AGATA @ ISOLDE

- Old and New Physics Cases
- Benefit of γ–ray Tracking
- AGATA @ HIE-ISOLDE ?
  - *opportunities*
  - *obstacles*
- Discussion

Peter Reiter
IKP, University of Cologne

81st ISOLDE Collaboration Committee meeting
6th February 2018

HIE-ISOLDE physics case

Physics case

2.1 Single-particle states and few-body correlations
- 2.1.1 Light nuclei: halo and cluster structure
- 2.1.2 Evolution of shell structure
- 2.1.3 Isospin symmetry
- 2.1.4 Pairing
- 2.1.5 Isomeric states
- 2.1.6 Beta-delayed particle emission

2.2 Evolution of collectivity
- 2.2.1 Evolution of collectivity throughout the nuclear chart
- 2.2.2 pn interaction
- 2.2.3 Shape coexistence
- 2.2.4 Octupole shapes
- 2.2.5 Pygmy resonances

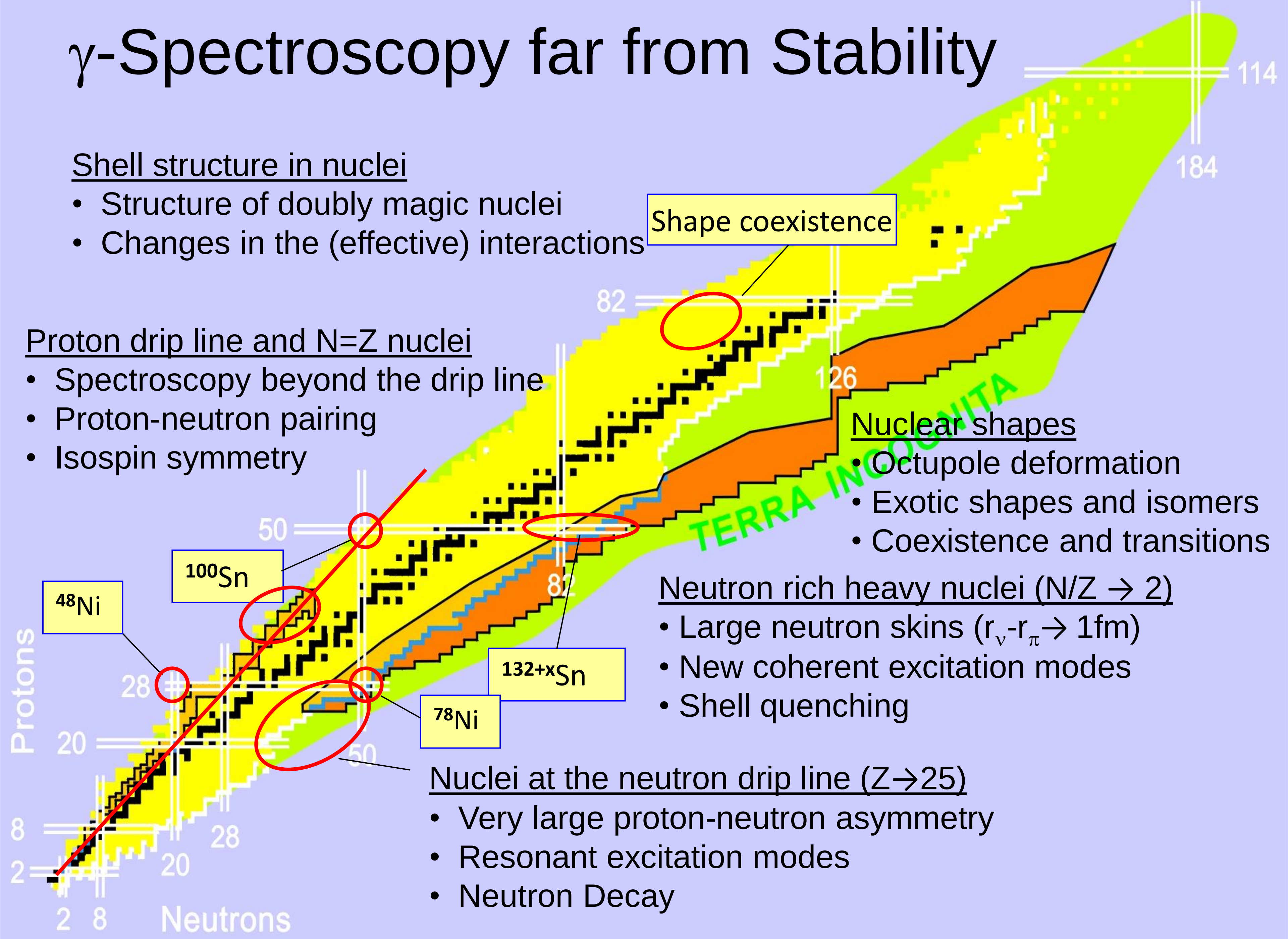
2.3 Order to chaos

2.4 Standard Model tests

2.5 Nuclear astrophysics
- 2.5.1 Novae, X-ray bursts and the rp process
- 2.5.2 The s process
- 2.5.3 The r process

ote-0002

γ-Spectroscopy far from Stability



<u>Shell structure in nuclei</u>

- Structure of doubly magic nuclei
- Changes in the (effective) interactions

<u>Proton drip line and N=Z nuclei</u>

- Spectroscopy beyond the drip line
- Proton-neutron pairing
- Isospin symmetry

<u>Nuclear shapes</u>

- Octupole deformation
- Exotic shapes and isomers
- Coexistence and transitions

<u>Neutron rich heavy nuclei (N/Z → 2)</u>

- Large neutron skins (r_ν-r_π → 1fm)
- New coherent excitation modes
- Shell quenching

<u>Nuclei at the neutron drip line (Z→25)</u>

- Very large proton-neutron asymmetry
- Resonant excitation modes
- Neutron Decay

AGATA white paper

AGATA @ ISOLDE Working group
Chair: M. Zielinska vice chair: P. Reiter

1. **Studies around magic numbers ^{208}Pb, ^{100}Sn, ^{132}Sn, ^{68}Ni, ^{78}Ni, …**
   coord. by R. Raabe, with J. Cederkäll, F. Didierjean, G. Duchêne, J. Pakarinen, G. Rainovski, P. Reiter, M. Zielinska
   Theoretical support by K. Sieja, F. Nowacki

2. **Studies of quadrupole shapes far from closed shells**
   (neutron-deficient Hg/Pb/Po, A~100, neutron-deficient Kr/Se)
   coord. by J. Pakarinen, with D. Doherty, L. Gaffney, A. Nannini, M. Zielinska

3. **Octupole collectivity possibly including higher-order deformation**
   coord. by L. Gaffney, with W. Korten, M. Zielinska
   Theoretical support by J. Dudek

4. **Nuclear astrophysics**
   coord. by D. Doherty with D. Jenkins, S. Courtin

5. **γ-ray strength function**
   A. Bracco, S. Siem expressed interest to contribute

HIE-ISOLDE perspectives

HIE-ISOLDE @ 10 MeV/u

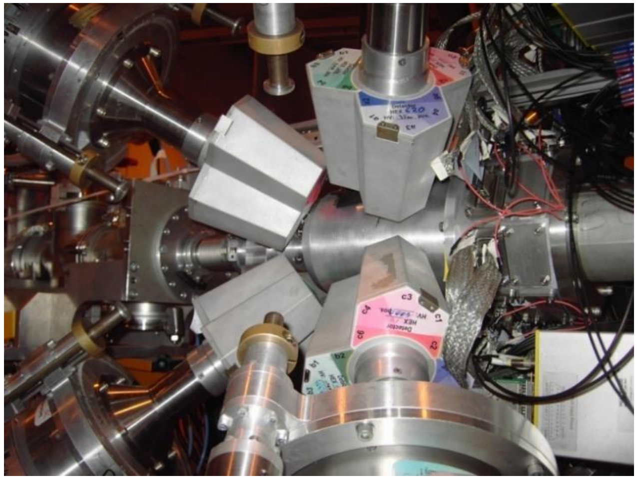
- ✓ Multiple-Coulomb excitation
- ✓ Single-particle reactions
- ✓ Transfer-reactions
- ✓ Multi-nucleon-transfer reactions
- ✓ Deep-inelastic reaction
- ✓ Fusion

particle γ coincidences
+ BaF or LaBr array
+ plunger device

γ-spectrometer:

- γ-ray multiplicity
- excitation energy
- Doppler effects $v/c=\beta\sim10\%$

MINIBALL was designed for high efficiency, and good energy resolution at low γ–ray multiplicity. Very poor line shape or P/T ratio.



HIE-ISOLDE requirements

Best possible energy resolution, high quality response function, large dynamic range, high solid angle coverage

identification of single particle state via γ–decay branch and ΔE of HPGe

high level density of odd nuclei, low energy transitions

X-ray spectroscopy

lifetime measurements with plunger (line shape analysis)

γ–ray angular distribution

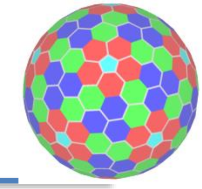
$\gamma\gamma$–correlation

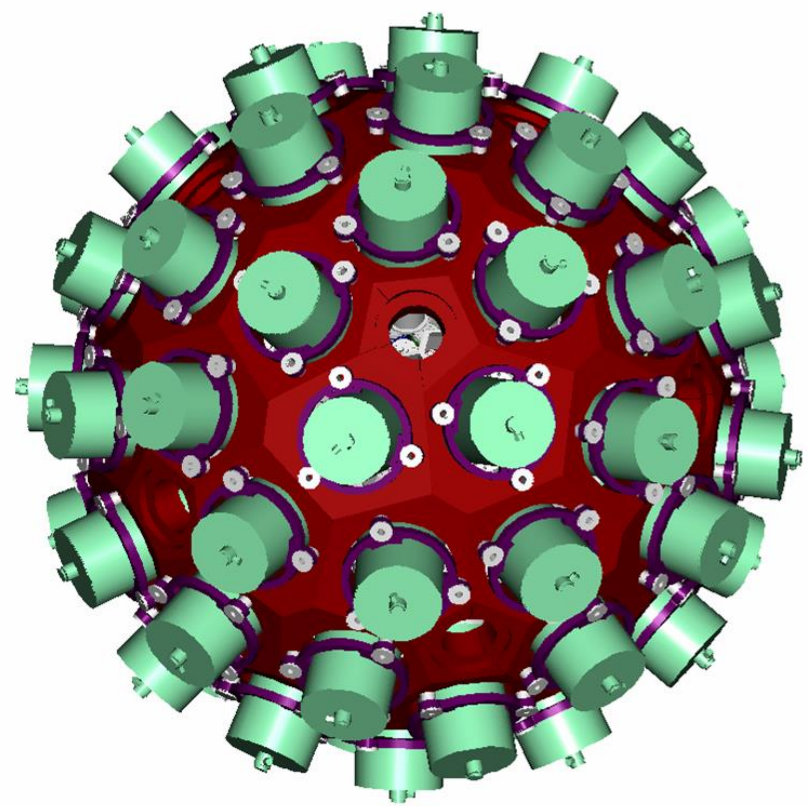
UNIQUE AT ISOL FACILITY

Need for efficiency and sensitivity

→AGATA

Advanced GAmma Tracking Array





180 hexagonal crystals	3 shapes
60 triple-clusters	all equal
Inner radius (Ge)	23.5 cm
Amount of germanium	362 kg
Solid angle coverage	82 %
36-fold segmentation	6480 segments
Singles rate	~50 kHz

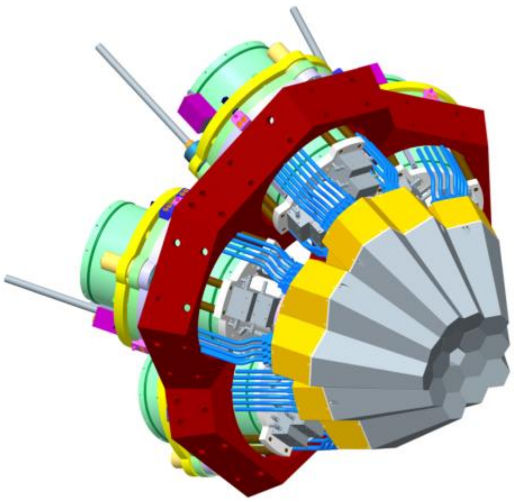
Efficiency: 43% (M_γ=1) 28% (M_γ=30)

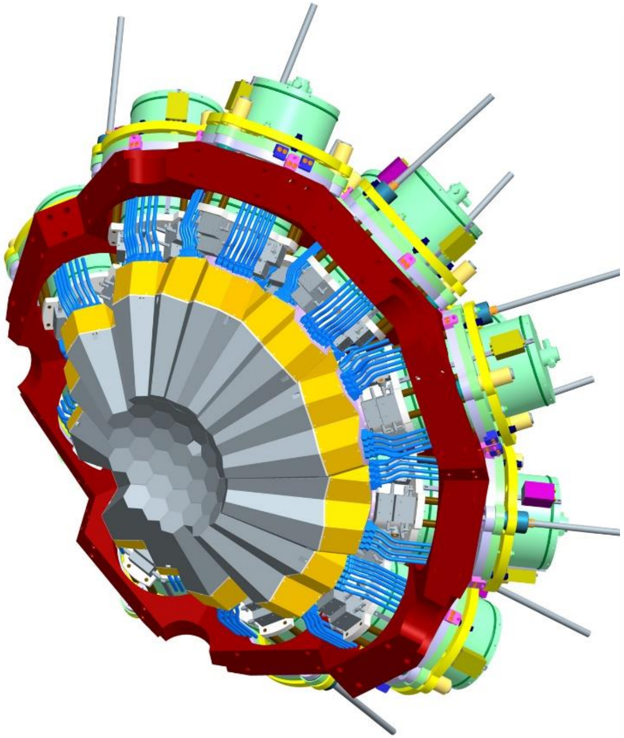
Peak/Total: 58% (M_γ=1) 49% (M_γ=30)

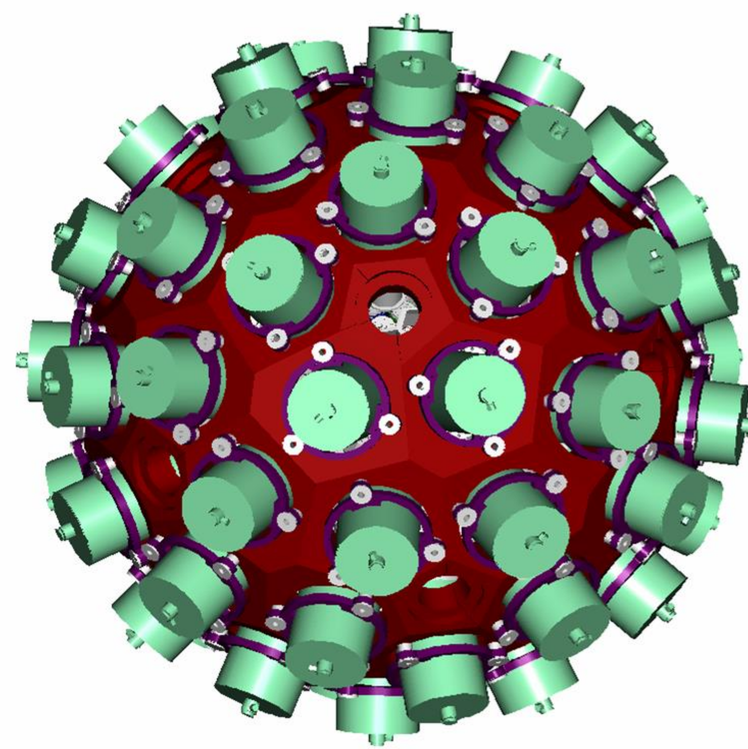
New γ-ray detection method

- 6660 high-resolution digital electronics channels
- Coupling to ancillary detectors for added selectivity

