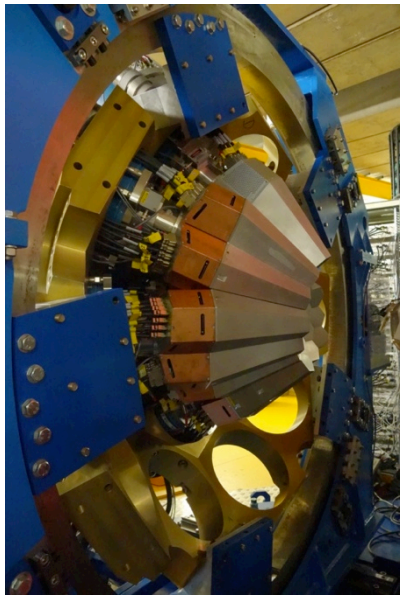
The AGATA Group at IFIC: Instrumental Developments Experimental Nuclear Structure

Andres Gadea (IFIC-CSIC, Spain)



Group: A.Gadea, C.Domingo-Pardo, R. Aliaga, T.Hüyük, R.M. Rerez-Vidal, J.Collado, M.Jurado

Activities Financed by:

- MINECO FPA2014-57196-C5 2015-17
- Generalitat Valenciana: PROMETEO II/2014/019 2014-17
- EU: Horizon 2020 G.A. 654002 (JRA PSeGe) 2016-19

Aims at: Perform world class Nuclear Structure experimental research at AGATA.
Contribute to the construction of the Advanced Gamma Tracking Array.
Develop advanced instrumentation for AGATA and its Trigger / Complementary Detectors.

Jornadas sobre los proyectos científicos del IFIC 19 -20 January 2017

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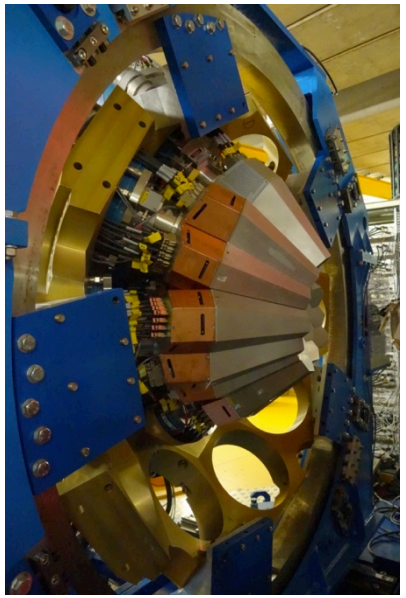
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

AGATA ADVANCED GAMMA TRACKING ARRAY

The AGATA Group at IFIC: Instrumental Developments Experimental Nuclear Structure



AGATA Spain Collaboration (Coordinated Project):
IEM-Madrid (IP A.Jungclaus), UAM (IP J.L. Egido), Uni.Salamanca (IP B.Quintana), Uni. Valencia – ETSE (IP V.González)

AGATA Collaboration has more than 350 Scientist and Engineers from more than 40 institutes in 12 European Countries.

Summary:

- Group relatively new in the IFIC, Spain in AGATA since 2010
- Dissemination ~140 publications: 7 PRL, 1 Nature, 5 PLB, 56 PRC, 3 EPJA, 16 NIM etc…
- Training: 3 successful PhD's since 2011 / 4 PhD Thesis ongoing
- International responsibilities: Project Management of AGATA

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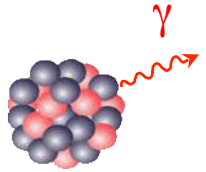
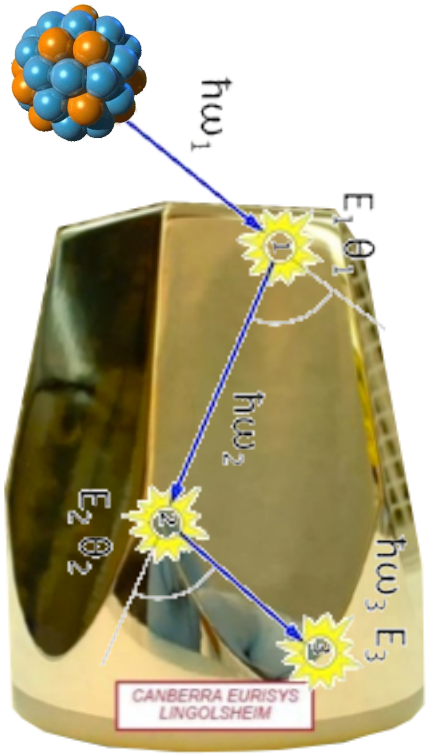
AGATA ADVANCED GAMMA TRACKING ARRAY

AGATA: High Resolution and High Sensitivity Detector for γ-rays

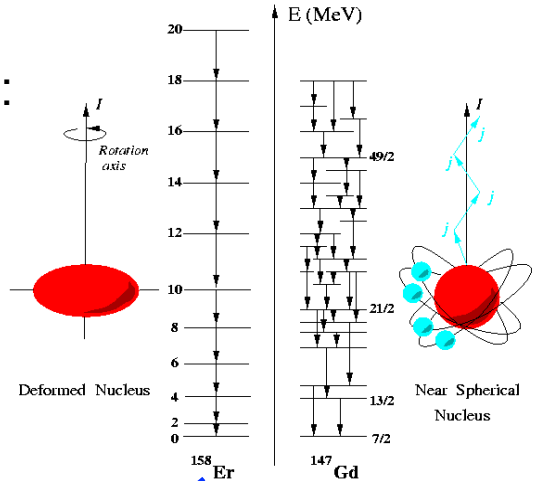


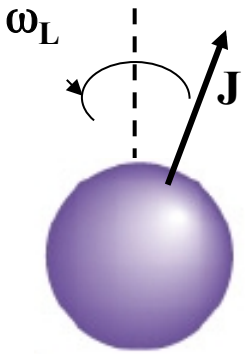
Determining all quantum numbers and properties of nuclear states



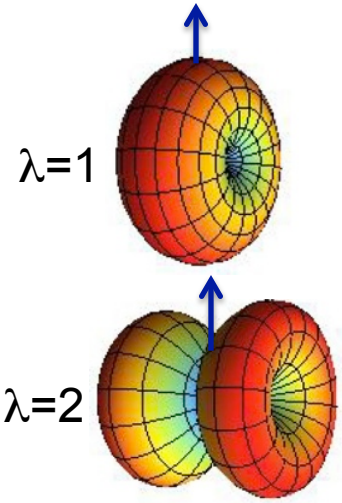
Position Sensitive

Sequence of Excited States: γ-ray Energy, intensity and coincidence analysis





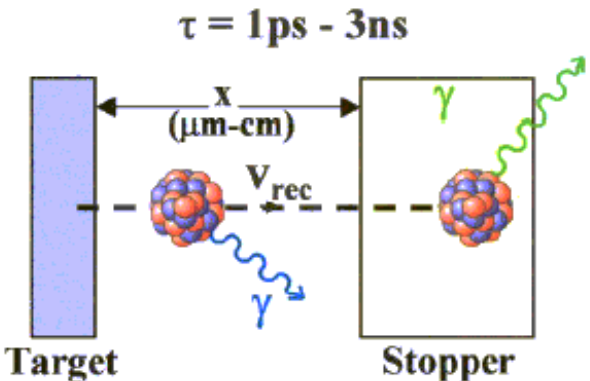
Nuclear Moments (e.g.: g-factors magnetic field)

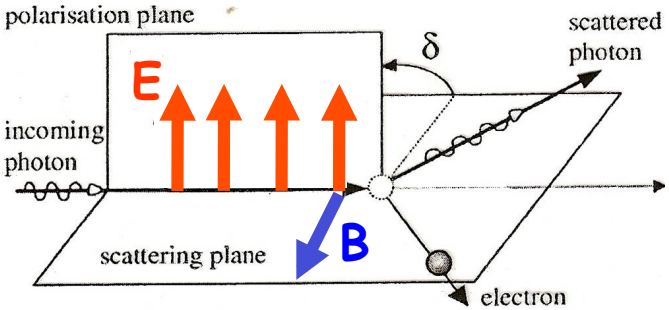


State Quantum numbers J^{π} angular distribution, correlations and linear polarization

Transition probabilities by Doppler or indirect methods

B(E/Mλ)

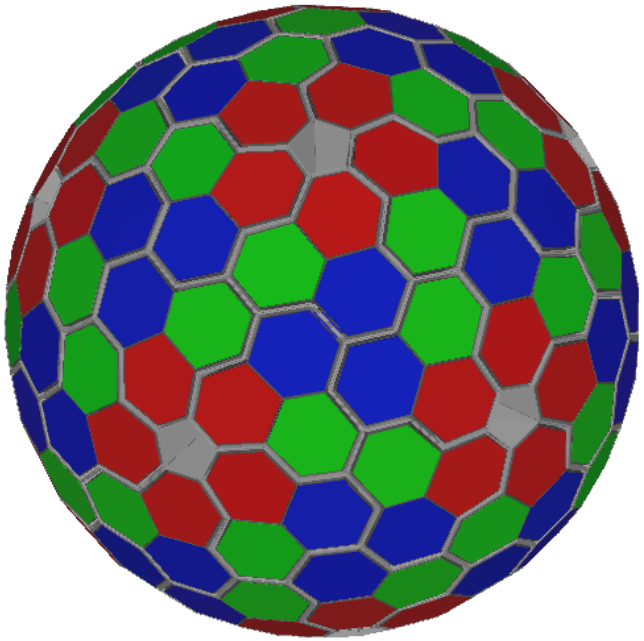




AGATA

(Advanced GAmma Tracking Array)

Encapsulation



Geodesic Tiling: 180 hexagons
+ 12 Pentagons

180 hexagonal crystals:	3 shapes
3 fold clusters (cold FET):	60 all equal
Inner radius (Ge):	23.5 cm
Amount of germanium:	362 kg
Solid angle coverage:	~82 %
36-fold segmentation	6480 segments
Crystal singles rate	~50 kHz
Efficiency (Mγ=1 [30]):	43% [28%]
Peak/Total (Mγ=1 [30]):	58% [49%]

AGATA Collaboration NIM A 668 (2012) 26

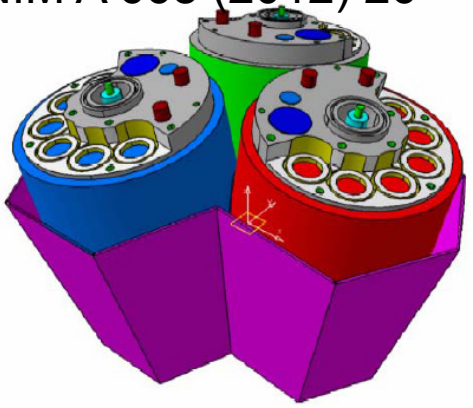
6660 high-resolution digital electronics channels

High throughput DAQ / Capability to record sampled pulses

Pulse Shape Analysis → position sensitive operation mode

γ-ray tracking algorithms → maximum efficiency and P/T

Sophisticated Detector and Mechanical infrastructures.



