UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI FISICA

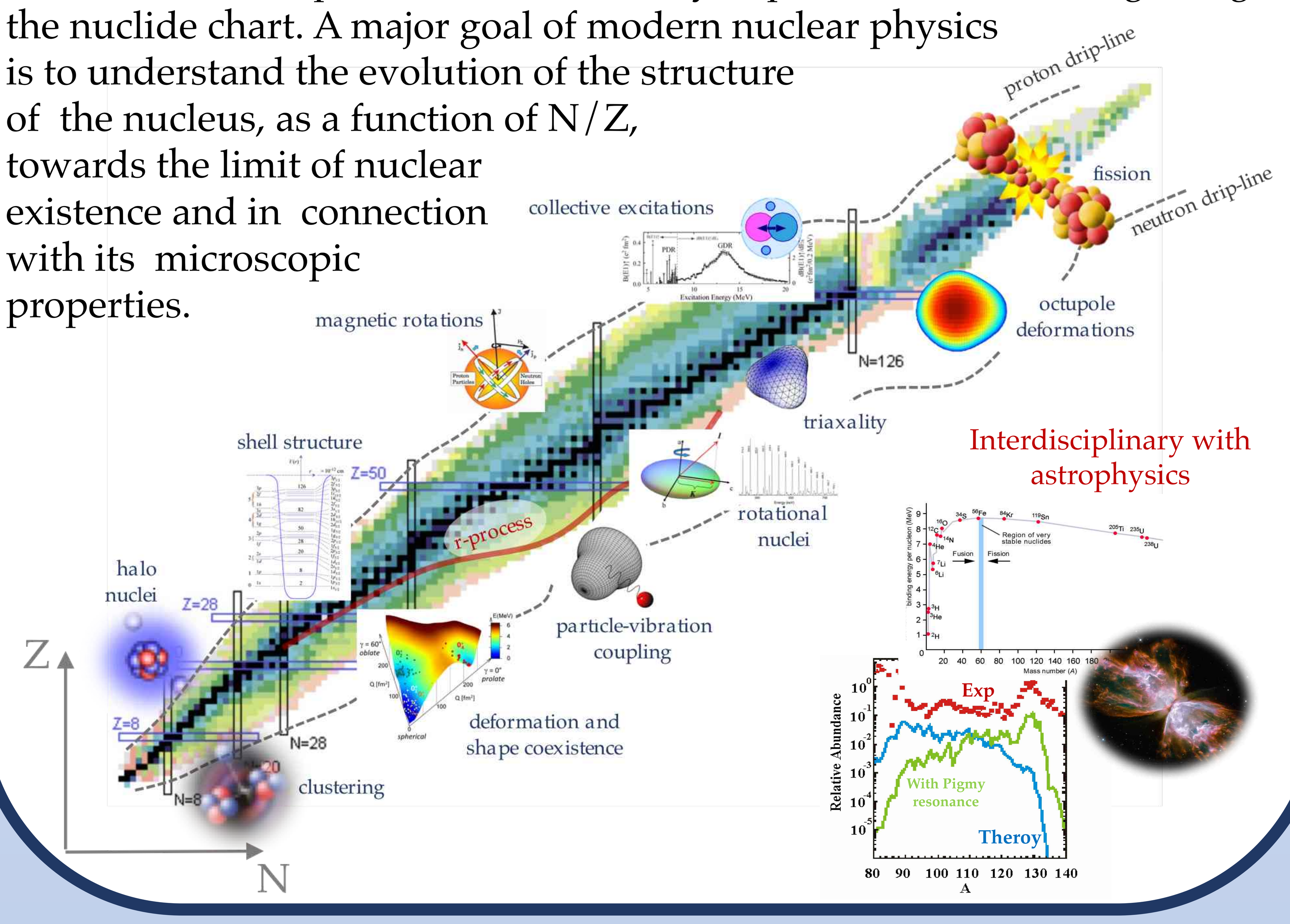
INFN

Shape coexistence and particle/hole – core couplings in atomic nuclei

S. Bottoni - on behalf of the Gamma Milano collaboration*

Atomic nuclei: laboratories for fundamental physics

The atomic nucleus is a many-body quantum system made of interacting fermions. Its complex structure and dynamics is governed by the nuclear force, which is responsible for the variety of phenomena occurring along the nuclide chart. A major goal of modern nuclear physics is to understand the evolution of the structure of the nucleus, as a function of N/Z, towards the limit of nuclear existence and in connection with its microscopic properties.



