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Allpix Squared

Silicon Detector Monte Carlo Simulations for Particle Physics and Beyond

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Université de Genève DPNC Seminar

27 October 2021

Silicon Detectors

for Particle Detection

2.1



allpix

Silicon Detectors in Particle Physics

Vital for many measurements due to

- Fine segmentation, fast readout: high track multiplicities
- Precise position measurement

Demands are high:

- Very high particle flux, tens of MHz / cm²
- Maximum resolution, minimum (scattering-) mass
- High granularity, fast readout, minimal dead time
- "Smart" detectors (zero suppression, on-chip processing, ...)

Many different technologies used for different applications: hybrid (sensor + mixed-mode CMOS), monolithic CMOS, LGADs, 3D sensors, ...

- → Wide range of available detector technologies
- → Thorough understanding of performance in realistic conditions





Particle Detection with Silicon Detectors



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Stage 1 – Energy Deposition

(heavy) charged particles:

Mean energy loss described by Bethe Bloch formula

- Strong fluctuations of energy loss: Landau-Vavilov distribution / Bichsel model
 - Varying number interactions, energy transfer
 - Secondary particles (e.g. delta rays)
 - Most probable value < Mean
- Photons:
 Photo effect, Compton effect, pair production
- Creation of e/h pairs: 3.64 eV / pair Fluctuations: **Fano** Factor $\sigma_{e/h} = \sqrt{N_{e/h}} \sqrt{F}$







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Stage 2 – Signal Formation

- Si sensor operated as diode in reverse bias → depleted volume
- Signal formed by motion of e/h pairs in electric field
- Contribution to motion:
 - **Diffusion Temperature-driven random motion**, mean free path ~ 0.1 μ m, mean 0
 - **Drift Directed motion**, depending on electric field and charge carrier mobility, different parametrizations for mobility available, depending on temperature, silicon, ...
- Motion stops, when...
 - Charge carriers reach readout electrode (conductor)
 - Charge carriers recombine/get trapped (depends on purity, doping, lattice defects, ...)
- When carriers reach electrodes, total induced charge is equivalent to collected charge



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Stage 3 – Signal Transfer

Coupling between sensor & front-end can be

- DC: bump bonds (hybrid pixel), direct (monolithic pixel), ...
- AC: glue layers (hybrid pixel), SiO₂ (strip detectors), ...

Stage 4 – Digitization

- Signal is amplified, shaped, zero-suppression (discriminator)
- Digitization of the signal via
 - Full ADC
 - Time-over -threshold
 - Threshold crossing (binary hit information)
- Buffering, encoding, data transmission...



Why Detector Monte Carlo Simulations?

Simulate full chain: energy deposition \rightarrow readout

- Detailed modeling of microscopic processes in sensor & front-end
- Include stochastic effects, fluctuations, secondaries

Allows to derive **performance parameters**

- Position resolution, timing, efficiency
- Combine with (TCAD / SPICE / ...) device simulations results to increase accuracy
- Provides detailed insight into characteristics not accessible in measurements

Requires **simplifications**:

- No self-interaction, static electric field, ...
- Empirical models for different stages of detection process





The Allpix² Framework

for Silicon Detector Monte Carlo Simulations

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The Allpix² Framework

Proliferation of many different codes for detector simulation:

- Experiment-specific, specialized on specific detectors,
- written as part of a PhD thesis, abandoned afterwards

Wanted: flexible MC simulation software with...

- I. Integration of Existing Toolkits
- II. Well-Tested & Validated Algorithms
- III. Low Entry Barrier for New Users
- IV. Clean & Maintainable Code





NIMA 901 (2018) 164 – 172

doi:10.1016/j.nima.2018.06.020



→ Allpix²: microscopic end-to-end MC simulations



I. Integration of Existing Toolkits

Many very powerful tools developed and employed over decades of detector R&D Leverage their capabilities by providing interfaces for their integration

Geant4 – simulating energy deposition of particles passing through matter

- Extensive toolkit, detailed simulation of many interactions & processes
- Cumbersome to use for beginners, complexity often overwhelming at first
- Provide abstraction layer that auto-generates models and calls Geant4 kernel

TCAD – solving Poisson's equation using doping information

- Detailed understanding of field configuration, sensor behavior
- Tools & knowledge widely spread in community
- Provide possibility to import results to complement MC simulations



II. Well-Tested & Validated Algorithms



Simulations provide insights into physical processes – but only if they model them correctly! Validation of algorithms is a crucial and time-consuming process.

