Heavy-Ion Binary Reactions as a Tool for Detailed Gamma Spectroscopy in Exotic Regions

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SPES
exotic beams for science

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LOI Collaboration

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Padova University and INFN
D. Bazzacco, E. Farnea, S. Lenzi, S.Lunardi, G. Montagnoli, D.Montanari, F.Scarlassara, C.Ur, et al.

Torino University and INFN
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IFIC, CSIC-University of Valencia, Spain
A. Gadea, …

Krakow, Poland
A. Maj, P. Bednarczyk, B. Fornal, M. Kmiecik, M. Ciemala et al.,

Ruder Boskovic Institute, Zagreb
S. Szilner, T. Mijatovic et al.

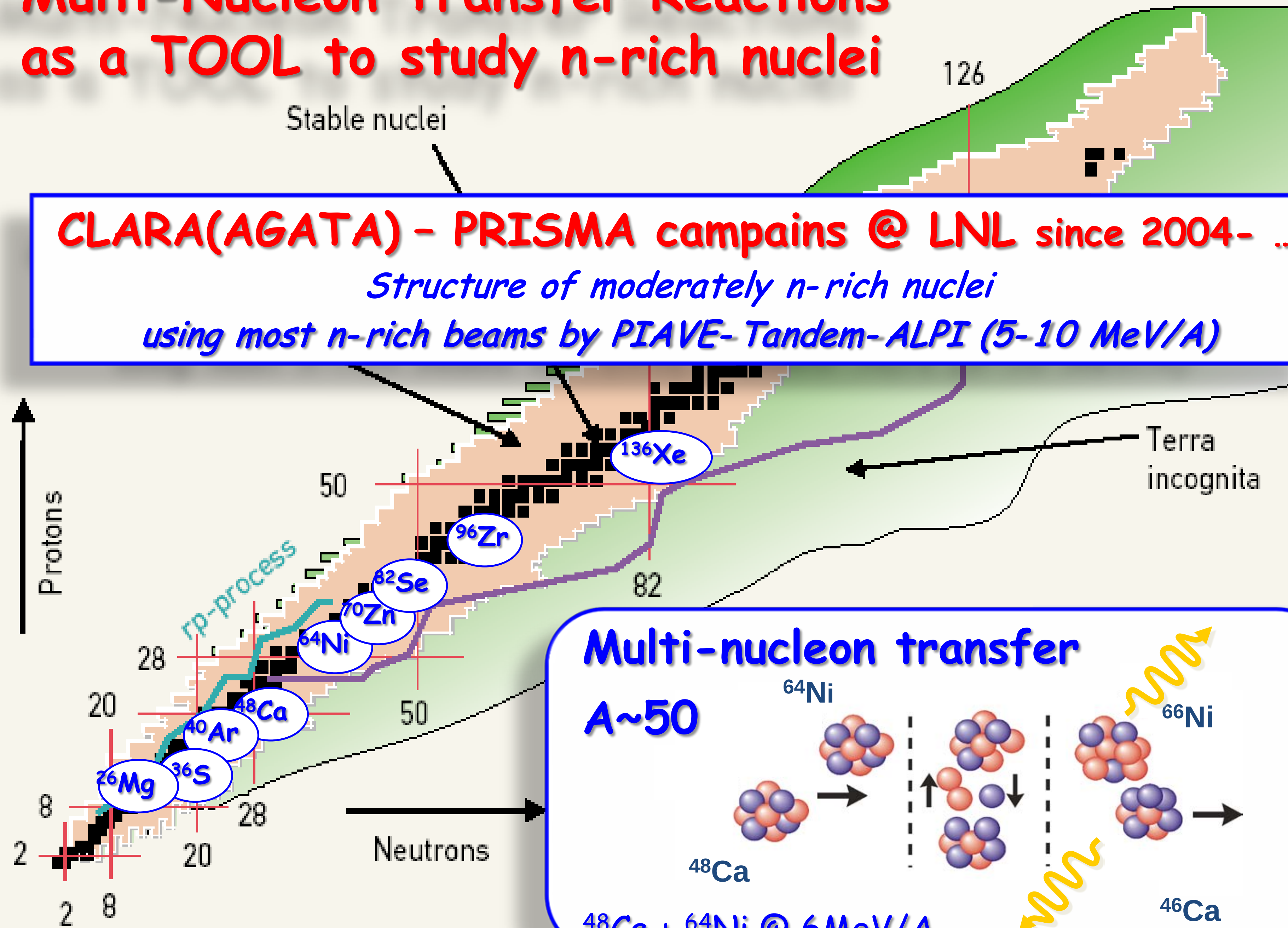
AGATA- PRISMA collaborations

Multi-Nucleon Transfer Reactions as a TOOL to study n-rich nuclei

CLARA(AGATA) – PRISMA campains @ LNL since 2004- …

Structure of moderately n-rich nuclei

using most n-rich beams by PIAVE-Tandem-ALPI (5-10 MeV/A)

