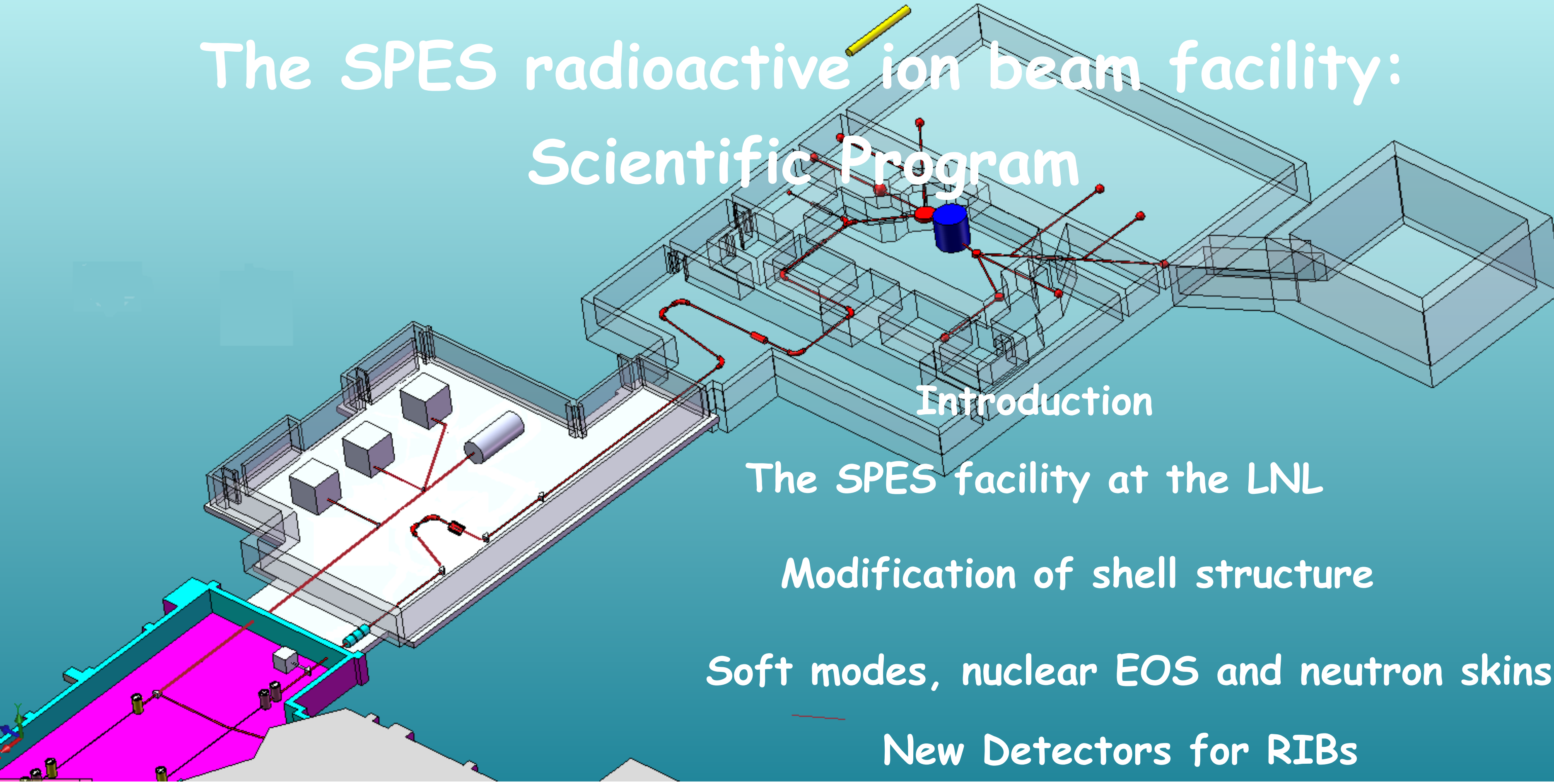
The SPES radioactive ion beam facility: Scientific Program



Introduction

The SPES facility at the LNL

Modification of shell structure

Soft modes, nuclear EOS and neutron skins

New Detectors for RIBs

Giacomo de Angelis

INFN Laboratori Nazionali di Legnaro

for The SPES collaboration

The goal of SPES

- **S**elective **P**roduction of **E**xotic **S**pecies

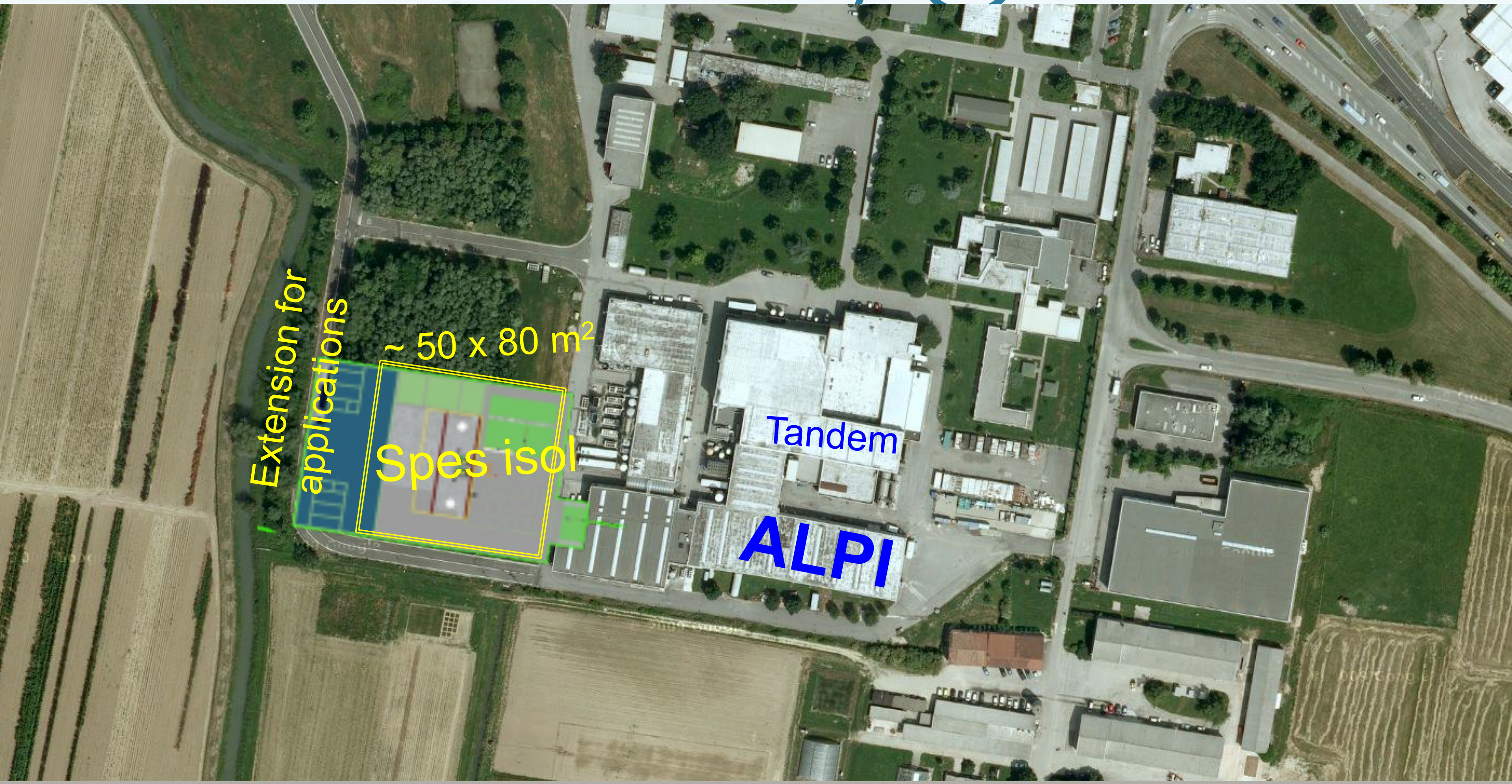
- Optimized use of the two exits high current proton driver

production of re-accelerated neutron-rich exotic beams
10^{13} fission/s in-target production, and re-acceleration at 10*A MeV (A=132)

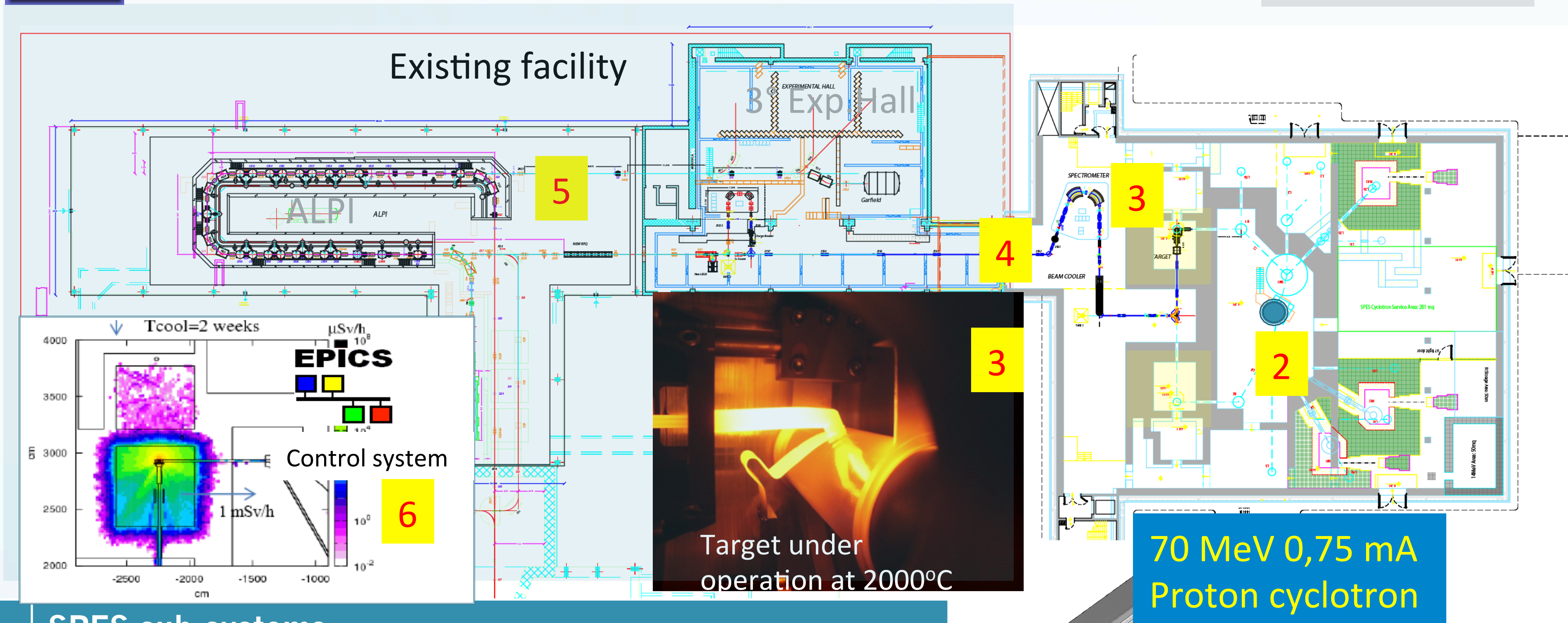
Radioisotope production & Medical applications
innovative radiopharmaceuticals (e.g. Sr-82, Cu- 64, Cu-67)

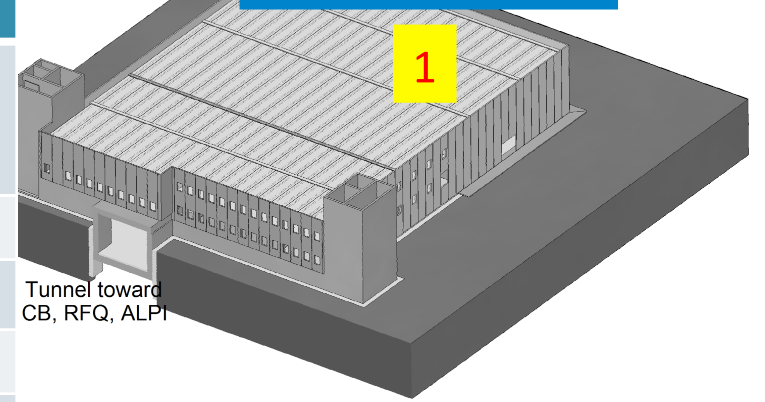
Fast neutron production & material applications: Atmospheric neutron spectra, QMN
Single Event Effect, neutron capture cross sections

SPES Facility @ LNL



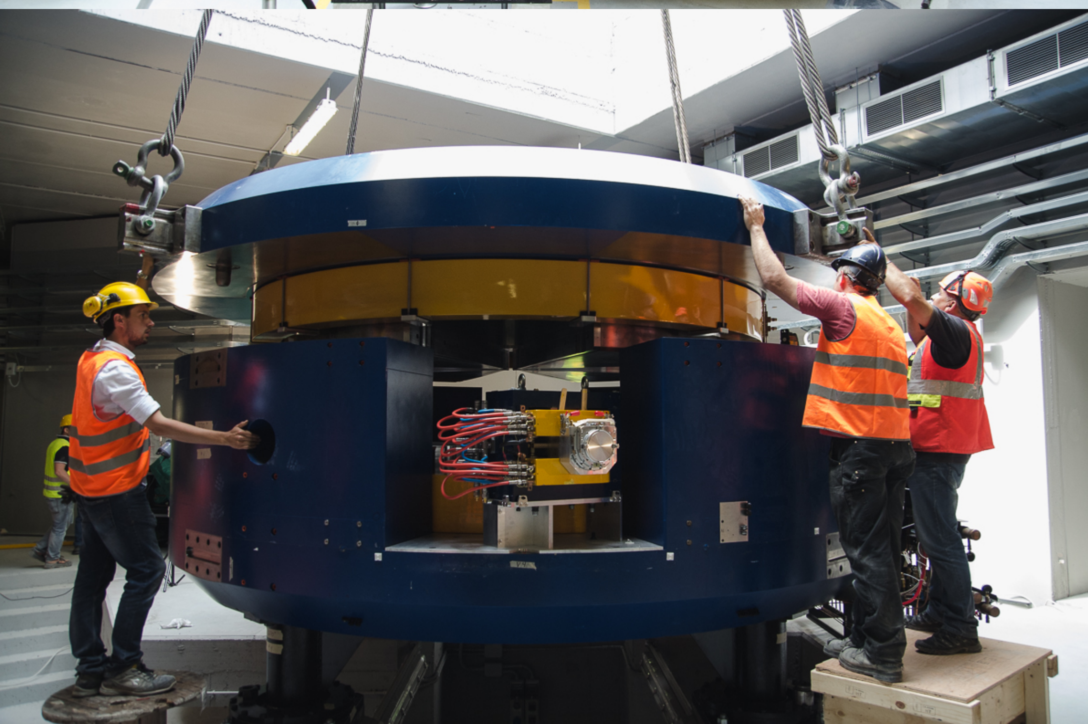
SPES Facility Layout

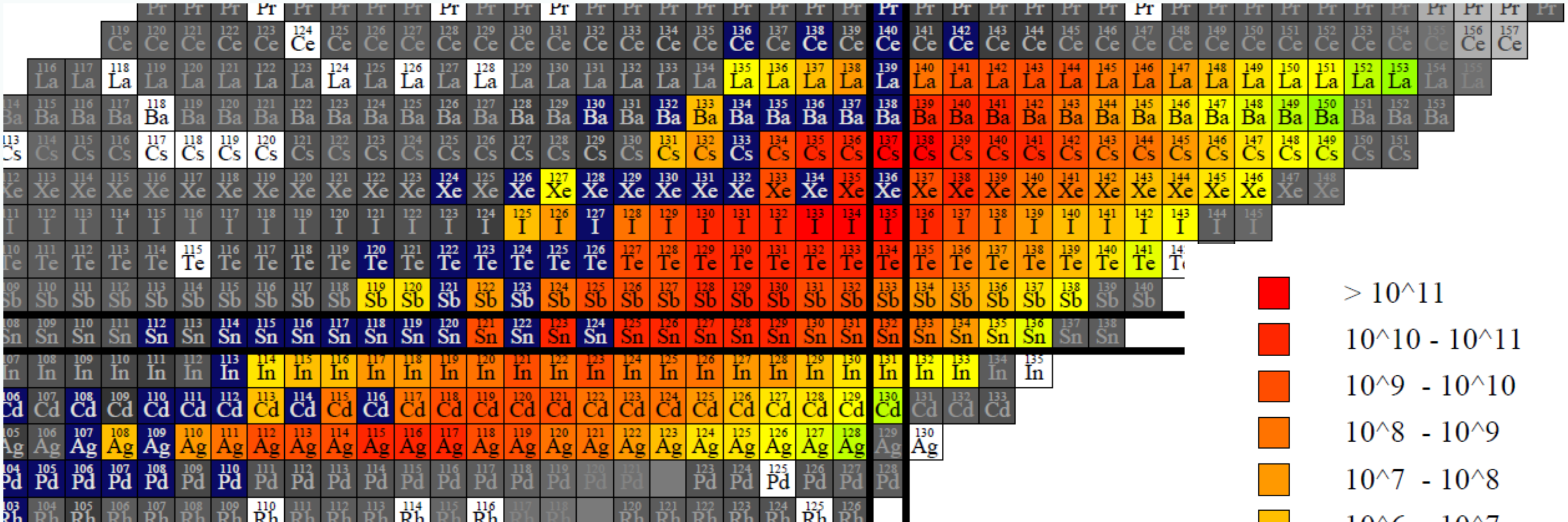


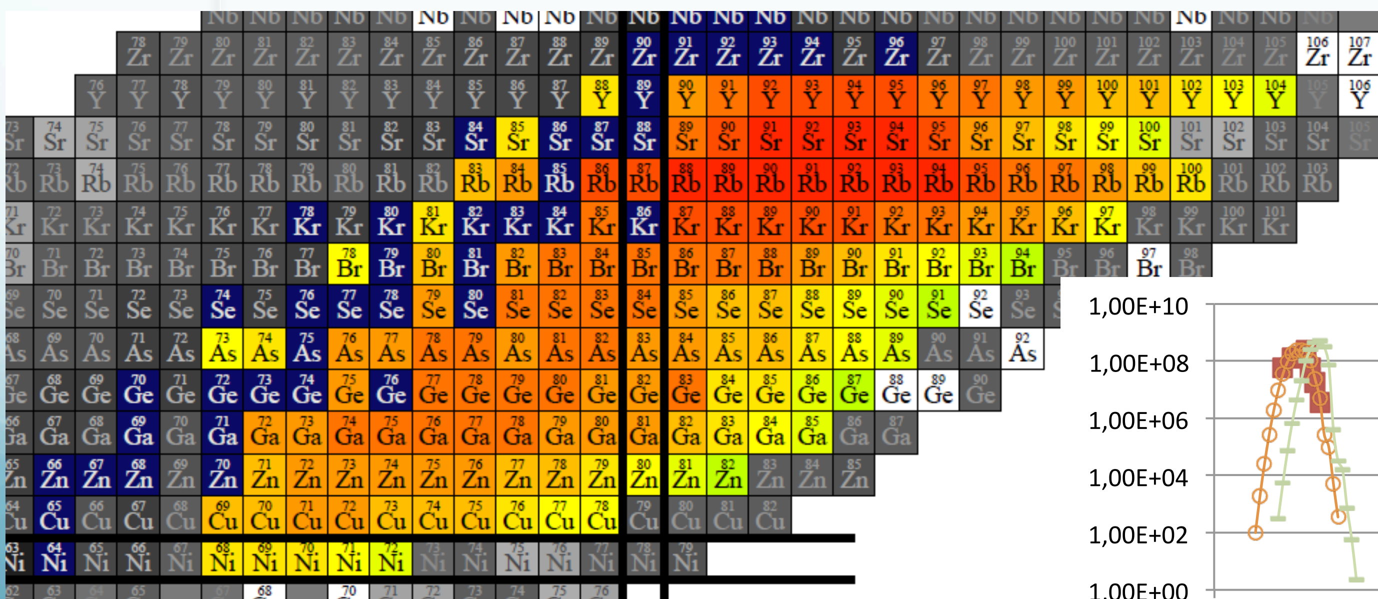


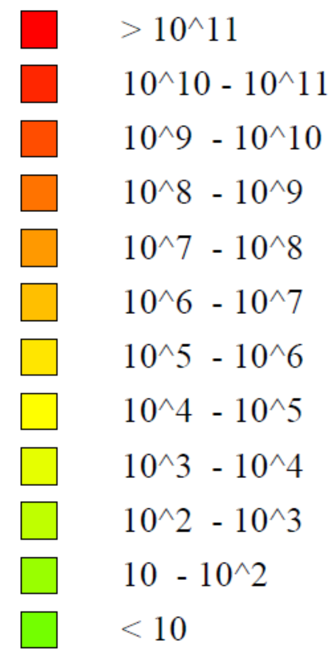
	SPES sub-systems
1	Building and infrastructures with 2 ISOL bunkers for radioactive beam and application area for radioisotopes and neutrons
2	Cyclotron 70 MeV protons with 2 independent exits
3	ISOL UCx target designed for 10^{13} f/s
4	Beam transport with High Resolution Mass Separation
5	Reacceleration with ALPI superconducting linac (10A MeV A=130)
6	Radioprotection, safety & controls

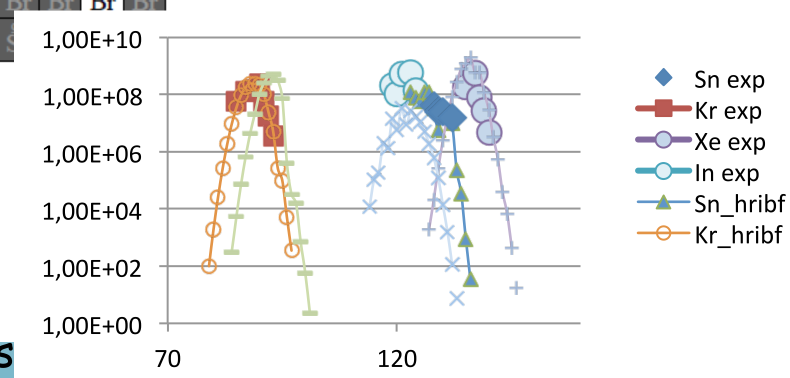
SPES
exotic beams for science











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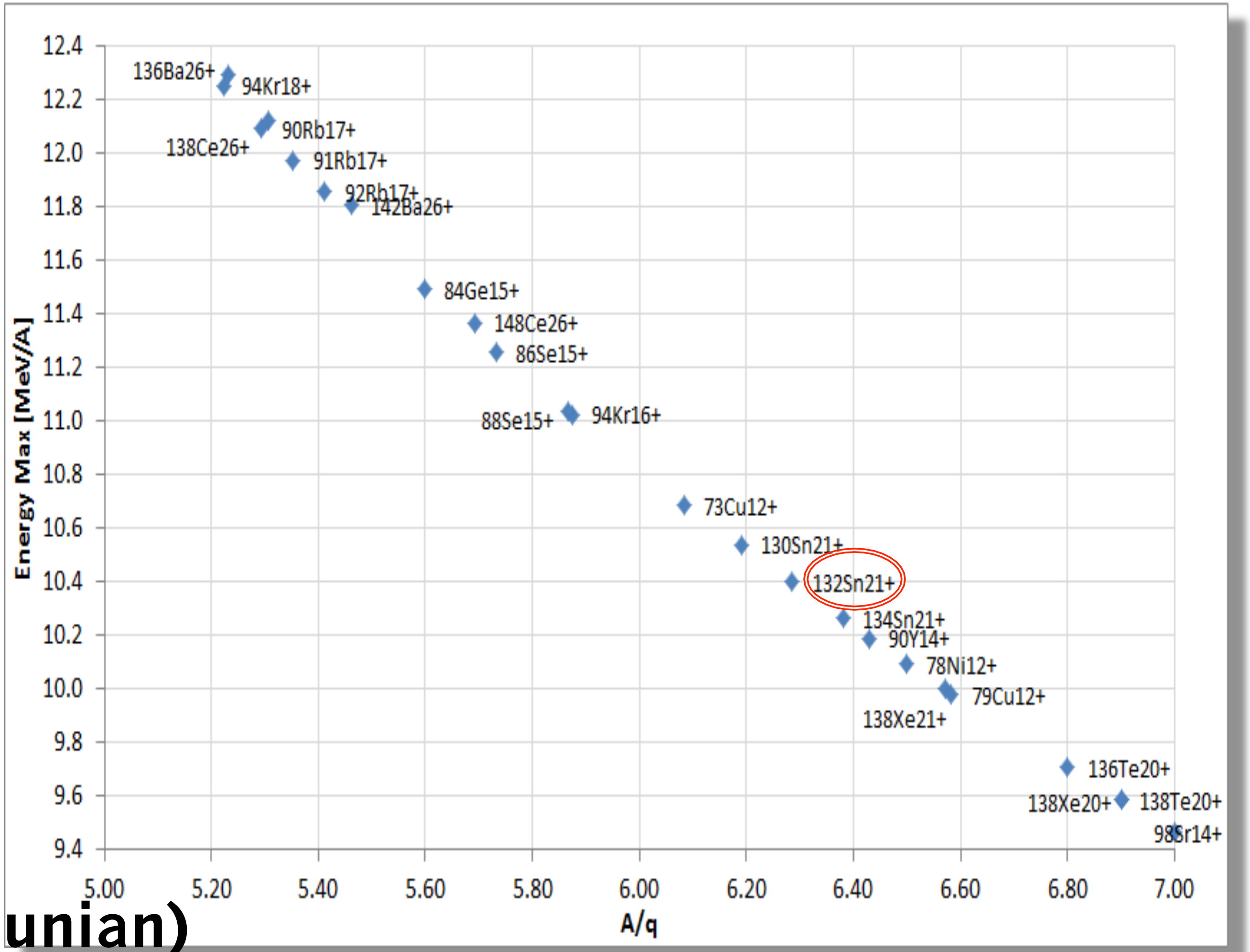
Energy from SPES Post-Accelerator as function of A/q



(M. Comunian)

Preliminary results from alpi performances with 2 cavities as margin, Low Beta=5 MV/m, Medium Beta=4.3 MV/m, High Beta=5.5 MV/m

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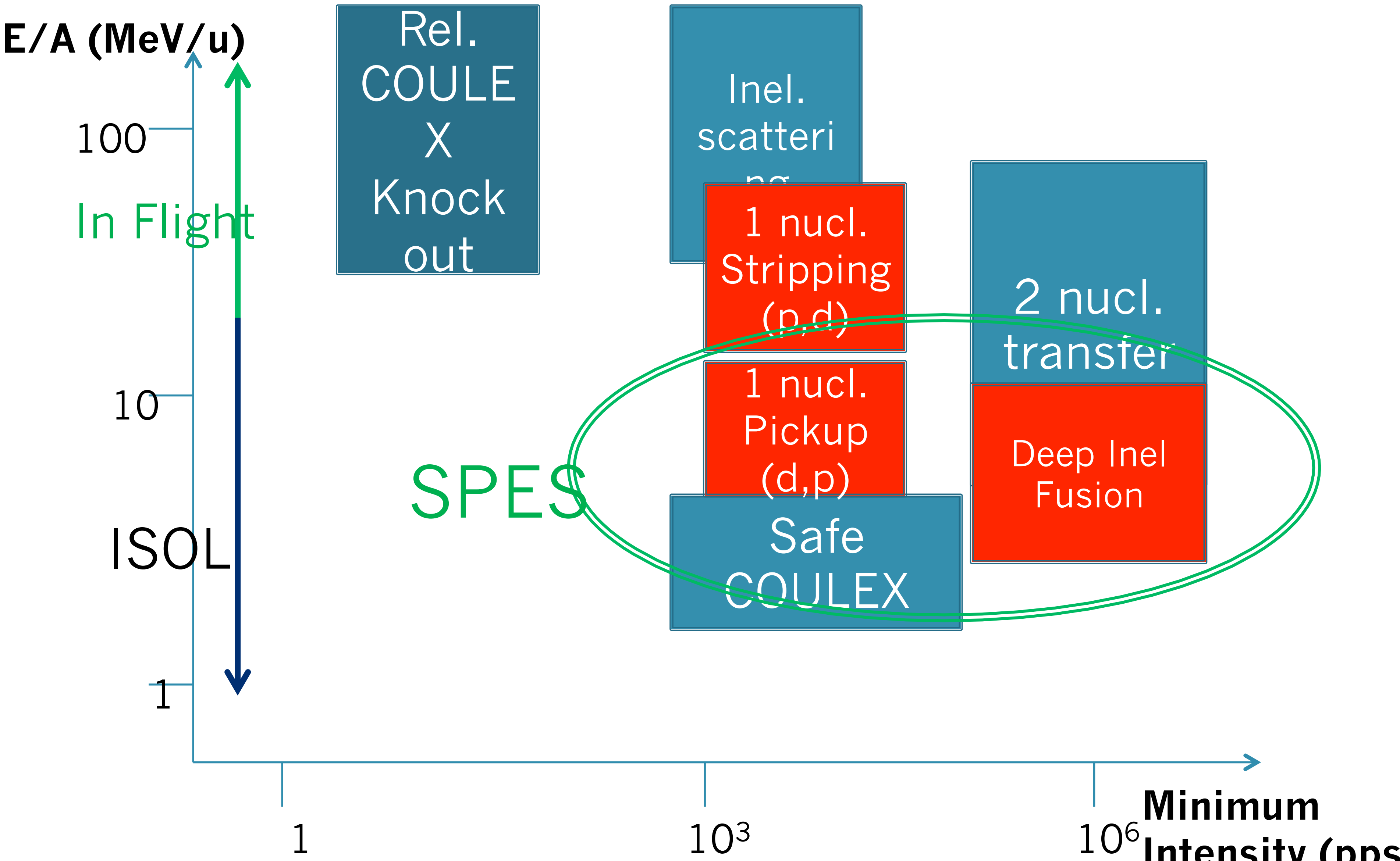
Reaction domains



Giacomo de Angelis

Scientific Advisory Committee

T.	Aumann	GSI
G.	de France	GANIL
B.	Fornal	Poland
K.	Gelbke	MSU
T.	Motobayashi	Riken
A.	Olmi	Firenze
P.	Van Duppen	Loeven
A.	Vitturi	Padova
A.	Cuttone	LNS
G.	Fiorentini	LNS
G.	Prete	LNL
G.	de Angelis	LNL

SPES Scientific Program

Project evaluation,
Evaluation of the LOI
and of the new instrumentation

Study group

A.	Bonaccorso	INFN Pisa
G.	Casini	INFN Firenze
G.	Colò	Università di Milano
G.	de Angelis	INFN LNL
A.	Di Pietro	INFN LNS
A.	Gargano	INFN Napoli
S.	Lenzi	Università di Padova
S.	Pirrone	INFN Catania
G.	Pollarolo	Università di Torino

Organization of workshops
On dedicated aspects of the
Project (one-day workshops: Ex.
Transfer Reactions Napoli, Coulex
Firenze, Collective modes Milano
Ground state properties and β-decay
Milano May 2015
Preparing the SAC evaluation phase

iCal export More Europe/Rome English Login

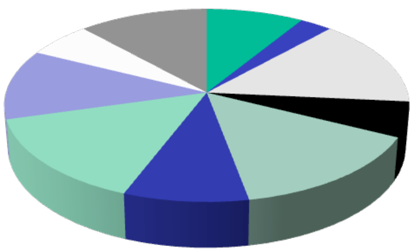
Second SPES International Workshop

26-28 May 2014 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

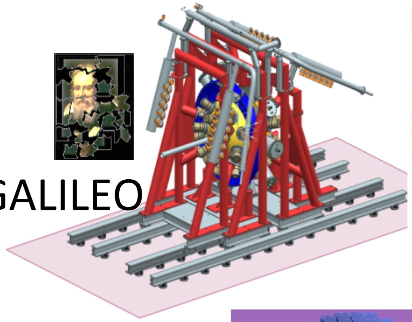
Presented 37 Letters of Intents

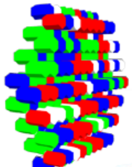
SPES2010 Workshop
(LNL- November 15^{th}-17^{th}, 2010)
24 LoI's for reaccelerated exotic beams

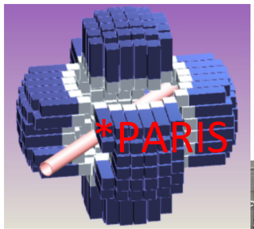
SPES LOIs Topics

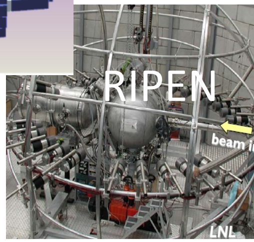


- GS properties
- moments
- Coulex
- DirReac with ActiveTarget
- DirReac with Si

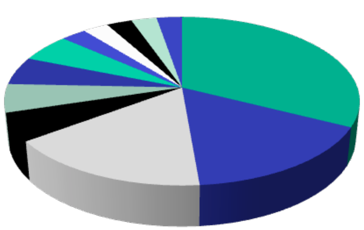




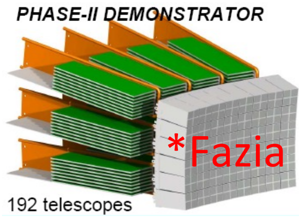


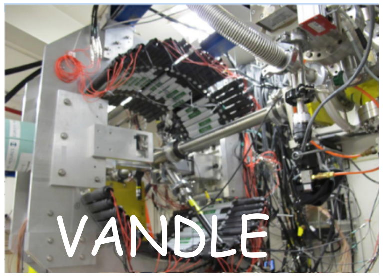


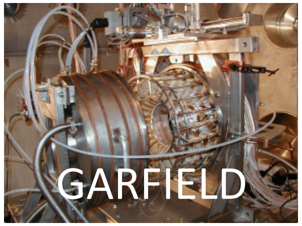
SPES LOIs Spokespersons



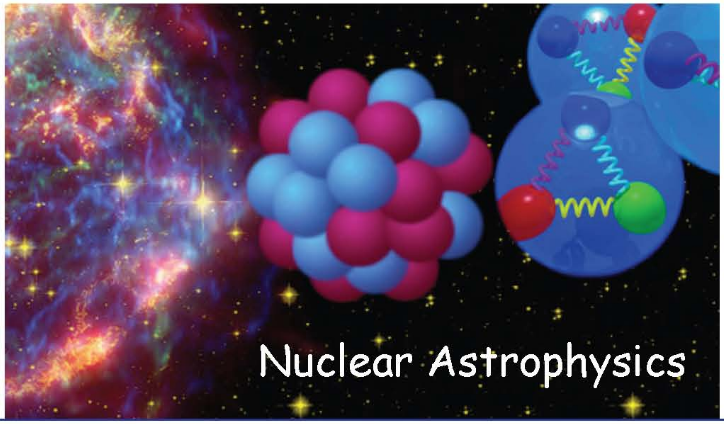
- Italy
- France
- Poland
- Russia
- USA
- Belgium
- Croatia
- Norway
- Bulgaria
- Spain
- Russia
- China



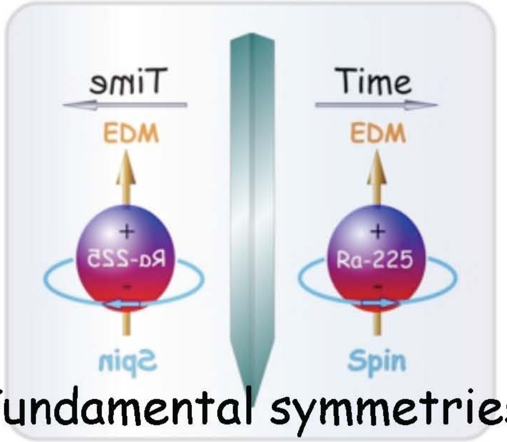




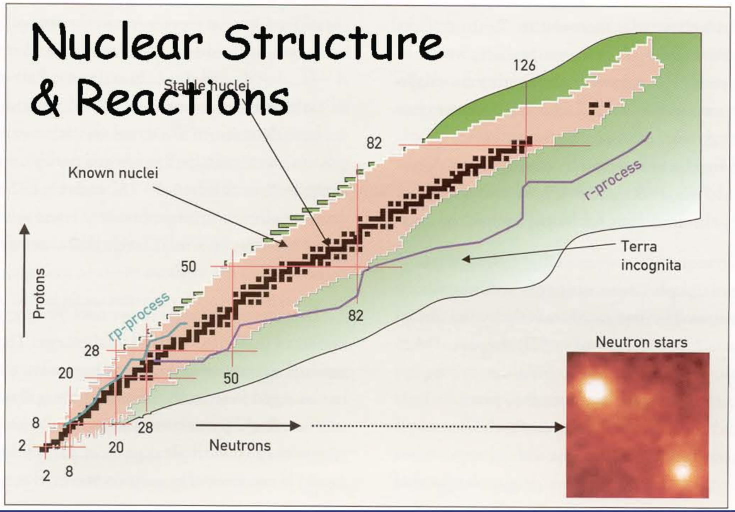
Which science drives physics with rare isotopes?



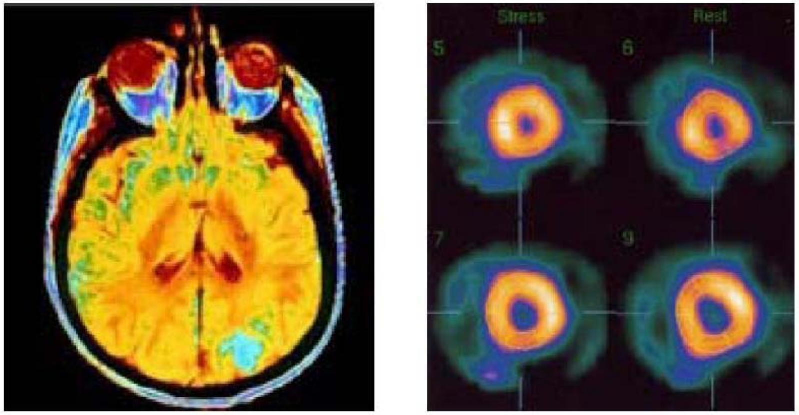
Origin of new elements, rare isotopes powering stellar explosions, neutron star crust



Use of rare isotopes as laboratories where symmetry violations are amplified.



Limits of existence: what makes nuclei stable? New shapes, new collective behavior.



Materials, medical physics, reactors,..

EFFECTIVE INTERACTIONS IN MEDIA

- When going from free space to medium the Interactions are modified (density dependent forces)
- When going from infinite to finite Hilbert space the Interactions are further modified (truncation schemes)

NUCLEAR STRUCTURE OF EXOTIC NUCLEI

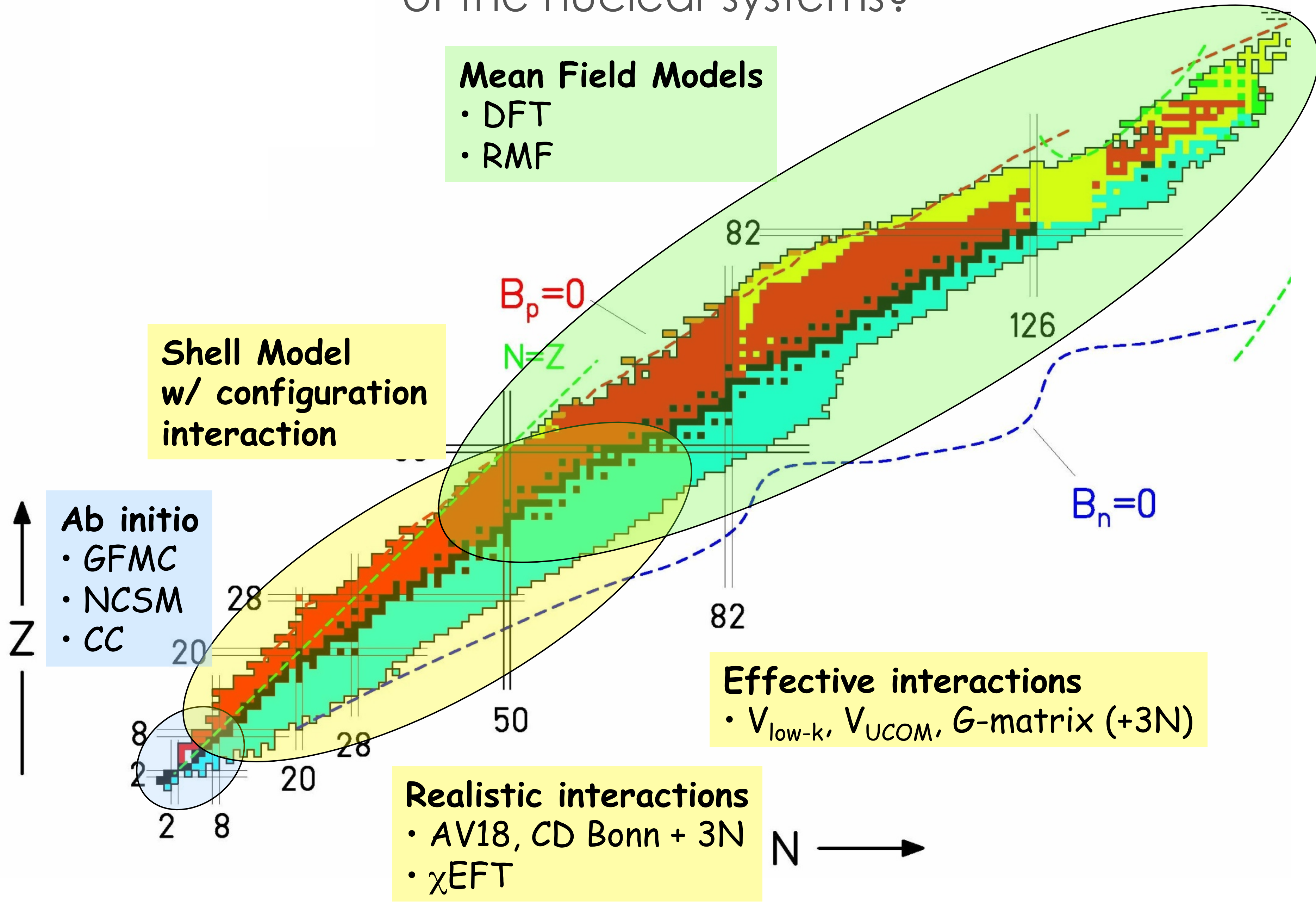
EFFECTIVE INTERACTIONS IN MEDIA

- When going from free space to medium the Interactions are modified (density dependent forces)
- When going from infinite to finite Hilbert space the Interactions are further modified (truncation schemes)

NUCLEAR STRUCTURE OF EXOTIC NUCLEI

Nuclei close to the dripline are important since they are correlations dominated

One of the challanges: Do we understand the structure of the nuclear systems?



