Laser-TCT with Allpix^2

Overview of the allpix::DepositionLaserModule and some comparisons with experimental data.

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4th Allpix Squared User Workshop
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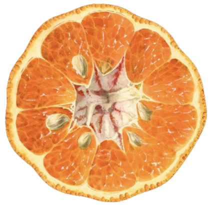
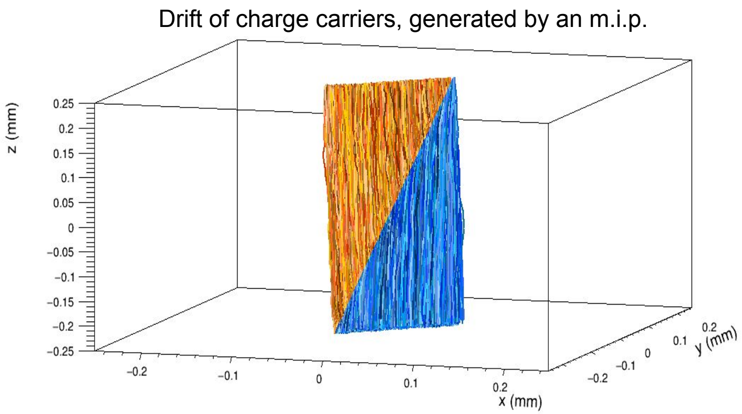


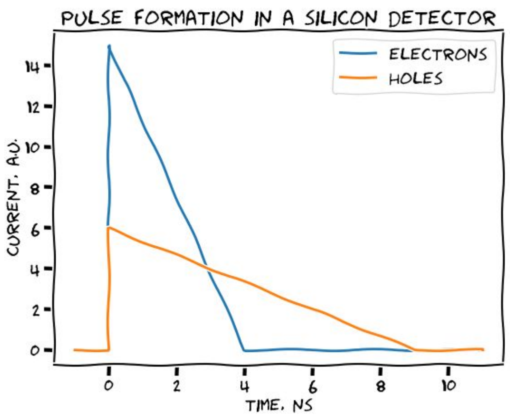
HELMHOLTZ

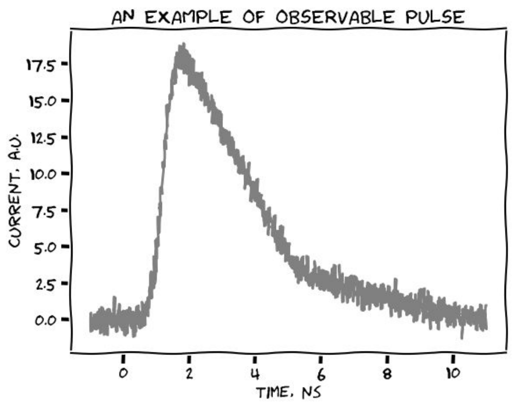
Transient Current Technique (TCT) basics

Signal formation principles and sensor features



$$I(t) = q\vec{v}(t) \cdot \vec{E_W}(\vec{r}(t))$$





Bulk spatial features that are *encoded* in the pulse shape:

- Electric field
- Weighting potential
- Depletion region

Application domains:

- Radiation-damaged sensors
- Sensors with complex structure

The experiment:

- inject charge in a *<u>controlled</u>* way
- study transient pulses

E.g., with a pulsed laser

How to simulate laser charge injection with Allpix^2?

Motivation

A dedicated event generator for energy deposition with pulsed lasers

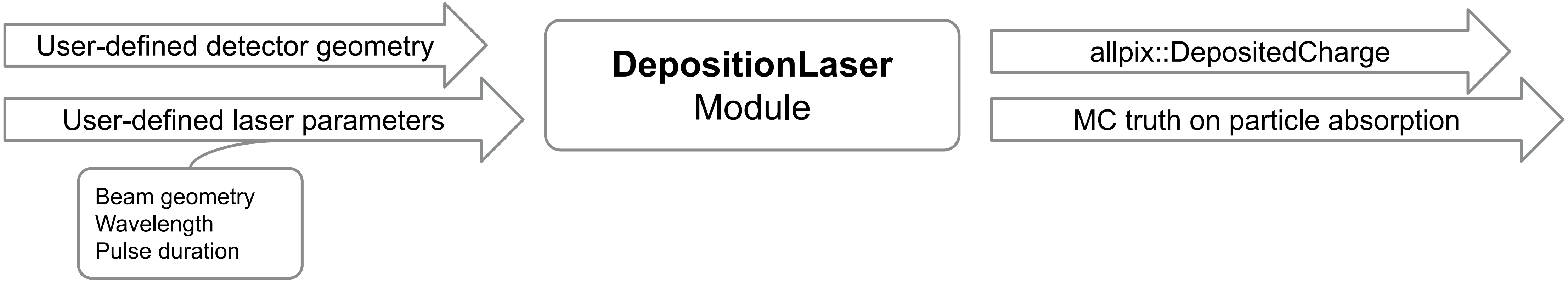
Allpix^2 offers an extensive toolkit for **transient current simulations**, but there was no option to simulate *charge injection with a laser*

- **`[DepositionGeant4]`** with `G4Gamma`?
- **`[DepositionGeant4]`** with `G4OpticalPhoton`?
- External script and **`[DepositionReader]`**?

