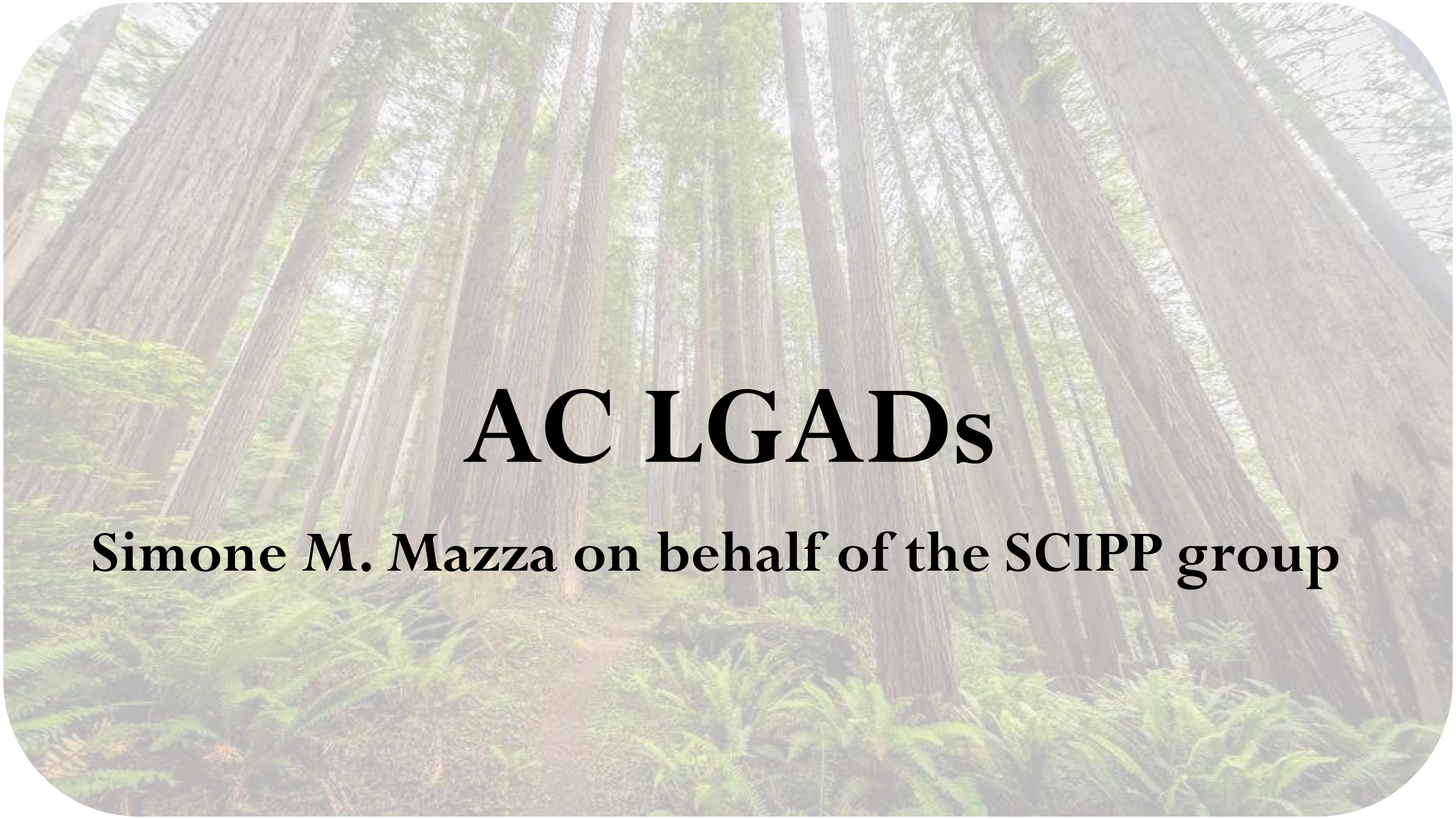
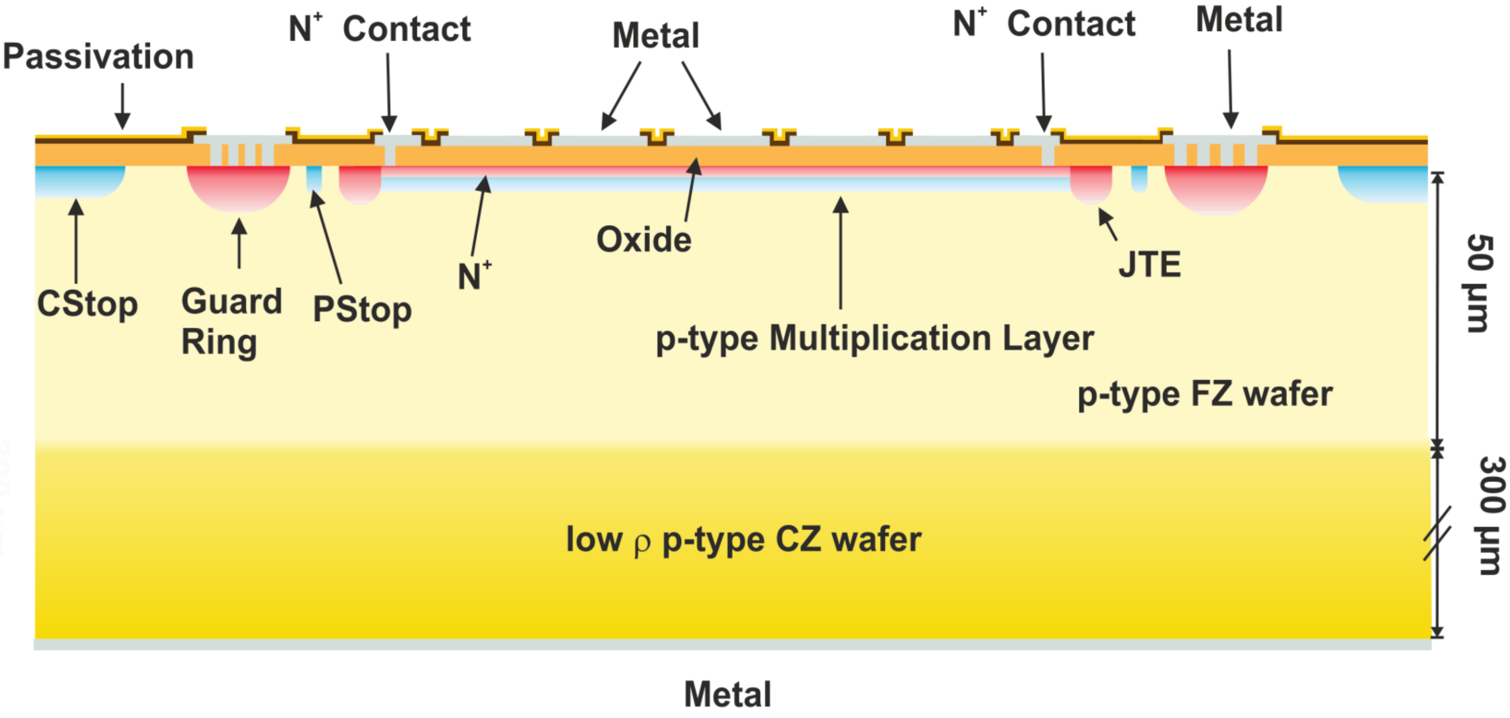


AC LGADs

Simone M. Mazza on behalf of the SCIPP group

AC LGADs

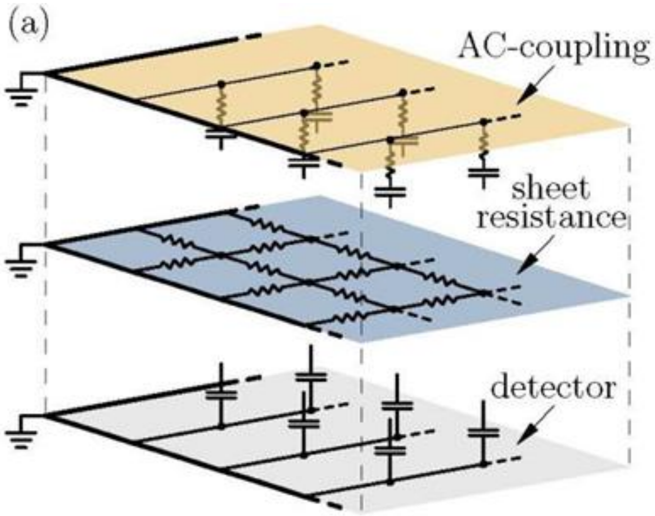
- AC-LGAD replaces the segmentation of the pad implants into continuous sheets of multiplication layer and n+ layer and **only segments the metal connected to the readout**
- The **signal is AC-coupled** into the metal pads by another continuous sheet of coupling oxide.



AC LGADs

- The difference in signal between strips is provided by the time over which the charge is held at a metal contact before it is collected at the N^+- contacts

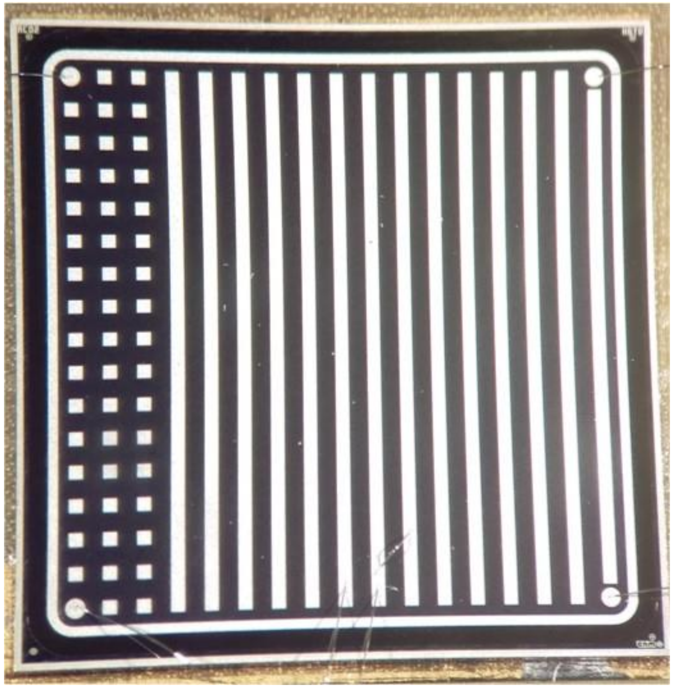
- For this to work, the parameters of the sensors have to be **optimized**:
  - The **sheet resistance** of the N^+ given by its resistivity divided by its thickness
  - The **capacitance** of the metal read-out, given by the area and the thickness of the oxide
  - Dimension and distance of the **read out pads**



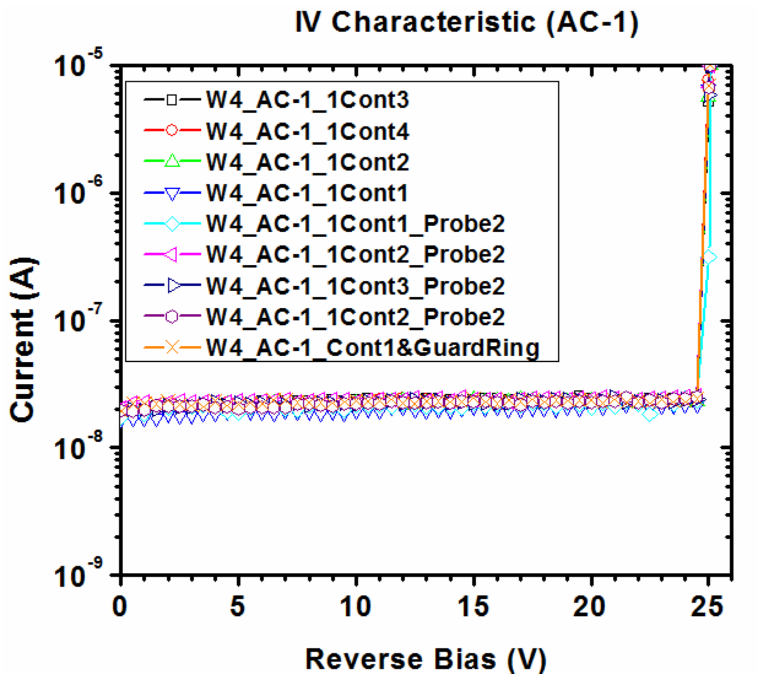
Testing AC detector from CNM

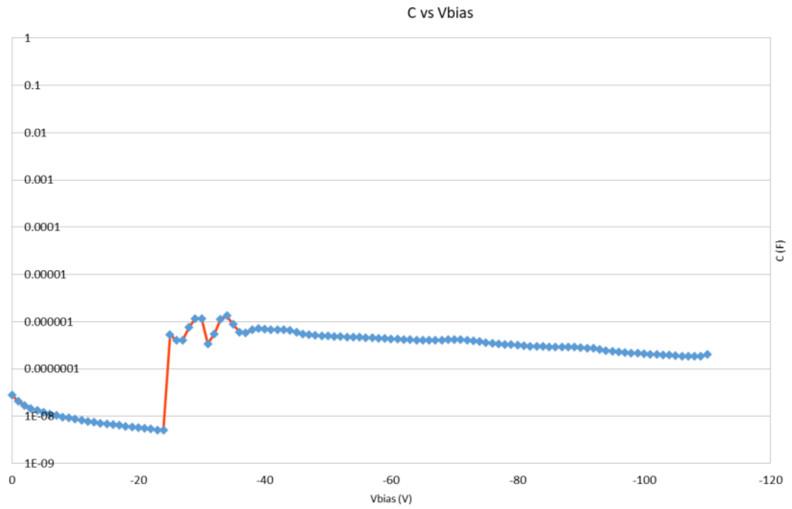
- Run 10478, Wafer 4, two AC detectors: AC-1 and AC-2
- Large detector (0.84 x 0.84 cm)
  - 50µm thin , 14 strips, 49 pixels
- DUT: AC-2 mounted on a 3 channel board with the N+ implant to ground trough 4x90 KΩ resistors

- **Test with TCT IR laser for different setups**
  - 1 pixel 1 strip connected
  - 1 pixel and 8 pixel connected together
  - 3 strips connected
  - 3 pixel connected, grounding all around
- Pulsing in different areas of the detector: parameter scan in Vbias and position
  - HV supply Keithley 2410
  - Triggering on the laser trigger
  - Room temperature



IV – CV of AC-1

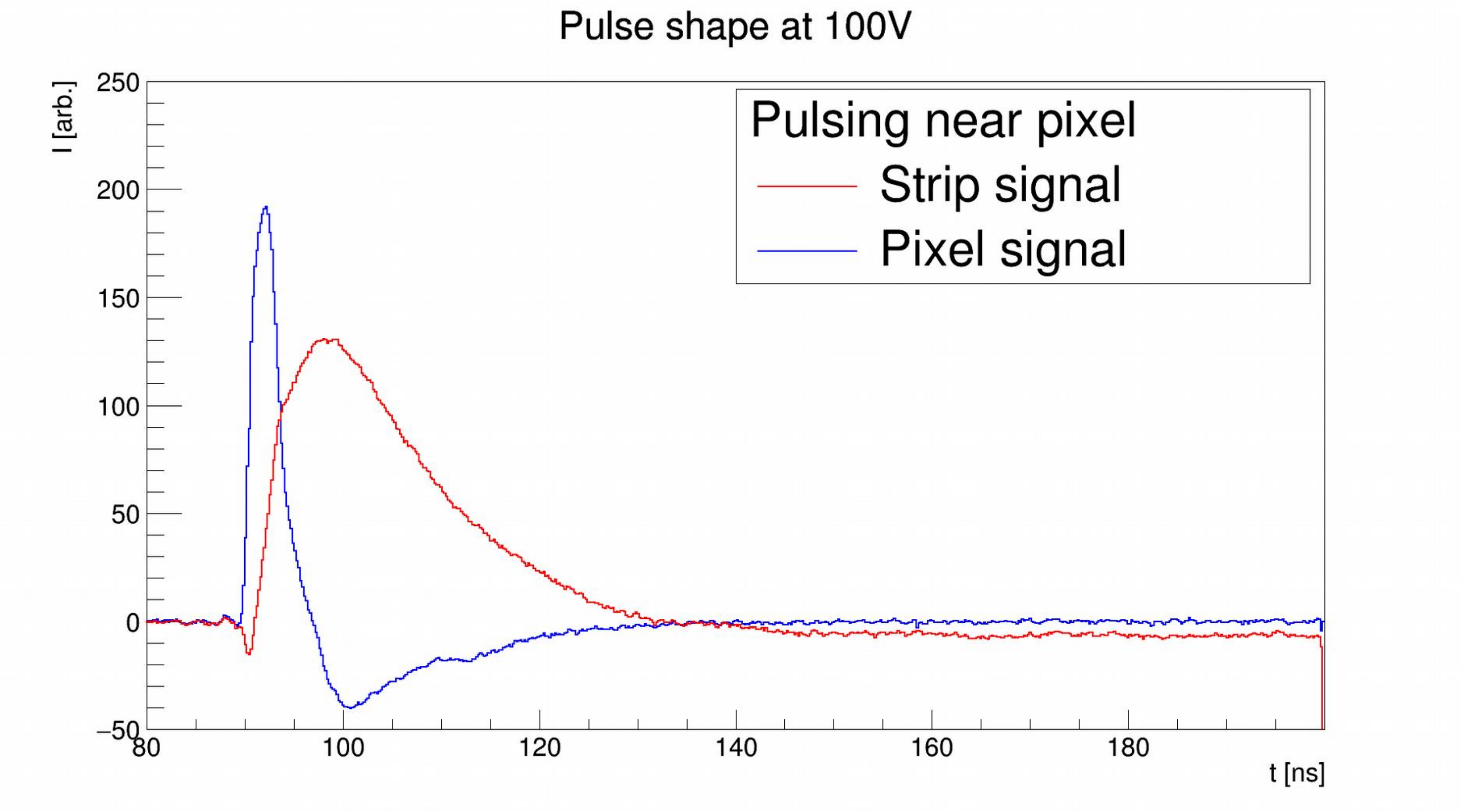




- Measurements done at Room temperature
  - The Guard Ring is floating or grounded
  - HV is applied at the backside
  - Probes on Nplus implant are grounded
  - Strips/pixels are floating
- **Rapid current increase on the detector at 25V**
  - AC-2 (tested on board) shows similar behavior
  - However the Pmax of the pulses increase with Vbias after 25V
  - Doesn’t seem like breakdown
- Impossible to measure CV because of the current rapid increase at 25V

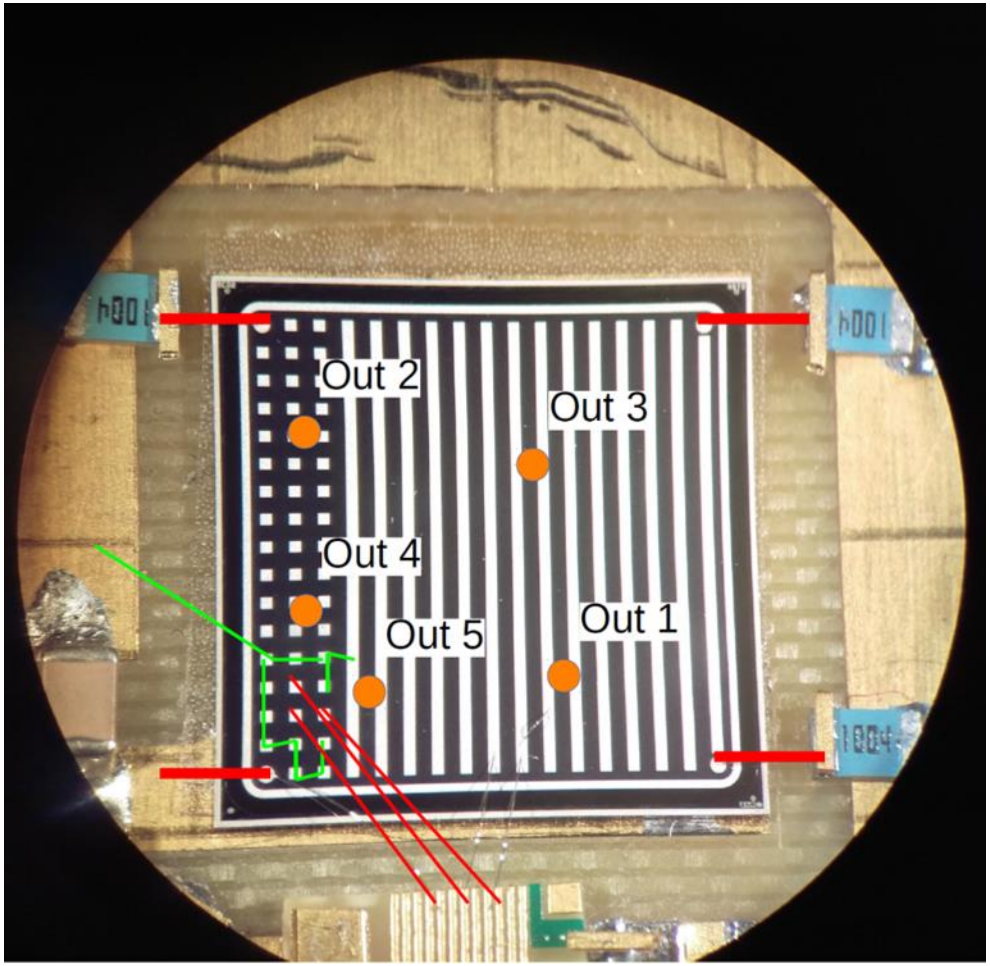
1 pixel and 1 strip connection

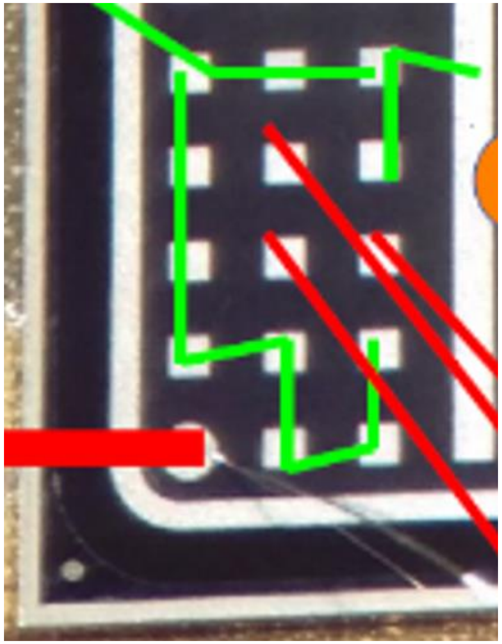
- 1 pixel and 1 strip connected to the read out, all the remaining pads are floating
- Difference in the pulse shape of a pixel with small capacitance and a strip with high capacitance
  - Pixel has clear undershoot, strip has long signal with very long undershoot
  - TCT laser pulse from the front side

