Università degli Studi di Padova
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Perspectives on the measurement of competitive double gamma decay with the AGATA tracking array

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Previous observations

- Observed in 1959 and later between $0^+ \longrightarrow 0^+$ states, **no single photon** emission is possible

Nuclear Physics **A474** (1987) 412–450
North-Holland, Amsterdam

NUCLEAR TWO-PHOTON DECAY IN $0^+ \rightarrow 0^+$ TRANSITIONS

J. KRAMP, D. HABS, R. KROTH, M. MUSIC,
J. SCHIRMER and D. SCHWALM

- Observed in 2015 between $\frac{11^-}{2} \longrightarrow \frac{3^+}{2}$, **single photon** emission is possible

LETTER

doi:10.1038/nature15543

Observation of the competitive double-gamma nuclear decay

C. Walz[1], H. Scheit[1], N. Pietralla[1], T. Aumann[1], R. Lefol[1,2] & V. Yu. Ponomarev[1]

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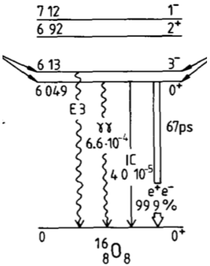

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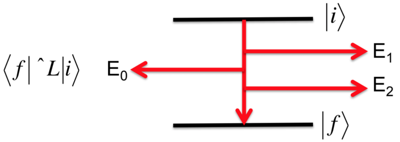
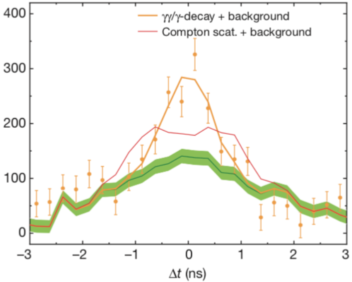
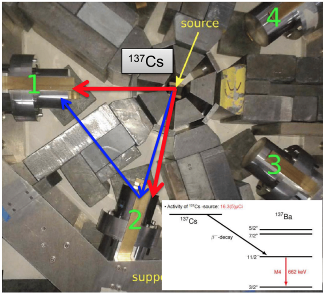


Challenges

- Never observed with HPGe but with fast $LaBr_3$ scintilltors
  - Main challenge posed by **Compton scattered events**



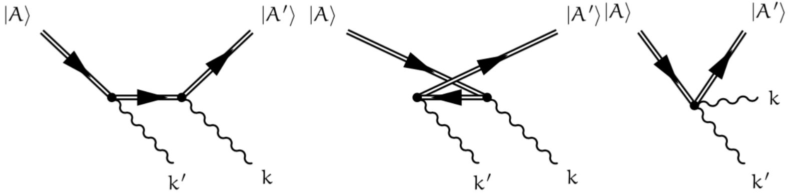


- Can the versatility of a new-generation segmented HPGe detector make up for the limited time resolution?
- Can gamma rays be reconstructed with sufficient precision?

C. Walz et al. "Observation of the competitive double-gamma nuclear decay." Nature (2015)

The (Competitive) Double Gamma Decay

- Second order **perturbative QED** and **nuclear structure** models combined
- Two photons are emitted in the decay between two nuclear states
  - Kramp et al. (1987) between $0^+ \to 0^+$ ^{16}O states
  - C. Walz et al. (2015) between $\frac{11^-}{2}^{+} \to \frac{3^+}{2}$ ^{137}Ba states



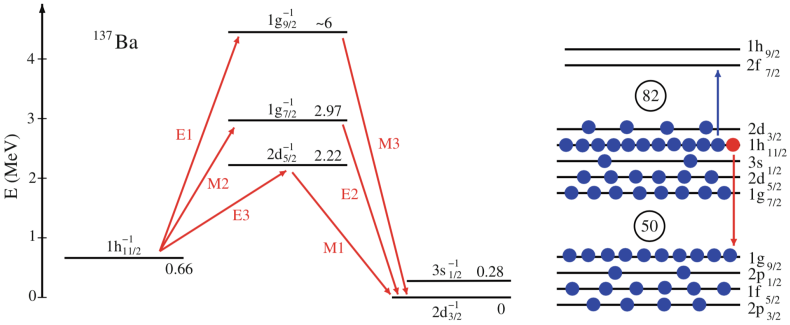
$$\mathcal{H}_{int} = \underbrace{\int d^3\mathbf{x}\; j_\mu(x) A^\mu(x)}_{\mathcal{H}_1} + \underbrace{\frac{1}{2}\int d^3\mathbf{x}\, d^3\mathbf{y}\;\; A^\mu(x) A^\nu(y) B_{\mu\nu}(x,y)}_{\mathcal{H}_2}$$