→ *We have developed a new module for that!*

allpix::DepositionLaserModule

A dedicated event generator for energy deposition with pulsed lasers



→ *The module is available in Allpix^2 since v2.4.0, and new features keep arriving!*
https://gitlab.cern.ch/allpix-squared/allpix-squared/-/tree/master/src/modules/DepositionLaser

Features:

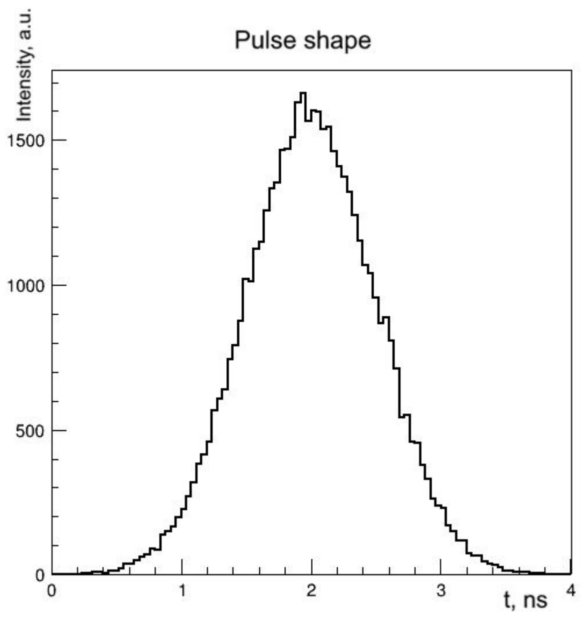
- No dependency on Geant4
- Follows modular approach of Allpix^2
- Full compatibility with Allpix^2 geometry (passive objects, multi-detector setups)
- Follows sustainable development philosophy of Allpix^2

