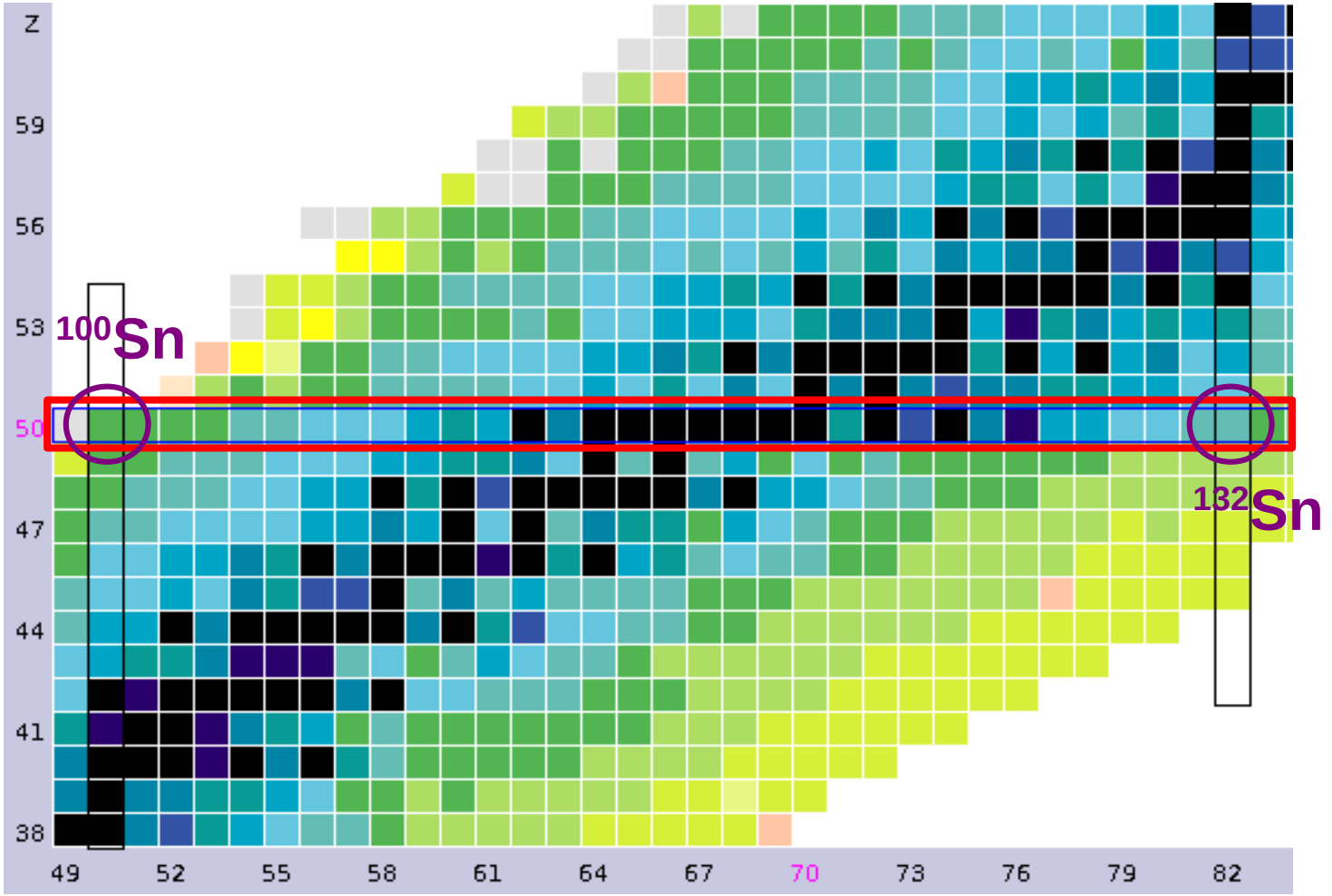
Lifetime measurements in the even-even $^{104\text{-}108}$Cd

Marco Siciliano
Irfu/CEA, Université de Paris-Saclay

NUSPIN 2019
Annual AGATA collaboration meeting

Orsay, 24-28 June 2019

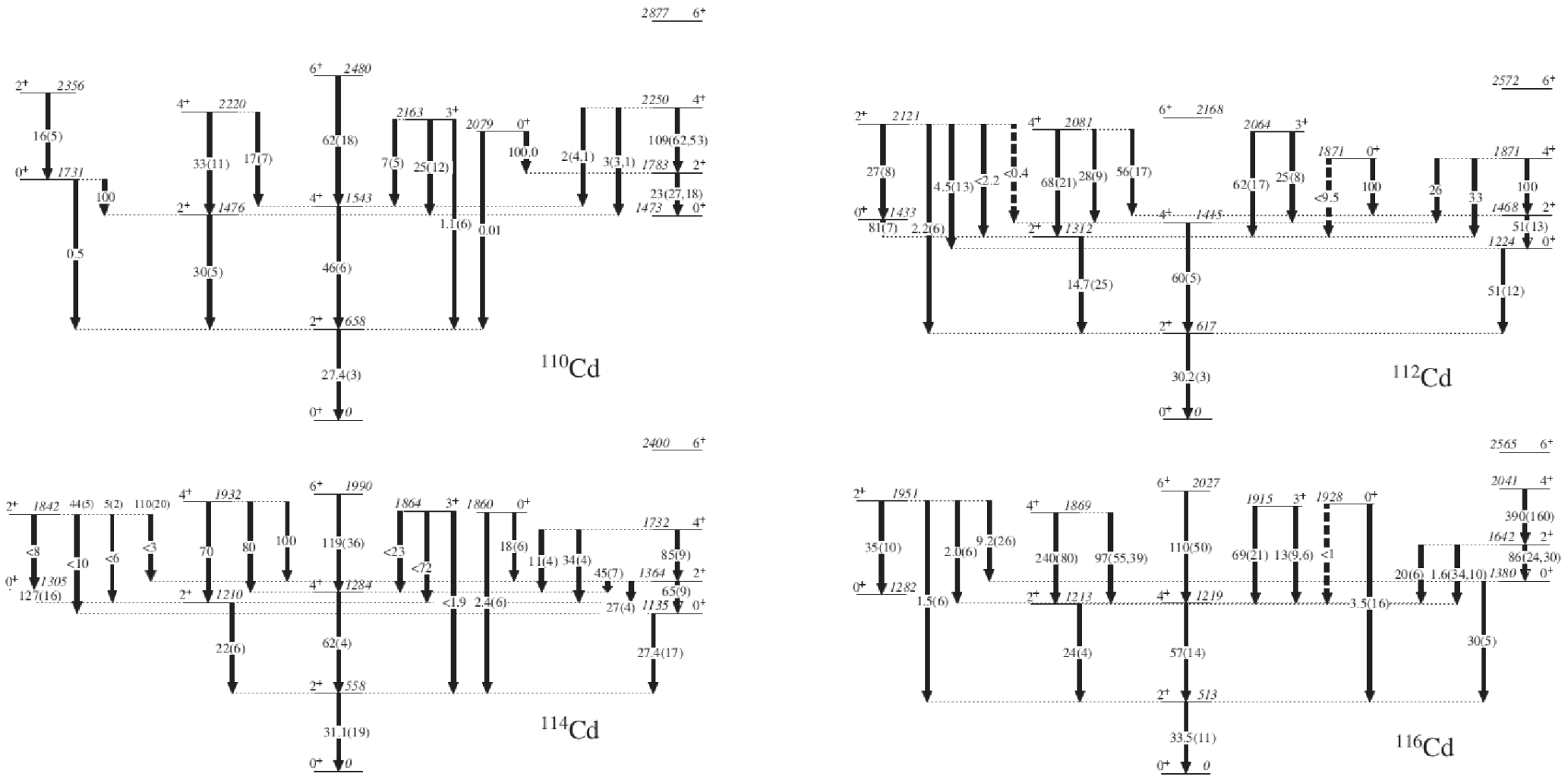
Z~50 PHYSICS CASE



- Longest isotopic chain between two experimentally accessible **doubly-magic nuclei**.
- Unique opportunity for **systematic studies** of the basic nuclear properties.
- Balance between the closed-shell effects and evolving collectivity.

Z=48 PHYSICS CASE
Vibrational…?