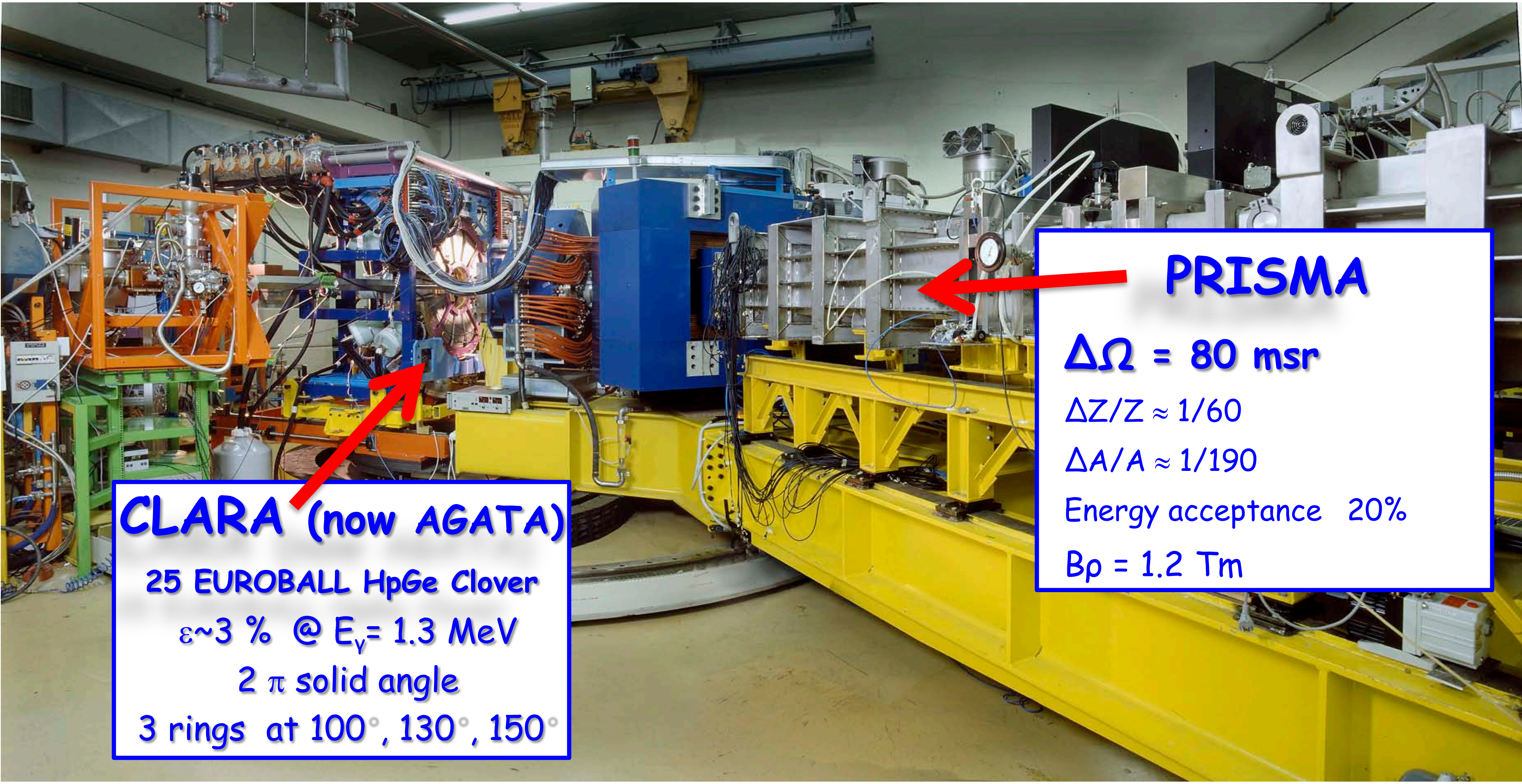


Multi-nucleon transfer

A~50

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

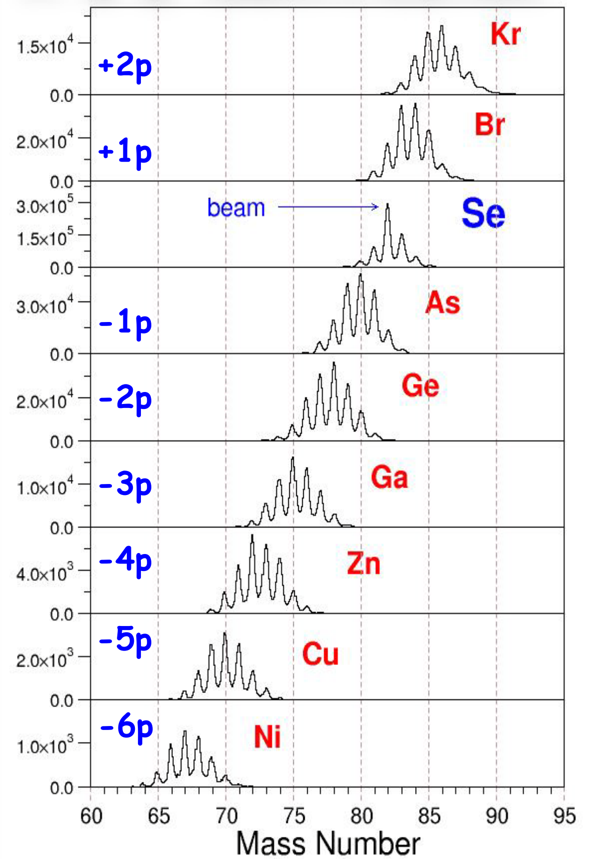
CLARA (ex-EUROBALL)/AGATA – PRISMA setup
Legnaro National Laboratory INFN (Italy)



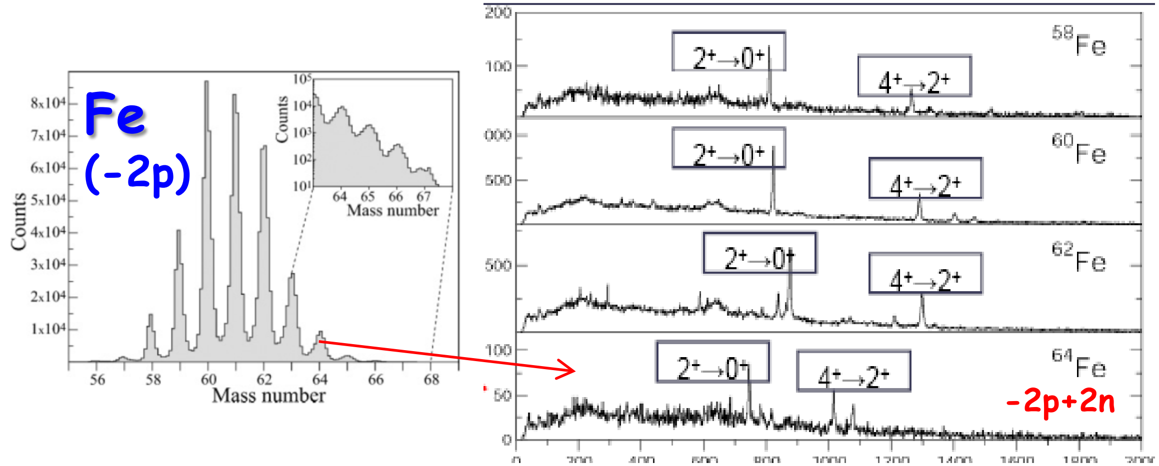
High-Efficiency $\gamma-$particle coincidence Measurements

