Status and expected performance of the SIGMA detector

Jonathan Wright
University of Liverpool

Outline

- Introduction / motivation
- SIGMA design
- Fields / charge transport models
- Drift time distributions
- Position sensitivity study
- Summary

Introduction

High performance γ-ray tracking and imaging detector

Excellent energy resolution especially at low energies

SIGMA

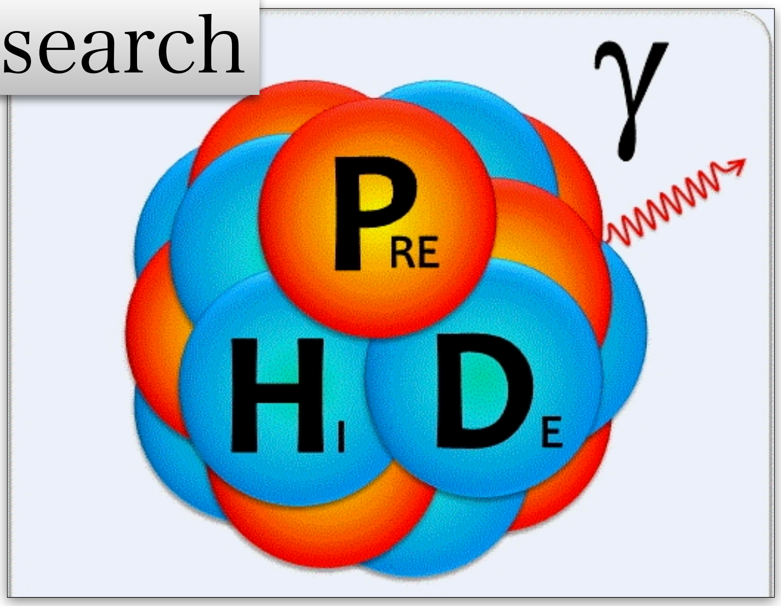
The **S**egmented **I**nverted-coaxial **G**er**MA**nium Detector

State-of-the-art position sensitivity

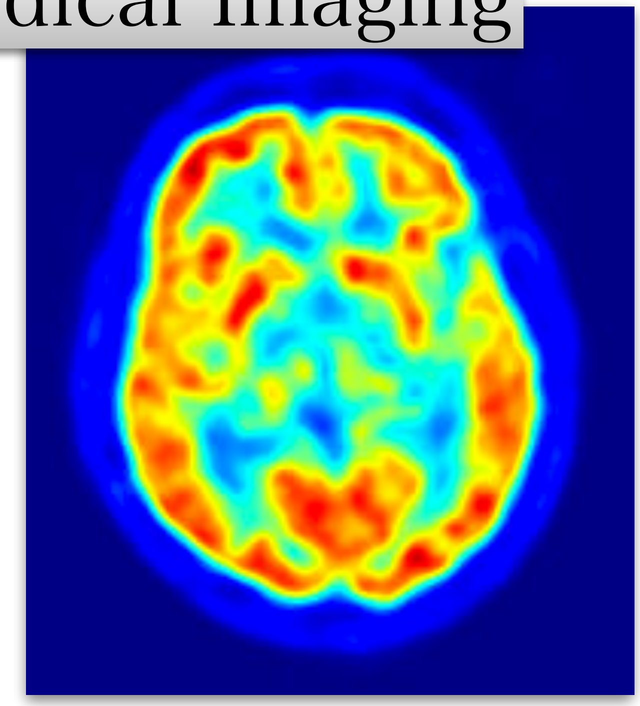
Large volume, high efficiency HPGe detector

Applications

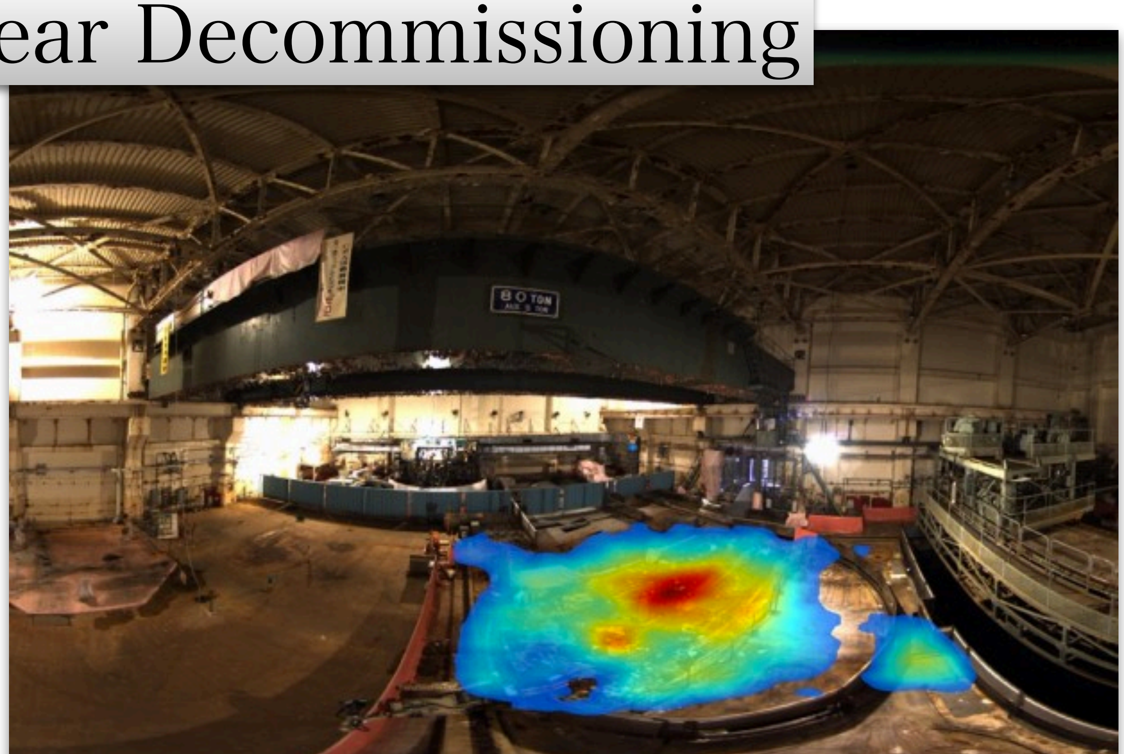
Research



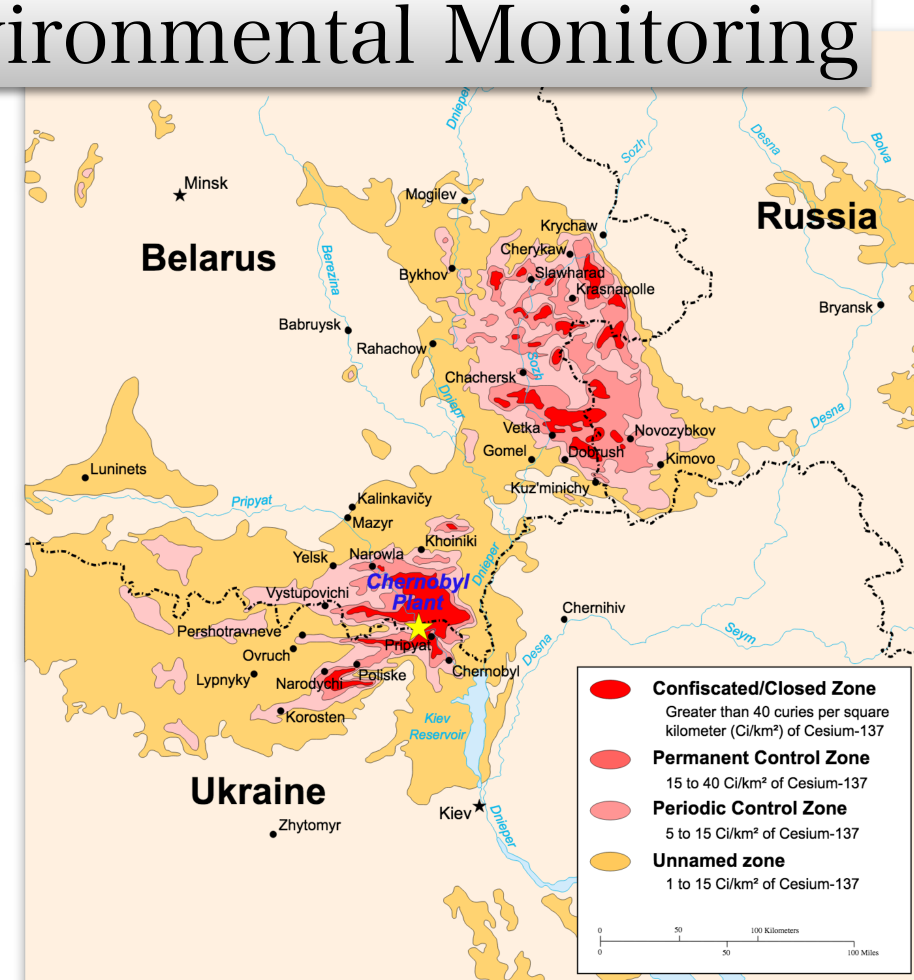
Medical Imaging



Nuclear Decommissioning



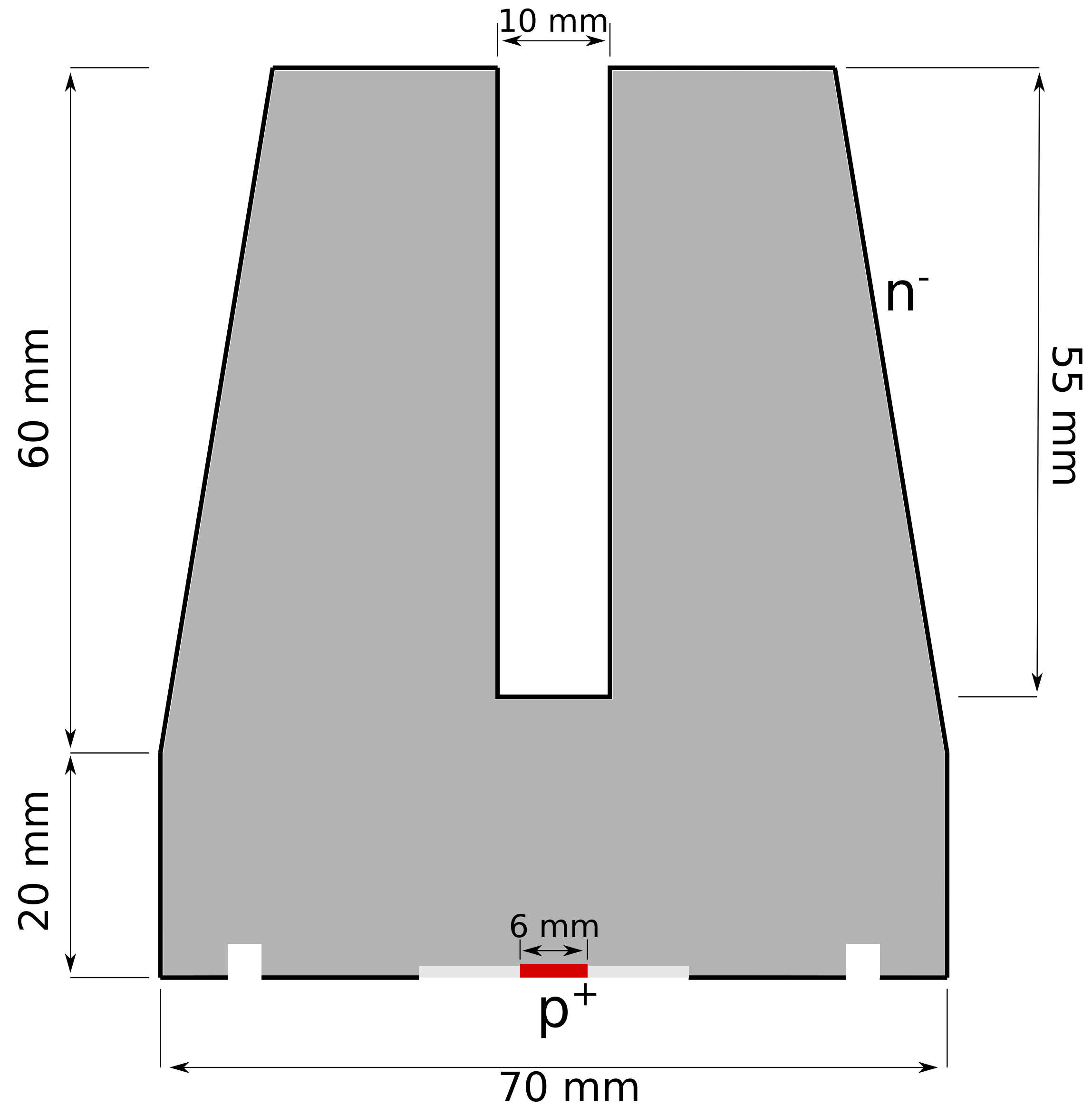
Environmental Monitoring



SIGMA Design

Detector Design

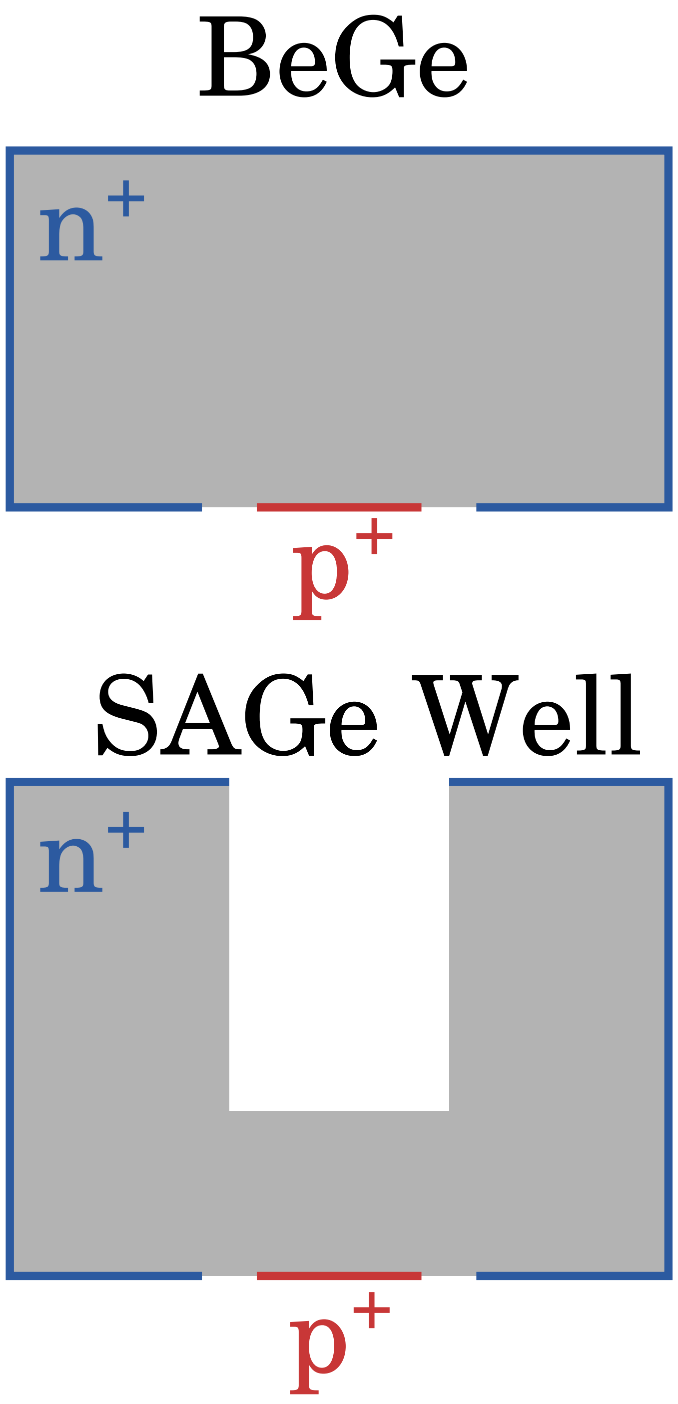
- P-type germanium inverted-coaxial detector
- N-type being investigated by LBNL/ORNL *
- Point contact technology
- Currently being manufactured by MIRION



