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UT Oak Ridge National Laboratory

2014 ATLAS User's Meeting

Heavy-Ion Induced Transfer Reactions using Particle-γ Coincidence Spectroscopy

(Sub Coulomb)

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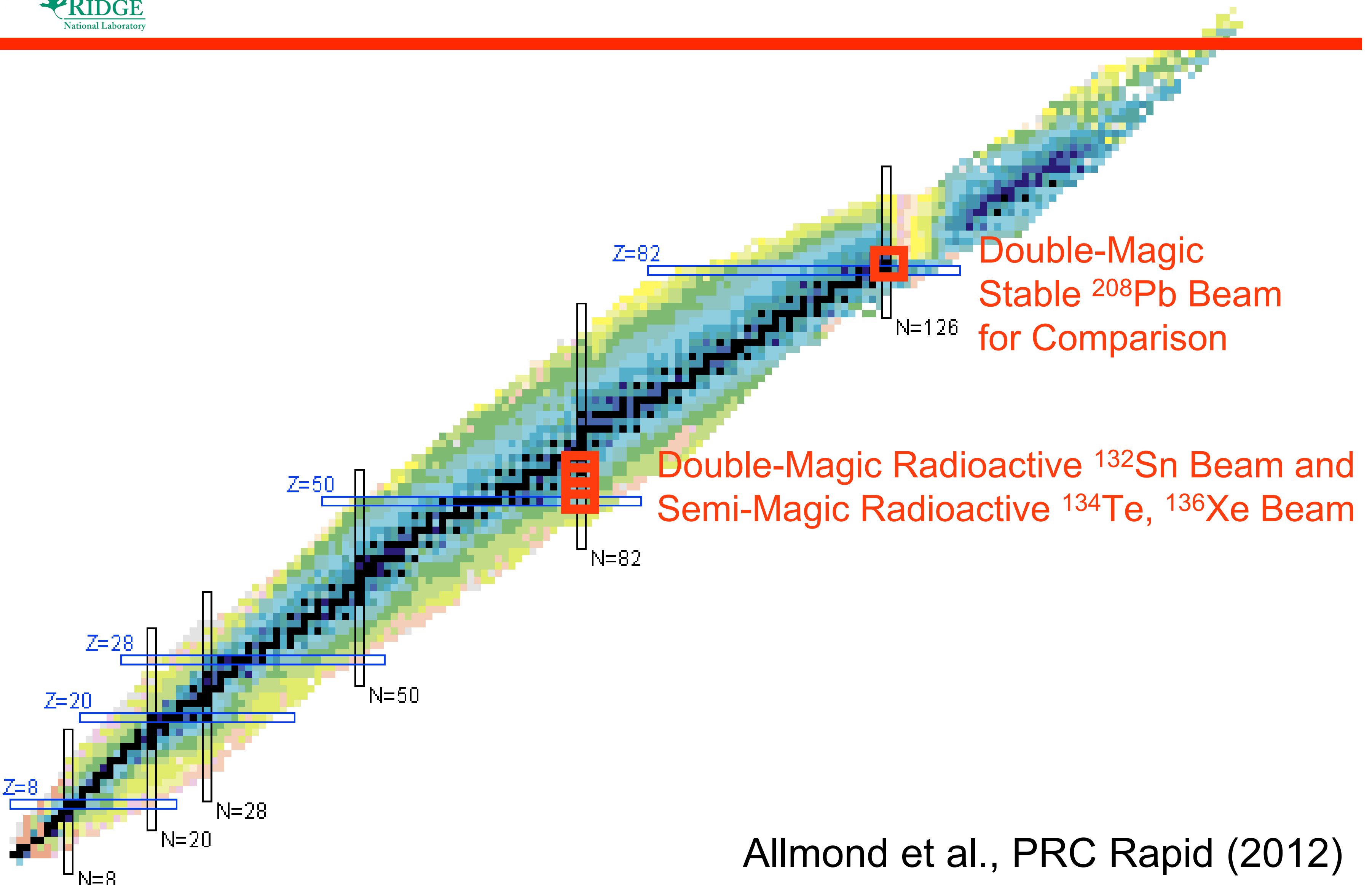
Example One-Neutron Transfer Studies



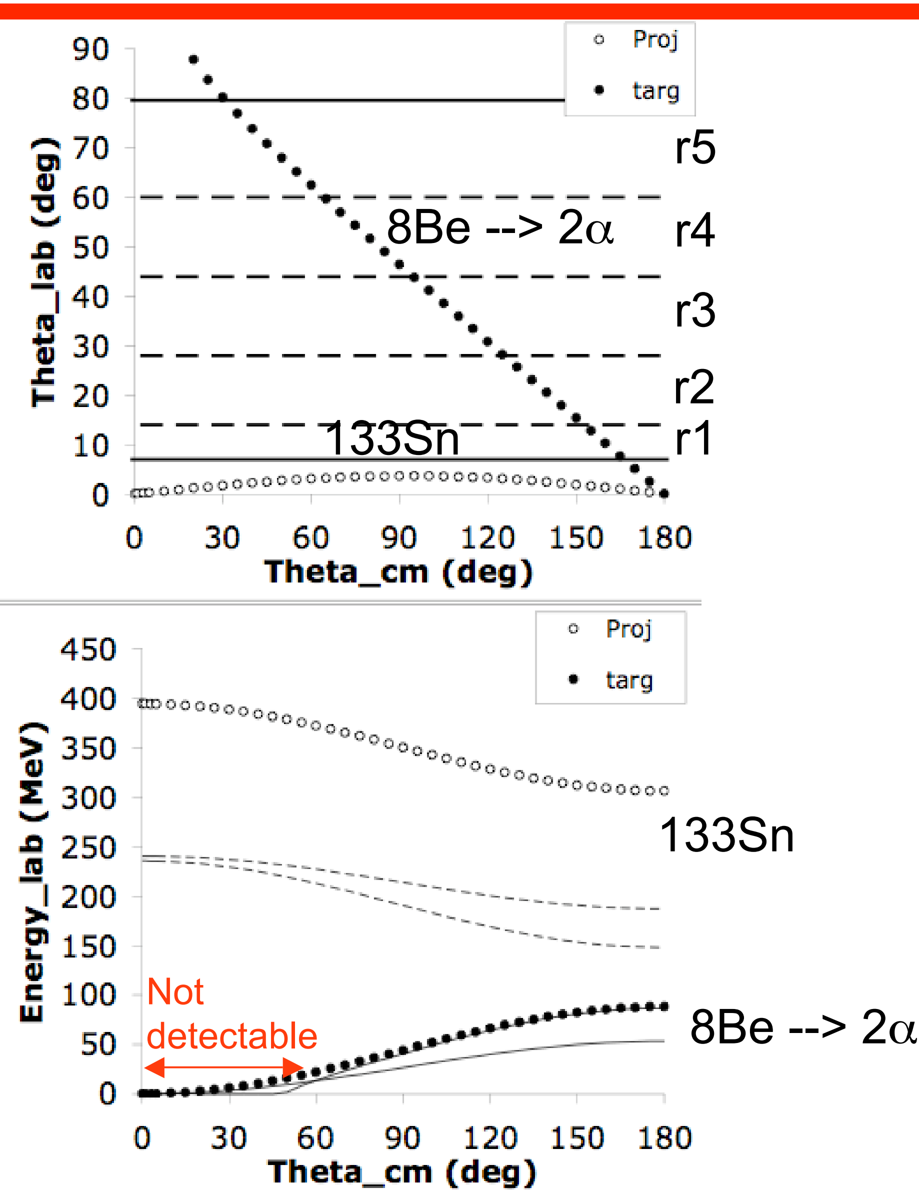
Allmond et al., PRC Rapid (2012)
Allmond et al., PRL (2014)

Inverse Kinematics: (^{9}Be, ^{8}Be->2α)

Energetic/detectable target-like recoils predominately at backward θcm

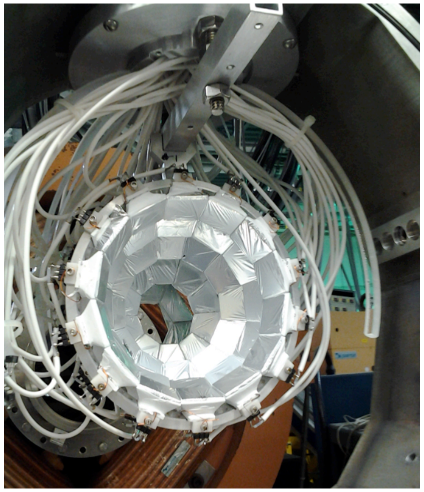
*Only need 2π particle detector

*Use sub-Coulomb to obtain reliable absolute cross-section normalization via Rutherford