First Excited States of Exotic Nuclei

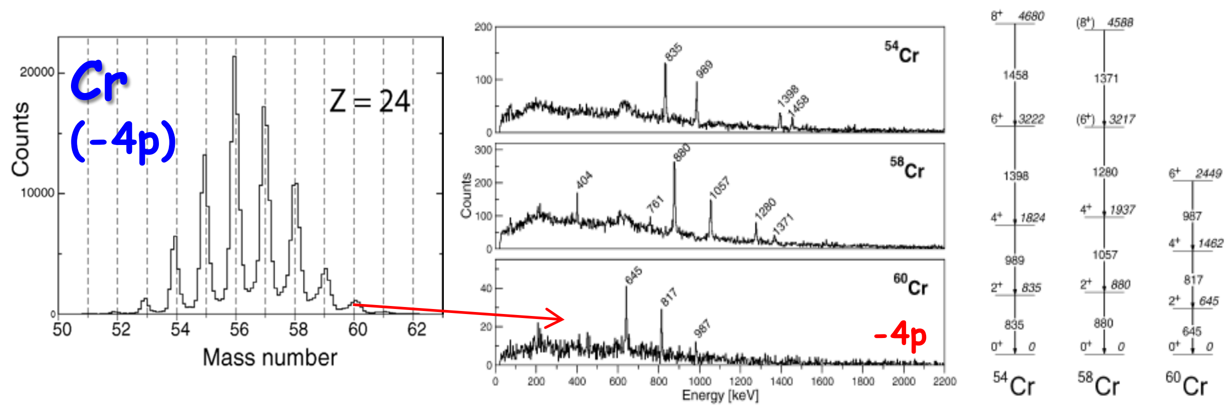
A & Z identification



Shape Evolution in Cr and Fe isotopes



$^{64}Ni + ^{238}U$ @ 6.3 MeV/A

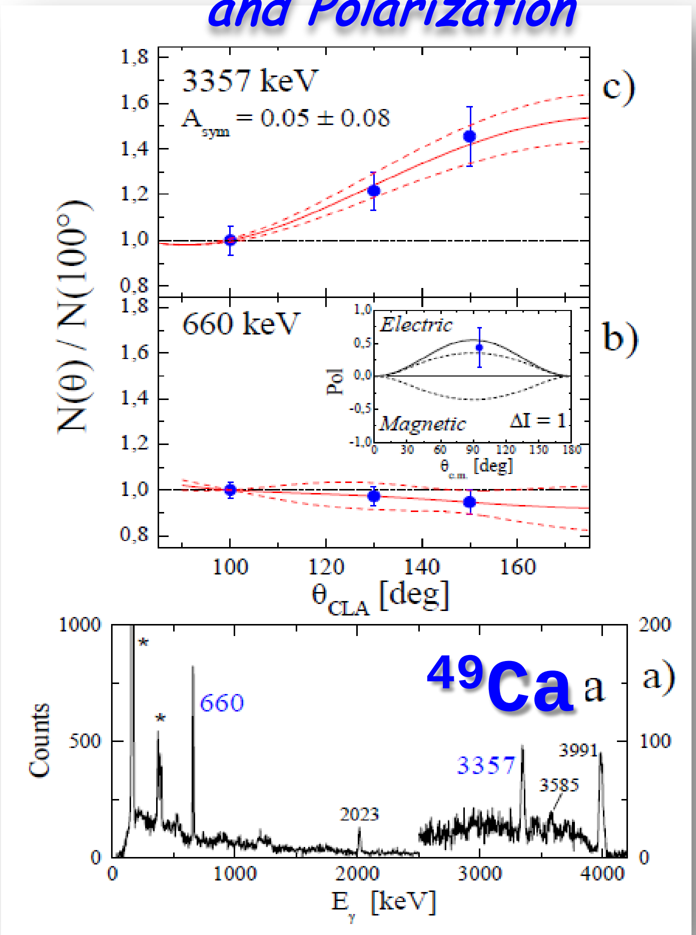


Beams ~ 10^9 pps

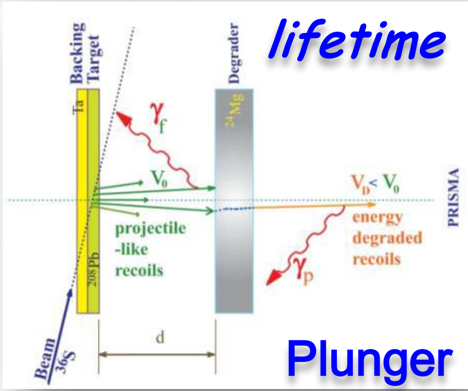
S. Lunardi et al., PRC76(2007)034303
N. Marginean et al., PLB633(2006)696

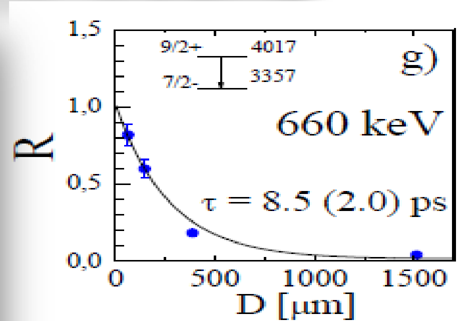
Complete γ-Spectroscopy: I^{π} and B(Eλ)

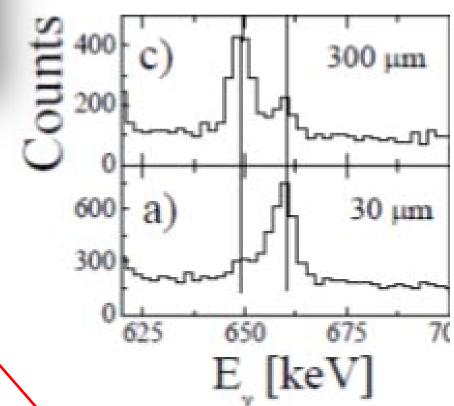
$^{48}Ca + ^{64}Ni$ @ 6 MeV/A
Angular Distribution
and Polarization

