AGATA Detector Library

First AGATA-GRETINA tracking arrays collaboration meeting

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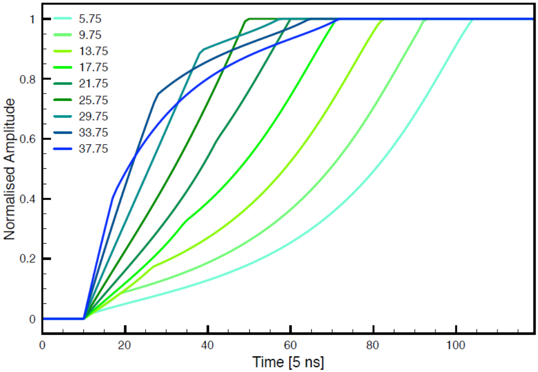
IKP Cologne

December 5th 2016

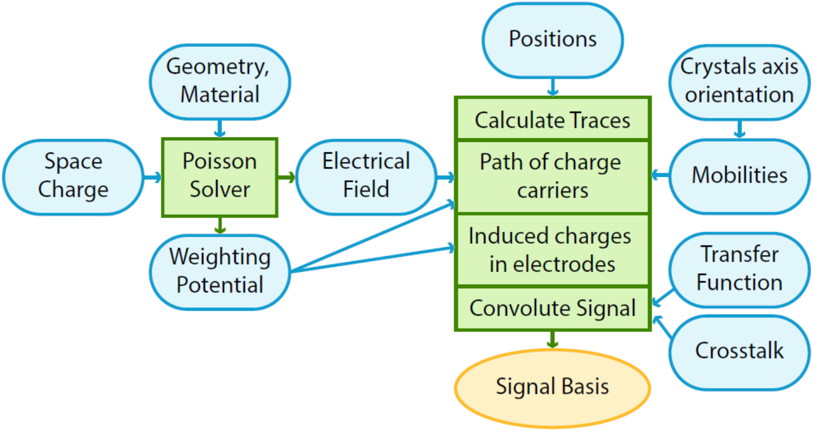
AGATA Detector Library

- AGATA Detector Library (ADL)[1]
- Simulated pulses for each interaction position
- Comparison with measurement



[1] B. Bruyneel, B. Birkenbach and Peter Reiter: Pulse shape analysis and position determination in segmented HPGe detectors: The AGATA detector library

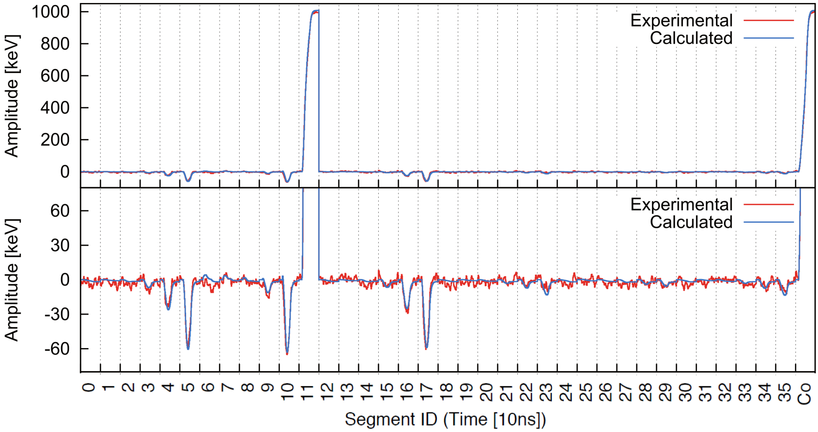
ADL Working Principle



B. Bruyneel, P. Reiter, G. Pascovici, Characterization of large volume HPGe detectors. Part I: Electron and hole mobility parameterization

B. Bruyneel, P. Reiter, G. Pascovici, Characterization of large volume HPGe detectors. Part II: Experimental results

ADL Working Principle



PSA Working Principle

Adaptive Grid Search [2]

- Assumption: One interaction per segment

NARVAL/femul framework provides [3]

- Crosstalk correction (proportional and differential)[4] [5]
- T_0 determination (constant offset and dynamic shift during PSA)
- Convolution of simulated signal with response function
- ...

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[2] R. Venturelli et. al.

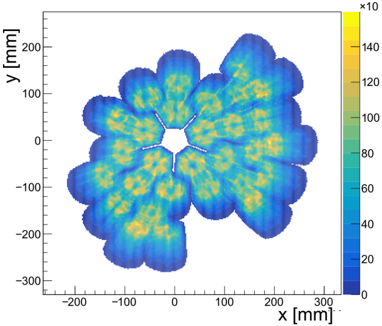
[3] D. Bazzacco, R. Venturelli, O. Stézowski et. al.

