Timing studies of MAPS in 65nm imaging process

TowArds the Next GEneRation of SIlicon Detectors

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UNIVERSITÄT BONN

HELMHOLTZ

The Tangerine Project

TowArds Next GEneRation SIlicoN DEtectors

Goal: Develop the next generation of monolithic silicon pixel detectors using a 65 nm CMOS imaging process

We investigate the potential for the following applications:

- **Trackers for future e^+e^- Colliders**
- **Reference detector at DESY-II test beam upgrade**

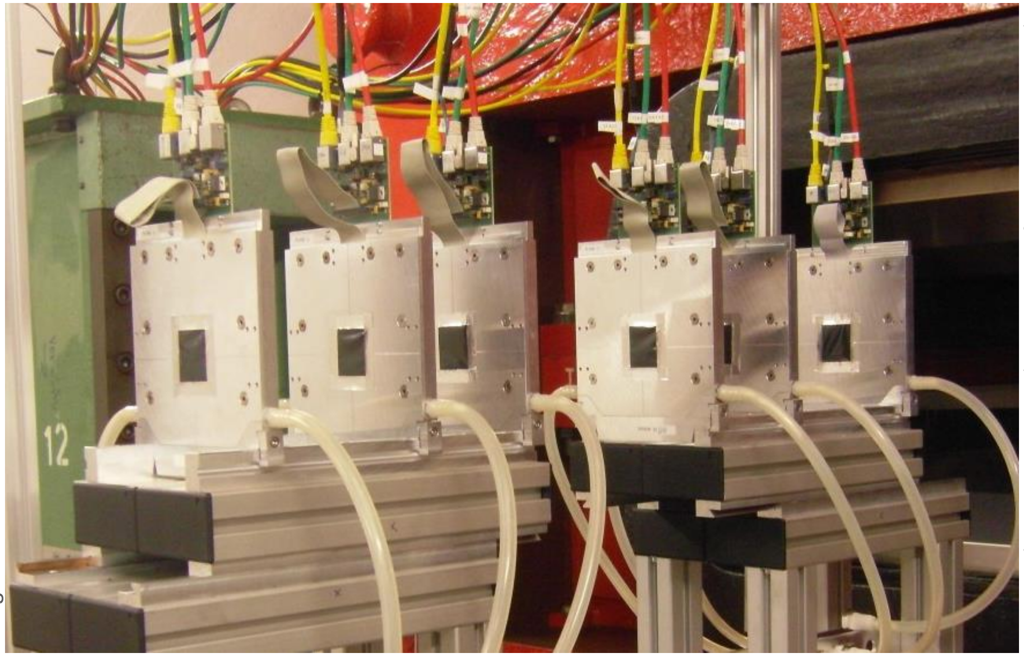


Image:DESY

https://newsline.linearcollider.org/2011/08/18/the-impact-of-ilc-detector-rd/desy-beam-telescope/

MIMOSA Telescope at the DESY II Facility

Requirements

- Spatial Resolution ~ 3 µm
- Time Resolution ~ ns
- Low material budget ~ 50 µm silicon (compared to hybrid sensors)

Motivation of these studies

To understand the process better and improve on

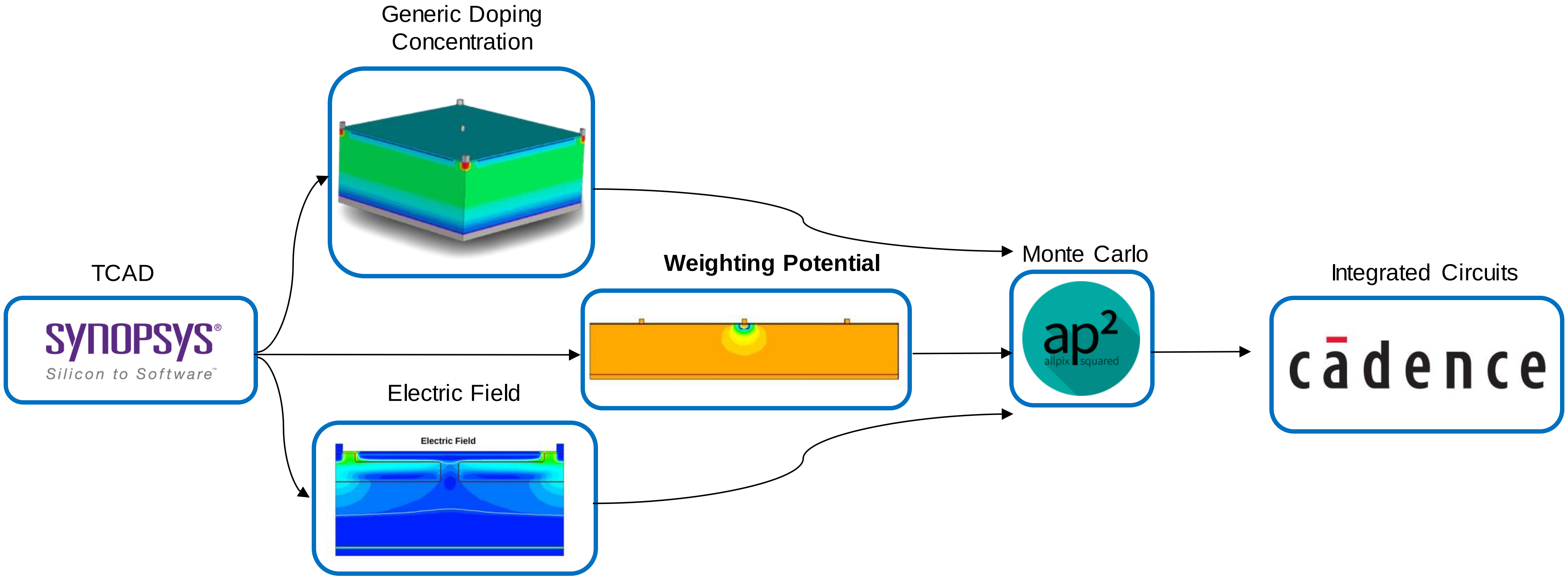
- Study the time resolution we might achieve with this process
  1. Understand how this is affected by the sensor and the electronics
  2. Understand where the limitations come from (sensor, electronics)
- For the sensor, in particular study how the particle incident position affects amplitude, timing, charge collection time...

→ **Simulation studies help to start to answer these questions**

Transient Simulations

Simulation Workflow

- Transient simulations allow us to study the **time evolution** of the response of a sensor, i.e. the **signal** evolution which is exactly what we want to achieve for our sensors.
- Electric field and generic doping profiles are imported into the Allpix Squared framework. This allows to produce **high statistics** simulations saving time compared to transient simulations in TCAD.
- In order to simulate the electronics, the **output signal** from Allpix Squared is imported into CADENCE

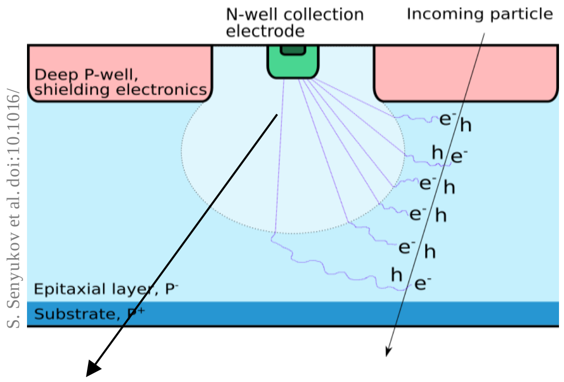


Electric field in thin silicon sensors

Designs

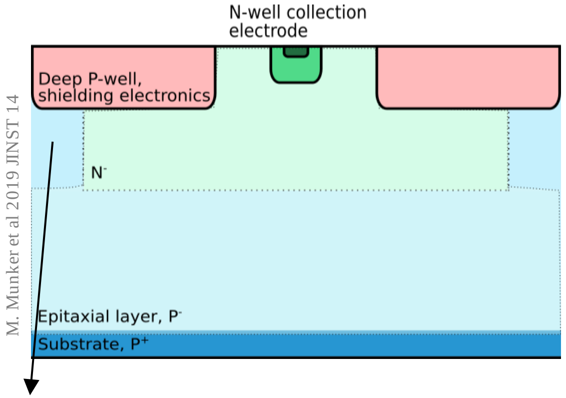
Layout geometry

Standard



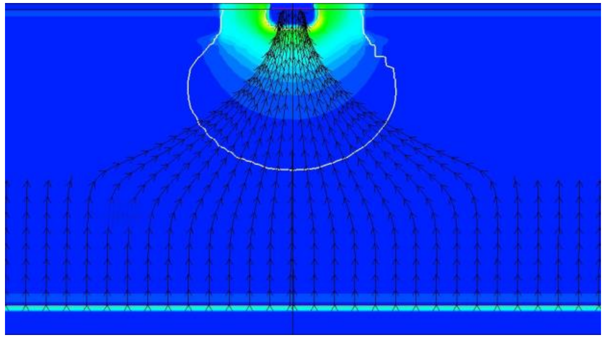
Drift predominates inside depleted region and **diffusion** outside