The (Competitive) Double Gamma Decay (^{137}Ba)

- The differential decay width is obtained by summing over all virtual nuclear states.

$$\frac{d^5\Gamma_{\gamma\gamma}}{d\omega\Omega\Omega'}\left(\alpha_{S'L'SL} = \sum \frac{\left\langle \frac{3^+}{2} \right| S'L' \left| I_n \right\rangle \left\langle I_n \right| SL \left| \frac{11^-}{2} \right\rangle}{E_n - E_0/2}\right) \tag{1}$$

- $Br(\gamma\gamma) \approx \Gamma_{\gamma\gamma}/\Gamma_{\gamma} = 2 \times 10^{-6}$



C. Walz et al. “Observation of the competitive double-gamma nuclear decay.” Nature 526

AGATA

- Segmented HPGe detector with unprecedented versatility

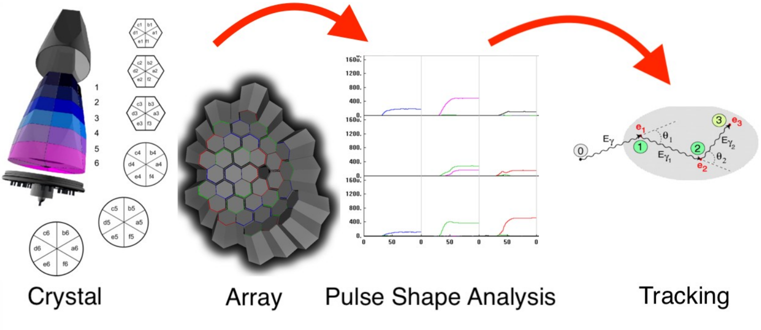
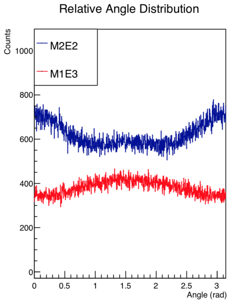


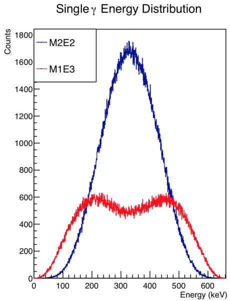
Figure: Left: One **segmented** HPGe crystal. Right: The full array in its current configuration

S. Akkoyun et al. "AGATA - Advanced GAmma Tracking Array.", NIM, (2012)

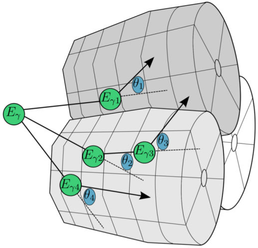
The Simulation

- Geant4 **simulation** with the array geometry returns the **interaction hits and deposited energy**
- 661.7 keV photons are simulated
  - double gammas are simulated with correct energy and angle distributions





The Tracking



S. J. Colosimo PhD Thesis .

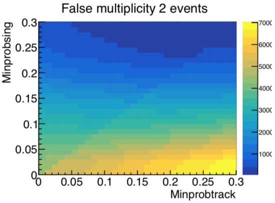
- **The tracking algorithm reconstructs Compton scattered photons** from the PSA hits
- Using the positions of interaction and energies, assigns to a set of interaction points a merit factor based on:
  - Distance travelled in Ge
  - Probability of Compton interaction: $\exp\left(-\frac{(E_{geom}-E_m)^2}{\sigma^2}\right)$
  - Probability of photoelectric interaction