Phases of AGATA







AGATA demonstrator

5 Triple cluster

Old MoU

AGATA 1/3 4π

5+15 Triple cluster

Actual MoU

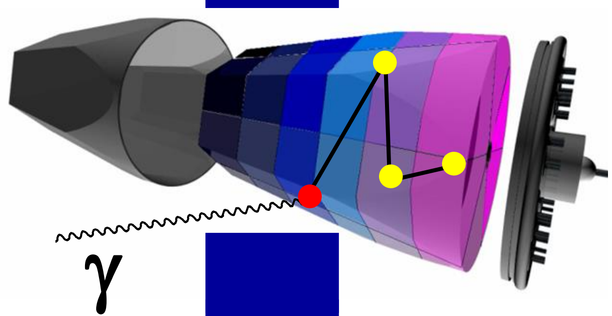
AGATA 4π

20+40 Triple cluster

Future MoU

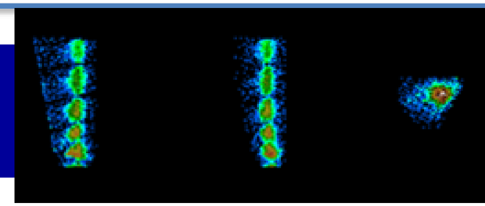
Ingredients of γ-ray tracking

Large Volume Segmented Germanium Detectors

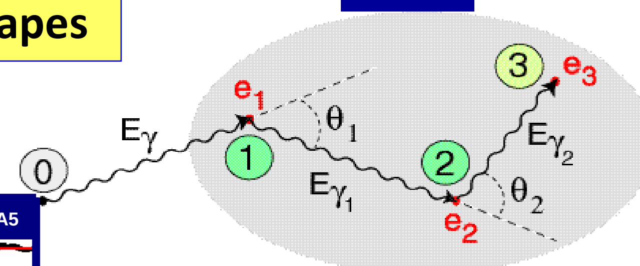


Identification of hits inside the crystal

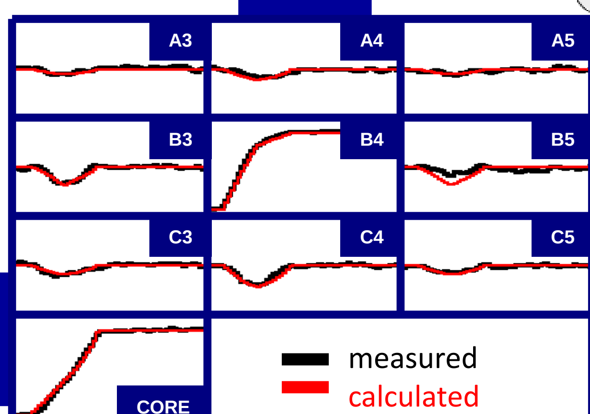
$(x,y,z,E,t)_i$



Reconstruction of individual gammas from the hits



Decomposition of signal shapes



Digital electronics

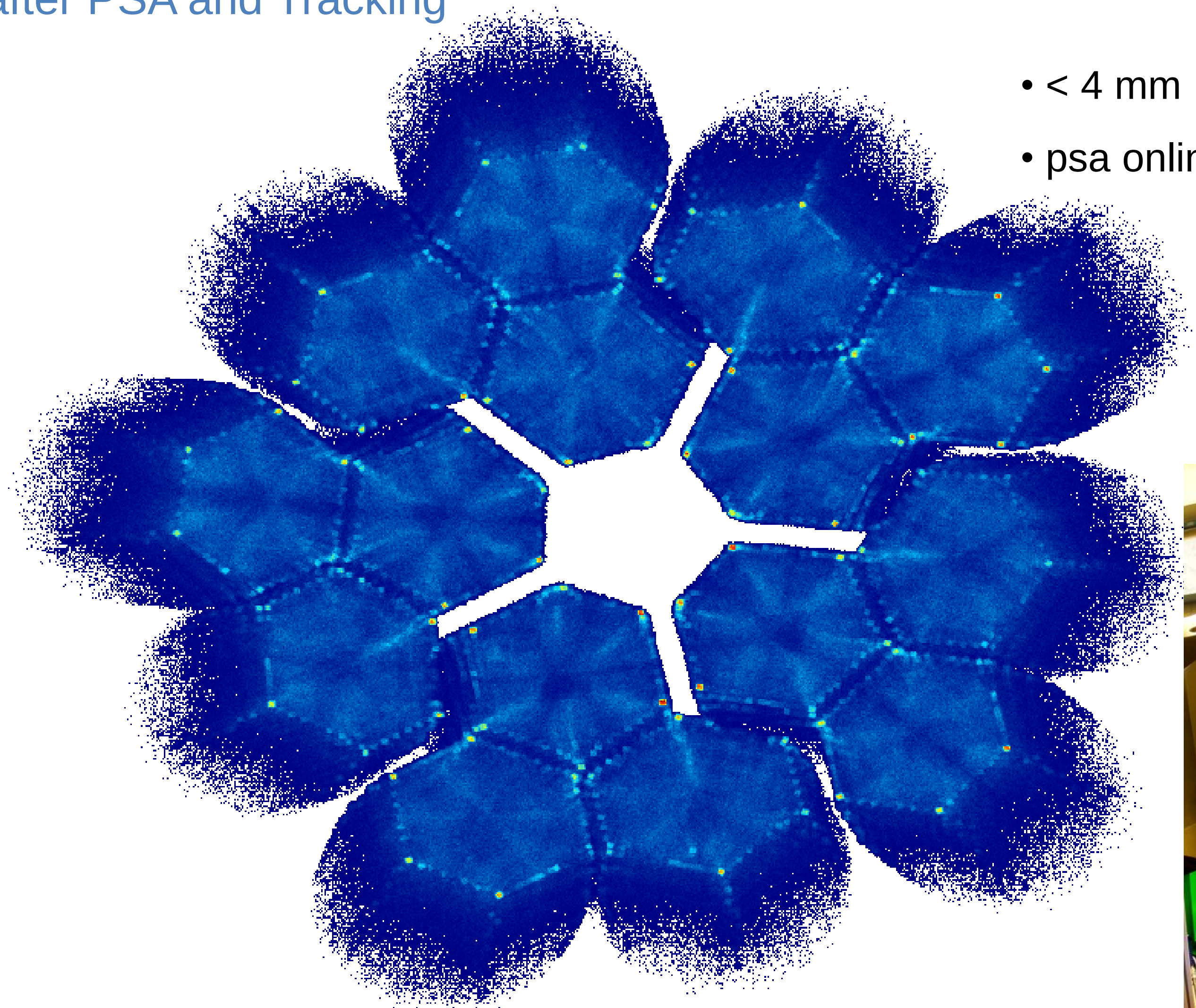
Energy and direction of the gamma rays

Result of AGATA tracking

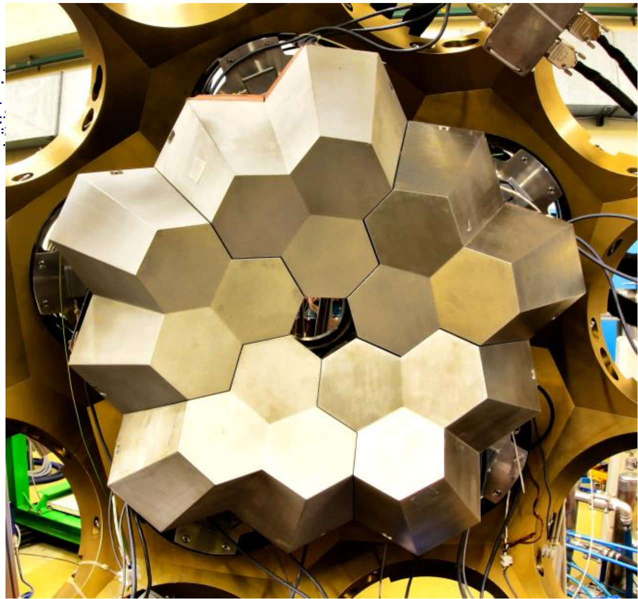
Reconstructed initial gamma rays with: - gamma ray energy
- 1st interaction position → Doppler correction
- 2nd interaction position → Polarization