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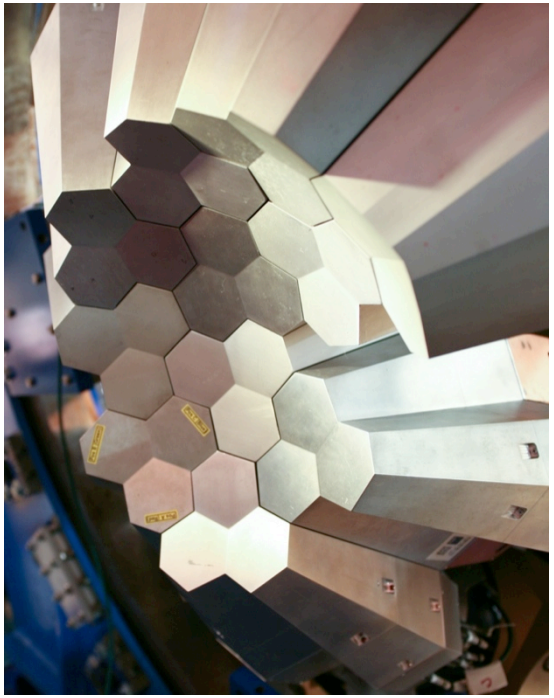

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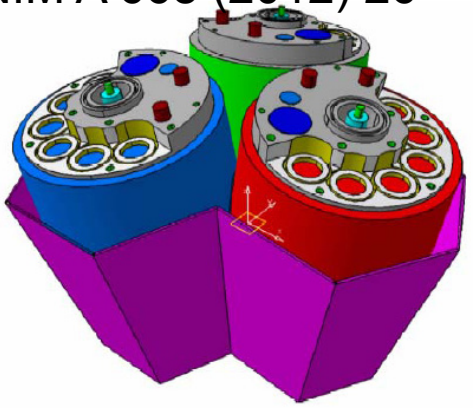
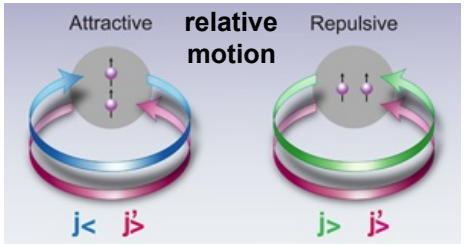
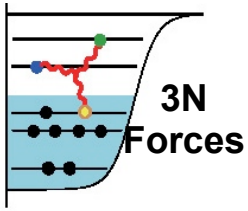


Scientific Opportunities with AGATA

Organization of Nuclear Matter and Emerging Phenomena. In-media Fundamental Interactions, Origin and Evolution of Nuclear Matter

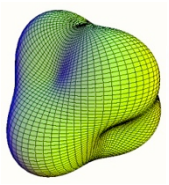


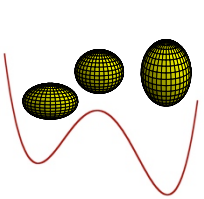
- **Shell Structure Far From Stability**: large nucleon asymmetry lead to shell modifications driven by the spin-isospin nucleon-nucleon interaction and close to the drip-line by the weakening of the spin-orbit interaction.

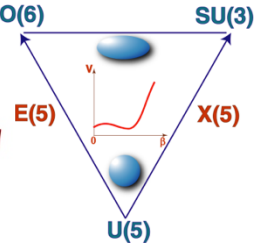


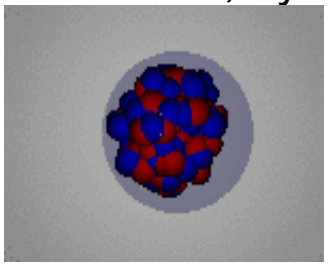
- **Three Body Forces:** testing the role of three nucleon (3N) forces in the microscopic description of the atomic nucleus. Indications of important role in the vicinity of proton as well as neutron drip-lines.

- **Nuclear Shapes**: coexistence of different nuclear shapes, Large deformation, high-rank symmetries, Quantum Phase Transition, dynamic and critical point symmetries.









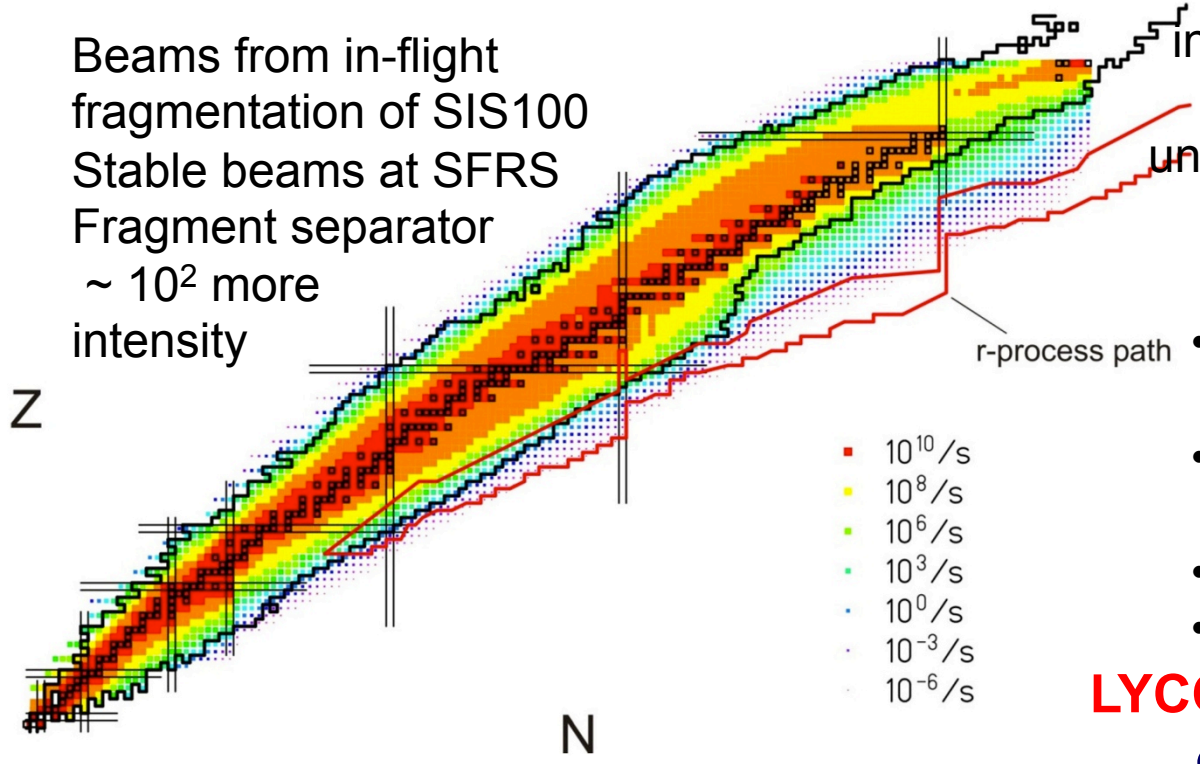
- **Spin-isospin Response Of Nuclei:** out-of-phase density oscillations of the neutron and proton fluids provided information on macroscopic nuclear properties associated with isovector fields.

- **Nuclear Matter Appearance and Evolution:** nuclear astrophysics, explosive scenarios and the rp-process, the origin of the elements heavier than Iron and the r-process

- **and Clustering in Nuclei, New forms of nuclear pairing, In-Media isospin breaking interactions, Study of Open Quantum Systems, etc …**

Scientific challenges to be realized in Future AGATA Campaigns at HISPEC-NUSTAR/FAIR

Beams from in-flight fragmentation of SIS100
Stable beams at SFRS Fragment separator
~ 10^2 more intensity

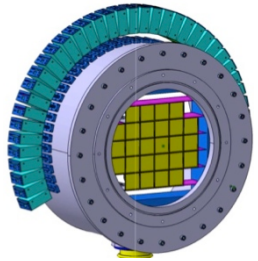


High Energies and competitive intensities across the Segrè Chart
Unique fully stripped in-flight unstable beams in the 208Pb region

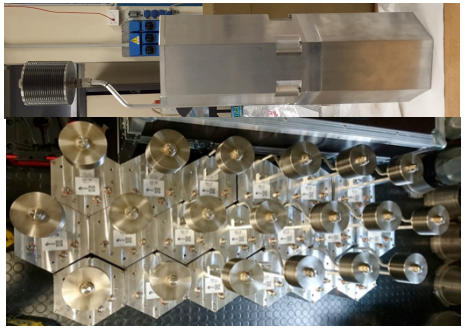
Fist beams ~2023
completion ~2025

- Shell Structure and Nuclear Astrophysics in heavy nuclei.
- Dipole response, pygmy resonances, in heavy nuclei
- Heavy N~Z Nuclei
- Shape evolution

LYCCA: Identification of secondary reaction products



- **Required HISPEC instrumentation: LYCCA, Plunger, Beam trackers, other detectors**
- **Highly relativistic conditions**
- **AGATA: best position resolution, large angular coverage for angular distributions and centroid shift lifetime measurements**
- **NEDA: tagging n-detector array, direct reactions**

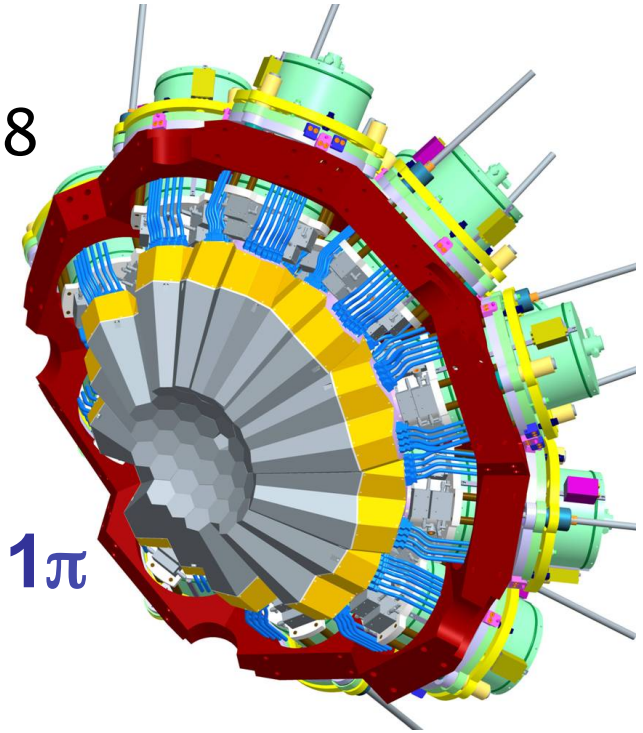


NEDA: n-tagging detector array

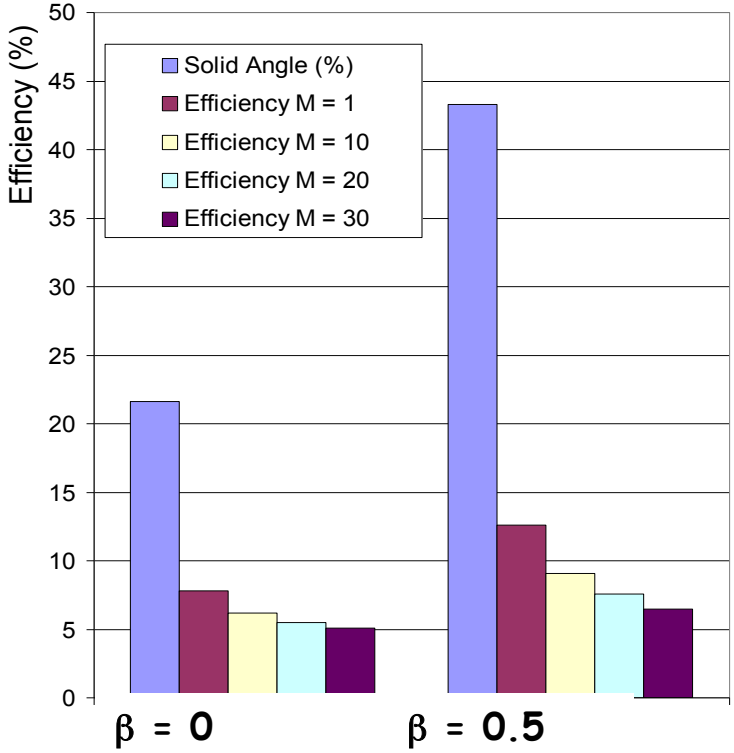
The AGATA Phase 1

2009-(2015) 2020

- Phase 1 of AGATA → 60 crystals (1/3)
- 47 detectors fully instrumented in 2018
- **78% MoU achieved, MoU ends 2020**
- Triple and Double clusters
- AGATA 1π the first real tracking array



AGATA 1π

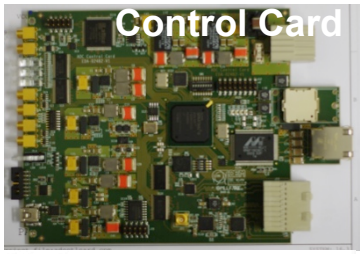


To be used at available RIB & High Intensity Stable beam facilities (SPIRAL, SPES, GSI, LNL, GANIL and in the future at NUSTAR/FAIR). Coupled to spectrometers, trackers neutron and LCP detector arrays…

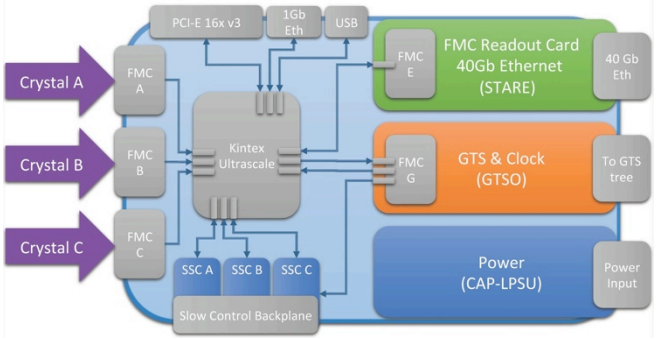
The AGATA Group at IFIC: Scientific and instrumental programme

Short Term: MINECO FPA2014-57196-C5 2015-17

- Contributing to the Completion of a batch of the 2nd generation AGATA electronics, instrumenting till 1π: IFIC, IFIC Mechanical services (J.V. Civera et al.), UVEG-ETSE.

