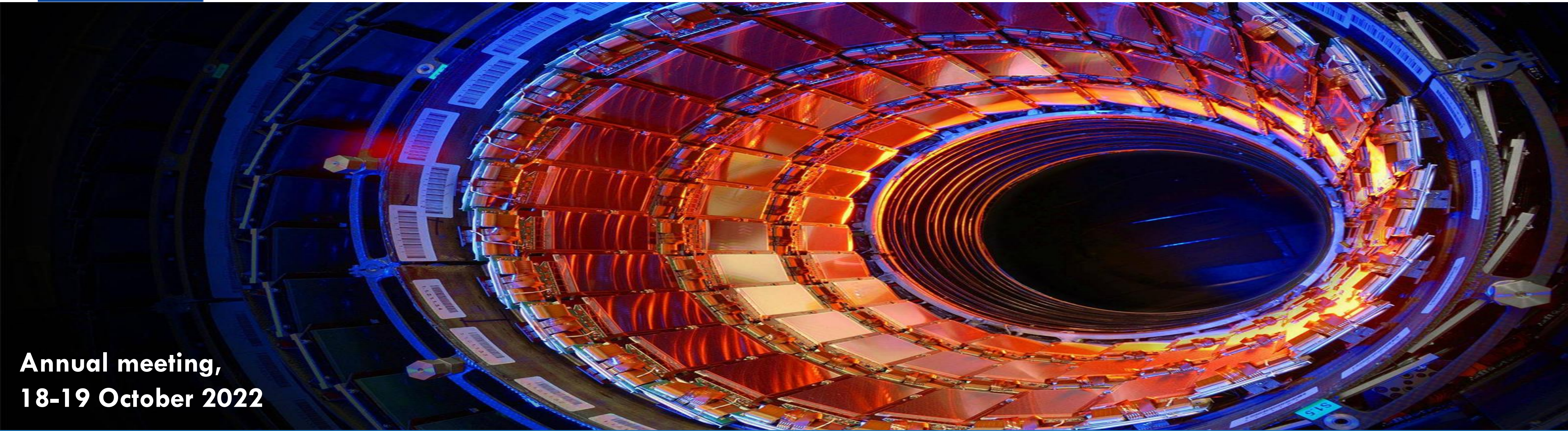
Rachid SEFRI
for the JRA9 group

Institut Pluridisciplinaire Hubert CURIEN STRASBOURG



Annual meeting,
18-19 October 2022

JRA9-Tracking and Ions Identifications with Minimal Material budget: TIIMM

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

PLAN OF PRESENTATION

1) Scientific results obtained since the last year

2) Modifications of the scientific Work Plan
(as compared to the initial plan in the Grant Agreement)

3) Possibilities/needs of another request for the extension of the project (beyond 30 November 2023)

CONTEXT

Tracking | **Identification**

TIIMM target =

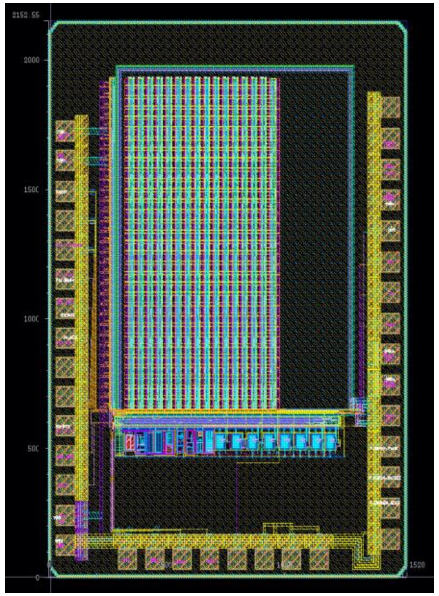
	Precision tracking $\sigma_{pos.} \leq 10$ µm +	Low material budget << % X_0 +	Energy loss measurement 1-10^3 MIPs
Current achievements			
Hybrid detectors	At the limit of feasibility	Limit around 1 % X_0	Strong point Thick substrate 300-1000 µ m
Monolithic sensors	~5 µm ALICE – ITS2 with 1-10 MIPs 5-10 µm FIRST, hadrontherapy Ions 150-300 MeV/u	0.3 to 0.8 % X_0 ALICE – ITS2 over 10 m^2 ~0.2 % X_0 FOOT prototype over 30 cm^2	Available for MIP level σ_E not investigated Initial work for >> MIPs Indirect estimation of ΔE