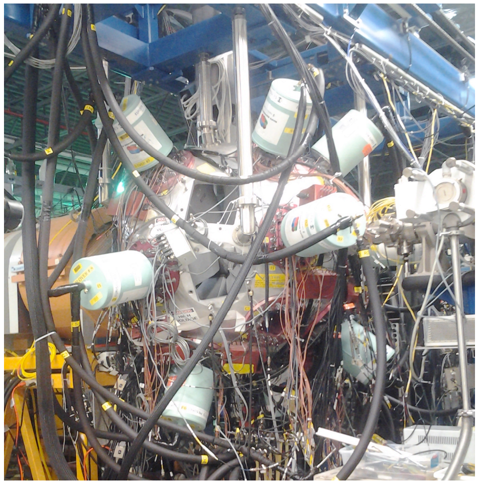
Hardware

CsI or Si*



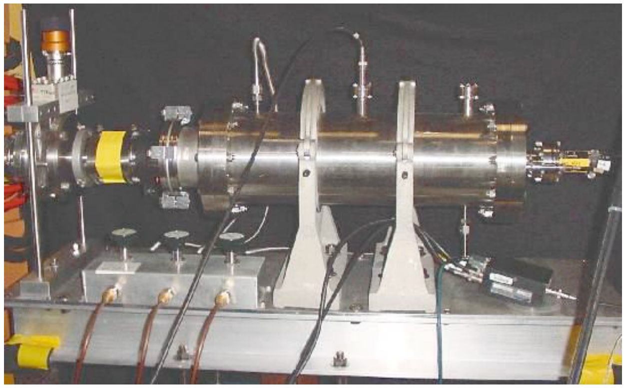
Particles

HPGe



γ-Rays

Zero-Degree Bragg



Target Thickness and Beam Composition

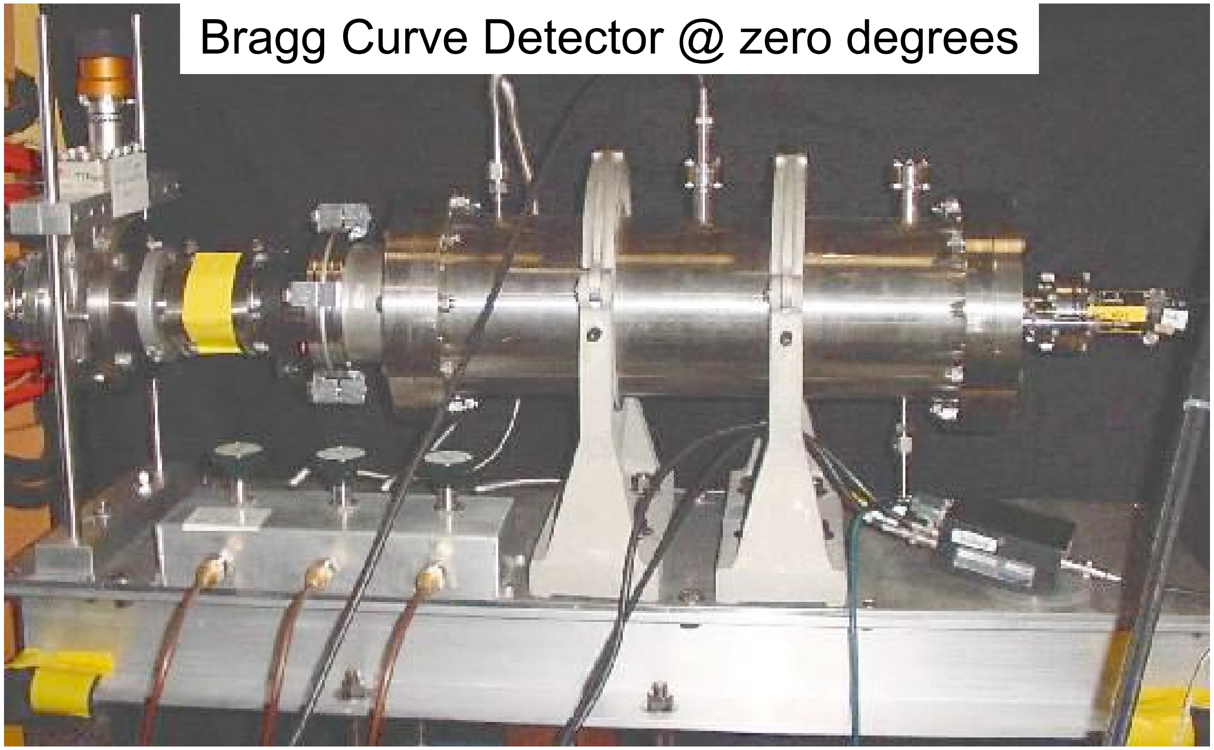
*Recoiling target-like Heavy Ion may not make it through
ΔE of Si telescope for PID: use (9Be, 8Be->2a) for clean tag in this case.

Measure Target Thickness / Eloss

Stopping powers are not known to high precision

$\frac{\sigma_{exp}}{\sigma_{thy}}$ and DSAM are sensitive to the target thickness and E_{loss}

WARNING!!!
Do not trust the energy loss calculated from the “nominal” target thickness.