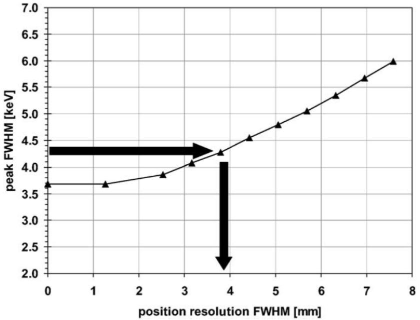
[4] Bart Bruyneel, Peter Reiter, Andreas Wiens, Jürgen Eberth, Herbert Hess, Gheorghe Pascovici, Nigel Warr, Dirk Weisshaar: Crosstalk properties of 36-fold segmented symmetric hexagonal HPGe detectors

[5] B. Bruyneel, P. Reiter, A. Wiens, J. Eberth, H. Hess, G. Pascovici, N. Warr, D. Bazzacco, F. Recchia, Crosstalk corrections for improved energy resolution with highly segmented HPGe-detectors

Results of PSA with ADL

- Position resolution 4-5 mm FWHM[6] [7]
- Well within specifications

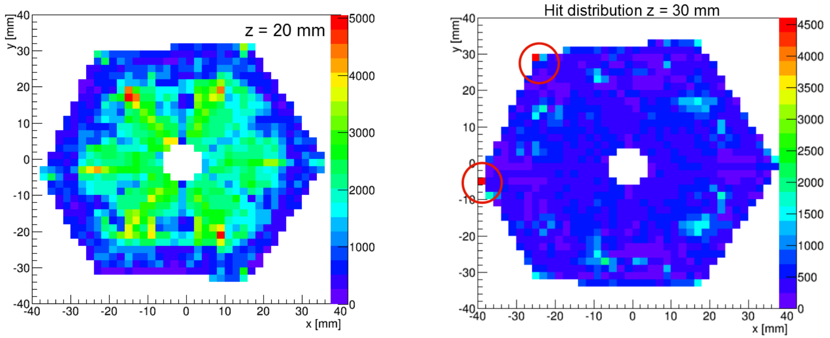




[6] F. Recchia et al., Position resolution of the prototype AGATA triple-cluster detector from an in-beam experiment

[7] P.-A. Söderström et. al. Interaction position resolution simulations and in-beam measurements of the AGATA HPGe detectors

Open Questions



- Clustering
- Segment structure
- High statistics grid points

PSA Optimization

Investigated parameters

Major / reasonable impact on PSA result

- Time alignment and T_0
- Distance metric
- Transfer function
- Energy scaling of simulation
- Transient weighting

Minor impact on PSA result

- Differential crosstalk
- Space charge distribution [a]
- Number of samples in FOM calculation
- Rounding of energy differences
- ...

[a] B. Birkenbach et. al. Determination of space charge segmented large volume HPGe detectors from capacitanc measurements

Determination of PSA parameters

Two approaches

^{22}Na Coincidence method

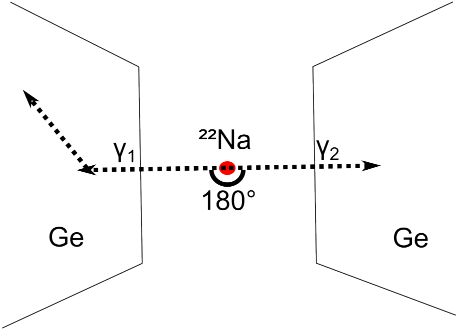
- 180° 511 keV γ rays
- Interaction position

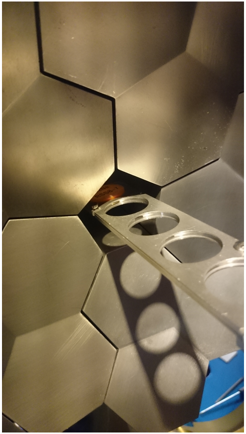
Statistical methods

- Source run (e.g. ^{152}Eu)
- Distribution of hits known
- Homogeneity of distribution

