Analysis and Improvement of PSA Performance employing ^{22}Na 511 keV $\gamma\gamma$ coincidences

3rd AGATA-GRETINA tracking arrays meeting

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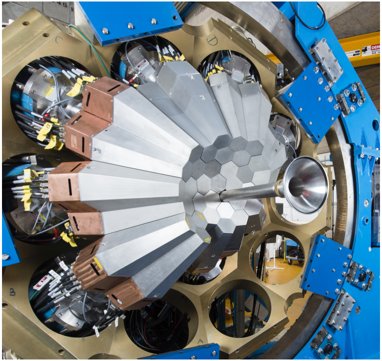
Content

- Introduction: PSA with ADL @AGATA
- Assessing PSA performance: ^{22}Na-coincidence method
- Improving PSA performance: Electronic response and simulation
  - Preamplifier rise times
  - Hole mobility
  - Electron mobility
- Improving PSA performance: Grid search algorithm
  - Weighting of transient signals
  - Distance metric

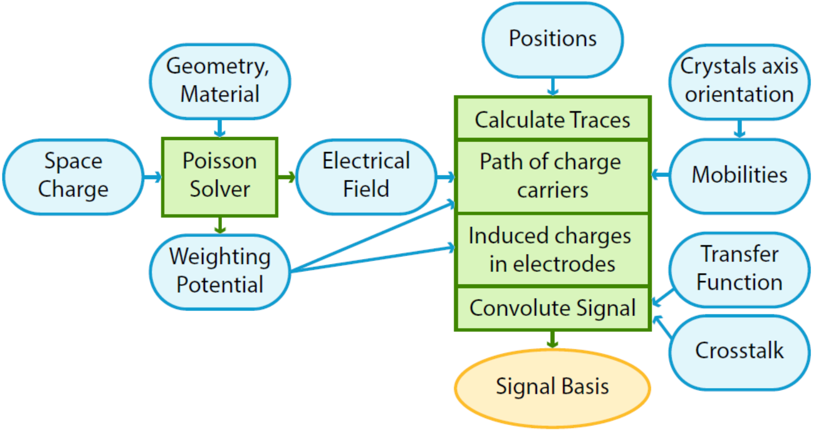
Introduction

AGATA

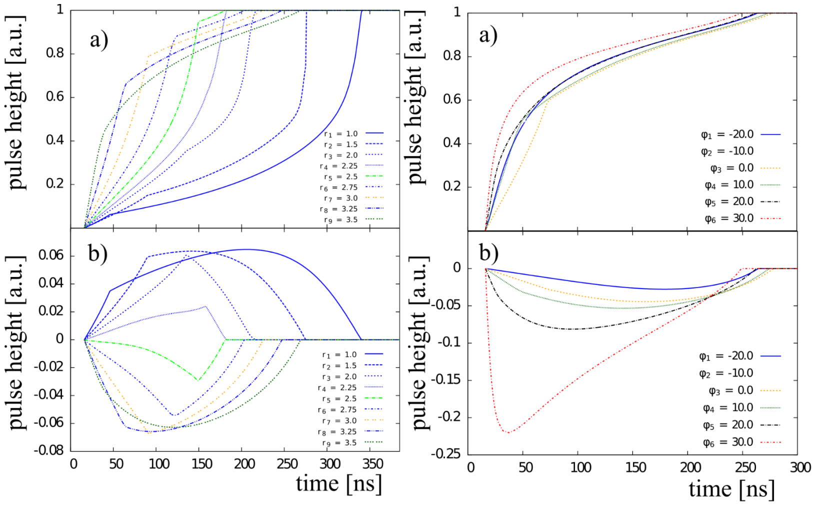
- 36 fold segmented HPGe detectors
- Induced charge on electrodes **characteristic** for each interaction position
- Compare with simulation (ADL, next slide)



