Lifetime measurements around A = 100 with pγ-coincidence DSAM

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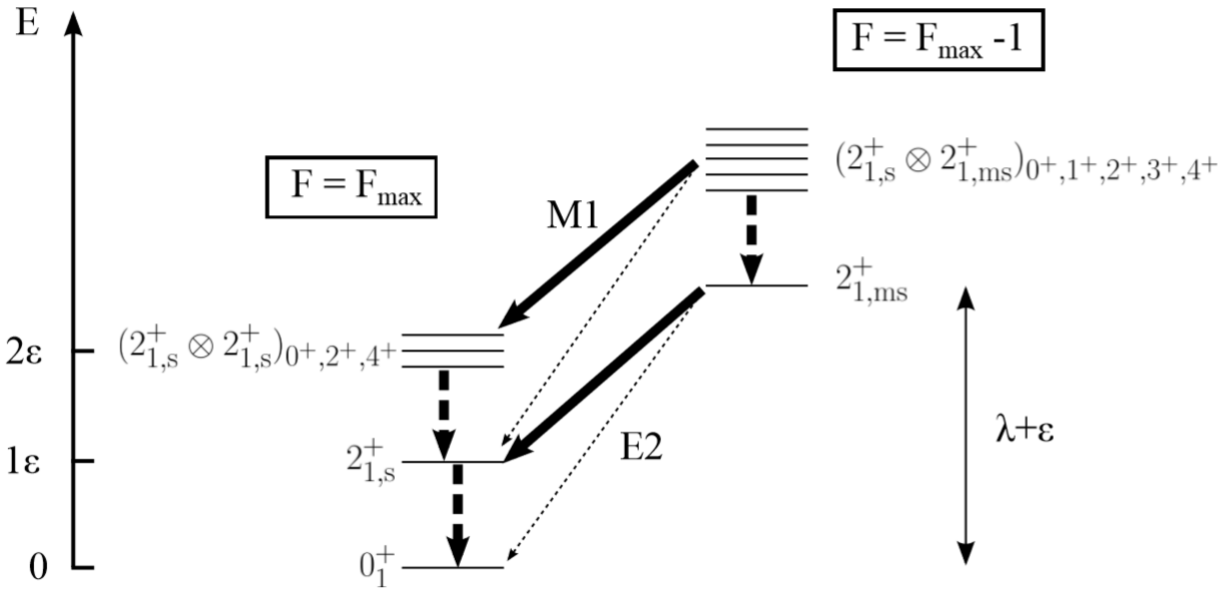
Lifetime measurements

Nuclear structure phenomena studied along isotopic chains show effects of adding single nucleons

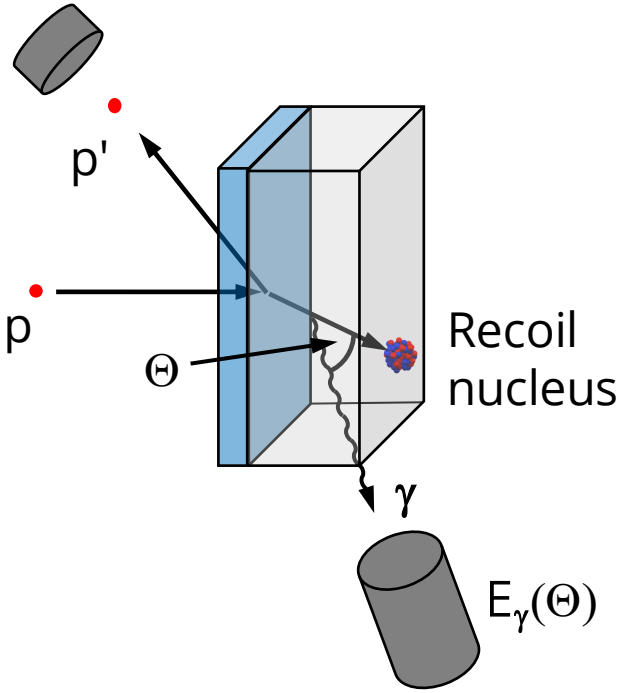
- Mixed-symmetry states, quadrupole-octupole coupled states, shape coexistence, …
- Accessed through transitions strengths
  - Level lifetimes needed

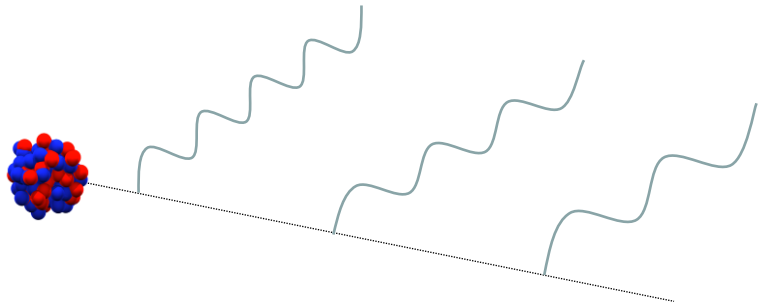
Characteristics of one- and two-phonon quadrupole mixed-symmetry states



N. Pietralla, P. von Brentano, and A.F. Lisetskiy, Prog. Part. Nucl. Phys. **60** (2008) 225
A. Hennig, PhD thesis, University of Cologne (2014)

The Doppler-shift attenuation method (DSAM)





$v_1 > v_2 > v_3$

$F(\tau) \approx 1 \longrightarrow F(\tau) \approx 0$

Centroid-energy shifts:

$$E_\gamma(v_0, \tau, \Theta) = E_\gamma^0\left(1 + \frac{v_0}{c} \cdot F(\tau) \cos\Theta\right)$$

unshifted energy

attenuation factor

angle between recoil nucleus and γ-ray

S. Prill *et al.*, PRC **105**, 034319 (2022)

Experimental setup in Cologne

SONIC@HORUS

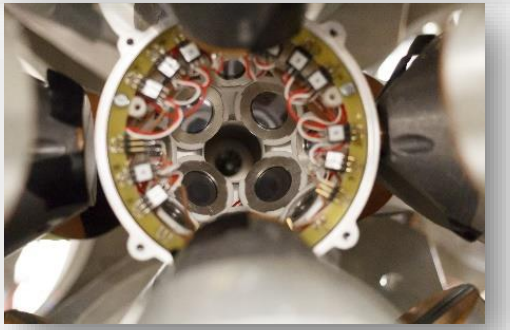
At the 10 MV FN tandem accelerator in Cologne

HORUS: 14 HPGe detectors γ

SONIC: 12 silicon detectors p'