* M. Salathe et. al, Nucl. Instr. Meth. A 868 (2017) 19-26

Point Contact Technology

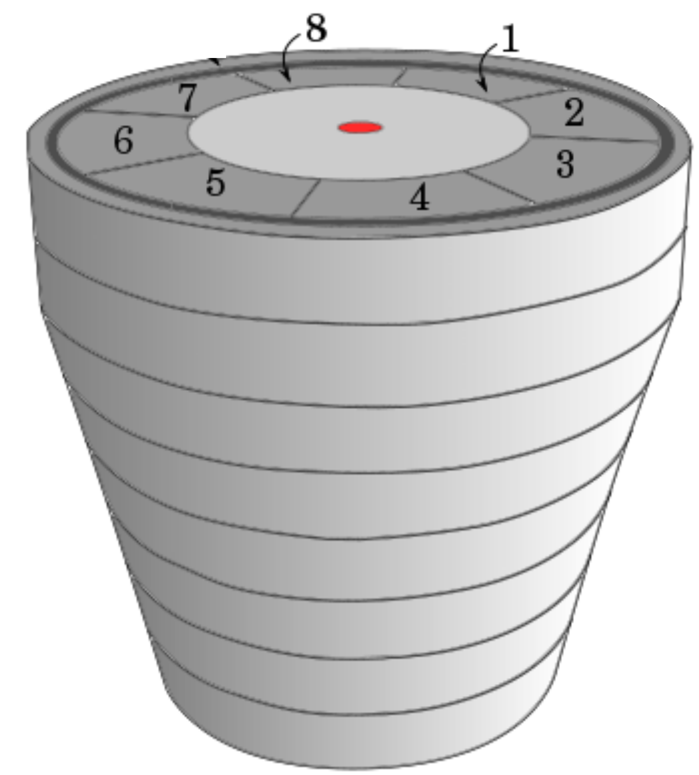
- Small, point-like contact with wrap around outer contact
- Low capacitance (~1 pF) due to small physical size of point-like contact
- Low C ⇒ low noise ⇒ improved ΔE
    - ~0.5 keV at E_γ = 122 keV*
    - 1.6 keV at E_γ = 1332 keV*
- Examples ⇒ BeGe, SAGe-well, etc

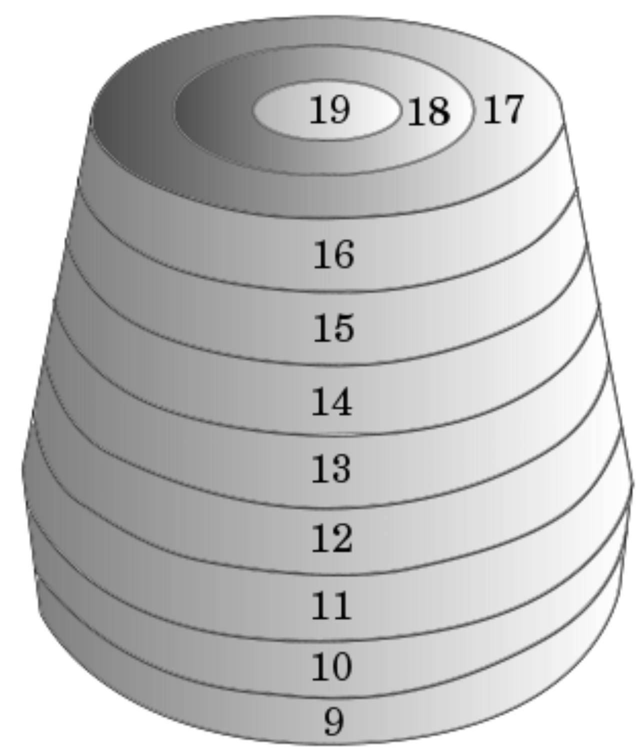


* L.J. Harkness-Brennan et. al, Nucl. Instr. Meth. A 760 (2014) 28-39

Segmentation Scheme

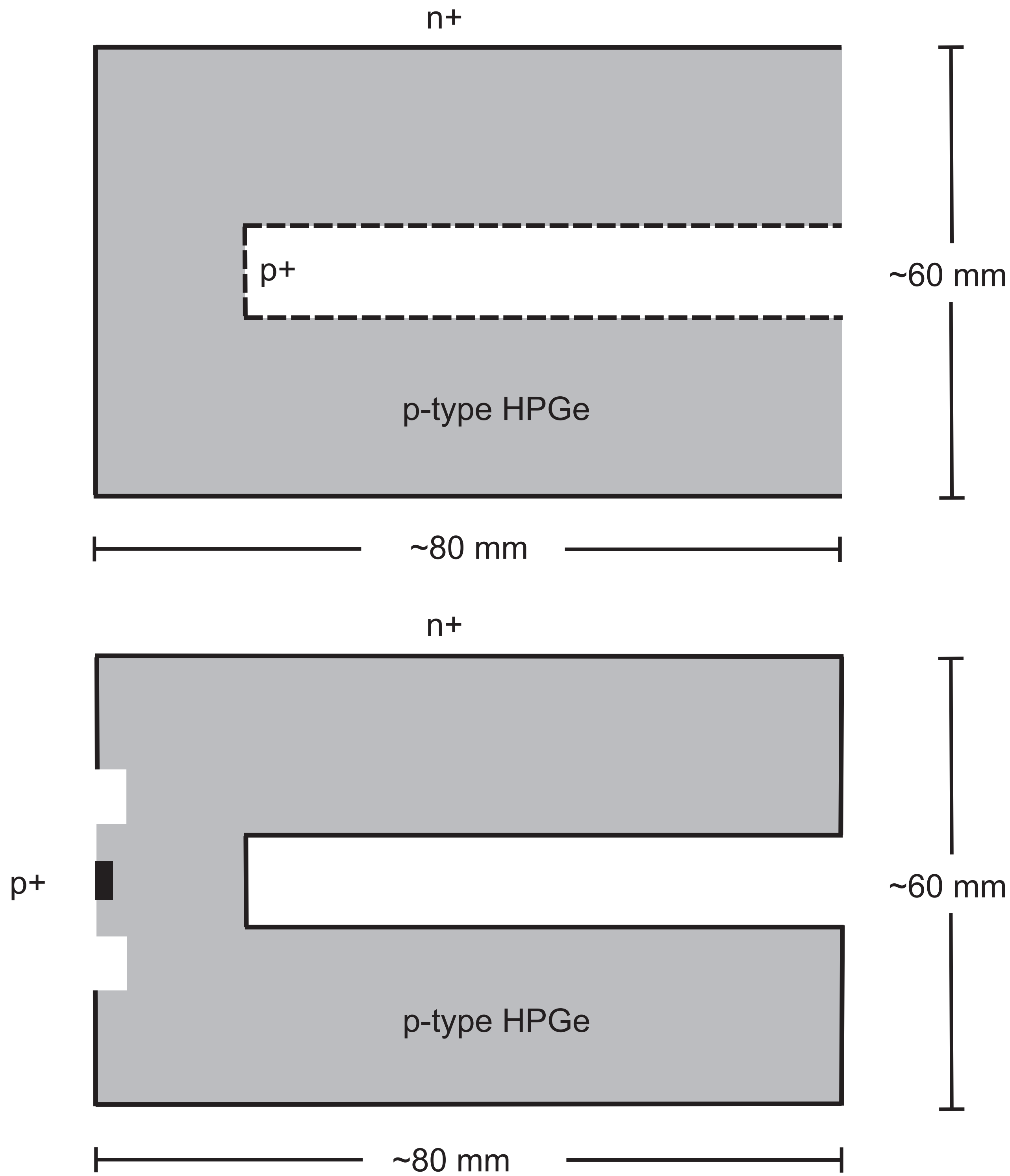
- 19 segments with 20 signals per event
  - Fewer digital readouts than current tracking detectors (AGATA, GRETA)
- 8 azimuthal segments (1-8) ⇒ φ resolution
- 8 longitudinal rings (8-16) ⇒ z resolution
- 2 concentric segments (17, 18) ⇒ r resolution
- Core (19) and point contact (red)

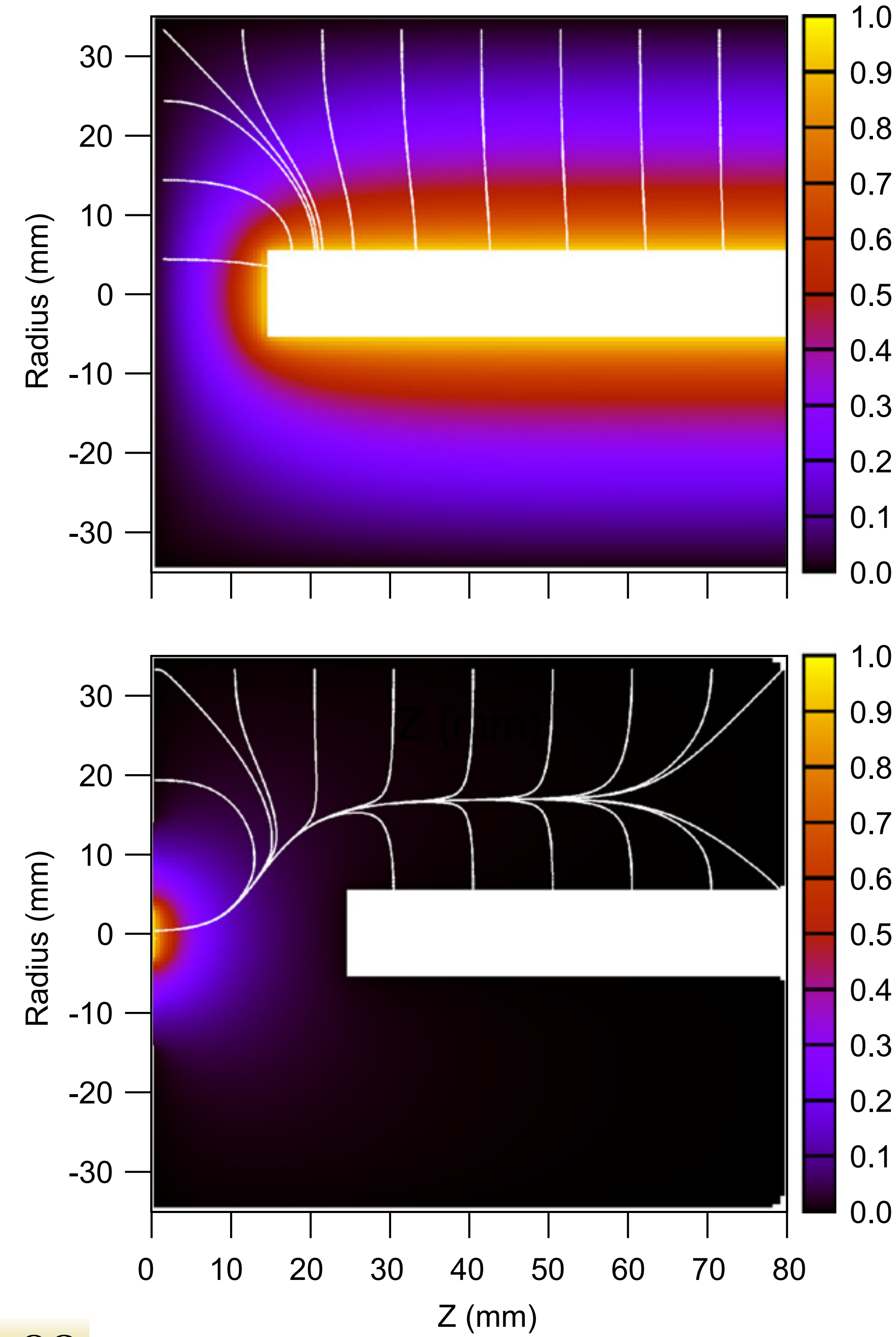




Inverted-coaxial

Much longer drift paths
⇒ increased drift
times upto 2 μs





* R.Cooper et. al, Nucl. Instr. Meth. A 665 (2011) 25-32

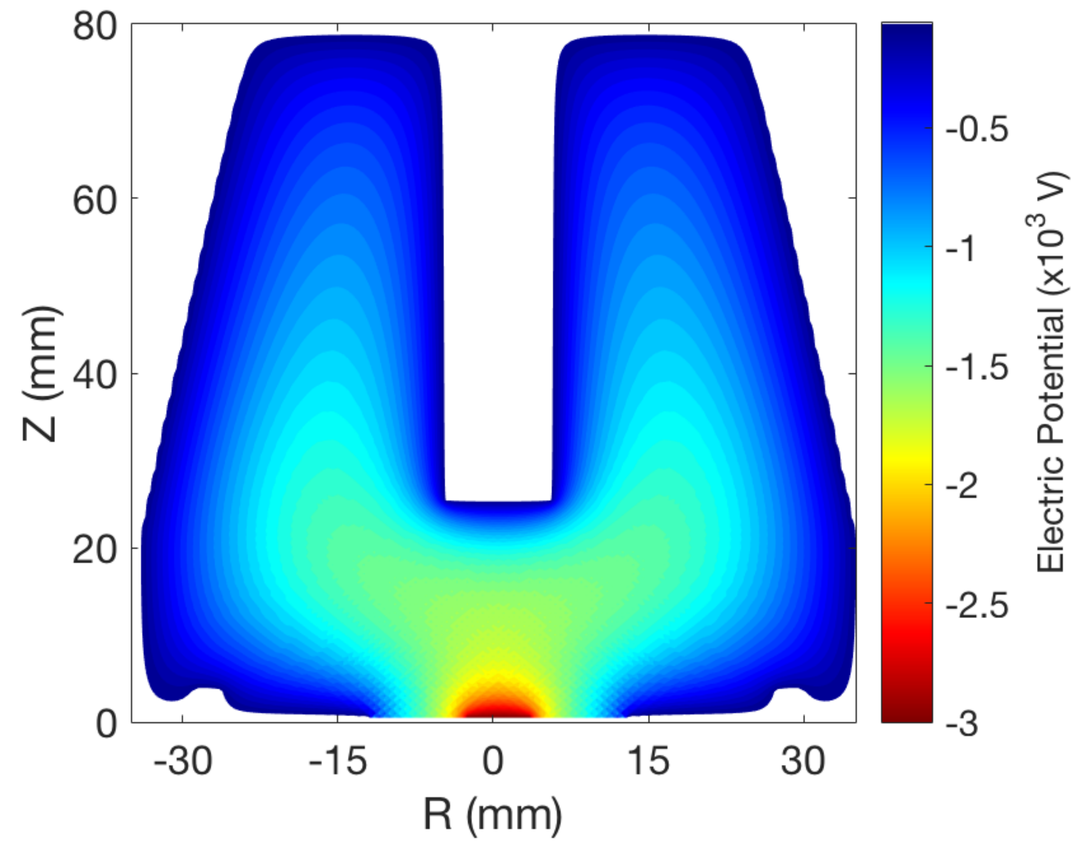
Field Simulations

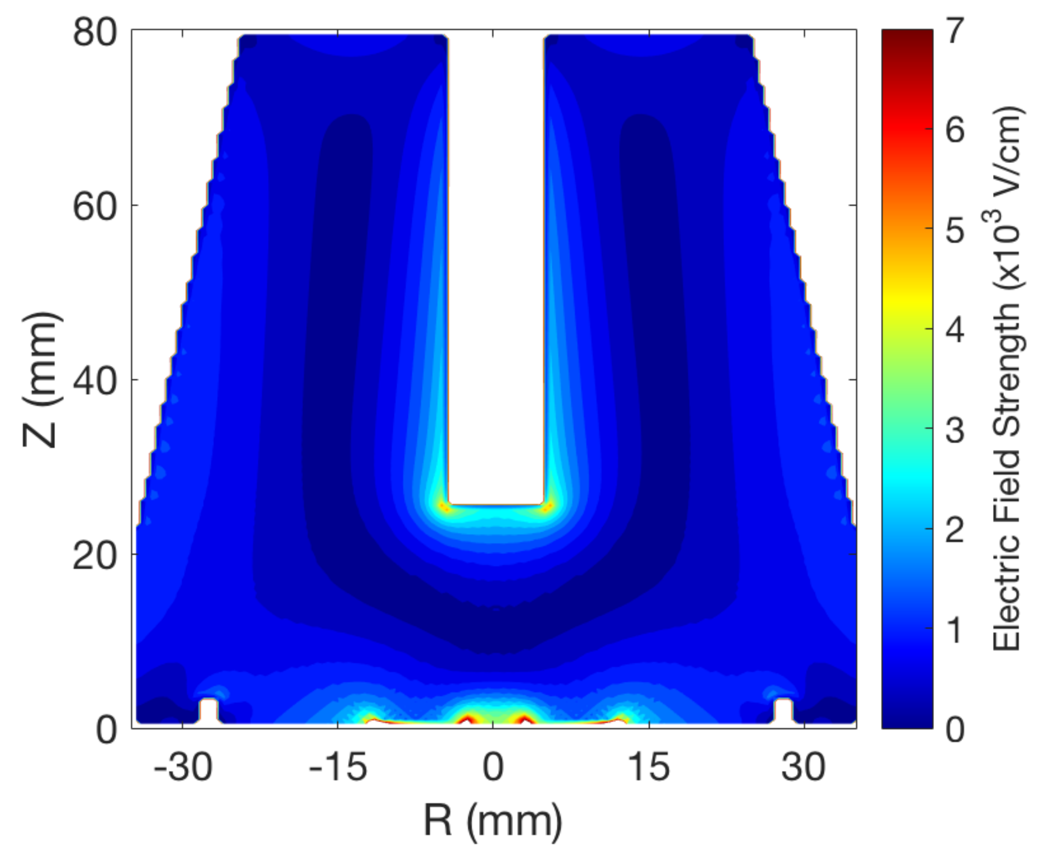
Field Simulations

- Electric field simulations done using an adaptation of the FieldGen software (ORNL)
- Fields calculated by solving the Poisson equation

$$\frac{d^2\Phi}{dx^2} + \frac{d^2\Phi}{dy^2} + \frac{d^2\Phi}{dz^2} = \frac{-\rho(x,y,z)}{\epsilon_0}$$

