# AGATA

## Plan

- Gamma-ray-matter interactions
- Escape suppression technique
- AGATA, the gamma-ray tracking technique and the Demonstrator installation
- AGATA performance and physics case
- AGATA organisation and construction

G. Duchêne

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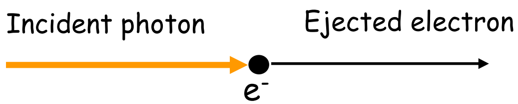
# Gamma-ray matter interaction

## Three interactions

- **Photoelectric effect**

  Total $\gamma$-ray energy transfered to the electron

  $E_e = E_\gamma - B_K$ is measured -> **peak**




- **Compton effect**

  Partial $\gamma$-ray energy transfered to the electron

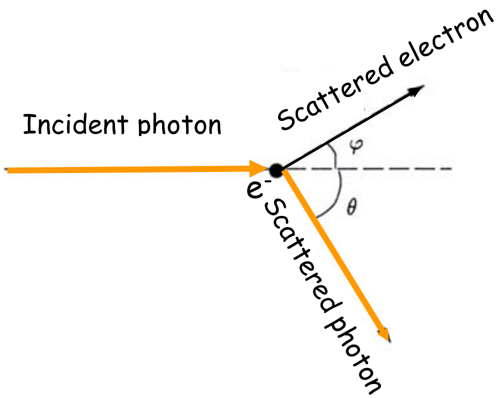
  $E_{S\gamma} = E_\gamma / (1 + \alpha(1 - \cos\theta))$ with $\alpha = E_\gamma / m_e c^2$

  $E_e = E_\gamma - E_{S\gamma}$ is measured -> **background**

  $E_\gamma = 1000$ keV $E_{S\gamma}(30°) = 792$ keV $E_e = 208$ keV

  $E_{S\gamma}(90°) = 338$ keV $E_e = 662$ keV

  $E_{S\gamma}(180°) = 203$ keV $E_e = 797$ keV

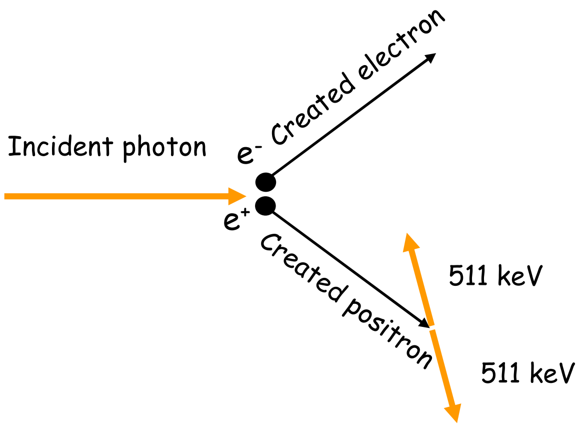



- **Pair creation effect**

  Creation of a pair of electron-positron

  $E_\gamma = T_+ + T_- + 2\, m_e c^2$ with $E_\gamma > 2\, m_e c^2$

  -> **3 peaks + background**

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# Gamma-ray matter interaction

## Gamma-ray absorption

- Transmission $I(x) = I_0 \times e^{-\mu x}$
- Absorption $A(x) = I_0 \times (1 - e^{-\mu x})$

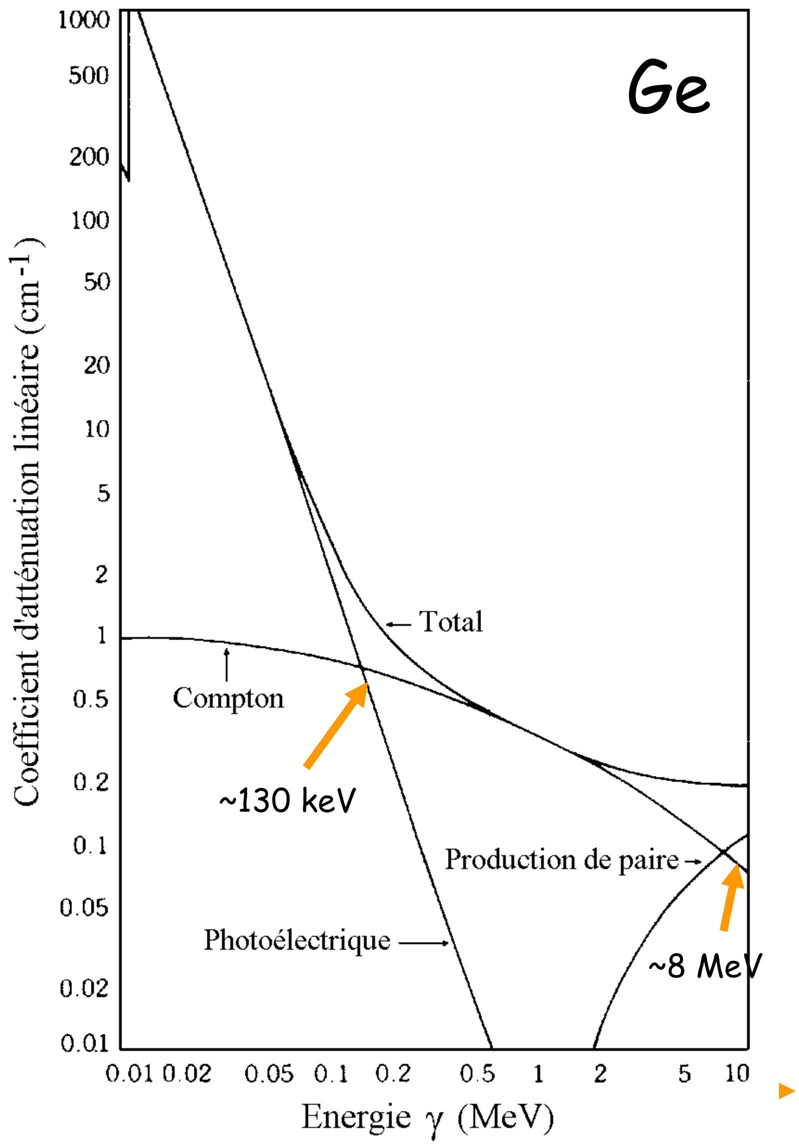
where x = thickness of matter
$\mu$ = linear absorption coefficient in $cm^{-1}$

$\mu_{Tot} = \mu_{Ph} + \mu_C + \mu_{PC} = f(E_\gamma, Z)$
with $\mu_i = \rho \times N_A \times \sigma_i(E_\gamma, Z) / A$

## Ge detector (Z=32)

- Excellente energy resolution
  ~ 2,0 keV at 1,3 MeV
  **γ-ray spectroscopy**
- Compton effect between
  130 keV and 8000 keV

**Compton background reduction**

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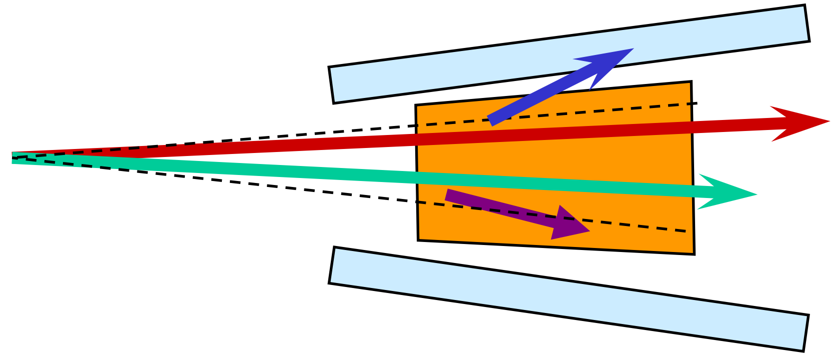
# Current spectrometers: suppression shields



**BGO suppression shield**

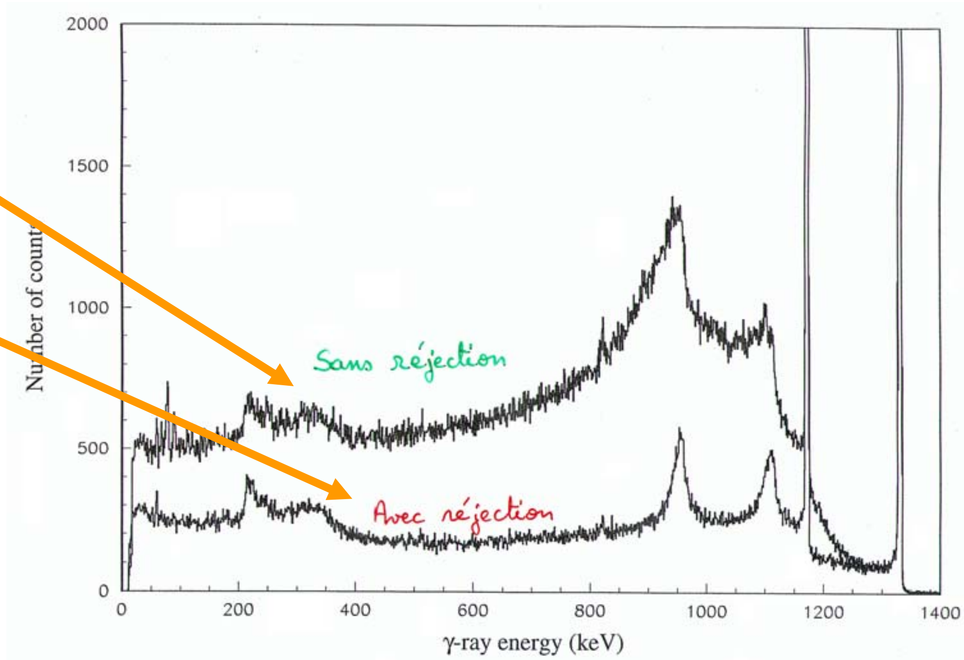
- Bare Ge crystal

  **P / T ~ 0,25**

- Suppressed Ge crystal

  **P/T ~ 0,60**

**Background reduction by a factor 3**

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# Current spectrometers: characteristics

Photopeak detection efficiency PE

Resolving power R

Observational limit L

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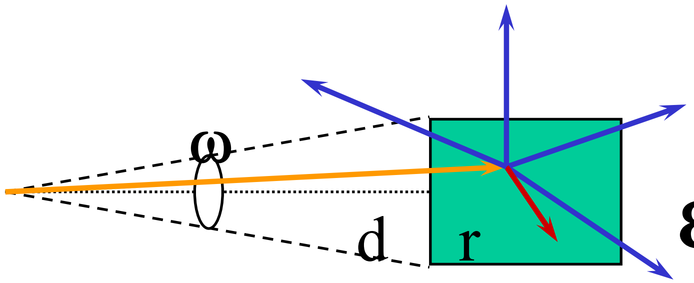
# Current spectrometers: characteristics

**Photopeak detection efficiency PE**

- **Full energy peak** = Multiple Compton scattering + photoelectric interaction
- $\varepsilon_p \omega$ = full energy detection efficiency (photopeak)
- Spectrometer composed of **N** identical detectors




$\varepsilon_p \sim 20\%$

$$PE = N\varepsilon_p\omega \quad \text{(probability < 1)}$$

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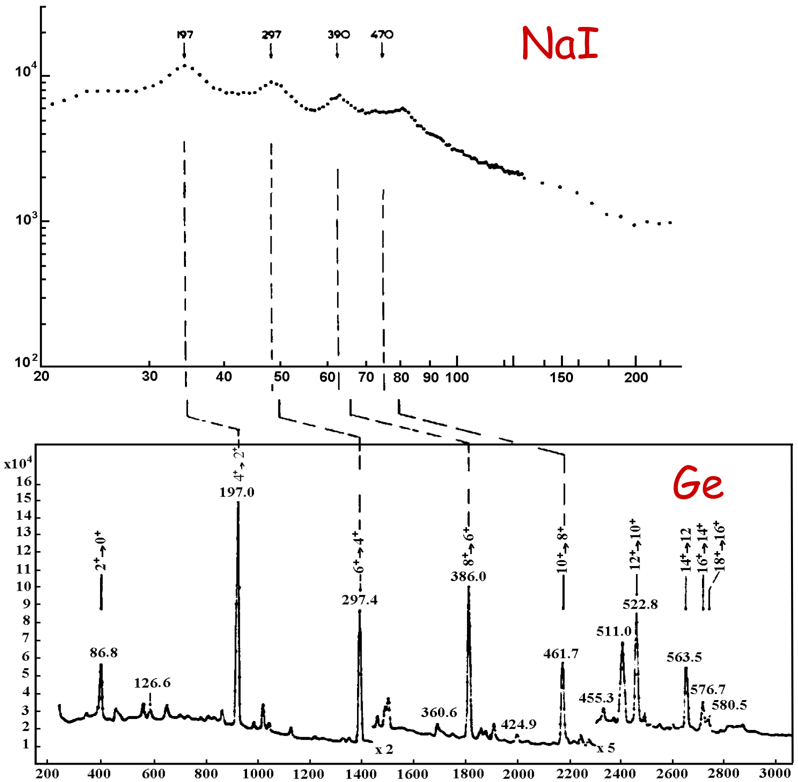
# Current spectrometers: characteristics