B. Alikhani, NIM A, 675(0):144 - 154, 2012.

1st interaction positions after PSA and Tracking

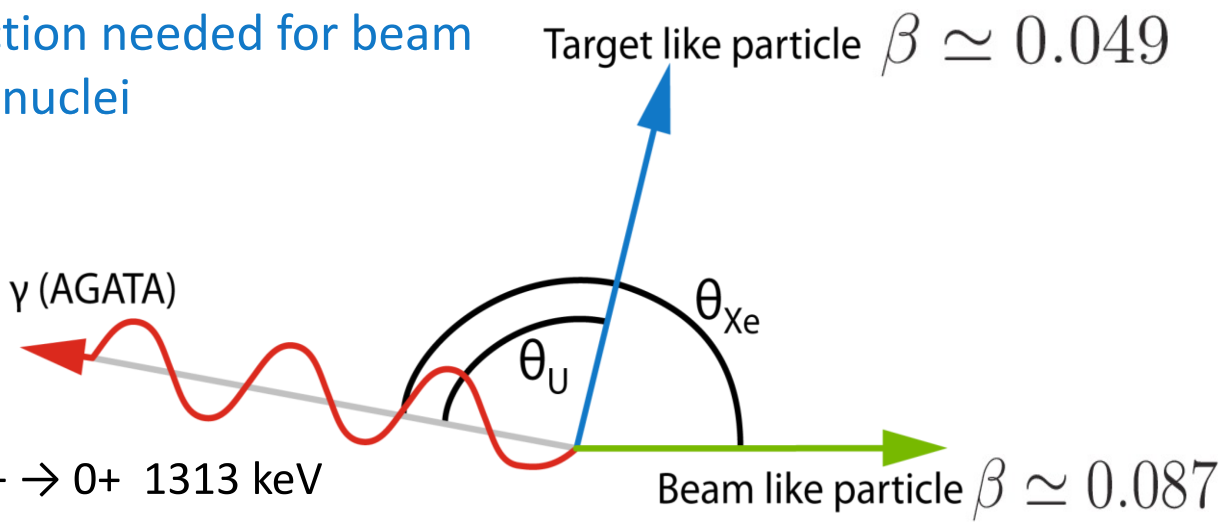


- < 4 mm FWHM resolution obtained
- psa online at rates > 5kHz per crystal



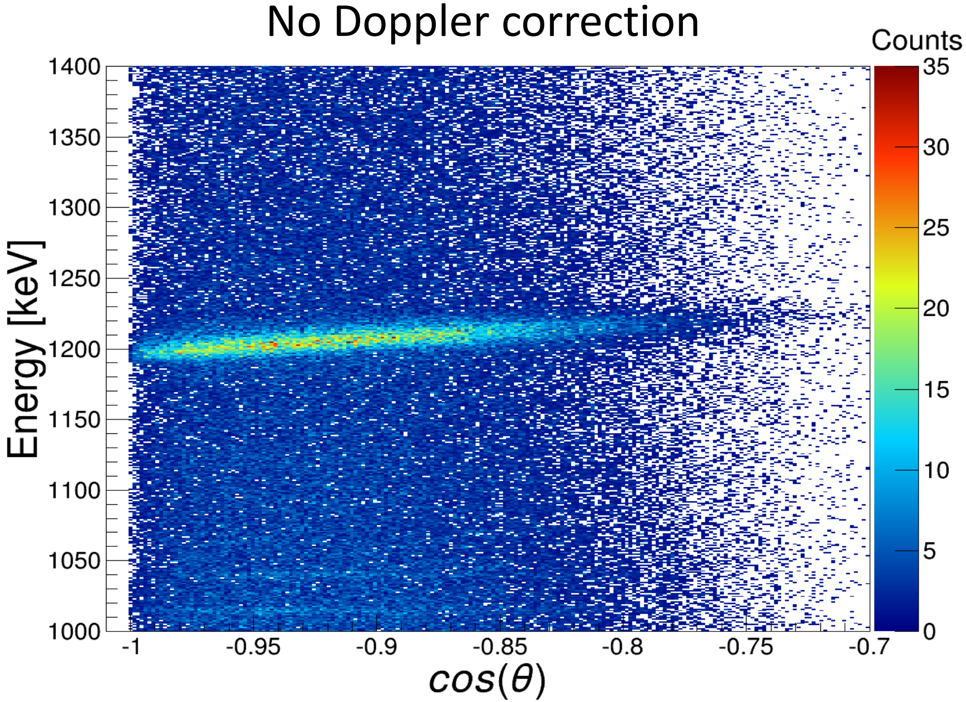
Position resolution & Doppler effects

Doppler correction needed for beam and target like nuclei

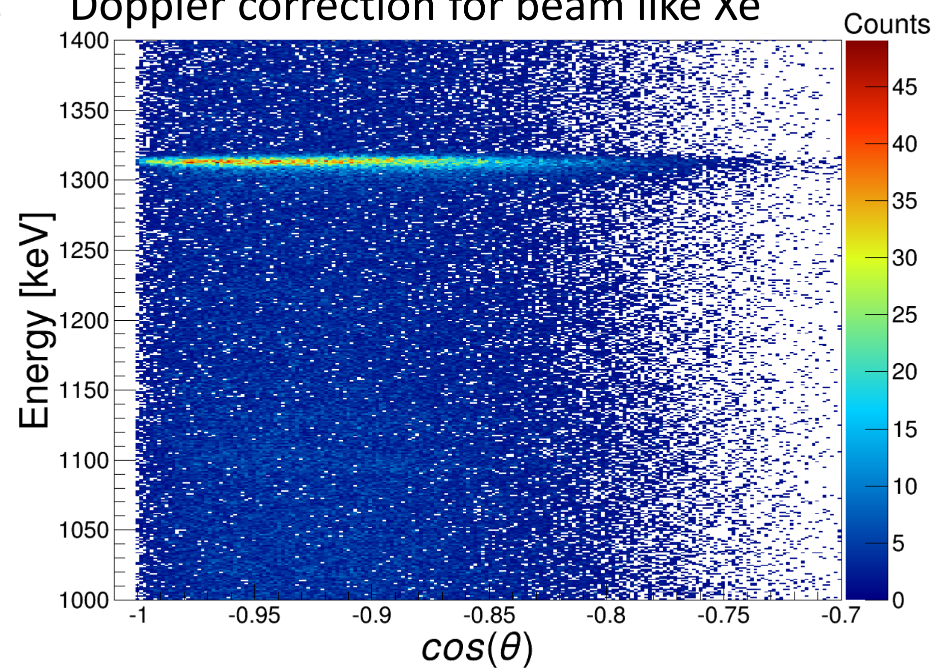


Example: ^{136}Xe: 2+ → 0+ 1313 keV

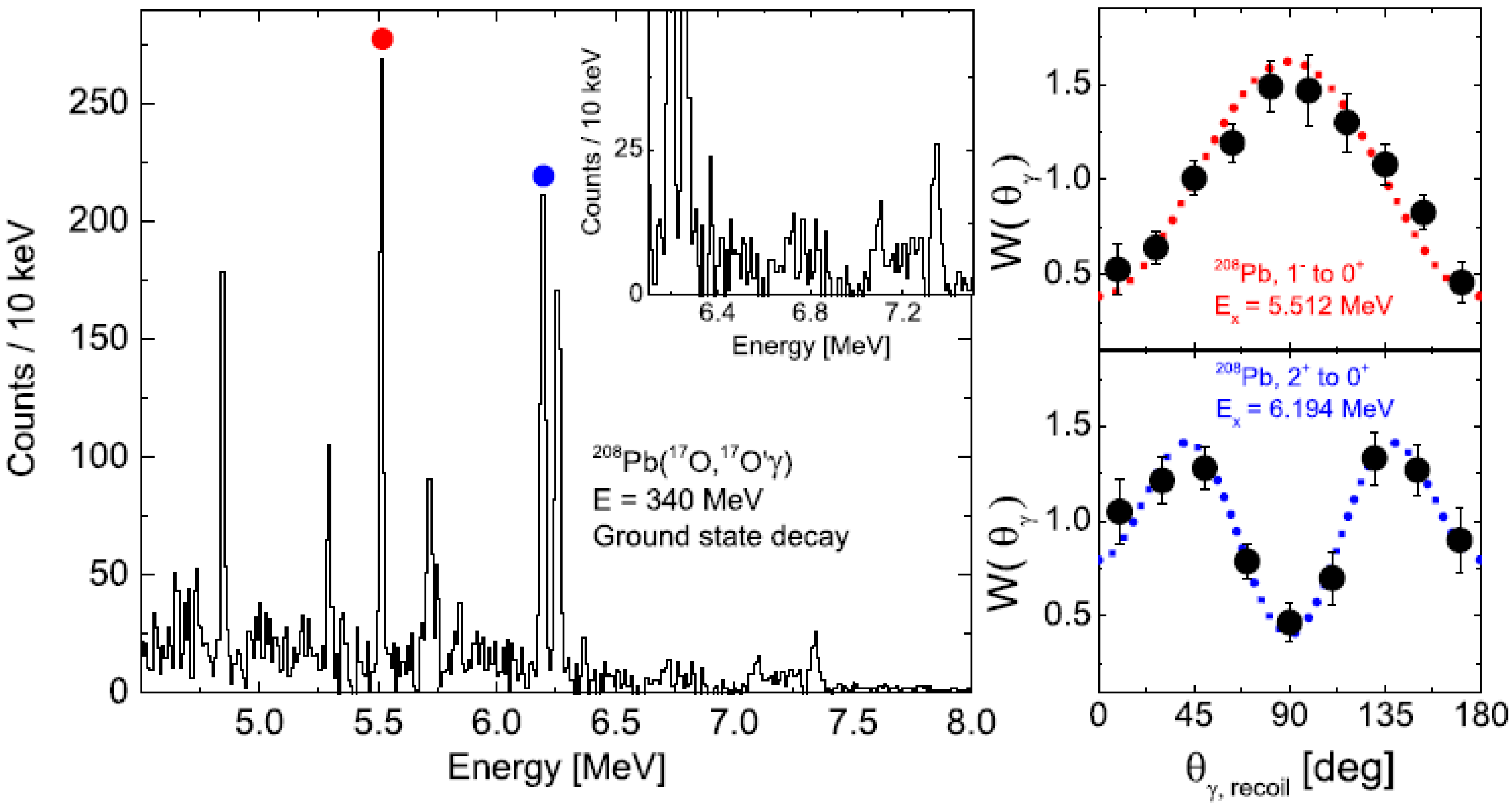
No Doppler correction



Doppler correction for beam like Xe



Line shape high γ-ray energy



Escape lines are identified and discriminated by γ-ray tracking

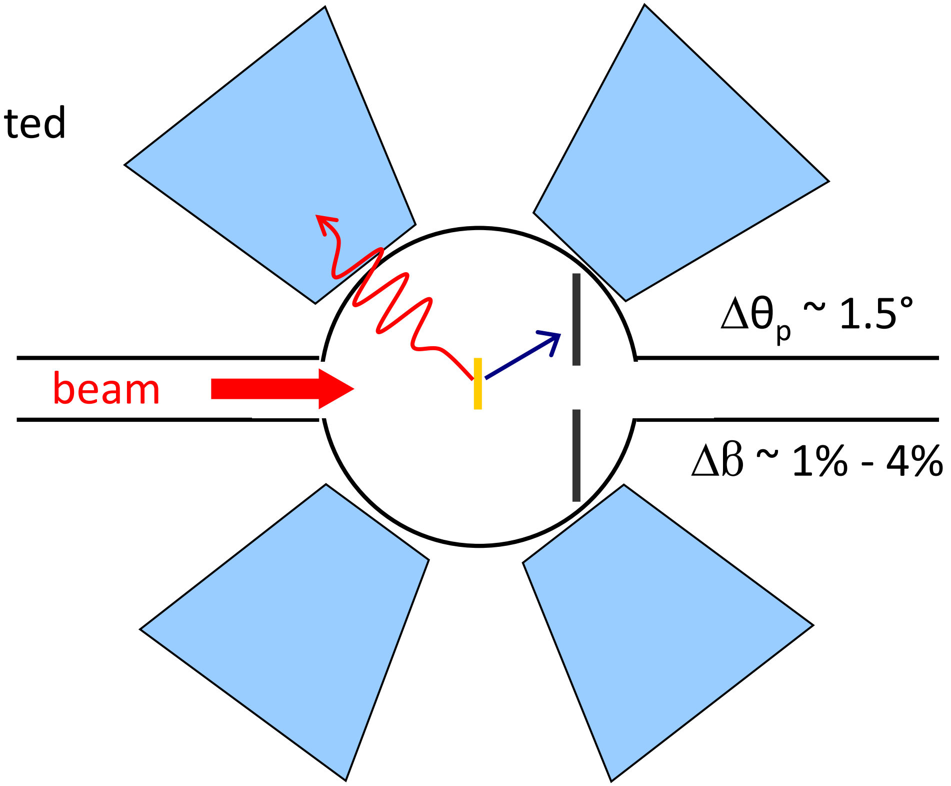
First interaction points yield angular distributions:

- E1 transition from the 1^- state at 5.512 MeV
- E2 transition from the 2^+ state at 6.194 MeV

F. Crespi, A. Bracco et al., Phys. Rev. Lett. **113**, 012501 (2014)

Detector Configuration MB

MINIBALL
8 cryostats
24 detectors
6-fold segmented



r_{MB} = 12 cm

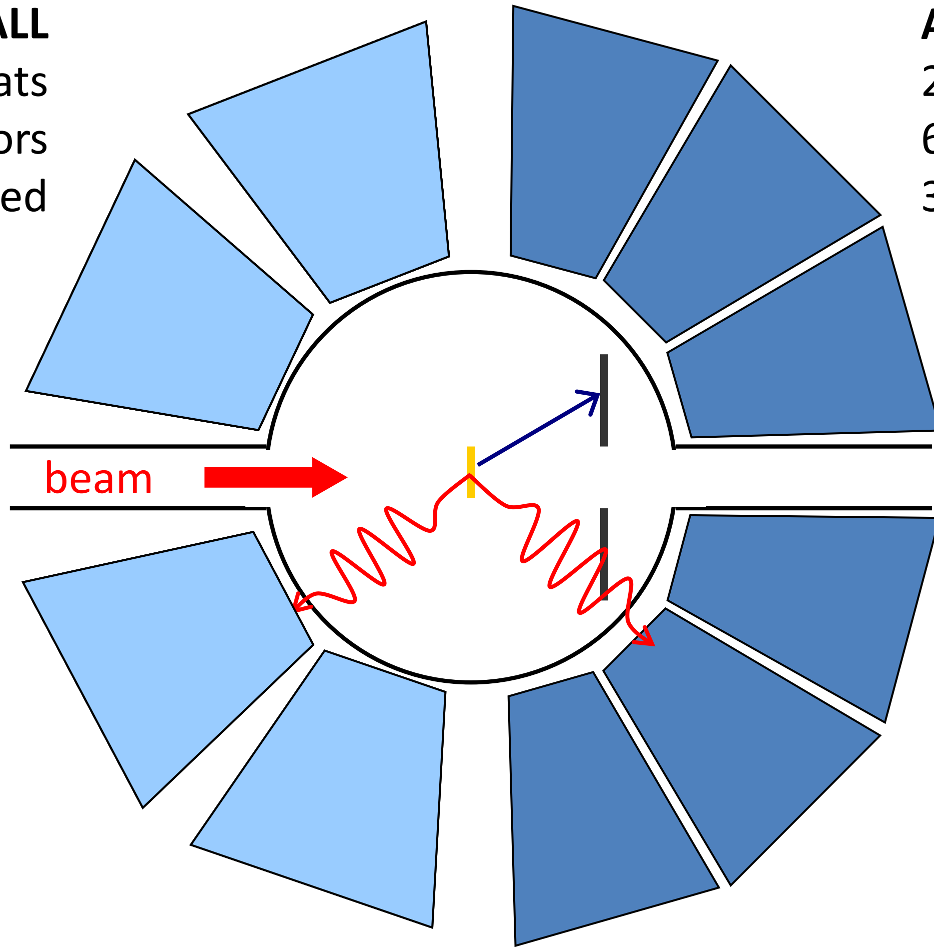
Δx = 17 mm (w/o PSA) $\Rightarrow$ $\Delta\theta_\gamma = 7°$

$\varepsilon_{photopeak}$ = 7.8% @ 1.3 MeV

MINIBALL - AGATA

MINIBALL
8 cryostats
24 detectors
6-fold segmented

AGATA (1π)
20 cryostats
60 detectors
36-fold segmented



r_{MB} = 20 cm

Δx = 17 mm (w/o PSA) $\Rightarrow$ $\Delta\theta_\gamma$ = 4.2°

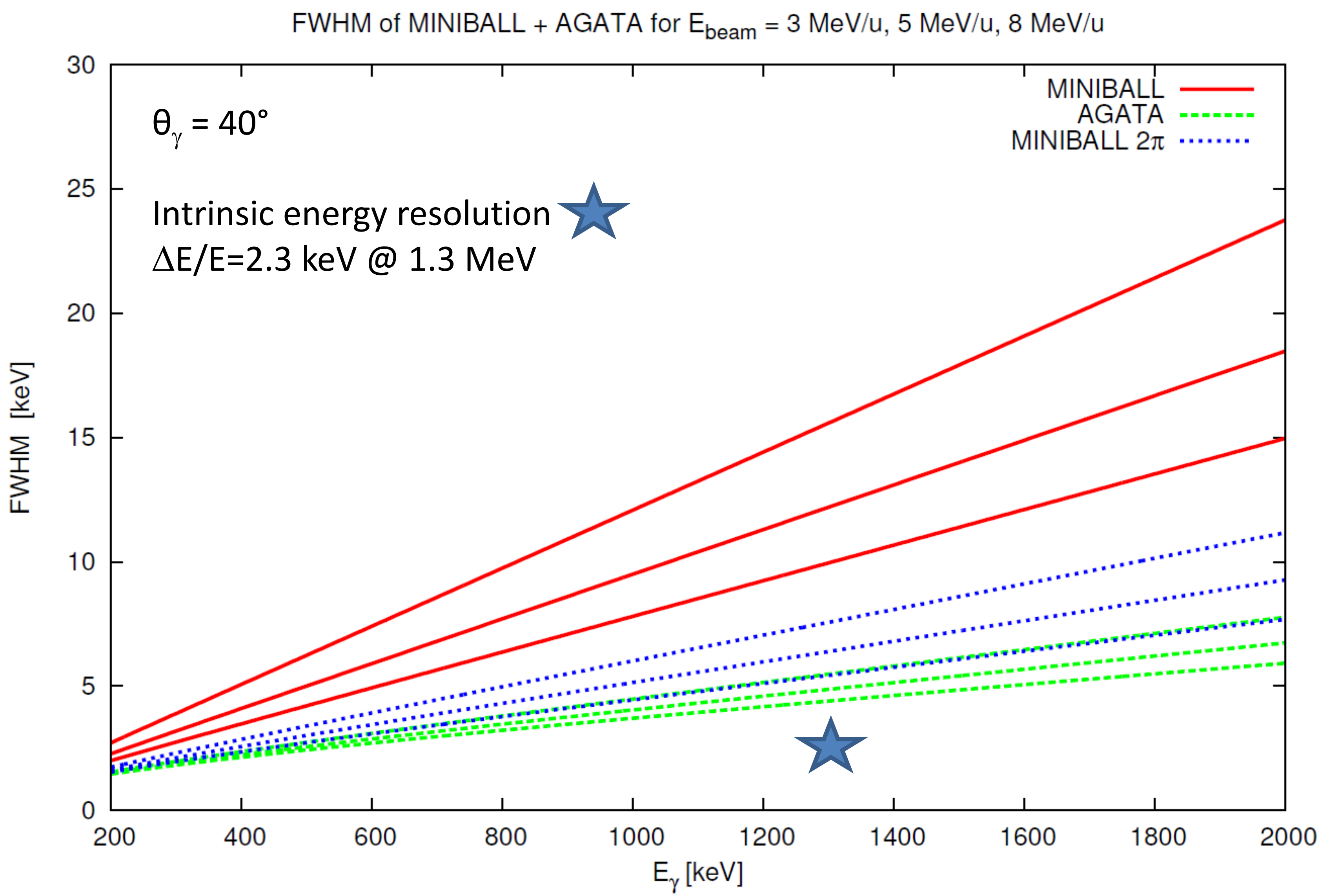
$\varepsilon_{photopeak}$ = 3.2% @ 1.3 MeV

r_{AGATA} = 23 cm

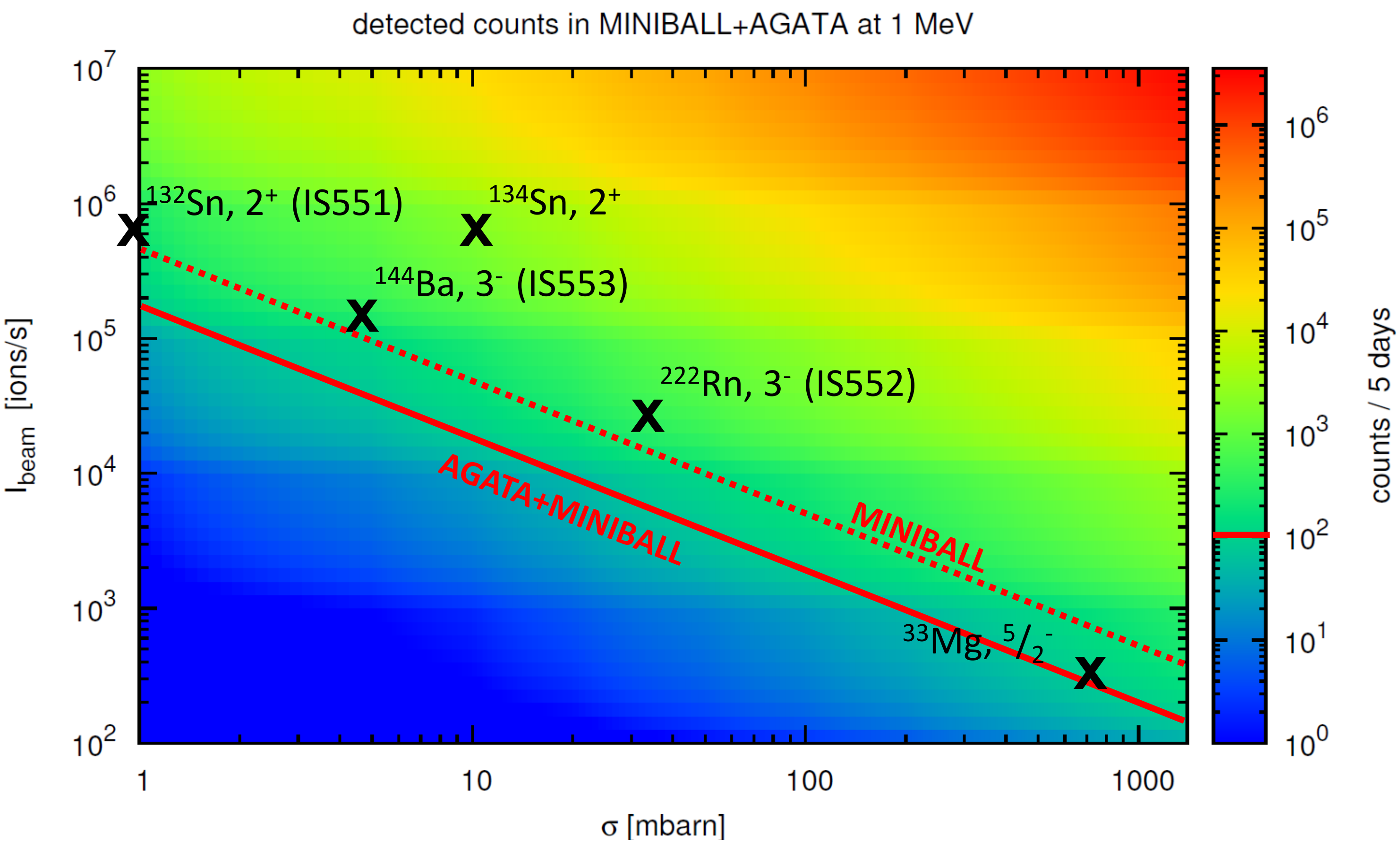
Δx = 4 mm (w/ PSA) $\Rightarrow$ $\Delta\theta_\gamma$ = 0.5°

$\varepsilon_{photopeak}$ = 18.0% @ 1.3 MeV

Energy resolution Doppler broadening



Detection sensitivity

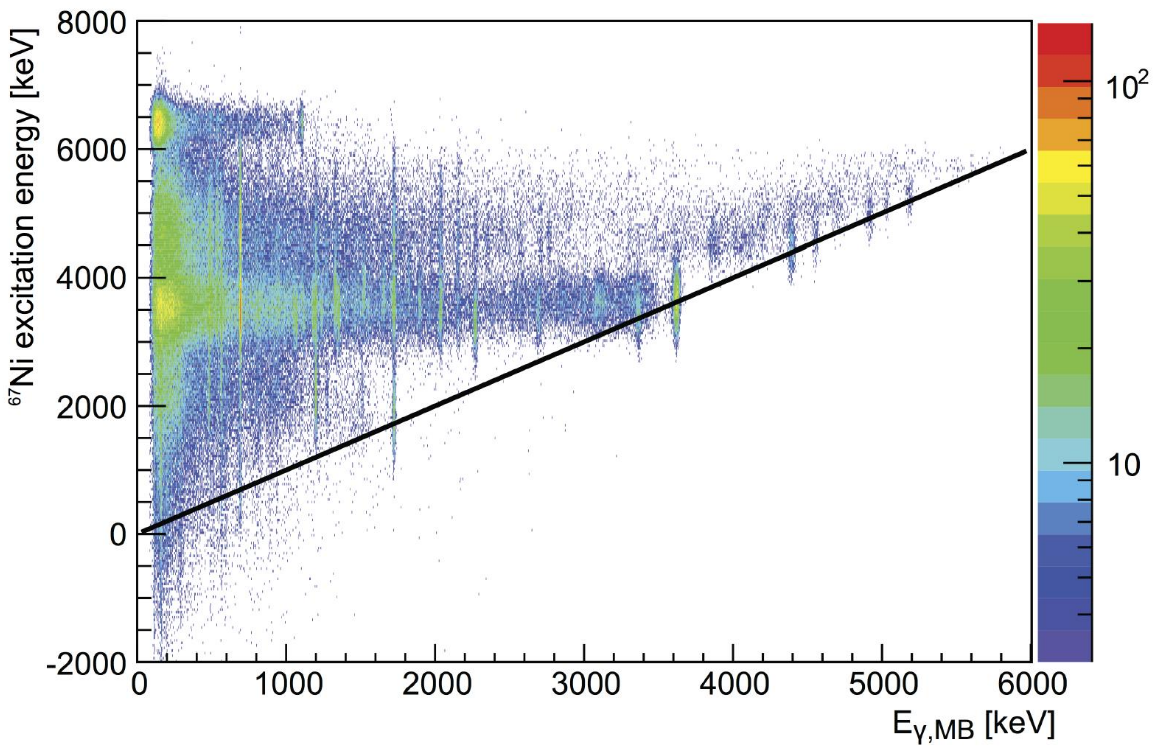


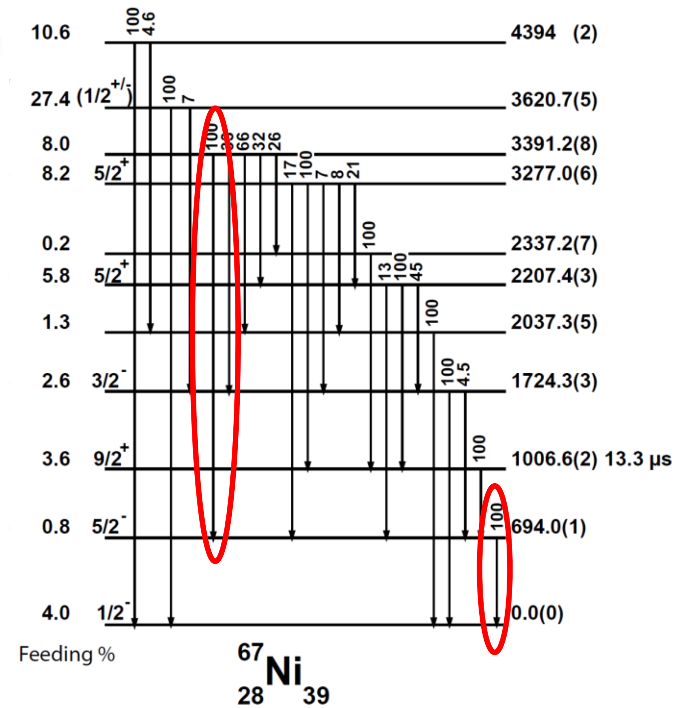
1 mg/cm² thick target (A ~ 200)

