Collectivity in self-conjugate nuclei

Chris Morse

Nuclear Science Division
Lawrence Berkeley National Laboratory

This material is based upon work supported by the U.S. Department of Energy,
Office of Science, Office of Nuclear Physics under Contract No. DE-AC02-05CH11231.

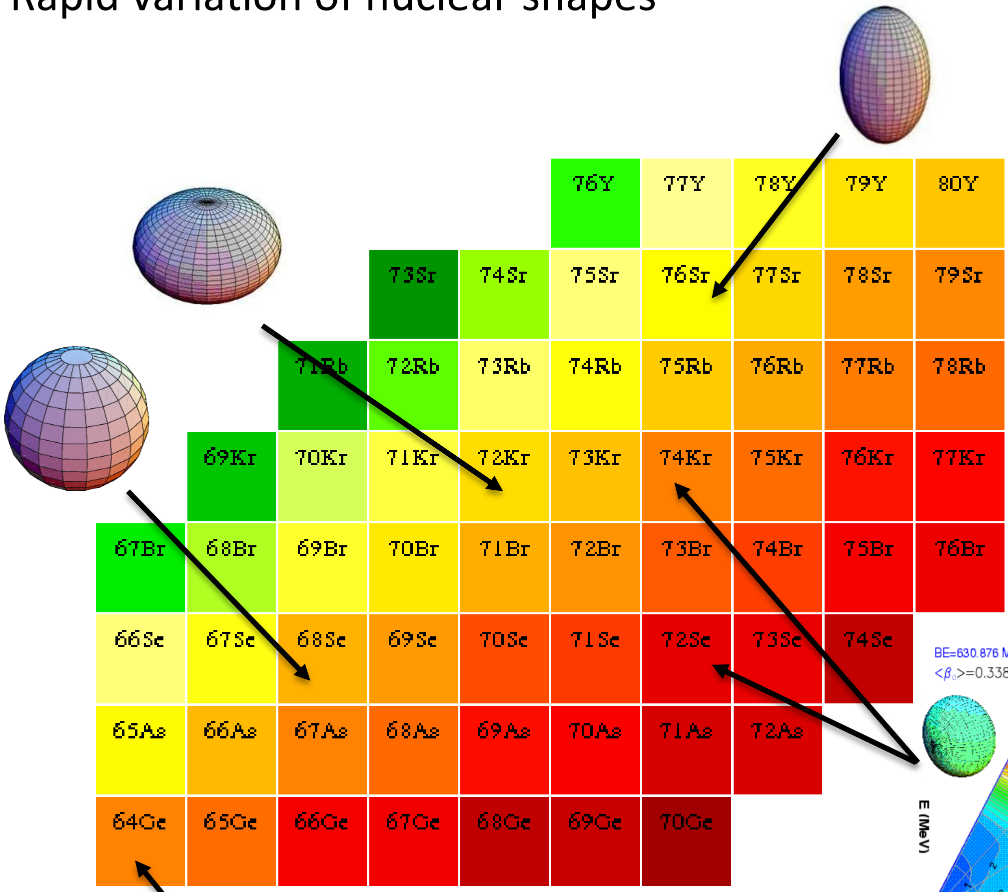
March 24, 2020

Outline

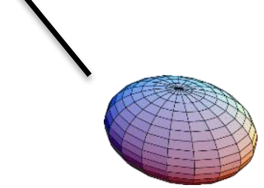
- Introduction
- New lifetime measurement technique
- Lifetime measurement in ^{74}Rb
- Discussion

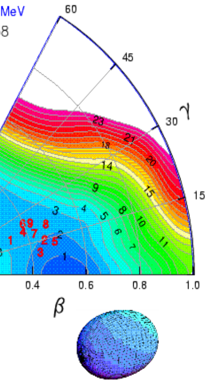
Collectivity in N=Z Nuclei

Rapid variation of nuclear shapes



					76Y	77Y	78Y	79Y	80Y
			73Sr	74Sr	75Sr	76Sr	77Sr	78Sr	79Sr
		71Rb	72Rb	73Rb	74Rb	75Rb	76Rb	77Rb	78Rb
	69Kr	70Kr	71Kr	72Kr	73Kr	74Kr	75Kr	76Kr	77Kr
67Br	68Br	69Br	70Br	71Br	72Br	73Br	74Br	75Br	76Br
66Se	67Se	68Se	69Se	70Se	71Se	72Se	73Se	74Se	
65As	66As	67As	68As	69As	70As	71As	72As		
64Ge	65Ge	66Ge	67Ge	68Ge	69Ge	70Ge			





K. Starosta et al., PRL 99, 042503 (2012)

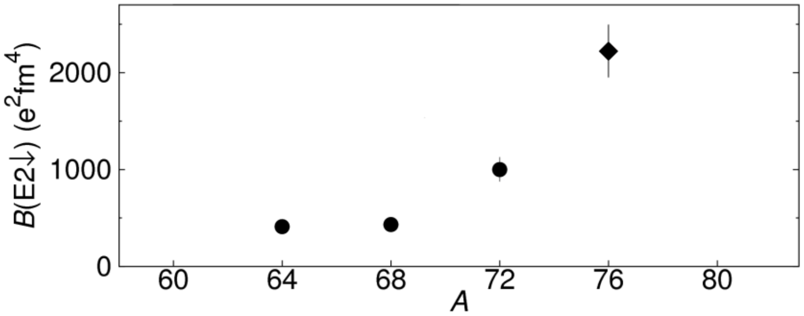
A. Obertelli et al., PRC 80, 031304 (2009)