With **Allpix**², we strive for:

- Validating as much as possible against known data
- Publishing reference studies including full simulation configuration used
- Providing automated tests for every new feature

Organizing User workshops for exchange with community, discussions, planning...



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13



III. Low Entry Barrier for New Users

Simulation frameworks often very complex: code complexity, lack of documentation, physics

Allpix² attempts to facilitate quick starts:

- Extensive documentation / user manual / help forum
- Human-readable configuration files
- Support for physical units
- No coding or code-reading required

Successfully used e.g. in university education, summer schools, ...



```
1 [AllPix]
2 log_level = "INFO"
3 number_of_events = 500000
4 detectors_file = "telescope.conf"
5
[GeometryBuilderGeant4]
world material = "air"
```



Allpix² User Manual

Paul Schütze (paul.schuetze@desy.de)

non Spannagel (simon.spannagel@cern.cl

July 0 202

Varcian v2.0.1

[DepositionGeant4]
physics_list = FTFP_BERT_LIV
particle_type = "Pi+"
number_of_particles = 1
beam_energy = 120GeV
...

[ElectricFieldReader]
model="linear"
bias_voltage=150V
depletion_voltage=50V
[GenericPropagation]
temperature = 293K
charge_per_step = 10
spatial_precision = 0.0025um
timestep max = 0.5ns

[SimnleTransfer]



IV. Clean & Maintainable Code

Collaborative software development requires well-defined procedures – Otherwise frameworks quickly becomes unmaintainable

- Allpix² implements *best practices* for software development
- Permissive open-source license: MIT

Efforts bear fruit: continuous development since 2017

By now > 40 contributors, many **applications in different fields in research & industry**



v2.0.2	2021-09-23
v2.0.1	2021-07-09
v2.0	2021-06-10
v1.6.2	2021-04-01
v1.6.1	2021-01-28
v1.6	2020-10-29
v1.5.2	2020-09-14
v1.5.1	2020-07-26
v1.5	2020-04-14
v1.4.4	2020-03-10
v1.4.3	2020-01-10
v1.4.2	2019-11-26
v1.4.1	2019-09-13
V1.4	2019-07-09
v1.3.4	2019-06-07
v1.3.3	2019-04-13
v1.3.2	2019-02-21
v1.3.1	2018-12-17
v1.3	2018-11-21
v1.2.3	2018-11-13
v1.2.2	2018-09-07
v1.2.1	2018-08-02
v1.2	2018-06-13
v1.1.2	2018-04-25
v1.1.1	2018-03-08
v1.1	2018-01-11
v1.0	2017-08-29

The Simulation Chain



Geometry Construction	Electric Field Config.	Energy Deposition	Charge Transport	Signal Transfer	Digitization	Monitoring	Writing Output Data		





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The Simulation Chain



- Building blocks follow individual steps of signal formation in detector
- Algorithms for each step can be chosen independently



The Simulation Chain



- Simulation very flexible: modules configurable on per-detector level
- Multiple instances can be run in at the same time (e.g. to simulate different front-ends)



The Monte Carlo Truth



- Allpix² keeps history for all simulated objects, every simulation step can be stored
- Cross-references available for convenient access & detailed analysis



Modules for Energy Deposition



- **DepositionGeant4:** Using established software for simulating particle interaction
 - Tracking of particles through entire setup, including magn. fields
 - Production and tracking of secondary particles
 - Provides MC truth information on all particles
 - Allows visualization of setup
- **DepositionCosmics:** Using cosmic ray simulation code to generate primaries & Geant4 for tracking
- **DepositionPointCharge:** Simple model, depositing charge at point or along line (LET)
 - Convenient for comparison with e.g. TCAD device simulations
- **DepositionReader:** Read in simulation results from external tools in different formats