**Resolving power R**

$R = (\Delta E \,/\, FWHM) \times P/T$

where $R > 1$

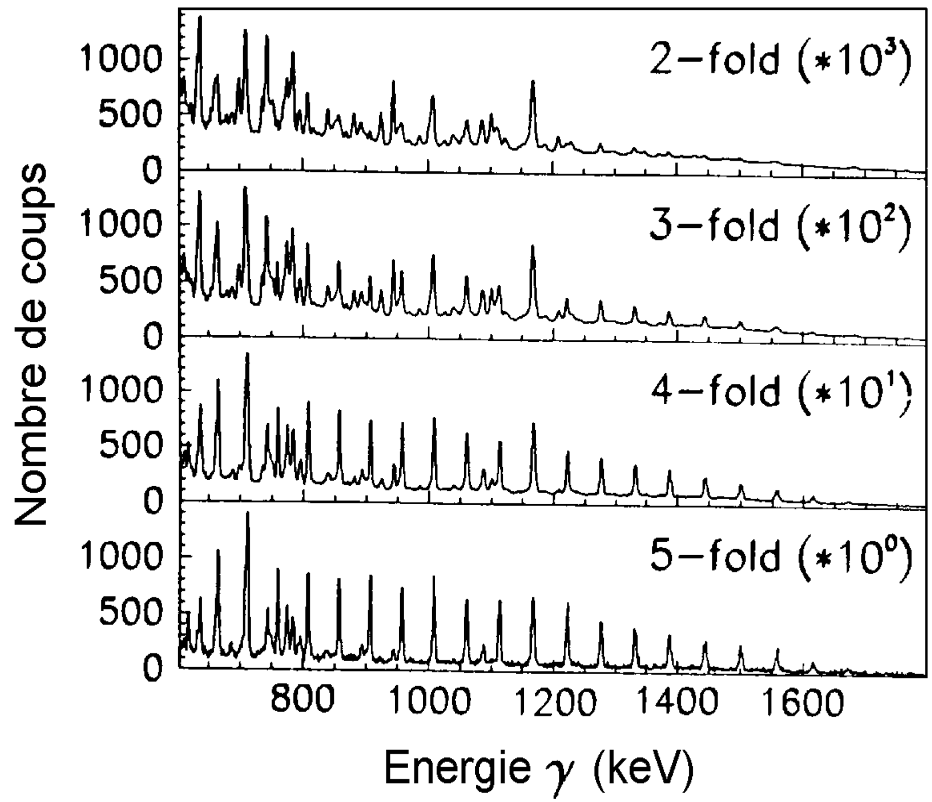



**Selectivity**

Fold = degree of coincidence

$\gamma\gamma$ -> fold = 2

$\gamma\gamma\gamma$ -> fold = 3

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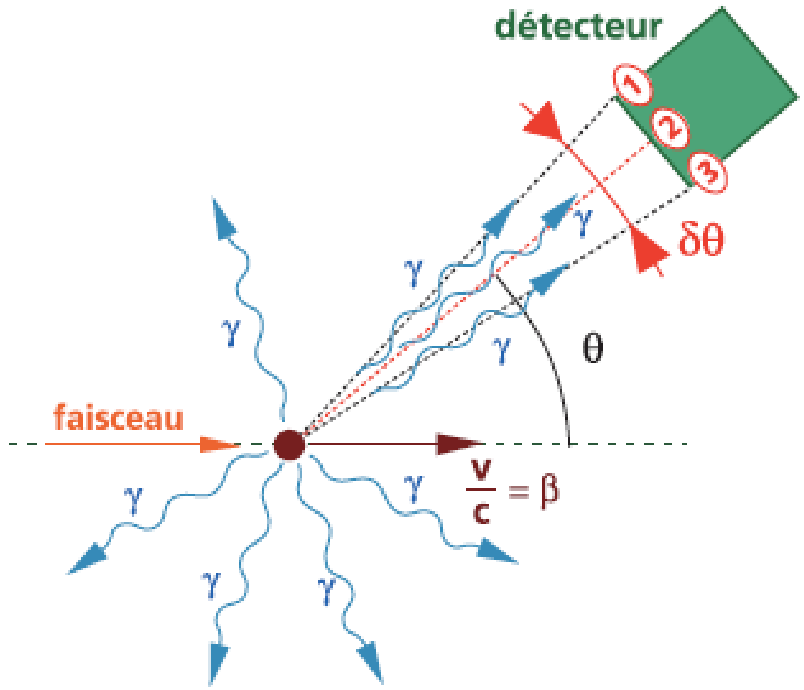
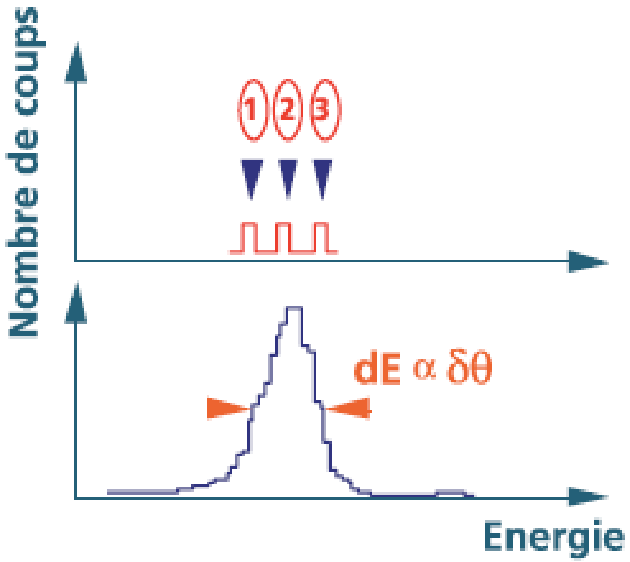
# $\gamma$ peak Doppler broadening




*B. Gall courtesy*

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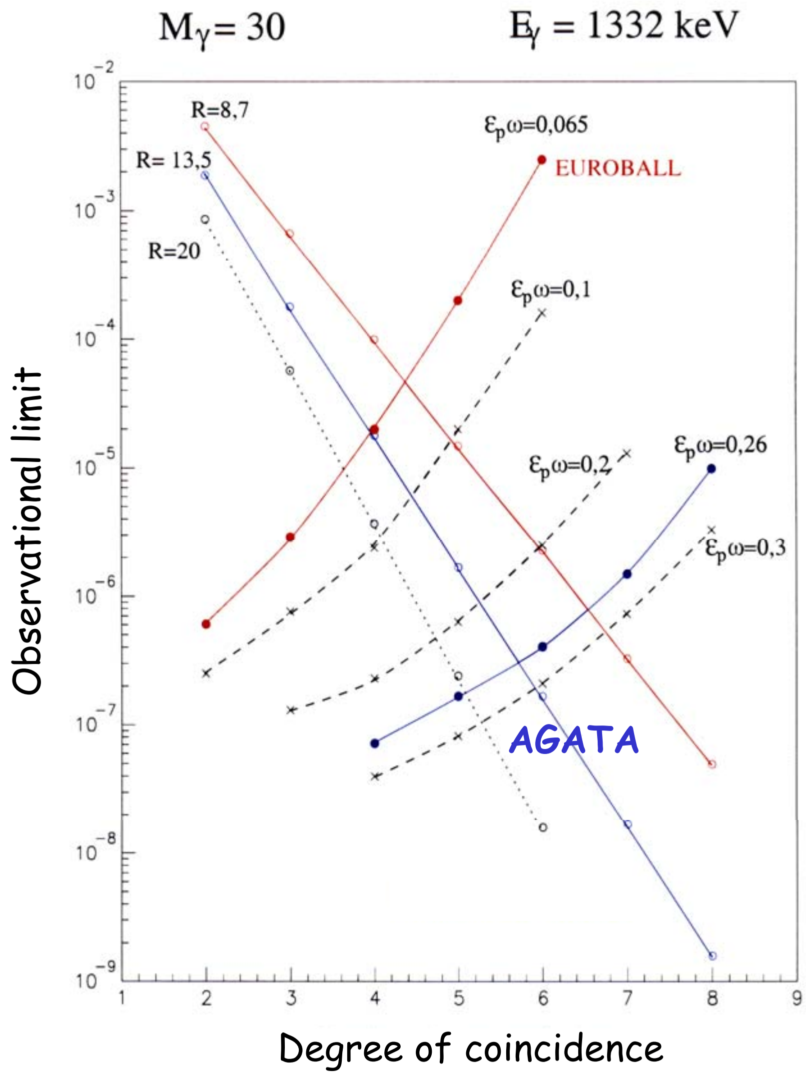
# Current spectrometers: characteristics

**Observational limit L**

$$L = (PE)^{fold} \times (R)^{fold}$$

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# Current spectrometers: arrays

High angular momentum

***EUROBALL***

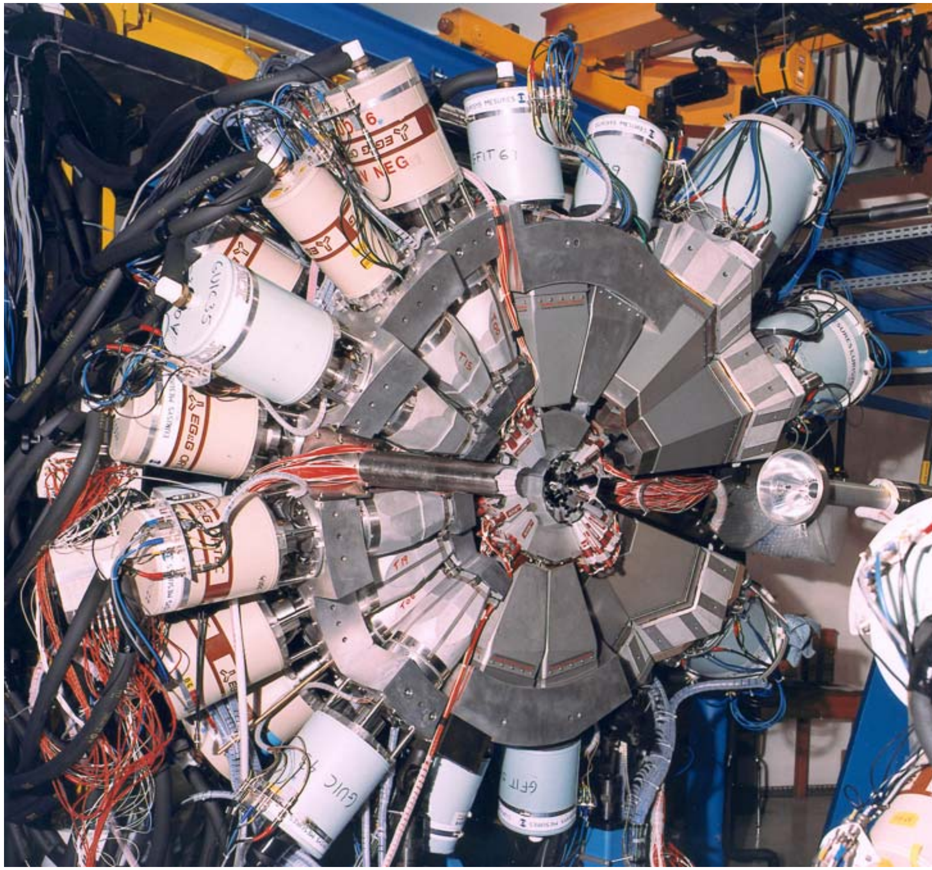
239 Ge crystals

- 30 tapered : single Ge crystal
- 26 clovers : composite detector (4 crystals)
- 15 clusters : composite detector (7 crystals)

PE = 0,094 R = 8,7

Average fold ~4 for $M_\gamma = 30$

$L \sim 10^{-4} - 10^{-5}$



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# Current spectrometers: arrays

High angular momentum

***Gammasphere (USA)***

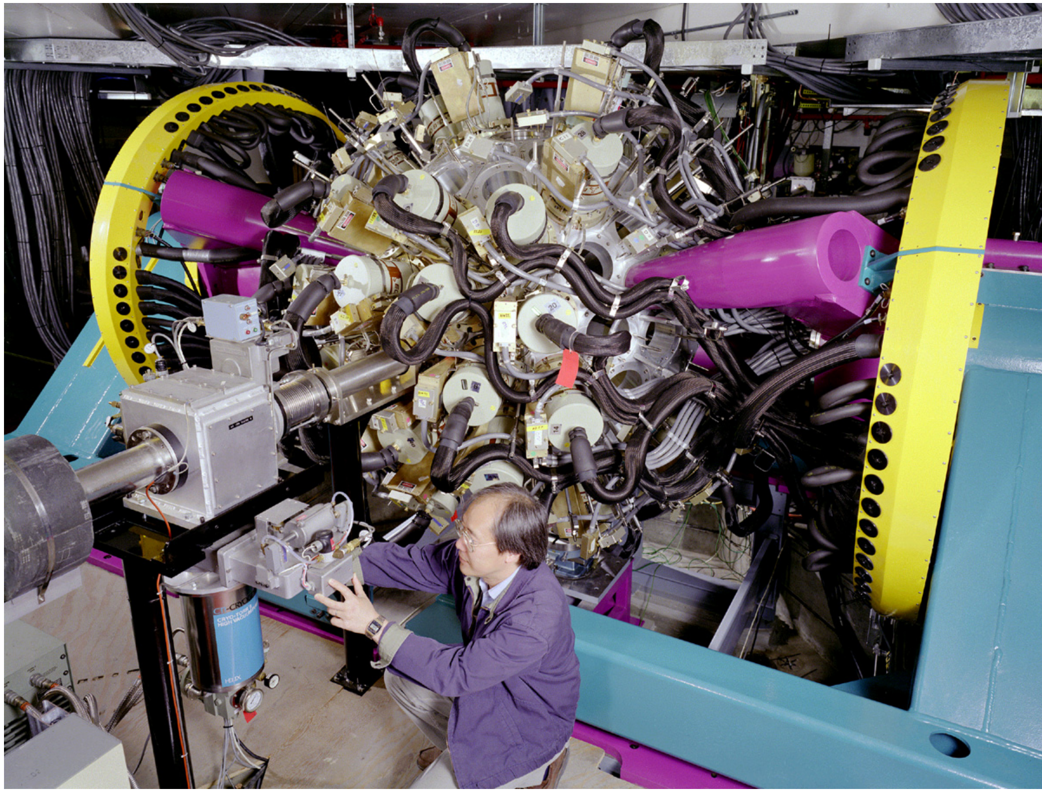
110 Ge crystals

- 40 tapered : single Ge crystal
- 70 tapered : single Ge crystal electrically segmented in 2

