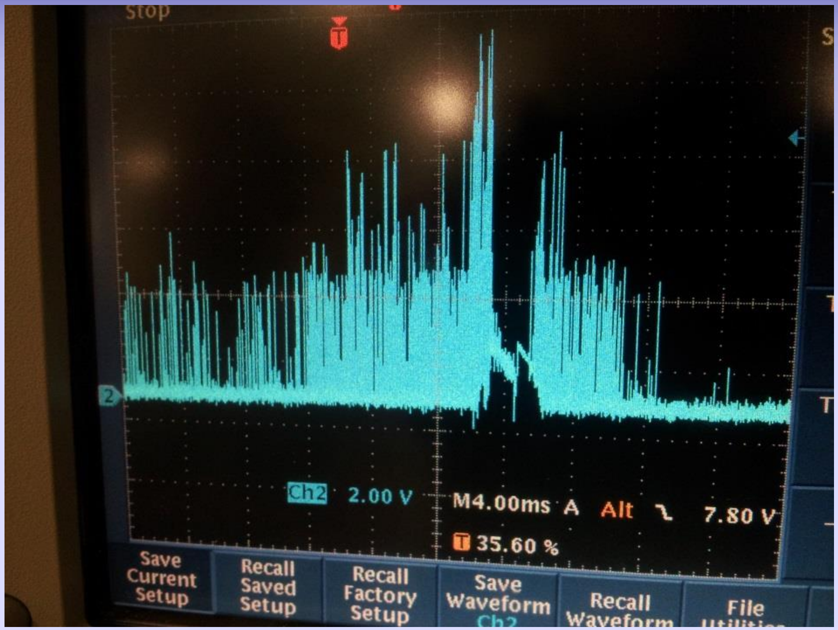
Need event-by-event coincidences and PID

