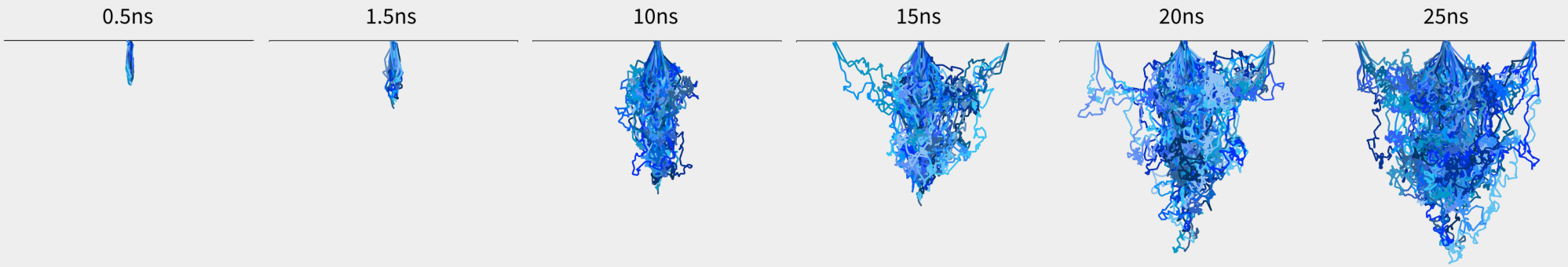
https://www.desy.de/



Ongoing & Future Developments

of the Allpix Squared Framework

Simon Spannagel, DESY

3rd Allpix Squared User Workshop

11 May 2022

Virtual

Upcoming Release: Allpix Squared 2.3

- Release most likely next week already
- Paul presented most features on Monday:
  - Support for different Semiconductor Sensor Materials
  - Mobility model “constant”
  - Temperature scaling of SRH recombination
  - Charge carrier trapping from radiation-induced damage, different models

- Subsequent release very likely v3.0 with…

Impact Ionization

Implementation of charge multiplication through impact ionization underway

- Multiple models available, selection via configuration file:
  - Massey
  - van Overstraeten-de Man
  - Okuto-Crowell
  - Bologna
- Fully documented in user manual

- **Implementation in Allpix^2 completed**, undergoing testing, Comparison with Weightfield2 & TCAD simulations

coefficient α and the length of the step l performed in the respective electric field. If the electric field strength stays below a configurable threshold E_{thr}, unity gain is assumed:

$$g(E,T) = \begin{cases} e^{l\cdot\alpha(E,T)} & E > E_{\text{thr}} \\ 1.0 & E < E_{\text{thr}} \end{cases} \tag{6.12}$$

The the following impact ionization models are available:

6.3.1 Massey Model

The Massey model [35] describes impact ionization as a function of the electric field E. The ionization coefficients are parametrized as

$$\alpha(E,T) = Ae^{-\frac{B(T)}{E}}, \tag{6.13}$$

where A and $B(T)$ are phenomenological parameters, defined for electrons and holes respectively. While A is assumed to be temperature-independent, parameter B exhibits a temperature dependence and is defined as

$$B(T) = C + D \cdot T. \tag{6.14}$$

The parameter values implemented in Allpix^2 are taken from Section 3 of [35] as:

$$A_e = 4.43 \times 10^5\,/\text{cm} \qquad A_h = 1.13 \times 10^6\,/\text{cm}$$
$$C_e = 9.66 \times 10^5\,\text{V/cm} \qquad C_h = 1.71 \times 10^6\,\text{V/cm}$$
$$D_e = 4.99 \times 10^2\,\text{V/cm/K} \qquad D_h = 1.09 \times 10^3\,\text{V/cm/K}$$

for electrons and holes, respectively.

This model can be selected in the configuration file via the parameter `multiplication_model = "massey"`.

