Characterization of an n-type Segmented Inverted Coaxial Point Contact (ICPC) Detector

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2nd Position Sensitive Ge Detectors and Application Workshop -- September 12, 2017

Outline

- Overview of the n-type Segmented Inverted Coaxial HPGe Point Contact Detector
- Challenges: Energy resolution from the point contact signal
  - Drift time corrections
  - Azimuthal angle reconstruction
- Full position (*r* and *z*) reconstruction
- Next steps toward complete signal decomposition
- In-beam characterization work – *under way*

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Marco Salathe

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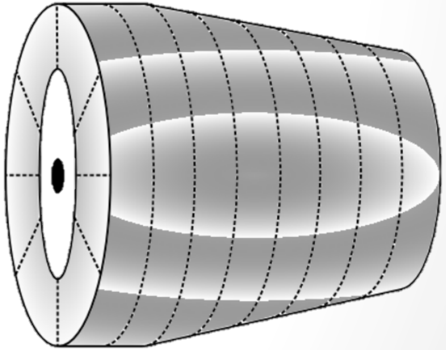
Inverted Coaxial HPGe Point Contact Detector

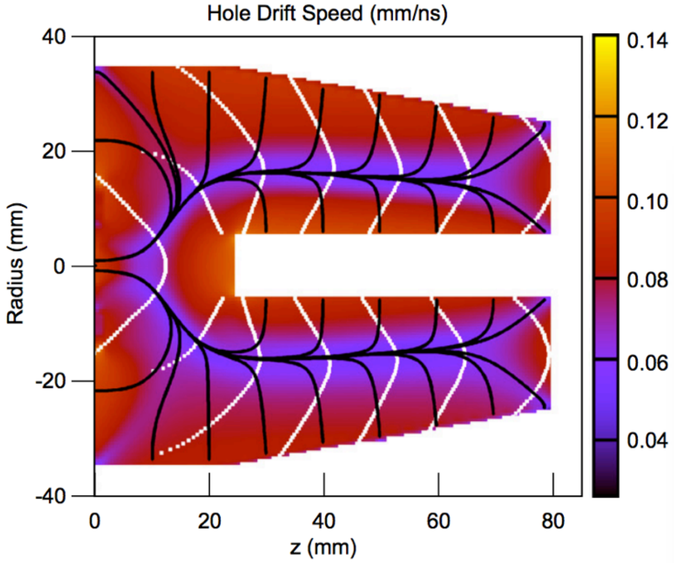
Novel, large-volume gamma-ray tracking detector combining electrode segmentation and point-contact technology

- Combines benefits of segmented (GRETA/AGATA) and point contact (MAJORANA/ GERDA) detector technologies
- Strong variation in charge drift time and highly localized point contact weighting potential allows **direct identification of number of interactions**
- Signal shape at point contact allows precise determination of charge arrival time
- Segmentation of outer contacts provides determination of interaction time
- Knowledge of drift time allows precise determination of interaction position from segments signals
  - *Predicted position resolution approximately σ = 0.2mm*
  - *Factor 3 -4 better than predicted for GRETINA*

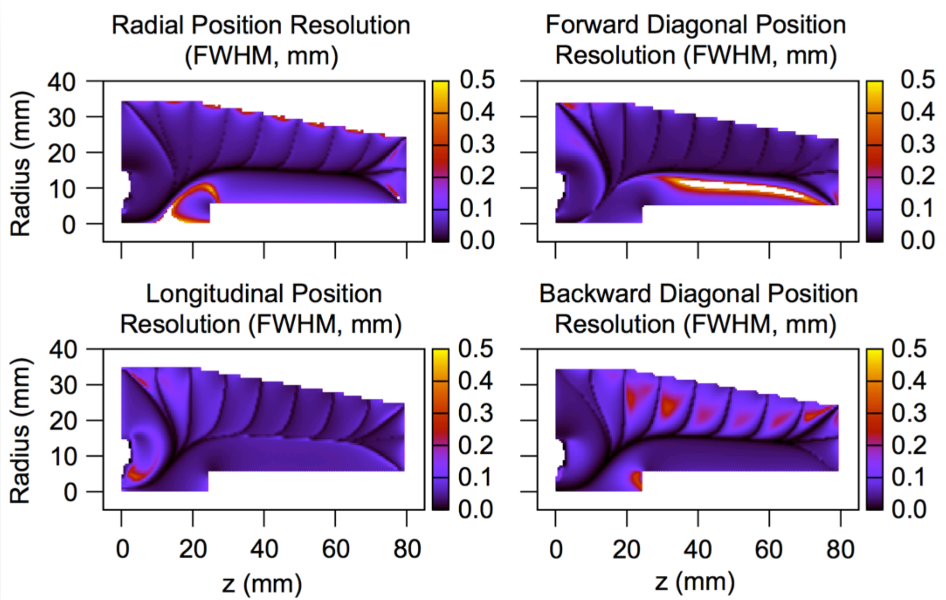


Vetter *et al.*, NIMA **452**, 223 (2000). | Cooper *et al.*, NIMA **665**, 25 (2011).

Inverted Coaxial HPGe Point Contact Detector



- Field, weighting potential and signal generation calculations have shown the potential performance gains for such a geometry



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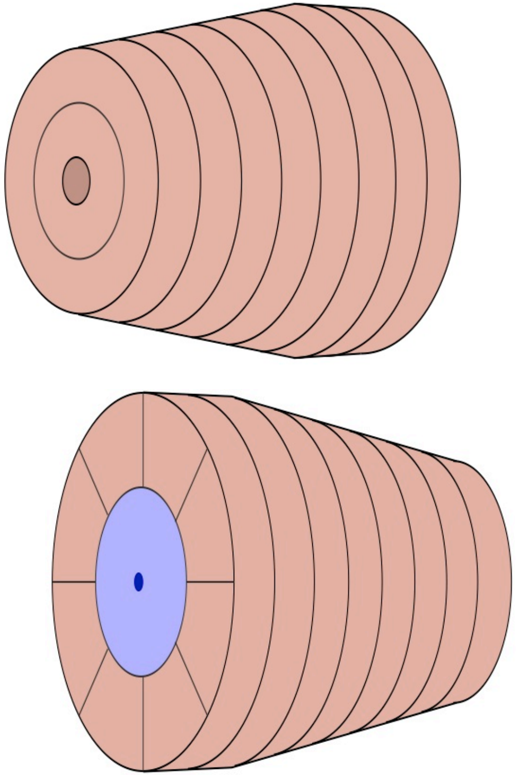
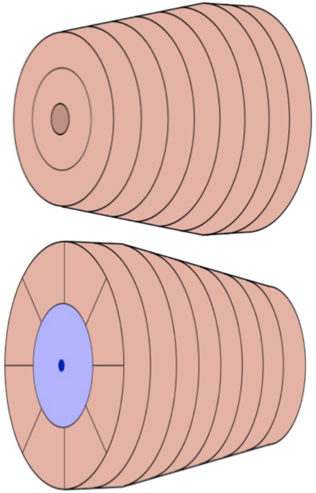
n-Type ICPC Prototype Detector

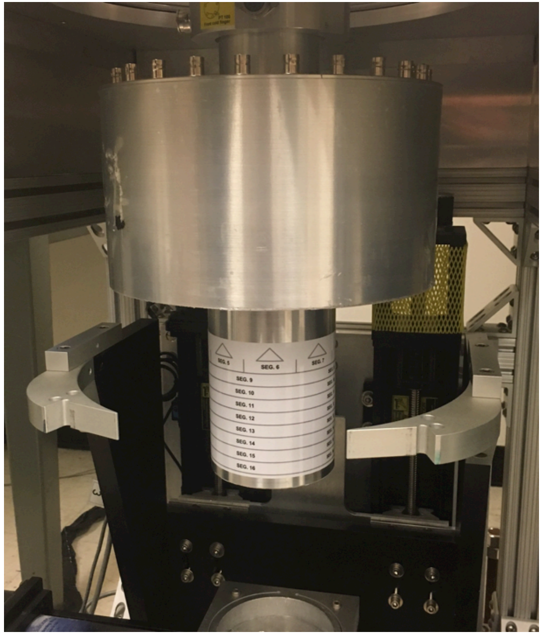


- Produced by Canberra France for David Radford (ORNL)
- 7 cm rear diameter; 8 cm length; 10 degree taper over 6 cm of length
- 20 individual segments
  - Point contact (full volume electrode) on the back
  - 8 wedges surrounding the point contact
  - 8 longitudinal slices on the sides
  - 2 concentric circular electrodes on the front
  - 1 contact in the bore hole (front)

Cooper *et al.*, NIMA **665**, 25 (2011).