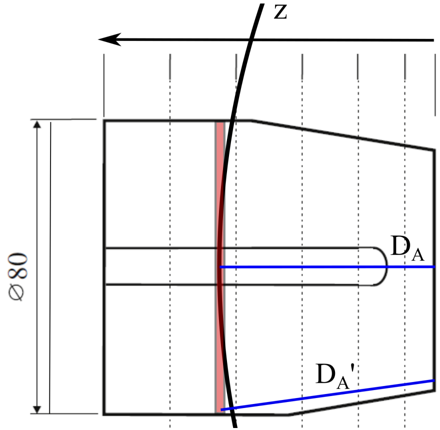
ADL


Positions
Geometry, Material
Crystals axis orientation
Calculate Traces
Space Charge
Poisson Solver
Electrical Field
Path of charge carriers
Mobilities
Weighting Potential
Induced charges in electrodes
Transfer Function
Convolute Signal
Crosstalk
Signal Basis

Simulated Signals

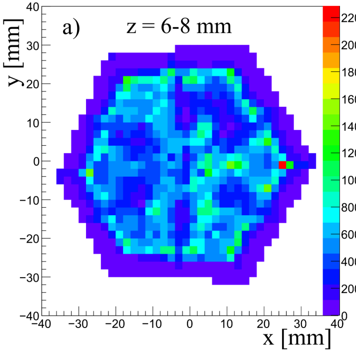


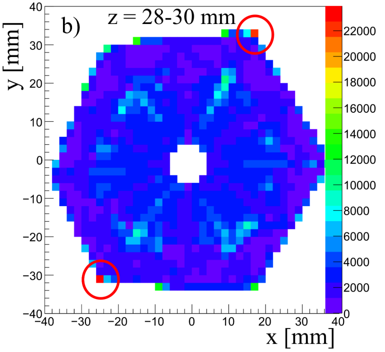
Results of the Pulse-Shape Analysis



- Source placed in center of AGATA sphere
- Same solid angle $\propto \frac{1}{r^2}$, same penetration depth D_A for xy-planes with fixed z

Results of the Pulse-Shape Analysis

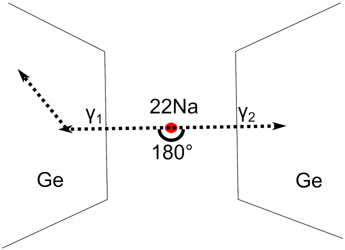




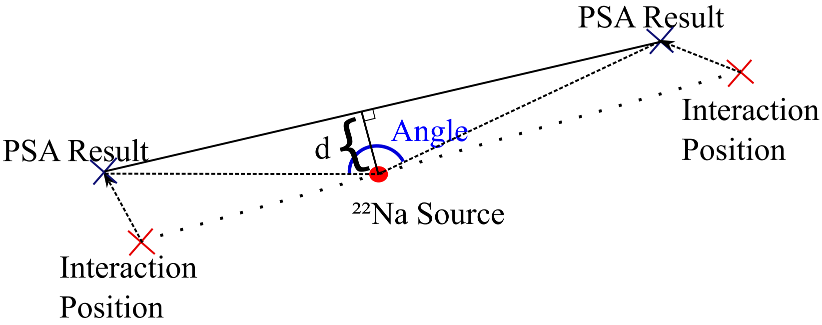
- Same expectation value for grid points with same z
- Crystal A001

^{22}Na-Coincidence Method

- ^{22}Na measurement for assessment of PSA performance

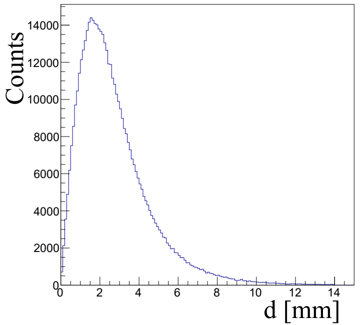


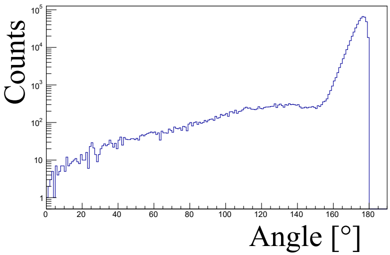
Principle



- β^+-decay of ^{22}Na
- Coincident detection of two 511 keV photo effects
- Difference PSA result and physical interaction position
- Distance describes PSA performance

