High Resolution γ-Spectroscopy at SPIRAL2 with AGATA and EXOGAM2

A. Gadea (IFIC Valencia, Spain)

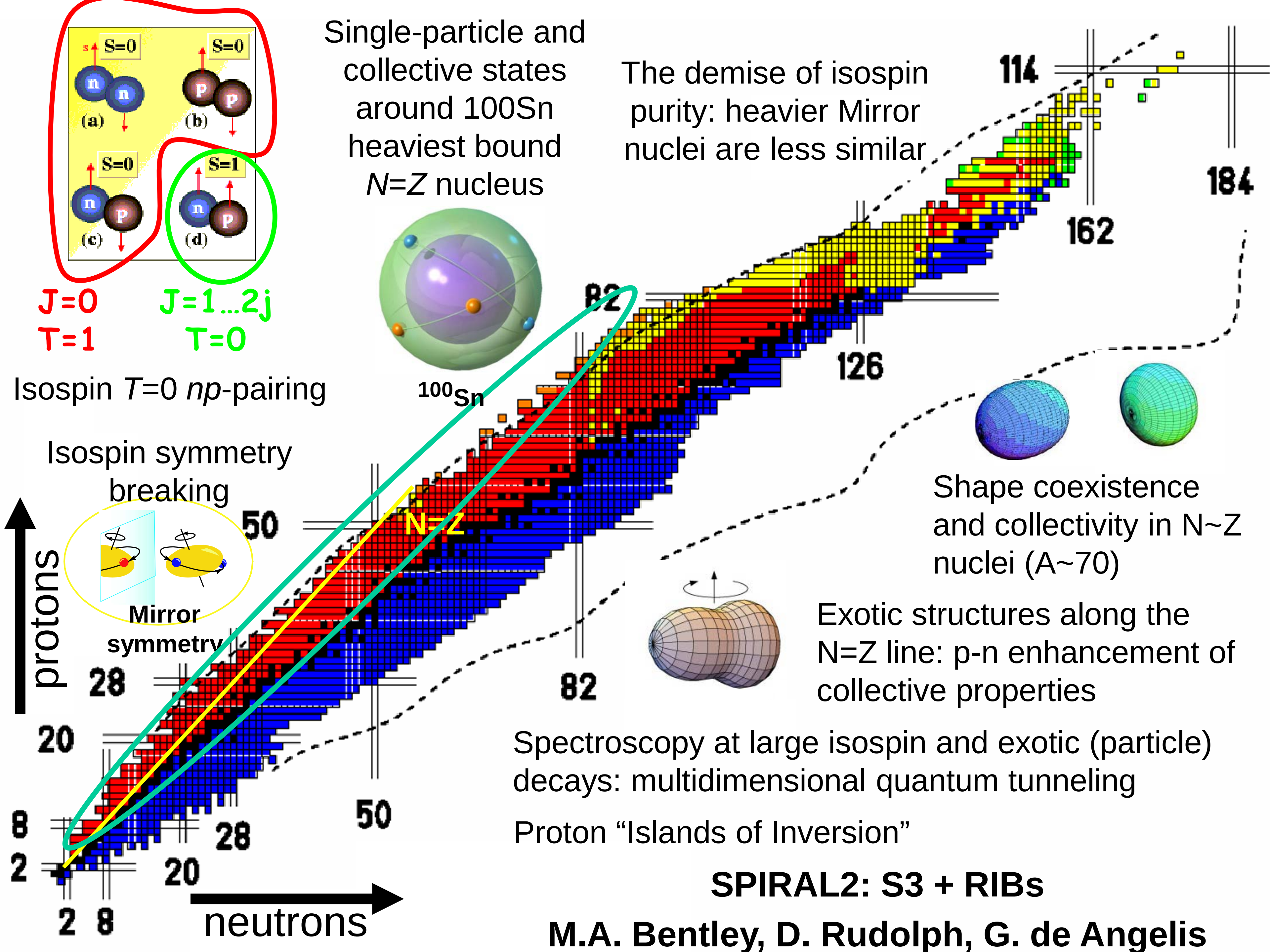
on behalf of the HRGS community

Physics Case, LoIs for SPIRAL2

- **Nuclei with N=Z (Symmetric nuclear matter)**
- **Nuclear shapes and high-spin spectroscopy**
- **Collective modes in the continuum**
- **Neutron-rich nuclei (Isospin degree of freedom)**
- **Nuclear electromagnetic moments**

Links with LoIs

- **Spectroscopy of the heaviest elements**
- **High-energy γ-rays as a probe of hot nuclei and reaction mechanisms**
- **Direct Reaction Studies of Exotic Nuclear Structure**

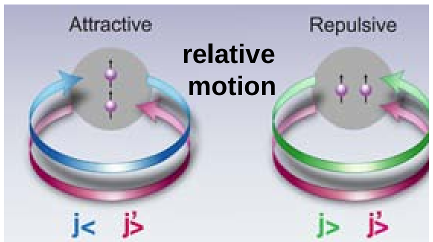


S=0
S=0
S=0
S=1
n n
(a)
p p
(b)
n p
(c)
n p
(d)
J=0
T=1
J=1…2j
T=0
Isospin T=0 np-pairing
Single-particle and collective states around 100Sn heaviest bound N=Z nucleus
100Sn
The demise of isospin purity: heavier Mirror nuclei are less similar
114
184
162
82
126
Isospin symmetry breaking
Mirror symmetry
50
N=Z
protons
28
20
8
2
2 8
20
28
50
82
neutrons
Shape coexistence and collectivity in N~Z nuclei (A~70)
Exotic structures along the N=Z line: p-n enhancement of collective properties
Spectroscopy at large isospin and exotic (particle) decays: multidimensional quantum tunneling
Proton “Islands of Inversion”
SPIRAL2: S3 + RIBs
M.A. Bentley, D. Rudolph, G. de Angelis

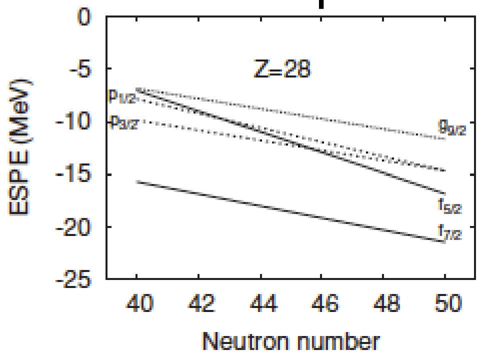
Structure of neutron-rich nuclei

•Evolution of the shell structure far from stability; single particle levels and shell gaps Evolution of shapes and collectivity

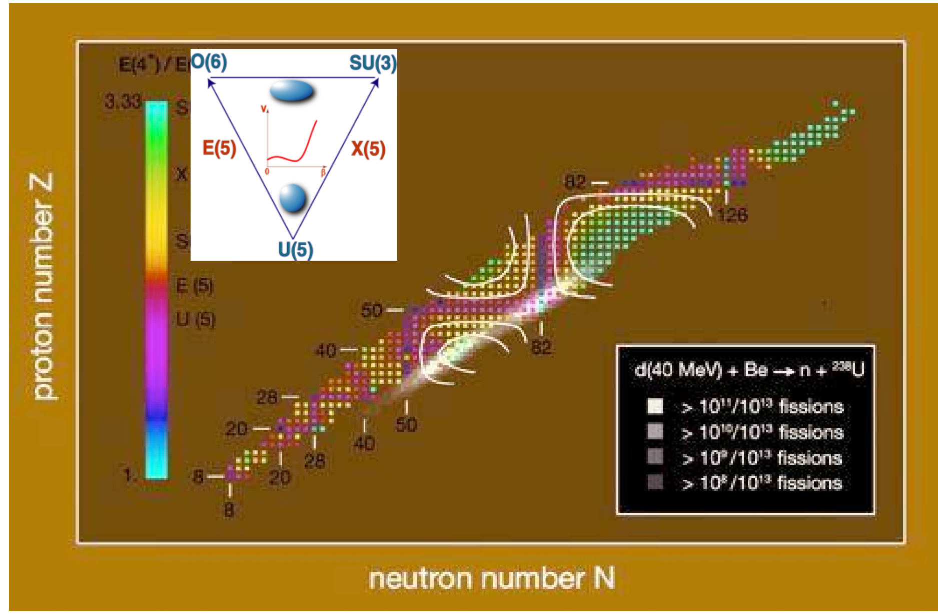
T.Otsuka PRL97 162501



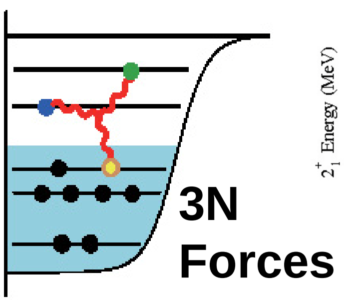
Tensor interaction

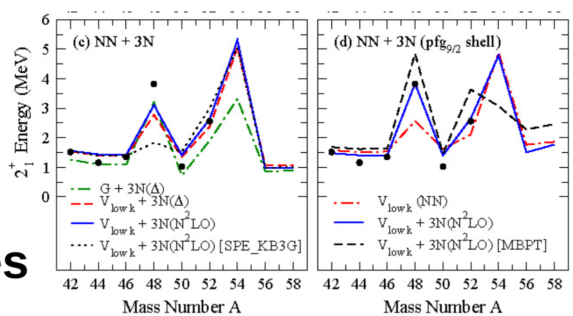


K. Sieja PRC81, 061303



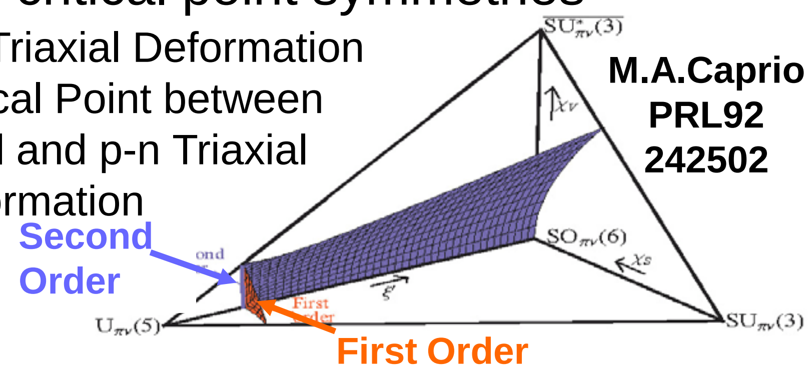
T.Otsuka PRL105 032501, J.D Holt arXiv:1009.5984v1



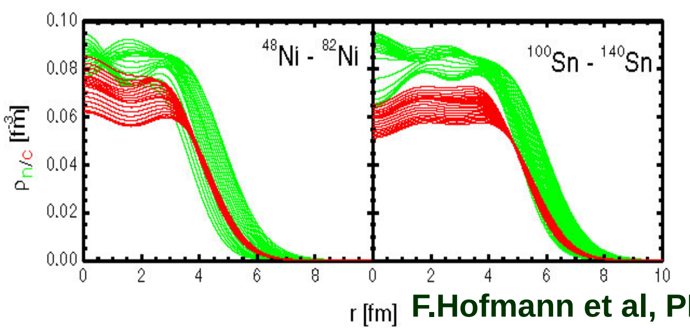


• Symmetries: New regions to study spherical, transitional and deformed nuclei, phase transitions. Dynamical and critical point symmetries

p-n Triaxial Deformation Critical Point between Axial and p-n Triaxial Deformation



