Development and simulation of a new preshower detector for the FASER experiment at the LHC

3rd Allpix Squared User Workshop

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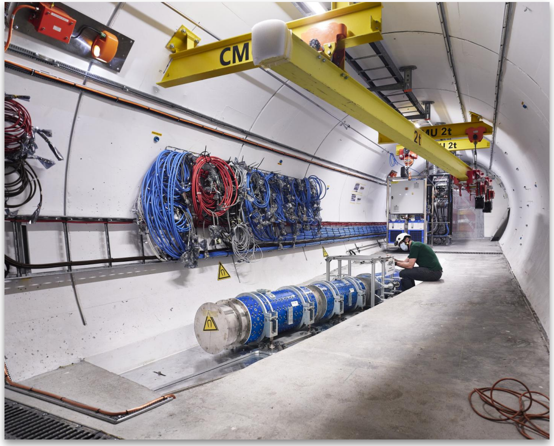
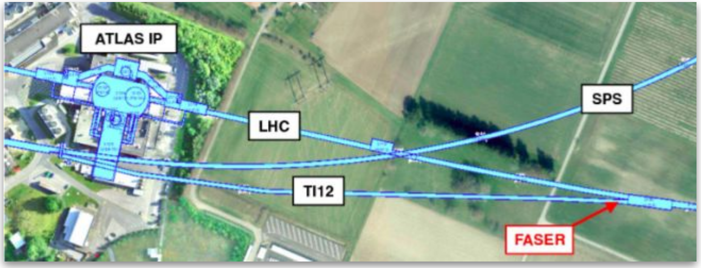
Outline

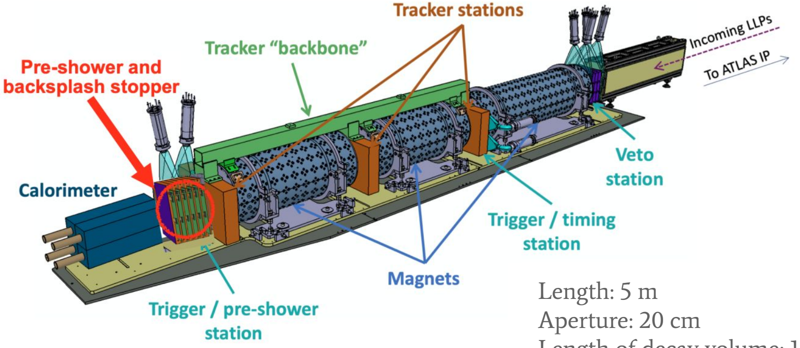
- The FASER experiment
- The goal of the new pre-shower detector
- The geometry of the preshower detector
- Detector ASIC
- Detector effects
- Simulation results
- The general simulation plan & Next steps

The FASER experiment at LHC

- New experiment - Run 3
- Location: 480 m from the ATLAS Experiment
- Energy scale 100 GeV until few TeV
- Designed to search for long-lived particles (**LLP**) produced at the LHC
- LLPs pass through the LHC infrastructure/rock without interacting and will decay into visible Standard Model particles, detected in ForwArd Search ExpeRiment (FASER)

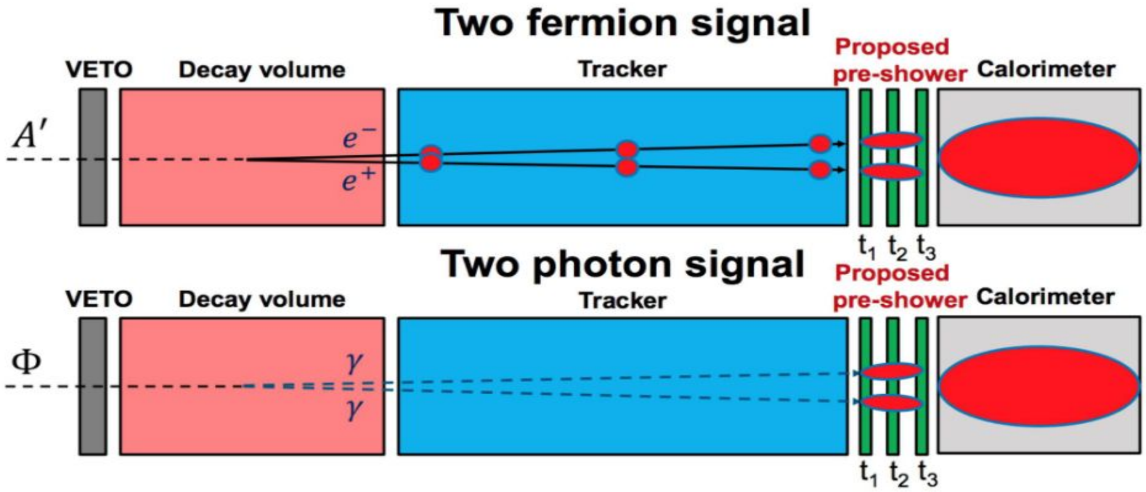






Length: 5 m
Aperture: 20 cm
Length of decay volume: 1.5 m

The goal of the new preshower

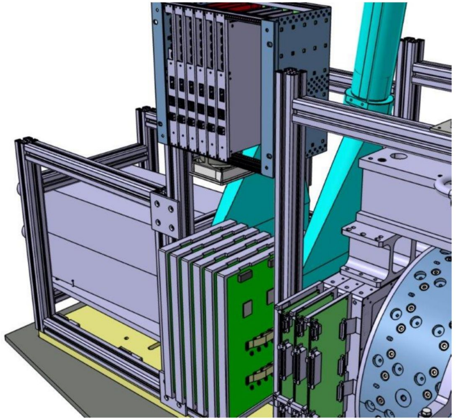


Independent measurement of two very collimated photons

The goal of the new preshower

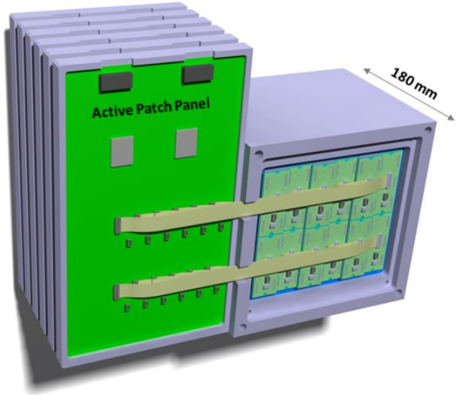
Our signal: **2 photons** with **200 μm separation**