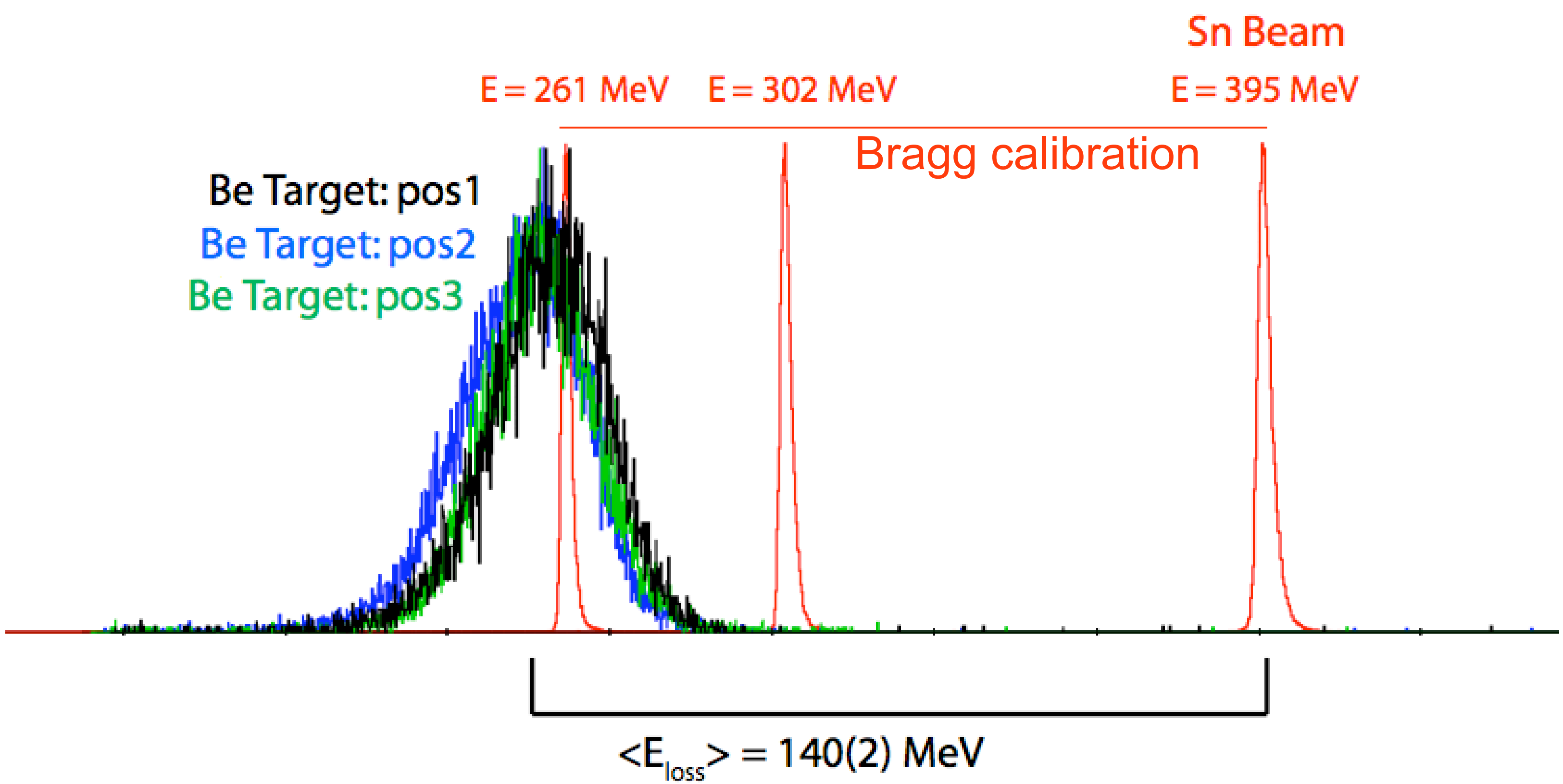
Bragg Curve Detector @ zero degrees

Measure Target Thickness / Eloss

Stopping powers are not known to high precision

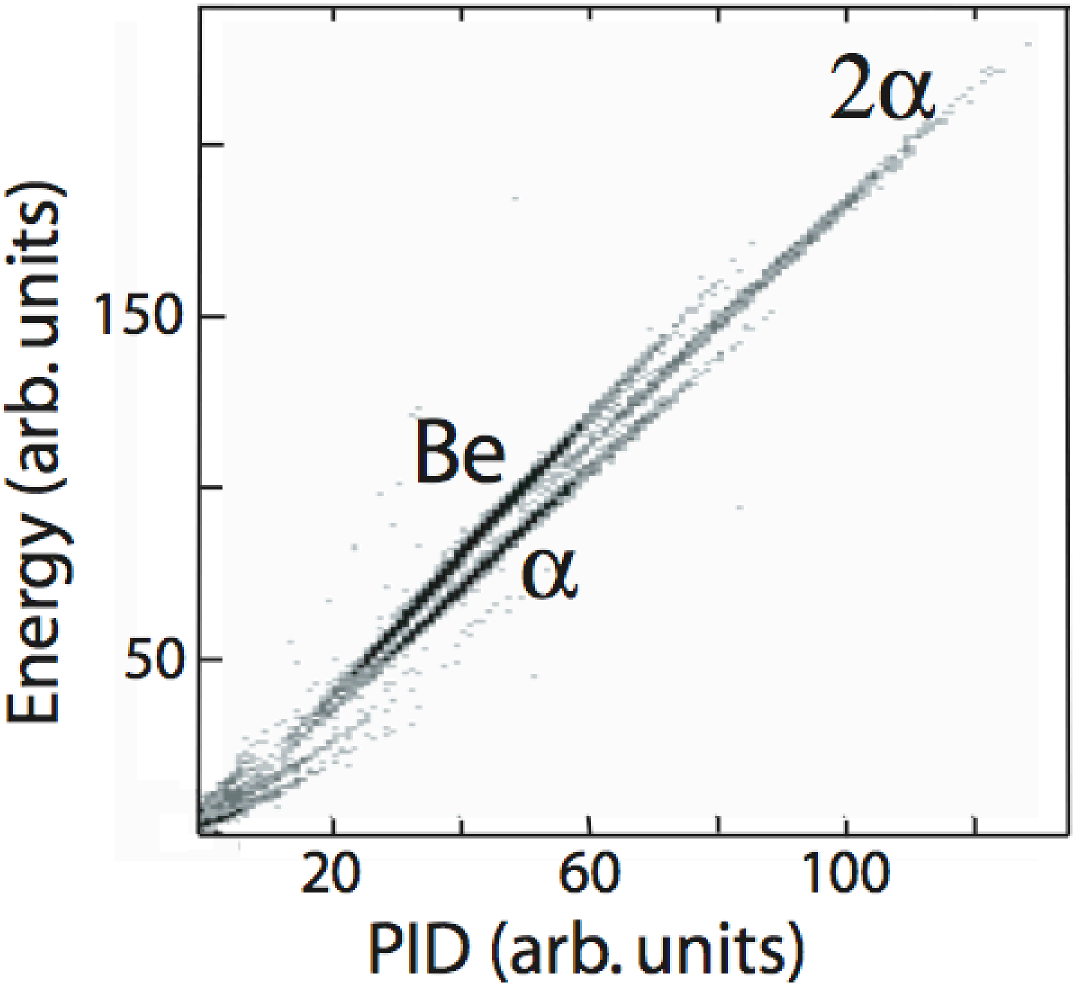
$\frac{\sigma_{exp}}{\sigma_{thy}}$ and DSAM are sensitive to the target thickness and E_{loss}

WARNING!!!
Do not trust the energy loss calculated from the "nominal" target thickness.



PID with CsI: (^{9}Be, ^{8}Be->2α)

^{8}Be($T_{1/2}$=8.2E-17s) decay to two correlated alphas provides clean trigger



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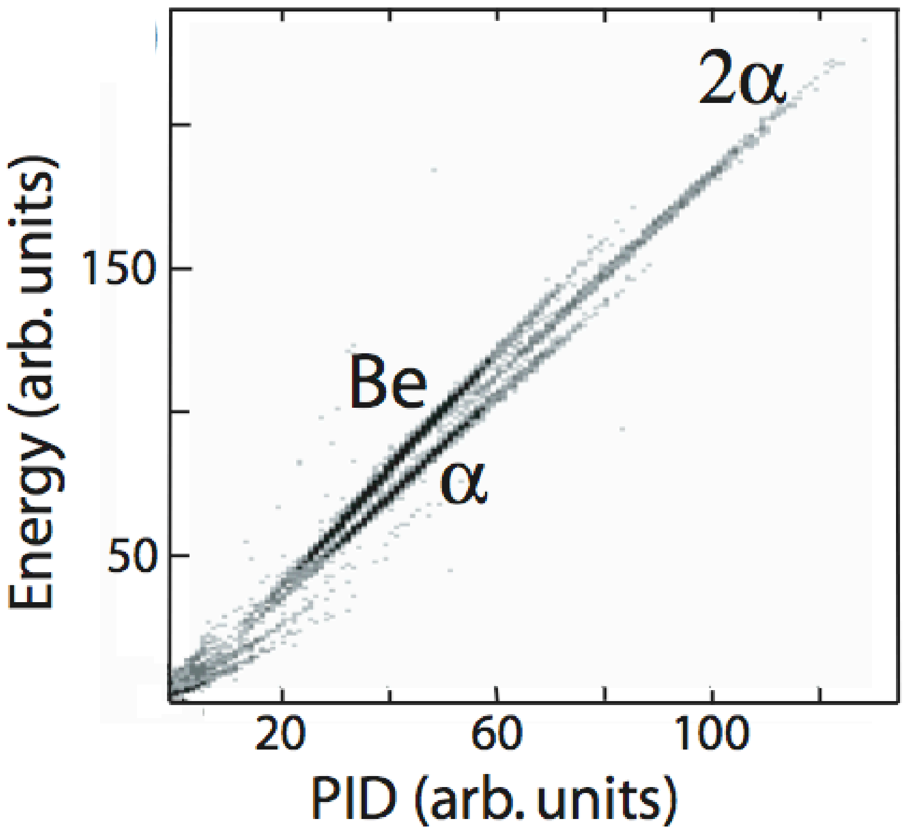
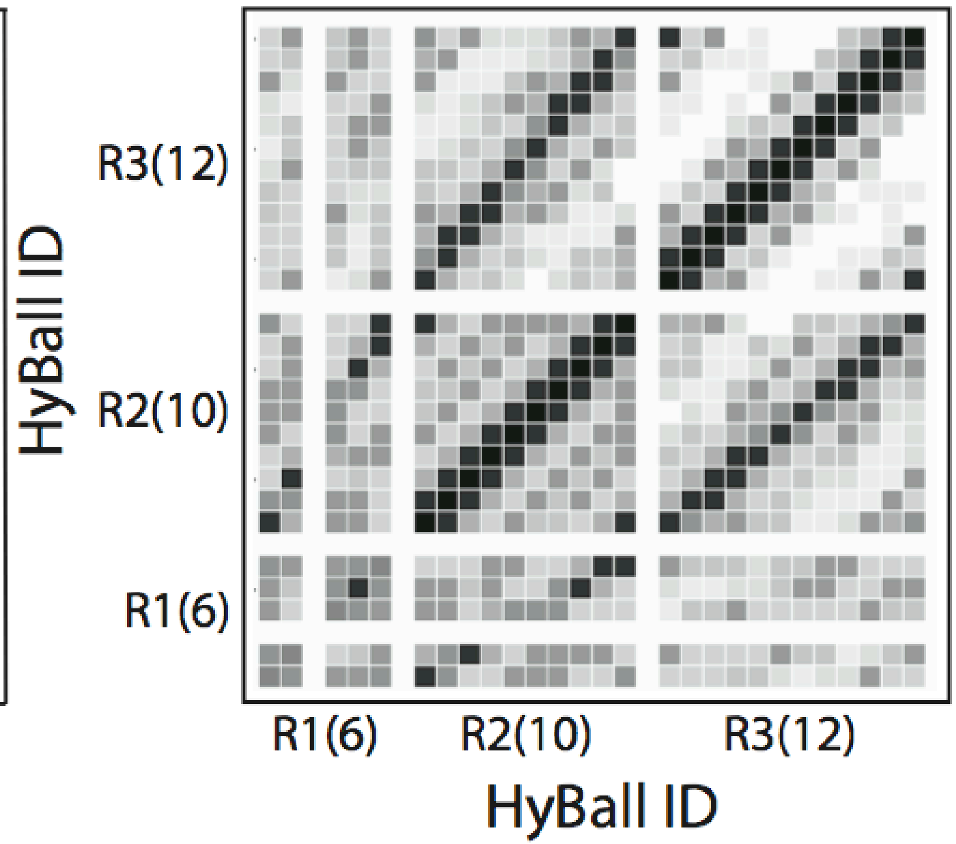