6.3.2 Van Overstraeten-De Man Model

The Van Overstraeten-De Man model [36] describes impact ionization using Chynoweth's law, given by

$$\alpha(E,T) = \gamma(T) \cdot a_\infty \cdot e^{-\frac{\gamma(T)\cdot b}{E}}, \tag{6.15}$$

For holes, two sets of impact ionization parameters $p = \{a_\infty, b\}$ are used depending on the electric field:

$$p = \begin{cases} p_{\text{low}} & E < E_0 \\ p_{\text{high}} & E > E_0 \end{cases} \tag{6.16}$$

Temperature scaling of the ionization coefficient is performed via the $\gamma(T)$ parameter following the Synposys Sentaurus TCAD user manual as:

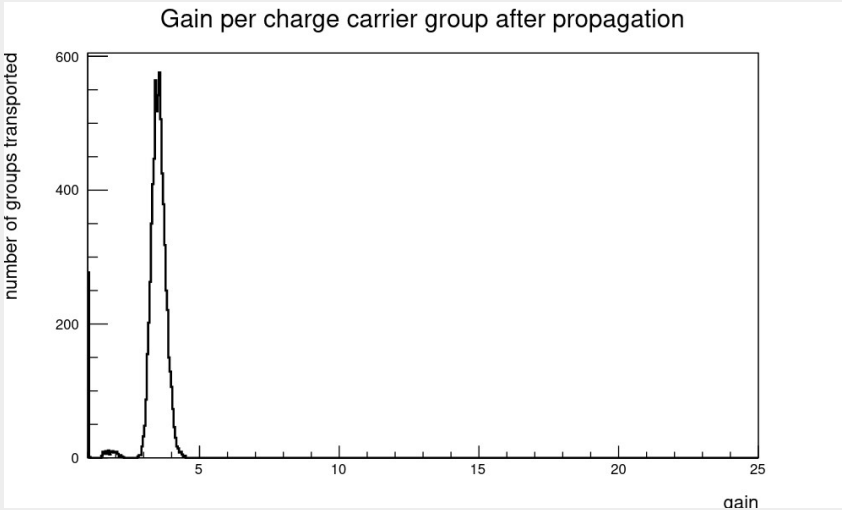
$$\gamma(T) = \tanh\left(\frac{0.063 \times 10^6\,\text{eV}}{28.6173 \times 10^{-5}\,\text{eV/K} \cdot T_0}\right) \cdot \tanh\left(\frac{0.063 \times 10^6\,\text{eV}}{28.6173 \times 10^{-5}\,\text{eV/K} \cdot T}\right)^{-1} \tag{6.17}$$

Impact Ionization – Example

Paul Schütze, Valentina Raskina,
Simon Spannagel, Annika Vauth

- Enable/select via configuration file:
  - Multiplication model
  - Electric field strength threshold field for multiplication

```
[GenericPropagation]
temperature = 293K
multiplication_model = "massey"
multiplication_threshold = 100kV/cm
```



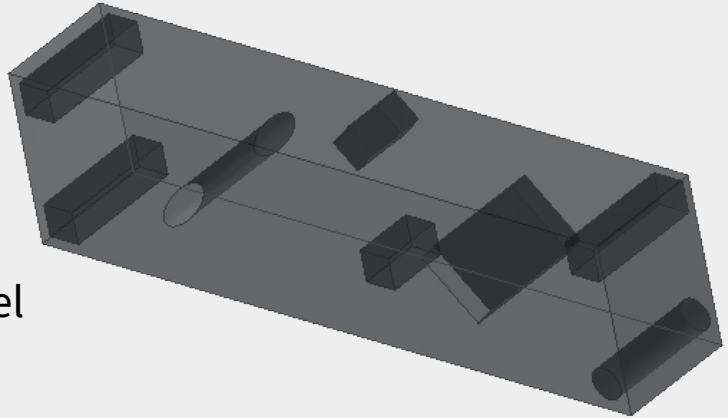
- Automatic check of propagation parameters (time stepping, ...)

```
(WARNING) [I:GenericPropagation:lgad] Charge multiplication enabled with maximum timestep larger than 1ps
                                      This might lead to unphysical gain values.
```

- Status MR !472

Simulation of 3D Sensors

- Definition of per-pixel implants via detector model file
  - Position with respect to pixel center
  - Shape & orientation
  - Material
  - front/backside
- Implants are repeated for each pixel
- Add as many implants as required,
  syntax similar to support layers (PCB etc)
- Requires matching electric field map
- Proper collision detection algorithms of charge carriers with implant volumes; motion stops immediately at implant border

