The Advanced Gamma Ray Tracking Array

AGATA

Dino Bazzacco, INFN Padova
on behalf of the AGATA collaboration

Motivation

need of a break-through in instrumentation for gamma-ray spectroscopy to match the challenging experimental conditions of

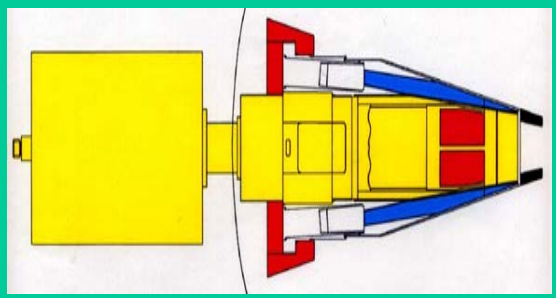
- next generation of radioactive beam facilities
  - GSI, GANIL, LNL, MAFF, EURISOL, …
- high intensity stable beam facilities
  - Legnaro, Jyväskylä, ...

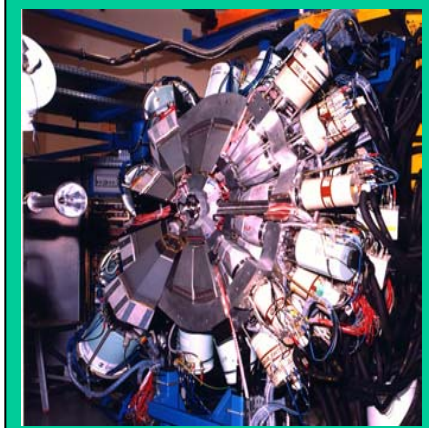
Gamma-Ray Tracking

The AGATA array

Radioactive Nuclear Beams 6, September 22-26, 2003, Argonne National Laboratory

Large Gamma Arrays based on Compton Suppressed Spectrometers





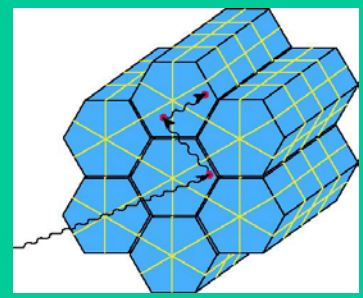
EUROBALL

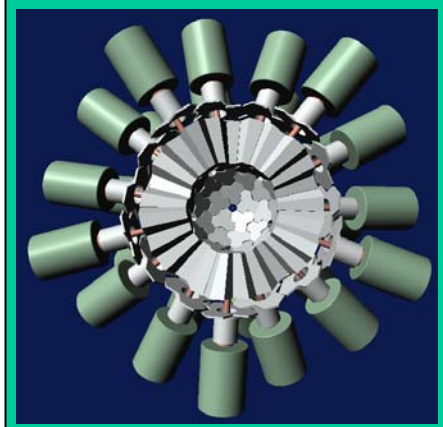
GAMMASPHERE

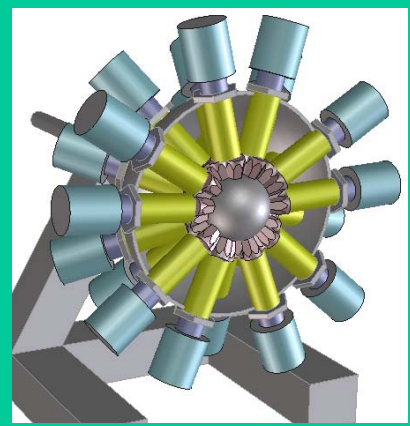
$\varepsilon \sim 10\ \%$ ($M_\gamma = 1$)

$5\ \%$ ($M_\gamma = 30$)

Tracking Arrays based on Position Sensitive Ge Detectors







AGATA

GRETA

$\varepsilon \sim 40\ \%$ ($M_\gamma = 1$)

$20\ \%$ ($M_\gamma = 30$)

Intermediate step : Exogam, Miniball, SeGa → optimized for Doppler correction but restricted to low γ-multiplicities

Gamma-Ray Tracking

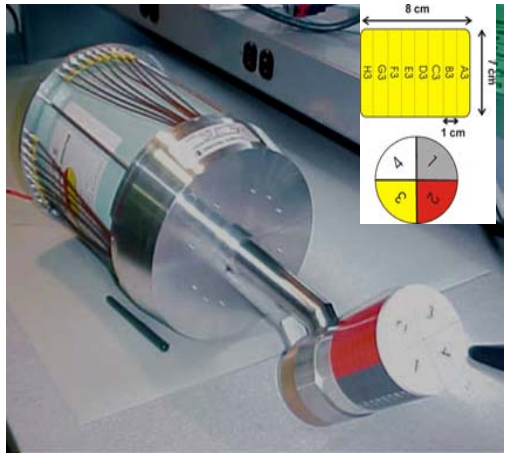
1) Large-volume, highly-segmented high-purity germanium detectors

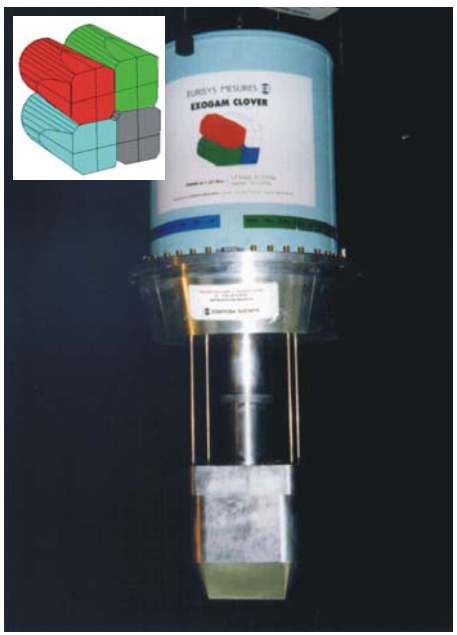
2) Digital electronics to record and process the segment signals

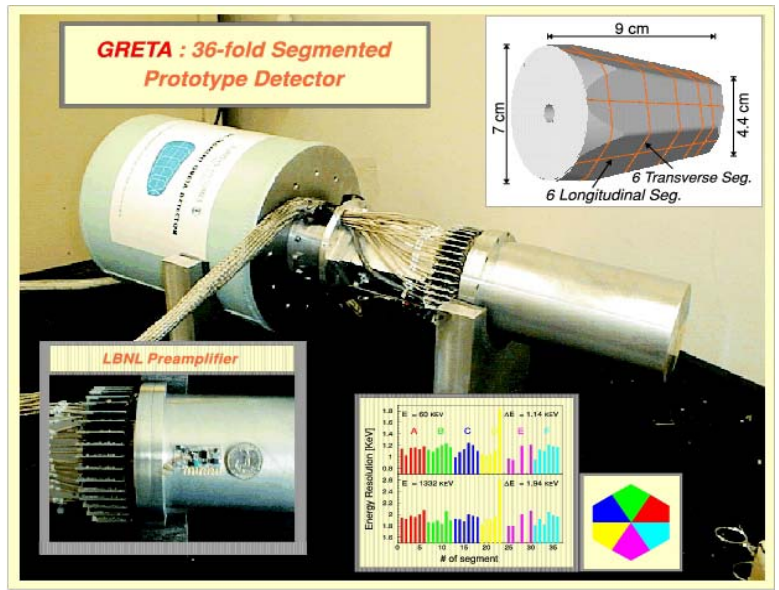
3) Pulse Shape Analysis of recorded waves to extract position and energy of interaction points