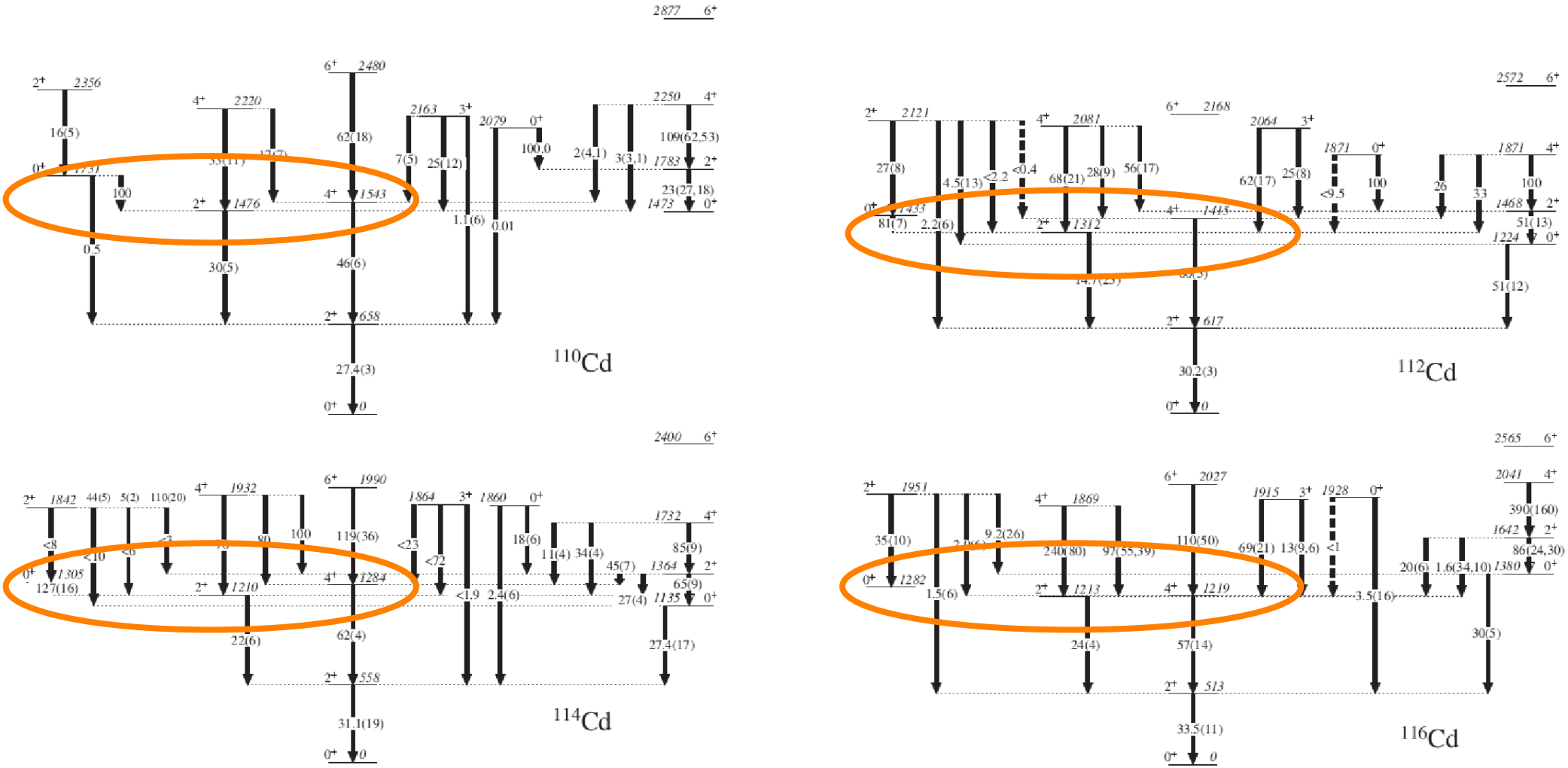
Vibrational-like character



P.E. Garrett and J.L. Wood, J. Phys. G: Nucl. Part. Phys. 37 (2010) 069701

Z=48 PHYSICS CASE
Vibrational…?

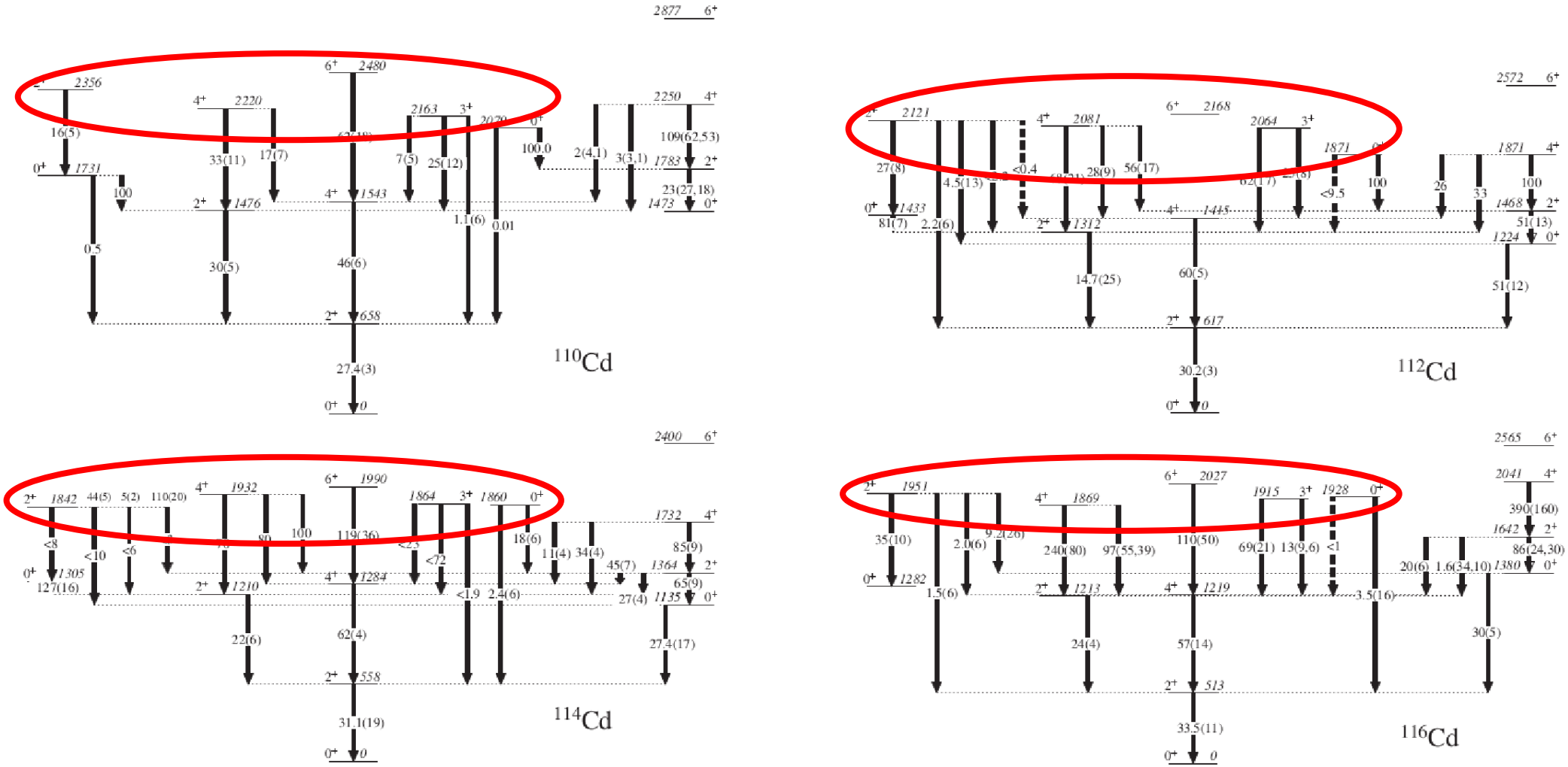
Vibrational-like character



P.E. Garrett and J.L. Wood, J. Phys. G: Nucl. Part. Phys. 37 (2010) 069701

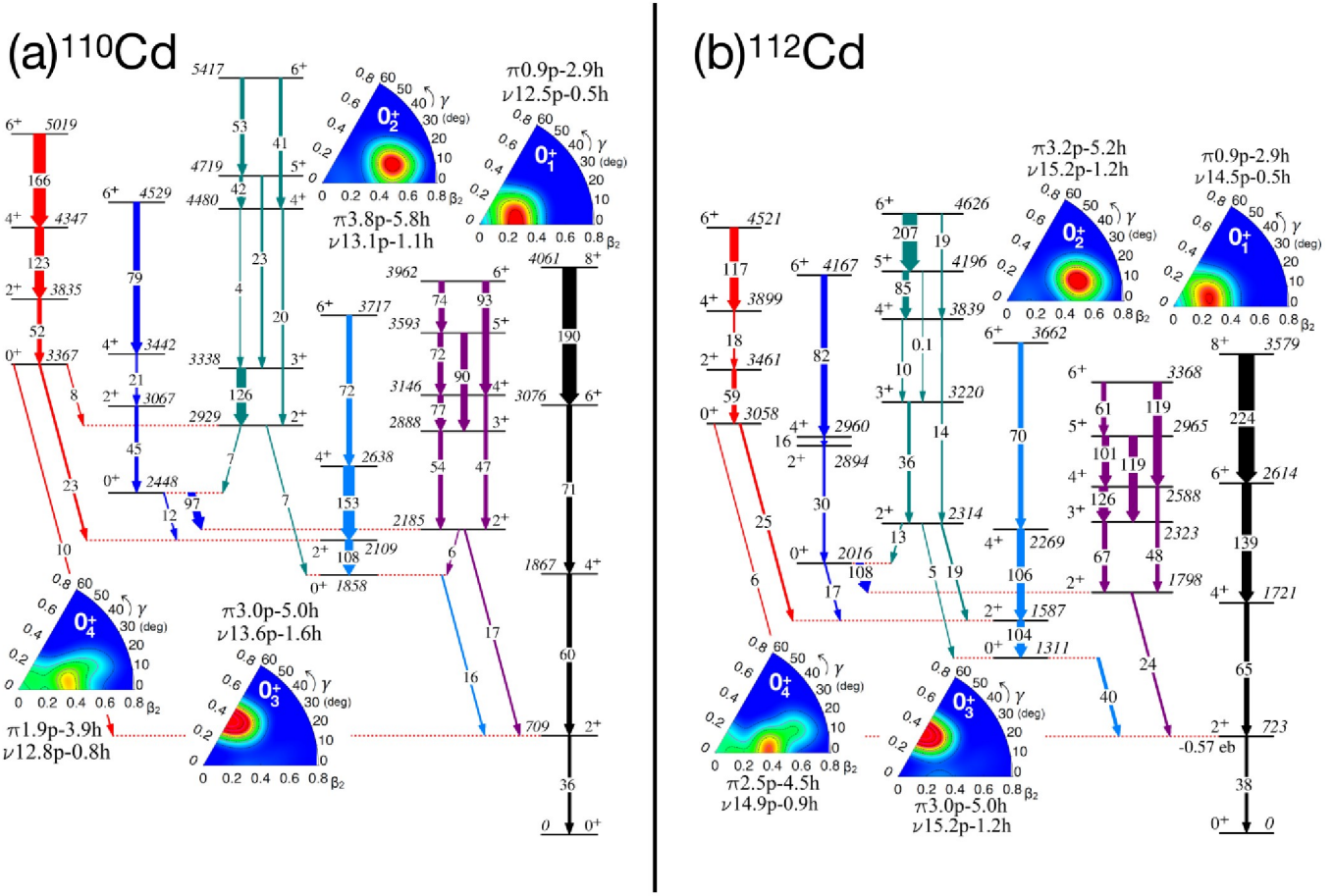
Z=48 PHYSICS CASE
Vibrational…?

