Imaging with a highly-segmented, position sensitive HPGe detector – The Cologne Compton camera

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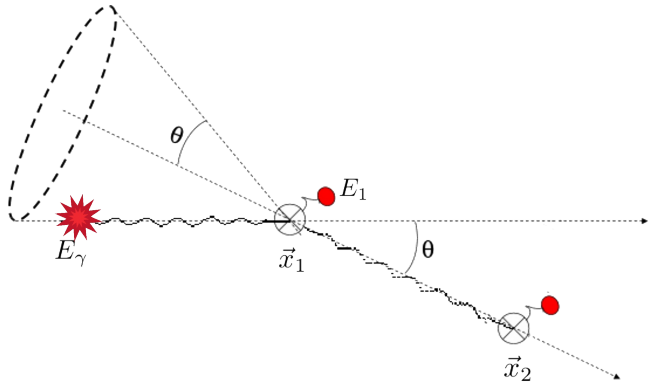
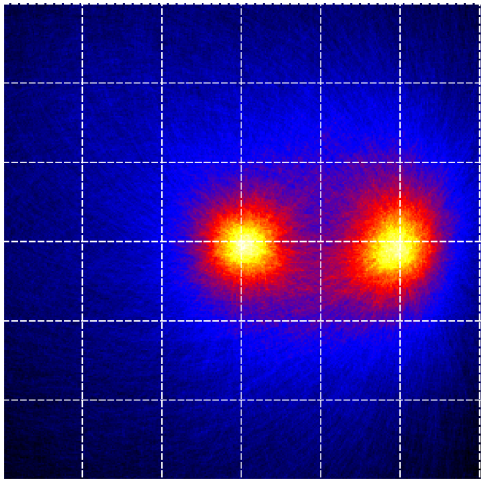
Overview

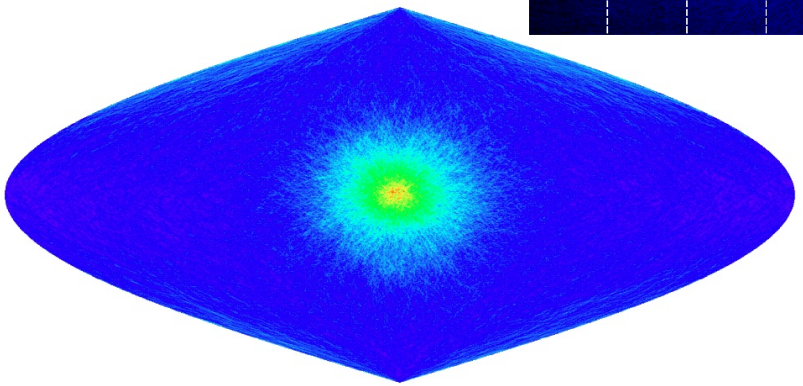
- Theoretical Background
- Experimental Setup



- Coincidence Mode
  - Measurements with Two Sources



- High-Efficiency Mode
  - PSA Optimization
  - Angular Resolution Depending on Interaction Point Distances

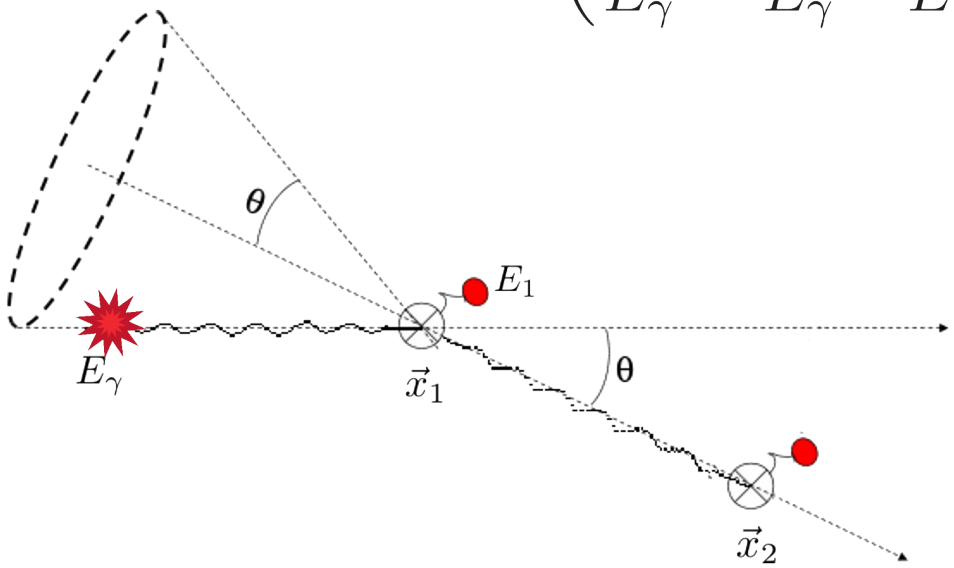


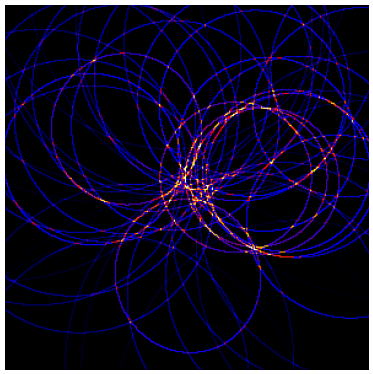
Principle of a Compton Camera

Imaging requires:

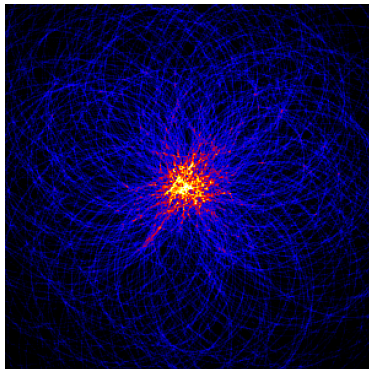
- Energy E_γ
- Energy loss by Compton scattering
- Interaction points
- Multiple interactions

$$\cos(\theta) = 1 + m_e c^2 \left(\frac{1}{E_\gamma} - \frac{1}{E_\gamma - E_1} \right)$$

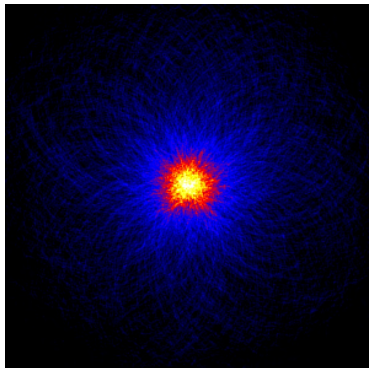




50 events

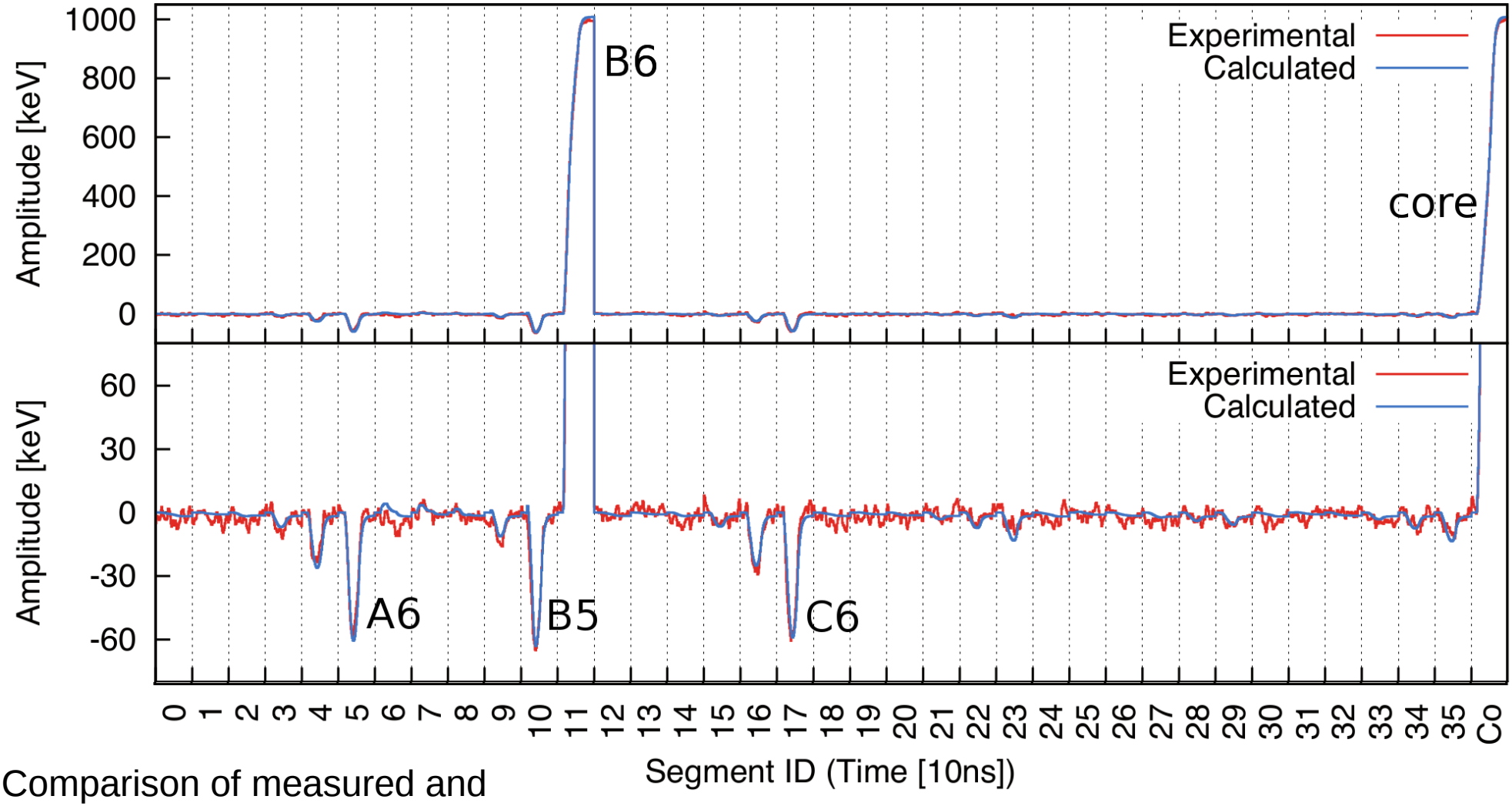


500 events



5000 events

Pulse Shape Analysis



Comparison of measured and simulated trace for all segments

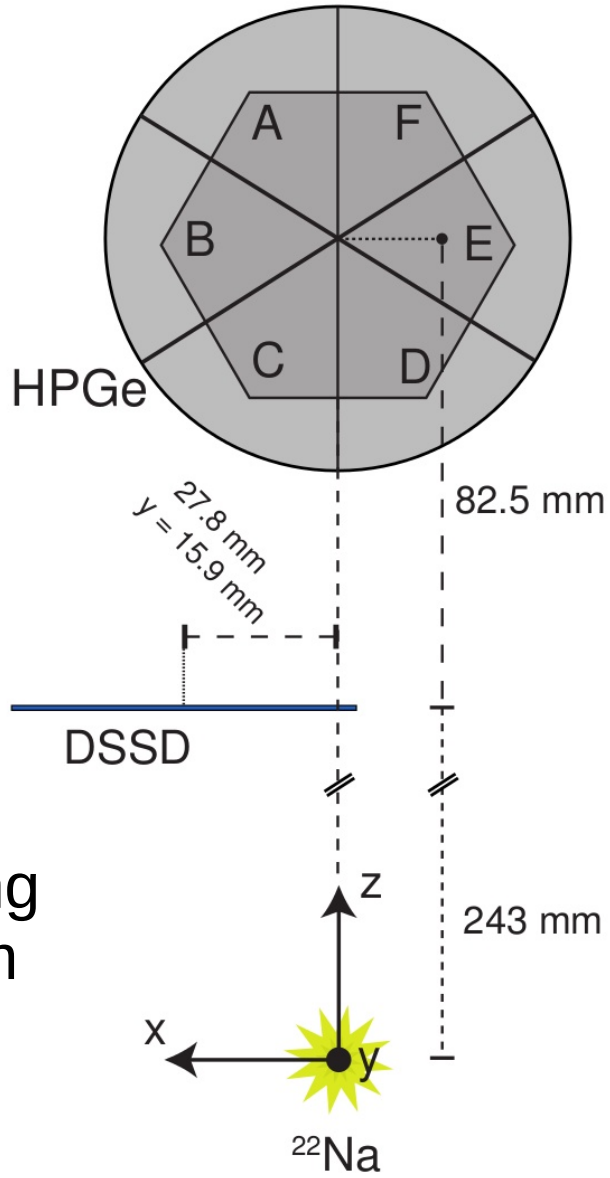
$$\text{Figure of Merit} = \sum_{i,j} |A^m_{i,j} - A^s_{i,j}|^p$$

Δx (PSA) ~ 4-5 mm

P.A. Söderström et al., NIM A 63

Coincidence Mode with DSSD

Complete energy absorption in two detectors



At least one coincident interaction in the HPGe detector Δx = 4-5 mm

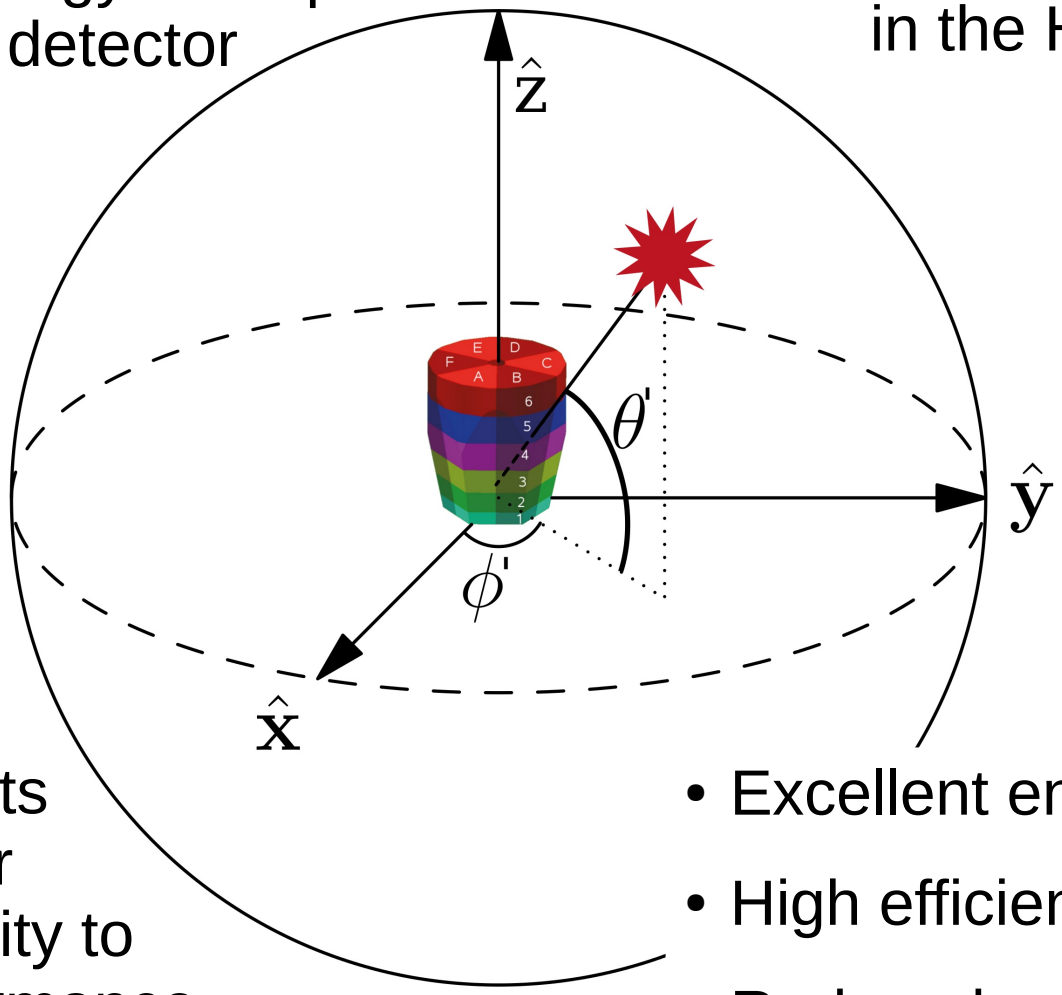
First interaction in the DSSD scattering detector Δx = 1 mm

