MIRION
TECHNOLOGIES

Radiation Safety. **Amplified.**

Simulation of radiation detectors at CANBERRA

SOFIE PUT, OLIVIER EVRARD

CANBERRA

Presentation Summary

- **Canberra at a glance**
- **Simulation tools**
- **Fixed charges and interface traps**

- **Shockley-Ramo theorem**
- **Applications on real detectors**
  - Si Drift detectors
  - HPGe

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CANBERRA at a Glance

- Worldwide leader in nuclear measurement
- 50 years in business
- 2012 revenues: over 200M Euros
- Approx 1,000 employees
- 250 customer-facing sales and service personnel
- 40 PhD’s
- 7 industrial sites
- 26 sales and service offices
- 35 distributors
- Over 5,000 customers
- Parent company--AREVA

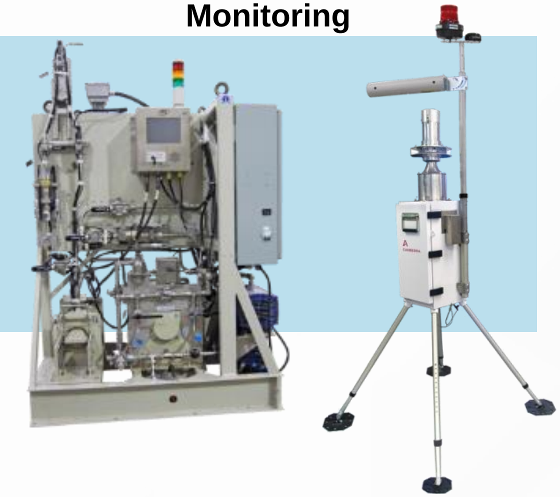
Applications

Radiochemistry

Health Physics

Tactical Military

Environmental and Process Monitoring



NDA Systems

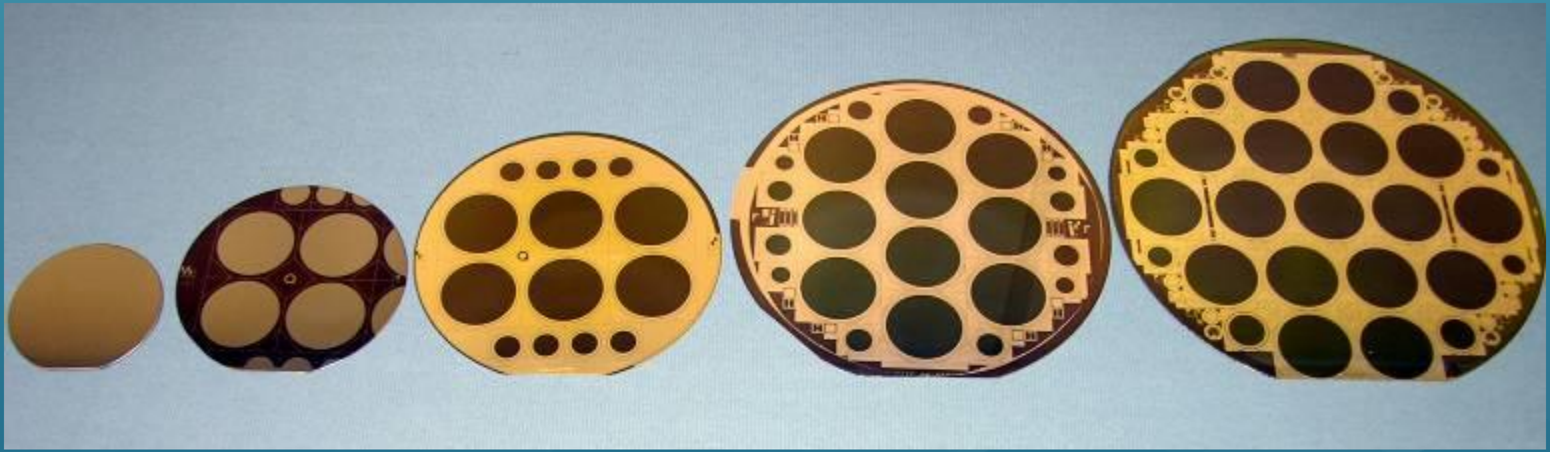
Containment and Surveillance

Canberra Olen at a glance…

- Development and the production of innovative semiconductor detector solutions
- 2 production lines, 1 R&D line
- 2 product lines (Ge and Si) nearly equal size
- R&D cost covered for > 50% by external funding
- Actually 47 collaborators

PIPS Detectors

- **Passivated implanted planar silicon detectors**



PIPS production in Olen

- Only site for Si-detector manufacturing and development for CANBERRA
- Full production and assembly capacity in Olen
- Engineering and fundamental research in-house

Radiochemistry segment A-Series

- Used for environmental monitoring, health physics, nuclear chemistry, earth and marine science

Health physics applications

- Continuous air monitoring of alpha and beta
- Smear and wipe samples in alpha beta counters

i-Solo®

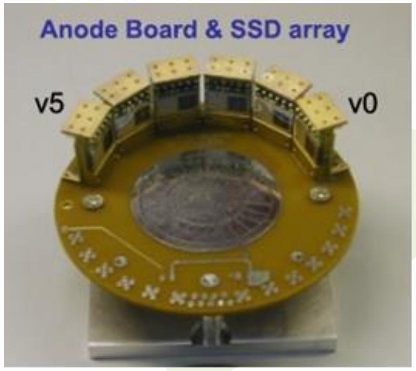
i-MaticTM

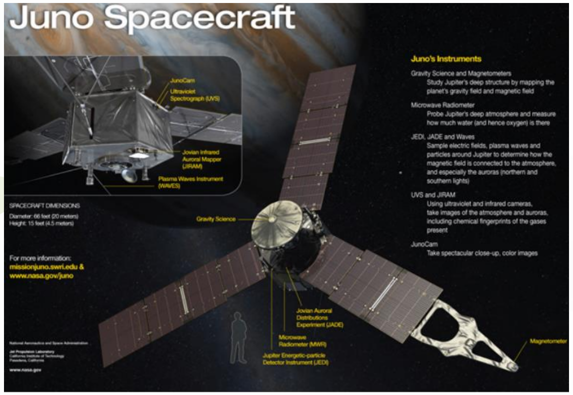
i-CAM

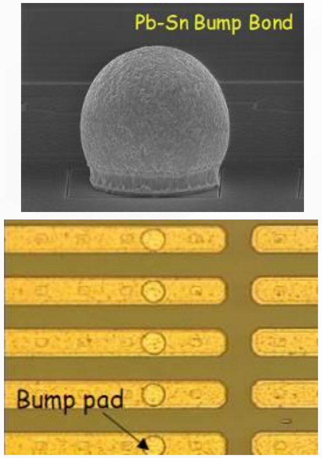
SPAB-15

CAM Sentry

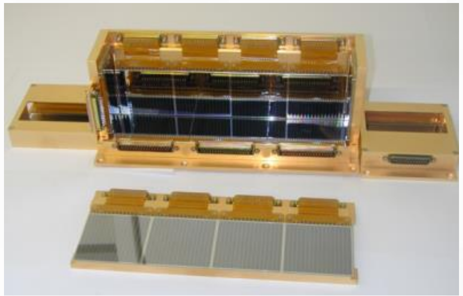
Research projects





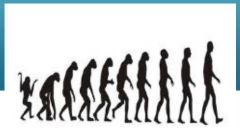


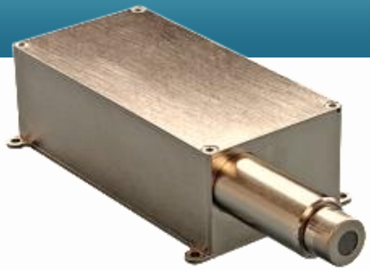
Imaging devices used at CERN



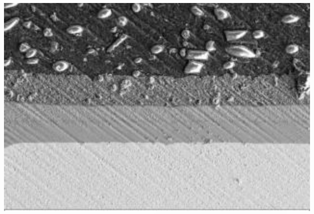
PIPS detectors used to detect new elements 112, 113, 114, 116, 118…

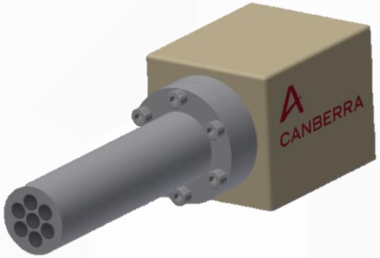
Sales to OEM - SDD



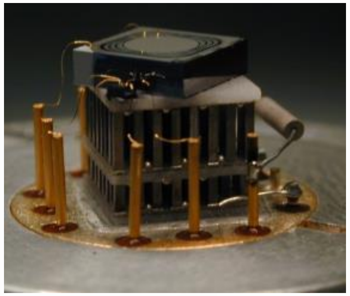


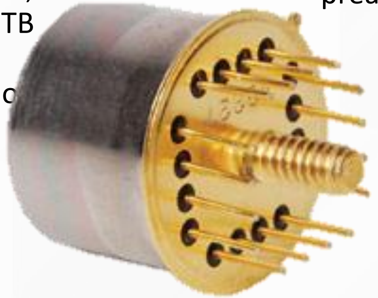
Multilayer collimator

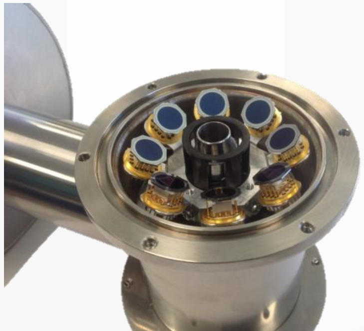




2004	2006	2008	2010	2012	2013	2015	2016
Launch of TEC cooled X-PIPS	1500µm detector	First SDD on the market	80mm² detector	Improved performances (multilayer collimator, better PTB and Resolutio	30mm² detector	CMOS front end Compact preamplifier	Mutli-element SDDs
190eV PTB>1100	**200eV PTB>1500**	**150eV PTB>4000**	**160eV PTB>4000**	**145eV PTB>10000**	**145eV PTB>10000**	**130eV PTB>12000**	**130eV PTB>12000**