M.A.Caprio PRL92 242502

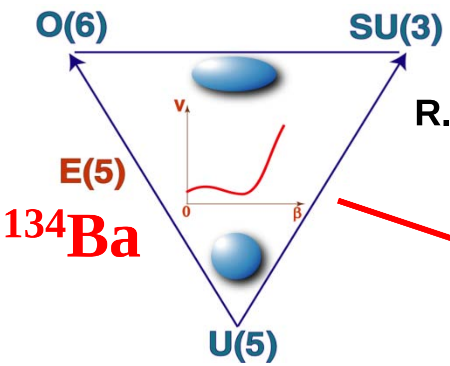


Effects of difuse nuclear matter

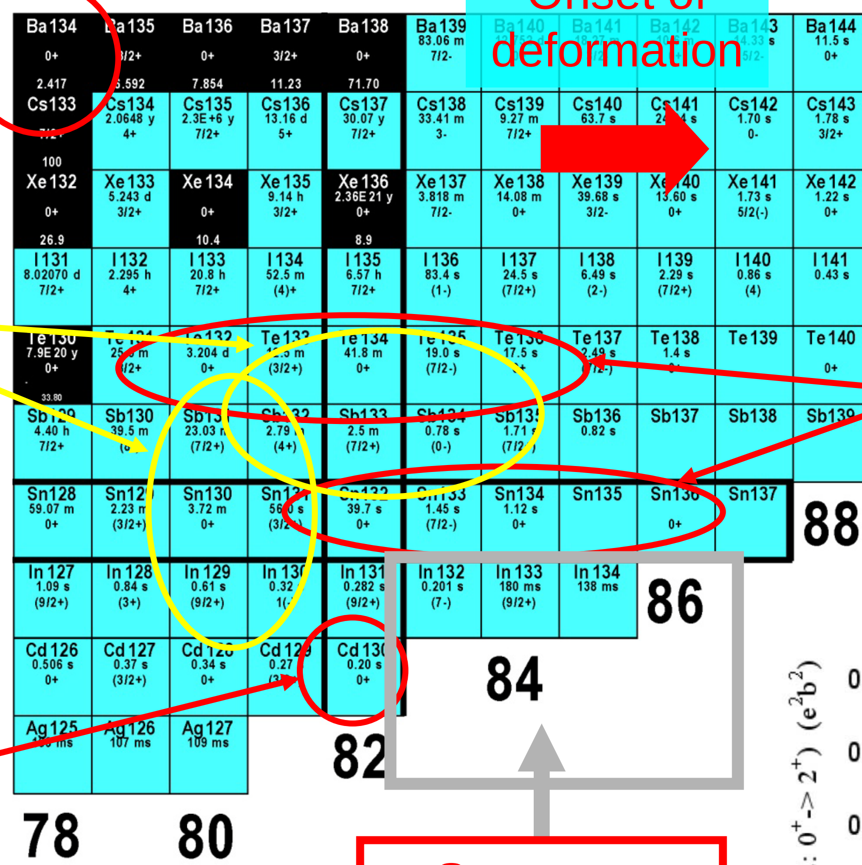
F.Hofmann et al, PRC 64(01)034314.

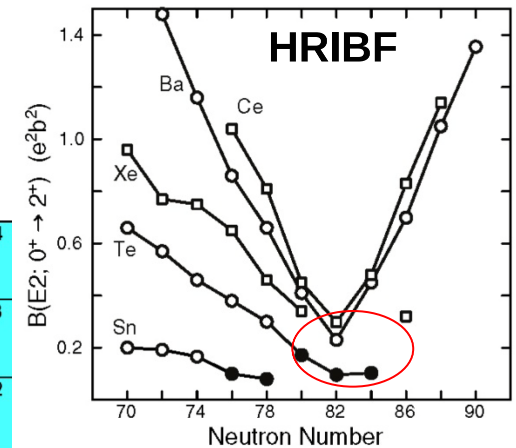
A.Gadea, G.Duchêne, U. Datta Pramanik

Structure in the ^{132}Sn region



R.F.Casten et al,
PRL 85 (00)



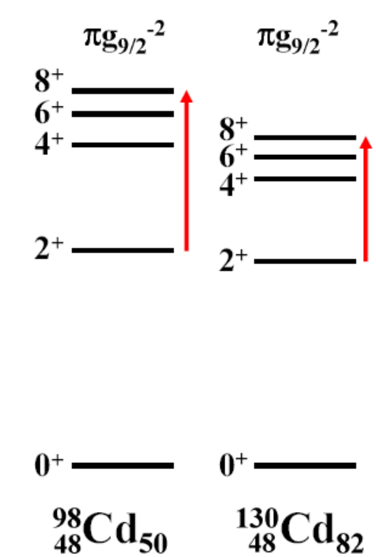


D.C.Radford et al,
PRL 88 (2002)

Shell Model nuclei
realistic CD-BONN
interaction

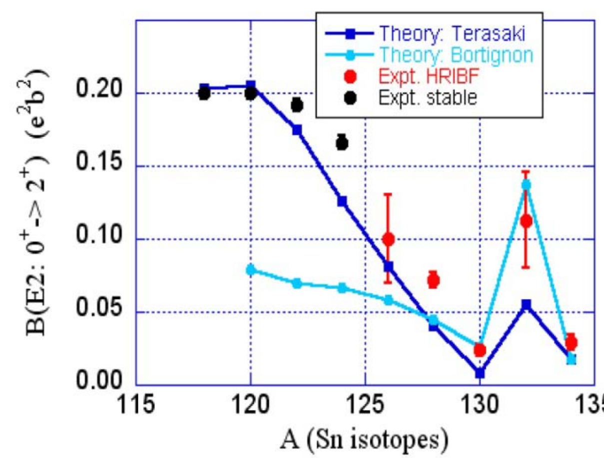
A.Sherillo et al, PRC70 (04)

J.Terasaki et al, PRC66 (02)
G.Colo et al., NPA722 (03)
A.Ansari, PLB623 (05)



Structure mostly unknown

Seniority Isomers
A.Jungclaus / M.Gorska
Rising: to be published



Collective modes in the continuum / Hot nuclei

Shape phase transitions

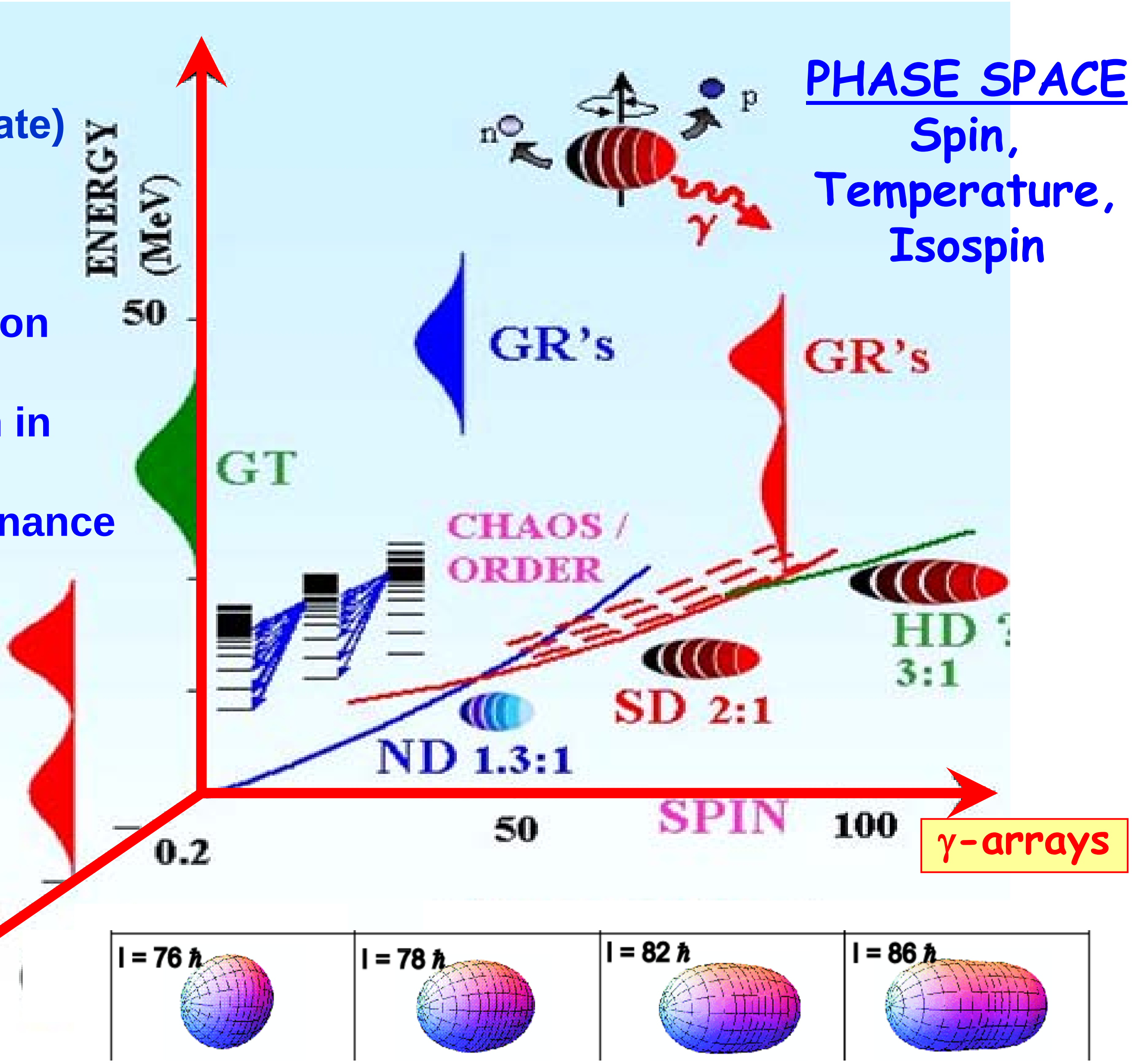
Jacobi transition
(Oblate → triaxial → prolate)
Poincaré transition
(Prolate → octupole)

Collective Rotation

- Order-to-Chaos Transition

Collective Vibrations

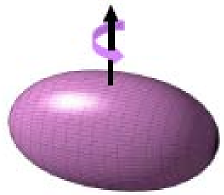
- Prompt dipole emission in CN reactions
- Giant Quadrupole Resonance
- Highly excited/Pygmy states in n-rich nuclei



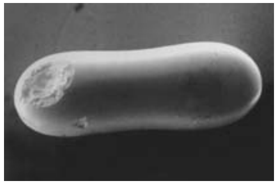
Elongated triaxial (Jacobi)