A. Gade et al., PRL 95, 022502 (2005)

J. H. Hamilton et al., PRL 32, 239 (1974)

E. Clément et al., PRC 75, 054313 (2007)

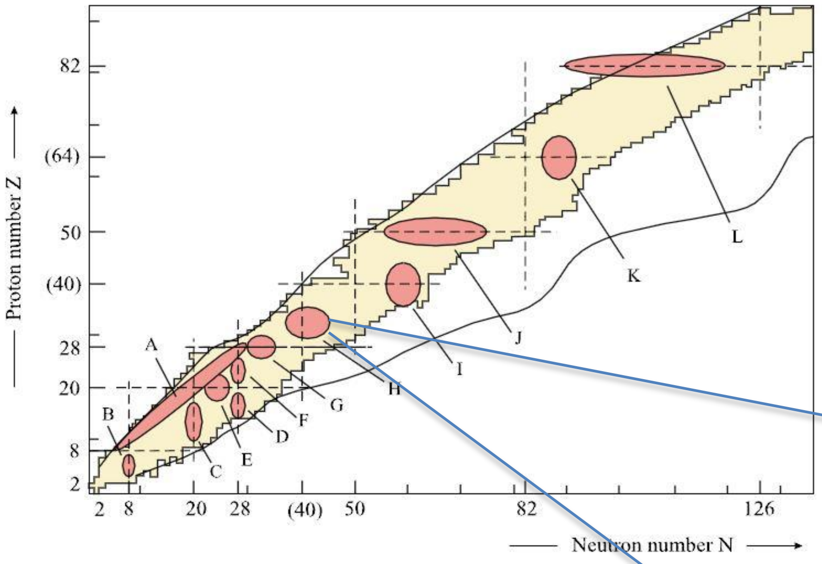
Sharp rise in collectivity

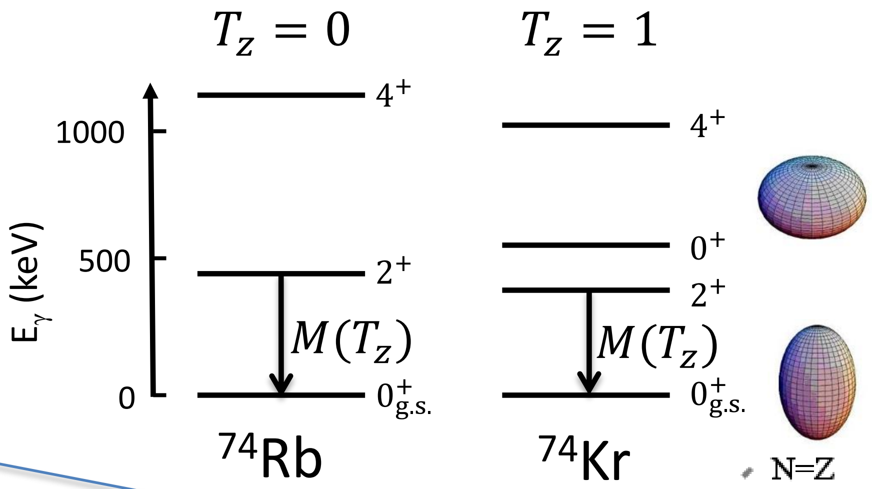


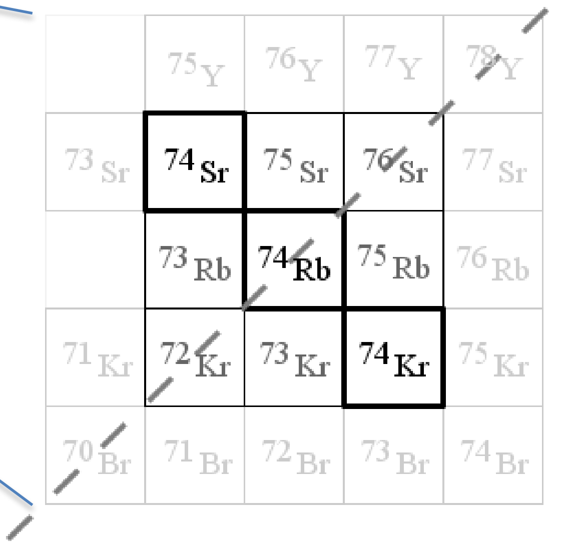
A. Lemasson et al., PRC 85, 041303 (2012)

Even-even N=Z nuclei have been well studied; what can we learn from the odd-odd nuclei in this region?

The A = 74 system







	^{75}Y	^{76}Y	^{77}Y	^{78}Y
^{73}Sr	^{74}Sr	^{75}Sr	^{76}Sr	^{77}Sr
	^{73}Rb	^{74}Rb	^{75}Rb	^{76}Rb
^{71}Kr	^{72}Kr	^{73}Kr	^{74}Kr	^{75}Kr
^{70}Br	^{71}Br	^{72}Br	^{73}Br	^{74}Br

Compare A=74 system to systematics along the N=Z line.

$$\frac{1}{2}(M_0 - T_z M_1) = M(T_z)$$

A.M. Bernstein et al., PRL 42 (1979) 425

Methodology

Connect lifetime with B(E2) strength via

$$\frac{1}{\tau} = \sum_{\pi,\lambda} \left(\frac{8\pi(\lambda+1)}{\lambda[(2\lambda+1)!!]^2} \right) \left(\frac{E_\gamma^{2\lambda+1}}{\hbar(\hbar c)^{2\lambda+1}} \right) \frac{\left| \langle J_f \| \mathcal{O}(\pi\lambda) \| J_i \rangle \right|^2}{2J_i+1}$$

$$B(E2\downarrow) = \frac{816}{E_\gamma^5 \tau} e^2 \mathrm{fm}^4 \mathrm{MeV}^5 \mathrm{ps}$$

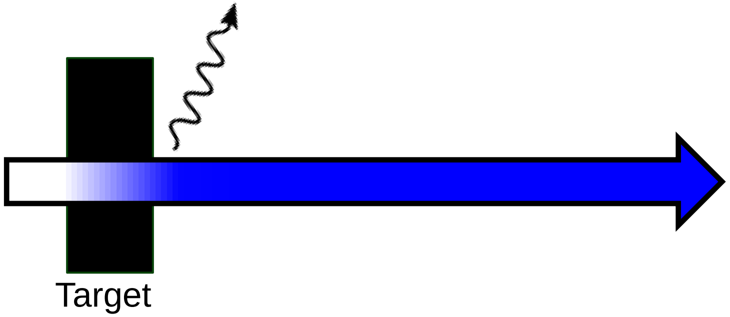
	$B(E2\downarrow)$ ($e^2\mathrm{fm}^4$)	E_γ (keV)	τ (ps)	
^{74}Kr	1223(22)	455.7	33.8(6)	$T_z = 1$
^{74}Rb	?	477.8	?	$T_z = 0$

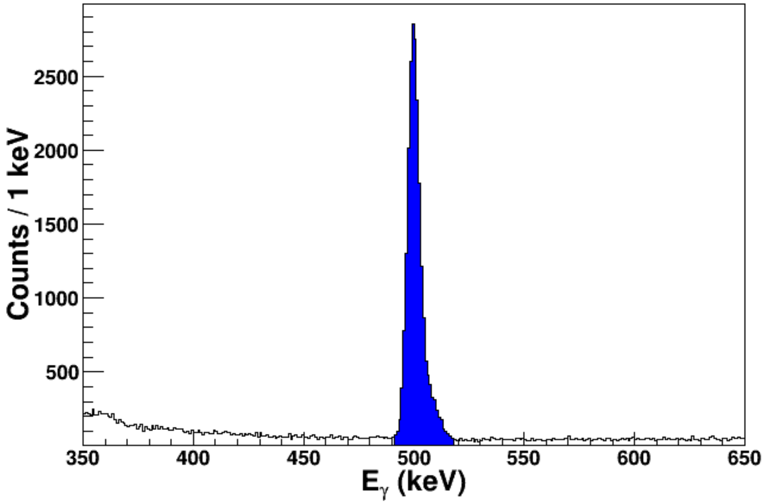
A. Görgen et al., Eur. Phys. J. A 26, 153 (2005)
S. Fischer et al., Phys. Rev. C 74, 054304 (2006)

$$\frac{1}{2}(M_0 - T_z M_1) = \sqrt{(2J_i+1) B(E2; J_i \rightarrow J_f)}$$

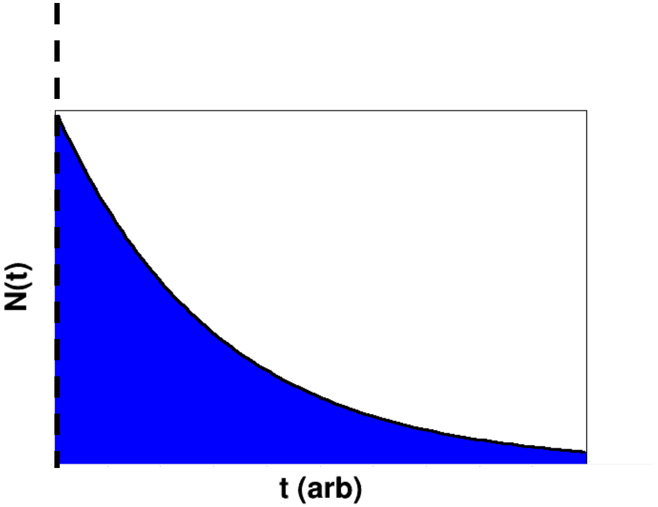
A.M. Bernstein et al., PRL 42 (1979) 425

