Isomeric yield ratios at IGISOL

In the quest of probing angular momenta of fission fragments

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S. Pomp and the IGISOL collaboration

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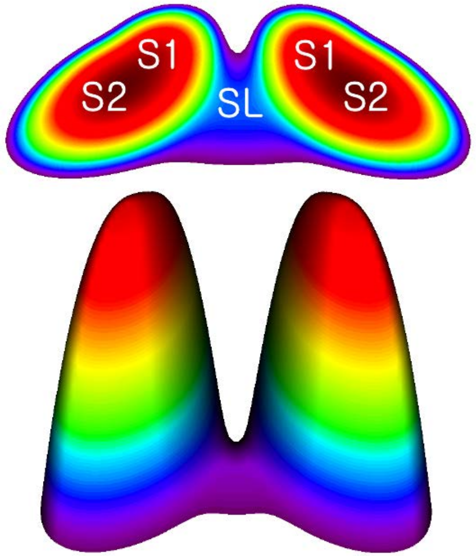
Fission is the mission

JRC
EUROPEAN COMMISSION

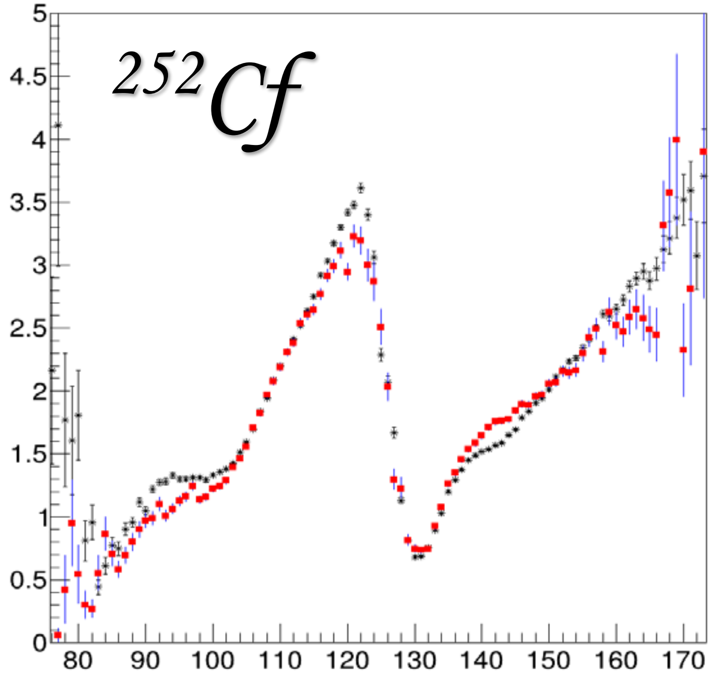
2E-2ν

VERDI

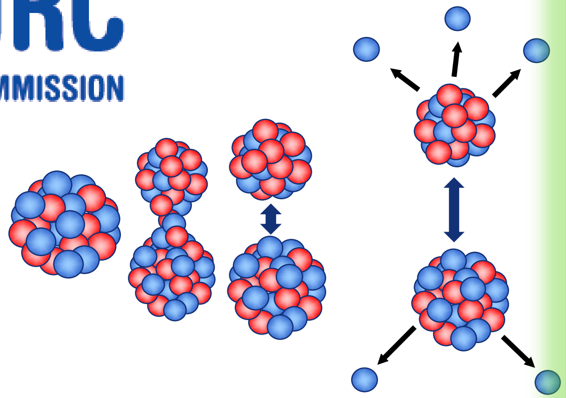
2E

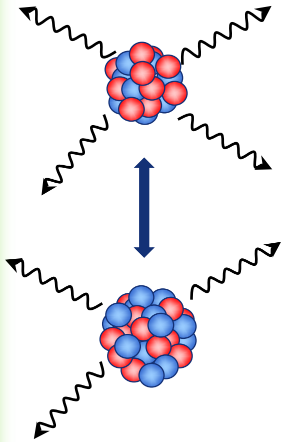


$^{235}U^{*}$



^{252}Cf





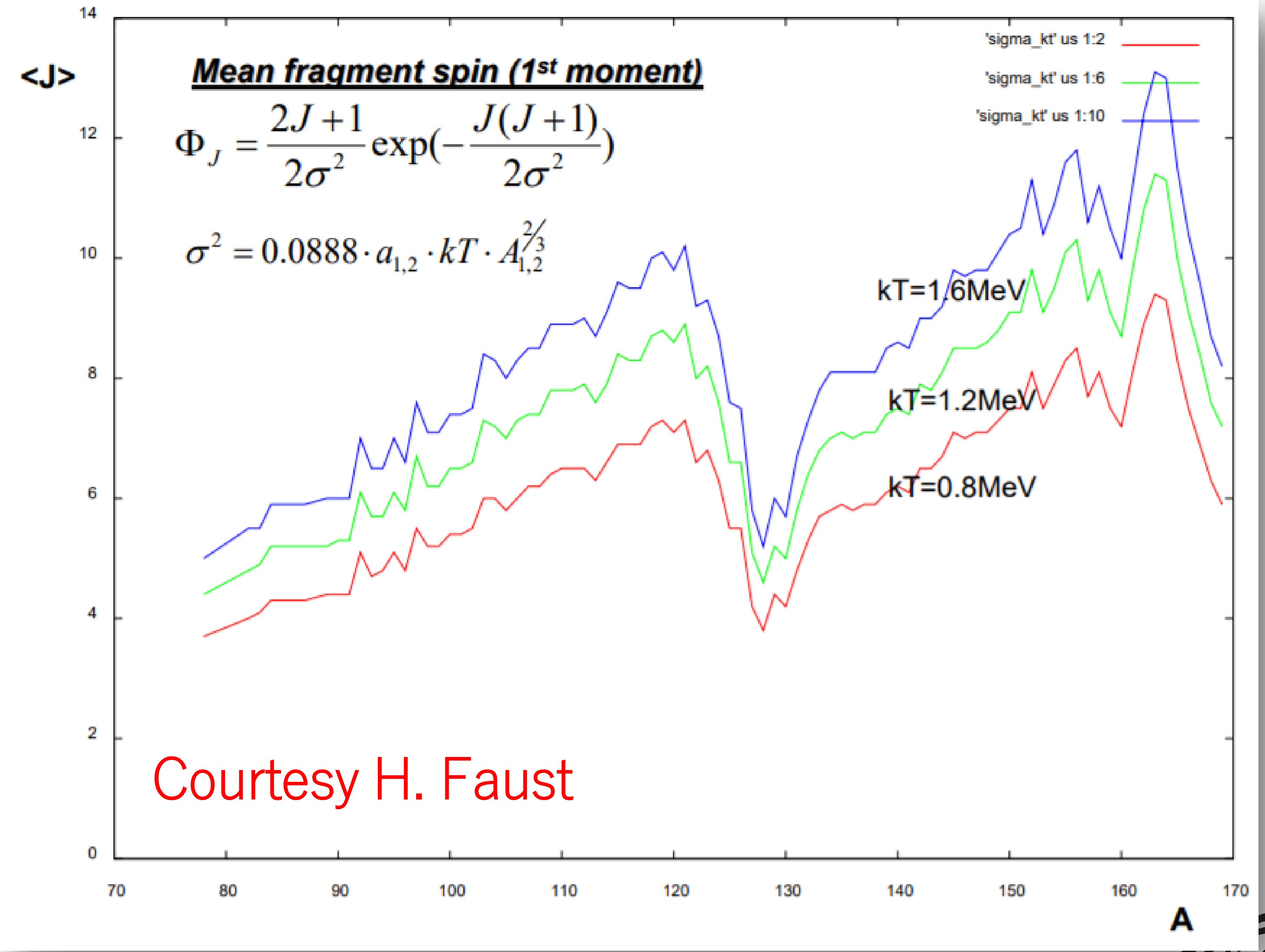
JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Motivation

