Inverted Coaxial HPGe Segmented Point Contact Detector

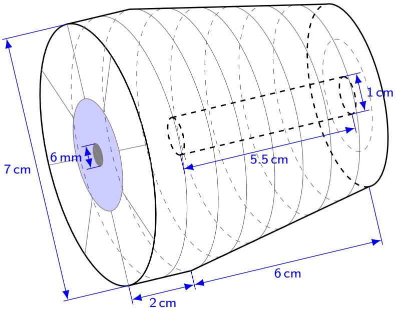
Marco Salathe, Heather Crawford, Ren Cooper
Lawrence Berkeley National Laboratory

David Radford
Oak Ridge National Laboratory

7 December 2016
First AGATA-GRETINA tracking arrays collaboration meeting,
Argonne National Laboratory

This work is supported by LBNL-LDRD funding under LDRD NS16-128, and by the U.S. Department of Energy, Office of Nuclear Physics, under contract no DE-AC02-05CH11231

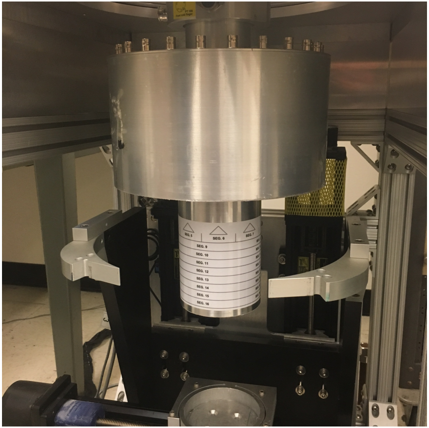
What is a Inverted Coaxial HPGe Segmented Point Contact Detector?



- Novel germanium detector technology indented for in beam γ-ray spectroscopy
- n-type material (for increased radiation hardness)
- $\sim$7 cm diameter, $\sim$8 cm height
- 20 individual segments
  - Point contact (central electrode) on the back
  - 8 wedges around the point contact
  - 8 circular segments on the side
  - 2 circular segments on the front
  - 1 segment in the bore hole

A novel HPGe detector for gamma-ray tracking and imaging. R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren. Nucl. Instr. and Meth. A 665 (2011) 25-32

What is a Inverted Coaxial HPGe Segmented Point Contact Detector?

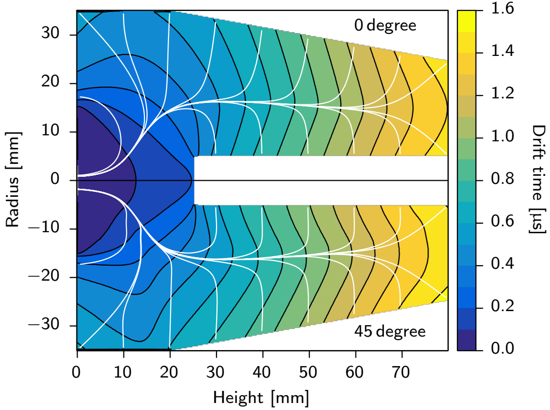


- Novel germanium detector technology indented for in beam γ-ray spectroscopy
- n-type material (for increased radiation hardness)
- $\sim$7 cm diameter, $\sim$8 cm height
- 20 individual segments
  - Point contact (central electrode) on the back
  - 8 wedges around the point contact
  - 8 circular segments on the side
  - 2 circular segments on the front
  - 1 segment in the bore hole
- First prototype build in 2012 and currently at LNBL for characterization and analysis

---

A novel HPGe detector for gamma-ray tracking and imaging. R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren. Nucl. Instr. and Meth. A 665 (2011) 25-32

Unusual charge collection for a detectors of this size!