Recoil Distance Method



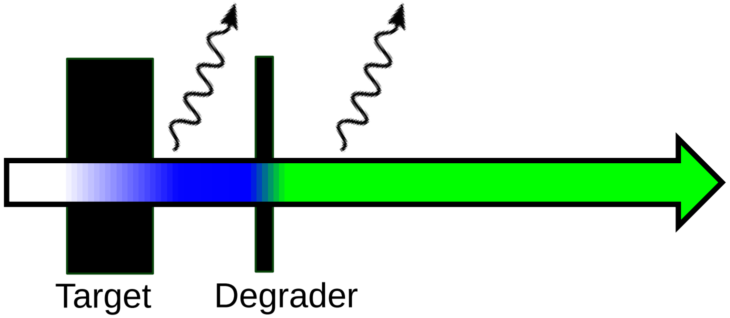


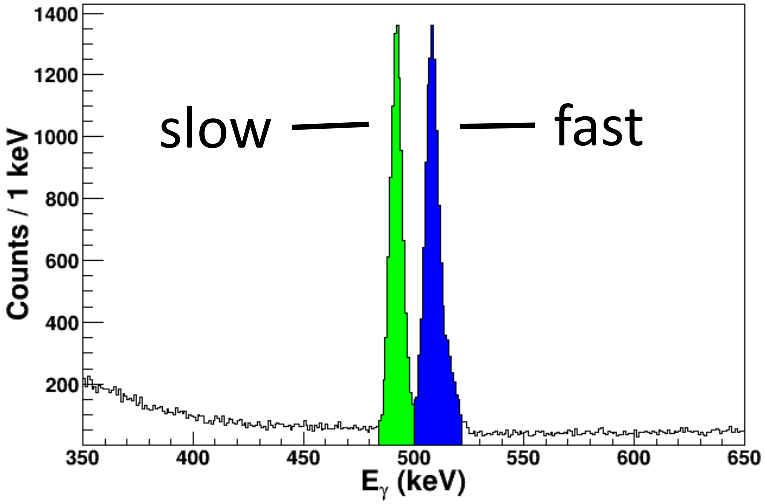
$$N(t) = N_0 e^{-t/\tau}$$



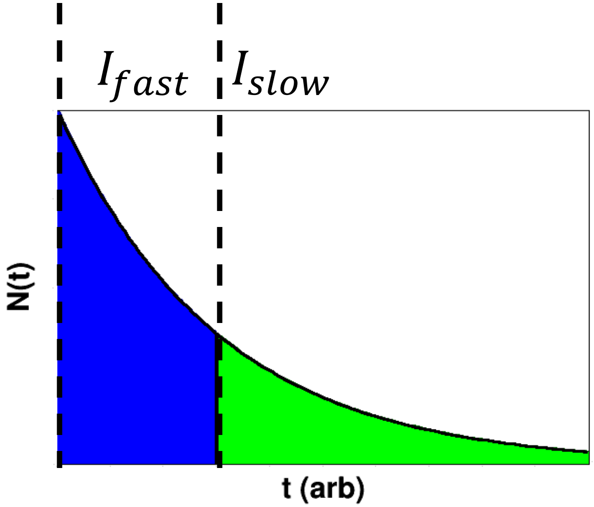
A. Dewald, S. Harissopulos, and P. von Brentano, Z. Phys. A334, 163 (1989)

Recoil Distance Method



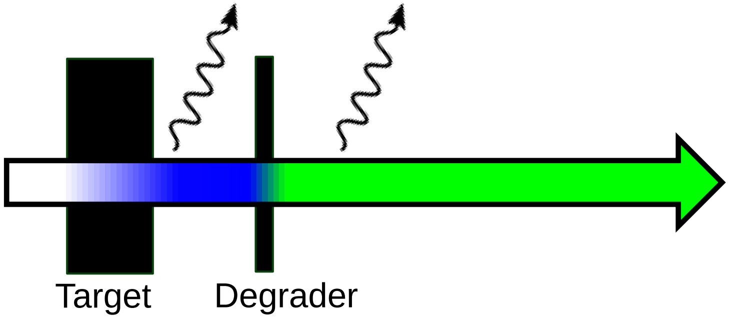


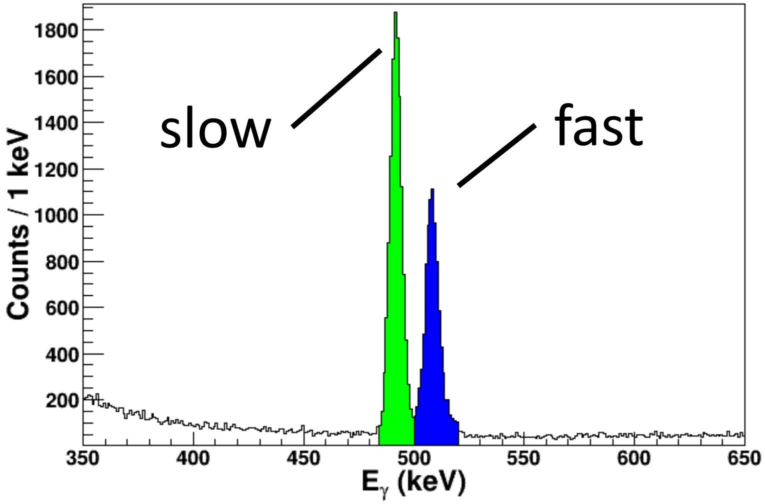
$$N(t) = N_0 e^{-t/\tau}$$



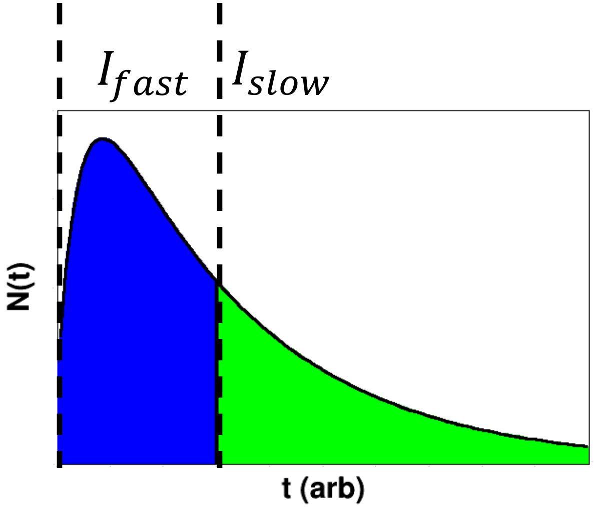
A. Dewald, S. Harissopulos, and P. von Brentano, Z. Phys. A334, 163 (1989)

