Allpix2

General

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Simulation pipeline

```
1.  [Allpix]
2.  random_seed_core = 0
3.  # Log level is set to INFO
4.  log_level = "WARNING"
5.  # Use the default logging format
6.  log_format = "DEFAULT"
7.  # Location of the detector configuration
8.  detectors_file = "luxe_gbp_detector.conf"
9.  # Simulate a total of 10000 events
10. number_of_events = 10000000

11. [GeometryBuilderGeant4]
12. world_material = "air"

13. # Initialize physics list and particle source
14. [DepositionGeant4]
15. # Use a Geant4 physics lists with EMPhysicsStandard_optio
16. physics_list = FTFP_BERT_LIV
17. # Use a photon as particle
18. particle_code = 22
19. # particle_type = "Pi+"
20. # Set the energy of the particle
21. source_energy = 1GeV
22. # Origin of the beam
23. source_position = 0 0 -10c
24. # The direction of the bea
25. beam_direction = 0 0 1
26. # Use a single particle in a single 'event'
27. number_of_particles = 1
28. # Energy needed to create a charge deposit
29. charge_creation_energy = 27eV
30. source_type = "beam"
31. # source_type = "point"
32. beam_size = 1320um
33. # Limit the maximal step length
34. # max_step_length = 1um
35. # Output plots
36. output_plots = true

37. # Set up a constant electric output plots field
38. [ElectricFieldReader]
39. model = "custom"
40. field_function = "[0]"
41. field_parameters = 50000V/mm
42. output_plots = true
43. # Adds a weighting potential (Ramo potential) to the detector.
44. # The potential was evaluated with the luxegbp.conf model
45. # [WeightingPotentialReader]
46. # name = "detStripX"
47. # model = "mesh"
48. # file_name = "gbp_weightingpotential.apf"
49. # output_plots = true

50. # Adds a doping profile to the detector
51. # This module is necessary in order to enable the finite carrier lifetime
52. [DopingProfileReader]
53. # For now it is assumed as a constant uniform
54. model  = "constant"
55. # The value is related to the carrier lifetime by the recombination_model.
56. # The 1e20 value corresponds to an electron lifetime of 1 ns
57. doping_concentration = 1e20/cm/cm/cm

58. # Propagate the charge carriers through the sensor
59. [GenericPropagation]
60. # Set the temperature of the sensor (defaults to room temperature 293.15K)
61. temperature = 300K
62. # Charge carrier mobility model to be used for the propagation. Defaults to jacoboni
63. mobility_model = "jacoboni"
64. # Propagate multiple charges at once
65. # charge_per_step = 10
66. # Recombination model
67. recombination_model = "srh"
68. # Determines if simple output plots should be generated for a monitoring of the simulation flow.
69. output_plots = true
70. #output_linegraphs = true
71. #output_animations = true

72. # Transfer the propagated charges to the pixels
73. [SimpleTransfer]
74. max_depth_distance = 100um
75. output_plots = true

76. # Simple digitization module which translates the collected charges into a digitized signal proportional to the
    input charge.
77. #[DefaultDigitizer]
78. # Noise added by the readout electronics
79. #electronics_noise = 100e
80. # Threshold for a hit to be detected (see line 359 of LUXE_tech_note_template.pdf)
81. #threshold = 62500e
82. # Threshold dispersion
83. # threshold_smearing = 30e
84. # Noise added by the digitisation
85. # qdc_smearing = 100e
86. #qdc_resolution = 12
87. #output_plots = true
88. #output_plots_scale = 30ke
89. #output_plots_bins = 100

90. [DetectorHistogrammer]
91. name = "detStripX"

92. #[ROOTObjectWriter]
93. #file_name = "output_gbp.root"
```

Geometry is written in the _detector.conf file.

Module which deposits charge carriers in the active volume of all detectors. It acts as wrapper around the Geant4 logic and depends on the global geometry constructed by the GeometryBuilderGeant4 module. It initializes the physical processes to simulate a particle source that will deposit charge carriers for every event simulated. The number of electron/hole pairs created is calculated using the mean pair creation energy charge_creation_energy, fluctuations are modeled using a Fano factor fano_factor assuming Gaussian statistics.