Modules for Charge Transport

• Most crucial (and time consuming) component in simulation chain

- Multiple charge carriers can be propagated together
 - Depending on initial statistics and required accuracy
 - Some models allow to ignore electrons or holes
- Models with different complexity:
 - **ProjectionPropagation** O(1), Projecting Charge Carriers
 - **GenericPropagation** O(N), Integration of Equations of Motion
 - **TransientPropagation** O(2xNxM), Induced Signal at Electrodes





Modules for Digitization

- Methods depend on available information from charge transport
- DefaultDigitizer: Simple front-end
 - Compare total charge against configured threshold
 - Add input noise, threshold dispersion, convert to ADC units
 - Possibility to simulate saturation
- **CSADigitizer:** Front-end with timing capabilities
 - Requires current pulse
 - Threshold crossings for time-of-arrival and time-over-threshold
 - Possibility to define custom transfer functions











Application Examples

CMOS Sensors, Timing, Calorimetry, Neutron Detection

picked from the 2nd Allpix² User Workshop – https://indico.cern.ch/e/apsqws2



Signal formation in CLICTD MAPS Prototypes

- K. Dort, Universität Gießen / CERN
- CLICTD prototype for CLICdet tracking detector ٠
- Using Allpix² for high-statistics Monte Carlo studies ۲
 - Electrostatic sensor simulation from TCAD ٠
 - End-to-end simulation with induced currents ٠
 - Intra-pixel studies of time & position resolution ٠
- Validation with data recorded at DESY II Testbeam •



IEEE TNS, vol. 67, no. 10 (2020), 2263



CLICTD: Allpix² Simulation Results

- Comparison of different sensor designs to data cluster size, resolution
- Validated simulation allows for predictions of current performance & future designs
- Some samples produced on high-resistivity Czochralski substrate, Resistivity of sensor material not precisely known – using simulation to confirm



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Transient Signal Formation

• Successive integration of motion, calculating induced charge per step via **Shockley-Ramo theorem**:

$$Q_n^{\text{ind.}} = \int_{t_{n-1}}^{t_n} I_n^{\text{ind.}} \, \mathrm{d}t = q[\phi(x_n) - \phi(x_{n-1})]$$

• Take each (group of) charge carrier

26

- Calculate mobility & velocity from local fields
- Make step, add diffusion offset from Gaussian distribution
- Get induced charge from weighting potential difference for pixel & neighbors
- Requires static TCAD simulation as input (e-field, weighting potential)
- Enables time-resolved simulation, much faster than TCAD transient simulation (Allpix² < 1 s/event, TCAD ~10 h/event)





Time Response Studies – Comparison with TCAD

- Simulate linear energy transfer in Allpix² replicate TCAD situation
- Import electrostatic field & weighting potential from TCAD
- Comparison of current pulse for different CMOS sensor designs:



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Wield the Power of MC Simulations

- Initial particle with Geant4: Landau, secondaries
- Resulting current pulse exhibits expected fluctuations

- Adding next step: Detector front-end simulation:
 - Analysis of pulse shape in FE electronics, folding with circuit response function
 - Detection of threshold crossings

 Here: time of threshold crossing at rising edge (ToA), expected timewalk behavior observed



DESY.

Sensor-level Simulation of MAPS ECAL Test-Beam Data

T. Rogoschinski, Universität Frankfurt

EPICAL-2: MAPS prototype for FoCal Forward EM calorimeter for ALICE experiment

- Fully digital calorimeter prototype
- 24 layers with two ALPIDE chips each + 3mm Tungsten
- 512 x 1024 pixels per chip

Simulation utilizing Allpix² with precise geometry implementation



layer geometry implemented in Allpix²









EPICAL-2: Allpix² Simulation Results

T. Rogoschinski, Universität Frankfurt

EPICAL-2 preliminary

Allpix² simulation

400

200

-200

top view

- Using electrostatic field of ALPIDE from TCAD simulations •
- Good agreement of simulation and test beam data •
- Remaining differences attributed to simplified simulation