- **High granularity** preshower
- **Sample and reconstruct EM shower**



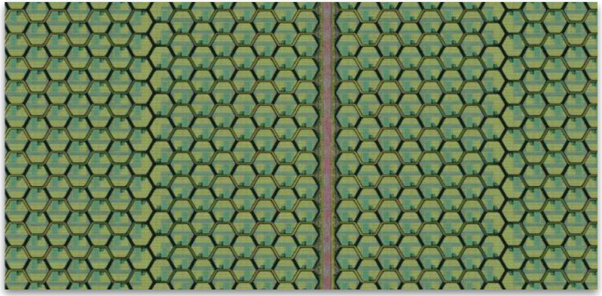
- 6 Layers of silicon planes with tungsten layers in between
- Targeting data taking in 2024/25, during LHC run 3 and during HL-LHC
- The technical proposal of the FASER preshower detector:

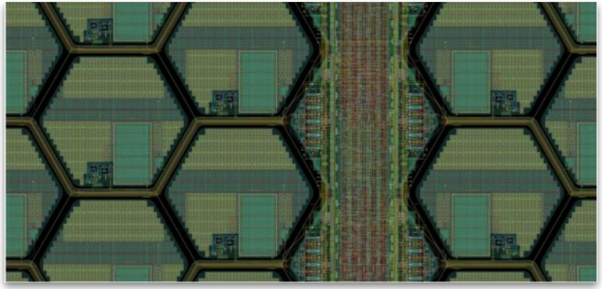
  https://cds.cern.ch/record/2803084/files/LHCC-P-023.pdf?version=1



Detector ASIC

- Monolithic ASIC in 130 nm SiGe BiCMOS technology from IHP microelectronics (design in collaboration between CERN, University of Geneva and KIT)
- Hexagonal pixels of 65 μm side and an active area of 21.6 mm x 14.3 mm
- Imaging/tracking core of EM shower
- EM shower core reconstruction based on signal charge distribution:
    - Possible space charge effects
    - Large dynamic range charge measurement



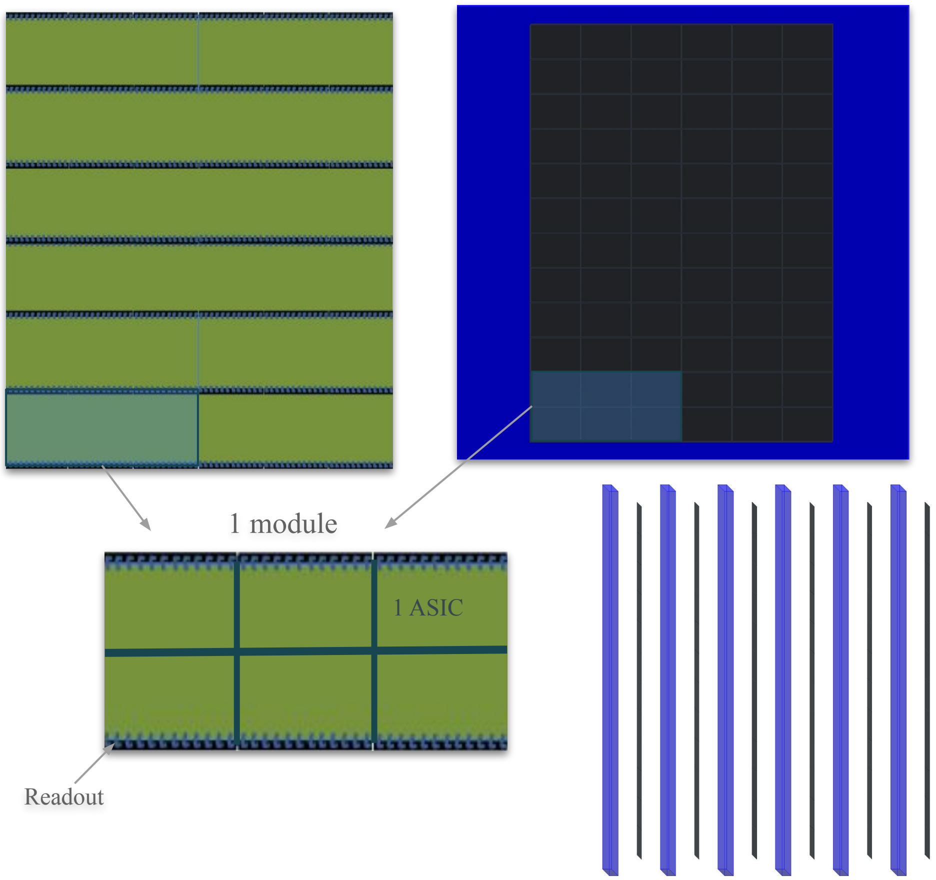


Detector Effects implemented in Allpix Squared will be presented in the next slides

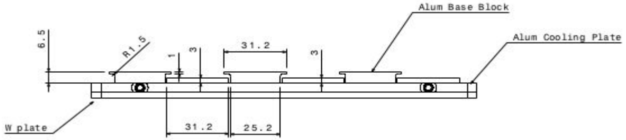
Allpix Squared geometry of the preshower detector of FASER

- Hexagonal pixels in Allpix a developing branch
  - 221x128 hexagonal pixels
  - Active area size = 21.6 mm x 14.3 mm

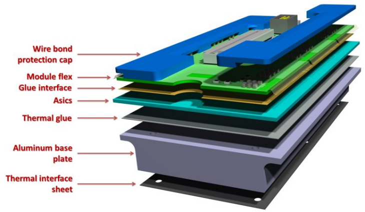
- Initial design:
  - 6 Tungstens: 200mm x 200mm x 4.6mm
  - 6 Planes: In each plane 12 modules and 72 chips

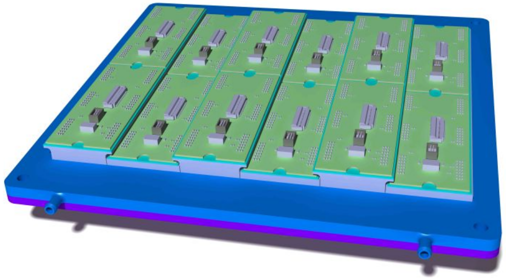


Updated Allpix Squared geometry of the preshower detector of FASER



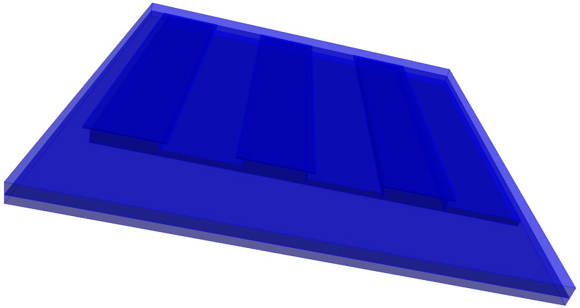
The half of the chips of the plane are elevated



