Temperature Dependence of Charge Carrier Transport in Germanium Detectors

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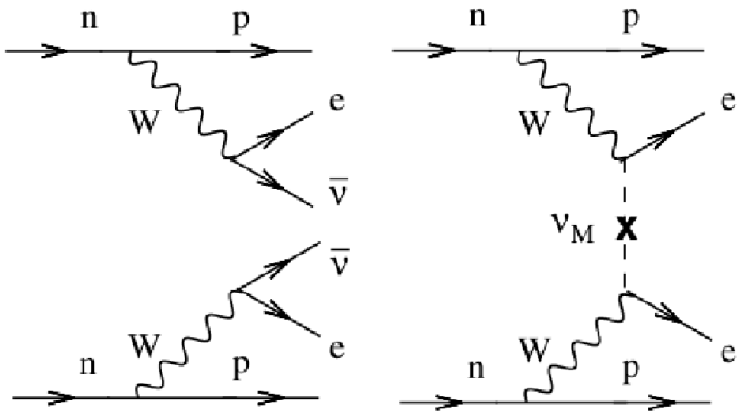
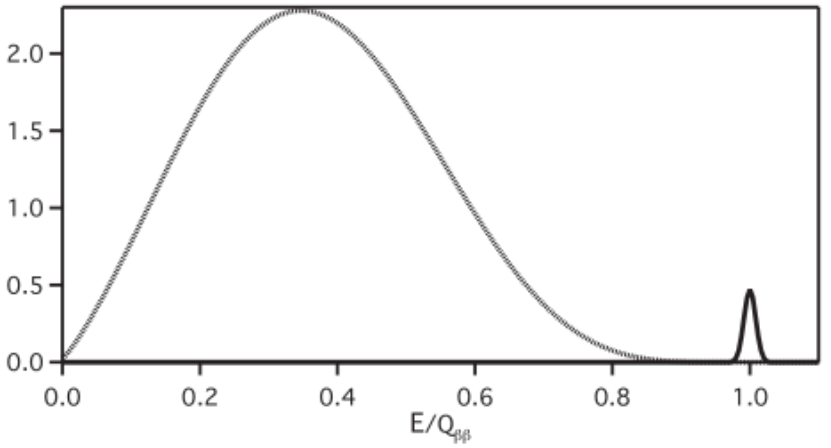
Structure and Outline

- Physics Motivation
- Detector & Experimental Setup
- Charge Carrier Drift & Crystal Axes
- First Results on Temperature Dependence
- Summary and Outlook

Physics Motivation

- Open Questions for Neutrinos
  - Nature of the neutrino: Dirac or Majorana
  - Inverted or Normal Hierarchy
  - Absolute mass scale
- Neutrinoless ββ Decay





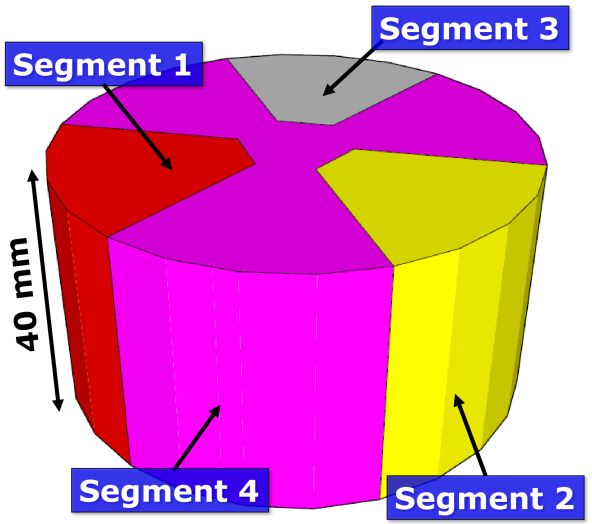
Germanium

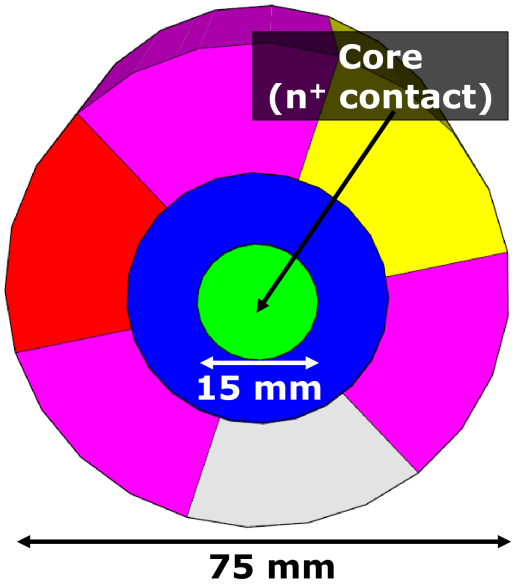
- Isotope ^{76}Ge is candidate for Neutrinoless ββ Decay
- (Enriched) Ge-Detectors: Act as both source and detector at the same time
  - → High detection efficiency
  - → Excellent energy resolution
- **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay
  - Collaboration is currently being formed

LEGEND
Large Enriched
Germanium Experiment
for Neutrinoless ββ Decay

  - High requirements concerning the understanding of Ge-Detectors in both hardware and analysis
  - Detector design and simulation: Mobilities / Temperature dependence?

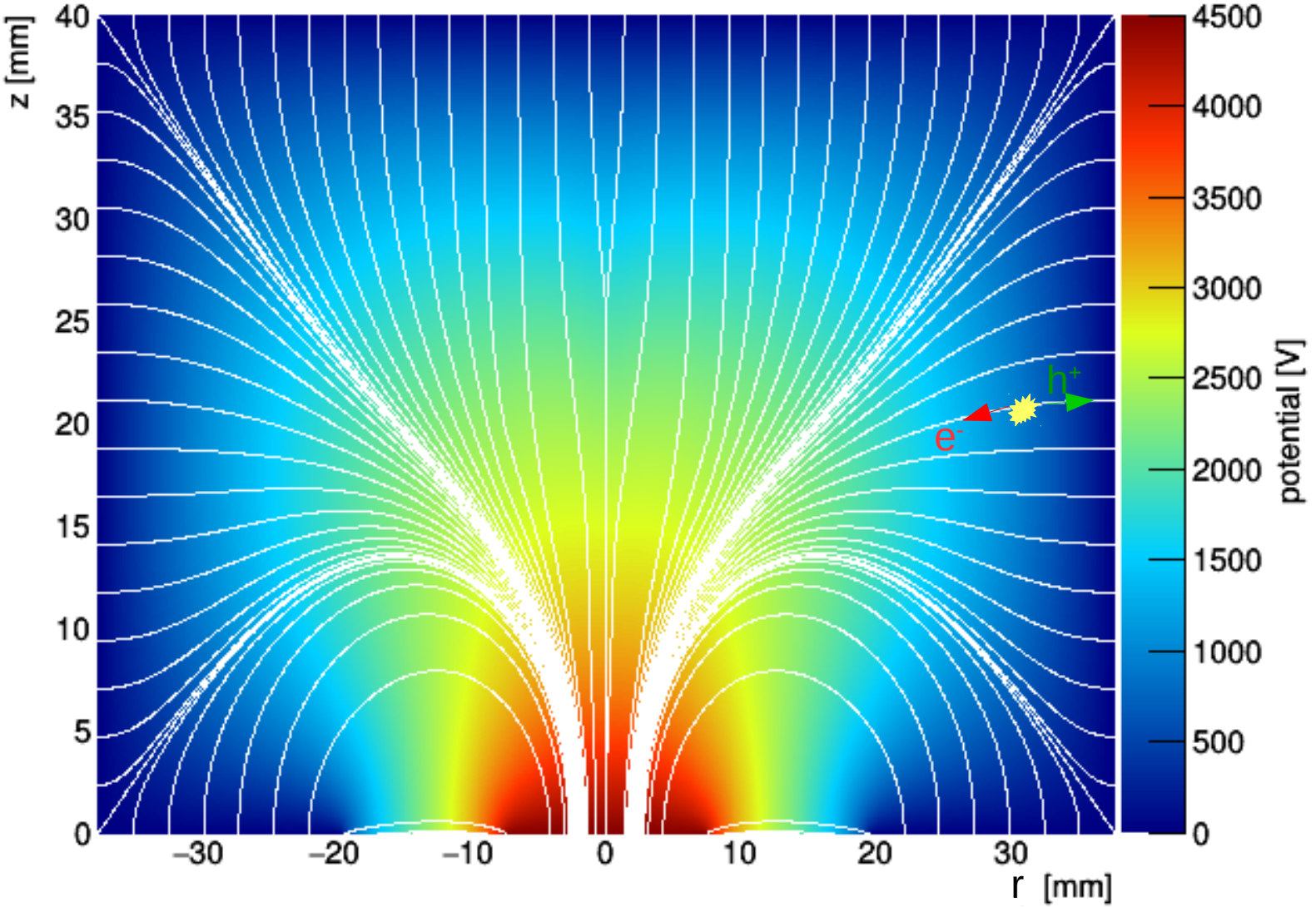
Segmented BEGe Detector



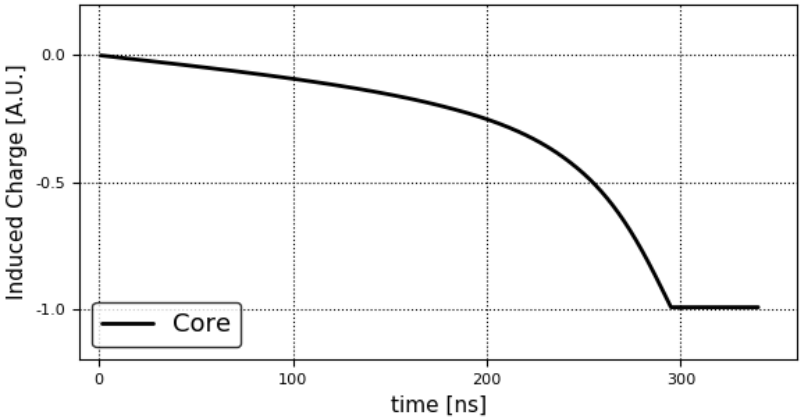


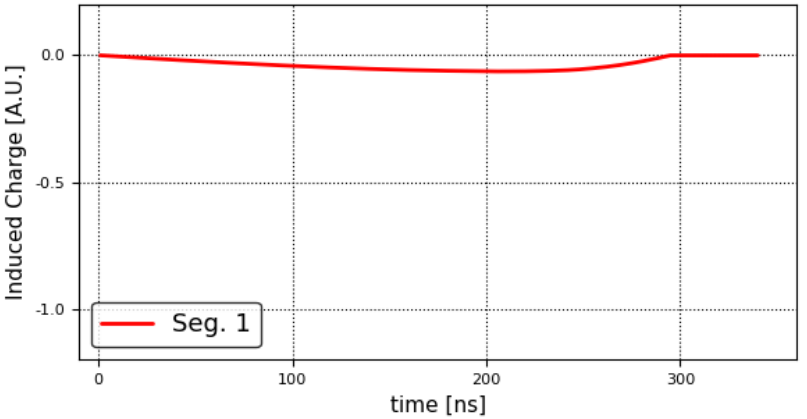
- Point Contact Detector
  - n-type
  - Distinct electric field
- 4-fold Sementation
  - Additional information
  - Understand Pulse Shapes
- Study Detector Properties to understand backgrounds
- T-dependence of charge carrier mobility