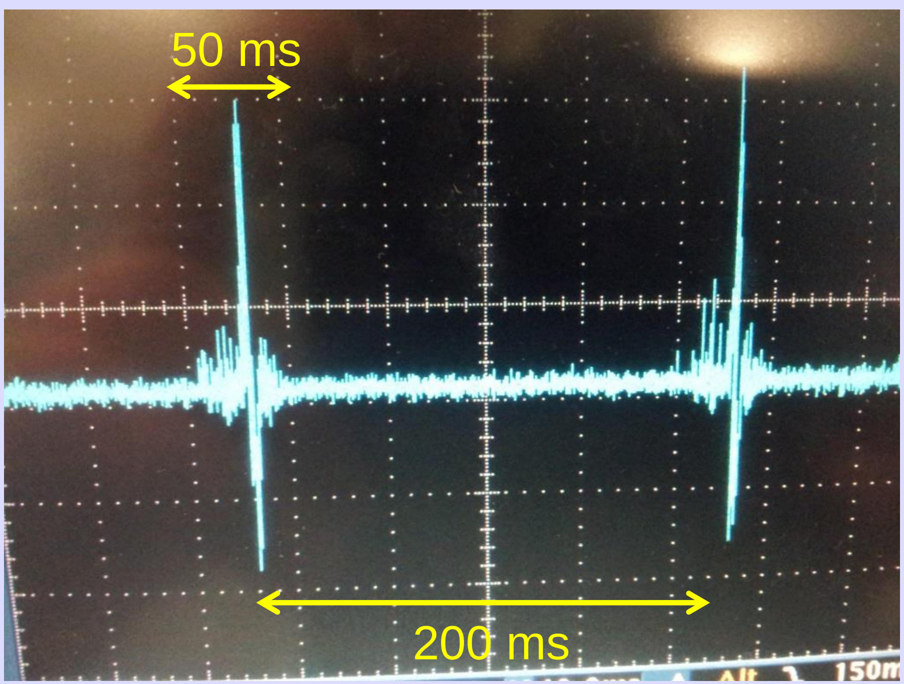


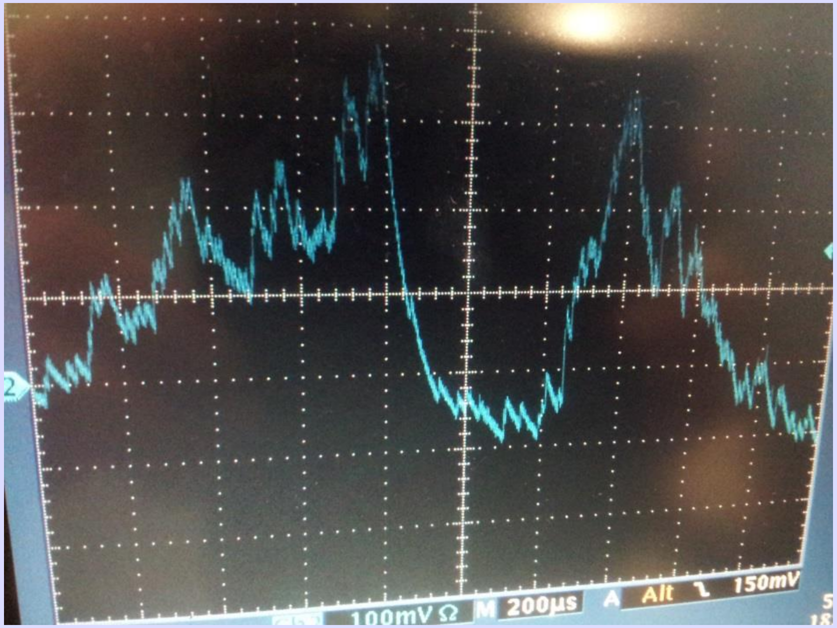


Reaccelerated beams using EBITs

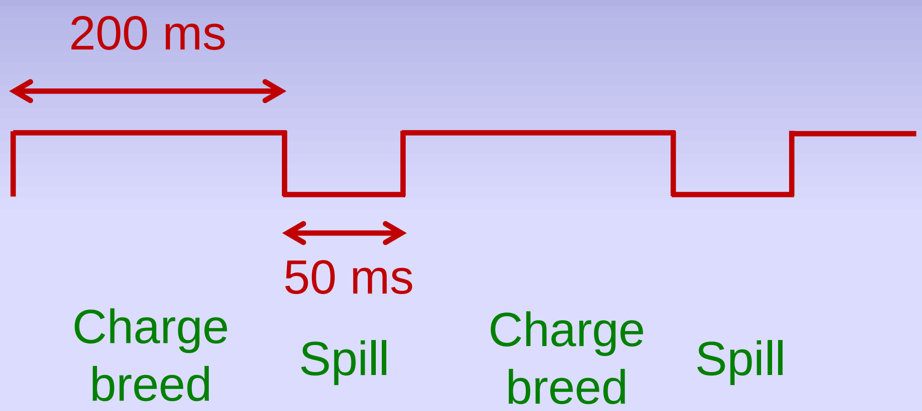


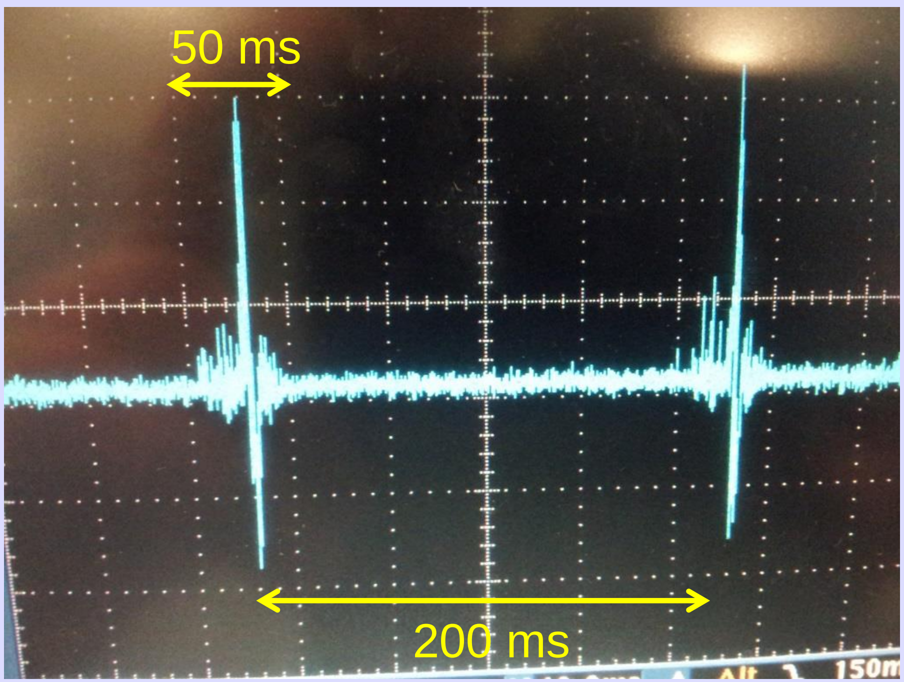


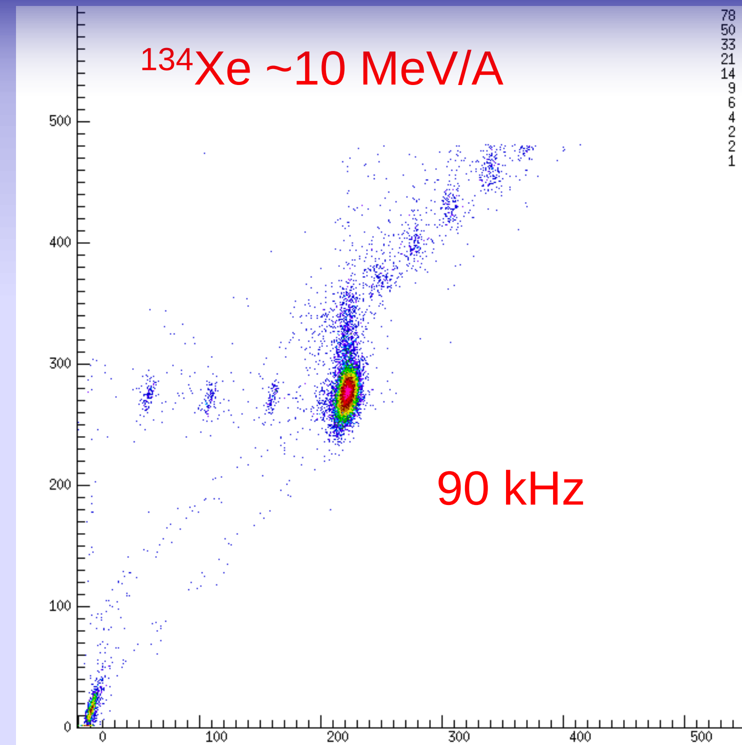


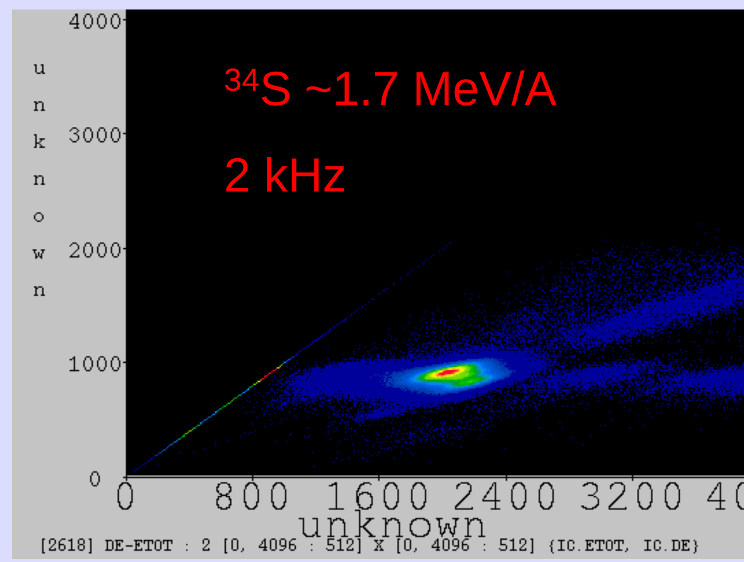