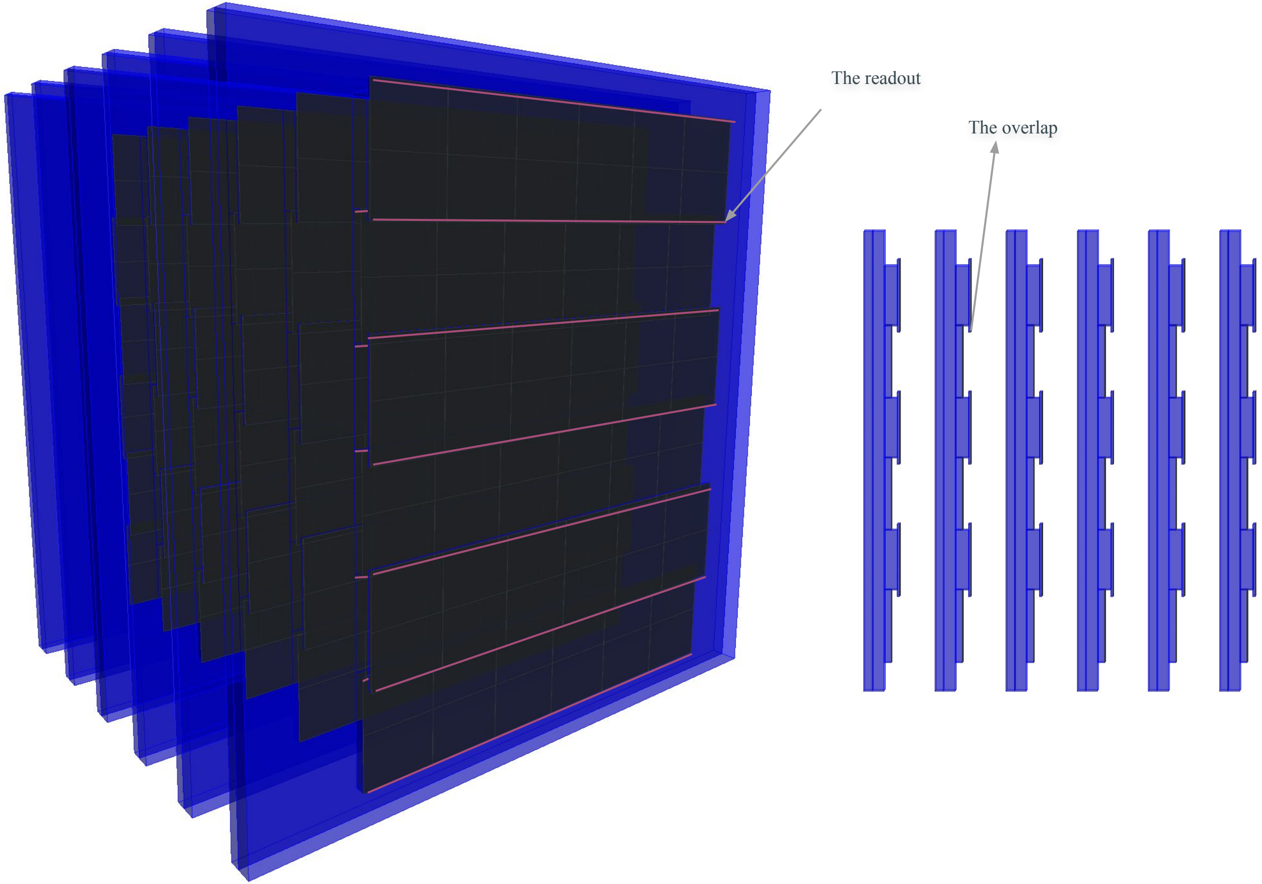


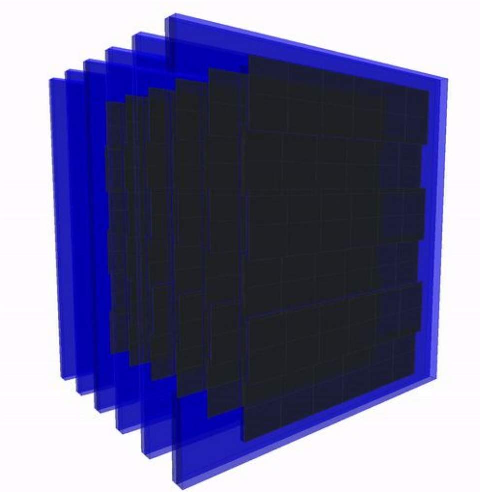
Now the readout side of each chip is in overlap in order to maximize the active area of the detector

The tungsten, the aluminum cooling plate and the aluminum base of the chips in the simulation visualization



Updated full Allpix Squared geometry of the preshower detector of FASER





Analysis not yet done in this layout of the preshower detector

The goal of the new preshower

Why: **Generate realistic simulation** data to feed to the reconstruction algorithms

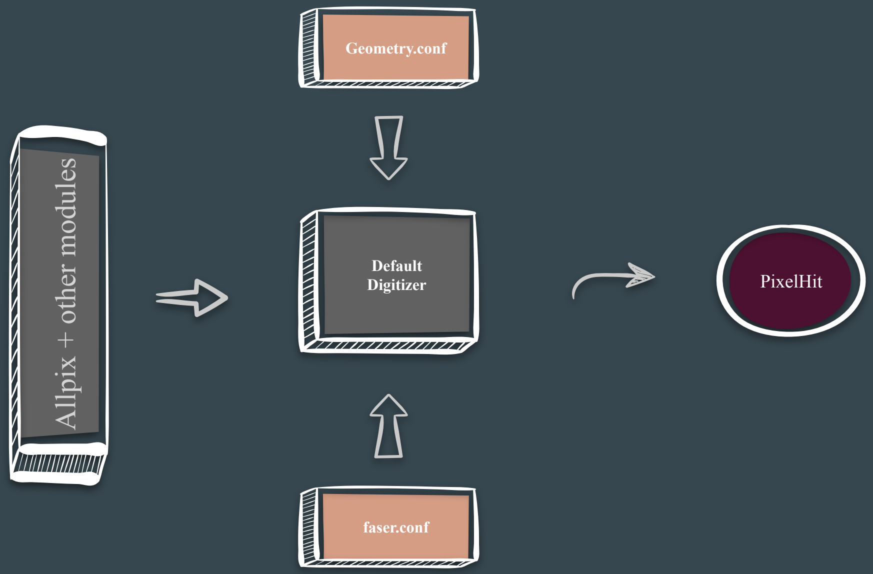
How: Implementation of the **calibration curves** from Cadence with pixel-to-pixel mismatch

↳ 3 Modules for our studies: one computational module & two serialization modules

Want to know more?