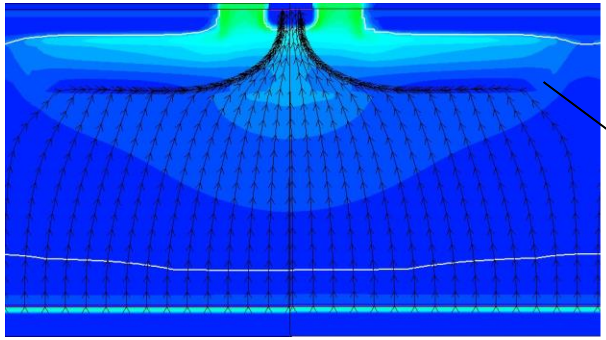
N-Gap



Gap in Continuous N-type Implant
Speed up charge collection

Electric Field lines



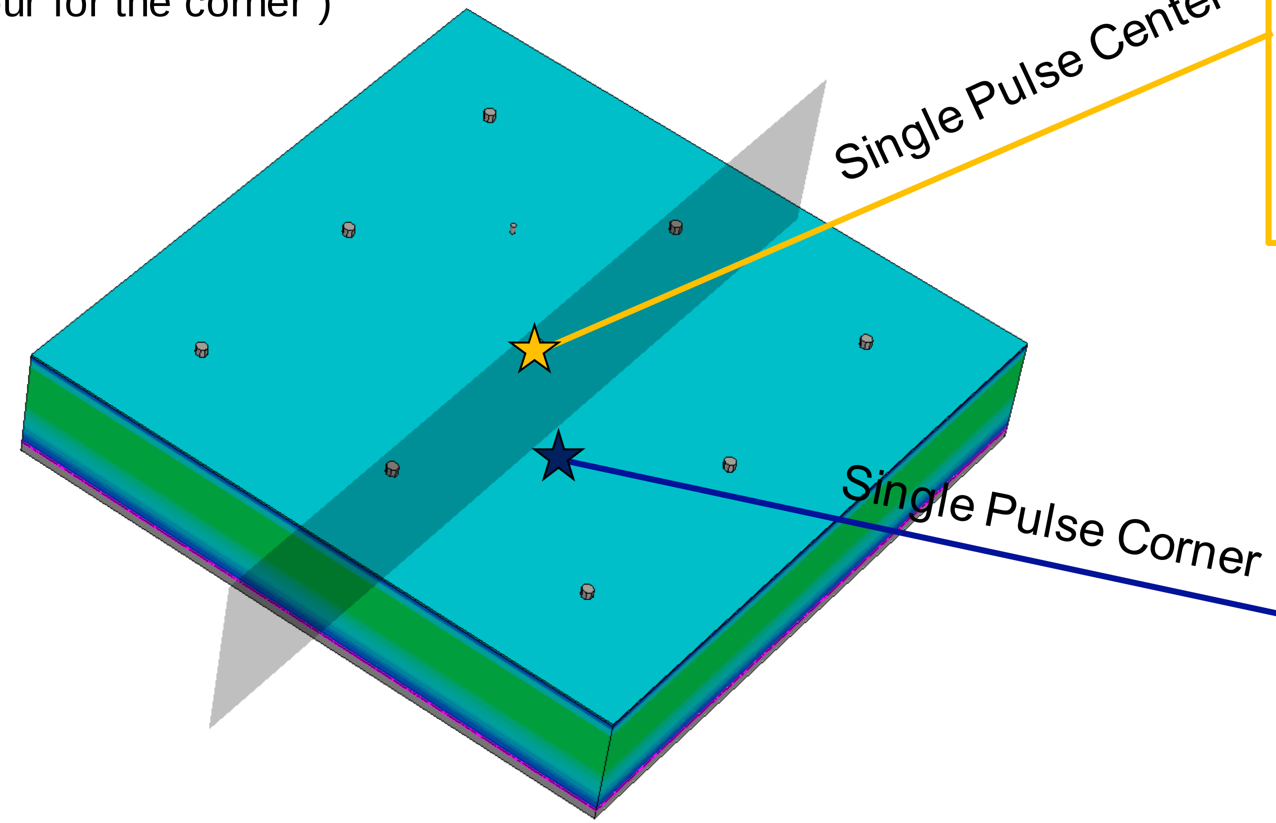


The electrons follow the direction of the **stream lines**

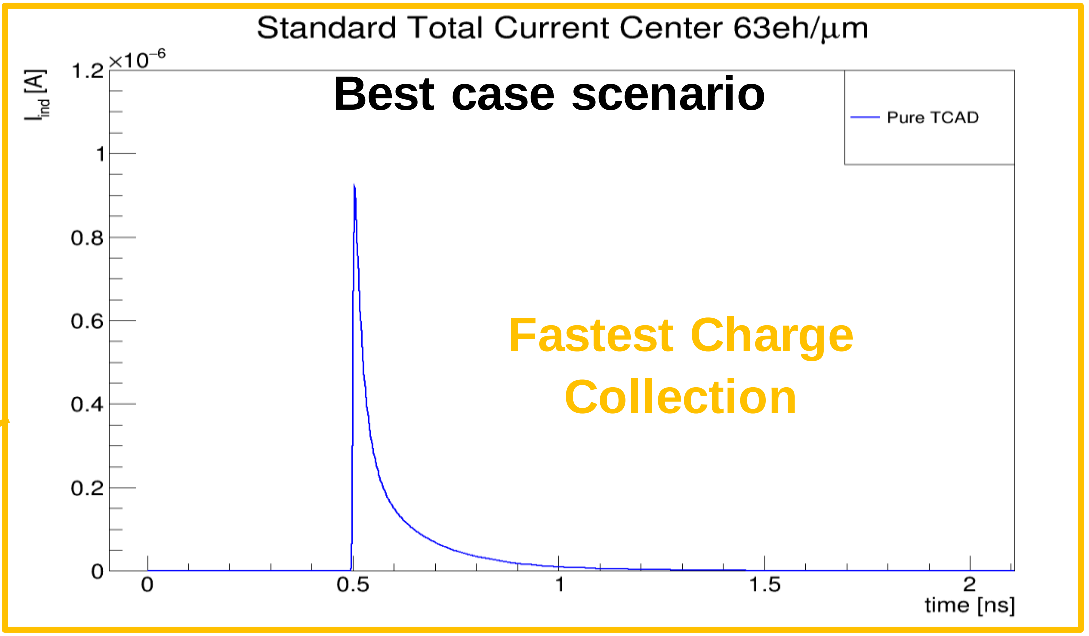
TCAD + Allpix^2 Simulations

Two extreme cases under study – Standard Layout

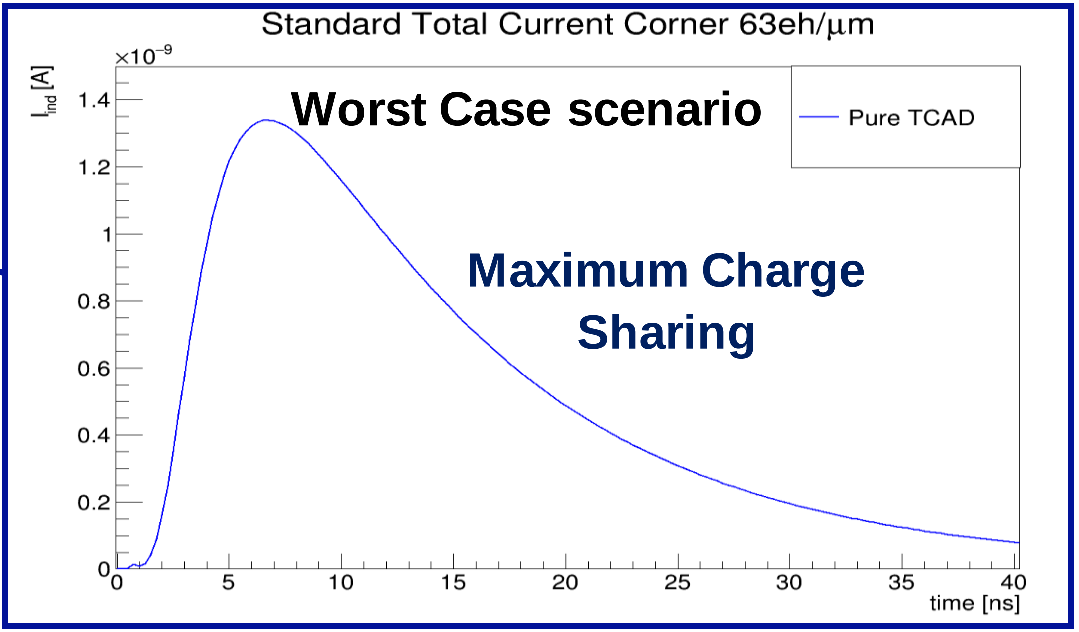
- Charge carriers injected alongside the pixel **corner** or **center**
- Fixed amount of charge carriers **63 eh/µm**
- Average of pixels over threshold calculated (One for center and four for the corner)