γ-ray and particle spectroscopy

γ-ray and particle spectroscopy is the most powerful tool to access the multifaceted nature of atomic nuclei. Experiments are performed at national and international facilities, employing stable and radioactive ion beams (up to relativistic energies) and intense neutron beams. Detection setups consist of state-of-the-art composite detector systems based on large-volume high-purity germanium crystals and novel scintillator materials, often coupled to magnetic spectrometers or particle detectors.

Ge detectors

Advanced γ-ray detectors with excellent energy resolution. Highly-segmented crystals (e.g. AGATA) achieve the best performances through γ-ray tracking.

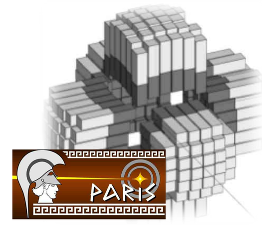
ΔE_γ ~ 2.3 keV @ 1.33 MeV
ε_γ ~ 40% (4π configuration)
(192 Ge x 36 segments each: 6780 segments)

Si detectors

Segmented charged-particle detectors (packed geometry) with high efficiency and possibility of detection low-energy particles through Pulse Shape Analysis.

60 square pads
ΔE ~ 50 keV

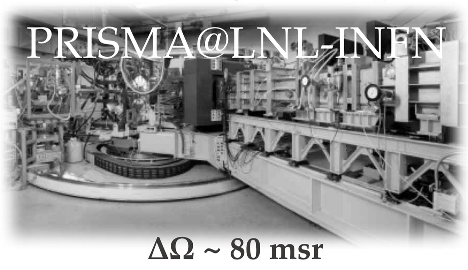
Scintillators



High-efficiency scintillator crystals (e.g. $LaBr_3$:Ce) for the detection of medium- and high-energy γ rays, characterized by good energy resolution and excellent timing.

ε_γ ~ 10% @ 2 MeV
(8 clusters at 23 cm)
($LaBr_3$ – NaI phoswiches)
ΔE_γ ~ 40 keV @ 1 MeV
Δt ~ 300 - 400 ps

Magnetic spectrometers



Large-acceptance spectrometers for the detection of heavy ions produced in multi-nucleon transfer reactions.

ΔΩ ~ 80 msr
ΔA/A ~ 1/190

Laboratories: LNL (Italy), GANIL and ILL (France), GSI (Germany), ISOLDE (CERN), IFIN-HH (Romania), RIKEN (Japan), IFJ PAN (Poland), ANL (U.S.A.), …

Shape coexistence

The shape is one of the most intriguing properties of the nucleus. Spherical shapes are most natural in the vicinity of double shell closures. Away from doubly-magic nuclei, different nuclear shapes may compete and coexist in the same nucleus, at low excitation energy, reflecting the microscopic configuration of the different intrinsic states. Well-defined minima may appear in the deformed regions of the Potential Energy Surface (PES) and a hindered transition between two configurations with different deformation may occur through metastable states (i.e. shape isomers), if the barrier between the two minima is high enough.

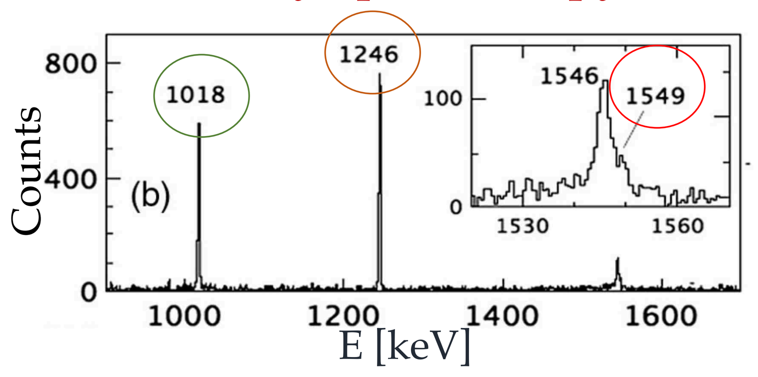
Observation of the lightest nucleus with a shape isomer: ^{66}Ni

