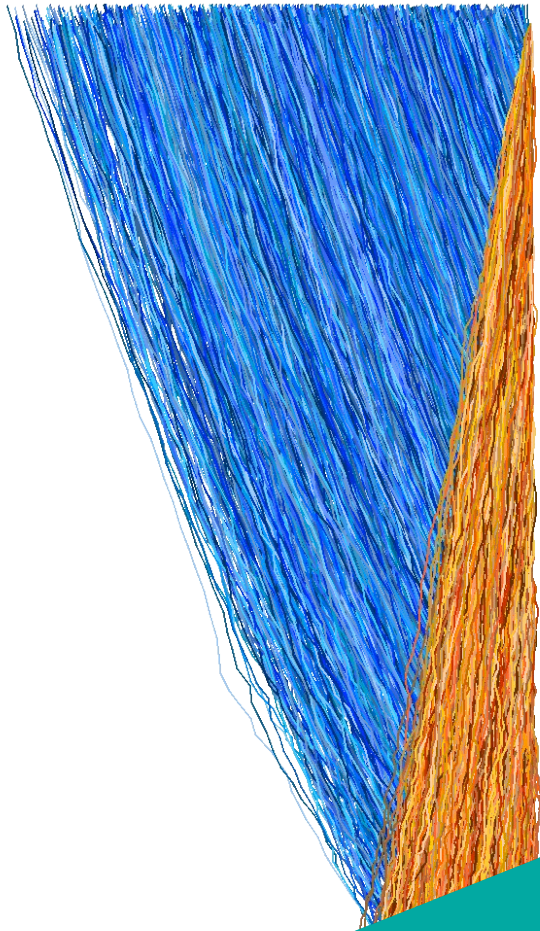
Allpix Squared in Education & Outreach

Paul Schütze

2nd Allpix Squared User Workshop
17th August 2021

Education



Allpix Squared in Education – Why!?

> *Paul, we'd like to have a tutorial on the resolution of silicon detectors for our researcher school, but there's no space at the Test Beam. Could you …?*

or

- Thinking back to university... Silicon detectors can be quite complex!

➔ Understanding of silicon detectors (not only on a students level) can profit from …

- Visualisation – e.g. for charge carrier transport
- "Hands-on" for getting a feeling for what influences the performance
  – sure a lab is cooler than a simulation, but who has got a test beam with a multi-Tesla magnet available?

- Positive side effect: training for skills in HEP software tools – Geant4, ROOT et al

Allpix Squared Lab Exercise

- Used within …
  - EDIT-2020 Young Researcher School (in-person)
  - Bonn-Cologne Graduate School Lab Courses (virtual)
- Task
  - Run Allpix Squared
  - Determine the resolution of a given detector
  - Improve the resolution by changing the setup or detector parameters

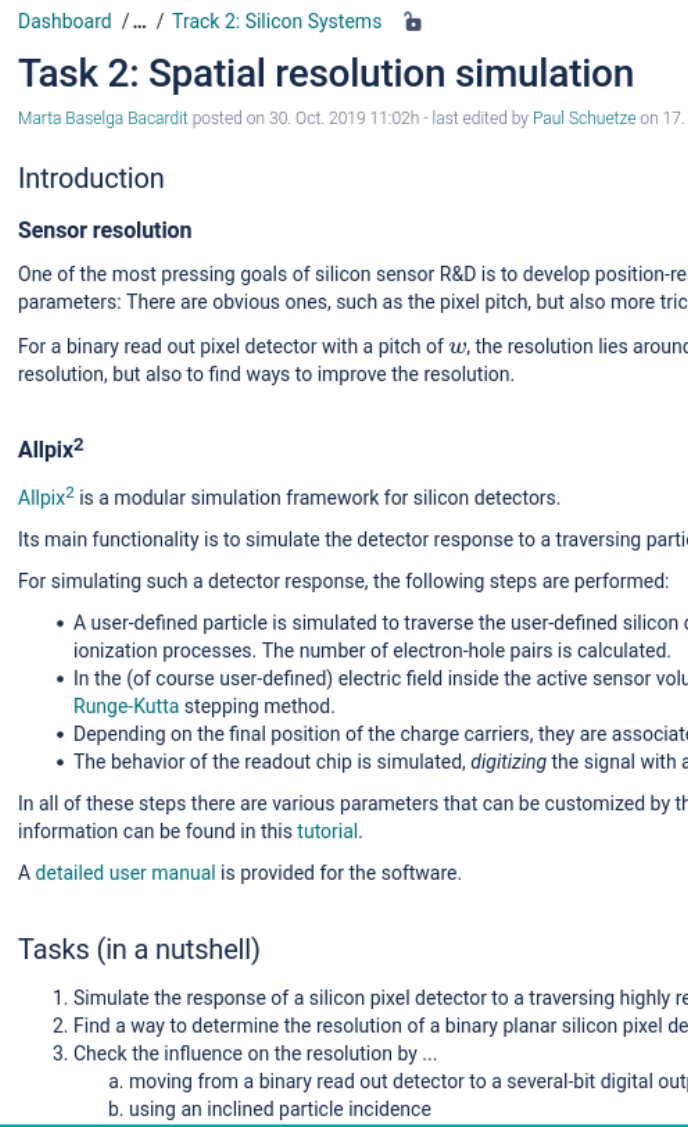
Technical Prerequisites

- How to equip everyone with ROOT, Allpix Squared & Geant4 …
  - ✗ Let participants install software themselves – incompatible OS, time consuming
  - ✗ Docker images – overhead in syntax, difficulty opening resulting ROOT files
  - ✔ CVMFS installation – Installation of / access to CVMFS, incompatible OS
  - ✔ Fully prepared computers – safe&simple, in-person events only, nothing to take home
  - ✔ VirtualBox – available for all* OS, take home, virtual event compatible *pretty much

- VirtualBox is *our* best solution for virtual events/tutorials
  - Machine with ROOT, Geant4, Allpix Squared (& Corryvreckan) is available
    - (Not regularly updated)
  - Instructions available

Materials I

- Depends on experience of participants
- Prepare document with …
  - Short introduction to Allpix Squared
  - A few words on silicon detector resolution
  - Optional: Intro & cheat sheet for/to command line, ROOT, Allpix Squared
  - Instruction on setup
  - Description of tasks
  - Hints on how to fulfil these



Dashboard / … / Track 2: Silicon Systems

Task 2: Spatial resolution simulation

Marta Baselga Bacardit posted on 30. Oct. 2019 11:02h - last edited by Paul Schuetze on 17.