PE = 0,094 R = 8,5

Average fold ~4 for $M_\gamma = 30$

$L \sim 10^{-4} - 10^{-5}$



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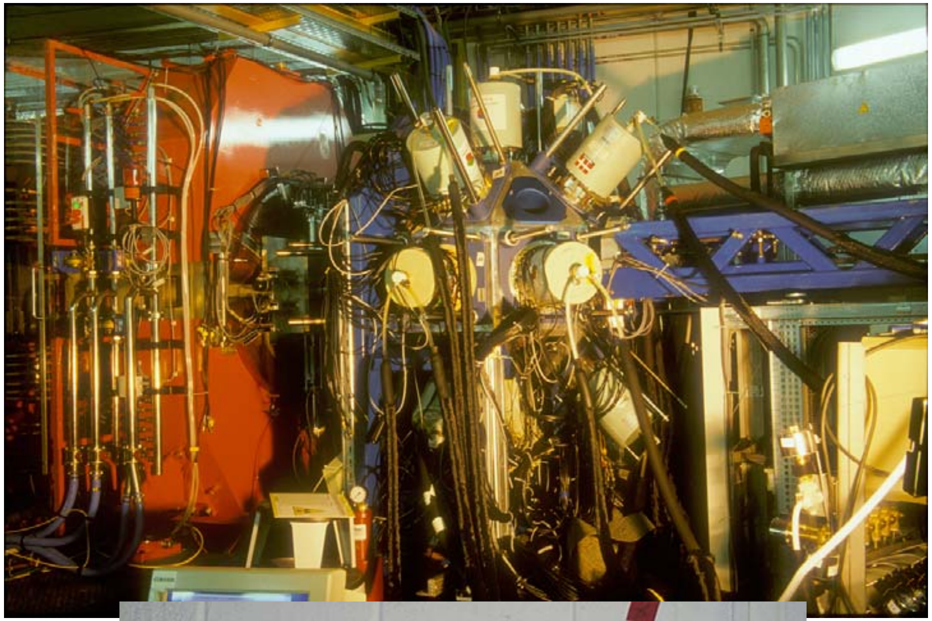
# Current spectrometers: arrays



Exotic nuclei and large recoil velocities

***EXOGAM***

**64 Ge crystals each segmented in 4**

- **16 clovers : composite detector (4 crystals)**
- **256 segments**

**PE = 0,16** **R ~ 8**

Average fold ~1-2 for $M_\gamma$ = 1-10

**L ~ 10 $^{-2}$**

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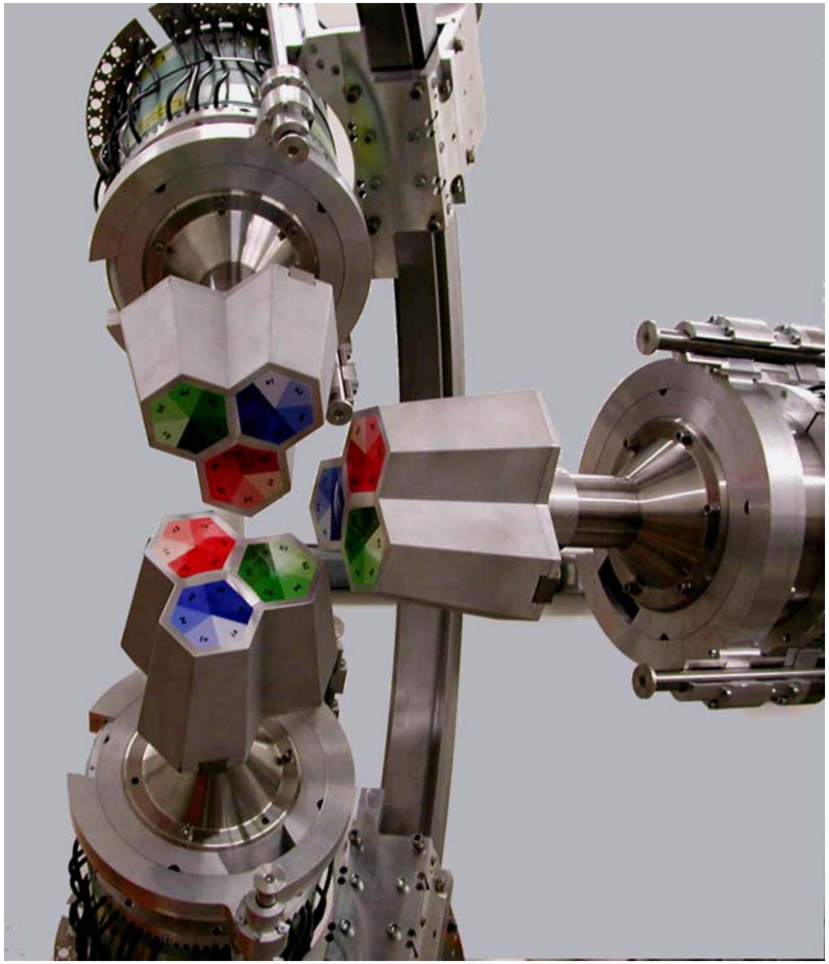
# Current spectrometers: arrays

Exotic nuclei and large recoil velocities

***MINIBALL***

**40 Ge crystals each segmented in 6**

- **8 clusters : composite detector (3 crystals)**
- **4 clusters : composite detector (4 crystals)**
- **240 segments**



**PE = 0,165** **R = 14**

Average fold ~1-2 for $M_\gamma$ = 1-10

**L ~ $10^{-2}$ - $10^{-3}$**

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# From Euroball to AGATA

## Current arrays

$\Omega_{ge}$ ~ 40 %
PE ~ 10 %
**R** ~ 8 for v/c = 2.5 %
**R** ~ 2 for v/c = 10 %

## New generation of spectrometers

$\Omega_{ge}$ ~ 80 %
PE ~ 40 %
**R** ~ 15 for v/c = 2.5 %
**R** ~ 8 for v/c = 10 %

## Technical possibilities

- Array of 900 Ge detectors of large volume
  - Inner radius ~ 50 cm
  - No suppression shields
  - Add-back partial energy deposite in adjacent crystals

**Expensive and performance not optimum**

- Array of 100-200 multi-segmented Ge detectors
  - Inner radius ~ 23 cm
  - Small elementary detection volume (segments)
  - Determination of γ-ray –Ge interaction points (Pulse Shape Analysis = PSA)
  - Tracking of γ-ray in Ge -> path reconstitution

***About 2 times less expensive***
***Technological challenge***

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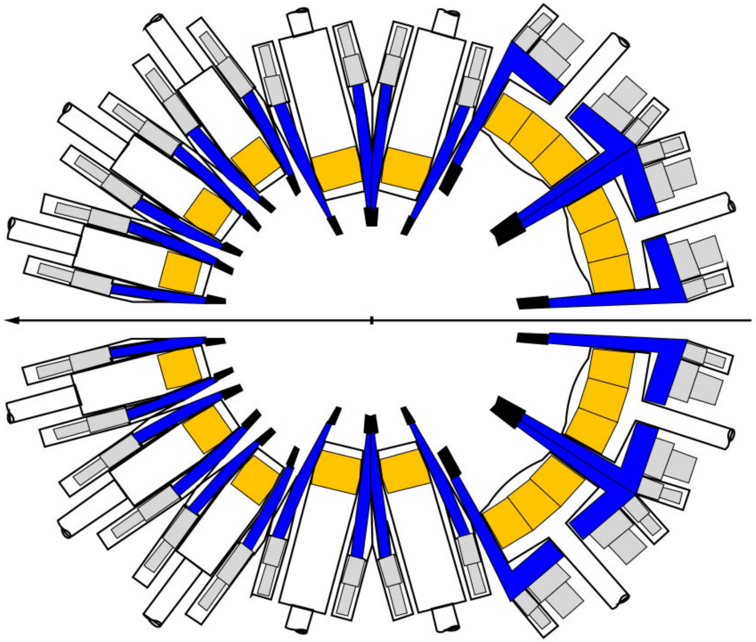
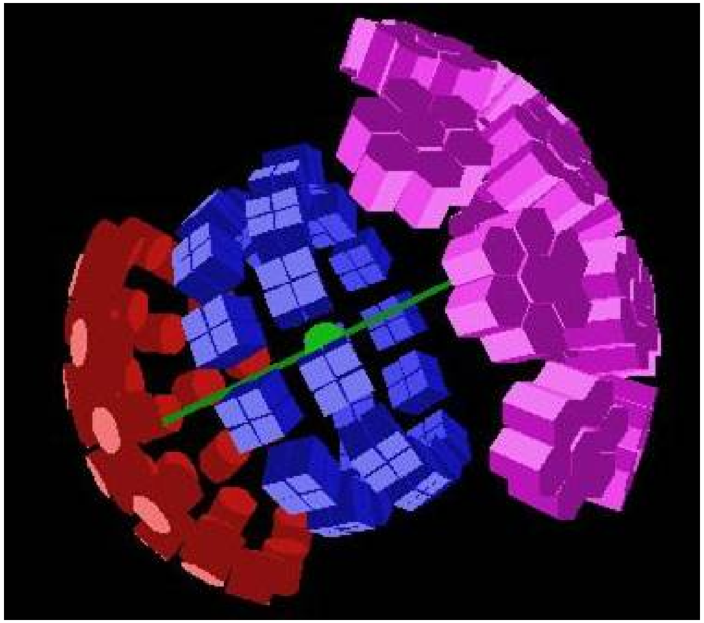
# From Euroball to AGATA



**EUROBALL**
**N = 239**



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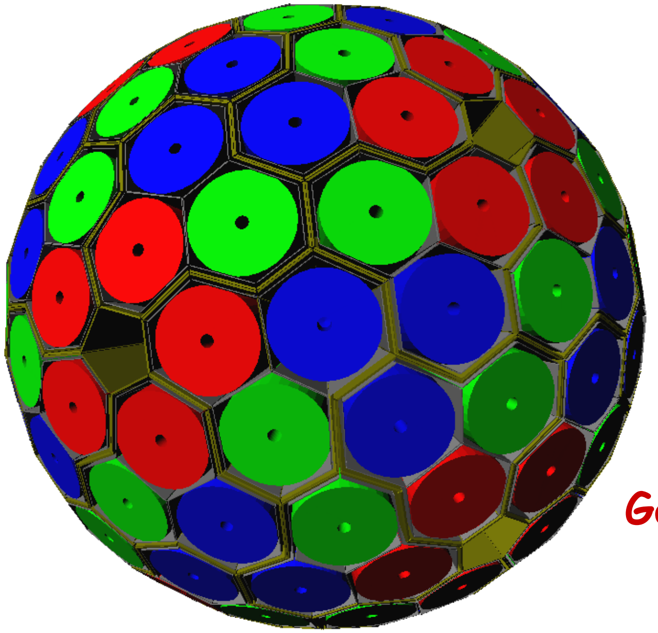
# AGATA geometry
# Advanced GAmma Tracking Arr



180 cristals of three types
~ 362 kg of Ge
60 identical triple clusters cryostats
6840 electronic channels
FWHM/E of 2‰
stability of $10^{-4}$
synchronisation 1 ns


**Gain 2 to 3 orders of magnitude**

| | Mγ=1 | Mγ=30 |
|---|---|---|
| Efficiency, Peak/Total: | 43%, 0,58 | 28%, 0,49 |
| Currently | 10%, 0,58 | 6%, 0,49 |
| FWHM (1MeV, V/C=50%) | 10 keV | |
| Currently | 65 keV | |
| Counting rates | 3 MHz | 300 kHz |
| Currently | 1 MHz | 20 kHz |

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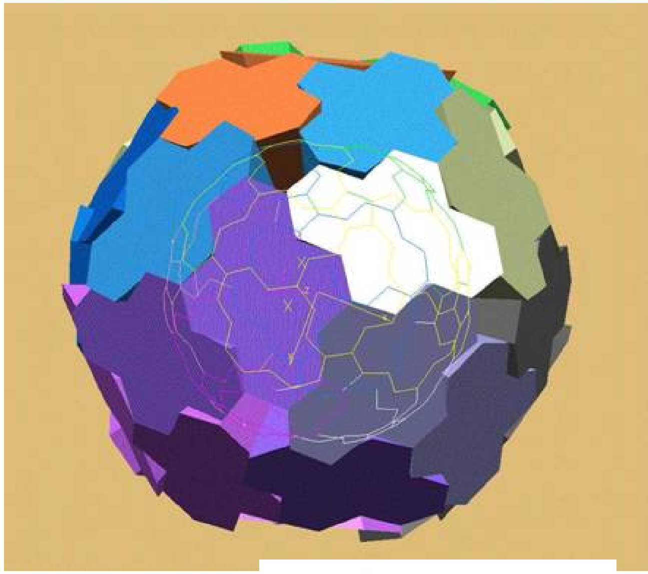
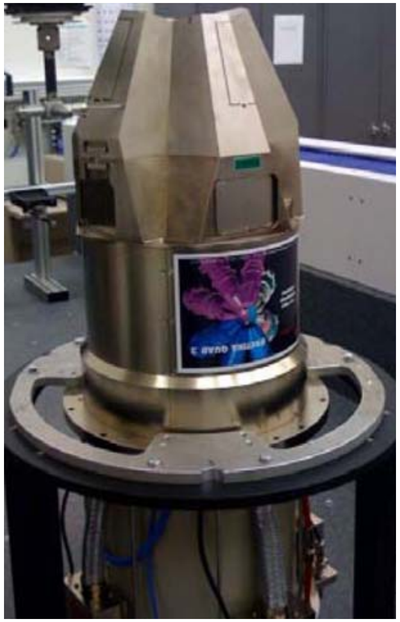
# GRETA / GRETINA

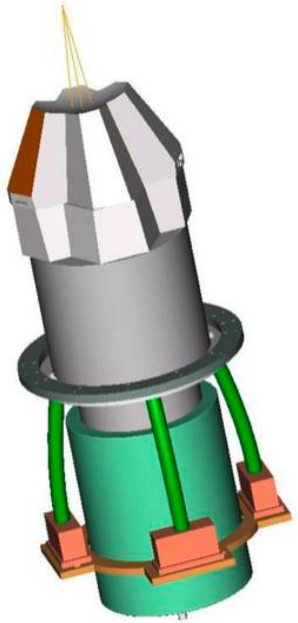


**US project**

**Characteristics**

- **120 cristals of 2 types each segmented in 36**
- **30 quadruple clusters**
  Segments: hot FETs (FWHM + 0,2 keV)
- 4440 electronic channels; **100 MHz, 14 bits**
- PSA : Evolutive Grid Search
- Tracking gamma : Forward tracking