SPES
exotic beams for science

EFFECTIVE INTERACTIONS IN MEDIA

When going from free space to medium the Interactions are modified (density dependent forces)
When going from infinite to finete Hilbert space the Interactions are further modified (truncation schemes)

Type 1 shell evolution

Shells do evolve, ... due to the tensor force (Type 1 evolution).

[Otsuka et al., *PRL* **95** (05) 232502]

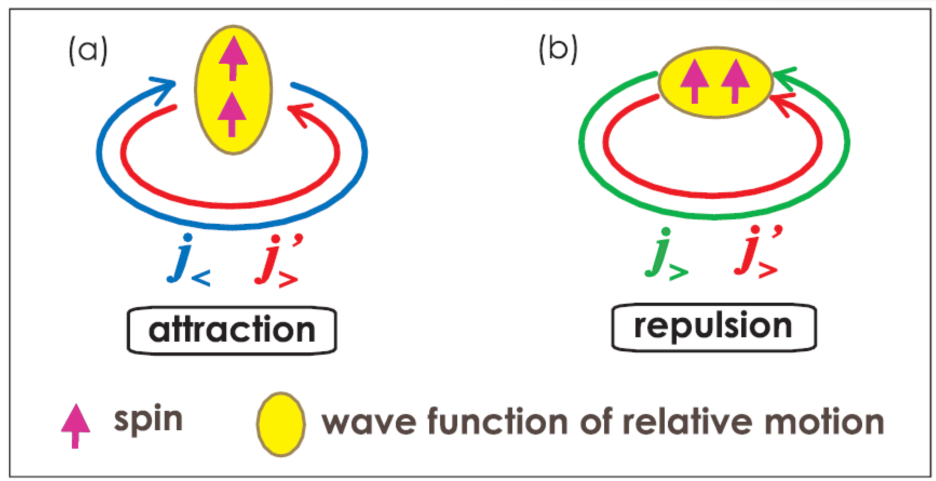
[Otsuka et al., *PRL* **97** (06) 162501]

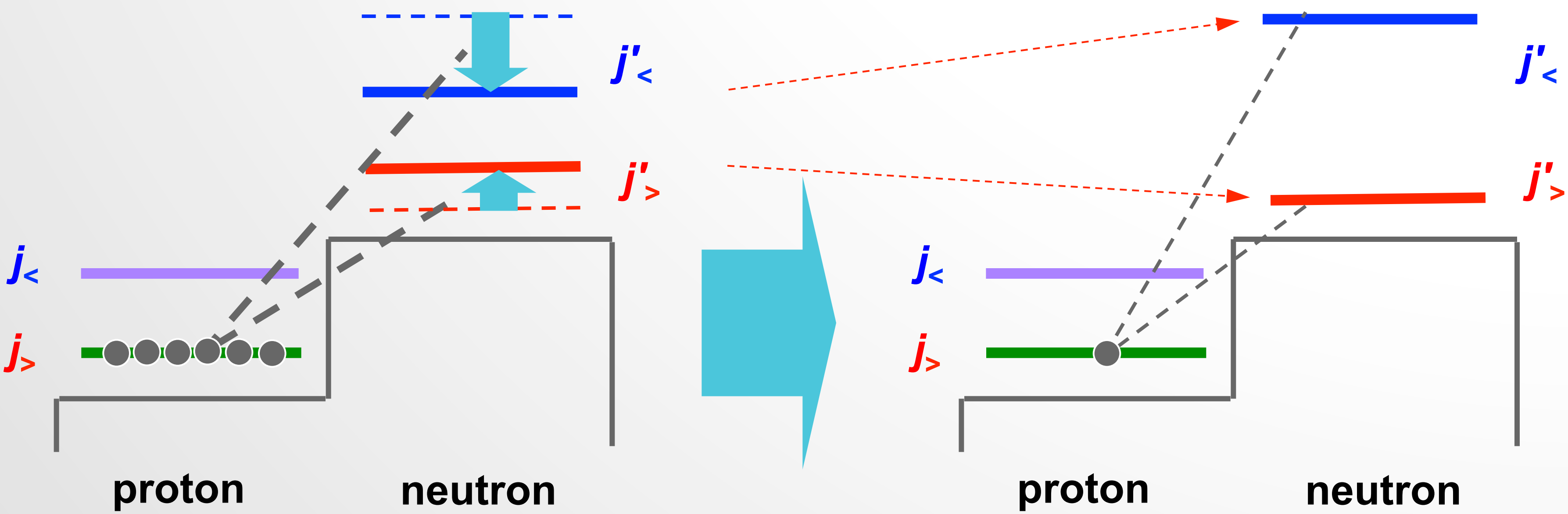
- Monopole energy of the tensor interaction

$$V^{\mathrm{T}}_{j,j'} = \frac{\sum_J (2J+1)\langle jj'|V|jj'\rangle_{JT}}{\sum_J (2J+1)}$$

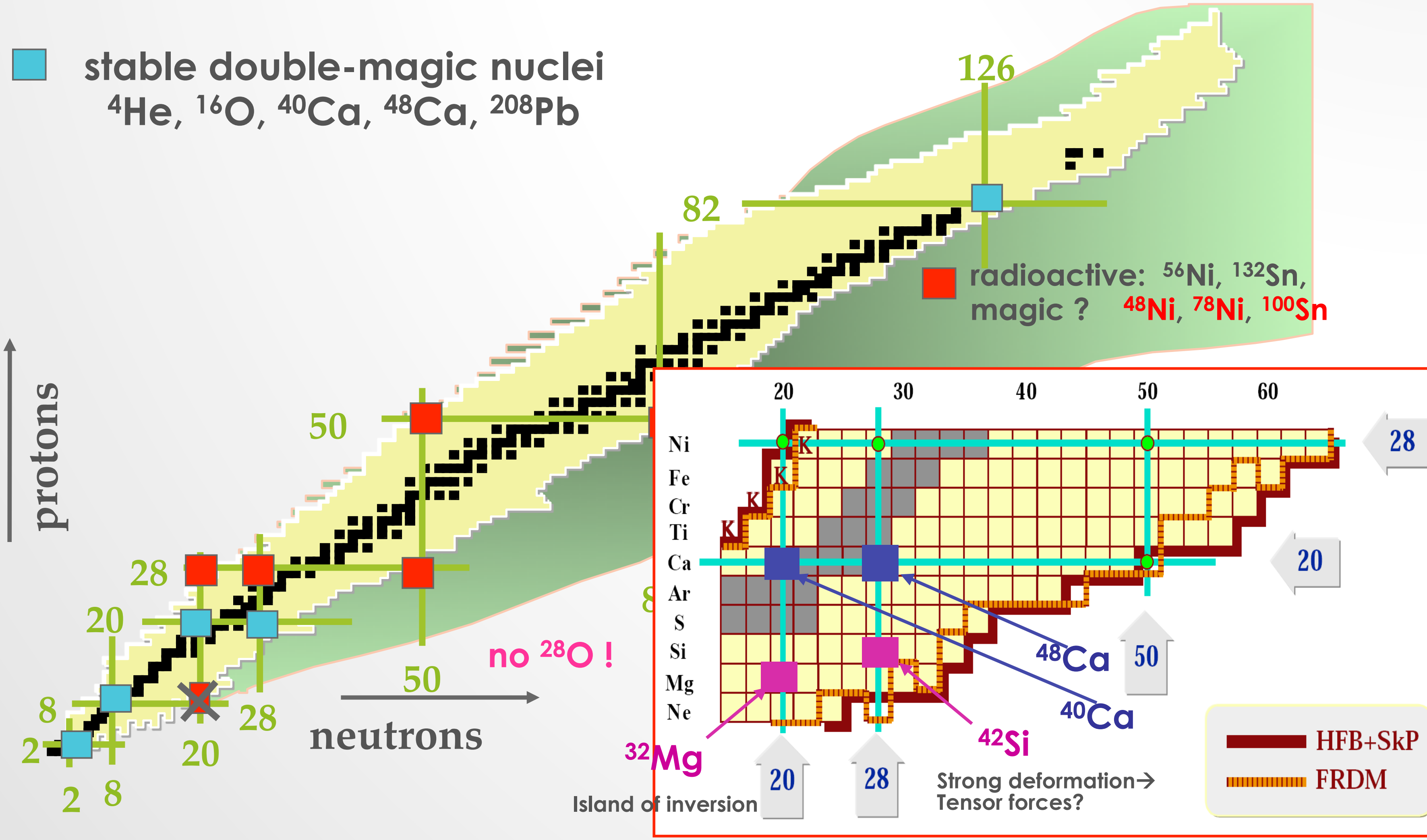
is

- attractive for $j_> - j_<'$, $j_< - j_>'$
- repulsive for $j_> - j_>'$, $j_< - j_<'$





One of the challanges: New magic numbers?



doi:10.1038/nature12522

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

D. Steppenbeck[1], S. Takeuchi[2], N. Aoi[3], P. Doornenbal[2], M. Matsushita[1], H. Wang[2], H. Baba[2], N. Fukuda[2], S. Go[1], M. Honma[4], J. Lee[2], K. Matsui[5], S. Michimasa[1], T. Motobayashi[2], D. Nishimura[6], T. Otsuka[1,5], H. Sakurai[2,5], Y. Shiga[7], P.-A. Söderström[2], T. Sumikama[8], H. Suzuki[2], R. Taniuchi[5], Y. Utsuno[9], J. J. Valiente-Dobón[10] & K. Yoneda[2]

Atomic nuclei are finite quantum systems composed of two distinct types of fermion—protons and neutrons. In a manner similar to that of electrons orbiting in an atom, protons and neutrons in a nucleus form shell structures. In the case of stable, naturally occurring nuclei, large energy gaps exist between shells that fill completely when the proton or neutron number is equal to 2, 8, 20, 28, 50, 82 or 126 (ref. 1). Away from stability, however, these so-called 'magic numbers' are known to evolve in systems with a large imbalance of protons and neutrons. Although some of the standard shell closures can disappear, new ones are known to appear[2,3]. Studies aiming to identify and understand such behaviour are of major importance in the field of experimental and theoretical nuclear physics. Here we report a spectroscopic study of the neutron-rich nucleus ^{54}Ca (a bound system composed of 20 protons and 34 neutrons) using proton knockout reactions involving fast radioactive projectiles. The results highlight the doubly magic nature of ^{54}Ca and provide direct experimental evidence for the onset of a sizable subshell closure at neutron number 34 in isotopes far from stability.

The shell structure of the atomic nucleus was first successfully described more than 60 years ago[1]. However, the question of how robust the standard magic numbers are in unstable nuclei with a large excess of neutrons—often referred to as 'exotic' nuclei—has been one of the main driving forces behind recent nuclear structure studies that focus on changes in the shell structure, called 'shell evolution'. A noteworthy example is the disappearance of the $N = 28$ (neutron number 28) standard magic number in ^{42}Si (ref. 4), a nucleus that lies far from the stable isotopes on the Segrè chart. On the contrary, exotic oxygen isotopes[3] provide evidence for the onset of a new shell closure at $N = 16$, one that is not observed in stable nuclei. In both cases, the tensor force, a non-central component of the nuclear force, has a key role in describing the experimental spectra[5].

The region of the Segrè chart around exotic calcium isotopes has also contributed valuable input to the understanding of nuclear shell evolution over recent years owing to experimental advances. Enhanced excitation energies of first $J^{\Pi} = 2^+$ states (spin, J; parity, Π) and reduced γ-ray transition probabilities, which are good indicators of nuclear shell gaps, for ^{52}Ca (refs 6, 7), ^{54}Ti (refs 8, 9) and ^{56}Cr (refs 10, 11) provide substantial evidence for the onset of a sizable energy gap at $N = 32$. This result was recently confirmed by high-precision mass measurements on neutron-rich Ca isotopes[12]. In the framework of tensor-force-driven shell evolution[5], the $N = 32$ subshell closure is a direct consequence of the weakening of the attractive nucleon–nucleon interaction between protons (π) and neutrons (ν) in the $\pi f_{7/2}$ and $\nu f_{5/2}$ single-particle orbitals (SPOs) as the number of protons in the $\pi f_{7/2}$ SPO is reduced and the magnitude of the $\pi f_{7/2}$–$\nu f_{5/2}$ energy gap increases (Fig. 1a–c).

A question that has been asked frequently over recent years is whether or not the onset of another subshell gap occurs in exotic $N = 34$ isotones, which was suggested qualitatively more than a decade ago[13] on the basis of the general properties of nuclear forces. The onset of an appreciable subshell closure at $N = 34$ is illustrated in Fig. 1d, indicating an energy gap between the $\nu p_{1/2}$ and $\nu f_{5/2}$ SPOs in ^{54}Ca that is comparable to the separation of the $\nu p_{3/2}$ and $\nu p_{1/2}$ spin–orbit partners, which is also implied by recent theoretical results; see, for example, ref. 14. We stress, however, that no $N = 34$ subshell closure was reported in the experimental investigations of ^{56}Ti (refs 9, 15) or ^{58}Cr (refs 11, 16), and notable doubt on this magic number for Ca isotopes has been raised[17,18]. Indeed, as indicated in Fig. 2a, theoretical predictions of the energy of the first $J^{\Pi} = 2^+$ state for ^{54}Ca vary considerably, ranging from ~1 MeV in some cases to as high as ~4 MeV in others[14–16,19–24], despite exhibiting close agreement for lighter isotopes; for example, the predictions of the same theories lie within only 0.4 MeV of the empirical result for ^{52}Ca. Such stark discrepancies at $N = 34$ reflect the need for direct experimental input on the matter.

To address this issue, we report on an experimental study of ^{54}Ca to clarify the strength of the $N = 34$ subshell gap in nuclei farther from stability. The energies of nuclear excited states were investigated using proton knockout reactions involving ^{55}Sc and ^{56}Ti projectiles on a Be target at the Radioactive Isotope Beam Factory, Japan, operated by the RIKEN Nishina Center and the Center for Nuclear Study, University of Tokyo. Experimental details are provided in Methods Summary. Particle identification plots indicating the radioactive species transported through the BigRIPS separator and ZeroDegree spectrometer[25], which were used to select and tag radioactive beam projectiles and reaction products, are presented in Fig. 3a and Fig. 3b, respectively. We emphasize that the intensity of the radioactive beam reported here, which was critical to the success of the experiment, is unique to the Radioactive Isotope Beam Factory. Excited-state energies were deduced using the technique of in-beam γ-ray spectroscopy.

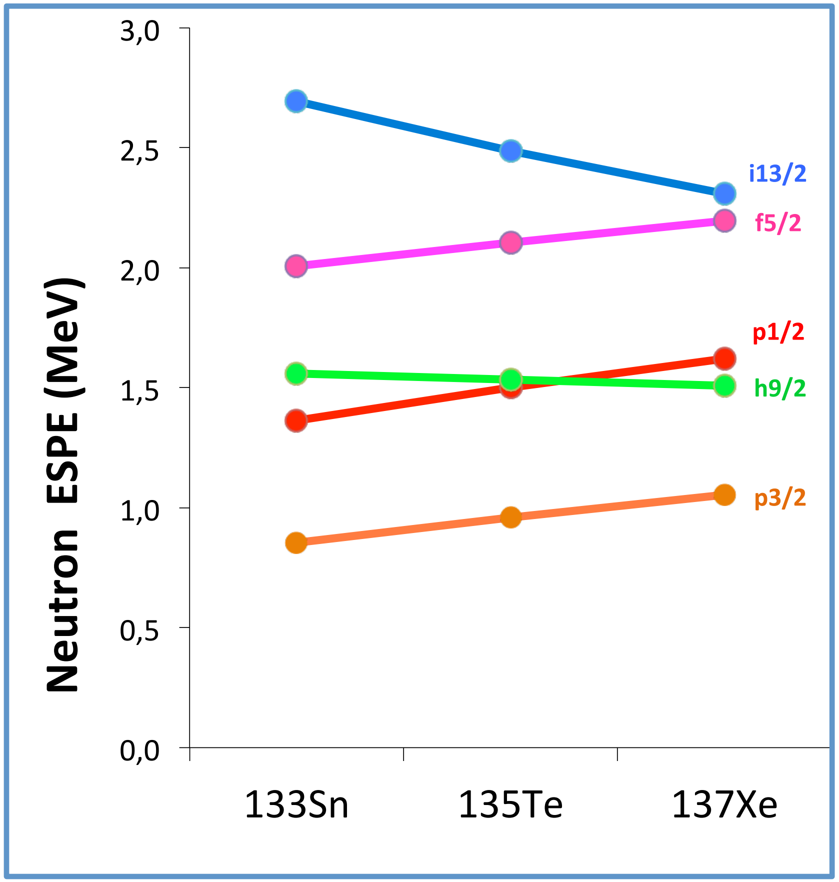
The γ-rays measured in coincidence with ^{54}Ca projectiles produced through the one- and two-proton knockout reaction channels are presented in Fig. 4a. The γ-ray energies measured in the laboratory frame of reference have been corrected for Doppler shifts, and so the transitions appear at the energies they would in the rest frame of the nucleus. The most intense γ-ray line in the ^{54}Ca spectrum, the peak at 2,043(19) keV (error, 1 s.d.) in Fig. 4a, is assigned as the transition from the first 2^+ state (2_1^+) to the 0^+ ground state. In addition, two weaker transitions are located at 1,656(20) and, respectively, 1,184(24) keV. Figure 4b shows a γ-ray spectrum obtained with the condition of a prompt coincidence (≤10 ns) with the 2,043-keV γ-ray, indicating that the weaker transitions were emitted in decay sequences involving the $2_1^+ \rightarrow 0^+$ ground-state transition. On the basis of the γ-ray relative intensities, the 1,656-keV transition is proposed to depopulate a level at 3,699(28) keV, as presented in the ^{54}Ca level scheme in the lower-right section of Fig. 4a. Placement of the 1,184-keV transition in the

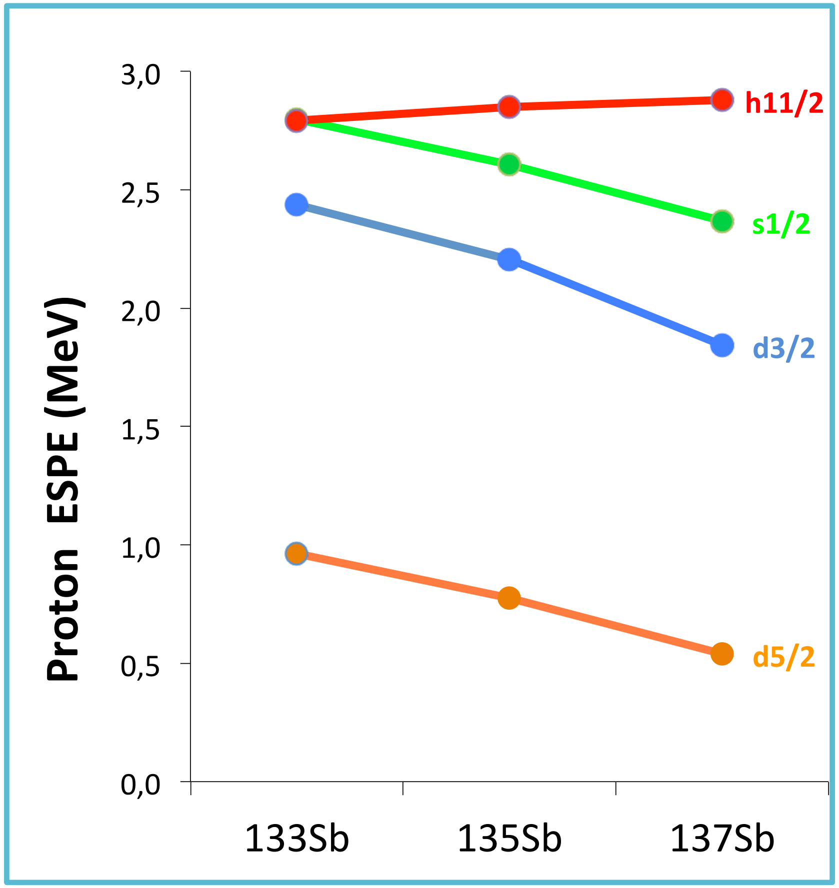
[1]Center for Nuclear Study, University of Tokyo, Hongo, Bunkyo, Tokyo 113-0033, Japan. [2]RIKEN Nishina Center, 2-1, Hirosawa, Wako, Saitama 351-0198, Japan. [3]Research Center for Nuclear Physics, University of Osaka, Ibaraki, Osaka 567-0047, Japan. [4]Center for Mathematical Sciences, Aizu University, Aizu-Wakamatsu, Fukushima 965-8580, Japan. [5]Department of Physics, University of Tokyo, Hongo, Bunkyo, Tokyo 113-0033, Japan. [6]Department of Physics, Tokyo University of Science, Noda, Chiba 278-8510, Japan. [7]Department of Physics, Rikkyo University, Toshima, Tokyo 171-8501, Japan. [8]Department of Physics, Tohoku University, Sendai, Miyagi 980-8578, Japan. [9]Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan. [10]Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Legnaro, Legnaro 35020, Italy.

Evolution of the single-particle states around ^{132}Sn

$$\bar{\varepsilon}_{j_\nu} = \varepsilon_{j_\nu} + \sum_{j_\pi} V^M(j_\nu j_\pi) N_{j_\pi}$$

$$\bar{\varepsilon}_{j_\pi} = \varepsilon_{j_\pi} + \sum_{j_\nu} V^M(j_\pi j_\nu) N_{j_\nu}$$





Courtesy of A. Gargano

LOI SPES D. Mengoni (Uni. Pd)

Evolution of the single-particle states around ^{132}Sn

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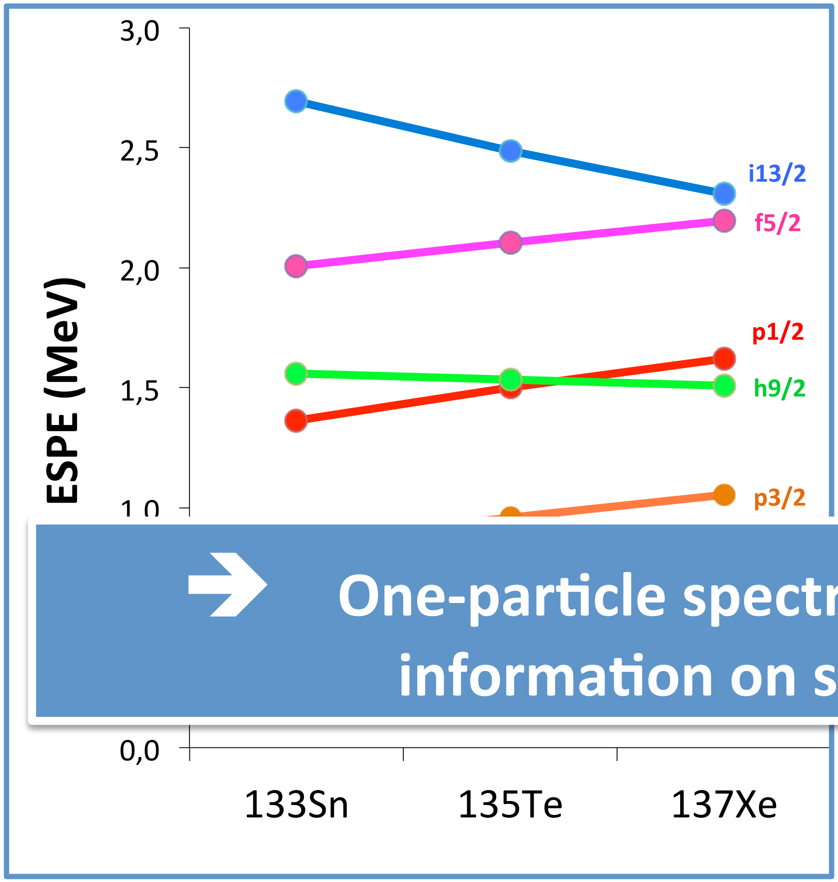
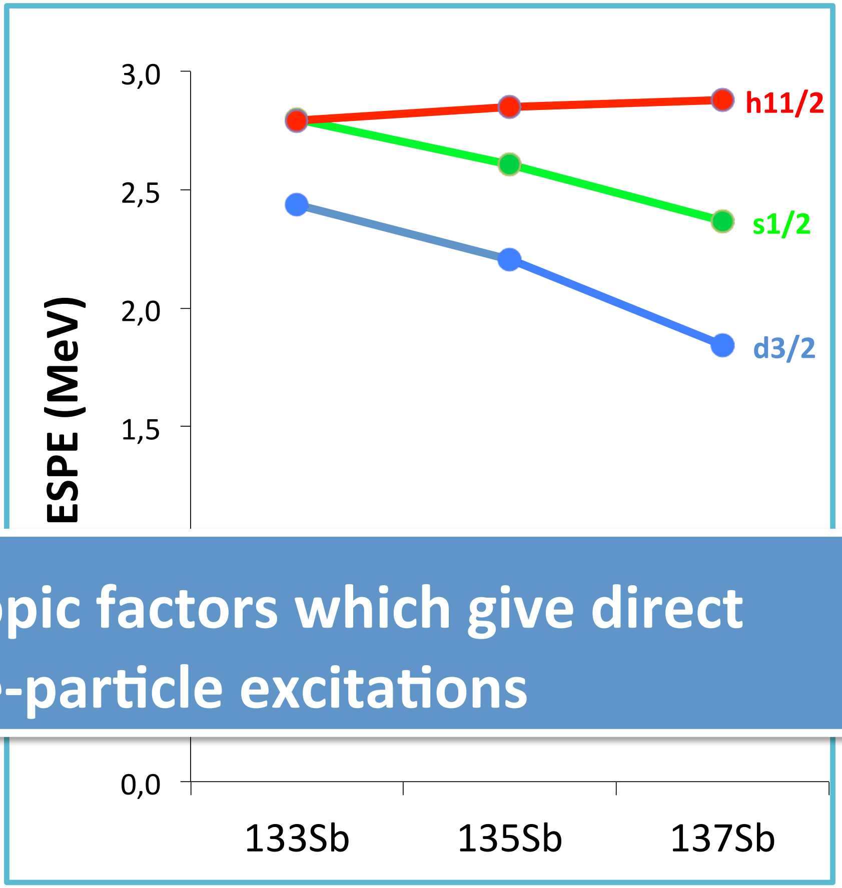




➔ **One-particle spectroscopic factors which give direct information on single-particle excitations**

Courtesy of A. Gargano

LOI SPES D. Mengoni (Uni. Pd)

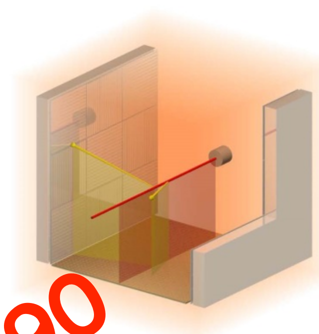
LOI from KU Leuven (Be)

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

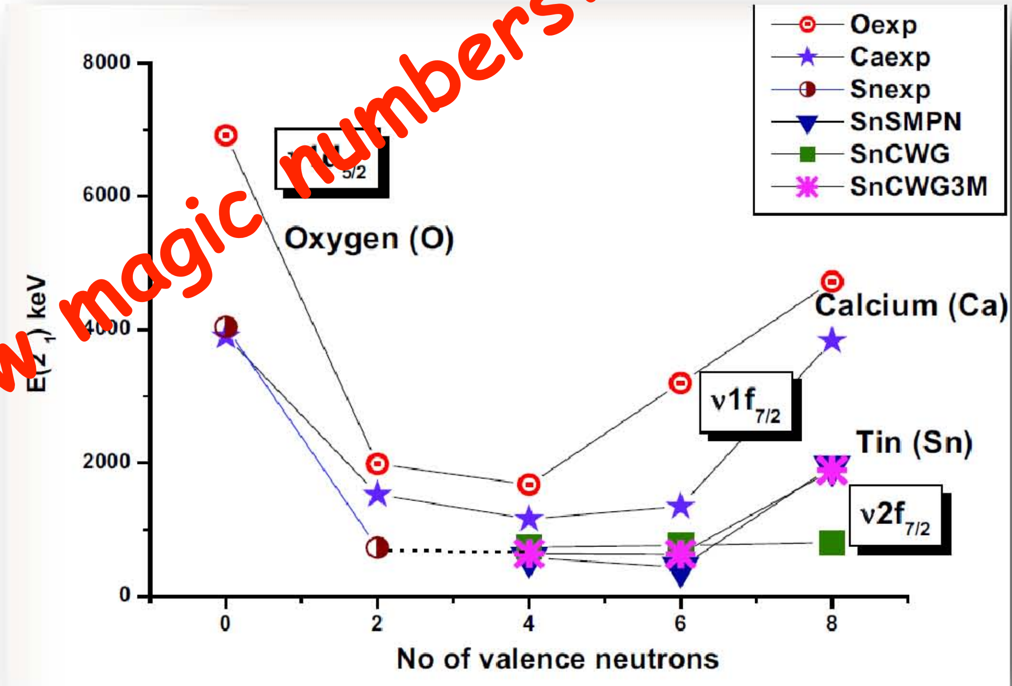
- ^{133}Sn well described by doubly-magic ^{132}Sn+n
- Beyond?
  Behaviour of $\nu f_{7/2}$ similar to that beyond ^{40}Ca
- Empirical or realistic interactions
  Role of n-n interaction and 3-body forces

(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



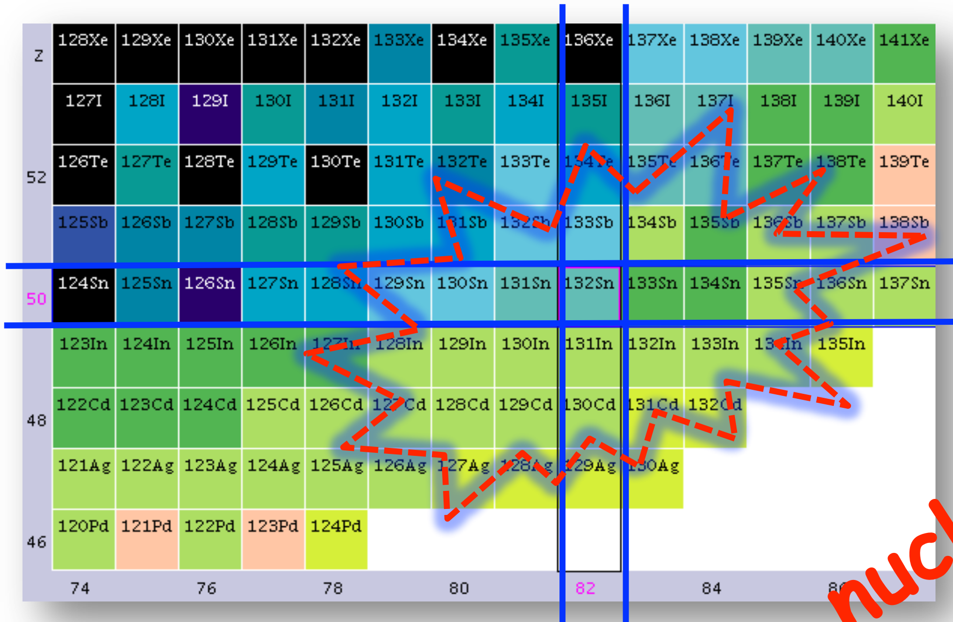
Sarkar and Saha Sarkar, JoPCS 267 (2011) 012040



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 (PL)



Z=50

N=82

STUDY OF NUCLEI

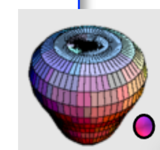
1 and 2 nucleons away from ^{132}Sn

→FOCUS ON

Particle-Phonon couplings

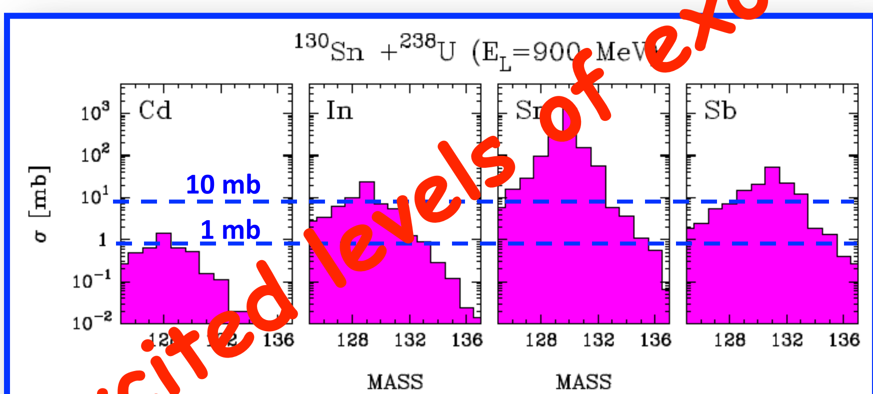
with 2+ (7.2 Wu) and 3- (> 7 Wu) of ^{132}Sn

(responsible for quenching of Spectroscopic Factors)



→ I^{π}, B(Eλ)

Excited levels of exotic nuclei: the ^{132}Sn region



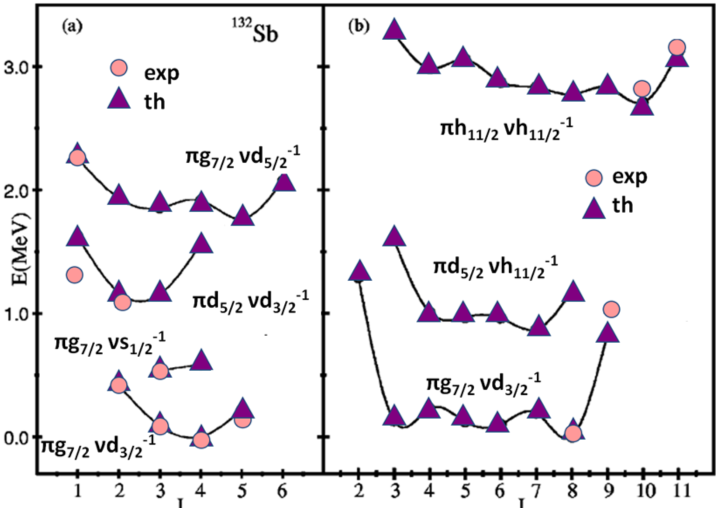
GRAZING calculations

***Conservative estimates** for more than 1 nucleon transfer*

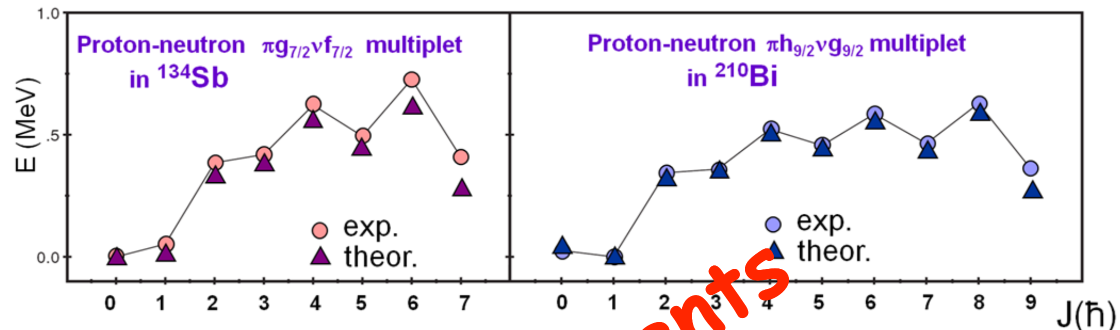
SPES Beams

^{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 -		

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



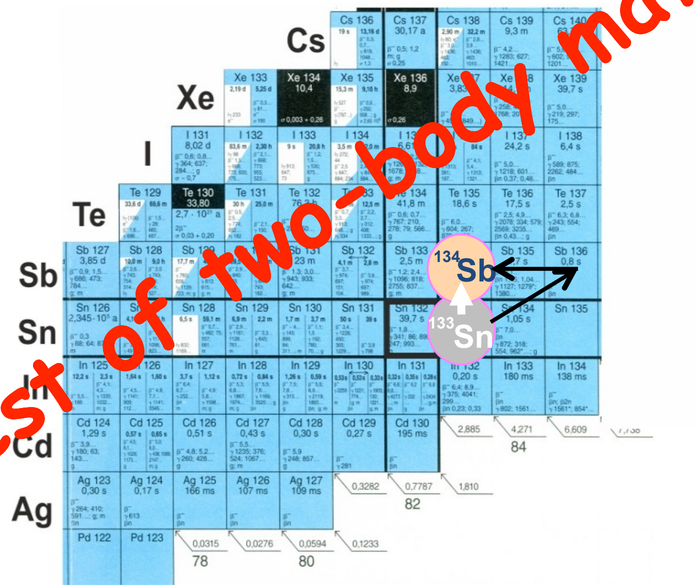
L. Coraggio et. al. PRC **66**, 064311 (2002)



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

Test of two-body matrix elements

for example:



^{133}Sn + ^{7}Li → ^{134}Sb+α+2n

Cluster transfer for higher selectivity

Giacomo de Angelis

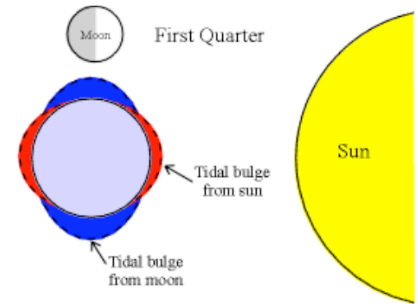
Shells do evolve ….due to 3 body interactions

N=34 subshell closure due to the effects of three body forces driving the monopole part of the nuclear Hamiltonian

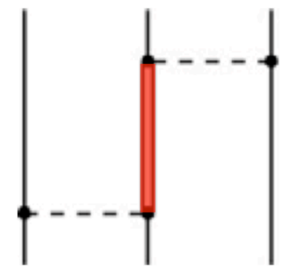
---

Why are there three-nucleon (3N) forces?