HPGe detectors

- **High purity germanium detectors**

MIRION TECHNOLOGIES

CANBERRA

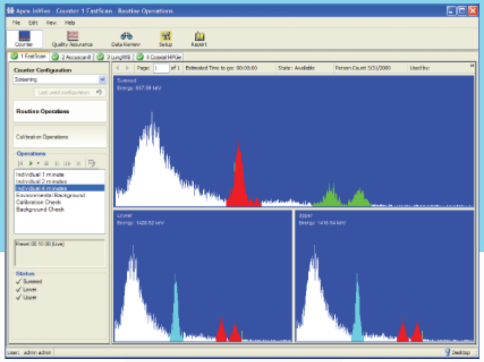
HPGe detector production in Olen

- Engineering and fundamental research in-house
- Manufacturing engineering focused on operational excellence

Leader in Gamma Spectroscopy Solutions

Proven Solutions for In Vivo Counting

Apex-InVivo™



Comprehensive Non-Destructive - Waste Assay Solutions

R&D at Olen

Image credit: NASA /JPL-Caltech/SwRI

Activities of the R&D division in Olen

- Develop novel and cost effective silicon and germanium based detector systems
  - For different radiations (α, β, γ and X ray detection)
  - For different applications (XRF, military, D&D,…)
- Collaborations: institutes and scientific community, funding novel research projects
- Creation and protection of IPs
- Maintain and upgrade an efficient technology watch process
- Support to local groups
  - Clean room and back end investments
  - Process development: devising of PFC, simulations: implantation, oxidation, carrier drift
  - Development of novel characterization techniques
  - Training and troubleshooting

Olen core competences

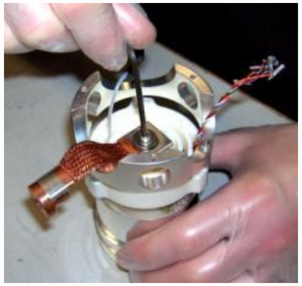
Core competences (1/3)

- Expert knowledge on HPGe detector processing and physics
  - Shaping (polishing, drilling…)
  - Implant
  - Etching
  - Contacts
  - Handling

- Expert level in silicon detector processing and physics
  - Material characterization
  - Clean room expertise
  - High quality oxide growing
  - Thin implantations and annealing steps
  - Etching
  - Metallization (aluminium, Aluminium Silicon…)
  - Detector characterization

Core competences (2/3)

- Fundamentals of cooled assemblies
  - < -100degr C => LN2, electrical pump, pulsed tube, JT-coolers
  - < -50degr C => Thermo-coolers
  - Vacuum encapsulation
- Expert knowledge on detector assemblies
  - Cryogenic assembly
  - Space qualified assemblies
  - Detector assembly as a whole
  - Wire bonding techniques (Au and Aluminium)
- Qualified soldering staff according to ESA norm



Core competences (3/3)

- Expert knowledge detection
  - Gamma-ray
  - X-ray and photon
  - Charged particles
  - Fundamentals of extreme low noise front end electronics
- Open innovation structure with partnerships
- Trained staff in innovation
- Black belt certified 6sigma staff
- Black belt certified lean staff
- Highly dedicated team, each and everyone assuming ownership to meet and exceed customer expectations

Recognizing Canberra Olen as one of the fastest growers in the region

Trends
GAZELLEN
2014

Canberra Semiconductor

behoort als snelst groeiende onderneming tot de Trends Gazellen 2014
van de provincie Antwerpen in de categorie middelgrote ondernemingen.

Uitgereikt te Antwerpen op 12.03.2014

In samenwerking met

acerta Gimv KBC KPMG NISSAN

Met dank aan:

kanaalZ Trends TOP B-information Provincie Antwerpen

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Sentaurus TCAD

- Sentaurus TCAD simulates the fabrication, operation and reliability of semiconductor devices.
- Solve fundamental, physical partial differential equations in 2D and 3D:
  - Poisson equation, hole and electron continuity equations

$$\nabla^2\Psi = -\frac{\rho_f}{\varepsilon} \qquad \rho_f = -q(p - n + N_d - N_a) - \rho_{trap}$$

$$\nabla \cdot \vec{J}_n = qR_{\text{net}} + q\frac{\partial n}{\partial t}$$

$$-\nabla \cdot \vec{J}_p = qR \qquad \partial p$$

q is the elementary electronic charge.

n and p are the electron and hole densities.

N_{D} is the concentration of ionized donors.

N_{A} is the concentration of ionized acceptors.

ρ_{trap} is the charge density contributed by traps and fixed charges

ε is the electrical permittivity.

R_{net} is the net recombination rate.

$\vec{J}_n$ is the electron current density.

$\vec{J}_p$ is the hole current density.

n and p are the electron and hole density

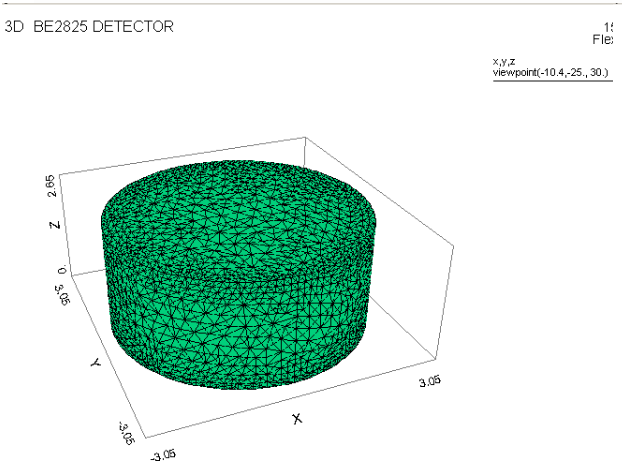
FLEX-PDE

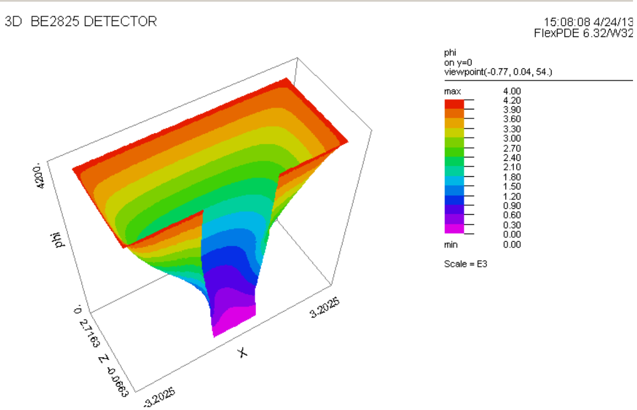
- FLEXPDE is a scripted finite element model builder and numerical solver
- FLEXPDE has no pre-defined problem domain or equation list
  - The choice of partial differential equations and boundary conditions is totally up to the user
- CANBERRA developed the SEMPHASE module to solve the Poisson Equation

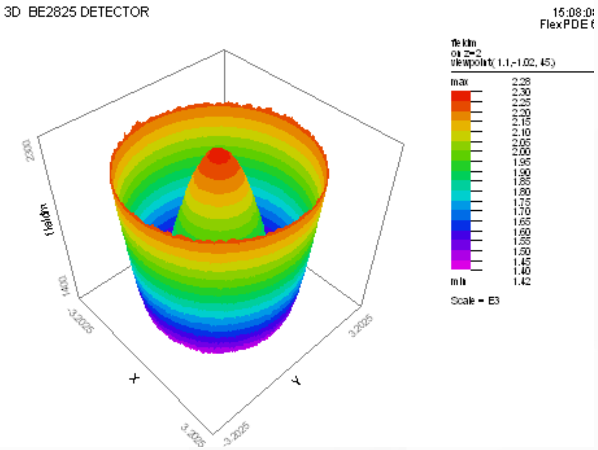
$$\nabla^2\Psi = -\frac{\rho_f}{\varepsilon}$$

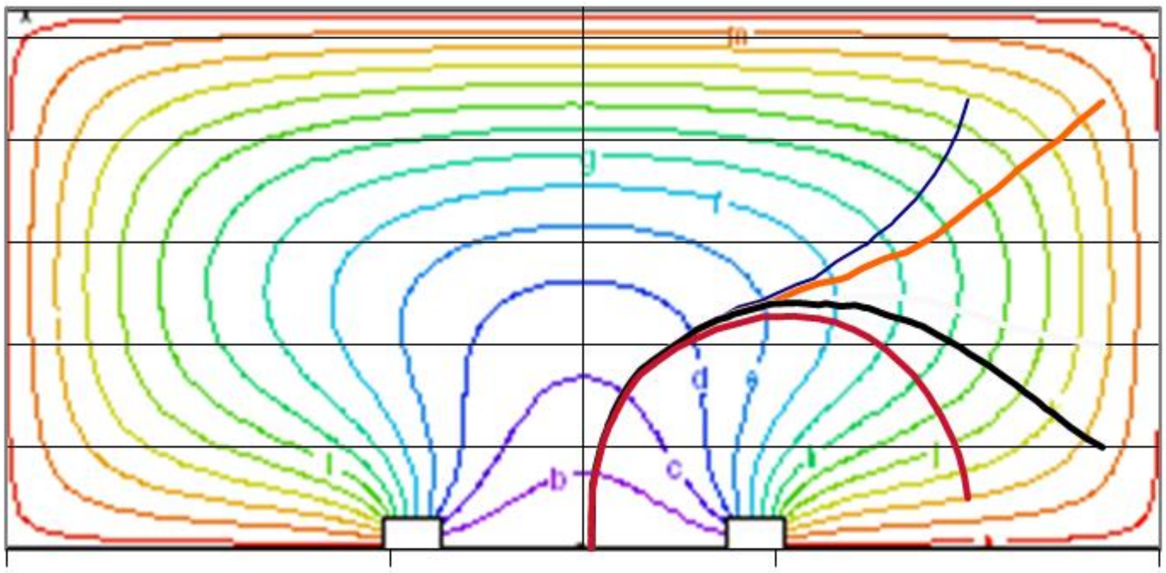
$$\rho_f = -q(p - n + N_d - N_a) - \rho_{trap}$$