3x3-cell model in TCAD

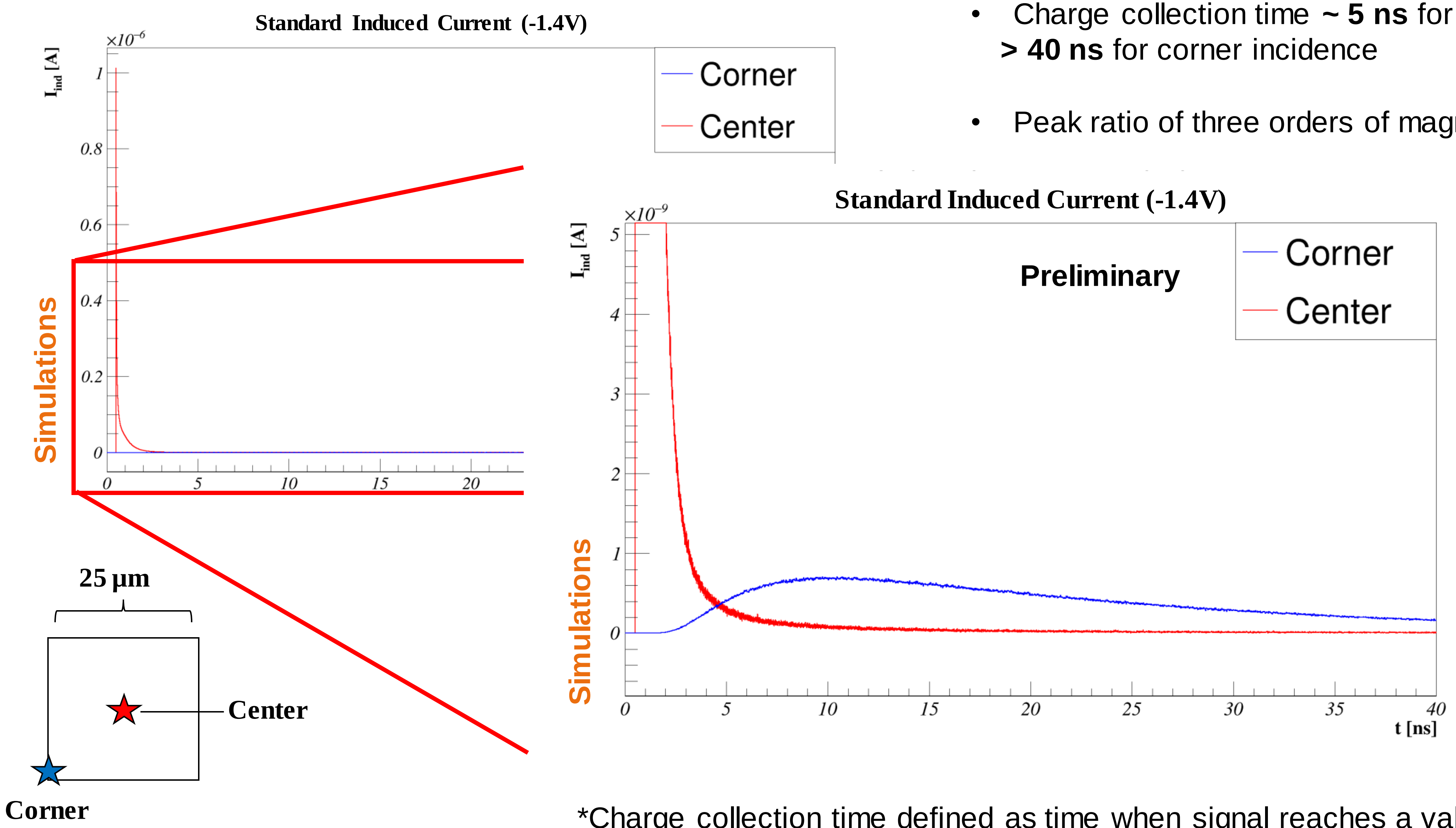


Not same time scale!



Detector response simulation

Standard Layout → No electronics included



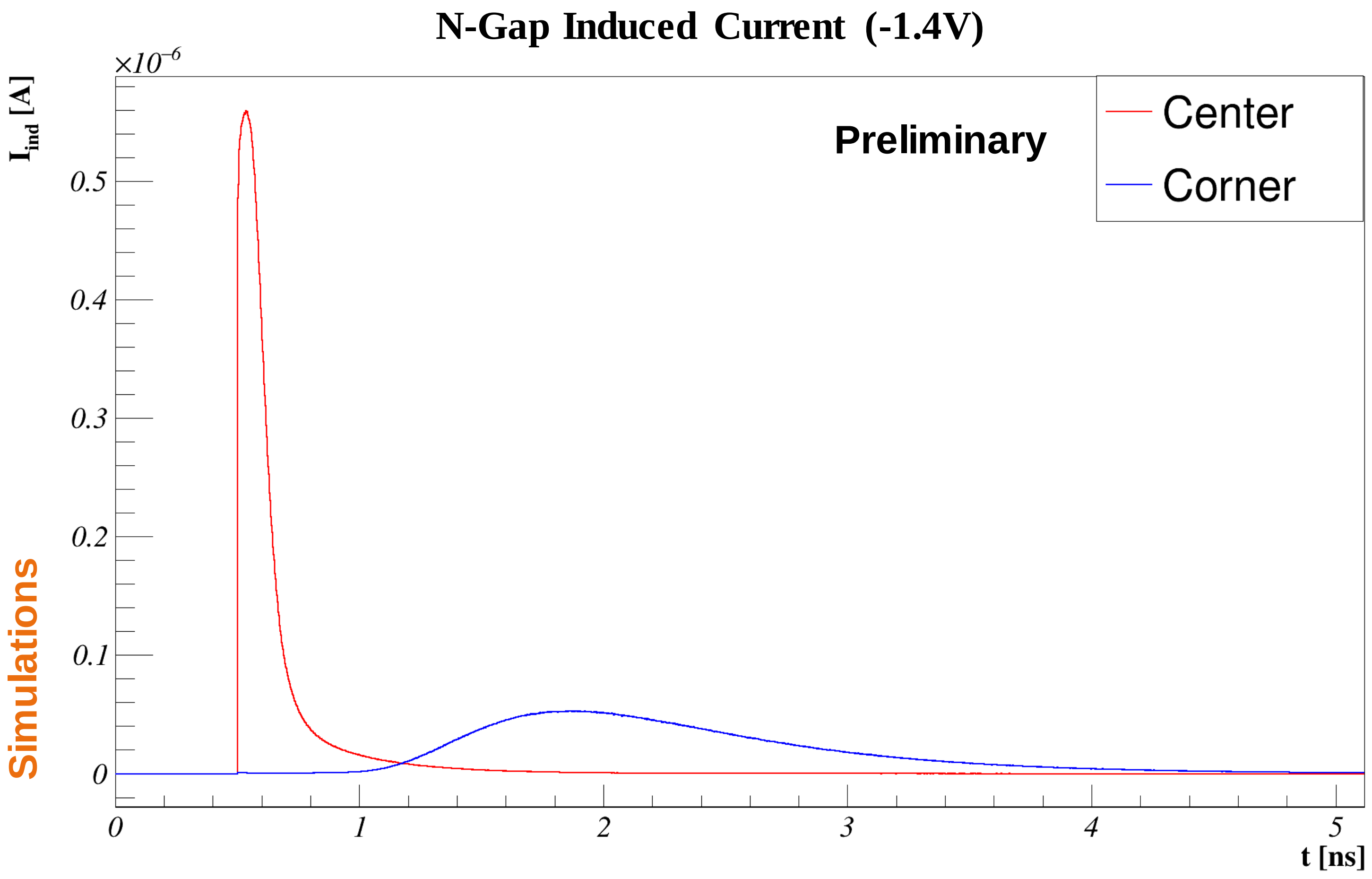
- **Pulse duration** depends heavily on particle incident position
- Charge collection time **~ 5 ns** for center incidence and **> 40 ns** for corner incidence
- Peak ratio of three orders of magnitude

*Charge collection time defined as time when signal reaches a value of 10^{-13} A

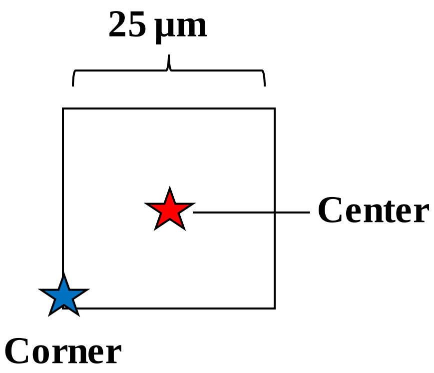
Detector response simulation

N-Gap Layout → No electronics included

Simulations



- **Pulse duration** difference not as marked
- Charge collection time < **5 ns** independent of incidence position
- Same order of magnitude peak of the signals

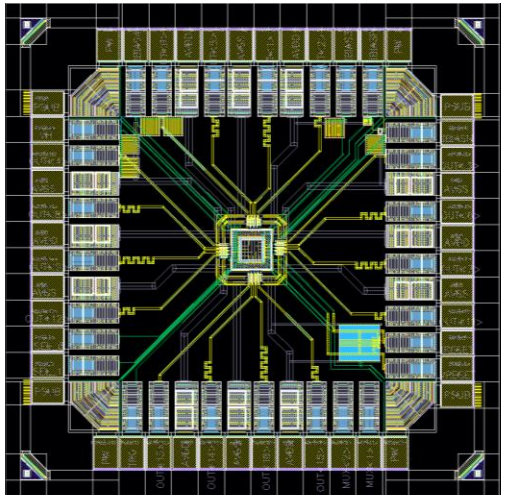


Detector response understood →

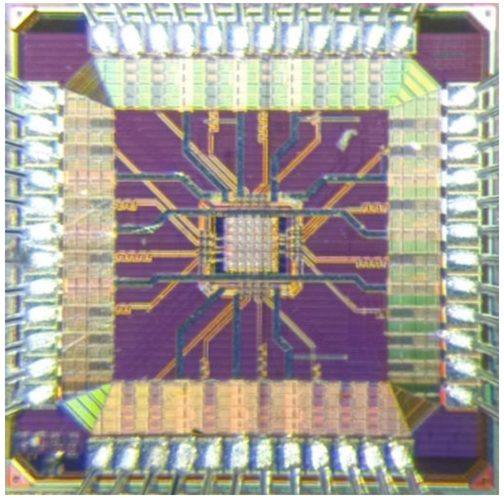
Next step: Study the electronic response (**technology dependent**)

Sensors in MLR1 production

Analogue Pixel Test Structures (APTS)



ASIC Design



Prototype

- Designed at **CERN** (DESY involved in the lab and TB characterization)
- 4x4 pixels structure with analogue output
- Different sensor pitches from 10 µm to **25 µm**
- Different sensor layouts: **Standard** and **N-Gap**
- Two versions of the output buffer

- The focus of this talk will be on the **Source Follower** version.

