Espectroscopía de rayos γ por reconstrucción de la trayectoria de los fotones: AGATA, the advanced γ-ray tracking array

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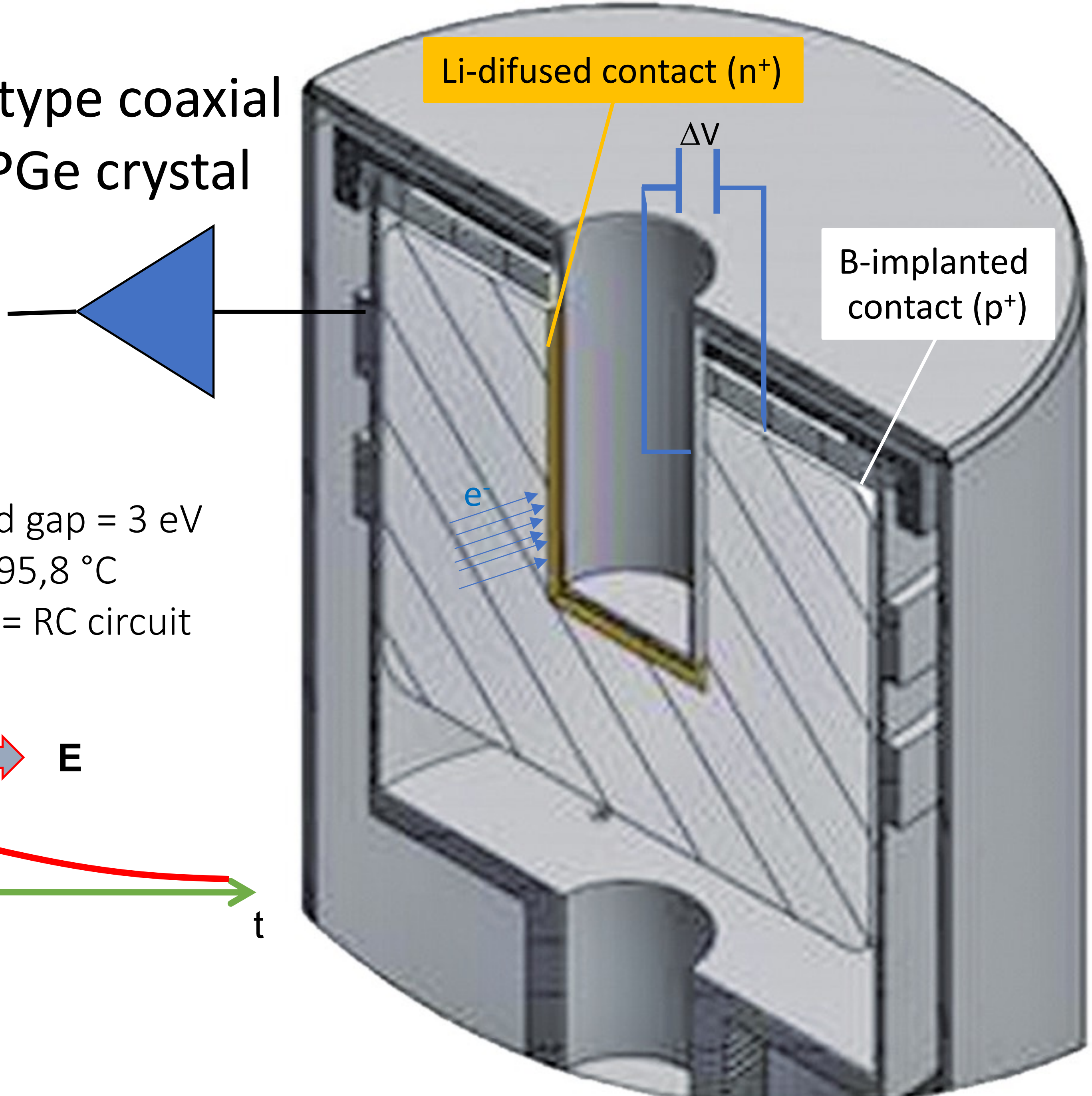
What will this talk be about?

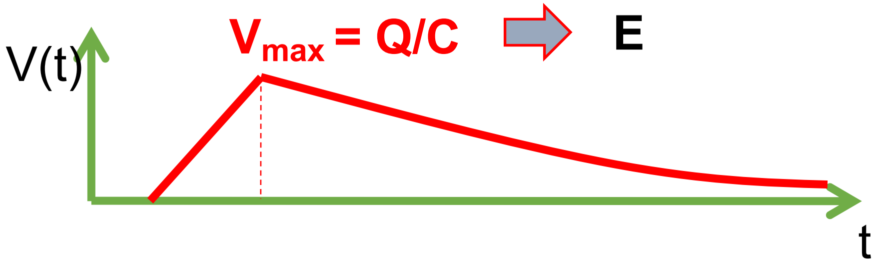
High resolution γ-ray spectroscopy with highly-segmented HPGe detectors

The before....

n-type coaxial HPGe crystal



Ge semiconductors band gap = 3 eV
Working T = T(LN_2) = -195,8 °C
Detector + preamplifier = RC circuit

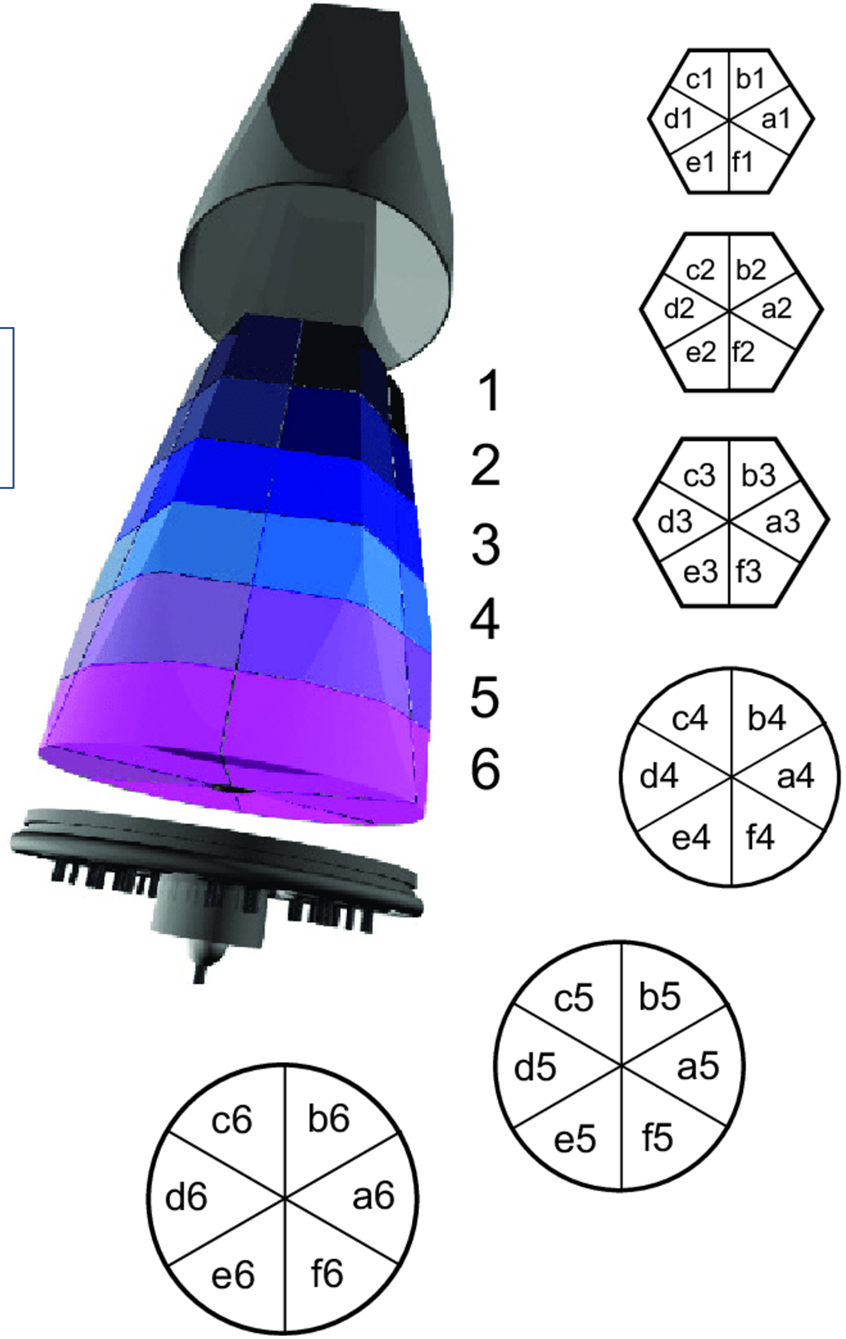


and now…

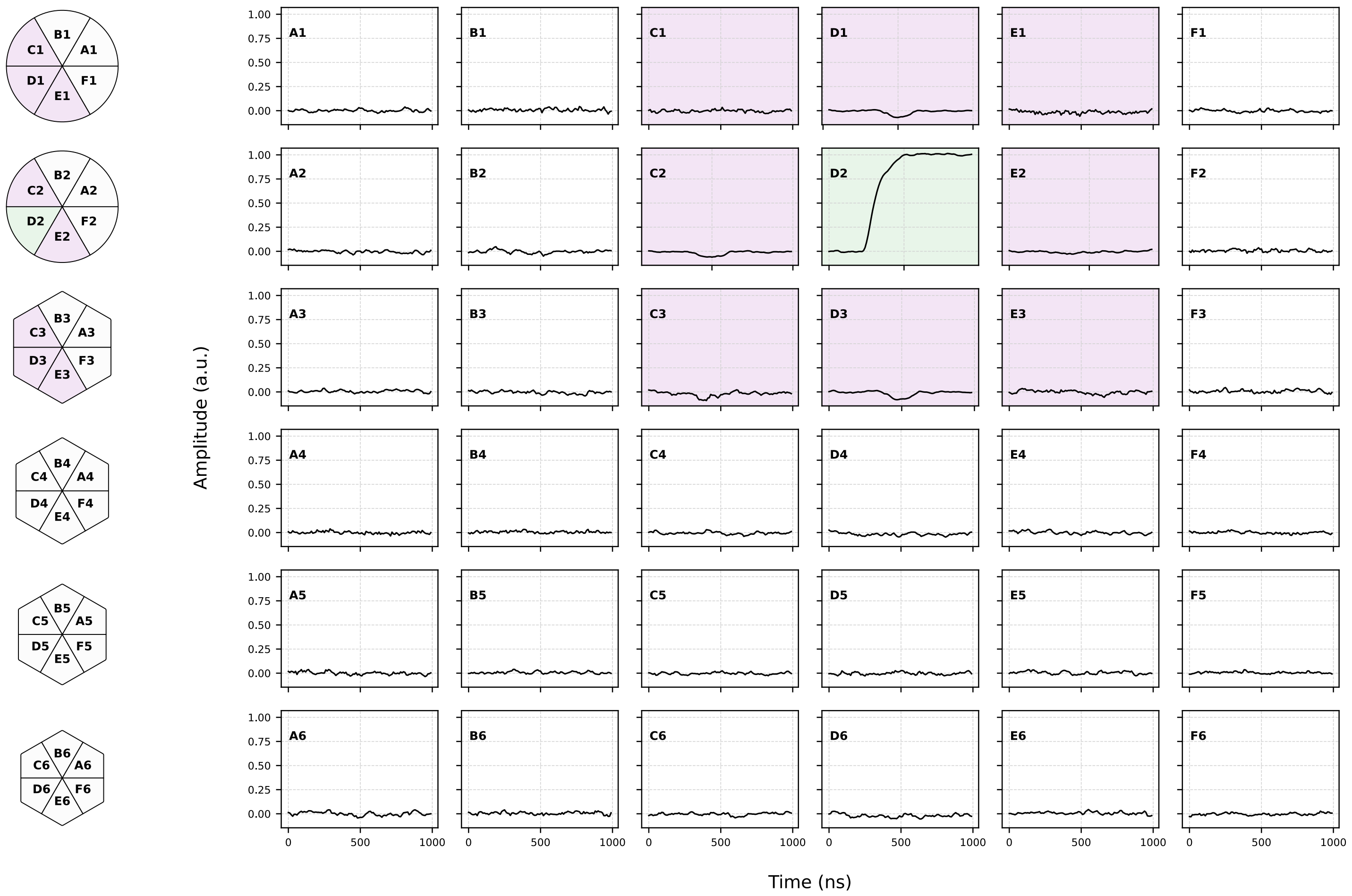
With n-type HPGe crystals with highly-segmented B contact

Not only E, but also (r,θ,z)

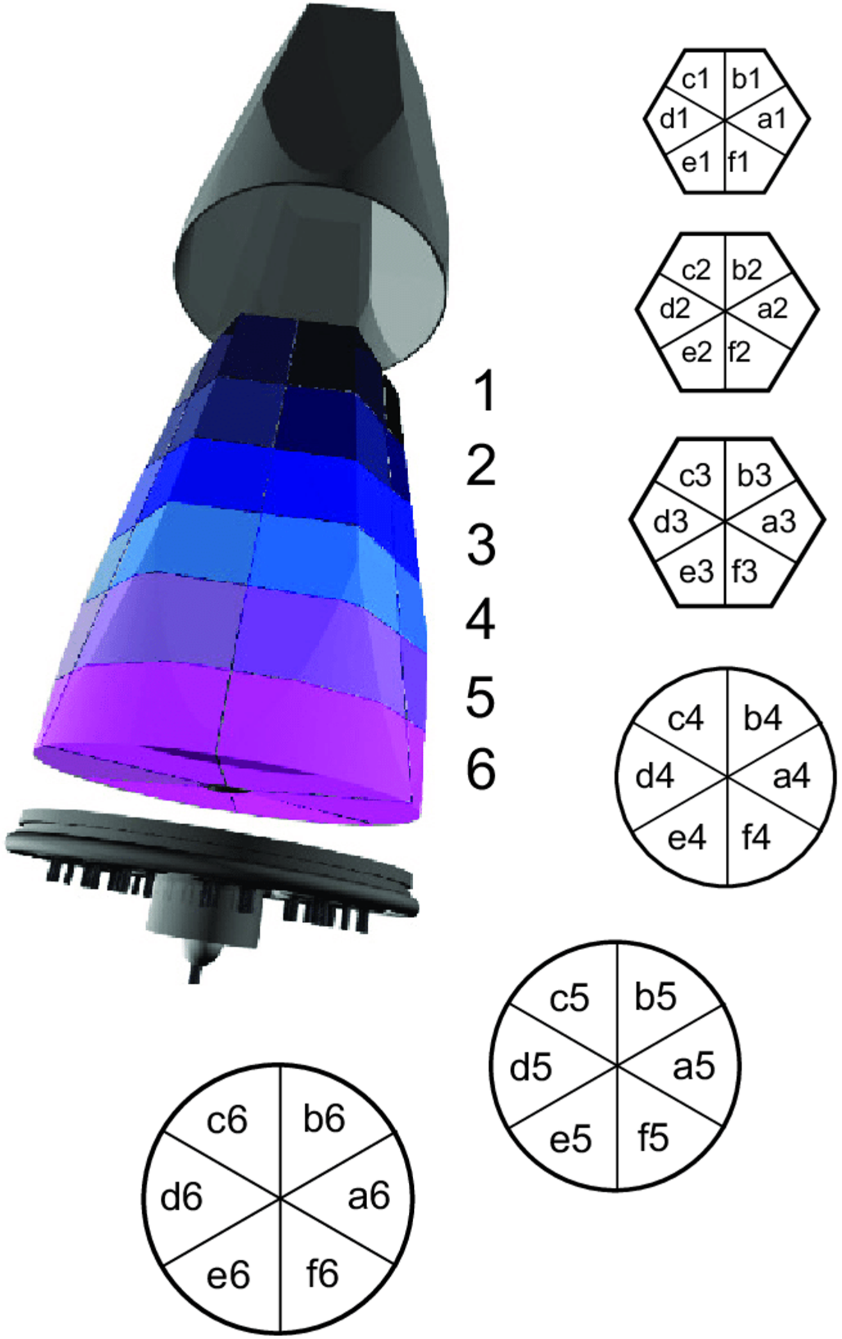
Position-sensitive HPGe detectors



How can it be?