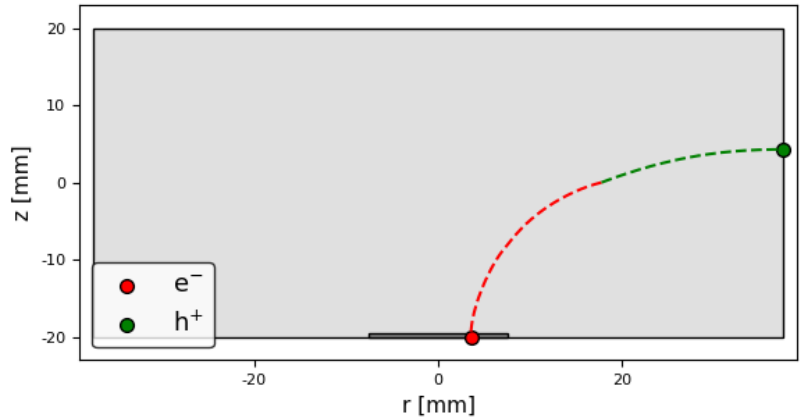
Working Principle of BEGe-Detectors

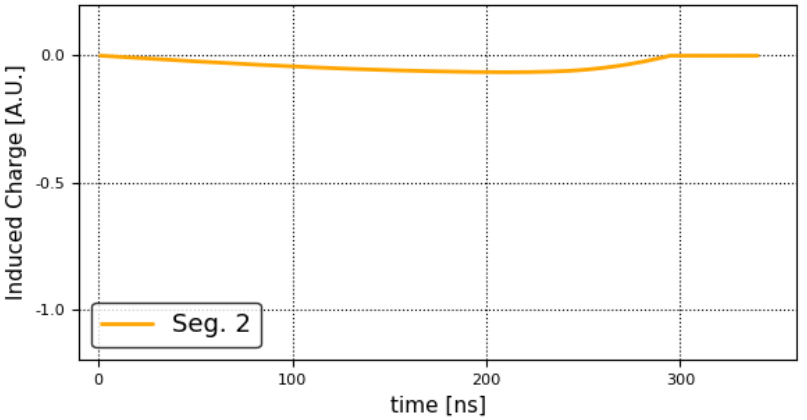


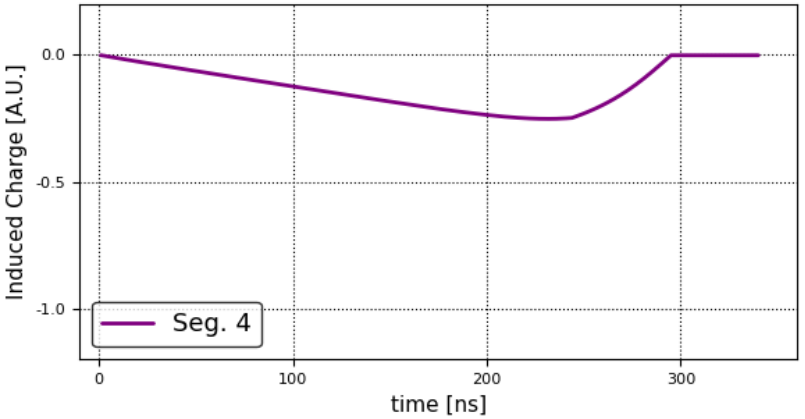
Signal Formation

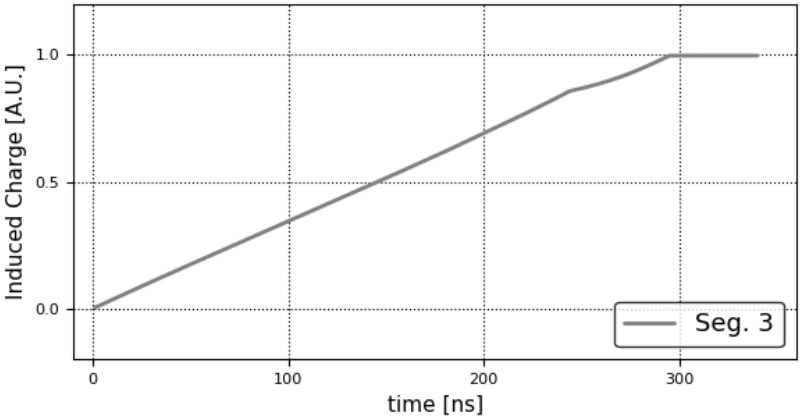




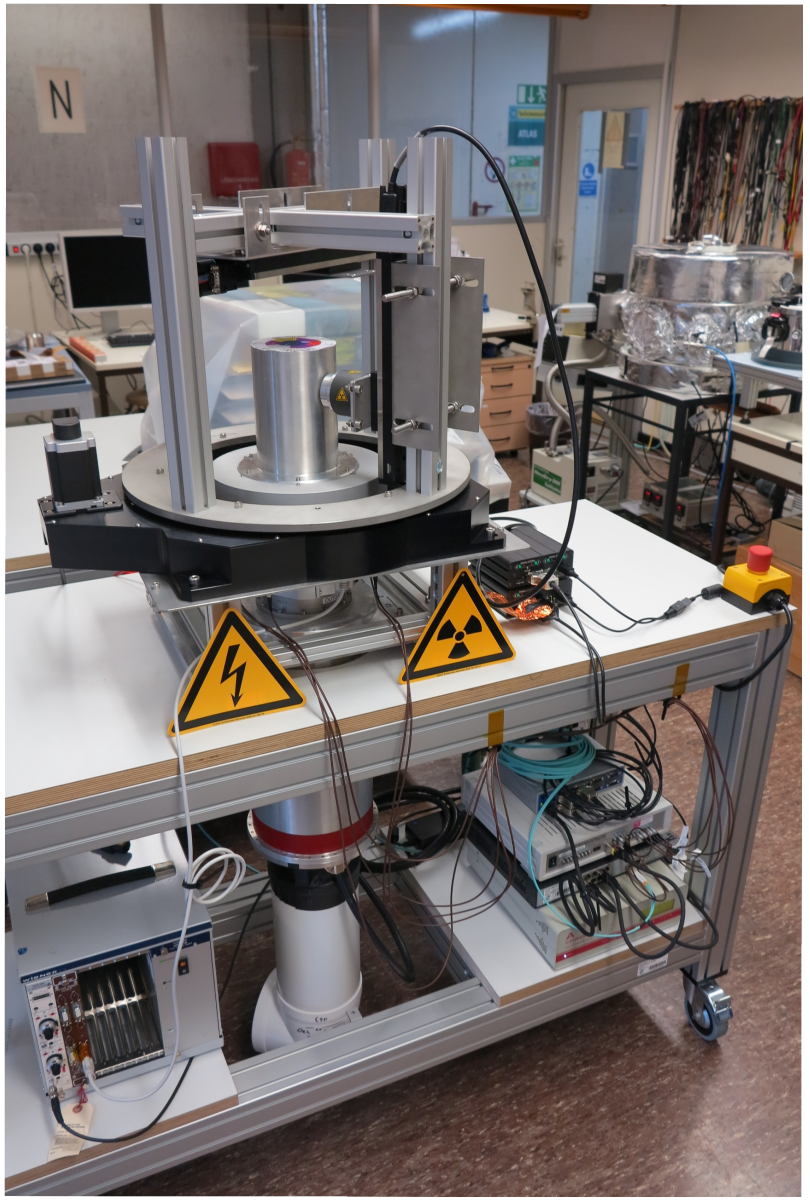






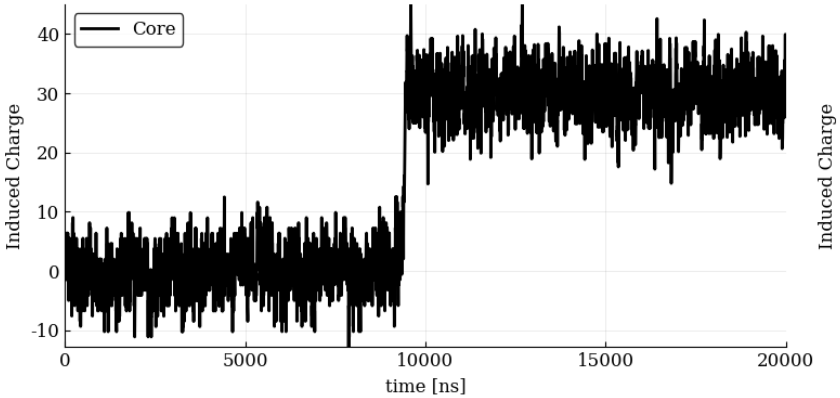


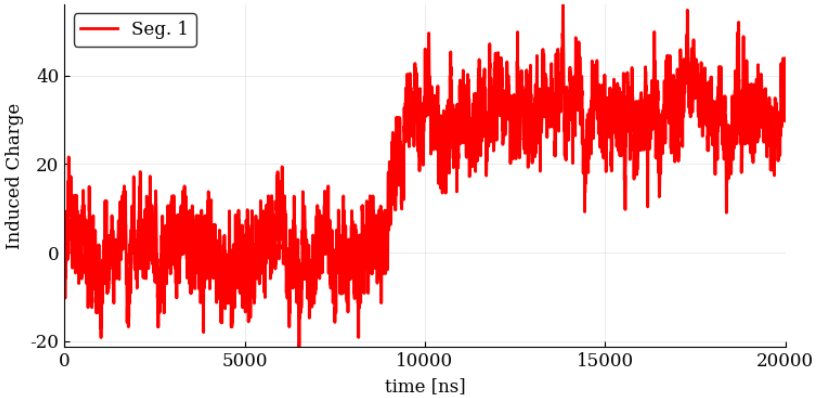
Experimental Setup: “K2”

