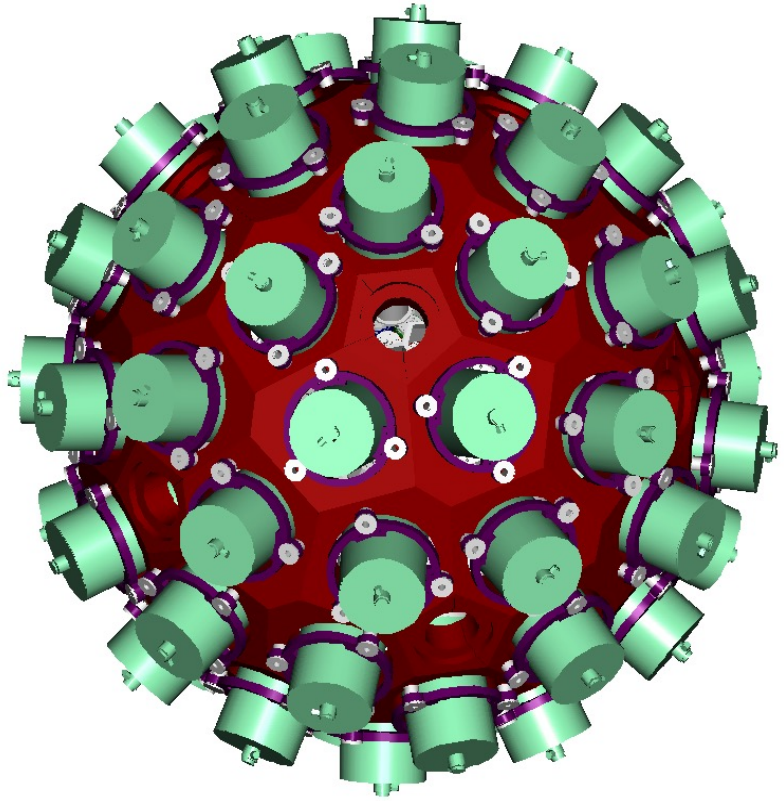
AGATA physics campaign at LNL

Magda Zielińska, CEA Saclay

Scientific Workshop on nu-Ball2, Milan, July 3-5, 2024

AGATA project



- 180 segmented crystals (60 triple units)
- 362 kg of Ge
- 82% solid angle
- counting rate: 50 kHz per Ge crystal
- angular resolution: ~1°
- efficiency: 35% (M_γ=1), 20% (M_γ=30)
- Peak/Total: ~40-50%
- large inner radius to accommodate ancillary devices

http://www.agata.org

S. Akkoyun *et al.*, Nucl. Instrum. Methods Phys. Res. A 668, 26 (2012).

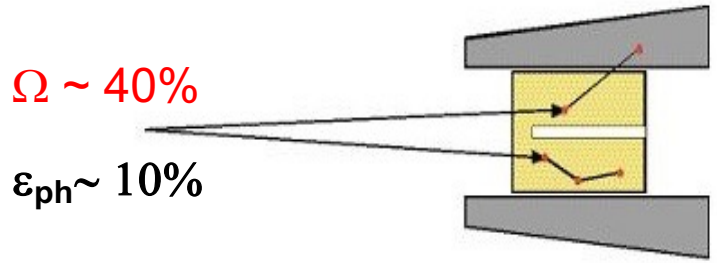
Tracking arrays

designed to maximize efficiency and peak-to-total ratio
of high-resolution γ-ray detector arrays

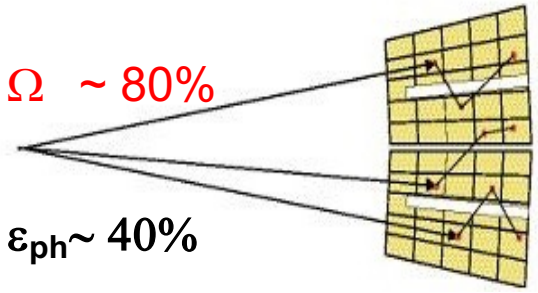
Aims:

- Maximizing the active solid angle without compromising peak-to-total ratio
- Improving the energy resolution in all experimental conditions, even at high emission velocities
- Maximizing the detector performance, even in conditions of heavy duty with radiation damage

Compton suppressed



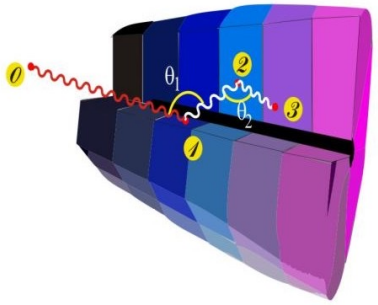
Tracking array



- Large solid angle
- Position sensitivity using PSA
- Large P/T using tracking for γ-ray reconstruction

Tracking ingredients

1



2

100 Mhz, 14 bit sampling of segment and central contact signals

3

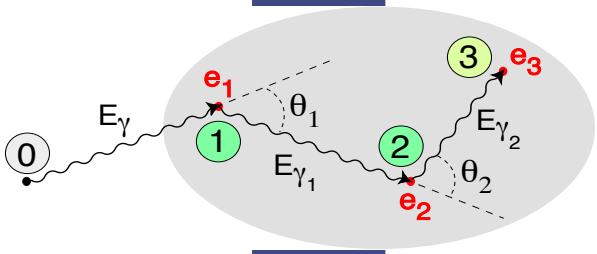
Pulse-Shape Analysis to decompose recorded waves

4

Identified interaction points

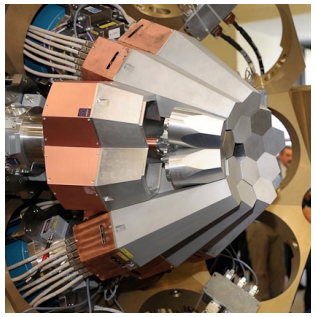
$(x,y,z,E,t)_i$

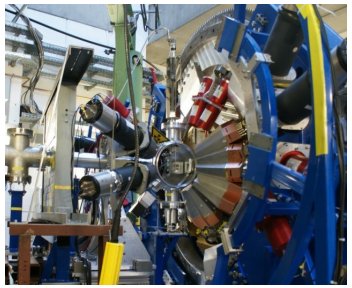
Reconstruction of photon trajectories by tracking algorithms

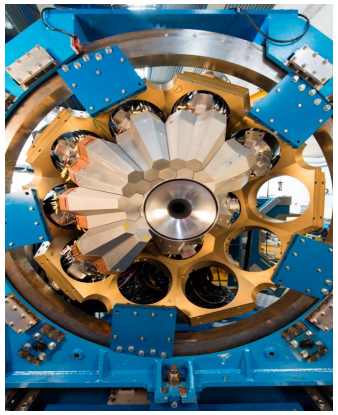


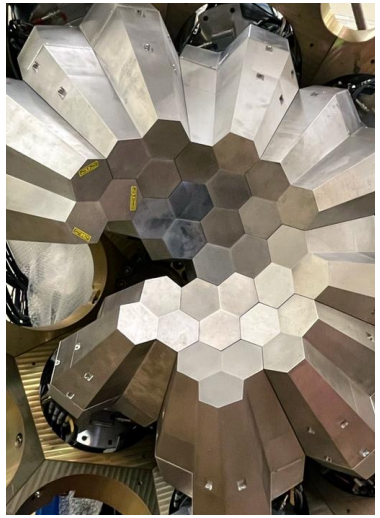
reconstructed γ-ray energies, emission and scattering directions

The AGATA timeline









Local Campaign Manager:
Jose Javier Valiente Dobón

Campaign spokesperson:
MZ

Legnaro
15 capsules
2010-2011

GSI
21 capsules
2012 - 2014

GANIL
41 capsules
2015 - 2021

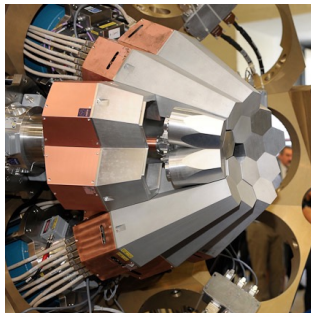
Legnaro
up to 90 capsules
2022 -

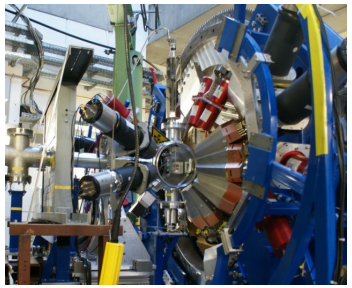
Phase 1

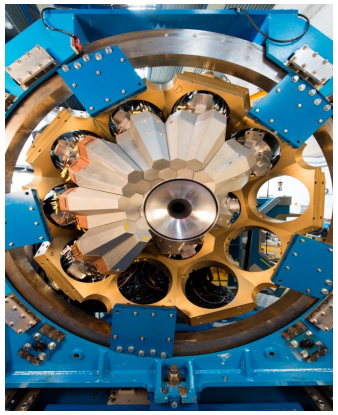
Phase 2

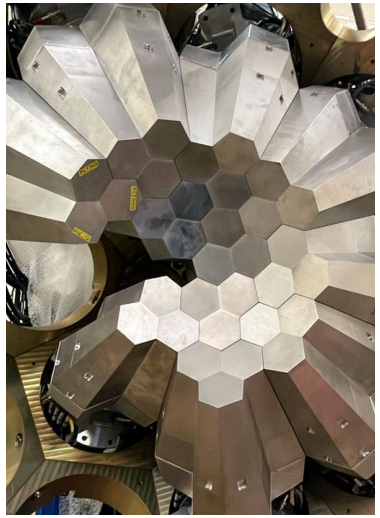
Celebration 10(+2) years

The AGATA timeline









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Legnaro
up to 90 capsules
2022 - 2026

Phase 1

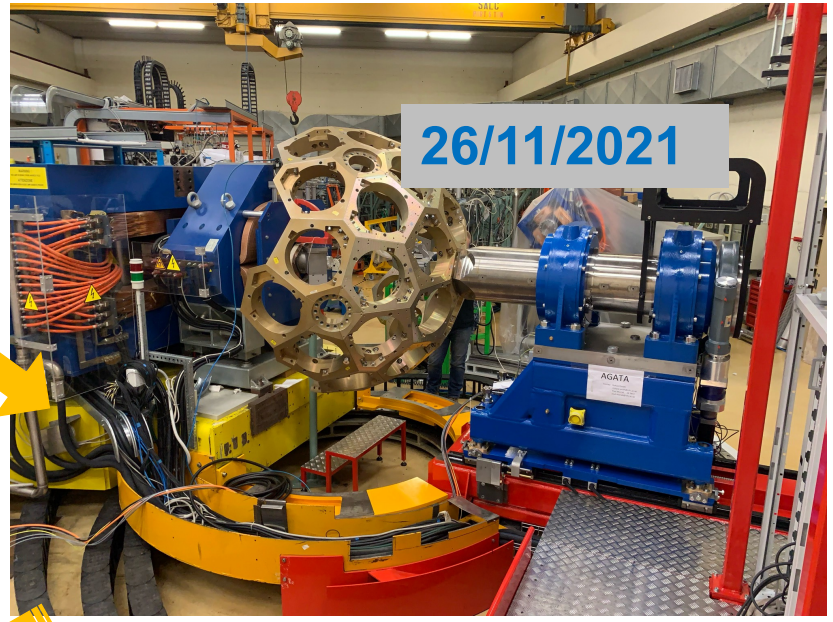
Phase 2

Taking on board the recommendations of the ACC, the ASC agreed to extend the stay in LNL until 31/12/2026. This allows the science programme at LNL in AGATA's current configuration and the zero-degree campaign to be performed.

Celebration 10(+2) years

AGATA installation at LNL

Ground breaking 10/3/2021



Commmissioning 26/4/2022

Since then: more than a year of beam-on-target time!