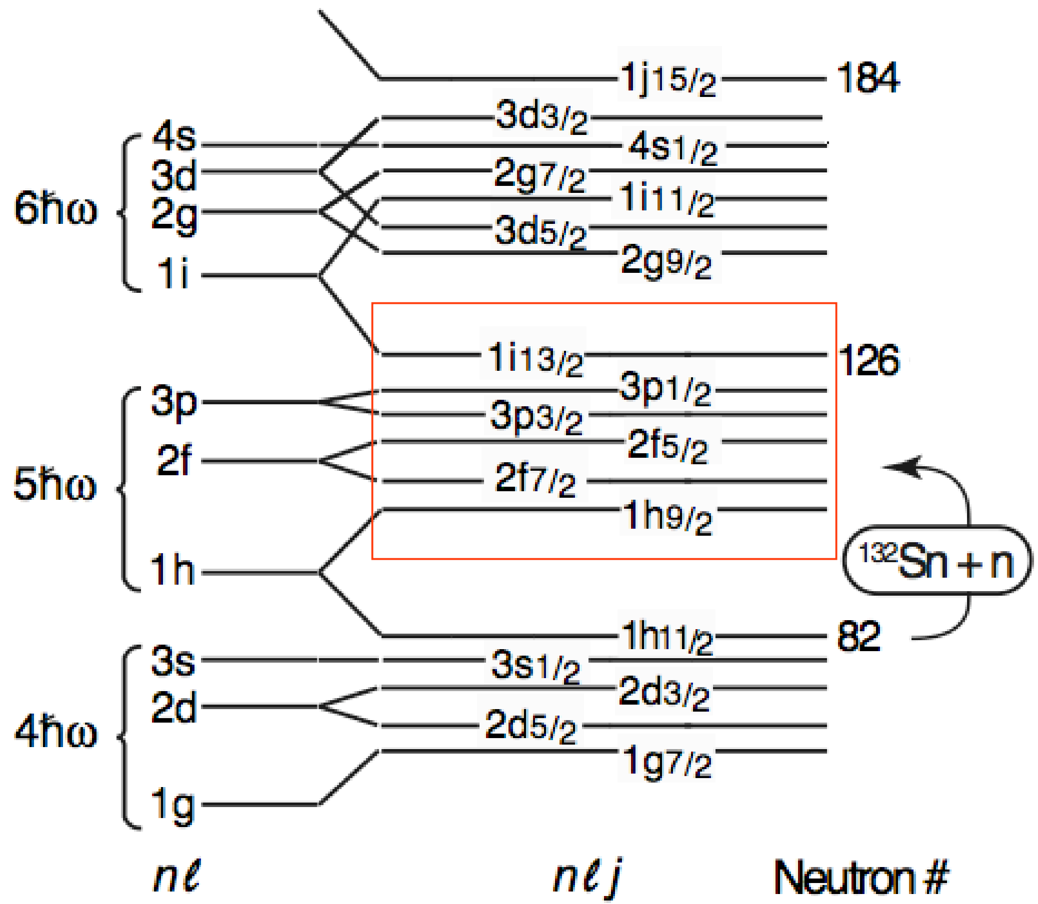
8Be --> 2 x 1α correlation
between CsI detector segments



*For Si detectors, use 2α hit in ΔE with equivalent energies for clean tag.

N=83 Single-Particle States

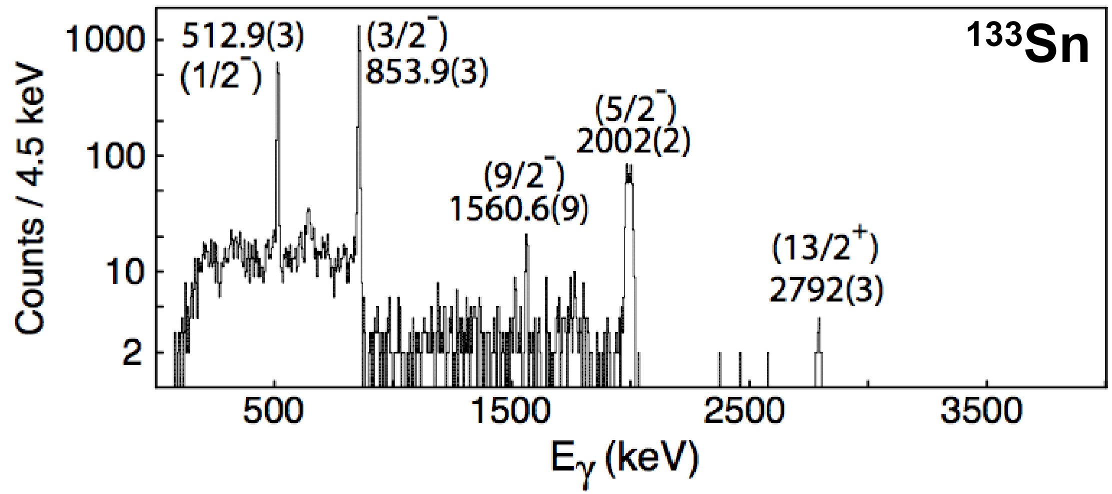
One-neutron transfer should select s.p. states above N=82 shell closure



Radioactive Beam

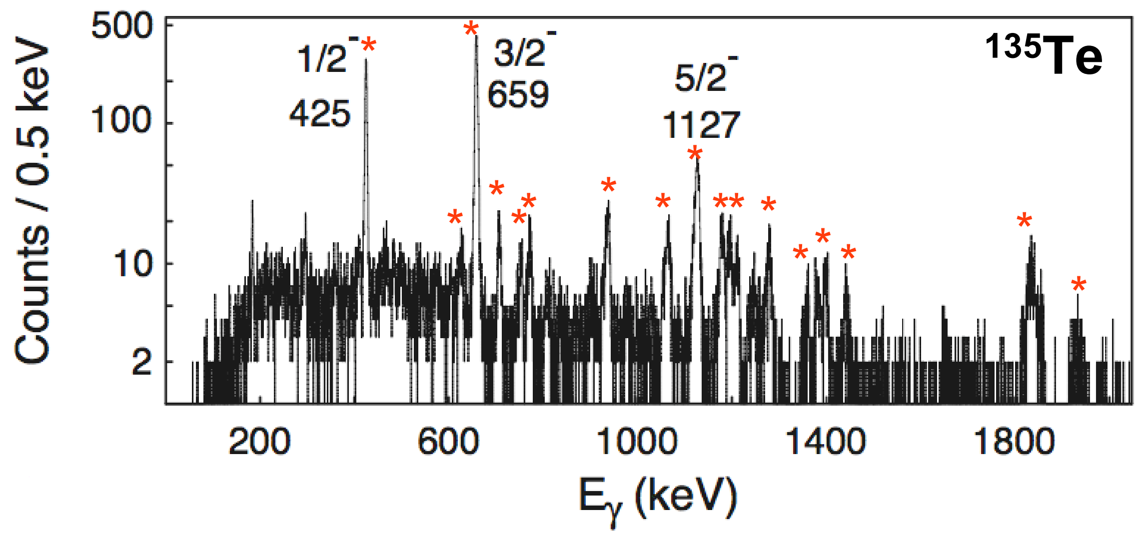
^{133}Sn versus ^{133}Sn + 2 Protons

Going from system of 1n to 1n+2p adds a lot of complexity



1 Active Neutron
"Simple"

Pure s.p. states

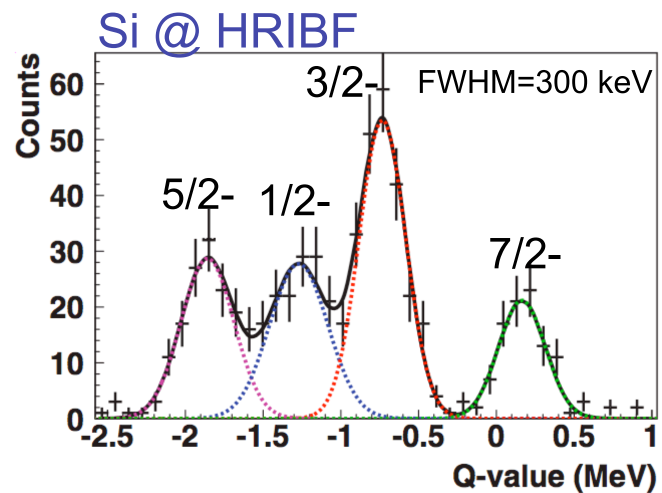


1 Active Neutron
2 Active Protons
"Complex"

Fragmented s.p. states

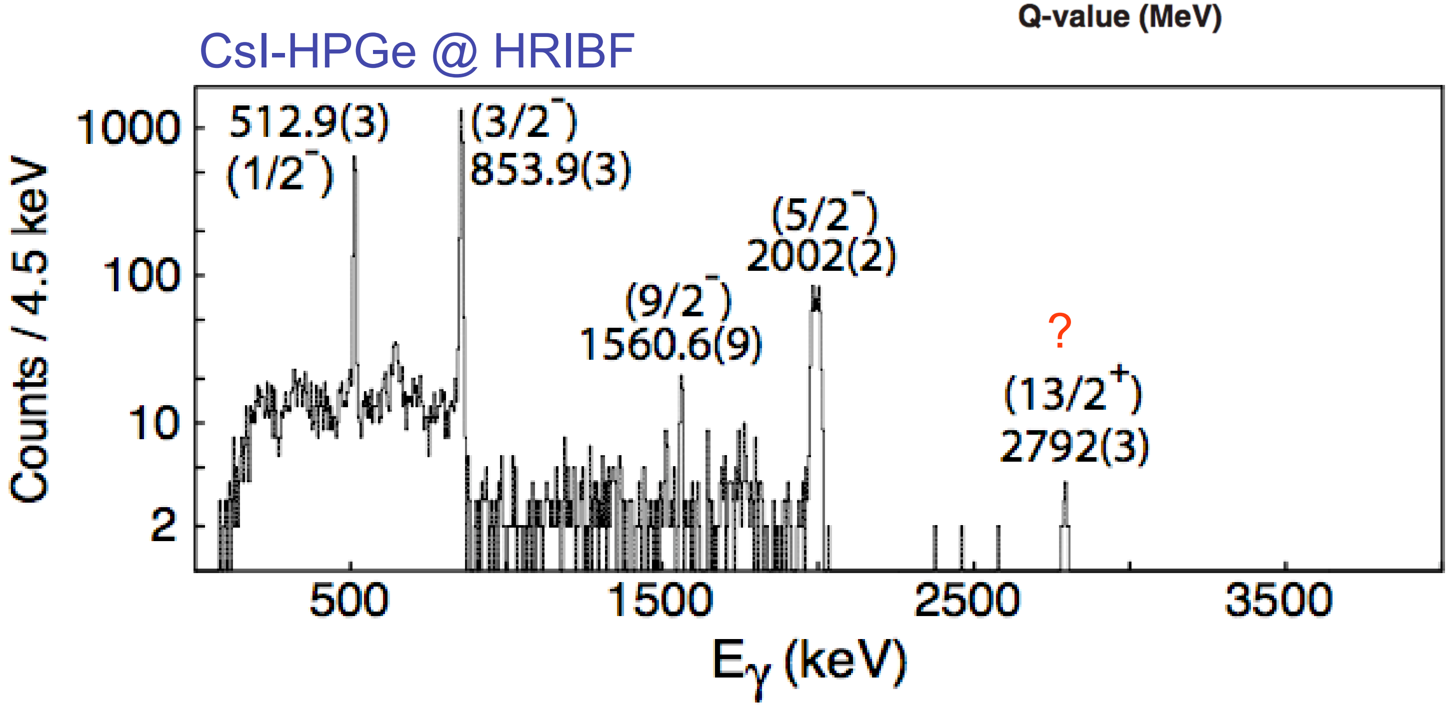
Particle vs Particle-γ Spectra: ^{133}Sn