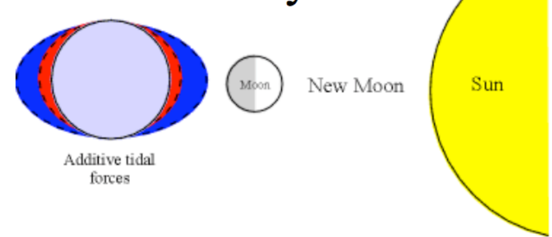
Nucleons are finite-mass composite particles, can be excited to resonances



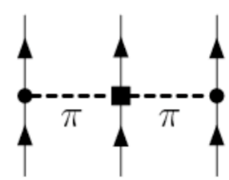
dominant contribution from Δ(1232 MeV)



tidal effects lead to 3-body forces in earth-sun-moon system



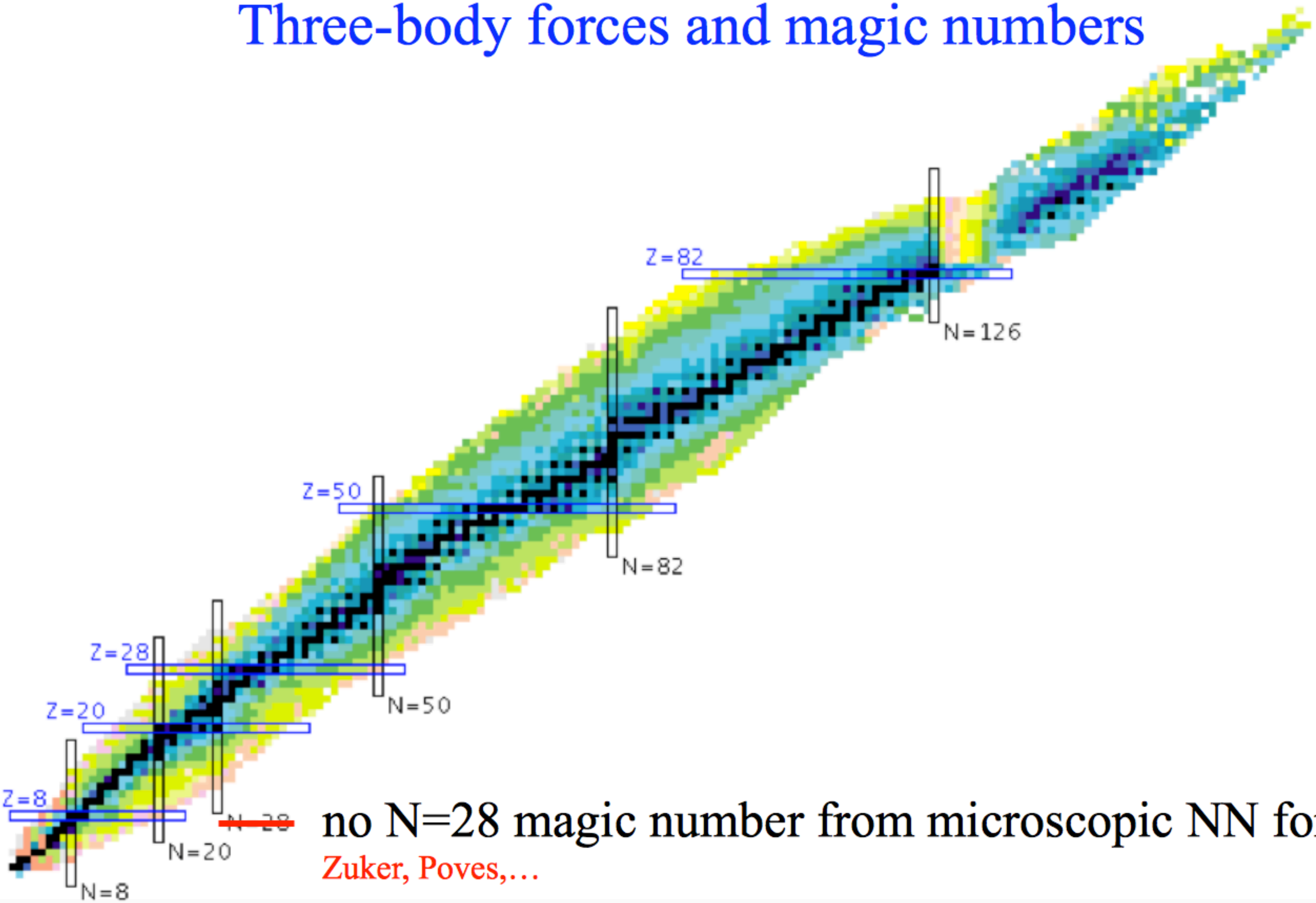
+ many shorter-range parts

in chiral EFT (Delta-less): 

+ shorter-range parts

Shell model calculations with effective interaction based on chiral Effective field theory and three body forces (G. Hagen PRL 109 2012)

Three-body forces and magic numbers



no N=28 magic number from microscopic NN forces

Zuker, Poves,…

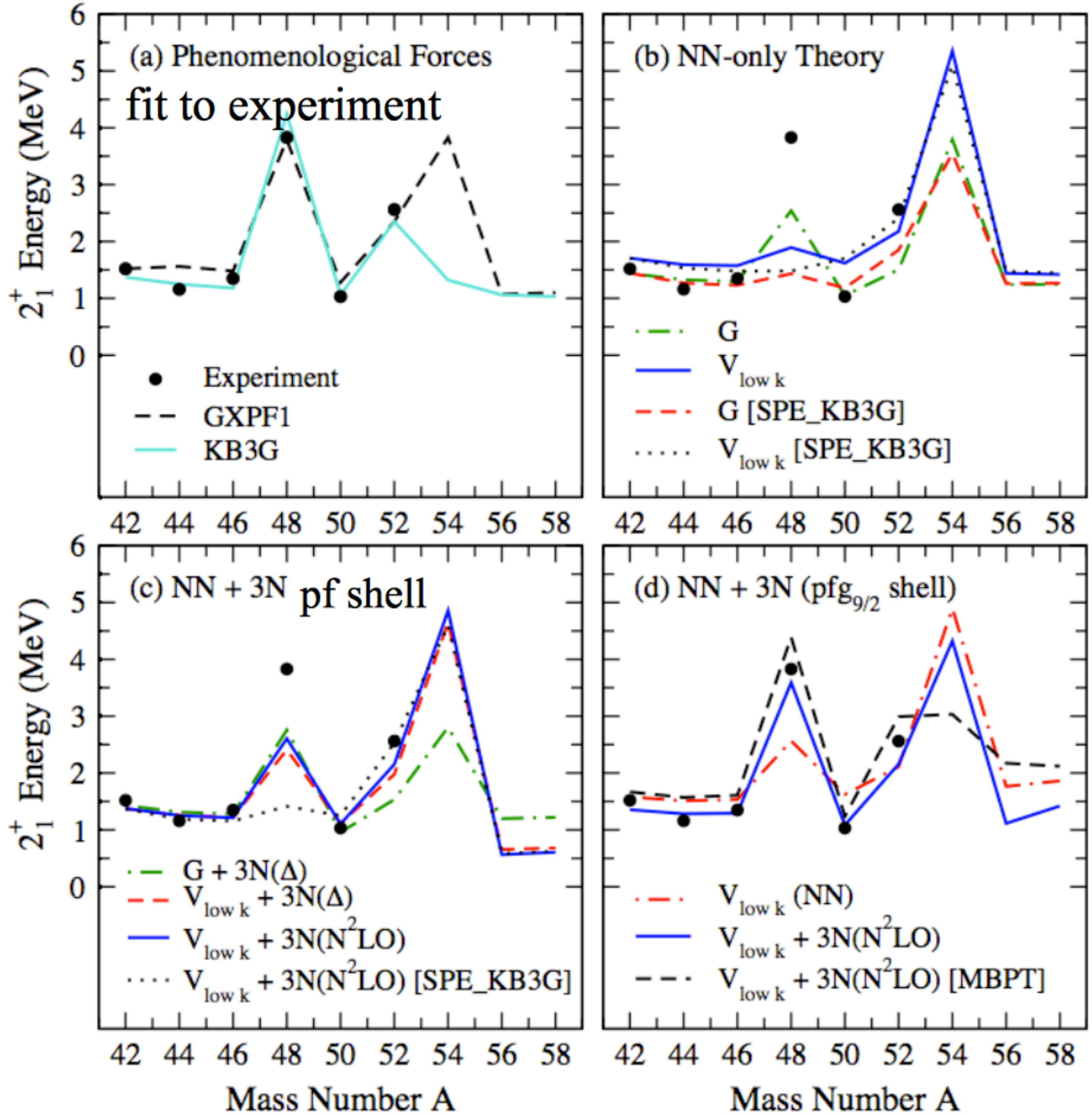
Three-body forces and magic numbers

3N mechanism important for shell structure

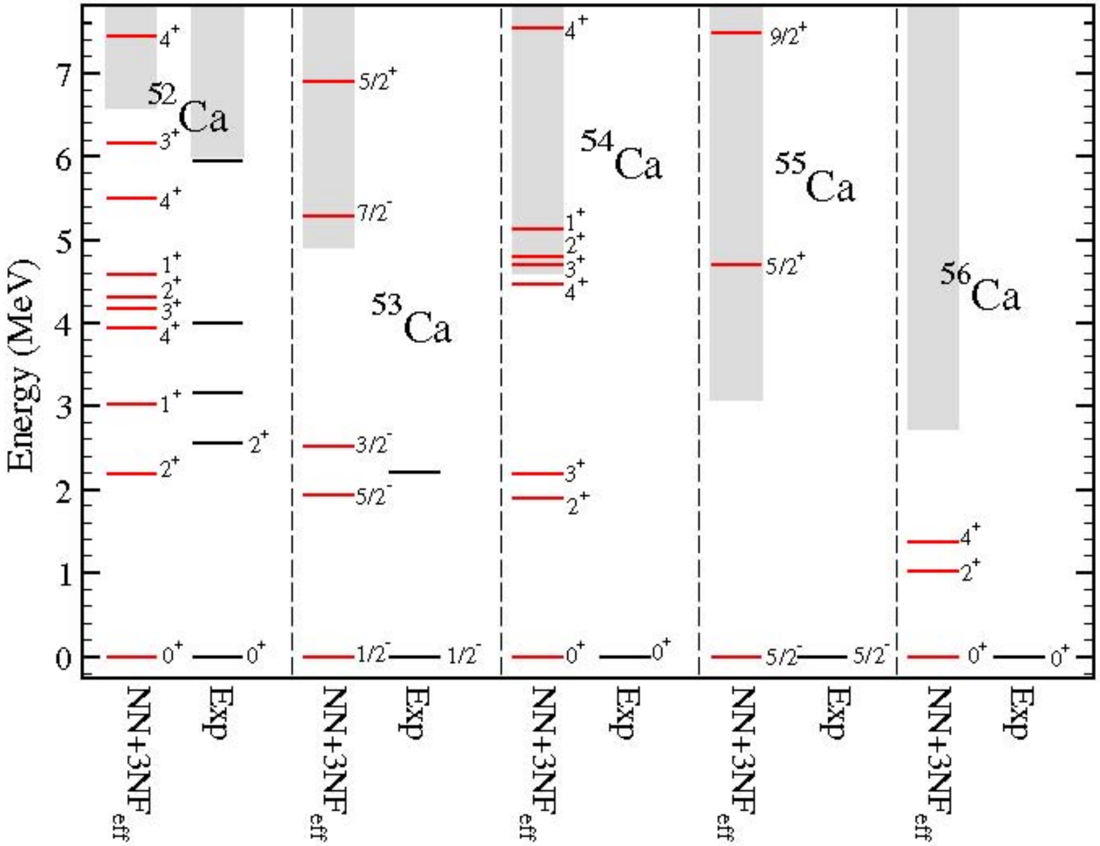
Holt et al., arXiv:1009:5984

N=28 shell closure due to 3N forces and single-particle effects (^{41}Ca)

N=34: predict high 2^+ excitation energy in ^{54}Ca at 3-5 MeV



N=34 subshell closure due to the effects of three body forces driving the monopole part of the nuclear Hamiltonian



Beta delayed
n spectroscopy
n-γ coincidences

LOI SPES A. Gottardo IPN Orsay

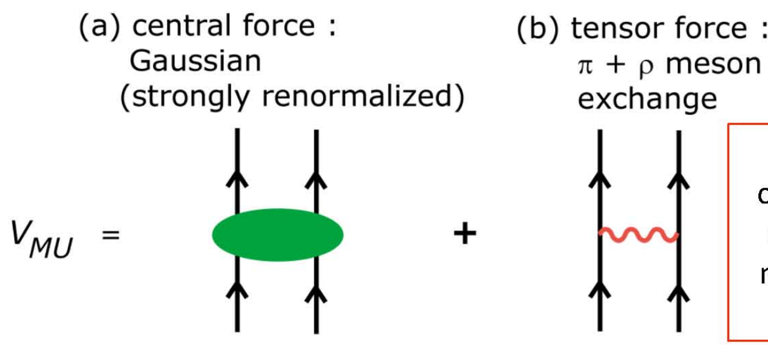
Shell model calculations with effective interaction based on chiral Effective field theory and three body forces (G. Hagen PRL 109 2012)

QUANTUM PHASE TRANSITIONS

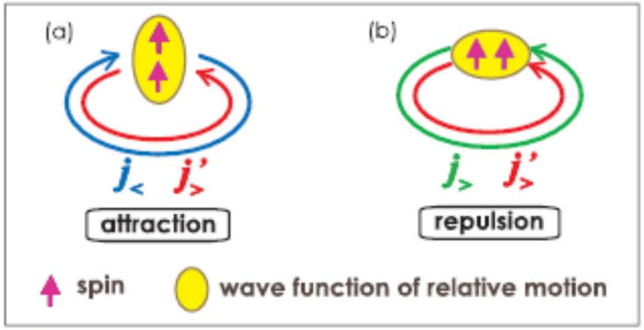
New shape phase transition regions?
Approach to criticality (critical symmetries) E5…
………..

Type 2 shell evolution

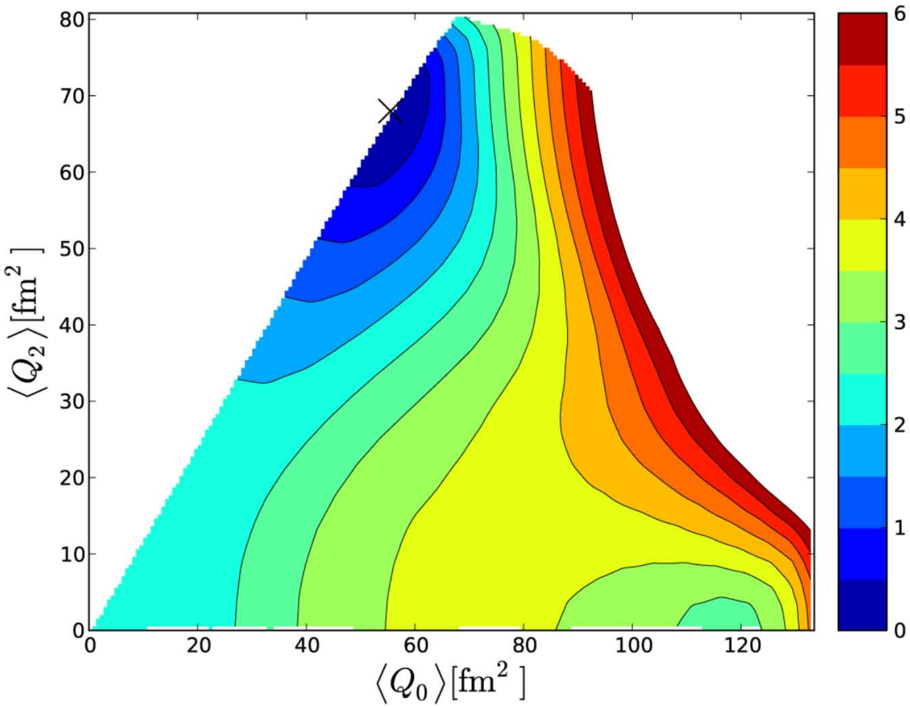
Shells do evolve..for increasing spin: Type II evolution

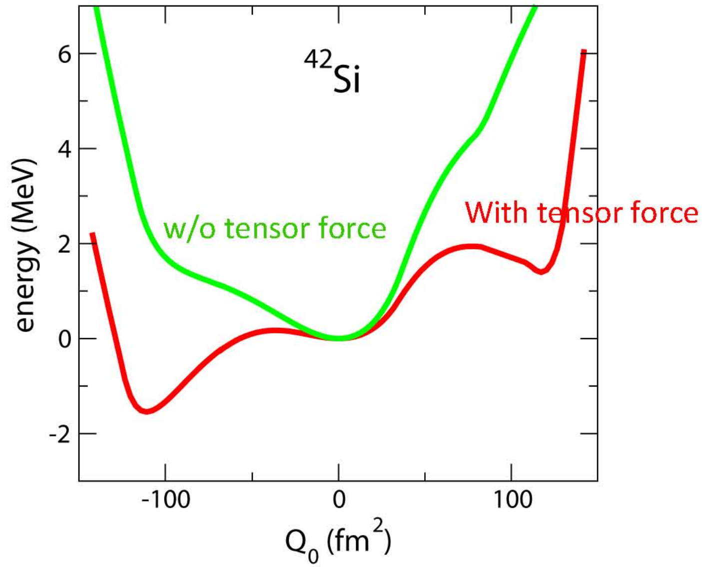


Monopole component is the same in nuclear medium and free space

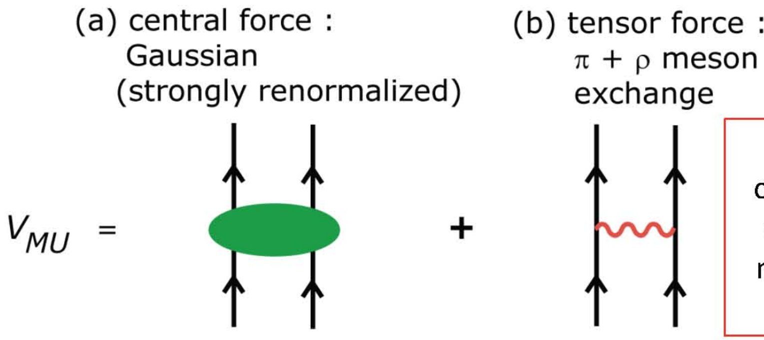


Tensor force

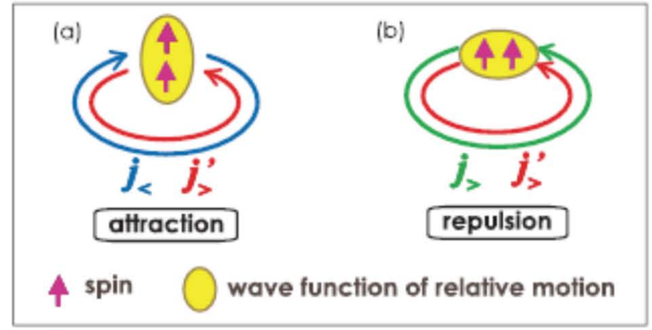




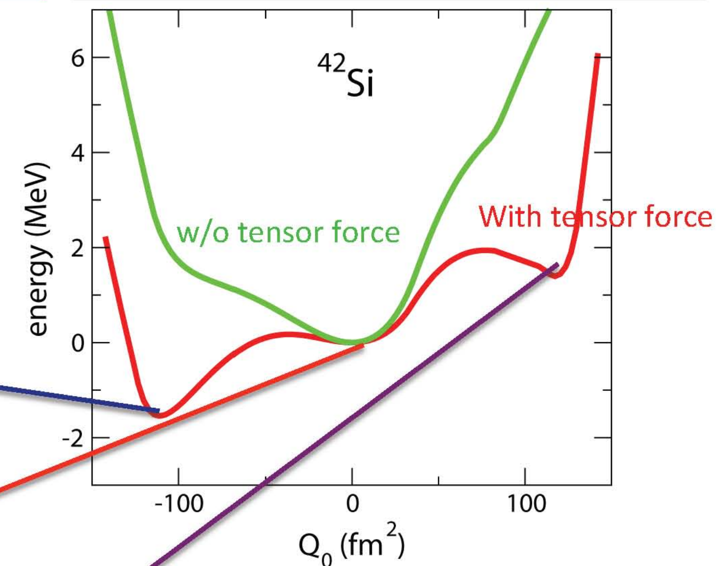
Otsuka, *et al.*

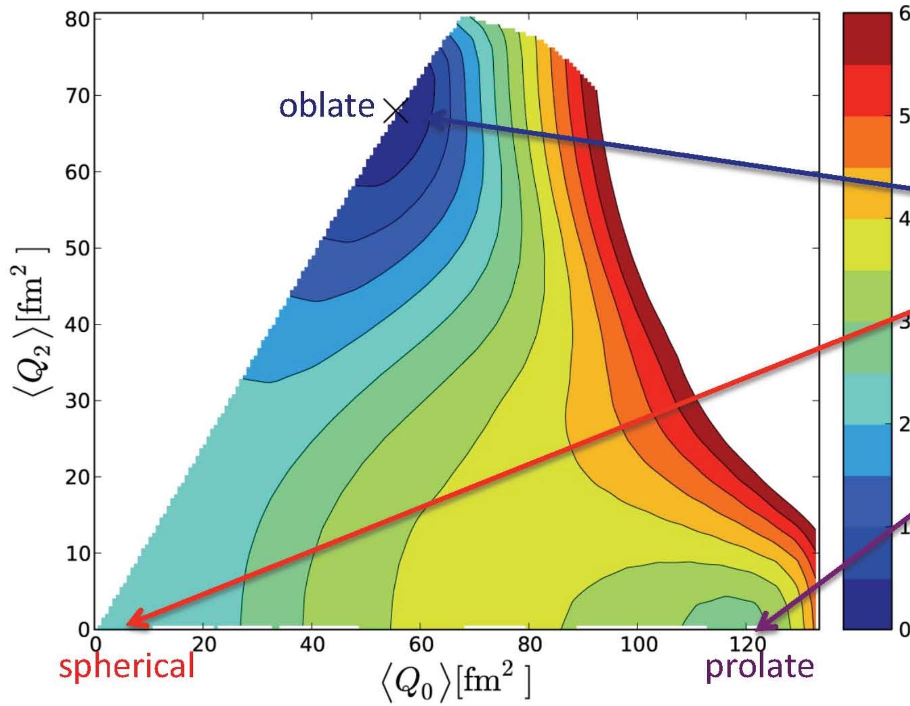


Monopole component is the same in nuclear medium and free space

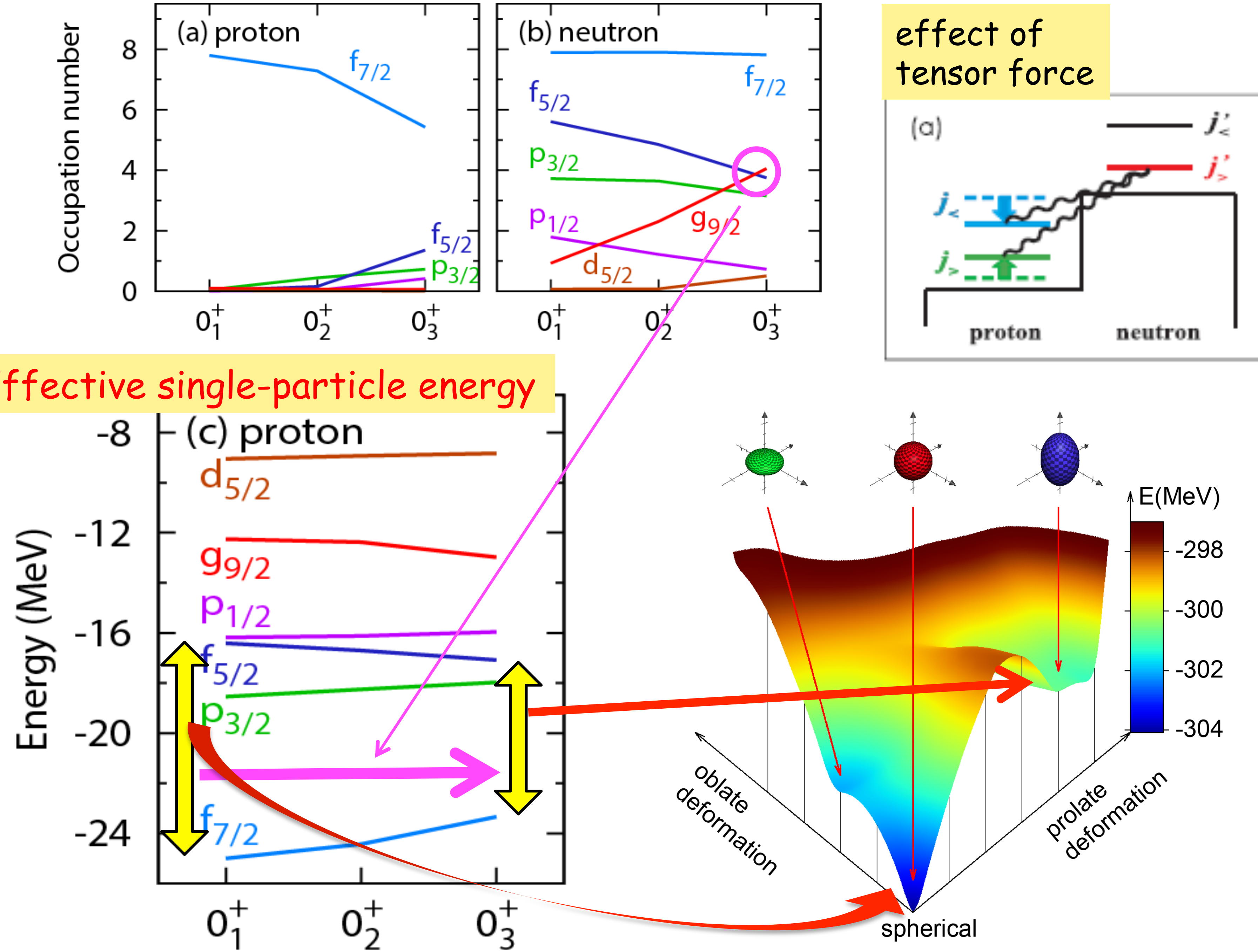


Tensor force





Otsuka, *et al.*



effect of tensor force
(a) proton
(b) neutron
Occupation number
f7/2
f5/2
p3/2
p1/2
g9/2
d5/2
0+1 0+2 0+3
(a)
j'<
j'>
j<
j>
proton
neutron
Effective single-particle energy
(c) proton
Energy (MeV)
-8
-12
-16
-20
-24
E(MeV)
-298
-300
-302
-304
oblate deformation
prolate deformation
spherical

SUMMARY OF SYMMETRIES AND PHASE TRANSITIONS IN NUCLEI

Nuclei show some of the best example of QPT.
The phases are between different shapes
(spherical, axially deformed…)
Also signature of critical behaviour
Have been suggested:
Critical symmetries

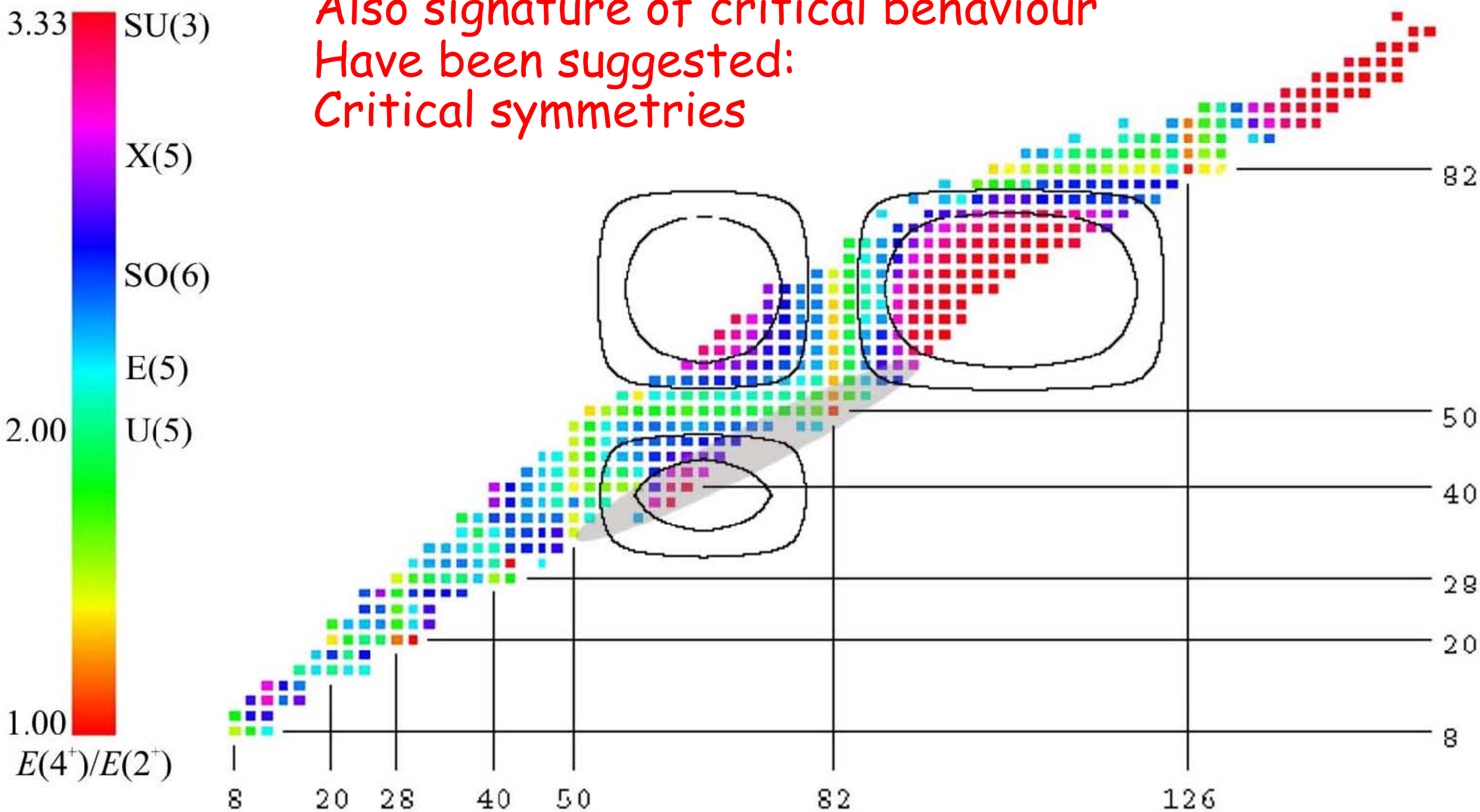
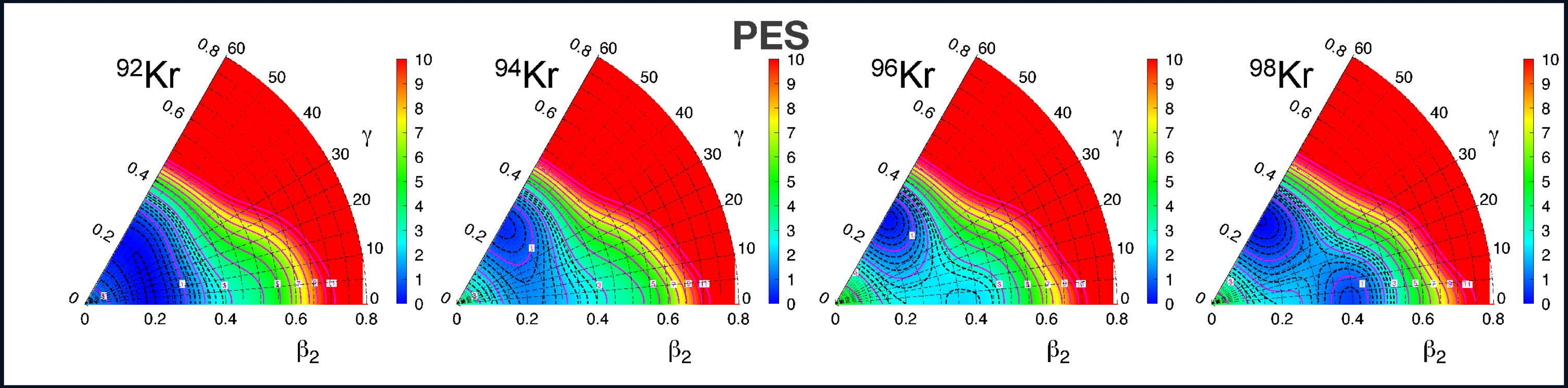


Figure courtesy of P. van Isacker

Giacomo de Angelis

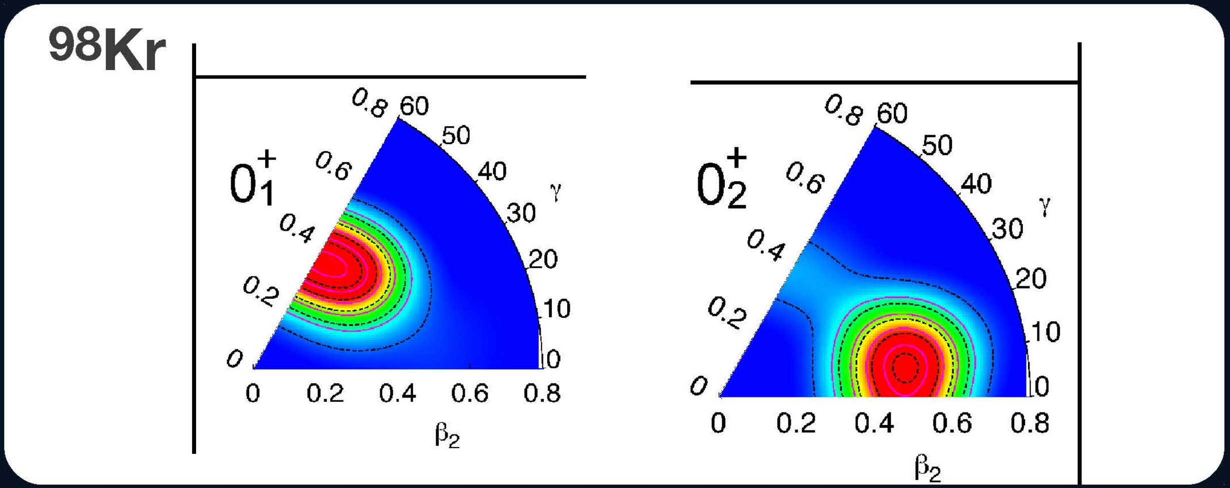
LOI LNL (I)....

Shapes in Kr

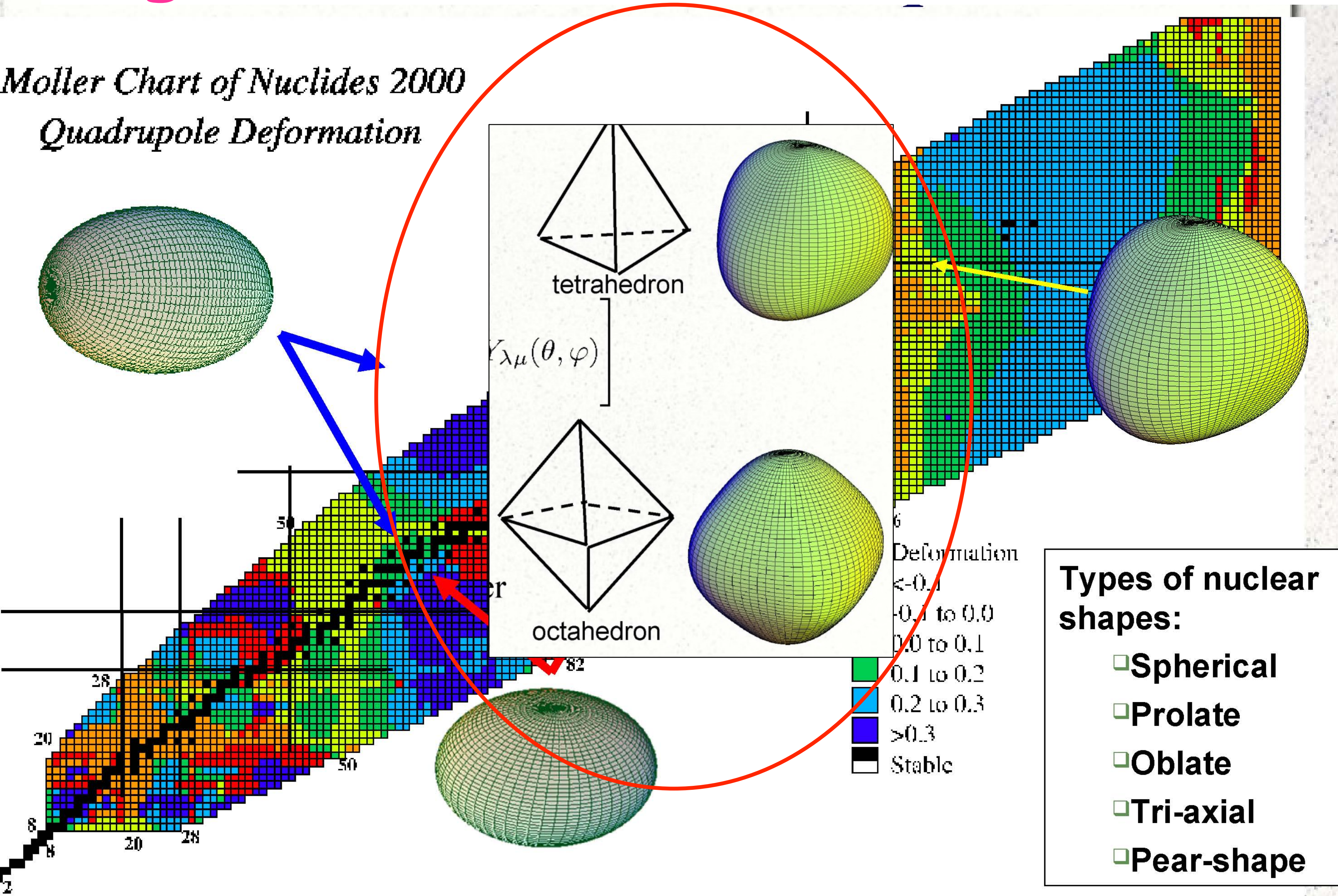


Oblate-Prolate shape coexistence in Kr at N=60: LNL

Shape transition to prolate shape on the second 0+, at N=62



High order Exotic deformations



Types of nuclear shapes:

- Spherical
- Prolate
- Oblate
- Tri-axial
- Pear-shape

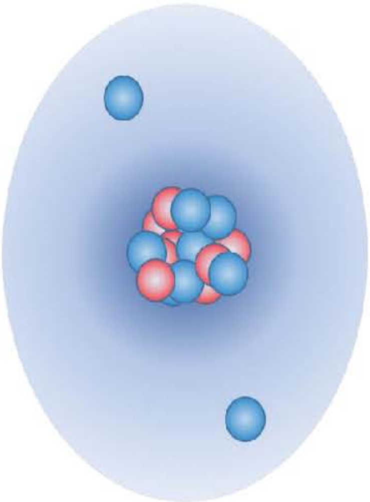
EFFECTIVE INTERACTIONS IN MEDIA

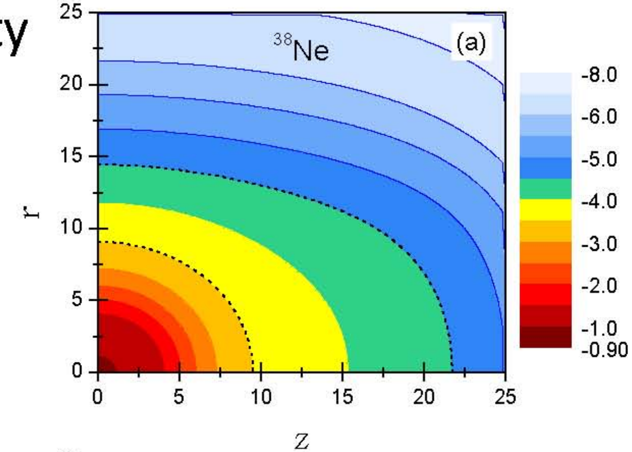
When going from free space to medium the Interactions are modified (density dependent forces)
When going from infinite to finete Hilbert space the Interactions are further modified (truncation schemes)

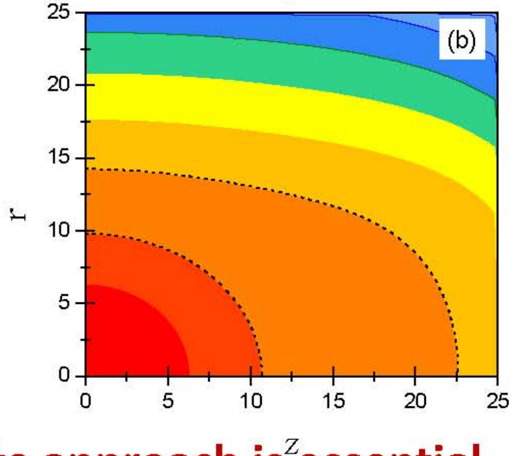
Configurational Isospin Polarization

Exotic egg-like halo structure

- Self-consistent calculations: SLy4 force + density dependent pairing
- 38Ne, (a) neutron density; (b) n pairing density
- About 2 neutrons in the halo
- Deformations: beta2 = 0.24, beta2_pair=0.48
- Mainly contributed by near-threshold continuum







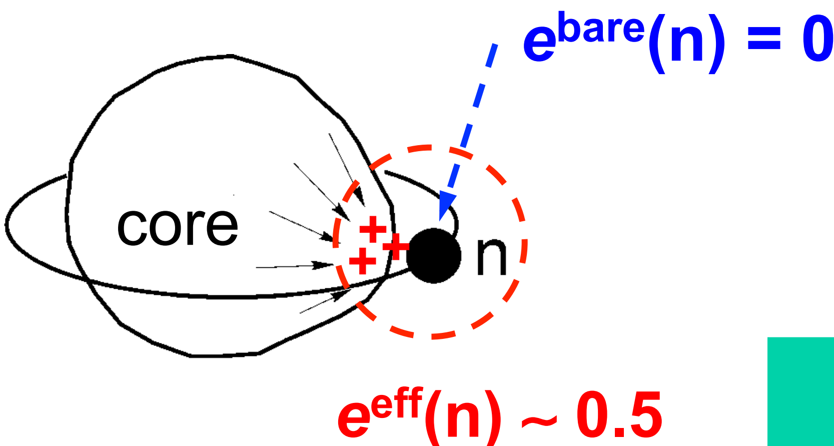
Isovector deformation: pygmy quadrupole resonances

New exotic "egg"-like halo structure obtained; accurate approach is essential

J.P., Y.N. Zhang, F.R. Xu, PRC (R) 87, 051302(2013)

Also,

<u>**decoupling of neutron from the core**</u>



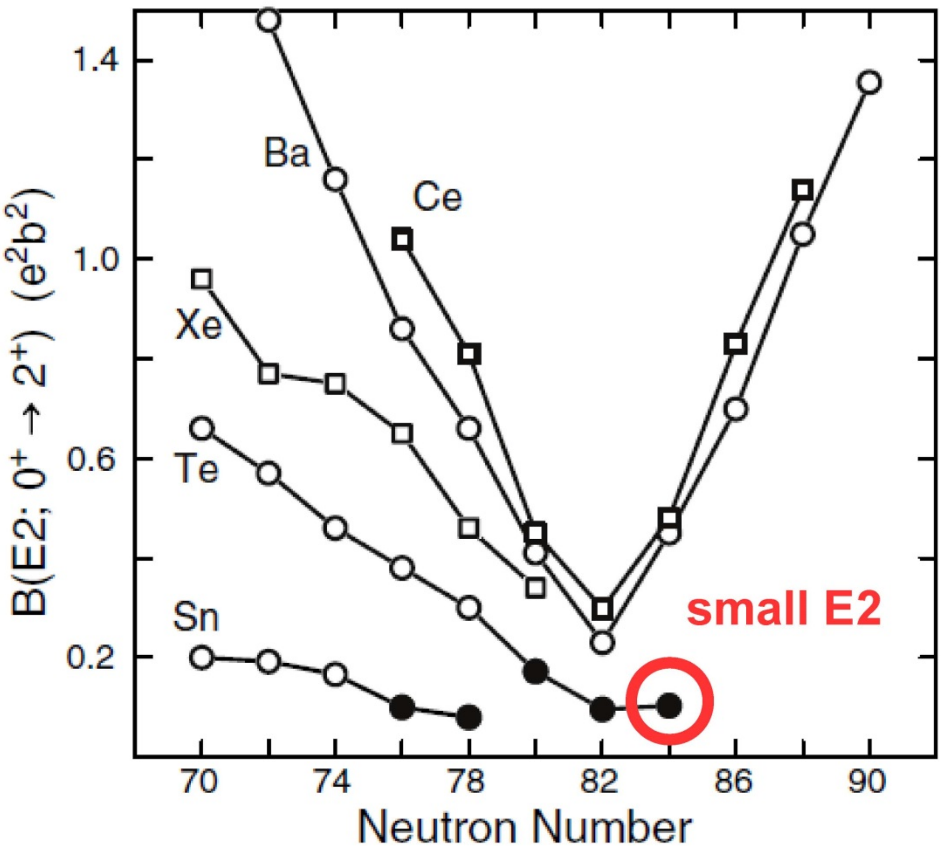
$e_{eff}(n) \sim 0$??