n-Type ICPC Prototype Detector @ LBNL





- Supported by LDRD funding at LBNL, prototype was moved from ORNL to LBNL (88” cyclotron) for characterization work
- GRETINA scanning table and infrastructure, capabilities for in-beam testing have allowed a thorough investigation of the detector

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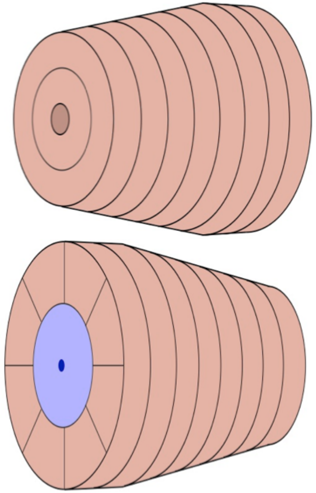
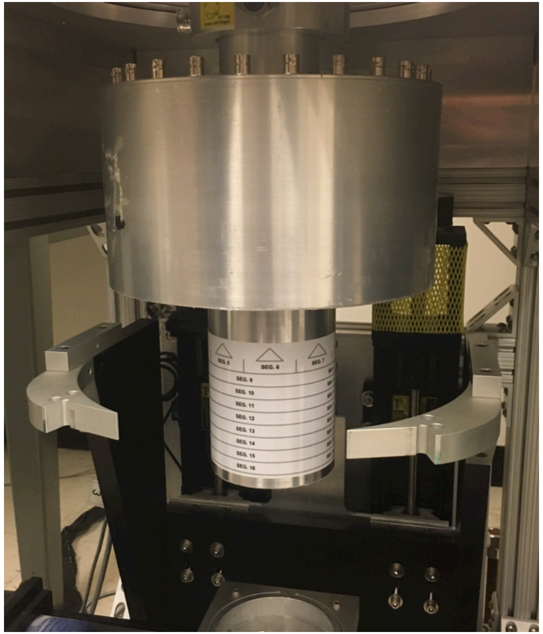
n-Type ICPC Prototype Detector @ LBNL





- Supported by LDRD funding at LBNL, prototype was moved from ORNL to LBNL (88" cyclotron) for characterization work
- GRETINA scanning table and infrastructure, capabilities for in-beam testing have allowed a thorough investigation of the detector
- Characterization and signal decomposition development is ongoing…

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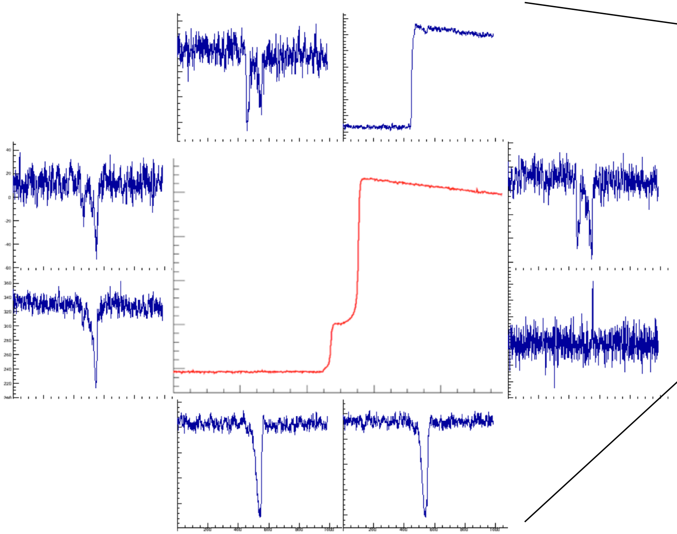
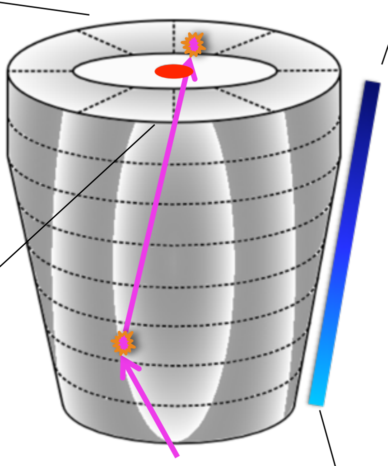
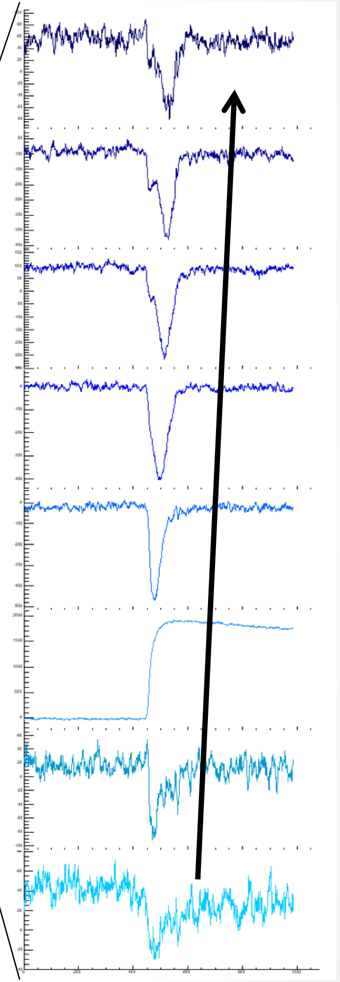
A representative event…





^{60}Co



- Individual event data shows power of slow-drift combined with segmentation
- Along z (vertical), slices clearly show drift of charge from first interaction point toward PC
- Second hit (back) is located by wedge signals (net + neighbours)
- Drift time (segment time --> PC time) refines z information

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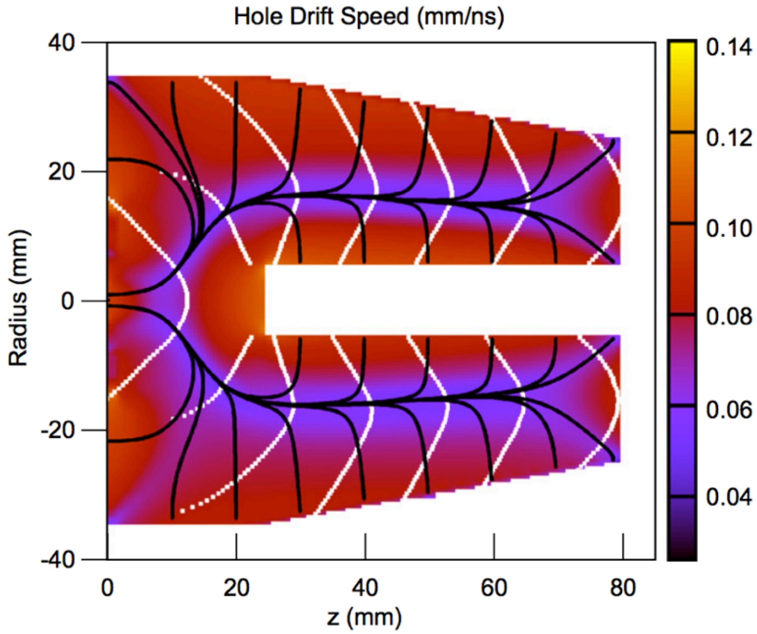
Inverted Coaxial HPGe Point Contact Detector



- With long drift times, energy resolution losses due to trapping must be recovered through pulse shape analysis
  - *Limit of performance is currently unknown*
- Drift times vary from few ns up to of order 2 us with large variation

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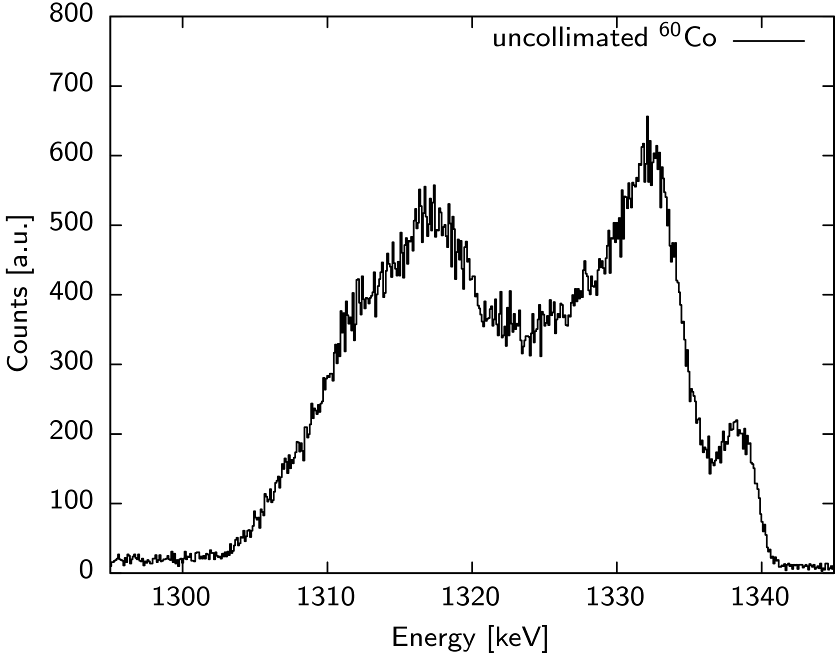
Charge Trapping in the n-type ICPC



- For n-type material electron trapping is significant even at standard impurity levels (without damage)
- Large variation in drift times, paths and the associated trapping strongly degrades the resolution (and peak shape)
- Can 'HPGe resolution' be recovered?