SENSOR'S OVERVIEW

CMOS Monolithic Active Pixel Sensor design in TowerJazz 180 nm process For position and energy measurements

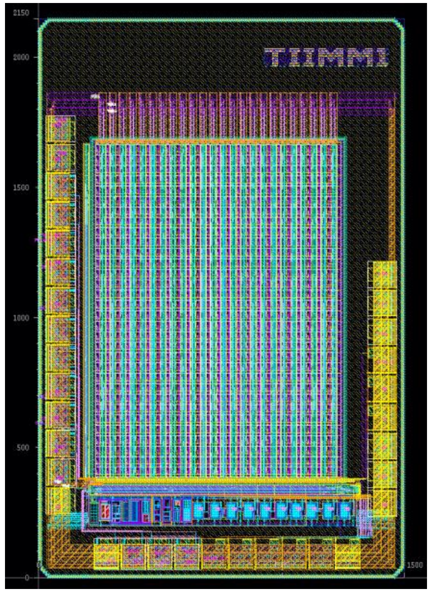
- First submission: preliminary prototype (TIIMM0) submitted in March 2020.

- Second submission: TIIMM0/TIIMM1/TIIMM1A/TIIMM1B prototypes received in August 2022



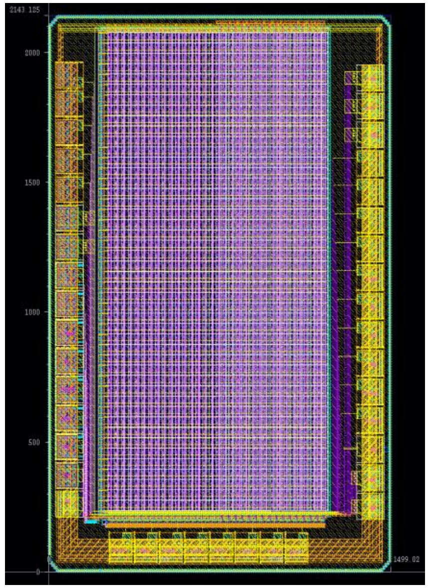
TIIMM0 (second submission)
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 16 (col)
Pixel pitch: 40 µm×40 µm

Corrected from the first submission



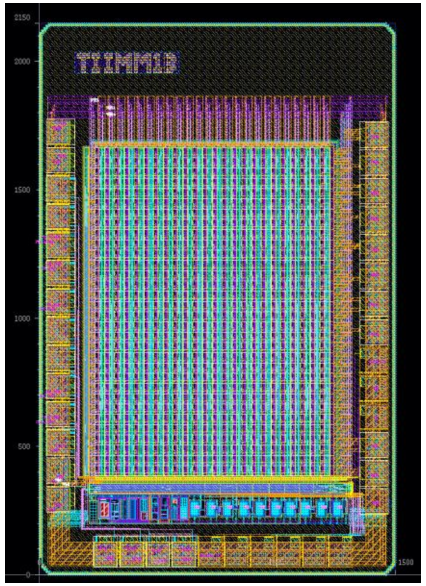
TIIMM1 sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 24 (col)
Pixel pitch: 41.2 µm×40 µm

New front-end



TIIMM1A sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 46 (rows) * 32 (col)