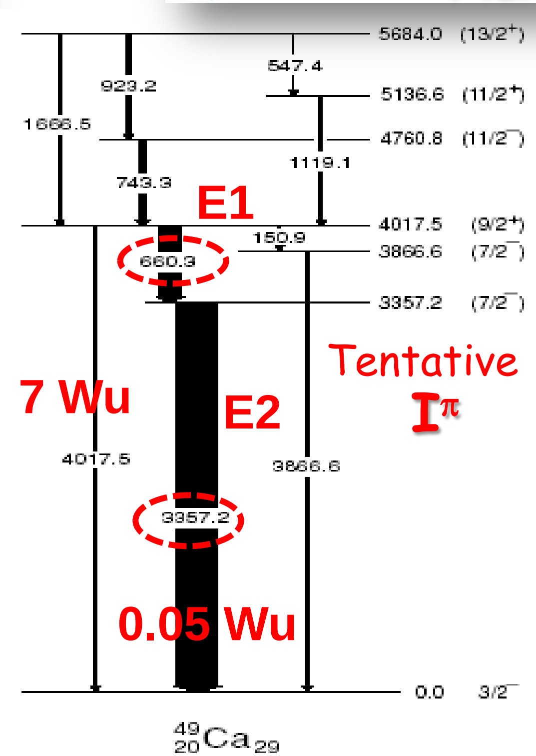


lifetime









9/2$^+$

7/2$^-$

$3^- \otimes p_{3/2}$: coupling
octupole Phonon -
single particle

$[f_{7/2}^{-1}, (p_{3/2}^2)_0]_{7/2^-}$
single particle

MNT Reactions: Strong SPIN Alignment perpendicular to reaction plane

D. Montanari et al., submitted for publication and J.J. Valiente-Dobon et al., PRL102(2009)242502

FIRST EXAMPLE of Multi-Nucleon transfer with RIB

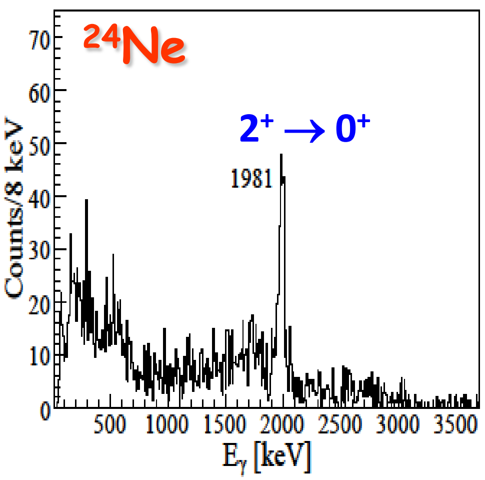
$^{24}Ne + ^{208}Pb$ *@ 7.9 MeV/A*

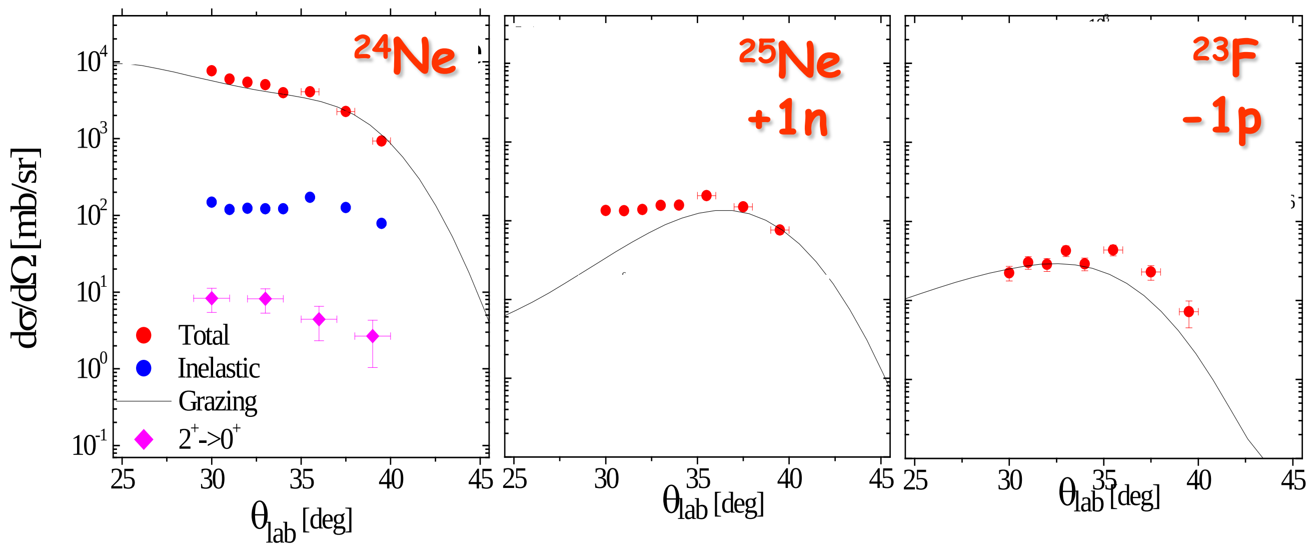
EXOGAM + VAMOS

SPIRAL Beam ^{24}Ne ~ 1.5 10^5 pps

Study of Reaction Dynamics and First excited states mostly ONE nucleon transfer channels

G. Benzoni, F. Azaiez et al., EPJA45(2010)287





*Semiclassical model **GRAZING** gives **reasonable agreement** also for reactions with radioactive beams*