- Germanium detector design principle in the past: majority charge carrier are collected at the nearest electrode
- This detector: majority charge carriers drift through the detector to the point contact
- Large variety in drift time of charge carrier
- Relatively long drift times (up to 1.6μs)
- After an initial phase, charge carrier follow similar trajectories

The drift time is a proxy for the z-position (height) of an interaction

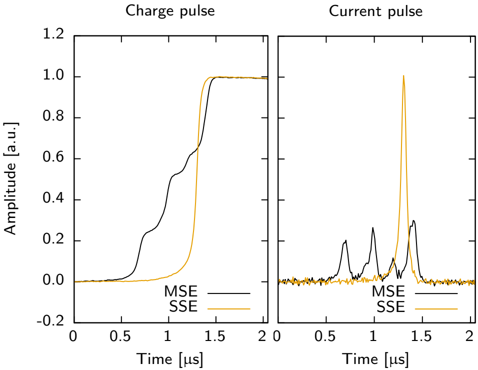
Good positional resolution and hit number discrimination

- In beam gamma-ray tracking requires good positional resolution for each interaction in an event
- Simulations suggest that the Inverted Coaxial HPGe Segmented Point Contact Detector has a positional resolution 4-5 times higher than GRETINA detectors

.

A novel HPGe detector for gamma-ray tracking and imaging. R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren. Nucl. Instr. and Meth. A 665 (2011) 25-32

Good positional resolution and hit number discrimination

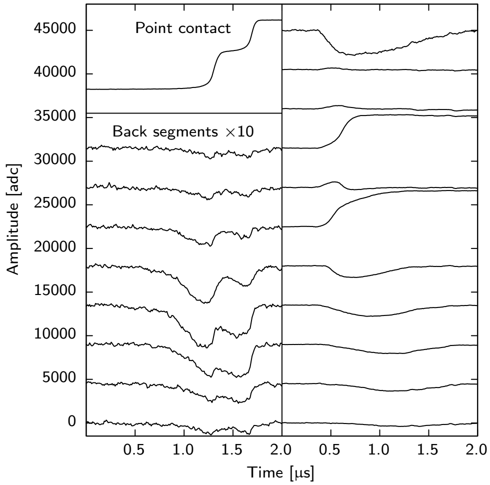


- In beam gamma-ray tracking requires good positional resolution for each interaction in an event
- Simulations suggest that the Inverted Coaxial HPGe Segmented Point Contact Detector has a positional resolution 4-5 times higher than GRETINA detectors
- Individual interactions can be distinguished because of variations in arrival time of electrons at the point contact

.

A novel HPGe detector for gamma-ray tracking and imaging. R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren. Nucl. Instr. and Meth. A 665 (2011) 25-32

Good positional resolution and hit number discrimination



.

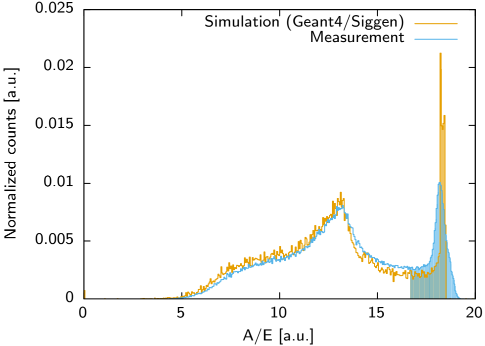
- In beam gamma-ray tracking requires good positional resolution for each interaction in an event
- Simulations suggest that the Inverted Coaxial HPGe Segmented Point Contact Detector has a positional resolution 4-5 times higher than GRETINA detectors
- Individual interactions can be distinguished because of variations in arrival time of electrons at the point contact
- Because of the long drift time multiple interactions can be observed separated on segments

---

A novel HPGe detector for gamma-ray tracking and imaging. R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren. Nucl. Instr. and Meth. A 665 (2011) 25-32