Reaccelerated beams using EBITs

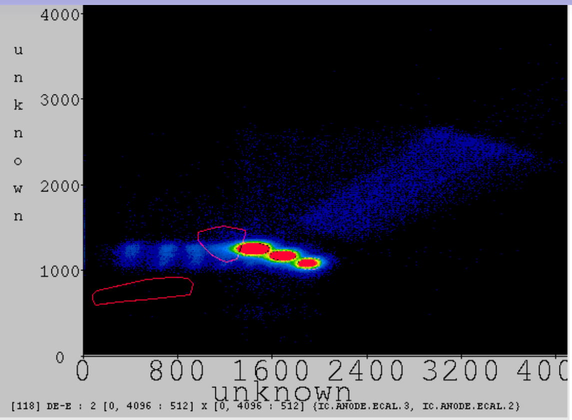


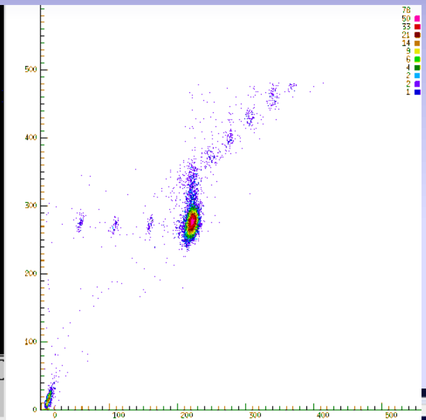






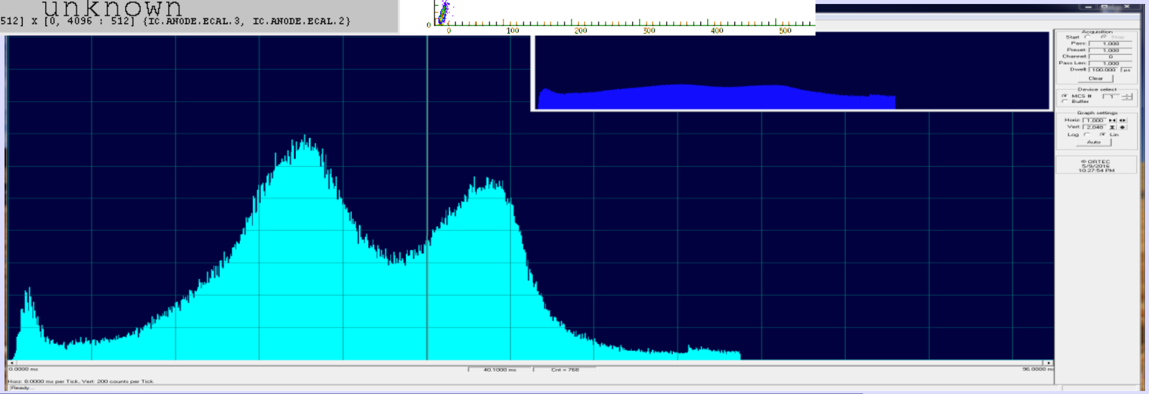
Reaccelerated beams using EBITs





Can be optimized, but still at best probably factor 10 in duty cycle

