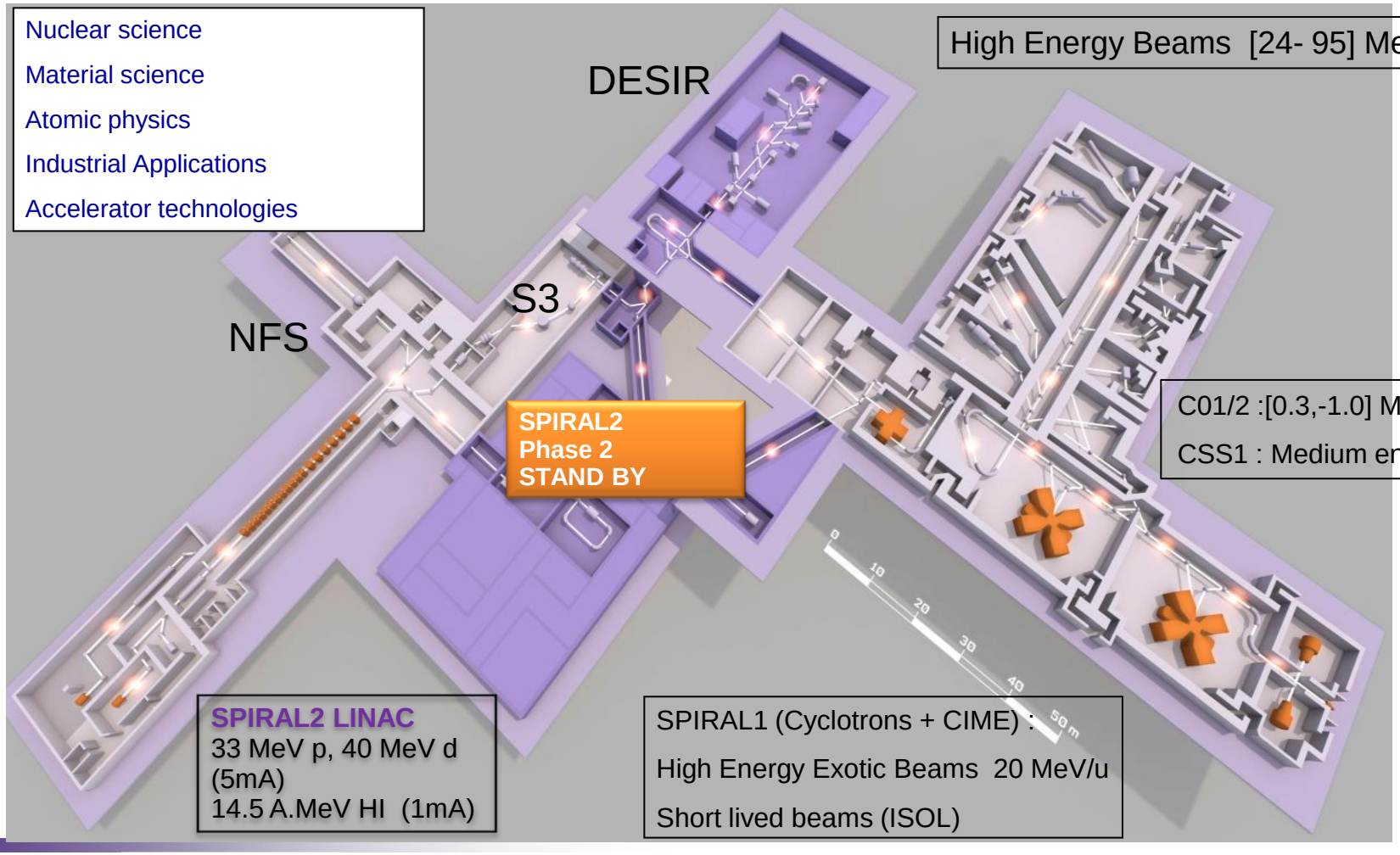
AGATA@GANIL
Status-Report

2018 NUSTAR Meeting

GANIL Today

- *Complete the SPIRAL2 LINAC for the first experiments*
- *Provide the maximum possible beam time*

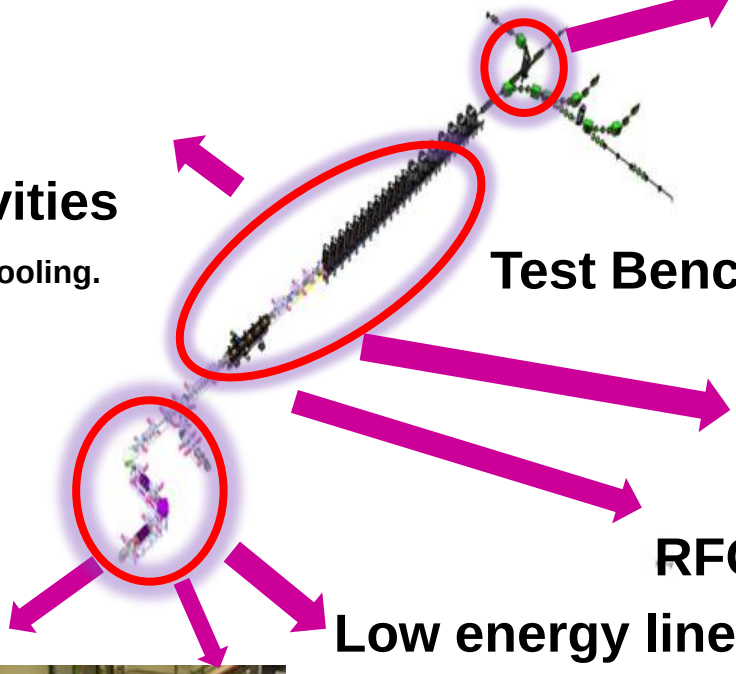


SPIRAL2 LINAC

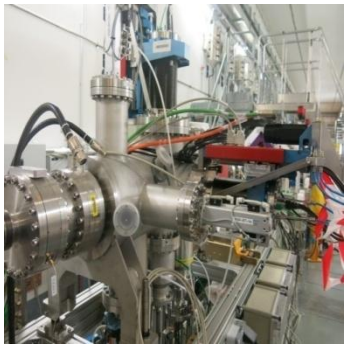
Superconducting cavities

- ✓ **30/11/2017: 1st complete LINAC cooling.**
- ✓ **Regulation in specifications**

High energy Beam lines



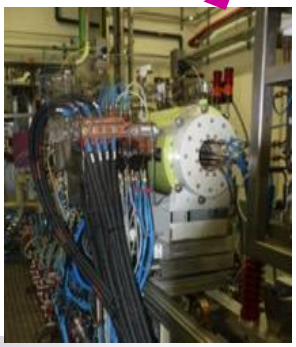
Test Bench

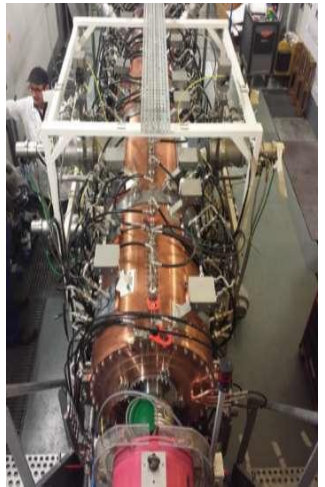


RFQ

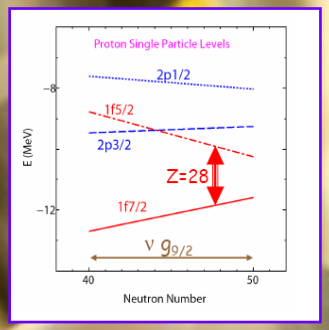
Low energy lines

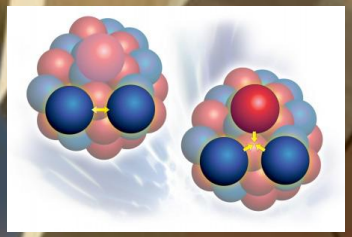
Ion sources





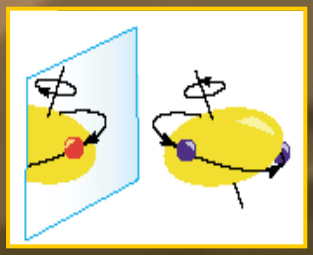
Shell evolution far from stability



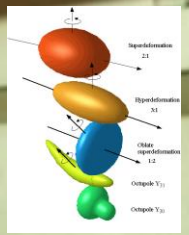


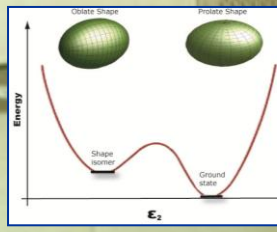
Three-body forces

Isospin symmetry breaking

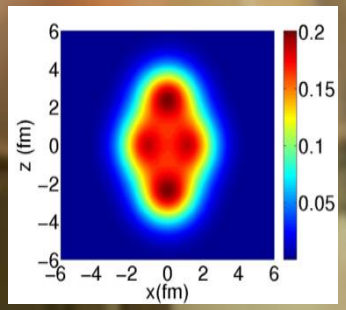


Nuclear shapes and coexistence



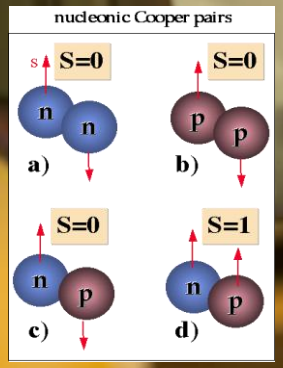


clusterization

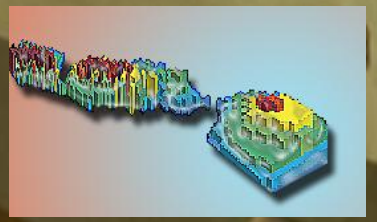


High-resolution gamma-ray spectroscopy is an optimum tool to study detailed nuclear structure properties and investigate how they emerge from fundamental interactions.

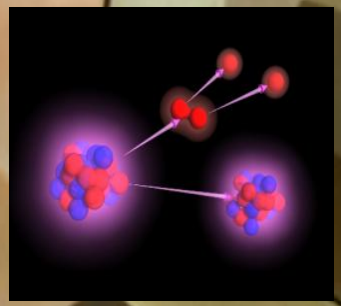
p-n pairing



Super heavy elements

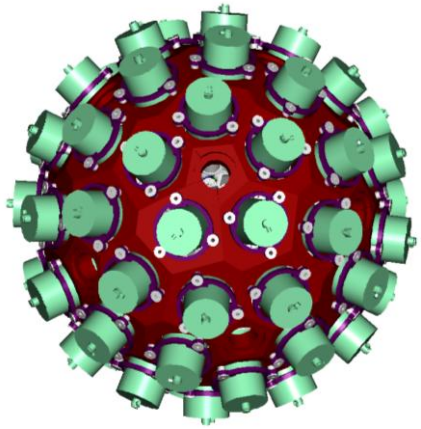


Nuclear Astrophysics



Coupling to the continuum

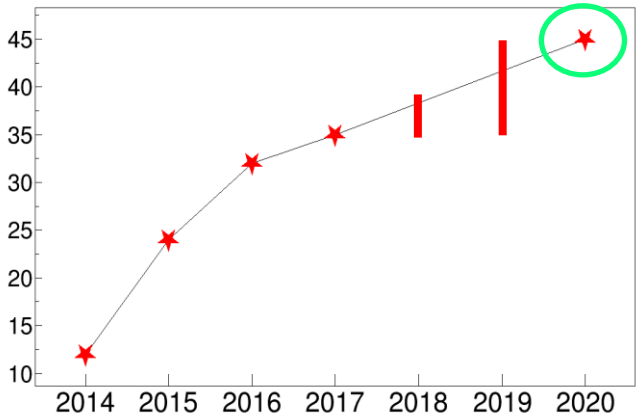
The AGATA project

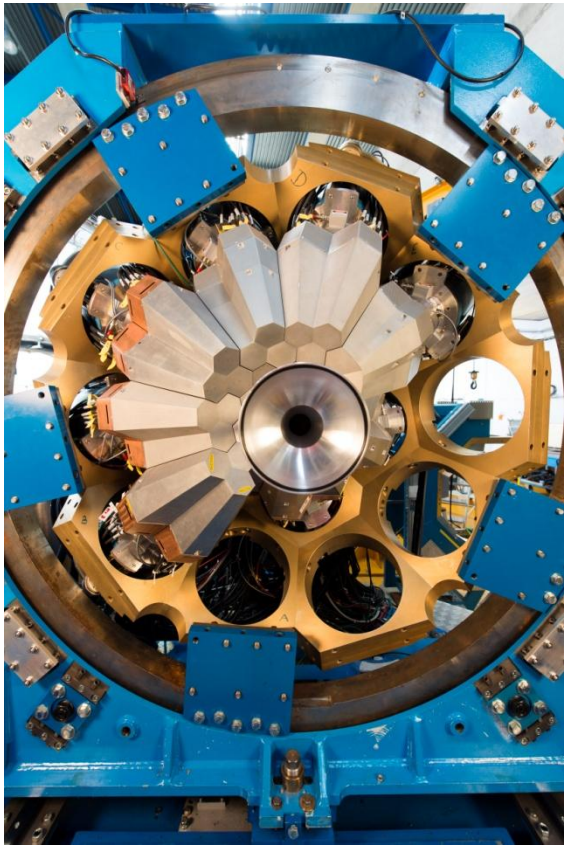


- 180 (60 triple-clusters) 36-fold segmented crystals
- Amount of germanium: 362 kg
- Solid angle coverage: 82 %
- Singles rate >50 kHz
- Efficiency: 43% (M_γ=1) , 28% (M_γ=30)
- Peak/Total: 58% (M_γ=1), 49% (M_γ=30)
- Angular Resolution: ~1º