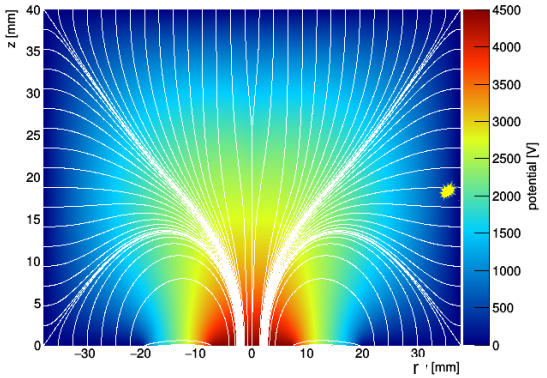


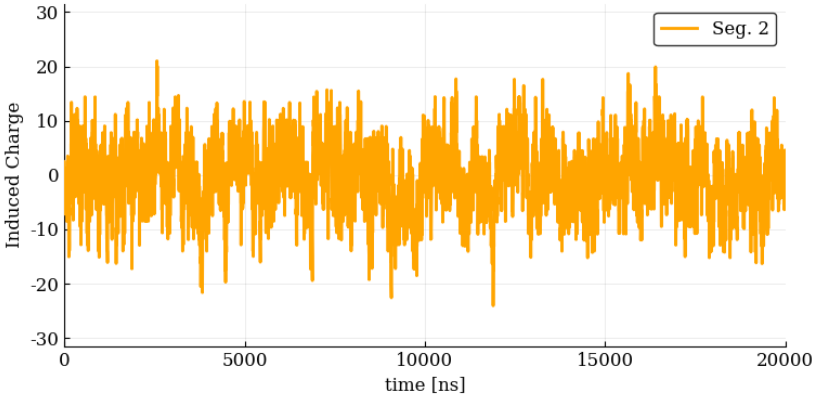
- Electrically cooled cryostat
- 3-axes scanning stages
- 250 MHz Data Acquisiton
- Collimated ^{133}Ba Source
  - Low energy lines to produce surface events