4) Reconstruction of gamma ray "tracks" from interaction points

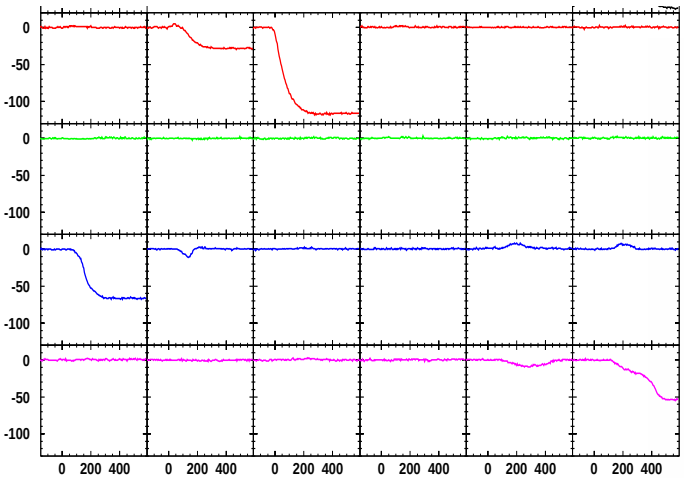
Highly segmented Ge Detectors

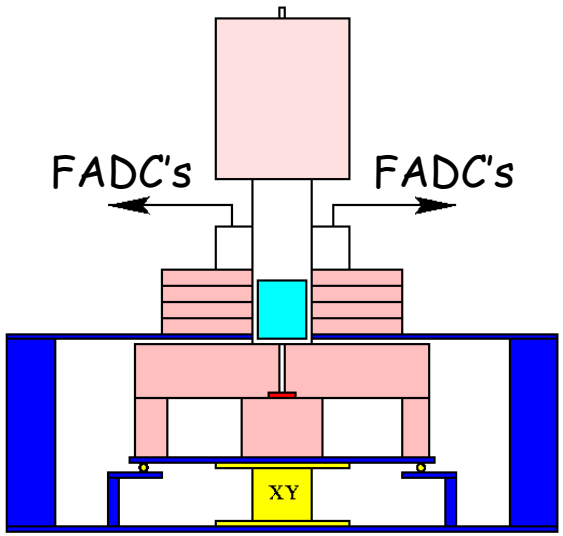


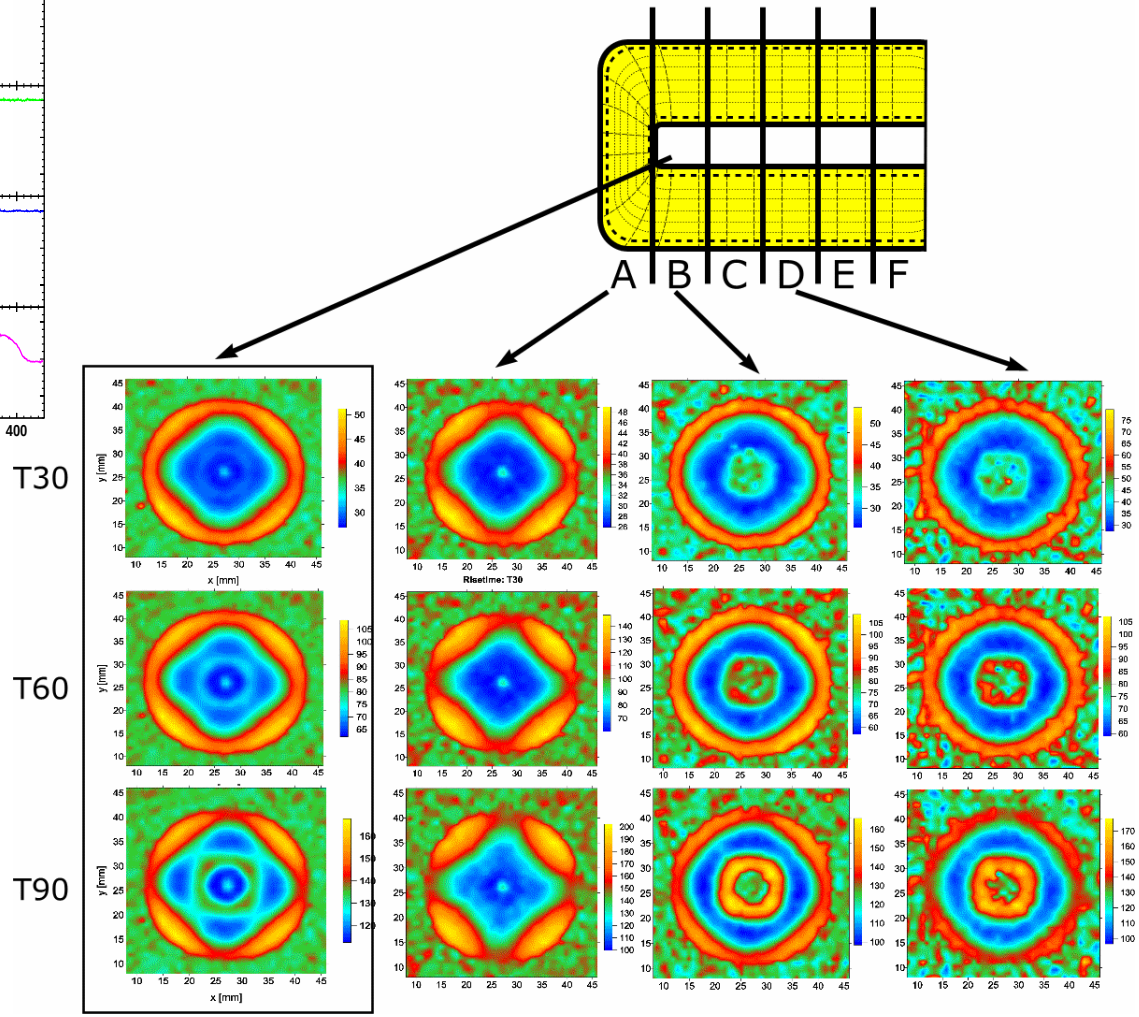




Pulse shapes



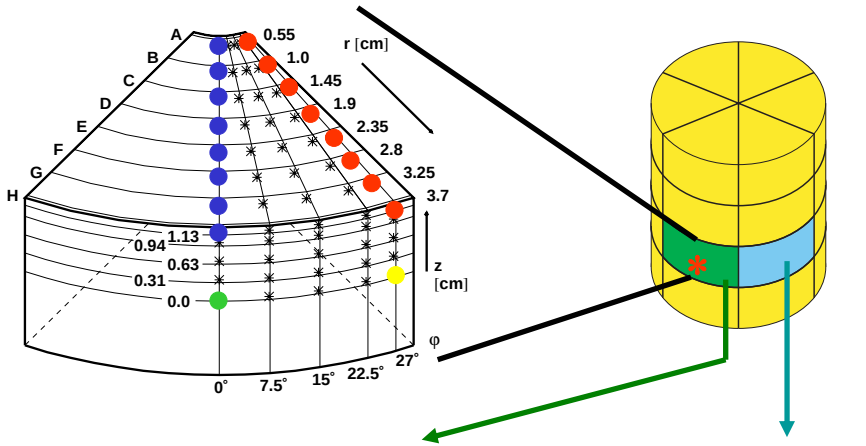




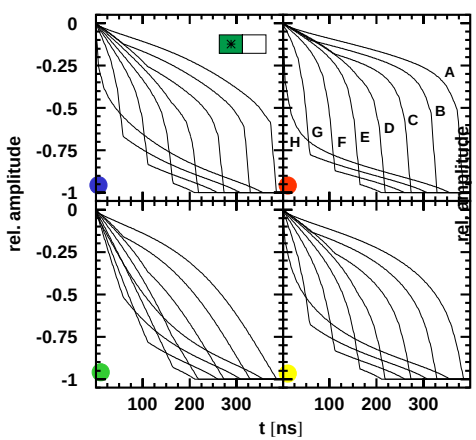
Measured with a C-E 6x6 detector at the Liverpool Automated Scanning Table