~10^4 pps limit to optimum performance



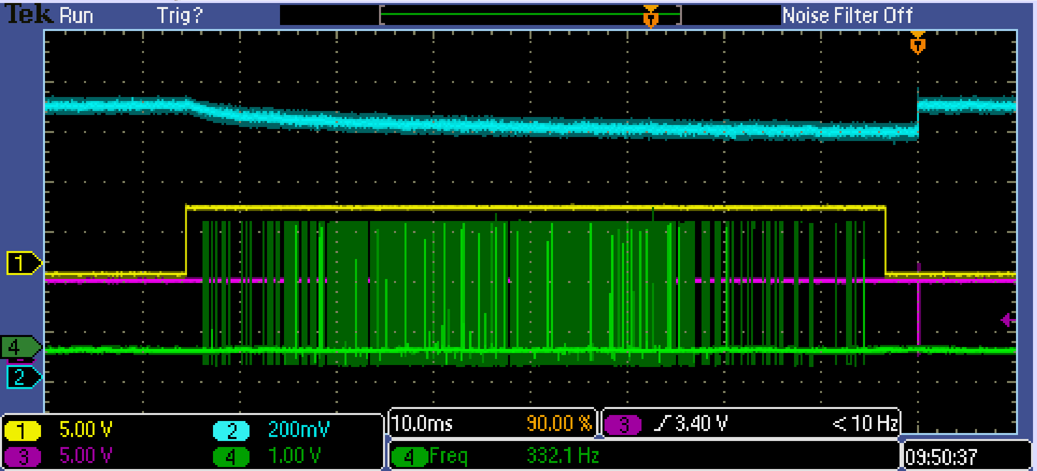
Solutions

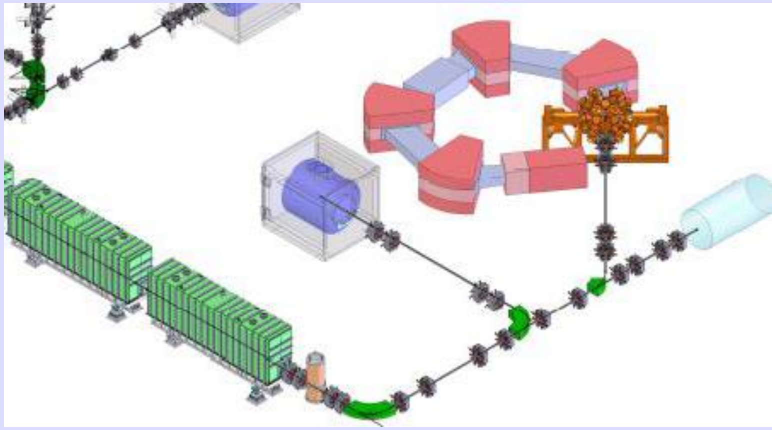
Faster detectors?

Faster IC?

Scintillators?

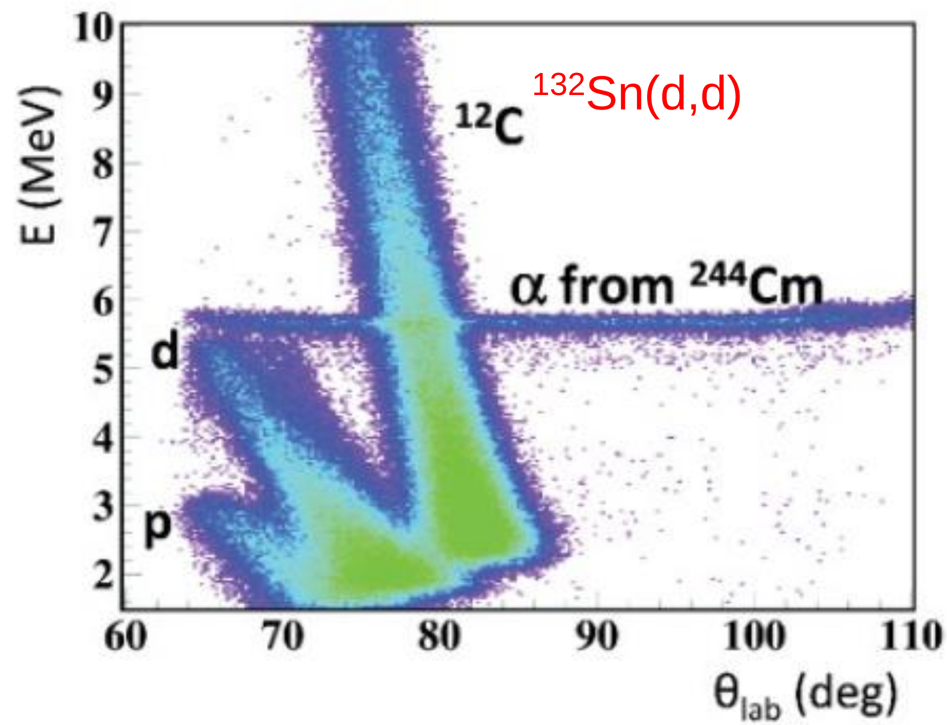
Coupling to large devices (ISLA, S800, HRS)

