Joint
LIA COLL-AGAIN COPIGAL POLITA
WORKSHOP
26-29 April 2016, LNS Catania

Review of Selected Experiments on Collective Modes via Gamma Spectroscopy

Fabio Crespi

Università degli Studi di Milano - INFN

… the efforts of a large collaboration

Milano University and INFN

A. Bracco, G. Benzoni, N. Blasi, F. Camera, F. Crespi, S. Leoni, B. Million, O. Wieland (Seniors)
R. Avigo, S. Bottoni, G. Bocchi, S. Ceruti, N. Cieplicka, A. Giaz, R. Nicolini, L. Pellegri, (PhD / young Postdocs)
P.F. Bortignon, G.Colò, X. Roca-Maza et al.

Legnaro INFN Laboratory

G. DeAngelis, D. Montanari, D. Napoli, J.J. Valiente-Dobon, L. Corradi, E. Fioretto, A. Stefanini et al.

Padova University and INFN

D. Bazzacco, E. Farnea, S. Lenzi, S.Lunardi, D. Mengoni, G. Montagnoli, F. Recchia, F. Scarlassara, C.Ur, et al.

IFJ-PAN, Krakow, Poland

A. Maj, B. Fornal, P. Bednarczyk,, M. Ciemala, N. Cieplicka, L. Iskra, M. Kmiecik, M. Krzysiek, B. Szpak et al.,

INFN Catania

E. G. Lanza

KU Leuven

R. Raabe et al.,

IFIN-HH Bucharest

N. Marginean, D. Bucurescu, C. Mihai, C. Nita et al.

CSIC-University of Valencia

A. Gadea

EXILL

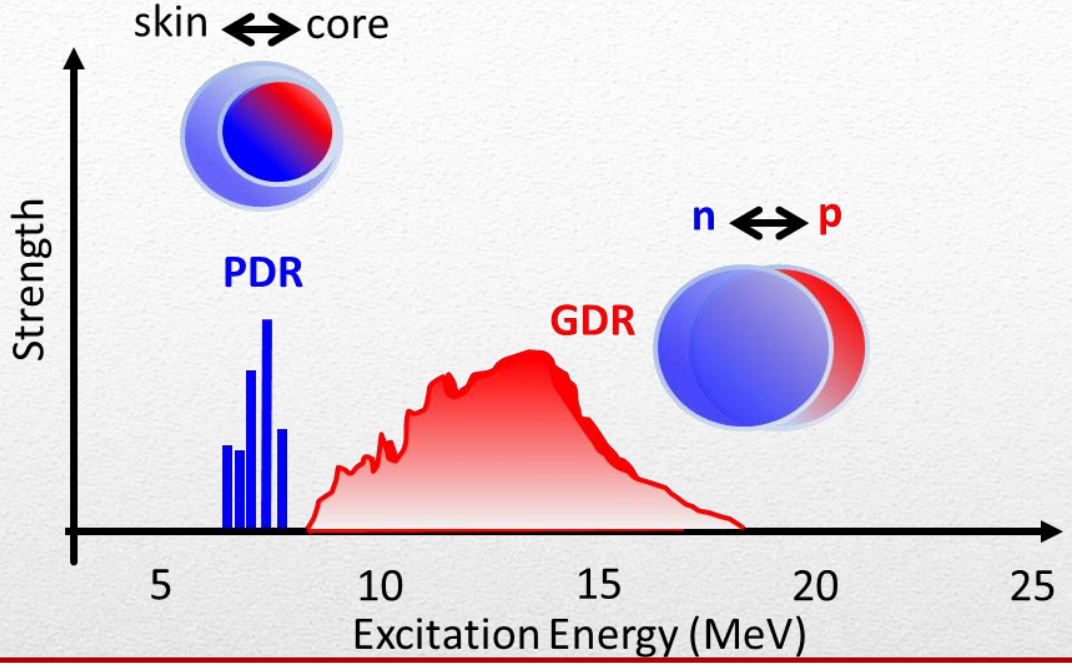
G. DeFrance, A. Blanc, U. Koster, M. Jentschel, **C. Michelagnoli**, P. Mutti, G. Simpson, J.M. Regis et al.

AGATA collaboration

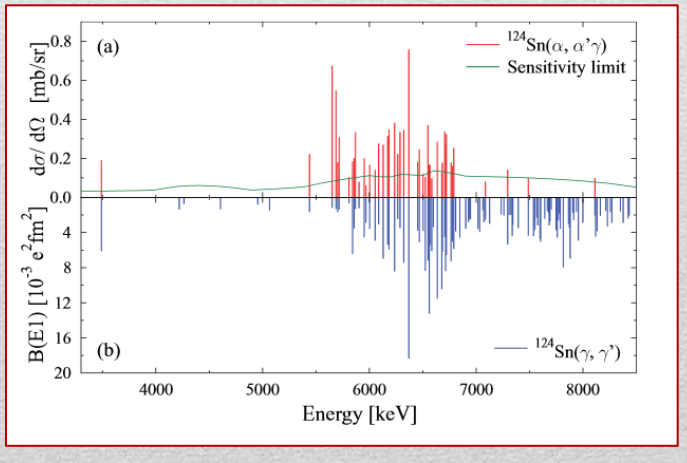
Outline

- **E1 strength at particle threshold: the Pygmy Dipole Resonance (PDR)**
  - *Inelastic scattering of ^{17}O (AGATA + HECTOR @ LNL)*
  - *Relativistic Coulomb excitation (AGATA + HECTOR @ GSI)*
- **Test of the isospin symmetry via Giant Dipole Resonance (GDR) γ-decay**
- **EXILL: γ-Spectroscopy Around Doubly Magic Nuclei**

Nuclear Structure information from the E1 response in Nuclei



The splitting in the population of the states reveals a different underlying structure



- low energy part → isoscalar character (*neutron-skin oscillations*)
- high-energy states → isovector nature (*transition towards the GDR*)

(*) figure from J. Endres et al., Phys. Rev. Lett. 105, 212503 (2010)

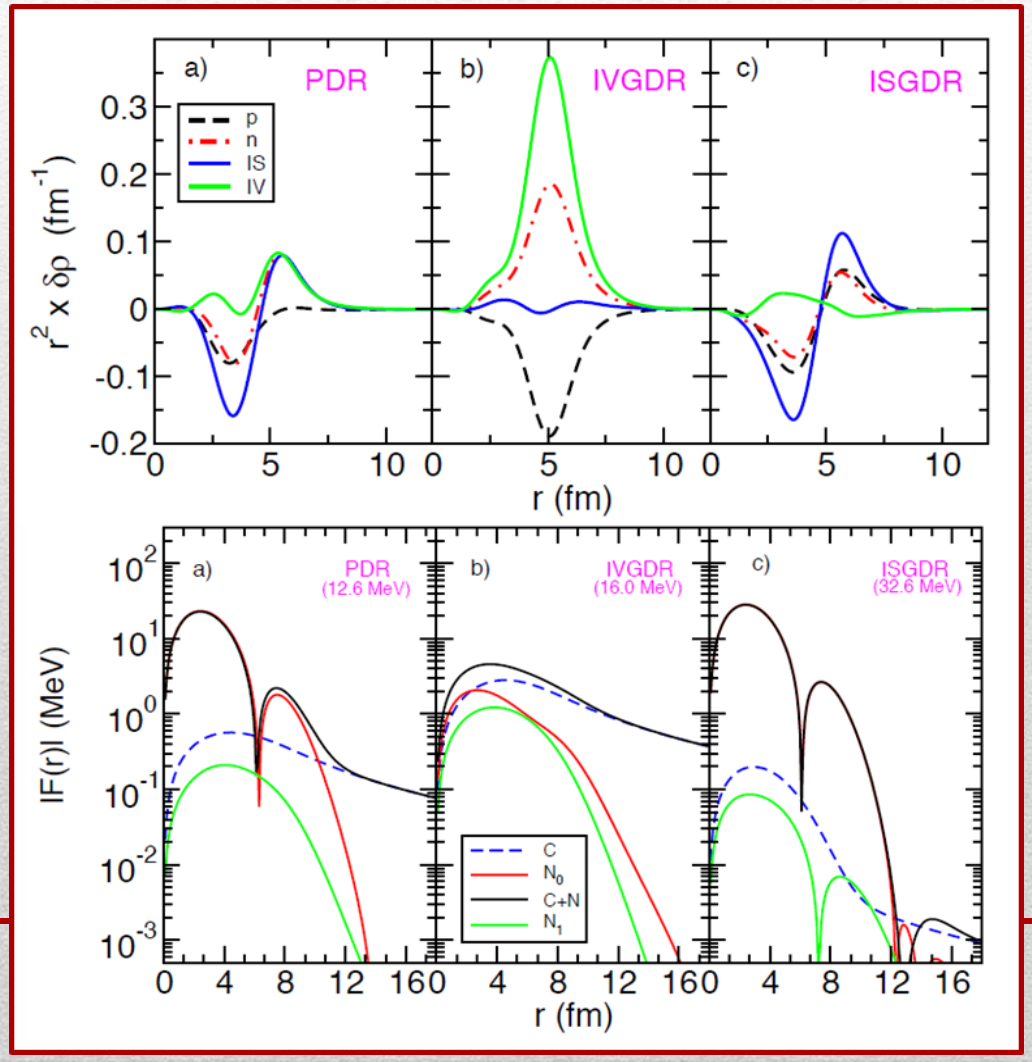
One important open problem for pygmy states is the cross section sensitivity to transition densities containing the nuclear structure information…

Transition Densities and Form Factors

«Different Peaks» (at different excitation energies) → different excitation modes →
→ **different structure of Transition Densities→ Different Form Factors**
→ need of predictions obtained with form factors deduced from microscopic transition densities which incorporate the main features of these states

^{90}Zr
Transition Densities

$^{17}O+^{90}Zr$
Form Factors



*E. G. Lanza et al.,
PRC 89 (2014) 041601
**A. Bracco, F.C.L. Crespi and E.G. Lanza, EPJA (2015) 51: 99