Recoil Distance Method





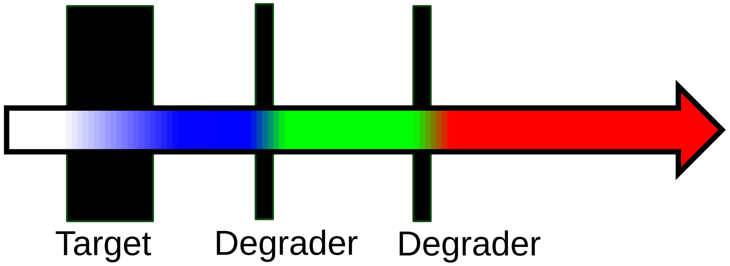
$$N(t) = N_0 e^{-t/\tau}$$

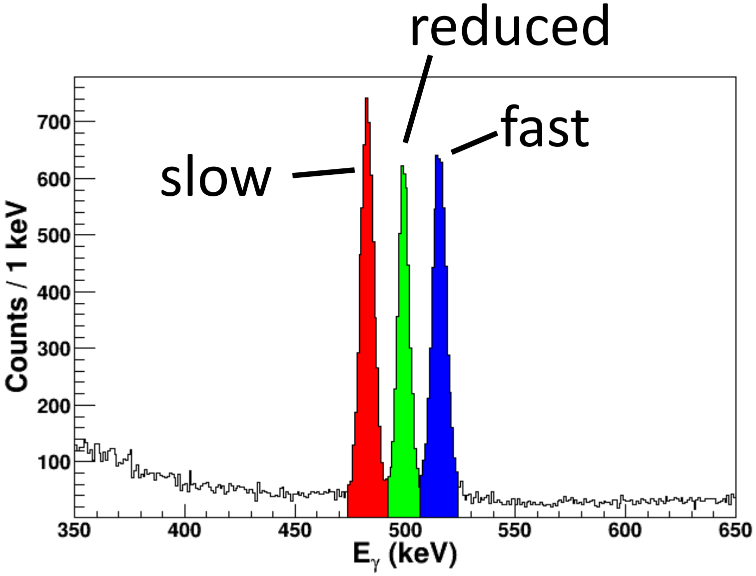


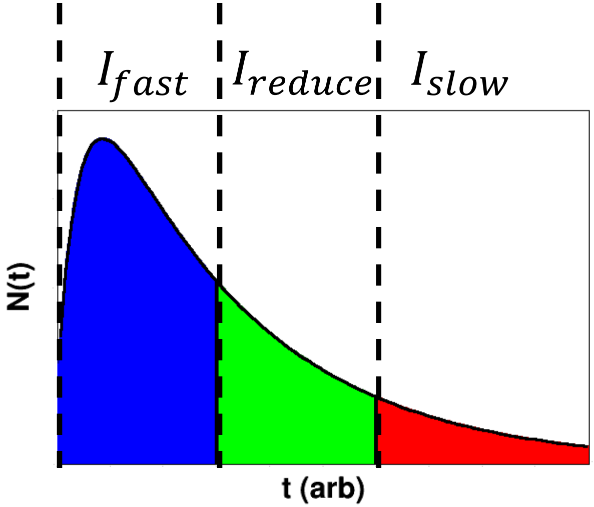
A. Dewald, S. Harissopulos, and P. von Brentano, Z. Phys. A334, 163 (1989)

Differential Recoil Distance Method

Differential Recoil Distance Method







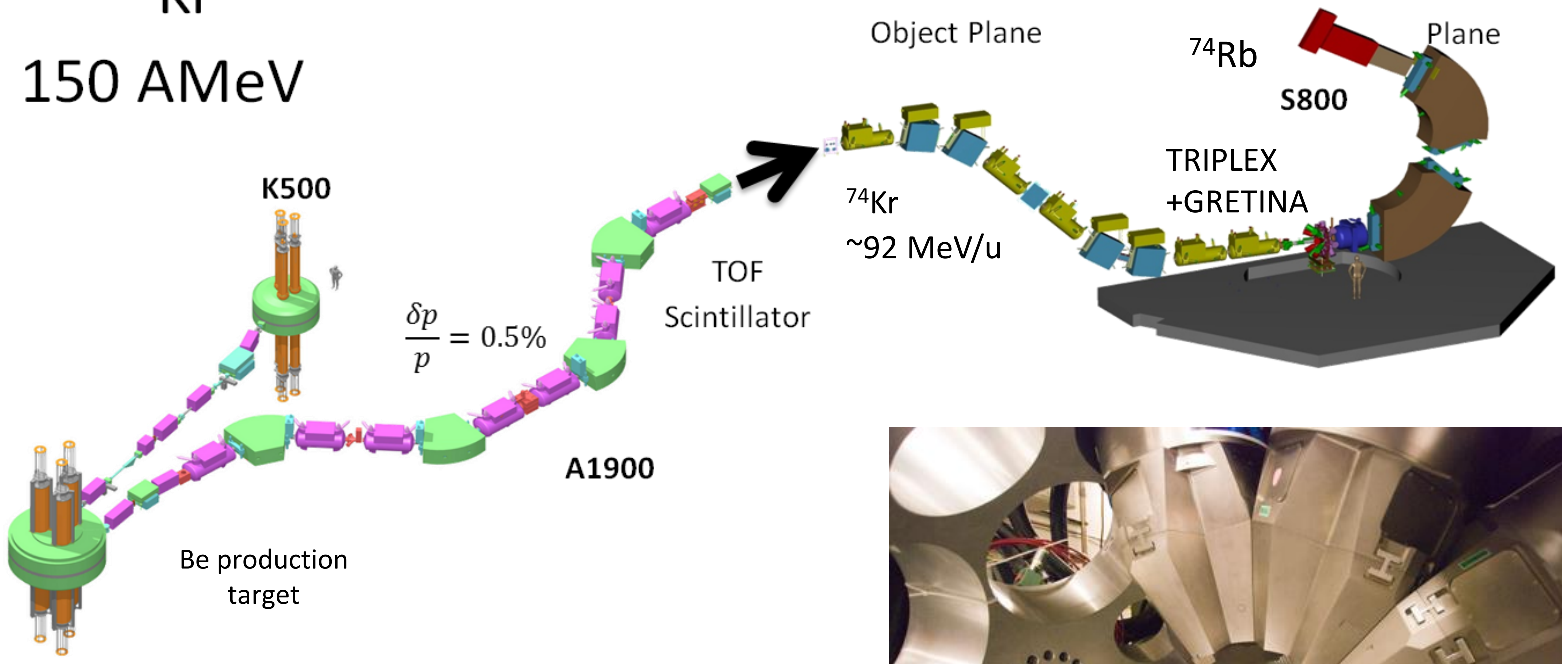
$$N(t) = N_0 e^{-t/\tau} = I_s$$

$$\left|\frac{dN(t)}{dt}\right| = \frac{N_0}{\tau} e^{-t/\tau} \approx \frac{I_r}{\Delta t}$$