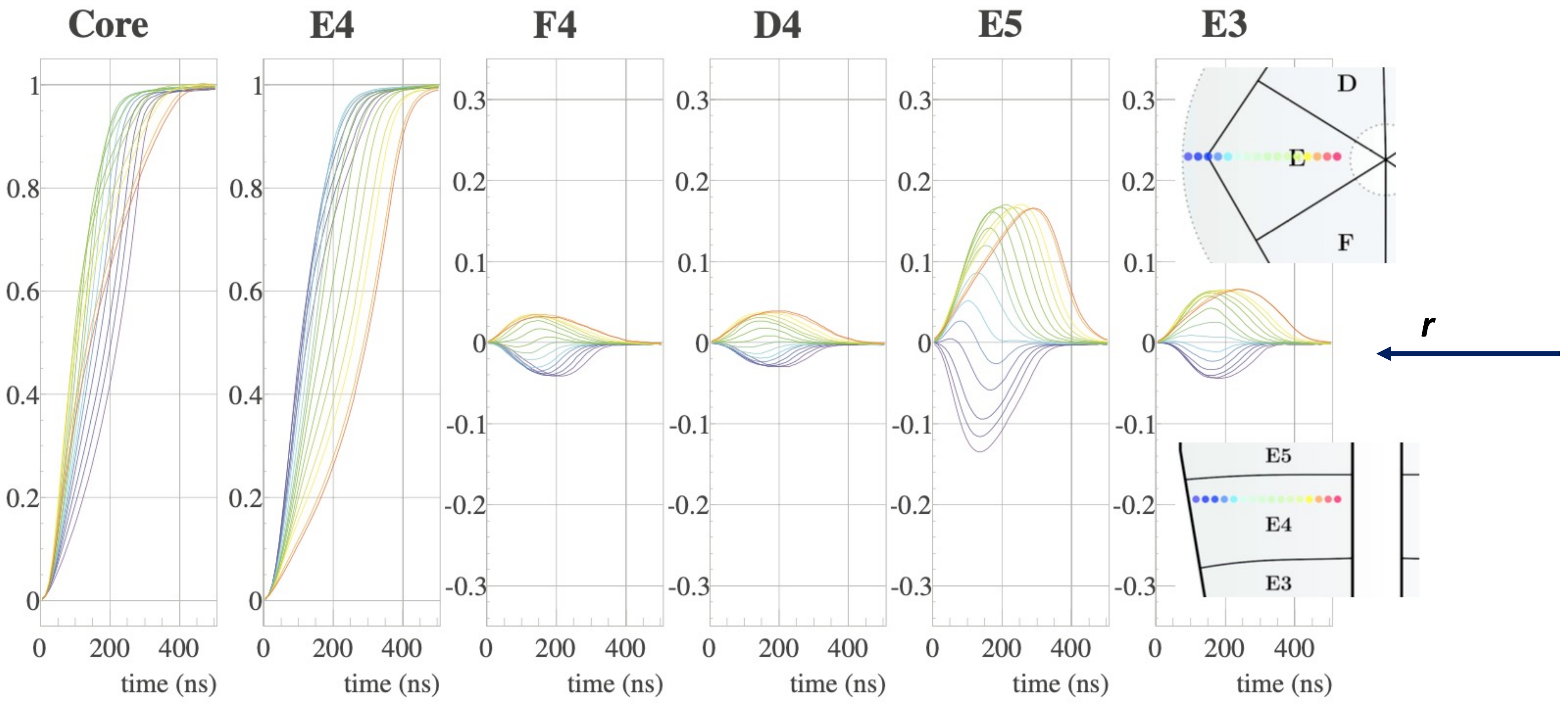
B1
A1
C1
D1
F1
E1
B2
C2
A2
D2
F2
E2
B3
C3
A3
D3
F3
E3
B4
C4
A4
D4
F4
E4
B5
C5
A5
D5
F5
E5
B6
C6
A6
D6
F6
E6
Amplitude (a.u.)
Time (ns)



1
2
3
4
5
6
c1 b1 d1 a1 e1 f1
c2 b2 d2 a2 e2 f2
c3 b3 d3 a3 e3 f3
c4 b4 d4 a4 e4 f4
c5 b5 d5 a5 e5 f5
c6 b6 d6 a6 e6 f6

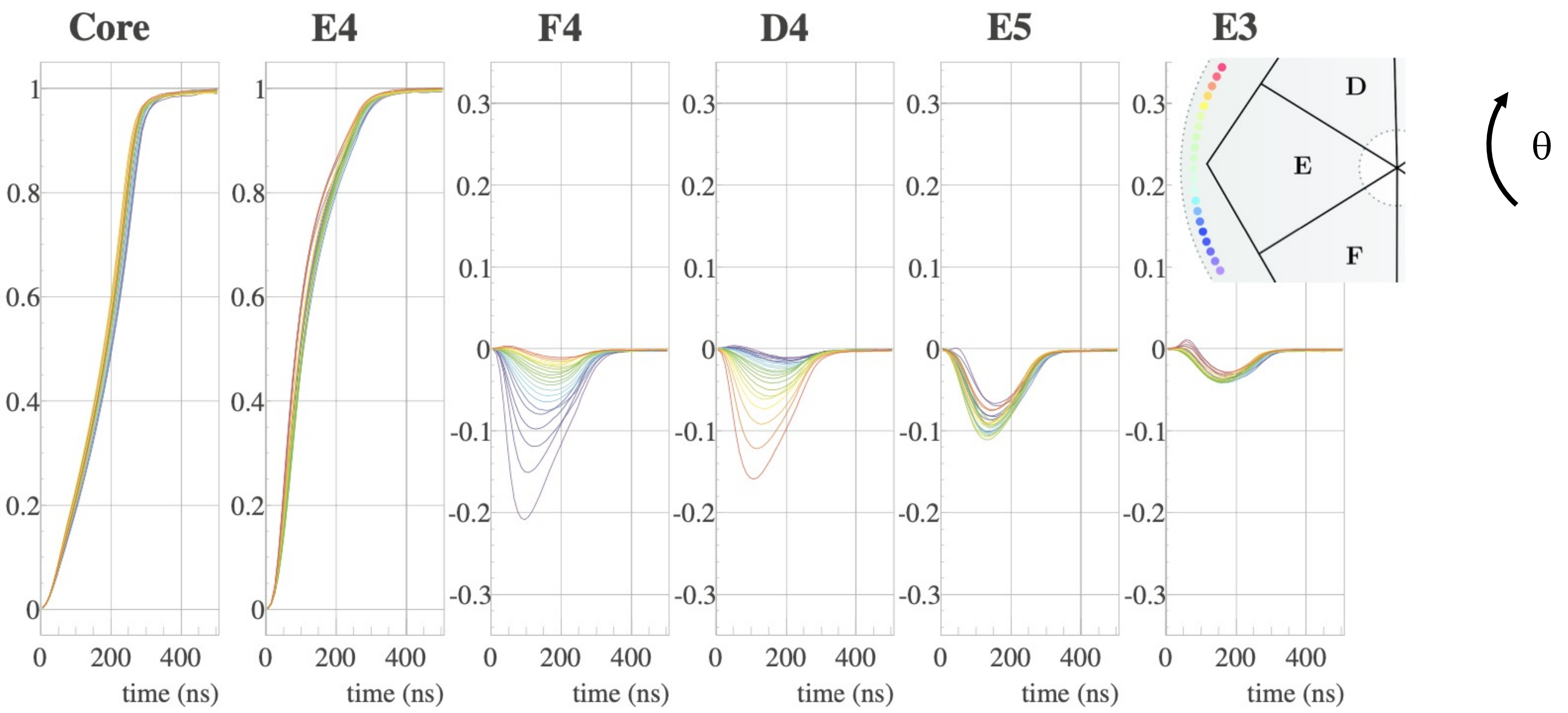
Position sensitive HPGe detectors…

Net signal shape provides the coordinate ***r***



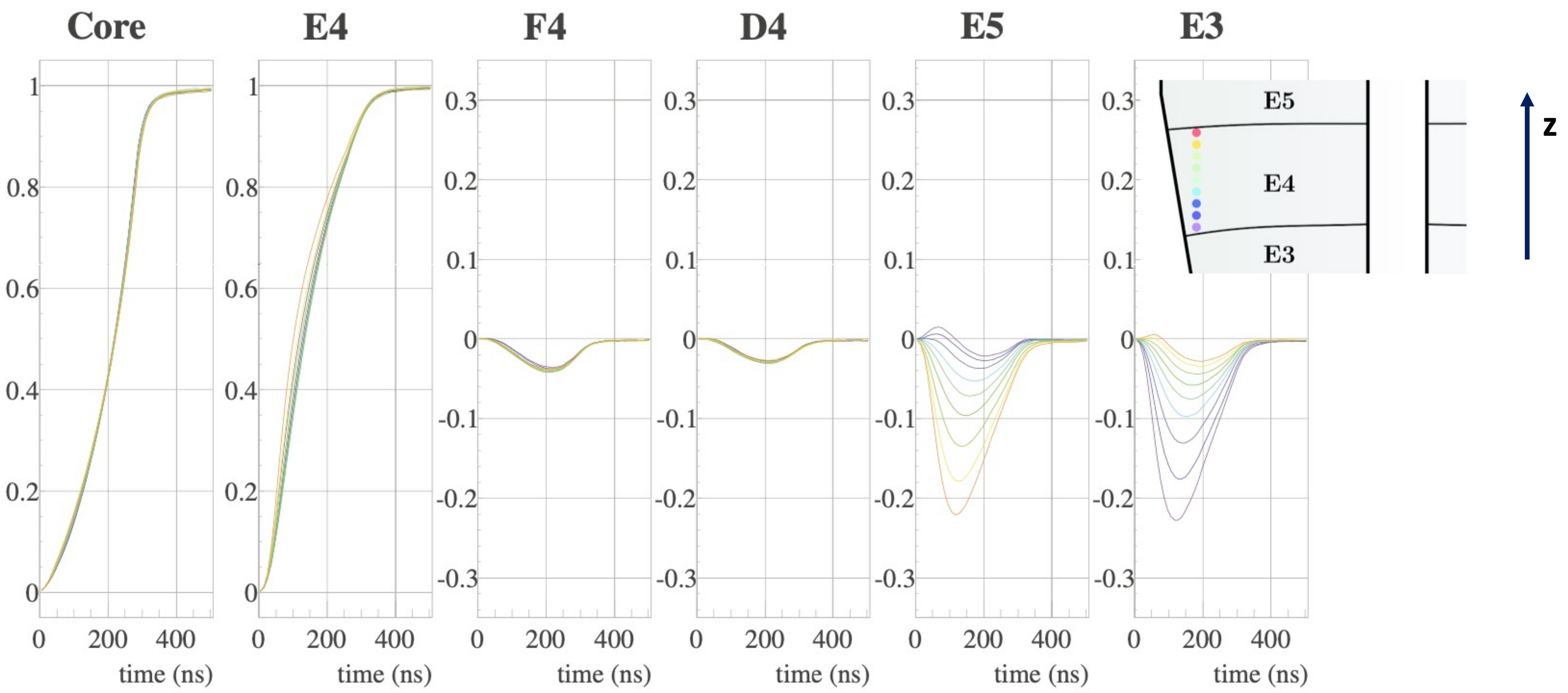
Position sensitive HPGe detectors…

Transient signal shapes in the neighbor segments provide coordinates θ and ***z***



Position sensitive HPGe detectors…

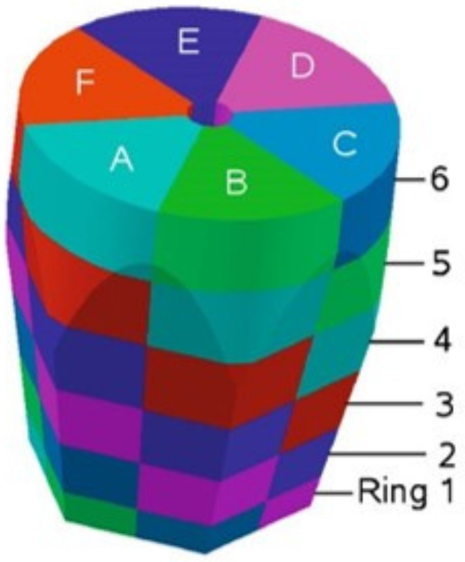
Transient signal shapes in the neighbor segments provide coordinates θ and *z*

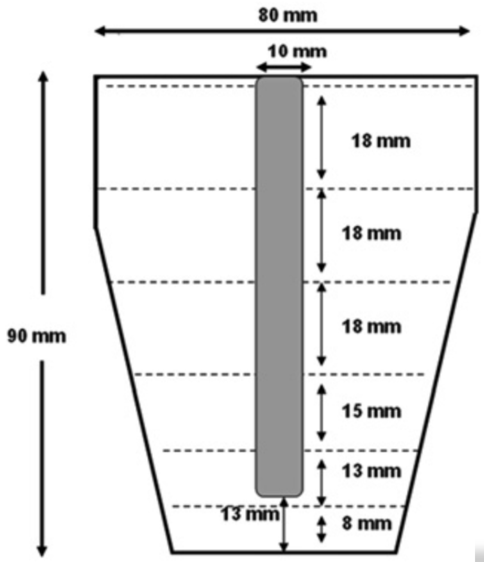


A particular case: the AGATA detectors

- $m_{Ge} \cong$ 2-3 kg, V $\cong$ 380 cm^3, n-type coaxial crystal
- Asymmetric tapered hexagonal geometry.
- The internal contact or *core* is Li-difussed (n-type)
- The external contact is B-implanted (p-type) and it is **electrically segmented**

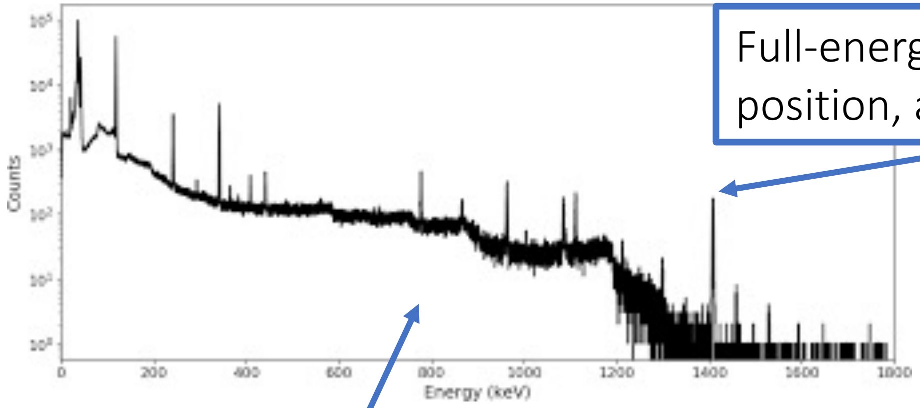
Volume subdivided in **36 segments + central core**





What to do with the interaction position?