E_{beam} = 5.5 MeV/u (IS551) and 4.0 MeV/u (IS552, IS553)

I_{beam} @ MINIBALL (I_{ISOLDE} typically factor 10-50 higher)

Detection sensitivity MB + AGATA





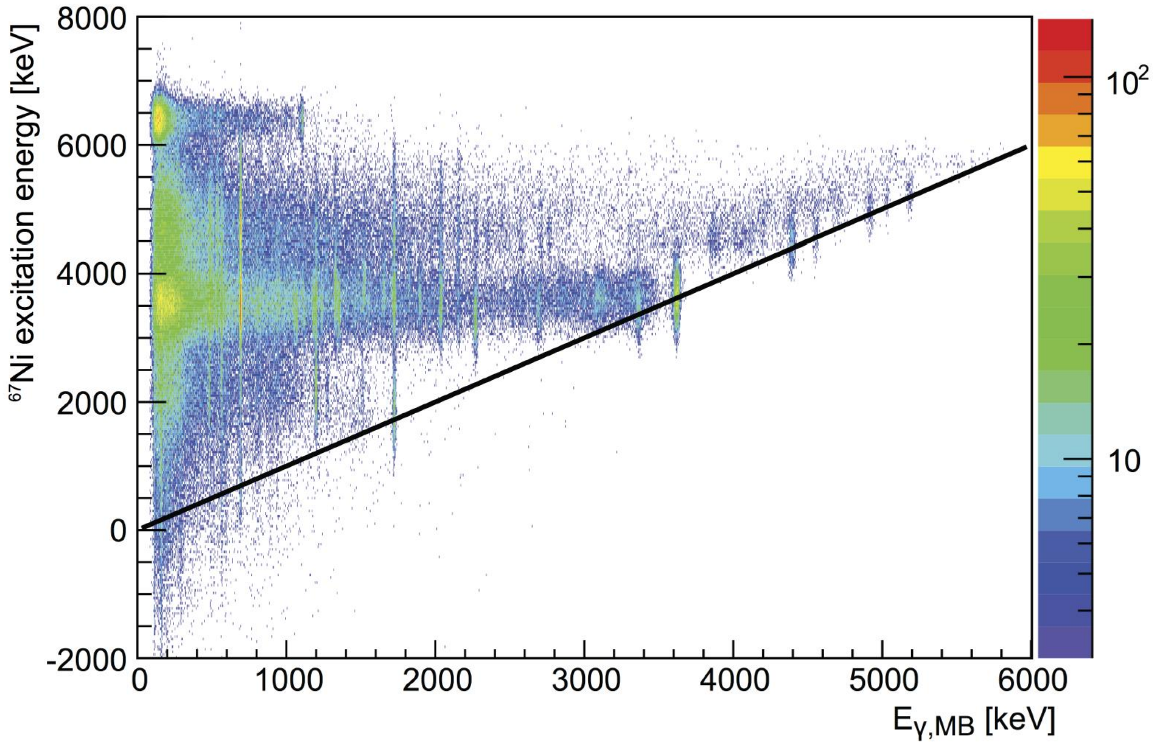
^{67}Ni: γ-ray cascade 2697 keV + 694 keV

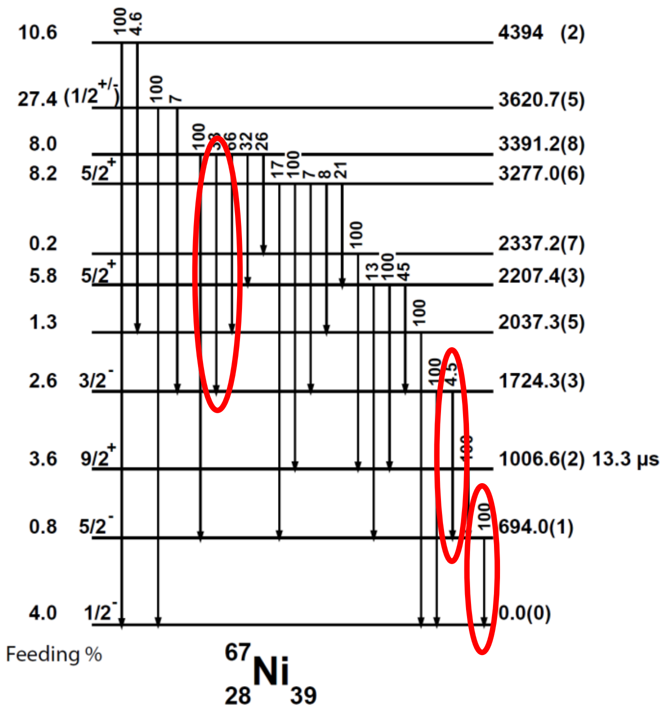
Increase in detection efficiency for γγ-coincidence:

AGATA	3.4 times more statistics than MB
AGATA + MINIBALL	5.0 times more statistics than MB

J. Diriken, et al.,Phys. Rev. C 91, 054321 (2015)

Detection sensitivity MB + AGATA





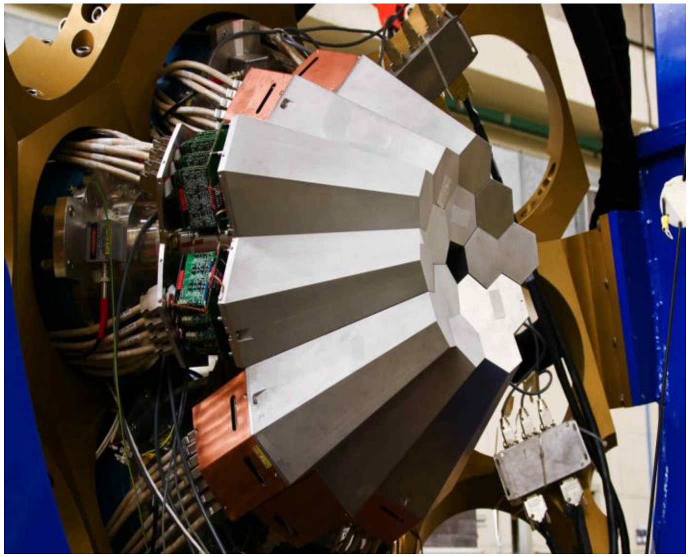
^{67}Ni: γ-ray cascade 1667 keV + 1030 keV + 694 keV

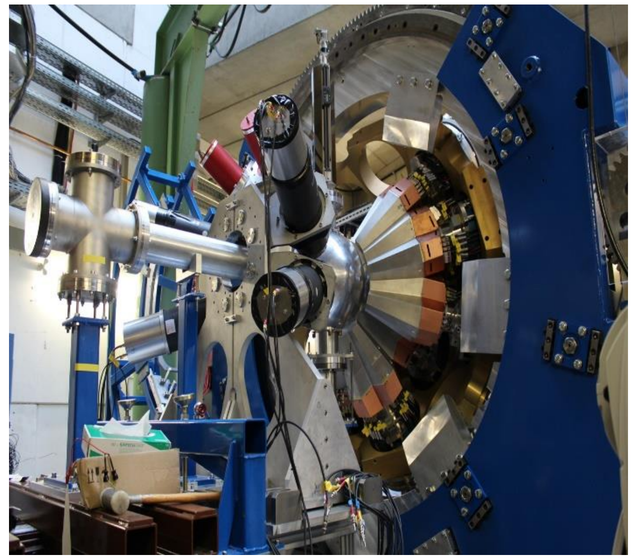
Increase in detection efficiency for 3γ-coincidences:

AGATA	3.9 times more statistics than MB
AGATA + MINIBALL	7.3 times more statistics than MB

J. Diriken, et al.,Phys. Rev. C 91, 054321 (2015)

AGATA campaigns





AGATA @ INFN Legnaro
2010-2011

AGATA @ GSI Darmstadt
2012-2014

AGATA @ GANIL (Caen)
2014-2020

stable beam → **RIB** → **stable beam**

RIB approx. 2018

Future AGATA campaigns

AGATA MoU

For the duration of this MoU the AGATA system is expected to be sited for at least 25% of its total operation time each at GANIL/SPIRAL2 (Caen, France), GSI/FAIR (Darmstadt, Germany), LNL/SPES (Legnaro, Italy).

The host collaborating institutions GANIL, GSI and LNL (hereinafter “Host” or “AGATA Host”) have agreed to host AGATA. AGATA will be an essential instrument for the future facilities FAIR, SPES and SPIRAL2.

Campaigns at any other host laboratory, in particular outside of the Collaborating Institutions, are subject to negotiations within the AGATA Steering Committee.

Letters received from potential future host labs

- GANIL now – 2020
- GANIL **SPIRAL2** period 2021-2025
- LNL **SPES** period 2023-2025
- JYFL period 2024-2026/27
- ISOLDE two possible time windows
  period 1 (May 2021 - November 2023) after LS2
  period 2 (May 2026 - November 2028) after LS3.
- **FAIR NUSTAR** period 2026/27

AGATA infrastructure at host lab

Basic infrastructure needed from the Host Laboratory to handle the AGATA array
Summary report
(November 25th, 2016)

AGATA collaboration will provide:

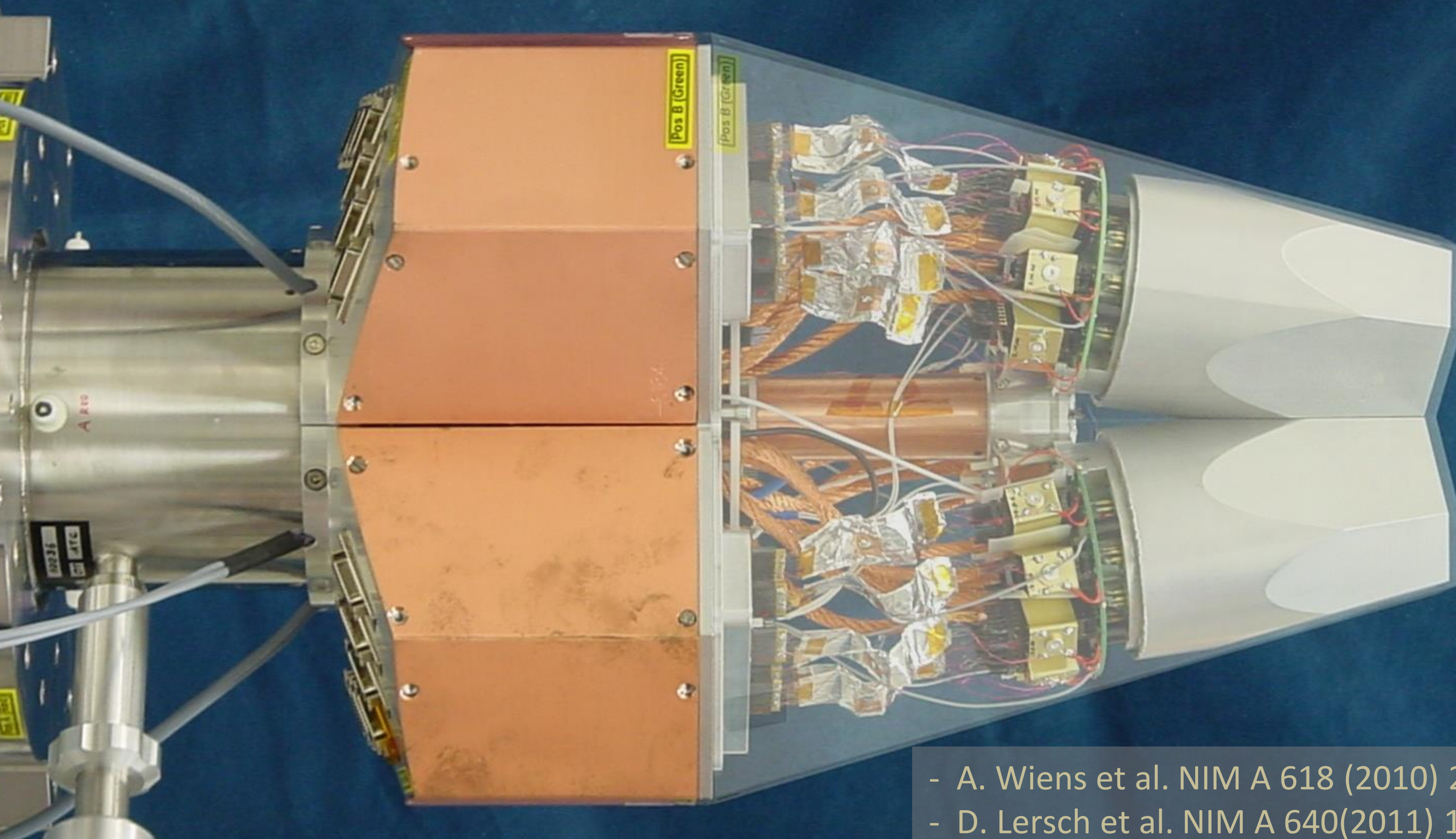
- triple cluster (TC) and double cluster detectors (DC), including all necessary mounting and operating tools (rings, spacers, LN_2 bayonets)
- detector holding structure
- LN_2 autofill control hardware and software
- low-voltage and high-voltage power supply systems
- cables required to operate the detectors
- digitizer cards and cool box, including the detector to digitizer cables
- pre-processing cards and their corresponding crates
- pulse shape analysis (PSA) units
- AGATA DAQ
- Optical connections except the links between the digitizer/AGAVA and the pre-processing units.