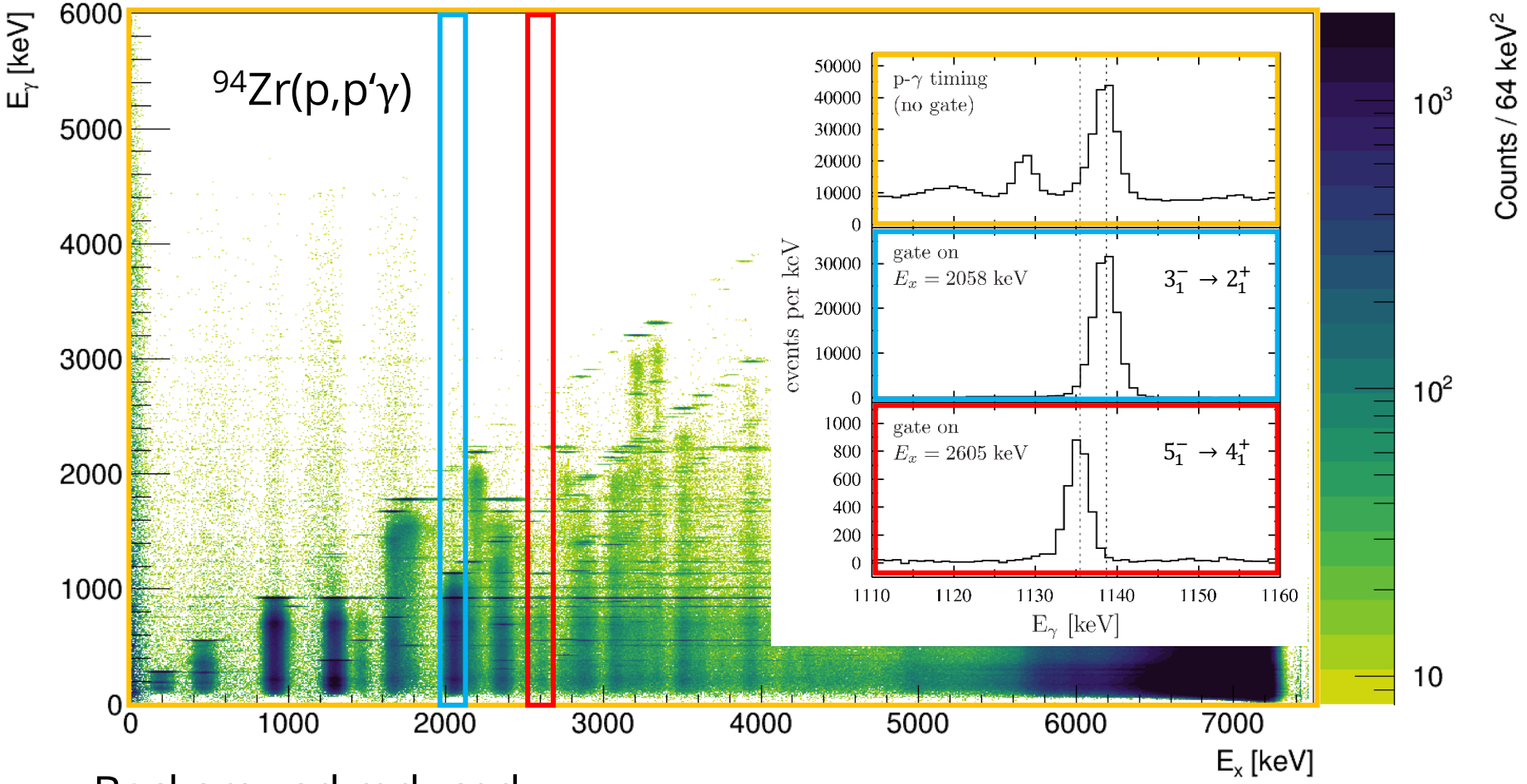
➡ 168 detector combinations

Combined setup allows particle-γ coincidence detection



S.G. Pickstone *et al.*, NIM A **875** (2017) 104

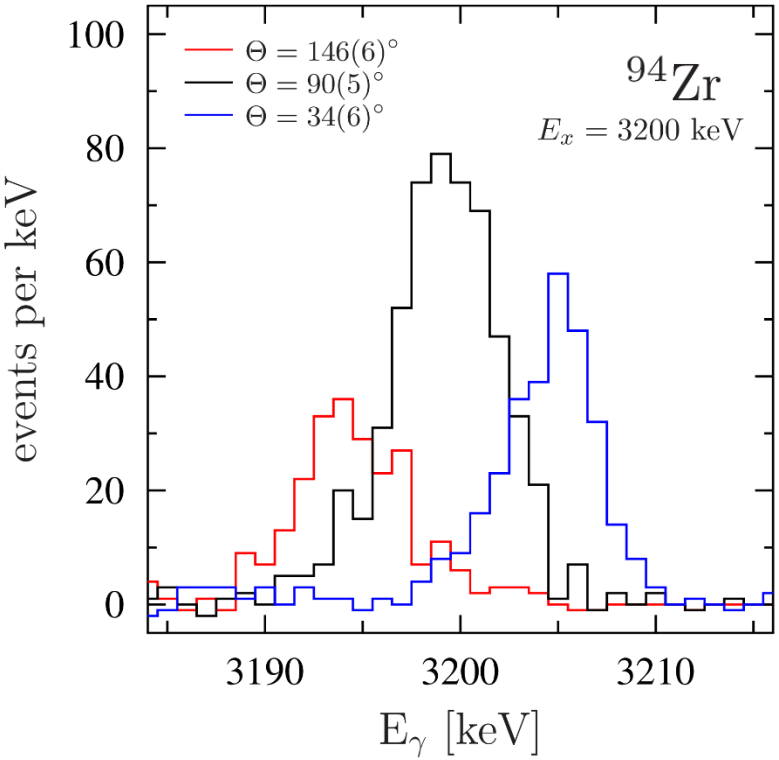
Excitation-energy gating

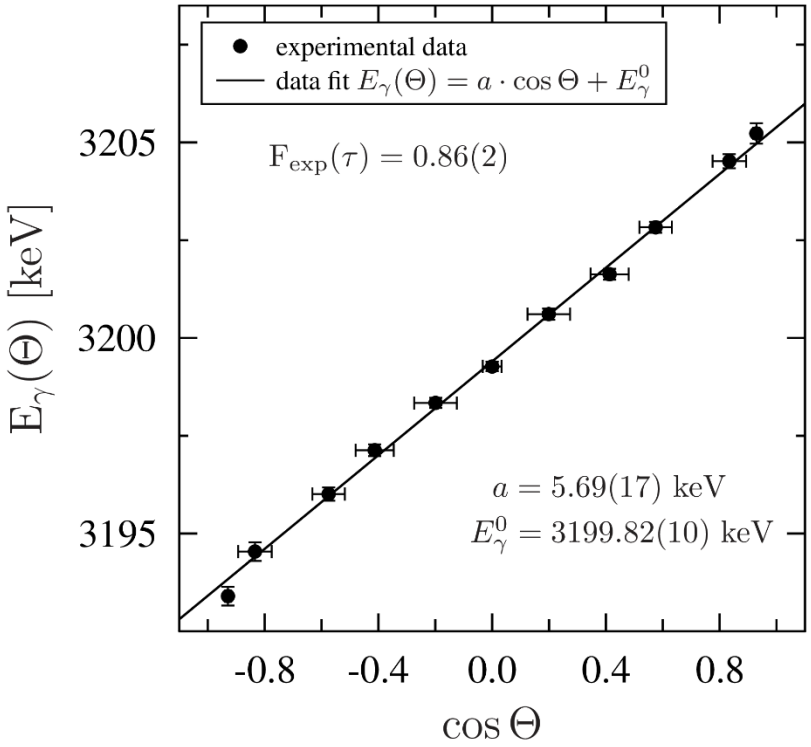


- Background reduced
- Weak transitions observable (BR ~ 1%)
- Feeding excluded

S. Prill *et al., J. Phys.: Conf. Ser.* **1643** 012157 (2020)

Experimental attenuation factor



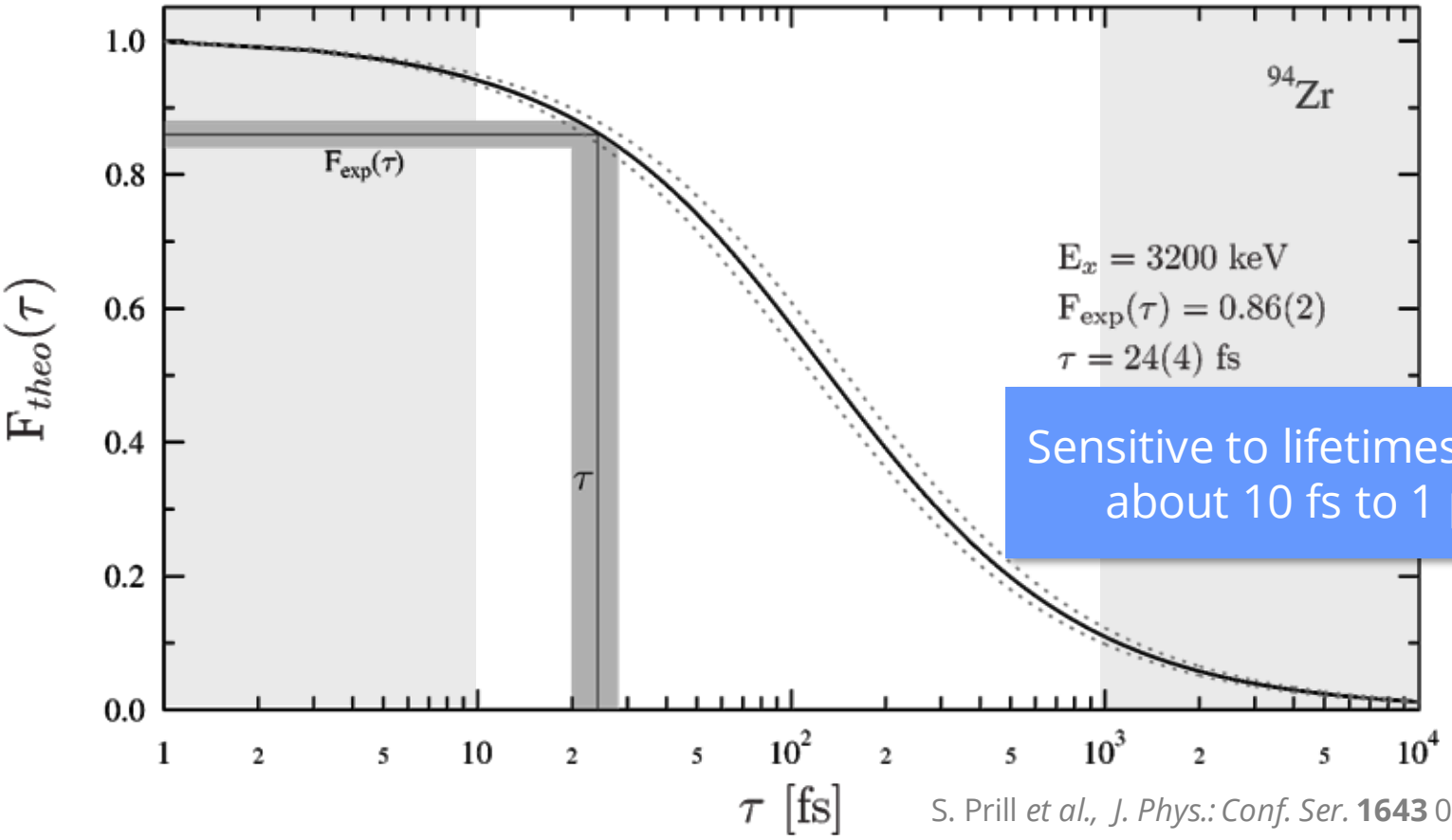


Doppler-shifted centroid energies $E_\gamma(\Theta) = a \cdot \cos\Theta + E_\gamma^0$

yield experimental attenuation factor $F_{exp}(\tau) = \frac{a}{E_\gamma^0 \cdot \frac{v_0}{c}}$

