

cern.ch/allpix-squared



#### The Allpix Squared Framework: New Developments

A Brief Overview of New Features, Releases and Plans

#### Simon Spannagel, DESY

CLICdp Collaboration Meeting 01 October 2020

### Outline



- Introduction
- Recently Added Features
  - Digitizing Pulses: The CSADigitizer Module
  - ProjectionPropagation:
     Diffuse Before Project
  - Passive Material: Things in the Beamline
  - Many new Simulation Modules

- Simulations
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  - Some Outside-HEP Application Highlights
- Outlook: Things Underway
  - Google Season of Docs
  - Multithreading Once More
  - Features currently under Development



# Introduction: Silicon Detectors Monte Carlo Simulation



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# Introduction: The Allpix<sup>2</sup> Framework

• Silicon Pixel Detector MC simulation software, that

...provides a **modular tool kit** to simulate signal formation in silicon detectors

... implements parametrized **detector models** 

... facilitates usage of precise electric fields

- Focus on usability & stability
  - Provide documentation (170p. user manual)
  - **Regular patch & feature releases,** 6 feature releases, 18 patch releases in 3.5 years
  - Community-driven, with by now more than 30 contributors





# **Recently Added Features** Releases 1.5 & 1.6



# Digitizing Pulses: CSADigitizer

- Implementation of charge-sensitive amplifier with Krummenacher feedback, configuration via:
  - Rise time, feedback time & capacitance "simple"
  - Detector cap., Krum. current, transconductance "csa"
- Integrated ToT / ToA sampling on different clocks



```
[CSADigitizer]
model = "simple"
feedback_capacitance = 5e-15C/V
rise_time_constant = 1e-9s
feedback_time_constant = 10e-9 s
integration_time = 0.5e-6s
threshold = 10e-3V
clock_bin_toa = 1.5625ns
clock_bin_tot = 25.0ns
```





# Digitizing Pulses: CSADigitizer Example

- Single pulse of CLICTD, modified process, bias -6V/-6V at p-wells/substrate
- 5.4 GeV electron beam
- Electric field & weighting potential imported from electrostatic TCAD
- CSADigitizer with *simple* model and default parameters:
  - Rise time: 1ns
  - Feedback: 10ns





# ProjectionPropagation: Diffuse Before Project

- ProjectionPropagation simplest & fastest charge transport module
  - Calculate total drift time, move to sensor surface, smear for diffusion
- Problem: does not work in partially-depleted sensors (e.g. CMOS)
- Solution: diffuse charge carriers in zero-field region before projection GenericPropagation ProjectionProp. (diffuse ON) ProjectionProp. (diffuse OFF)



Better description of MIMOSA26, see new example!

01/10/2020

Paul Schütze



# Passive Materials: Things in the Beamline



Paul Schütze

- Added possibility to define passive material in the geometry Koen van den Brandt
- Different shapes, automatic merging of multiple shapes / hierarchy resolution
- Completely transparent to core framework through new parameter "role"





# Many New Simulation Modules

DESY.

- CSADigitizer: *covered before*
- DepositionPointCharge:
  - Deposit energy at a single point or along line, e.g. for comparison with TCAD
- DepositionReader
  - Generate energy depositions externally (e.g. full-experiment G4 simulation)
  - Read deposited energy from file and dispatch for configured detectors
- DatabaseWriter (Enrico Jr. Schioppa)
  - Write simulation result directly into PostgreSQL databases





# **Transient MC Simulations**



Magdalena Munker

- Goal: understand timing performance of CMOS prototypes, predict timing performance of future CMOS detectors
- Transient TCAD simulations provide detailed insight into signal formation, but are computationally heavy
  - $\rightarrow$  use MC simulations via Shockley-Ramo theorem



# **Transient MC Simulation: Validation**



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- Comparison: TCAD transient / Allpix Squared transient + TCAD static
  - Comparing different CMOS sensor designs in worst-case scenario (pixel corner)



# Transient MC Simulations: Scaling Out

- Validated MC+TCAD simulation allows:
  - Random sampling of position in pixel cell
    - Too time-consuming in TCAD
    - Obtain full picture, not individual scenarios
  - Usage of Geant4 for realistic performance
    - Landau fluctuations
    - Secondaries
- Compatibility should be validated for every design
- Have seen some deviations in extreme cases,
   e.g. doping-dependent mobility in TCAD etc



# Some Outside-HEP Application Highlights



- Outside particle physics
  - NASA / Space Radiation Analysis Group
     ISS radiation monitor simulations
  - Kansas State University
     Silicon neutron detector with LiF trenches
- Education
  - EDIT Detector School & Bonn-Cologne Graduate School
     Lab exercise on resolution of pixel detectors
  - Beam Line 4 Schools 2019
    - Simulation of beam telescope with absorbers
  - Uni Dortmund
    - Bachelor thesis on time-of-flight measurements





# Outlook

# Things Underway

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

\ref InvalidModuleStateException will be raised if the module failed to su

#### ule(Configuration& config, std::shared\_ptr<Detector> detector);

ential 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;



ap<sup>2</sup>

# Google Season of Docs

... is *not* Google Summer of Code!

- Scholarship for experienced technical writers to work on documentation of open source projects
- Allpix Squared is participating through HEP Software Foundation
- Technical Writer Sabita Rao started her work on September 14
  - Goal: revision of online appearance
  - Focus on integration of online user manual
  - Improvements to tutorials/examples
- Three-month project
- Mentorship by Paul Schütze, me







# Multithreading – Once More

- Fully parallel event processing already in preparation since 2018
- Overcame some road blocks in the past months
  - Full random number distribution audit now possible to trace PRNG usage
  - Wrapping of ROOT's Tref removes bottleneck, allows scaling to 100+ cores with ~100% utilization
- Still a few issues to be solved
  - Some memory handling
  - TProcessID assignment to objects
  - Some rare race conditions to be solved
- Getting into very good shape!



Time







#### S. Spannagel - The Allpix Squared Framework: New Developments

# Features Currently Under Development/Validation

- Charge multiplication / gain (Florian Pitters, HEPHY Vienna)
  - Implementations of Oeverstraten and Massey models
  - Comparison with TCAD simulations of LGADs underway
- Hexagonal pixels (Tasneem Saleem, Paco Iguaz Gutierrez, Synchrotron SOLEIL)
  - Mapping of charge carriers from sensor onto hexagonal front-end pixels
  - Working prototype, framework integration pending
- Trapping / radiation damage (Sinuo Zhang, Uni Bonn)
- Sensor implants for 3D sensor studies (me)









#### In a nutshell...



01/10/2020



S. Spannagel - The Allpix Squared Framework: New Developments

# Summary



- Allpix Squared continues to be developed & used by broad community
- Many new features added recently
  - Transient simulations, charge-sensitive amplifier
  - Better treatment of partially depleted sensors in fast simulation
  - Passive materials can be added to geometry
  - Many new modules
- First detailed looks on transient simulations of CMOS sensors
- Several ongoing projects (GSDocs, Multithreading, ...)



# 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



