

Struttura nucleare ai LNL tramite spettroscopia γ

... verso SPES

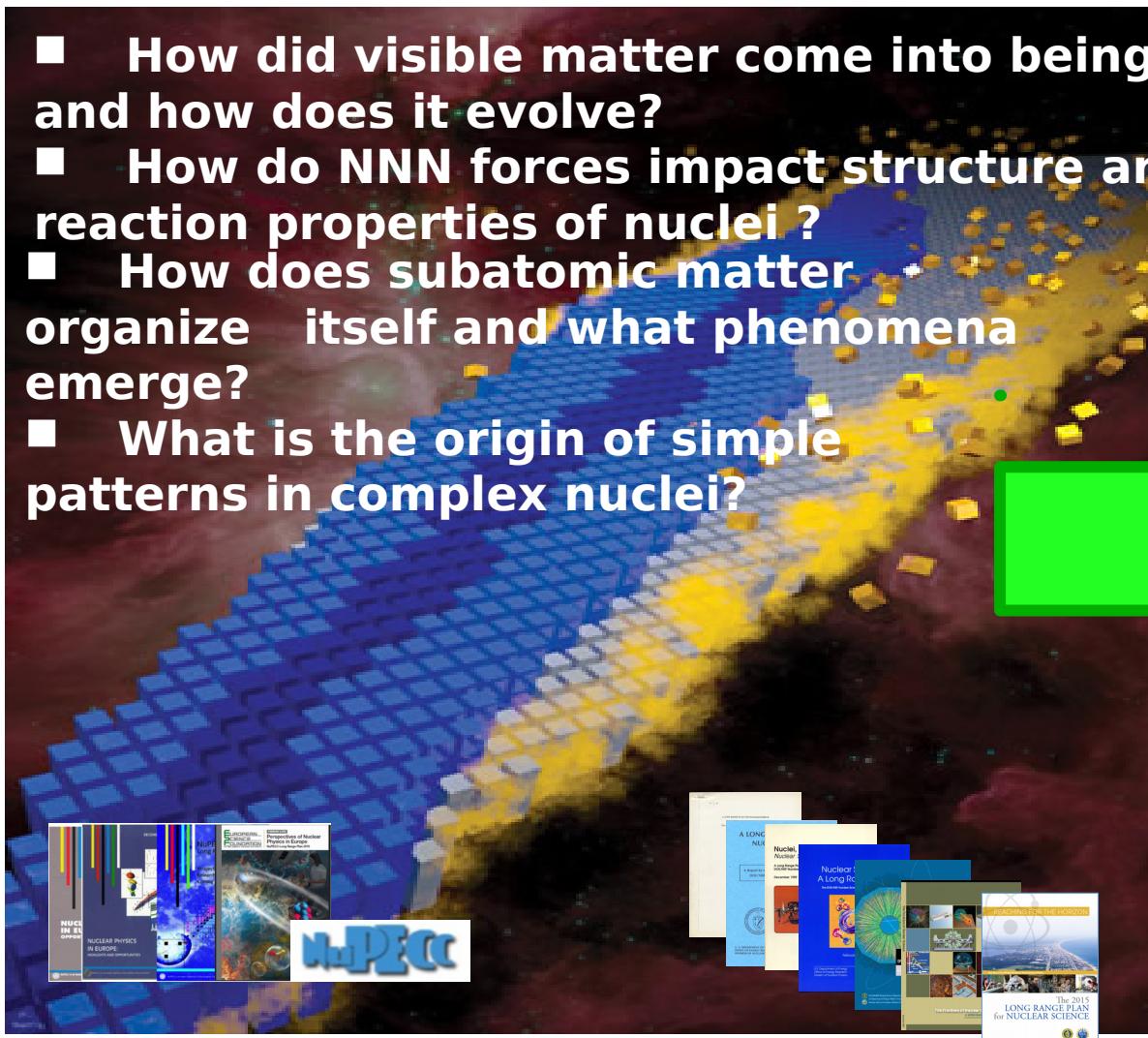
Daniele Mengoni

Università e INFN, Padova, Italia



Nuclear physics at the frontier

- How did visible matter come into being and how does it evolve?
- How do NNN forces impact structure and reaction properties of nuclei ?
- How does subatomic matter organize itself and what phenomena emerge?
- What is the origin of simple patterns in complex nuclei?



Nuclear Physics ladder: bridge between the “smallest” and the “largest”

Astronomical observations

Astrophysical simulations

Stellar nucleosynthesis

Stellar explosions

Nuclear structure and reactions observables

- Experiments
- Theoretical calculations

Large Scale
Shell Model

Energy Density
Functionals

No Core
Shell Model

Coupled
cluster method

Fermionic
Molecular
Dynamics

...

Phenomenological nuclear interactions

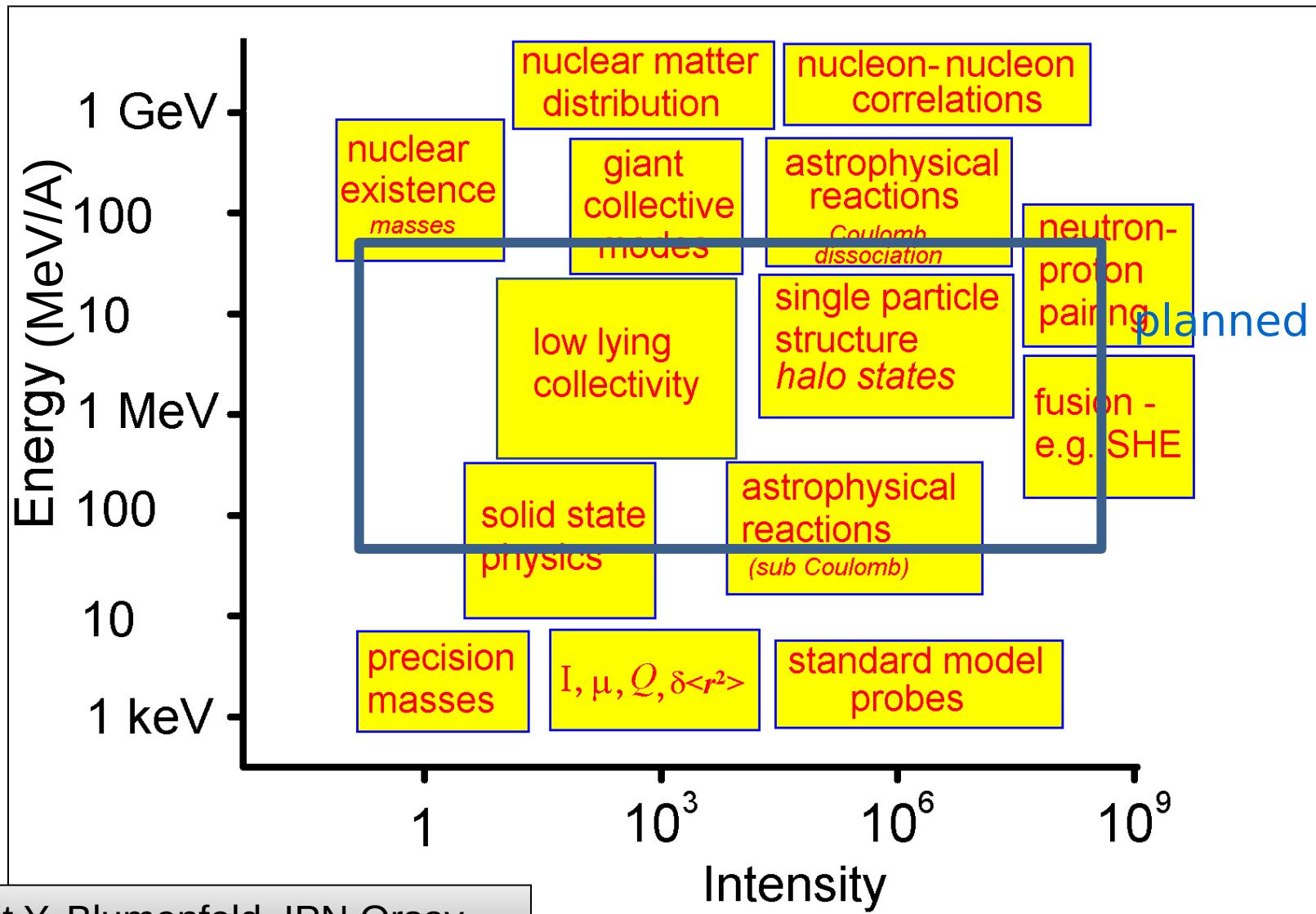
Unitary Transformations (SRG, UCOM, ...)

Chiral Effective Field Theory

Low energy QCD

Courtesy T. Rodriguez

RIB Physics Reach



The nuclear many-body problem

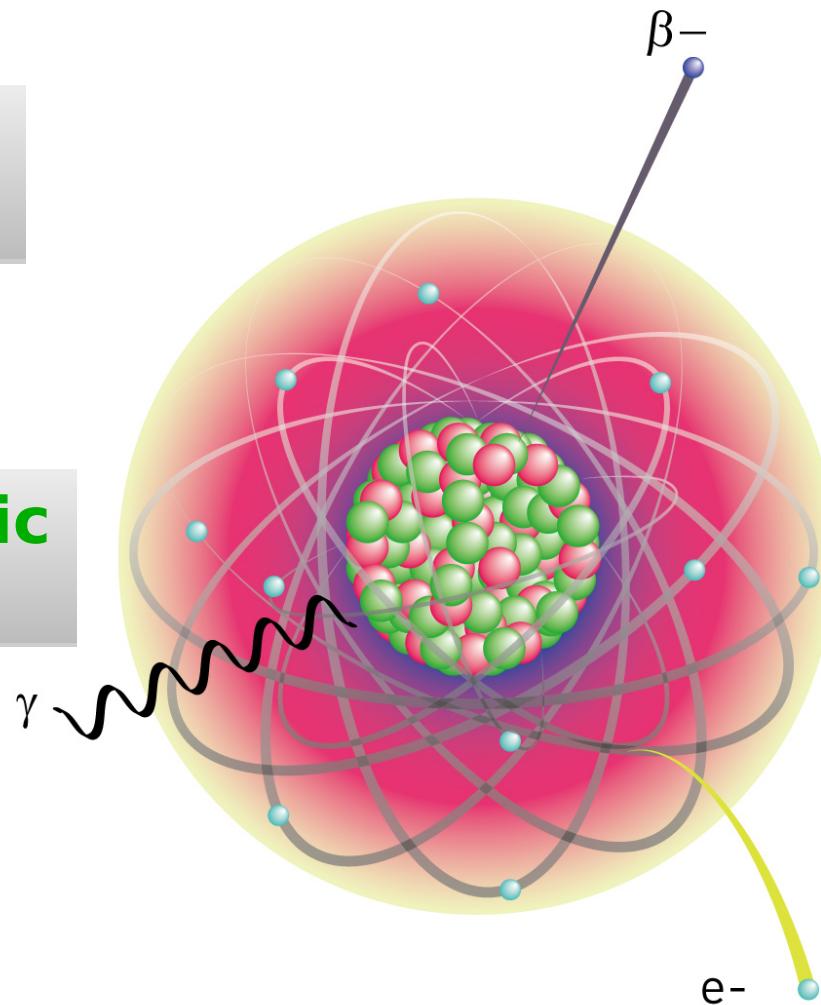
Nuclear
moments

Spectroscopic
factors

J^π

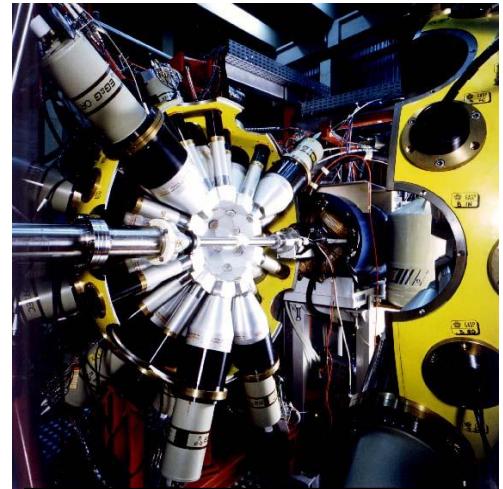
γ energy

Transition
probability:
 $B(M1), B(E2), \dots$



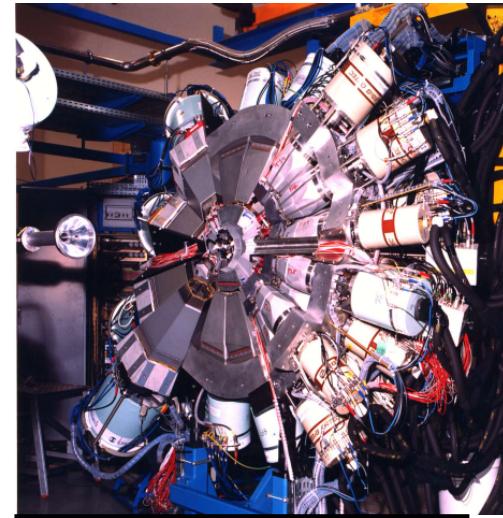
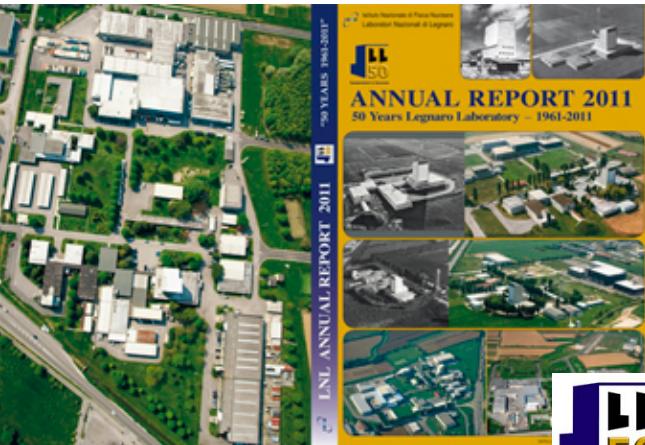
Nuclei are many-body quantal systems consisting on many nucleons, up to 300, resulting on a rich variety of quantum phenomena.

γ -ray spectroscopy at LNL

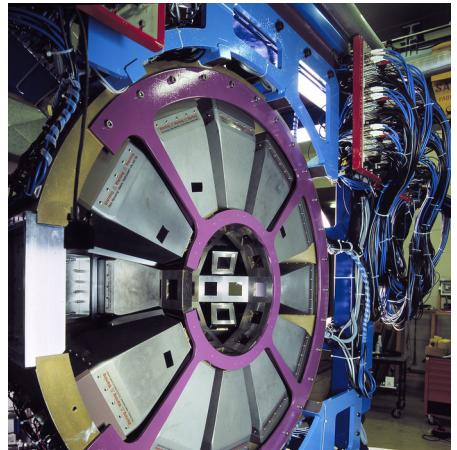


GASP 1992

- 80% nuclear physics research
- 50% γ -ray spectroscopy
- Proton- and neutron-rich nuclei



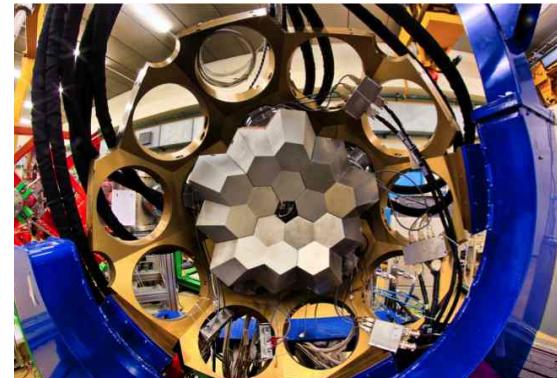
EUROBALL 1998



CLARA 2004



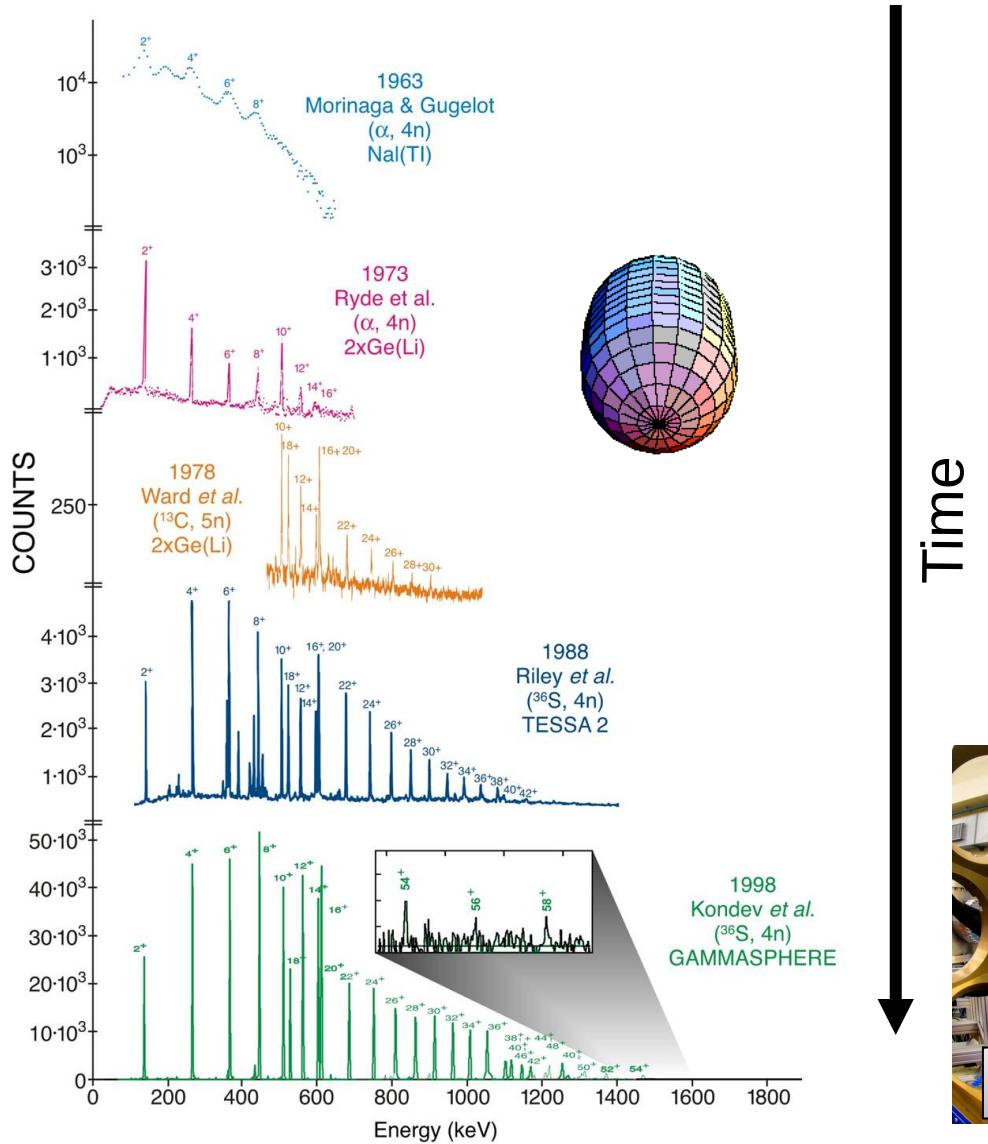
2015 - ...



AGATA 2008 → 2019..

Evolution of the γ spectrometers

History of the spectroscopy: Rotational band of ^{156}Dy



The technical development has allowed us to reach a deeper understanding of the nucleus.





THIRD INTERNATIONAL SPES WORKSHOP



OCTOBER 10-12, 2016

LABORATORI NAZIONALI DI LEGNARO (PADOVA), ITALY



Dipartimento
di Fisica
e Astronomia
Galileo Galilei

UNDER THE PATRONAGE OF



UNIVERSITÀ
DEGLI STUDI
DI PADOVA

ORGANIZING COMMITTEE

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S. LENZI	PADOVA
S. PIRRONI	CATANIA
G. POLLAROLO	TORINO
G. PRETE	LEGNARO

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J.J. VALIENTE DOBÓN	LEGNARO
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D. MENGONI	PADOVA
D.R. NAPOLI	LEGNARO
F. RECCIA	PADOVA
A. VITTURI	PADOVA

CONFERENCE SECRETARIES

ANNA D'ESTE	INFN LNL
ADRIANA SCHIAVON	UNIVERSITY OF PADOVA

CONTACT

SPES2016@NL-INFN.IT
HTTP://AGENDA-INFN.IT/EVENT/SPES2016



LABORATORI NAZIONALI DI LEGNARO
VIALE DELL'UNIVERSITÀ 2,
35020 LEGNARO PD - ITALY



THE VALE OF VILLAVICENNE, STAINED BY M. DANIELE, COURTESY OF TURIN MINISTRY OF CULTURAL HERITAGE AND TOURISM, PROTO REGIONALE DEL VENETO AND MEDIEQUA BENEDETTO



THIRD INTERNATIONAL SPES WORKSHOP



OCTOBER 10-12, 2016

LABORATORI NAZIONALI DI LEGNARO (PADOVA), ITALY

42 LoI presented from around the world

■ GS properties

■ moments

■ Coulex

■ DirReac with ActiveTarget

■ DirReac with Si

■ Mn transfer

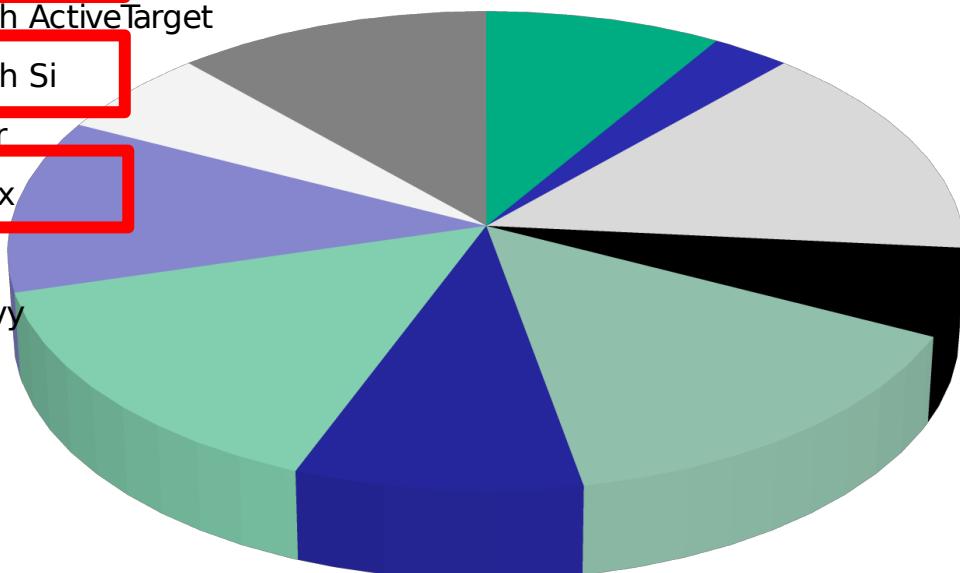
■ Collective ex

■ Fusion

Super Heavy

■ Dymamics

SPES LOIs Topics



Shell
evolution

Collective
modes



Shell evolution
Spettroscopia γ

A microscopic image showing the internal structure of a shell, likely a mollusk, displaying various growth layers and mineral inclusions. The image is overlaid with white text.

© MICRO
COSMO

The new magic number N=40

VOLUME 74, NUMBER 6

PHYSICAL REVIEW LETTERS

6 FEBRUARY 1995

$N = 40$ Neutron Subshell Closure in the ^{68}Ni Nucleus

R. Broda, B. Fornal, W. Królas, and T. Pawłat

H. Niewodniczański Institute of Nuclear Physics, PL-31-342 Kraków, Poland

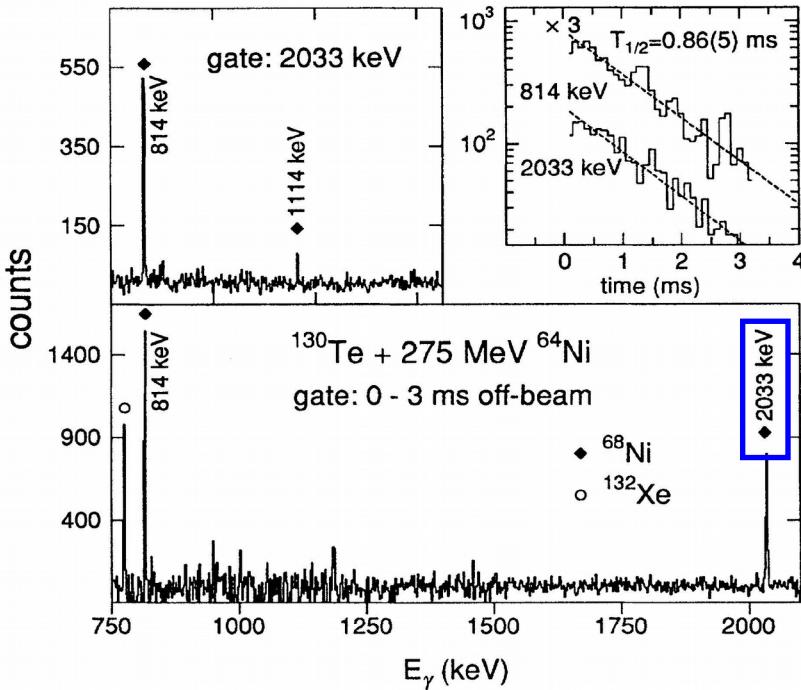
D. Bazzacco, S. Lunardi, C. Rossi-Alvarez, and R. Menegazzo

Dipartimento di Fisica dell'Università di Padova and INFN, I-35131 Padova, Italy

G. de Angelis, P. Bednarczyk, J. Rico, and D. De Acuña
INFN Laboratori Nazionali di Legnaro, I-35020 Legnaro, Italy

P. J. Daly, R. H. Mayer, and M. Sferrazza
Chemistry Department, Purdue University, West Lafayette, Indiana 47907

H. Grawe, K. H. Maier, and R. Schubart
Hahn-Meitner-Institut Berlin, D-14109 Berlin, Germany
(Received 28 June 1994)



GASP (Legnaro) 1995

The increase of the ^{68}Ni 2^+ excitation energy indicates a significant shell closure at N=40

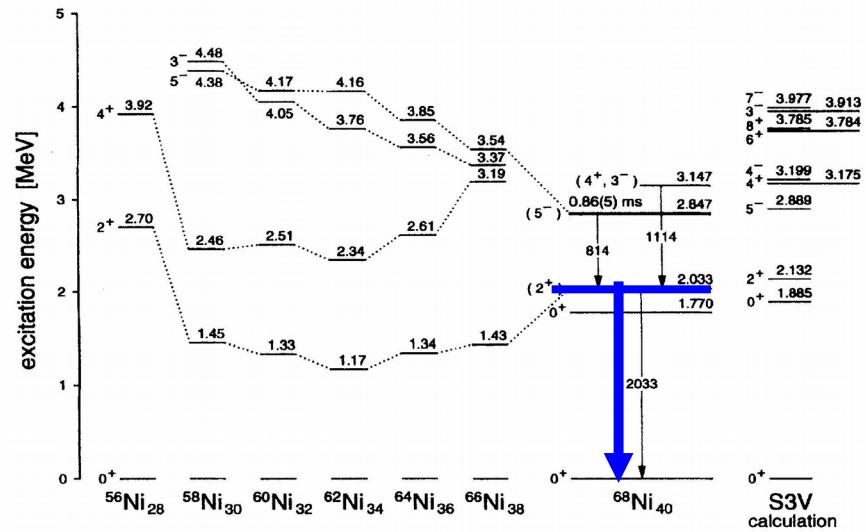
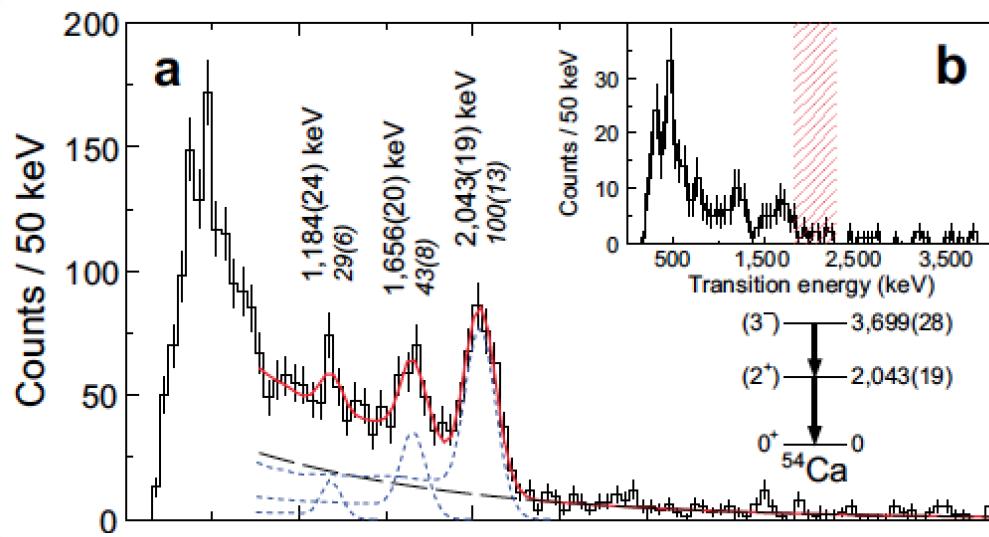
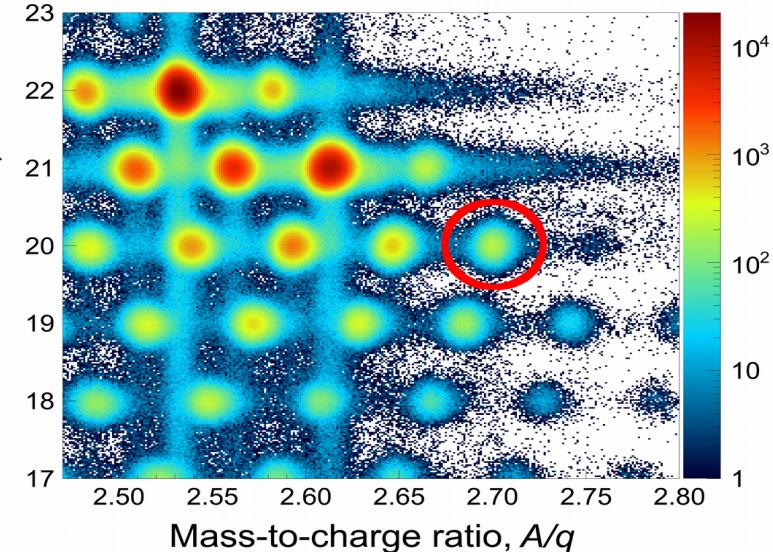


FIG. 3. Systematics of selected states in even Ni isotopes. The ^{68}Ni results are prominently displayed and compared with the S3V shell model calculations (see text).