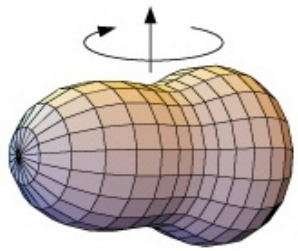


- Stating R&D for the 3rd generation of AGATA electronics to be produce in 2020 and beyond. Read-out on high bandwidth Ethernet. Goal increase data taking rate & pre-processing capabilities (J.Collado PhD).



- Leading Scientific experimental programme on **Nuclear Shapes**: Reinforcement of reflection asymmetry in symmetric p-n nuclei.

Completion of studies on deformation in the pf-shell and shell structure in N=50 (T.Hüyük and R.M. Perez-Vidal PhD's): IFIC, IFIC Computing Serv. & GRID e-Science.



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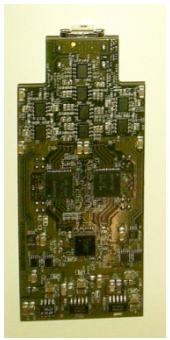
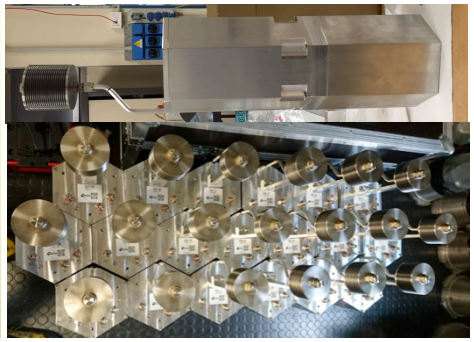
The AGATA Group at IFIC: Scientific and instrumental programme

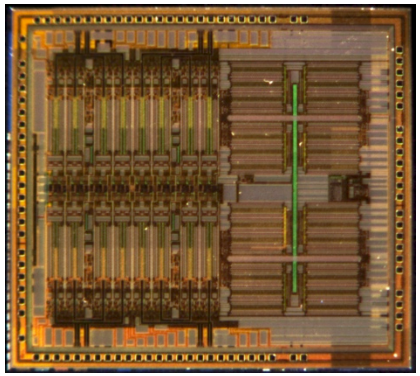
Short Term: PROMETEO II/2014/019 2014-17

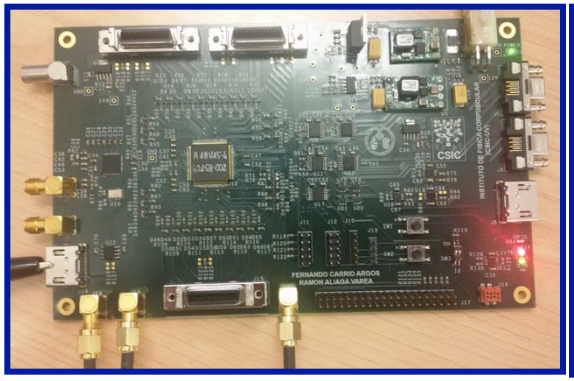
- Contribution to the construction of NEDA neutron detector array for AGATA at HISPEC-NUSTAR/FAIR. Detector construction. Conceptual design, design and production of the FADC mezzanine: IFIC, UVEG-ETSE

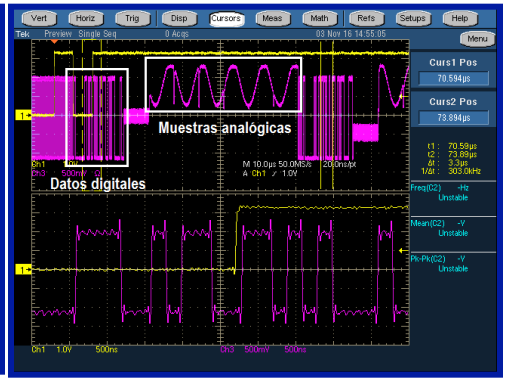


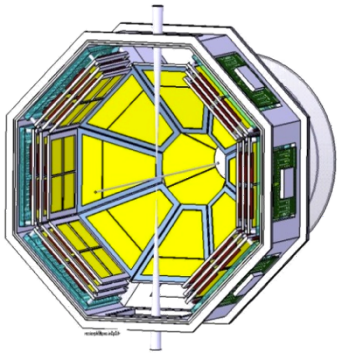


- Microelectronics R&D for the readout of the GHT light charged particle DSSSD/Si-PAD telescope detector array as tagging detector for AGATA. Development of an ASIC with synchronized analogue buffers: signal sampling for particle identification: IFIC (R.Aliaga) Electronics serv. (F.Carrio, P.Bernabeu), UPV-I3M, UVEG-ETSE.









GHT

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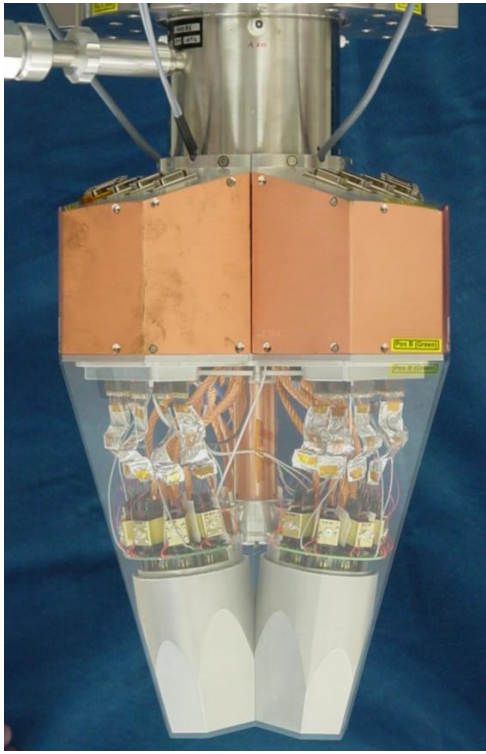
The AGATA Group at IFIC: Scientific and instrumental programme

Medium Term: MINECO FPA2017

- Completion of the Spanish contribution to the AGATA Phase 1
  Missing one detector capsule. Total contribution of Spain: 5% of the AGATA Phase 1 construction.
  Goal of the Coordinated Project

- Completion of the R&D for the 3rd generation of AGATA electronics. Goal of IFIC & UVEG-ETSE

- Leading Scientific experimental programme with radioactive Ion beams from EURISOL-DF (SPIRAL / SPES). Preparation for the Early NUSTAR-FAIR AGATA Campaign.



Medium Term: Horizon 2020 G.A. 654002 (JRA PSeGe)

- R&D on position Ge detector technology for the future AGATA detector capsules: IFIC, IMB-CNM

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AGATA ADVANCED GAMMA TRACKING ARRAY

Outlook

- The AGATA project is inline with the recommendations identified by NuPECC (EU) and DOE/NSF (USA), in their Long Range Plans, regarding the necessity of γ-ray tracking arrays for the Nuclear Structure programmes at the world-class Radioactive Ion Beam Laboratories.

- The AGATA construction continues with a contribution of ~5% of Spain, to be completed for the Phase 1 within 2020 and for the next phases beyond that date.

- We also contribute successfully to the construction of the AGATA trigger/ complementary detectors NEDA and GHT (Trace), to be able to pursue our physics programme.

- Acknowledgement to the IFIC Services and collaborators supporting AGATA and the AGATA developments.

Thank You!

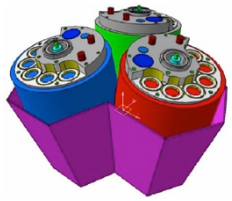
MINECO, Grant n. FPA2014-57196-C5
GVA Grant PROMETEO II/2014/019
Horizon 2020 Grant 654002 (JRA PSeGe)

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

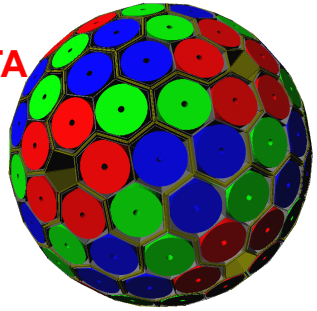
UNIÓN EUROPEA
Cofinanciado por el Fondo Europeo de Desarrollo Regional
Una manera de hacer Europa

GENERALITAT VALENCIANA
CONSELLERIA D'EDUCACIÓ, FORMACIÓ I OCUPACIÓ

Concept of γ-Tracking

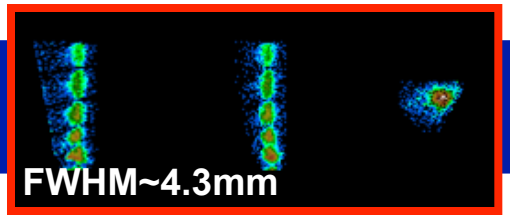


AGATA



AGATA
ADVANCED GAMMA TRACKING ARRAY

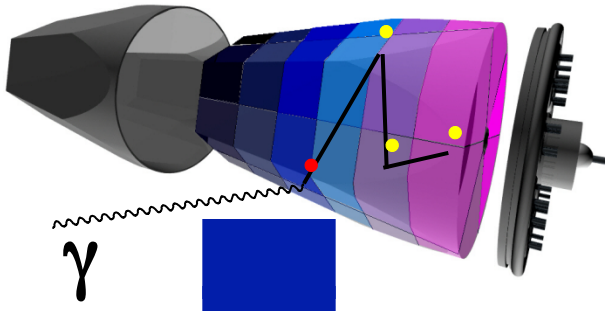
Highly segmented HPGe detectors
NOVEL PRE-AMPS



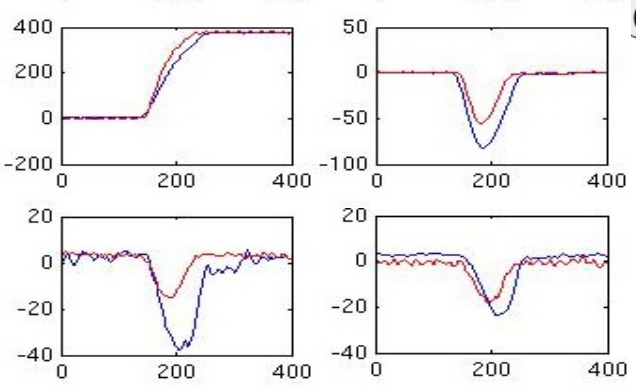
Identified interaction points

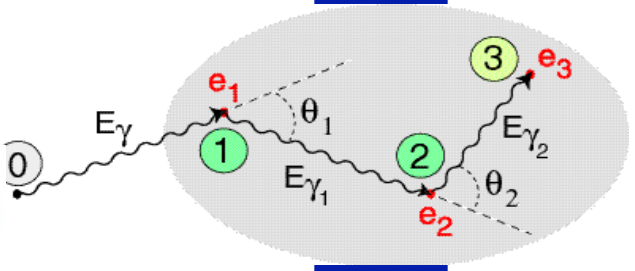
$(x,y,z,E,t)_i$

Reconstruction of interaction tracks (tracking algorithms on interaction points)
DAQ TRACKING-FARM



Pulse Shape Analysis to de-convolute the recorded waves
DAQ PSA - FARM

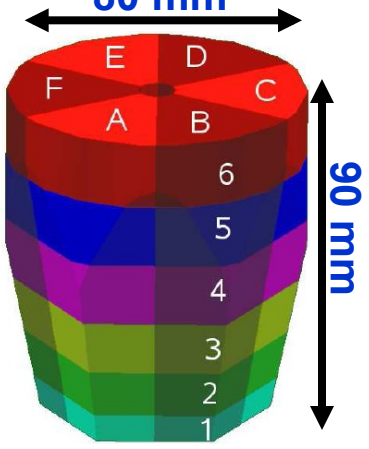




Synchronized digital electronics
record and process the segment signals
DIGITIZERS + PRE-PROCESSING

On-line reconstruction of γ-rays

AGATA Detectors & Cryostats

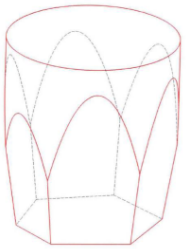


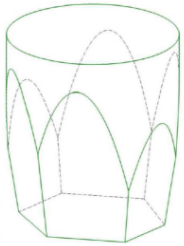
6x6 segmented

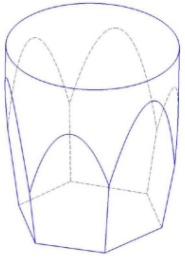
A. Wiens NIM A 618 (2010) 223
D. Lersch NIM A 640(2011) 133

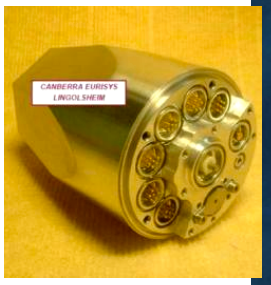
- AGATA capsules procured at Canberra/Mirion-Lingolsheim. AGATA Crysostat provided by CTT (Spin-off of IKP-Köln)
- Detectors mounted and maintain within the collaboration.
- Cold FET technology for all signals

FWHM @ 1332 keV
Core: 2.35 keV
Segments: 2.10 keV


(d) A - red


(e) B - green


(f) C - blue



AGATA capsules by Canberra-Lingolsheim

- 111 high resolution spectroscopy channels
- Mounted on Triple & Double cryostats
- 40 detectors delivered / 47 Ordered (45 is 1π)
- Aiming 35 capsules setup in 2017
- R&D on encapsulation and detector technology ongoing EU ENSAR2 JRA.