S. Leoni, E. Khan, D. Pierroutsakou

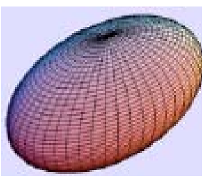
Exotic nuclear shapes



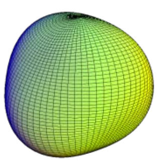
Superdeformation
Hyperdeformation



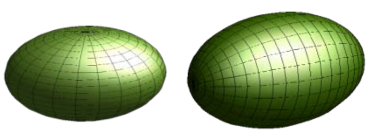
Jacobi shapes



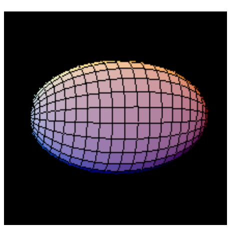
Triaxial shapes
3-dimensional rotation



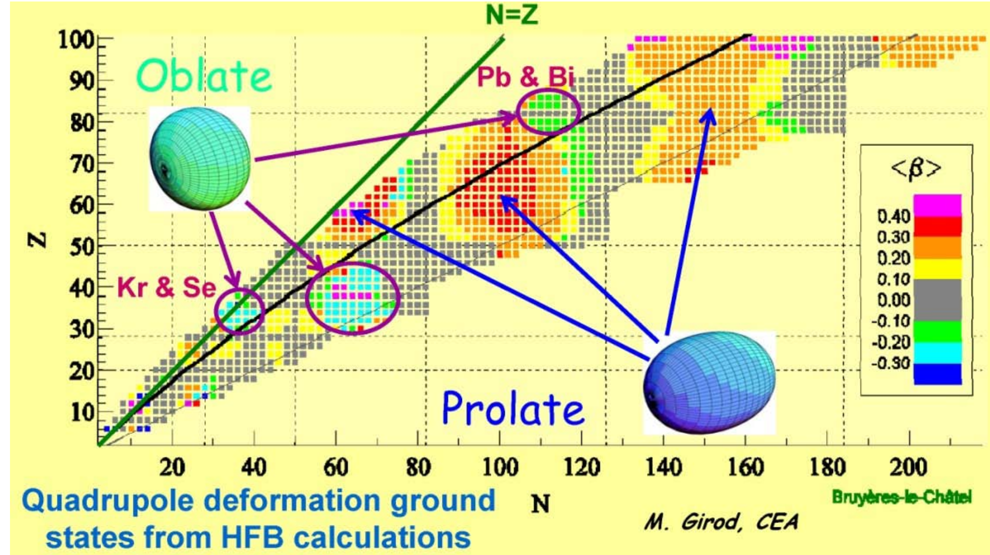
Higher-order shapes
(with high-rank symmetrie):
tetrahedral, octahedral



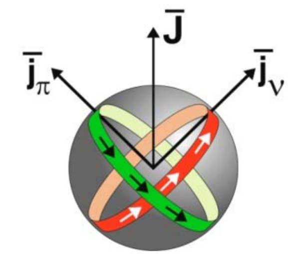
Shape coexistence



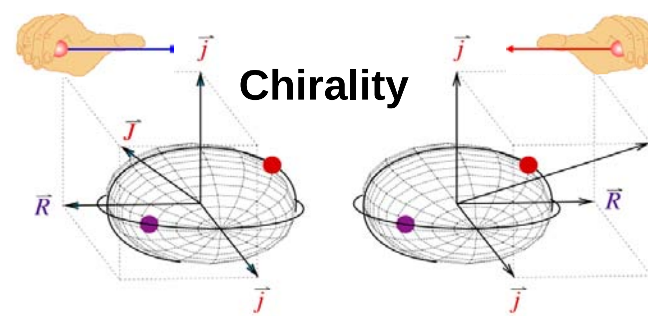
dynamic deformation
vibrations etc.



Phenomena associated:



Tidal Waves **Magnetic Rotation**



As well: Band termination Collapse of pairing, wobbling modes, phase transitions, etc…

A. Görgen, N. Redon, J. Simpson

Nuclear Electro-magnetic Moments

revealing the interplay between single-particle and collective nuclear properties

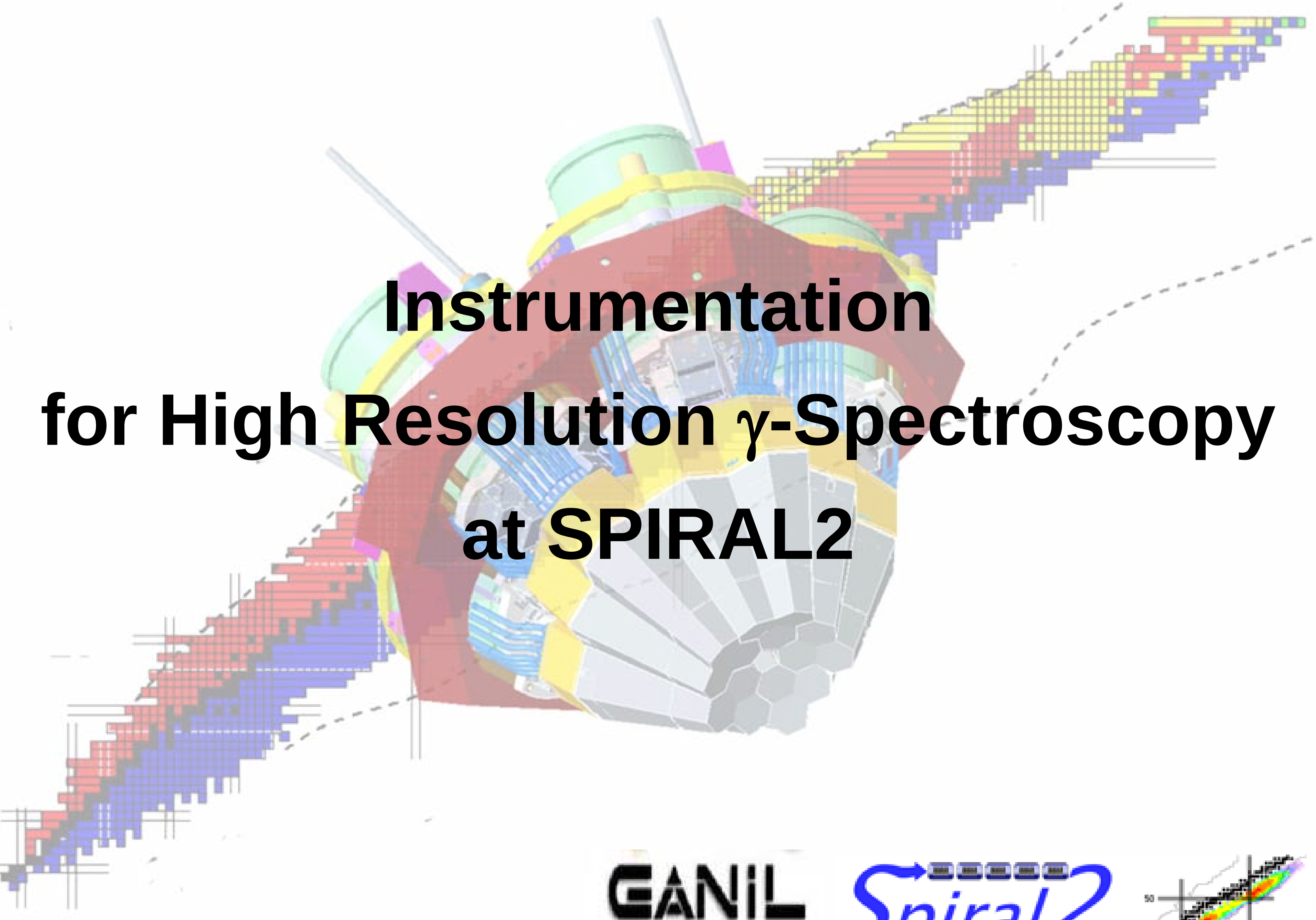
Large variety of techniques have been developed (mainly for stable beams)

- Lifetime and multipolarity measurements (transition strengths for all multipoles)
  - Doppler-shift methods (fs-ps), fast timing methods (ns-ms)
  - Linear polarisation measurements (Compton scattering) (Characterization of AGATA as Compton polarimeter ongoing)
  - Conversion coefficients
- Nuclear orientation techniques (static E2/M1 moments)
  - Perturbed Angular Distributions/Correlations (mainly ns-ms isomers)
  - Transient Fields and Recoil in Vacuum Techniques (short-lived states)
  - Tilted-foil techniques (polarization from atomic-surface interaction)
- Coulomb excitation (static E2 and transitional E2/M1 moments)

Transformation of these stable-beam techniques to be used with radioactive beams and with the new instrumentation (AGATA).

G. Georgiev, D.L. Balabanski, A. Görgen,

Instrumentation for High Resolution γ-Spectroscopy at SPIRAL2



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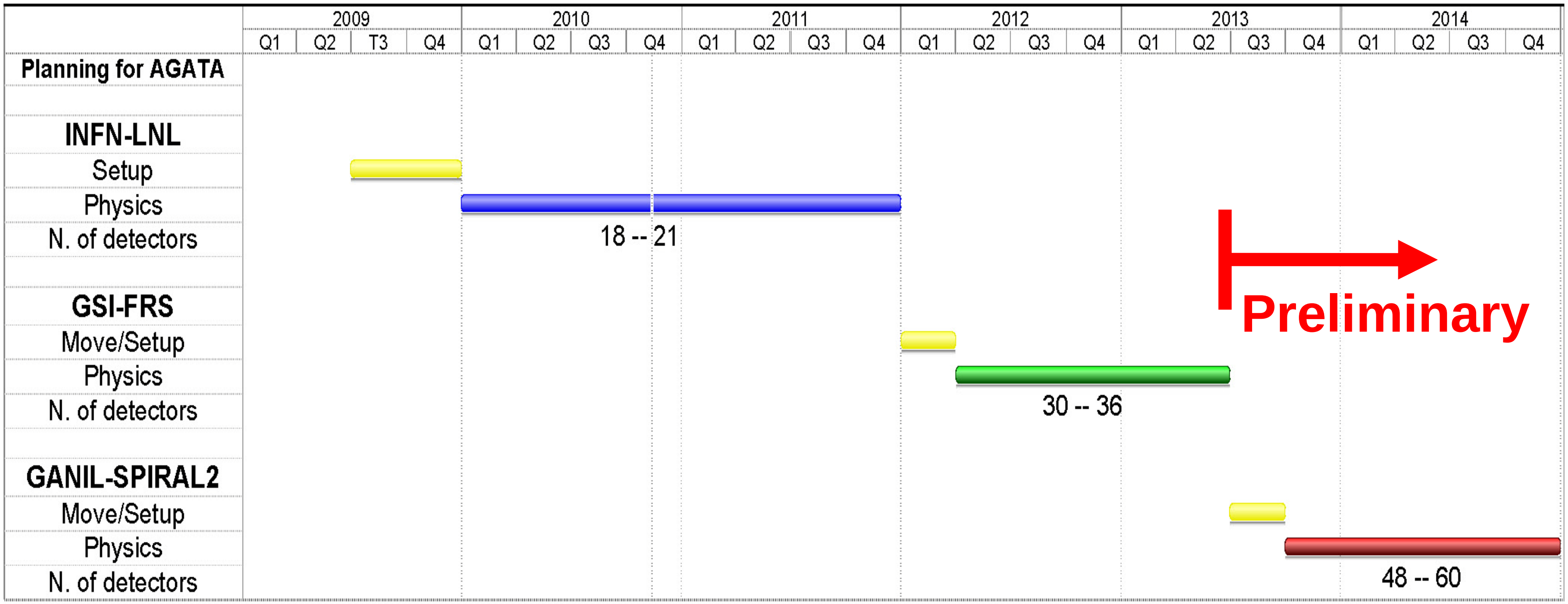
GRAND ACCELERATEUR NATIONAL D'IONS LOURDS
LABORATOIRE COMMUN DSM/CEA-IN2P3/CNRS