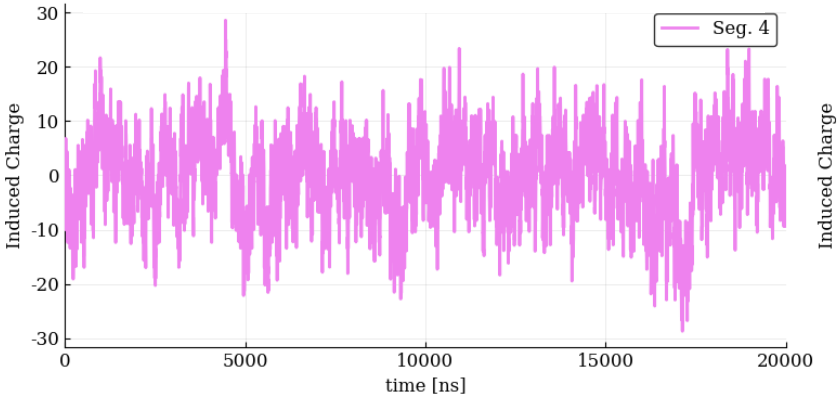
Example Pulse

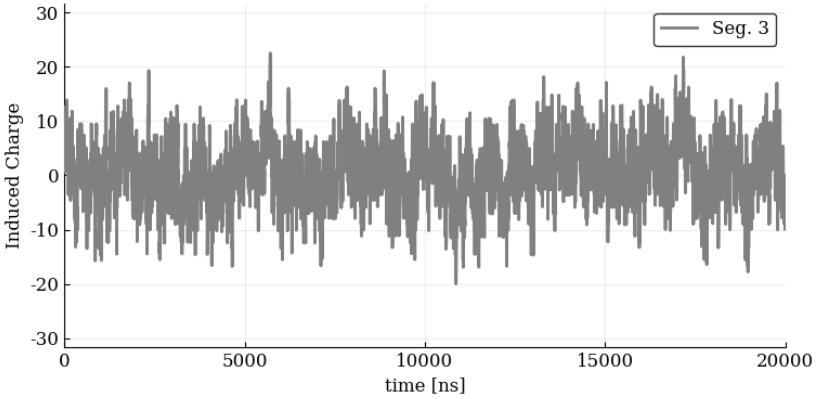






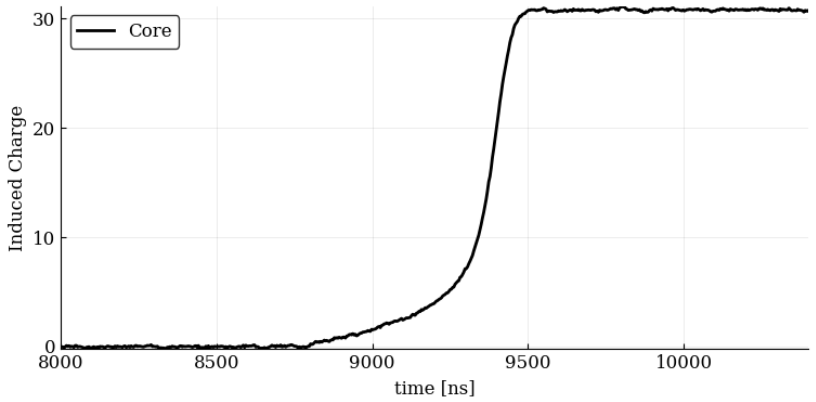


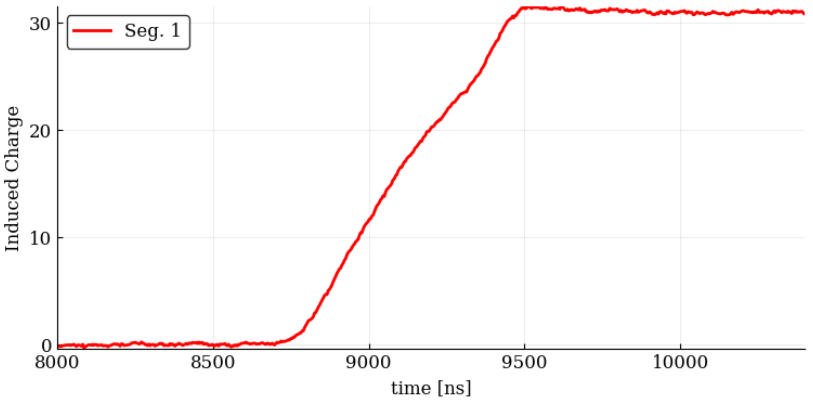


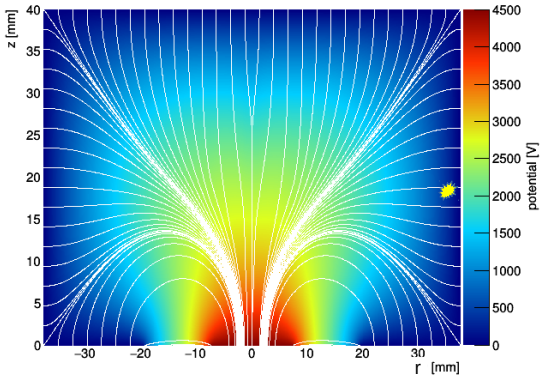


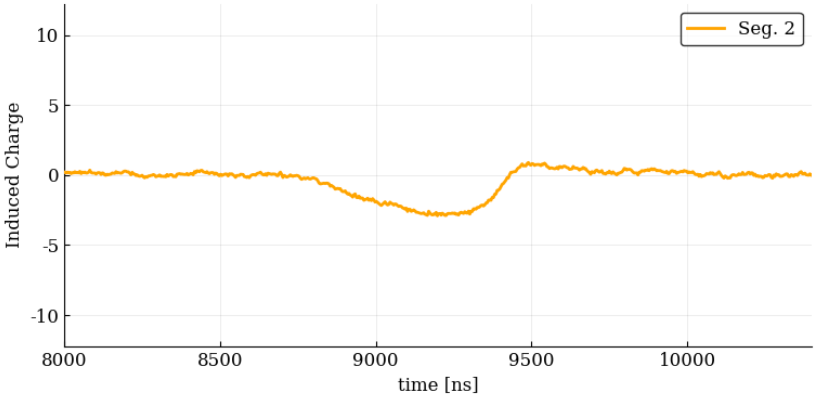
Φ=160 deg, E=31 keV, T=98 K

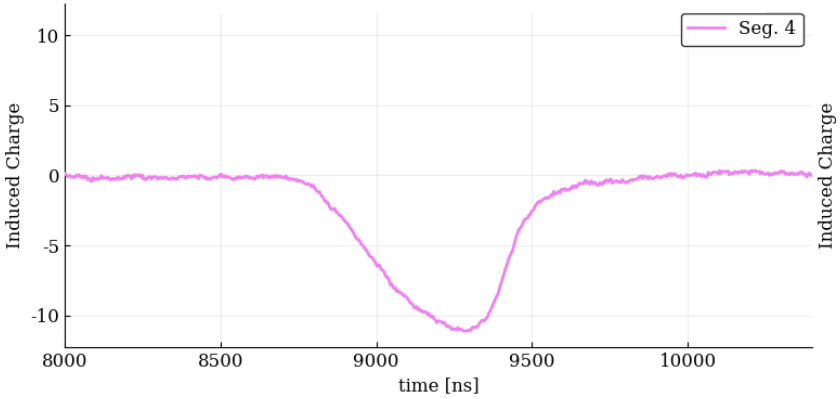
Super Pulse

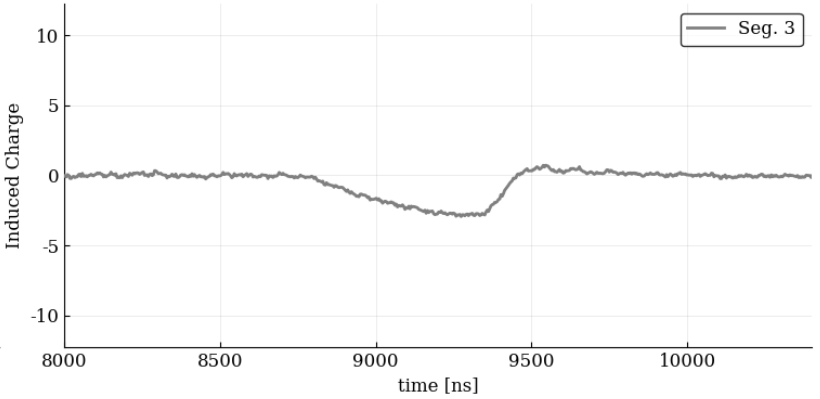






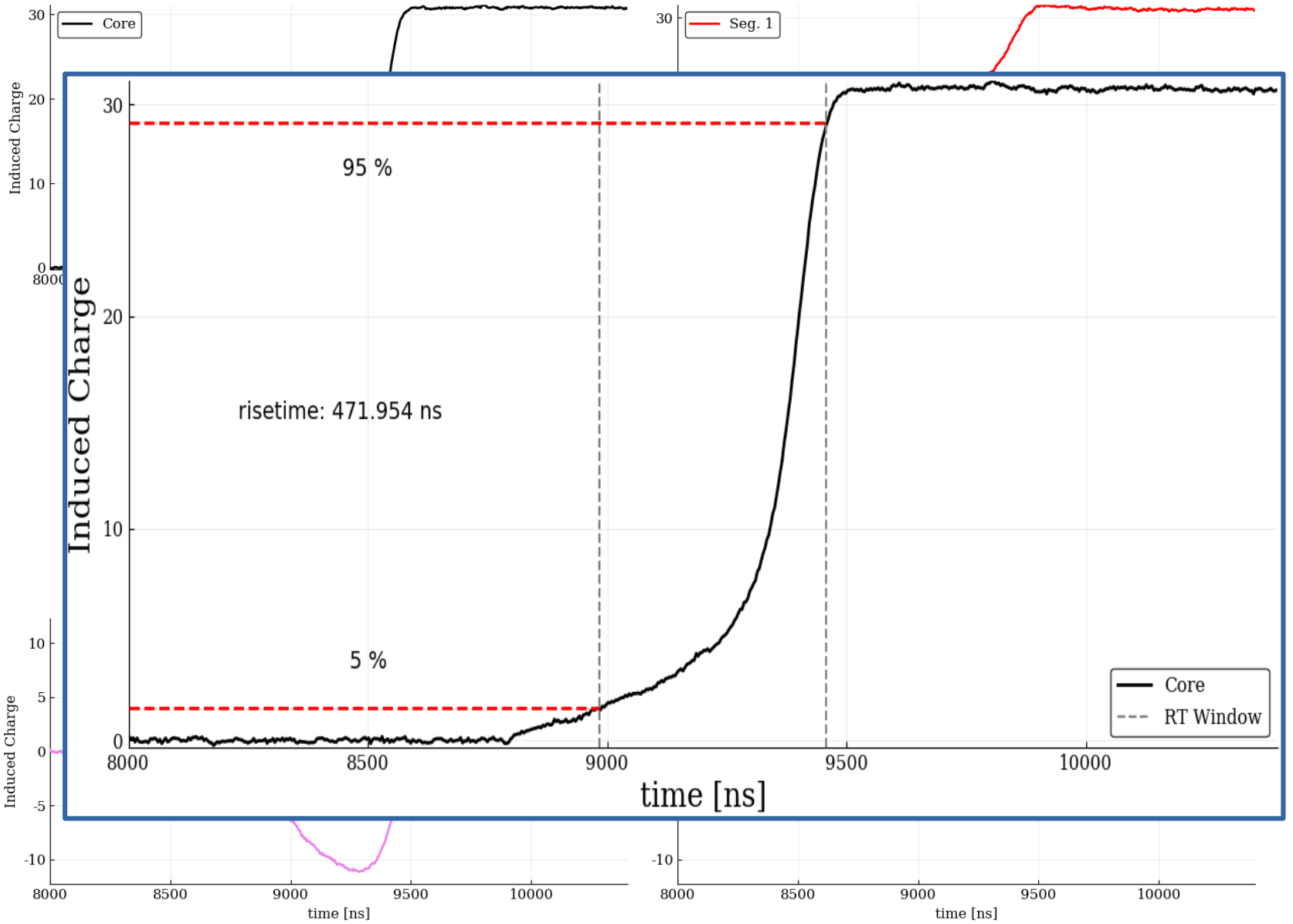






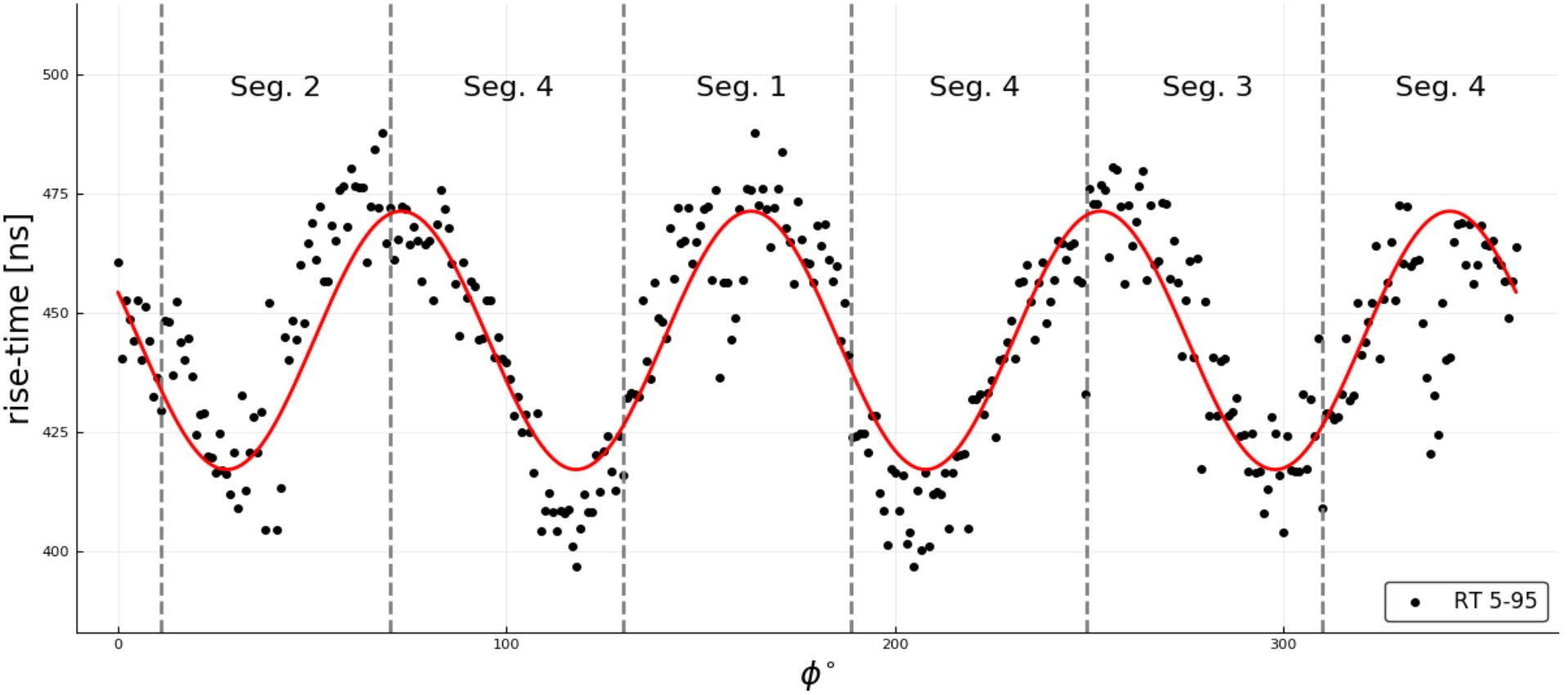
Φ=160 deg, E=31 keV, T=98 K

