Design and Monte Carlo simulations for AGATA

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We need simulations to ...

• Optimize the geometry of the array
• Evaluate the expected performances
• Test the tracking algorithms with “standard” datasets
• Test the analysis programs with “standard” datasets
• ............
Simulations

GLP: Conceptual Design

DAQ: Key Experiments

Ancillary: Impact

This presentation
## Preliminary list of contributors

<table>
<thead>
<tr>
<th>Padova</th>
<th>Saclay</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI</td>
<td>Sofia</td>
</tr>
<tr>
<td>Köln</td>
<td>Strasbourg</td>
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<tr>
<td>Krakow</td>
<td>UK (to be defined)</td>
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<tr>
<td>LNL</td>
<td>Uppsala</td>
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<tr>
<td>Lyon</td>
<td>Warsaw</td>
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<tr>
<td>Orsay</td>
<td>Debrecen (?)</td>
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</tbody>
</table>

*Underlined: Conceptual design*

**Plus:** interaction with the Ancillary Detectors WG
Conceptual Design phase

- Performance of the array in “standard” conditions
- Comparison (and choice) of various possible geometrical configurations
- Datasets to test the tracking algorithms
- Identify the requirements for source position and velocity measurements

Development of a Monte Carlo code
Status

• A simulation code has been developed meeting the requirements of this phase
• Preliminary results are available
• Requirements for source position and velocity measurement: to be done soon (first half 2004)
• Documentation on the code should be improved!
• After concluding this phase, the team will likely merge into the Simulation of Key Experiments team
The code

- C++, object-oriented
- Based on Geant4
- Major problem (solved): implementation of irregular geometrical shapes (it is not possible to load the geometry from CAD files)
Class structure of the program

Agata

*Agata RunAction
*Agata EventAction
Agata Analysis
CSpec1D
CSpec2D
*Agata GeneratorAction
*Agata GeneratorGamma
*Agata GeneratorNeutron
Agata GeneratorEmitter
Agata GeneratorOmega
Agata DetectorConstruction
*Agata DetectorArray
CConvex Polyhedron
*Agata DetectorReadOut
Agata DetectorAncillary
Agata SensitiveDetector
Agata DummySD
*Agata DetectorSimple
*Agata DetectorShell
*Agata SteppingAction
*Agata SteppingOmega

* Possibility to change parameters via a messenger class

*Agata VisManager
*Agata PhysicsList
Agata SteppingAction

*Agata Messenger classes are not shown!
Geodesic Tiling of Sphere using 60–240 hexagons and 12 pentagons
Building a Geodesic Ball (1)

Start with a platonic solid e.g. an icosahedron

On its faces, draw a regular pattern of triangles grouped as hexagons and pentagons. E.g. with 110 hexagons and (always) 12 pentagons

Project the faces on the enclosing sphere; flatten the hexagons.
Building a Geodesic Ball (2)

A radial projection of the spherical tiling generates the shapes of the detectors. Ball with 180 hexagons.

Space for encapsulation and canning obtained cutting the crystals. In the example 3 crystals form a triple cluster.

Add encapsulation and part of the cryostats for realistic MC simulations.

Al capsules 0.7 mm spacing
0.8 mm thick

Al canning 2 mm spacing
2 mm thick
Comparison of various configurations

A120, A120G: triple clusters, different explosion of the icosahedron
A120C4: quadruple clusters
A180: triple clusters

<table>
<thead>
<tr>
<th>Ge crystals size: length 90 mm, diameter 80 mm</th>
</tr>
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<td>Passivated areas: 1 mm at the back and around the coaxial hole</td>
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<table>
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<tr>
<th></th>
<th>A120</th>
<th>A120G</th>
<th>A120C4</th>
<th>A180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of crystals</td>
<td>120</td>
<td>120</td>
<td>120</td>
<td>180</td>
</tr>
<tr>
<td>Amount of germanium (kg)</td>
<td>212</td>
<td>213</td>
<td>226</td>
<td>320</td>
</tr>
<tr>
<td>Solid Angle (%)</td>
<td>72</td>
<td>72</td>
<td>78</td>
<td>79</td>
</tr>
<tr>
<td>$\varepsilon_{ph} / PT$ at $M = 1$ (%)</td>
<td>33 / 52</td>
<td>32 / 52</td>
<td>37 / 52</td>
<td>38 / 53</td>
</tr>
<tr>
<td>$\varepsilon_{ph} / PT$ at $M = 30$ (%)</td>
<td>19 / 44</td>
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<td>21 / 44</td>
<td>24 / 46</td>
</tr>
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</table>

Efficiency and P/T values at $E_\gamma = 1$ MeV and recoil velocity $\beta = 0$.
Values obtained after tracking with standard position resolution (5 mm @ 100 keV).
Cryostats and capsules included in the simulation.
Why cluster the detectors?