Evidence for a new nuclear ‘magic number’ from the level structure of ^{54}Ca

D. Steppenbeck¹, S. Takeuchi², N. Aoi³, P. Doornenbal², M. Matsushita¹, H. Wang², H. Baba², N. Fukuda², S. Go¹, M. Honma⁴, J. Lee², K. Matsu⁵, S. Michimasa¹, T. Motobayashi², D. Nishimura⁶, T. Otsuka^{1,5}, H. Sakurai^{2,5}, Y. Shiga⁷, P.-A. Söderström⁸, T. Sumikama⁸, H. Suzuki², R. Taniguchi⁵, Y. Utsuno⁹, J. J. Valiente-Dobón¹⁰ & K. Yoneda²

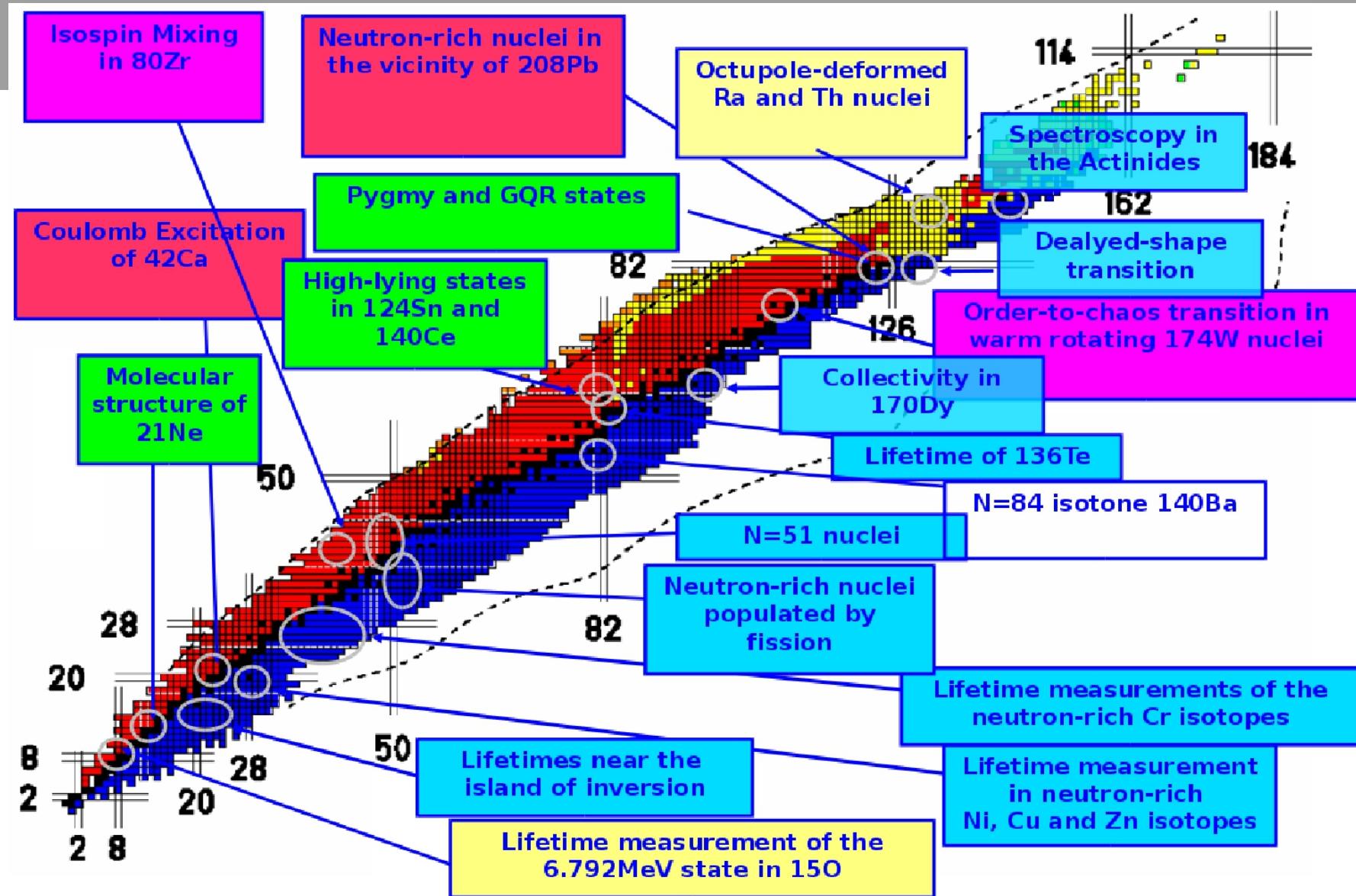




Struttura nucleare alla frontiera Spettroscopia γ a tracciamento

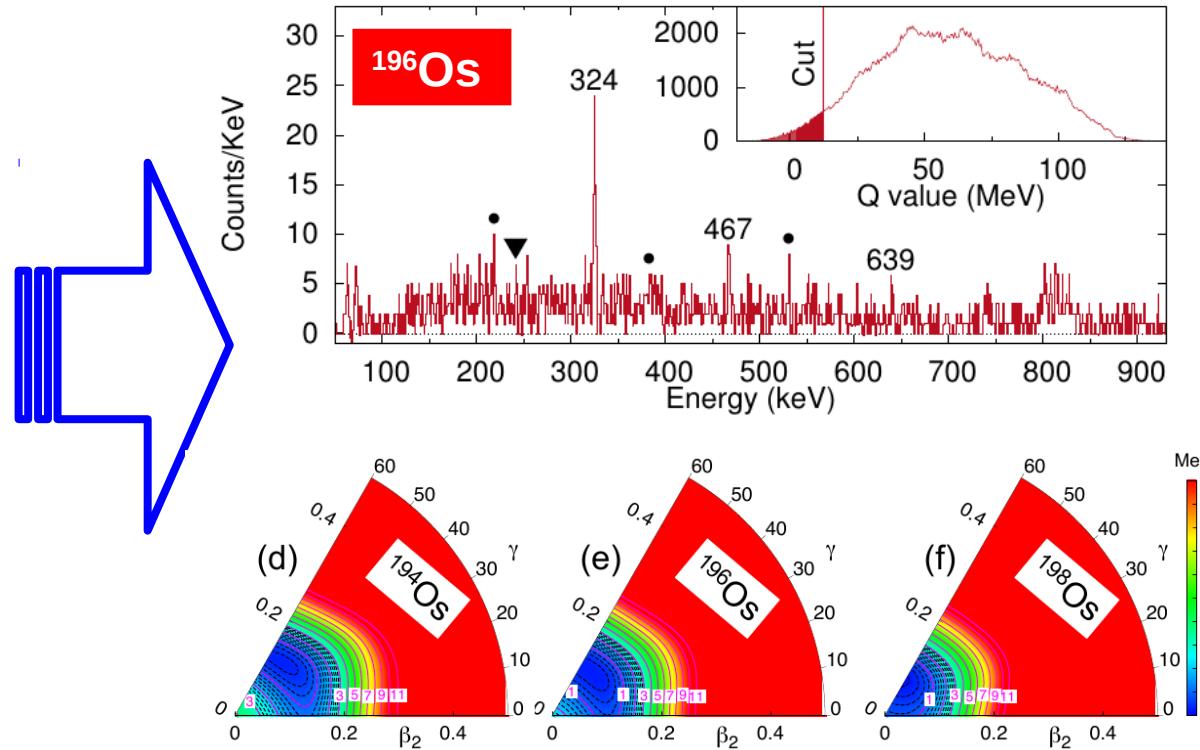
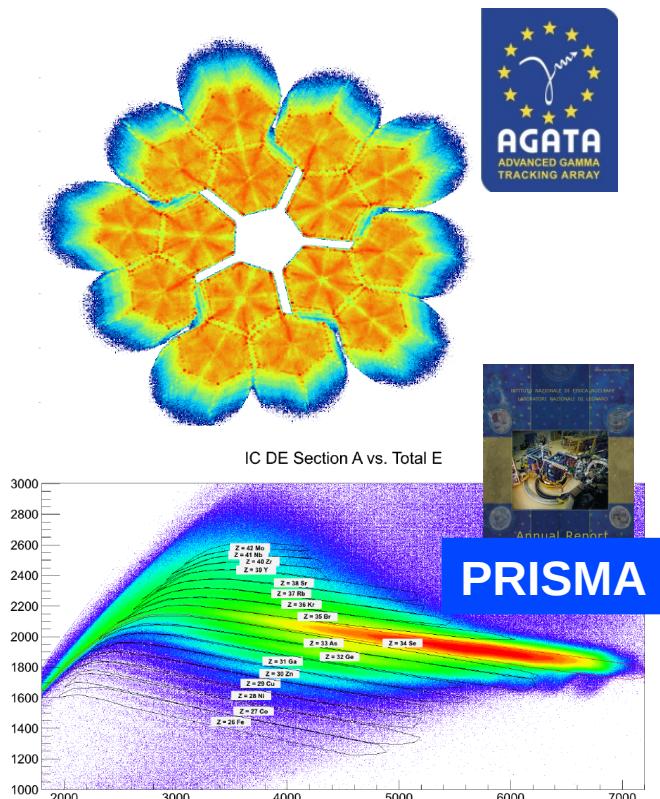


LNL EXPERIMENTS: 20 exps, 148 days, 3500 hs



More than 20 pub. Out of the physics campaign, and counting ...

... one example for shell evolution/shape deformation

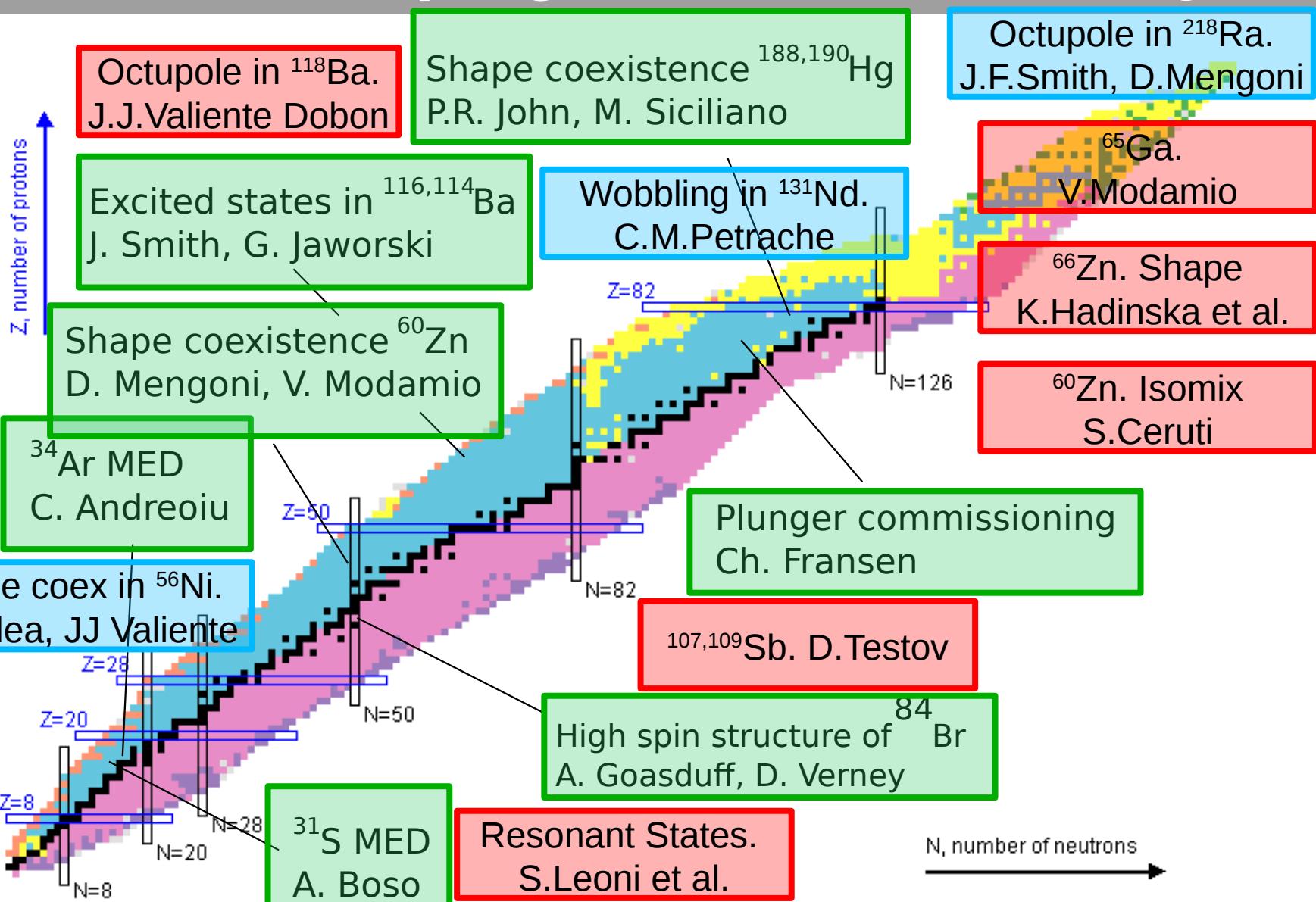


- Yrast band measured for the first time
- $E(4^+)/E(2^+)$ close to 2.5 (γ -soft nucleus)



- 25 HPGe
- 25 BGO shields
- 240 digital channels

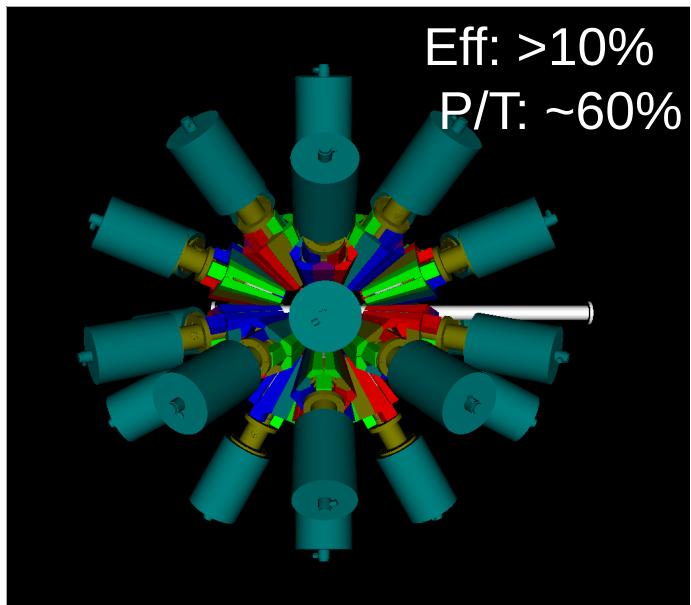
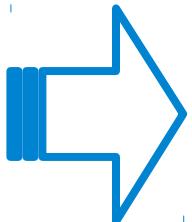
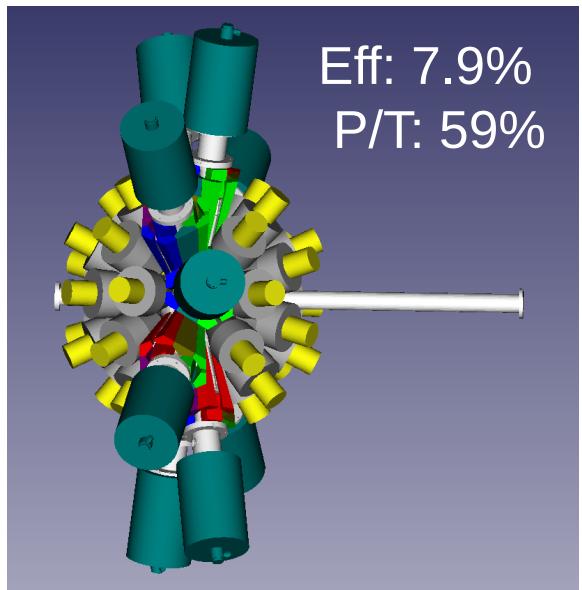
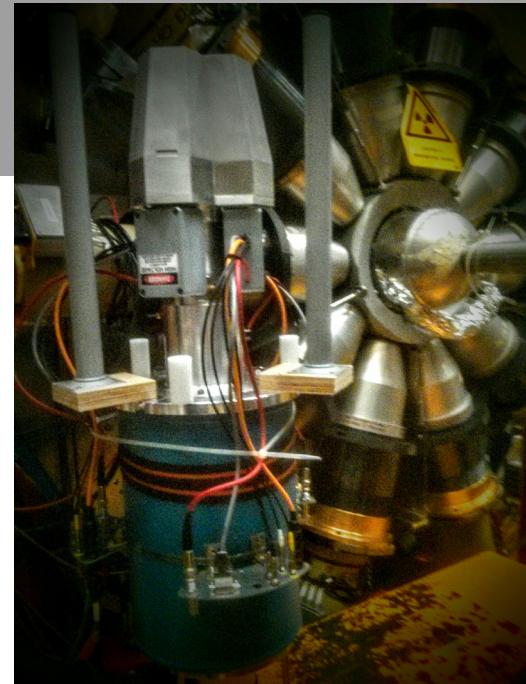
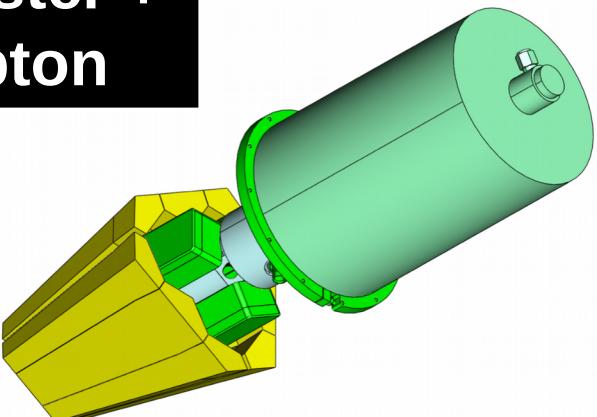
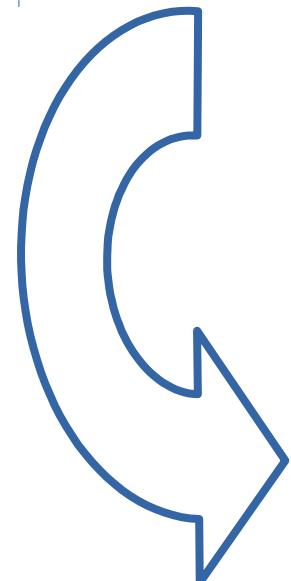
Science Campaign: Fall 2015 - today



GALILEO – phase 1 → 2 → 3



**Triple Cluster +
Anticompton**



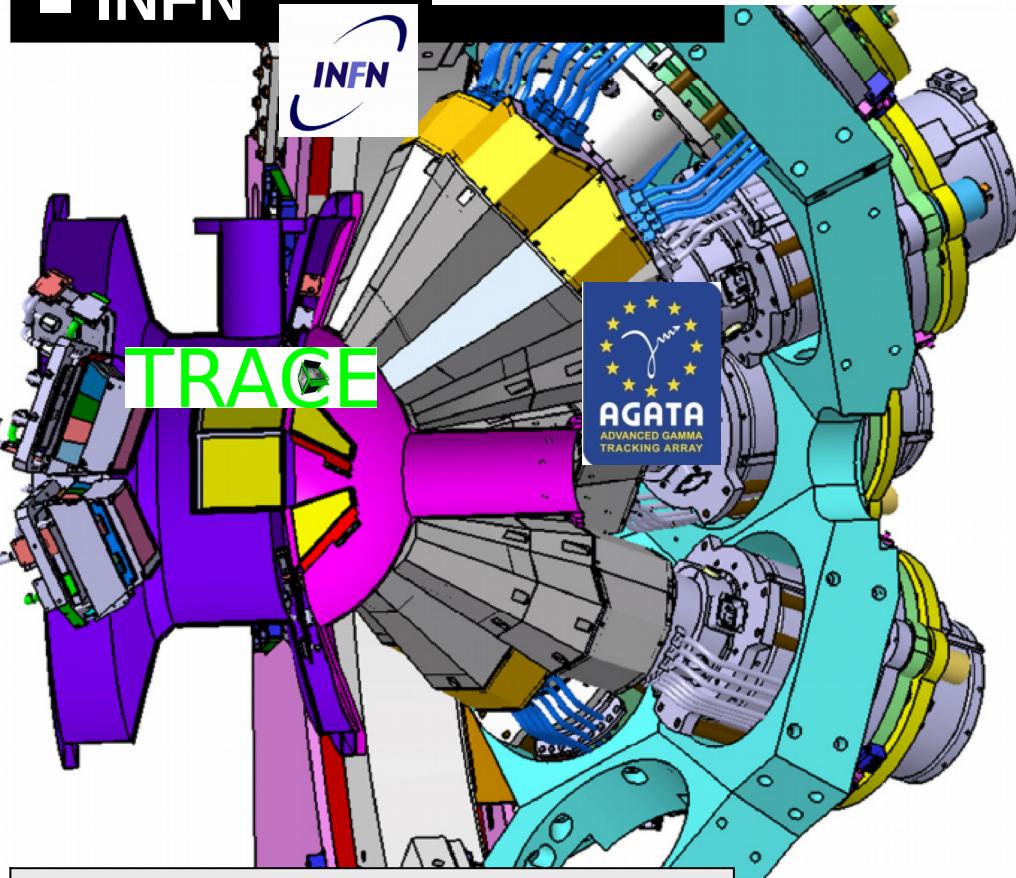
TRACE-MUGAST:

Nuclear structure by detecting light-charged particles

- FIRB 2010-2014
- CaRiPaRo
- INFN

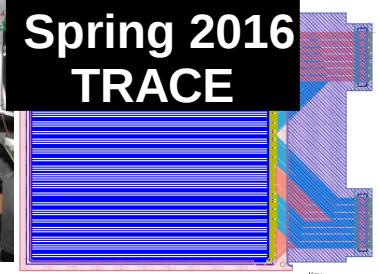
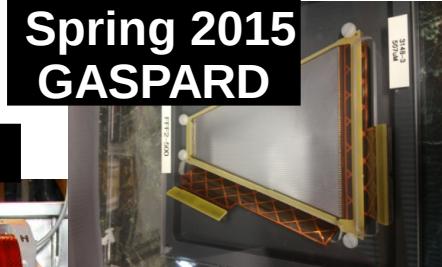


MINISTERO DELL'ISTRUZIONE, DELL'UNIVERSITÀ E DELLA RICERCA



International Collaboration

- Science campaign with AGATA at GANIL (>20 physics Lols/proposals)



