Nuclear structure of the semi-magic tin isotopes close to ^{100}Sn: Lifetime measurements of low-lying states in ^{106}Sn and ^{108}Sn

PhD Thesis Award

Istituto Nazionale di Fisica Nucleare

Marco Siciliano

REDUCED TRANSITION PROBABILITY

Within the shell model framework, the nuclear interaction can be described via multipole expansion:

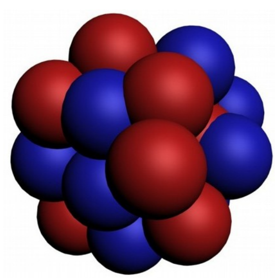
$$H = H_0 + \sum H_\lambda$$

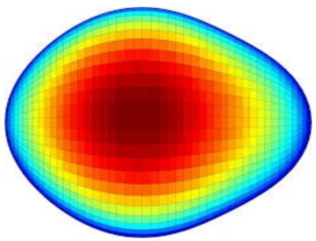
Monopolar Hamiltonian:

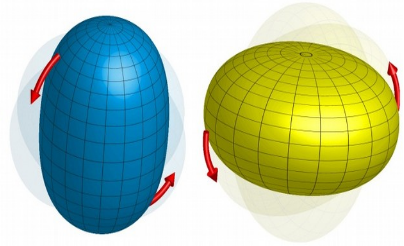
- Represent a spherical mean field extracted from the interacting shell model
- Information on the single-particle energies as function of neutron and proton number

Multipole Hamiltonian:

- Strong correlations between nucleons entails collective motions
- Pairing force drives the nuclear surface to a spherical shape

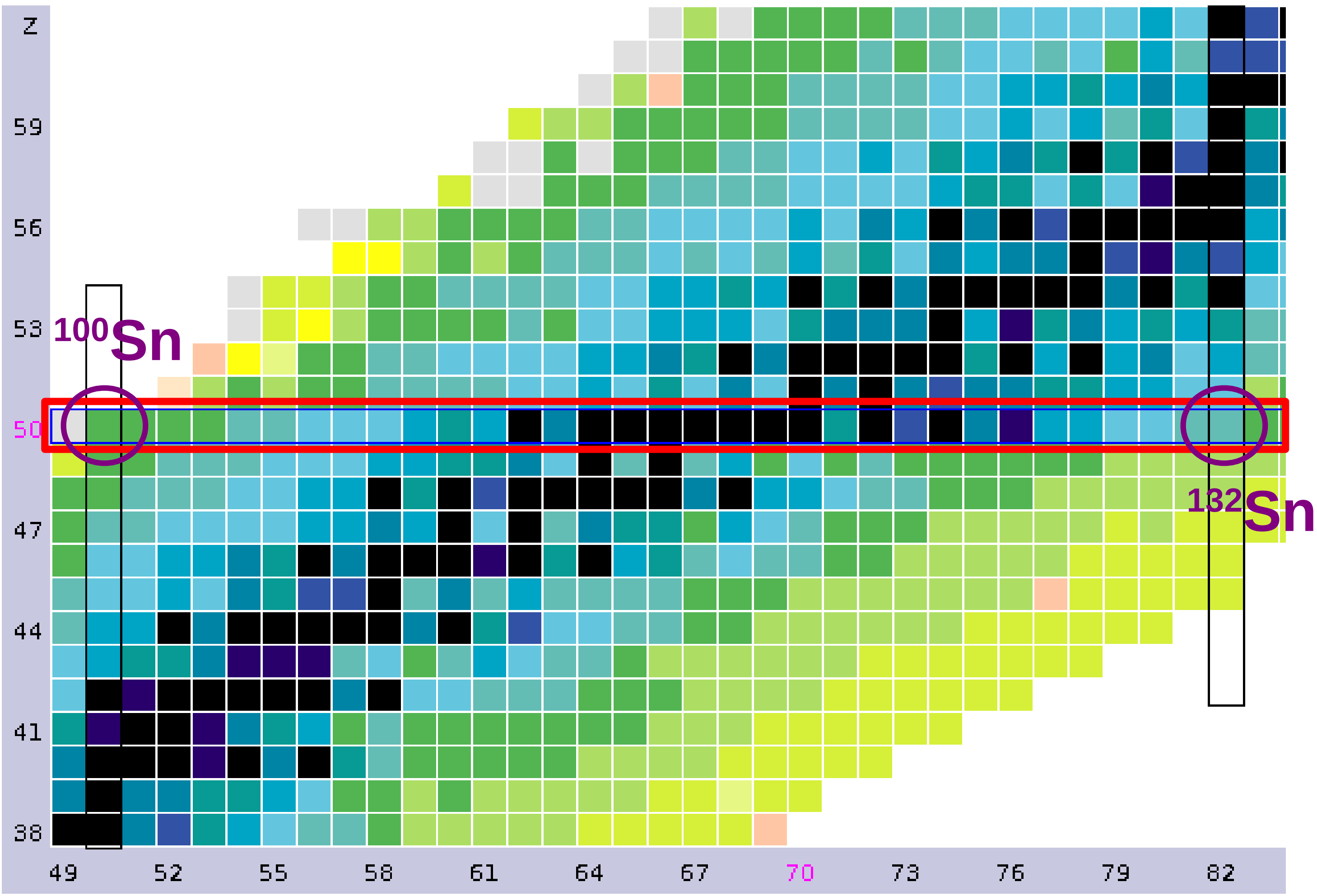






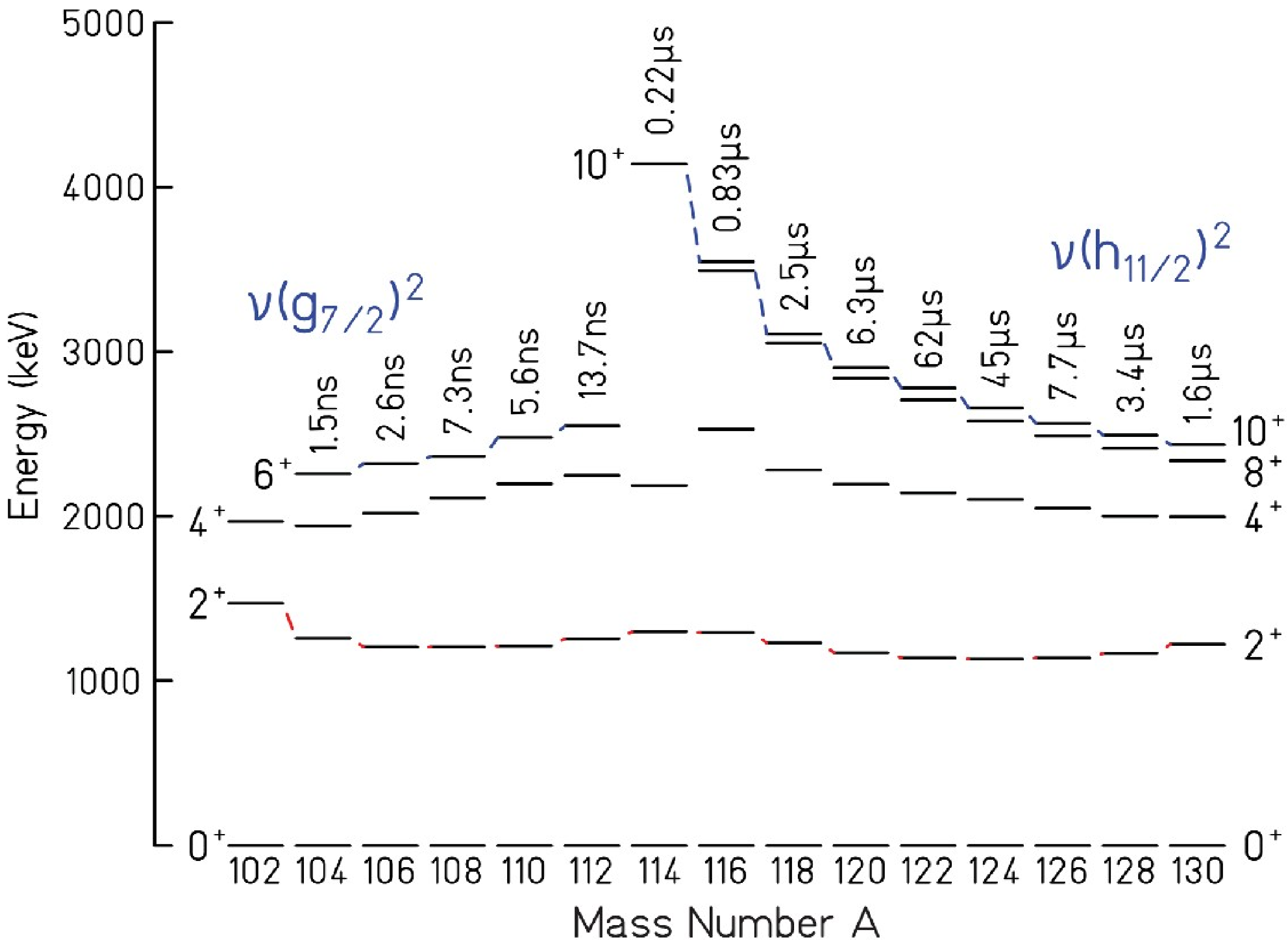
The balance between the proton-neutron multipole force and the pairing forces determine the nuclear shape and in particular the existence of the **magic numbers**.