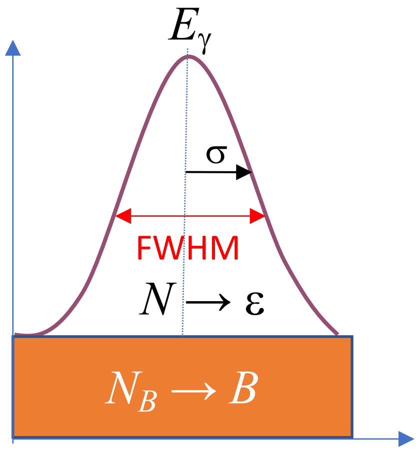
First, some basics of γ-ray spectroscopy



Full-energy absorption peaks: position, area -> E_γ ,p_γ

Spectral continuum: Compton effect of photons from the source not absorbed in the detector and bremsstrahlung of charge particles

SENSITIVITY LIMITED BY THE BACKGROUND UNDER THE PEAK



- ✓ Peak-to-total (P/T)
- ✓ Factor of merit : ε^2/B
- ✓ Detection limits:

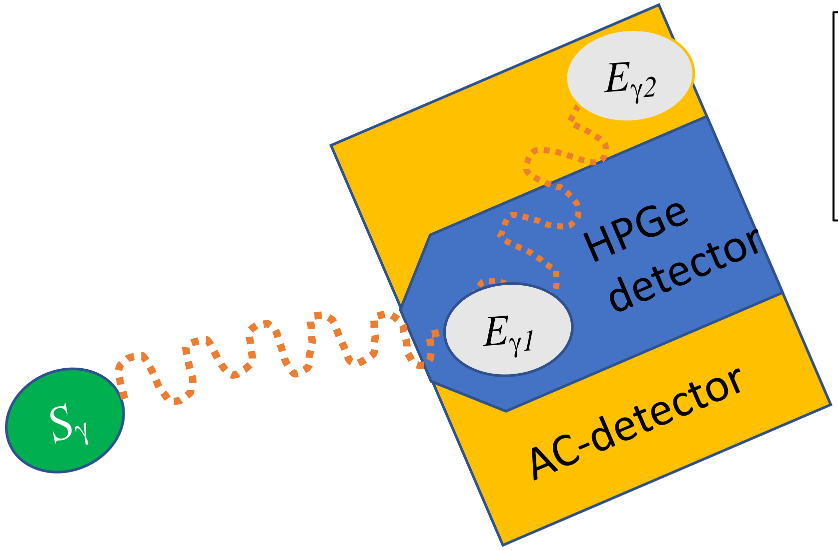
$$L_C = k_\alpha \sqrt{2N_B}$$

What to do with the interaction position?

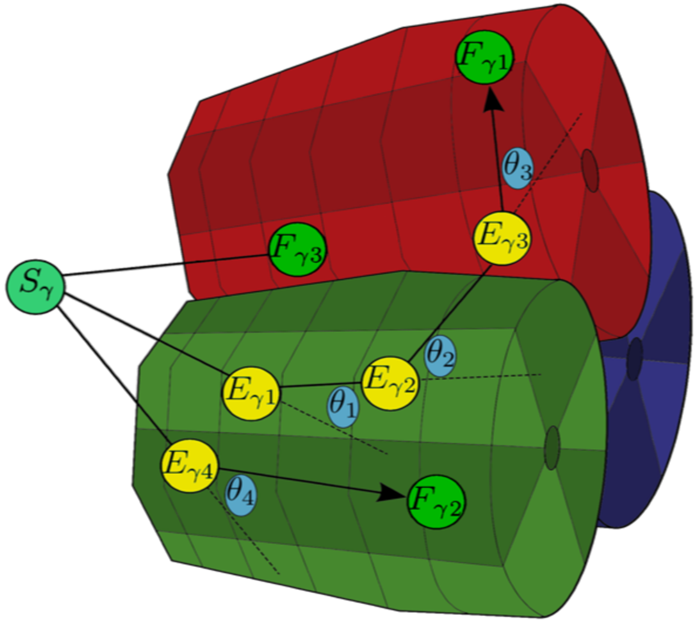
Second, how to reduce the Compton background?

The "classical" method: the Compton suppression

But, with the interaction position…TRACKING!!!

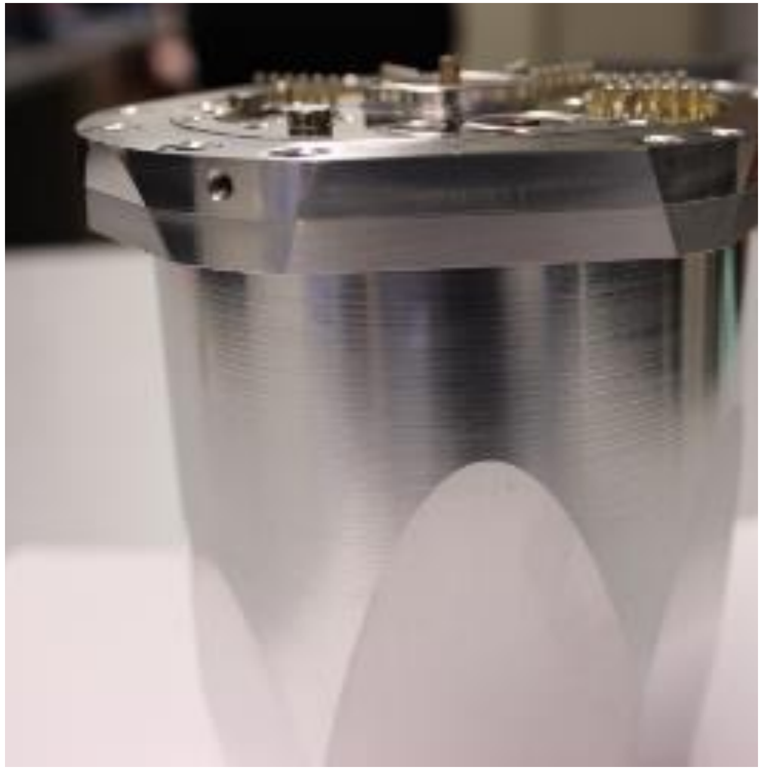
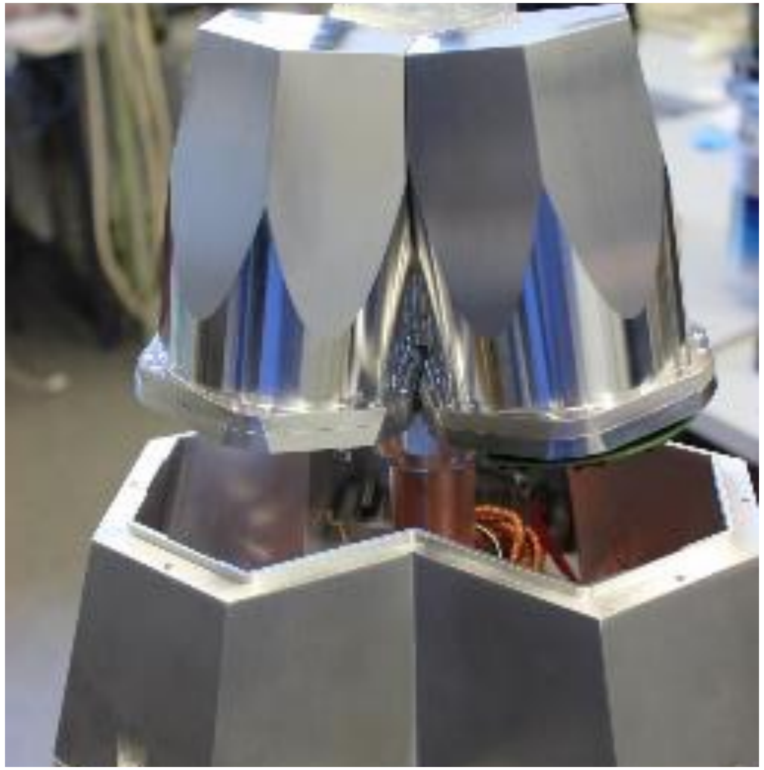
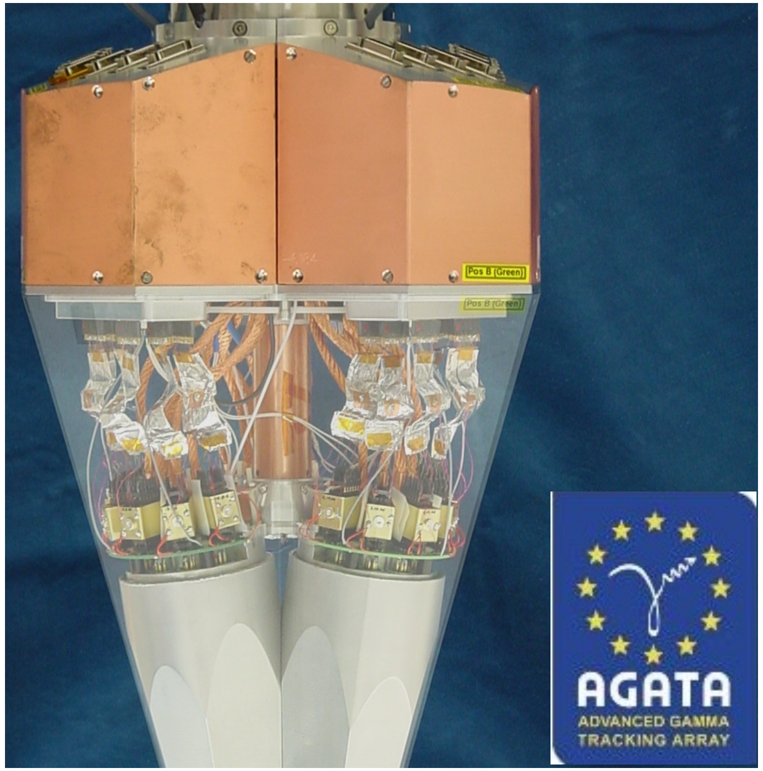


$$E_f = \frac{E_0}{1 + \frac{E_0}{m_e c^2}(1 - \cos\theta)}$$



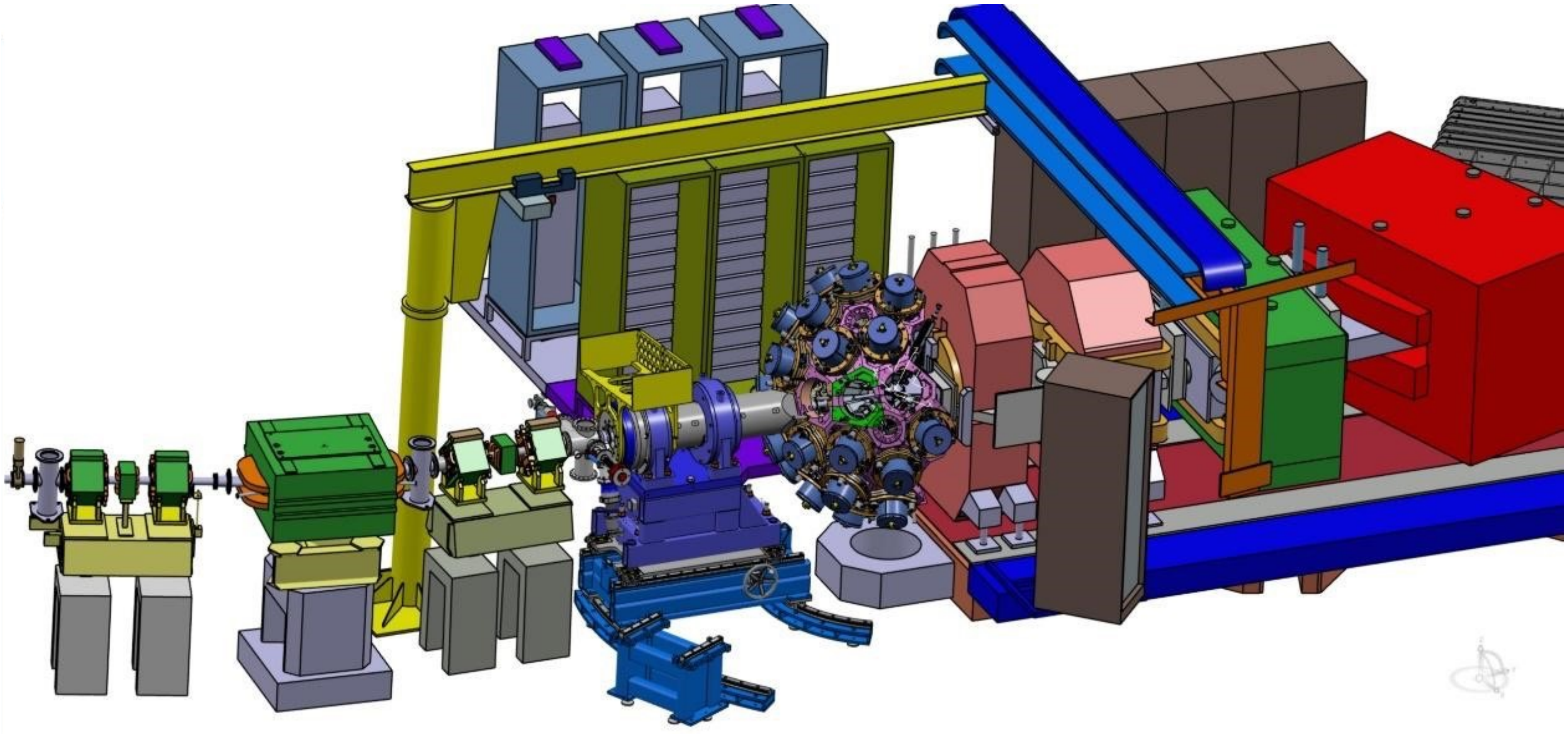
The development of clusters of highly segmented HPGe detectors

- Compound or cluster detectors were developed in Europe in the nineties and used for first time in Euroball. This is the starting point up to reach the development of highly-segmented HPGe detectors…

Why?...