Spiral2

Current planning

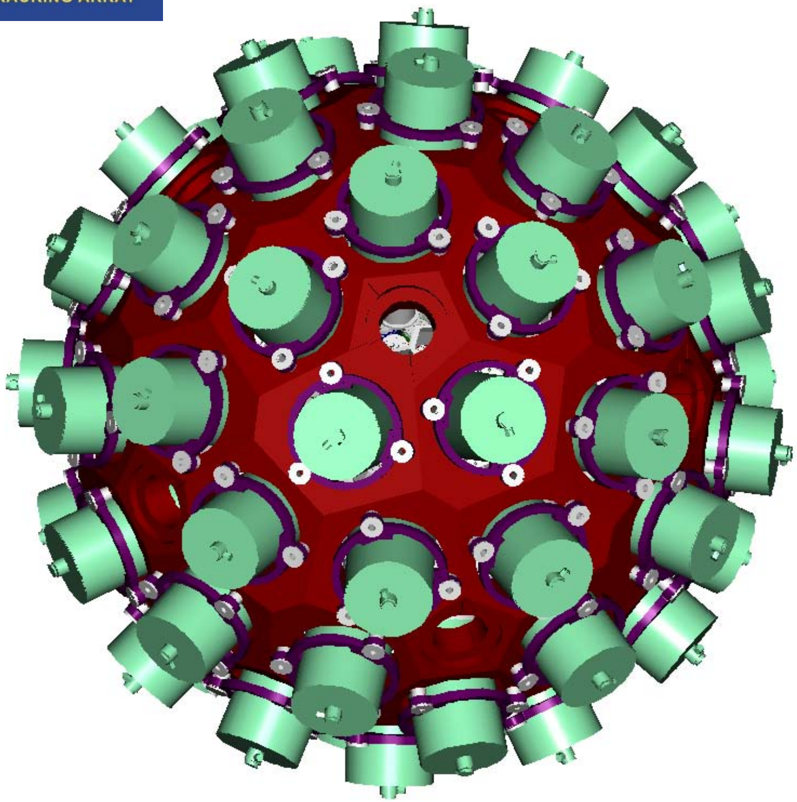


Proposed deployment of AGATA for the experimental campaigns at the three AGATA host Laboratories

AGATA

(Advanced GAmma Tracking Array)

Encapsulation



180 hexagonal crystals	3 shapes
60 triple-clusters	all equal
Inner radius (Ge)	23.5 cm
Amount of germanium	362 kg
Solid angle coverage	82 %
36-fold segmentation	6480 segments
Singles rate	~50 kHz

Efficiency:	43% (M_γ=1)	28% (M_γ=30)
Peak/Total:	58% (M_γ=1)	49% (M_γ=30)

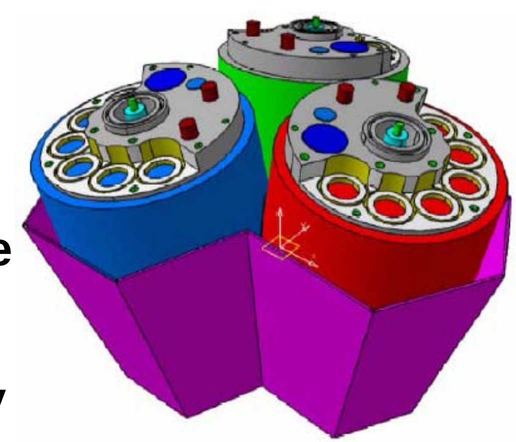
6660 high-resolution digital electronics channels

High throughput DAQ

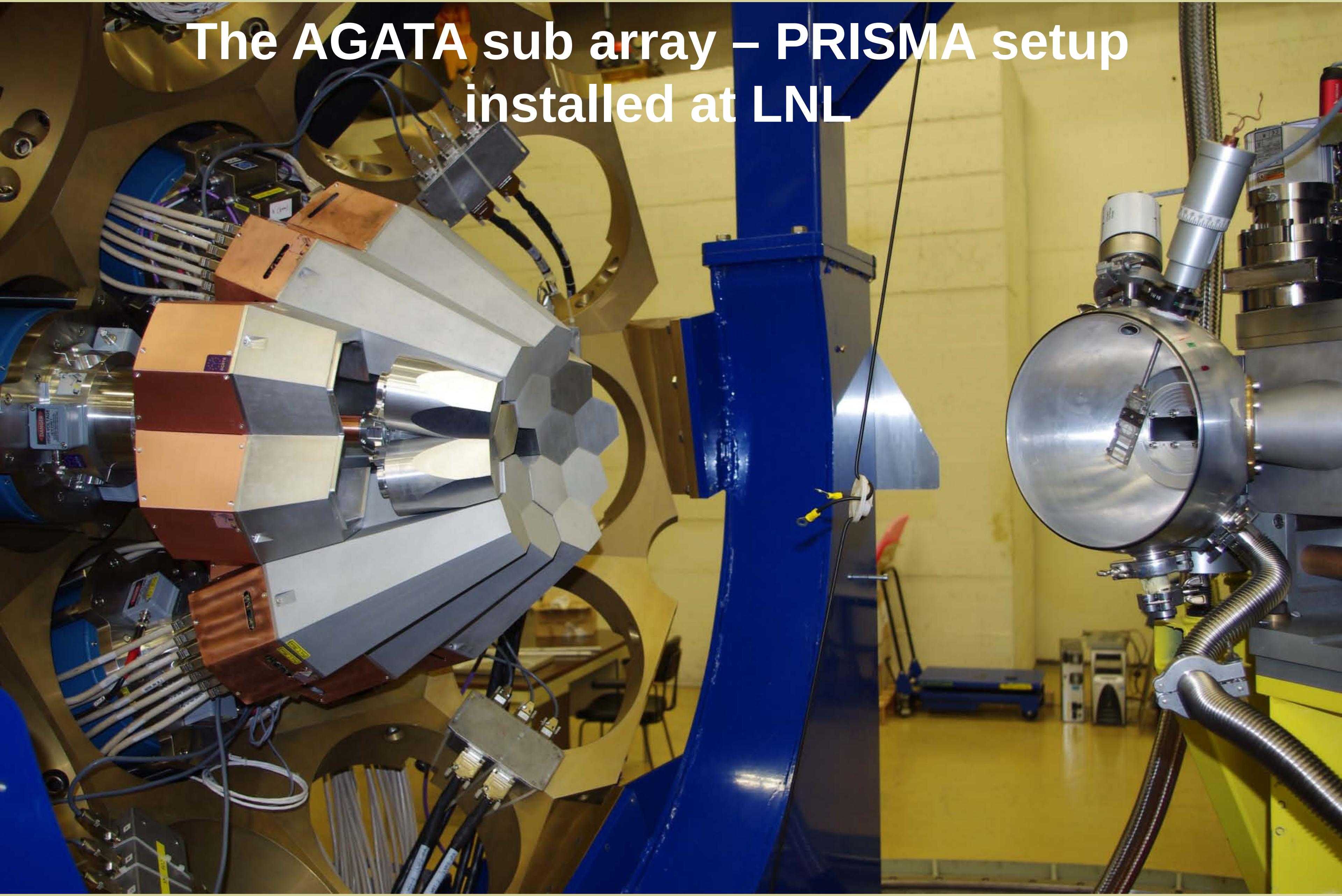
Pulse Shape Analysis → position sensitive operation mode

γ-ray tracking algorithms to achieve maximum efficiency

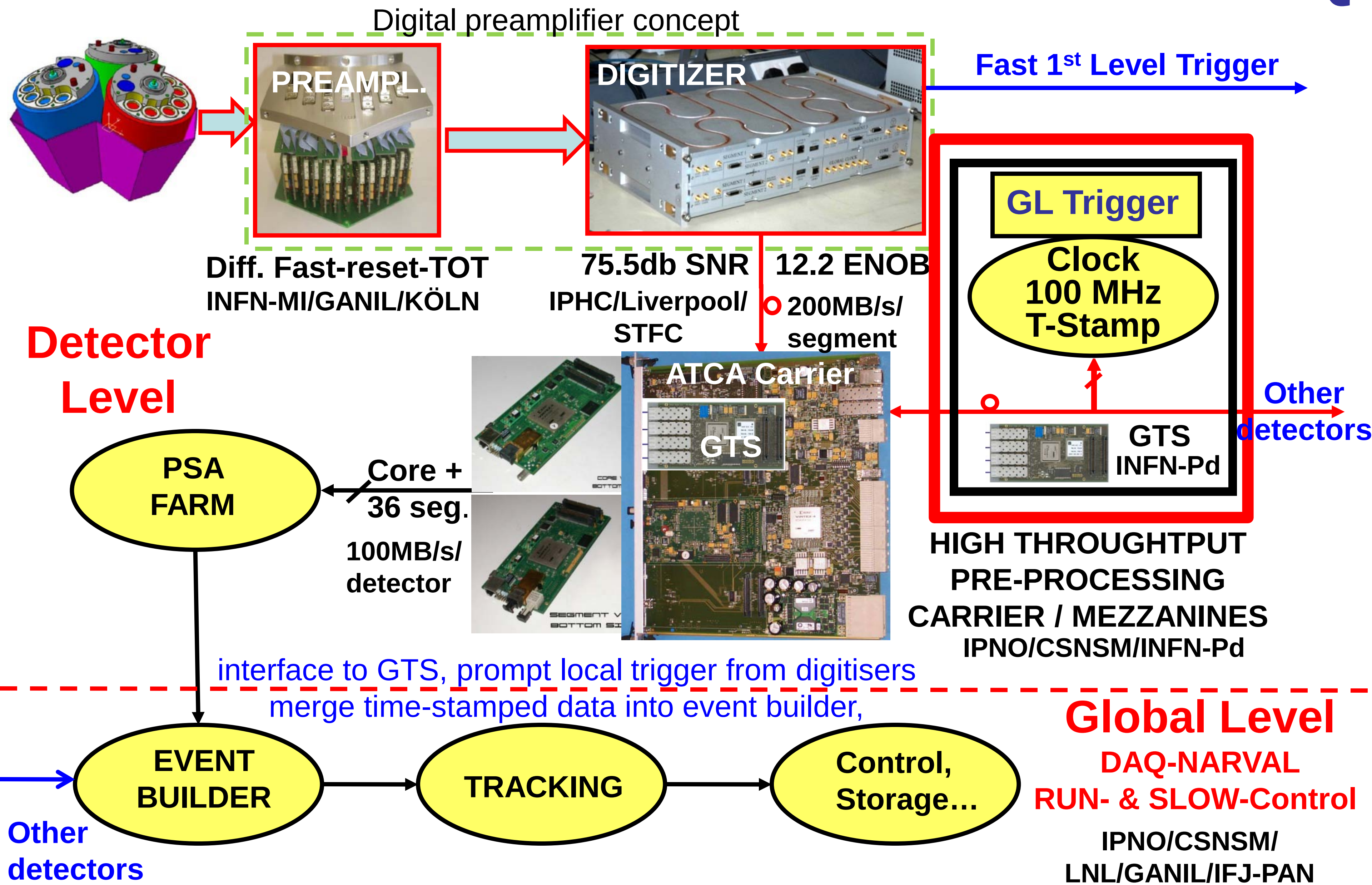
Coupling to complementary detectors for added selectivity