Super Pulse



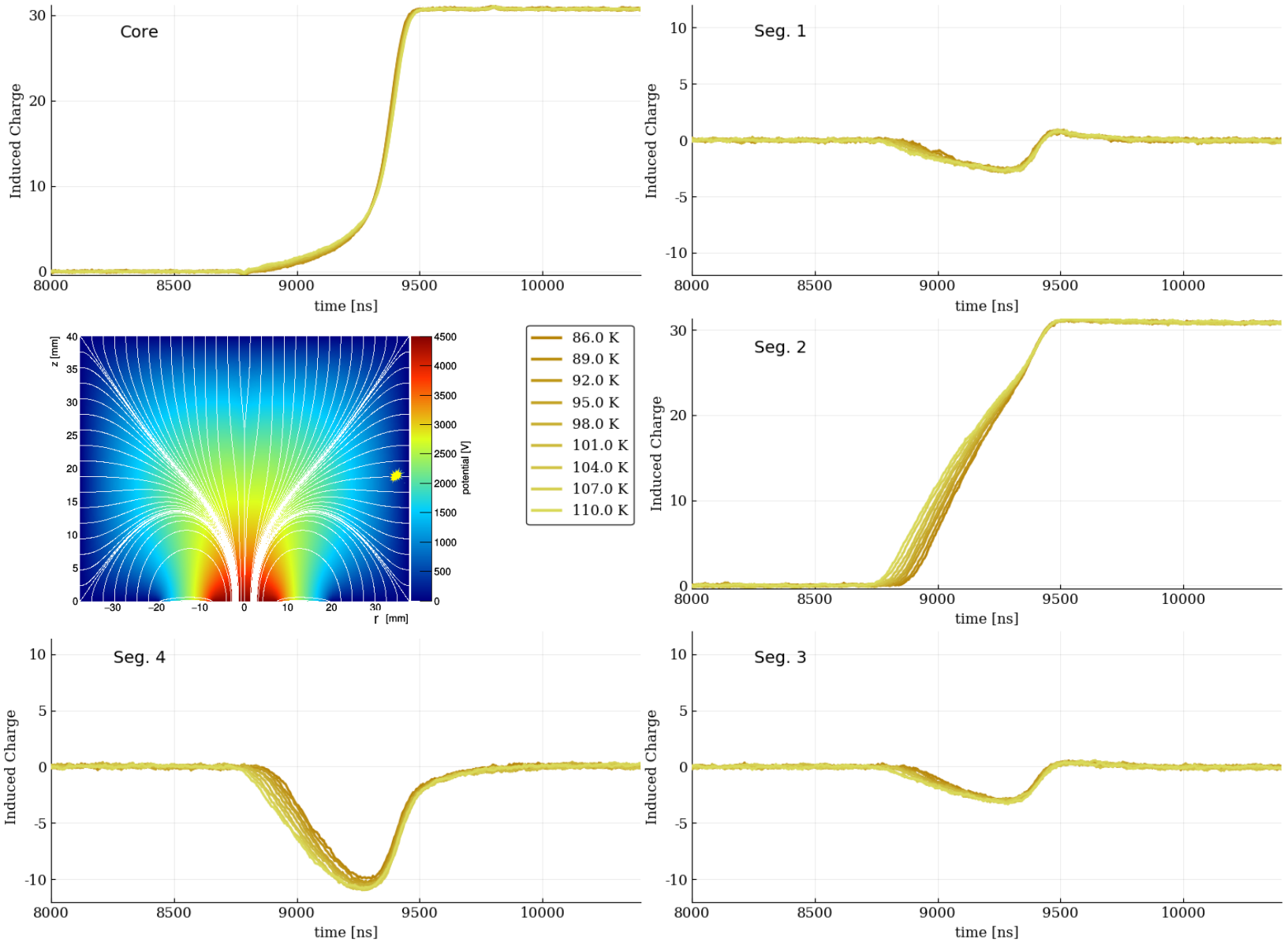
Φ=160 deg, E=31 keV, T=98 K

Influence of Crystal Axes



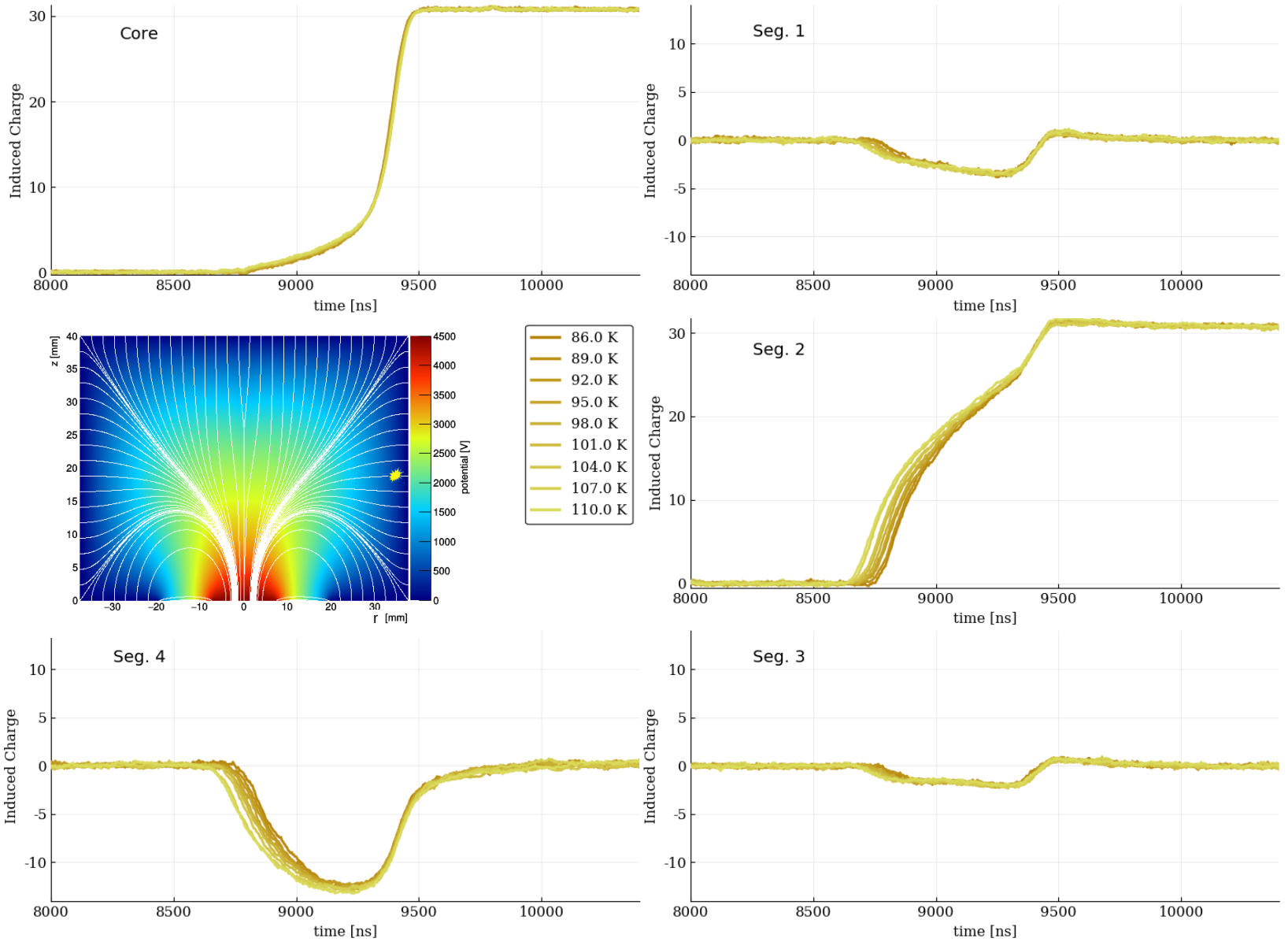
- 360 deg scan around the side of the detector
- Core rise-times from 5-95% from 31 keV Supe Pulses
- “Slow Axes”: <110> and “Fast Axes”: <100>, <010>

First Results on T-dependence



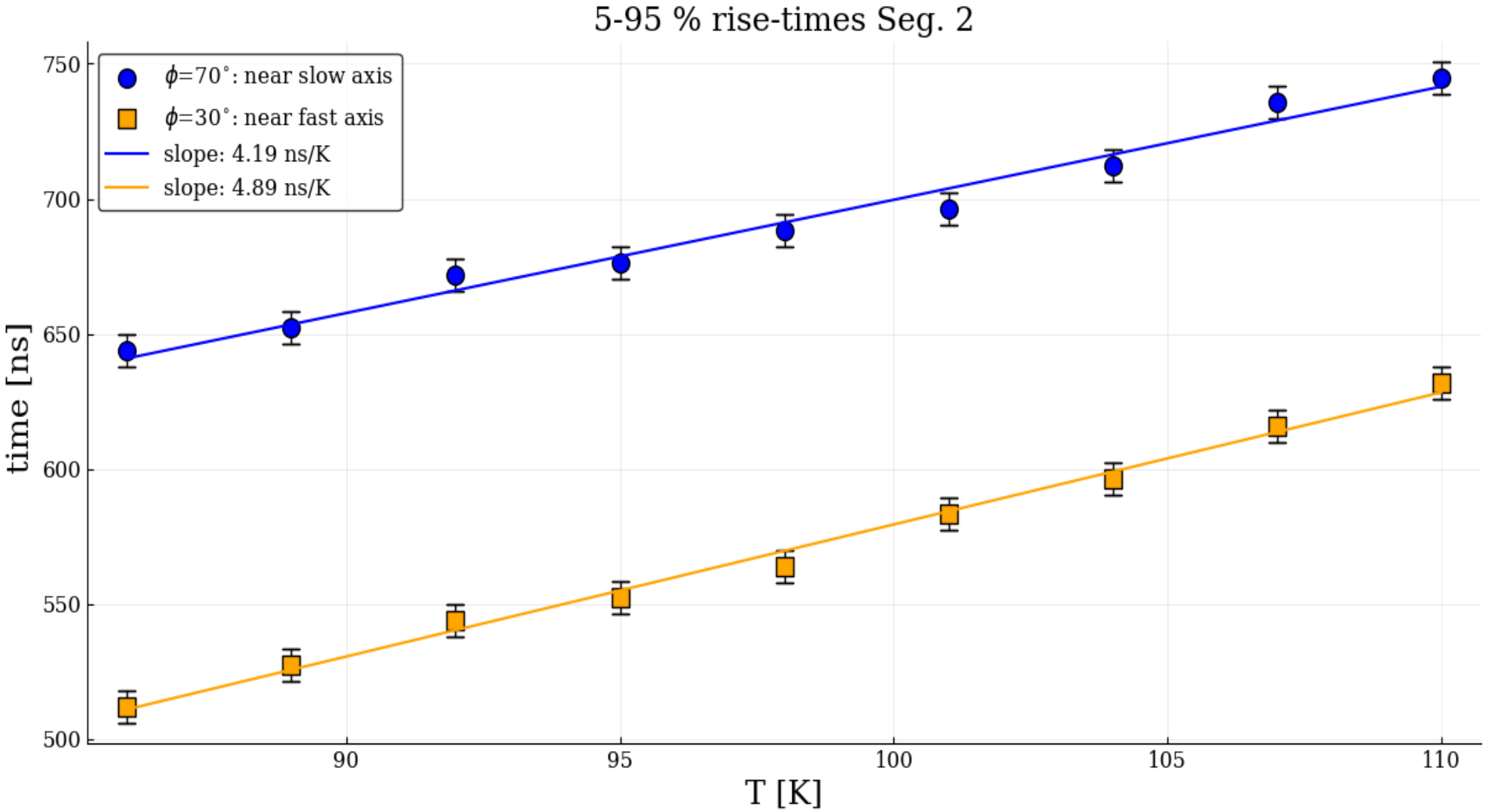
Φ=30 deg, E=31 keV, T=98 K, near “Fast Axis”

First Results on T-dependence



Φ=70 deg, E=31 keV, T=98 K, near “Slow Axis”

