AGATA – phase 2

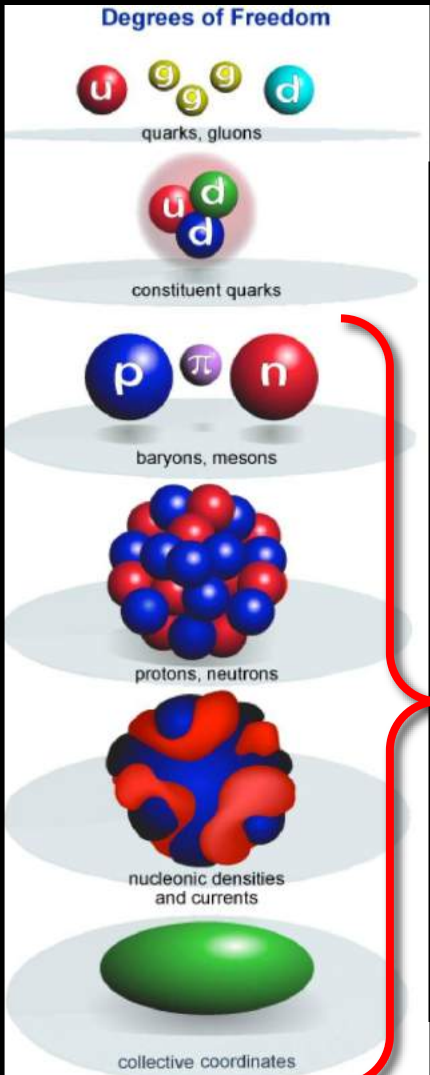
Prepared by the AGATA-France community
(in2p3,GANIL,CEA)

AGATA
ADVANCED GAMMA
TRACKING ARRAY

Outline

- Nuclear science & γ-ray emission
- AGATA
- Organisation, Milestones & achievements
- Phase 2: upgrade of AGATA to a 4π array

The nucleus: a complex system

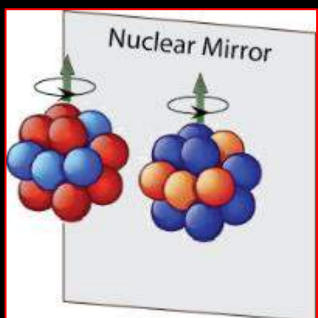


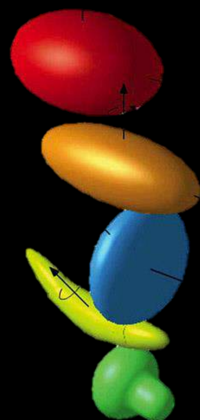
Physics of Nuclei

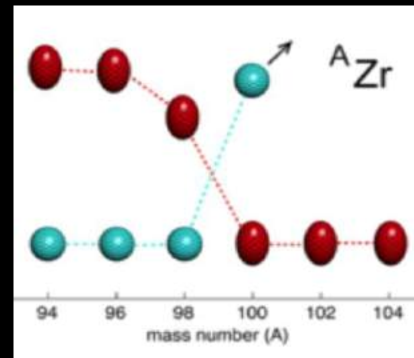
1) How to understand the rich structure of the atomic nuclei in terms of interactions between nucleons

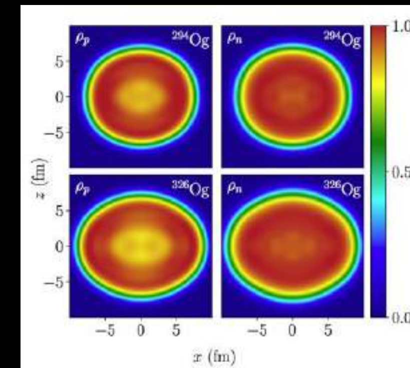
1) How to relate the strong nuclear interaction to the underlying QCD that governs the physics of quarks and gluons.

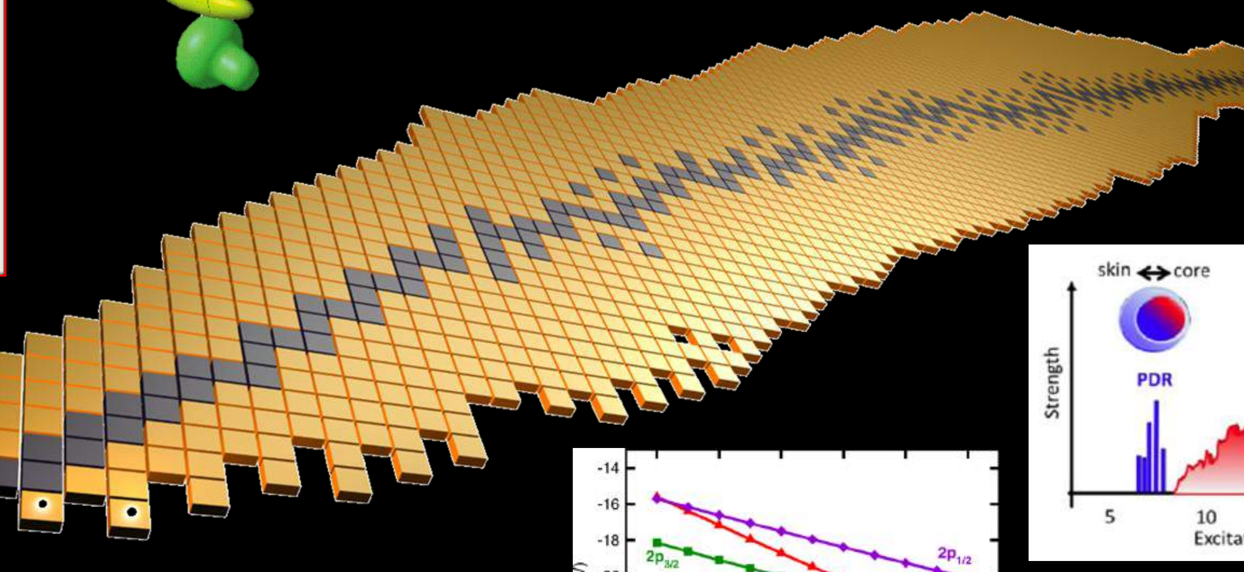
A variety of different phenomena

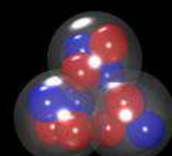


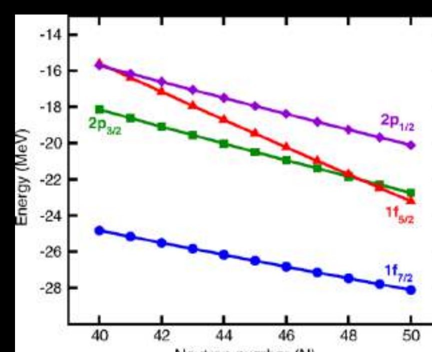


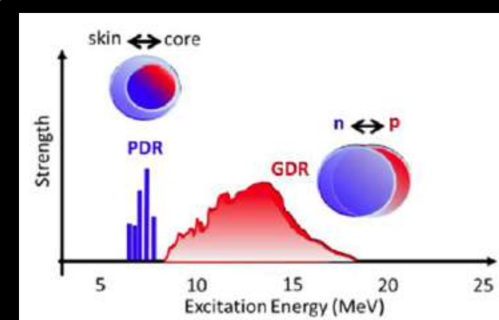




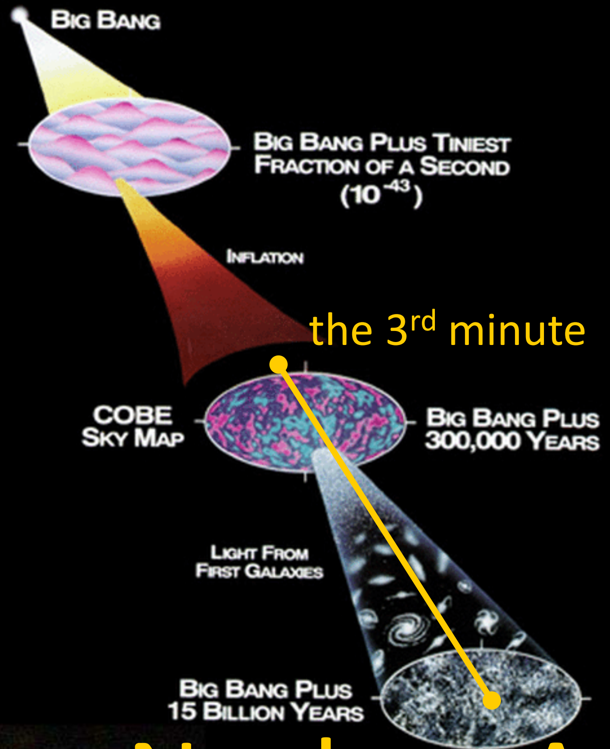






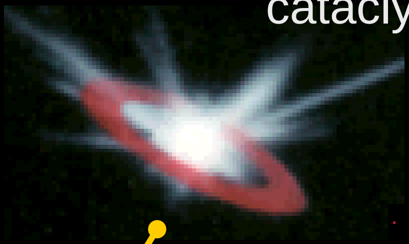


From nucleons, to nuclei, to stars…

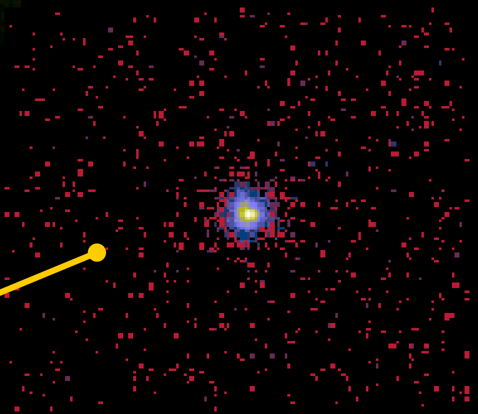


the 3rd minute

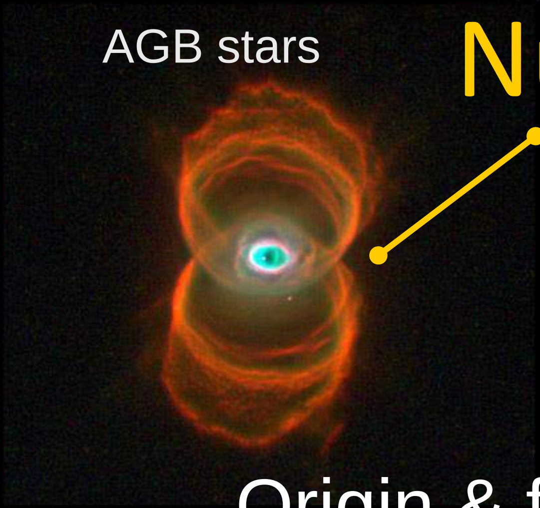
cataclysmic binaries



stellar evolution

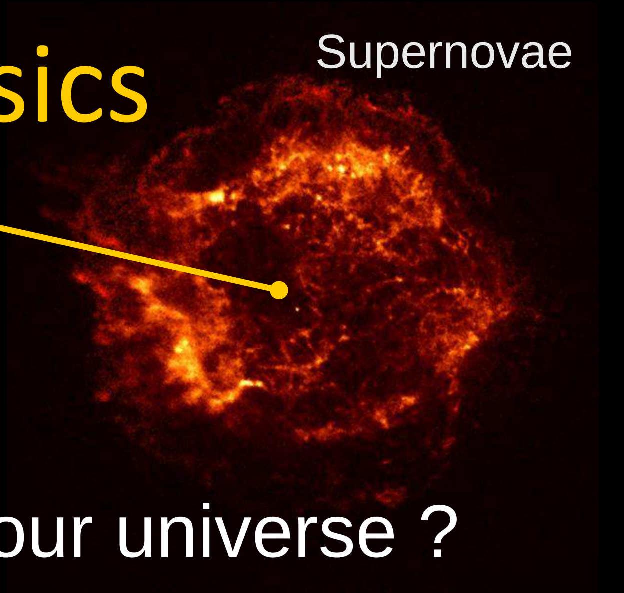


AGB stars



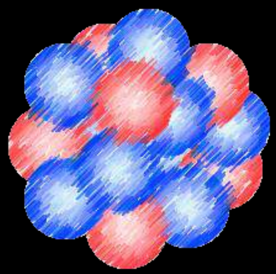
Nuclear Astrophysics

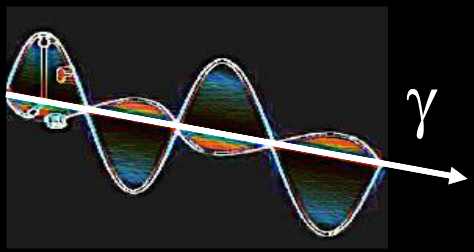
Supernovae



Origin & fate of the elements in our universe ?

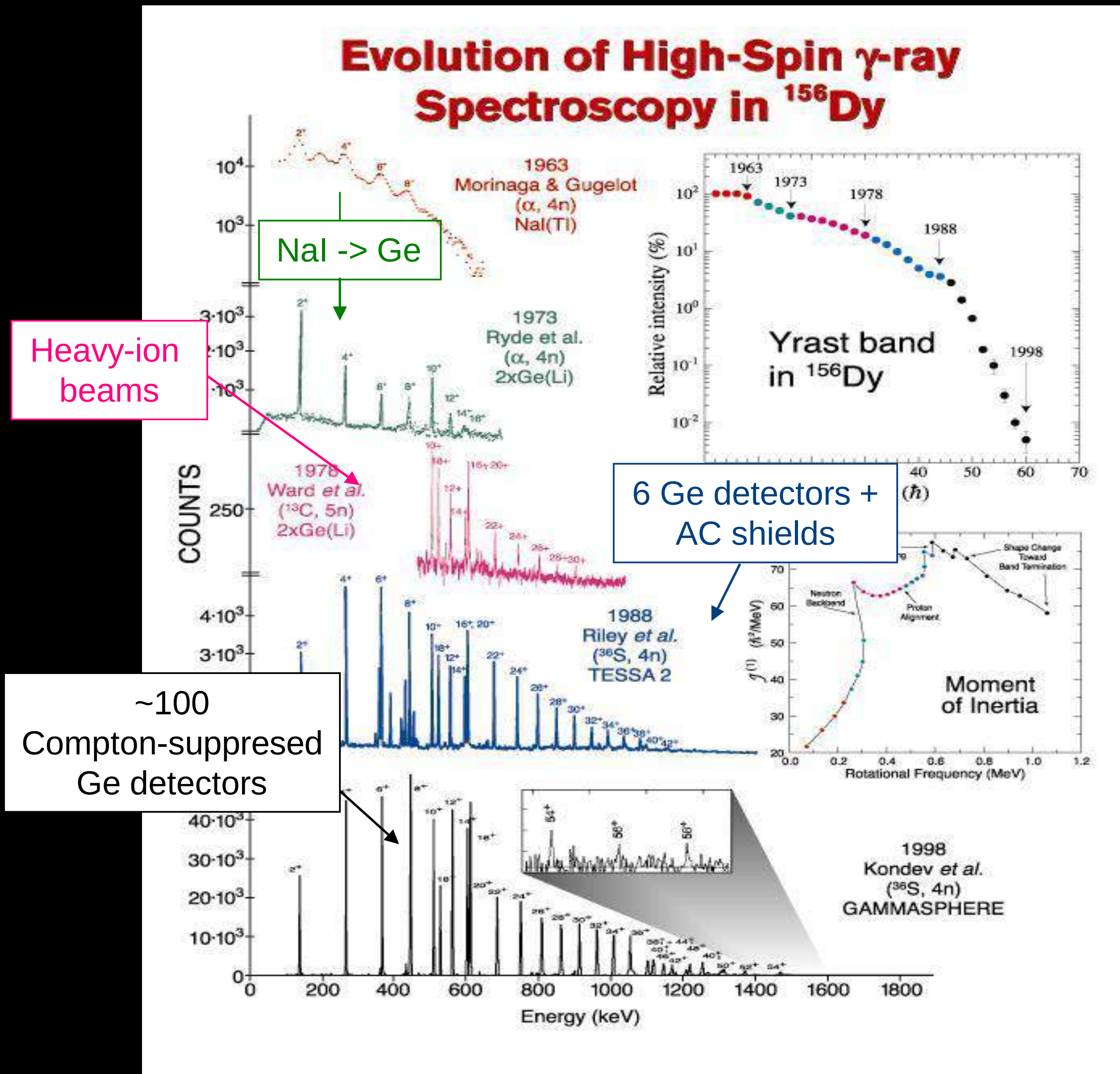
The most sensitive probe of the nuclear wavefunction: its EM radiation

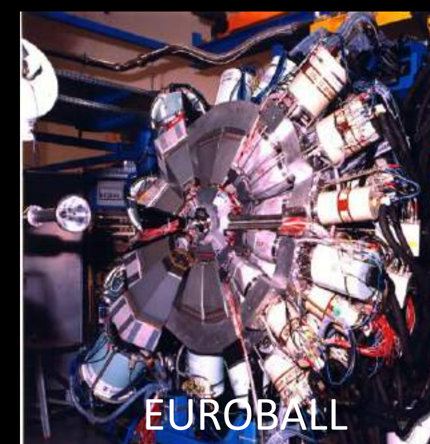




- Angular distribution/correlation ⇨ spin, multipole mixing ratios
- Doppler shift ⇨ lifetime
- Linear polarization ⇨ parity
- Intensity ⇨ branching ratios, BE(λ), cross sections
- Coincidence relation ⇨ level scheme
- …

Evolution of γ-ray spectroscopy: Arrays of Compton-suppressed Ge detectors

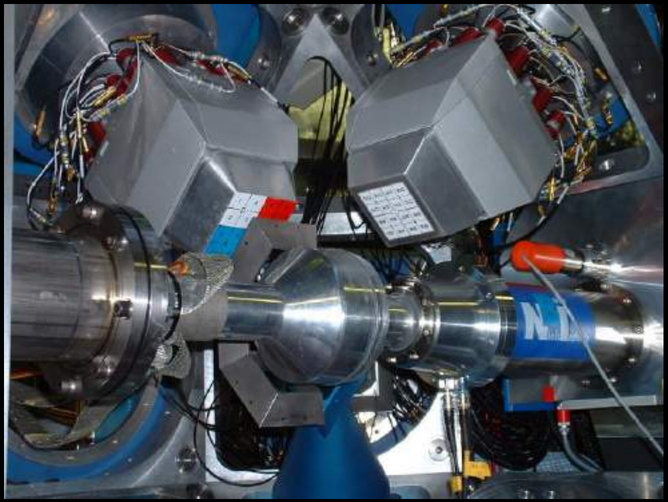


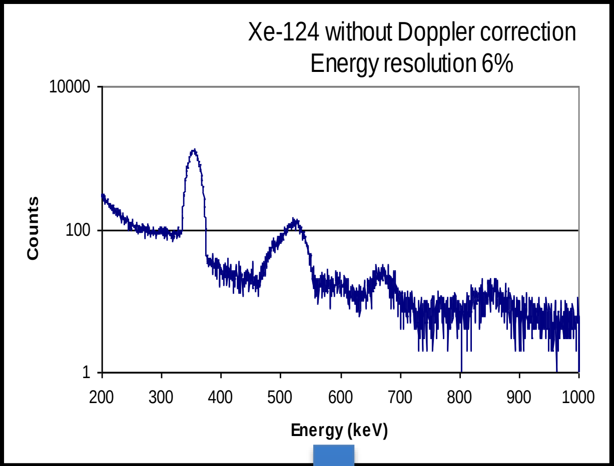


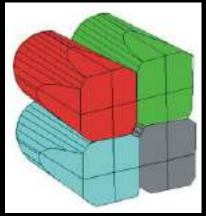
Optimized for high γ-ray multiplicities

Efficiency ~10%

Evolution of γ-ray sectroscopy: Arrays of segmented Ge detectors

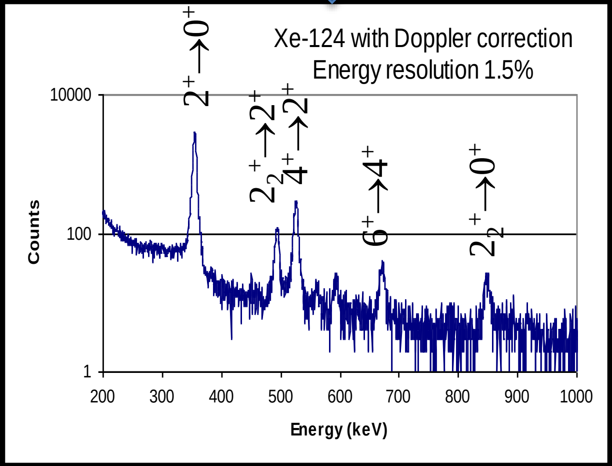


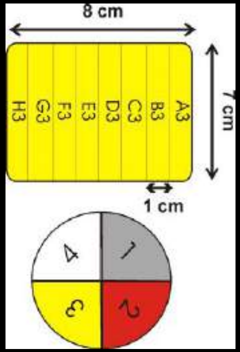




EXOGAM

MINIBALL

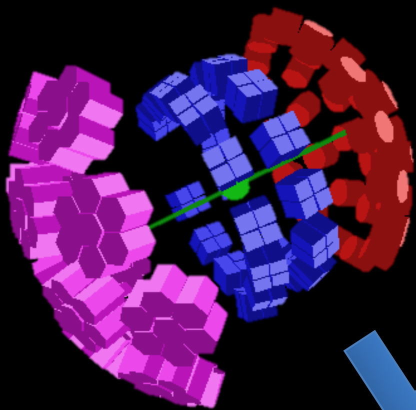


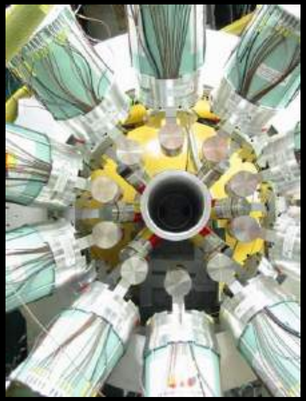


SeGA

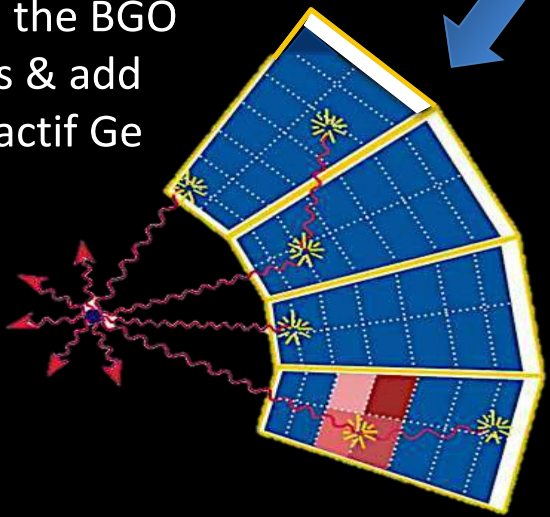
Optimized for Doppler correction at low γ-ray multiplicities: Efficiency ~ 20%

How to combine the properties of both types of arrays & enhance the overall performance ?