Dual Sided Micro-Structured Neutron Detector S. Sharma, Kansas State University

- n-type Si sensor with LiF trenches for neutron conversion $(n \rightarrow t + a)$
- COMSOL used to generate electric field maps
- End-to-end simulation of entire detection system with Allpix²





Sneak Peek

New & Upcoming Features





Mobility & Recombination

Introduced possibility to select charge carrier mobility model

- Field dependent ٠
- Doping concentration dependent •
- Optimized for high-field situations •

Support for position-dependent doping maps & lifetime calculation

- With fast signal formation: all e/h pairs reach electrodes ٠
- Finite charge carrier lifetime interesting in: ٠
 - **High-dopant regions** ٠
 - Low electric fields, signal formation via diffusion ٠
- Shockley-Read-Hall, Auger models & combination of both •
- Recently published & available in Allpix² 2.0 →



temperature = 293K

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 Allpix² completed, undergoing testing, Comparison with Weightfield2 & TCAD simulations
- Looking for interested collaborators for validation of simulation with data

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:

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

The the following impact ionization models are available:

6.3.1 Massey Model

The Massey model $\overline{35}$ 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 Allpix² are taken from Section 3 of 35 as:

 $\begin{array}{ll} A_e = 4.43 \times 10^5 \,/ {\rm cm} & A_h = 1.13 \times 10^6 \,/ {\rm cm} \\ C_e = 9.66 \times 10^5 \,{\rm V/cm} & C_h = 1.71 \times 10^6 \,{\rm V/cm} \\ D_e = 4.99 \times 10^2 \,{\rm V/cm/K} & D_h = 1.09 \times 10^3 \,{\rm V/cm/K} \end{array}$

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

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

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

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

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

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



Hexagonal Pixel Geometries

Extension of Allpix² geometry subsystem to enable simulation of different (-*i* 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 Allpix² completed, undergoing testing:
 - Using axial coordinate system
 - Support for "pointy" & "flat" hexagon orientation, regular (same-pitch) and distorted (different pitch) hexagons

Other geometries also in preparation (e.g. radial strips @ ATLAS ITk)







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First Simulations with Hexagonal Pixels

- Performed implementation tests with hexagonal pixel detector ٠ 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





A Word On...

x failed

passed

Sustainable Development

 \checkmark

 \checkmark

odule { end class ModuleManager; and class Messenger;

f Base constructor for unique modules n config Configuration for this module

Module(Configuration& config);

Base constructor for detector modules config Configuration for this module detector Detector bound to this module g Detector modules should not forget to forward their detector to the ba

ule(Configuration& config, std::shared ptr<Detector> detector);

ntial virtual destructor.

s all delegates linked to this module

();

a module is not allowed

e&) = delete; const Module&) = delete;

ve behaviour (not possible with references)

ept = delete; le&&) noexcept = delete



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)

Sustainable Development of Common Software Tools



CRU Time: Total

Snin Time

0.0%

0.0%

0.0%

0.0%

Effective Time by Utilizatio

Idle Poor Ok Ideal Ove

61.4%

44.7%

0.0% 0.0%

13.0%

1.1%

0.4%

0.1%

0.1%

Implementing algorithms such, that they are...

...validated with prototype data & device simulations

...well documented & tested

...making efficient use of computing resources

...maintainable over a period longer than O(1 fellow) / O(1 PhD)

Development of Allpix²: spend considerable time on

- Writing documentation ٠
- Implementing automated testing, compilation ٠
- Code review for new features
- Benchmarking / optimization ٠

- lower barrier for new users
- ensure software always works \rightarrow
- ensure functionality/compatibility \rightarrow

0: +

Thread (TID: 27402) Thread (TID: 2740)

Ebroad (TID: 27404 Thread (TID: 27409 Thread (TID: 27408 alloix (TID: 27368 ls (TID: 27382)

Idd (TID: 27390) CPU Time

operator

operator

▶ func@0xdae0

b func@0xe1b0

allpix::GenericPropagationModule::propagate allpix::RungeKutta<double. (int)6. (int)3>::step

> IOutside any known module ▶ log ▶ func@0xdade allpix::Detector::getElectricField