Introduction

Sensor resolution

One of the most pressing goals of silicon sensor R&D is to develop position-re
parameters: There are obvious ones, such as the pixel pitch, but also more tric

For a binary read out pixel detector with a pitch of w, the resolution lies aroun
resolution, but also to find ways to improve the resolution.

Allpix²

Allpix² is a modular simulation framework for silicon detectors.

Its main functionality is to simulate the detector response to a traversing parti

For simulating such a detector response, the following steps are performed:

- A user-defined particle is simulated to traverse the user-defined silicon
  ionization processes. The number of electron-hole pairs is calculated.
- In the (of course user-defined) electric field inside the active sensor volu
  Runge-Kutta stepping method.
- Depending on the final position of the charge carriers, they are associat
- The behavior of the readout chip is simulated, *digitizing* the signal with a

In all of these steps there are various parameters that can be customized by th
information can be found in this tutorial.

A detailed user manual is provided for the software.

Tasks (in a nutshell)

1. Simulate the response of a silicon pixel detector to a traversing highly re
2. Find a way to determine the resolution of a binary planar silicon pixel de
3. Check the influence on the resolution by ...
   a. moving from a binary read out detector to a several-bit digital outp
   b. using an inclined particle incidence

Materials II

- Default configuration files for different scenarios

- Optional:
  Simulation data files with large statistics
  - Files with *PropagatedCharges* for different rotations or magnetic fields with 100 kEvents
  - Sparing out the two most time consuming simulation steps

```
% ls -ltrh start
total 2,5K
-rw-r--r-- 1                1,6K 28. Jan 2020  animation.conf
-rw-r--r-- 1                  80 18. Feb 2020  detector.conf
-rw-r--r-- 1                 709 18. Feb 2020  visual.conf
-rw-r--r-- 1                1,8K 19. Feb 2020  start.conf
-rw-r--r-- 1                1,1K 19. Feb 2020  replay.conf
% ls -ltrh simFiles/data
total 159G
-rw-r--r-- 1              8,8G 17. Jan 2020  EDIT_0deg_0T_data.root
-rw-r--r-- 1              9,1G 17. Jan 2020  EDIT_0deg_1T_data.root
-rw-r--r-- 1              9,2G 17. Jan 2020  EDIT_0deg_2T_data.root
-rw-r--r-- 1              9,3G 17. Jan 2020  EDIT_0deg_3T_data.root
-rw-r--r-- 1              9,4G 17. Jan 2020  EDIT_0deg_4T_data.root
-rw-r--r-- 1               10G 17. Jan 2020  EDIT_10deg_0T_data.root
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-rw-r--r-- 1              9,4G 17. Jan 2020  EDIT_0deg_6T_data.root
-rw-r--r-- 1               12G 17. Jan 2020  EDIT_35deg_0T_data.root
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-rw-r--r-- 1               11G 17. Jan 2020  EDIT_25deg_0T_data.root
-rw-r--r-- 1              9,6G 17. Jan 2020  EDIT_0deg_7T_data.root
```
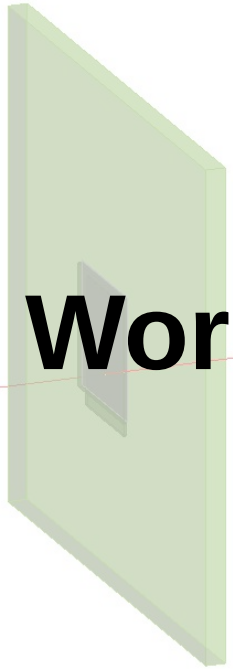
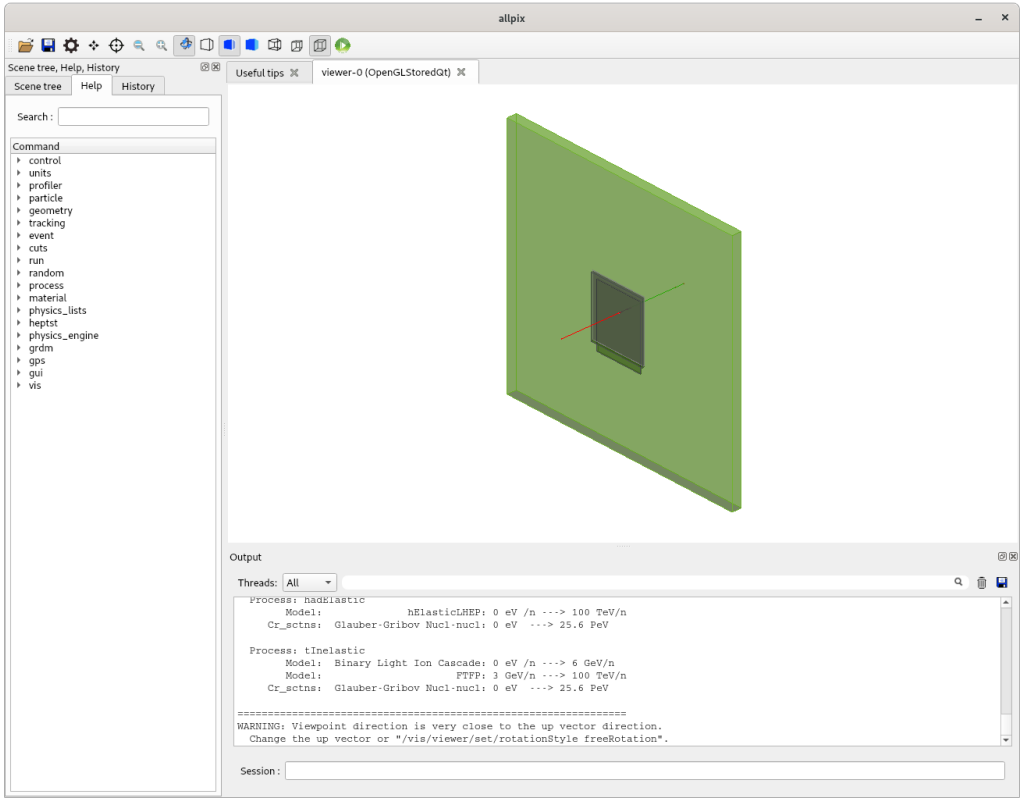