First Results on T-dependence

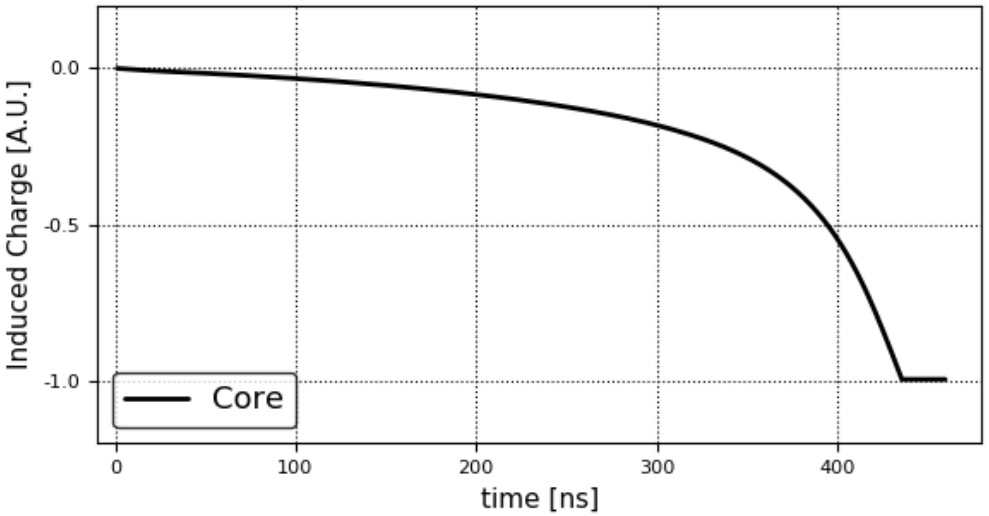


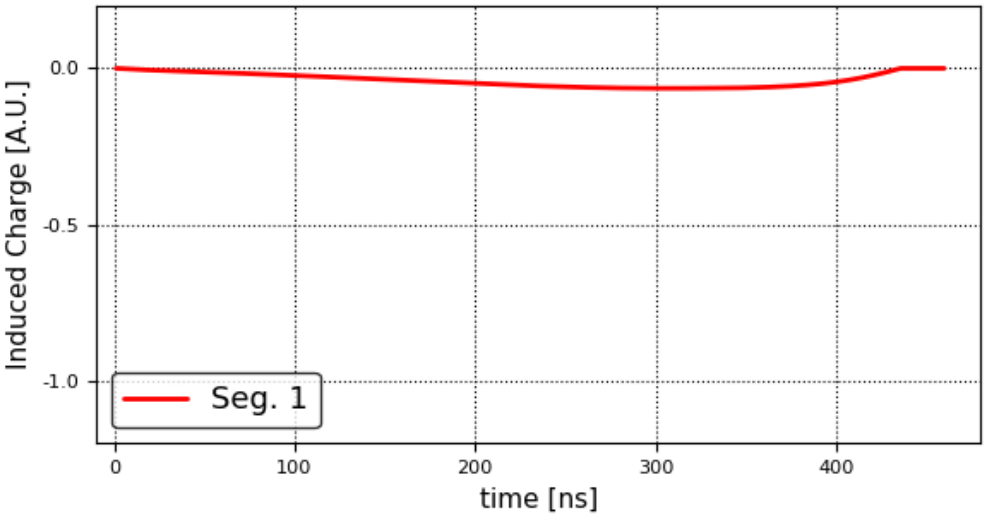
From E=31 keV Super Pulses

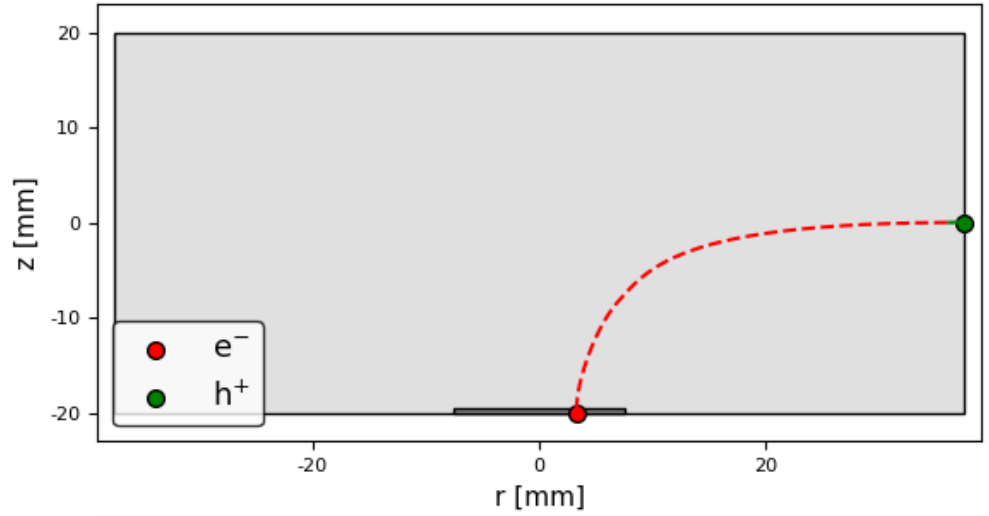
Summary & Outlook

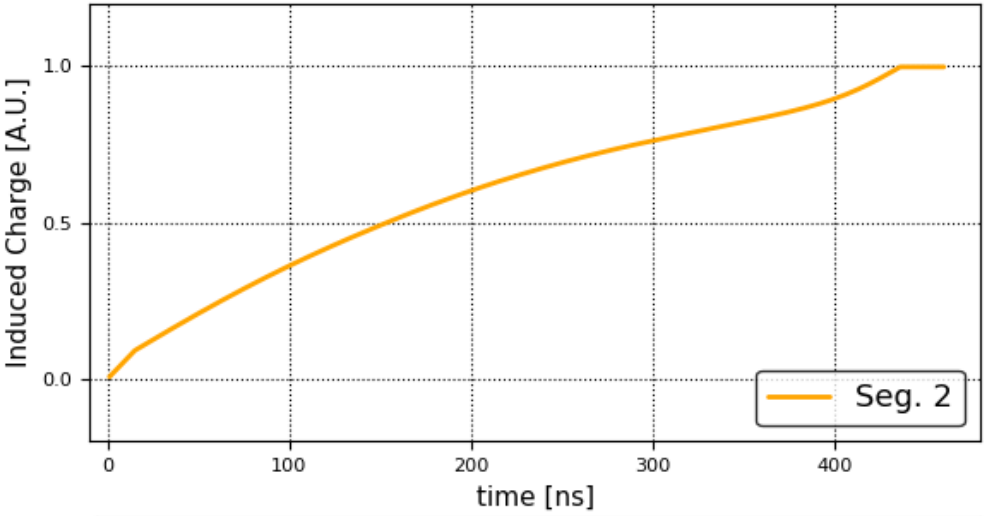
- Summary
  - Temperature dependence of drift velocity of charge carriers is not well studied
  - At higher T, the charge collection takes longer (e^- drift)
  - The T dependence is correlated with the crystal axes
- Outlook
  - Further scans are being taken
  - Relation of T- dependence and crystal axes in detail
  - Check whether rising the Voltage changes things
  - p-type detector: hole drift
  - Comparison with simulations to learn about mobilities

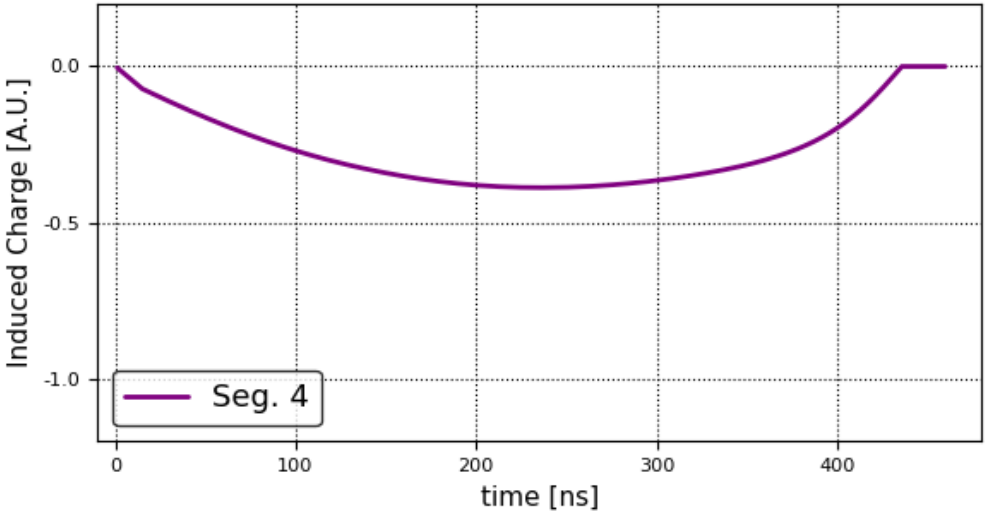
Backup

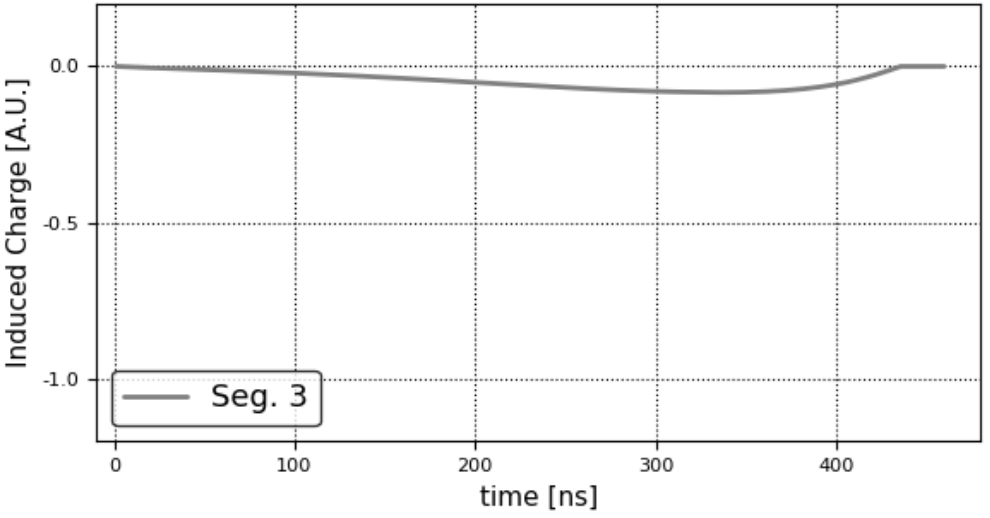

Induced Charge [A.U.]
0.0
-0.5
-1.0
Core
0
100
200
300
400
time [ns]

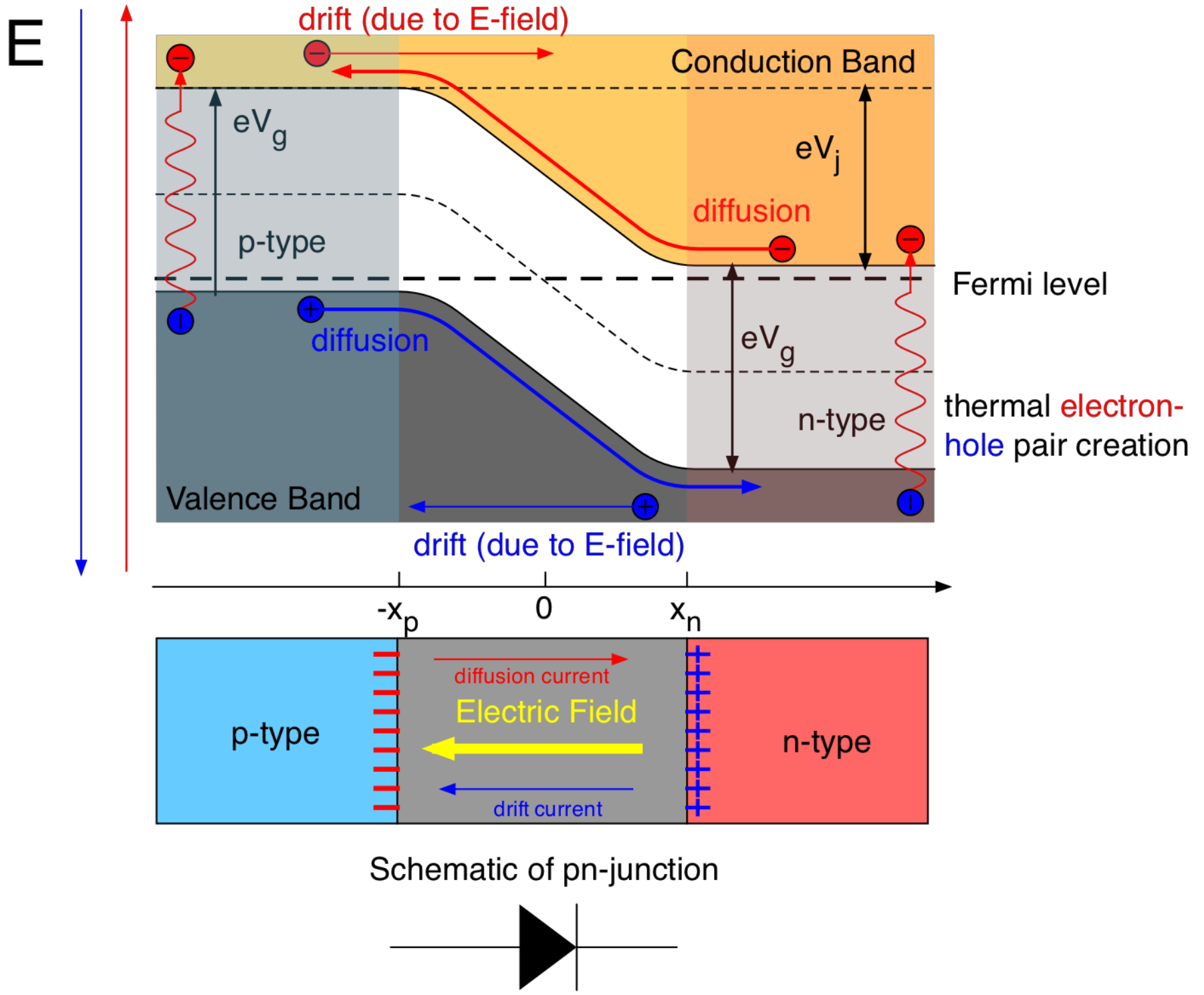

Induced Charge [A.U.]
0.0
-0.5
-1.0
Seg. 1
0
100
200
300
400
time [ns]