Two different configurations

Nuclear Inst. and Methods in Physics Research, A 1049 (2023) 168040

Contents lists available at ScienceDirect

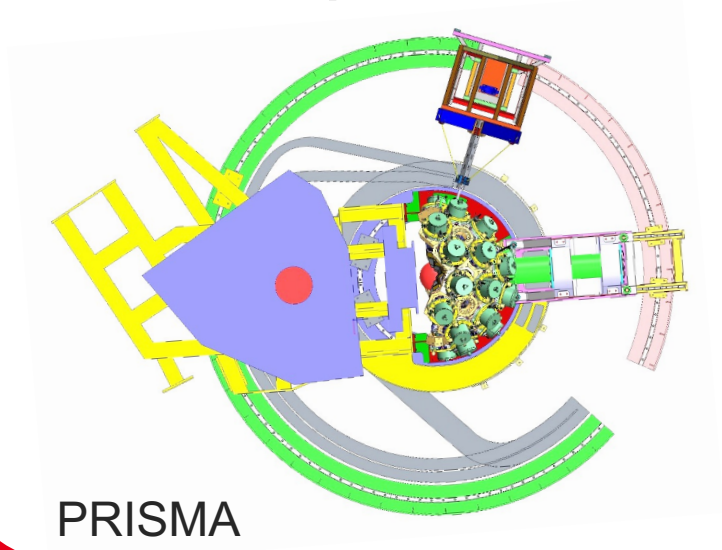
Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Full Length Article

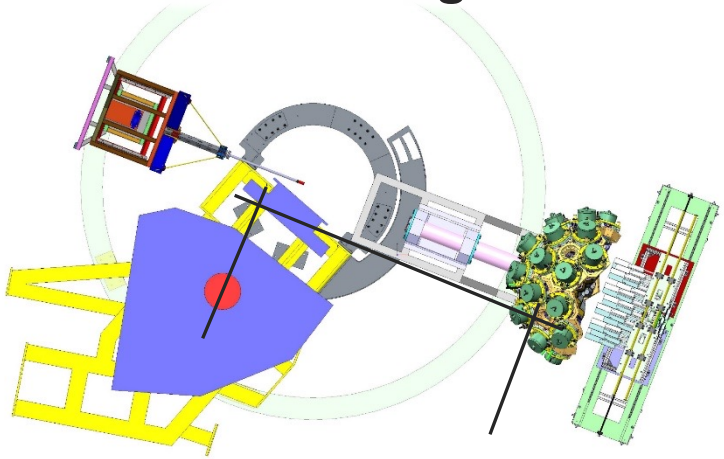
Conceptual design of the AGATA 2π array at LNL

AGATA coupled with PRISMA



PRISMA

AGATA zero degrees

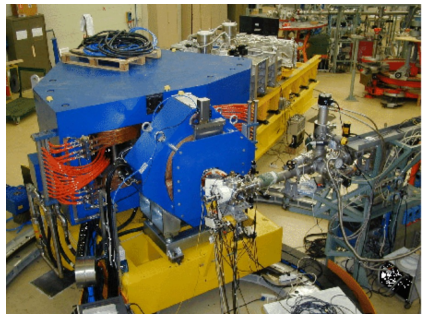


NEDA

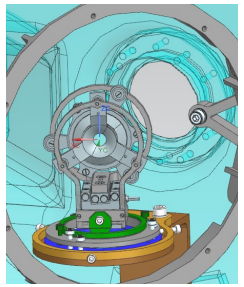
TANDEM + PIAVE + ALPI beams
SPES beams

Current configuration: commissioning 26/4/2022

Complementary detectors

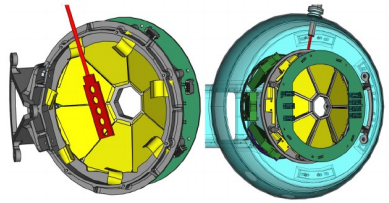


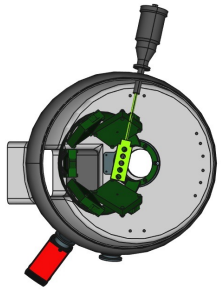
PRISMA

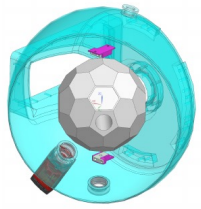


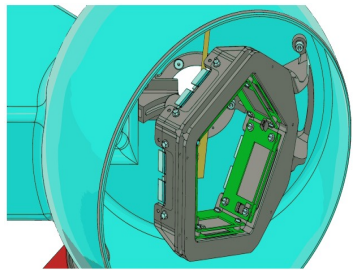
SPIDER
DANTE
Plunger

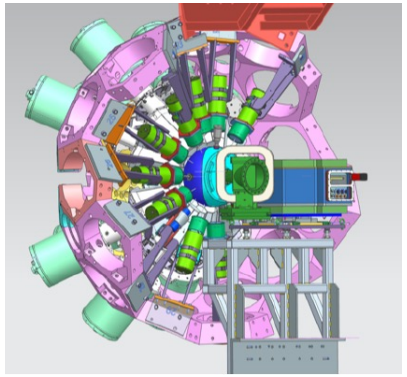
GAL-TRACE
EUCLIDES
Gamma-ray scintillators



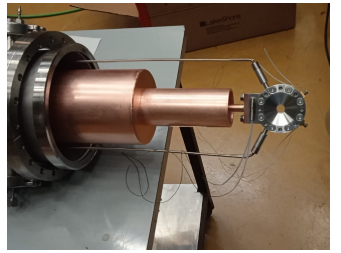


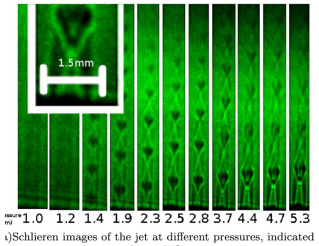






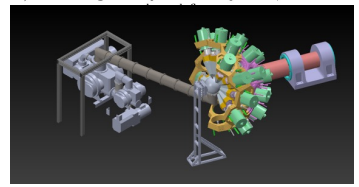
Targets: CTADIR + SUGAR

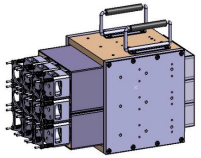




a)Schlieren images of the jet at different pressures, indicated

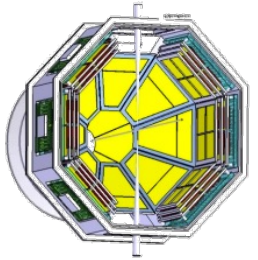
PARIS





SLICES
CHYMENE
TRACE

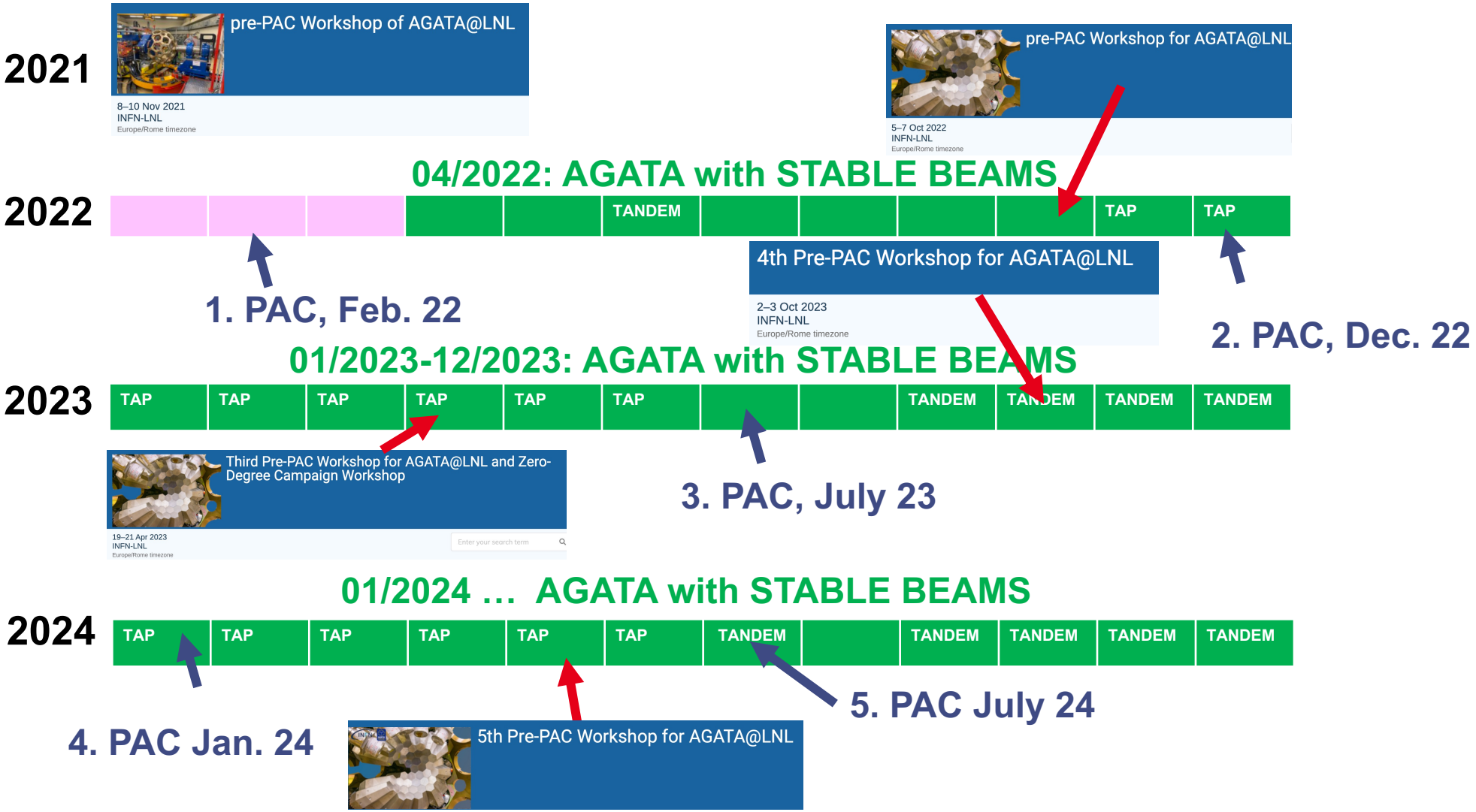
NEDA



GRIT

2022-2024 campaign: timeline and experimental constraints

- stable beams from the Tandem-ALPI-PIAVE complex
- ancillaries compatible with PRISMA



PAC meetings at LNL

February 21-23, 2022
TAP beams

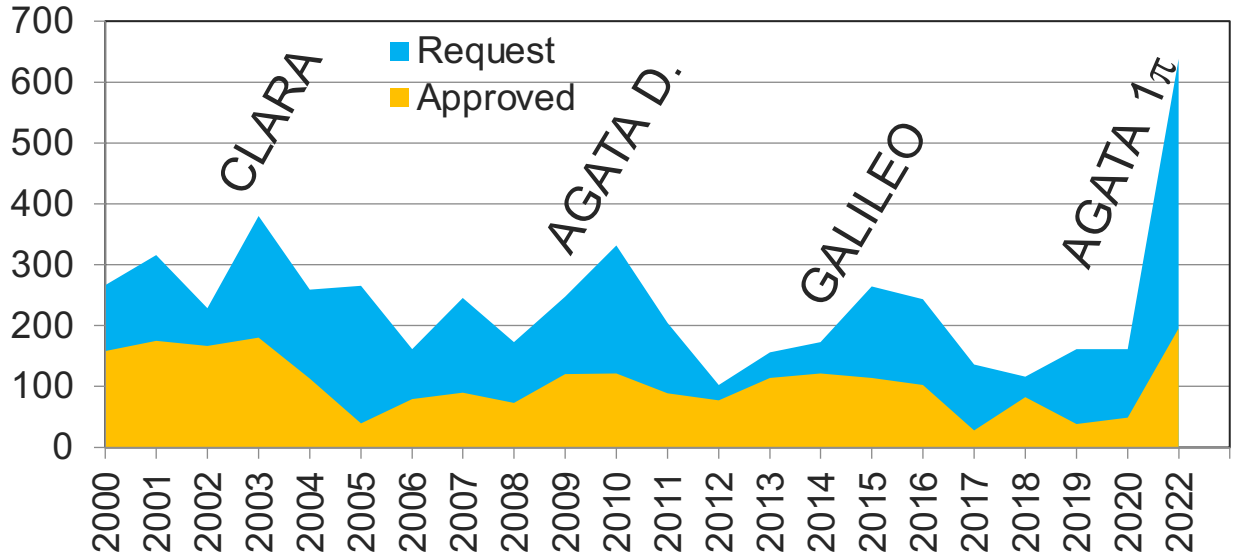
28 proposals submitted
- **10** (+3 commissioning) priority A
- **5** priority B