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=50 PHYSICS CASE
Excitation Energy

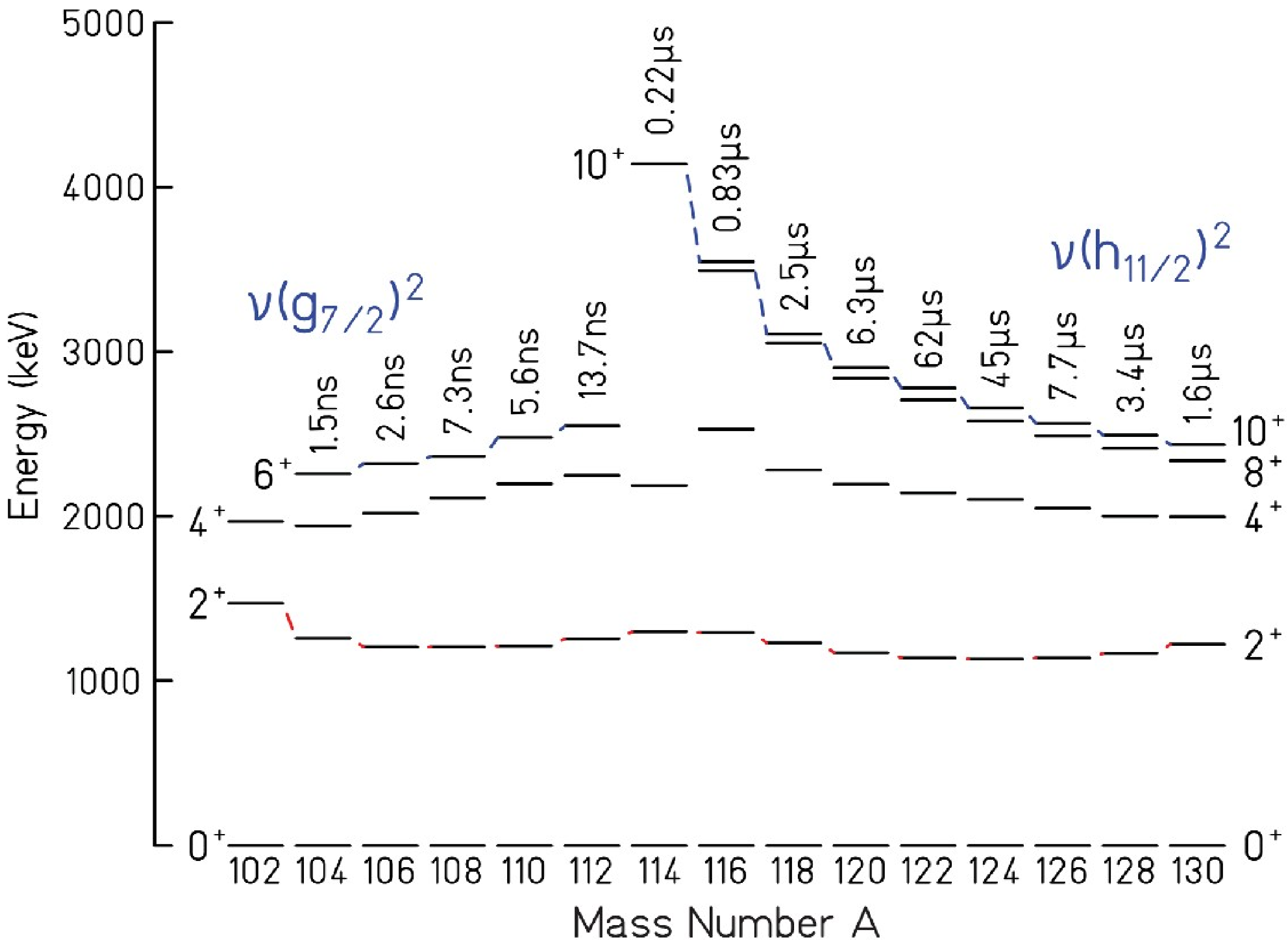


Low-lying isomer

Rather constant excitation energy

R. Kumar et al., Phys. Rev. C 81 (2010) 024306.

Z=50 PHYSICS CASE
Excitation Energy

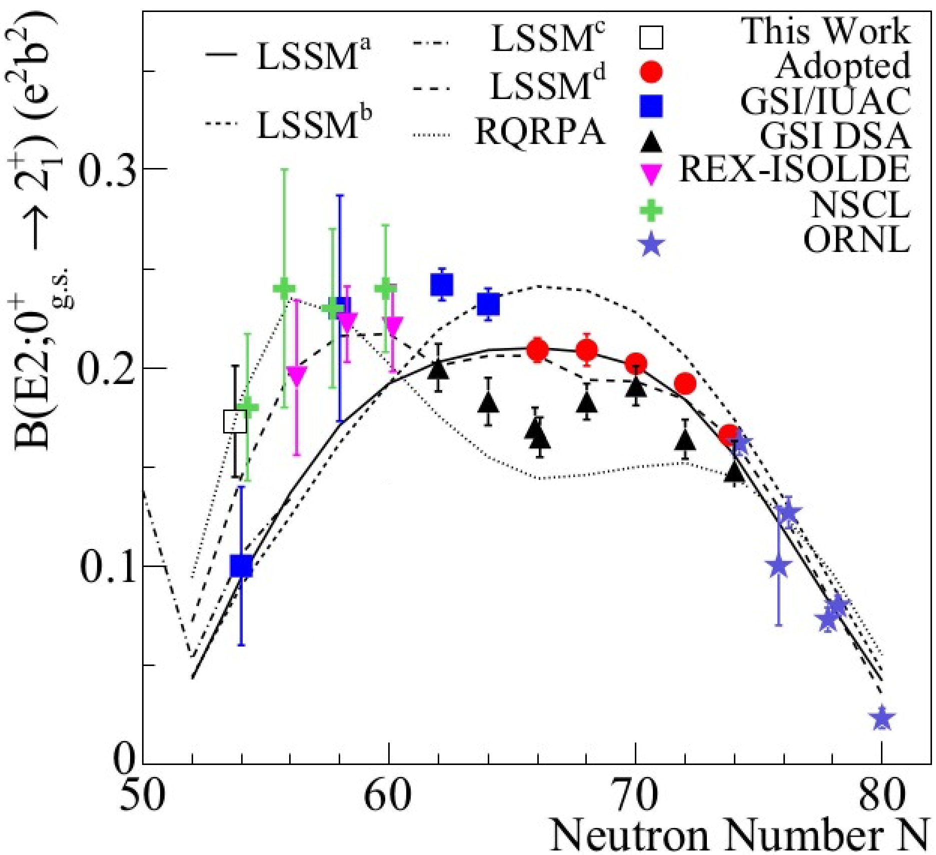


R. Kumar et al., Phys. Rev. C 81 (2010) 024306.

Pairing dominance?

Z=50 PHYSICS CASE
Reduced Transition Probability

The systematics of the low-lying states excitation energy suggest the **seniority** to be a symmetry of the nuclear Hamiltonian.
Thus, the $B(E2;\, 2_1^+ \rightarrow 0_{g.s.}^+)$ should present a parabolic behavior with a maximum in the mid-shell.