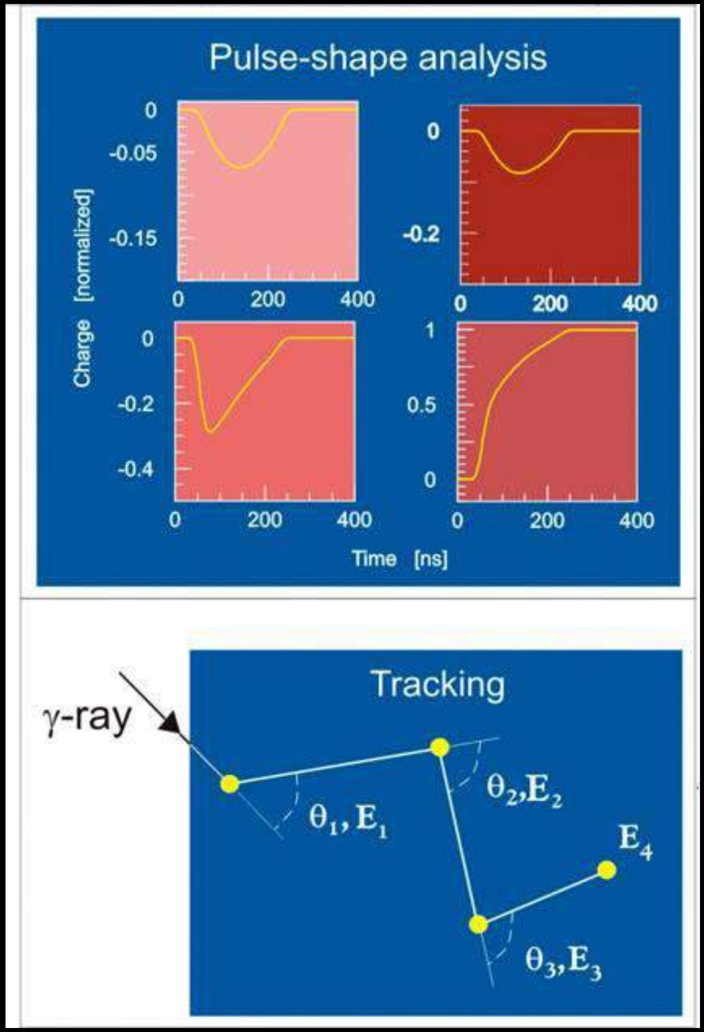




Remove the BGO shields & add more actif Ge

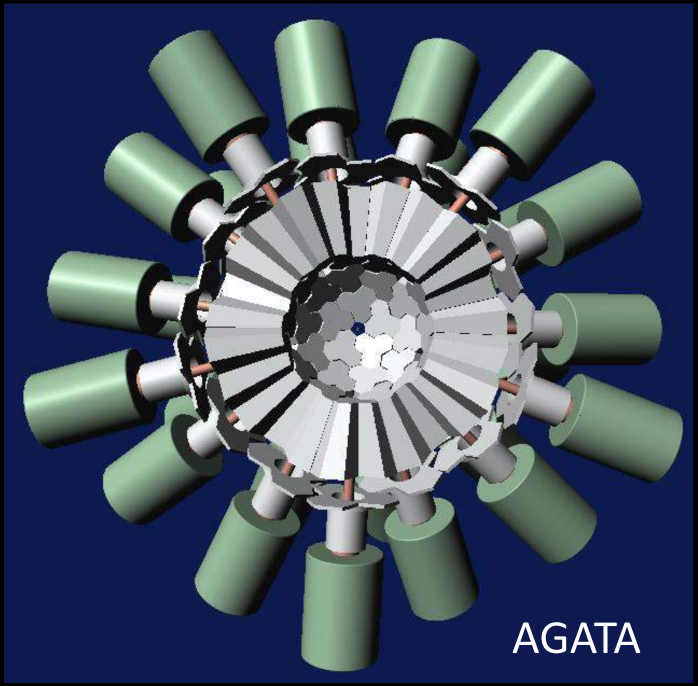


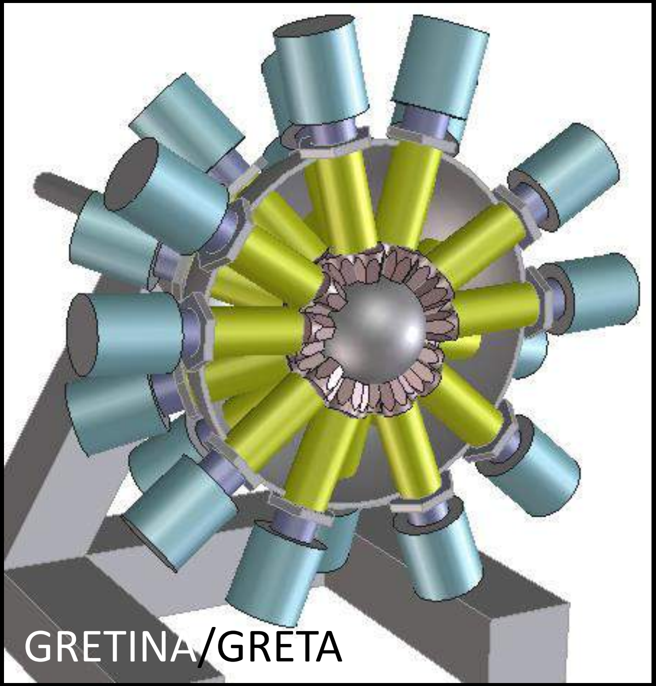
Segment further to determine the interaction points & track the photons



Increase count rate capability

γ- tracking arrays





High position resolution
High efficiency
High resolving power
High counting rate
Background rejection

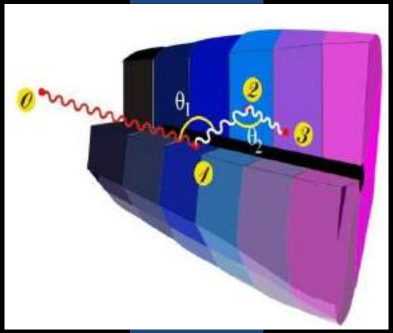
→

Large recoil velocitites
Low beam intensities
Rare events
Large background

Tracking ingredients

1

36-fold segmented HPGe detectors



2

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

3

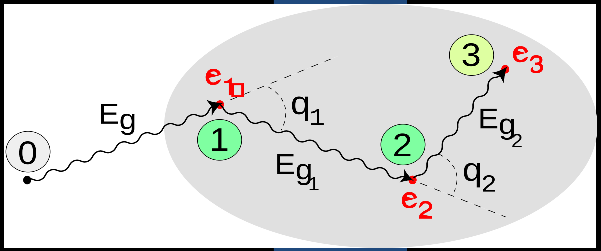
Pulse Shape Analysis to decompose recorded waves

Identified interaction points

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

4

Reconstruction of photon trajectories by tracking algorithms

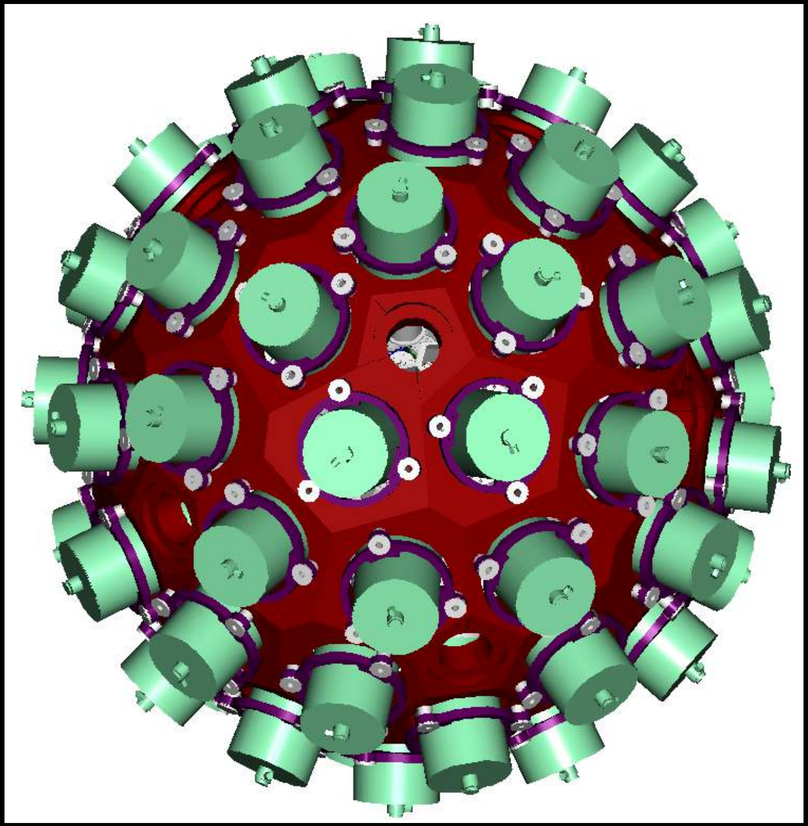


reconstructed γ-ray energies, emission & scattering directions

AGATA project

AGATA
ADVANCED GAMMA
TRACKING ARRAY

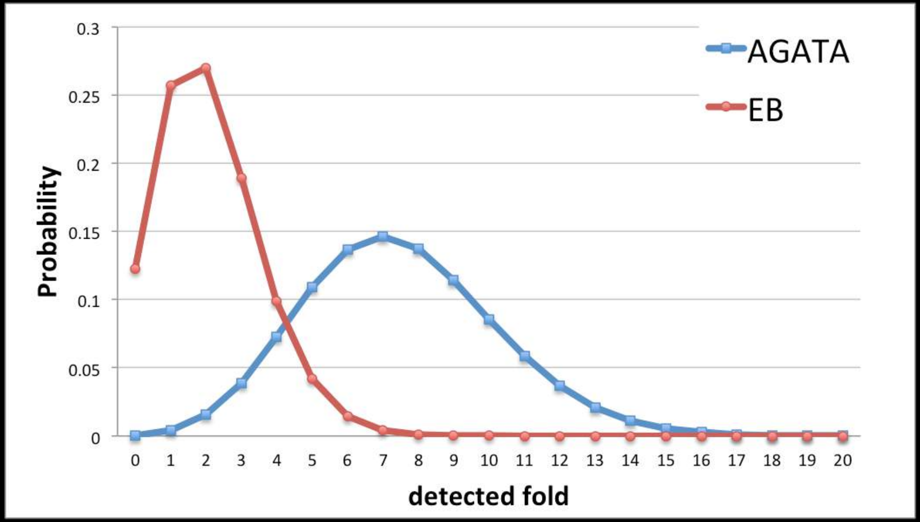
http://www.agata.org



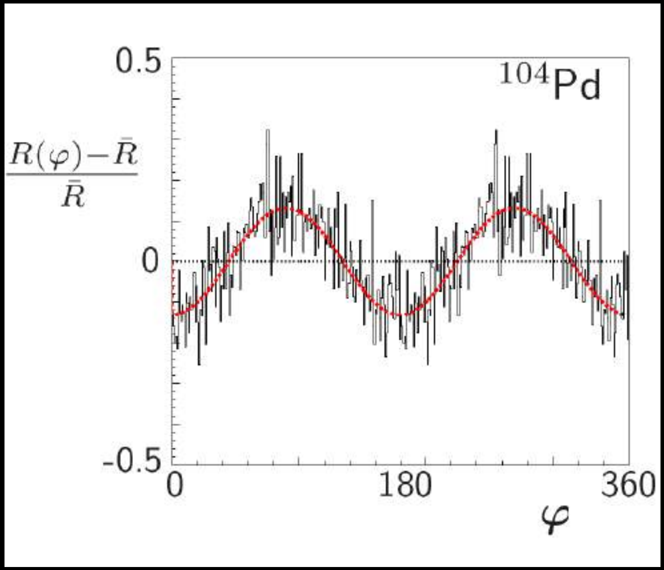
- 180 segmented crystals (60 triple units)
- 362 kg of Ge
- 82 % solid angle
- 50 kHz Ge crystal counting rate
- Angular resolution : ~1º
- Efficiency: 35 % (M_γ=1) , 20% (M_γ=30)
  Pic/Total: ~40-50%
- Large inner radius to accommodate ancillary devices

Powers of AGATA

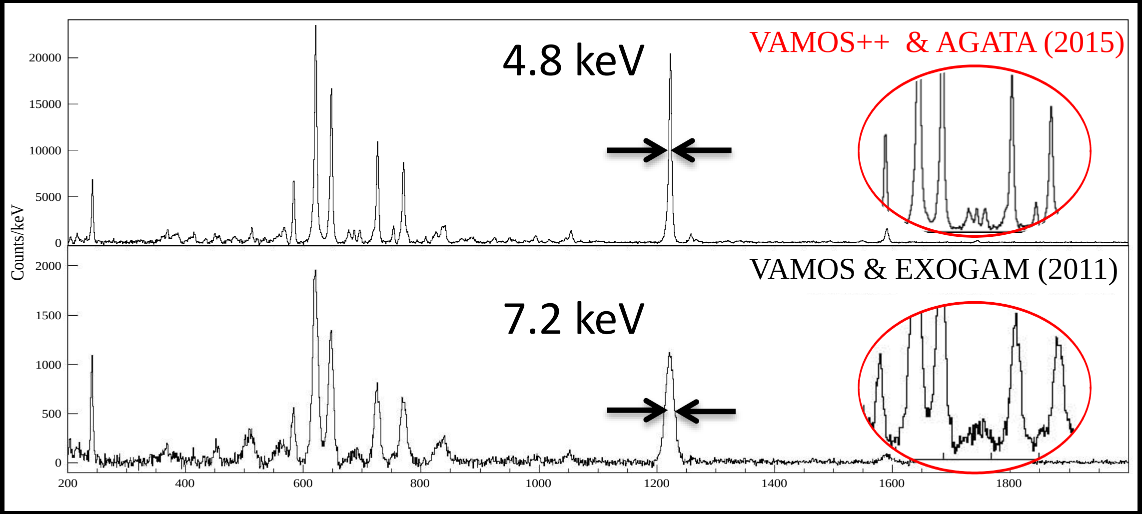
Response to high-multiplicities (Mγ=30)



P.G. Bizzeti, Eur. Phys. J. A51 (2015) 49



Polarization sensitivity



Doppler correction capability (^{98}Zr, v/c~10%)

AGATA collaboration

AGATA Steering Committee (ASC)

AGATA Collaboration Council (ACC)

AGATA Management Board (AMB)

Agata Management Board (AMB)

A. Gadea (Project Manager)

A. Boston, B. Million, A. Korichi, H. Hess, F.Recchia, P. Reiter **(ASC)** and W.Korten **(ACC)**.
J. Gerl (LCM-GSI), E. Clement (LCM-GANIL)

AMB Chairman
Project Manager
A.Gadea

Resource Manager

B. Million

AGATA Working Groups

AGATA Working Groups	AGATA Teams			
Detector Module H. Hess	Detector & Cryostat H. Hess	R & D on gamma Detectors & Applications		
Front-end Electronics (A.Gadea)	Pre-Amplifier Digitizer A. Pullia	Global Trigger & Synchronization M. Bellato	Pre-processing I. Lazarus	
Data Flow A.Korichi	Hard/Software DAQ support G. Lalaire	Slow control & FEE Monitoring E. Legay	Data Analysis & TRACKING O. Stézowski A. Lopez-Martens	Data distribution and re-processing F. Crespi, J. Dudouet
Characterisation PSA A.Boston	Detector Characterisation J. Simpson	PSA Algorithm Development L.J Harkness		
Infrastructure. Comp. Det. B.Million	Detector array Infrastructure R. Menegazzo	Complementary Detectors J.J. Valiente	Mechanical Infrastructure A. Grant	
Performance and Simulation F.Recchia	AGATA Performance C. Michelagnoli J. Ljungvall	AGATA Commissioning P.R. John	AGATA Physics & exp. Simulation M. Labiche	
Technical Coordinator (Engineering Advi.	Compatibility EMC, Interfacing	Specification control	Quality Control	Documentation & Security Issues

Local Campaign Managers (LCM)

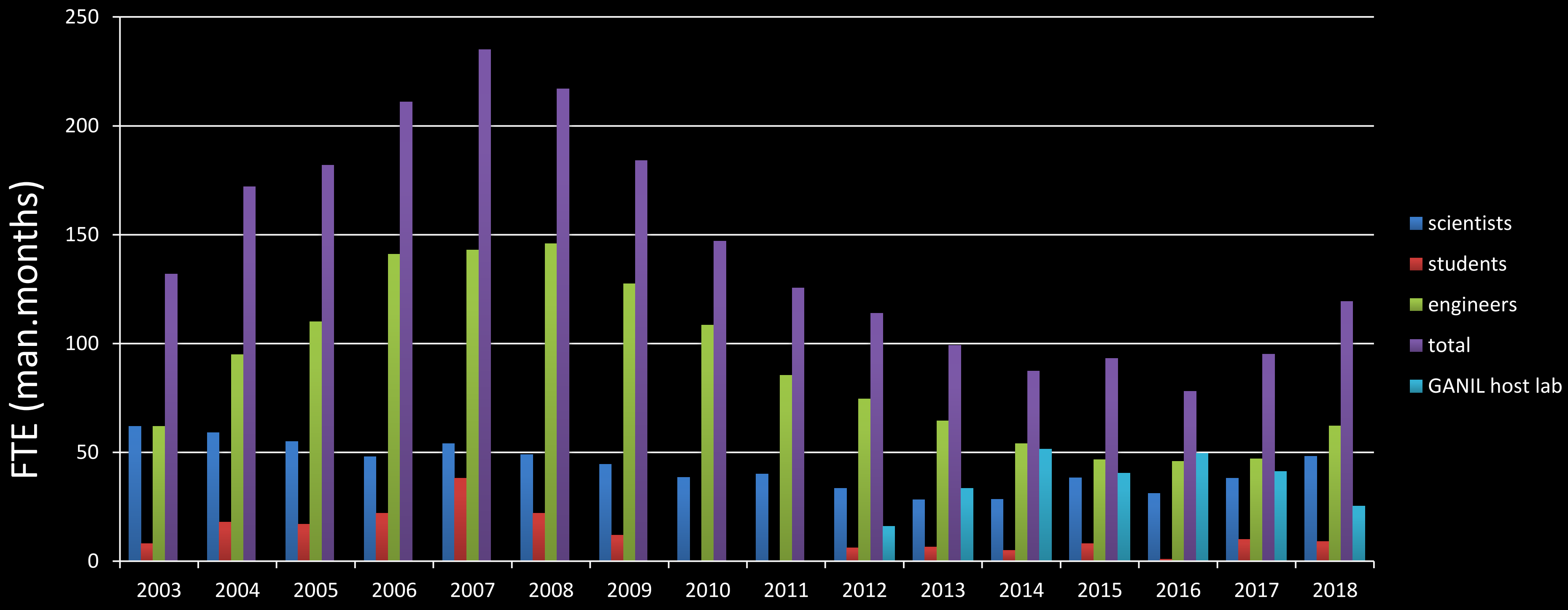
INFN-LNL	GSI	GANIL-SPIRAL2
Legnaro	Darmstadt J.Gerl	Caen E.Clement