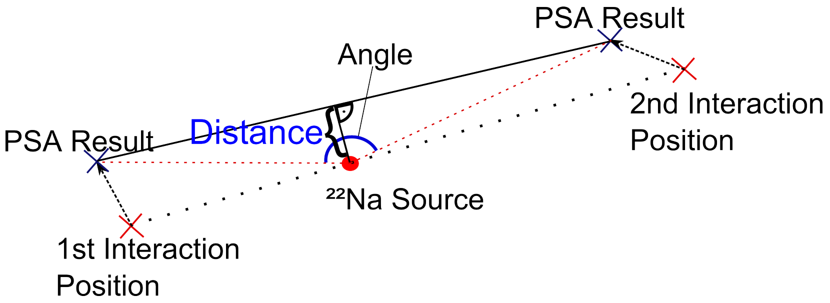
^{22}Na Coincidence Method

- β^+ from ^{22}Na
- e^+e^- annihilation
- Two 511 keV γ rays at 180 °



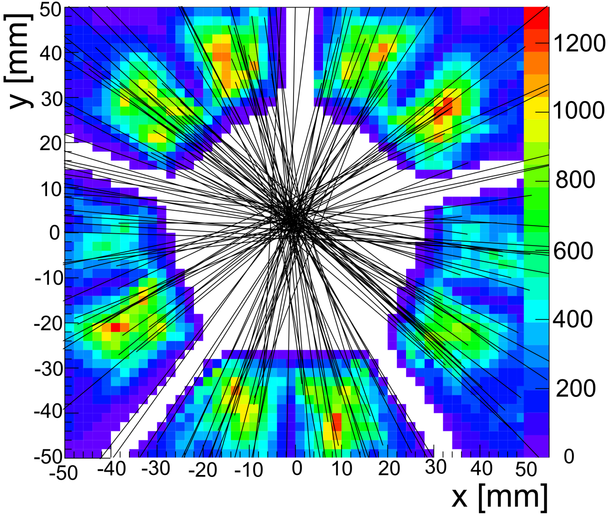


Principle

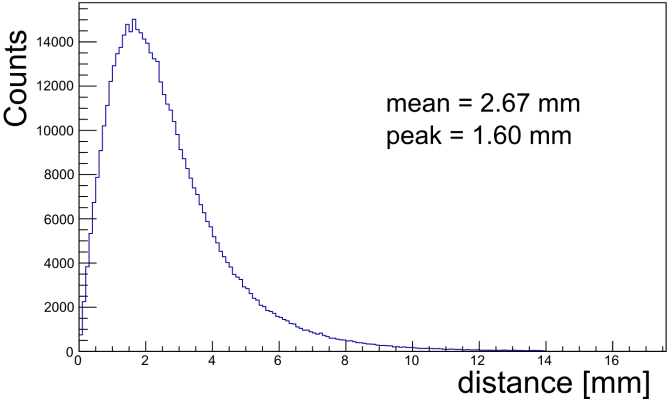


- Coincident detection
- Difference of PSA result and physical interaction position
- Distance describes PSA performance

Visualization



Distance to Source



- Distance of line to source position
- Mean distance of all coincidences is used to optimize PSA

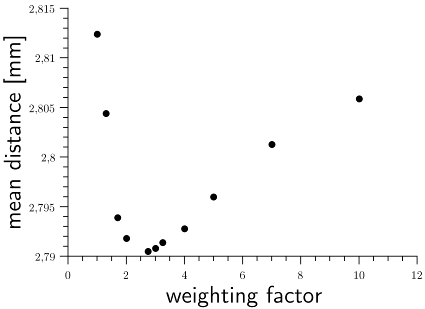
Weighting of Transient Signals

- Stronger weighting for signals of neighboring segments

Weighting of Neighboring Segments

$$\text{Figure of Merit} = \sum_j \mathbf{w_j} \sum_{t_i} |A_j^m[t_i] - A_j^s[t_i]|^p$$

w_j=1 for hit segment and core, to be determined for neighboring segments



- w_j=2.75

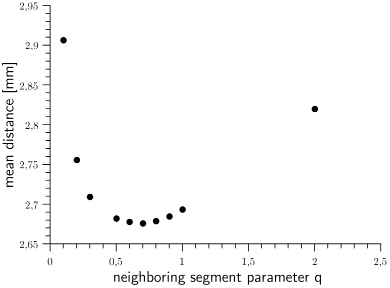
Distance Metric

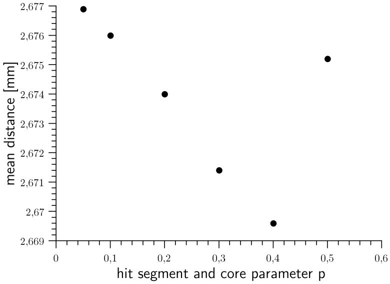
- New approach: Different metrics for hit segment/core and neighboring segments

New Figure of Merit

$$\text{Figure of Merit} = \underbrace{\sum_{j,t_i} |A_j^m[t_i] - A_j^s[t_i]|^p}_{\text{hit segment and core}} + \underbrace{\sum_{j,t_i} |A_j^m[t_i] - A_j^s[t_i]|^q}_{\text{neighboring segments}}$$