- High angular resolution
- Moderate energy resolution
- Reduced efficiency

High-Efficiency Mode

Complete energy absorption in the HPGe detector

At least two interactions in the HPGe detector



Uncertainty in interaction points dominates error

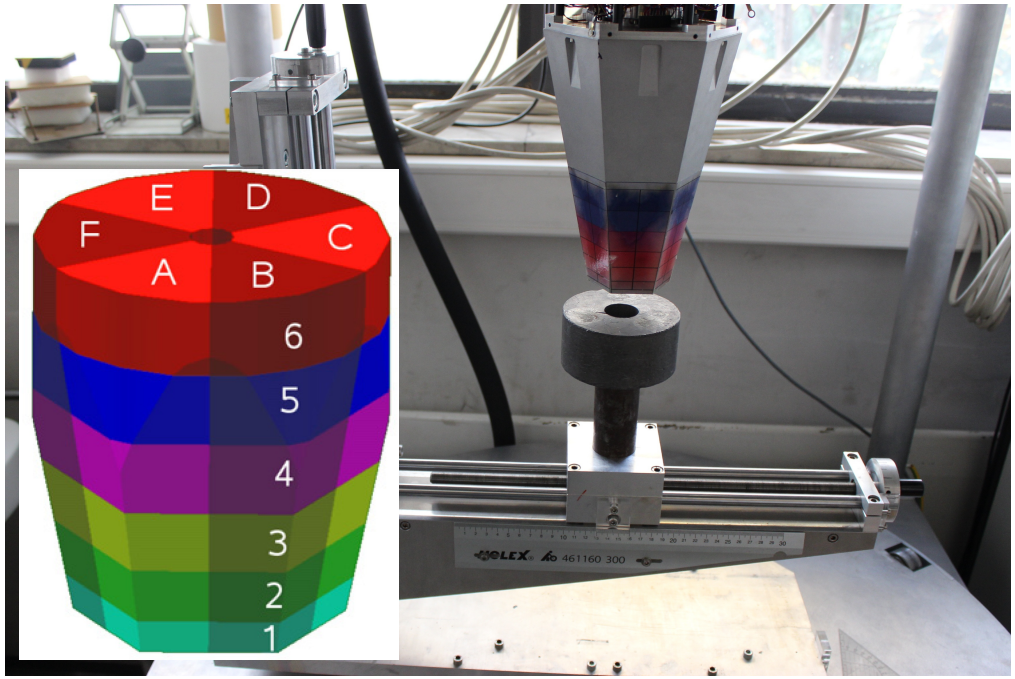
→ high sensitivity to PSA performance

- Excellent energy resolution
- High efficiency
- Reduced angular resolution

Experimental Setup

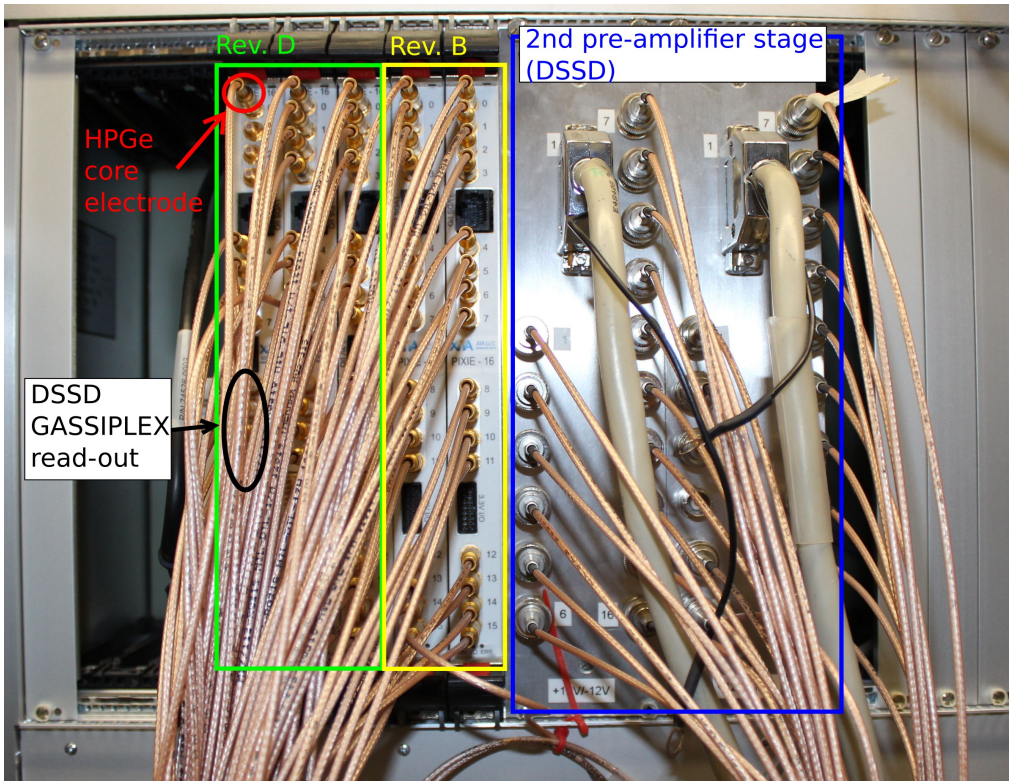
Highly-segmented AGATA-HPGe detector

- 36 segments
- Pulse-shape analysis (PSA) sensitive to interaction position

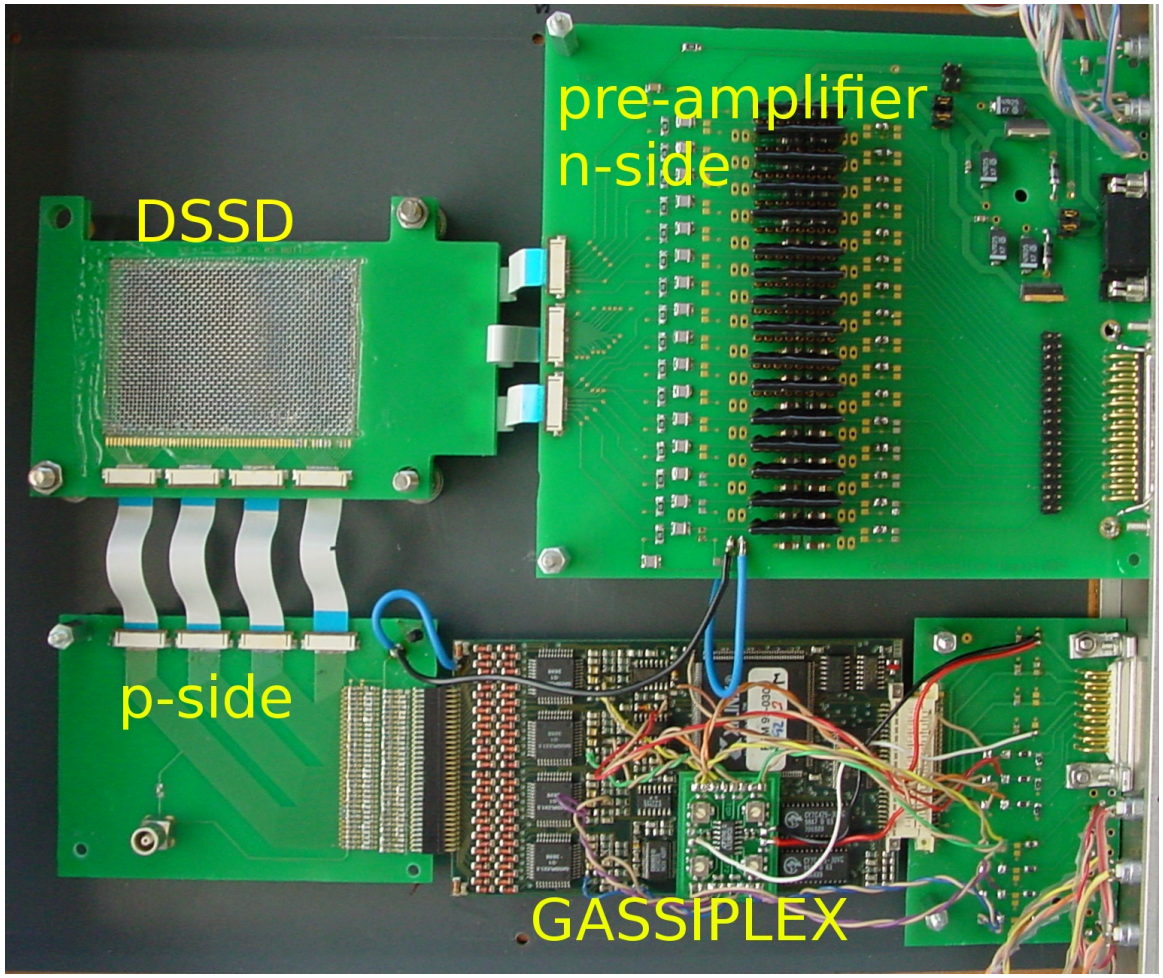


Digital Pixie-16 elektronics

- 5 Pixie-16 modules
- Listmode data
- 12 bit ADC
- 100 MSPS

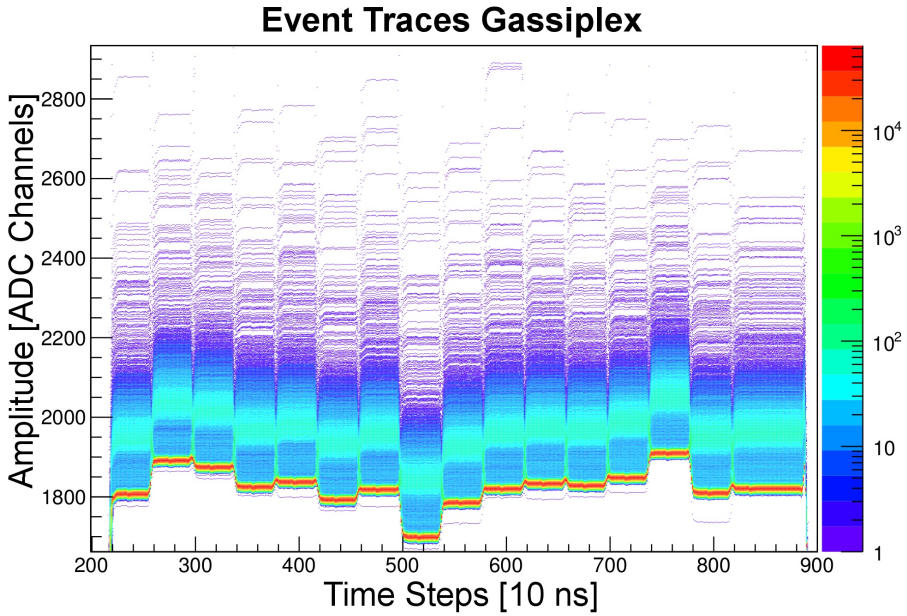


Experimental Setup

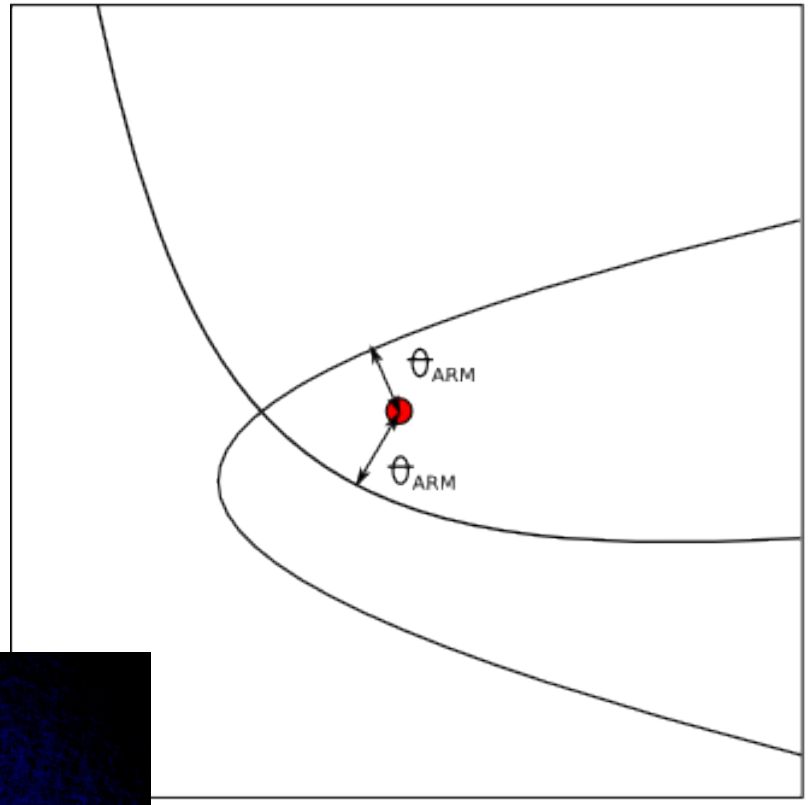


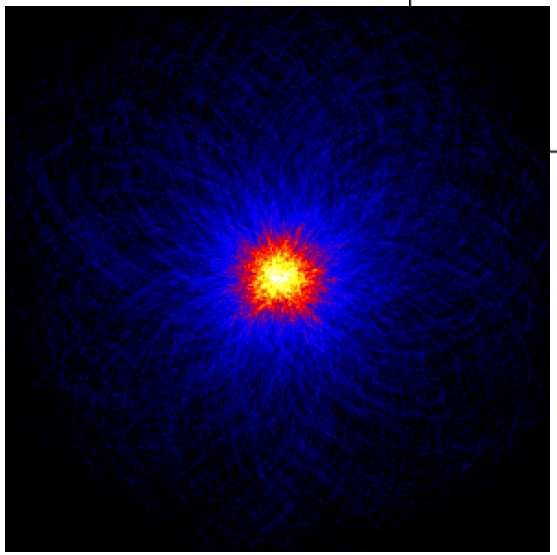
DSSD scattering detector

- 60x40x1 mm^3
- read-out
  - n-doped side
    32 pre-amplifier
  - p-doped side
    4 GASSIPLEX chips