AGATA France

http://agata.in2p3.fr

Coordinateur Scientifique	Coordinateur Technique
A. Lopez-Martens	E. Legay

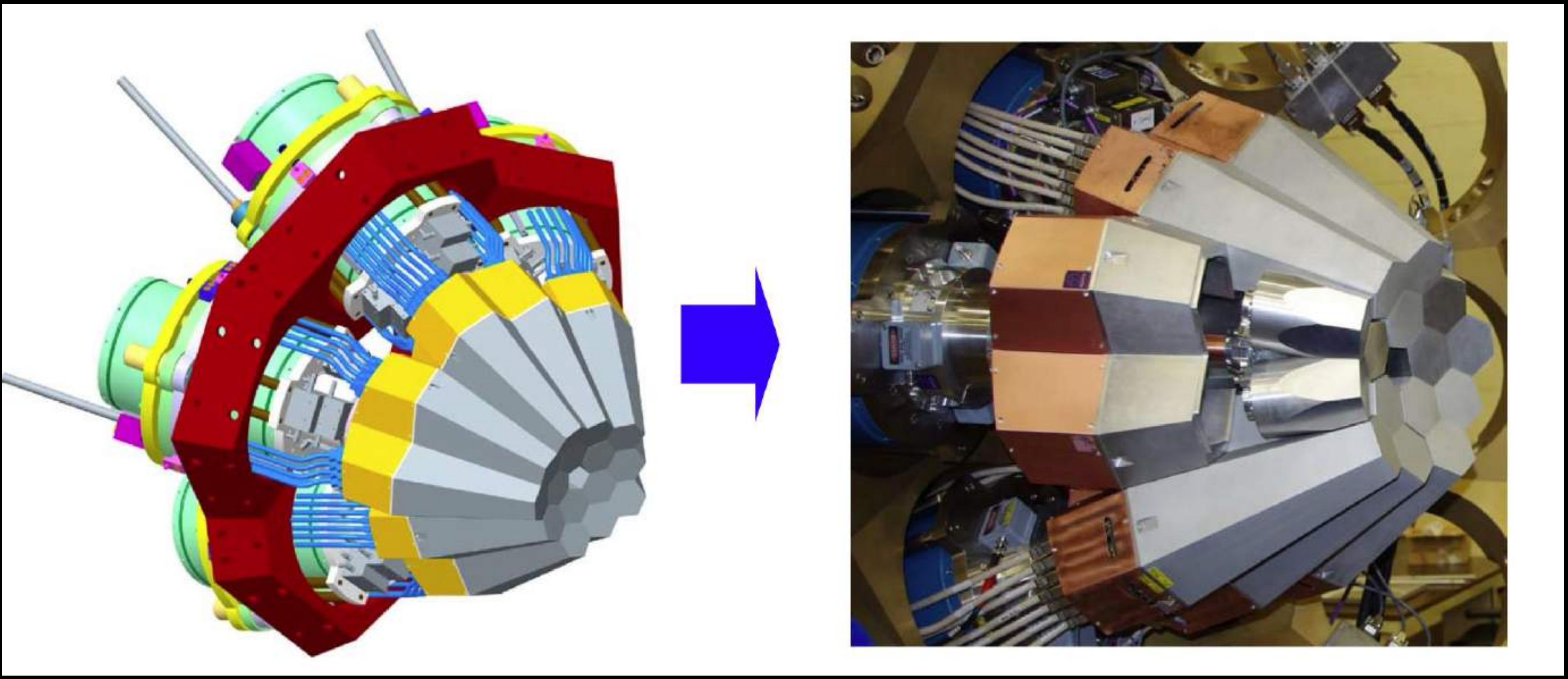
CSNSM	IPHC	IPNL	IPNO	GANIL	CEA
A. Korichi	G. Duchêne	N. Redon	D. Verney	G. De France	M. Zielinska



Demonstrator Phase (2003-2008)

Positive feedback from the Scientific Council of in2p3 in 2001
MoU signed in 2002 by 12 european countries

5 triple clusters , online PSA & tracking, in-beam commissioning at Legnaro



Agata Technical Design Report (2008, http://npg.dl.ac.uk/agata_acc/publications_documentation/TDR_EUJRA.pdf)

AGATA – Advanced GAmma Tracking Array: S. Akkoyun et al., Nucl. Instr. Meth. A 668 (2012) 26–58

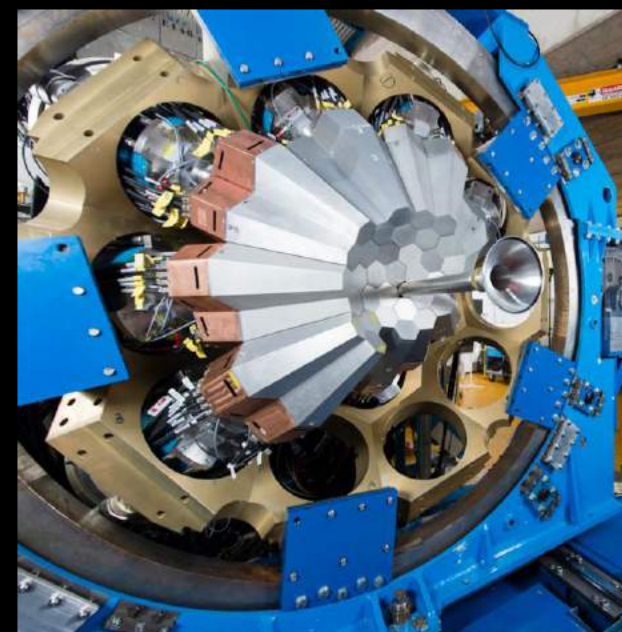
Construction phase 1 (2009-2020) ➔ 4/3π

Positive recommendations from the Scientific Council of in2p3 in 2009
MoU signed in 2009 and renewed in 2015

15 detectors
LNL
Coupled to the magnetic spectrometer PRISMA

22 detectors
GSI
Fast radioactive beams coupled to Lycca

41 detectors (2019)
GANIL
Coupled to VAMOS, NEDA/N-Wall, DIAMANT, FATIMA, PARIS, MUGAST

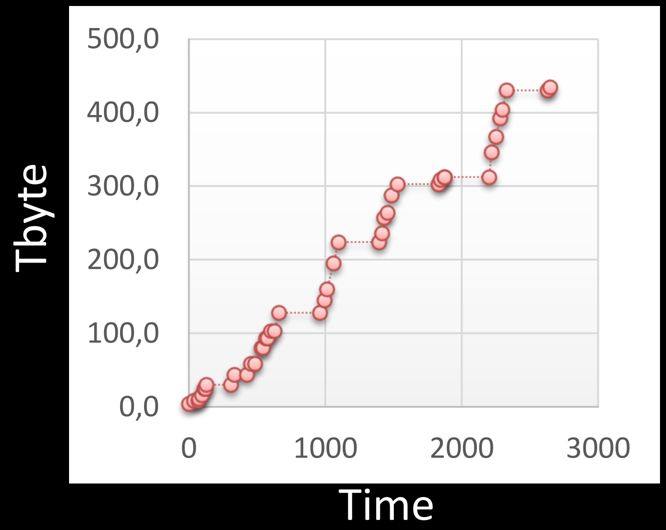


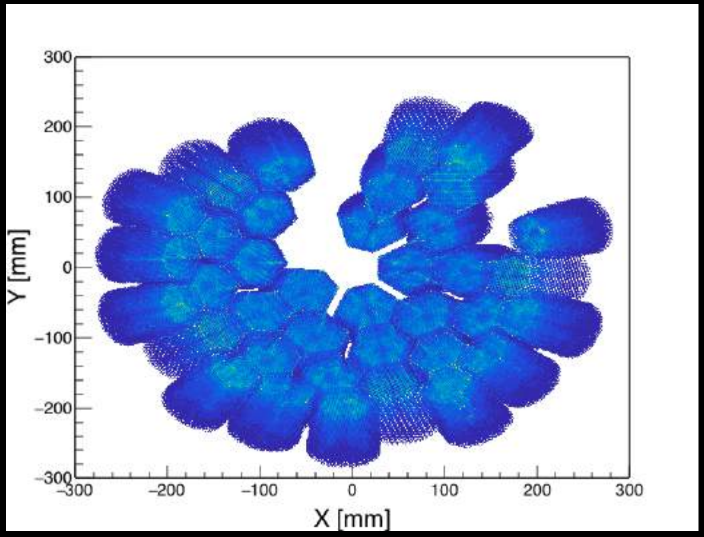
LNL 2010-2011 ➔ **GSI 2012-2014** ➔ **GANIL 2015-2021**

~60 weeks of beam on target, 57 scientific and 40 technical papers since 2010

Achievements

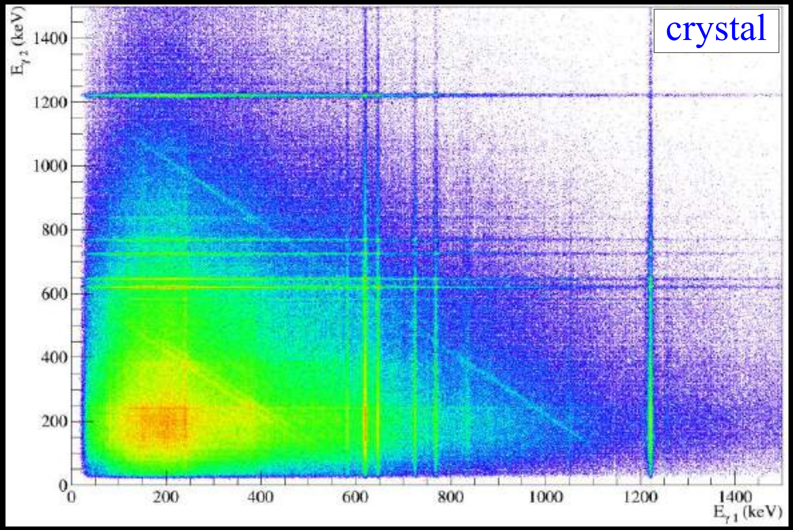
Data accumulation at GANIL

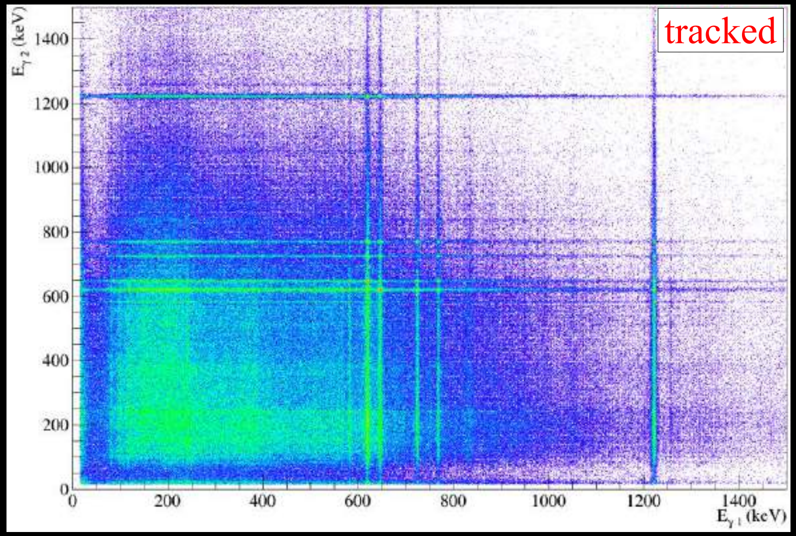




Hit patterns from PSA analysis

γ–γ coincidences



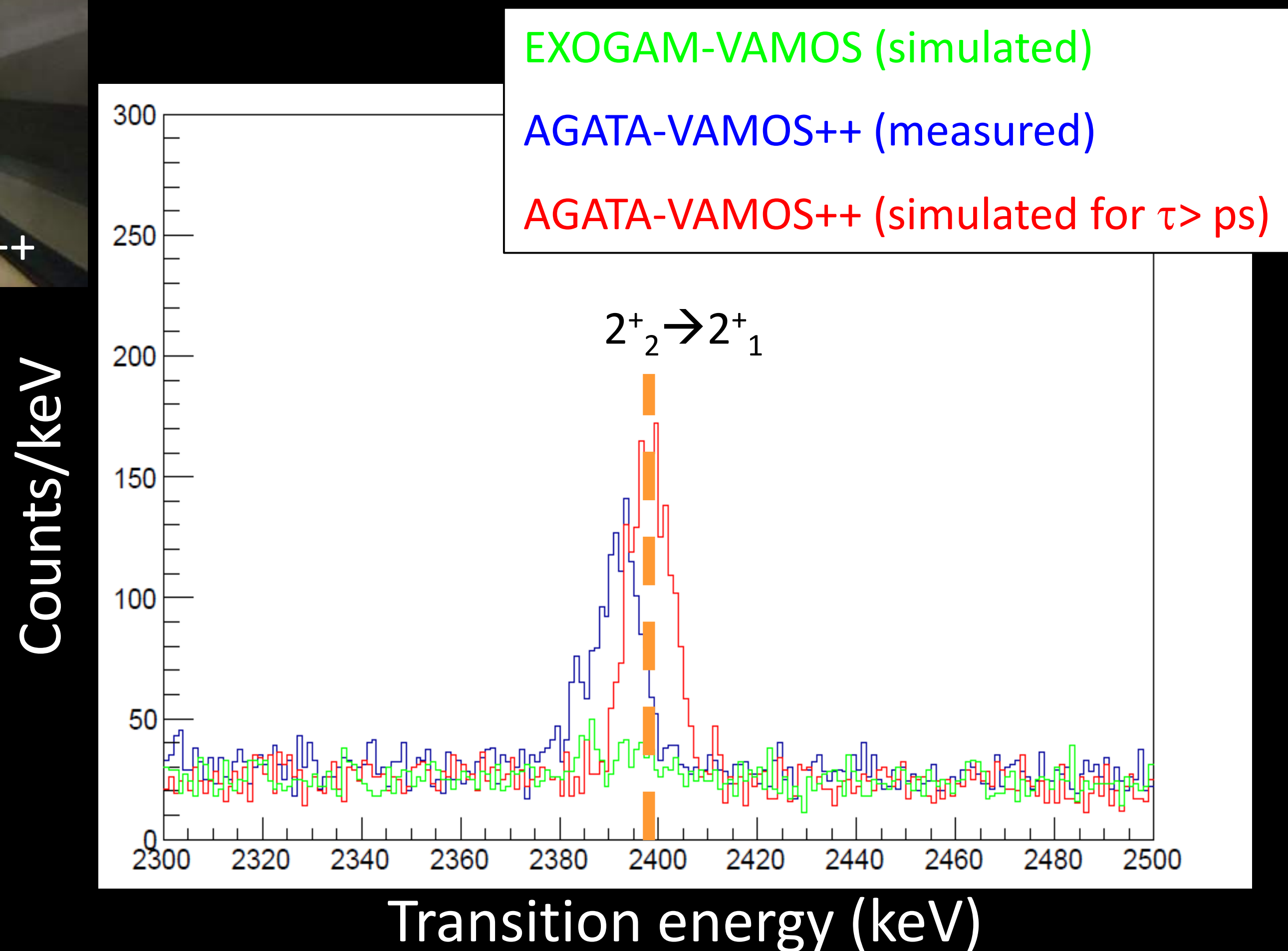


Achievements

M. Ciemala, S. Leoni, B. Fornal et al.

Unique lifetime measurements

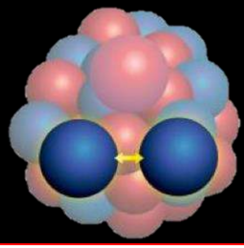
$^{181}Ta(^{18}O, ^{20}O)$

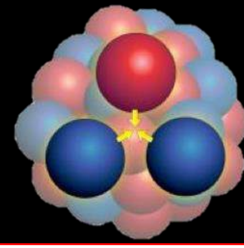


Some highlights

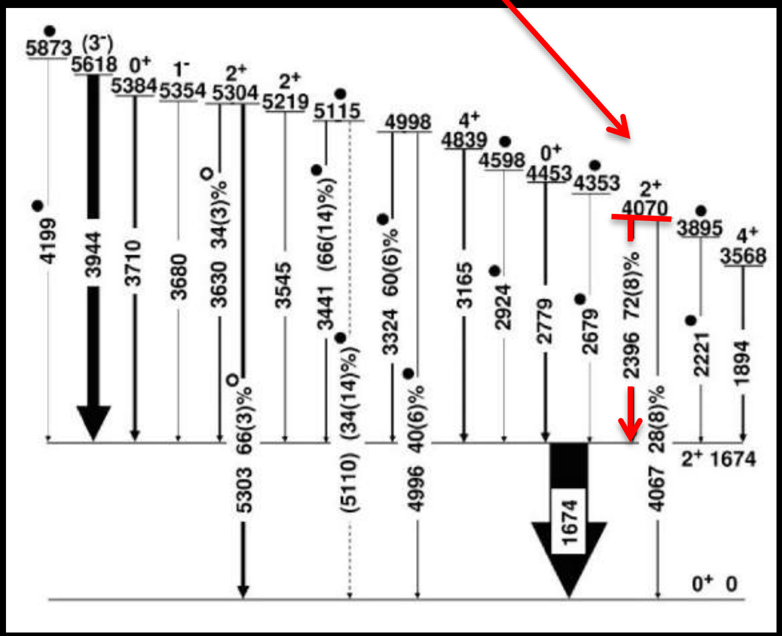
M. Ciemala, S. Leoni, B. Fornal et al.

^{181}Ta(^{18}O, ^{20}O)





$t_{1/2}$=0.32 ps	$t_{1/2}$=0.20 ps
δ(E2/M1) =0.24	δ(E2/M1)=0.04



Preliminary result: $\tau = 150 \begin{smallmatrix} +80 \\ -30 \end{smallmatrix}$ fs

M. Ciemala et al., Letter in preparation

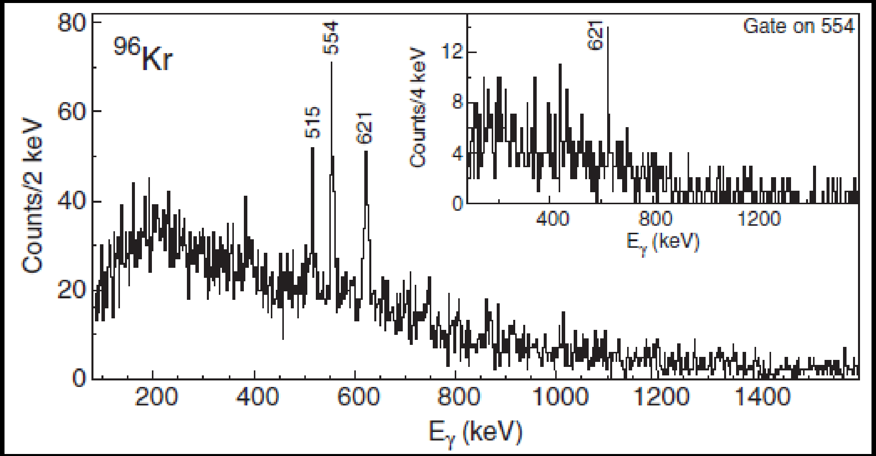
This result is not compatible with theoretical lifetimes calculated including 2-body terms only

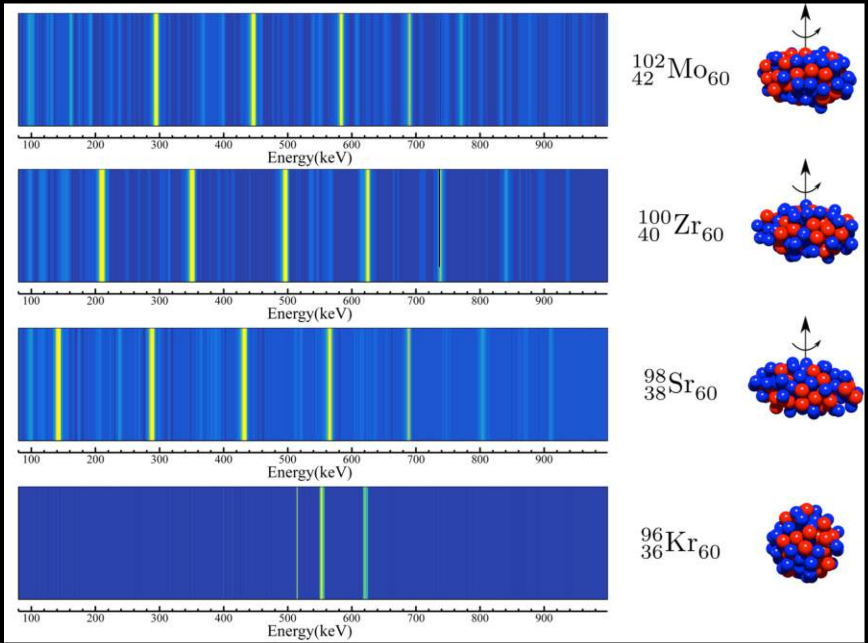
Some highlights

^{238}U @ 6.2 MeV/u on ^{9}Be

AGATA @ VAMOS ++

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



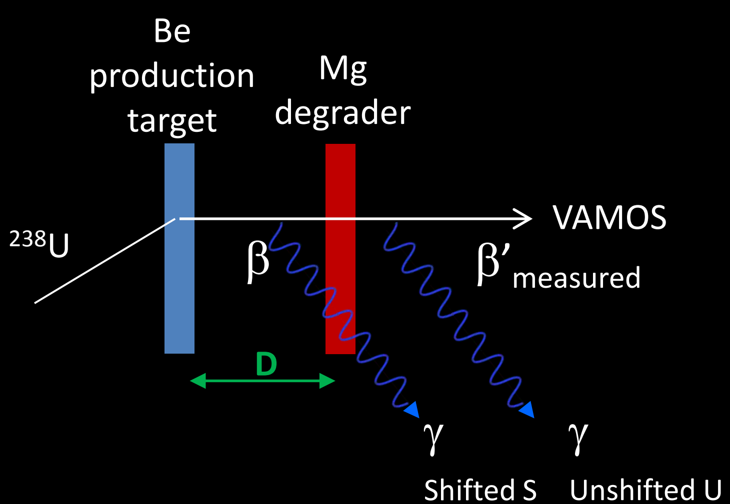


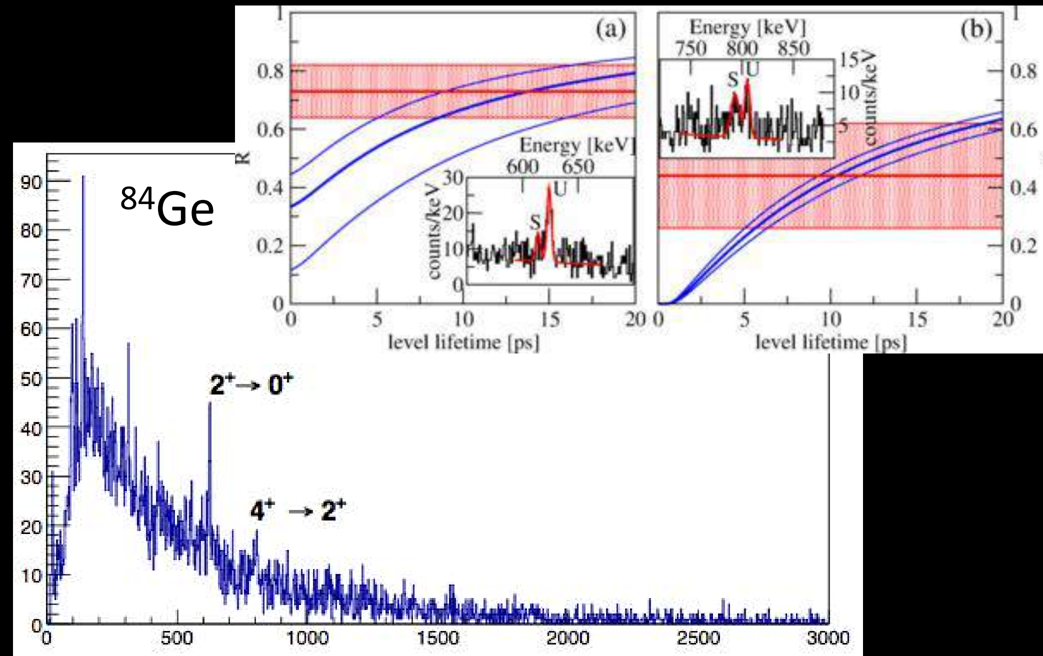
Sharp shape transition at N=60 when moving from Sr to Kr