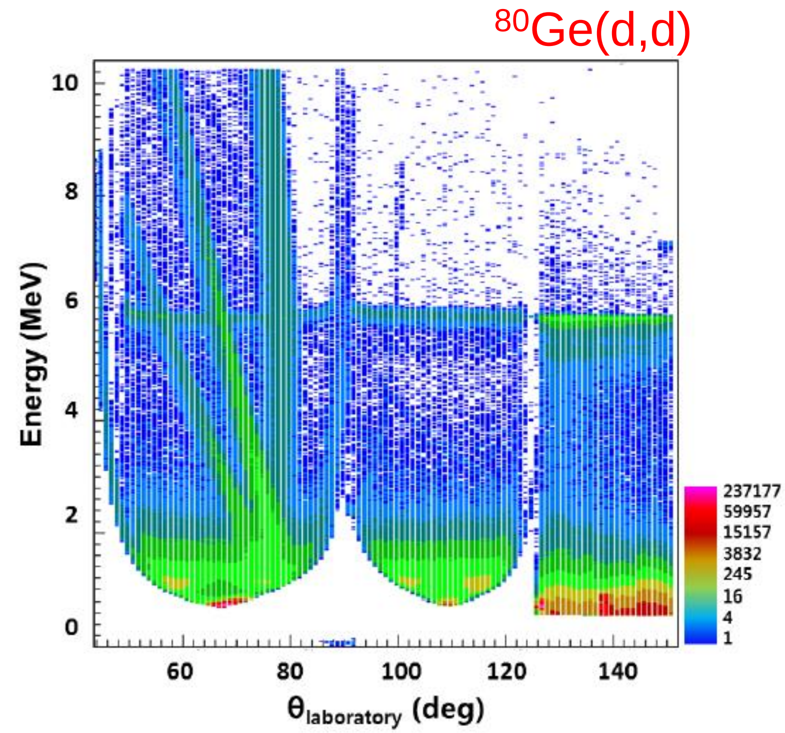


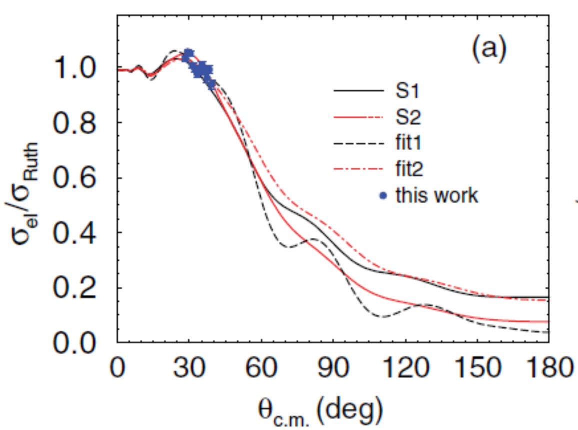


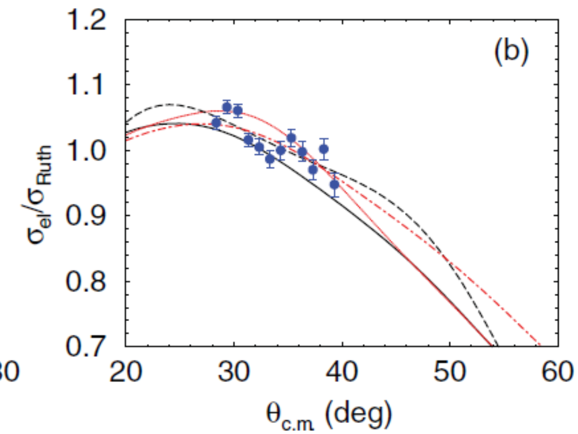
What about measuring elastics?

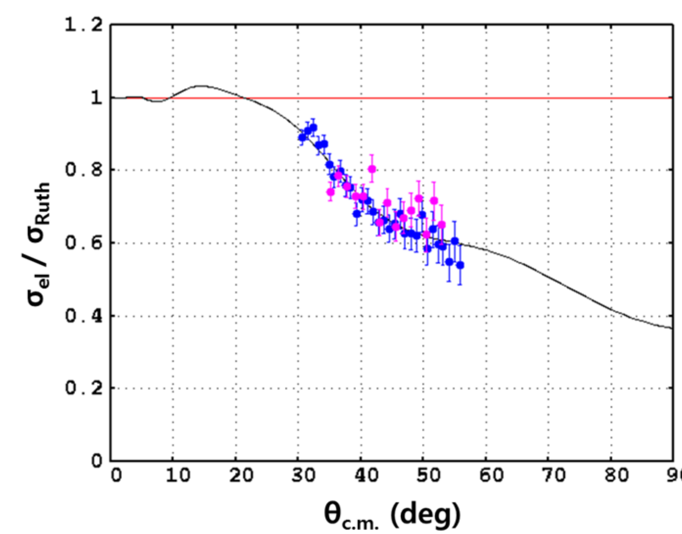
Measuring elastics – a tough job in inverse kinematics