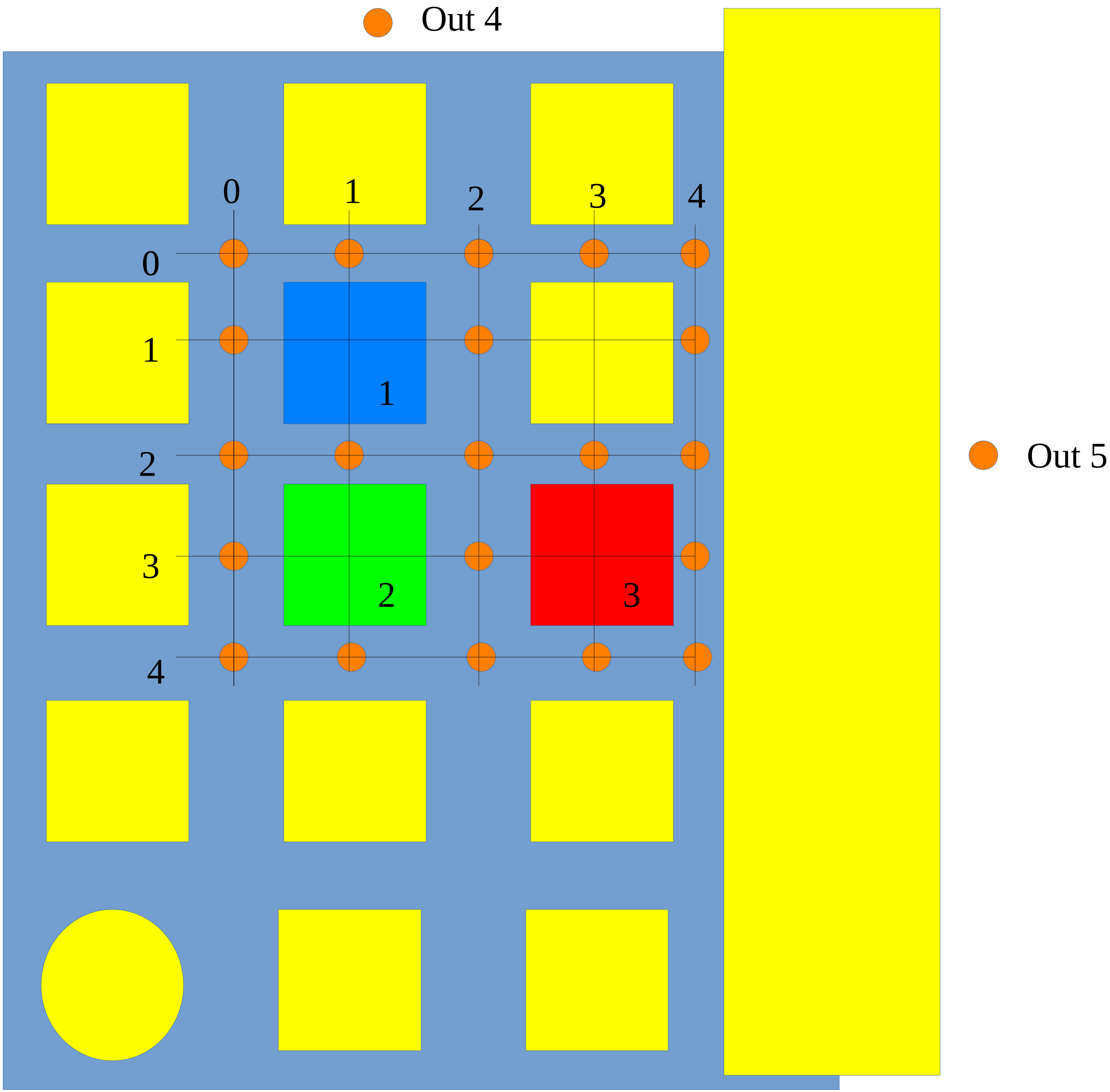


Connection setup

- 3 pixels (left side of the detector) in the middle are read out
- All the pixel and strip around them are grounded
- Register the pulse shapes from a laser pulse in a grid around the 3 pixels and in outside points
  - Laser at 38%, 1 KHz
- Each pulse is mean of the pulses in a 200x200 um area around the grid position






Out 4
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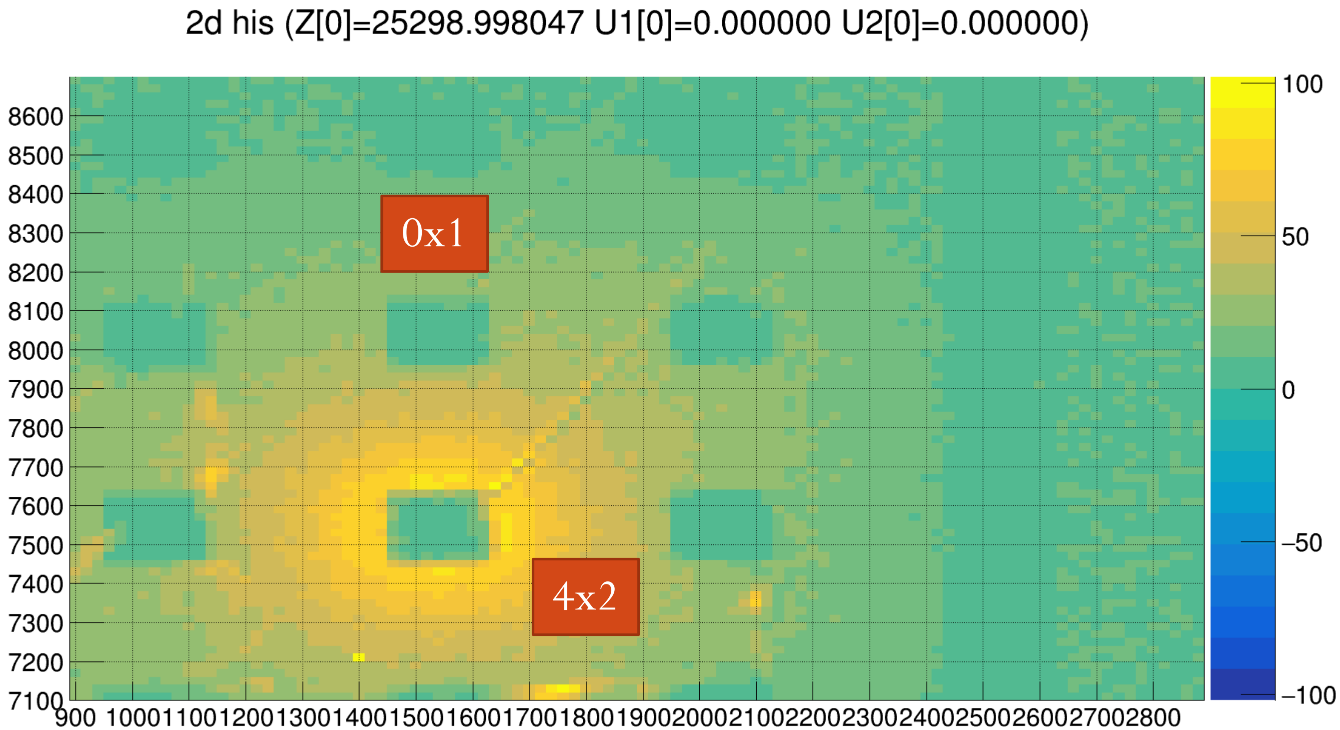
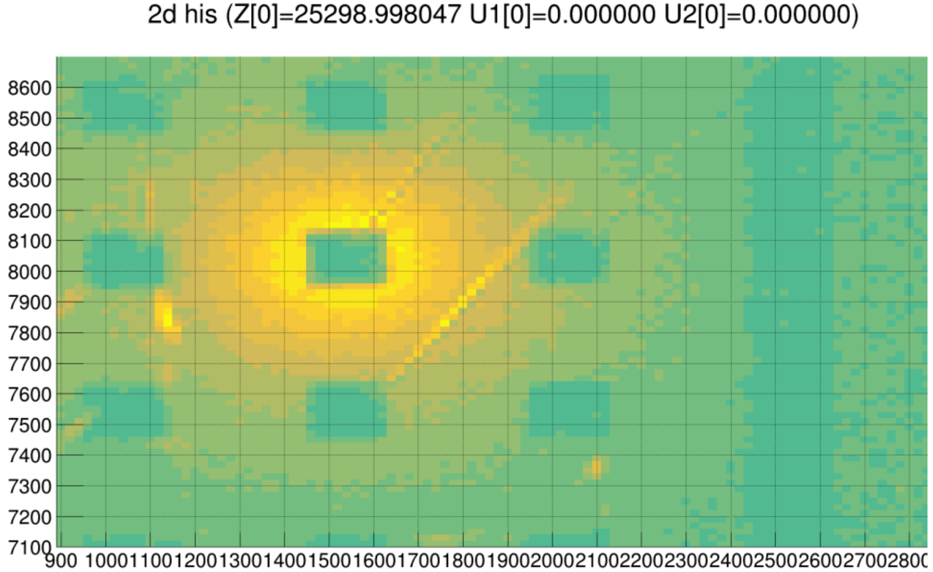
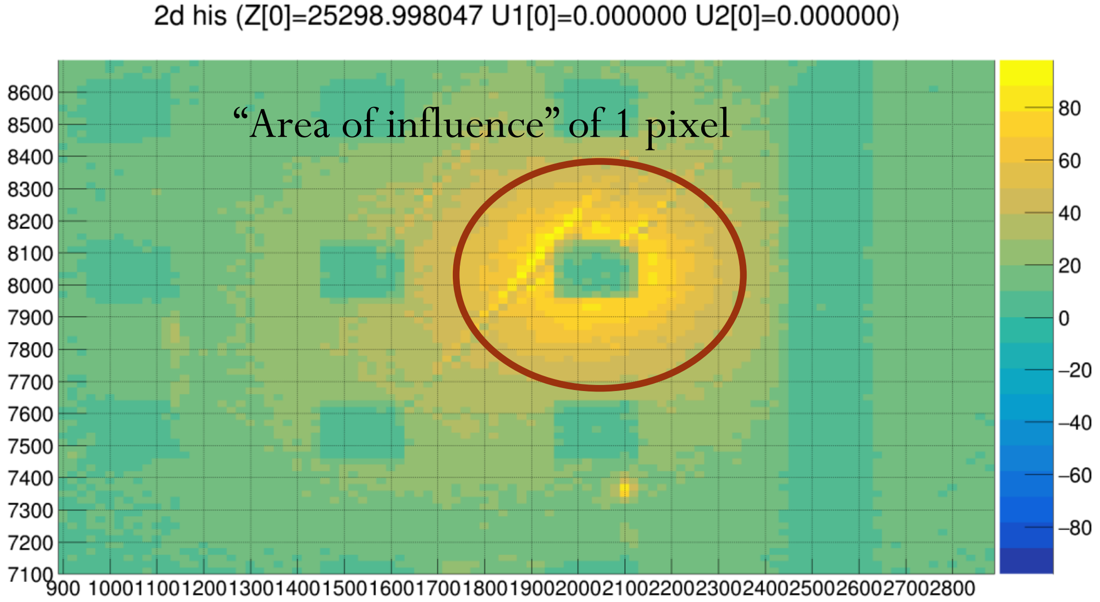
Out 5



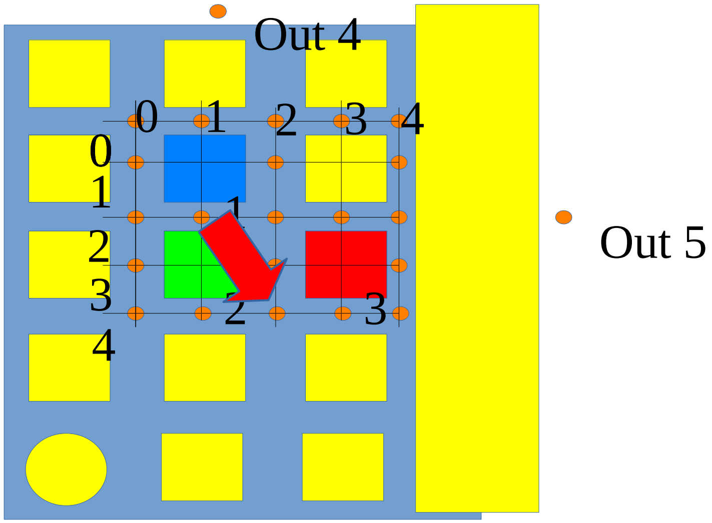
0x1

4x2





“Area of influence” of 1 pixel


Out 4
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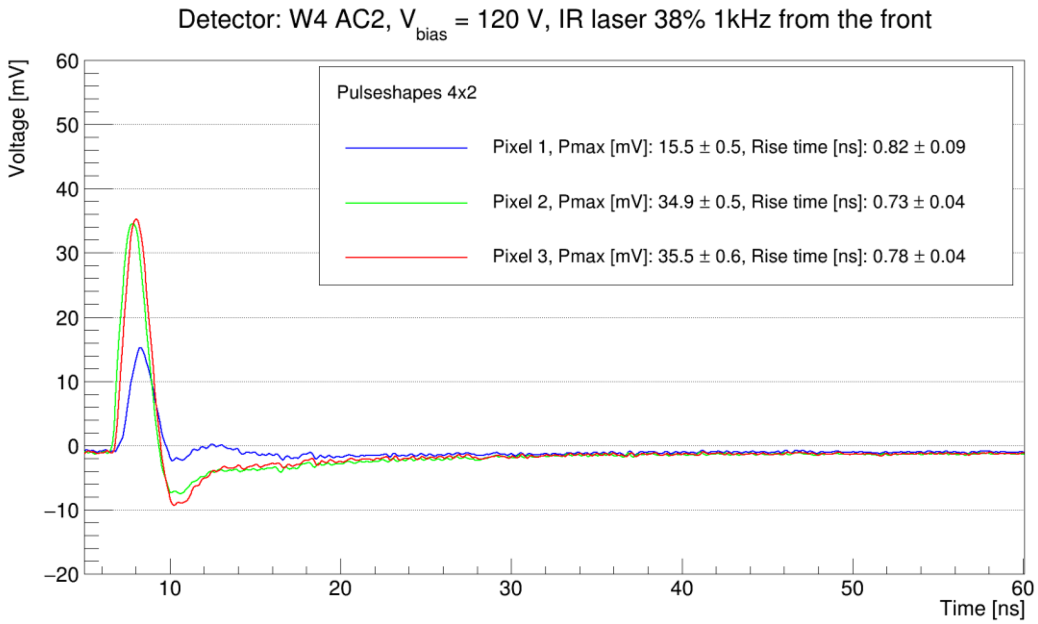
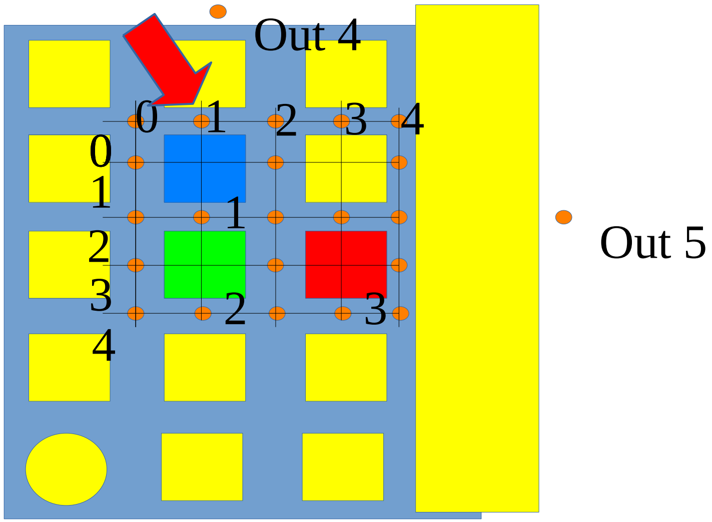
Out 5


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
Time [ns]
60
50
40
30
20
10
0
−10
−20
10
20
30
40
50
60
Pulseshapes 4x2
Pixel 1, Pmax [mV]: 15.5 ± 0.5, Rise time [ns]: 0.82 ± 0.09
Pixel 2, Pmax [mV]: 34.9 ± 0.5, Rise time [ns]: 0.73 ± 0.04
Pixel 3, Pmax [mV]: 35.5 ± 0.6, Rise time [ns]: 0.78 ± 0.04


Out 4
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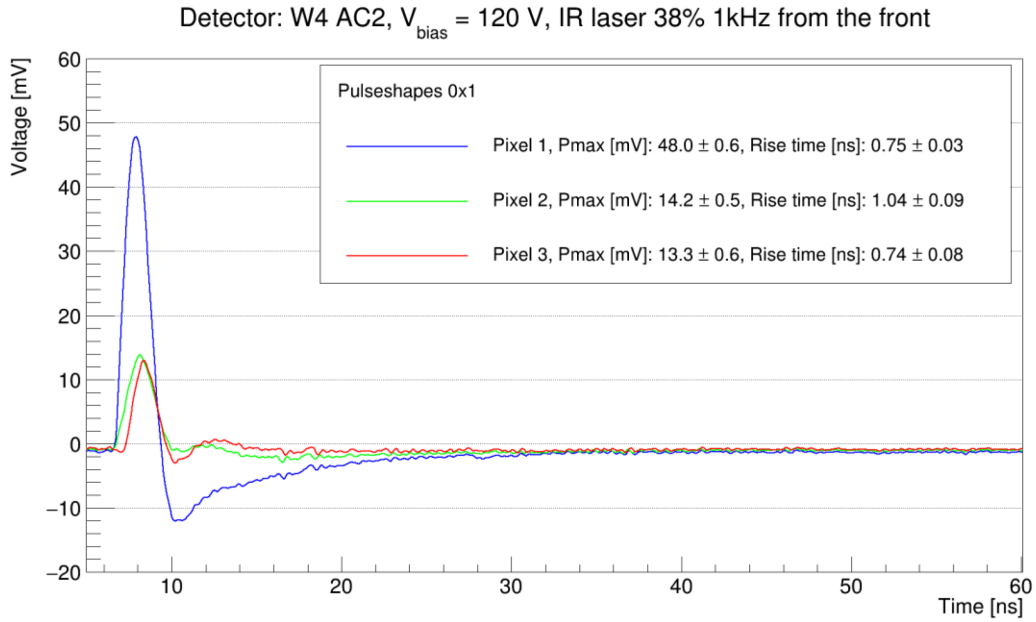
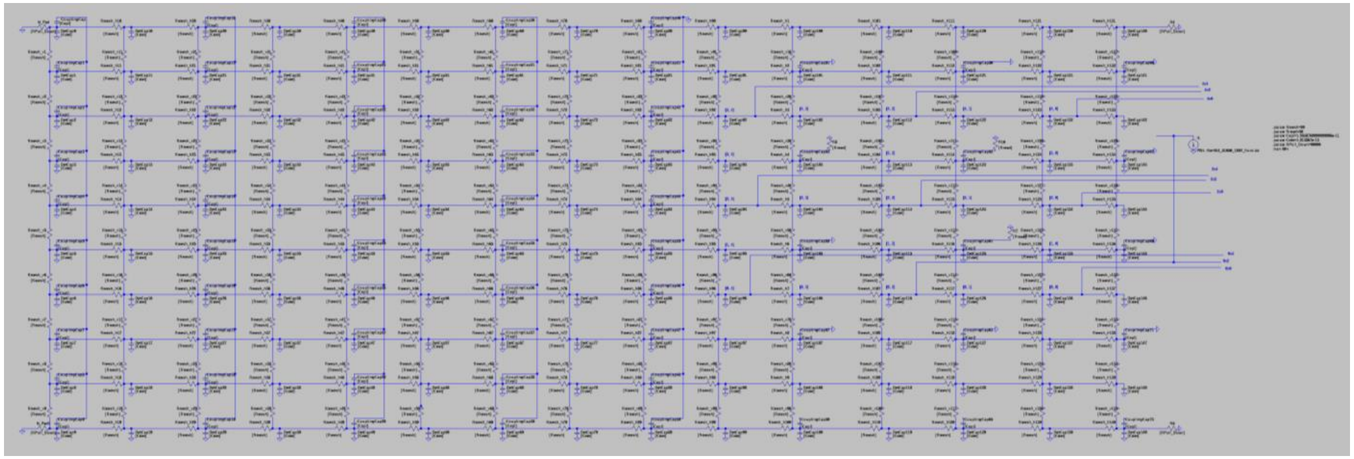
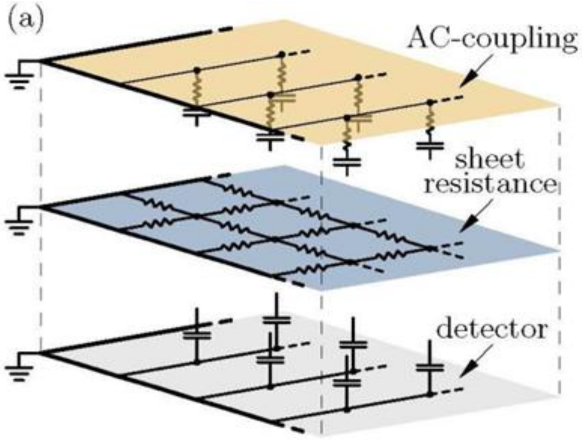
1
2
3
Out 5