Challenge for theory to reproduce all the observables in this region, which is important for the r-process

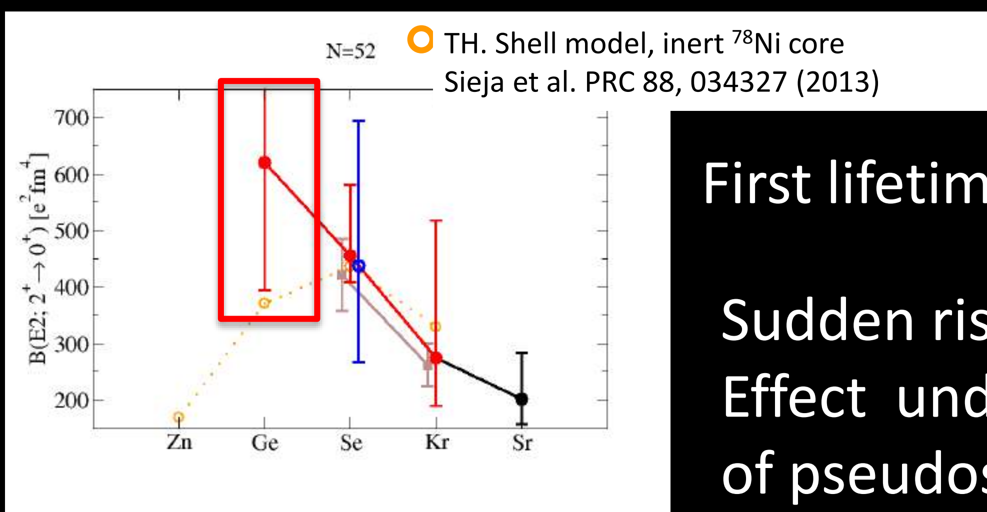
Some highlights

AGATA+OUPS @ VAMOS++





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

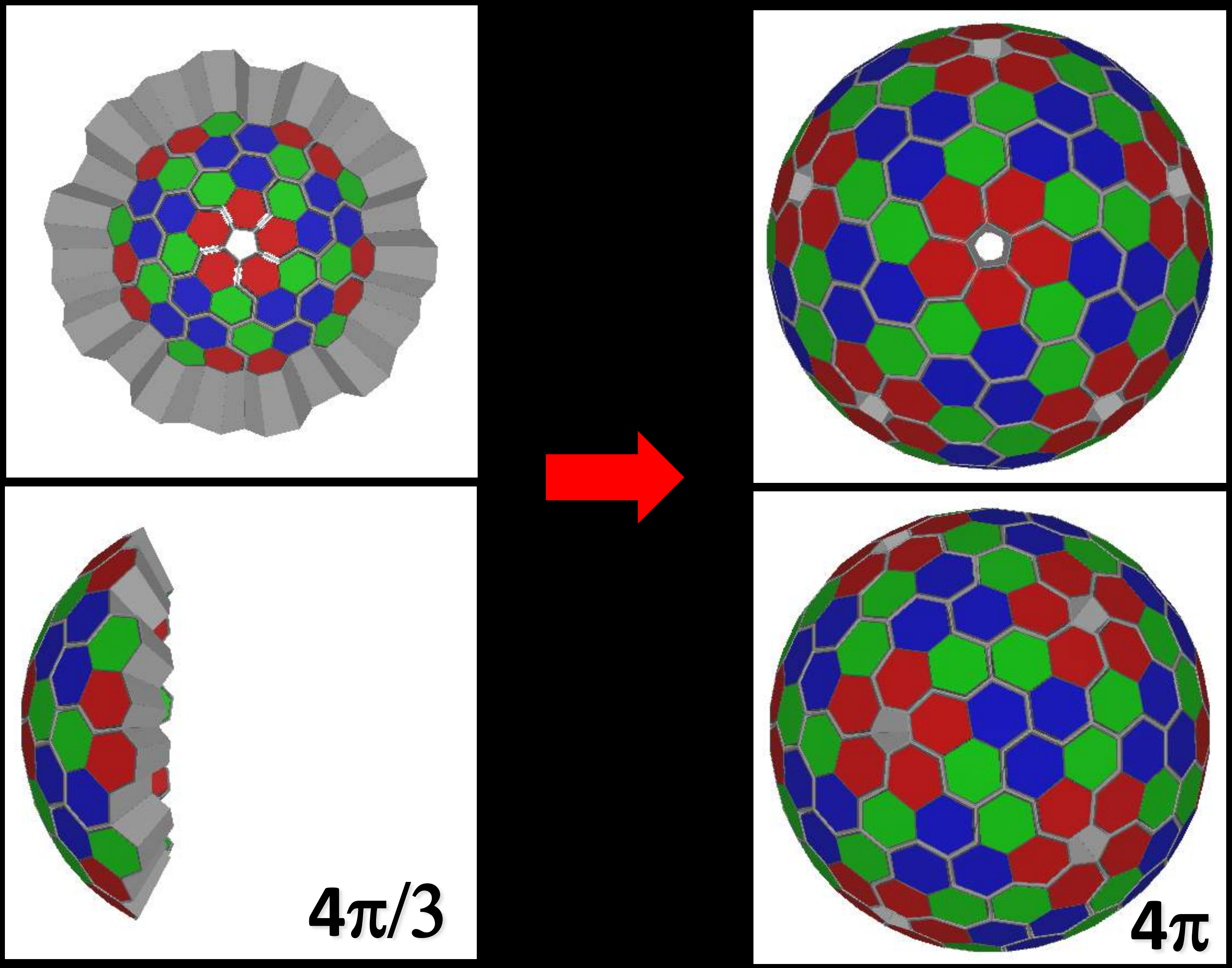


First lifetimes measured in very exotic ^{84}Ge

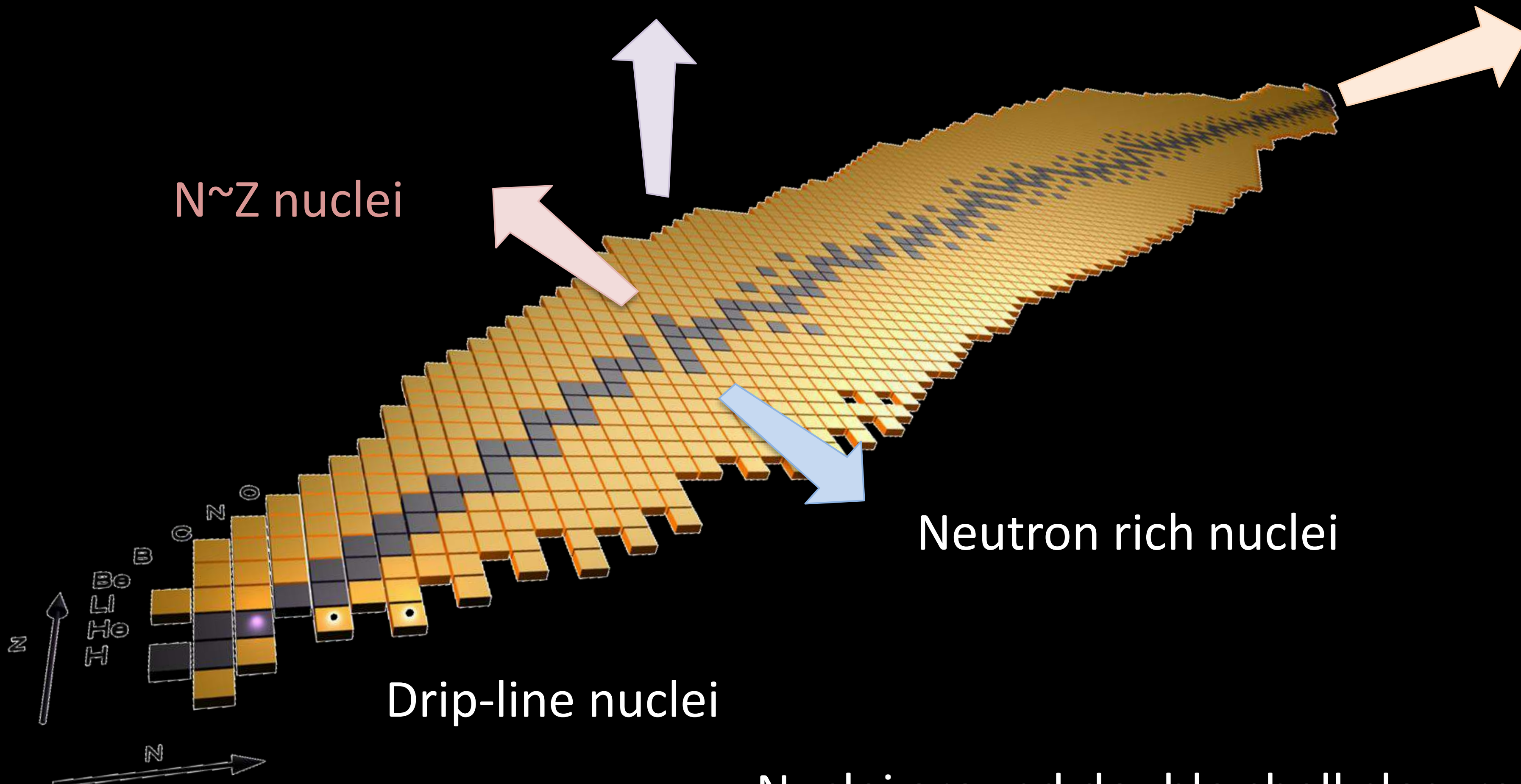
Sudden rise of collectivity at Z=32

Effect understood as the manifestation of pseudospin symmetry

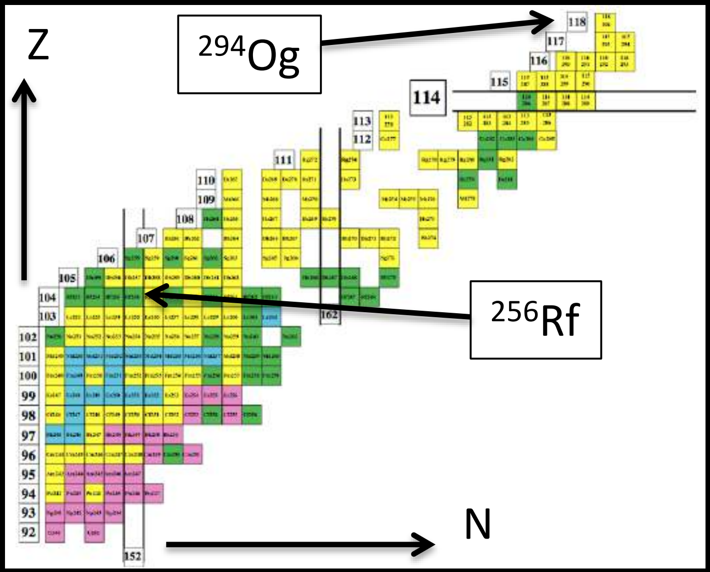
AGATA upgrade:
construction phase 2 ➔ 4π

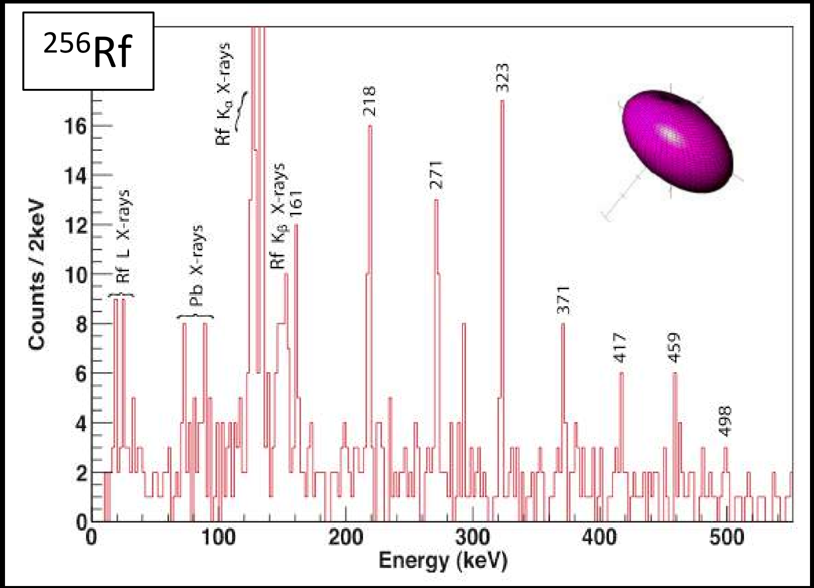


AGATA upgrade: Physics Program

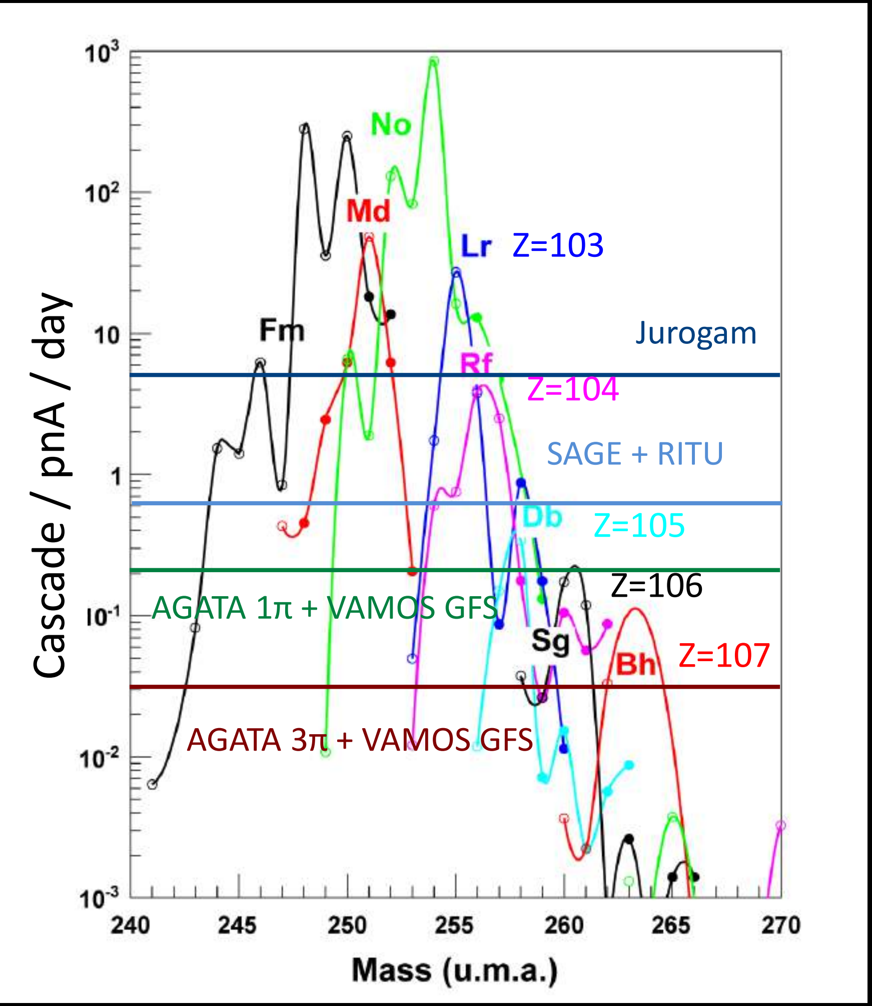


Pushing the limits of Z & A



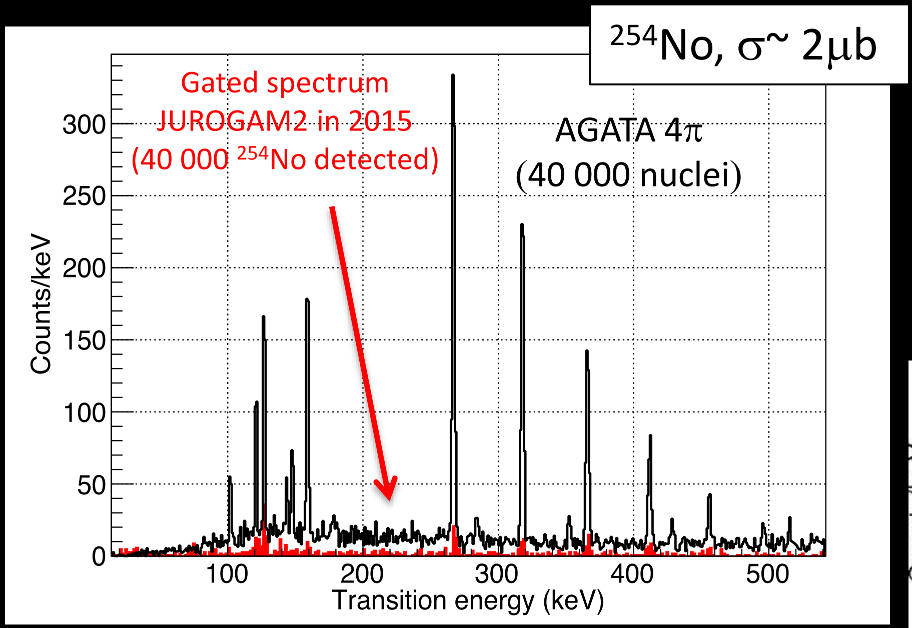


P.T. Greenlees, Phys. Rev. Lett. 109 (2012) 012501

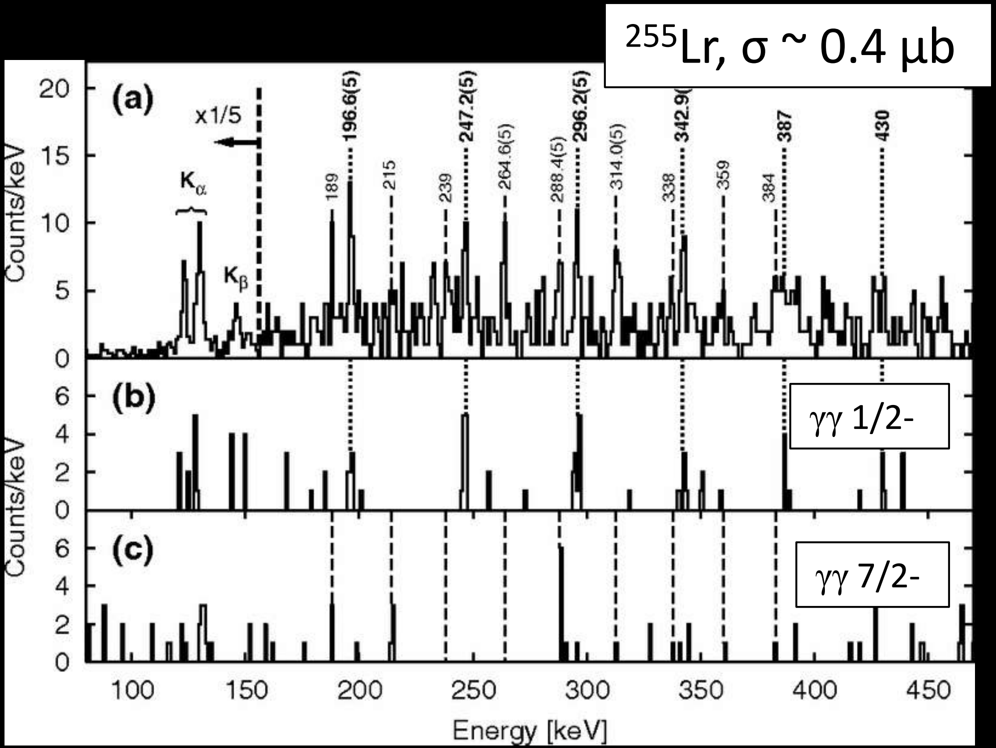


+ huge gain in γ^n statistics

Pushing the limits of Z & A



Enhanced resolving power gives acces to detailed sub-μb spectroscopy



S. Ketelhut et al., Phys. Rev. Lett. 102, 212501 (2009)

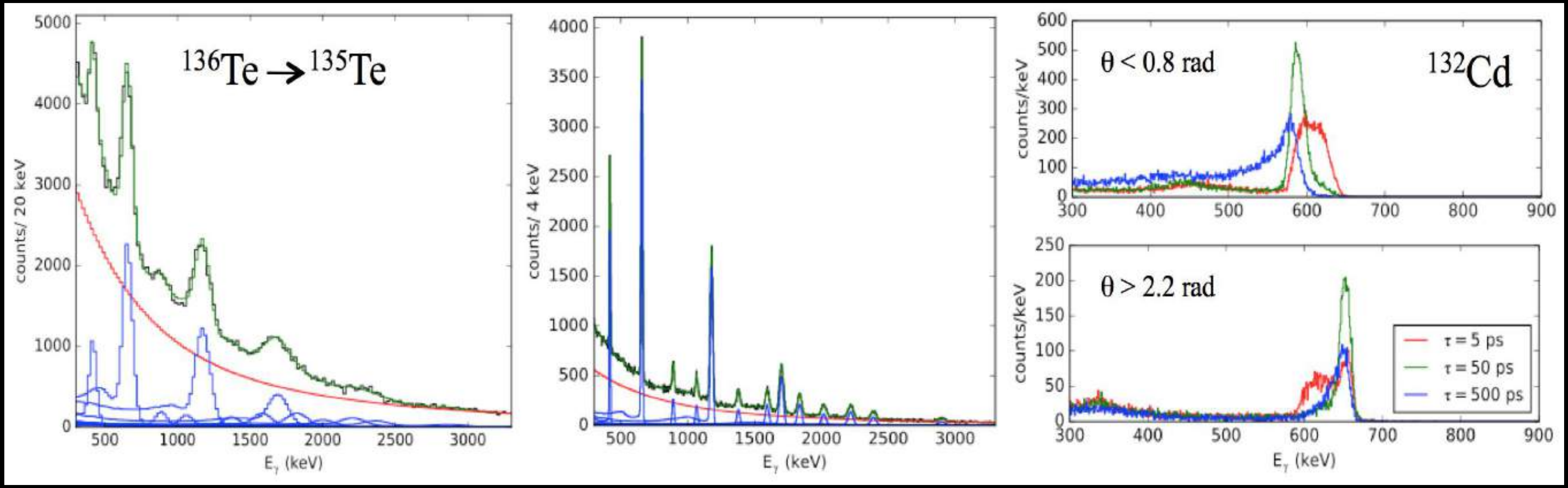
Pushing the limits of isospin

From 1st spectroscopy to high-precision measurements north & south east of ^{132}Sn: particle-hole excitations and transition probabilities