IKP-Köln, Uni. Liverpool, IRFU-Saclay, INFN-LNL, IFIC, Uni. Salamanca

Structure of Electronics and DAQ

Digital preamplifier concept

Fast 1st Level Trigger

Other Detectors

Diff. Fast-reset-TOT
INFN-MI/GANIL/KÖLN

75.5db SNR
IPHC/Liverpool/
STFC

12.2 ENOB

200MB/s/
segment

GL Trigger

Clock
100 MHz
T-Stamp

Other
detectors

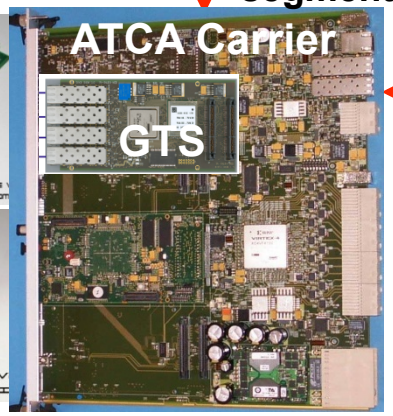
GTS
INFN-Pd

Detector
Level

PSA
FARM

Core +
36 seg.

100MB/s/
detector



HIGH THROUGHTPUT
PRE-PROCESSING
CARRIER / MEZZANINES
IPNO/CSNSM/INFN-Pd

EVENT
BUILDER

TRACKING

Control,
Storage…

Other
detectors

Global Level
DAQ-NARVAL
RUN- & SLOW-Control
IPNO/CSNSM/
LNL/GANIL/IFJ-PAN

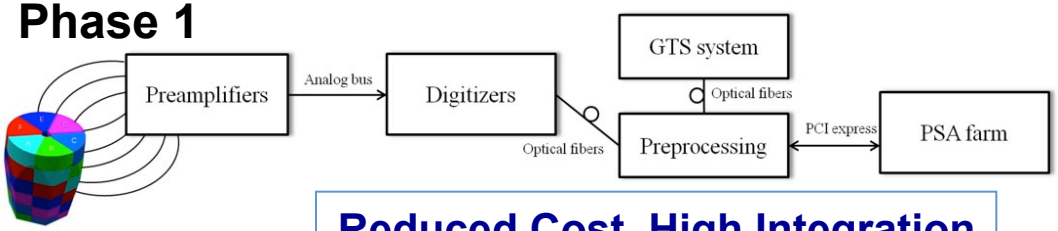
AGATA Collaboration NIM A 668 (2012) 26

interface to GTS, merge time-stamped data into event builder, prompt local trigger from digitisers

Advanced Phase 1 Electronics

INFN-Padova INFN-Milano INFN-LNL
IFIC-Valencia ETSE-Uni-Valencia

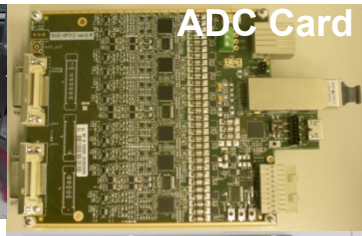
Phase 1



Reduced Cost, High Integration

D. Barrientos, et al., *Proc. 18th IEEE Real Time Conf.* (2012) 1

Installed 10 channels. Expected to instrument with it up to 45 channels (+ spares) i.e. 1π of AGATA



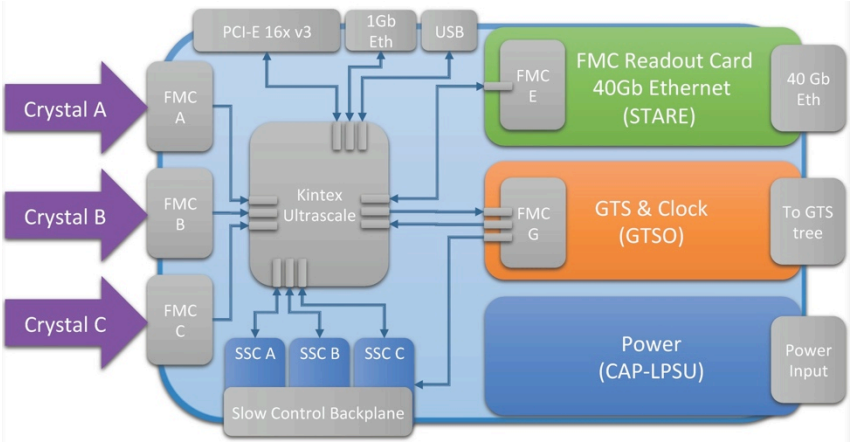
Pre-Processing

R&D for Electronics beyond 1π

Needed due to component obsolescence, more integration reduction of long optical fibers, use of standardized protocols/hardware for data transfer, increase pre-processing capability

- Improved Digitizer Board
- One Triple cluster unit process by the same FPGA.
- Maintained the GTS capability
- Ethernet readout

CSNSM-Orsay, INFN-Milano
ETSE-Uni-Valencia IFIC-Valencia

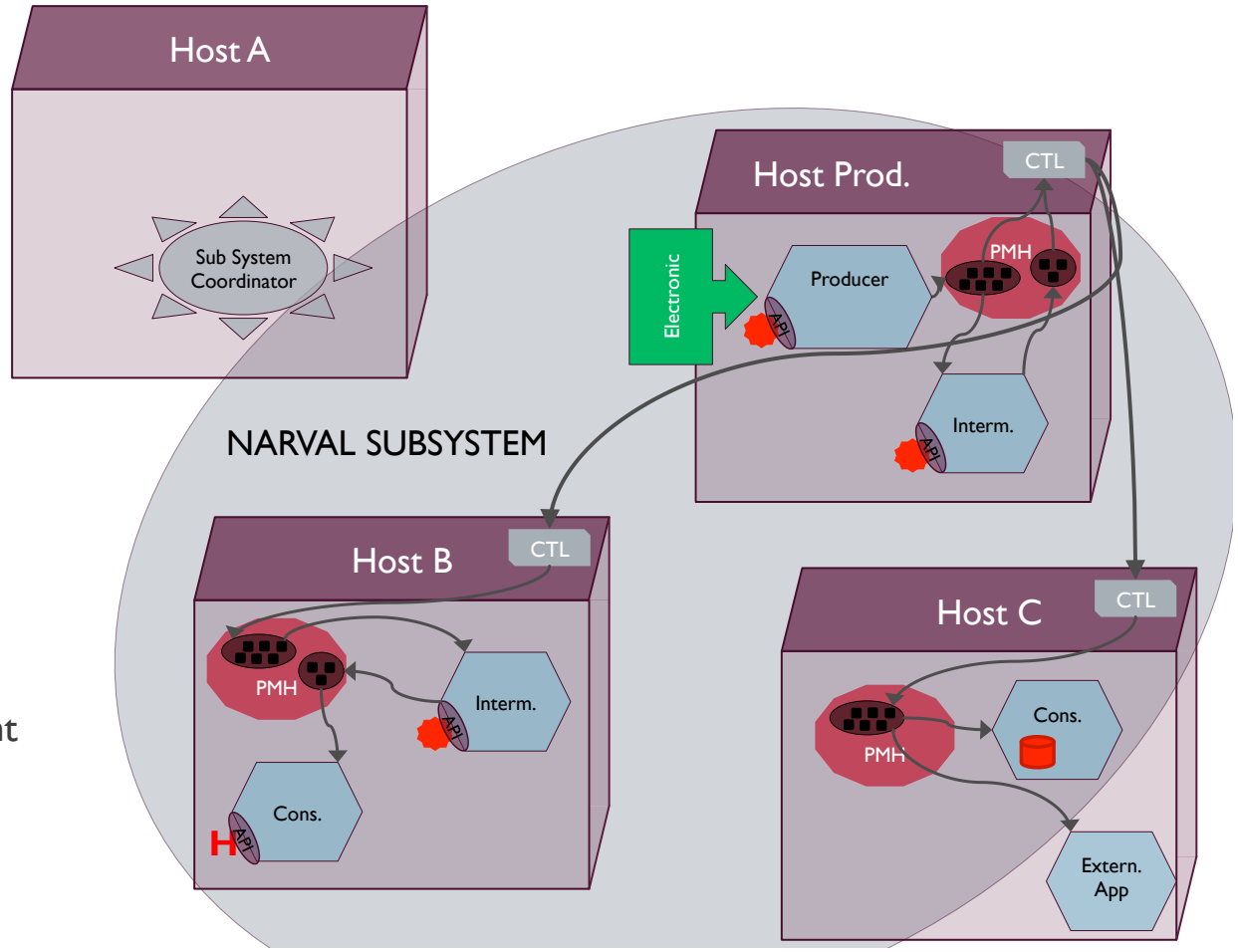


Phase 1 AGATA Data Flow NARVAL at GANIL

WITH DCOD

- Edge
  - Distributed
  - Modular
  - EC outsourced
  - Library for domain code
  - Rewritten in english
- New features
  - Numerous buffering politics
  - Network: data flow management
  - Friendly external application