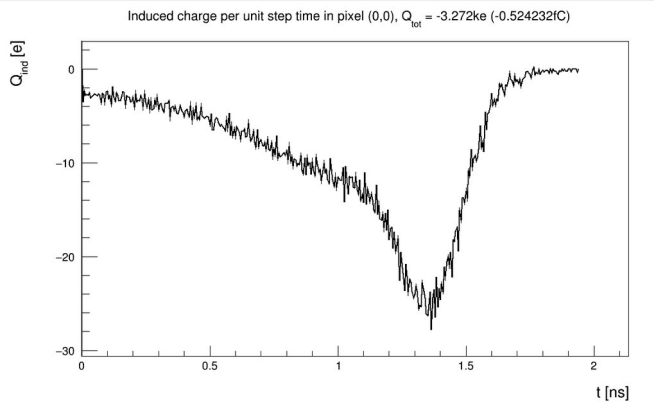


```
type = "monolithic"

number_of_pixels = 20 20
pixel_size = 250um 50um

sensor_thickness = 50um
sensor_excess = 10um

[implant]
type = frontside
shape = ellipse
size = 13um 13um 50um
offset = 62.5um 0
material = silicon

[implant]
type = frontside
shape = ellipse
size = 13um 13um 50um
offset = -62.5um 0
material = silicon

[implant]
type = backside
shape = ellipse
size = 13um 13um 49um
offset = -125um -25um
material = aluminum
```

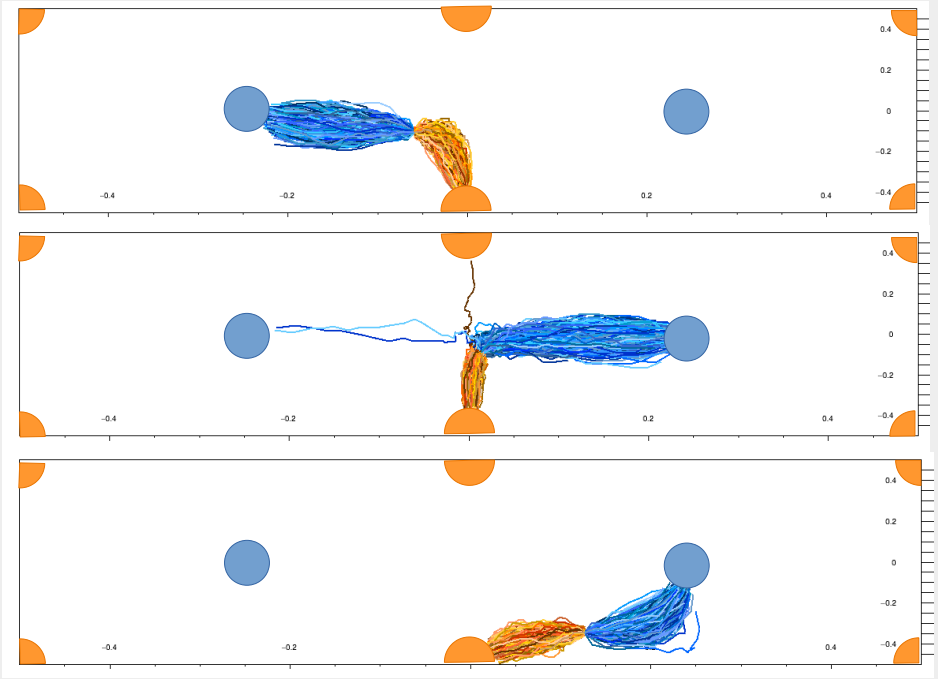
Simulation of 3D Sensors – Example

Marco Bomben, Gilberto Giuliarelli,
Gian-Franco Dalla Betta, Simon Spannagel

- First simulations with ATLAS 3D sensor geometry
  - Two central front-side columns (collect charge)
  - Six Ohmic backside contact columns
- Charge collection / sharing works as expected
- Transient simulations produce pulses
- Status: MR !672