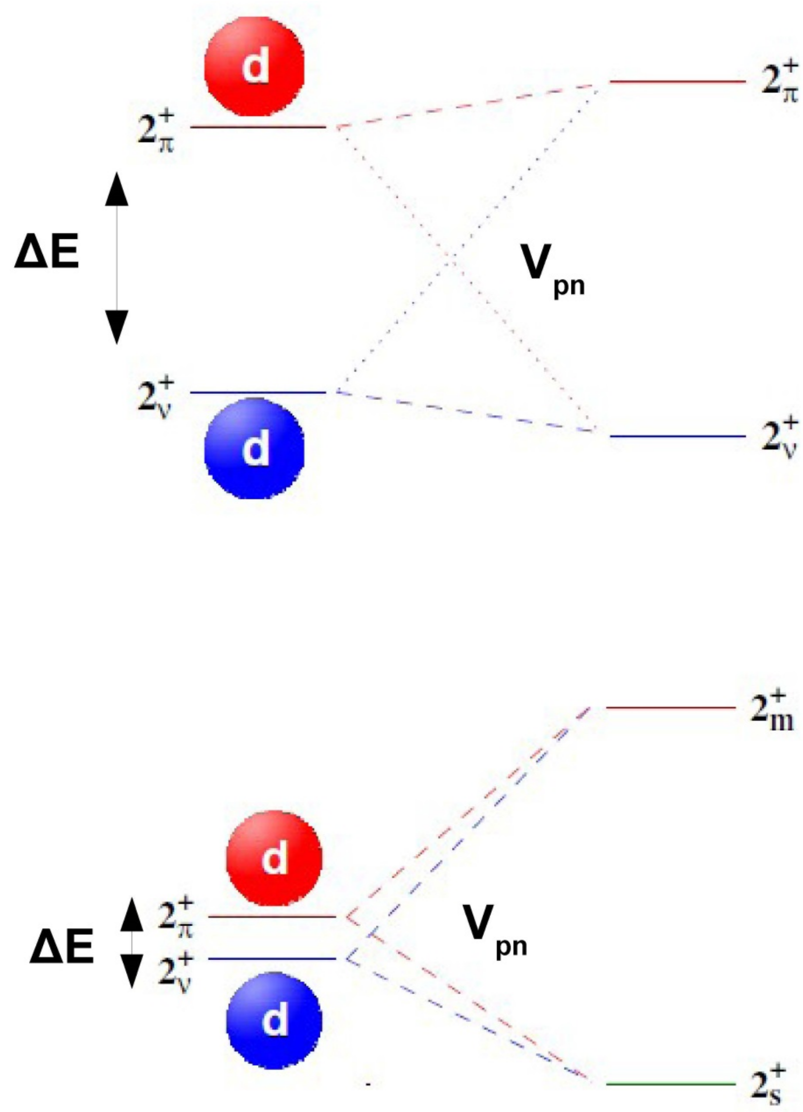
(in a normal nucleus)

(in a n-rich nucleus)

Such an effect can be detected through measurement of electric quadrupole moments *Q* associated with nuclear spin.

Configurational Isospin Polarization: B(E2)s for nuclei with n-excess





Shell Model:
N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)

QRPA:
J. Terasaki et al., PRC 66, 054313 (2002)

New CIP case predicted: 136Te

TECHNISCHE UNIVERSITÄT DARMSTADT

2+1 and 2+2 have significant E2 -> 1-phonon states
Strong M1 between them -> 2+2 = 2+1,MS
2+1 neutron dominated, 2+2 large proton amplitudes

-> CoulEx at SPES !

The neutron rich Sn region

	$\lambda_i^\pi = 2_i^+$	Energy (MeV) Expt.	Energy (MeV) Theory	Structure	$B(E2;0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Expt.	$B(E2;0_{gs}^+ \to 2_i^+)$ (e^2fm^4) Theory	$B(E2;2_i^+ \to 2_1^+)$ (e^2fm^4) Expt.	$B(E2;2_i^+ \to 2_1^+)$ (e^2fm^4) Theory	$B(M1;2_i^+ \to 2_1^+)$ (μ_N^2) Expt.	$B(M1;2_i^+ \to 2_1^+)$ (μ_N^2) Theory
^{136}Te	2_1^+	0.606	0.92	$97\%[2_1^+]_{QRPA}$	1030±150	1120				
	2_2^+	1.568	2.01	$94\%[2_2^+]_{QRPA}$		740		20		0.51

	State	Energy (MeV)	$B(M1;2_i^+ \to 2_1^+)$ (μ_N^2)	$B(E2;0_{gs}^+ \to 2_i^+)$ (e^2fm^4)	$\{n_1l_1j_1, n_2l_2j_2\}_\tau$	X	Y	%
^{136}Te	$[2_1^+]_{QRPA}$	1.05		1010	$\{2f_{7/2}, 2f_{7/2}\}_\nu$	1.32	0.14	86
					$\{2d_{5/2}, 2d_{5/2}\}_\pi$	0.32	0.13	4
					$\{1g_{7/2}, 1g_{7/2}\}_\pi$	0.30	0.12	4
	$[2_2^+]_{QRPA}$	2.20	0.44	920	$\{2f_{7/2}, 2f_{7/2}\}_\nu$	-0.52	0.13	13
					$\{2d_{5/2}, 2d_{5/2}\}_\pi$	0.82	0.04	34
					$\{1g_{7/2}, 1g_{7/2}\}_\pi$	0.83	0.04	34

QPM: A. Severyukhin *et al.*, submitted to PRC

➔ probe bulk properties of nuclei

➔ in-medium modification of NN interaction

➔ symmetry energy

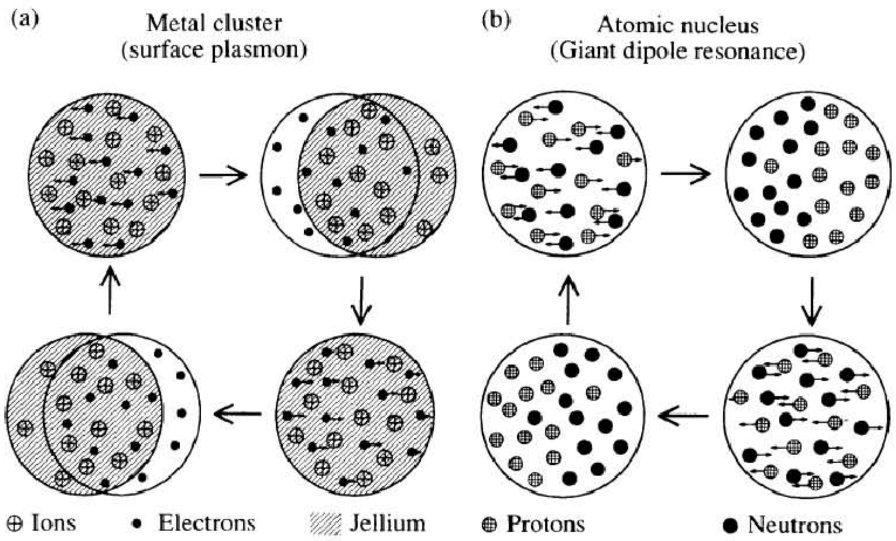
➔ compressibility

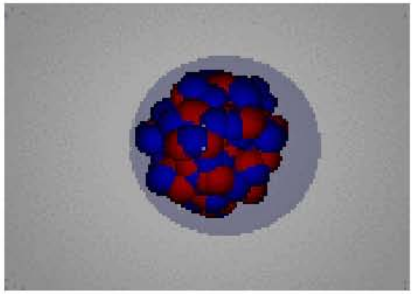
➔ New soft modes

Collective Modes

Radioactive beams allow study of isospin dependence

Low-lying dipole excitation via nuclear probes in exotic nuclei: INFN Ct and Uni Pd

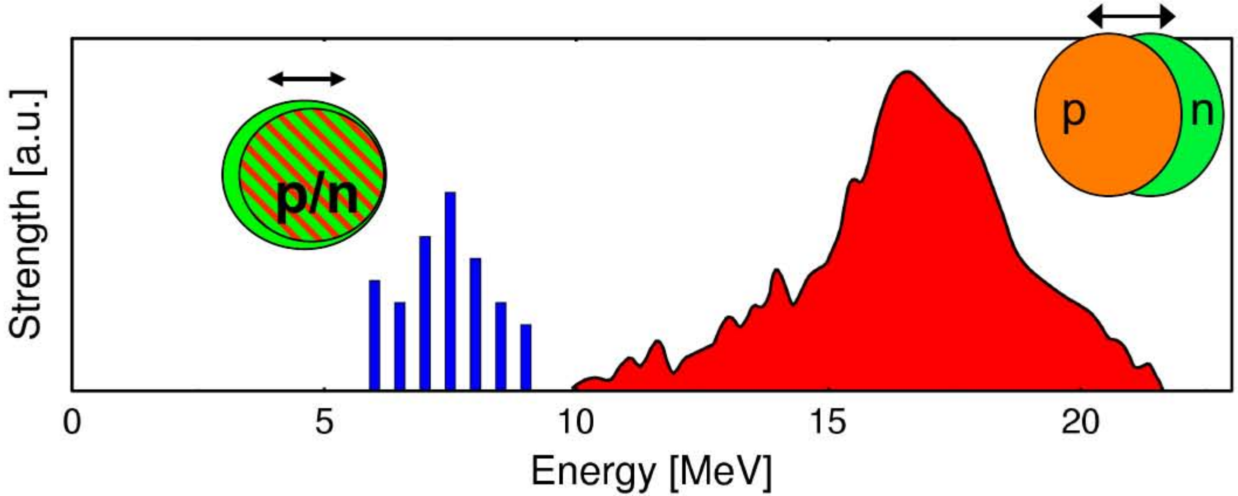




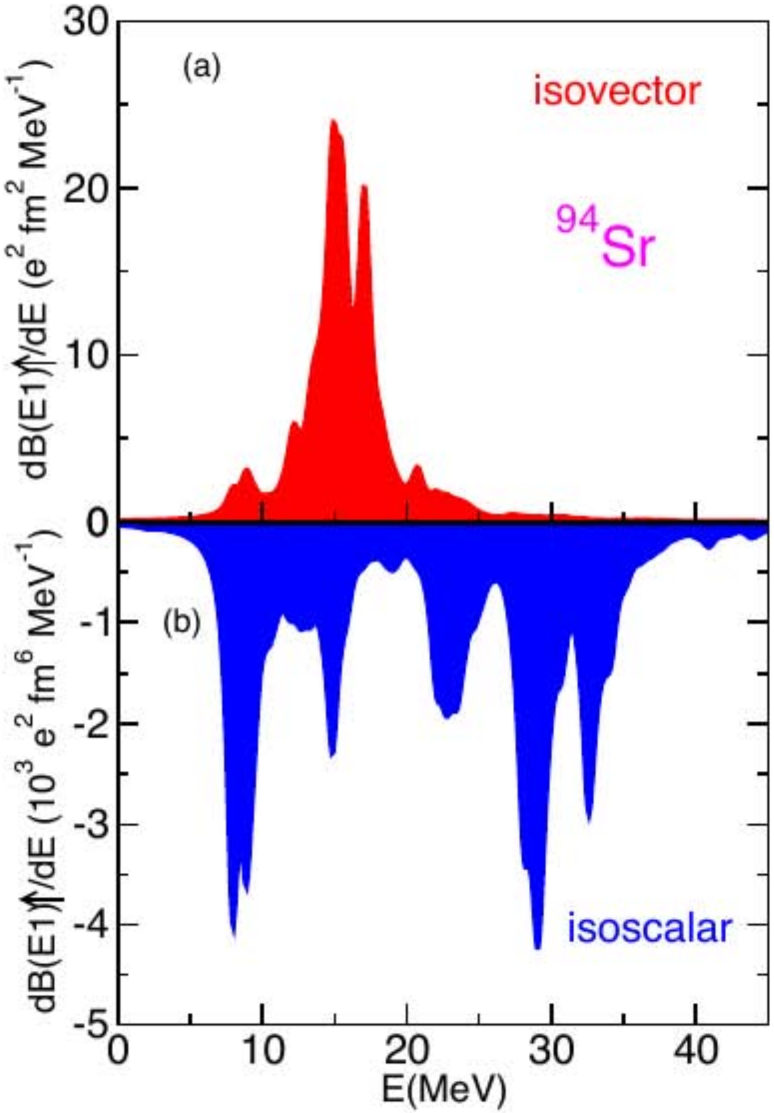
GDR
Universal phenomenon

Accumulation of strength at lower energy: *pygmy*

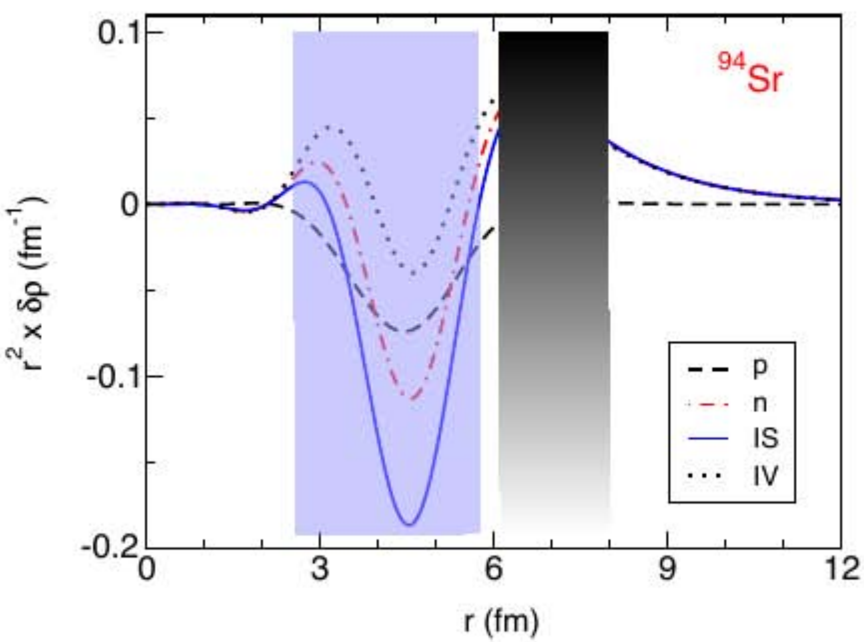
D. Savran , T. Aumann , A. Zilges
Progr.Part. Nuc.Phys 70 (2013) 210–245



RPA structure calculations

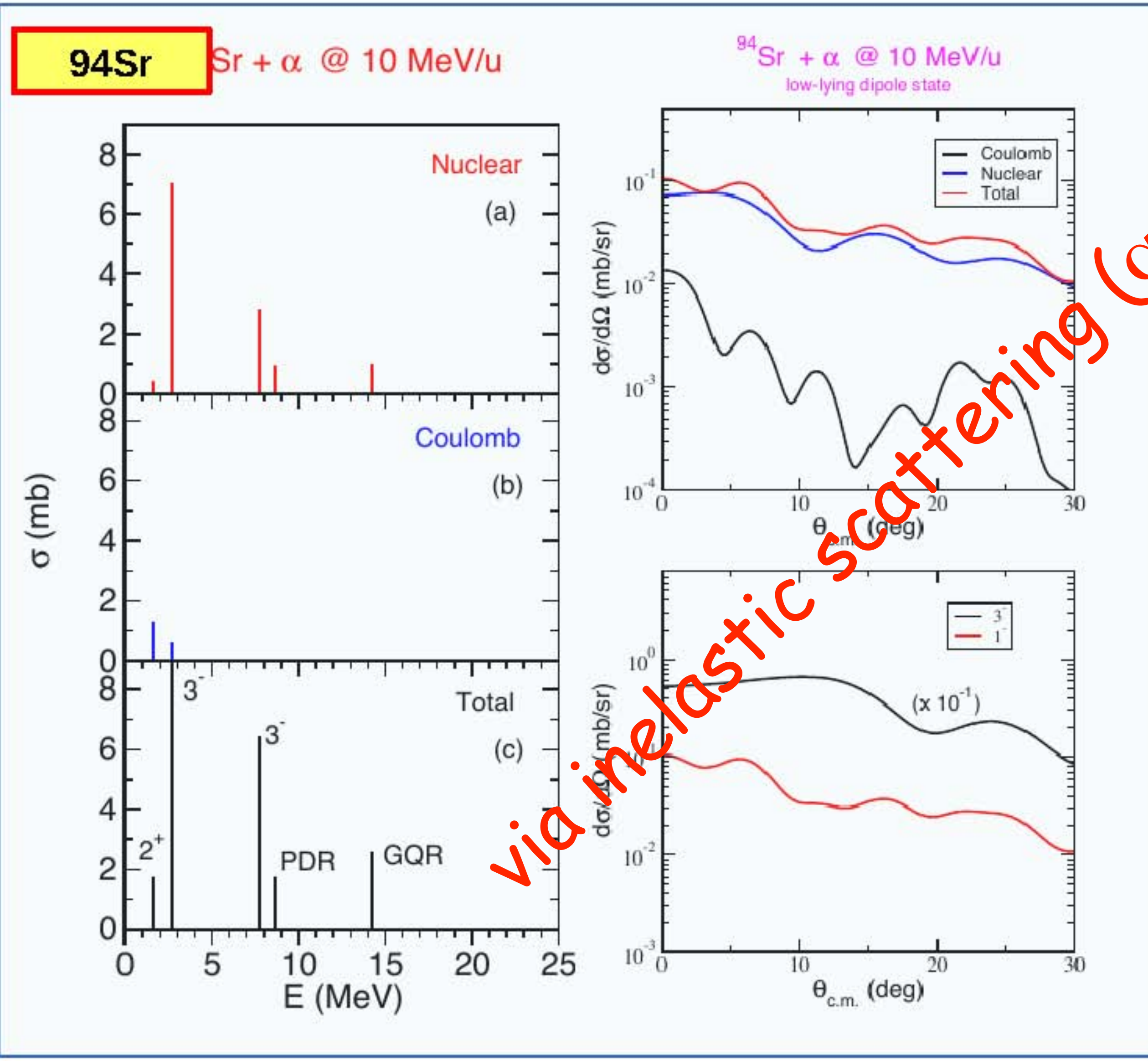


- IS effect CORE
- IS~IV surface

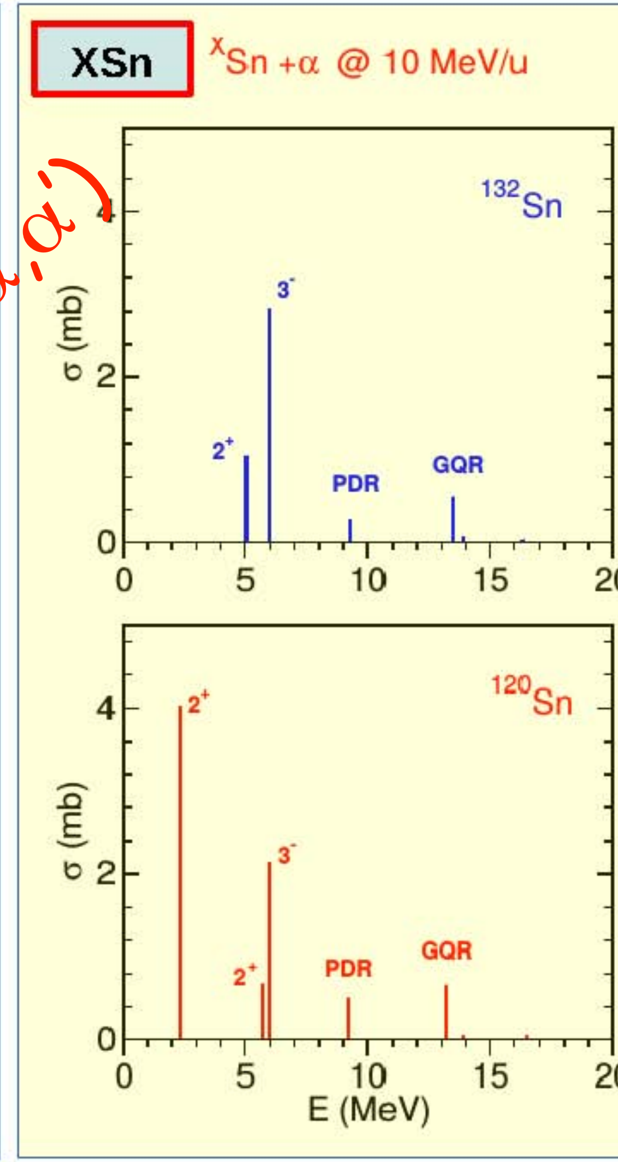


Cross section calculations: semiclassical model

LOI Ct, LNL



via inelastic scattering (α,α')

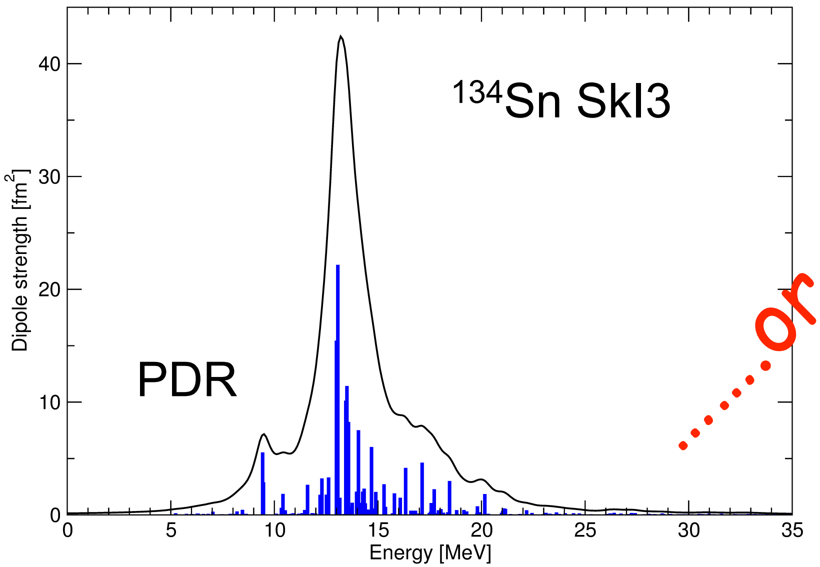


The large Q_β-value window (> 12 MeV) allows populating at least the PDR

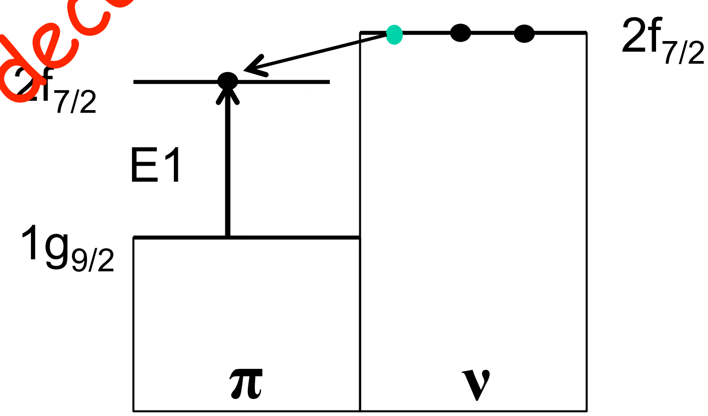
The β decay could populate states which are the PDR on the IAS(R) of the mother nucleus

Example: ^{134}In -> ^{134}Sn (Q_β= 14.7 MeV)
$\nu f_{7/2}$ -> $\pi g_{9/2}$

β decay: $\nu 2f_{7/2}$ -> $\pi 2f_{7/2}$, $\pi 2f_{5/2}$;



......or via β-decay



QRPA calculations with the SkI3 interaction: PDR at 10 MeV

^{133,134}In rates @ ALTO: 1000 pps ; 25 pps (100 times higher at SPES)

Pair Transfer

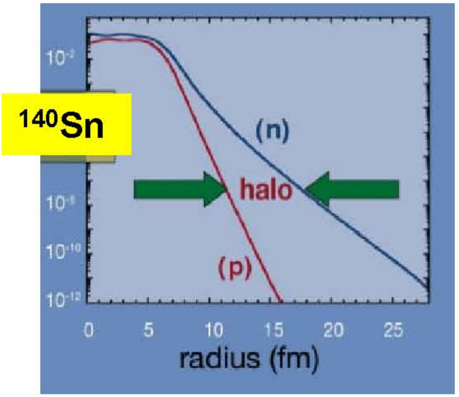
Pair Transfer Processes with SPES beams: INFN LNL

Multinucleon transfer reactions with radioactive beams

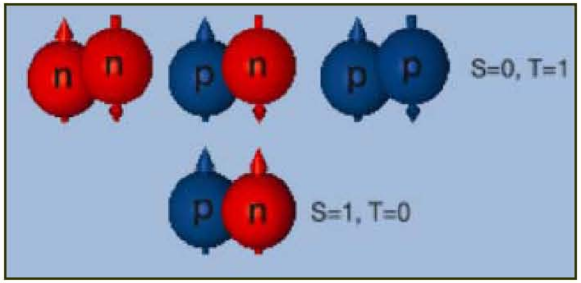
Do the degrees of freedom and the corresponding matrix elements tested with stable beams hold with RIBs ?

Do the form factors for one and two particle transfer and their strength need to be modified with RIBs ?

modification of nn correlations (neutron rich nuclei)

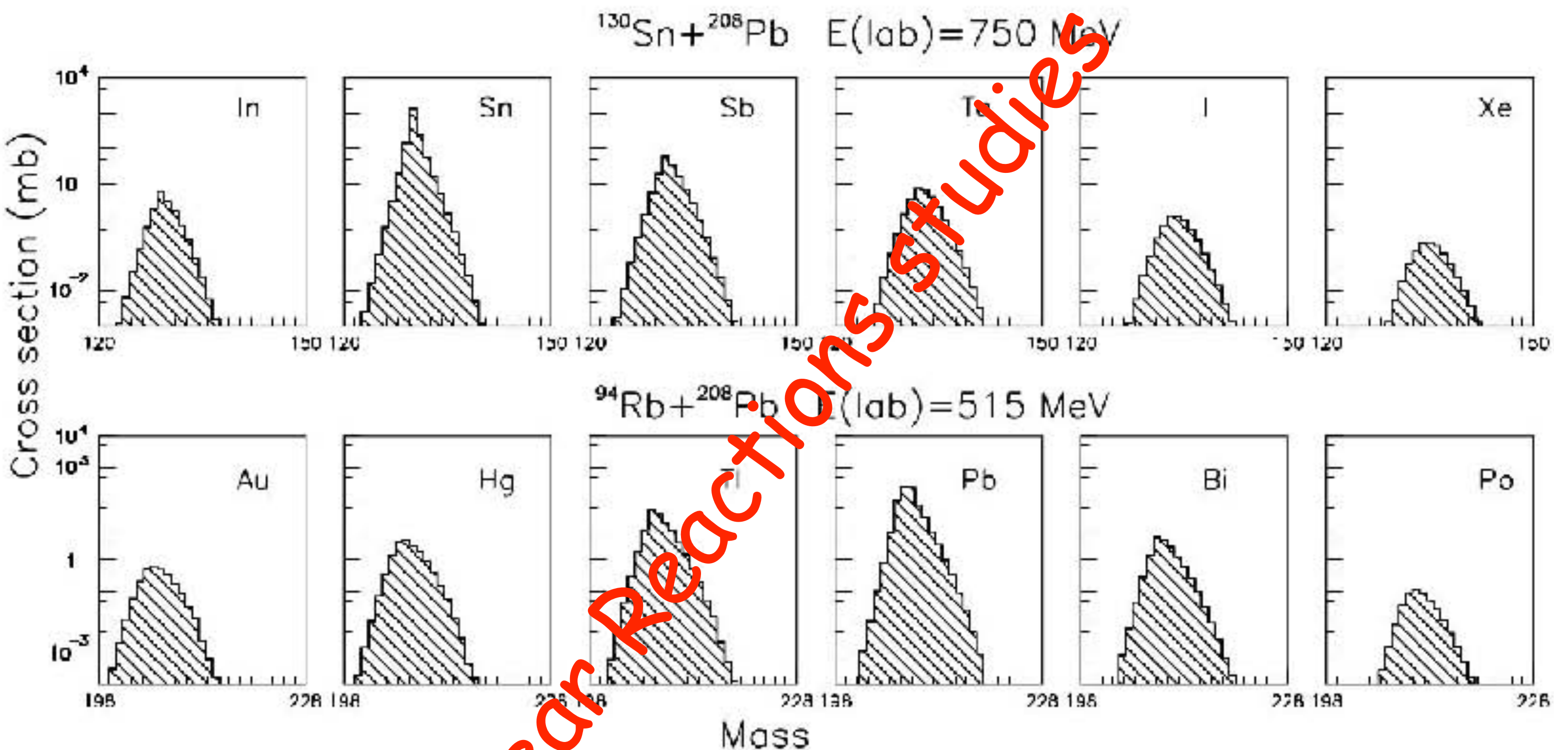


neutron-proton correlations (proton rich nuclei)



Giacomo de Angelis

Neutron-rich heavy nuclei explored via multinucleon transfers: Uni. Zagreb, IRES Strasbourg

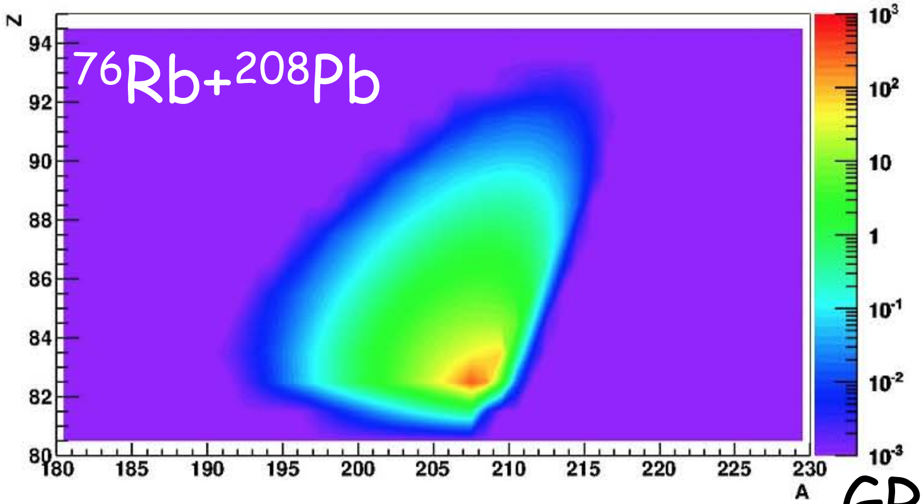


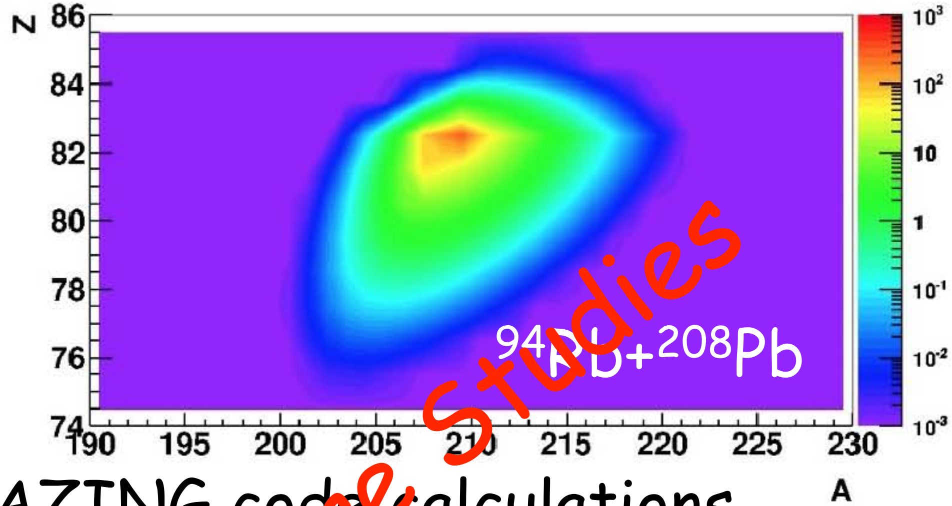
Calculation performed with GRAZING code: cross section

projectile-like reaction products in ^{130}Sn+^{208}Pb

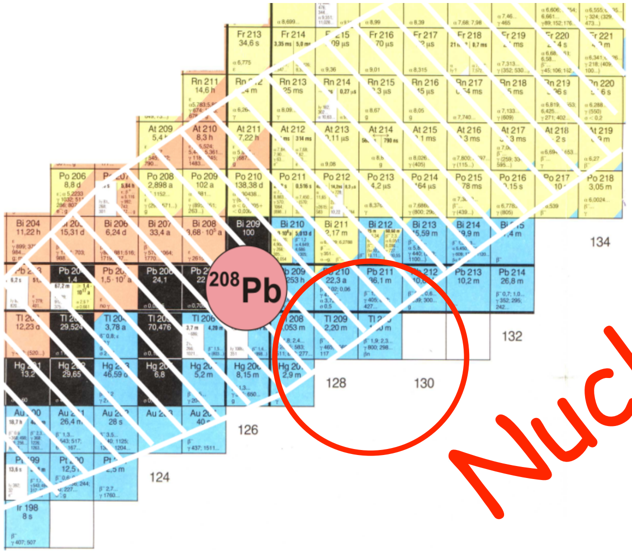
target-like reaction products in ^{94}Rb+^{208}Pb

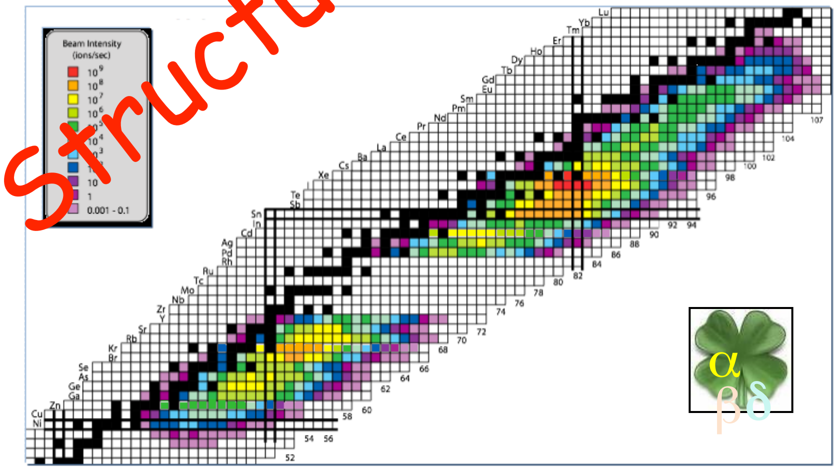
Deep Inelastic and Multinucleon Transfer Reactions with RIBS





GRAZING code calculations





Nuclear Structure Studies

Second SPES International Workshop

26-28 May 2014 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

INFN Istituto Nazionale di Fisica Nucleare

Letter of Intent for SPES

Measurement of the cross sections for the production of new neutron rich heavy nuclei using the beams of accelerated fission fragments

Yu. Itkis, G. Knyazheva, E. Kozulin, K. Novikov, V. Zagrebaev
Flerov Laboratory of Nuclear Reactions, JINR, Dubna, Russia

L. Corradi, E.Fioretto, A.M.Stefanini
INFN - Laboratori Naziolali di Legnaro, Italy

G.Montagnoli, F.Scarlassara
Dipartimento di Fisica, Universita' di Padova and INFN, Italy

S.Szilner, T.Mijatovic
Ruder Boskovic Institute, Zagreb (Croatia)

S.Courtin, A.Goasduff, F.Haas, D.Montanari
IPHC,CNRS/IN2P3 and Universite' de Strasbourg, Strasbourg, France

E. Vardaci,
Università di Napoli and INFN Napoli, Italy

D.Ackermann, S. Heinz,
GSI, Darmstadt, Germany

Nuclear Reactions studies

Super Heavy Elements

Second SPES International Workshop

26-28 May 2014 *INFN Laboratori Nazionali di Legnaro*
Europe/Rome timezone

The search of double magic superheavy nucleus in the region of neutron shell at N=184

We propose to perform the measurements of the cross sections for the production of new neutron rich nuclei located along the closed neutron shell N=184 using the beam **of ^{140}Xe** providing by SPES facility in collisions with **^{248}Cm** target by the two-arm detection system **PRISMA or PRISMA+CORSET.**

Structure: New magic number at Z=120,126

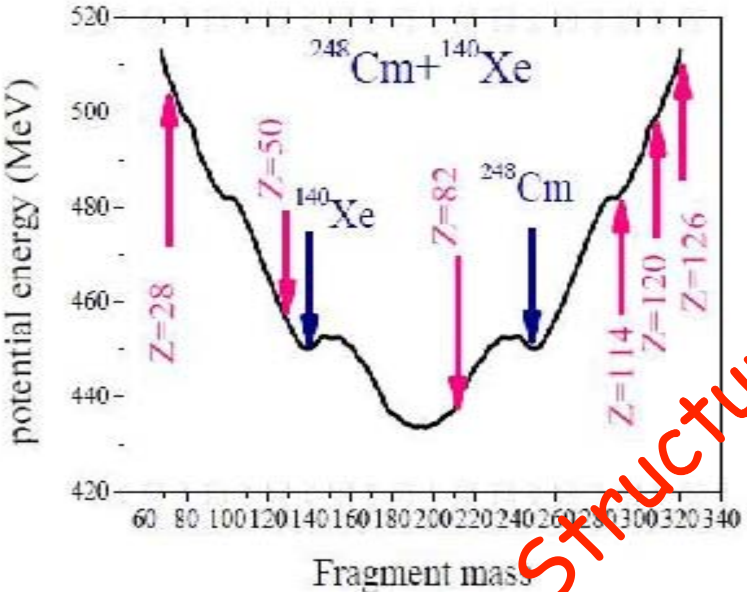


Figure 4. Potential energy at scission point as a function of the primary fragment mass in the reaction ^{248}Cm+^{140}Xe. The arrows indicate the positions of proton shells.

