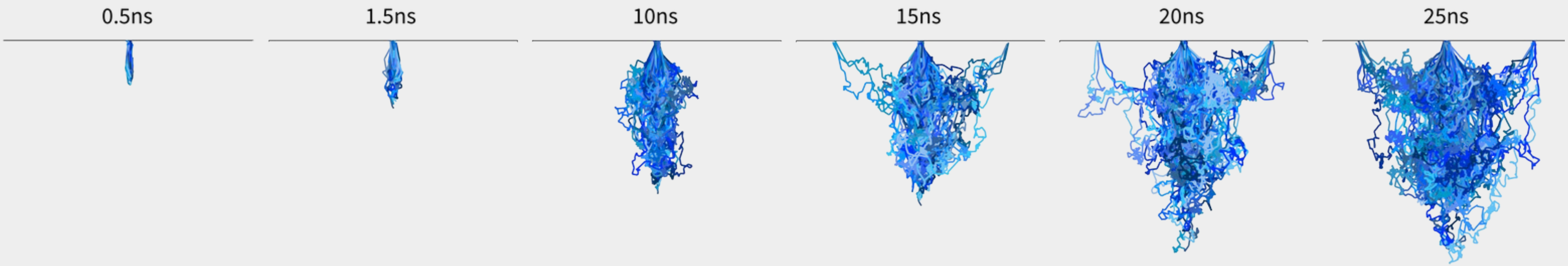
ap²

allpix squared

cern.ch/allpix-squared



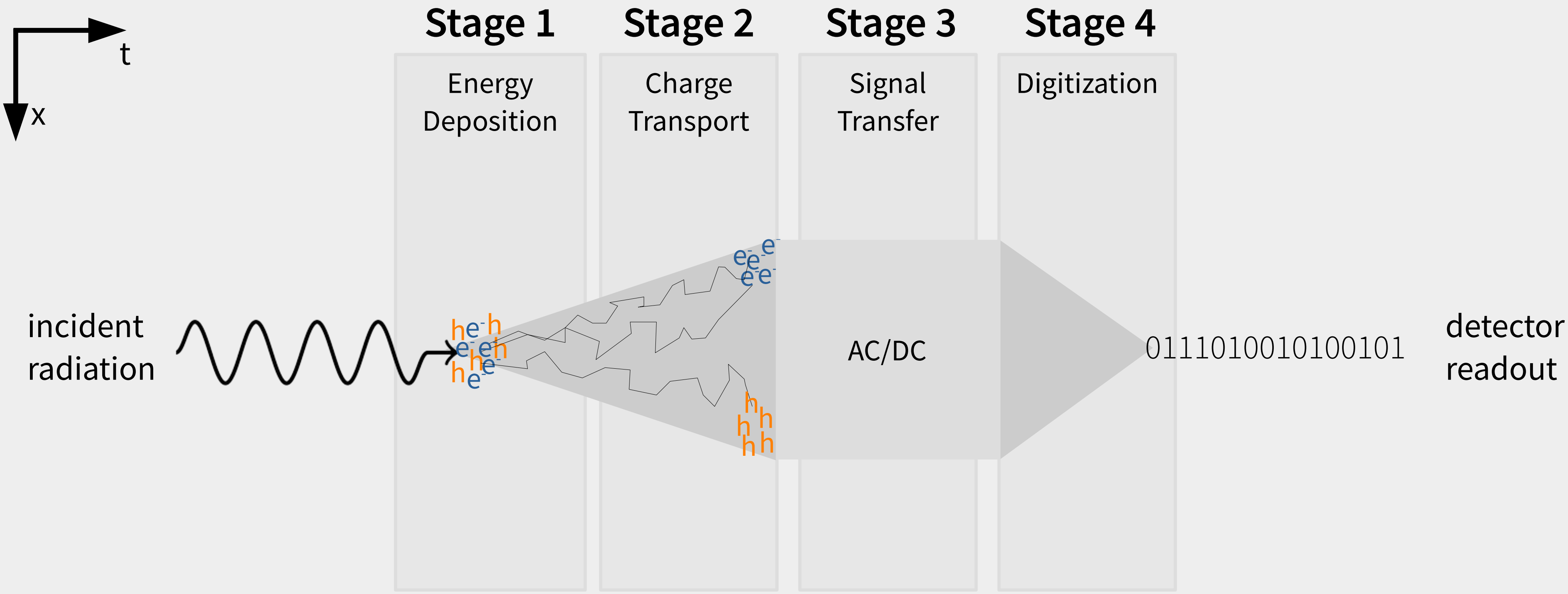
What's New With Allpix Squared?

A Brief Overview of New Features, Releases and Plans

Paul Schütze & Simon Spannagel, DESY

9th Beam Telescopes & Test Beams
10 February 2021
Virtual Lecce

Introduction: Silicon Detectors Monte Carlo Simulation



Introduction: The Allpix² Framework

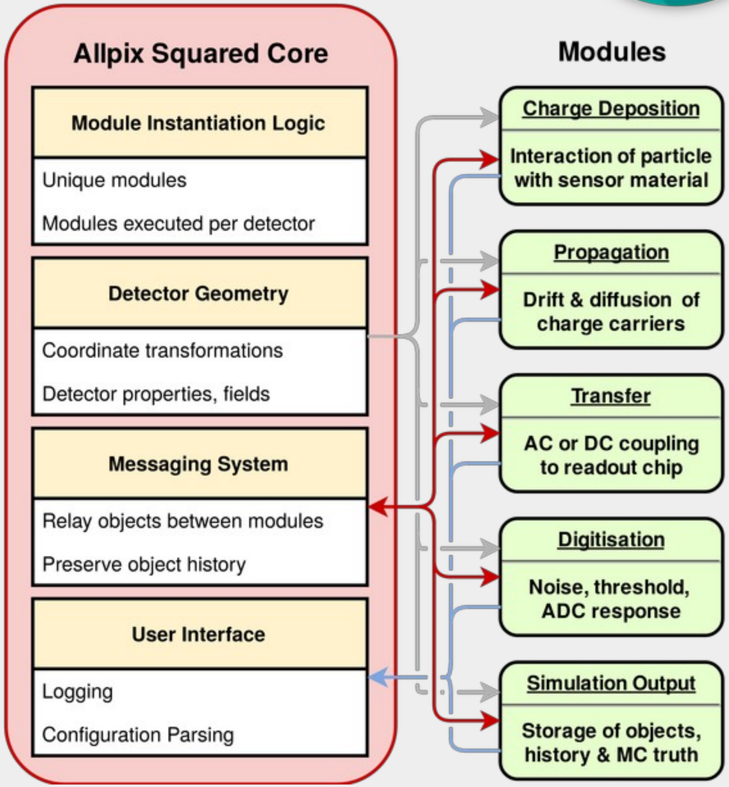
- Silicon Pixel Detector MC simulation software, that