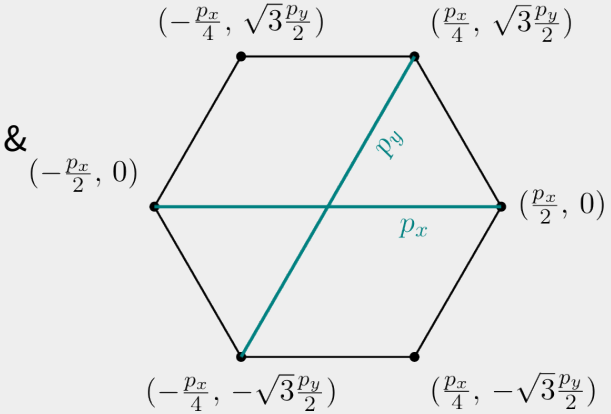
single pixel,
top view

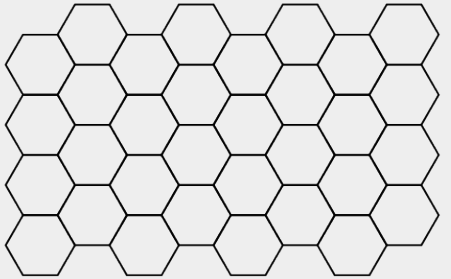


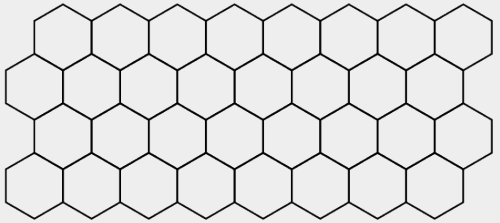
Hexagonal Pixel Geometries

Extension of Allpix^2 geometry subsystem to enable simulation of different pixel shapes & matrix arrangements

- Hexagonal geometry interesting for many applications
  - Avoid problematic field regions in corners
    (small electrodes: low fields, large electrodes: high fields)
  - Symmetry more close to circle – more uniform response
- **Implementation in Allpix^2 completed**, undergoing testing:
  - Using **axial coordinate system**
  - Support for “pointy” & “flat” hexagon orientation,
    regular (same-pitch) and distorted (different pitch) hexagons
- Used already by several groups
  (see Raffaela’s talk on FASER, Paco’s talk on Ge-Detector)