LOI LNL, Dubna (Ru)

Probing the Island of Stability with SPES beams

Reaction mechanism: synthesis of SHE

E. Vardaci, A. Brondi, G. La Rana, D. Pierroutsakou, P.R. Rath
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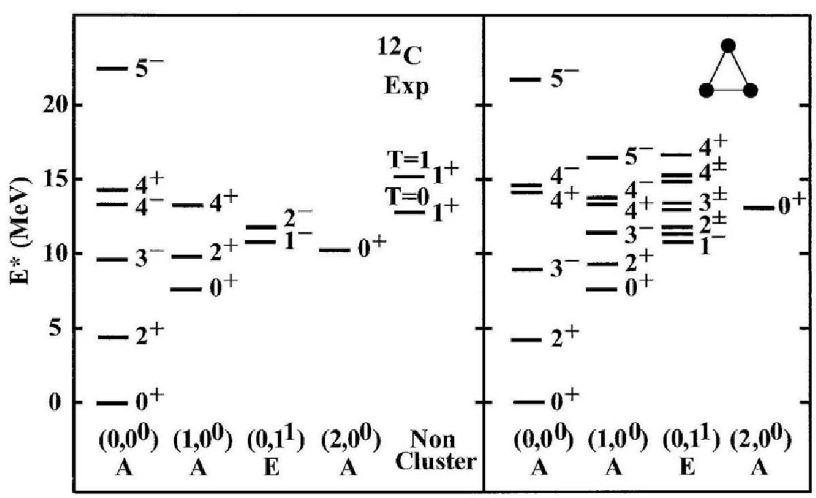
S. Heinz, O. Beliuskina, T. Dickel, H. Geissel, C. Heinz, W. Plass, C. Scheidenberger,
GSI Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt and Justus-Liebig-Universität, Germany

Cluster model

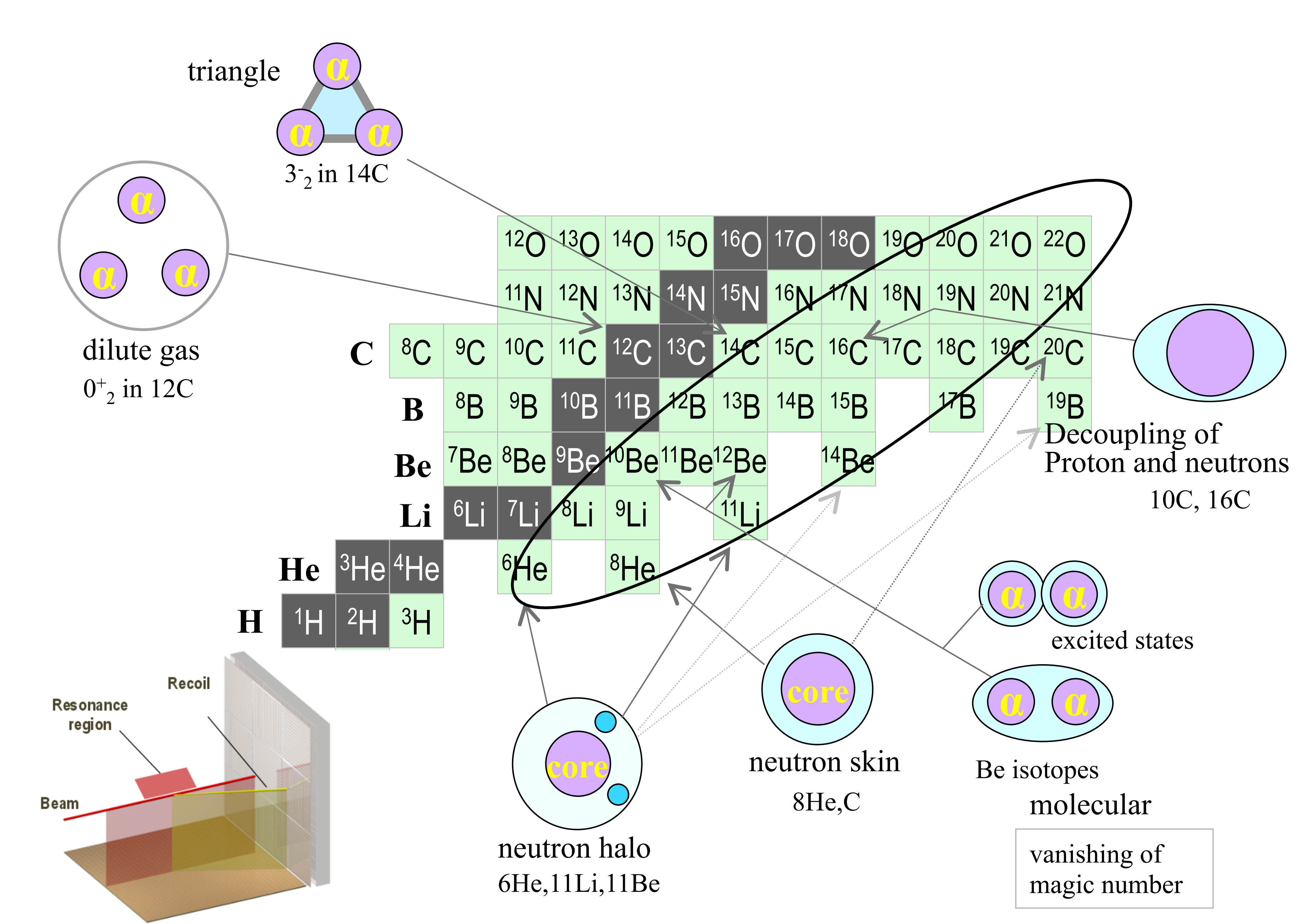
Role of discrete symmetries (D3h,Td…) in dense systems?
Motion of neutrons in a mean field with discrete symmetry in diffuse systems?

Cluster Structures

Evidence of D_3 symmetry in ^{12}C



Study of cluster states using the Resonance Scattering Method: LNS



Preequilibrium emission: a tool to study dynamic effects and clustering structure in exotic nuclei : LNL, NUClex

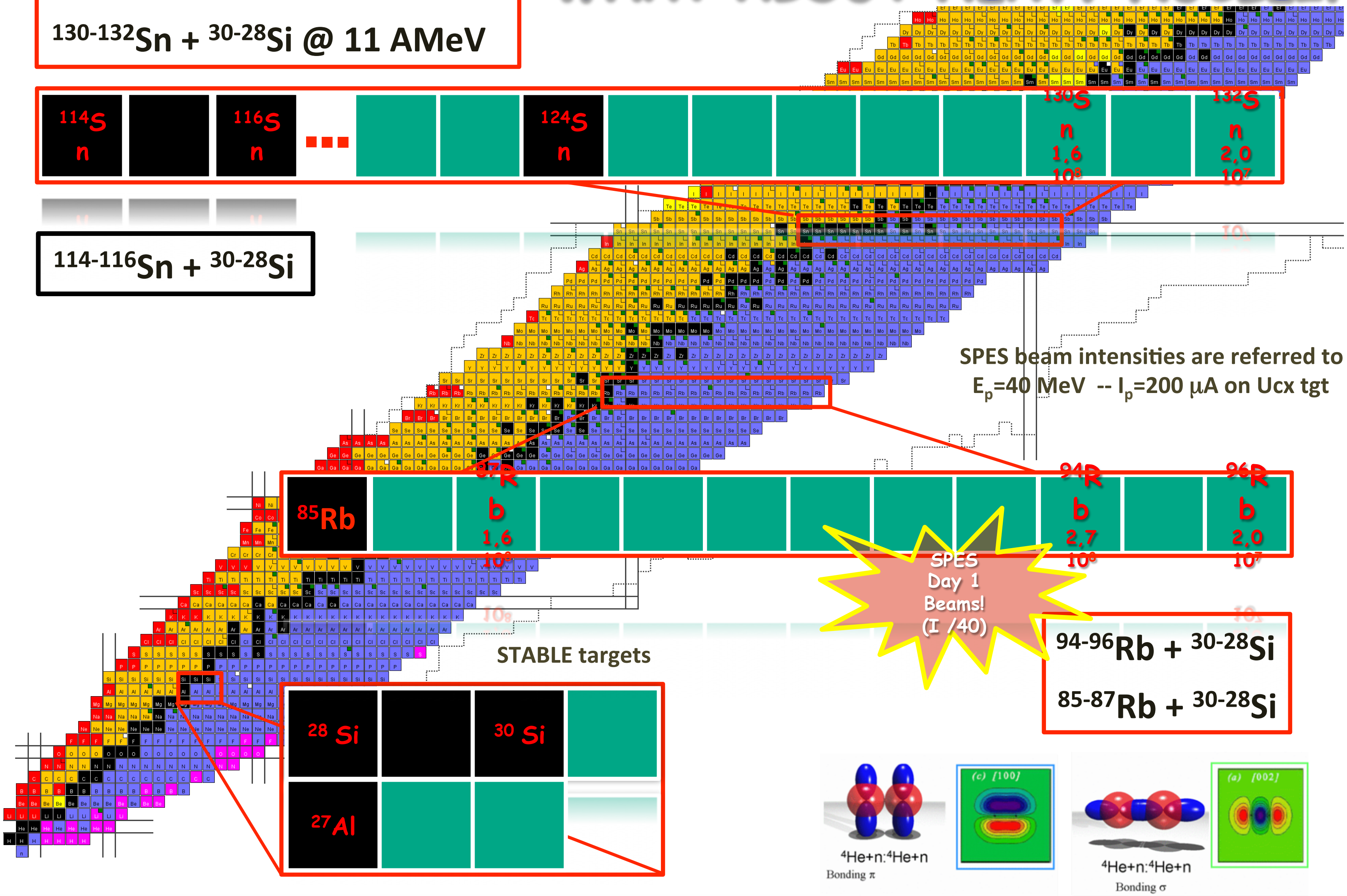
^{132}Sn + ^{27}Al @ 11 AMeV

$^{130-132}$Sn + $^{30-28}$Si @ 11 AMeV

WHAT ABOUT HEAVY NUCLEI?

$^{114-116}$Sn + $^{30-28}$Si

SPES beam intensities are referred to E_p=40 MeV -- I_p=200 μA on Ucx tgt



$^{94-96}$Rb + $^{30-28}$Si

$^{85-87}$Rb + $^{30-28}$Si

G.A.R.F.I.E.L.D.

General ARray for Fragment Identification and for Emitted Light particles In Dissipative collisions

Isospin Effects in Nuclear Reactions

Effective interaction and Symmetry Energy

$$E/A\,(\rho) = E(\rho) + E_{sym}(\rho)\,\beta^2$$

β=(N-Z)/A

Often used parametrization:

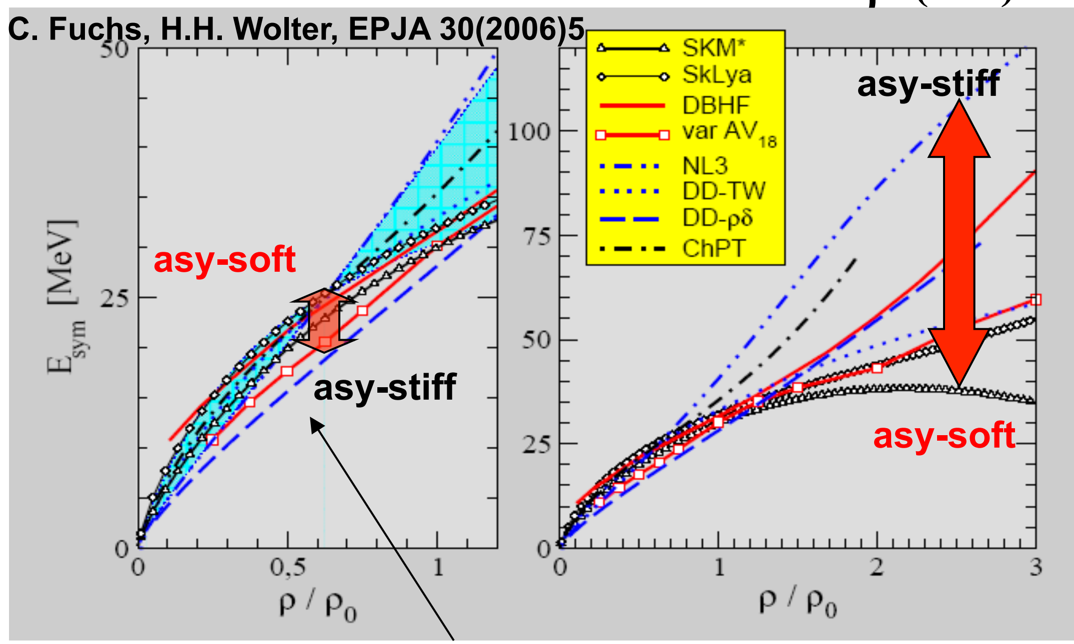
$$E_{sym}^{pot} \approx (\rho/\rho_0)^{\gamma}$$

$\gamma<1$ **asy-soft**, $\gamma>1$ **asy-stiff**

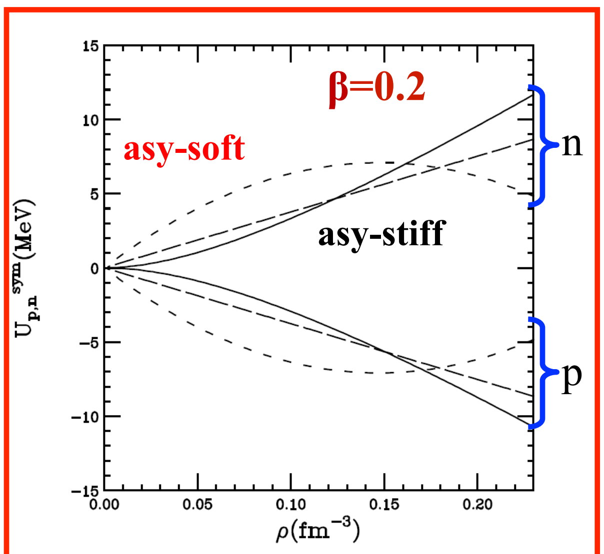
$$E_{sym}(\rho) = \underset{or\ J}{S_0} + L\,\frac{\rho-\rho_0}{3\rho_0} + \ldots$$

$$\gamma = L/(3S_0)$$

C. Fuchs, H.H. Wolter, EPJA 30(2006)5

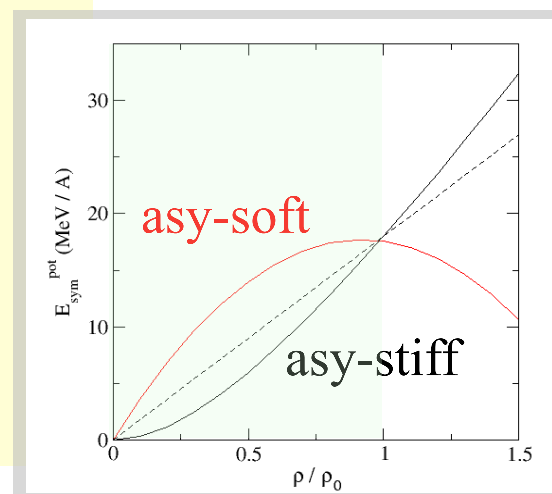


zoom at low density



Symmetry potential :

- *Below normal density :* larger per **asy-soft**
- *Above normal density:* larger for **asy-stiff**



One of the challenges: Isospin Effects
on Nuclear Structure & Reactions

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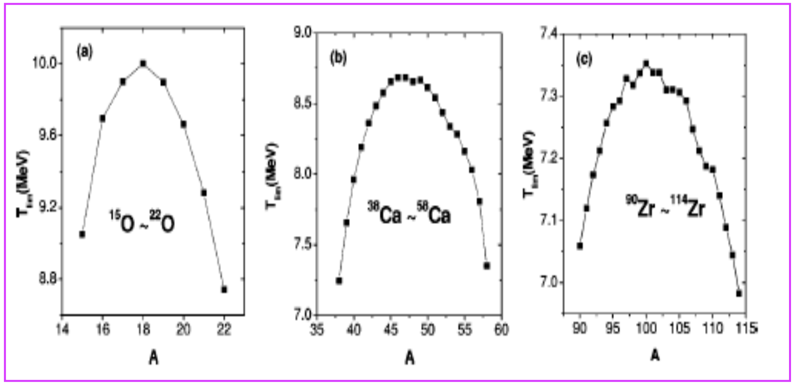
SPES exotic beams for science

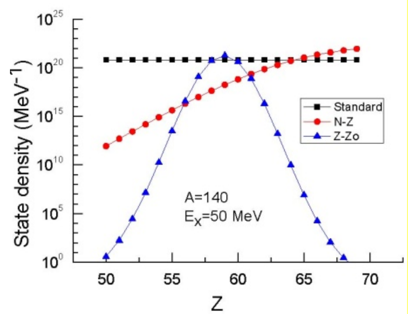
The role of ISOSPIN in
the dynamics & thermodynamics of Nuclear Reactions

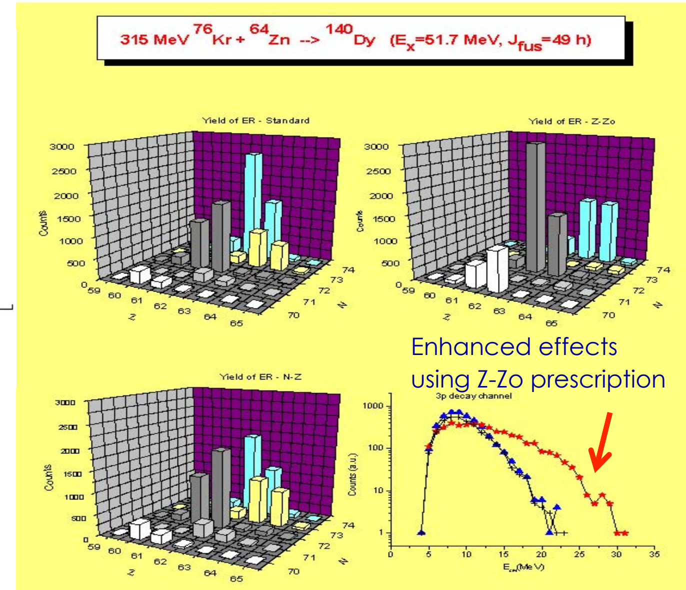
1) Effect on the **Limiting Temperature**



Limiting temperatures calculated for isotopes of O, Ca and Zr [from Li, Z. *et al*. Phys. Rev. C **69**, 034615 (2004)]

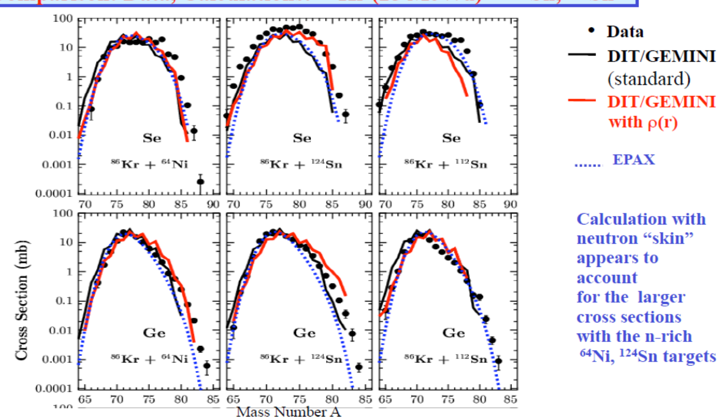
2) Effect on the **Level Density**

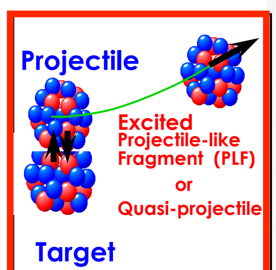




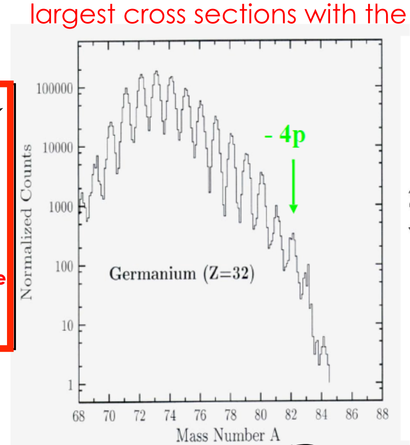
3) Effect on the **nucleon exchange /drift**

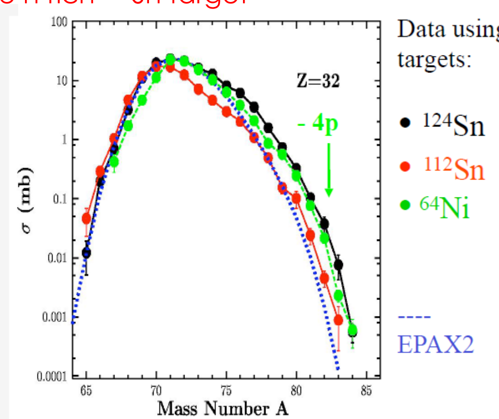
Comparison: Data, Calculations: ^{86}Kr (25 MeV/u) + ^{124}Sn, ^{112}Sn*





largest cross sections with the n-rich ^{124}Sn target





* G.A. Souliotis, M. Veselsky et al., Phys. Rev. Lett. 91 022701 (2003)
M. Veselsky, G.A. Souliotis, Nucl. Phys. A 765, 252 (2006)

LOI SPES G. Casini Uni. Fi

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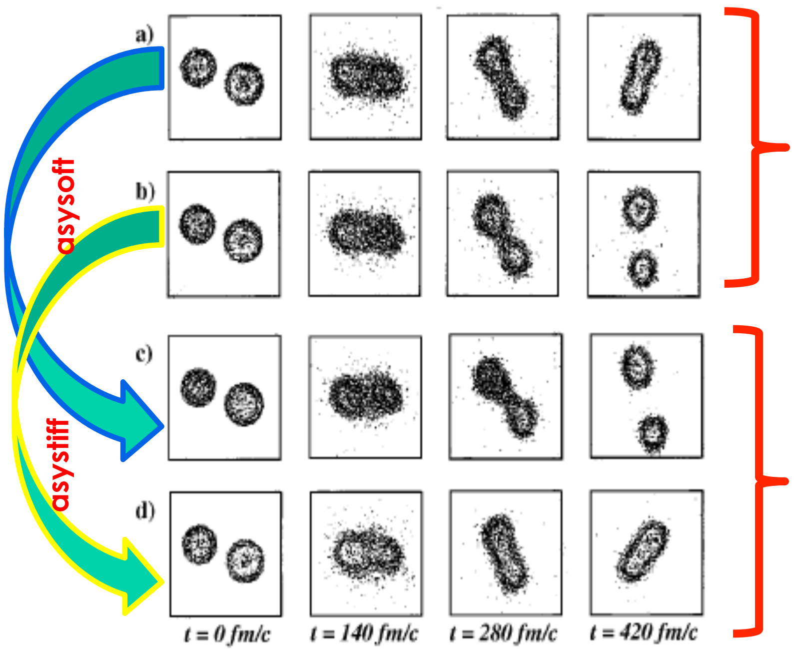
SPES exotic beams for science

Competition of reaction mechanisms:

fusion versus break-up processes (deep inelastic and fragmentation)



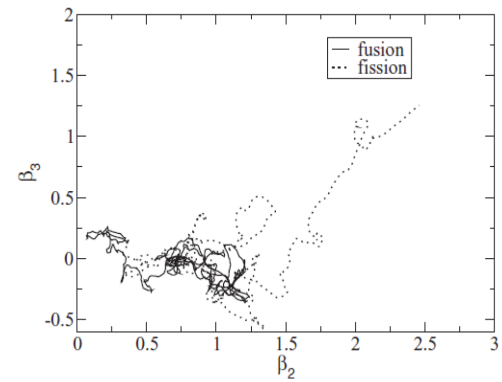
n-rich
$^{46}Ar+^{64}Ni$
$N_P/Z_P=1.56$
$N_T/Z_T=1.29$

n-poor
$^{46}V+^{64}Ge$
N=Z

Fig. 5-1. Density plots at different times in a reaction between neutron-rich ions (a, b: $^{46}Ar + ^{64}Ni$) and neutron-poor ions (c, d: $^{46}V + ^{64}Ge$). (a, c): *asysoft* symmetry term; (b, d): *asystiff*. See text

n-rich → **asysoft** → less repulsion → **fusion**
n-poor → **asysoft** → more repulsion (larger Coulomb) → **deep inel.**

Less repulsion at low density (**neck**) **larger surviving probability**
Presence of the **neck**: observable to constraint the **symmetry energy**



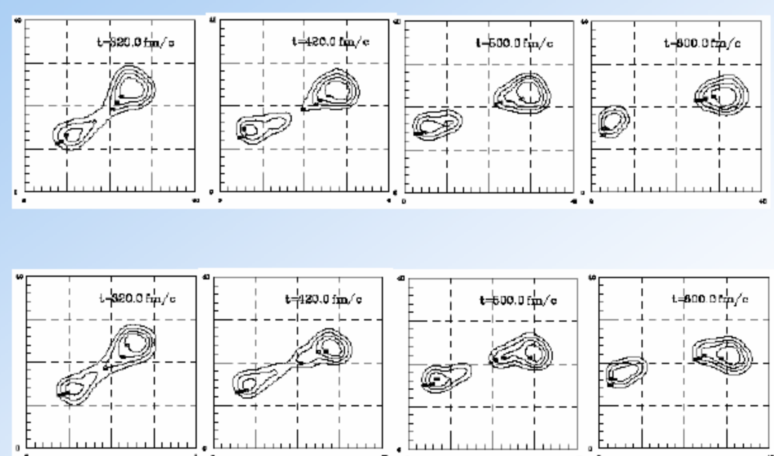
Example of trajectories leading either to **fusion** or to **break-up** (correlations between quadrupole and octupole moments

BNV calculation: $^{124}Sn+^{64}Ni$ @ 10 A.MeV b=7fm

Maria Colonna: stochastic BNV calculations (private communication)

asy soft =>

asy stiff =>



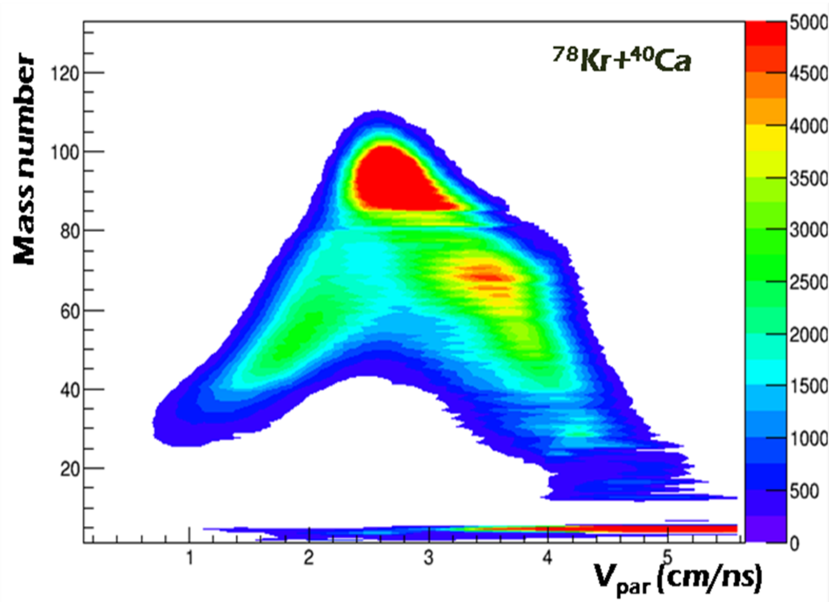
LOI @ SPES 2014

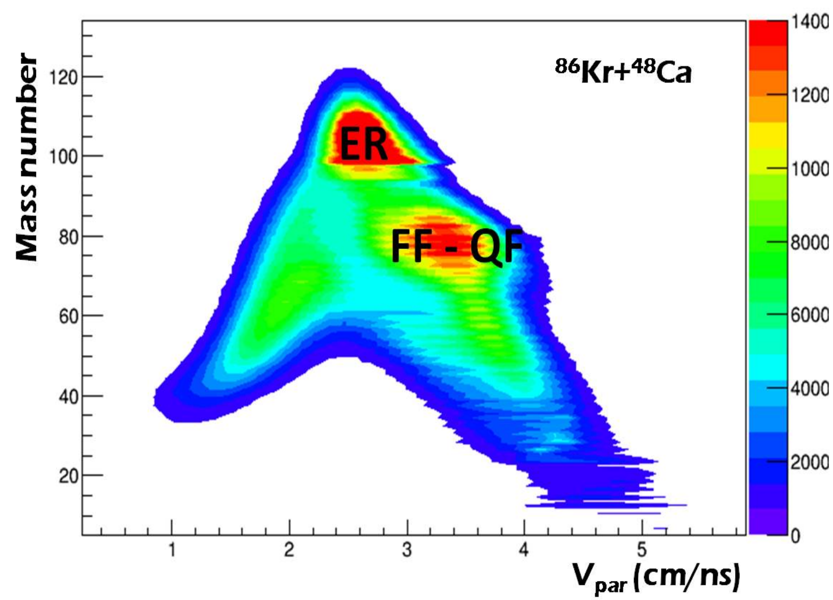
ISOSPIN DEPENDENCE OF COMPOUND NUCLEUS FORMATION AND DECAY

E. DeFilippo, J. D. Frankland, S. Pirrone, G. Politi , P. Russotto et al.

Neutron richness of a compound nucleus is expected to play a crucial role in the competition between various de-excitation channels

-> Information about level density, fission barrier, viscosity





G.Politi et al, ARIS 2014 - JPS Conf. Proc.

Novel information can be obtained by the study of the fission cross section across long isotopic chains of compound nuclei, extending from the neutron-rich to neutron-poor side

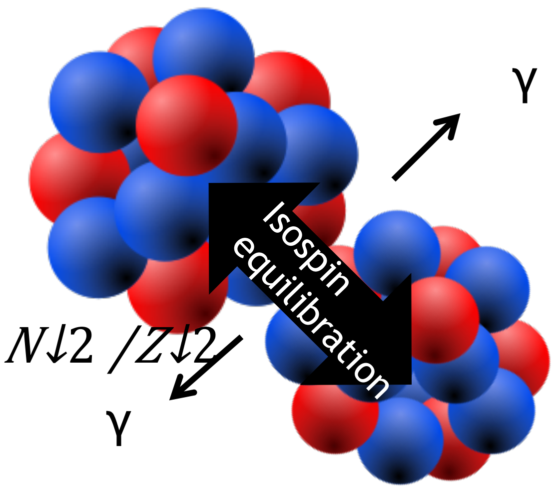
^{88,94}Kr+ ^{40,48}Ca @ E/A = 10 - 12 MeV/A

Dynamical Dipole Resonance with SPES Beams

The Dynamical Dipole Resonance (DDR) is a collective oscillation occurring at the beginning of the interaction between nuclei with different N/Z.

Earlier stage of nuclear interaction

N_1/Z_1



$N_1/Z_1 \ll N_2/Z_2$

N_2/Z_2

Dynamical Dipole γ emission from a not equilibrated source

The centres of mass of protons and neutrons don’t coincide and a dipole moment oscillation develops in the mean-field of the system, with emission of high energy gamma.

The damping of the DD emission is connected to the dynamical evolution of the system towards the isospin equilibration.

LOI for SPES

Study of the Dynamical Dipole Resonance mode with the SPES radioactive beams

D. Pierroutsakou[1], C. Parascandolo[1], R. Alba[2], V. Baran[3], M. Colonna[2], A. Del Zoppo[2], A. Guglielmetti[4], T. Glodariu[3], M. La Commara[5], G. La Rana[5], C. Maiolino[2], M. Mazzocco[6], A. Pakou[7], C. Rizzo[2], D. Santonocito[2], C. Signorini[6], O. Sgouros[7], F. Soramel[6], V. Soukeras[7], S. Stiliaris[8], E. Strano[6], L. Stroe[3], D. Torresi[6], E. Vardaci[5]

[1]*INFN - Sezione di Napoli, via Cinthia, I-80126, Napoli, Italy*
[2]*INFN, Laboratori Nazionali del Sud, via Santa Sofia, I-95123 Catania, Italy*
[3]*NIPNE-HH, 077125 Magurele, Romania*
[4]*Università degli Studi di Milano, Milano, Italy and INFN- Sezione di Milano, via Celoria 16, I-20133 Milano, Italy*
[5]*Dipartimento di Scienze Fisiche, Università di Napoli, via Cinthia, I-80126, Napoli, Italy*
[6]*Dipartimento di Fisica and INFN - Sezione di Padova, via Marzolo 8, I-35131, Padova, Italy*
[7]*Department of Physics and HINP, The University of Ioannina, 45110 Ioannina, Greece*
[8]*Department of Physics, National and Kapodistrian,University of Athens and the Institute of Accelerating Systems & Applications, (IASA), 15771 Athens, Greece*

The proposed experiments: CN reactions

Energy range 6-12 AMeV

LOI INFN Mi etc.

Reaction	N/Z	CN	D0 (fm)
$^{133}Cs+^{48}Ca$	1.42 - 1.40	^{181}Re	1.2
$^{141}Cs+^{40}Ca$	1.56 - 1.00	^{181}Re	36
$^{142}Cs+^{40}Ca$	1.58 - 1.00	^{182}Re	36

SPES beam (UCx 200 μA)

^{141}Cs : 2.6* 10^8pps
^{142}Cs : 2.69* 10^7 pps
^{90}Kr : 8.74* 10^7 pps
^{132}Sn : 3.11* 10^7 pps

New subject

Reaction	N/Z	CN	D0 (fm)
$^{124}Sn+^{56}Fe$	1.48 - 1.15	^{180}Os	25
$^{90}Kr+^{90}Zr$	1.50 - 1.25	^{180}Os	21.5

Possible DDR dependence on the mass asymmetry between projectile and target (same initial dipole, obtained with a mass asymmetric and symmetric system to test possible difference in the dynamics of interaction)

Reaction	N/Z	CN
$^{124}Sn+^{58}Ni$	1.48 - 1.07	^{182}Pt
$^{124}Sn+^{64}Ni$	1.48 - 1.29	^{182}Pt
$^{132}Sn+^{58}Ni$	1.64 - 1.07	^{190}Pt

Reaction	N/Z	CN
$^{124}Sn+^{48}Ca$	1.48 - 1.40	^{172}Yb
$^{132}Sn+^{40}Ca$	1.64 - 1.00	^{172}Yb

^{132}Sn: the “monster” resonance

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^{132}Sn: the “monster” resonance

Nuclear Astrophysics

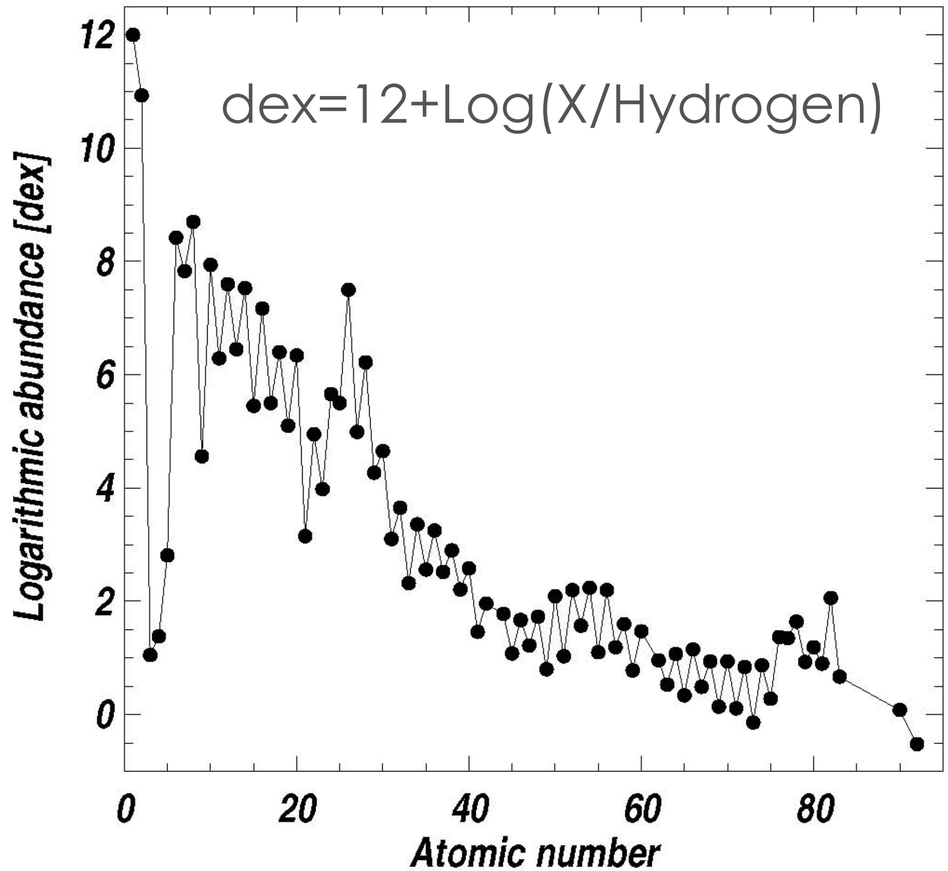
One of the challenges: Origin of the elemental abundances in the solar system

Stars are mostly made of hydrogen and helium, but each has a fairly unique pattern of other elements

The abundance of elements tells us about the hystory of events prior to the formation of our Sun

The plot shows the composition of the Sun Photosphere

How are these elements created prior to the formation of the Sun?



Asplund M. et al.
Ann. Rev. Astr. 47, 481 (2009)

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SPES exotic beams for science

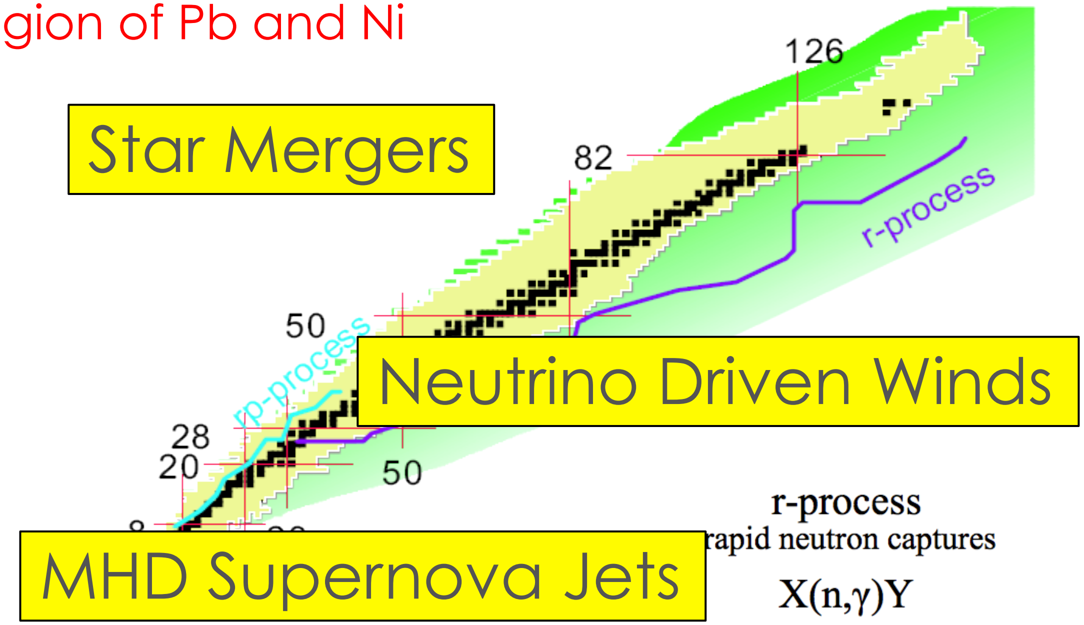
n-rich region of Pb and Ni

- β-decay half-lives
- neutron emission probabilities

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

$$\tau_{\beta\,SPH} \sim \mathbf{10}\ \mathbf{x}\ \tau_{\beta DEF}$$

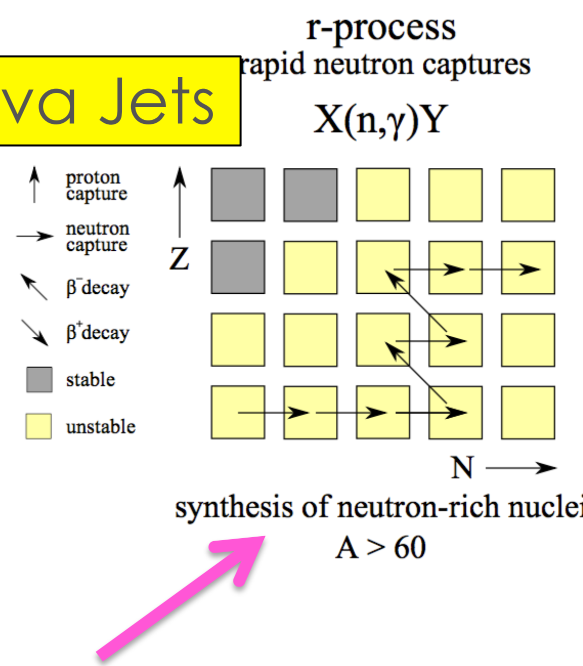
$$P_{nSPH} \sim \mathbf{0.5} \times P_{nDEF}$$



→ Large uncertainty in r-process location
→ difficulty to extrapolate to more exotic regions

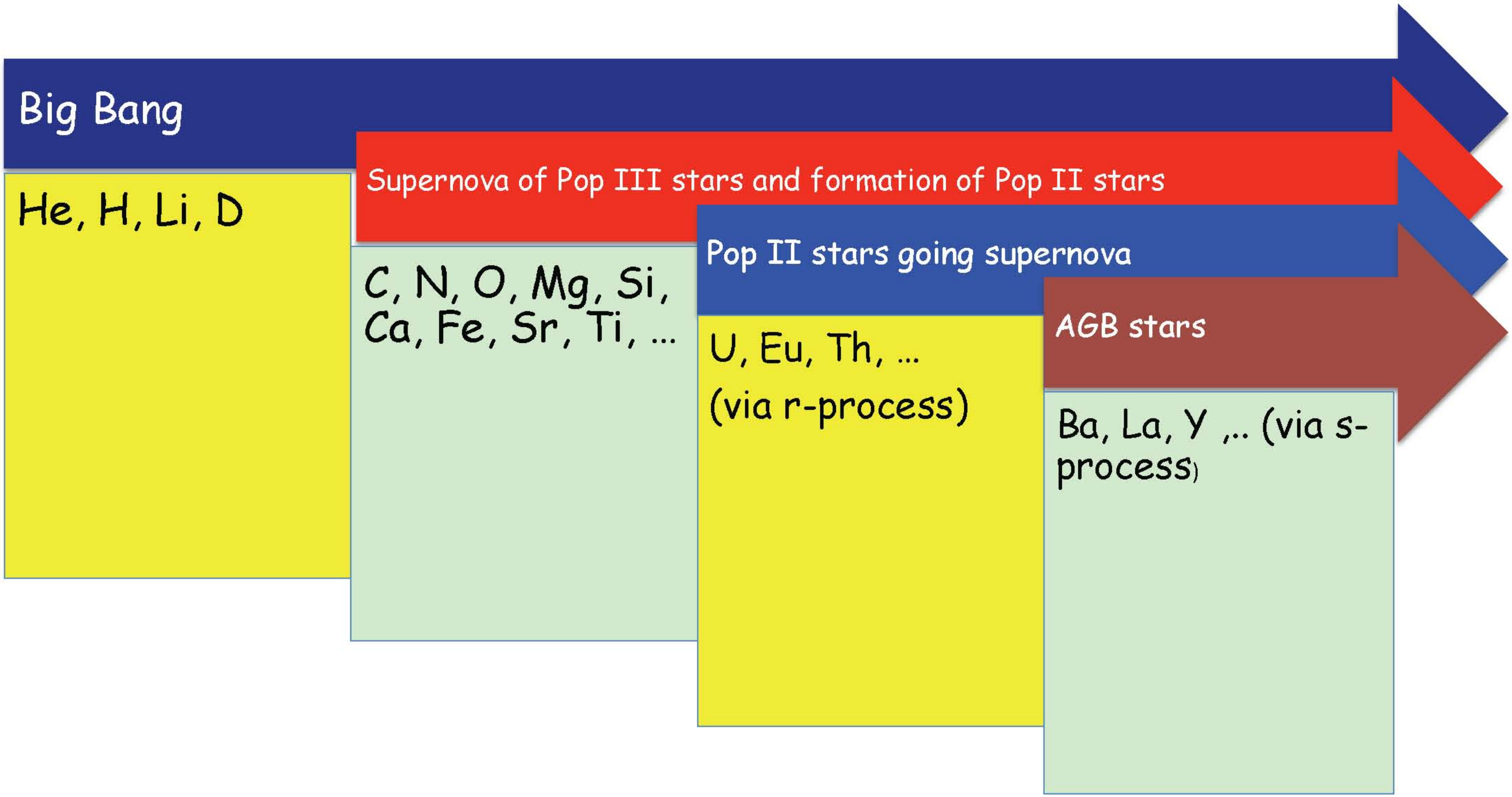
Importance of Nuclear Structure studies in the vicinity/towards r-process path:

… first excited states
... Isomeric states
... β decay lifetimes



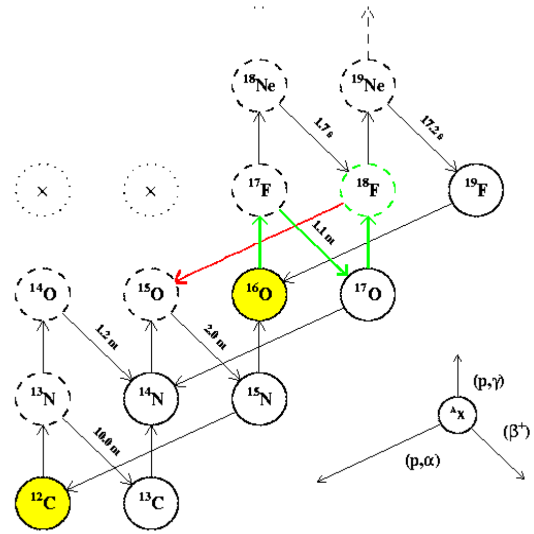
LOI SPES D. Mengoni (Uni. Pd)

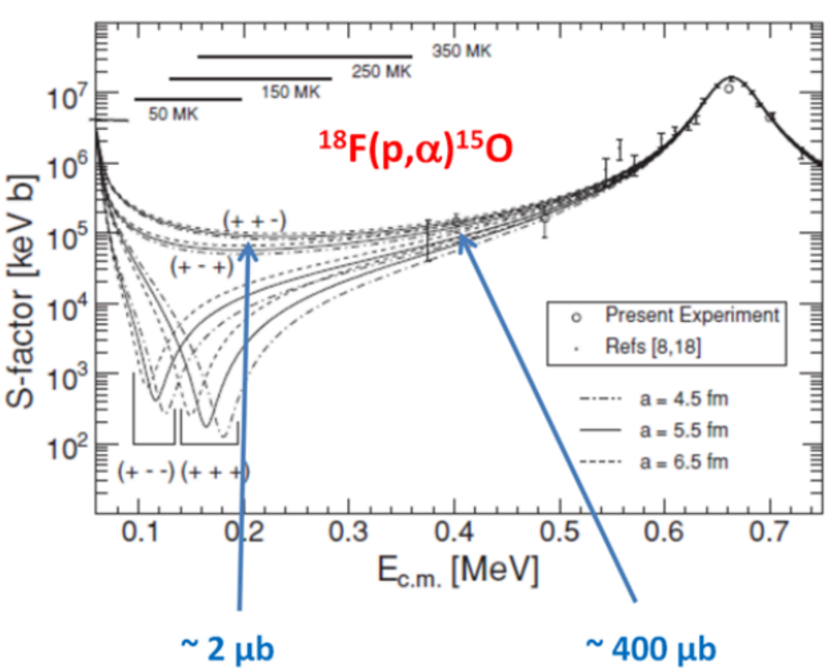
Where chemical elements are made

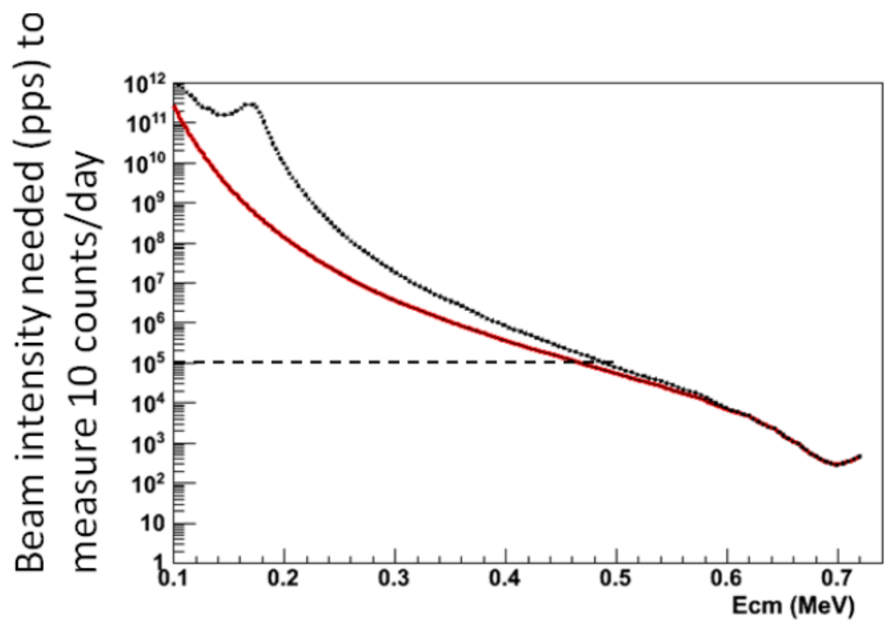


Neutrinos play a crucial role in many nucleosynthesis scenarios.