Distance Metric





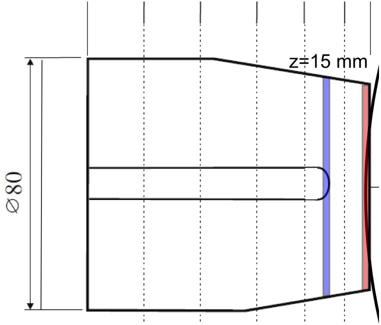
- Minimum at q=0.7
- Minimum at p=0.4
- Iterative procedure
- Improvement compared to standard figure of merit calculation (and weighted)
- Mean d=2.67 mm (old: d=2.73 mm)

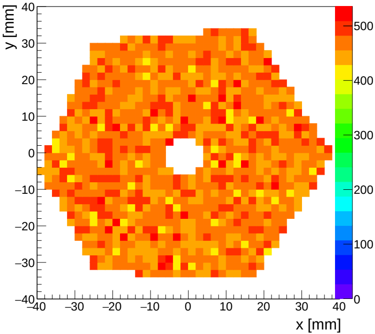
Summary: ^{22}Na coincidence method

- Efficient and reliable
- Good for determining "global" properties
- Position uncertainty of both interactions enters result
- PSA performance on detector or segment level: Different approach needed

Additional criteria for PSA performance

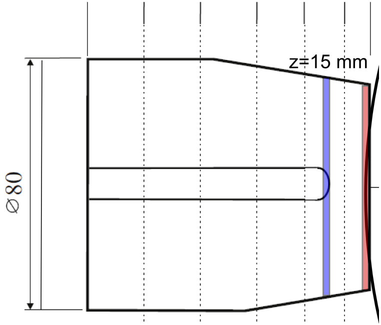
- For source run distribution of hits is known (except statistical fluctuation)
- $\Rightarrow$ Deviation from the expectation
- Randomly allocated hits (no position uncertainty)

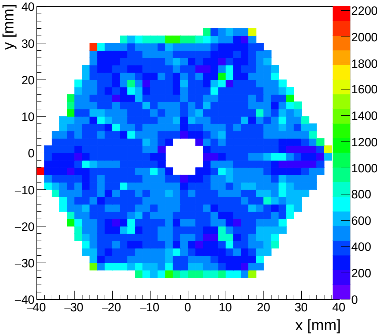




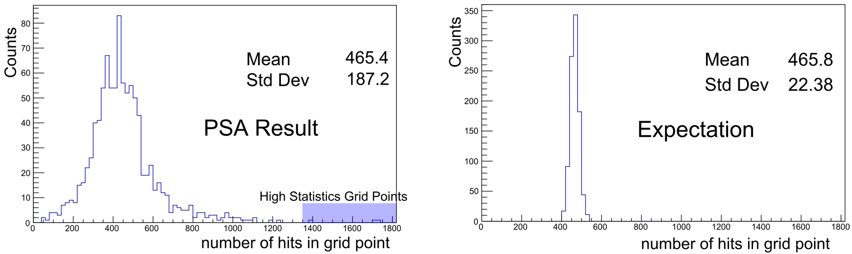
Additional criteria for PSA performance

- Several criteria (consistency)





Additional criteria for PSA performance



- For each grid point: Number of hits filled into histogram
- Ideal expectation $\sigma = \sqrt{m}$ (Poisson), but $\sigma_{\mathrm{PSA}} \gg \sqrt{m}$, mean m
- Large tail, high statistics grid points

Ratio

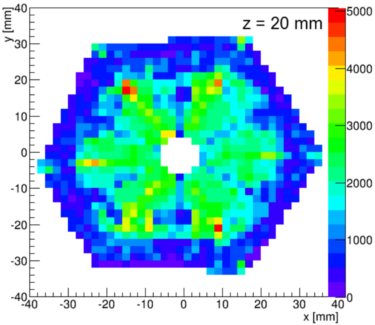
- Define threshold: 3.5$\cdot m$
- Above threshold: "High Statistics Grid Point" (HSGP)

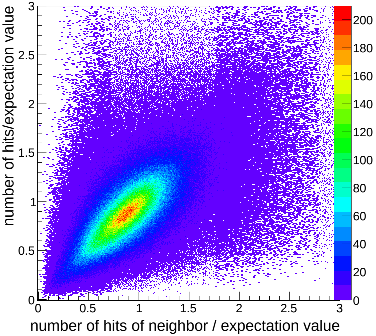
Ratio

$$\text{Ratio} = \frac{\text{Hits}_{\text{threshold}}}{\text{Hits}_{\text{rest}}}$$