(unique example apart from the heavy actinide systems)

multi-nucleon transfer reactions at sub-barrier energies (IFIN-HH – Bucharest)

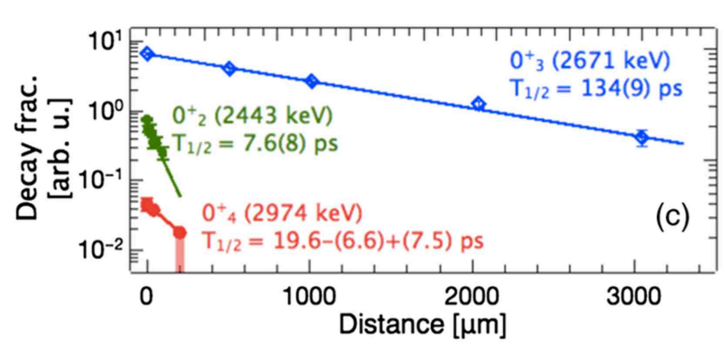
$^{18}O + ^{64}Ni \rightarrow ^{16}O + ^{66}Ni$
E(^{18}O beam) = 39 MeV

γ-ray spectroscopy



High-resolution γ-ray spectroscopy with the ROSPHERE Ge array

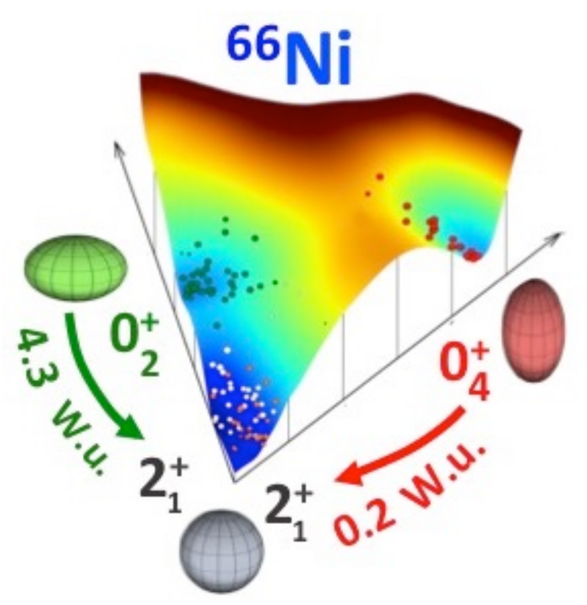
Lifetime measurement

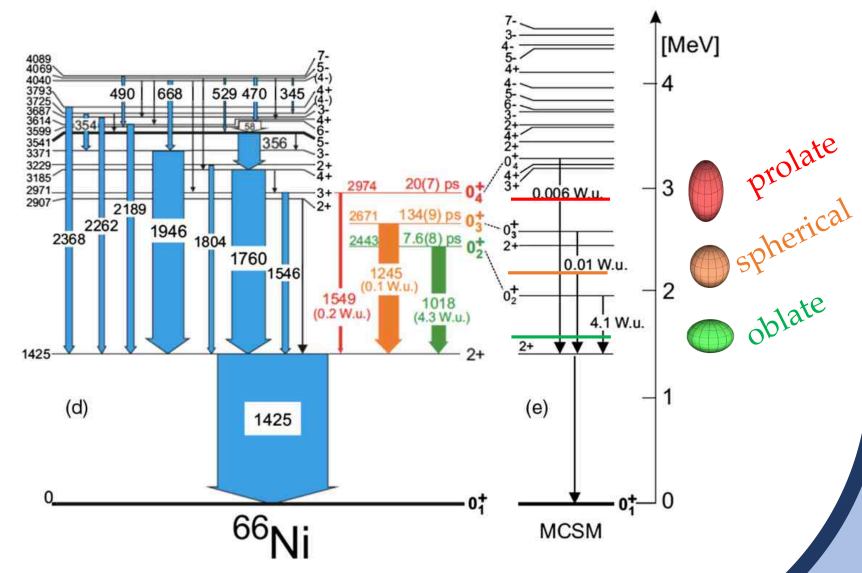


Lifetime measurements in the picosecond region (PLUNGER technique)