Vibrational-like character



P.E. Garrett and J.L. Wood, J. Phys. G: Nucl. Part. Phys. 37 (2010) 069701

Z=48 PHYSICS CASE
Vibrational…?



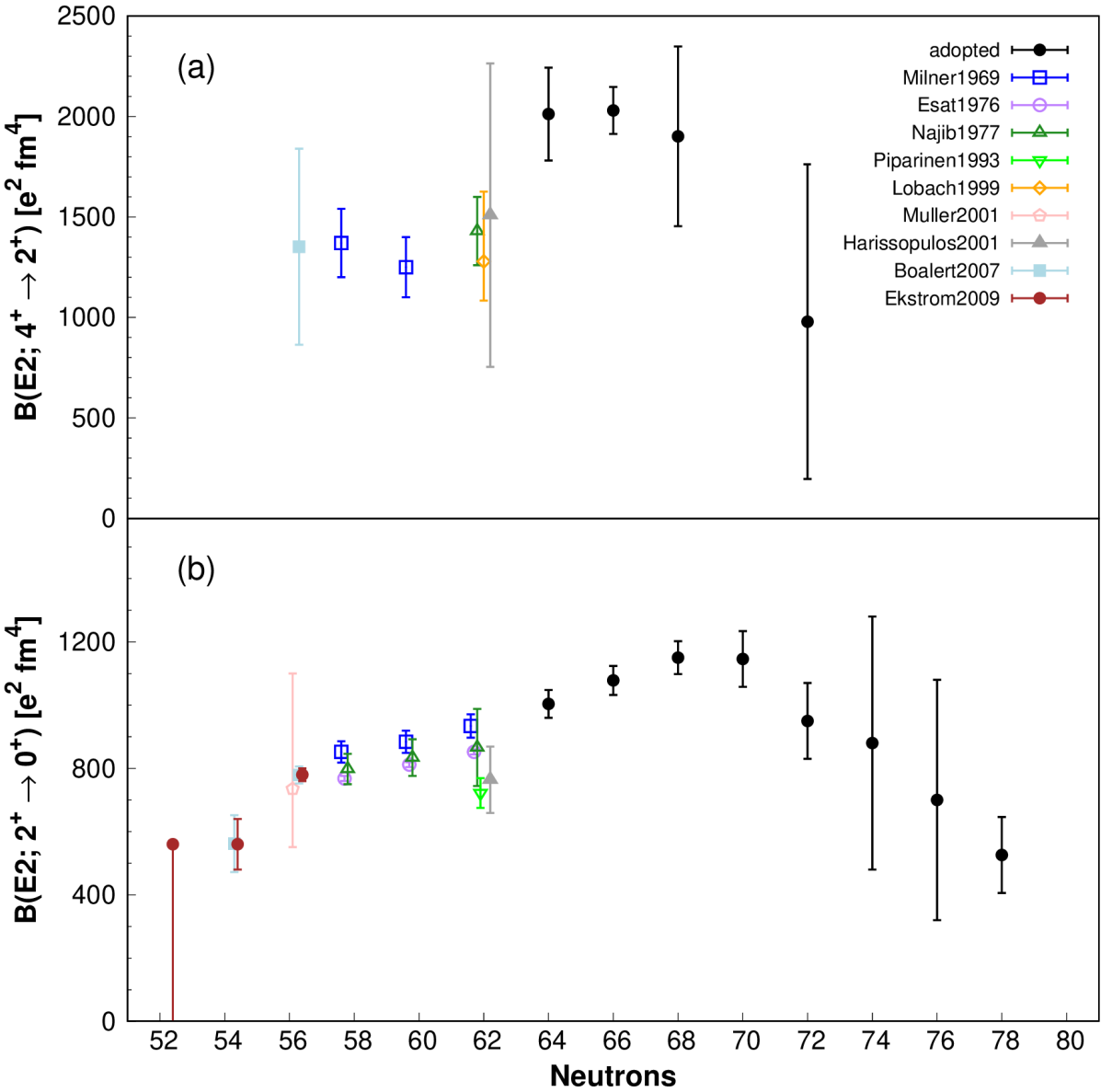
Courtesy of P.E. Garrett

- Reduced transition probabilities and quadrupole moments
- Unobserved transitions between the three-, two- and one-phonon statates

P.E. Garrett and J.L. Wood have proposed a reinterpretation of the stable Cd nuclei:

- Shape coexistence between rotational deformed structures

Z=48 PHYSICS CASE
Vibrational…?



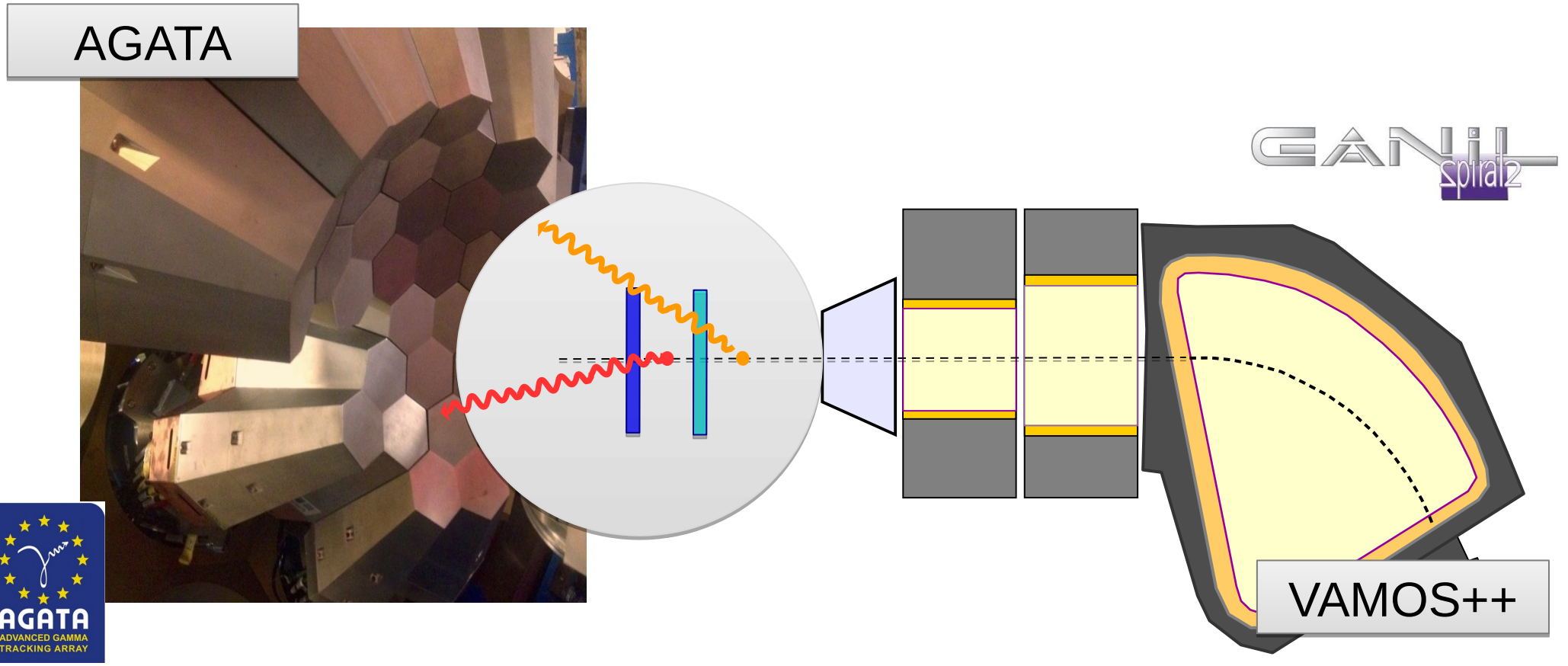
EXPERIMENT

Deep-inelastic reaction to investigate the neutron-deficient Cd isotopes:

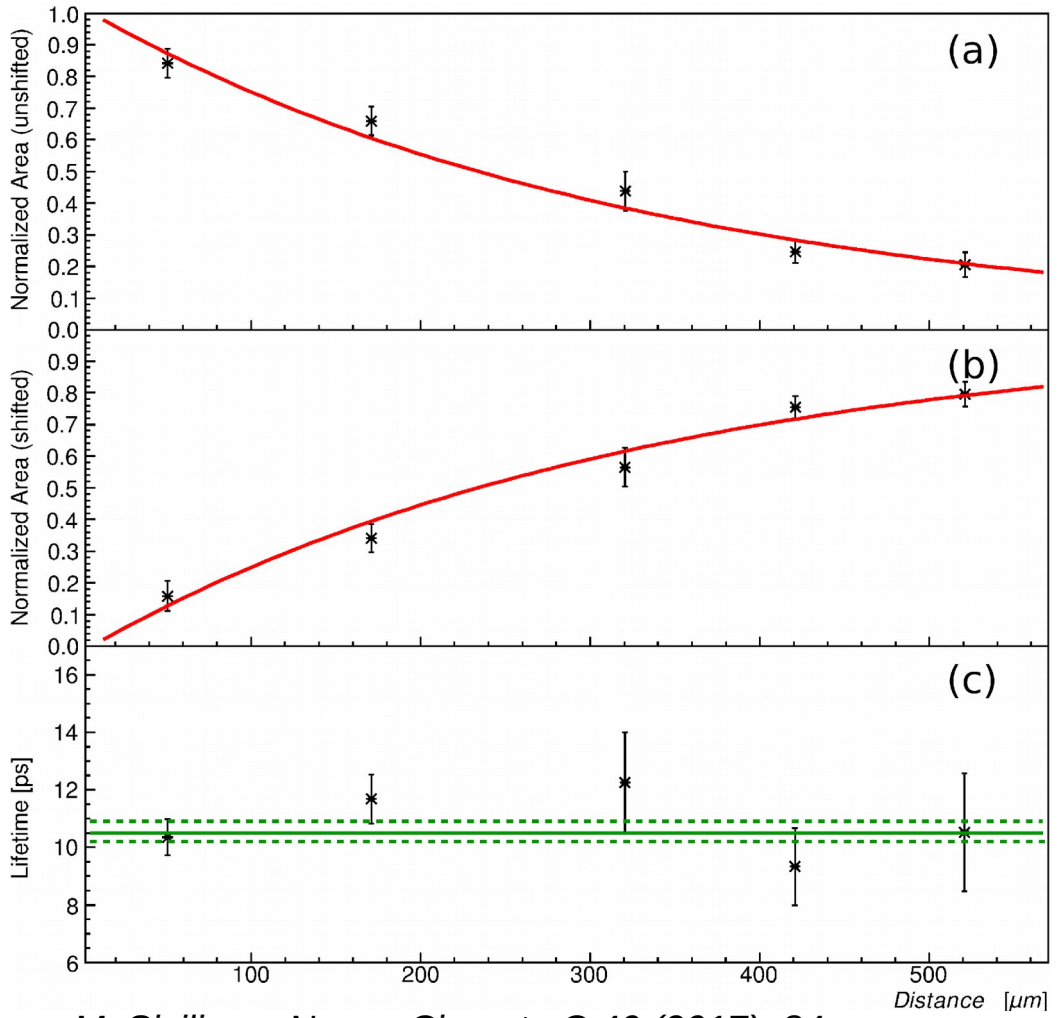
- Stable beam with **higher intensity** than previous experiment with radioactive beams