Experiments with stable and radioactive beams to study nuclear structure at the frontier of knowledge



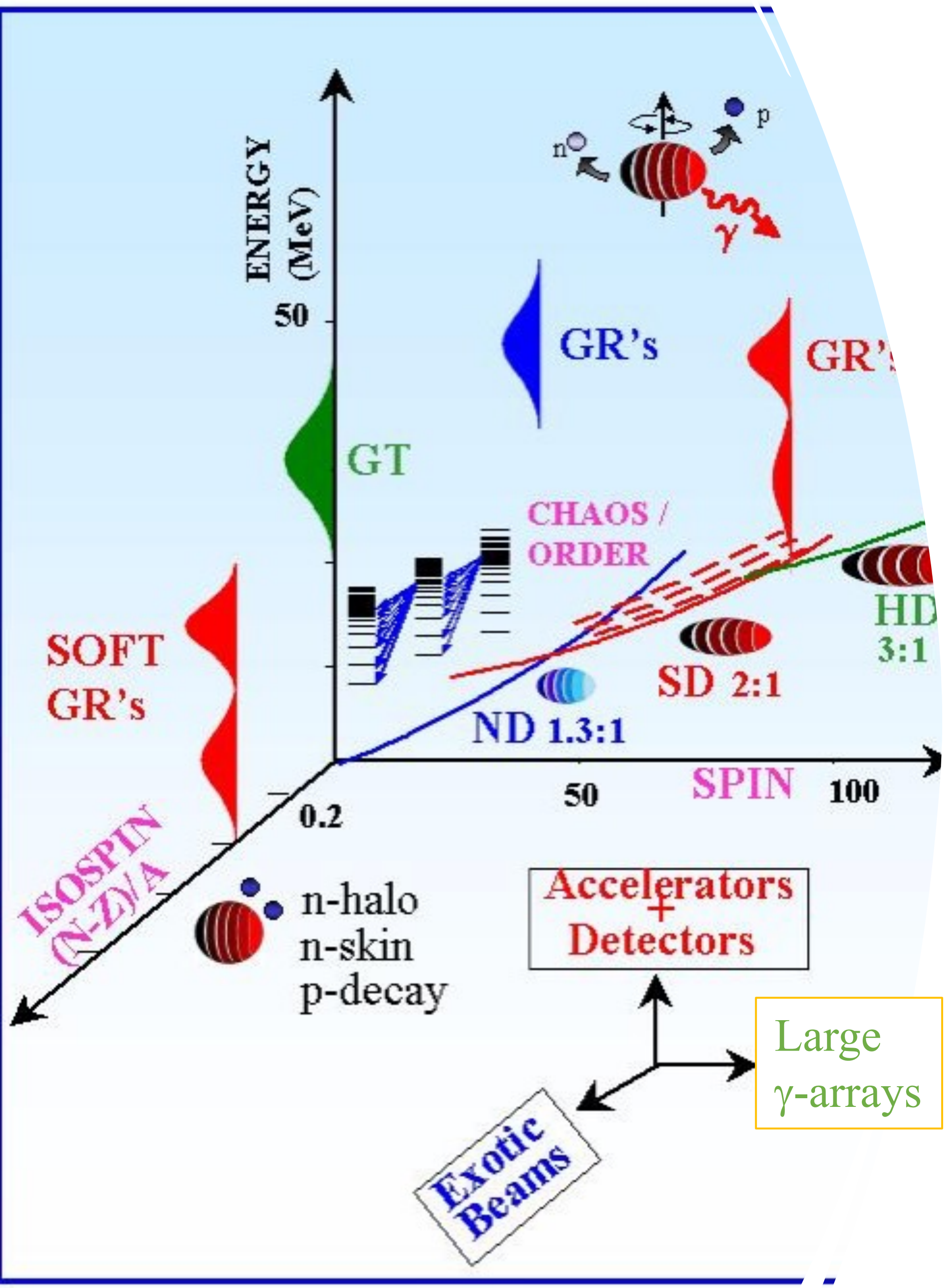
But, why to study the atomic nucleus?

To reveal fully the characteristics of the nuclear forces, which are the glue of matter in the Universe

Nucleus properties determine the stability of matter.

Non stable nucleus are used in many applications so useful for the society as nuclear medicine and nuclear energy.

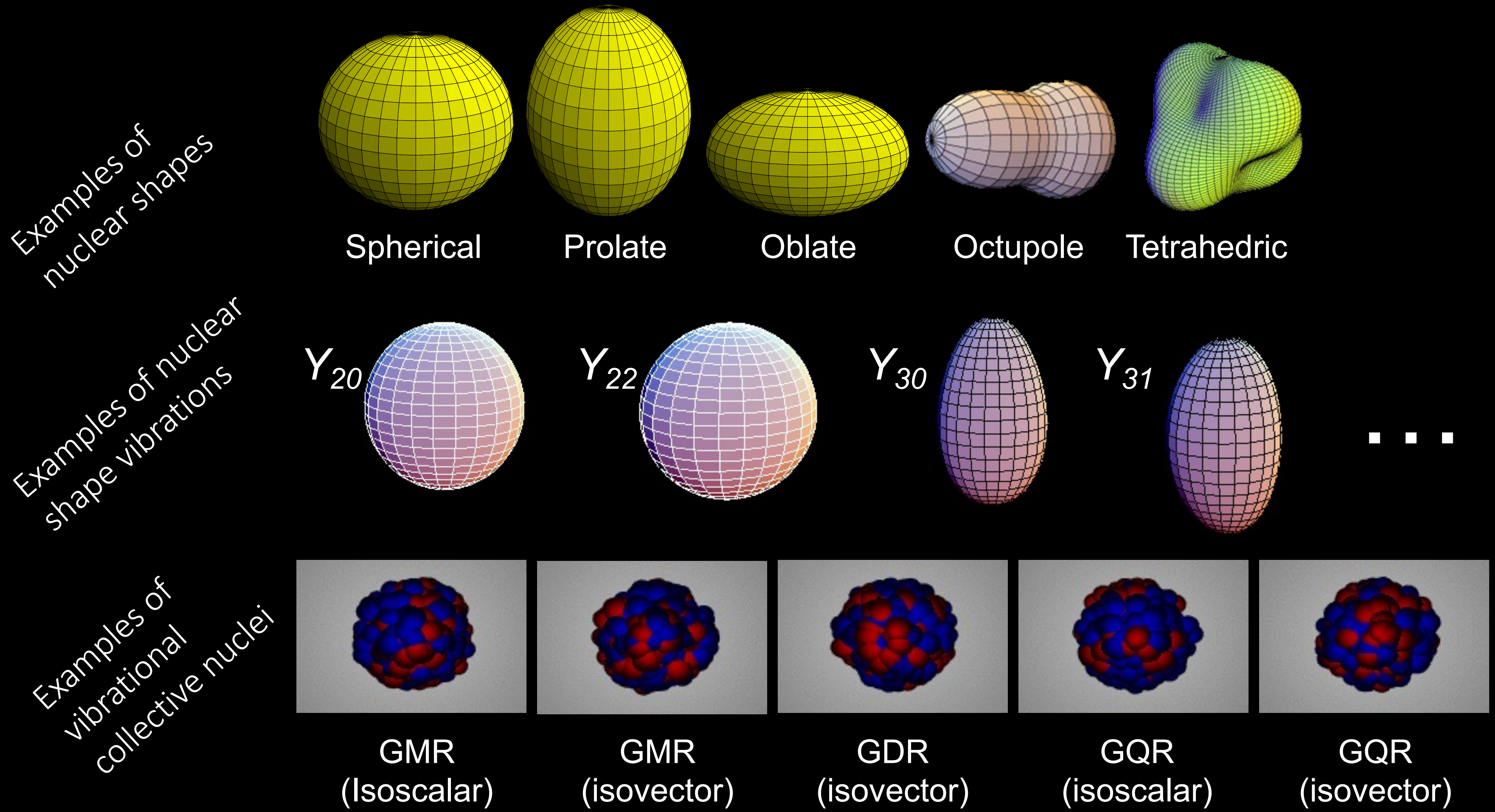
To create new nucleus leads to discover new nuclear properties and then, new matter…



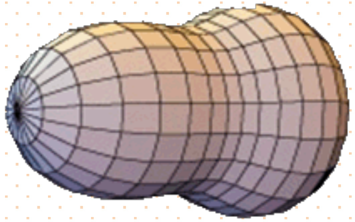
Some topics…

- Evolution of shells and collectivity
- Magic number evolution in highly excited nucleus
- Very heavy nucleus towards new magic numbers
- Disintegration modes of exotic nuclei
- Cross sections of nuclear reactions for new nuclei
- Neutron-halo (proton-halo?)
- Neutron skin
- Unbound systems…

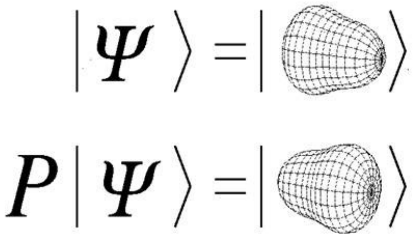
Evolution of nuclear shells and collectivity



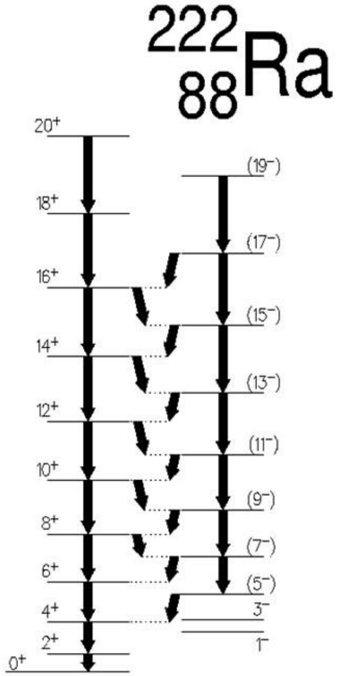
Where to look at into the nucleus ?