December 5-6, 2022
TAP beams

24 proposals submitted
- **6** priority A
- **10** priority B

July 10-12, 2023
TANDEM only beams

15 proposals submitted
- **8** priority A
- **3** priority B



January 22-24, 2024
TAP beams

18 proposals submitted
- **7** priority A
- **4** priority B

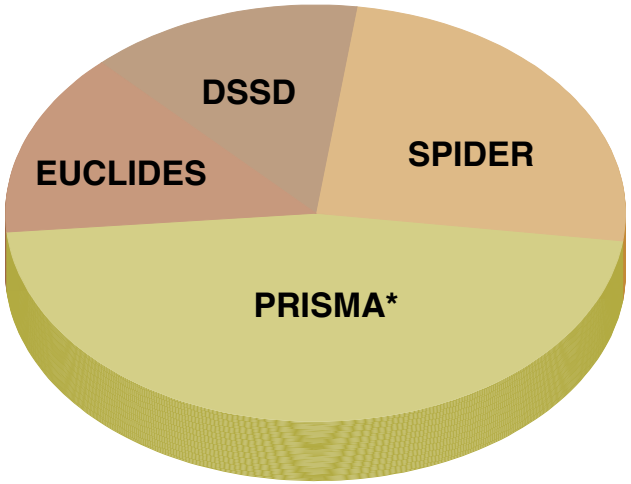
July 15-16, 2024
TANDEM only beams

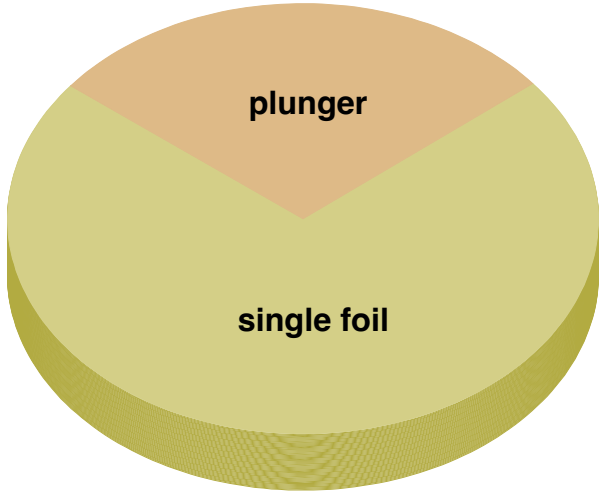
9 proposals submitted

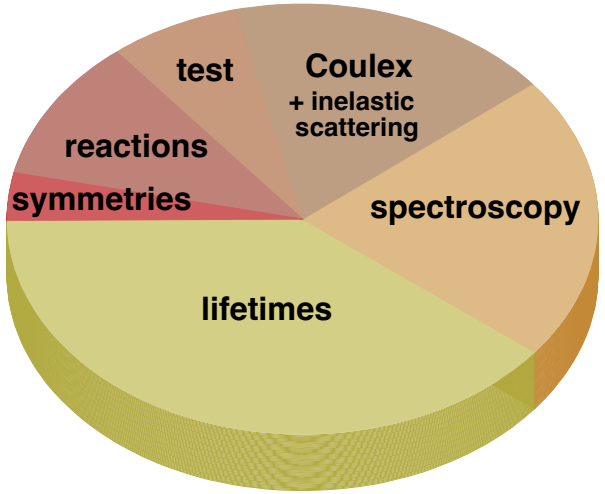
April 2022-June 2023: 22 experiments – 9 months of beam time for AGATA - 80% beam time (without beam preparation)

A total of 32 experiments performed since the campaign began (not counting the commissioning)

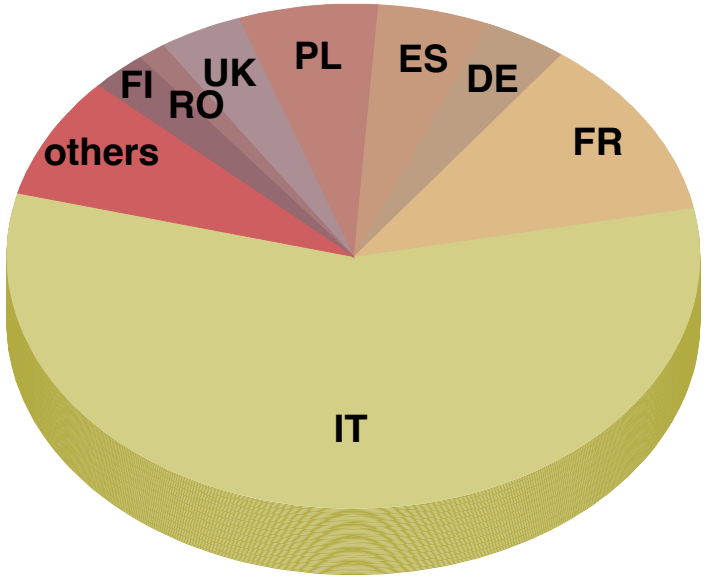
Accepted proposals (priority A + scheduled priority B)







- Experiments involving PRISMA constitute almost one half of the total (plot includes those that use DANTE or LaBr together with PRISMA)
- Good balance between spectroscopy, lifetime measurements (plunger and DSAM), and Coulomb excitation/inelastic scattering; reaction mechanism studies important
- Good representation of most countries of the AGATA collaboration among the spokespersons, with a fair participation of other countries

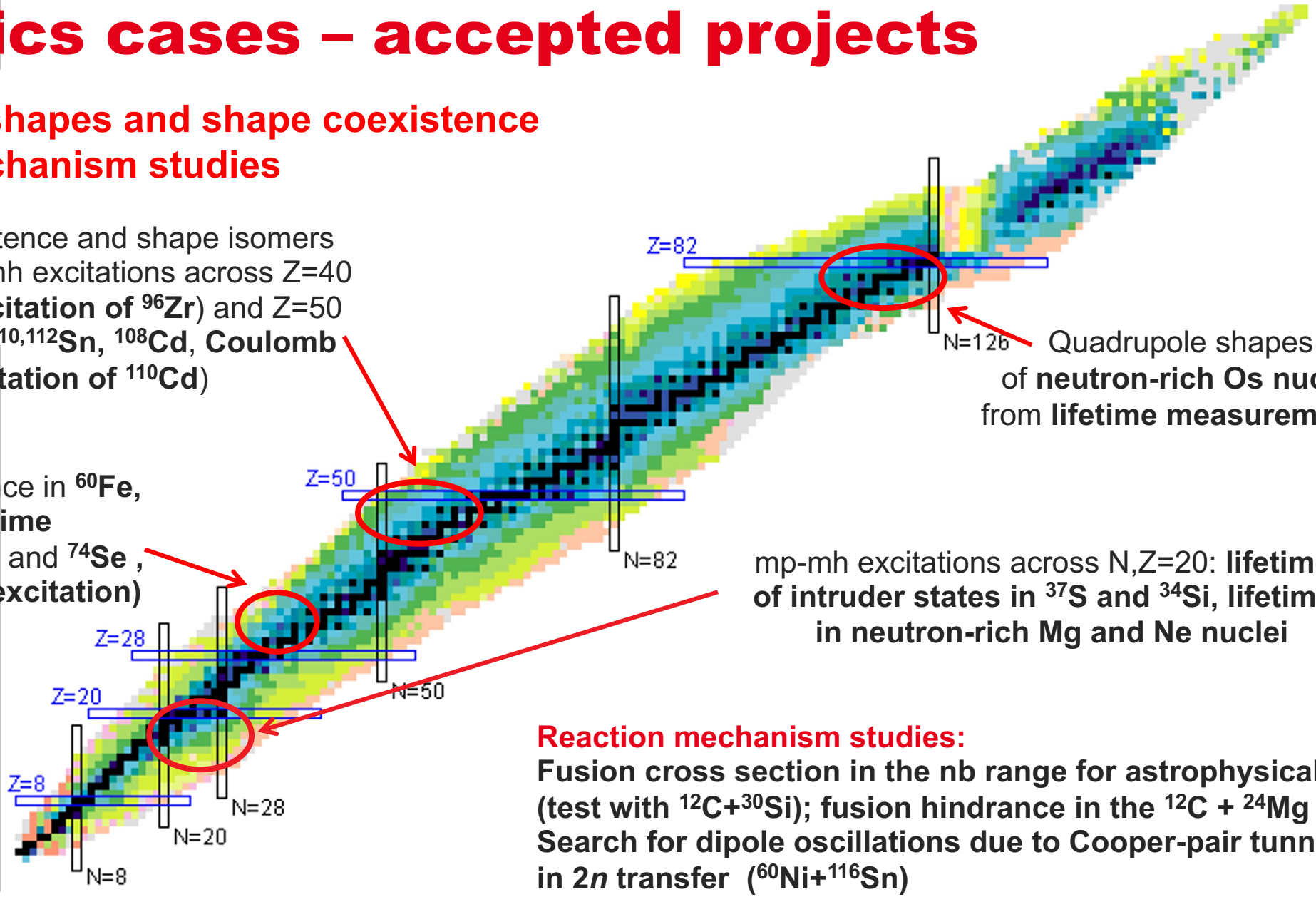


Physics cases – accepted projects

Quadrupole shapes and shape coexistence
Reaction mechanism studies

Shape coexistence and shape isomers related to mp-mh excitations across Z=40 (**Coulomb excitation of ^{96}Zr**) and Z=50 (**lifetimes in ^{110,112}Sn, ^{108}Cd**, **Coulomb excitation of ^{110}Cd**)

Shape coexistence in **^{60}Fe, ^{60}Zn (lifetime measurements)** and **^{74}Se , ^{60}Ni (Coulomb excitation)**