EP R&D

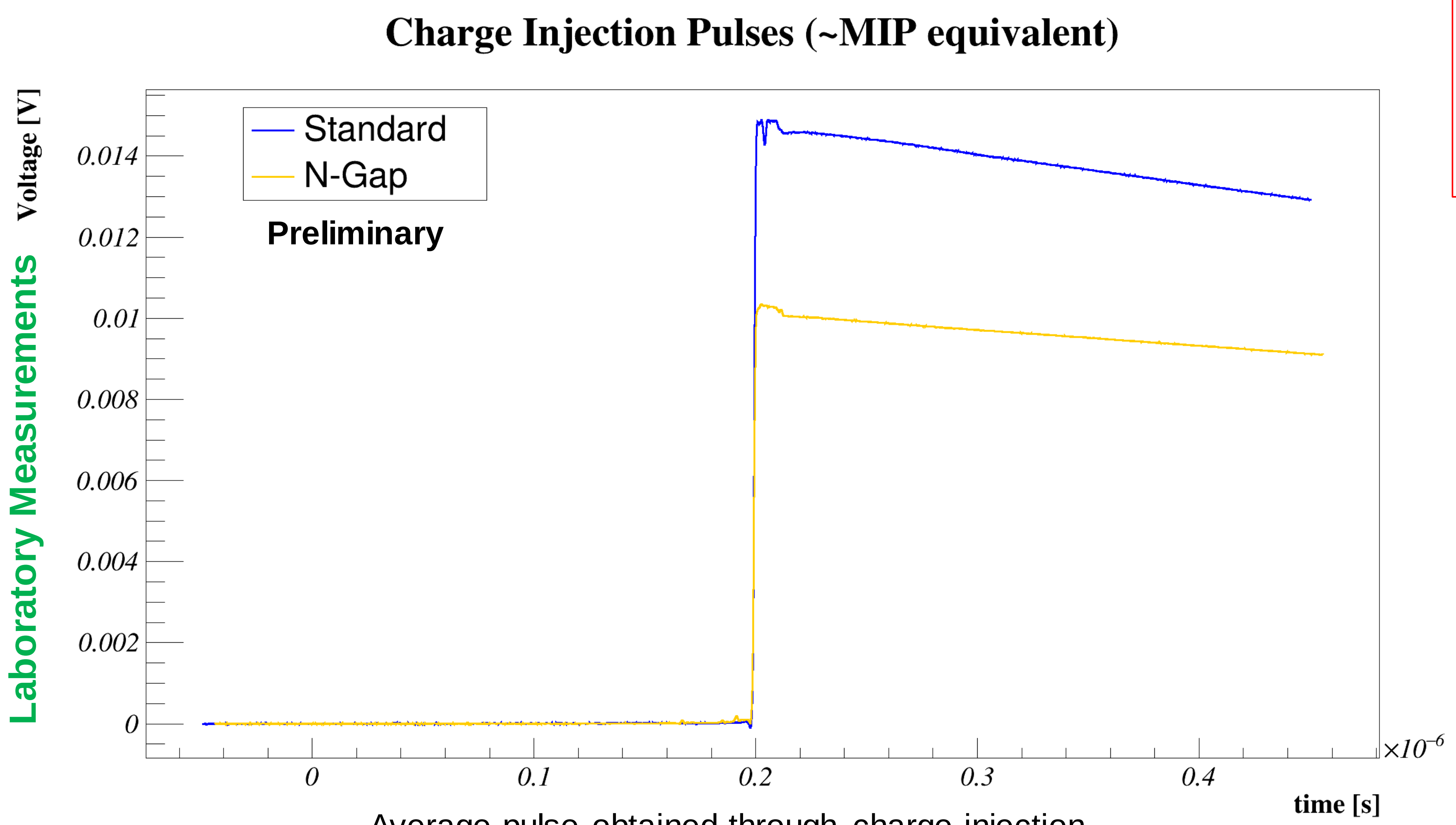
ALICE

Test pulses using built-in charge injection capacitor

Chip settings

IBIASN 400 uA
IBIASP 40 uA
IBIAS3 500 uA
IBIAS4 6 mA
IRESET 1 uA
VRESET 0.48 V
PWell/PSub -1.2 V

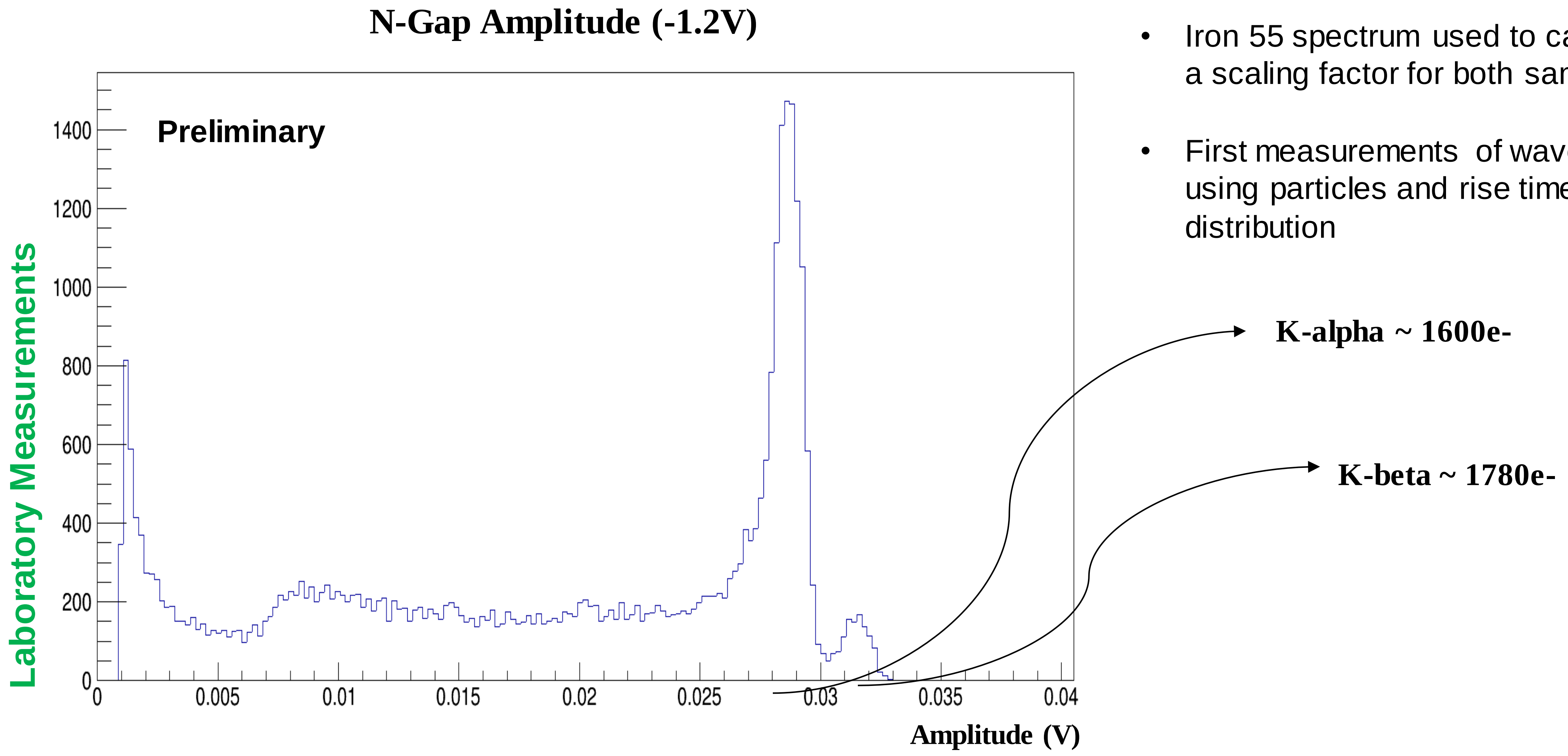
$25x25um^2$
APTS



Average pulse obtained through charge injection.
Even though both share same output layout there is a difference in peak due to capacitance.