As first approximation, the initial beam is modelled as a gaussian beam, whose characteristics are extracted from the realistic beam ptarmigan data.

Electrostatic field produced by the biasing voltage is calculated and stored in a dat file. However, early simulations adopted a constant E field to speed up computation times

Doping concentration is related to carriers lifetime by the recombination model (67)

Simulates the propagation of electrons and/or holes through the sensitive sensor volume of the detector. The propagation consists of a combination of drift and diffusion simulation.

Combines individual sets of propagated charges together to a set of charges on the sensor strips and thus prepares them for processing by the detector front-end electronics.

Deposited charge

- The number of electron/hole pairs created is calculated using the mean pair creation energy in sapphire (27 eV) [1]. Fluctuations are modeled using a Fano factor (0.115) assuming Gaussian statistics. [2]

- As first approximation of the initial particle beam, a gaussian beam was used. Its parameters were extracted fitting the realistic beam from Ptarmigan.
- Accurate reproduction of the initial beam can be implemented, in an analogous manner of what done in Geant4 StandaloneGBP. This requires 10 days of work (not spoiling multi-threading requires special care)

Electrostatic field

- The external electrostatic field in the detector – i.e. not including polarisation effects produced during charge transport – can be calculated numerically with a tool which comes with allpix2. The computation needs to be made once and it takes 12/24 hours.
  Detector geometry and the bias voltage are the inputs of the E-field computation. The output is a INIT/APF file (the former is compatible with PixelAV) with a 3d map of the vector field.

- The electrostatic field is imported via the "ElectricFieldReader" module which allows to implement the E field either with a constant/parametric formula or by reading the E field from a file.

- At present time, for the preliminary simulation a constant E field of intensity 5 V/um is used. Polarisation effects – e.g. local E-field produced by trapped charges – are not accounted yet. They may be encompassed by using a E-field profile quadratic in the sensor thickness z (as done in ref. [1])

Charge carrier propagation

- The [DepositionGeant4] module produces charge carriers.
- Electrons & holes are then propagated toward the collecting implants with a drift/diffusion model.
- Jacoboni-Canali model is the one used.
- Default silicon parameters are replaced with the sapphire parameters from [1] e [3]. Some adaptations were needed since the two models are different

6.1.1 Jacoboni-Canali Model

The Jacoboni-Canali model [25] is the most widely used parametrization of charge carrier mobility in Silicon as a function of the electric field E. It has originally been derived for $\langle 111 \rangle$ silicon lattice orientation, but is widely used also for the common $\langle 100 \rangle$ orientation. The mobility is parametrized as

$$\mu(E) = \frac{v_m}{E_c} \frac{1}{\left(1 + (E/E_c)^\beta\right)^{1/\beta}}, \tag{6.1}$$

where v_m, E_c, and β are phenomenological parameters, defined for electrons and holes respectively. The temperature dependence of these parameters is taken into account by scaling them with respect to a reference parameter value as

$$A = A_{ref} \cdot T^\gamma \tag{6.2}$$

where A_{ref} is the reference parameter value, T the temperature in units of K, and γ the temperature scaling factor.

The parameter values implemented in Allpix^2 are taken from Table 5 of [25] as:

$$\begin{aligned} v_{m,e} &= 1.53 \times 10^9 \cdot T^{-0.87}\,\mathrm{cm/s} & v_{m,h} &= 1.62 \times 10^8 \cdot T^{-0.52}\,\mathrm{cm/s} \\ E_{c,e} &= 1.01 \cdot T^{1.55}\,\mathrm{V/cm} & E_{c,h} &= 1.24 \cdot T^{1.68}\,\mathrm{V/cm} \\ \beta_e &= 2.57 \times 10^{-2} \cdot T^{0.66} & \beta_h &= 0.46 \cdot T^{0.17} \end{aligned}$$

for electrons and holes, respectively.