Correlation

- Clustering ⇒ Correlation of neighboring grid points





Final Figure of Merit

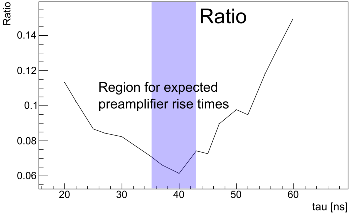
Reminder: Figure of Merit

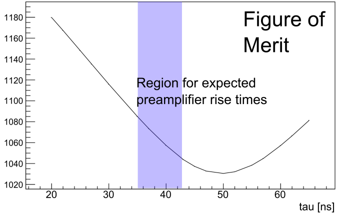
$$\text{Figure of Merit} = \sum_{j} \sum_{t_i} |A_j^m[t_i] - A_j^s[t_i]|^p$$

- Final figure of merit for the best fitting trace
- For constant energy: Lower value $\Rightarrow$ better matching of measurement and simulation

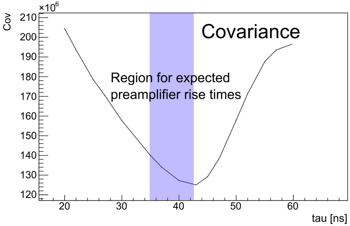
Transfer Function

- Transfer function of preamplifier and digitizer
- Performed for every segment (and all cores)

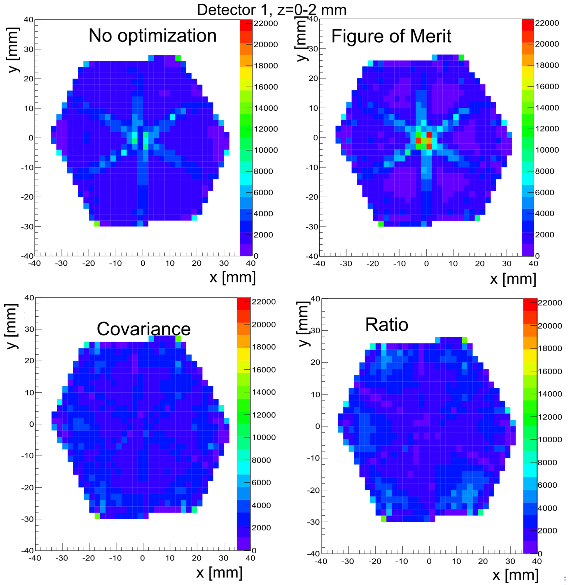




-Minima correspond to optimal tau value
-Shown exemplarily for one segment

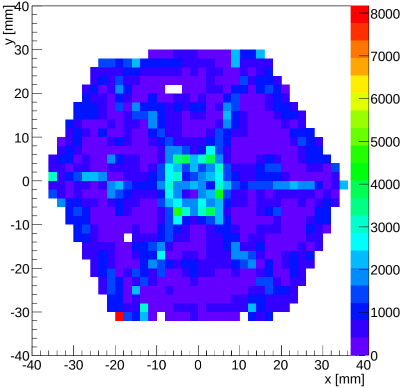


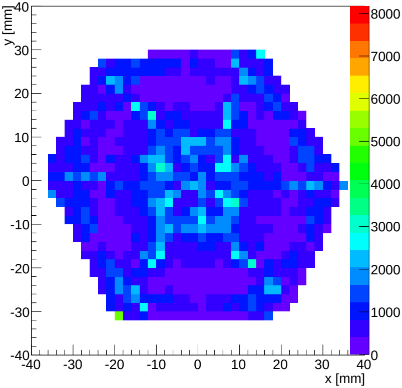
Impact on hit distribution



Optimization

- Before (left) and after (right) complete Optimization
- Exemplarily for det 1, z=10-12 mm. All energies





Summary

^{22}Na coincidence method

- Precise and reliable
- Information on physical interaction position
- Only relative PSA performance
- Good for global properties

Statistical methods

- No information on physical interaction position
- Very scalable - good for detector or segment properties
- Energy- or z-dependence
- Characterization of whole array with **one** measurement

Outlook

Possible cause for remaining problems

- One interaction per segment
- ADL: Charge carrier mobilities, point like charge cloud
- ...

Outlook

- Combination of the two complementary approaches
- Investigation of other input parameters
- Something missing?
- New solutions like measured data bases

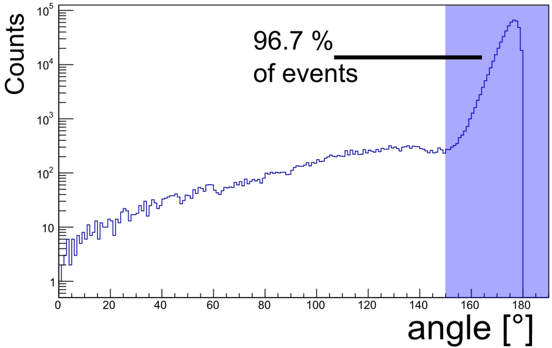
Thank you

Thank you for your attention!