A120: triple clusters
A120C4: quadruple clusters
A180: triple clusters
A180S: individual cryostats

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<td>------------------------</td>
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</tr>
<tr>
<td><strong>Solid Angle (%)</strong></td>
</tr>
<tr>
<td><strong>γ = 1 MeV and recoil velocity β = 0</strong></td>
</tr>
<tr>
<td><strong>Efficiency and P/T values</strong></td>
</tr>
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<td><strong>ε_{ph} / PT at M = 1 (%)</strong></td>
</tr>
<tr>
<td><strong>ε_{ph} / PT at M = 30 (%)</strong></td>
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Values obtained after tracking with standard position resolution (5 mm @ 100 keV). Cryostats and capsules included in the simulation.
Two candidate configurations

Ge crystals size:
length 90 mm
diameter 80 mm

120 hexagonal crystals 2 shapes
40 triple-clusters 2 shapes
Inner radius (Ge) 17 cm
Amount of germanium 212 (290) kg
Fraction of germanium used: 73%
Solid angle coverage 72%
4320 segments
Efficiency: 33% (M_γ=1) 19% (M_γ=30)
Peak/Total: 52% (M_γ=1) 44% (M_γ=30)

180 hexagonal crystals 3 shapes
60 triple-clusters all equal
Inner radius (Ge) 21 cm
Amount of germanium 320 (430) kg
Fraction of germanium used: 74%
Solid angle coverage 79%
6480 segments
Efficiency: 38% (M_γ=1) 24% (M_γ=30)
Peak/Total: 53% (M_γ=1) 46% (M_γ=30)
## Comparison of the 2 configurations

<table>
<thead>
<tr>
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<th>A-120</th>
<th>A-180</th>
</tr>
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<tr>
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<tr>
<td>Inner free space (cm)</td>
<td>17</td>
<td>21*</td>
</tr>
<tr>
<td>Number of clusters / types</td>
<td>40 / 2</td>
<td>60 / 1</td>
</tr>
<tr>
<td>Rings of clusters</td>
<td>3-7-10-10-7-3</td>
<td>5-10-15-15-10-5</td>
</tr>
<tr>
<td>Angular coverage of rings</td>
<td>irregular</td>
<td>very regular</td>
</tr>
<tr>
<td>Electronics channels</td>
<td>4440</td>
<td>6660</td>
</tr>
</tbody>
</table>

To reduce cost of germanium, A-180 could be squeezed to similar size as A-120. Efficiency reduces also but all nice symmetries remain; smaller crystals simplify PSA.
Configuration A=180
Configuration A=120
# Peak Efficiency and P/T at $E_\gamma = 1 \text{ MeV}$

AGATA Crystals: 9 cm long, 8 cm diameter (at the back), balanced volumes. Arranged in triple-clusters. Recoil velocity $\beta = 0$. 

<table>
<thead>
<tr>
<th>Number of crystals</th>
<th>$\Omega$ (%)</th>
<th>Resp. funct.</th>
<th>$M_{\gamma}$ 10</th>
<th>$M_{\gamma}$ 20</th>
<th>$M_{\gamma}$ 30</th>
<th>Eff. (%)</th>
<th>P/T (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 (Ball, 21.8 – 30.8 cm) no dead materials</td>
<td>78.6</td>
<td>51.0</td>
<td>46.1</td>
<td>33.5</td>
<td>30.6</td>
<td>28.2</td>
<td>56.9</td>
</tr>
<tr>
<td>180 (Ball, 21.8 – 30.8 cm) with capsules and cryostats</td>
<td>78.6</td>
<td>41.1</td>
<td>38.3</td>
<td>28.5</td>
<td>25.8</td>
<td>24.0</td>
<td>46.2</td>
</tr>
<tr>
<td>180 (Ball, 21.8 – 30.8 cm) + Al chamber 2 mm thick</td>
<td>78.6</td>
<td>39.6</td>
<td>36.8</td>
<td>27.2</td>
<td>24.9</td>
<td>23.0</td>
<td>43.9</td>
</tr>
<tr>
<td>120 (Ball, 18.2 – 27.2 cm) no dead materials</td>
<td>71.4</td>
<td>42.8</td>
<td>38.6</td>
<td>27.0</td>
<td>24.2</td>
<td>21.8</td>
<td>52.9</td>
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<td>41.6</td>
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Response function

Individual $\gamma$-rays are fired and the energy releases within the array are summed. Passivated areas, cryostats and capsules are considered.