Calculation of particle trajectories with FLEX-PDE & SEMPHASE









Trajectories calculated from

$$v = \mu \cdot E$$

$$E_x = \frac{d\Psi}{dx}$$

$$E_y = \frac{d\Psi}{dy}$$

Shockley-Ramo theorem

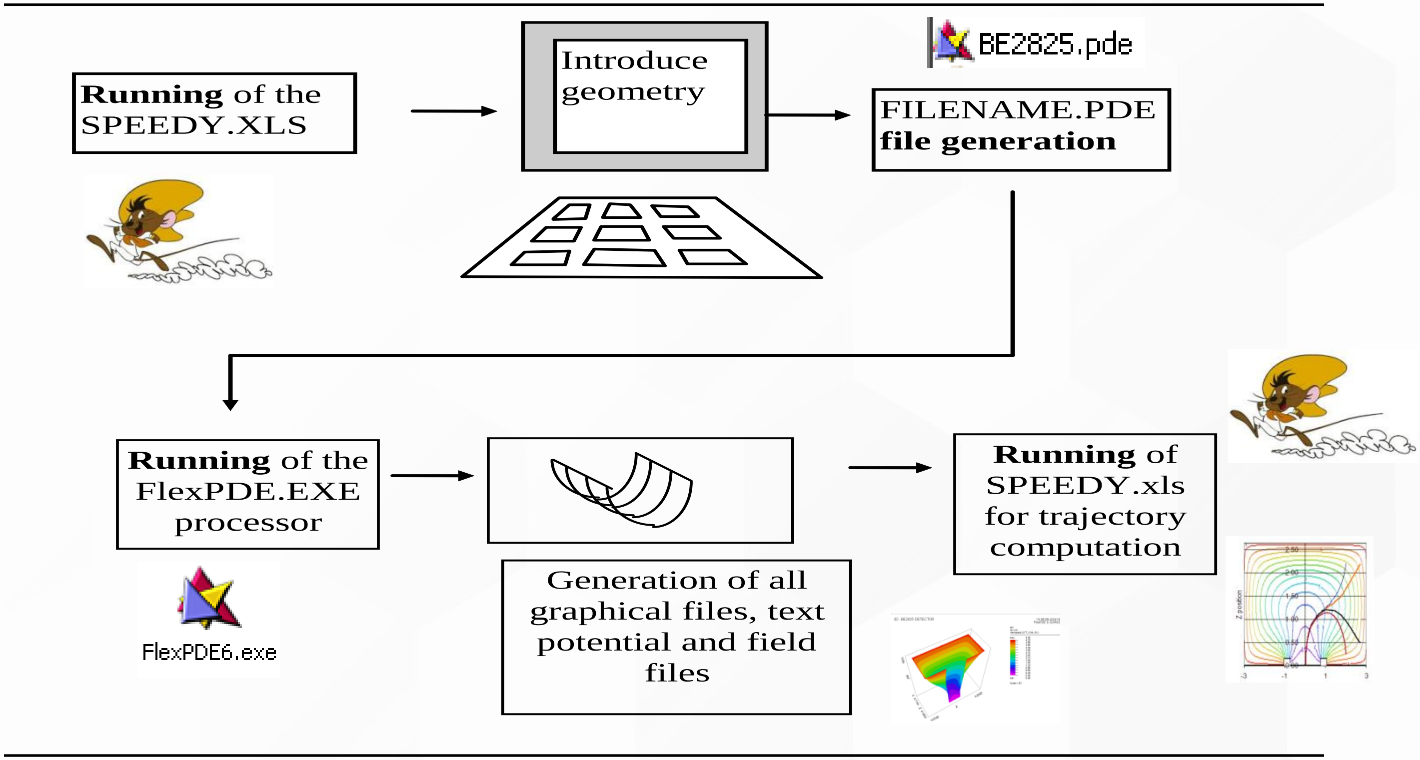
- Detector output pulse forms as soon as incident particle deposit its energy
- The current pulse can be calculated from:

$$i = q \cdot \vec{v} \cdot \overrightarrow{E_0}$$

- With $\vec{v}$ speed and $\overrightarrow{E_0}$ the weighting field
- $\overrightarrow{E_0}$ can be calculated by:
  - Voltage on electrode for which to induced charge = 1
  - Other electrodes to 0
  - Solve Poisson without trapped charge
  - Solution is weighting potential, its gradient is weighting field

Can be done with FLEX PDE

- SPEEDY: Simulator of signal Pulse for Partial EnErgy Determination and Inference



Running of the SPEEDY.XLS

Introduce geometry

FILENAME.PDE **file generation**

Running of the FlexPDE.EXE processor

Generation of all graphical files, text potential and field files

Running of SPEEDY.xls for trajectory computation

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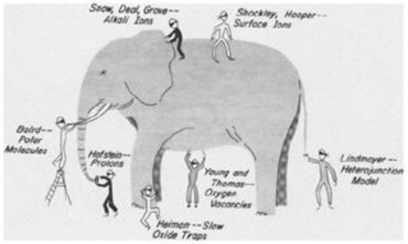
Charges in Si/SiO_2 interface

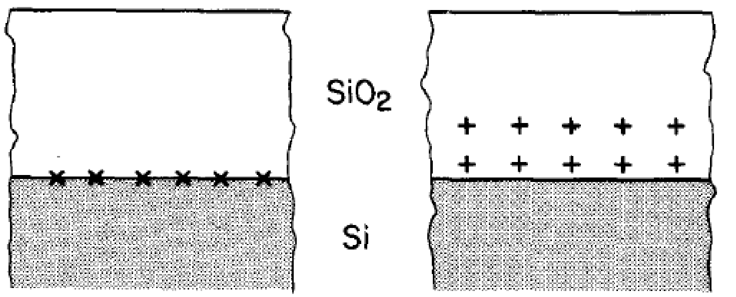


The Current Understanding of Charges in the Thermally Oxidized Silicon Structure

Bruce E. Deal*

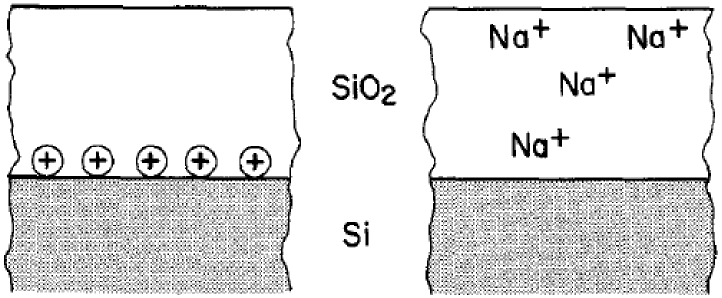
J. Electrochem. Soc.: REVIEWS AND NEWS

June 1974



FAST SURFACE STATES, N_{st}

TRAPS IONIZED BY RADIATION, N_{ot}

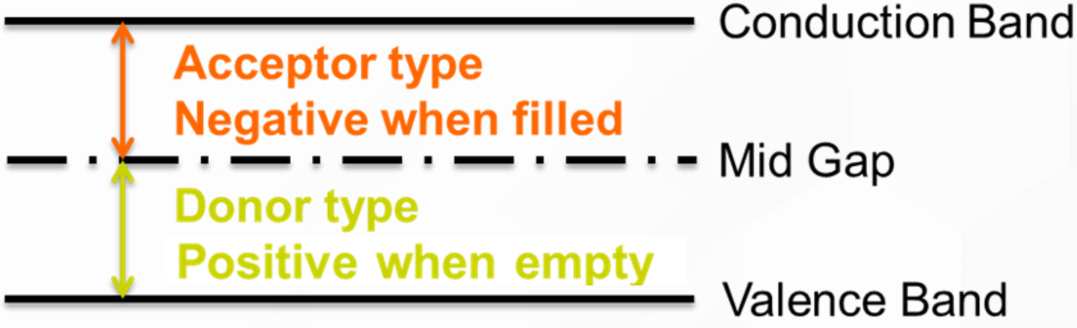


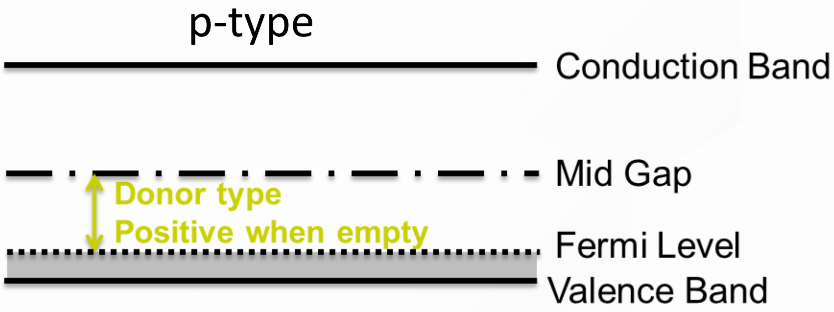
FIXED SURFACE-STATE CHARGE, Q_{SS}

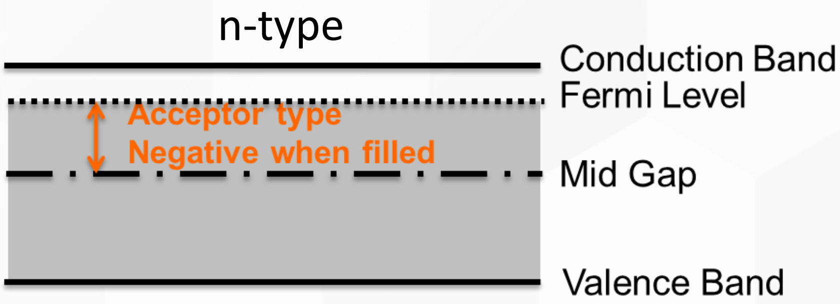
MOBILE IMPURITY IONS, Q_0

Surface states: Positively or Negatively charged?