G. Pollarolo. A.Winther, Nucl.Phys.A594 (1995)203

Multi-Nucleon transfer with SPES beams @ 5-10 MeV/A

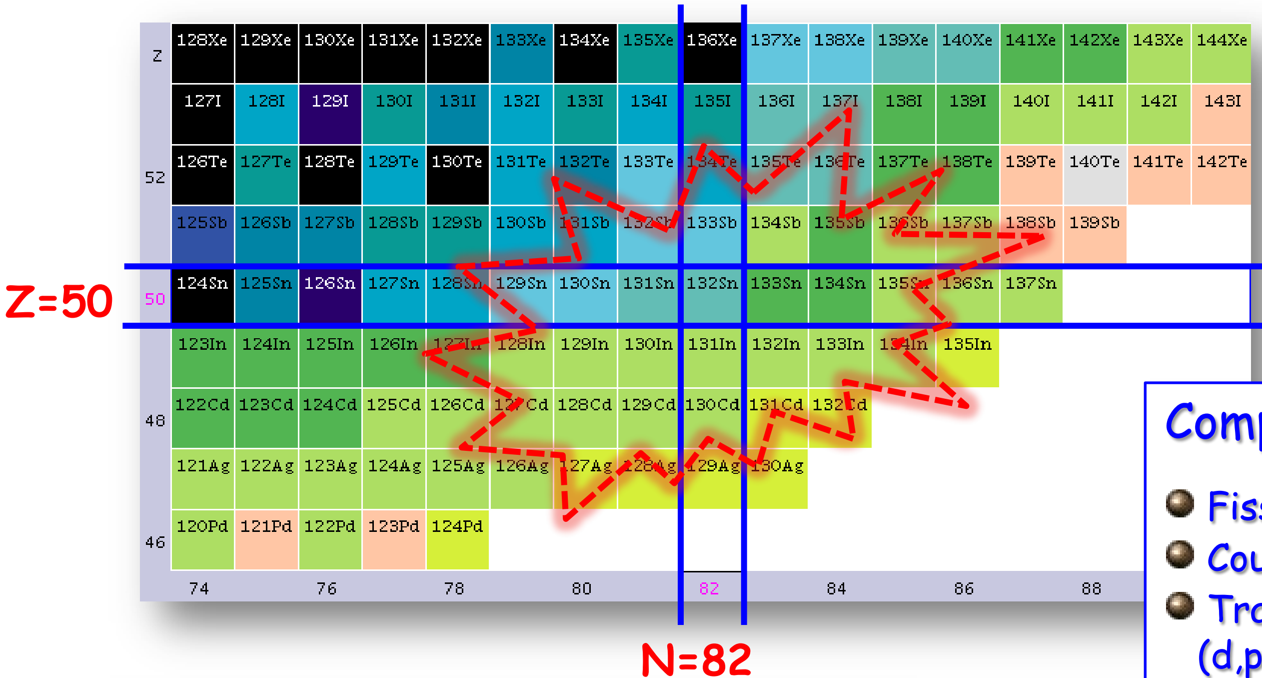
Physics Cases with 10^8-10^9 pps

- γ spectroscopy around ^{132}Sn
- r-process nuclei beyond N=50

SIMILAR/BETTER quality as today experiments (with 10^9 pps)

→ *factor ≥ 3 higher detection efficiency (CLARA →AGATA)*
→ *factor 3 longer beam time (1 week →3 weeks)*

CASE 1: the magicity of ^{132}Sn



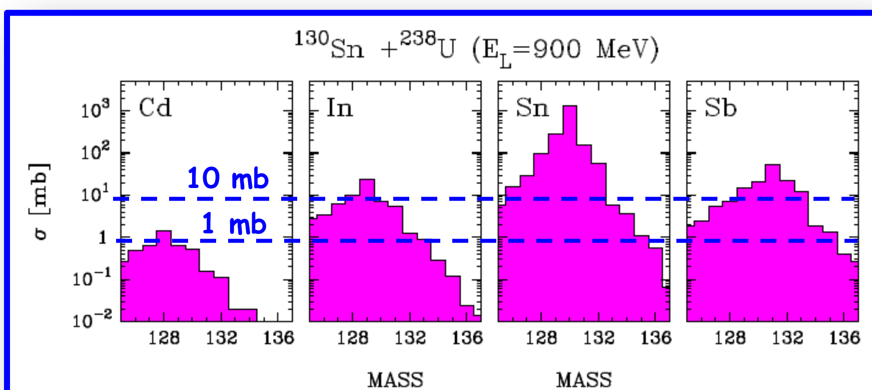
STUDY OF

- Single particle states
- particle-phonon couplings
- high spins

I^{π}, $B(E\lambda)$

Complementary to

- Fission and β-decay
- Coulomb excitation
- Transfer with light targets (d,p), (d,t), …



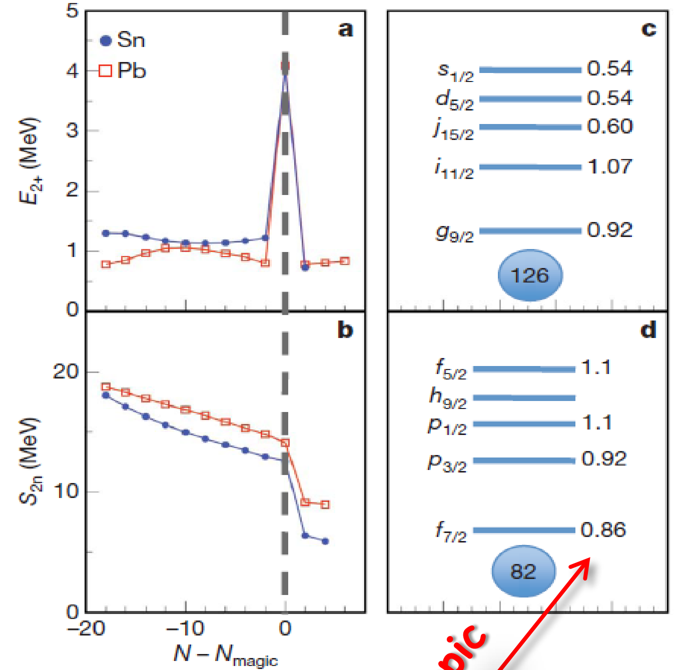
GRAZING calculations
Conservative estimates for more than 1 nucleon transfer

SPES Beams

^{130}Sn 1.6 10^8	^{131}Sn 6.8 10^7	^{132}Sn 3.1 10^7	^{133}Sn 2.8 10^6	^{134}Sn 5 10^5
^{129}In 1.1 10^5	^{130}In 1.5 10^4	^{131}In 2.8 10^3	^{132}In 1.9 10^3	^{133}In -
^{128}Cd 2.9 10^3	^{129}Cd 2.5 10^2	^{130}Cd -		

^{132}Sn – ^{133}Sn

Sb	131Sb	132Sb	133Sb	134Sb	135Sb	1:
Sn	130Sn	131Sn	132Sn	133Sn	134Sn	1:
In	129In	130In	131In	132In	133In	1
Cd	128Cd	129Cd	130Cd	131Cd	132Cd	