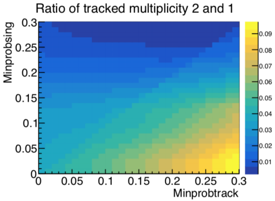
- Three parameters can be set:
  1. *sigma˙thet* Position resolution factor
  2. *minprobsing* Minimum probability to accept a cluster as a single interaction point
  3. *minprobtrack* Minimum figure of merit value to accept a cluster

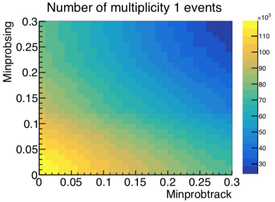
A. Lopez-Martens et al., "γ ray tracking algorithms: a comparison" NIM (2004)

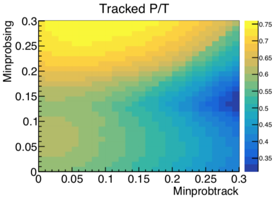
Optimizing the parameters

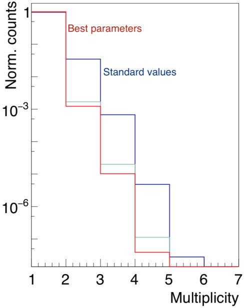
- The best parameter combination needs to:
  - Track correctly double gammas (not reject a considerable amount)
  - **Not track single gammas as fold-2**







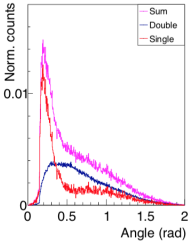


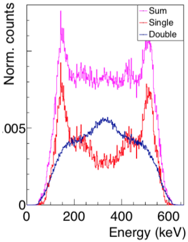


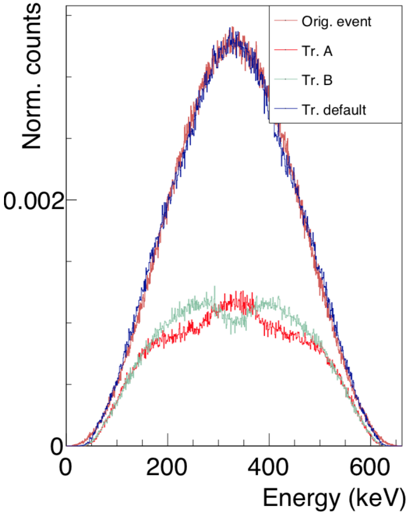
- Fewer single gammas are tracked as double gammas

The simulation

- The tracking, with optimal parameters is generating a **bias on the energy distribution** of the double gammas
- Nearby events are mostly incorrectly reconstructed events

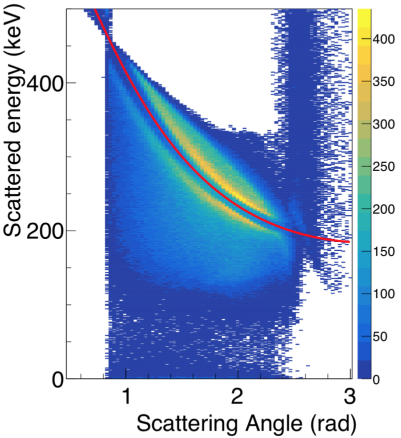






How do the new parameters perform?

- Standard parameters



- Compton kinematic restriction
  $E' = \frac{E_0}{1+\frac{E_0}{m_e c^2}(1-\cos\Theta)}$

- **OFT has improved the rejection of Compton scattered events**

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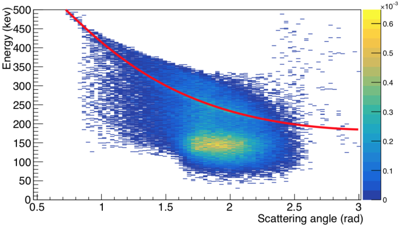

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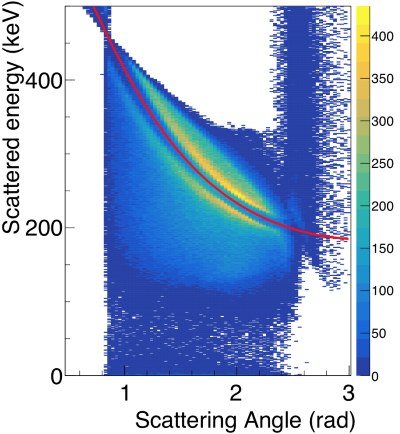