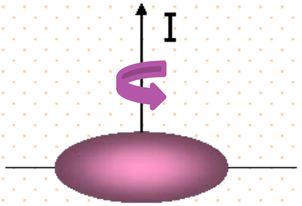


$\beta_3 \neq 0$

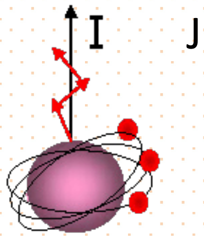


$$P|\Psi\rangle \neq |\Psi\rangle$$





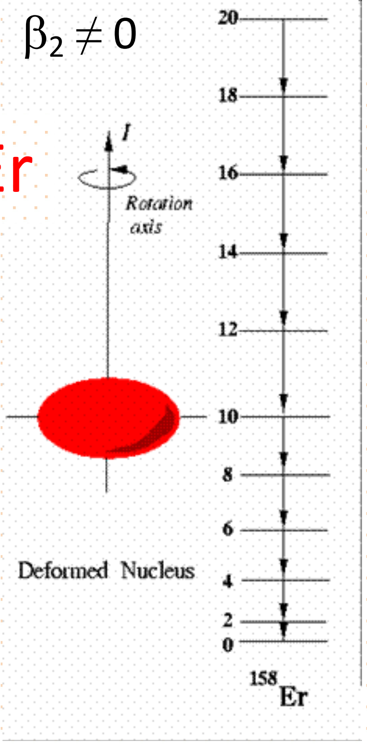
$I = J\omega$



$I = \Sigma\, I_i$

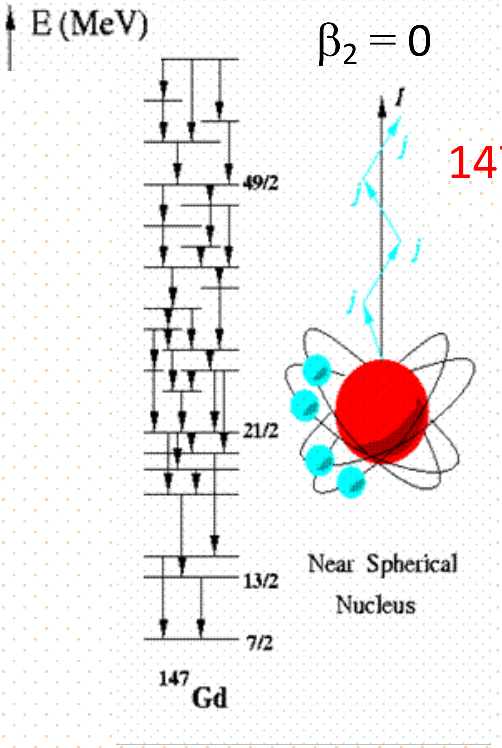
$\beta_2 \neq 0$

^{158}Er

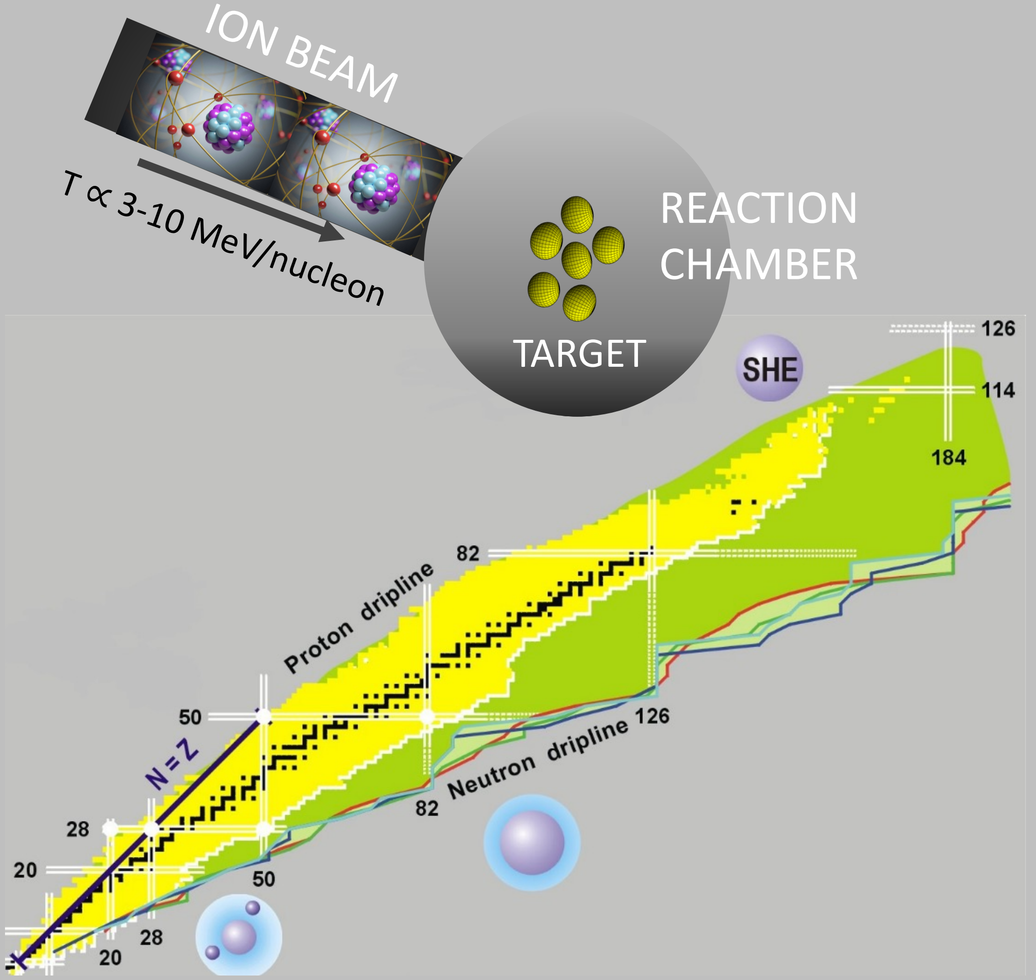


$\beta_2 = 0$

^{147}Gd



How to generate and measure exotic nuclei? …

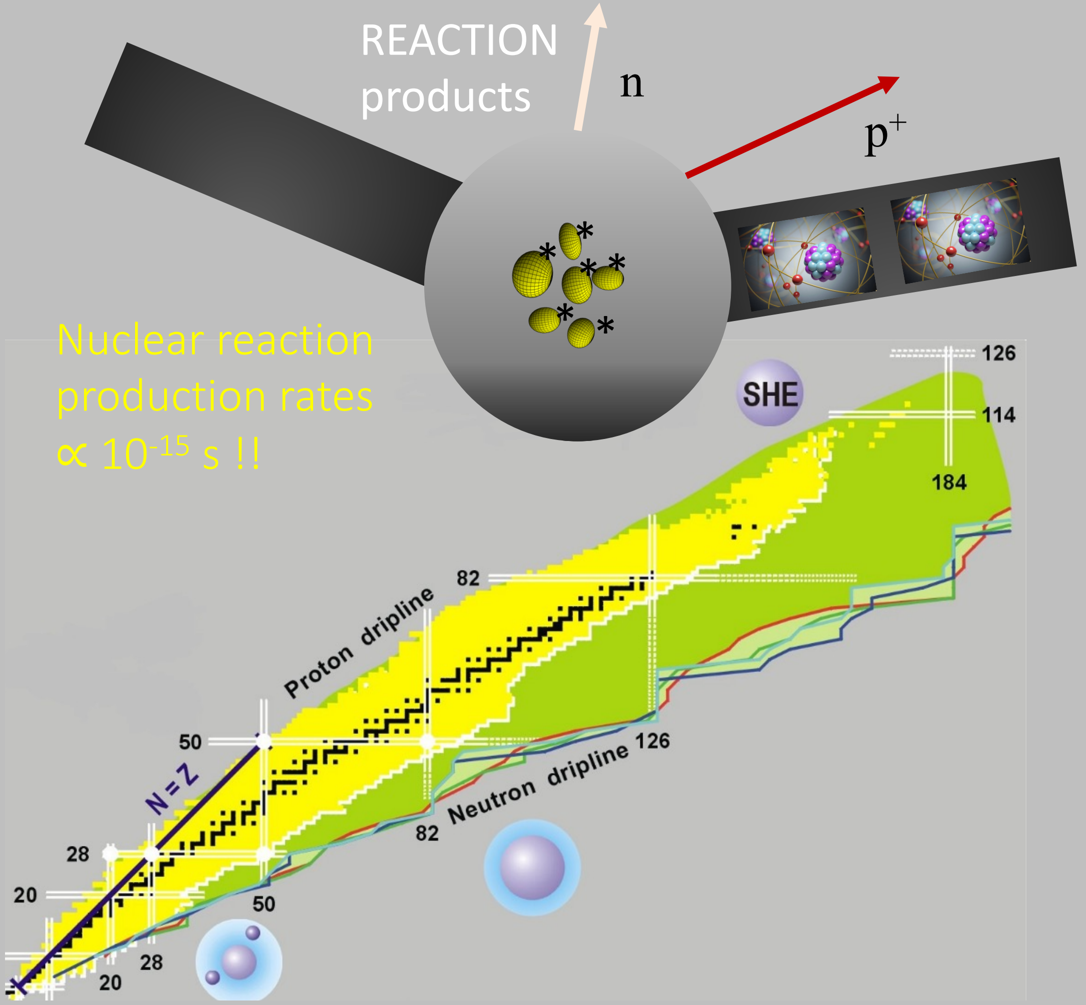


$$ {}^{A}_{Z}X + {}^{A'}_{Z'}Y \rightarrow {}^{A''}_{Z''}W + {}^{A'''}_{Z'''}V + mp^{+} + jn + i\alpha + \cdots (delayed\ \beta^{\pm}) $$

COULEX	${}^{A}_{Z}X + {}^{A'}_{Z'}Y \rightarrow {}^{A}_{Z}X^{*} + {}^{A'}_{Z'}Y^{*}$	$\sigma_1 \propto$ 1 bar
MNT+Ev	${}^{A}_{Z}X + {}^{A'}_{Z'}Y \rightarrow {}^{A+1}_{Z-1}V^{*} + {}^{A'-2}_{Z'}Y^{*} + p^{+}$	$\sigma_2 \propto$ 1 mbar
Fu-Ev	${}^{A}_{Z}X + {}^{A'}_{Z'}Y \rightarrow {}^{A+A'-2}_{Z+Z'}W^{*} + 2n$	$\sigma_3 \propto 10^{-2}$ mbar

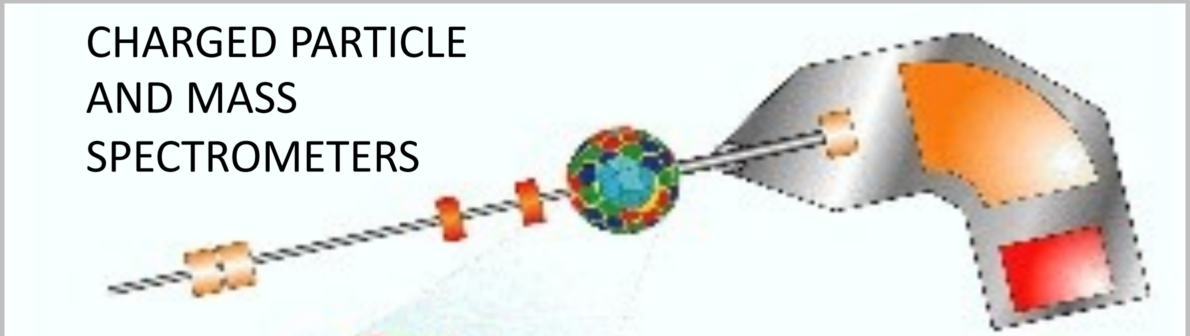
$$\sigma_1 >> \sigma_2 >> \sigma_3$$

How to generate and measure exotic nuclei? …



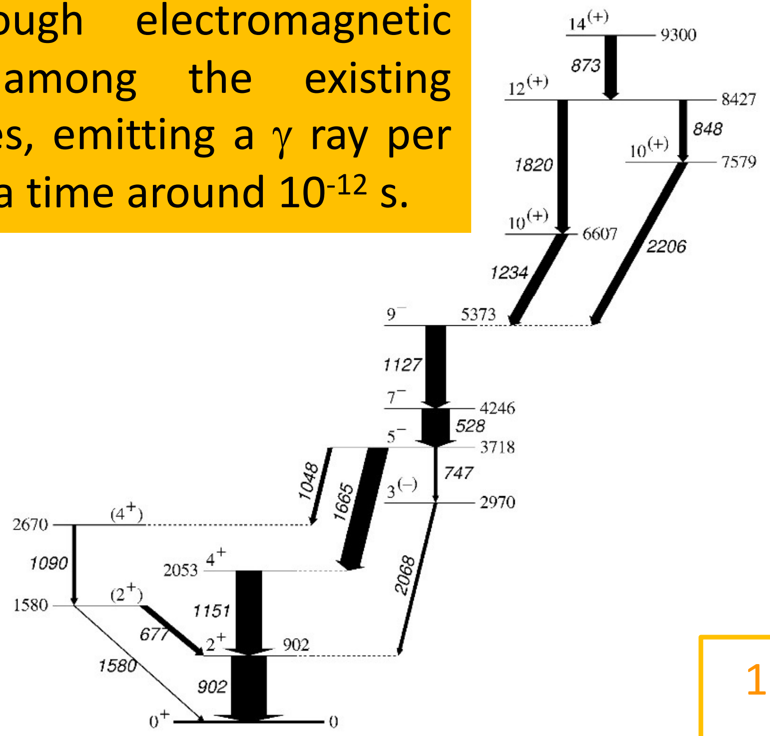
Key aspects

- The nucleus to be studied “must” be in an excited state
- Direct detection of the “prompt” de-excitation γ-rays emitted by the nucleus of interest
- The detection system needs to be installed around the reaction point
- In addition to the γ-ray detector, frequently, complementary detectors and ancillary devices are necessary to improve selectivity or to perform a particular measurement.



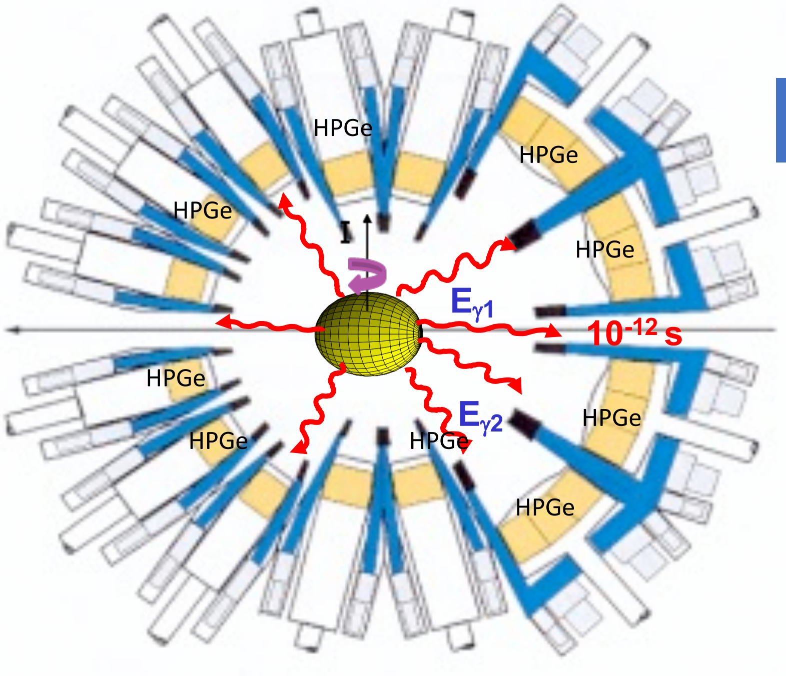
High-resolution in-beam γ-ray spectroscopy to study the nuclear structure far from stability

The excited nuclear state produced in a given nuclear reaction de-excites through electromagnetic transitions among the existing nuclear states, emitting a γ ray per transition in a time around 10^{-12} s.