S. Prill *et al.*, *J. Phys.: Conf. Ser.* **1643** 012157 (2020)

Lifetime determination



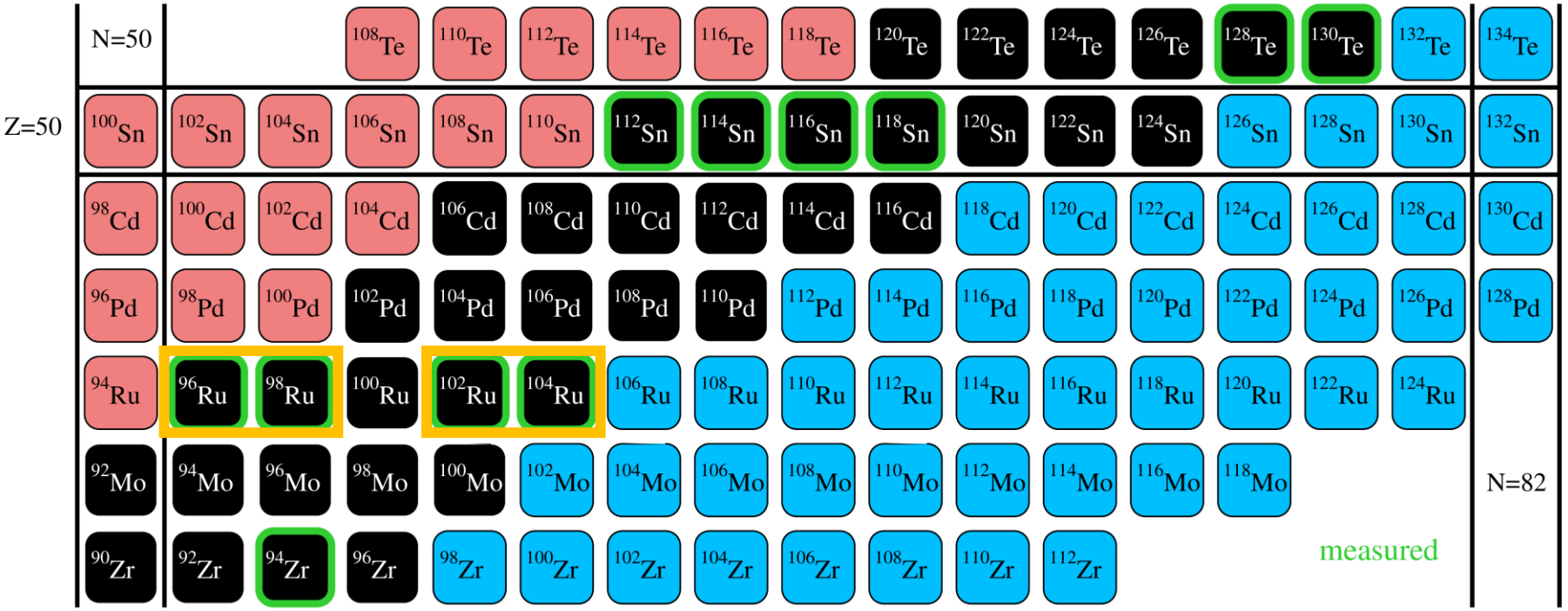
Sensitive to lifetimes from about 10 fs to 1 ps

S. Prill *et al.*, *J. Phys.: Conf. Ser.* **1643** 012157 (2020)

~ 20 to 30 lifetimes can be determined in one experiment with SONIC@HORUS

$J^{\pi} = (0^{+} - 5^{-})$

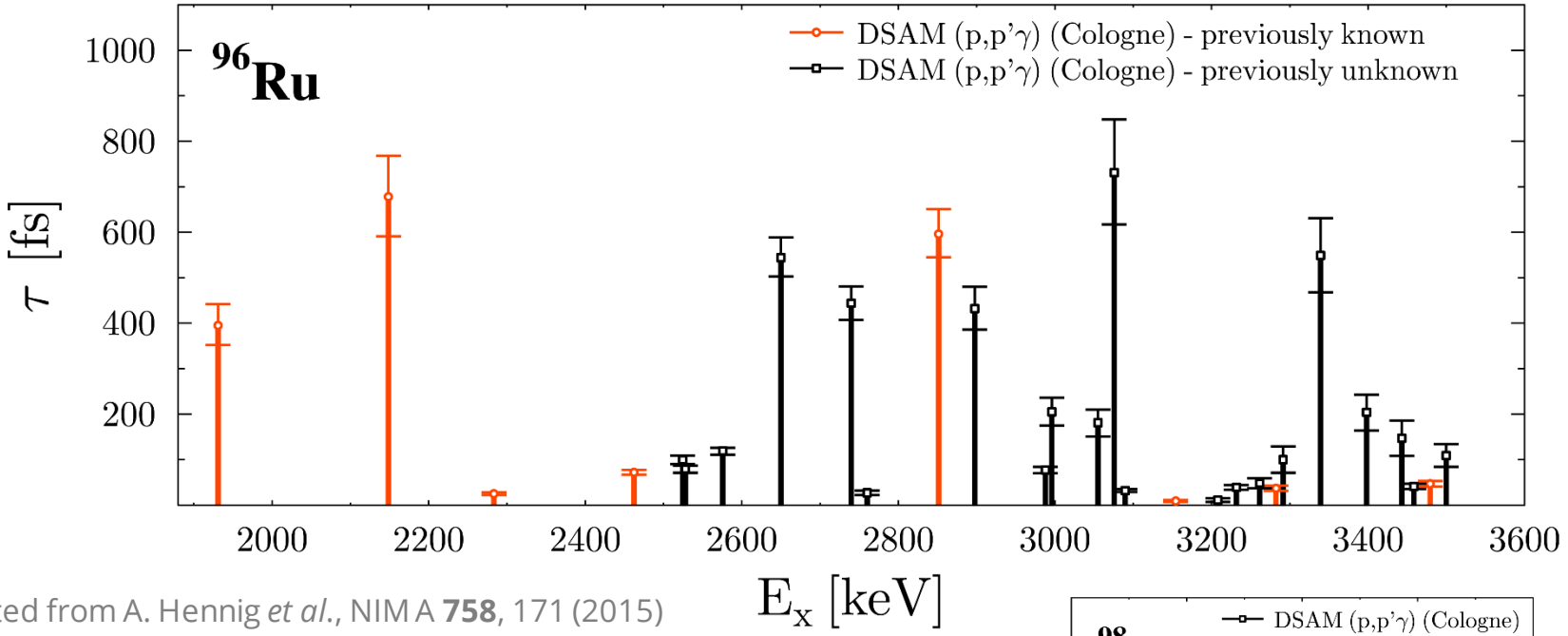
Experiments



A. Hennig *et al.*, PRC **90**, 051302(R) (2014)
A. Hennig *et al.*, PRC **92**, 064317 (2015)

M. Spieker *et al.*, Phys. Rev. C **97**, 054319 (2018)
S. Prill *et al.*, *J. Phys.: Conf. Ser.* **1643** 012157 (2020)
S. Prill *et al.*, PRC **105**, 034319 (2022)