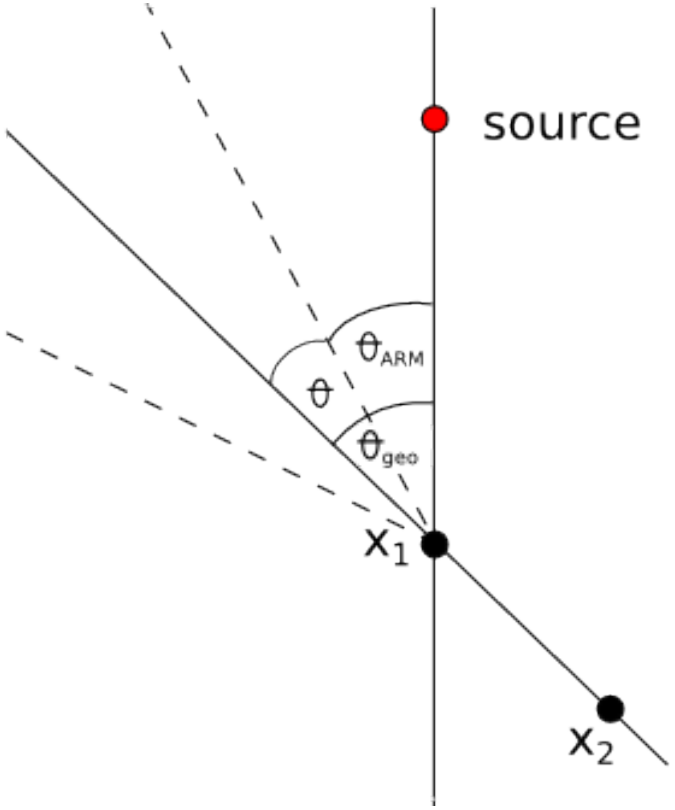
Angular Resolution Method (ARM)





Minimal distance
- Compton cone intersection with plane/sphere
- Real source position

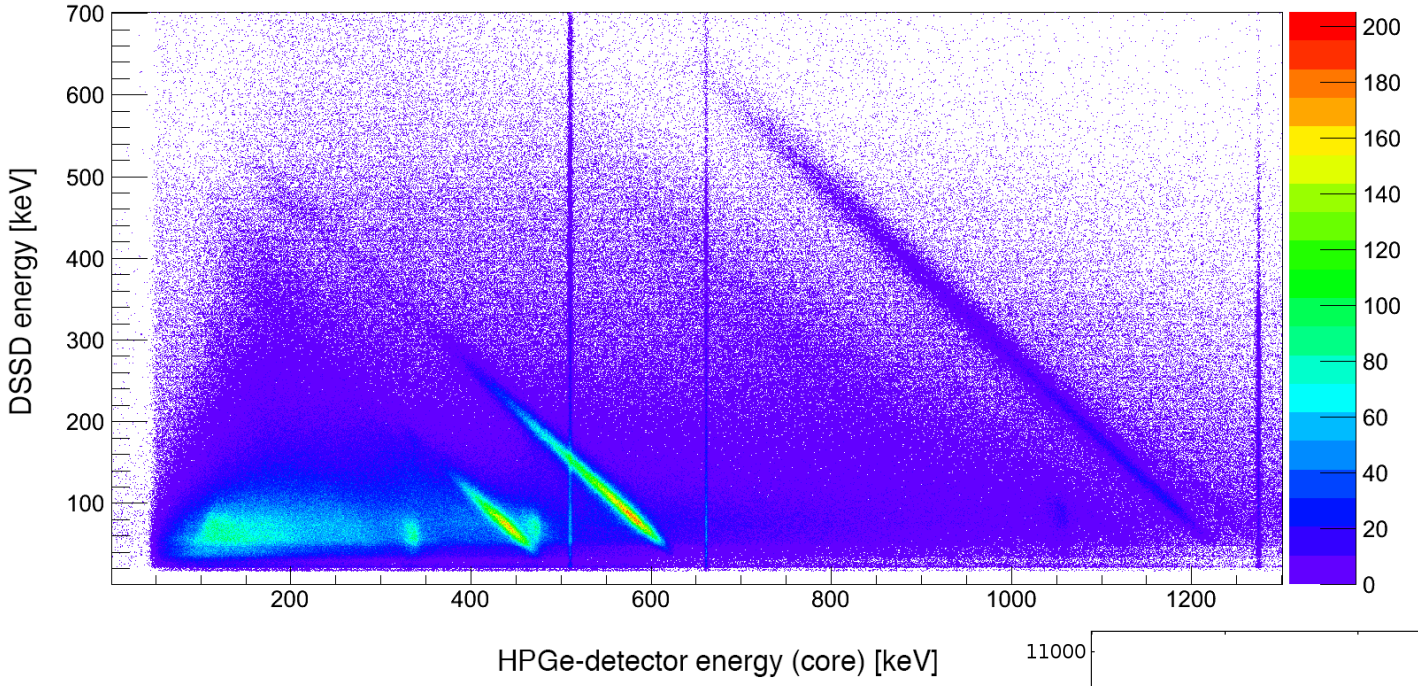
Expressed in an angle



$$\Theta_{ARM} = \Theta - \Theta_{geo}$$

- Calculated angle from Compton formula
- Geometrical angle between Compton cone axis and source position

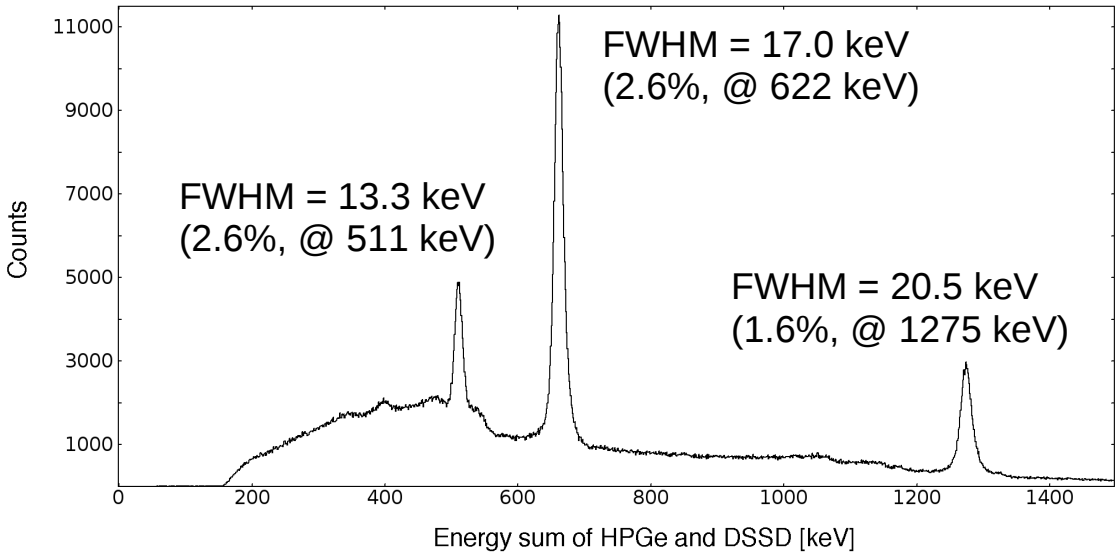
Coincidence Mode



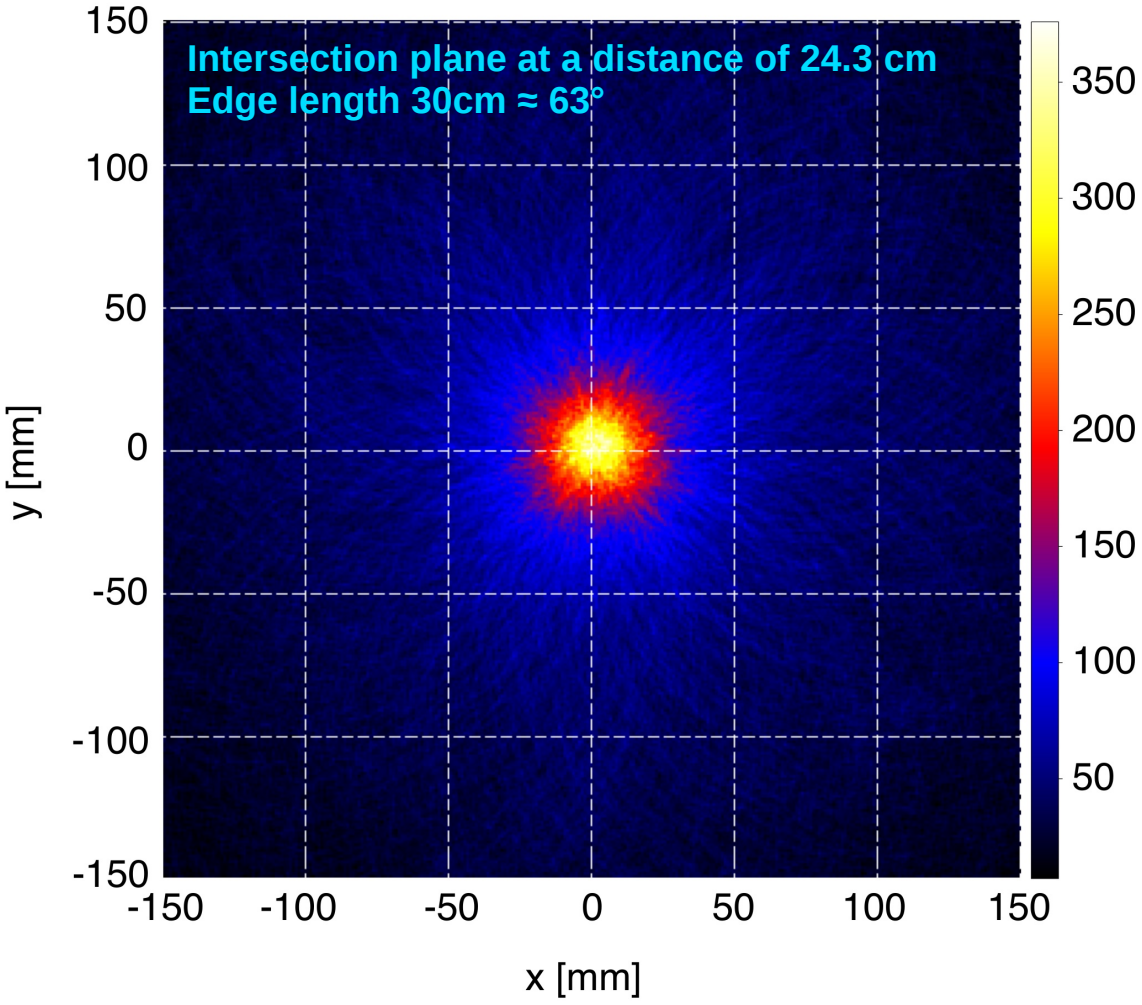
Coincident events with energy deposition in both detectors

Energy resolution dominated by DSSD

Compton scattering angle dominates angular resolution



Coincidence Mode



Source: Na-22 (E_γ = 1275 keV)

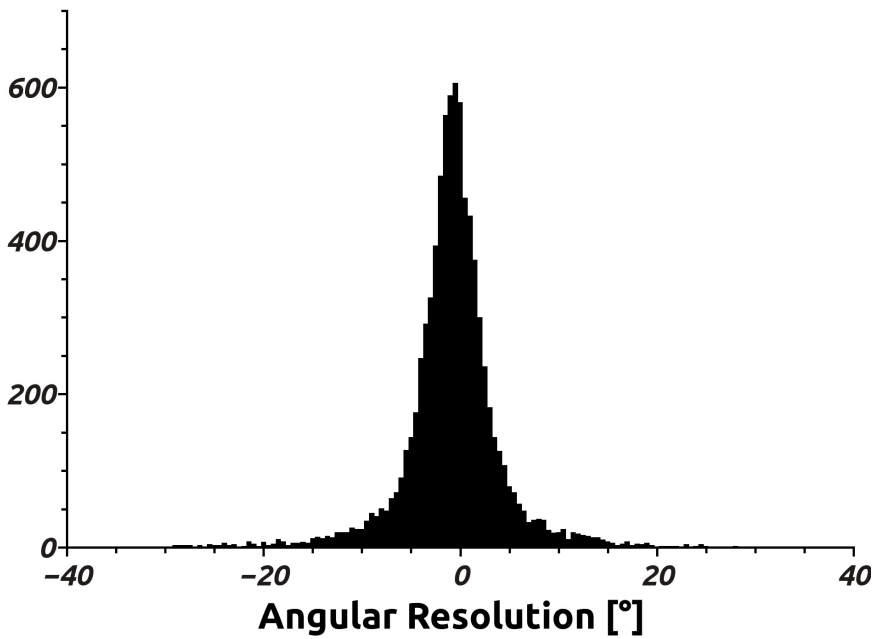
Activity: 450 kBq

Distance source ↔ DSSD: 24.3 cm

Exact DSSD Position: (27.8 mm,15.9 mm)

Efficiency: ~ 1.7×10^{-5}

Angular resolution (AR): $\Delta\theta = 4{,}6°$

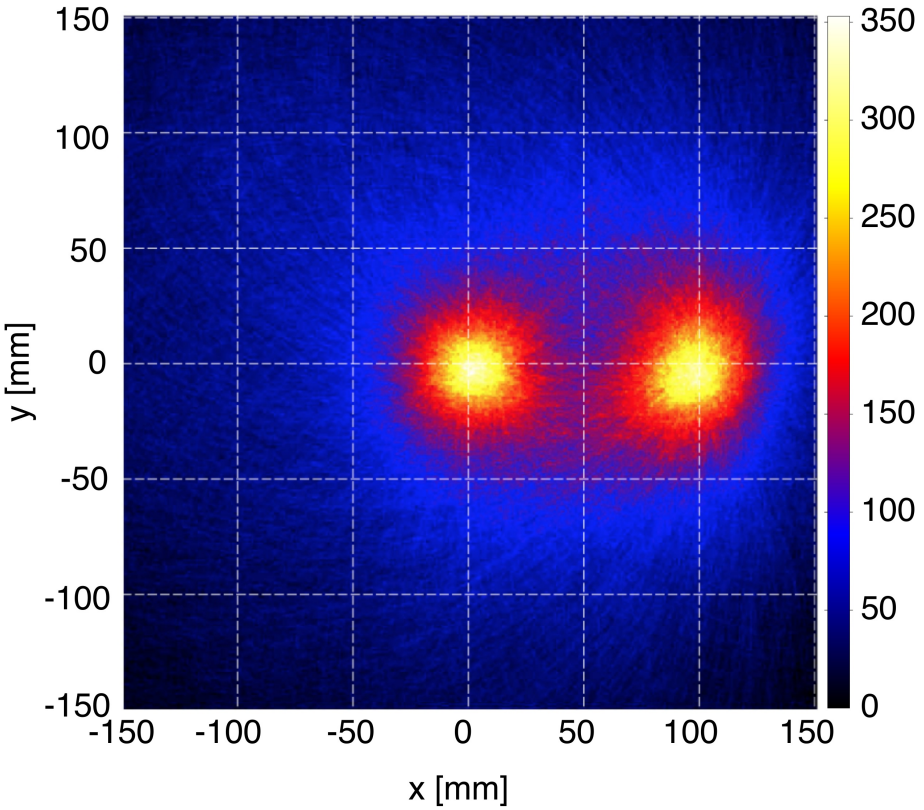


Imaging with Two Sources

Sources: 2 x Cs-137 (E_γ = 661 keV)