$$\tau = N(t) \Big/ \left|\frac{dN(t)}{dt}\right|$$

A. Dewald, S. Harissopulos, and P. von Brentano, Z. Phys. A334, 163 (1989)

Experimental Setup



^{78}Kr

150 AMeV

K500

K1200

Be production target

$\frac{\delta p}{p} = 0.5\%$

A1900

TOF Scintillator

Scintillator at Object Plane

^{74}Kr

~92 MeV/u

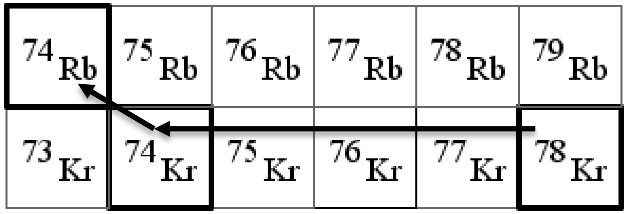
^{74}Kr

^{74}Rb

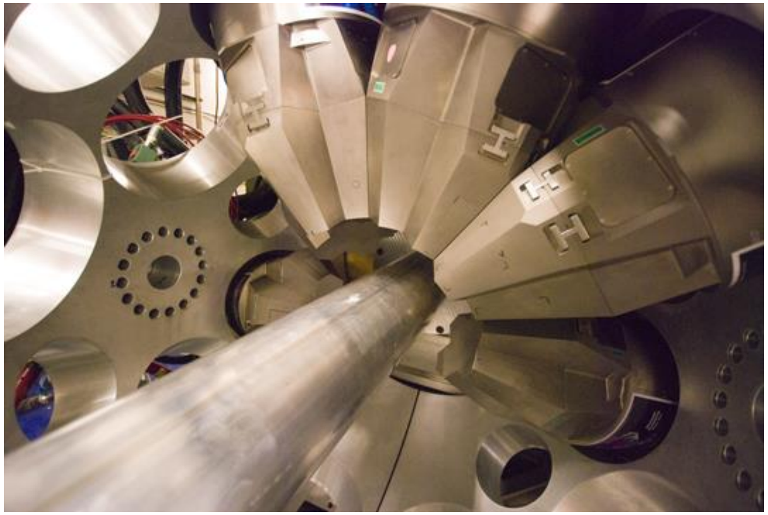
S800

TRIPLEX +GRETINA

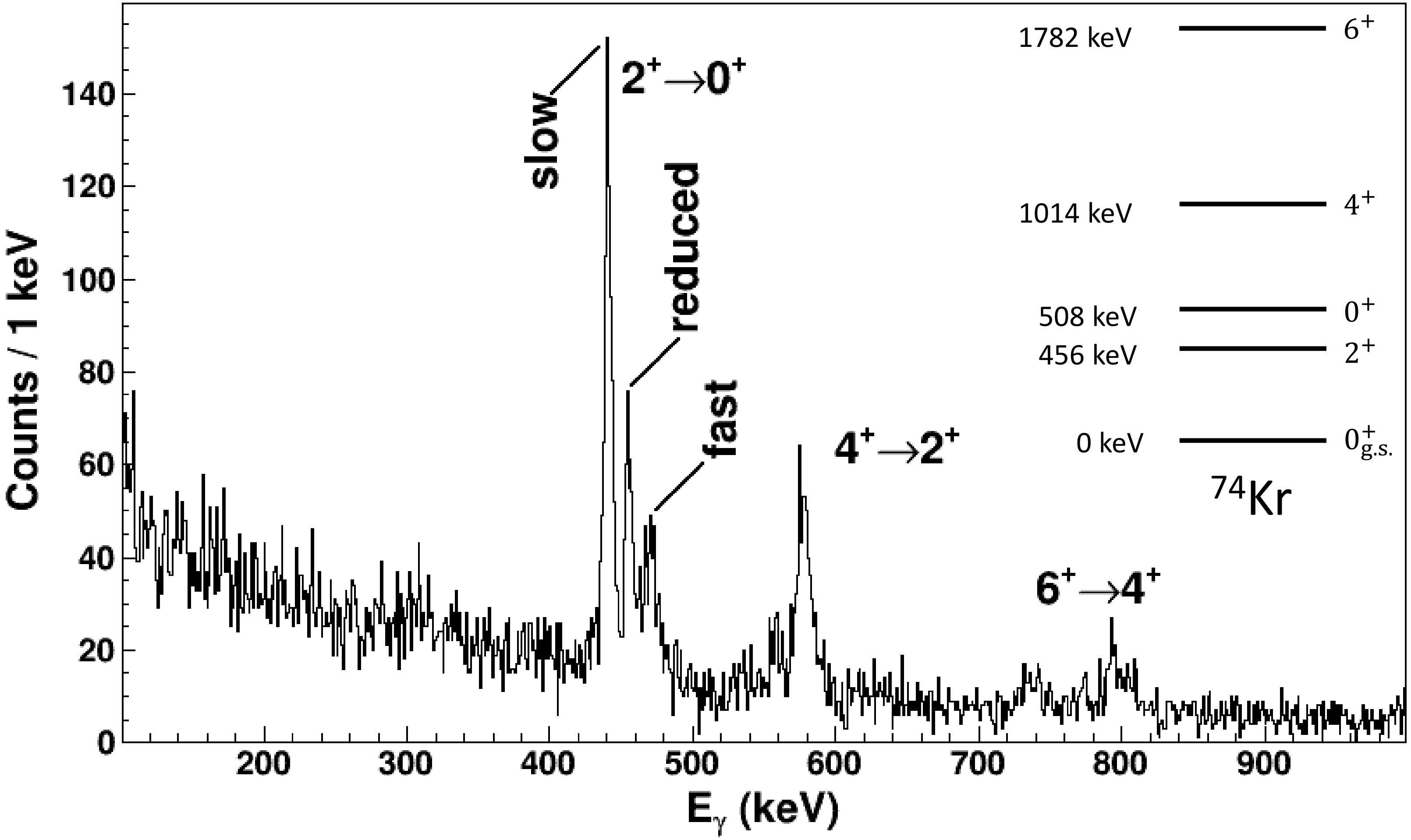
Focal Plane



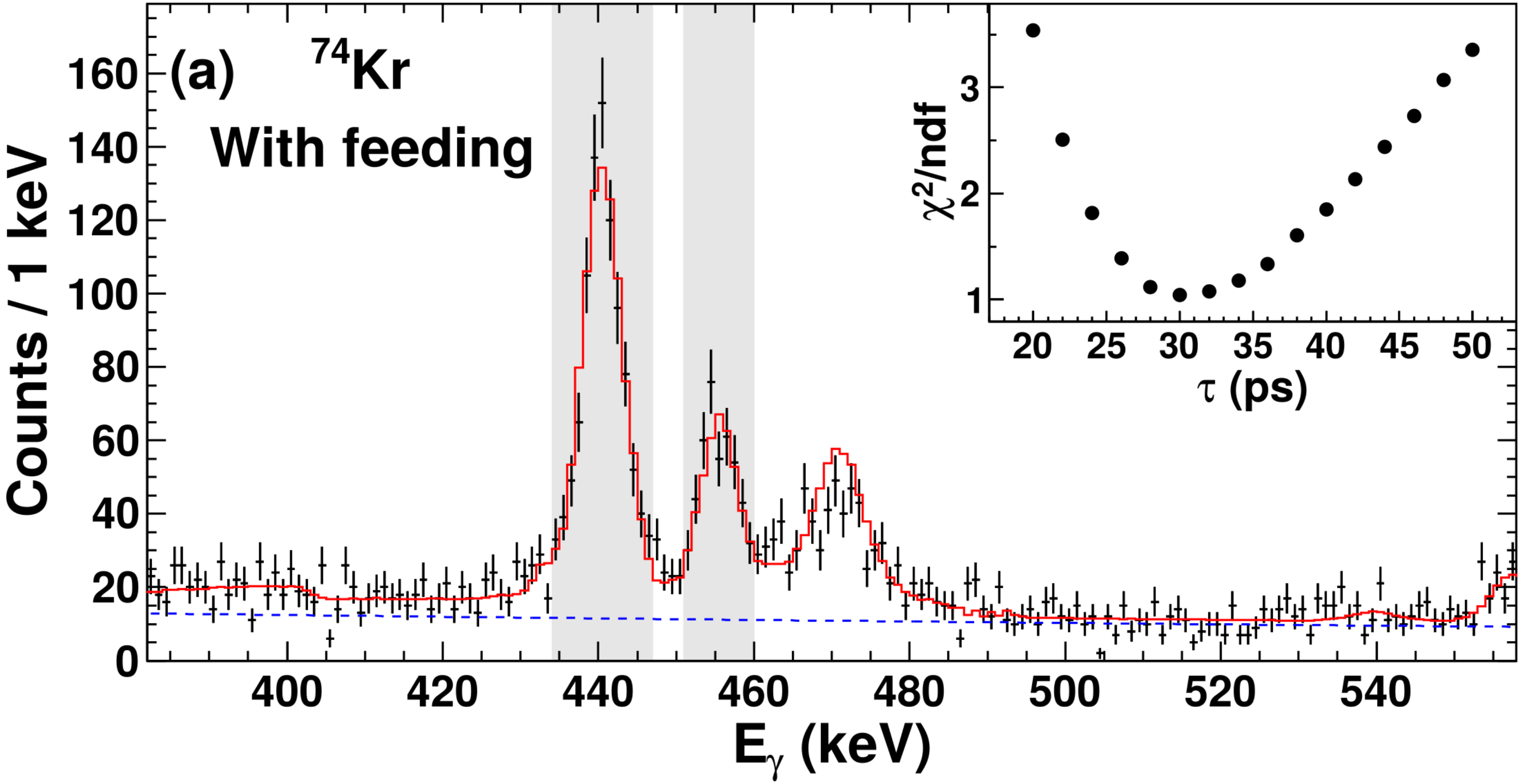
^{74}Rb	^{75}Rb	^{76}Rb	^{77}Rb	^{78}Rb	^{79}Rb
^{73}Kr	^{74}Kr	^{75}Kr	^{76}Kr	^{77}Kr	^{78}Kr



