The AGATA Campaign at GANIL

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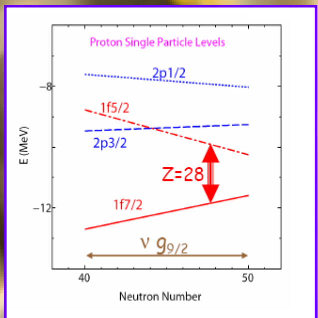
University of Padova and INFN

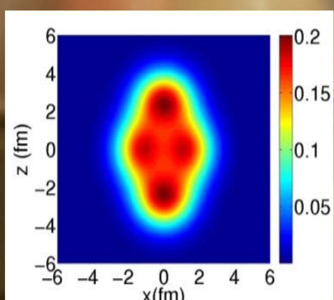
NUSTAR

Annual Meeting 2019

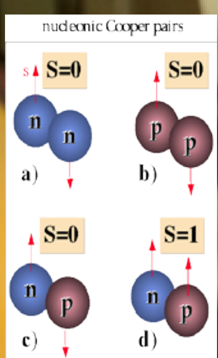
Shell evolution far from stability

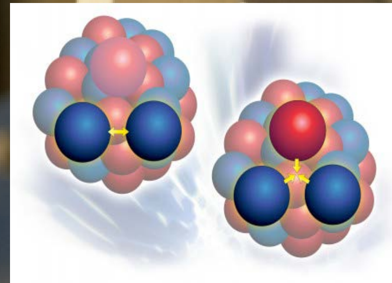


clusterization



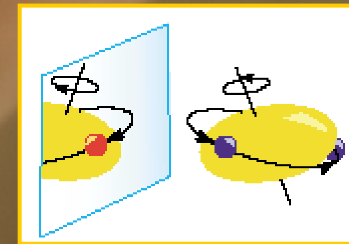
p-n pairing





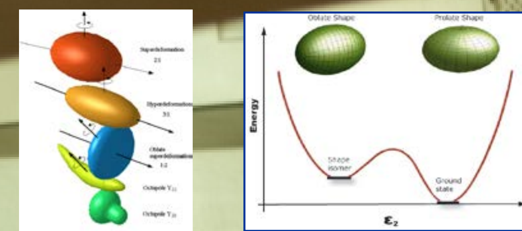
Three-body forces

Isospin symmetry breaking



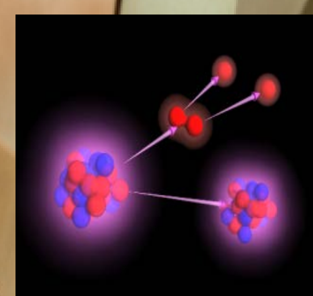
High-resolution gamma-ray spectroscopy is an optimum tool to study nuclear structure properties and investigate how they emerge from fundamental interactions.

Nuclear shapes and coexistence



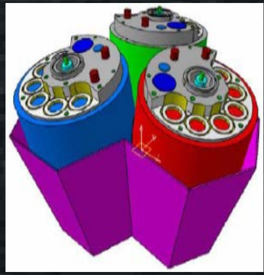
Super heavy elements

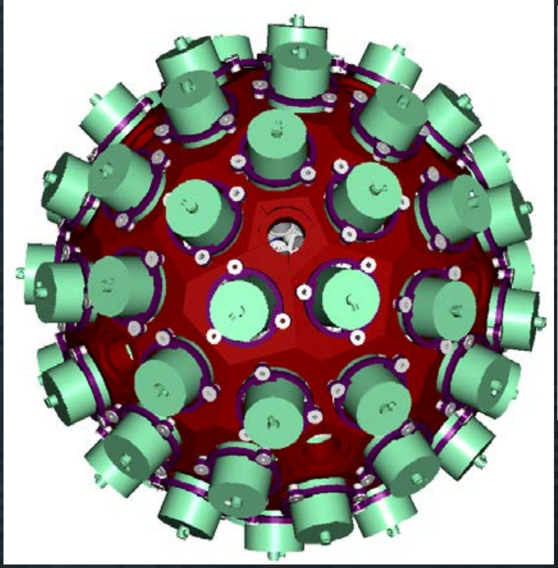
Nuclear Astrophysics



Coupling to the continuum

The AGATA project

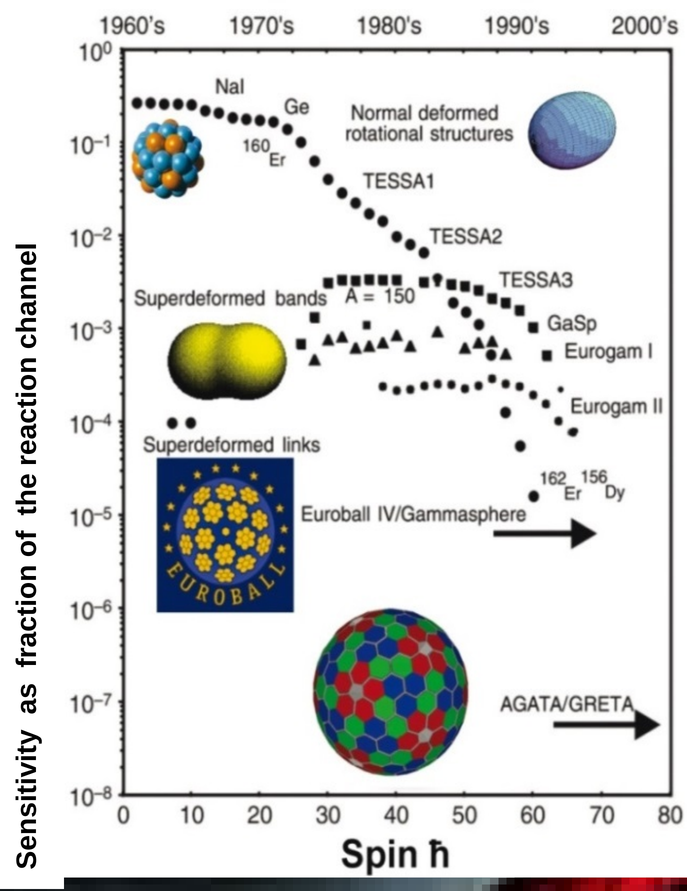




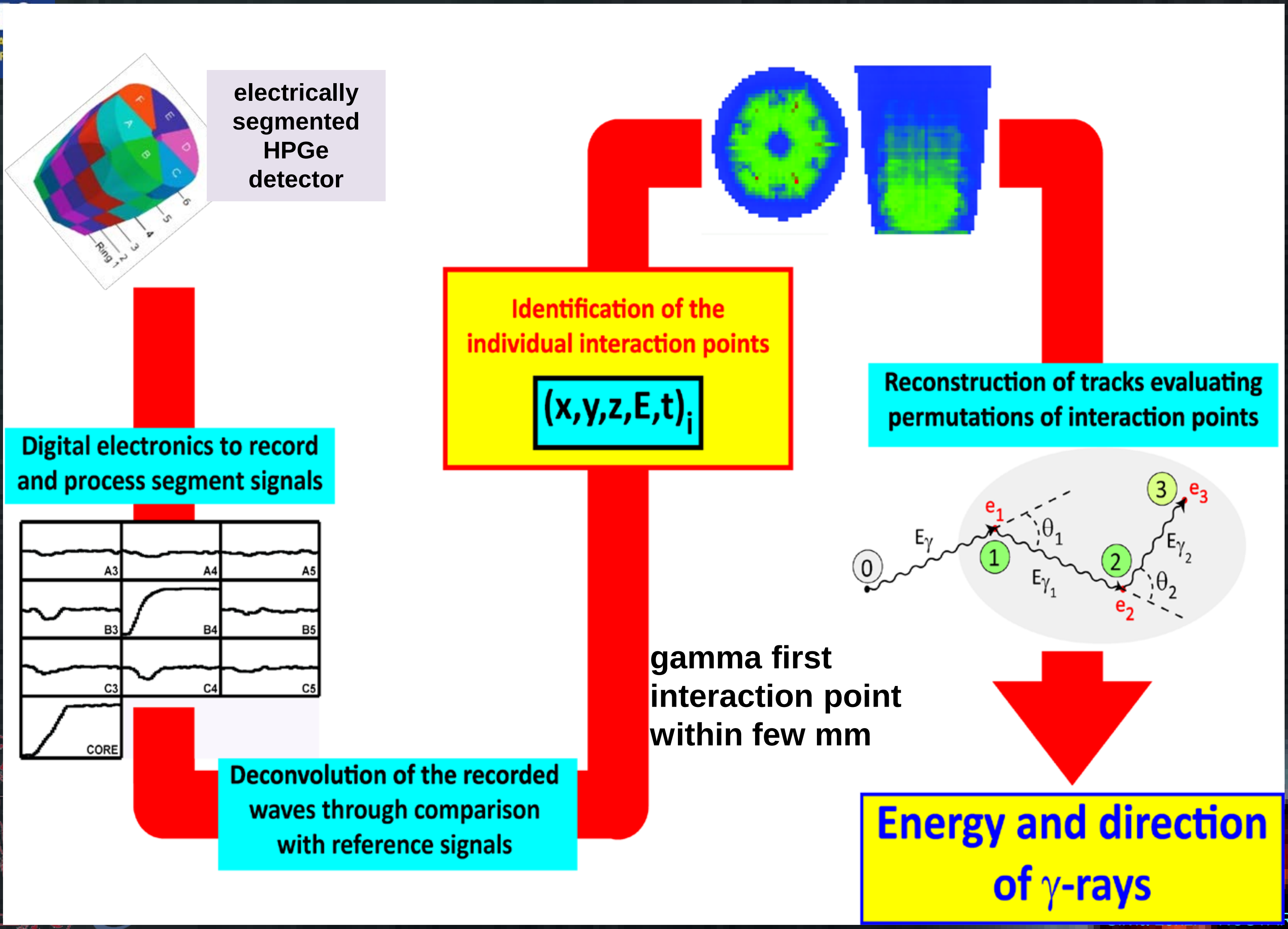
180 (60 triple-clusters) 36-fold segmented crystals
Amount of germanium: 362 kg
Solid angle coverage: 82 %
Singles rate >50 kHz
Efficiency: 43% (M_g=1) , 28% (M_g=30)
Peak/Total: 58% (M_g=1), 49% (M_g=30)
Angular Resolution: ~1º

<u>Combination of:</u>

- ❑ segmented detector
- ❑ pulse shape analysis
- ❑ tracking the γ-ray
- ❑ digital electronics



The AGATA concept



AGATA Physics Campaigns

Demonstration phase at **LNL** and Physics Campaign

Coupled to the magnetic spectrometer PRISMA

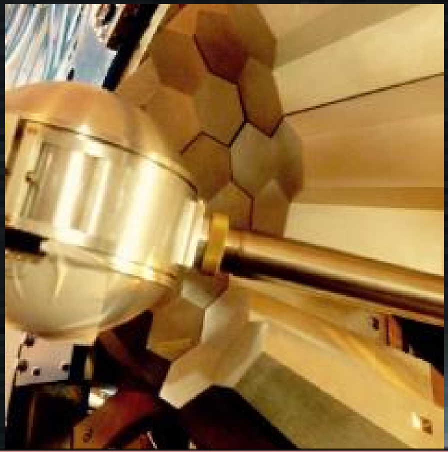
Construction phase and Physics Campaigns

GSI

Fast radioactive beams coupled to Lycca

GANIL

Coupled to VAMOS, NEDA/N-Wall, MUGAST



LNL 2010-2011 → **GSI 2012-2014** → **GANIL 2015-2020**

Beams and setups

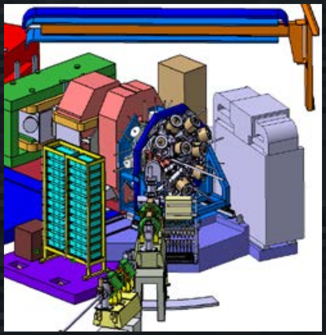
GANIL beams

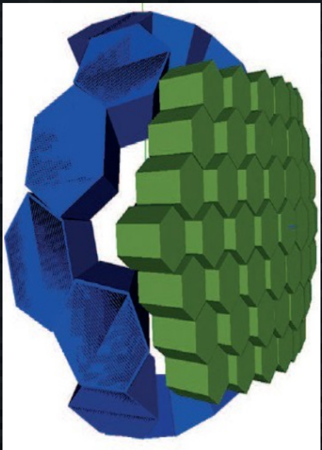
High intensity stable beams up to ^{238}U

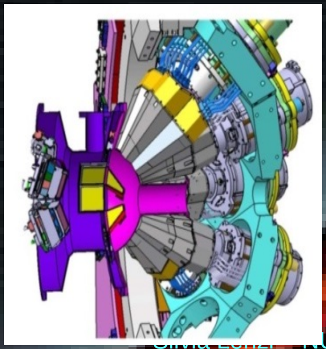
- Multi-nucleon transfer
- Fusion-fission
- Fusion-evaporation

Radioactive SPIRAL1 beams

- Coulomb excitation
- Transfer reactions


VAMOS


NEDA


MUGAST

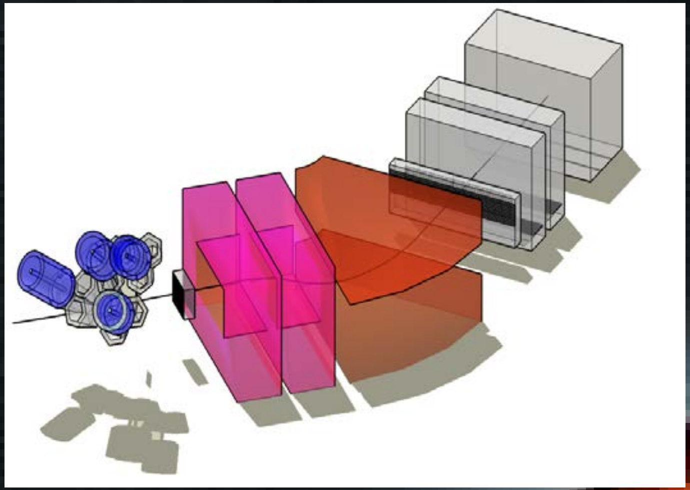
AGATA Physics Campaign in GANIL

The Campaign has been organized in a bottom-up approach following calls for LoI, discussed in dedicated annual collaboration workshops.