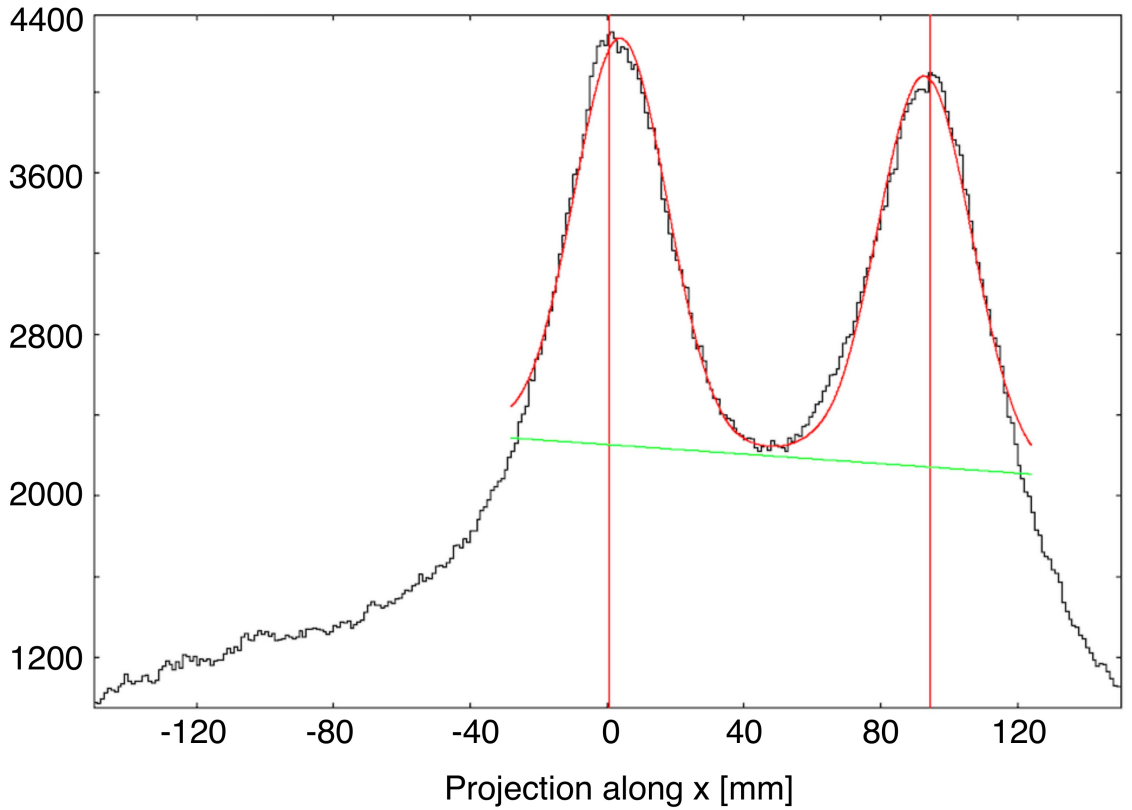
Distance DSSD ↔ Image plane: 24.3 cm

Distance sources: 9 cm (20°)



Measured position on x-axis

3.7 mm 92.6 mm

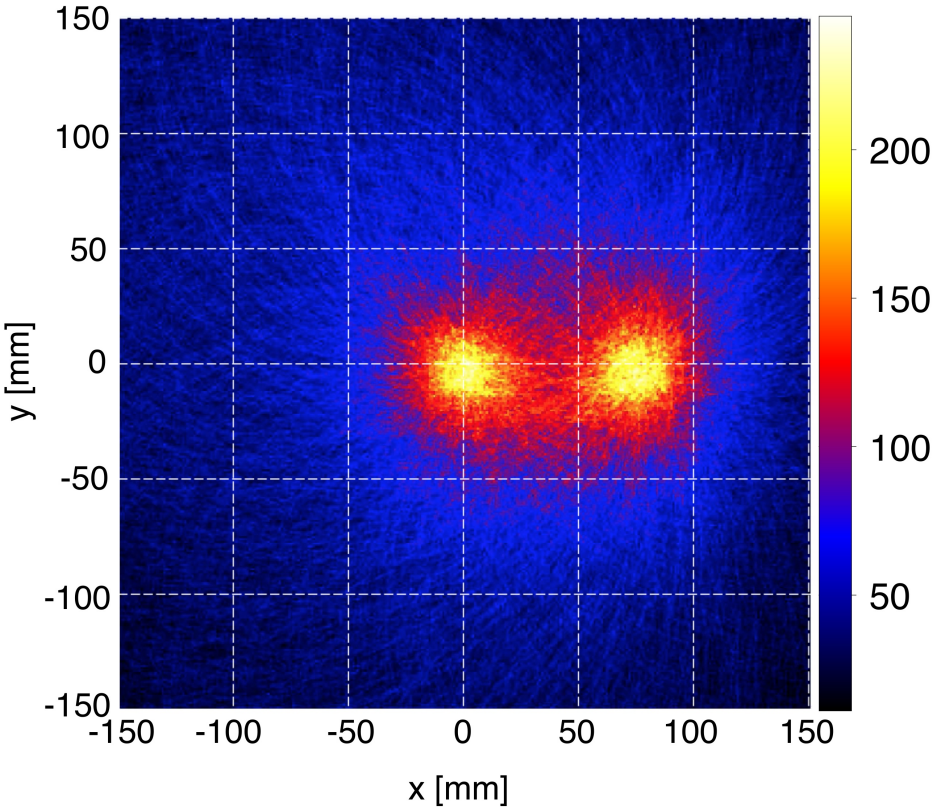


Imaging with Two Sources

Sources: 2 x Cs-137 (E_γ = 661 keV)

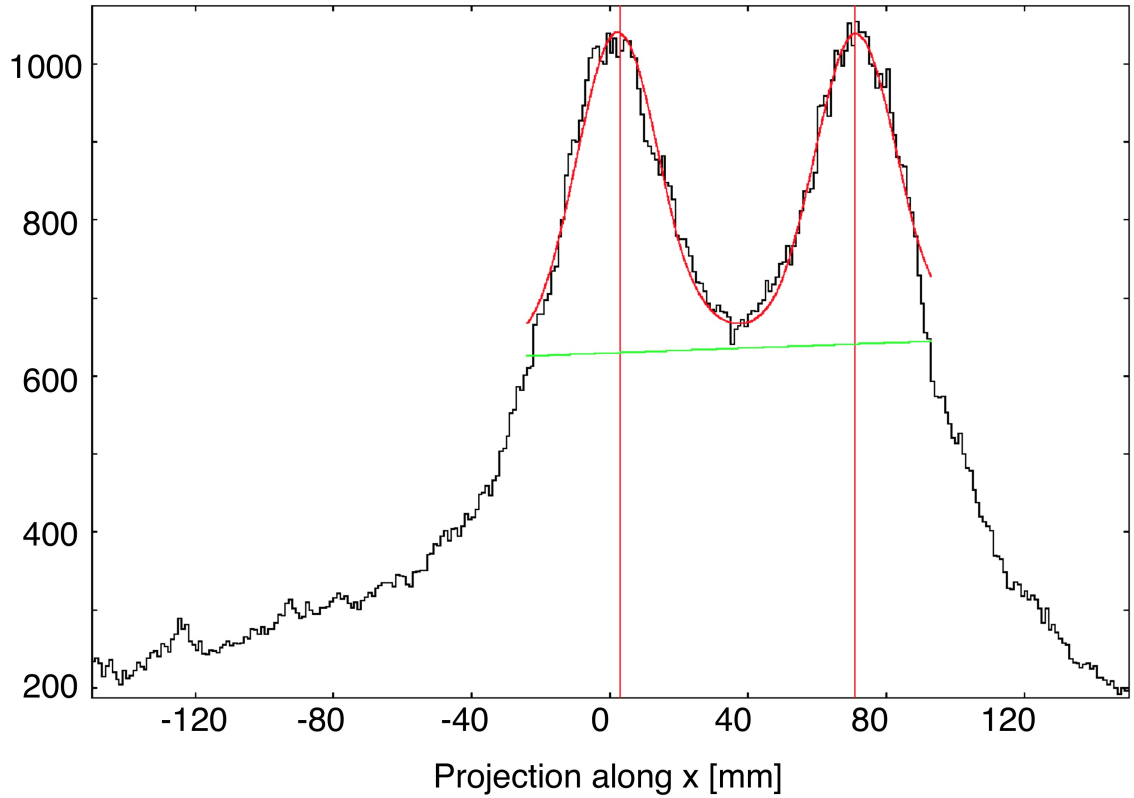
Distance DSSD ↔ Image plane: 24.3 cm

Distance sources: 7 cm (16°)



Measured position on x-axis

2.0 mm 71.0 mm

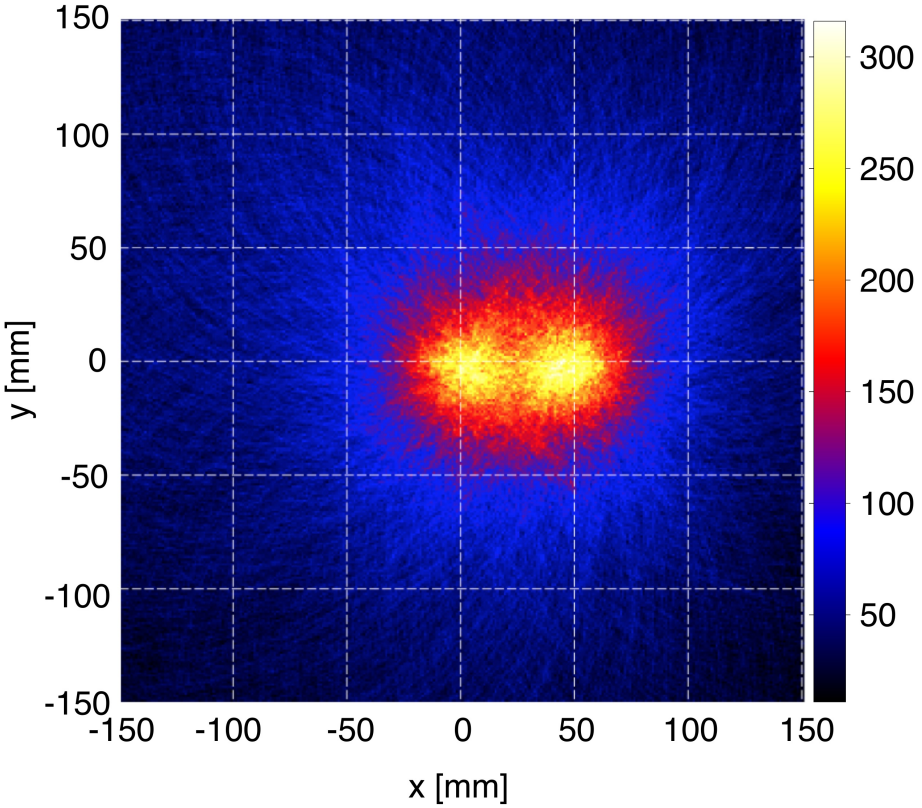


Imaging with Two Sources

Sources: 2 x Cs-137 (E_γ = 661 keV)

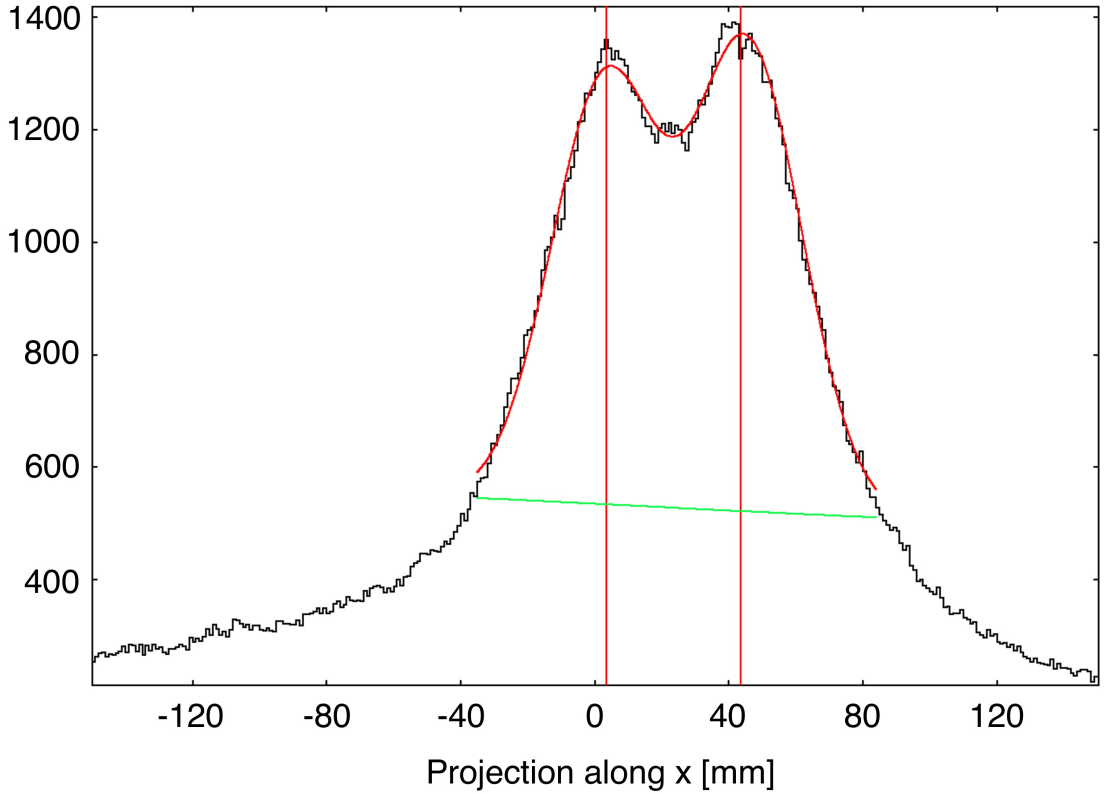
Distance DSSD ↔ Image plane: 24.3 cm

Distance sources: 4.5 cm (10.5°)