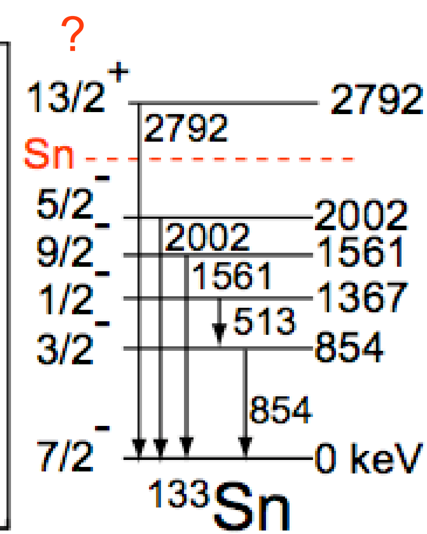
Transitions / states are well resolved in inverse kinematics by particle-γ



$d(^{132}Sn,p)^{133}Sn$

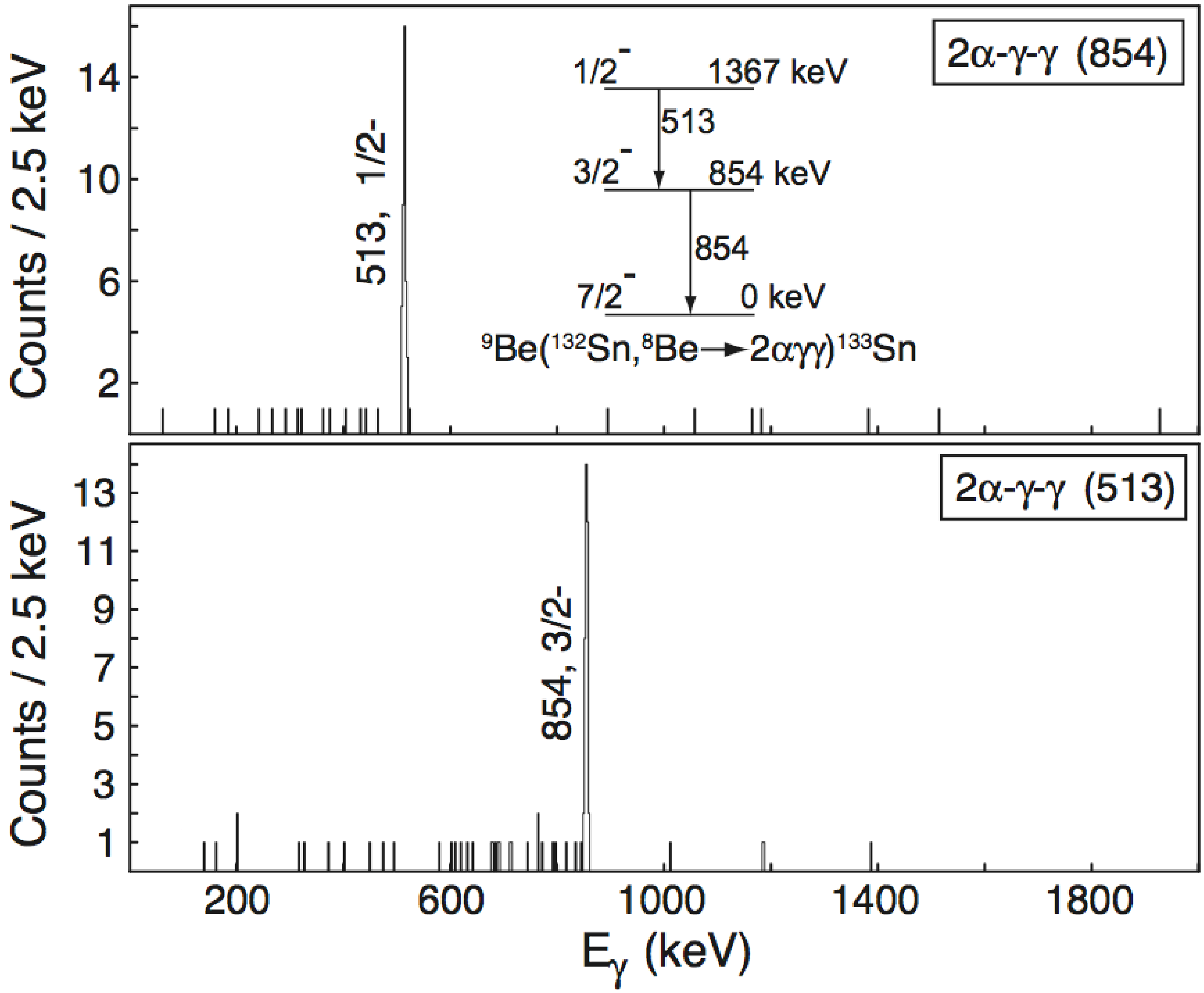
K. L. Jones et al., Nature (London) 465, 454 (2010).