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
Time [ns]
60
50
40
30
20
10
0
−10
−20
10
20
30
40
50
60
Pulseshapes 0x1
Pixel 1, Pmax [mV]: 48.0 ± 0.6, Rise time [ns]: 0.75 ± 0.03
Pixel 2, Pmax [mV]: 14.2 ± 0.5, Rise time [ns]: 1.04 ± 0.09
Pixel 3, Pmax [mV]: 13.3 ± 0.6, Rise time [ns]: 0.74 ± 0.08

Simulation

- Spice/Pyspice to simulate the behavior of the AC detector
- Grid of resistor with on the 3 pixels the AC connection to 50 Ω (amplifier readout)
  - Other grounded nodes are AC connected to ground
  - The component resistance of the grid is equal to the sheet resistance of the Wafer
- For W4 the sheet resistance should be ~60-100 Ω
  - Measured on wafer by CNM
- Goals: test if the data is in agreement with the simulation and evaluate what is the optimum value of the sheet resistance



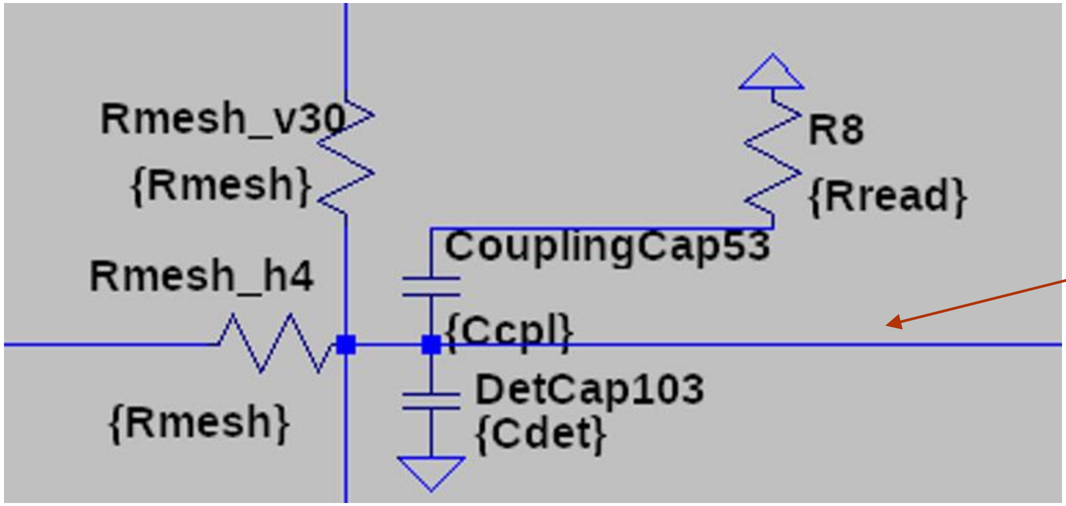


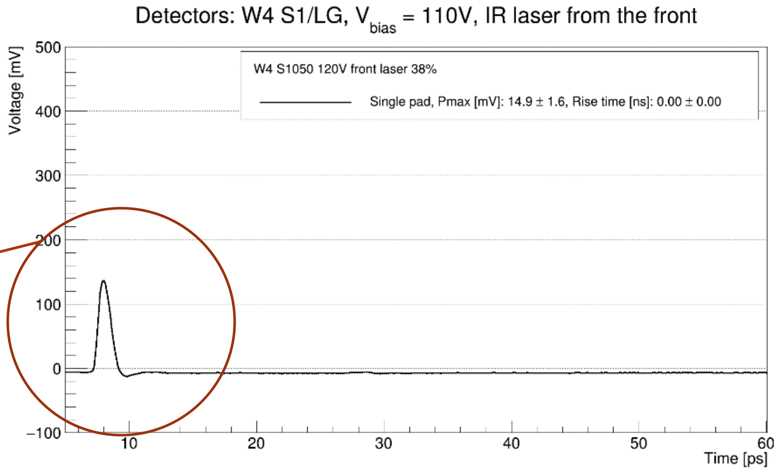
Many thanks to Marco Mandurrino (Torino)

Simulation

- Inject the signal in the resistance grid and look at the output of the 3 pixels
  - Parameters of interest: ratio of the Pmax of the output pulse, the shape (and undershoot) and the pulse width

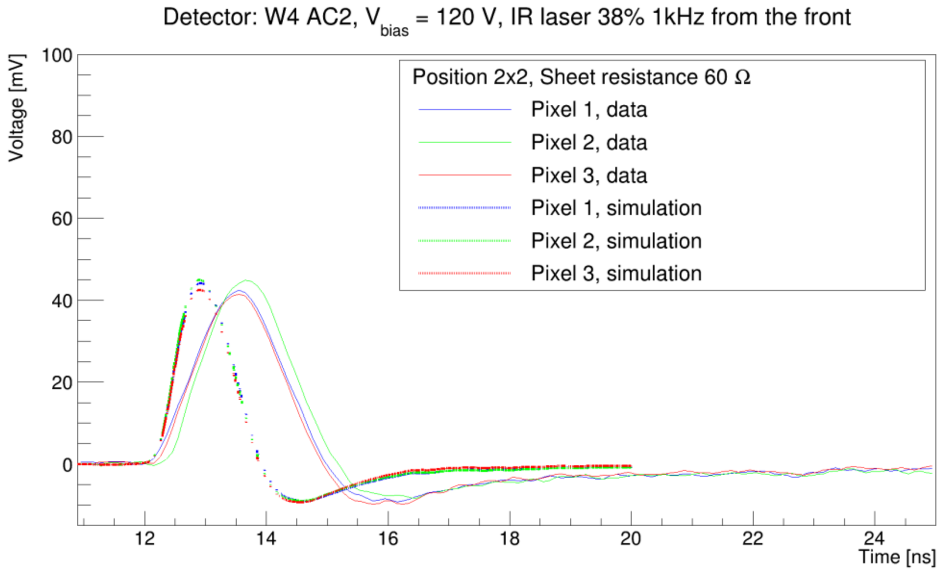
- Use as signal the pulse shape from CNM S1 detector from W4
  - S1050, same wafer and structure as the AC detector (mean of 1000 pulses)
  - To get the response to TCT of the DC coupled N+ implant
  - Using IR laser from the front with same intensity as in the AC detector

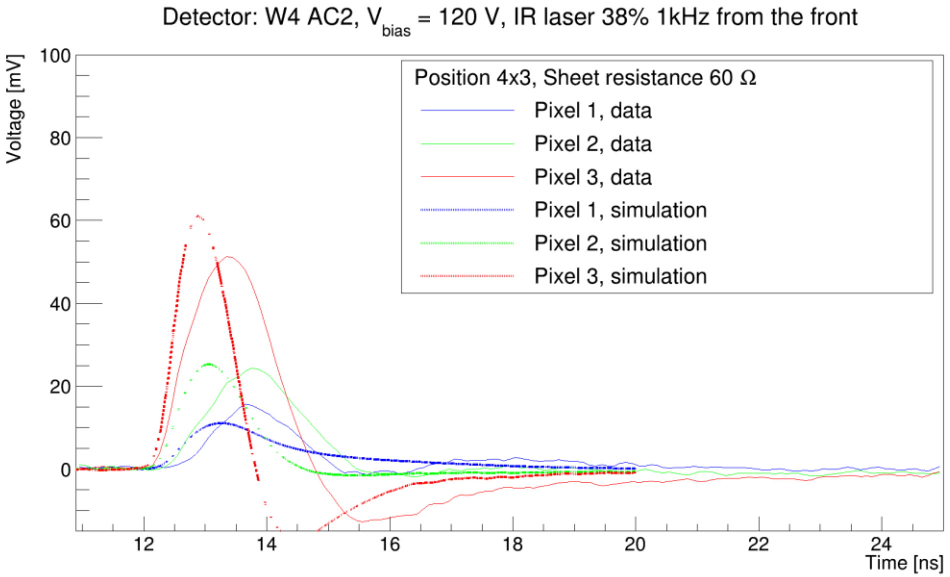


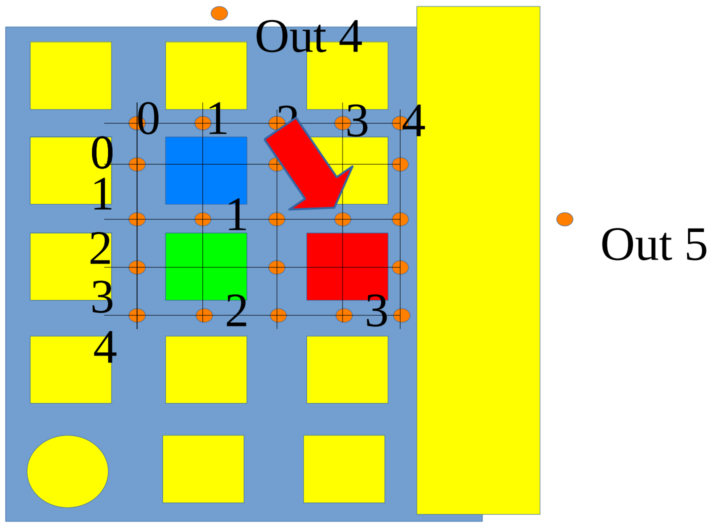


Simulation

- Run the simulation for sheet resistances of:
  - 5 - 100 Ω (5 Ω step), 100 - 1000 Ω (50 Ω step)
- Compare the simulated pulses with data
  - Take a simulation/data scale factor (for each sheet resistance) from position 2x2 in the center of the grid
  - Use the scale factor to normalize the data/simulation pulses on every position
  - Scale factors evaluated in each position have variations of ~10 % but with sporadic high variations
- Simulated pulses have less width than data
  - Simulation starts from S1 detector (1x1 mm) pulse while data is from a 0.84x0.84 cm detector






Out 4
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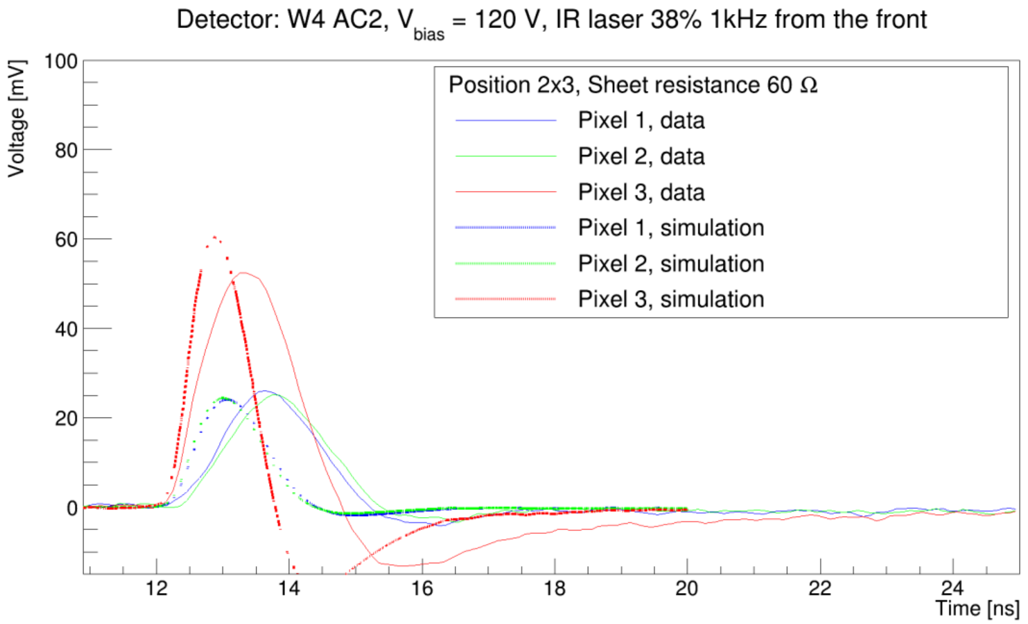
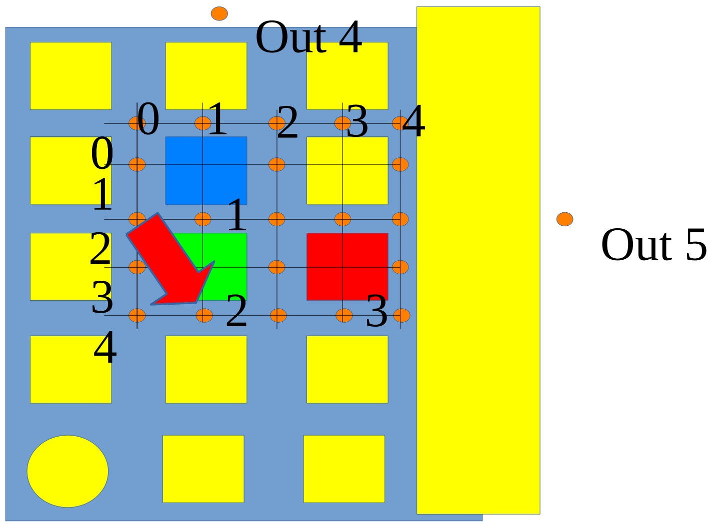
Out 5


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
100
80
60
40
20
0
12
14
16
18
20
22
24
Time [ns]
Position 2x3, Sheet resistance 60 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation


Out 4
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2
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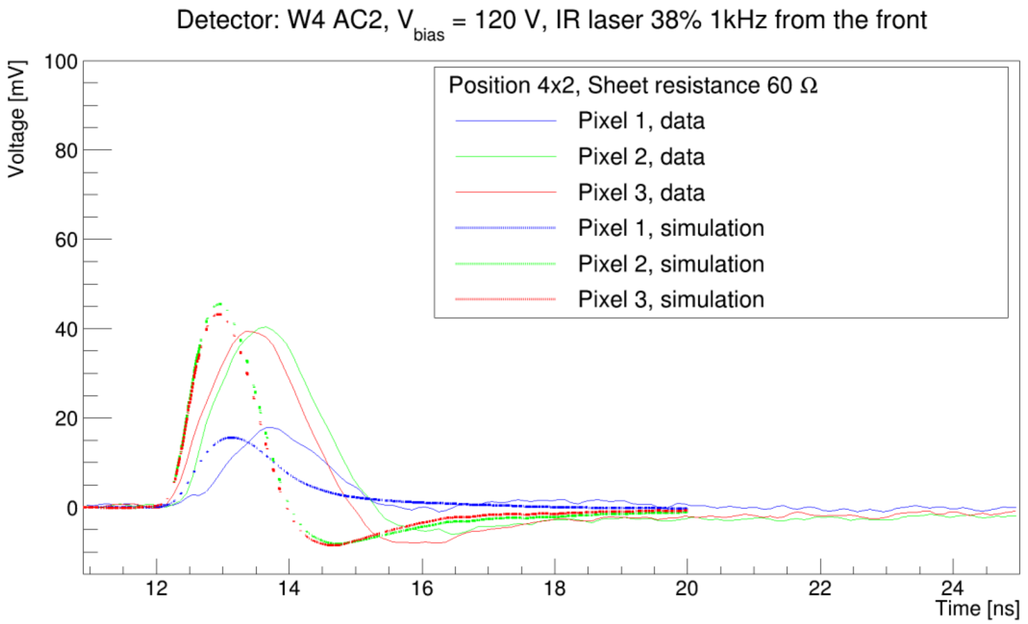
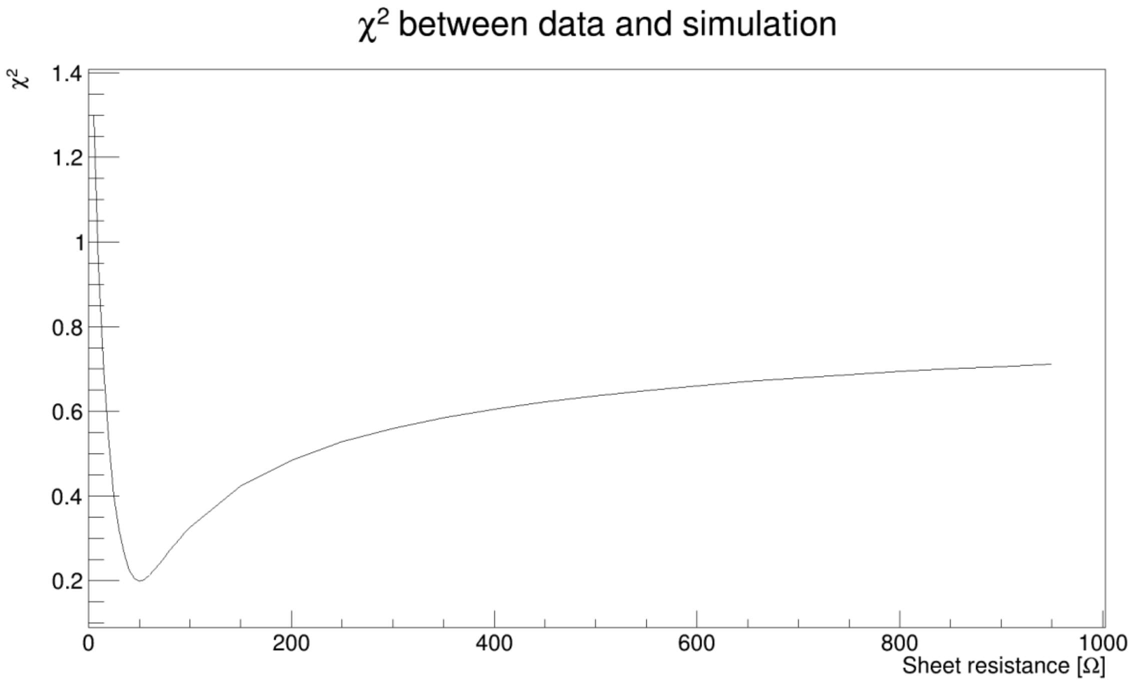
Out 5


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
100
80
60
40
20
0
12
14
16
18
20
22
24
Time [ns]
Position 4x2, Sheet resistance 60 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation

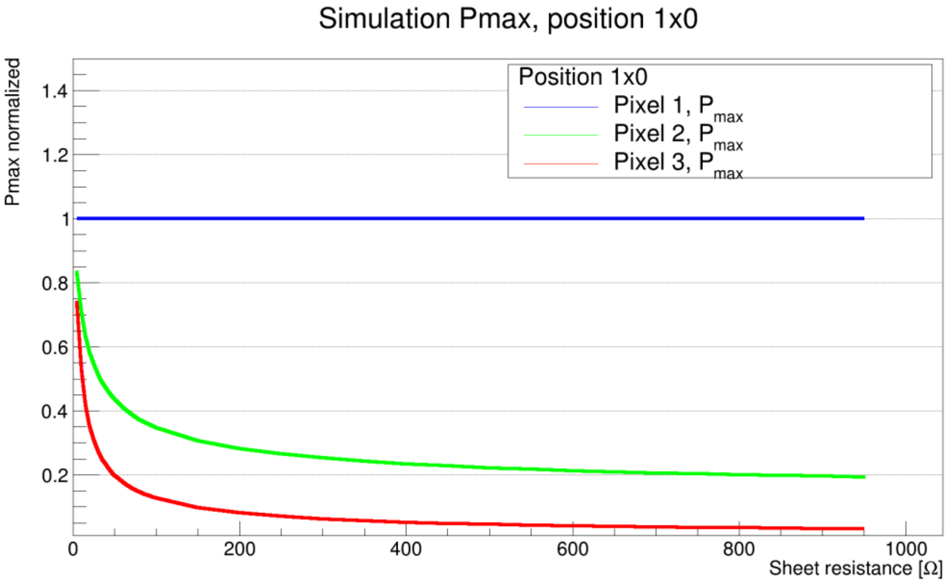
Chi2 distribution

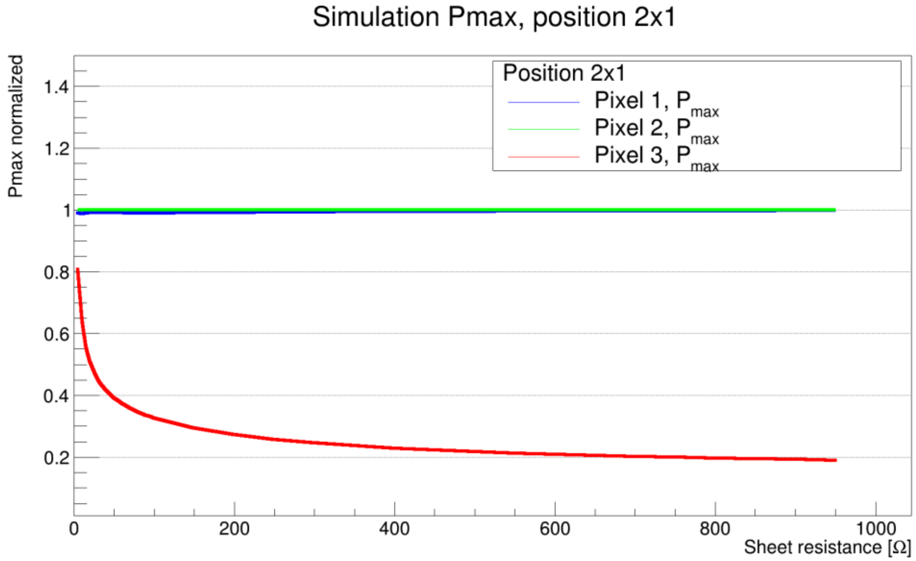
- Evaluated the Chi2 value for Pmax(data - simulation) after the rescaling
  - Sum over each position and each pixel for each one of the sheet resistances
  - σ for the chi2 is taken as RMS of the maximum of the pulse in the 200x200um scanned area in the grid point
- 60 Ω seems like the best fit between the tested values



