Couplings between particle and phonons around neutron-rich doubly-magic nuclei

Silvia Leoni
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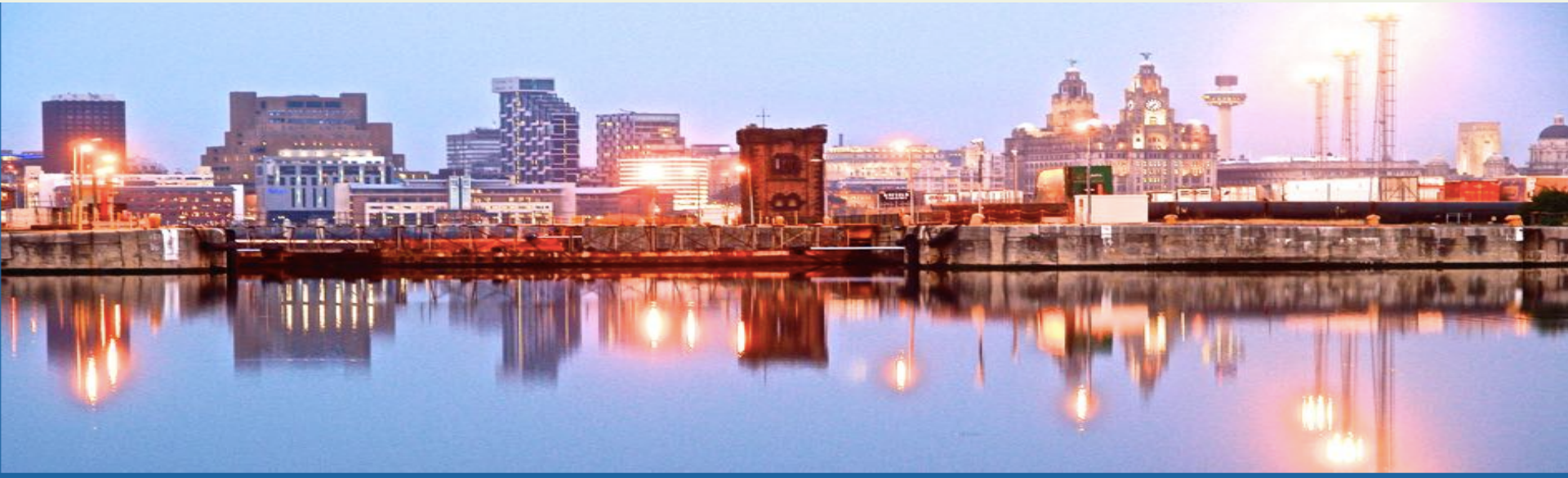


OUTLINE

INTRODUCTION

Models aimed at describing Excited States in Nuclei

SHELL Model and Particle-Phonon Coupling Model

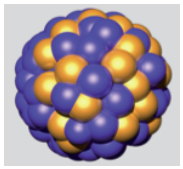
→ *Limitation and Future Perspectives for Unified Picture*

SURVEY of RECENT *γ – spectroscopy* RESULTS around DOUBLY MAGIC NUCLEI

1. ^{48}Ca – *Multinucleon Transfer*
2. ^{132}Sn – *Neutron Induced Fission*
3. ^{208}Pb – (n,γ)

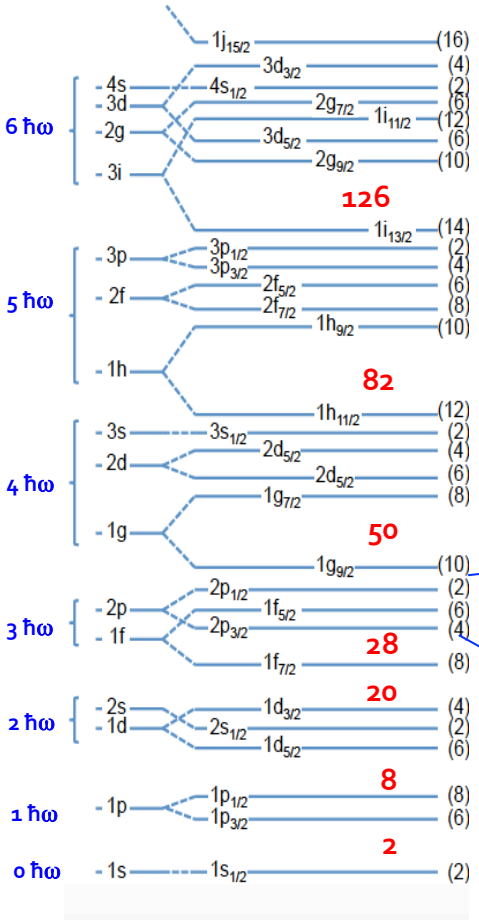
Challenges in MODERN NUCLEAR PHYSICS

Quest for a UNIFIED DESCRIPTION of ALL Nuclei



Many Body
Finite Quantum
System

Shell Structure
for p and n



Configuration Space

$$\binom{K}{A} = \frac{K!}{(K-A)!A!}$$

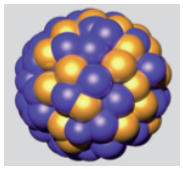
Number of ways to distribute A nucleons over K orbitals

N=Z		Number of configurations
44	^{88}Ru	$\approx 10^{28}$
28	^{56}Ni	$\approx 10^{10}$
24	^{48}Cr	$\approx 10^{7}$
22	^{44}Ti	$\approx 10^{4}$

MICROSCOPIC Structure of Nuclei:
a computational challenge …

Challenges in MODERN NUCLEAR PHYSICS

Quest for a UNIFIED DESCRIPTION of ALL Nuclei



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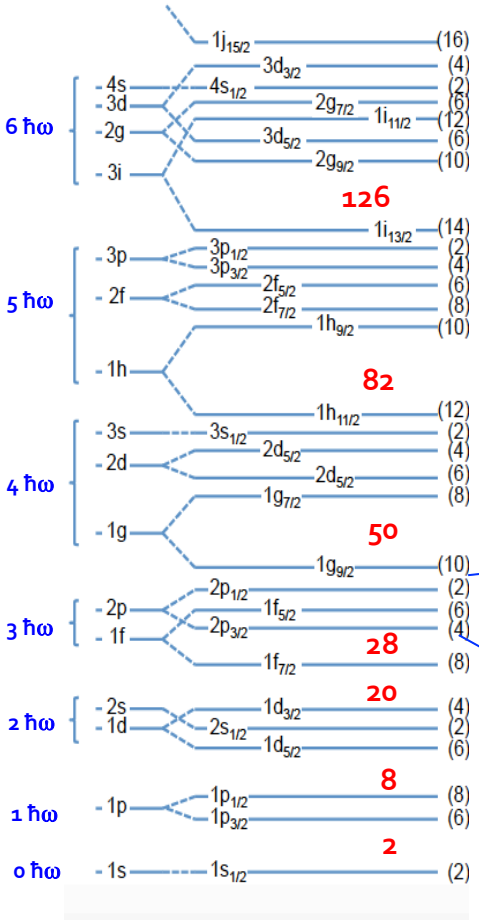

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SHELL Model

Large Scale Calculations With Frozen CORE

- A up to ≈ 100
- Around Closed shell

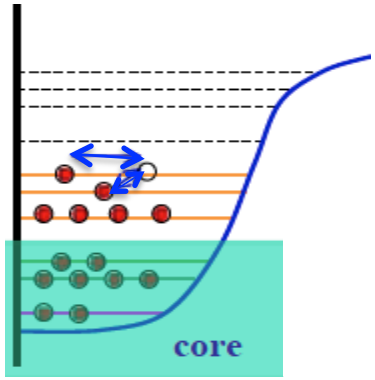
T. Otsuka, ...
A.Brown, ...
F. Nowacki, ...
L. Coraggio, ...
...

MICROSCOPIC Structure of Nuclei: a computational challenge ...

SHELL MODEL Approach

SHELL GAPS as Truncation Scheme

VALENCE Nucleons



Frozen CORE

Doubly magic nucleus
^{4}He, ^{16}O, ^{40}Ca,
^{132}Sn, ^{208}Pb

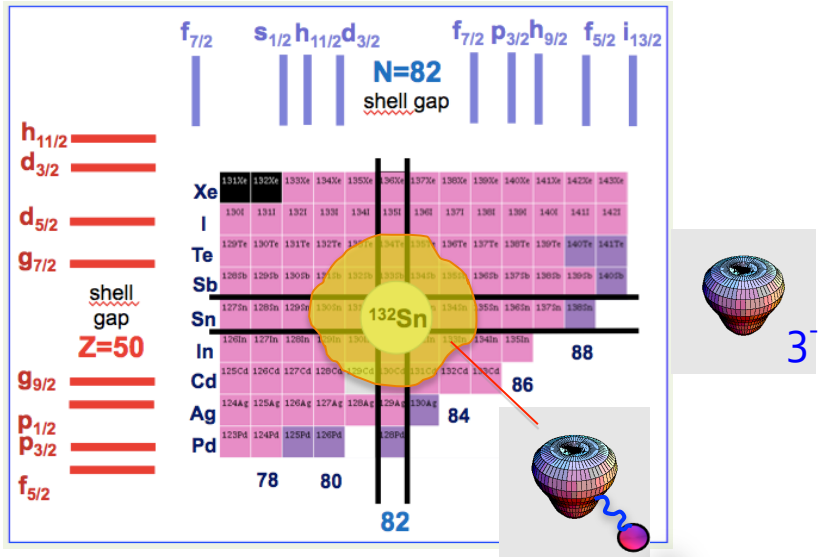
LIMITATION

- Interactions among **VALENCE nucleons**:
  excitations restricted to ONE-TWO oscillator SHELL
- **CORE excitations** NOT fully included:
  NOT always doable, few nucleons only

Relevance of CORE Excitations

Complex, collective excitations dominate
Low Lying states in **DOUBLY MAGIC** Nuclei

2^{+}, 3^{-}, 4^{+}, … **PHONONS**



The Structure of Nuclei with
one or **two valence particles** is influenced by

Particle-PHONON couplings

Key Ingredient for:

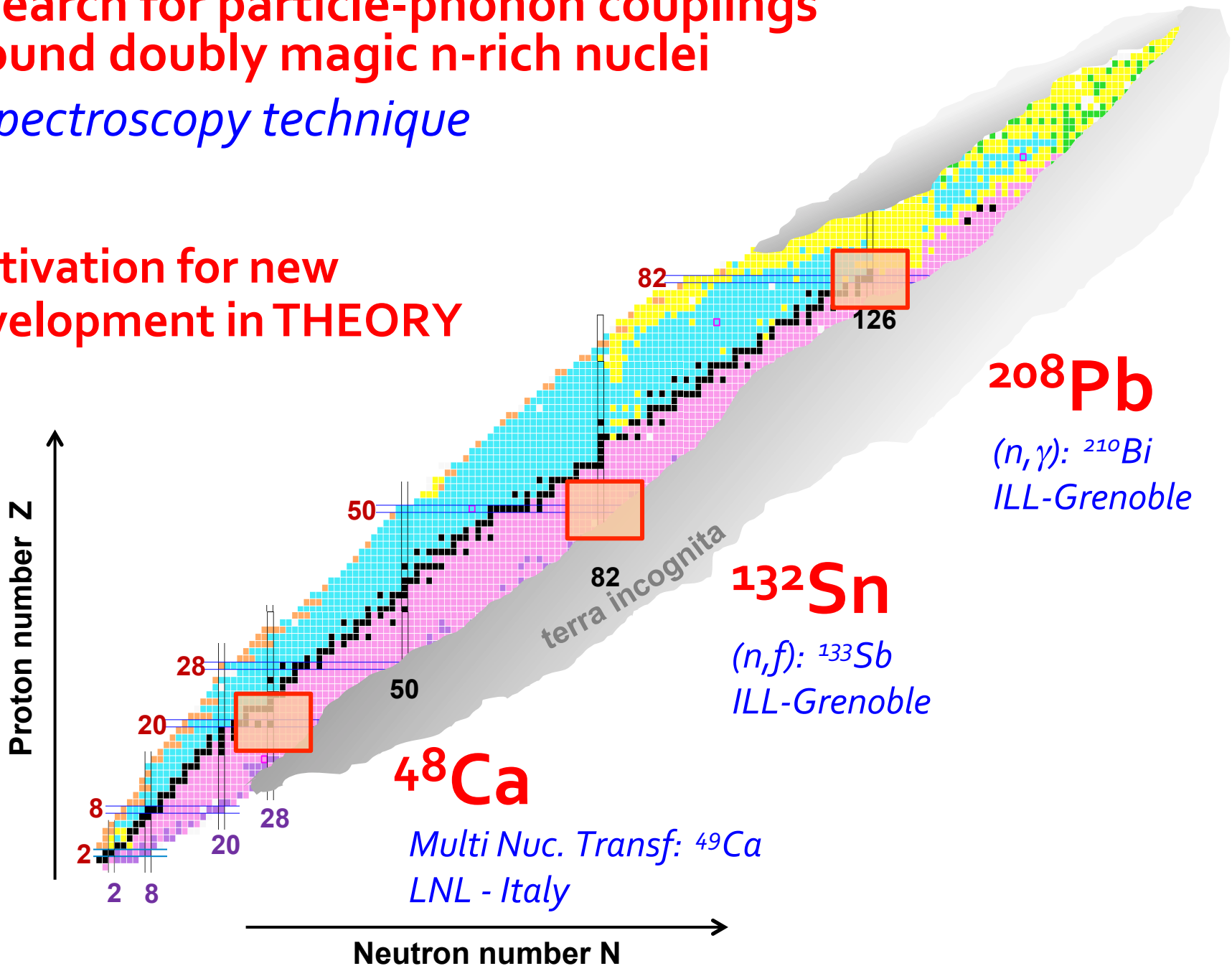
- Quenching of Spectroscopic Factors
- Anharmonicity of vibrational spectra
- Damping of Giant Resonances, …

PHENOMENOLOGICAL models (Bohr-Mottelson)
MICROSCOPIC models (Dobaczewski, Sagawa, Colò, …)

A search for particle-phonon couplings around doubly magic n-rich nuclei

γ-spectroscopy technique

Motivation for new development in THEORY



A search for particle-phonon couplings around doubly magic n-rich nuclei

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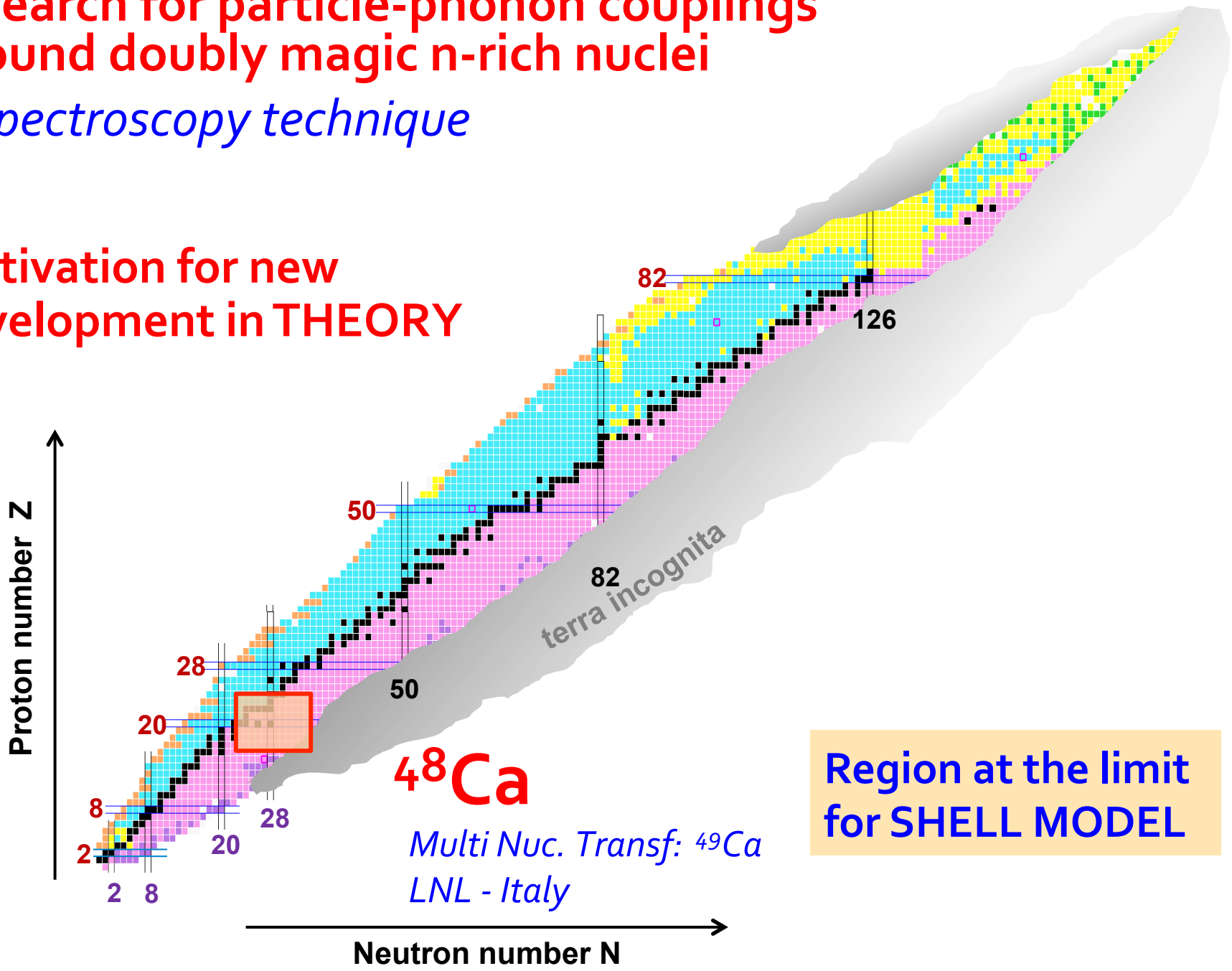