Salathe *et al.*, NIMA **868**, 19 (2017).

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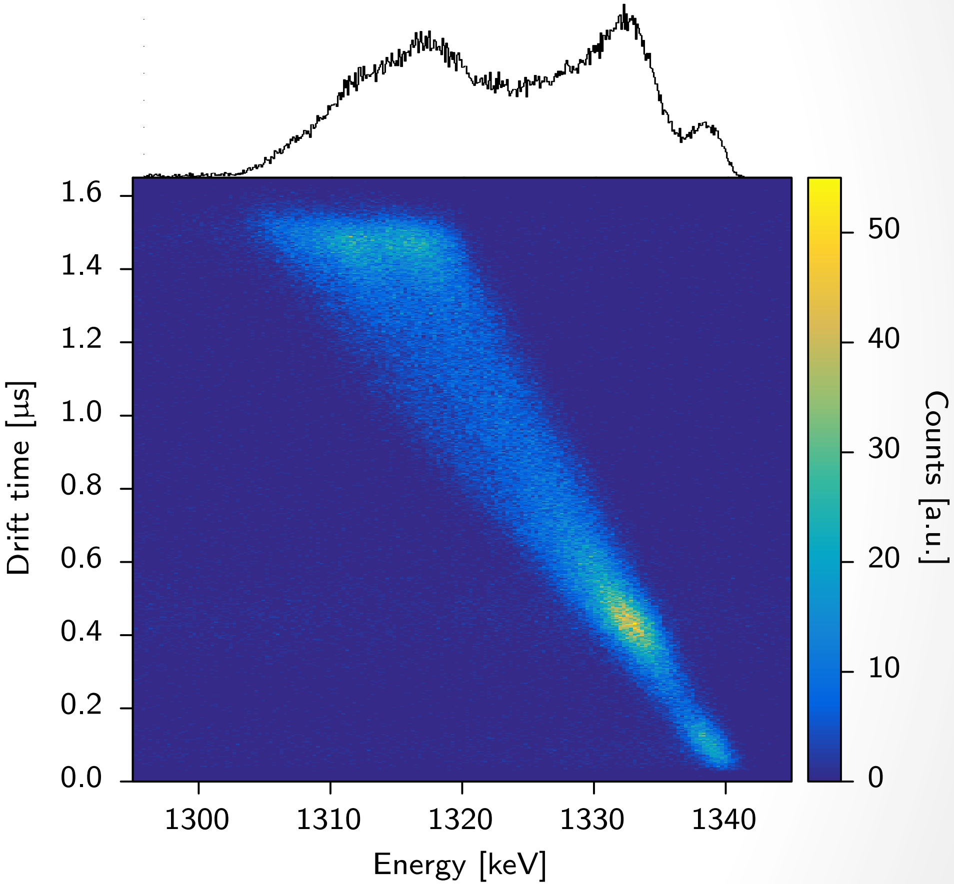
Charge Trapping: Drift Time Correction

- To a first approximation, charge trapping increases linearly with drift time
- Division of data into (100ns) drift-time slices and calculation of centroid provides first linear correction



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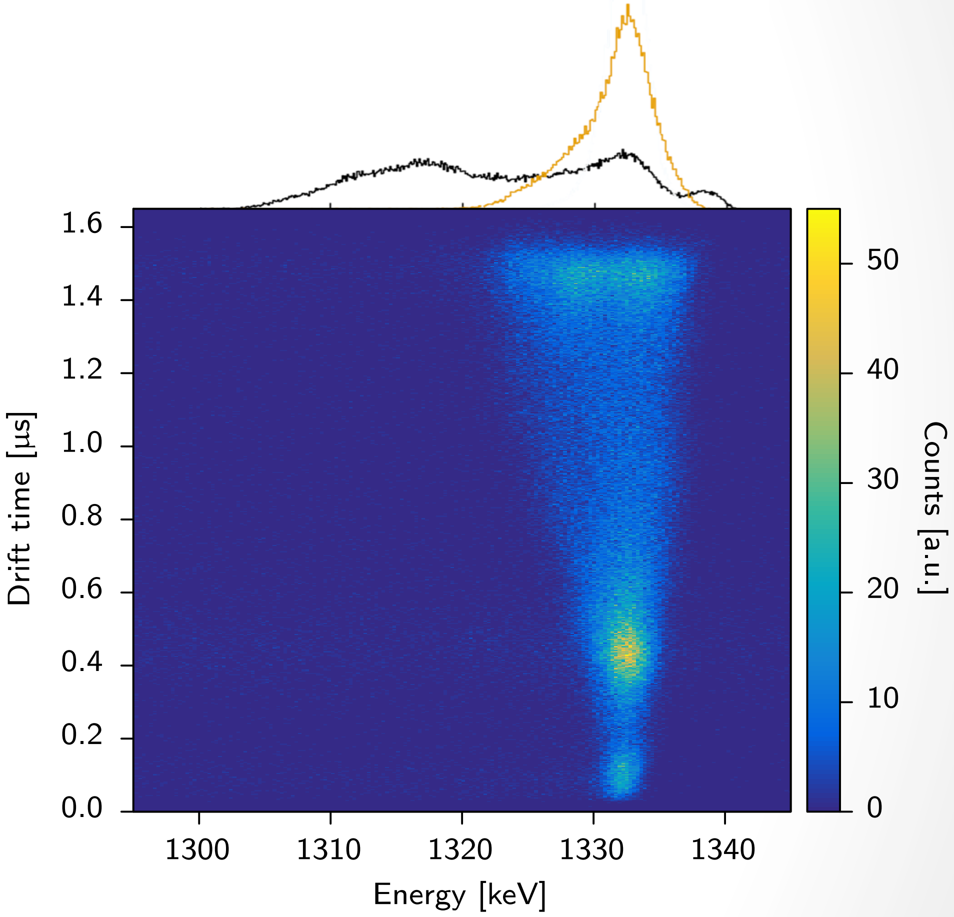
Charge Trapping: Drift Time Correction

- Simple linear correction works well at low drift-times, i.e. close to the PC where electrons are ultimately collected
- Divergence at long drift-times shows clear dependence of resolution on other parameters