^{74}Kr reference

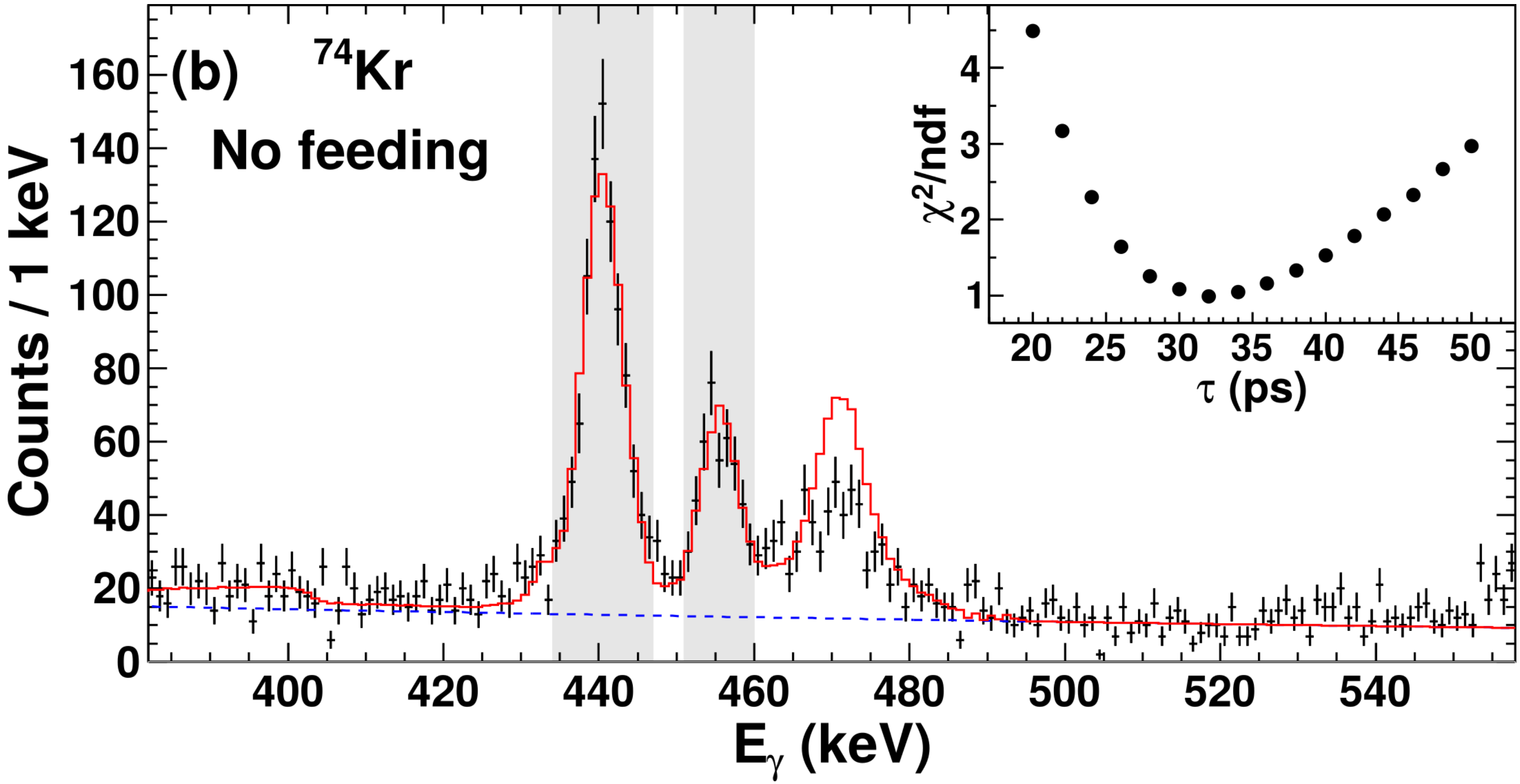


^{74}Kr reference



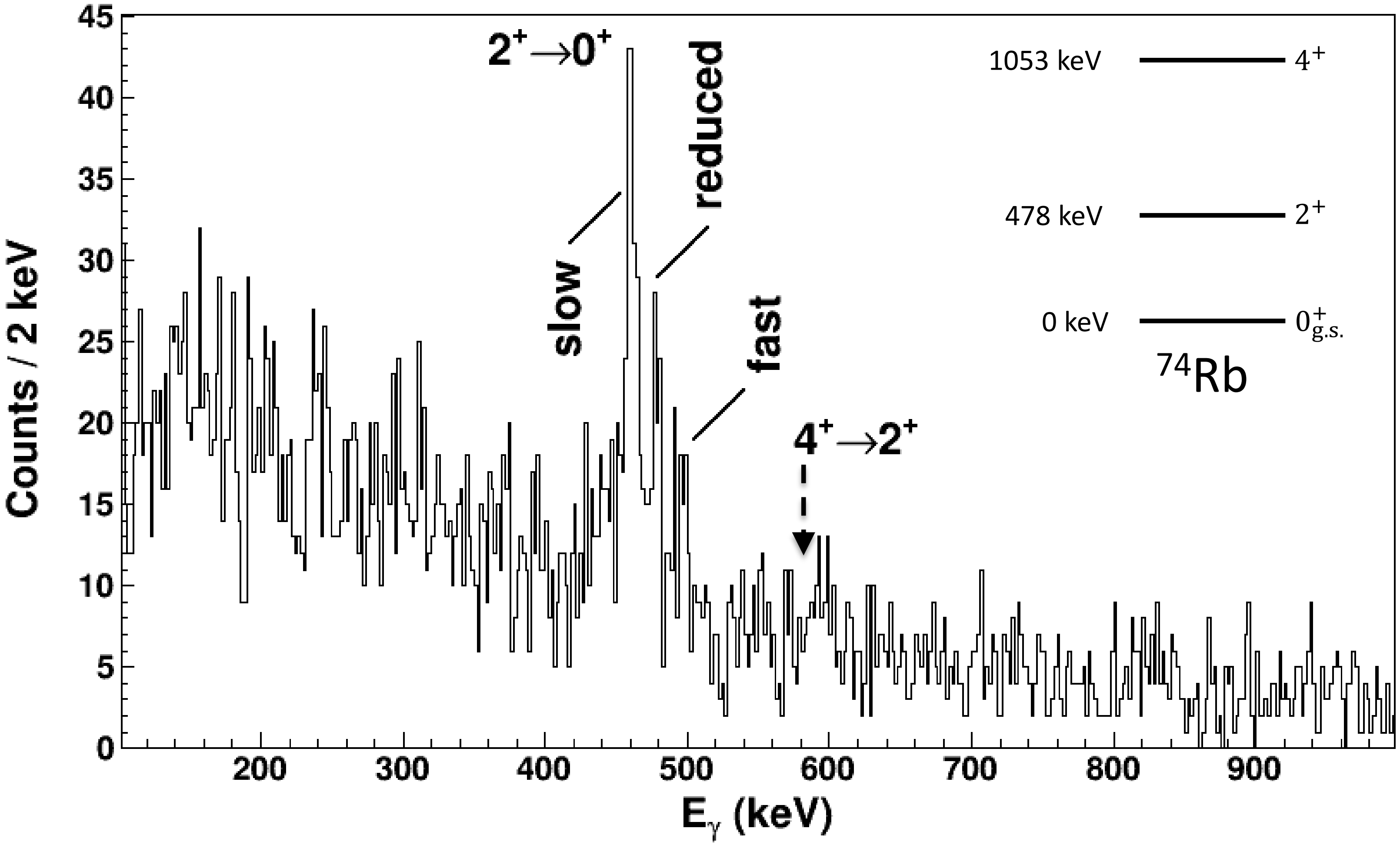
$\tau = 31(3)$ ps $\qquad \tau_{lit} = 33.8(6)$ ps