P. Doornenbal et al., *Phys. Rev. C 90 (2014) 061302R*

For the neutron-deficient nuclei, several experiments have been performed:

- The 6_1^+ isomers limit the investigation of the electromagnetic properties of the low-lying states.
- Coulomb excitation measurements have been performed with radioactive beams, extracting information only on the 2_1^+ states

Multi-nucleon transfer reactions represent a possible solution to overcome the experimental limitations:

- Direct population of the states
- Stable beams

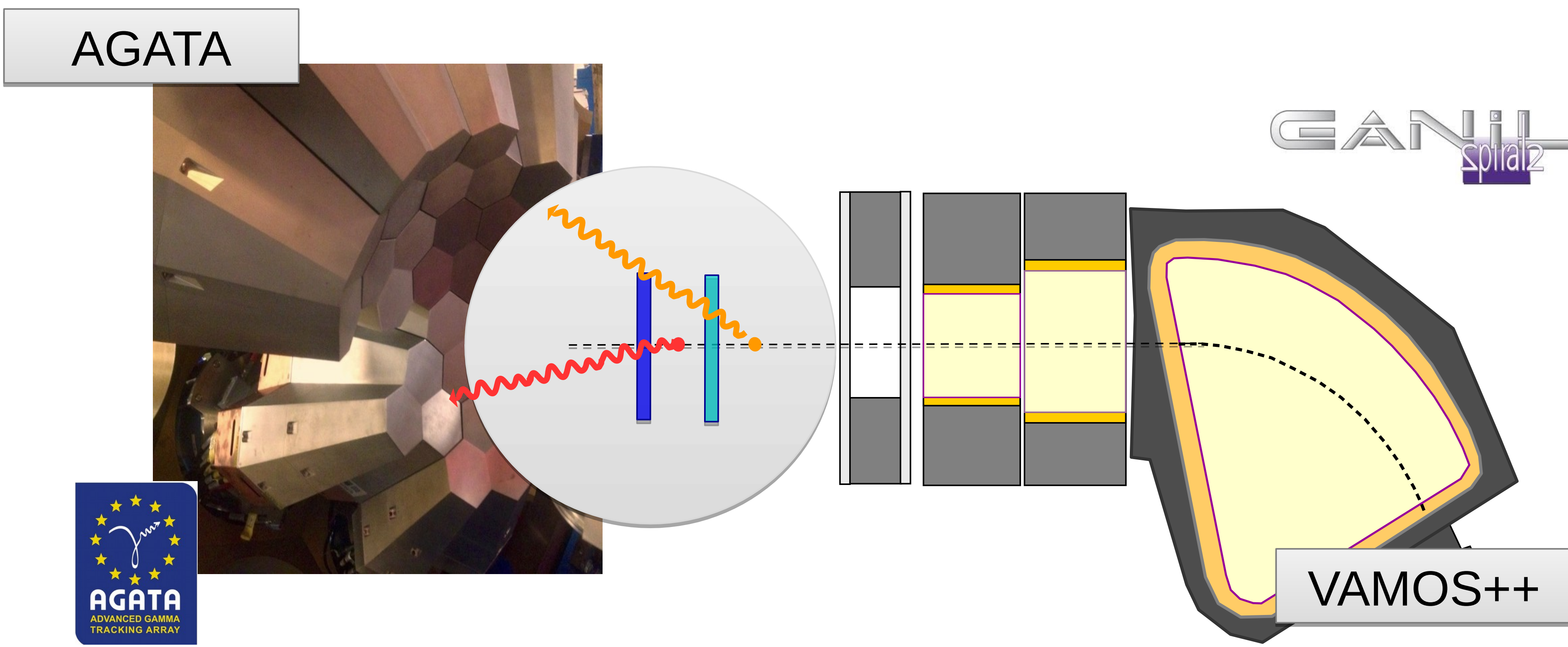
EXPERIMENTAL SETUP

MNT reaction to investigate the neutron-deficient Sn isotopes:

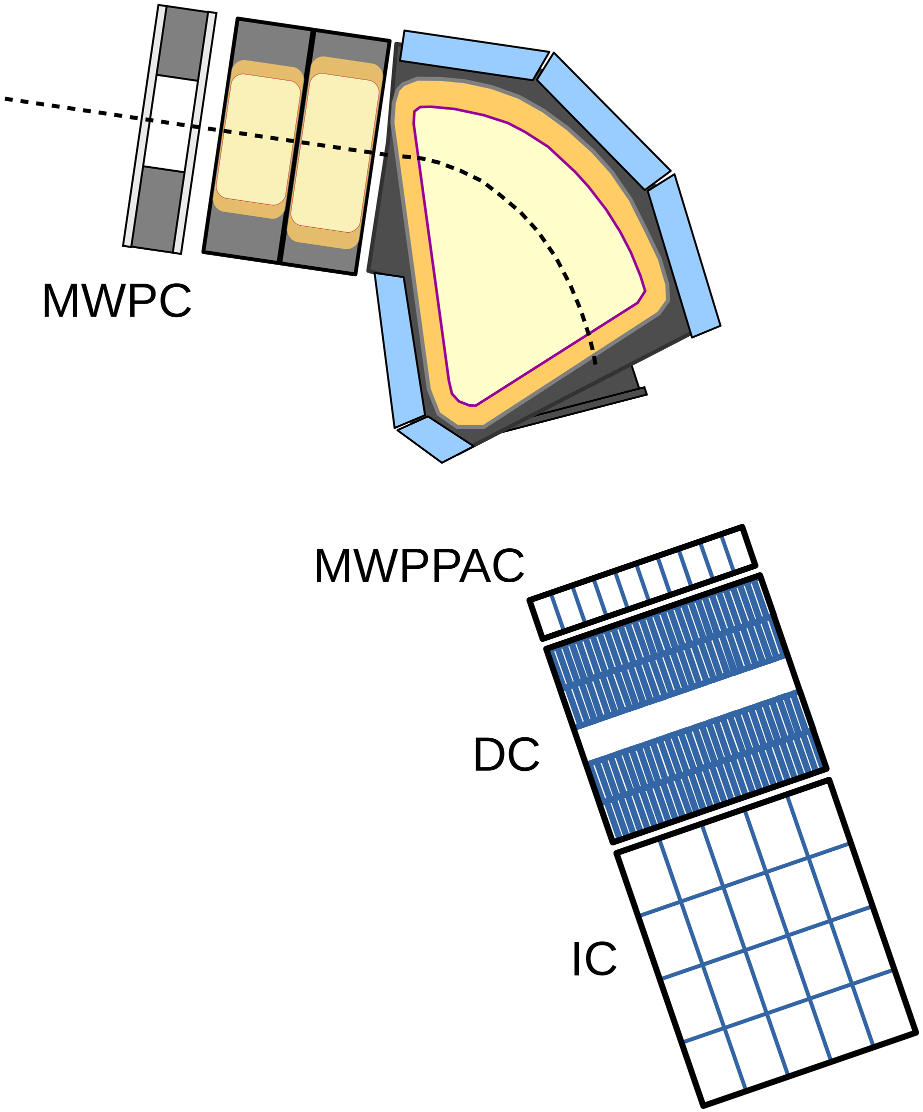
- Stable beam with **higher intensity** than previous experiment with radioactive beams
- **Direct population** of the excited states allows to study also the 4_1^+ states in ^{106,108}Sn