The AGATA sub array – PRISMA setup installed at LNL



AGATA Structure of Electronics and DAQ



GTS: Synergy with EXOGAM2, NEDA, TRACE, etc…

EXOGAM2

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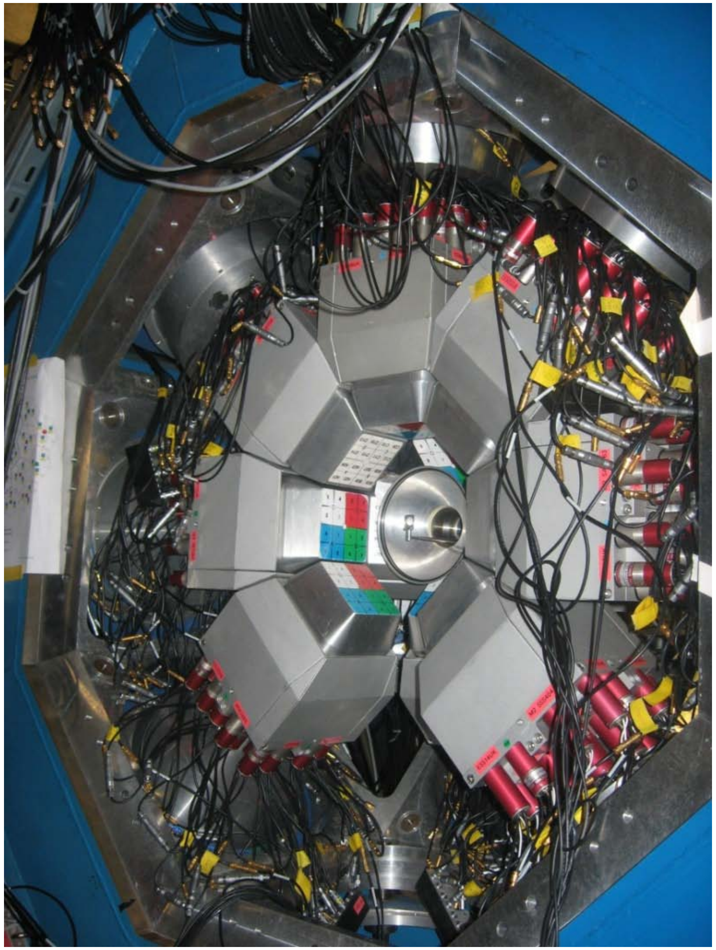


Spokesperson: G. de France
GANIL

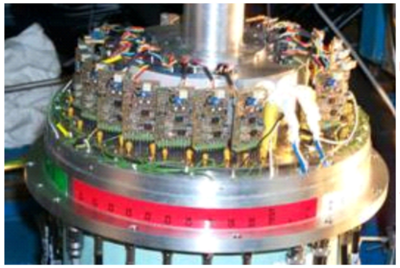
Upgrade of the compact array EXOGAM (FP7 SPIRAL2 preparatory phase).

- Upgrade to digital electronics. New FEE and data processing →synergy with AGATA.
- Digital electronics and high counting rate capability by digital pulse processing.
  - -Capability to stand high background counting rates from RIBs.and high intensity stable beams
- Very efficient with reactions providing limited angular momentum
- Foreseen:
  - Use of KALMAN processing for higher counting rates ~100kHz/crystal.
  - Under study the use of PSA to improve performance

EXOGAM2 general architecture

Preamplifiers

16 clovers
=
64 crystals



7 analog signals per crystal
(ICR < 100kHz per crystal)

One test per crystal

Differential stages
and
test pulse generator

Connexion
box

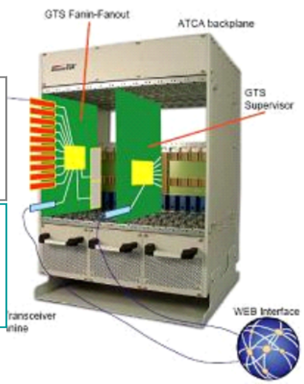
64 crystals
=>
64 boxes

7 differential
analog links
per NIM board

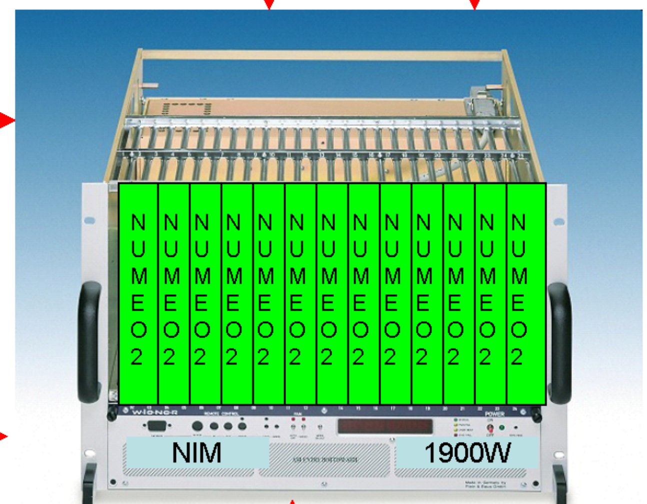
Control
link

Global Trigger
and
Synchronization

1 GTS supervisor
and
16 GTS mezzanines



1 optical link per NIM board



Digitizing,
Processing
and
Dating

1 crystal
Per
NIM board
=>
64 NIM
boards

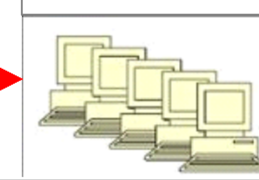
KALMAN
processing

1 optical link per NIM board (< 2 Gb/s)

1 link
per NIM board
(6 MB/s per crystal)