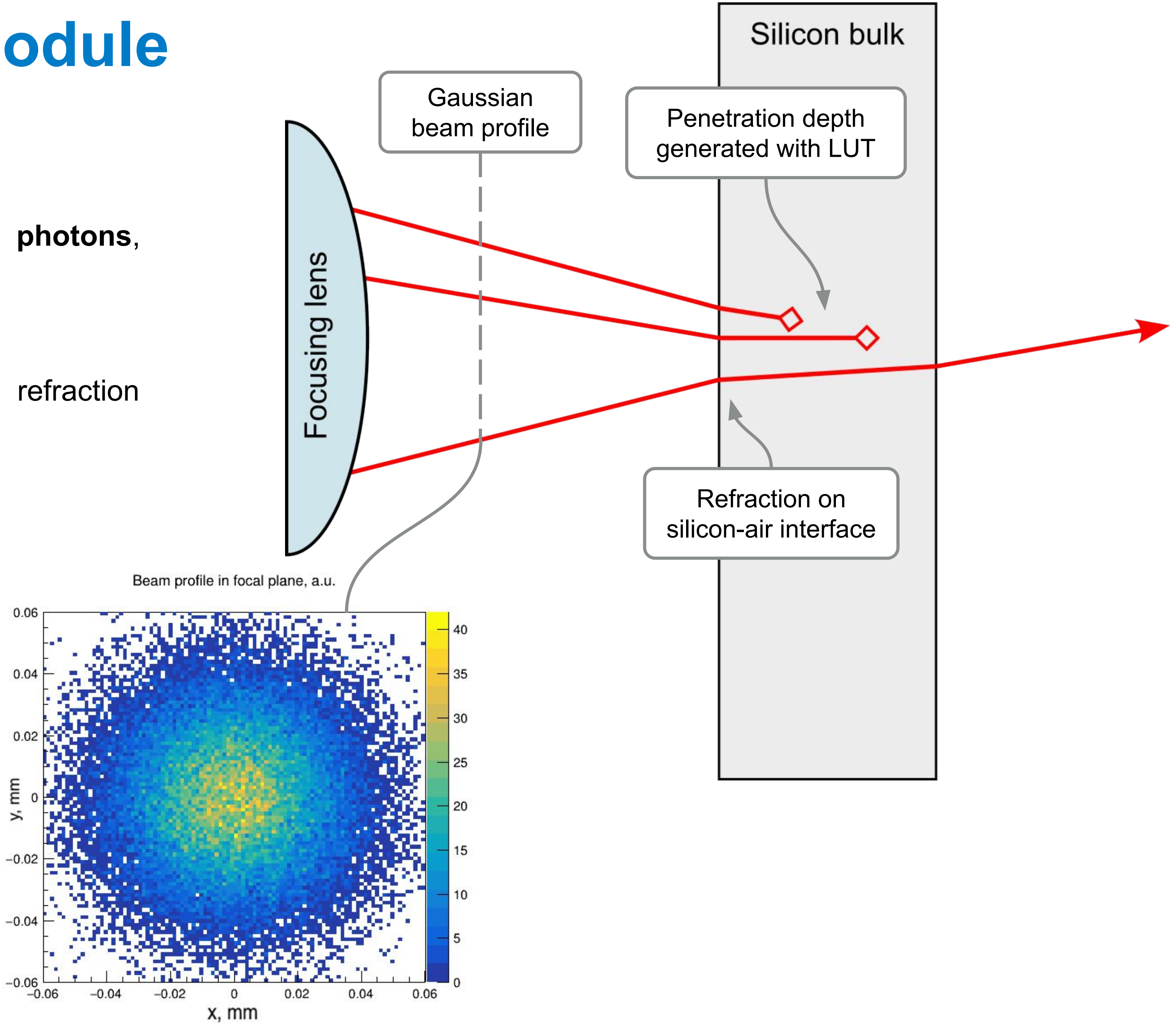
allpix::DepositionLaserModule

Simulation principle

Simulation features:

- Laser pulse is modelled as a set of **individual photons**, each considered a *straight line*
- Intensity distribution reproduces a **gaussian beam**
- Adjustable **pulse duration**
- Experimental **lookup table** with absorption and refraction coefficients for different wavelengths



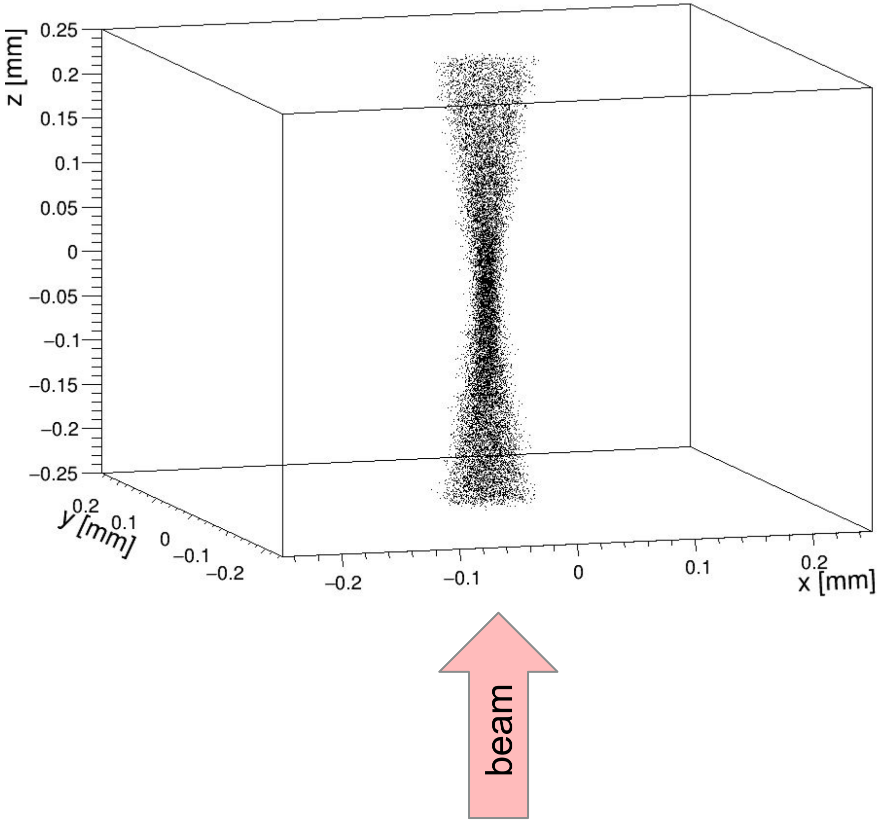


DepositionLaserModule showcases

Spatial distributions of laser-injected charge: 500 μm thick silicon plate as a target

1064 nm (**IR**) **converging** beam:

- uniform distribution along the whole bulk
- converging-diverging beam shape



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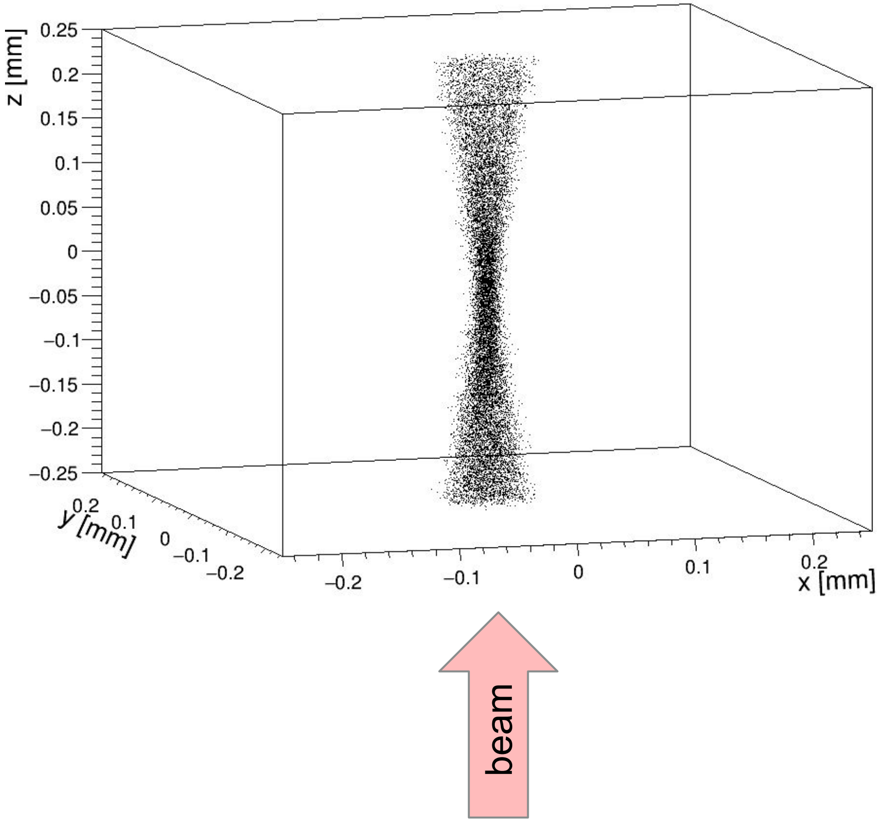
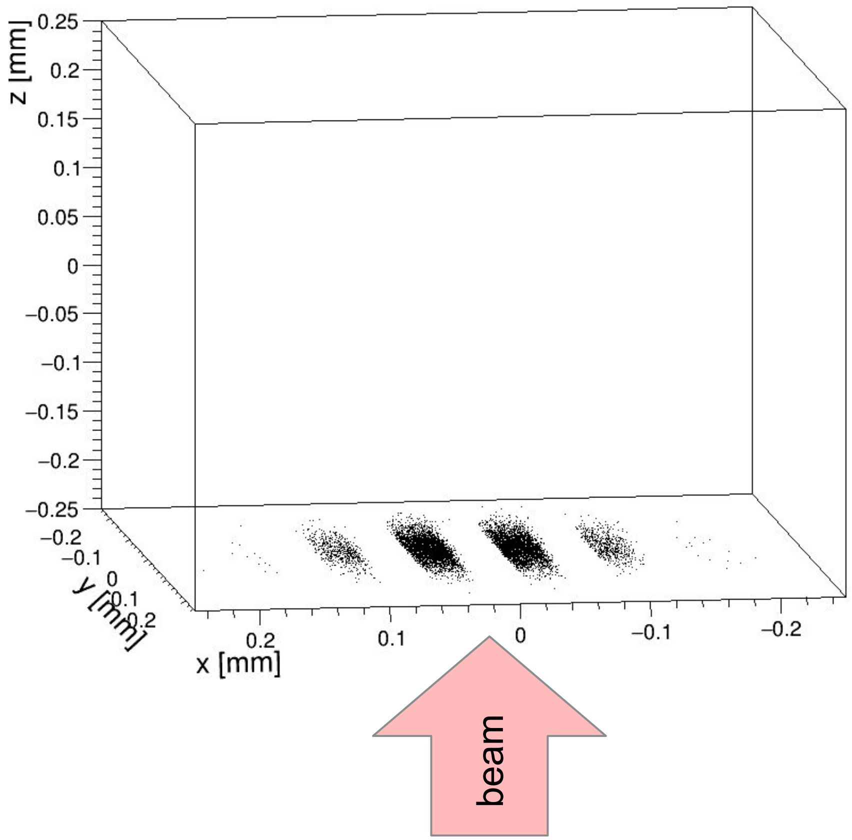


660 nm (**red**) beam + metal **strips** on surface:

- absorption in a thin surface layer
- light partially blocked by opaque strips



Module usage and features

```
[Allpix]
number_of_events = 1
```

A few events (or one) is usually enough

Each event is compute-heavy! Consider using `group_photons`

Module usage and features

```
[Allpix]
number_of_events = 1

[DepositionLaser]

# Specify beam geometry
source_position = 0mm 0mm -5mm
beam_direction = 0 0 1
beam_geometry = "converging"
beam_waist = 10um
focal_distance = 5mm
beam_convergence_angle = 20deg
```