Summary

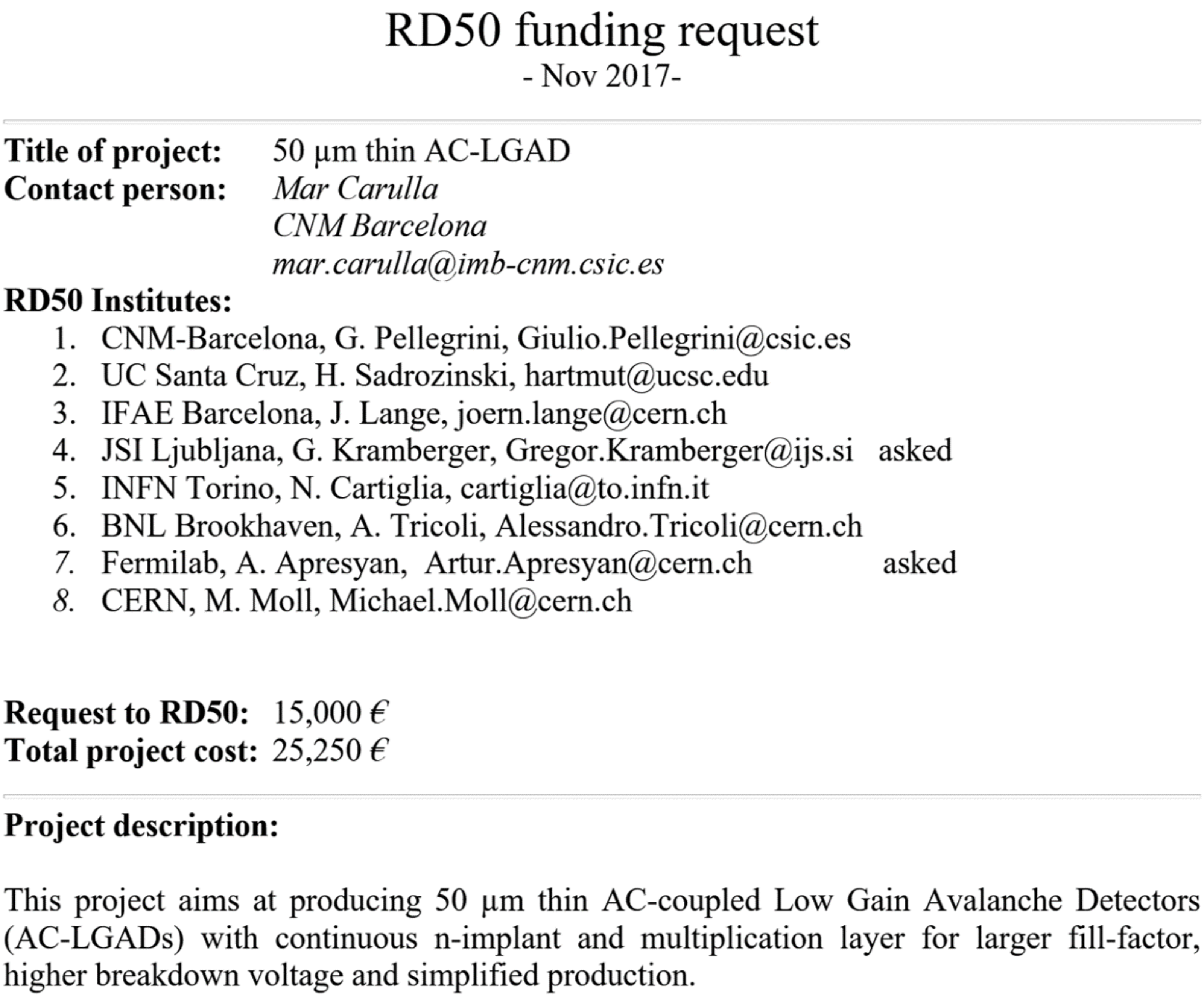
- The spice simulation is simulating quite well the behavior of the AC detector in the given setup
  - However different signal width and not perfect ratios between signal
- From simulation it looks like a variation of x3 – x5 of the present sheet resistance sufficiently improves the readout difference between pixels
  - A bigger variation (x50) doesn't improve much and might be technically impossible


Simulation Pmax, position 1x0


Simulation Pmax, position 2x1

Work in progress

- Do β–source charge collection on AC detectors
- Do a more refined grid simulation to also optimize the dimension of the pads and the distance between pads
- Run the simulation also for other setups (strips, strips + pixels)
- Use Weightfield or Sentaurus to simulate the pulse or use the pulse of the AC-2 N+ implant
- Sentaurus or Silvaco TCAD to simulate the behavior (takes time to reproduce this intricate pattern)



RD50 funding request

- Nov 2017-

Title of project: 50 µm thin AC-LGAD
Contact person: *Mar Carulla*
CNM Barcelona
mar.carulla@imb-cnm.csic.es

RD50 Institutes:

1. CNM-Barcelona, G. Pellegrini, Giulio.Pellegrini@csic.es
2. UC Santa Cruz, H. Sadrozinski, hartmut@ucsc.edu
3. IFAE Barcelona, J. Lange, joern.lange@cern.ch
4. JSI Ljubljana, G. Kramberger, Gregor.Kramberger@ijs.si asked
5. INFN Torino, N. Cartiglia, cartiglia@to.infn.it
6. BNL Brookhaven, A. Tricoli, Alessandro.Tricoli@cern.ch
7. Fermilab, A. Apresyan, Artur.Apresyan@cern.ch asked
8. CERN, M. Moll, Michael.Moll@cern.ch

Request to RD50: 15,000 €
Total project cost: 25,250 €

Project description:

This project aims at producing 50 µm thin AC-coupled Low Gain Avalanche Detectors (AC-LGADs) with continuous n-implant and multiplication layer for larger fill-factor, higher breakdown voltage and simplified production.

Summary

- Simulation studies shows that we understand the behaviour of AC-LGADs and we need to optimize the production parameters (sheet resistance, dimension and distance between pads, capacitance of the oxide layer, multiplication layer)
- Plan for after production
  - Initial electrical characterizations (C-V/I-V)
  - Measurements of proprieties by studying pulse shapes with TCT and ^{90}Sr beta
  - Irradiation with neutrons at JSI Ljubljana and protons at IRRAD CERN

Activity	Institutes
Device simulations	CNM
SPICE simulations	UCSC, Torino
Silvaco simulations	BNL
Wafer processing	CNM
Electrical characterization	CNM, JSI, Torino, UCSC, BNL
TCT measurements	JSI, Torino, UCSC, BNL
^{90}Sr beta particles	JSI, Torino, UCSC, BNL
Irradiations	JSI, CERN

Planned activities and participation of the institutes.

Project schedule

- Parameter optimization with simulations (1 month)
- Layout of wafer (1 month)
- Device fabrication at CNM clean room facilities (3-4 months)
- Device electrical characterization, gain and isolation measurements (2-3 months)
- Irradiation of devices (neutrons at JSI, protons at IRRAD). (partly in parallel with 4.) (2-3 months)
- Device electrical characterization, gain and time resolution measurements after irradiation. (3 months)

Contributors

This work was supported by the United States Department of Energy, grant DE-FG02-04ER41286

This work was partially performed within the CERN RD50 collaboration.

Part of this work has been financed by the European Union's Horizon 2020 Research and Innovation funding program, under Grant Agreement no. 654168 (AIDA-2020) and Grant Agreement no. 669529 (ERC UFSD669529), and by the Italian Ministero degli Affari Esteri and INFN Gruppo V.

E. Estreda, P. Freeman, Z. Galloway, **C. Gee,** V. Gkougkousis, **A. Goto**, H. Grabas, **Z. Luce,** F. Martinez-Mckinney, S. M. Mazza, **R. Rodriguez**, H. F.-W. Sadrozinski, A. Seiden, E. Spencer, M. Wilder, **Yuzhan Zhao**
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R. Arcidiacono, N. Cartiglia, **M. Ferrero,** M. Mandurrino, A. Staiano, V. Sola
Univ. of Torino and INFN, Torino, Italy

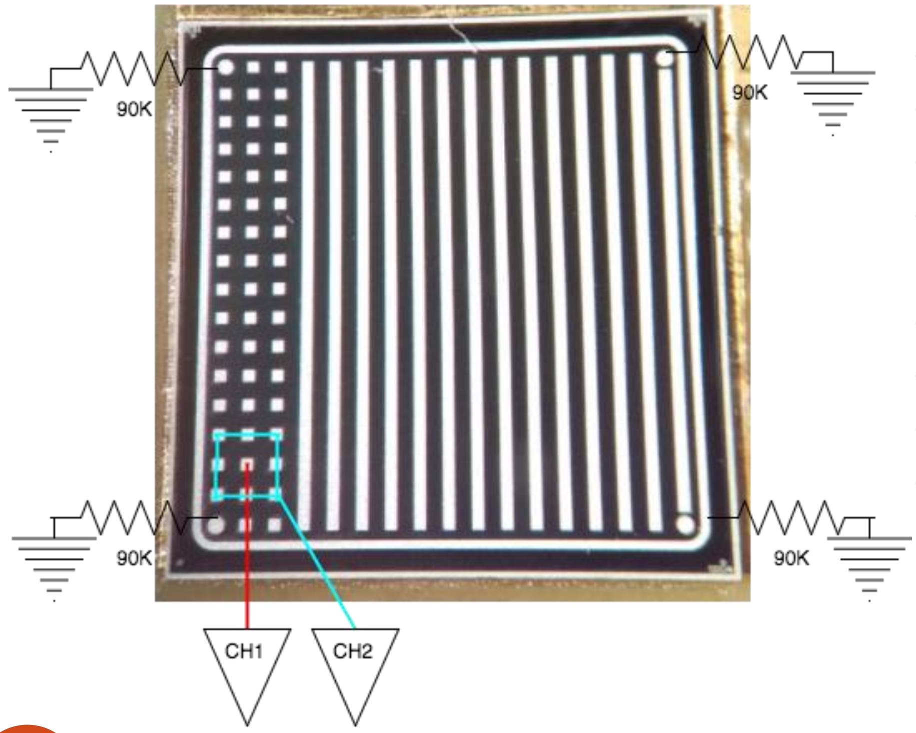
G. Pellegrini, S. Hidalgo, **M. Baselga, M. Carulla, P. Fernandez-Martinez,** D. Flores, A. Merlos, D. Quirion
Centro Nacional de Microelectrónica (CNM-CSIC), Barcelona, Spain

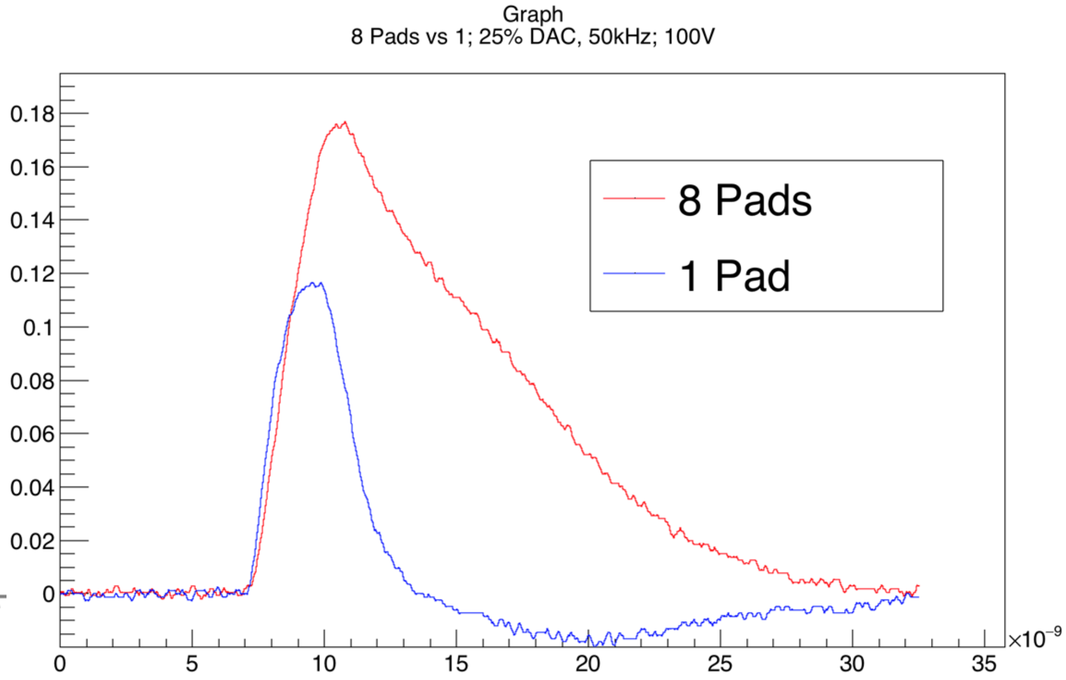
*Students in **bold***

Backup

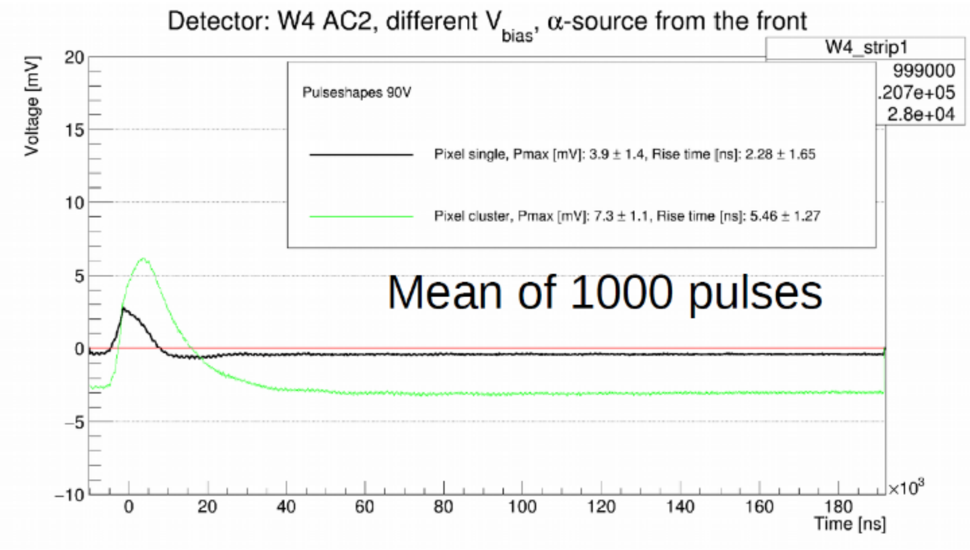
9 pixel setup - TCT

- Connection 1 pixel to Ch1 and 8 pixels to Ch2
  - All the other pads are floating
- The pulse of the 8 pixels combined together (resulting in a large capacitance) is similar to the pulse of a strip
  - TCT laser pulse

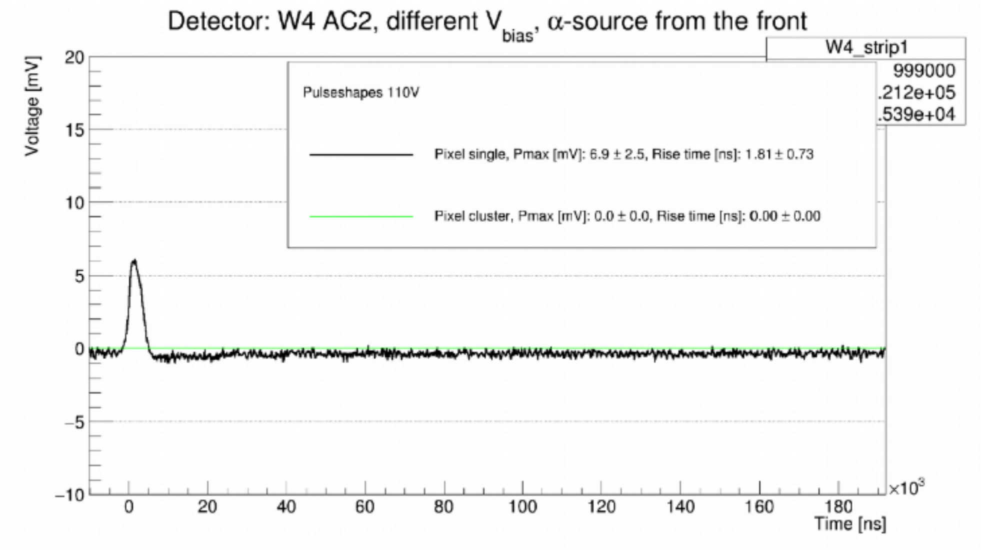


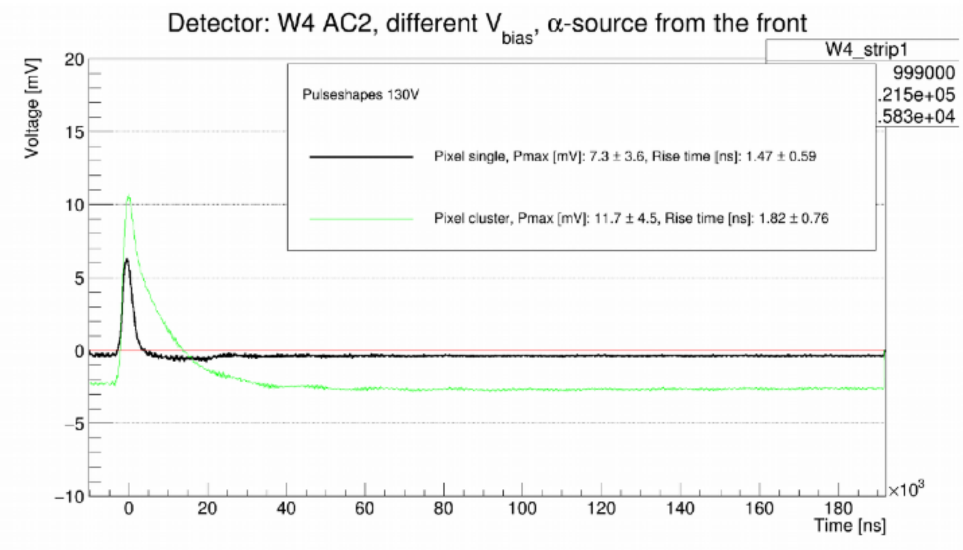


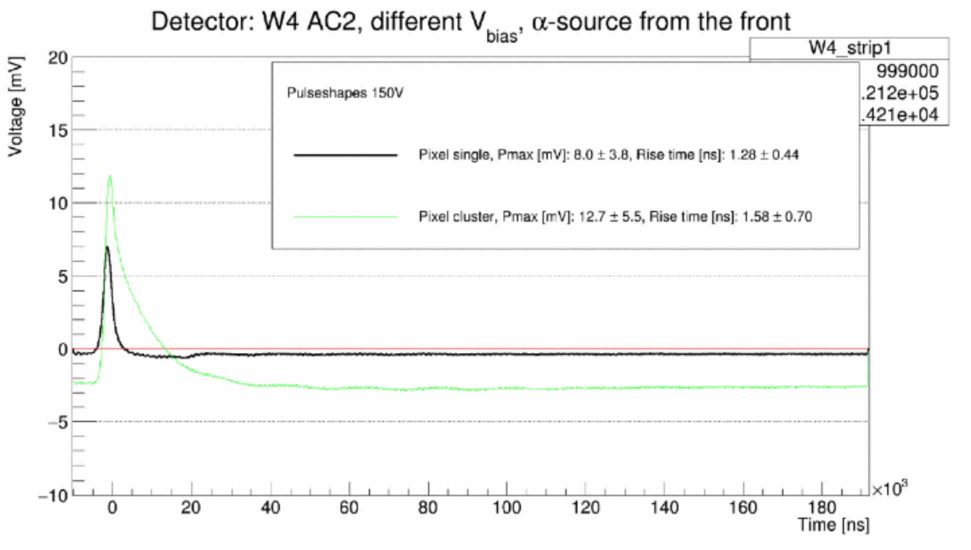
9 pixel setup – α-source charge collection