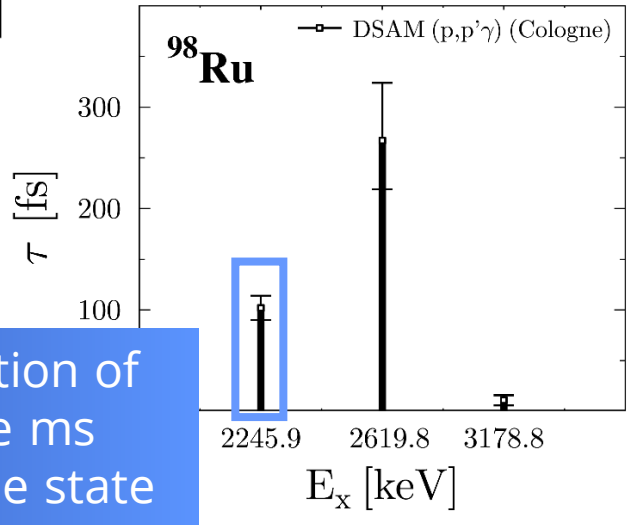
Results on ^{96,98}Ru



Adopted from A. Hennig *et al.*, NIM A **758**, 171 (2015)

Main goal of the experiments:

Study of mixed-symmetry (ms) quadrupole and hexadecapole states

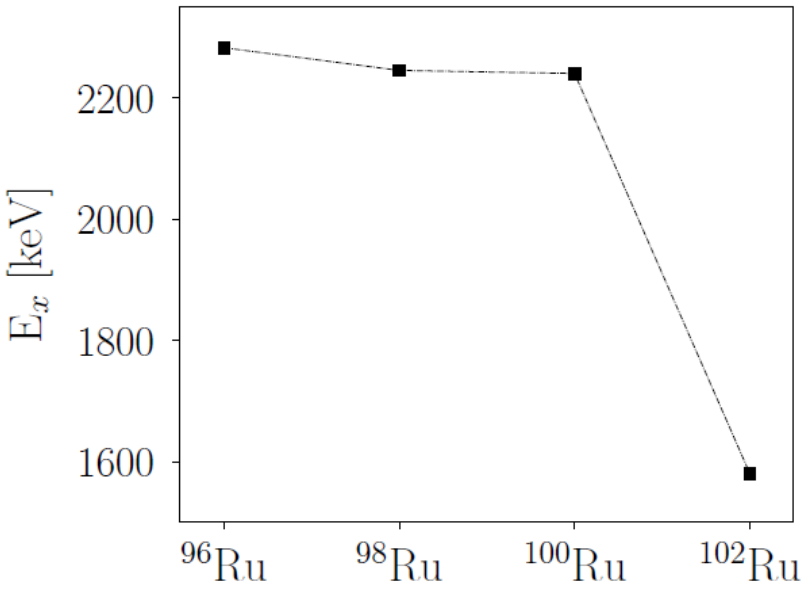


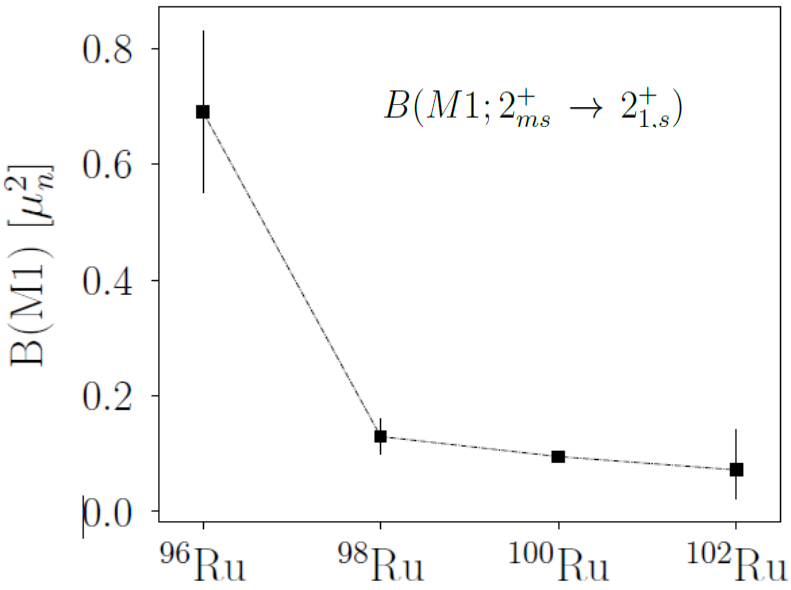
Identification of possible ms quadrupole state

See:
A. Hennig *et al.*, PRC **90**, 051302(R) (2014)
A. Hennig *et al.*, PRC **92**, 064317 (2015)

Vera Vielmetter, Bachelor's thesis, University of Cologne (2016)