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

  ...implements parametrized **detector models**

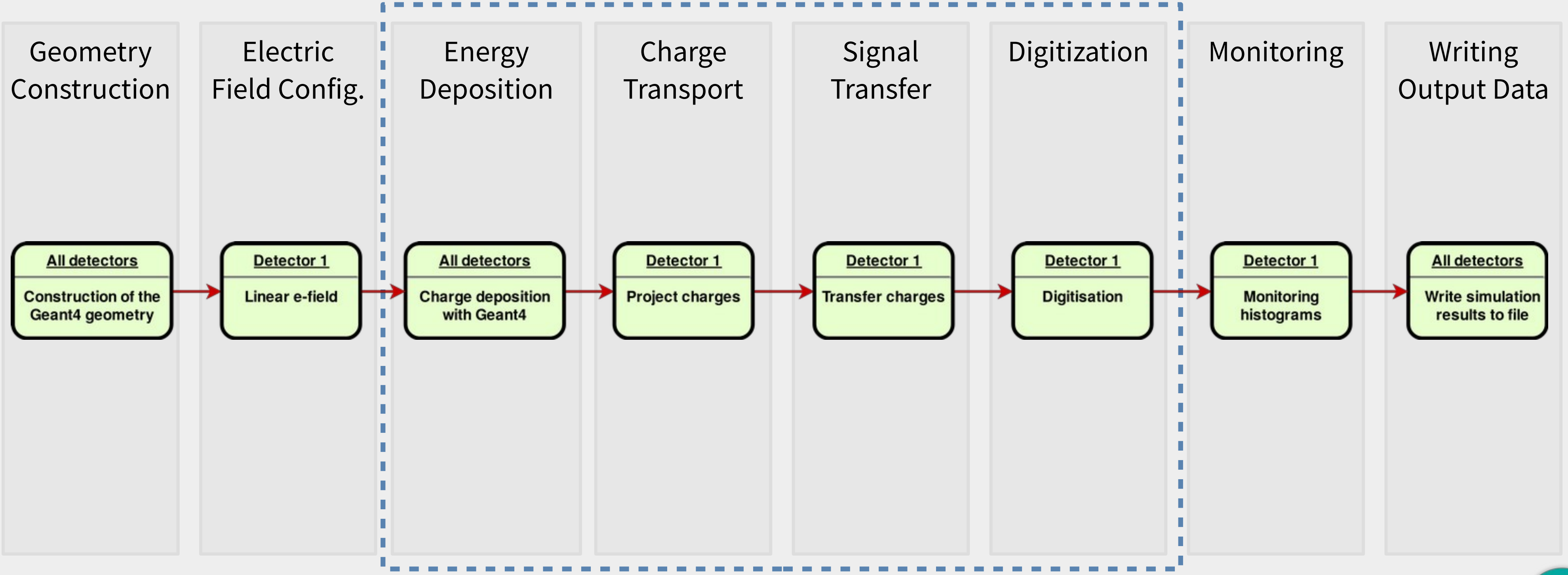
  ...facilitates usage of **precise electric fields**

- Focus on usability & stability
  - Provide documentation (170p. user manual)
  - **Regular patch & feature releases,**
    7 feature releases, 16 patch releases in 4 years
  - Community-driven, with by now **more than 30 contributors**