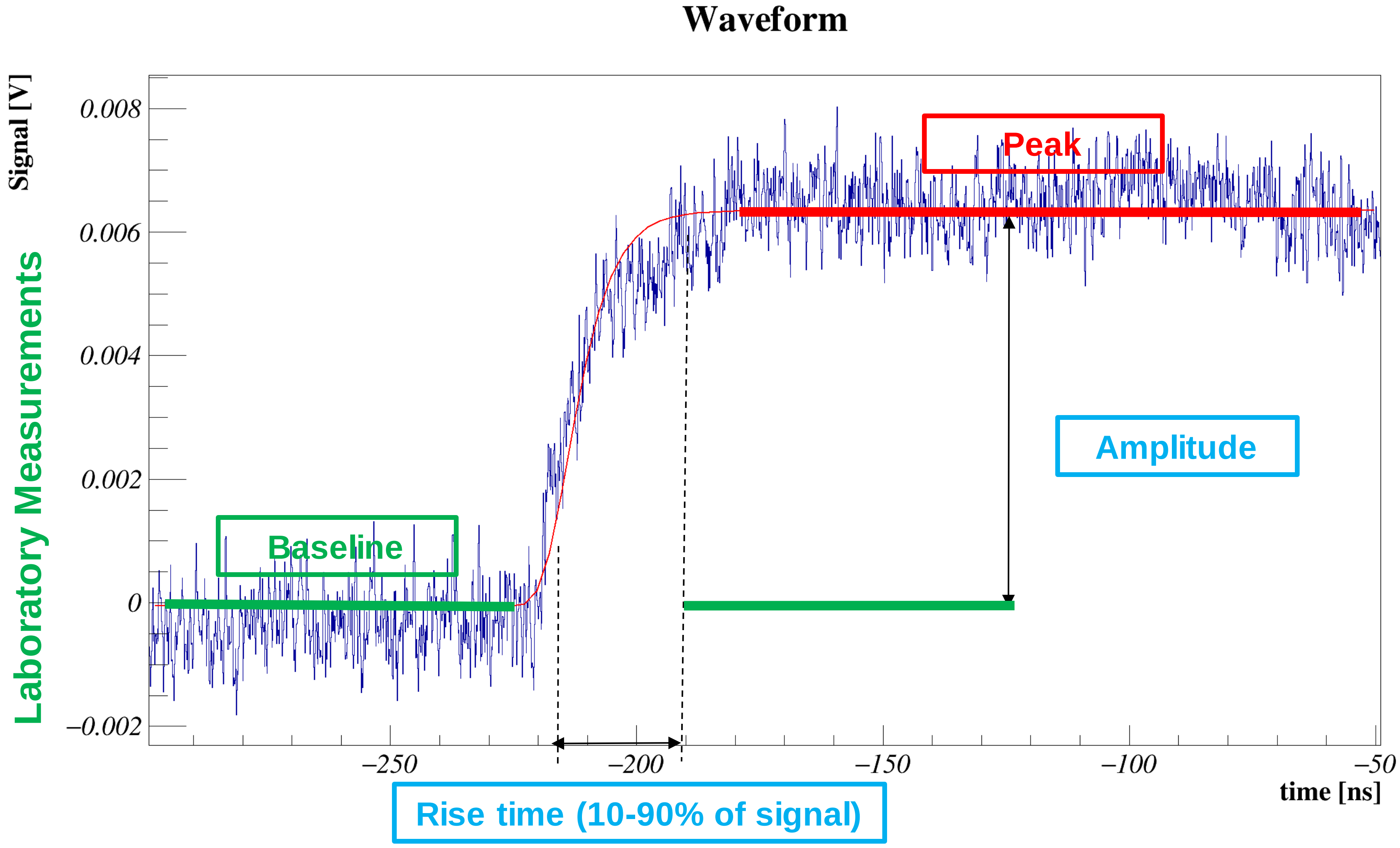
Calibration with Fe-55

N-Gap "Capacitance"



- Iron 55 spectrum used to calculate a scaling factor for both samples
- First measurements of waveforms using particles and rise time distribution

Waveform Simplified Analysis



Chip settings

IBIASN 400 uA
IBIASP 40 uA
IBIAS3 500 uA
IBIAS4 6 mA
IRESET 1 uA
VRESET 0.48 V
PWell/PSub -1.2 V

Used in the simulations as well

25x25um^2 APTS

The rise time* is an intrinsic quantity of the electronics response due to the signal induced in the detector. This can be directly compared to simulations

*Dominated by the electronics, but consist in a convolution of the electronics response and transient from the detector.

Comparison with CADENCE simulation

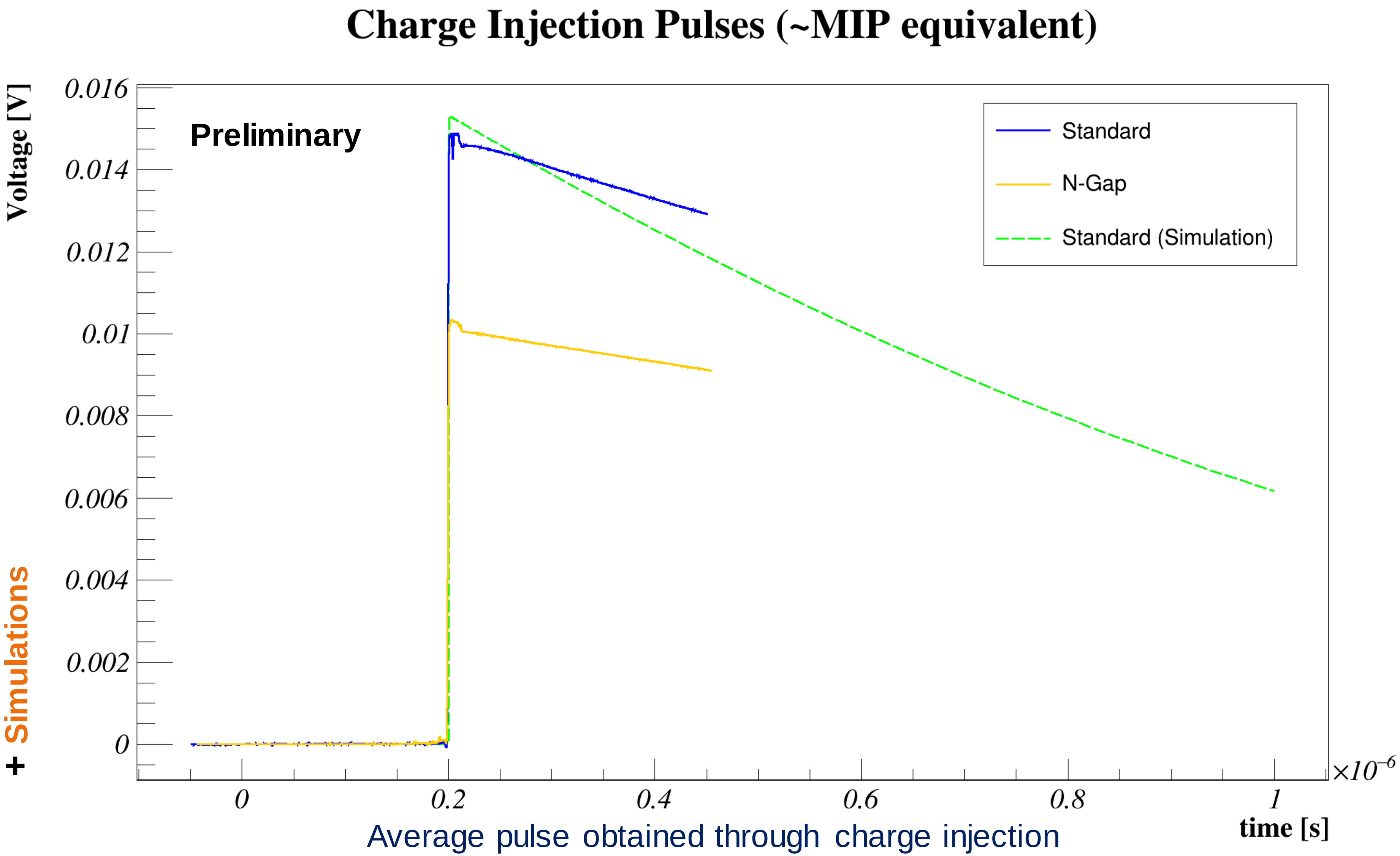
Chip settings

IBIASN 400 uA
IBIASP 40 uA
IBIAS3 500 uA
IBIAS4 6 mA
IRESET 1 uA
VRESET 0.48 V
PWell/PSub -1.2 V

Used in the simulations as well

25x25um^2
APTS

Laboratory Measurements + Simulations



Average pulse obtained through charge injection

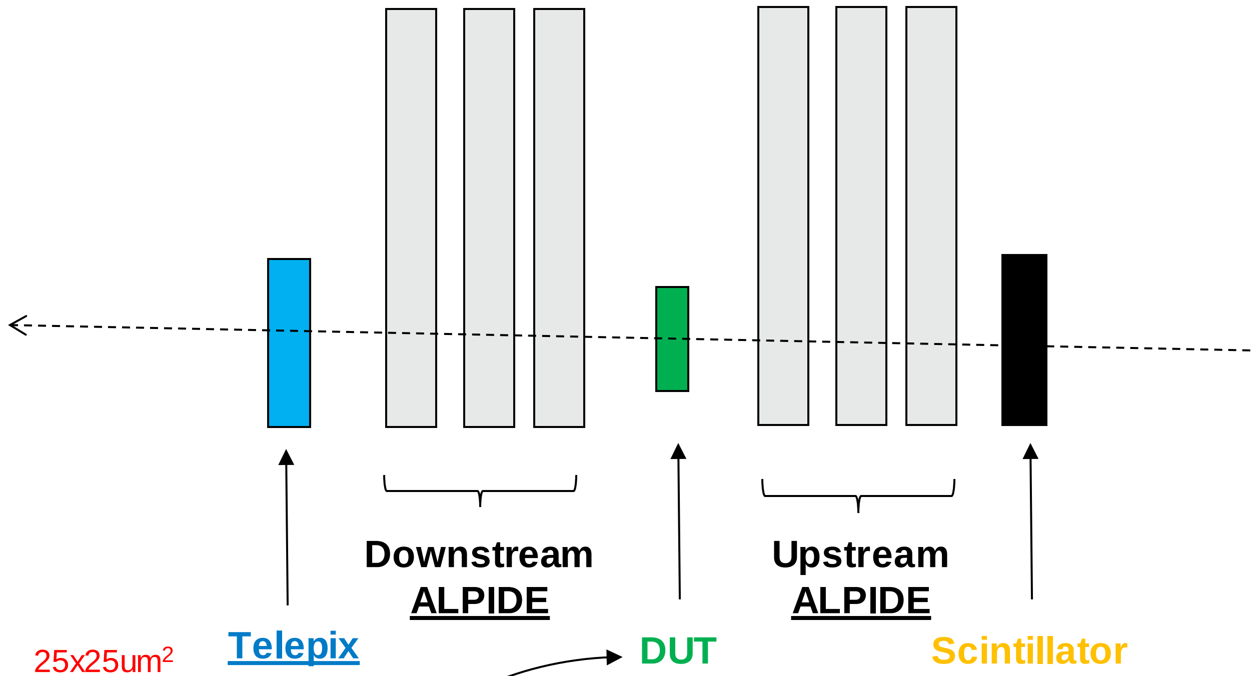
*Difference in slope due to differences in how the reset current is distributed between simulation and APTS

Test Beam Setup (June & December 2023)