Combination of:

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





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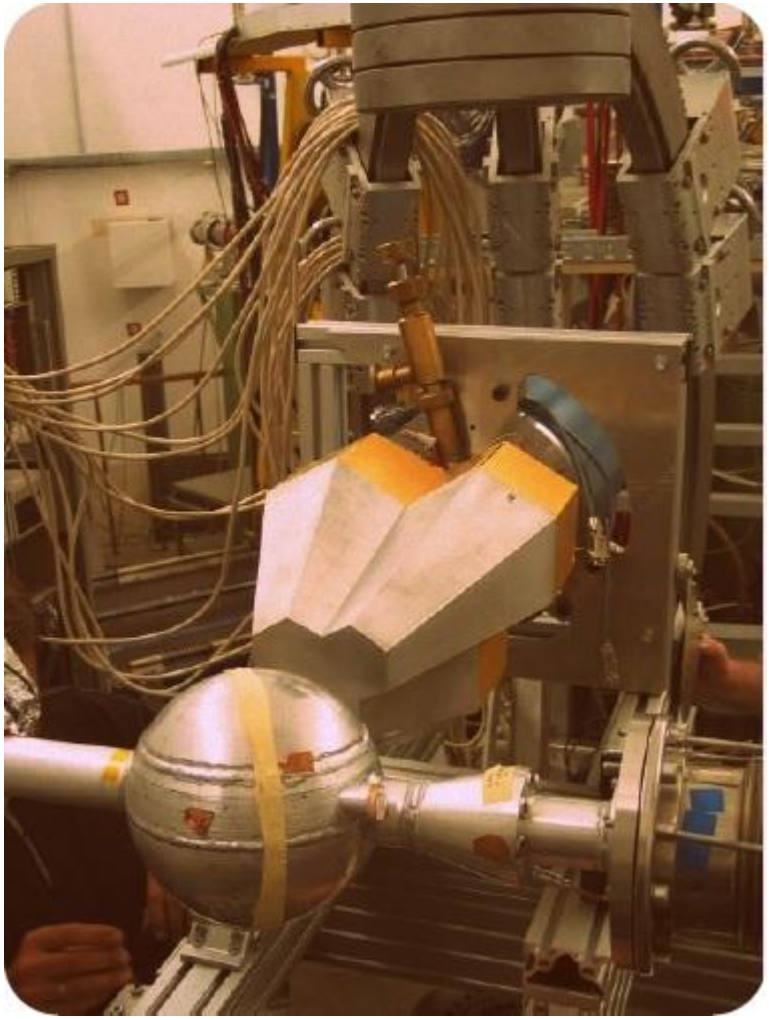
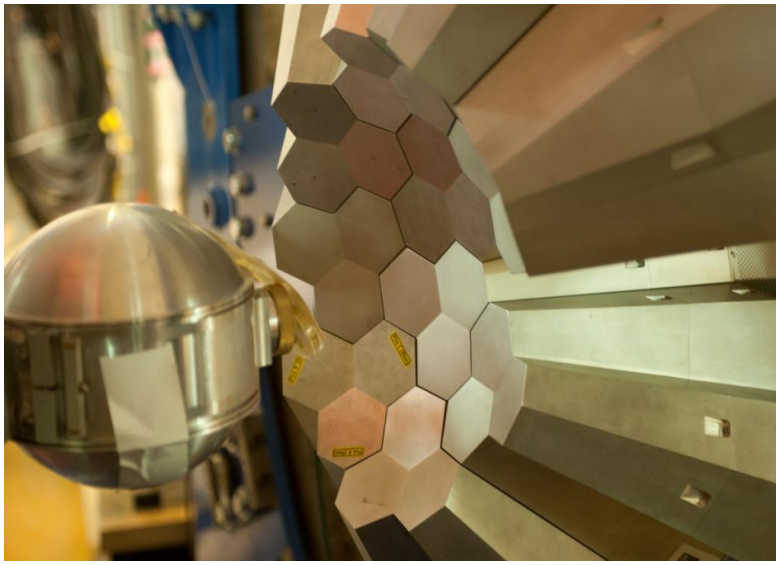
S. Akkoyun, et al, NIMA 669, 26-58 (2012)

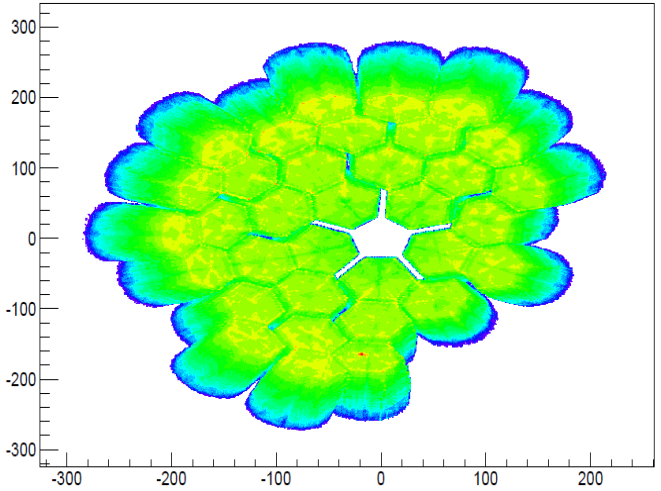
The AGATA project

August 2005 at IKP 3 symetric capsules



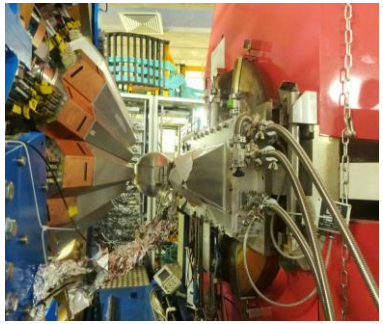
March 2015 at GANIL 24 asymetric capsules

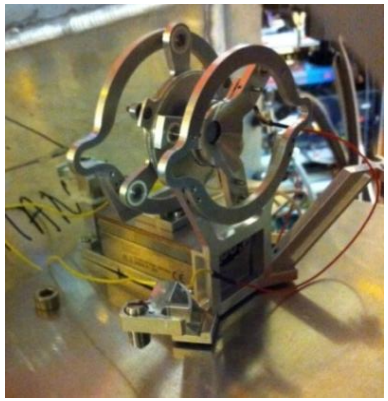




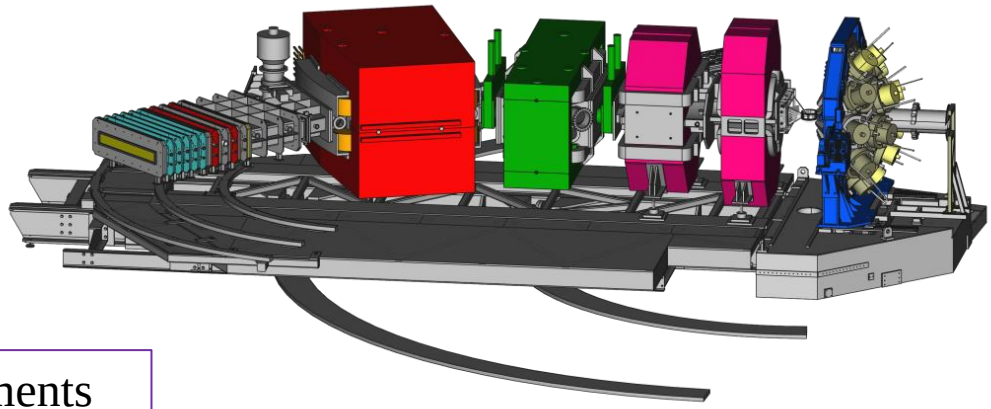
35 (March 2017)

The GANIL Campaign



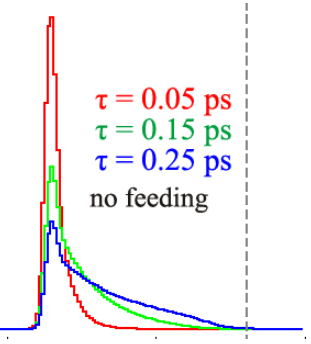


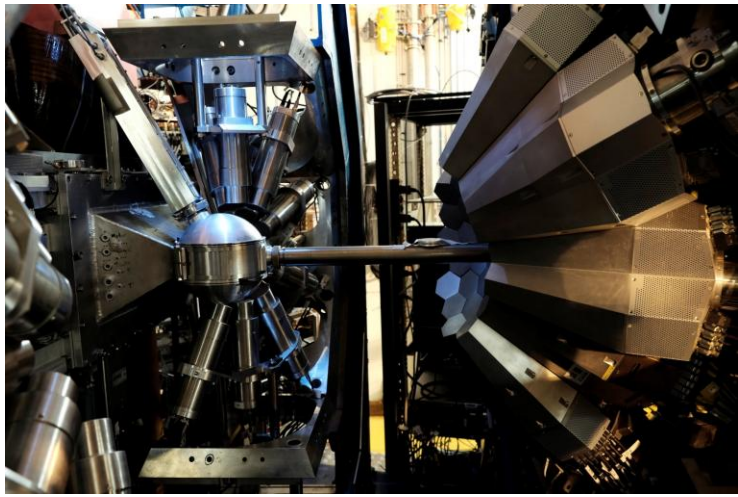
2017 : 35 detectors on-line : Single efficiency measured at 3.4(1)% in nominal position at 1.408 MeV (GEANT4 = 3.6%)



Lifetime measurements

2015-2017: 93% of performed experiments are lifetime measurements from fs to μs



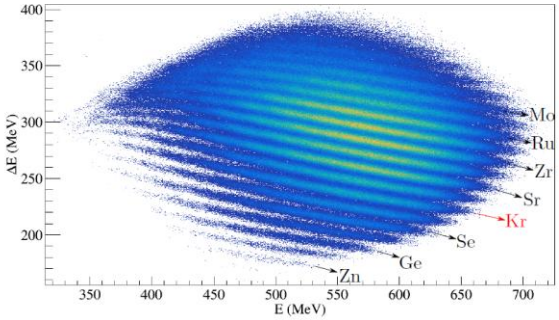


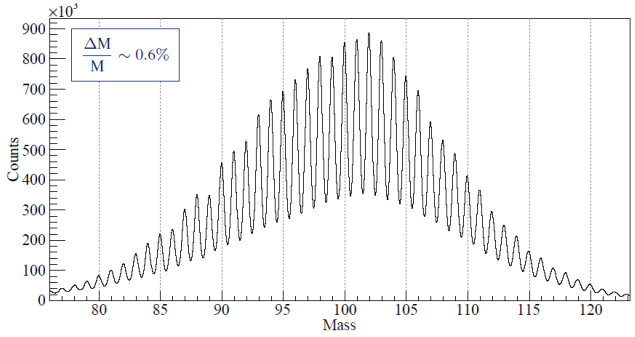
FATIMA-PARIS detectors coupled to AGATA

E. Clément et al., NIMA 855, 1-12 (2017)
Y. H. Kim et al., Eur.Phys.J. A 53, 162 (2017)

The GANIL Campaign

Courtesy J. Dudouet





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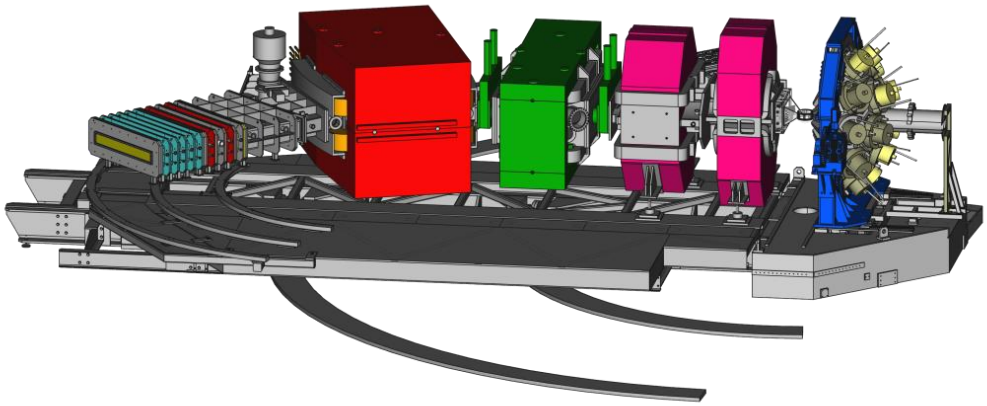
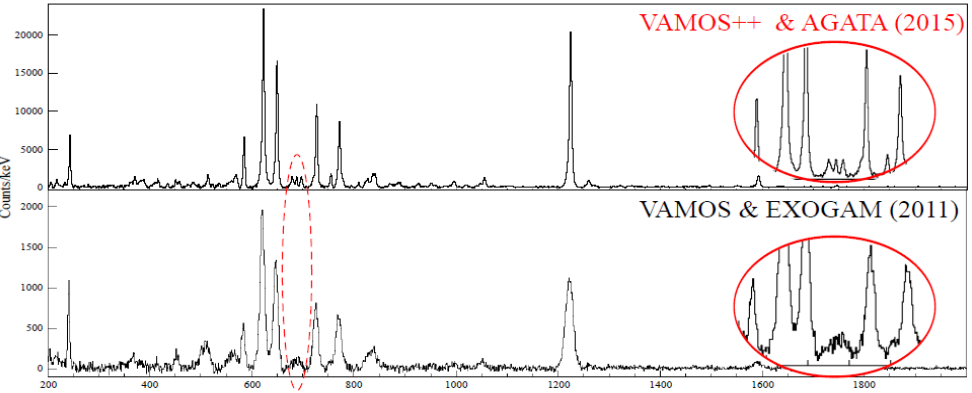
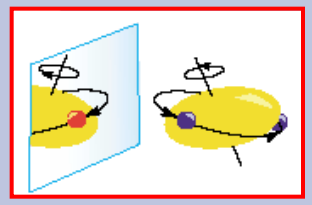