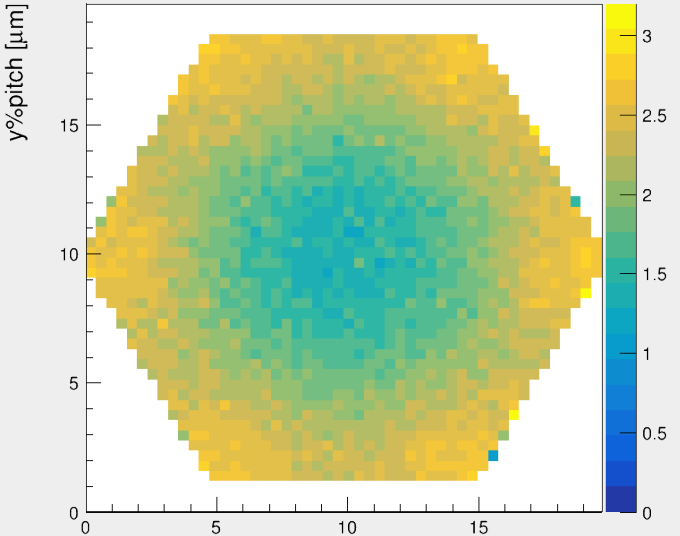


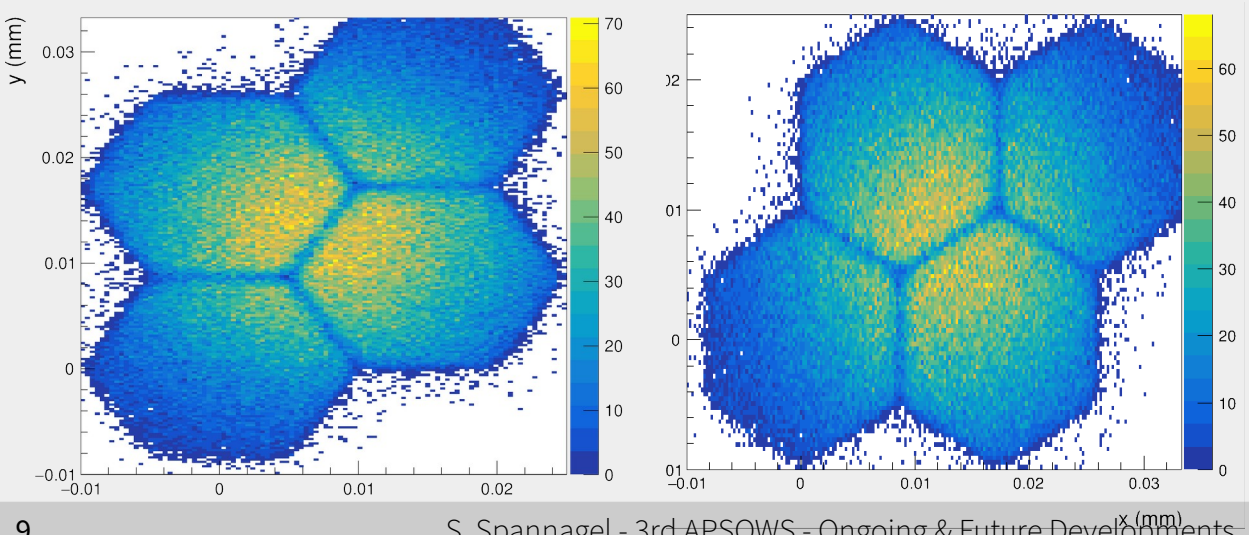


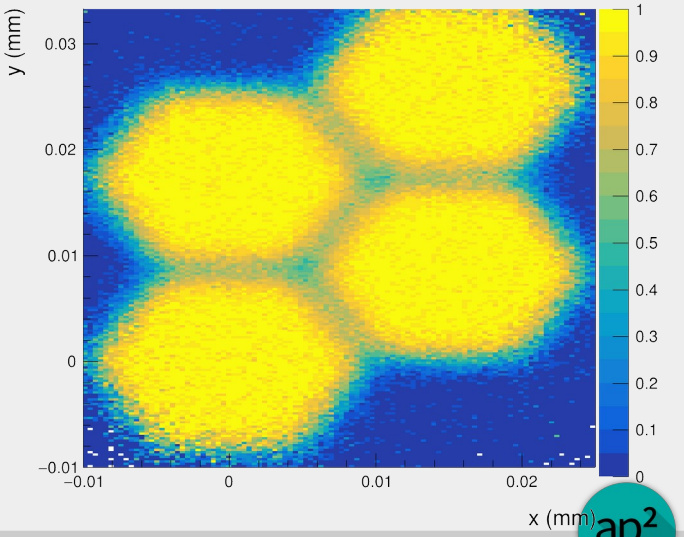
Other geometries already merged (e.g. radial strips @ ATLAS Itk, see Radek’s talks)

Some Nice Plots – with Hexagonal Pixels

- Performed implementation tests with hexagonal pixel detector
  large pixels, linear electric field, high charge threshold
- Analysis of basic properties
  - Recovery of radial beam profile from pixel matrix
  - In-pixel cluster size distribution
  - Efficiency fall-off at hexagon edges