✦ Nuclear structure- and astro-physics studies

✦ Effect of delayed neutrons in reactors

✦ **Origin of angular momentum in Fission Fragments**



Angular momentum

Nuclear fission: a review of experimental advances and phenomenology

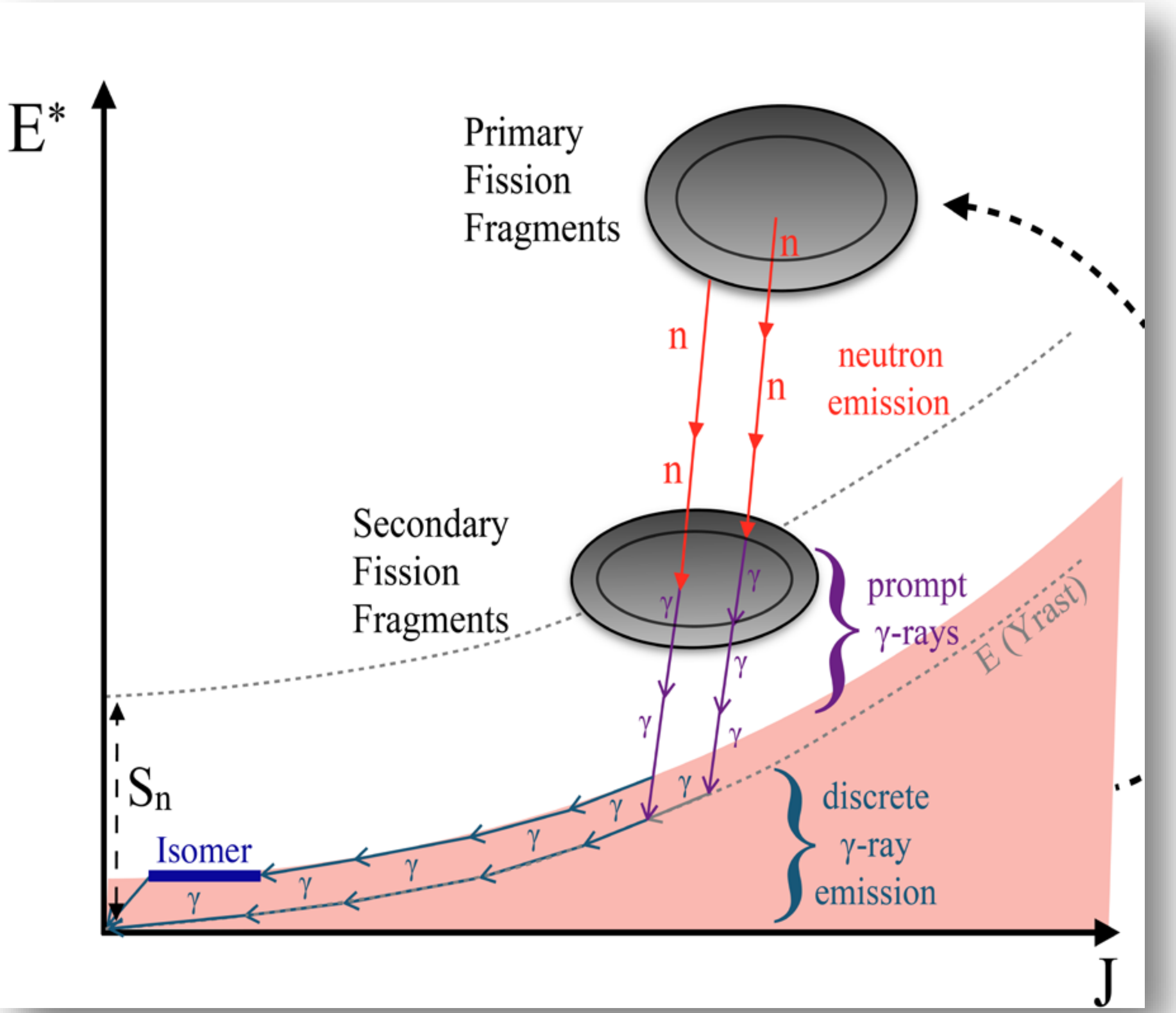
Rep. Prog. Phys. 81 (2018) 016301 (61pp)

A N Andreyev[1,2], K Nishio[2] and K-H Schmidt[3]

6. Some of the open questions in fission

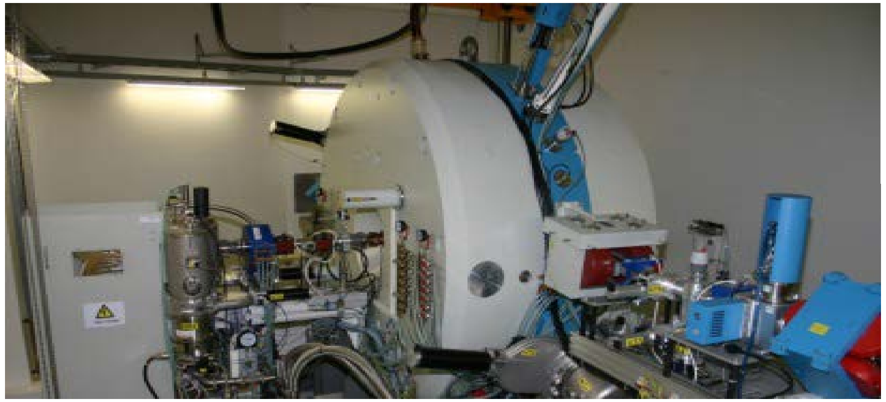
6.3. Fission-fragment angular momentum

- Thermal excitation
- Quantum-mechanical uncertainty
- Angular-momentumbearing modes
- Coulomb excitation after scission