Single-site event (SSE) cut

662 keV peak of 1 mm collimated ^{137}Cs at 0°



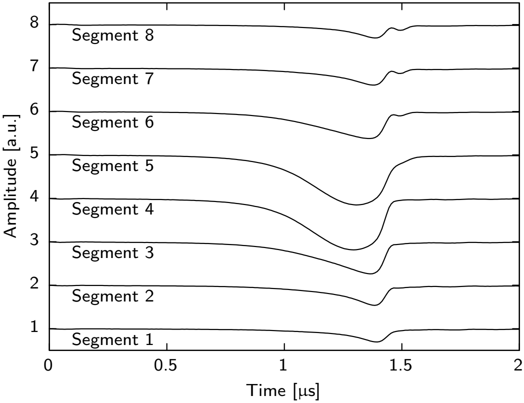
- The amplitude of the current pulse measured at the point contact is normalized by the uncalbrated energy $\Rightarrow$ A/E qualifier
- A/E distribution measured in Compton edge, cut levels defined at ± 2 FWHM of SSE peak centroid
- Distribution from simulation and measurements agree well
- SSE fractions (measurement): 19.2% at 662 keV 13.6% at 1173 keV, 12.8% at 1332 keV

For simplicity only events with a single interaction are considered in further discussion

Computation of azimuthal angle

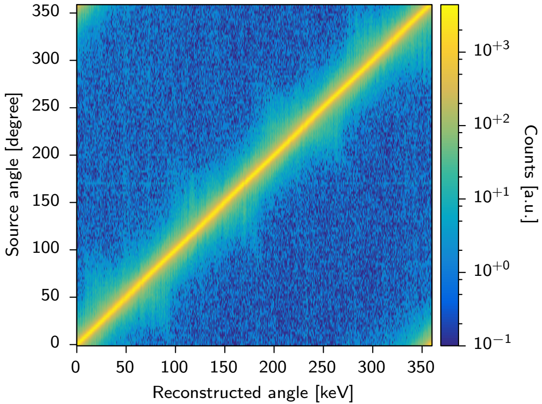
Positional reconstruction

Up to now only the azimuth of a given event is computed.



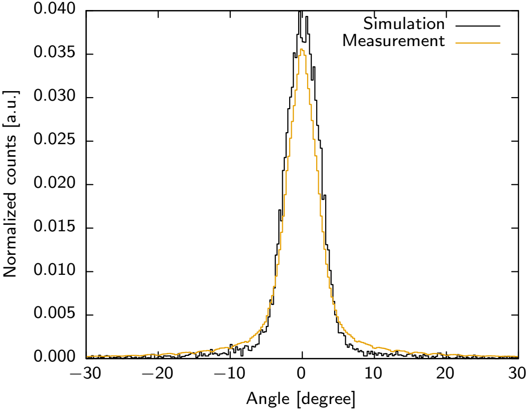
- Measurements at 2.5 degree increments: highly collimated (1 mm diameter) ^{137}Cs source at a radius of 24 mm
- Only consider single site events in 661.7 keV peak
- Using the eight wedges on the back (no angular information on remaining segments)
- Build average pulse shape for each angle (example at 180 degree)
- Compare each individual event with average pulse shape and find the best match (χ^2 difference)

Results - Azimuthal angle reconstruction



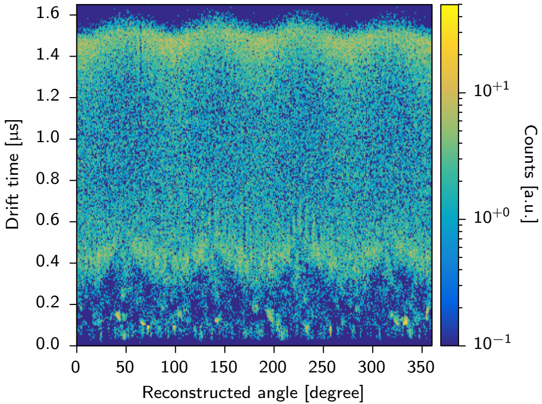
- Source angle and reconstructed angle agree well (highly collimated ^{137}Cs source at a radius of 24 mm and 2.5 degree increments)