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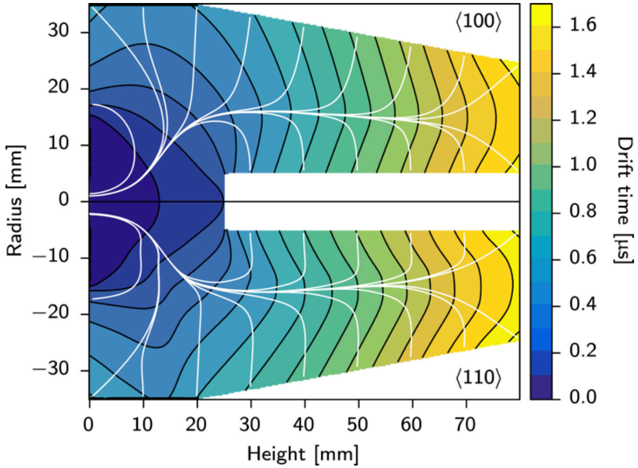
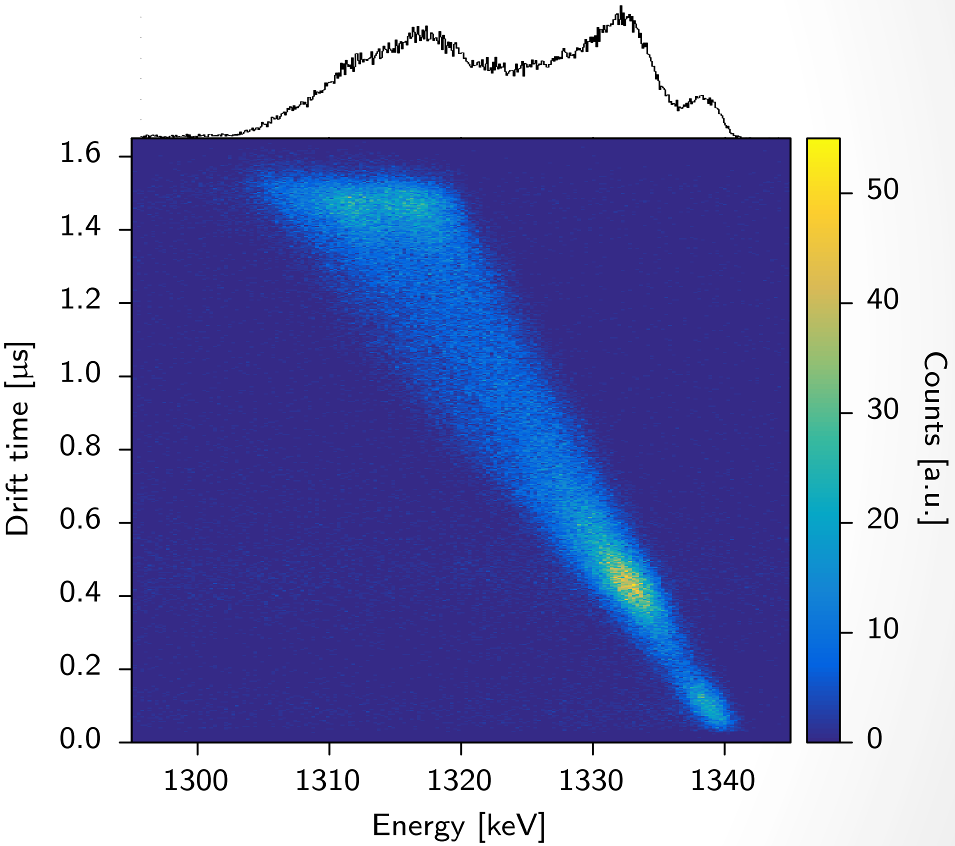
Charge Trapping: Azimuthal Angle Effect

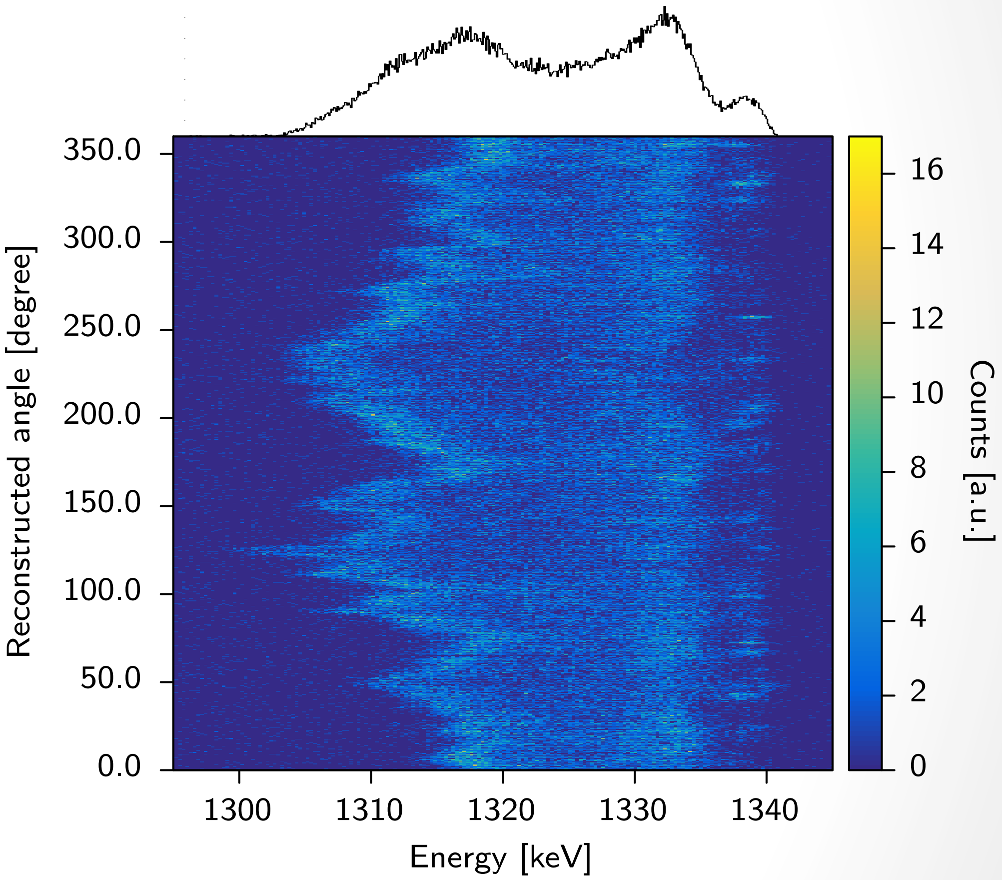
- Beyond drift-time -- an approximate proxy for depth (z) -- other obvious parameters are radius and azimuthal angle





Charge Trapping: Azimuthal Angle Effect

- Beyond drift-time -- an approximate proxy for depth (*z*) -- other obvious parameters are radius and azimuthal angle
- Strong variation in the amount of trapping is clearly observed at different azimuthal angles



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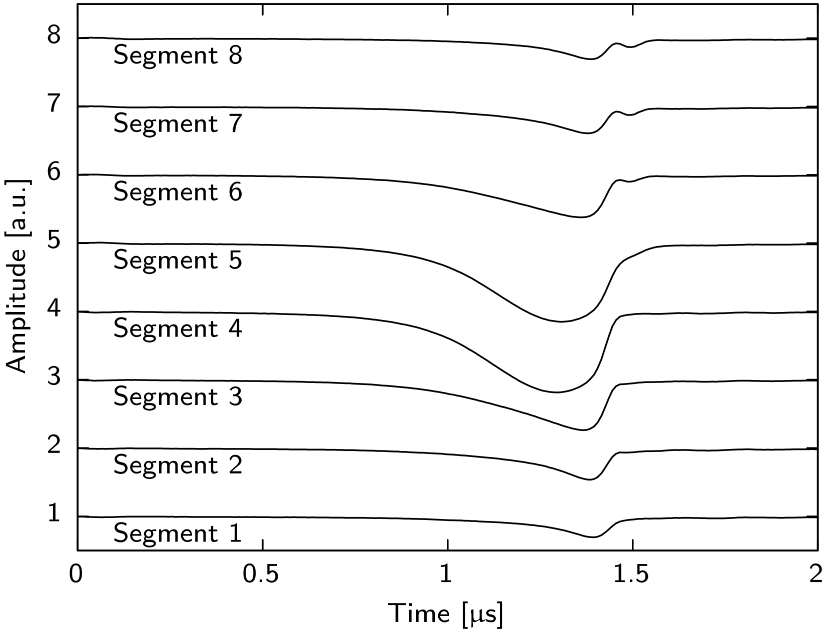
Azimuthal Angle Reconstruction: Building a Basis



- An experimental basis for azimuthal angle reconstruction was built

1. A ring of collimated vertical ^{137}Cs measurements were taken in the detector at a radius of 24 mm, with 2.5 degree spacing
2. Photopeak events satisfying A/E cut were averaged to build a basis at each angle, considering on the rear 8 wedge segments

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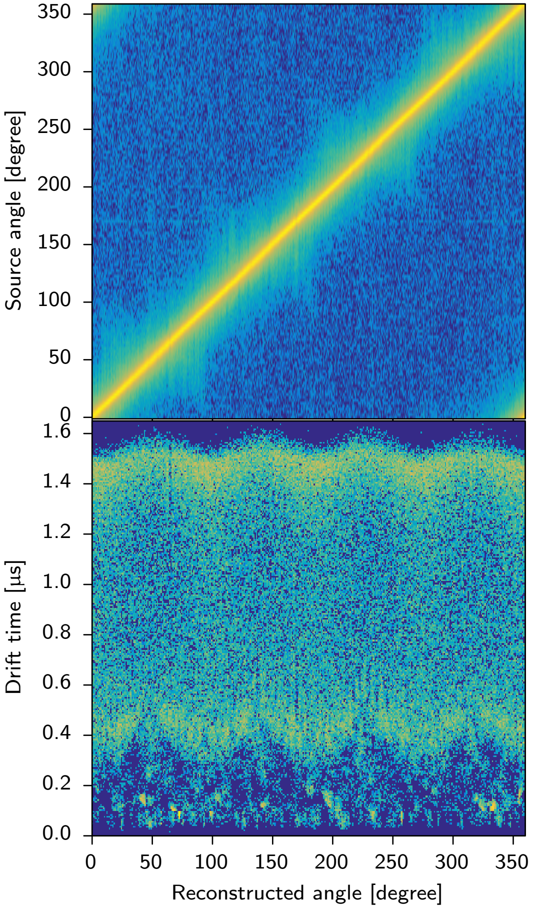
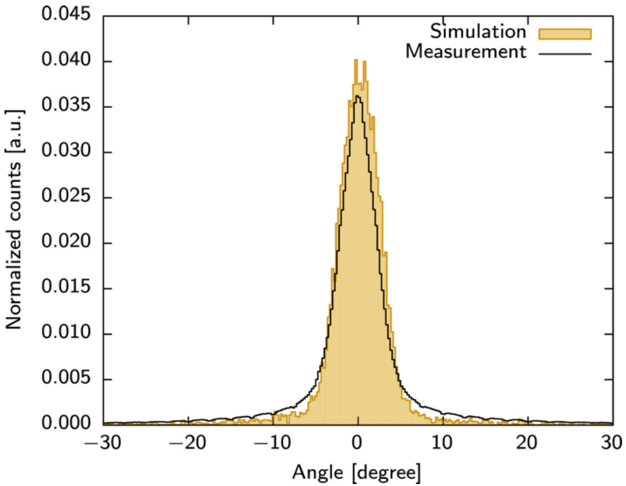
Azimuthal Angle Reconstruction