In-coincidence measurements: TRIGGER with conditions

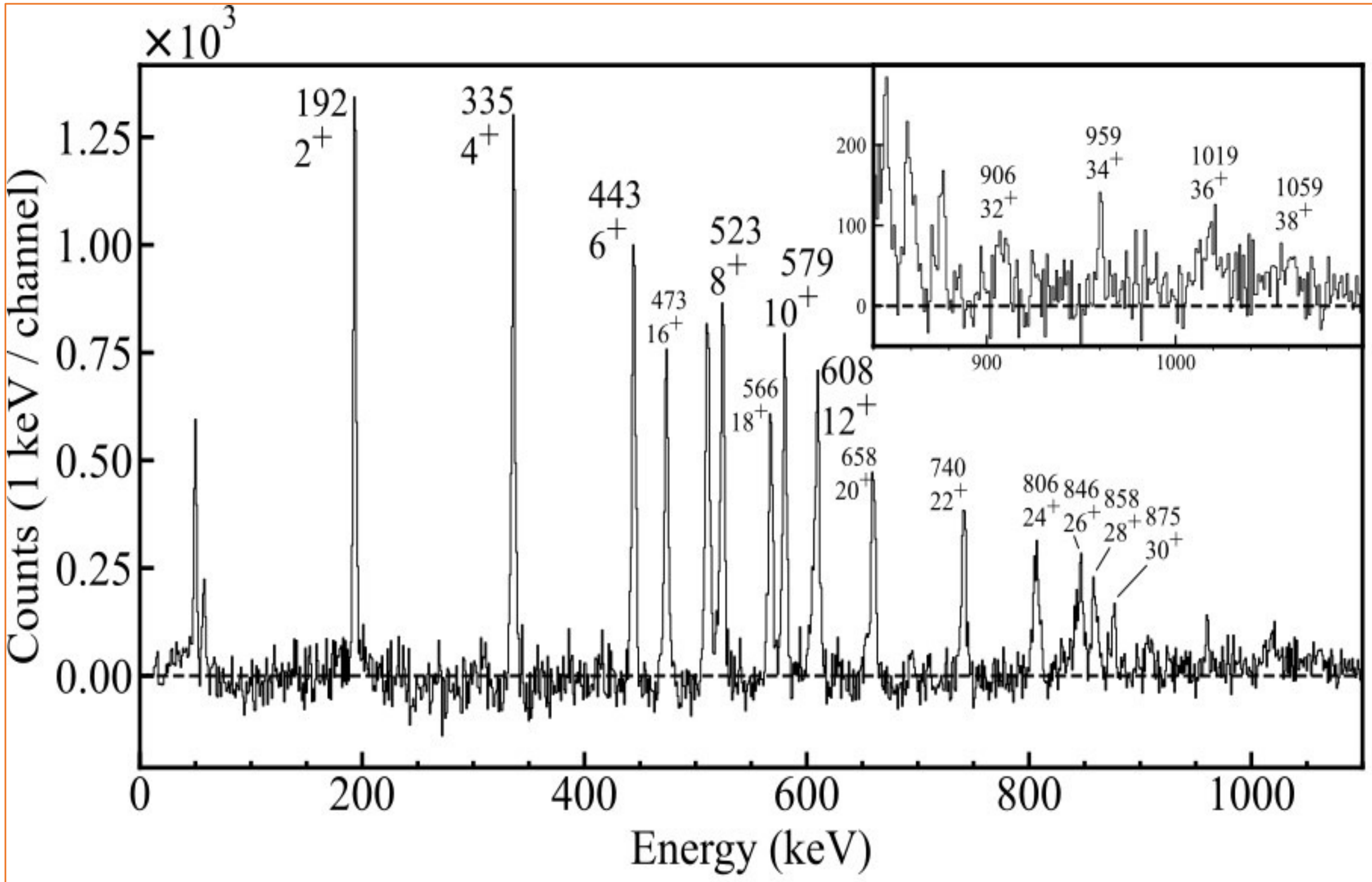
Time window: 10 ns →500 ns



EUROBALL

1. Selectivity and multiplicity
2. Factors that matters are ε and P/T, i.e. signal-to-noise ratios

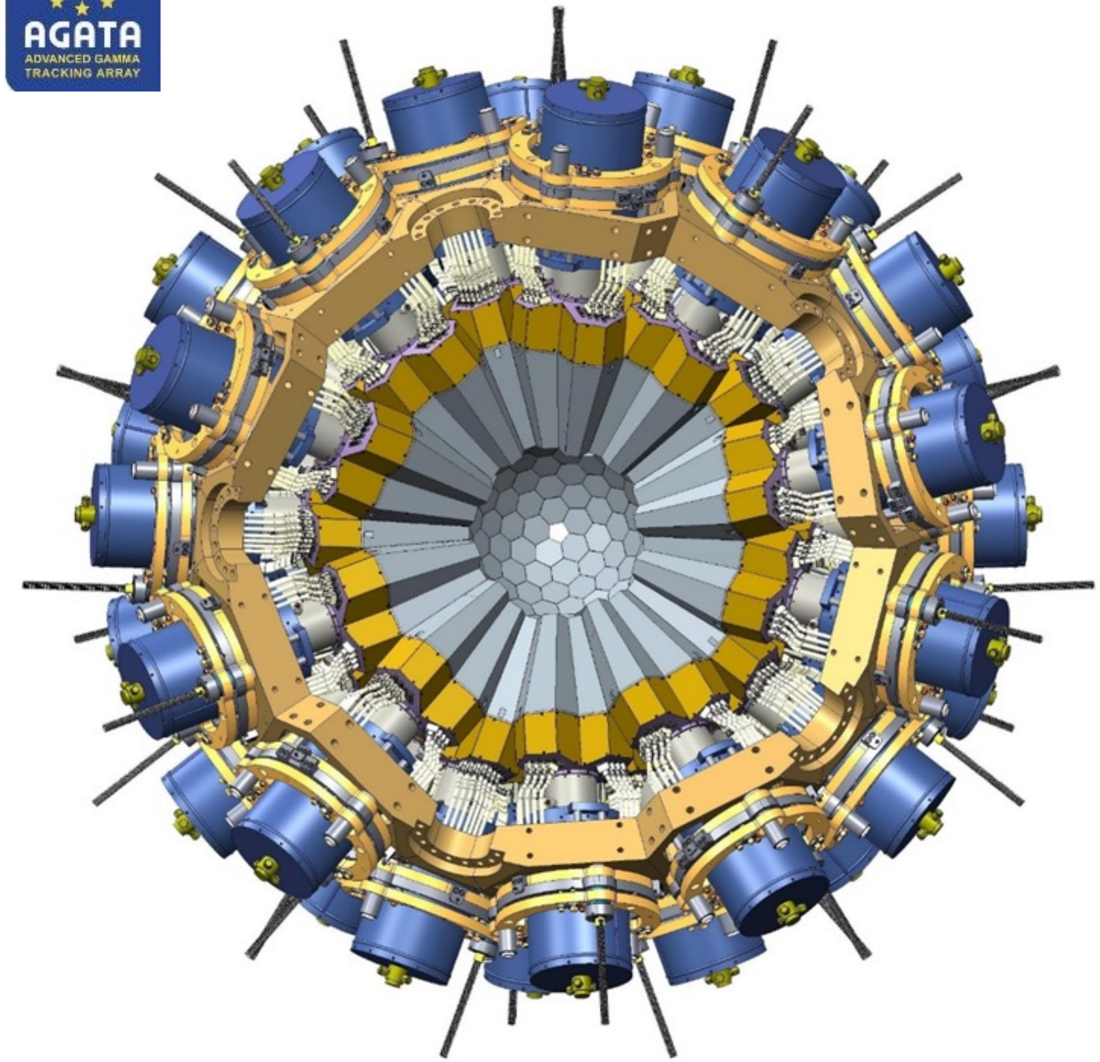
What could we expect from a “clean” γ-ray spectrum?



E_γ, I_γ and even decay times from peak shapes

AGATA
(the Advanced GAmma Tracking Array)

- Number of encapsulated 36-fold segmented HPGe = 180
- Number of high-resolution digital electronics channels = 6660
- High throughput DAQ
- Position sensitive operational mode

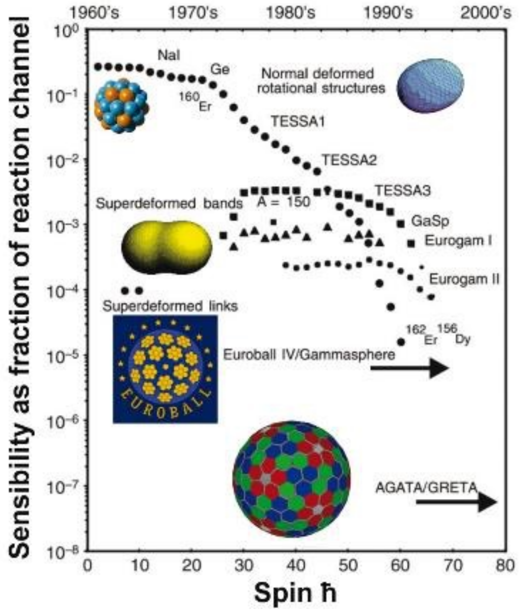


$m_{Ge} \cong 450$ kg
$V_{Ge} \cong 68 \cdot 10^3$ cm^3
$\Omega \cong 80\text{-}82$ % of 4π

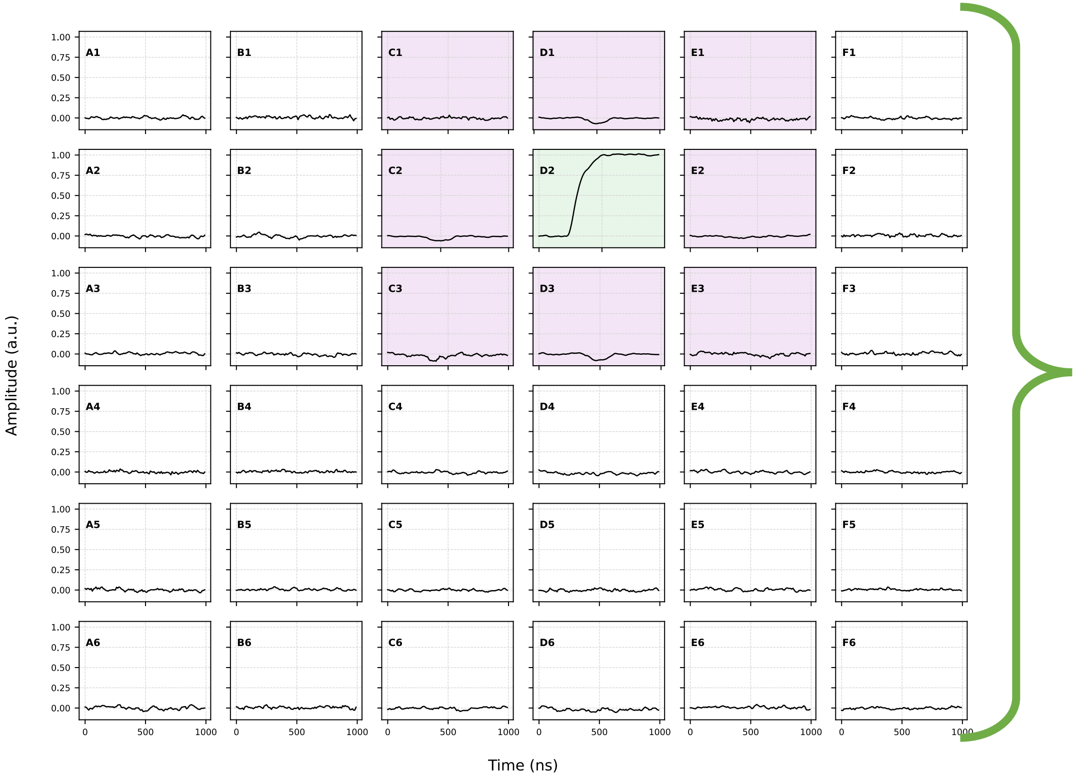
With γ-ray tracking algorithms

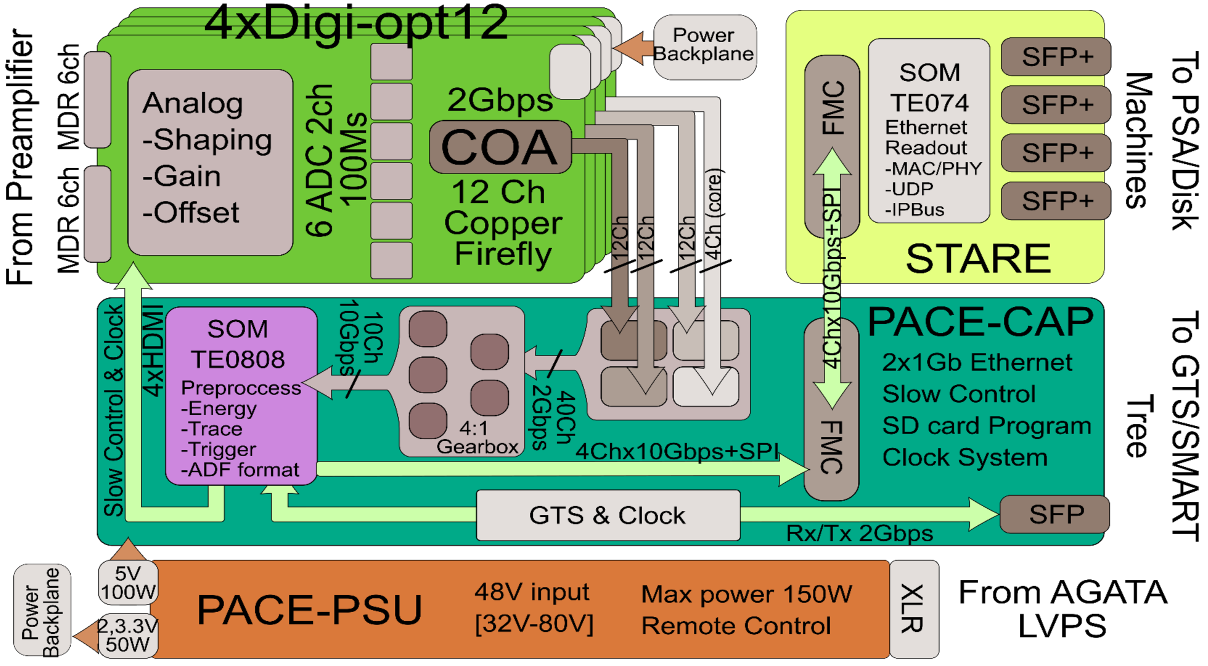
⇩

maximum ε and P/T



Signal readout and processing: digitisation





Digitiser (DIGOPT12) and pre-processing specifications:

1. Analog electronics of very low noise to obtain signal with spectroscopic quality.
2. Analog-to-digital conversor: effective number of bits (ENOB) = 11,5 -12 ∼ SIGNAL AMPLITUDE PRECISSION= 1/4096
3. Sampling frecuency: 100 MHz, band width = 30 MHz ∼ τ = 10 ns, (Teorema de muestreo de Nyquist)
4. PSA uses the first μs

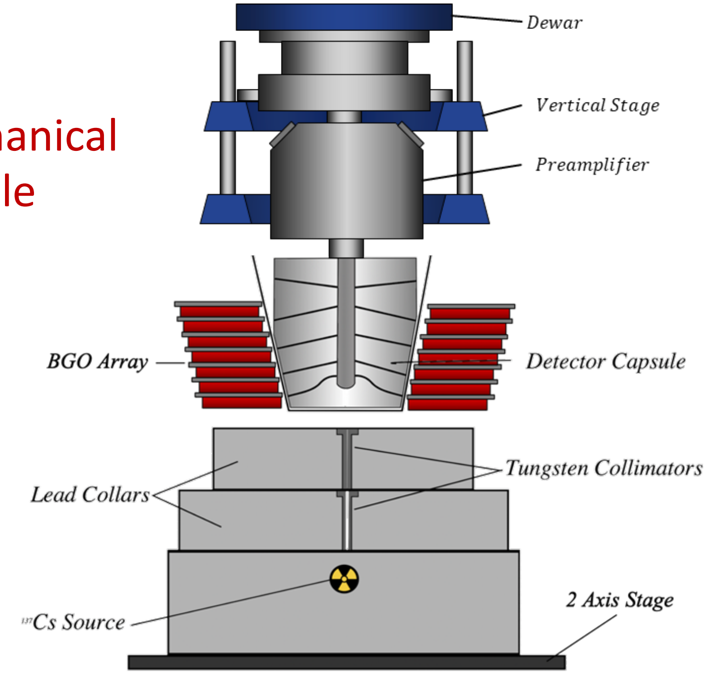
INFN-Milano, CSNSM-Orsay, IPHC-Strasbourg, STFC-Daresbury, IFIC & ETSE-Valencia

But, what to do with the pulse shapes?

First step...

Characterization of the highly-segmented detector electrical response *versus* interaction position

Liverpool´s mechanical scanning table



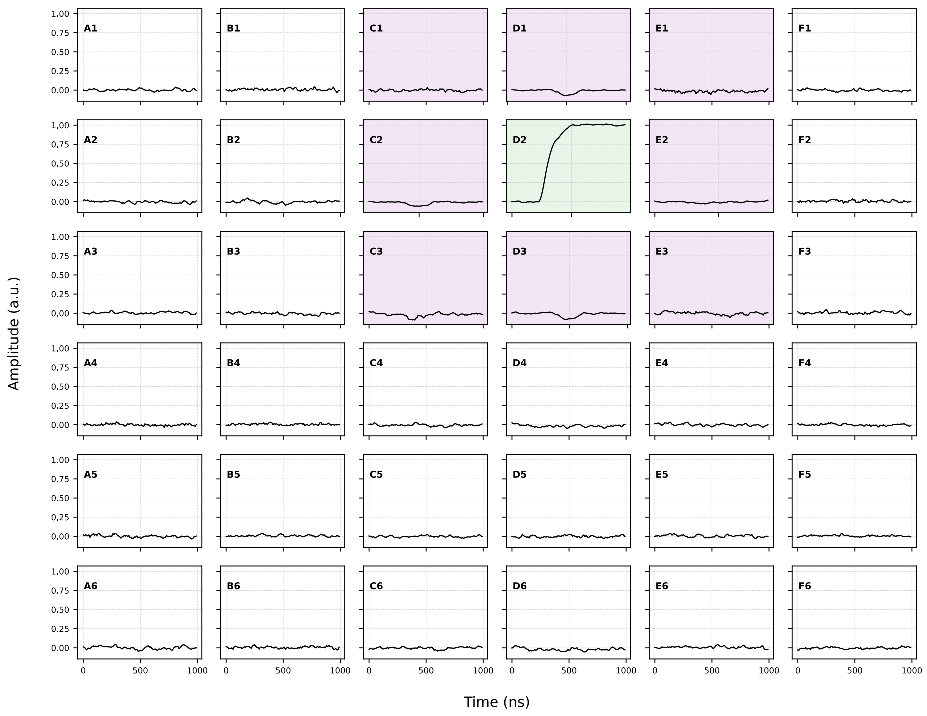
DATABASE:
pulse shapes
⇩
interaction position (r,θ,z)

DB built from simulated pulse shapes is the current method used in AGATA

See Gala's poster to know SALSA, the R&D characterisation system under development in Salamanca

And, what's next?