Results - Azimuthal angle reconstruction



- Source angle and reconstructed angle agree well (highly collimated ^{137}Cs source at a radius of 24 mm and 2.5 degree increments)
- Angular distribution of events (same measurement as previous) agrees with a Monte Carlo simulation (Geant4)

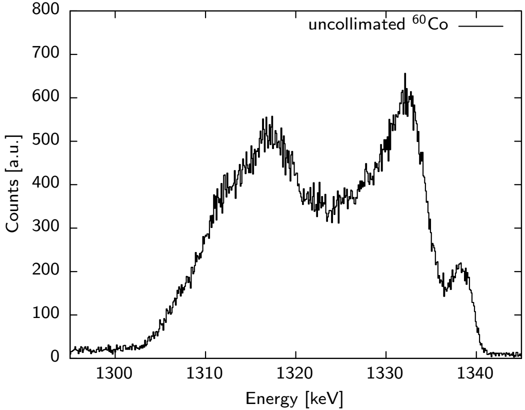
Results - Azimuthal angle reconstruction



- Source angle and reconstructed angle agree well (highly collimated ^{137}Cs source at a radius of 24 mm and 2.5 degree increments)
- Angular distribution of events (same measurement as previous) agrees with a Monte Carlo simulation (Geant4)
- Relatively homogeneous distribution observed in a flood measurement (uncollimated ^{60}Co source at 4 inch distance)

Charge trapping effects

A fraction of the charge carrier in germanium detector gets stuck (trapped) during the drift from the interaction site to the read-out electrode

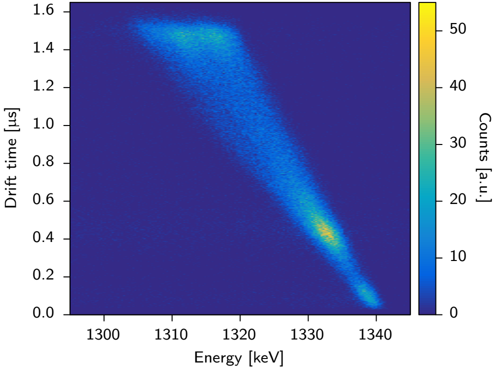


- In n-type material electron trapping (majority charge carrier) even at standard impurity levels
- Charge trapping degrates peak shape

Is there a way to restore the characterstic resolution of germanium detectors?

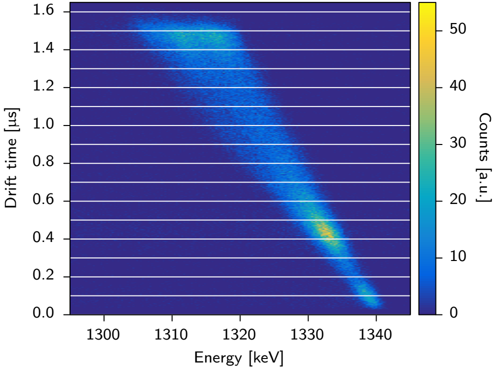
Drift time correction

Charge trapping increases roughly linearly with drift time



Drift time correction

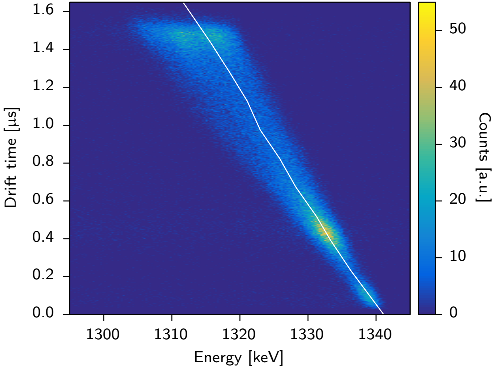
Charge trapping increases roughly linearly with drift time