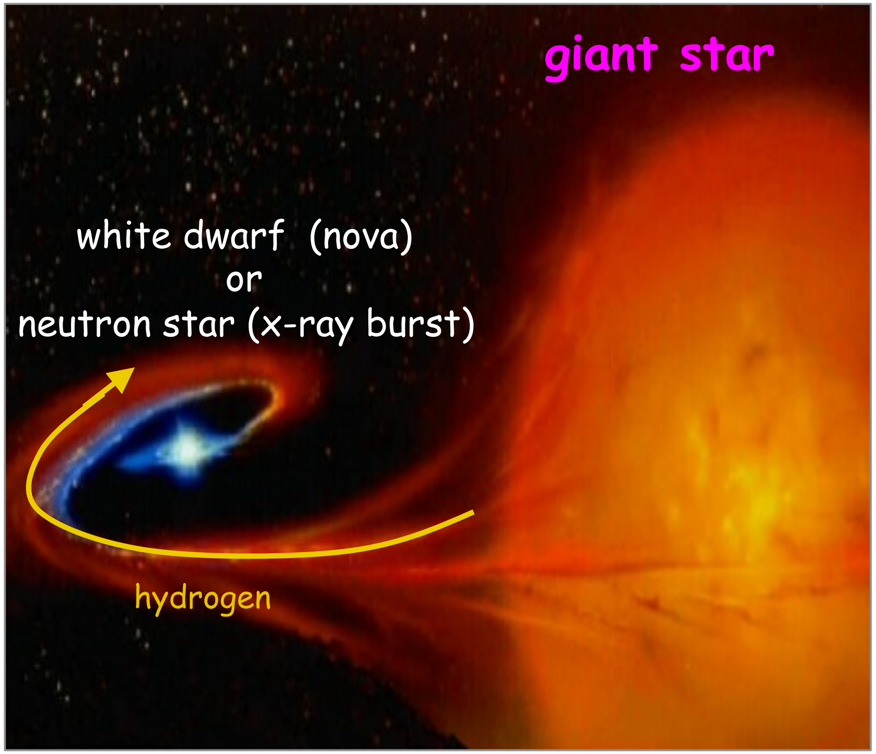
Direct reaction in Novae $^{18}F(p,\alpha)^{15}O$, $^{30}P(p,\gamma)^{31}S$, and $^{25}Al(p,\gamma)^{26}Si$,

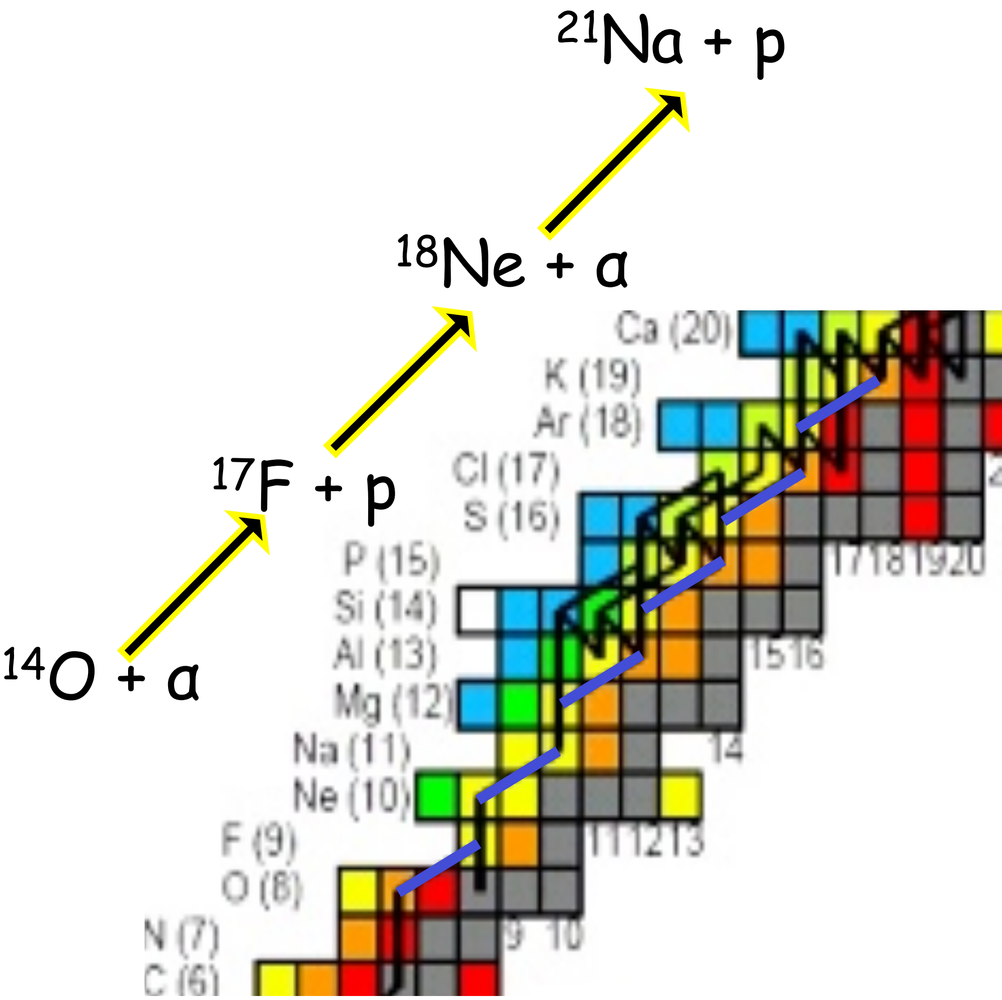






Direct reactions in x-ray bursts

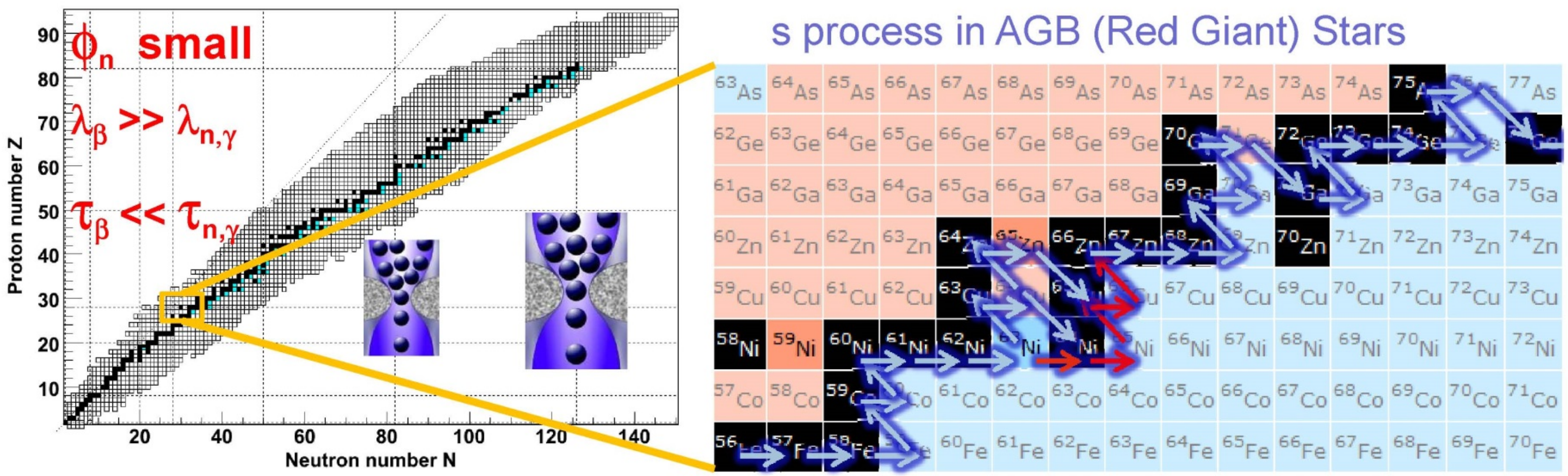


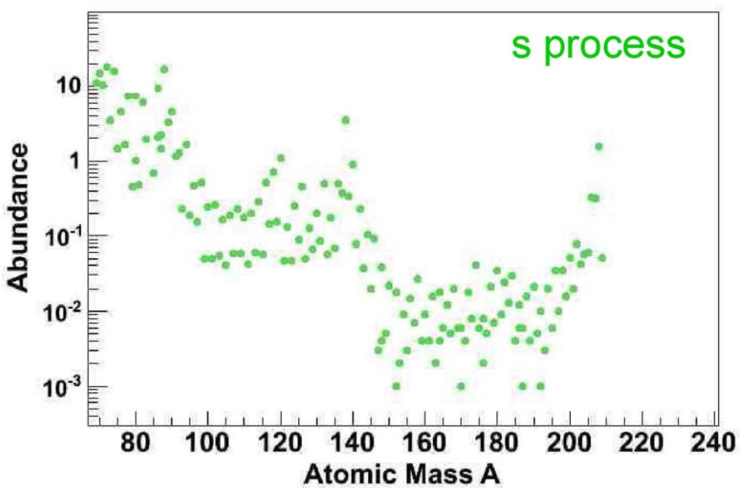


$^{14}O(\alpha,p)^{17}F$, $^{18}Ne(\alpha,p)^{21}Na$, and $^{30}S(\alpha,p)^{33}Cl$

s-process nucleosynthesis and stellar n-flux

Stellar nucleosynthesis: the **s process**

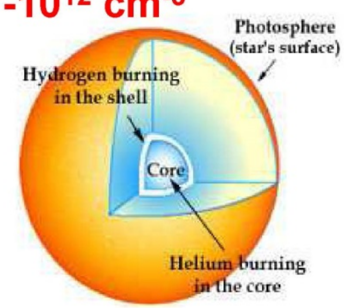




core He-burning
3-3.5·10^8 K
kT=25 keV
10^6 cm^{-3}

shell C-burning
~1·10^9 K
kT=90 keV
10^{11}-10^{12} cm^{-3}

^{22}Ne(α,n)



Arlandini et al. , Ap. J. 525 (1999)
Gallino et al., Ap. J. 497 (1998)
Raiteri et al. , Ap. J. 419 (1993)

s-process nucleosynthesis and stellar n-flux

AGB- and Massive Stars: the neutron source of the S-PROCESS

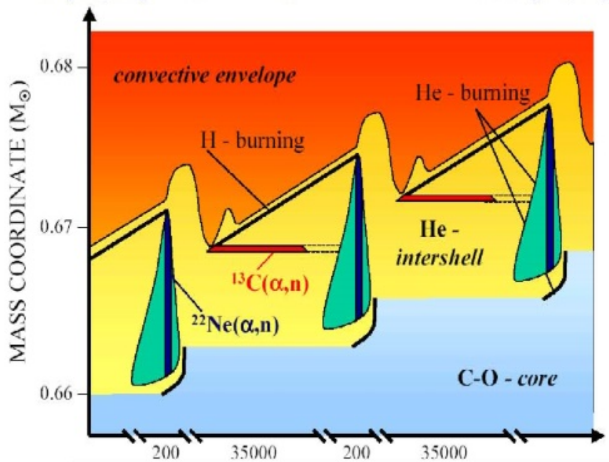
s-process sites

Two components were identified and connected to stellar sites:

Main s-process 90<A<210

TP-AGB stars 1-3 $M_\odot$

shell H-burning	He-flash
$0.9 \cdot 10^8$ K	$3\text{-}3.5 \cdot 10^8$ K
kT=8 keV	kT=25 keV
$10^7\text{-}10^8$ cm^{-3}	$10^{10}\text{-}10^{11}$ cm^{-3}
$^{13}C(\alpha,n)^{16}O$	$^{22}Ne(\alpha,n)^{25}Mg$

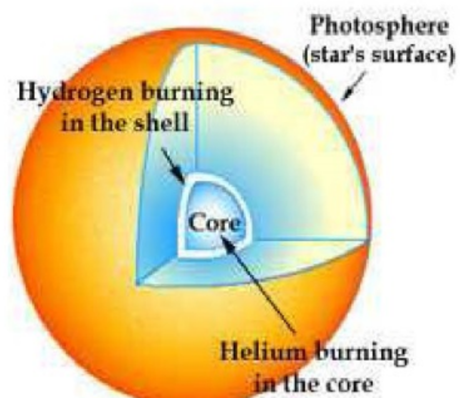


Weak s-process A<90

massive stars > 8 $M_\odot$

core He-burning	shell C-burning
$3\text{-}3.5 \cdot 10^8$ K	$\sim 1 \cdot 10^9$ K
kT=25 keV	kT=90 keV
10^6 cm^{-3}	$10^{11}\text{-}10^{12}$ cm^{-3}

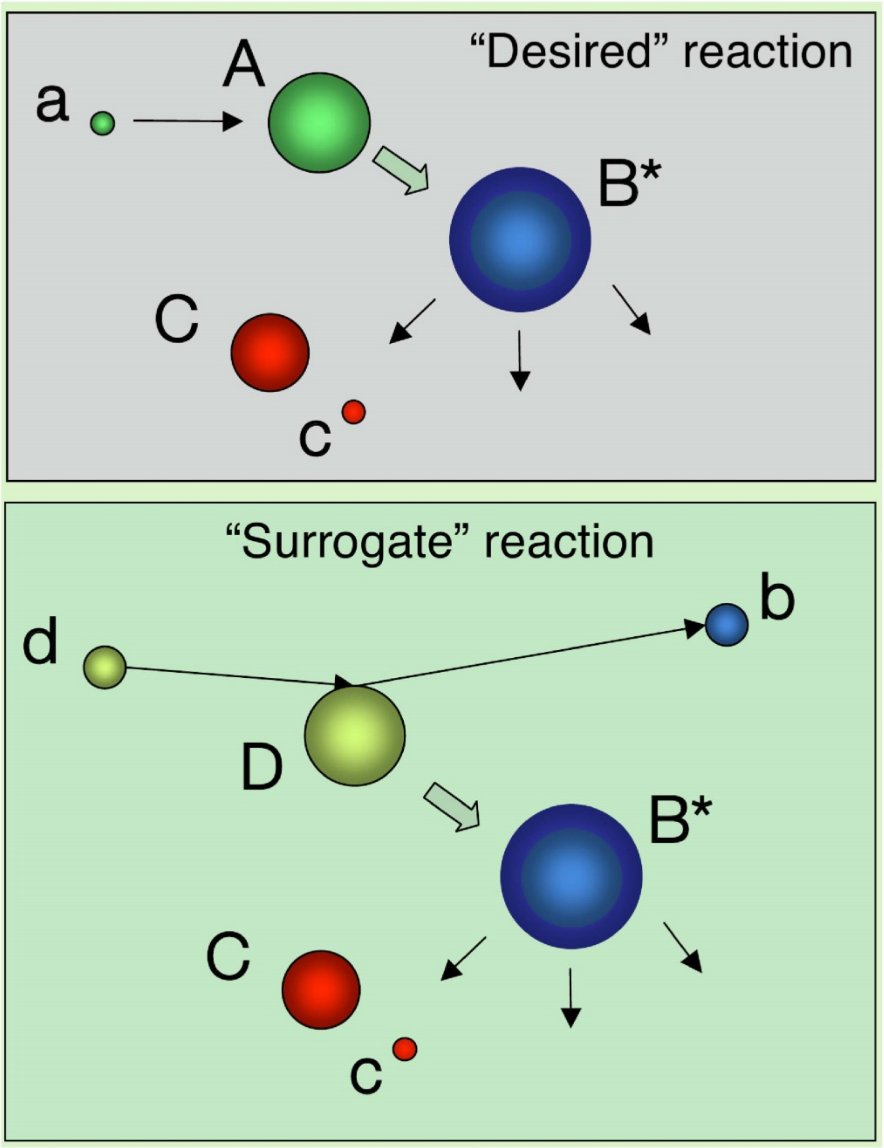
$^{22}Ne(\alpha,n)\ ^{25}Mg$



SPES LOI: The $^{79}Se(n,\gamma)$ capture cross section via the surrogate $^{79}Se\ (d,p)\ ^{80}Se$ reaction IFIC Spain

s-process nucleosynthesis and stellar n-flux

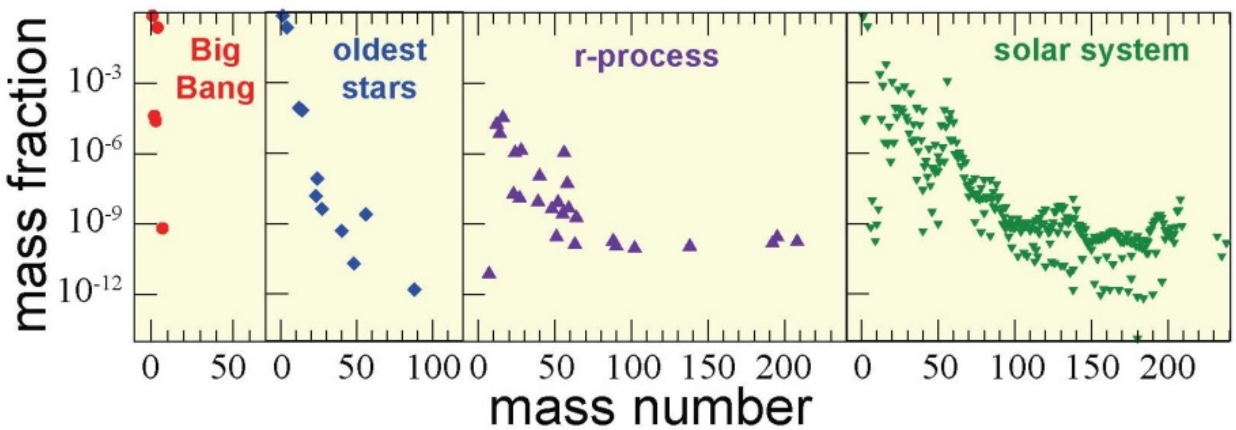
Indirect Determination of Cross Sections

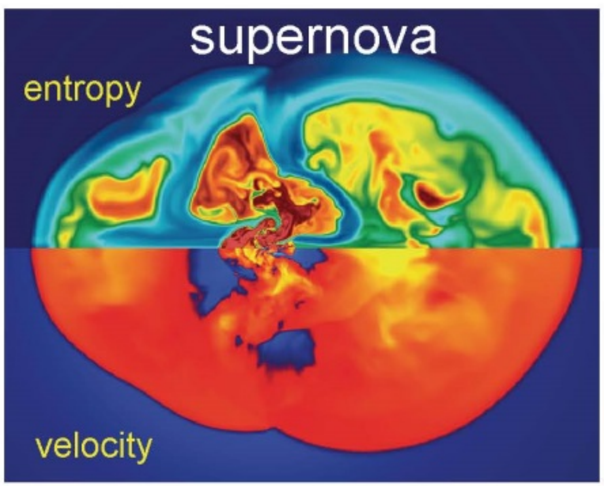


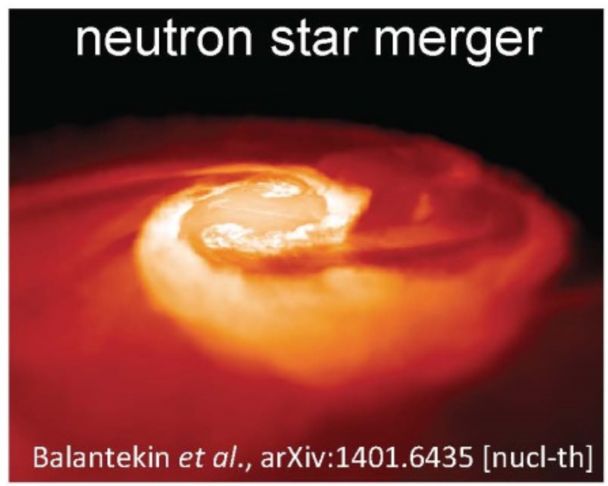
The Surrogate Nuclear Reactions approach is an indirect method for determining XS of CN reactions difficult to measure directly.

r-process nucleosynthesis

The origin of elements





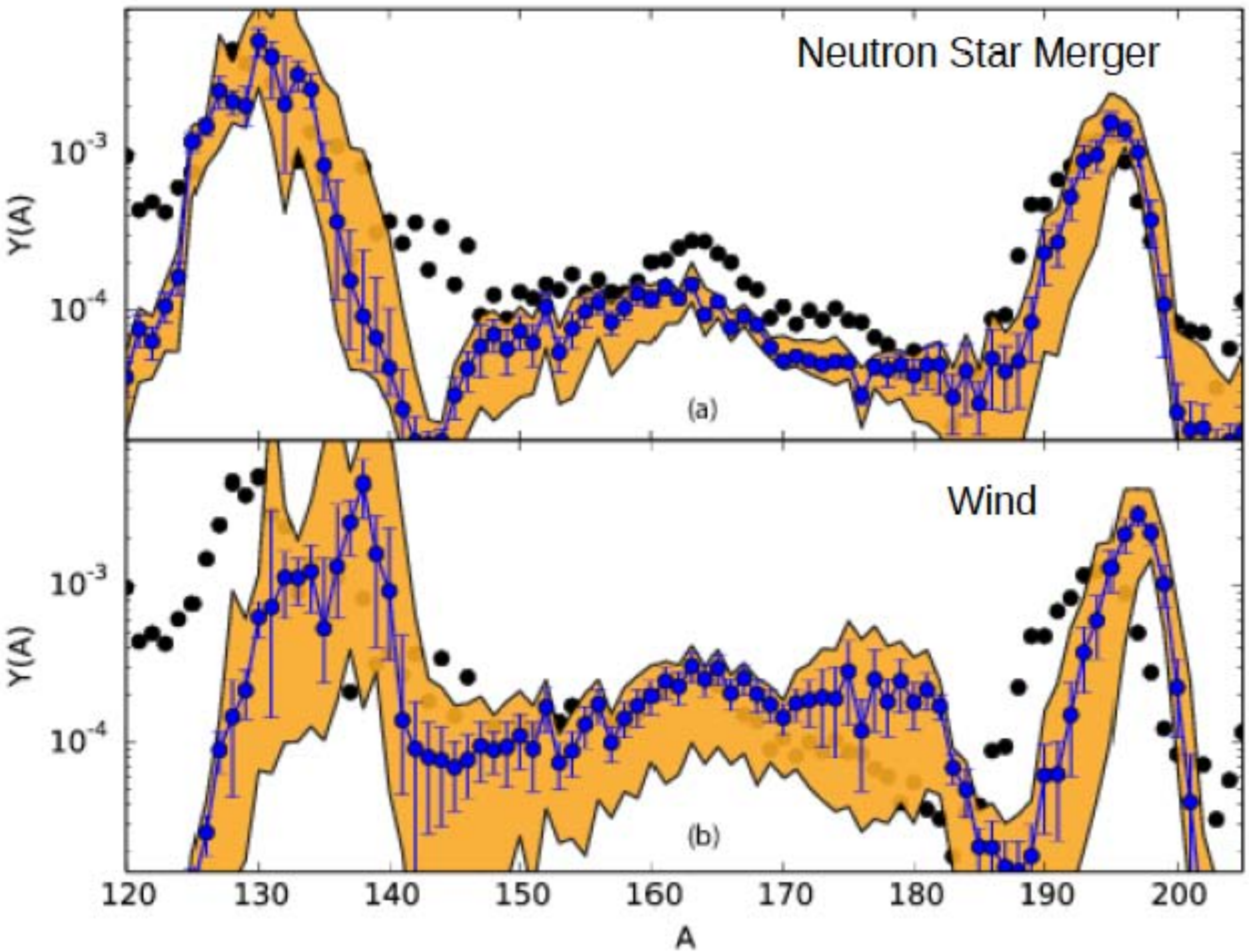


Possible sites for the r-process

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.

r-process nucleosynthesis

Estimated Final Abundances With Uncertainties

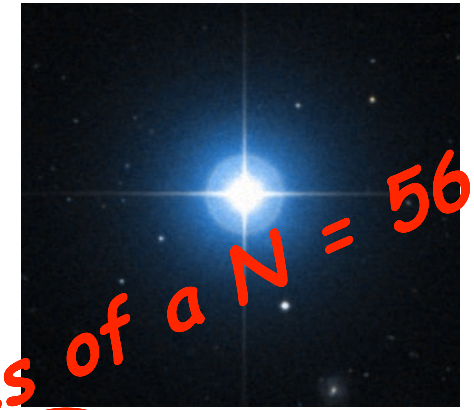


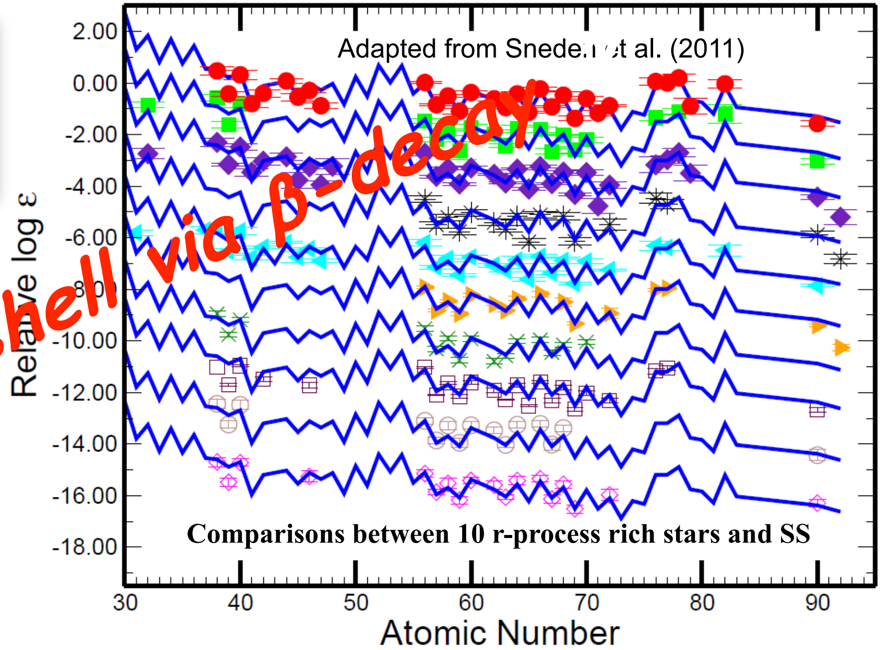
Variations in masses of N~82 and N~126 nuclei of +/- **1** MeV

Mumpower et al. (in prep)

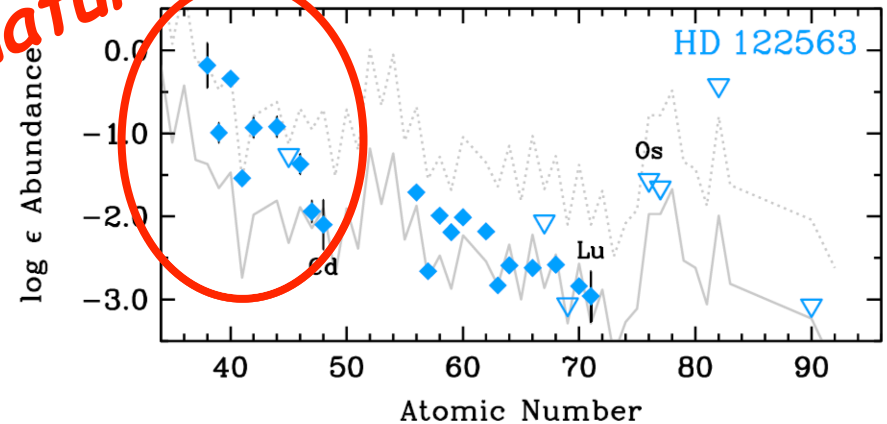
UMP giants stars provide crucial constraints to the stellar nucleosynthesis.

Its elemental abundances are consistent with the solar r-process elemental distribution.





Signatures of a N = 56 subshell via β-decay



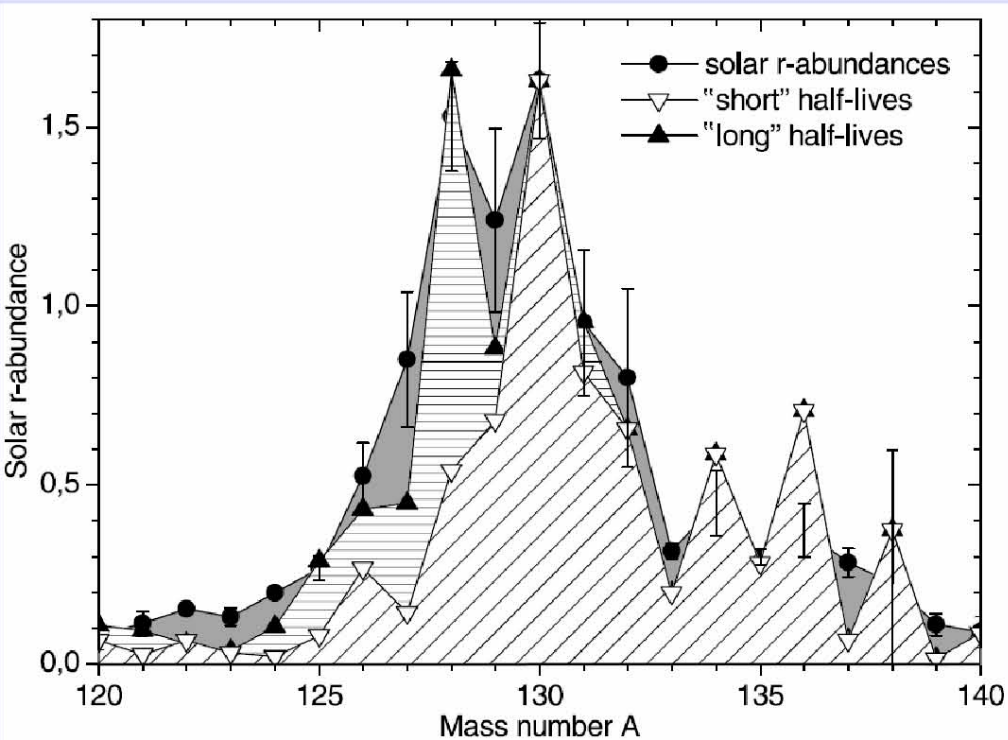
Overproduction of stable Sr, Y, and Zr isotopes in some UMP, compared to the SS r-process pattern.