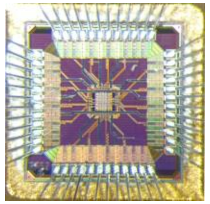
DESY II Test Beam Facility

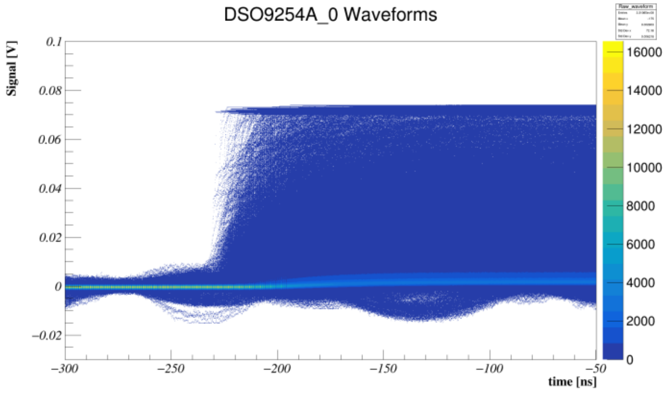
- Telepix and scintillator used in coincidence as trigger, and the former as **time reference**
- Telepix **masked** used to reduce trigger area
- NIM logic used along with TLU to introduce a BUSY signal while the oscilloscope records data