PhD thesis
V. Rakopoulos

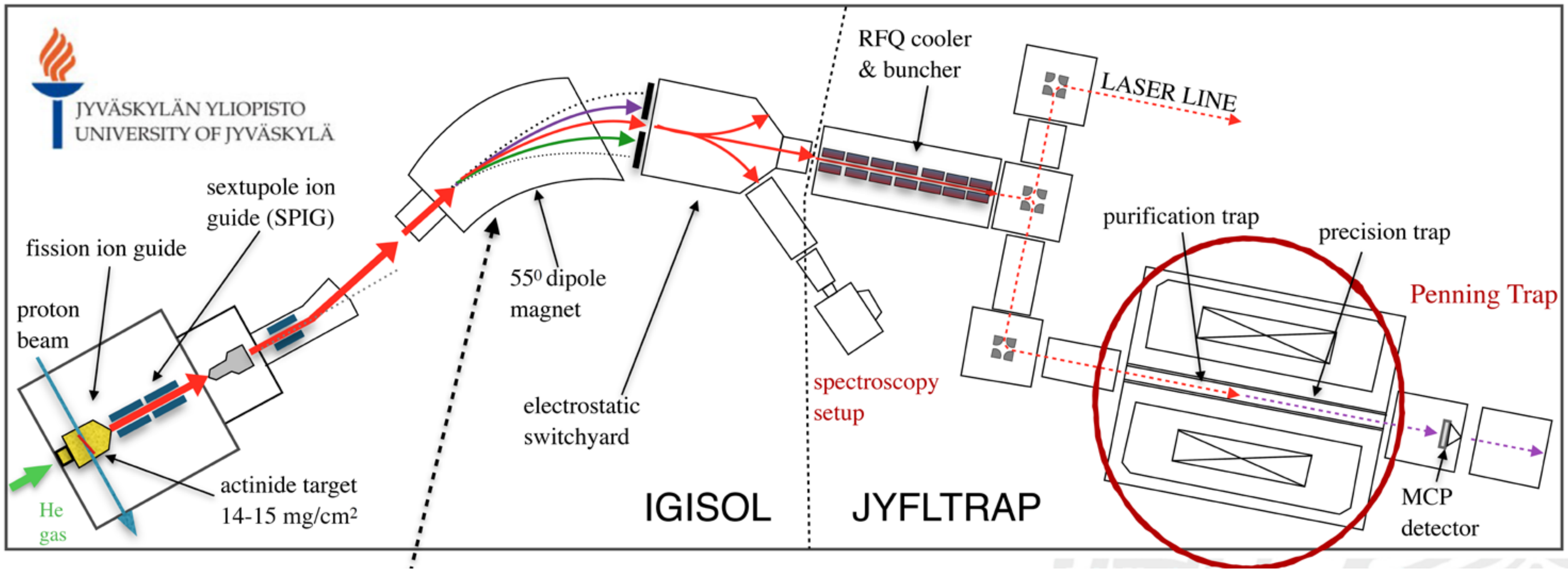
Experiments

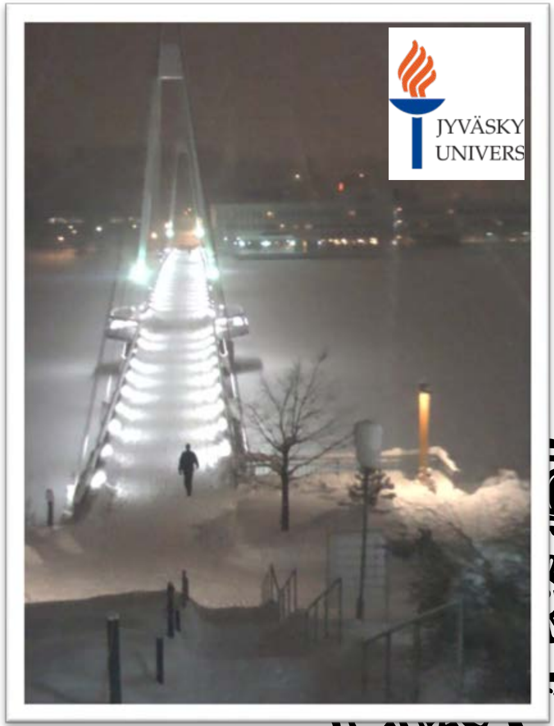


MCC30/15 Cyclotron
p: 18 – 30 MeV @ 100 μA
d: 9 – 15 MeV @ 50 μA

IGISOL = Ion Guide Isotope Separation OnLine

JYFLTRAP = JYväskylä physics Laboratory penning TRAP

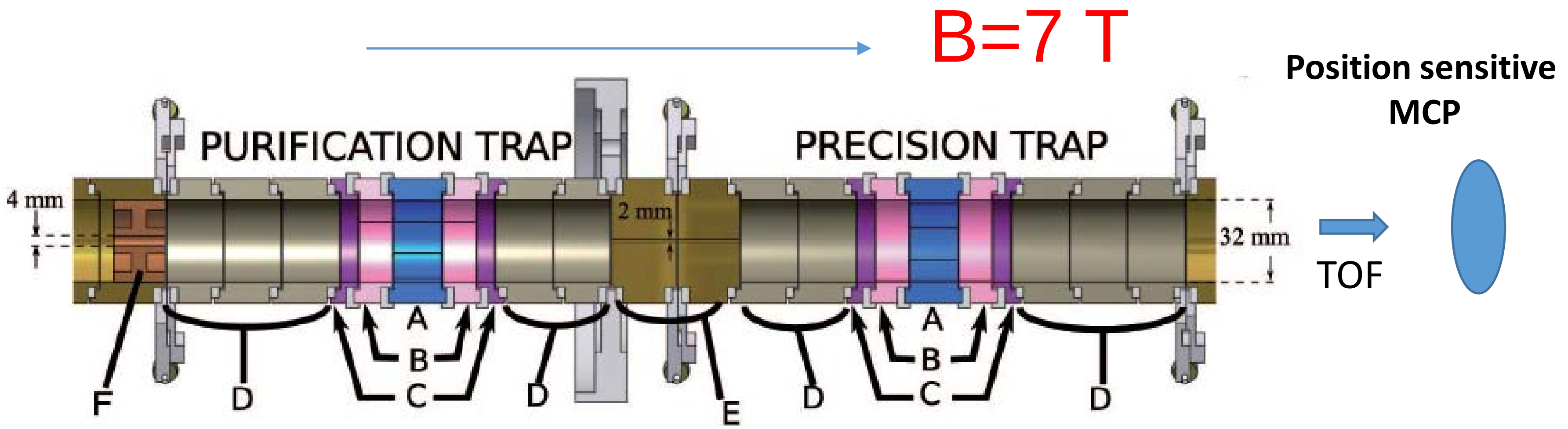




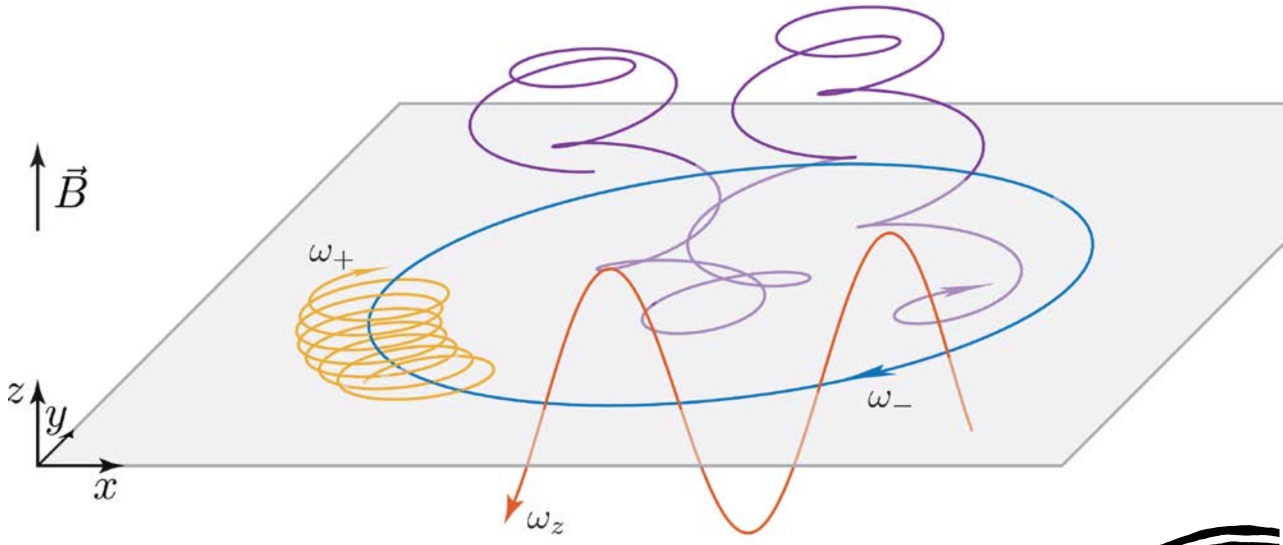
Mass resolving power M/ΔM = 500

Mass filter with resolving power M/ΔM > 10^5

Penning trap



- **Strong homogeneous magnetic field**
- **Weak electric 3D quadruople field**



Cyclotron frequency

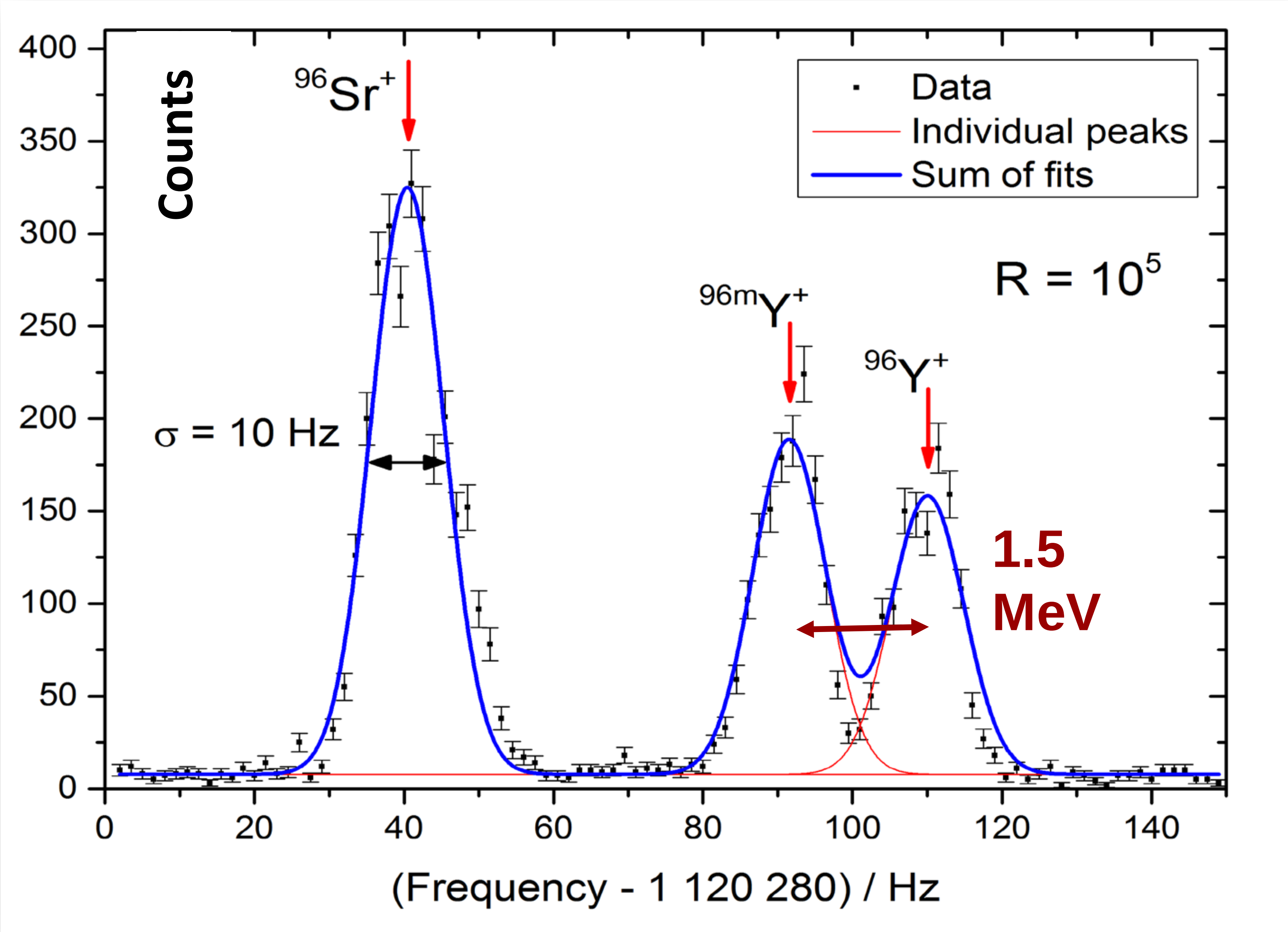
Each nuclide is identified by its unique frequency.