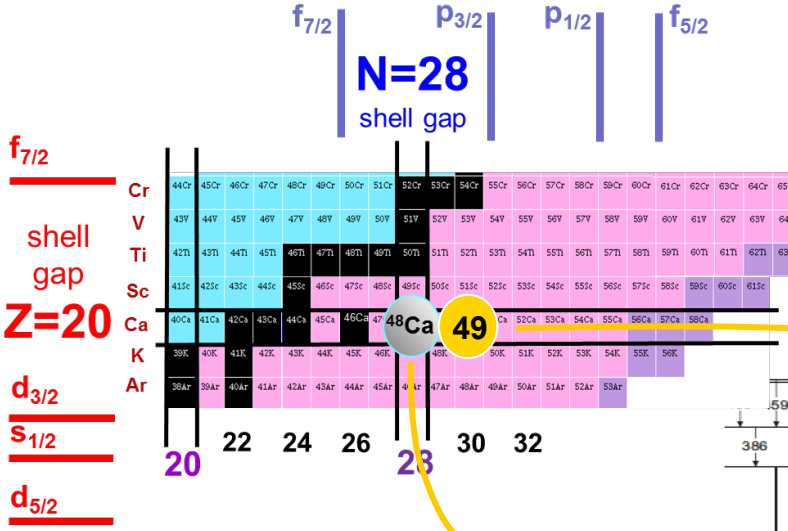
^{48}Ca

Multi Nuc. Transf: ^{49}Ca
LNL - Italy

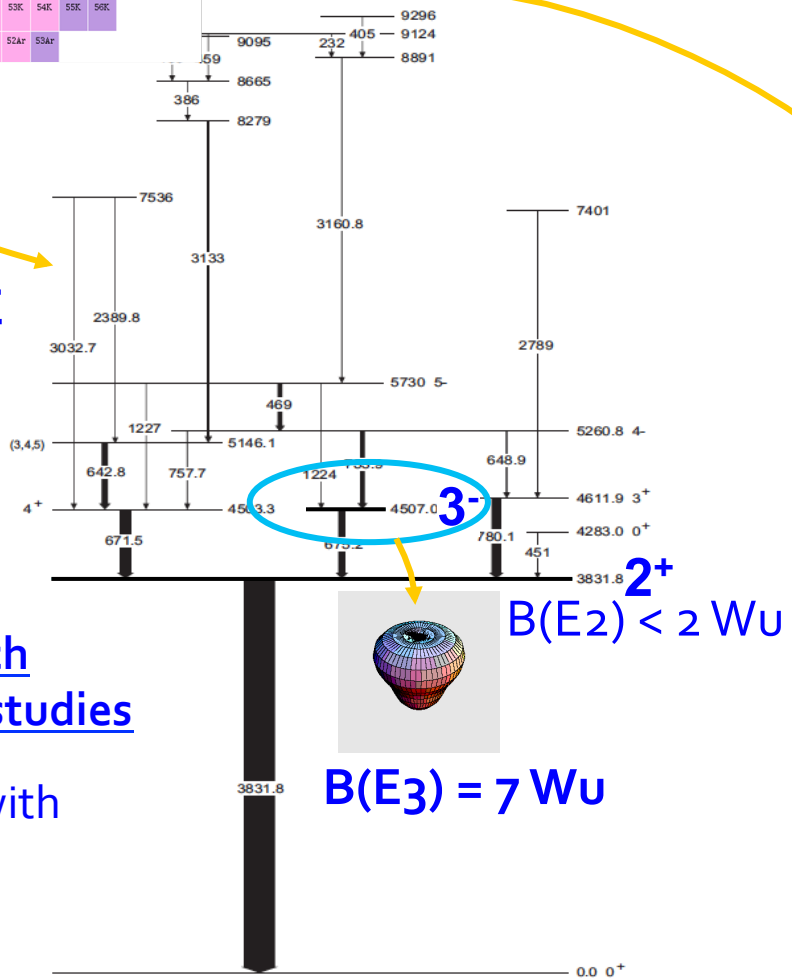
Region at the limit for SHELL MODEL

^{49}Ca

- *Single particle levels*
- ***Couplings** between proton and 3$^-$ phonon*

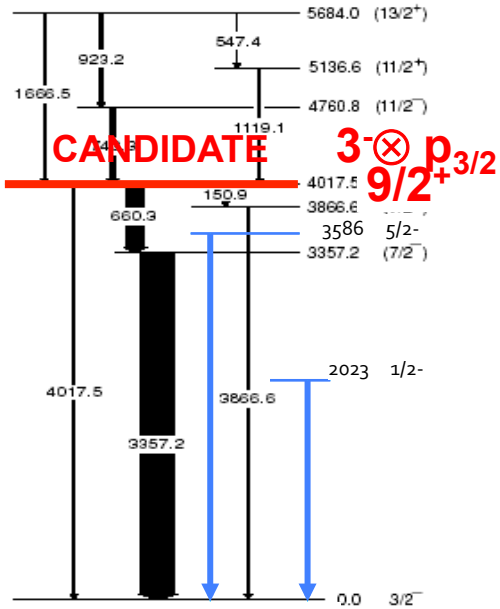


Double SHELL CLOSURE at theValley of Stability



B(E2) < 2 Wu

B(E3) = 7 Wu



[Nuclei hard-to-reach for yrast spectroscopic studies](#)

Multi nucl. transfer with **THICK** targets

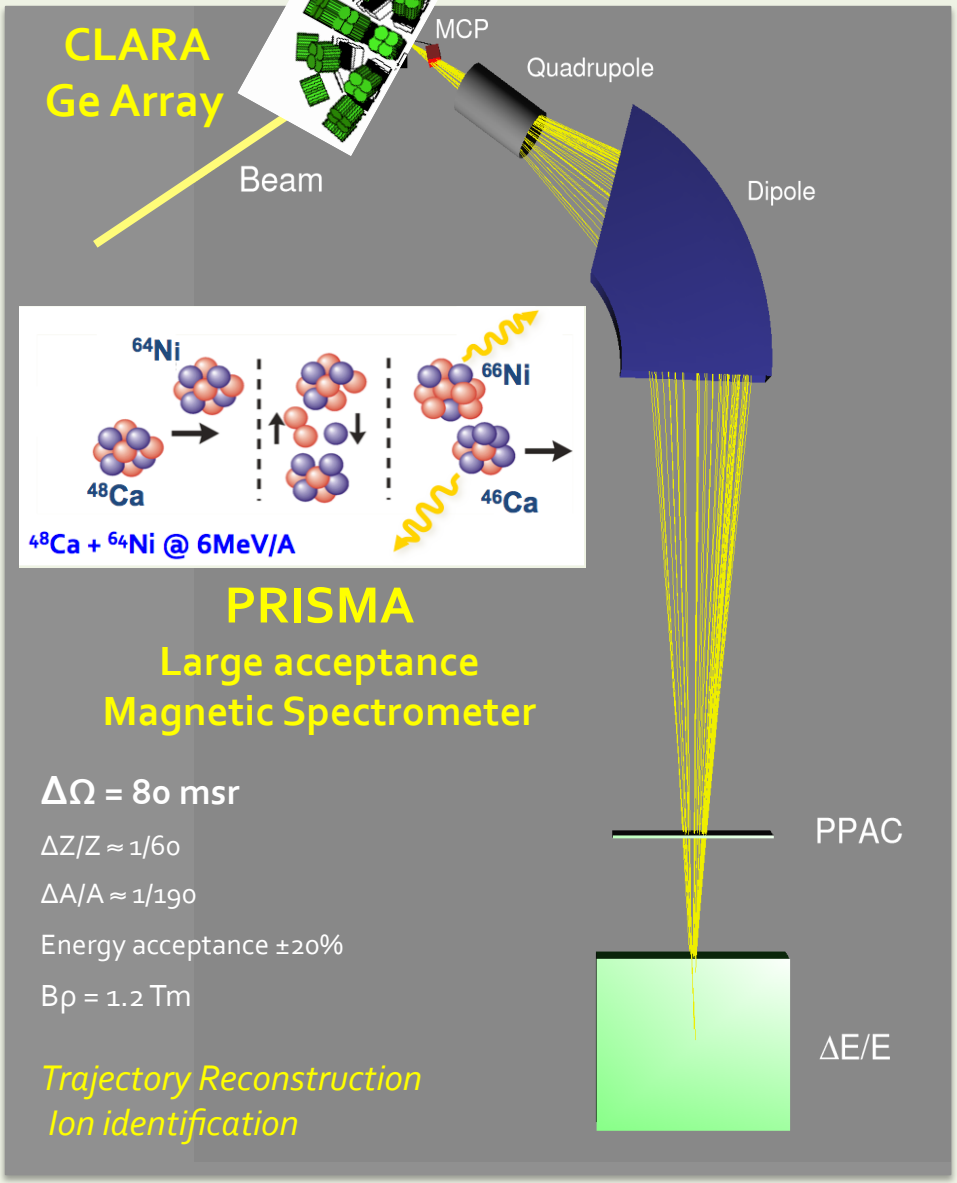
Krakow group: R. Broda, B. Fornal et al., …

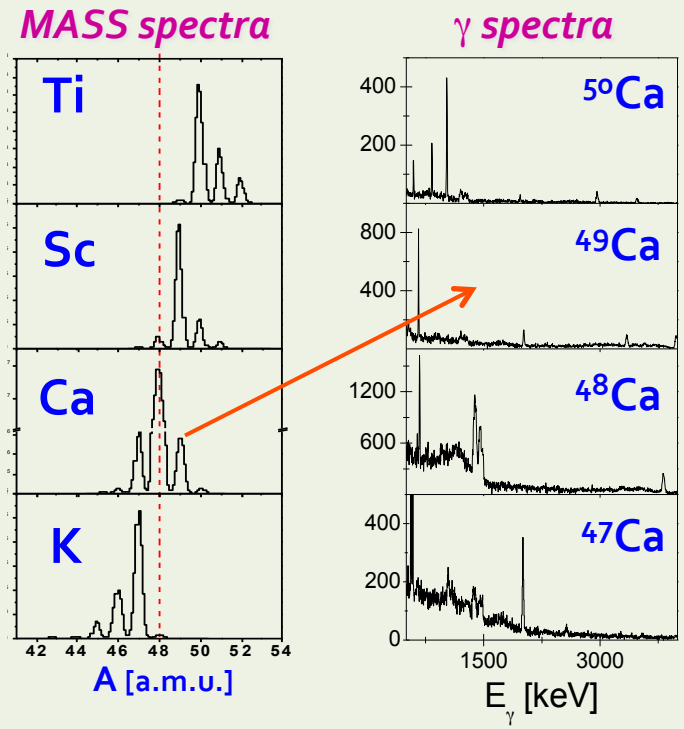
^{48}Ca

^{49}Ca

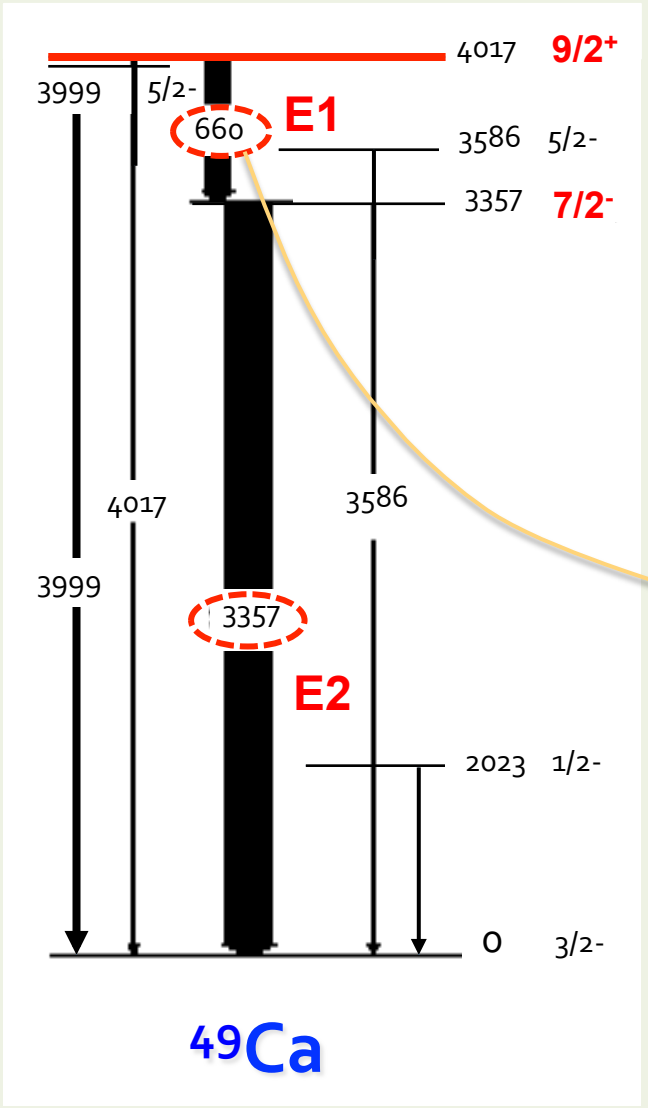
Multi Nucl. Transfer with THIN targets: GE ARRAY + MAGNETIC SPECTROMETER