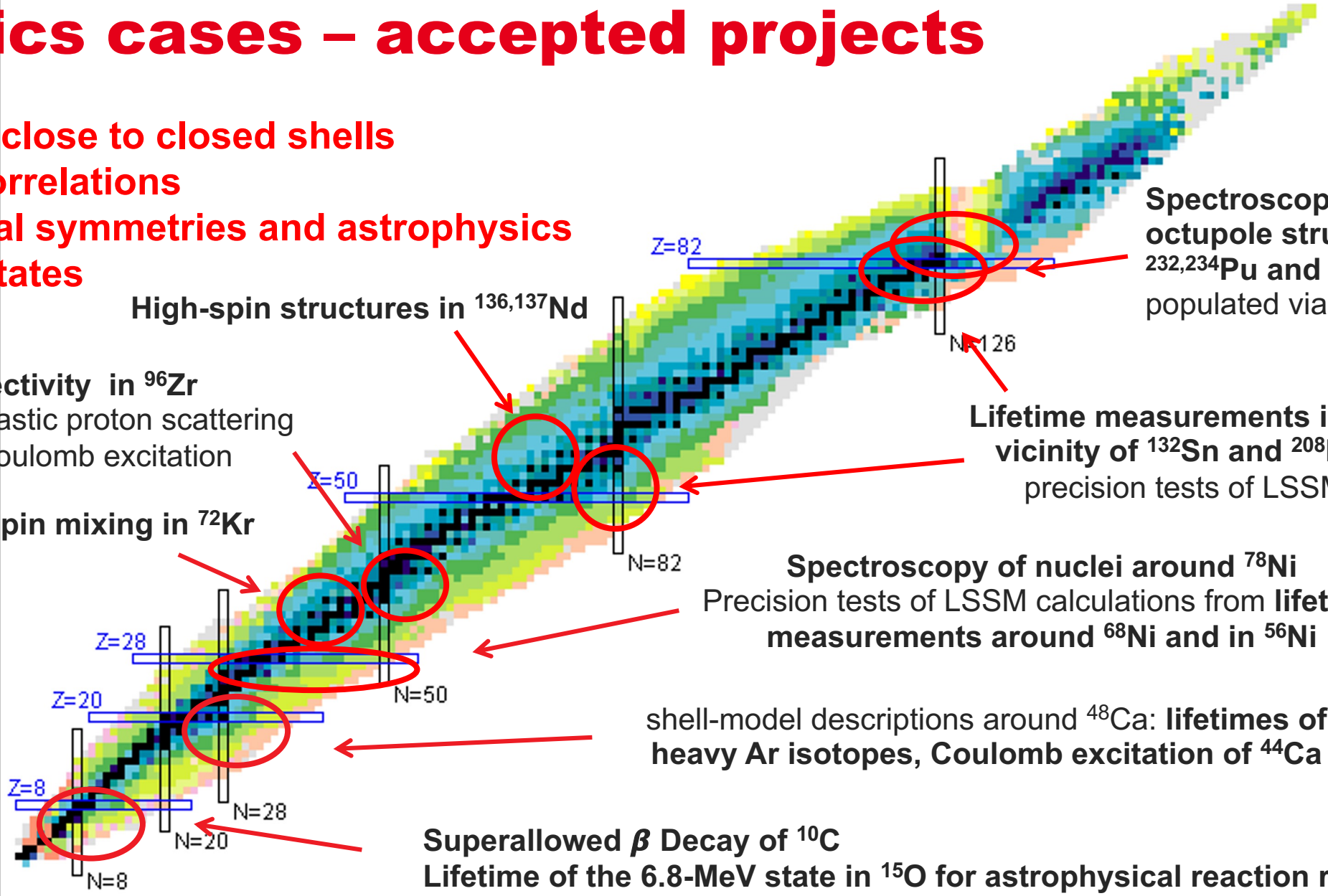
Quadrupole shapes of **neutron-rich Os nuclei** from **lifetime measurements**

mp-mh excitations across N,Z=20: **lifetimes of intruder states in ^{37}S and ^{34}Si, lifetimes in neutron-rich Mg and Ne nuclei**

Reaction mechanism studies:
Fusion cross section in the nb range for astrophysical scenarios (test with ^{12}C+^{30}Si); fusion hindrance in the ^{12}C + ^{24}Mg system
Search for dipole oscillations due to Cooper-pair tunnelling in 2*n* transfer (^{60}Ni+^{116}Sn)
Probing nucleon-nucleon correlations (^{48}Ca+^{208}Pb)

Physics cases – accepted projects

Collectivity close to closed shells
Octupole correlations
Fundamental symmetries and astrophysics
High-spin states



High-spin structures in ^{136,137}Nd

Octupole collectivity in ^{96}Zr
studied via inelastic proton scattering and "unsafe" Coulomb excitation

Isospin mixing in ^{72}Kr

Spectroscopy of octupole structures in ^{232,234}Pu and $^{224\text{-}228}$U populated via MNT

Lifetime measurements in the vicinity of ^{132}Sn and ^{208}Pb: precision tests of LSSM

Spectroscopy of nuclei around ^{78}Ni
Precision tests of LSSM calculations from **lifetime measurements around ^{68}Ni and in ^{56}Ni**

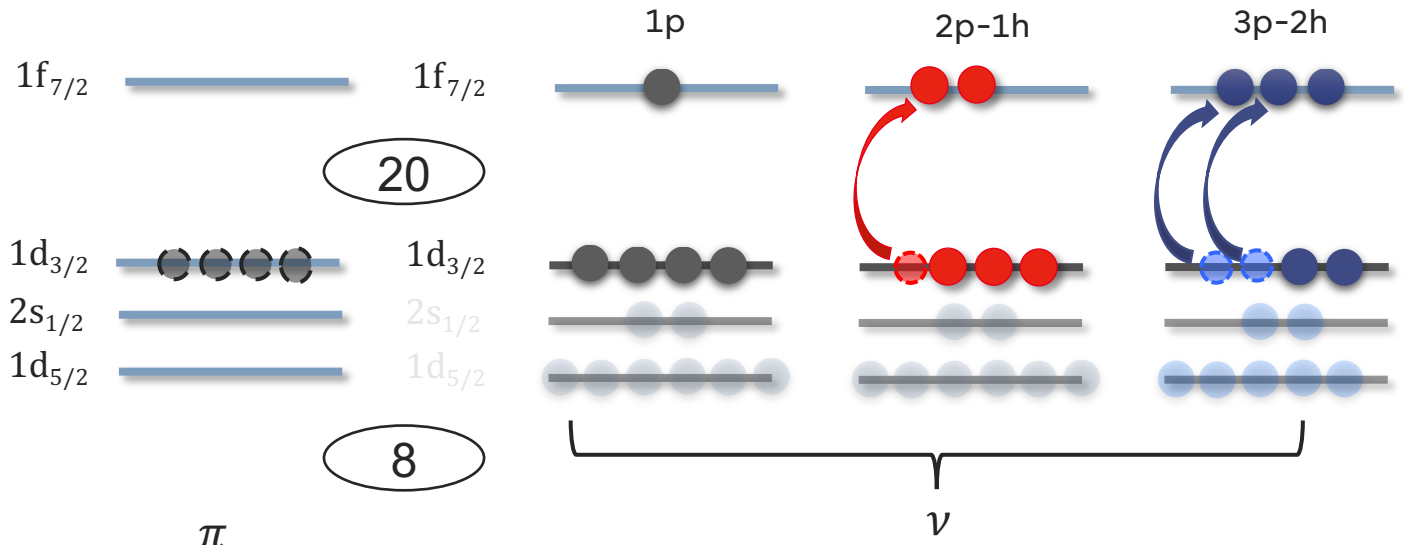
shell-model descriptions around ^{48}Ca: **lifetimes of heavy Ar isotopes, Coulomb excitation of ^{44}Ca**

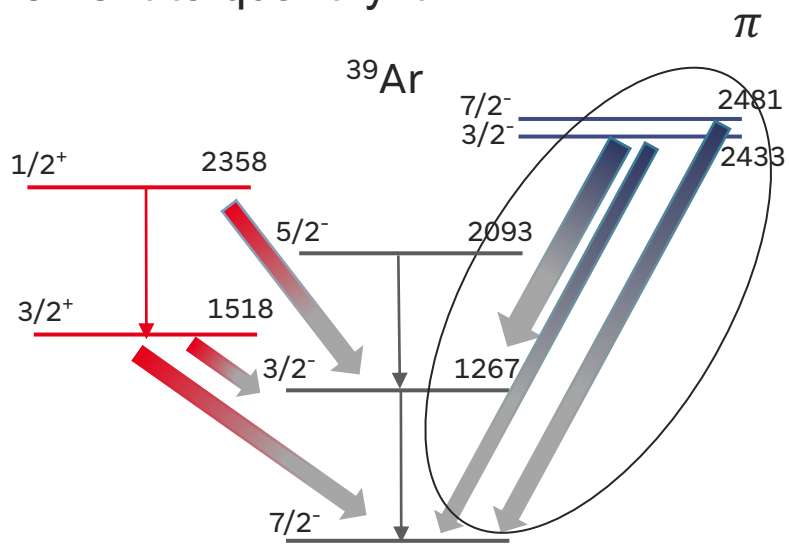
Superallowed β Decay of ^{10}C
Lifetime of the 6.8-MeV state in ^{15}O for astrophysical reaction rates

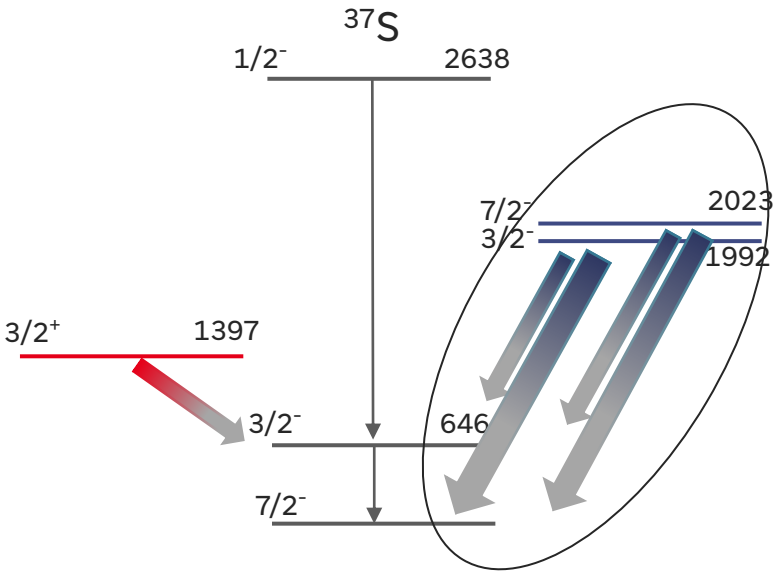
First experiment of the campaign: properties of intruder states in ^{37}S

Analysis and slide courtesy: L. Zago, LNL

- Intruder 2p-1h and 3p-2h states appearing in N=21 ^{39}Ar and ^{37}S
- ^{39}Ar well described by state-of-the-art SM calculations, but a strong branch from the 3p-2h 7/2- state in ^{37}S to the first excited state not reproduced
- Mixing of normal and intruder states? Lifetime measurement to quantify it



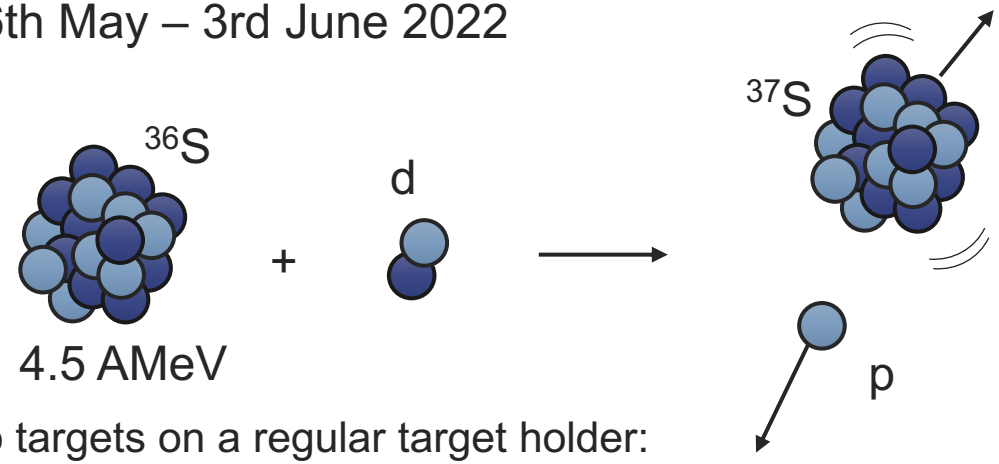




EXP_001 (LNL PAC 22.07)

Analysis and slide courtesy: L. Zago, LNL

26th May – 3rd June 2022



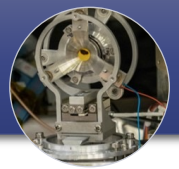
Two targets on a regular target holder:
1 mg/cm^2 CD_2 + 30 mg/cm^2 ^{197}Au
and **0.3 mg/cm^2 CD_2** for DSAM only measurements