Lab Course Workflow



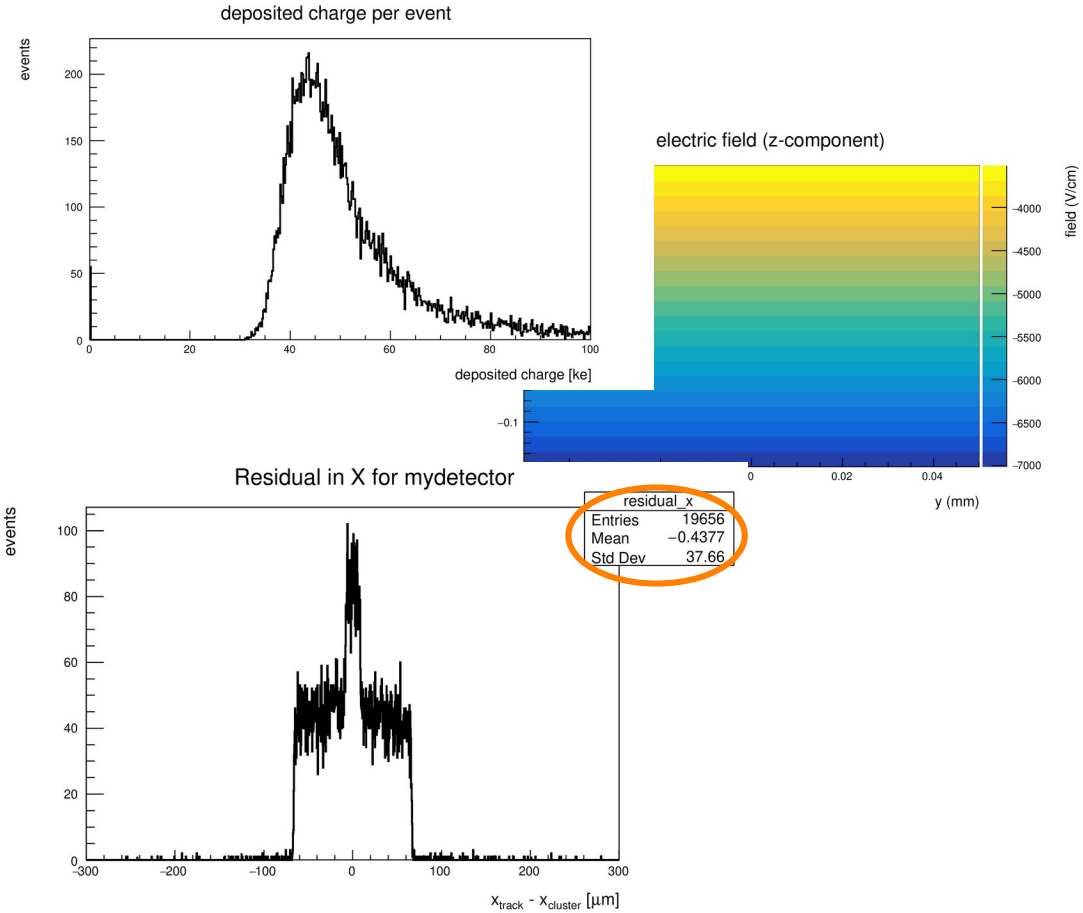
Visual Inspection

- Run with module *VisualisationGeant4*
- Instructions:
  - How to change detector geometry
  - How to change beam description



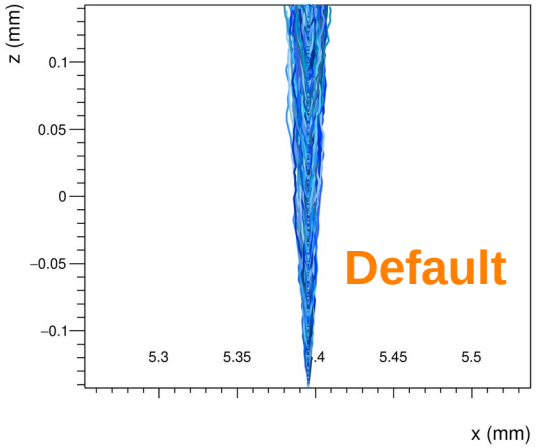
First Simulation & Spatial Resolution

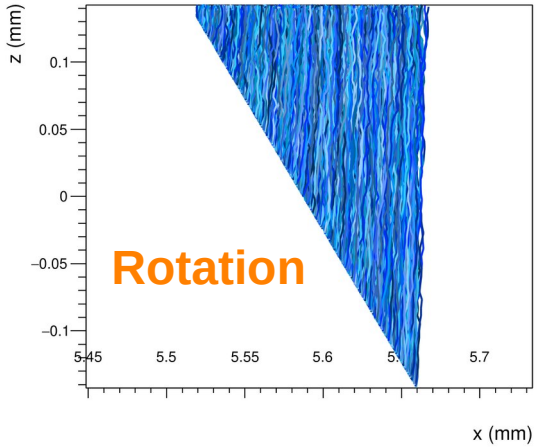
- Run pre-defined setup at …
  - Binary readout
  - 0° rotation angle
  - 0 T magnetic field
- Look at graphs & discuss
- Extract resolution from residual plot
  - Standard deviation?
  - Fit to normal distribution?