Magnetron to Cyclotron motion

Example

Side band cooling

IYR via Gaussian fits



Results 1

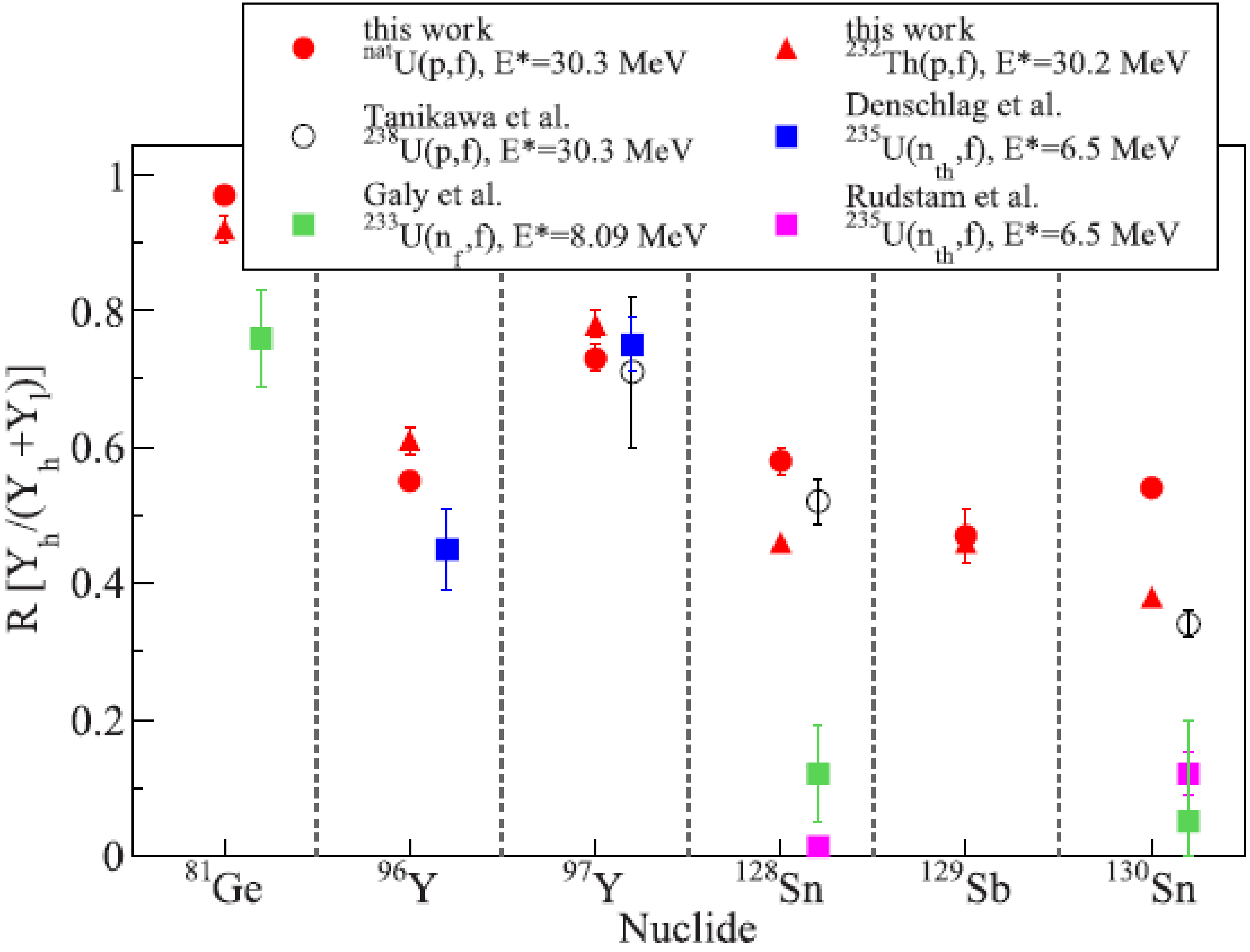
$$R = \frac{Y_h}{Y_l + Y_h}$$

$^{nat}U(p,f)$ & $^{232}Th(p,f)$ at 25 MeV

V. Rakopoulos et al., PRC 98, 024612 (2018)

[red box] = measured for the first time

Nuclide	$^{238}U(p,f)$ R	$^{232}Th(p,f)$ R
^{81}Ge	0.97 (1)	0.92 (2)
^{96}Y	0.55 (1)	0.61 (2)
^{97}Y	0.73 (2)	0.78 (2)
^{128}Sn	0.58 (2)	0.46 (1)
^{129}Sb	0.47 (4)	0.46 (1)
^{130}Sn	0.54 (2)	0.38 (1)