Charge carriers. Literature

- From reference [3] one reads…
  - the room temperature mobility of electrons (holes) as **\mu_e \sim 600 cm2/Vs (\mu_h = 60)**
  - that at 40K the e^- mobility is \simeq 30000 cm2/Vs in high purity sapphire (in Si it holds \mu = AT^{-\gamma} with A=1.43 \cdot 10^9 and \gamma=2.42 for temperatures T \geq 50 K)
  - that *impurities play a role* constraining chg. mobility to \sim 4000 cm2/Vs

- In reference [1]…
  - polarisation effects, i.e. internal electric field produced by trapped charges, are accounted using a resulting electric field with parabolic shape (E= A(y-d/2)^2 + B)
  - the drift velocity is assumed to be directly proportional to the electric field strength (\ni_e = \mu_e E(y))
  - charge carrier lifetime is assumed to be constant \tau_e = const.
  - in the case where the mean lifetime is much smaller than the time necessary to travel to the implants, there is a dependence of the CCE from the biasing voltage V
  - a fraction (\sim 0.5) of charge carriers recombines immediately after creation

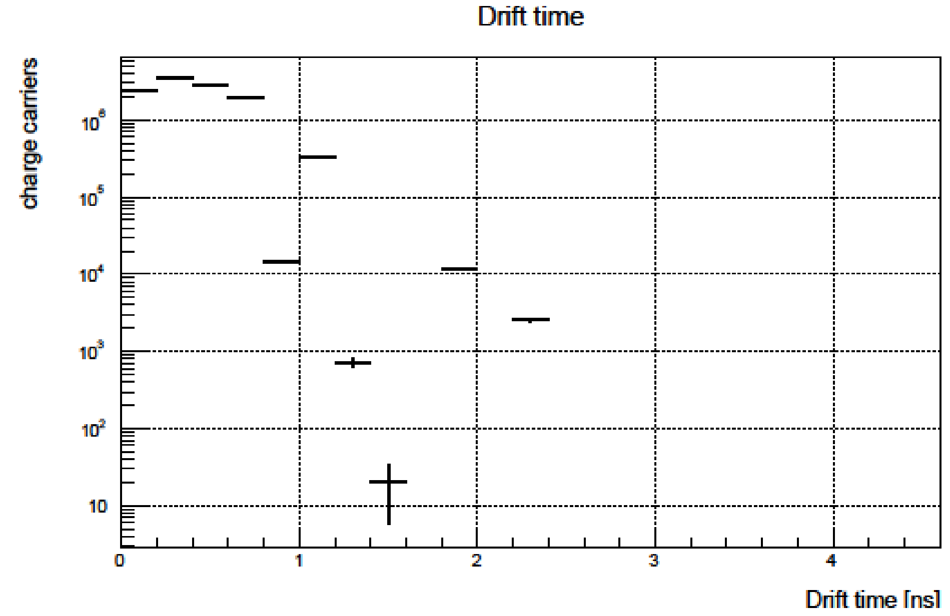
Simulation time & output data