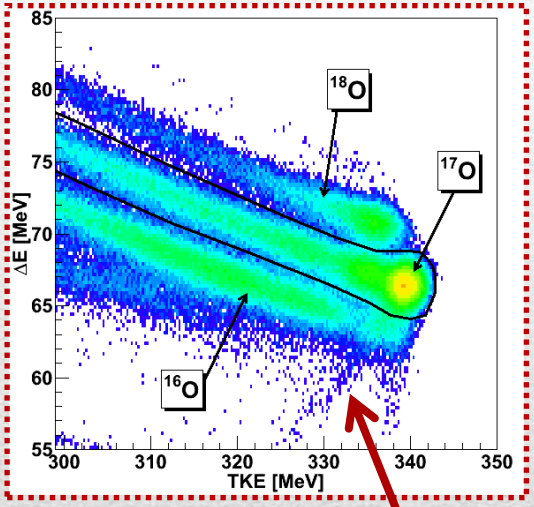
Experimental Technique

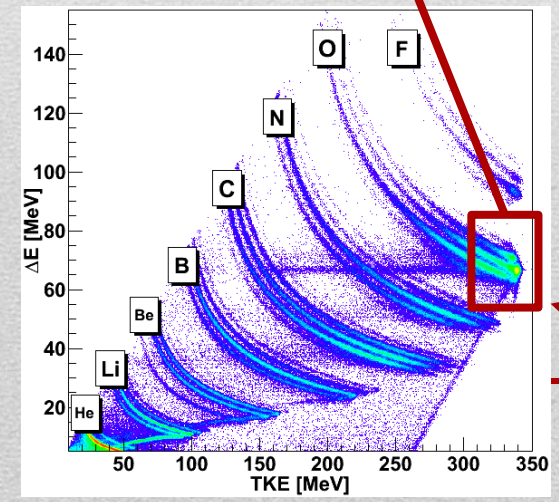
Inelastic scattering of ^{17}O @ 20 MeV/u on different targets + γ-rays in coincidence

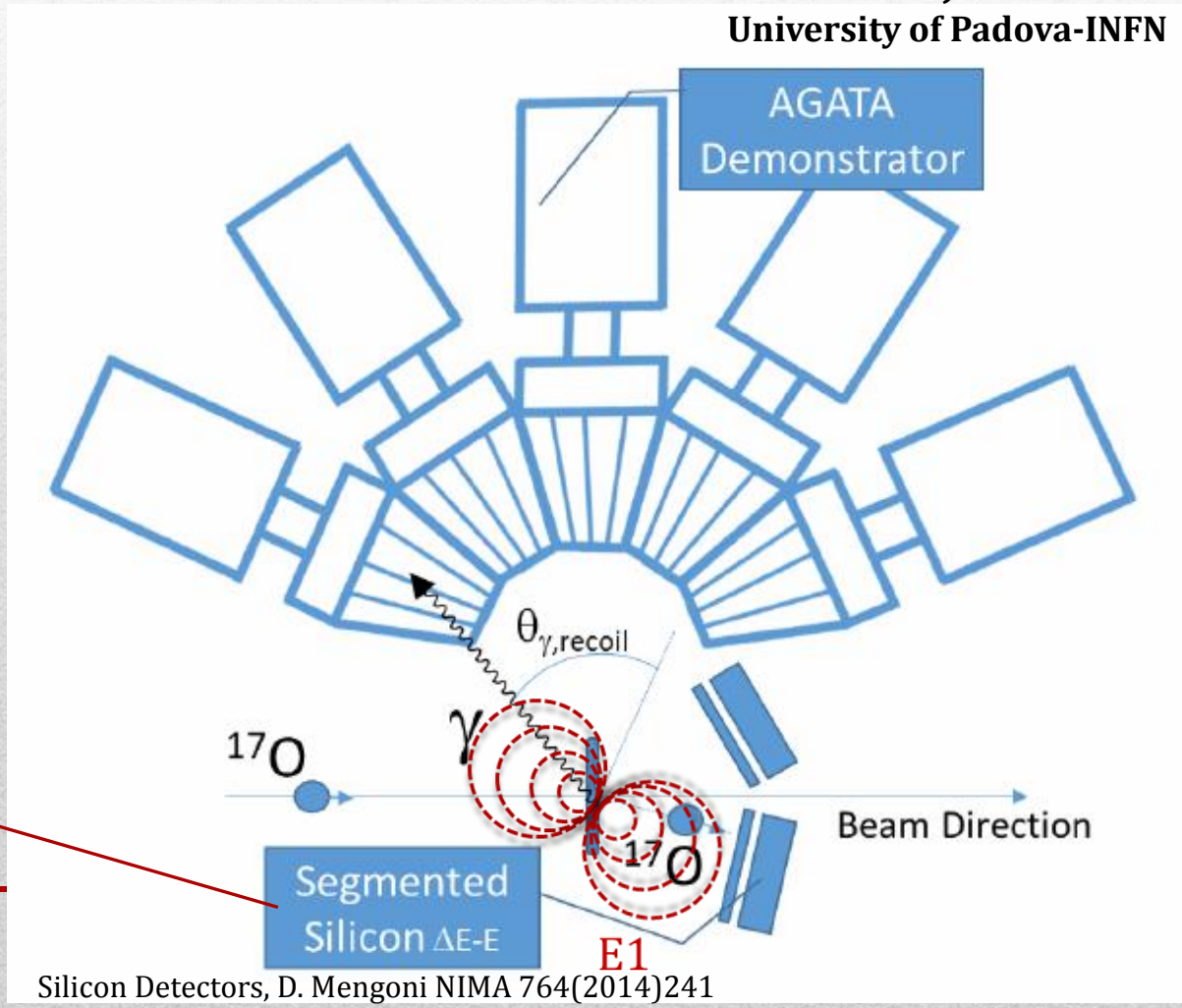
- Large cross-section for the population of the giant resonance region
- ^{17}O is loosely bound (S_n = 4.1 MeV)
- Clean removal of projectile excitation

Experiments at Legnaro

Proposals: **University of Milan-INFN**
IFJ-PAN Cracow
University of Padova-INFN





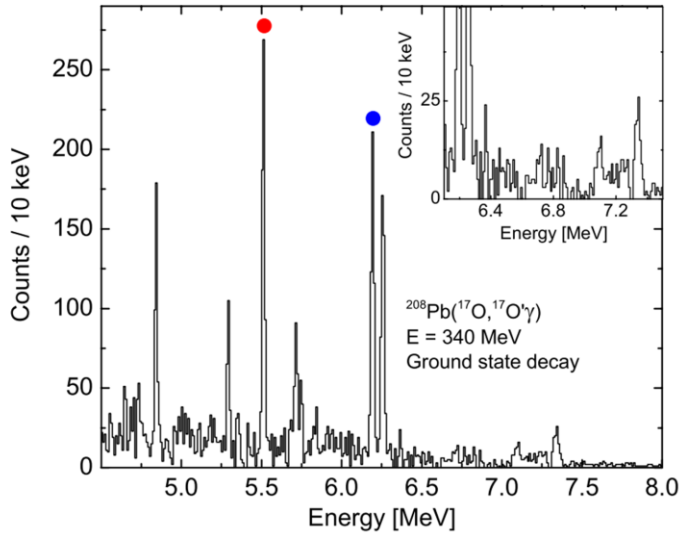


Silicon Detectors, D. Mengoni NIMA 764(2014)241

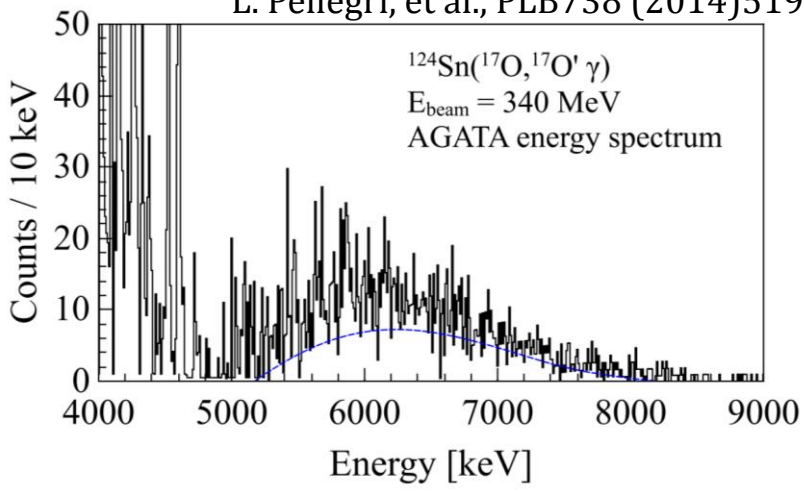
Identification of the Multipolarity

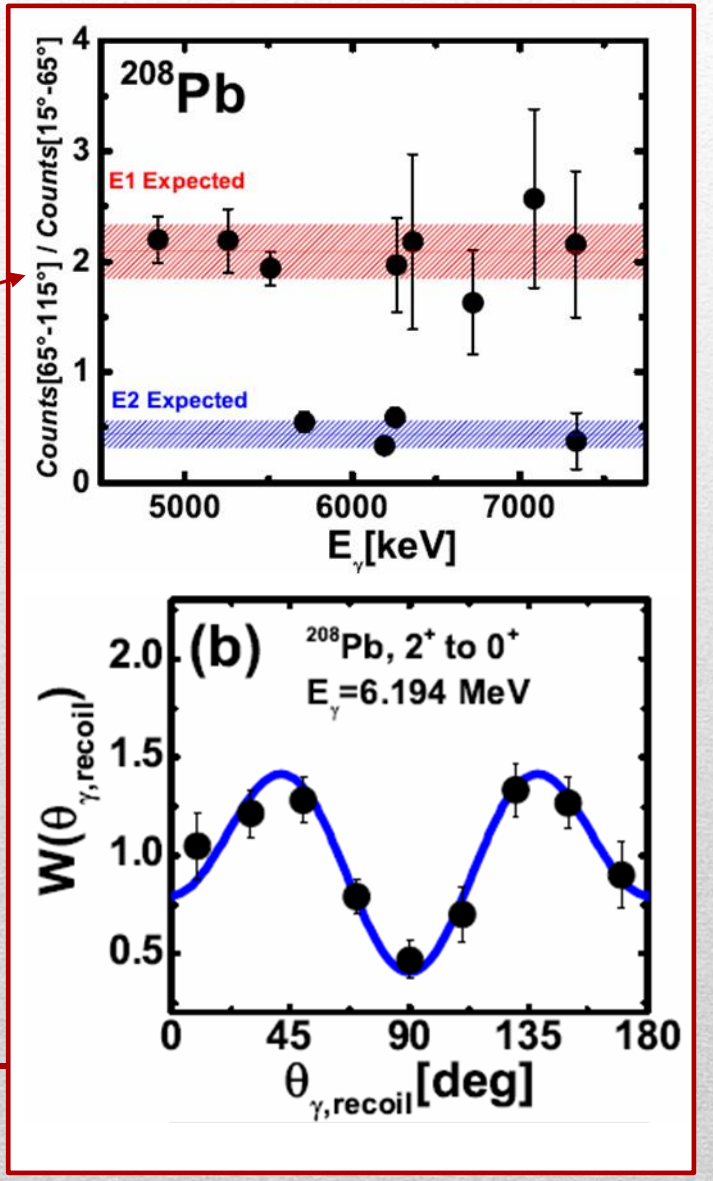
In contrast with light ions, for ^{17}O the pattern of the differential cross section for inelastic scattering as a function on angle does not characterize well the multipolarity of the excited states
→ *angular dist. of gamma-rays*