^{74}Kr reference

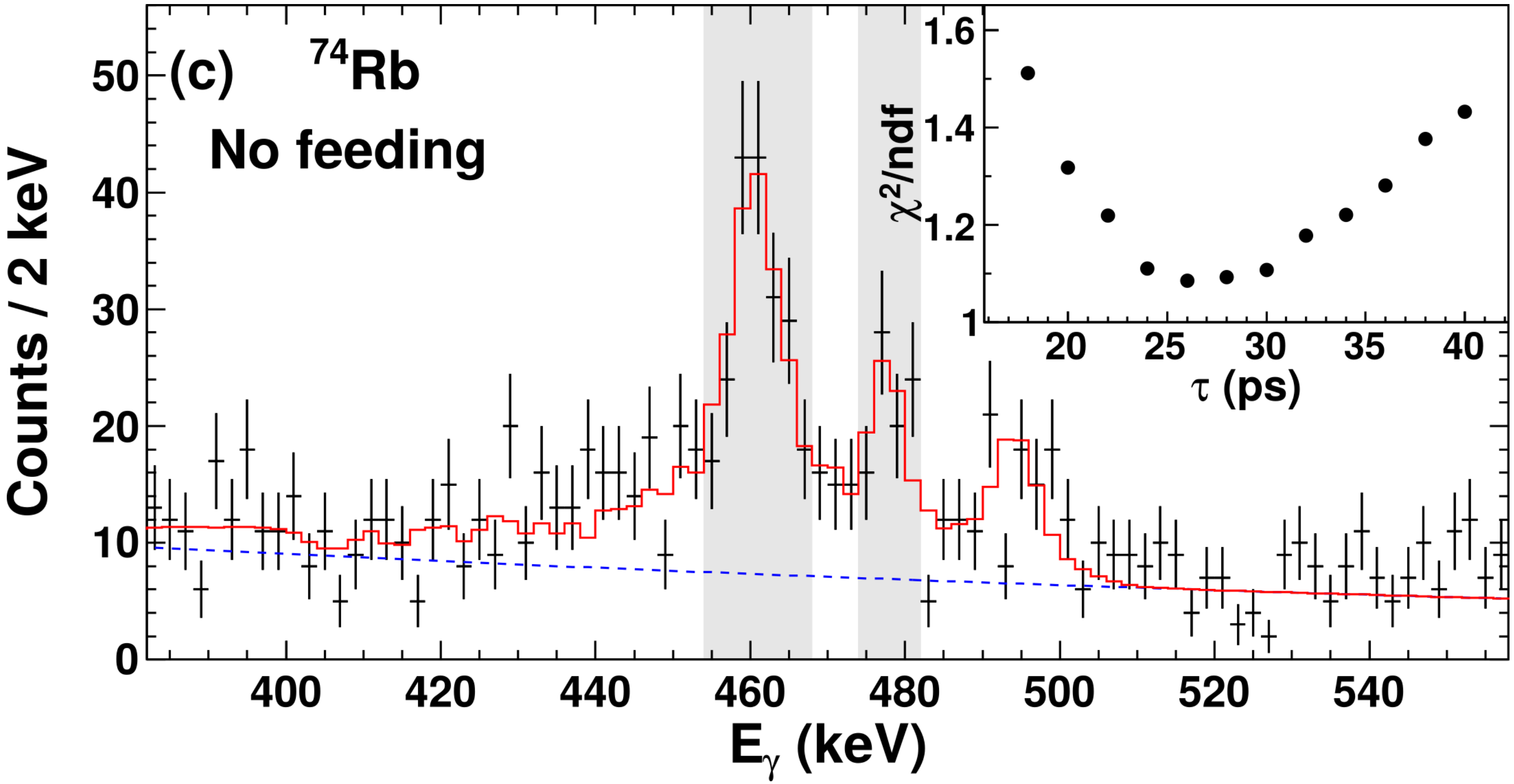


$\tau = 33(3)$ ps $\qquad \tau_{lit} = 33.8(6)$ ps

^{74}Rb data


45
40
35
30
25
20
15
10
5
0
Counts / 2 keV
200
300
400
500
600
700
800
900
E_γ (keV)
$2^+ \rightarrow 0^+$
slow
reduced
fast
$4^+ \rightarrow 2^+$
1053 keV
4^+
478 keV
2^+
0 keV
$0^+_{g.s.}$
^{74}Rb

^{74}Rb data



$$\tau = 27(6)\ \mathrm{ps}$$

Discussion

	$\boldsymbol{B(E2\downarrow)}$ $(\boldsymbol{e^2\mathrm{fm}^4})$	$\boldsymbol{E_\gamma}$ (keV)	$\boldsymbol{\tau}$ (ps)
^{74}Kr	1223(22)	455.7	33.8(6)
^{74}Rb	1227(276)	477.8	27(6)

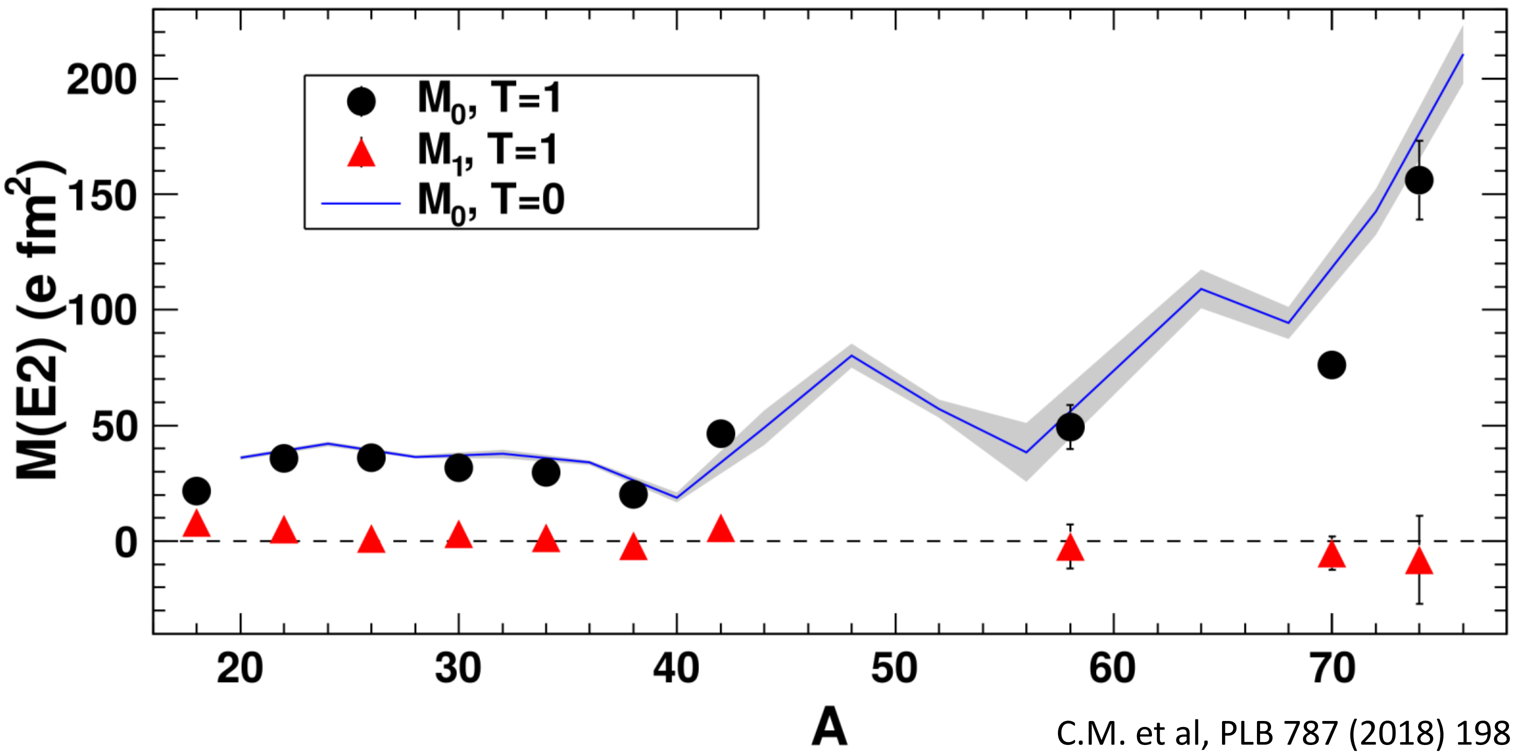
Decompose matrix elements (i.e. B(E2) values) into isoscalar and isovector parts[1]

$$\frac{1}{2}(M_0 - T_z M_1) = \sqrt{(2J_1 + 1)B(E2; J_i \rightarrow J_f)}$$

^{74}Rb $(T_z = 0)$: $M_0 = 160(20)e\mathrm{fm}^2$ ^{74}Kr $(T_z = 1)$: $M_1 = -10(20)e\mathrm{fm}^2$