NEDA

Nuclear structure by detecting neutrons



- FIRB 2010-2014
- Spiral2 – Prep.Phase
- INFN



- Science campaign with AGATA at 
laboratoire commun CEA/DSM CNRS/IN2P3

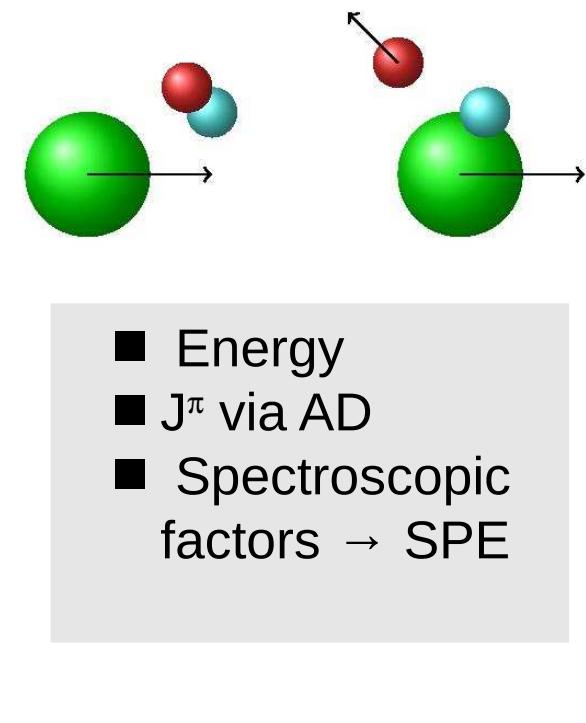
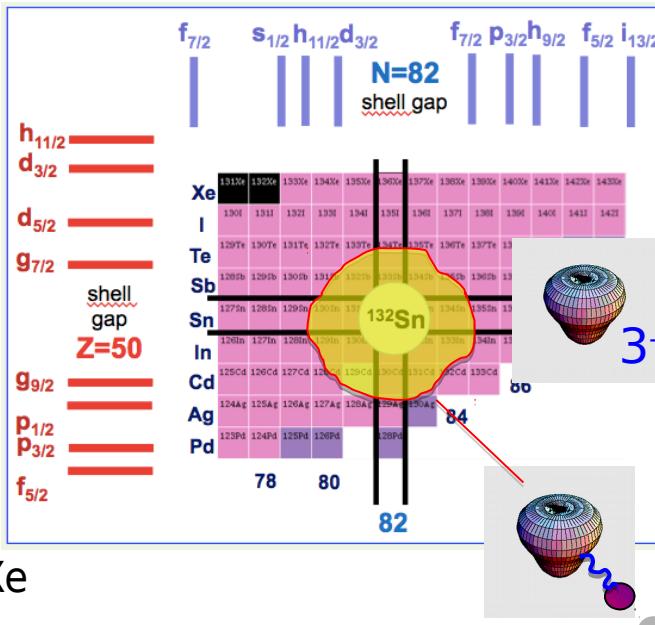
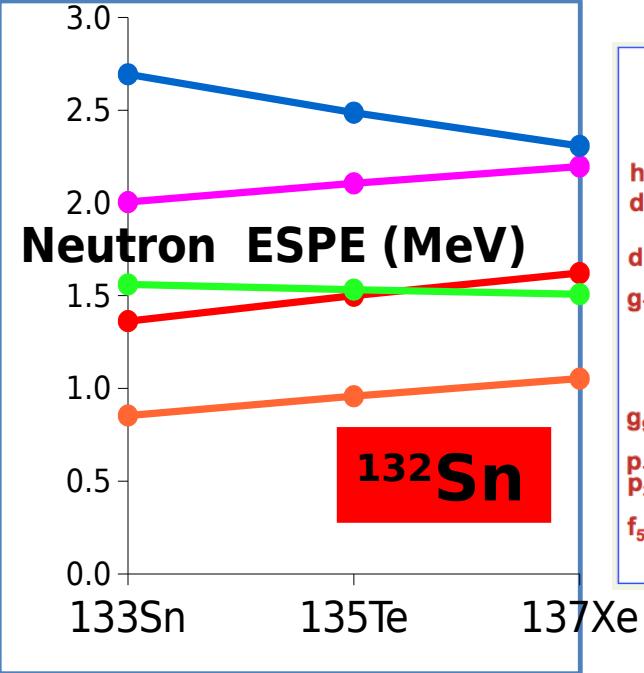
International Collaboration

TRANSFER

Evolution of the single-particle states

L. Coraggio, A. Covello, A. Gargano,

P.F. Bortignon, G. Colò,



Spectroscopic factors around and beyond magic nuclei

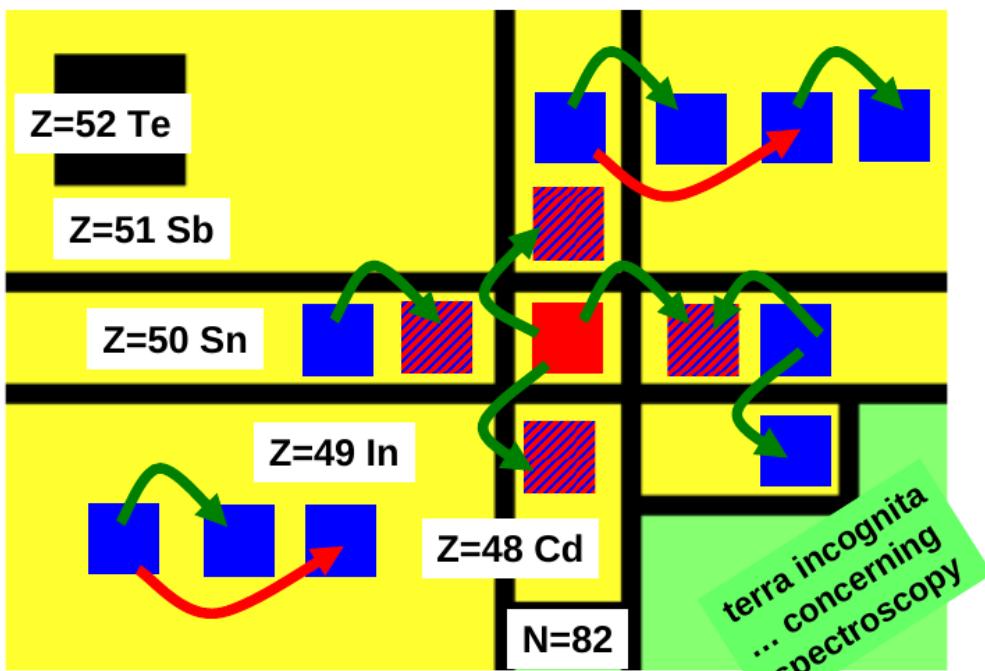
- D. Mengoni et al. (Uni. - INFN Pd)
- J.J. Valiente-Dobon et al. (INFN LNL)
- S. Leoni et al. (Uni. - INFN Mi)
- S. Pain et al. (ORNL)
- Lozeva et al. (IPHC Strasbourg)
-



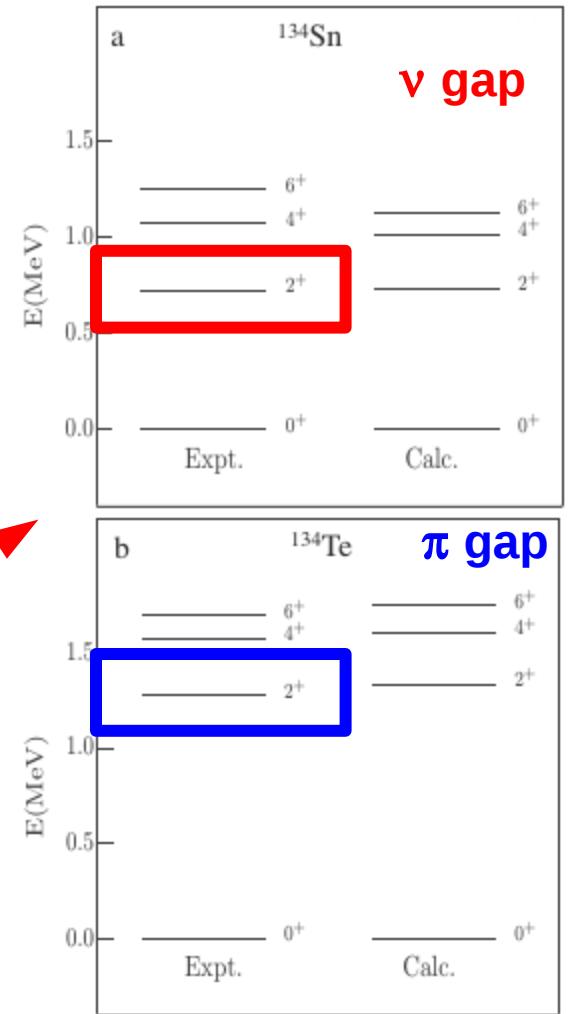
TRANSFER

Probe of the nuclear effective interaction

Luigi Coraggio talk

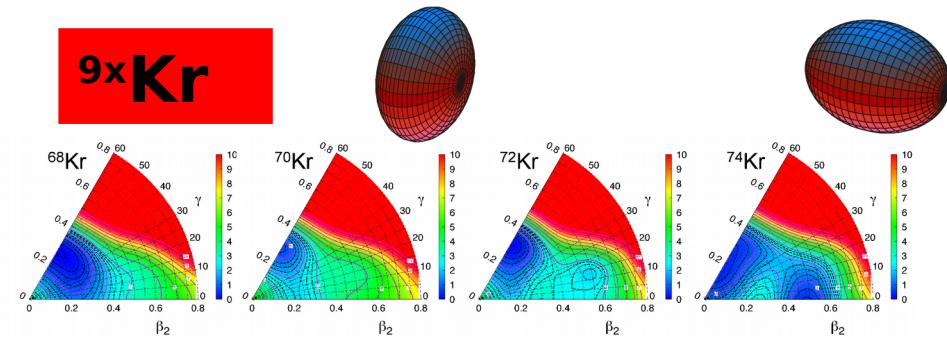
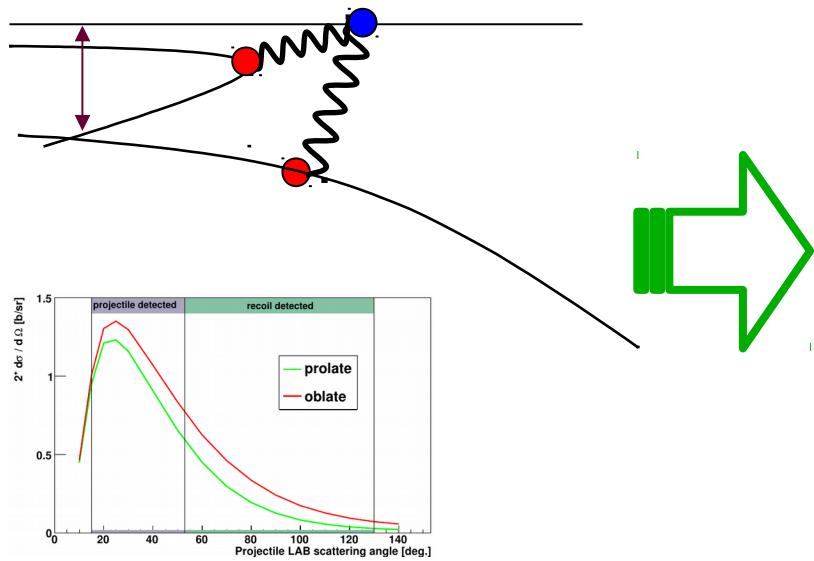


- SF → single particle energies
- $^{134}\text{Sn}, ^{134}\text{Te} \rightarrow \pi\pi, \nu\nu$ pairing term
- $^{137}\text{Xe} \rightarrow \nu\pi$ tensor force tailoring
- Collective excitation from the core
- ν, π holes below ^{132}Sn → erosion of shell closure?
Island of inversion?
- $^{128}\text{Cd}, ^{130}\text{In} \rightarrow$ trimmer the interaction ν, π holes configurations



Coulomb Excitation

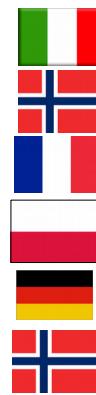
Nuclear shapes and collectivity



- Deformation
- Intrinsic shape
- Shape coexistence

Spectroscopic quadrupole moment

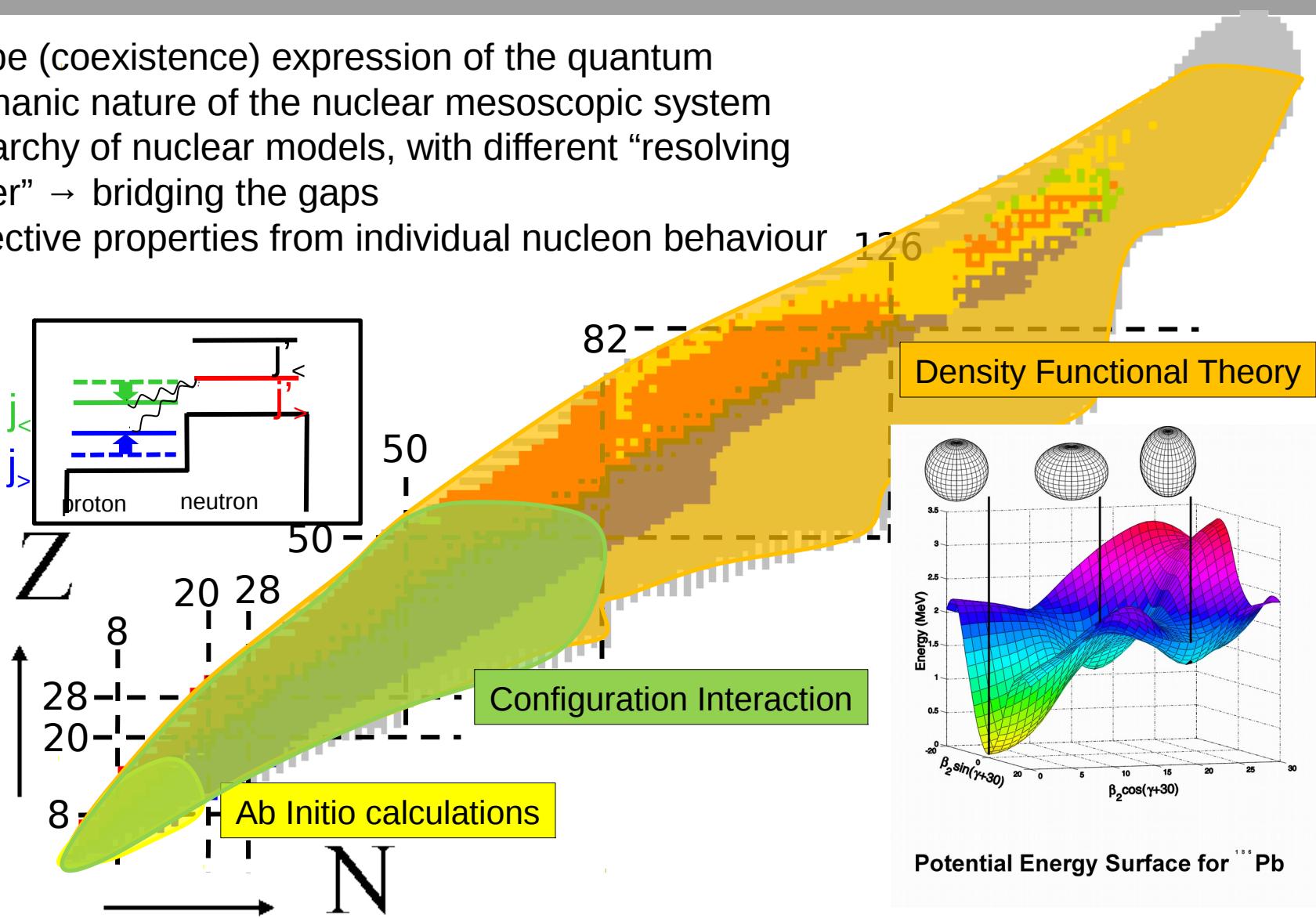
- B. Melon et al. (Uni. - INFN Fi)
- V. Modamio et al. (Univ Oslo)
- M. Zielinska et al (CEA Saclay)
- M. Kmiecik et al (IFJ PAN, Krakow)
- N. Pietralla et al. (IKP, Darmstadt)
- E. Sahin et al. (Uni Oslo)
-



Coulomb Excitation

Microscopic underpinning of collective model

- Shape (coexistence) expression of the quantum mechanic nature of the nuclear mesoscopic system
- Hierarchy of nuclear models, with different “resolving power” → bridging the gaps
- Collective properties from individual nucleon behaviour





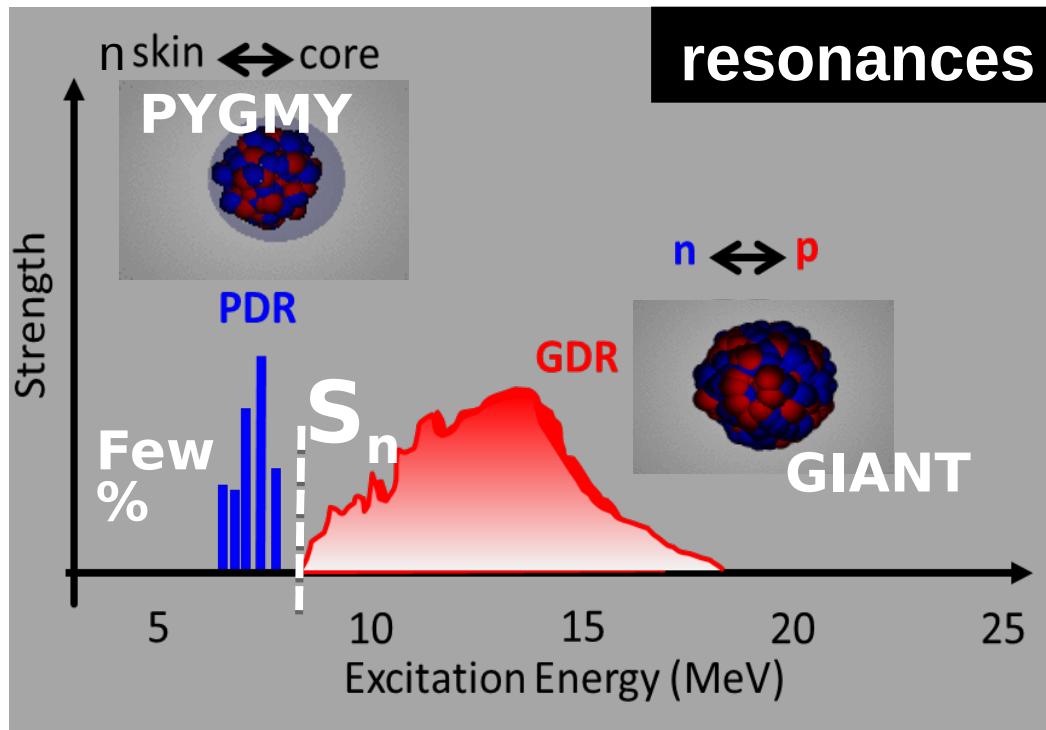
Moti Collettivi Spettroscopia γ

The DIPOLE response in nuclei

Xavier Roca Maza talk

Long Standing Research Activity in MILANO

Collaborations:
Krakow, LNL, ...



- **Astrophysics:**
Nucleosynthesis, Neutron Stars
- **Nuclear Structure:**
Microscopic Nature



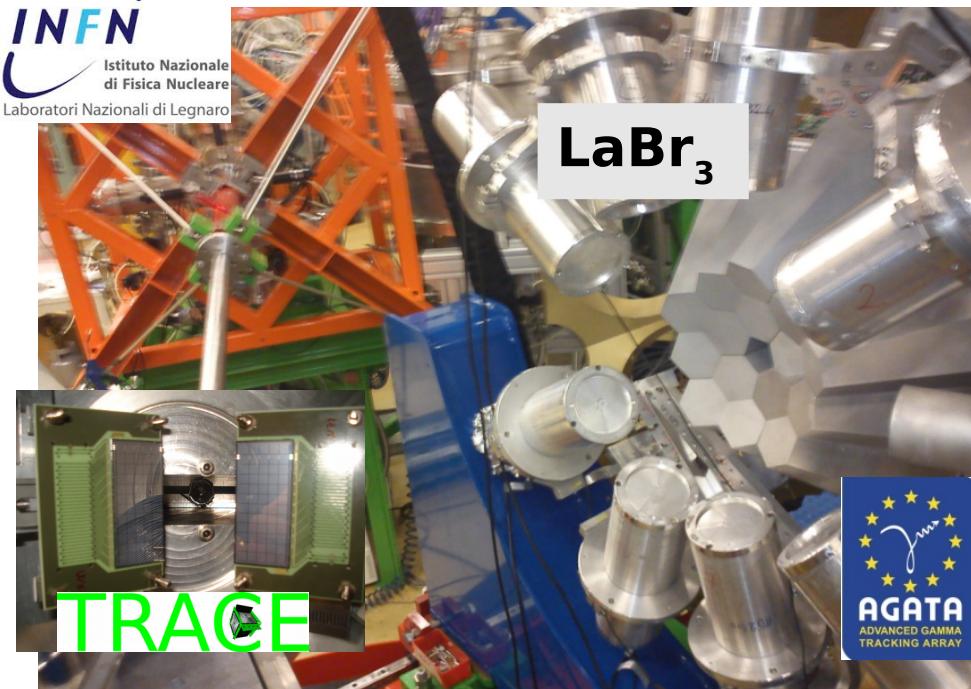
- **Collective Excitation/Damping:**
(Nuclear Shapes, ...)
- **ISOSPIN Symmetry in**
N=Z systems, ...

LaBr₃



Pygmy Dipole Resonance (PDR) In Stable Nuclei

Heavy-Ion Inelastic Scattering



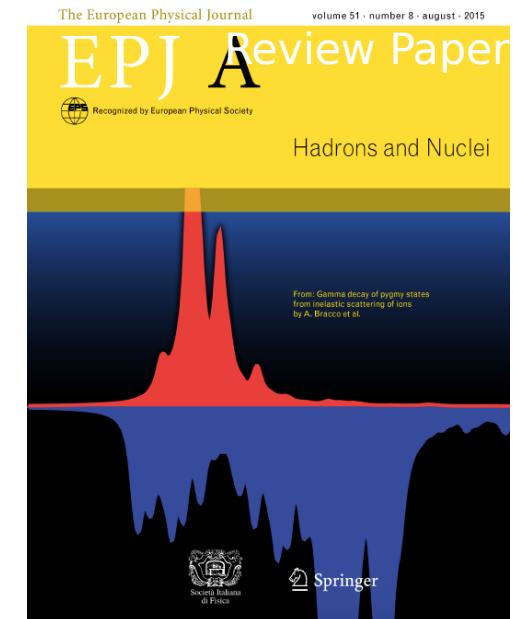
- Pygmy Strength (E1):
1-3% EWSR isoscalar E1
- IS and IV Admixture
- **A NEW OBSERVATION:**
 ^{124}Sn – QUADRUPOLE PYGMY!!

^{208}Pb : F. Crespi, A. Bracco et al., PRL113 (2014) 012501

^{124}Sn : L. Pellegrini, A. Bracco et al., PLB738 (2014) 519,
L. Pellegrini, A. Bracco et al., PRC92, 014330 (2015)

^{90}Zr : F. Crespi et al, PRC 91 (2015) 024323

^{140}Ce : M. Krzysiek et al, PRC 93, 044330 (2016)

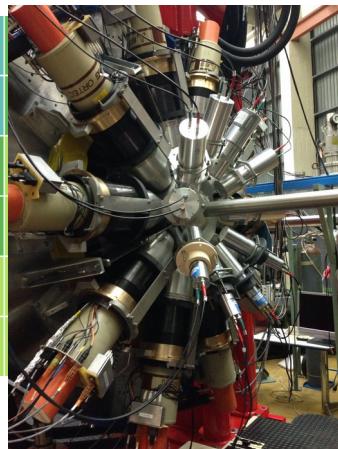


A. Bracco, F. Crespi, E. Lanza,
Eur. Phys. J. A51 (2015) 99

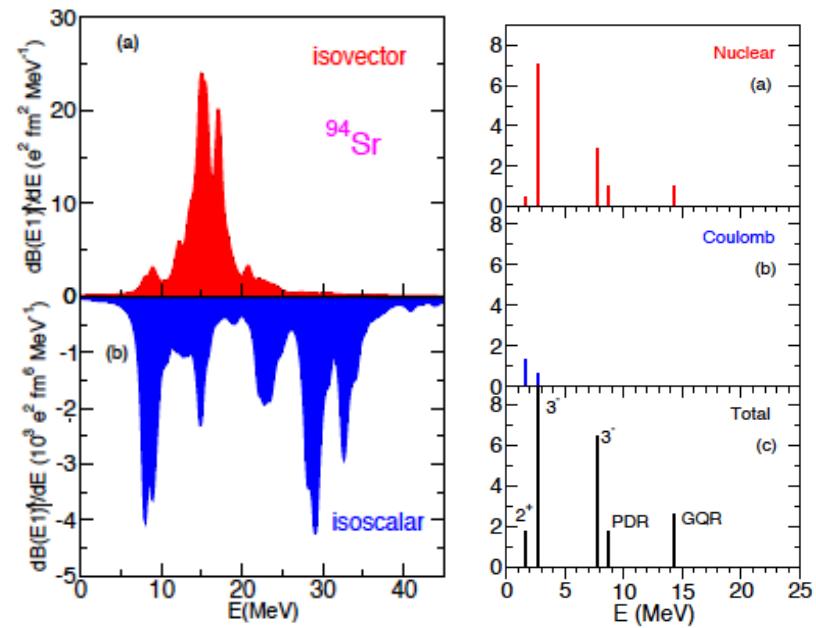
PDR in EXOTIC NUCLEI @ SPES

Inverse kinematics inelastic scattering

- Evolution of PYGMY Structure along isotopic chains: Sr, Sn, Te,
- RIB beam 10-20 MeV/A
- Liquid H, He and solid ^{13}C targets, active target



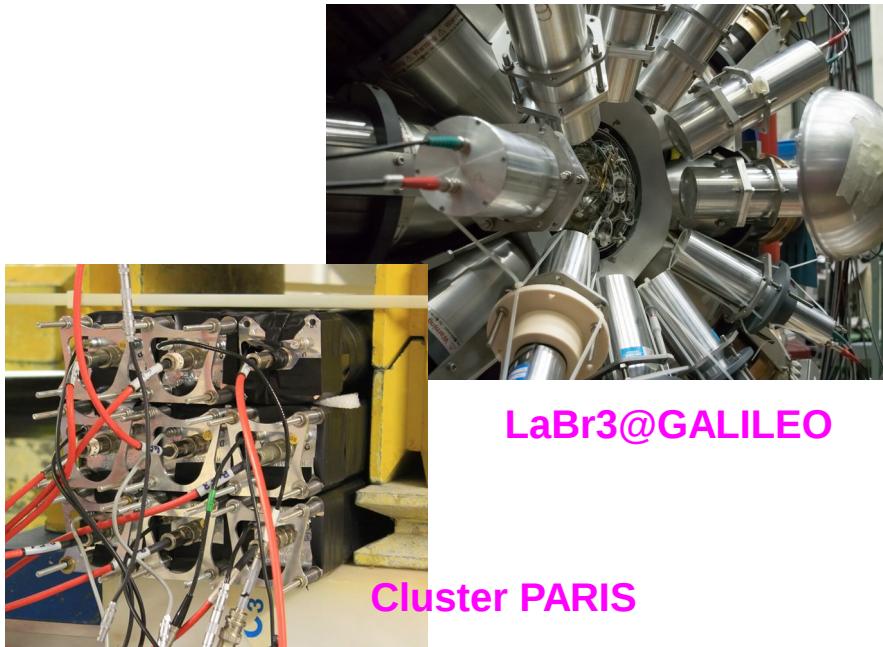
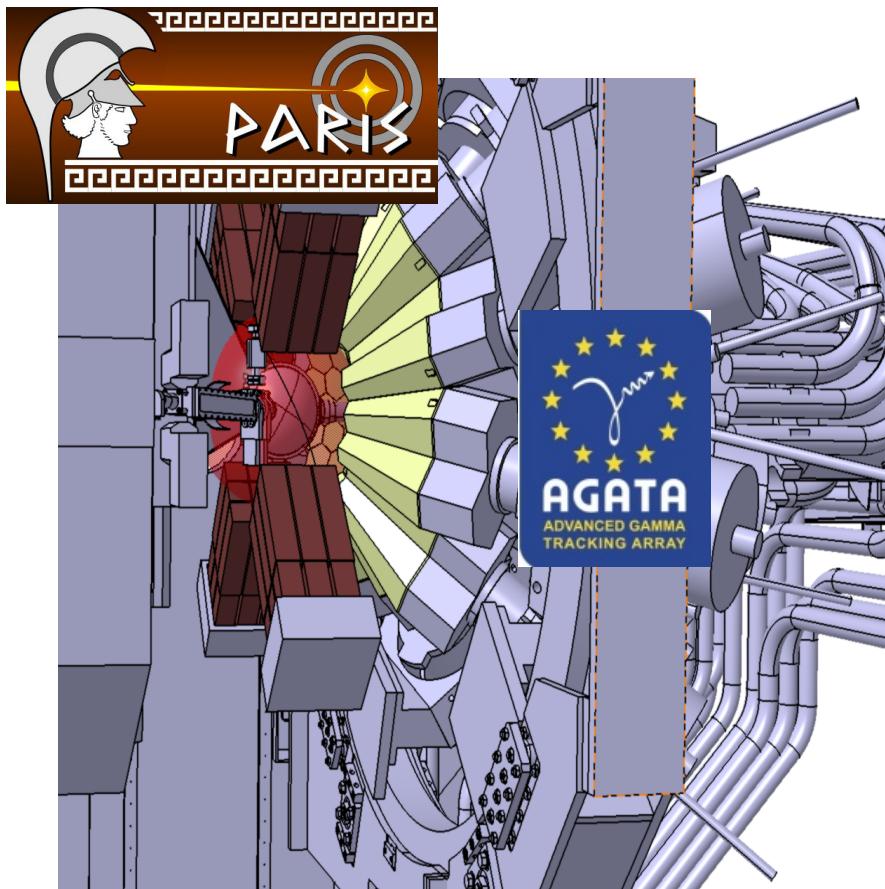
- AGATA/GALILEO
- Si Telescopes (TRACE)
- Scintillators (LaBr_3 /PARIS)