- Weak fields & long drift paths ⇒ long drift times to point contact



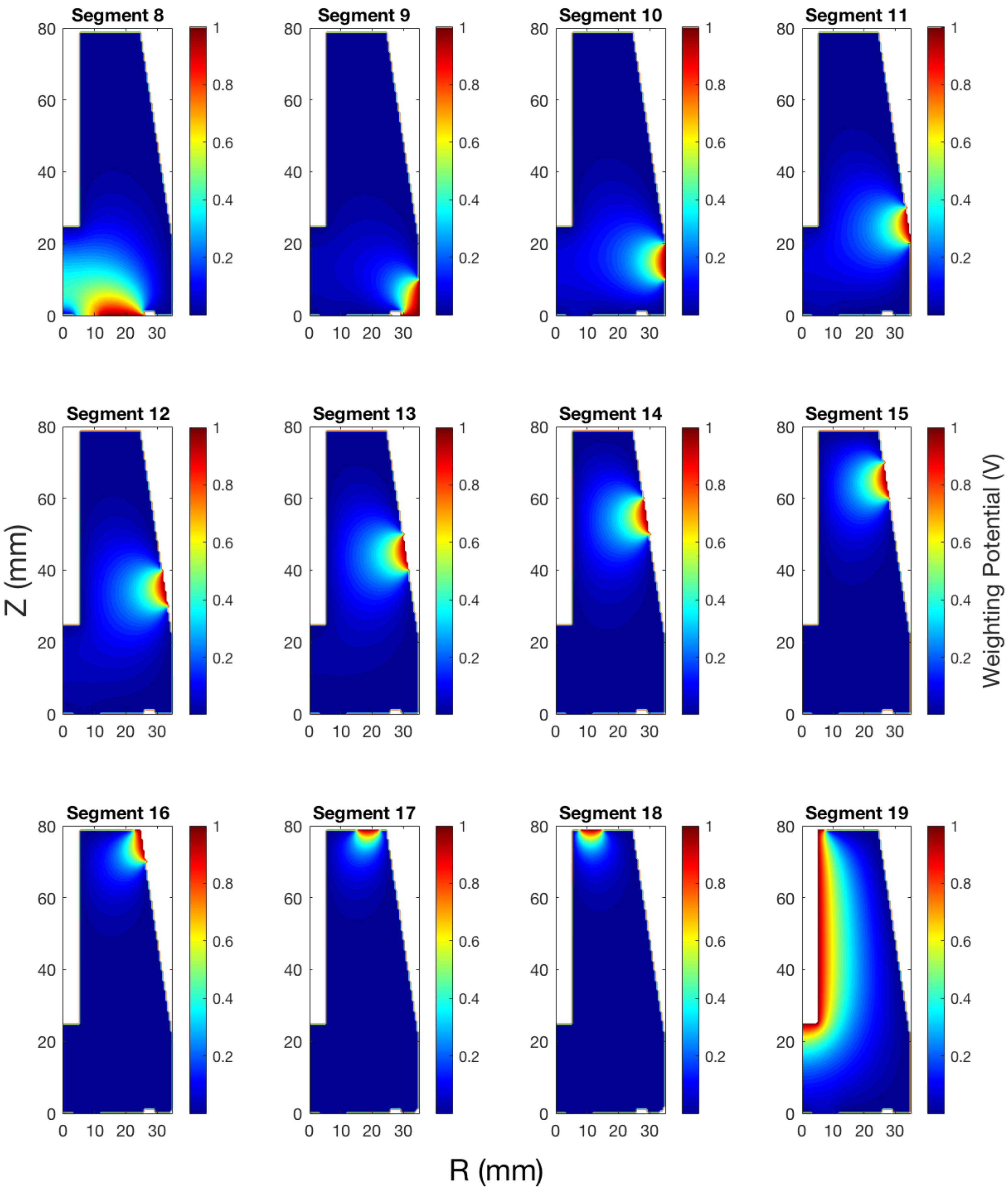


Weighting Potentials

- Shockley-Ramo theorem
- Voltage on electrode of interest set to 1 V
- All other electrodes set to 0 V

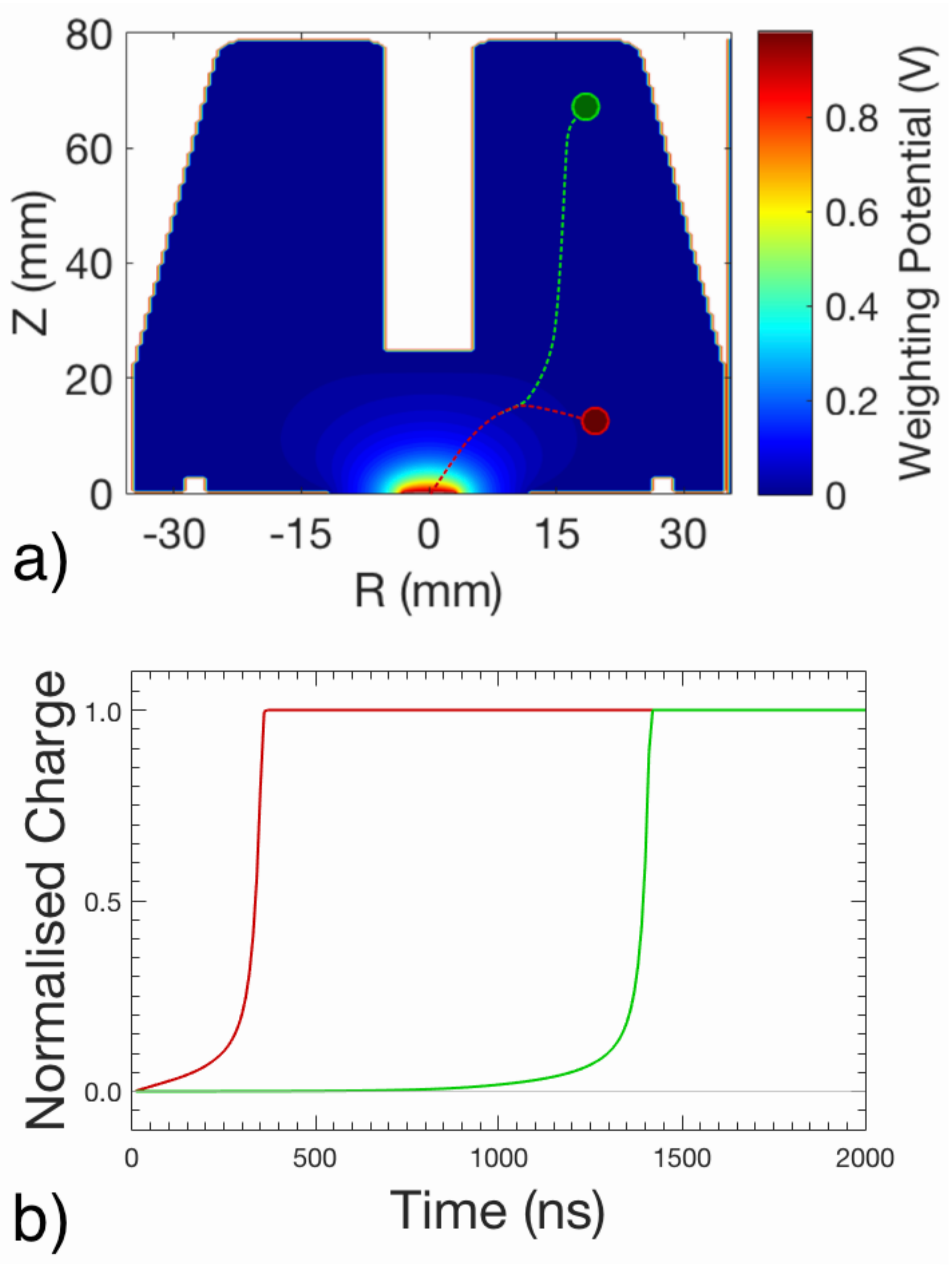
$$i = q\overrightarrow{v} \cdot \overrightarrow{E}$$

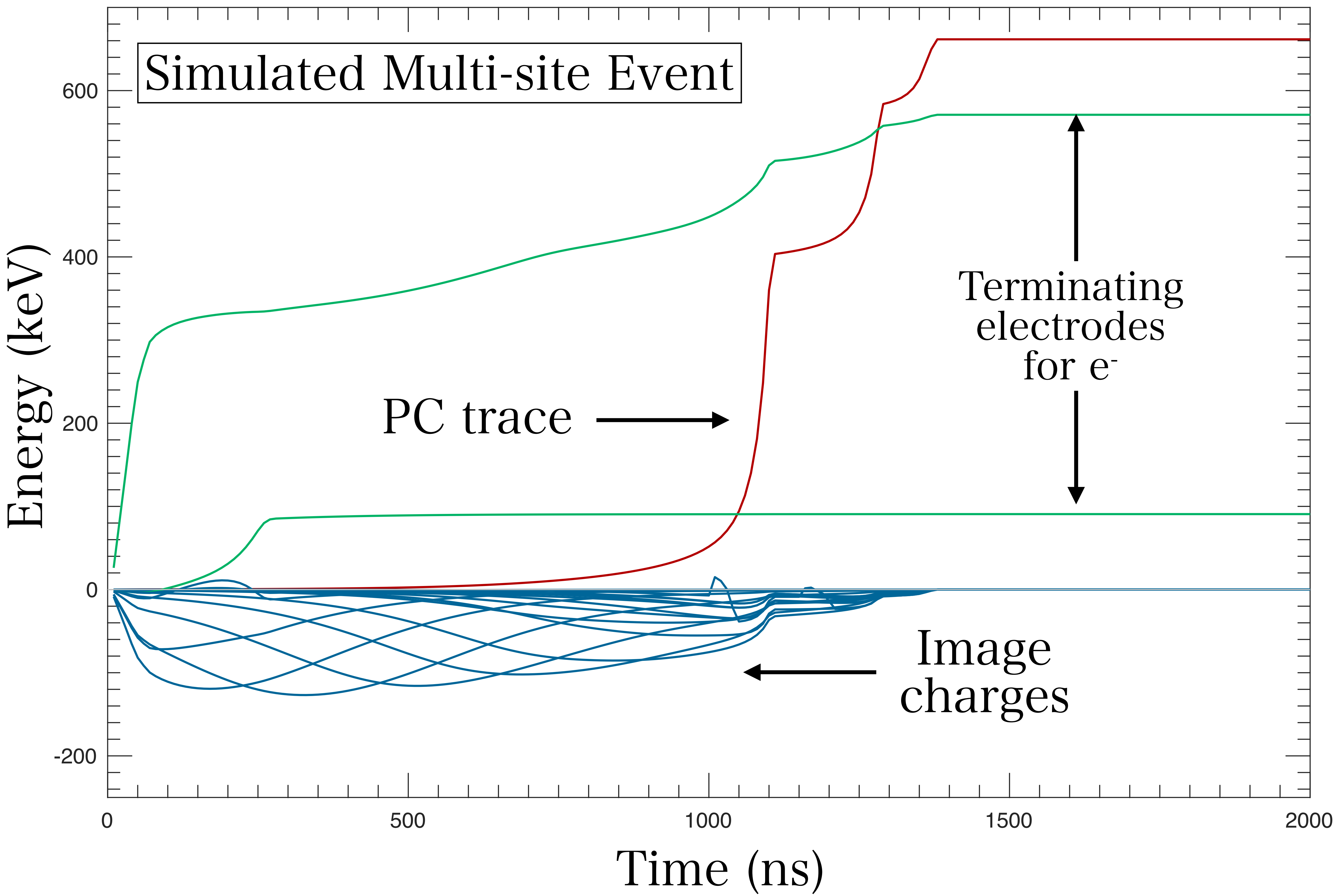
$$Q = q\Delta\varphi_0$$



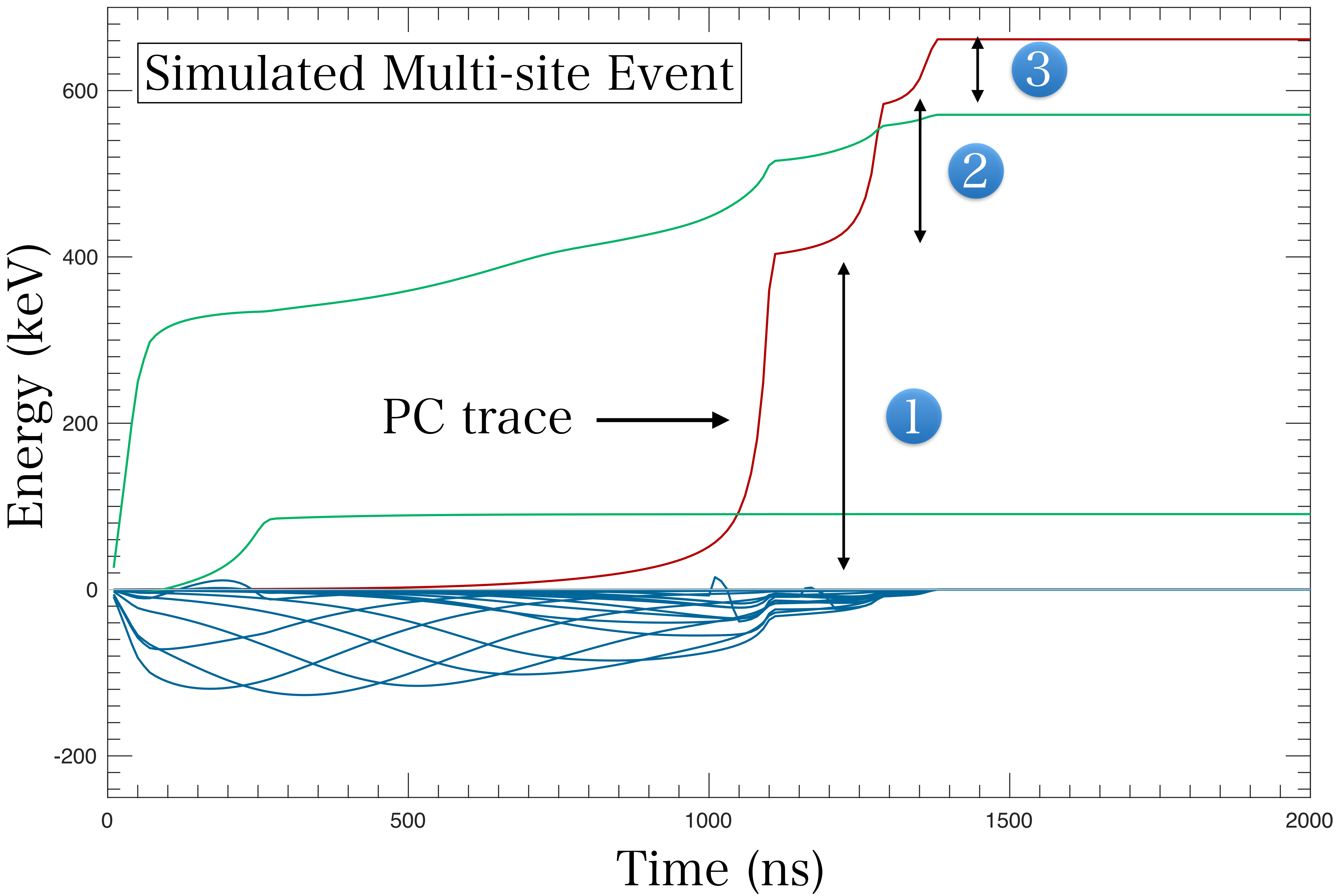
Charge Transport

- Charge transport calculated using adaptation of SigGen software (ORNL)
- Calculations account for polarity, temperature, crystallographic axis, crystal impurity, etc
- Short range field near point contact gives sharp rise in charge pulses
- Easy to distinguish multiple interactions