- All the simulations in Allpix Squared done in the hexagonal pixel branch: https://gitlab.cern.ch/allpix-squared/allpix-squared/-/merge_requests/539
- An example of an output root file of the is in: /afs/cern.ch/user/r/rkotitsa/public/reco
- The calibration branch, with the new module and the analysis files: https://gitlab.cern.ch/rkotitsa/allpix-squared/-/tree/calibration

Data flow

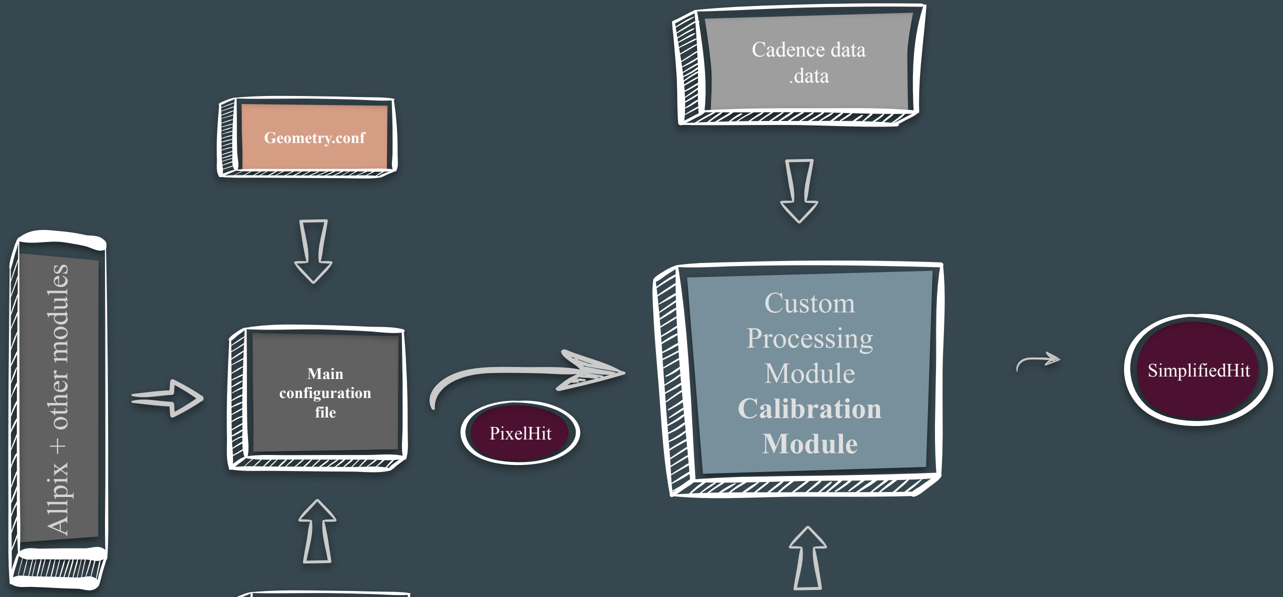


Allpix & Standard Modules

- Supports user-defined geometry!
- Supports used-defined chip design (with the hexagonal geometry)
- Extensible module architecture
- Direct use of previous computation results through events

```
#type= "monolithic"
type = "hexagonal"
pixel_type = "hexagon_flat"
pixel_size = 130.3um
128.98005um
number_of_pixels = 221 128
sensor_thickness = 50um
sensor_excess_top = 260um
sensor_excess_bottom = 720um
sensor_excess_left = 260um
sensor_excess_right = 260um
chip_thickness = 18um
```

Data flow




```
[Calibration]
reference_data = "data.data"
bin_from = 700
bin_to = 1200
bin_size = 31.5
mean = 0
stddev = 1.6
```

The Detector Effects code

01 — Q,V

Import and fit the Monte Carlo data from Cadence:

Sets of (Q,V) pairs

⇓

$y = a + b(1 - e^{c(x-d)})$

⇓

f_i

02 — "PixelHit"

PixelHit

⇓

Q_s, (x, y)

03 — Conversion

Apply random f_i to Q_s.

$f_i(Q_s) = V_s$

04 — Add Noise

Add gaussian noise

V_s ⇒ V_{sn}

05 — Discretization

16 equal bins in the range of V

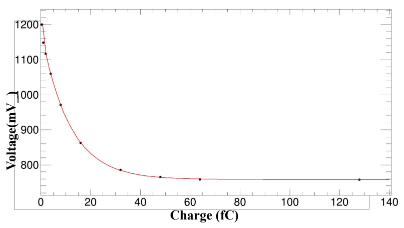
V_{sn} ⇒ V_f

06 — Inversion

$f^{-1}_1(V_f) = Q_{meas}$

07 — Qmeas

Q_{means_s}, (x, y)