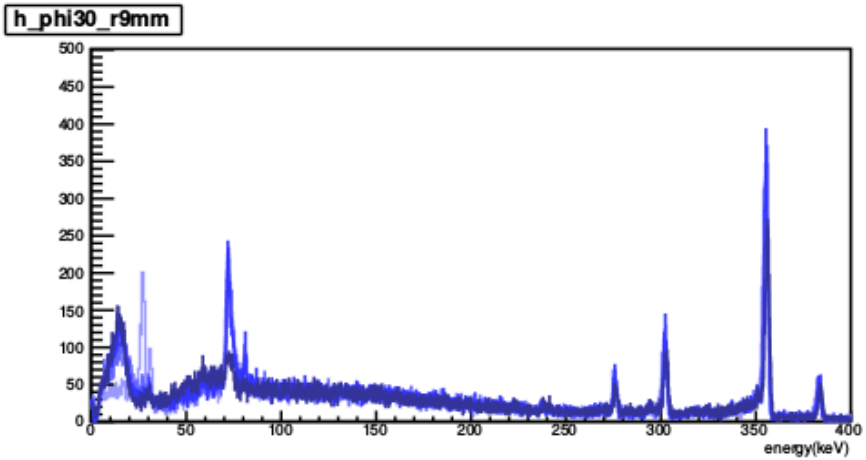

z [mm]
20
10
0
-10
-20
e⁻
h⁺
-20
0
20
r [mm]

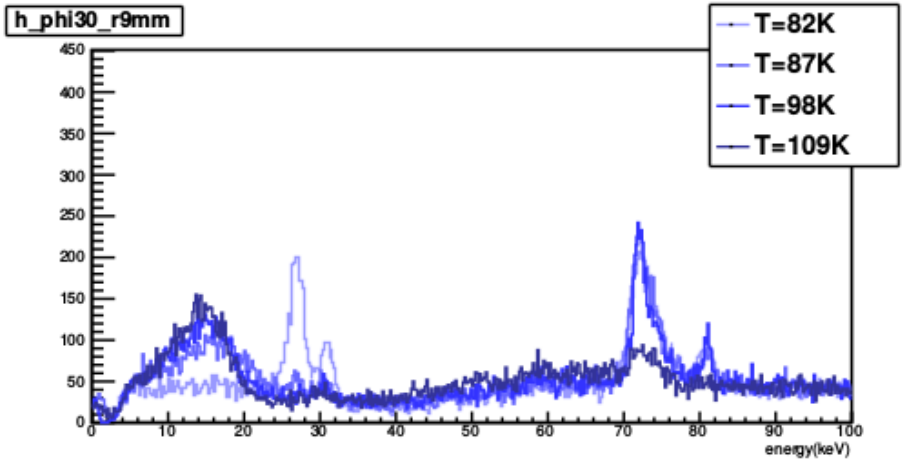

Induced Charge [A.U.]
1.0
0.5
0.0
Seg. 2
0
100
200
300
400
time [ns]

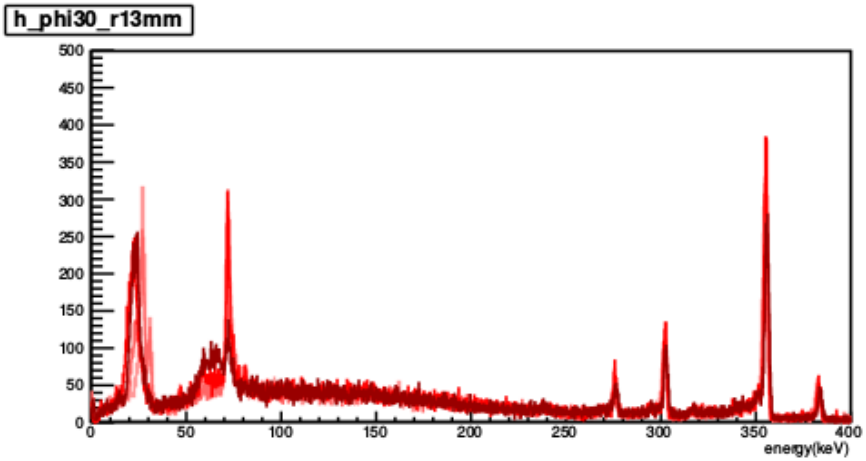

Induced Charge [A.U.]
0.0
-0.5
-1.0
Seg. 4
0
100
200
300
400
time [ns]

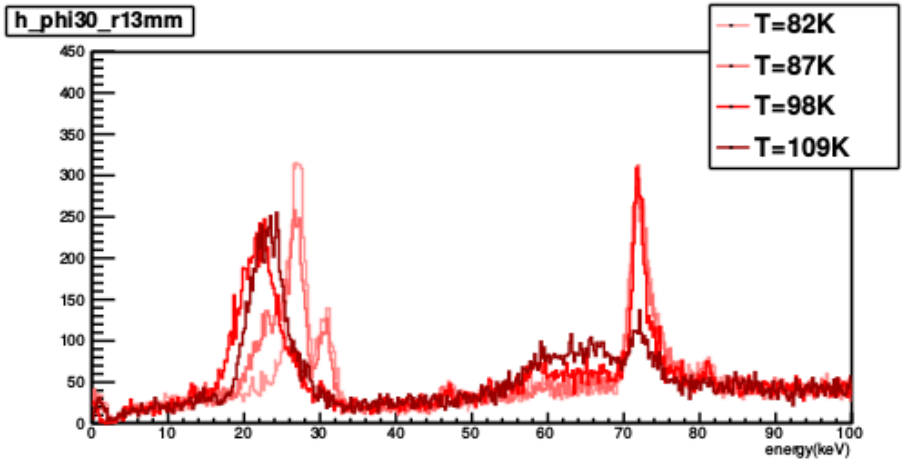

Induced Charge [A.U.]
0.0
-0.5
-1.0
Seg. 3
0
100
200
300
400
time [ns]

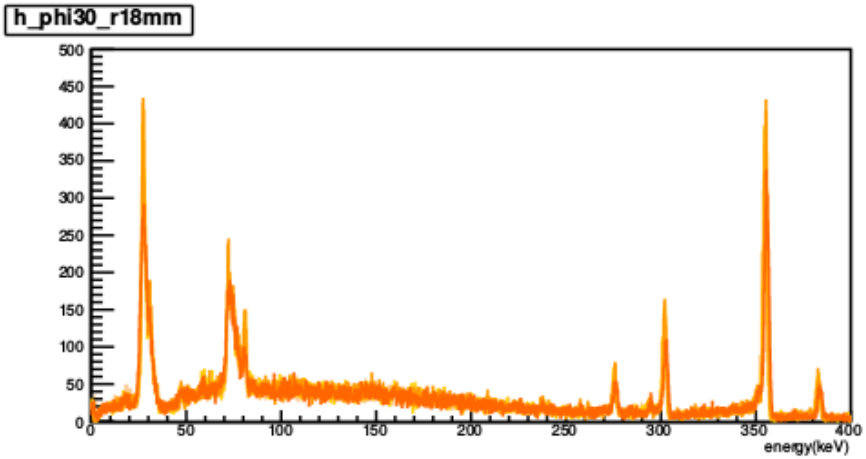

E
drift (due to E-field)
Conduction Band
eV_g
eV_j
diffusion
p-type
Fermi level
diffusion
eV_g
n-type
thermal electron-hole pair creation
Valence Band
drift (due to E-field)
-x_p
0
x_n
diffusion current
Electric Field
p-type
n-type
drift current
Schematic of pn-junction

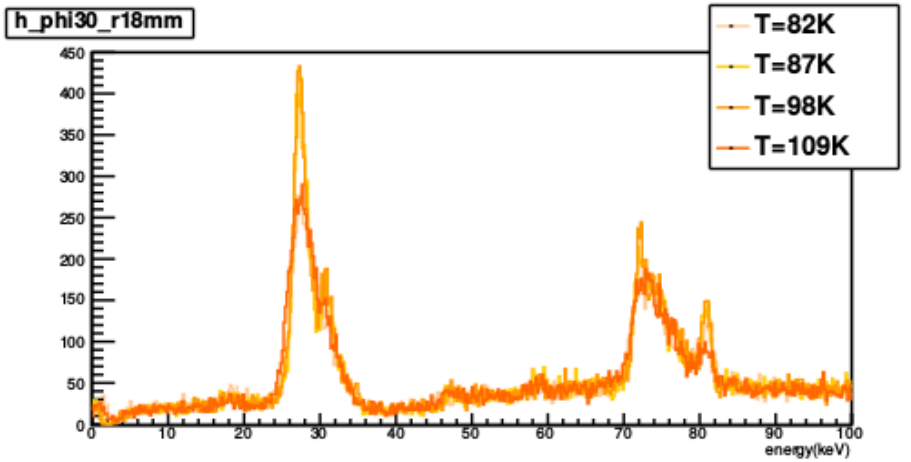

h_phi30_r9mm
energy(keV)

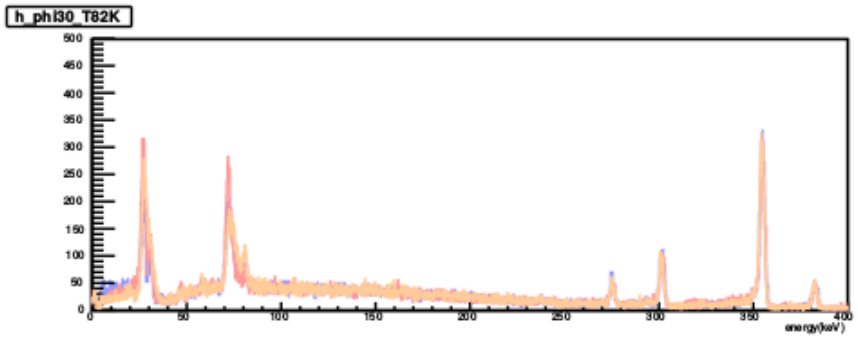

h_phi30_r9mm
T=82K
T=87K
T=98K
T=109K
energy(keV)

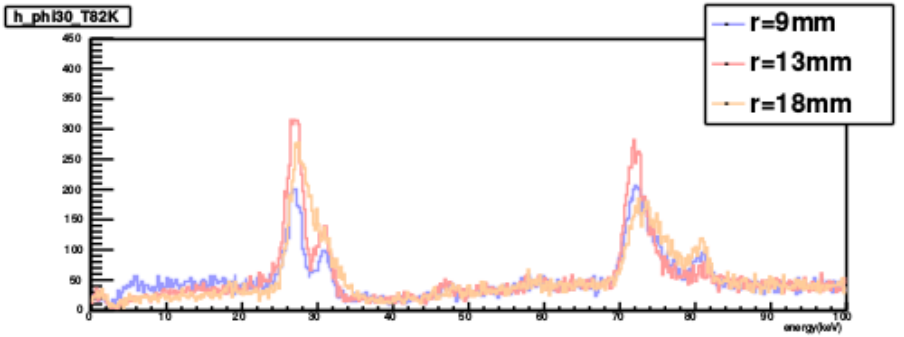

h_phi30_r13mm
energy(keV)