Studies of Moderately N-Rich Nuclei



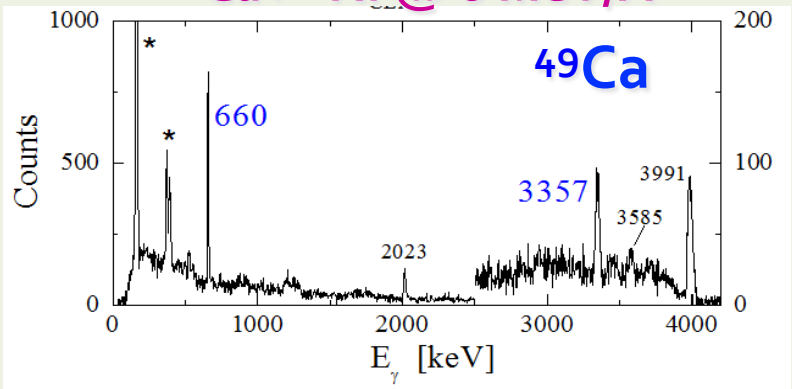


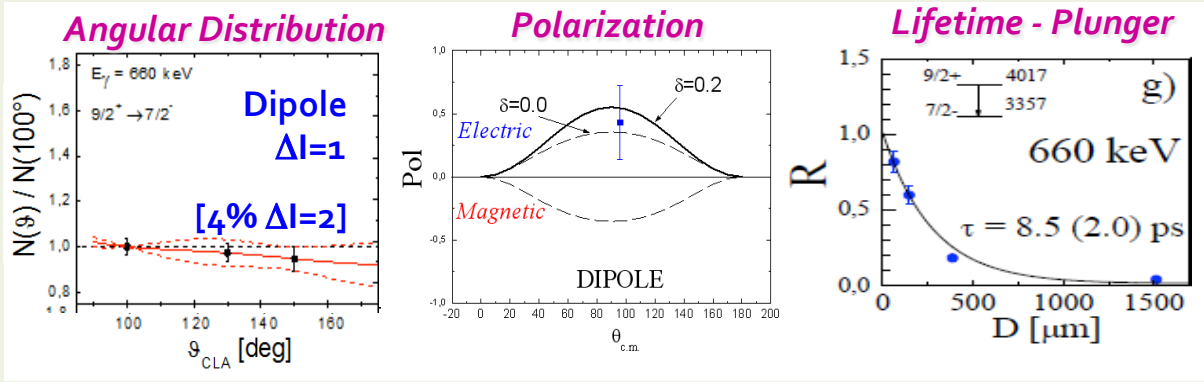
Spectroscopy of ^{49}Ca: Spin, Parity and Lifetimes



$3^- \otimes p_{3/2}$

^{48}Ca+^{64}Ni @ 6 MeV/A





E = 4017.5 keV **$I^\pi = 9/2^+$**

B(E3) = 7.9 ± 2 Wu similar to B(E3) of 3^- in ^{48}Ca

$3^- \otimes p_{3/2}$ = **9/2+**, 7/2+, 5/2+, 3/2+

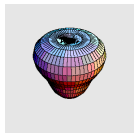
D. Montanari, S. Leoni et al., PLB697 (2011) 288

Interpretation of 9/2+ state of ^{49}Ca

Particle-Vibration Coupling

Weak coupling

Phenomenological Model (Bohr-Mottelson)



3⁻ **Theory** 4.507

7/2⁺ 4.41

5/2⁺ 4.33

3/2⁺ 4.19

9/2⁺ 4.00

RPA Calculation

$B(E3)_{TH} \approx 7$ WU

3 components (64, 29, 2%)

$B(E3)_{EXP} \approx 7$ WU

$3^- \otimes p_{3/2}$

$B(E3)_{TH} \approx 7$ WU

0⁺

^{48}Ca

G. Colò, P.F. Bortignon, … (Milano)

Large Scale SHELL Model

FULL sd-pf-sdg shell still NOT possible

Truncation scheme sd+pf+sdg (2.515.437 conf)

with V_{MU} interaction

9/2+ 4.017

5/2⁺, 7/2⁺

3/2⁺

9/2⁺ 3.80

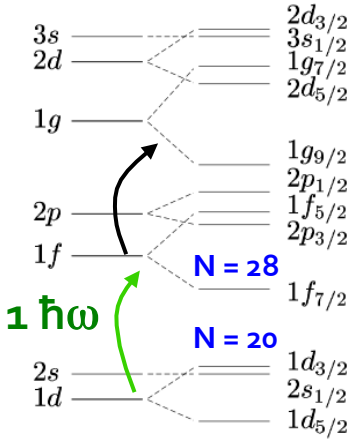
$3^- \otimes p_{3/2}$

$B(E3)_{TH} \approx 6.2$ WU

$B(E3)_{EXP} \approx 7.9\ (2)$ WU

3/2⁻

^{49}Ca



SPEC. FACTOR (9/2+)