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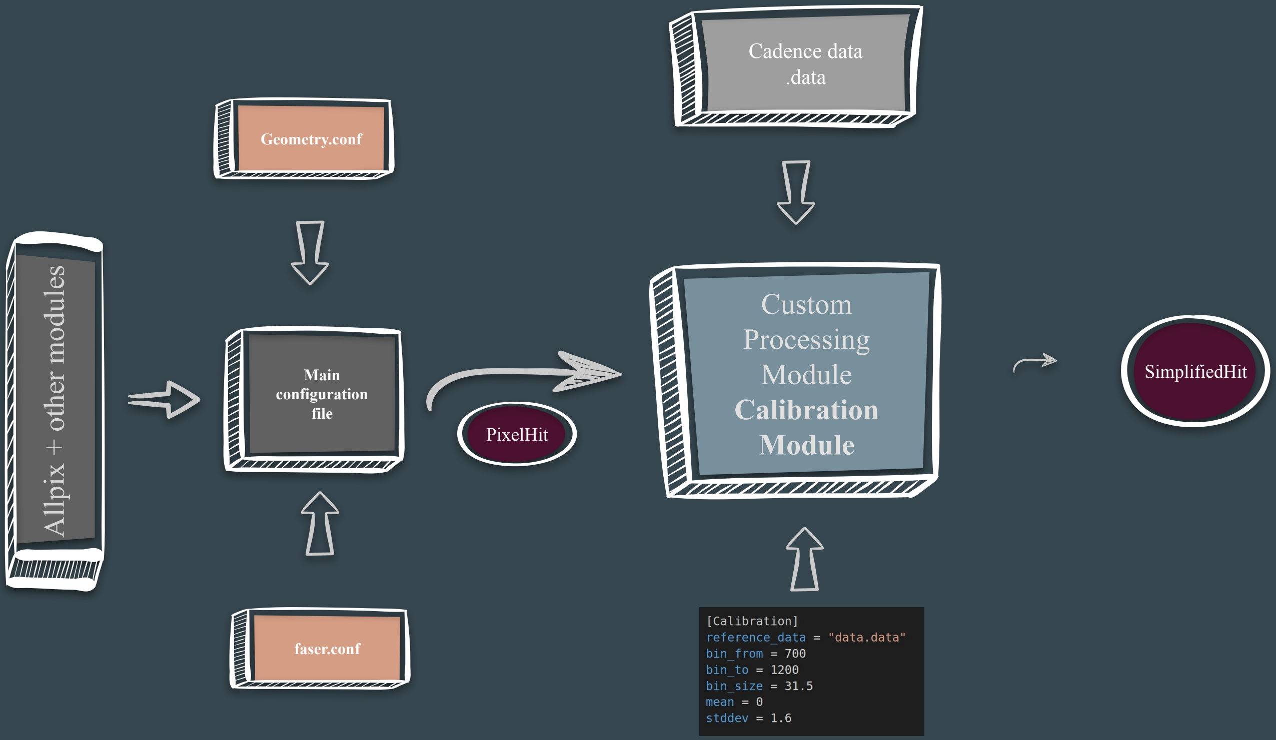
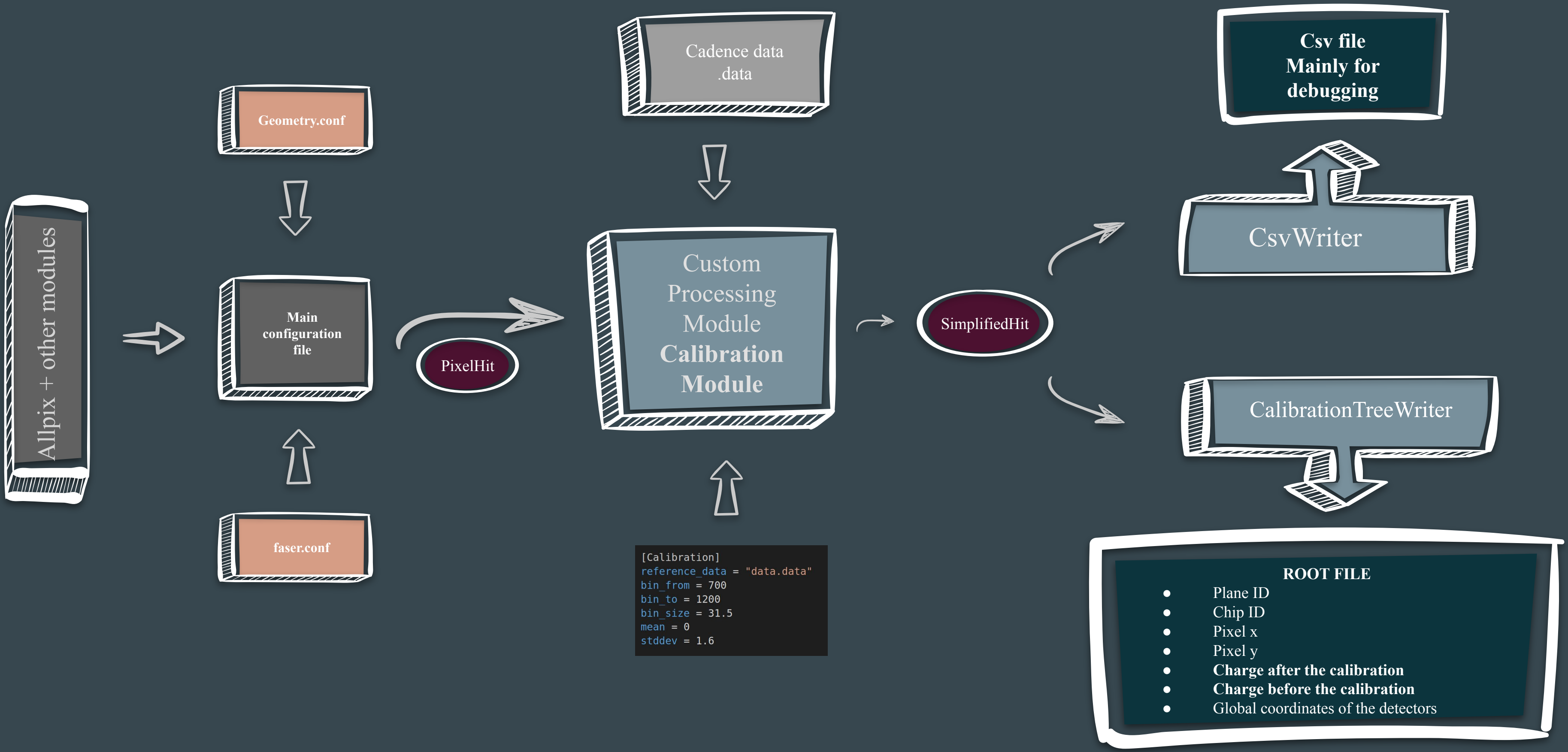
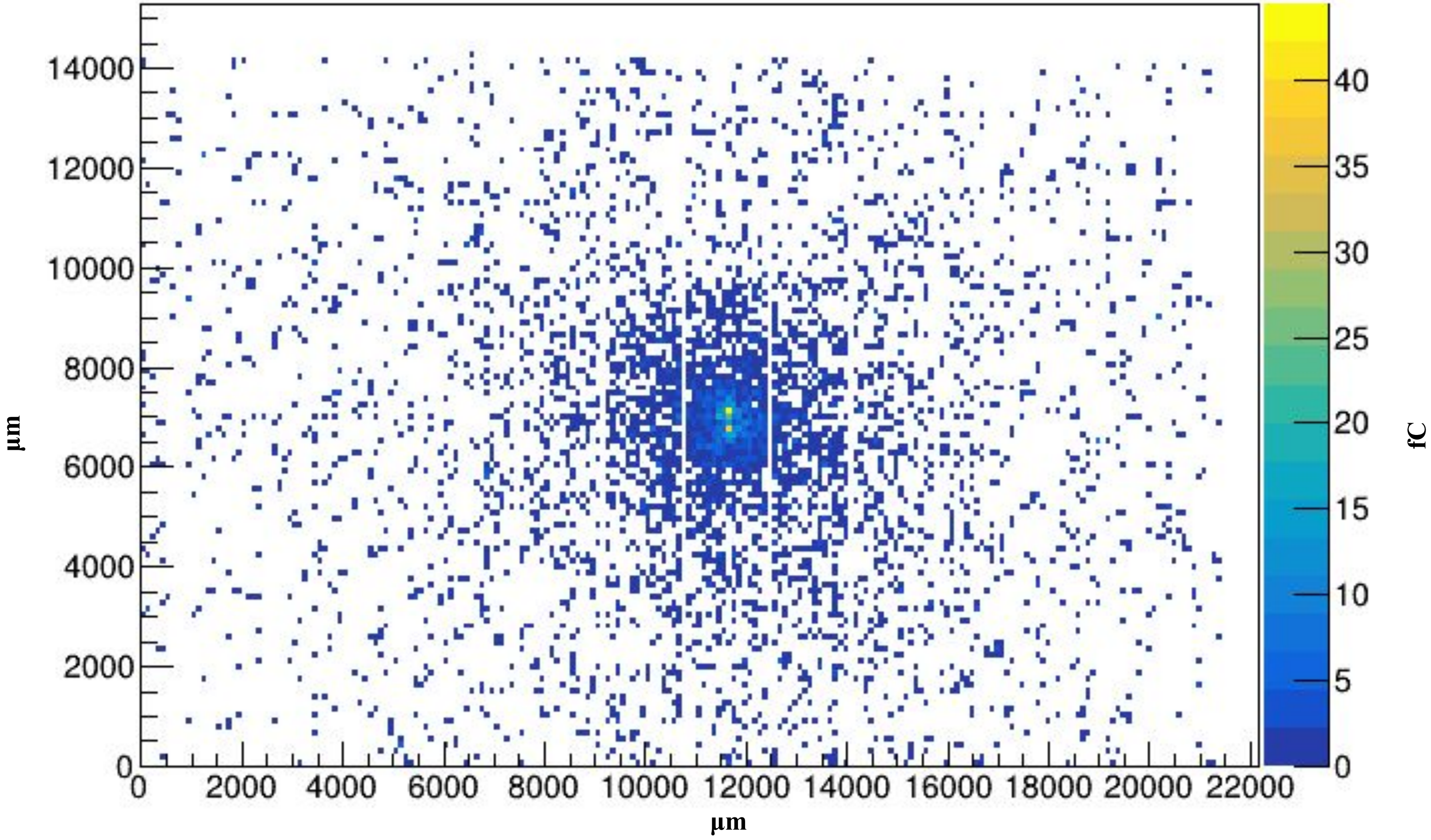
Data flow