Beam: ^{106}Cd @ 770 MeV

Target: ^{92}Mo 0.715 mg/cm^2
Degrader: ^{24}Mg 1.6 mg/cm^2



RESULTS
Lifetimes in ^{106}Cd



M. Siciliano, Nuovo Cimento C 40 (2017), 84

- Verify the experimental procedure
- Lifetime measurement via both DDCM and DCM to check the real target-degrader distances (i.e. plunger zero-offset)

$\tau_{NNDC}(2^+)$ = 10.5(1) ps

$\tau_{DCM}(2^+)$ = 10.7(4) ps

$\tau_{DDCM}(2^+)$ = 10.4(2) ps

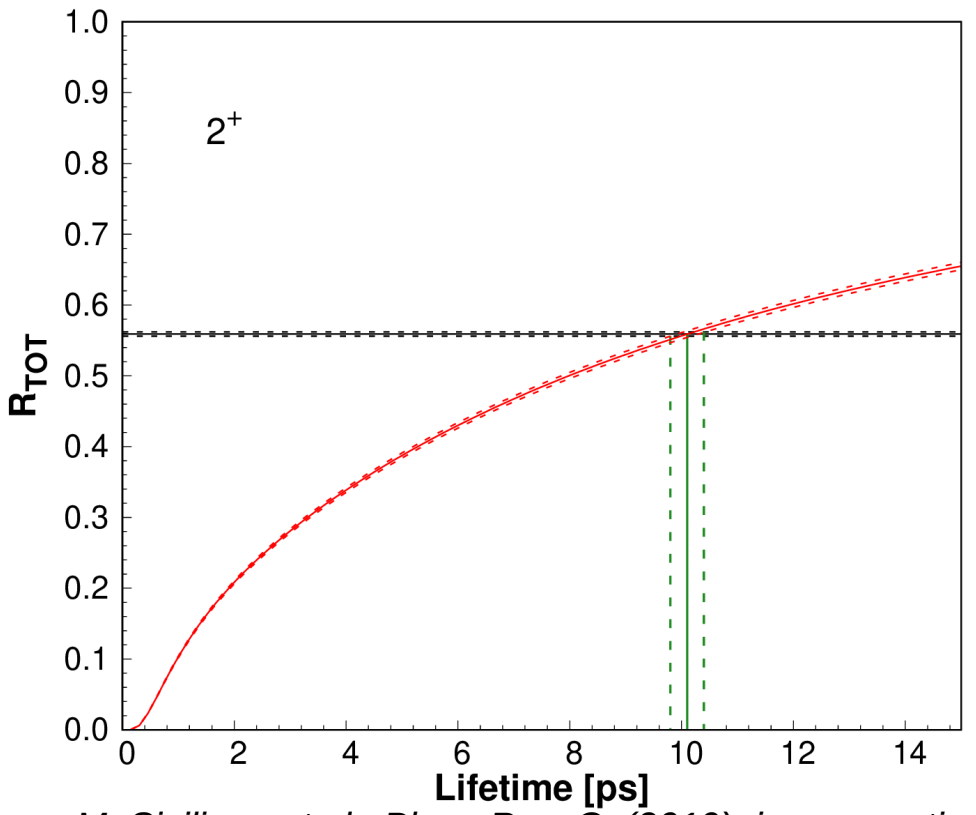
RESULTS
Lifetimes in ^{106}Cd

$\tau_{NNDC}(2^+)$ = 10.5(1) ps

$\tau_{TOT}(2^+)$ = 10.1(3) ps

$$R_{TOT}(\tau)=\frac{\sum_{j=1}^{n} I_{u,j}}{\sum_{j=1}^{n}(I_{u,j}+I_{s,j})}=\sum_{j=1}^{n} n_j e^{\frac{-1}{\tau}\frac{x_j}{\beta_{TD}c}}$$

J. Litzinger et al., Phys. Rev. C 92, 2064322 (2015)

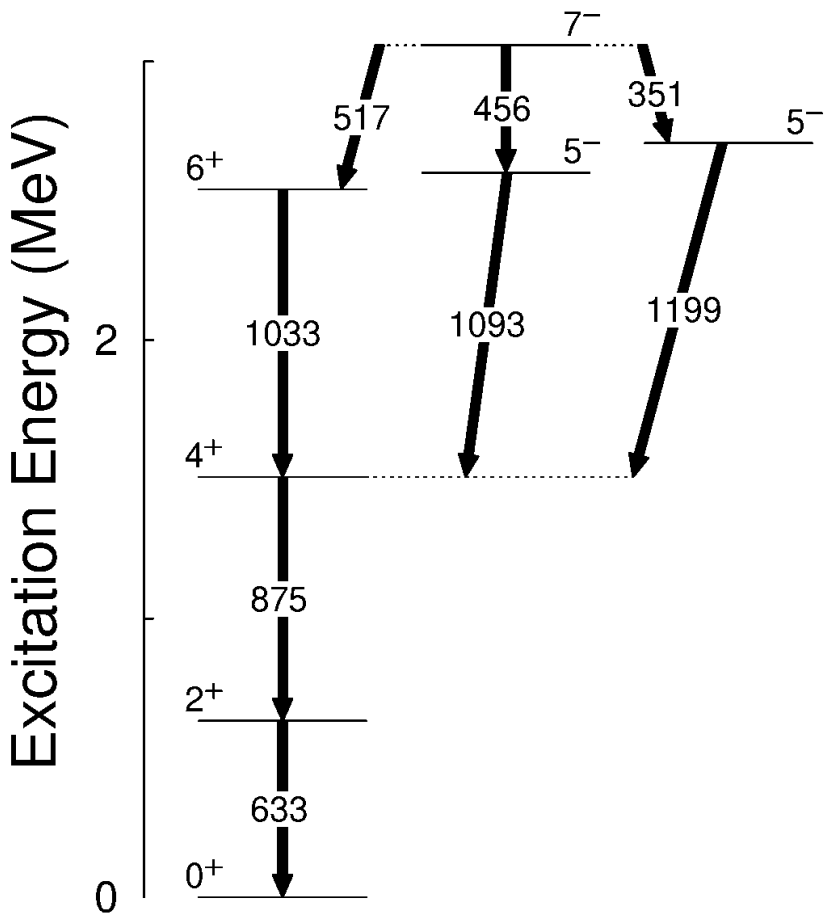


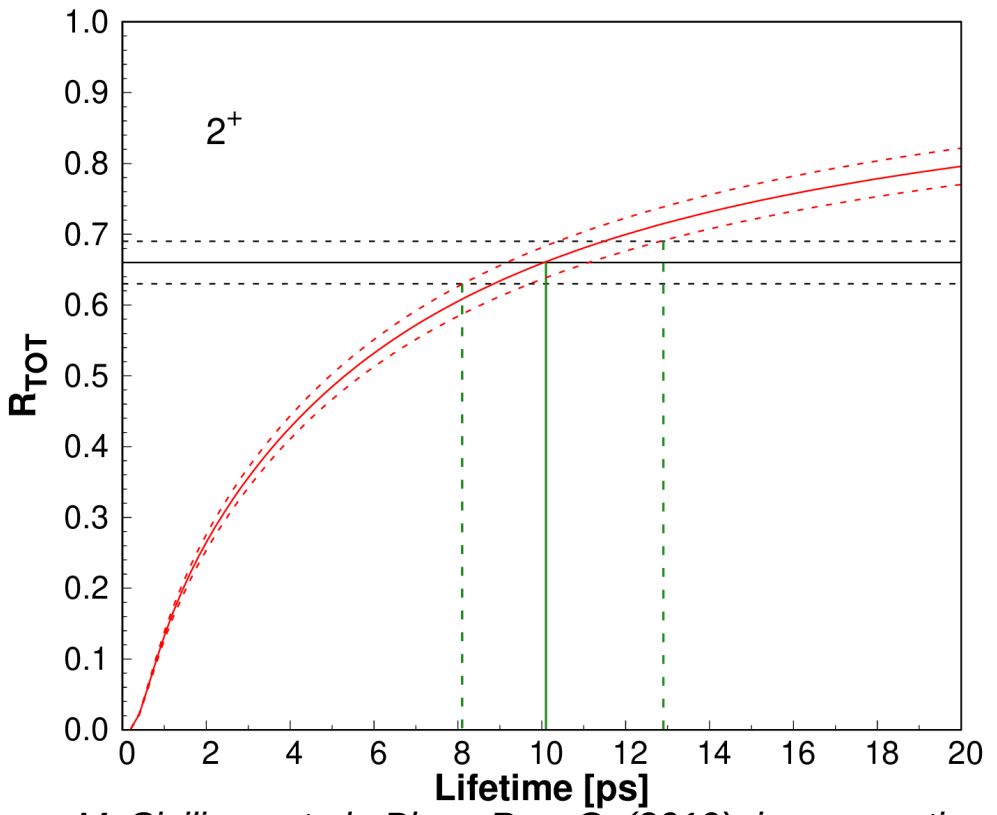
M. Siciliano et al., Phys. Rev. C. (2019), in preparation