- A fit of individual events to the available basis signals, using a χ^2 minimization, and then a linear interpolation between grid points allows reliable azimuthal angle determination



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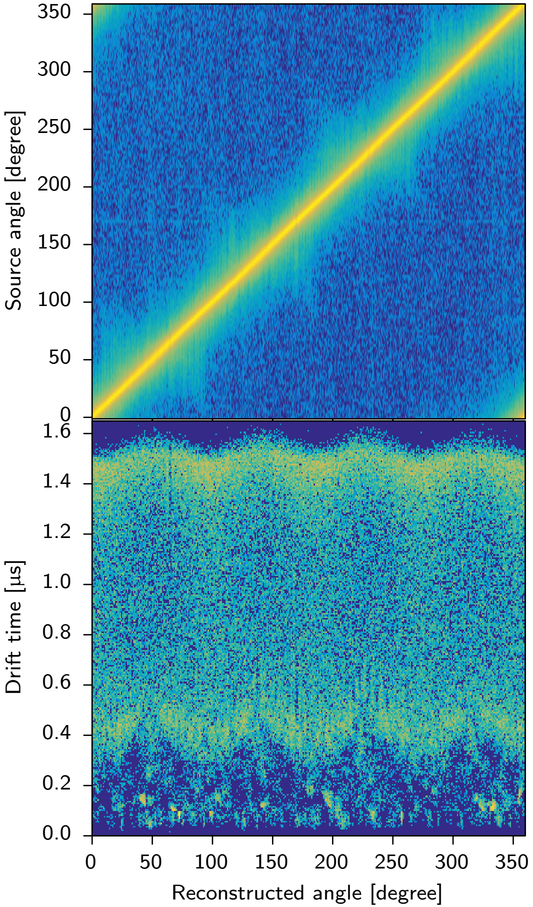
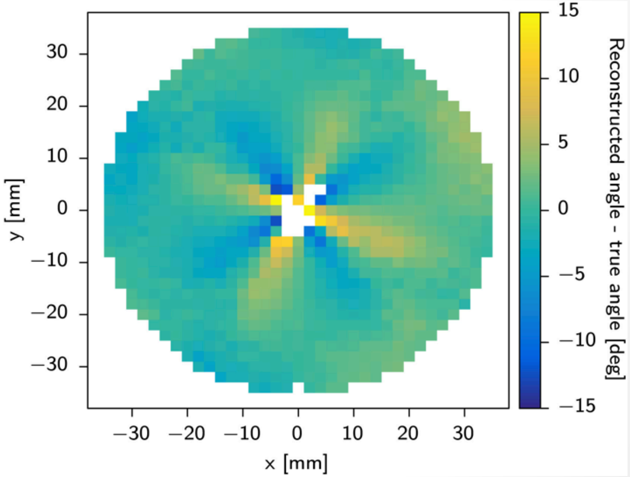
Azimuthal Angle Reconstruction



- A fit of individual events to the available basis signals, using a χ^2 minimization, and then a linear interpolation between grid points allows reliable azimuthal angle determination
- Measures the angle 'observed' at the rear of the crystal, i.e. the angle of the main part of the charge carrier drift



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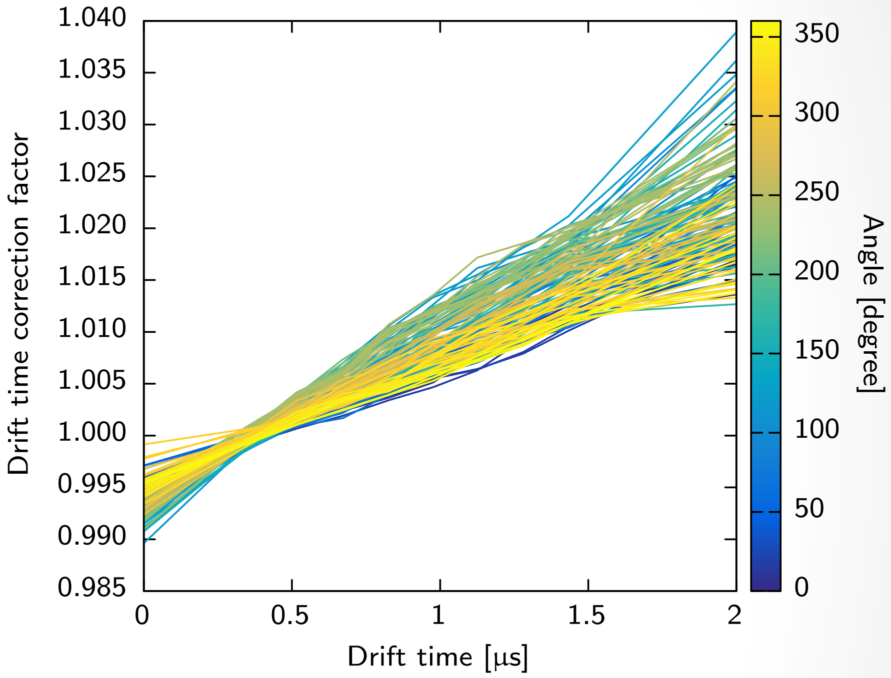
Azimuthal Angle Reconstruction

- Drift time correction curves were determined for each angular position – variation is significant, several percent deviation between correction curves



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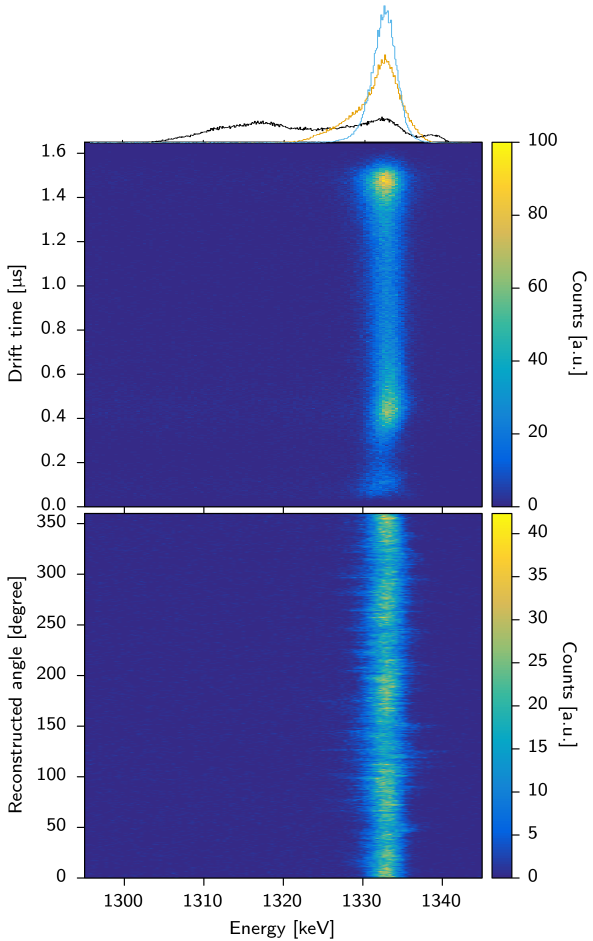
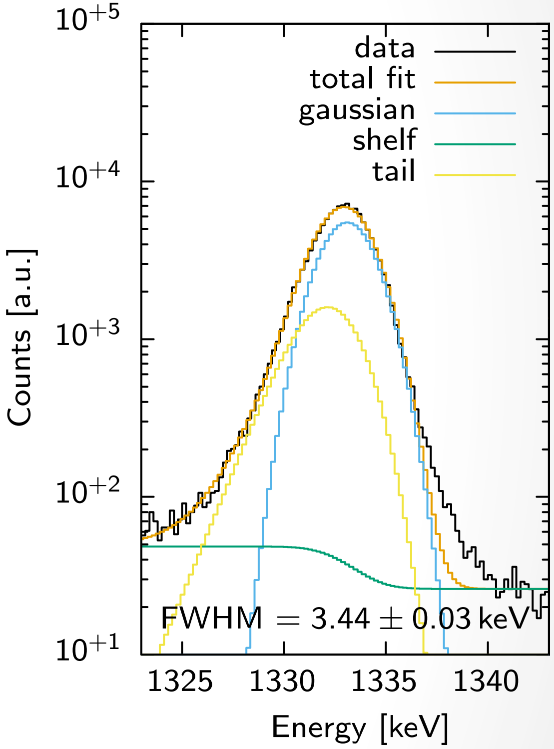
Charge Trapping: Drift and Angle Correction