**GRETINA**

- **1π configuration**
- **Approuved in oct. 2007**
- 7 Quad.
- Technical tests and commissioning in feb. 2011
  ~6 months at Laurence Berkeley Lab.
- In operation at NSCL, ORNL and ANL
  2012-2013

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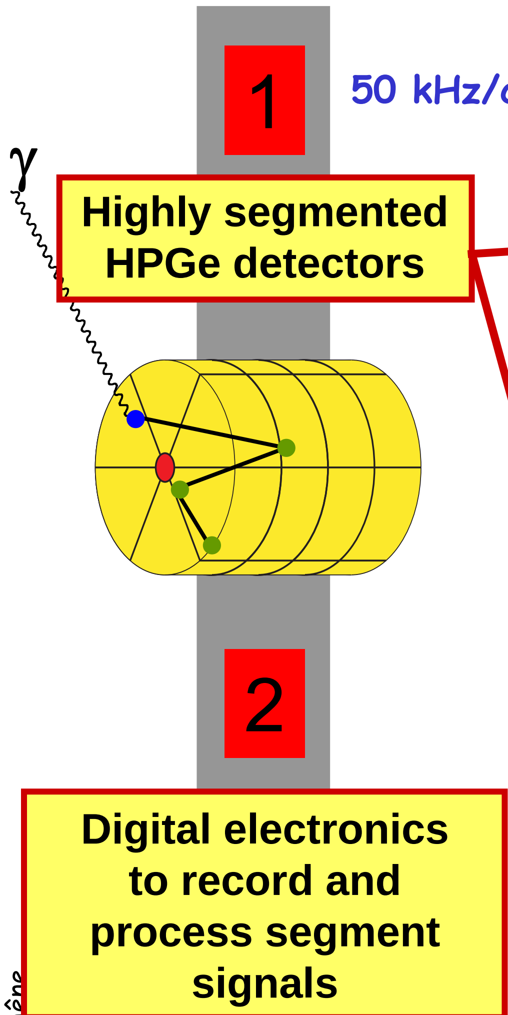
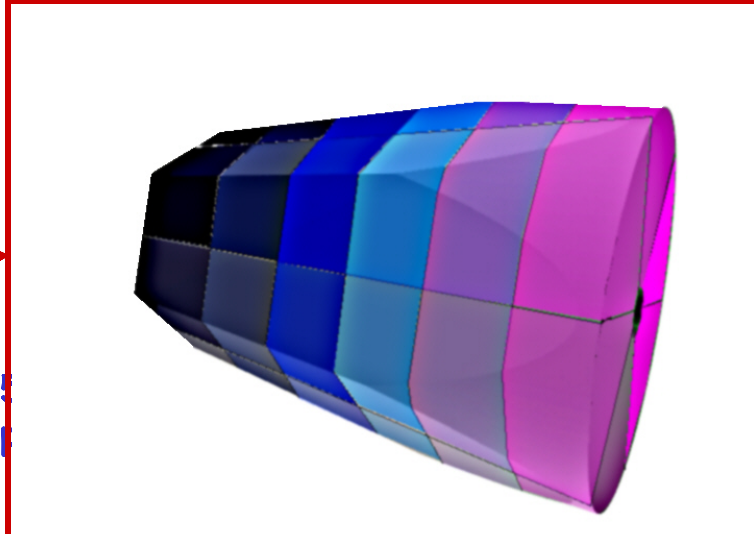
# Gamma-tracking principle

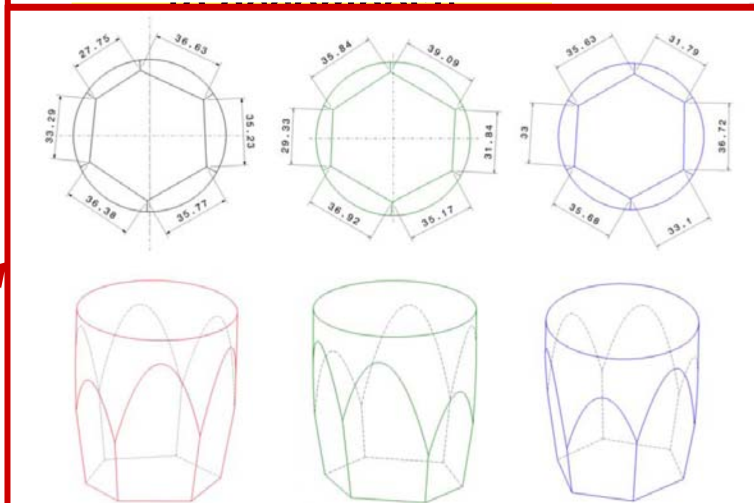
Data Rate in full Agata : 300 kHz @ Mγ = 30

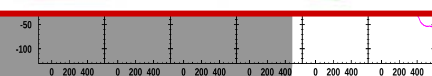
15 x 5 MB/s : 75 MB/s
180 x 5 MB/s : 900 MB/s

50 kHz/crystal






**N-type HP Ge crystals segmented in 36**

- Transversal segmentation
  6 slices
- Longitudinal segmentation
  6 sectors
- Vacuum tight encapsulation in aluminium can
- Asymmetric hexaconical shaping
  **3 shapes**
- Three shapes gathered in the same cryostat
  **Unique triple cluster**

**reconstructed γ-rays**

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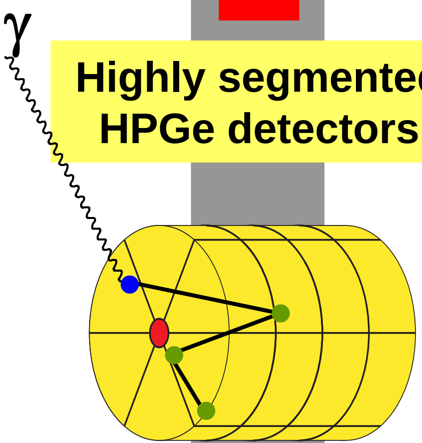
# Gamma-tracking principle

15 x 5 MB/s : 75 MB/s
180 x 5 MB/s : 900 MB/s

Data Rate in full Agata : 300 kHz @ $M_\gamma$ = 30

1

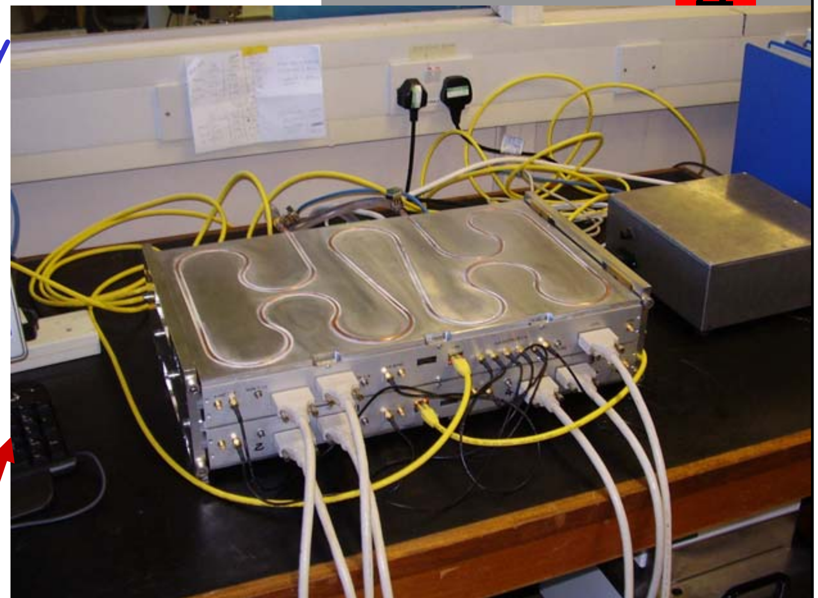
50 kHz/cry




**Highly segmented HPGe detectors**

2

**Digital electronics to record and process segment signals**



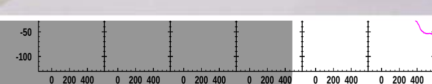
4

**Digitiser**
Development : **IPHC**
+ Liverpool + Daresbury
Team Leader: P.Medina

- 36 channels + 2 total energy dynamics
- Sampling conditions
  100 MHz, 14 bits
- Slow control in standalone

- **1 Digitiser per Ge cristal**
- 2 modules core and segment

- Average performance :
  ENOB = 12,3 (TNT2 = 11,8)
  SNR = 75,8 dB (TNT2 = 72,8




**reconstructed γ-rays**

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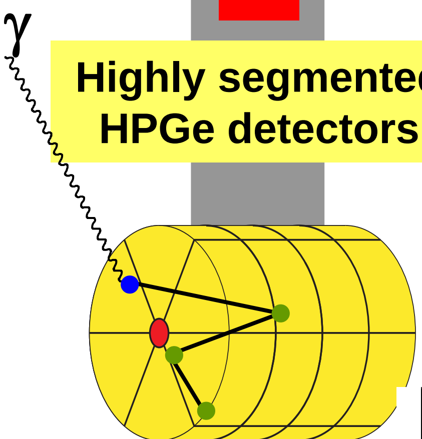


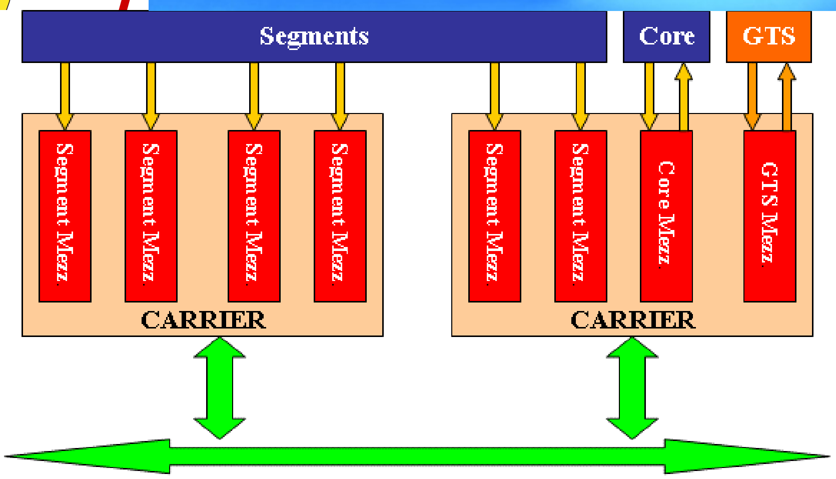


2

Digital electroni to record and process segme signals

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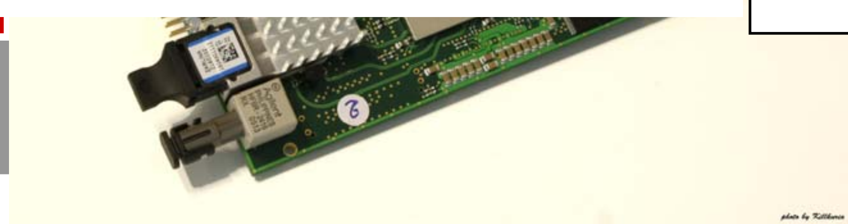
**Pre-processing**
Development : Orsay
+ Padova + Daresbury

- Receive the Digitiser signals
- Perform in real time and channel/channel :
  - **Calculation of the deposited energy per channel** (IPHC)
  - **Extract the leading edge of the charge signal**
  - **Timestamp the events**
  - Transfer data to the PSA farm
  - Receive/distribute Trigger and clock

- ***Standard ATCA*** (2 TC/crate)
- 2 Carrier cards per crystal
- 8 mezzanine cards per crystal



onstructed γ-rays

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## Pulse shape analysis (PSA)

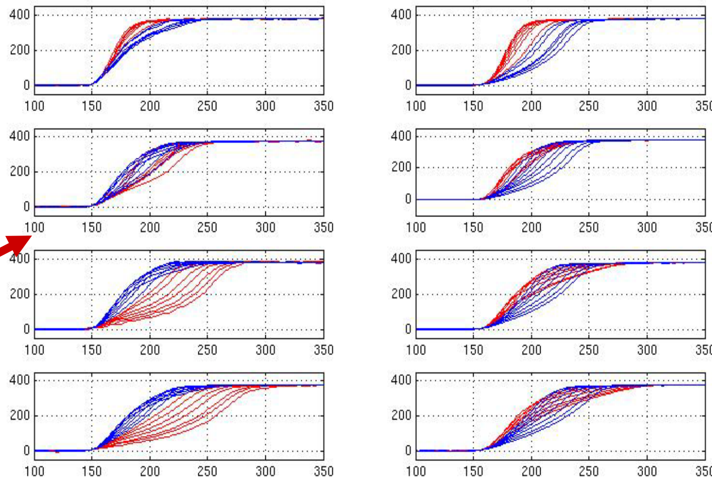
- PSA : key point of the project
  - On-line calculation
  - Several interactions/segment
  
  = sum of signals generated/interaction

- Several algorithms (FWHM, CPU time)
  - Grid search (5 mm, 3 msec)
  - Genetic (2,5 mm, 1000 msec)
  - Wavelets (5 mm, not evaluated)
  - Neural network (3,5 mm, 6 msec)
  - Matrix method (1,2 mm, 20 msec)
  
  (Multiple int. :3 à 7 mm, 50 msec)