Signals corresponding to an experimental event in a given detector



Pulse Shape Comparison (PSC)

PSC algorithms use statistical criteria to compare between the experimental signals and the DB ones (χ^2, Wilcoxon test,…)

OUTPUT

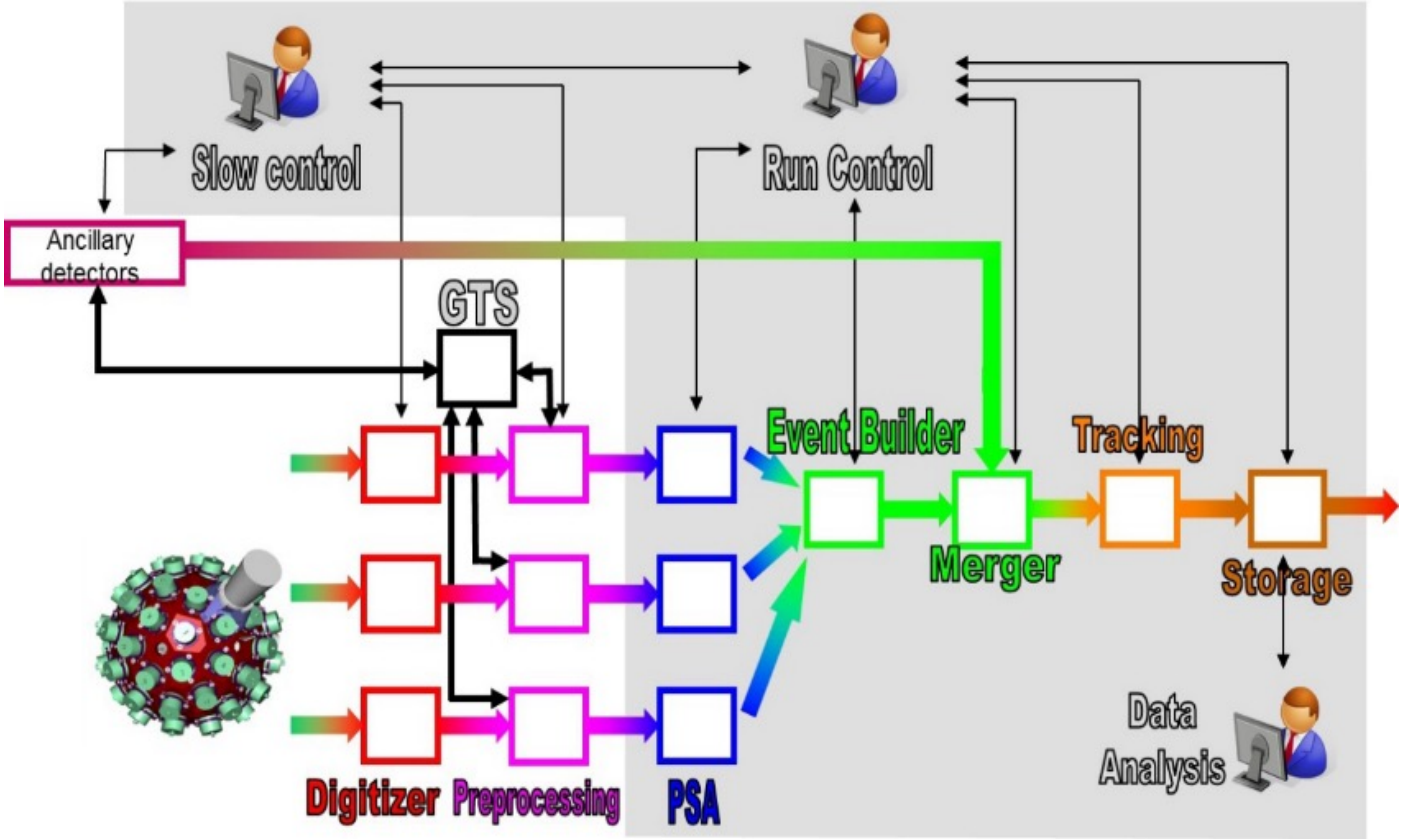
Interaction position coordinates corresponding to the pulses recorded:
(r, θ, z)

TRACKING

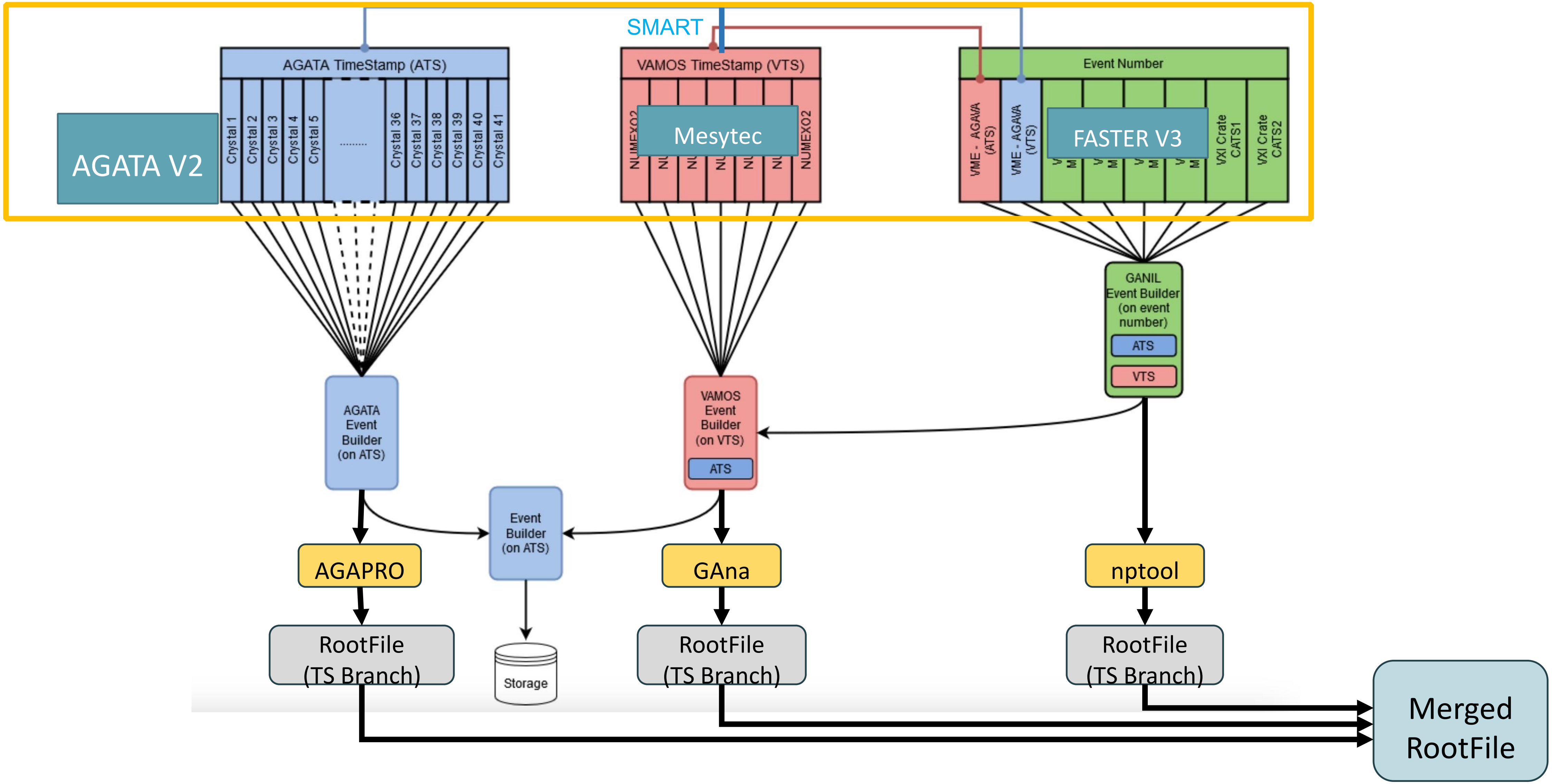
From a set of interaction positions corresponding to a given in-coincidence event, the most probable trajectory is evaluated through tracking algorithms that are based on the Compton Scattering formula

Signal readout and processing: PSA farms and data storage

Data flow, control and storage

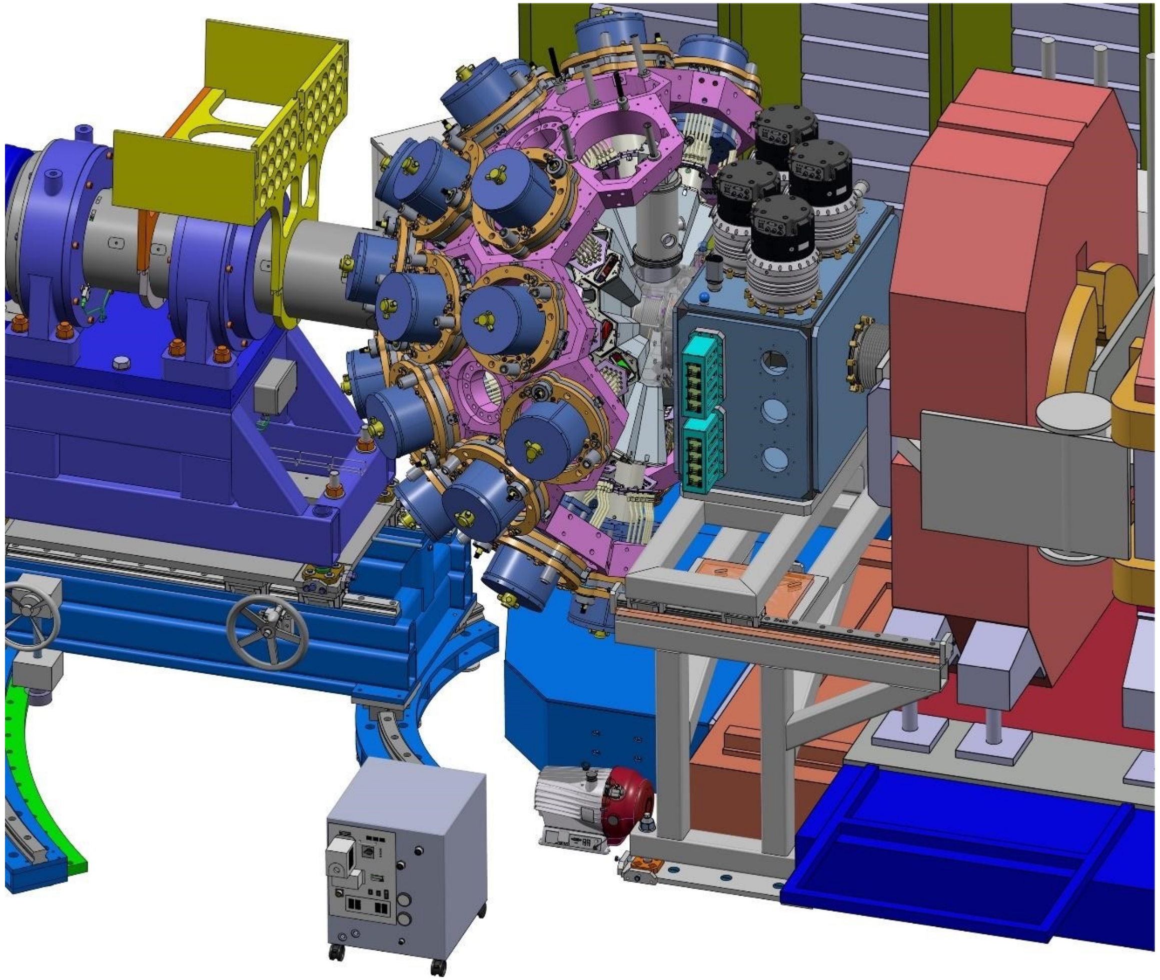


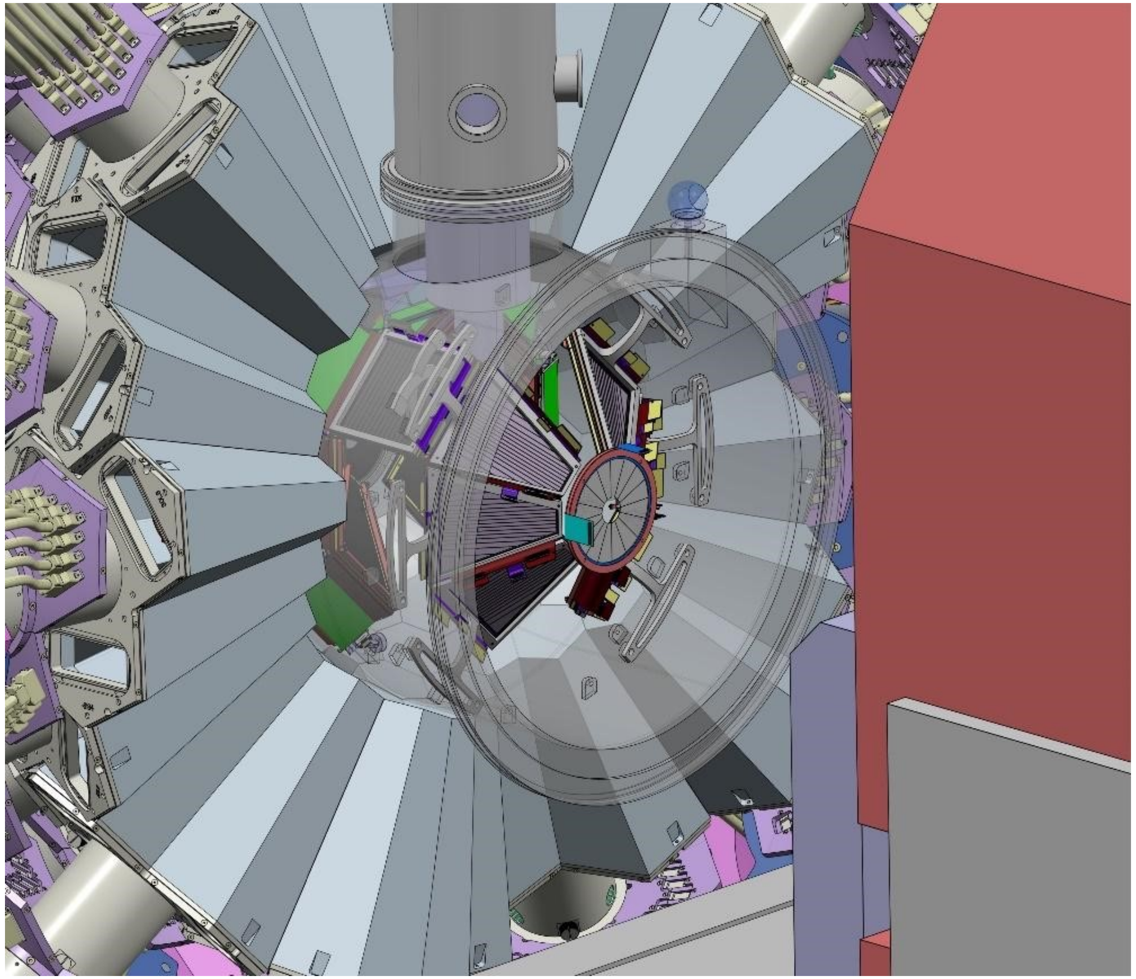
Data merging process at GANIL



D. Ramos from Ganil adapted

Infrastructures





Infrastructure: hall and rooms

Experimental hall

AGATA array + front-end electronics area + pre-processing electronics and GTS Tree