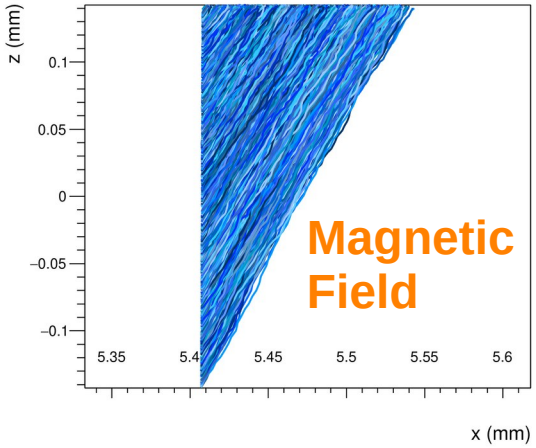


Drift-diffusion Visualisation

- Switch on *output_linegraphs* for *GenericPropagation* module
  - Vary rotation angles
  - Vary magnetic field
- Gain/deepen understanding of charge transport in silicon detectors



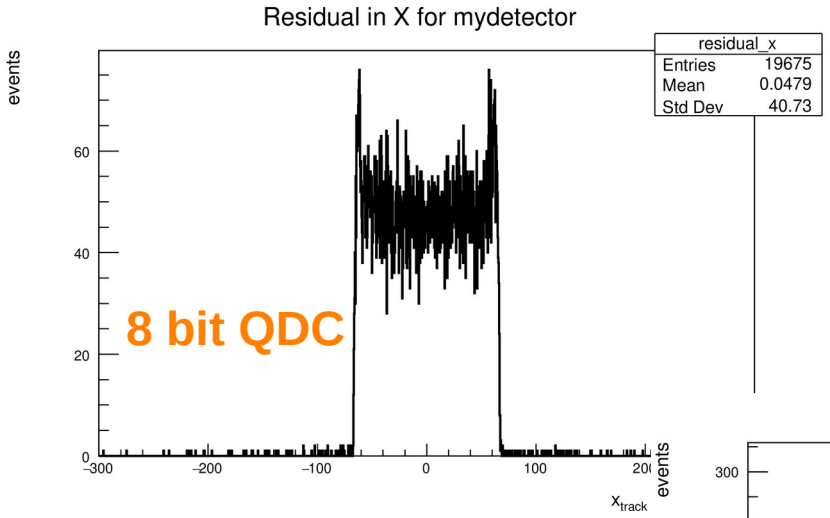


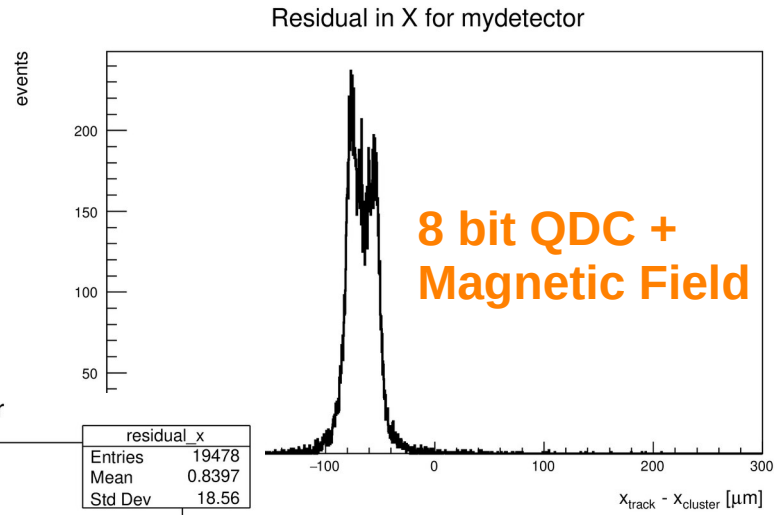


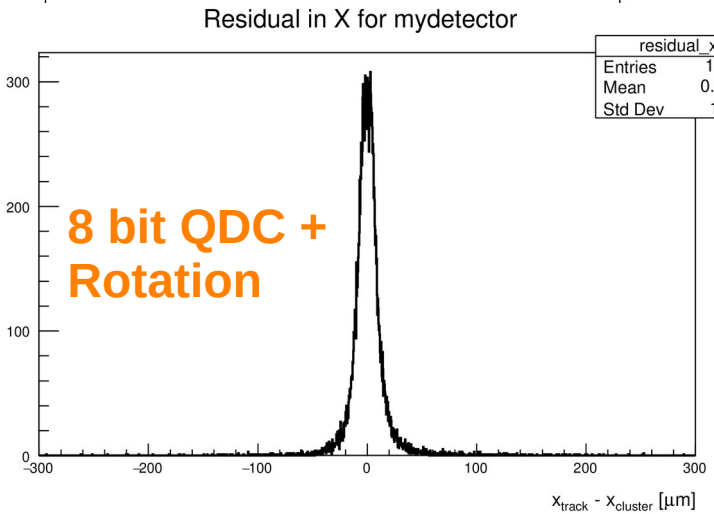
Improve the Resolution I

- Suggested parameters to investigate:
  - Digitization:
    - How does the QDC resolution (in bits) affect the detector resolution?
    - Does the threshold have an influence?
  - Rotation:
    - At which rotation angle does one achieve the best resolution? Why?
    - Is this influenced by the QDC resolution?
  - Magnetic field:
    - At which magnetic field does one achieve the best resolution? Why?
    - Is this influenced by the QDC resolution?
- Supported by prepared data files to speed up the simulation