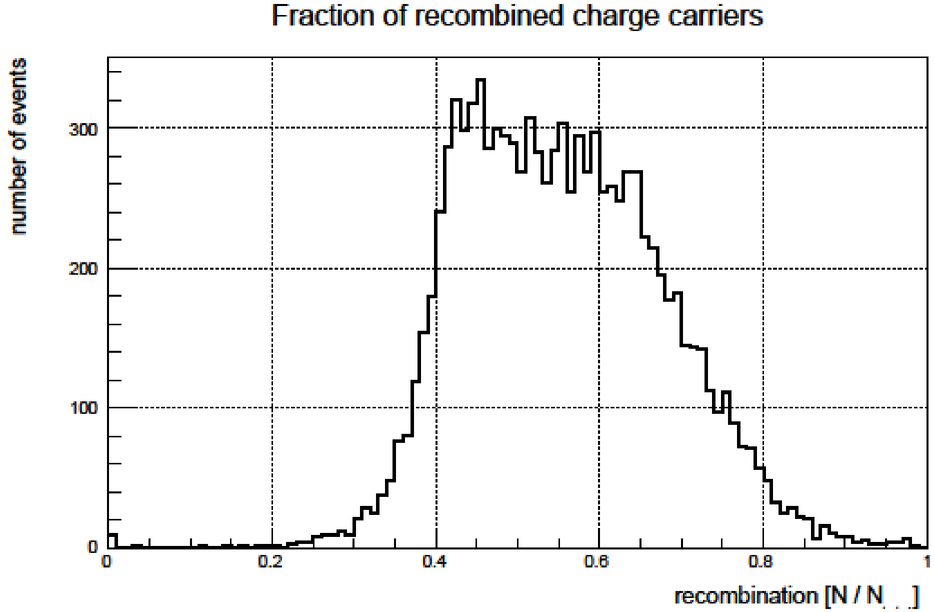
- By default, Allpix2 outputs a small (\sim 3 MB) summary in ROOT format
  - It contains a list of predefined histograms to inspect each module (e.g. DepositionGeant4, GenericPropagation, etc.).
- If called, the module 'ROOTObjectWriter' record all the 'raw' simulation data in a ROOT file (size \sim 0.5 GB).
  - The summary report can be reconstructed by using ROOT macros.
  - Allpix2 symbols allow for a deeper analysis using the 'raw' data

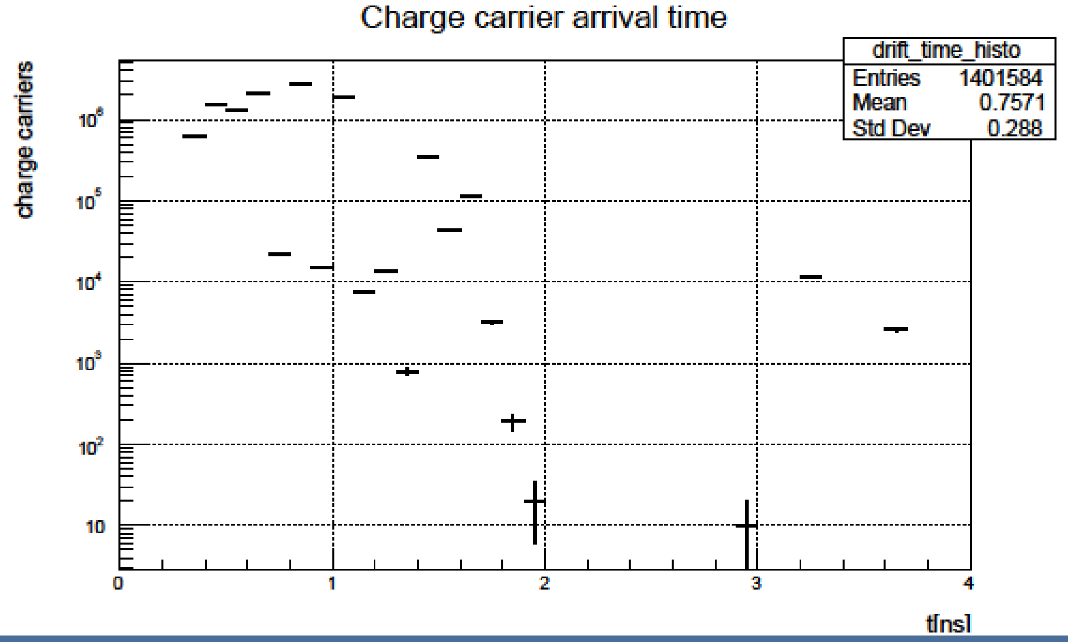
- Simulation bottleneck is in the file I/O:
  - summary only (\sim **4 minutes**)
  - with 'raw' root file (\sim **3.3 days**)

- It is important to set the quantities of interest, in order to optimize simulation time by reducing file IO. For instance I focused over observables for studying the CCE; charge recombination; and the best operating conditions

Preliminary results







- In each step, charge carrier lifetime (\tau) is determined and a survival probability is calculated: a random 0\leq r \leq 1 is compared with dt / \tau with dt the time step of the last charge carrier movement