Calculation and analysis of pulse shapes

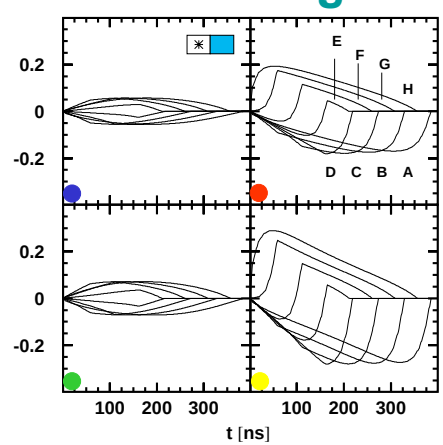
Calculation of the signals induced on the contacts using the weighting field method

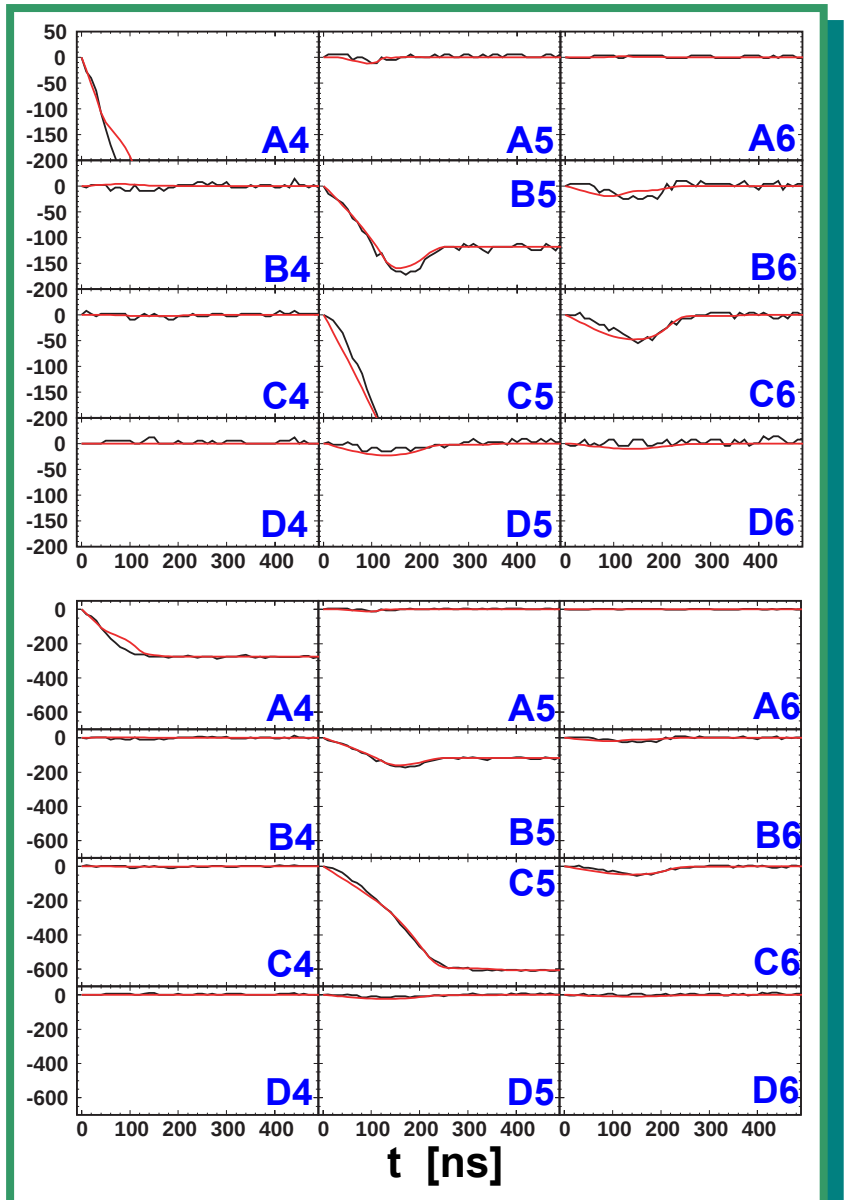


net charge signals



transient signals





Experimental data from GRETA detector

Verifying goodness of PSA from quality of Doppler shift correction

$^{56}Fe \rightarrow {}^{208}Pb$
@ 240 MeV
v/c ~ 8 %

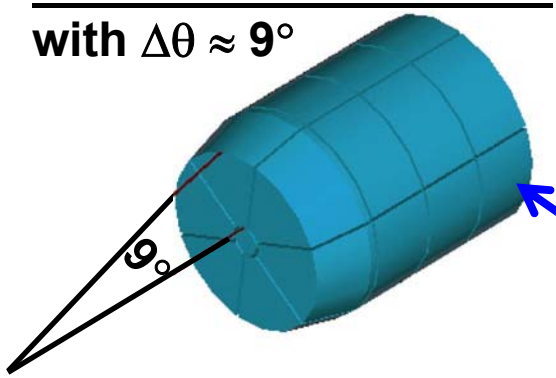
Expected final results:

No position information
→ 16 keV

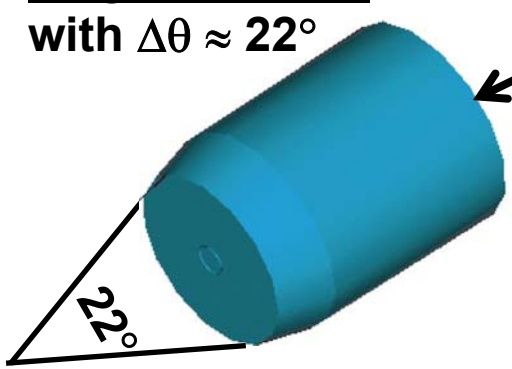
perfect tracking
→ 3.4 keV

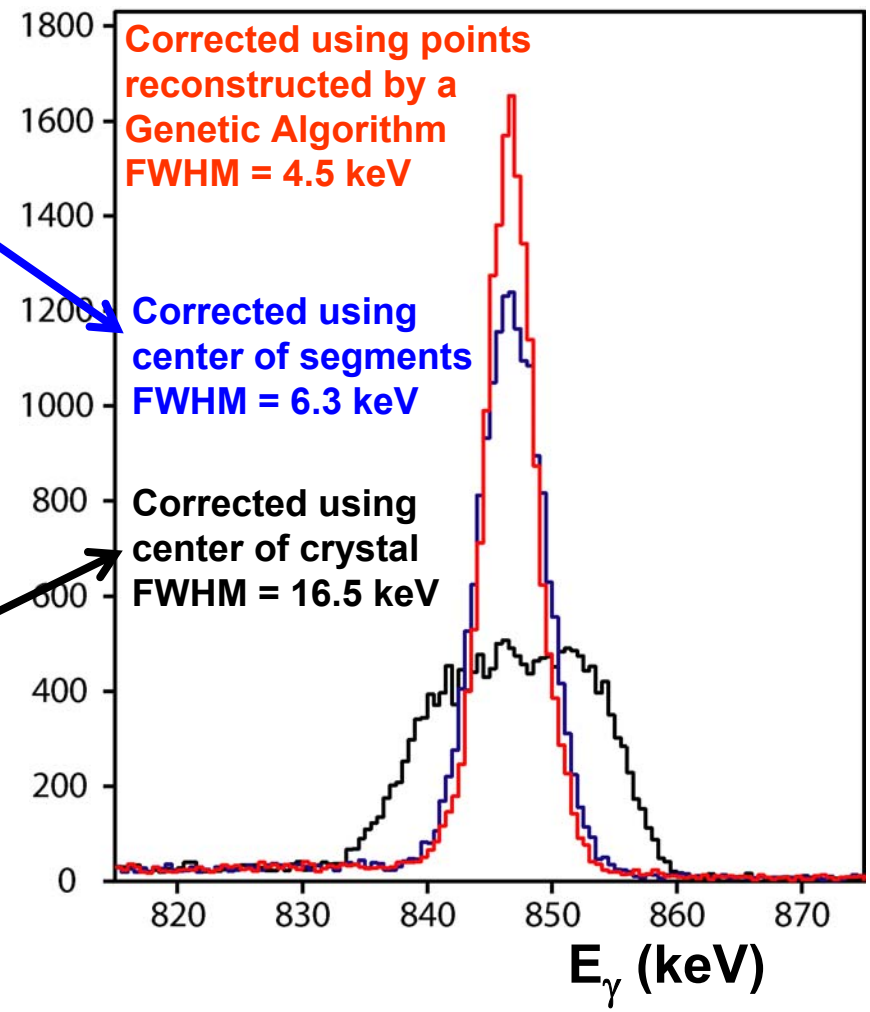
positional error
<d> ≈ 5 mm
→ 4.2 keV

24 individual detectors
with $\Delta\theta \approx 9°$



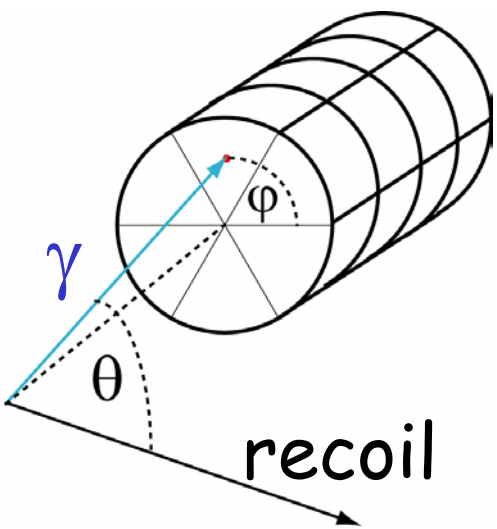
single detector
with $\Delta\theta \approx 22°$

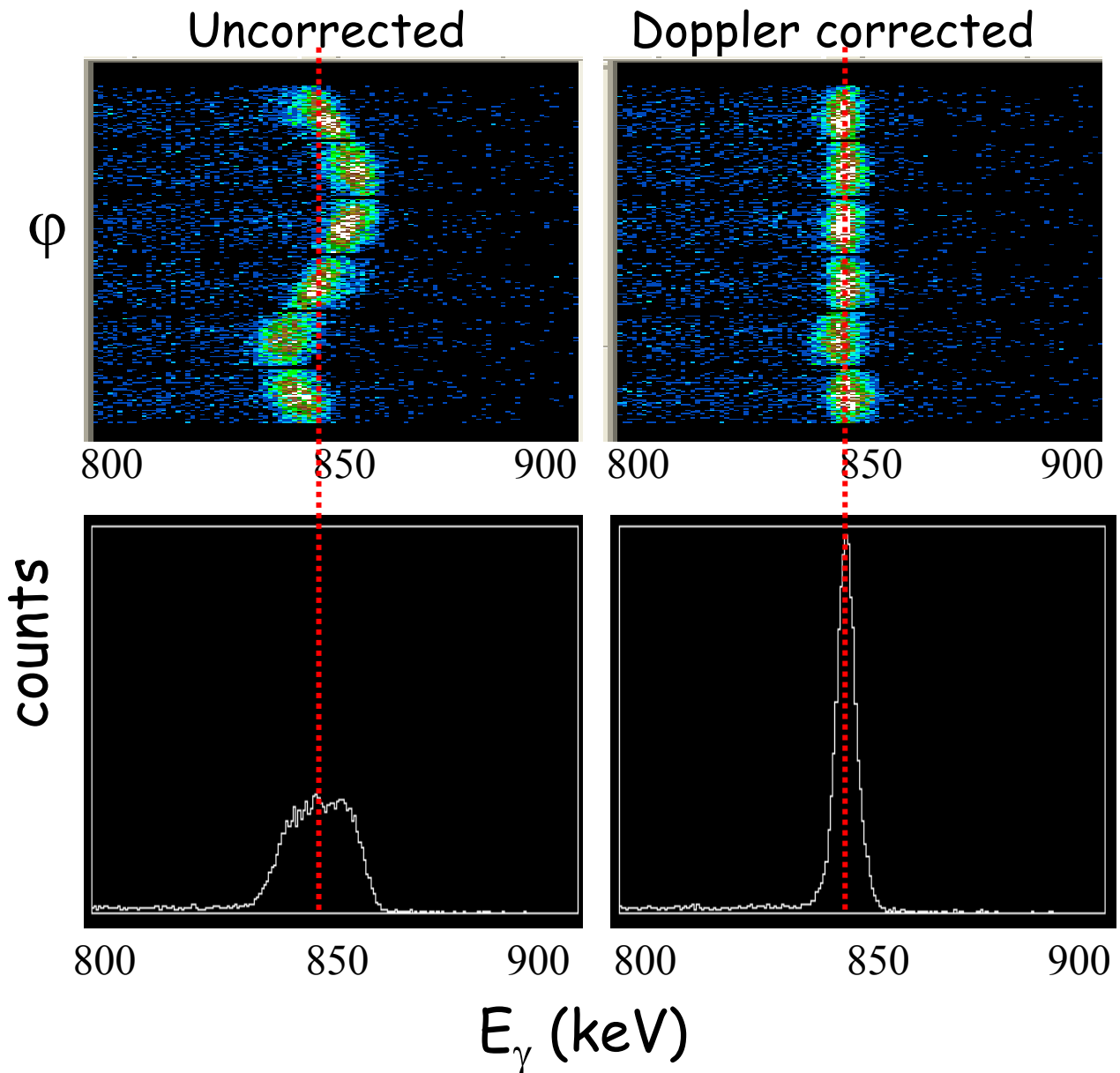




Tapered detectors will perform better as some of the difficult front part is cut away