A few events (or one) is usually enough

Each event is compute-heavy! Consider using `group_photons`

No need to call `[GeometryBuilderGeant4]`

Module usage and features

```
[Allpix]
number_of_events = 1

[DepositionLaser]

# Specify beam geometry
source_position = 0mm 0mm -5mm
beam_direction = 0 0 1
beam_geometry = "converging"
beam_waist = 10um
focal_distance = 5mm
beam_convergence_angle = 20deg

# Specify parameters of the pulse
wavelength = 1064nm
number_of_photons = 10000
pulse_duration = 1ns
```

A few events (or one) is usually enough

Each event is compute-heavy! Consider using `group_photons`

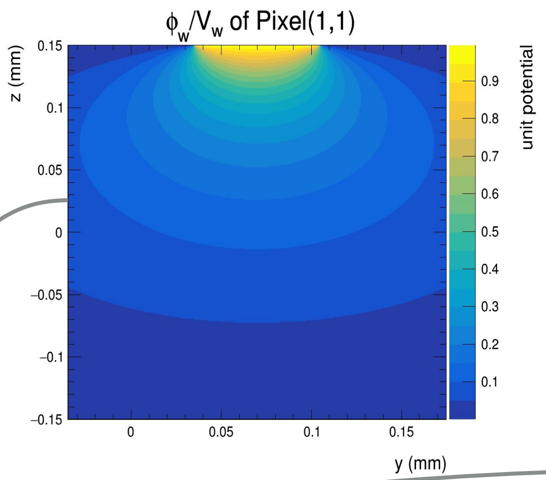
No need to call `[GeometryBuilderGeant4]`

Or explicitly define `absorption_length` and `refractive_index`

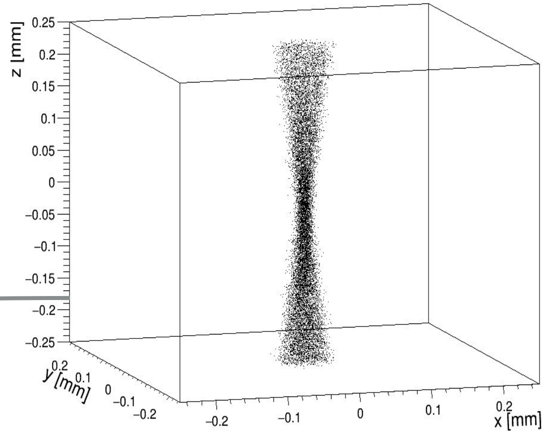
One cannot usually know these a priori

Example simulation pipeline

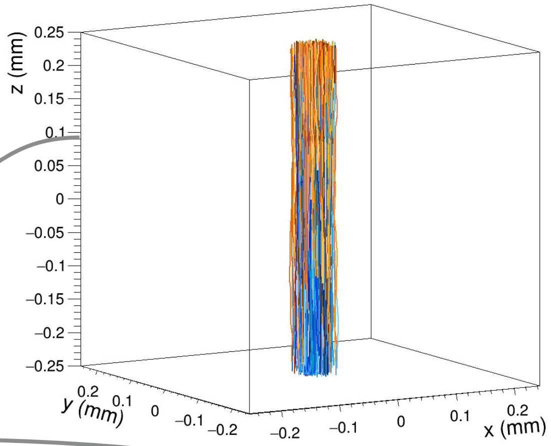
ElectricFieldReader & **WeightingPotentialReader**
define e.field and w.potential distributions



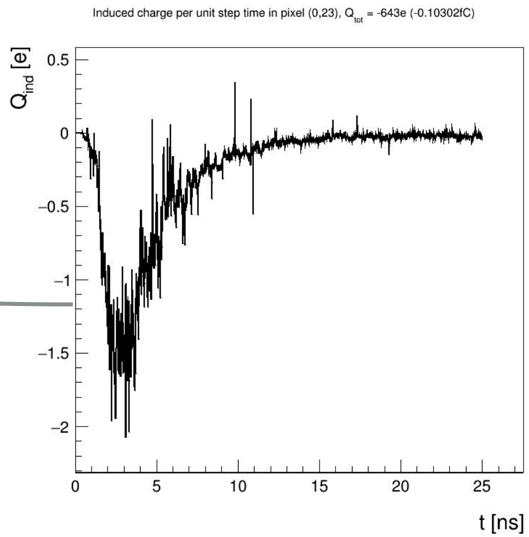
DepositionLaser
generate charge carriers, deposited in the bulk



TransientPropagation
track individual carriers through the bulk and
calculate induced currents (Shockley-Ramo)