SPES LOI:

Low-lying dipole excitations via nuclear probes in exotic nuclei
F. Crespi, E. Lanza, D. Mengoni

High-efficiency gamma detectors PARIS, HECTOR+, HELENA



- ## Science campaign
- GANIL: 4 proposals accepted
 - Orsay – IPNO : 6 proposals accepted
 - 7 Lols at SPES

Conclusioni e prospettive

- SPES: **opportunità unica** per la fisica nucleare Italiana
- Rivelatori dedicati per SPES: GALILEO-AGATA), TRACE-MUGAST, NEDA, LaBr₃-PARIS
- Un ampio e ricco panorama di fisica atteso
- Grosse **aspettative internazionali** per l'avvio di SPES
- **Teoria-esperimento**: due pilastri della Fisica Nucleare

BACKUP

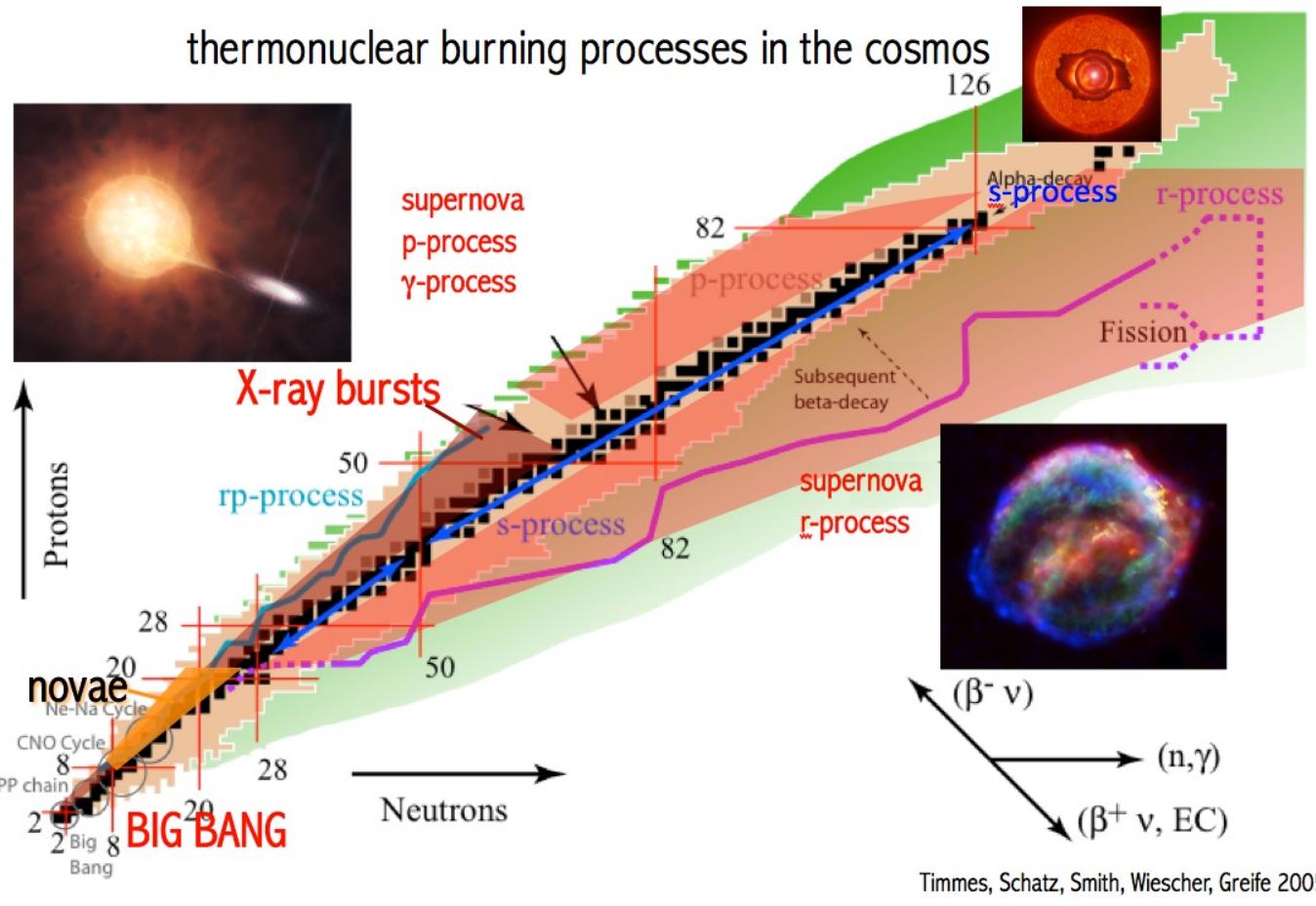
Astrofisica

Spettroscopia γ



Basics of nucleo-synthesis processes

Implications on nuclear astrophysics

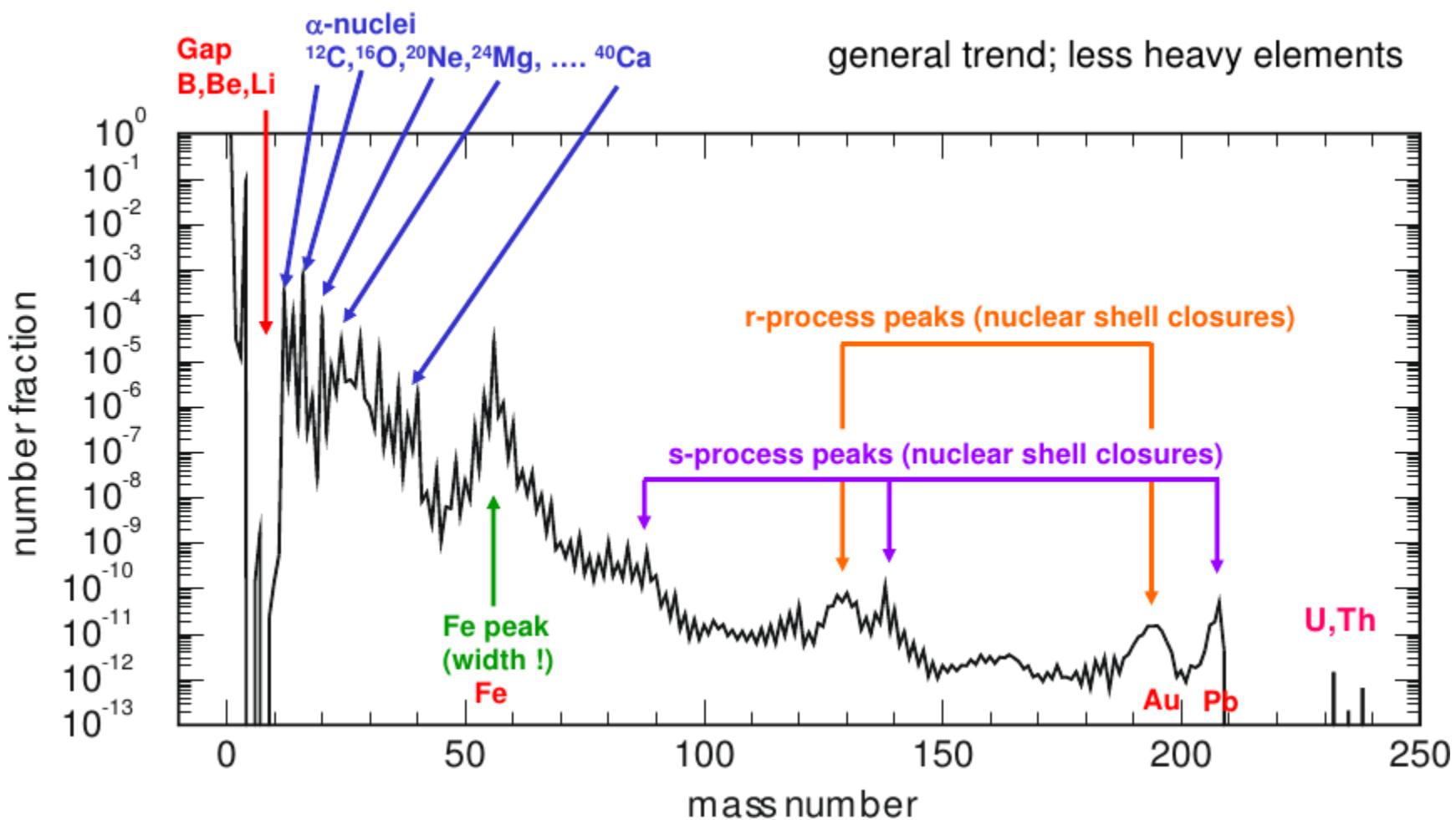


- The s and r processes produce almost all heavy elements ($A > 60$)
- Processes are linked to stellar Evolution
- Abundance patterns predicted by models, require **nuclear physics input**

- Burbidge, Burbidge, Fowler, Hoyle, Rev. Mod. Phys. 29 (1957) 547
- A.G.W. Cameron, 1982

Solar abundances

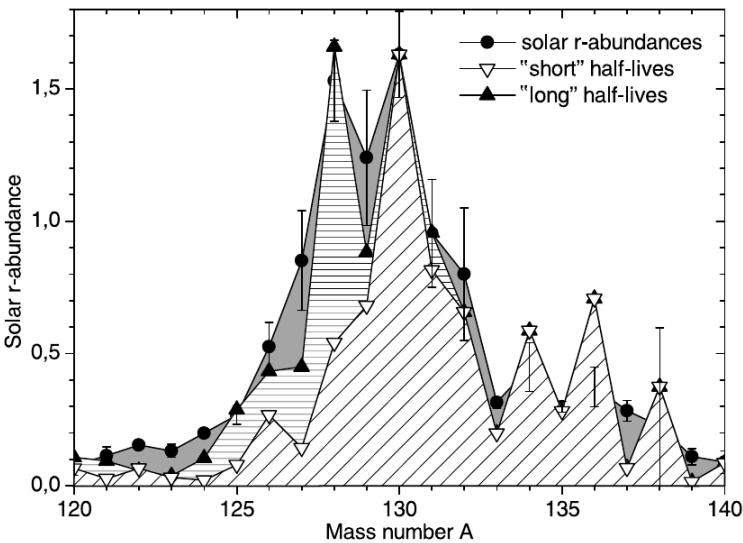
Implications on nuclear astrophysics



determined from solar and stellar spectra and from meteorites

Nuclear Physics of the *r*- and *s*- process transfer to constrain the n-cross section at SPES (β decay)

- █ Lifetime
- █ Masses
- █ *n*-capture rate
- █ ... nuclear structure



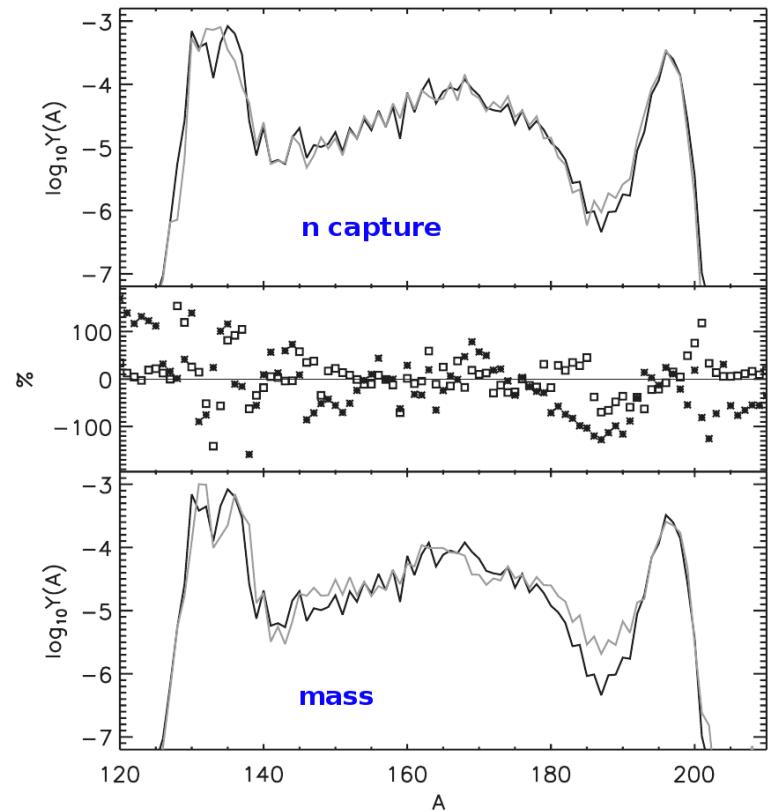
I. Dillmann et al., Phys.Rev.Lett. 91, 162503 (2003).

D. Mengoni et (Uni. - INFN Pd)

S.Leoni et al. (INFN-Mi)

S.Pain et al. (ORNL)

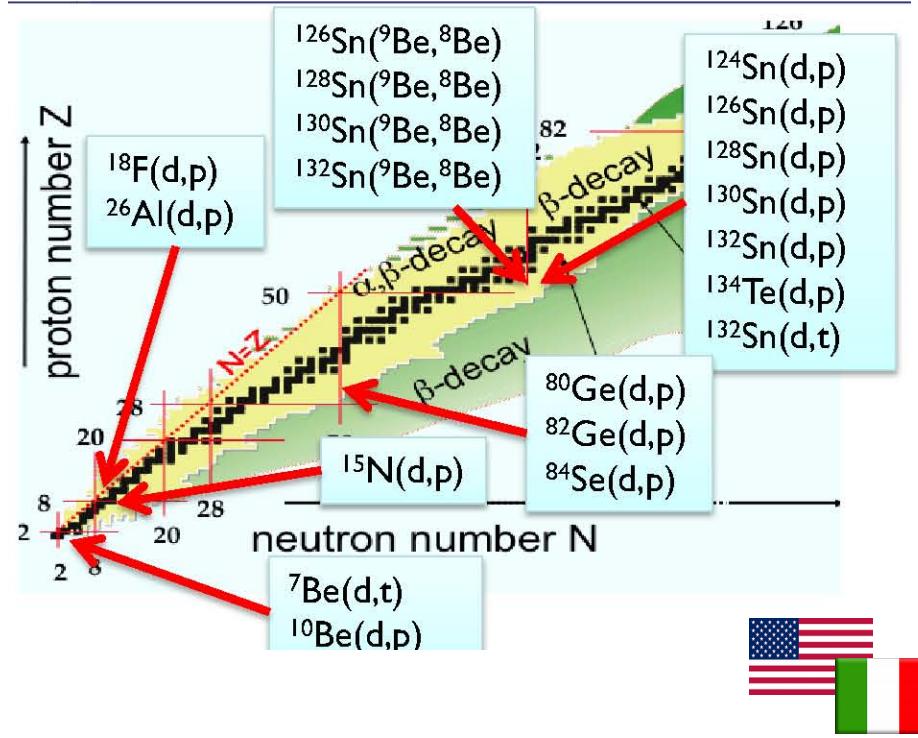
C.Domingo Pardo et al. (IFIC- Valencia)



R. Surman, J. Beun, G. C. McLaughlin and W. R. Hix
Phys.Rev.C79, 045809 (2009).



one-nucleon and cluster transfer at the relevant astrophysics sites



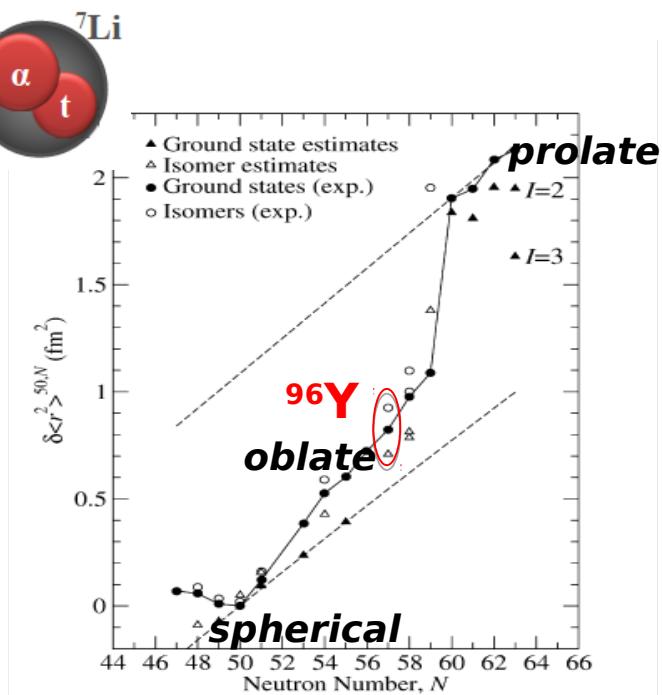
SPES LOI:

Address uncertainties by the measurement of transfer reactions on neutron-rich nuclei
S.Pain, D.Mengoni et al

SPES LOI:

Search for deformed oblate structures in ^{96}Y by γ -spectroscopy and **cluster transfer** reactions with a ^{95}Sr SPES beam

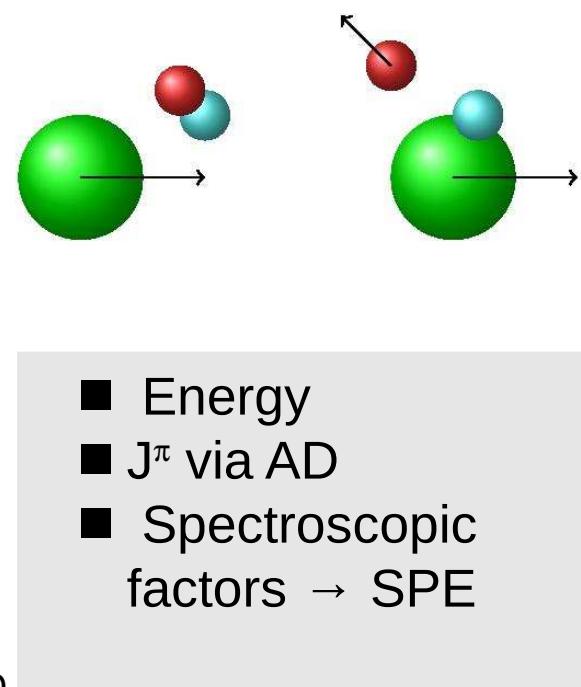
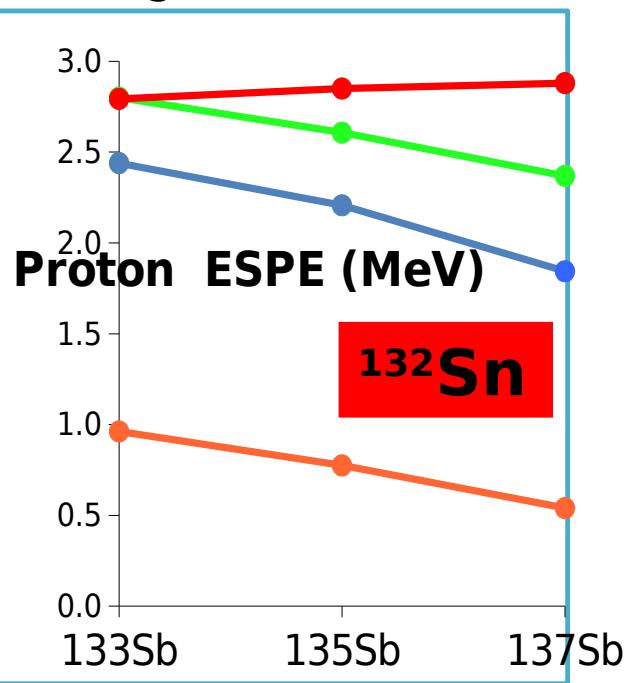
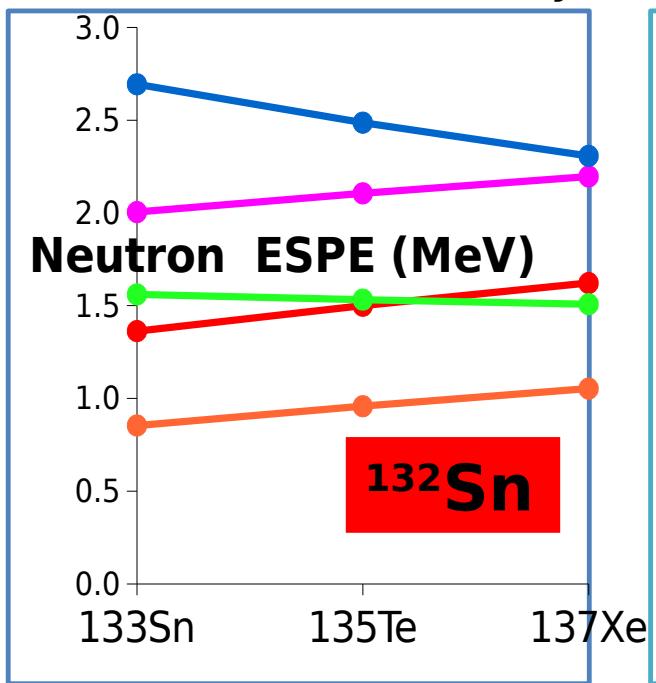
B. Fornal, S. Leoni ...



TRANSFER

Evolution of the single-particle states

Courtesy of A. Gargano

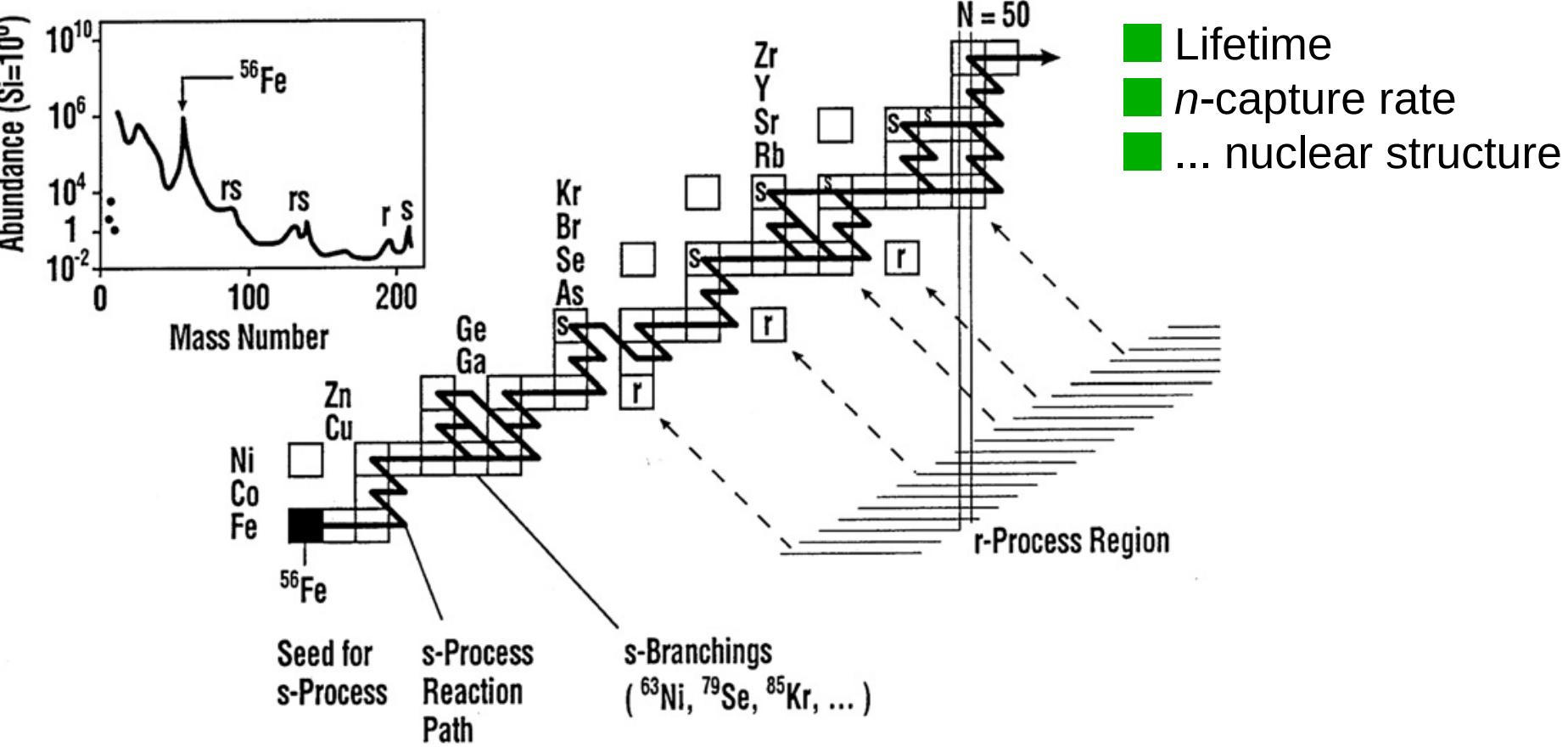


Spectroscopic factors around and beyond magic nuclei

- D. Mengoni et al. (Uni. - INFN Pd)
- J.J. Valiente-Dobon et al. (INFN LNL)
- S. Pain et al. (ORNL)
- Lozeva et al. (IPHC Strasbourg)
-



Nuclear Physics of the s process transfer at the branching points (β decay)



- C.Domingo Pardo (IFIC- Valencia) 
■ D.Mengoni (Uni. INFN - Pd) 

The DIPOLE Response In Nuclei

0 Relevant in ASTROPHYSICS

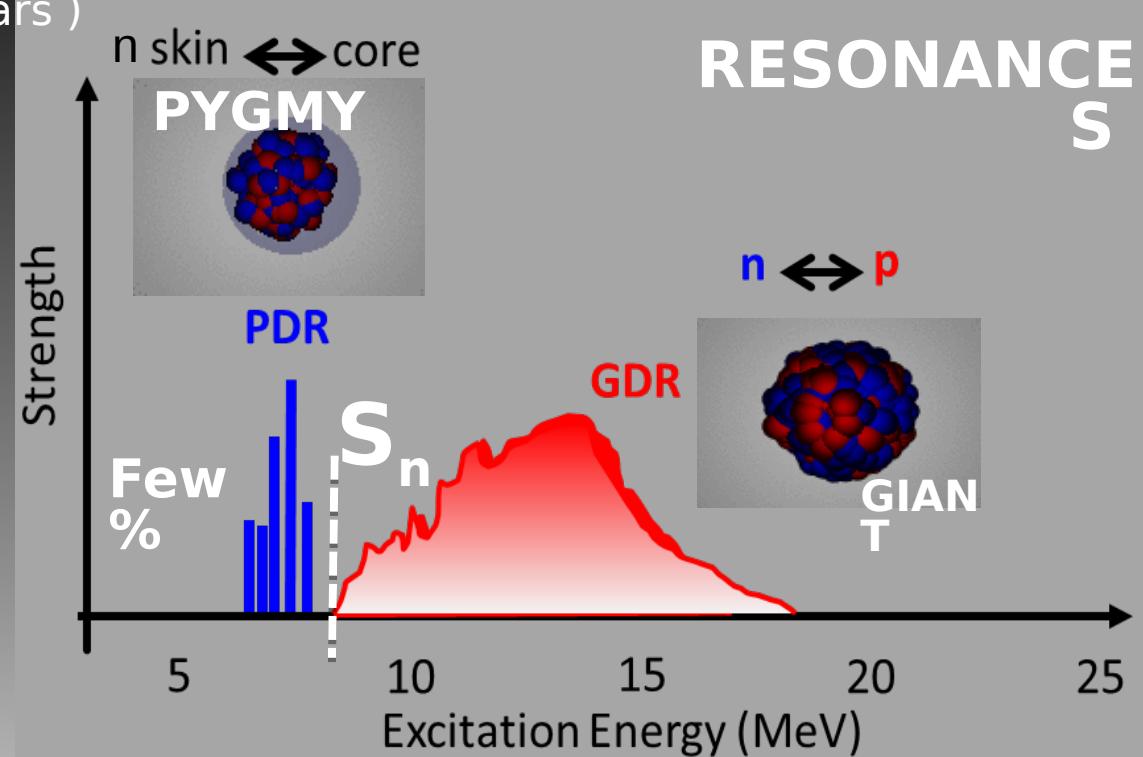
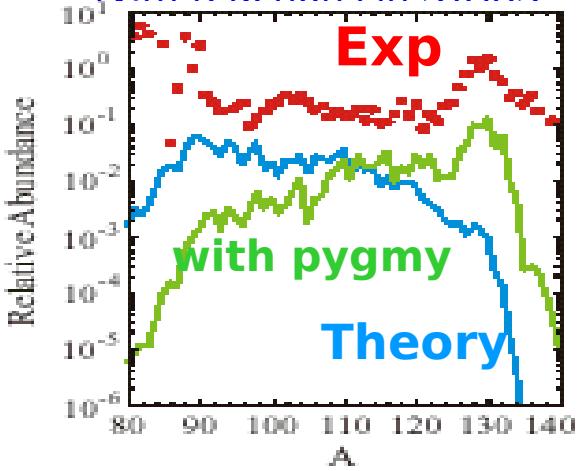
(Nucleosynthesis, Neutron Stars)

0 Relevant in NUCLEAR STRUCTURE

(Microscopic Nature...)