11 ATC
Full traces written on disk:
~31 TB/7 days
No trigger condition applied in data taking.

AGATA

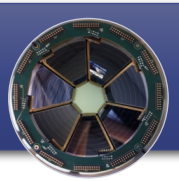
Two targets on the Cologne plunger
0.5 mg/cm^2 CD_2 + 4 mg/cm^2 ^{197}Au
0.5 mg/cm^2 CD_2 + 6 mg/cm^2 ^{197}Au
all facing a **^{181}Ta stopper**.
8 plunger distances,
about 1 day/distance

Plunger



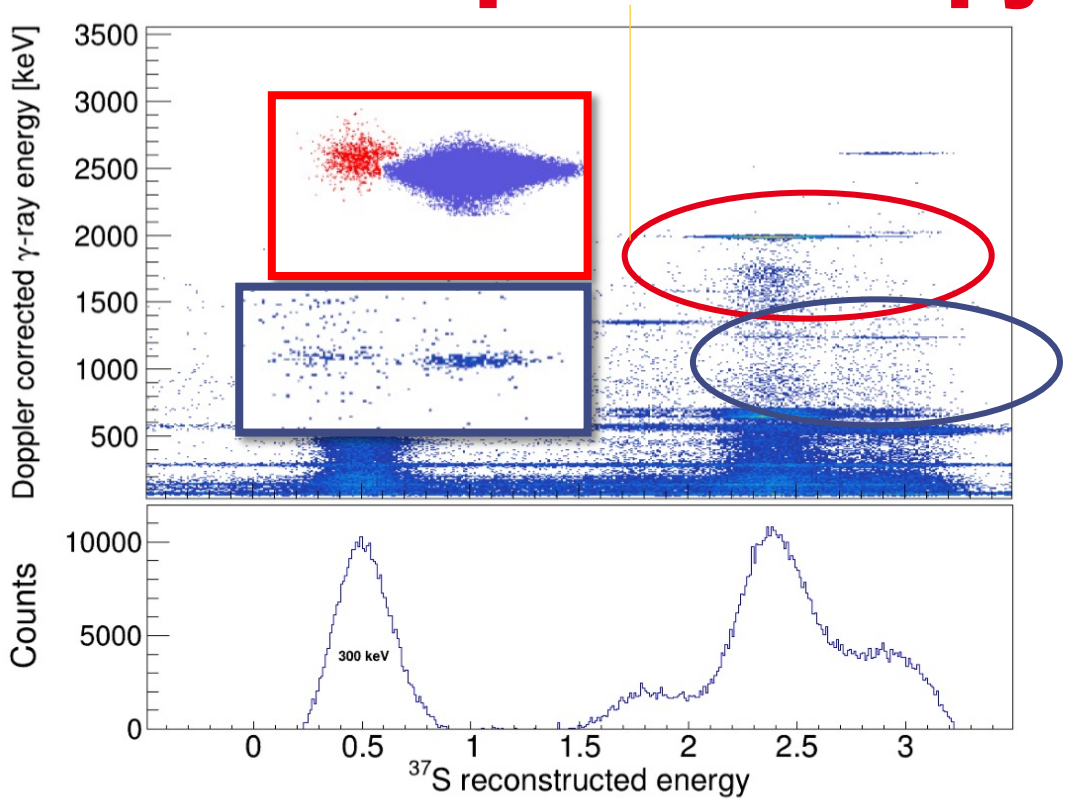
7x8 segmentation
Angular range covered: **124°-161°**
($\Delta\Omega$ = 17%)
Low energy protons near the detection threshold (~500 keV).