- Divide data in 100 ns slices
- Calculate peak position for each slice

Drift time correction

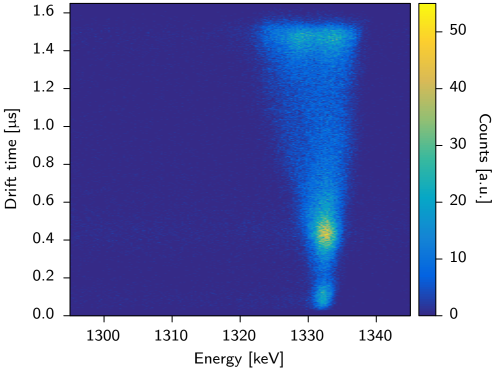
Charge trapping increases roughly linearly with drift time



- Divide data in 100 ns slices
- Calculate peak position for each slice
- Produce a drift time correction curve from peak positions
- Linear interpolate between peaks

Drift time correction

Charge trapping increases roughly linearly with drift time



- Divide data in 100 ns slices
- Calculate peak position for each slice
- Produce a drift time correction curve from peak positions
- Linear interpolate between peaks
- Correct energy according to drift time curve

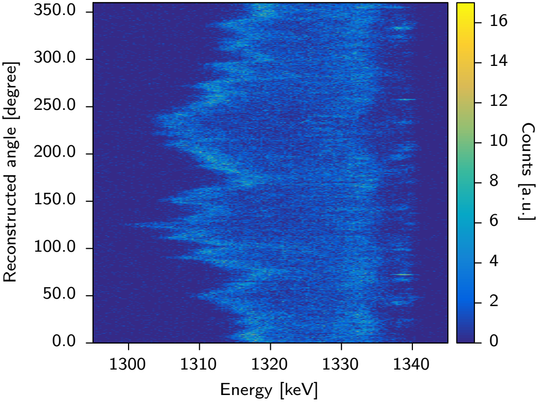
Works well at low drift times, however large spread at long drift times

Charge trapping effects

Charge trapping must depend on other variables:

Charge trapping effects

Charge trapping must depend on other variables:
Obvious solution ⇒ Angular dependence



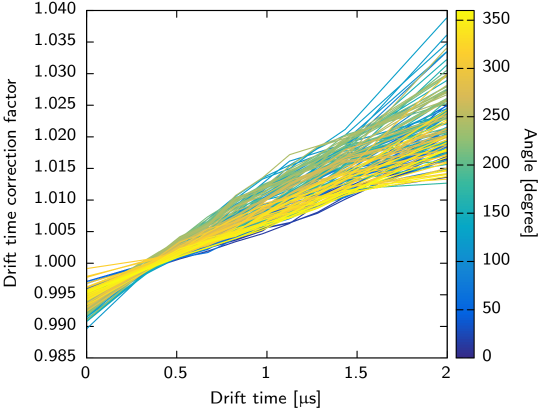
- Angle can be reconstructed from eight wedges on the back
- Strong variations in trapping strength observed at different angles

The angular dependence of charge trapping can be measured
⇒ Correction is possible

Angular charge trapping correction

Measurements

Highly collimated (1 mm diameter) ^{137}Cs measurement at a radius of 24 mm. Individual measurements at 2.5 degree increments. Only consider single site events in 661.7 keV peak.

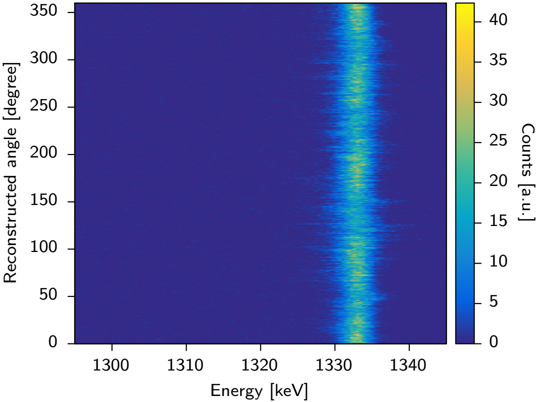


- Extract charge trapping strength as a function of drift time for each measurement (angle) separately
- Reconstruct azimuthal angle of an event with previously described algorithm
- Correct energy as a function of drift time with the correction extracted for a given angle