DAQ

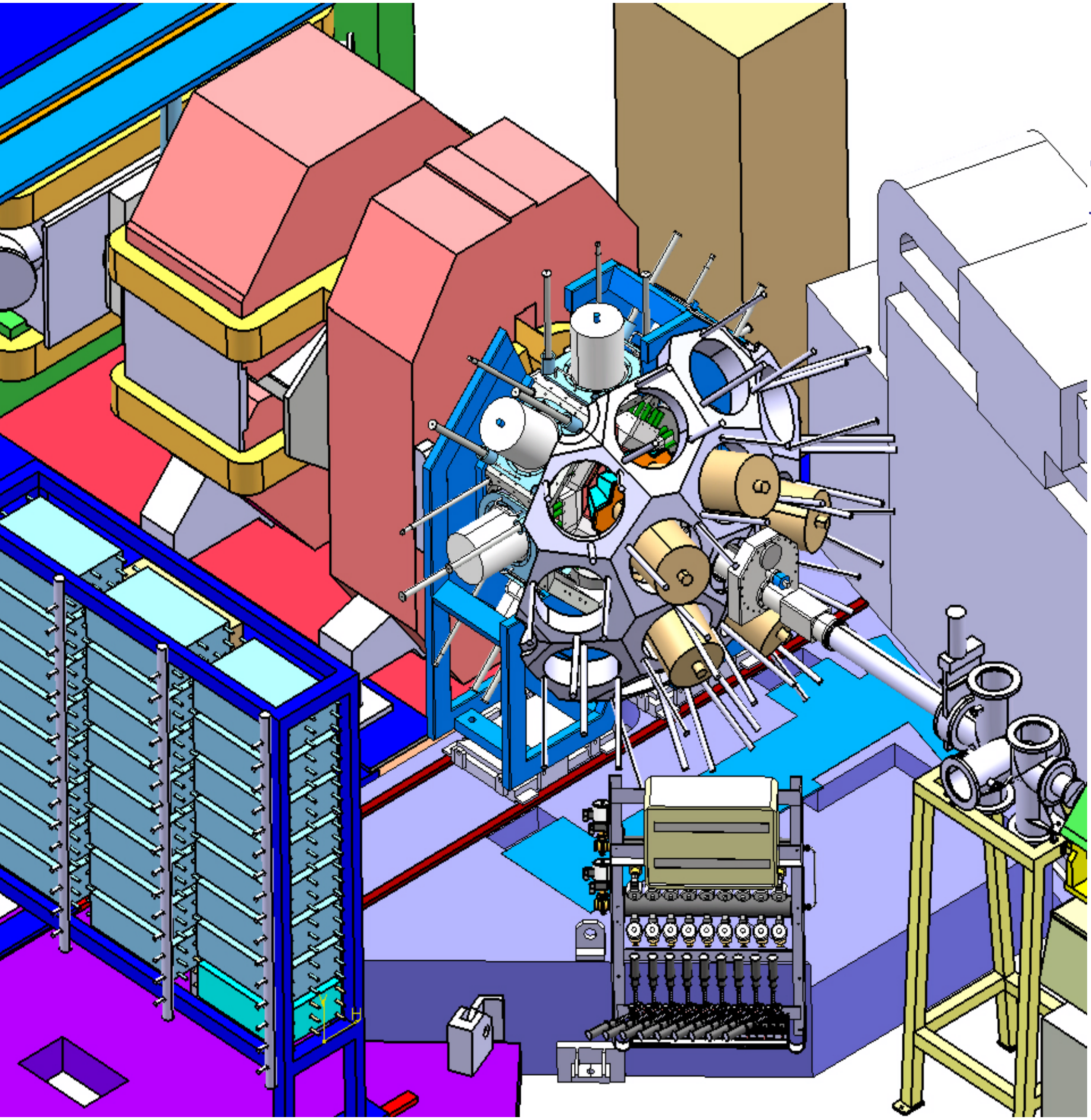
Ethernet Switch



Synergy with AGATA in GTS

Responsible: M. Tripon GANIL

AGATA at GANIL

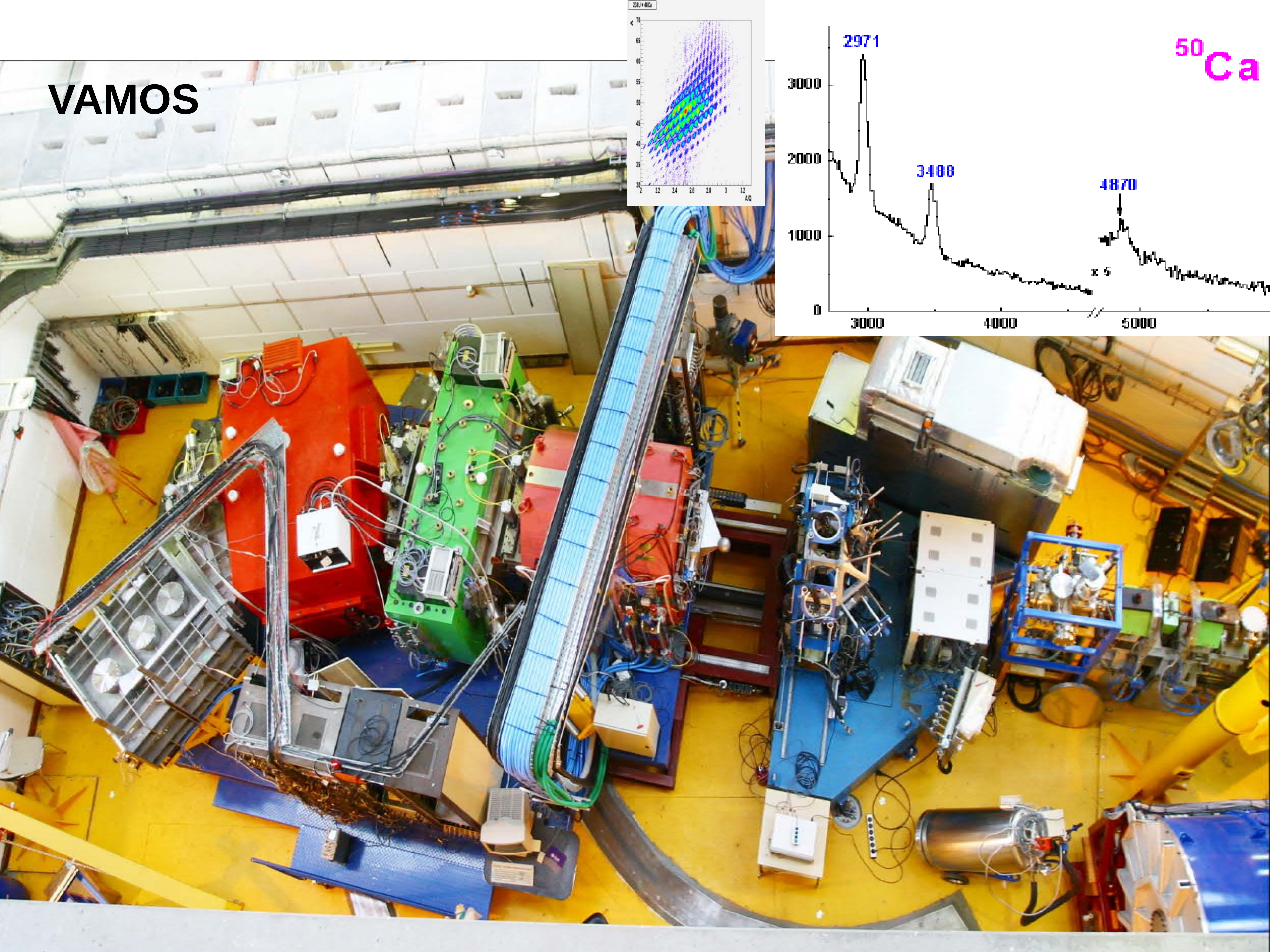


2013/14 :
up to 15 triple clusters at VAMOS

Stable ions (C-U) @ 5-100A.MeV
- Deep-inelastic & fission products

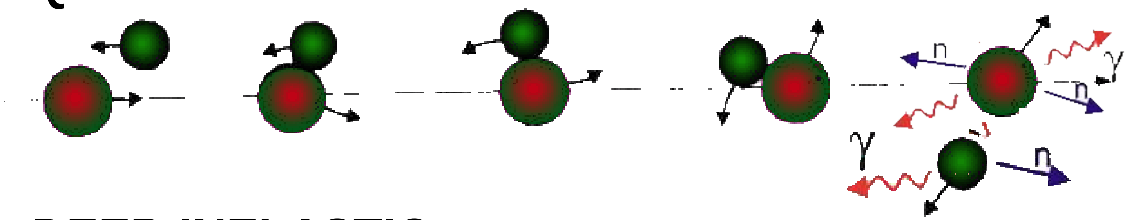
SPIRAL2 RIBs: 3-20A.MeV
- Coulomb & inelastic excitation, transfer reactions, fusion-evaporation

VAMOS

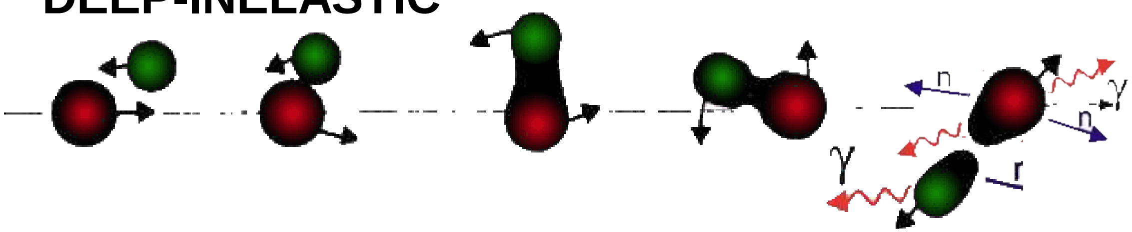


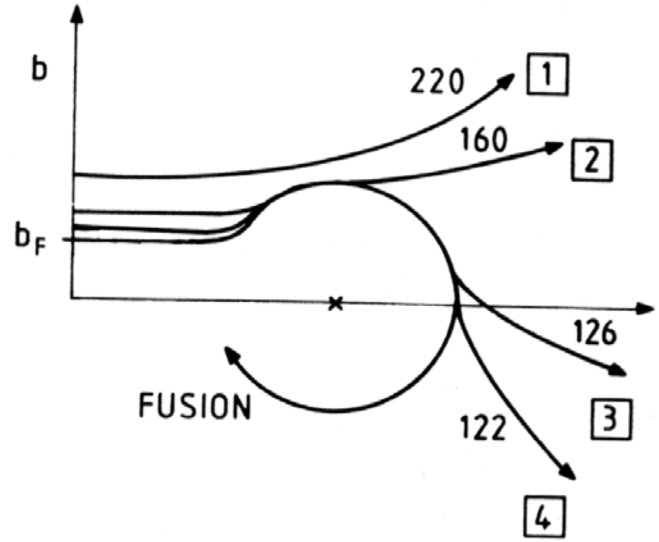
GRAZING and DIC REACTIONS

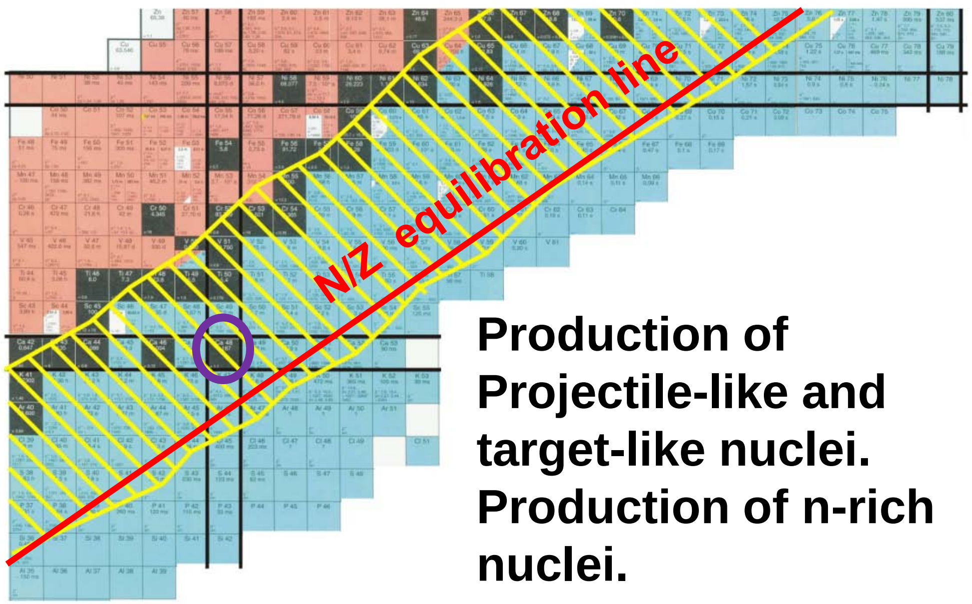
QUASI-ELASTIC



DEEP-INELASTIC

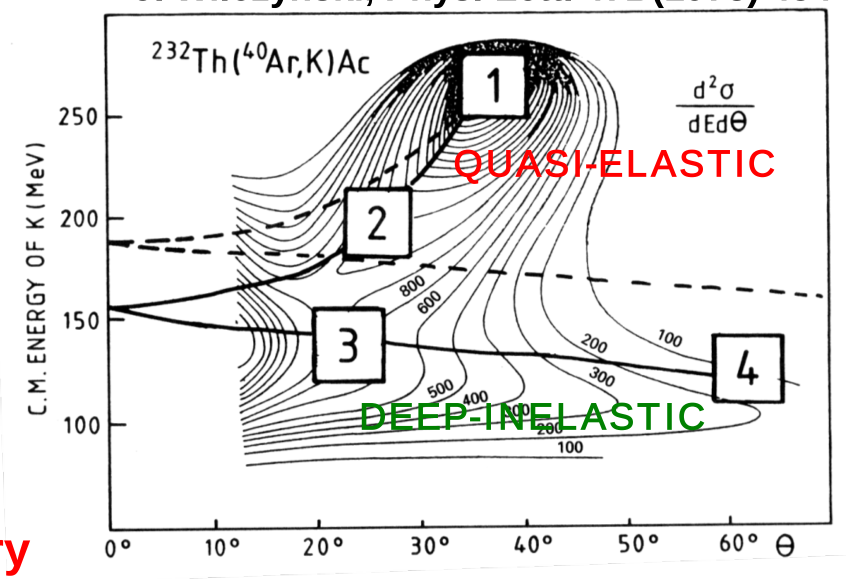






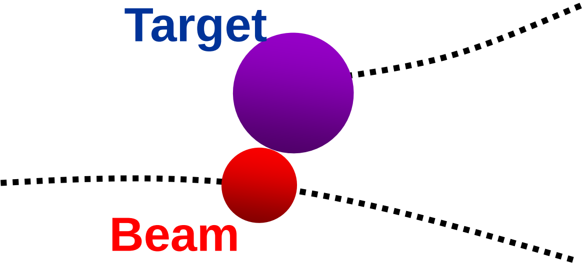
Production of Projectile-like and target-like nuclei. Production of n-rich nuclei.

J. Wilczynski, Phys. Lett. 47B(1973) 484



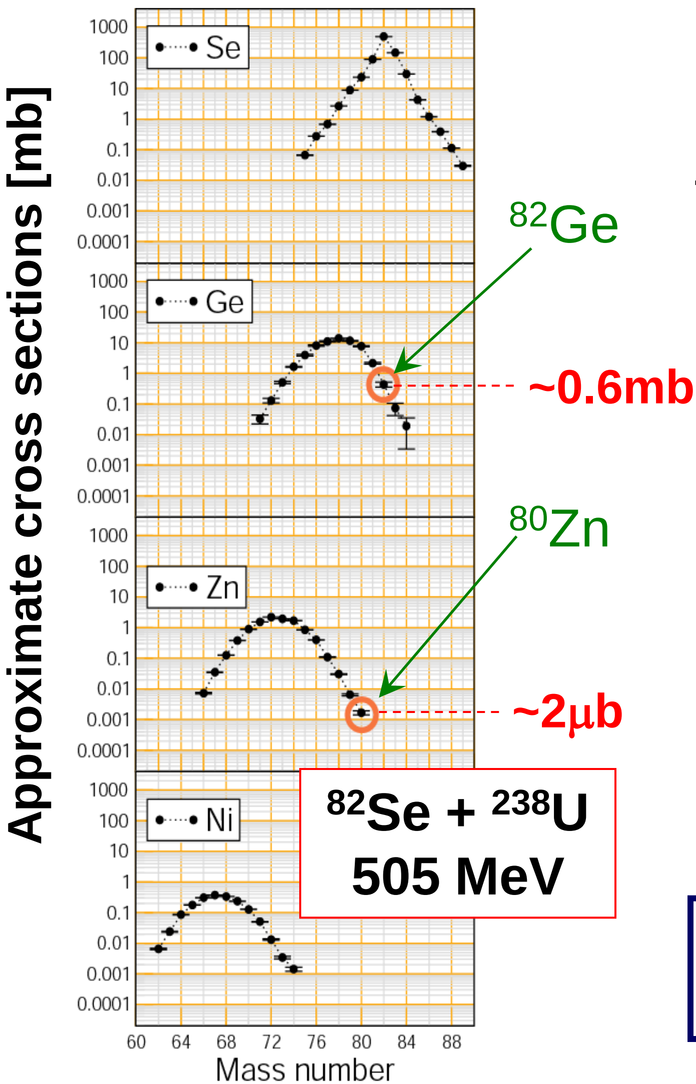
Identification of products with complementary detectors or by γ-spectroscopy of the partners is required