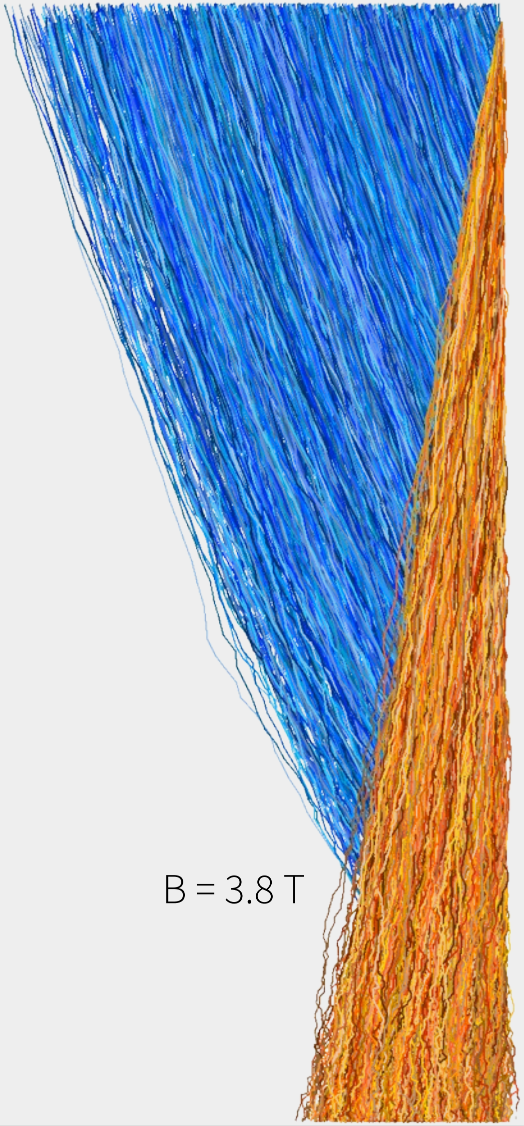
Introduction: The Simulation Chain

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

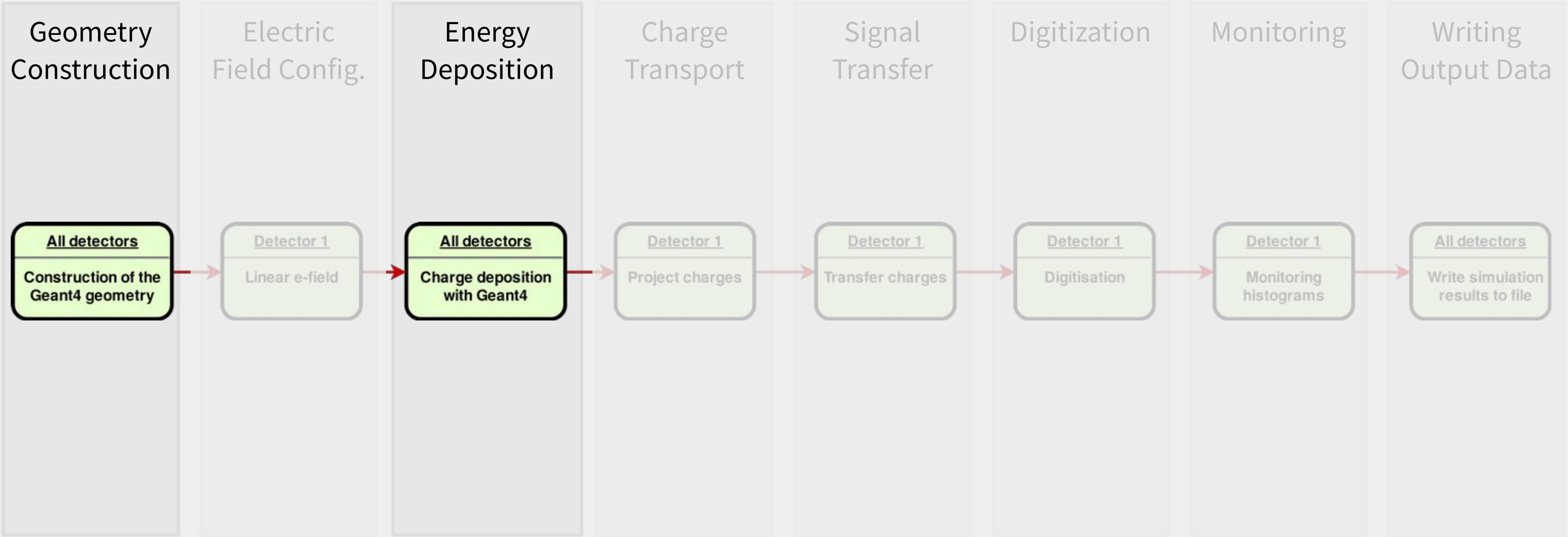


Recently Added Features

Releases 1.4, 1.5 & 1.6



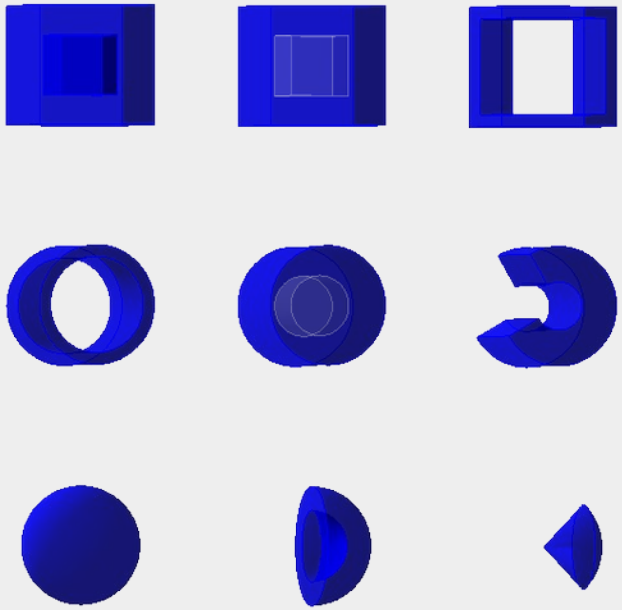
Geometry / Energy Deposition



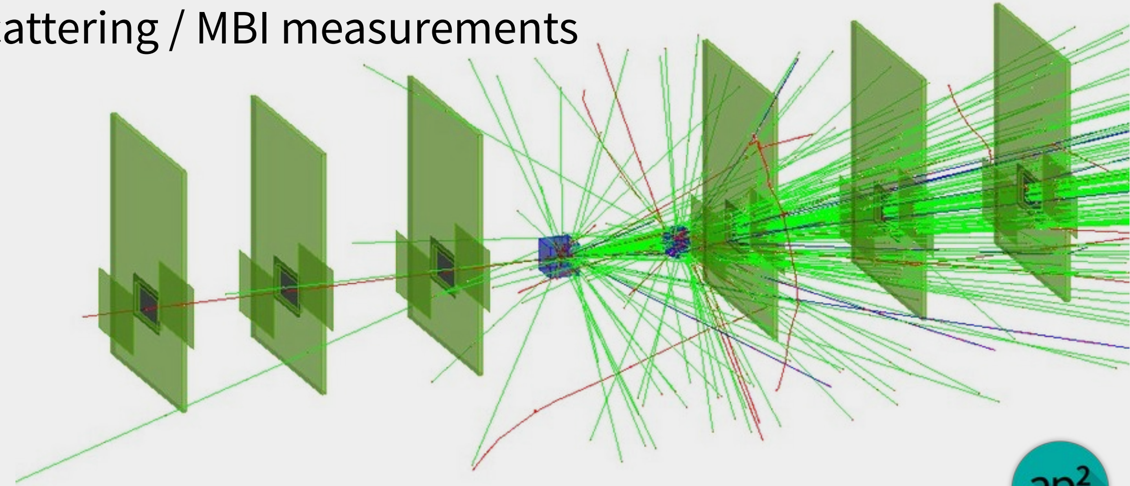
Passive Materials: Things in the Beamline

Paul Schütze, DESY
Koen van den Brandt, Nikhef

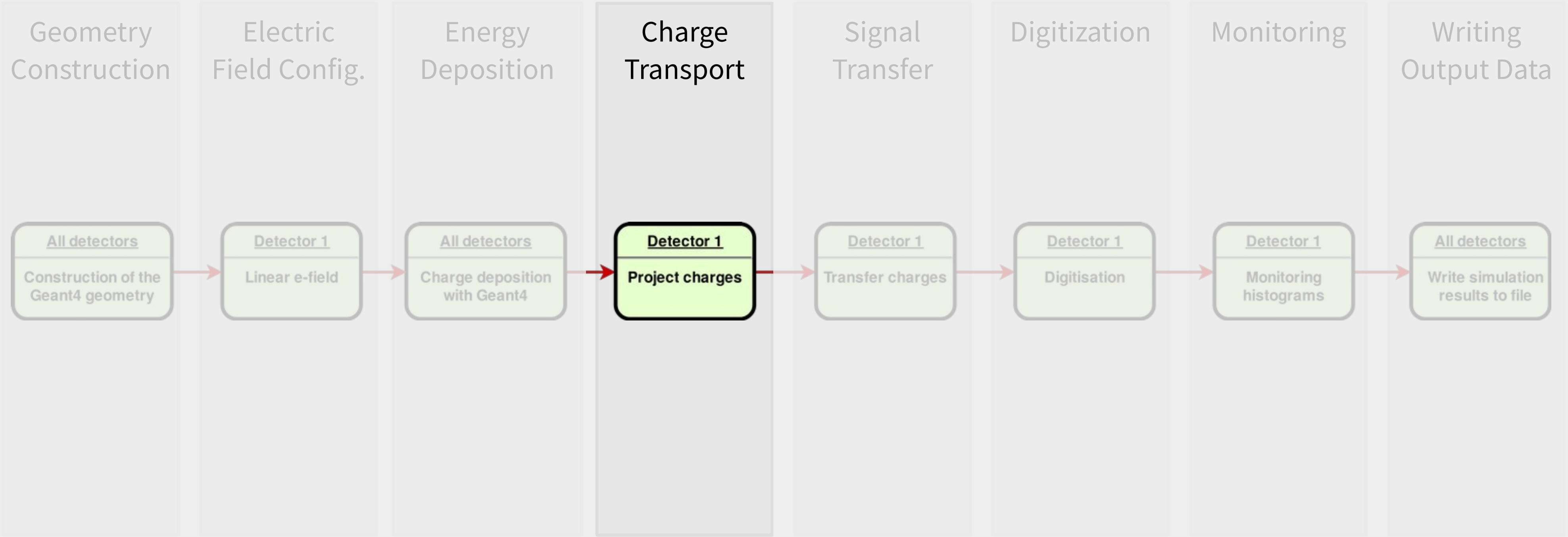
- Added possibility to define passive material in the geometry
- Different shapes, automatic merging of multiple shapes / hierarchy resolution
- Completely transparent to core framework through new parameter “*role*”