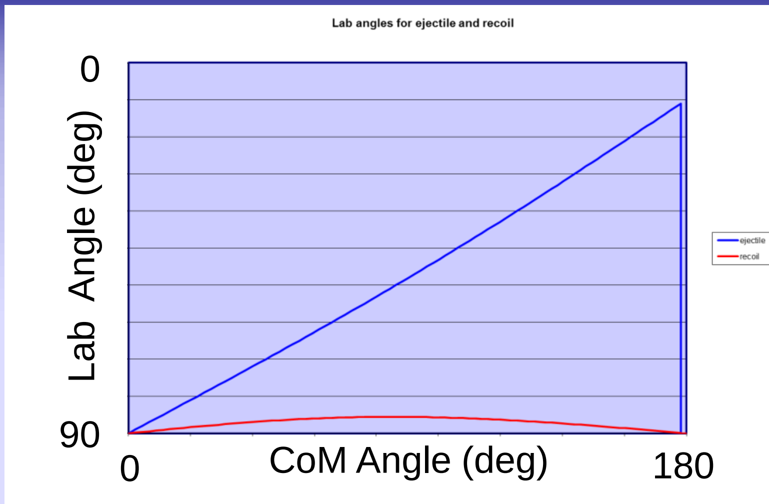




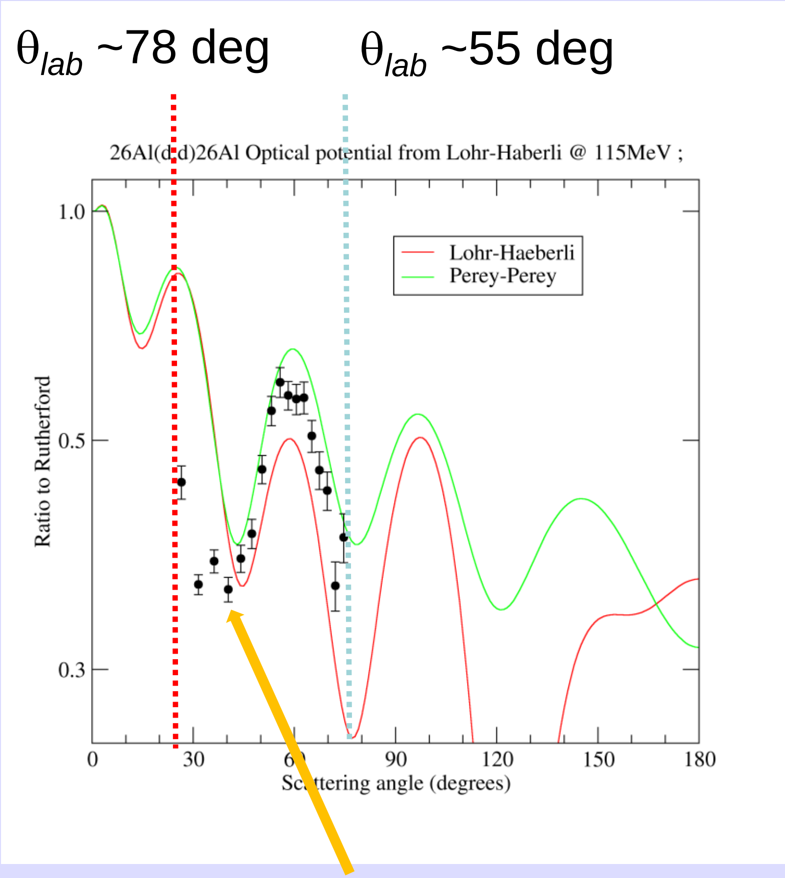


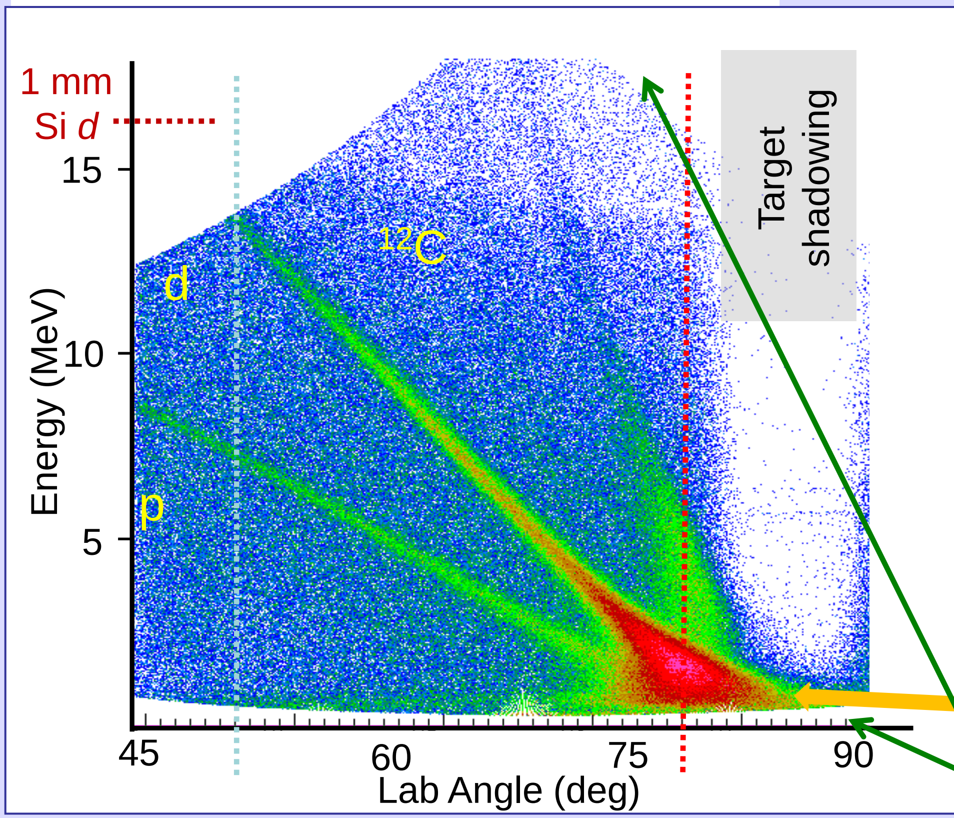


Measuring elastics – a tough job in inverse kinematics



- Factor of 2 angular compression
- Target shadowing
- Low particle energies





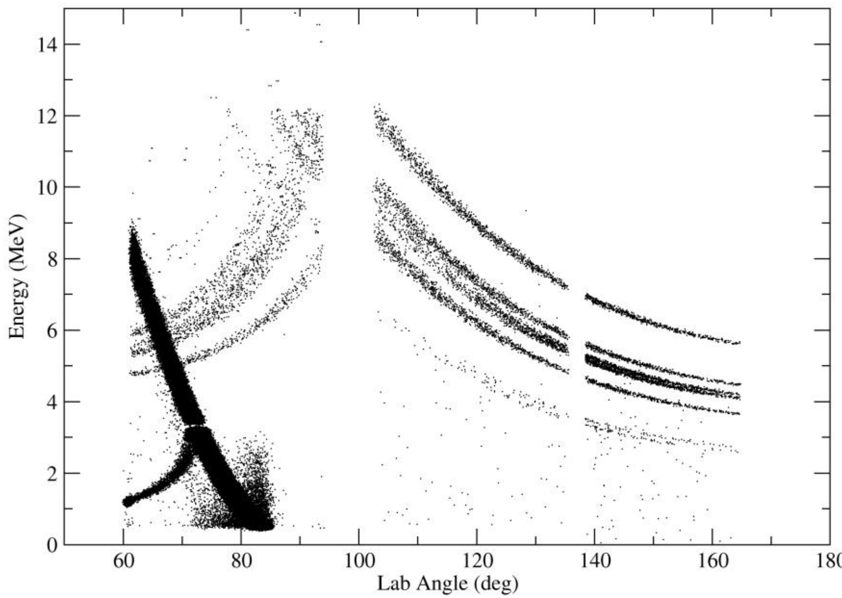
ADC thresholds

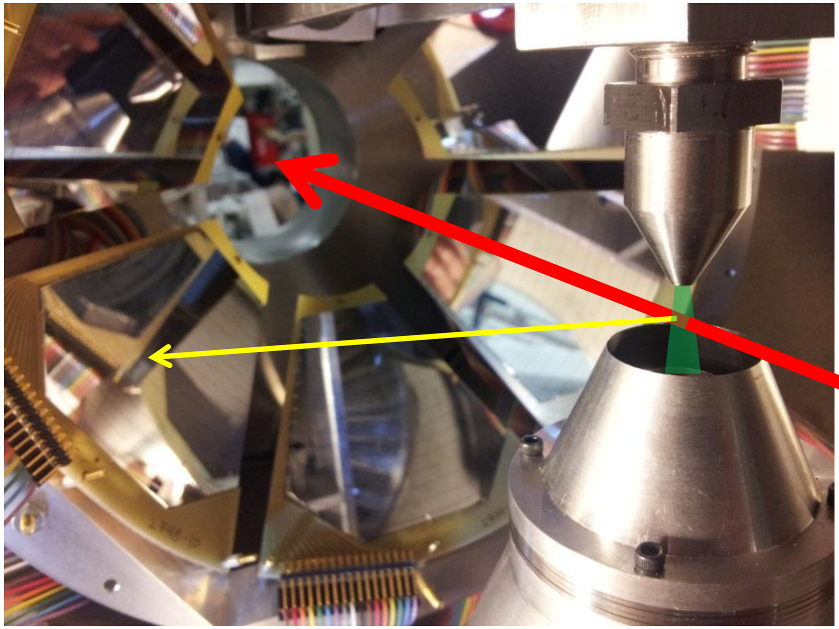
Loss of efficiency by trigger thresholds

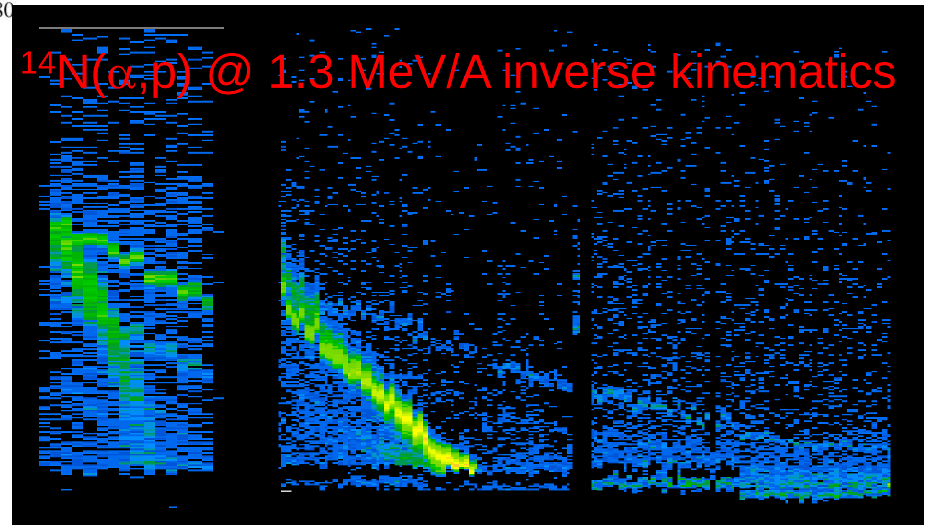
How far can we improve things on the particle side (and how much do we need)?

Will JENSA help?