PulseTransfer
accumulate induced currents and store data



Pulse post-processing (external)
account for the amplifier effects

TCT experiments:
Data/MC comparisons

Laser TCT experiments

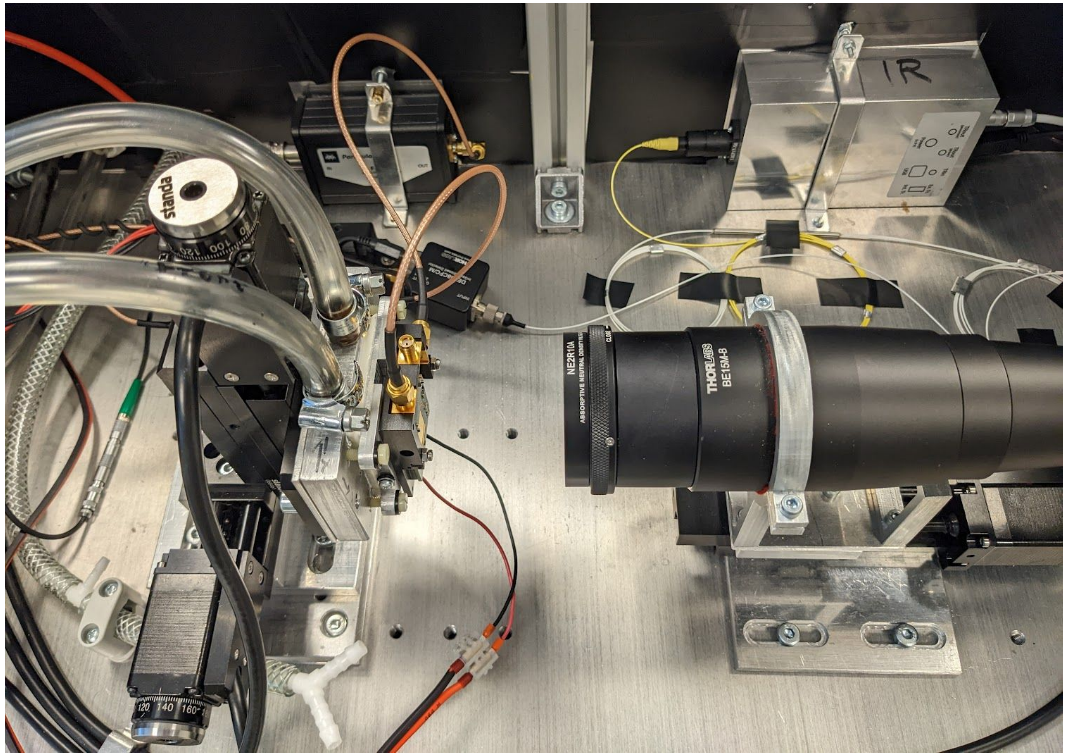
A flexible testbench for sensor R&D

Pulsed lasers are a common tool for charge injection:

- micrometer aim precision
- high repeatability
- tunable intensity

Red
pen.depth O(1 μm)
= *heavy particle absorption*

Near infrared
pen.depth O(1 mm)
= *m.i.p passage*



Experimental setup at DESY

A few more components to make a complete setup:

- Focusing optics
- Positioners
- High-bandwidth amplification and readout

Red (640 nm) and IR (1064 nm) lasers:

- stable beam radius of **12 μm** at focus
- pulse duration of approx. **2 ns**
- intensity fluctuations **<2%**