4

Identified interaction points

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

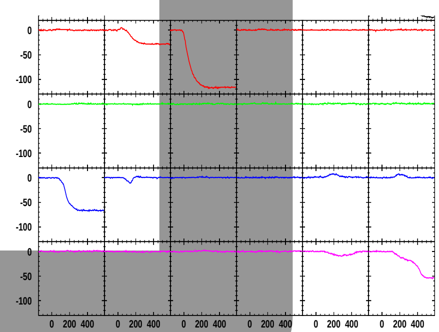



ΜB/s
crystal

Pulse Shape Analysis to decompose recorded waves

0 MB/s
r crystal

3




~8 MB/s
< 100 MB/s

reconstructed γ-rays

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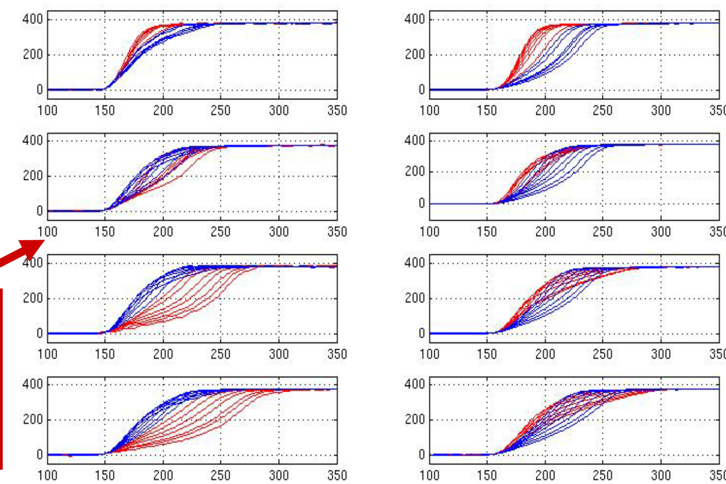
4

Identified interaction points
$(x,y,z,E,t)_i$

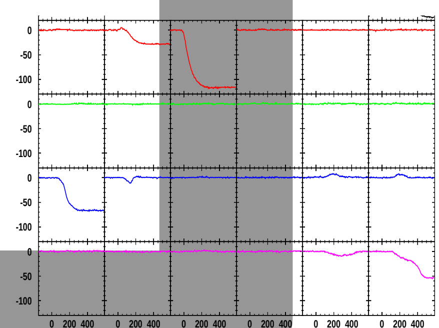
B/s
crystal



Pulse Shape Analysis to decompose recorded waves

0 MB/s
crystal

3



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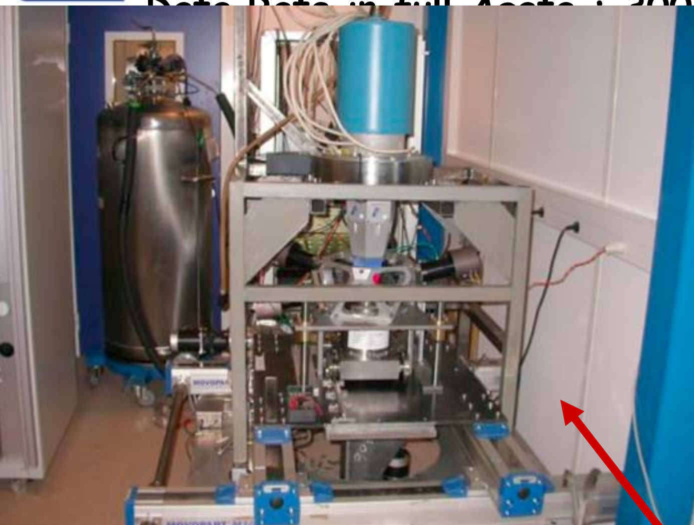
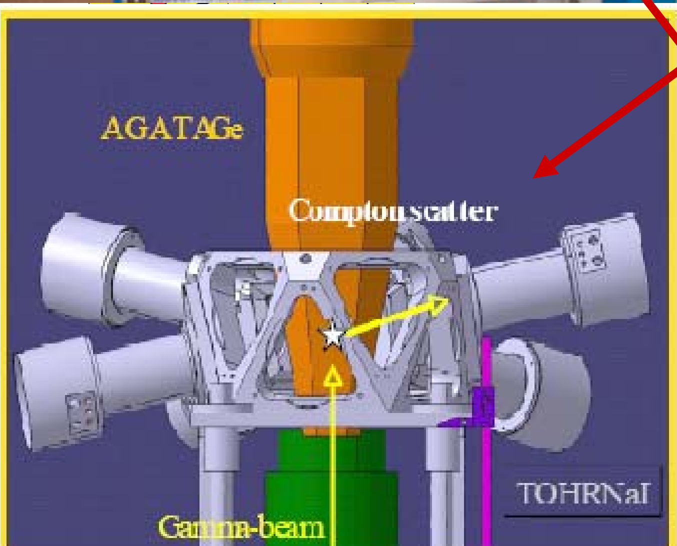





**Identified interaction points**

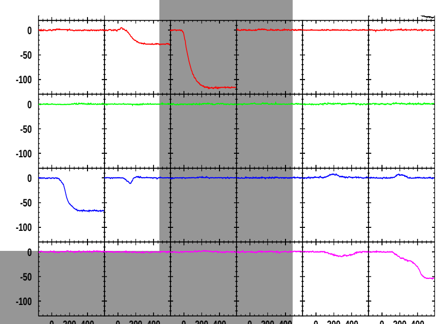
**$(x,y,z,E,t)_i$**

**Pulse Shape Analysis to decompose recorded waves**

B/s
crystal

0 MB/s
crystal

3




reconstructed γ rays

## Ge detector characterisation

- XYZ scanning table
  Liverpool / CSNSM / GSI / IPHC
  - **Table + TOHR**
  - $^{137}$Cs source of 500 MBq activity
  - **TOHR: NaI + 200μm collimators**
  - Ge – NaI coincidences
- Performance
  - 400 pulses/h front of crystal
  - 8 pulses/h back of crystal

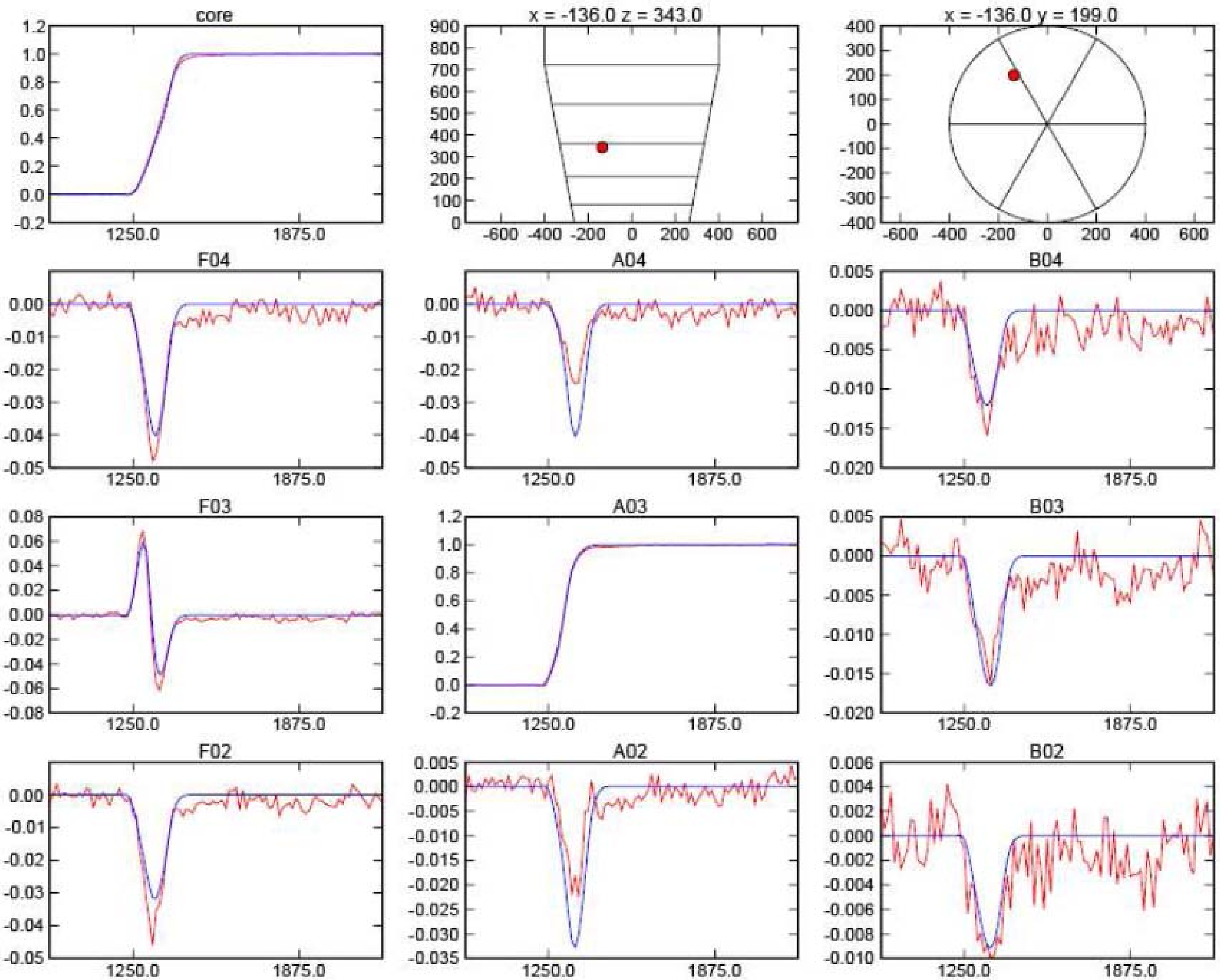
**One crystal scan in ~1,5 month**
3 months in Liverpool
(~260 measurement points)

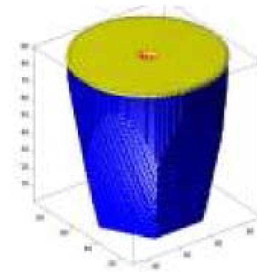
- Future (GSI – IPHC)
  - New scanning concept
  - Direct measurement – no coincidences

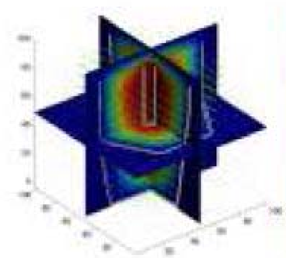
**One crystal scan in 1-2 weeks**
(~15000 measurement points)

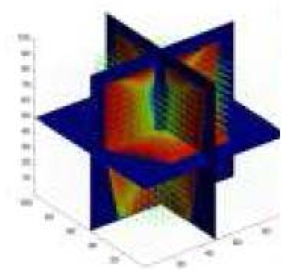
# Gamma-tracking principle

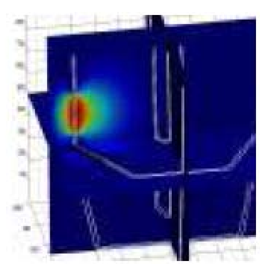
## Scan data vs. detector simulation





Geometry


Electric field


Drift velocities


Weighting potential

Excellent overall agreement between simulation and scan data

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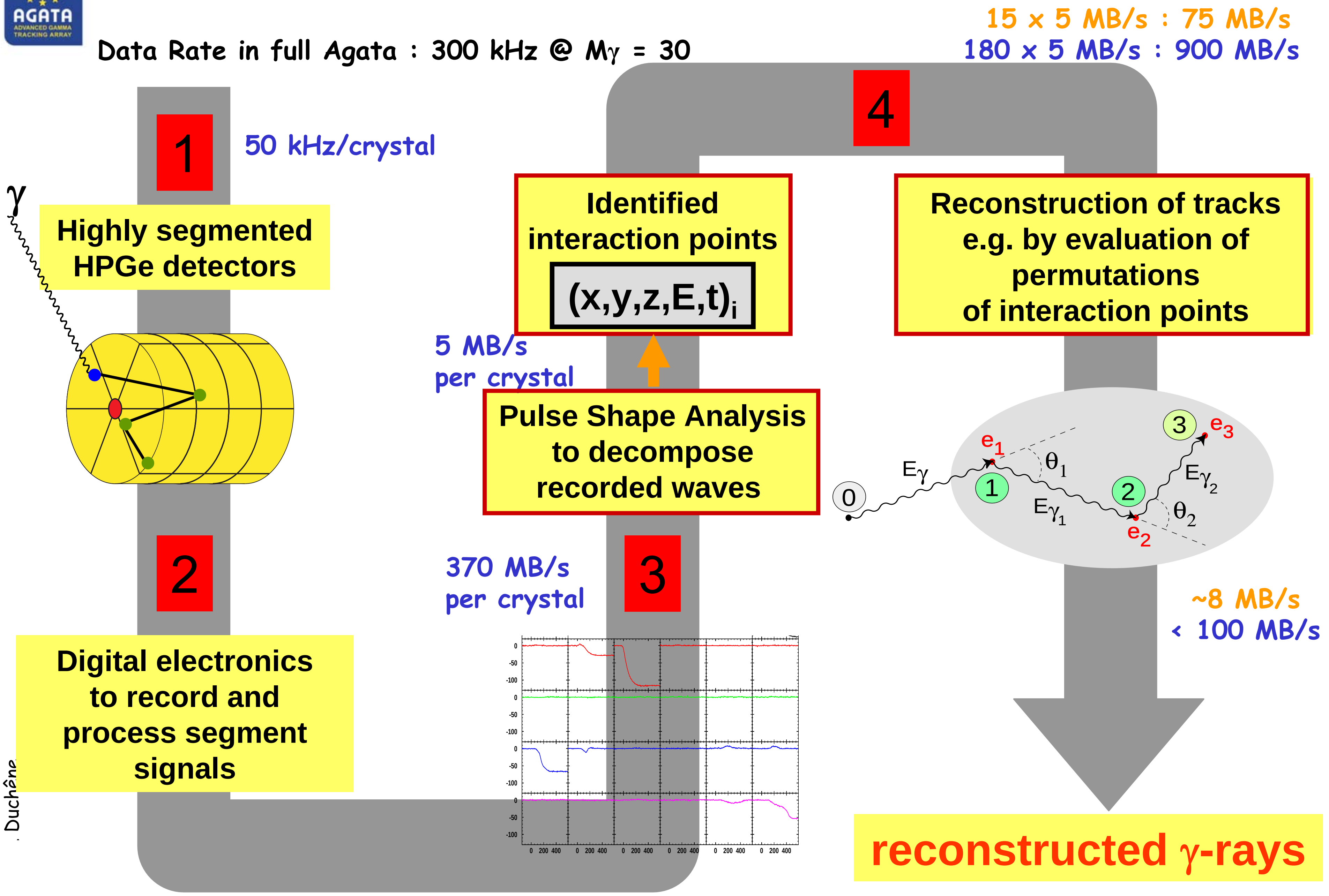
Duchêne