Beam: ^{106}Cd @ 770 MeV

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



EXPERIMENTAL SETUP
VAMOS++ Spectrometer

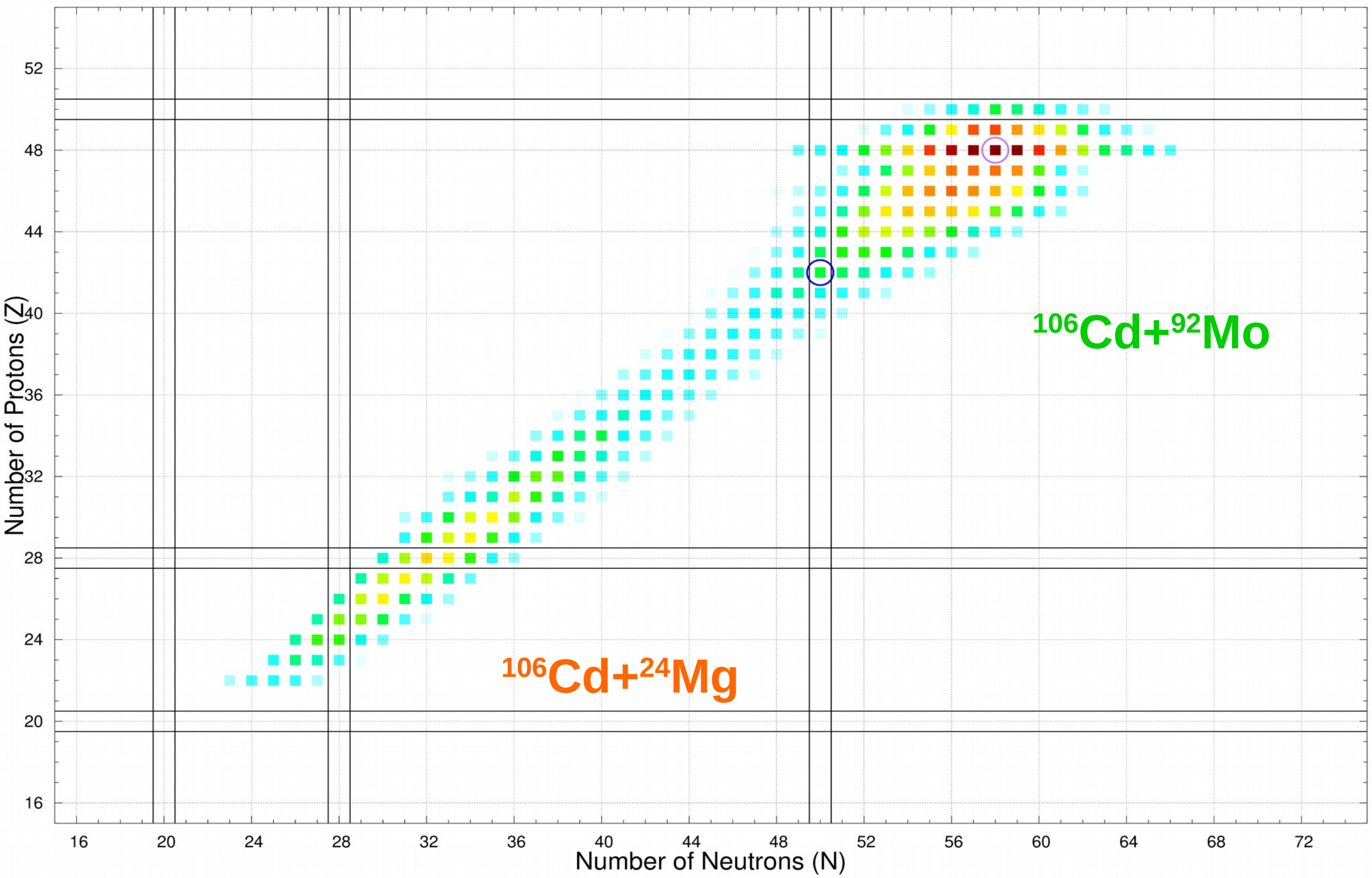


The **VA**riable **MO**de **S**pectrometer is a large acceptance magnetic spectrometer used to fully identify the reaction products, providing the atomic number Z and mass A.

- **Optical elements** focalise (2 magnetic quadrupoles) and bend (1 magnetic dipole) the recoil trajectories according to their A/q.
- The dual position sensitive **Multi-Wire Proportional Counter** gives the recoil entrance velocity $\vec{\beta}$, crucial for the Doppler-correction.
- Together with the MWPC, the **Multi-Wire Parallel Plate Avalanche Counter** measures the time-of-flight.
- The **Drift Chambers** provides the fragments direction at the focal-plane position, allowing the trajectory reconstruction.
- The **Ionisation Chamber** measures the reaction products energy loss, providing information about their atomic number (Bethe-Bloch formula).

EXPERIMENTAL SETUP
VAMOS++ Spectrometer

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



From the yield of the identified ions, two region were mainly populated:

- 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

EXPERIMENTAL SETUP

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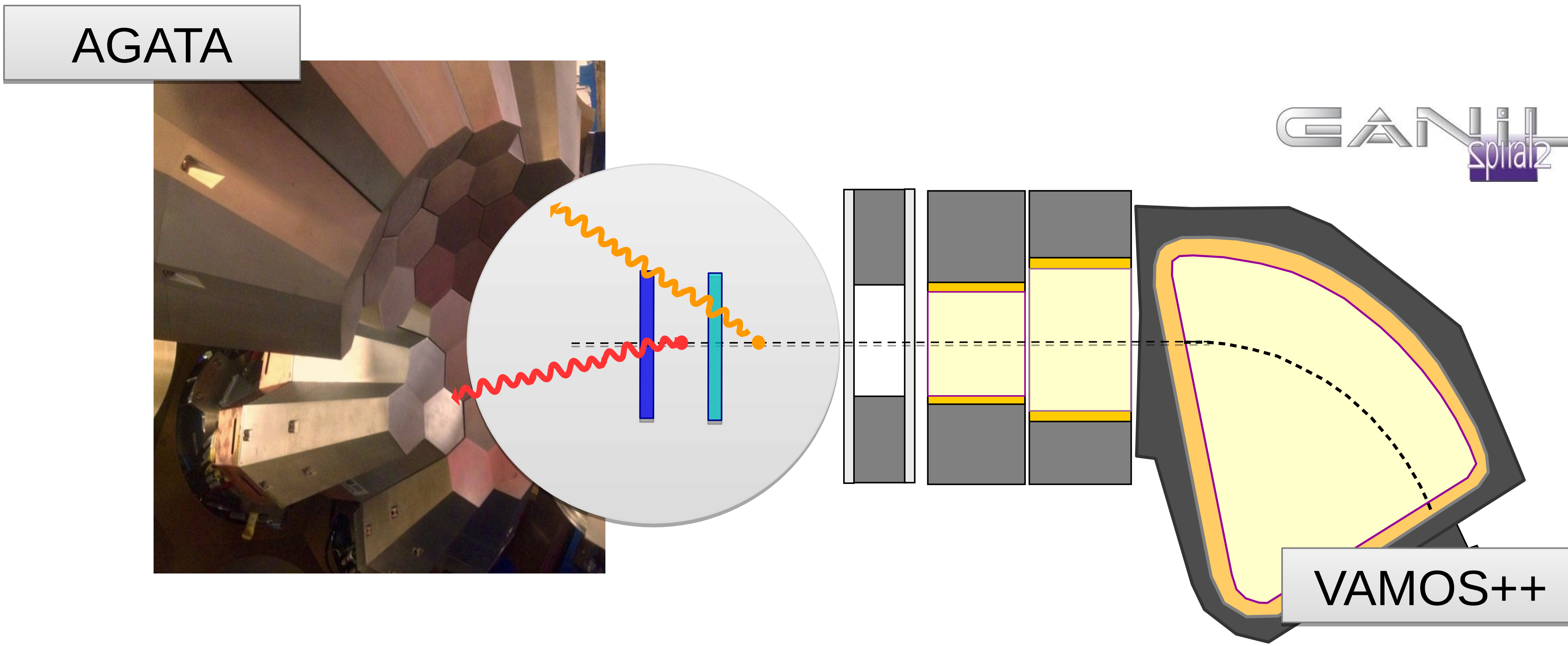


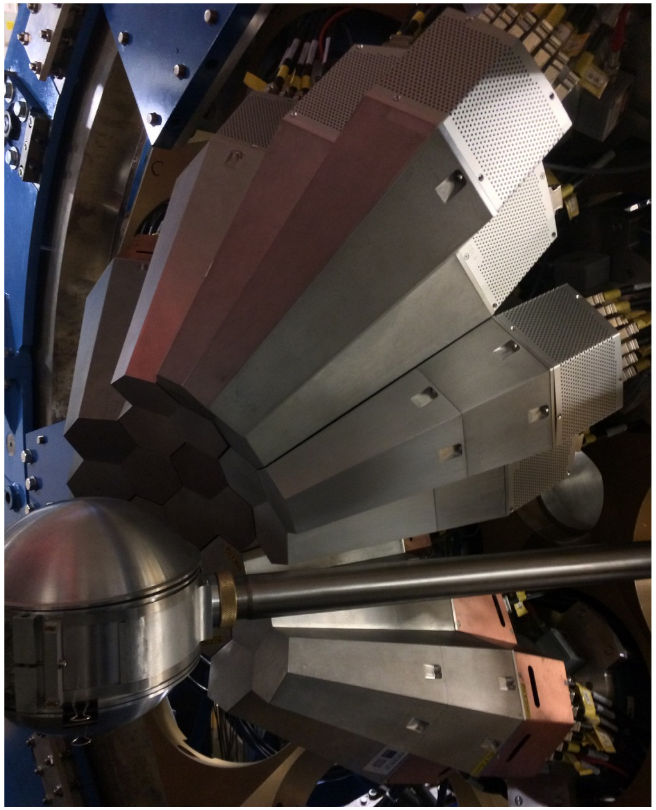
EXPERIMENTAL SETUP
AGATA Spectrometer

Advance **GA**mma **T**racking **A**rray:

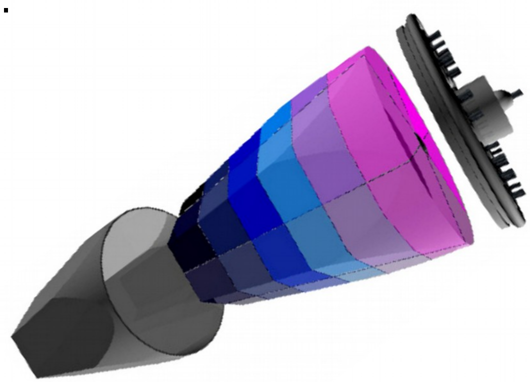
→ no anti-Compton shields to increase the active-volume angular coverage and so the **efficiency**

→ segmentation of the germanium crystal to improve the **position sensitivity**

→ most advance digital electronics allows **high counting rates**



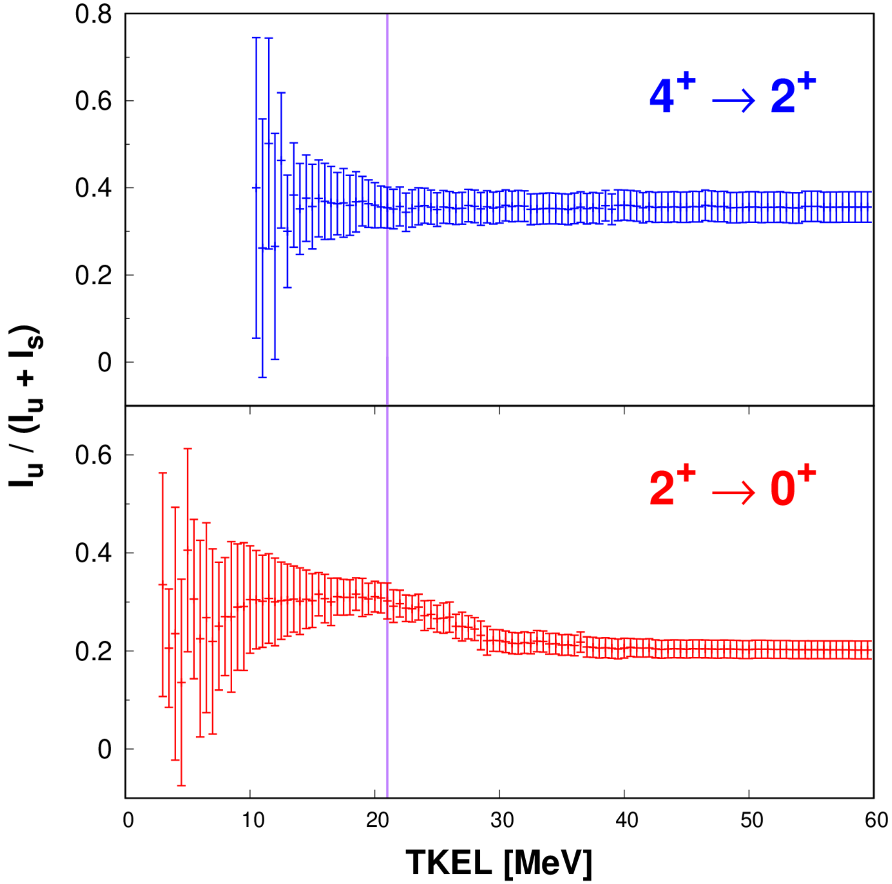
Per each detector 38 signals (36 segments + 2 central contact) are collected together with their traces.



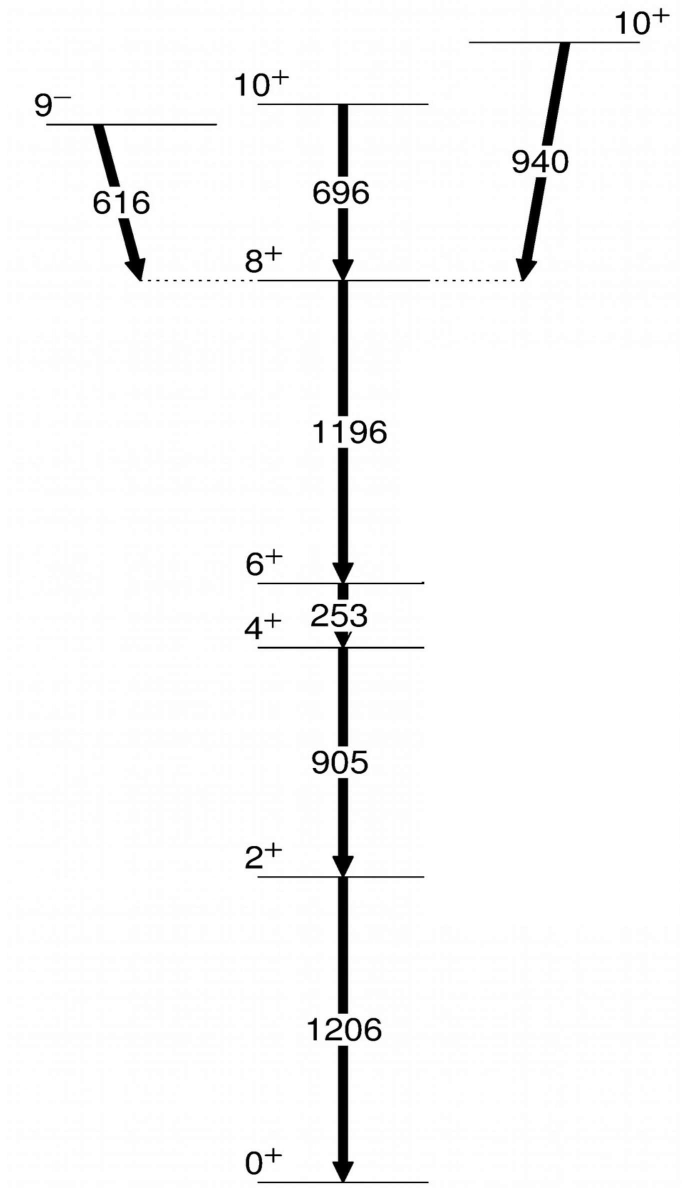
From the comparison between the segments and the central contact signals, various corrections can be applied to **improve or restore the performances** of the apparatus.

RESULTS
^{108}Sn Lifetimes

The TKEL can be used to **control the direct population** of the excited states and to simplify the decay chain.



M. Siciliano et al., Eur. Phys. J.: Conf. (2019), submitted



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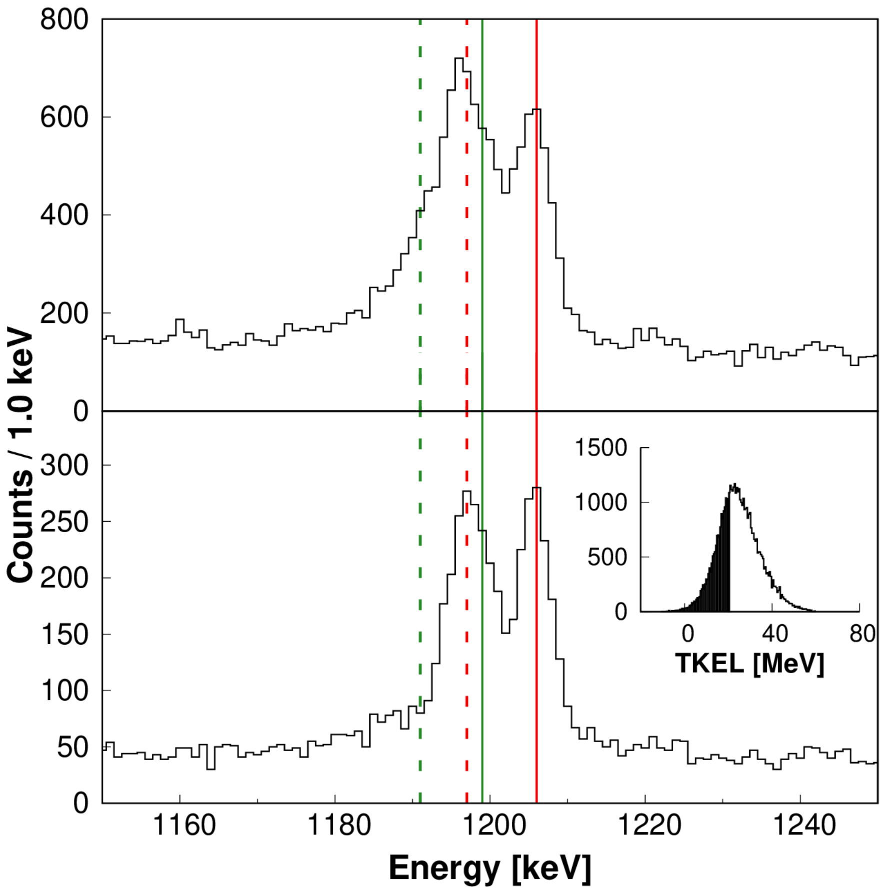