SHELL MODEL = 0.42

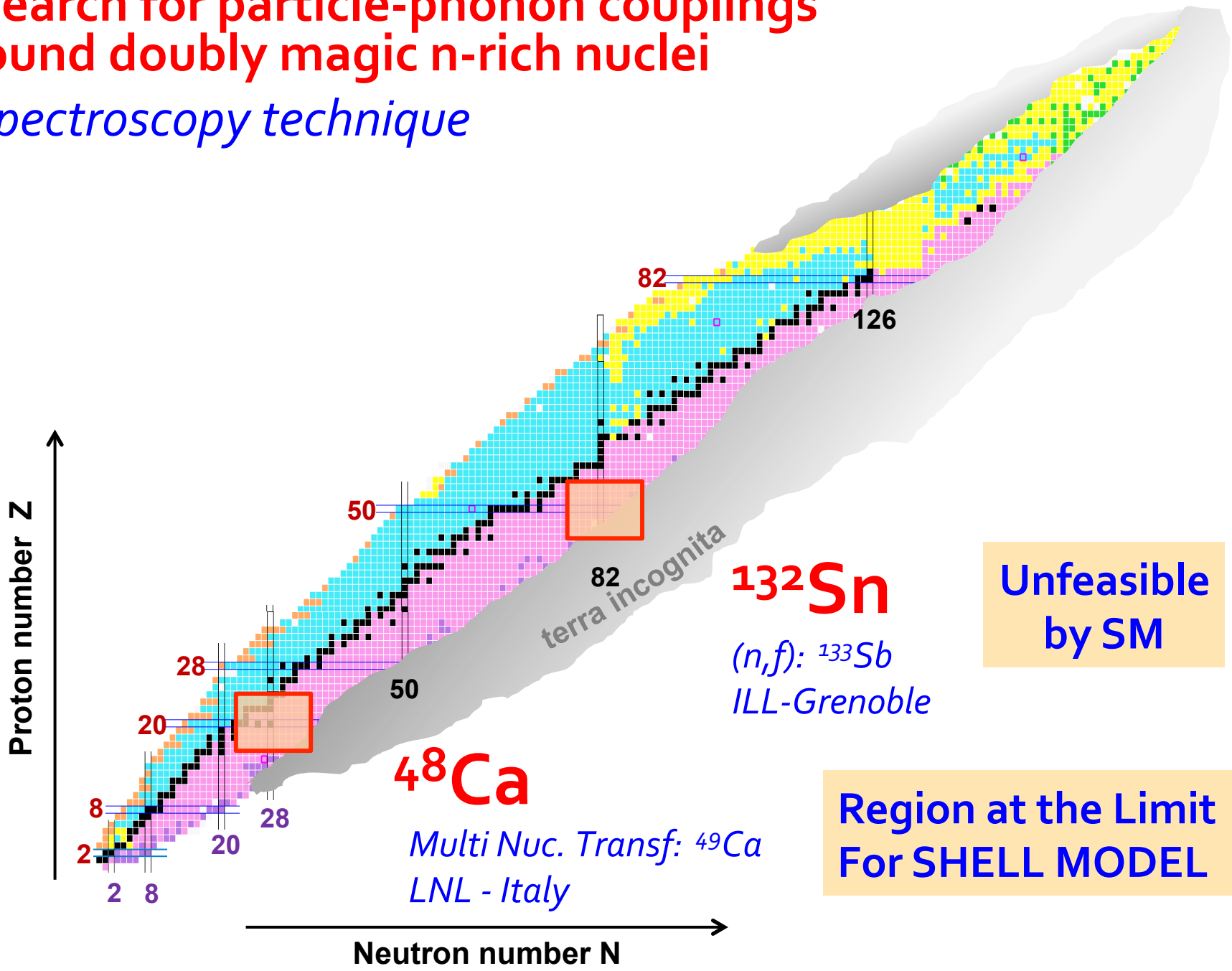
EXP ≈ 0.14

Y. Uozumi et al., NPA 576, 123 (1994)

Y. Utsuno, T. Ostuka, … (Japan)

A search for particle-phonon couplings around doubly magic n-rich nuclei

γ-spectroscopy technique



^{132}Sn

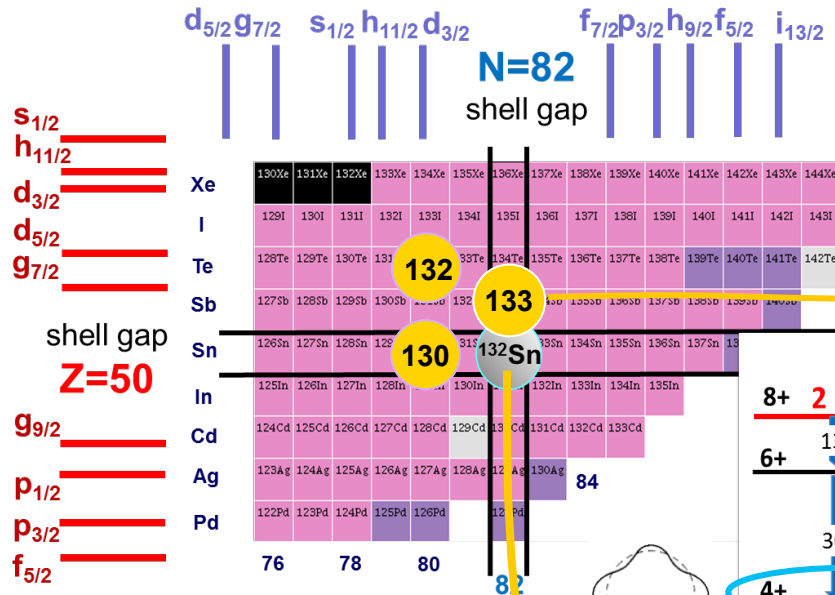
(n,f): ^{133}Sb
ILL-Grenoble

Unfeasible by SM

^{48}Ca

Multi Nuc. Transf: ^{49}Ca
LNL - Italy

Region at the Limit For SHELL MODEL



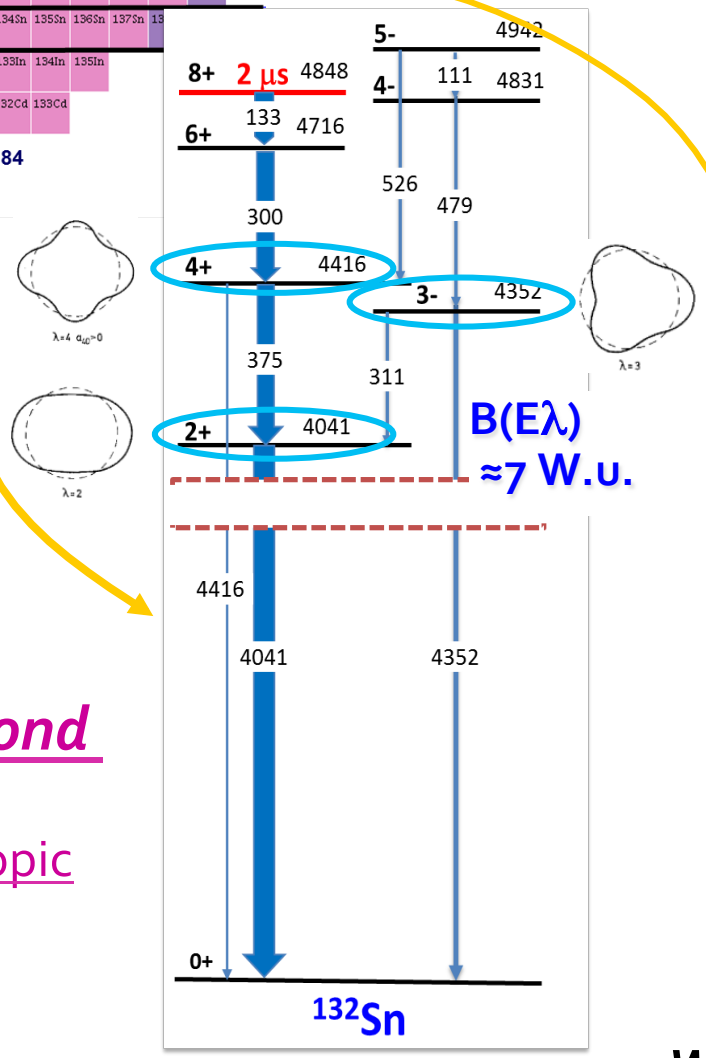
^{133}Sb

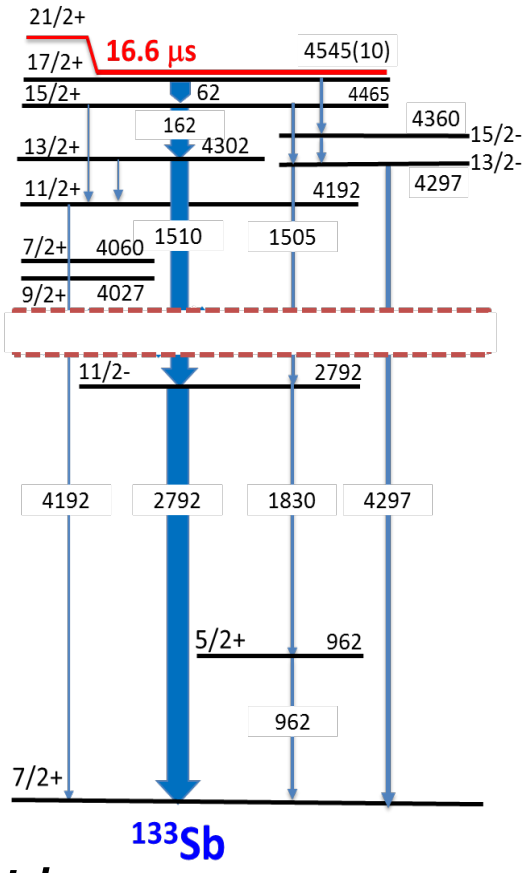
- *Single particle levels*
- ***Couplings** between particle and phonons*

Double SHELL CLOSURE away from Valley of Stability

long-lived microsecond isomers

limited yrast spectroscopic studies



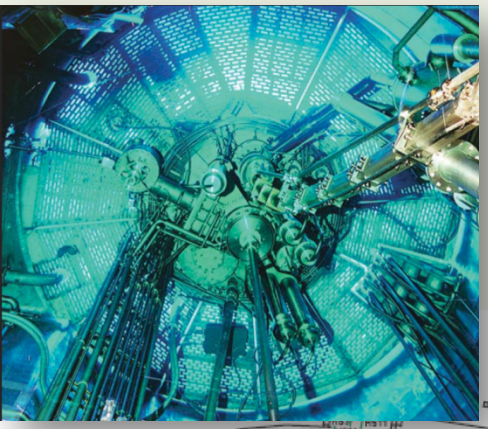


***W. Urban** et al., PRC79(2009)037304*

The γ-Spectroscopy Campaign @ ILL-reactor (Grenoble)

2012-2013: 2 Reactor Cycles (100 days, 95% DATA Taking)

58 MW REACTOR



World Brightest Continuum neutron source

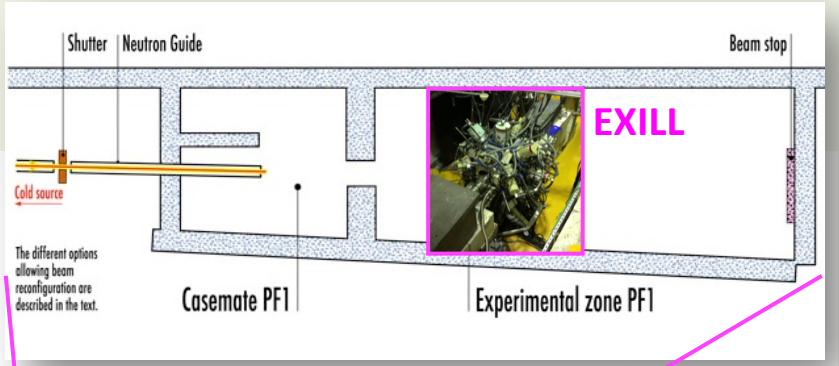
In pile

$\Phi_n = 5\times10^{14}$ n cm^{-2} s^{-1}

Dedicated ballistic neutron guide

Highly collimated beam (1 cm²)
Cold neutrons (meV)

$\Phi_n = 2\times10^{8}$ n cm^{-2} s^{-1}



Reactor hall ILL 5
Experimental level (C)

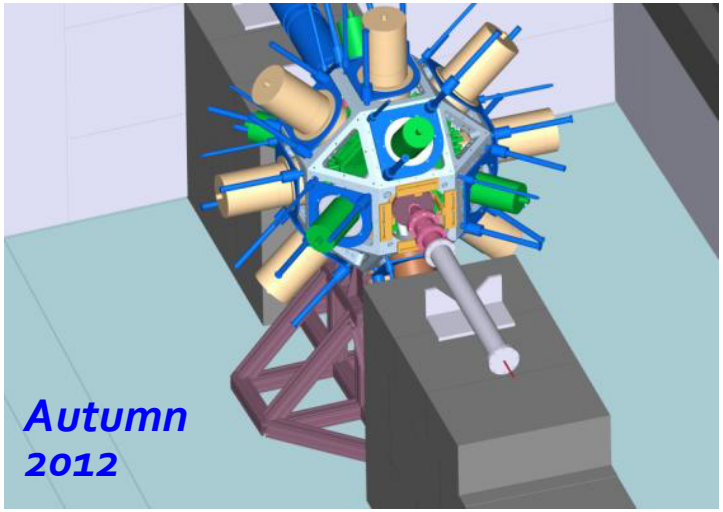
Neutron guide hall - ILL 7
Chartreuse side (EAST)

First time a large HPGe array (52 Ge crystals) installed around a highly collimated cold-neutron beam

SETUP 1

γ – spectroscopy

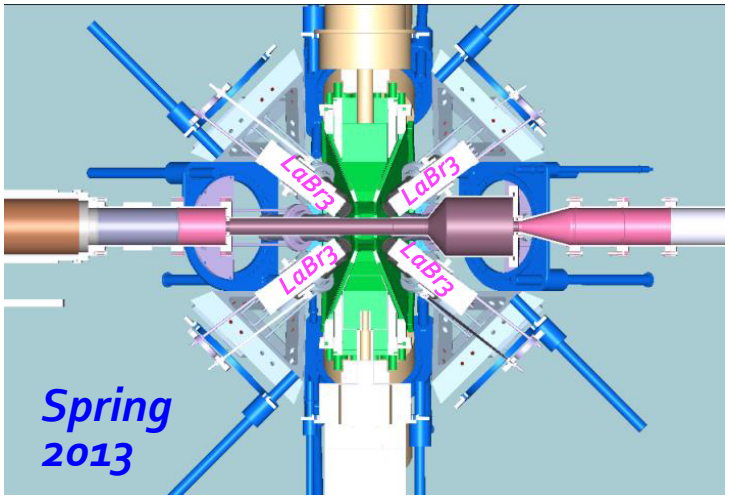
10 EXOGAM – Clovers + 6 Ge GASP
6% efficiency