Four main setups (campaigns) have been identified:

- VAMOS (vacuum)
- NEDA-N-Wall + DIAMANT
- MUGAST (SPIRAL1 beams)
- VAMOS (gas-filled)

First Campaign AGATA+VAMOS

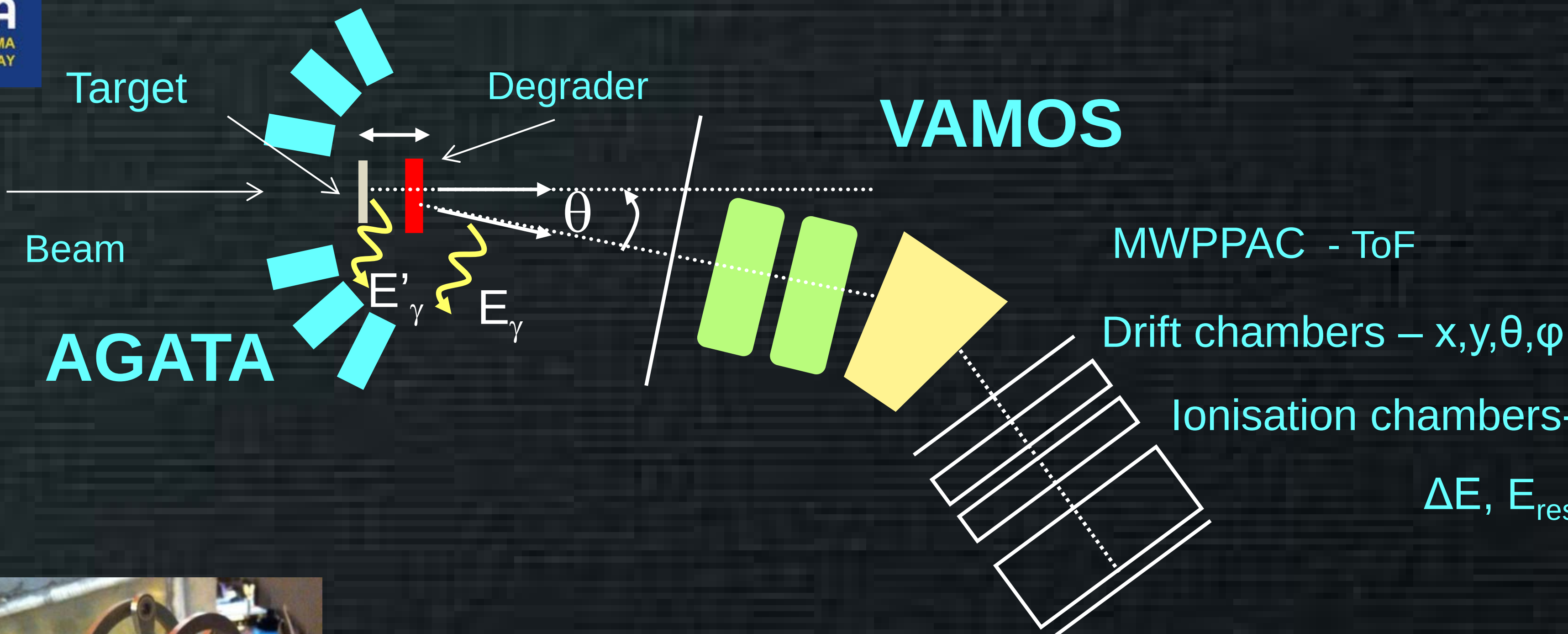


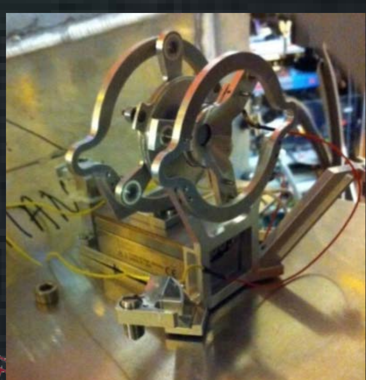
AGATA
ADVANCED GAMMA TRACKING ARRAY

Campaign 2015-2016
AGATA+VAMOS

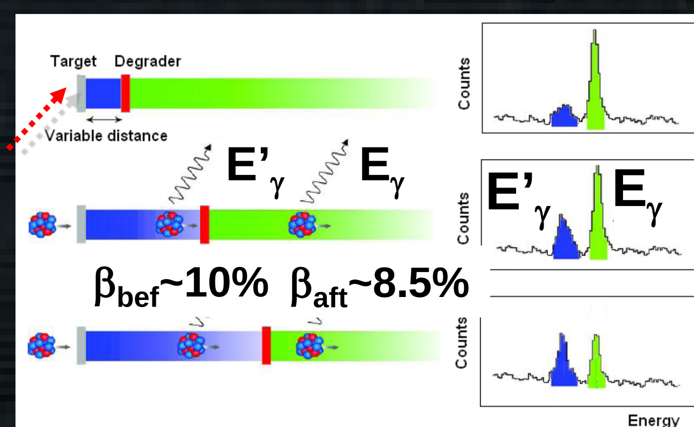
INFN
Istituto Nazionale
di Fisica Nucleare

Experimental setup 2015-2016





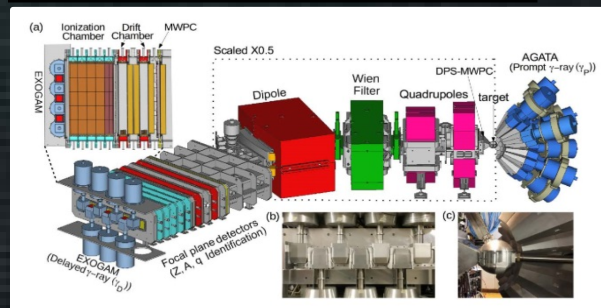
Plunger for lifetime measurements



Physics campaign 2015-2016

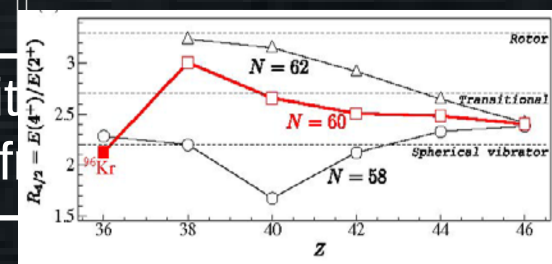
AGATA
ADVANCED GAMMA TRACKING ARRAY

Y.H.Kim et al., EPJA 53, 162 (2017)



single-particle and correlations around ^{208}Pb

Excit
in fission f

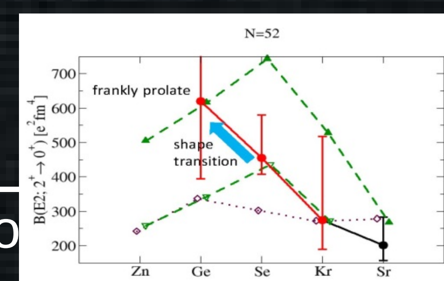


J. Dudouet et al.,PRL 118, 162501 (2017)

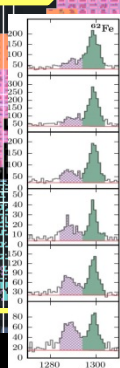
Single particle and collectivity approaching ^{100}Sn

Single-particle and correlations towards ^{78}Ni

Quadrupole collectivity south o



C.Delafosse et al., PRL 121, 192502 (2018)



es for nuclear astrophysics interest

M. Klintefjord et al., PRC 95, 024312 (2017)

Istituto Nazionale di Fisica Nucleare

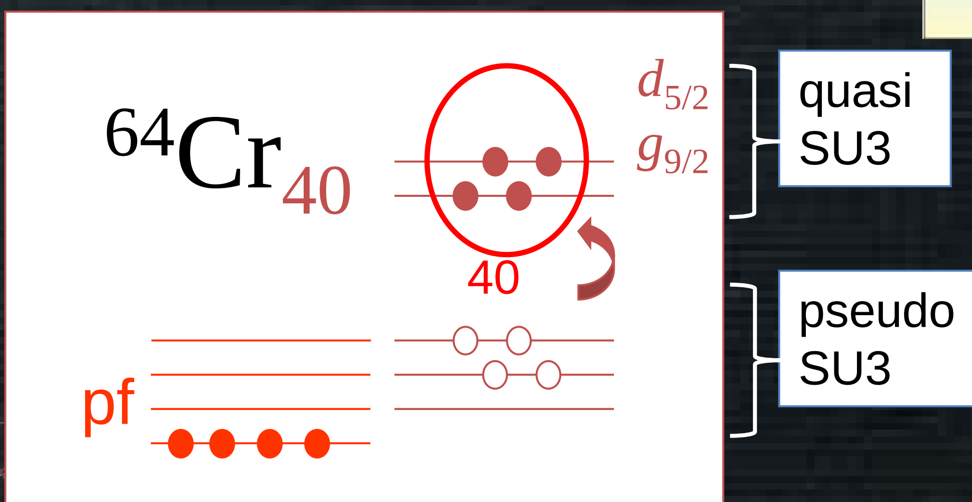
Shell evolution and Islands of Inversion

Some selected results

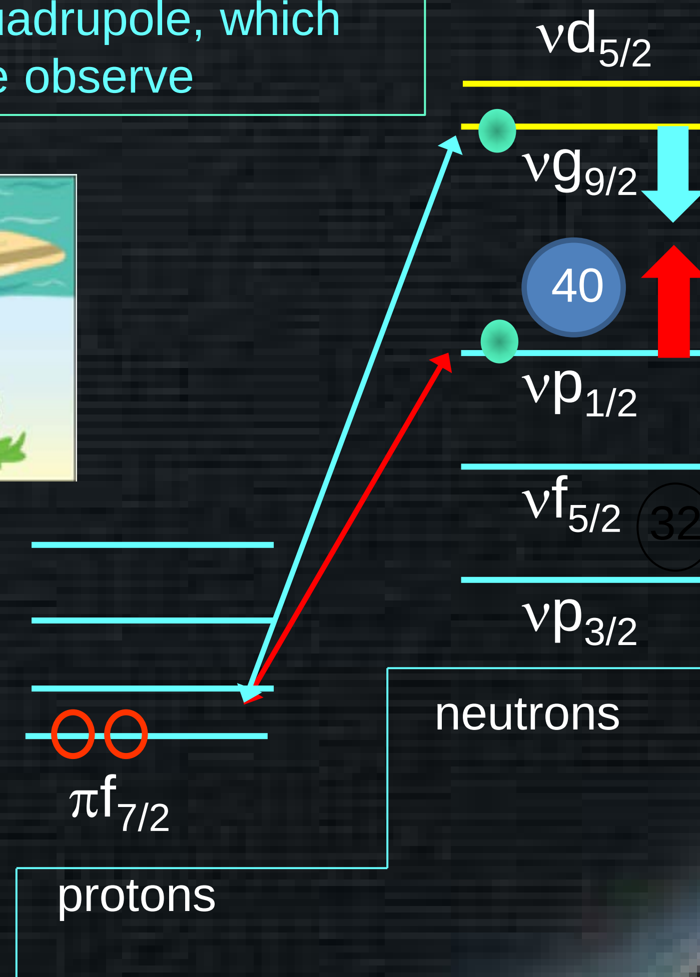
The Island of inversion at N=40

It is the interplay of the monopole terms of the interaction with multipole terms, like pairing and quadrupole, which determines the different phenomena we observe

This explains the development of the Islands of inversion at the “traditional” magic numbers



Zuker, et al., PRC 92, 024320 (2015)
Lenzi, Nowacki, Poves, Sieja (LNPS), PRC 82, 054301 (2010)



T. Otsuka et al., PRL 104, 012501 (2010)
N.A. Smirnova et al., PLB 686, 109 (2010)

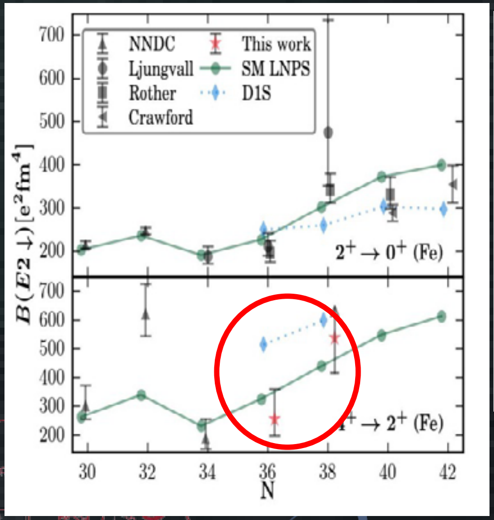
Mapping the Island of inversion at N=40

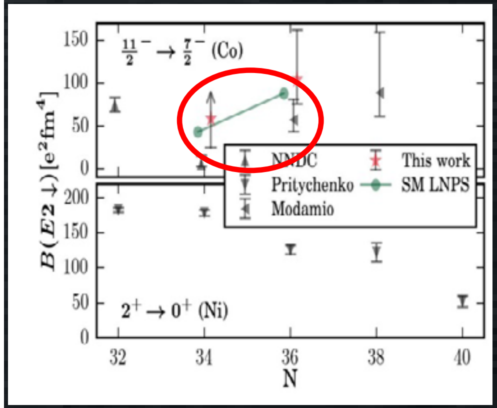
Spokespersons: J. Ljungvall and A. Görgen

Lifetime measurement to understand the development and the trend of deformation in the third island of inversion.