~ 16.700.000,- €

~20 AGATA Triple Cryostats

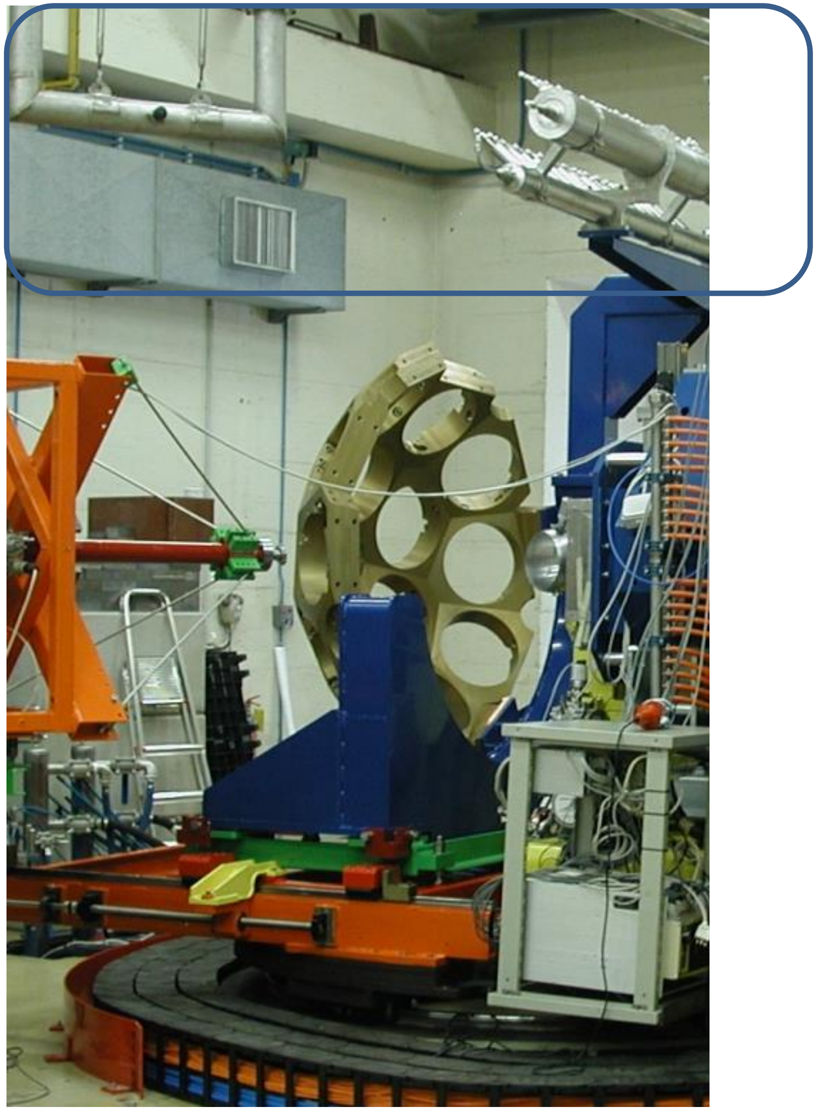
- integration of 111 high resolution spectroscopy channels
- cold FET technology for all signals

Challenges:
- mechanical precision
- LN2 consumption
- microphonics
- noise, high frequencies



- A. Wiens et al. NIM A 618 (2010) 223–233
- D. Lersch et al. NIM A 640(2011) 133-138

AGATA infrastructure at LNL

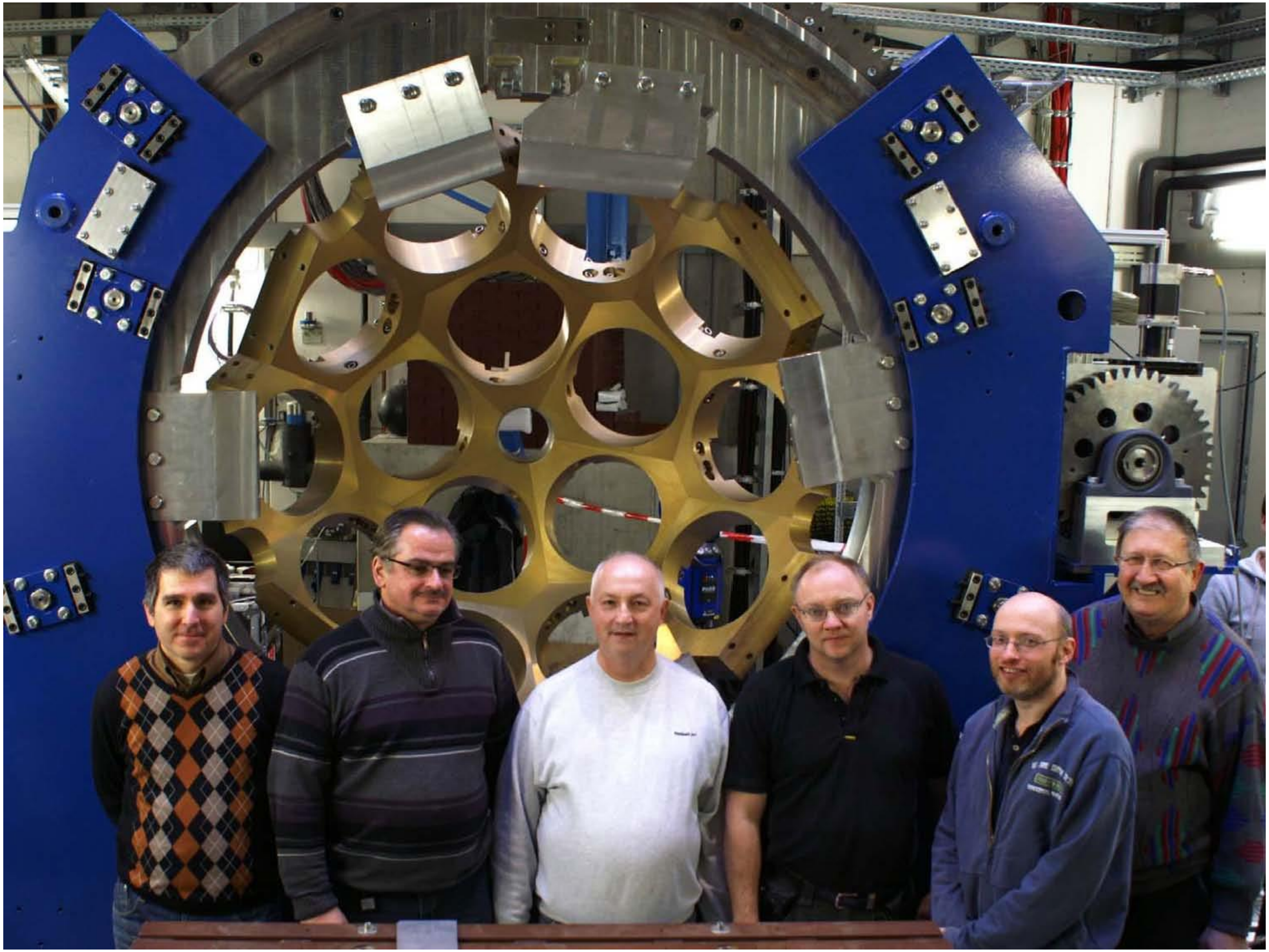


LN2 filling system
-> host lab

Holding structure
15 cluster detectors
-> AGATA

New holding structure
Design studies at STFC

AGATA holding structure at GSI



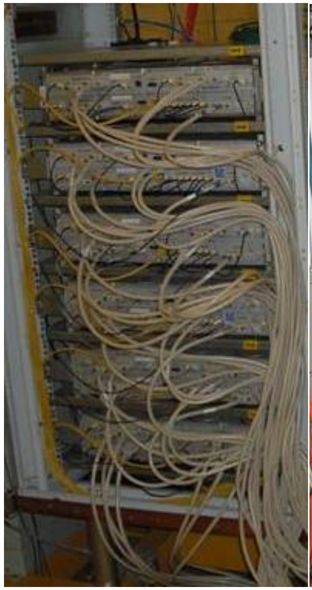
AGATA Digital Electronics

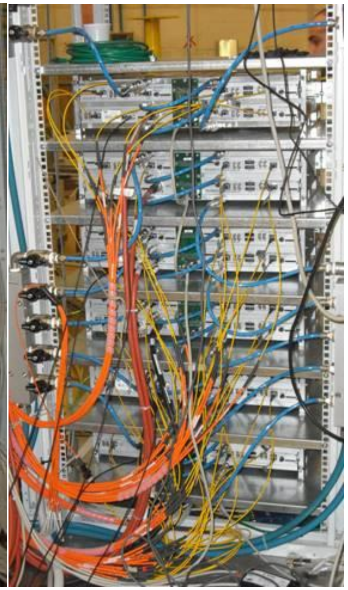
Digitisers
in the experimental hall

Digital proc. electronics
in the users area

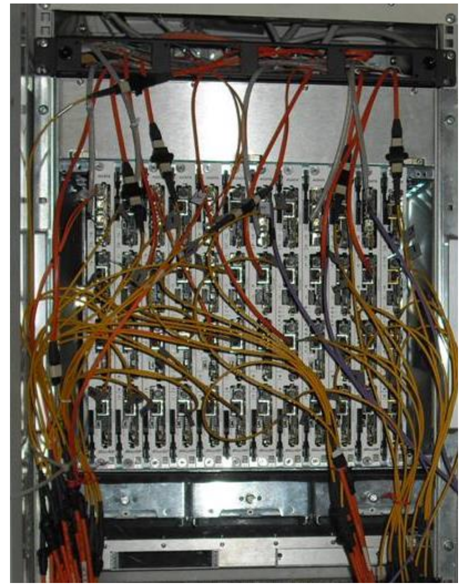
Computer farm
in the computing room

10 m long MDR cables

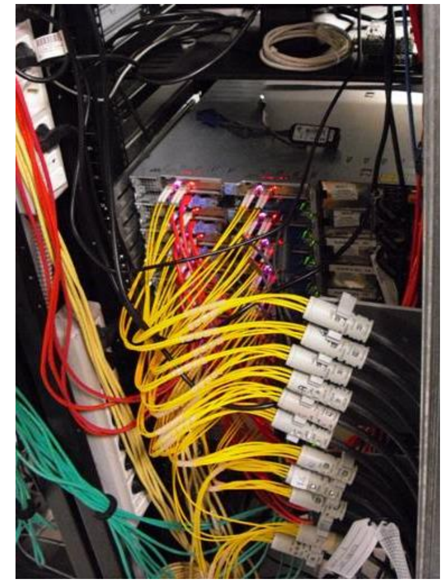




80 m long optical fibers



20 m long optical fibers



LAN to the disk servers

100Mhz, 14 bit
Synchronous &
continuous

→ (7.6GB/s/crystal)

Triggering
Energy
Trace capture

→ (10 kB/evt/crystal)

Preprocessing
PSA
Tracking

Global
Triggering
System

GTS

Clock &
Trigger validation

AGATA DAQ computing

Disc array

Disc array back

DAQ servers

AGATA infrastructure at host lab

Basic infrastructure needed from the Host Laboratory to handle the AGATA array
Summary report

Host lab contribution for 60 capsule AGATA array:

Floor Space & room

- Array + FE electronics area (experimental hall)
- Pre-processing electronics area
- DAQ area
- Control room
- Detector Laboratory and Repository area

Infrastructure:

- Mechanics for array and FEE in experimental hall:
  - equipped Beam-line
  - cable trails
  - water cooling system
  - Optical links (length in use 60 m, maximum length 100 m).
- HPGe detector LN_2 cooling infrastructure:
  - buffer tanks, LN_2 transport system, manifold, valves, temperature sensors, dialer, LN_2 supply

AGATA infrastructure at host lab

Services

- Water cooling
- Air conditioning
- Detector laboratory equipment

Man power

- surveyor measurements
- mechanics maintenance
- alignment + mounting/dismounting HPGe detectors
- LN_2 system maintenance (with support from the collaboration),
- global survey of the array and LN_2 filling procedure on a 24/7 basis,
- Technical support:
  - General experiment support (mechanics, infrastructure, detectors, optical link and cable installation)
  - electronics and DAQ: local specialised personnel on a 24/7 basis during data taking.
  - first-level technical assistance to the experimental group, on a day-to-day basis, in collaboration with the AGATA experts
  - detector laboratory.

Summary

- Appealing physics case and unique opportunities
- Combination of HIE-ISOLDE & AGATA is feasible
- Best conditions for in-beam γ-ray spectroscopy
- Efficiency and high detection sensitivity
  - reduced Doppler broadening
  - efficiency at higher energies and higher multiplicity events
- Considerable effort from AGATA collaboration and ISOLDE collaboration! To be continued?

People and Institutions

Nuclear Instruments and Methods in Physics Research A 668 (2012) 26–58

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AGATA—Advanced GAmma Tracking Array

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A B S T R A C T

The Advanced GAmma Tracking Array (AGATA) is a European project to develop and operate the next generation γ-ray spectrometer. AGATA is based on the technique of γ-ray energy tracking in electrically segmented high-purity germanium crystals. This technique requires the accurate determination of the energy, time and position of every interaction as a γ ray deposits its energy within the detector volume. Reconstruction of the full interaction path results in a detector with very high efficiency and excellent spectral response. The realisation of γ-ray tracking and AGATA is a result of many technical advances. These include the development of encapsulated highly segmented germanium detectors assembled in a triple cluster detector cryostat, an electronics system with fast digital sampling and a data acquisition system to process the data at a high rate. The full characterisation of the crystals was measured and compared with detector-response simulations. This enabled pulse-shape analysis algorithms, to extract

AGATA infrastructure at host lab

Basic infrastructure needed from the Host Laboratory to handle the AGATA array
Summary report
(November 25th, 2016)

AGATA infrastructure for installation and maintenance:

- mechanics
- electronics and the associated cooling system
- high-voltage power supply (HV) and its control system
- preamplifier power supply
- uninterruptible power supply (UPS)
- Ge cooling (LN_2 autofill system)
- detector laboratory

Space in the experimental, the pre-processing and the acquisition areas

Manpower for maintenance and assistance to experiment

Configuration is an array of 60 HPGe crystals in 20 AGATA Triple Clusters (ATC),
as given in the AGATA Memorandum of Understanding (MoU).

AGATA management board

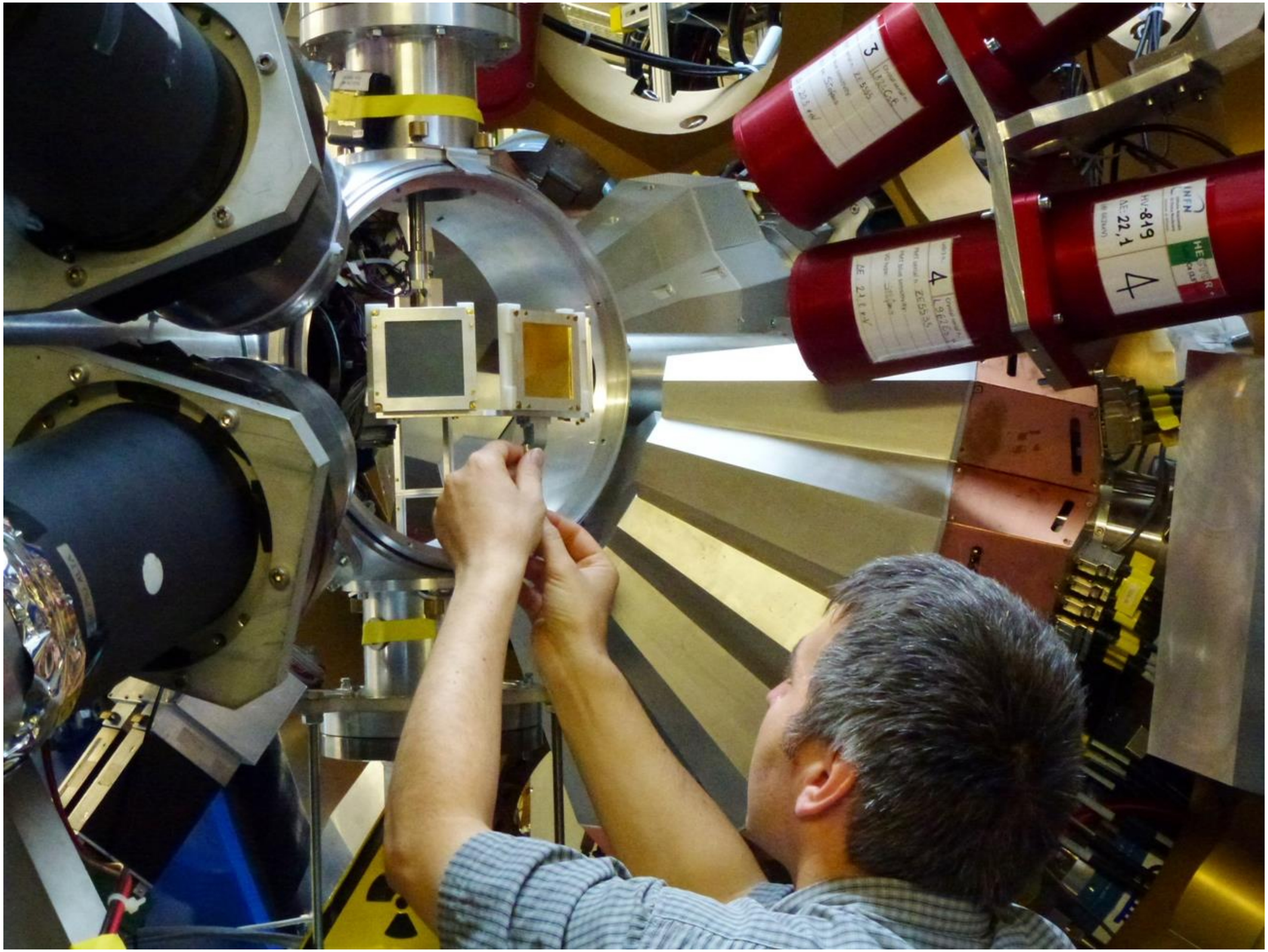
A. Gadea (Project Manager)
A.Boston, B. Million, A. Korichi, F. Recchia, P. Reiter (ASC) and W. Korten (ACC).
J. Gerl (LCM-GSI), E. Clement (LCM-GANIL)

	AGATA Working Groups	AGATA Teams			
	Detector Module P. Reiter	Detector & Cryostat H.Hess	Detector Characterisation H.Hess	Detector CAT &Testing H. Boston	R & D on gamma Detectors & Applications
AMB Chairman Project Manager A.Gadea	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 A.Boston	Data Analysis & TRACKING O. Stezowski A. Lopez-Martens	PSA Algorithm Development L. J. Harkness	GRID Data managing and Analysis	
Resource Manager	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	

Local Campaign Managers (LCM)

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

AGATA & HECTOR at GSI



AGATA steering committee

D. Tonev (Bulgaria) P. Greenlees (Finland)

G. Duchêne (chair) and W. Korten (France)

J. Gerl and P. Reiter (vice-chair) (Germany)

n.n. (Hungary)