LOI ORNL (USA)

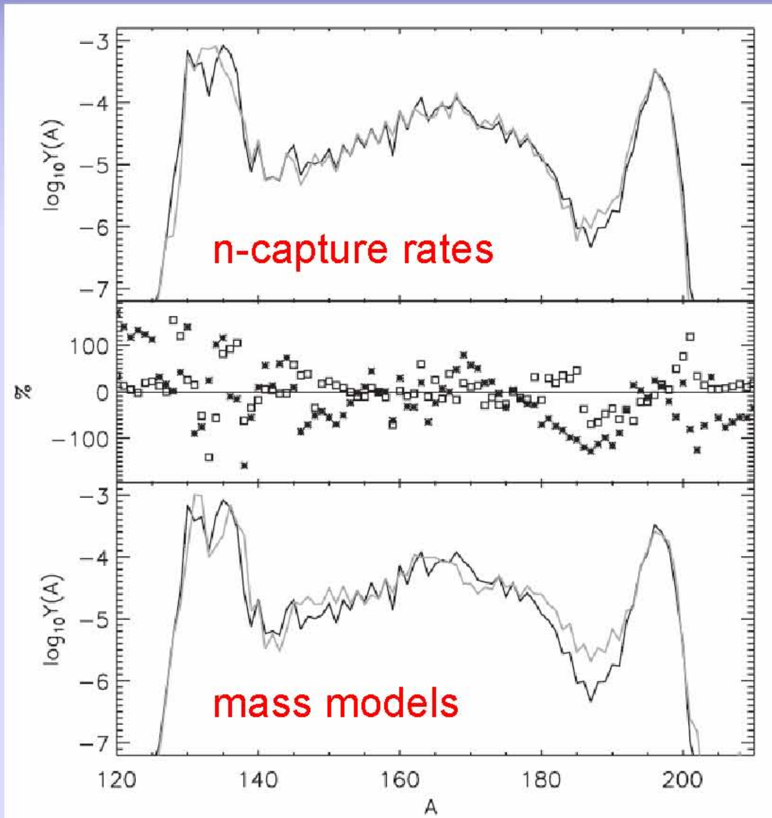
r-process sensitivities

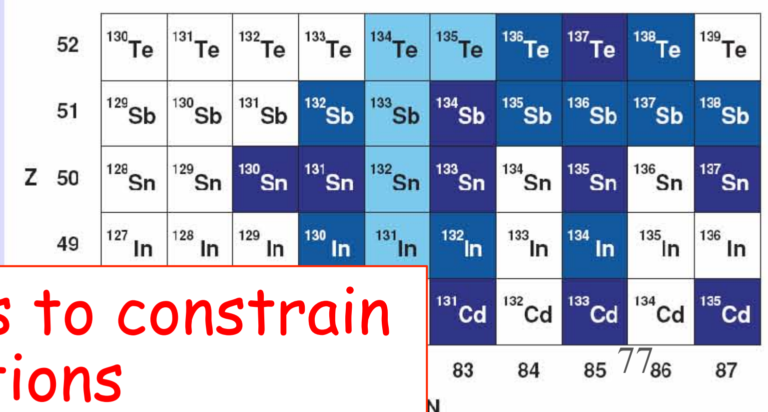
Sensitivities to global structure, and to individual n-capture rates

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



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



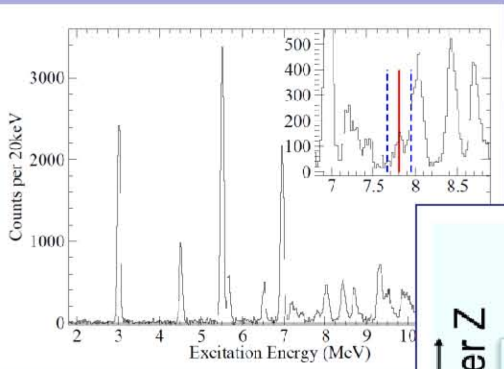


R. Surman, J. Beun, G.

Ph

Transfer reactions to constrain
Capture cross sections

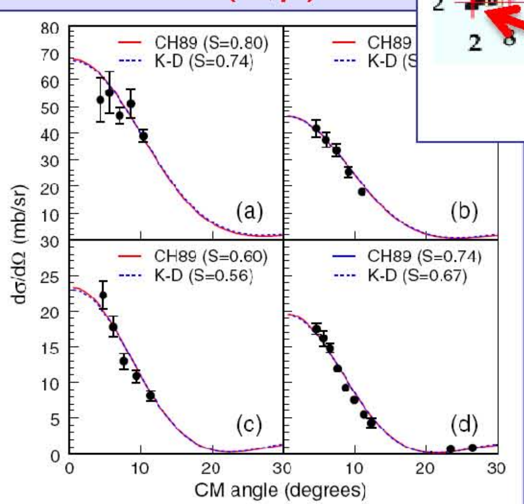
LOI ORNL (USA) Surrogate method



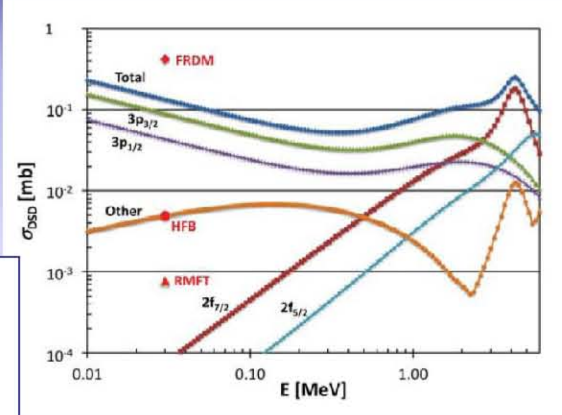
^{26}Al(d,p)

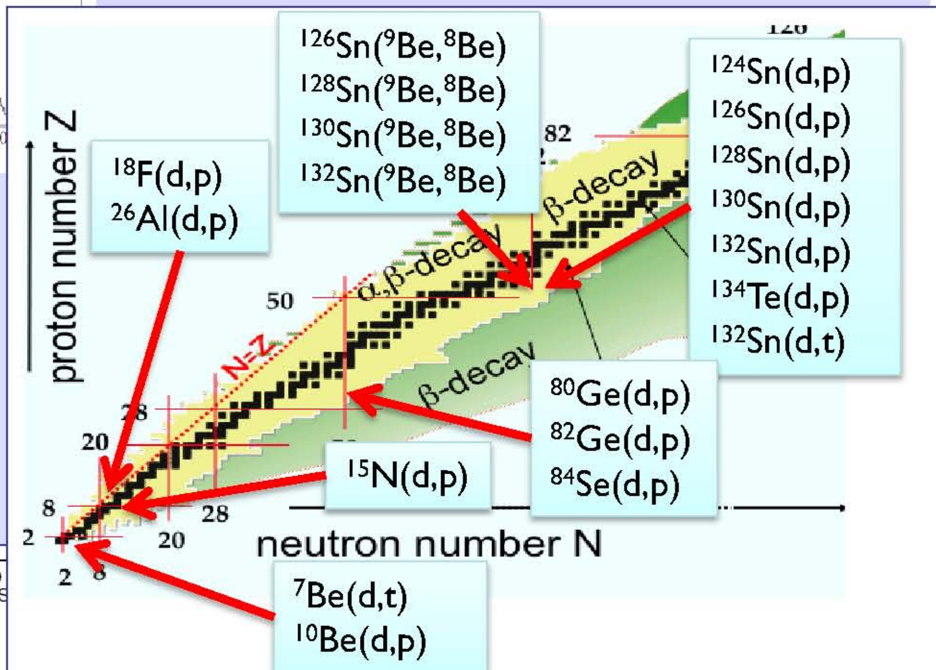
FWHM ~ 75 keV (CoM)

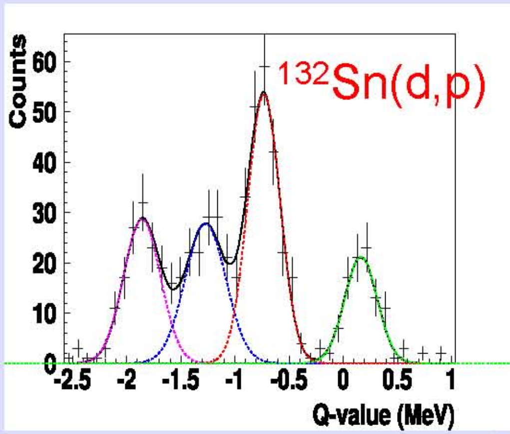
^{10}Be(d,p)

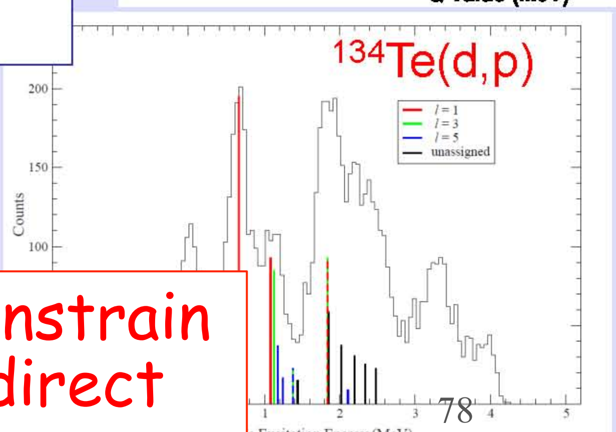


Constraint of DSD n-capture via ^{130}Sn(d,p)



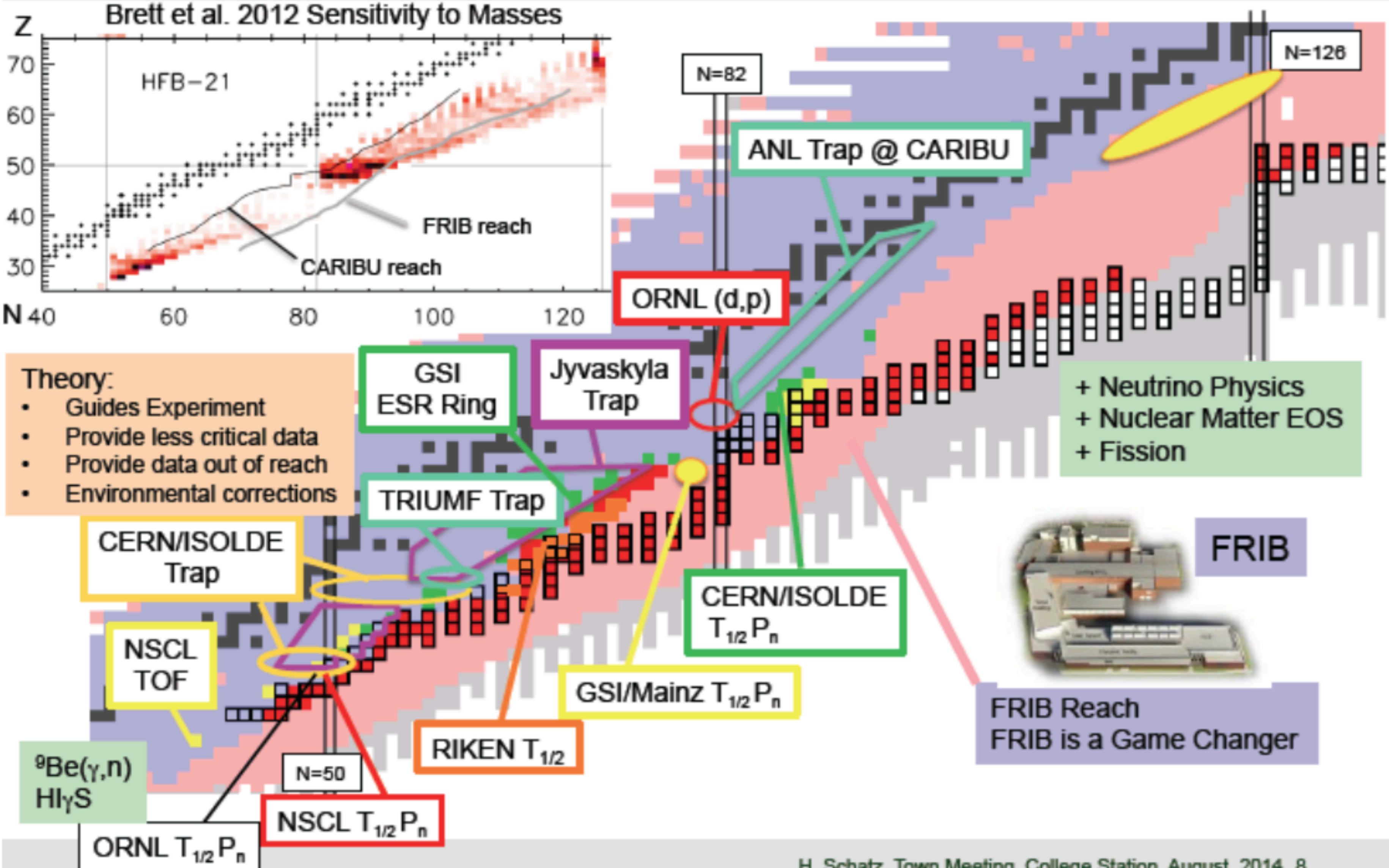




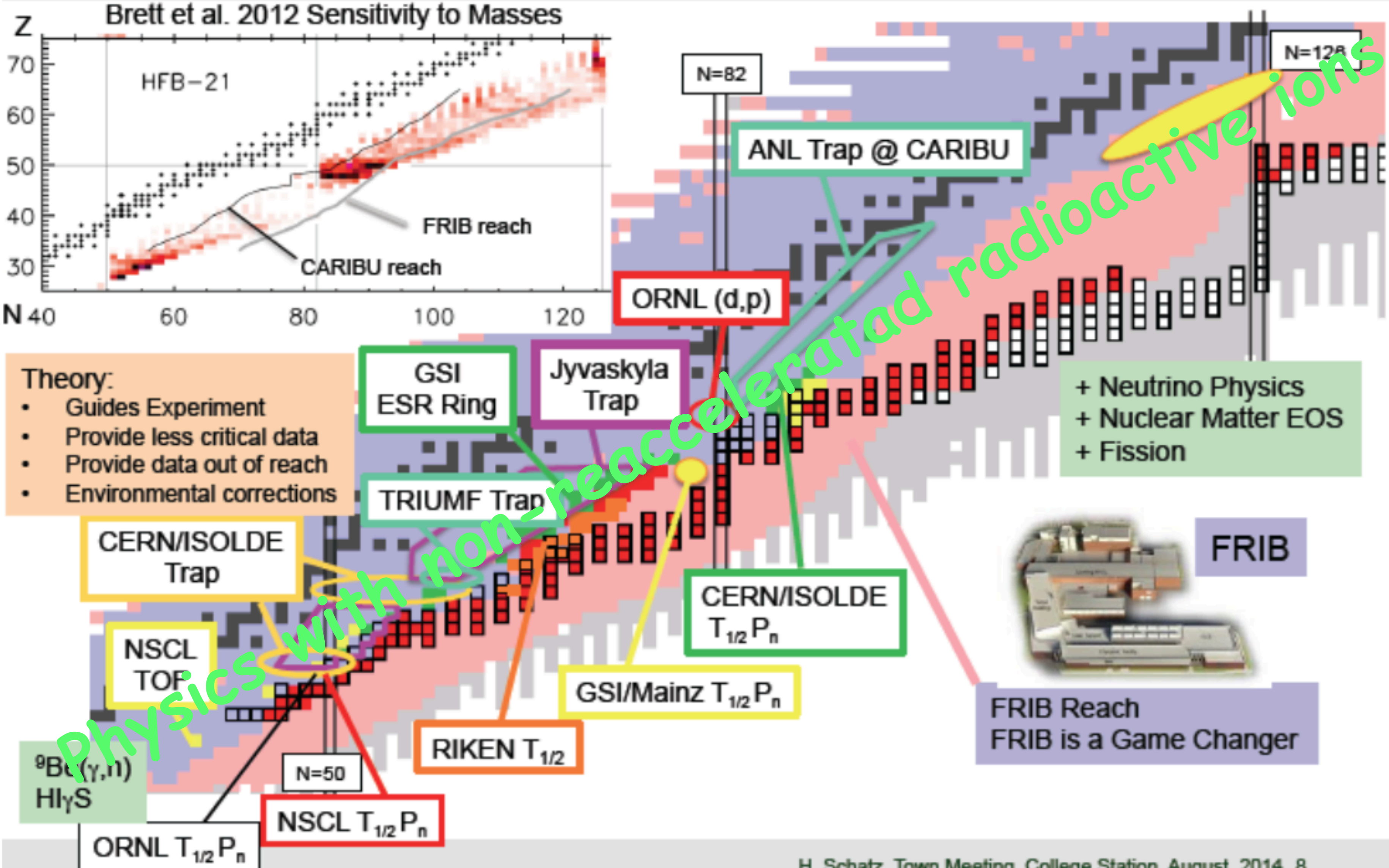


Transfer reactions to constrain capture cross sections (direct or statistical)

The Quest for r-process Nuclear Physics



The Quest for r-process Nuclear Physics



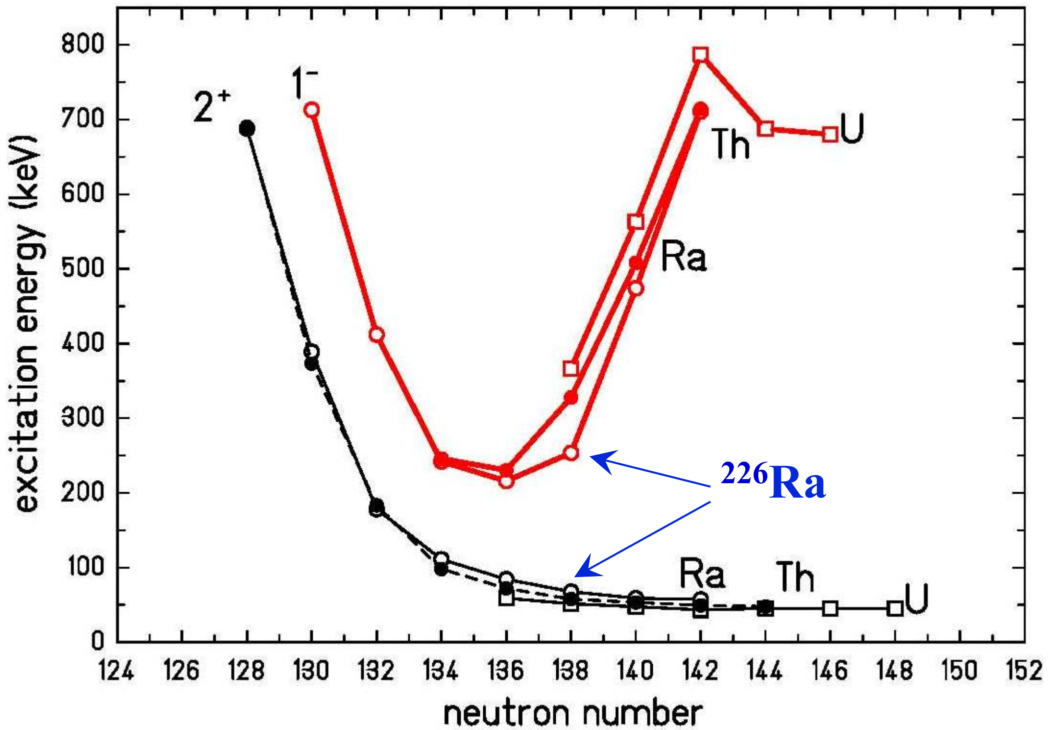
Fundamental Symmetries

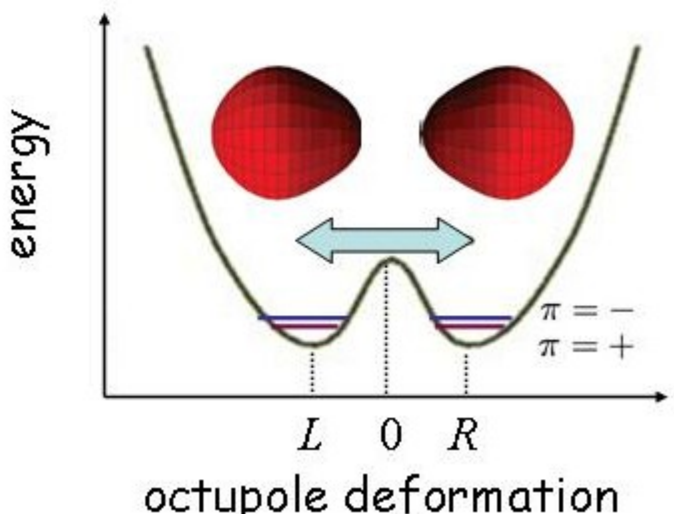
ONE OF THE CHALLENGES: REFLECTION ASYMMETRIC NUCLEI AND STATIC ELECTRIC DIPOLE MOMENT

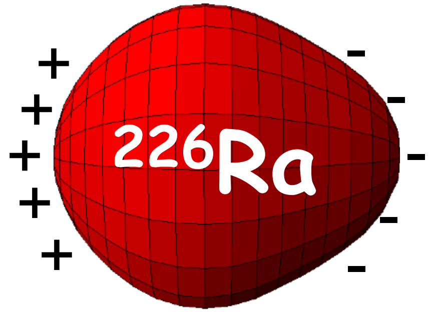
The lopsided nuclei, described today (May 8) in the journal Nature, *could be good candidates for researchers looking for new types of physics beyond the reigning explanation for the bits of matter that make up the universe* (called the Standard Model), said study author Peter Butler, a physicist at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

Octupole collectivity







In an **octupole** deformed nucleus the center of mass and center of charge tend to separate, creating a non-zero **electric dipole moment**.

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

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

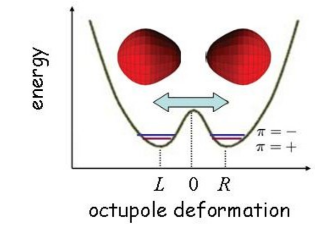
related to Q_3

P,T-violating n-n interaction

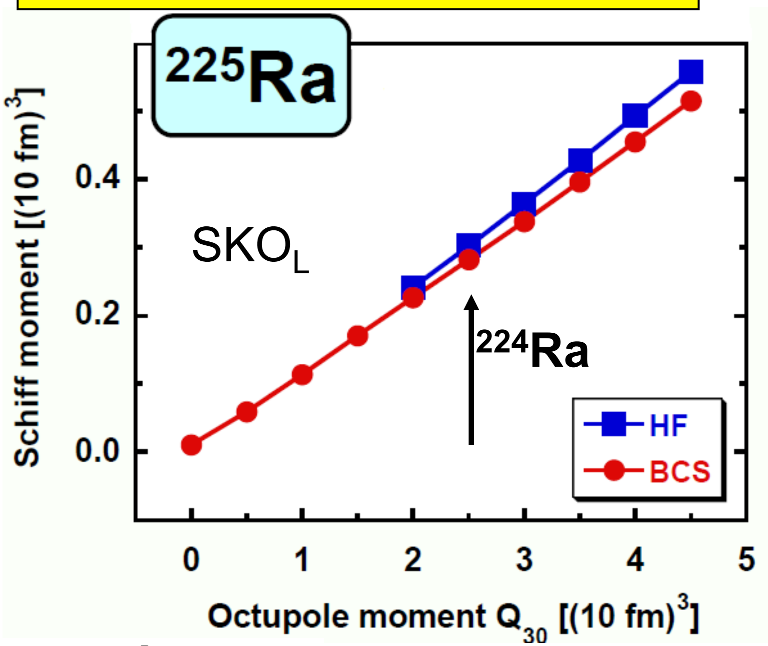
Schiff moment:

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

energy splitting of parity doublet

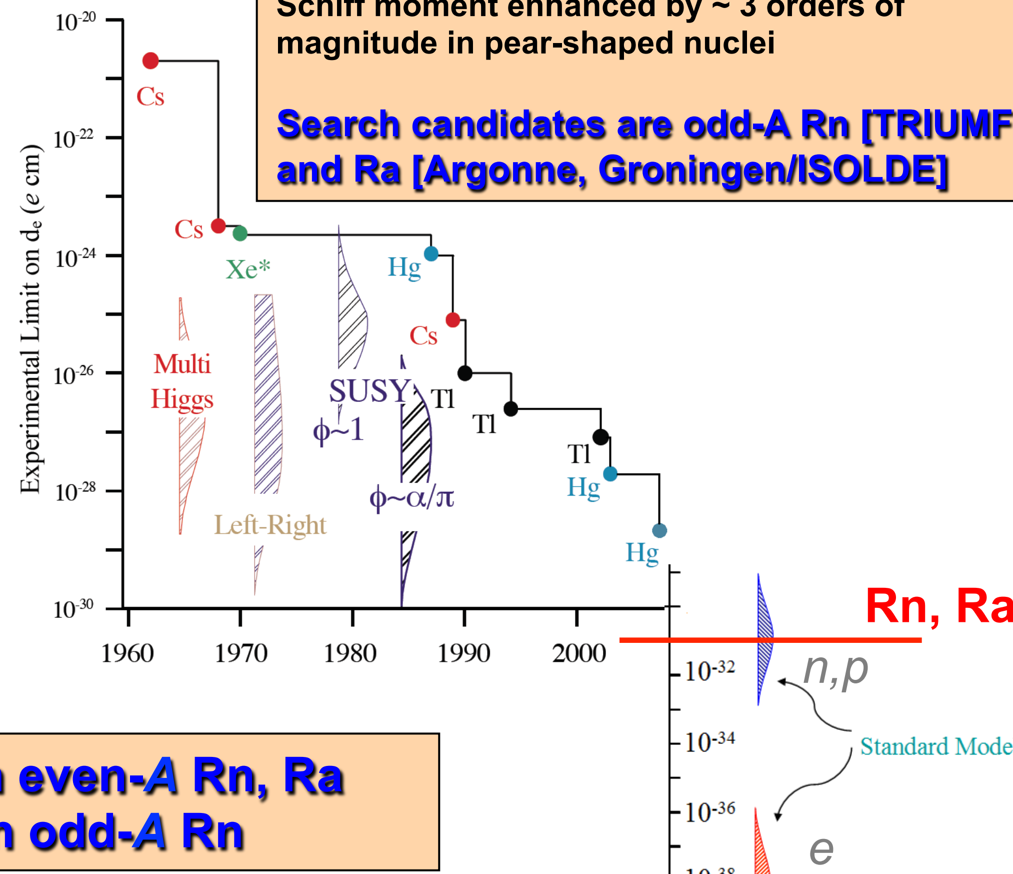


J Dobaczewski (Trento, 2010)



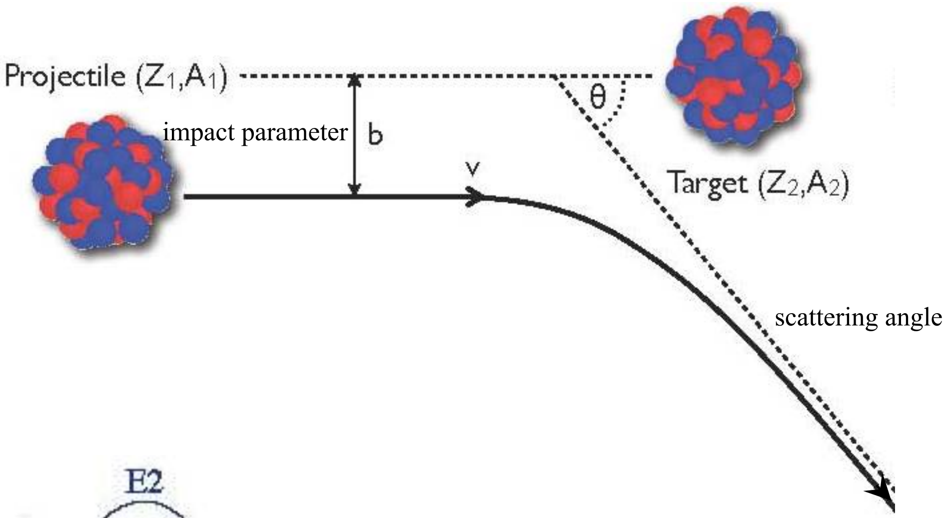
Schiff moment enhanced by ~ 3 orders of magnitude in pear-shaped nuclei

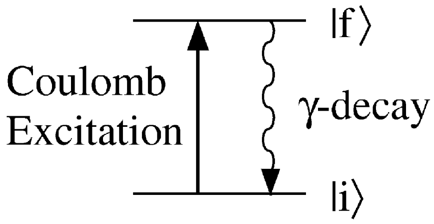
Search candidates are odd-A Rn [TRIUMF] and Ra [Argonne, Groningen/ISOLDE]



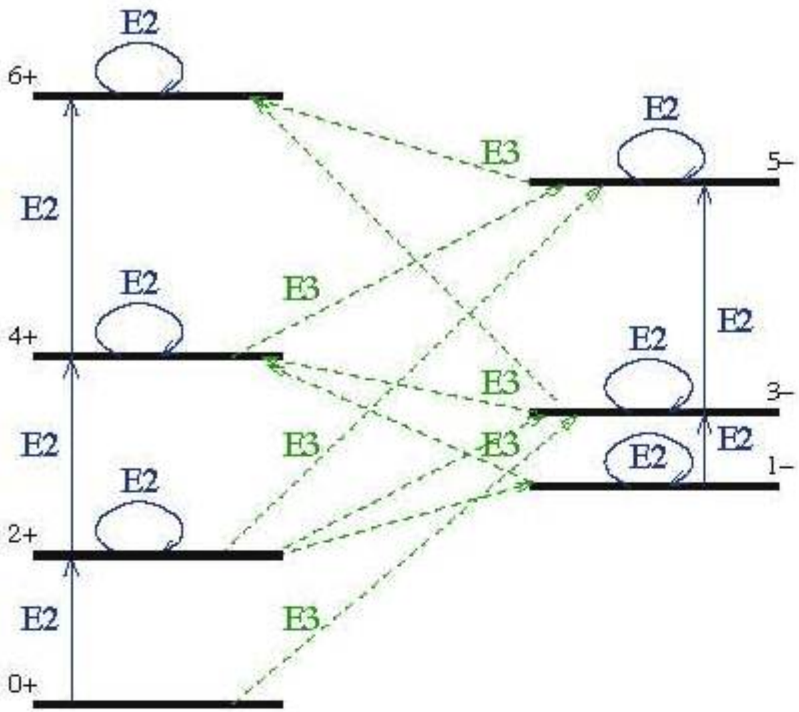
Measure: Q_3 in even-A Rn, Ra
ΔE in odd-A Rn

Coulomb excitation





$$\frac{d\sigma_{i\to f}}{d\Omega_{cm}} = P_{i\to f}\cdot\frac{d\sigma_{Ruth}}{d\Omega_{cm}}$$



$$d\sigma_{E2} \cong 4.819\cdot\left(1+\frac{A_1}{A_2}\right)^{-2}\cdot\frac{A_1}{Z_2^2}\cdot E_{MeV}\cdot B\left(E2; I_i \to I_f\right)\cdot df_{E2}(\eta,\xi)\ [b]$$

Goal: Octupole deformation in ^{229}Pa

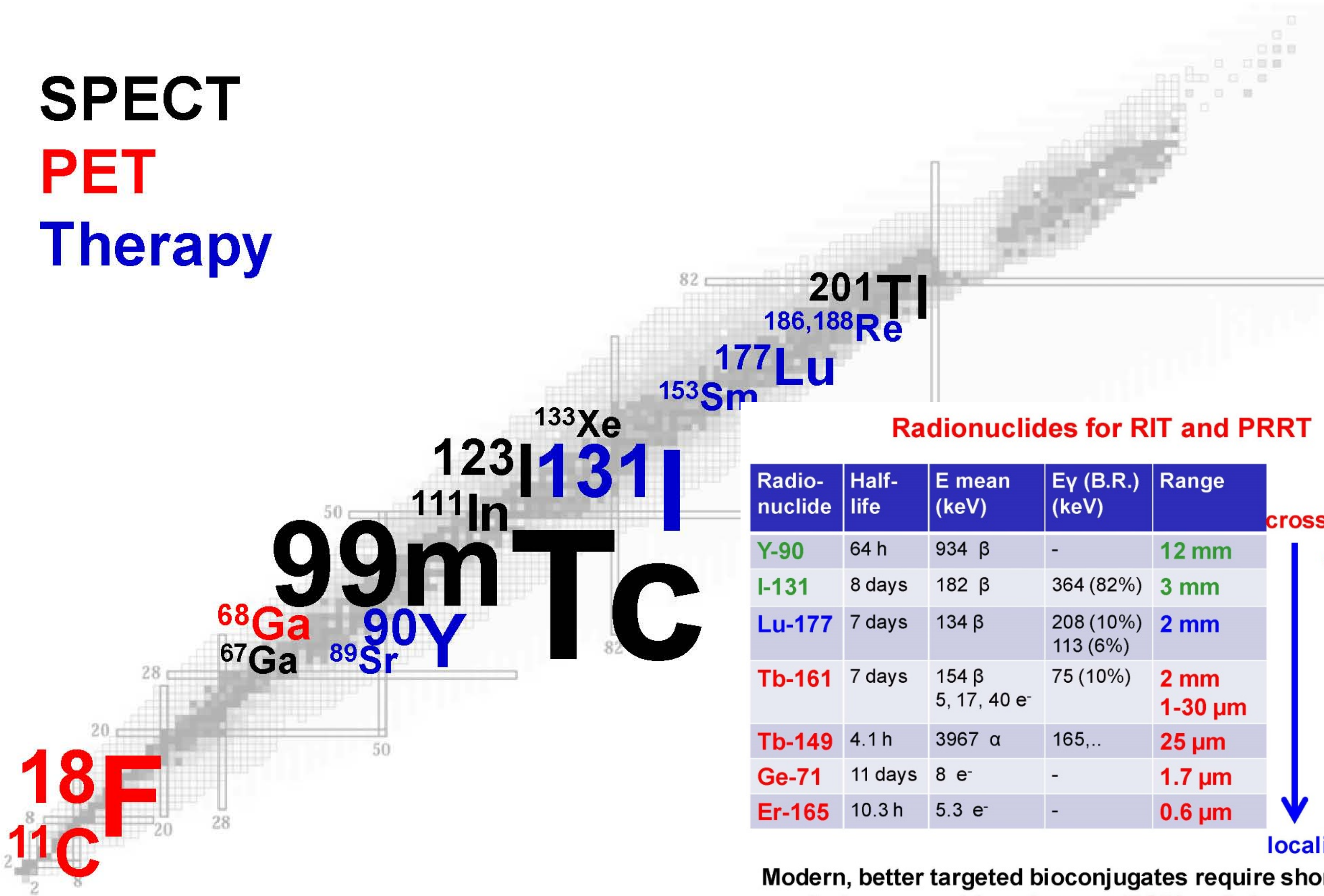
^{229}Pa by 232Th(p,4n) reaction
Octupole strength measured via Coulex

Application of Isotopic Beams

ONE OF THE CHALLENGES: RADIONUCLEI FOR MEDICINE

The chart of nuclides – nuclear medicine perspective

SPECT
PET
Therapy



Radionuclides for RIT and PRRT

Radio-nuclide	Half-life	E mean (keV)	Eγ (B.R.) (keV)	Range
Y-90	64 h	934 β	-	12 mm
I-131	8 days	182 β	364 (82%)	3 mm
Lu-177	7 days	134 β	208 (10%) 113 (6%)	2 mm
Tb-161	7 days	154 β 5, 17, 40 e^-	75 (10%)	2 mm 1-30 μm
Tb-149	4.1 h	3967 α	165,..	25 μm
Ge-71	11 days	8 e^-	-	1.7 μm
Er-165	10.3 h	5.3 e^-	-	0.6 μm

cross-fire

Estab-lished isotopes

Emerging isotopes

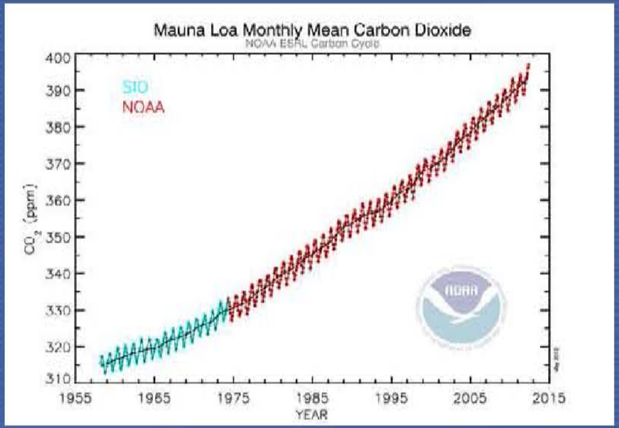
R&D isotopes: supply-limited!

localized

Modern, better targeted bioconjugates require shorter-range radiation ⇒ need for adequate (R&D) radioisotope supply.

Ocean acidification

Ocean Acidification is a major, global environmental pressure due to increasing atmospheric CO_2 concentration in surface marine water.



It is predicted to have **major impact** on key marine ecosystems, including on biodiversity, safety and security of seafood resources and ecosystems services, especially in fragile ecosystems such as tropical coral reefs and polar regions.

Giacomo de Angelis

Ocean acidification - numbers

- Ocean/atmosphere exchanges of CO_2 are very important
- Net uptake by oceans of 25-30% of man-made CO_2 emissions: ***24 million tons*** CO_2 per day!
- Key defence (buffer) against global warming, but drawback: causing an increase in acidity (decrease in pH).
- Acidity of the oceans has increased by ***30%*** since the onset of the industrial revolution.
- If CO_2 emissions continue at the current rate, acidity will increase by ***150%*** by 2100 (highest acidity experienced by marine ecosystems since at least ***800 000 years***).
- The current rate of pH change is unprecedented for ***300 millions years***.

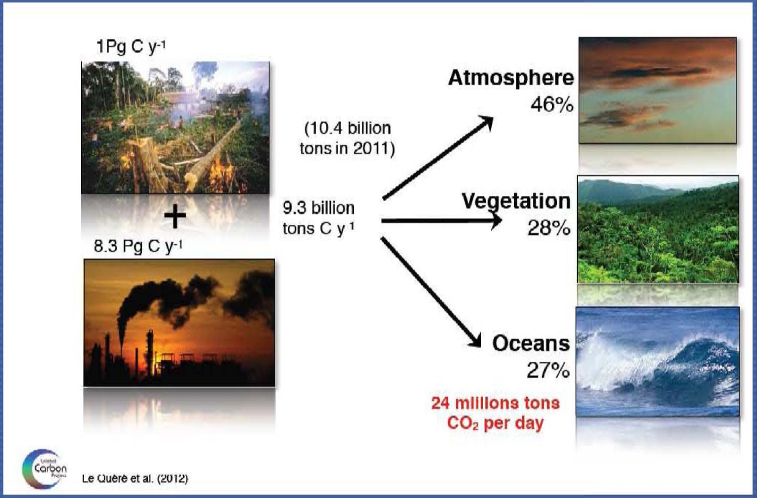


*Image courtesy of **J.-P. Gattuso***

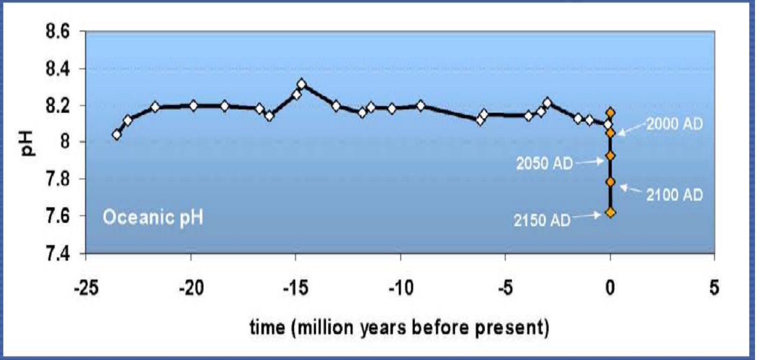


*Image courtesy of **C. Turley***

Giacomo de Angelis

Ocean acidification – Nuclear and isotopic applications

Unique tools to assess biological effects under projected $p\mathrm{CO_2}$ scenarios, identify vulnerable organisms, evaluate potential coastal economic impacts (fisheries, aquaculture, ecosystem services), e.g.:

- Use of Ca-45 to assess growth and calcification rates
- Use of C-14 to assess primary production of marine phytoplankton
- Use of radio-tracers to assess change in pollutant availability

Giacomo de Angelis

Actual status

Already done:

- **Building**: international bid completed, just works starting
- **Cyclotron:** on construction by BEST (Canada)
- **ISOL target:** prototype developed and under operation in lab
- **Safety & control:** authorization to the cyclotron operation just obtained, a Quality and Safety System under implementation

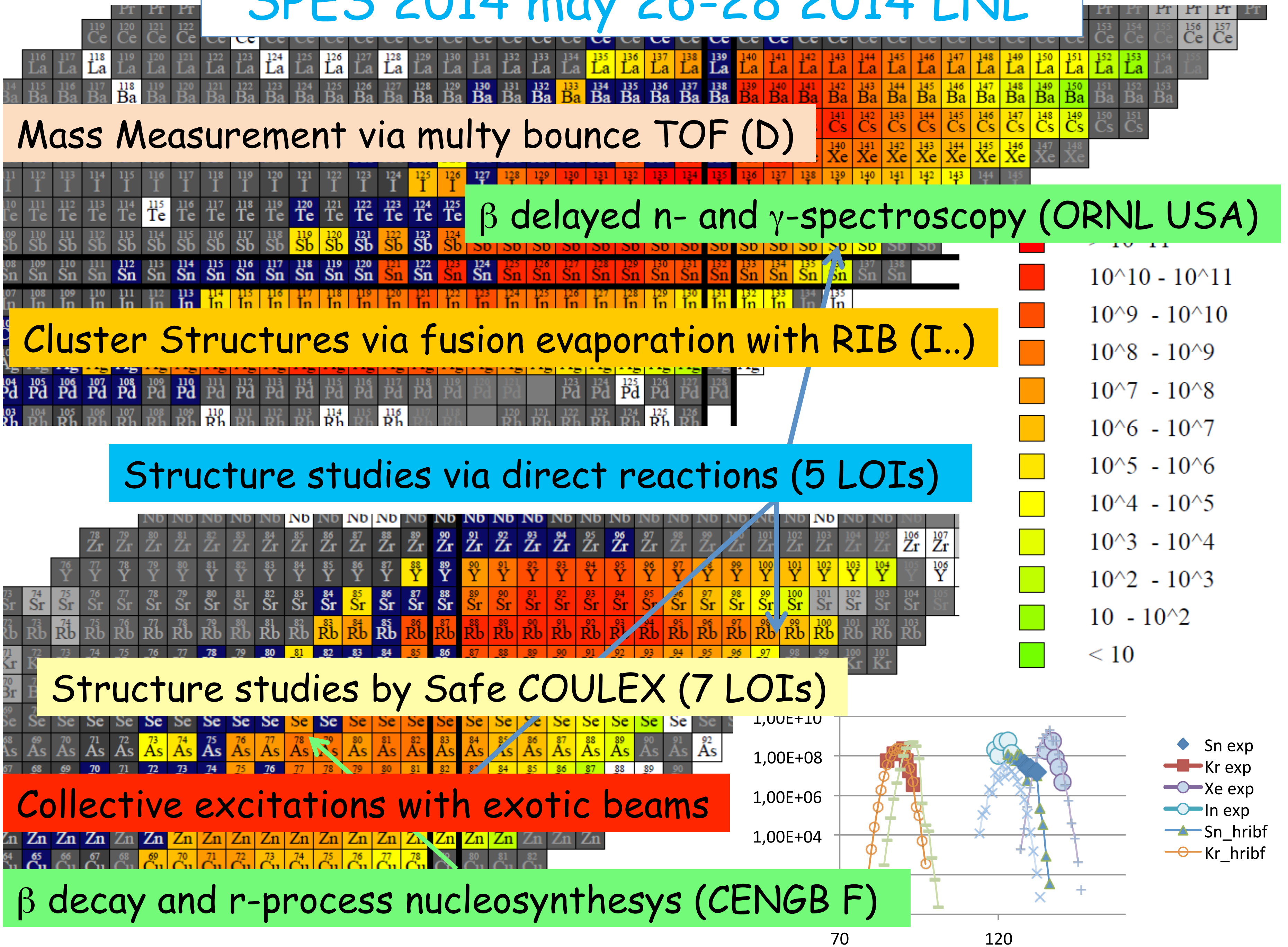
FULLY FUNDED

To be done:

- **Radioactive beam selection and transport** partially FUNDED
- **Charge breeder for increasing the charge state** FUNDED
- **RFQ for pre-acceleration** FUNDED
- **Upgrade of the ALPI superconductive Linac** partially FUNDED
- **General control system and safety** partially FUNDED

Complete funding expected in three years. Total cost: 51 Meuro

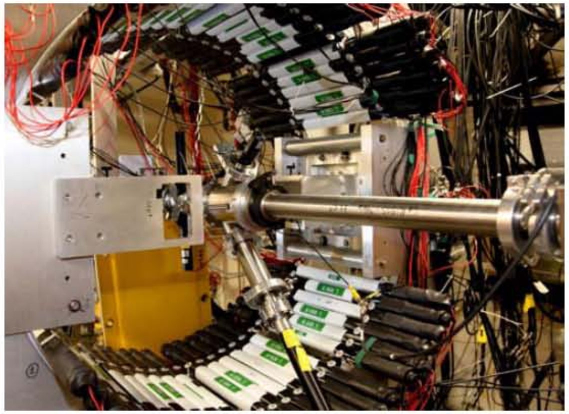
SPES 2014 may 26-28 2014 LNL



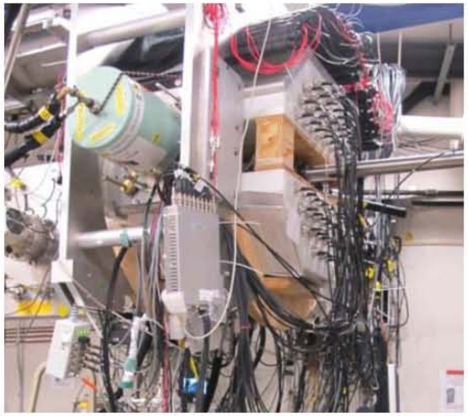
Decay spectroscopy techniques to study neutron-rich fission fragments at SPES

Krzysztof P. Rykaczewski, Robert Grzywacz, Carl J. Gross, Daniel W. Stracener, Yuan Liu
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831-6371, USA
in collaboration with
C. Mazzocchi, A. Korgul, M. Karny, K. Miernik, U. of Warsaw, Warsaw, Poland
W. Krolas, Institute of Nuclear Physics PAN, Krakow, Poland

MTAS = Modular Total Absorption Spectrometer



VANDLE = Versatile Array of Neutron Detectors for Low Energy

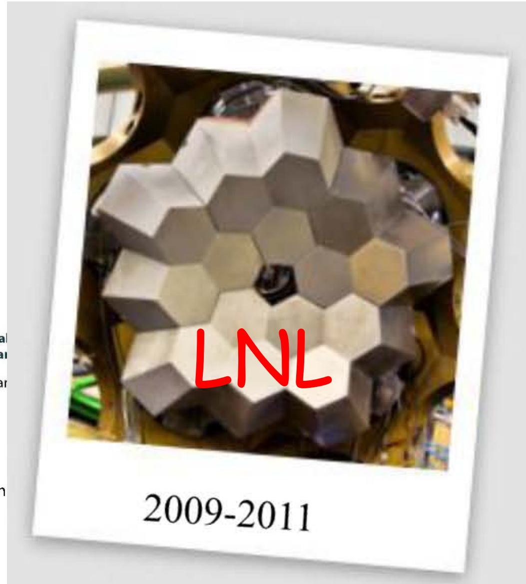


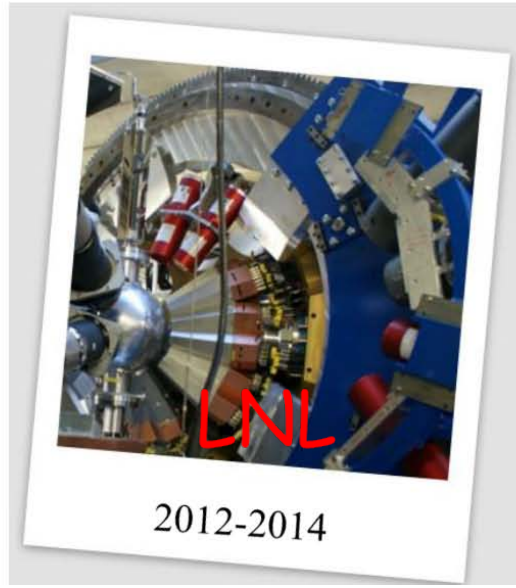
3Hen = Helium-3 Neutron Detectors
Hybrid-3Hen = 3Hen + Clover Ge

The physics of neutron-rich fission fragments

- nuclear structure evolution as N >> Z
- spectroscopy near and above the neutron separation energy
- rapid-neutron capture half-lives and beta-delayed neutron branchings
- societal impact in better data for modeling neutron-rich environments such as nuclear reactors
- more detailed understanding of the anti-neutrino spectra from reactors

Istituto Nazional
di Fisica Nuclear
Laboratori Nazionali di Legnar





To Prof. Giovanni Fiorentin

Director of LNL

Dear Gianni,

Let us first convey to you, on behalf of the AGATA Steering Committee (ASC) and AGATA Collaboration Council (ACC), the message that the full scientific community around AGATA has appreciated the interest of the LNL laboratory in the AGATA physics program and in particular in the scientific potential of the AGATA detector in combination with the exotic radioactive ion beams of the SPES facility. In view of the wide scientific program of AGATA at SPES, already envisaged by the scientific community through the presentation of 15 LOIs, the AGATA Steering Committee has agreed to install the AGATA detector at LNL-SPES for running an experimental campaign in the period 2019-2020.