**Photopeak efficiency**

**Peak-to-total ratio**
Photopeak efficiency

30 photon rotational cascade
$E_\gamma = E_0 + n\Delta E_\gamma$

Recoil velocity
$\beta = 0$
In addition to cryostats and capsules, a scattering chamber (2 mm aluminium thick) is considered in the simulation.
Effect of ancillary devices

In addition to cryostats, capsules and scattering chamber, an “ancillary” sphere is considered in the simulation. Only the results for A180 are shown.

Absolute photopeak efficiency

Peak-to-total ratio (response function)
High-energy peaks

14 photon rotational cascade
+ 10 MeV $\gamma$
Recoil velocity $\beta = 0$
Effect of the recoil velocity - 1

Photopeak efficiency

30 photon rotational cascade
\[ E_\gamma = E_0 + n \Delta E_\gamma \]

A180 configuration (no scattering chamber)

Recoil direction:
- \( z \) axis
- \( \beta \): constant (event by event)

Recoil velocity perfectly known when reconstructing
Effect of the recoil velocity - 2

30 photon rotational cascade \( (E_\gamma = E_0 + n\Delta E_\gamma) \)
A 180 configuration (no scattering chamber)
Recoil direction: \textbf{z axis}, \( \beta \): constant (event by event)
Recoil velocity perfectly known when reconstructing

Reconstructed FWHM
Effect of the recoil velocity - 3

30 photon rotational cascade
\( E_\gamma = E_0 + n\Delta E_\gamma \)
A180 configuration (no scattering chamber)
Velocity direction variable event-by-event (recoil opening angle: 5°)

White: recoil direction perfectly known when reconstructing
Red: only average recoil direction known (=z axis)

At \( \beta = 5\% \):
- 3.824 keV @ 2710 keV
- 12.578 keV @ 2710 keV

At \( \beta = 20\% \):
- 7.756 keV @ 2710 keV
- >80 keV @ 2710 keV!!!
• Segmentation is included in the code as an alternative segmented read out geometry which can be optionally enabled

• The effective shape of the segments can be approximated with “elementary” shapes
Segmentation - 2

Segmented polyhedron

The whole array (A=120)
Array of planar germanium detectors

- $4\pi$ geometry: 72 stacks of four planar crystals
  - 6 rings of (8, 14, 14) x 2 stacks
  - 230 kg of Ge
- Average distance to the target ~ 16 cm
Performance of the planar Ge array

Data were reconstructed with the probabilistic method

Absolute photopeak efficiency

Peak-to-total ratio (response function)
A brief planar/coaxial comparison

• The performances of AGATA at $\beta=0$ deduced with the present simulation and tracking codes are of the same order of magnitude of the results of the Strasbourg group for the array of planar detectors, obtained with quite a different approach. It would be sensible to simulate both arrays in a consistent way, this comparison has not yet been fully done.

• At medium-high $\beta$, the Doppler correction capabilities of the planar array are not sufficient; in order to improve them, additional information (“pulse shape”?) is needed.
Simulation of Key Experiments

- Identification and simulation of key experiments to test the analysis programs
- Develop algorithms to discriminate $\gamma$-ray hits from spurious hits (mainly from neutrons)

The simulation code should be upgraded with a less schematic event generator

Ancillary detectors should be considered not only as passive objects
**Status**

- **Classes of key experiments** generically identified in the first meeting of the Working Group
- Upgrade of the simulation code: in progress, should be completed by the end of 2003 (including the definition of a protocol for the event generator)
- Specification of key experiments and identification of the specific experimental problems: should start immediately, possibly have some preliminary specification by first half of 2004
- Results from the simulation: later (2005?)
Classes of Key Experiments

• Radioactive beams
• High $\beta$
• High spin
• Far from stability
• Hypernuclei
• ......
Upgrade of the simulation code

- The possibility to read the event structure from an external file is being implemented.
- Given the object-oriented structure, the event generator can be changed by modifying a single class (with no need to touch the rest of the code).
- The possibility of using special Geant4 classes should be explored!
- Planned upgrade of the geometry description: define the clusters in the simulation rather than defining individual crystals and pack later.