Modeling the collective motion of charge carriers in Ge semiconductor detectors

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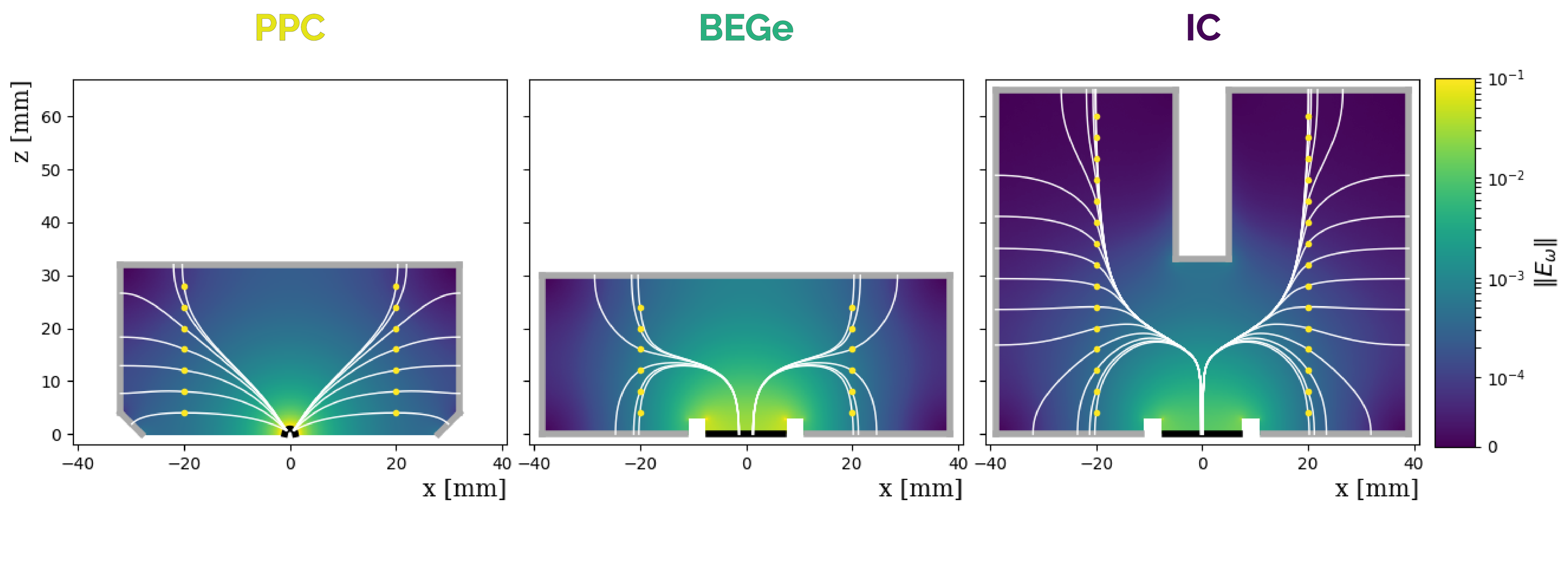
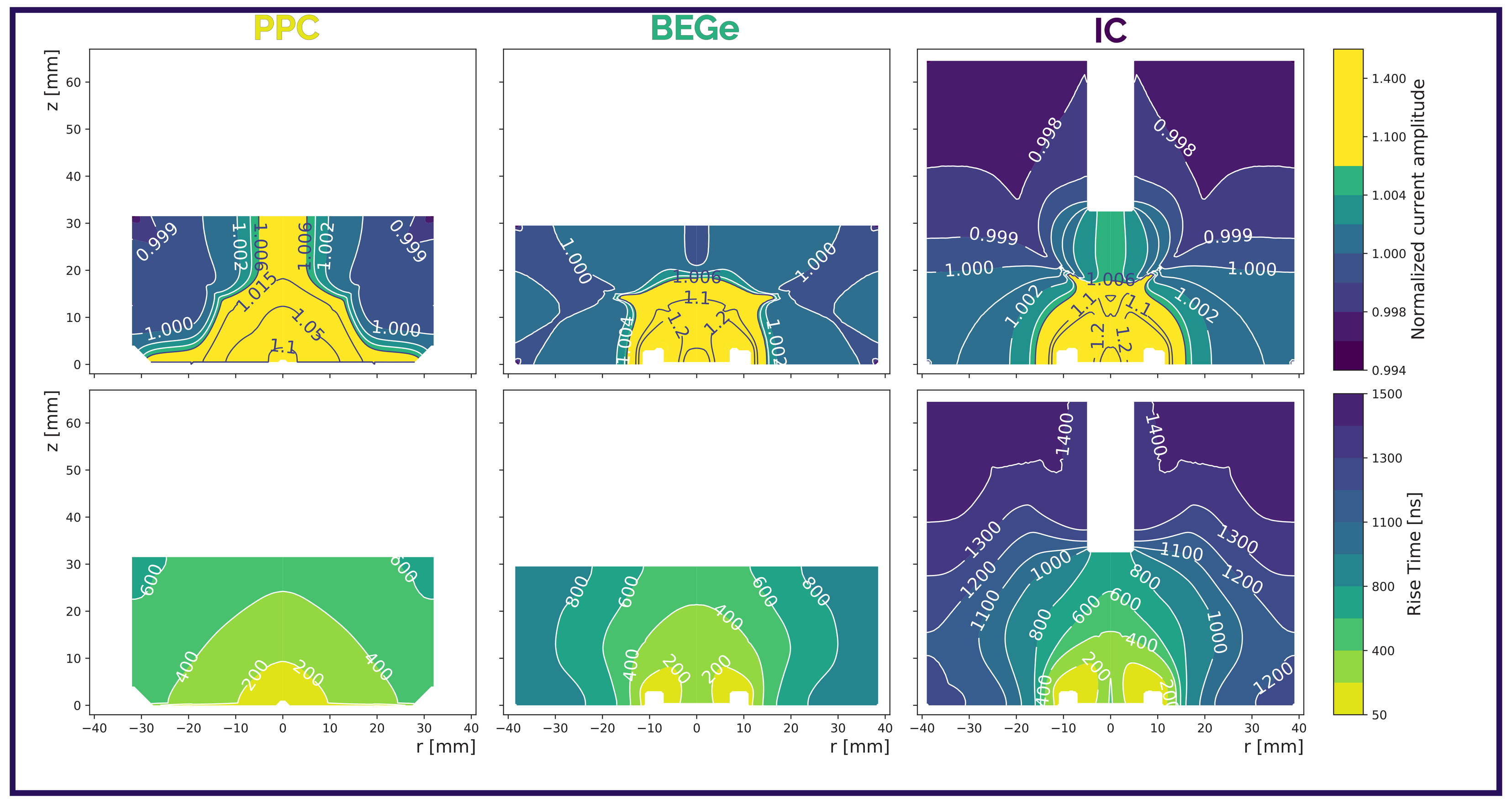