Correlation E_γ - φ





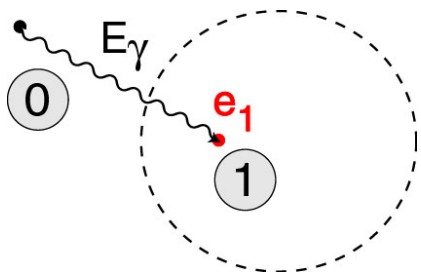
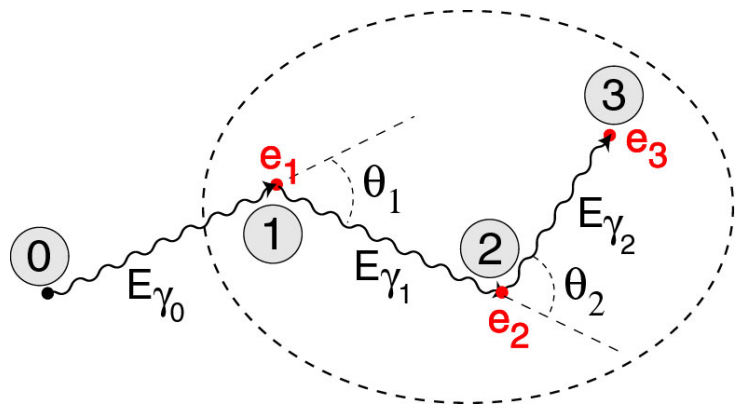
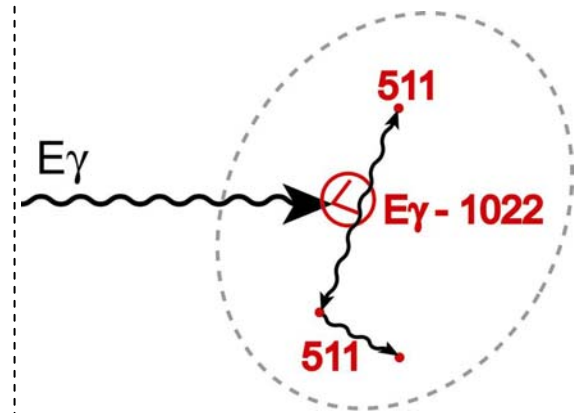
Doppler correction

$$E_\gamma^{CM} = E_\gamma^{Lab} \frac{1-\beta\cos(\theta)}{\sqrt{1-\beta^2}}$$

depends on θ which is correlated to φ

Interaction / Reconstruction Mechanisms

~ 100 keV ~1 MeV ~ 10 MeV γ-ray energy

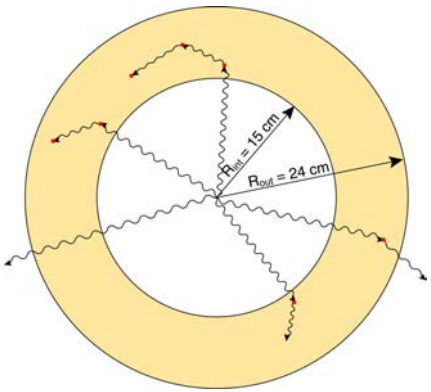
Photoelectric	Compton Scattering	Pair Production
		
Isolated hits	Angle/Energy	Pattern of hits
Probability of interaction depth	$E_{\gamma'} = \dfrac{E_\gamma}{1 + \dfrac{E_\gamma}{m_0 c^2}(1 - \cos\theta)}$	$E_{1st} = E_\gamma - 2\ mc^2$

Algorithms: ClusterTracking, ProbabilisticTracking, FuzzyTracking, BackTracking

Reconstruction efficiency limited by position resolution and Compton profile.

The "Standard" Germanium Shell - 1

Idealized configuration to determine maximum attainable performance.



R_i = 15 cm
R_o = 24 cm
230 kg of Ge

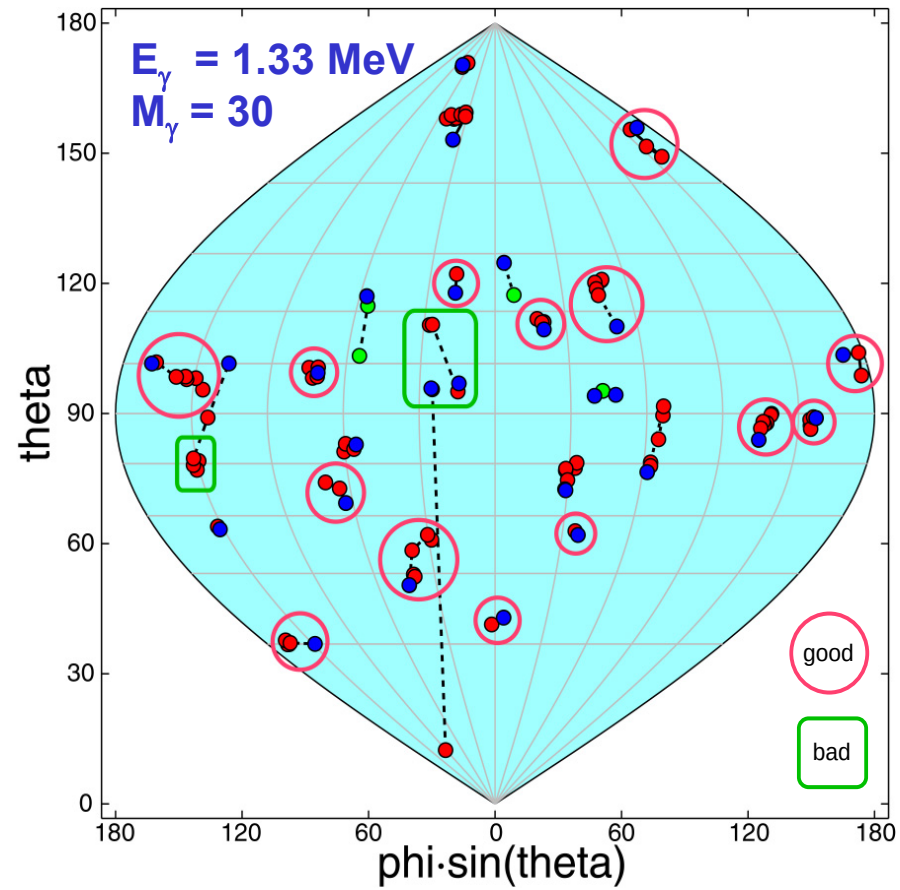
Events simulated using GEANT4
Response of shell at 1.33 MeV:

ε_{ph} = 70% P/T = 77%

Reconstruction by Cluster-Tracking
Packing Distance: 5 mm
Position Resolution: 5 mm **(at 100 keV)**

1.33 MeV	$M_\gamma = 1$	$M_\gamma = 30$
ε_{ph} (%)	65	36
P/T(%)	85	60

A high multiplicity event



27 gammas detected -- 23 in photopeak
16 reconstructed -- 14 in photopeak

AGATA

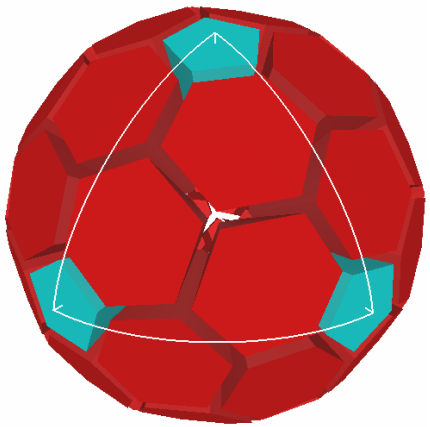
An implementation of the gamma-ray tracking concept