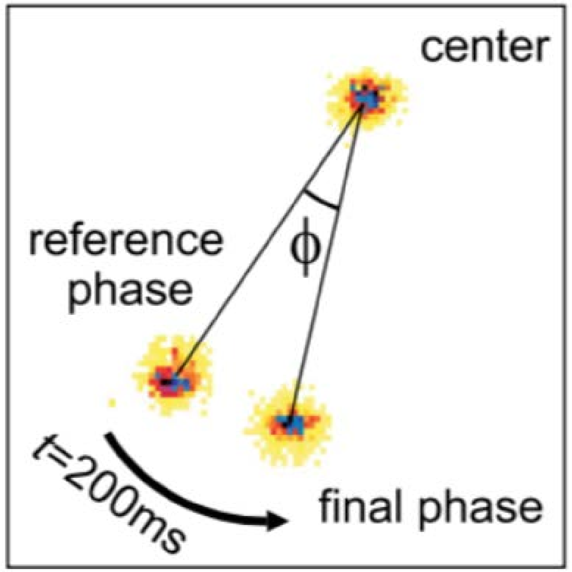
Dependency on CN

Comparison with Data

PI-ICR

Phase-Imaging Ion Cyclotron Resonance technique

S. Eliseev et al., PRL 110, 082501 (2013)   S. Eliseev et al., Appl. Phys. B 114, 107 (2014)

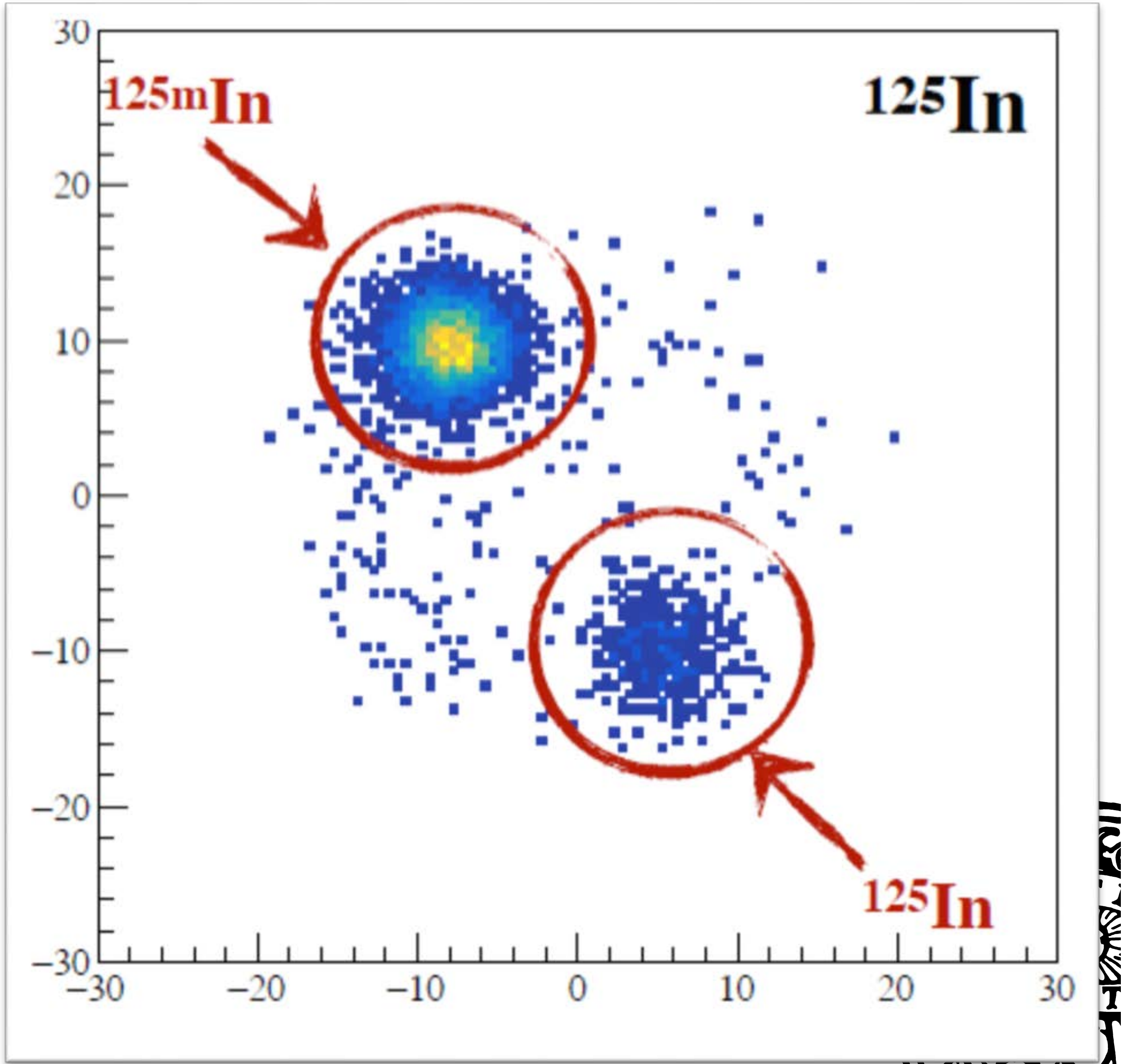


$$\varphi_g = 2\pi \cdot f_g \cdot t$$
$$\varphi_m = 2\pi \cdot f_m \cdot t$$

$$\Rightarrow \Delta\varphi = 2\pi \cdot (f_g - f_m) \cdot t$$

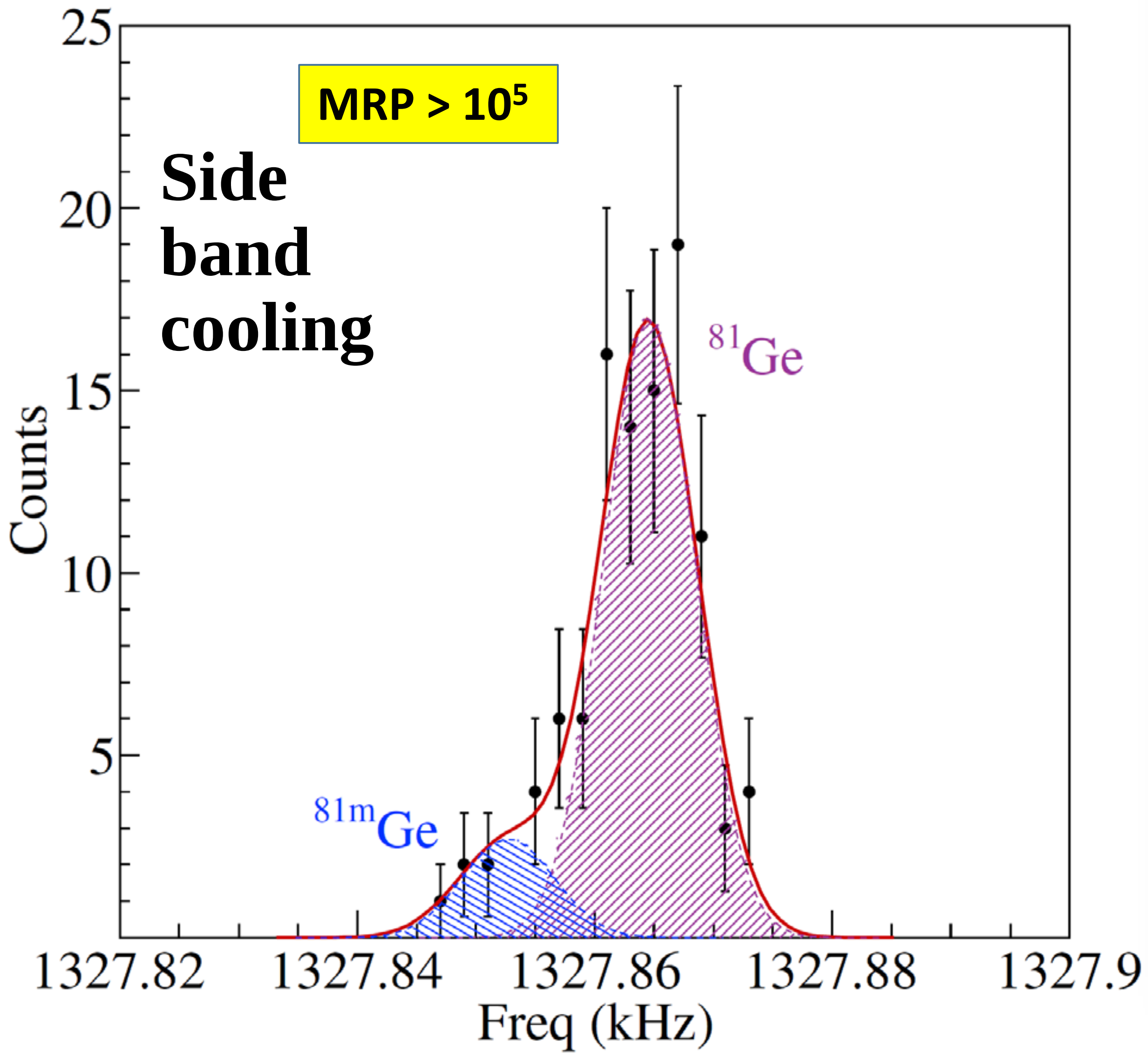
$$\Downarrow$$

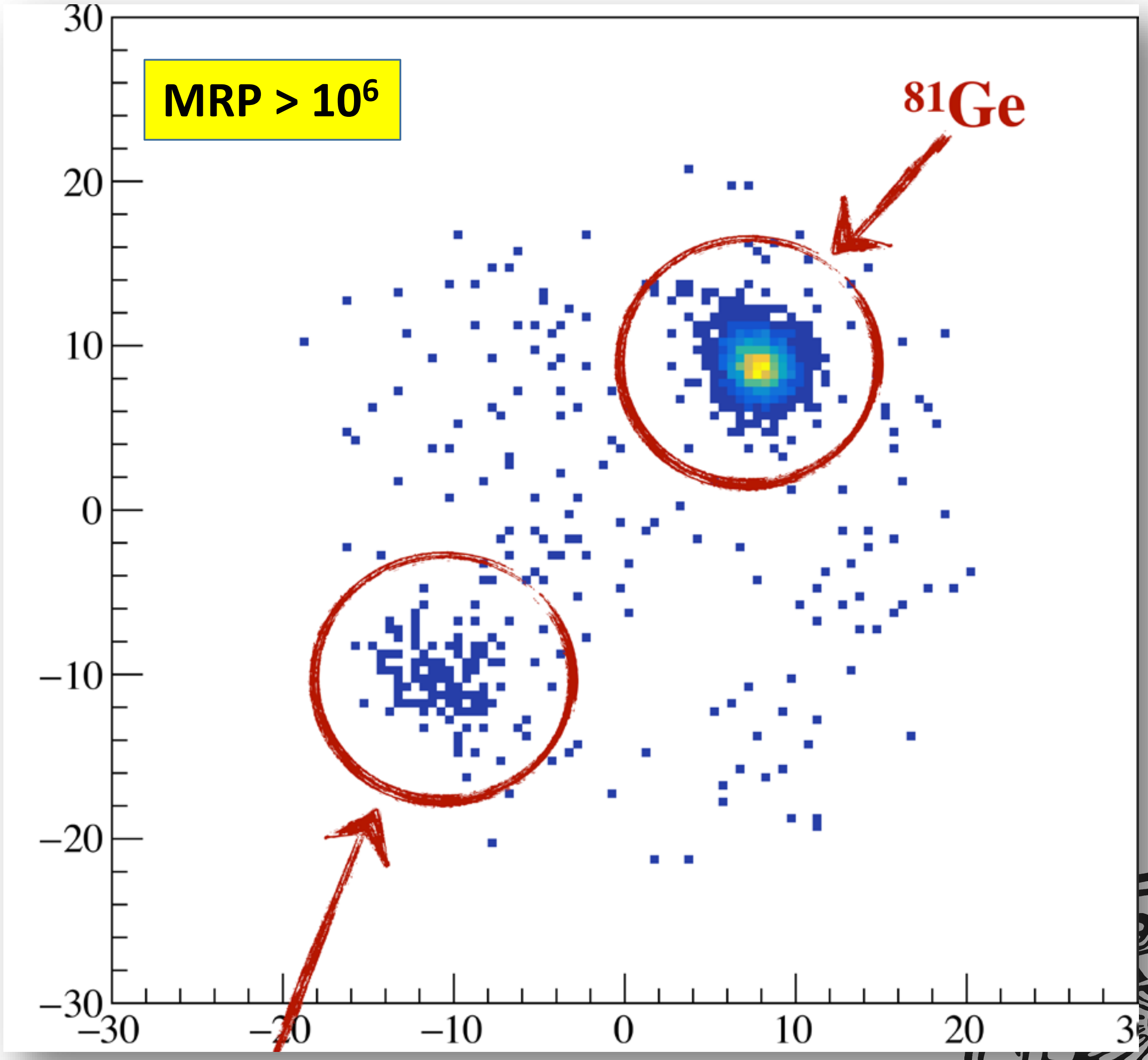
max separation: $\Delta\varphi = \pi$



PI-ICR

$E^{*m} = 679.1\ keV$





Results PI-ICR

Measured odd Cd and In isotopes

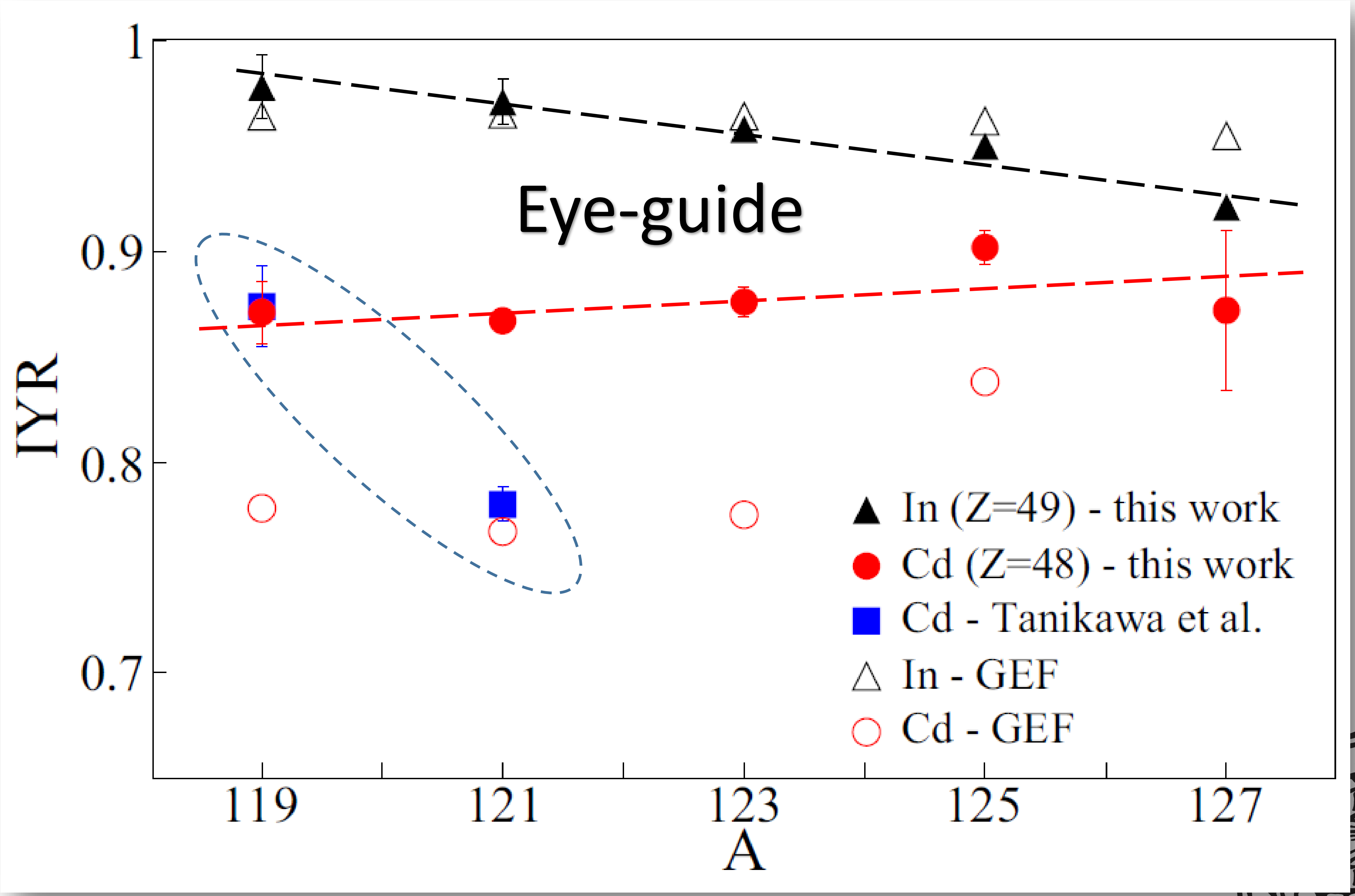
Same set of spin configurations

Perfect agreement between the two campains

Nuclide	Ground state		Isomeric state			IYR
	I^π	$T_{1/2}$	I^π	$T_{1/2}$	E_x (keV)	
^{81}Ge	$9/2^+$ #	8 (2) s	$(1/2^+)$	8 (2) s	679.14(4)	0.975(7)
^{119}Cd	$1/2^+$	2.69 (2) m	$11/2^-$	2.20 (2) m	146.54(11)	0.871(15)
^{121}Cd	$3/2^+$	13.5 (3) s	$11/2^-$	8.3 (8) s	214.86(15)	0.867(4)