Mean of 1000 pulses

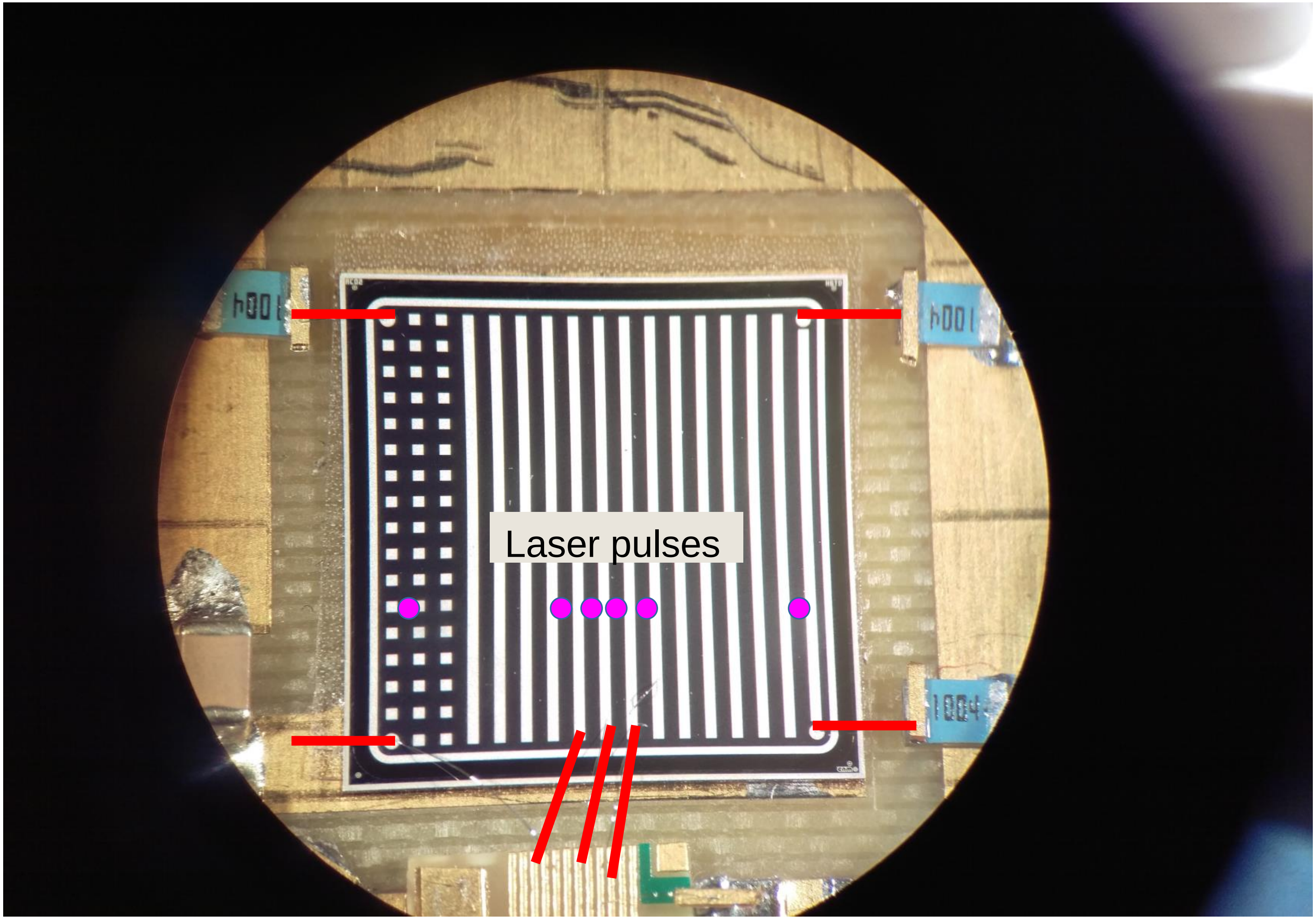


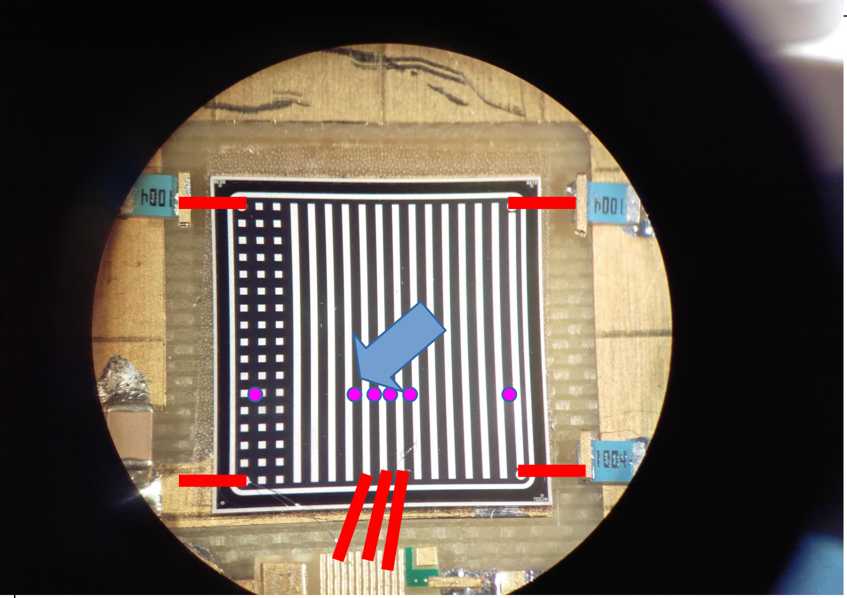


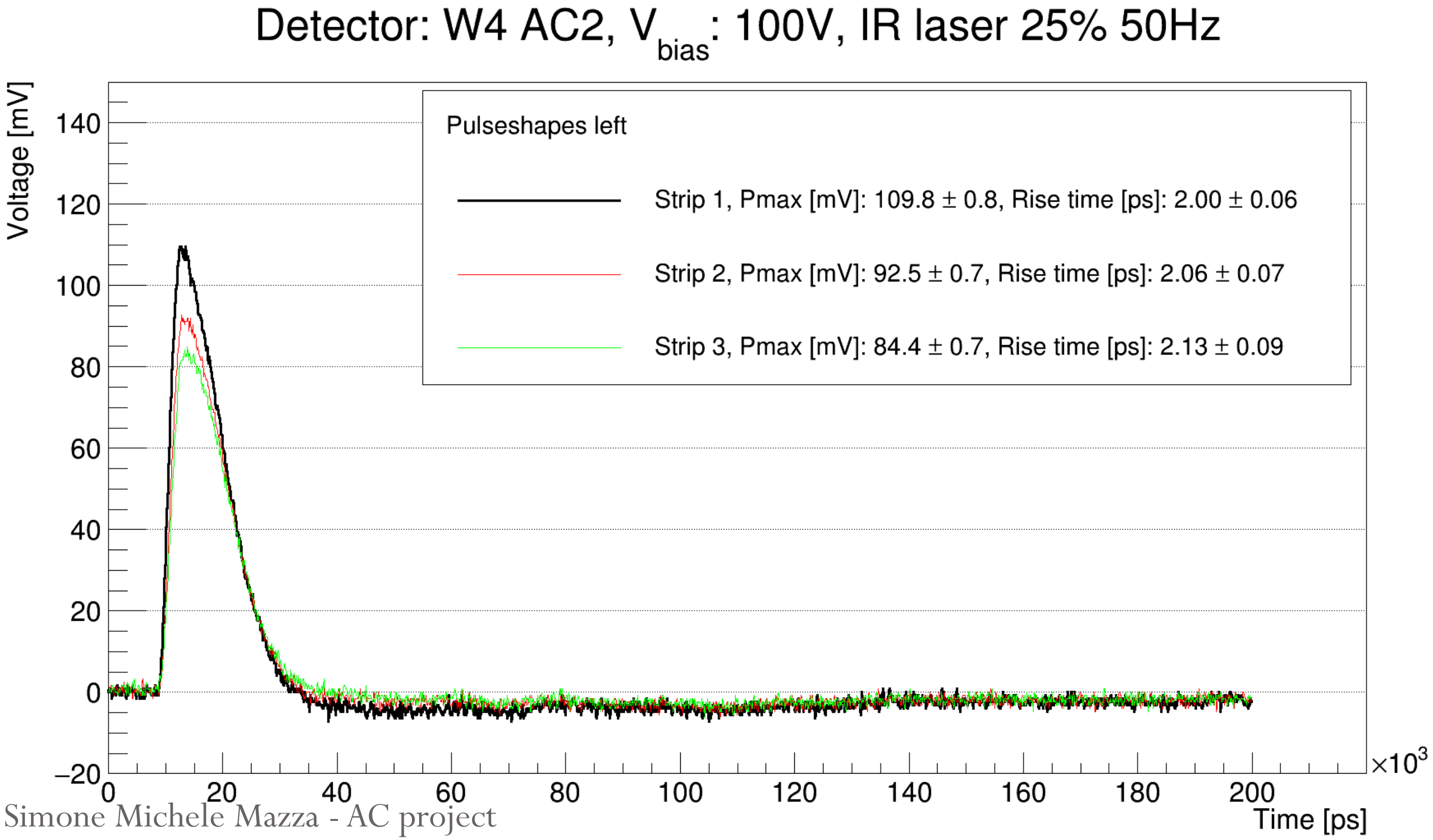


Strips setup

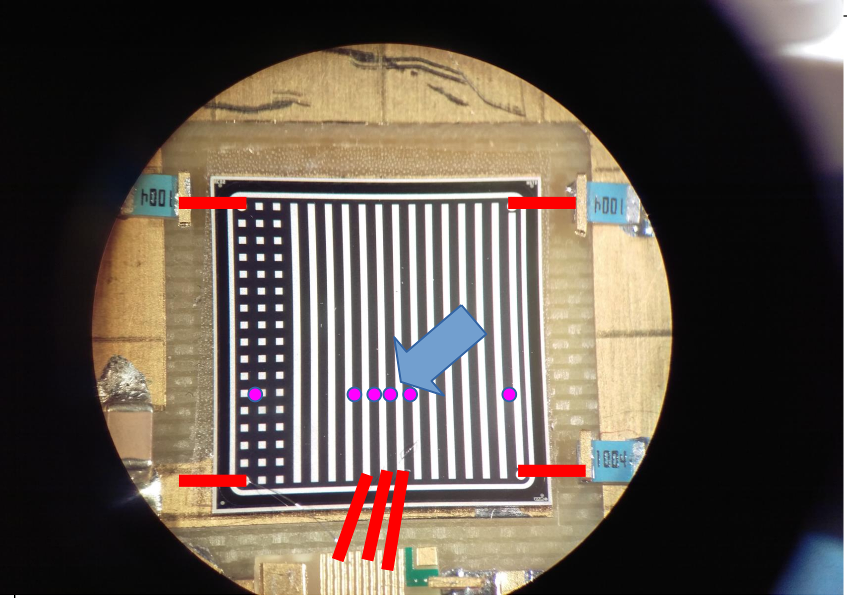
Connections

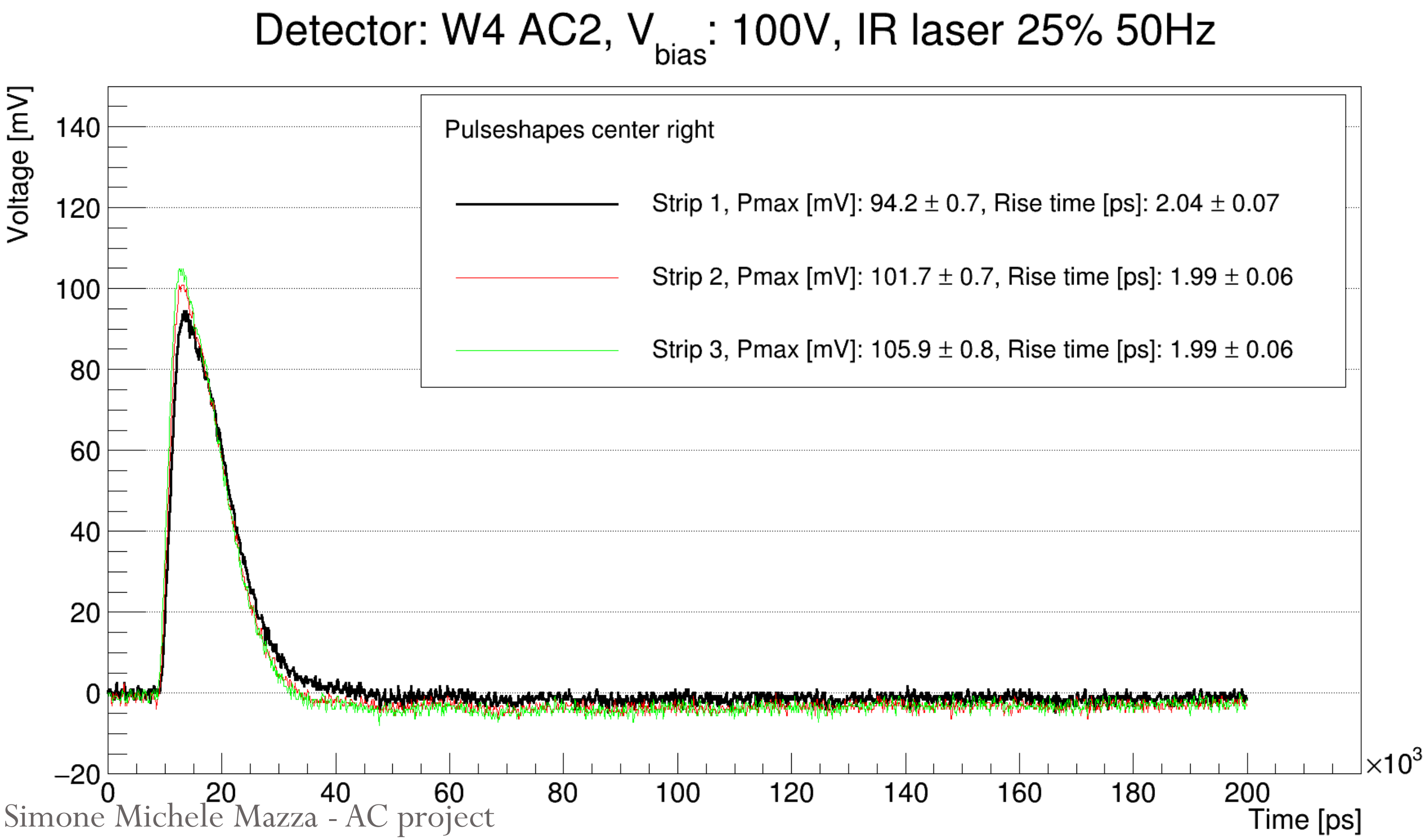




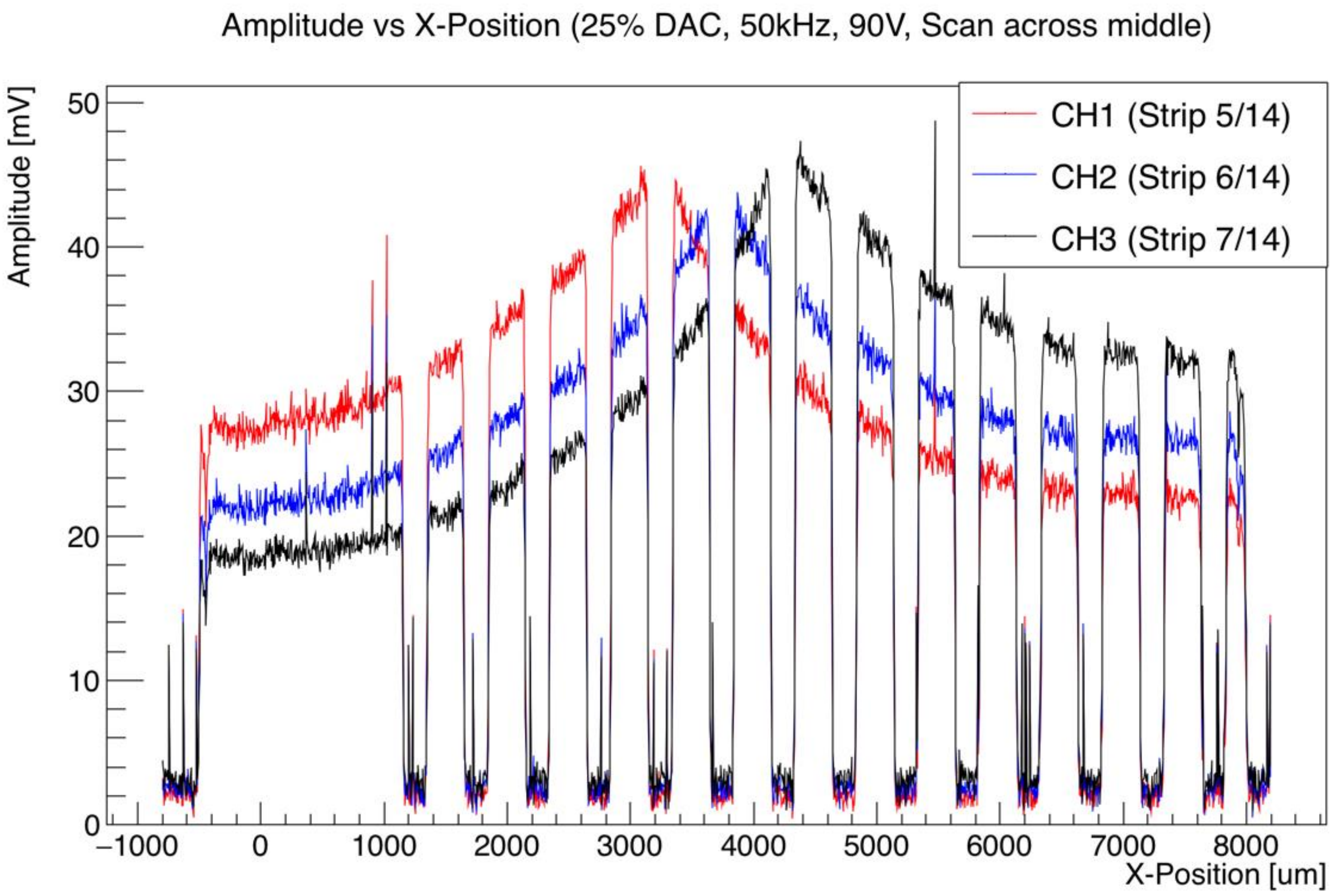


Detector: W4 AC2, V_{bias}: 100V, IR laser 25% 50Hz

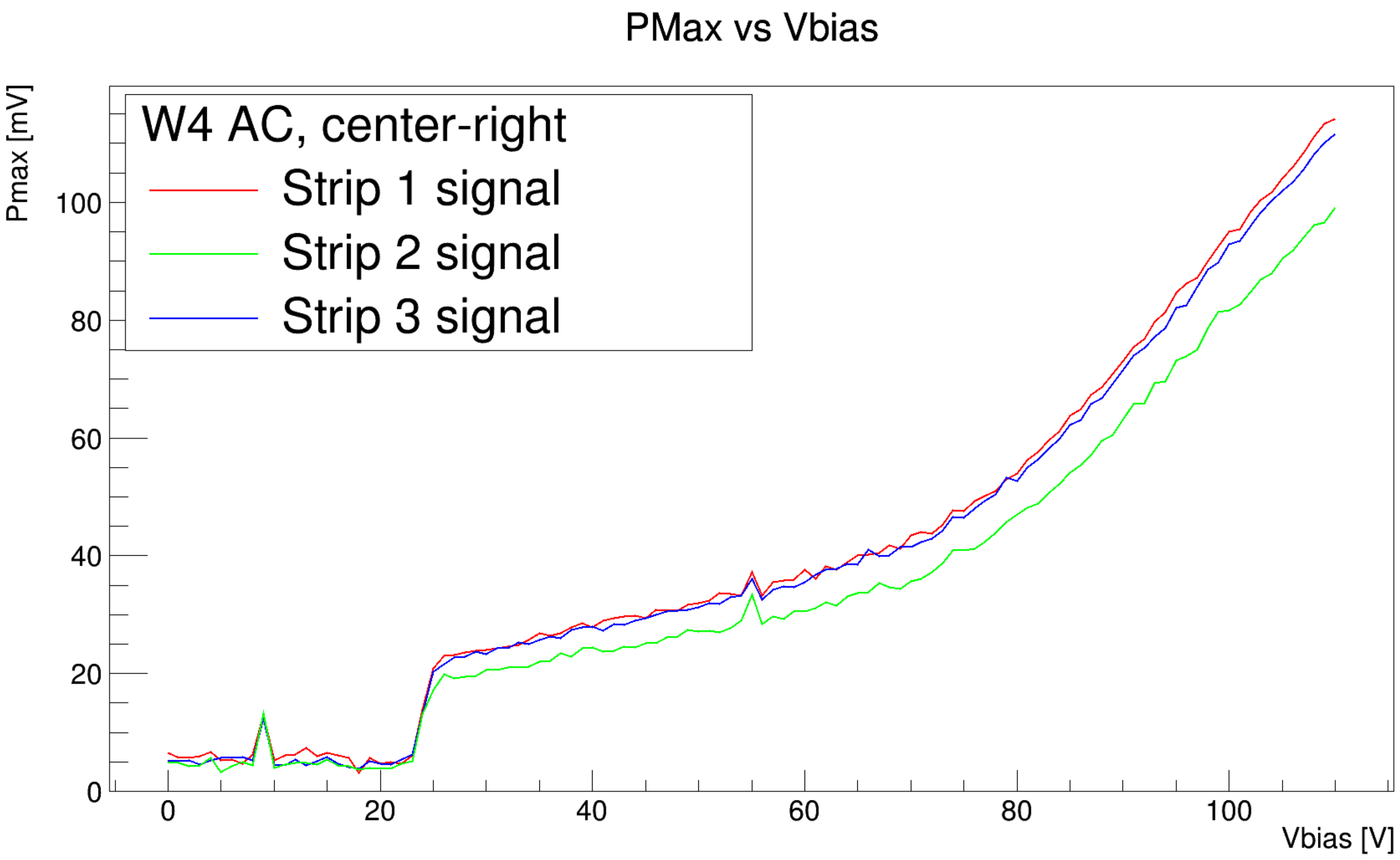




Detector: W4 AC2, V_{bias}: 100V, IR laser 25% 50Hz



Amplitude vs X-Position (25% DAC, 50kHz, 90V, Scan across middle)