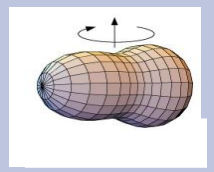


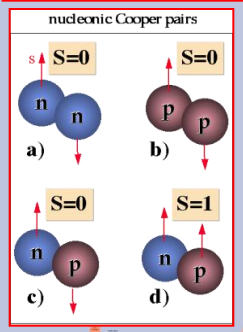
- ✓Nucleons transfer
- ✓Fusion-fission
- ✓Transfer-fission

The physics of AGATA@GANIL is the in-beam high resolution γ-ray spectroscopy of exotic nuclei populated by heavy-ions collisions

- ***Nucleon-nucleon(-nucleon) interaction close to magic nuclei***
- ***Astrophysical measurements***
- ***Collective mode in nuclei***
- ***Clusterization phenomena***







^{208}Pb

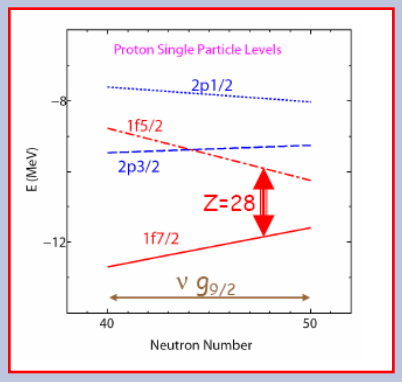
^{100}Sn

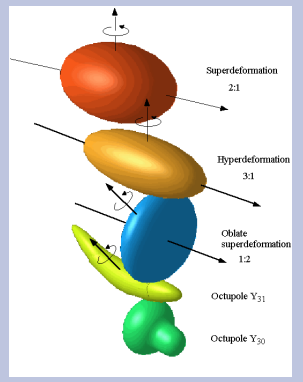
^{132}Sn

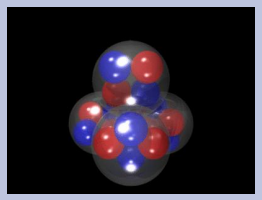
^{68}Ni

^{78}Ni

^{48}Ca







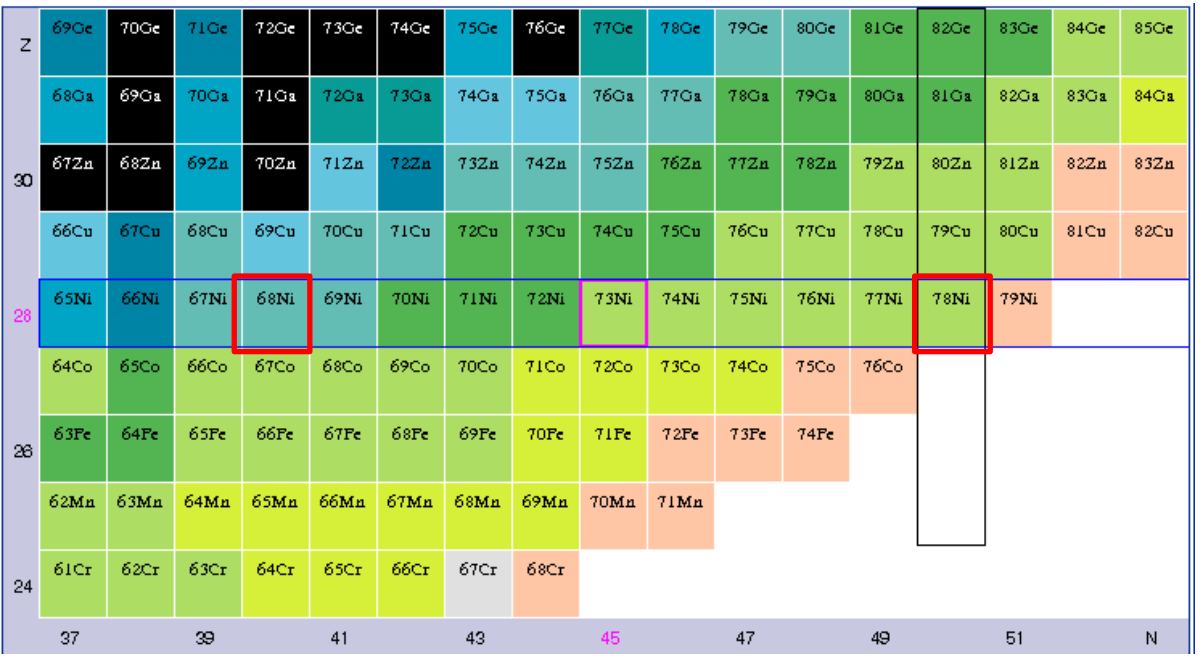
- *High resolution γ-ray spectroscopy of very exotic nuclei*

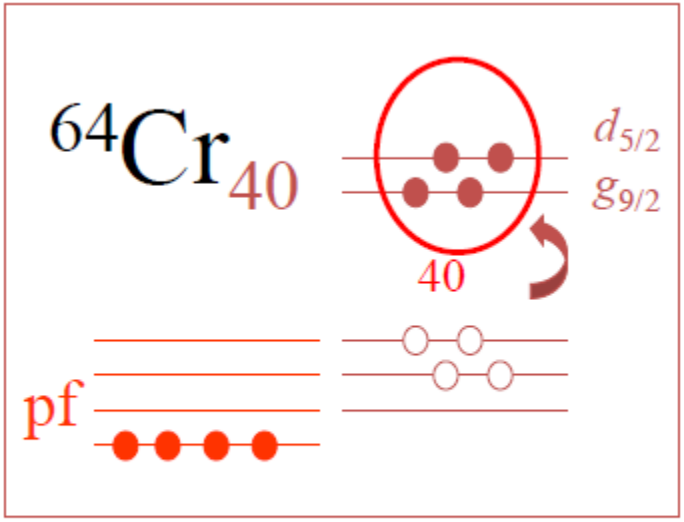
- *Lifetime measurement of excited states in the range of fs to μs*

Shell evolution around Z=28

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

- Characterizing the islands of inversion, formed near the magic numbers.
- These are new regions of deformation with configurations involving intruder orbitals from the above main shell.
- While a signature of deformation is given by the energy of the first excited states, their lifetimes allow a better understanding of their properties by comparison with LSSM calculations





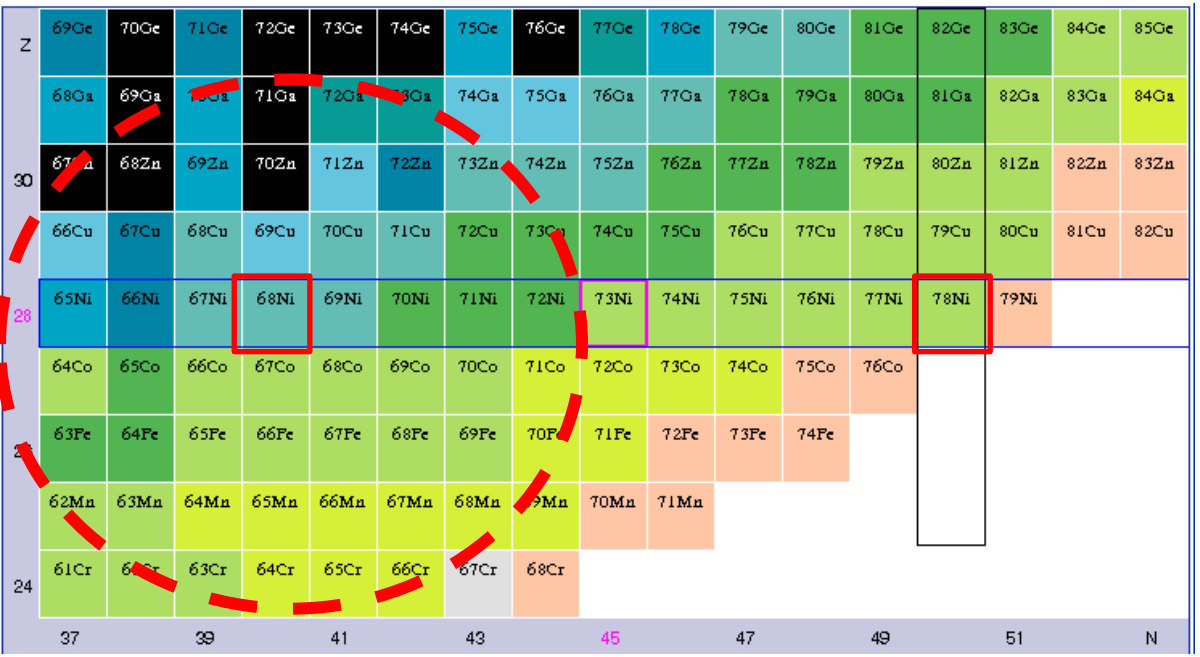
LPNS interaction

Shell evolution around Z=28

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

Collecting spectroscopic data like transition probability constraining the theoretical description of the Island of inversion from N=28 to N=40 :

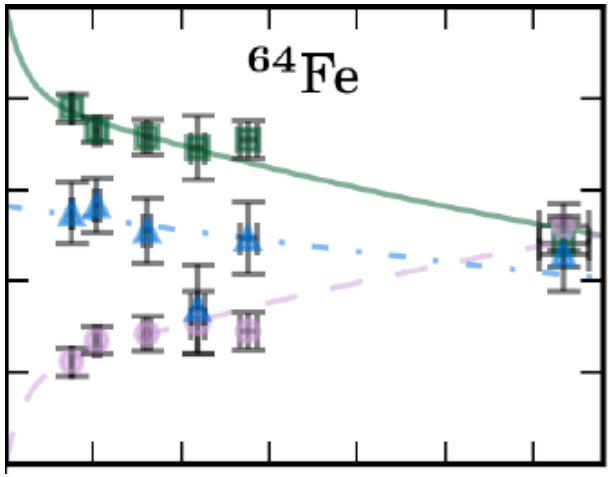
- What is the influence of the νg9/2 and νd5/2 orbits ?
- What is the influence of the proton excitations across Z=28 ?
- How collectivity change when decreasing the number of proton in the f7/2 orbital



Measurement of lifetimes in $^{62;64}$Fe, $^{61;63}$Co and ^{59}Mn

2015 Data.

Lifetimes of the 4^+ states in $^{62;64}$Fe and the $11/2^-$ in $^{61;63}$Co and ^{59}Mn



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

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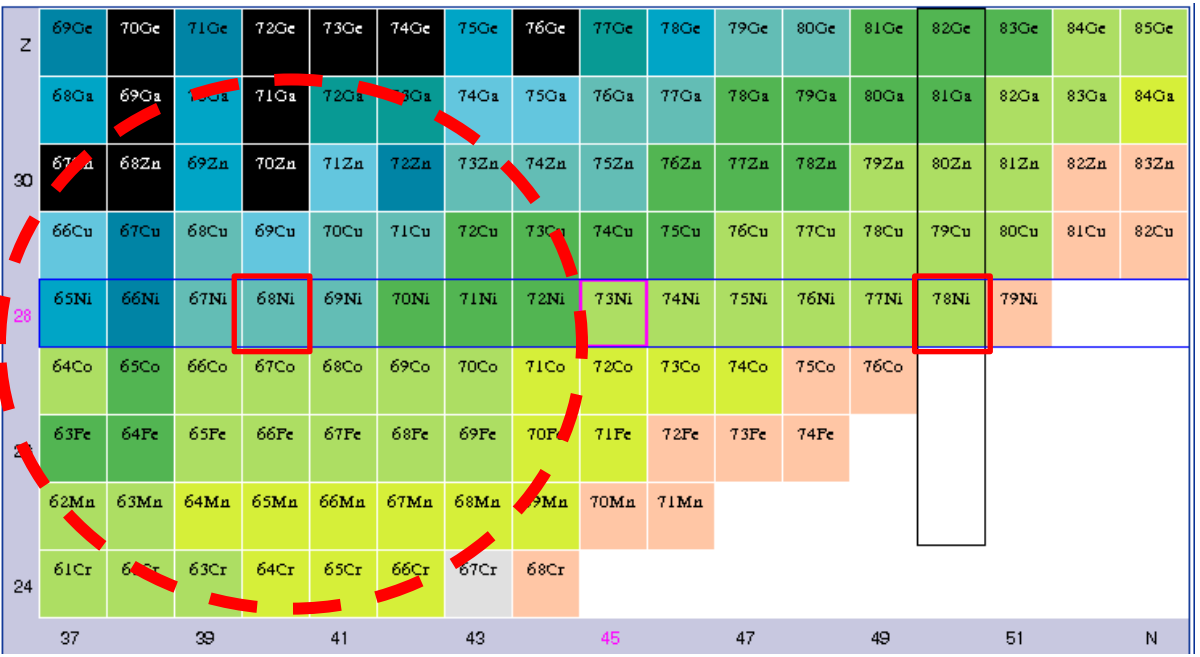
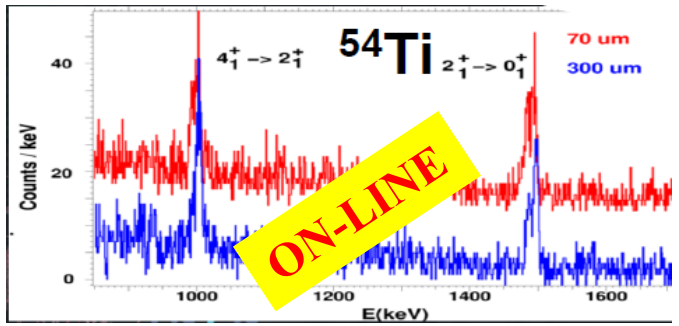


Lifetimes in ^{56}Ti and ^{55}V

2016 Data

Shape evolution: subshell closures and development of deformation



Ch. Fransen et al.