Therefore the AGATA Steering Committee has decided for a commitment of the detector until 2020 (GANIL 2017-2018, LNL 2019-2020).

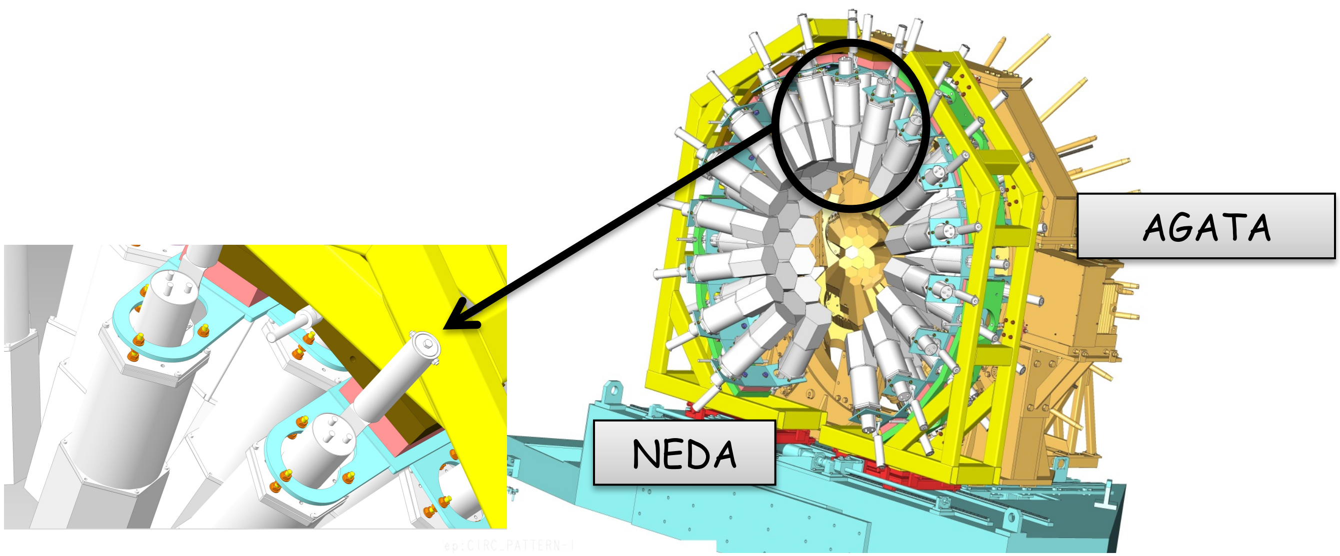
Best Regards,

G. de Angelis (ASC Chair) and J. Nyberg (ACC Chair)

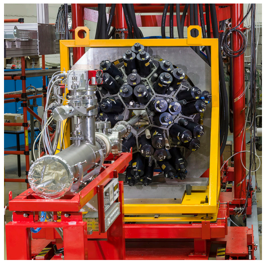
AGATA @ SPES 2019-2020

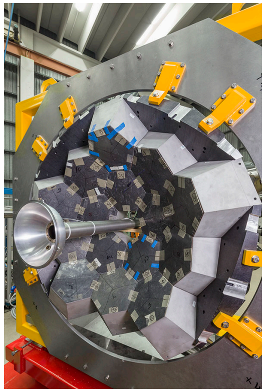
Neutron Detector Array

- Versatile neutron detector to be coupled to gamma-ray arrays
- Neutron detection is based on the liquid scintillator EJ301 with good neutron-gamma discrimination capabilities.
- Single hexagonal detector FEE fully digital system:
  - 200 MHz and ENOB 11,3
  - Global Trigger System - GTS



Predecessor
Neutron Wall

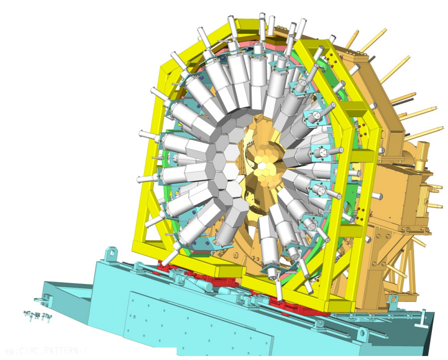


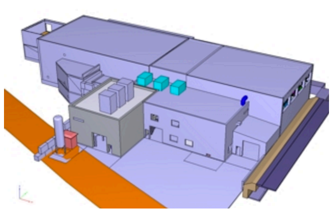


Time line of NEDA

2016 2017 2018 2019 2020 2021

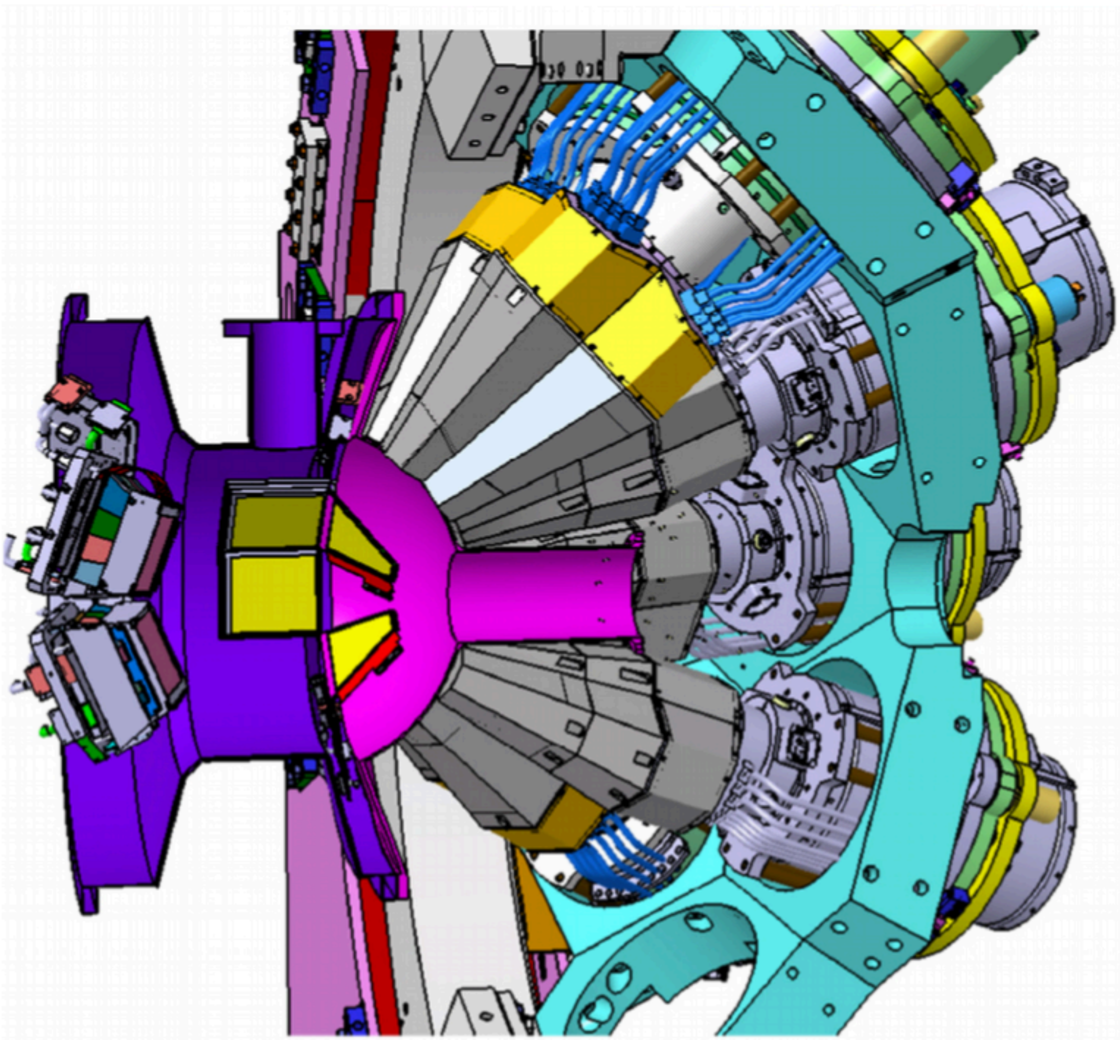
Production of NEDA	NEDA/ AGATA@GANIL	NEDA HIE-ISOLDE??	NEDA SPES





SPES
exotic beams for science

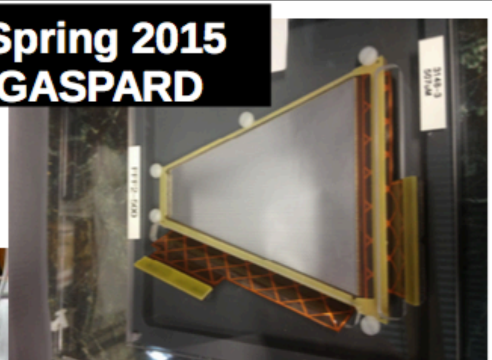
MUST2+GASPARD+TRACE: MUGAST



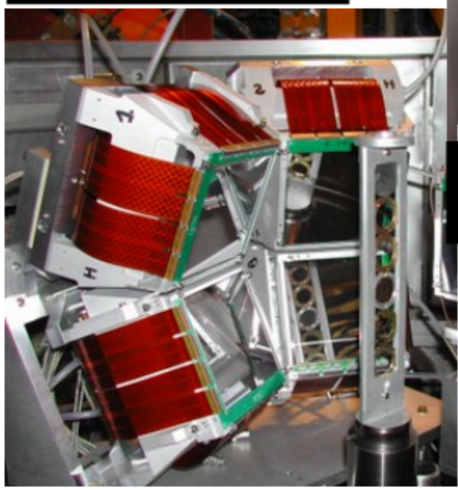
- Structure and reaction studies
- AGATA+MUGAST +VAMOS, ...
- LoI@GANIL PAC

NEW TRACE GASPASRD PROTO + MUST2

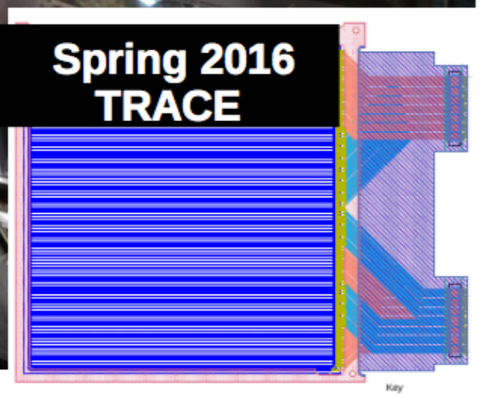
Spring 2015 GASPARD



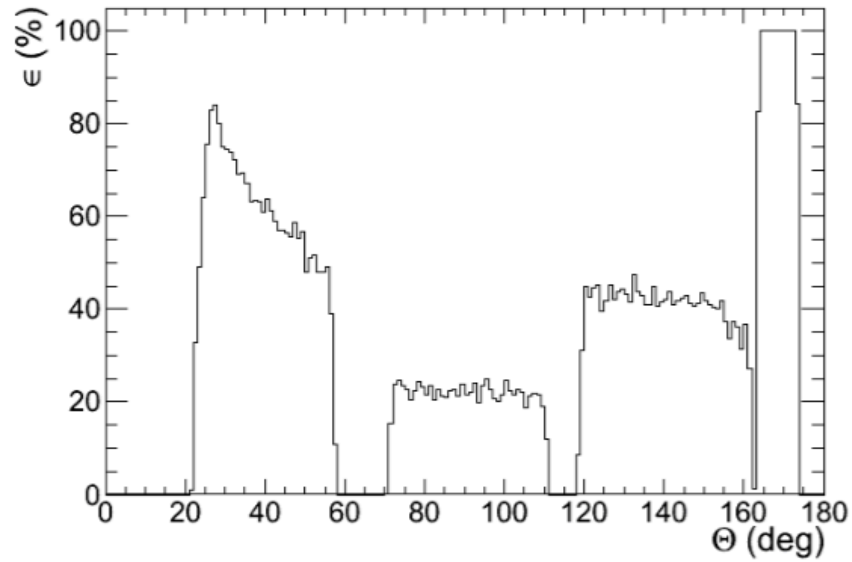
MUST2



Spring 2016 TRACE



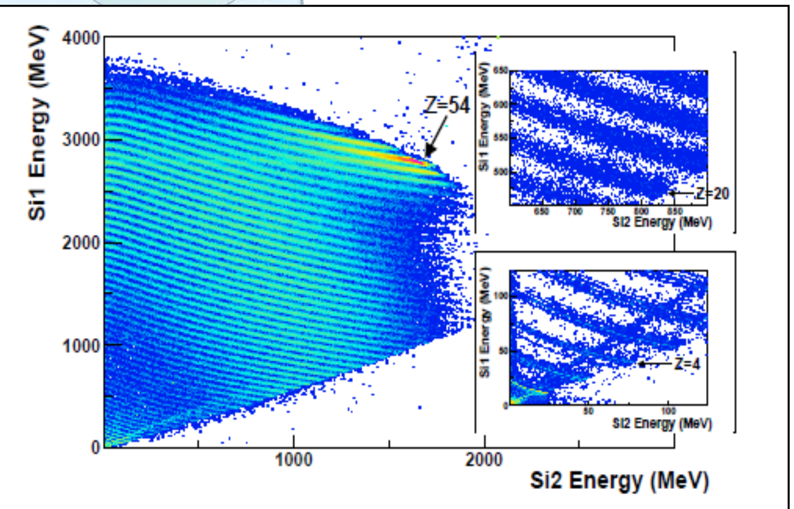
Efficiency MUGAST **geometrical**

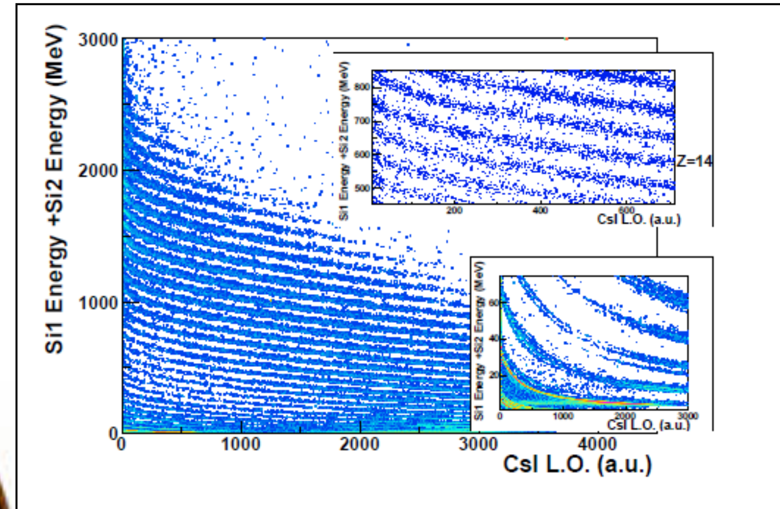


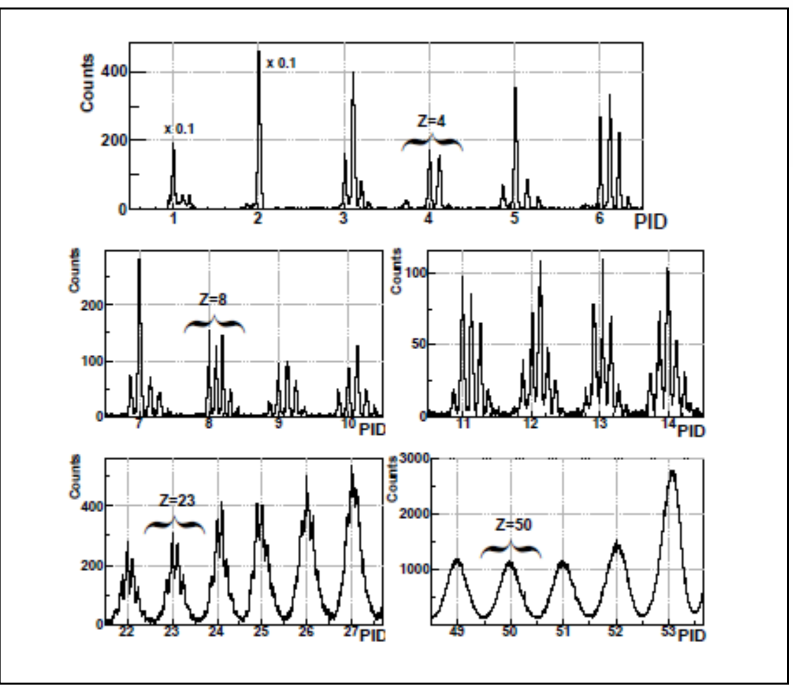
- Forward: 4 Must2 telescopes
- Backward: 4 Trape DSSD 500um
- 2 square DSSD 500um
- 1 Annular (back or forward)

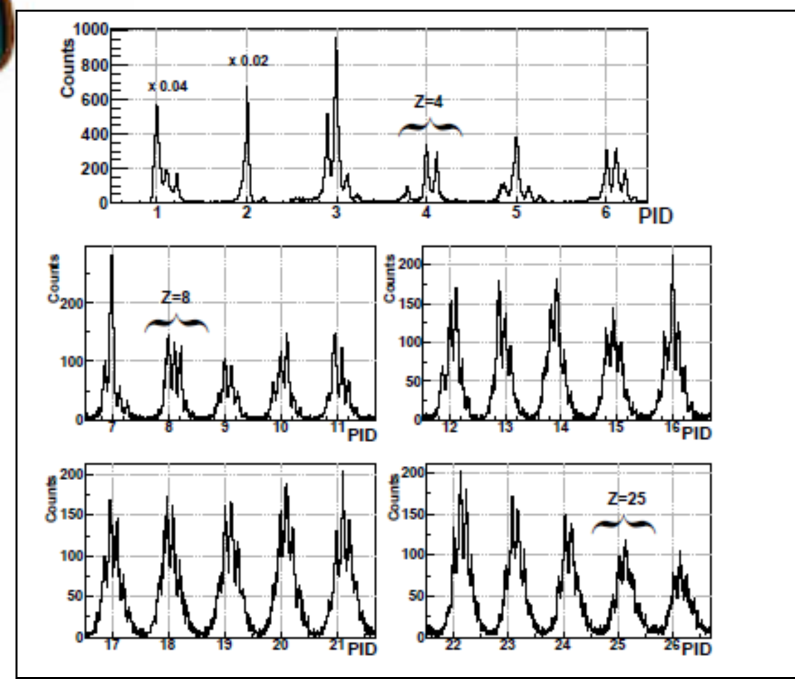
- Large Area
- Large Eff
- NTD

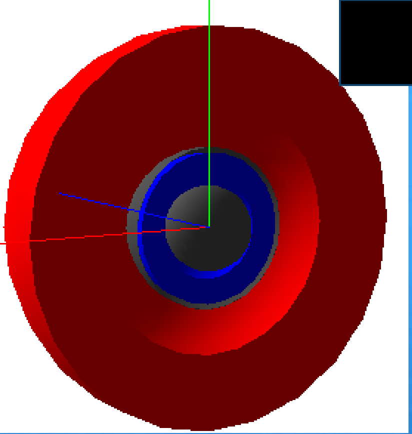
The FAZIA project

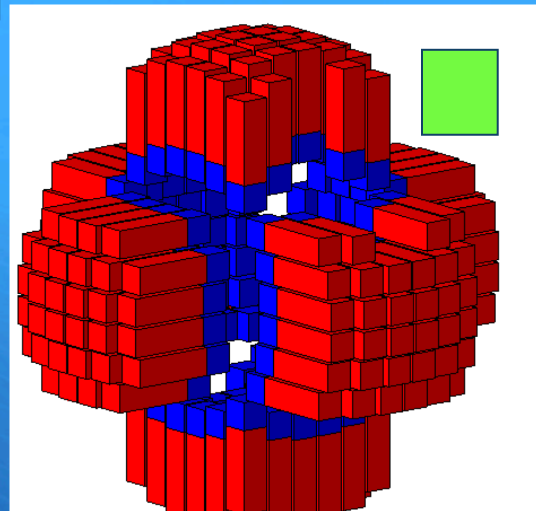


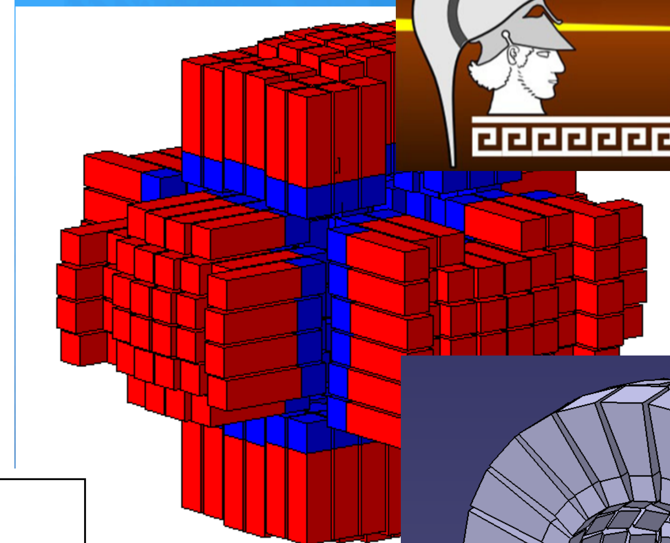


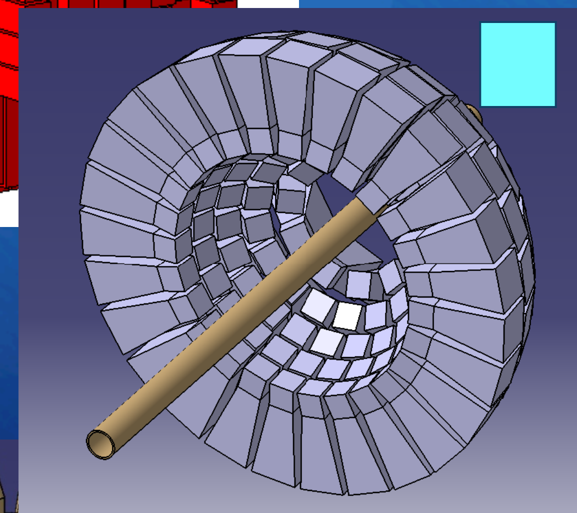


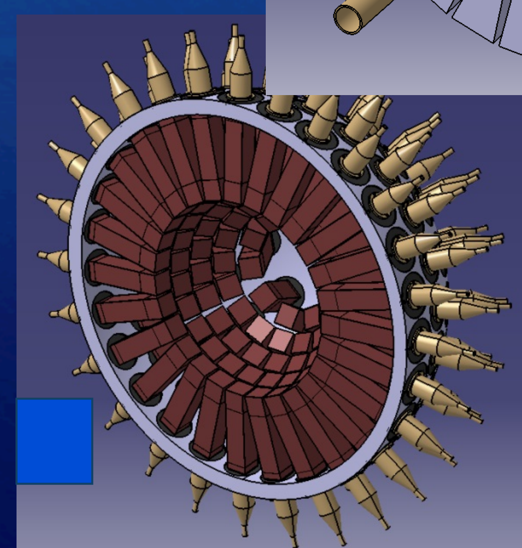


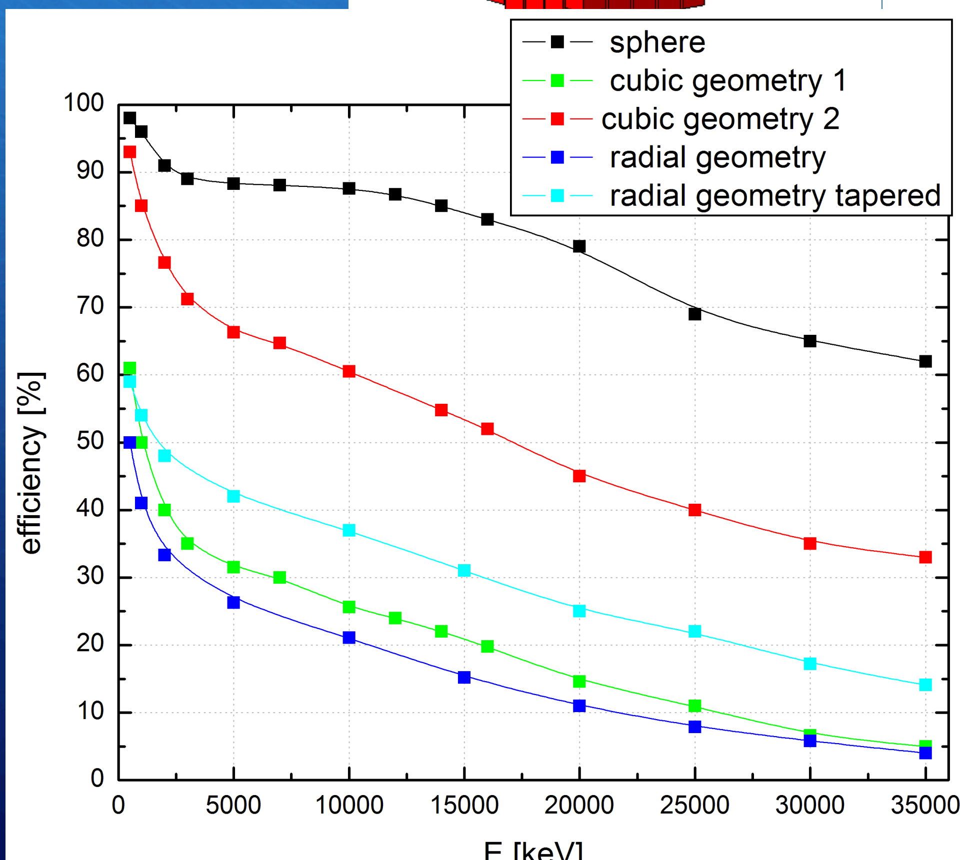











sphere
cubic geometry 1
cubic geometry 2
radial geometry
radial geometry tapered
efficiency [%]
E [keV]
0
10
20
30
40
50
60
70
80
90
100
5000
10000
15000
20000
25000
30000
35000

Active Target Detectors: ACTAR

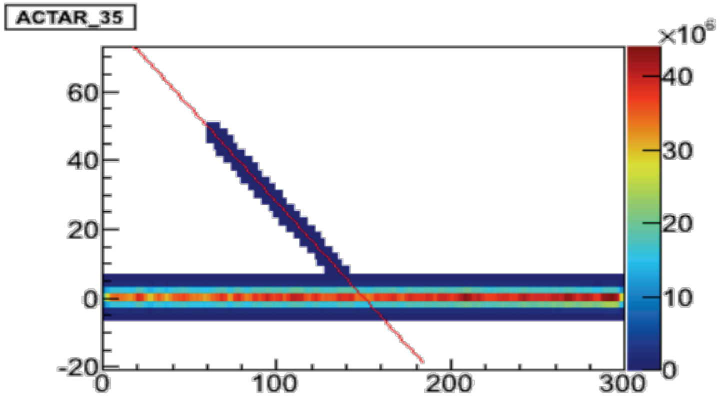
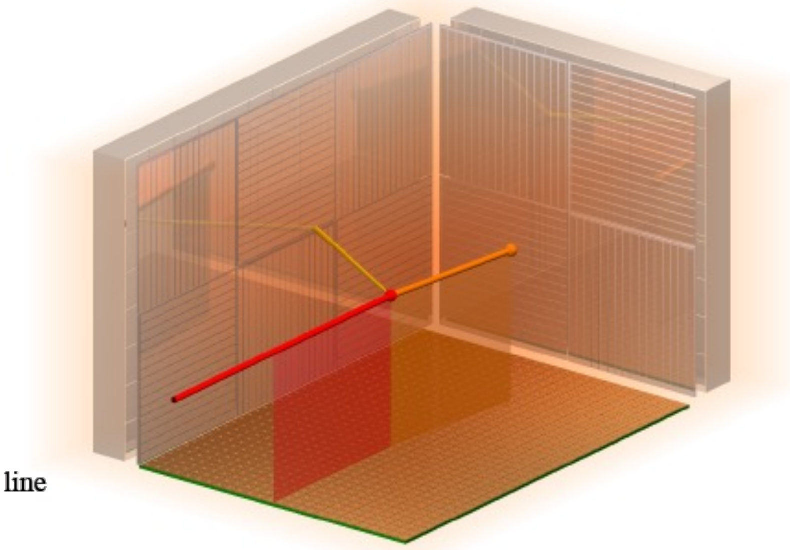
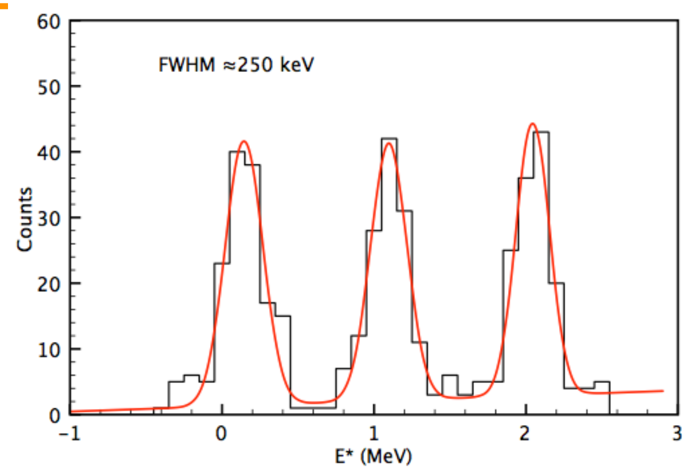
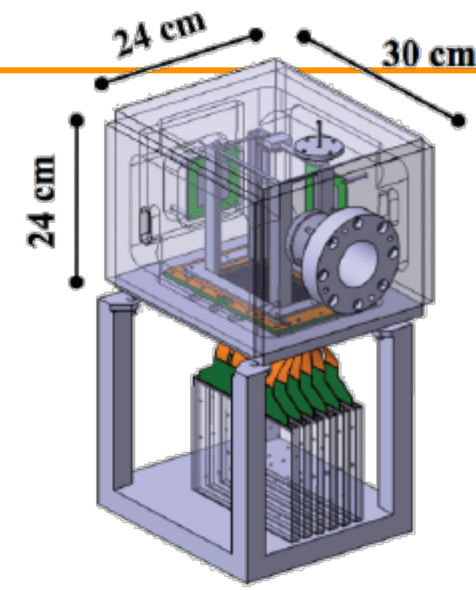


Fig. 4: Sample digitized trace for a ^{132}Sn(d,p) reaction with 2x2mm^2 sized pads. The red line corresponds to the fitted trajectory used for determining the range of the proton.

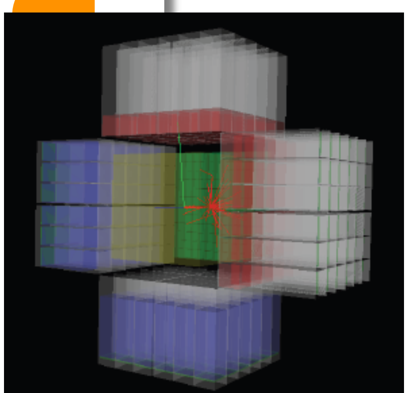




Proton energy resolution for the ^{78}Ni(d,p) reaction at 8 AMeV with 4x4 mm^2 pads



ACTAR + γ-ray array

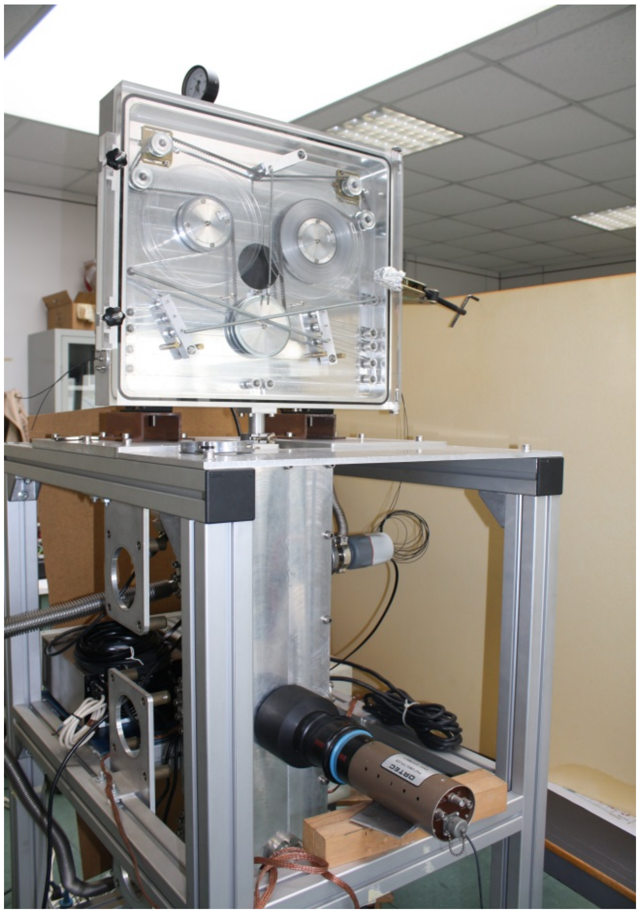


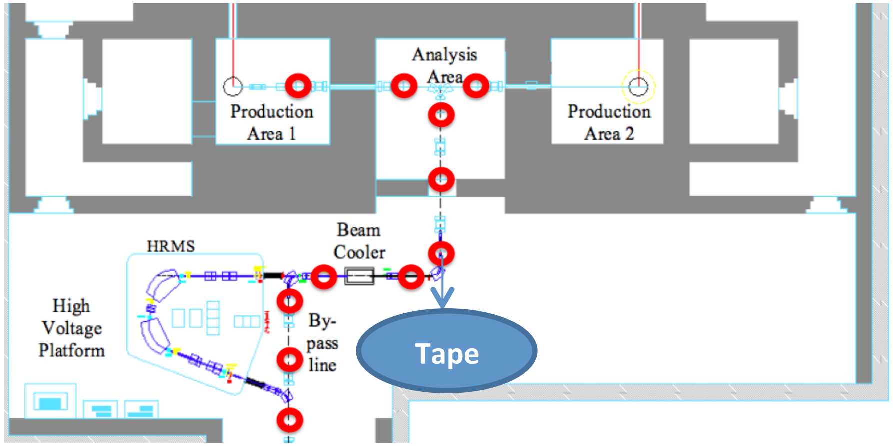
ERC: ACTAR TPC - G. Grynier - GANIL
ERC: SpecMAT - R. Raabe - K.U. Leuven

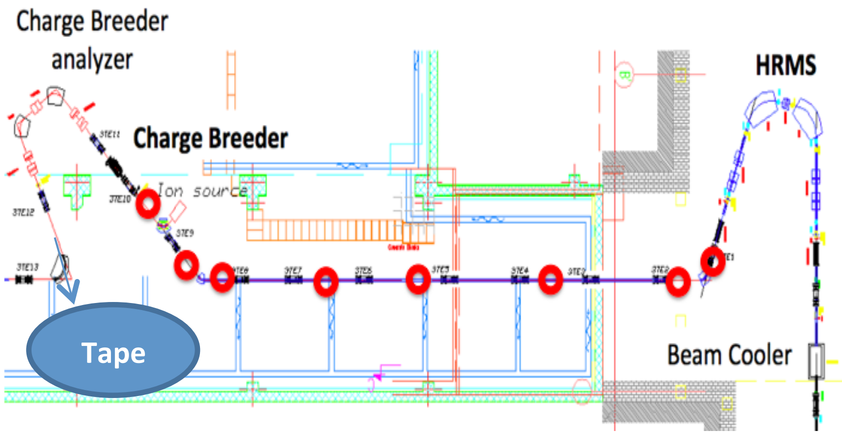
erc

[ACTAR collaboration: http://pro.ganil-spiral2.eu/spiral2/instrumentation/actar-tpc]

Decay Station at SPES: LOI Mi ,.....

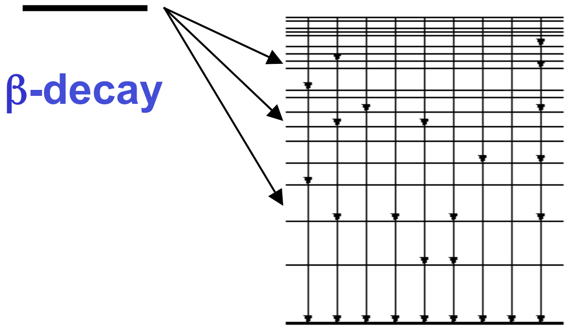




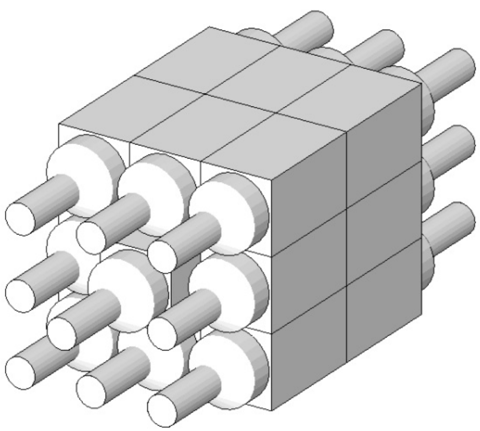


Total Absorption Spectrometer (TAS) or MTAS (ORNL)

Courtesy of B. Rubio

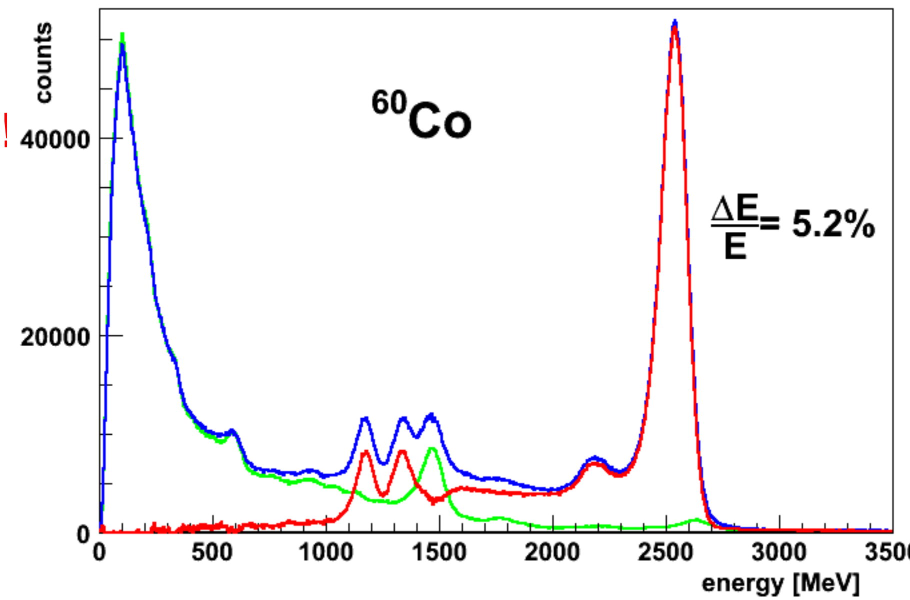


Information on the **multiplicity** of the gamma cascade



TDR submitted in 2012 and accepted!

16 × NaI(Tl) crystals:
- $15 \times 15 \times 25\ cm^3$
- Minimum dead-material
- 5” PMT: ETL9390




INFN
SPES
Thanks for attention
THANK YOU
19/06/2014
13:00