RESULTS
Lifetimes in ^{108}Cd

$\tau_{NNDC}(2^+) = 9.9(1)$ ps

$\tau_{TOT}(2^+) = 10.1^{+2.8}_{-2.0}$ ps





M. Siciliano et al., Phys. Rev. C. (2019), in preparation

RESULTS
Lifetimes in ^{104}Cd

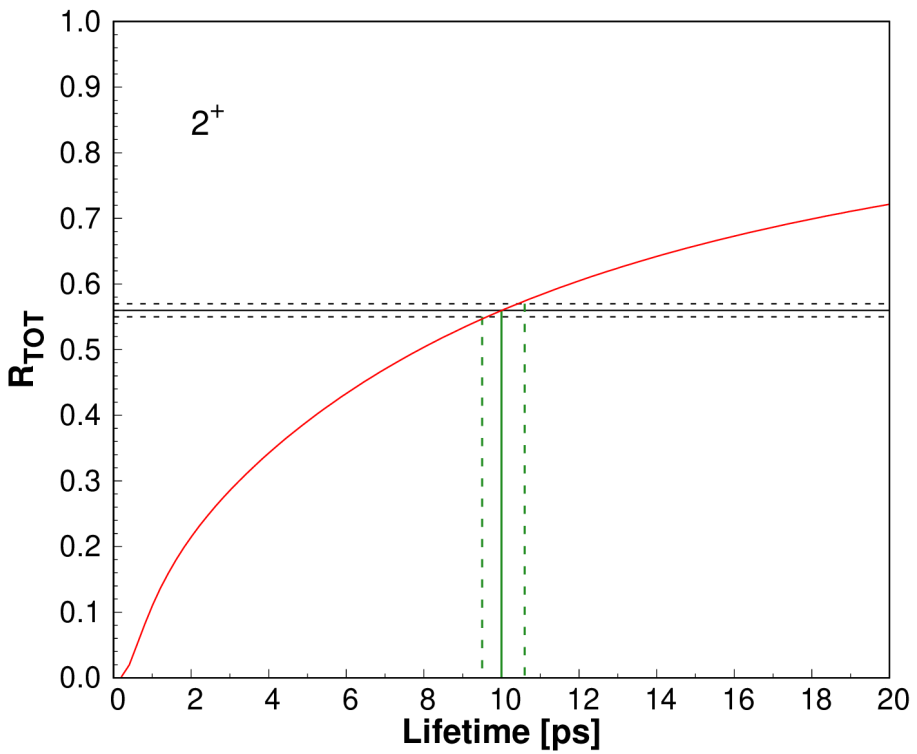
$\tau_{lit}(2^+) = 8.5(12)$ ps

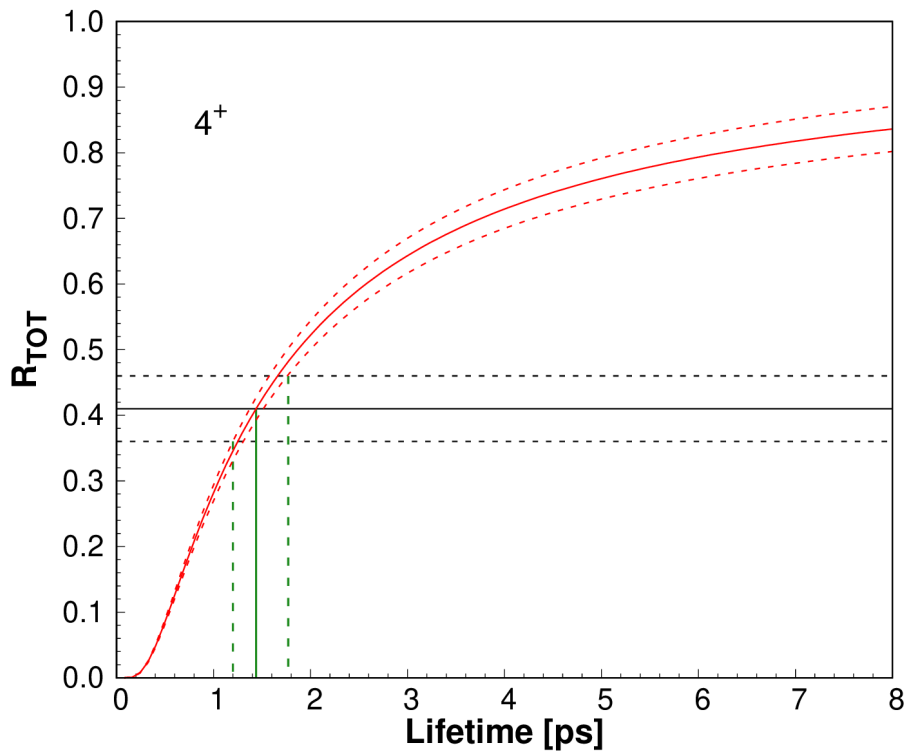
$\tau_{lit}(4^+) = 1.5(5)$ ps

N. Boalert et al., Phys. Rev. C 75 (2007), 054311

$\tau_{TOT}(2^+) = 10.0^{+0.6}_{-0.5}$ ps

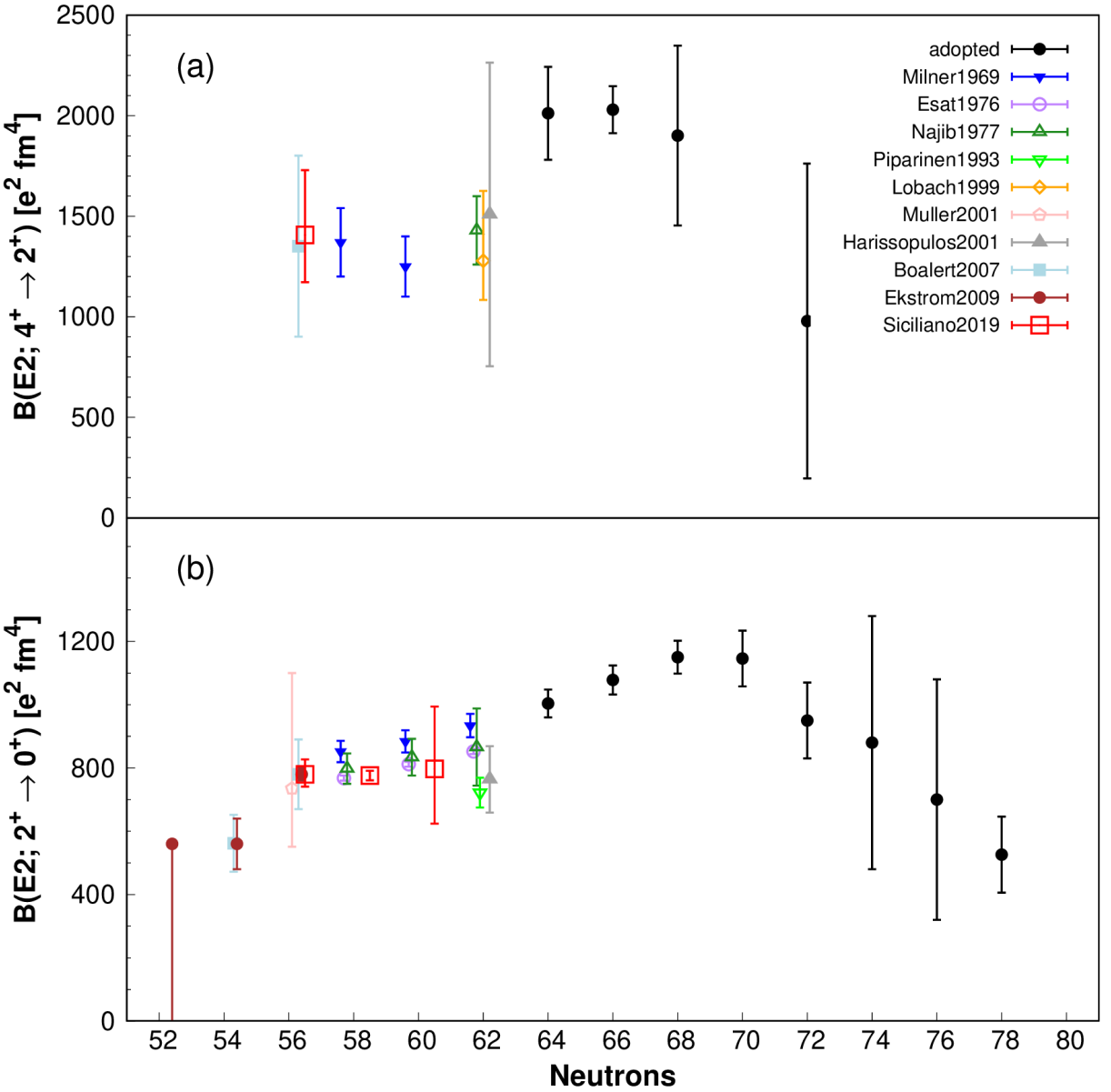
$\tau_{TOT}(4^+) = 1.44^{+0.33}_{-0.24}$ ps