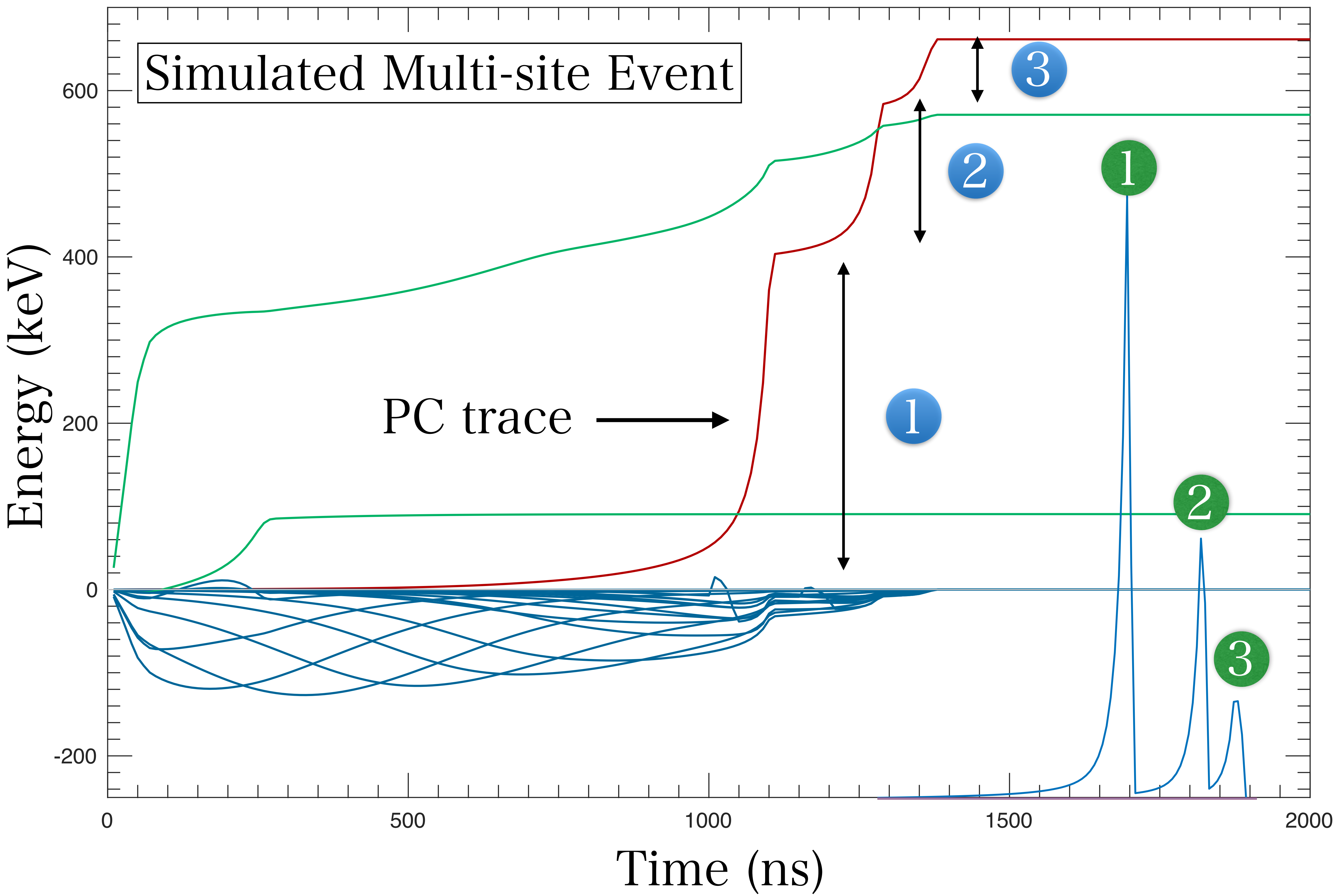




Simulated Multi-site Event
PC trace
Terminating electrodes for e-
Image charges
600
400
200
0
-200
0
500
1000
1500
2000
Energy (keV)
Time (ns)



Simulated Multi-site Event
PC trace
1
2
3
Energy (keV)
Time (ns)
600
400
200
0
-200
0
500
1000
1500
2000


Simulated Multi-site Event
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1
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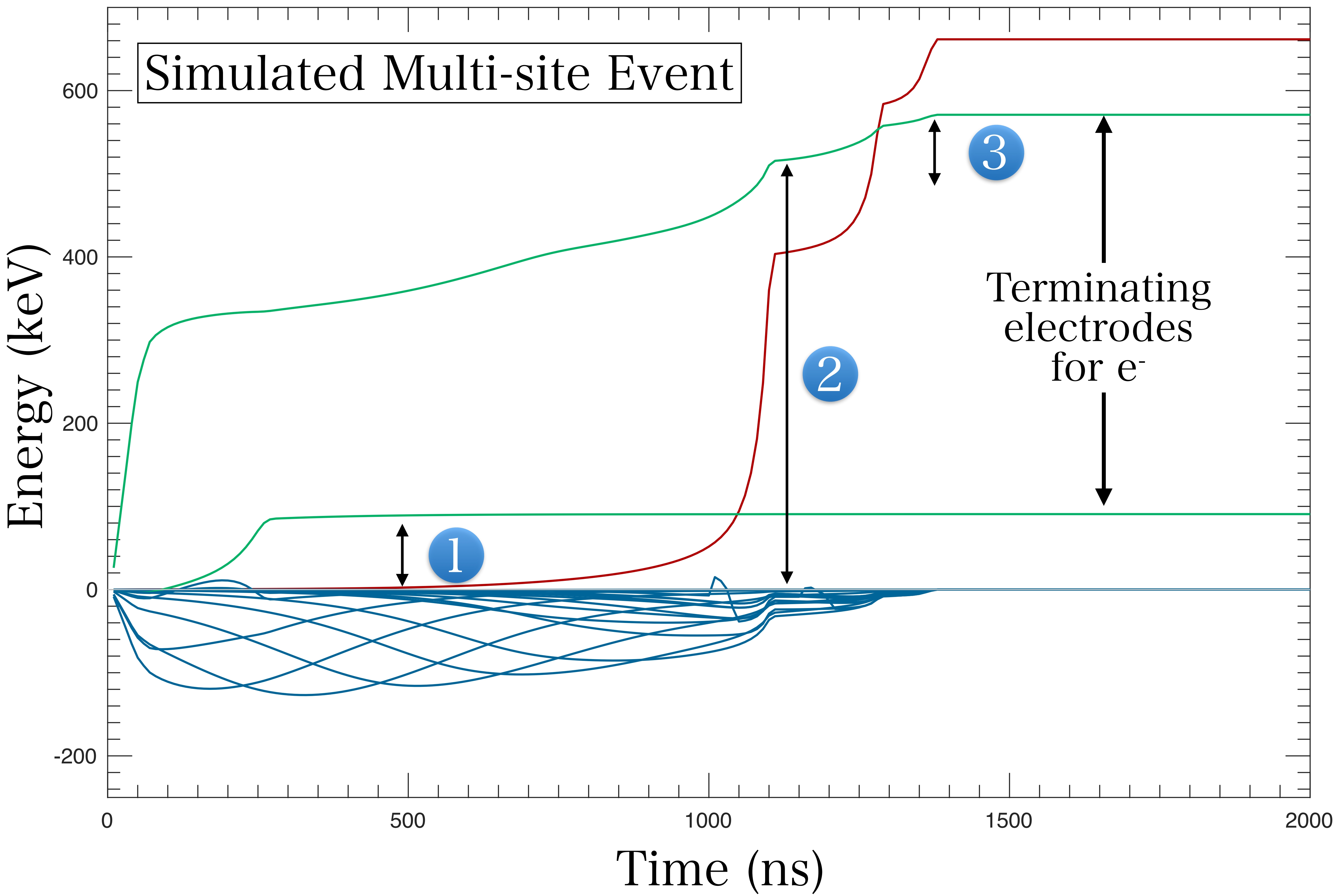
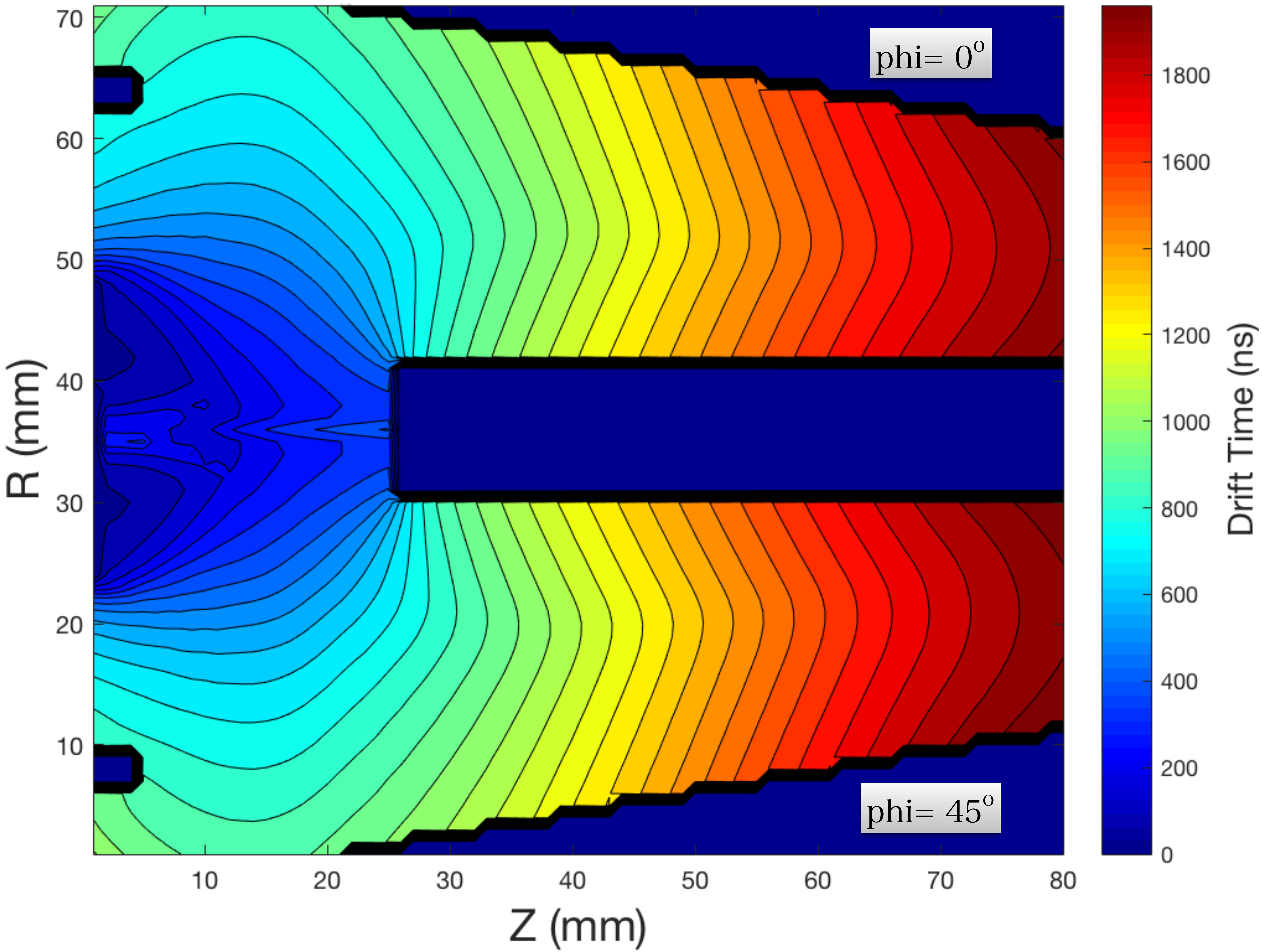
2000

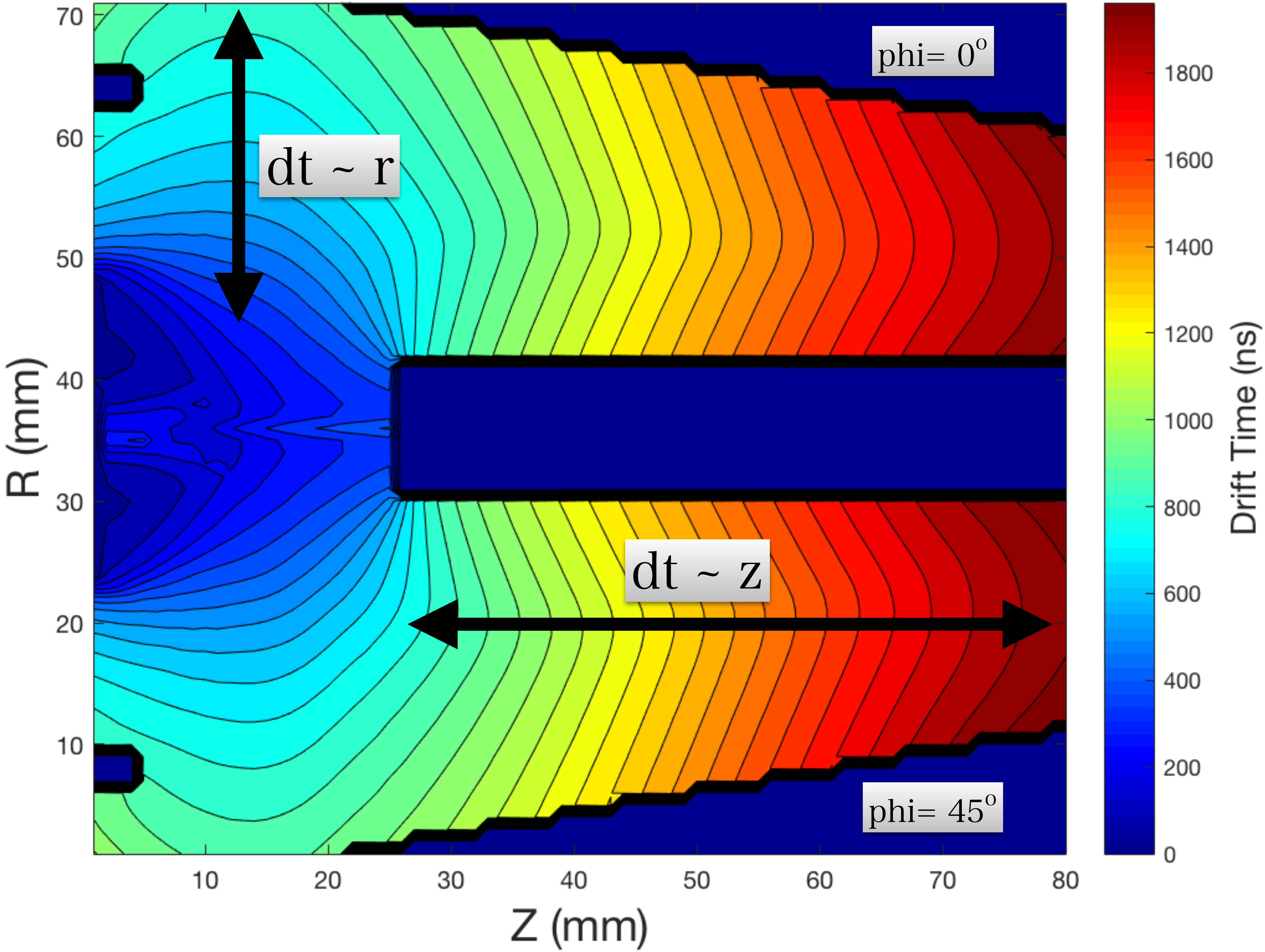


Simulated Multi-site Event
600
400
200
0
-200
Energy (keV)
0
500
1000
1500
2000
Time (ns)
1
2
3
Terminating electrodes for e-