DAQ area

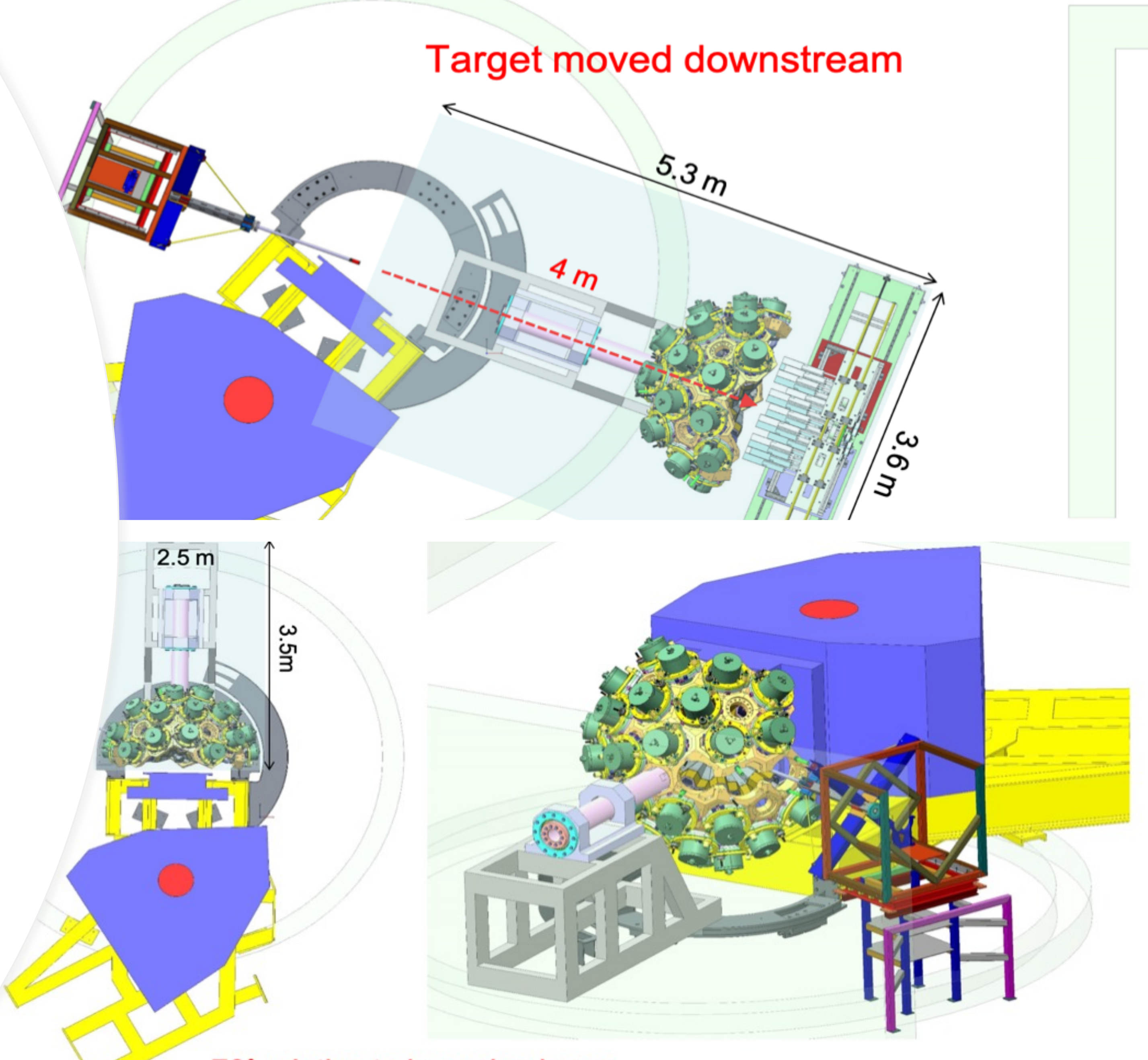
Pre-processing GGP

(optical links of usual lengths = 60 m)

Control room

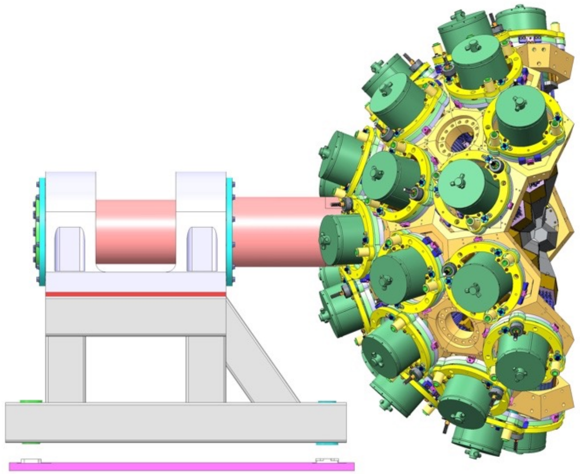
An area of ~25m² to install all workstations required for the experiment control, data taking and on-line analysis with fast access to the GRID network for data archive

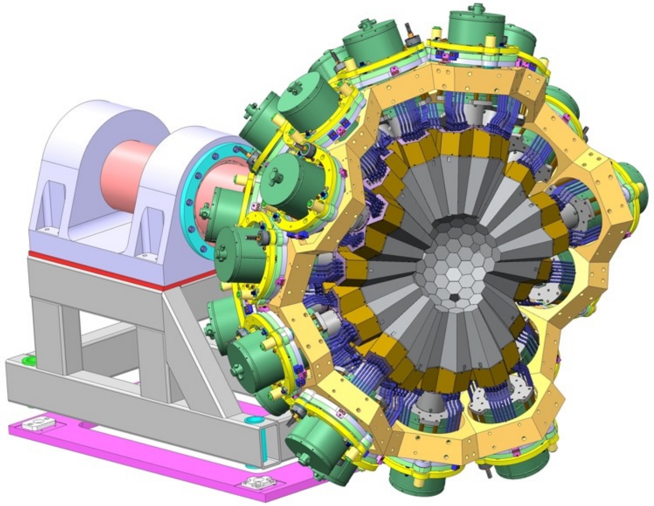
Maintenance: Detector Laboratory and Repository area

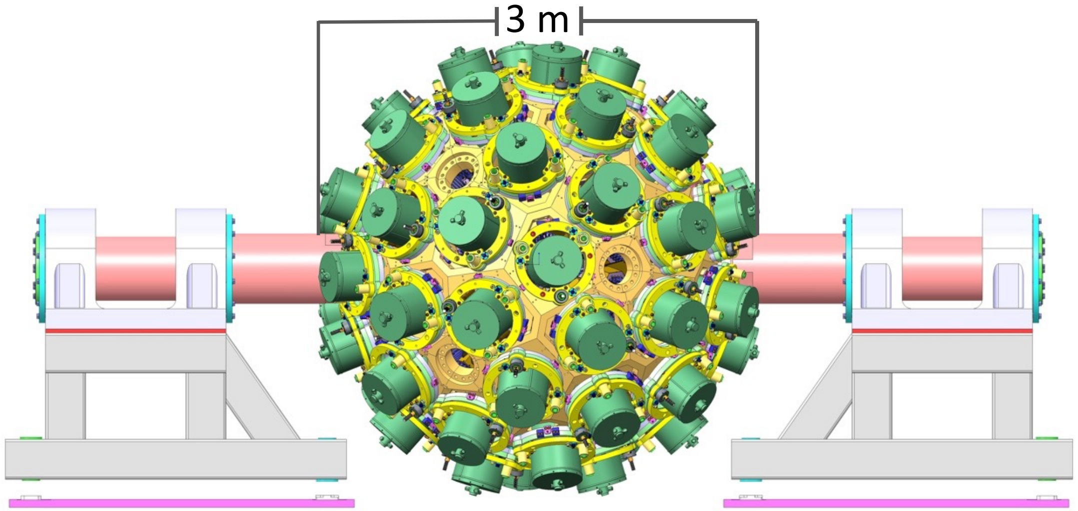


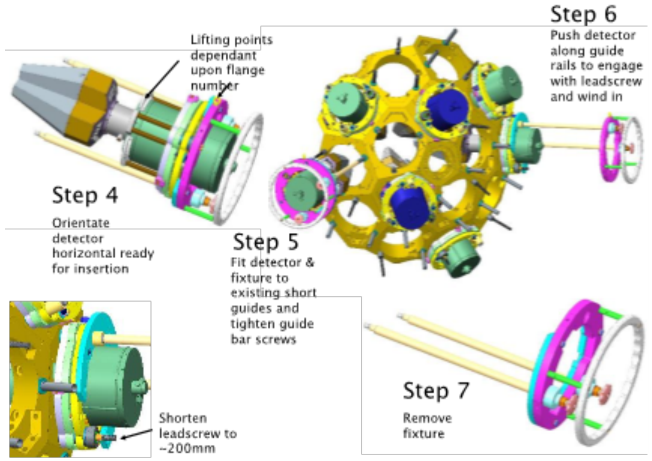
70˚ relative to incoming beam

Mechanical Infrastructures









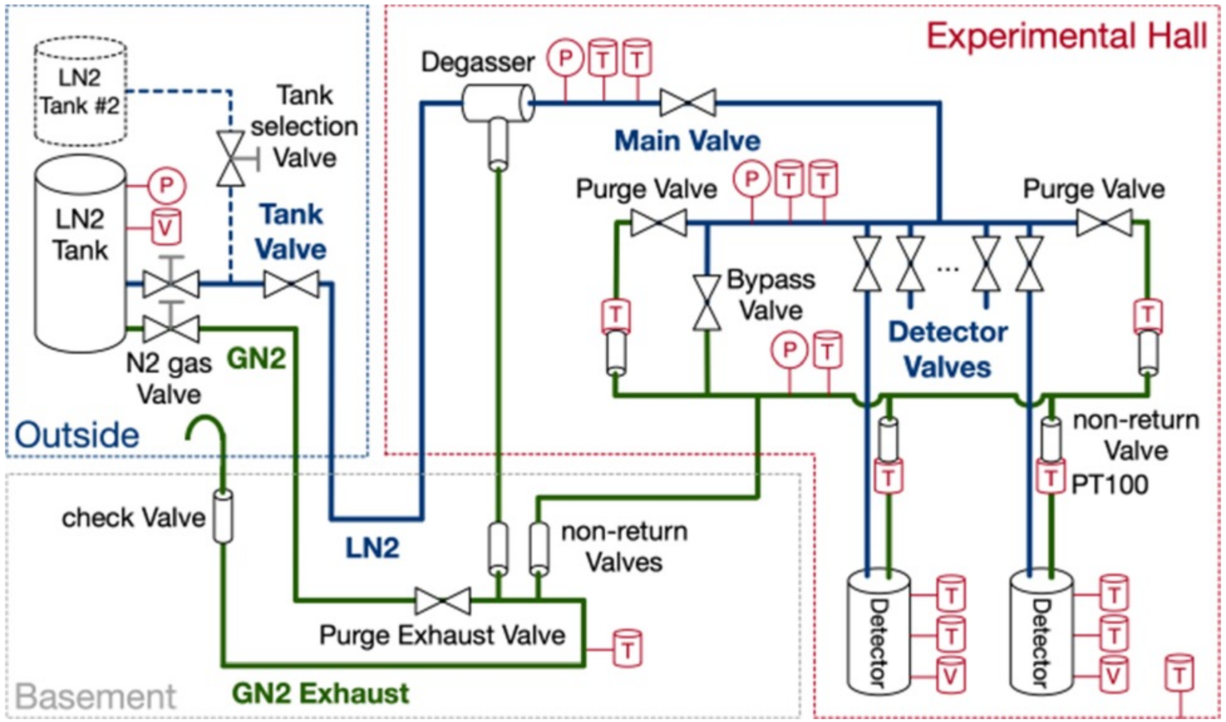
STFC-Daresbury, GANIL, INFN-Milano, INFN-Padova

Basic infrastructures

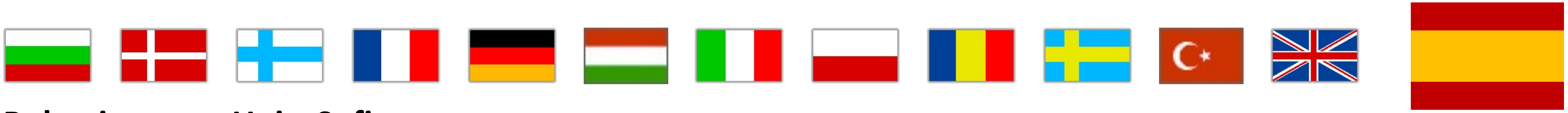
- ❑ Uninterruptible Power Supply (UPS)
- ❑ Detector high-voltage (HV) power supply and its control system
- ❑ Digitizer and detector low-voltage power supply (LVPS), water cooling system for the electronics

LN_2 autofill system for Ge cooling:

- Water-free LN_2 at 1.5 bar
- ATC with 4.5 L Dewar vessel needs four filling cycles per day, 5.2 L cycle ⇨ 90 ATCs needs 1,25 m^3 a day
- Additional LN_2 (about 7 L, in the GANIL configuration) is used at every filling cycle to purge the unwanted N_2 gas and cool the transfer line
- Total LN2 volume per week = 10 – 11 m^3
- Detector Support System (DSS) to control detector temperatures



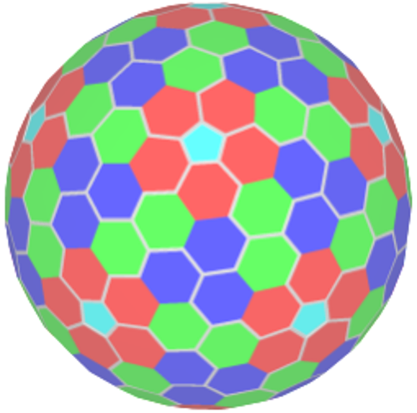
The AGATA Collaboration



Bulgaria:	Univ. Sofia
Denmark:	NBI Copenhagen
Finland:	Univ. Jyväskylä
France:	GANIL Caen, IPN Lyon, CSNSM Orsay, IPN Orsay, CEA-DSM-DAPNIA Saclay, IPHC Strasbourg, LPSC Grenoble
Germany:	GSI Darmstadt, TU Darmstadt, Univ. zu Köln, TU München
Hungary:	ATOMKI Debrecen
Italy:	INFN-LNL, INFN and Univ. Padova, Milano, Firenze, Genova, Napoli,
Poland:	NINP and IFJ Krakow, SINS Swierk, HIL & IEP Warsaw
Romania:	NIPNE & PU Bucharest
Sweden:	Univ. Göteborg, Lund Univ., KTH Stockholm, Uppsala Univ.
Turkey:	Univ. Ankara, Univ. Istanbul, Technical Univ. Istanbul
UK:	Univ. Brighton, CLRC Daresbury, Univ. Edinburgh, Univ. Liverpool, Univ. Manchester, Univ. West of Scotland, Univ. Surrey, Univ. York
Spain:	IFIC-CSIC, IEM-CSIC Madrid, LRI-USAL

Countries > 12

Institutions > 40



Thank you for your attention