# Gamma-tracking principle

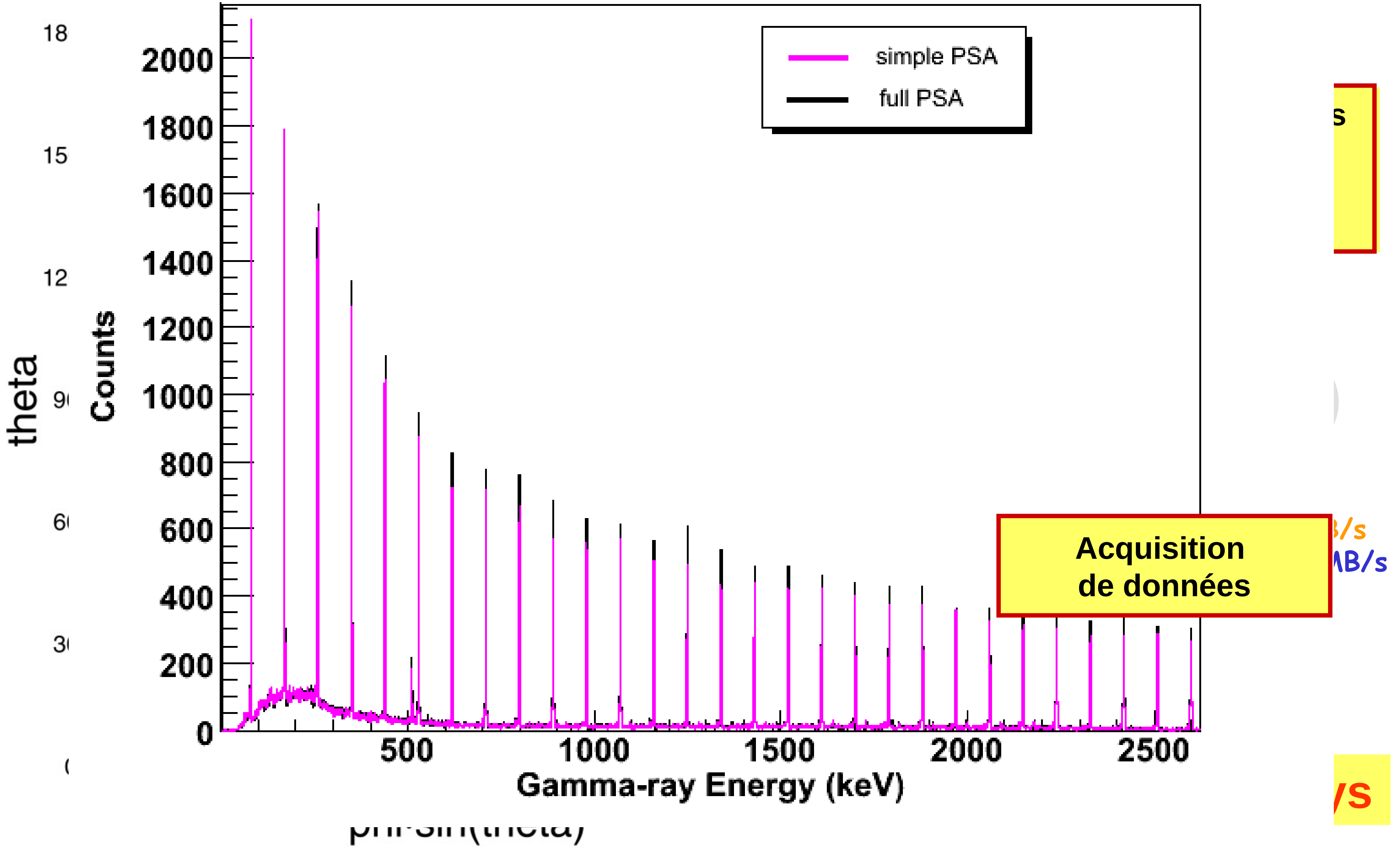


# Gamma-tracking principle

15 x 5 MB/s : 75 MB/s

180 x 5 MB/s : 900 MB/s

Data Rate in full Agata : 300 kHz @ Mγ = 30



# Gamma-tracking principle

Data Rate in full Agata : 300 kHz @ M

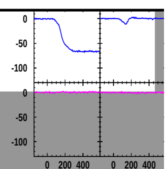
## Data acquisition (DAQ)

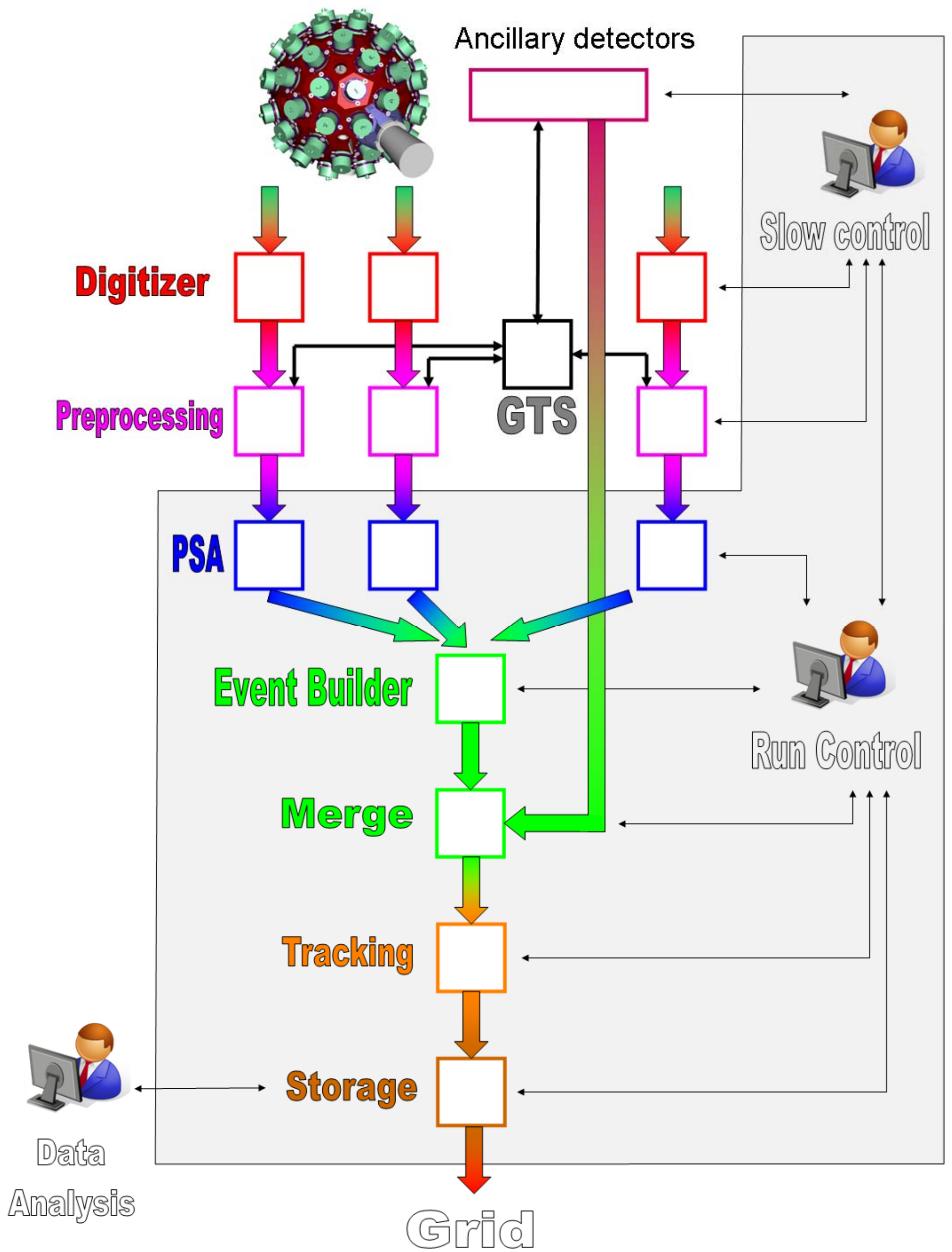
- **Large data flow to handle**
  - Manages the data flux from electronics output down to data storage
  - Based on NARVAL (ADA language) developed at Orsay
  - 370 MB/sec per crystal before PSA farm
  - 5 MB/sec per crystal after PSA farm
  - 900 MB/sec in the tracking farm
  - < 100 MB/sec on disk

**About 60 TB for a one week experiment**

- **Hardware**
  - Based on 1U pizza boxes
  - 1 pizza box per crystal + 14 U common services

signals

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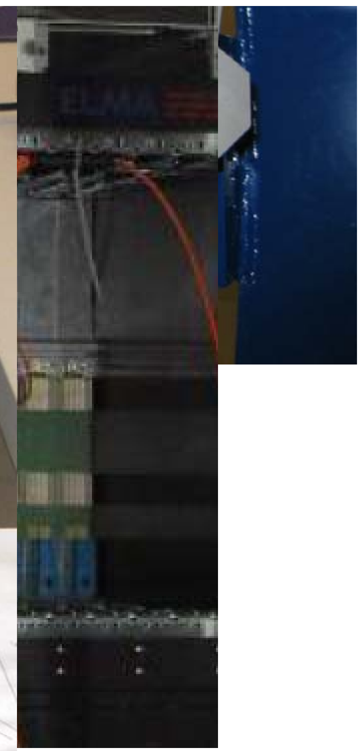
# Installation at Legnaro National Lab. (It)

**One full AGATA data acquisition chain validated in beam !**

The AGATA Demonstrator is operational

5 TCs are being integrated and commissioned up to december 2009

Physics campaign at LNL early 2010 for at least one year

Parallel production and construction of phase 1/3 of AGATA

Unique tool when coupled to SPIRAL 2

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# AGATA

## Plan

- Gamma-ray-matter interactions
- Escape suppression technique
- AGATA, the gamma-ray tracking technique and the Demonstrator installation
- **AGATA performance and physics case**
- AGATA organisation and construction

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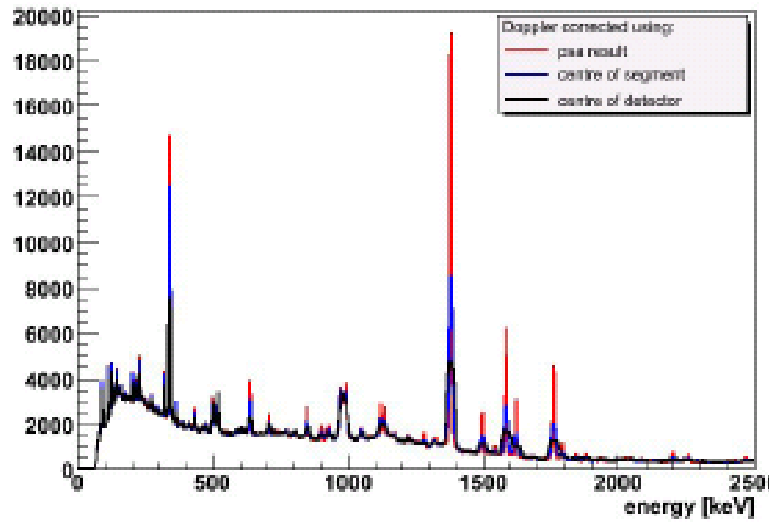
# The AGATA Demonstrator

**AGATA Demonstrator** (~10% of AGATA)

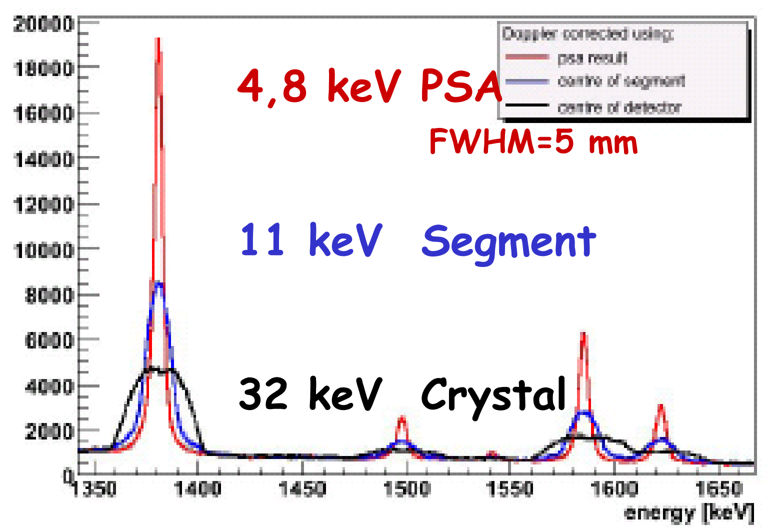
- 5 triple clusters (TC)
- 15 segmented crystals
- 570 electronic channels




**Performance at 1 MeV**

(13,5 cm to target)

| | | |
|---|---|---|
| | **Mγ=1** | **Mγ=20** |
| Eff, P/T: | 6,7%, 0,52 | 4,8%, 0,51 |
| | **β=0%** | **β=10%** |
| FWHM | 2,0 keV | 2,4 keV |