- Uncollimated ^{60}Co measurement (from the crystal front) shows performance of angle-drift time correction
- For single-site events, obtained ~3.44 keV at 1332 keV with only these corrections



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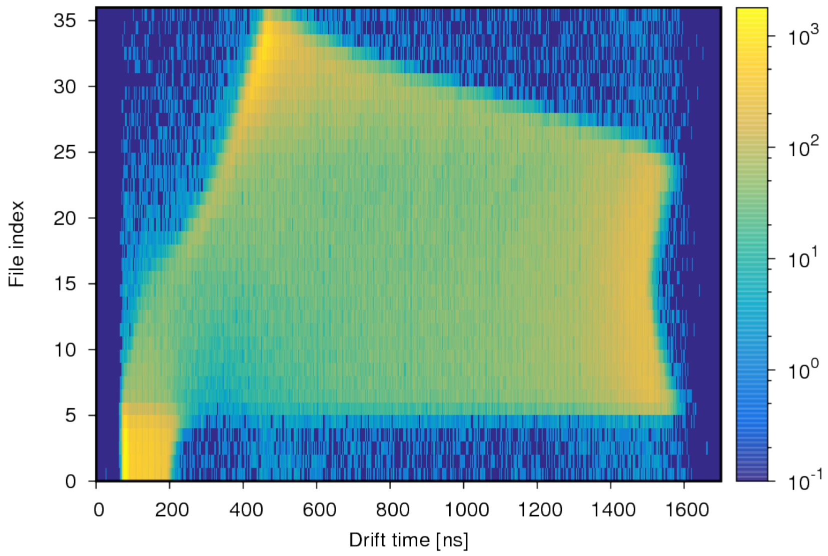
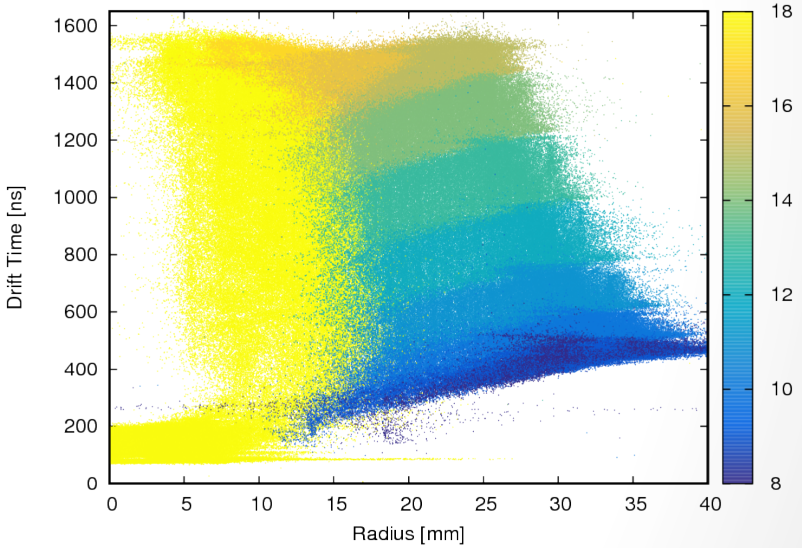
Radial Position Reconstruction

- Collimated ^{137}Cs scans from the center to the outside of the crystal at specific angles were used to build up the *r* basis
- Signals from the front and longitudinal segments included; basis was built indexed by observed net segment, *φ* and drift time





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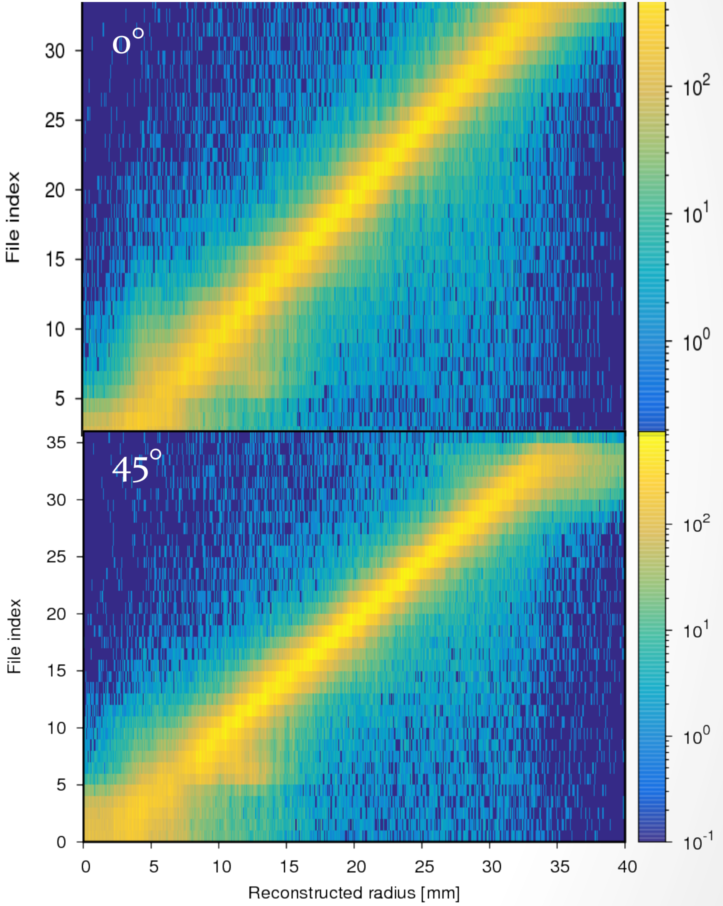
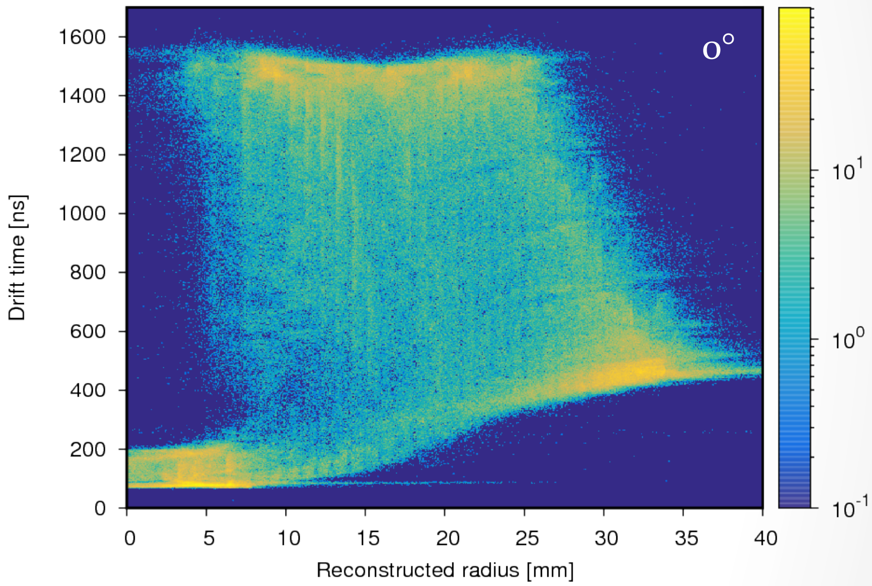
Radial Position Reconstruction

- Radial reconstruction is performed following φ determination
- Least-squares χ^2 minimization and interpolation between basis points determines r position
- Good performance achieved with (at this point) single iteration of fitting step, except in region very near point contact ($r = 0$)