- Interface traps are amphoteric
  - Donor traps (positive when empty, neutral when charged)
  - Acceptor traps (neutral when empty, negative when charged).







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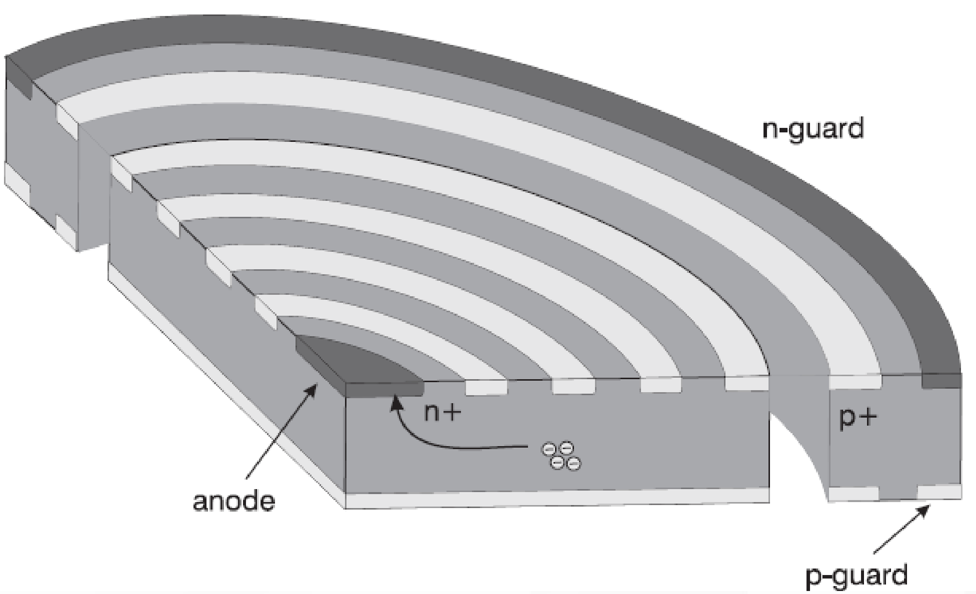
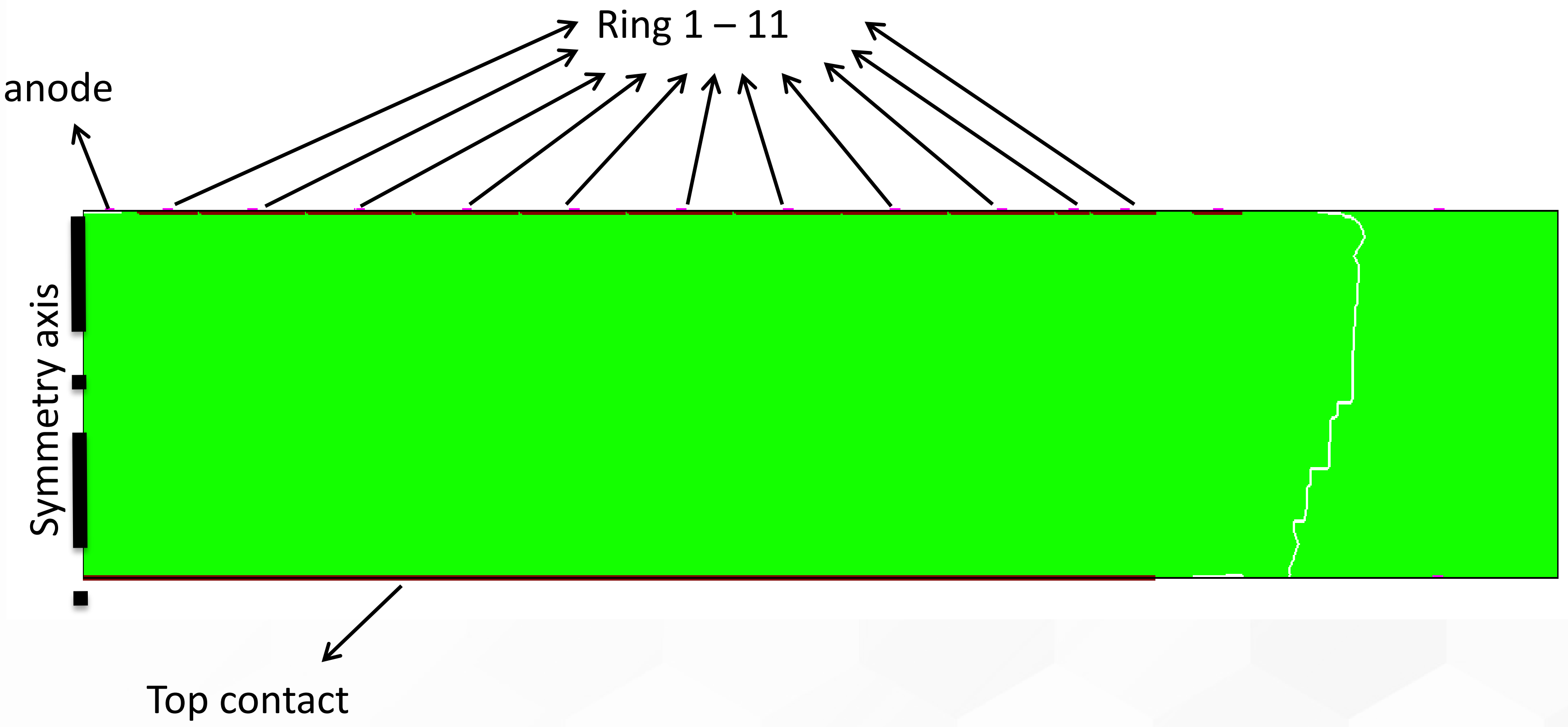
Si Drift Detector

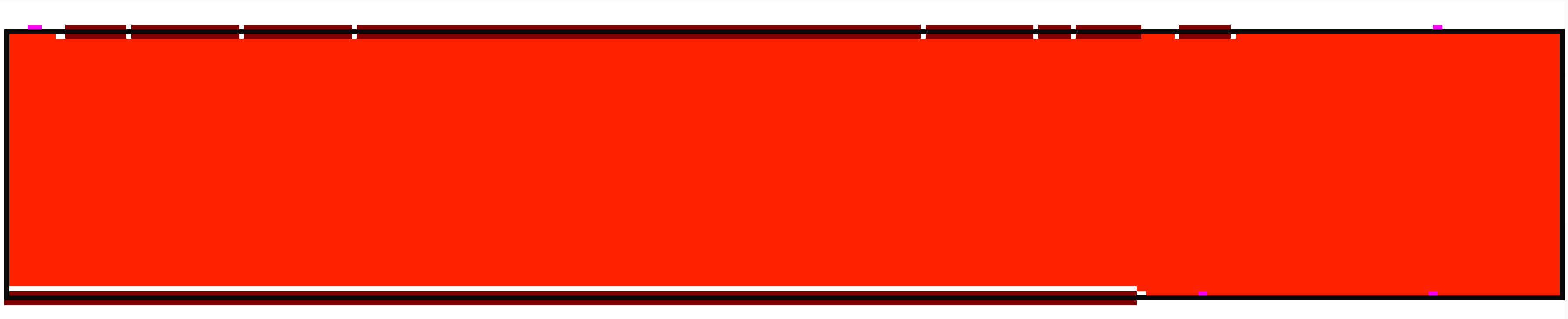
- Small n+ anode
  - Small read out capacitance
- Voltage gradiant at p+ junctions
  - Create a lateral drift field towards n+ anode