Eunction Starl

std::function<Figen::Matrix<double. (int)3. (int)0. (int)3. (int)1> (double. Figen::Matrix<d

Eigen::MatrixBase<Figen::Matrix<double.(int)3.(int)1.(int)0.(int)3.(int)1>>::norm

Eigen::Matrix<double. (int)3. (int)1. (int)0. (int)3. (int)1>::Matri

Eigen::Matrix<double. (int)3. (int)1. (int)0. (int)3. (int)1>::Matrix<Eigen::CwiseBinaryOp<Eigen</p>

ROOT::Math::PositionVector3D<ROOT::Math::Cartesian3D<double>, ROOT::Math::Defau 0.3% ▶ std:: shared ntr access<allnix::Detector const (__gnu_cxx:: Lock_policy)2 (bool)0 (bool)</p>

ROOT::Math::DisplacementVector3D<ROOT::Math::Cartesian3D<double>, ROOT::Math::E

Grouping: Call Stack

run as efficiently as possible \rightarrow



Multithreading Support



Allpix² supports event-based multithreading while retaining strong reproducibility, exact same result independent of number workers, fully transparent to user / simulation



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Code Review via Merge Requests

No new code lands in Allpix² without review by another party

- Using GitLab's code review / approval tools
- Extensive discussions about code, but also style, naming schemes

Proven to be very effective

- Several bugs found before the merge
- New users appreciate guidance

Proven to be labor-intensive

- Reading (and understanding) every change
- Always be supportive, positive

... just some of them

Slight alteration to progress percentage calculation, to avoid integer overflow.	MERGED ⊘ ♣ Approved ♣ 9
1554 · created 3 weeks ago by Haakan Wennloef	updated 3 weeks ago
Prepare Patch Release v2.0.2	MERGED () () & Approved () 0
1534 · created 1 month ago by Simon Spannagel ① Patch v2.0.2	updated 4 weeks ago
DetectorModel: fix calculation of pixel center	MERGED 🕢 & Approved 🛱 0
1540 · created 1 month ago by Simon Spannagel (bug) (detector models)	updated 1 month ago
Moving model-specific methods to DetectorModel	MERGED ⊘ よ Approved 🛱 24
1515 · created 3 months ago by Radek Privara	updated 1 month ago
DepositionGeant4: check for possible nullptr dereference	MERGED 🕢 & Approved 🛱 1
1536 · created 1 month ago by Simon Spannagel ① Patch v2.0.2 bug	updated 1 month ago
Hit transform matrix	MERGED 🕢 よ Approved 🛱 11
1532 · created 1 month ago by Radek Privara	updated 1 month ago
Enhance Github Cl	MERGED 📀 💒 Approved 🛱 1
1533 · created 1 month ago by Paul Jean Schutze continuous Integration	updated 1 month ago
DepositionGeant4: add debug output when using ions as source	MERGED () () & Ar Approved () 0
1530 · created 1 month ago by Simon Spannagel	updated 1 month ago
modified chip thickness and support material	MERGED 😠 & 1 left 🛱 1
1480 · created 5 months ago by Reem Hani M Taibah	updated 1 month ago
Minor fixes and changes to eudet rd53a example	MERGED ⊘ ♣ Approved दि 5
1529 · created 1 month ago by Paul Jean Schutze	updated 1 month ago



Testing Compilation Formatting Performance Documentation Packaging Deployment (\mathbf{o}) fmt:cc7-llvm-for... 0 Core:cc7-acc $(\mathbf{0})$ C cmp:doxygen 0 pka:cc7-acc 0 (0) C cmp:cc7-acc perf:cc7-acc deploy-cymfs C cmp:cc7-llvm (\mathbf{O}) (C) fmt:cc7-llvm-lint Concusermanual (pkg:slc6-gcc 0 🕢 deploy-docker-t... C cmp:lxplus-gcc Core: xplus-acc $(\mathbf{0})$ 🐼 fmt:slc6-llvm-for... 🧿 📀 deploy-docume... (😳 📀 core:mac1013-c... 💿 🕢 deploy-eos 50 🕑 cmp:mac1013-c 🕲 🕝 fmt:slc6-llvm-lint 🛛 😳 reference Docke 0 C cmp:slc6-qc Core:slc6-gcc Documentation generation Core:slc6-llvm Automated deployment U Tar ball for distribution examples /EOS, CC8, execution time Performance testing mod:cc7-gcc 0 Static code Analysis code formatting & linting pt mew testin 7 CVMFS, website ပ်ပ frai user manual Compilation Automated Clang, ৵ Packaging modules monitor GCC,

Continuous Integration & Deployment Pipeline



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DESY.