Shell evolution around Z=28

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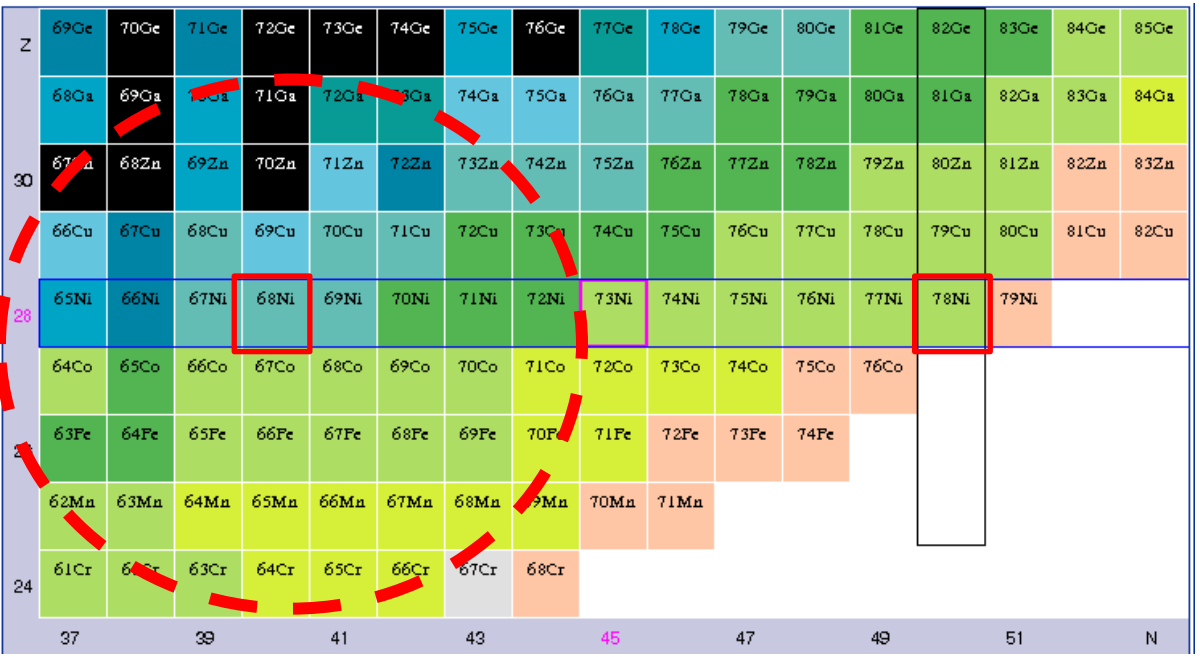
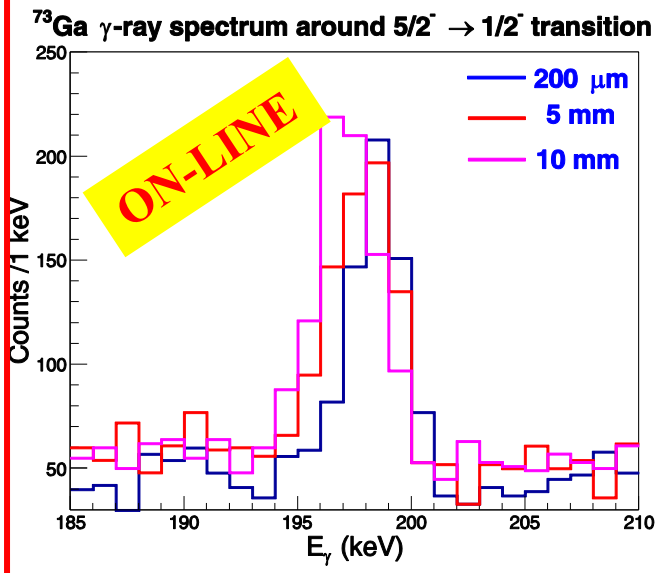


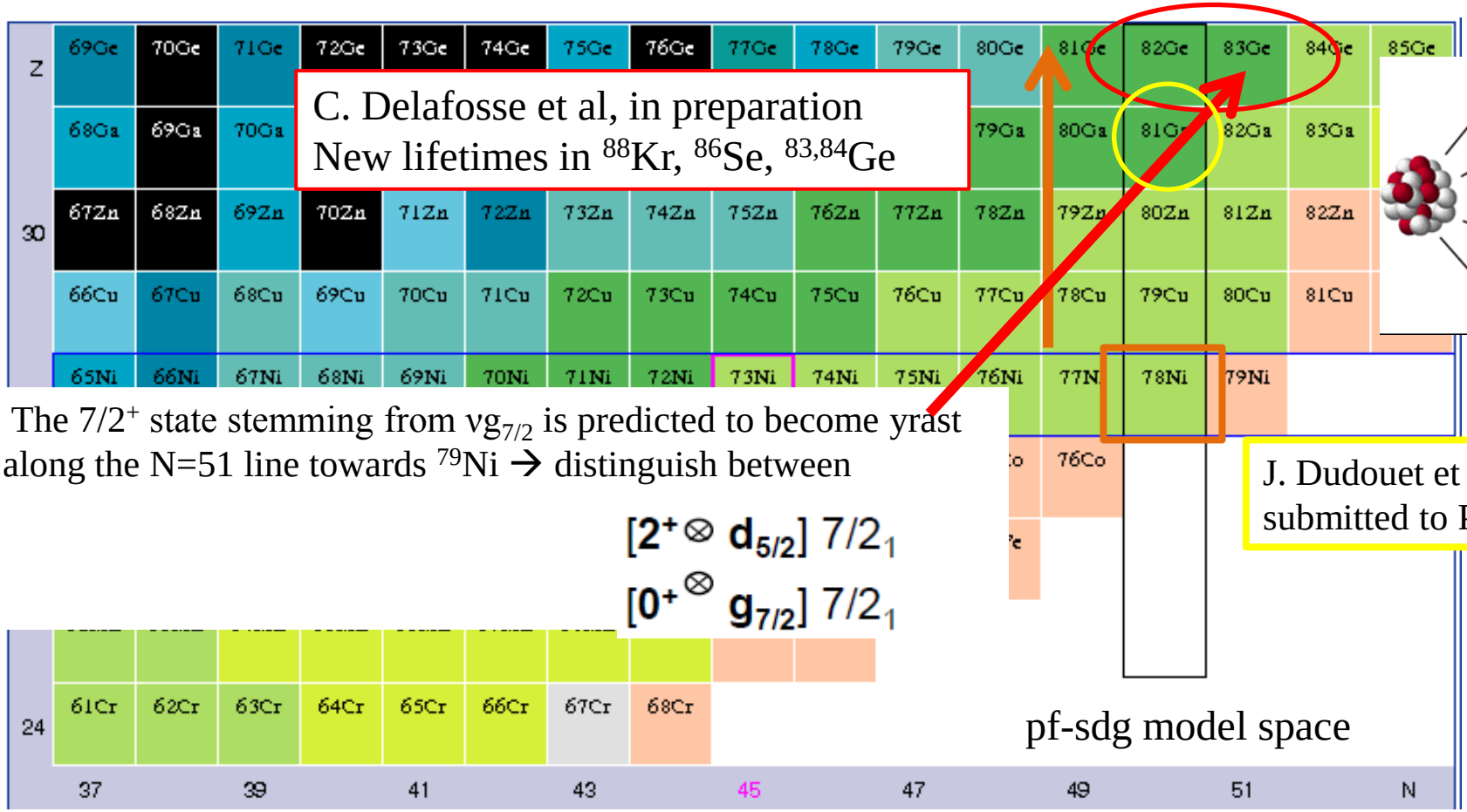
Lifetime of the $5/2^-$ state in Ga decaying to the "$1/2^-$, $3/2^-$ ground state doublet" . Determining the multipolarity



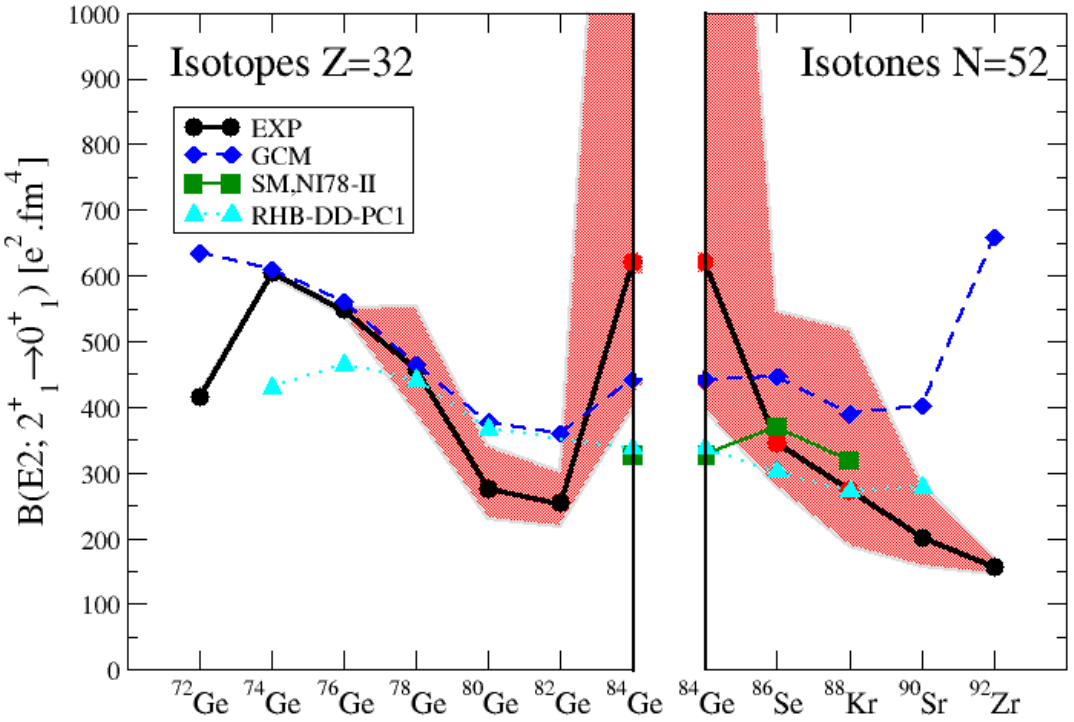
I. Celikovic, C. Michelagnoli et al.