Usage examples:
- Realistic test beam setup (cooling box)
- Calorimeter simulation
- Multiple Scattering / MBI measurements



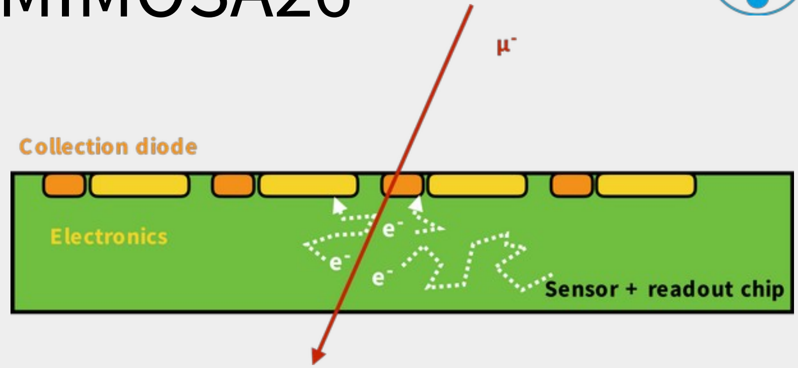
Charge Transport

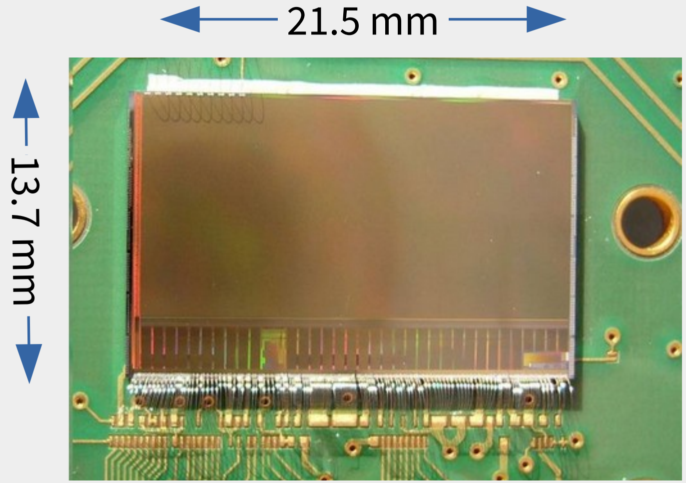


Simulations of Telescopes @ DESY – MIMOSA26

- MIMOSA26: Monolithic active pixel sensor
  - 18.4 µm x 18.4 µm pitch, binary readout
  - Limited bias voltage: small depletion volume
  - Well known from beam telescopes

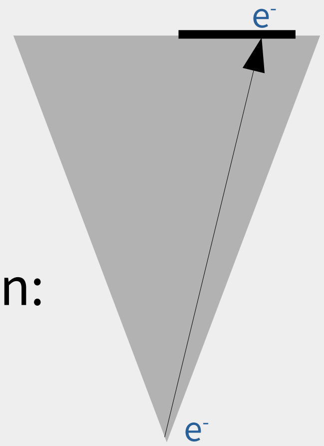
    → used as reference detectors, simulation should be fast!





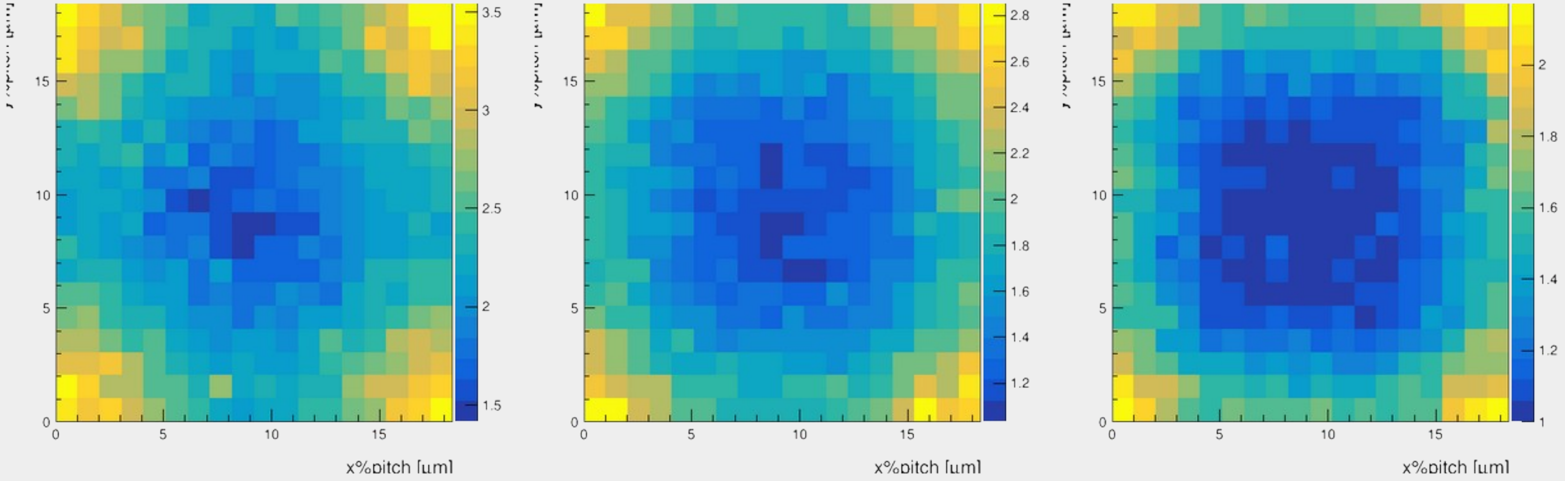
ProjectionPropagation: Diffuse Before Project

Paul Schütze, DESY



- *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**)



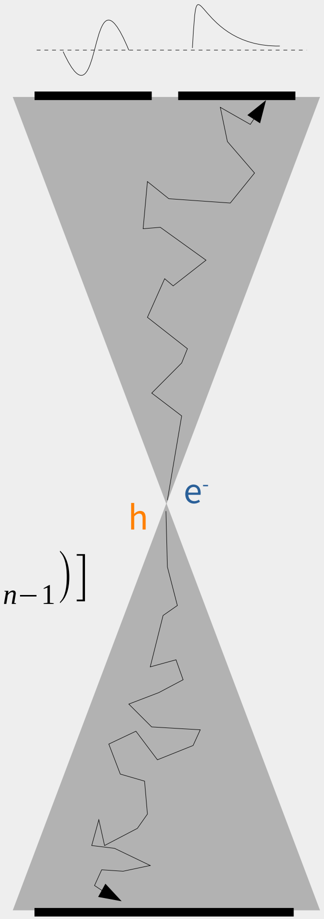
Better description of under-depleted sensors,
new example in repository!