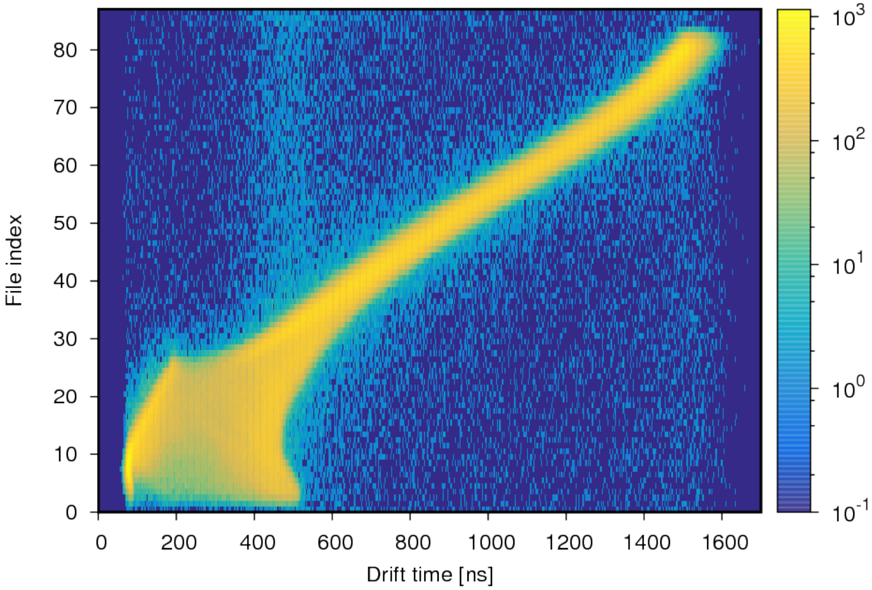
Radial Position Reconstruction

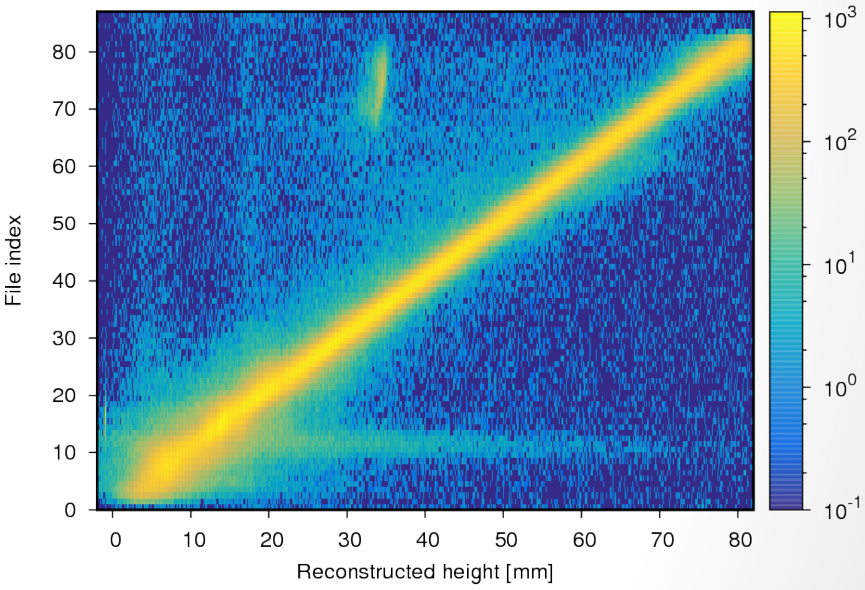
- ^{60}Co flood field measurement from the front of the crystal show fairly uniform illumination of crystal after *r* reconstruction (for a given φ)
- Minimal artifacts are observed – some intensity dips at longitudinal segment boundaries, likely due to charge sharing events dominating in those regions (not yet treated fully)



Depth (z) Reconstruction

- With φ and r reconstruction, determination of z is 'simply' a look-up table to map drift time to depth
- Challenges near the PC arise due to double-valued z vs drift time relationship





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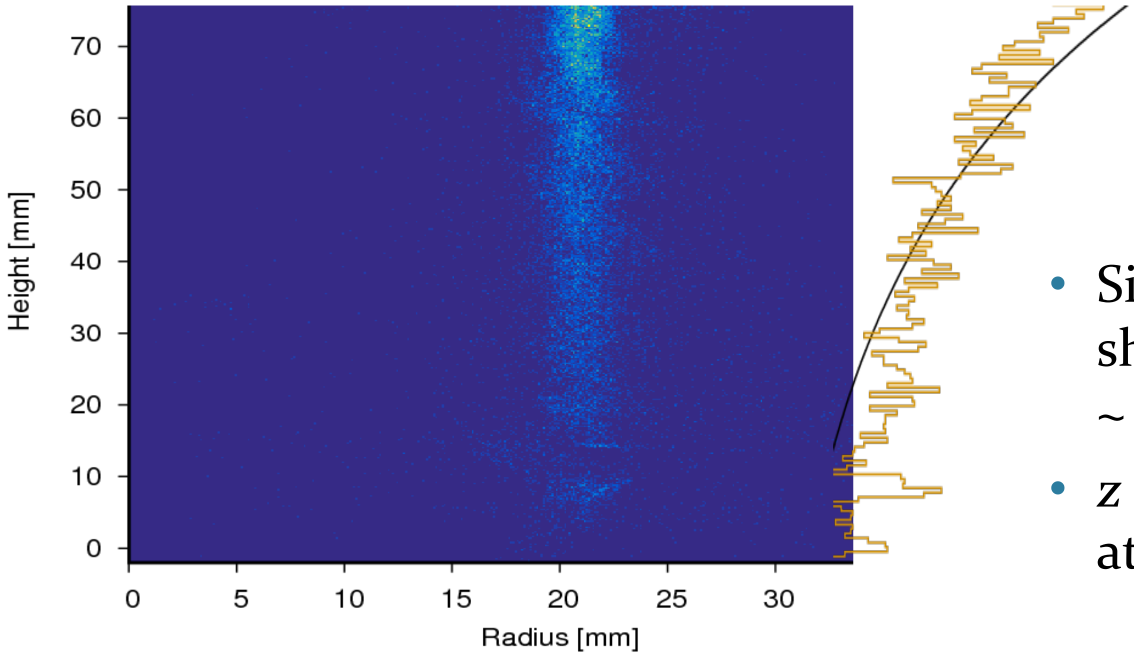
Pencil Beams: Attenuation in HPGe

- Overall position reconstruction approach is well-understood
- Performance for single-site interactions is good – better than 1 mm in φ, of order 1 mm in r, z from scanning results through most of crystal volume



- Single pencil beam shows *r* with FWHM of ~ 2.5-3 mm;
- *z* profile matches well attenuation length in Ge

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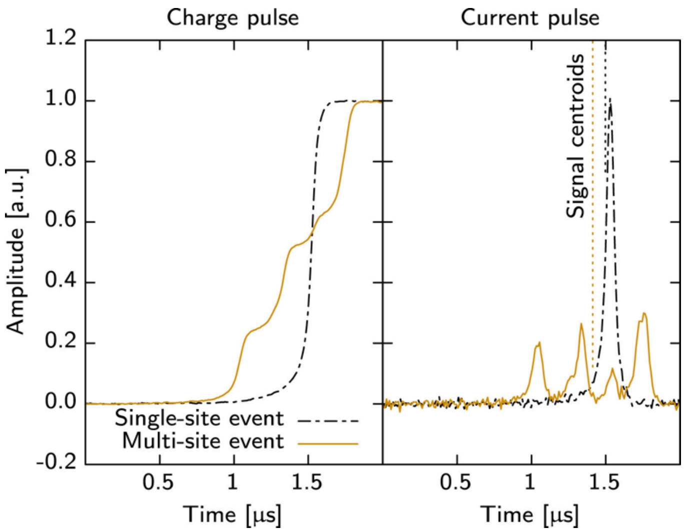
Next Steps Toward Full Signal Decomposition

- Main effort to date has been on single-site events (A/E cut, and segment multiplicity = 1)
- Next steps are to extend position reconstruction to include (a) charge sharing events and (b) multi-site events
  - Number of interactions will be constrained by point contact signal and number of net charge segments
  - Maintain azimuthal, and then *r* reconstruction approach, but iterate over solution(s) as multiple interactions are added
  - Add PC signal to the basis as additional constraint on χ^2 fit



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In-Beam Test of Position Resolution

- $^{84}Kr(^{12}C, 4n)^{92}Mo$ – ^{84}Kr at 395 MeV onto 45μg/cm² C target
- ^{92}Mo residues recoil at v/c ~ 0.09
- Doppler broadening is dominated by effective position resolution (opening angle)
- Placement of detector within ~6cm (at 90°) of target position allows measurement of position resolution with precision < 0.5 mm