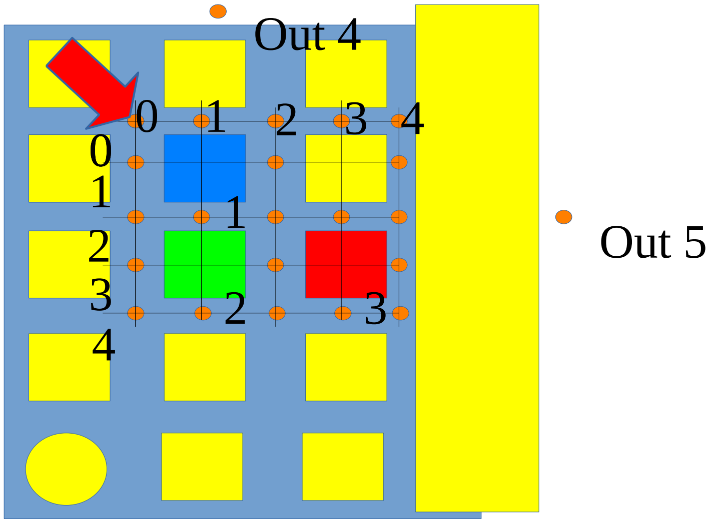


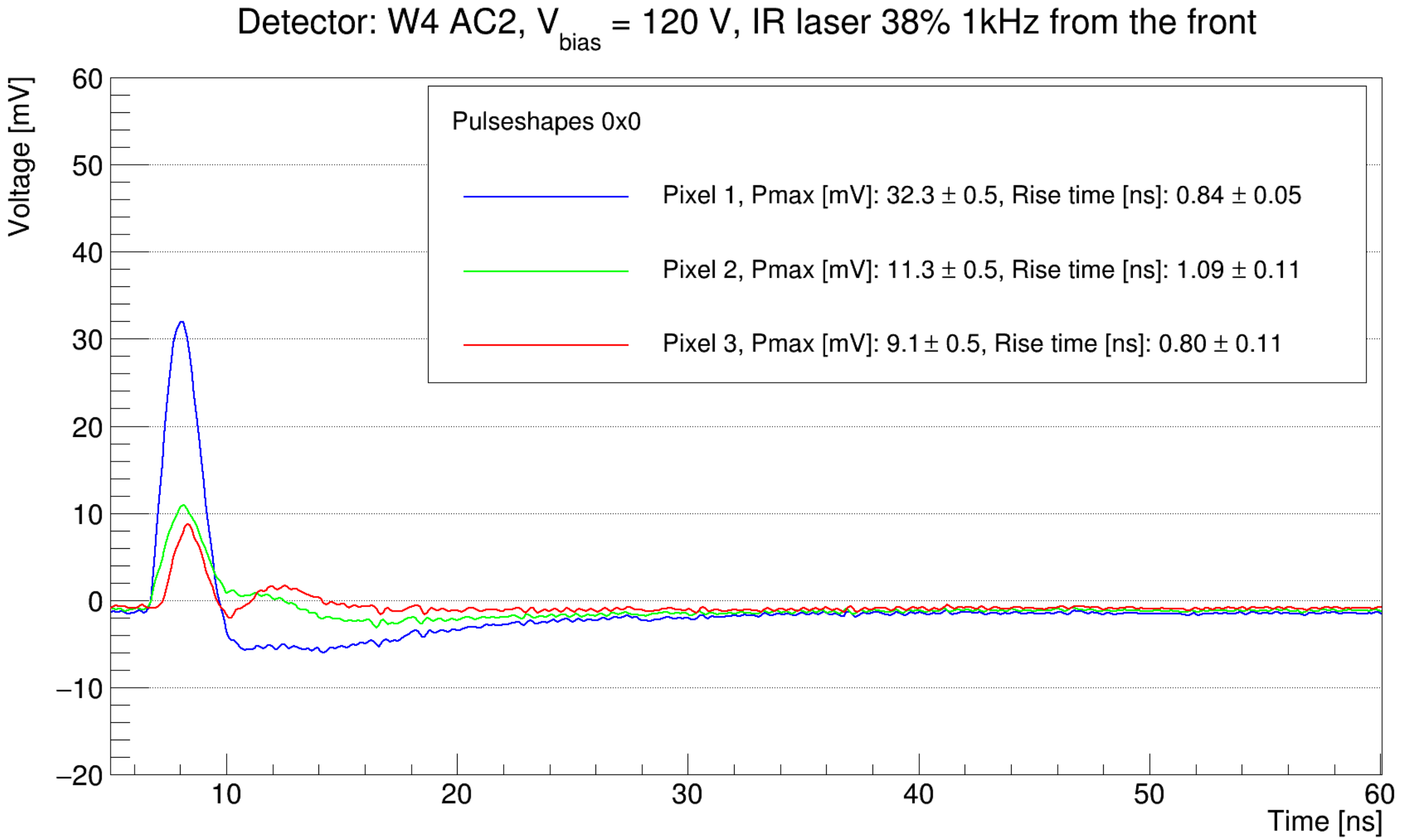
- First gain increase at ~25 V, second increase at ~75 V

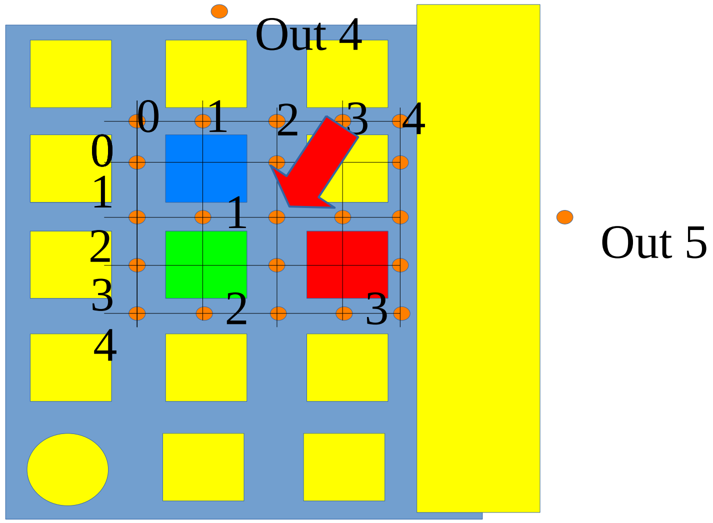
Summary

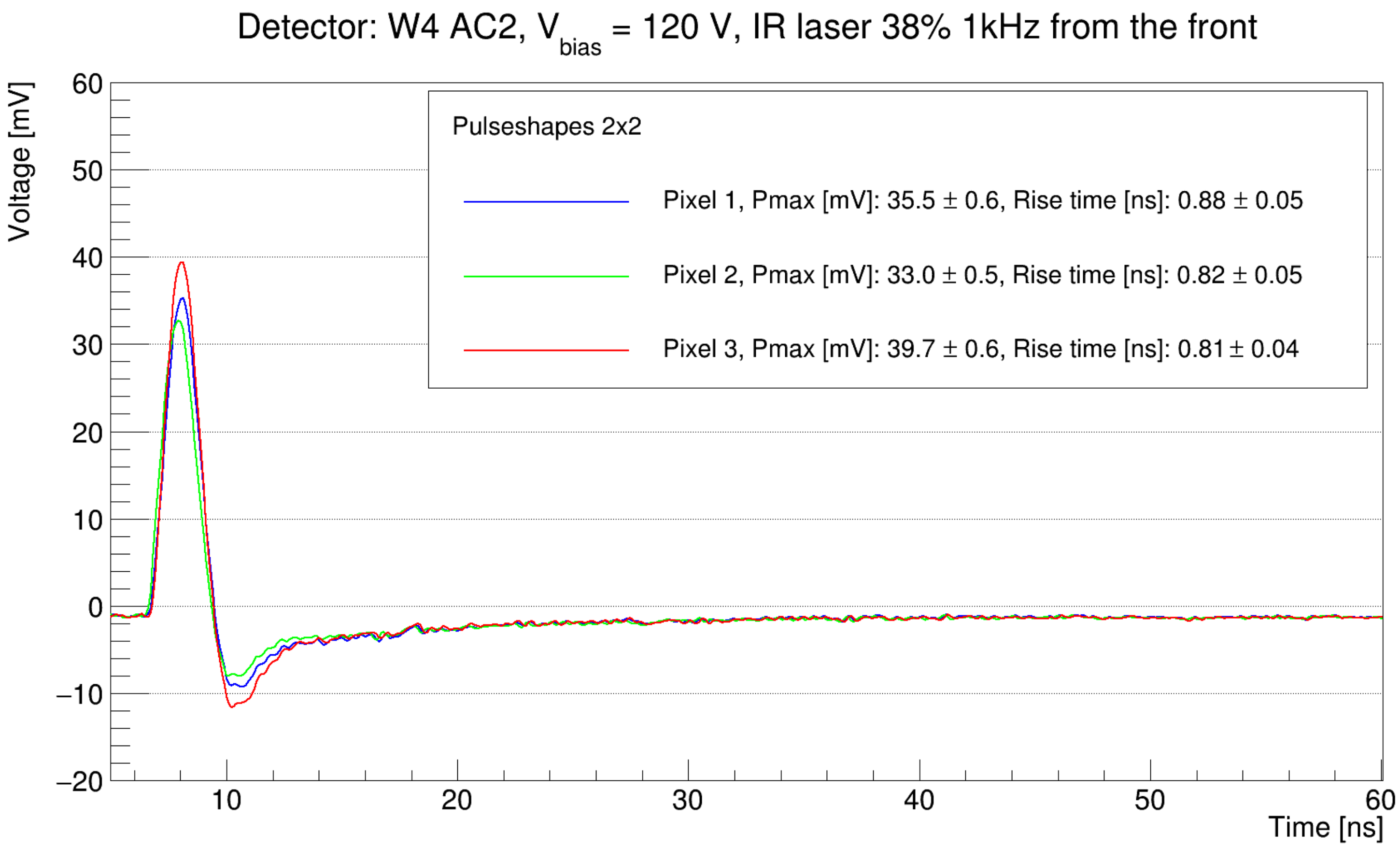
- Rapid current increase at 25 V is not breakdown
  - Pulses are still clear and Pmax depends on Vbias
  - Rapid increase of Pmax at 25 V and then at 75 V
- Pulses are 10ns long with extremely long undershoot
  - Because of the high capacitance of the strips
  - Pixels however have shorter pulses with clear undershoot
- Difference in amplitude between the strips is not much
  - Maximum 20% difference
  - Probably N+ implant is too conductive
  - Need to optimize the parameters of the wafer

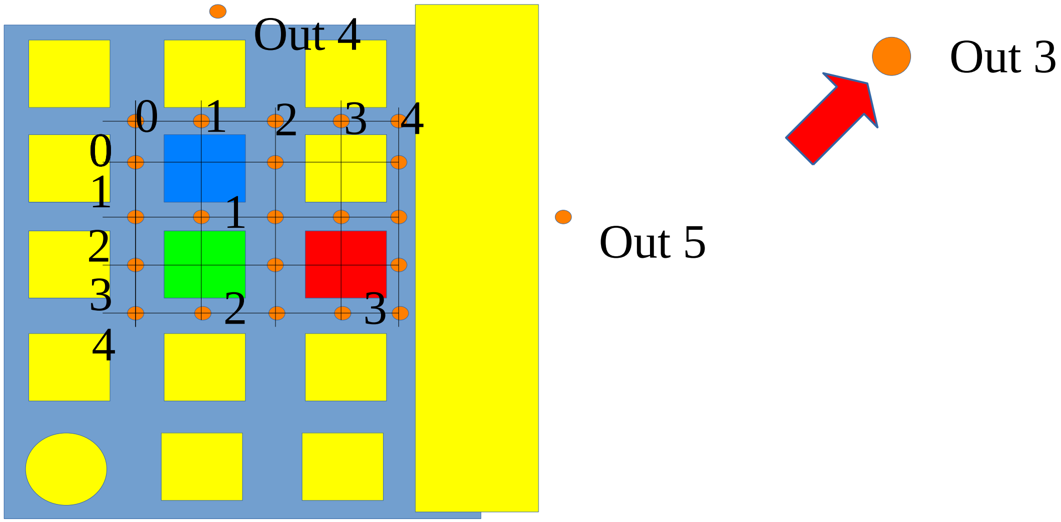
Pixels setup - data



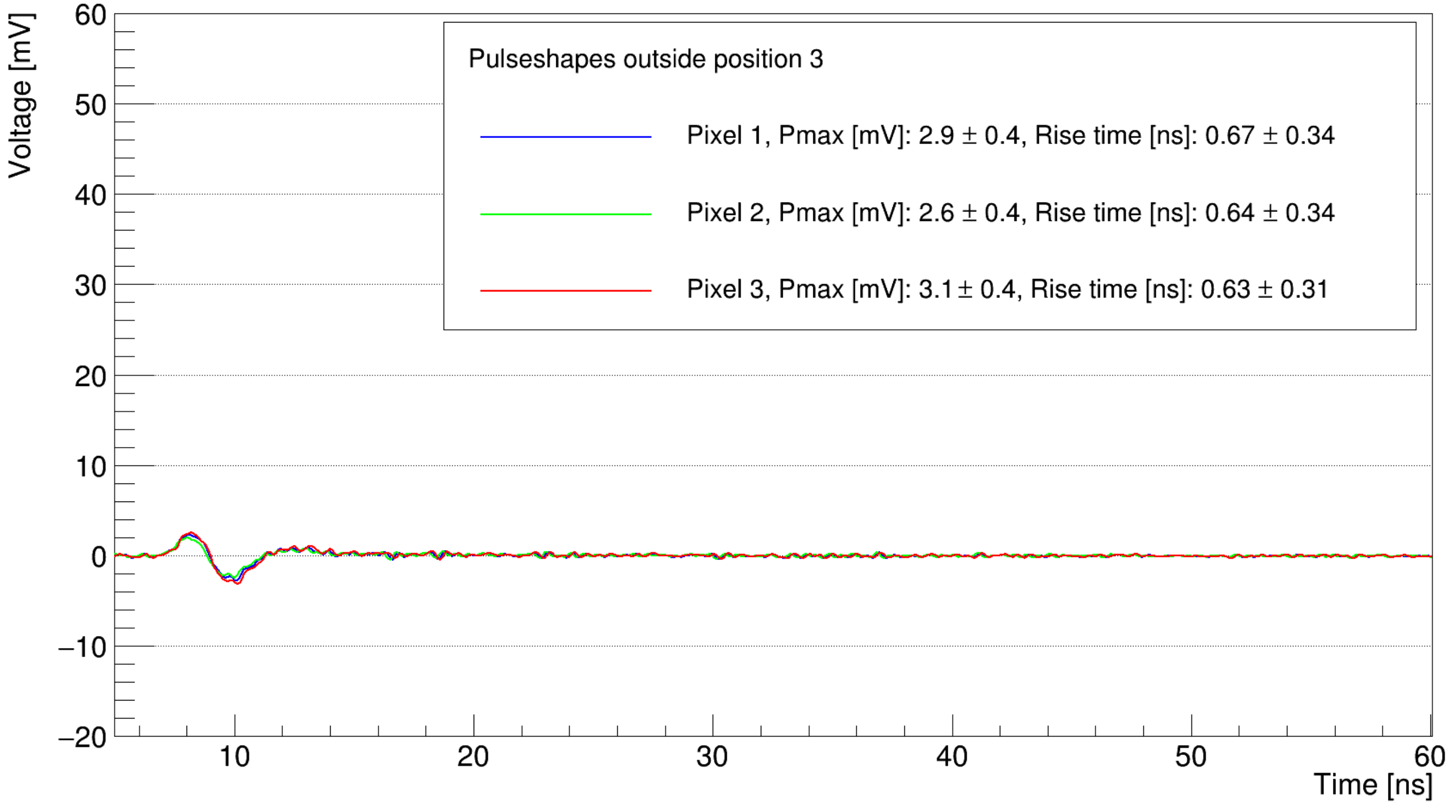

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front


Out 4
0
1
2
3
4
0
1
2
3
4
1
2
3
Out 5

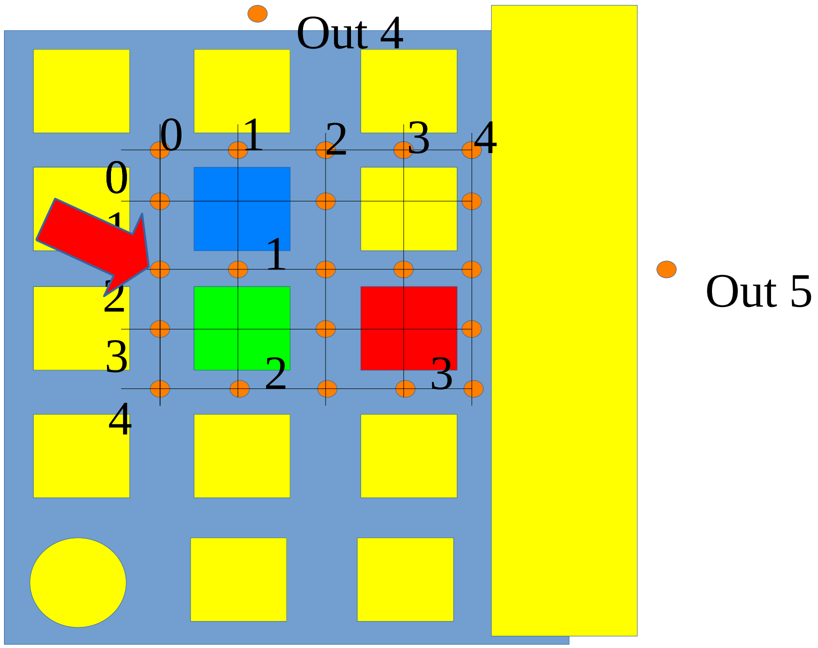

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Pulseshapes 2x2
Pixel 1, Pmax [mV]: 35.5 ± 0.6, Rise time [ns]: 0.88 ± 0.05
Pixel 2, Pmax [mV]: 33.0 ± 0.5, Rise time [ns]: 0.82 ± 0.05
Pixel 3, Pmax [mV]: 39.7 ± 0.6, Rise time [ns]: 0.81 ± 0.04
Voltage [mV]
60
50
40
30
20
10
0
−10
−20
10
20
30
40
50
60
Time [ns]

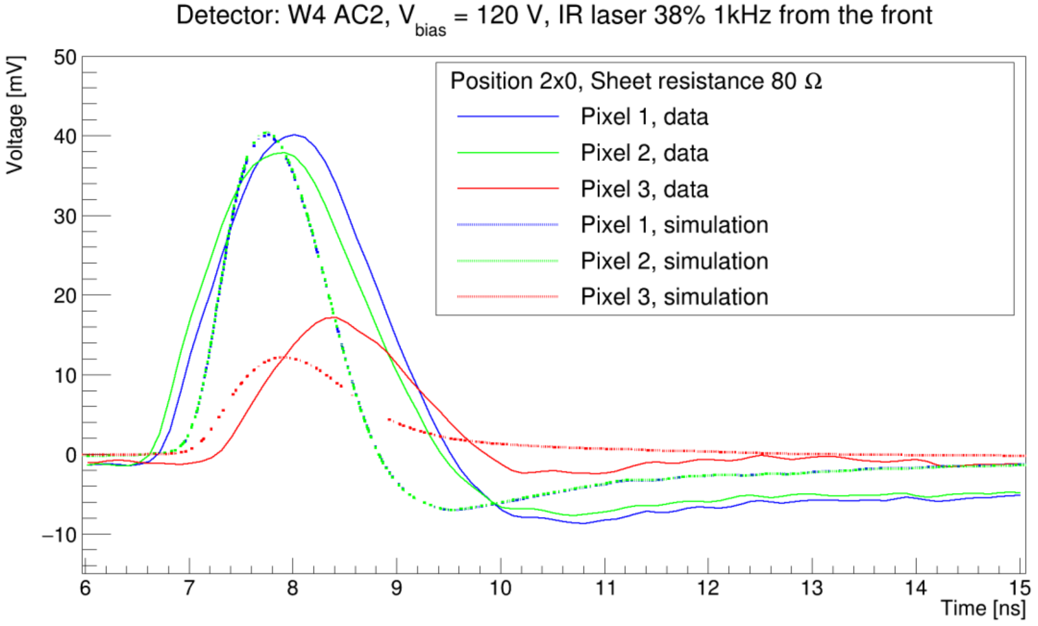


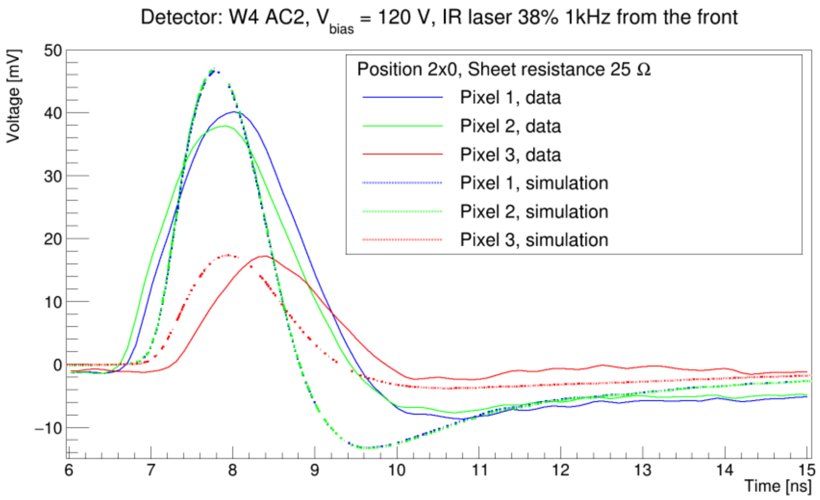
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