Drift Time Distributions

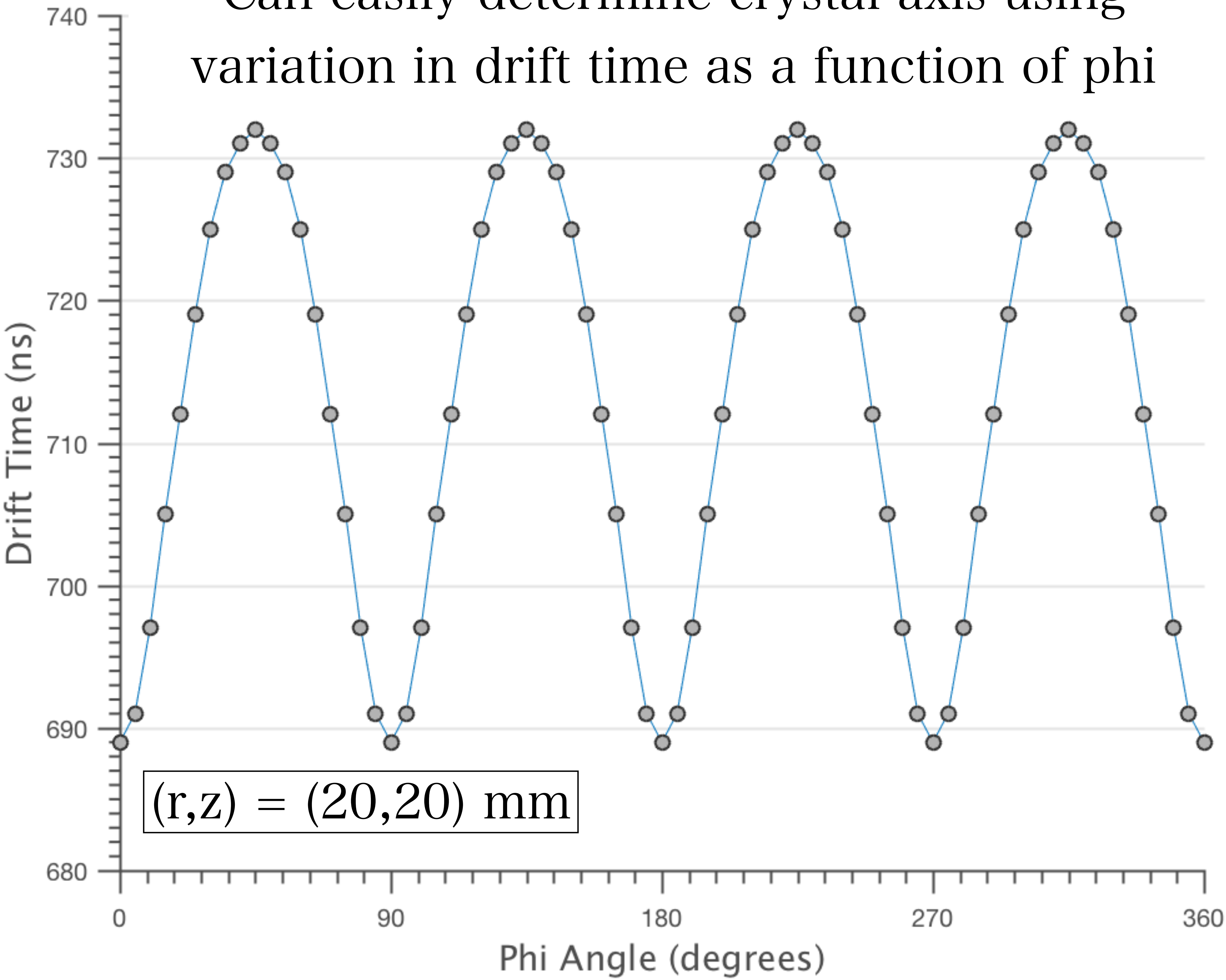


phi= 0°
phi= 45°
R (mm)
Z (mm)
Drift Time (ns)
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
1800

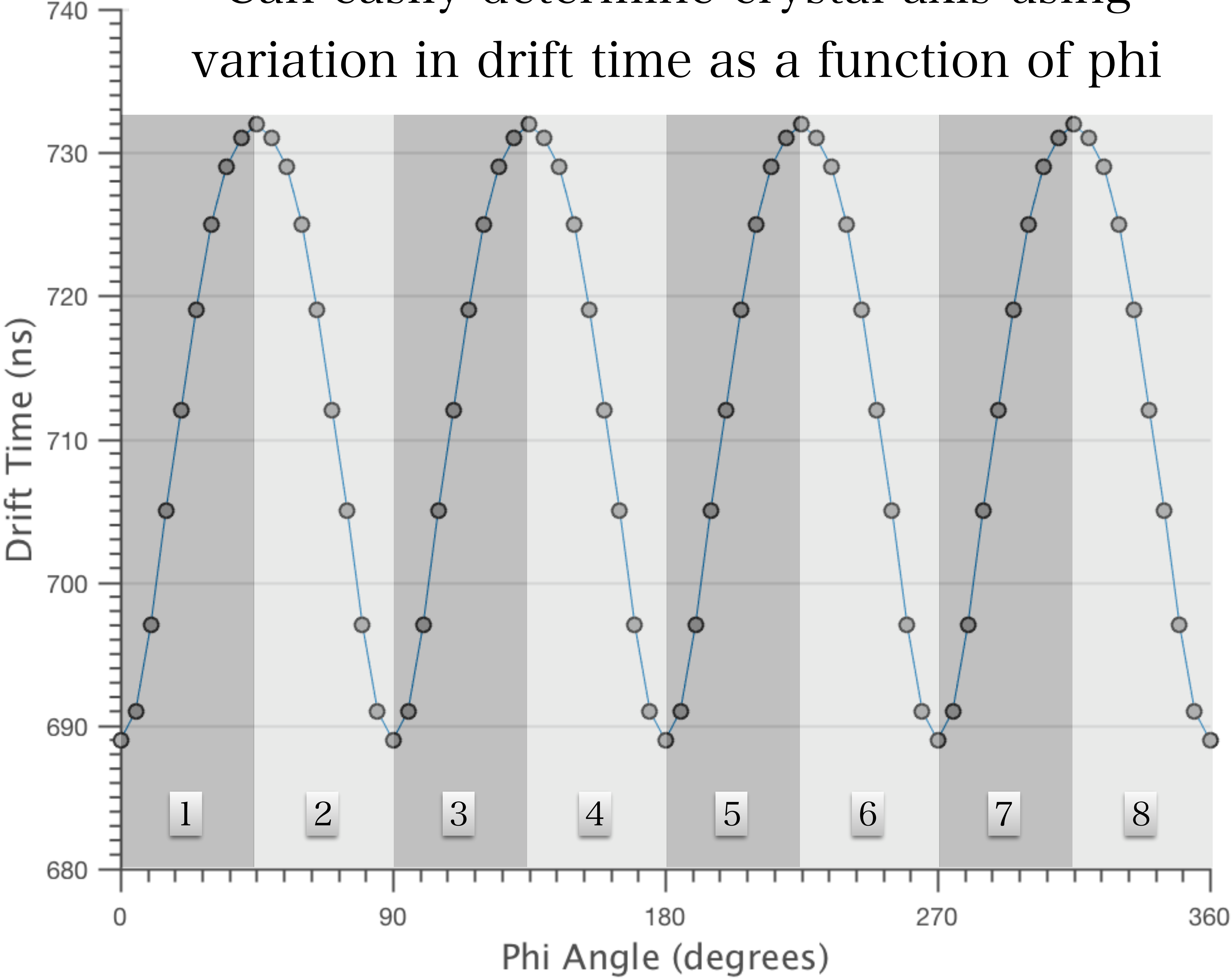


dt ~ r
dt ~ z
phi= 0°
phi= 45°
R (mm)
Z (mm)
Drift Time (ns)
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
1800

Can easily determine crystal axis using variation in drift time as a function of phi

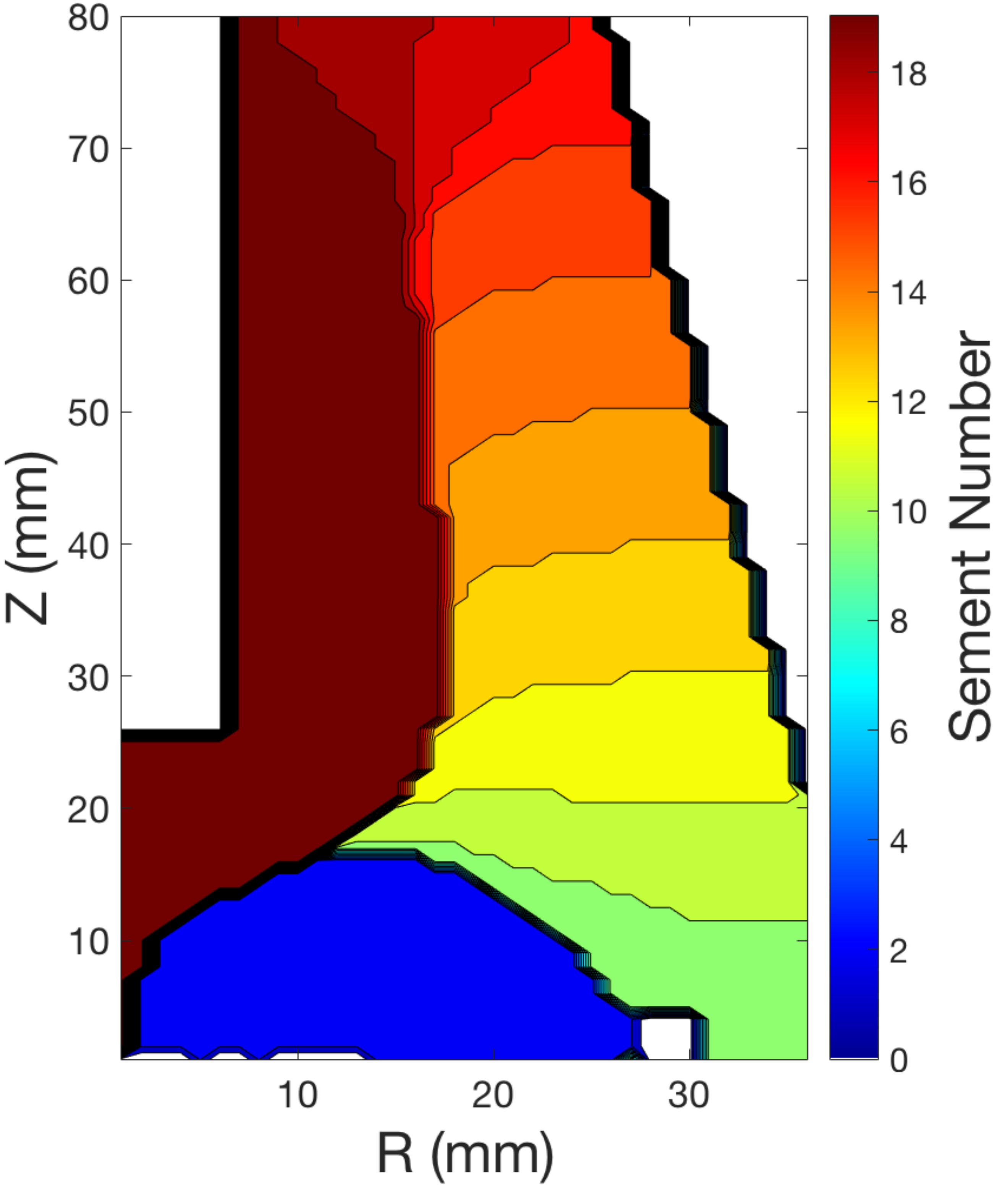


Can easily determine crystal axis using variation in drift time as a function of phi

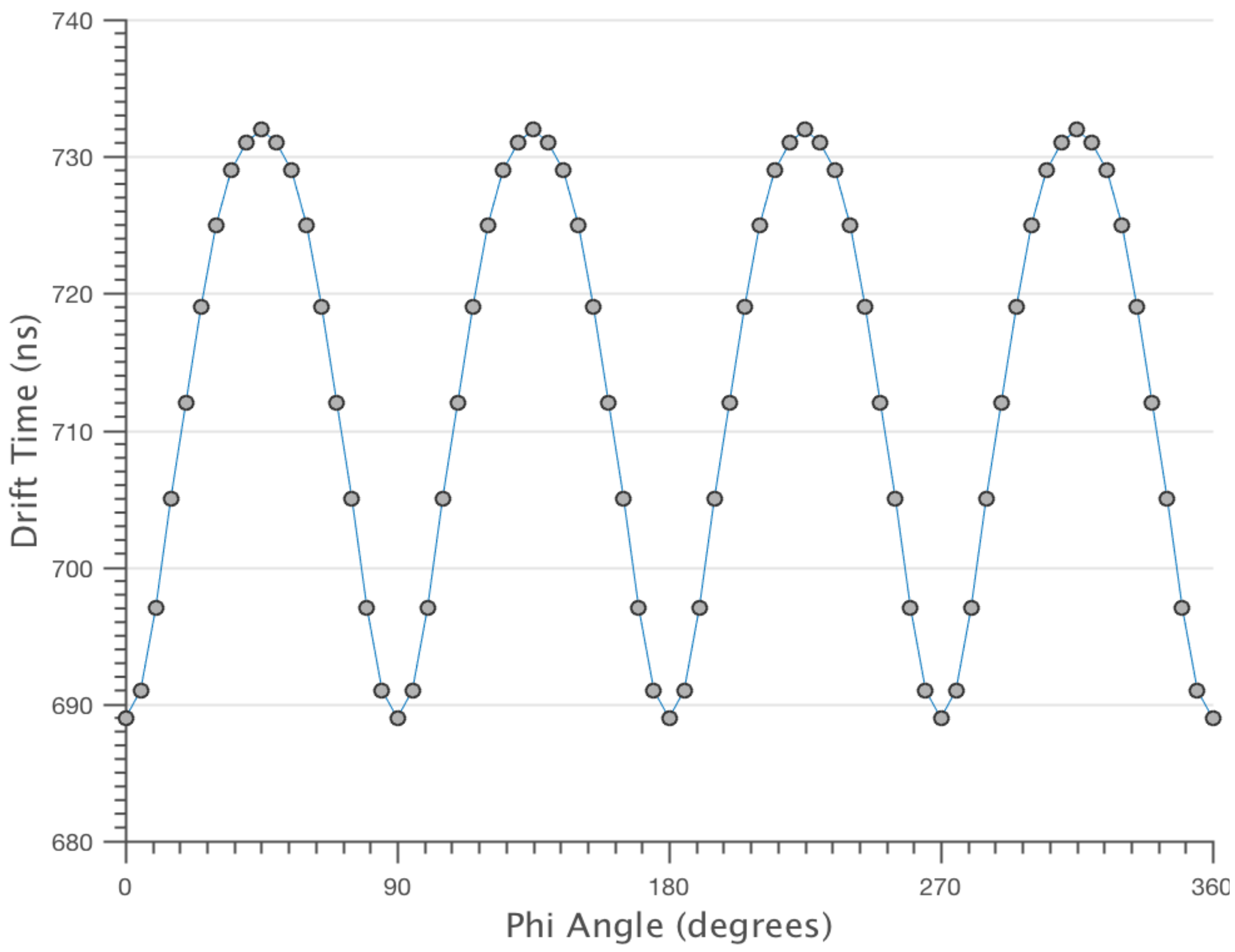


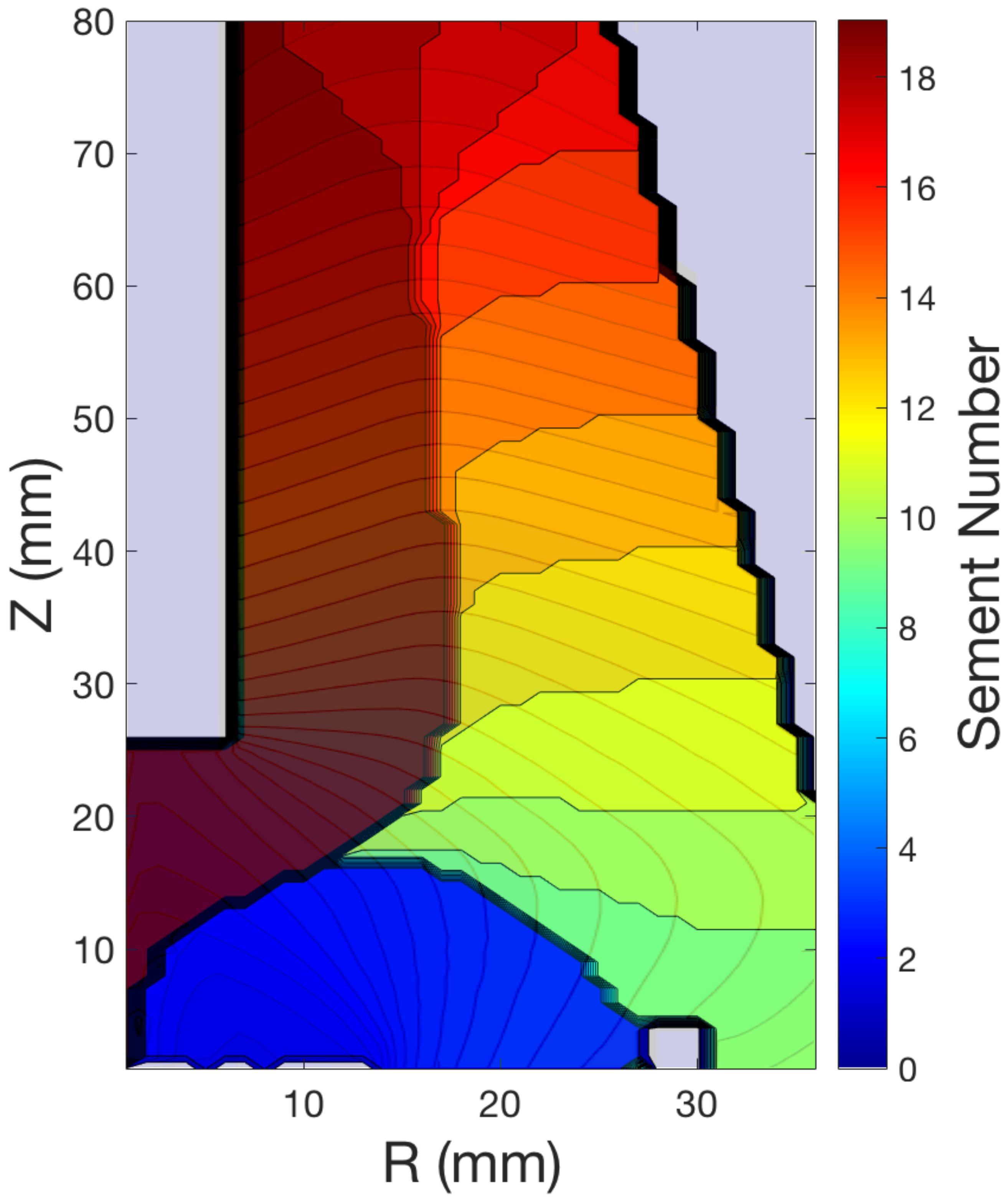
Drift Paths of Electrons

- Final terminating electrode of electrons as function of position
- Relative importance of each segment
- Gates on hit segment and drift time enable interaction positions to be localised to narrow region