Possible mixed-symmetry states in Ru

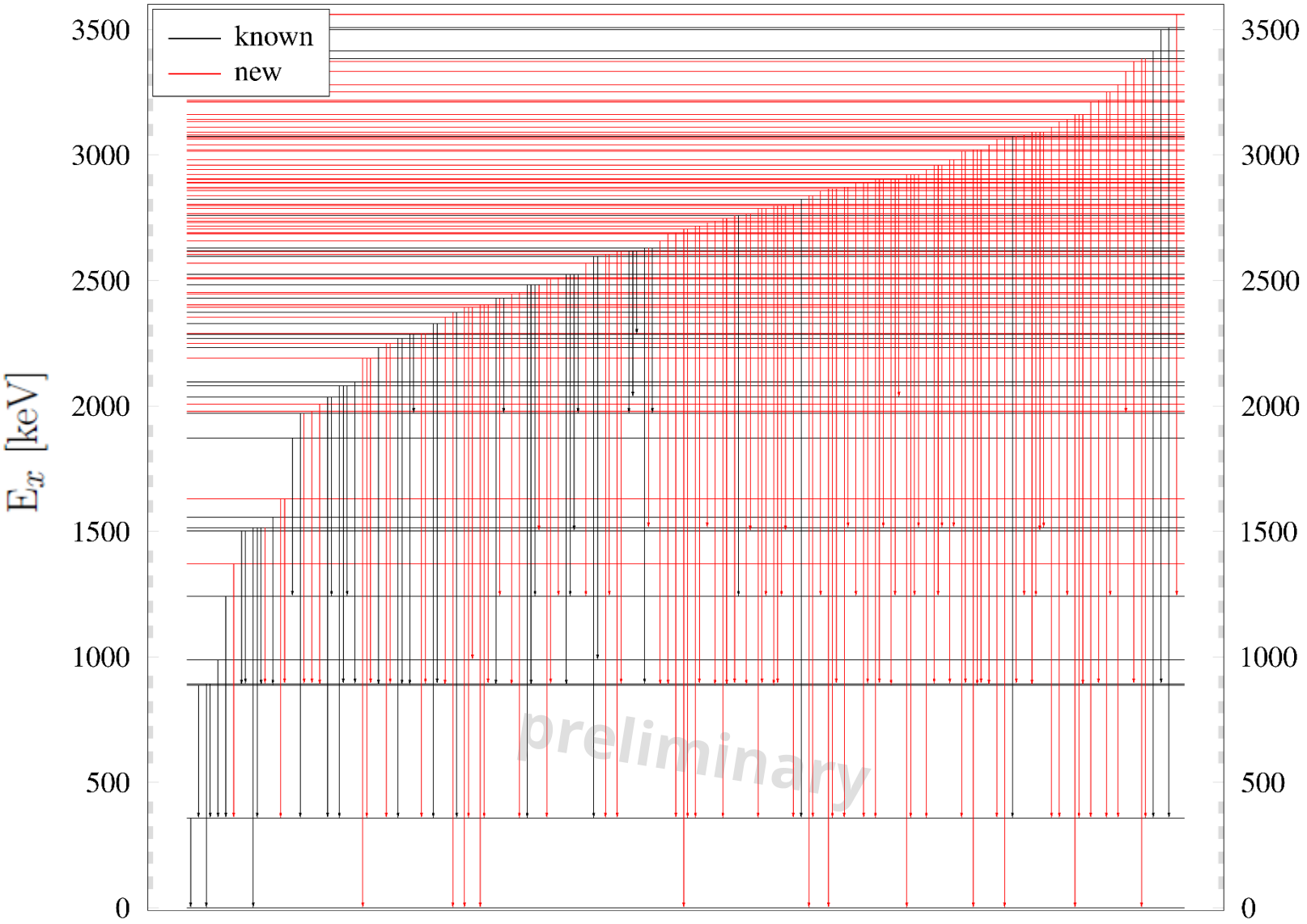




What about ^{104}Ru?

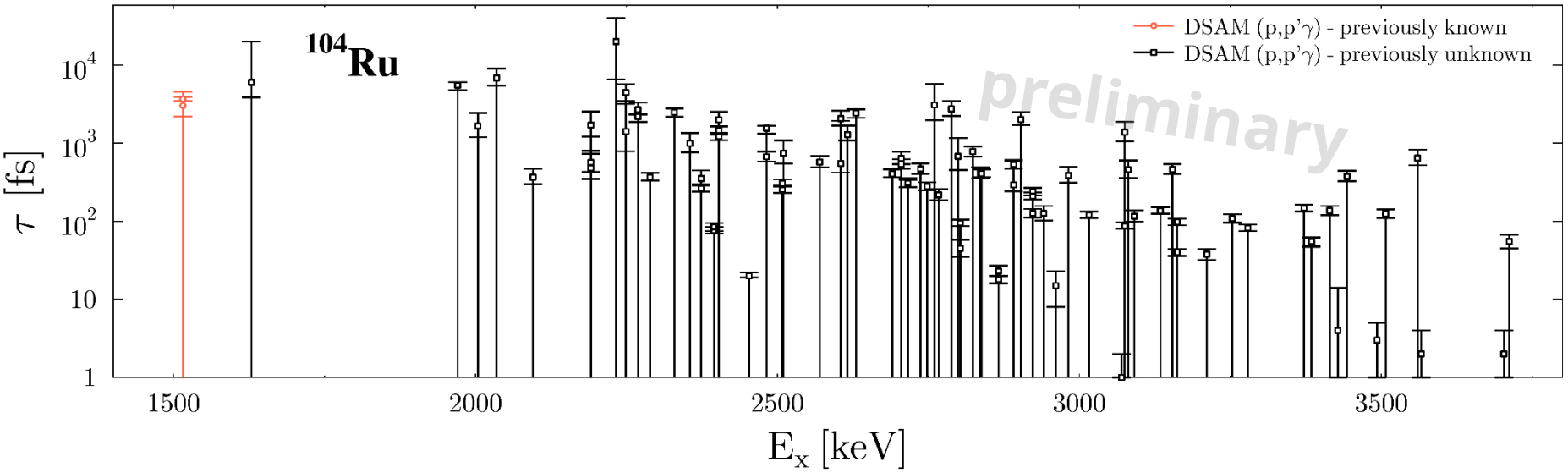
Vera Everwyn, Master's thesis, University of Cologne (2020)

^{104}Ru: Level scheme



provided by Anna Bohn

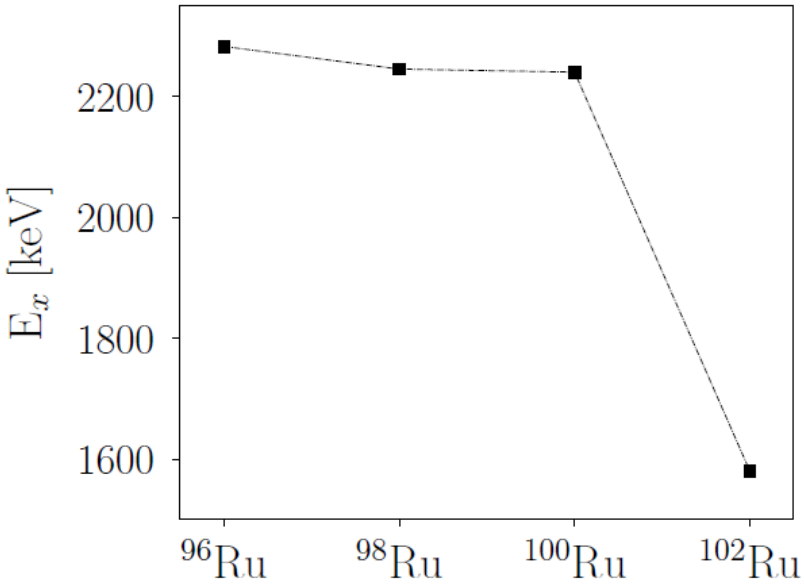
^{104}Ru: Lifetimes

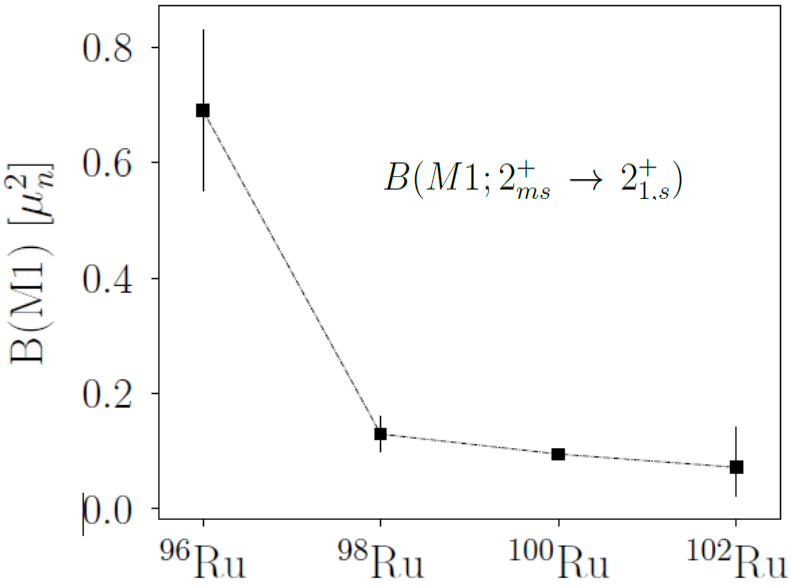


- 67 level lifetimes, **66 for the first time**
- No lifetimes in the order of fs previously known