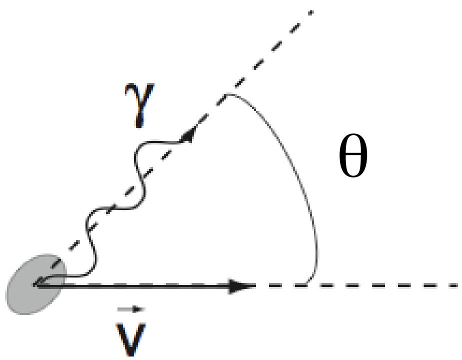
^{133}Sn(N=83) Decay Paths by γ-γ

γ–γ coincidences can be used to determine decay paths



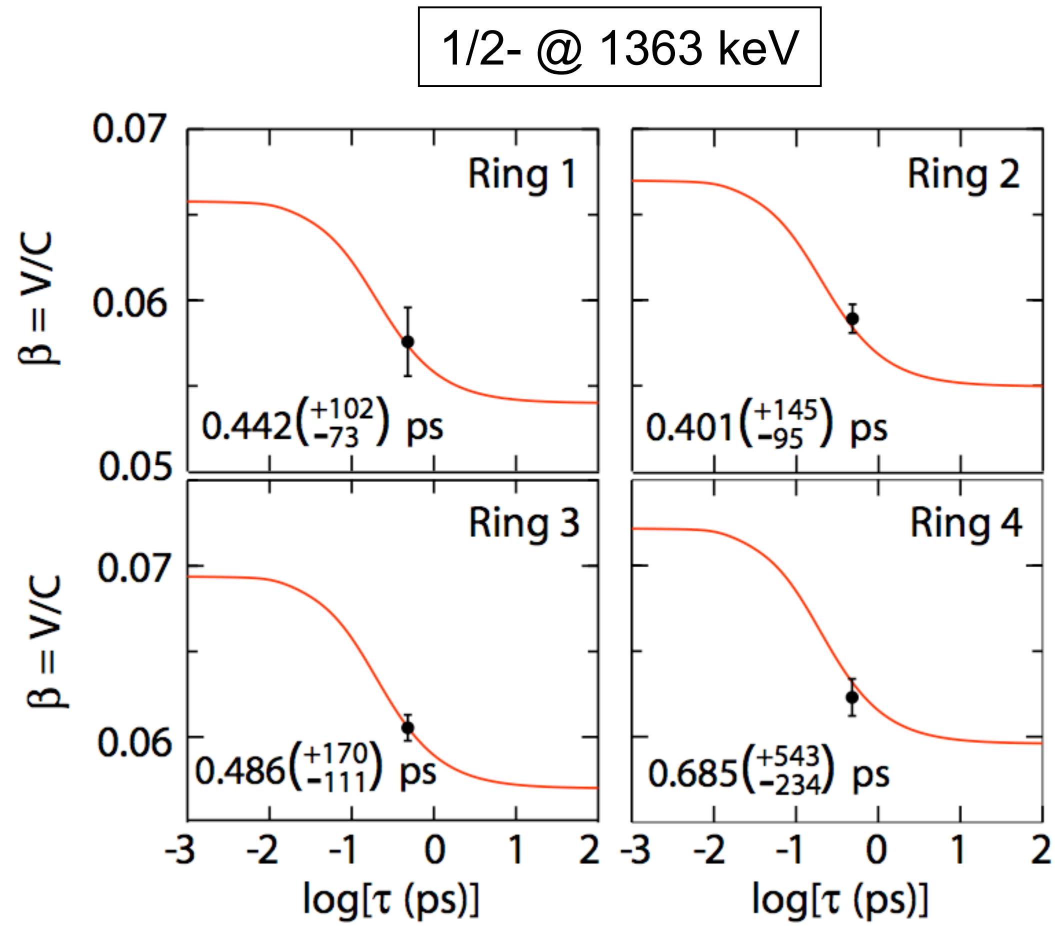
Lifetimes by Doppler Shift

Lifetimes can be measured if comparable to flight time through target



$$E_\gamma = E_\circ \frac{\sqrt{1-\beta^2}}{1-\beta\cos\theta}$$

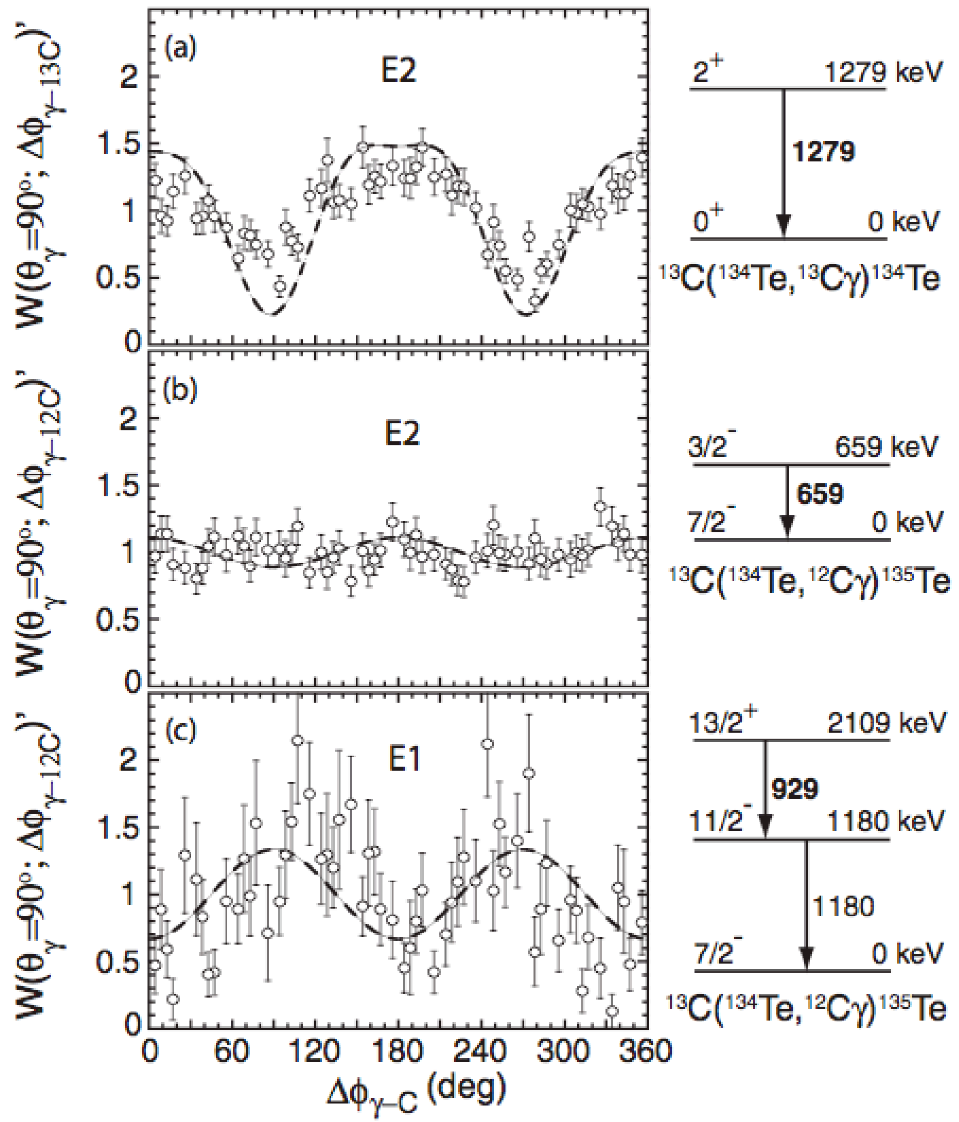
Experimentally Measure



τ=0.48(13) ps

Particle-γ Angular Correlations

Can use particle-γ correlations to determine multipolarity of transitions

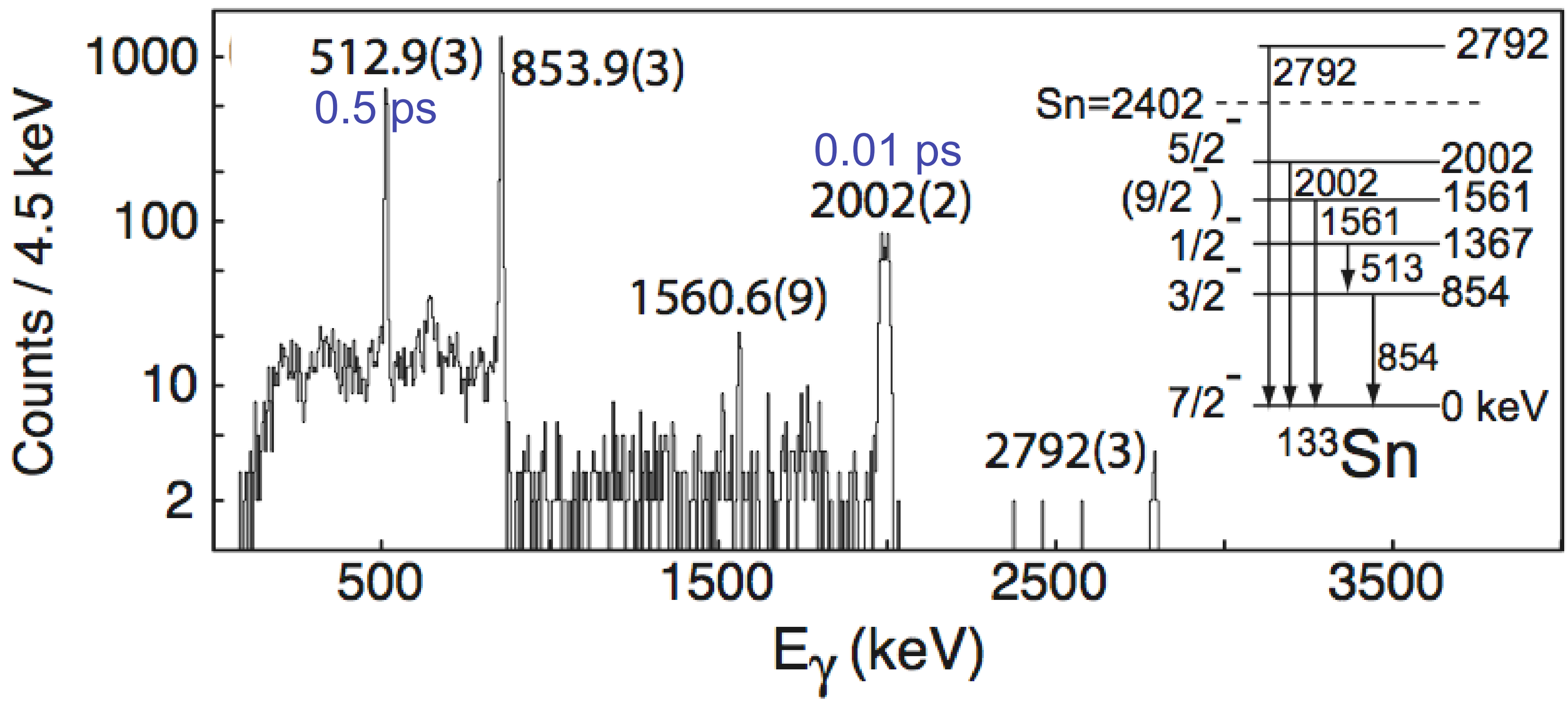


(^{9}Be, ^{8}Beγ)^{133}Sn Summary

Extensive spectroscopic information determined

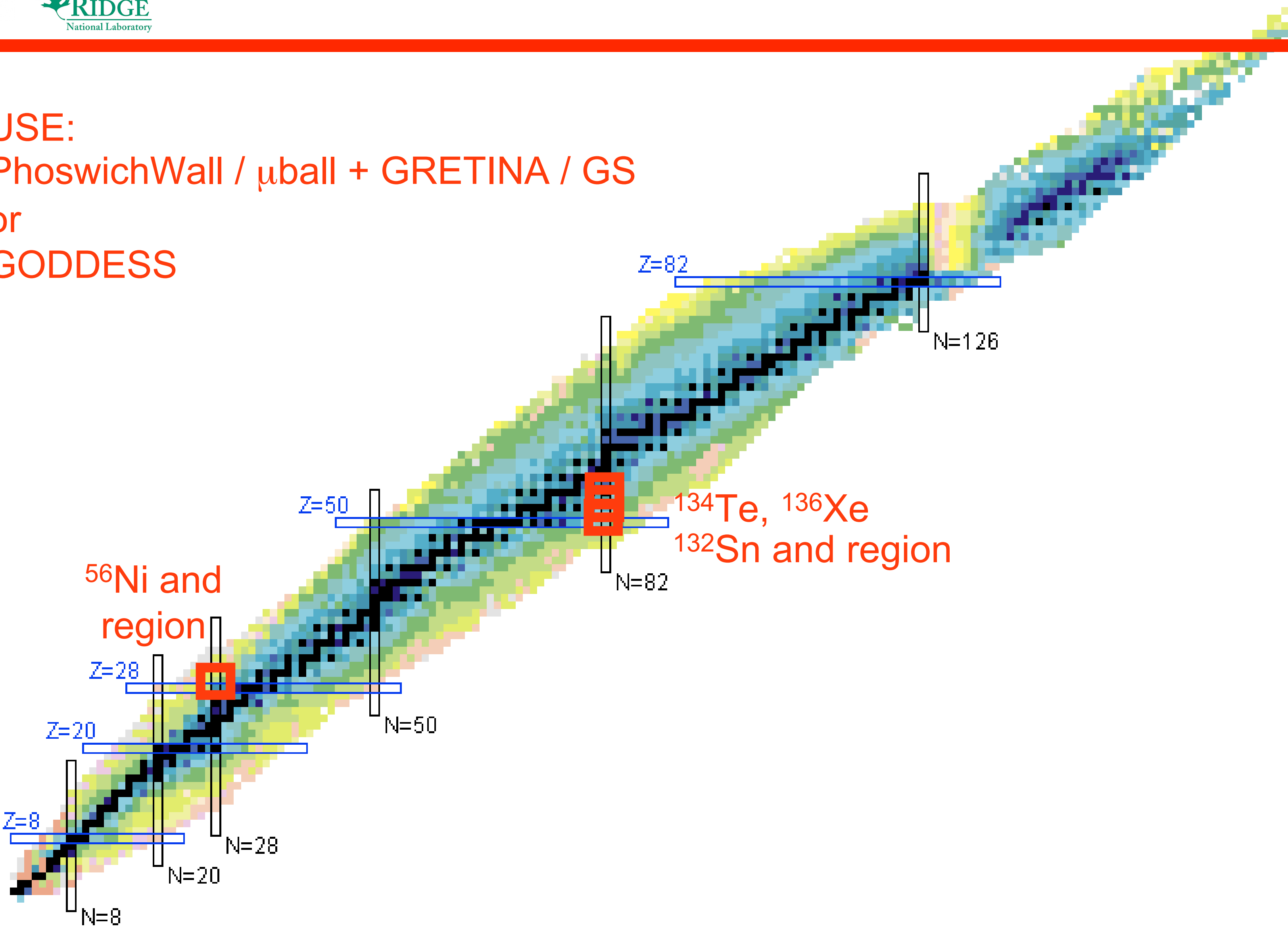
Complete Spectroscopy by Particle-γ

J^π -- p-γ, γ paths, and target I+/- 1/2 selectivity
$E(J^\pi)$ -- γ-ray Energies
$\tau(J^\pi)$ -- Doppler Shift