Requirements:

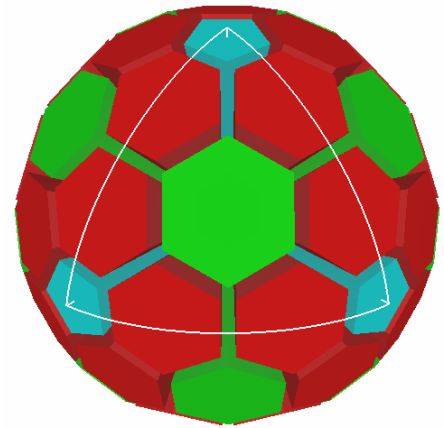
efficiency, energy resolution, dynamic range, angular resolution, timing, counting rate, modularity, angular coverage, inner space

Quantity	Specified for	Target Value
Photo-peak efficiency (ε_{ph})	E_γ = 1 MeV, M_γ = 1, $\beta < 0.5$ E_γ = 1 MeV, M_γ = 30, $\beta < 0.5$ E_γ = 10 MeV, M_γ = 1	50 % 25 % 10 %
Peak-to-total ratio (P/T)	E_γ = 1 MeV, M_γ = 1 E_γ = 1 MeV, M_γ = 30	60 - 70 % 40 - 50 %
Angular resolution ($\Delta\theta_\gamma$)	$\Delta E/E < 1\%$	better than 1°
Maximum event rates	M_γ = 1 M_γ = 30	3 MHz 300 kHz
Inner space for ancillaries		> 170 mm

Geodesic Tiling of Sphere using hexagons and 12 pentagons



60



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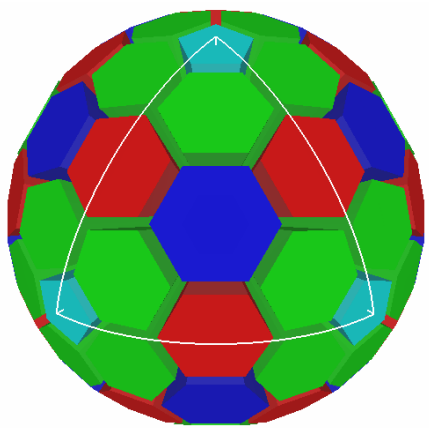

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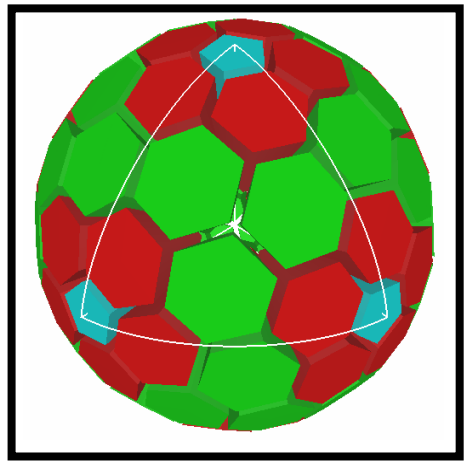

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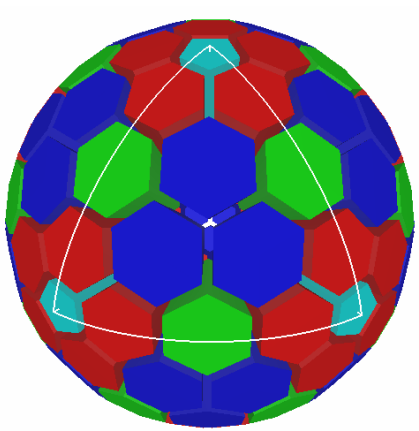

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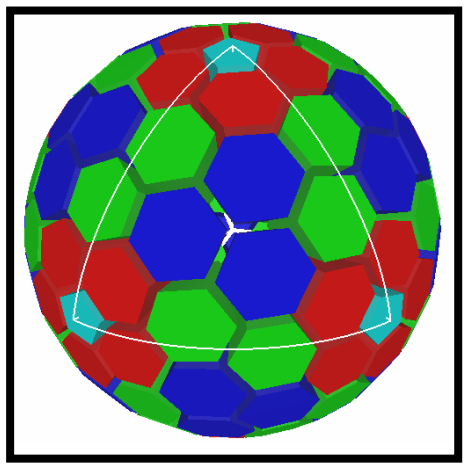

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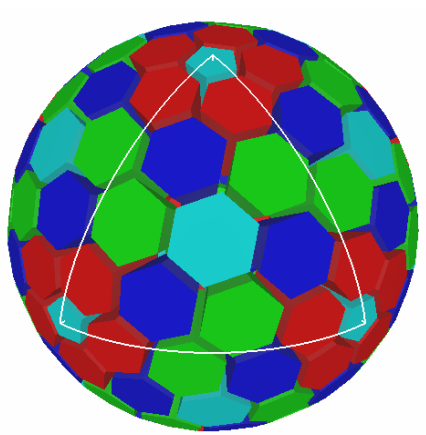

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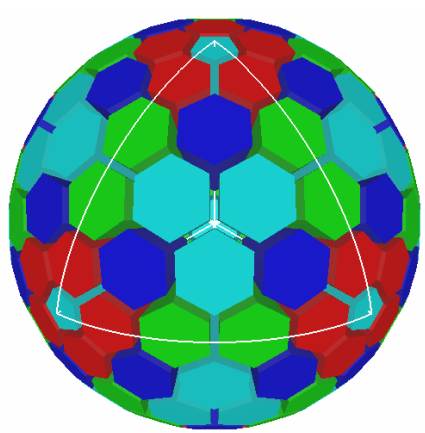
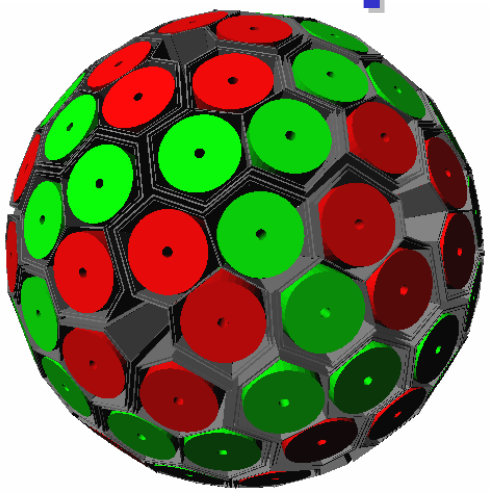
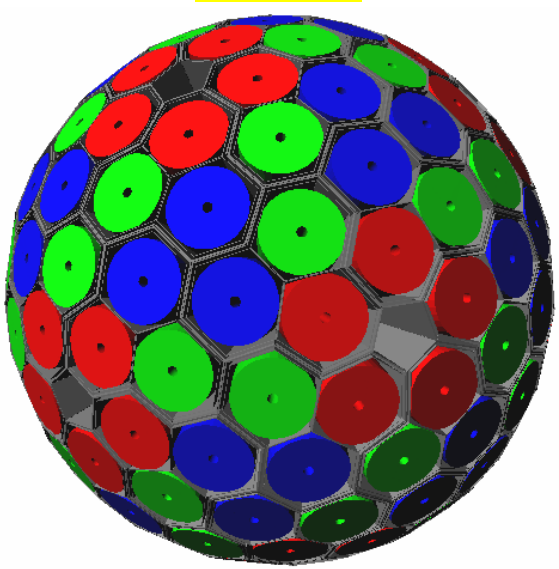