Element Abundance

Relevant ENERGY window for (ν, n) reactions in STARS



long Standing research Activity in MILANO

. Bracco, F. Camera, O. Wieland, F. Crespi,)

Collaborations:

Krakow, LNL, ...

0 Collective Excitation/Dam

(Nuclear Shapes, Fission, ...)

0 ISOSPIN Symmetry

(N=Z systems, ...)

In recent years ...



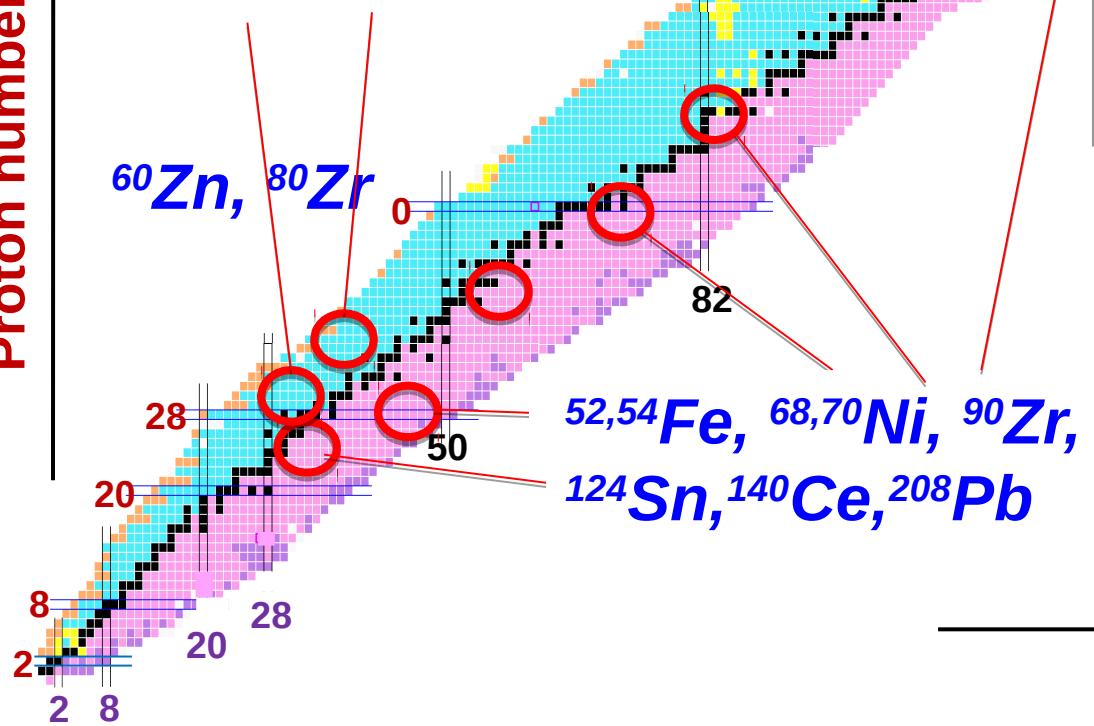
GIANT DIPOLE
RESONANCE

AGATA/LaBr₃@LN

L

GALILEO/LaBr₃@
LNL

Proton number



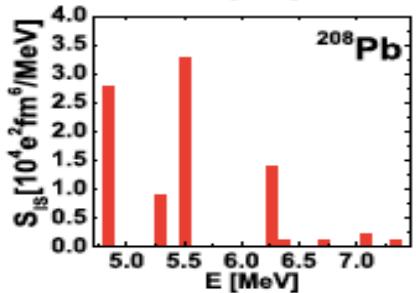
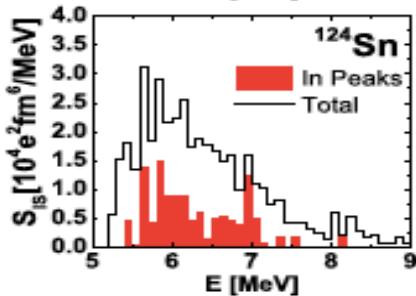
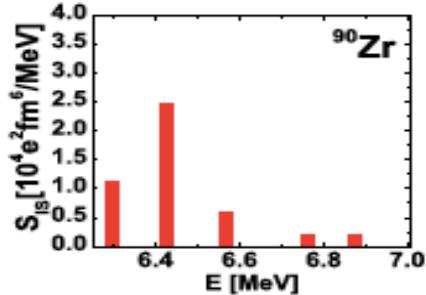
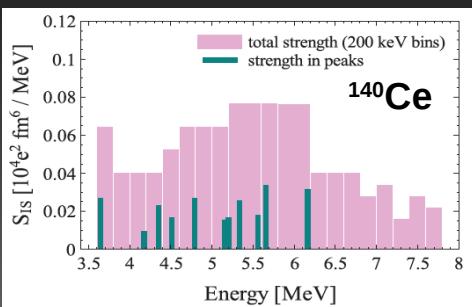
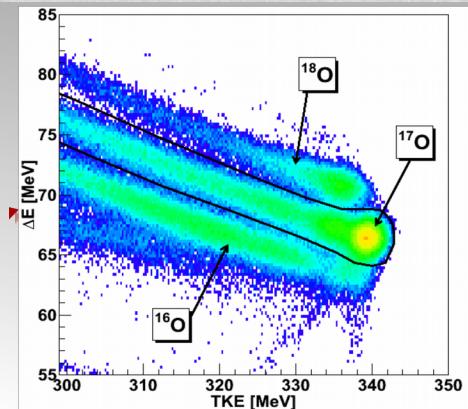
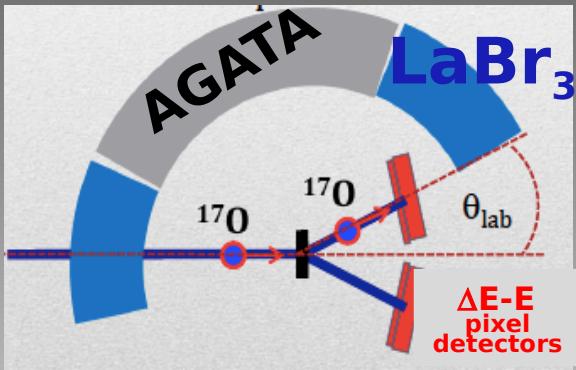
PYGMY
RESONANCES

in STABLE and
EXOTIC Nuclei

AGATA@LNL
AGATA@GSI
LaBr₃@RIKEN

YGMY in STABLE NUCLEI

Heavy-Ion Inelastic Scattering: a probe sensitive to the surface



LNL Campaign

AGATA +
Si Telescopes (TRACE)+
Scintillators (LaBr3)
 ^{17}O @ 20 MeV/A on
 ^{208}Pb , ^{124}Sn , ^{90}Zr ,
 ^{140}Ce

Pygmy Strength (E1) :

1-3% EWSR isoscalar E1
Isoscalar and

Isovector
admixture:

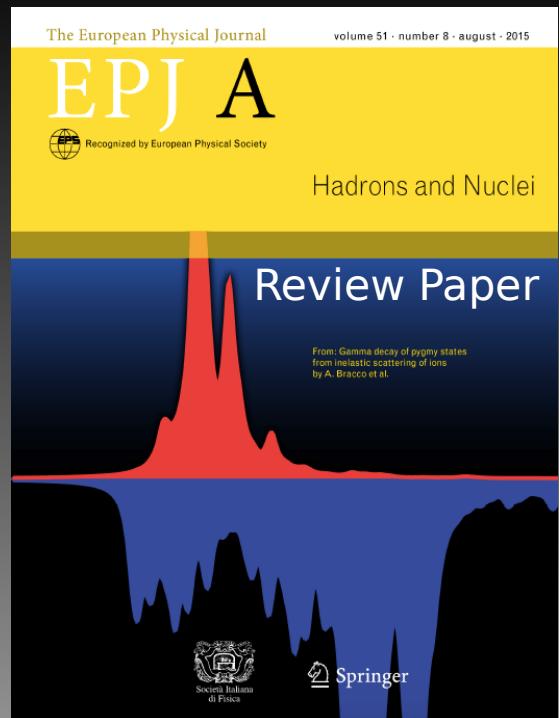
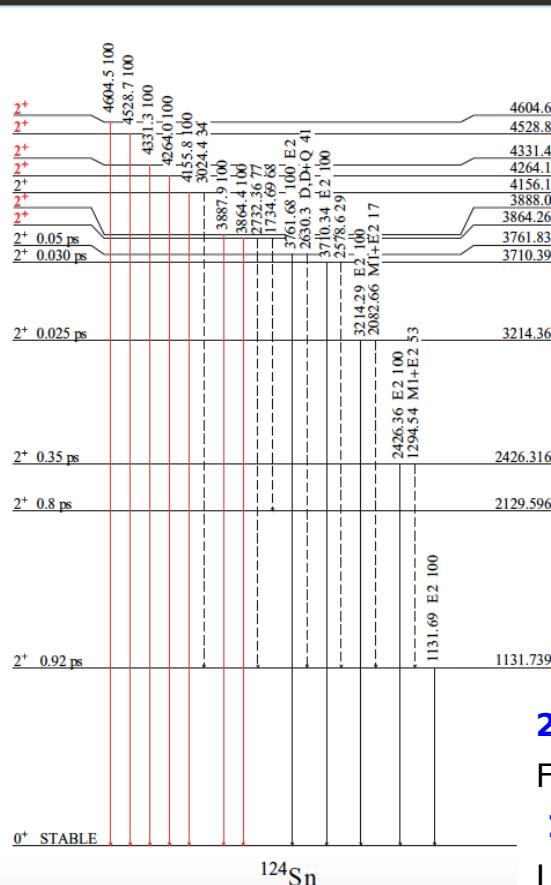
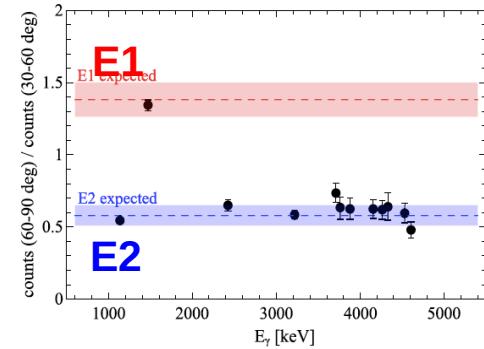
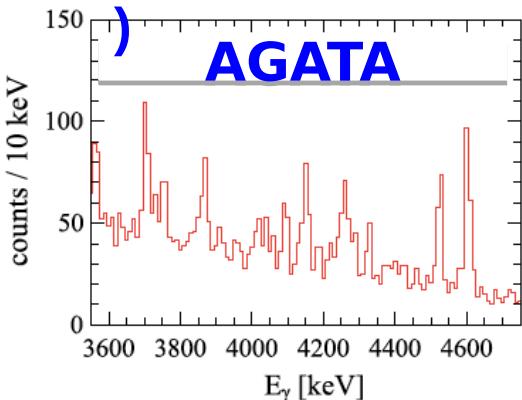
SKIN

7 < E < 9 MeV:

A NEW OBSERVATION: ^{124}Sn - QUADRUPOLE PYGMY!!

Multitude of 2^+ discrete

states
 $^{124}\text{Sn}(\text{O}^{17},\text{O}^{17}\gamma)$



A. Bracco, F. Crespi,
E. Lanza,
Eur. Phys. J. A 51 (2015)

^{208}Pb :

F. Crespi, A. Bracco et al., PRL113 (2014) 012502

^{124}Sn :

L. Pellegrini, A. Bracco et al., PLB738 (2014) 519

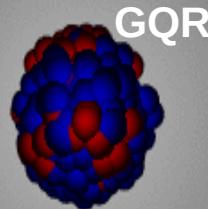
L. Pellegrini, A. Bracco et al., PRC92, 014330 (2015)

^{90}Zr :

F. Crespi et al, PRC 91 (2015) 024323

^{140}Ce :

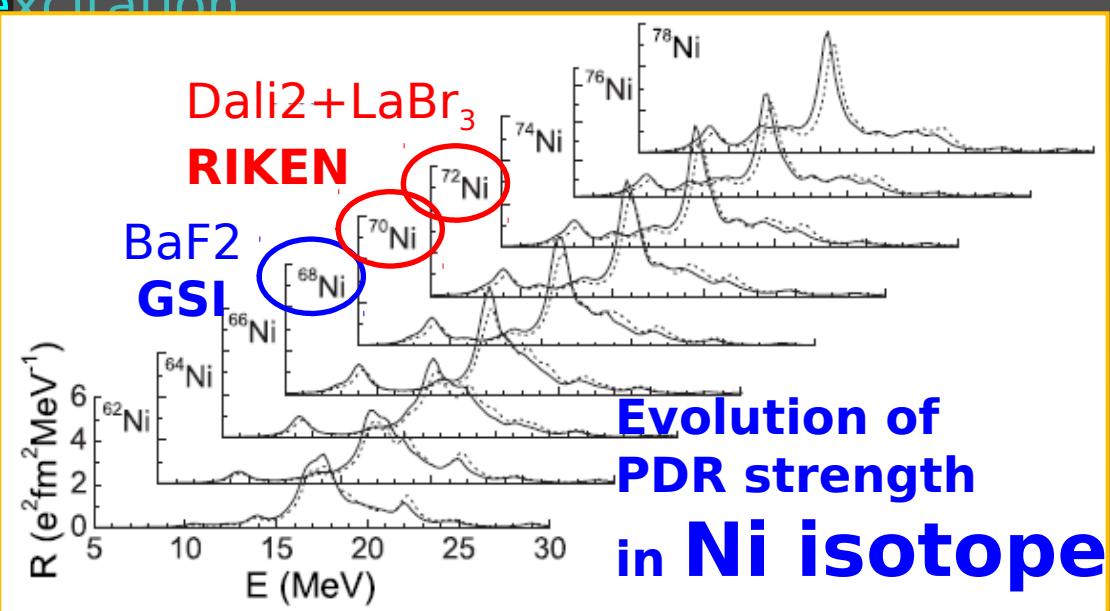
M. Krzysiek et al, PRC 93, 044330 (2016)



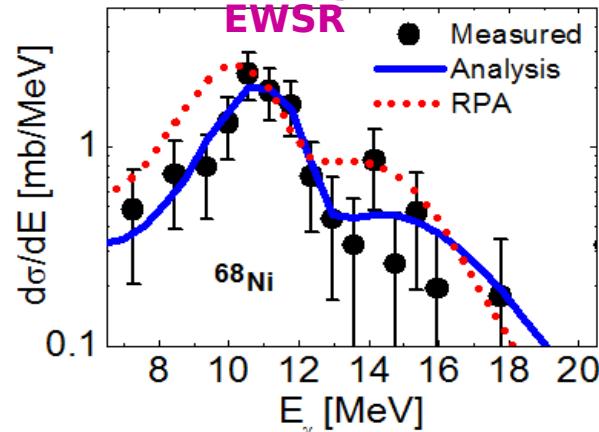
Concentration of E2 Strength
much below the
GIANT QUADRUPOLE
resonance

PGMY in EXOTIC NUCLEI - up to now

Relativistic Coulomb Excitation: high selectivity for E1 excitation

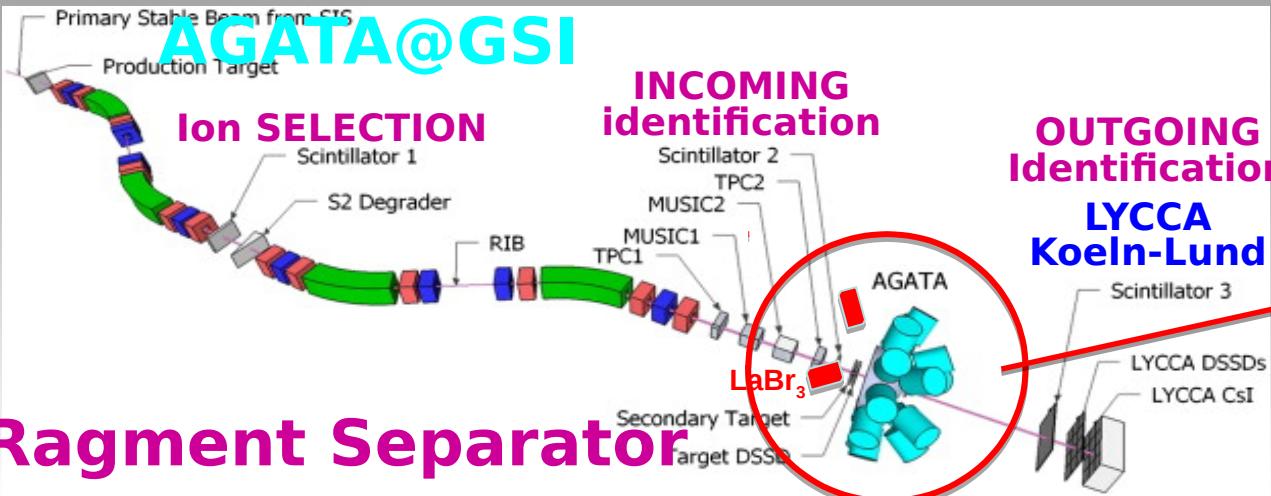


FIRST Case - GSI: ⁶⁸Ni
(2005: EUROBALL Clusters + BaF2)
PYGMY Strength: 5-9 % EWSR



J.Wieland, A. Bracco et al., PRL 102, 092502 (2004)

Pygmy in ^{62,64}Fe:
AGATA@GSI



GMY in EXOTIC NUCLEI @ SPES

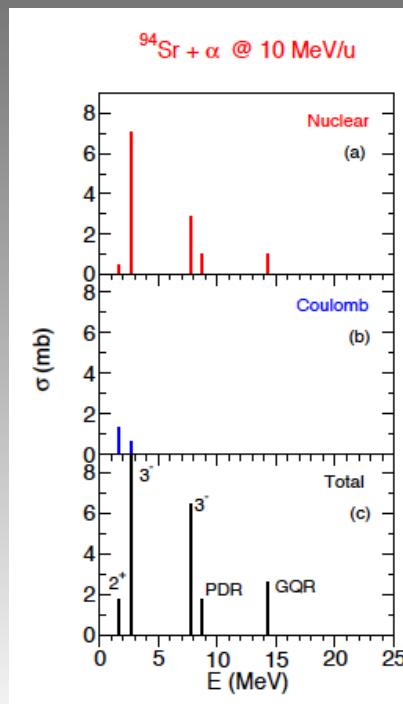
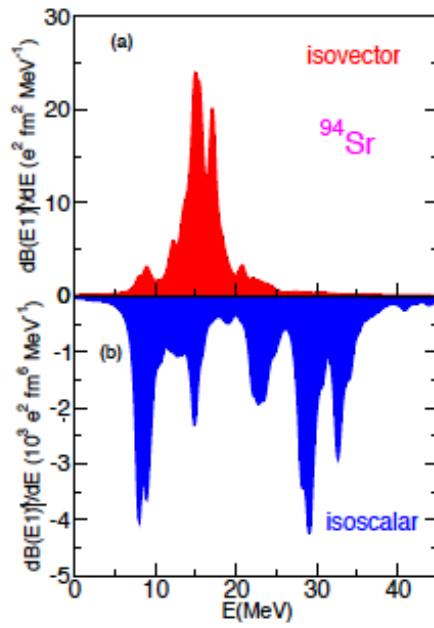
Inverse kinematics inelastic scattering

- RIB beam 10-20 MeV/A
- Liquid H, He and solid ^{13}C targets

Evolution of PYGMY Structure along isotopic chains: Sr, Sn, Te, ...

ES LOI:

-lying dipole excitations via nuclear probes in exotic nuclei
Anza, D. Mengoni, F. Crespi,



AGATA/GALILEO
+
Si Telescopes
(TRACE)+

90Nb	91Nb	92Nb	93Nb	94Nb	95Nb	96Nb	97Nb	98Nb	99Nb	100Nb	101Nb
89Zr	90Zr	91Zr	92Zr	93Zr	94Zr	95Zr	96Zr	97Zr	98Zr	99Zr	100Zr
88Y	89Y	90Y	91Y	92Y	93Y	94Y	95Y	96Y	97Y	98Y	99Y
87Sr	88Sr	89Sr	90Sr	91Sr	92Sr	93Sr	94Sr	95Sr	96Sr	97Sr	98Sr
86Rb	87Rb	88Rb	89Rb	90Rb	91Rb	92Rb	93Rb	94Rb	95Rb	96Rb	97Rb
85Kr	86Kr	87Kr	88Kr	89Kr	90Kr	91Kr	92Kr	93Kr	94Kr	95Kr	96Kr

Day 1 Beams
 $^{90,92,94}\text{Sr}$: $10^6 - 10^7$ pps

Complex Excitations around Doubly Magic systems

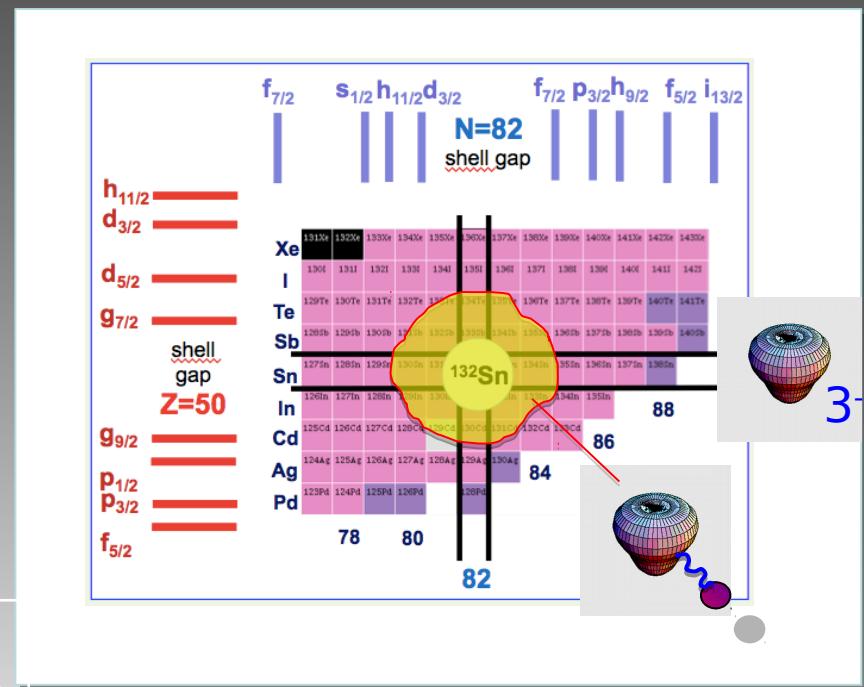
Complex, collective excitations dominate
Low Lying states in **DOUBLY MAGIC** Nuclei

2^+ , 3^- , 4^+ , ... **PHONONS**

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

Particle-PHONON couplings

- o Quenching of Spec. Factors,
- o Anharmonicity of vibrational spectra,
- o Damping of Giant Resonances,
- o ...



Research Activity in MILANO
(S. Leoni, A. Bracco, G. Colò, P.F. Bortignon....)

Collaborations:
Krakow, LNL, ...