Monte-Carlo Shell Model

Large-scale Shell-Model calculations, performed with 10^6-core supercomputers (University of Tokyo), in the full $pfg_{9/2}d_{5/2}$ valence space



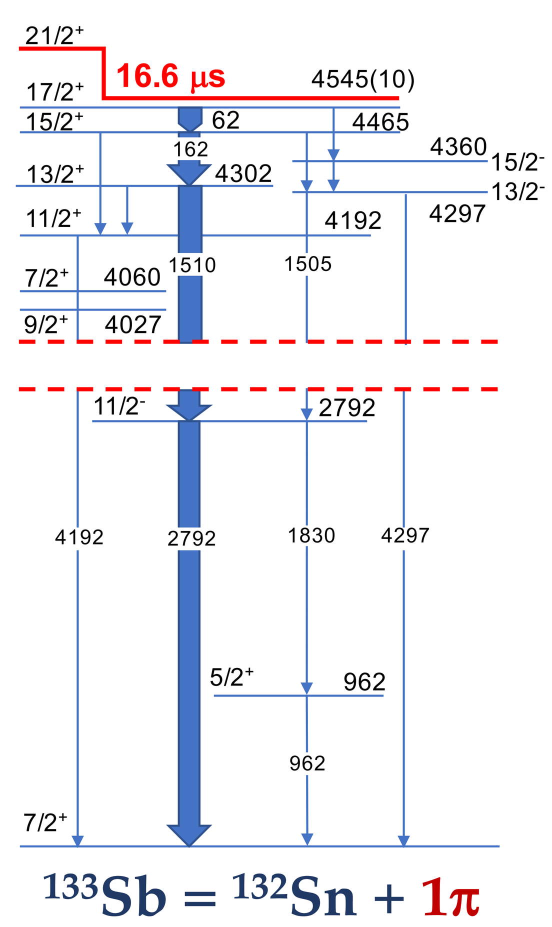


S. Leoni *et al.*, Phys. Rev. Lett. **118**, 162502 (2017)

Particle/hole – core couplings

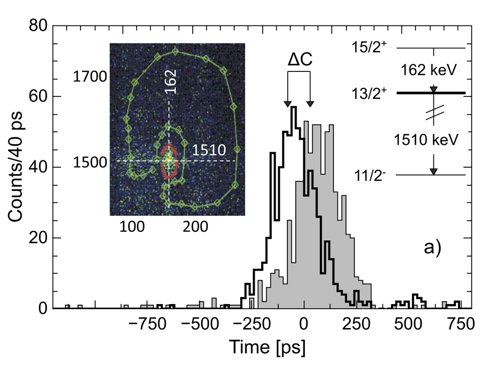
The interplay between single-particle/hole excitations and collective responses of the nucleus generates very complex nuclear excitations. They can be studied in systems made of one valence particle/hole and a doubly magic core. At low excitation energies, single-particle/hole states coexist with coupled states between the latter and collective (phonons) and non collective core excitations. This phenomenon is the key ingredient in explaining the damping of giant resonances, the anharmonicity of vibrational spectra and the quenching of spectroscopic factors. Due to the divergent number of configurations involved, shell-model approaches can not be applied and alternative models must be developed.