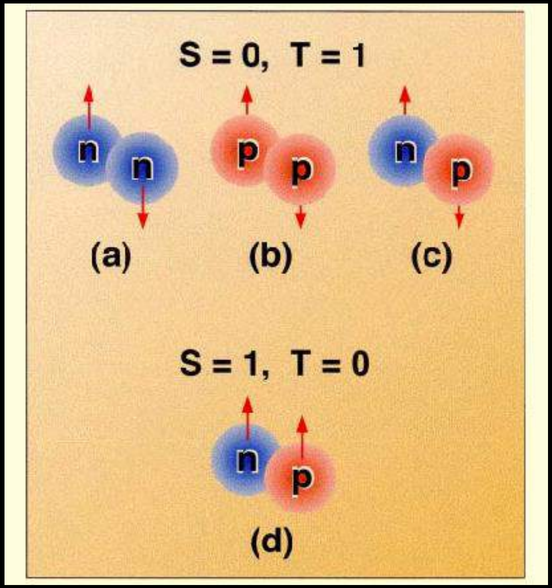
Knockout with DALI2 @RIKEN

Knockout with AGATA@FAIR

Coulex with AGATA@FAIR



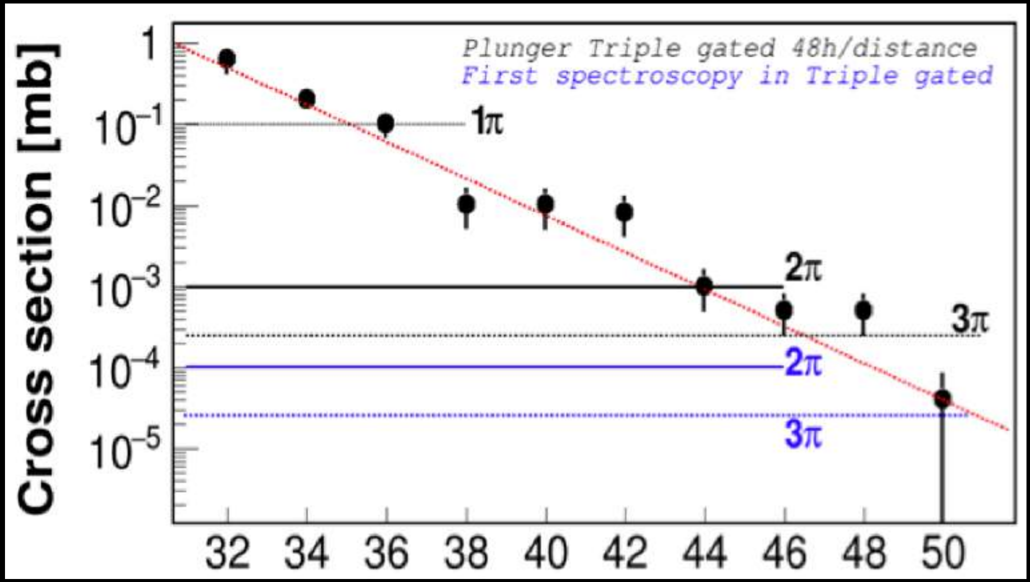
Pushing the limits of isospin



Access to heavier N~Z systems than currently accessible

Fusion-evaporation reactions with stable beams

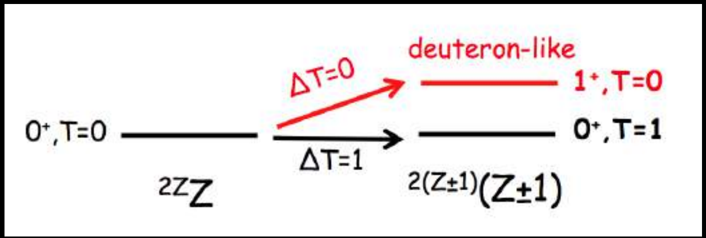
AGATA
+ 1π neutron array
+ charged-particle detector



N=Z

(^{3}He,p) reactions with SPIRAL1 beams

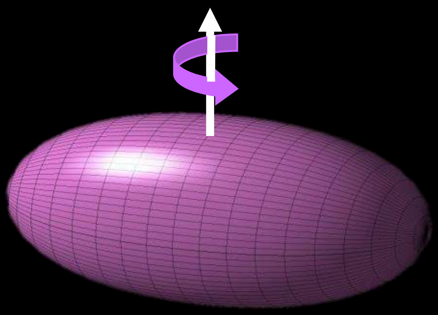
AGATA + GRIT + VAMOS

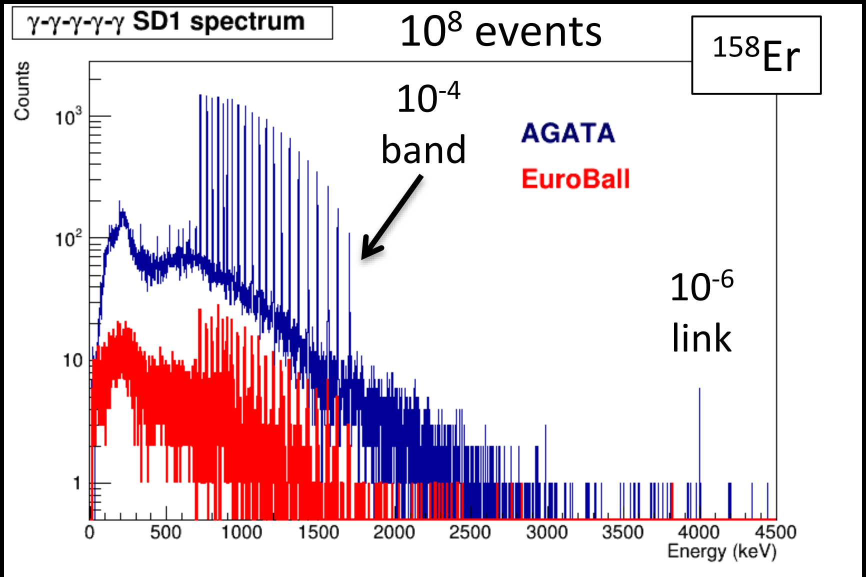


Exotic shapes

‘Top unexpected physics discoveries of the last five years’
(D. Kleppner, Physics Today, 1991)

High Tc superconductivity
Atom cooling and atom optics
Large-scale structure of the universe
Supernova 1987A
Superdeformed Nuclei
Buckyballs



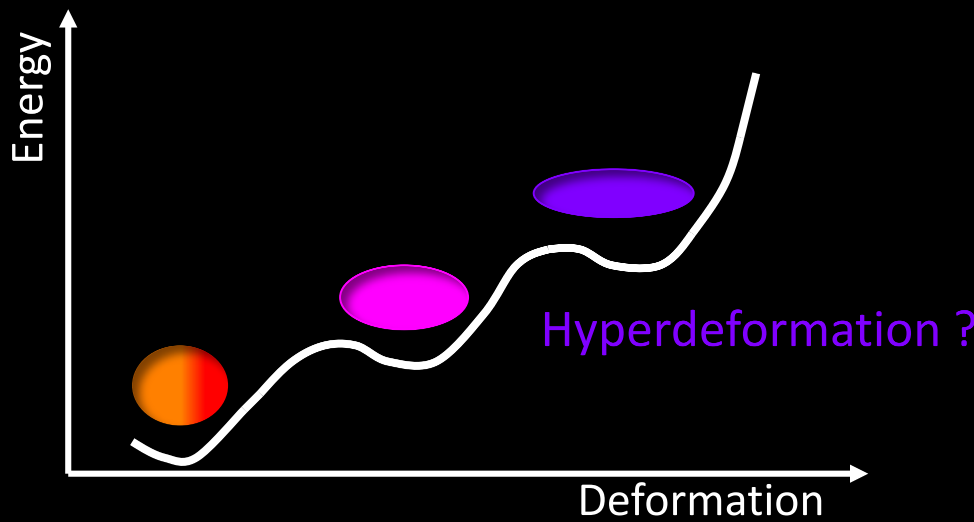


Many questions remain unanswered:

Decay-out from superdeformed states ?
Clusterisation & exotic decays in light nuclei ?
Superdeformation in neutron-rich nuclei ?
High-K superdeformed states ?
Population mechanism ?

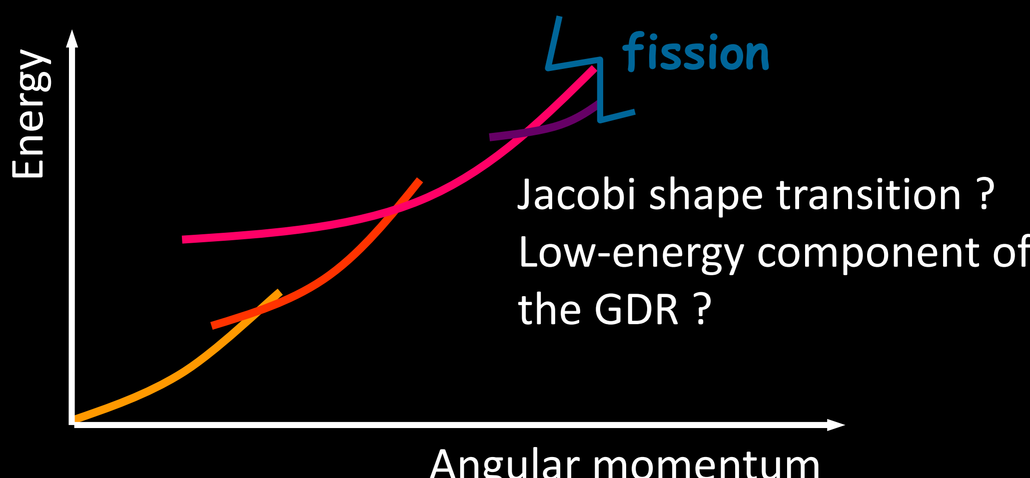
Exotic shapes

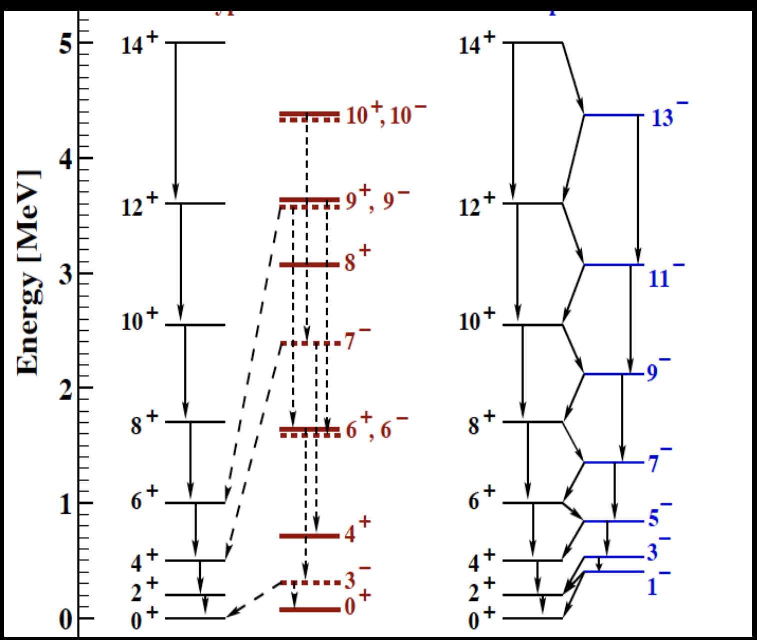
Can we observe the signatures of more exotic shapes of the nucleus?



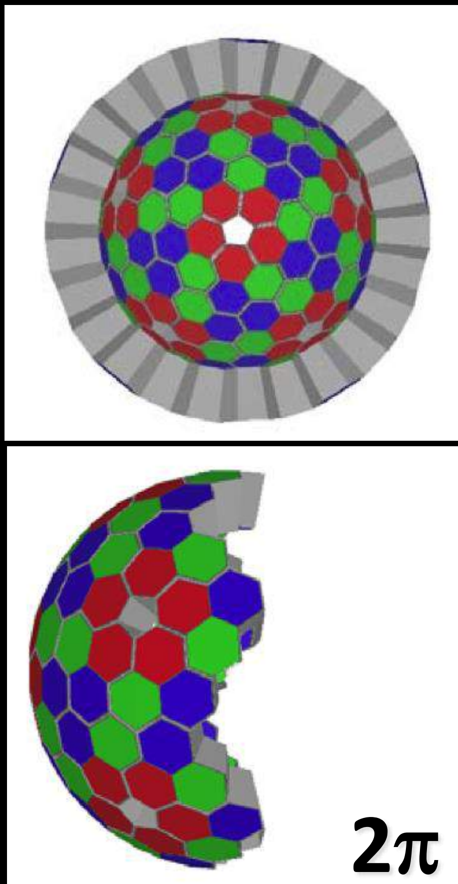
Tetrahedral deformation

Octupole deformation

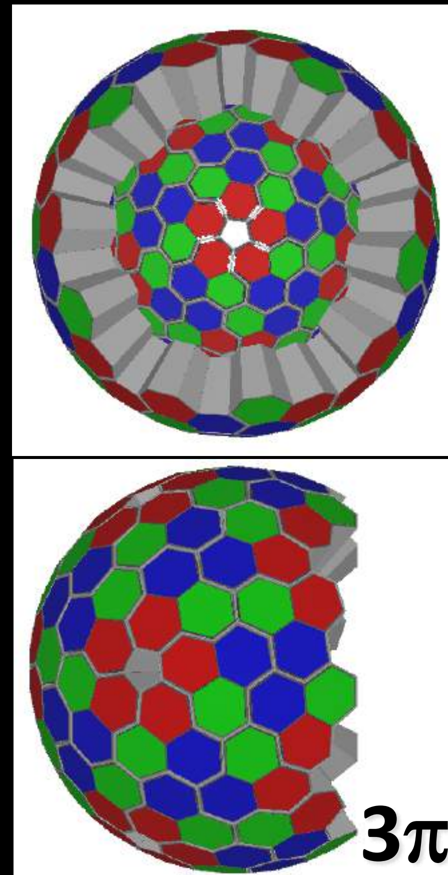




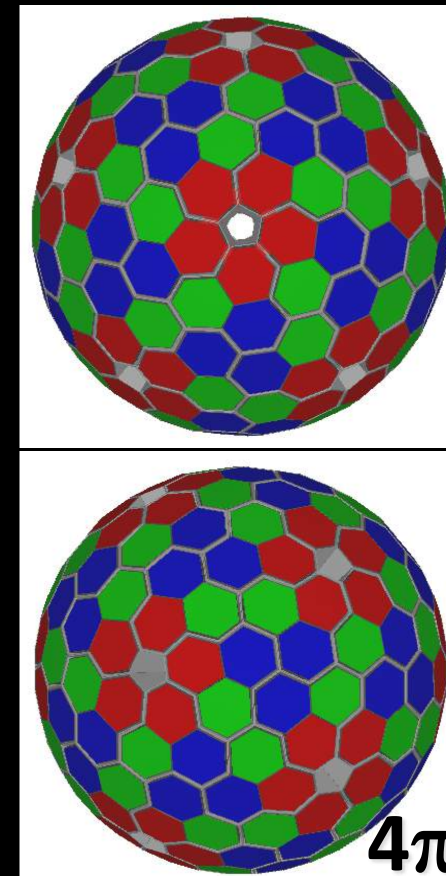
AGATA upgrade: 4π in 2030
Timeline & host laboratories



Stable beams &
accelerated ISOL beams



Radioactive ion beams
(projectile fragmentation & fission)



Stable beams &
accelerated ISOL beams

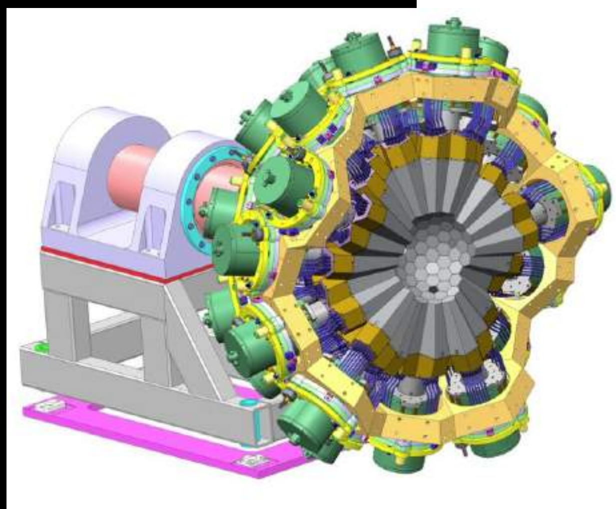
LNL 2022-2025

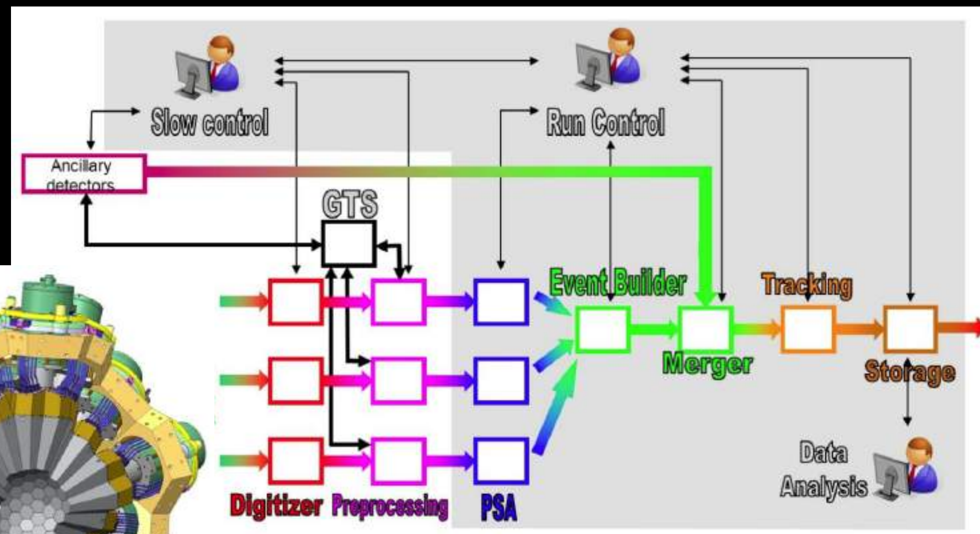
FAIR/ISOLDE 2026-2028 ?

JYFL/GANIL 2029-2030 ?