Yes, and no…

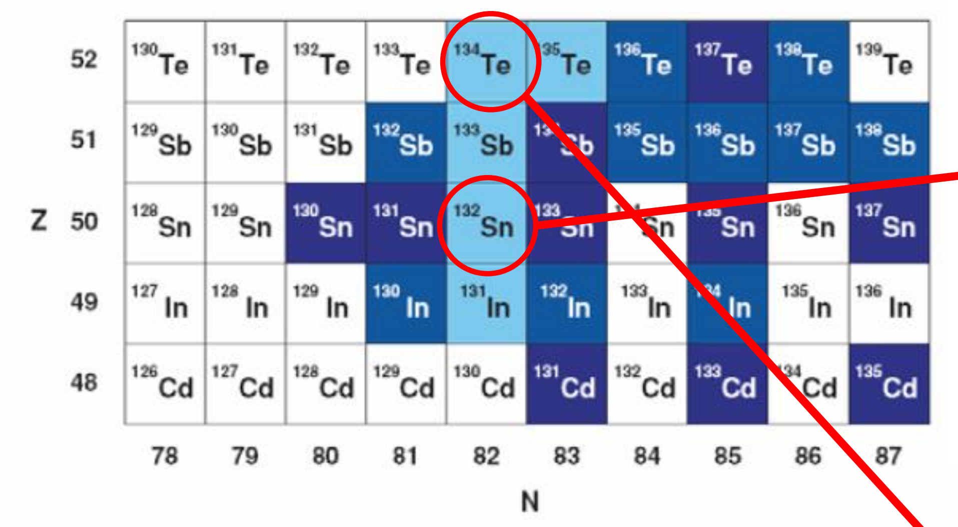


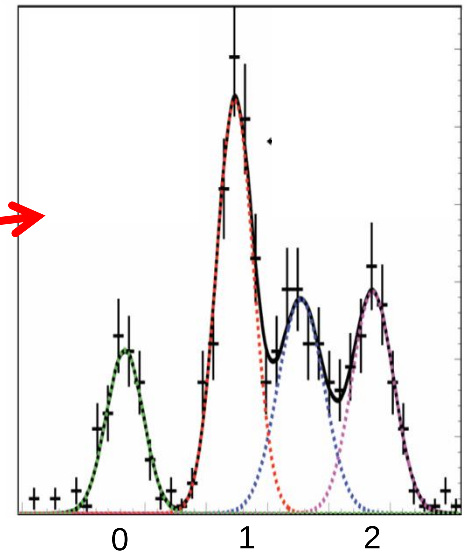




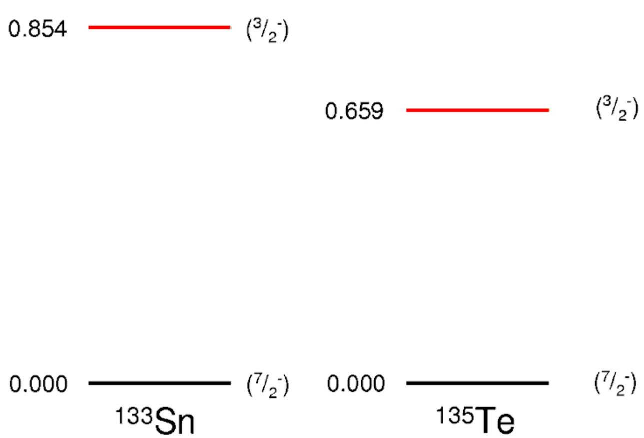
Level Densities

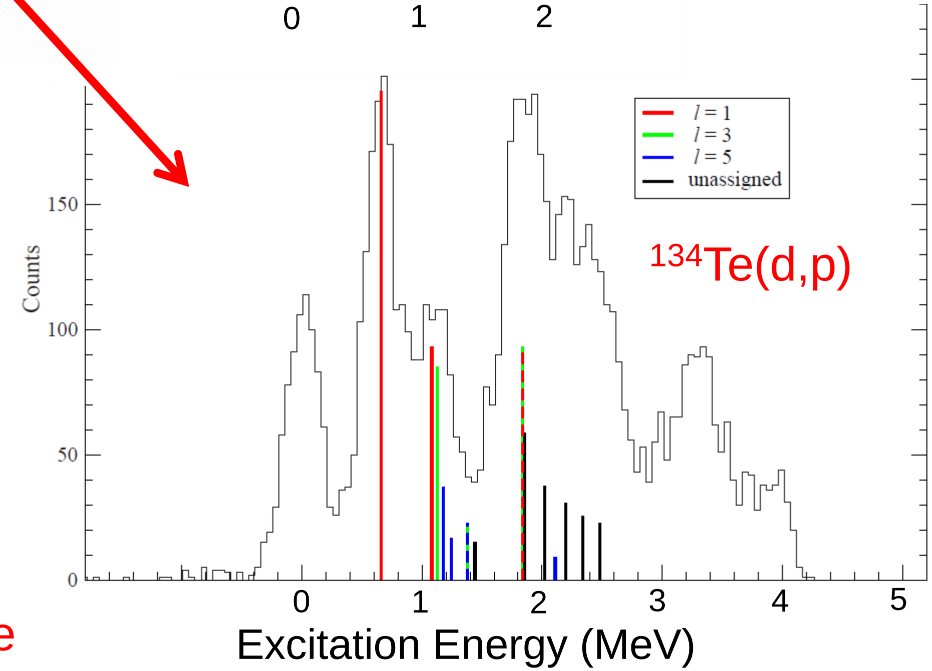
Level spacings as low as 20 keV





^{132}Sn(d,p)

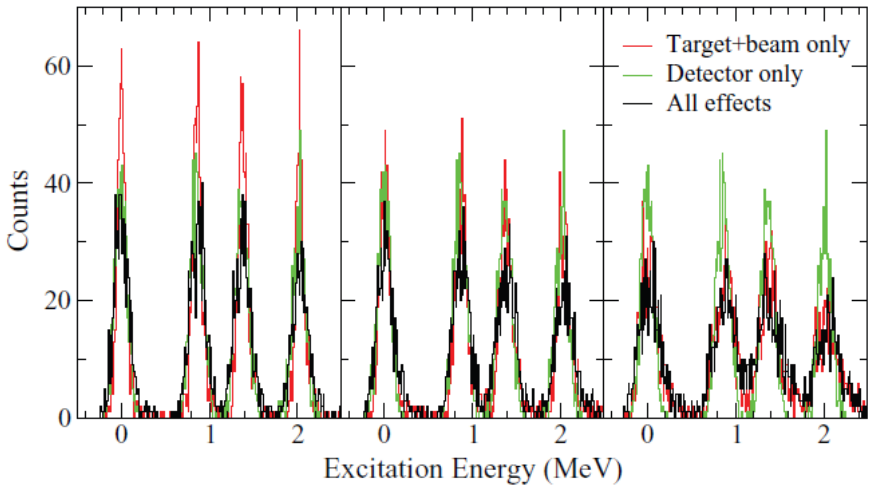


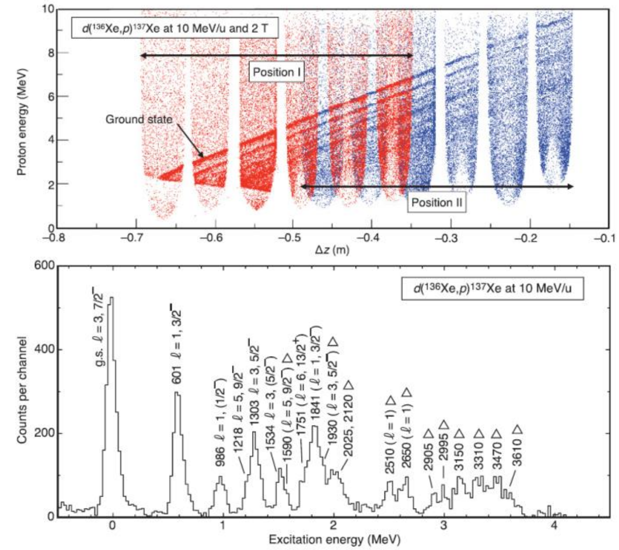


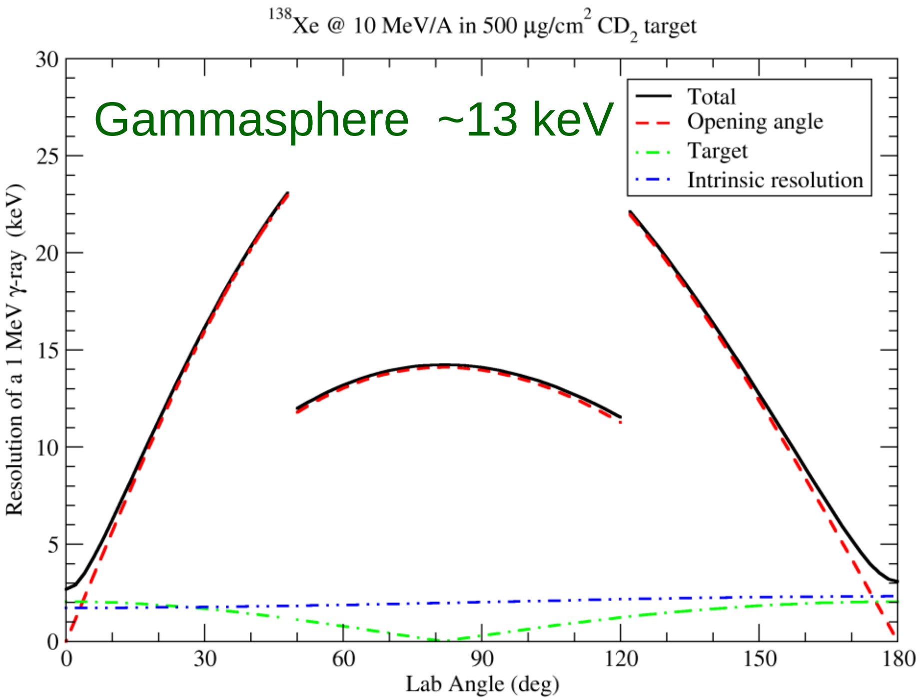
^{134}Te(d,p)