analysis by Anna Bohn

Possible mixed-symmetry states in Ru





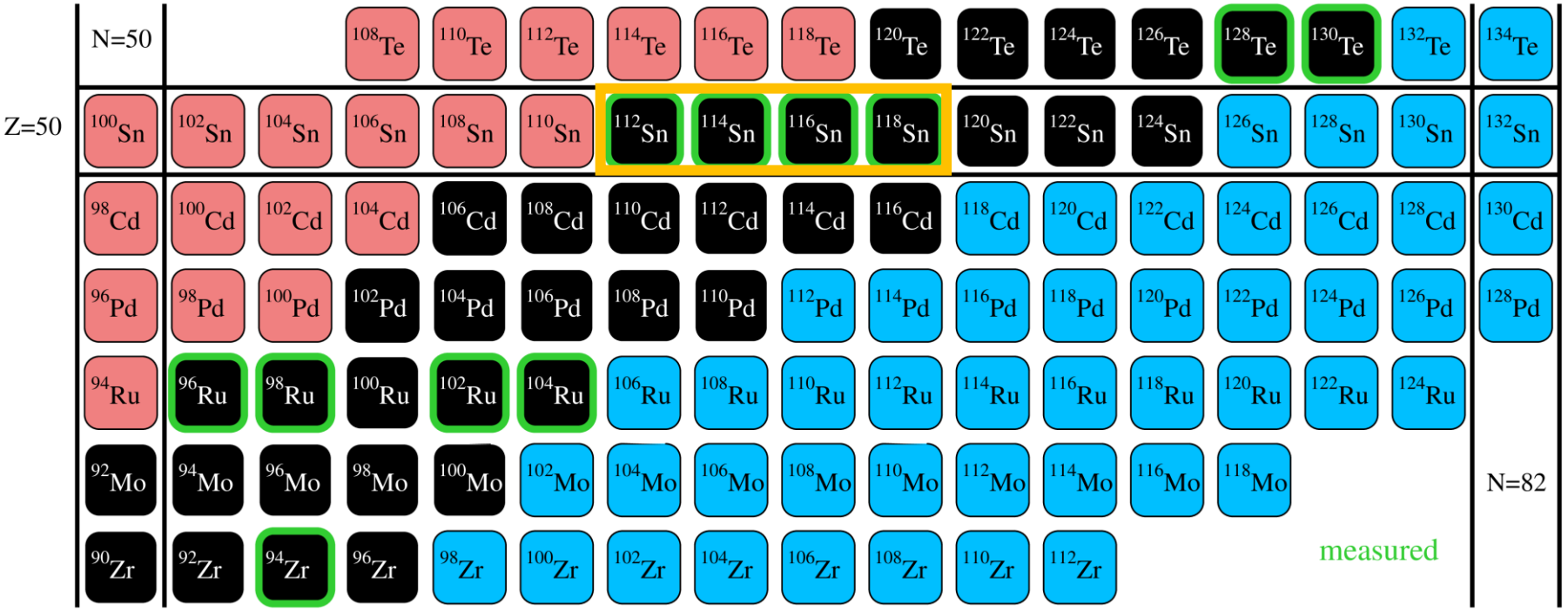
What about ^{104}Ru?

- Several possible candidates at E_x=2200-2500 keV
- Based on lifetime and decay behaviour

Angular correlations to determine J^π and δ

Vera Everwyn, Master's thesis, University of Cologne (2020)

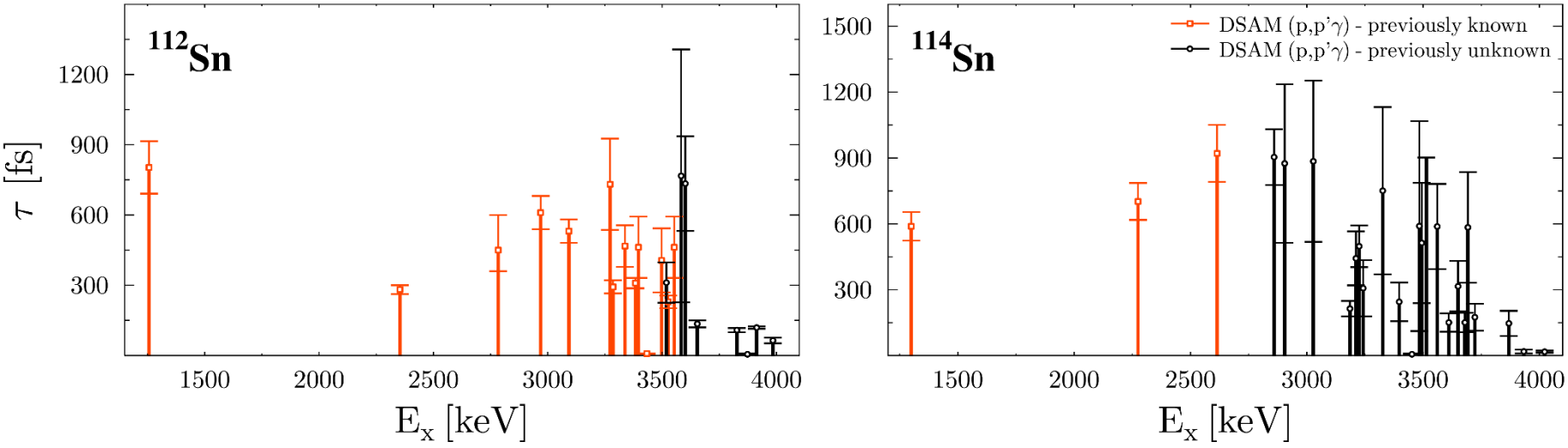
Experiments



A. Hennig *et al.*, PRC **90**, 051302(R) (2014)
A. Hennig *et al.*, PRC **92**, 064317 (2015)

M. Spieker *et al.*, Phys. Rev. C **97**, 054319 (2018)
S. Prill *et al.*, *J. Phys.: Conf. Ser.* **1643** 012157 (2020)
S. Prill *et al.*, PRC **105**, 034319 (2022)

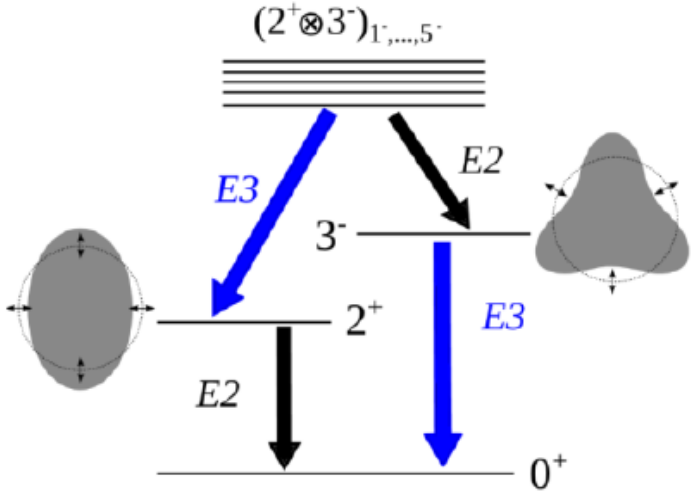
Results on ^{112,114}Sn



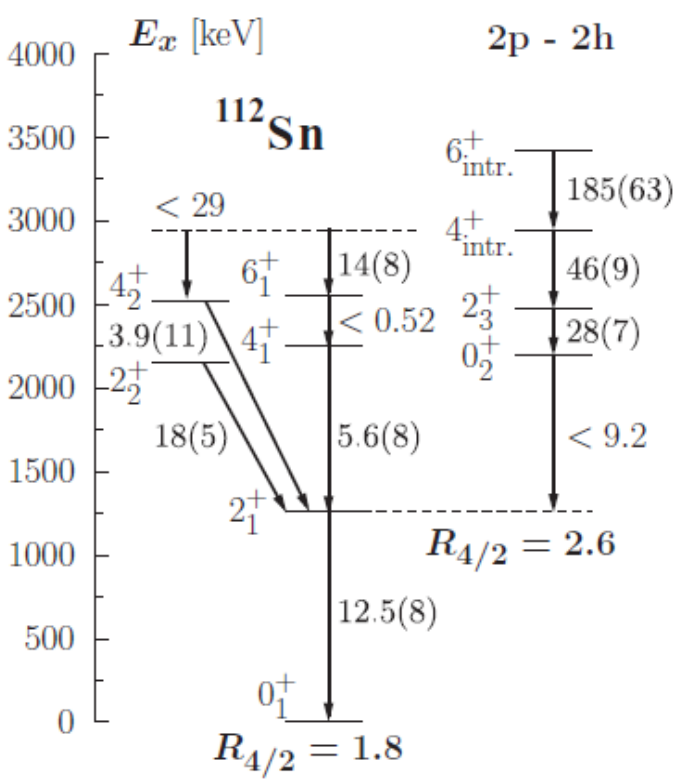
M. Spieker *et al.*, Phys. Rev. C **97**, 054319 (2018)