^{123}Cd	$3/2^+$	2.10 (2) s	$11/2^-$	1.82 (3) s	143(4)	0.876(7)
^{125}Cd	$3/2^+$	680 (40) ms	$11/2^-$	480 (30) ms	186(4)	0.902(8)
^{127}Cd	$3/2^+$	360 (40) ms	$11/2^-$	450 (120) ms	276(15)	0.872(38)
^{119}In	$9/2^+$	2.4 (1) m	$1/2^-$	18.0 (3) m	311.37(3)	0.978(15)
^{121}In	$9/2^+$	23.1 (6) s	$1/2^-$	3.88 (10) m	313.68(7)	0.971(11)
^{123}In	$(9/2)^+$	6.17 (5) s	$(1/2)^-$	47.4 (4) s	327.21(4)	0.958(2)
^{125}In	$9/2^+$	2.36 (4) s	$(1/2)^{(-)}$	12.2 (2) s	360.12(9)	0.950(3)
^{127}In	$(9/2^+)$	1.09 (1) s	$1/2^-$ #	3.67 (4) s	408.9(3)	0.921 (2)
			$(21/2^-)$	1.04 (10) s	1870 (60)	
^{129}Sb	$7/2^+$	4.366 (26) h	$(19/2^-)$	17.7 (1) m	1851.31(6)	0.441(32)

$T_{1/2}$ for ^{127}Cd: by C. Lorenz et al. At JYFLTRAP (priv. comm.)

Results
PI-ICR



Estimation of angular momentum J

$$\overline{E}_{1,2}(A) = \overline{\mathrm{TXE}}(A) \times \frac{\overline{\nu}_{1,2}(A)}{\overline{\nu}_1(A) + \overline{\nu}_2(A)}$$

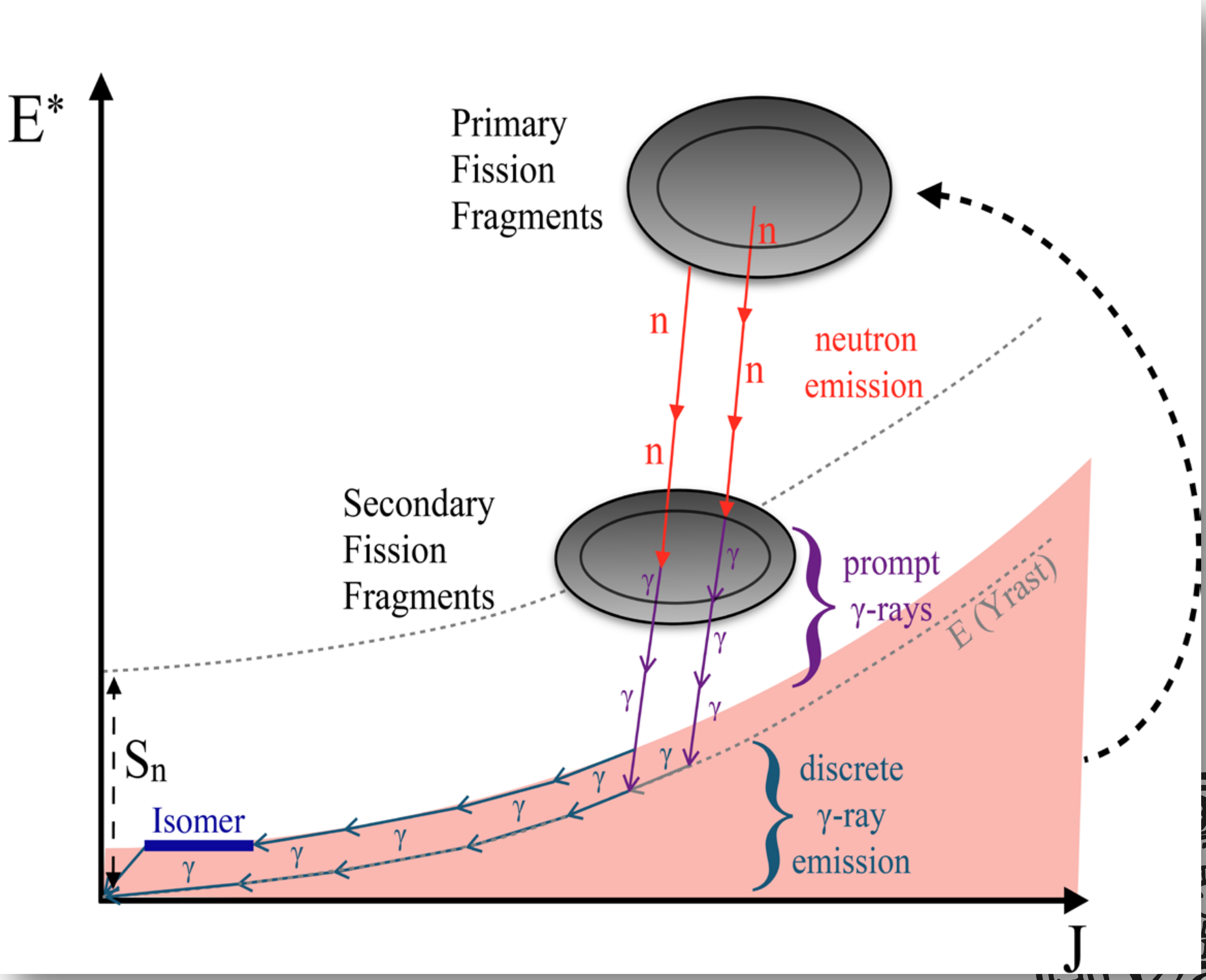
input $E_{exc}(A,Z)$

input $\bar{\nu}(A)$

input $P(J)$

TALYS

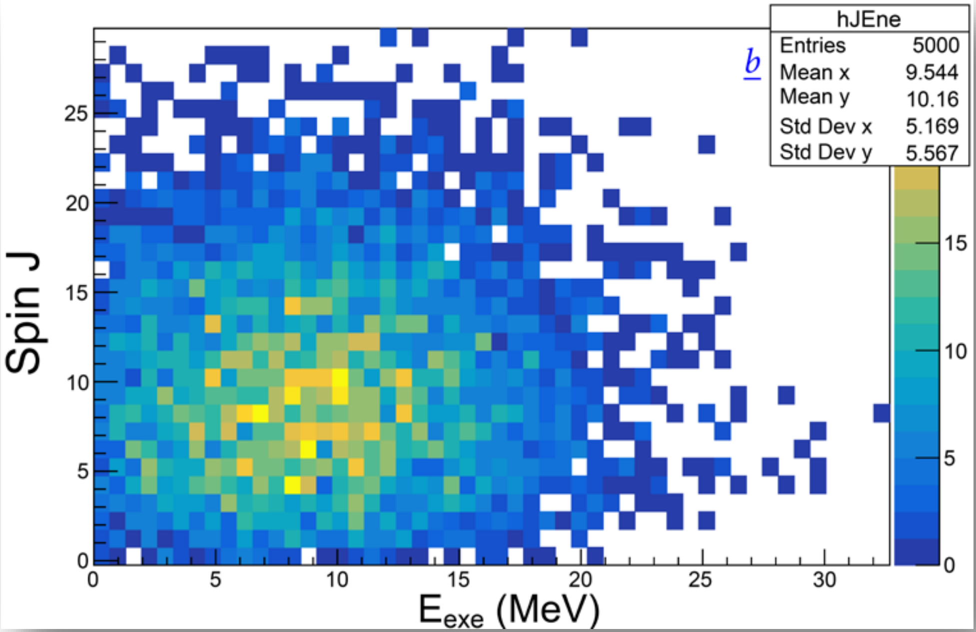
(Hauser Feshbach)