CSNSM - N. DOSME / X. GRAVE / E. LEGAY



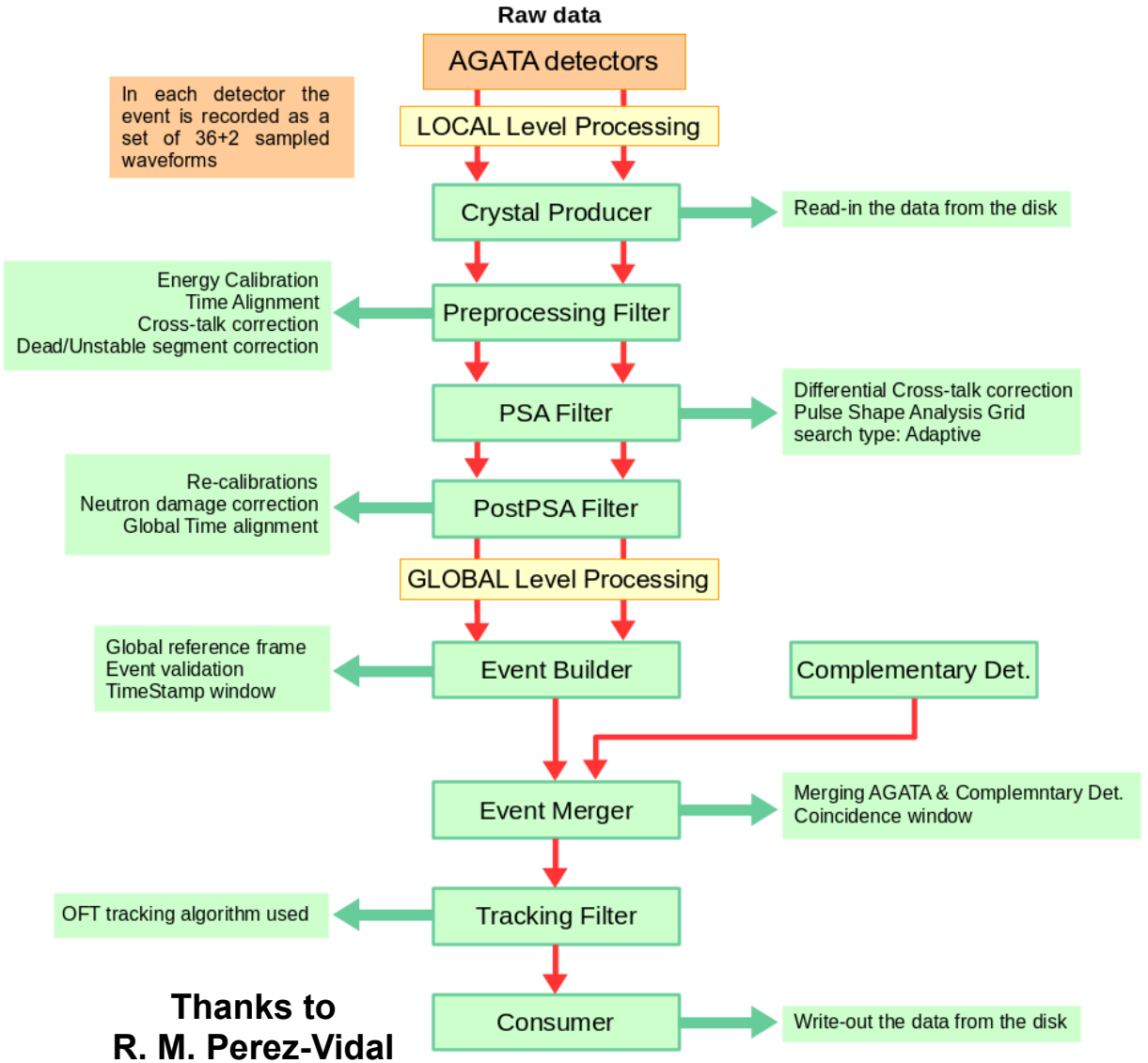
- DCOD / NARVAL distributed Data Flow system dealing with the complexity of AGATA. Buffer management improved
- Run Control and Topology Manager interconnected and User Friendly.
- New CEPH disk storage with Improved performance: bandwidth x 6

CSNSM-Orsay, GANIL, IPNO-Orsay

On the AGATA Data Analysis

Detailed presentation on AGATA Data Analysis, PSA and Tracking in O.Stézowski, A.Lopez-Martens, A.Boston, A.Korichi and L.Lewandowski, contributions

- Tracking arrays performances strongly depend on the data processing and processing parameters.
- Drawback of the AGATA processing → AGS PSA algorithm is limited one interaction per segment.
- Development of algorithms supporting PSA of multiple interactions per segment is ongoing



Thanks to
R. M. Perez-Vidal

AGATA Performance

- The AGATA Performance team –led by C.Michelagnoli– is in charge of evaluating experimentally the performance figures of AGATA.
- The results are compared with the realistic simulations performed by the AGATA simulation team –led by M.Labiche–.

Checking of:

- Energy Resolution
  - Detector resolution
  - Neutron-Damage correction
  - In-beam resolution after Doppler Correction
- Efficiency
  - Core
  - Calorimetric
  - Tracking Efficiency
- Peak-to-Total

Additionally:

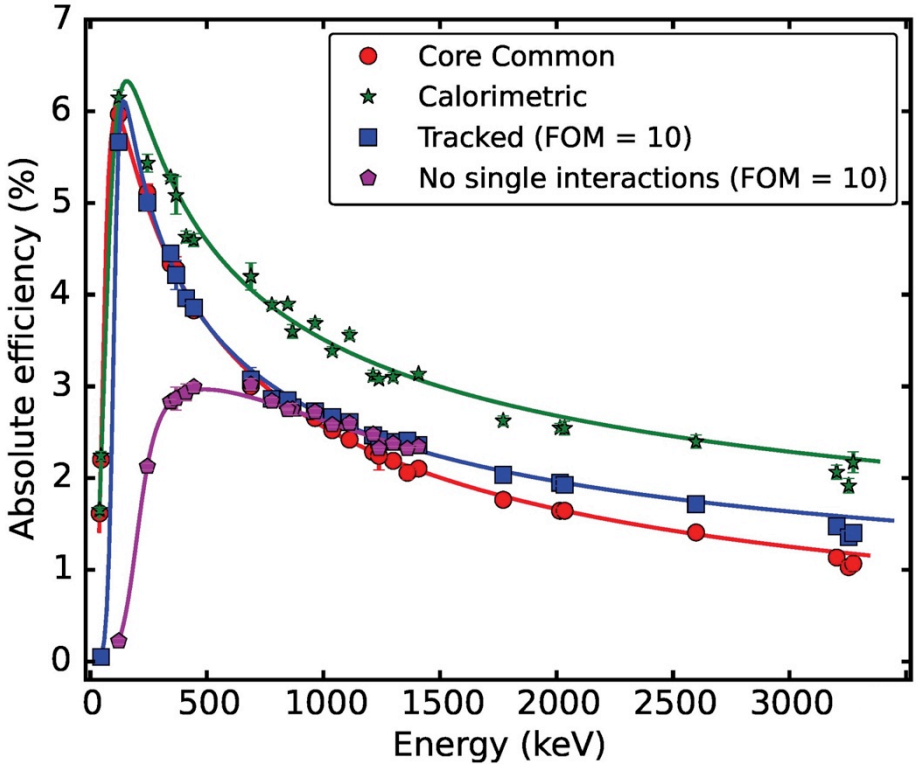
- Position Resolution
- Counting Rate capabilities and performance at high Counting rate
- Polarization and Angular Distribution/Correlation performance
- Performance on Lifetime measurements

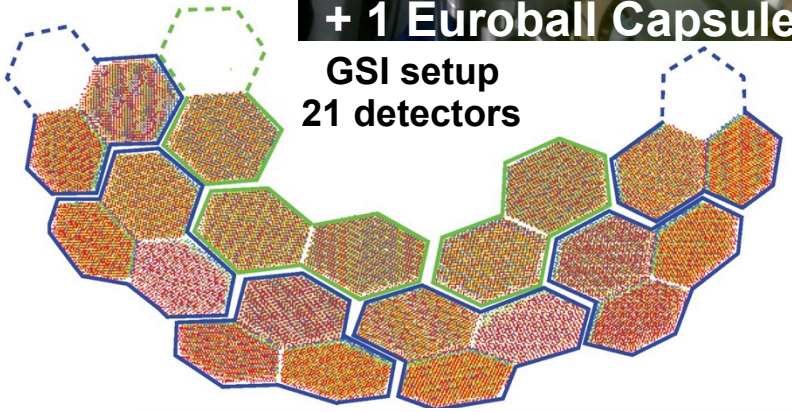
AGATA Performance measurements

Two **AGATA Performance Measurements**
Run at GSI on May 2014 with 21 detectors
Run at GANIL on March 2016 with ~30 detectors

Run with 21 Capsules:

N. Lalović et al. NIM A 806 (2016) 258





for 1172 keV

	Efficiency (%)	P/T (%)
AGATA (external trigger method)		
Core common	2.38(2)	18.3(2)
Calorimetric	3.30(2)	32.2(3)
Tracked with single interactions	2.55(3)	37.5(4)
Tracked without single interactions	2.53(3)	42.3(5)
Add-back 100 mm	2.86(4)	24.6(2)

Realistic simulations, See M.Labiche talk

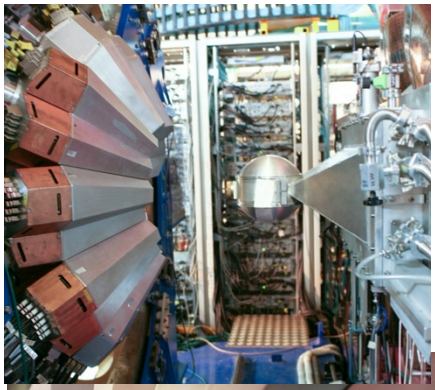
1172 keV	ε_{Sim} (%)	P/T_{sim} (%)
Core Common	2.55(14)	23
Calorimeter	3.71(17)	42

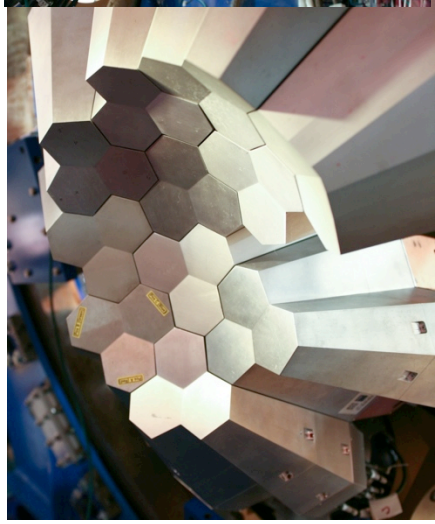
Uni. Lund, GSI, IFIC, Uni. Uppsala, INFN-Padova, STFC Daresbury, CSNSM- Orsay, Uni Liverpool

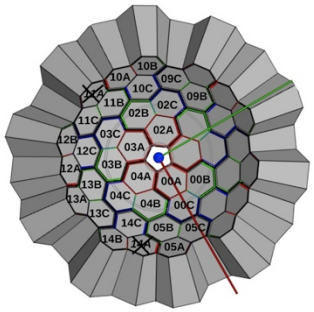
AGATA Performance measurements II

Run with 30 Capsules in 2016
Data Analysis on-going
only preliminary results

	Eff(%) Nominal	Eff(%) Compact
Core Common singles	2,97	5,42
Core common gating 13C	3,11	5,37
Core common Sum peak	3,36	6,63
Core Common Simulation*	3,63	6,90
Calorimeter singles	3,77	5,84
Calorimeter gating 13C	4,43	7,59
Calorimeter Sum peak	5,08	10,55
Calorimeter Simulation*	5,50	10,57







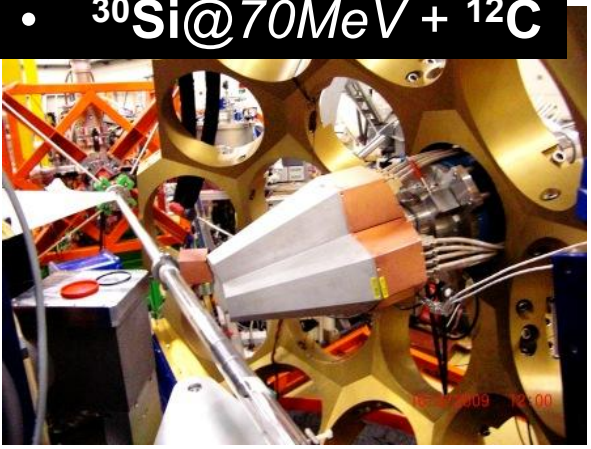
Results without tracking from R.M.Perez-Vidal, C.Michelagnoli, et al.
*Simulations by M.Labiche

Tracking Analysis ongoing!
Non-tracked Results scale nicely from from the 21 Capsules set-up

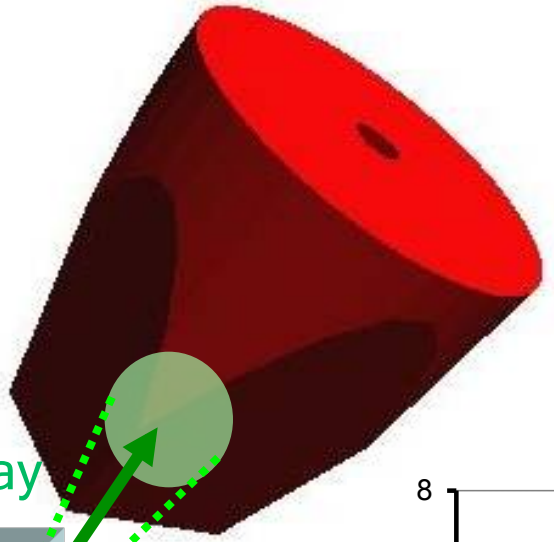
GANIL, CSNSM- Orsay, Uni. Lund, IFIC, Uni. Uppsala, INFN-Padova, STFC Daresbury, Uni Liverpool

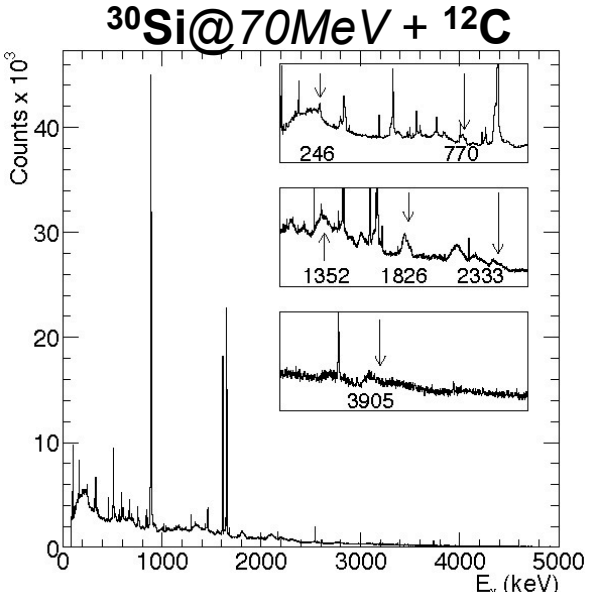
Position Resolution from in-beam tests.