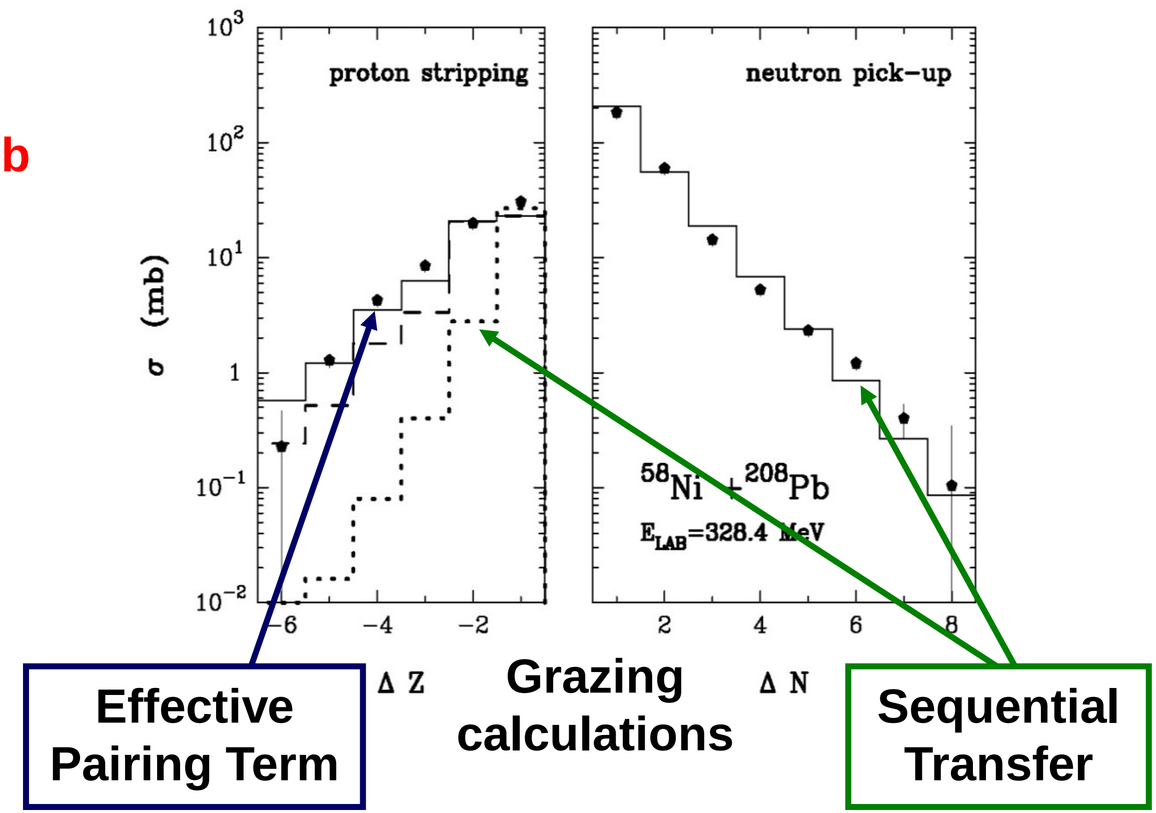
Grazing reactions transferring several nucleons, a tool to study neutron-rich nuclei



Deep-inelastic reactions used since thick target pioneering work of R.Broda et al. (PLB 251 (90) 245)

Use of Multinucleon-transfer at the grazing angle triggered by the LNL reaction mechanism group.



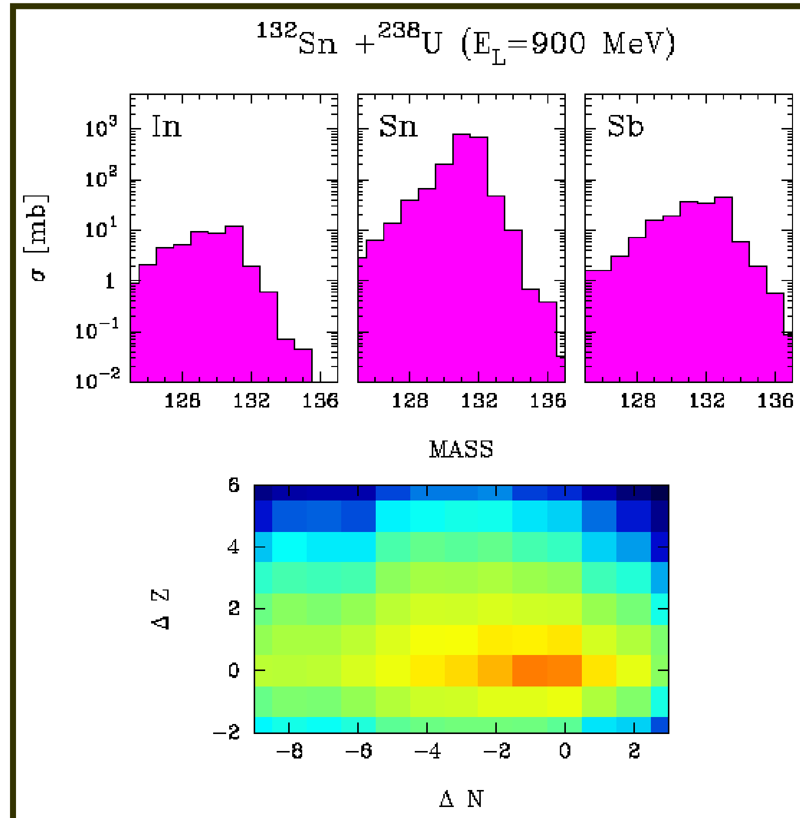


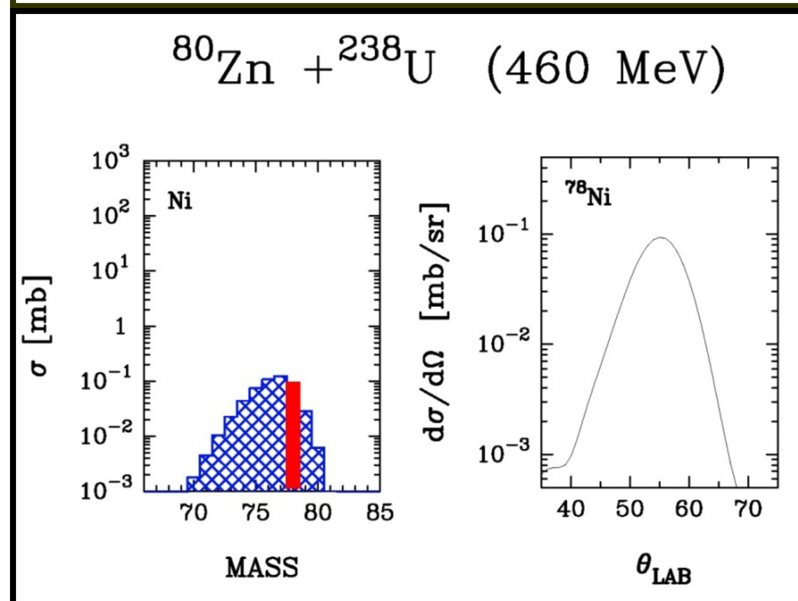
L.Corradi et al., Phys.Rev.C59 (99)261, Theory: G.Pollarolo

Intensities from n-induced fission

Isotope	Half life		E_{nom} /A·MeV	$I(E_{nom})$ /pps	E_{min} /A·MeV	$I(E_{min})$ /pps	E_{max} /A·MeV	$I(E_{max})$ /pps
79Zn	995	ms	6.2	2.1E+04	1.5	2.1E+04	12.3	2.0E+03
80Zn	545	ms	6.0	6.2E+03	1.5	6.4E+03	12.0	6.1E+02
86Kr	stbl		7.1	5.8E+08	1.8	5.7E+08	14.4	5.8E+07
87Kr	76.3	m	6.9	5.9E+08	1.7	5.9E+08	14.1	5.9E+07
88Kr	2.84	h	6.8	7.0E+08	1.7	7.0E+08	13.8	7.0E+07
89Kr	3.15	m	6.6	7.5E+08	1.6	7.5E+08	13.5	7.5E+07
90Kr	32.32	s	6.5	6.4E+08	1.6	6.4E+08	13.2	6.4E+07
91Kr	8.57	s	6.3	5.2E+08	1.6	5.2E+08	12.9	5.2E+07
92Kr	1.84	s	6.2	2.6E+08	1.5	2.7E+08	12.6	2.6E+07
93Kr	1.286	s	6.1	8.8E+07	1.5	8.9E+07	12.3	8.6E+06
94Kr	210	ms	5.9	1.2E+07	1.5	1.3E+07	12.1	1.1E+06
95Kr	114	ms	5.8	1.1E+06	1.4	1.3E+06	11.8	1.0E+05
96Kr	80	ms	5.7	1.1E+05	1.4	1.2E+05	11.6	9.2E+03
131Sn	56	s	5.1	8.2E+06	1.3	8.2E+06	9.7	8.2E+05
131Snm	58.4	s	5.1	3.0E+07	1.3	3.0E+07	9.7	3.0E+06
132Sn	39.7	s	5.0	1.8E+07	1.2	1.8E+07	9.6	1.8E+06
133Sn	1.45	s	4.9	6.3E+05	1.2	6.4E+05	9.4	6.2E+04
134Sn	1.12	s	4.8	5.9E+04	1.2	6.0E+04	9.3	5.8E+03
136Te	17.63	s	5.2	1.6E+07	1.3	1.6E+07	9.8	1.6E+06
135Xe	9.14	h	5.3	1.6E+09	1.3	1.6E+09	9.9	1.6E+08
35Xem	15.29	m	5.3	2.7E+08	1.3	2.7E+08	9.9	2.7E+07
136Xe	stbl		5.2	1.9E+09	1.3	1.9E+09	9.8	2.0E+08
137Xe	3.818	m	5.1	1.4E+09	1.3	1.4E+09	9.6	1.4E+08
138Xe	14.08	m	5.1	1.2E+09	1.3	1.2E+09	9.5	1.2E+08
139Xe	39.68	s	5.0	8.2E+08	1.2	8.2E+08	9.3	8.2E+07
140Xe	13.6	s	4.9	4.9E+08	1.2	4.9E+08	9.2	4.9E+07
141Xe	1.73	s	4.9	1.0E+08	1.2	1.0E+08	9.1	1.0E+07
142Xe	1.22	s	4.8	2.9E+07	1.2	2.9E+07	9.0	2.8E+06

Attention: early productions more compatible with direct reactions and Coulomb excitation





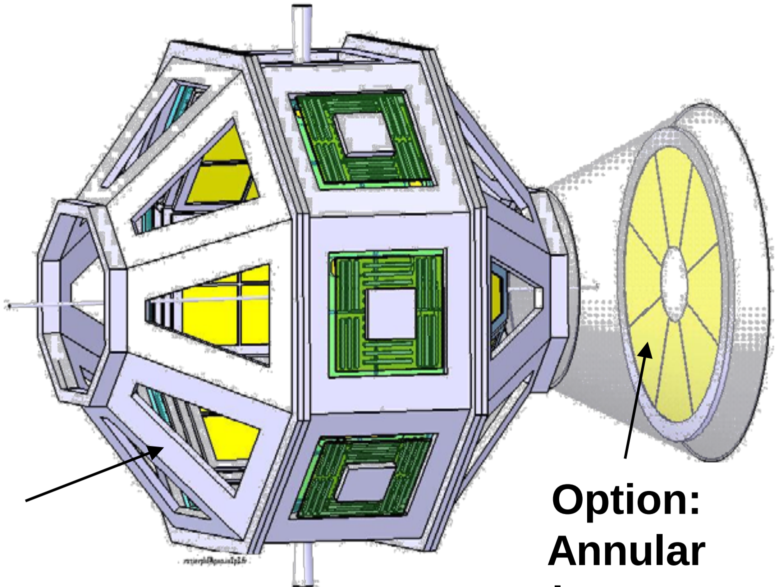
GASPARD *Preliminary design*

GAmma SPectroscopy and PArticle Detection

"GASPHYDE" design - **fit inside AGATA**

Towards a common project with HYDE

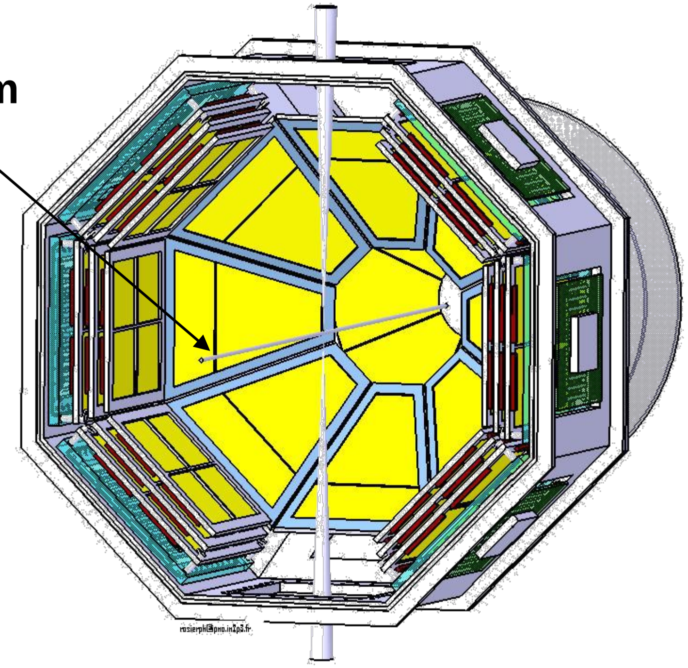
Basis: DSSD's, 4" technology



Trapezoidal shapes for endcaps

Option: Annular detectors

Beam



- **Improved PID for light particle**
  - ✓ **PSA with DSSD's**
- **Integrate special targets**
  - ✓ **Pure&windowless H/D (the CHYMENE project)**
  - ✓ **He cooled gas**