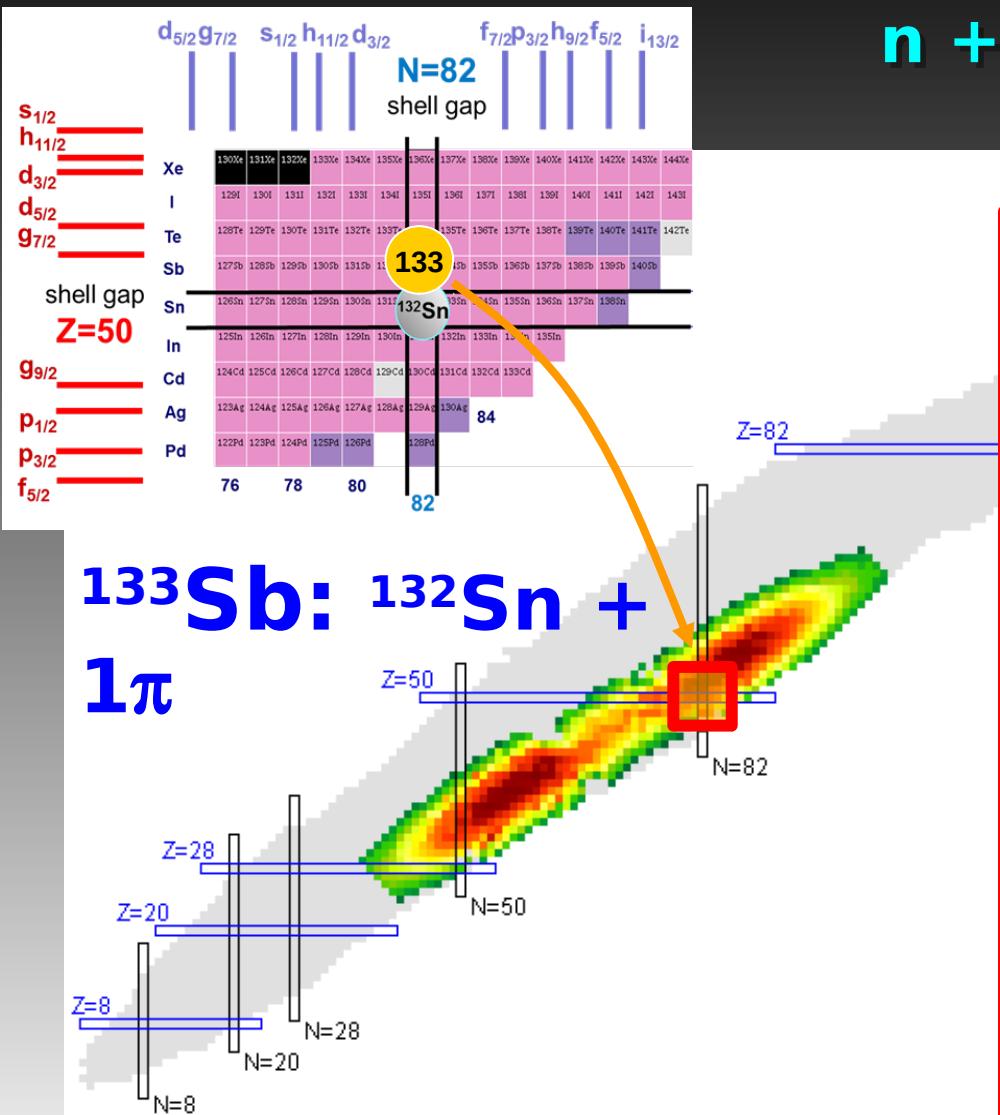
132Sn - region

In Recent years ...

Neutron-induced FISSION



$$n + {}^{235}\text{U}; n + {}^{241}\text{Pu}$$



FEEDING of the ISOMER up to $25/2^+$

From Lifetimes

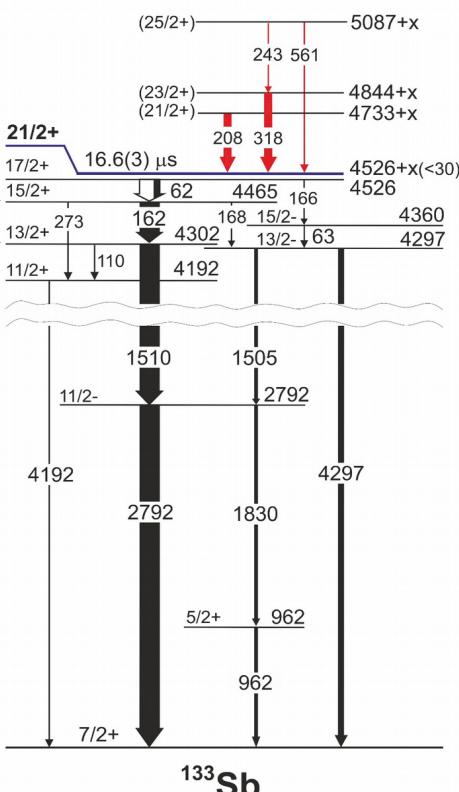
B(M1) [W.u.]

0.24

0.004

Not Simple Configurations

**NO SHELL MODEL is Possible:
too large configuration space**



In Recent years ...

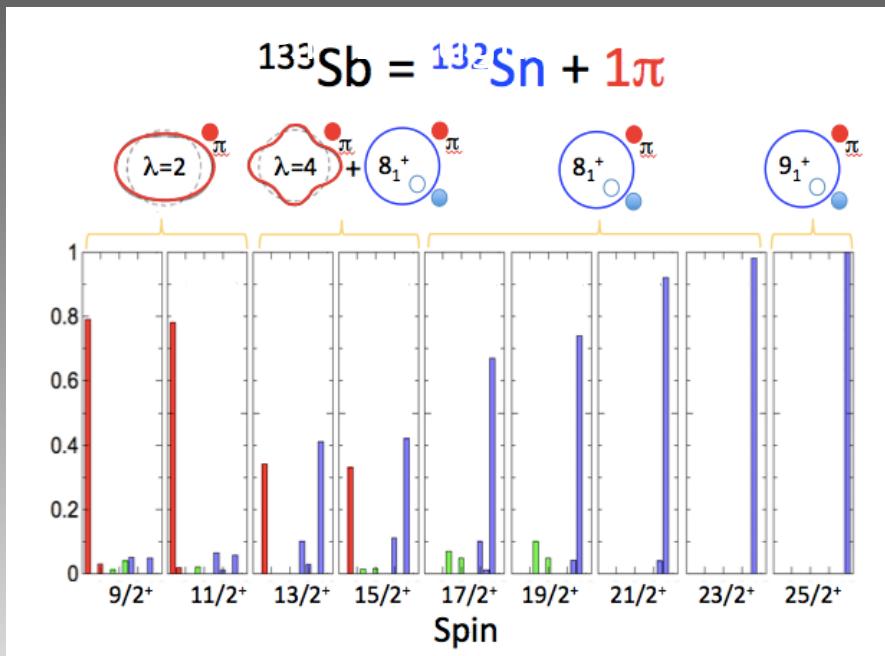
Neutron-induced FISSION

$$n + {}^{235}\text{U}; n + {}^{241}\text{Pu}$$



ILL
NEUTRONS
FOR SCIENCE

New “HYBRID” Model Developed: CORE Excitations Included



Fast Change of wave function with spin:

couplings with different CORE

FEEDING of the ISOMER up to $25/2^+$

From Lifetimes

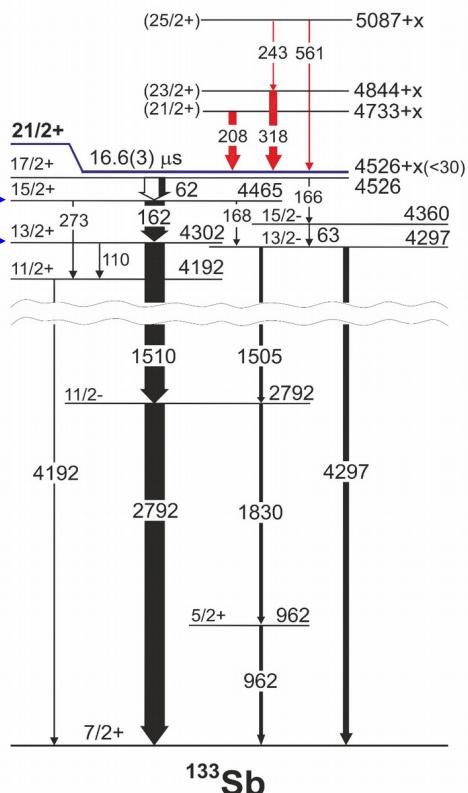
$B(M1)$ [W.u.]

0.24

0.004

Not Simple Configurations

NO SHELL MODEL is Possible:
too large configuration space



Further @ SPES

STUDY OF NUCLEI

1 and 2 nucleons away
from ^{132}Sn

→ FOCUS ON COUPLINGS
Particle-CORE
excitations: Γ^π , $B(E\lambda)$

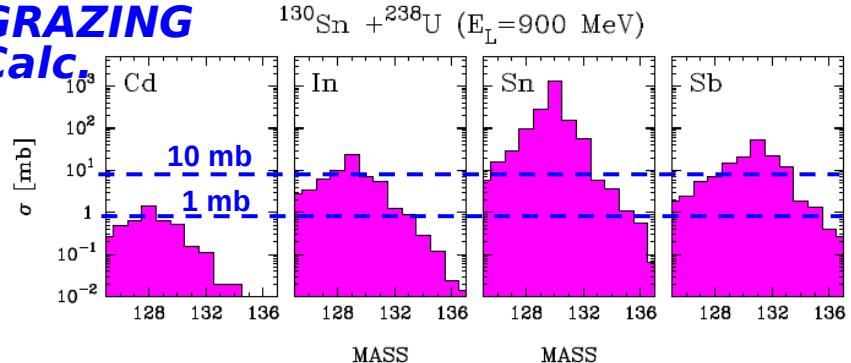
→ New Hybrid Model
predictions

AGATA/GALILEO + PRISMA

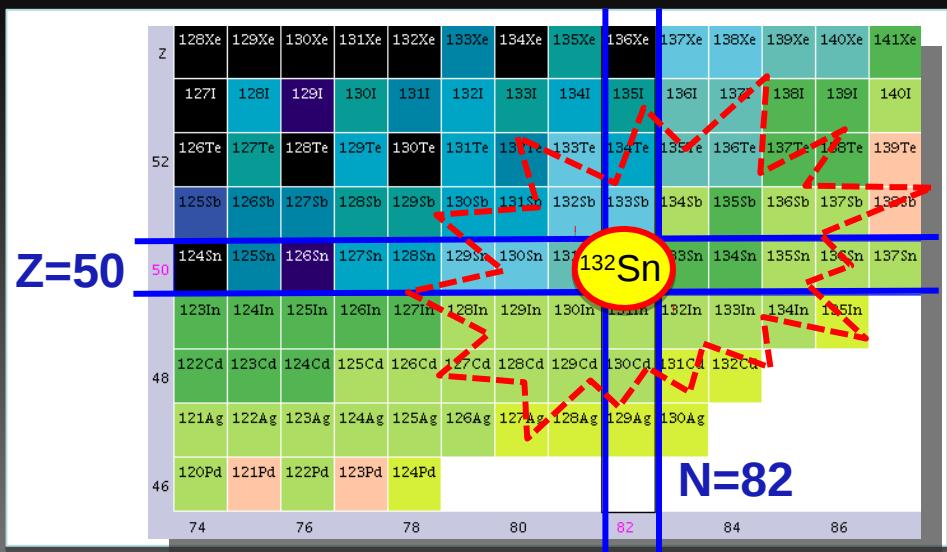
SPES LOI:
Heavy-ion binary reactions as a tool
for detailed γ -spectroscopy in
exotic regions

Silvia Leoni, Adam Mai

**GRAZING
Calc.**



0-131,132,133Sn (7 MeV/A, > 10⁶ pps) + 238U

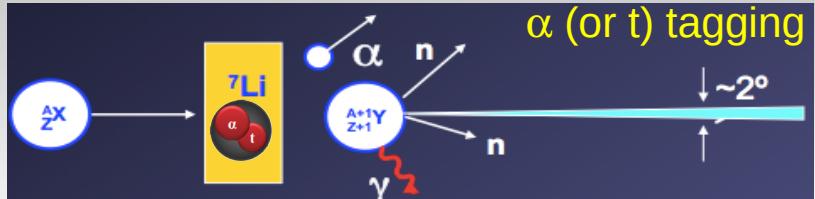


AGATA/GALILEO + Si Telescopes
SPES LOI:(TRACE)

Structure of Sb and Te nuclei
around ^{132}Sn as a testing ground for
realistic shell model interactions,
B. Szpak, Silvia Leoni , B. Fornal, ...

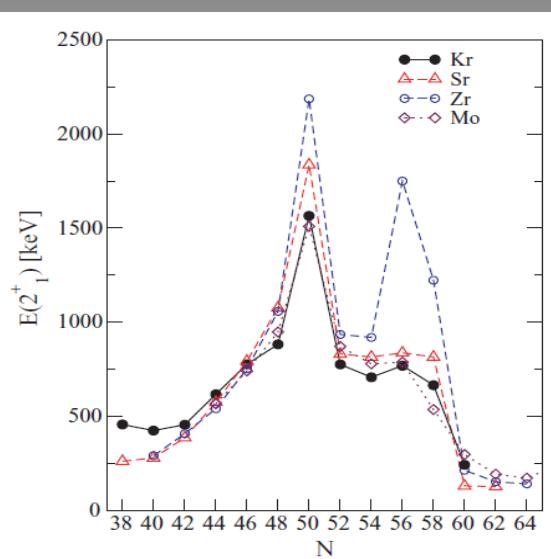
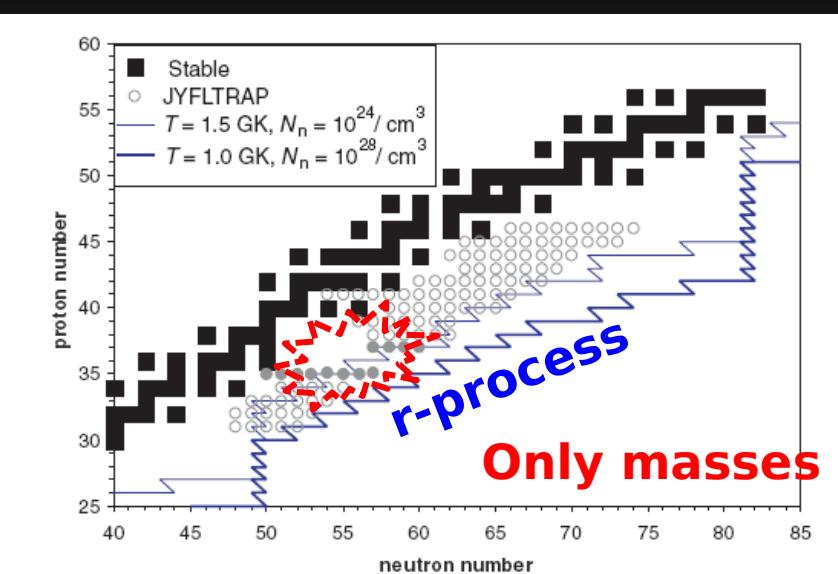
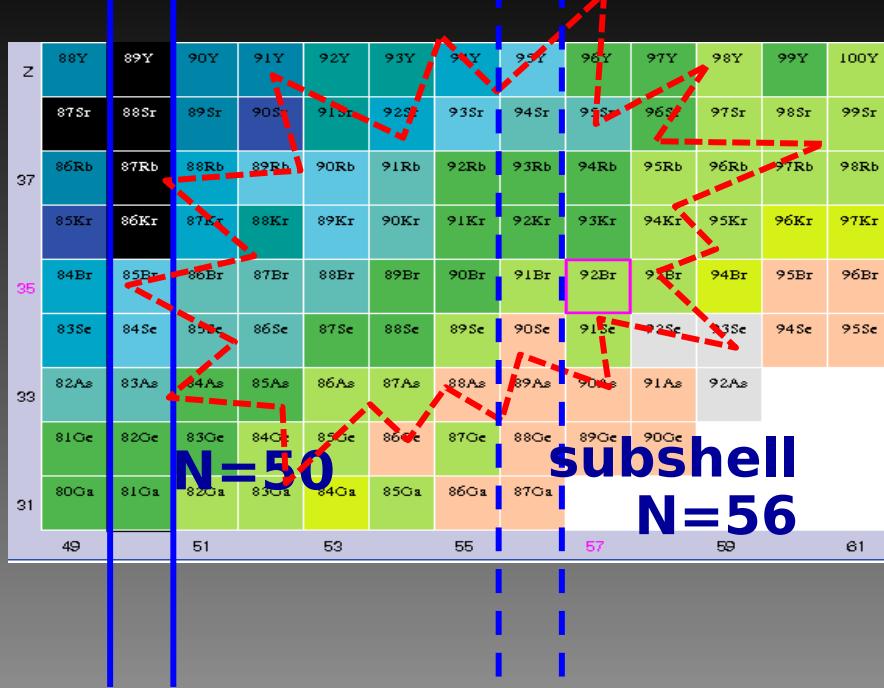
Off Yrast - medium spin states populated by
Cluster Transfer Reactions with ^7Li target:

126-133Sn beams (5 MeV/A, > 10⁶ pps)



Tested at ISOLDE, S. Bouche et al., PRC92, 024322 (2015)

Far Structure of r-process nuclei, beyond



**REGION OF
STRONG
Shape changes
with N number**

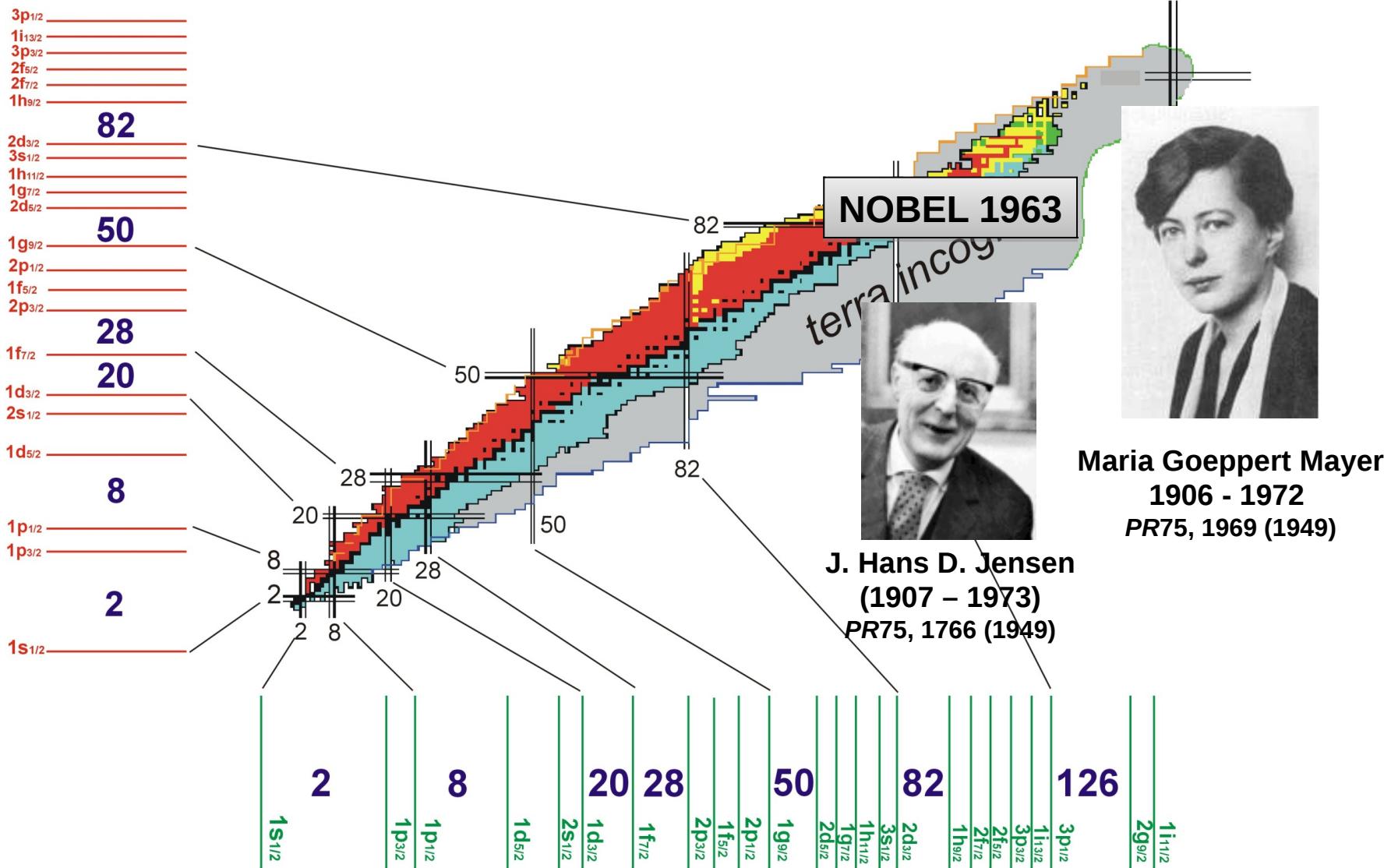
- o Large uncertainties in r-process location
- o difficult extrapolations to more exotic re

β -decay half-lives and neutron emission probabilities are different in DEFORMED and SPHERICAL nuclei

$$\begin{aligned}\tau_{\beta \text{ SPH}} &\sim 7 \times \tau_{\beta \text{ DEF}} \\ P_{n \text{ SPH}} &\sim 0.5 \times P_{n \text{ DEF}}\end{aligned}$$

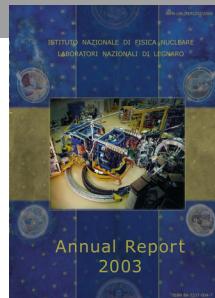
“On closed shells in nuclei”

Mayer et al., PR75, 1969 (1949) & Jensen et al., PR75 1766 (1949)



Isospin symmetry: Mirror energy differences

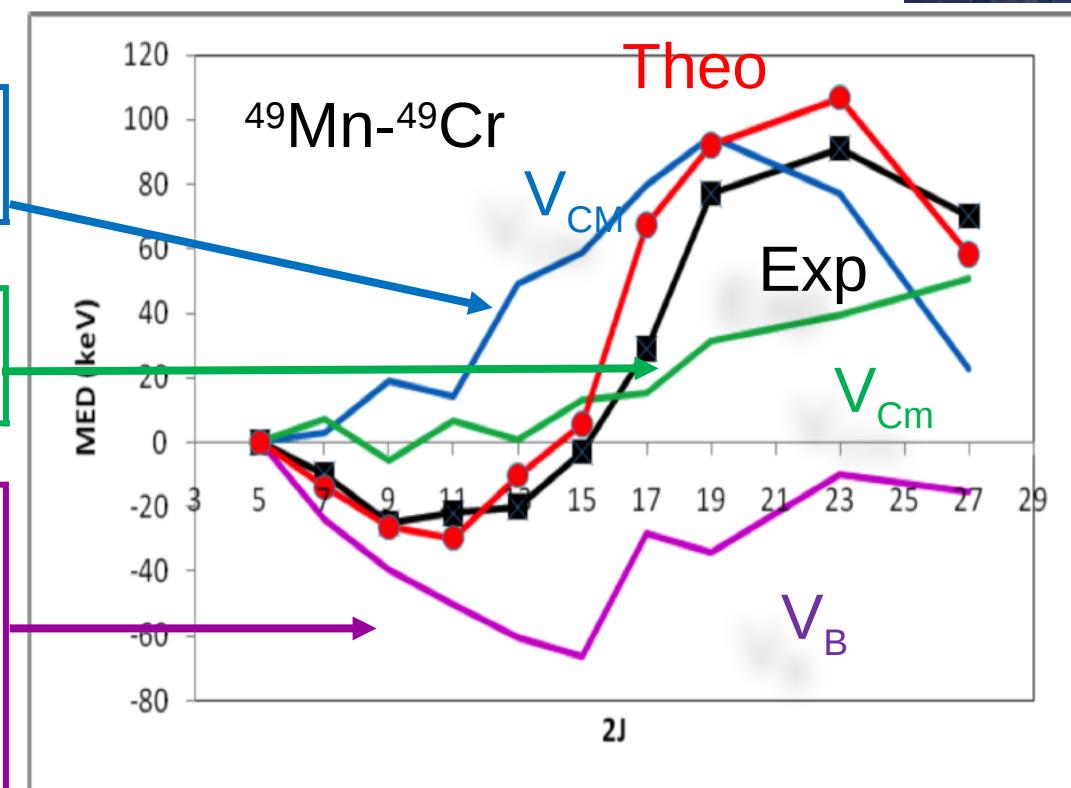
Mirror Energy Differences MED, difference in excitation energies between isobaric analog states.



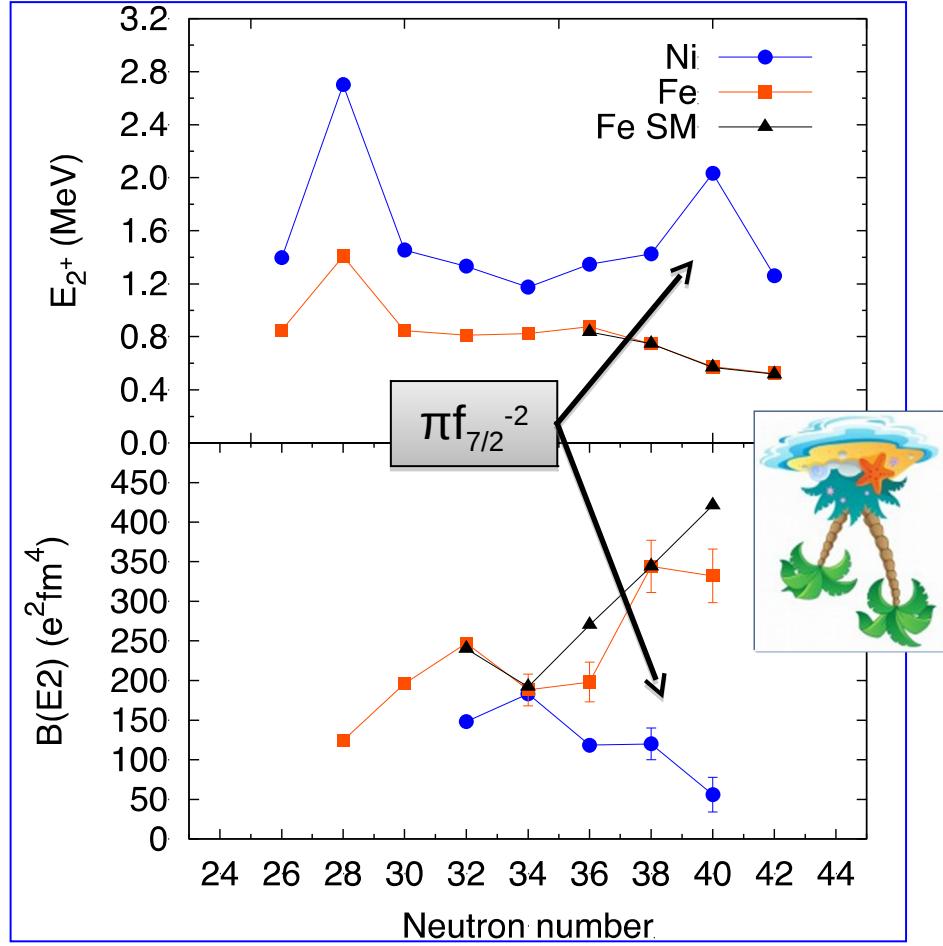
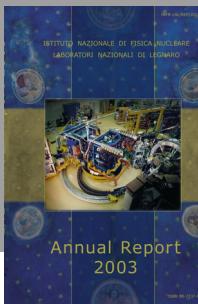
VCM: gives information on the nucleon alignment or recoupling

VCm: gives information on changes in the nuclear radius

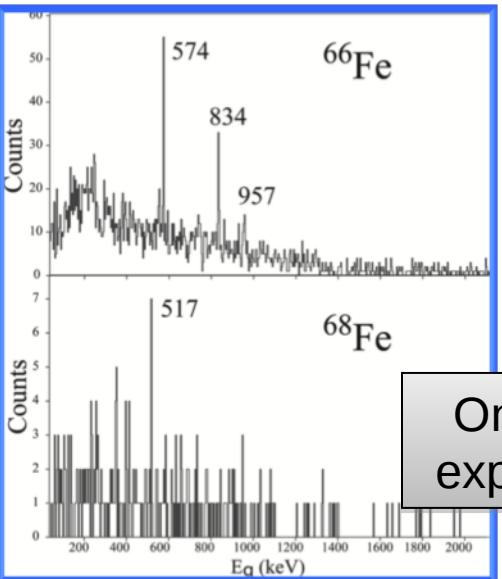
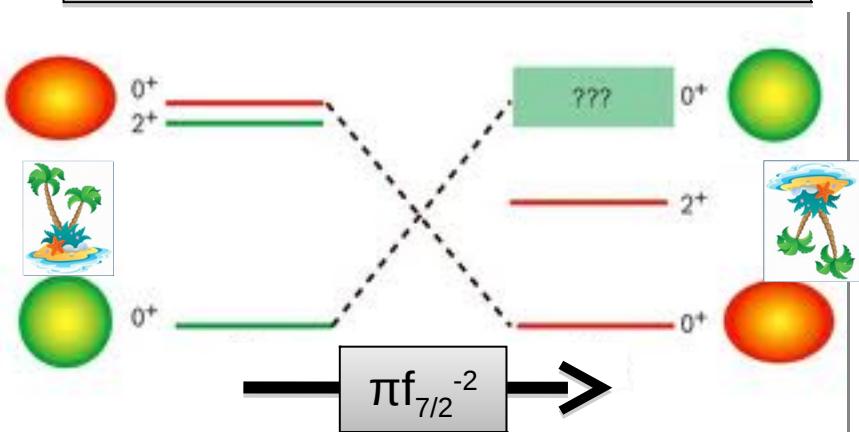
Important contribution from the isospin non conserving NN
VB term: $V(\pi[f_{7/2}f_{7/2}]_2) = 100 \text{ keV}$
of the same order as the Coulomb contributions!