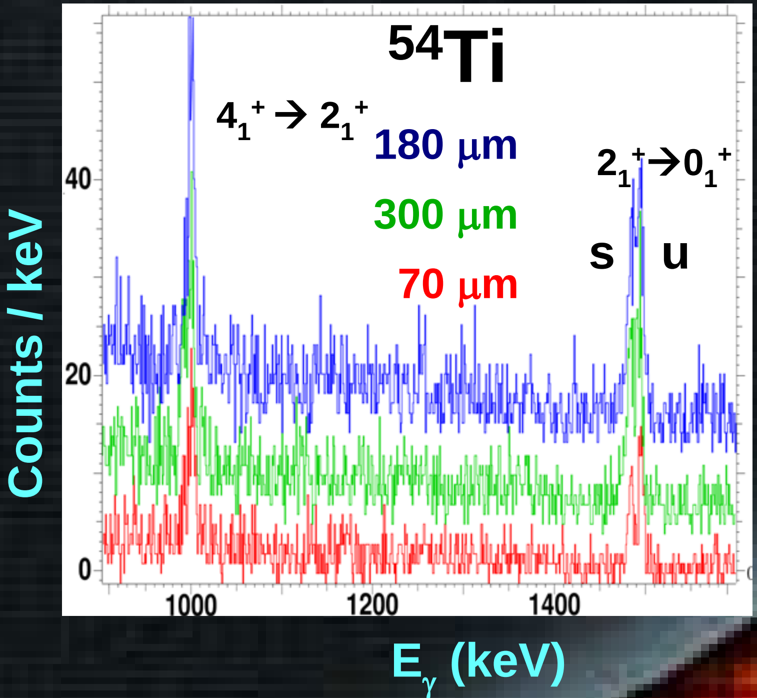
Spokesp: Ch. Fransen and A. Dewald

Lifetimes in ^{54}Ti and in neighbouring isotopes have been determined





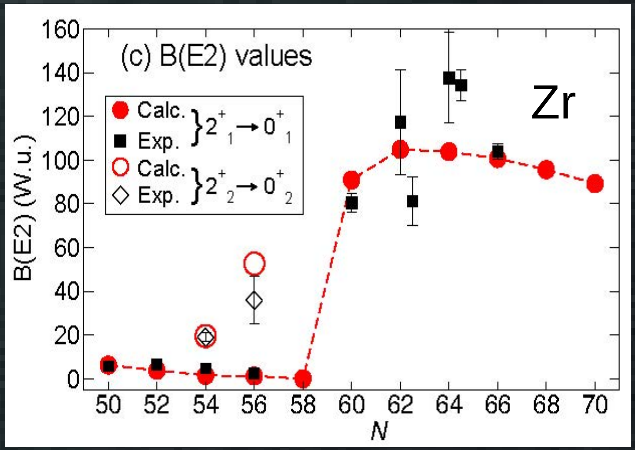
M. Klintefjord et al., PRC 95, 024312 (2017)



Courtesy of Ch. Fransen and A. Goldkuhle

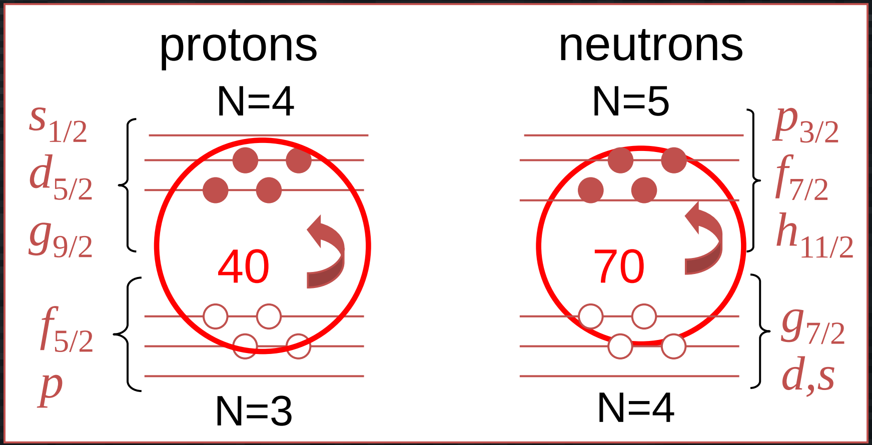
Island of deformation at Z~40, N~60

Sudden shape transition at N=60 in Zr isotopes



quasi SU3

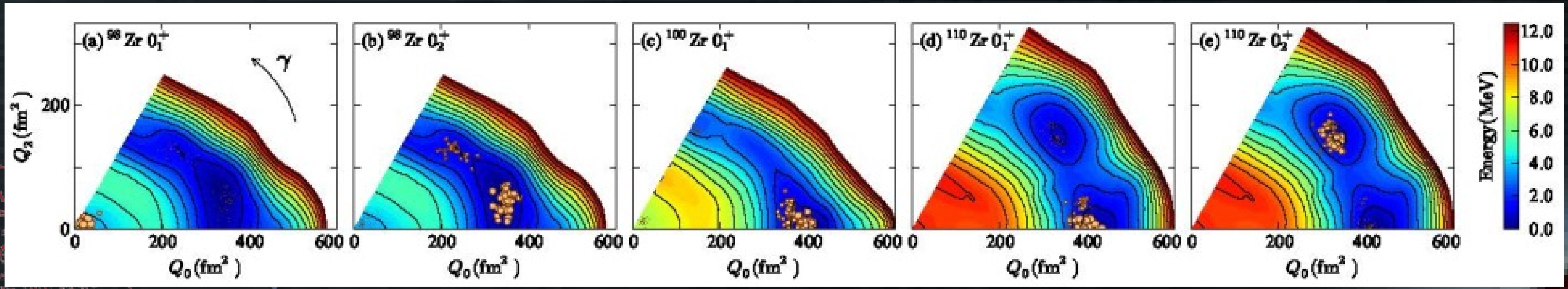
pseudo SU3



quasi SU3

pseudo SU3

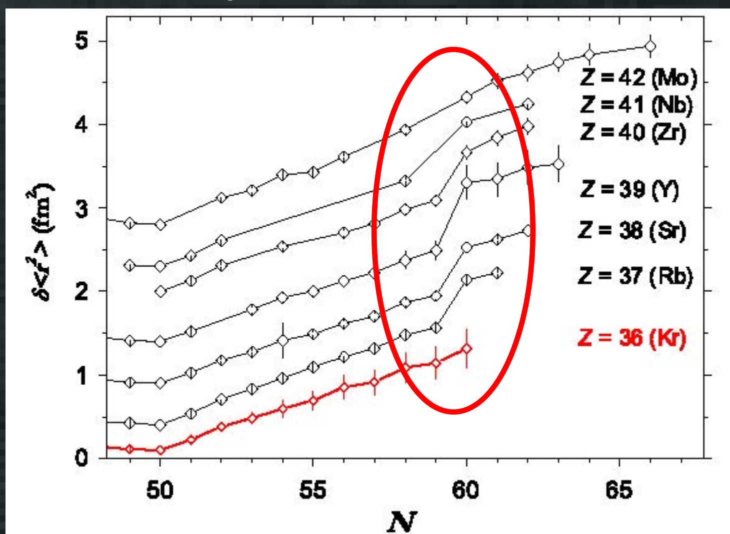
N=58 N=60 N=70



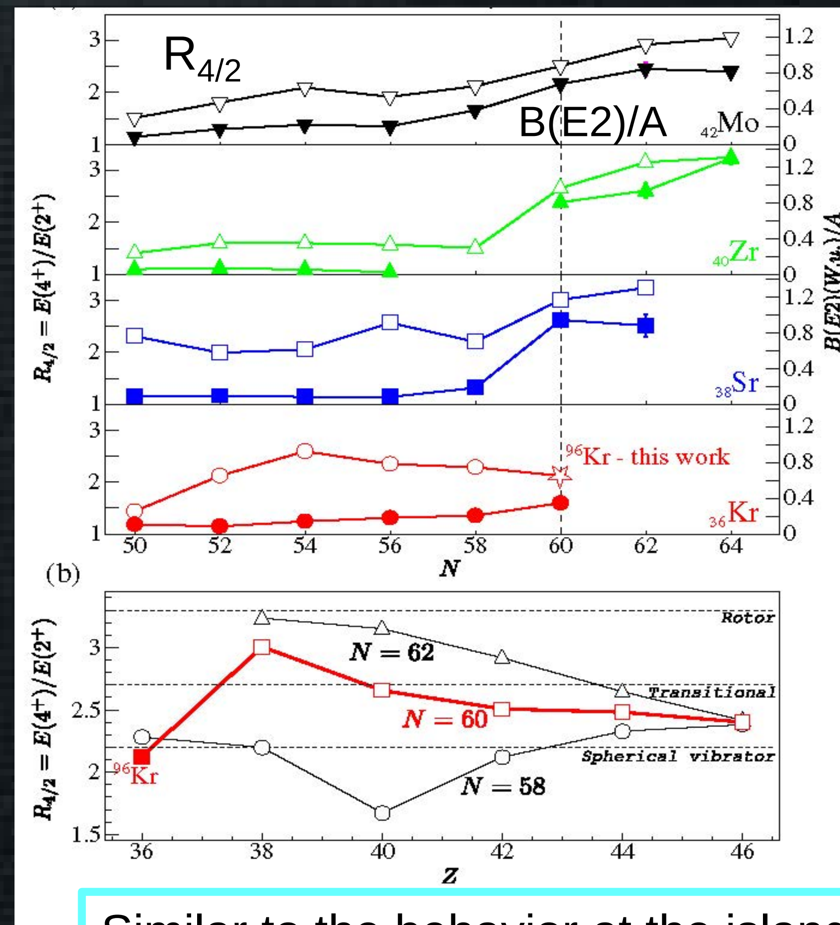
T. Togashi et al, Phys. Rev. Lett. 117, 172502 (2016)

Limits of the Island of deformation at Z~40, N=60

Isotopes shifts at N~60



S. Naimi *et al*., PRL 105, 032502 (2010)



Charge radii suggest that Kr (Z=36) lies outside the Island of deformation.

This has been recently confirmed:
J. Dudouet et al, PRL 118, 162501 (2017)

Similar to the behavior at the island of inversion at N=40. Large deformation starts at N=38 in Cr isotopes

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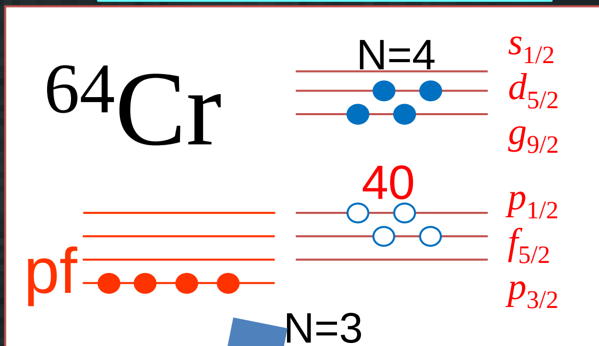
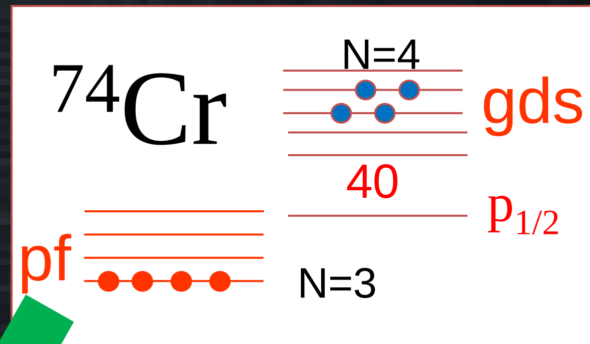
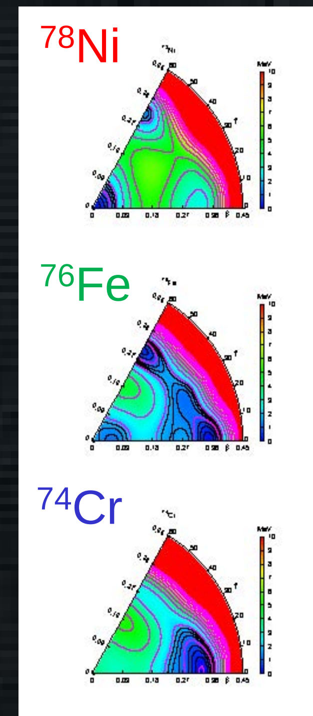
Extension of the Island of Inversion from N=40 to N=50