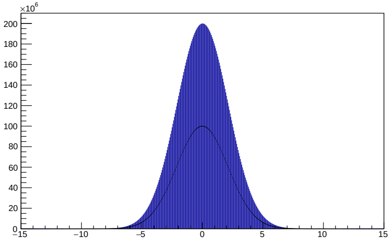
TEMPLATE

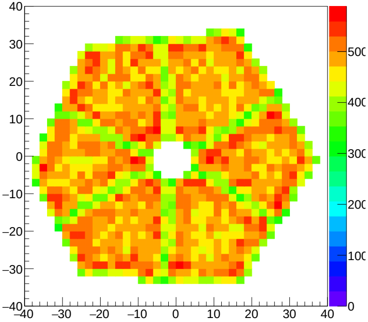
Coincident Detection

- Gate on:
  - Multiplicity $= 2$ (not in same detector)
  - Individual energy of 511 ± 3 keV
  - Angle $> 150°$



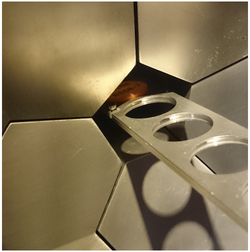
Random Interaction Points Shifted Within Segment

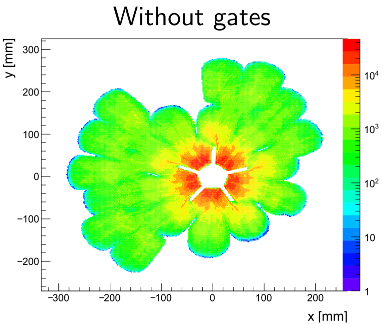


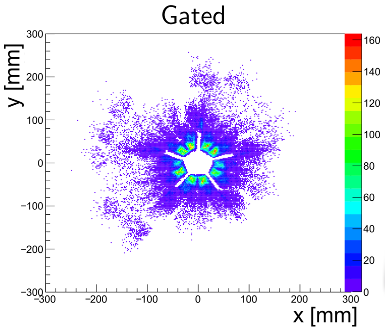


Setup

- ^{22}Na source placed inside pentagon
- Rates per crystal $< 1\,$kHz for inner ring, < 200 for rest

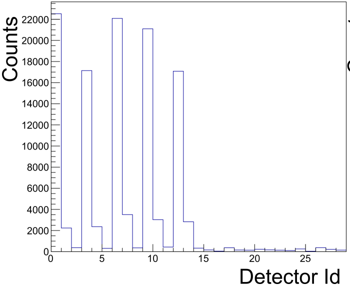


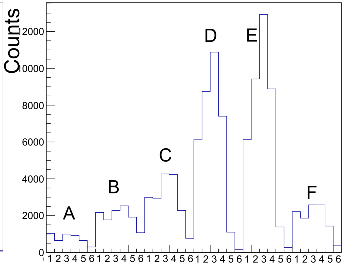


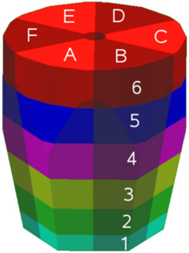


Coincidences

- Coincidences mainly in inner ring of detectors
- All segments hit
- Full characterization of inner detectors possible







Additional criteria for PSA performance: Deviation from the mean

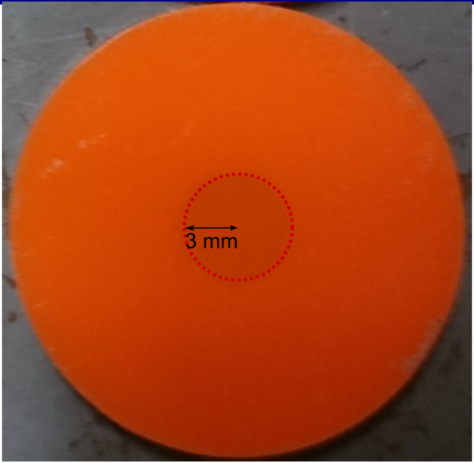
- Very similar to variance
- Distribution should be Poisson like
- Set M can be chosen to be a xy plane, segment, detector or whole array

Deviation from the mean

$$\text{Deviation} = \sum_{x,y,z \in M} (\text{Hits}_{x,y,z} - < \text{Hits}_{x,y,z} >)^2$$