Shell evolution around Z=28

- Understanding the single-particle evolution above N = 50 towards ^{78}Ni
- Shape transition at N=60



Lifetime at N=52 and Z=32



courtesy of C. Delafosse

Sudden rise of collectivity after the N=50 shell closure

Collectivity still rises from Se to Ge at N=52 …

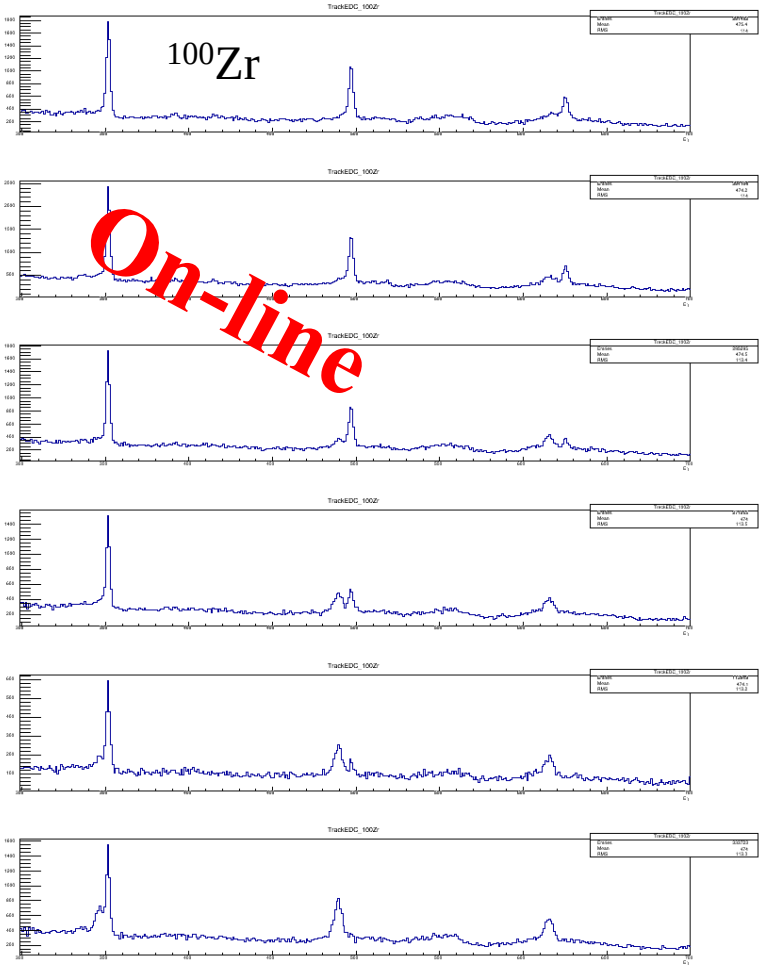
… in contradiction with shell model calculation

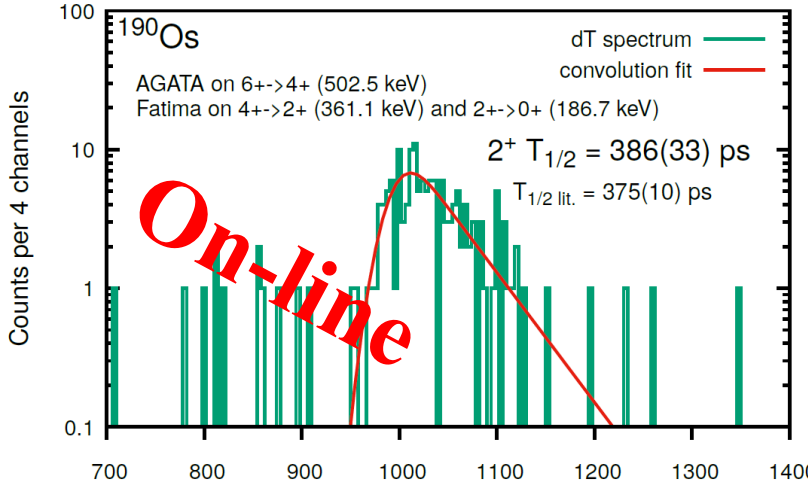
Shape evolution in fission fragments in the A~100 region

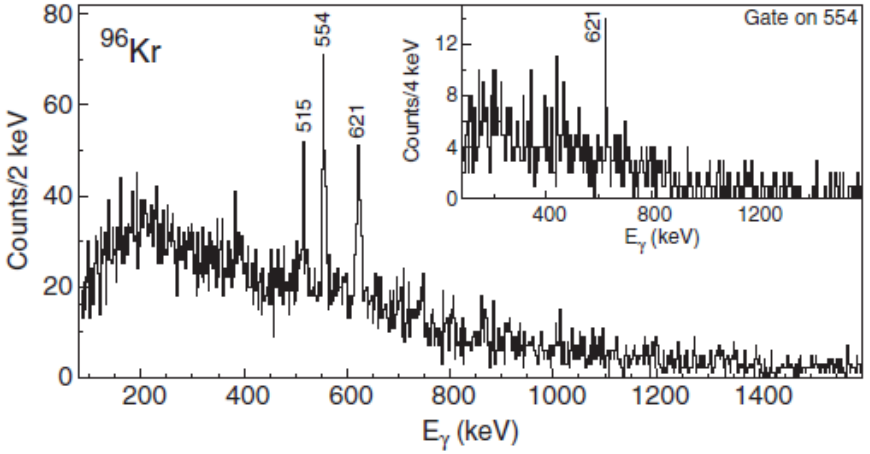
AGATA-VAMOS and a plunger + FATIMA for lifetime measurements using the ^{9}Be(^{238}U,FF) reaction

W. Korten, A. Görgen et al, 2017 Data

Ph. John 2017 Data



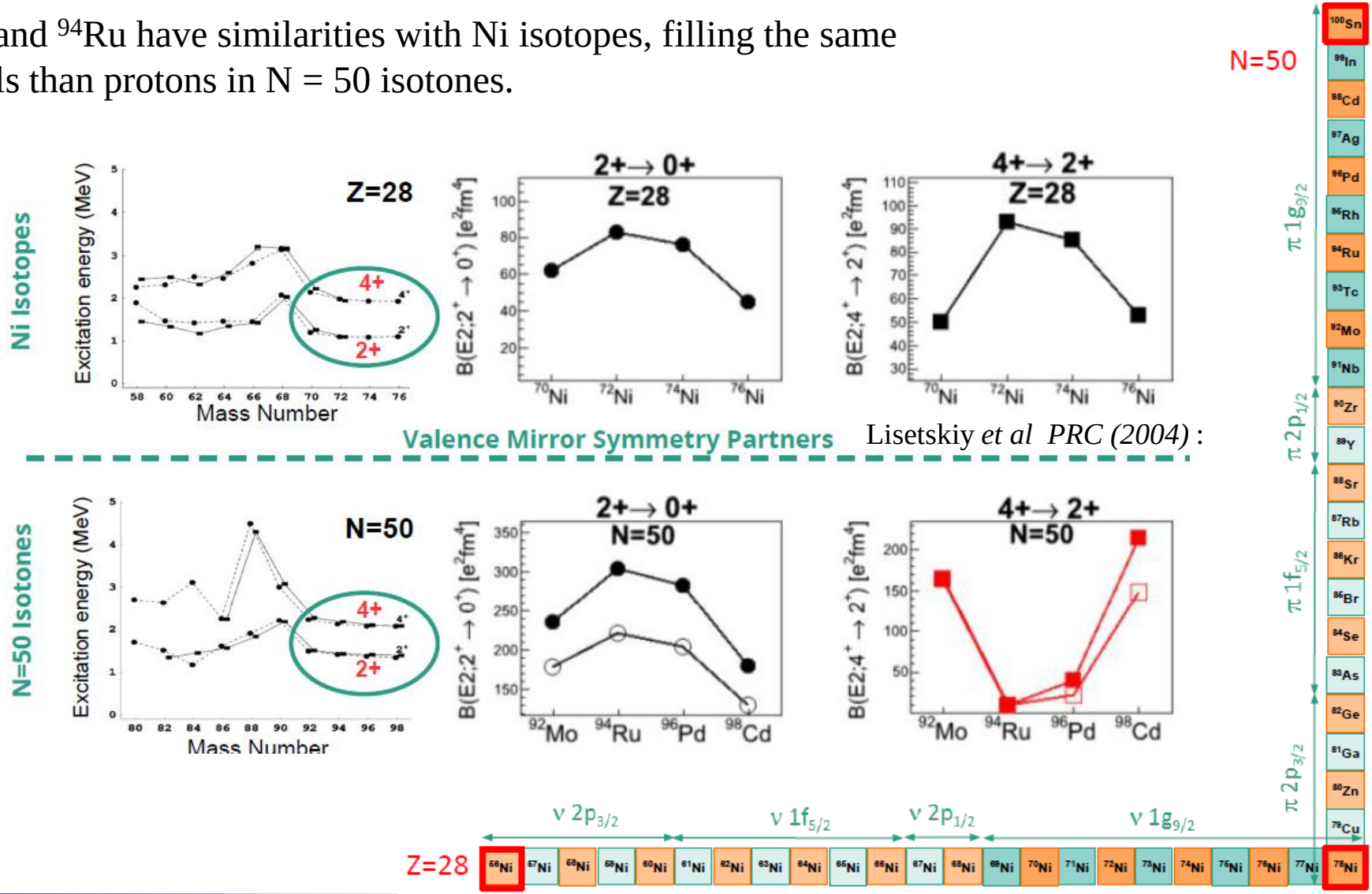




High resolution spectroscopy of ^{96}Kr
J. Dudouet et al. Phys. Rev. Lett. 118, 162501 (2017)

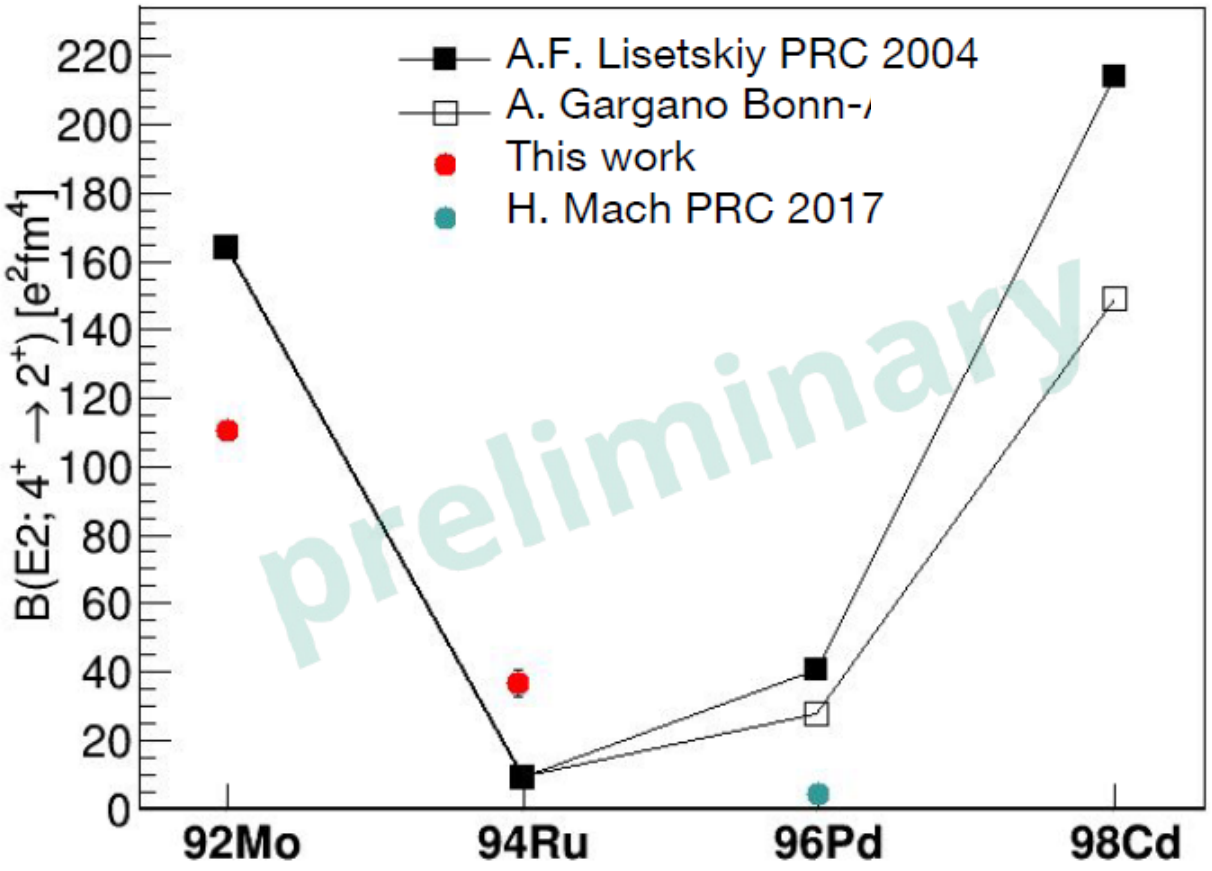
Shell evolution around ^{100}Sn

^{92}Mo and ^{94}Ru have similarities with Ni isotopes, filling the same orbitals than protons in N = 50 isotones.



courtesy of R. Perez Vidal

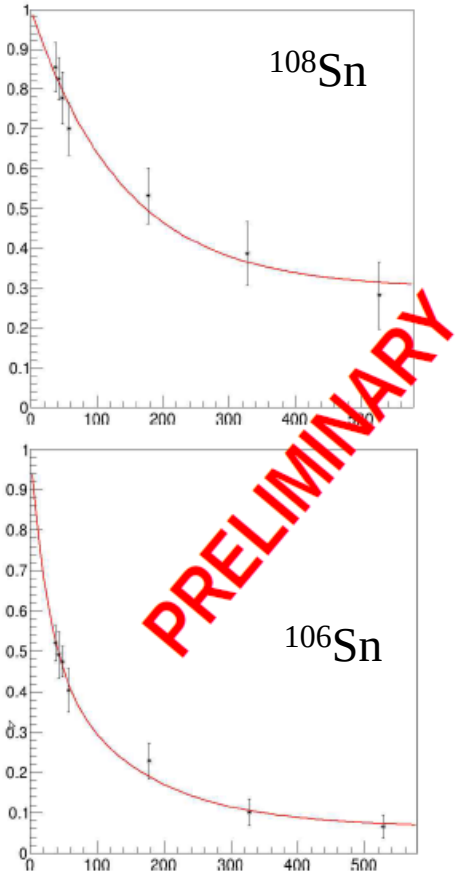
Shell evolution around ^{100}Sn



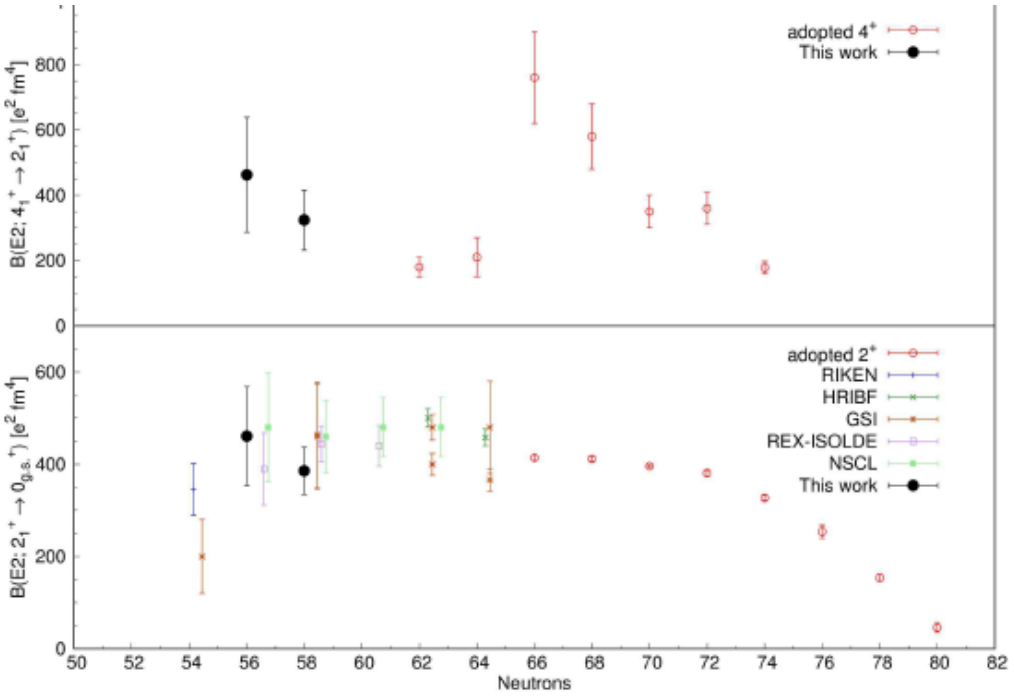
courtesy of R. Perez Vidal

Lifetime measurement in N=Z=50 region

- Examine the robustness of the proton shell closure when N=50 is approached.
- Different experimental approach (not Coulex, not fusion-evaporation)
- Use of the MNT in a charge exchange reaction from a Cd beam and control the entry point