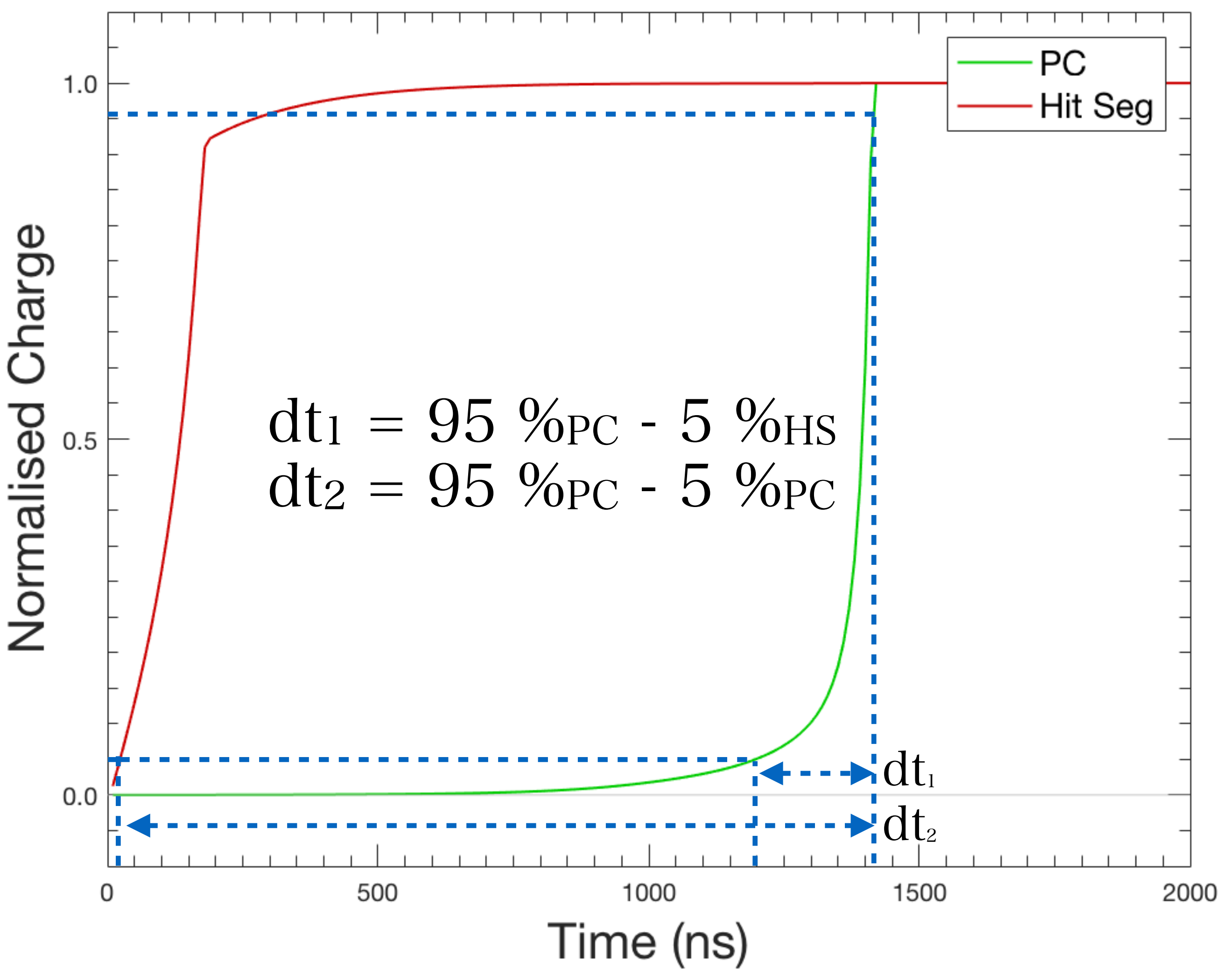
- Lots of information available from just studying the drift times





Drift time calculation

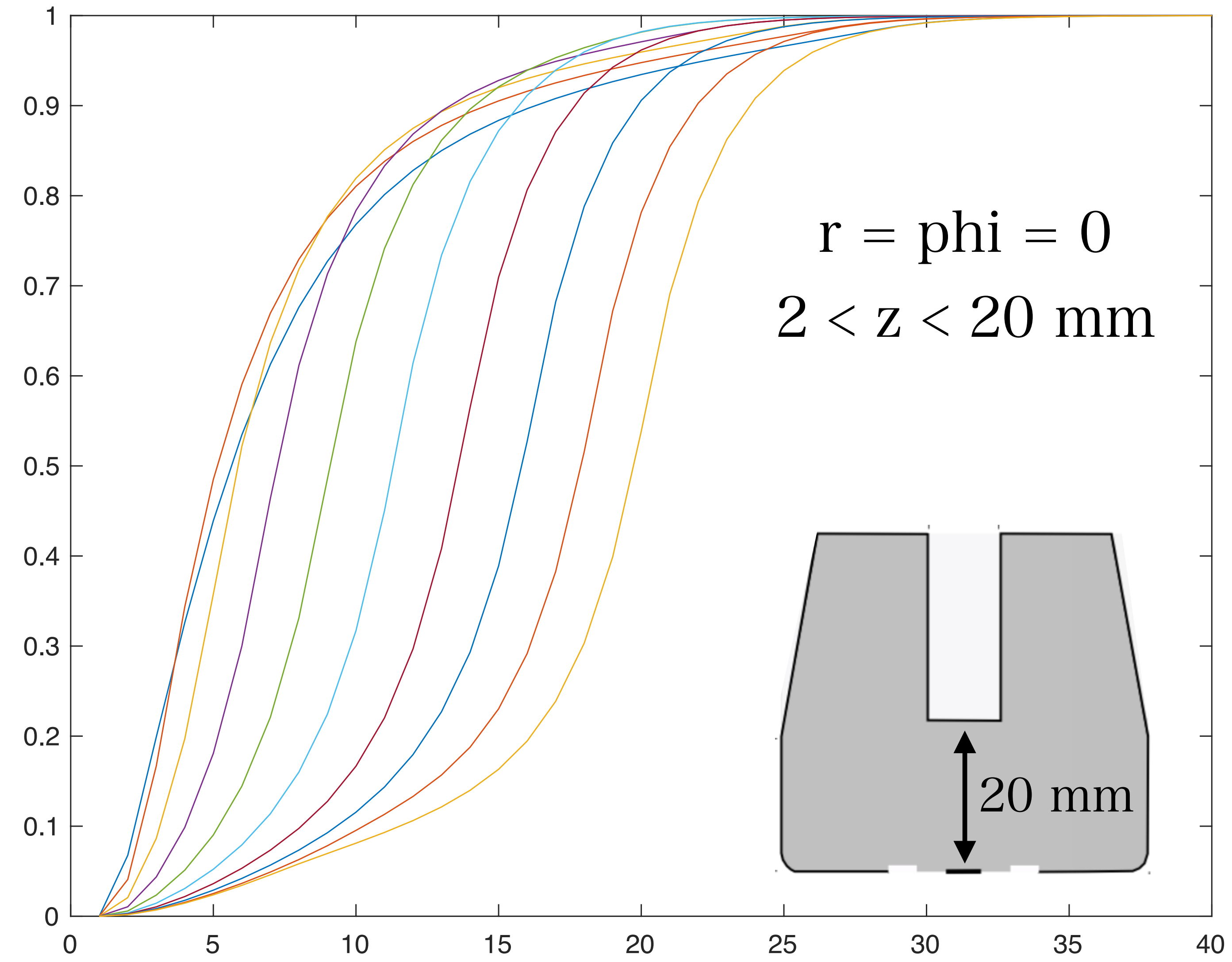
- Point contact trace flat for most of trace
- Hit segment rises early -> enabling better determination of t_0
- Drift time calculated as time from 5% of hit segment to 95% point contact
- These are preliminary limits, true limits will be tested when real detector arrives



Position Sensitivity Study

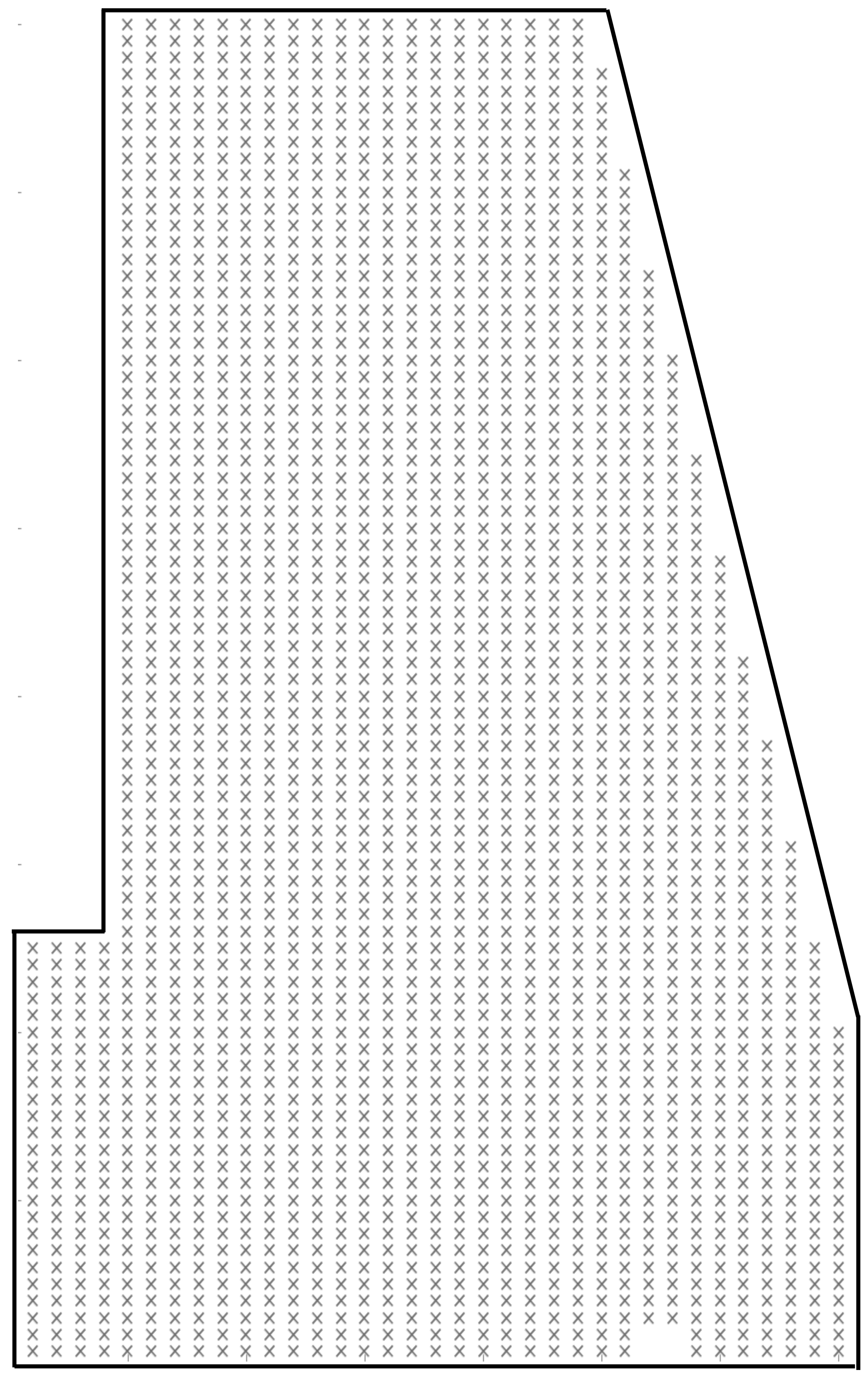
Pulse Shape Analysis

- Interactions occurring in different locations result in different charge pulses
- Comparing experimental pulses to a simulated database enables better position sensitivity



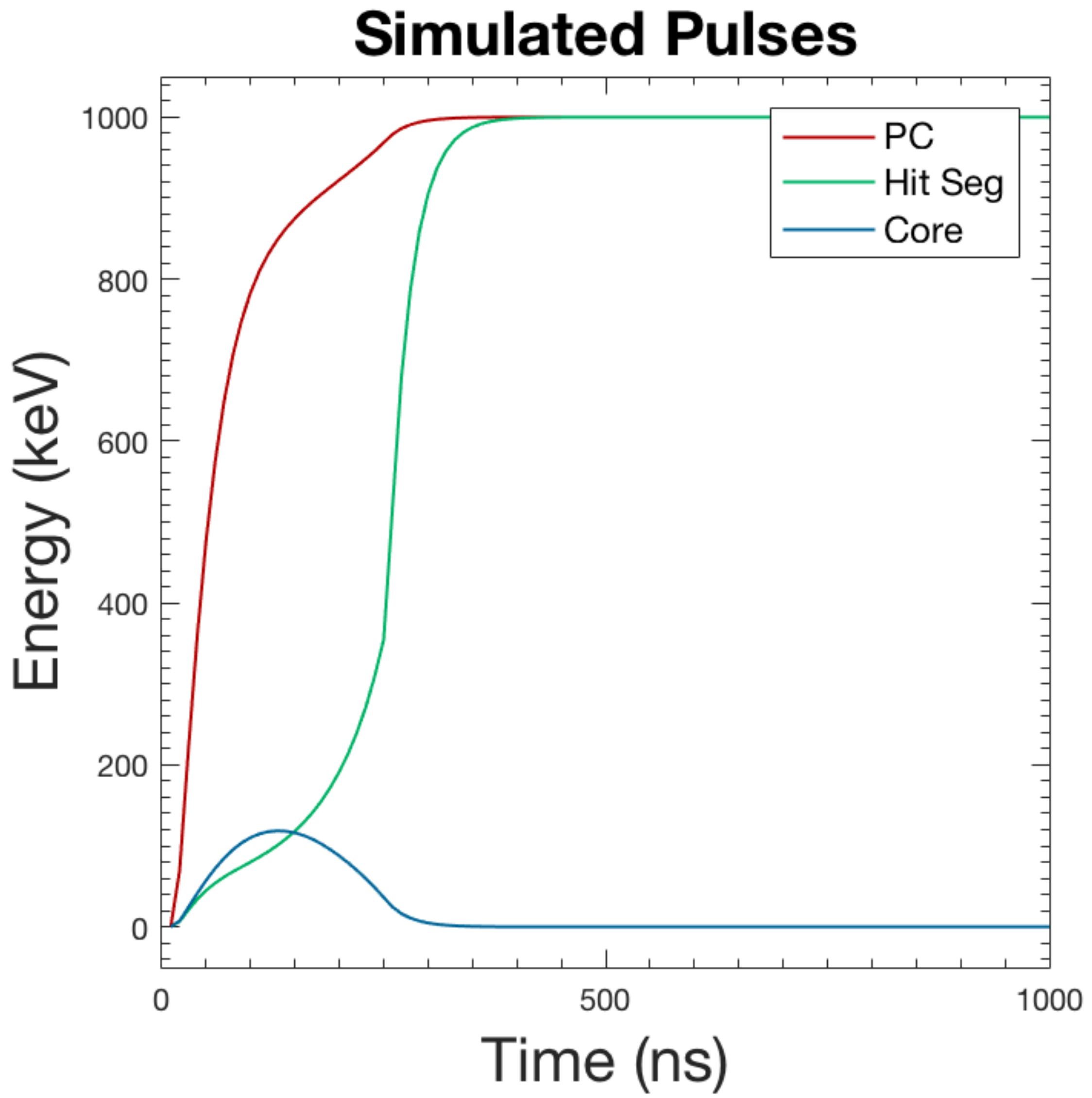
Pulse Shape Database

- Pulses generated for every position on a 1 mm x 1 mm x 3 degree grid
- 200 x 10 ns samples per pulse
- Data output at each position contains
  - 20 pulses
  - Drift times
  - x,y,z & r,phi,z coords
  - Hit segment number