With $< \text{Hits}_{x,y,z} >= m_z$

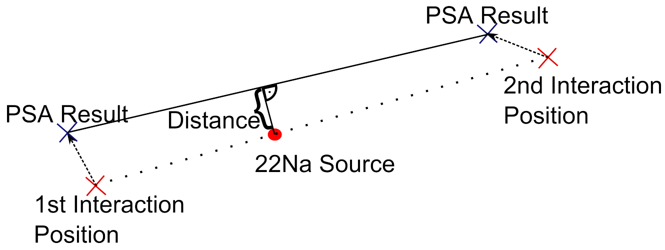
Source Position



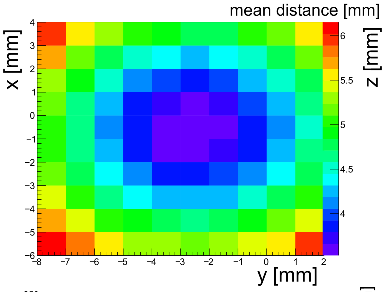
- Finite size of radioactive material and finite range of β^+
- Mean deviation of annihilation pos. to source pos. $\approx 1.5\,\text{mm}$
- No **systematic** deviation $\Rightarrow$ no problem for analysis

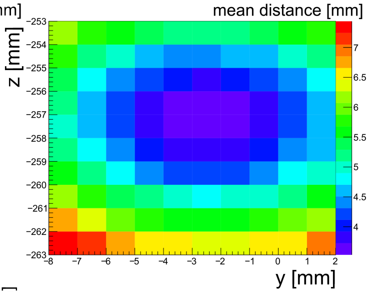
Source Position

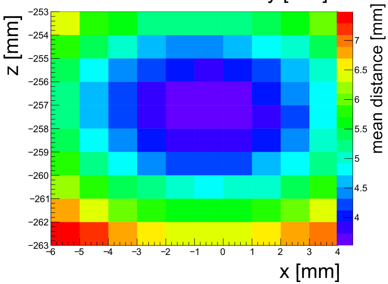
- Source position has to be known as precisely as possible
- Calculate distance d on event by event basis
- Vary source position (PSA remains constant) and minimize mean distance



Variation of Source Position

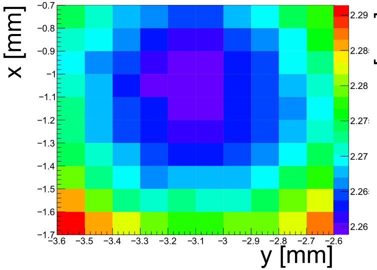


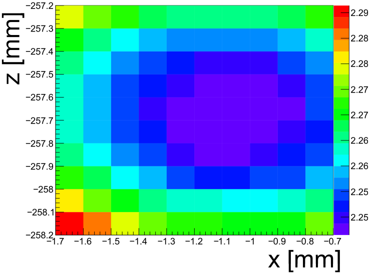


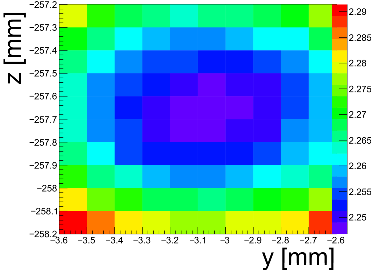


- Source position is varied in steps of 1 mm
- Smallest mean distance is most probable source position

Variation of Source Position







- Source position varied in steps of 0.1 mm around previous minimum
- Final result in lab system
  x = 1.1 mm
  y = -3.1 mm
  z = -257.8 mm

PSA Optimiziation

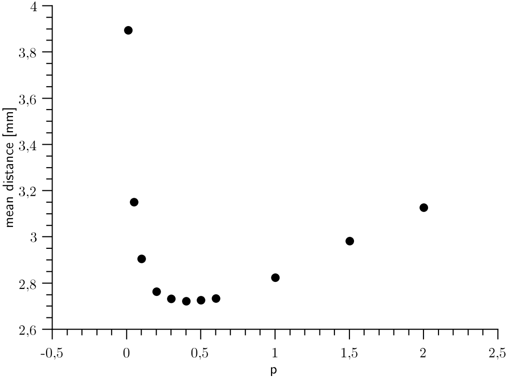
Figure of Merit

$$\text{Figure of Merit} = \sum_j \sum_{t_i} |A_j^m[t_i] - A_j^s[t_i]|^p$$

$A_j^m[t_i]$ ($A_j^s[t_i]$) is measured (simulated) signal of segment j at time step t_i

- Consider distance metric
- Exponent p changes which simulated signal minimizes the Figure of Merit