[1] A.M. Bernstein et al., PRL 42 (1979) 425

Discussion



C.M. et al, PLB 787 (2018) 198

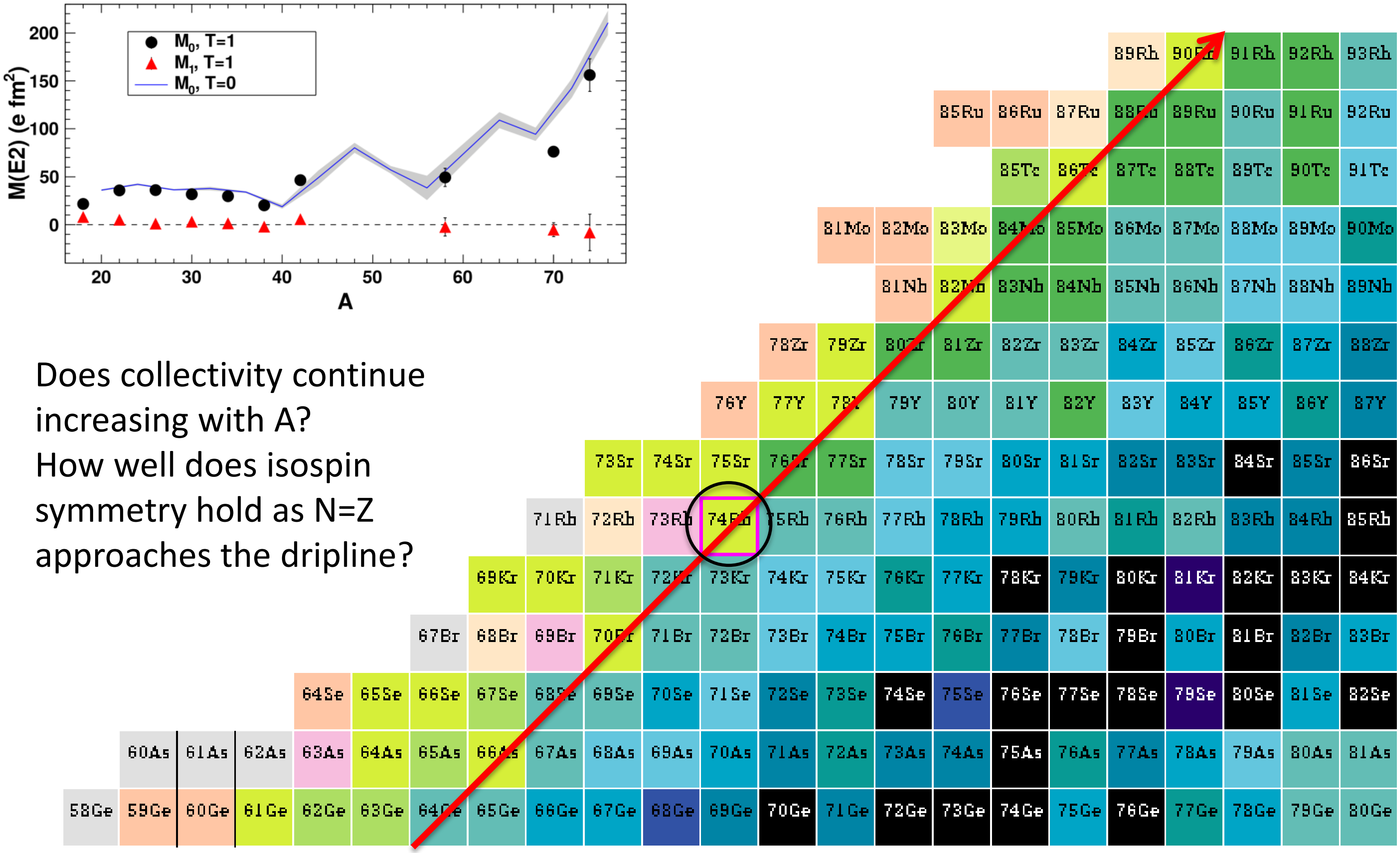
Identical evolution of the matrix elements in T=0 and T=1 systems suggests that the collectivity in these nuclei has a common origin.

Consistent with proposal by A.O. Macchiavelli *et al.* that $T = 1$ pairs give rise to collectivity, while $T = 0$ pairs are not collective.[1]

---

[1] A.O. Macchiavelli et al, PLB 480 (2000) 1

Looking forward



Does collectivity continue increasing with A?

How well does isospin symmetry hold as N=Z approaches the dripline?

																		89Rh	90Rh	91Rh	92Rh	93Rh
															85Ru	86Ru	87Ru	88Ru	89Ru	90Ru	91Ru	92Ru
																85Tc	86Tc	87Tc	88Tc	89Tc	90Tc	91Tc
													81Mo	82Mo	83Mo	84Mo	85Mo	86Mo	87Mo	88Mo	89Mo	90Mo
														81Nb	82Nb	83Nb	84Nb	85Nb	86Nb	87Nb	88Nb	89Nb
												78Zr	79Zr	80Zr	81Zr	82Zr	83Zr	84Zr	85Zr	86Zr	87Zr	88Zr
											76Y	77Y	78Y	79Y	80Y	81Y	82Y	83Y	84Y	85Y	86Y	87Y
									73Sr	74Sr	75Sr	76Sr	77Sr	78Sr	79Sr	80Sr	81Sr	82Sr	83Sr	84Sr	85Sr	86Sr
								71Rb	72Rb	73Rb	74Rb	75Rb	76Rb	77Rb	78Rb	79Rb	80Rb	81Rb	82Rb	83Rb	84Rb	85Rb
							69Kr	70Kr	71Kr	72Kr	73Kr	74Kr	75Kr	76Kr	77Kr	78Kr	79Kr	80Kr	81Kr	82Kr	83Kr	84Kr
						67Br	68Br	69Br	70Br	71Br	72Br	73Br	74Br	75Br	76Br	77Br	78Br	79Br	80Br	81Br	82Br	83Br
				64Se	65Se	66Se	67Se	68Se	69Se	70Se	71Se	72Se	73Se	74Se	75Se	76Se	77Se	78Se	79Se	80Se	81Se	82Se
	60As	61As	62As	63As	64As	65As	66As	67As	68As	69As	70As	71As	72As	73As	74As	75As	76As	77As	78As	79As	80As	81As
58Ge	59Ge	60Ge	61Ge	62Ge	63Ge	64Ge	65Ge	66Ge	67Ge	68Ge	69Ge	70Ge	71Ge	72Ge	73Ge	74Ge	75Ge	76Ge	77Ge	78Ge	79Ge	80Ge

Thank you for
your attention!