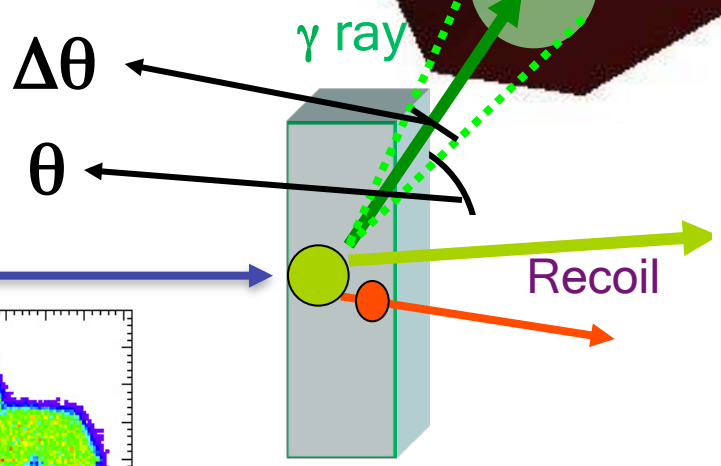
- ^{30}Si@*70MeV* + ^{12}C

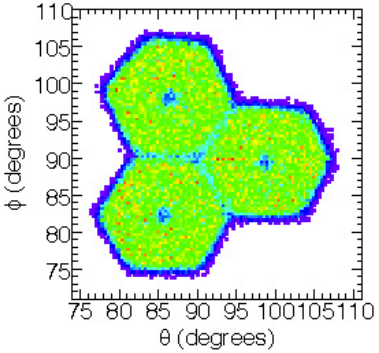


Position of first interactions at AGATA nominal distance

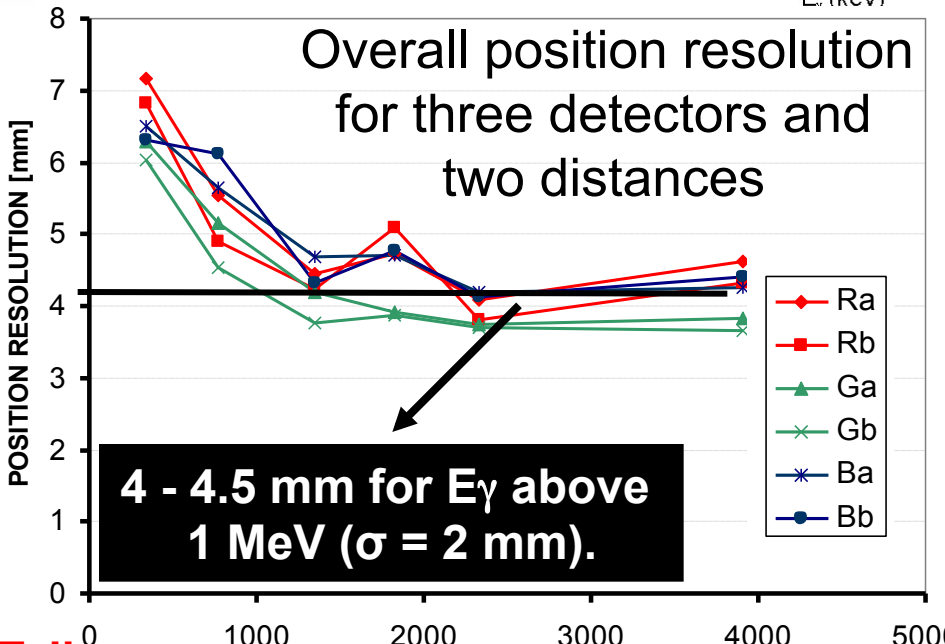






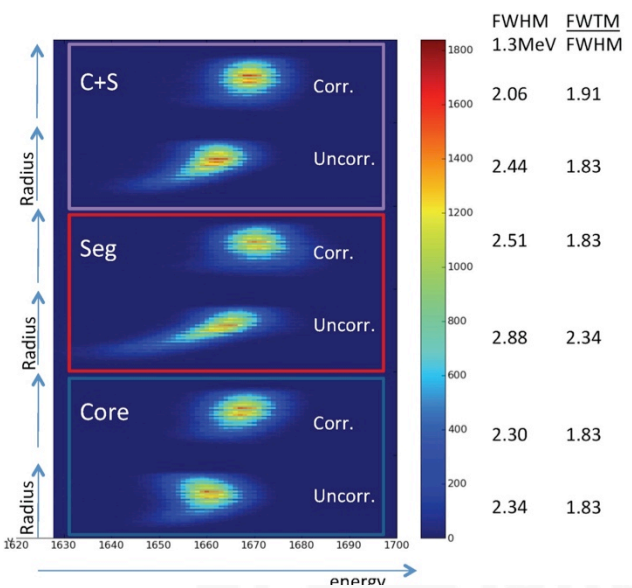


P-A Söderström (Uppsala)
F. Recchia (INFN-PD)
NIM A 638 (2011) 96

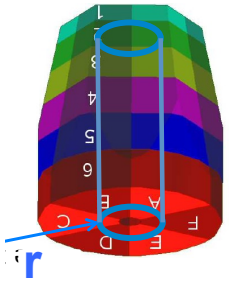


Optimization of PSA: See L.Lewandowski Talk

AGATA Neutron Damage Correction



	FWHM 1.3MeV	FWTM FWHM
	2.06	1.91
	2.44	1.83
	2.51	1.83
	2.88	2.34
	2.30	1.83
	2.34	1.83



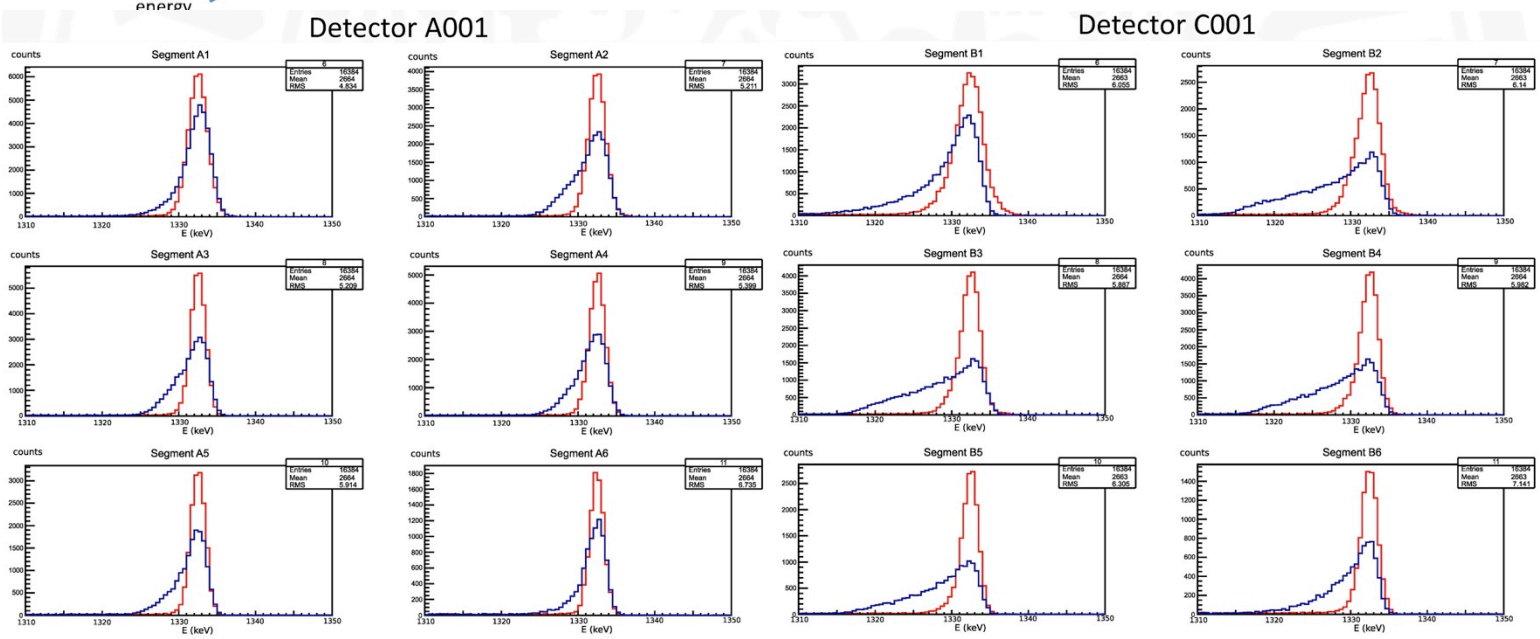
Radial dependency of charge trapping established.

B.Bruyneel EPJ A 49 (2013) 61

Recent improvements on neutron damage correction parameters determination by R.Hetzenegger et al. IKP-Cologne

$$E_{korr} = \frac{E_0}{1 + \frac{tSG_e}{\lambda_e} + \frac{tSG_h}{\lambda_h}}$$

Determination of $\lambda_{e,h}$:inverse trapping centre density (e,h) N in cm^3

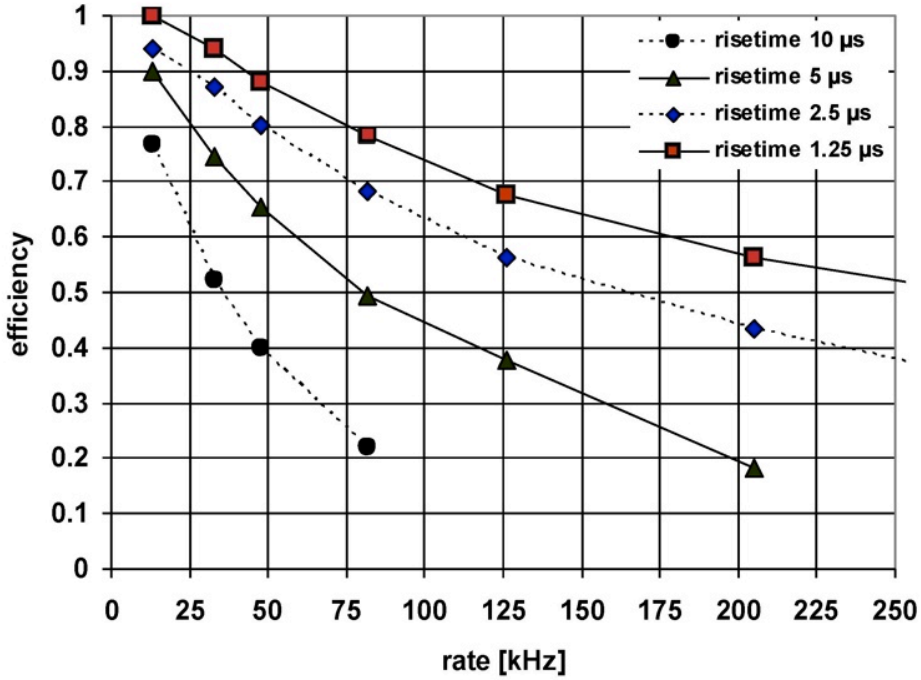


IKP-Cologne

AGATA Counting Rate Performance

AGATA electronics has been designed for high counting rates in the detectors: Specification 50 kHz, some experiments performed at ~70 kHz.