1. Introduction

- Time profile of the signal in germanium detectors reveals information on the topology of the event
- On a typical event, millions of charge carriers are generated inside the detector as one or multiple clusters
- Collective effects deform each cluster and, in turn, the signal shape
- Study these effects with SigGen[6] software and their impact on the event discrimination capabilities, with focus on neutrinoless double-beta decay experiments

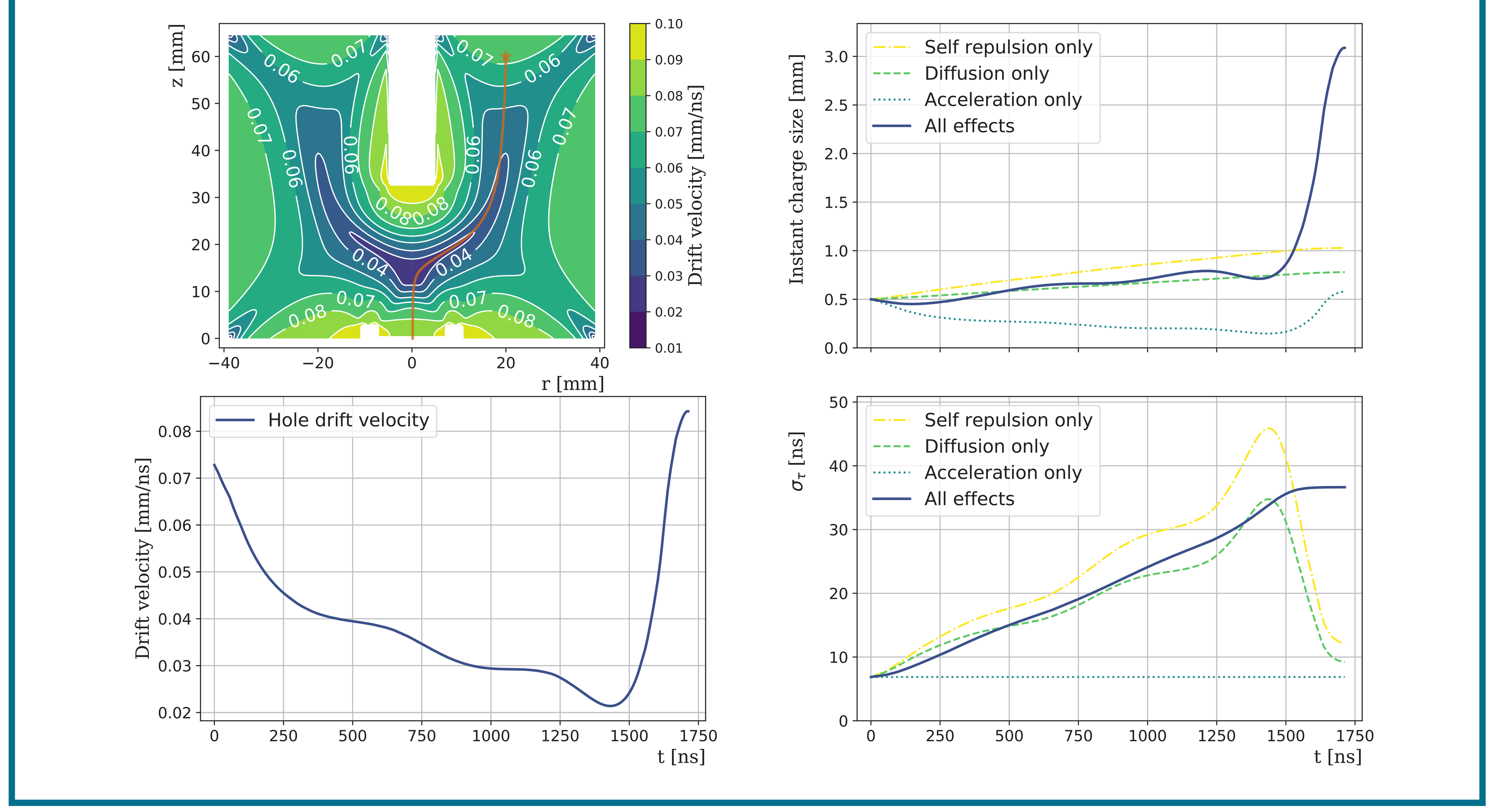


2. Modeling Germanium Detectors

- Signal formation described by Shockley-Ramo theorem[1,2]:

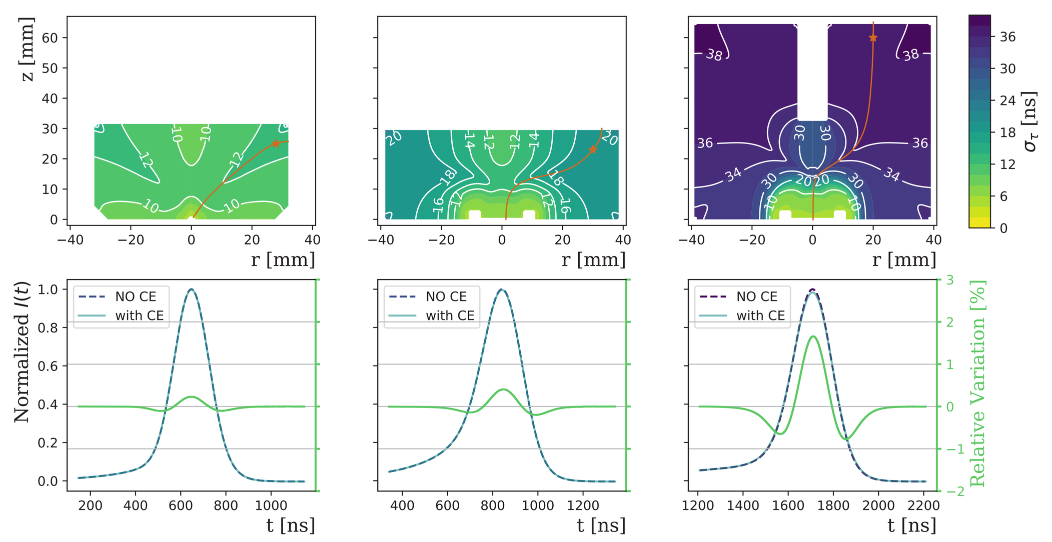
$$I(t) = q\, \mathbf{v}(\mathbf{r}(t)) \cdot \mathbf{E}_w(\mathbf{r}(t))$$