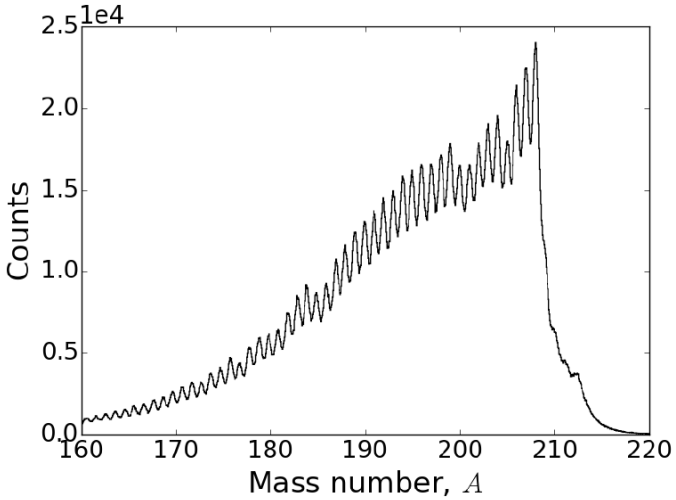


B(E2; $2^+ \rightarrow 0^+$) suffer from **large experimental uncertainties (~20%).**
Being |Ψ2+> and |Ψ4+> similar, information on the B(E2; 4+→2+) values would help to make a more robust physical interpretation

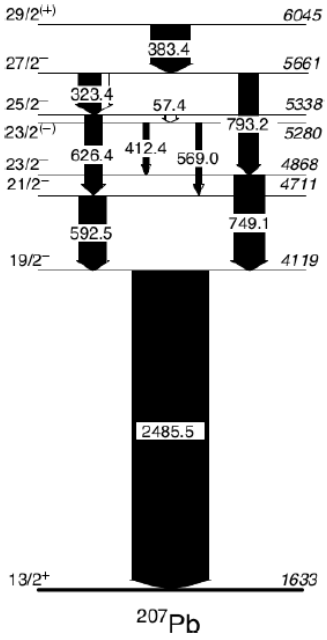


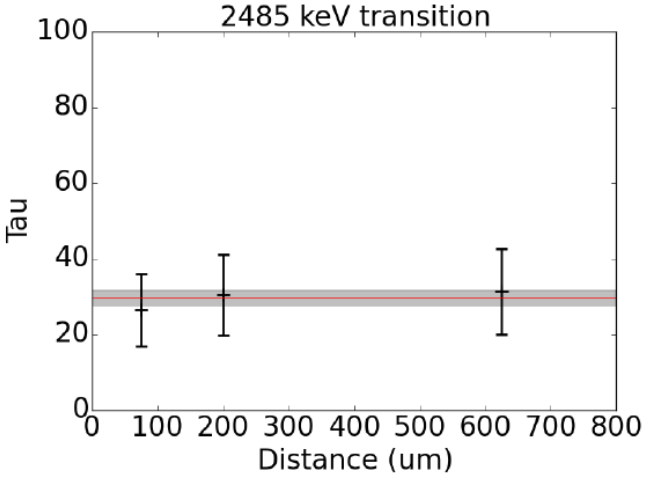
courtesy of M. Siciliano

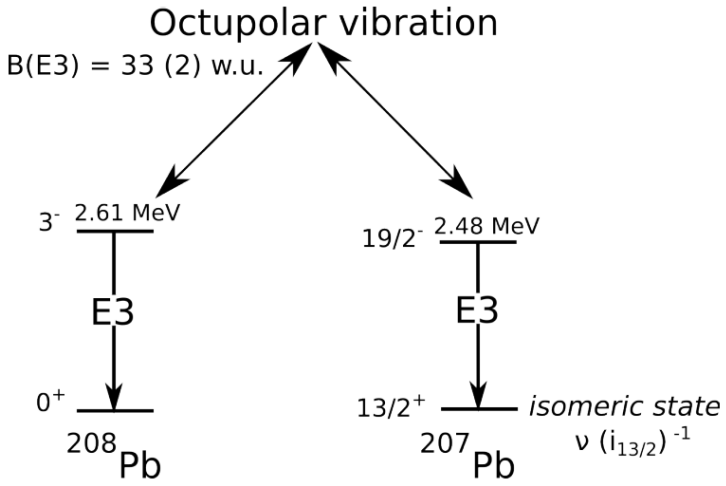
Shell evolution around ^{208}Pb



Study of the two-phonon vibrational states in the ^{208}Pb region
Case of the ^{207}Pb $\nu(i_{13/2})^{-1}$ state band structure





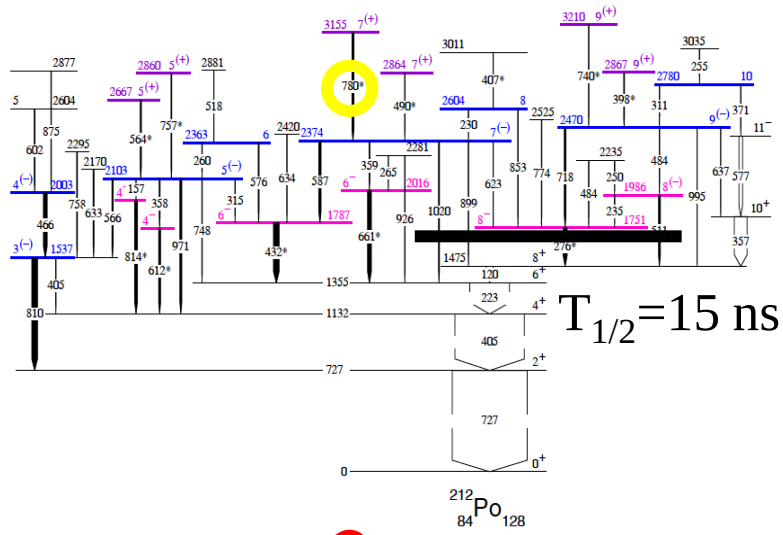


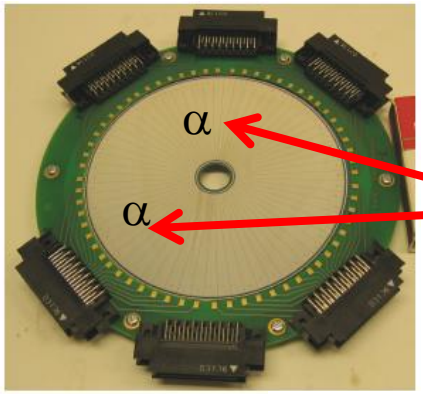
D. Ralet in preparation
D. Ralet et al., Phys.Scr. 92, 054004 (2017)

Cluster Structure

Search for the alpha cluster structure in heavy elements: case of ^{212}Po (^{208}Pb+α)