F.C.L. Crespi, et al., PRL113 (2014) 012501



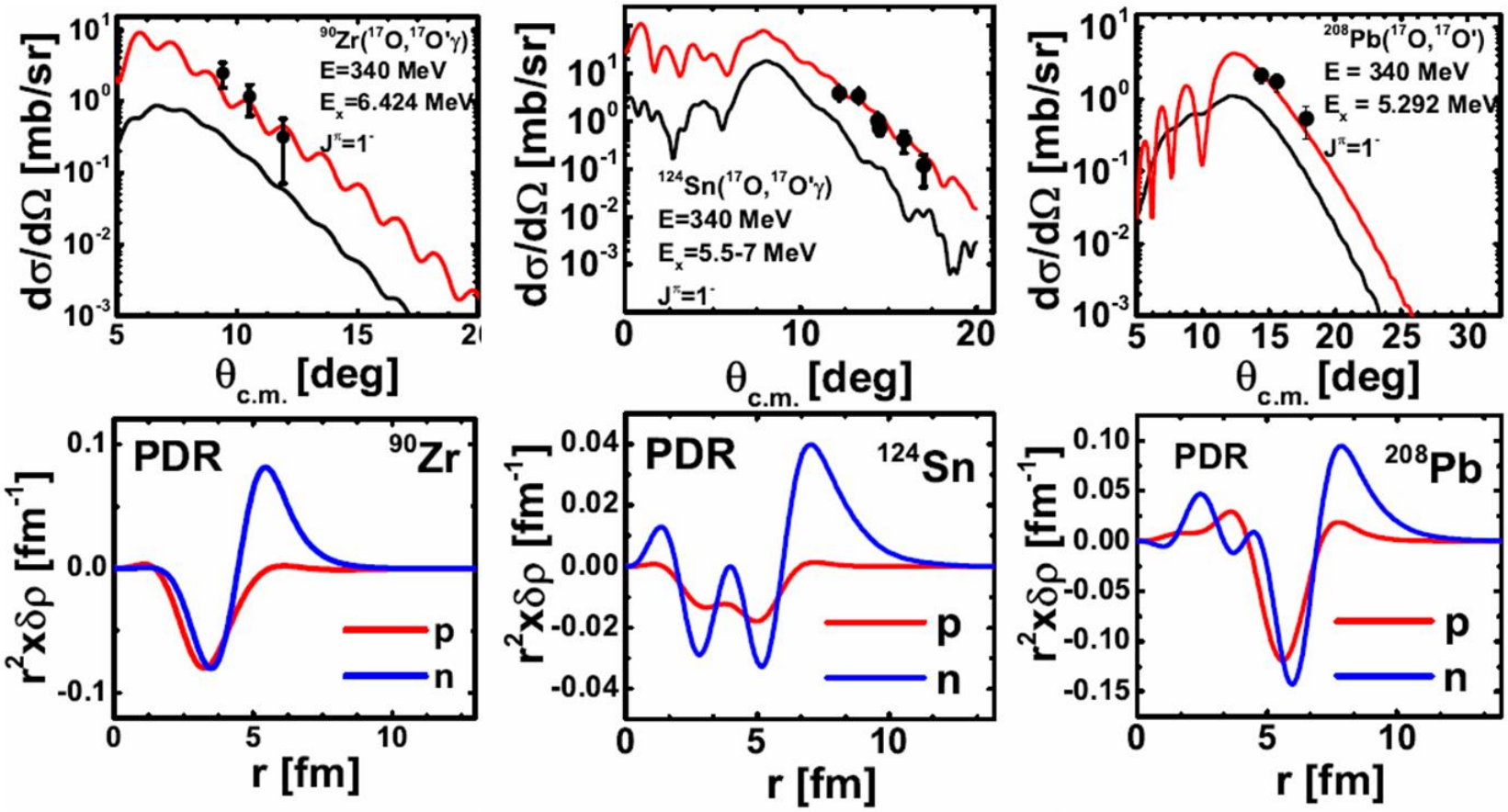
L. Pellegri, et al., PLB738 (2014)519





Results on the Low-Lying E1 Strength

- DWBA calculation were performed (red solid lines) using microscopic form factors based on the transition density associated to the E1 PDR states*

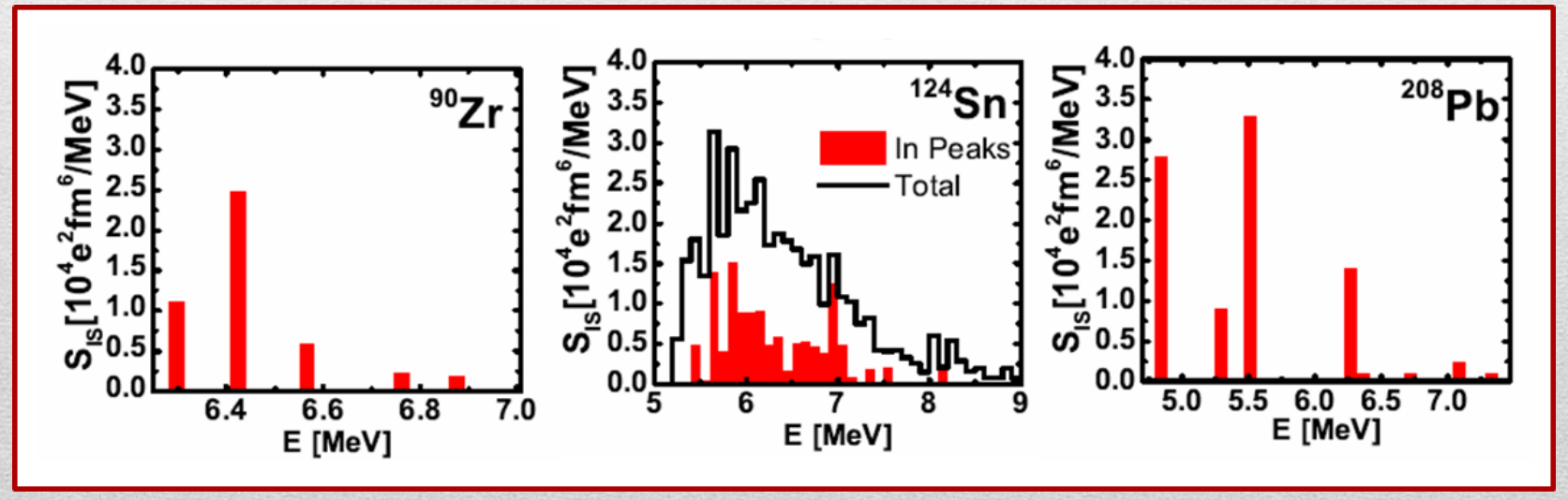


Calculated transition densities:
*(for 124Sn) E. Litvinova, et al., PRC 78 (2008)014312, **E.G. Lanza, et al.,PRC 89 (2014) 041601

The isoscalar strength in the pygmy region

The main objective of the data analysis was the extraction of the values of the isoscalar strength from the measured cross section

- The cross section has **two contributions**: one being the **Coulomb** and the other the **Nuclear** - *Isoscalar* –
- For the Coulomb contribution we fixed the value corresponding to the known B(E1)
- For the Nuclear contribution the reference value used was that associated to the microscopic form factor used, corresponding to a specific value of the isoscalar strength.



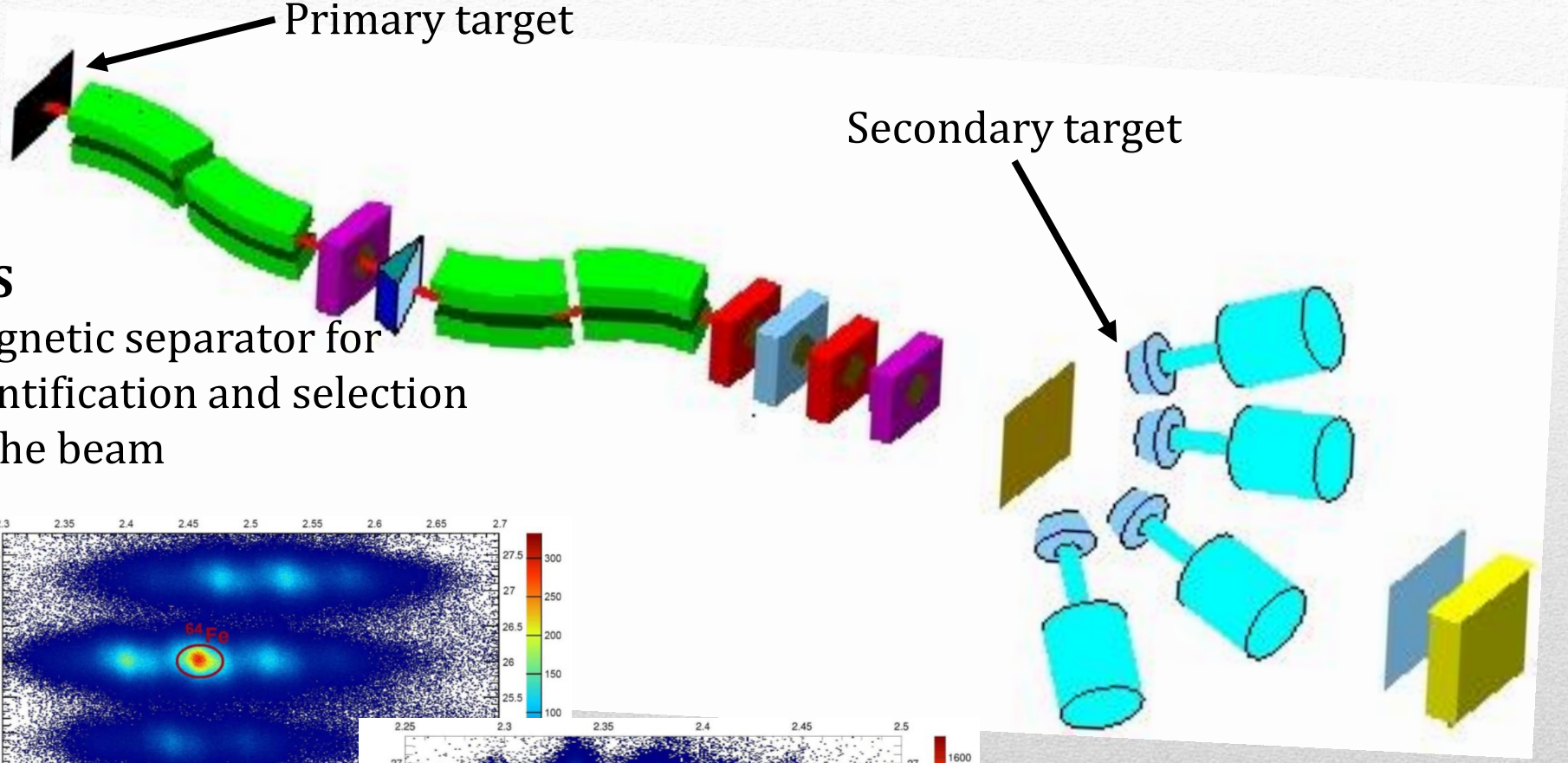
F.C.L. Crespi, et al., PRL113 (2014) 012501
L. Pellegri, et al., PLB738 (2014)519