Motivation: Obtain waveforms associated with a track and a rise time

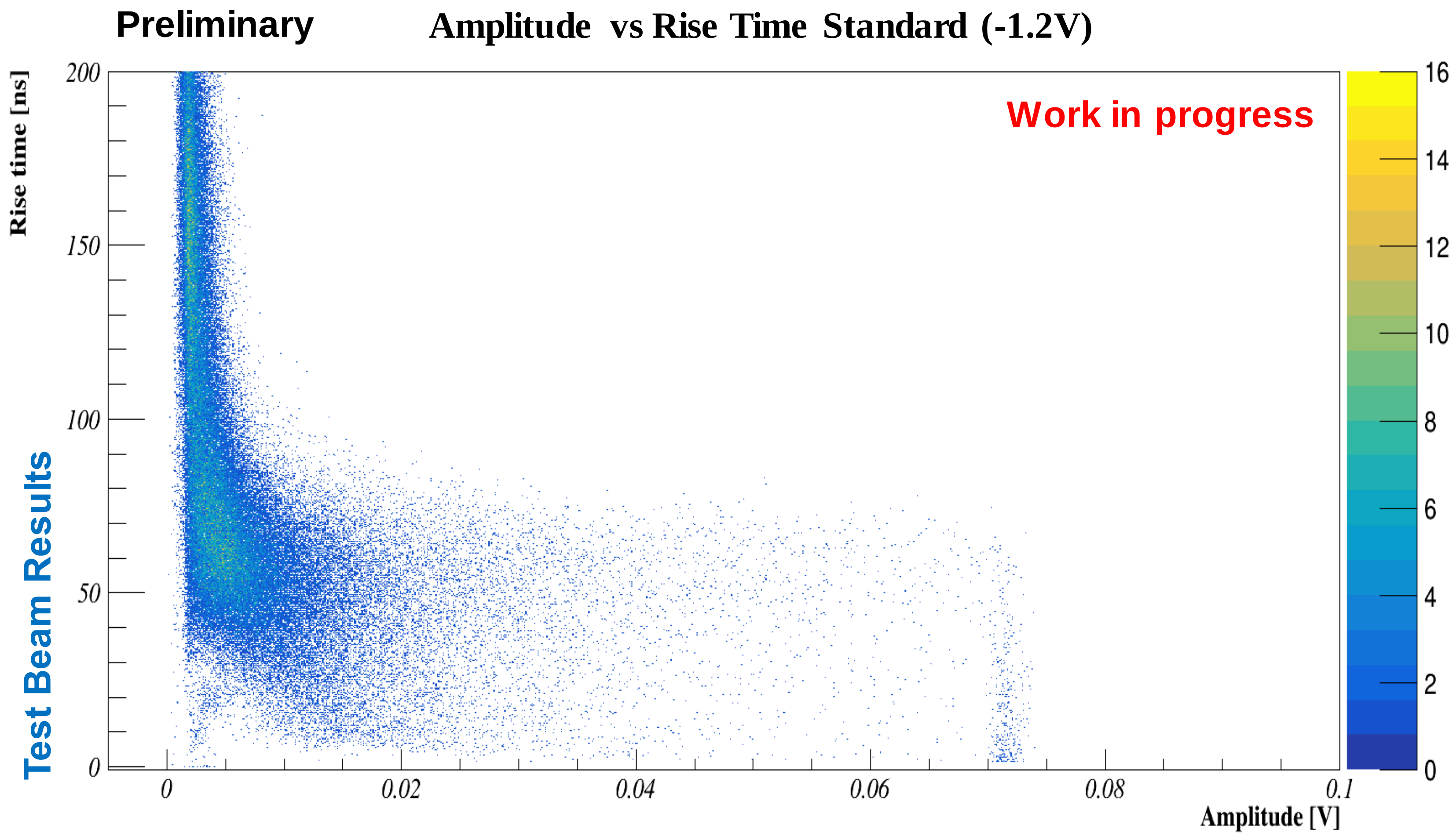


$25x25um^2$
Standard and N-Gap



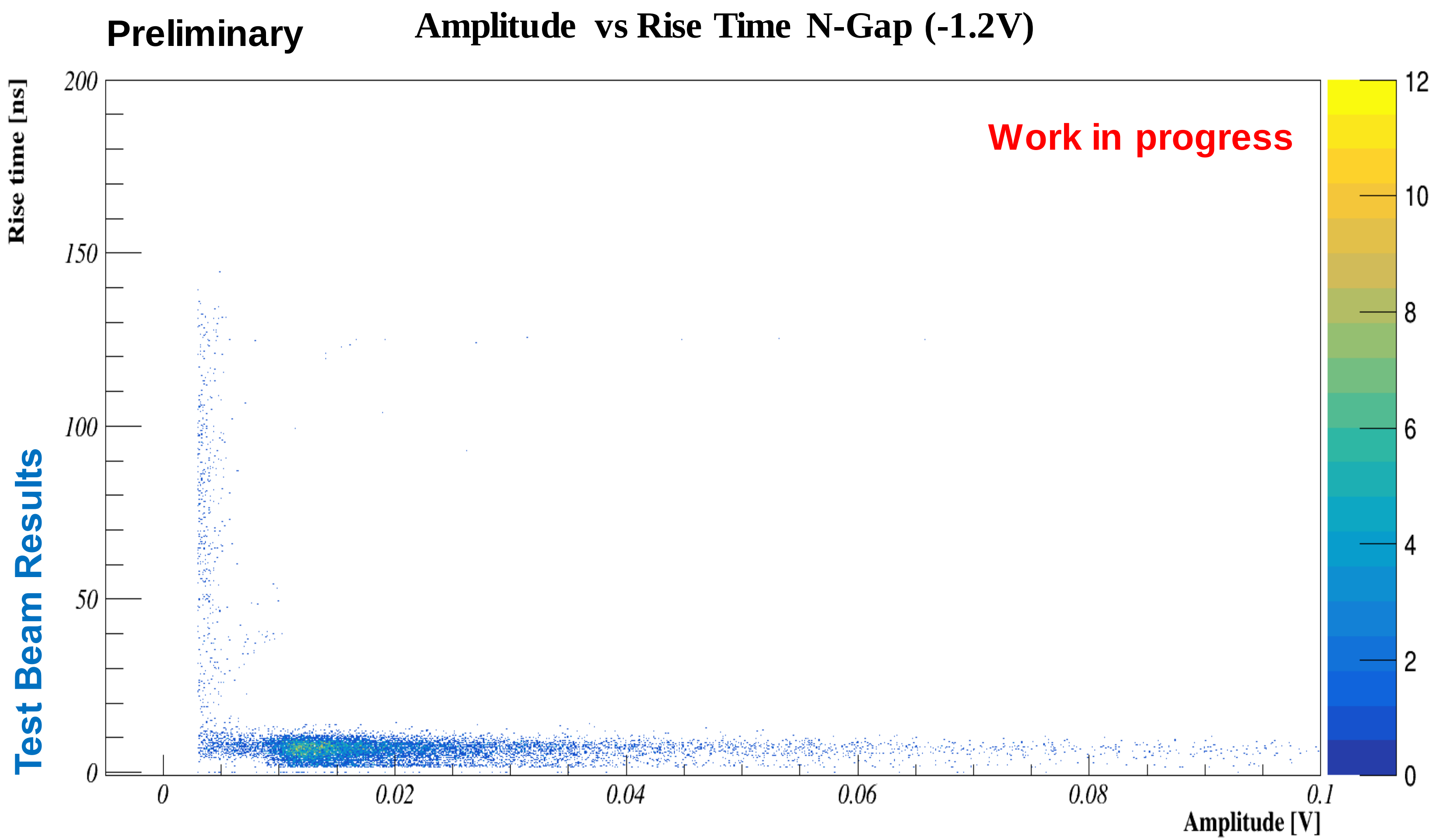


Amplitude vs Rise time distribution



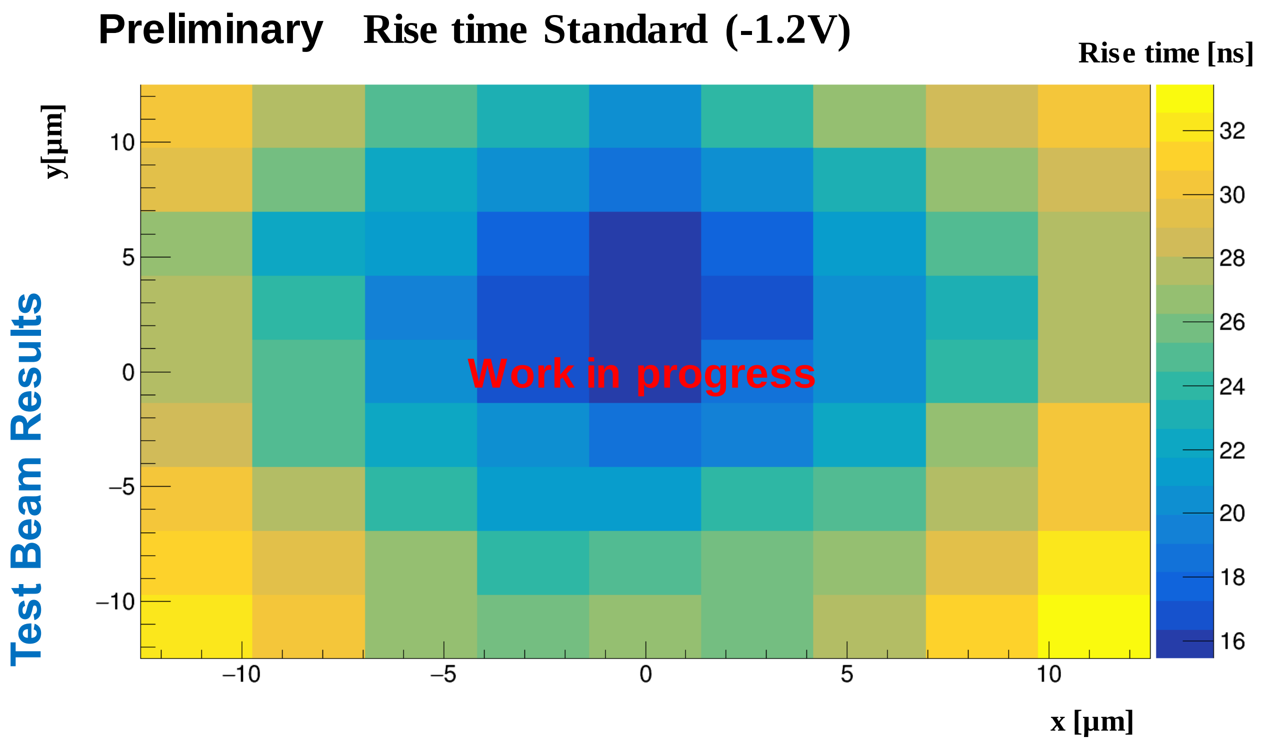
- Fast rise time values achieved for larger values of the amplitude.
- Wide range of rise time distribution.

Amplitude vs Rise time distribution

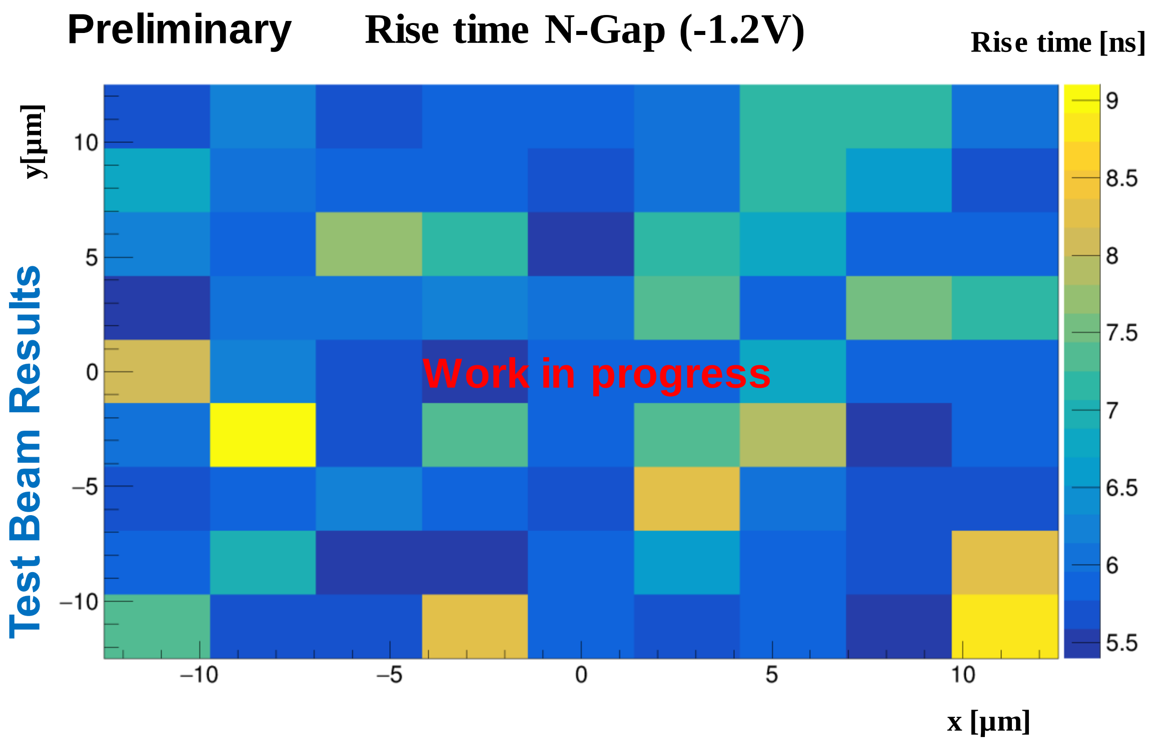


- Clear trend where regardless of signal amplitude, a fast rise time is achieved.
- Only for small signals, large values of rise time appear.

In pixel rise time distribution (Qualitative trend values)



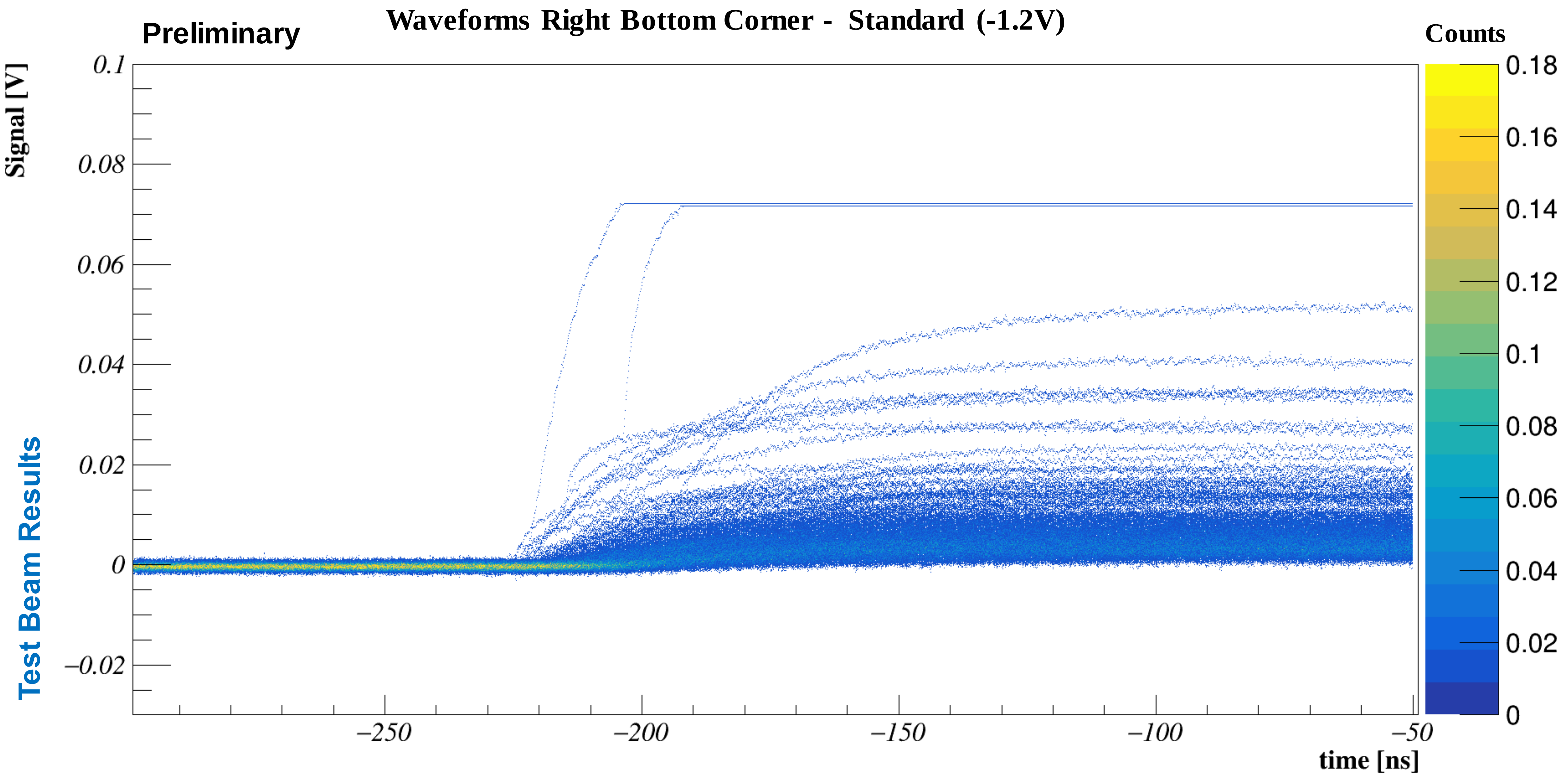
- Clear dependence of particle incident position and rise time