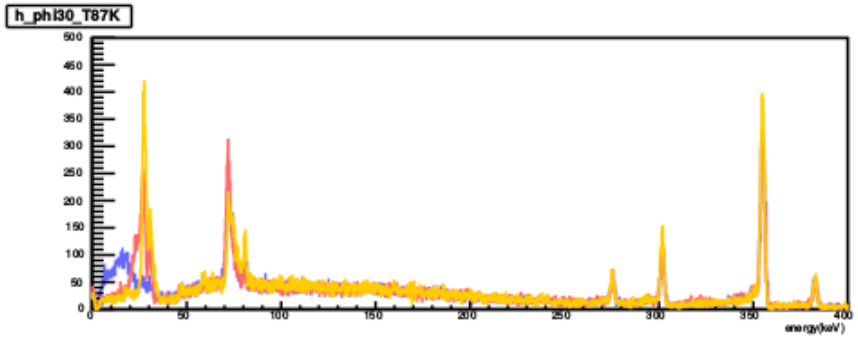

h_phi30_r13mm
T=82K
T=87K
T=98K
T=109K
energy(keV)

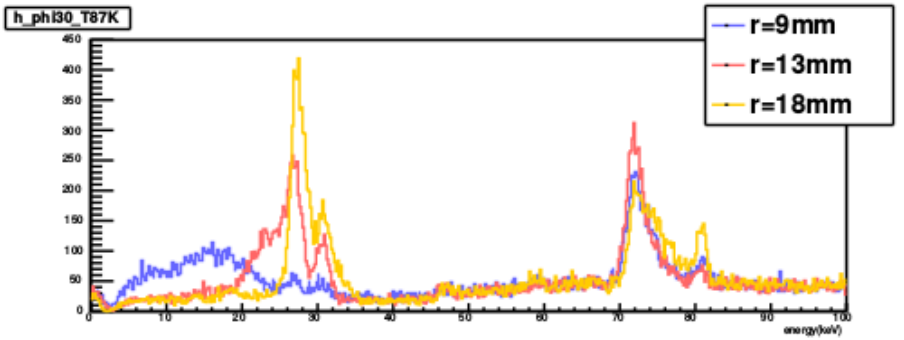

h_phi30_r18mm
energy(keV)

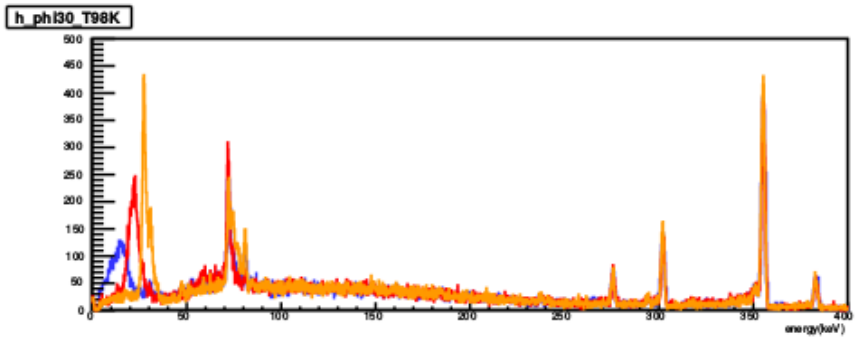

h_phi30_r18mm
T=82K
T=87K
T=98K
T=109K
energy(keV)

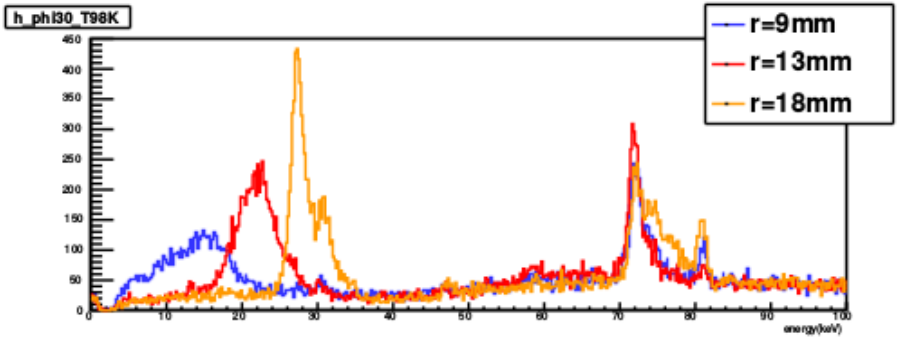

h_phl30_T82K
energy(keV)

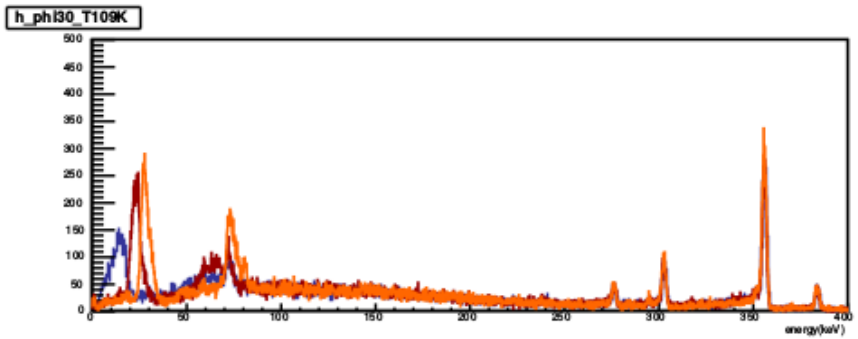

h_phl30_T82K
r=9mm
r=13mm
r=18mm
energy(keV)

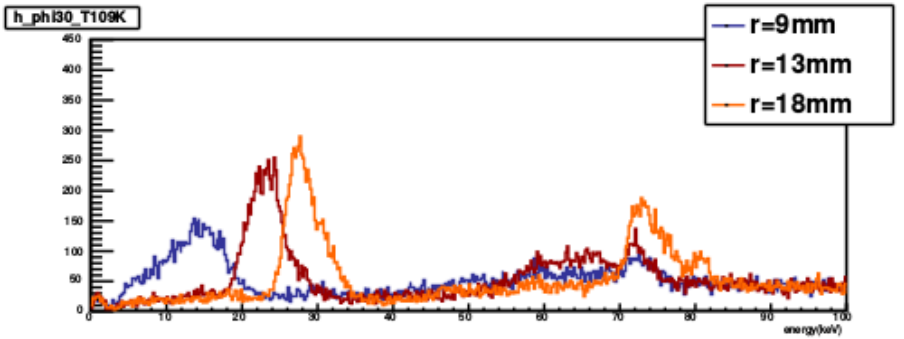

h_phl30_T87K
energy(keV)

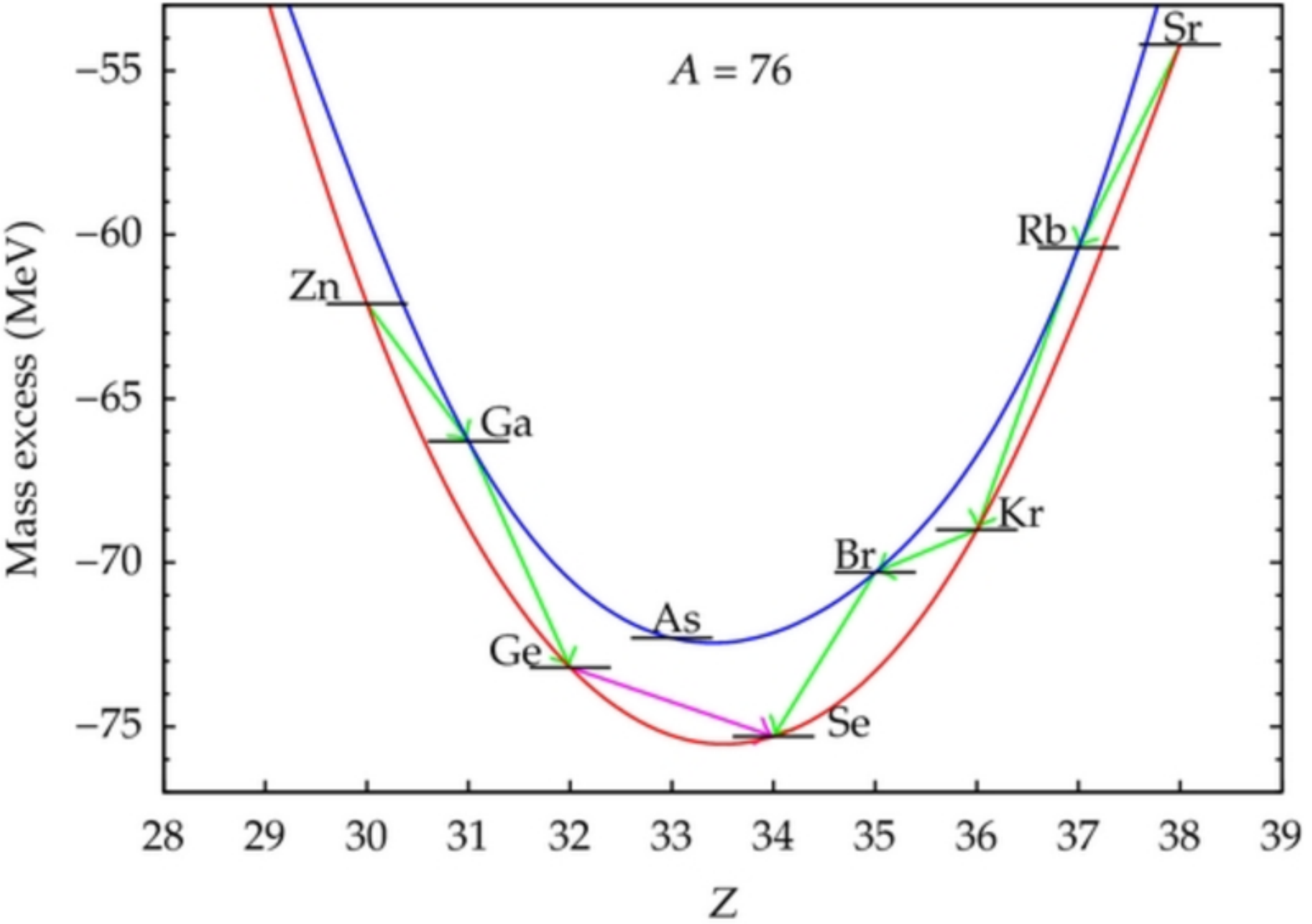

h_phl30_T87K
r=9mm
r=13mm
r=18mm
energy(keV)


h_phl30_T98K
energy(keV)


h_phl30_T98K
r=9mm
r=13mm
r=18mm
energy(keV)


h_phl30_T109K
energy(keV)


h_phl30_T109K
r=9mm
r=13mm
r=18mm
energy(keV)


A = 76
Mass excess (MeV)
−55
−60
−65
−70
−75
Z
28
29
30
31
32
33
34
35
36
37
38
39
Zn
Ga
Ge
As
Se
Br
Kr
Rb
Sr