A. Jungclaus, A. Astier et al, 2017 Data



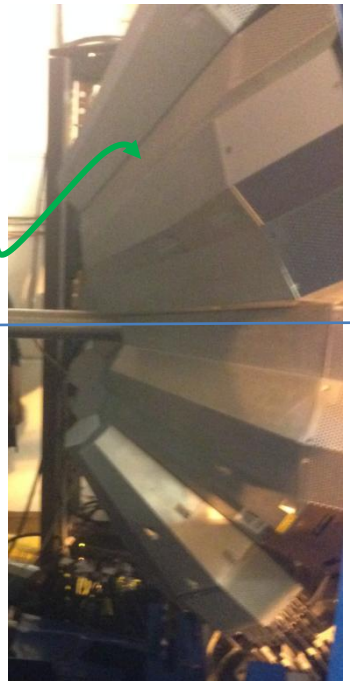


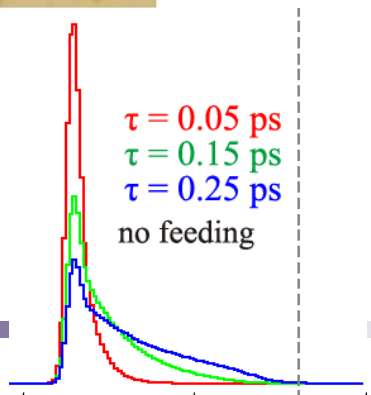
DSAM

^{212}Po

^{208}Pb

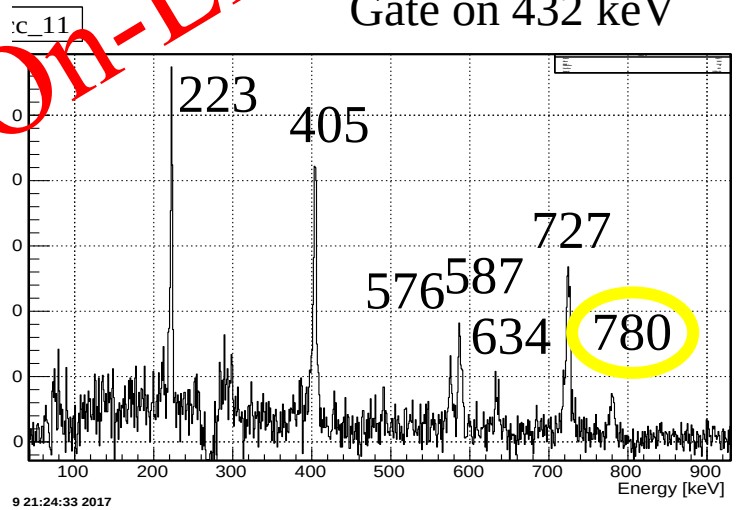
Au ^{12}C





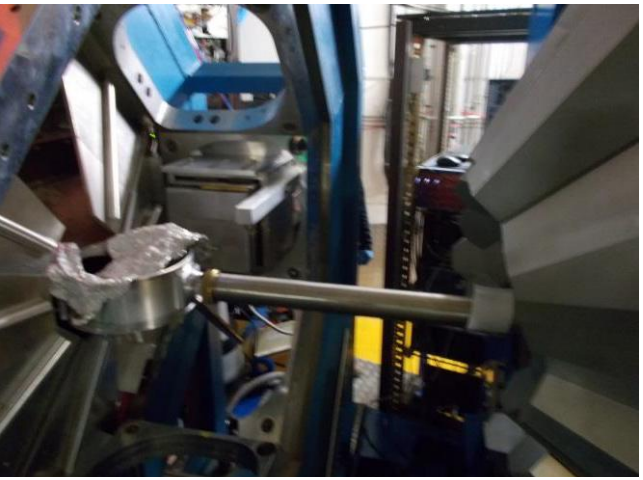
On-Line

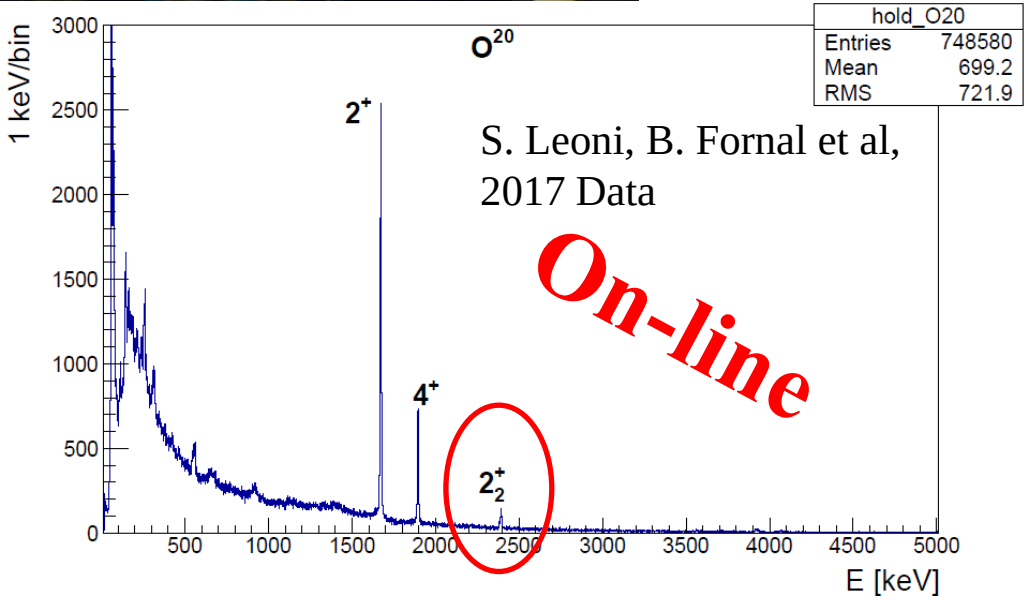
Gate on 432 keV

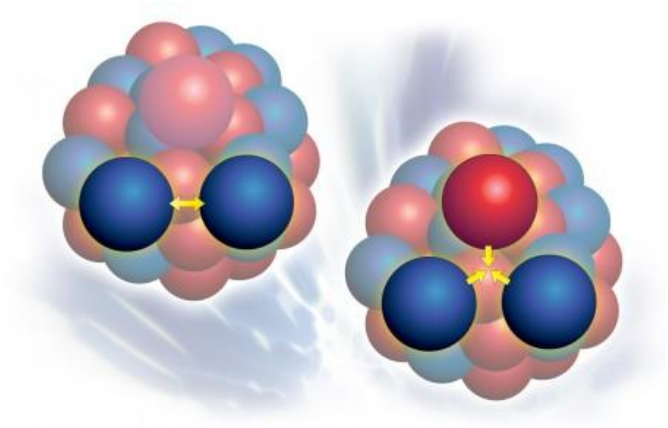


3-body contribution

Lifetime measurement in the non-yrast excited states of neutron rich C and O isotopes to probe the 3 body- contribution in the nuclear interaction



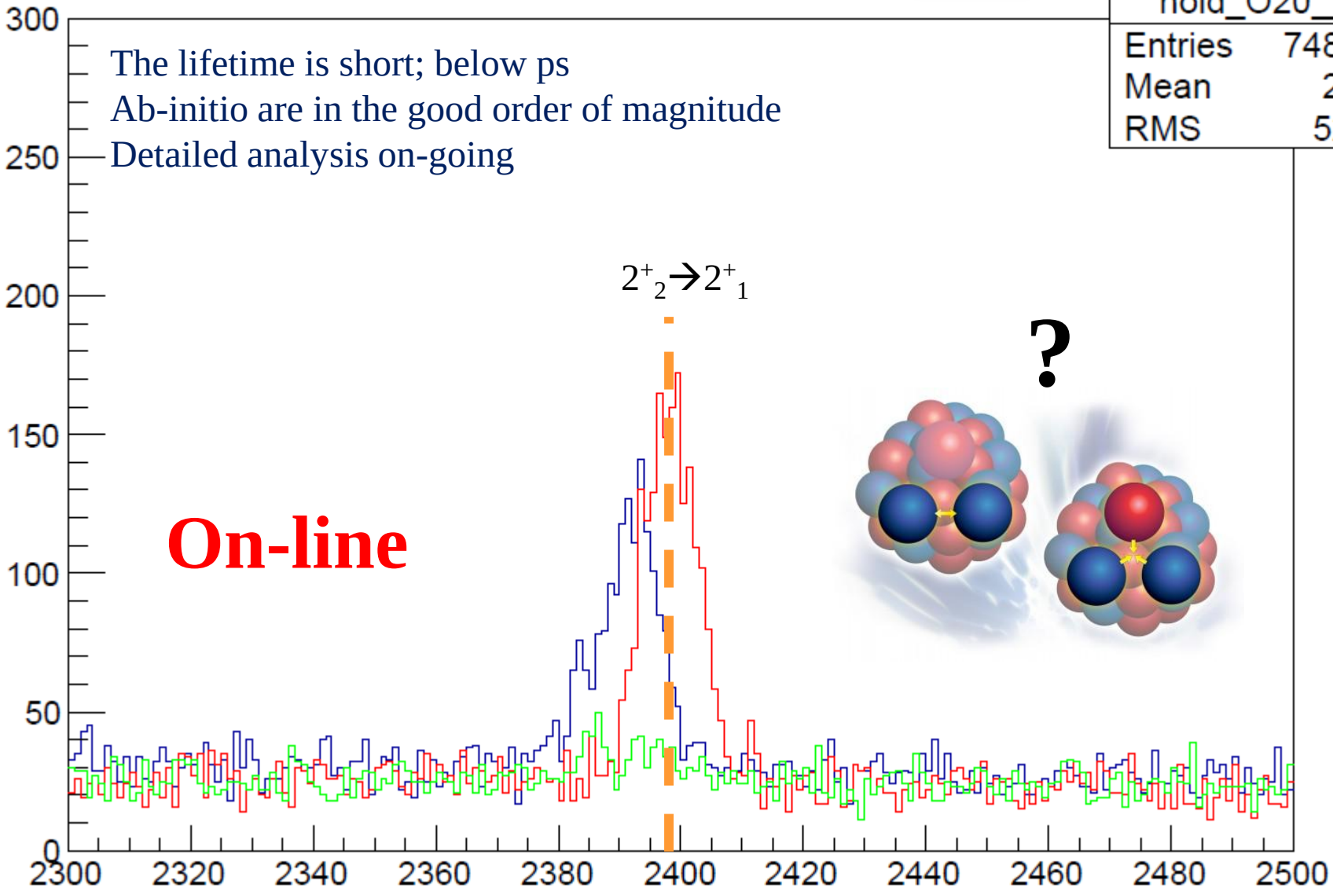




Nucleus	Excited state	Interactions: lifetime τ [ps] (*ab initio* NN)	Interactions: lifetime τ [ps] (*ab initio* NN+ NNN)	Interactions: mixing ratio δ (E2/M1) for $2^+_2 \rightarrow 2^+_1$ (*ab initio* NN)	Interactions: mixing ratio δ (E2/M1) for $2^+_2 \rightarrow 2^+_1$ (*ab initio* NN+NNN)	Experiment τ [ps]
^{16}C	2^+_1	24	24			11.4(10) - 18.3(50)
	2^+_2	**0.23**	**0.08**	**0.30**	**0.08**	< 4
^{18}C	2^+_1	19.4	20			22.4(3.5)
	2^+_2	**2.2**	**1.1**	**0.02**	**0.04**	< 4.6
^{20}O	2^+_1	10,3	11,7			10.70(40)
	2^+_2	**0.32**	**0.20**	**0.24**	**0.04**	-
^{22}O	2^+_1	**0.40**	**0.46**			0.69(28)
	2^+_2	**0.064**	**0.043**	**0.33**	**0.05**	-

Performances of AGATA

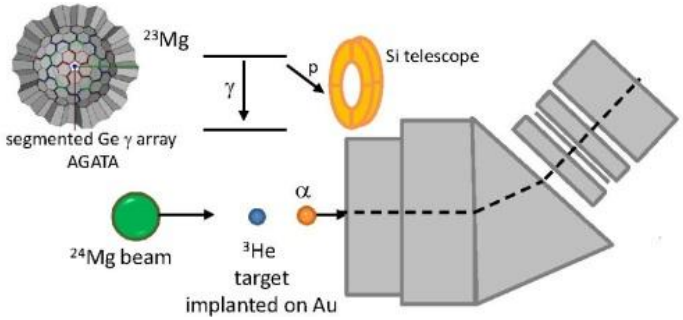
The lifetime is short; below ps
Ab-initio are in the good order of magnitude
Detailed analysis on-going

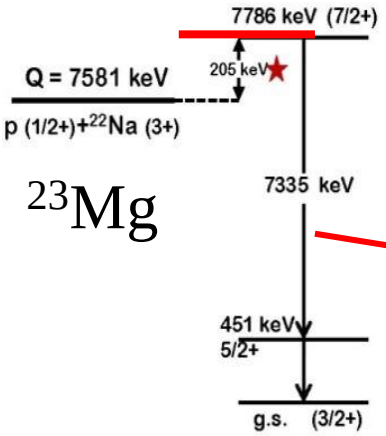


Nuclear Astrophysics

The determination of the rate of destruction of ^{22}Na is crucial for nova models

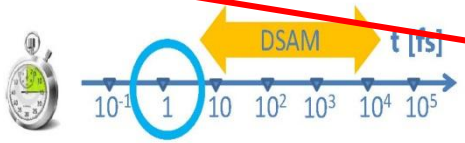
^{24}Mg(^{3}He,αγ)^{23}Mg

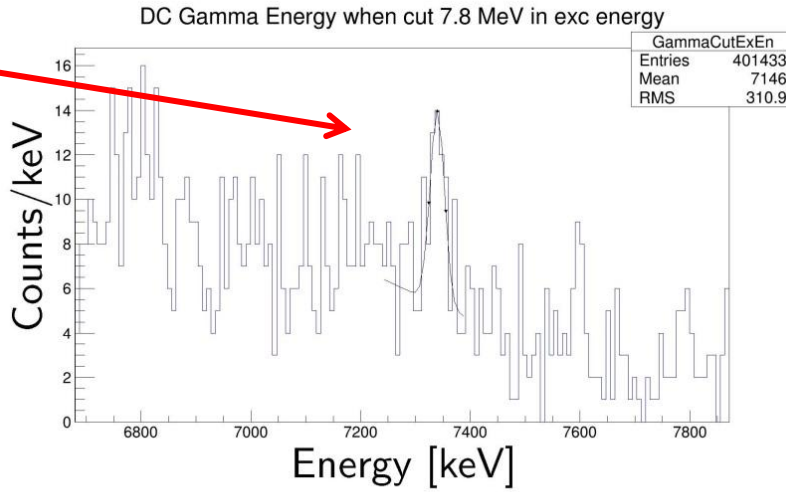




^{22}Na(p,γ)^{23}Mg

dominated by the resonance at 205 keV above threshold





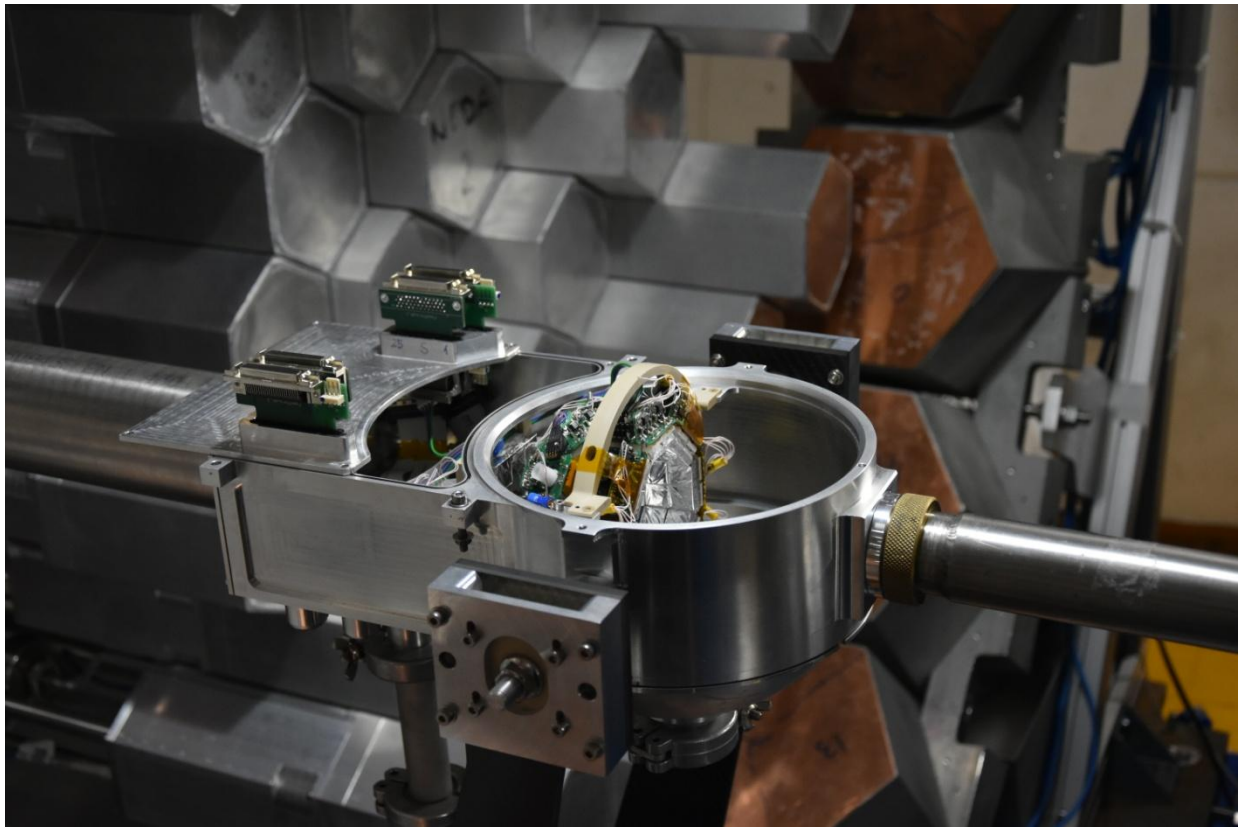
Measurement: lifetime of the 7.786 MeV state in ^{23}Mg,