AGATA upgrade – Technical Details

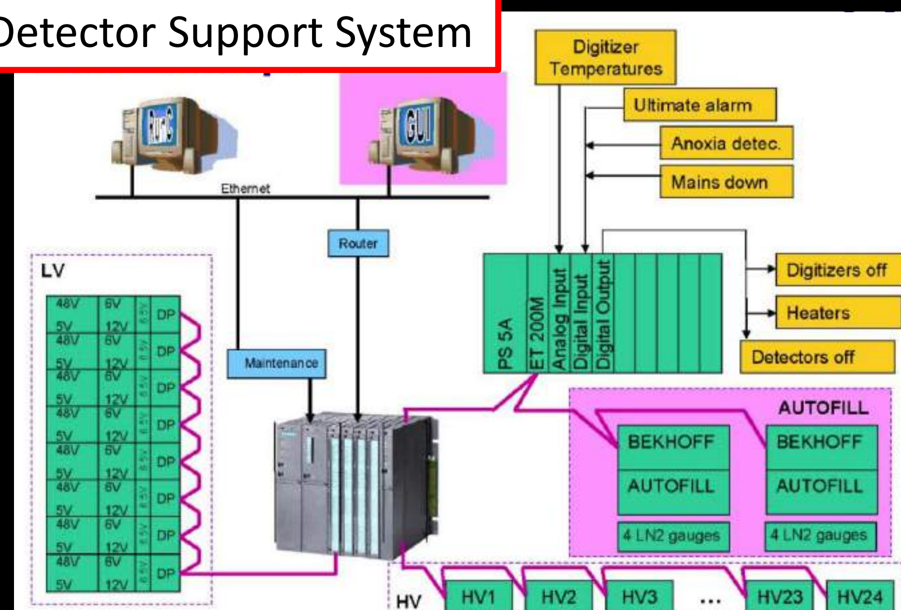
New honeycomb holding & detector-mounting structures





Upgraded DAQ based on NARVAL/ DCOD & improved Algorithms

New Detector Support System



New Electronics with 10 GB ethernet readout

Estimated capital investment

Item	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Capsules/Clusters	72/24	84/28	96/32	108/36	120/40	132/44	144/48	156/52	168/56	180/60	
Detector	2528,5	2566,4	2604,9	2643,9	2683,6	2723,9	2764,7	2806,2	2848,3	2891	27061,4
Cryostat	468,5	475,5	483,6	489,9	497,2	504,7	512,2	519,9	527,7	535,6	5014,8
Electroics	97,7	0	97,7	488,5	488,5	0	488,5	0	488,5	0	2149,4
Electronics Upgrade	390,8		390,8								
GTS/SMART	0	120									120,0
PSA/DAQ	0	483				343				357	1183,0
Storage		112,5				112,5				112,5	337,5
Analysis		10				10				10	30,0
Infrastructure	415,1			440,6							855,7
Mechanics	230,3			330							560,3
Total	**4130,9**	**3767,4**	**3577**	**4392,9**	**3669,3**	**3694,1**	**3765,4**	**3326,1**	**3864,5**	**3906,1**	**38093,7**
France	**826,2**	**753,5**	**715,4**	**878,6**	**733,9**	**738,8**	**753,1**	**665,2**	**772,9**	**781,2**	**7618,7**
IN2P3	**504,0**	**459,6**	**436,4**	**535,9**	**447,7**	**450,7**	**459,4**	**405,8**	**471,5**	**476,5**	**4647,4**

In2p3 contribution is calculated on the basis of the actual sharing between French partners

An application to become Infrastructure de Recherche will be made in 2020

Estimated Operation Costs

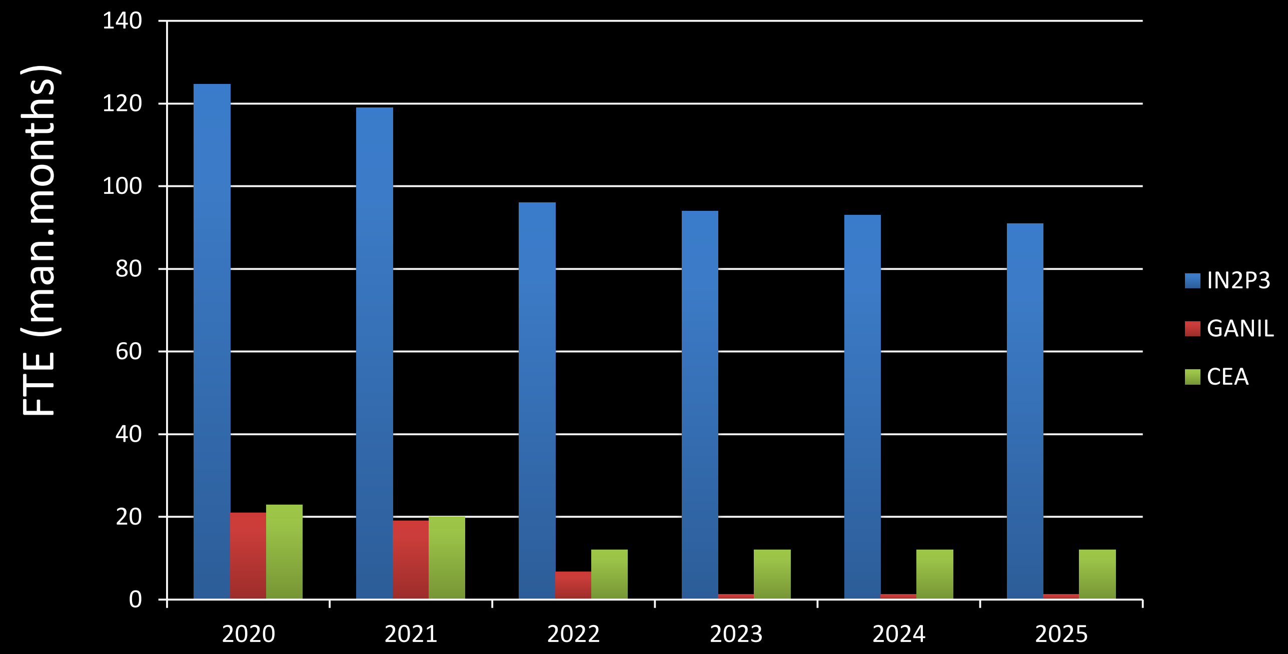
Operational / Maintenance Costs

Item	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
Capsules in setup	60	60	72	84	96	108	120	132	144	156	162	180	180	180
Expected Capsule failures	5	5	6	7	8	9	9	10	11	12	13	14	14	14
failures Under Warranty	1	1	1	2	2	2	2	2	2	2	2	2	1	0
Detectors in setup	20	20	24	28	32	36	40	44	48	52	54	60	60	60
Detectors														
LN2	73.5	73.5	85.5	97.5	109.5	121.5	133.5	145.5	157.5	169.5	175.5	193.5	193.5	193.5
Capsule maintenance/repair	206.0	209.1	265.3	269.3	328.0	388.4	394.3	457.4	522.2	589.0	657.6	728.1	800.6	875.2
Detector&Cryostat maintenance /repair	77.6	78.7	95.9	113.5	131.7	150.4	169.6	189.4	209.7	230.5	243.0	274.0	278.2	282.3
Including Preamplifer exchange…														
and Other repairs (feedthrough, cabling,…)														
Detector laboratories	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Infrastructure														
HV/LV, Autofill, infrastructure	21.8	21.8	26.1	30.5	34.8	39.2	43.5	47.9	52.2	56.6	58.7	65.3	65.3	65.3
Electronics and DAQ														
Elect. maintenance/replacement	0.0	42.0	42.0	100.8	115.2	129.6	144.0	158.4	172.8	187.2	194.4	216.0	216.0	216.0
DAQ maintenance/replacement	63	63	75.6	88.2	100.8	113.4	126	138.6	151.2	163.8	170.1	189	189	189
Other costs														
Grid costs	24	24	24	24	24	24	24	24	24	24	24	24	24	24
Shipping costs	25	25	27	29	31	33	33	35	37	39	41	43	43	43
Mechanics	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Total operation & maintenance costs	**558.8**	**605.1**	**709.4**	**820.8**	**943.0**	**1067.5**	**1135.9**	**1264.1**	**1394.6**	**1527.6**	**1632.3**	**1800.9**	**1877.6**	**1956.2**

French contribution should be ~17% of the total

In the present MoU, the In2p3 share is 2/3 of the French contribution

Manpower for the upgrade



Falling ETPs up to 2022 are due to end of phase 2 development (DSS, electronics, DAQ) and start of maintenance regime
From 2025->2030, the expected manpower should stay stable

The numbers do not include the manpower to perform & analyze experiments, which also involve physicits from many other collaborations

Conclusion & Perspectives

- AGATA is a successful collaboration
- AGATA is a precision tool to be used in conjunction with other state-of-the-art detectors at European RIB and stable beam facilities
- Broad program of studies
- Of interest to a large community

Support to the completion of AGATA in full geometry

AGATA represents the state-of-the-art in gamma-ray spectroscopy and is an essential precision tool underpinning a broad programme of studies in nuclear structure, nuclear astrophysics and nuclear reactions. AGATA will be exploited at all of the large-scale radioactive and stable beam facilities and in the long-term must be fully completed in full 60 detector unit geometry in order to realise the envisaged scientific programme. AGATA will be realised in phases with the goal of completing the first phase with 20 units by 2020.

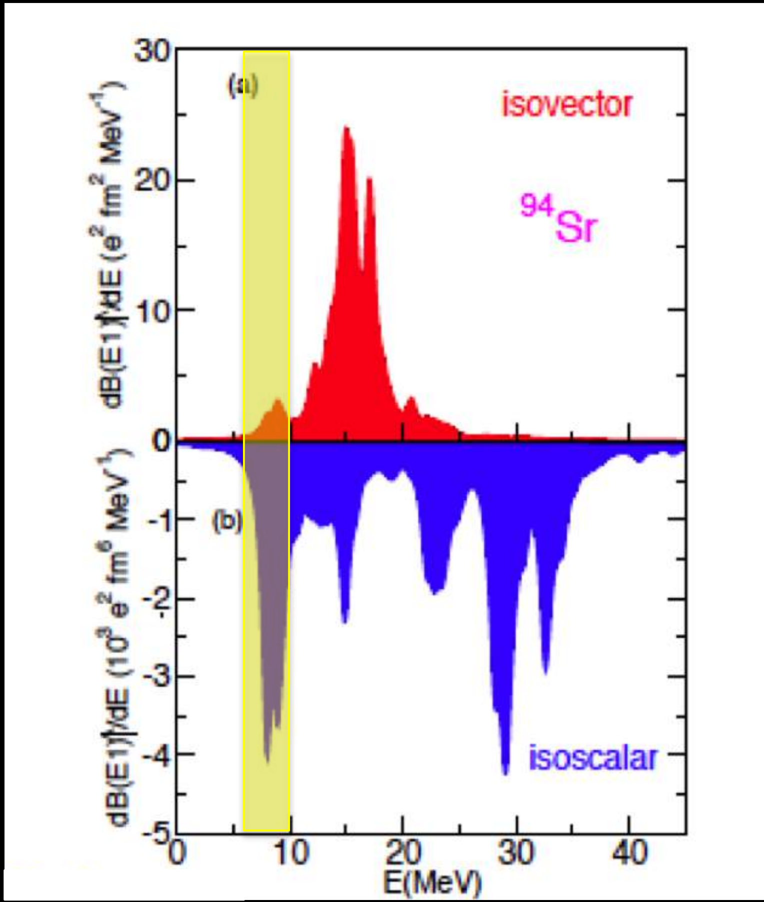
http://www.nupecc.org/lrp2016/Documents/lrp2017.pdf

Backup

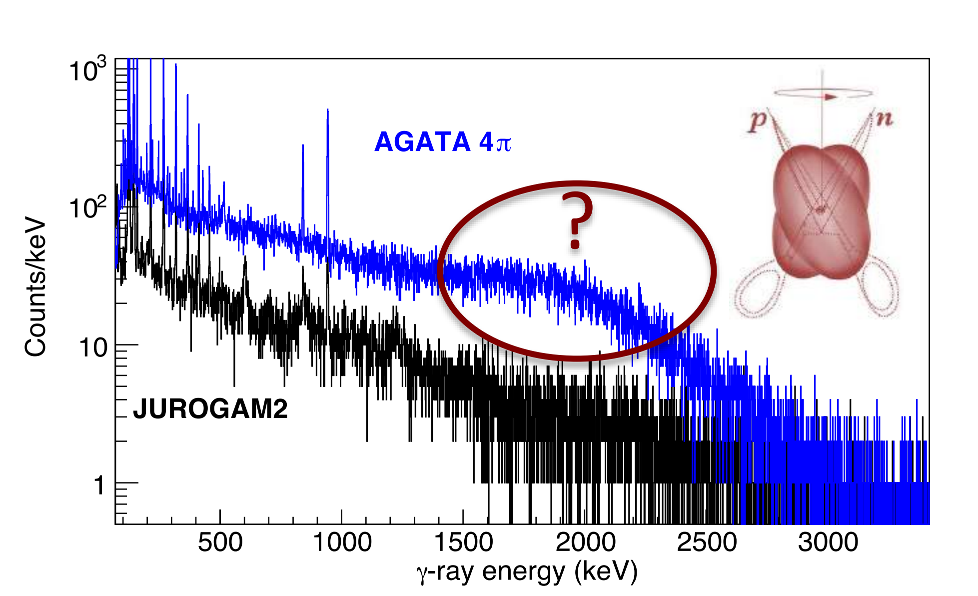
Exotic modes

Exploit AGATA's efficiency and polarization capabilities to measure new collective modes

Pygmy Dipole Resonance in neutron rich nuclei



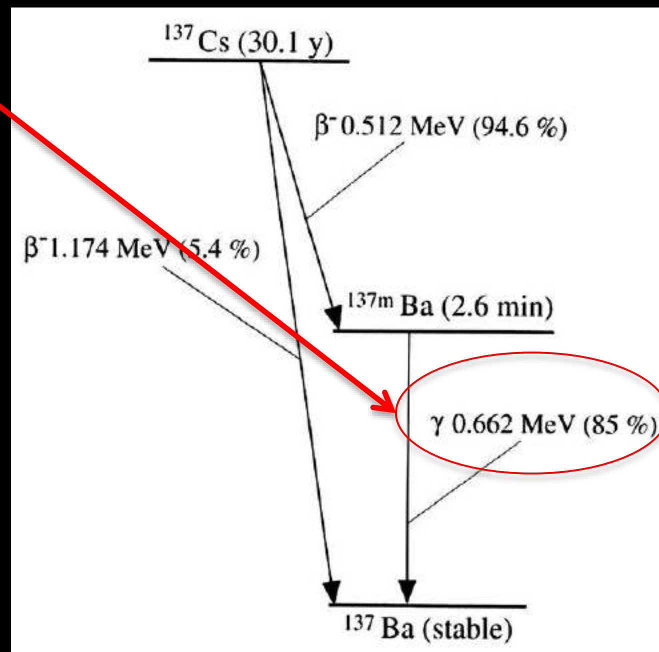
Scissors resonance in deformed super heavy nuclei

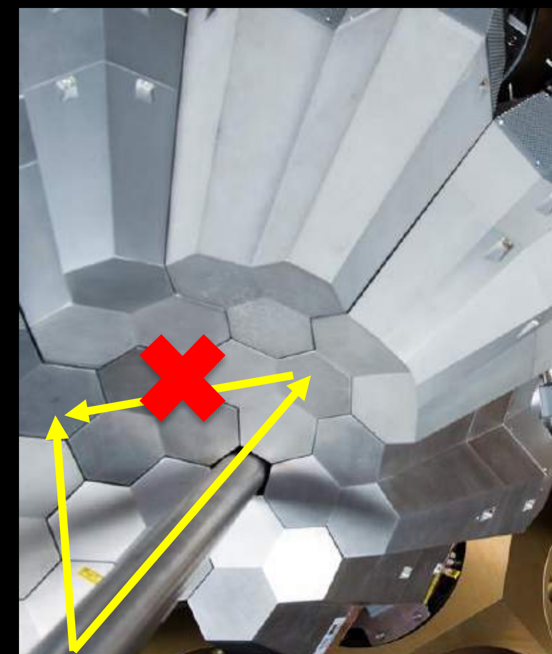


Exotic decays

Can decay as a cascade of two gamma ($P \propto 2\ 10^{-6}$) with a dominant M2-E2 and a minor E3-M1 contribution

C. Walz et al., *Nature* **volume 526**, pages 406–409 (2015)





^{137}Cs

Could $\gamma\gamma$ decays be used to obtain information on $0\nu\beta\beta$ Nuclear Matrix Elements ?

Detector laboratory

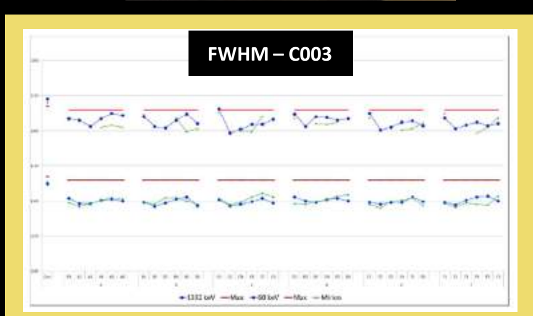
Capsules

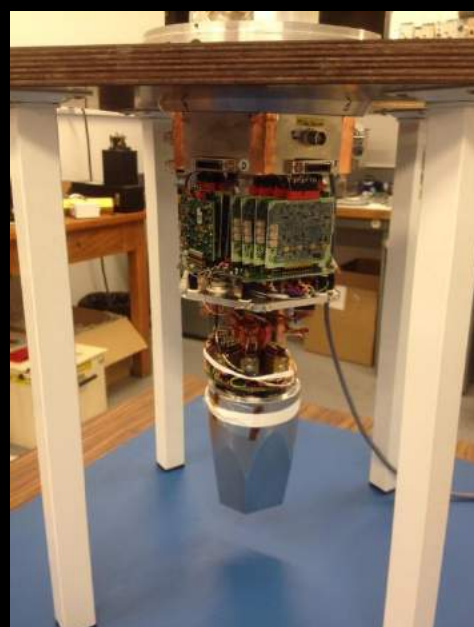
- Capsule FAT at MIRION -> tests and validation
- Capsule CAT at IPHC -> mounting of the capsule in test cryostat, cabling, tests and validation

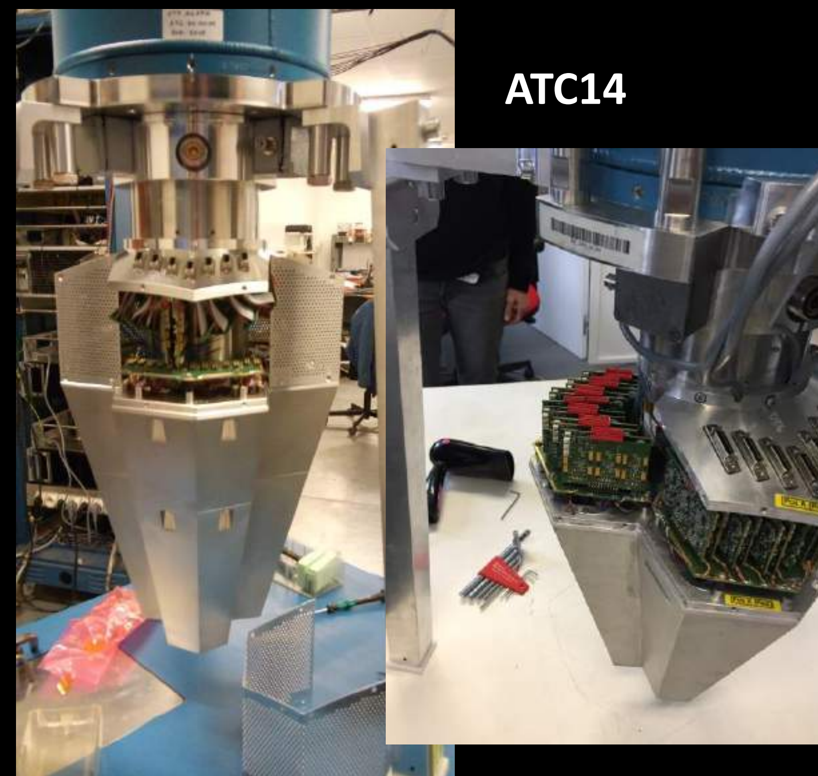
Triple detector

- Triple detector mounting (ATC14 – IN2P3) at IPHC and IKP Cologne
- Triple detector maintenance (ATC3) at GANIL and IKP Cologne

CATs







ATC14

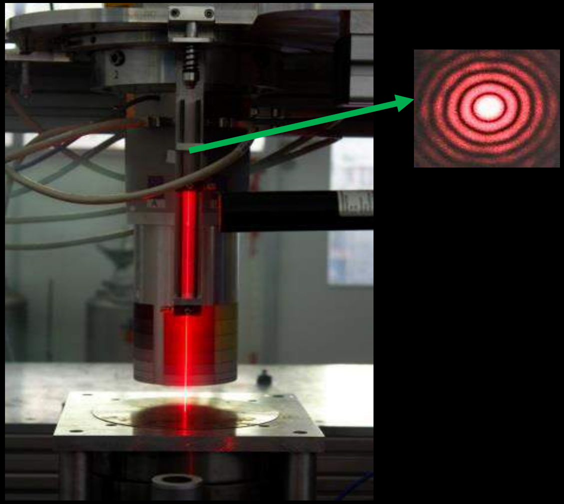
Collaboration with LNL on Ge surface treatment