SETUP 2

Lifetime Measurement

8 EXOGAM – Clovers + 16 LaBr3
***FATIMA ARRAY:** Fast Timing*



The ACQUISITION SYSTEM

A Fully Digital Approach, TRIGGERLESS

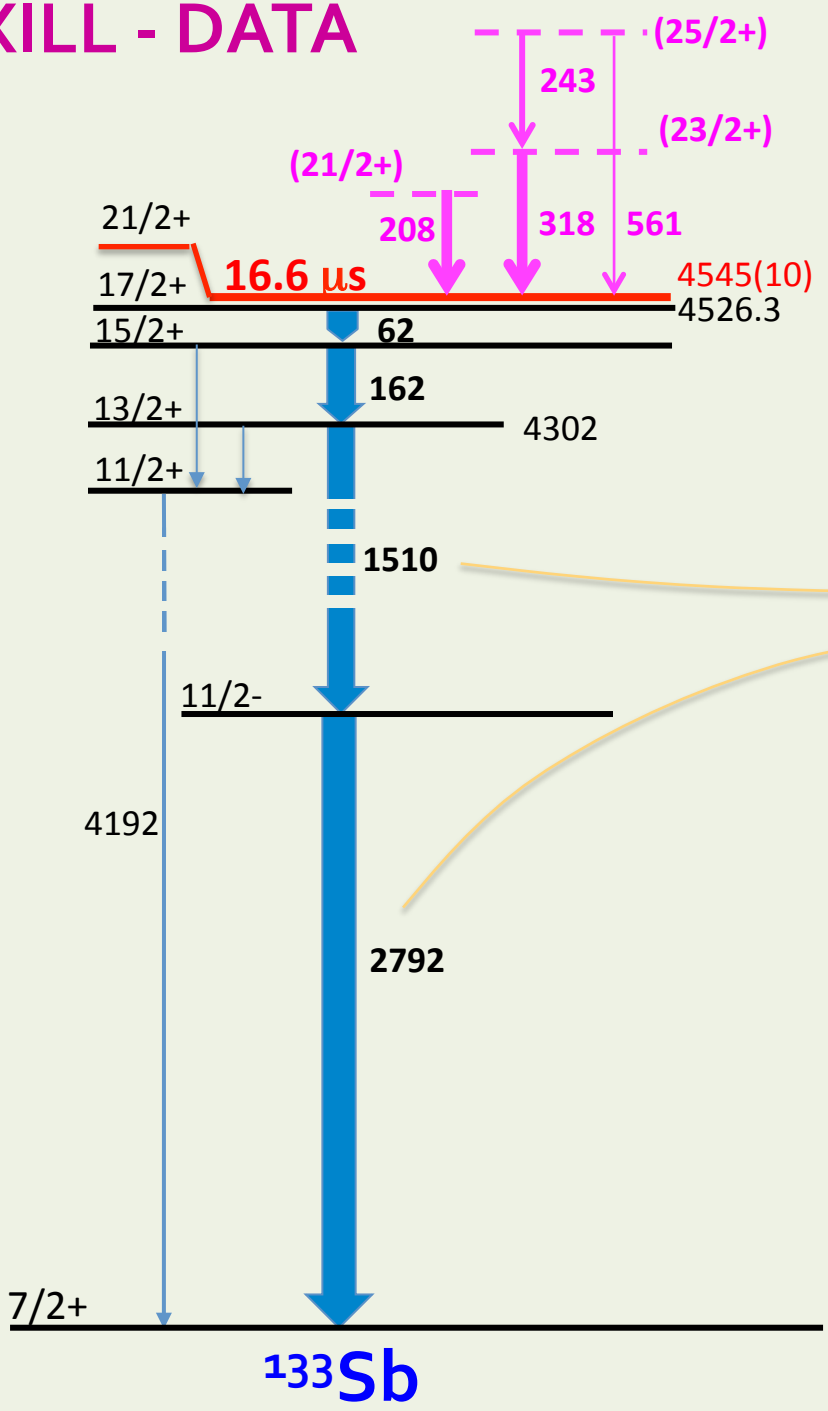
>10 kHz/crystal, **>600 kHz total, 10 ns clock**

*Unique opportunity for **γ-coincidences** over **several μs** time window*

→ ***n-induced fission** on ^{235}U and ^{241}Pu and **(n,γ)** on several targets*

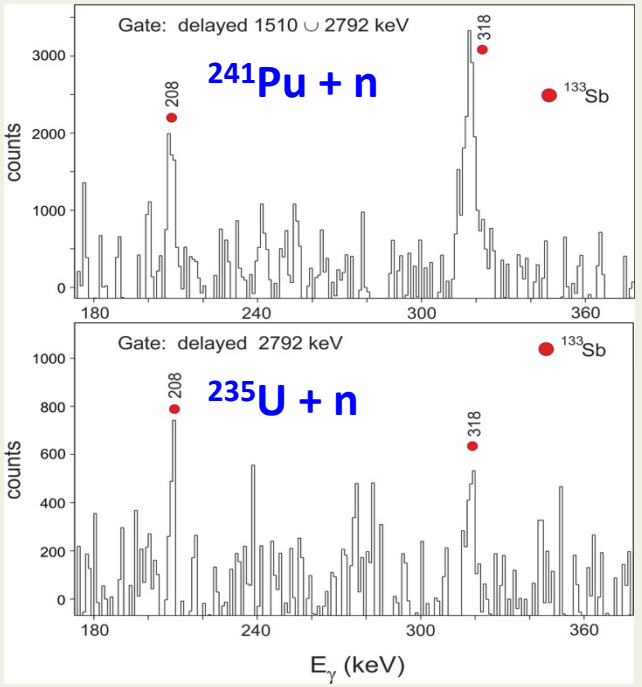
G. DeFrance, A. Blanc, U. Koster, M. Jentschel, P. Mutti, G. Simpson, J.M. Regis, C. Ur et al.

EXILL - DATA



Prompt-Delayed Coincidences

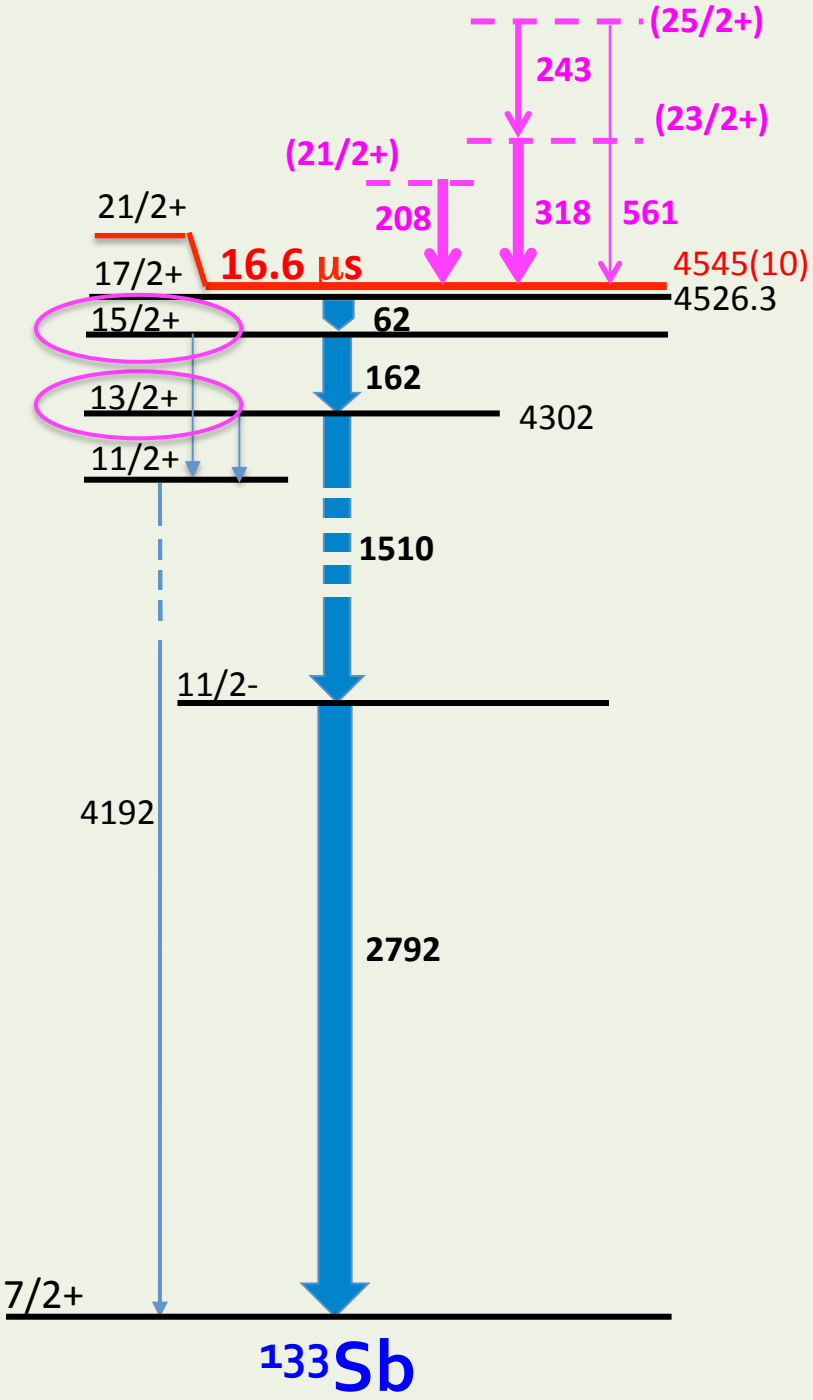
over μs time range



Feeding of the ISOMER

Spins up to 25/2+

B. Fornal – IFJ PAN, Krakow
G. Bocchi – PhD Thesis, Milano



INTERPRETATION

Multiplet of states

$11/2^+, 13/2^+, \ldots 25/2^+$

Lifetimes Analysis with Scintillators

	τ_{EXP}	B(M1,I→I-1)	
15/2+	≈10 ps	0.7 W.u.	> 100
13/2+	≈40 ps	0.005 W.u.	

Not Simple Configurations !

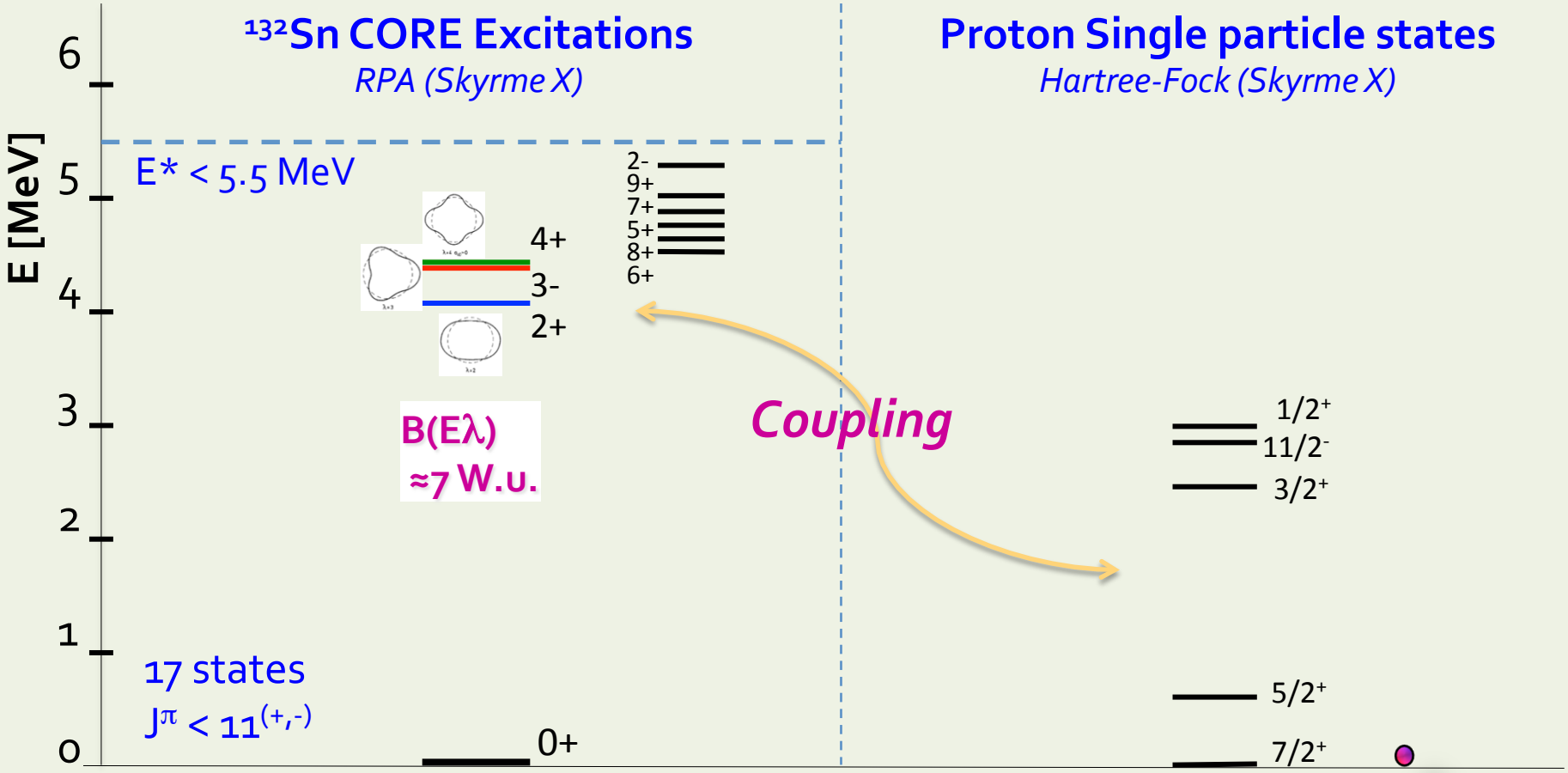
PROBLEM:

LARGE SHELL Model Calculations Involving complex **CORE-excitations** **are NOT possible !**

HYBRID Model – (G. Colò, P.F. Bortignon - Milano)

Extended Microscopic Particle-Vibration Coupling Model

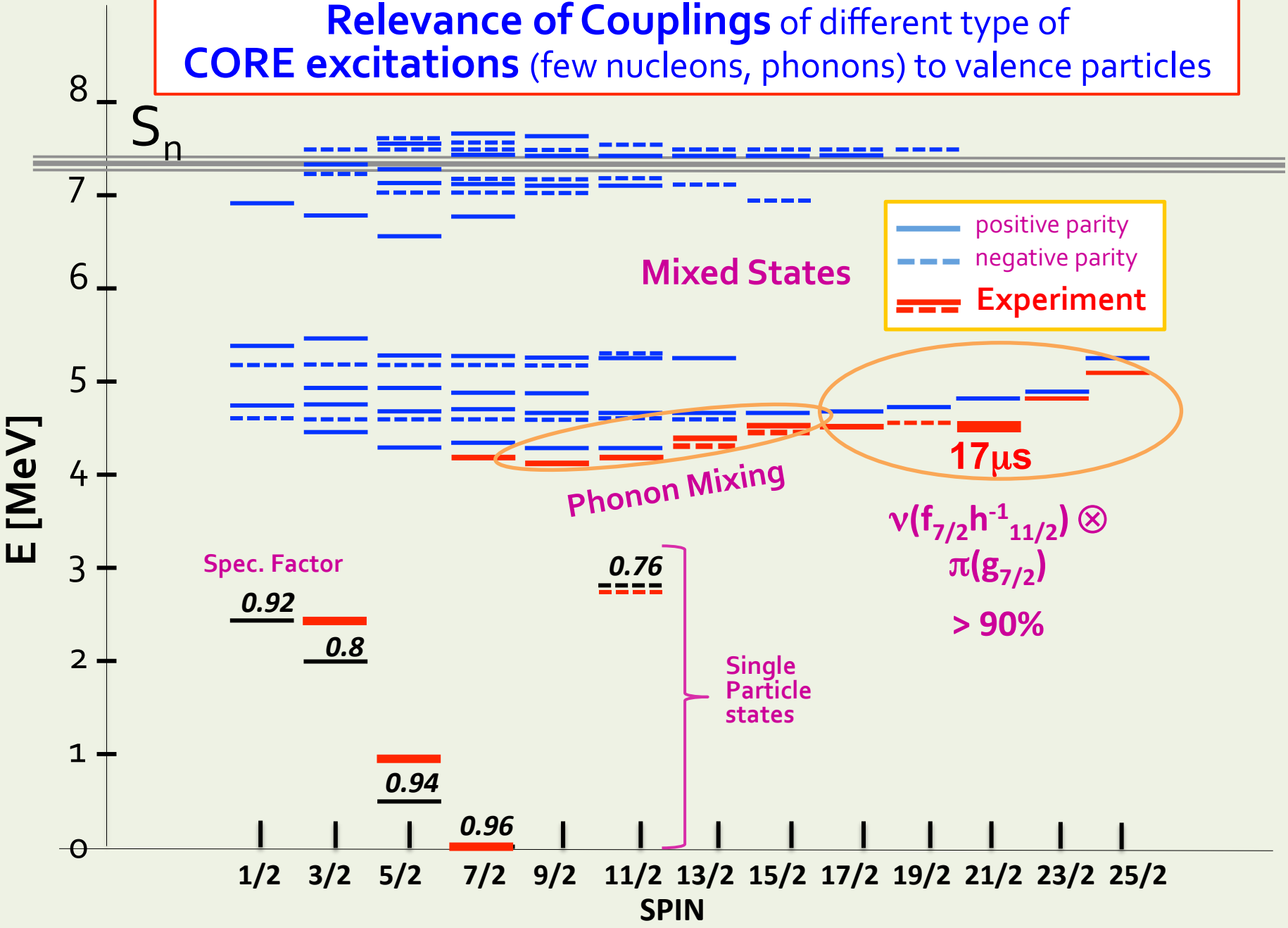
^{133}Sb: ^{132}Sn + 1π



→ ***Coupling matrix elements*** *between* ***single particle*** *and* ***CORE excitations*** *are consistently calculated with the* ***same SkX interaction:*** ***NO FREE PARAMETERS***

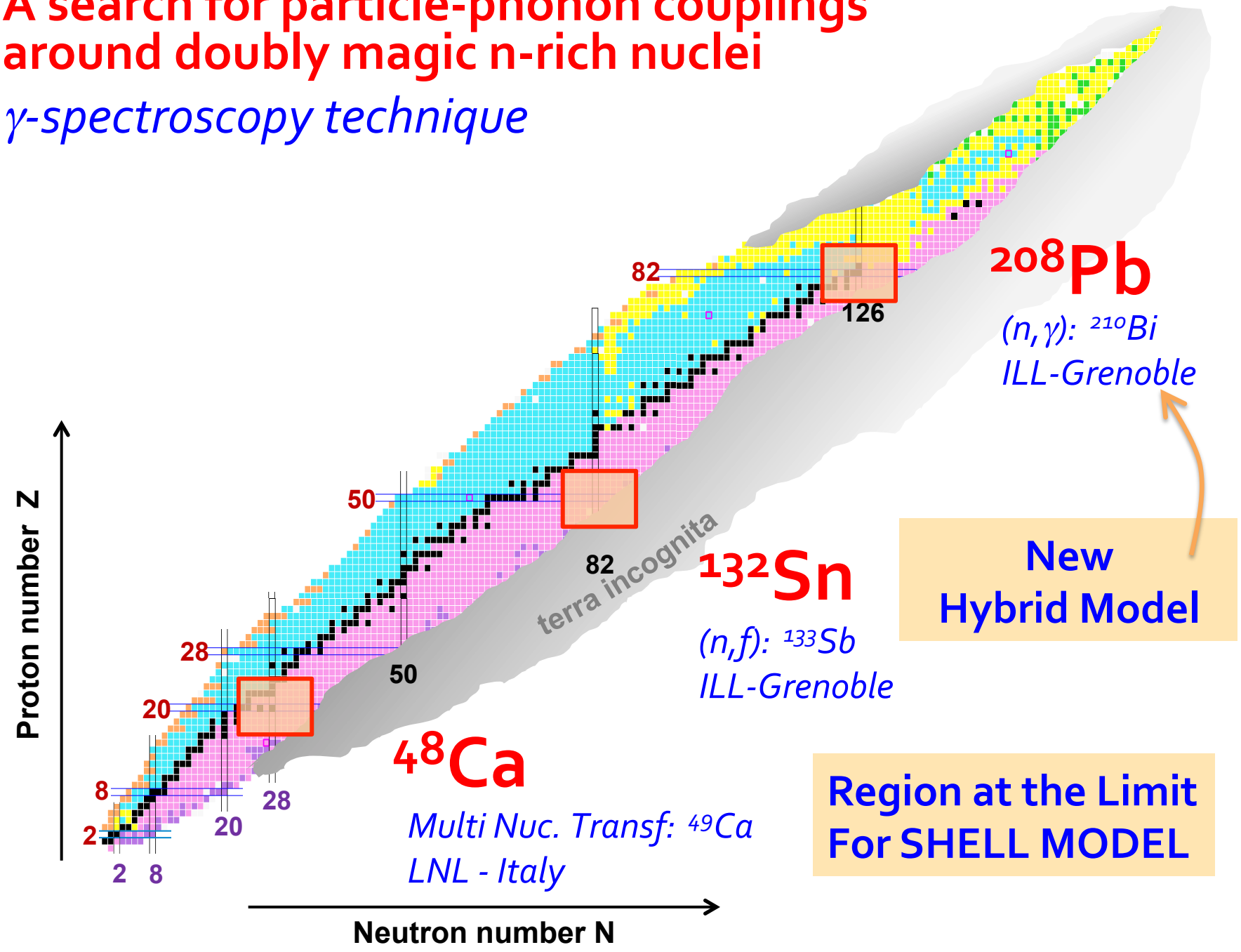
HYBRID Model – ^{133}Sb Spectrum

Relevance of Couplings of different type of
CORE excitations (few nucleons, phonons) to valence particles