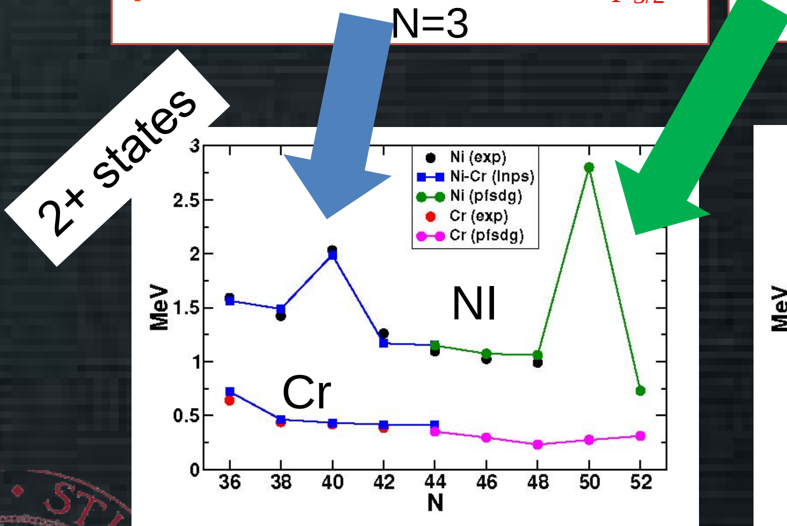
LNPS Model space

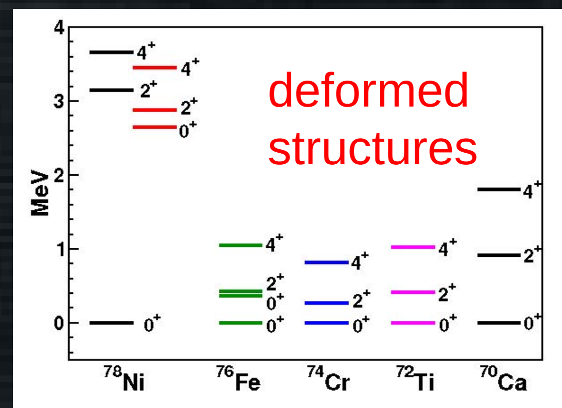


pf-sdg Model space







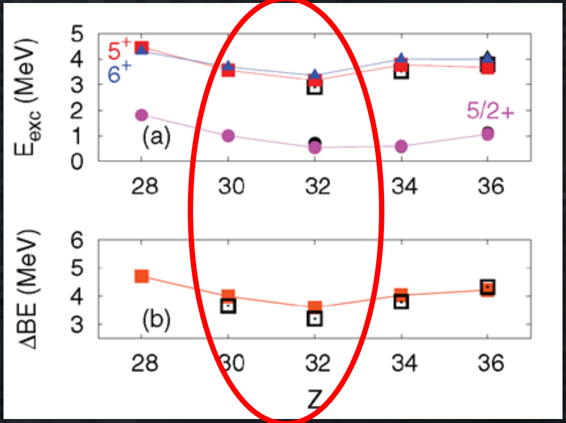


Shell model calculations by
F. Nowacki et al., Phys. Rev. Lett. 117, 272501 (2016)

Test of the N=50 gap

Spokespersons: G. Duchene and G. de Angelis

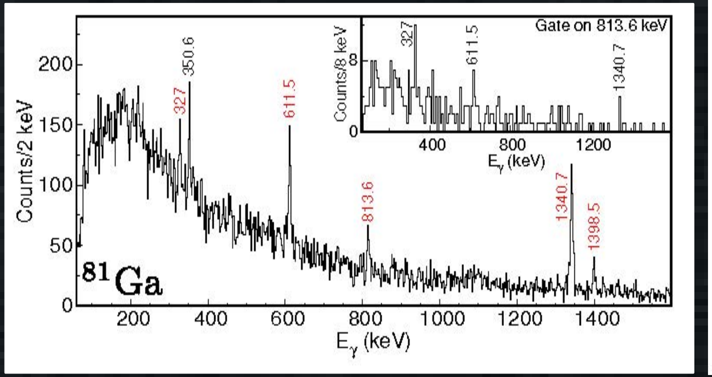
The quenching of the N=50 gap towards ^{78}Ni can be investigated looking at the excitation energy of high-spin states involving particle-hole excitations across the N=50 gap

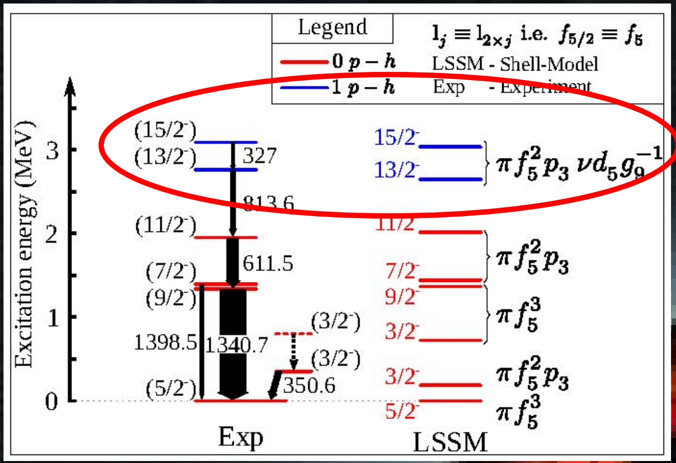


K. Sieja and F. Nowacki, PRC 85 051301(R) (2012)

New results on $^{81}_{31}Ga_{50}$

J. Dudouet et al., submitted to PRL

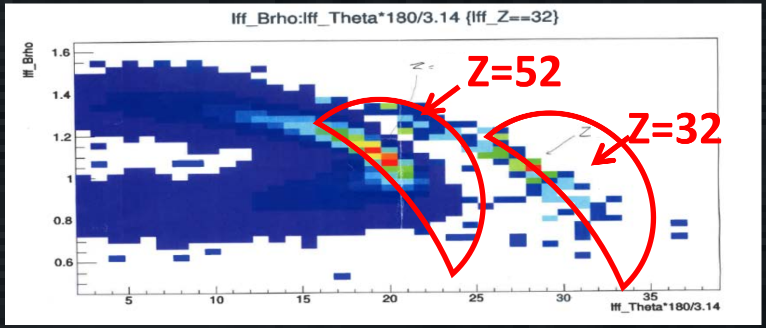




Nuclear structure above ^{78}Ni

Spokesperson: D. Verney

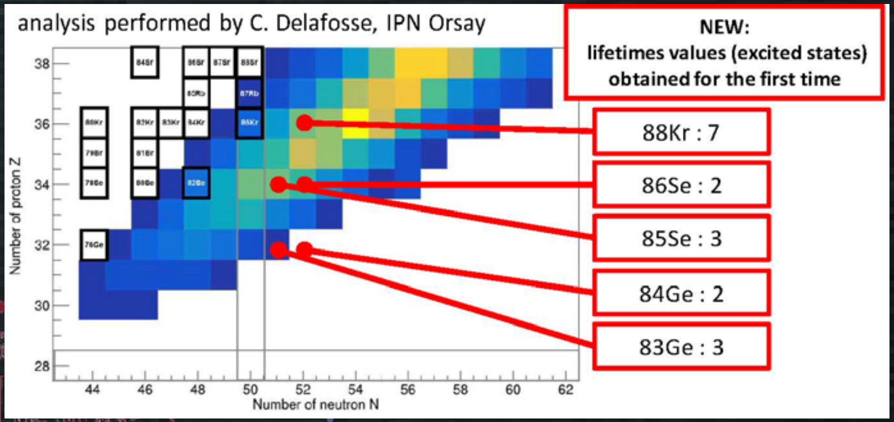
Lifetimes measurement with RDDS

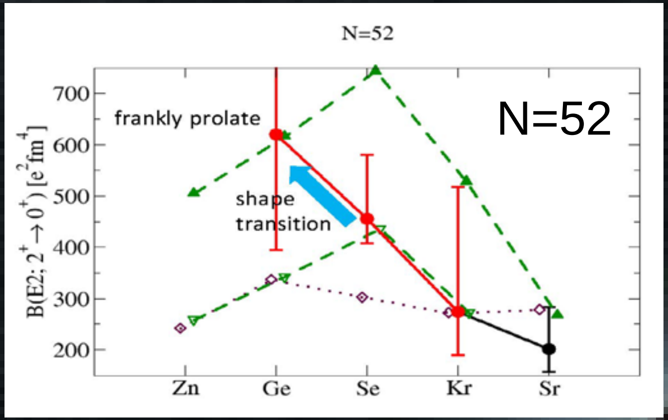


Fusion-fission reaction
^{238}U+^{9}Be + Plunger

Magnetic spectrometer placed at large angle to select the lowest mass region.

Suggested shape transition from soft-triaxial Z=34 to prolate Z=32



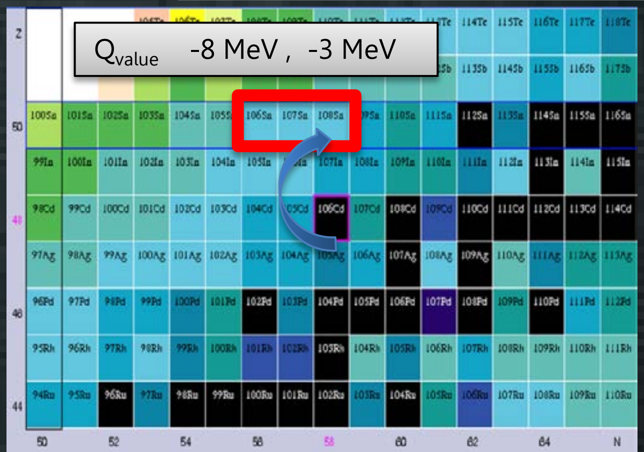


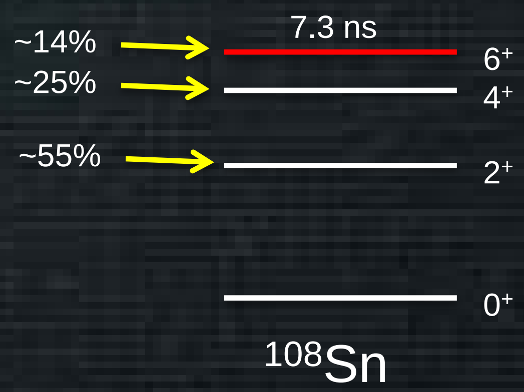
Courtesy of D. Verney and C. Delafosse

C.Delafosse *et al*., PRL 121, 192502 (2018)

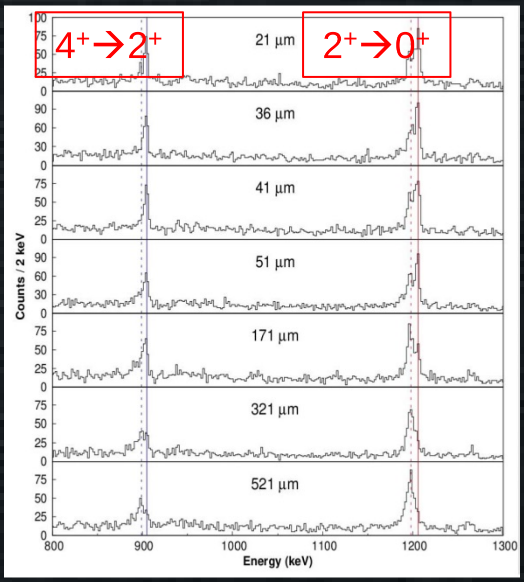
Towards ^{100}Sn: B(E2)'s in ^{106,108}Sn

Spokesperson: J.J.Valiente-Dobon



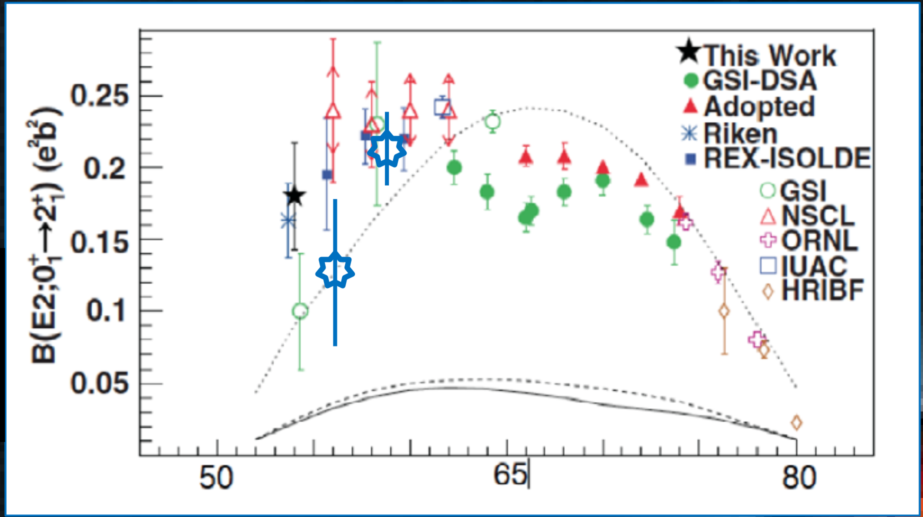


^{108}Sn



Experimental method: proton-rich populated in multinucleon transfer reactions to selectively populate states below the isomers.