Improve the Resolution II





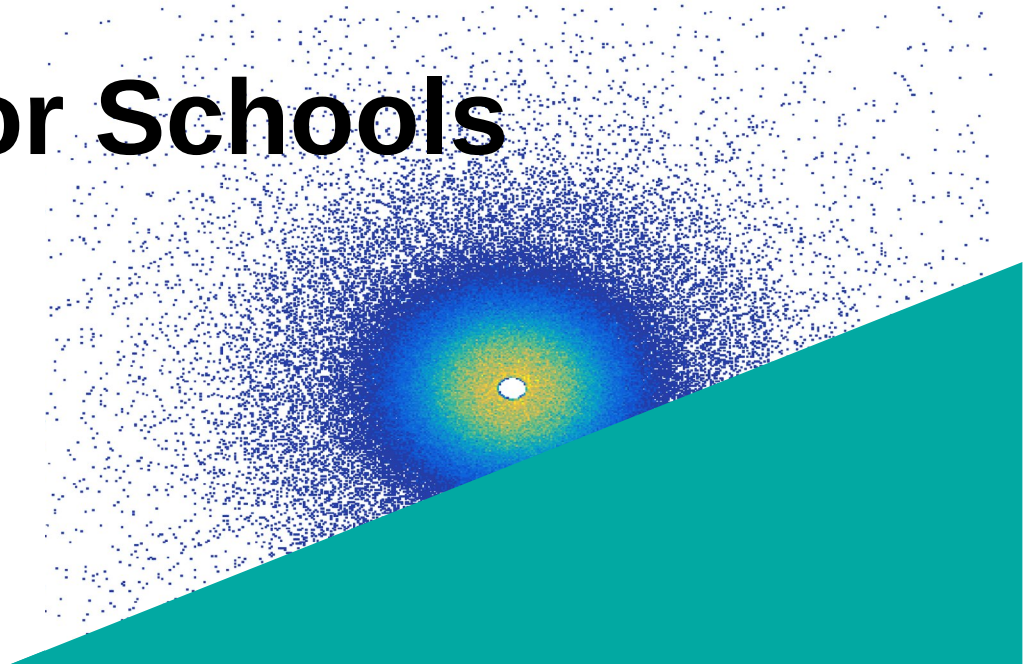


Learning Objectives

- Command line usage (mostly for students)
- Getting to know HEP software tools (mostly ROOT, glimpse to Geant4)
- Silicon detectors …
  - Operation principle
  - Charge transport
  - Digitisation
  - Detector resolution

Outreach

Beamline for Schools



Beamline for Schools

- Worldwide competition for teams of high school students
- Teams design & propose experiments that use a particle beam and particle detectors
- First prize:
  - Trip to a research laboratory with a test beam facility
  - Realization of the proposed experiment, guided by scientists

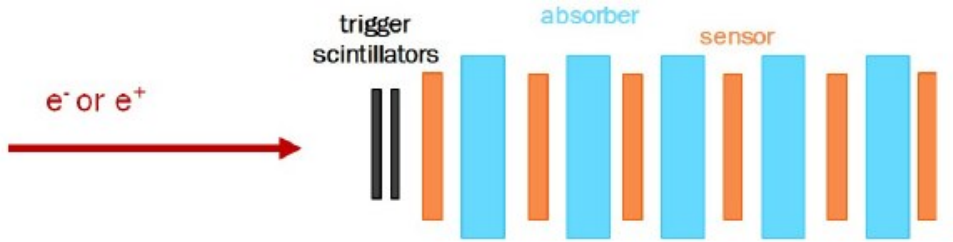
Allpix Squared as a Test Stand for Ideas

- Usage of Geant4 & Allpix Squared for …
  - inquiring on the feasibility of experimental concepts
  - more detailed studies during the experiment preparation

- Allpix Squared offers flexible geometry for building arbitrary setups
- Geant4 brings in the “physics under test”

Example – EM Shower Development

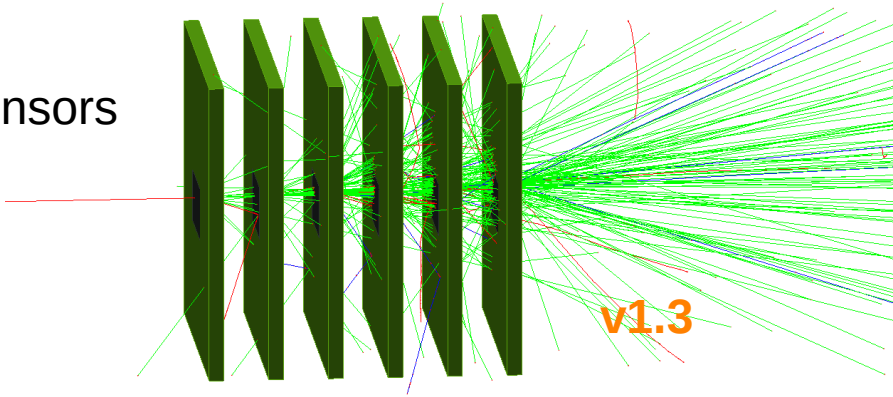
- Proposal: study the shape of electromagnetic showers
- Technique: position resolving detectors interleaved with absorber materials



- Test of feasibility before decision
  - Are the sensors of our telescope large enough to see the lateral development?
- Preparation of the experiment
  - Dimensioning of setup & absorbers