$\sigma(J^\pi)$ -- γ-ray Intensities
Spectroscopic Factors (questionable)
Asymptotic Normalization Coefs. (reliable)



Initial Cases for CARIBU / AIRIS

USE:
PhoswichWall / μball + GRETINA / GS
or
GODDESS



Thanks to all of the Collaborators

D.C. Radford[2], A. Galindo-Uribarri[2,3], A.E. Stuchbery[4], J.R. Beene[2], R.L. Varner[2], E. Padilla-Rodal[5],
A. Ayres[3], A. Bey[3], J.C. Batchelder[6], C.R. Bingham[2,3], M.E. Howard[7], K.L. Jones[3], J.F. Liang[2], B. Manning[7], P.E. Mueller[2], C.D. Nesaraja[2], S.D. Pain[2], W.A. Peters[6], A. Ratkiewicz[7], K.T. Schmitt[2,3], D. Shapira[2], M.S. Smith[2], N.J. Stone[3,8], and C.-H. Yu[2]

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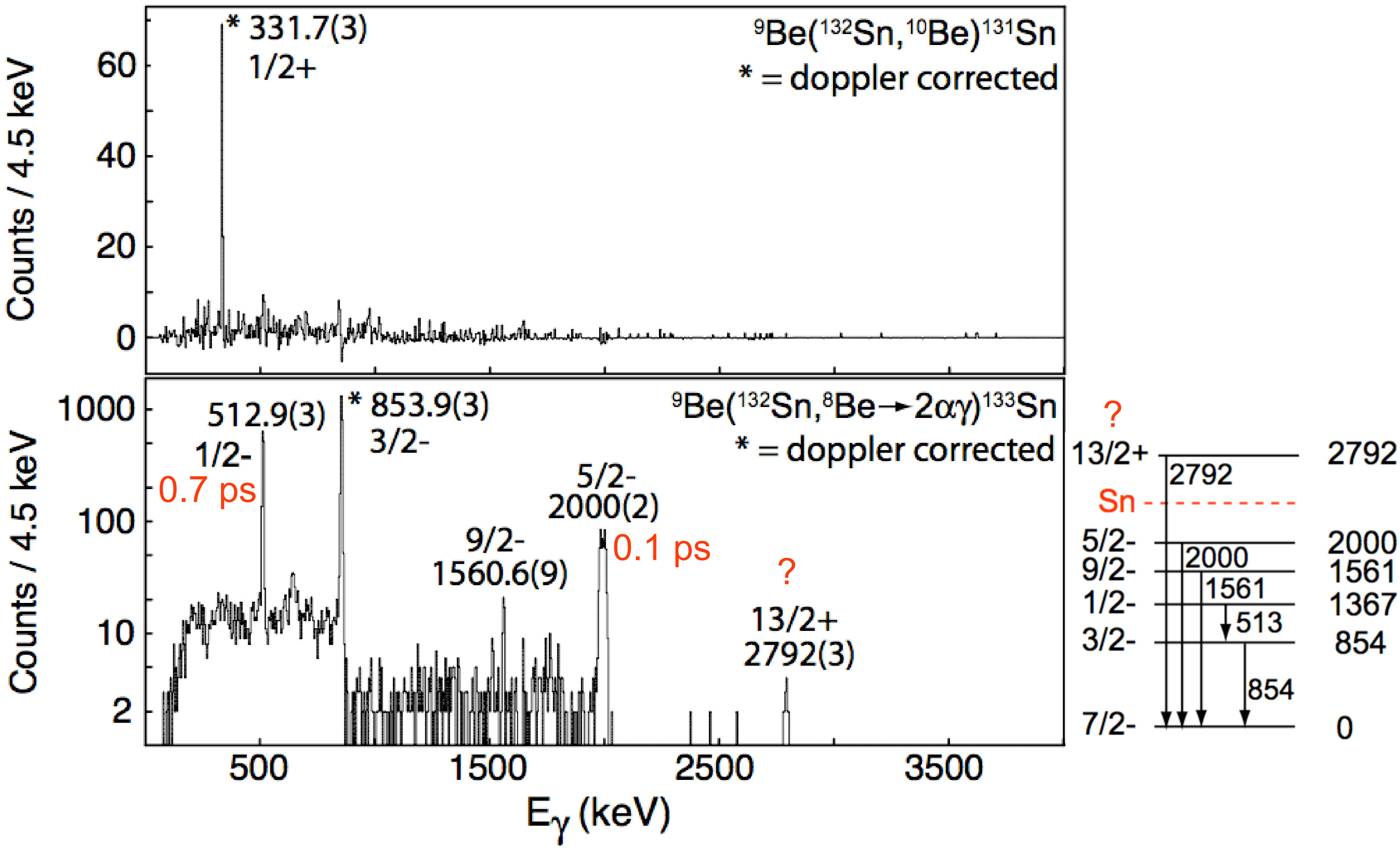
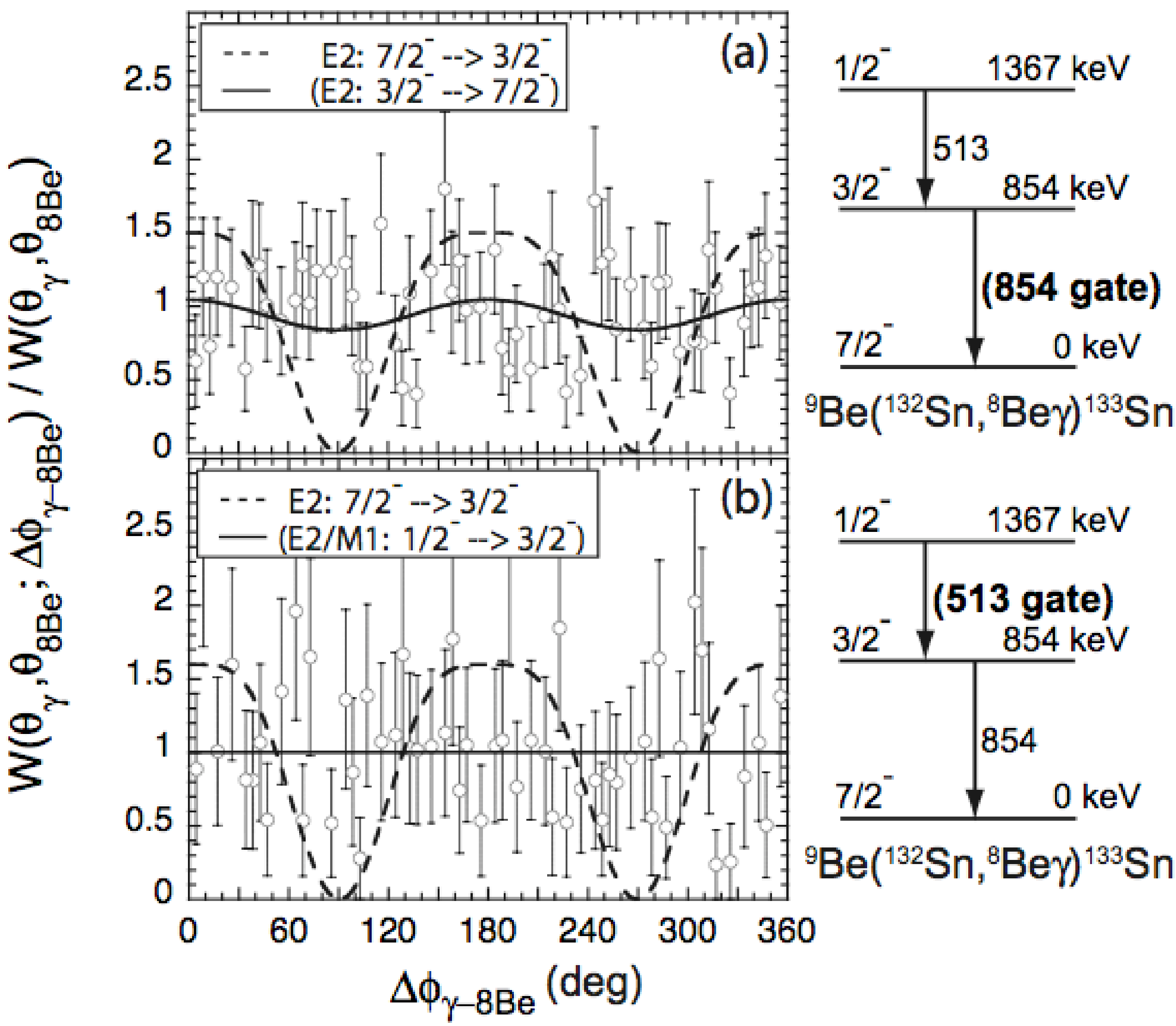
(^{9}Be, ^{10}Beγ)^{131}Sn and (^{9}Be, ^{8}Beγ)^{133}Sn