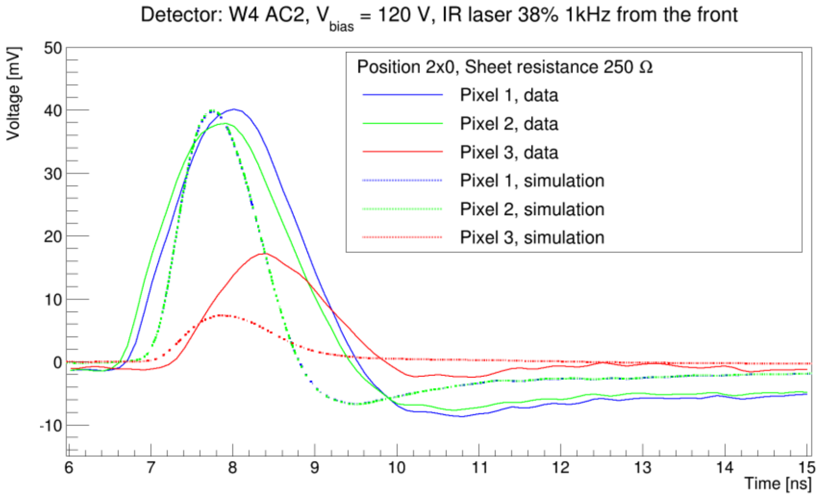


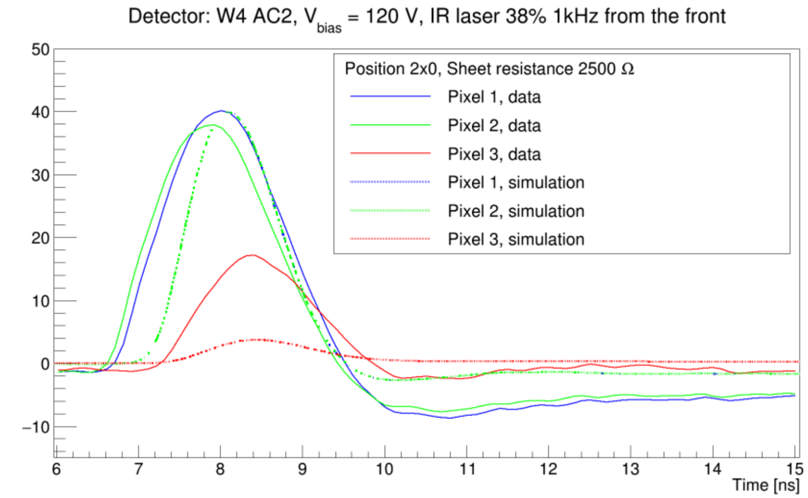
Pixels setup - simulation

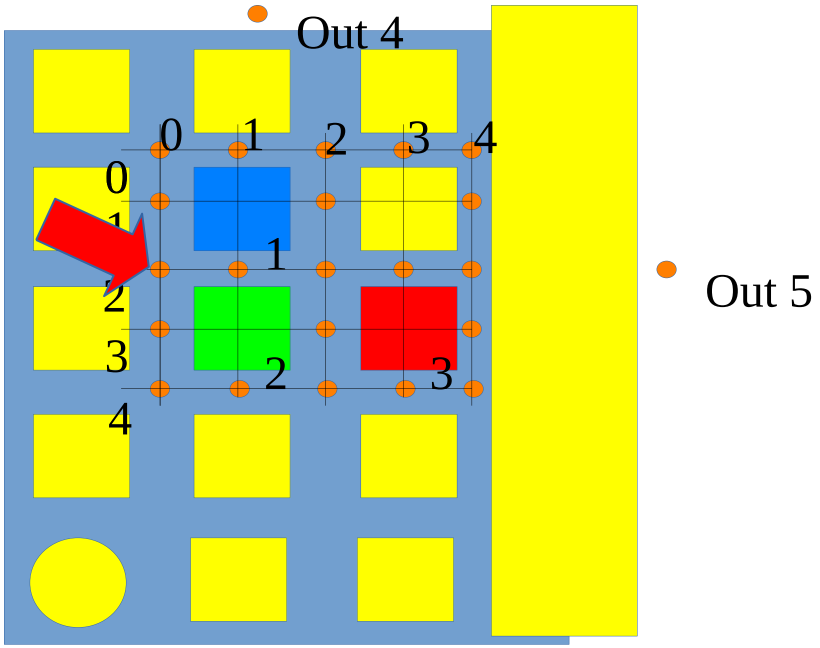

Out 4
Out 5
0
1
2
3
4
0
1
2
3
4
1
2
3


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Position 2x0, Sheet resistance 80 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
Voltage [mV]
Time [ns]
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15

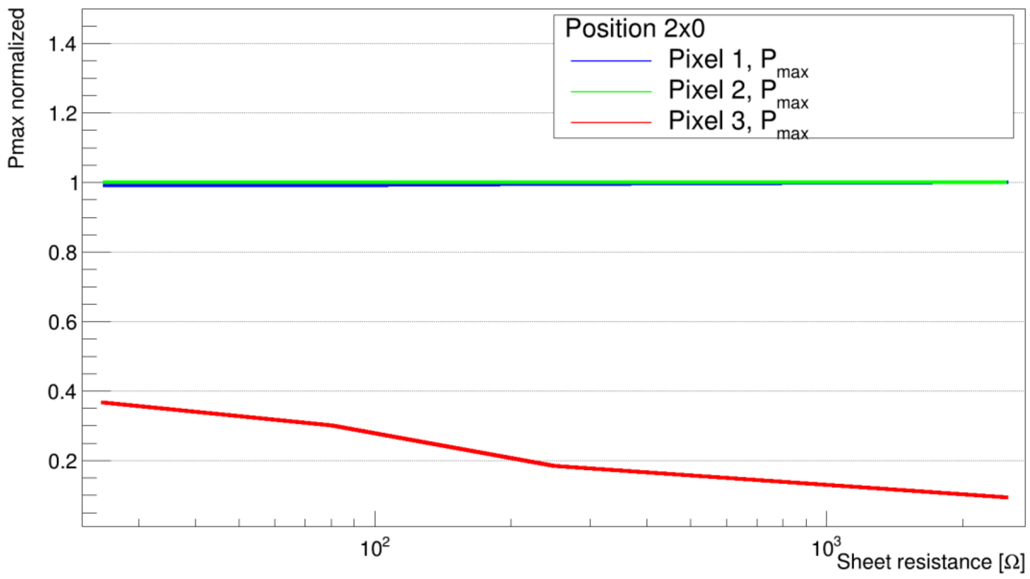

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Position 2x0, Sheet resistance 25 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
Voltage [mV]
Time [ns]
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Position 2x0, Sheet resistance 250 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
Voltage [mV]
Time [ns]
50
40
30
20
10
0
-10
6
7
8
9
10
11
12
13
14
15

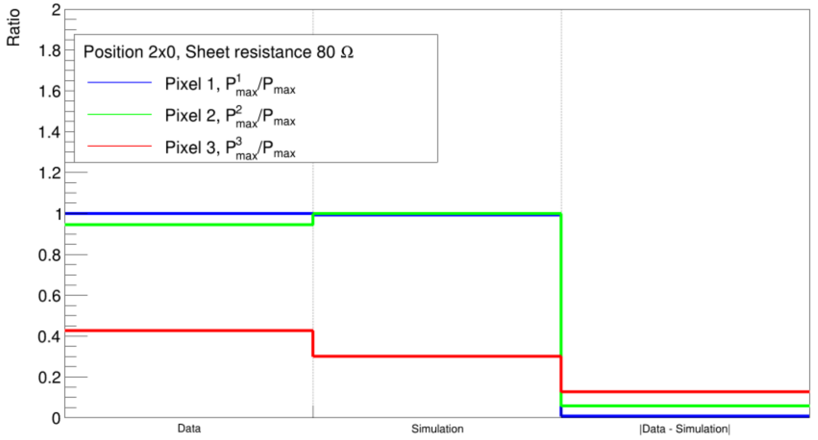

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Position 2x0, Sheet resistance 2500 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
Voltage [mV]
Time [ns]
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15



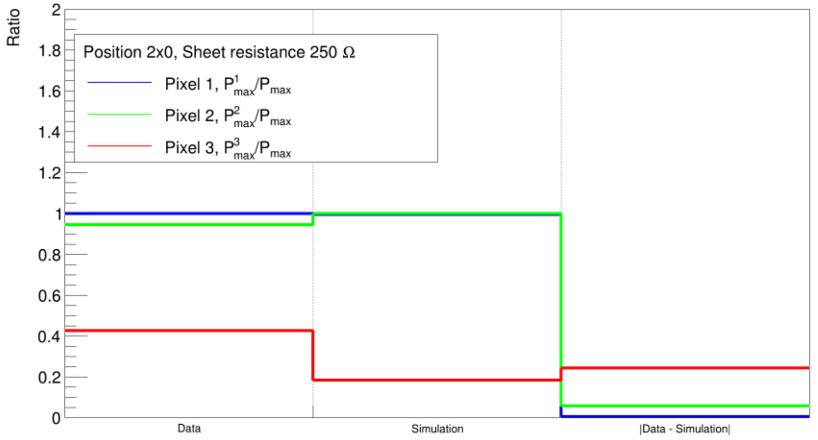
Simulation Pmax, position 2x0



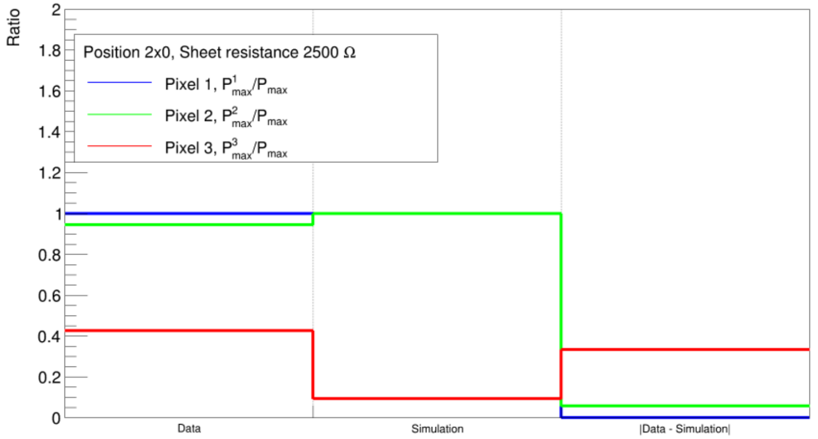
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

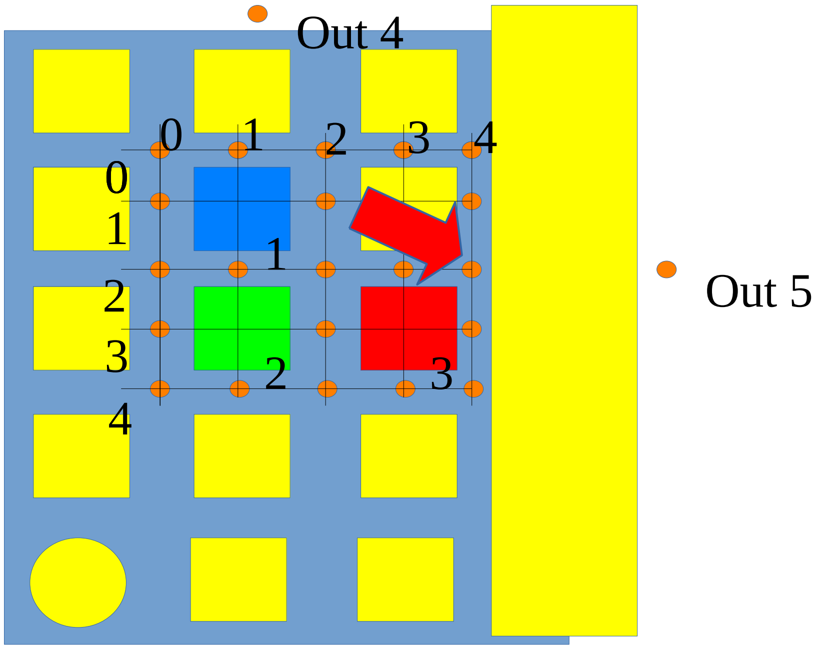


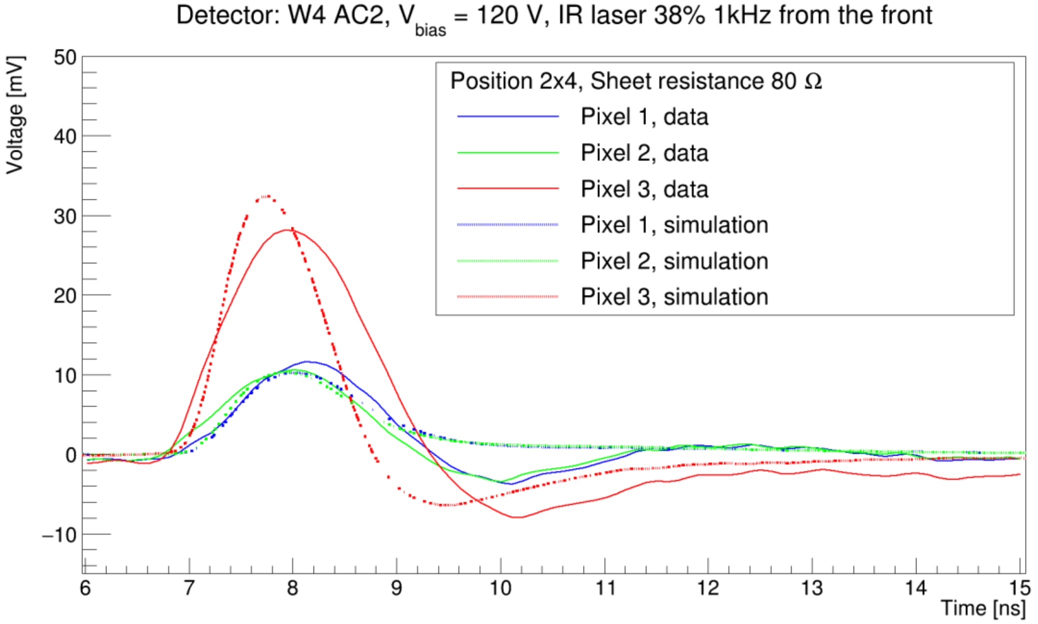
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

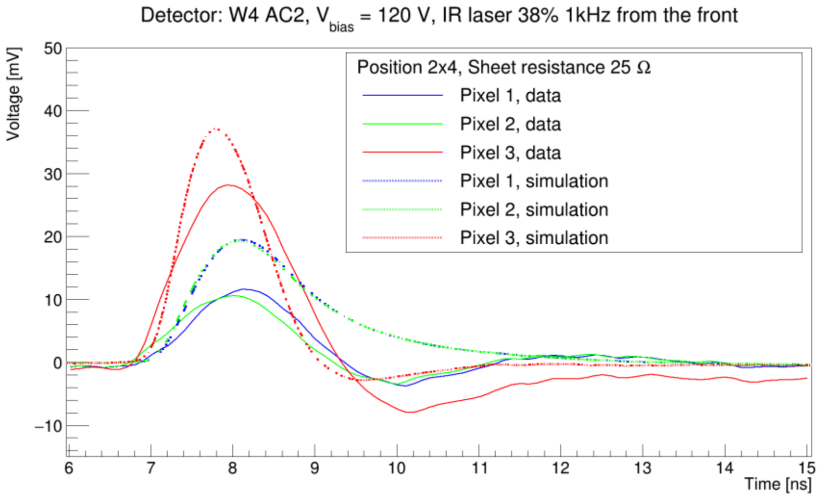


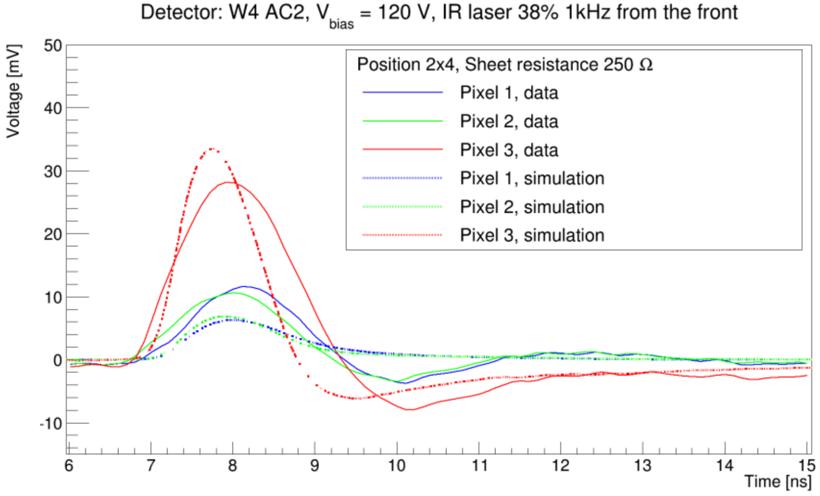
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

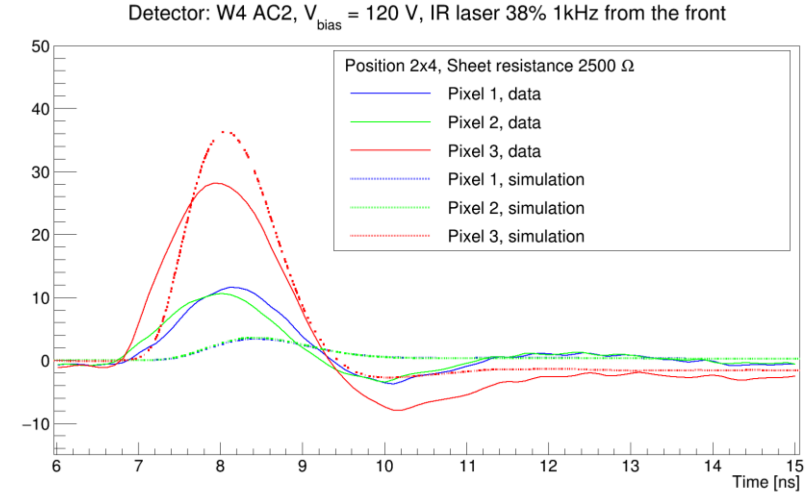


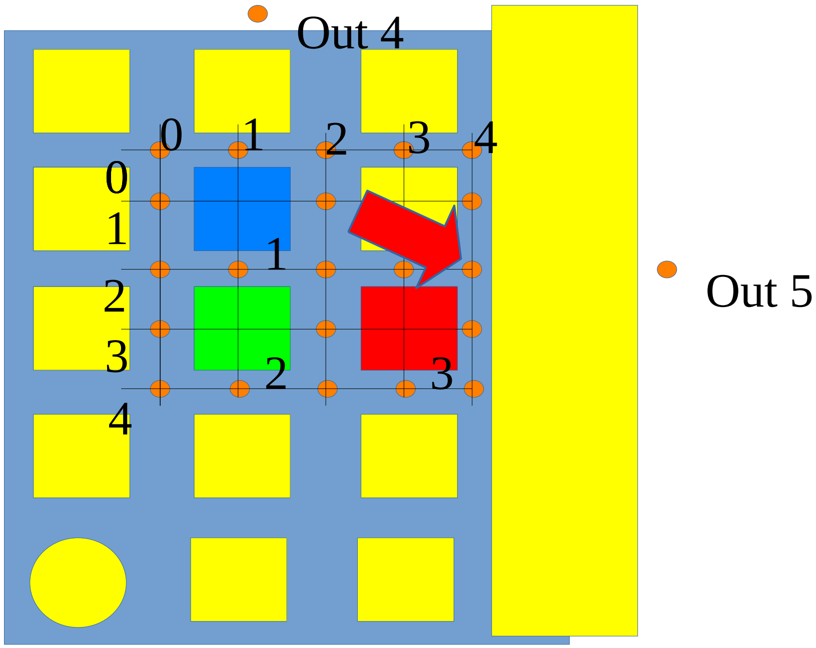

Out 4
Out 5
0
1
2
3
4
0
1
2
3
4
1
2
3

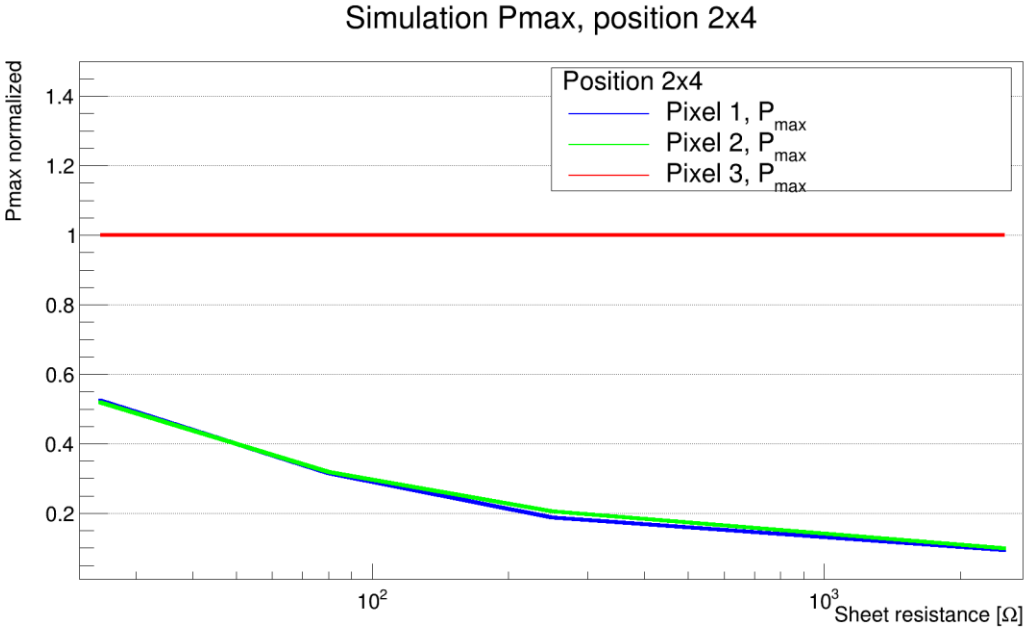

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
Time [ns]
Position 2x4, Sheet resistance 80 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15