Transient Simulation – Induced Signal at Electrodes

- Successive integration of motion, calculating induced charge per step
- Take each (group of) charge carrier
  - Calculate mobility & velocity from local fields
  - Make step, add diffusion offset from Gaussian distribution
  - Get induced charge from weighting potential difference for all neighbors
  - Repeat until sensor surface is reached
- Allows time-resolved simulation

$$Q_n^{ind.} = \int_{t_{n-1}}^{t_n} I_n^{ind.} \, dt = q \left[\Phi(x_n) - \Phi(x_{n-1}) \right]$$

  - Requires weighting potential, might not be trivial to obtain
- Time consuming:
  - Calculation for all neighboring electrodes for every step
  - Requires propagating both electrons and holes

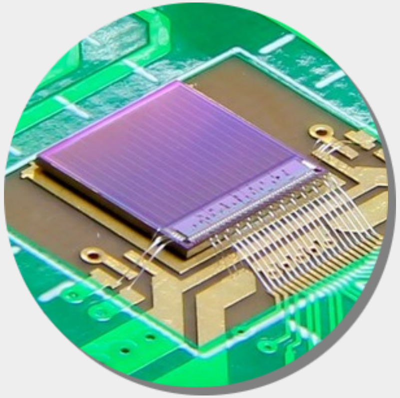


Transient Simulations – The CLICTD MAPS Prototype

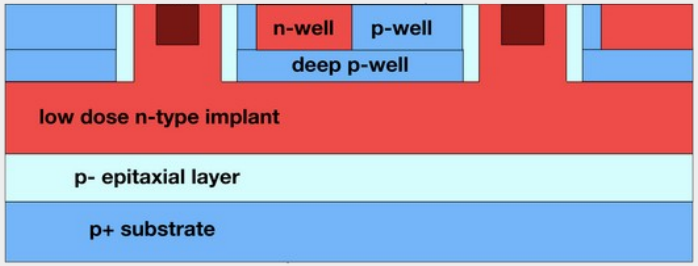
Katharina Dort, CERN
Magdalena Munker, CERN

- Goal: understand & predict timing performance of CMOS prototypes

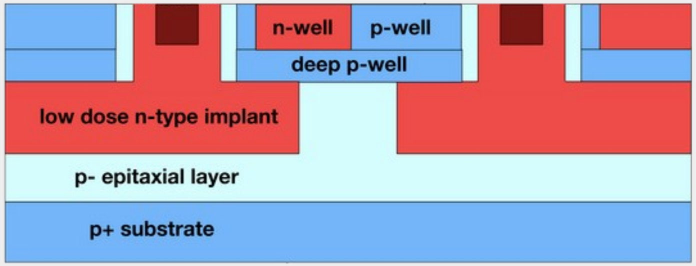
- Example: CLICTD for CLIC tracking detector → Talk by Katharina yesterday
  - 180 nm CMOS imaging process, small collection electrode
  - Pixel pitch: 37.5 µm x 30 µm, 30 µm epitaxial layer
  - Fully-integrated sensors, simultaneous ToA/ToT measurement



- Test bench for testing different sensor designs:



"continuous *n*-layer"

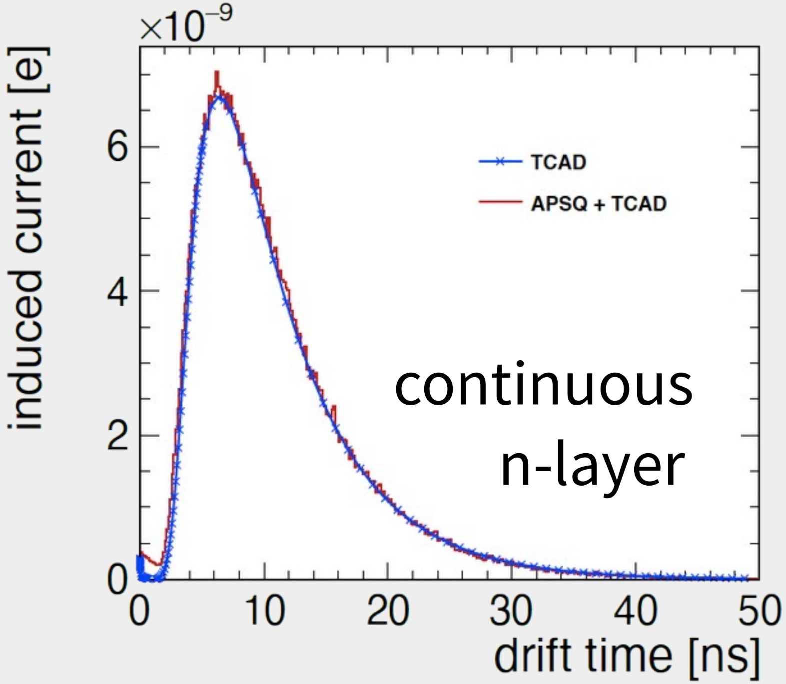


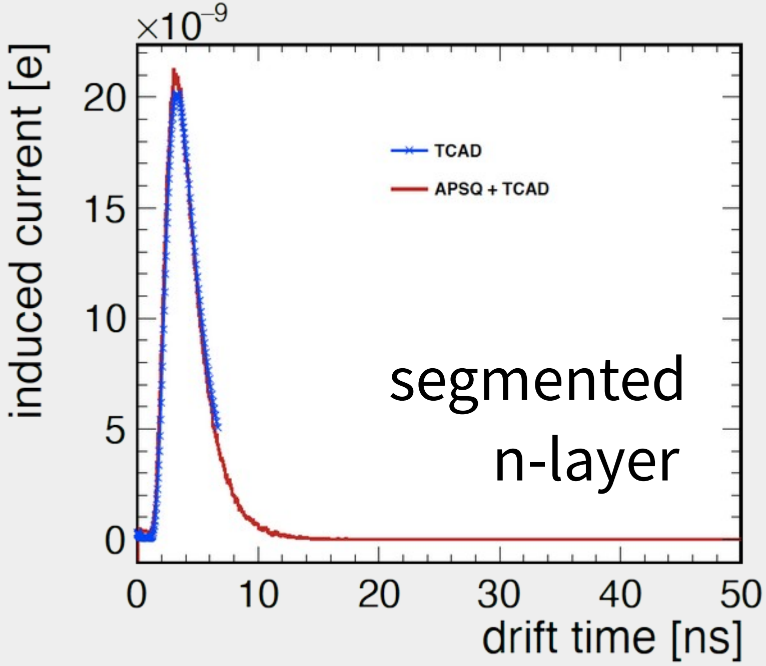
"gap in *n*-layer"