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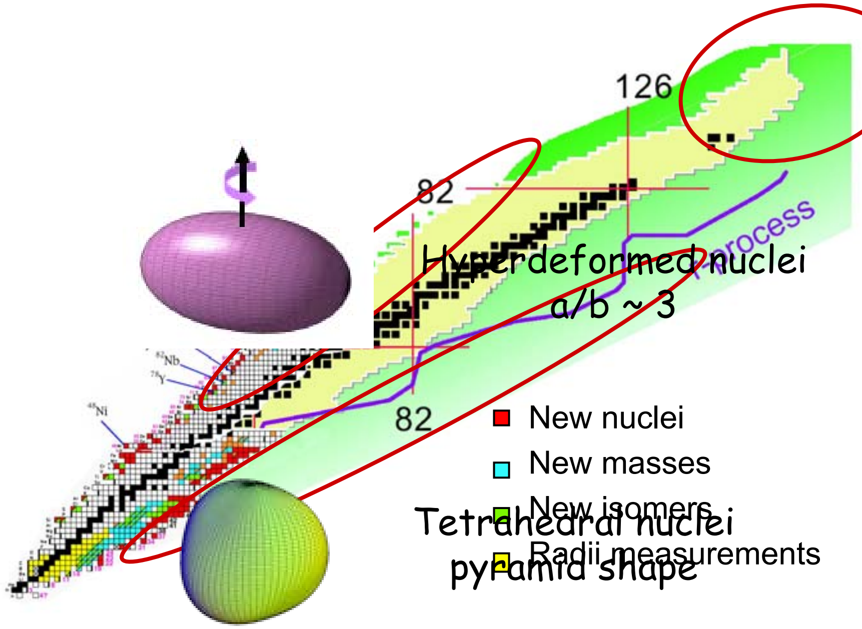
# Physics case

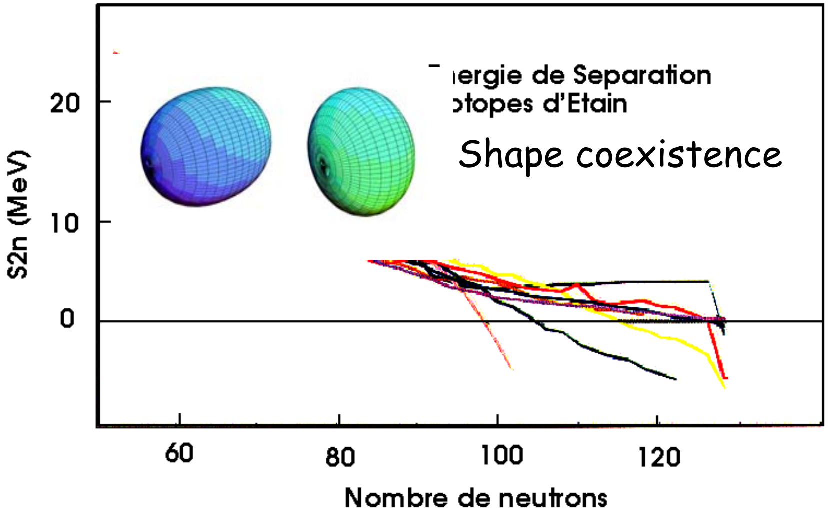
**Nuclear structure study in extreme conditions**

- Exotic nuclei
  (N/Z -> proton or neutron richness)
- Deformed nuclei
  (exotic shapes)
- Super-heavy nuclei
  (large proton number)

- Goal

Extension of the validity domain of the effective forces in the theoretical models

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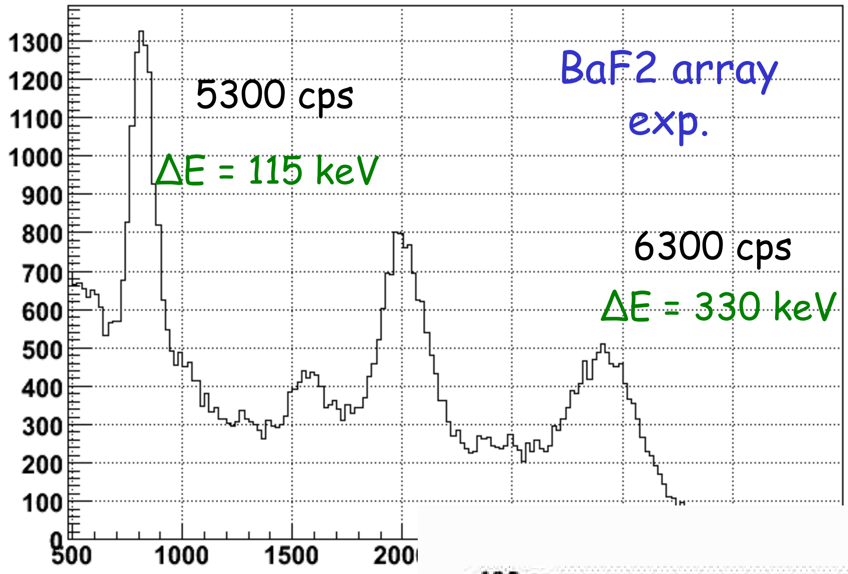
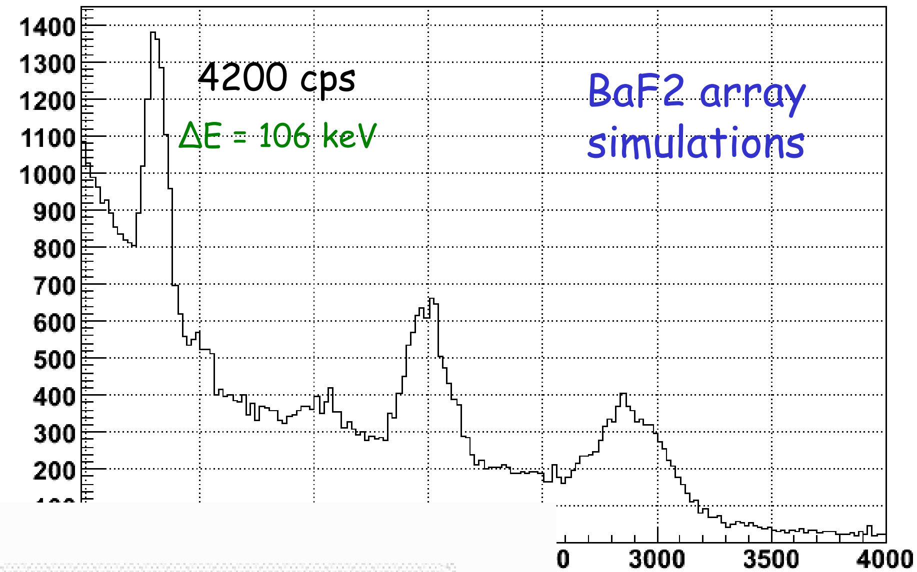
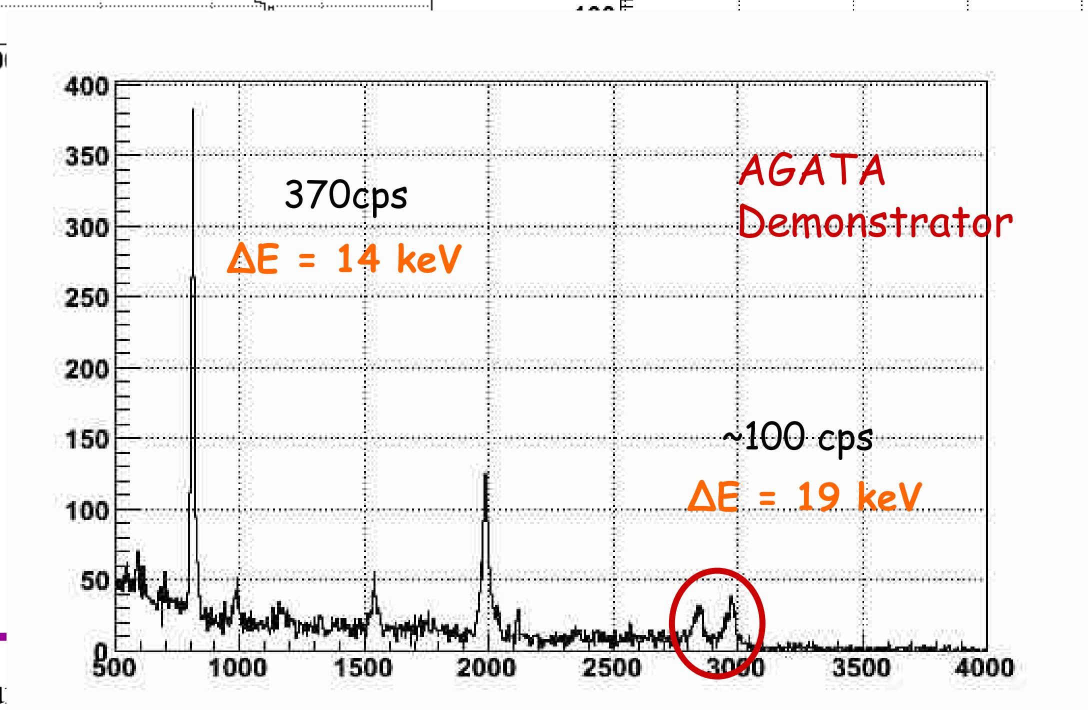
# Proton-rich nucleus $^{33}Cl$