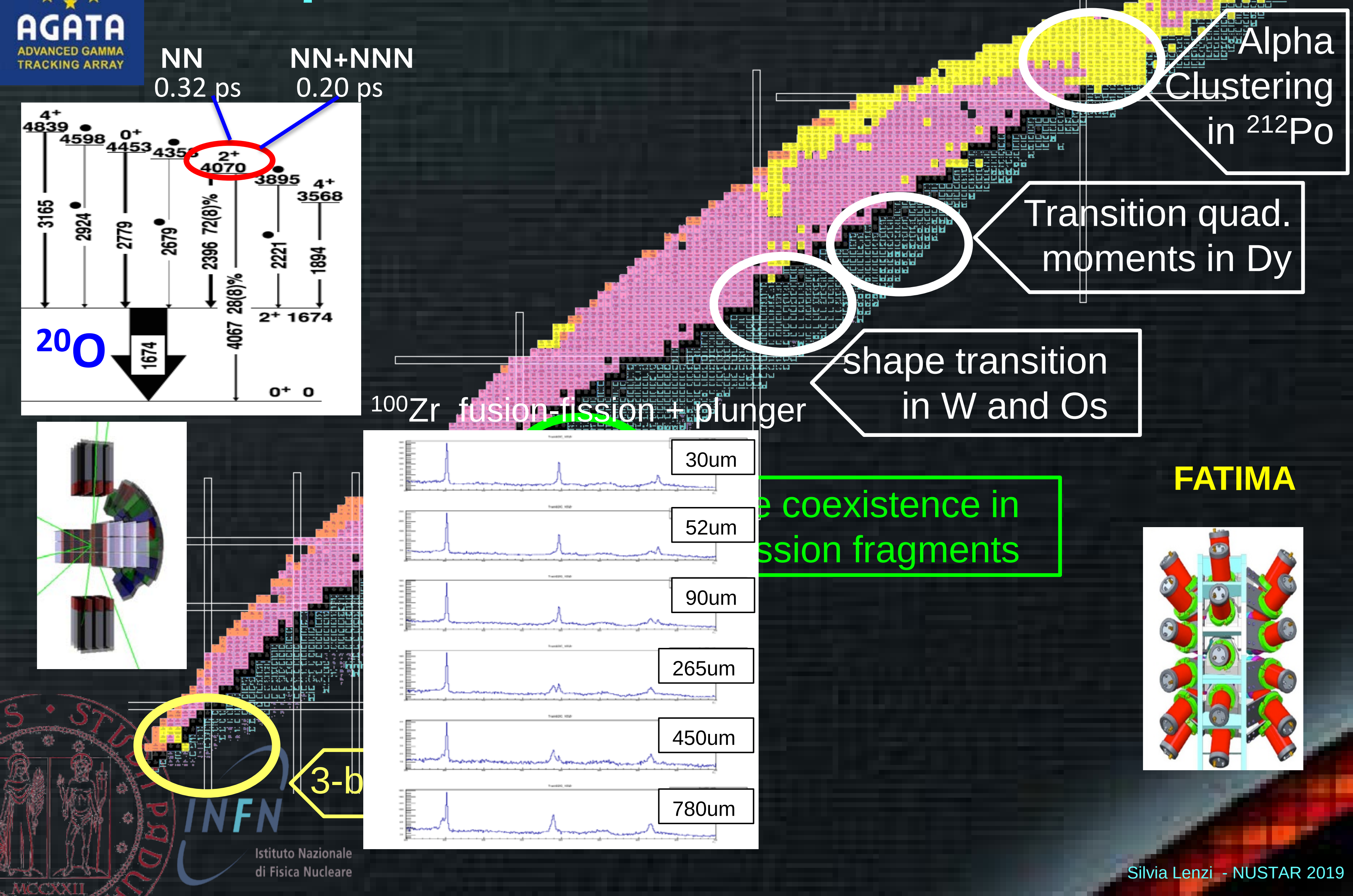
- Lifetimes of the 2$^+$ and 4$^+$ in ^{106,108}Sn
- interesting interplay between pairing and quadrupole correlations



M. Siciliano et al., submitted to PRL


Campaign 2017
AGATA+VAMOS+
FATIMA/PARIS

Experiments in 2017

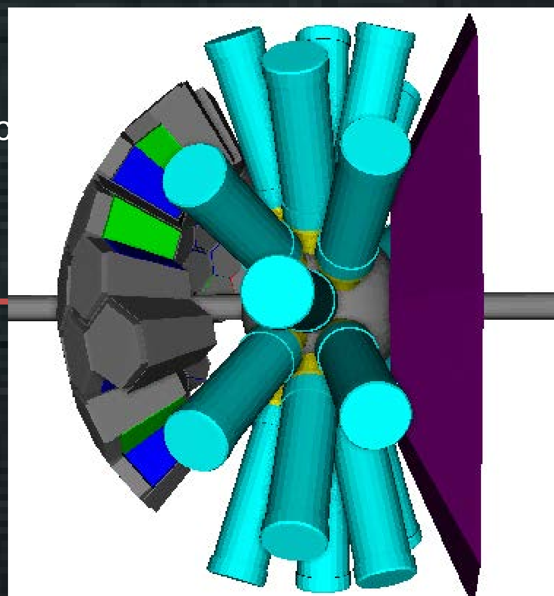


In-flight studies of fission fragments

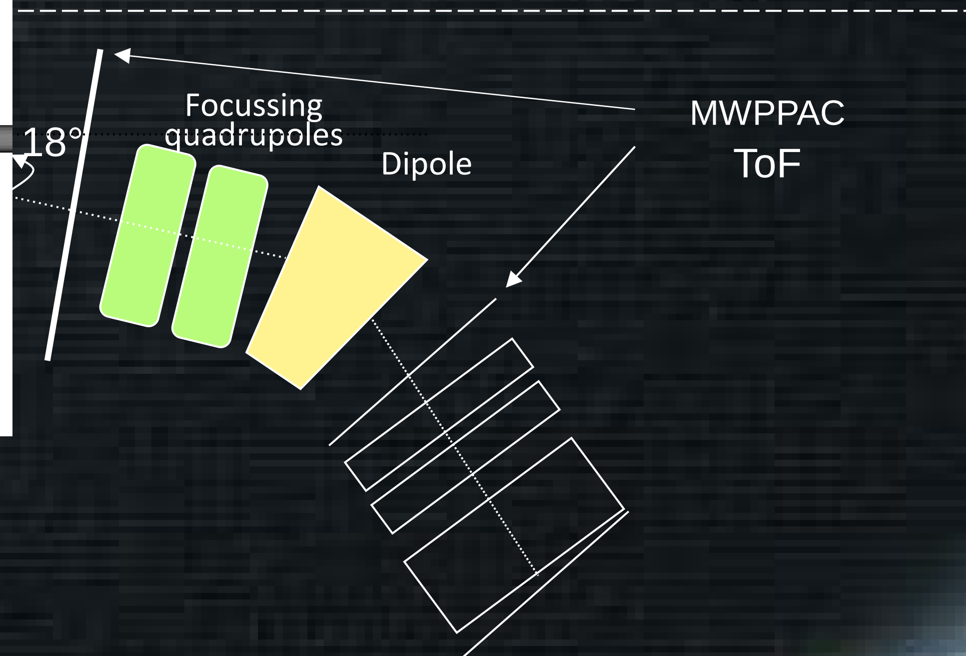
- Fusion-fission reaction ^{238}U + ^{9}Be in inverse kinematics (→ ^{247}Cf @ E* ≈ 45 MeV)
- RDDS lifetimes from plunger set-up

Target
^{9}Be 2.3 mg/c

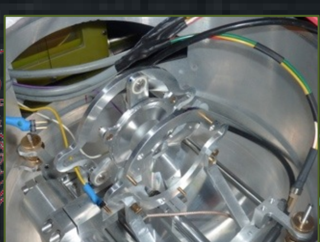
^{238}U 6.2 MeV/u



Spokespersons:
W. Korten and A. Görgen



Orsay Plunger
8 distances :
~30 → 2650 μm
τ ~ 1- 100 ps



AGATA
35 Ge detectors

FATIMA
24 LaBr3 detectors

Courtesy of W. Korten

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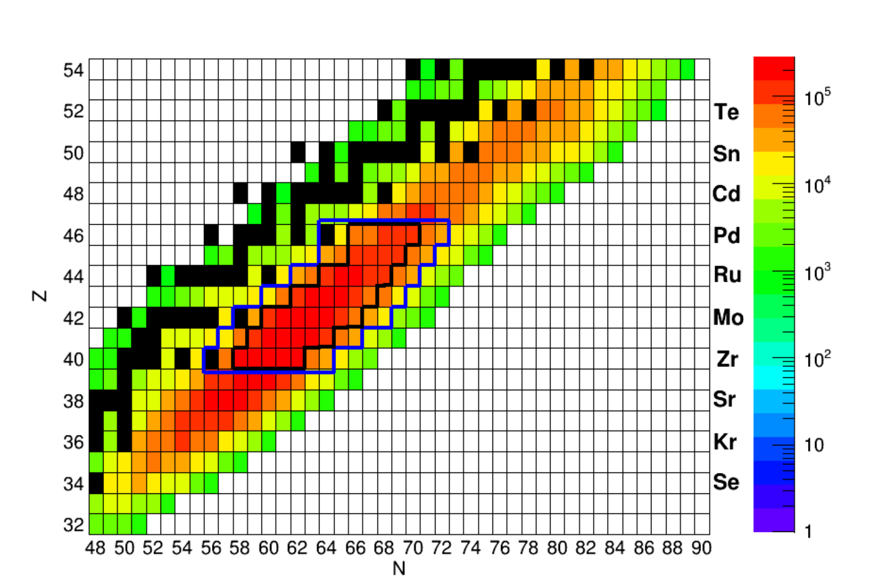
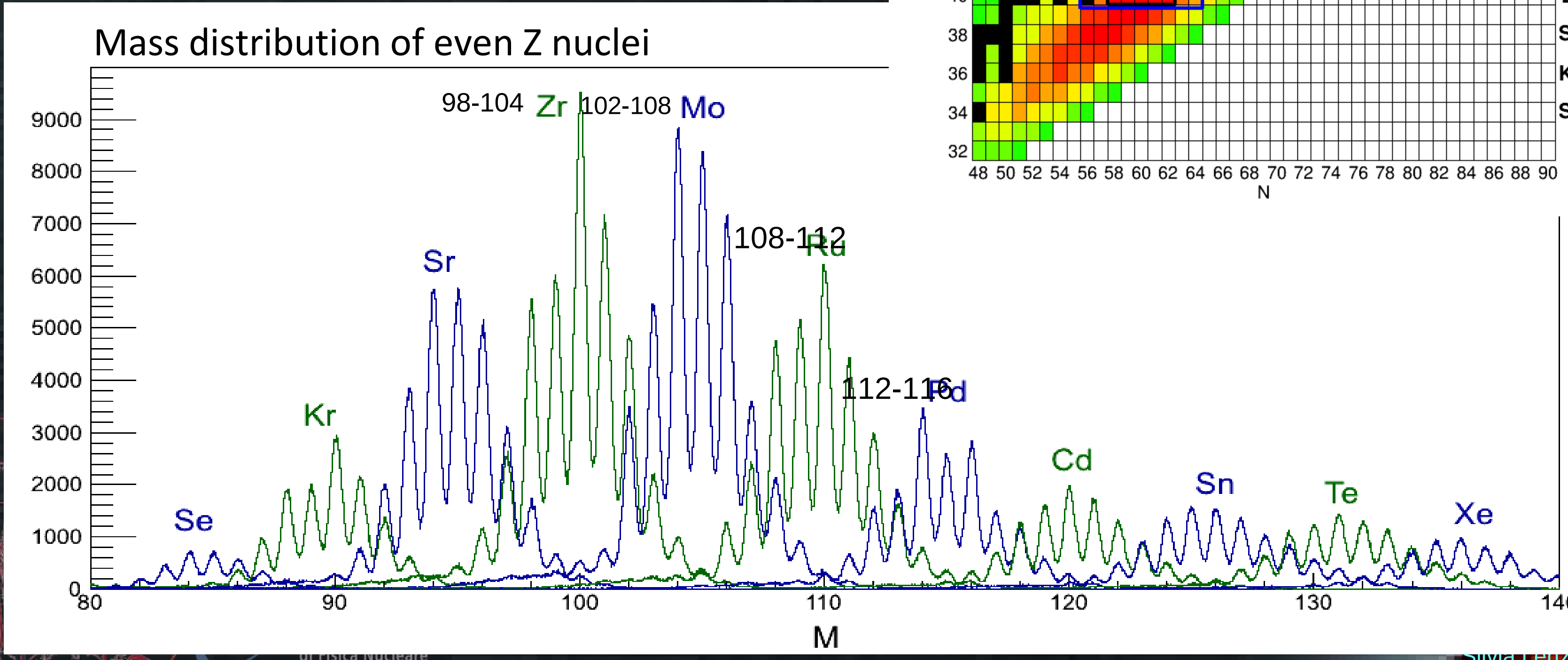
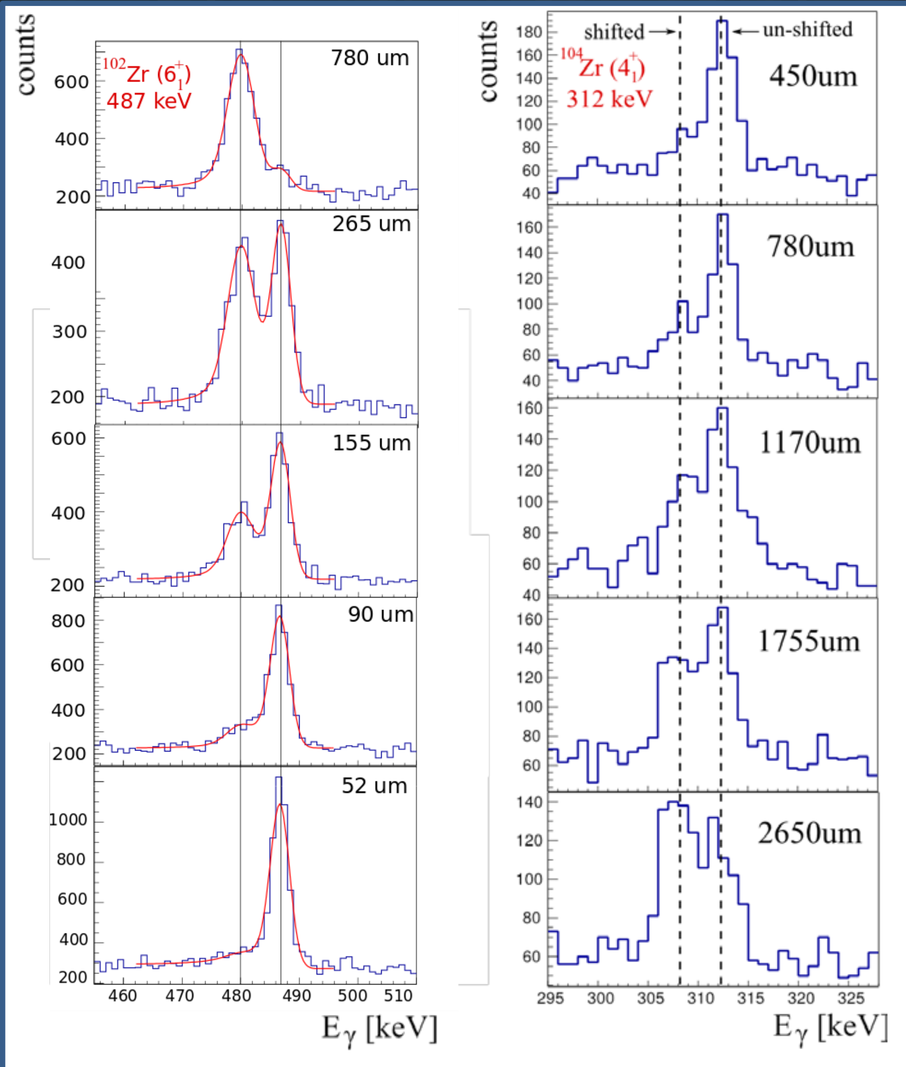
In-flight studies of fission fragments