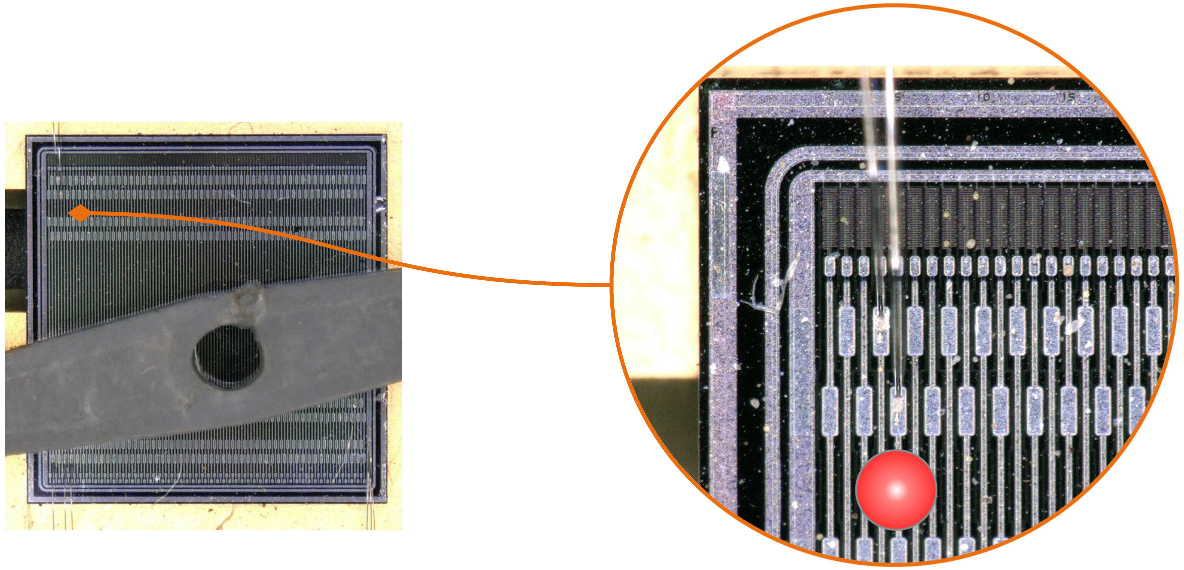
Experimental dataset

for simulation comparisons/validation

A test strip structure for ATLAS12 sensors

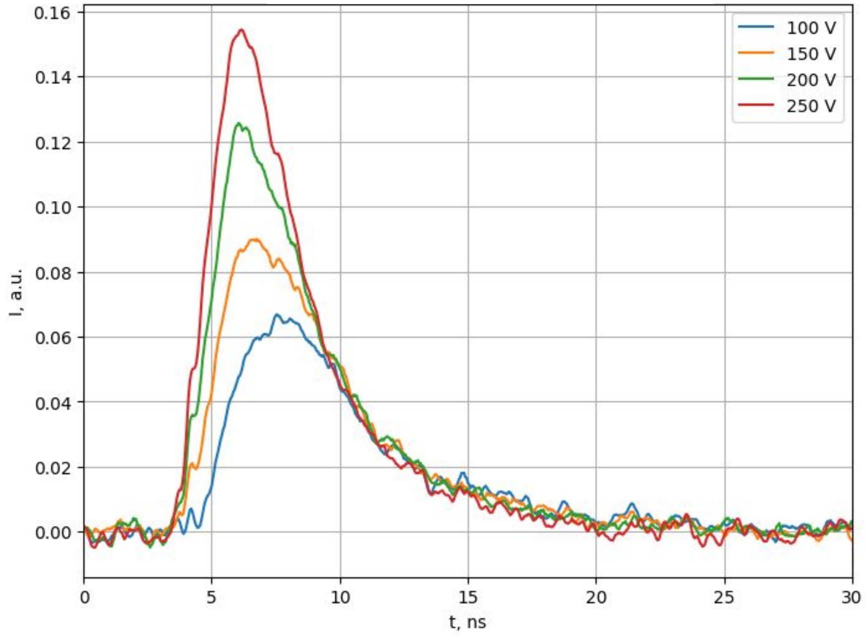
- **n^+-on-p** type (electron collecting)
- 310 µm thickness
- 74.5 µm pitch
- Depletion at ~360V

- Laser is focused in a ~100 µm spot and aimed at a strip, connected to readout
- Output signals are amplified with a wide-band amp
- The readout is synchronized with the laser and records and averages signals, induced on that strip
- Bias voltage scans are taken with both **red** and **IR** lasers