Particle-core couplings in exotic, neutron rich nuclei

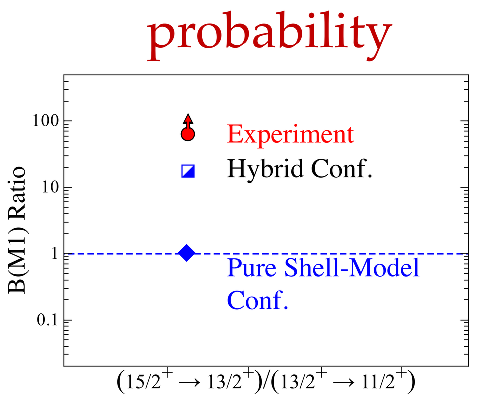


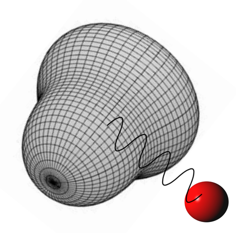
$^{133}Sb = ^{132}Sn + 1\pi$

Lifetime measurement



Reduced transition probability





EXILL – FATIMA CAMPAIGN @ ILL

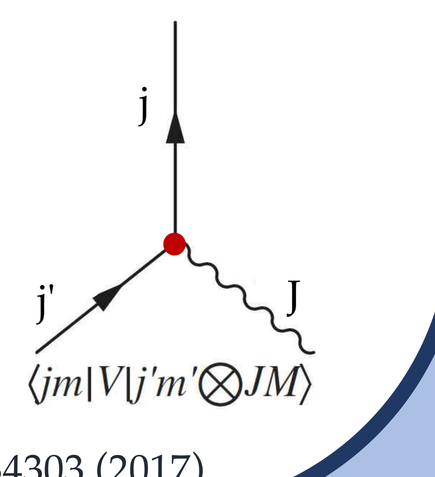
γ spectroscopy of neutron-rich nuclei, produced in neutron- induced fission of ^{235}U and ^{241}Pu, performed with Ge detectors and $LaBr_3$ detectors for measuring lifetimes with fast-timing techniques

G. Bocchi *et al.*, Phys. Lett. B **760**, 273 (2016)

Recently-developed Hybrid Configuration Mixing Model – ^{49}Ca and ^{133}Sb

(Hartree-Fock + Random Phase Aprrox. with Skyrme effective interaction)

$$H = H_0 + V,$$
$$H_0 = \sum_{jm} \varepsilon_j a^\dagger_{jm} a_{jm} + \sum_{NJM} \hbar\omega_{NJ} \Gamma^\dagger_{NJM} \Gamma_{NJM},$$
$$V = \sum_{jmj'm'} \sum_{NJM} h(jm; j'm', NJM) a_{jm} \left[a^\dagger_{j'} \otimes \Gamma^\dagger_{NJ}\right]_{jm}$$



G. Colò, P. F Bortignon and G. Bocchi, Phys. Rev. C **95**, 034303 (2017)

*Collaboration: S. Leoni, G. Bocchi, G. Benzoni, N. Blasi, A. Bracco, F. Camera, F. C. L. Crespi, B. Million, O. Wieland, P. F. Bortigonon, G. Colò *(Università degli Studi di Milano and INFN, Milano, Italy)*, B. Fornal, M. Ciemała, N. Cieplicka-Orynńzak, Ł.W. Iskra, M. Kmiecik, A. Maj *(Institute of Nuclear Physics IFJ-PAN, Krakow, Poland)*, N. Marginean, D. Bucurescu, C. Costache, D. G. Ghita, R. Marginean, C. Mihai, A. Negret, C. R. Nita, C. Sotty *(IFIN-HH, Bucharest, Romania)*, C. A. Ur *(ELI-NP, Bucharest, Romania)*, M. Sferrazza *(Université libre de Brussels, Buxelles, Belgium)*, D. Bazzacco, A. Goasduff, D, Mengoni, F. Recchia *(University of Padova, Padova, Italy)*, *D. Napoli*, J. J. Valiente-Dobon *(Laboratori Nazionali di Legnaro, Legnaro, Italy)*, A. Blanc, M. Jentschel, U. Köster, C. Michelagnoli, P. Mutti, T. Soldner *(Institut Laue-Langevin, Grenoble, France)*, T. Otsuka, Y. Tsunoda *(University of Tokyo, Tokyo, Japan)*.