All expected N=83 single-particle states accounted for in ^{133}Sn



Particle-γ Angular Correlations in ^{133}Sn

The two transitions are consistent with low-spin initial states



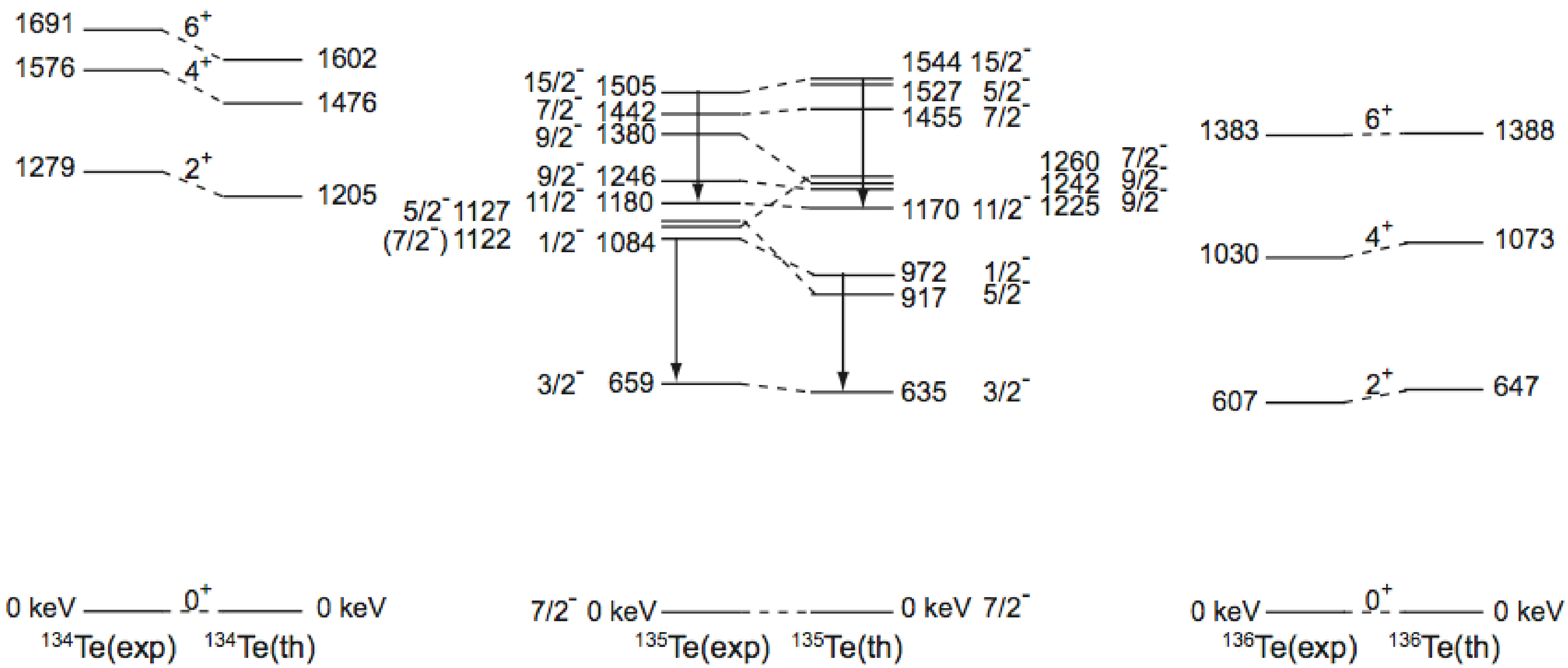
Results

E_x (keV)	J^{π} [a]	E_γ (keV)	τ (fs)	σ (mb)	σ_{thy} (mb)	Present (^{9}Be, ^{8,10}Be) S	[25,51] (d,p) S	Present (^{9}Be, ^{8,10}Be) C^2 (fm^{-1})	[25,51] (d, p) C^2 (fm^{-1})	[53] (^{13}C, ^{12}C) C^2 (fm^{-1})
					^{9}Be (^{208}Pb, ^{8}Be) ^{209}Pb					
0	$9/2^+$				0.0013(4)		1.21(36)		2.20(17)	2.25(29)
778.9(3)[b]	$11/2^+$				0.0005(2)		1.57(47)		0.00187(13)	0.0037(5)
1423(1)[b]	$15/2^-$				0.0001(1)		1.19(36)		$2.5(2) \times 10^{-5}$	
1566.0(9)	$5/2^+$	1566.0(9)		0.13(4)	0.084(21)	1.5(6)	1.08(32)	14(5)	13.0(7)	
2031(1)	$1/2^+$	464.5(4)		0.28(2)	0.22(5)	1.3(3)	1.04(31)	45(8)	48.7(30)	41.7(54)
2489(2)	$7/2^+$	2489(2)		0.10(2)	0.062(19)	1.6(6)	1.27(38)	0.026(6)	0.025(2)	
2535(1)	$3/2^+$	969.4(6)	87(24)	0.43(3)	0.38(9)	1.1(3)	1.11(33)	2.3(4)	2.93(20)	
					^{9}Be (^{132}Sn, ^{10}Be) ^{131}Sn					
0	$(3/2^+)$				0.15(11)					
331.7(3)	$(1/2^+)$	331.7(3)		0.68(8)	0.17(12)	4(3)				
1654.53(8)[b]	$(5/2^+)$				0.03(2)					
					^{9}Be (^{132}Sn, ^{8}Be) ^{133}Sn					
0	$7/2^-$				3(1)		0.86(7)		0.64(5)	
853.9(3)	$3/2^-$	853.9(3)		12(1)	13(3)	0.9(2)	0.92(7)	6.0(14)	5.6(4)	
1366.8(4)	$1/2^-$	512.9(3)	$480(^{+160}_{-100})$	11(1)	12(3)	0.9(2)	1.1(2)	2.5(5)	2.6(6)	
1560.6(9)	$(9/2^-)$	1560.6(9)		0.58(10)	1.1(4)	0.5(2)		$5.1(15) \times 10^{-6}$		
2002(2)	$5/2^-$	2002(2)	$13(^{+10}_{-13})$	8.6(6)	9.6(24)	0.9(2)	1.1(2)	0.0020(4)	0.0009(2)	
2792(3)		2792(3)		0.38(9)	0.18(7)[c]					

Results

Nuclide	Transition	$B(M1)^{exp}$	$B(M1)^{thy}$
^{209}Pb	$3d_{3/2} \rightarrow 3d_{5/2}$	0.72(20)	0.71[b]
^{207}Pb	$3p^{-1}_{3/2} \rightarrow 3p^{-1}_{1/2}$	0.47(6)[a]	0.40[b]
^{133}Sn	$2f_{5/2} \rightarrow 2f_{7/2}$	$0.55(^{+\infty}_{-14})$	0.52[c]
^{133}Sn	$3p_{1/2} \rightarrow 3p_{3/2}$	$0.88(^{+23}_{-22})$	0.67[c]

Results


1691
1576
1279
6+
4+
2+
1602
1476
1205
0 keV
0+
0 keV
134Te(exp)
134Te(th)
15/2- 1505
7/2- 1442
9/2- 1380
9/2- 1246
11/2- 1180
5/2- 1127
(7/2-) 1122
1/2- 1084
3/2- 659
7/2- 0 keV
135Te(exp)
1544 15/2-
1527 5/2-
1455 7/2-
1260 7/2-
1242 9/2-
1225 9/2-
1170 11/2-
972 1/2-
917 5/2-
635 3/2-
0 keV 7/2-
135Te(th)
1383
6+
1388
1030
4+
1073
607
2+
647
0 keV
0+
0 keV
136Te(exp)
136Te(th)