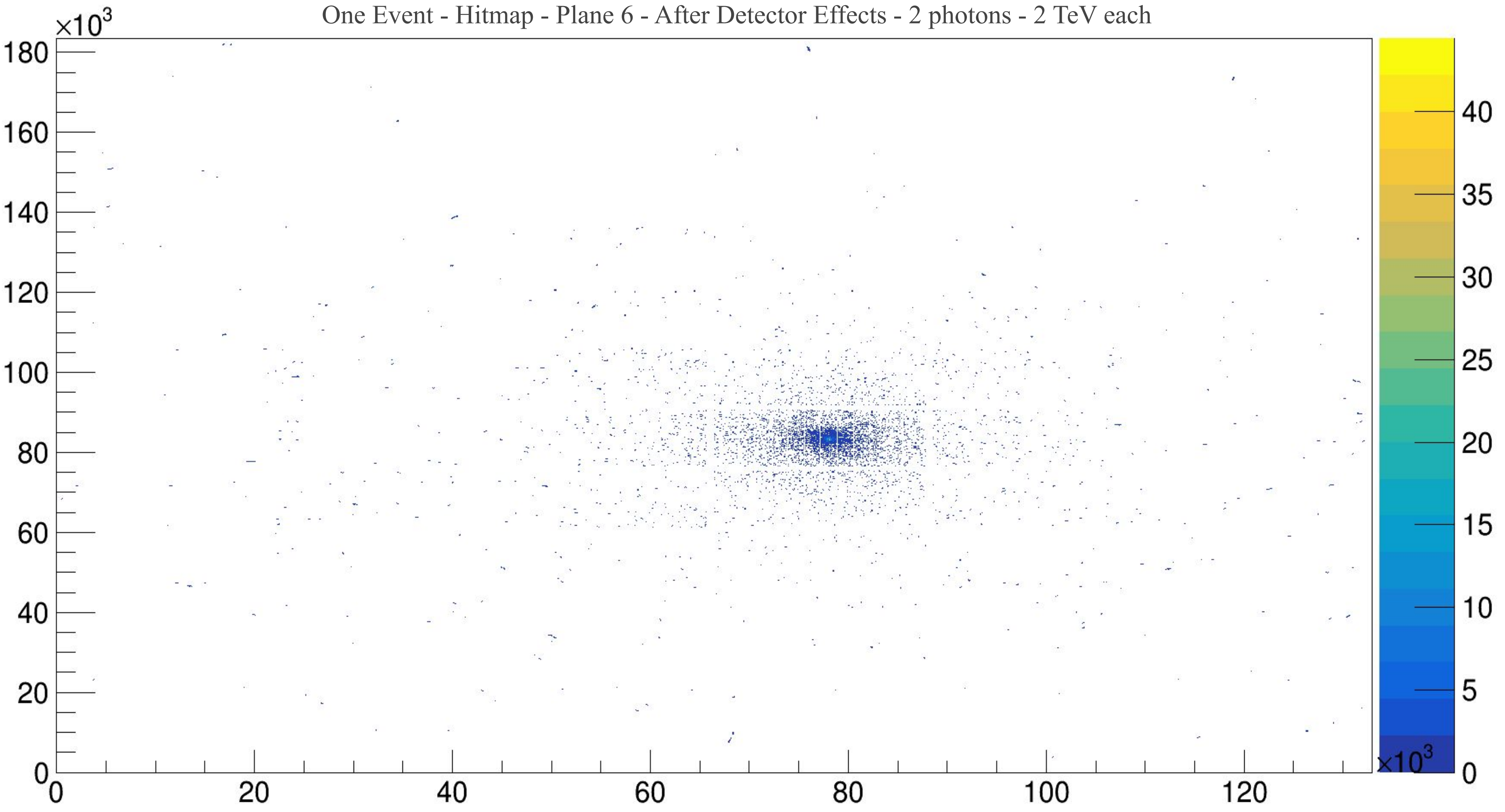

Cadence data
.data
Geometry.conf
Allpix + other modules
Main
configuration
file
PixelHit
Custom
Processing
Module
Calibration
Module
SimplifiedHit
faser.conf
[Calibration]
reference_data = "data.data"
bin_from = 700
bin_to = 1200
bin_size = 31.5
mean = 0
stddev = 1.6

Data flow


Allpix + other modules
Geometry.conf
Main configuration file
faser.conf
PixelHit
Cadence data
.data
Custom Processing Module
Calibration Module
[Calibration]
reference_data = "data.data"
bin_from = 700
bin_to = 1200
bin_size = 31.5
mean = 0
stddev = 1.6
SimplifiedHit
CsvWriter
Csv file
Mainly for debugging
CalibrationTreeWriter
ROOT FILE
Plane ID
Chip ID
Pixel x
Pixel y
Charge after the calibration
Charge before the calibration
Global coordinates of the detectors