240

Two possible configurations



A120

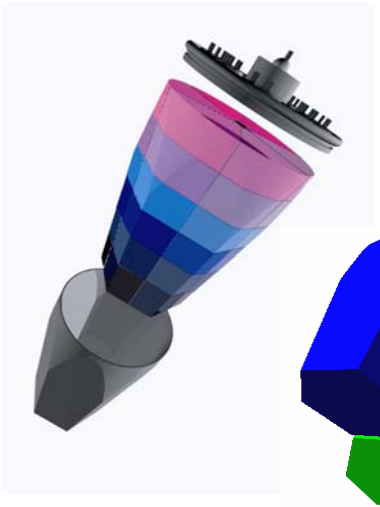


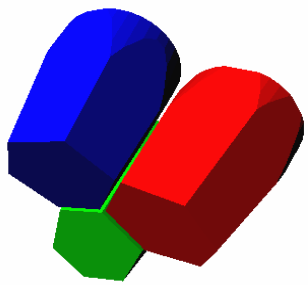
A180

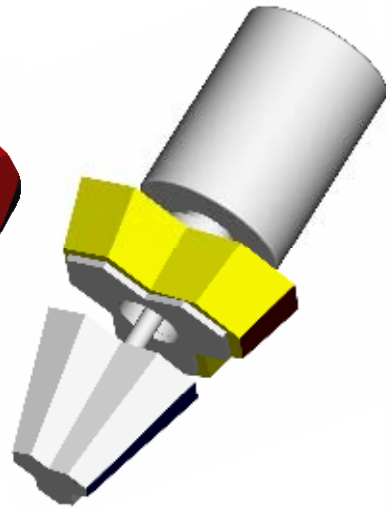
Number of crystals	120	180
Solid Angle (%)	74	80
Amount of germanium (kg)	220	310
Eff. / PT at M_γ = 1 (%)	33 / 52	38 / 53
Eff. / PT at M_γ = 30 (%)	19 / 44	24 / 46
Inner free space (cm)	17	21
Counting rate (kHz)	70	50
Angular resolution		better
Number of clusters / types	40 / 2	60 / 1
Rings of clusters	5-10-15-10-5	5-10-15-15-10-5
Angular coverage of rings		more regular
Electronics channels	4440	6660
Cost	30 % lower	~40 M €

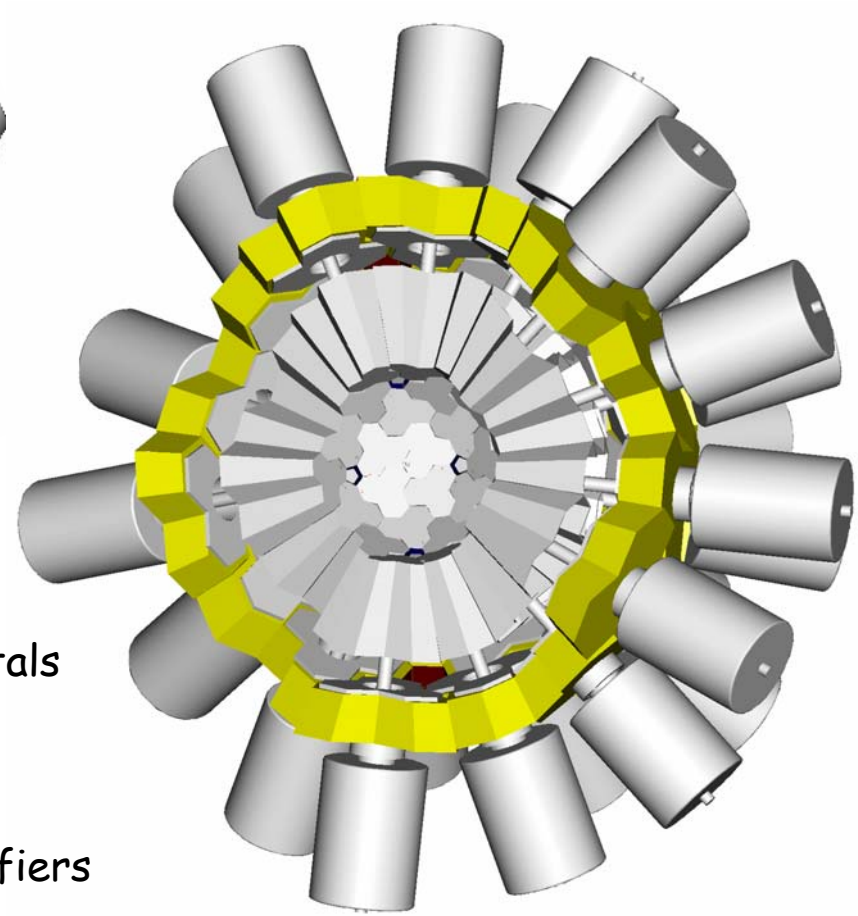
Crystals: 9 cm long, 8 cm diameter (at the back); balanced volumes.
GEANT4 simulations include dead layers, capsules and cryostats.
Full energy efficiency and P/T at E_γ = 1 MeV
Crystals arranged in triple-clusters. Recoil velocity v/c = 0.

Detectors









Ge crystals:
Hexaconical shape
90-100 mm long
80 mm max diameter
36 segments
Al encapsulatation:
0.6 mm spacing
0.8 mm thickness

Triple clusters:
3 encapsulated crystals
Al end-cap:
1.5 mm spacing
1.5 mm thickness
111 cold FET preamplifiers

Distance between faces of crystals:
in same cluster ~3 mm
in adjacent clusters ~9 mm

Total weight of the 60 clusters of the AGATA-180 configuration ~2.5 tons
Mounted on a self-supporting structure

Electronics and DAQ

Fully synchronous system with central 100 MHz clock and time-stamp distribution (GTS)

Digitizers: 100 Ms/s, 14 bit
Optical fiber read-out of full data stream to pre-processing electronics
Outout of digitizers ~ 200 MB/s/channel