New island of inversion



CLARA-PRISMA (Legnaro) 2007



One week
experiment.

S. Lunardi et al., PRC76, 034303 (2007).

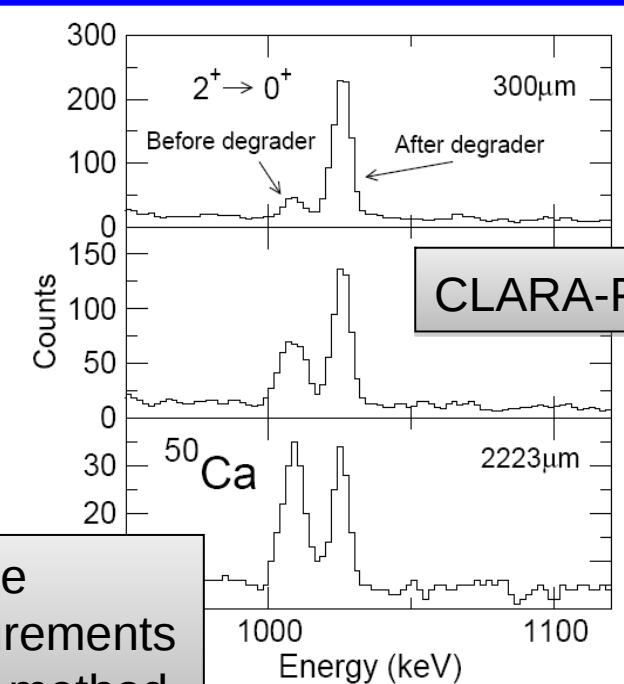
S. M. Lenzi et al., PRC82, 054301 (2010).

W. Rother et al., PRL106, 022502 (2011).

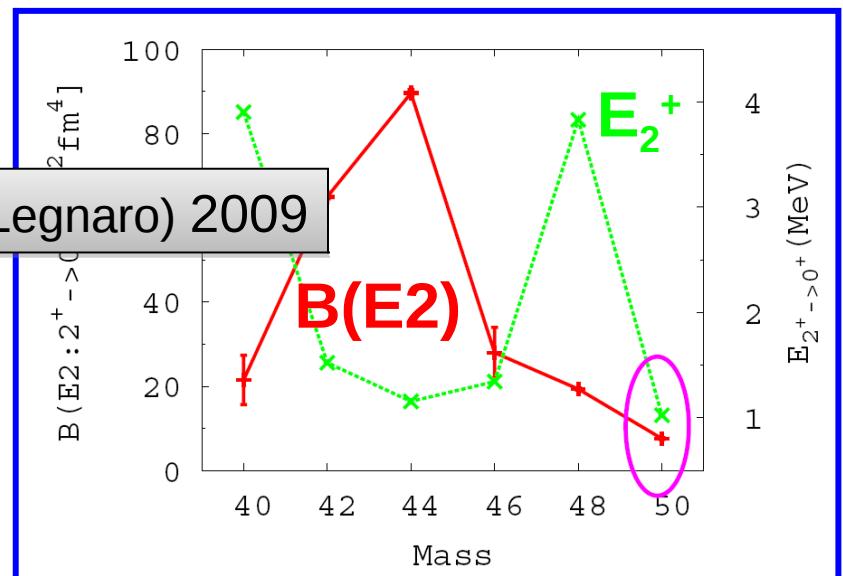
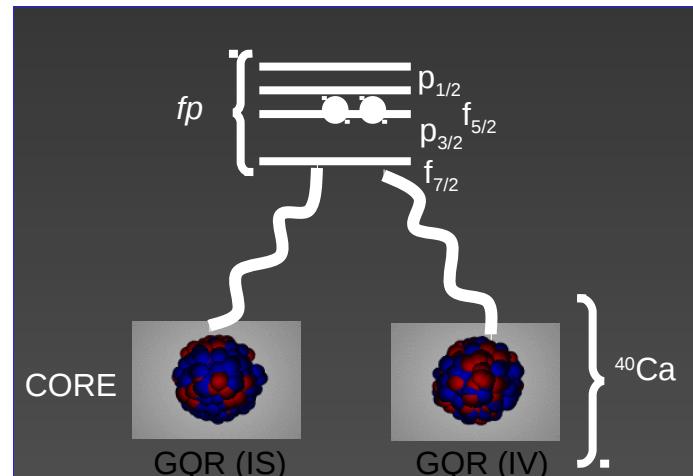
Core polarization

Effective charges take into account the core polarization, that can be understood in terms of the coupling between the particles and the collective oscillations associated with deformations of the core.

Nuclear Structure, Bohr and Mottelson.



Lifetime measurements
RDDS method



JJVD et al., PRL102, 242502 (2009).

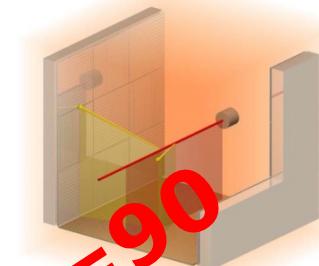
LOI from KU Leuven (Be)

Beyond ^{132}Sn : a new magic number at N=90?

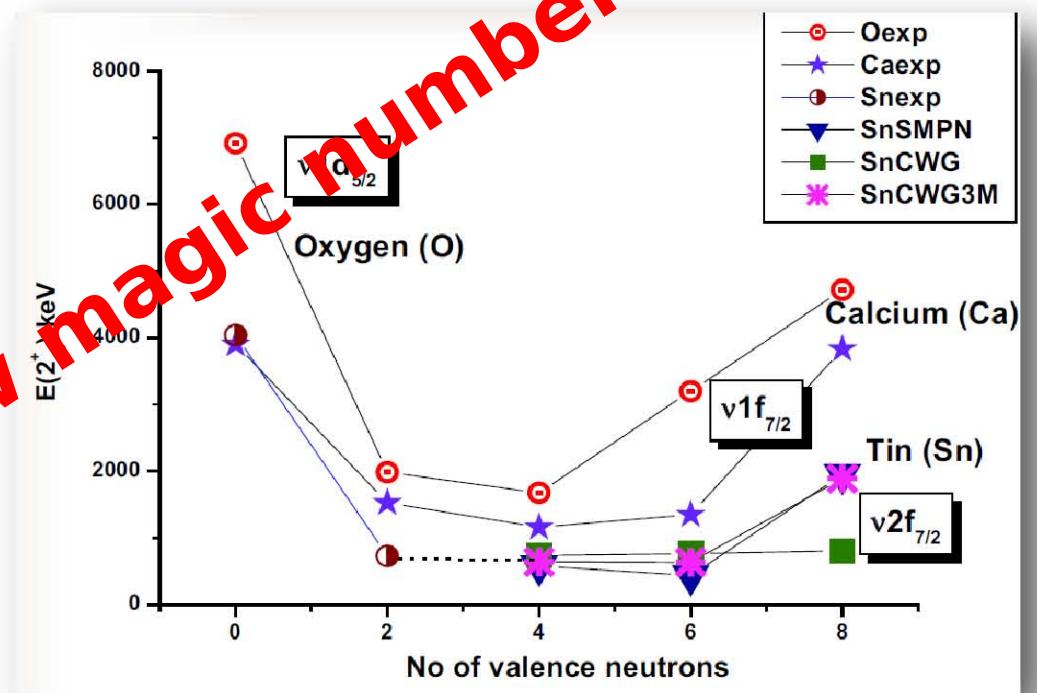
- ^{133}Sn well described by doubly-magic $^{132}\text{Sn} + \text{n}$
- Beyond?
Behaviour of $v f_{7/2}$ similar to that beyond ^{40}Ca
- Empirical or realistic interactions
Role of n-n interaction and 3-body forces

(d,p) and (p,p') in an active target

- Large luminosity without loss in energy resolution
→ measurement feasible with weak intensities
- (d,p): protons at backward angles stopped in the gas or in auxiliary detectors
- (p,p'): protons in forward direction
- γ -ray detection possible



Sarkar and Saha Sarkar JPCCS 267 (2011) 012040

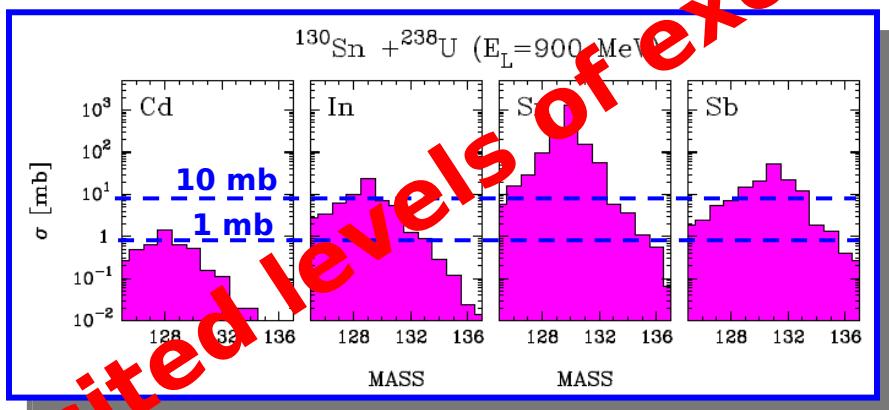


Search for new magic numbers: N=90

KU LEUVEN

NUCLEAR AND RADIATION PHYSICS

Heavy-ion binary reactions as a tool for detailed gamma spectroscopy in exotic regions: Univ. Mi (I), INP Krakow



*MAZING calculations
conservative estimates for more than 1 nucleon transi-*

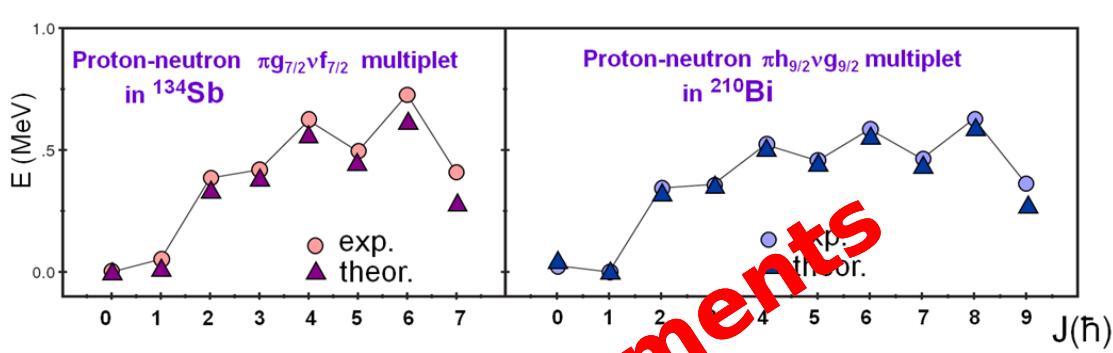
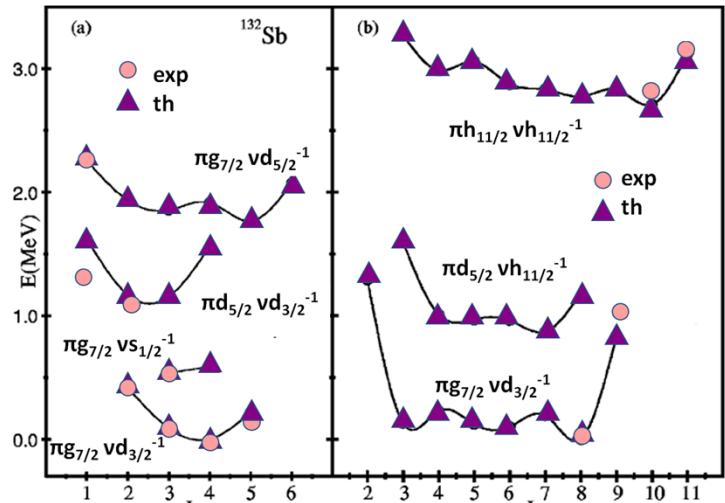
STUDY OF NUCLEI
1 and 2 nucleons
away
from ^{132}Sn

→FOCUS ON
Particle-Phonon
couplings
with 2+ (7.2 Wu) and
3- (> 7 Wu) of
 ^{132}Sn
(responsible for
quenching of
Spectroscopic Factors)

$I^\pi, B(E\lambda)$

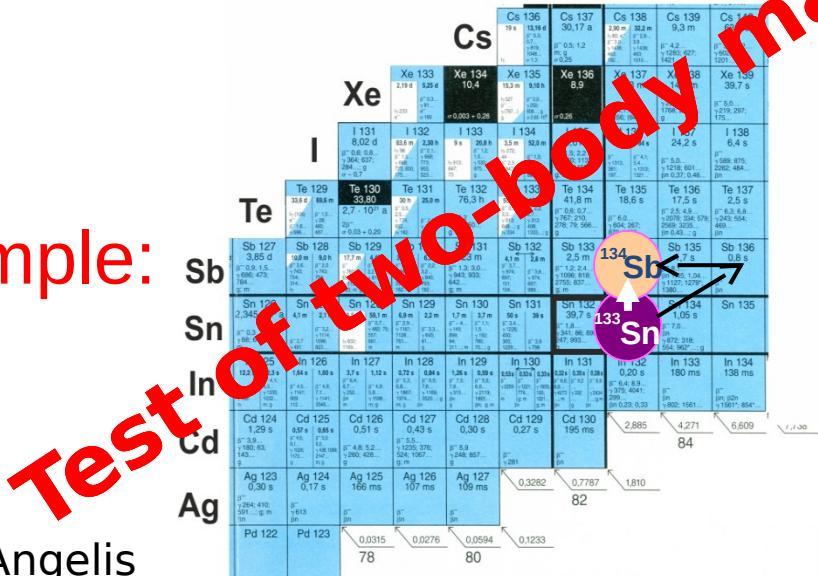
	10^7	10^7	10^6	10^5
^{129}In	1.6 10^8			
^{130}In	1.1 10^5	1.5 10^4		
^{131}In		2.8 10^3		
^{132}In		1.9 10^3		
^{133}In		-		

Structure of Sb nuclei around ^{132}Sn as a testing ground for realistic shell model interactions INP Krakow (PL)



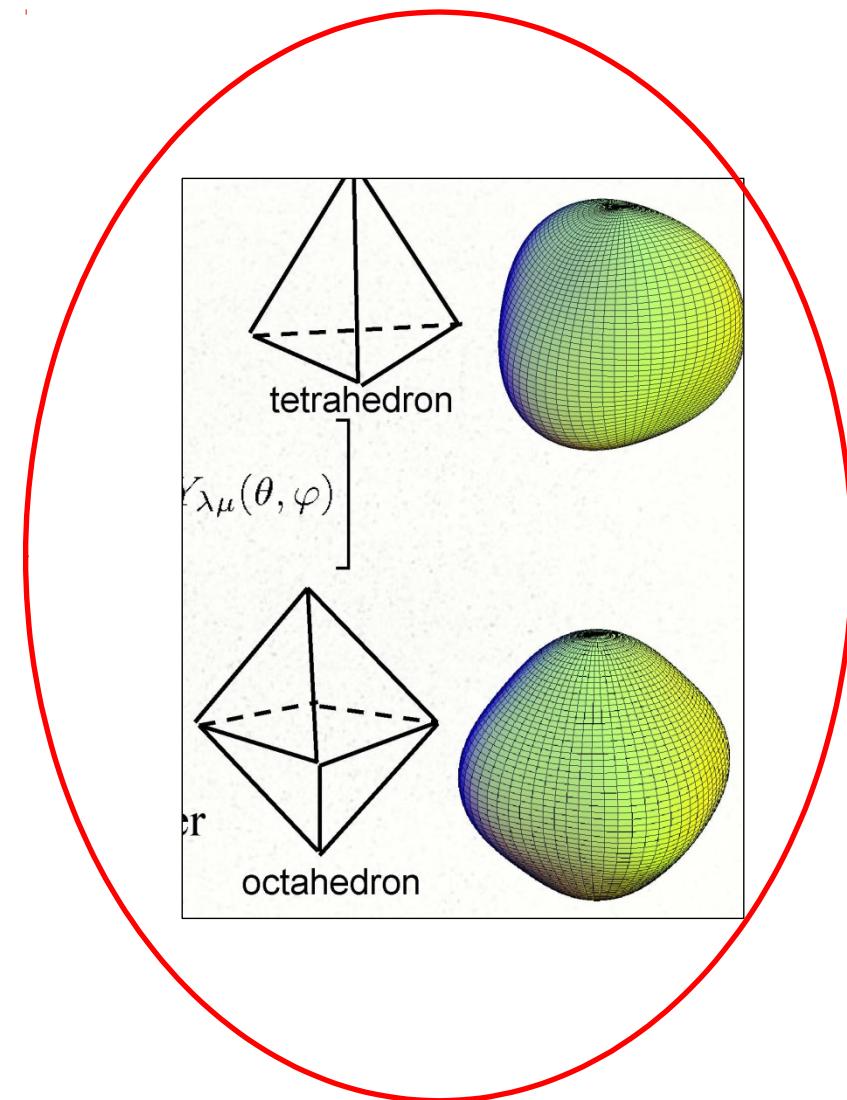
L. Coraggio, A. Covello, A. Gargano, N. Itaco, PRC **80**, 021305(R) (2009)

L. Coraggio et. al. PRC **66**, 064311 (2002)



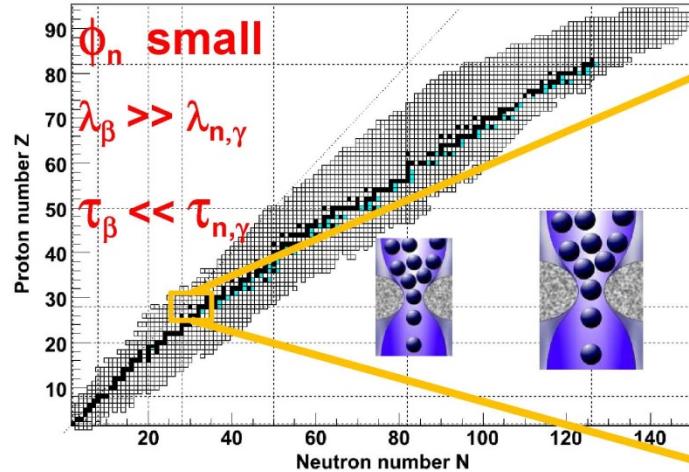
Cluster transfer for higher selectivity

High order Exotic deformations

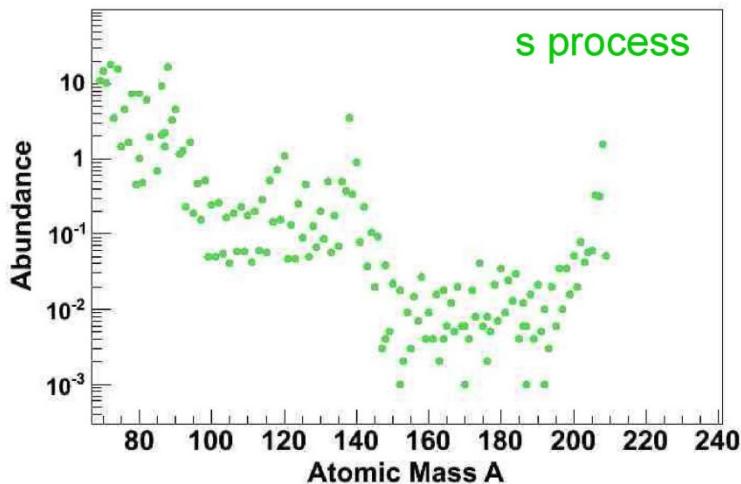
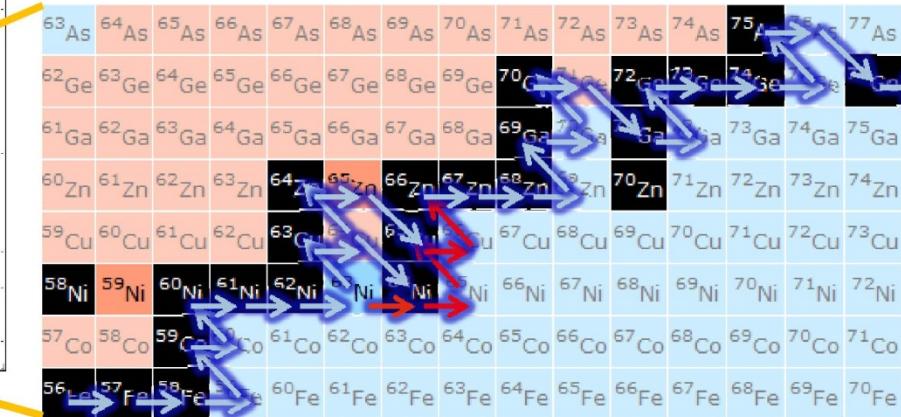


s-process nucleosynthesis and stellar n-flux

Stellar nucleosynthesis: the s process



s process in AGB (Red Giant) Stars



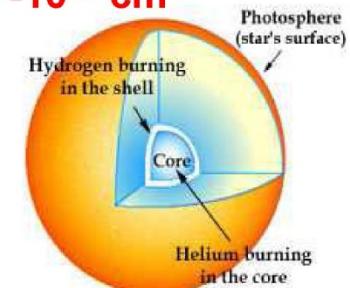
core He-burning

$3\text{--}3.5 \cdot 10^8 \text{ K}$
 $kT = 25 \text{ keV}$
 10^6 cm^{-3}

shell C-burning

$\sim 1 \cdot 10^9 \text{ K}$
 $kT = 90 \text{ keV}$
 $10^{11}\text{--}10^{12} \text{ cm}^{-3}$

$^{22}\text{Ne}(\alpha, n)$



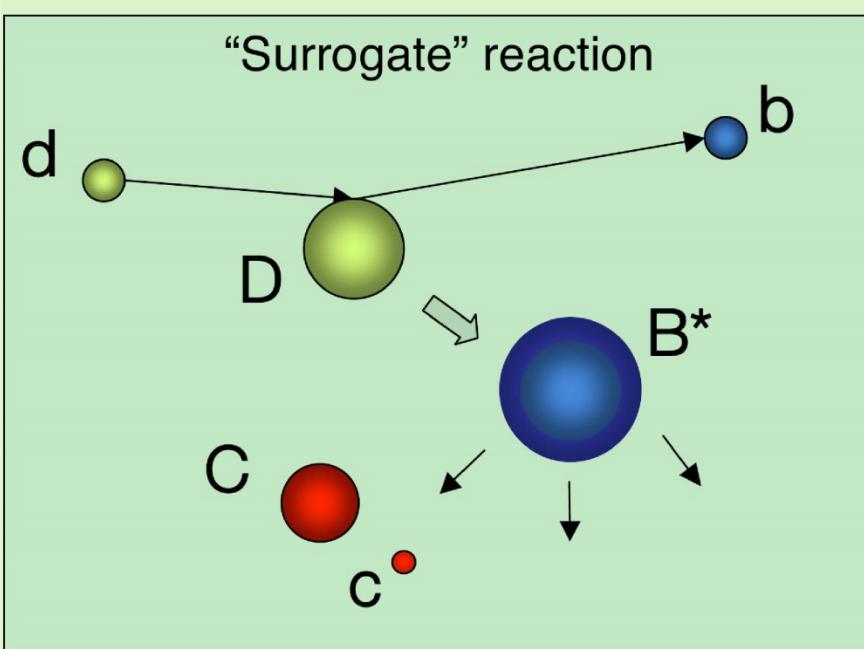
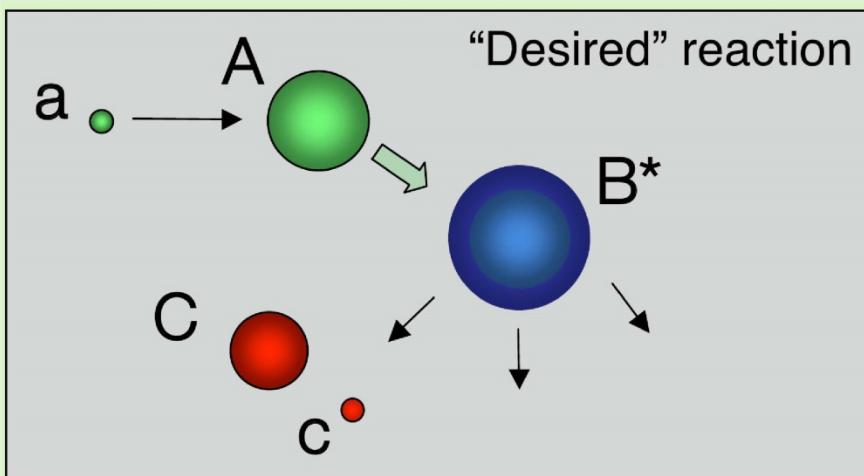
Arlandini et al., Ap. J. 525 (1999)

Raiteri et al., Ap. J. 419 (1993)