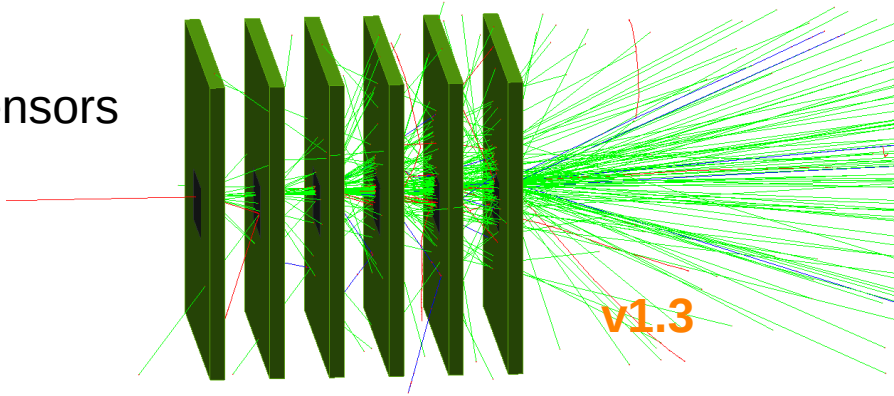
Example – EM Shower Development

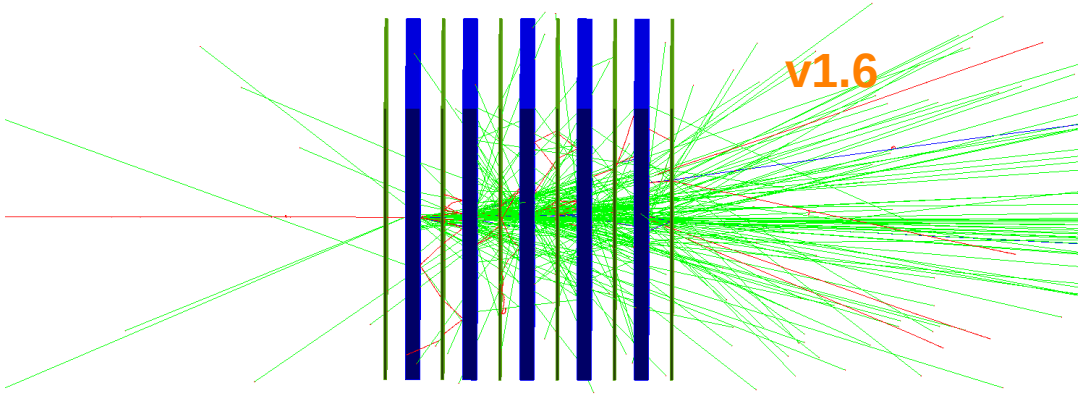
- Started with v1.3 …
  - Hack: Absorbers as “support structure” of sensors



Example – EM Shower Development

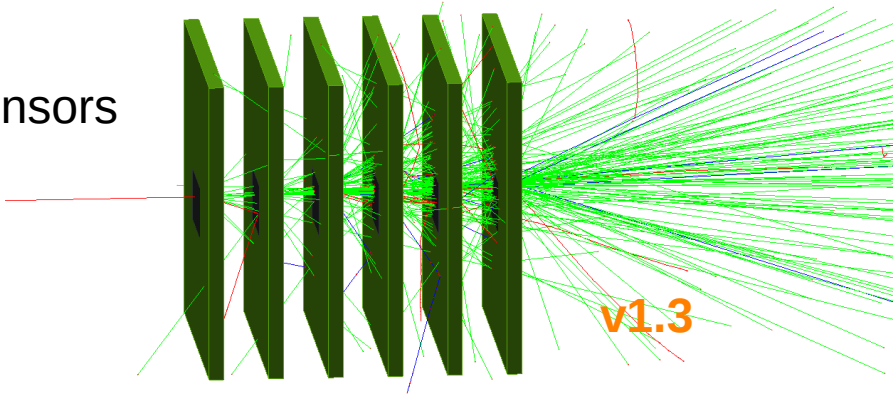
- Started with v1.3 …
  - Hack: Absorbers as “support structure” of sensors
- Since v1.6 …
  - Passive materials are introduced …

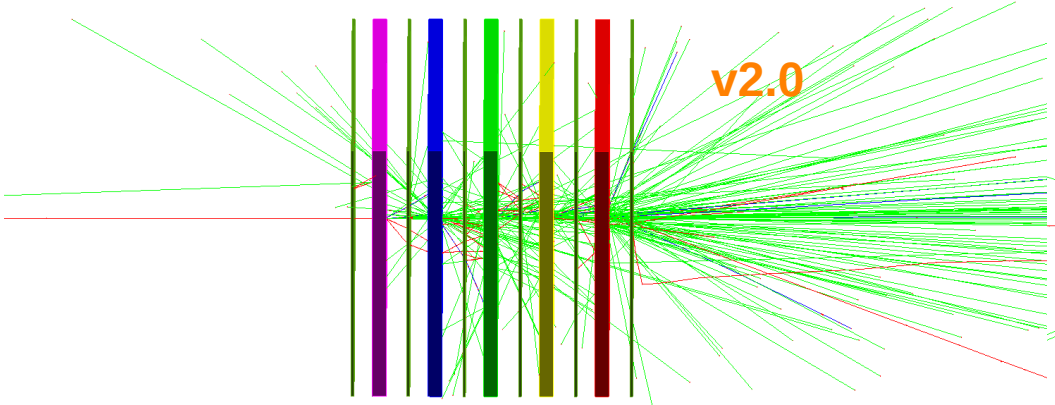


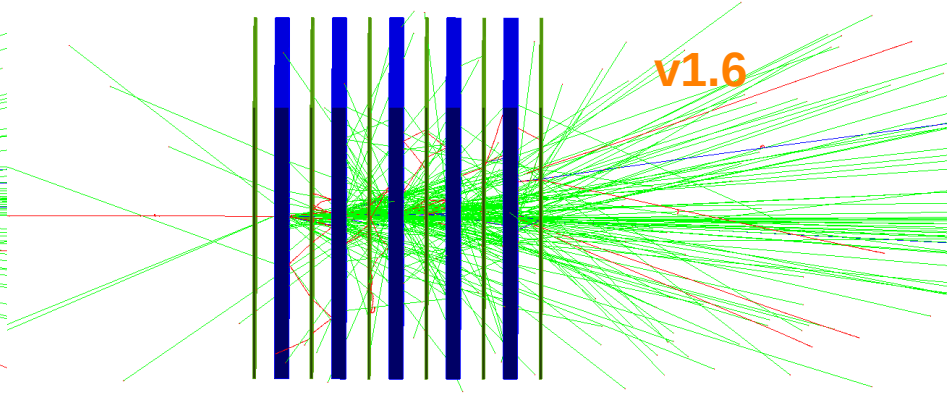


Example – EM Shower Development

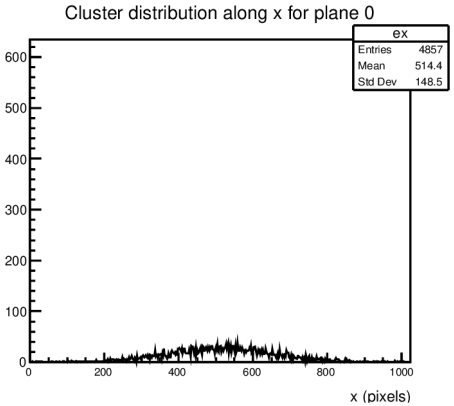
- Started with v1.3 …
  - Hack: Absorbers as “support structure” of sensors
- Since v1.6 …
  - Passive materials are introduced …
- Since v2.0 … :-)