Measured position on x-axis

3.0 mm 45.5 mm



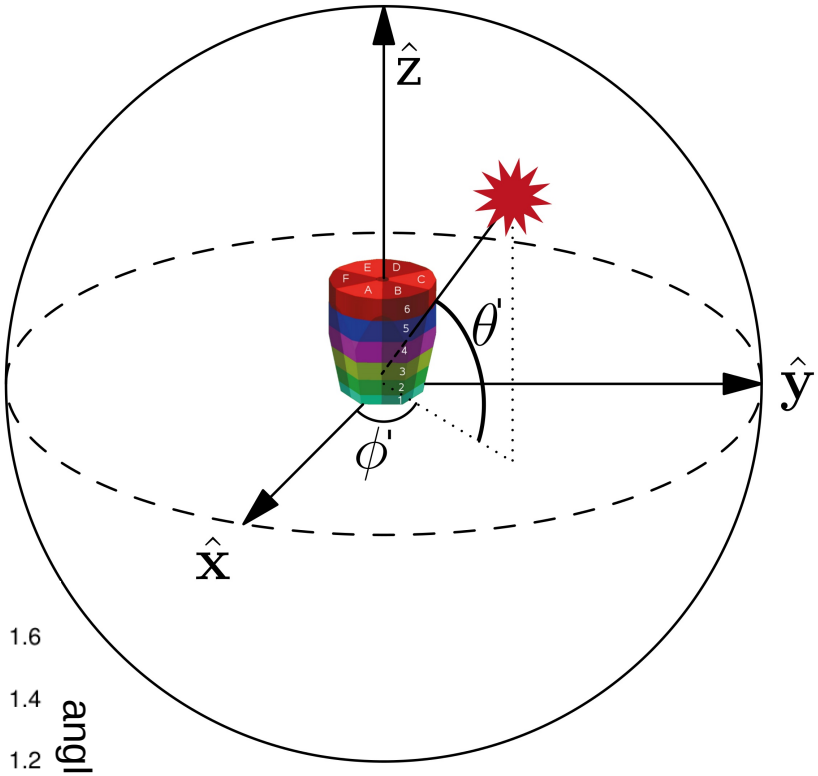
High-Efficiency Mode

Intersection with sphere

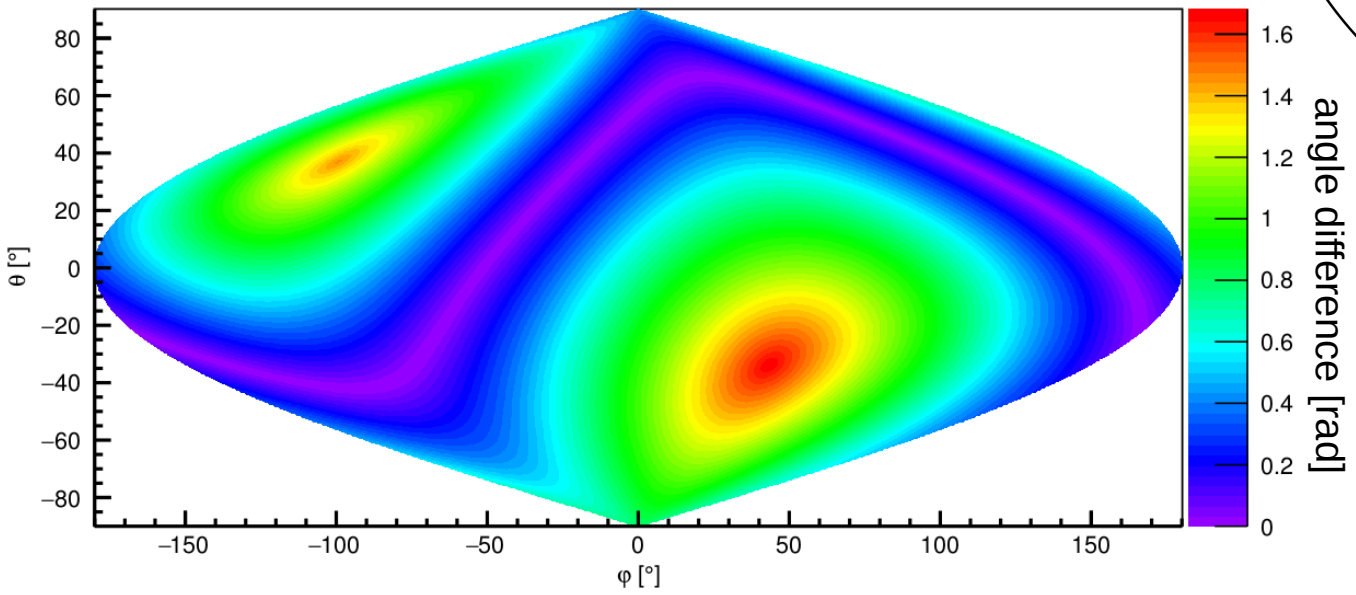
- Near-field imaging
- Walking algorithm

  S. J. Wilderman et al.,, IEEE Transactions on Nuclear Science 45 (3) (1998) 957–962.

- Sensitive to nearly 4π solid angle



Sinusoidal map projection



Error of the high-efficiency mode dominated by error of Compton cone axis

→ sensitive to PSA results

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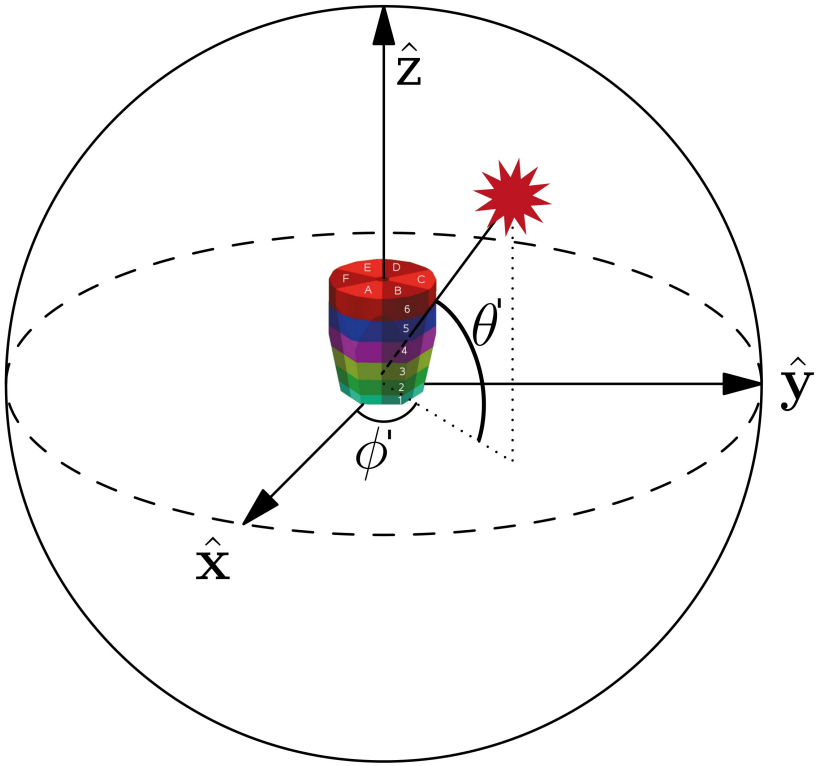

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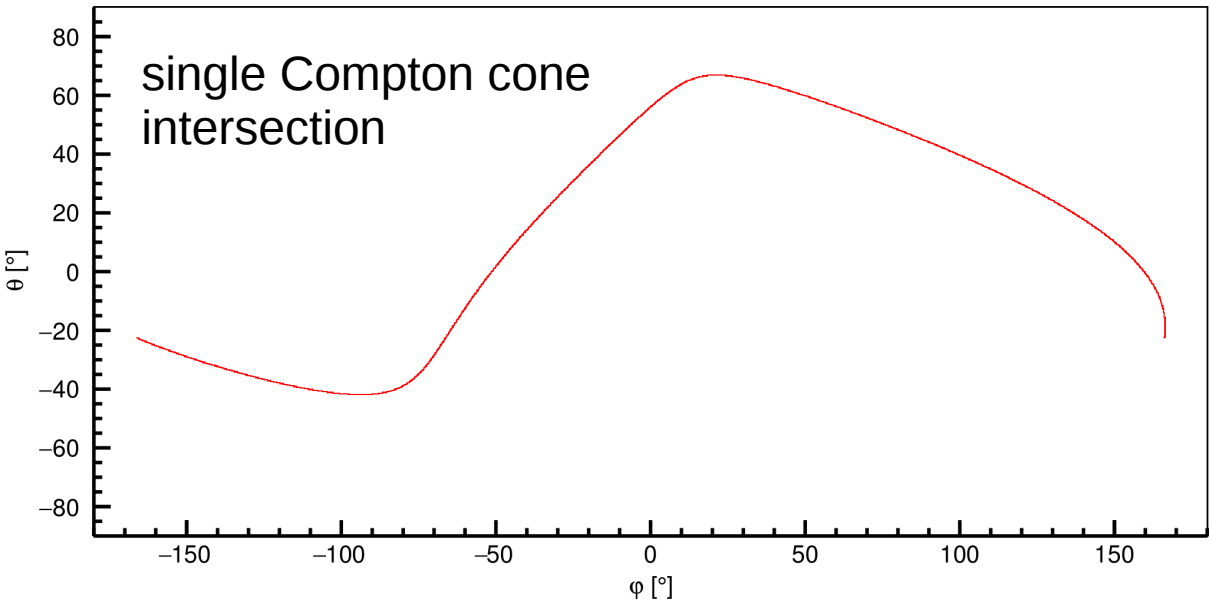
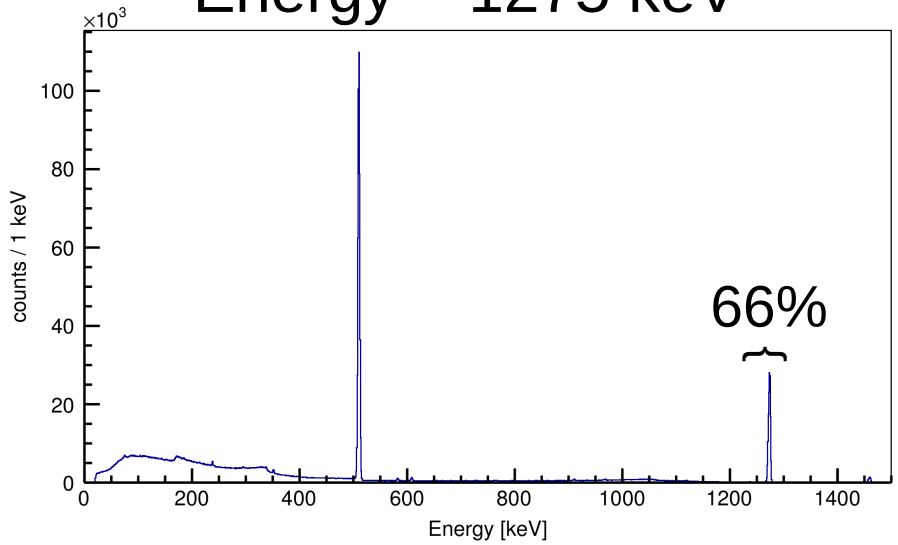


Error of the high-efficiency mode dominated by error of Compton cone axis

→ sensitive to PSA results

Conditions Necessary for the High-Efficiency Mode

Energy ~ 1275 keV



Source: Na-22 (75 kBq)

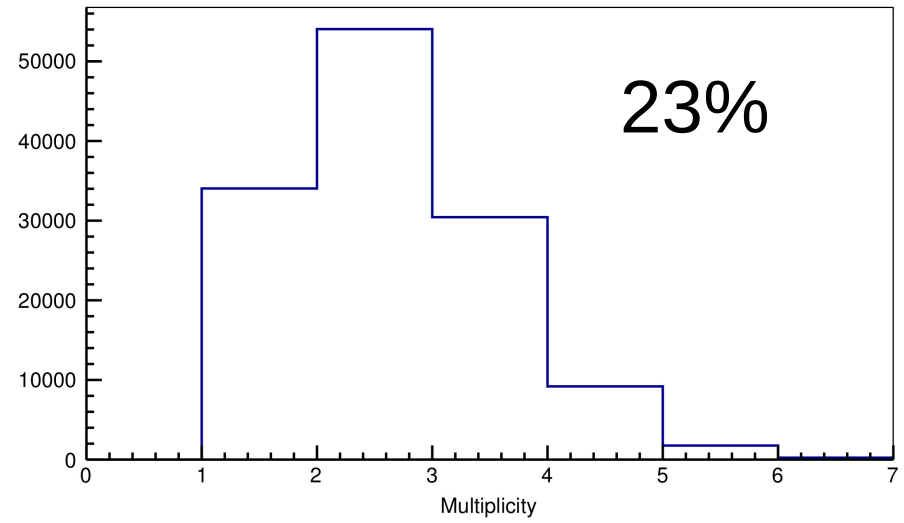
Duration of measurement: 30 min

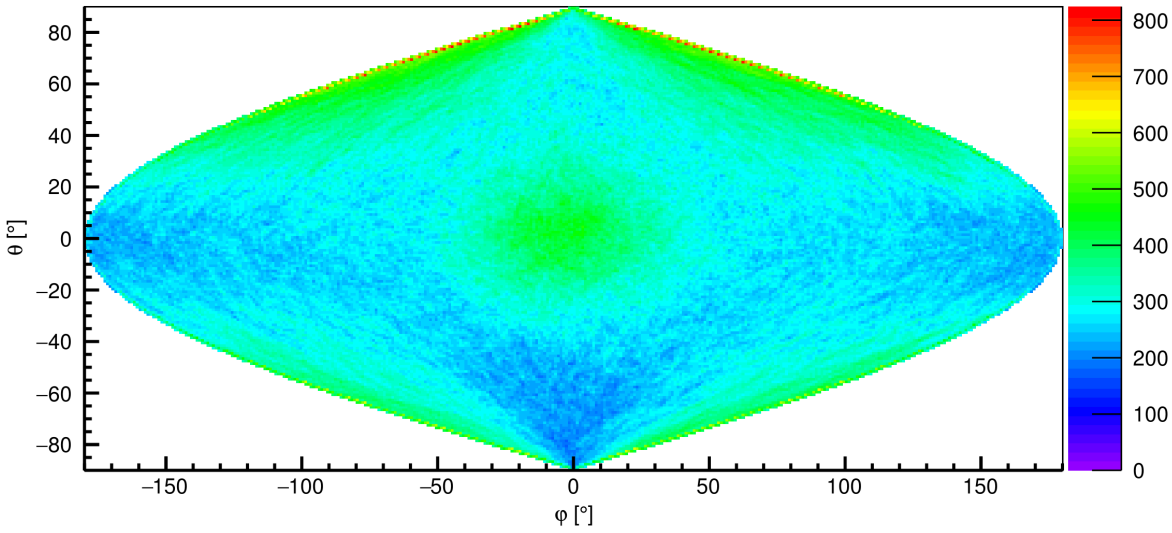
Distance source ↔ HPGe: 33 cm

Efficiency: 23 % (corrected for activity and geometry)