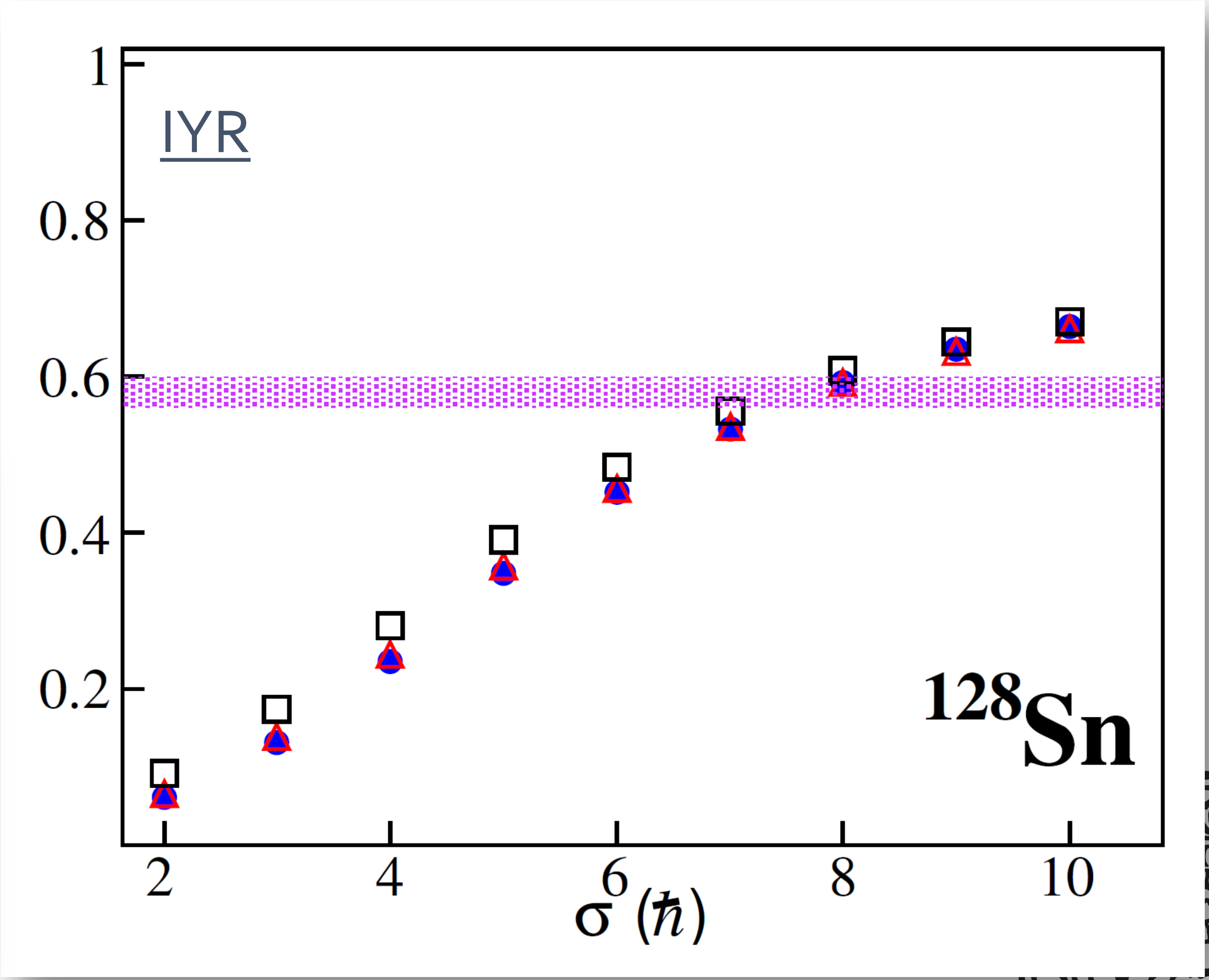


Estimation of angular momentum J

$$P(J) \propto (2J+1)\exp\left(-\frac{(J+0.5)^2}{2b^2}\right)$$

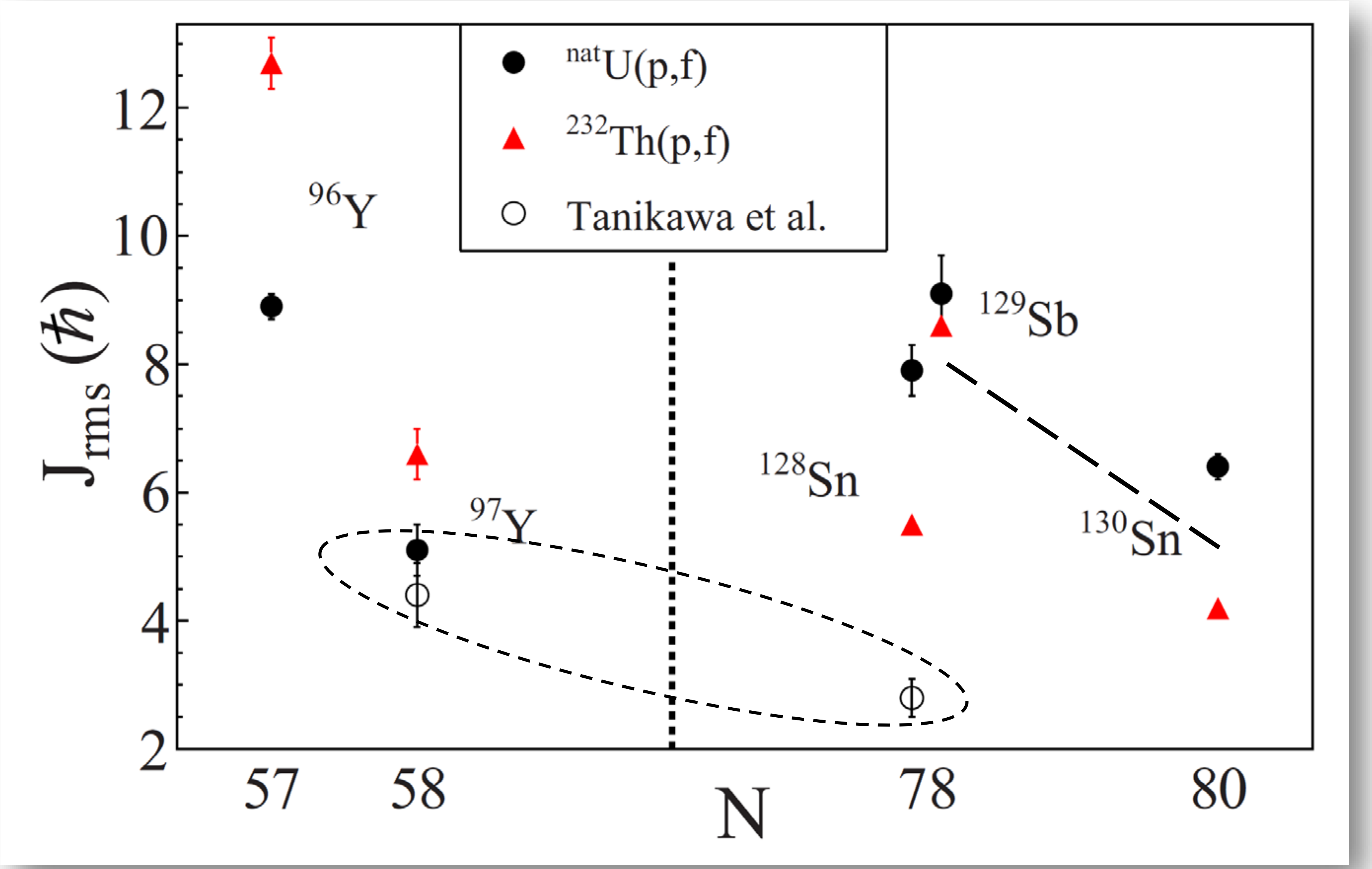
b=σ= Spin cut-off paramter





Extracted J

Rakopoulos et al.
PhysRevC.98.024612 - 2018

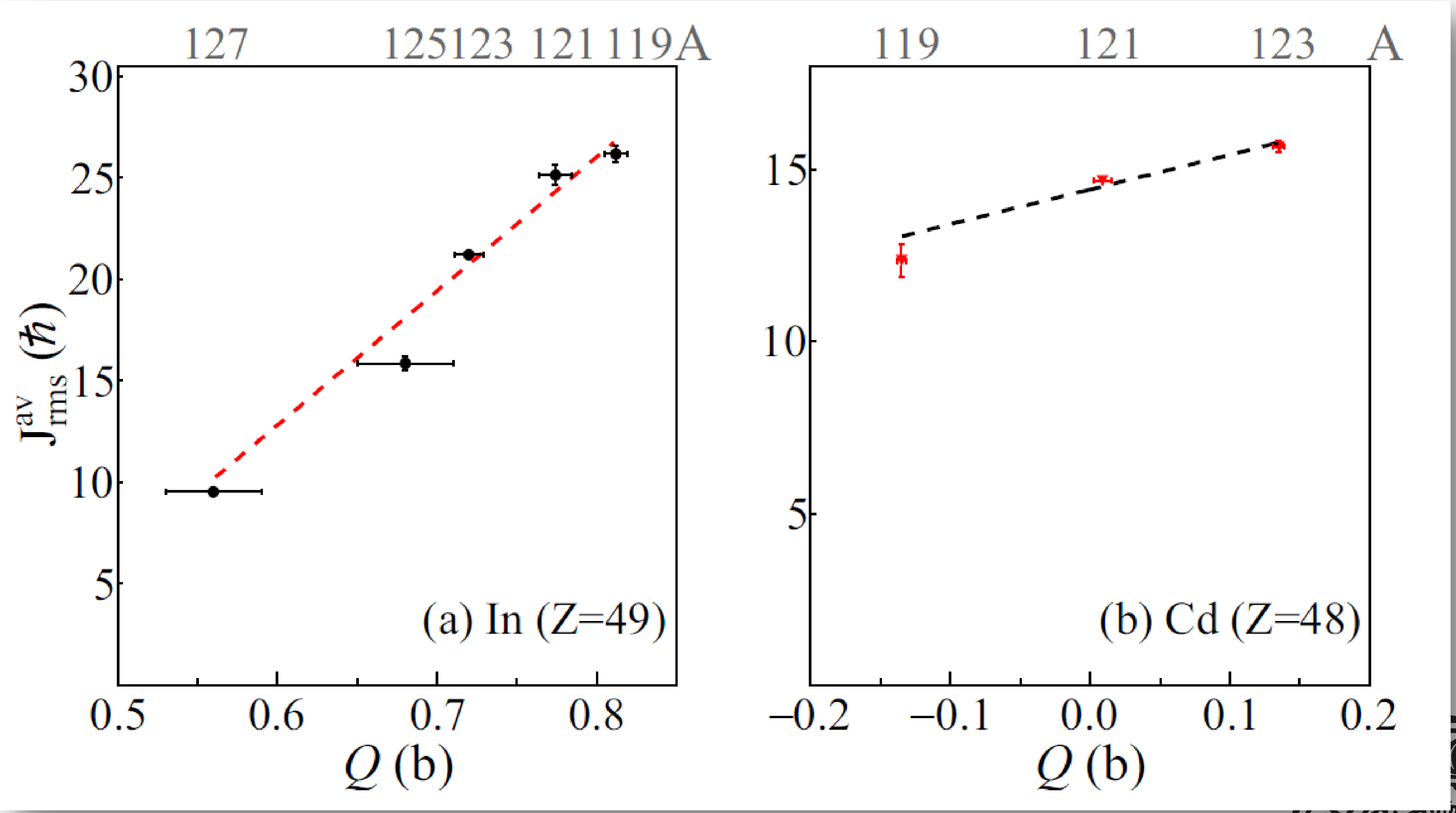


Extracted J

Rakopoulos et al.
PhysRevC.99.014617 2019

Q for In
Stone, At. Data Nucl. Data Tables 111-112 (2016)

Q for Cd
Yordanov et al., PRL 110, 192501 (2013)



Improve the method → **FIFRELIN calculations**