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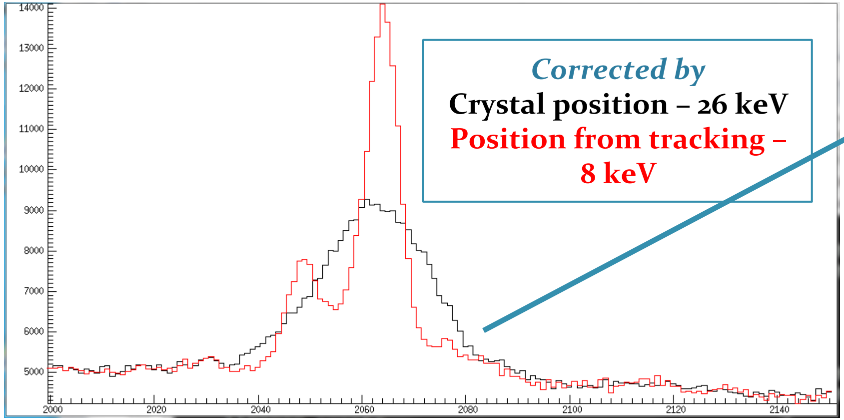

Corrected by
Crystal position – 26 keV
Position from tracking – 8 keV

Measurement performed for GRETINA engineering run – at 18 cm distance, σ = 2 mm in GRETINA translates to ~ 8keV FWHM for 2 MeV peak(s)

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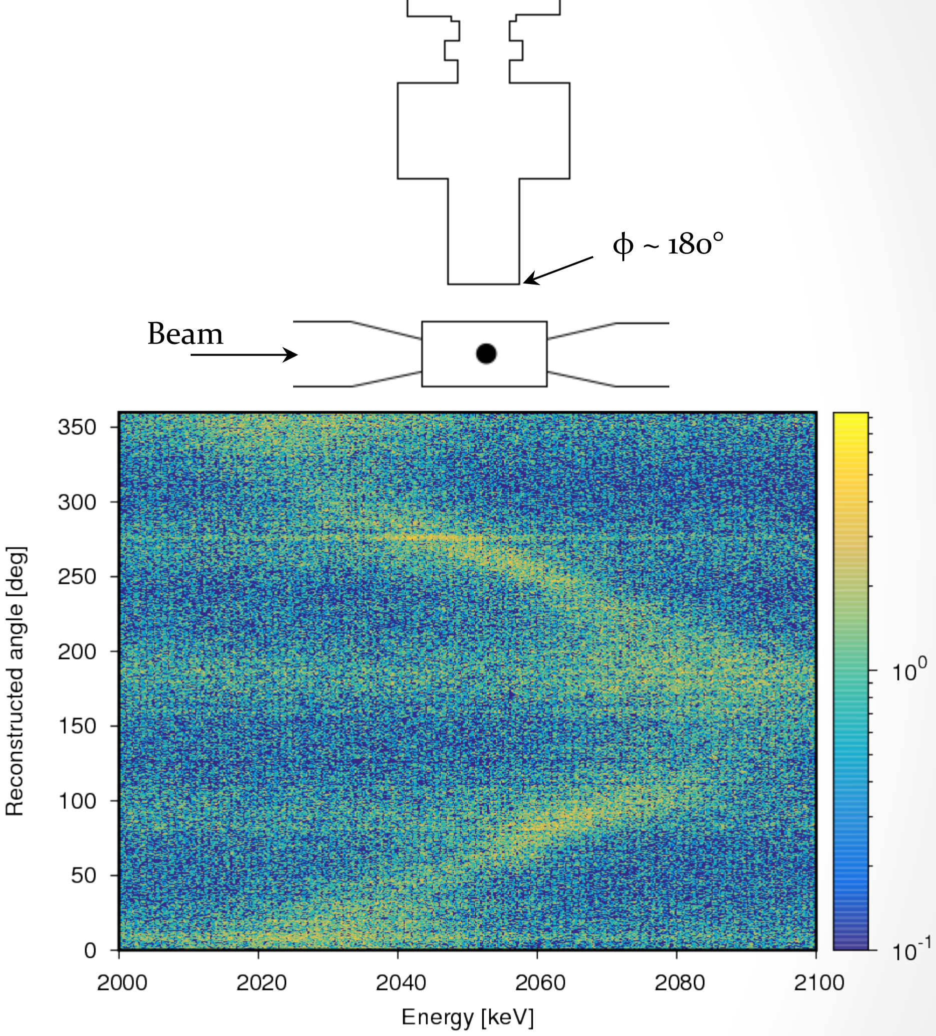
First Look…

- Point contact data nicely shows Doppler shift as a function of angle
- First attempt at reconstruction for single-site events gives ~ 12 keV FWHM for ICPC



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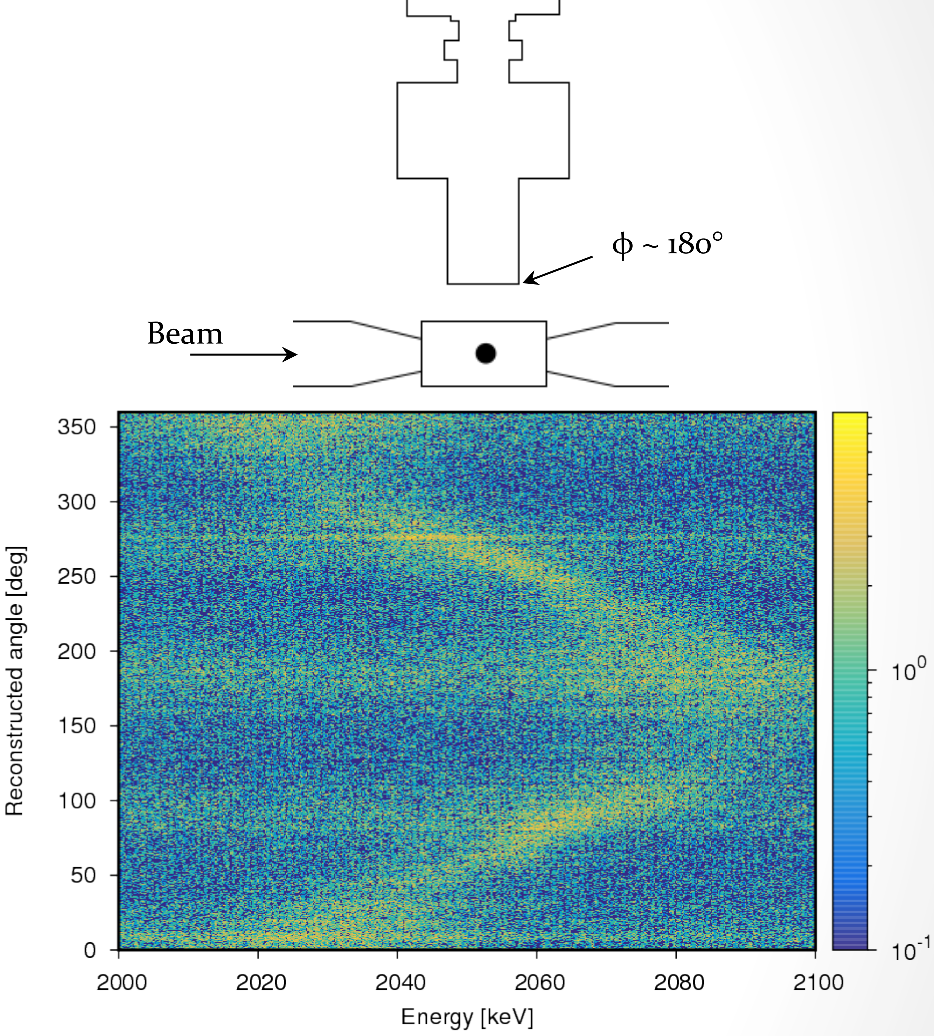
First Look…

- Point contact data nicely shows Doppler shift as a function of angle
- First attempt at reconstruction for single-site events gives ~ 12 keV FWHM for ICPC
- Scaling from previous results with GRETINA, ICPC position resolution is promising



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Summary

- n-type segmented ICPC prototype characterization measurements have been underway at LBNL for last 18 months
- Energy resolution after correction for position of interaction (primarily drift time and φ) has reached 3 keV at 1332 keV – resolution is recovered
- Full position (φ, r and z) reconstruction for single-site events has been achieved with promising first results
- Next steps toward complete signal decomposition are understood
- In-beam characterization data is also available, promising results thus far… stay tuned!

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Acknowledgements

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Energy reconstruction of an n-type segmented inverted coaxial point-contact HPGe detector

CrossMark

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Thank you!

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Backup

Drift Time – Simulation vs. Experiment