Results - Angular charge trapping correction

Measurement

Uncollimated ^{60}Co source centered in the front of the detector (~4 inch distance)

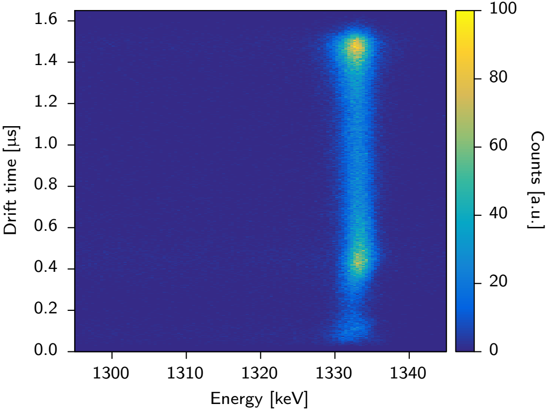


- Relatively constant peak location/width at all angles

Results - Angular charge trapping correction

Measurement

Uncollimated ^{60}Co source centered in the front of the detector (∼4 inch distance)

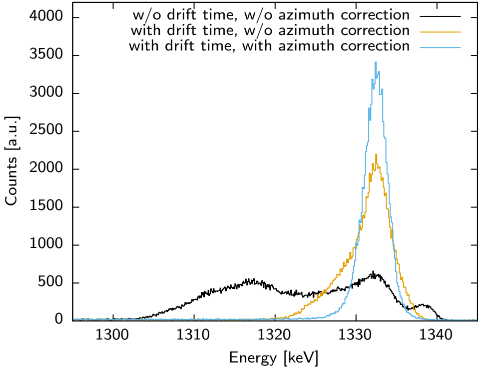


- Relatively constant peak location/width at all angles
- Constant peak location/width at all drift times

Results - Peak shape

Measurement

Uncollimated ^{60}Co source centered in the front of the detector (∼4 inch distance)

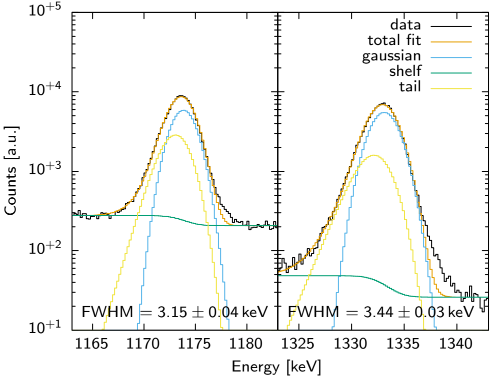


- Without any correction peak is strongly distorted
- Drift time correction (without considering the azimuth) improves the energy resolution, but strong low energy tail remains
- Azimuth correction removes most of the tail

Results - Peak shape

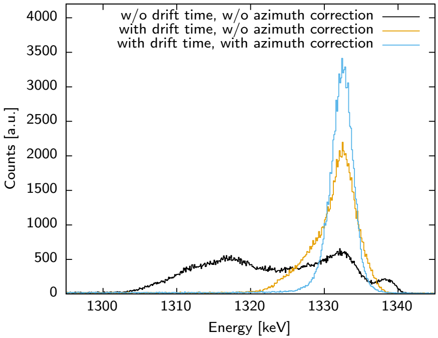
Measurement

Uncollimated ^{60}Co source centered in the front of the detector (∼4 inch distance)



- Without any correction peak is strongly distorted
- Drift time correction (without considering the azimuth) improves the energy resolution, but strong low energy tail remains
- Azimuth correction removes most of the tail
- Peak is mostly Gaussian, but a small amount of tailing remains
- Resolution of 3.44 keV for single site events