^{208}Pb

^{132}Sn

Spectroscopic factors

Collective Properties of ^{132}Sn:

2^+: E = 4041 keV, B(E2) = 7.2 Wu

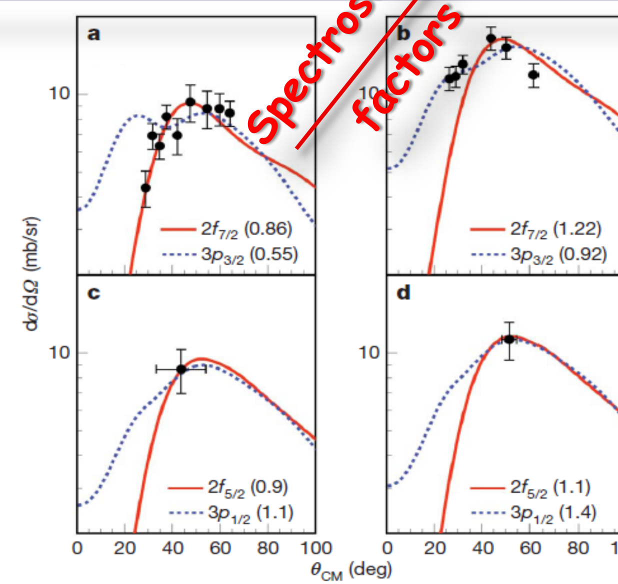
3^-: E = 4352 keV, B(E3) > 7 Wu

Complemenary INFOs from MNT

Single particle states in ^{133}Sn:

Low beam Intensity: ~ 10^5 pps

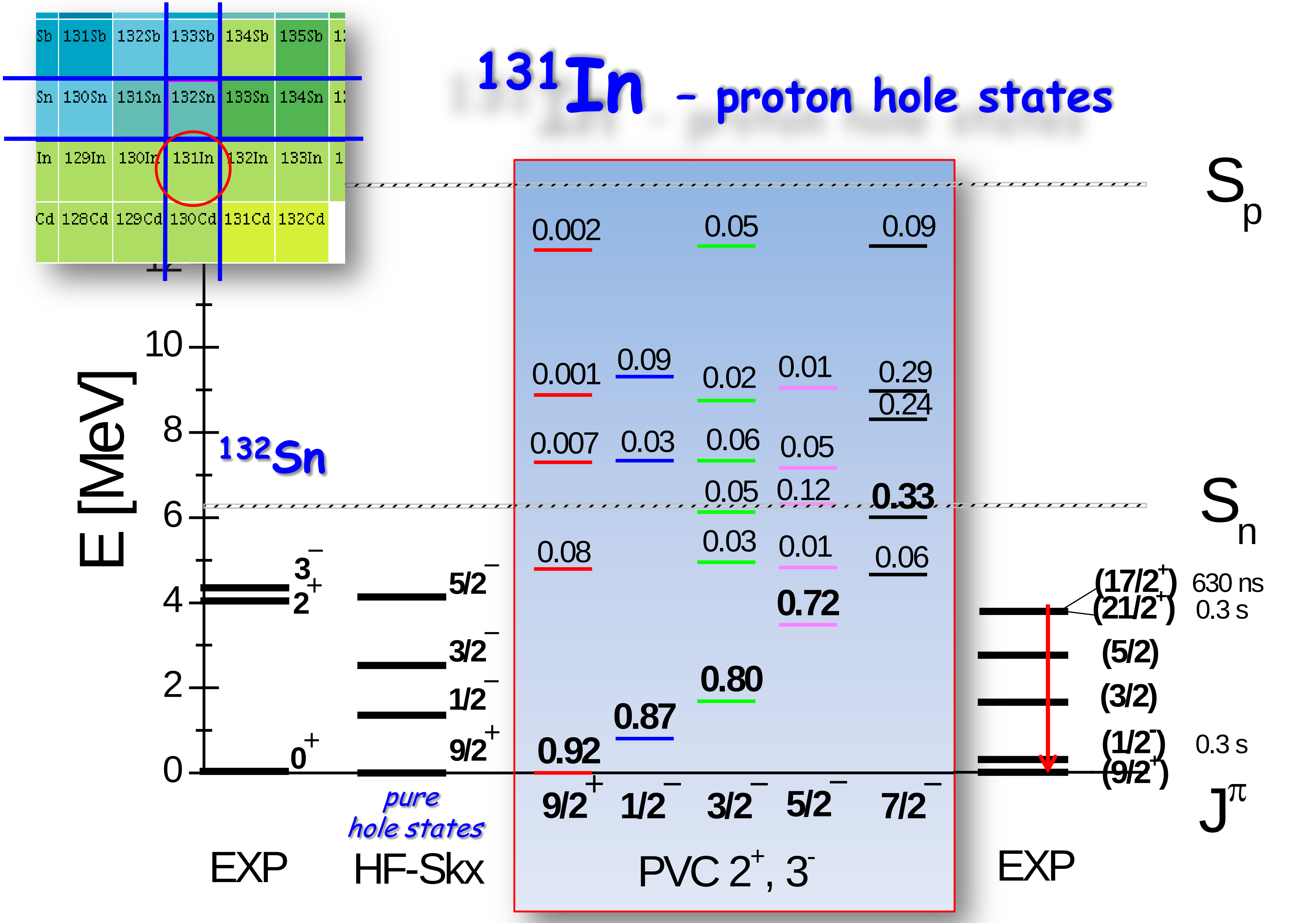
Extraction of SF (~ 30% error)