F.C.L. Crespi et al, PRC 91 (2015) 024323
A. Bracco, F.C.L. Crespi and E.G. Lanza, EPJA (2015) 51: 99

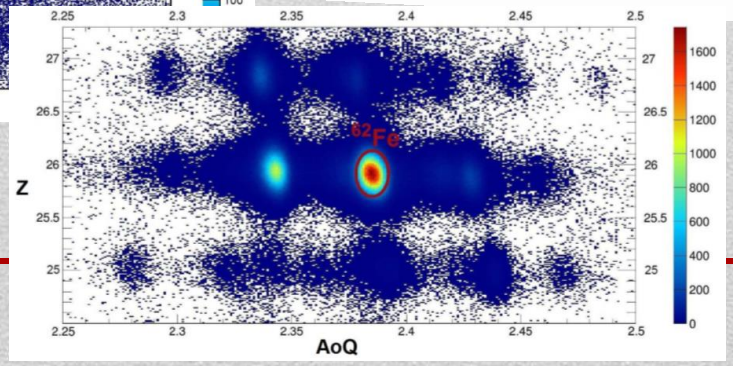
- **Isospin Properties of pygmy dipole states investigated using the (17O, 17O'γ) reaction at 340 MeV**
- Angular distributions measured both for the γ rays and the scattered ^{17}O ions
- The data analysis with the DWBA approach gives a good description of the elastic scattering and of the inelastic excitation of the low lying 2^+ and 3^- states
- For 1^- transitions a form factor obtained by folding a microscopically calculated transition density (PDR) allowed to reproduce the data remarkably well
  - *Extracted the isoscalar component of the 1^- excited states*

- **^{140}Ce target (→** M. Krzysiek talk)
- **Experiments at RCNP Osaka (PDR in ^{90}Zr,^{96}Zr) and CCB Cracow (GQR)**

Beam identification system

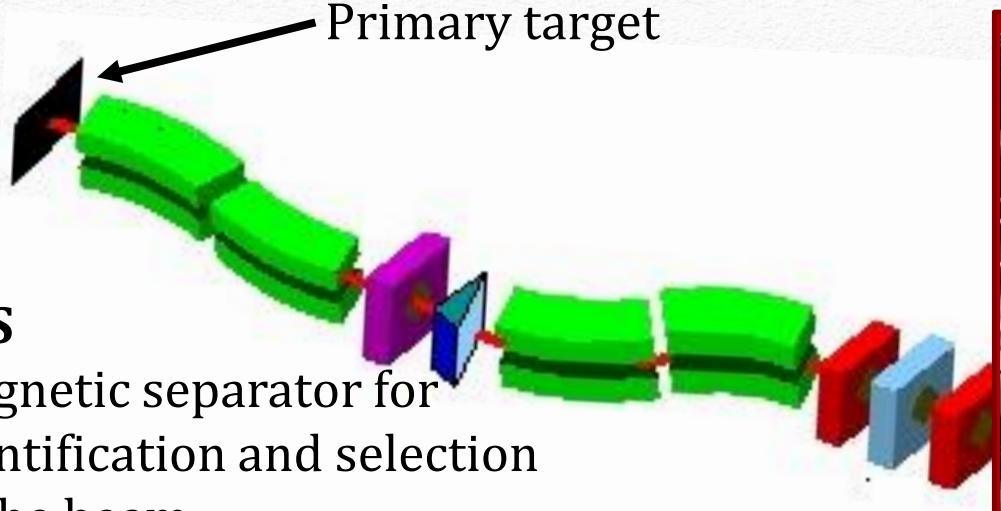


FRS
Magnetic separator for identification and selection of the beam



LYCCA
Ion tracking and E-ΔE telescopes to identify and track the ions on reaction target

Beam identification system



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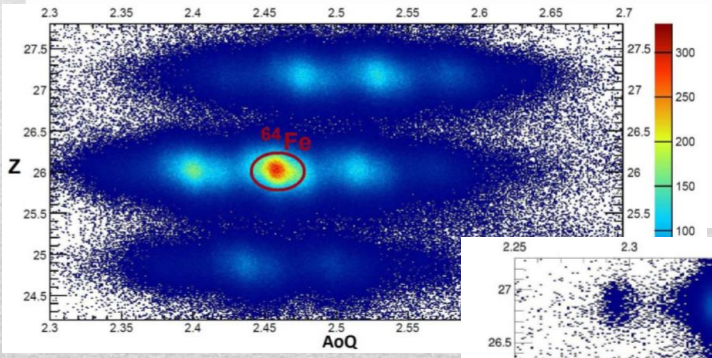
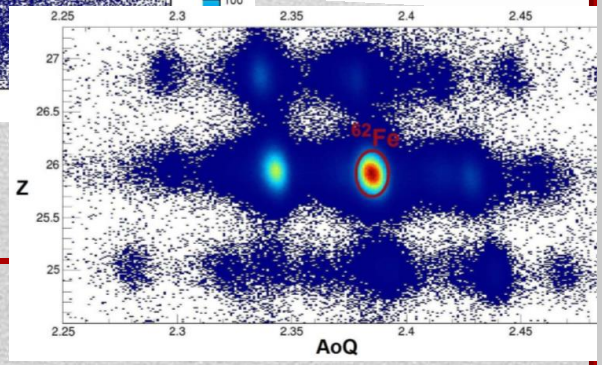
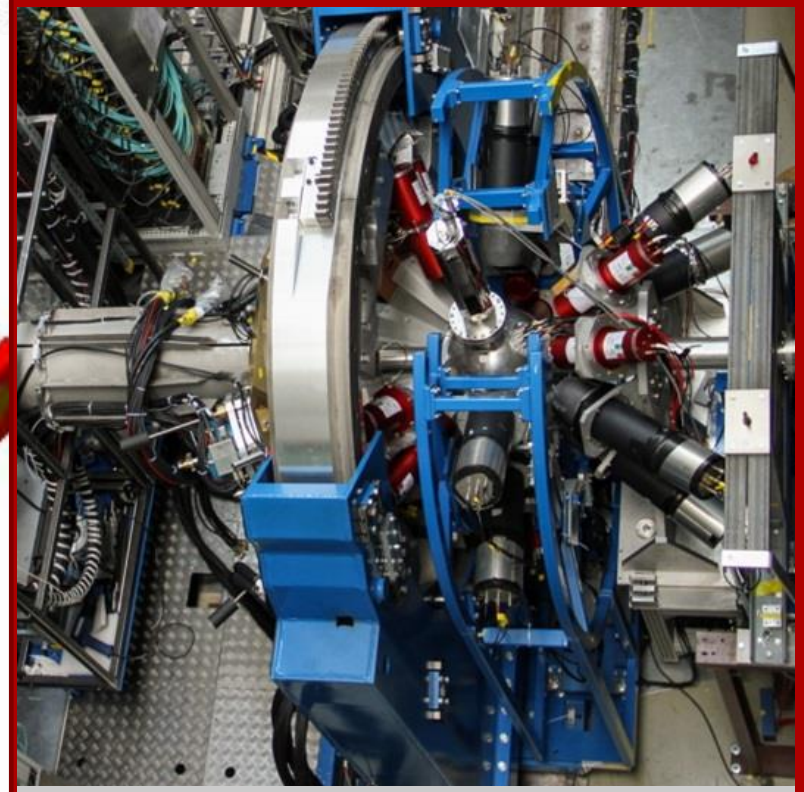


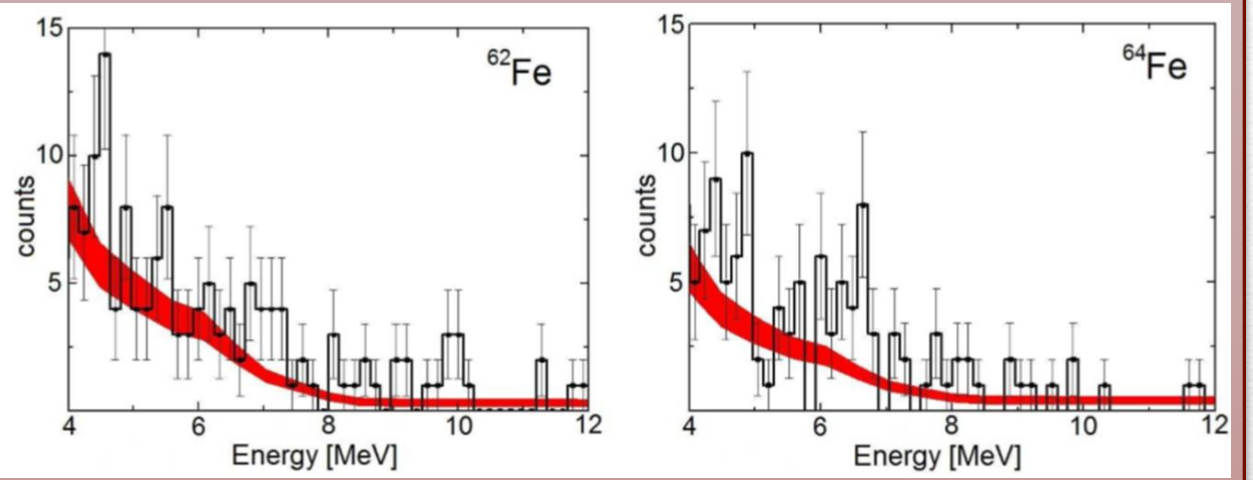




PreSPEC – AGATA setup @ GSI

Relativistic coulomb excitation of neutron rich Fe isotopes

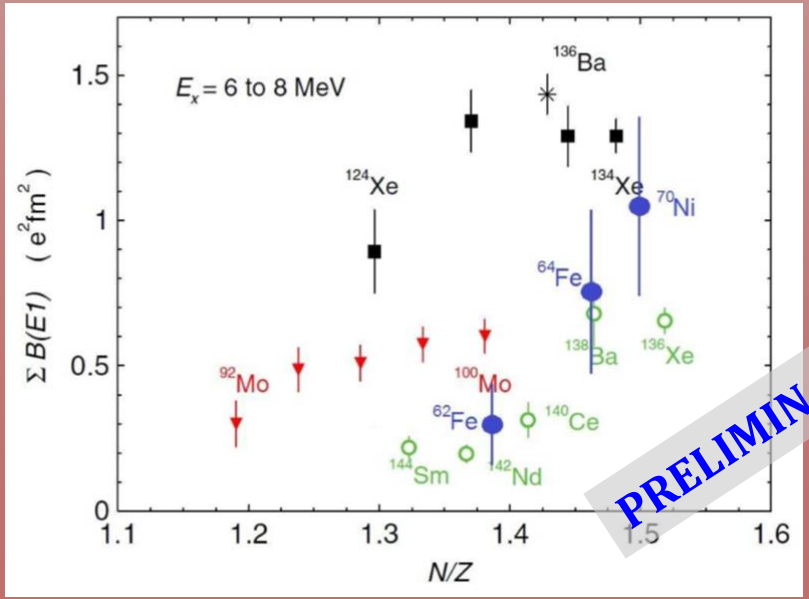
GDR GAMMA yield in experimental spectra



Comparison of summed B(E1)