ELECTRONICS:

~ 15000 channels (Digital)

- **Integration and effects on γ-ray now under study (simulations)**
  Preamps to be under vaccuum

Neutron Detector Array: NEDA

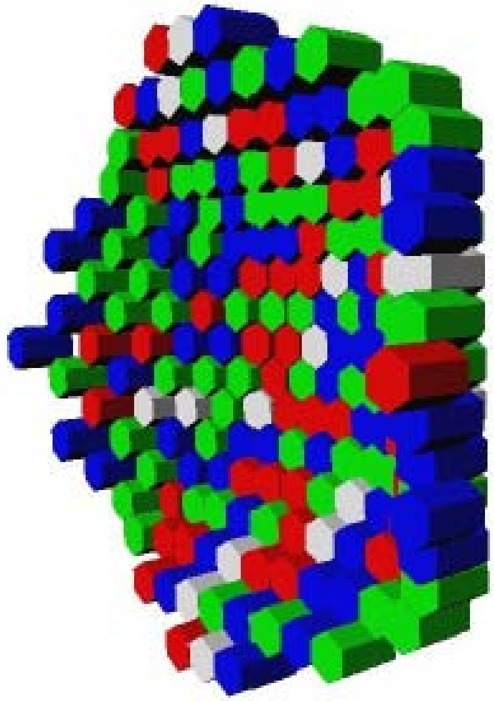
There are two possible main geometries, either spherical or planar.

•Optimize for efficiency (within the solid angle coverage)

•Minimizing the cross talk (interaction in more detectors) with Planar geometry:

-Flexibility – different arrangements of the detectors, e.g. zig-zag

-Different focal posistions (500cm, 1000cm, 2000cm)



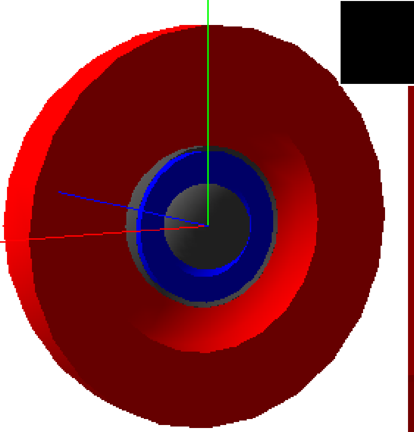
Step-spherical

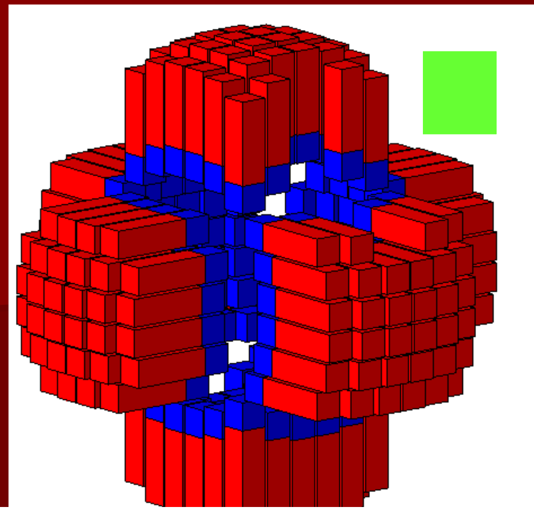
Spherical

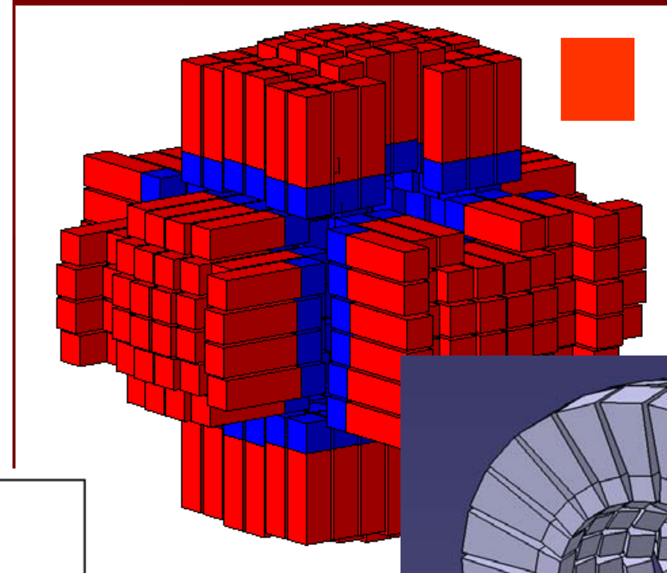
For N~Z studies needed as well a 4π light charged particle detector: DIAMANT (GANIL)

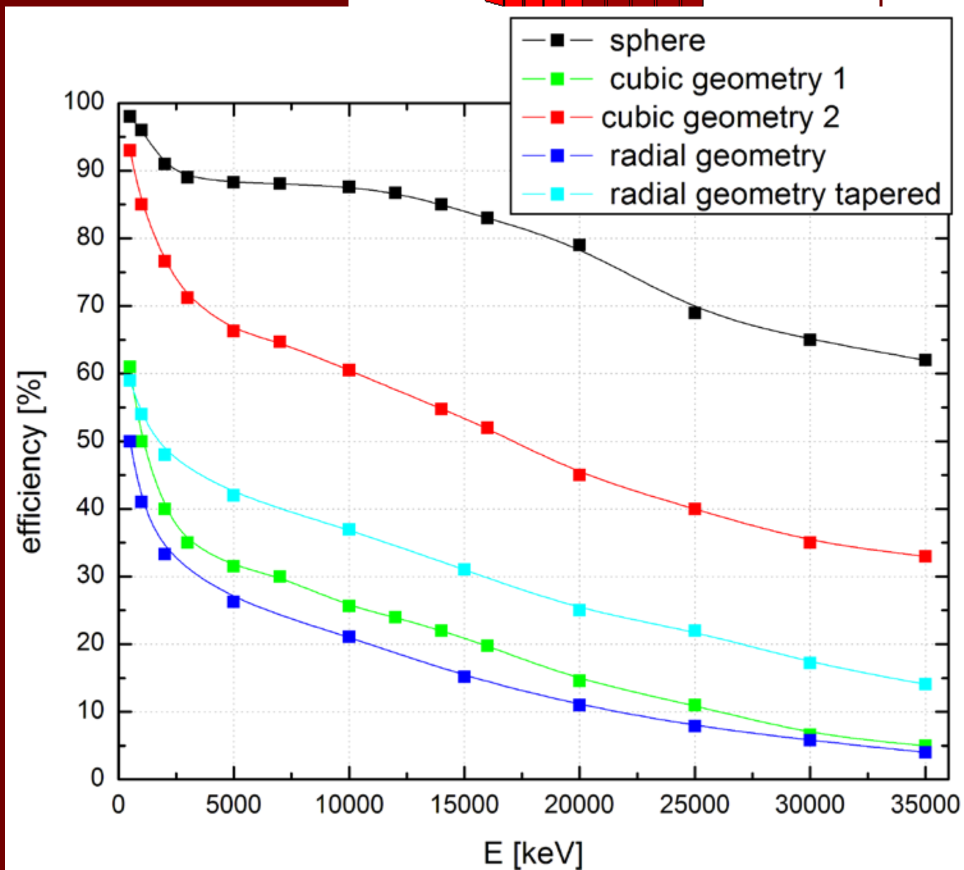
Spiral2

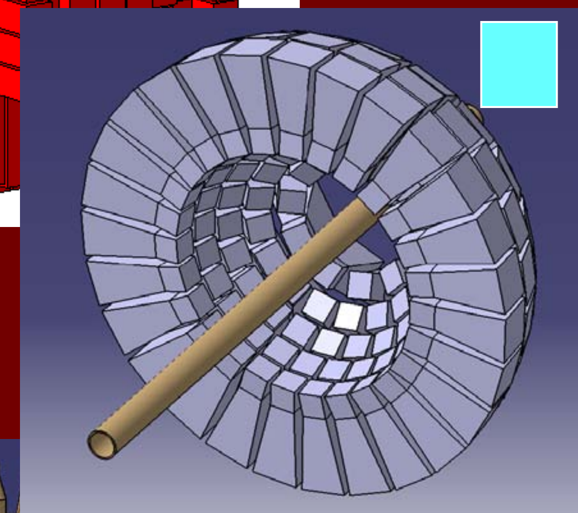
High Energy γ-ray detector array PARIS

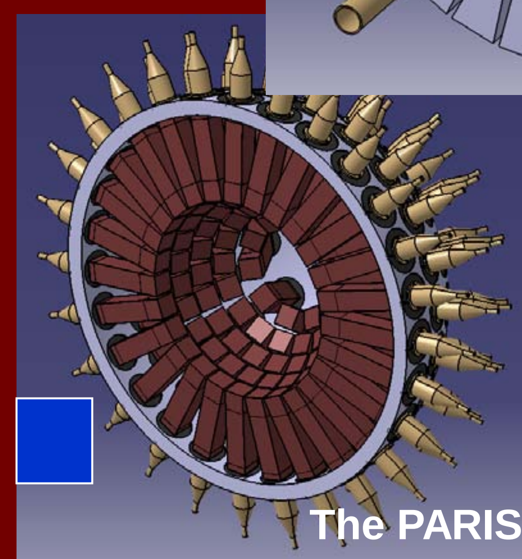












The PARIS Collaboration

Summary:

- High Resolution γ-Spectroscopy is a essential technique to study the nuclear structure in the new generation RIB facilities.

- Several topics in n-rich as well as p-rich nuclei and on collective excitations are in te physics program of HRGS for SPIRAL2.

- A large effort is being done to build and upgrade the instrumentations to cope with the challenging use of RIB's.

- Experimental LoI are now required: they are important to define the beam-development program at SPIRAL2 day 1

GANIL

GRAND ACCELERATEUR NATIONAL D'IONS LOURDS

LABORATOIRE COMMUN DSM/CEA-IN2P3/CNRS

Spiral2