(d,p): $^{132}Sn + CD_2$

K.L. Jones et al., Nature, 465(2010)454

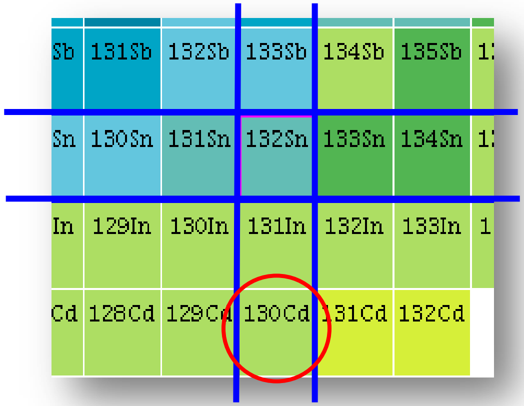
^{131}In – proton hole states



G. Colò and P.F. Bortignon

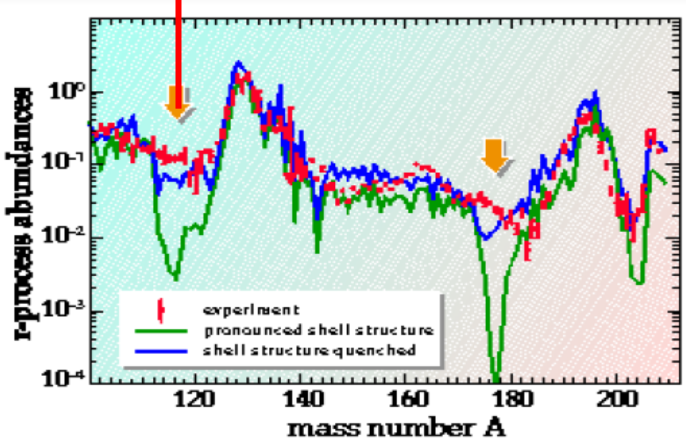
M.Gorska et al., PLB672(2009)313

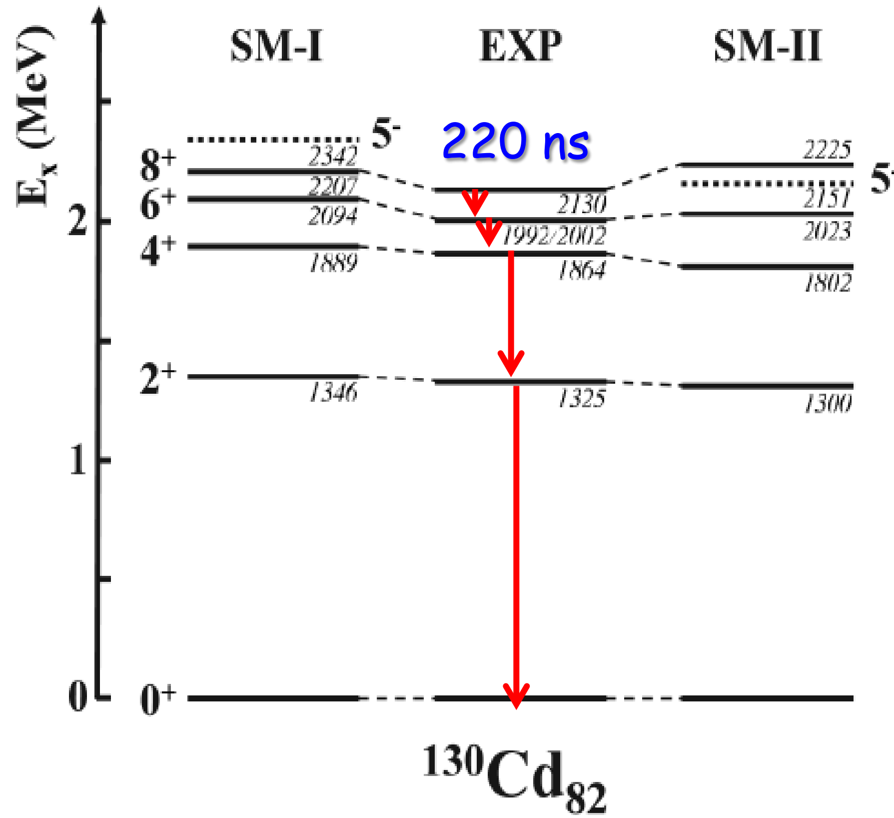
^{130}Cd – 2 proton holes states



- Tentative I$^{\pi}$ assignment
- Tentative B(Eλ) values
- Missing levels

→Strength of **PAIRING** interaction
→ **SHELL** quenching below ^{132}Sn

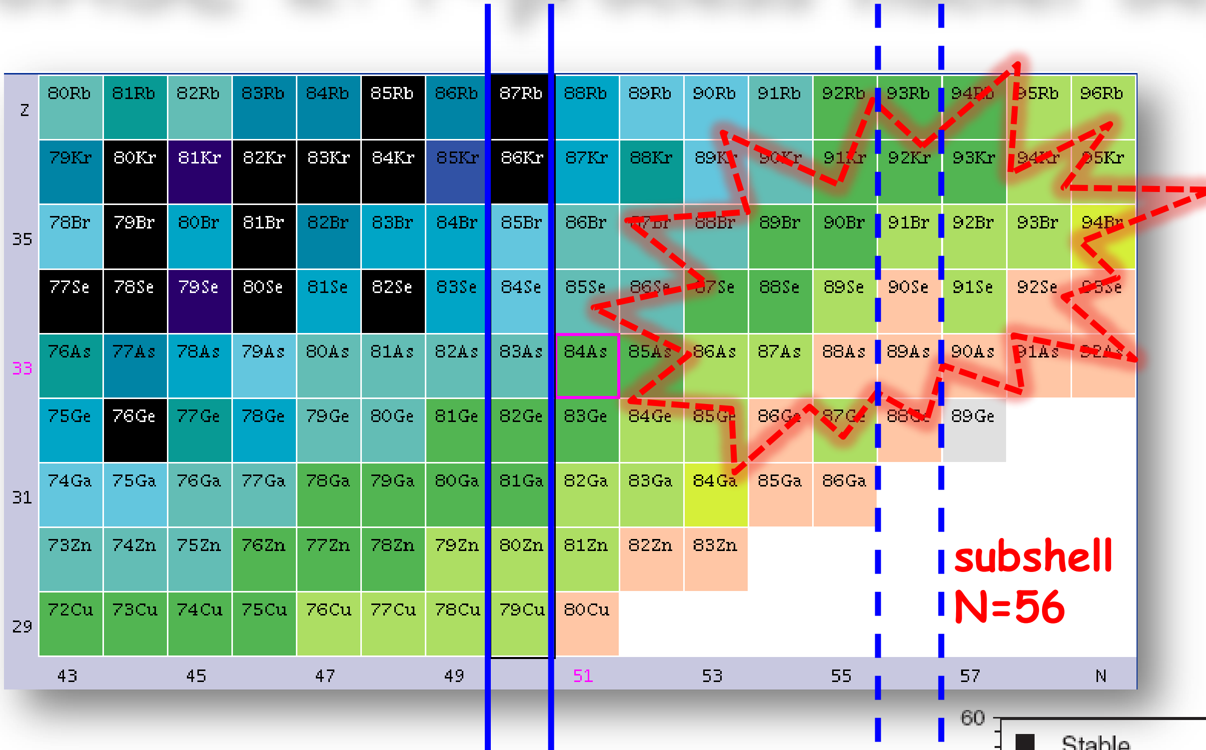




GSI: Projectile fragmentation
^{136}Xe (750 MeV/A) + Be

A. Jungclaus et al., PRL99(2007)132501

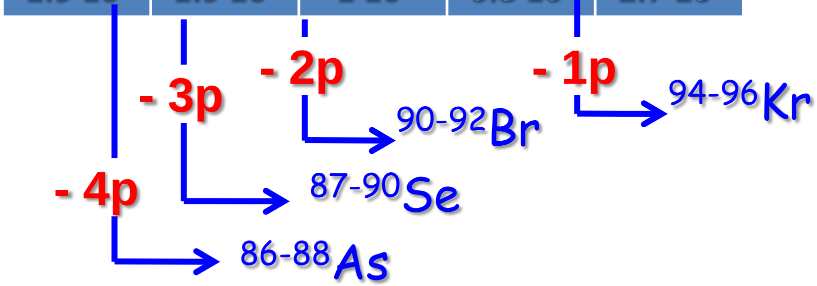
CASE 2: r-process nuclei beyond N=50

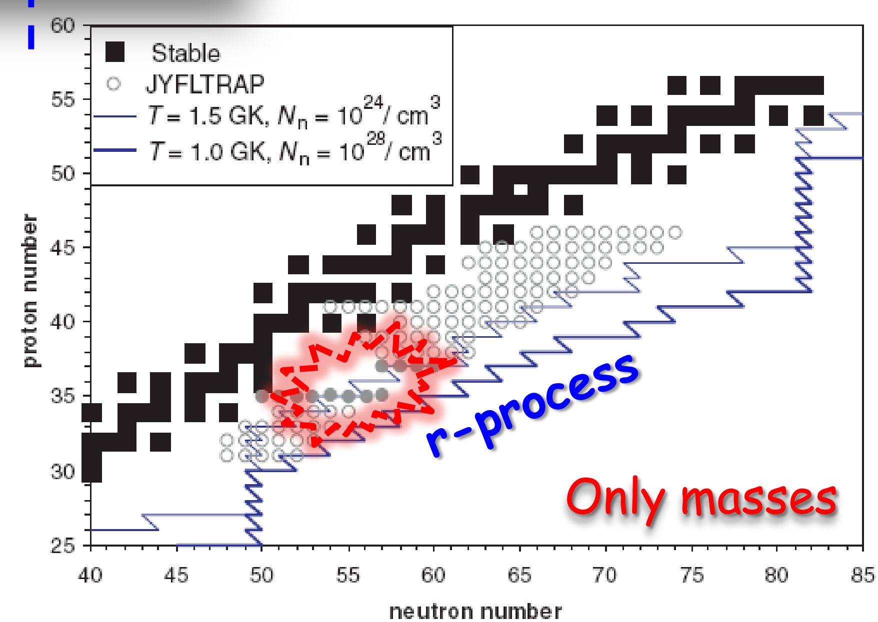


Shape changes with N number

SPES Beams

^{90}Rb	^{91}Rb	^{92}Rb	^{93}Rb	^{94}Rb
1.9 10^9	1.9 10^9	1 10^9	6.8 10^8	2.7 10^8





Importance of Nuclear Deformation for r-process

β–decay half-lives** and **neutron emission probabilities

*are different in **DEFORMED** and **SPHERICAL** nuclei*

Isotope	$T_{1/2}$ [ms] spherical	P_n [%] spherical	$T_{1/2}$ [ms] deformed	P_n [%] deformed	$T_{1/2}$ [ms] experiment	P_n [%] experiment
Ge-85	832	8.3	186	5.4	540(50)	14(3)
Ge-86	627	31.5	177	5.4		