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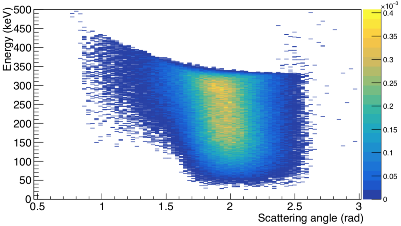
- Double gamma events can also be simulated



- The difference of the normalized histograms tells us where correctly reconstructed events are located

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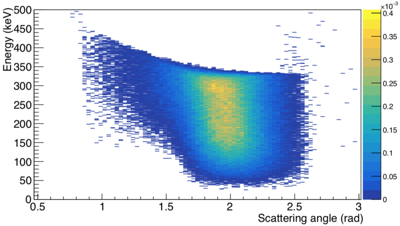
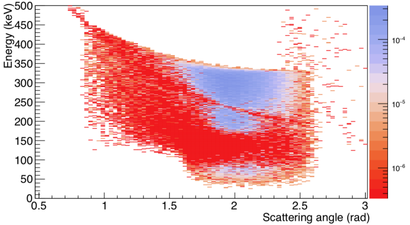
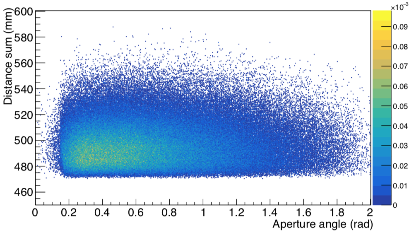
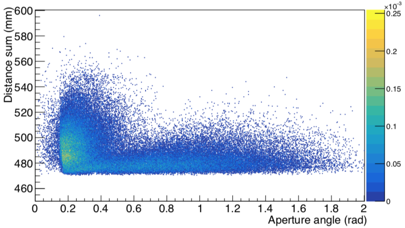


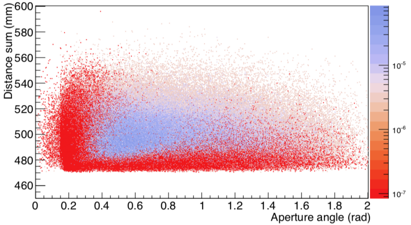


- The difference of the normalized histograms tells us where correctly reconstructed events are located

- Distance from the source and aperture angle permit to **identify photons scattering from one side to the other**







- On the surface of the detector many Compton scattered events are reconstructed as double gammas.

Preliminary results

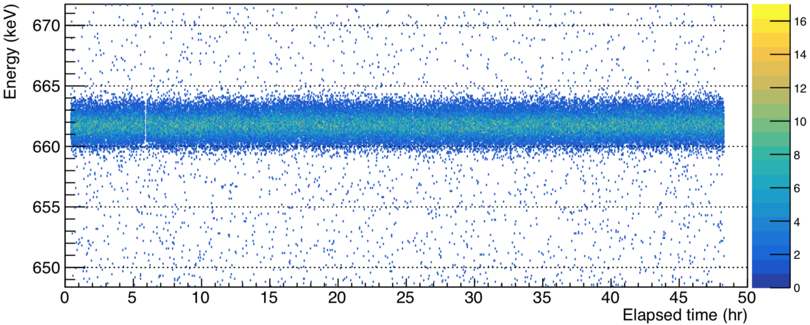
Event Type	N_{obs}/N_{sim}	N'_{obs}/N_{sim}
γ	7.04×10^{-5}	3.81×10^{-6}
$\gamma\gamma$	3.27×10^{-3}	1.15×10^{-3}
Ratio $\gamma/\gamma\gamma$	2.15×10^{-2}	3.31×10^{-3}

Where

- N_{obs} number of observed multiplicity two gammas
- N'_{obs} number of observed multiplicity two gammas after further event selection
- N_{sim} number of simulated events

Preliminary experimental approach

- Taking into account the discard rate and the detection efficiency, in order **to observe** 10^4 **double gammas** 259 **Tb of disk space are needed**
- The **stability of the array** over time is another crucial aspect