Position Resolution Study

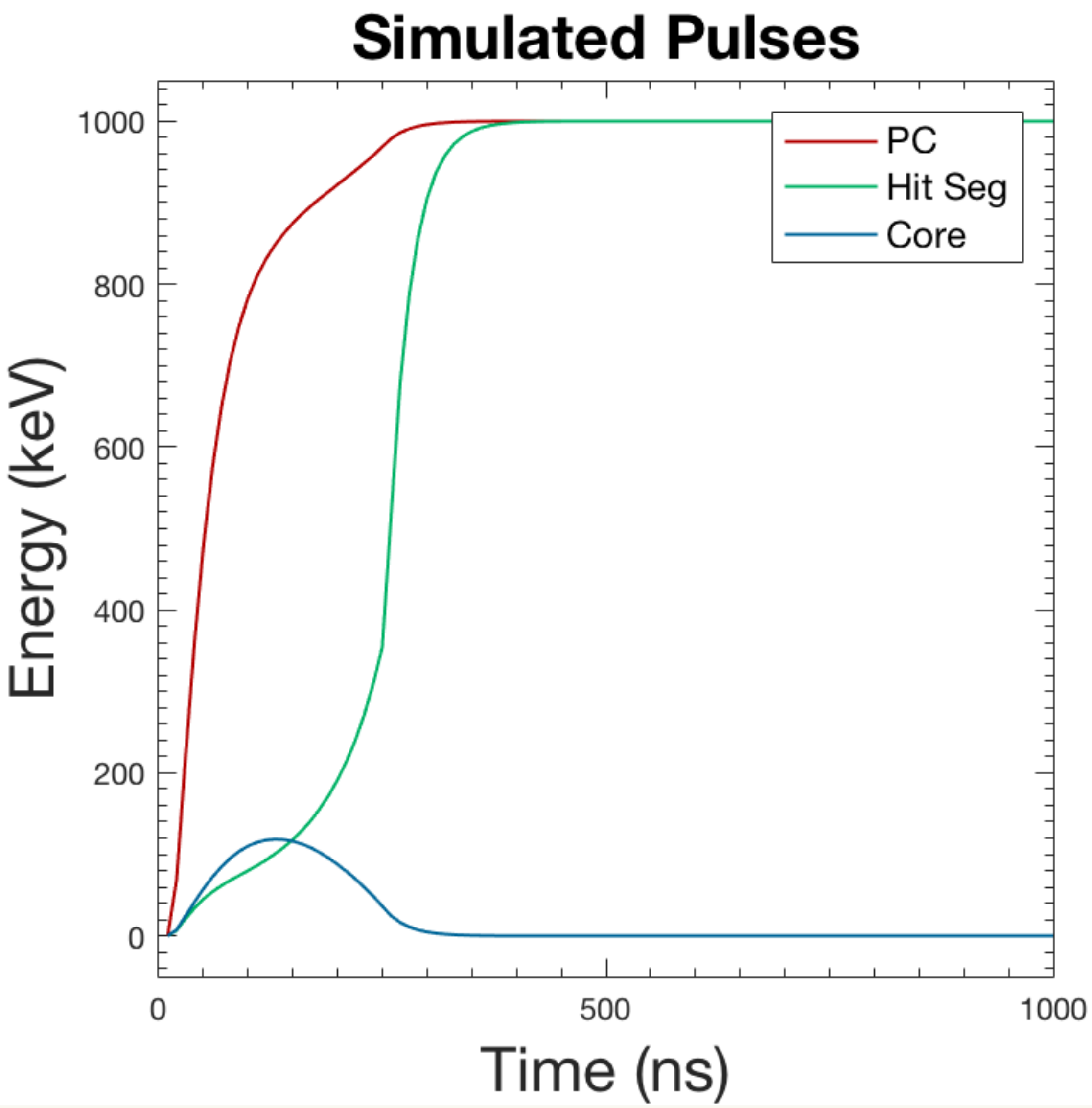
1. Select pulse from basis

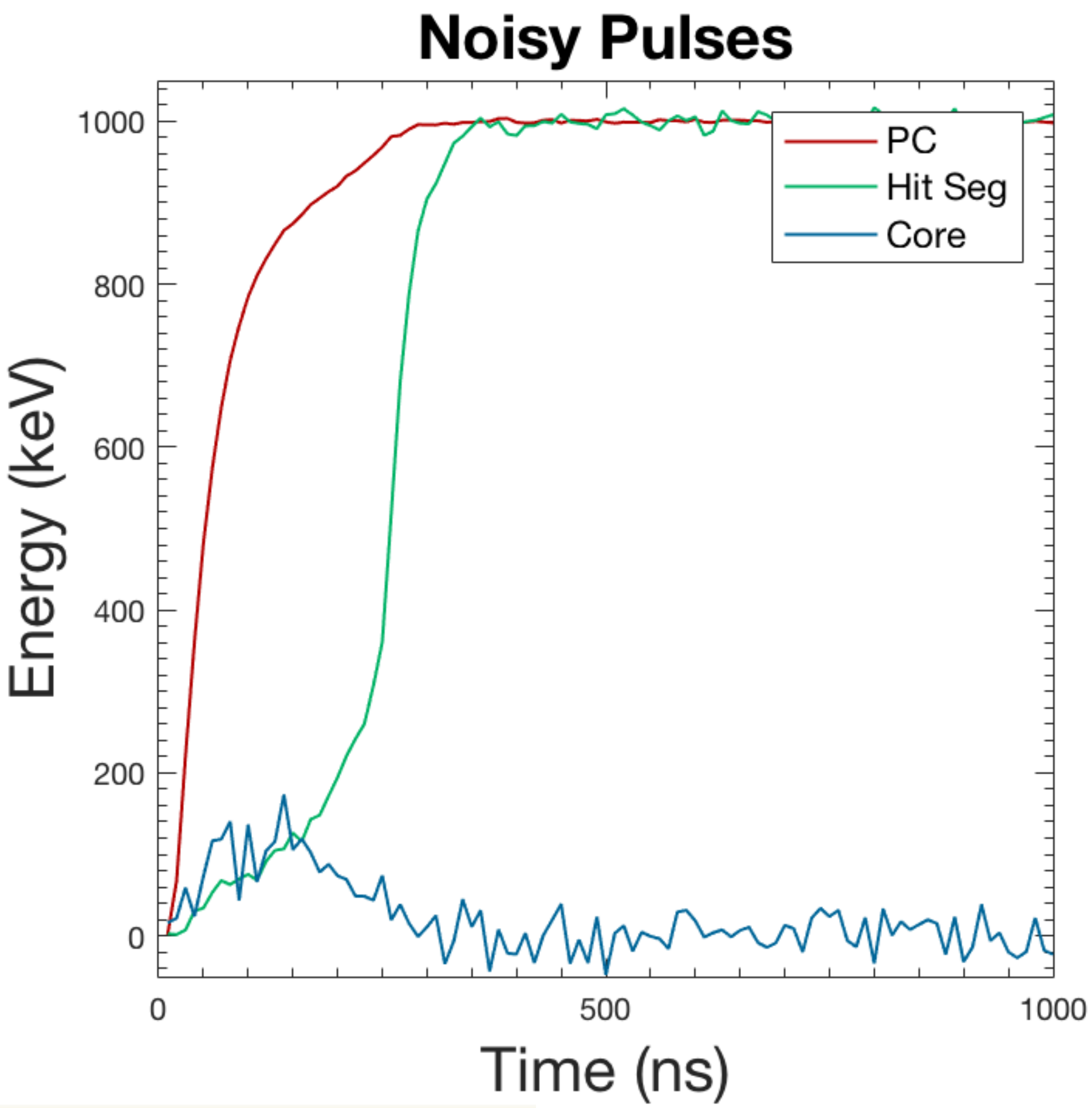


Position Resolution Study

1. Select pulse

2. Add realistic noise to all pulses - $V_{p\text{-}p}$ ~ 1 mV* for point contact, $V_{p\text{-}p}$ ~ 5-20 mV for outer segments,





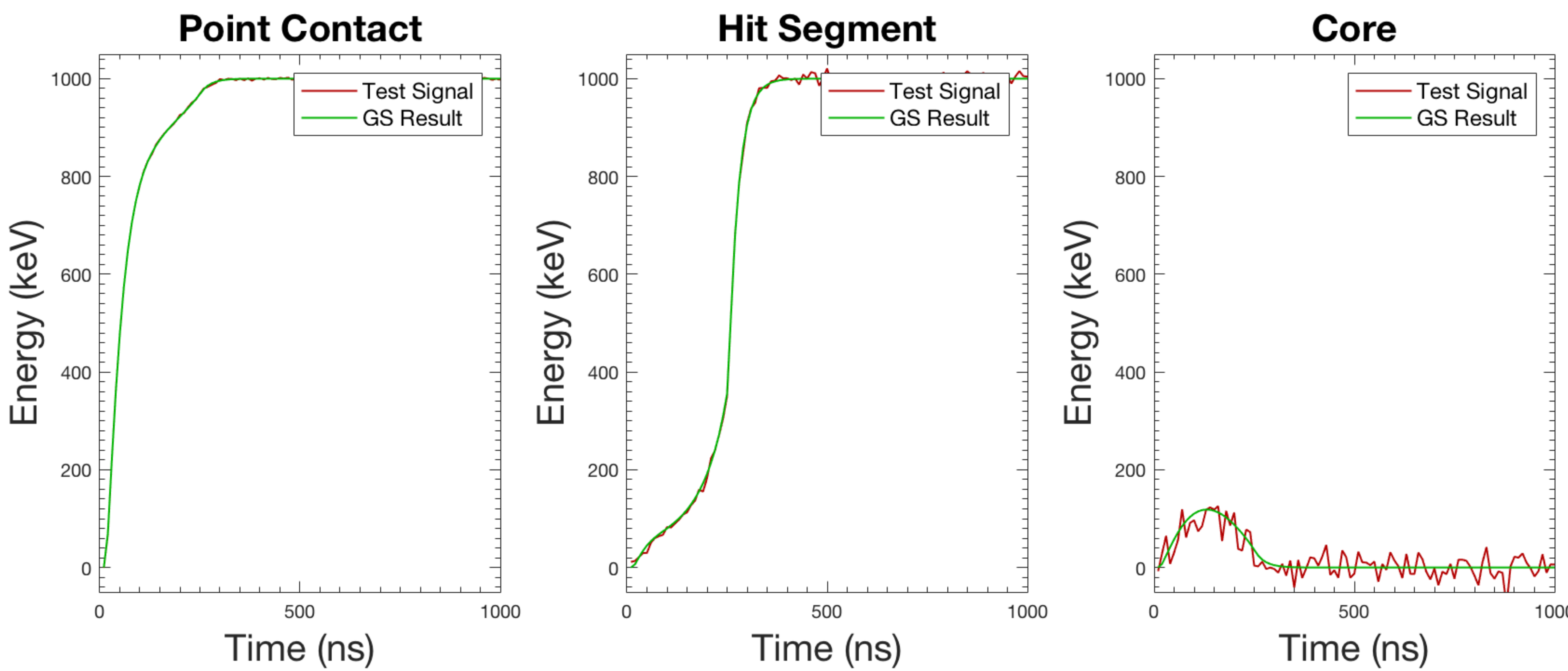
* L.J. Harkness-Brennan et. al, Nucl. Instr. Meth. A 760 (2014) 28-39

1. Select pulse

2. Add noise

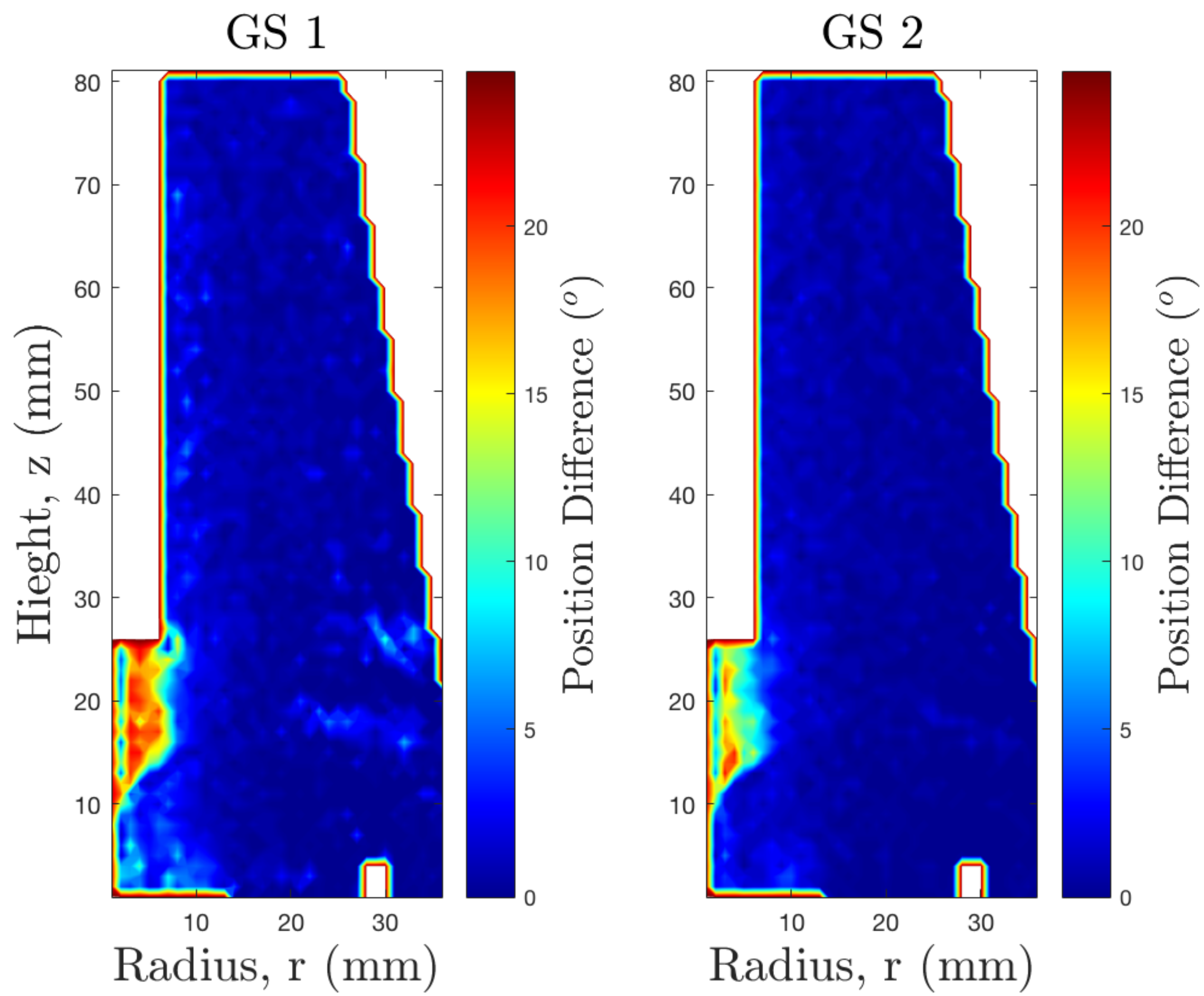
3. Run through grid search algorithm, performing chi2 minimisation to find most likely interaction position

$$\chi^2 = \sum_{i,j} |S^{m}_{i,j} - S^{s}_{i,j}|^2$$



Phi deviation as a function of interaction position

- Addition of azimuthal segs significantly improves phi resolution
- Addition of remaining sigs slightly improves resolution but increases time to perform search
- Drift time and hit segment cuts help reduce search time