Conclusions and Outlook

- **Accurate IYRs at IGISOL!**

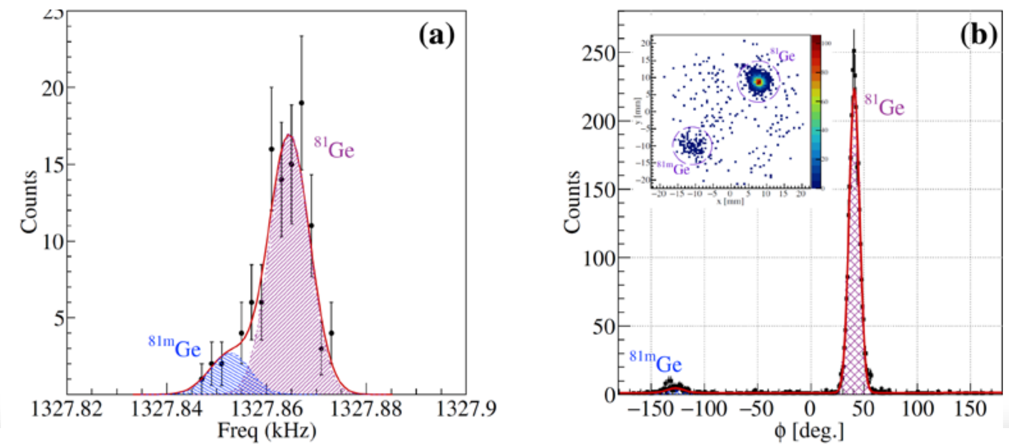
E>50-100 keV & T>100 ms

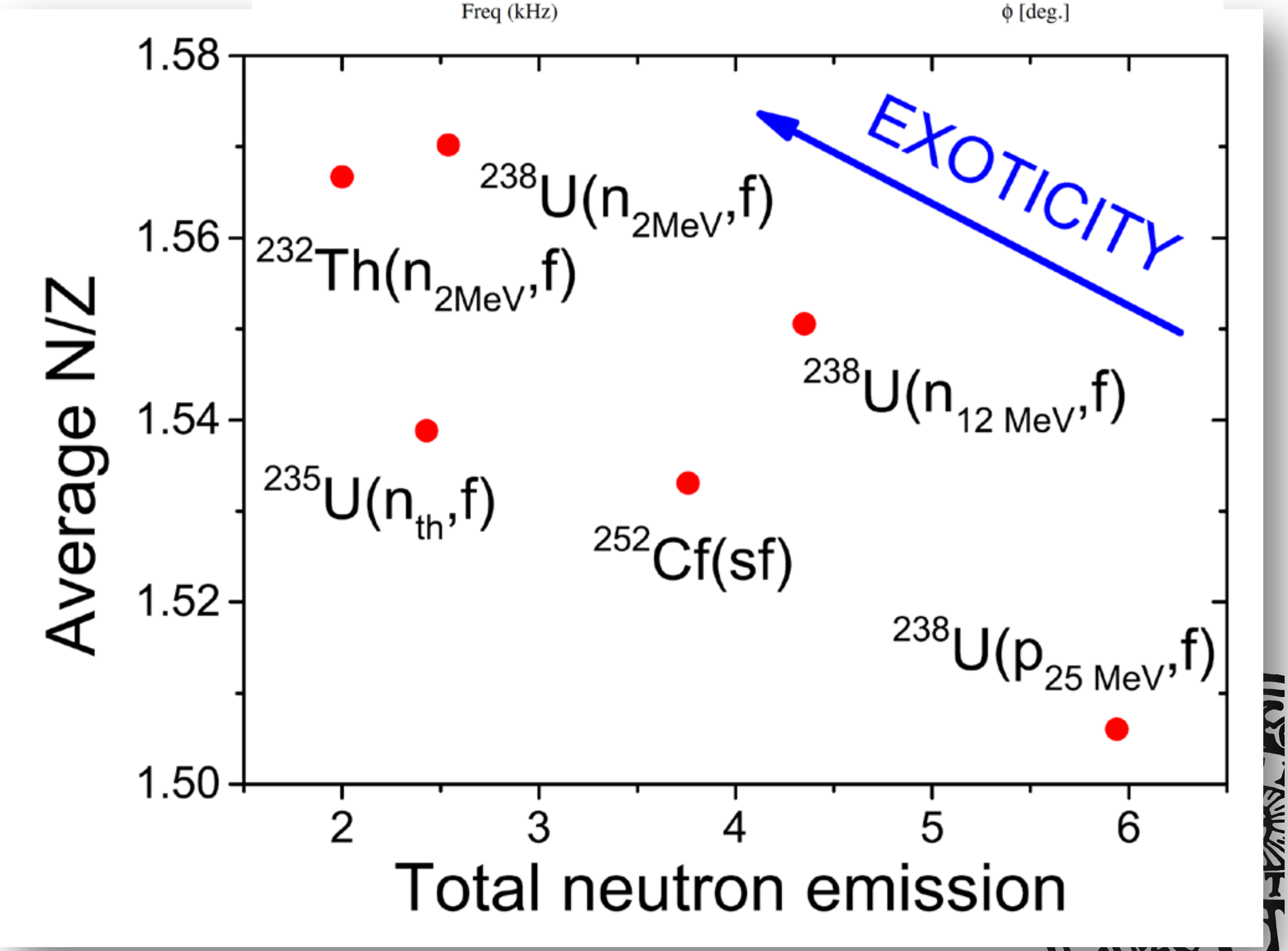
- **“TALYS method” to extract J.**

We are looking for interesting cases to study!

Change CN, projectile, E^{exc}

We welcome any support in refining the J_{rms} extraction!





Isomeric yield ratios at IGISOL

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and the IGISOL collaboration

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Thanks for your attention!