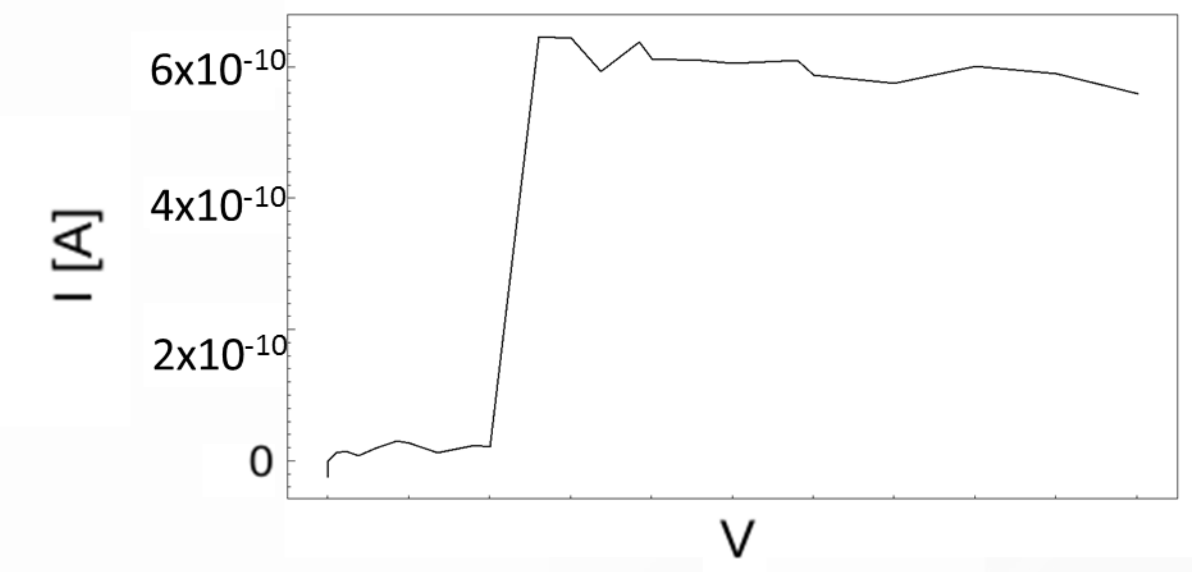
Structure simulated



Depletion of detector by increasing bias voltage at rings and at radiation side



Leakage current as a function of biasing



Validation with theory

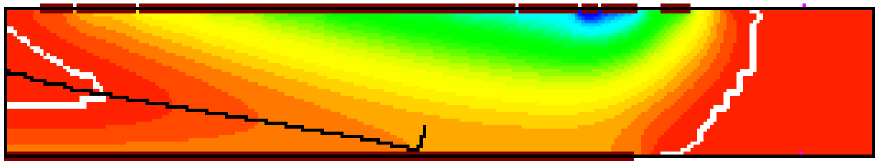
$$J_{bulk} = \frac{q \cdot n_i \cdot W}{2 \cdot \tau} = 0.64\, nA/cm^2$$

- With q= 1.6e-19 C, n_i= 8e9 cm^{-3}, W= 500 µm, τ= 50 ms
- Close to simulation value

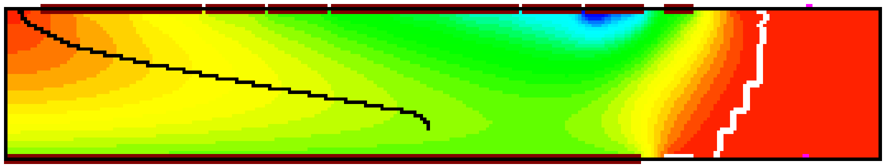
Convergence of the electron highway

- Electron trajectory as a function of voltage at the radiation side (Vrad)

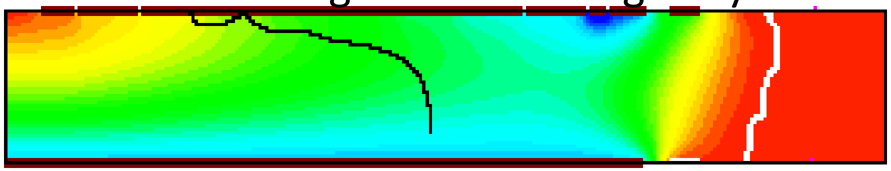
|Vrad| to low
Detector not yet depleted



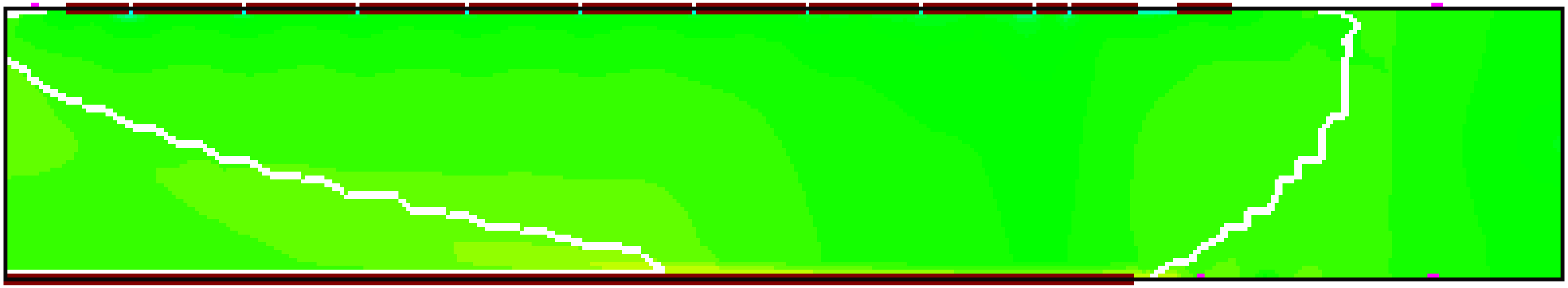
|Vrad| optimal
Convergence of electron highway



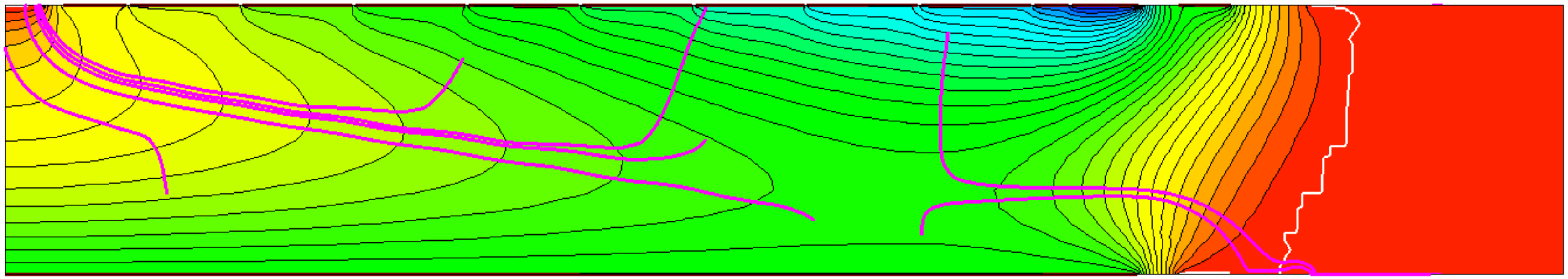
|Vrad| too high
Crashing of electron highway



Electron current density as a function biasing



Electron trajectories: effect of saddle point



- Saddle point: electrons generated at the right of the saddle point are collected by the edge ring

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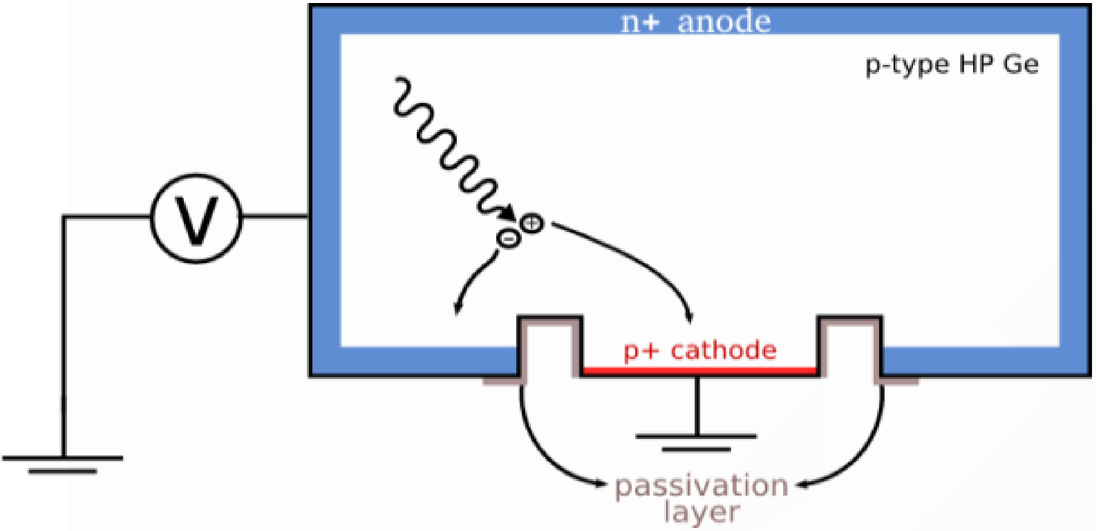
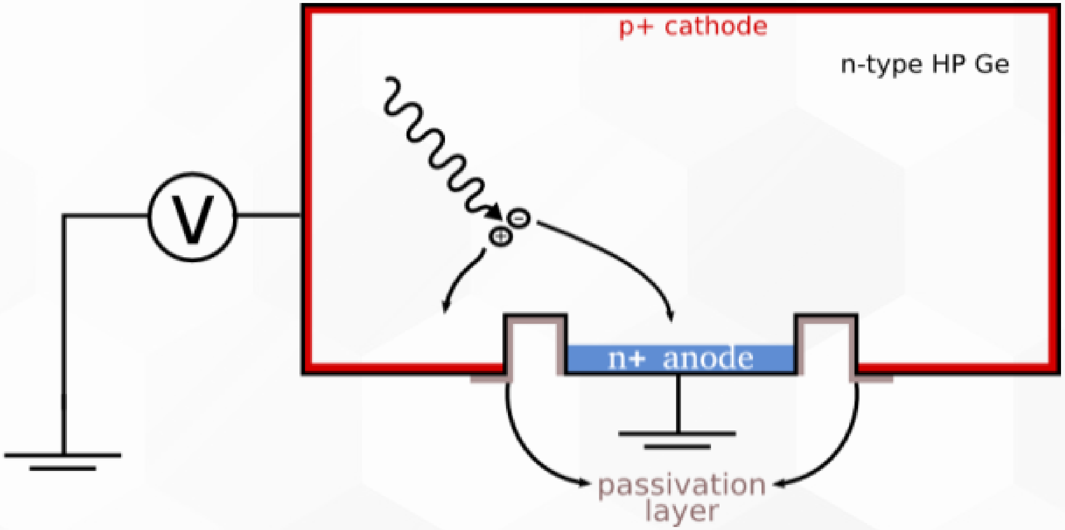
HPGe Detector