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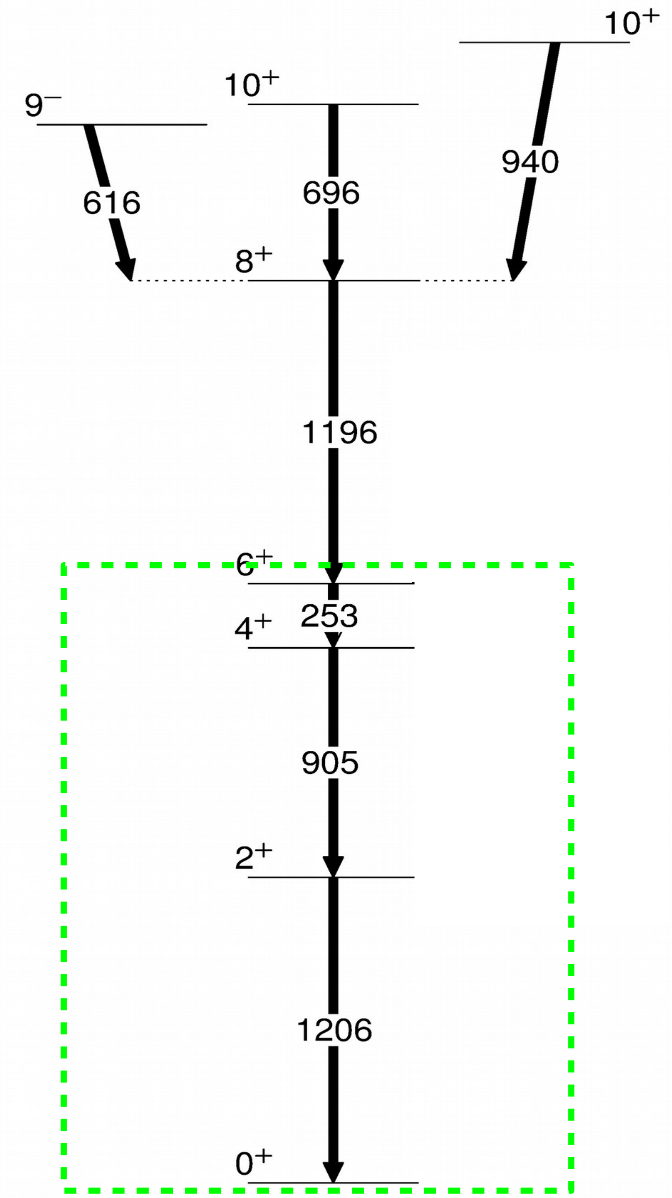

^{108}Sn Lifetimes

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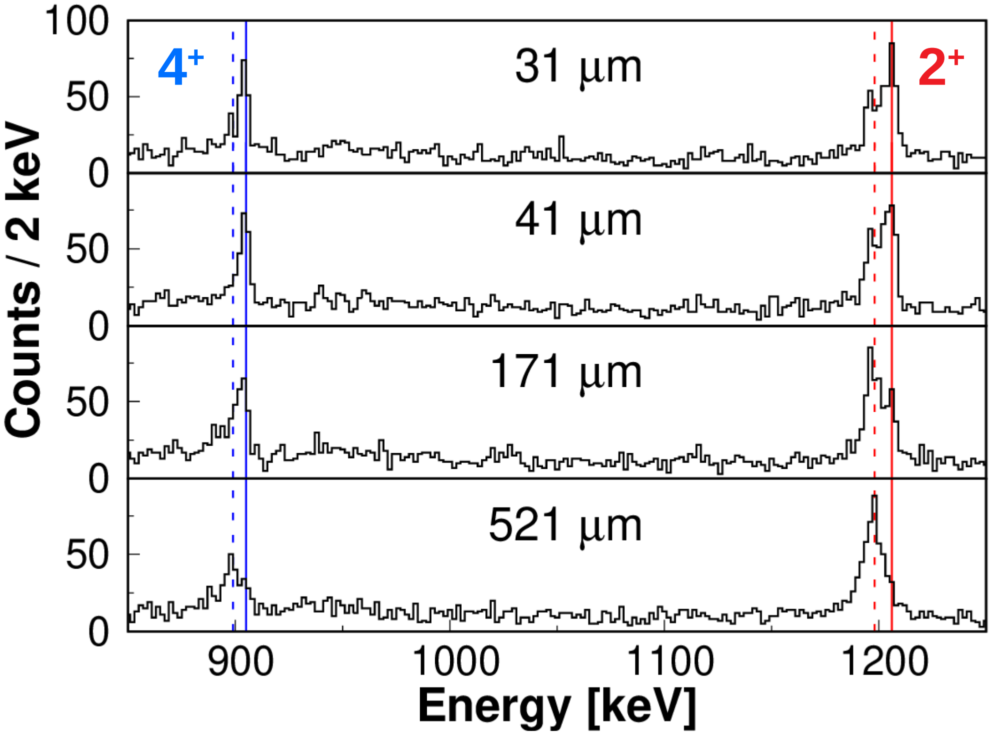
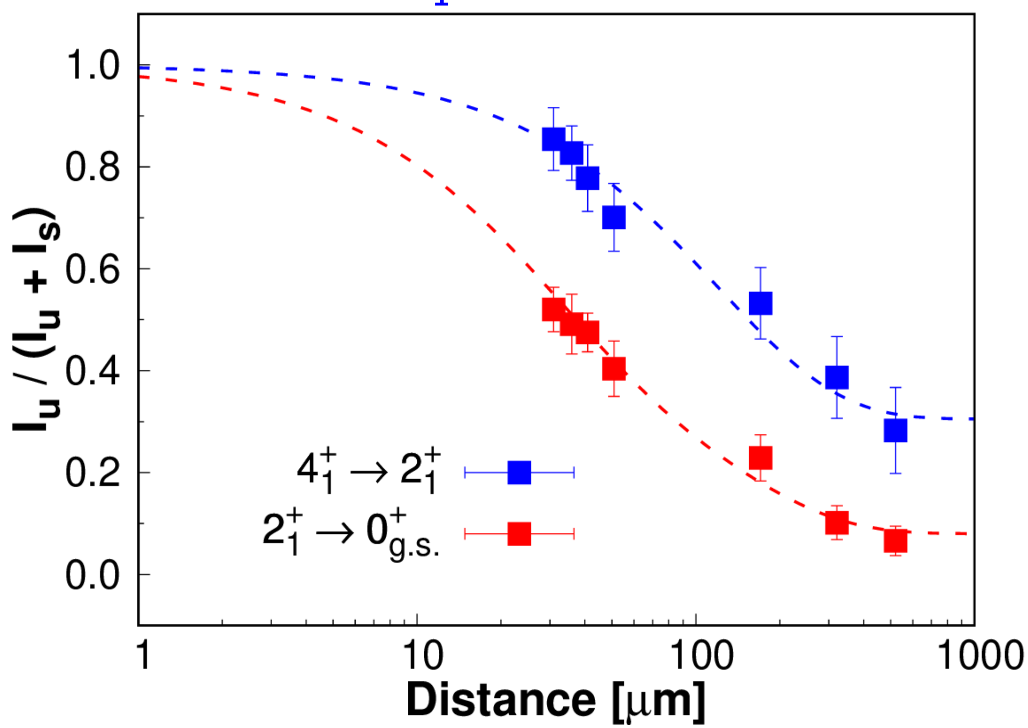
$\tau(2_1^+) = 0.69(17)$ ps