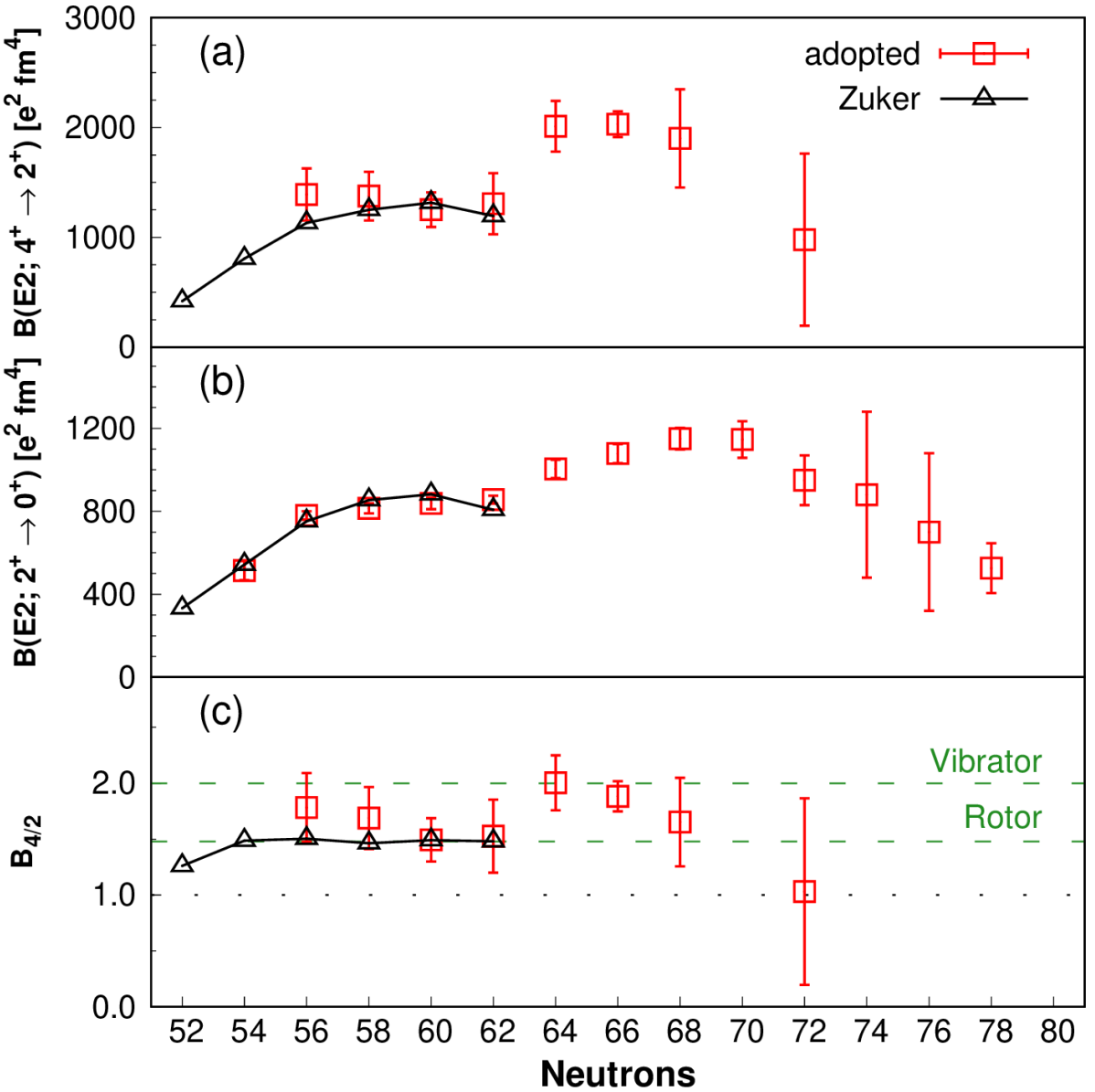


M. Siciliano et al., Phys. Rev. C. (2019), in preparation

RESULTS
Reduced Transition Probability



THEORETICAL INTERPRETATION
Quadrupole-Pairing Interplay



Large-scale shell-model calculation, performed by the Strasbourg group, to explain the systematic of the reduced transition probability in the neutron-deficient Cd isotopes.

- Realistic potential: N3LO (CD-Bonn and AV18 provide same results)
- Renormalization: 30% for quadrupole force
  40% for pairing force
- Monopole-free
  ^{100}Sn single-particle spectrum, given by GEMO
- Full *gds* valence space
  1p-1h excitations in the $(g_{9/2})^{\pi}$

Deformed structures

CONCLUSIONS

- Deep-inelastic collisions are a powerful tool for populating the region close to ^{100}Sn.
  Thanks to the direct population of the states, electromagnetic properties of the low-lying states can be investigated.

- **Lifetime of 2_1^+ states** has been measured in the even-even **$^{104\text{-}108}$Cd**.
  Lifetime of 4_1^+ state has been measured for **^{104}Cd**.
  The results confirm the values obtained in previous experiments.

- The extracted B(E2) values have been compared with LSSM calculations in the full *gds* valence space to explain the trend of neutron-deficient Cd isotopes.

FUTURE…?

Further investigation of neutron-deficient Cd nuclei via Coulomb excitation or lifetime measurements, to study the nature of side bands.

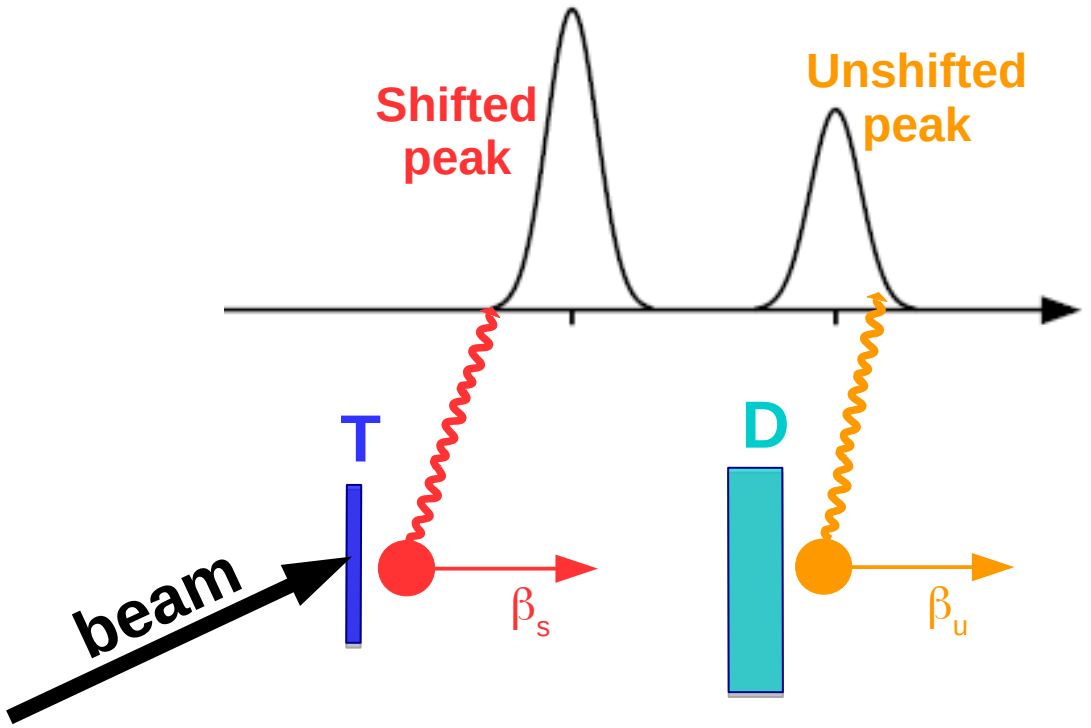
M. Siciliano[1,2,3], J.J. Valiente-Dobón[1], A. Goasduff[1, 2, 4], D. Bazzacco[4], A. Lopez-Martens[6], E. Clément[7], G. Benzoni[8], T. Braunroth[9], N. Cieplicka-Oryńczak[8,10], F.C.L. Crespi[8, 11], G. de France[7], M. Doncel[12], S. Ertürk[13], C. Fransen[9], A. Gadea[14], G. Georgiev[6], A. Goldkuhle[9], U. Jakobsson[15], G. Jaworski[1,16], P.R. John[2,4,17], I. Kuti[18], A. Lemasson[7], H. Li[15], T. Marchi[1], D. Mengoni[2,4], C. Michelagnoli[7,19], T. Mijatović[20], C. Müller-Gatermann[9], D.R. Napoli[1], J. Nyberg[21], M. Palacz[16], R.M. Pérez-Vidal[14], B. Sayğı[1, 22], D. Sohler[18], S. Szilner[20], D. Testov[2,4], and AGATA collaboration