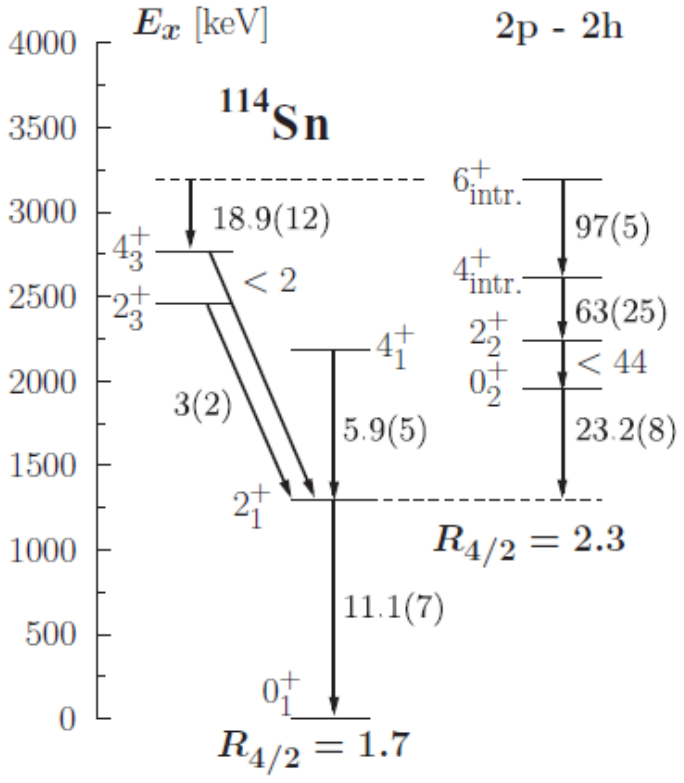
Main goals of the experiments:

- Determine lifetimes in ^{114}Sn
- Study low-lying collective structures
- Complete systematics on quadrupole-octupole coupled states in Sn isotopes
  - QOC quintuplet members identified



2p-2h intruder band





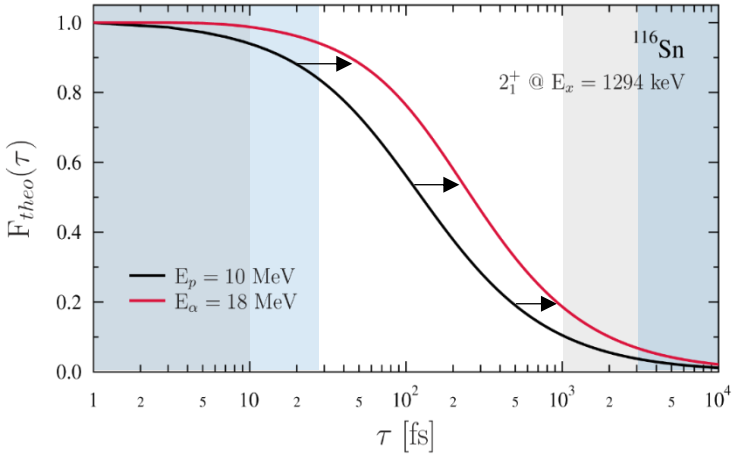
- Identified via interband transitions
- ^{116,118}Sn?

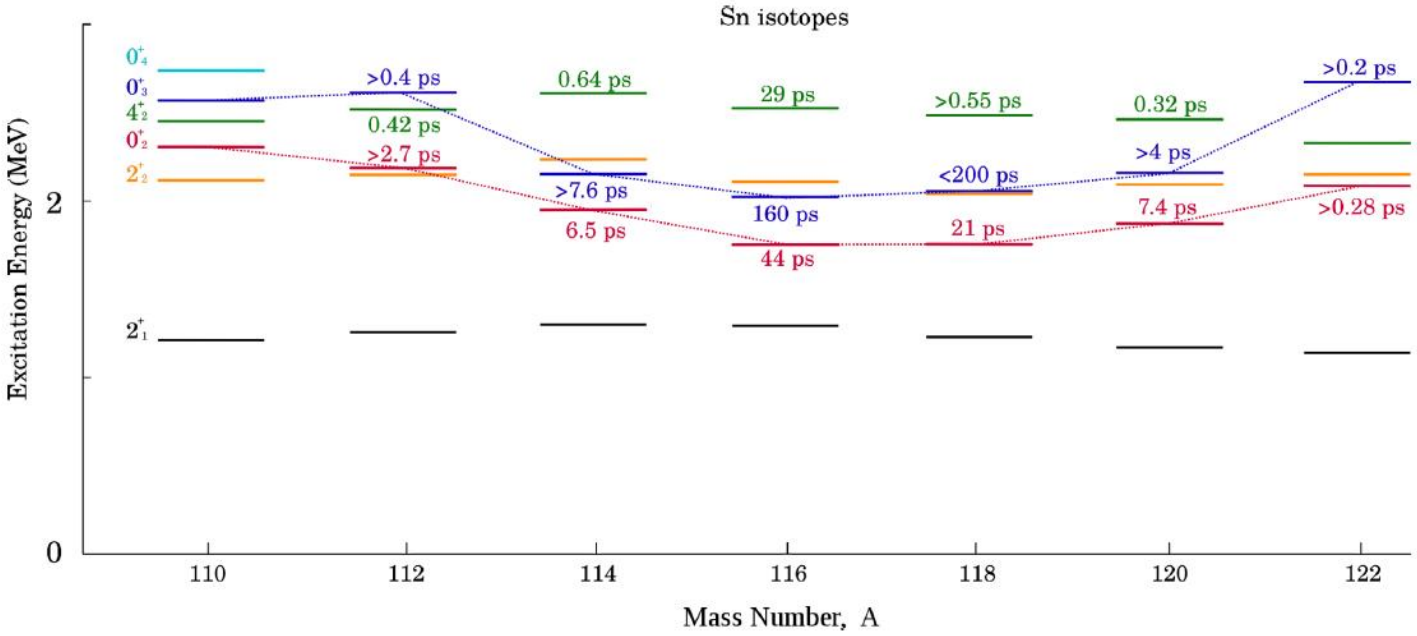
M. Spieker *et al.*, Phys. Rev. C **97**, 054319 (2018)

Results on ^{116,118}Sn

- Four experiments performed:
  - ^{116}Sn(p,p'γ) and ^{118}Sn(p,p'γ) @ 10 MeV
  - ^{116}Sn(α,α'γ) and ^{118}Sn(α,α'γ) @ 18 MeV

- Shifts extracted for over a dozen levels in ^{116}Sn(p,p'γ)



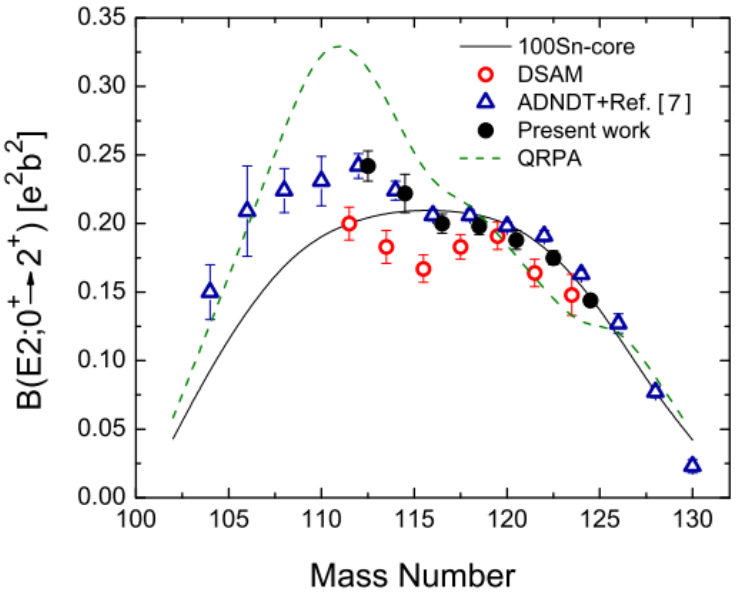


Determine τ of 2_1^+ in ^{116,118}Sn

C. Petrache *et al.*, Phys. Rev. C **99**, 024303 (2019)

$\tau(2_1^+)$ of ^{116}Sn

Discrepancies between $B(E2; 0_1^+ \rightarrow 2_1^+)$ values in ^{116}Sn



source	$\tau(2_1^+)$ ^{116}Sn [fs]
NNDC [1]	540(14)
Coulex [2]	564(20)
DSAM [3]	664(43)
(α,α'γ)-DSAM	540^{+57}_{-41}