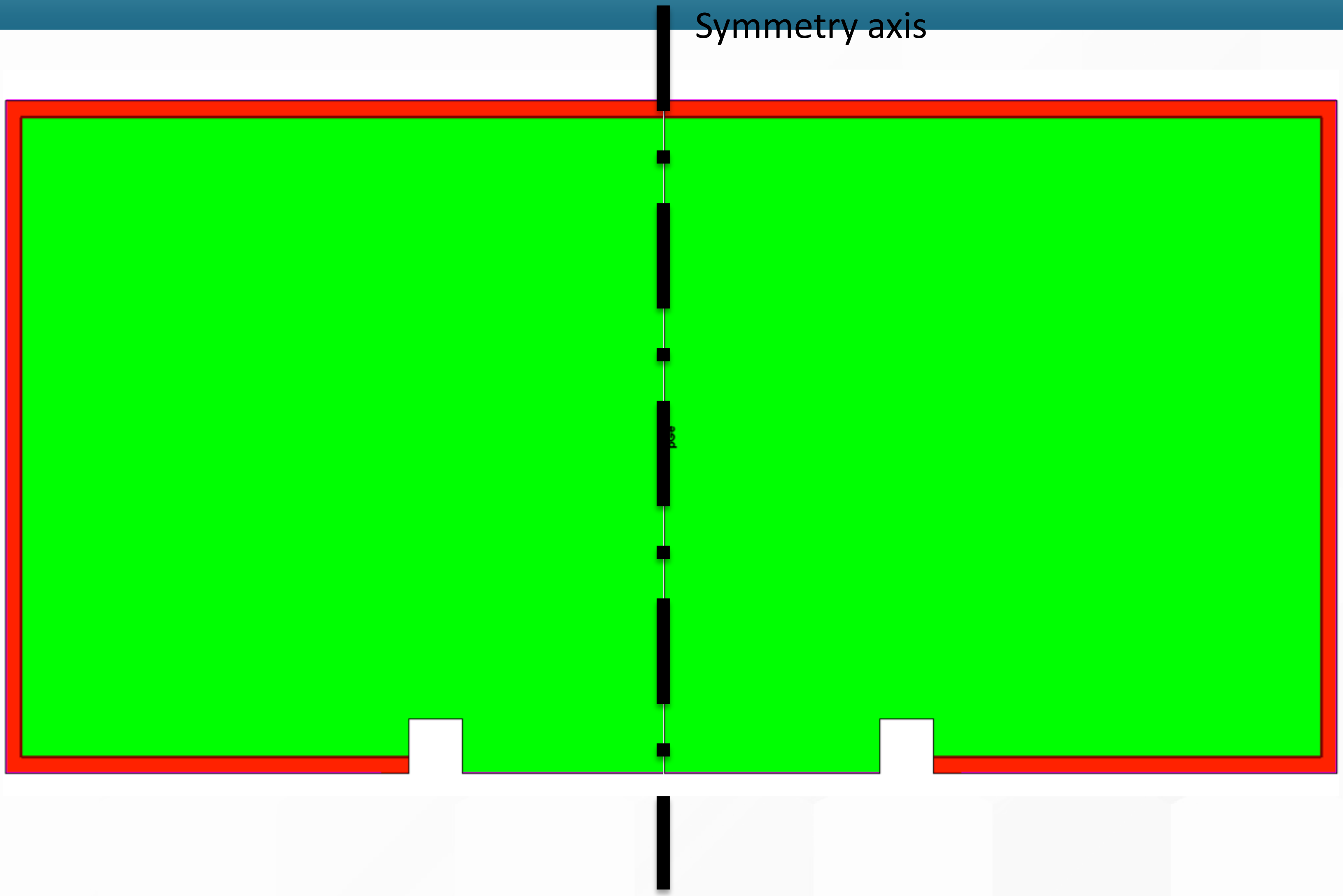


- p-type Broad Energy Germanium(BEGe®)
- E-range 3 keV-3MeV

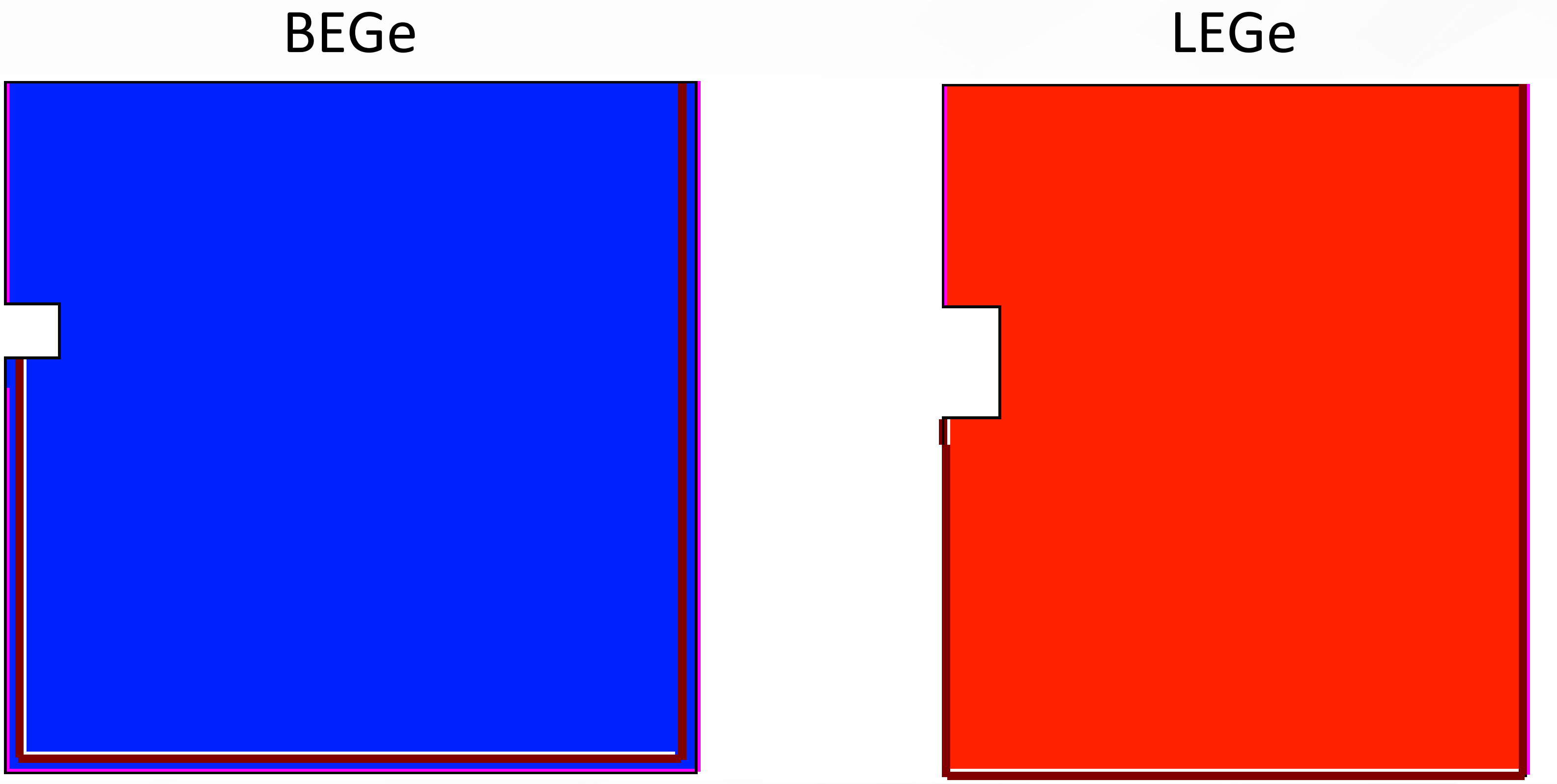


- n-type Low Energy Ge (LEGe®)
- Optimized for low and moderate energies (3 keV-500 keV)