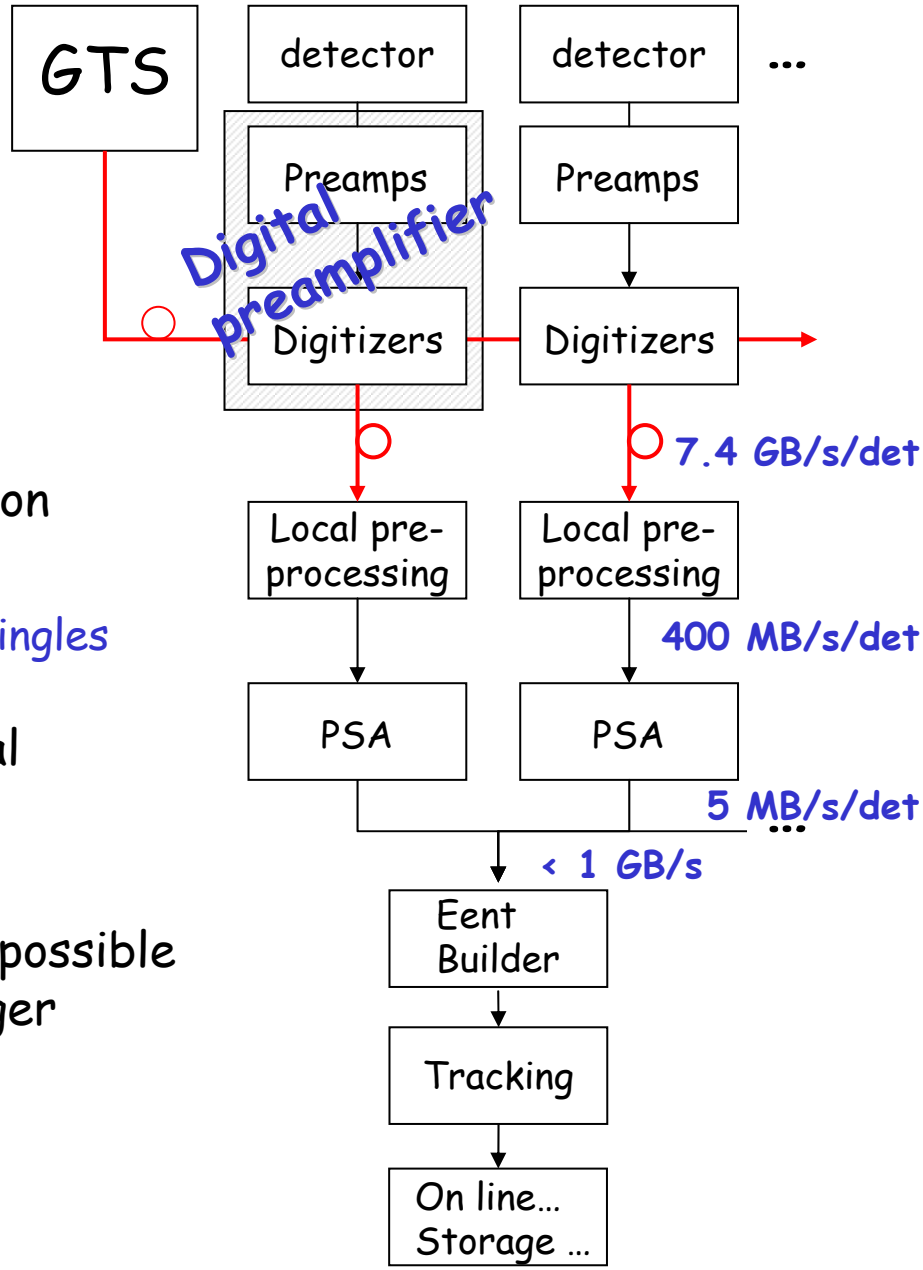
Local processing triggered by Ge common contact. Determine energy and isolate ~ 600 ns of signal around rise-time
Output of preproc. ~ 400 MB/s at 50 kHz singles

Transfer buffers of time-stamped local events to PSA stage for decomposition
Output of PSA ~ 5 MB/s at 50 kHz singles

Trigger-less system but global trigger possible
Global event builder and software trigger

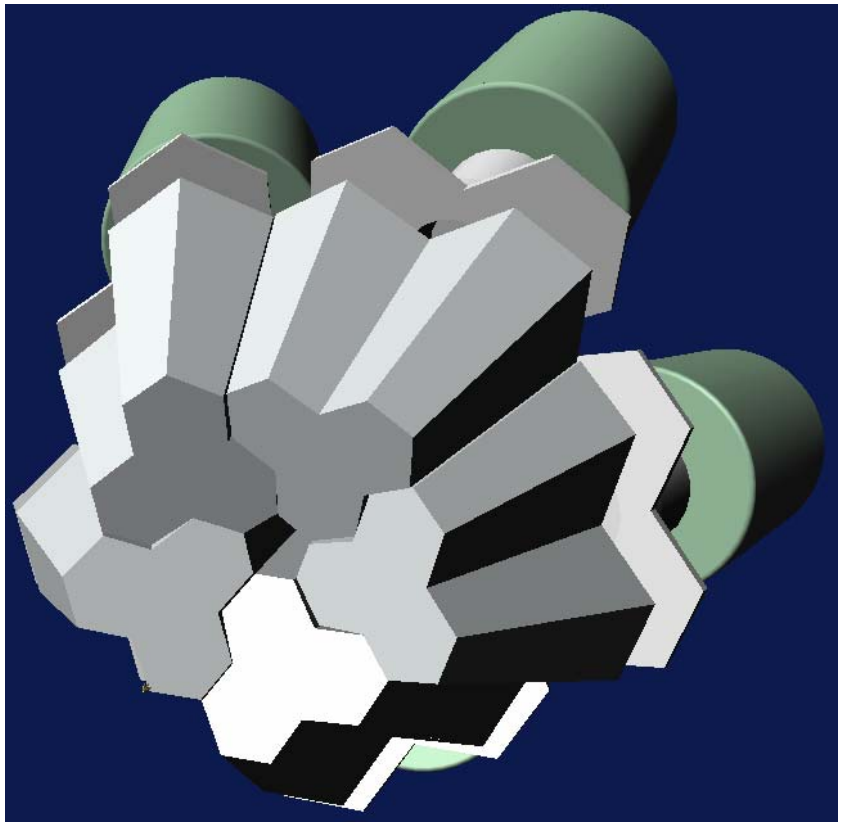
On-line gamma-ray tracking

Control and storage, …



The First Step:
The AGATA Demonstrator

Objective of the final R&D phase 2003-2007



1 symmetric triple-cluster

5 asymmetric triple-clusters

36-fold segmented crystals

540 segments

555 digital-channels

Eff. 3 – 8 % @ $M_\gamma = 1$

Eff. 2 – 4 % @ $M_\gamma = 30$

Full ACQ

with on line PSA and γ-ray tracking

Test Sites:

GANIL, GSI, Jyväskylä, Köln, LNL

Cost ~ 7 M €

Status of AGATA

- MoU for demonstrator phase (2003-2007) signed by national institutions.
- Structure of collaboration defined:
  - ASC, AMB, AWG, AWT
- First 3 encapsulated crystals and cryostat ordered
  - Symmetric triple-cluster ready end 2004
- Asymmetric cluster (3 capsules and cryostat) to be ordered after choice of geometrical configuration
- Demonstrator ready (with full electronics and DAQ for real-time operation) by the end of 2006.
- Tests and first experiments in 2007
- Construction of AGATA in phases, starting from 2008
  - Major problem: cost of detectors

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, IReS Strasbourg
Germany:	HMI Berlin, Univ. Bonn, GSI Darmstadt, TU Darmstadt, FZ Jülich, Univ. Köln, LMU München, TU München
Italy:	INFN/Univ. Padova, Milano, Legnaro, Firenze, Camerino, Napoli, Genova
Poland:	NINP & IFJ Krakow, SINS Swierk, HIL & IEP Warsaw
Romania:	NIPNE & PU Bucharest
Sweden:	Univ. Lund, KTU Stockholm, Univ. Uppsala
UK:	CLRC Daresbury, Univ. Brighton, Keele, Liverpool, Manchester, Paisley, Surrey, York