Efforts on angular distributions and correlations with AGATA

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Angular correlation & distribution: a power tool for gamma spectroscopy

- Relation between gamma angular distribution and multipolarity of transition
- Accessible experimentally in two cases:
  - Polarization of emitting nuclei (magnetic field, reaction...)
  - Gamma cascade
- Case of gamma cascade the relative angle $\theta(\gamma_{\text{ini}}-\gamma_{\text{fin}})$ contains the information

$$ W(\theta) = \sum_{i=0,\text{even}}^{\infty} A_{ii} P_i(\cos(\theta)) $$

$$ W(\theta) \sim A_{00}(1+a_2 P_2(\cos(\theta)) + a_4 P_4(\cos(\theta))) $$

Smith et al. NIMA 922 2019

Study of $\gamma$-$\gamma$ angular correlations with AGATA

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Angular γ-γ correlations with a advance gamma ray tracker

AGATA provides high efficiency and tracking resolution

Ideal tool for angular distribution study?
Angular γ-γ correlations with a advance gamma ray tracker

AGATA provides high efficiency and tracking resolution

Ideal tool for angular distribution study?

What is the AGATA response function on angular distribution?

Two main filters affecting angular correlation studies:

• PSA algorithm
• Tracking algorithm

To investigate
Reference work on $^{60}\text{Co}$ angular correlations: what to expect

**Starting point:** $^{60}\text{Co}$ beta decay

Well known transition in $^{60}\text{Ni}$:

$$4^+ \rightarrow 2^+ \rightarrow 0^+$$

$E\gamma_1 [1173.23 \text{ keV}] \rightarrow E\gamma_2 [1332.50 \text{ keV}]$

Angular correlation characterised (E2/M1):

$$a_2 = 0.1005(22) \quad a_4 = 0.0094(3)$$

$$W(\theta) \sim (1 + a_2 P_2(\cos(\theta)) + a_4 P_4(\cos(\theta)))$$

Huge data set available for AGATA.

**Starting point of study:**

Run 1105 from e673 (2017)

More than 10h

$^{60}\text{Co}$ source ($\sim 7000 \text{ Bq}$) centred

Study of $\gamma-\gamma$ angular correlations with AGATA
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Angular correlation characterised (E2/M1):

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Value</th>
</tr>
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<tbody>
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Study of $\gamma-\gamma$ angular correlations with AGATA

* S. Leblond  
* AGATA WEEK 2019
If AGATA was not a tracking array: back to basic crystal information

Using AGATA as **simple HpGe array**
- No PSA
- No tracking

Looking for $^{60}$Ni $\gamma$-$\gamma$ events:
- Using core energy
- Interaction position is the middle of the triggered crystal

Finite number of detectors:
- Minimum angle $\sim 14^\circ$
- Maximum angle $\sim 108^\circ$
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Sensitive to AGATA angular response
Geometrical effect, Individual efficiency

Uncorrelated contribution

How to normalize data?

Study of $\gamma$-$\gamma$ angular correlations with AGATA
If AGATA was not a tracking array: Pair counting & efficiency

Using AGATA as \textbf{simple HpGe array}

AGATA angular mainly affected by:
- Geometrical acceptance
- Individual detector efficiency

\textbf{Normalisation procedure:}
- Counting number of crystal pairs per angle
- Weight each event by individual detector efficiency

\textbf{Look simple procedure}
If AGATA was not a tracking array: Pair counting & efficiency

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Study of γ-γ angular correlations with AGATA
If AGATA was not a tracking array: Pair counting normalisation

Using AGATA as **simple HpGe array**

**Normalisation procedure:**
- Counting number of crystal pairs per angle
- Weight each event by individual detector efficiency

**Results & comments**
- Shape is not correct
- Minimum of distribution is not observed at 90°

Not working !! Something missing ?
If AGATA was not a tracking array:
Event mixing