A.Bracco and G. De Angelis (Italy)

P. Bednarczyk (Poland) B.Quintana (Spain)

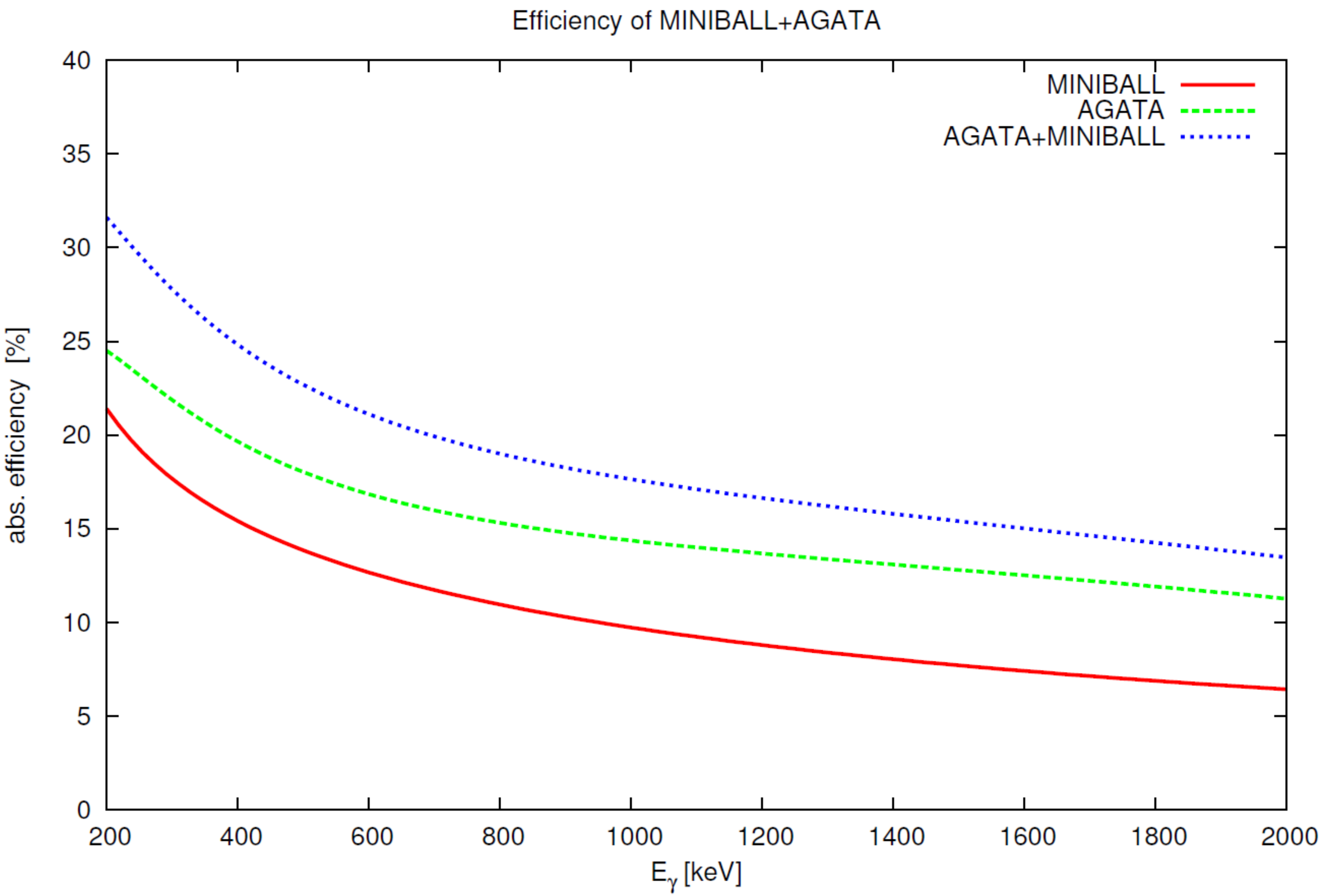
B. Cederwall (Sweden) A. Atac (Turkey)

P. Nolan and J. Simpson (UK)

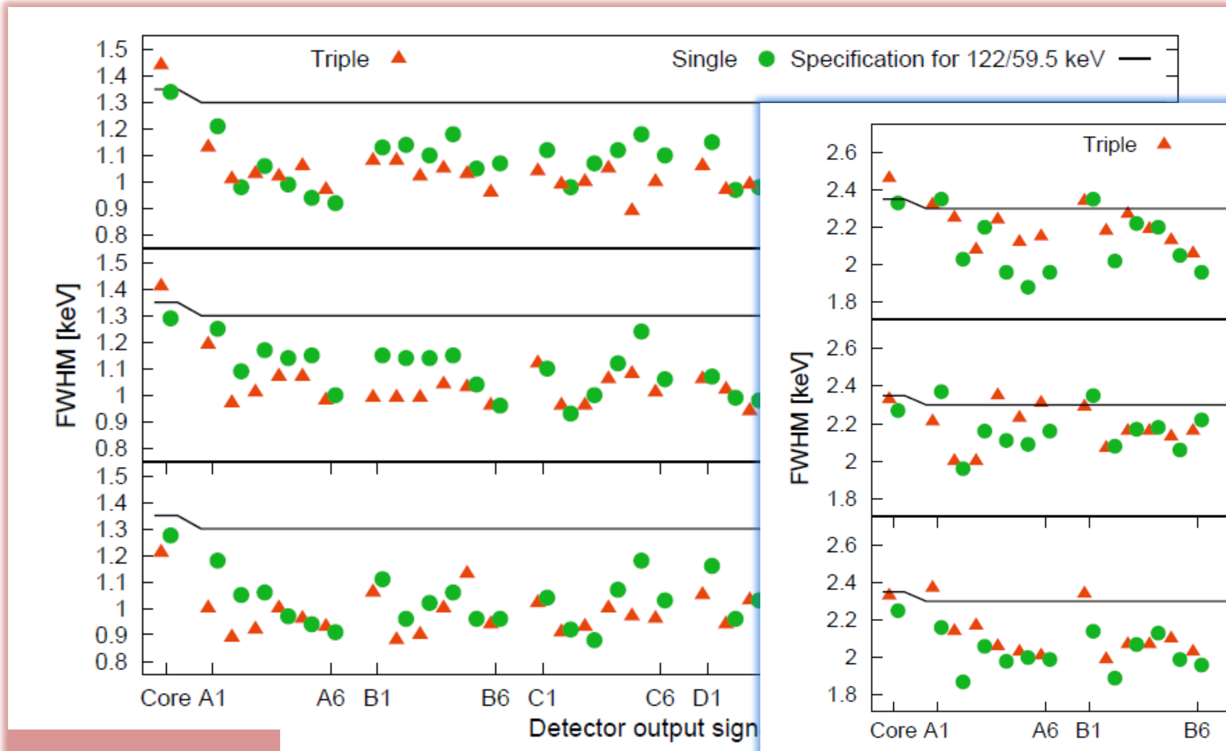
A.Gadea (PM and AMB chair)

W. Korten (ACC chair)

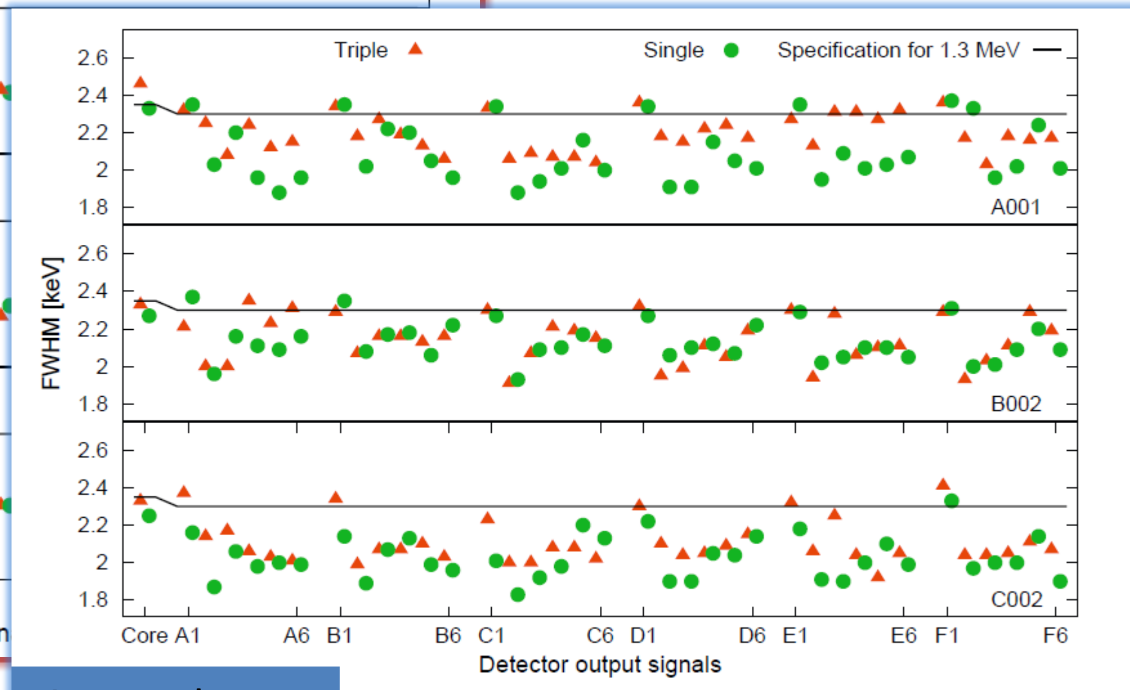
Detection Efficiency



Performance: Energy resolution



@ 60 keV



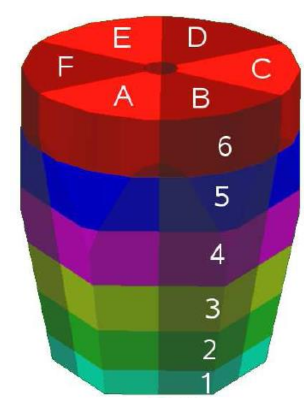
@ 1333 keV

Averages of the segment resolutions
@ **60 keV :**

A001:	1011 +/- 53 eV
B002:	1039 +/- 70 eV
C002:	965 +/- 63 eV

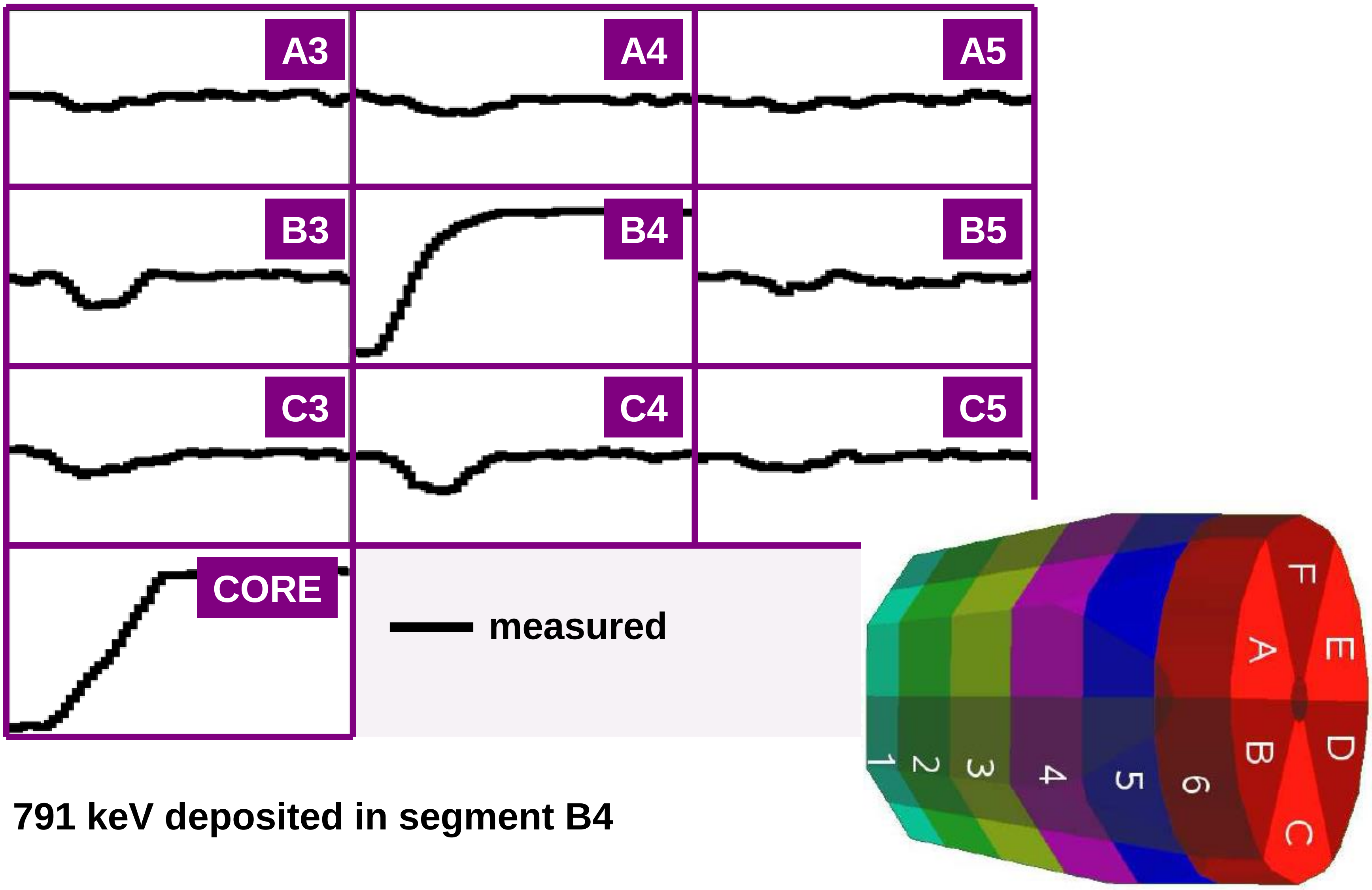
Averages of the segment resolutions
Measured in Köln and Legnaro
@ 1333 keV :

	IKP	/	Legnaro
A001:	2,19 keV	/	2,00 keV
B002:	2,09 keV	/	1,98 keV
C002:	2,1 keV	/	1,94 keV