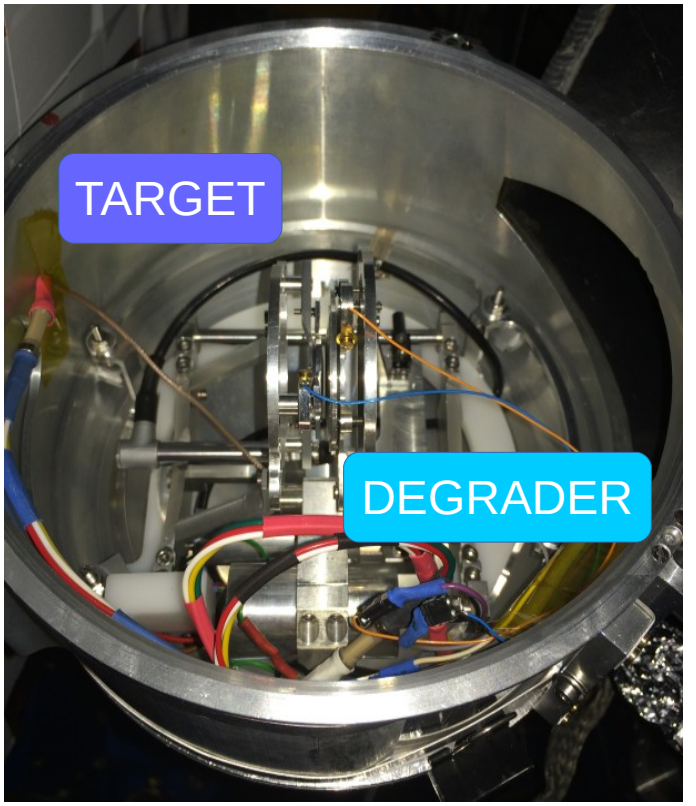
[1]INFN, Laboratori Nazionali di Legnaro, Italy. [2]Dipartimento di Fisica e Astronomia, Università di Padova, Italy.
[3]Irfu/CEA, Université de Paris-Saclay, Gif-sur-Yvette, France. [4]INFN, Sezione di Padova, Italy.
[5]IPHC, CNRS/IN2P3 Université de Strasbourg, France. [6]CSNSM, CNRS/IN2P3, Université de Paris-Saclay, Orsay, France.
[7]GANIL, Irfu/CEA/DRF and CNRS/IN2P3, Caen, France. [8]INFN, Sezione di Milano, Italy.
[9]Institut für Kernphysik, Universität zu Köln, Germany. [10]IFJ, Polska Akademia Nauk, Krakow, Poland.
[11]Dipartimento di Fisica, Università di Milano, Italy. [12]Universidad de Salamanca, Spain.
[13]Ömer Halisdemir Üniversitesi, Niğde, Turkey. [14]IFIC, CSIC-Universidad de Valencia, Spain.
[15]Kungliga Tekniska Högskolan, Stockholm, Sweden. [16]HIL, Uniwersytet Warszawski, Warsaw, Poland.
[17]Institut für Kernphysik, Technische Universität Darmstadt, Germany. [18]INR, Hungarian Academy of Sciences, Debrecen, Hungary.
[19]Institut Laue-Langevin, Grenoble, France. [20]Ruder Bošković Institute and University of Zagreb, Zagreb, Croatia.
[21]Institutionen för Fysik och Astronomi, Kärnfysik, Uppsala Universitet, Sweden. [22]Ege Üniversitesi, İzmir, Turkey.

THANKS FOR YOUR ATTENTION

EXPERIMENT
Differential Plunger

The nuclear reaction takes place in the thin target and then the reaction products are slowed down by the degrader foil.
Because of the two different velocities, per each γ-ray transition two components are observed.





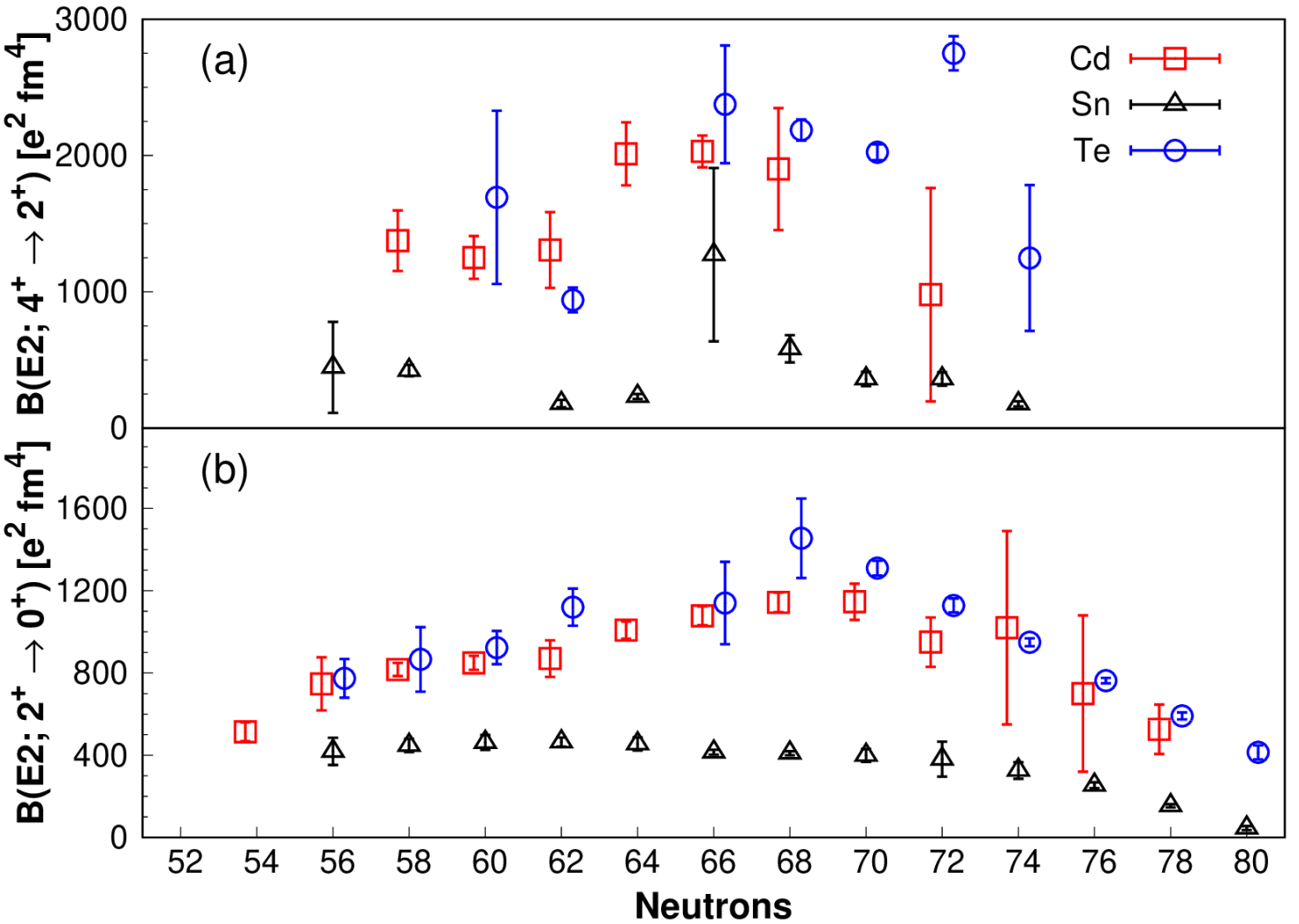
The γ-ray energy is Doppler corrected for β_u (measured by VAMOS++), so in the spectrum a second under-corrected shifted peak appears.

The relative intensity of the two peaks depends on the target-degrader TOF (β_s, distance) and **lifetime**.

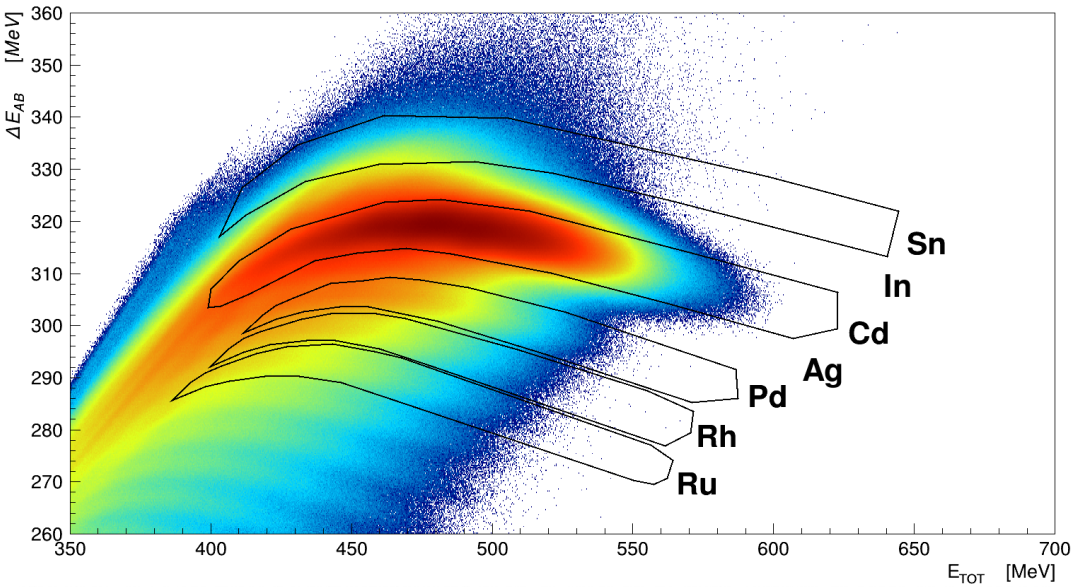
Z~50 PHYSICS CASE

Information of the shell gap and collectivity evolution can be experimentally obtained from

- the excitation energy of the low-lying states
- the reduced transition probability



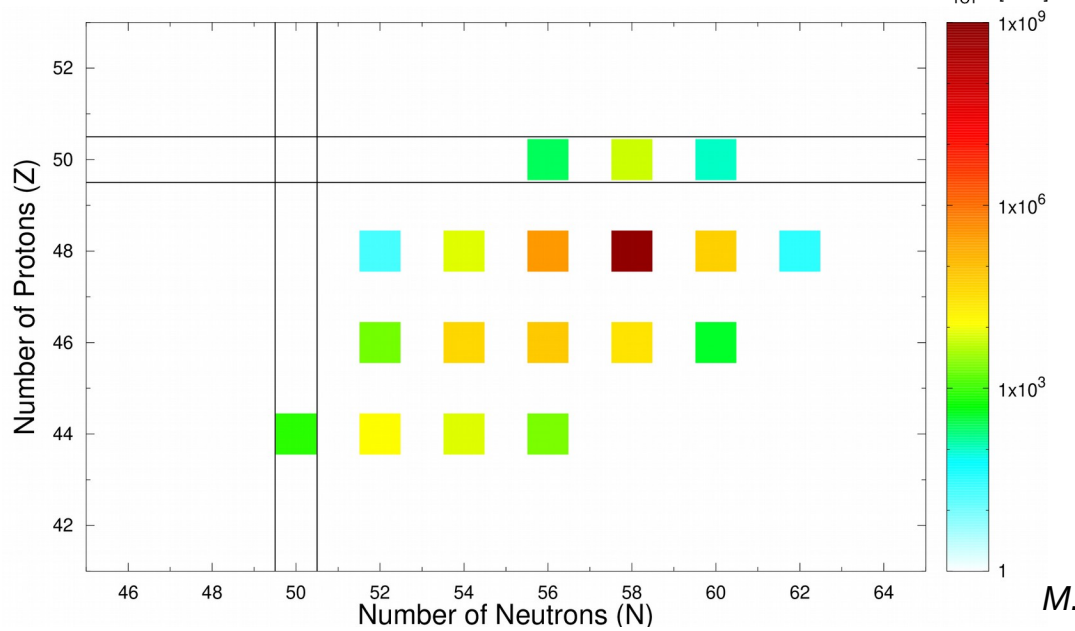
REACTION FRAGMENTS IDENTIFICATION
Beam-like fragments



Due to the almost symmetric reaction, the recoils energy was at the limit for the identification in the IC.