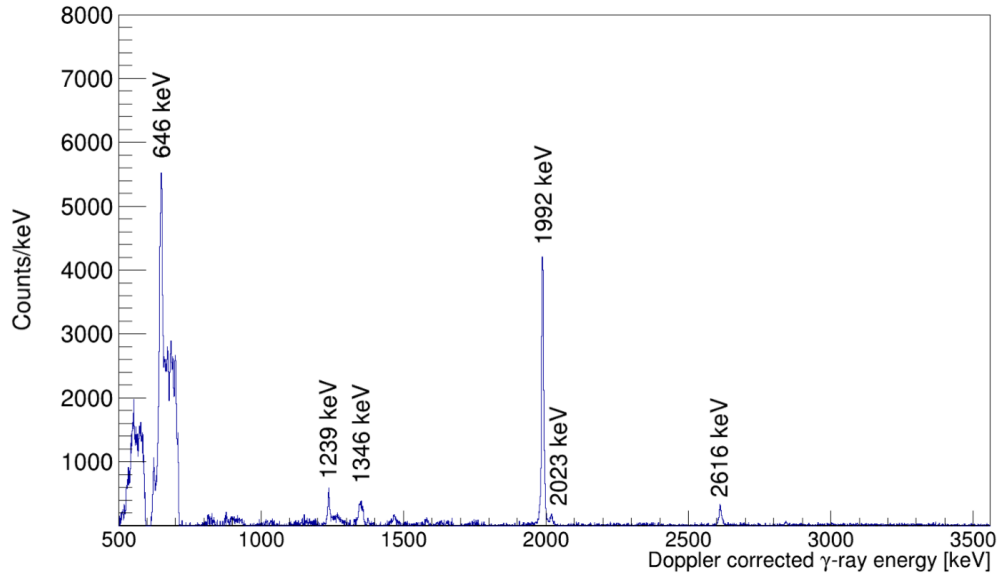
SPIDER

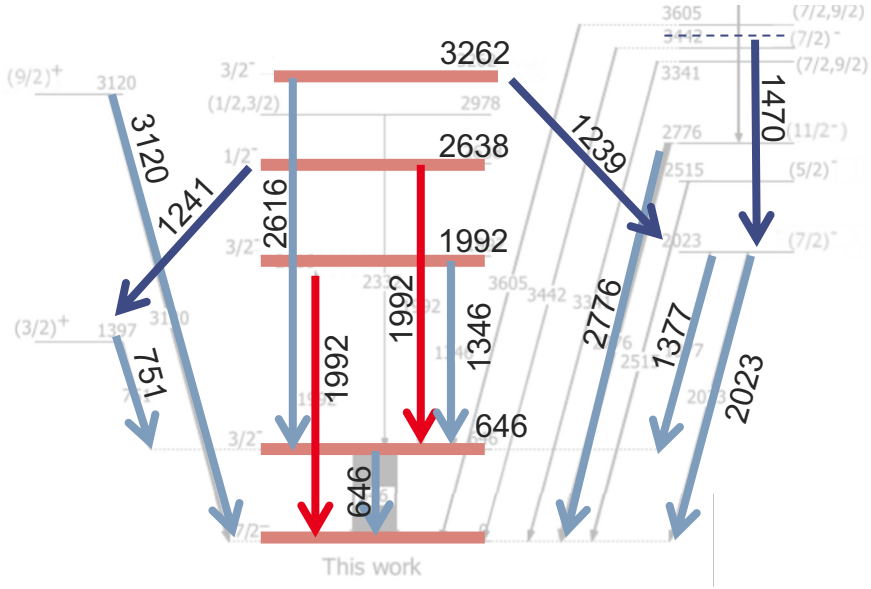


First results: spectroscopy of ^{37}S

Analysis and slide courtesy: L. Zago, LNL



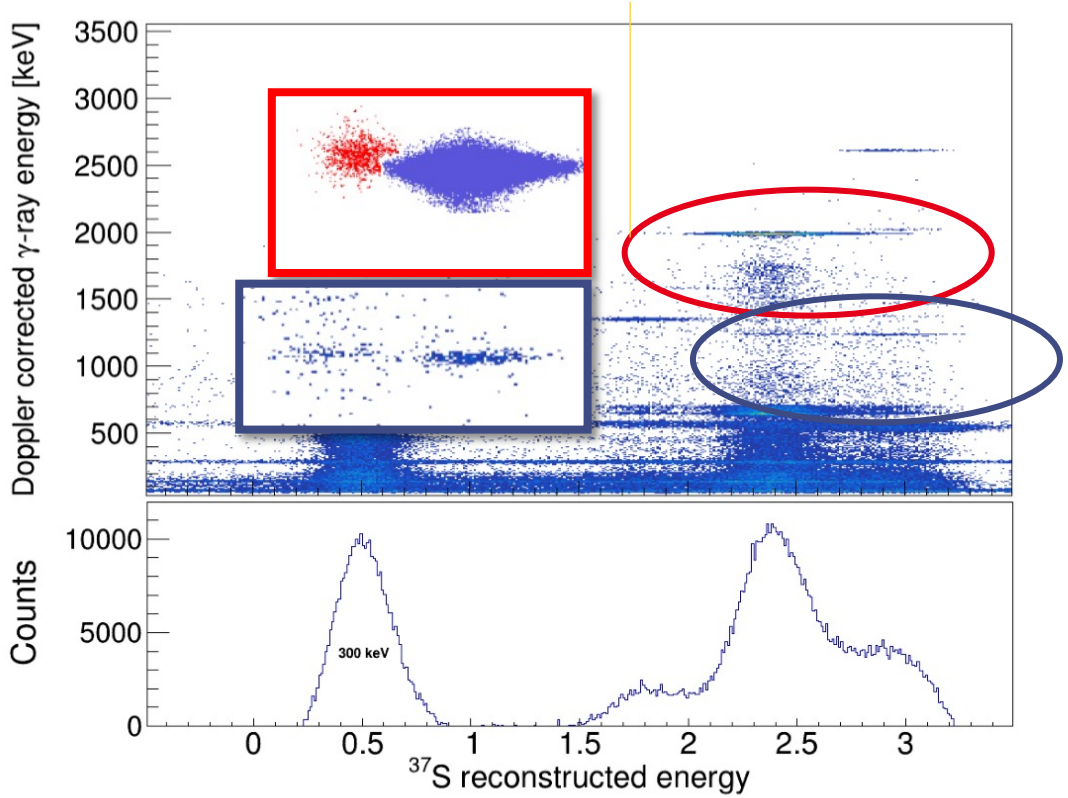


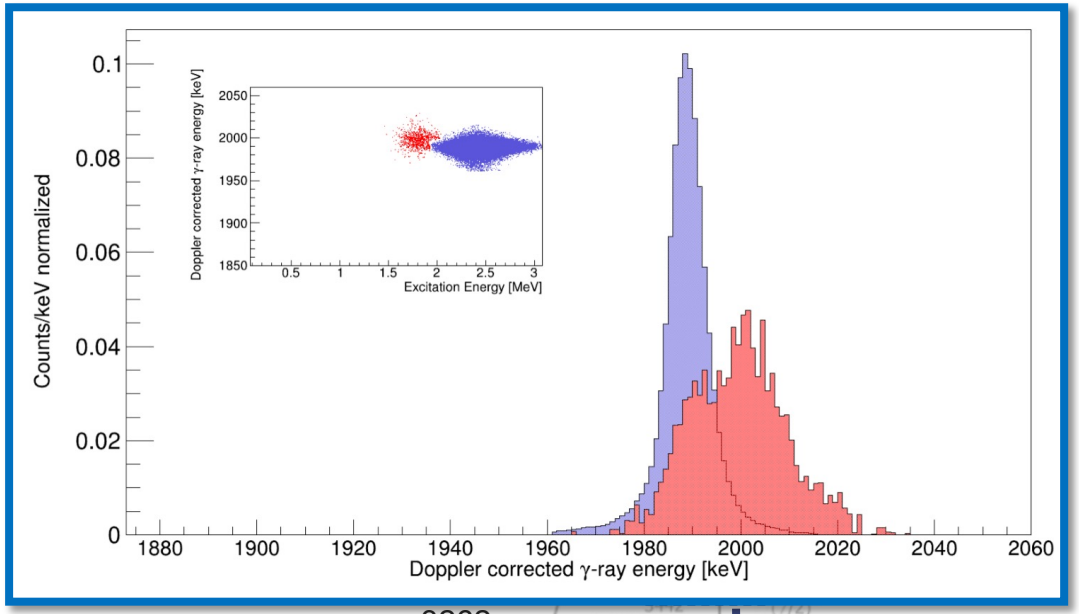


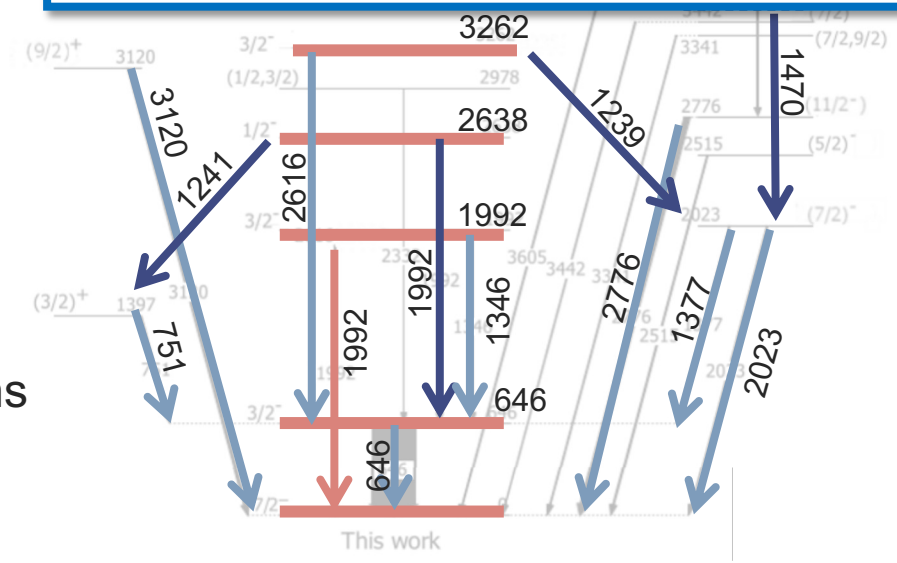
- First observation of several new transitions, including 1241-keV line being in a doublet that can be pulled apart due to excitation energy reconstruction
- Statistics is fairly low for the intruder states, but the 2D matrix is very clean

First results: lifetimes in ^{37}S

Analysis and slide courtesy: L. Zago, LNL

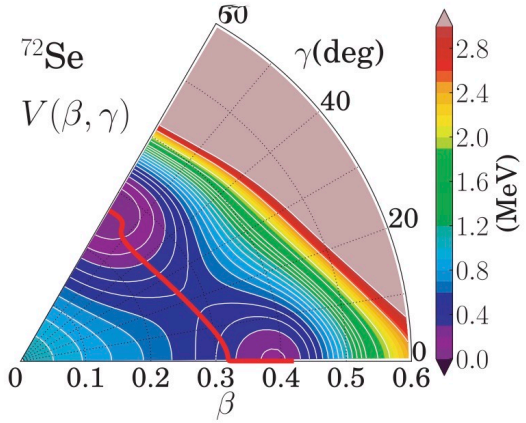




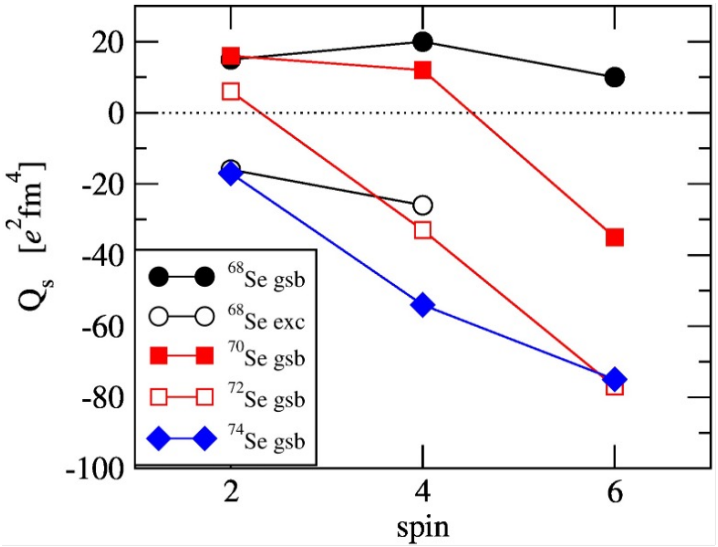


- Very short lifetime of the single-particle 2638-keV state (no lineshape effect) – limit on a lifetime
- Longer lifetime of the intruder 1992-keV state (tens of fs) can be determined via DSAM analysis

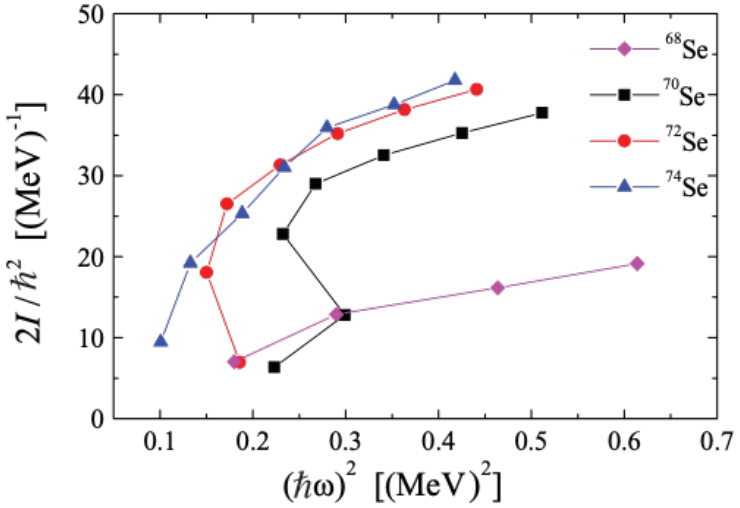
Shape evolution and coexistence in Se isotopes

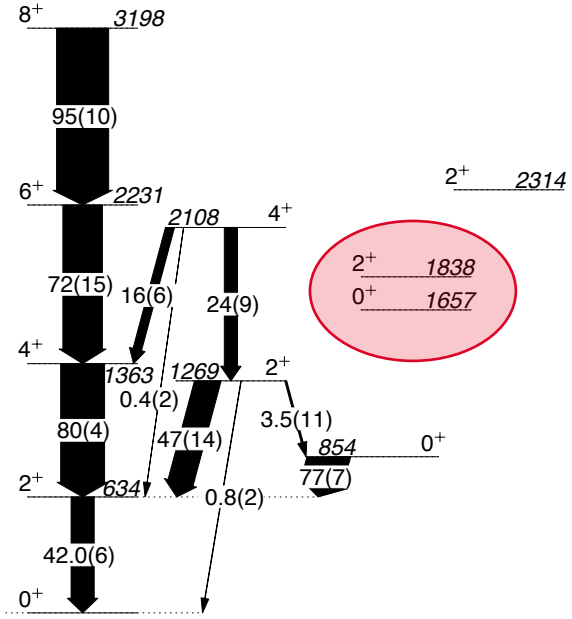


N. Hinohara et al, PRC 82, 064313 (2010)



J.P. Delaroche et. Al., HFB-D1S GCM(GOA)

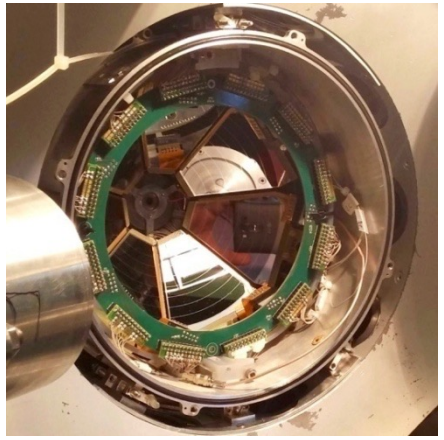




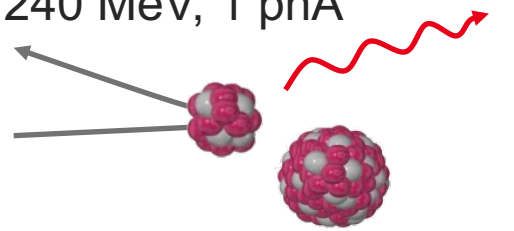
E McCutchan et al., PRC 87, 014307 (2013)

- Oblate ground-state and shape coexistence predicted for $^{68\text{-}72}$Se
- Moments of inertia suggest different shapes of the yrast band in ^{68}Se and ^{74}Se, and appearance of coexisting structures at very low energy in ^{70,72}Se
- alternative IBM-based interpretation: weakly deformed vibrational states (ground-state band, 0^+_2) coexisting with well deformed states (0^+_3, 2^+_4)

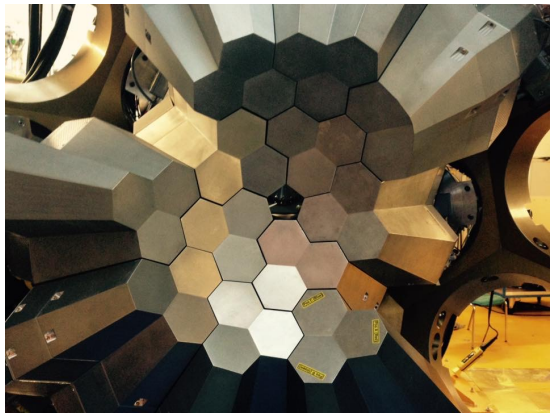
Coulomb excitation of ^{74}Se with AGATA + SPIDER