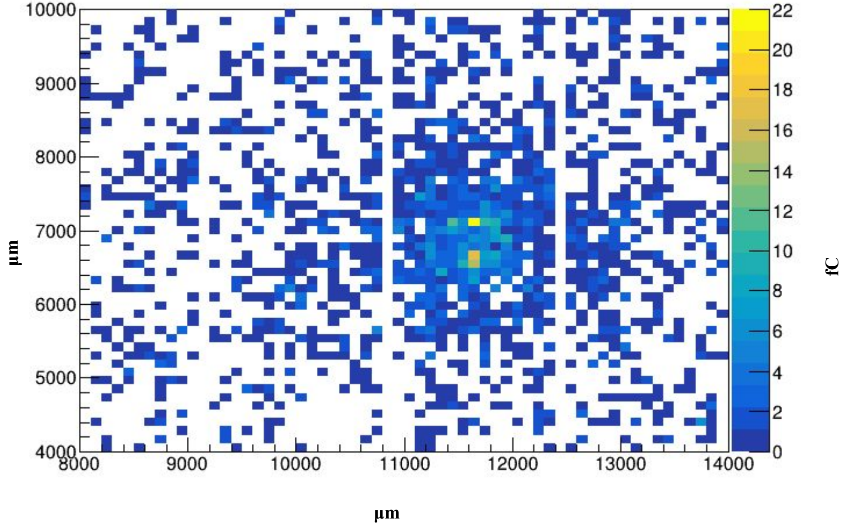
One Event - Hitmap - Chip 405 -2 photons - 2 Tev each - 500 μm Distance - After the Detector Effects



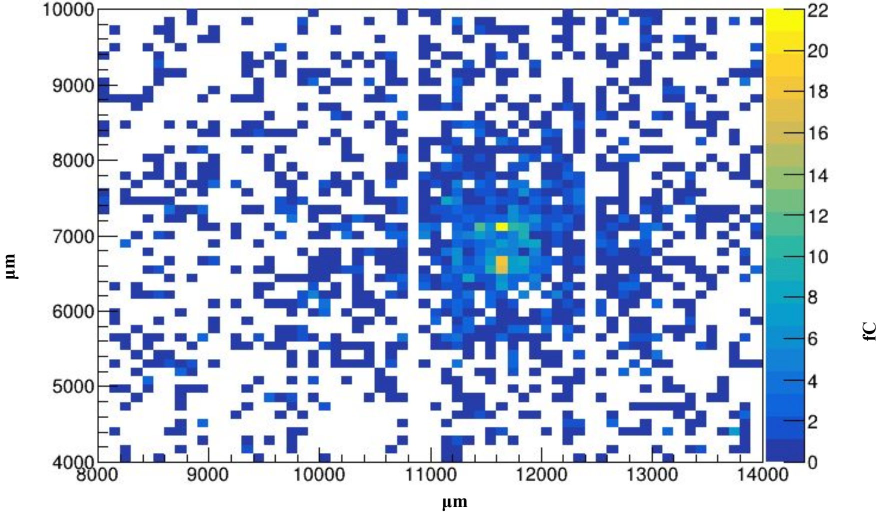

One Event - Hitmap - Plane 6 - After Detector Effects - 2 photons - 2 TeV each
×10^3
180
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
×10^3
40
35
30
25
20
15
10
5
0
×10^3

One Event - Hitmap - Chip 405 -2 photons - 1 Tev each - 500 µm Distance - After the Detector Effects