The identification of the fragments is challenging because of the high atomic number, close to the resolution limit of the IC.

- Empirical corrections to improve the resolution
- A systematic investigation was performed to identify the Z=50 channel



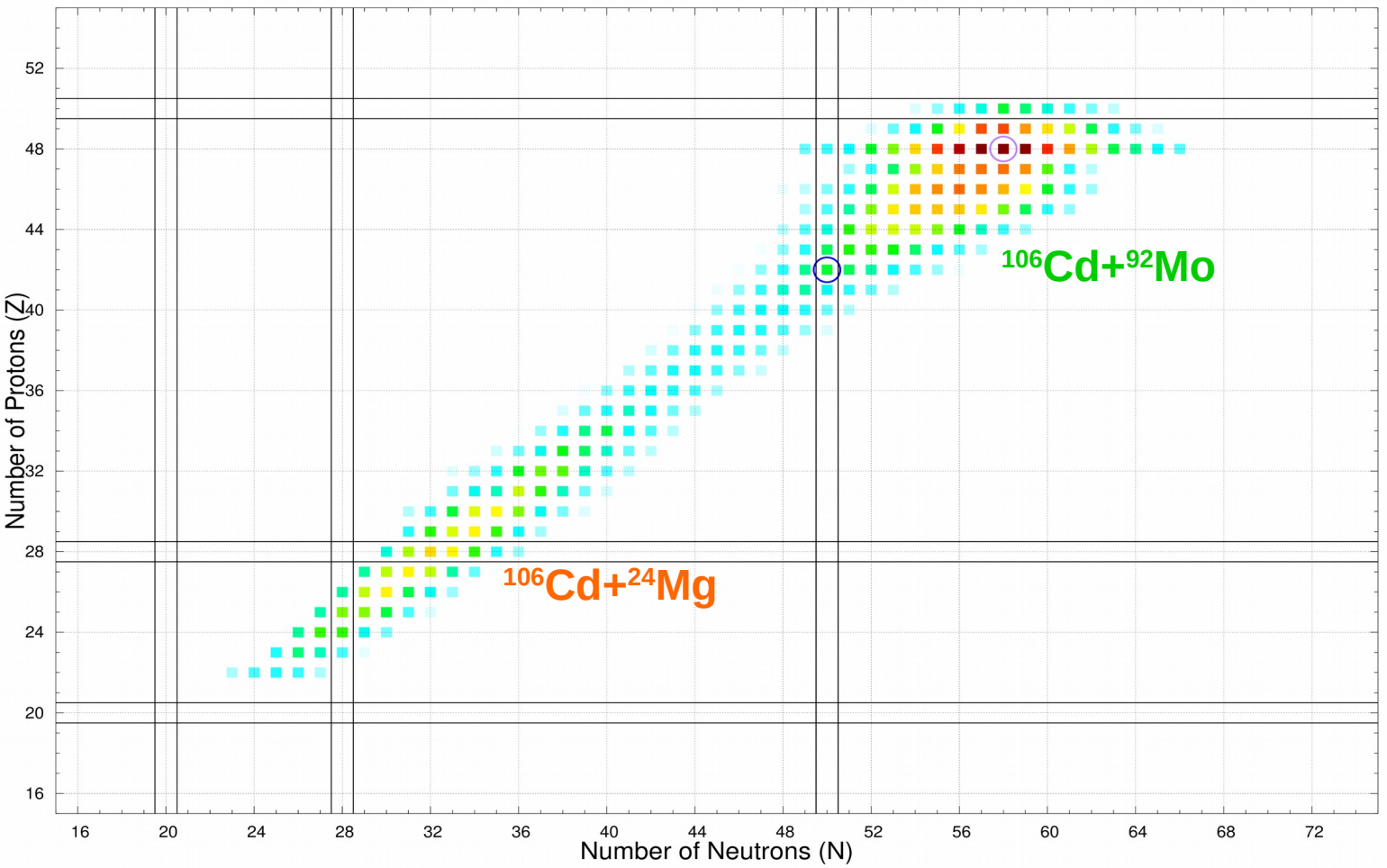
A good estimation for the even-even nuclei yield is given by the efficiency-corrected area of the peak related to $2_1^+ \rightarrow 0_{g.s.}^+$ transition.

- Yields asymmetry for Z≥48
- Yields symmetry for Z≤46

M. Siciliano et al., INFN-LNL Annual Report 2017 (2018) 57

REACTION FRAGMENTS IDENTIFICATION

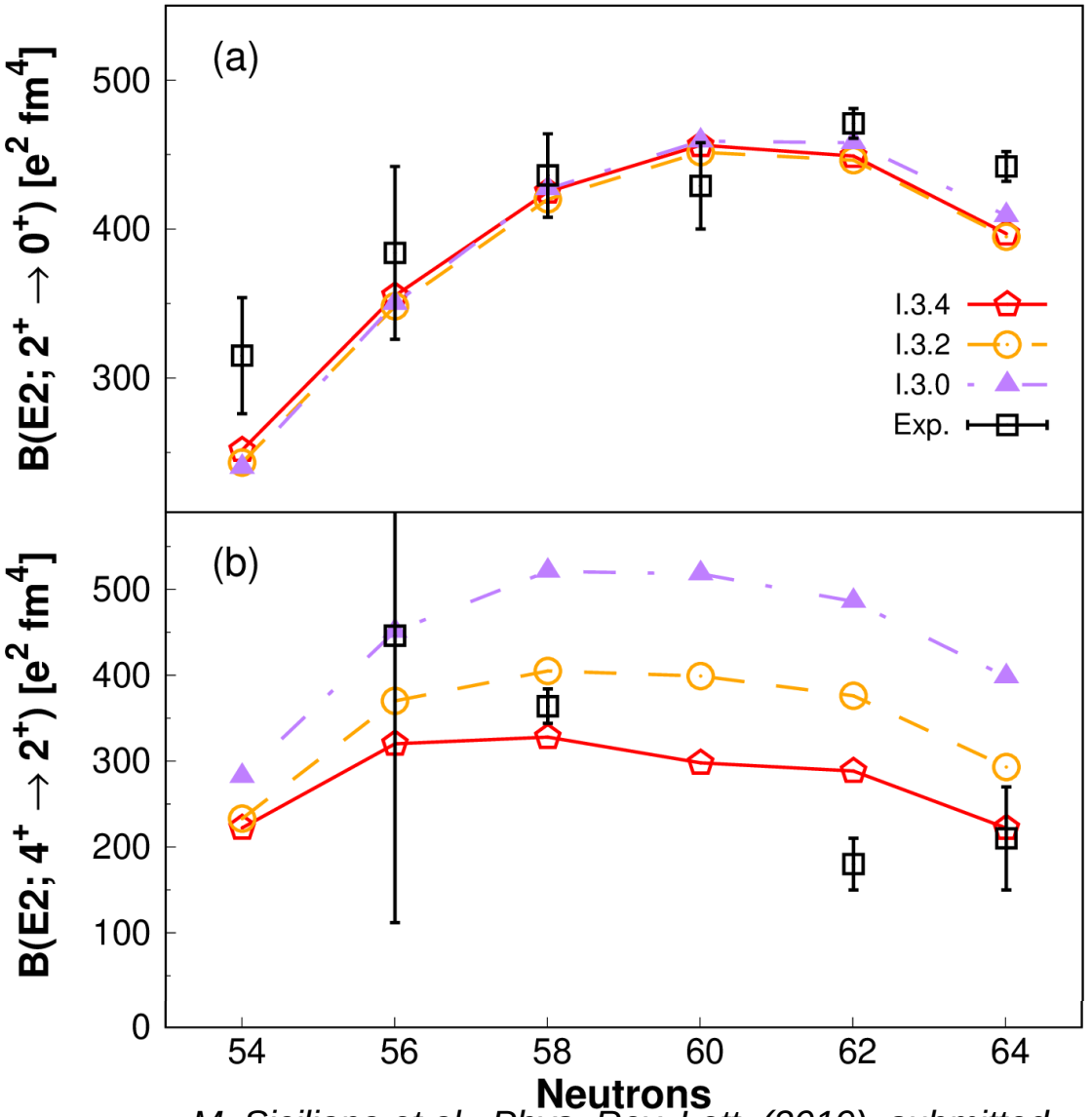
The VAMOS++ spectrometer allows the **complete identification** of the reaction products, providing the atomic number Z and mass A.



M. Siciliano et al., INFN-LNL Annual Report 2017 (2018) 57

- Light ions with **Z~28** were populated via the fusion-fission reaction of the beam with the degrader material
- Beam-like ions with **Z~48** were obtained via both multi-nucleon transfer reactions and deep-inelastic collisions of the beam with the target

THEORETICAL INTERPRETATION
Quadrupole-Pairing Interplay in Sn



M. Siciliano et al., Phys. Rev. Lett. (2019), submitted
A.P. Zuker, Phys. Rev. Lett. (2019), submitted

- Realistic potential: N3LO (CD-Bonn and AV18 provide same results)
- Renormalization: 30% for quadrupole force
  0-40% for pairing force
- Monopole-free
  ^{101}Sn single-particle spectrum, given by GEMO
- Full *gds* valence space
  2p-2h excitations in the $(g_{9/2})^{\pi}$

Pairing force takes its revenge on quadrupole correlation

Results in ^{108}Sn allow to firmly define the pairing force