B(E1) values were summed over the energy range 6-8 MeV and compared with the values of the nuclei avilable in literature:

R. Avigo PhD thesis



Test of the isospin symmetry via GDR γ-decay

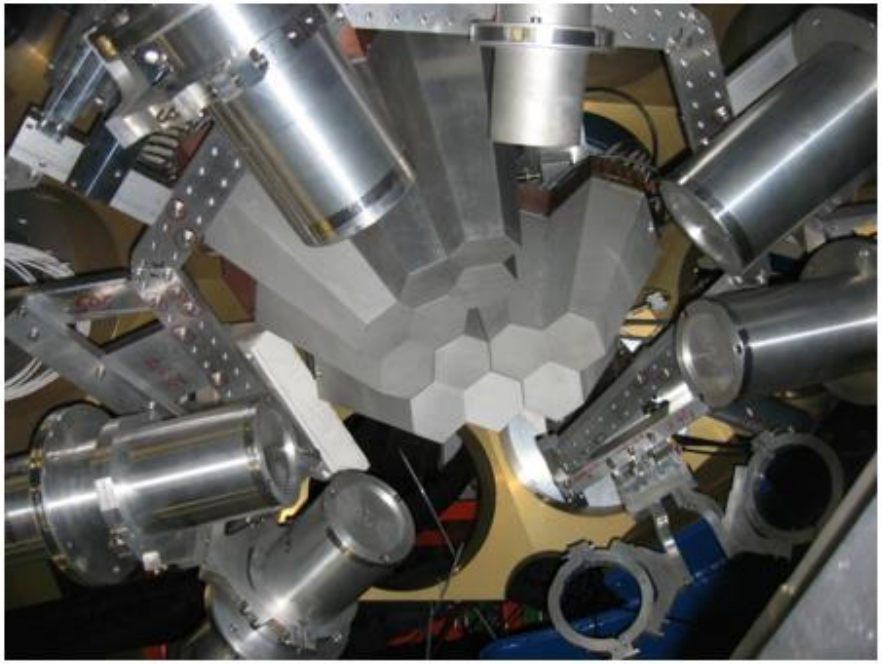
Isospin mixing in N=Z nucleus ^{80}Zr at medium temperature

(spokespersons A. Giaz, F. Camera Univ. Of Milan-INFN)

AGATA – HECTOR^{+} array @ LNL

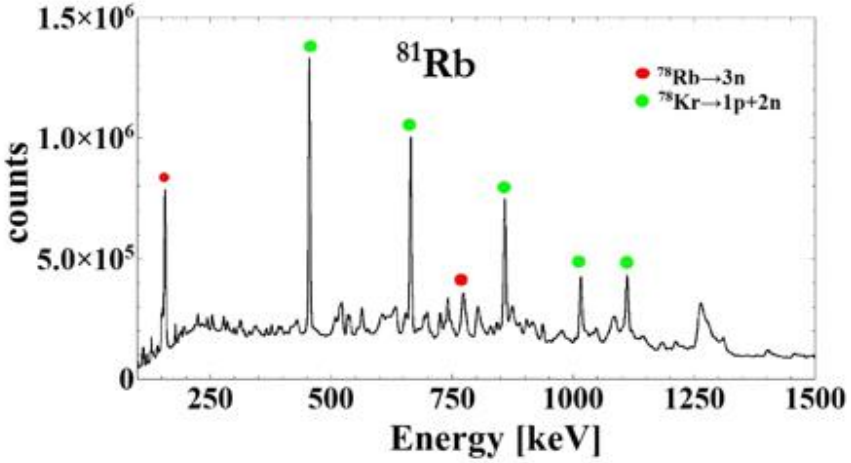
4 AGATA Clusters (12 capsules)

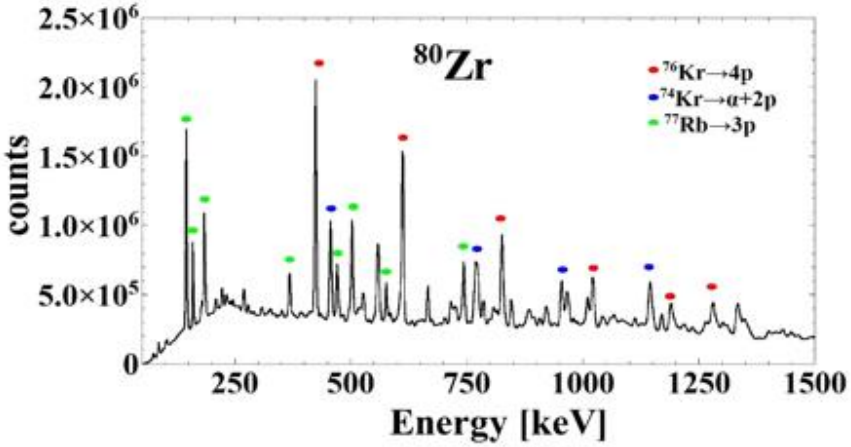
6 $LaBr_3$:Ce (3.5" x 8")



$E^* = 54$ MeV $T = 2$ MeV

With **AGATA** we identify the evaporation residues to tune statistical model

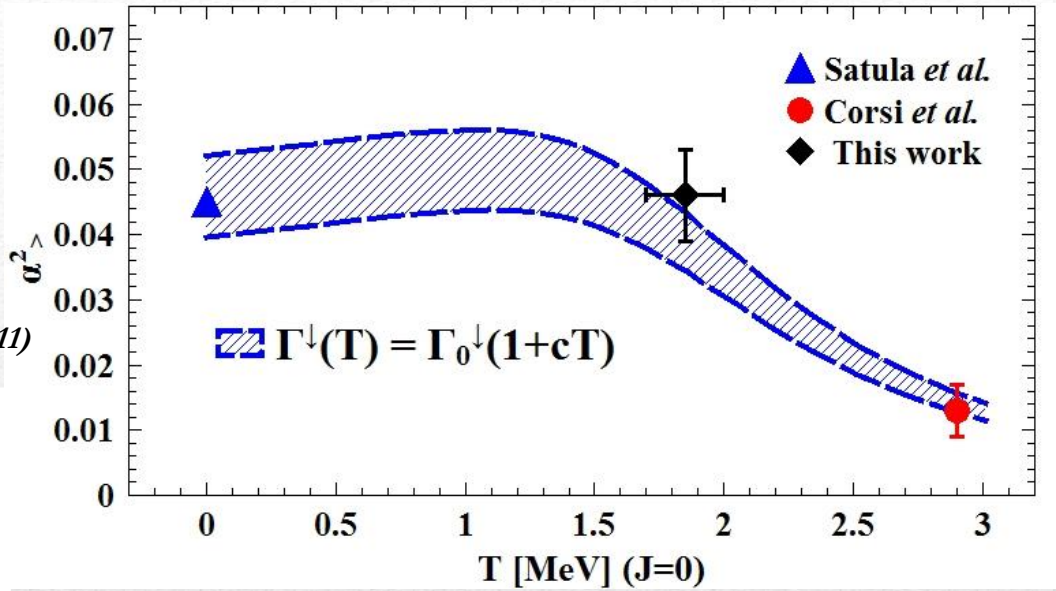




Test of the isospin symmetry via GDR γ-decay

[1] *Satula, Acta Phys.Polon. B42 (2011)*
[2] *A.Corsi et al. PRC 84, 041304(R) (2011)*

α^2 (T=0)=
0.046±0.009

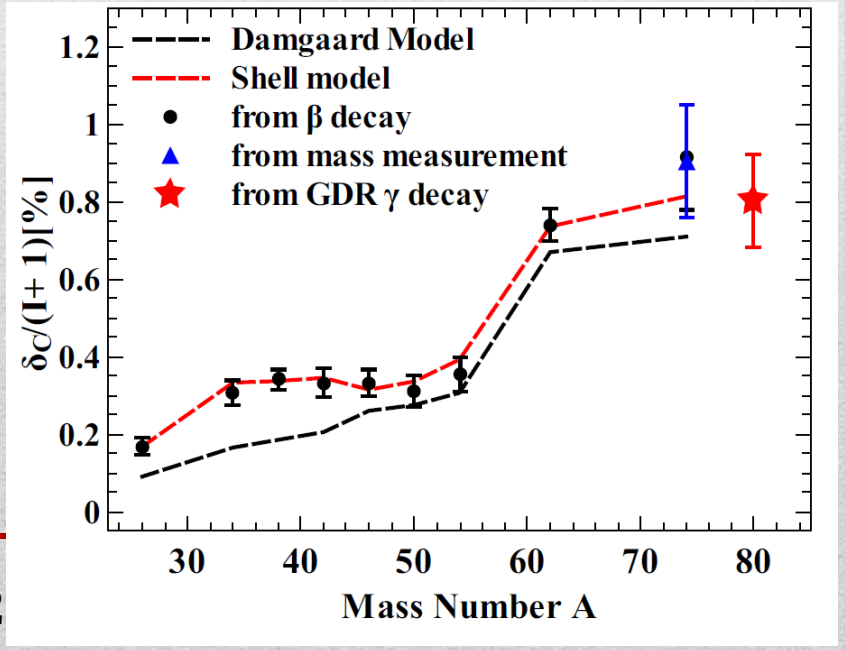


Beyond nuclear structure: CKM matrix

$$\delta_C = 4(I+1)\frac{V_1}{41\xi A^{2/3}}\alpha^2$$

Isospin mixing

- The δc term extracted from GDR is in good agreement both the experimental and theoretical trend