A. Banu et al., Phys. Rev. C 72.(2005) 061305

$\tau(2_1^+) = 0.76(8)$ ps

$\tau(4_1^+) = 3.6(5)$ ps





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

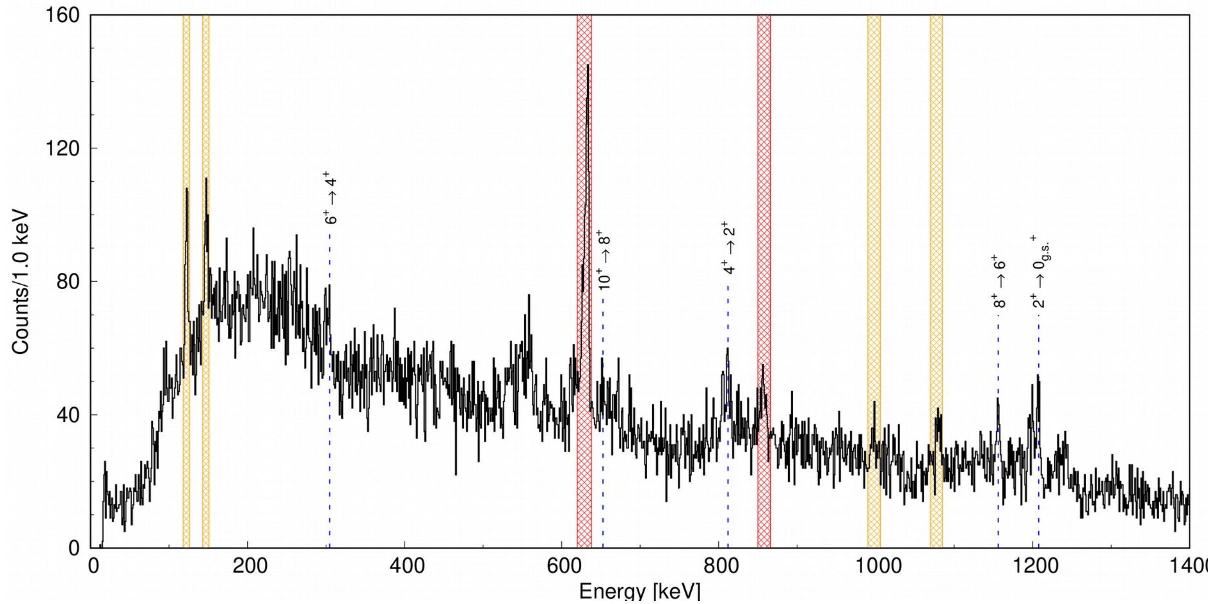
RESULTS
^{106}Sn Lifetimes

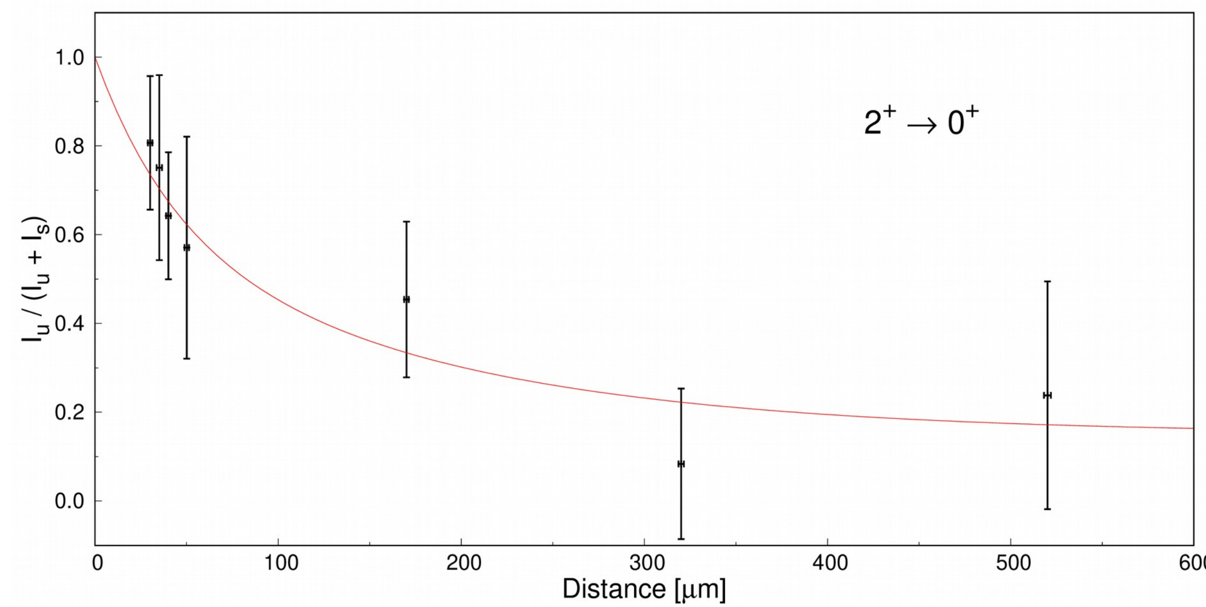
Despite the low cross section of the exotic channel, the neutron-deficient ^{106}Sn was successfully populated and observed.

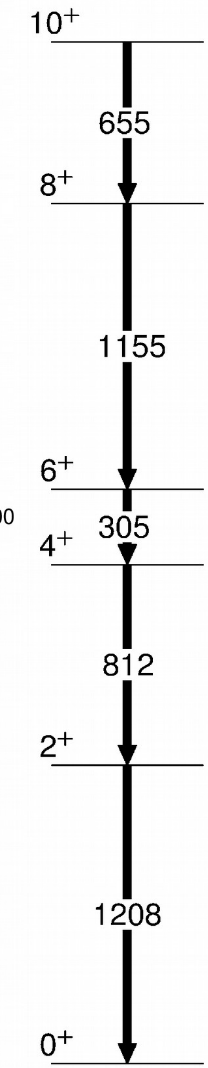
Contamination from inelastic-scattered beam and In events does not affect the measurement.

The statistics of ^{106}Sn allow to extract only the decay curve of $2_1^+ \rightarrow 0_{g.s.}^+$ transition.

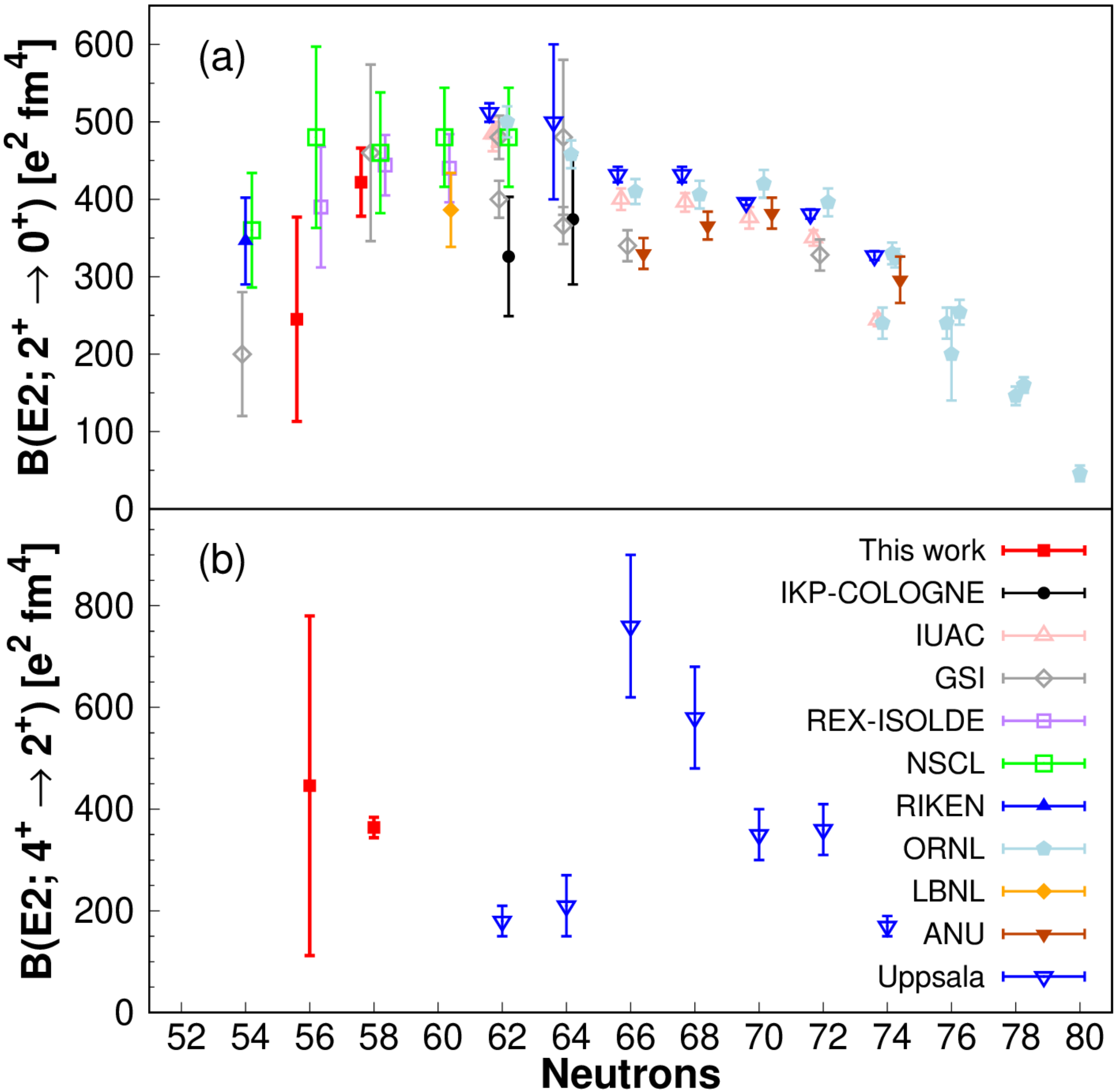
$\tau(2_1^+) = 1.2(7)$ ps
$\tau(4_1^+) = 5.2(39)$ ps