View of the sensor under test
Laser spot shown schematically with a red circle

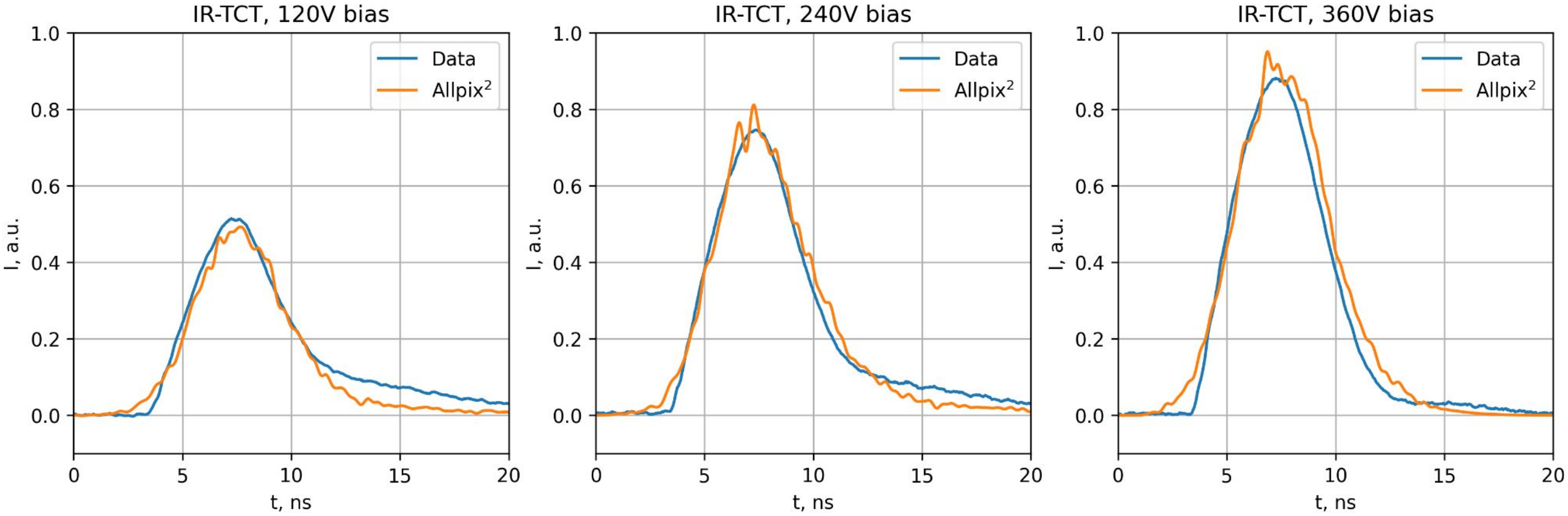
Measured waveforms, **IR**



Recorded signals
scan over bias voltage, IR laser

Induced pulse comparison

Infrared laser

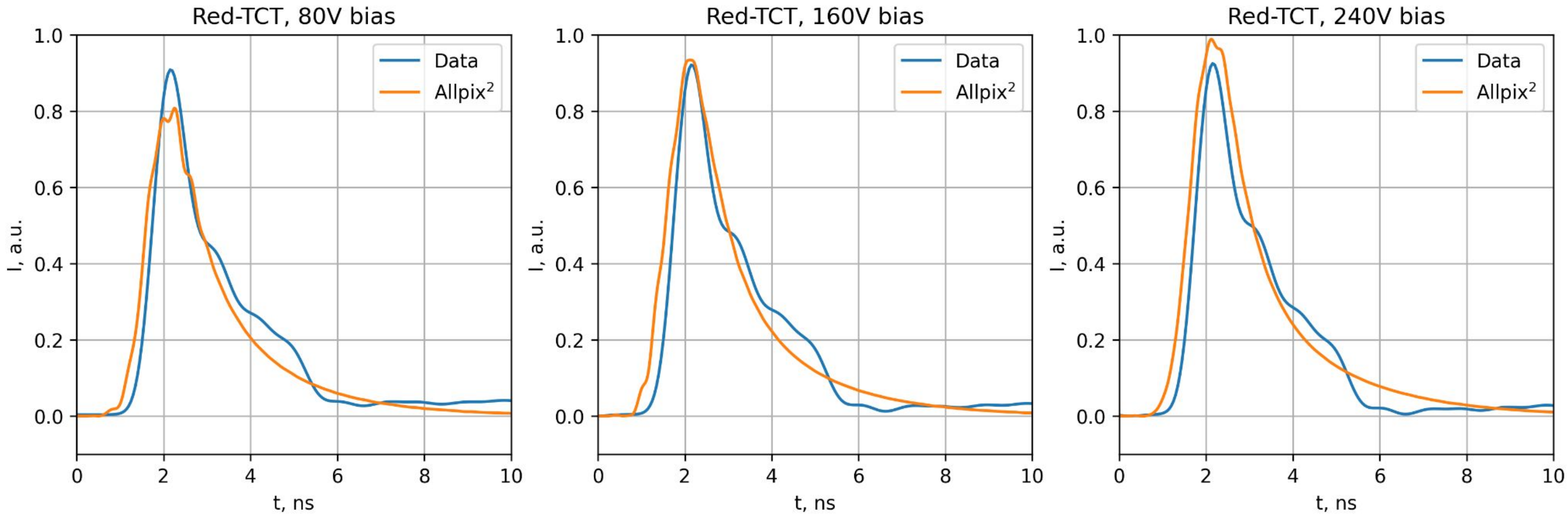


Characteristic signal features are reproduced with the simulation:

- **Overall shape** → electron and hole contributions
- **Amplitude vs bias** → depletion characteristics
- **Width** → laser pulse properties

Induced pulse comparison

Red laser



For the **red** laser, signal formation is happening in a *thin surface layer* thus it is highly prone to **border effects**

↳ more accurate detector model required

Conclusions

- The **deposition generator** for laser-TCT simulations is complete and functional
- With it, Allpix^2 is capable of reproducing sensor response in different scenarios of **TCT experiments**
  - Certain scenarios show **good match** to experimental data
  - However, **further tuning** of simulation is required for better precision and to cover wider range of use cases

That's it!

Thank you for attention!