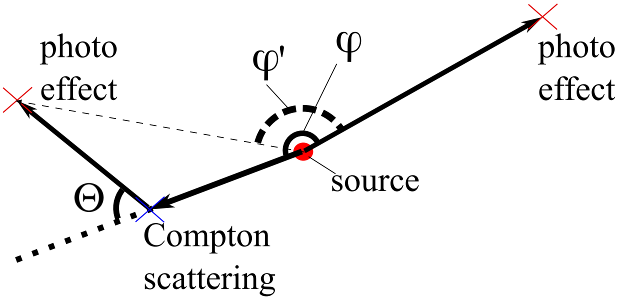
Distance Line to Source and Angle





- Distance and angle for two 511 keV single interactions

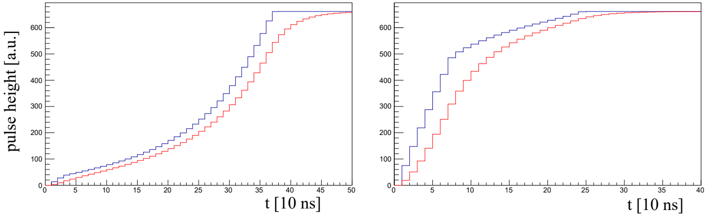
Coincidences Including a Compton Scattering



- One Compton scattering, followed by photo effect
- Same principle

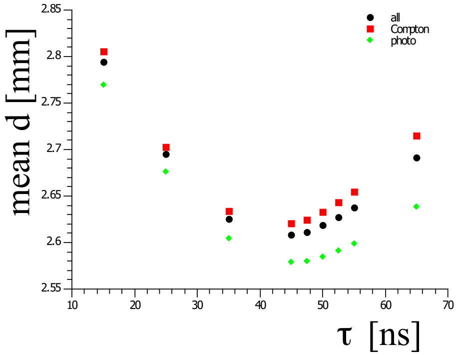
Transfer Function

- Measured signals shaped by preamplifier
- Convolution of simulation with transfer function
- Typically used approximation: Exponential response



- Simulated traces without and with exponential response $\tau = 35\,\text{ns}$

PSA Performance for Different Electronic Responses



- Variation of τ for exponential response
- Mean distance of ^{22}Na-coincidence method for PSA performance
- Two photo effects ("photo") or one photo effect, one Compton scattering ("Compton")

Results of τ Variation

- Optimal value at $\tau = 45\,\text{ns}$ obtained, compared to $\tau = 35\,\text{ns}$ standard
- Empiric approach $\Rightarrow$ ambiguity due to other PSA parameters
- Hole mobility has similar influence on pulse shape
- $\Rightarrow$ Complementary investigation

Drift Velocity of Holes

Empirical model for hole drift velocity

$$v_D = \frac{\mu E}{(1 + (\frac{E}{E_0})^{\beta})^{\frac{1}{\beta}}}$$

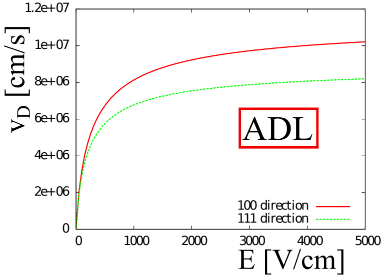
v_D drift velocity, μ hole mobility, E electrical field, E_0, β empirical parameters

Hole mobility parameters in $\langle 1\,0\,0 \rangle$ direction in ADL

$\mu = 62.934 \, \frac{\mathrm{cm}^2}{\mathrm{mVs}}$

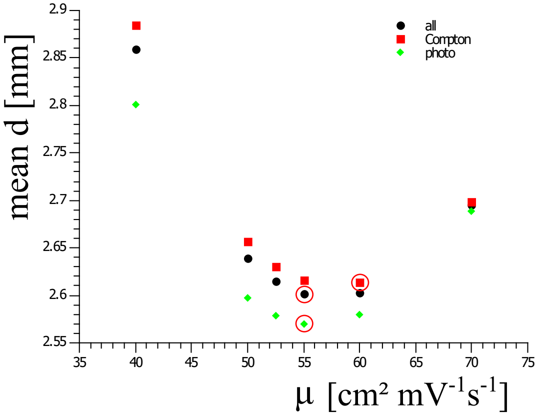
$E_0 = 181.9 \, \frac{\mathrm{V}}{\mathrm{cm}}$ $\beta = 0.735$