Simulations: cylindrical symmetry

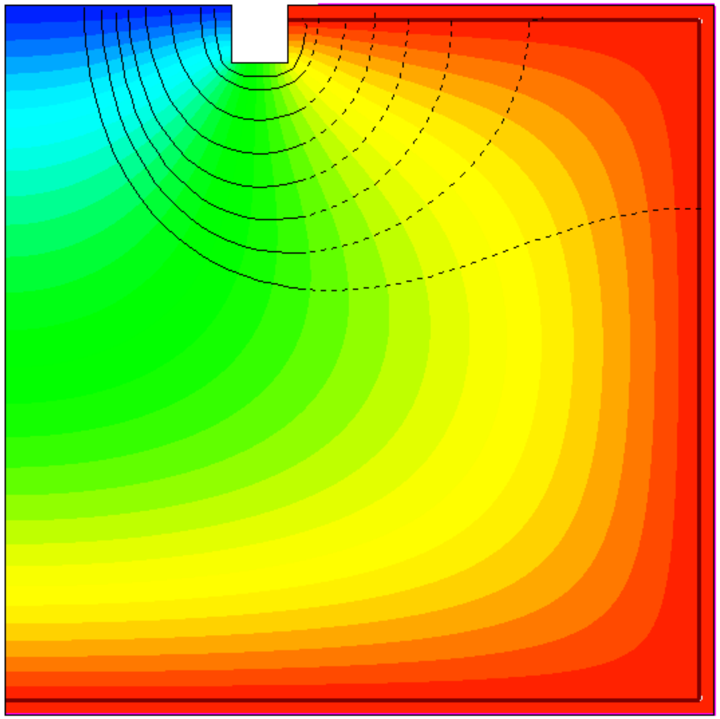


Depletion of HPGe detector

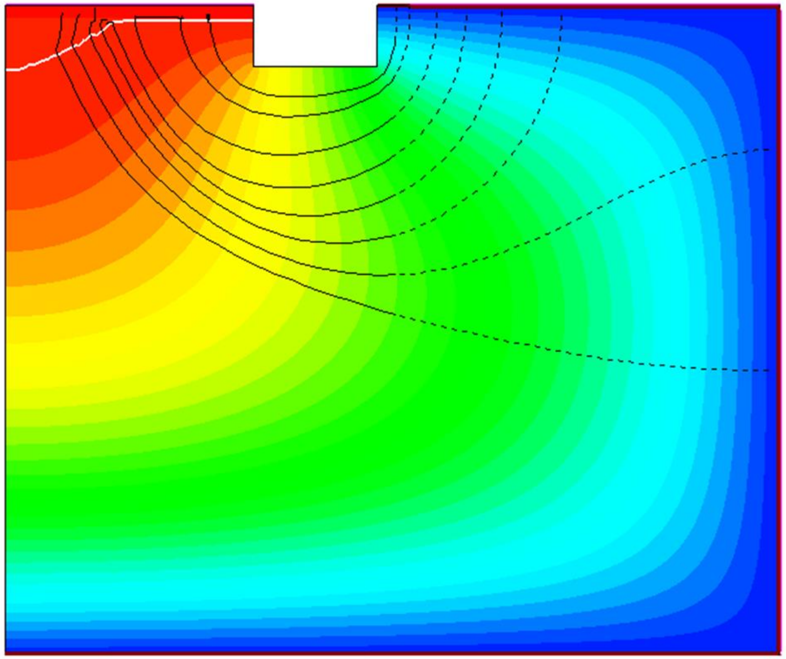


LEGe

BEGe

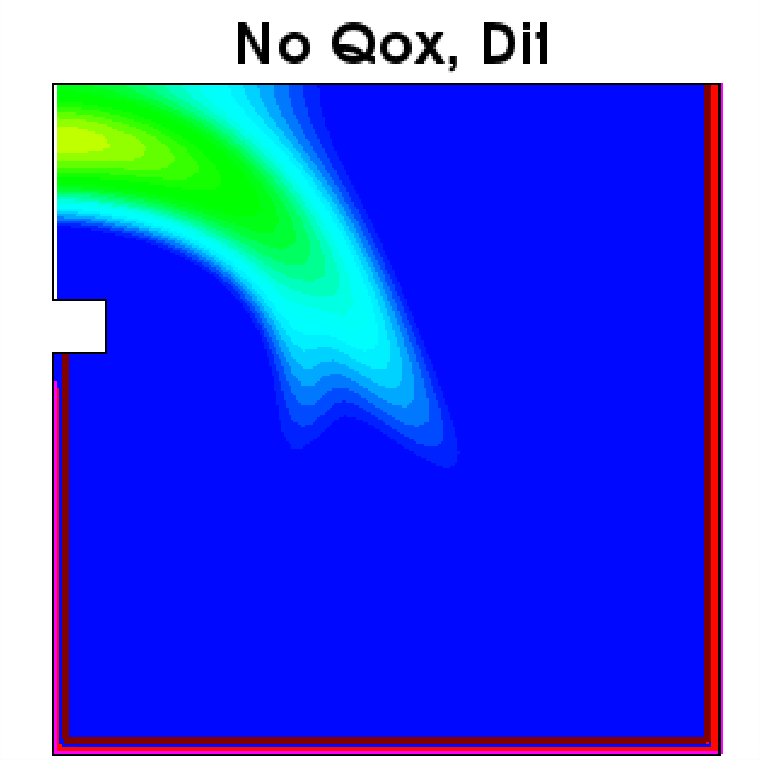


LEGe

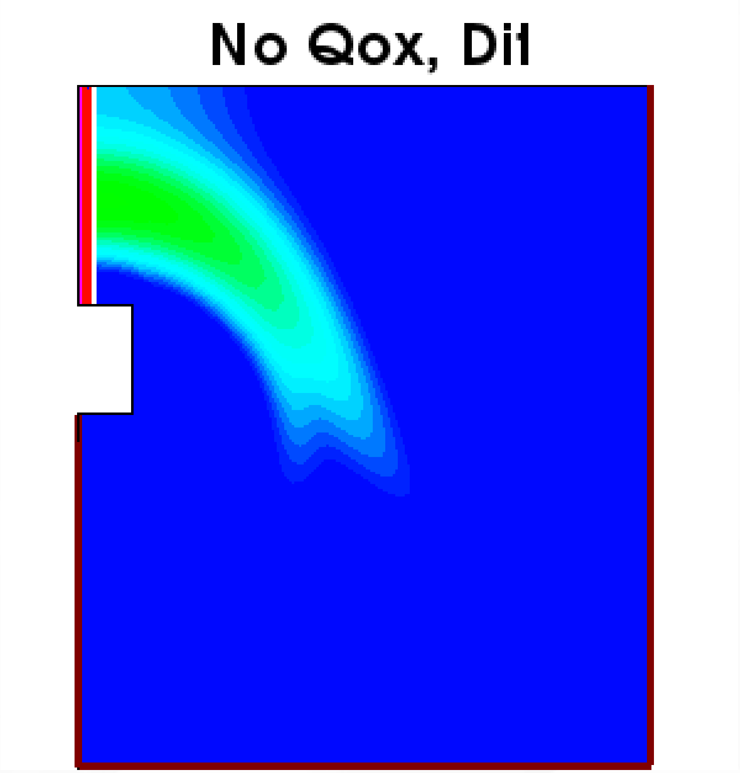


Current density

BEGe

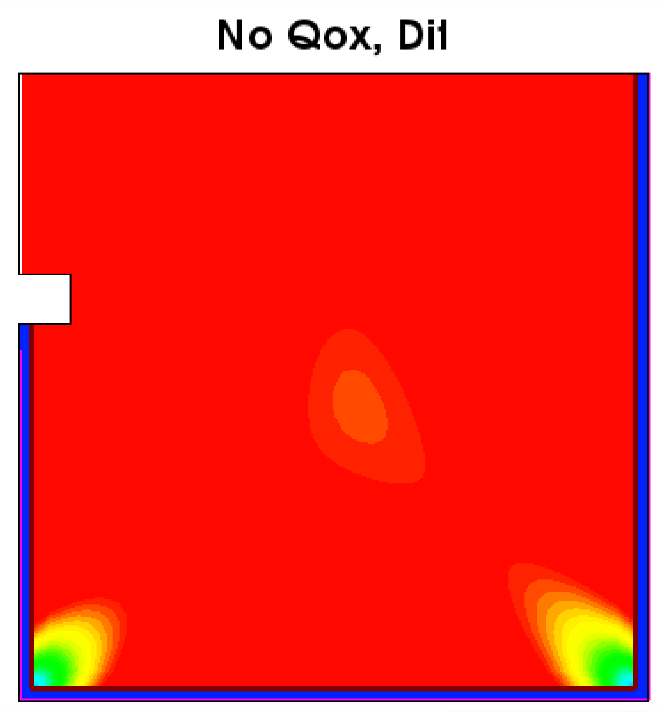


LEGe



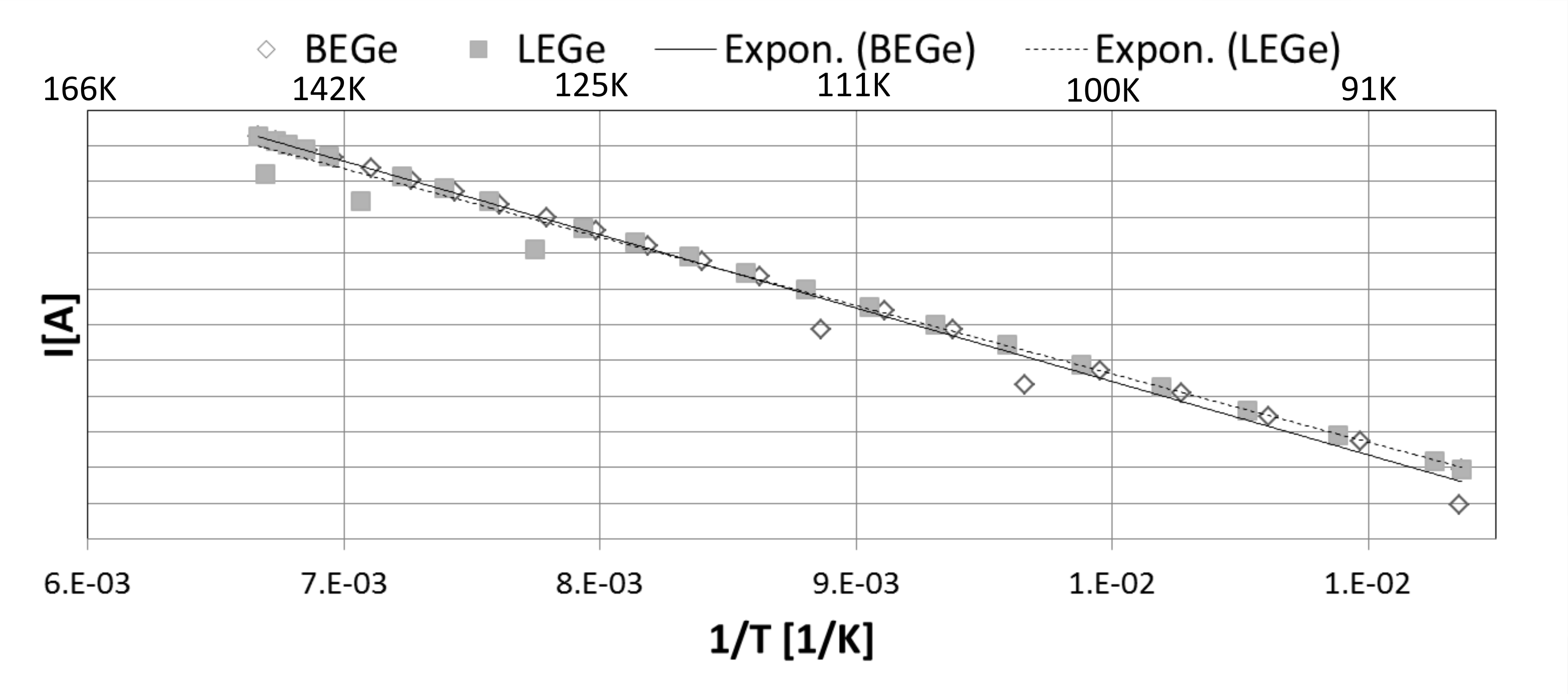
Electrical field

BEGe



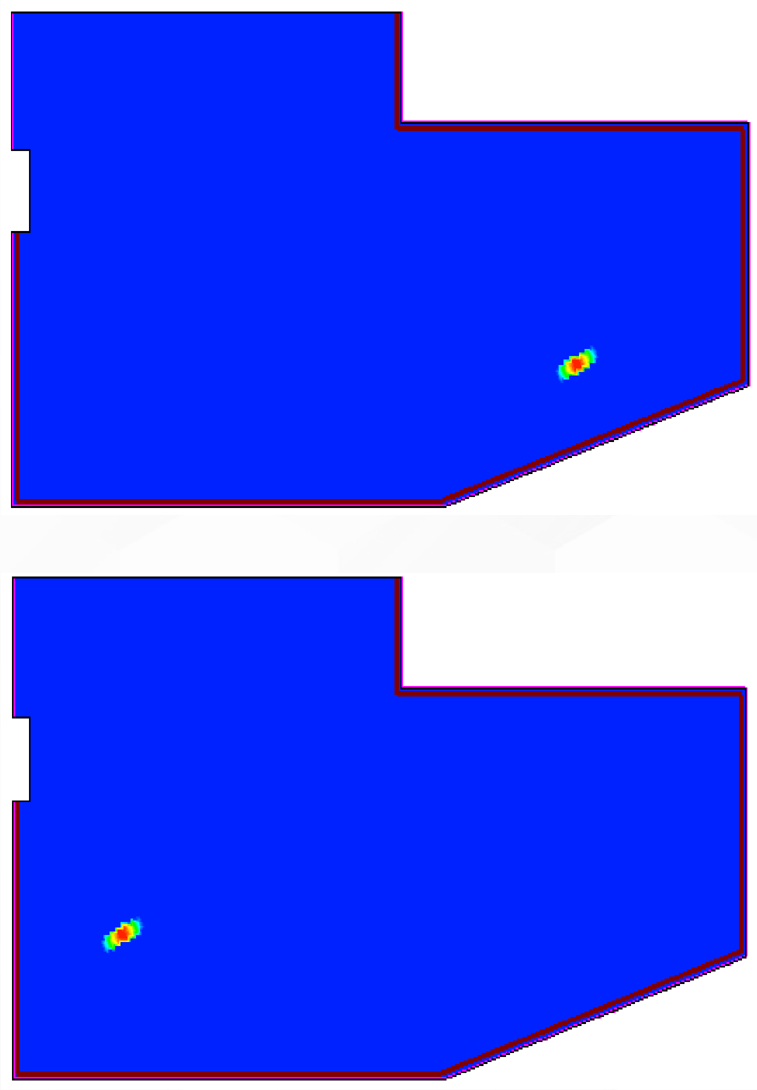
LEGe

Leakage current vs Temperature (150K -> 88K)



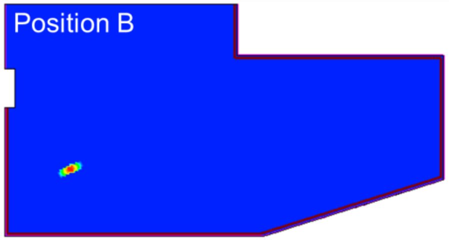
Transient simulations

- Pulse Optical Generation