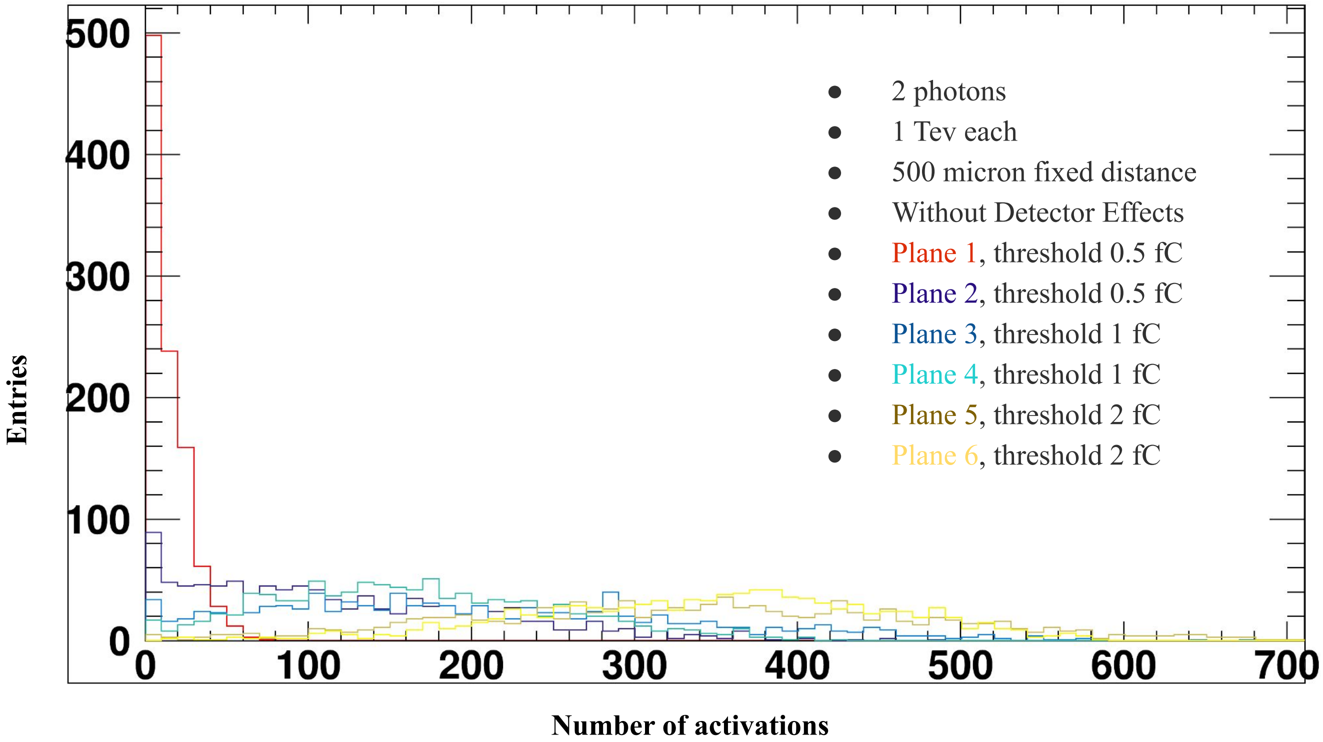
Before the Detector Effects



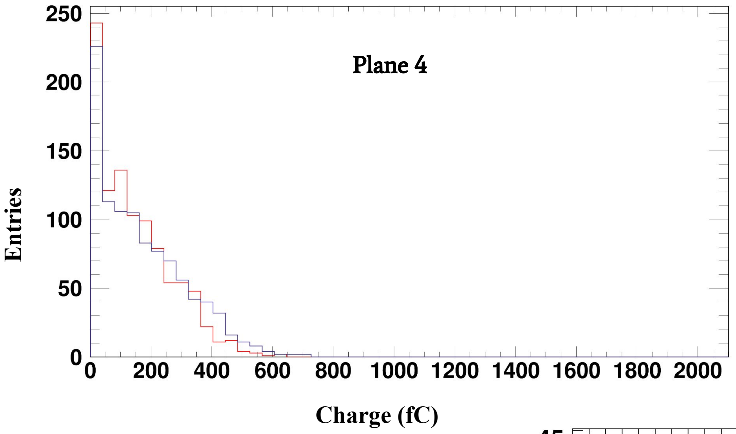
After the Detector Effects

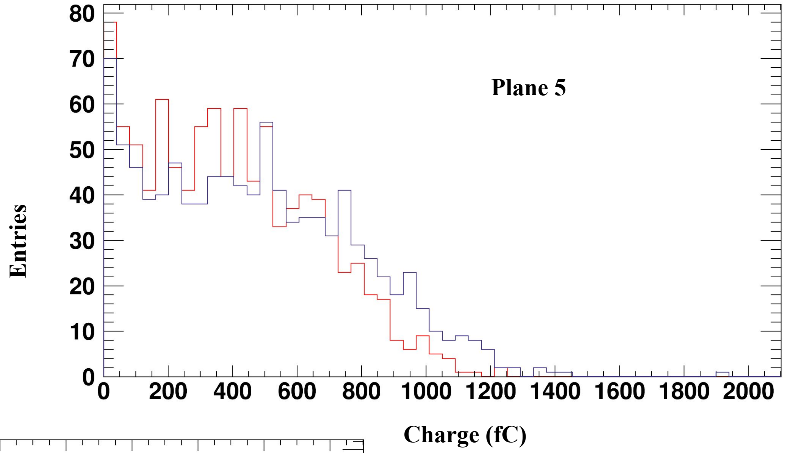


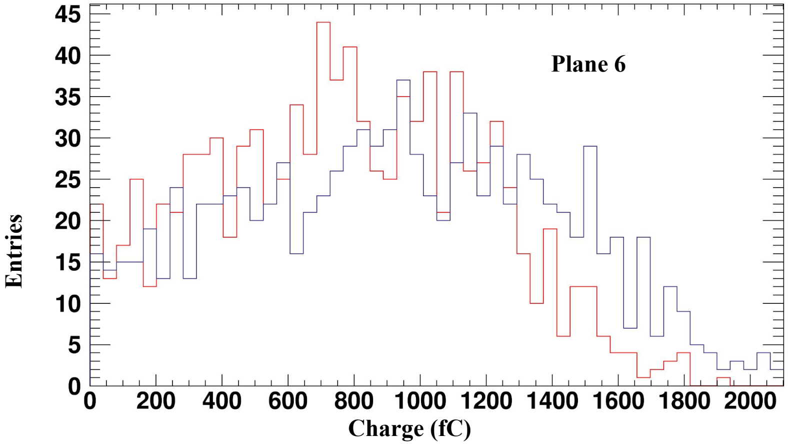
Occupancy plot in different thresholds through the planes, 0.5 mm distance



Charge Distribution in Planes 4,5,6 - 1 TeV photons - 1000 events - Different run







Before & after the detector effects

Reconstruction & other uses of the Allpix Squared Simulation

- **Reconstruction**: Correlating local maxima among different detector planes to identify the shower cores, and suppress possible fake cores.
- Uniform photon/muon flux for readout simulations - 2 photons in the whole plane

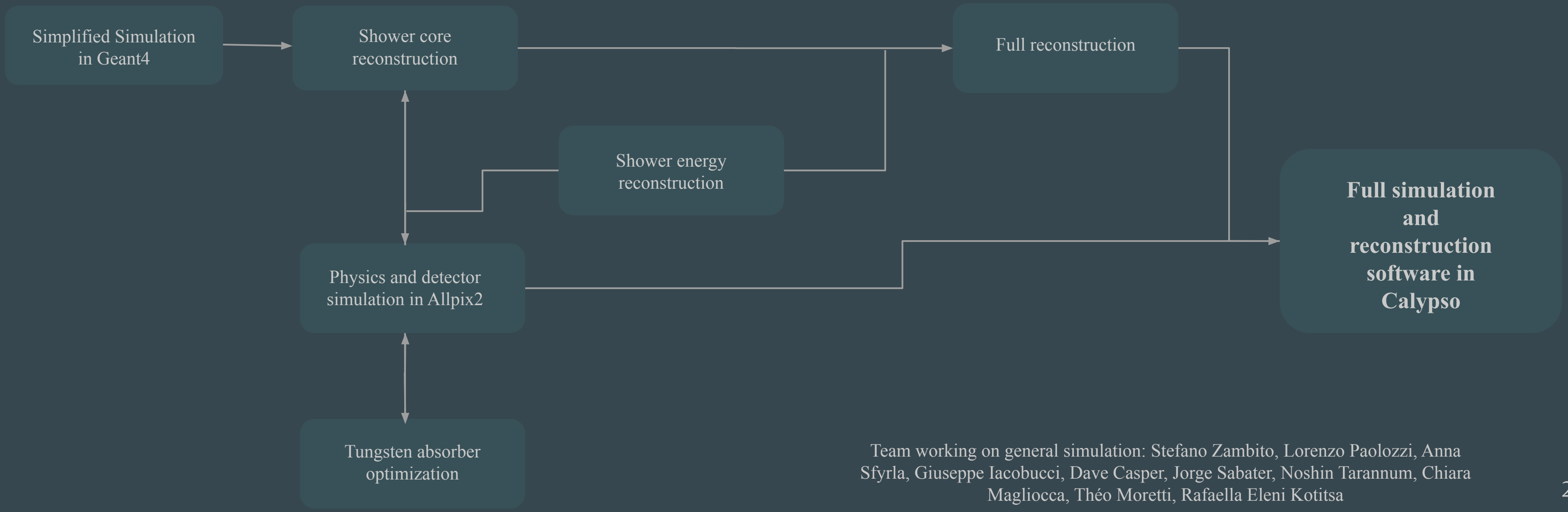
  ↳ Used to provide specifications for **readout design**

- Background
  - **Muons**
  - **Neutrinos**

    ↳ Genie module - Deposition generator module (Thank you Simon!)

Next Steps & Optimization of the whole simulation framework

- Preshower & calorimeter studies together with the detector effects
- Optimization of the final layout of the preshower detector (W-absorber thickness)
- Integrating the space charge effects



Team working on general simulation: Stefano Zambito, Lorenzo Paolozzi, Anna Sfyrla, Giuseppe Iacobucci, Dave Casper, Jorge Sabater, Noshin Tarannum, Chiara Magliocca, Théo Moretti, Rafaella Eleni Kotitsa

Summary - Why Allpix Squared?

- Fast implementation on the monolithic detectors
- Implementation of the hexagonal geometry
- Fast implementation of the geometry
- Well documented
- Extensible module architecture
- User support, adapting the framework to their needs

Allpix Squared is a very important tool for the design of our detector!!

Thank you for listening!!