- Modeling in germanium -> development of three geometries used in present and future double-beta decay experiments:
  - *P-type Point-Contact* (**PPC**)[3]
  - *Broad Energy Germanium* (**BEGe**)[4]
  - *Inverted Coaxial* (**IC**)[5]
- All geometries developed to create high E_w close to readout electrode
  - Signal degeneracy
- IC exhibits drift paths which are double the length as for BEGes and PPCs

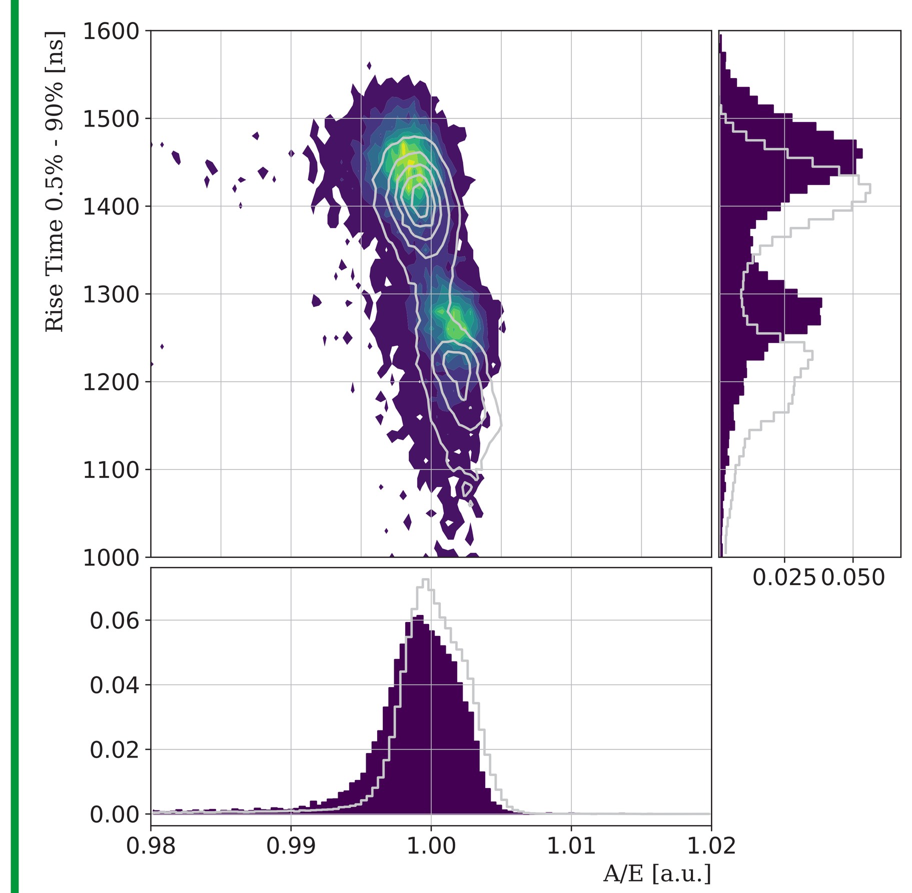


3. Collective motion of charge carriers

- Informations on collective effects in q -> $g(x(t))$
- What deforms the signal shape:
  - *Initial cluster size*
    - *determines initial g(x(0))*
  - *Accelerations*
    - *acceleration -> enlargement*
    - *deceleration -> shrinkage*
  - *Coulomb self repulsion*
    - *always enlarges cluster*
  - *Stochastic diffusion*
    - *always enlarges cluster*
- Interplay of effects gives deformation of cluster in time
- Describe through new parameter σ_τ
- The bigger σ_τ, the lower I(t) -> relevant for IC