$E_{0,\langle 1\,1\,1 \rangle} = 143.9 \, \frac{\mathrm{V}}{\mathrm{cm}}$



- Measured by Bruyneel et al. NIM A 569 (2006) doi:10.1016/j.nima.2006.08.129
- Change drift velocity by variation of hole mobility

Variation of Hole Mobility



- Optimal mobility at 55 $\frac{\mathrm{cm}^2}{\mathrm{Vms}}$ close to ADL value

Electron Drift Velocity

Empirical model for electron drift velocity

$$v_D = \frac{\mu_e E}{\left(1 + \left(\frac{E}{E_0}\right)^{\beta}\right)^{\frac{1}{\beta}}} - \mu_n E$$

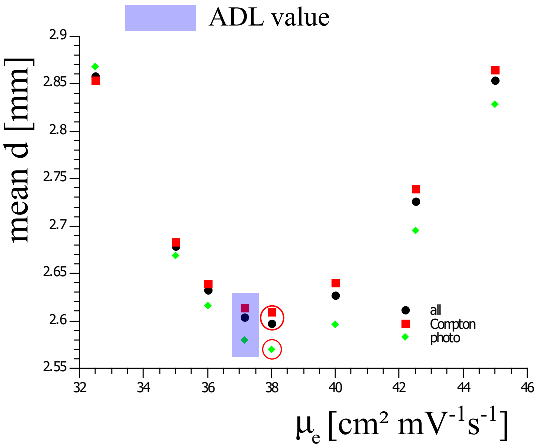
μ_e electron mobility, μ_n phonon scattering (Gunn effect)

Electron mobility parameters in $\langle 1\,0\,0 \rangle$ direction in ADL

$\mu_e = 37.165\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$
$E_0 = 507.7\ \frac{\mathrm{V}}{\mathrm{cm}}$
$\beta = 0.804$
$\mu_n = -0.145\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$

- Drift velocity in $\langle 1\,1\,1 \rangle$ direction calculated from $\langle 1\,0\,0 \rangle$ parameters (see B. Bruyneel et al. doi:10.1016/j.nima.2006.08.130)
- Variation of μ_e

Variation of Electron Mobility



- Minimum nearly at ADL value obtained
- μ_e easier to measure via rise time determination

Improvement of Grid Search Algorithm: Weighting of Transient Signals

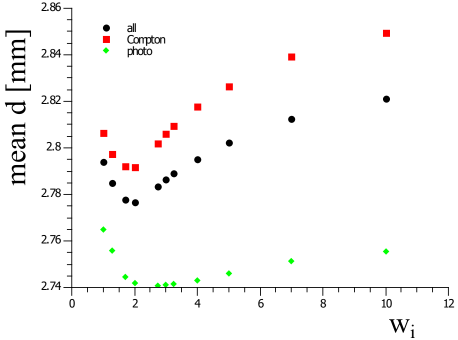
Figure of Merit with weighting coefficient w_i

$$\mathrm{FOM} = \sum_{\text{segments } i} w_i \sum_{t_j} |A_{i,\mathrm{sim}}(t_j) - A_{i,\mathrm{meas}}(t_j)|^p$$

$A_i(t_j)$ pulse height of segment i at time step t_j

- Weighting coefficient $w_i = 1$ for hit segment core, to be determined for neighboring segments
- Variation of w_i

Variation of Weighting Coefficient



- Best results with weighting coefficient of 2-3
- Slightly different results for photo vs Compton
- Detector multiplicity 1 (photo) vs 1-2 (Compton)
- Smaller signal to noise ratio for Compton scattering