Compare: coinc. measurement: ~1.7x10^{-5}

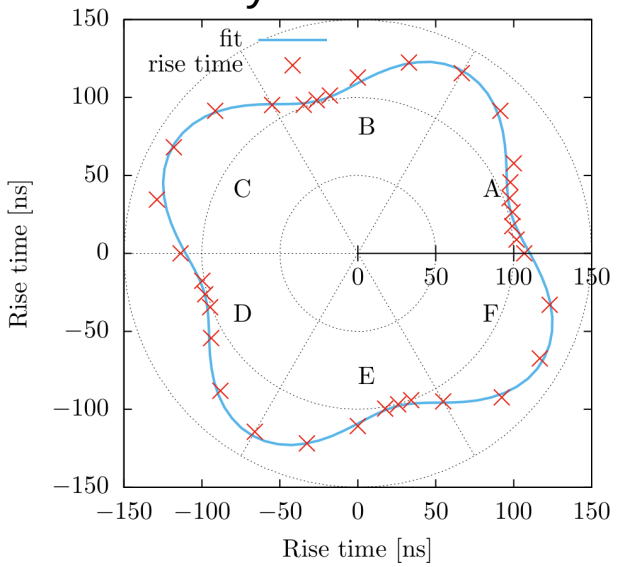
Segment Multiplicity = 2



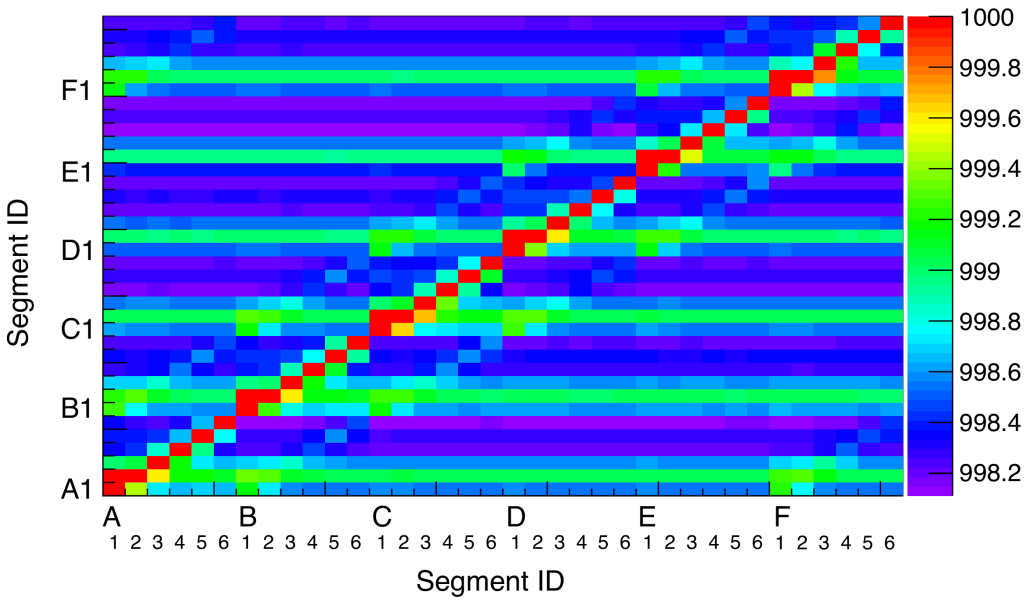


PSA Optimization

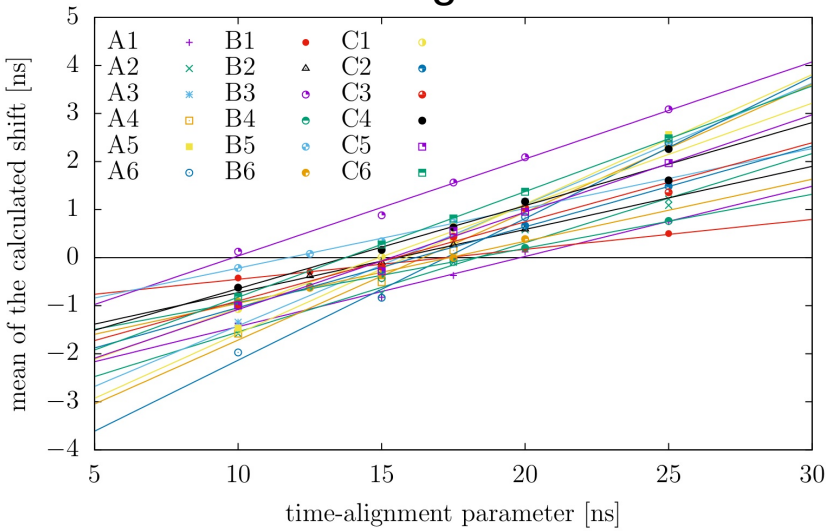
Crystal axis



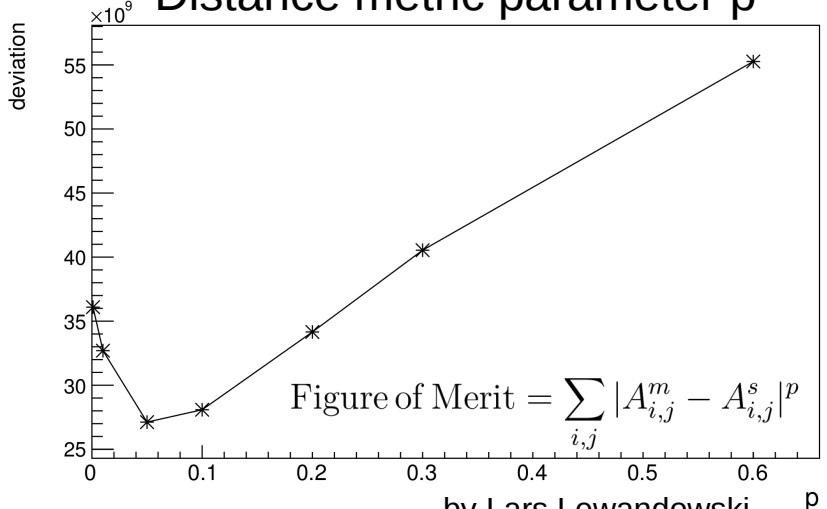
Crosstalk



Time alignment

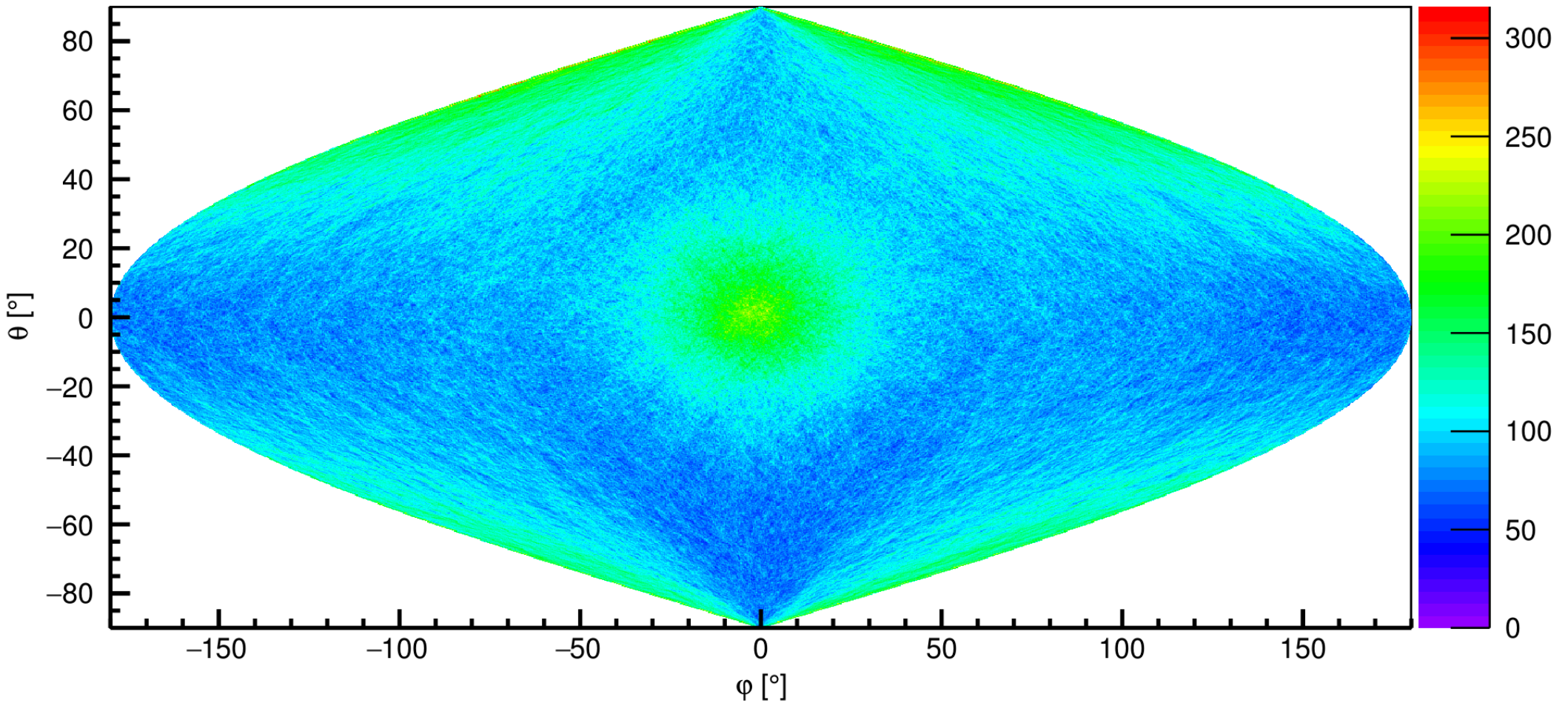


Distance metric parameter p



by Lars Lewandowski

High-Efficiency Imaging after PSA Optimization



Angular resolution: 31.8°

Interaction Point Sequence

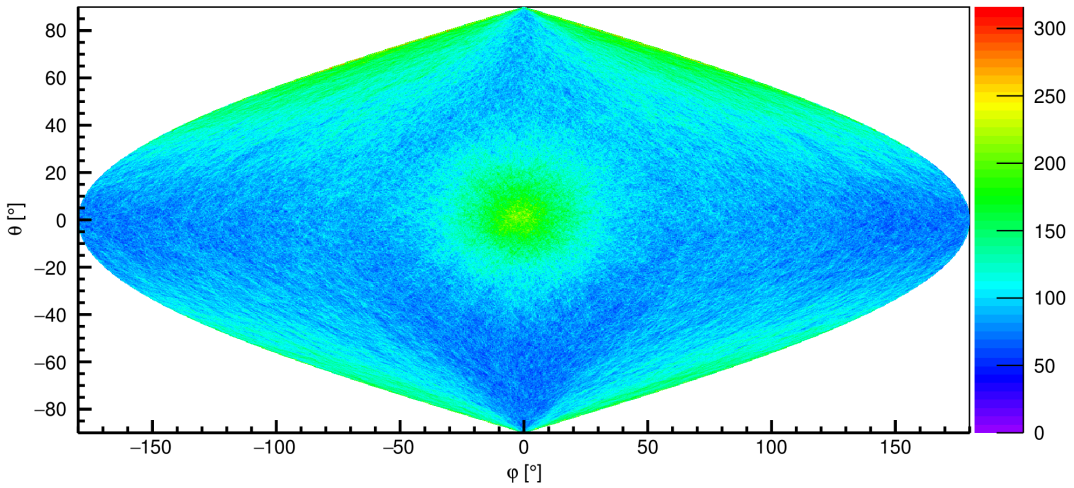
Up to now:

Higher energy deposition

→ First interaction

Exchanged only if first energy deposition exceeds the energy of the Compton edge (~1060 keV)

→ Reduced forward scattering



Now: Tracking

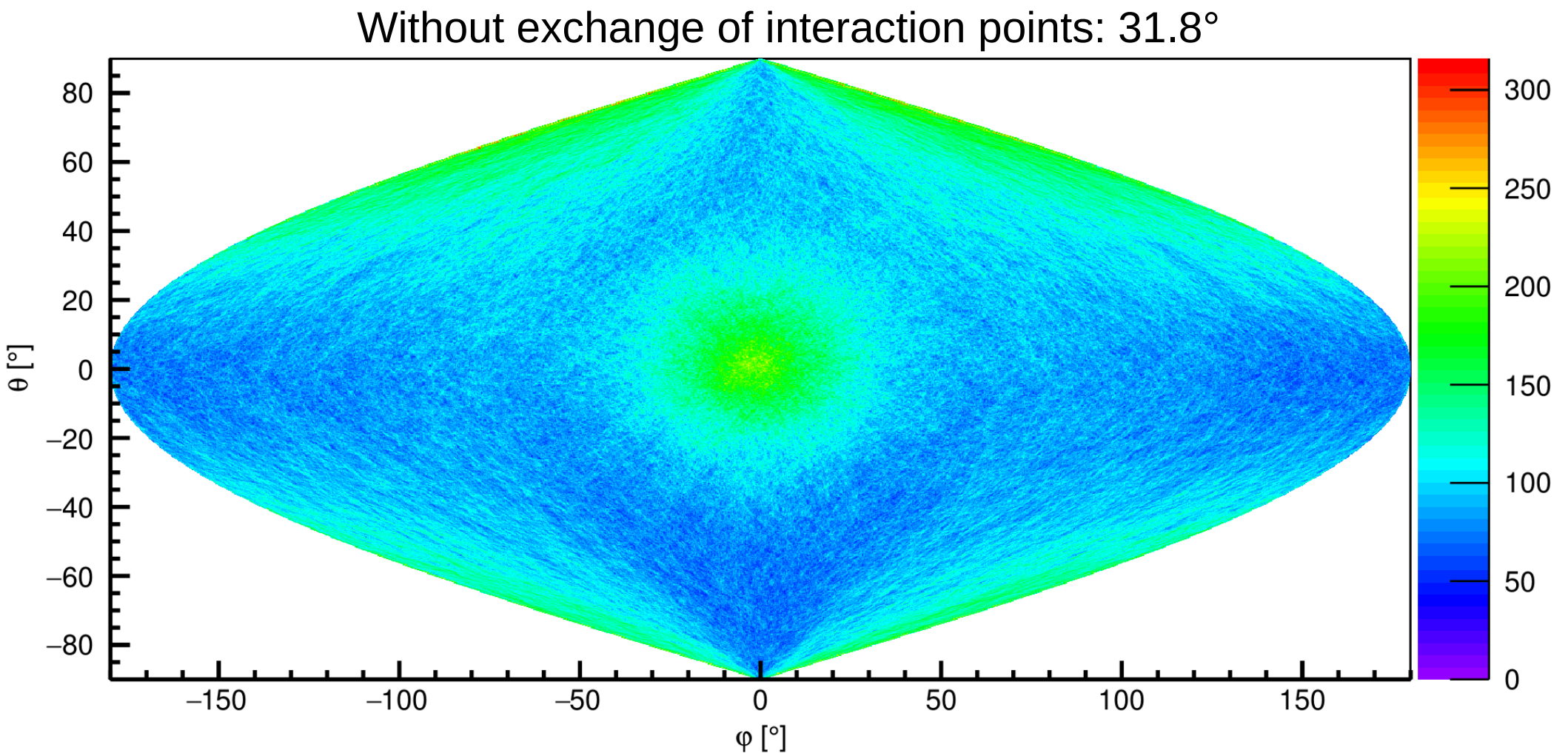
- Accumulation point roughly known
- Segment multiplicity = 2