4. Impact on neutrinoless double-beta decay

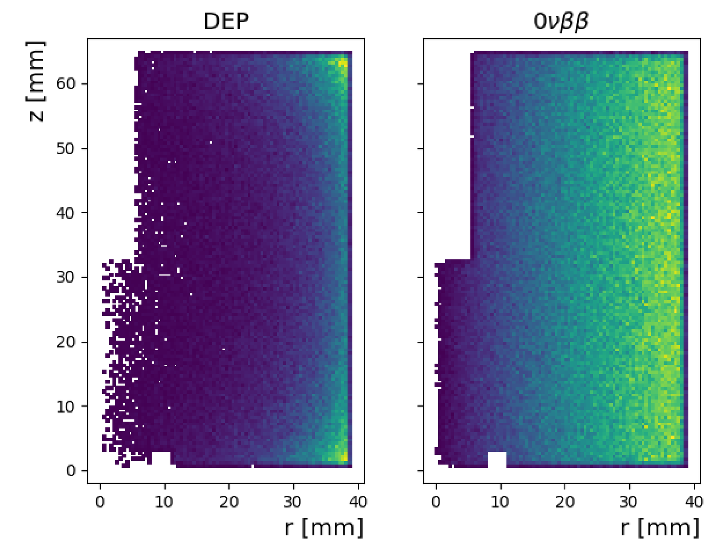


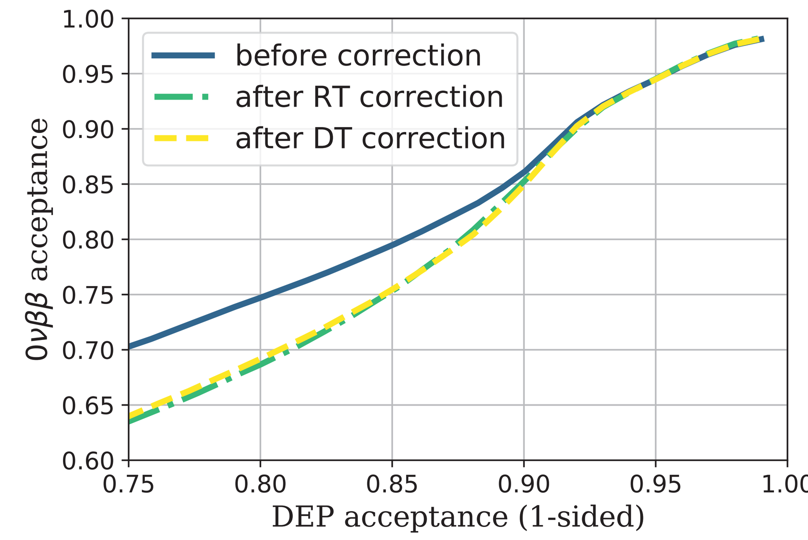
- Maximum of the current I(t) -> Pulse Shape Discrimination (PSD) parameter (A/E[4]) in neutrinoless double-beta decay experiments
- Collective effects bring an undesired position dependence of A/E
  - *Longer drift path -> lower A/E*
- Impact on dicrimination capabilities?
  - *Test in terms of:*
    - *$0\nu\beta\beta$ acceptance*
    - *background rejection*
- Investigated correction based on drift path to restore position independence
- Simulations validated by experimental data

Event class	Simulations: IC Standard		Simulations: IC RT corr		Simulations: BEGe[19, 22] Standard		Data: IC (this work) Standard		Data: IC (this work) RT corr		Data: BEGe [10, 22] Standard	
^{208}Tl DEP	90.00	(8)	90.08	(8)	90	(1)	90.1	(8)	90.1	(8)	90	(1)
^{208}Tl SEP	5.1	(3)	5.8	(3)	8	(1)	5.0	(3)	5.3	(3)	5.5	(6)
^{208}Tl FEP	7.4	(1)	8.1	(1)	12	(2)	7.64	(5)	7.92	(5)	7.3	(4)
CC @$Q_{\beta\beta}$ (^{208}Tl)	45.1	(3)	46.7	(3)	42	(3)	32.3	(2)	33.1	(2)	34	(1)
CC @$Q_{\beta\beta}$ (^{214}Bi)	20.3	(4)	21.8	(4)	–		–		–		21	(3)
$0\nu\beta\beta$	86.07	(6)	85.47	(6)	88	(2)	–		–		–	

5. Outlook

- Detector volumes keep on increasing
  - *Impact of collective effects might get stronger*
  - *Background composition changes with geometry*
  - *Possibility to tune PSD cut to increase $0\nu\beta\beta$ acceptance*
- Explored impact of electronics noise on PSD in IC
- Explored impact of collective effects in longer IC detectors





6. Conclusions

- Discussed collective effects in germanium detectors and impact on signal formation
- Determined that collective effects are relevant for long drift paths
- Checked impact of collective effects on IC discrimination capabilities
- Validated simulation with experimental data
- Performances of IC are suitable for search for neutrinoless double beta decay

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