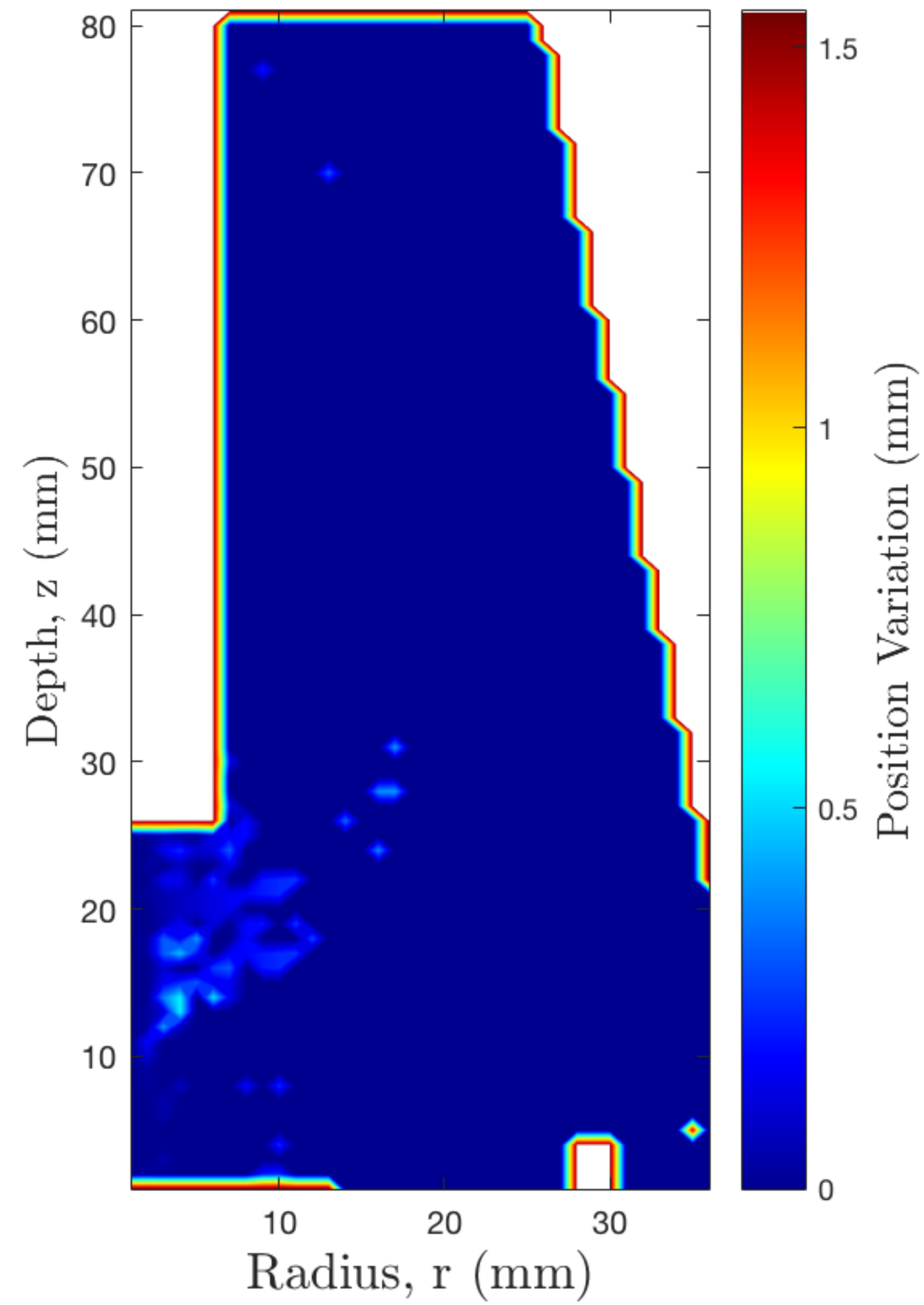


GS 1 = PC + HS + Core
GS 2 = GS 1 + 8 x Azimuthal

FWHM as a function of interaction position

1. Select pulse
2. Add noise
3. Grid search algorithm
4. Measure average deviation from known position for 10 independent samples per basis position
   FWHM = **0.41 mm** averaged throughout detector

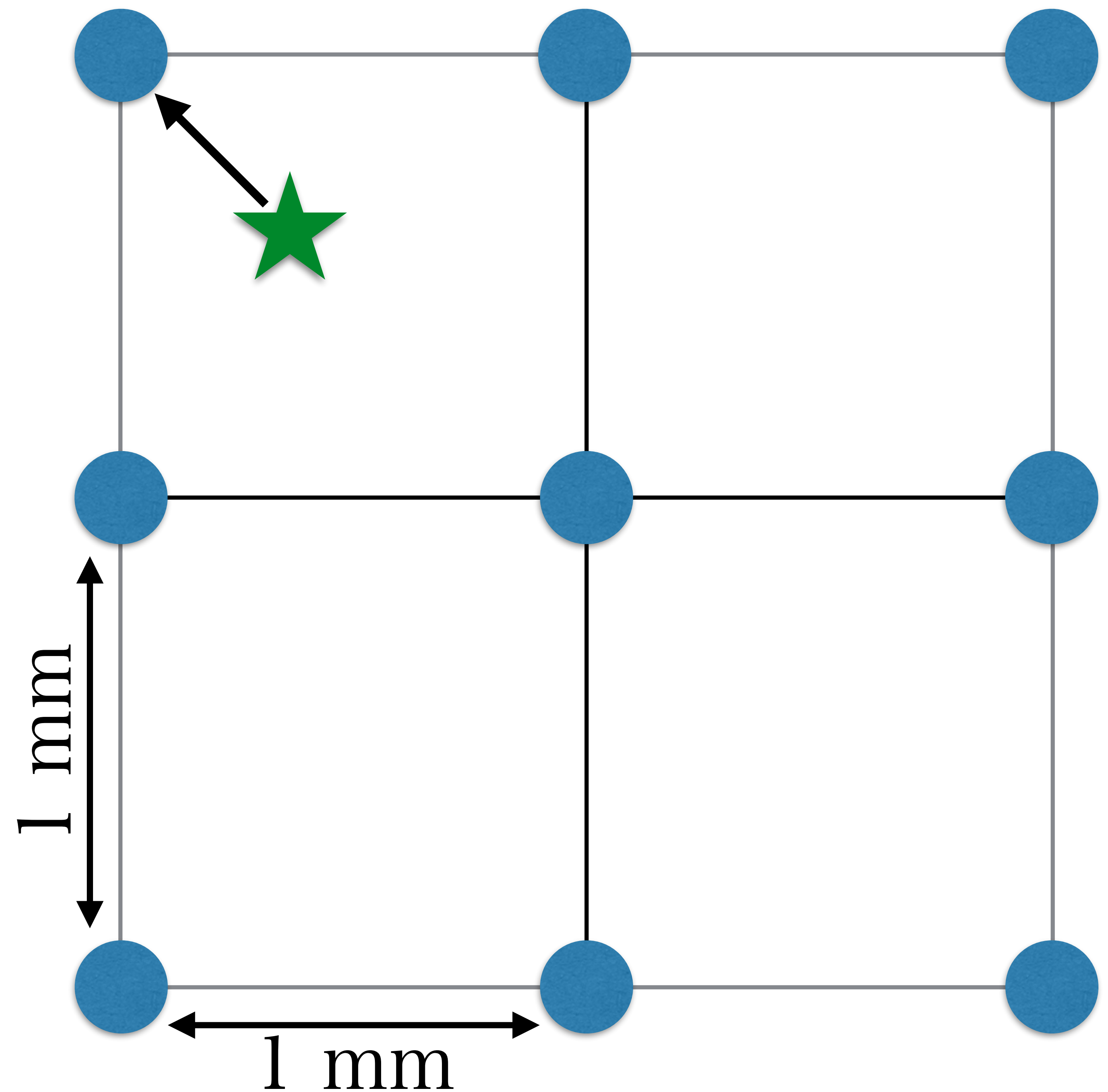
$$FWHM = 2.35\sigma = 2.35\sqrt{\frac{\sum_N \Delta_{x,y,z}^2}{N}}$$



GS 5 = All segs + dt cut + hit_seg cut

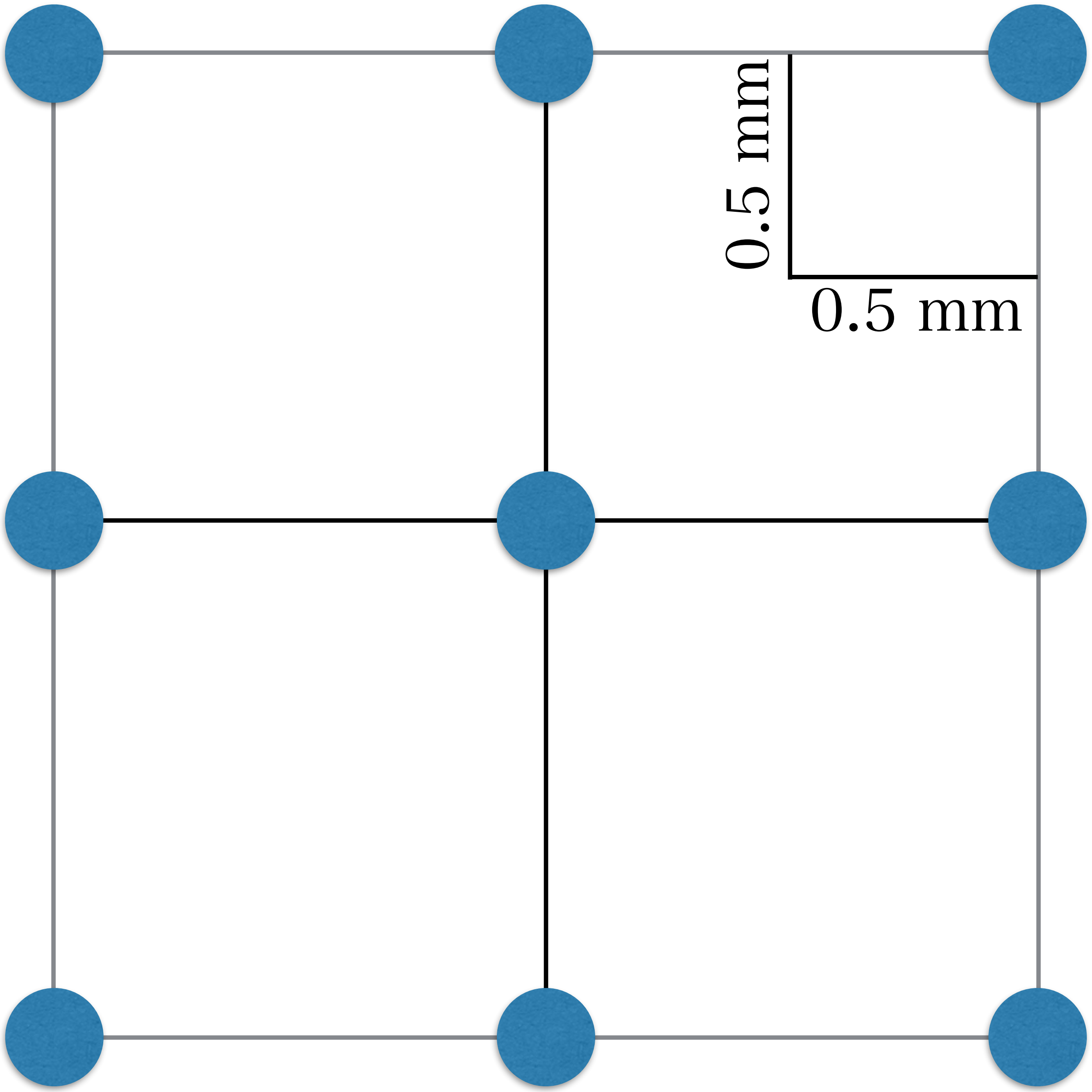
Grid Size Issue

- In reality, interactions can occur in between grid points
- Events will jump to nearest basis point



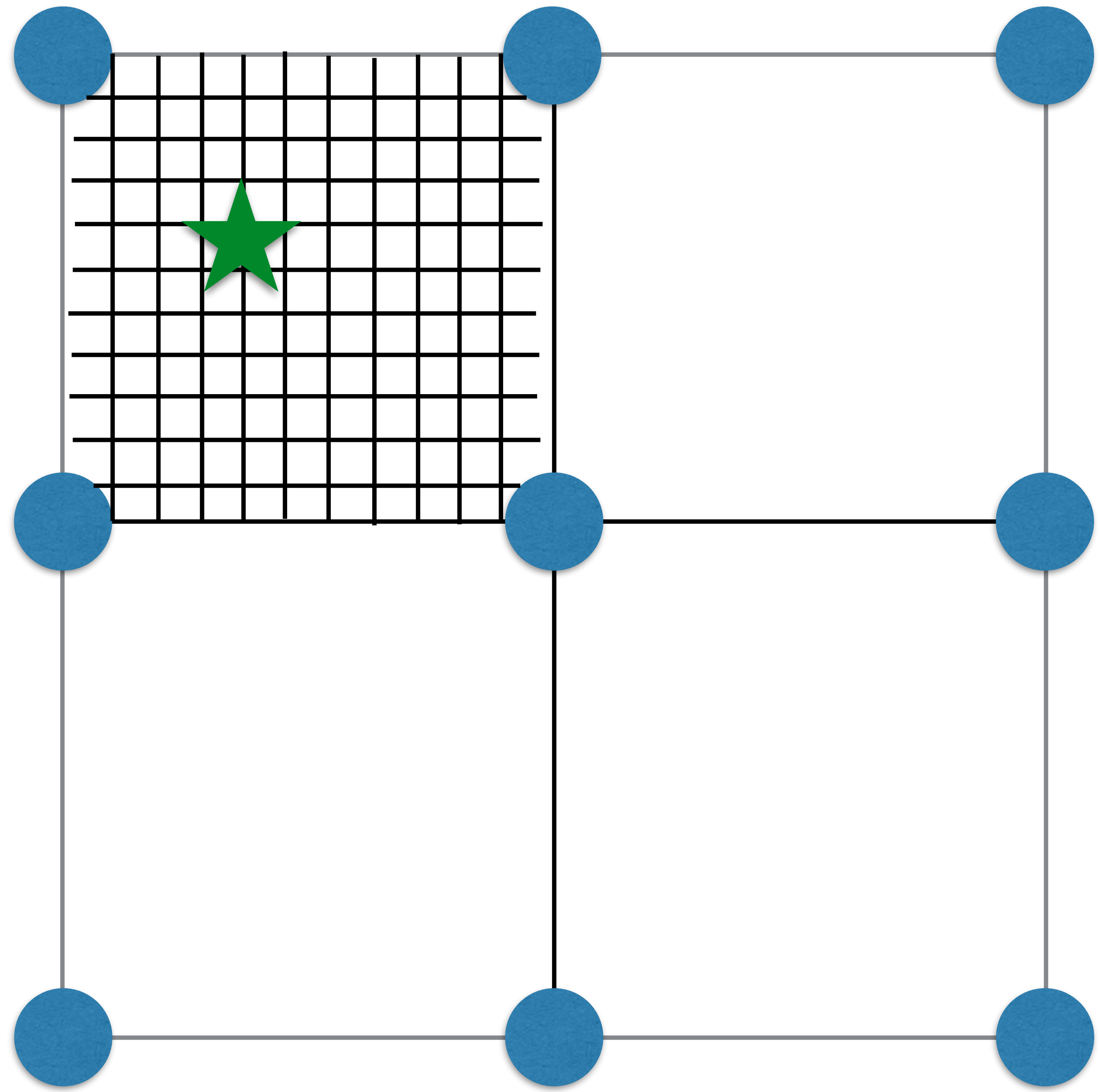
Grid Size Issue

- Max error when interaction occurs in centre of grid ~0.71 mm



Grid Size Issue

- Max error when interaction occurs in centre of grid ~0.71 mm
- Reducing basis grid size removes error
- FWHM remains ~0.4 mm with smaller grid size of 0.1 x 0.1 mm



Summary

- A novel detector has been designed and characterised through simulation
- A test model will be tested in the lab upon arrival
- Sub mm position resolution predicted
- Tracking and Imaging performance to be investigated

Collaborators

J.P.Wright[1], L.J.Harkness-Brennan[1], A.J.Boston[1], D.S.Judson[1], M.Labiche[2], P.J.Nolan[1], R.D.Page[1], F.Pearce[1], D.C.Radford[3], J.Simpson[2], C.Unsworth[1]

[1] University of Liverpool, UK
[2] STFC Daresbury, UK
[3] Oak Ridge National Laboratory, USA

UNIVERSITY OF LIVERPOOL

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Thank you

Any Questions?