Automated Testing





Test project /builds/allpix-squared/allpix-squared/build					
<pre>Start 53: test_core/test_01-1_globalconfig_detectors.conf</pre>					
<pre>Start 54: test_core/test_01-2_globalconfig_modelpaths.conf</pre>					
<pre>Start 55: test_core/test_01-3_globalconfig_log_format.conf</pre>					
<pre>Start 56: test_core/test_01-4_globalconfig_log_level.conf</pre>					
<pre>1/22 Test #53: test_core/test_01-1_globalconfig_detectors.conf</pre>	Passed	0.81 sec			
<pre>Start 57: test_core/test_01-5_globalconfig_log_file.conf</pre>					
<pre>2/22 Test #56: test_core/test_01-4_globalconfig_log_level.conf</pre>	Passed	2.11 sec			
3/22 Test #55: test_core/test_01-3_globalconfig_log_format.conf	Passed	2.11 sec			
<pre>Start 58: test_core/test_01-6_globalconfig_missing_model.conf</pre>					
<pre>Start 59: test_core/test_01-7_globalconfig_random_seed.conf</pre>					
<pre>4/22 Test #57: test_core/test_01-5_globalconfig_log_file.conf</pre>	Passed	1.11 sec			
[]					

100% tests passed, 0 tests failed out of 22

Test framework & modules by automatically running simulation configurations with known outcomes

- Each test is a configuration file:
 - Run single event with fixed seed
 - Reproduces same output
 - Matching regular expressions
- Single change (1e difference) fails test
 → adaptation of test in case of expected change
- Invaluable for monitoring framework
 → catching issues before merging code



User Manual & Code Reference

- Source code documentation for every class & method
 - Doxygen markup for code reference
 - CI checks for complete & correct documentation
 - Deployed to the website for every release
- User Manual (currently) in LaTeX
 - Module documentation as Markdown
 - Document module parameters, algorithms
 - Included in manual via Pandoc
 - Manual automatically compiled by CI
 - Deployed to the website for every release

```
Allpix<sup>2</sup>
                                        v2.0.1
                      Generic simulation framework for pixel detectors
               Main Page Modules Classes - Files -
             allpix Configuration
                                                          Classes | Publ
             allpix::Configuration Class Reference
                                                             Static P
             Generic configuration object storing keys, More...
             #include <Configuration.hpp>
             Classes
               class AccessMarker
                    Helper class to keep track of key access. More,
              struct parse node
                    Node in a parse tree. More.
             Public Member Functions
namespace
                                                 Configuration (std::stri
                                                 Construct a configurat
                                            bool has (const std::string &
      * @br
                                                 Check if key is defined
                                       unsigned int count (std::initializer_li
     * Con
                                                 Check how many of the
      * properties are stored in its DetectorModel inste
    class Detector {
         friend class GeometryManager;
    public:
          * @brief Constructs a detector in the geometry
          * @param name Unique name of the detector
          * @param model Model of the detector
          * @param position Position in the world frame
          * @param orientation Rotation matrix represent
         Detector(std::string name,
                    std::shared ptr<DetectorModel> model,
                    ROOT::Math::XYZPoint position,
                    const R00T::Math::Rotation3D& orientat
          * @brief Get name of the detector
          * @return Detector name
         std::string getName() const;
```

GenericPropagation

Maintainer Kom Wohren (kom wohreng)com ch), Smon Spannagel (simon spannagelg)com c Status Functional Input Departed Charge Order: Proceeding

Description

Simulation the propagation of electrons and/or helies through the sensitive sense volume of the detector. It allows to propagate starts of thorge currents together in order to growed pub samulations while maintaining bure-regional accuracy. The propagation process for these sensitis is fully independent and/no interaction is simulated. The maintain stars of these set of propagation cancers and the sensitis is fully independent and/no interaction is simulated. The maintain stars of these set of propagation cancers and the sensitis is fully independent and/no interactions.