Limitations are the built-in pile-up protection and finally the trigger rate that is limited by the storage band-width due to the traces recording

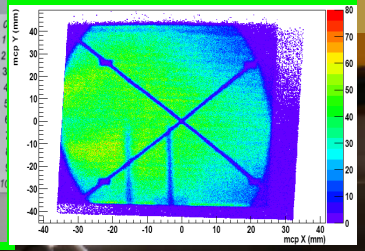


- Pile-up rejection in the pre-processing electronics risetime+ 1.06 µs
- Dead-time for the GTS trigger system 1 µs per event

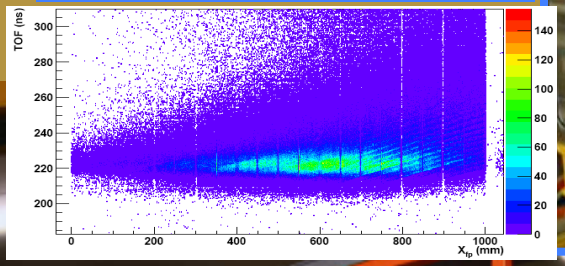
Relative efficiency as a function of counting rate for different risetime -pre-processing parameter- values

F. Recchia, D. Bazzacco et al., LNL Annual Report 2010 p. 60 (2011)

MCP Start Det. X,Y & T_I

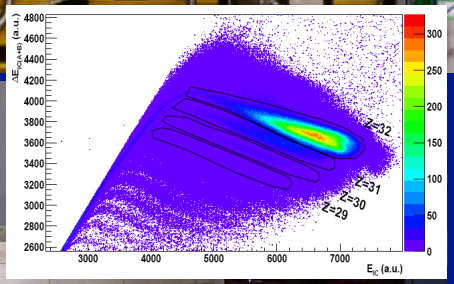


MWPPAC X,Y & T_F



10 sect.

6m TOF



10x4 sect.

First AGATA Campaign at INFN-LNL: AGATA coupled with PRISMA: Tracking Magnetic Spectrometer.

Nuclear Structure using Multi Nucleon Transfer reactions (and more with complementary instrumentation)

Ionisation Chamber ΔE - E

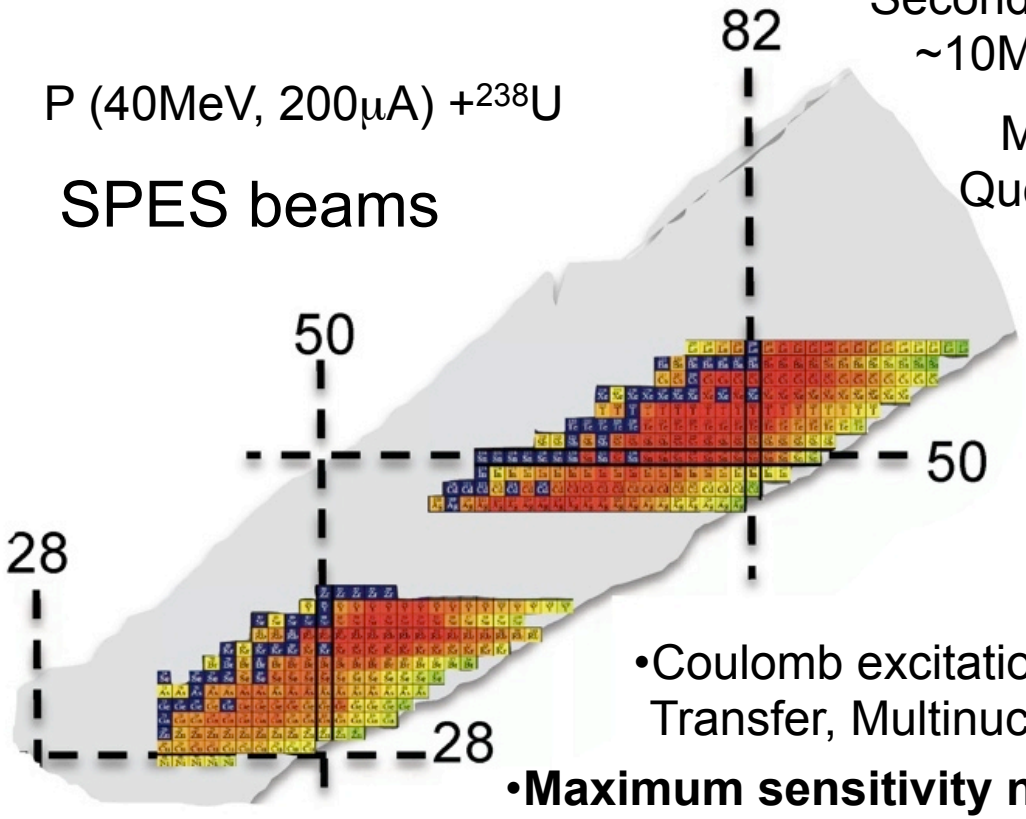
Scientific challenges for the Future AGATA Campaigns at SPES (LNL-INFN)

SPES is an ISOL RIB facility. The unstable beams are produce by proton induced fission of ^{238}U.

Secondary Beams at the LNL-ALPI energies. ~10MeV/u up to 10^9 pps (10^7 pps day 0).

P (40MeV, 200μA) +^{238}U

SPES beams

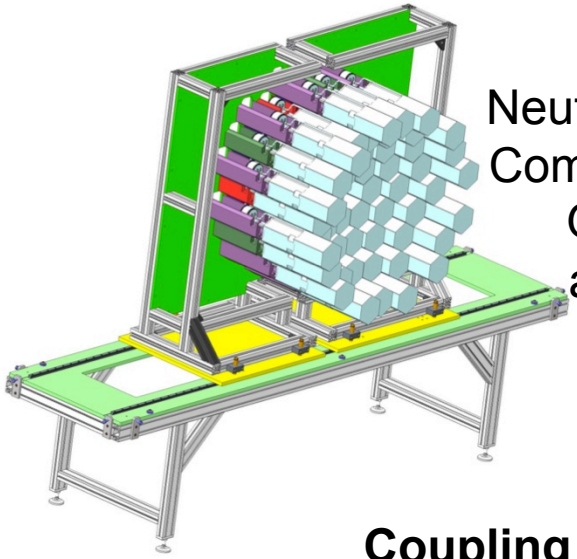


Credits to S.Leoni
INFN-Milano

Many body Finite Quantum Systems:
Quest for an unified description of nuclei:

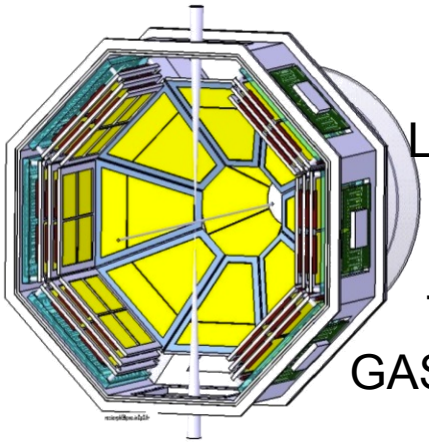
- Shell Structure in the ^{78}Ni and ^{132}Sn Regions.
- Complex excitation in nuclei: Multiplets of complex nature core excitations), Dipole response, pygmy resonances, Quadrupole pygmy?
- Shape evolution: Phase transitions
- Coulomb excitation, Inelastic excitations Transfer, Cluster Transfer, Multinucleon Transfer.
- **Maximum sensitivity needed: AGATA**
  High velocity products, maximizing efficiency and resolution, lifetime measurements advanced techniques with AGATA
- Fundamental: Complementary instrumentation

Complementary Instrumentation for the AGATA Campaigns at SPES (LNL-INFN)



NEDA

Neutron Detector array
Common development
GANIL/SPIRAL
and LNL/SPES

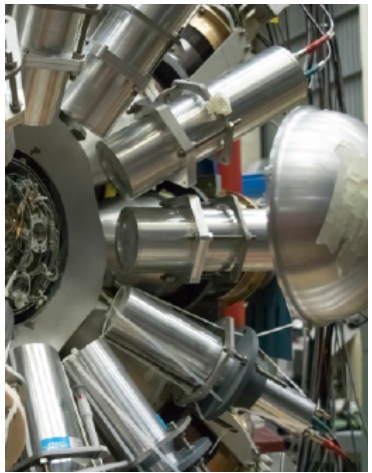


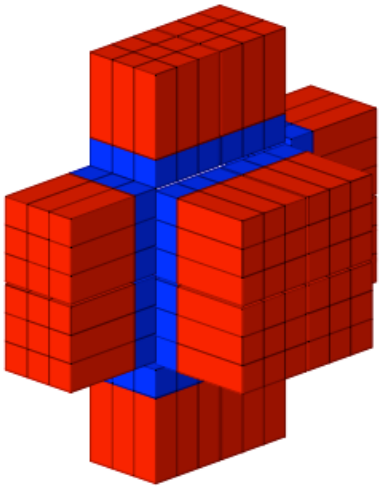
GHT

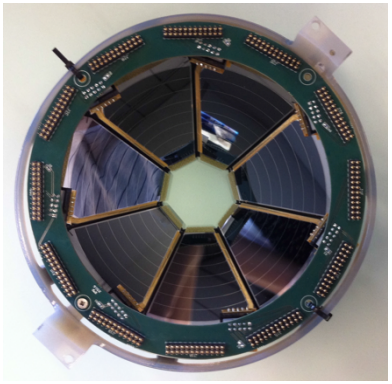
Light Particle DSSSD
Telescope array
Collaborations
TRACE: LNL/SPES
GASPARD GANIL/SPIRAL

Coupling with other instrumentation foreseen/possible

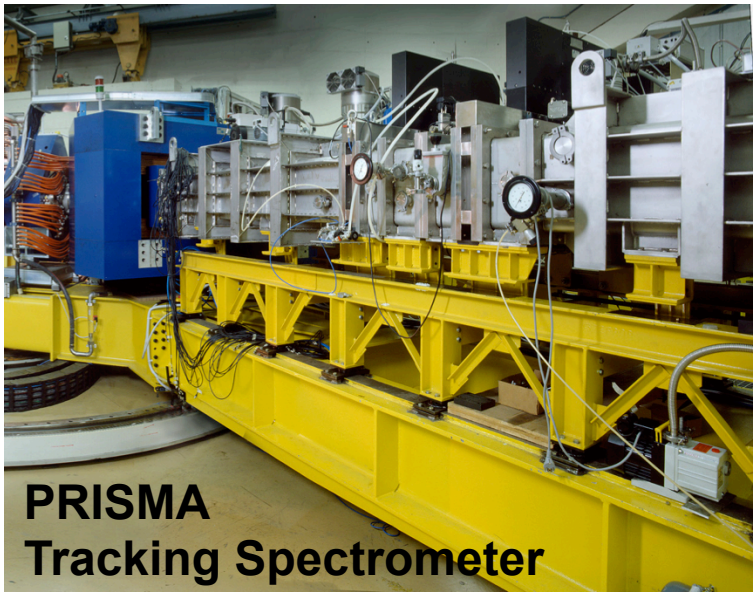
High γ-Energy Detector arrays: $LaBr_3$ & PARIS