- **RDDS measurement** with **isotopically identified fission fragments**
- Spectroscopy possible for more than 100 isotopes from Se (Z=34) to Xe (Z=54) and up to 10 neutrons far from the line of stability
- Lifetimes for **~20 isotopes** (even and odd mass)

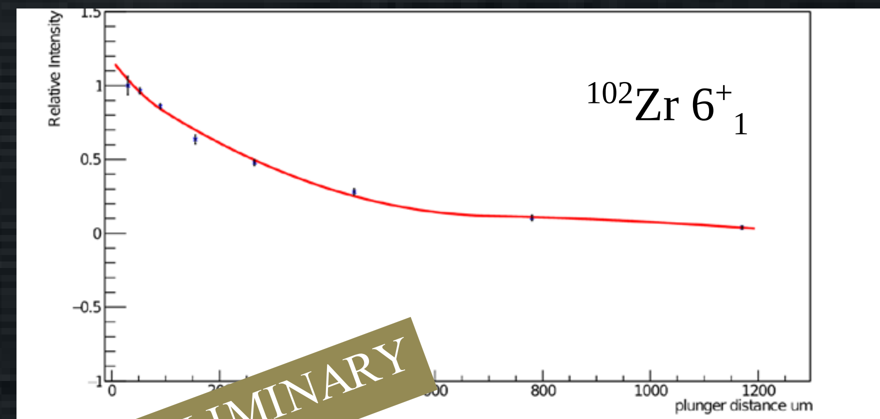


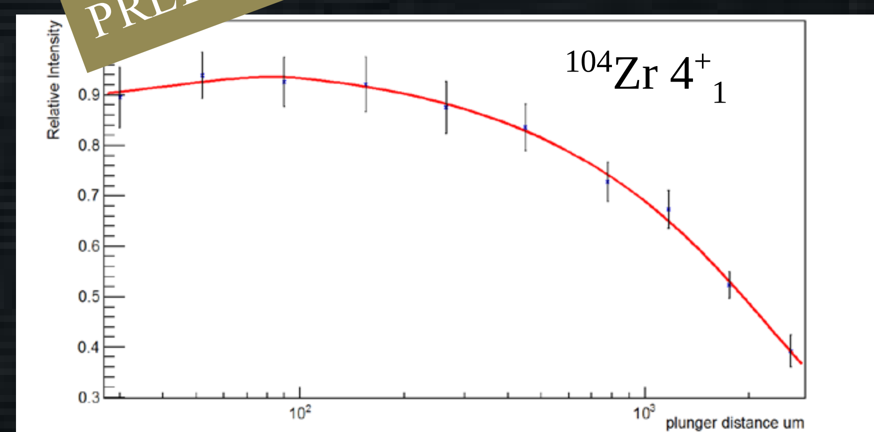


Preliminary results from E706



Lifetime analysis in progress





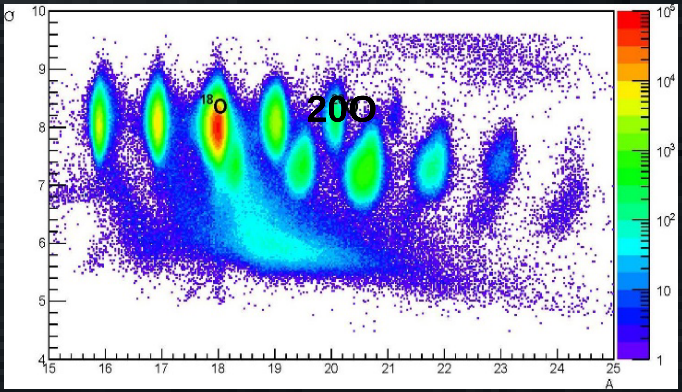
Courtesy of W. Korten

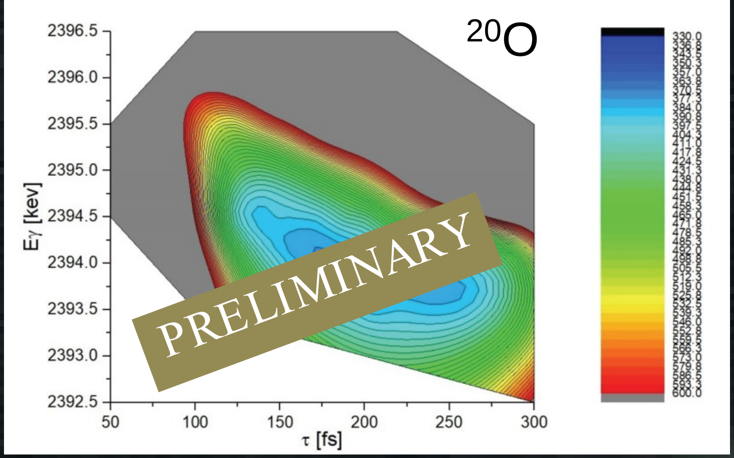
Lifetime of excited states in neutron-rich C and O isotopes

Spokespersons: S. Leoni, B. Fornal, M. Ciemala

Goal:
Measure lifetimes of the second 2^+ state in ^{20}O and ^{16}C, and its decay branches to the ground state and to the first 2^+ state.

Strong sensitivity of the electromagnetic transition probabilities to the details of the nucleon-nucleon interactions, especially in connection with the role played by the three-body forces.

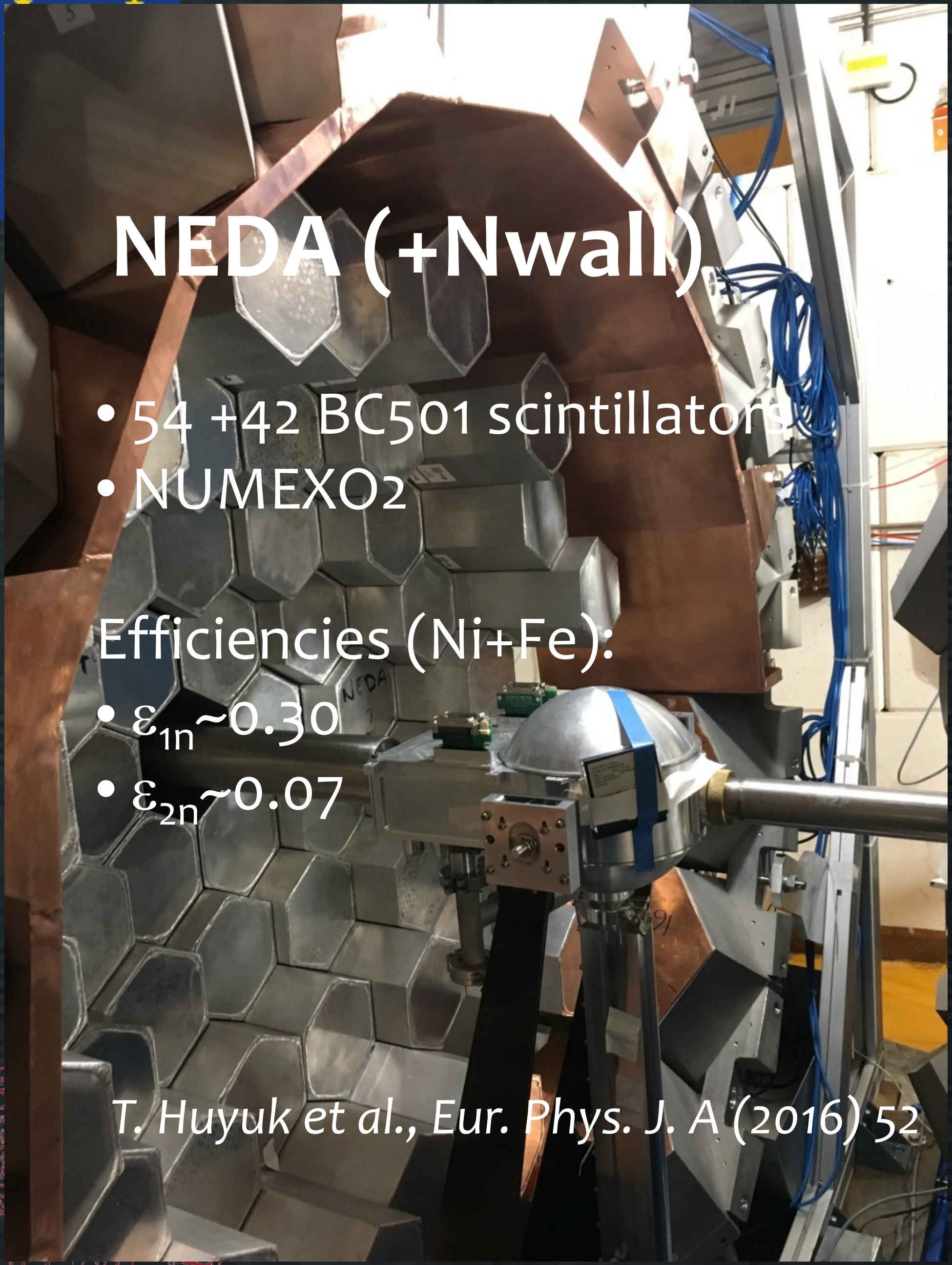




χ^2 distribution obtained for the $2^+_2 \rightarrow 2^+_1$ transition in ^{20}O, considering 75 exp. points

Courtesy of M. Ciemala et al.

Campaign 2018
NEDA+N-Wall+DIAMANT



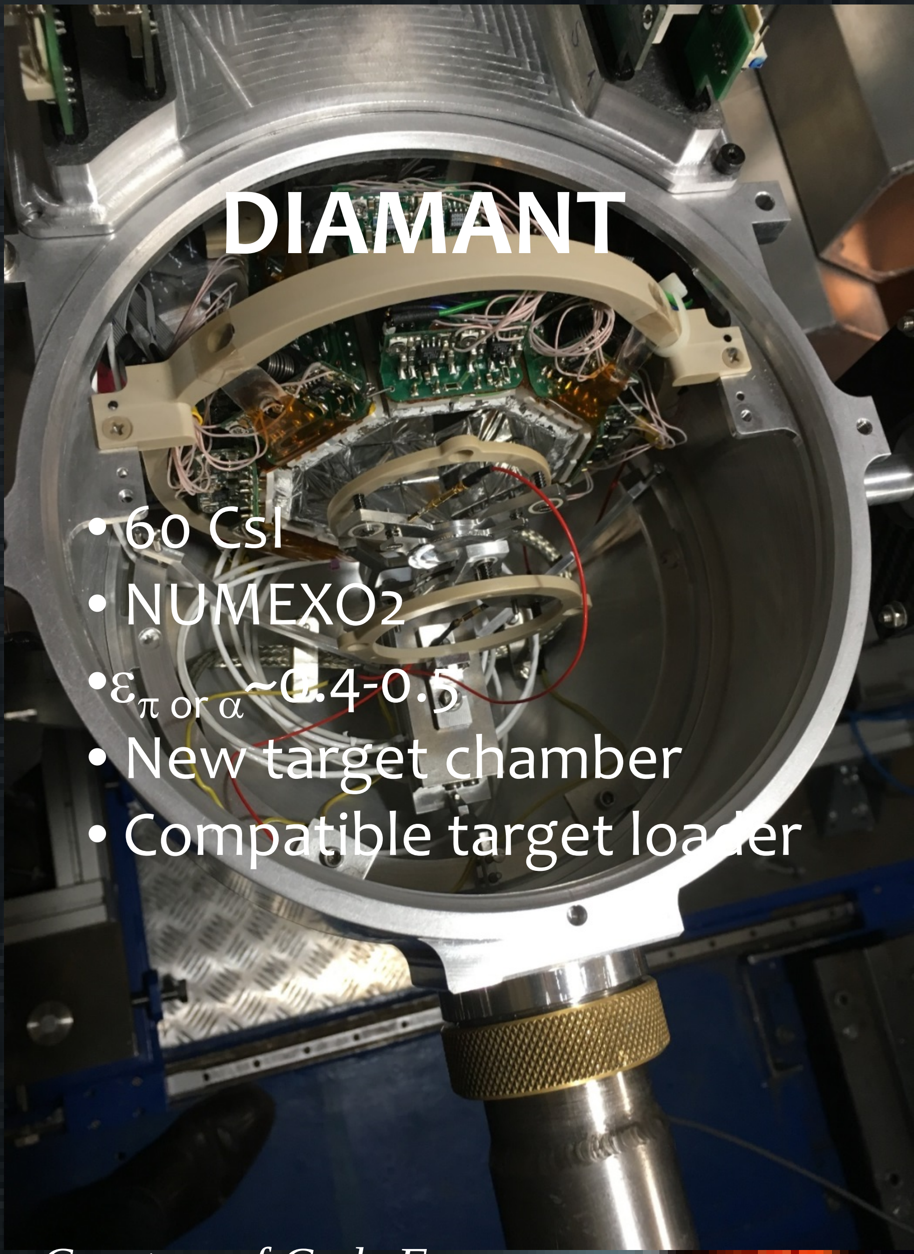
NEDA (+Nwall)