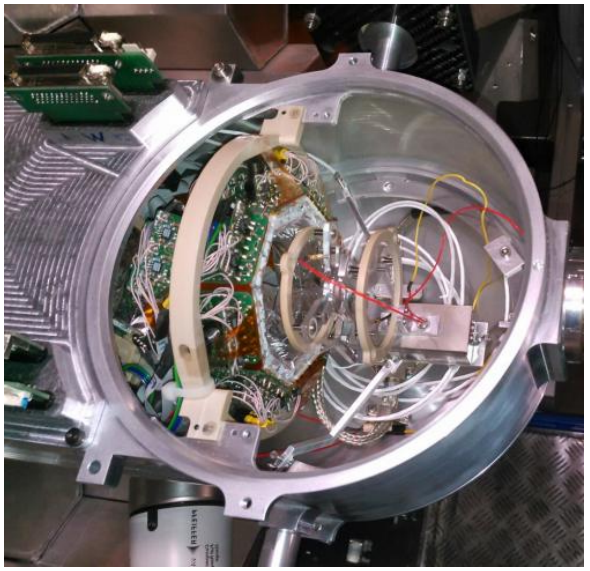
The lifetime and proton branching ratio obtained from the same experiment will provide a precise determination of the rate of the ^{22}Na(p,γ)^{23}Mg reaction

courtesy of C. Michelagnoli

2018 run *NEDA campaign*

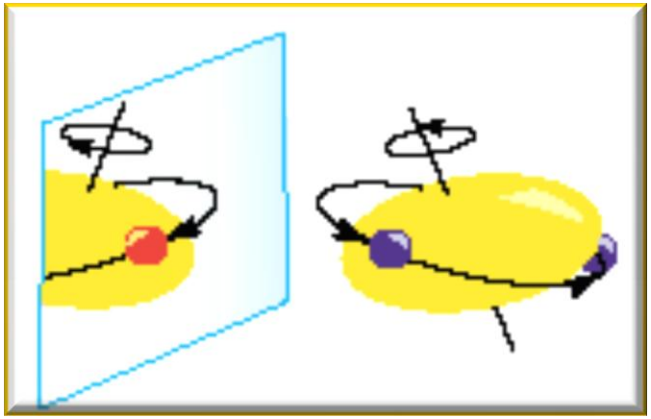
5 experiments scheduled using AGATA+NEDA +DIAMANT+plunger



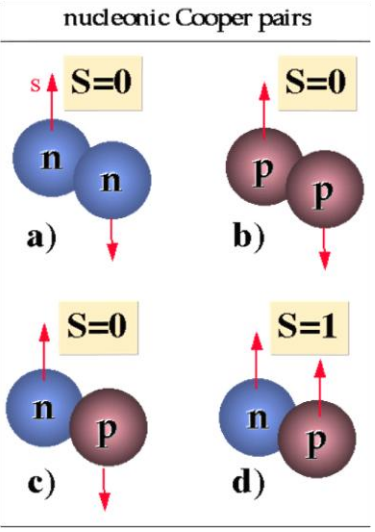


Pre-installation in G2 with in-beam tests done before Christmas 2017
Mechanical Installation completed in front of AGATA in February 2018
Last commissioning during the first week of April

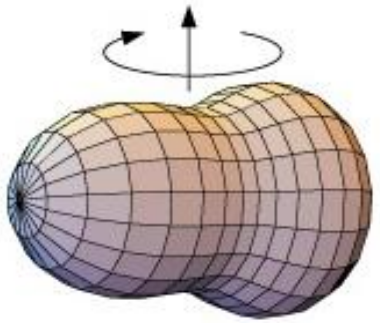
2018 run *NEDA campaign*



Isospin Symmetry Breaking in the A=63,71 mirror nuclei



Octupole correlation in ^{112}Xe



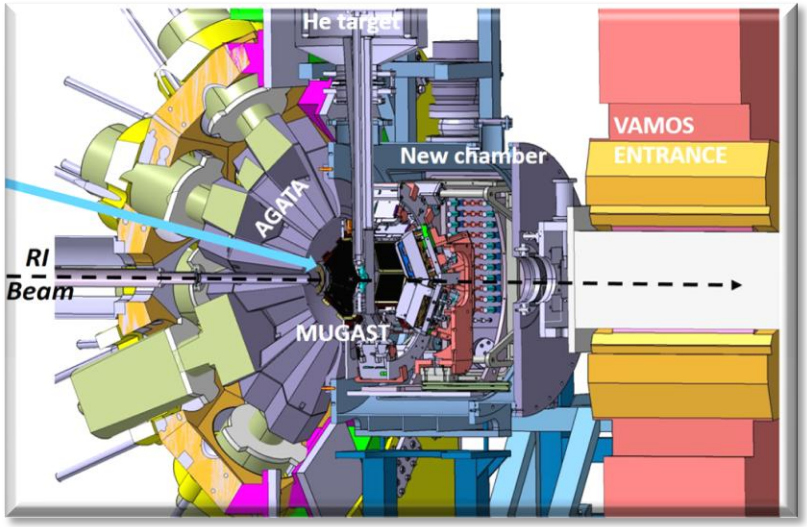
Search for isoscalar pairing in the N=Z nucleus

Studies of excited states in ^{102,103}Sn

Perspectives with SPIRAL1 ISOL beams 2019-2020

Transfer reactions using post-accelerated ISOL beams from SPIRAL1

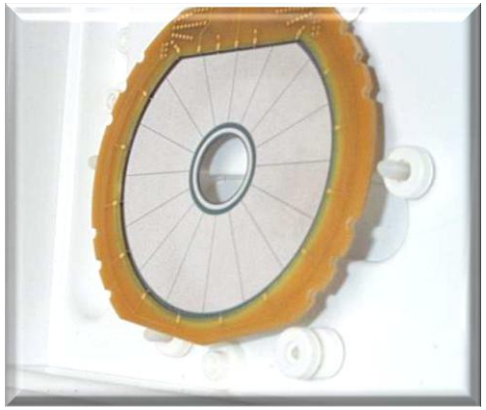
- Bound and resonant states
  - Spectroscopic Factors
  - L transferred → Spin



- Bρ and velocity measurement → vertex reconstruction
- Cryogenic Targets
- Lifetimes
  - RDDSAM
  - $LaBr_3$

Safe Coulomb excitation of radioactive using post-accelerated ISOL beams from SPIRAL1

- Reduced Transition probabilities and spectroscopic quadrupole moment



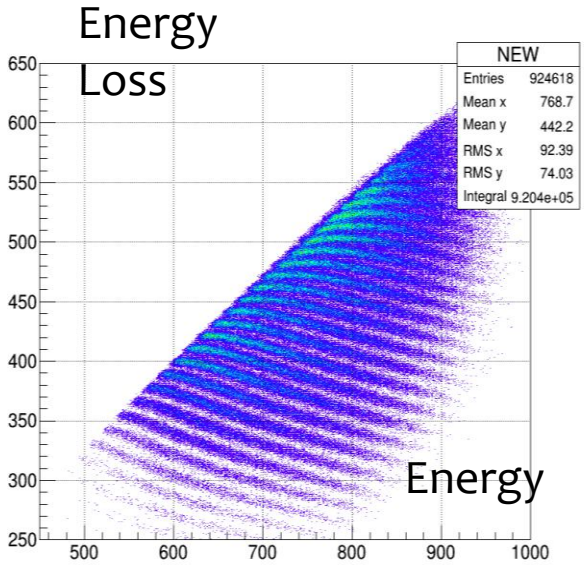
Perspectives with stable beams beyond 2020?

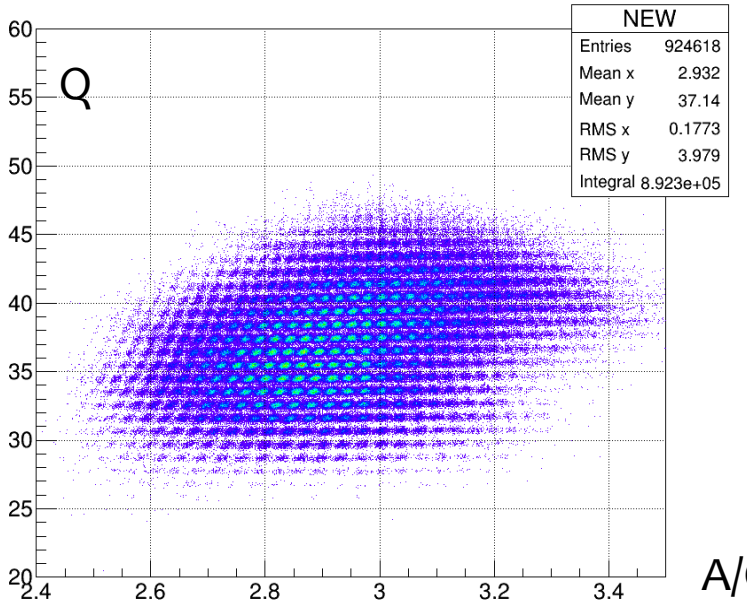
- VAMOS magnetic spectrometer : Isotopical identification - particularly successful with high intensity heaviest ion beams

- The identification techniques of heaviest species, around Pb and U can be improved

- Prompt and delayed ɣ-spectroscopy
- Lifetime measurements
- Moving towards better quantification of :
  - angular distributions
  - polarization
  - g-factor

- New stable beams could be developed

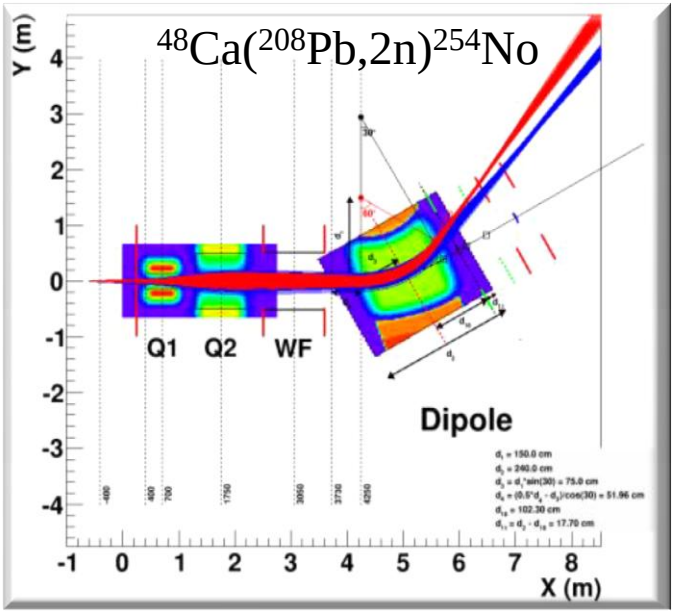




Perspectives with stable beams beyond 2020?

- Prompt ɣ-spectroscopy of heavy nuclei produced in fusion-evaporation reactions or Multi-Nucleon Transfer
- Physical separation obtained by a 0^0 degree large acceptance VAMOS gas filled separator

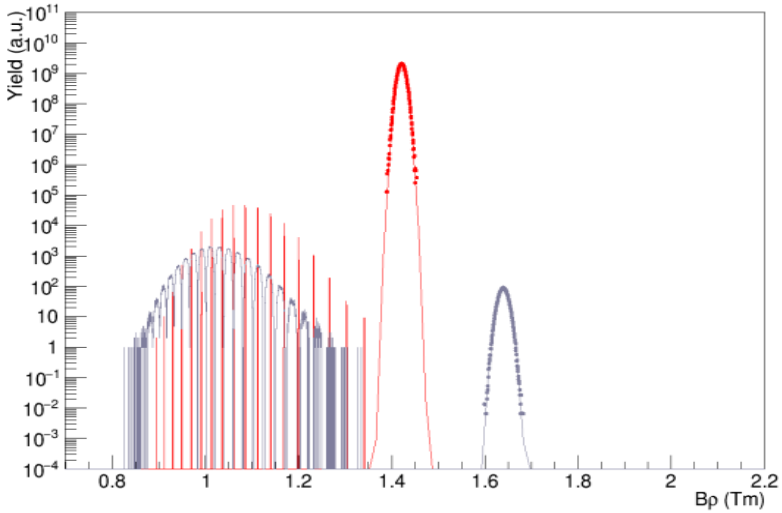
- Recoil decay tagging techniques in MUSETT
- The use of inverse kinematics could be tested $^{48}Ca(^{208}Pb,2n)^{254}No$
- Heavy beams with heavy target
- Lifetime measurements using the plunger technique



$^{136}Xe + ^{208}Pb$

Beam

Target and MNT products



Conclusion

•AGATA is operated since 2014 at GANIL and 17 experiments have been performed
- 4 Papers published (2015-2016 data)
- 5 Papers in preparation (2015 data)
- 3Technical papers in preparation
- 11 Experiments under analysis (2016-2017)
- 3 PhD defended in 2017 and 6 in preparation using GANIL data

•The number of detectors is increasing and stability of the system is improved year after year

• Many results are coming all along the nuclear chart for many different physics topics

• AGATA 1π setup at GANIL is very competitive for lifetime measurement from fs to ns in transfer, fission and fusion induced reactions

• There are a lot of opportunities which are today limited by the reduced beam time available at the facility leading to difficult choices