Gallino et al., Ap. J. 497 (1998)

s-process nucleosynthesis and stellar n-flux

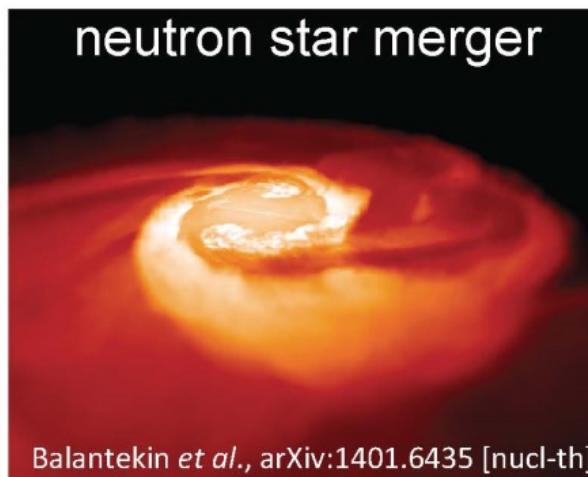
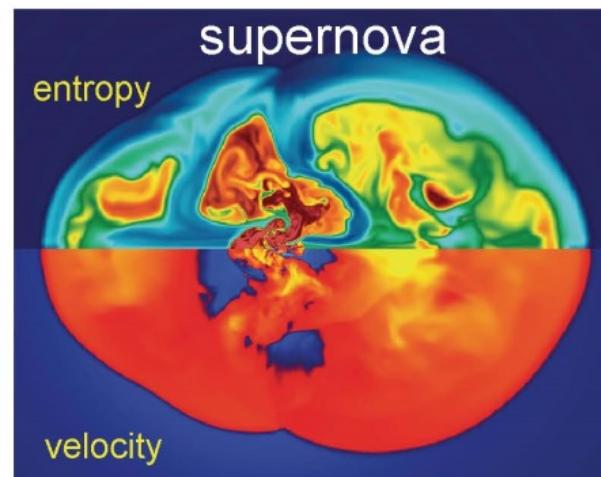
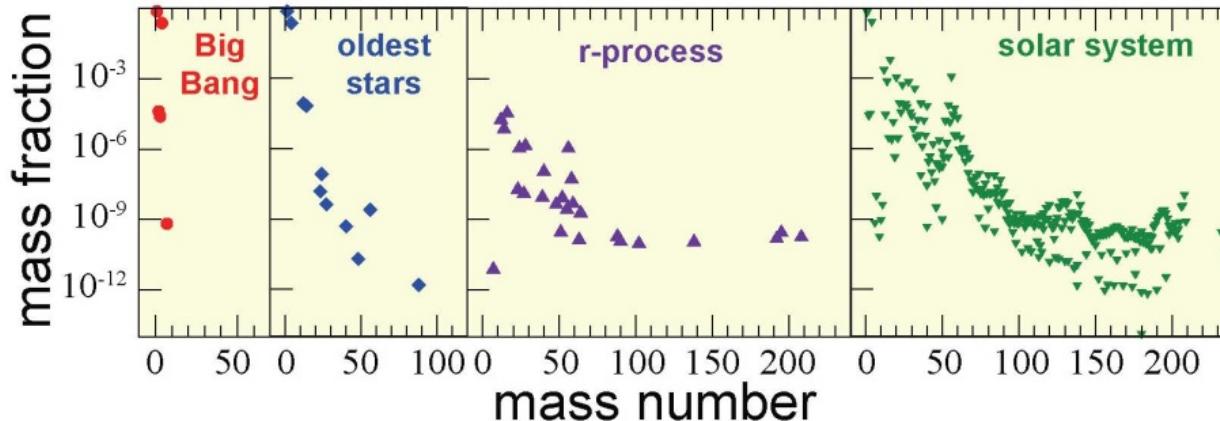
Indirect Determination of Cross Sections



The Surrogate Nuclear Reactions approach is an indirect method for determining XS of CN reactions difficult to measure directly.

r-process nucleosynthesis

The origin of elements



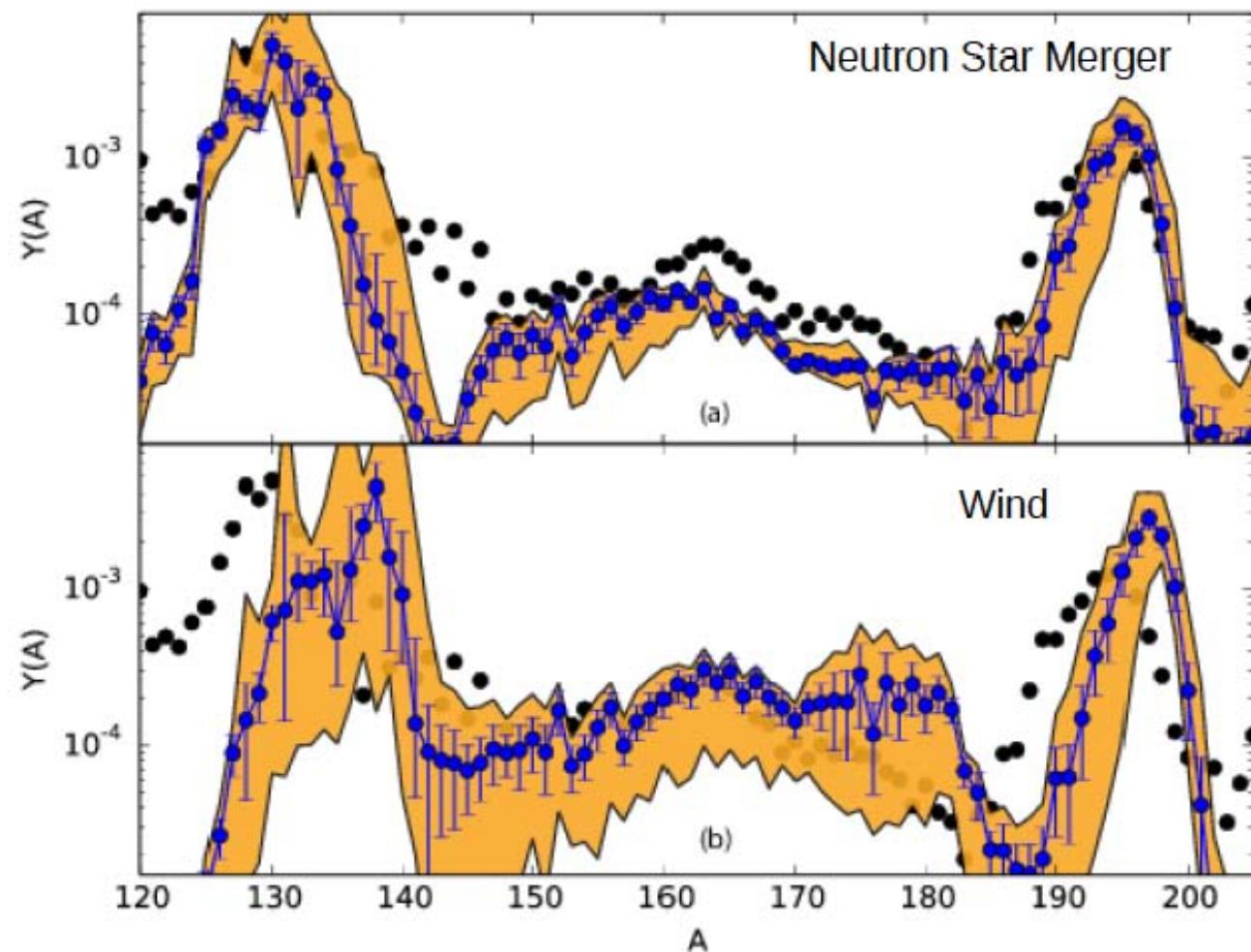
Balantekin *et al.*, arXiv:1401.6435 [nucl-th]

Neutrinos not only play a crucial role in the dynamics of these sites, but they also control the value of the electron fraction, the parameter determining the yields of the r-process.

Possible sites for the r-process

r-process nucleosynthesis

Estimated Final Abundances With Uncertainties

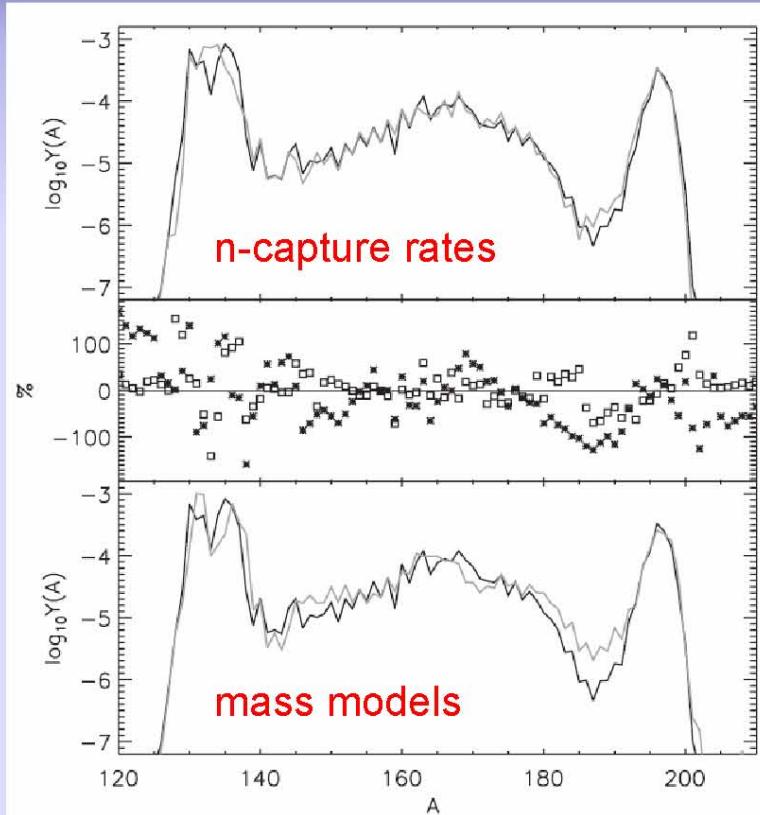
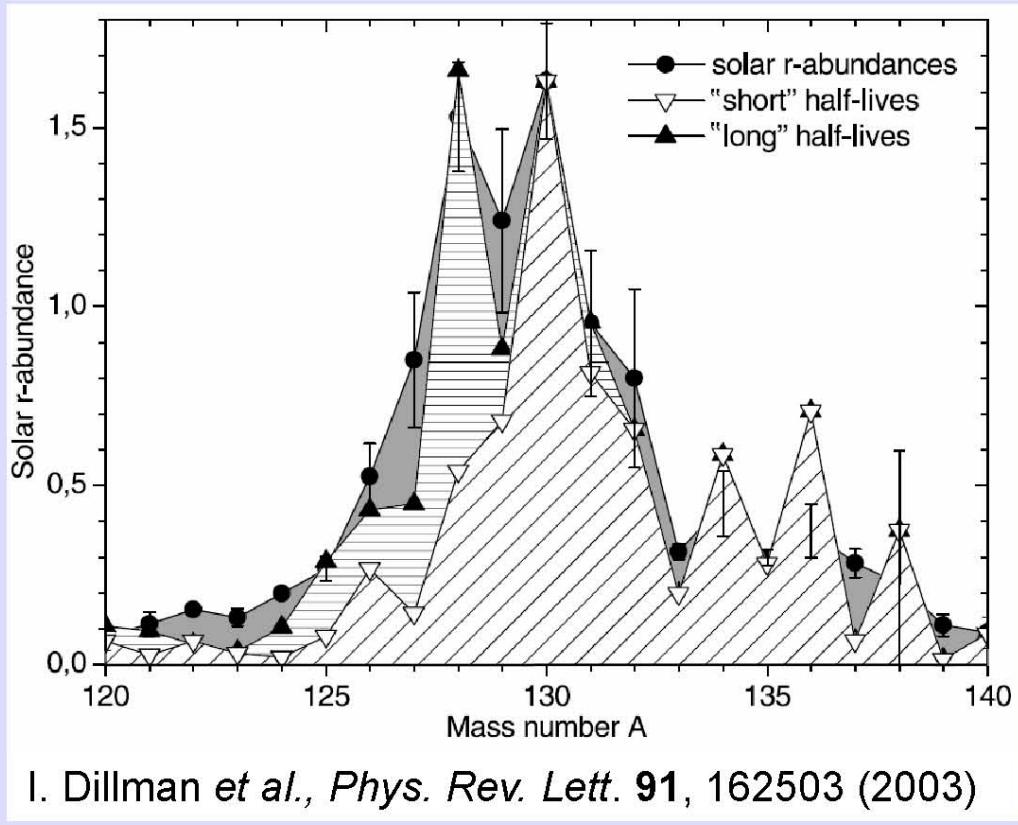


Variations in masses of N~82 and N~126 nuclei of +/- 1 MeV

Mumpower⁶¹ et al. (in prep)

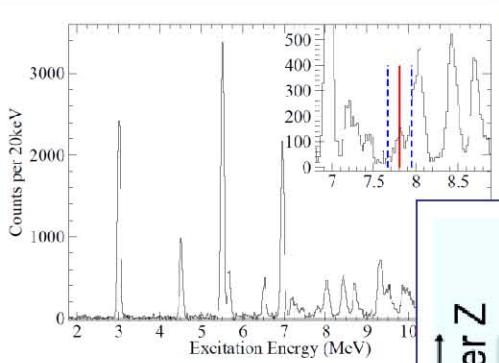
Sensitivities to global structure, and to individual n-capture rates

Adjustment of TBME to reproduce 1+ state in ^{130}In

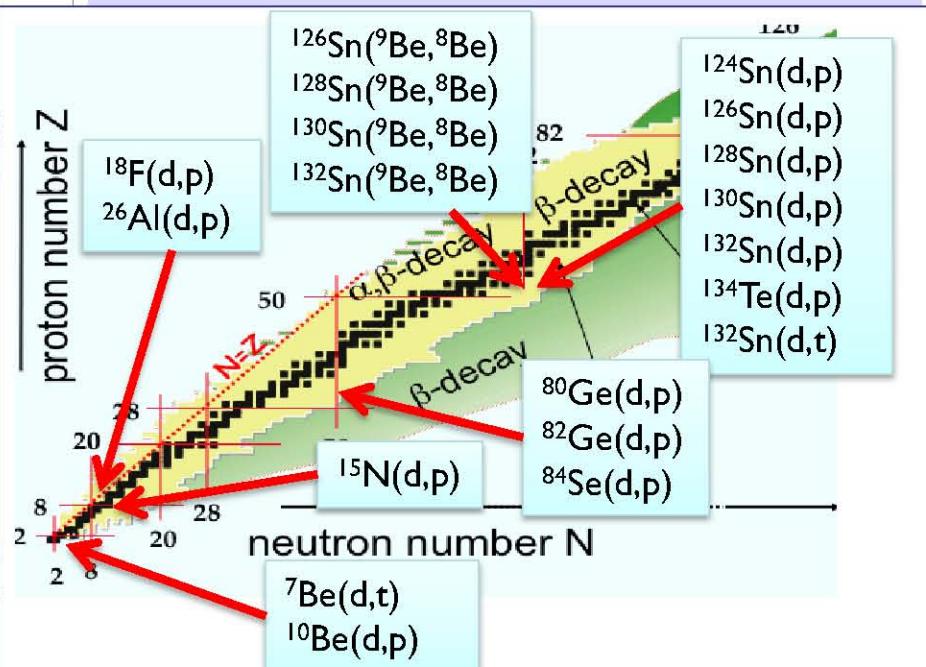
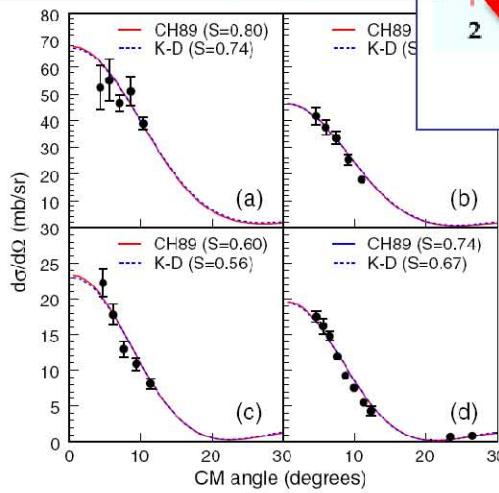


52	^{130}Te	^{131}Te	^{132}Te	^{133}Te	^{134}Te	^{135}Te	^{136}Te	^{137}Te	^{138}Te	^{139}Te
51	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb	^{133}Sb	^{134}Sb	^{135}Sb	^{136}Sb	^{137}Sb	^{138}Sb
50	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn	^{133}Sn	^{134}Sn	^{135}Sn	^{136}Sn	^{137}Sn
49	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In	^{133}In	^{134}In	^{135}In	^{136}In
	^{131}Cd	^{132}Cd	^{133}Cd	^{134}Cd	^{135}Cd					
	83	84	85	86	87					

LOI ORNL (USA) Surrogate method

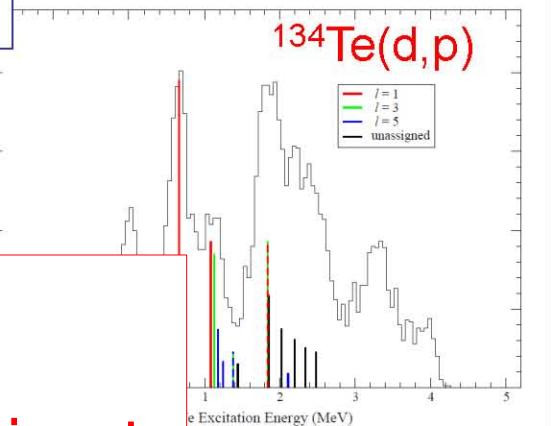
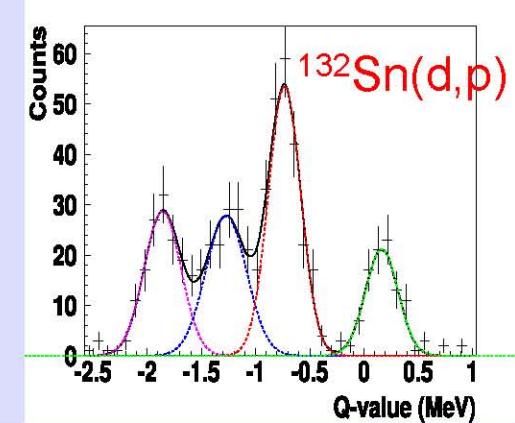
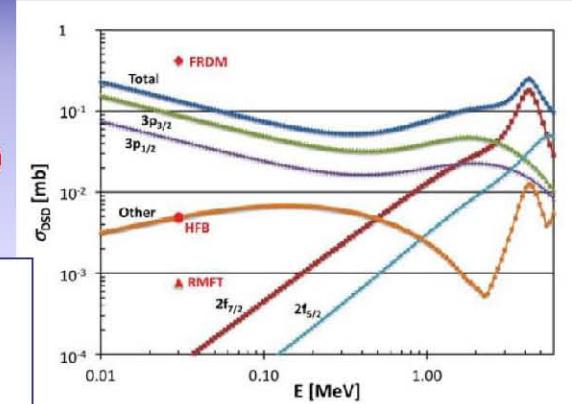


$^{10}\text{Be}(\text{d},\text{p})$



Transfer reactions to constrain capture cross sections (direct)

Constraint of DSD n-capture via $^{130}\text{Sn}(\text{d},\text{p})$



Structure of r-process nuclei, beyond

SPES LOI:

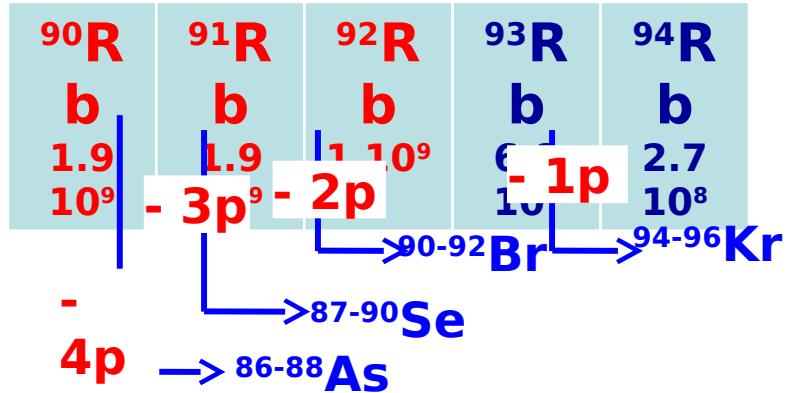
Heavy-ion binary reactions as a tool
for detailed γ -spectroscopy in
exotic regions

S. Leoni, A. Maj, ...

Multi-Nucleon Transfer at 5-10 MeV/A

AGATA/GALILEO
Scintillators (LaBr₃/PARIS)
PRISMA

SPES Beams on ²³⁸U target



SPES LOI:

Search for deformed oblate structures in ⁹⁶Y by γ -spectroscopy and cluster transfer reactions with a ⁹⁵Sr SPES beam

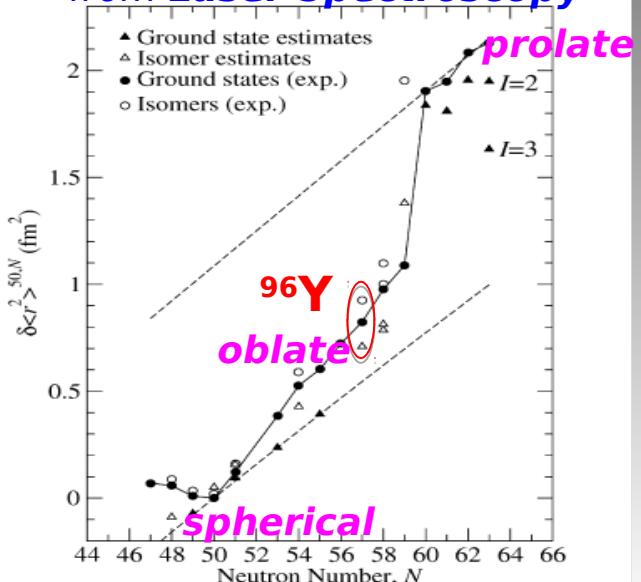
B. Fornal, S. Leoni, ...

Yttrium isotopic chain (A=96-100) shows coexistence of Spherical and Deformed shapes

(FISSION data studio, Krakow, Milano)
Cluster Transfer Reactions with ⁷Li target
Sr beams (5 MeV/A, > 10⁶ pps)



Ground State Properties from Laser Spectroscopy



Spettroscopia γ

Simmetrie fondamentali



ONE OF THE CHALLENGES: REFLECTION ASYMMETRIC NUCLEI AND STATIC ELECTRIC DIPOLE MOMENT



The lopsided nuclei, described today (May 8) in the journal *Nature*, could be good candidates for researchers looking for new types of physics beyond the reigning explanation for the bits of matter that make up the universe (called the [Standard Model](#)), said study author [Peter Butler](#), a physicist at the University of Liverpool in the United Kingdom.

The findings could help scientists search for physics beyond the Standard model, said [Witold Nazarewicz](#). An *electric dipole moment would provide a way to test extension theories to the Standard Model, such as supersymmetry, which could help explain why there is more matter than antimatter in the universe.*

ONE OF THE CHALLENGES: REFLECTION ASYMMETRIC NUCLEI AND STATIC ELECTRIC DIPOLE MOMENT

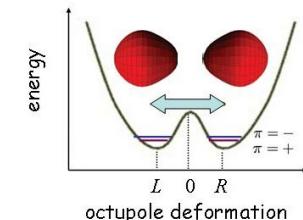
V Spevak, N Auerbach, and VV Flambaum
PR C 56 (1997) 1357

Schiff moment:

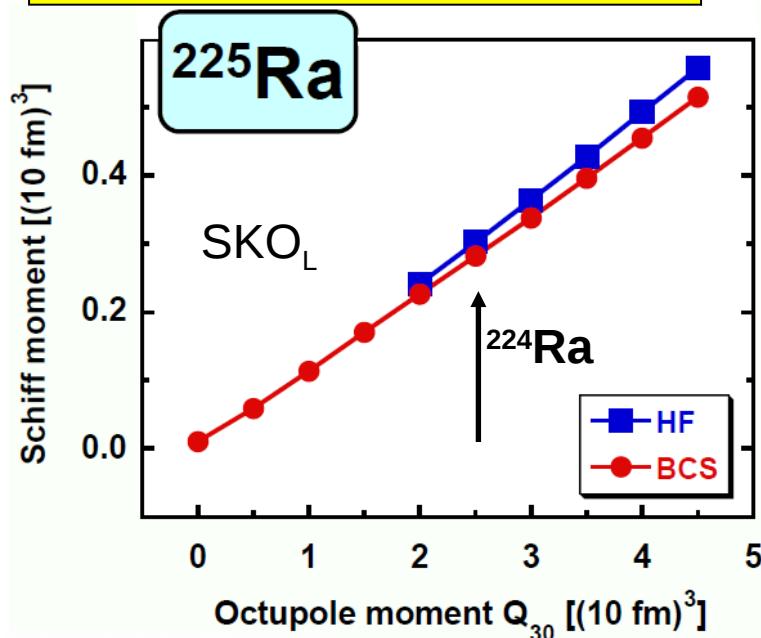
$$S = -2 \frac{J}{J+1} \frac{\langle \hat{S}_z \rangle \langle \hat{V}_{PT} \rangle}{\Delta E}$$

related to Q_3

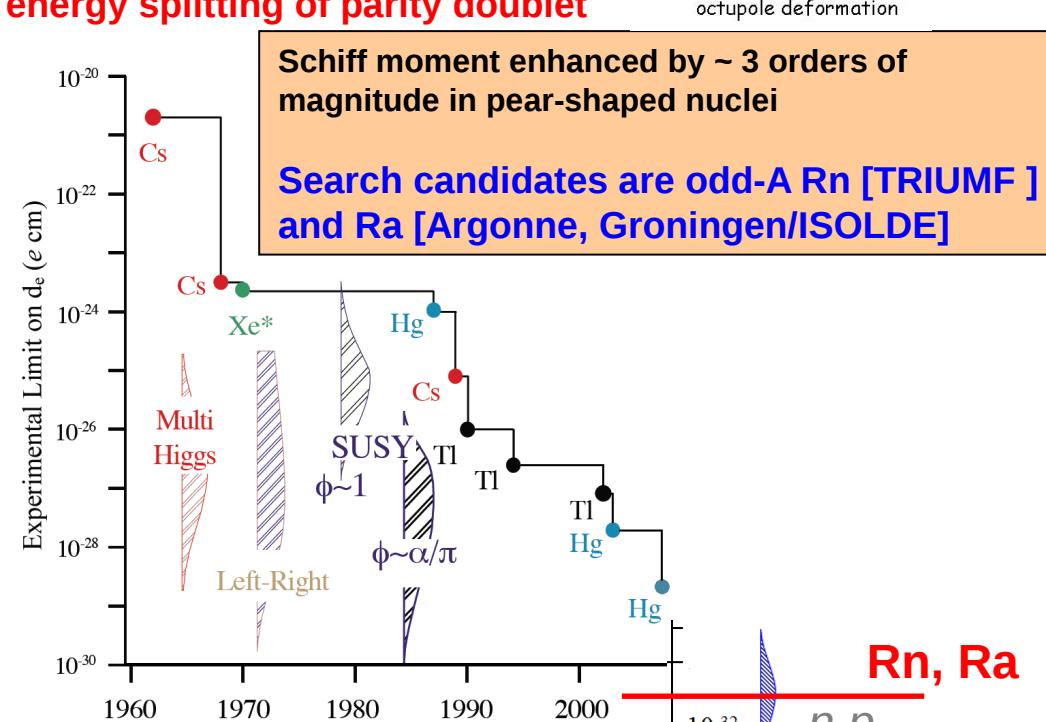
P,T-violating n-n interaction



J Dobaczewski (Trento, 2010)



Measure: Q_3 in even-A Rn, Ra
 ΔE in odd-A Rn



Rn, Ra