^{74}Se beam
240 MeV, 1 pnA

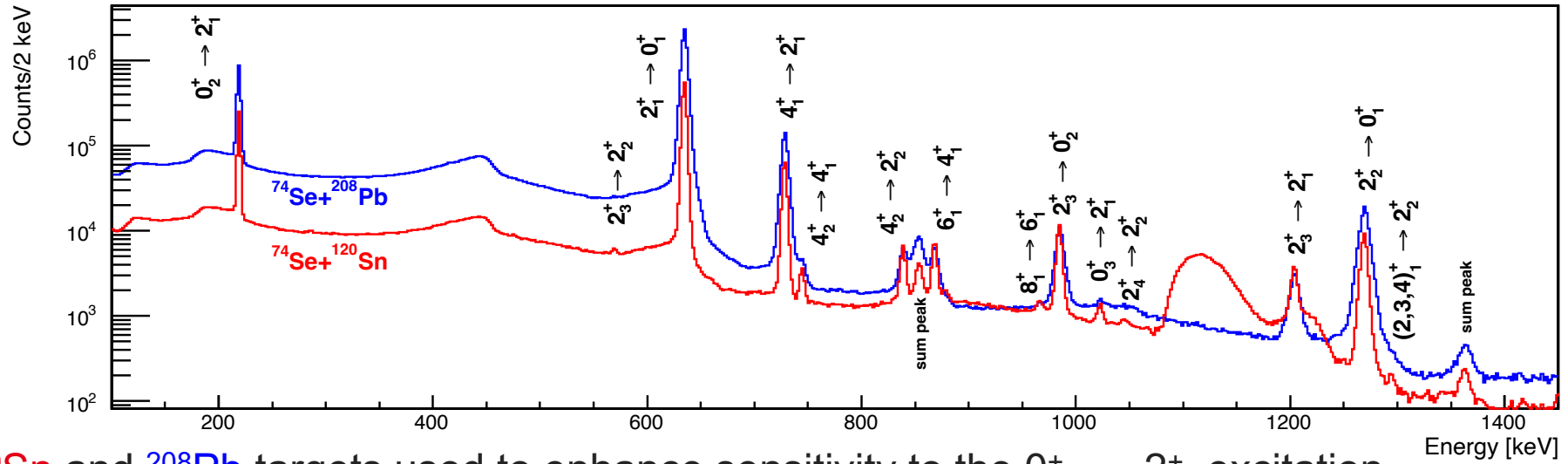


^{120}Sn, ^{208}Pb targets



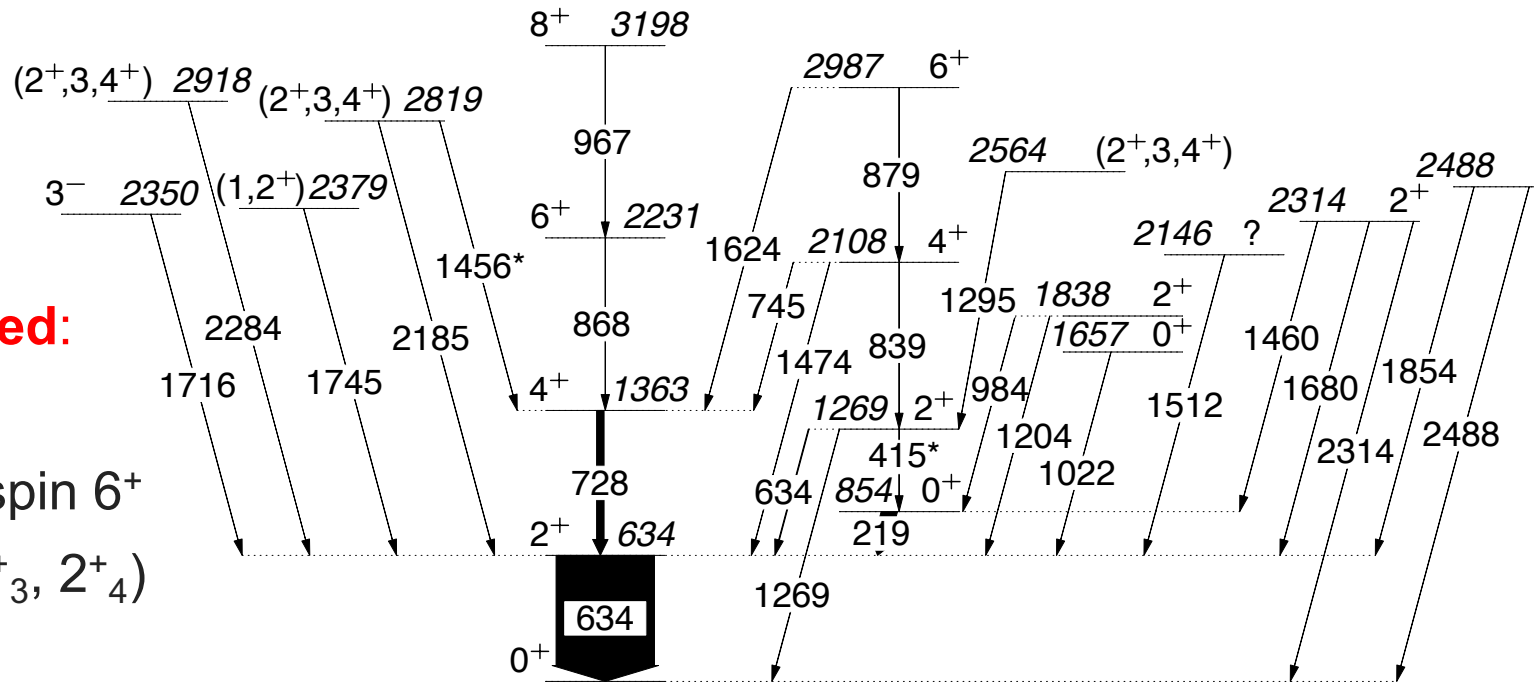
Data taking:

October 27-31, 2022



^{120}Sn and ^{208}Pb targets used to enhance sensitivity to the $0^+_3 \rightarrow 2^+_4$ excitation path crucial to distinguish between the two scenarios

Coulomb excitation of ^{74}Se – results



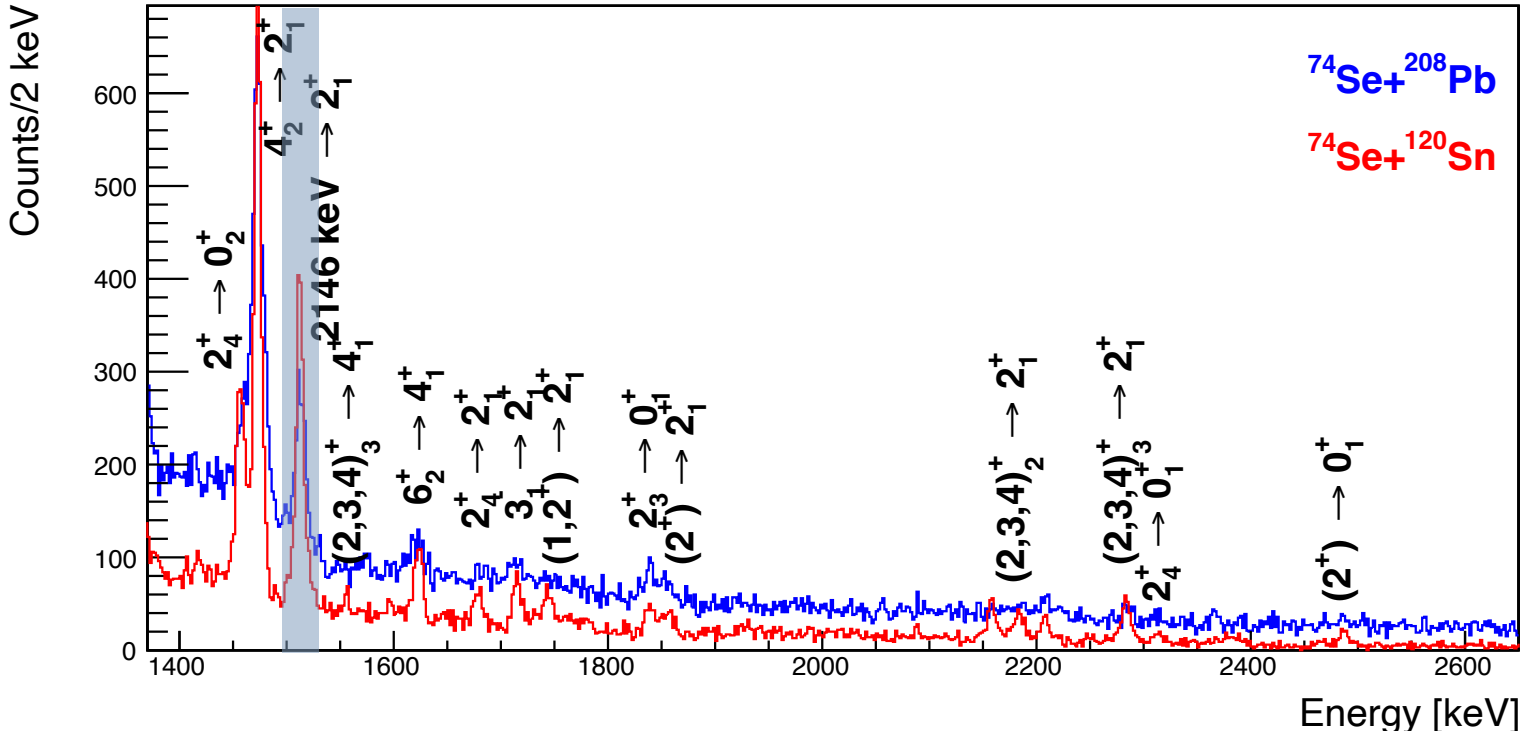
A very rich level scheme populated:

- ground-state band up to spin 8^+
- band built on the 0^+_2 state up to spin 6^+
- presumed deformed structure (0^+_3, 2^+_4)
- 3^- octupole state
- multiple other states of uncertain spin at excitation energies over 2 MeV

- additional information on weaker transitions or doublets from gamma-gamma coincidences

Data analysis: PhD of Robin Kjus, CEA Saclay

Coulomb excitation of ^{74}Se – results



- Biggest surprise: an intense 1512 keV line that has never been seen before in gamma-ray spectroscopy of ^{74}Se
- It is likely to originate from the 2146-keV state observed previously only in particle spectroscopy following two-neutron transfer
- Its strong population in the present data suggests a 0^+ spin-parity: to be verified in a complementary two-neutron transfer experiment

FUTURE: dedicated campaign with ^{238}U beam

- authorisation obtained, beam in an advanced development stage (expected to be available in the second half of 2025)
- discussion of possible experimental projects using this beam at the 5th Pre-PAC (May 2024)
  - four projects presented for a total of 11 weeks of beamtime:

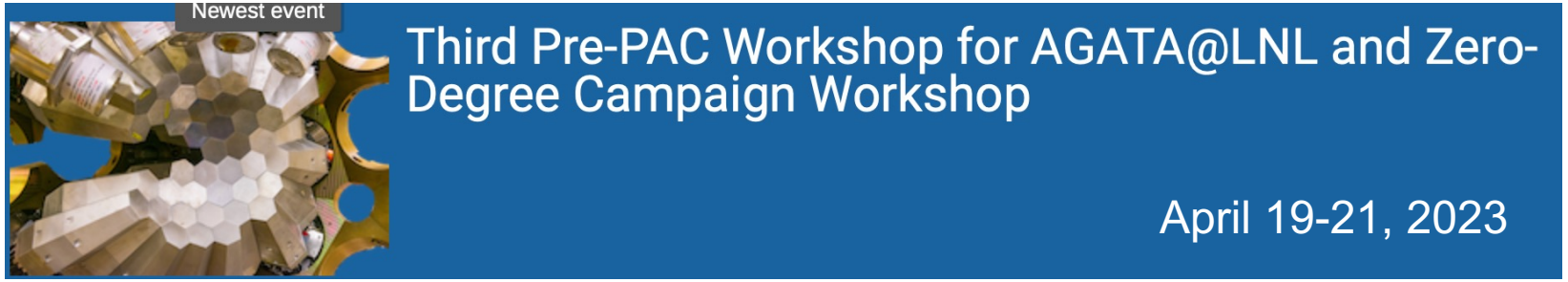
nuclear structure:
gamma-ray spectroscopy and DSAM lifetime measurements around ^{78}Ni (4 and 3 weeks of beam on target, respectively)

reaction mechanism studies,
in particular in the context of production of very heavy nuclei via multinucleon transfer (2 x 10 days)

5th Pre-PAC Workshop for AGATA@LNL

May 13-14, 2024

FUTURE: campaign at zero degrees



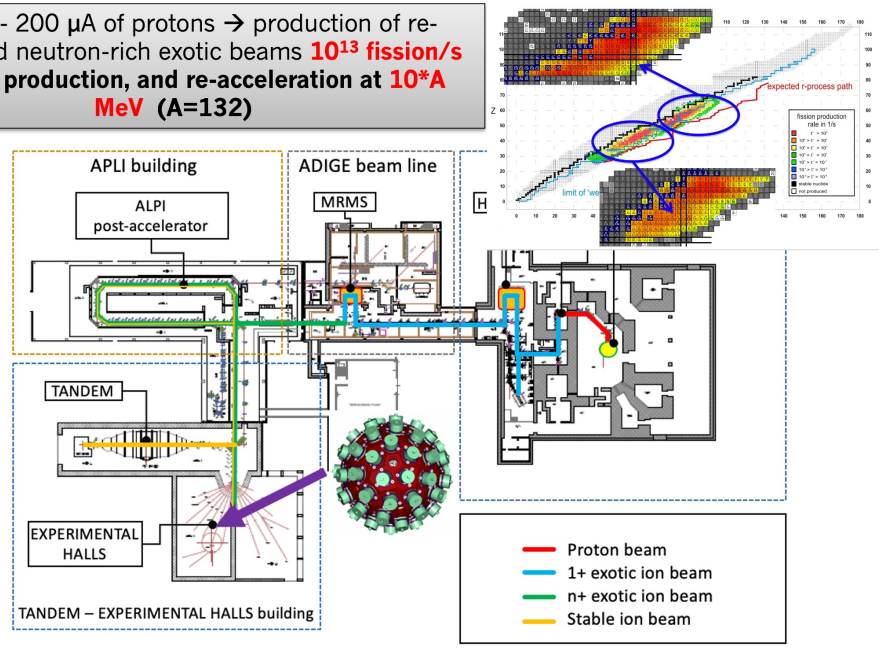
Discussion of the future campaign involving AGATA at zero degrees → preliminary information about **DayOne SPES beams**

List of possible first SPES beams:

Primary target	Beam	Intensity (pps)	Max energy (MeV/A)
TiC	43Sc	2,40E+07	10
TiC	44Sc	2,25E+08	10
TiC	42K	3,70E+07	10
UCx	130Sn	3,95E+06	10
UCx	132Sn	7,70E+05	10
UCx	132Te	2,11E+07	10
UCx	132Sb	9,50E+05	10
UCx	134Te	1,50E+04	10
UCx	94Rb	6,80E+06	10
UCx	75Ga	1,10E+05	10

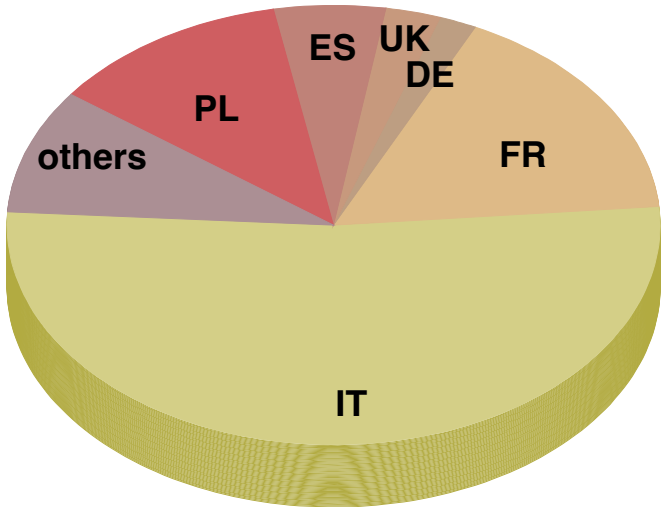
The intensities are to be considered at the target position.