The propagation consists of a correlativition of drift and diffusion simulation. The drift is calculated using the charge carrier velocity deviced from the charge carrier mobility parameterization by C. Jacobori et al. (<u>Speckori</u>: The correct mobility for either electrons or holes is automatically chasers, based on the type of the charge carrier under consideration. Thus, also input with both electrons and holes is transfer paraly.

The hosp ensemblers a propagate, electrons and propagate to bies about control defails type of drang control is propagated to their majore beneformed. There are of the control system can be setedice it starts can be propagated. It takes and the propagate it takes are propagated to their system of the control system can be extended as the taket and a target to an other the weath of the detaction of the propagation departs on the detaction. The detaction of the taket are not taket the taket are the control system and the control of the propagation departs on the detaction. The detaction are used on the taket are acculated are acculated are acculated to the implicit table. For hours electric fields, as warring to instand of approaches interording startarts in detacted.

A foarth-order Range-Kutte Fehleng method with fifth-order error entimation is used to integrate the electric field. After every Range-Kutta used, the officialism is accounted for by applying an offiset drawn from a Gaussian distribution calculated from the Emission relation.

$\sigma = \sqrt{\tfrac{2\pi T}{r}} \mu t$

using the carrier mobility μ_i the temperature T and the time step δ . The propagation stops when the set of charges reaches any surface of the sensor.

The propagated stage scalars and from the part of a stage states. These results a 2D registed of the process and from the part of a discussion in the end of the end of the states of a through the states of the end of the states of the state

Dependencies

This module requires an installation of Eigen3.

Parameters

- temperature: Temperature of the sensitive device, used to estimate the diffusion constant and therefore the strength of the diffusion Defaults to room temperature (202118);
 charge operates "Medicine market of device carries to propagate together. Divides the total number of deviced
- Charge per use in the investment areas or charge carriers to propagate agence. Division the total names or deposited charge carriers at a specific pairt into acts of this names of charge carriers and a set with the remaining charge carriers. A value of 10 charges per name to solve by default if this value is not specified.
- spart in precision: Spartial precision to aim for. The timestep of the Range Kutta propagation is adjusted to reach this
 apatial precision after calculating the uncertainty from the fifth-order error method. Defaults to 0.1 mm.
- timestep_start: Threatep to initialize the Range-Kutta integration with Appropriate initialization of this parameter
 reduces the time to optimize the timestep to the spatial precision parameter. Default value is 0.07 m.
- timestep_min
 Winimum step in time to use for the Range-Kutta integration regardless of the spatial precision. Defaults
 to 0.5ps.
- timestep_max Maximum step in time to use for the Range-Kutta integration regardless of the apartial precision.
 Defaults to 0.1m.
 The aparticle of time. The authin which channe carriers are reconstrained affect according to the constraints of the reconstraints.
- Integration_time: Three within which charge carries are propagated. After exceeding this tarter, no harther propagation is performed for the respective carriers. Defaults the LHC banch crossing time of 25m.
 propagate electron: Select whether electron-type charge carries should be propagated to the electrodes. Defaults
- propagate_electrons:Select whether electron-type charge carriers should be propagated to the electrodes. Defaults to true.
- propagate holes: Select whether hole-type charge carriers should be propagated to the electrodes. Defaults to false.
 output_plots: Determines if output plots should be generated for every event. This causes a significant slow down of
- the simulation, it is not recommended to enable this option for nurs with more than a couple of events. Disabled by default output, plots, it is not recommended to enable this option for nurs with more than a couple of events. Disabled by default output, plots, it is not recommended to enable the second output to points plotted. Indirectly determines the amount of points plotted. Default to interview must find enables to second.
- output_plots_theta : Viewpoint angle of the 3D animation and the 3D line graph around the world X-axis. Defaults to zero.
- output_plots_phi_Vexpoint angle of the 3D animation and the 3D line graph around the world 2-axis. Defaults to zero
 output_plots_use_plots_units_Determines if the plots should use plots as unit instead of metric length scales.
- Defaults to haloe (thus using the metric system).