Exchange of interaction point sequence, if

a) absolute angle difference $\Theta_{ARM} > 35°$

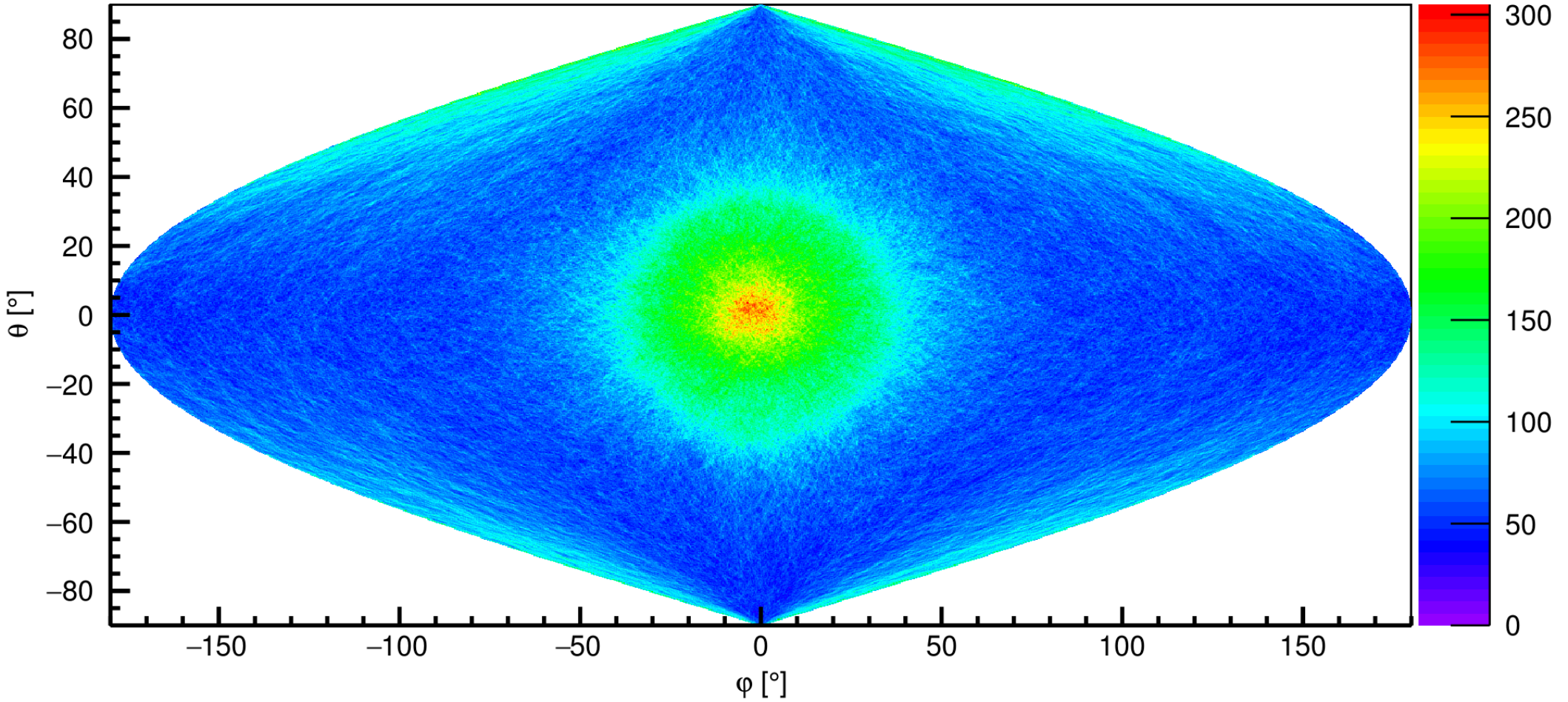
b) absolute angle difference Θ_{ARM} reduced

High-Efficiency Imaging with Exchange of Interaction Points



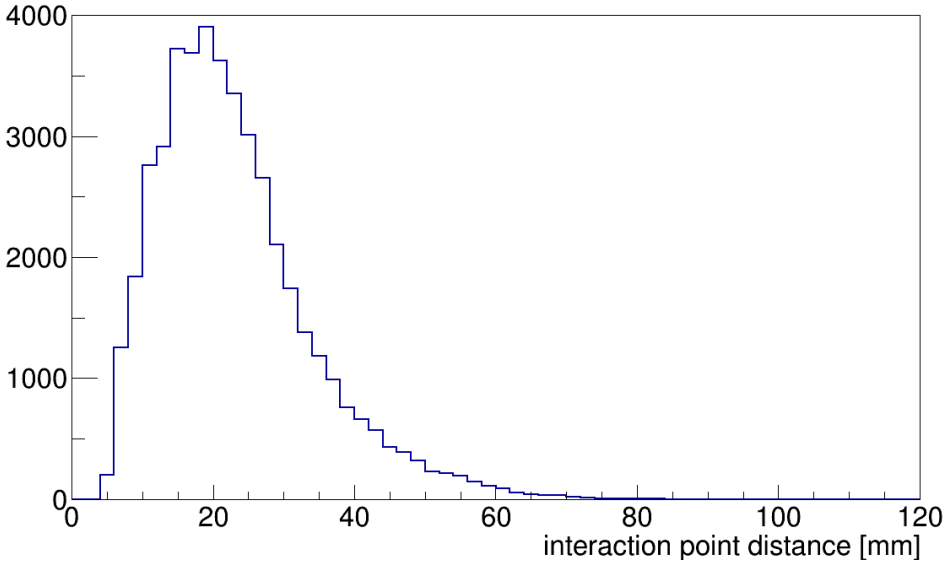
High-Efficiency Imaging with Exchange of Interaction Points

With exchange of interaction points: 30.9°



Comparison: Without exchange of interaction points: 31.8°

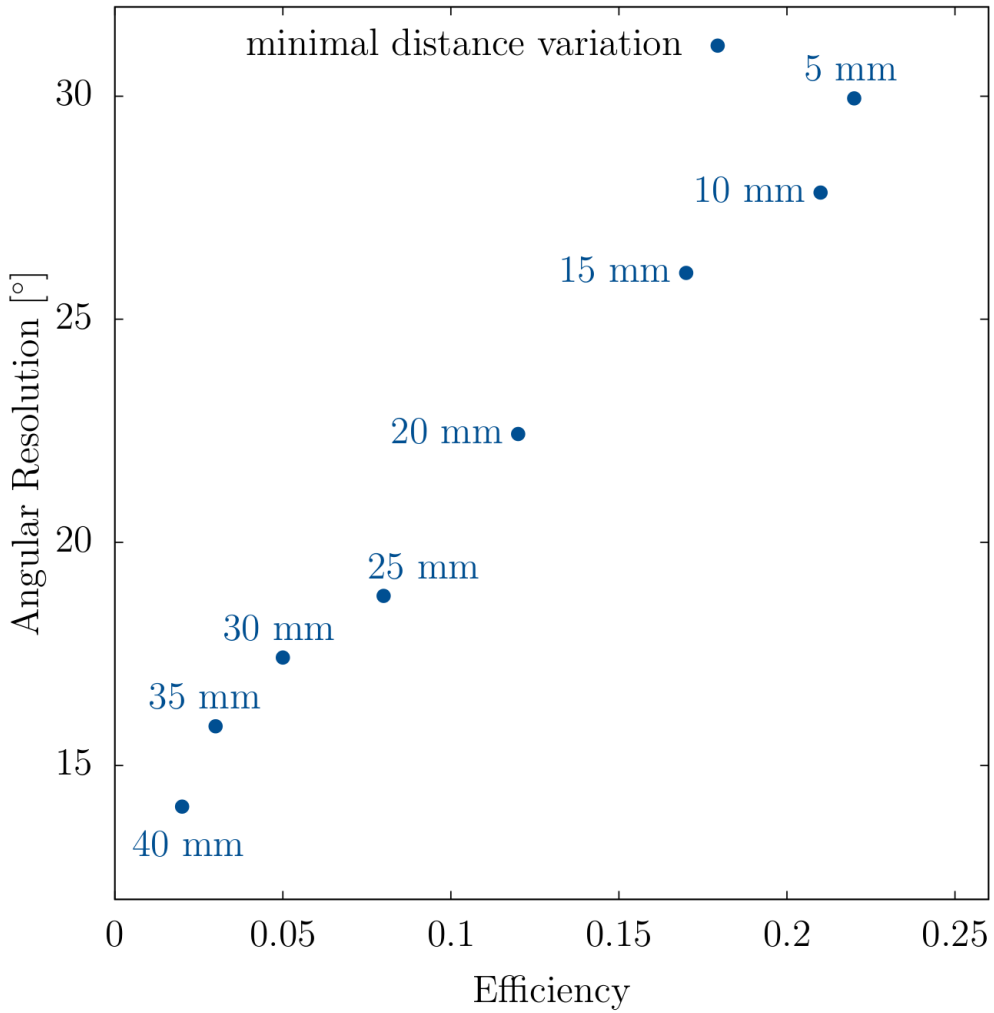
Angular Resolution Dependant on Interaction Point Distance



Distance between interaction points defines error of the cone axis

Δx (PSA) ~ 4-5 mm

P.A. Söderström et al., NIM A 638, 96 (2011)



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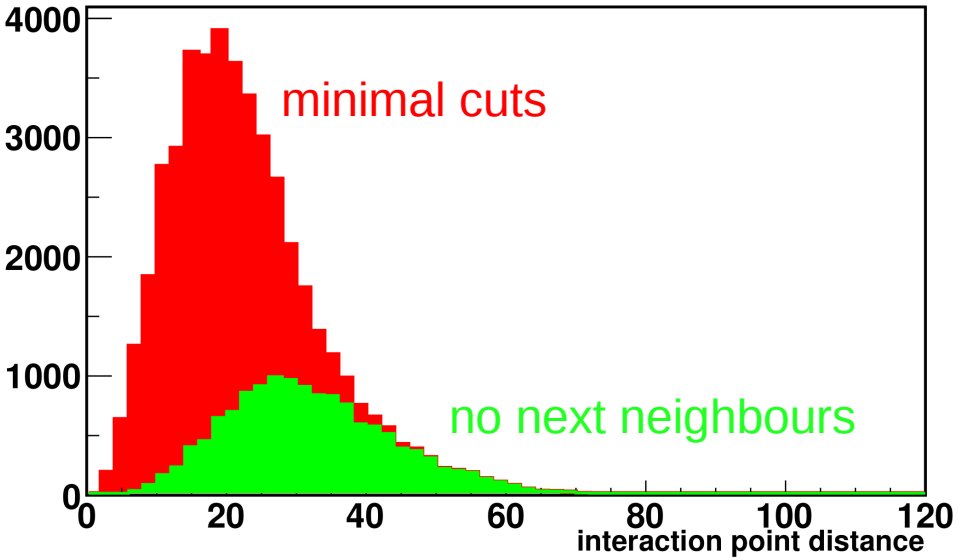

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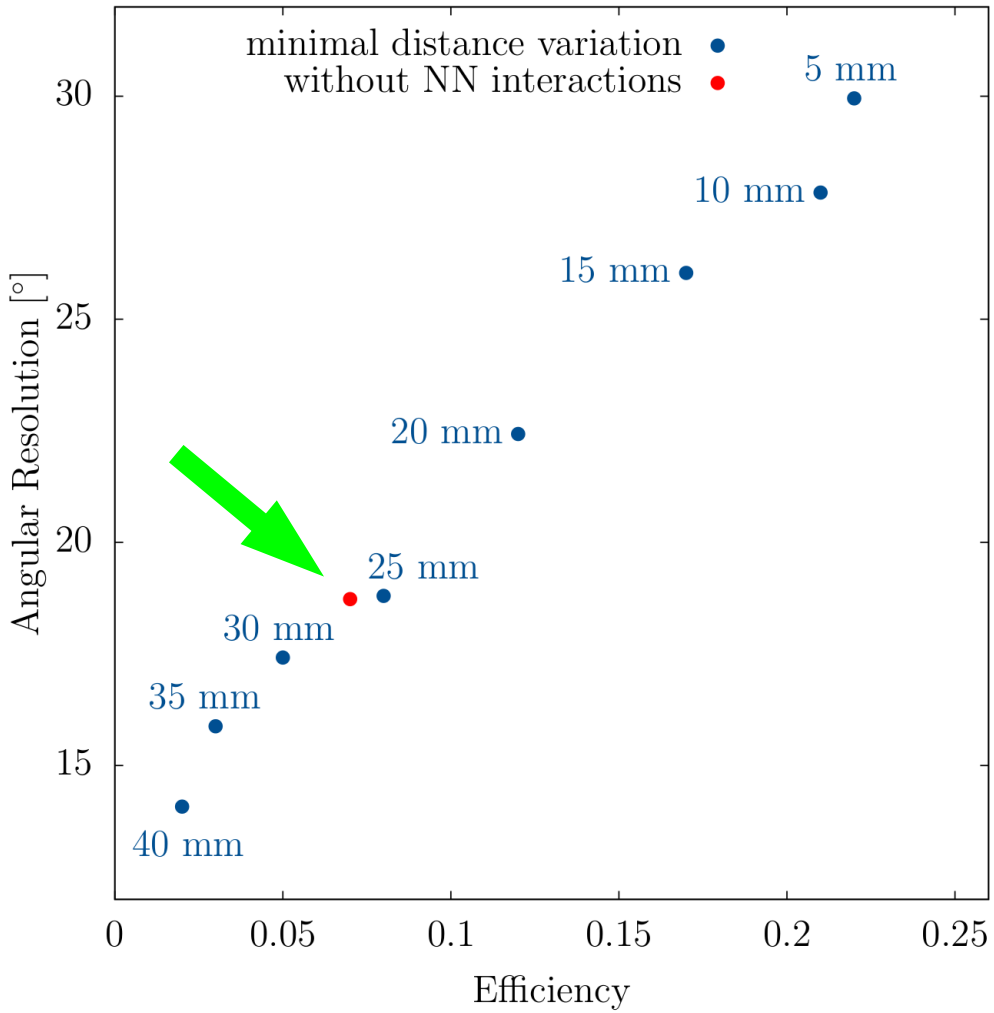
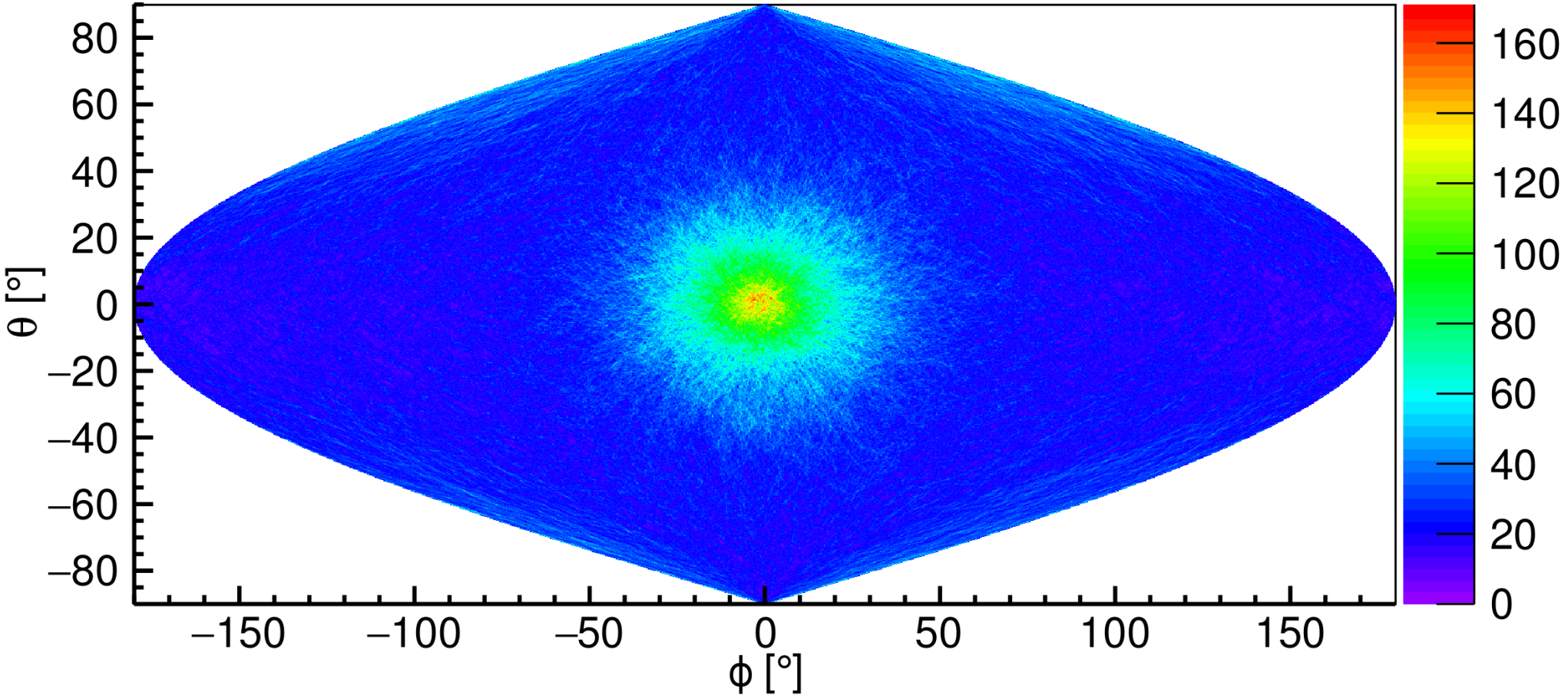
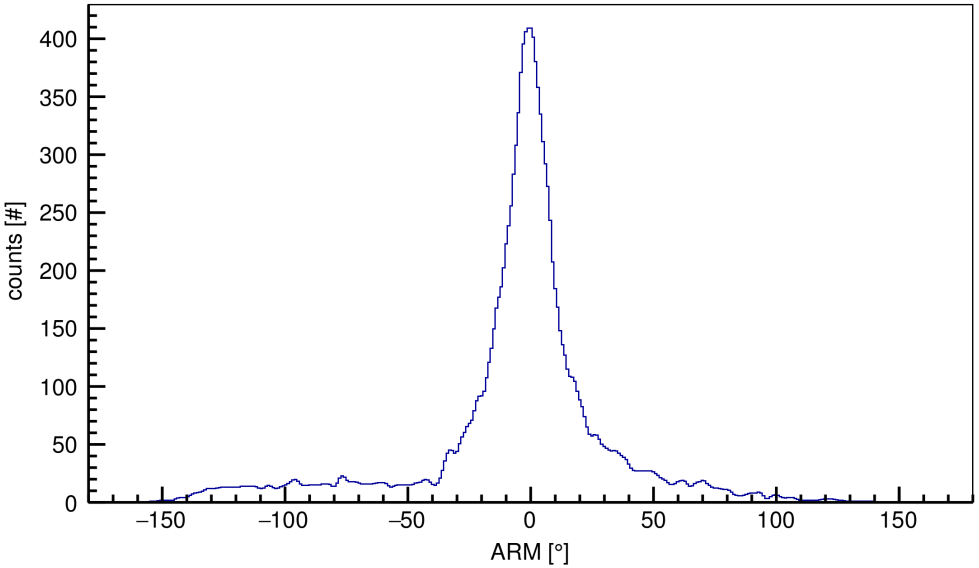