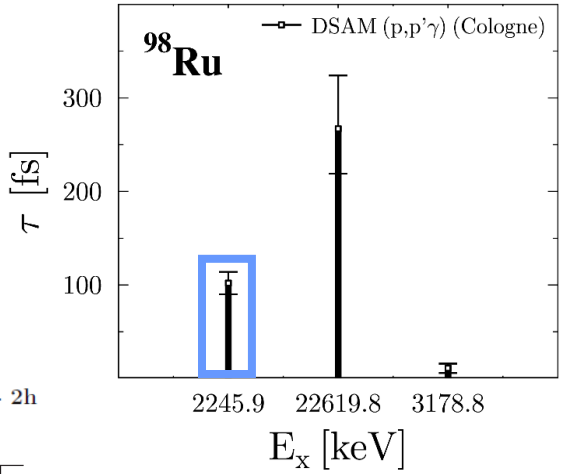
[2] R. Kumar *et al.*, Phys. Rev. C **96**, 054318 (2017)

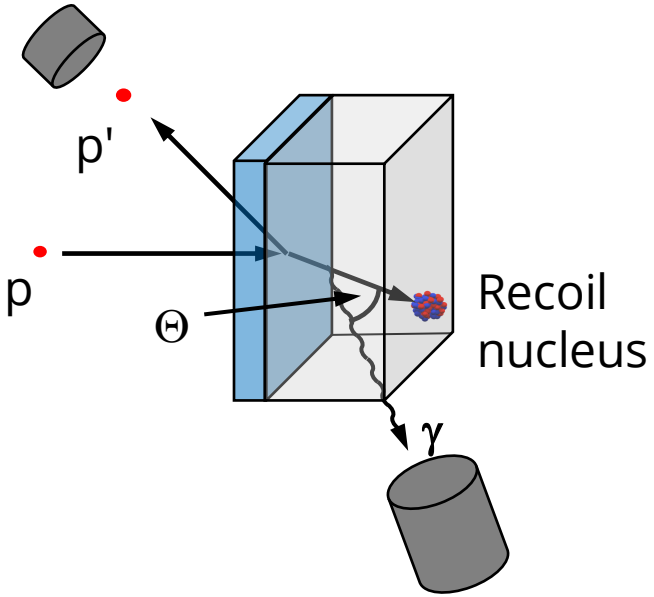
- ^{118}Sn analysis ongoing

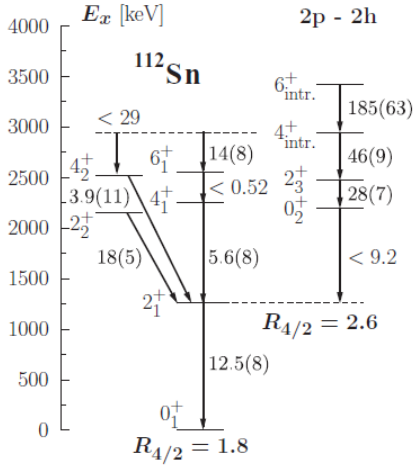
[1] J. Blanchot, Nucl. Data Sheets 111, 717 (2010)
[3] A. Jungclaus *et al.*, Phys. Lett. B **695**, 110-114 (2011)

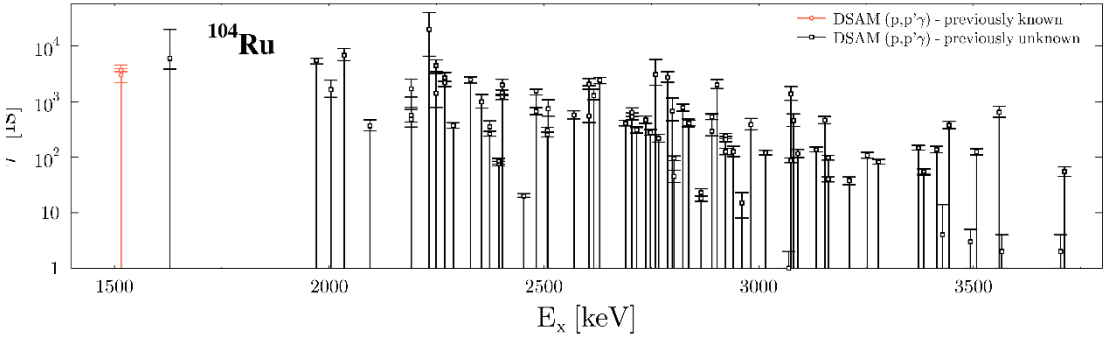
Summary

- (p,p'γ) DSA coincidence technique
- Different nuclear-structure phenomena can be studied
- Results on Ru and Sn isotopic chains





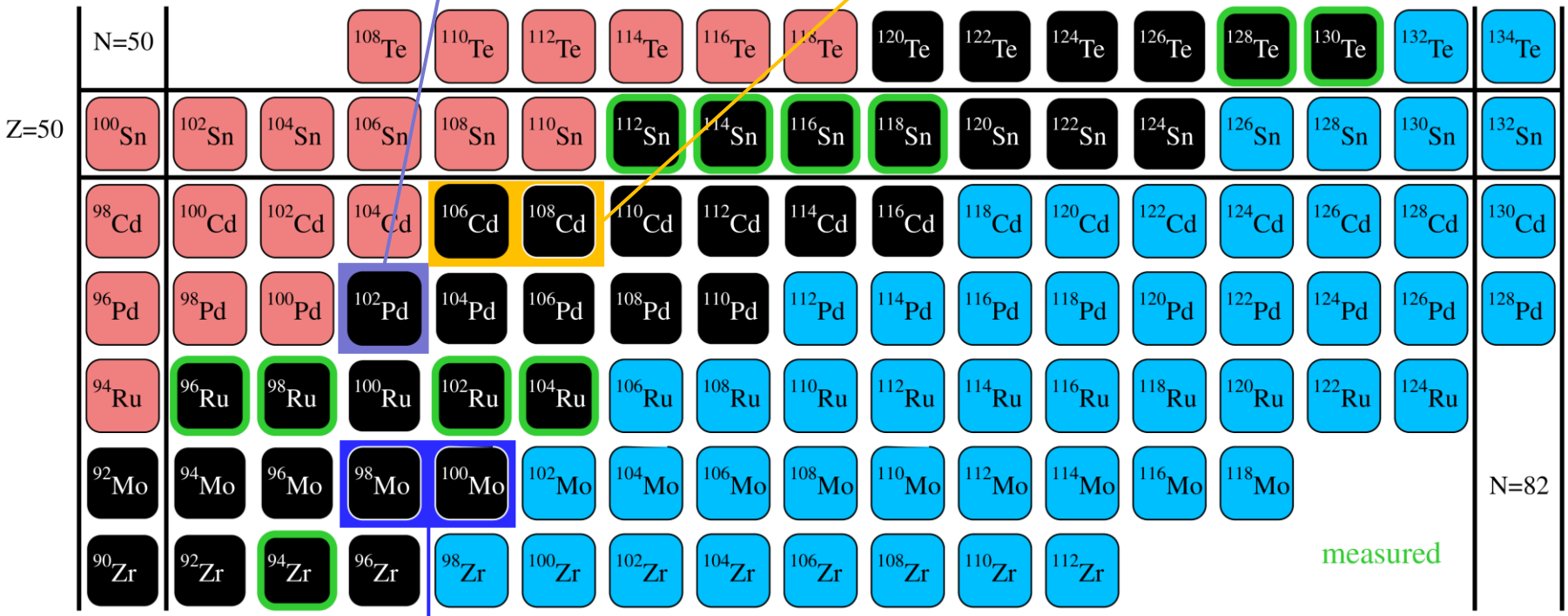




Future experiments

- Natural abundance ~1%
- Too expensive for INS-DSAM

- Natural abundance ~1%
- Shape coexistence
  - studied in ^{110,112}Cd [1]



- Shape coexistence
- Quadrupole-octupole multiplet

[1] P.E. Garrett *et al.*, Phys. Rev. Lett. **123**, 142502 (2019)