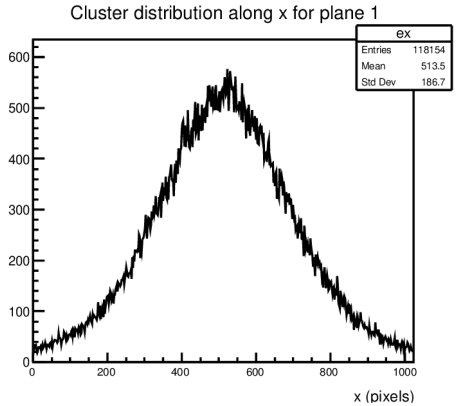


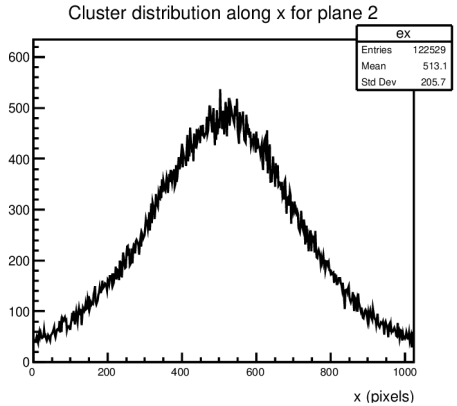


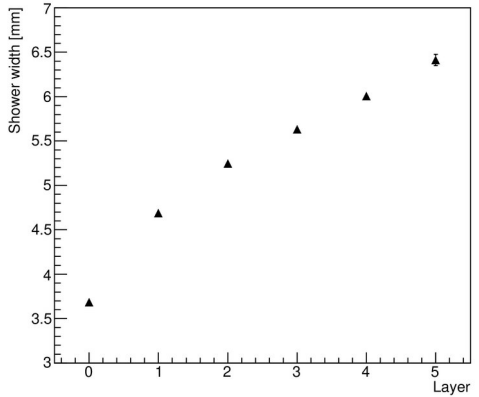


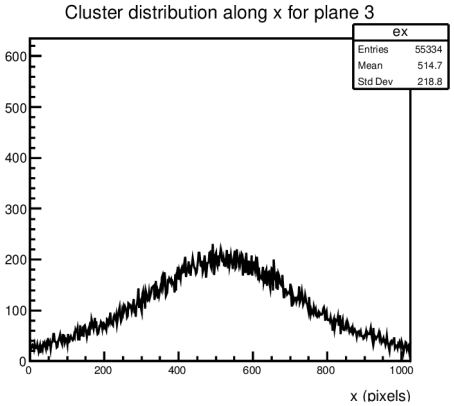
Example – EM Shower Development

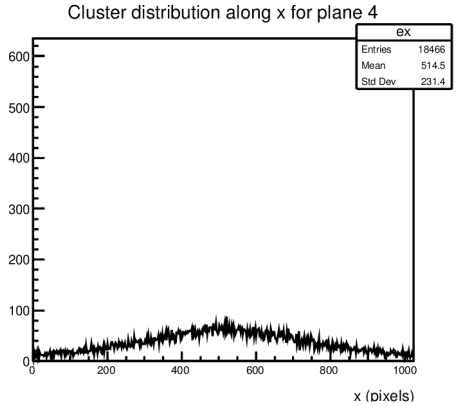


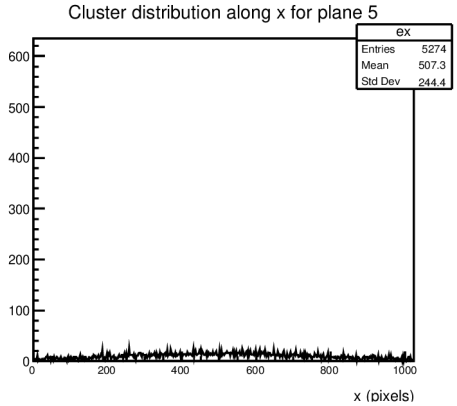


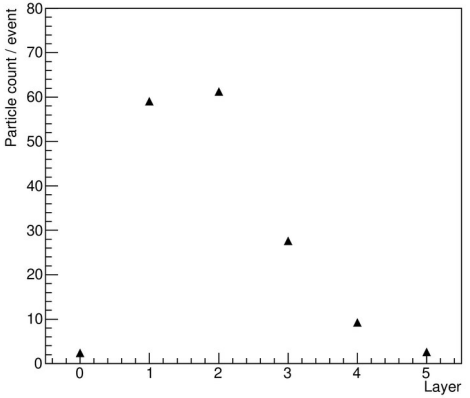










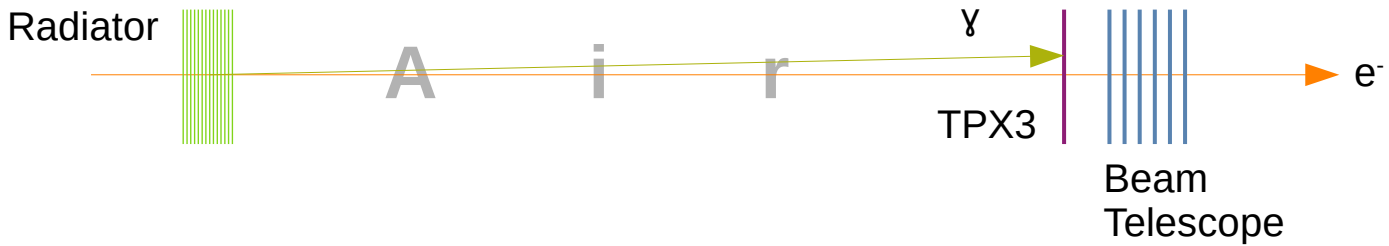


Example – EM Shower Development

- After the experiment is before the analysis
  - Equipped the team with Allpix Squared installation
  - Taught them how to use it and how to interpret the data @BTTB8
    - ➔ Configure & Run
    - ➔ No C++ skills required
  - Working on a publication comparing data & simulation