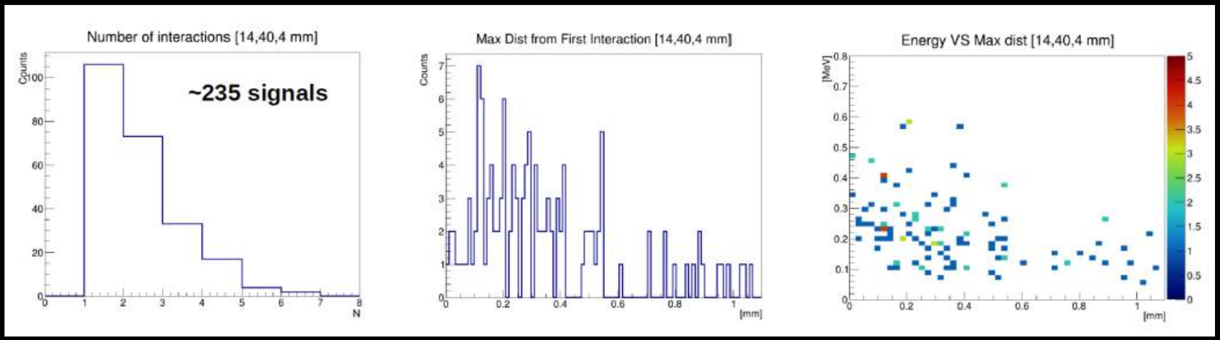
Ge scans + simulations

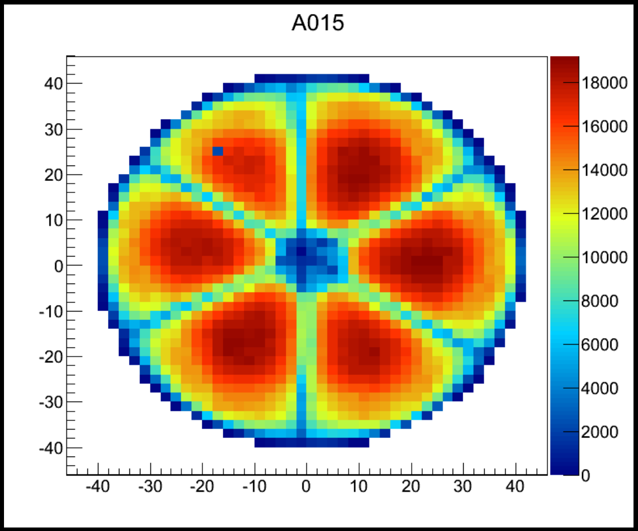
Fast scanning table based on PSCS technique (48500 points in 2 weeks)

CNRS-MIRION cofinanced PhD for detector and pulse-shape simulations

OASIS ANR -> collimator upgrade and 152Eu source (unique)

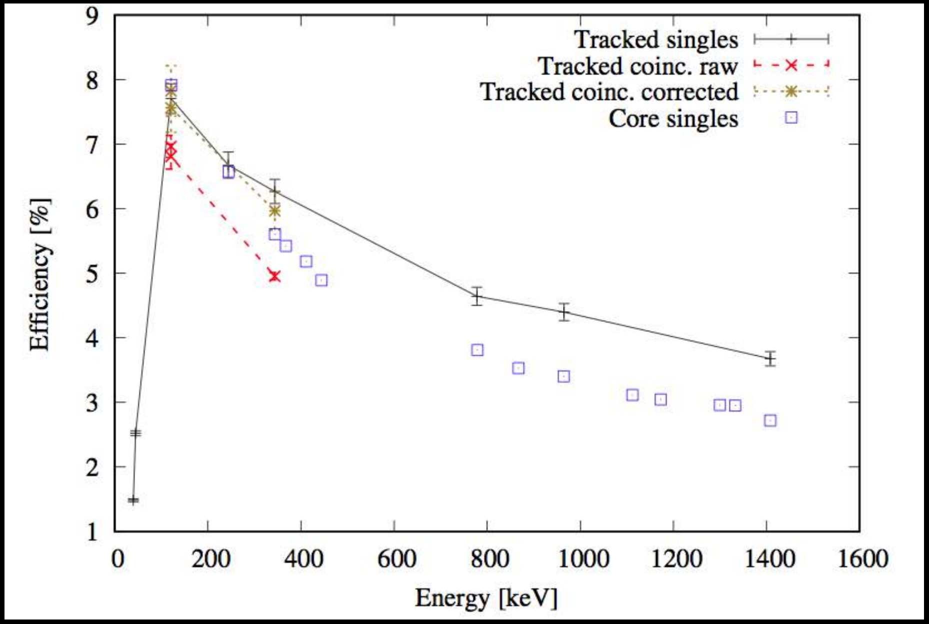




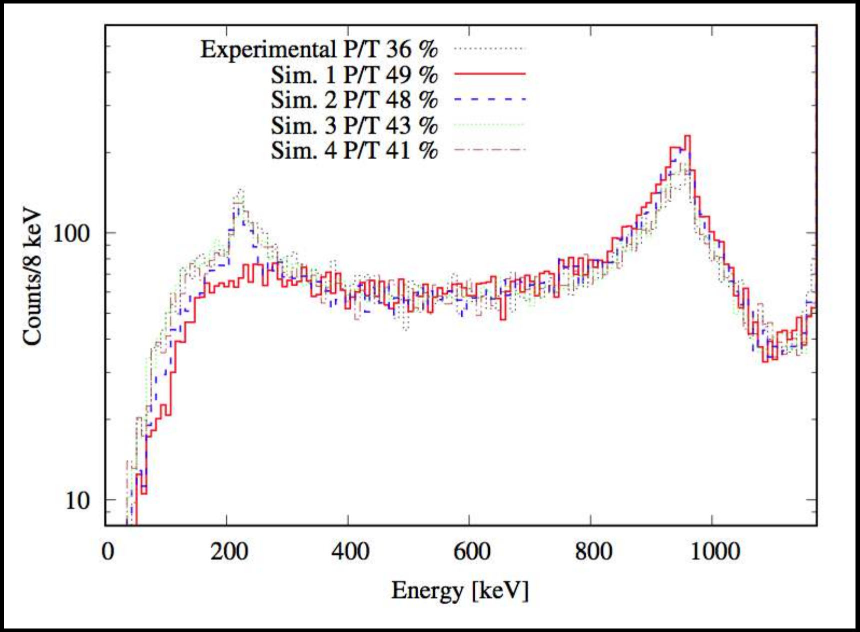


AGATA performance

J. Ljungvall et al., AGATA@GANIL Performance, submited



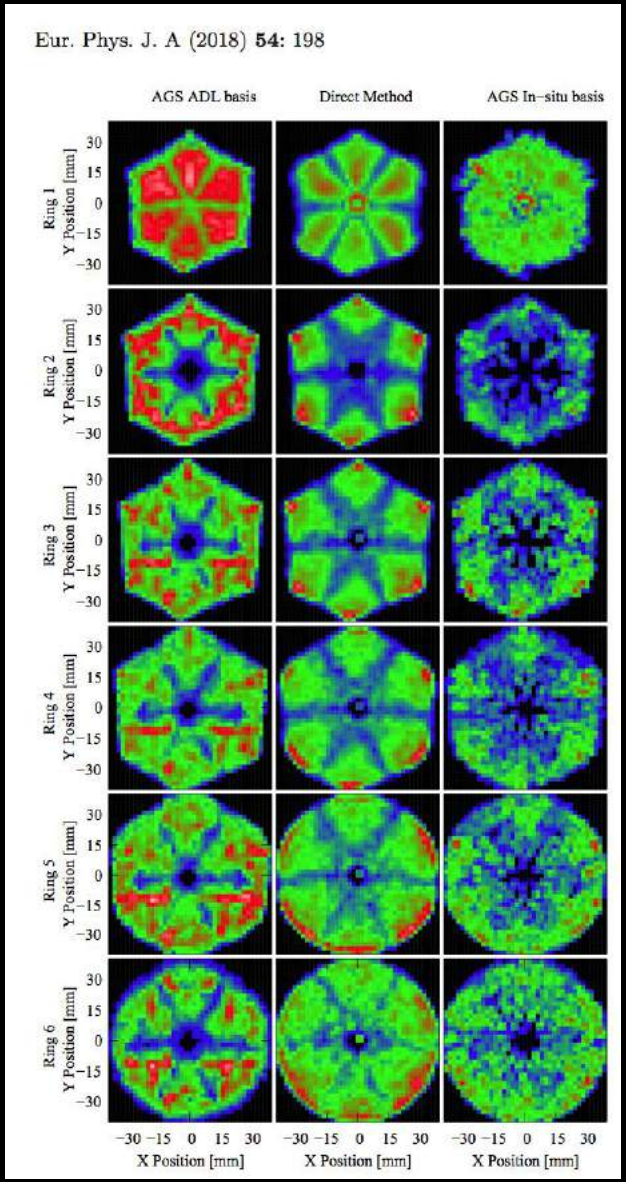
Singles & coincidence tracking efficiency



Understanding the measured P/T

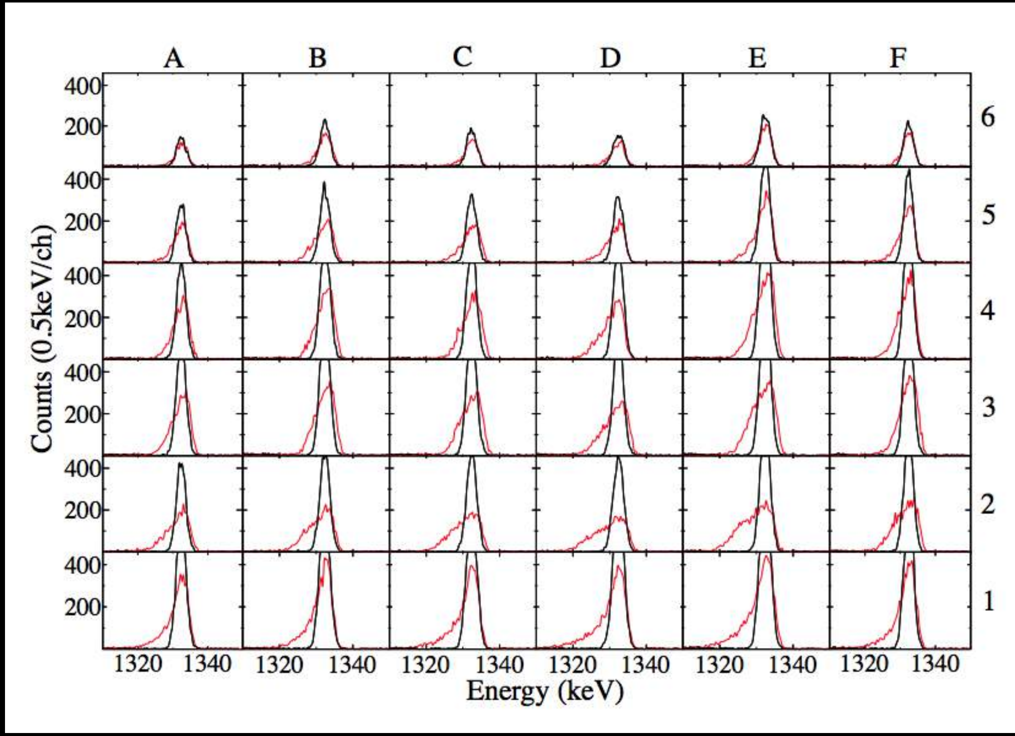
ANR OASIS (Optimization of AGATA science production ,2018-2021)
Implementation of machine learning techniques

PSA



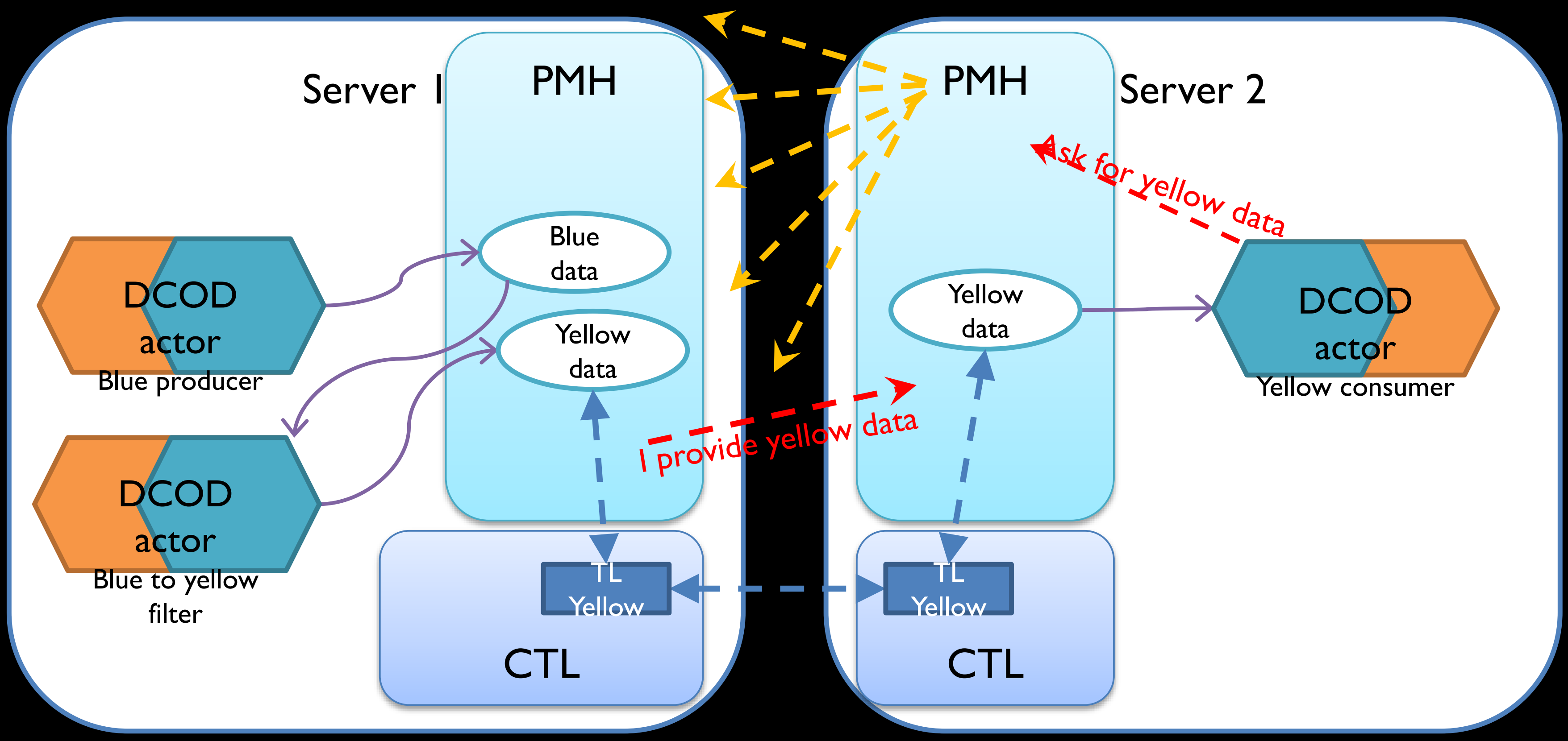
Non-homogeneous hit distributions <- non fidelity of the pusle shape basis
No improvement with experimentally determined basis
Application of GRETA PSA: ongoing

Better PSA is required for tracking & also neutron damage correction



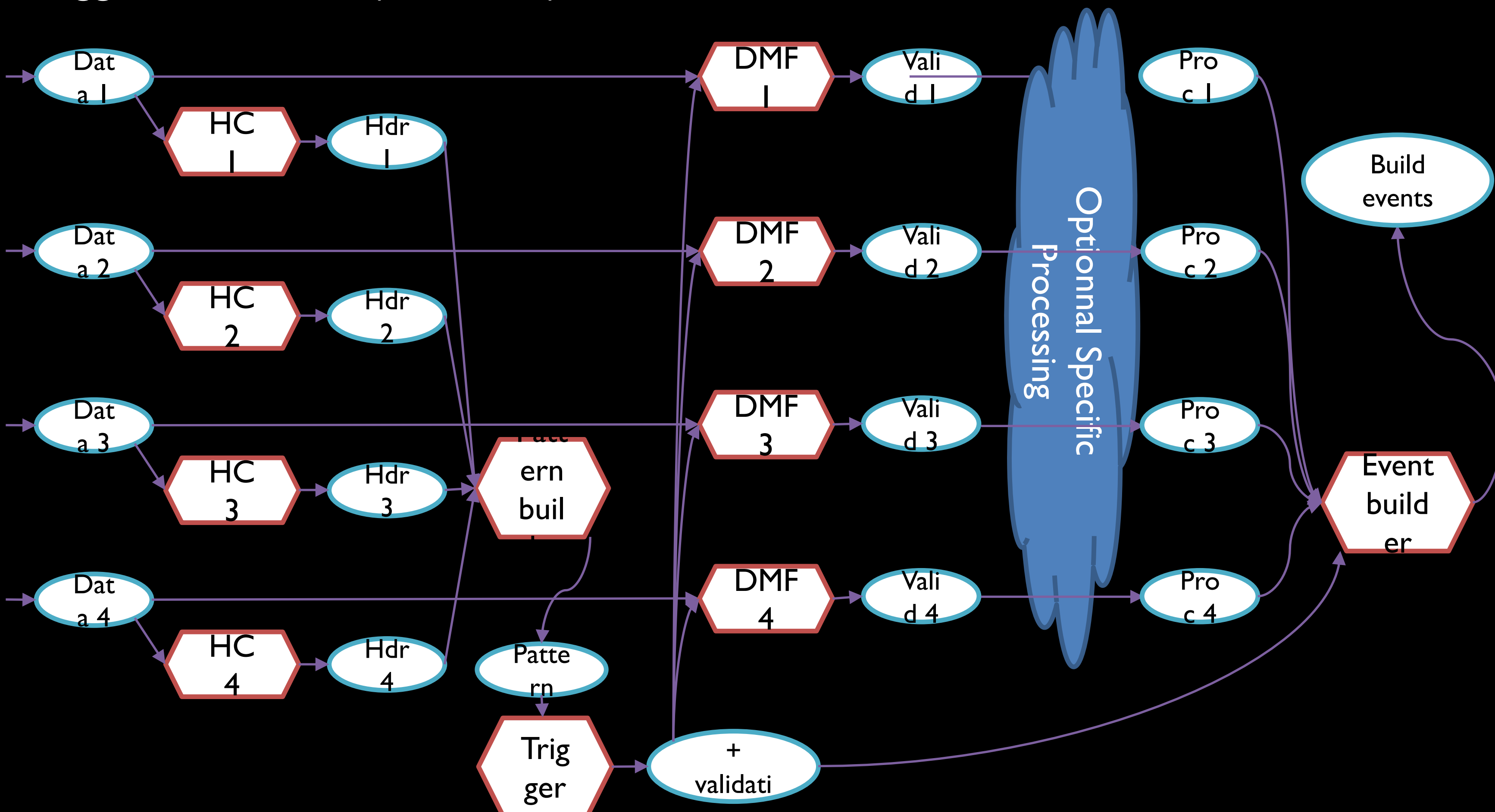
DAQ

Evolution to DCOD – Posix Memory Handler



DAQ

Trigger soft scheme (4 Chanels)



Data processing / analysis

LNL | GSI | GANIL | FUTURE

Infrastructure

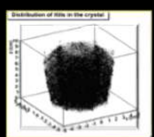
svn
make ☛ cmake
AGAPRO: online installation

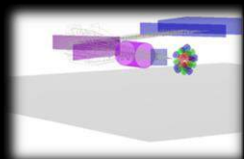
git, modern cmake
continuous integration

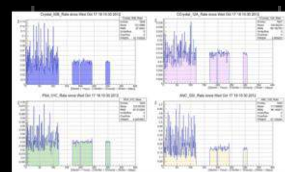
unit testing
containerised applications

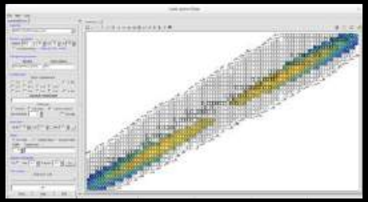
Schools on data analysis … documentations … Schools on data analysis … user's guides …forums … Schools on data analysis

developpments



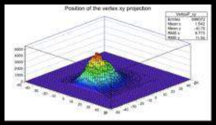






ADF library to deal with:

- AGATA data format, data files
- algo integrations in NARVAL
- Integration of ancillaries



Machine Learning [ML] :
PSA / tracking
processing : quality checks
Processing on
GPU / FPGA, CLOUDS …

NEDA/DIAMANT
GANPRO package
PSD NEDA ML online

GW online/offline analysis

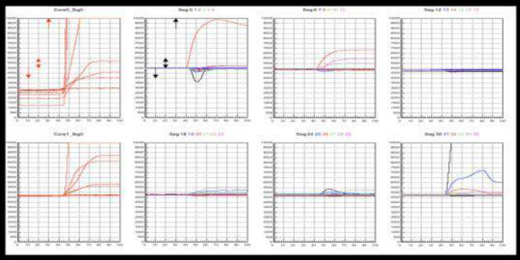
- adf to spectra/TTree
- Integration of ancillaries (data, algorithms)