IEEE TNS, vol. 67, no. 10 (2020), 2263
doi:10.1109/TNS.2020.3019887

Transient MC Simulation: Validation

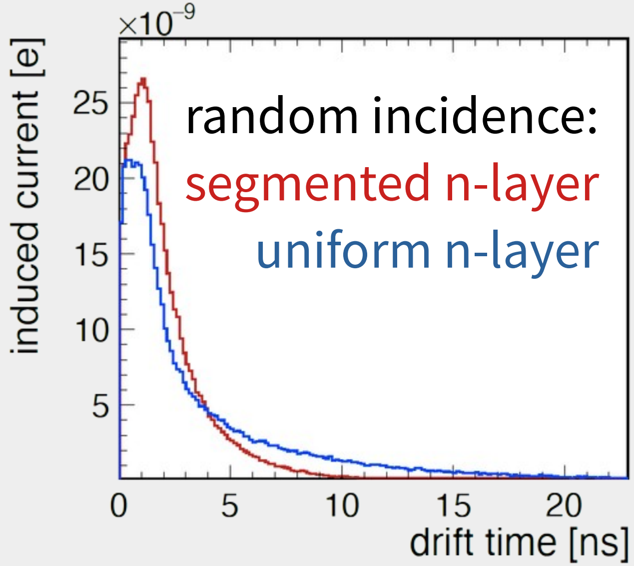
- Comparison: TCAD transient / Allpix Squared transient + TCAD static
  - Comparing different CMOS sensor designs in worst-case scenario (pixel corner)
  - Uniform deposition of e.g. 63e/h per um along line to replicate TCAD transient