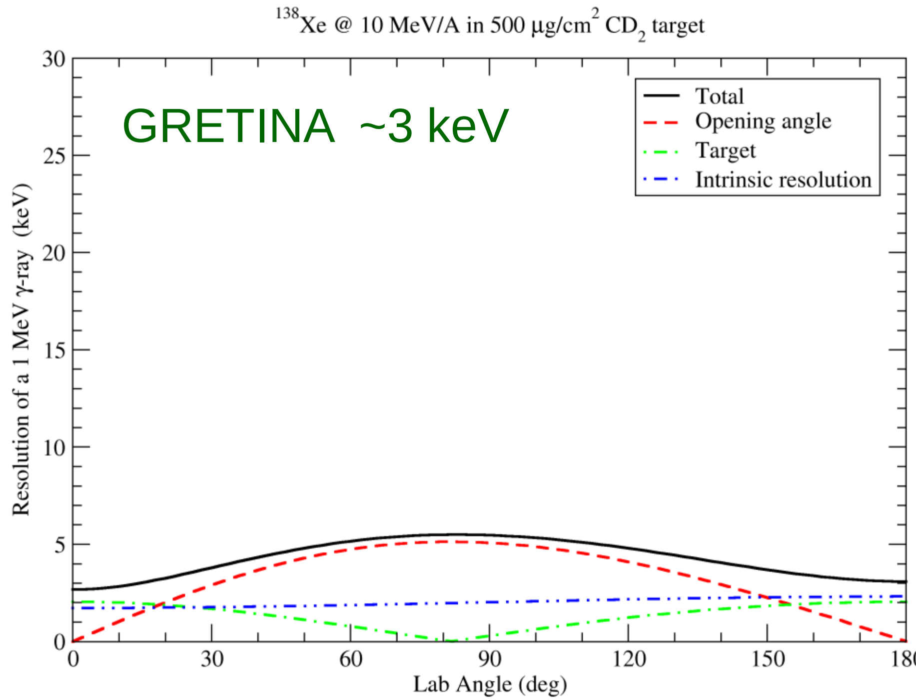
^{134}Te(^{9}Be,^{8}Be)^{135}Te

Level Densities

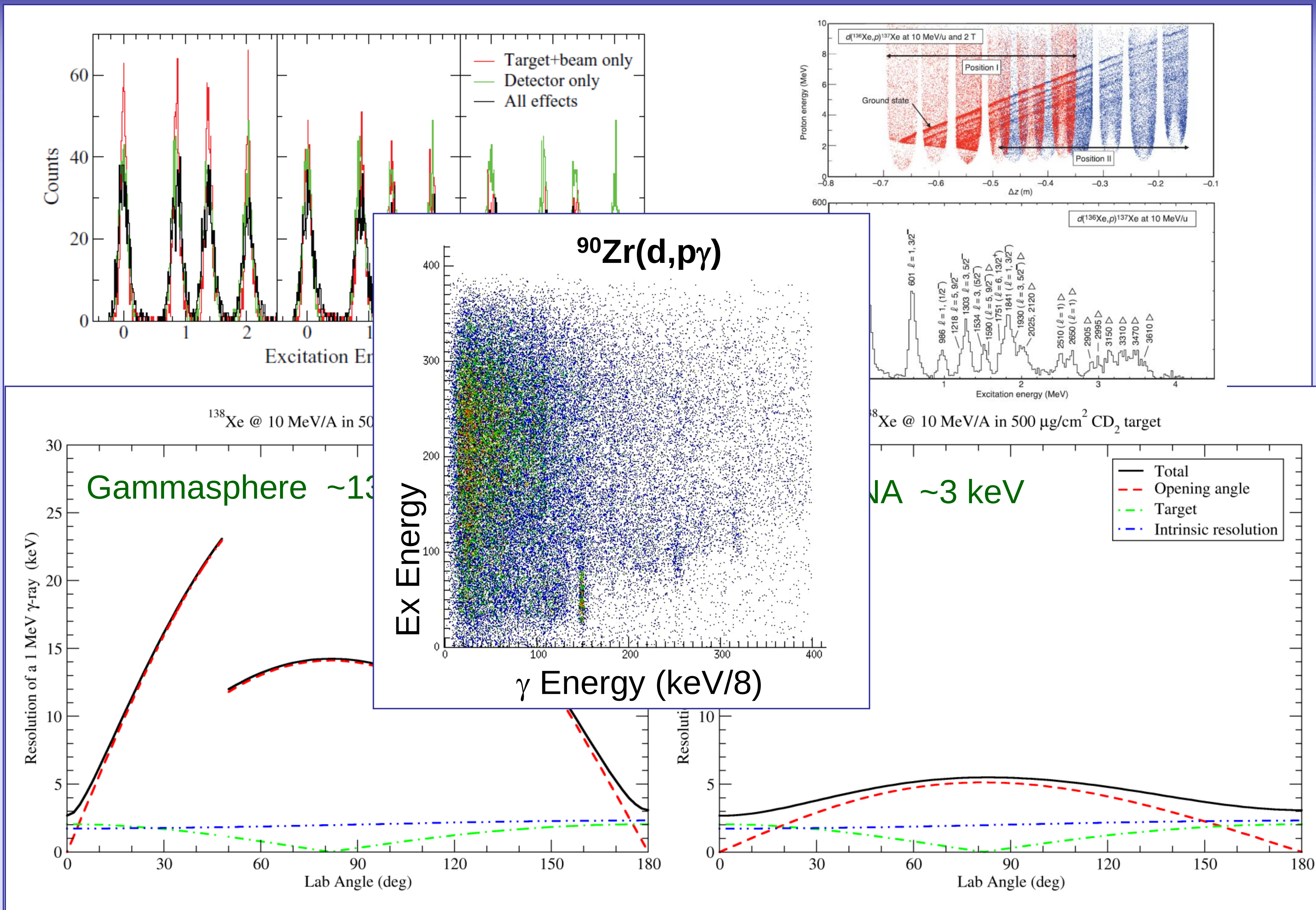








Level Densities



Summary

- The quality of inverse-kinematic (d,p) measurements depend on many factors
- Dominant factors vary from experiment to experiment, including detector energy resolution, beam quality, target thickness, and angular resolution.
- Kinematic compression is most strongly impacted by Q value, rather than beam mass, for energies ideal for transfer reactions (E > ~10 MeV/A)
- Particles will never get you the resolution you need for many cases - really want gamma rays in (d,p) measurement
- Dealing with beam purity is about to get harder due to EBIT duty factors
- Elastic scattering over ~30-90 deg (CoM) fairly straightforward; harder (not impossible!) to get beyond this range