- 54 +42 BC501 scintillators
- NUMEXO2

Efficiencies (Ni+Fe):

- ε_{1n}~0.30
- ε_{2n}~0.07

T. Huyuk et al., Eur. Phys. J. A (2016) 52

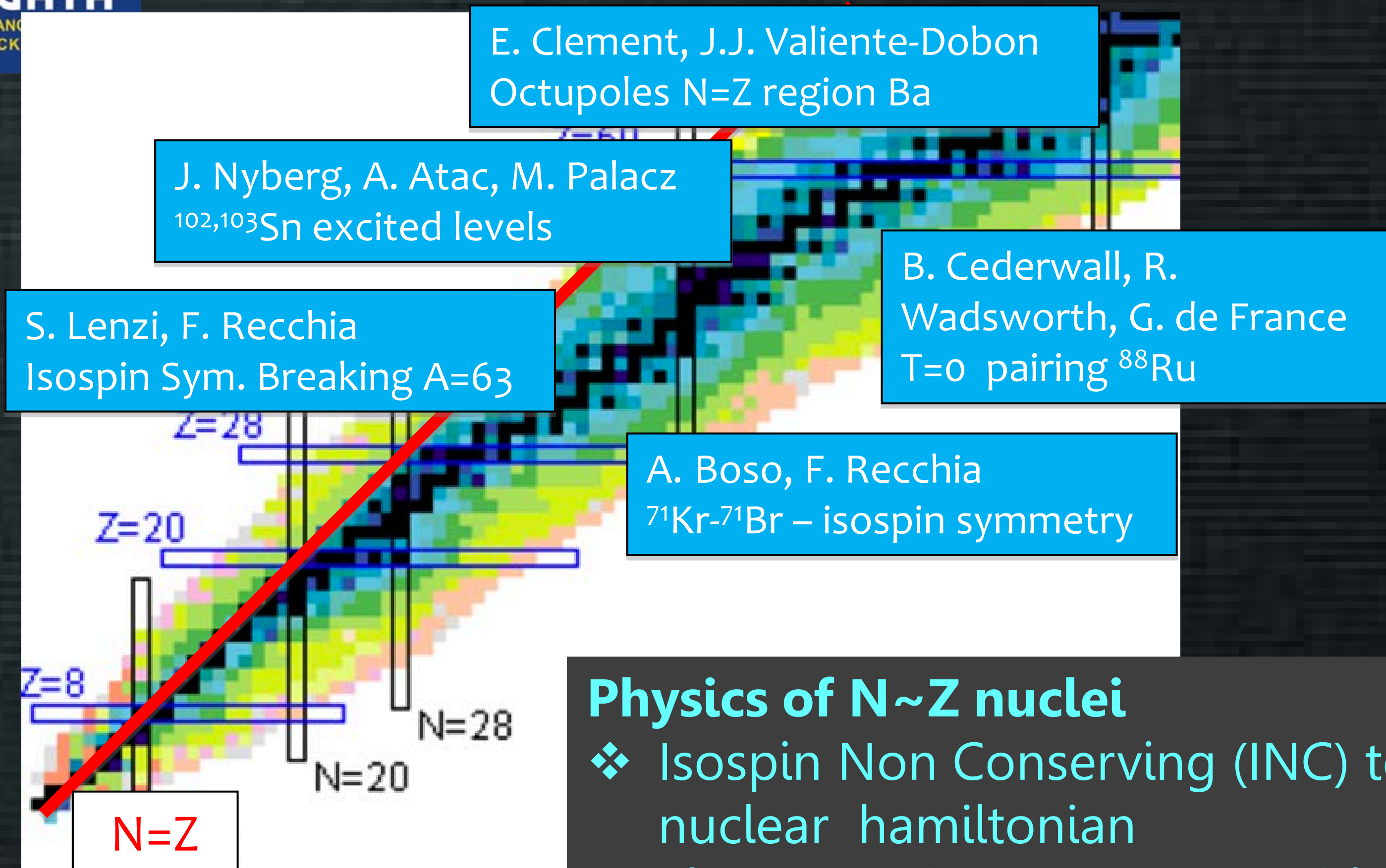


DIAMANT

- 60 CsI
- NUMEXO2
- $\varepsilon_{\pi\ or\ \alpha}$~0.4-0.5
- New target chamber
- Compatible target loader

Courtesy of G. de France

Physics case

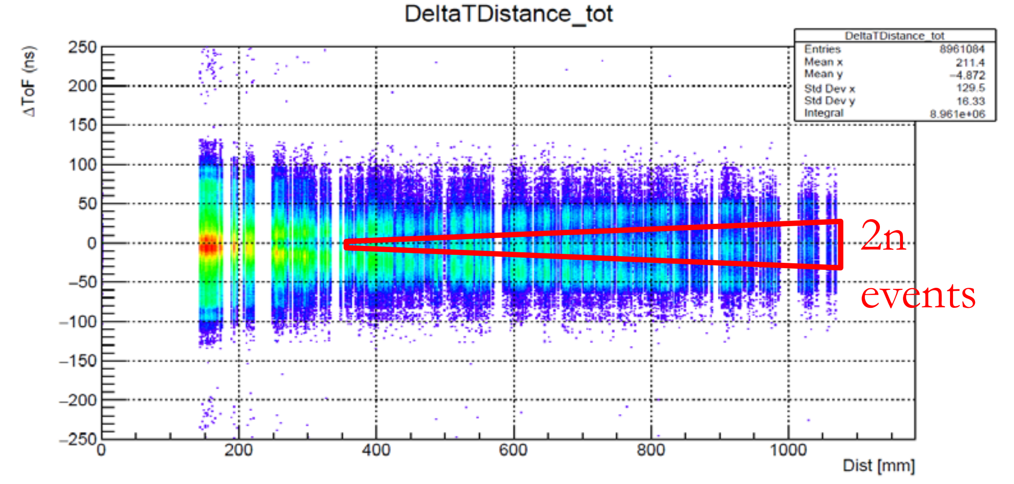


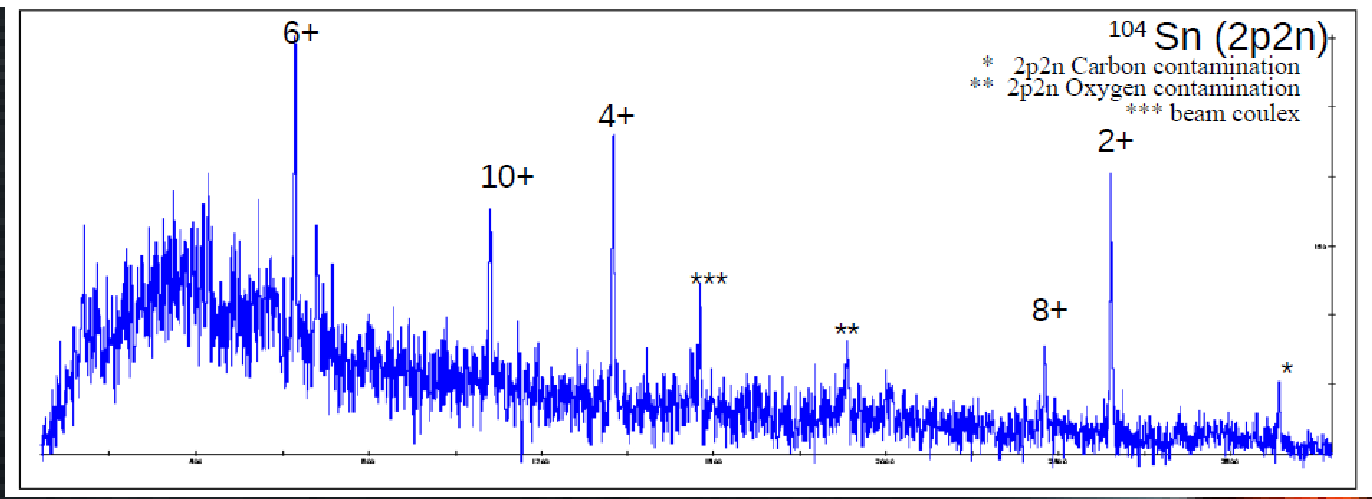
Courtesy of G. de France

Physics of N~Z nuclei

- Isospin Non Conserving (INC) terms in the nuclear hamiltonian
- Shape coexistence vs INC with DSAM
- Rot.ational properties of N=Z nuclei and T=0 pairing strength
- TBME and core excitations close to ^{100}Sn
- Octupole vs Quadrupole excitations in light Xe