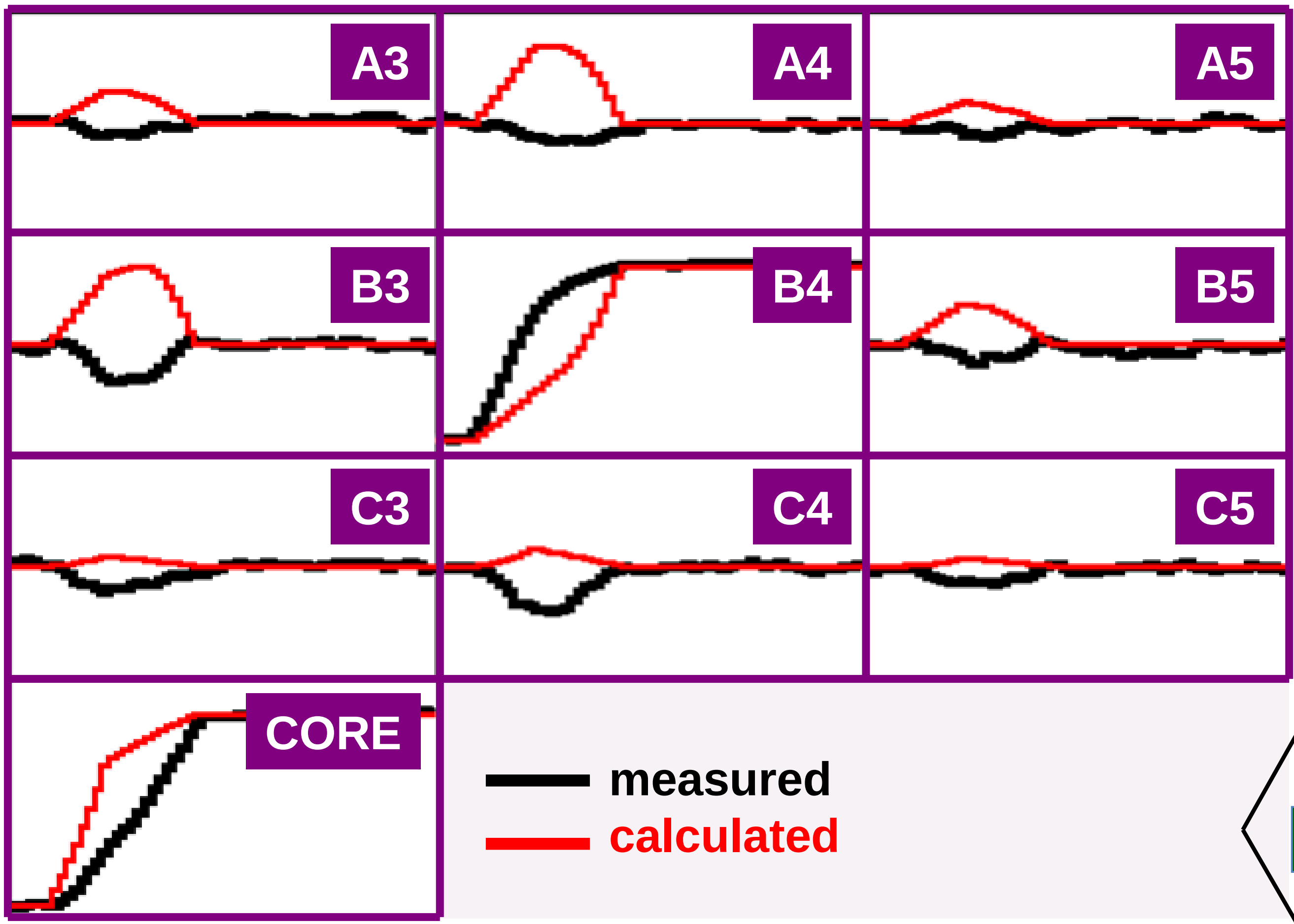
Segment labeling

Pulse Shape Analysis concept

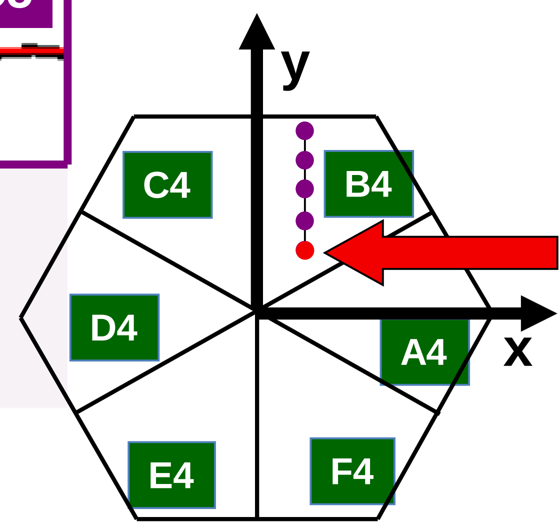


791 keV deposited in segment B4

Pulse Shape Analysis concept



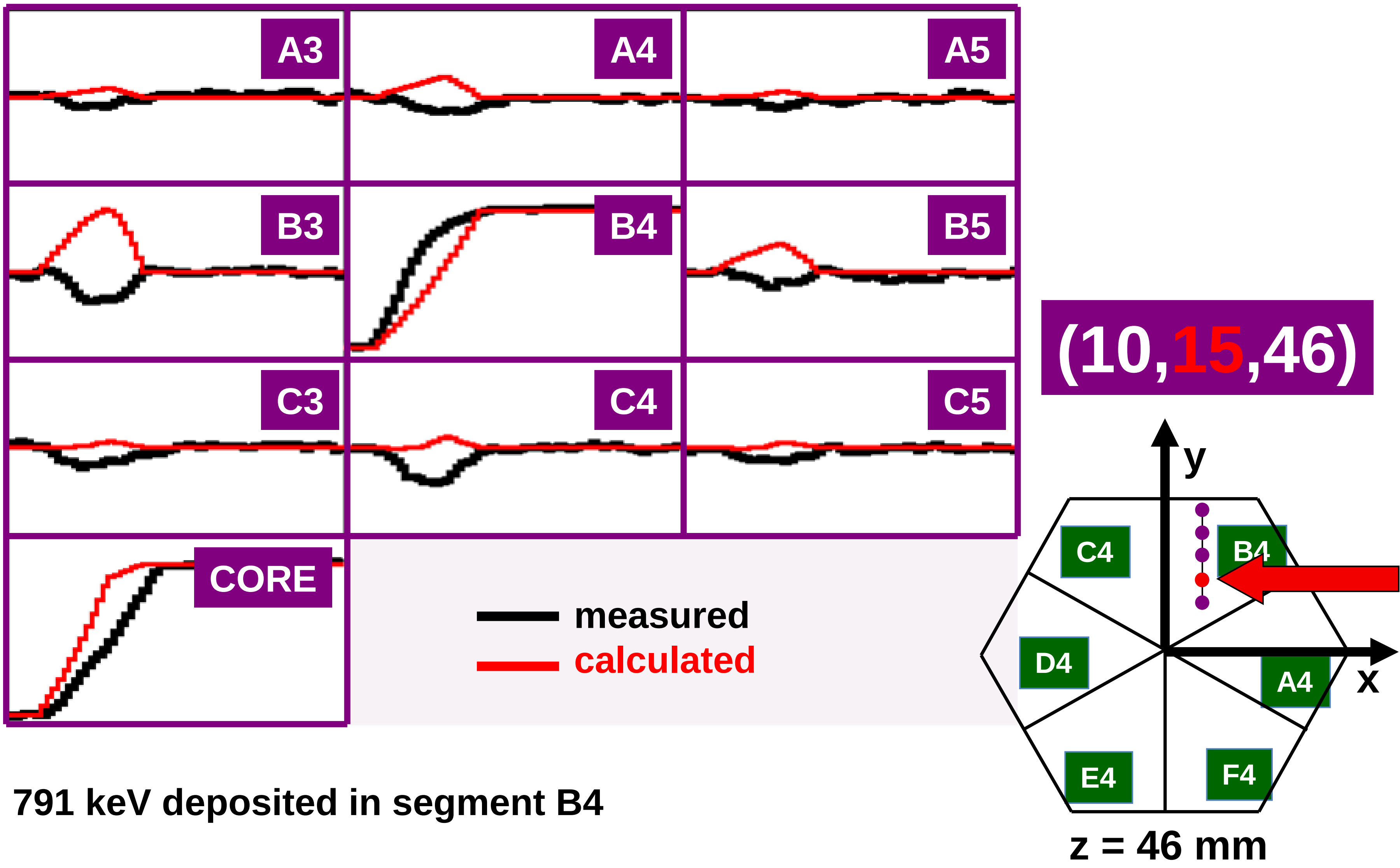
(10,10,46)