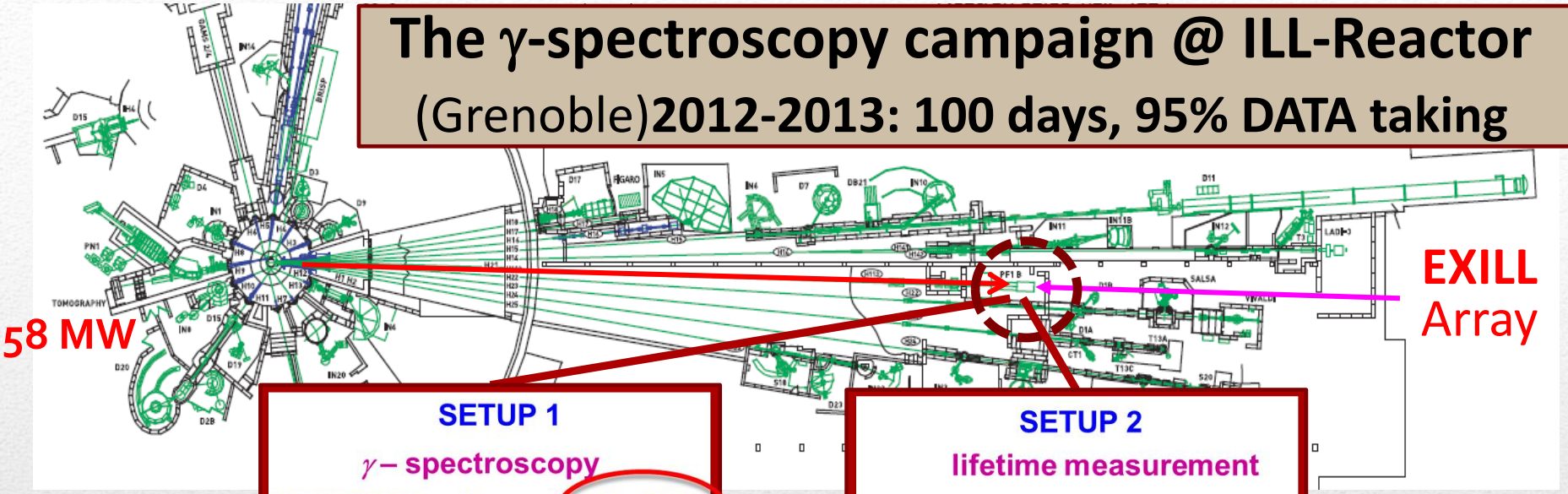


→ **S. Ceruti et al., PRL115 (2015) no.22, 222502**

EXILL: γ-Spectroscopy Around Doubly Magic Nuclei

The γ-spectroscopy campaign @ ILL-Reactor

(Grenoble)**2012-2013: 100 days, 95% DATA taking**

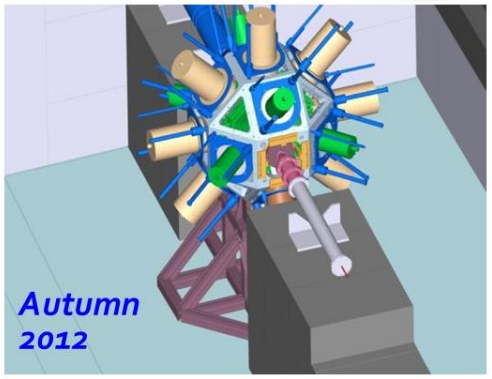


SETUP 1

γ – spectroscopy

10 EXOGAM – Clovers + 6 Ge GASP

6% efficiency

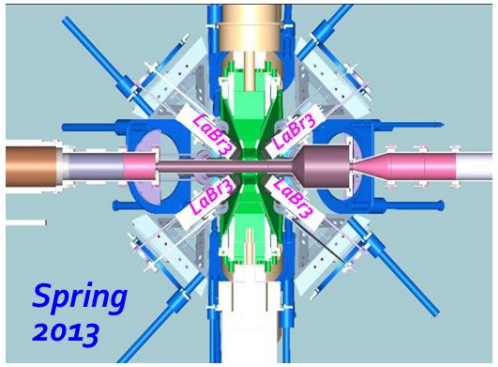


SETUP 2

lifetime measurement

8 EXOGAM – Clovers + 16 LaBr3

FATIMA ARRAY



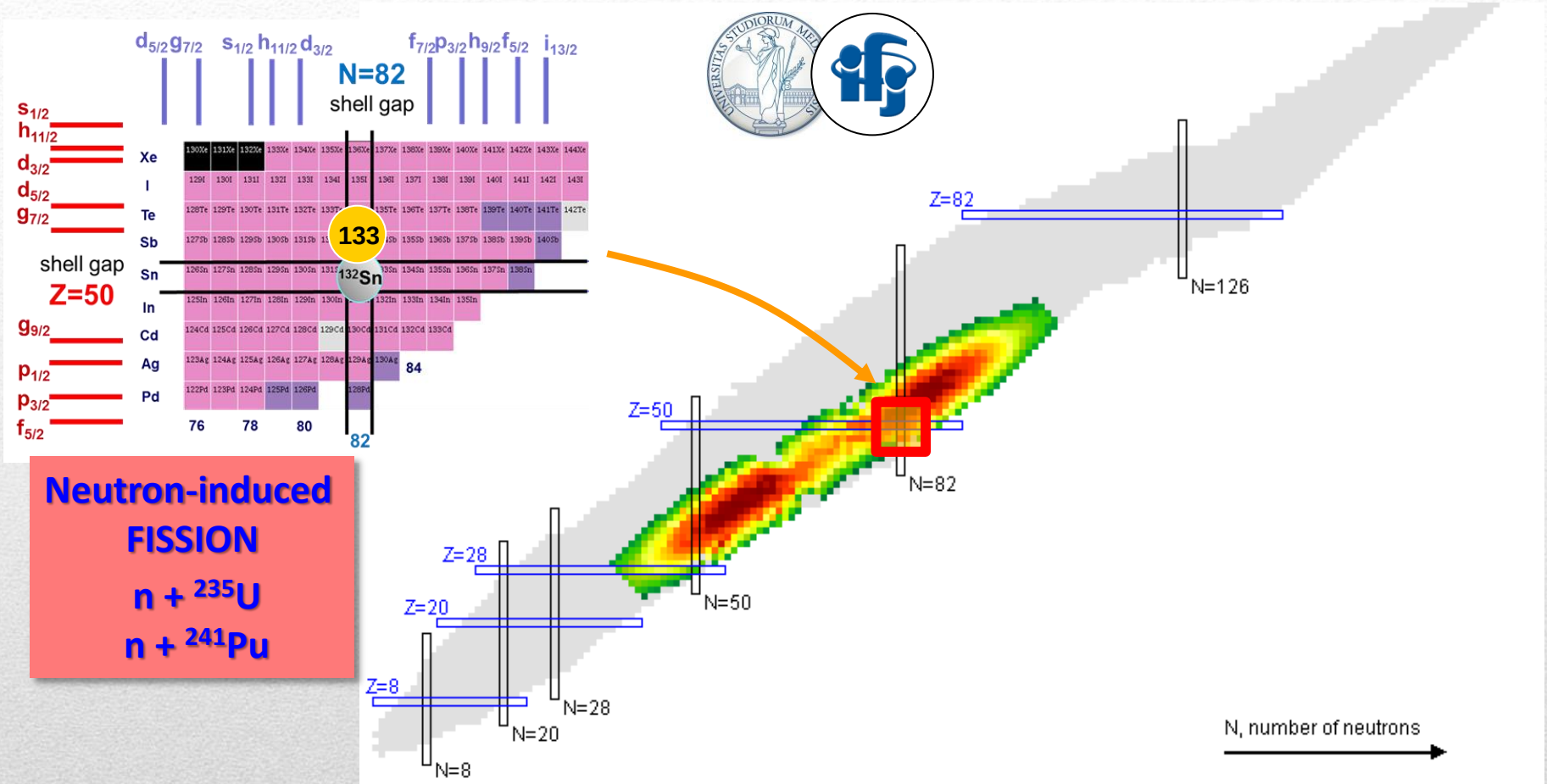
15 (n,γ) and cold-neutron induced **fission** on ^{235}**U** and ^{241}**Pu**