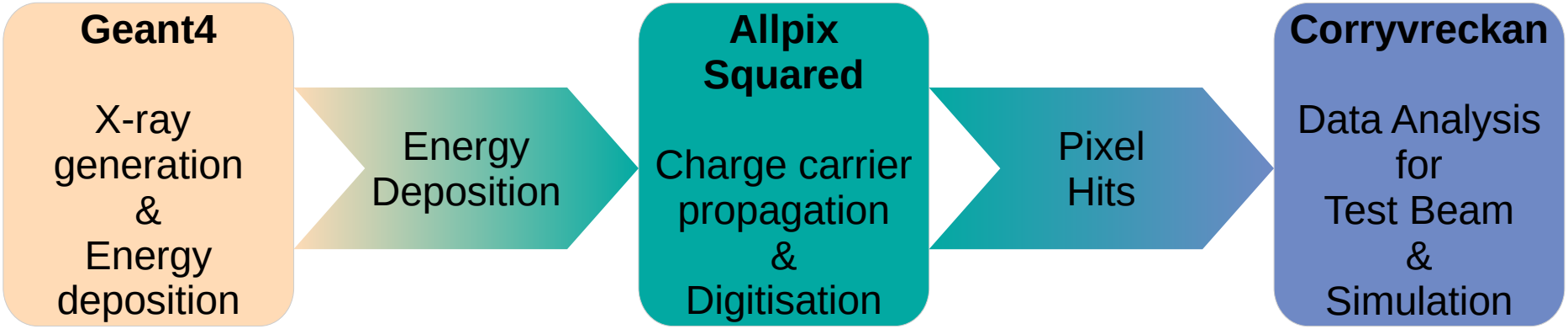
Example – Transition Radiation Detection

- Proposal: Study the characteristics and feasibility of transition radiation detection
- Technique: transition radiation via a stack of foils – detect X-rays in silicon detectors



- Preparation of the experiment
  - Design of foil stack (foil thickness & distance)
  - Dimensioning of setup (required / possible distance between radiator and detector)
- Preparation of data analysis scheme

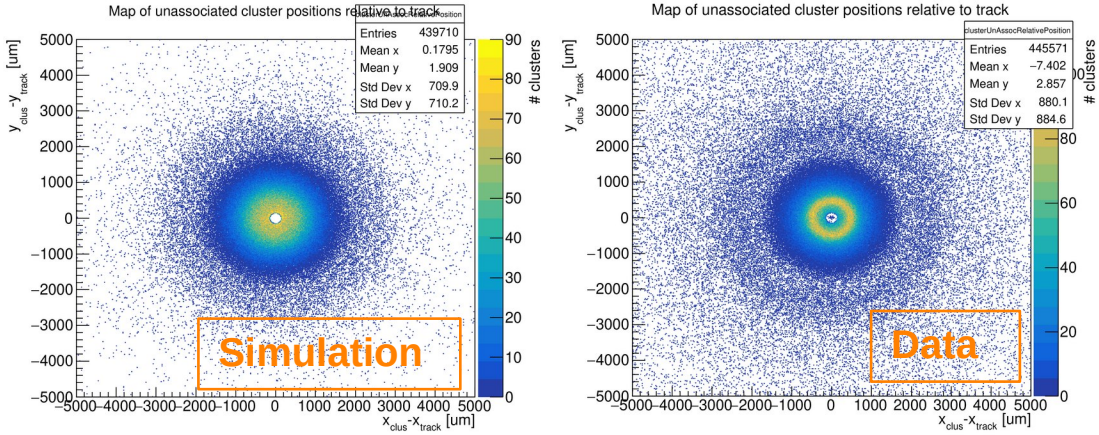
Example – Transition Radiation Detection



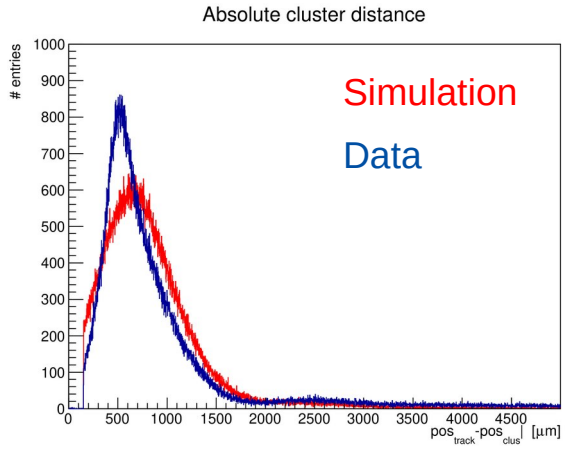
- Made use of a simulation of transition radiation available in the Geant4 examples (*examples/extended/electromagnetic/TestEm10*)
  - Energy deposition extracted as CSV file
- Allpix Squared modules *DepositionReader* and *CorryvreckanWriter* as interfaces
- Corryvreckan for data analysis – design data analysis prior to the test beam campaign

Example – Transition Radiation Detection

- Interpretation
  - Photon yield comparable for data & simulation
  - Photon distribution differs



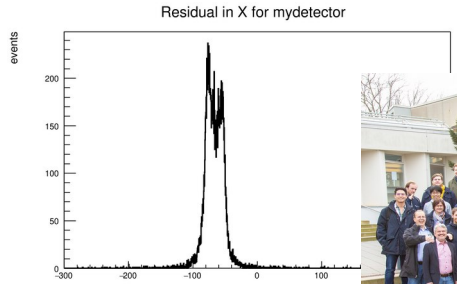
- *Message …*
  Simulations are enormously useful in preparation!
  Measuring stuff is (luckily) unavoidable!

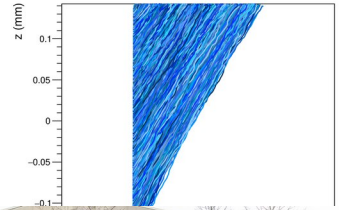


Conclusion

Conclusions

- Developed lab course using Allpix Squared on a university to PhD level
  - Main goal: insight to Silicon Pixel Detectors





- Use of the framework for fast feasibility studies
  - Benefits from built-in flexible geometry & interface to Geant4