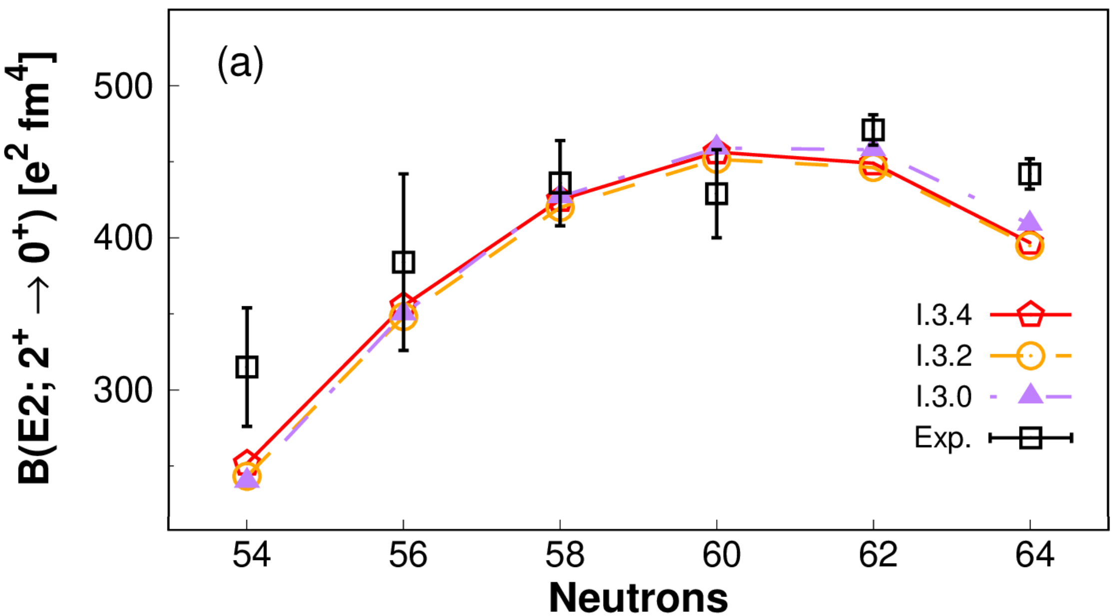


RESULTS
Reduced Transition Probabilities



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 Sn isotopes.

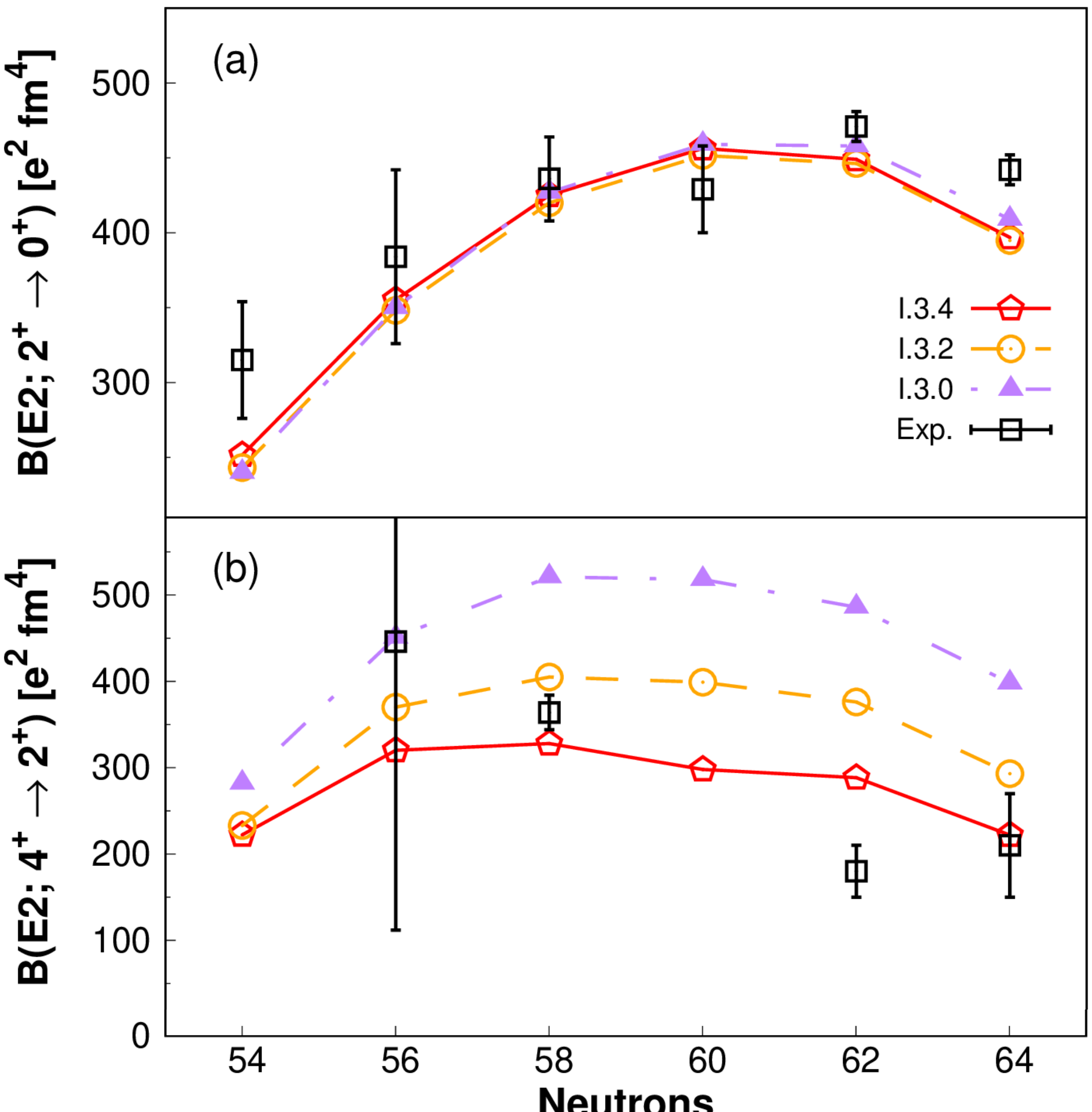


M. Siciliano et al., Phys. Rev. Lett. (2019), submitted
A.P. Zuker, Phys. Rev. Lett. (2019), accepted

- 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 $(g_{9/2})^{\pi}$

Quadrupole dominance

THEORETICAL INTERPRETATION
Quadrupole-Pairing Interplay



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Pairing force takes its revenge on quadrupole correlation

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

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.

- For the very first time **the lifetime of the 2_1^+ and 4_1^+ states has been measured for $^{106\text{-}108}Sn$.**

- The extracted B(E2) values have been compared with LSSM calculations to explain the trend of neutron-deficient Sn isotopes.

  - Despite quadrupole force is reduced to its realistic value, the **$B(E2;2_1^+ \rightarrow 0_{g.s.}^+)$ values are not affected by pairing** renormalization. Quadrupole correlations dominate.

  - The **$B(E2;4_1^+ \rightarrow 2_1^+)$ values are sensitive** to the form of the nuclear interaction.
    The precise results in ^{108}Sn allow to firmly define the amount of pairing renormalization

The very precise measurements in ^{108}Sn have shown to open new perspectives in the understanding of the quadrupole-pairing interplay.

THANKS FOR YOUR ATTENTION...

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