40 MeV - 200 μA of protons → production of re-accelerated neutron-rich exotic beams **10^{13} fission/s in-target production, and re-acceleration at 10*A MeV (A=132)**



Details of the call for LoIs

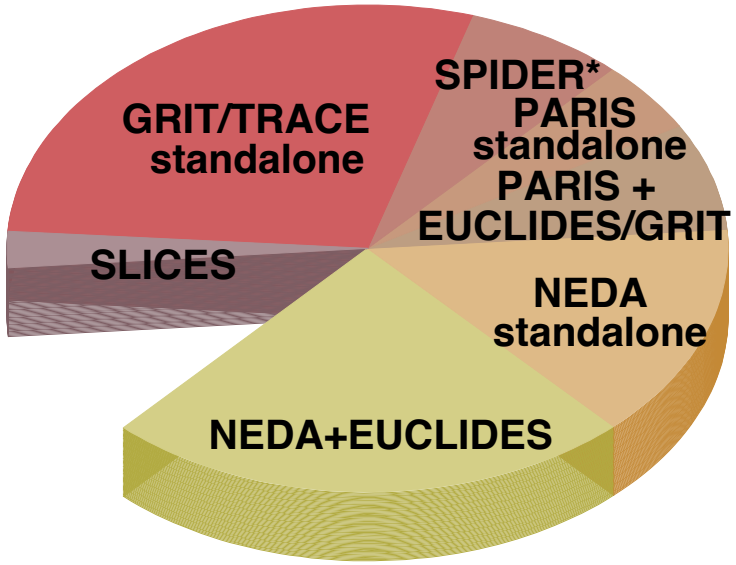
- stable beams from the Tandem-ALPI-PIAVE complex or first SPES beams
- complementary set-ups compatible with AGATA at zero degrees: NEDA, PARIS, GRIT, TRACE, gas/cryogenic targets (SUGAR, CTADIR, CHYMENE) but also some that are used in the present campaign: EUCLIDES, SPIDER, DANTE
- overwhelming response from the community:
  42 “physics” LoIs + 4 umbrella proposals



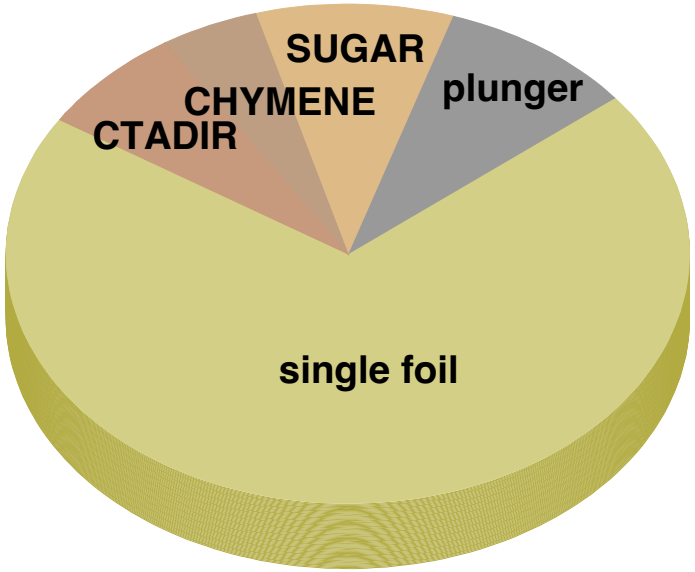
- large majority (33) with at least one Italian spokesperson; percentage of Italian co-spokespersons consistent with earlier AGATA Pre-PACs at LNL
- particularly strong representation of France and Poland
- co-spokespersons from outside the AGATA collaboration: Mexico, US, Korea, Brazil

LoIs for ZD campaign - statistics

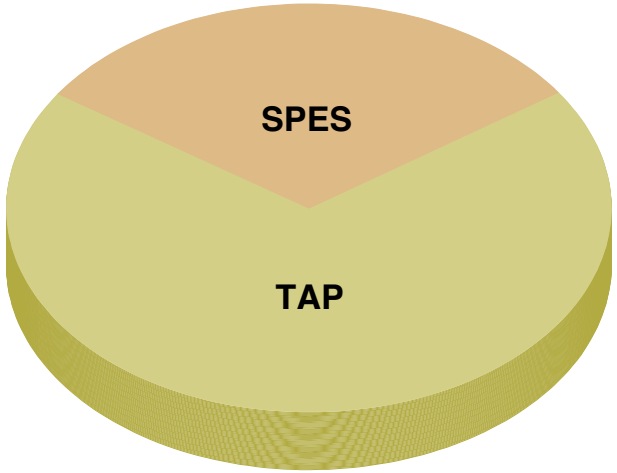
complementary detectors



targets

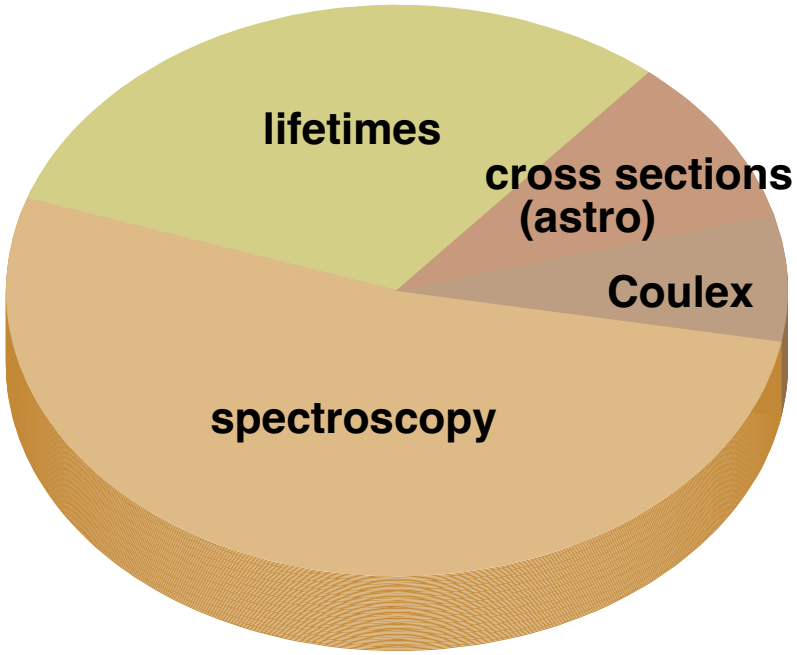


- there is no “preferred” set-up (in contrast to the PRISMA campaign)
- fewer plunger measurements, fair interest in studies using gas/cryogenic targets
- enthusiastic reception of SPES beams, at the same time a large fraction of projects (2/3) relies on existing TAP beams

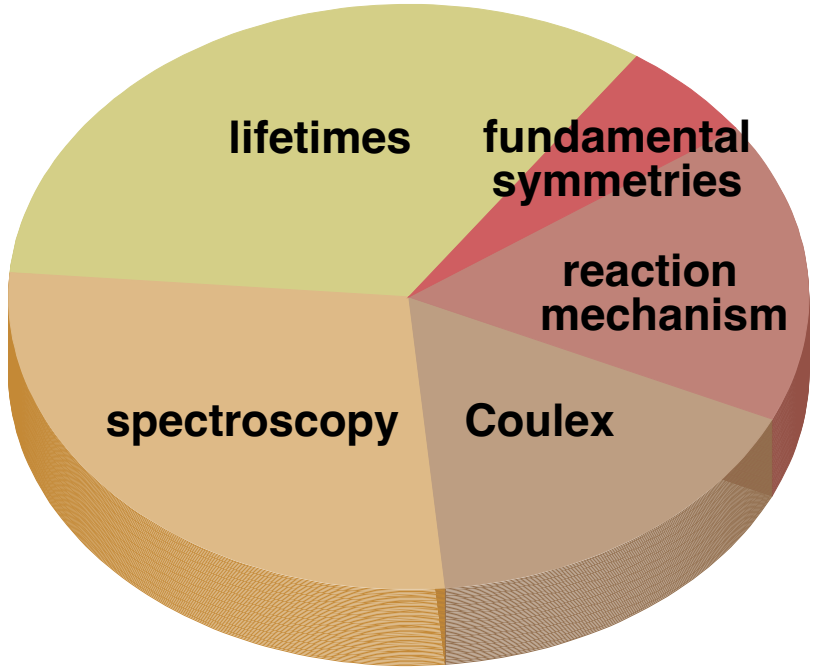


LoIs for ZD campaign - statistics

ZD LoIs

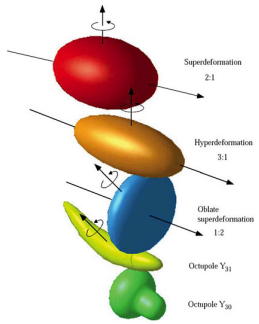


Priority A + scheduled B

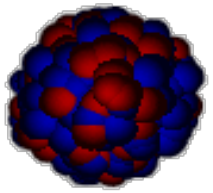


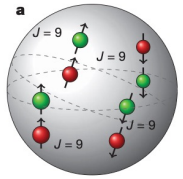
- more spectroscopy, fewer transition probabilities and reaction mechanism studies
- renewed interest in reactions relevant for astrophysics
- return of high-spin physics

Physics cases for the ZD campaign

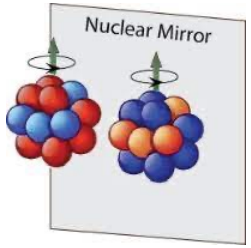


Hot rotating nuclei, GDR, superdeformation, high-spin states…





Isospin symmetry, proton neutron pairing and spectroscopy of N~Z nuclei



Direct reactions, Coulomb excitation and lifetimes around ^{132}Sn

Reactions relevant for astrophysics, structure of ^{12}C, three-body force in ^{16}C

Summary and outlook

- A rich and intense experimental campaign thanks to a overwhelming response from the community and excellent local support (32 experiments performed so far)
- Campaign extended until end of 2026, decisions for 2027-2031 to be taken in October 2024 (there is a bid from LNL for a further extension)
- Strong community intending to perform measurements in the zero-degree configuration; timeline of the change under discussion, but early 2026 seems likely

- Exciting results from the performed experiments to come!

Big thanks to the AGATA collaboration, GAMMA group and LNL/PD/Mi technical staff

..and all the youngsters behind it!