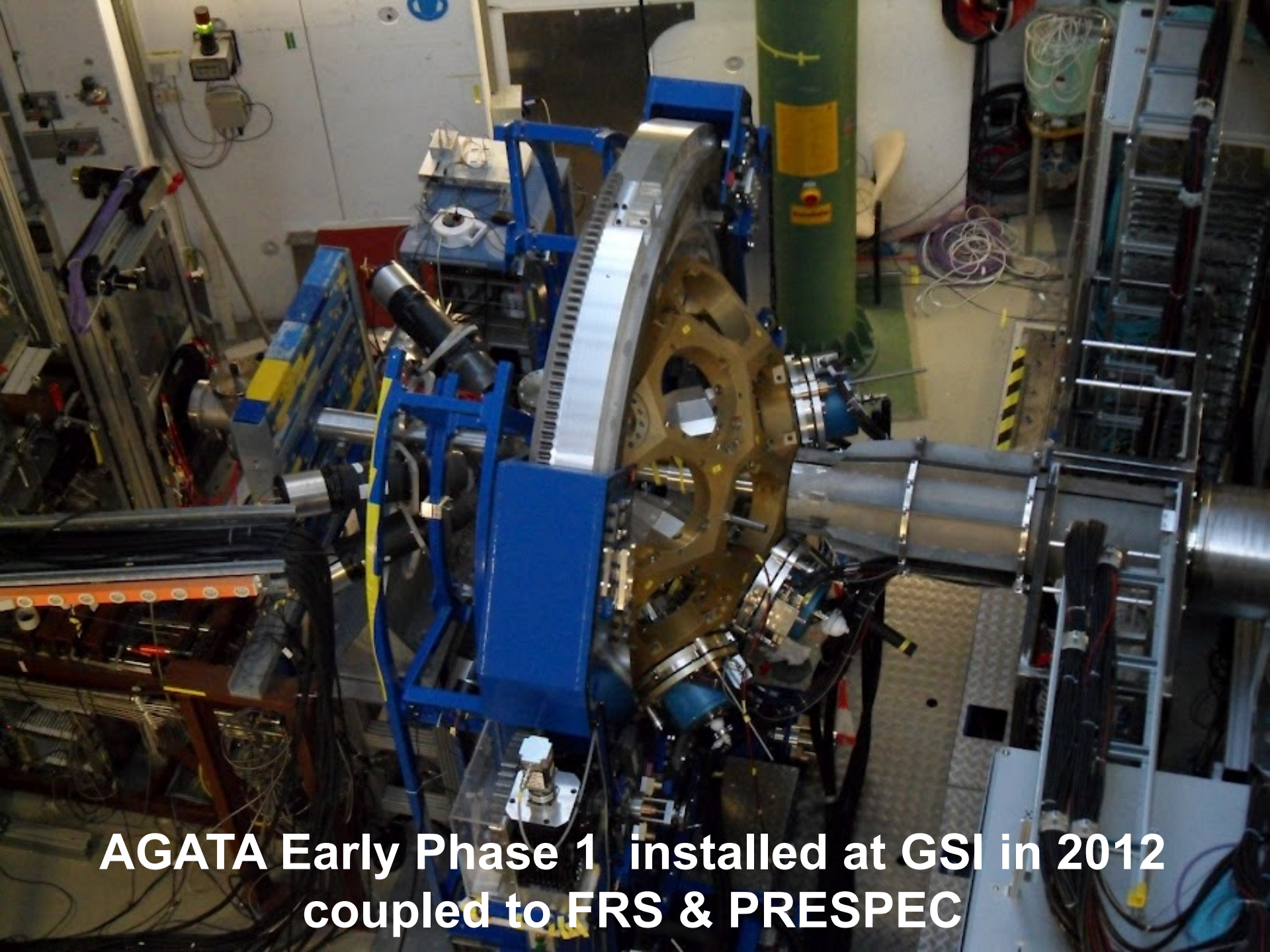


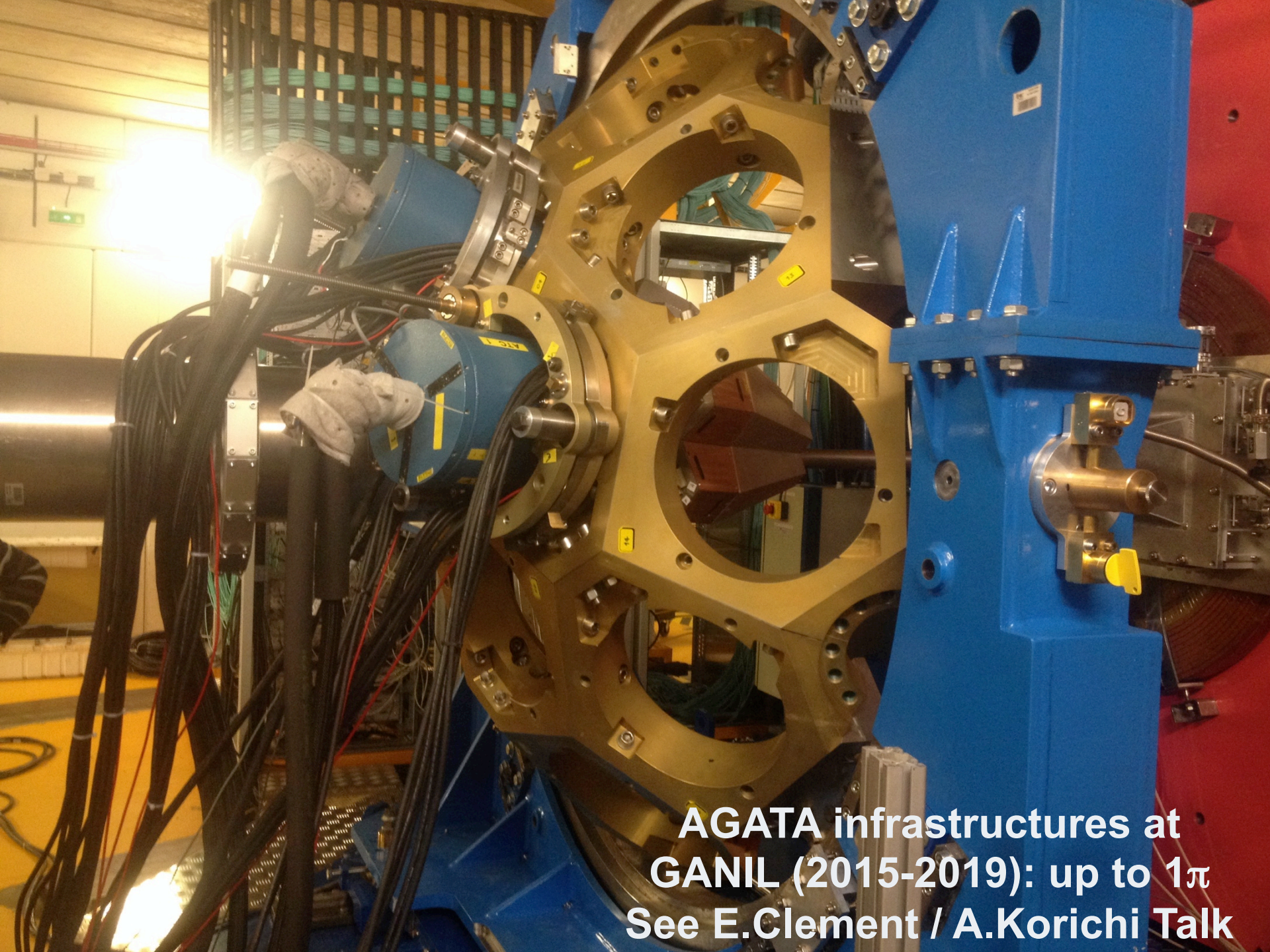


SPIDER
DSSSD Array
for Coulex



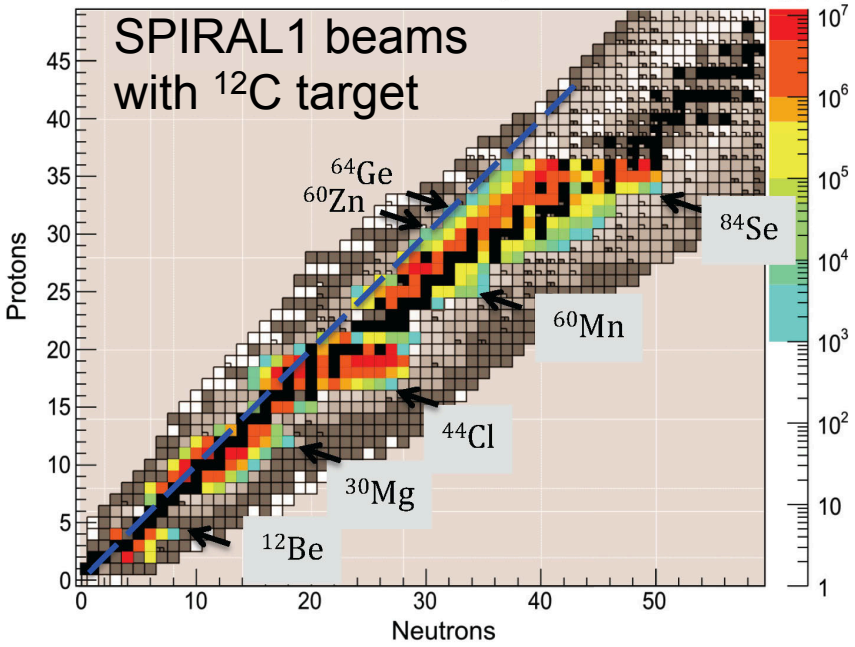
PRISMA
Tracking Spectrometer

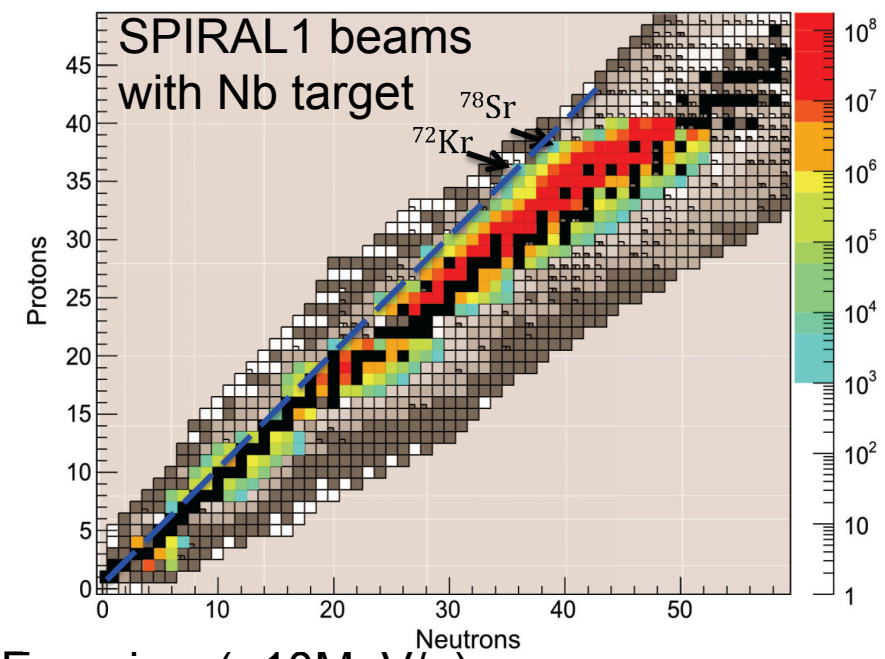

AGATA Early Phase 1 installed at GSI in 2012
coupled to FRS & PRESPEC


AGATA infrastructures at
GANIL (2015-2019): up to 1π
See E.Clement / A.Korichi Talk

Scientific challenges for the Future (and coming) AGATA Campaigns at GANIL-SPIRAL

Improved ISOL beams at SPIRAL 1 available in 2019 with AGATA, SPIRAL 2 beams in the future

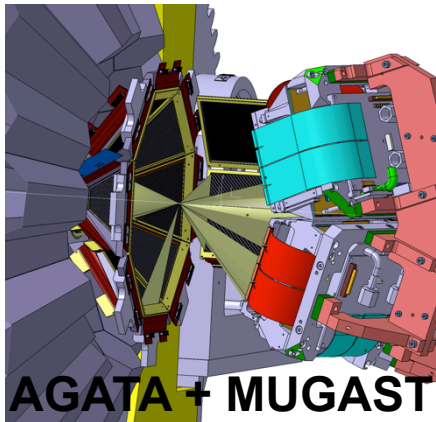




Secondary Beams at the SPIRAL1 CIME Energies (~10MeV/u)

Direct Reactions (inverse kinematics) to investigate Exotic Nuclei and Nucleosynthesis:

- Shell structure evolution & deformation N~18, N~28, etc…
- Neutron-proton pairing in medium mass nuclei
- Clustering in Nuclei, Dipole response
- Astrophysics



AGATA TEAMS

A. Gadea (Project Manager)

A. Boston, B. Million, A. Korichi, F. Recchia, (P.Reiter), G. Duchêne (ASC), J.Nyberg (ACC).
J. Gerl (LCM-GSI), E. Clement (LCM-GANIL)

AGATA Working Groups	AGATA TASKS			
Detector Module (P.Reiter)	Detector & Cryostat H.Hess	Detector Characterisation H.Hess	Detector CAT &Testing H. Boston	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	Software: Flow, Services & GRID X. Grave	Hardware: Local Infr. & Network N. Ménard	Slow Control & FEE Monitoring E. Legay	
Data Analysis A.Boston	Data Analysis & TRACKING O. Stezowski A. Lopez-Martens	PSA Algorithm Development L. J. Harkness	GRID Data managing and Analysis	
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	AGATA Commissioning	AGATA Physics & exp. Simulation M. Labiche	
Technical Coordinator Engineering Advi.	Compatibility EMC, Interfacing	Specification control	Quality Control	Documentation

AMB Chairman
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Thanks to the AGATA Teams and Team Leaders

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