 output_plots_use_equal_scaling: Determines if the plots should be produced with equal distance scales on every
- main (also if this implies that some points will fail out of the graph). Defaults to true.
 output [plots, allogn plant]: Determines if the plot includes adgreed on plots, defaults to fails. If evabled the start
 worth word if the unit will be used to see the unit when the intervence to be.
- output_animations: In addition to the output plots, also write a GEF minution of the charges drifting towards the
 electrodes. This is very about and writing the entimation takes a considerable arrount of three, therefore defaults to false.
 This output addressed are about a second and the second addressed at the second addressed addressed at the second addressed addressed at the second addressed at
- output animations, time scaling: Scaling for the animation used to convert the actual aimulation time to the time step is the extension Scale day to 10 million and the animation and the step latter is an of a second step in the step is the extension Scale day to 10 million and the animation and the step latter is an of a second step in the step is the extension Scale day to 10 million and the animation and the step in the step latter is an of a second step in the step is the extension of the step in the
- step in the animation. Defaults to 1.0x9, meaning that every nanosecond of the aimstation is equal to an animation step of a single second. • output animations marker size: Scales for the markers on the animation, defaults to one. The markers are already
- output animations marker size :Scaling for the markers on the animation, defaults to one. The markers are already internally scaled to the charge of their step, normalized to the maximum charge.
 output animations contour max scalino :Scaling to use for the contour color axis from the theoretical maximum
- charge at every single plot step. Default is 10, meeting that the maximum of the color scale sets is equal to the total amount of charges devices provided by ten (values above this are displayed in the same maximum color). Parameter can be used to improve the color scale of the contrast plots.
- to improve the color scale of the contour plots.

 output animations color markers: Determines if colors should be for the markers in the animations, defaults to

Usage

```
A example of generic propagation for all sensors of type "Timepix" at norm temperature using packets of 25 charges is the
following
```

```
[GenericPropagation]
type = TimpLe"
temporature = 208K
dwarp.per_step = 25
```

-

How To Contribute – A Cookbook

- **Get in touch** mail, forum, issue tracker, CERN Mattermost... Let's discuss the idea, maybe we have input, maybe others are working on it already
- Fork the repository

Creating your own copy of the code with which you can mess as much as you want

• Start hacking

Implement the desired functionality, come back to us when you have doubts or questions

• Make sure the CI passes

Enable the CI in your fork and publish your new code there – check that the CI works!

• File a Merge Request

This provides us a central point to discuss and review all your code changes

• See your code being merged and published!

unnecessary copies [performance-unnecessary-value-param,-warnings-as-errors] electric field .setGrid(field, sizes, scales, offset, thickness domain);

warnings treated as errors

std::move()

/builds/allpix-squared/allpix-squared/src/core/geometry/Detector.cpp:191:33: error: parameter 'function' is passed by value and only copied once; consider moving it to avoid unnecessary copies [performance-unnecessary-value-param,-warnings-as-errors] electric_field_.setFunction(function, thickness_domain, type);

/builds/allpix-squared/allpix-squared/src/core/geometry/Detector.cpp:185:29: error:

parameter 'field' is passed by value and only copied once; consider moving it to avoid

std::move()

/builds/allpix-squared/allpix-squared/src/core/geometry/DetectorField.hpp:51:27: error: member initializer for 'field_type_' is redundant [modernize-use-default-member-init,warnings-as-errors]

DetectorField() : field_type_(FieldType::NONE){};











Summary

allpix squared



Summary

- Silicon Detector Monte Carlo simulations: vital component of understanding & interpreting detector performance
- Allpix Squared:

comprehensive MC simulation framework for silicon detectors

- integrates existing toolkits
- provides validated algorithms
- is easy-to-get-started and well documented
- has a clean and solid code bases
- Used in many areas: CMOS sensors, calorimetry, DSMS neutron detectors, ...
- Continuous development and support, many new features already underway







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