- Uniform rise time distribution regardless of incident position

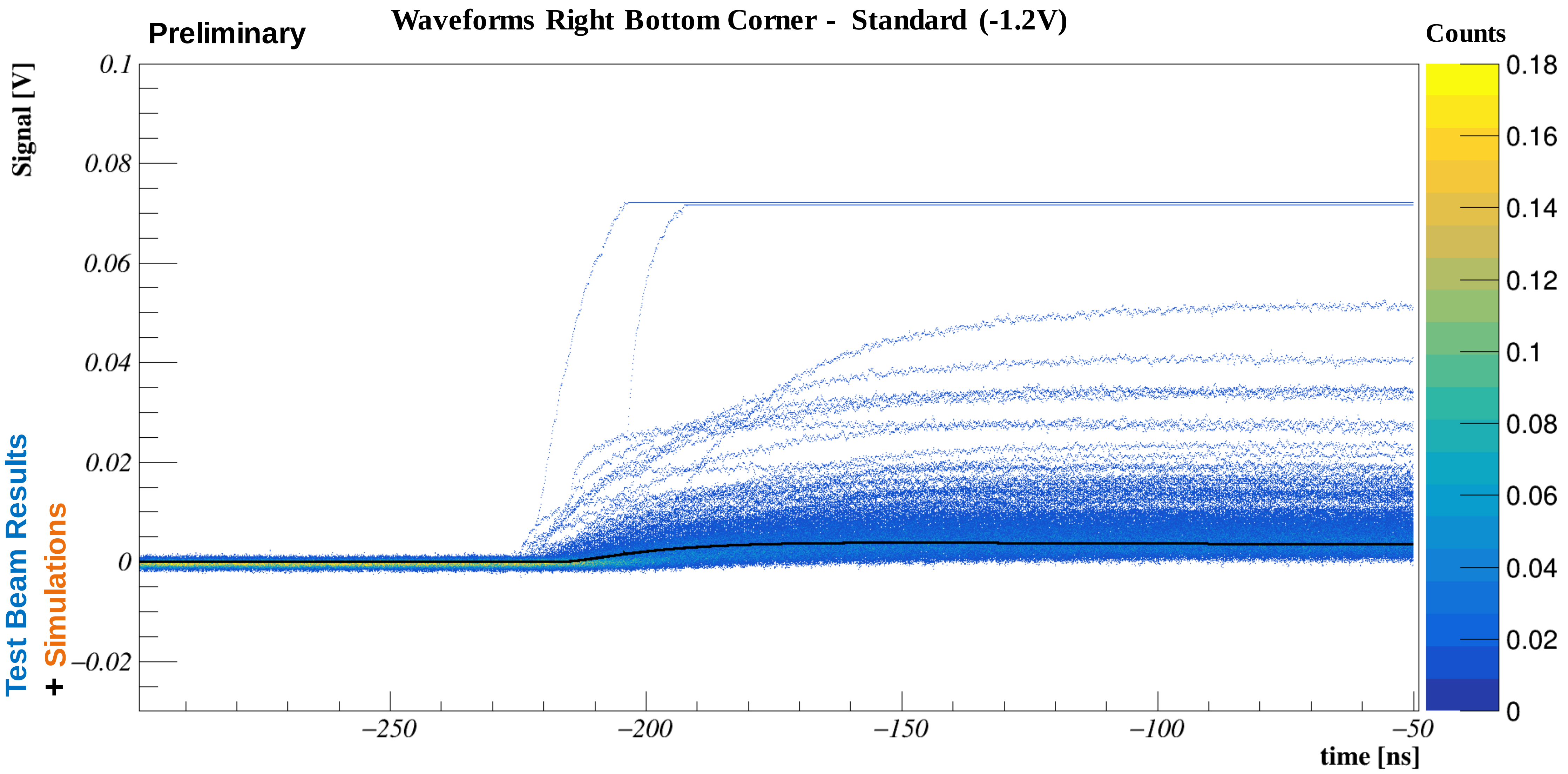
<u>Note that the spatial resolution for ADENIUM telescope for 4 GeV ~ 3-4 µm</u>

Waveforms in the corner of the pixel – Standard Layout



Waveforms with most probable value of deposited charge carriers appear more yellow

Waveforms in the corner of the pixel – Standard Layout



Simulation using most probable value of deposited charge carriers in black

Summary and Outlook

Summary

- The Tangerine group investigates the **65 nm CMOS imaging** technology
- Simulations are a powerful tool to predict and understand the behavior of new detector technology
- Simulations, lab measurements and test beams were performed in order to understand how the incident position affects the charge collection time, amplitude, rise time and thus the **timing performance**
- Large differences between rise time distributions between both layouts with trends predicted by simulations

Outlook

- Improve robustness of analysis (Amplitude and rise time fluctuations depending of definition)
- Reproduce laboratory and test beam results through simulations
- Study time residuals using time reference and DUT to obtain in pixel plots
- Obtain the time performance of the sensors

Thank you for your time!

Contact

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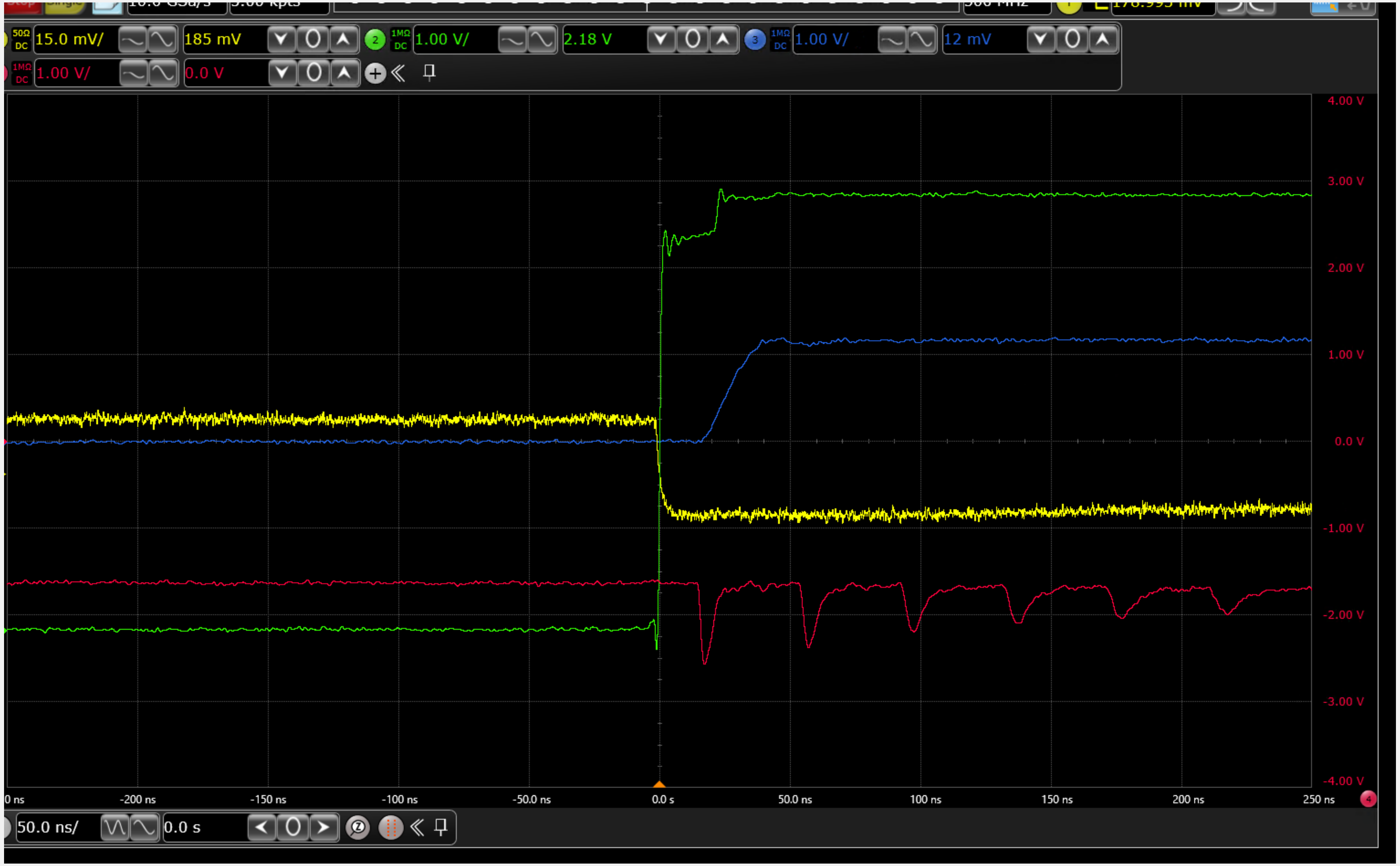
Oscilloscope trigger signals

DUT

Telepix

Scintillator

OUT Trigger



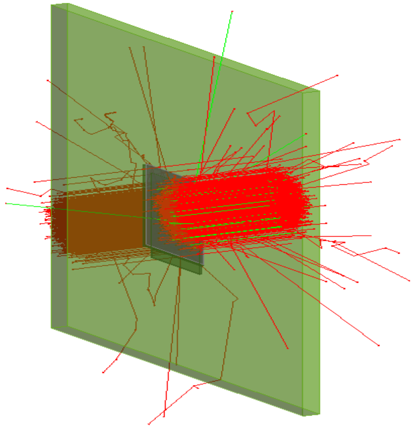
Tools that we use in our simulations

Technology **C**omputer-**A**ided **D**eisgn

SYNOPSYS®
Silicon to Software™

Allpix Squared: a Monte Carlo simulation framework for semiconductor detectors

- High statistics Monte Carlo simulations of semiconductor detectors
- Full detector simulation chain, from energy deposition and charge carrier propagation to signal digitization
- Integration with GEANT4 and TCAD.
- Development carried out at DESY
- Detailed documentation and continuous support



Particle beam passing through a single sensor in Allpix^2