Ge-87	364	33.9	56.7	6.3		
Ge-88	171	69.4	45.8	6.7		
As-86	834	19.4	286	11.7	945(8)	26(7)
As-87	739	46.7	238	82.9	560(110)	17.5(25)
As-88	445	32.1	70.7	41.9		
As-89	218	77.0	63.0	93.3		
As-90	21.1	8.9	22.8	42.5		
As-91	61.1	92.2	33.2	95.7		
Se-89	1646	0.5	137	0.6	410(40)	7.8(25)
Se-90	724	0.6	141	1.1		
Se-91	39.3	0.2	37.6	1.3	270(50)	21(10)
Se-92	137	2.3	62.3	2.7		
Se-93	24.0	14.5	51.6	7.1		
Se-94	39.0	3.7	48.2	23.9		
Br-94	33.4.	14.2	113	56.6	70(20)	68(16)
Br-95	53.2	93.8	70.2	79.1		
Br-96	19.2	31.9	36.7	56.2		
Br-97	20.2	97.2	42.4	92.0		

$$\tau_{\beta\,SPH} \sim 7 \times \tau_{\beta DEF}$$

$$P_{nSPH} \sim 0.5 \times P_{nDEF}$$

- ***Large uncertainty in r-process location***
- ***difficoult to extrapolate to more exotic regions***

P. Moller et al., Phys. Rev. C67, 055802 (2003) and ref. therein.

CONCLUSIONS

Multi-Nucleon Transfer at 5-10 MeV/A are powerfool tool to reach exotic nuclei

with **most intense SPES** beams $^{130-132}$Sn and $^{90-92}$Rb

- γ spectroscopy around ^{132}Sn
- r-process nuclei beyond N=50

In LOI:

- Inelastic Scattering with Heavy-Ions

  to populate Highly-excited dipole states

  → *preparatory work is needed*

  excitation function with stable beams 5-10-15 MeV/A