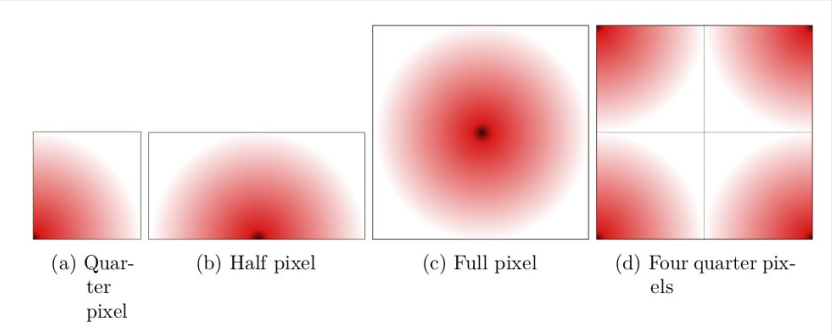


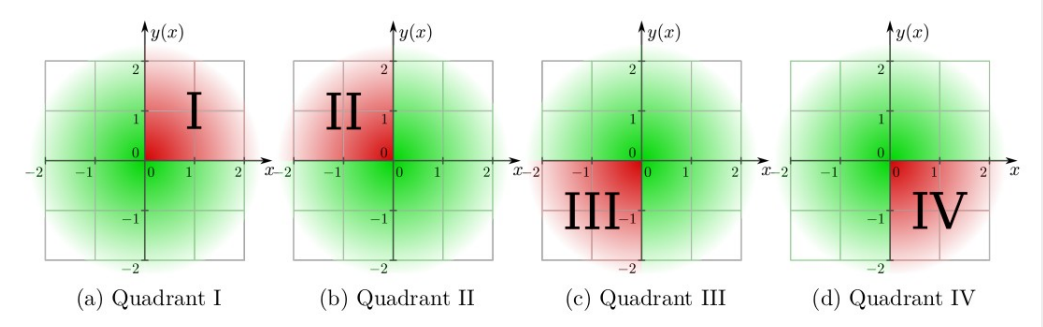




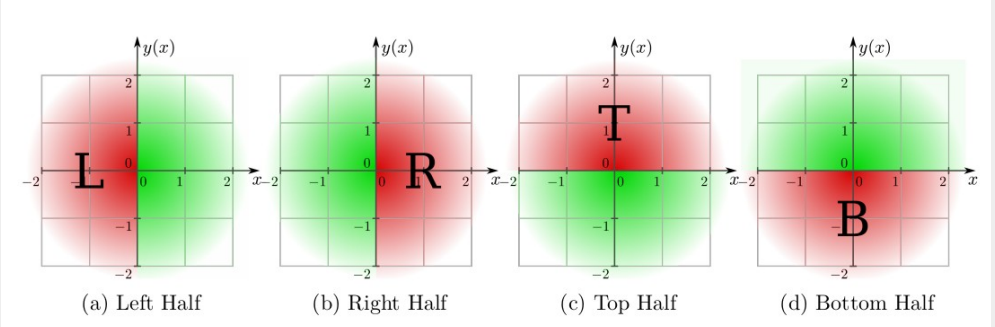
Rework Loading Electric Field Maps

- Current loading of field maps is very flexible…
  …but only works for rectangular geometries!
- Started implementation of new mapping of fields to pixels
  per-pixel lookup of fields
- Has some advantages (lookup possible for any pixel shape)
  and some disadvantages (not possible to provide multi-pixel fields)
- Final solution likely will keep current mapping (as default)
  with new possibility (full, half, quarter pixels)


(a) Quarter pixel (b) Half pixel (c) Full pixel (d) Four quarter pixels



(a) Quadrant I (b) Quadrant II (c) Quadrant III (d) Quadrant IV



(a) Left Half (b) Right Half (c) Top Half (d) Bottom Half

End of the Workshop… almost

Thank you for participating again!

Discussion

- Wishes, ideas, suggestions, questions, …
- “Things we should have on our radar”

Questionnaire

- We would like to get some feedback!
- On the workshop, the framework, our support, …
- Please fill the survey on Indico: https://indico.cern.ch/event/1126306/surveys/3180

Allpix Squared Resources

Website
https://cern.ch/allpix-squared

Repository
https://gitlab.cern.ch/allpix-squared/allpix-squared

Docker Images
https://gitlab.cern.ch/allpix-squared/allpix-squared/container_registry

User Forum:
https://cern.ch/allpix-squared-forum/

Mailing Lists:

allpix-squared-users https://e-groups.cern.ch/e-groups/Egroup.do?egroupId=10262858

allpix-squared-developers https://e-groups.cern.ch/e-groups/Egroup.do?egroupId=10273730

User Manual:
https://cern.ch/allpix-squared/usermanual/allpix-manual.pdf


DESY.