ACQUISITION SYSTEM :fully digital approach, TRIGGERLESS

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

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

EXILL: γ-Spectroscopy Around Doubly Magic Nuclei



Neutron-induced FISSION

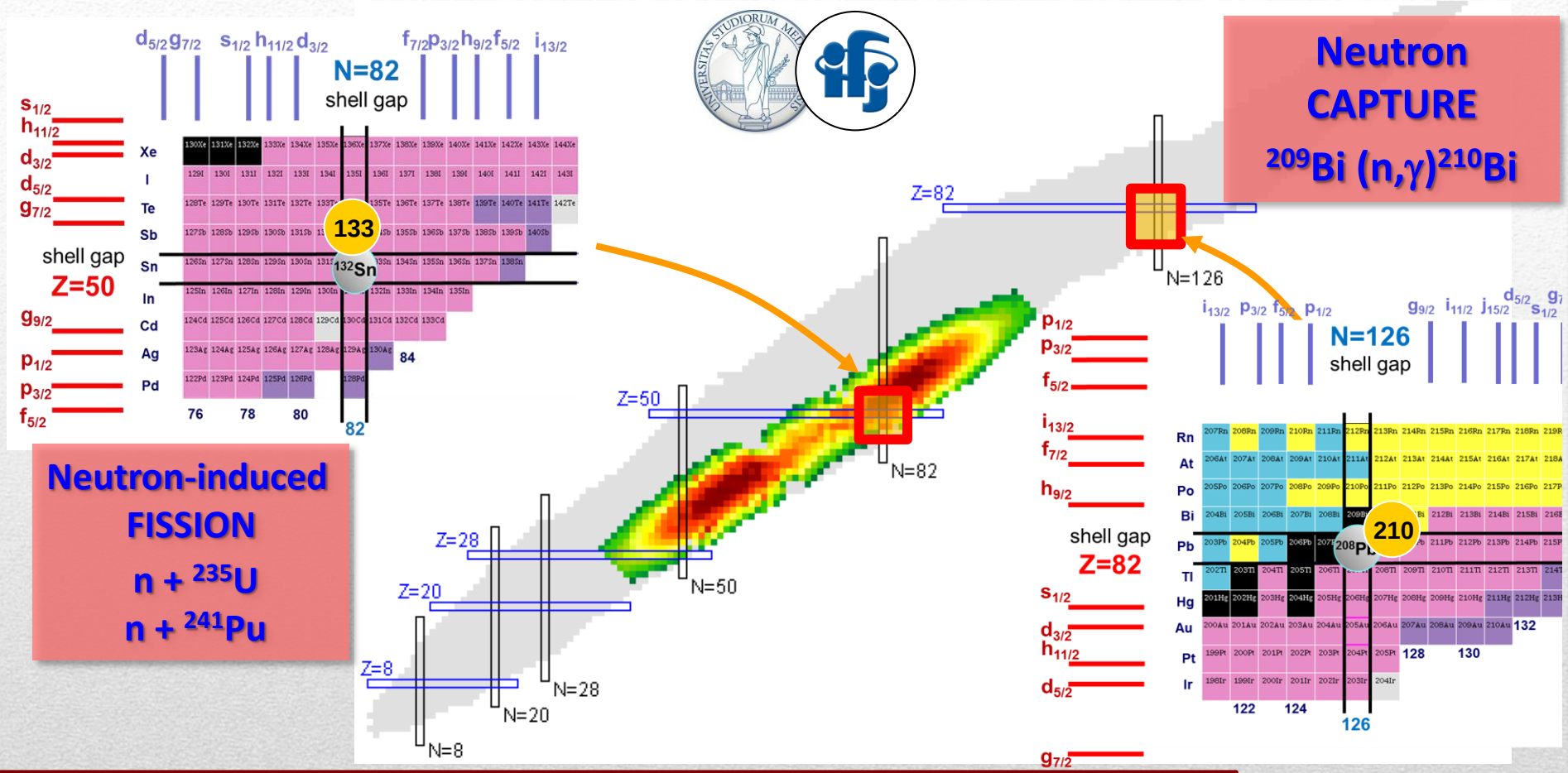
n + ^{235}U

n + ^{241}Pu

^{132}Sn – DOUBLE SHELL Closure away from stability **^{133}Sb**: ^{132}Sn + 1 π

G. Bocchi, S. Leoni , B. Fornal, … (Milano, Krakow)

EXILL: γ-Spectroscopy Around Doubly Magic Nuclei



Neutron CAPTURE

^{209}Bi (n,γ)^{210}Bi

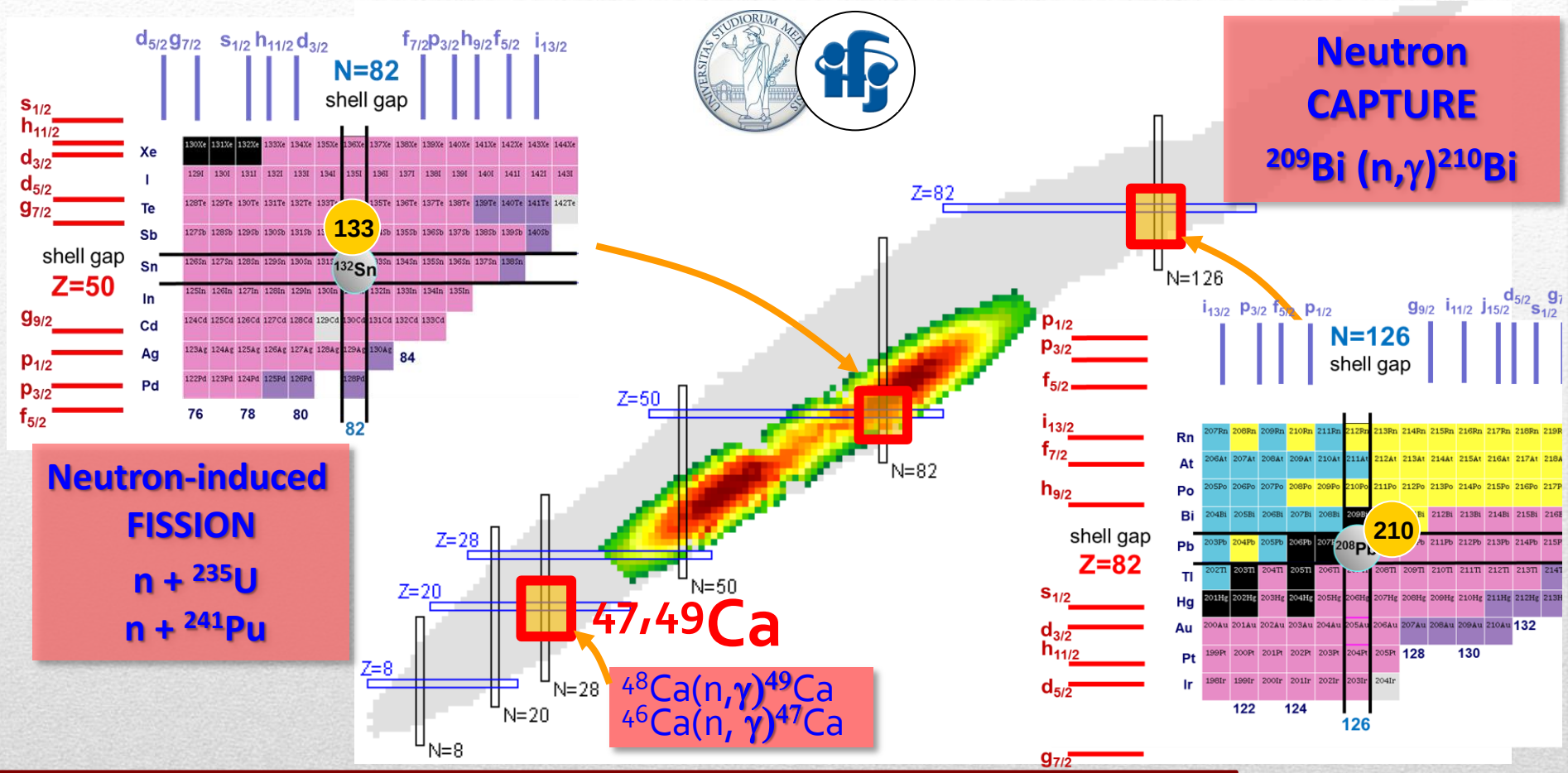
Neutron-induced FISSION

n + ^{235}U

n + ^{241}Pu

^{132}Sn – DOUBLE SHELL Closure away from stability **^{133}Sb**: ^{132}Sn + 1 π	G. Bocchi, S. Leoni , B. Fornal, … (Milano, Krakow)
^{210}Bi: ^{208}Pb + 1 π + 1 ν	N. Cieplicka, B. Fornal, S. Leoni, … (Milano, Krakow)

EXILL: γ-Spectroscopy Around Doubly Magic Nuclei



^{132}**Sn** – DOUBLE SHELL Closure away from stability ^{133}**Sb**: ^{132}Sn + 1 π	G. Bocchi, S. Leoni , B. Fornal, … (Milano, Krakow)
^{210}**Bi**: ^{208}Pb + 1 π + 1 ν	N. Cieplicka, B. Fornal, S. Leoni, … (Milano, Krakow)

^{49}**Ca,** ^{47}**Ca** (core +/- 1 nucleon)

Y isotopes (shape transitions)→ **L. Iskra talk**

EXILL: γ-Spectroscopy Around Doubly Magic Nuclei

Prompt-delayed coincidences
over μs time range

FEEDING of the ISOMER up to 25/2+

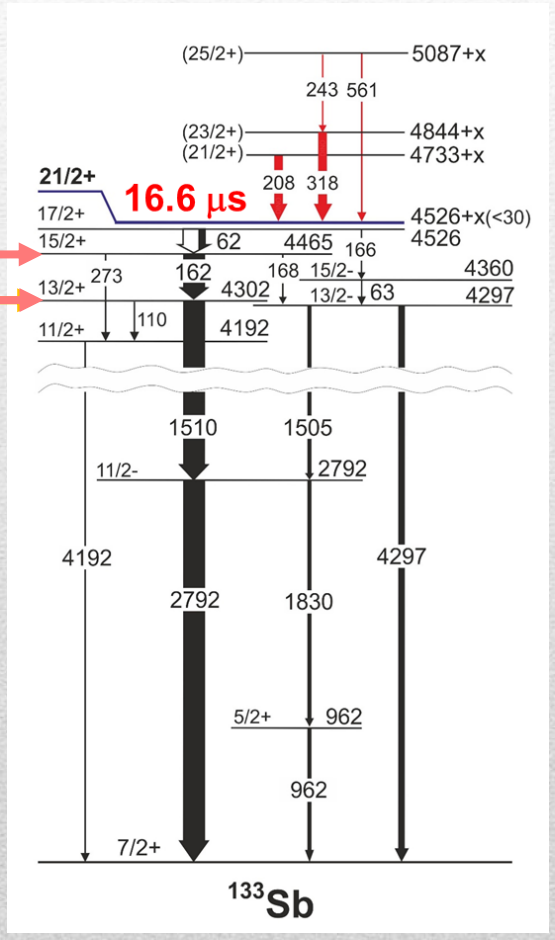
From Lifetimes

B(M1) [W.u.]

0.24

0.004

Not Simple Configurations



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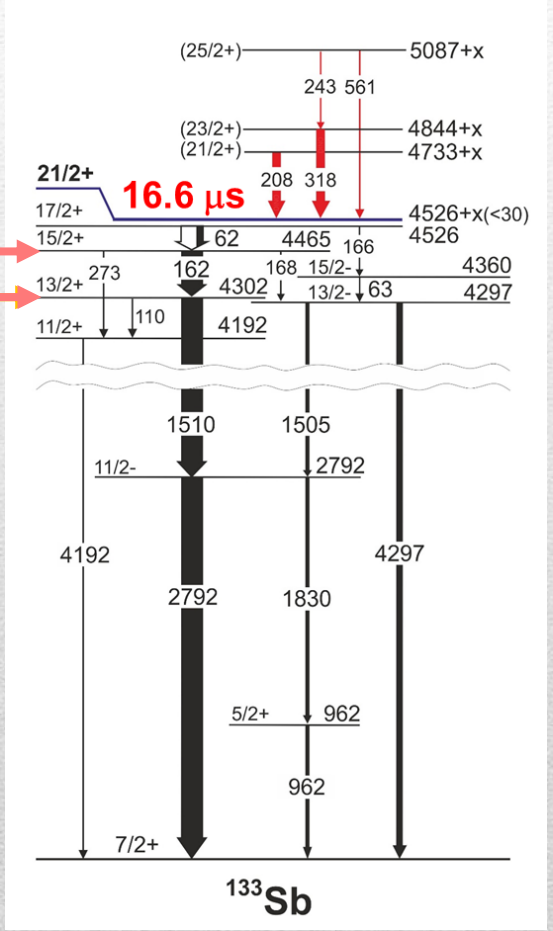
0.004

Not Simple Configurations

SHELL Model Calculations NOT possible:

Too Large Space !!