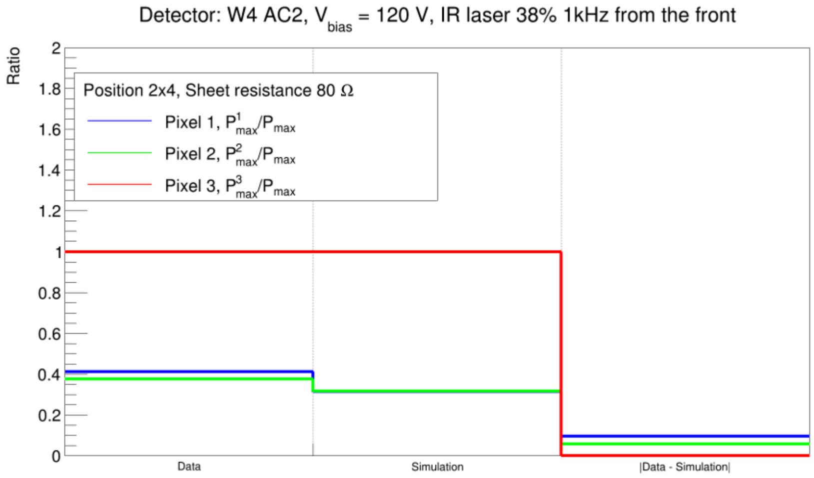

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
Time [ns]
Position 2x4, Sheet resistance 25 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15

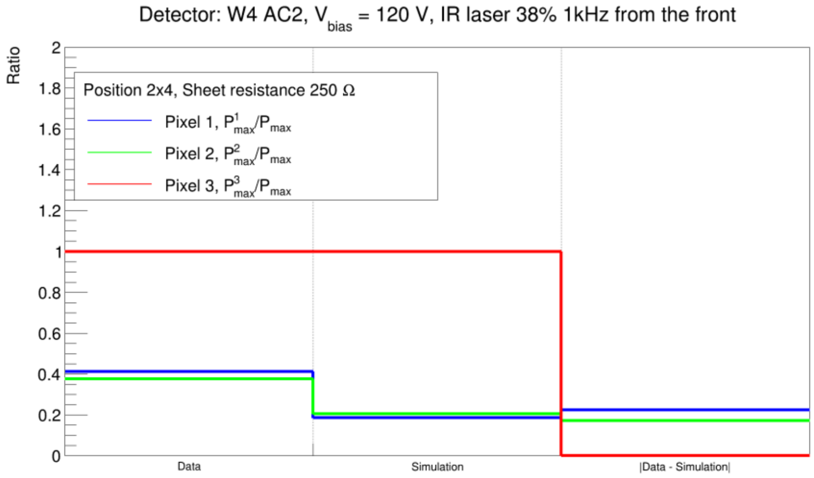

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Voltage [mV]
Time [ns]
Position 2x4, Sheet resistance 250 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
50
40
30
20
10
0
-10
6
7
8
9
10
11
12
13
14
15

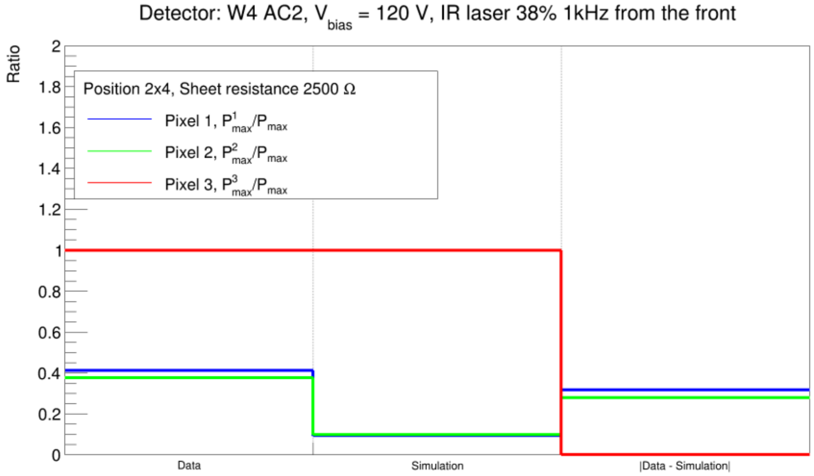

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Time [ns]
Position 2x4, Sheet resistance 2500 Ω
Pixel 1, data
Pixel 2, data
Pixel 3, data
Pixel 1, simulation
Pixel 2, simulation
Pixel 3, simulation
50
40
30
20
10
0
−10
6
7
8
9
10
11
12
13
14
15

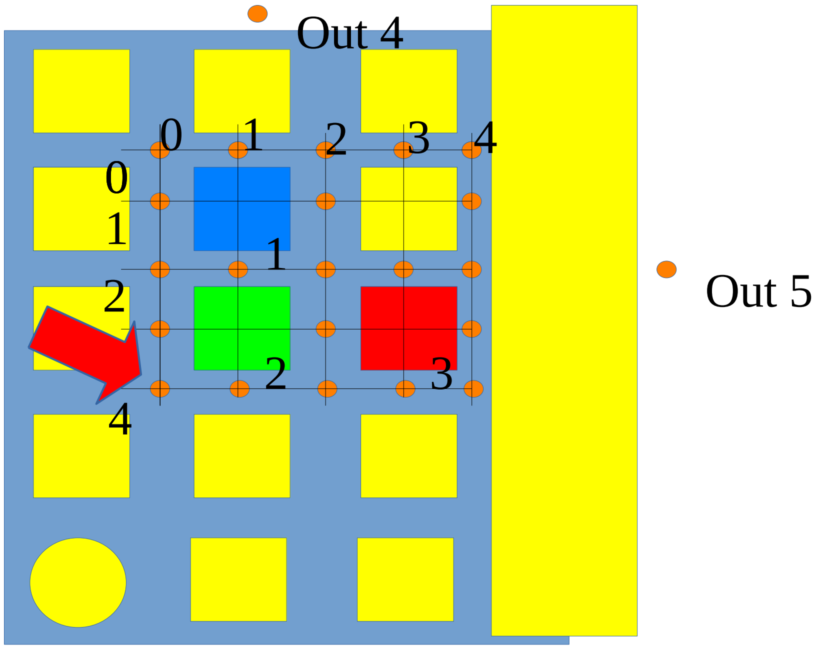


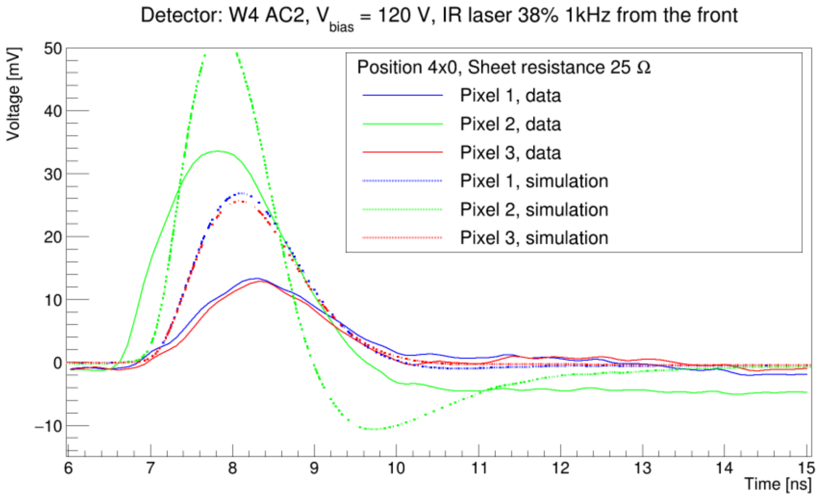

Simulation Pmax, position 2x4


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

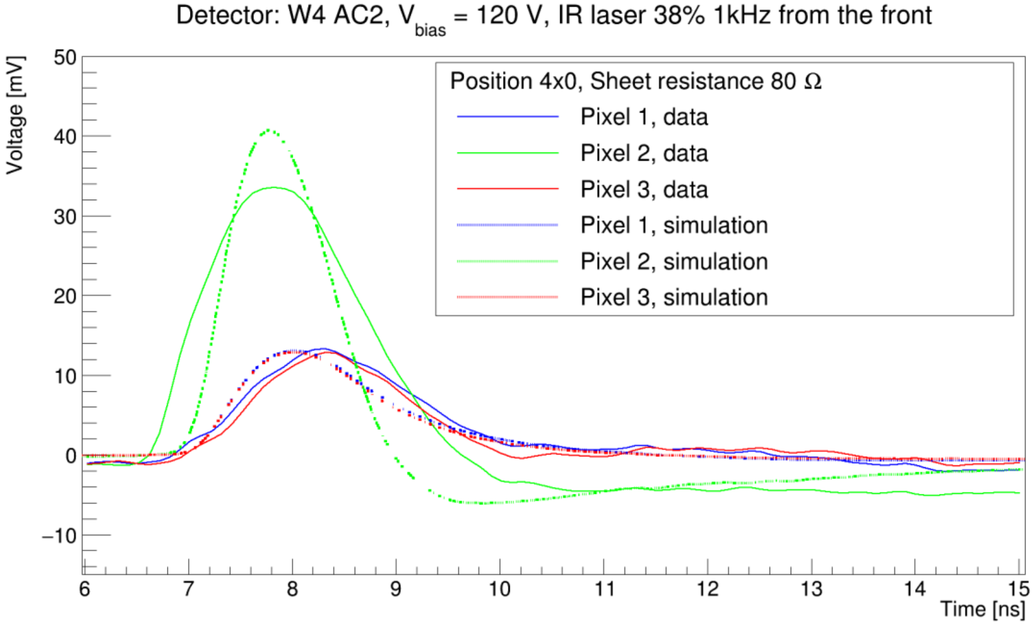

Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

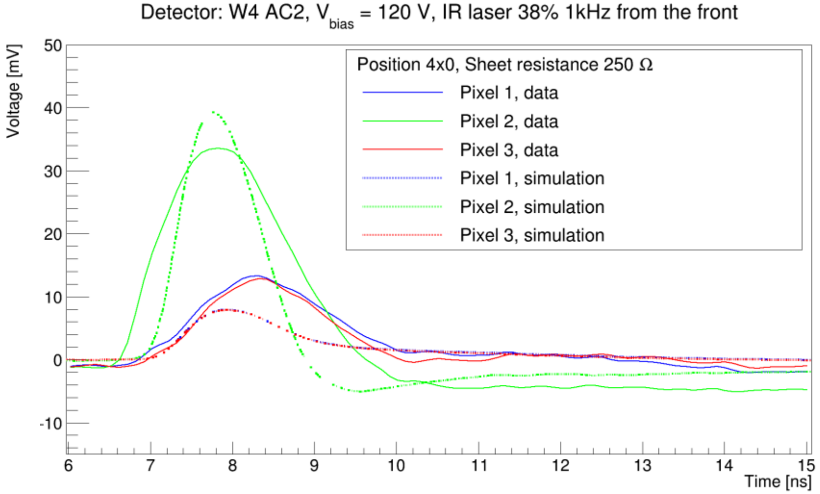




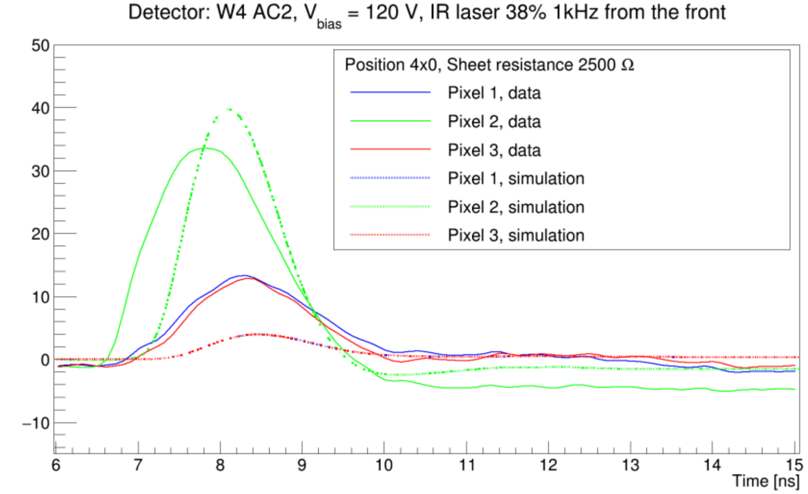
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front



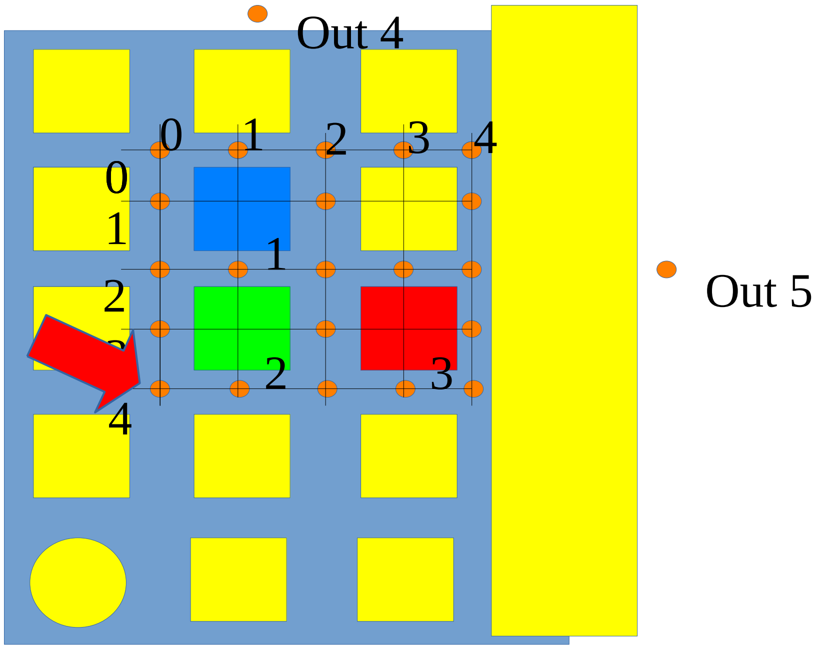
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

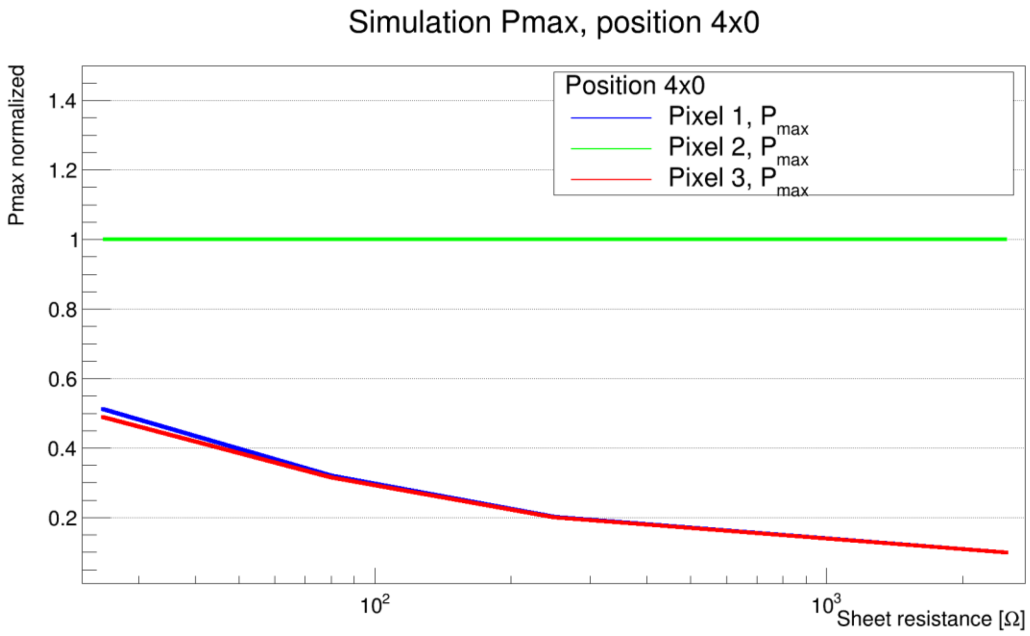


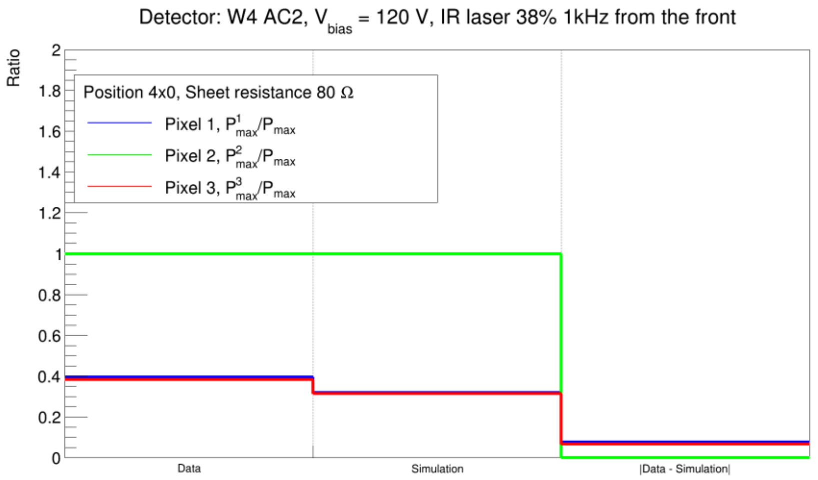
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front

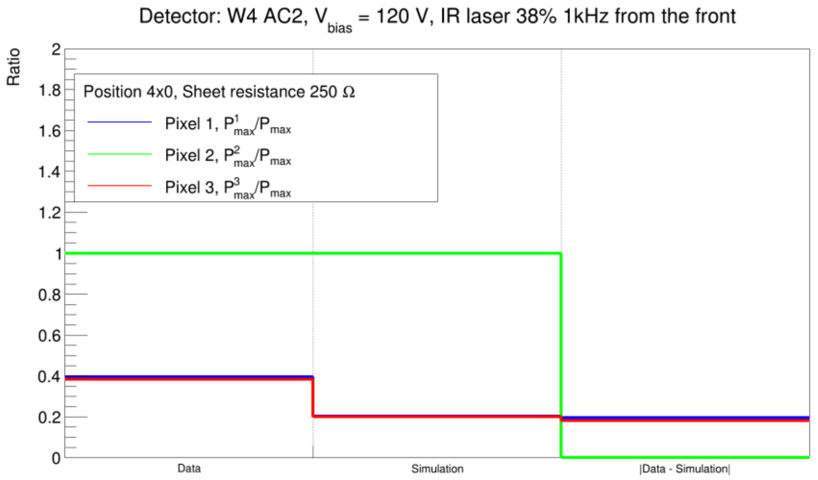


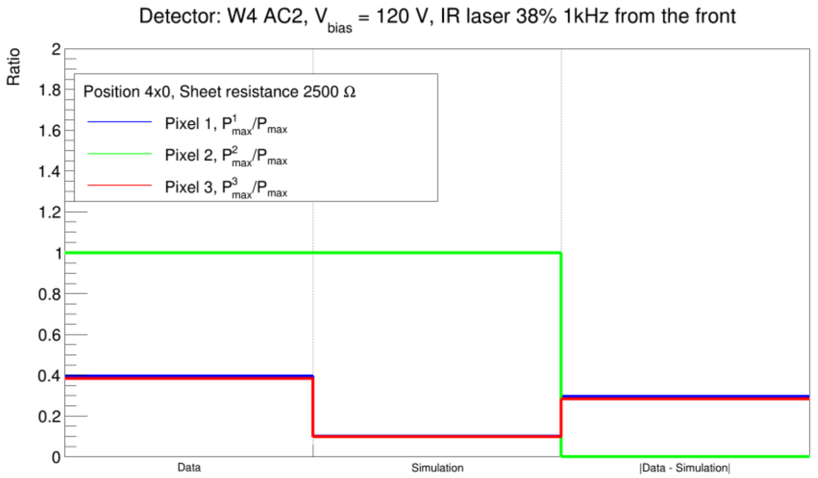
Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front


Out 4
0
1
2
3
4
0
1
2
3
4
1
2
3
Out 5


Simulation Pmax, position 4x0
Pmax normalized
1.4
1.2
1
0.8
0.6
0.4
0.2
10^2
10^3
Sheet resistance [Ω]
Position 4x0
Pixel 1, P_{max}
Pixel 2, P_{max}
Pixel 3, P_{max}


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Ratio
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Position 4x0, Sheet resistance 80 Ω
Pixel 1, P^1_{max}/P_{max}
Pixel 2, P^2_{max}/P_{max}
Pixel 3, P^3_{max}/P_{max}
Data
Simulation
|Data - Simulation|


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Ratio
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Position 4x0, Sheet resistance 250 Ω
Pixel 1, P^1_{max}/P_{max}
Pixel 2, P^2_{max}/P_{max}
Pixel 3, P^3_{max}/P_{max}
Data
Simulation
|Data - Simulation|


Detector: W4 AC2, V_{bias} = 120 V, IR laser 38% 1kHz from the front
Ratio
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Position 4x0, Sheet resistance 2500 Ω
Pixel 1, P^1_{max}/P_{max}
Pixel 2, P^2_{max}/P_{max}
Pixel 3, P^3_{max}/P_{max}
Data
Simulation
|Data - Simulation|