High-Efficiency Imaging without Interaction in Neighbouring Segments

Efficiency: 7 % Angular Resolution: $\Delta\theta$=18,7°



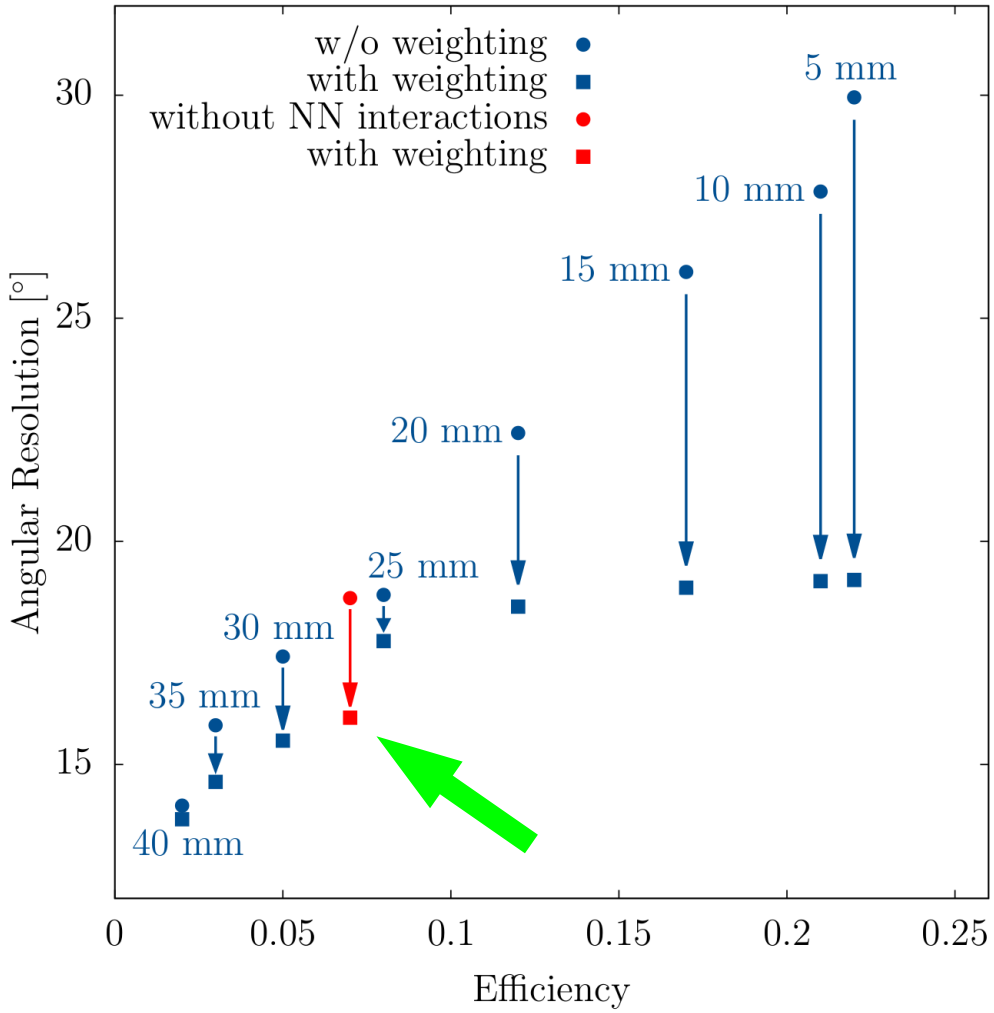
Weighting by the interaction point distance



Weighting by interaction point distance

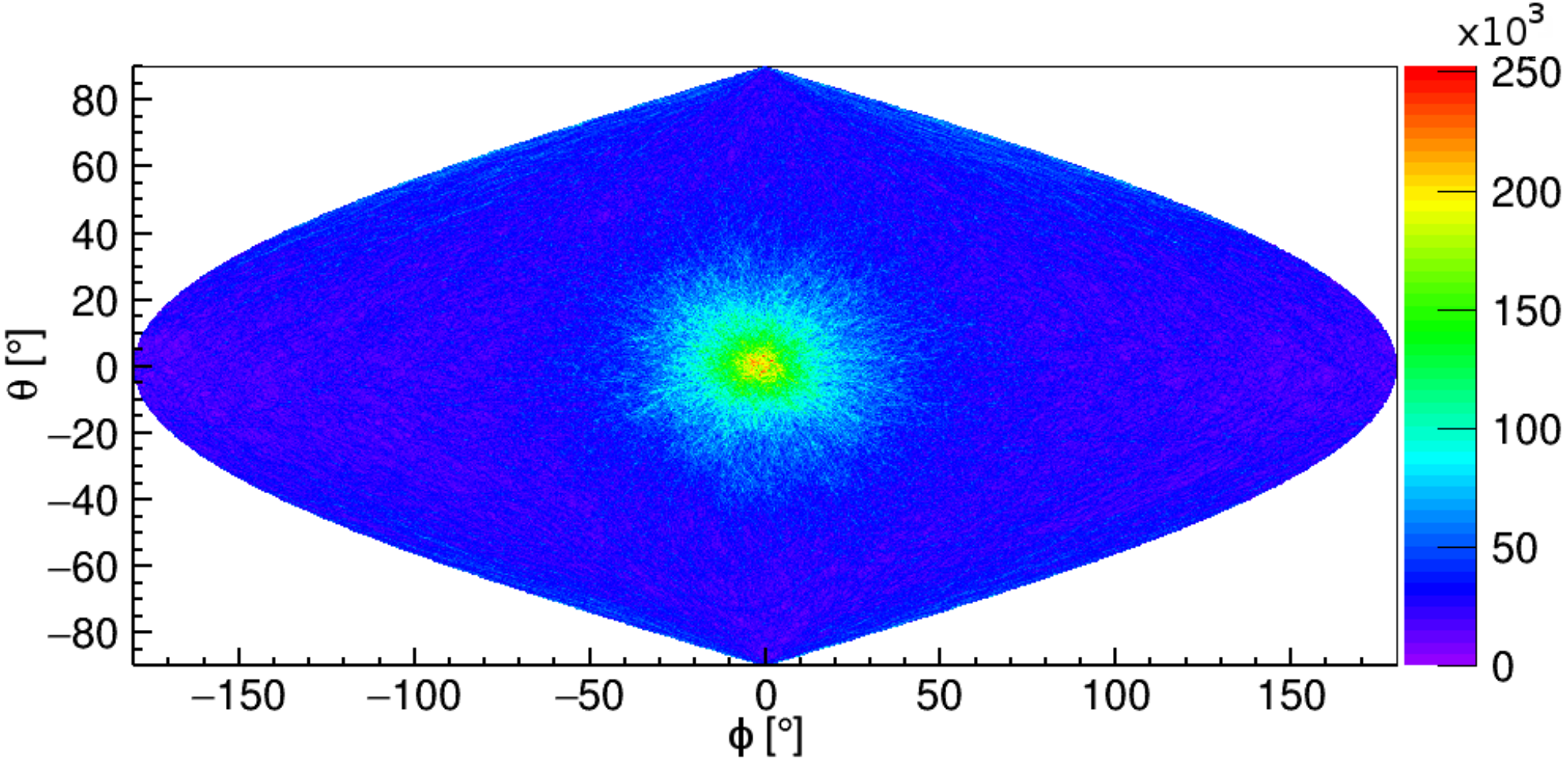
$$w = \frac{1}{\Delta_{axis}} \approx \frac{r_{1,2}}{\sqrt{\delta r_1^2 + \delta r_2^2}} \propto r_{1,2}$$

F. Recchia et al. , Nucl. Instr. Meth. Phys. Res. A 604 (12) (2009) 60 – 63.



High-Efficiency Imaging without Interaction in Neighbouring Segments

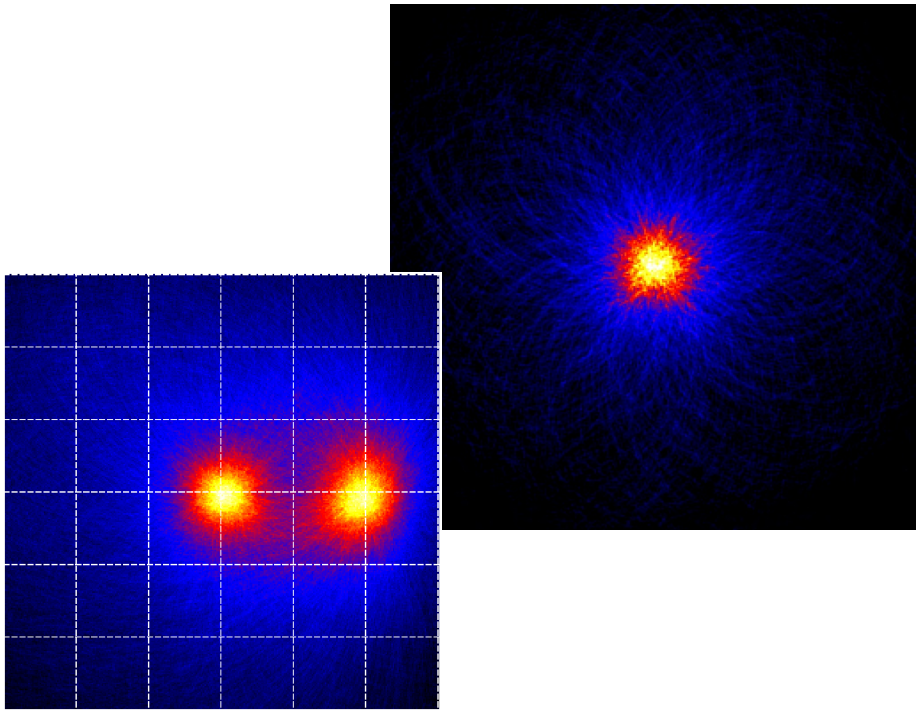
Efficiency: 7 % Angular Resolution: $\Delta\theta$=16,1°



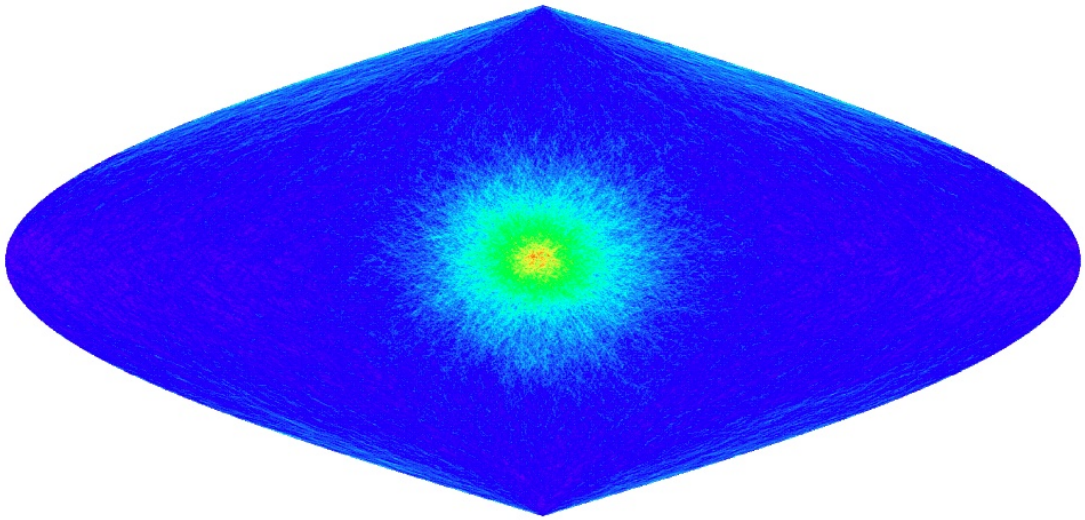
Two Different Modes

→ 2 complementary modes operate simultaneous

- Coincidence mode
  - Angular resolution 4.6°
  - Efficiency 1.7×10^{-5}



- High-Efficiency mode
  - Angular resolution (between 14° and 19°)
  - Efficiency up to 23%



Comparison

- Coincidence mode
  - Angular resolution 4.6°
  - Efficiency 1.7×10^{-5}
- High-Efficiency mode
  - Angular resolution (between 14° and 19°)
  - Efficiency up to 23%

- Setup with AGATA HPGe and double-sided planar HPGe detector

  S. Moon et al., Journal of Instrumentation 6 (12) (2011) C12048.

  Source: Cs-137 (E_γ = 662 keV)

  2-dimensional Lorentzian peak fit
  FWHM between 8.9° and 11.2°

- Comparable Setup

  F. Recchia et al., Nucl. Instr. Meth. Phys. Res. A 604 (12) (2009) 60 – 63

  Source: Co-60 (E_γ = 1332 keV)

  FWHM of the projections
  - 17.0° for φ
  - 22.5° for θ

Outlook

Possible improvement

- Segment Multiplicity > 2 in the High-Efficiency mode
- Distinguish interactions in one segment
- Optimizing PSA

EPJ A to be submitted

Compton Imaging with a highly segmented, position-sensitive HPGe Detector

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Thank you for your attention

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