  - Electron hole pairs deposited in structure
  - Gaussian Profile

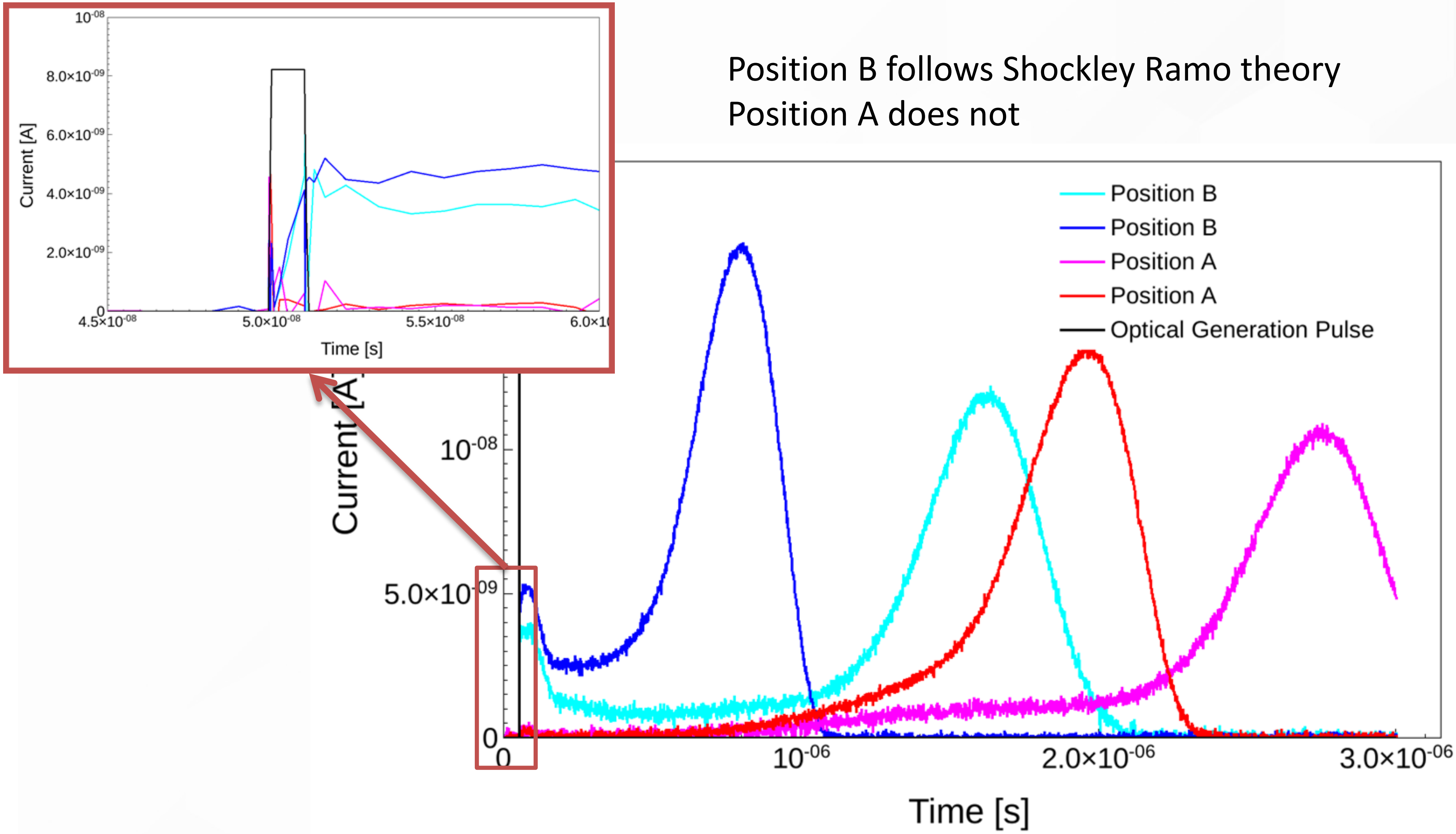


Pulse Generation

Ra



Position B follows Shockley Ramo theory
Position A does not



Conclusions

- Simulation of detectors has several advantages
  - Narrowing experimental matrix
    - New detector design
    - Biasing
  - Understand physical mechanisms of observations
- FLEX-PDE
  - Home-made module to solve Poisson equations
  - Carrier drift with simple calculations
  - Limited cost
- Sentaurus TCAD
  - Poisson equation, electron and hole continuity equations
  - Supported with several physical models