2n selection and 1n scattering rejection

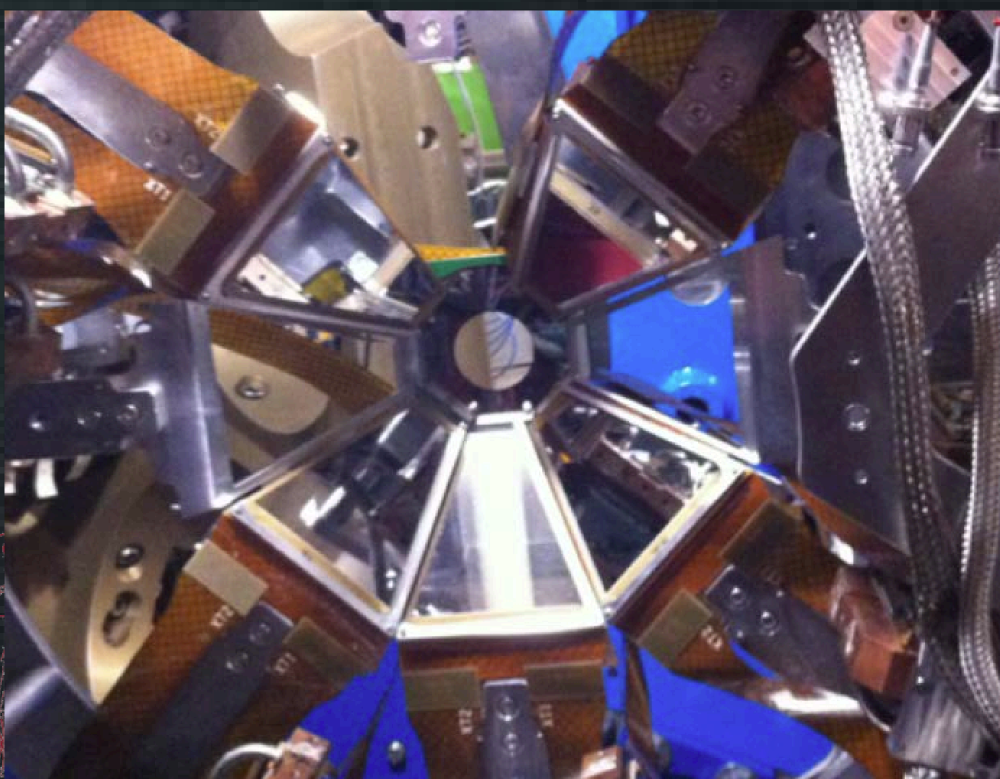


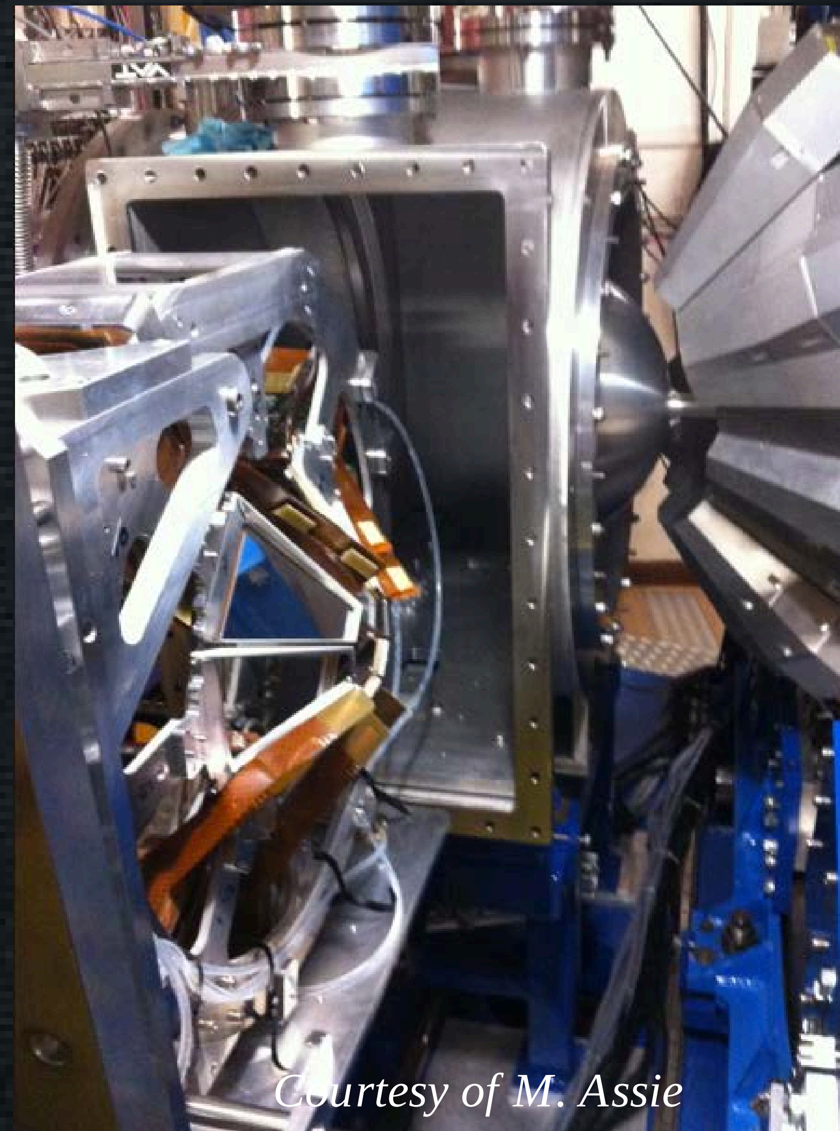


O. Atkas, M. Palacz

Campaign 2019

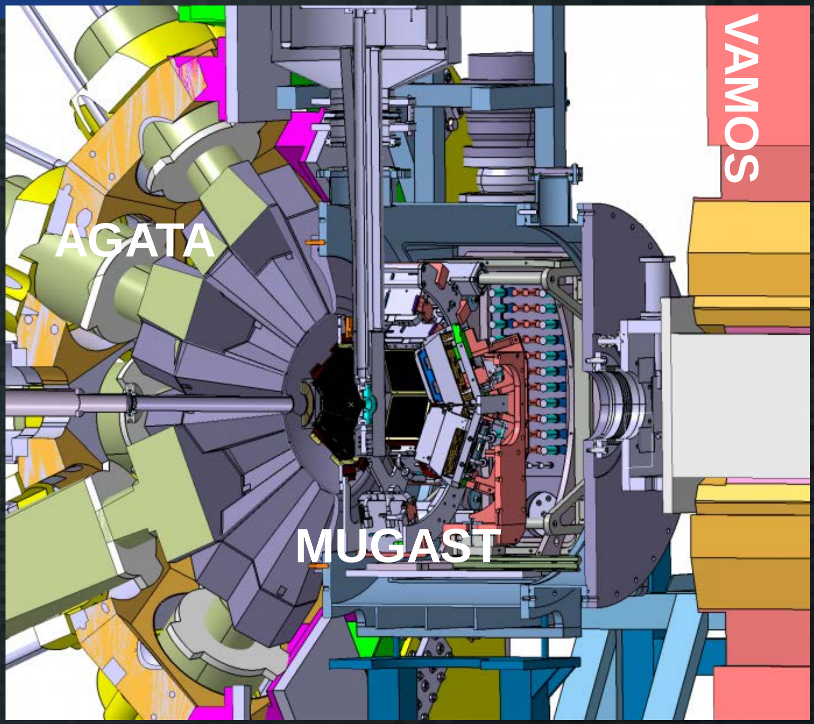
MUGAST + VAMOS

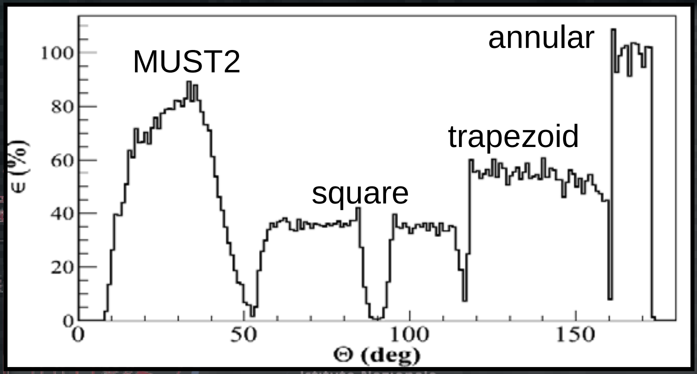




Courtesy of M. Assie

MUGAST+VAMOS setup





MUGAST
- one-layer of silicon backward & 90˚
- well-suited for stripping measurements
- specific target (cryogenic)

VAMOS
- large acceptance spectrometer at 0˚

AGATA efficiency at 1.3 MeV

	35 caps (2017-2018)	41 caps (2019)
D=23.5 cm	4.4% (5.6%)	5.25% (6.7%)
D=18 cm	7.7%	9.5%

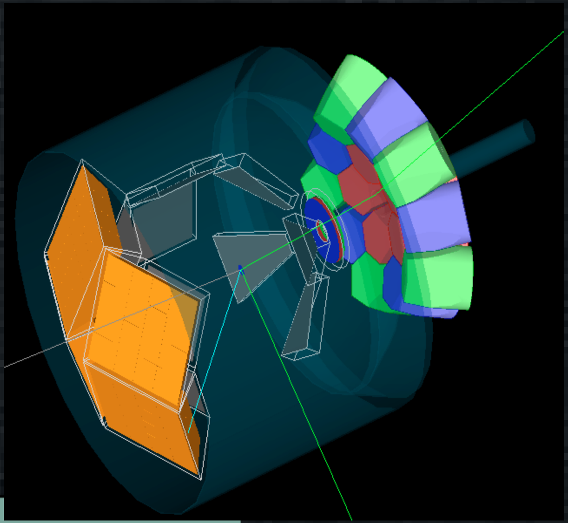
Courtesy of M. Assie

MUGAST: Future experiments

PAC 2015 & 2016

24 LoI submitted (17+7)

--> mainly stripping reactions (backward)

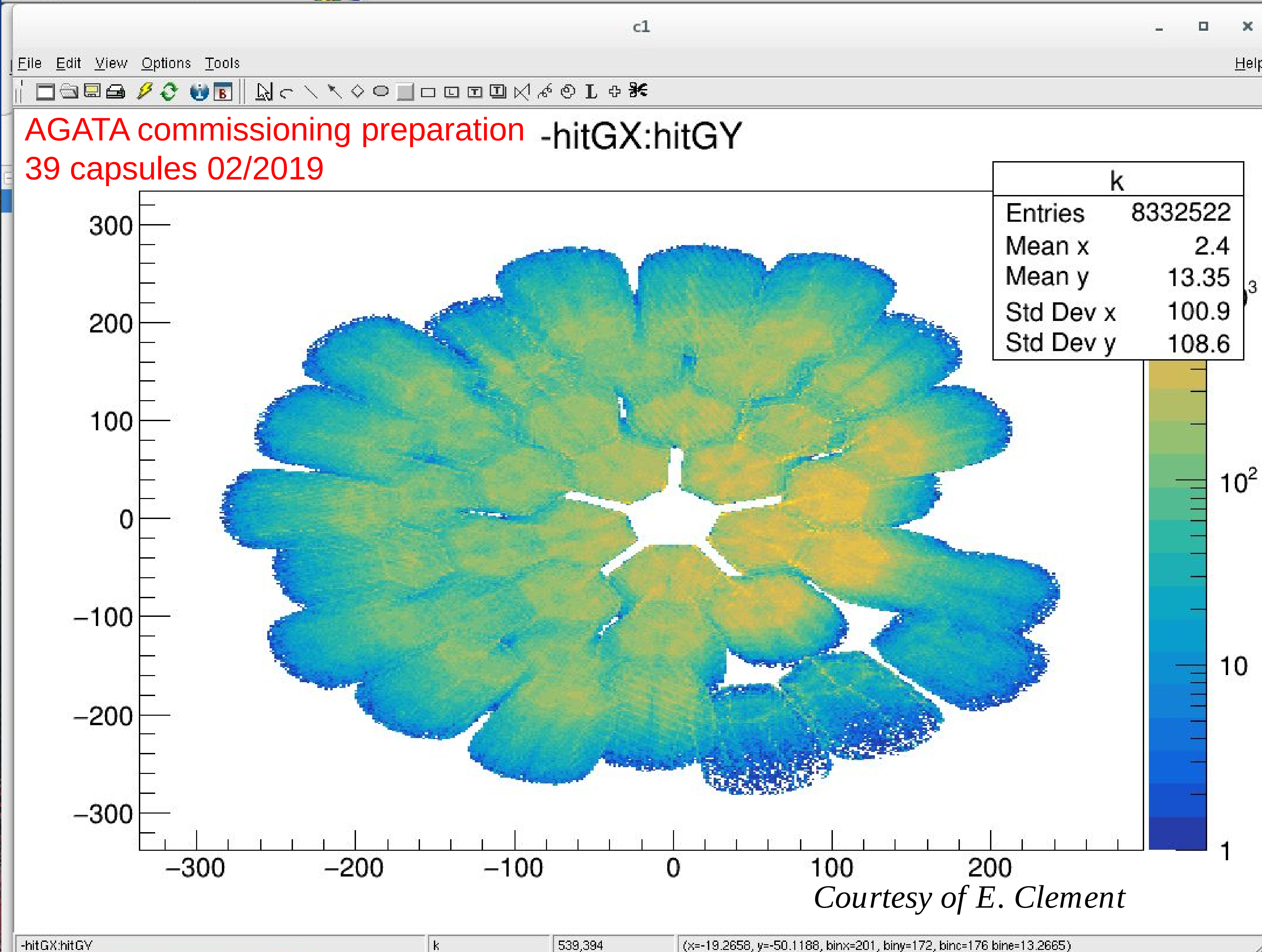


to be performed in 2019

Reaction	Spokesperson	
^{15}O(^{6}Li,d)^{19}Ne	C. Diget, N. de Séréville	Approved
^{14}O(p,p')	I. Stefan, F. de Oliveira	Approved
^{46}Ar(^{3}He,d)^{47}K	A. Gottardo, M. Assié	Approved
^{19}O (d,p) ^{20}O	E. Clément, A. Goasduff	Approved
^{45}Ar(d,p)	A. Lemasson	Proposal
^{28}Mg(d,p)	A. Matta	Proposal
^{46}Ar(d,p)	D. Mengoni, D. Beaumel	Proposal
^{56}Ni(d,p)^{57}Ni	F. Flavigny, O. Sorlin	LoI
^{56}Ni(^{3}He,p)^{58}Cu	M. Assié	LoI
^{69}Cu, ^{46}Ar, $^{49-50}$Sc (t,^{4}He)	S. Bottoni	LoI

PAC 2017 & 2018

Courtesy of M. Assie


c1
File Edit View Options Tools
Help
AGATA commissioning preparation
39 capsules 02/2019
-hitGX:hitGY
k
Entries 8332522
Mean x 2.4
Mean y 13.35
Std Dev x 100.9
Std Dev y 108.6
300
200
100
0
−100
−200
−300
−300
−200
−100
0
100
200
10^2
10
1
Courtesy of E. Clement
-hitGX:hitGY
k
539,394
(x=-19.2658, y=-50.1188, binx=201, biny=172, binc=176 bine=13.2665)

Publications and Thesis

- J. Dudouet *et al.*, *$^{96}_{36}Kr_{60}$-Low-Z Boundary of the Island of Deformation at N=60,*
  Phys. Rev. Lett. 118, 162501 (2017)
- C. Delafosse et al., *Pseudospin Symmetry and Microscopic Origin of Shape Coexistence in the ^{78}Ni Region: A Hint from Lifetime Measurements,*
  Phys. Rev. Lett. 121, 192502 (2018).
- M. Klintefjord et *al.*, *Measurement of lifetimes in $^{62,64}Fe$, $^{61,63}Co$, and ^{59}Mn.*
  Phys. Rev. C 95, 024312 (2017)
- Y.H.Kim *et al.*,
  Eur. Phys. Jour. A 53, 162 (2017)
- J. Dudouet *et al.*, *^{81}Ga – Three valence protons coupled to N = 50 neutron-core excitations*, submitted to Phys. Rev. Lett.
- M. Siciliano *et al.*, *First lifetime measurements of low-lying states in the neutron-deficient $^{106,108}Sn$ isotopes and the pairing-quadrupole interplay in $^{102\text{-}114}Sn$,*
  to be submitted to Phys. Rev. Lett.
- D. Ralet *et al.*, *First evidence of two phonon octupole-vibrational state of ^{208}Pb,*
  to be submitted to Phys. Rev. Lett.
- A. Goldkuhle *et al.*, publication in preparation.
- R. Perez-Vidal *et al.*, publication in preparation.
- S. Biswas *et al.*, publication in preparation
- R. Banik *et al.*, publication in preparation

PhD Thesis:

M. Klintefjord (Univ. of Oslo), C. Delafosse (Univ. Paris Sud), M. Siciliano (Univ. of Padova)
R. Perrez-Vidal (Univ. of Valencia), A. Goldkuhle (Univ. Cologne), S. Ansari (Univ. Paris-Saclay)

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and specially to the GANIL team leaded by
the project manager Emmanuel Clément

Thank you
for your attention