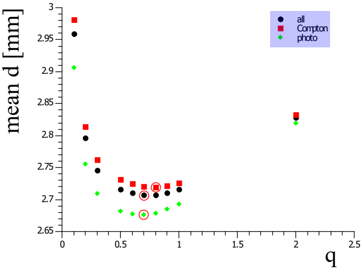
Individual Distance Metric for Transient Signals

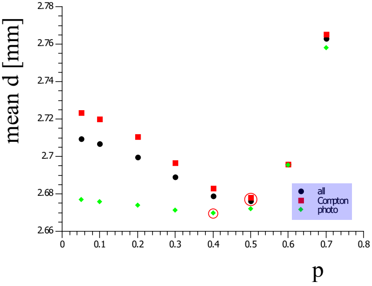
Split Figure of Merit

$$\mathrm{FOM} = \underbrace{\sum_{l,t_i} |A_{l,\mathrm{m}}(t_i) - A_{l,\mathrm{s}}(t_i)|^q}_{\text{neighboring segments}} + \underbrace{\sum_{j,t_i} |A_{j,\mathrm{m}}(t_i) - A_{j,\mathrm{s}}(t_i)|^p}_{\text{hit segment and core}}$$

- Variation result with same exponent: $p = 0.4$
- Now: Different exponents p and q for hit segment & core and transient signals
- Iterative variation

Variation of split Distance Metric

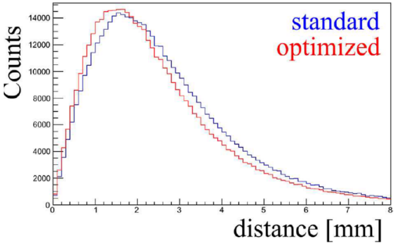




- p exponent hit segment & core
- q transient signals
- q > p main improvement
- Final result: q=0.7 p=0.4 (0.5)
- Similarities to weighting

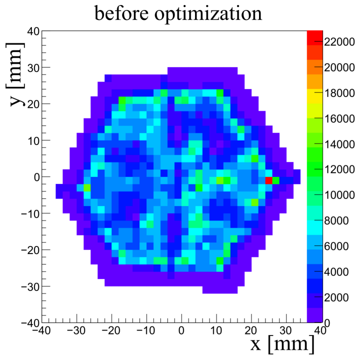
Final Results

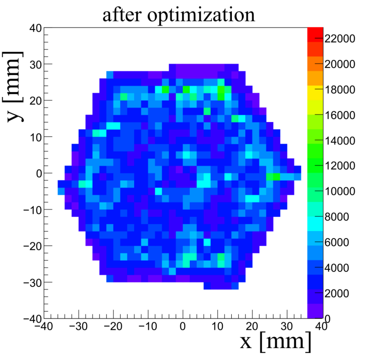
Parameter	Initial value	Result after variation
p	0.3	0.4
q	0.3	0.7
w_j	1	2.75
$\mu_{\langle 1\ 0\ 0 \rangle}$	$62.934\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$	$55\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$
$\mu_{\langle 1\ 1\ 1 \rangle}$	$62.383\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$	$55\ \frac{\mathrm{cm}^2}{\mathrm{mVs}}$
τ	35 ns	40 ns



- Standard configuration: mean distance 2.73 mm, standard deviation 1.85 mm
- Optimized configuration: mean distance 2.54 mm, standard configuration 1.80 mm