A search for particle-phonon couplings around doubly magic n-rich nuclei

γ-spectroscopy technique



^{208}Pb

(n,γ): ^{210}Bi
ILL-Grenoble

New Hybrid Model

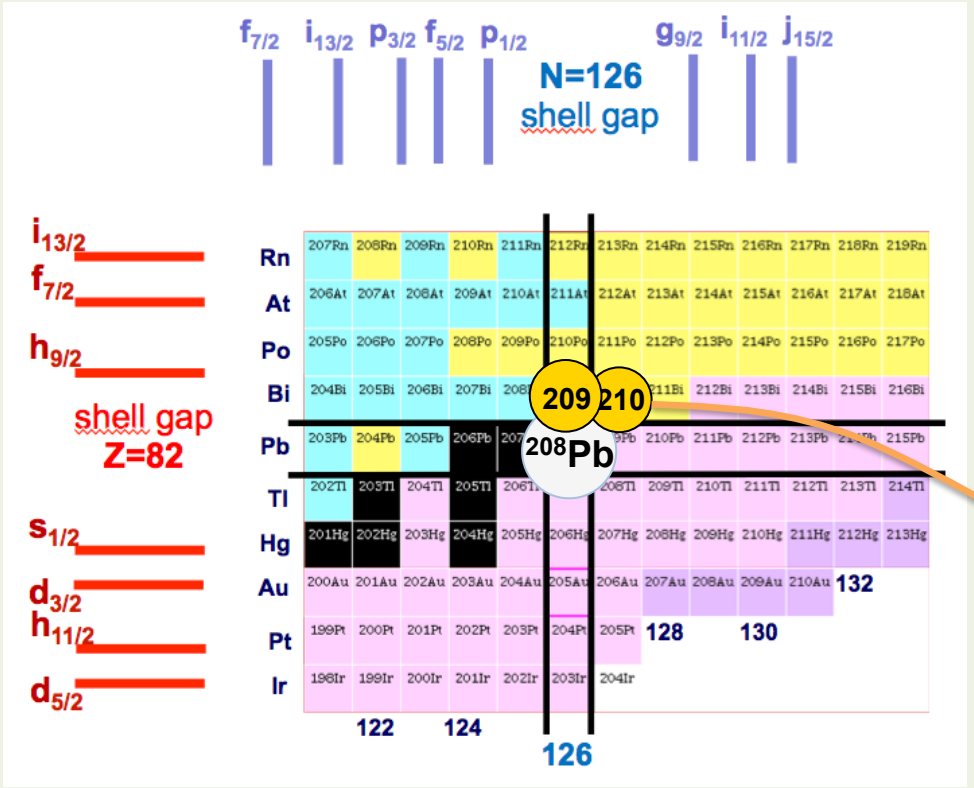
^{132}Sn

(n,f): ^{133}Sb
ILL-Grenoble

^{48}Ca

Multi Nuc. Transf: ^{49}Ca
LNL - Italy

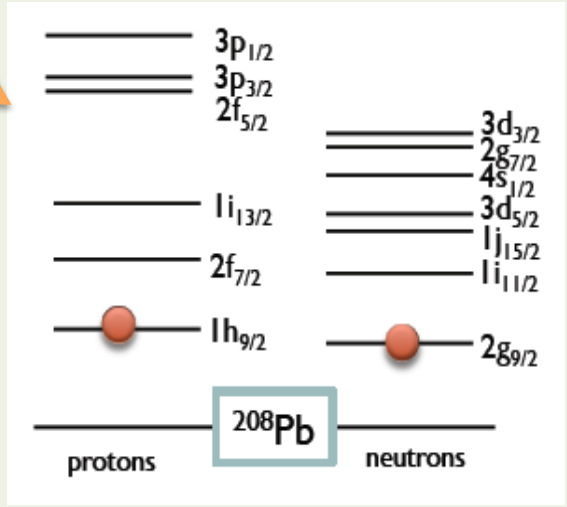
Region at the Limit For SHELL MODEL

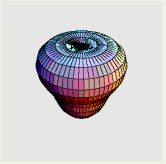


^{210}Bi

- ***Couplings*** *between valence proton and neutron*
- ***Couplings*** *between phonons and pn - pair*

^{208}Pb + 1π + 1ν





3- in ^{208}Pb (34 Wu)

Doubly-magic SHELL CLOSURE At the Valley of Stability

The nuclei around ^{208}Pb are ***strongly influenced*** by the very collective ***3$^-$ octupole phonon*** of ^{208}Pb, E_x = 2.6 MeV, B(E3) = 34 W.u

Particle-Phonon Multiplet in **^{209}Bi**: ^{209}Bi(d,d'), ^{209}Bi(α,α'), …, Bohr-Mottelson Model (1970)

$^{209}Bi(n,\gamma)^{210}Bi$ – ILL Grenoble

54 primary transitions (31 new)

3081

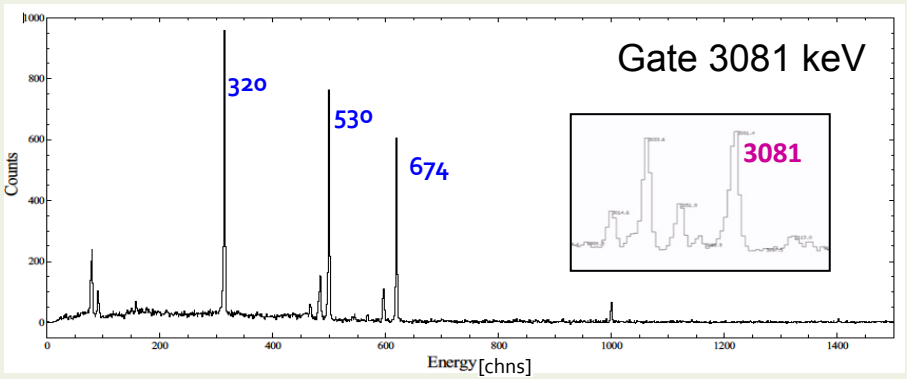
4605.2(1) keV S_n
4⁻,5⁻

61 excited states (24 new)

530

674

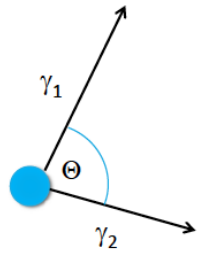
320



Angular Correlations

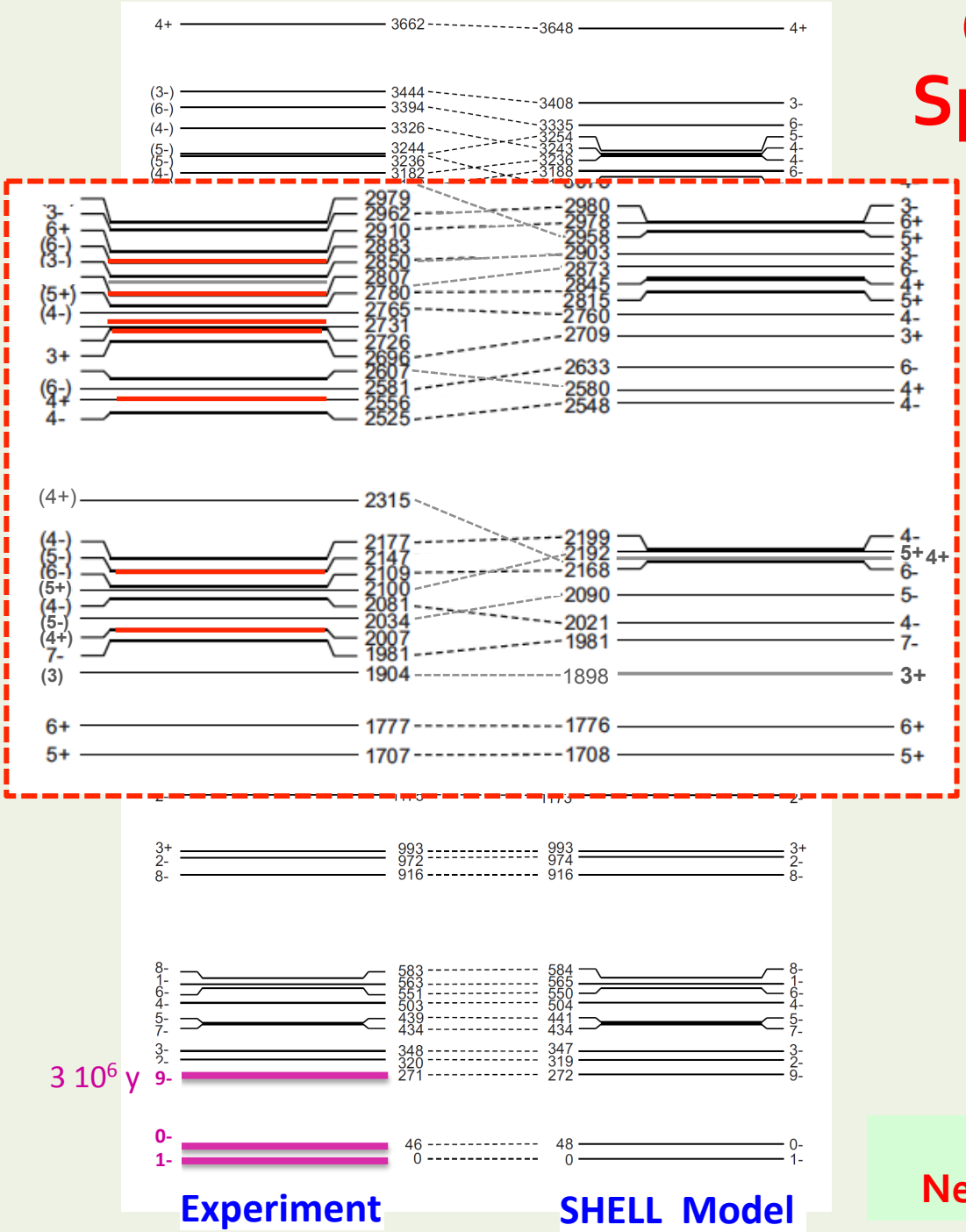
$$W(\Theta) = 1 + A_2 P_2(\cos\Theta) + A_4 P_4(\cos\Theta)$$

Multipolarities of γ-decay
Spin (Parity) of States



N.Cieplicka, PhD-Thesis, Krakow

Complete Low Spin Spectroscopy of ^{210}Bi



Comparison with SHELL Model

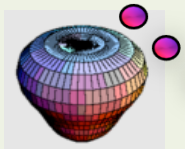
considering
one valence proton and
one valence neutron

outside ^{208}**Pb frozen CORE**

Only **few** Low-Spin States
in the interval **2-3 MeV**
NOT described by
SHELL Model

Possible
$3^- \otimes (\pi h_{9/2} \nu g_{9/2})$
configuration ?

$E_x(3^-)$ = 2.6 MeV



TESTING GROUND for
New HYBRID Model – CORE + 1 p + 1 n

Conclusions

✧ **Studies of COUPLINGS between PARTICLE and CORE excitations around DOUBLE SHELL CLOSURES**

→ ***Key ingredients for***

quenching of Spectroscopic factors,
damping phenomena,
hanarmonicity of vibrational spectra, …

Very difficult to be described by SHELL MODEL Calculations for A > 50
Up to now Mainly interpreted Phenomenologically

✧ **SURVEY of RECENT γ-spectroscopy DATA on excited structures near doubly magic nuclei (hard to reach)**

^{49}Ca – *Multinucleon Transfer*

^{133}Sb – *Neutron Induced Fission*

^{210}Bi – (n,γ)

from Legnaro-INFN Laboratory and ILL (Grenoble)

→ ***Experimental evidence for particle-phonon states***

✧ **New Microscopic Approach: The Hybrid Model**

→ ***Possible Basis for Future Theoretical Description of Complex excitations in Heavy Nuclei***

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Thank You for the Attention

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