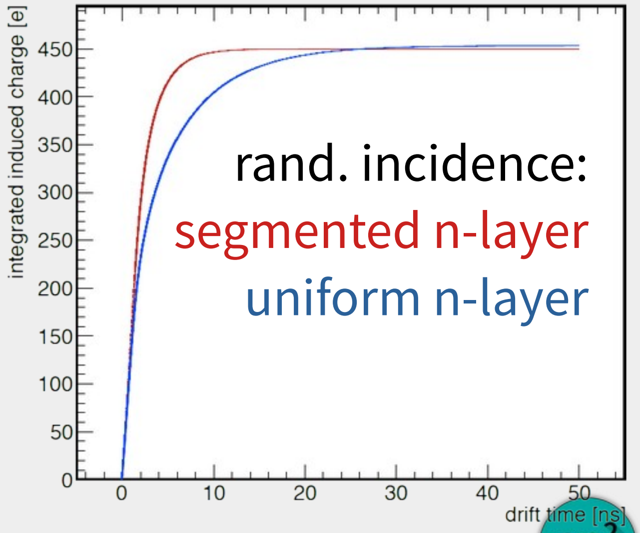




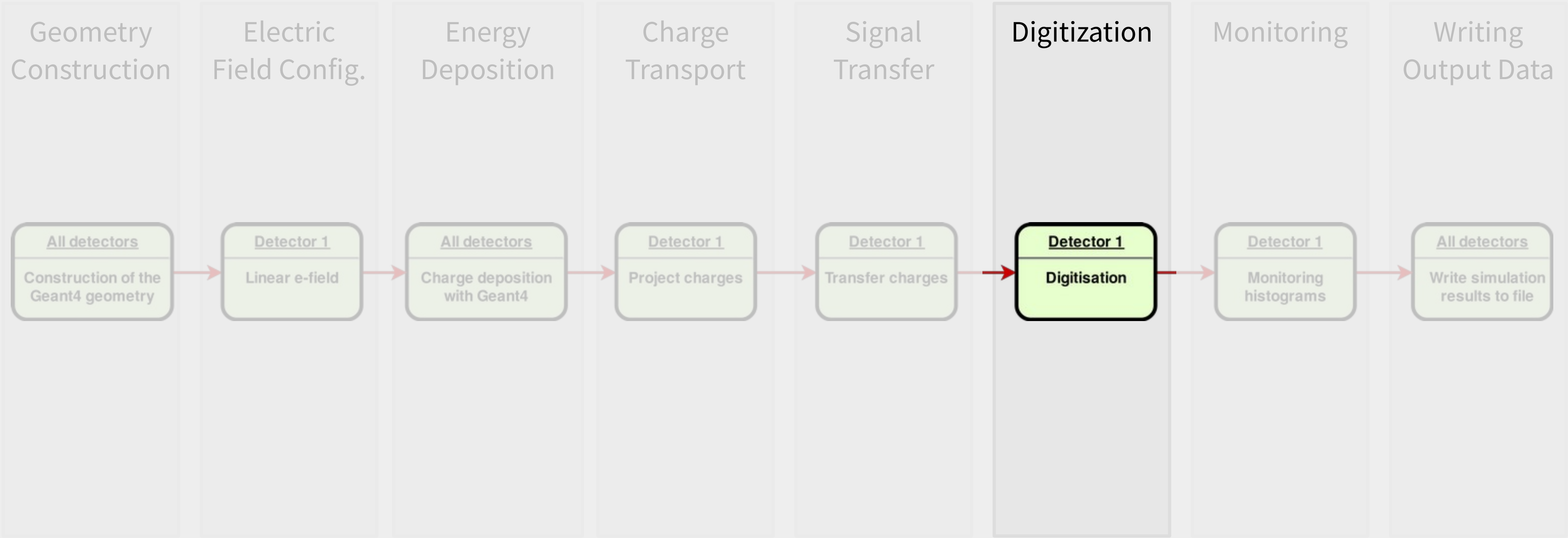
Transient MC Simulations: Scaling Out

- 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





Digitization

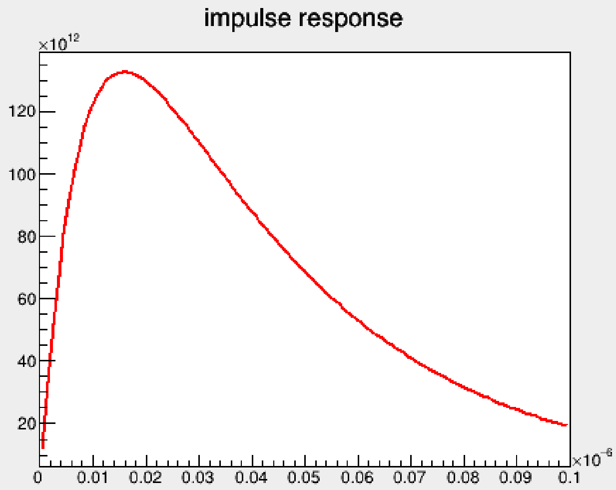


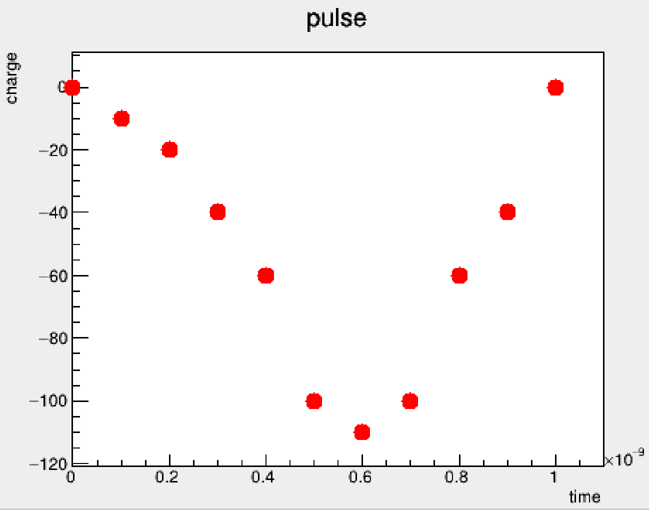
Digitizing Pulses: CSADigitizer

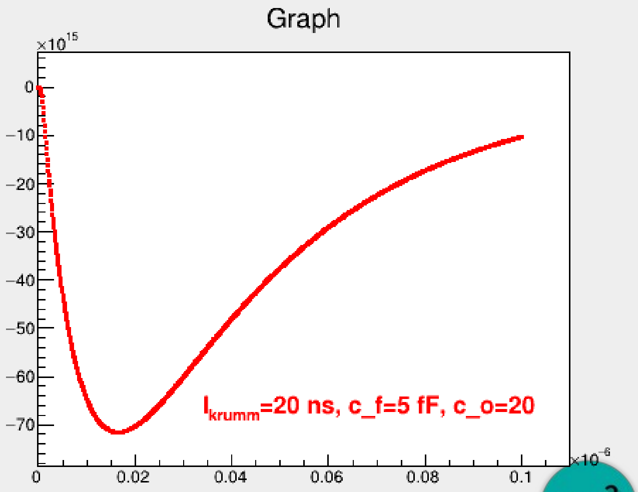
Annika Vauth, UniHH/DESY

- 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
```

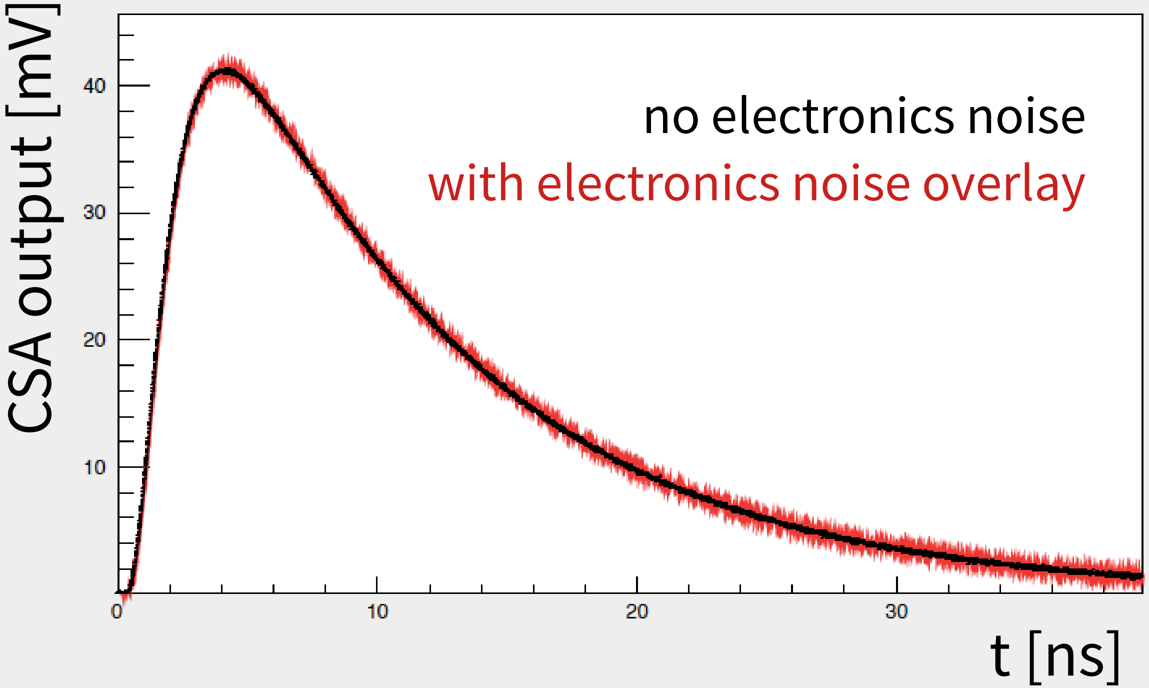






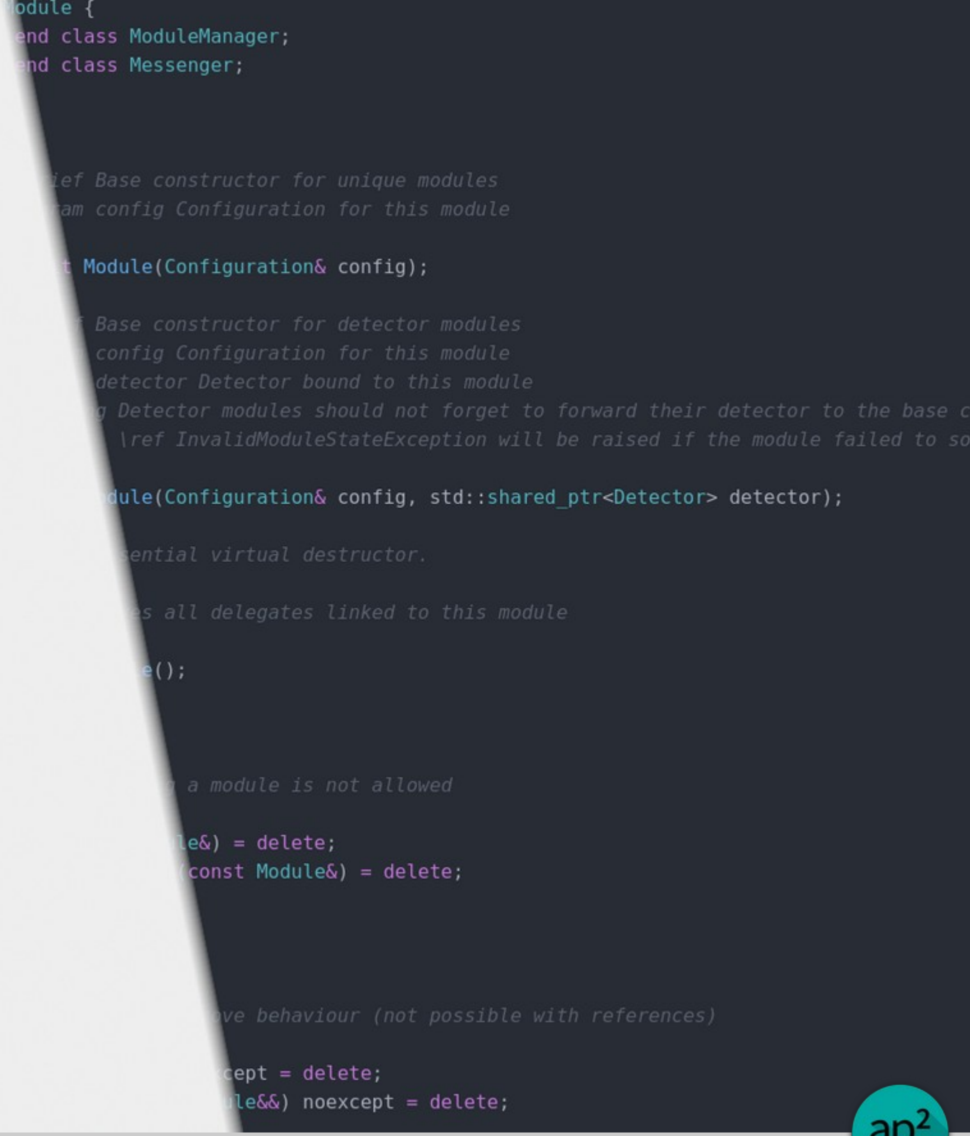
Digitizing Pulses: CSADigitizer Example

- 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



And Much More…

Documentation, Modules



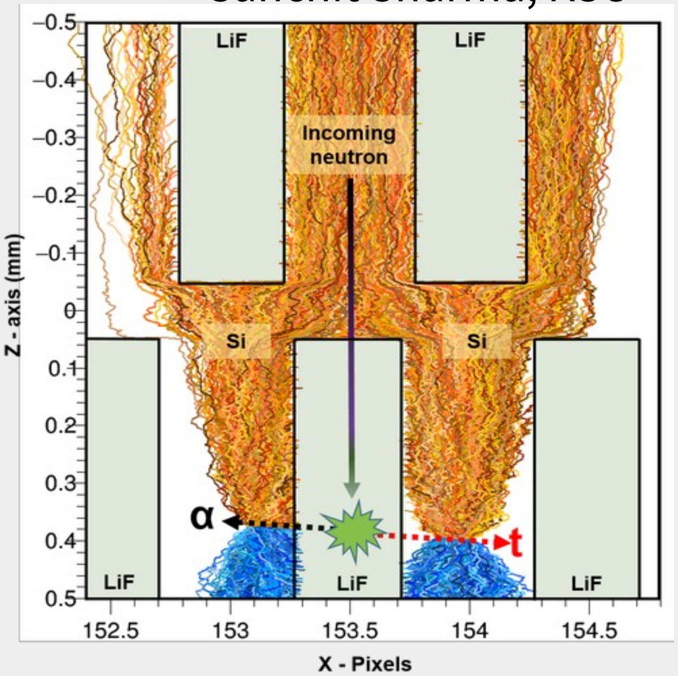
Many New Simulation Modules

- 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, Uni Salento)
  - Write simulation result directly into PostgreSQL databases

Some Selected 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
  - Beamline for Schools 2019
    – Simulation of beam telescope with absorbers
  - Uni Dortmund
    – Bachelor thesis on time-of-flight measurements

Sanchit Sharma, KSU



A Word on Writing Code for MC Simulations

- Implementation of algorithms is not the most time-consuming part
- Most time-consuming part is to do it such, that the algorithms are...

  ...validated with prototype data & device simulations

  ...well documented

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