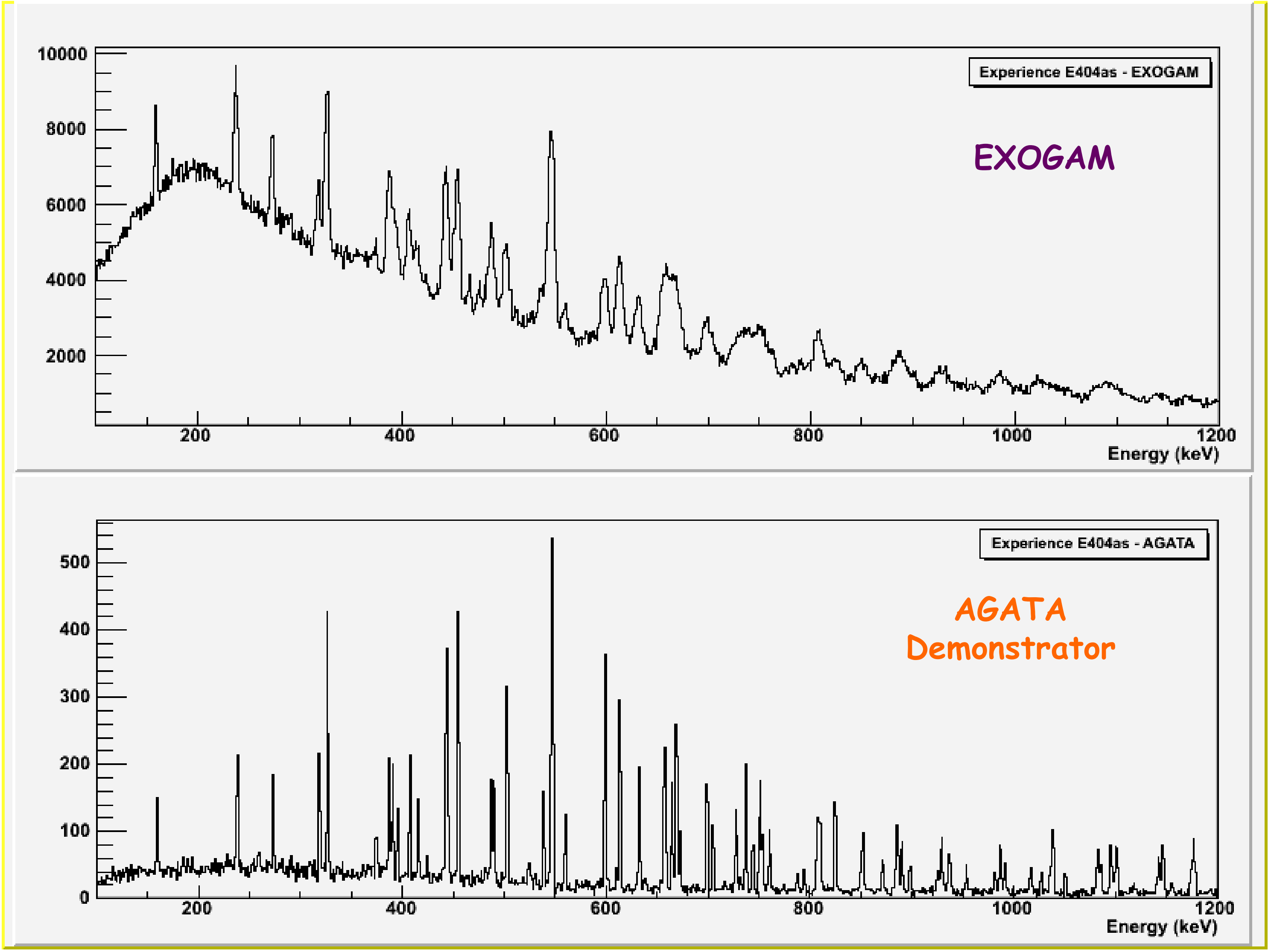




*Görgen et A. Bürger*

G. Duchêne

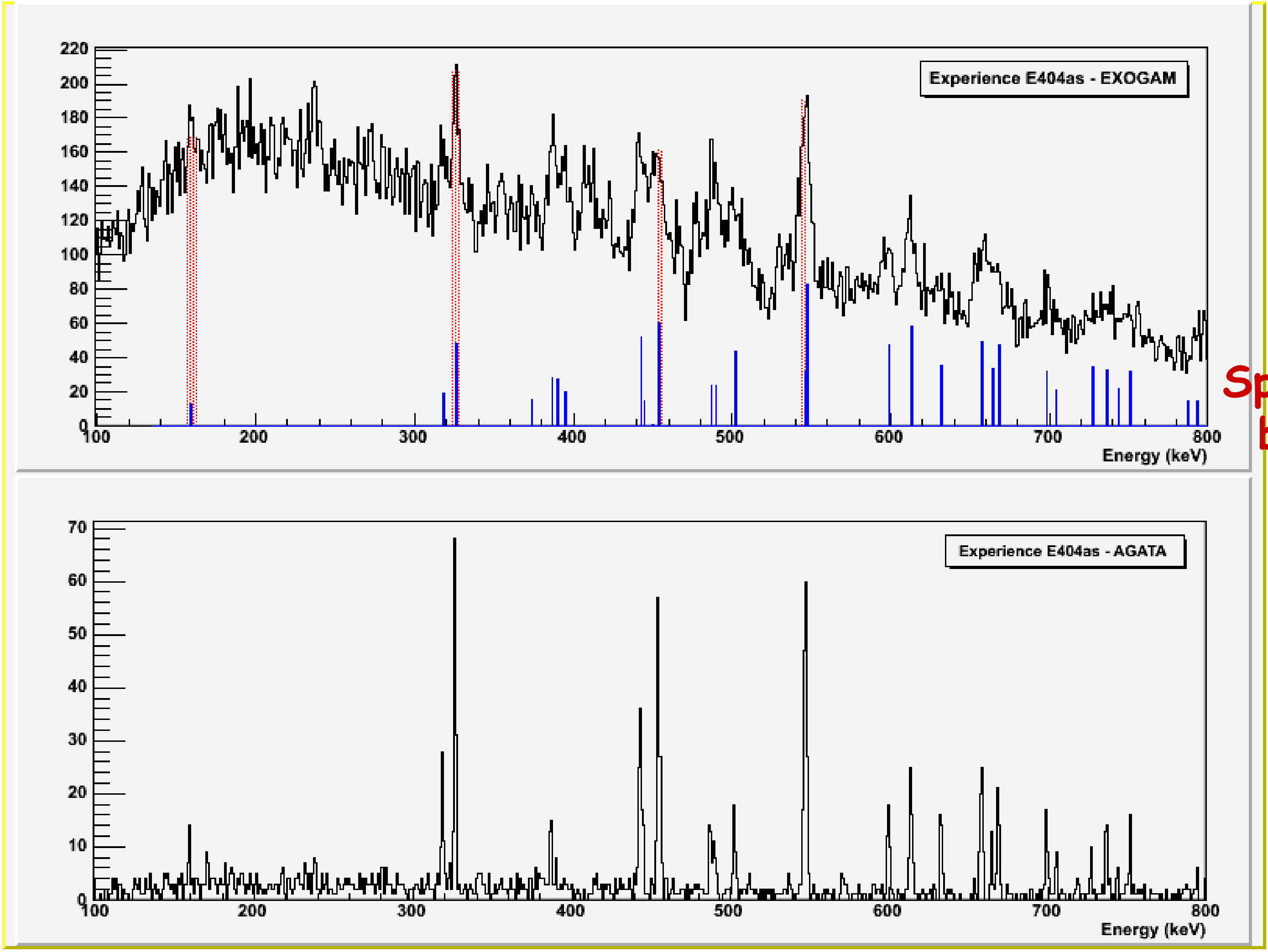
# Superdeformed nucleus $^{130}$Nd




*Q.T. Doan, B. Rossé et O. Stézowski*

*G. Duchêne*

# Superdeformed nucleus $^{130}$Nd




**EXOGAM**
εω ~ 13 %
P/T ~ 0.31
FWHM ~ 11 keV

**Spectra conditionned by 4 γ transitions**

**AGATA Demonstrator**
εω ~ 4 %
P/T ~ 0.48
FWHM ~ 2.5 keV

*Q.T. Doan, B. Rossé and O. Stézowski*

*G. Duchêne*

## Plan

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# AGATA collaboration

International collaboration of 10 countries

Bulgaria, Finland, France, Germany, Italy,
Poland, Romania, Sweden, Turkey, UK

About 40 laboratoires and ~150 physicists and engineers in the R&D

Construction phase of 1/3 of AGATA (60 crystals) from 2009 – 2012

Exploitation up to 2015

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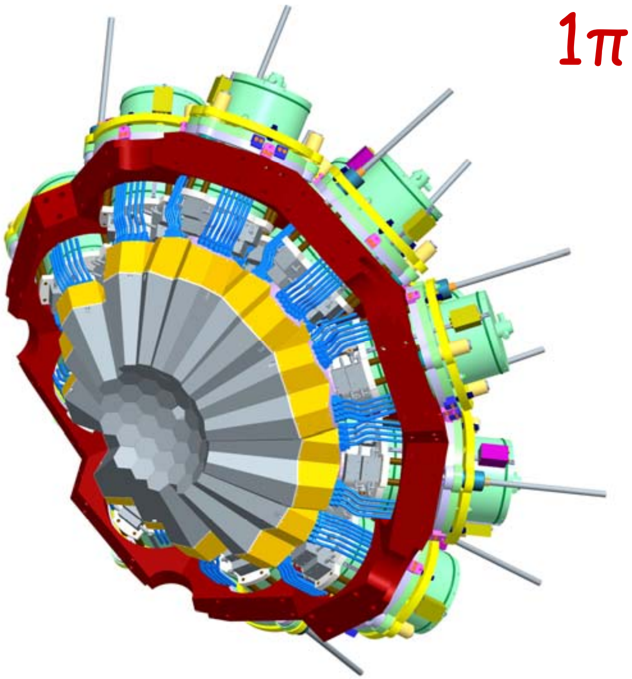
# AGATA 1/3

**AGATA 1/3 = AD + 1π**

- 5 TCs + 15 new TCs
- 15 + 45 new segmented crystals
- 570 + 1710 new electronic channels




**Performance at 1 MeV**

(13,5 cm / 23,5 cm to target)

| | Mγ=1 | Mγ=20 |
|---|---|---|
| **Eff :** | **24% / 13%** | **17% / 10%** |
| | **β=10%** | **β=50%** |
| **FWHM :** | **2,5 keV** | **7 keV** |

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# Conclusions

- AGATA is a new generation $\gamma$-ray spectrometer based on $\gamma$-ray tracking
- Its Demonstrator (about 10% of the full array) is being built; one full data acquisition chain has been succesfully tested at Legnaro National Lab., Italy
- The simplest pulse-shape analysis algorithm reaches the goal of 5 mm spatial resolution
- The first physics campaign with the Demonstrator is planned early 2010 at Legnaro National Lab., Italy
- AGATA performance is expected to be 2 to 3 orders of magnitude better then the ones of the present $\gamma$-ray spectrometers which opens new perspectives for nuclear studies in the coming 15 years in the Terra Incognita of exotic, super-heavy and extremely deformed nuclei

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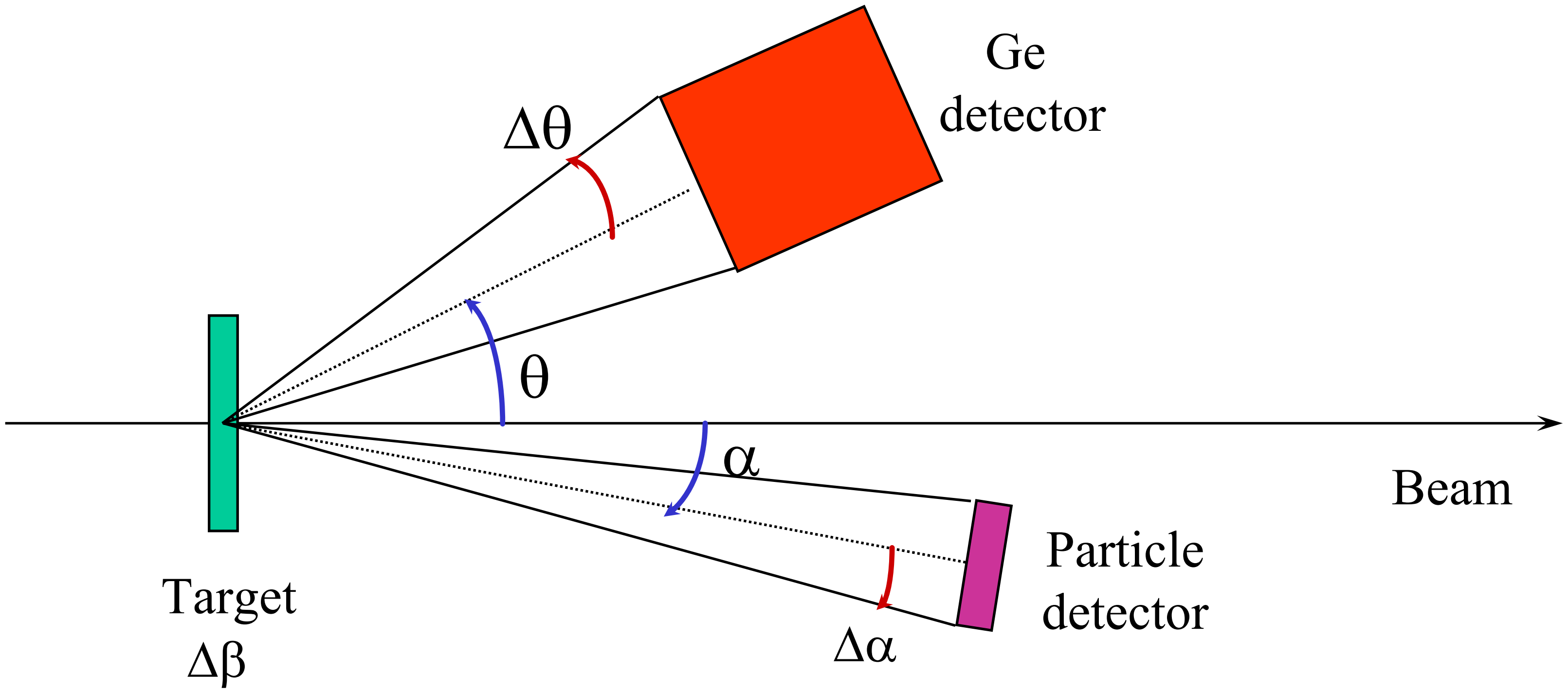
# $\gamma$ peak Doppler broadening




$$\text{FWHM} = \left\{ \text{FWHM}^2_{int} + \text{FWHM}^2_{\Delta\theta} + \text{FWHM}^2_{\Delta\alpha} + \text{FWHM}^2_{\Delta\beta} \right\}^{1/2}$$

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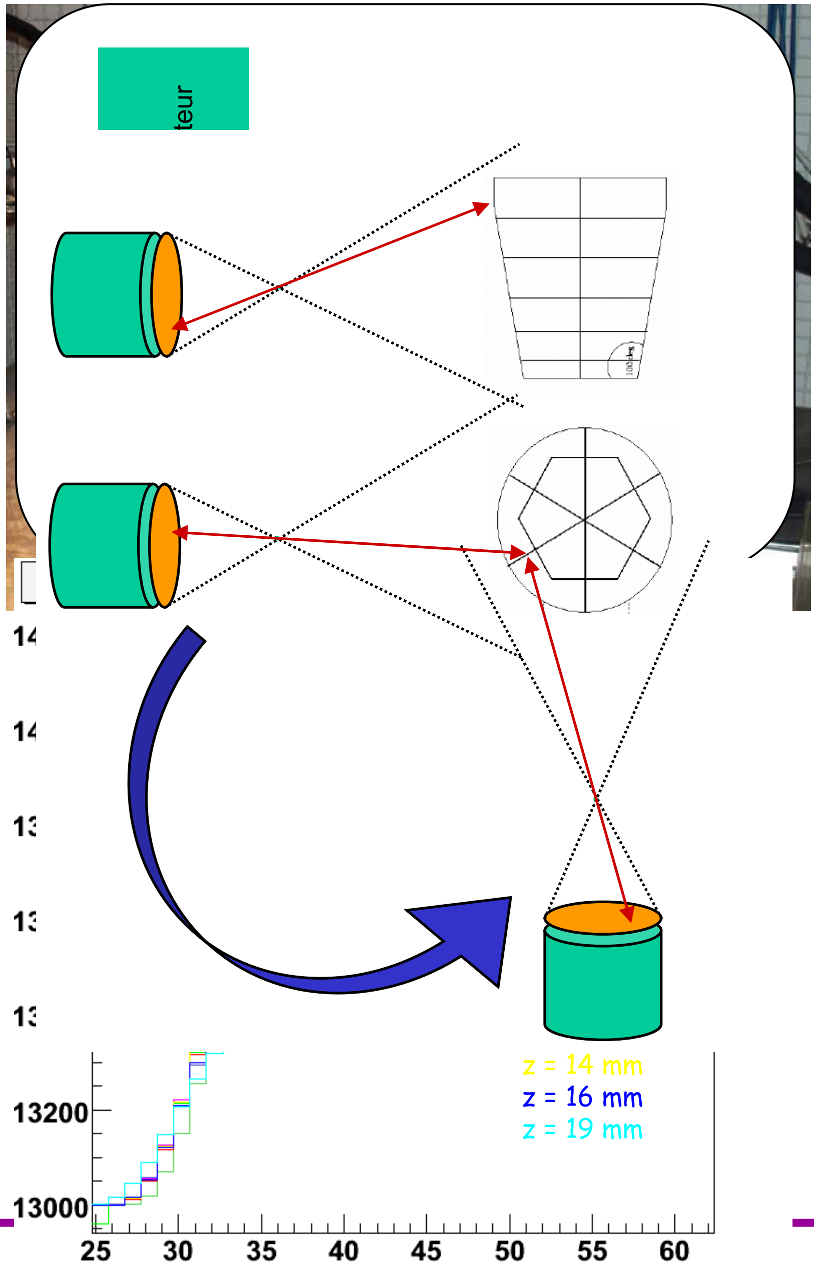
# Caractérisation des Ge

**Développement d'une table de scanning 3D rapide (IPHC + GSI)**

F. Didierjean, M.H. Sigward, M. Filliger, G. Duchêne
+ mécanique + équipe Spiral 2

- Table existante 2D
- Scan manuel dans la troisième dimension
  - Technique classique de coincidence
  - Test des mêmes détecteurs sur tables de IPHC et GSI (nouveau concept) pour validation du concept
- Nouveau concept de table de scanning
  - Source émettrice de deux 511 keV à 180° ~400 kBq
  - Un scintillateur/PM segmenté 16x16 qui détermine la direction du gamma incident sur le Ge à 1 $mm^2$ prêt
  - Eclairage latéral du Ge
  - Plusieurs mesures à 3-4 angles différents




~24h par angle
scan complet en une semaine (à vérifier)

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# DAQ

1 pizza/cristal => 15 ou 18 pizzas (5 ou 6 TC)

1 event builder => 1

1 producteur ancillaire => 1

1 merger => 1

1 tracking => 1

3 disk servers => 3

2 services (marsouin+marsouinbis) => 2

2 slow control => 2

2 analyse => 2

1 spare => 1

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Somme totale => 29 ou 32

G. Duchêne