Summary



Inverted Coaxial HPGe Segmented Point Contact Detector (n-type)

- First characterization has been performed
- The point contact signal helps to extract number of interactions
- The azimuth of a single site event can be reconstructed
- The angular and longitudinal charge trapping strength has been mapped out and a correction function implemented
- A large improvement in energy resolution was achieved

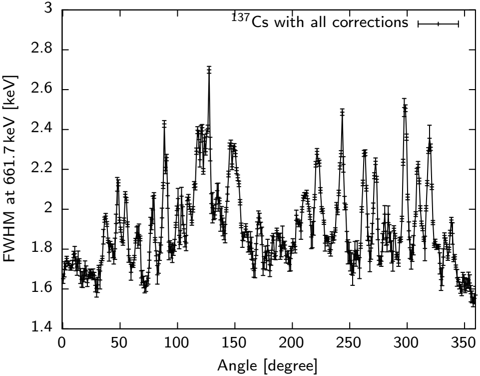
Outlook

- Full reconstruction of event position (radial/longitudinal position)
- Signal decomposition of multiple site events

Further considerations

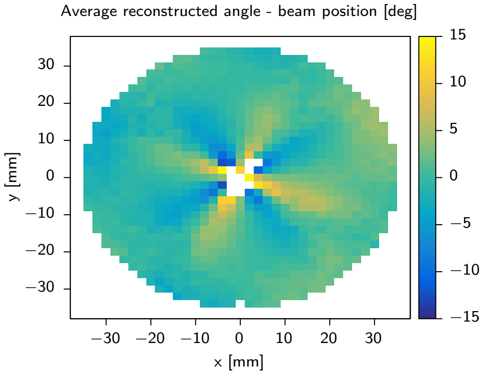
- Is it possible to improve the resolution even further?
- Does the azimuth reconstruct works at all radius?
- What about events with multiple interactions?

Further considerations



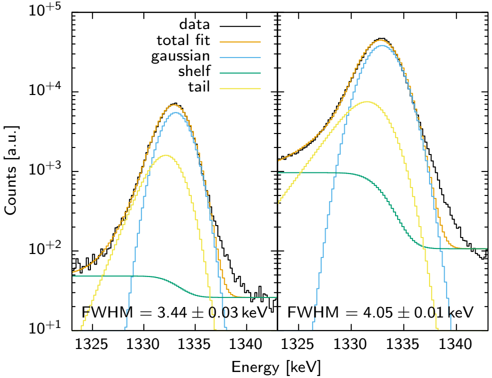
- Is it possible to improve the resolution even further?
  ⇒ Variations at different angles seem to be intrinsic properties, a large improvement is unlikely. By performing the drift time correction on individual 1° slices the resolution improves by roughly 0.1 keV.
- Does the azimuth reconstruct works at all radius?
- What about events with multiple interactions?

Further considerations



- Is it possible to improve the resolution even further?
  ⇒ Variations at different angles seem to be intrinsic properties, a large improvement is unlikely. By performing the drift time correction on individual 1° slices the resolution improves by roughly 0.1 keV.
- Does the azimuth reconstruct works at all radius?
  ⇒ No, at radius different from 24 mm there is an additional angular shift. The shift does not affect the energy resolution.
- What about events with multiple interactions?

Further considerations



- Is it possible to improve the resolution even further?
  ⇒ Variations at different angles seem to be intrinsic properties, a large improvement is unlikely. By performing the drift time correction on individual 1° slices the resolution improves by roughly 0.1 keV.
- Does the azimuth reconstruct works at all radius?
  ⇒ No, at radius different from 24 mm there is an additional angular shift. The shift does not affect the energy resolution.
- What about events with multiple interactions?
  ⇒ Already single site event procedure works relatively well. Further improvement expected from signal decomposition.