- Development of Allpix^2: we spend considerable time on
  - Writing documentation → lower barrier for new users
  - Implementing automated testing, compilation → ensure software always works
  - Code review for new features → ensure functionality/compatibility

User Manual & Code Documentation

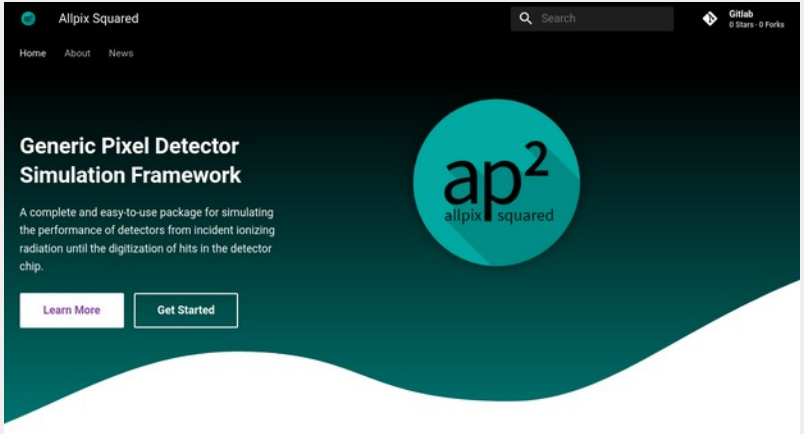
- Focus from the very beginning on well-documented framework
- Source code documentation for every class, method
  - Doxygen markup for code reference
  - Deployed to the website for tags
- Extensive User Manual in LaTeX
  - Automatically compiled by CI
  - Module documentation as Markdown
    - Document module parameters, algorithms
    - Included in manual via Pandoc

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** worked for three months on documentation/website
  - Goal: revision of online appearance
  - Focus on integration of online user manual
  - Improvements to tutorials/examples
- Finalization still pending

Sabita Rao
Paul Schütze, DESY
Simon Spannagel, DESY



In a nutshell…

Summary

- Allpix Squared continues to be developed & used by broad community
- Many new features added recently
  - Passive materials can be added to geometry
  - Better treatment of partially depleted sensors in fast simulation
  - Transient simulations
  - Digitization with a charge-sensitive amplifier
  - Many new modules
- Several ongoing projects

Get involved!

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.