Distance Metric



- Minimum at p=0.4 with d_{mean}=2.72
- 13% improvement compared to Euclidian metric ($\Rightarrow \chi^2$)

Mobility of Electrons and holes

766 B. Bruyneel et al. / Nuclear Instruments and Methods in Physics Research A 569 (2006) 764–773

Table 1

An overview of charge carrier mobility data in Ge at 78 K. The fit parameters to Eq. (1) for the electron and hole mobility along the ⟨1 0 0⟩ and the ⟨1 1 1⟩ direction are presented. The parameters obtained from the data by Reggiani et al. [16] correspond to the fit shown in Fig. 6

Ref.	⟨1 0 0⟩ direction				⟨1 1 1⟩ direction			
	μ_0	β	E_0(V/cm)	μ_n	μ_0	β	E_0(V/cm)	μ_n
(A) *Electron mobility parameters* (μ in (cm^2/Vs))								
[14]	40180	0.72	493	589	42420	0.87	251	62
[10]	38609	0.805	511	−171	38536	0.641	538	510
(B) *Hole mobility parameters* (μ in (cm^2/Vs))								
[16]	66333	0.744	181	–	107270	0.580	100	–
[10]	61824	0.942	185	–	61215	0.662	182	–

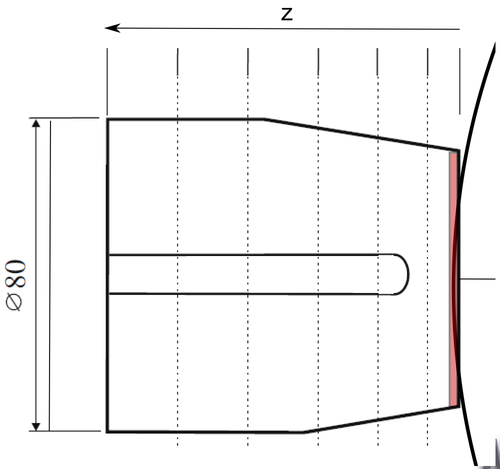
Mobility of Electrons and holes

Direction	μ_0 (cm^2/V s)	β	E_0 (V/cm)	μ_n (cm^2/V s)
Electron mobility parameters				
$\langle 1\,0\,0 \rangle$	38609	0.805	511	−171
$\langle 1\,1\,1 \rangle$	38536	0.641	538	510

Direction	μ_0 (cm^2/V s)	β	E_0 (V/cm)
Hole mobility parameters			
$\langle 1\,0\,0 \rangle$	61824	0.942	185
$\langle 1\,1\,1 \rangle$	61215	0.662	182

Results of PSA with ADL

- Investigate PSA in more detail
- ^{152}Eu source in the center of AGATA
- Circle marks points with same distance to the source
- In good approximation equal expectation for all points in plane



Additional criteria for PSA performance: Correlation

- Covariance: Negative $\Rightarrow$ anti correlation, zero $\Rightarrow$ no correlation, positive $\Rightarrow$ correlation

Covariance

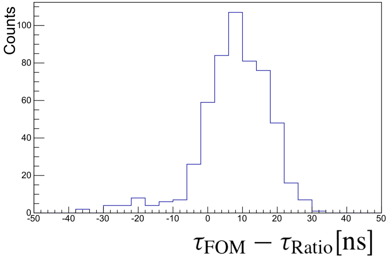
$$\text{Covariance} = \sum_{x,y,z \in M} (\text{Hits}_{x,y,z} - <\text{Hits}_{x,y,z}>) \cdot (\text{Hits}_{x+2\,\text{mm},y,z} - <\text{Hits}_{x+2\,\text{mm},y,z}>) + \ldots$$

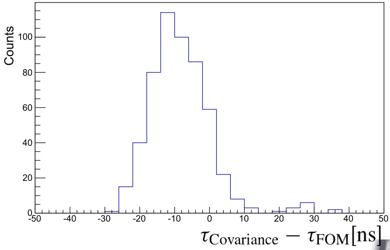
With $<\text{Hits}_{x,y,z}> = m_z$, additional terms are for $x - 2\,\text{mm}, y \pm 2\,\text{mm}, z \pm 2\,\text{mm}$

- 2 mm is size of grid points
- Set M can be chosen as needed

Transfer Function

- Minima positions are similar, but do not coincide 100%
- Differences of optimal τ values derived via different determination methods





Transfer Function

- τ_{chi} is systematically bigger than τ_{cov} and τ_{ratio}
- τ_{cov} and τ_{ratio} coincide very well
- $\frac{\tau_{cov}+\tau_{ratio}}{2}$ is used for optimizing all channels