Using AGATA as simple HpGe array

Basic concept:
Detected γ in data are affected by the AGATA response function

Idea: Event mixing
construct the uncorrelated distribution from artificial γ-γ pairs

Normalizing Procedure:
• Loop over all data
• Find two random γ-γ events e1 & e2
• Reconstruct artificial angles:
  \( \theta(e_{1173} - e_{1332}) \neq \) Crystal ID!
  \( \theta(e_{1333} - e_{1173}) \)
• Normalize by obtained distribution
If AGATA was not a tracking array:
Event mixing normalisation

Using AGATA as **simple HpGe array**

**Normalizing Procedure:**
- Loop over all data
- Find two random γ-γ events e₁ & e₂
- Reconstruct artificial angles:
  \[ \theta(e₁_{1333} - e₂_{1173}) \]
  \[ \theta(e₁_{1333} - e₂_{1173}) \]
- Normalize by obtained distribution

**Results & comments**
- Trend is well reproduced
- Slight offset in amplitude (depends on normalization range)

```plaintext
Success?
```

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Study of γ-γ angular correlations with AGATA

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**AGATA WEEK 2019**
If AGATA was not a tracking array: Normalisation comparison

Using AGATA as **simple HpGe array**

Two normalisation procedures:
- Number of Pair / angle + individual efficiency
- Event mixing

Overall results
- Pair normalisation is not working
- Mixing seems to provide reasonable results, expecting for the normalisation

Can we apply to same method to AGATA working as a tracking array?

Study of γ-γ angular correlations with AGATA
Using AGATA with all filters
- PSA
- Tracking

Looking for $^{60}\text{Ni} \gamma-\gamma$ events:
- Using tracked energy
- Interaction position is given by the tracking

Much higher energy and angle resolution
- Near-infinite number of angle pairs
- Large angle distribution

Normalisation algorithm
- Event mixing
AGATA as tracking array: Normalisation with event mixing

Using AGATA with all filters

**Normalizing Procedure:**
- Loop over all data
- Find two random γ-γ events e1 & e2
- Reconstruct artificial angles:
  \[ \theta(e_{1333} - e_{21173}) \]
  \[ \theta(e_{1333} - e_{21173}) \]
- Normalize by obtained distribution

**Results & comments**
- Overall is well reproduced
- Failing at low angles
- Huge deviation at large angle

These deviations strongly affect the normalisation

Study of γ-γ angular correlations with AGATA
AGATA as tracking array: Normalisation with event mixing

Using AGATA with all filters

Normalizing Procedure:
- Loop over all data
- Find two random $\gamma$-$\gamma$ events $e_1$ & $e_2$
- Reconstruct artificial angles:
  \[ \theta(e_{1333} - e_{21173}) \]
  \[ \theta(e_{1333} - e_{21173}) \]
- Normalize by obtained distribution

Results & comments
- Overall is well reproduced
- Failing at low angles
  - Mixing after tracking !!!
- Huge deviation at large angle
  - These deviations strongly affect the normalisation
AGATA as tracking array: Crystal VS PSA + Tracking

Two normalisation procedures:
- Number of Pair / angle + individual efficiency
- Event mixing

Two angle reconstruction:
- Crystal level
- PSA + tracking

General:
- Event mixing seems to provide better normalisation
- Tracking provide better resolution but is not as good at low angles
- Understanding the response function is critical for normalisation
Conclusions & outlooks

I. Investigation of AGATA angular response function with $^{60}$Co source
   • AGATA as classical HPGe array
     - Normalization by number of crystal pairs
     - Normalization by event mixing
   • AGATA as a tracking array
     - Normalization by event mixing

II. Preliminary observations
   • Event mixing seems to provide reasonable results
   • Clear evidence for effect of the tracking filter
   • Understanding AGATA response function is critical to perform correctly the normalisation

III. Outlooks
   • Perform properly the event mixing before the tracking
   • Investigate effect of PSA?
   • Look at in-beam data