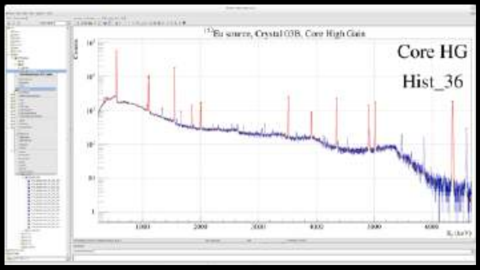
PRESPEC
dev. @ GSI

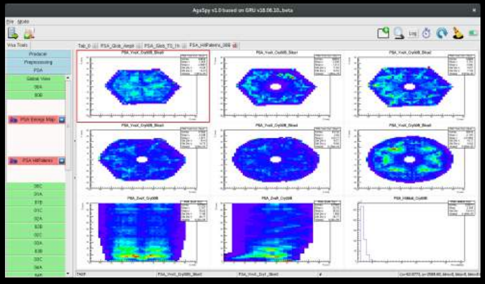
VAMOS
dev. @ GANIL

TTree in AGAPRO

AGASPY dev. @ CSNSM/IP2I
Online monitoring

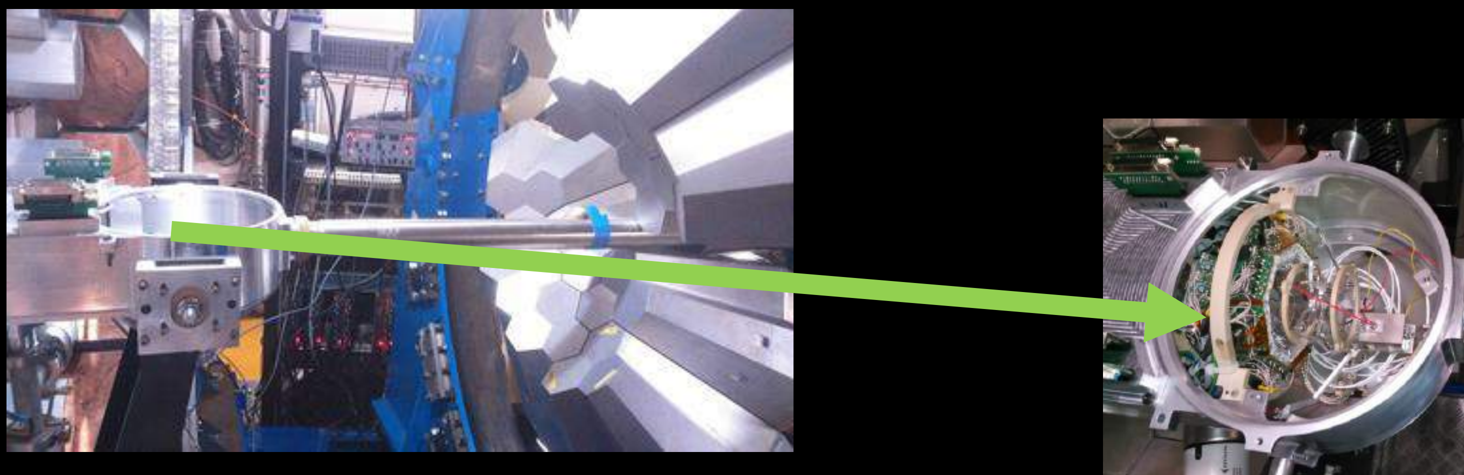






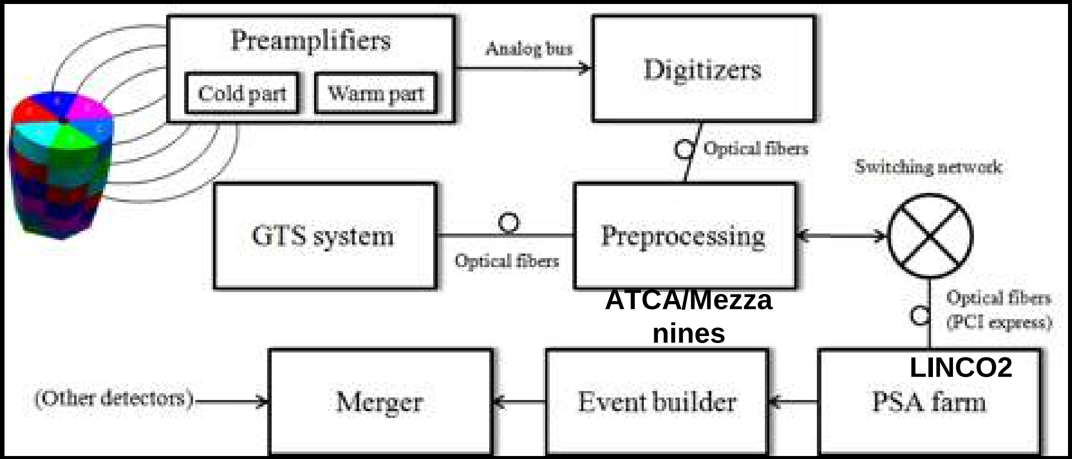
Reaction chamber for AGATA/NEDA/DIAMANT campaign

Pre-installation in G2 with in-beam tests done in November-December 2017
Mechanical Installation completed in front of AGATA in February 2018



3 experiments using AGATA+NEDA +DIAMANT+plunger with 35 AGATA detectors in 2018

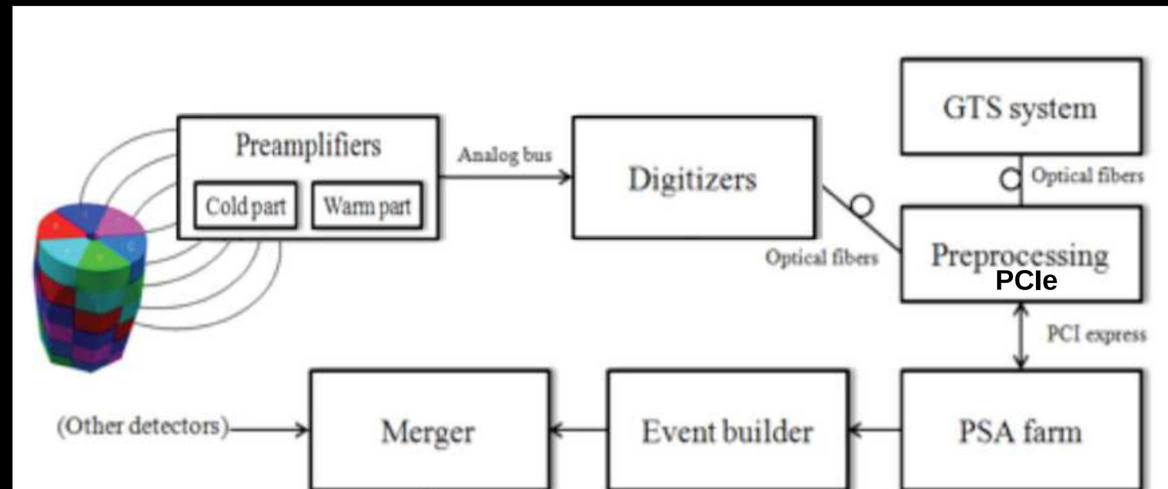
Electronique Phase 0



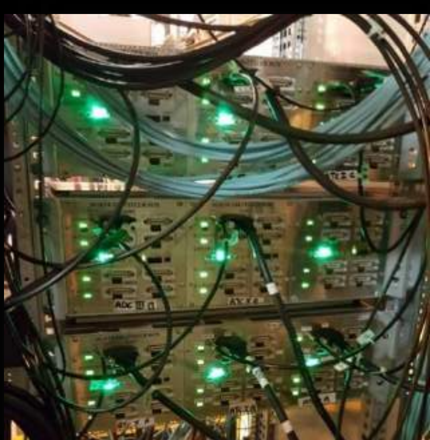
- Designed in 2004
- 24 channels available
  - 2006-2009 : 15 channels
  - 2010-2012 : 19 channels
  - 2012- Now : 24 channels
- Price : 90-100 k€ / crystal
- Not included cost :
  - 7 optical fibers from digitizer to ATCA
  - 4 optical fibers from ATCA to computing node
  - 1 server per crystal

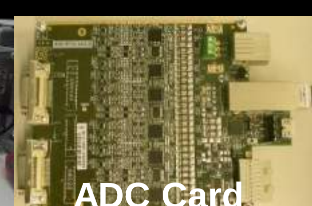
IN2P3 IPHC - Uni.Liverpool STFC Daresbury - IN2P3 IPNO - IN2P3 CSNSM - INFN Padova

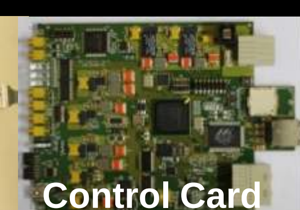
Electronique phase 1



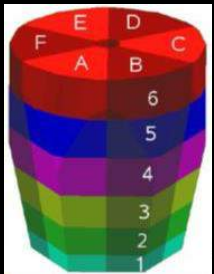
- Designed in 2012
- 10 channels available (+ Galileo)
  - 2014-2018 : 10 channels
  - 2018- : 22 channels
- Price : 30 k€
- Hidden cost
  - 4 Optical fibers from digitizer to computing node
  - 1 server per crystal

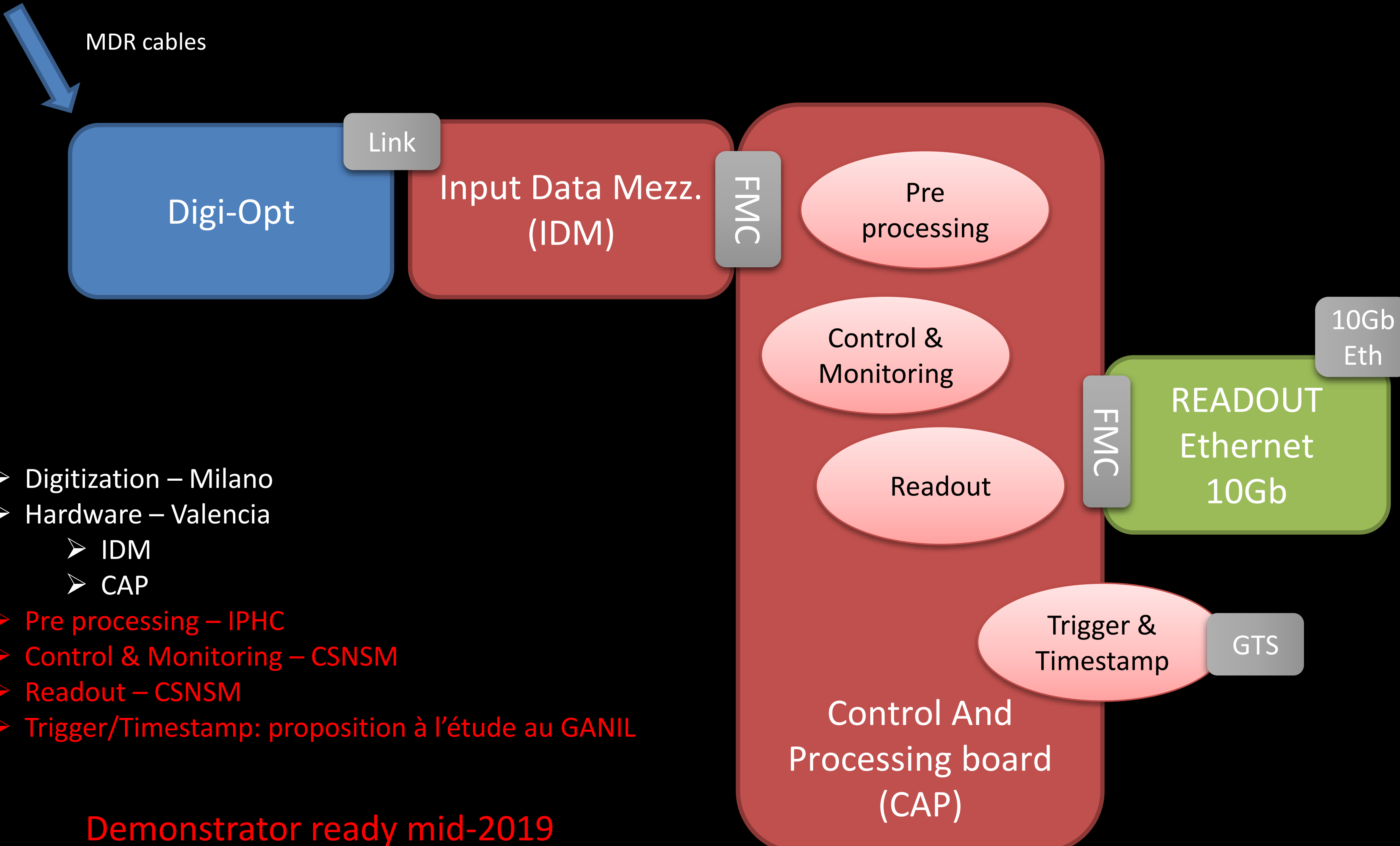






Electronique Phase 2 – R&D (2016-now)



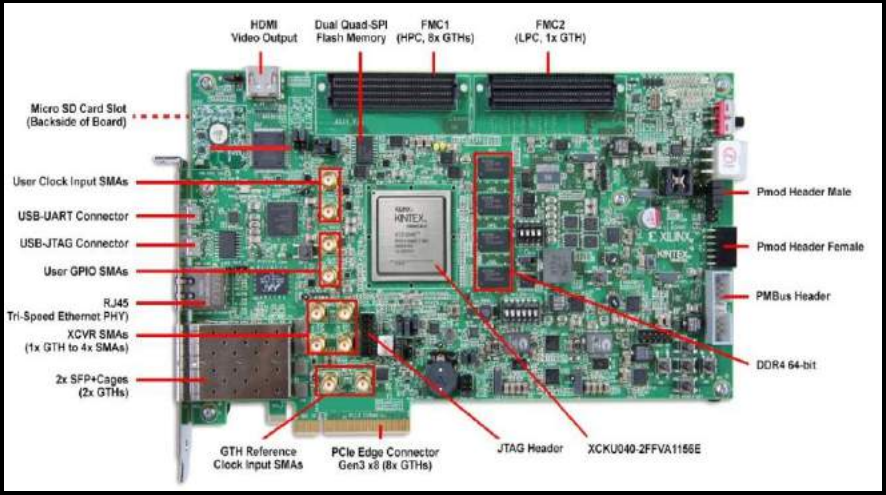


- Digitization – Milano
- Hardware – Valencia
  - IDM
  - CAP
- Pre processing – IPHC
- Control & Monitoring – CSNSM
- Readout – CSNSM
- Trigger/Timestamp: proposition à l’étude au GANIL

Demonstrator ready mid-2019

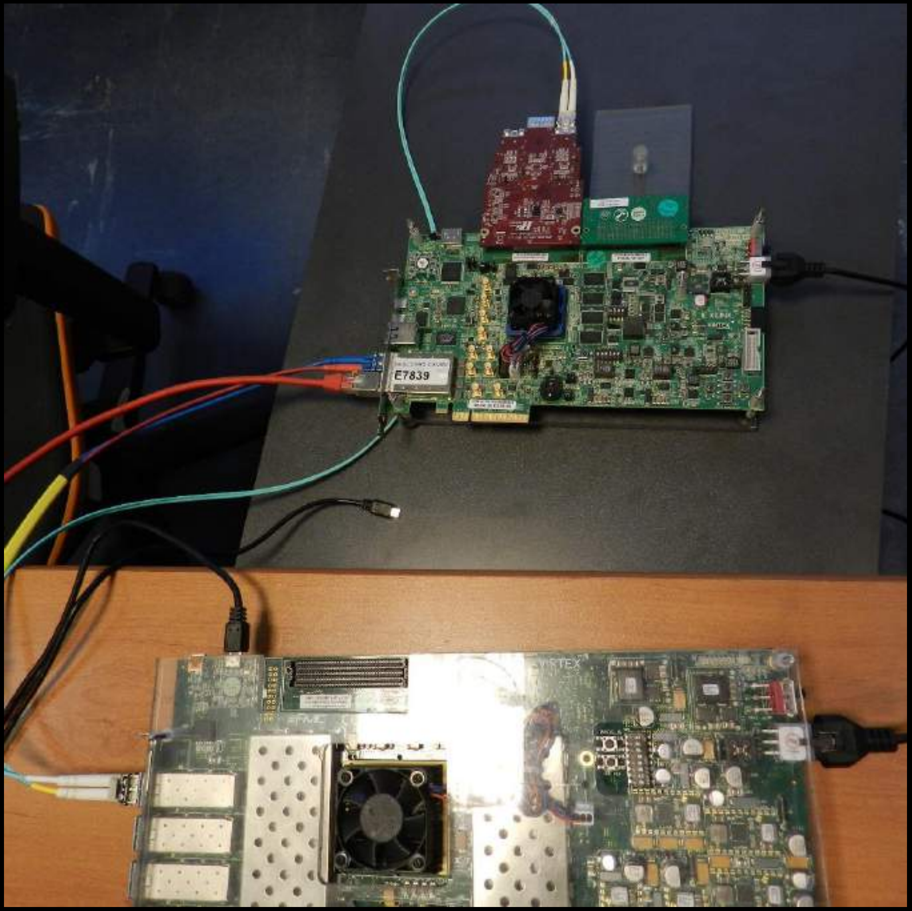
Electronics phase 2

FPGA firmware development for data pre-processing (get 36 signals, trigger, time stamp, energy calc, pulse shape selection, generation of an event block, transfert of the blocks to 10GB-Ethernet card)

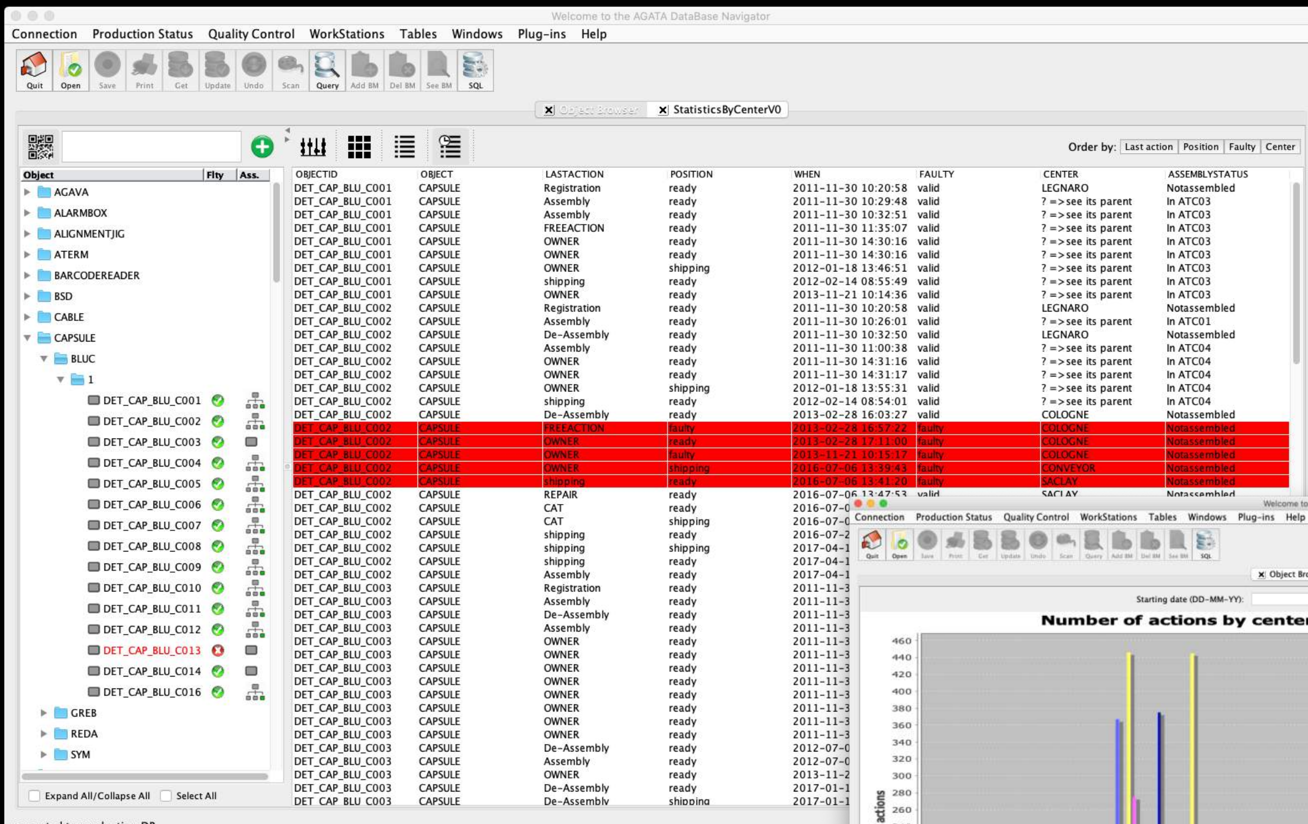


Fast digital oscilloscope software development

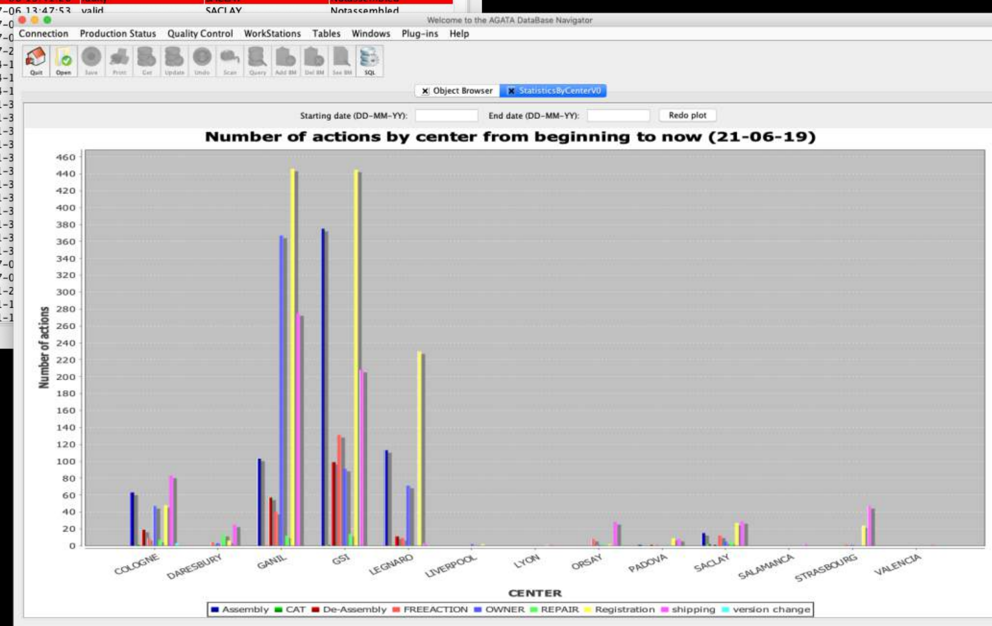
10 Gb readout card : Stare prototype



DETECTOR DATABASE



Barcodes on
objects & transfer boxes



Set up also for :
EXOGAM, PARIS, NEDA …