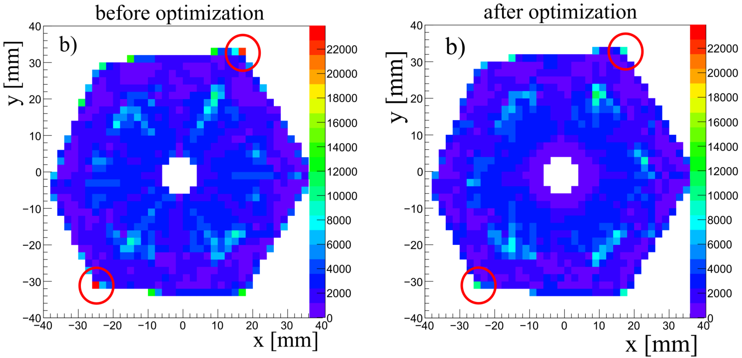
Impact on Hit Distributions





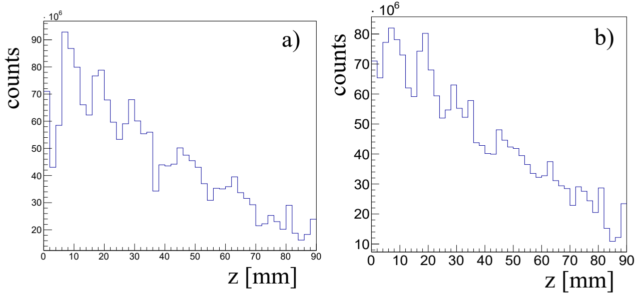
- Exemplary hit distributions (crystal A001)
- $z = 6 - 8\,\mathrm{mm}$

Impact on Hit Distributions



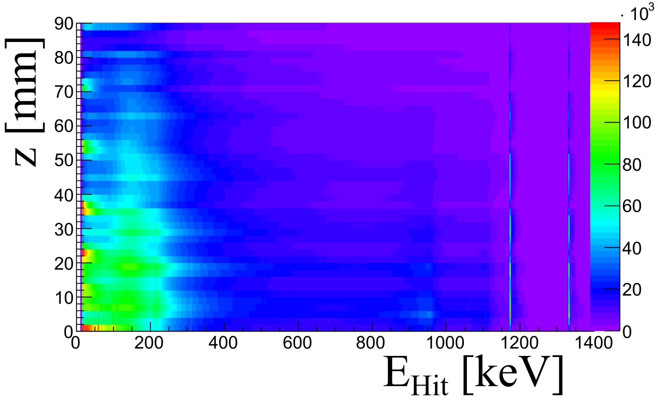
- Exemplary hit distributions (crystal A001)
- $z = 28 - 30\,\mathrm{mm}$

Hit Distribution in Dependence of Detector Depth



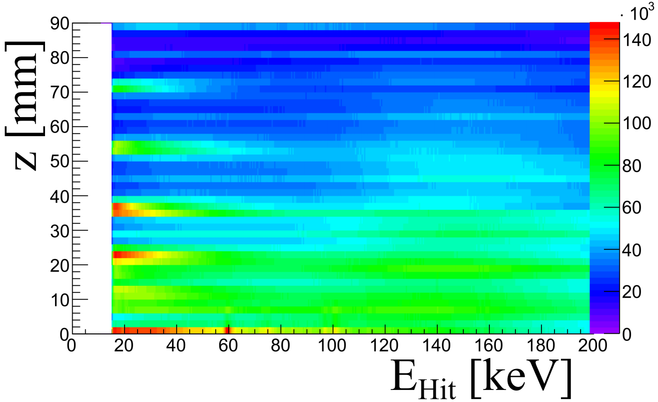
- a) standard b) optimized configuration
- $\propto \frac{1}{z^2}$ (solid angle coverage) and $\propto e^{-\sigma z}$ (absoprtion) expected

Detector Depth vs Hit Energy



- Energy of individual hits
- Energy dependence of clustering

Detector Depth vs Hit Energy at low Energies



- Clustering at very low energies below 50 keV
- Suggestion: ^{241}Am measurement for low energy position resolution

Summary and Outlook

Summary

- Investigation and optimization of PSA performance, including:
  - Transfer function
  - Hole mobility
  - Electron mobility
  - Weighting of transient signals
  - Split distance metric for transient signals
- Improved PSA results, but still not ideal
- Published in EPJ A 2019 doi 10.1140/epja/i2019-12752-0

Summary and Outlook

Possible future PSA improvements

- Two hits inside one segment (existing, but not working well)
- Handling of multiplicity
- Space charge distribution
- Dead layers
- "Smart" search algorithm (best grid search depends on energy, multiplicity, interaction position, ...)
- Interplay of tracking and PSA (e.g. bad tracking $\chi^2 \Rightarrow$ test for two interactions)

...But all not trivial

Thank you for your attention!