Summary and perspectives

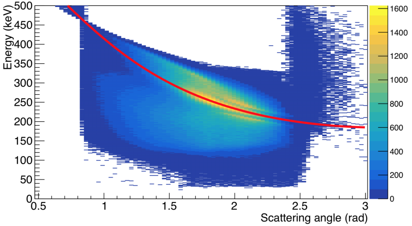
1. A simulation at the emission of single and double gamma was performed
2. Optimal parameters for the tracking were found
3. Event selection was performed
4. Some preliminary experimental considereation were made

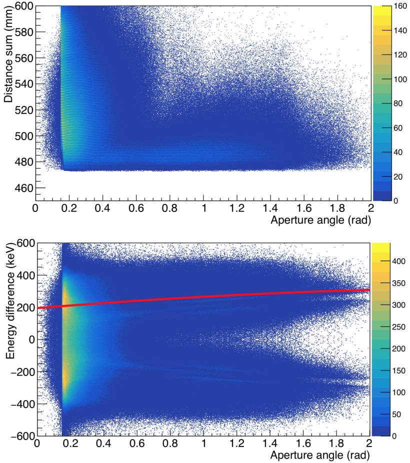
Future perspectives

- AGATA 4π would increase the efficiency $\epsilon_\gamma = 52.2\%$ $\epsilon_[\gamma\gamma] = 32.5\%$
- New tracking algorithms are developed namely with a Bayesian statistical approach
- Improvements in the Pulse Shape Analysis, with focus on a error estimation

Thank you for your attention

Some experimental results

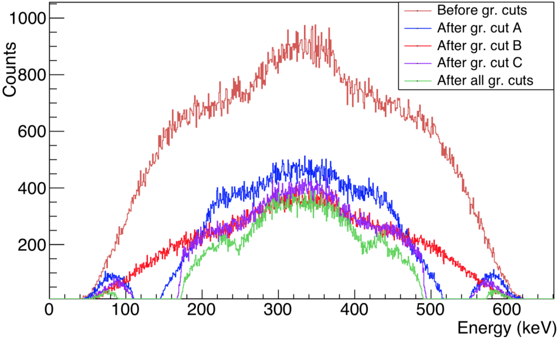




- Experimental data with 28 kBq ^{137}Cs source, acquisition time 47 hr

How much is an observable affected

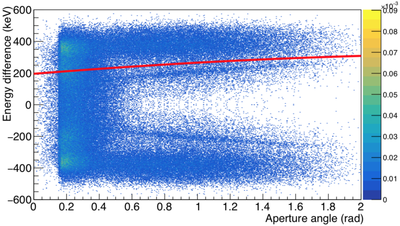
- The energy distribution of the double gammas before and after the 2D gates

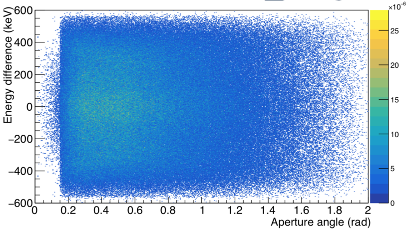


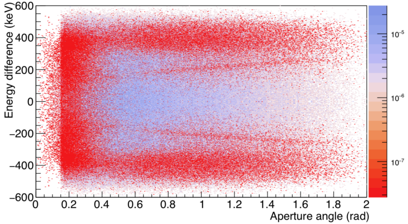
- Many double gamma events are also lost
- Some of the gates are compromising more than the rest the distribution

The simulation

- Aperture angle and energy difference makes for another possible event selection 2D gate

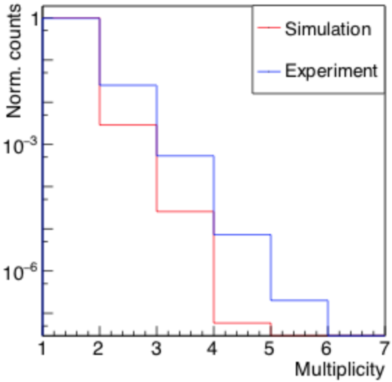






Multiplicity

- Multiplicity in the simulation and during the experiment, where background is present.



Random coincidences

- **Random coincidences** pose another challenge to the measurement