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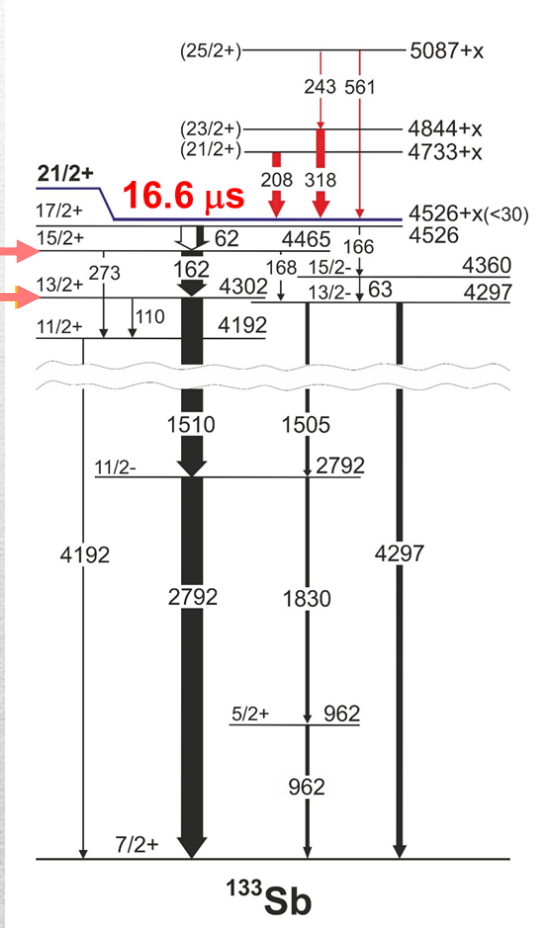
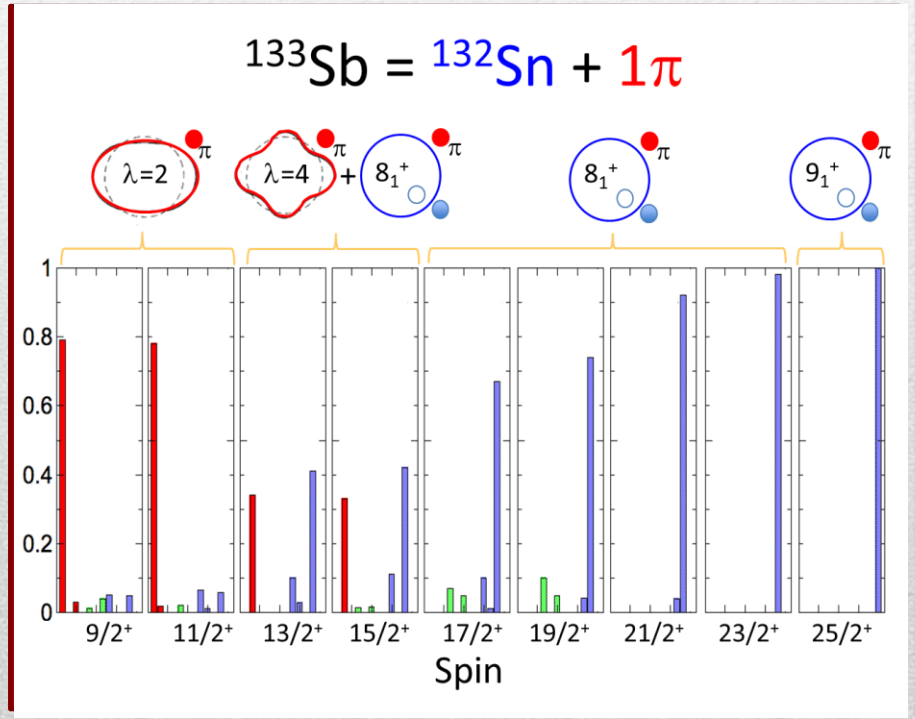


The New "HYBRID" Model

(G. Colò, P.F. Bortignon - Milano)

^{133}Sb -MAIN Results

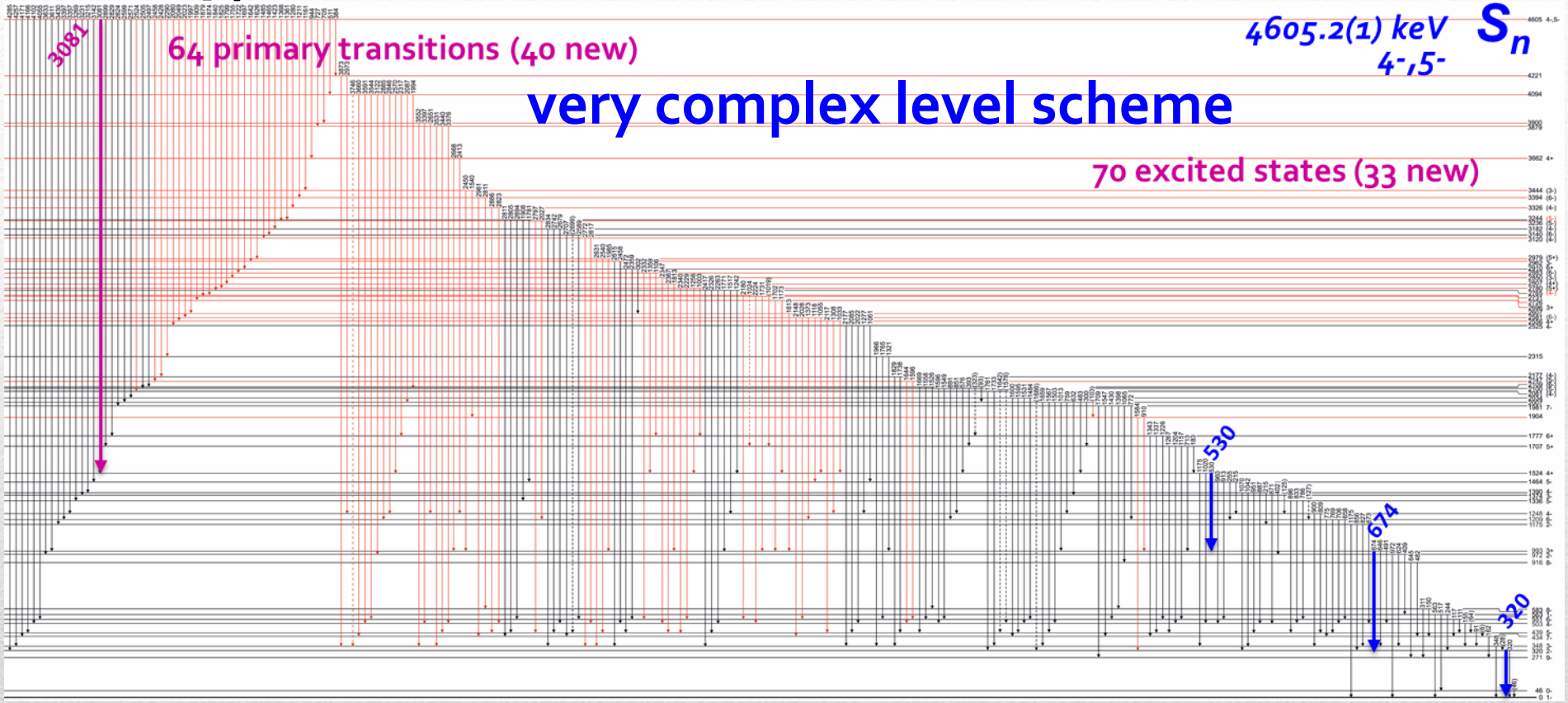
Core excitations with RPA
Coupling with single particle states



EXILL: γ-Spectroscopy Around DOUBLY MAGIC Nuclei

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

N. Cieplicka, B. Fornal, S. Leoni, … (Milano, Krakow)



Complete Low Spin Spectroscopy of ^{210}Bi

Comparison with SHELL Model

$^{208}Pb + 1\pi + 1\nu$

frozen CORE

12 Low-Spin States

2 < E < 3 MeV

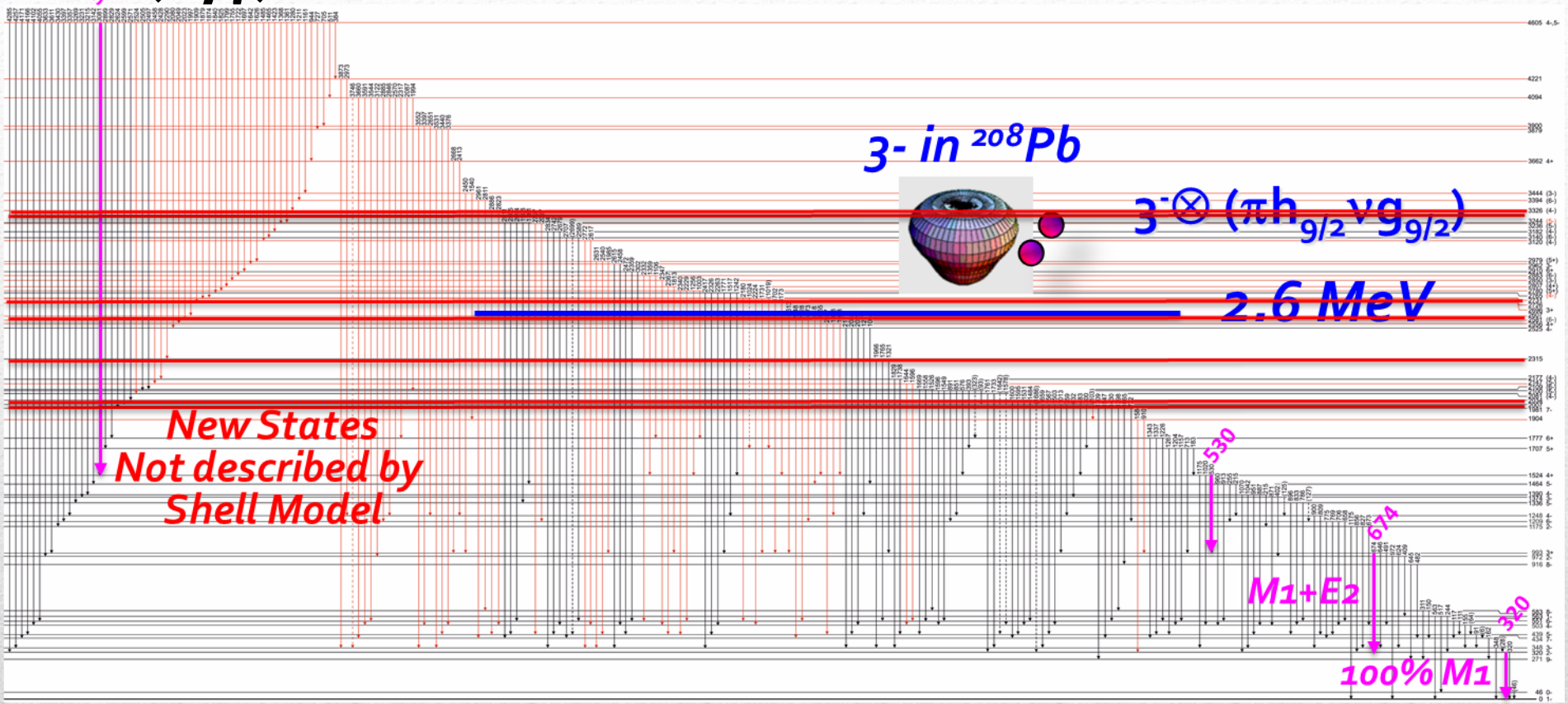
VALENCE Particles

NOT described by **SHELL Model**

EXILL: γ-Spectroscopy Around DOUBLY MAGIC Nuclei

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

N. Cieplicka, B. Fornal, S. Leoni, … (Milano, Krakow)



Complete Low Spin Spectroscopy of ^{210}Bi

Comparison with SHELL Model

$^{208}Pb + 1\pi + 1\nu$

frozen **12** Low-Spin States — VALENCE Particles

CORE — $2 < E < 3$ MeV

NOT described by **SHELL Model**

Couplings with **CORE Excitations ?**

$E_x(3^-) = 2.6$ MeV,

$B(E3) = 34$ W.u.

New Hybrid Model?

Review of Selected Experiments on Collective Modes via Gamma Spectroscopy

- Gamma decay of PDR states from inelastic scattering of ions and virtual photon scattering
- Isospin mixing and GDR γ-decay
- EXILL: γ-Spectroscopy Around Doubly Magic Nuclei

➢ strong collaboration between Milano and Cracow groups!

… the efforts of a large collaboration

Milano University and INFN

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