z = 46 mm

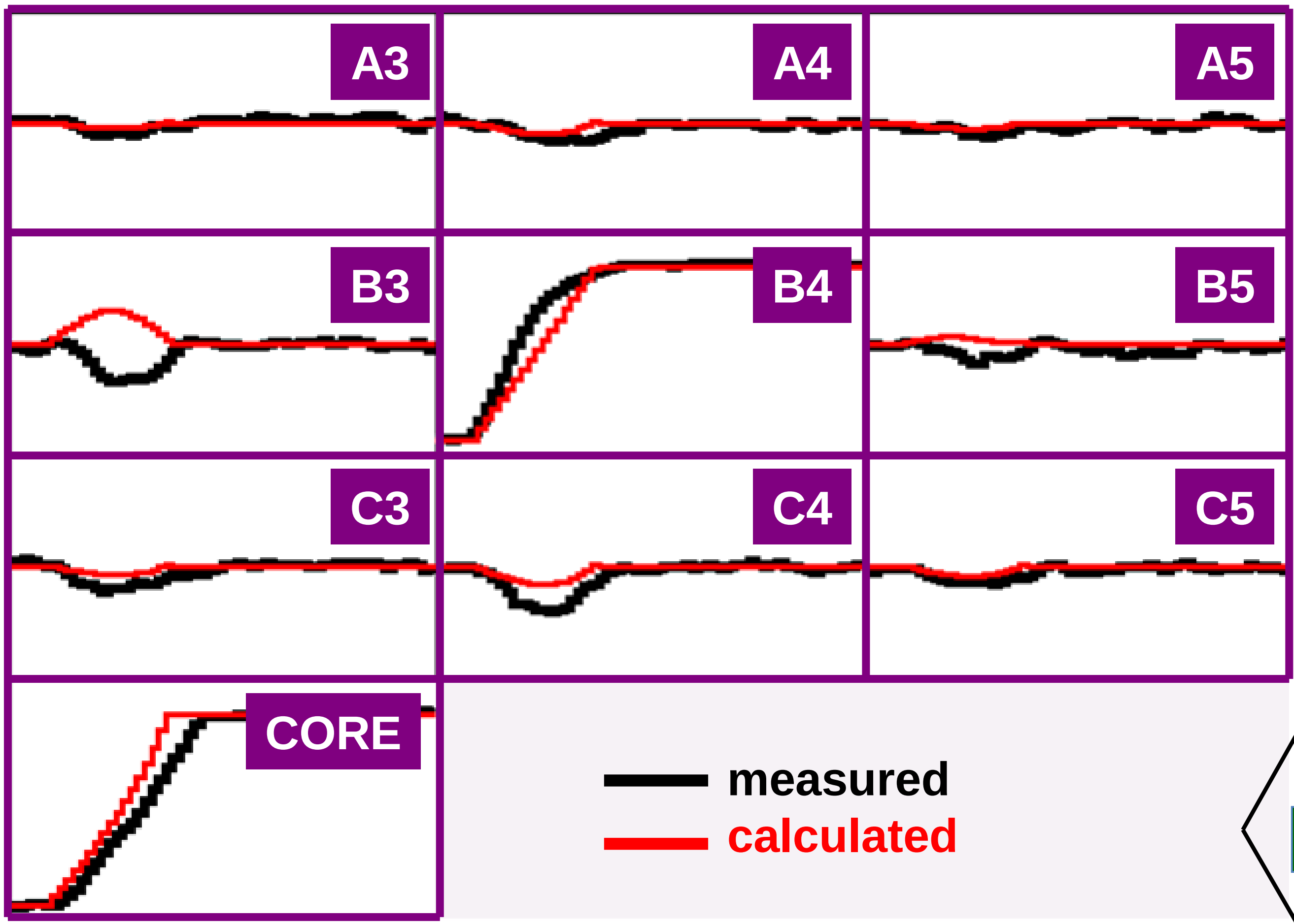
791 keV deposited in segment B4

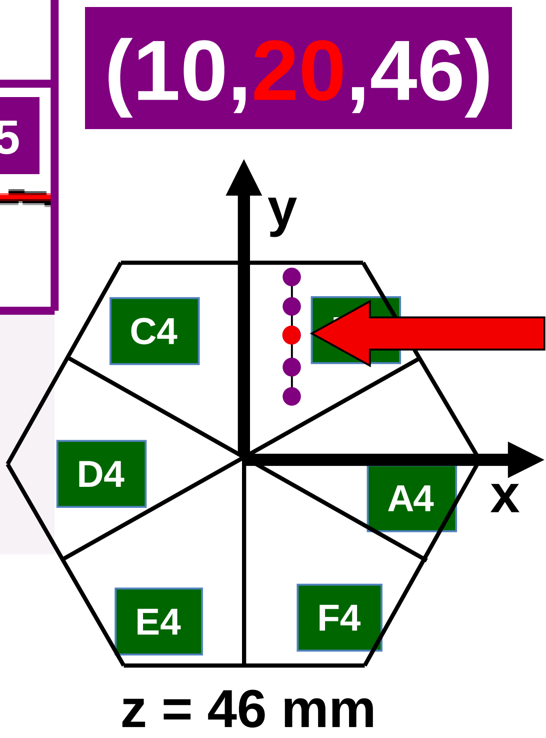
Pulse Shape Analysis concept



791 keV deposited in segment B4

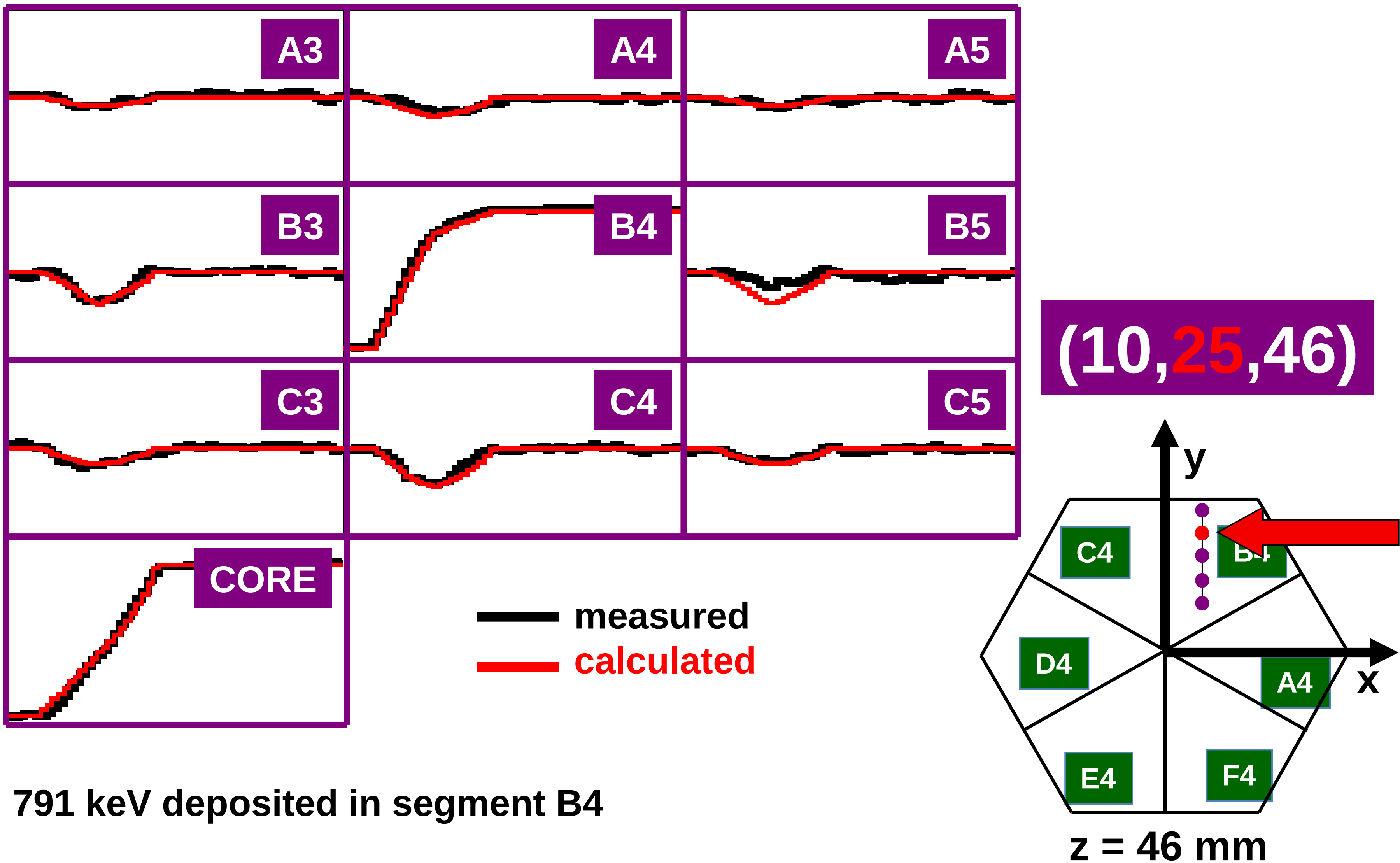
Pulse Shape Analysis concept





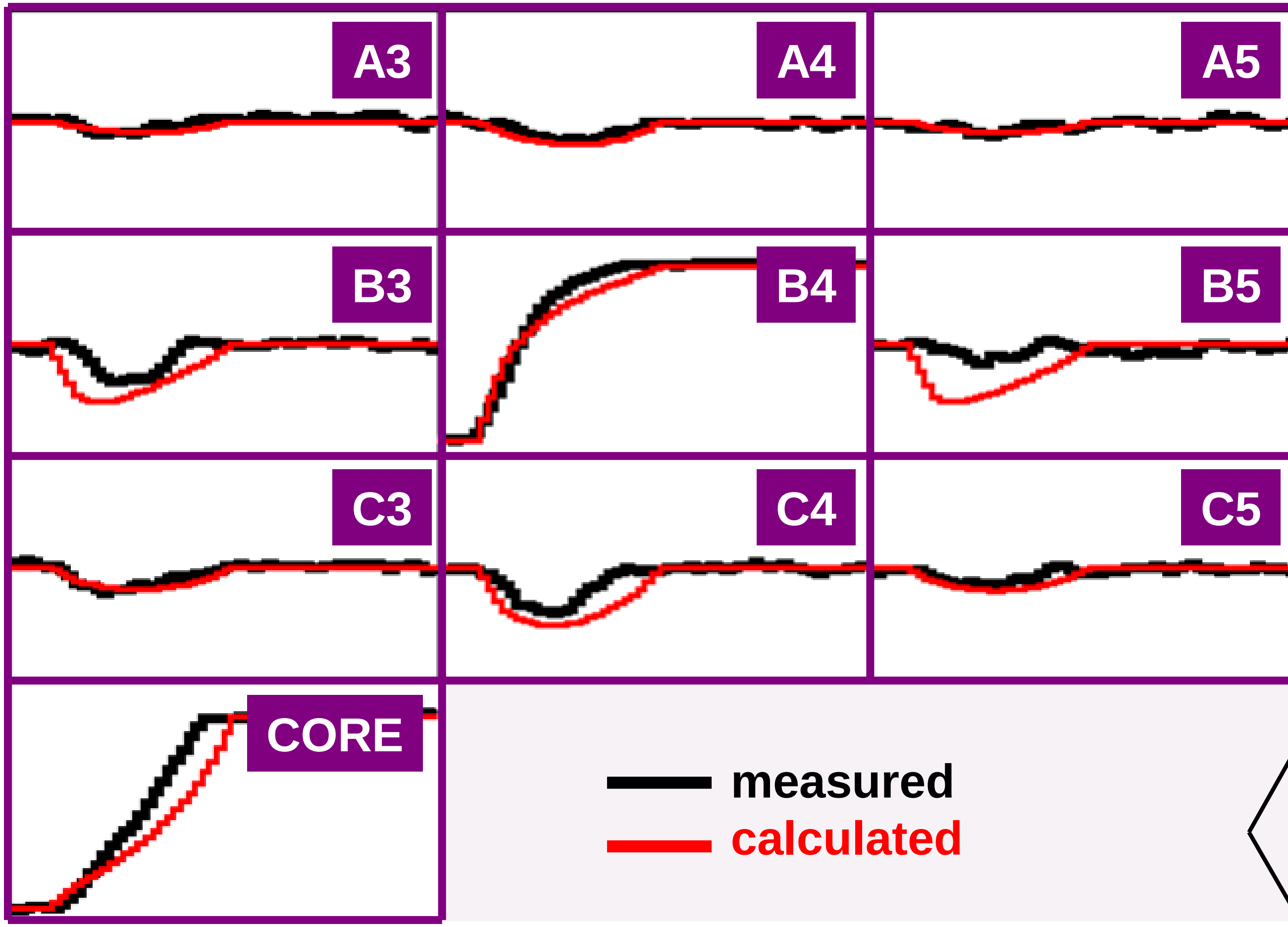
791 keV deposited in segment B4

Pulse Shape Analysis concept



791 keV deposited in segment B4

Pulse Shape Analysis concept



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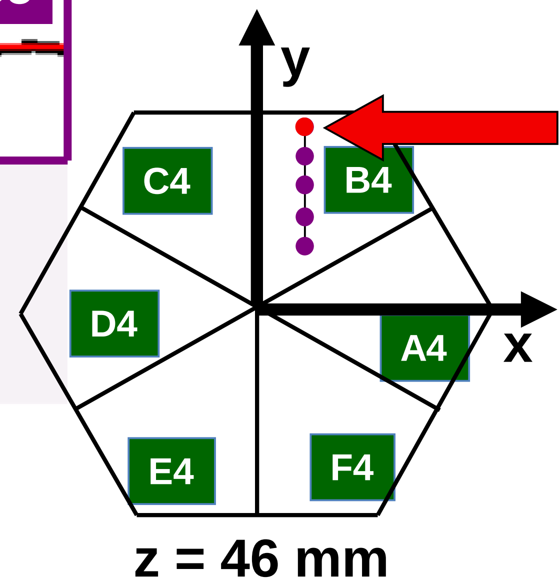
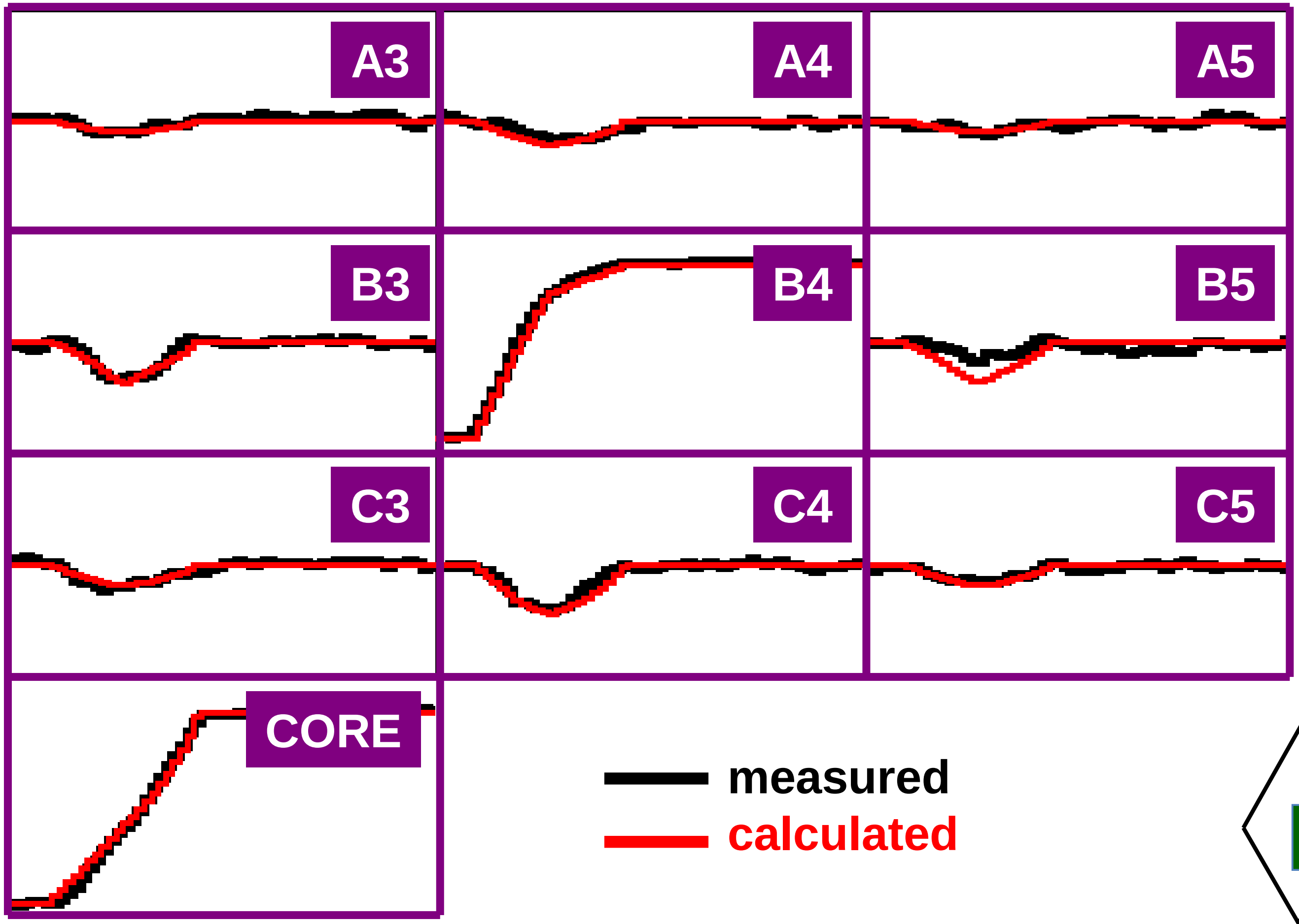


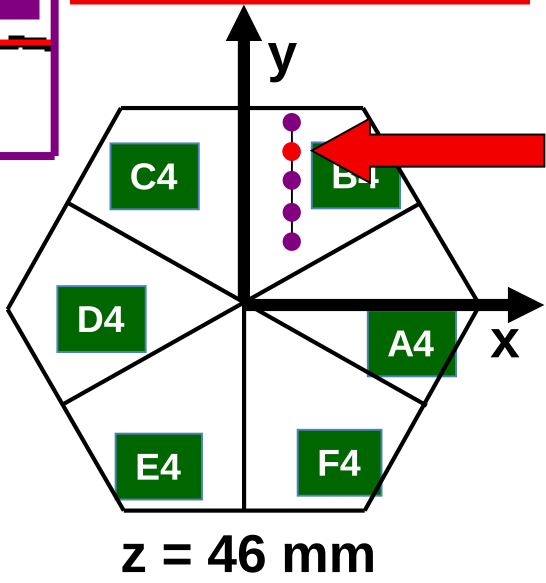
791 keV deposited in segment B4

Pulse Shape Analysis concept



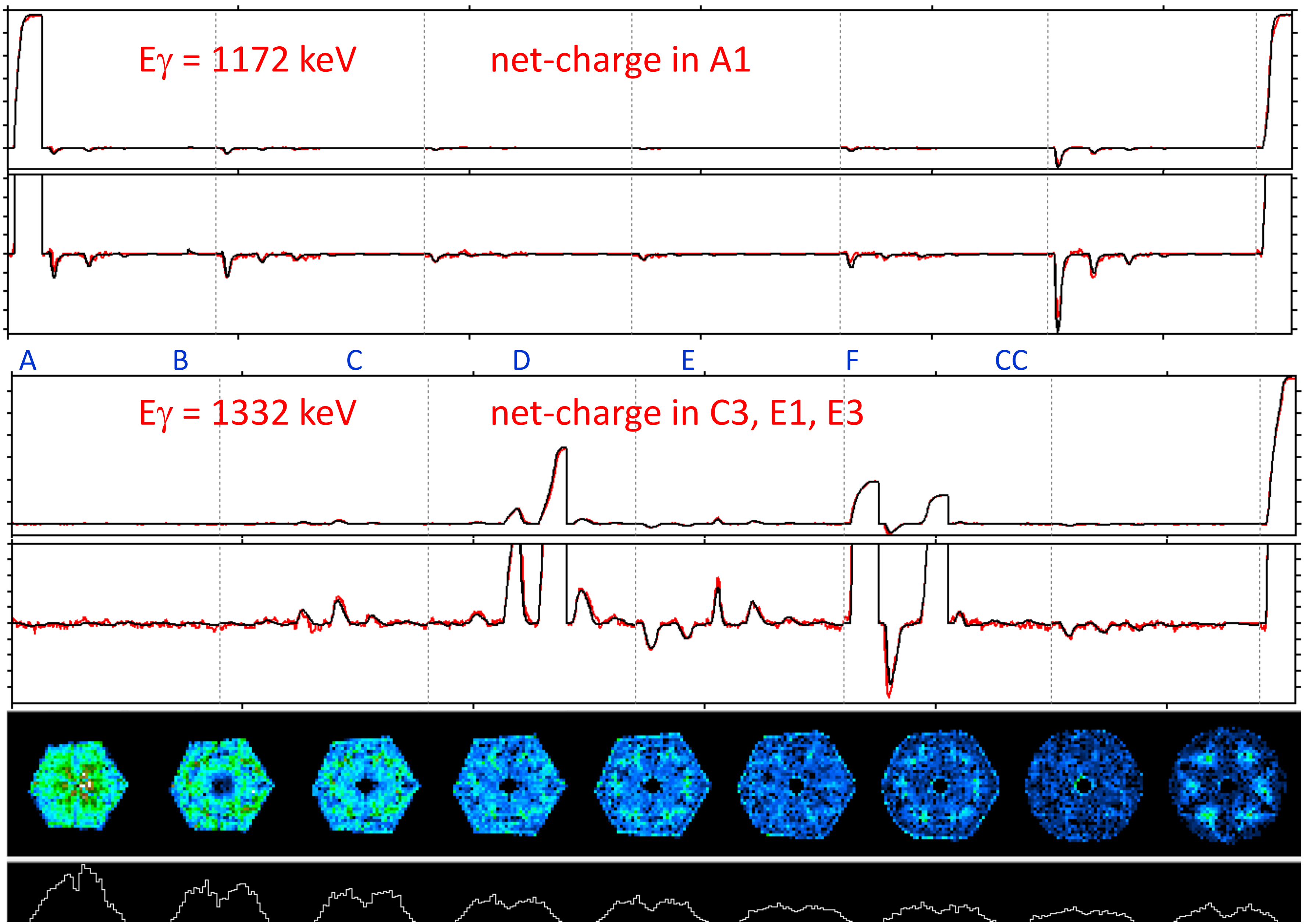
Result of *Grid Search* Algorithm

(10,25,46)



791 keV deposited in segment B4

AGATA signal decomposition

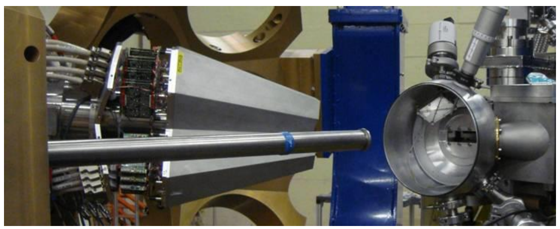


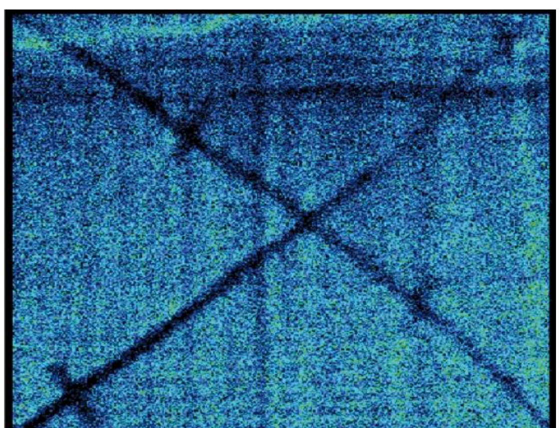
AGATA position resolution

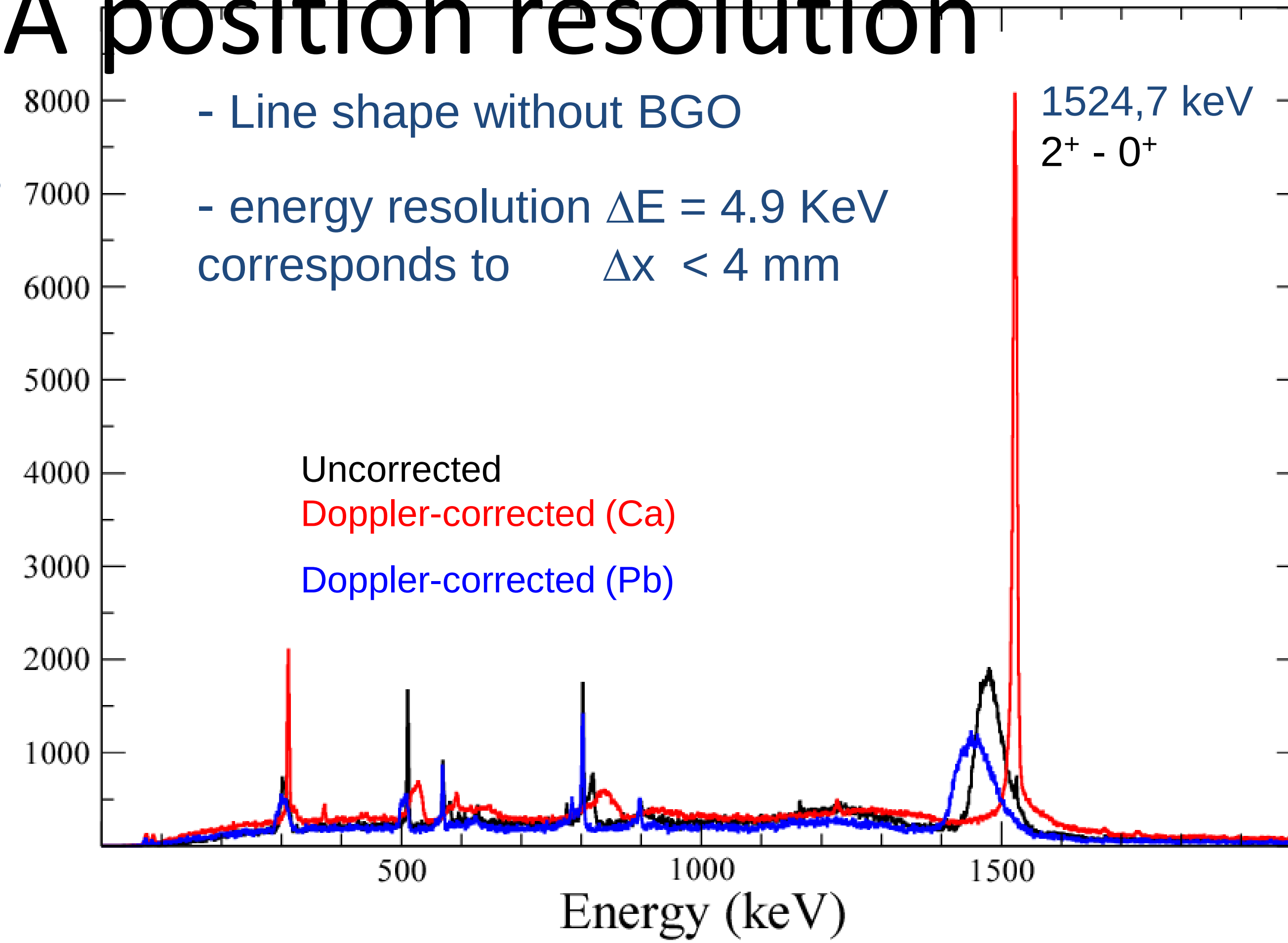
^{42}Ca@170MeV + ^{208}Pb

Kinematical coincidences

Position sensitive MCP







AGATA position resolution

Δx FWHM	Method	
5.2 mm	Doppler corr. meas.	F. Recchia et al. NIM A (2009)
4.0 mm	Doppler corr. meas	P.-A. Söderström et al. NIM A (2011)
3.5 mm	511keV source meas.	S. Klupp, M.Schlarb, R. Gernhäuser