New front end
Analog part study only



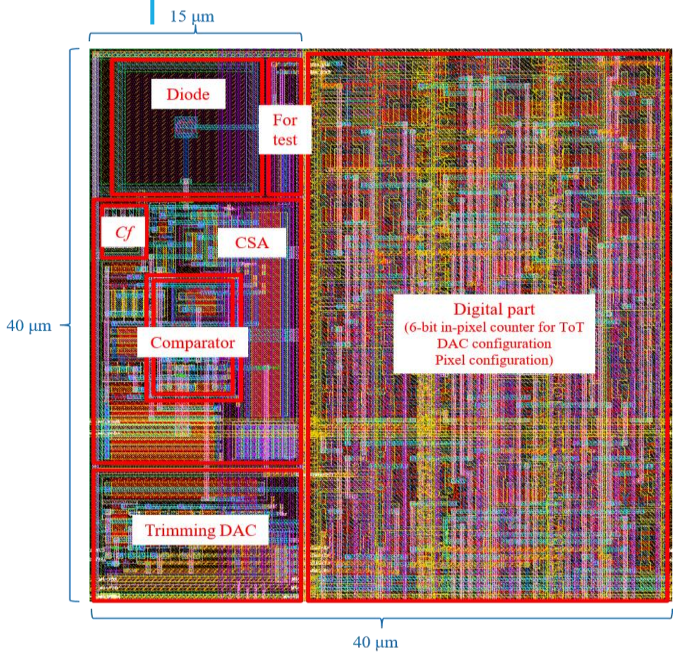
TIIMM1B sensor
Chip area: 2.2 mm * 1.5 mm
Matrix: 32 (rows) * 24 (col)
Pixel pitch: 41.2 µm×40 µm

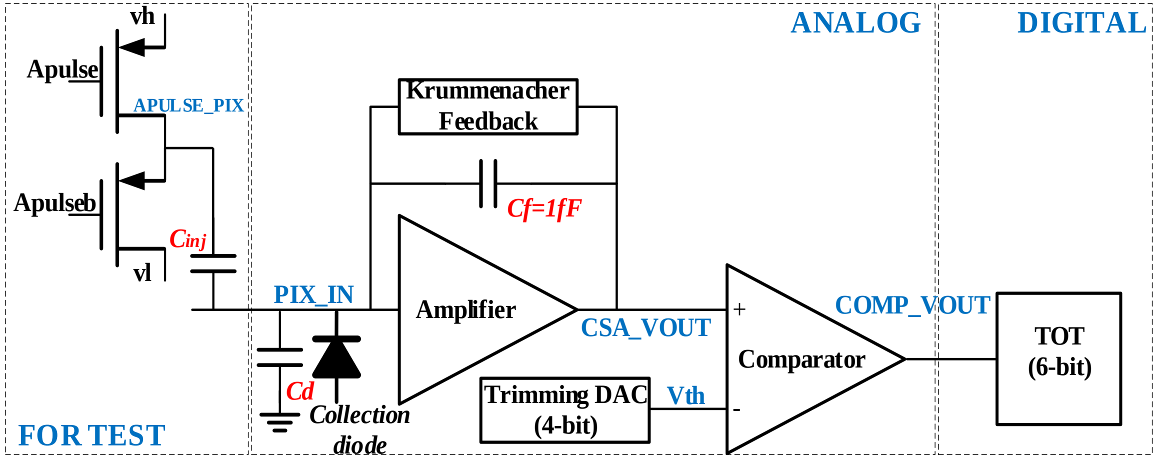
New front-end enhanced

7 sensing layer variants

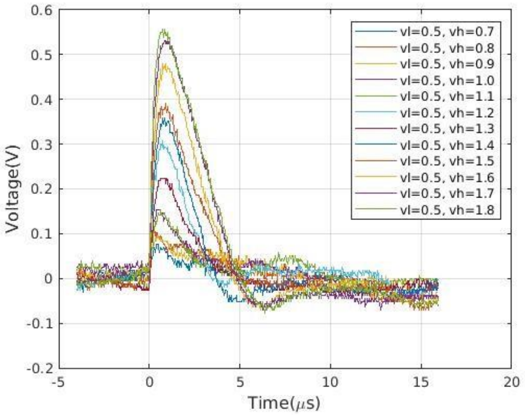
Thickness	Process	
25 µm Epi High Res.	Standar	1. Non-uniform N- layer 2. Uniform N- layer + Extra Deep
50 µm Epi High Res.	1. Non-uniform N- layer 2. Uniform N- layer + Extra Deep P	
100 µm Epi High Res.	1. Non-uniform N- layer 2. Uniform N- layer + Extra Deep P	

SENSOR'S OVERVIEW – TIIMM0 *(FIRST SUBMISSION)*





Measurements



CSA analogue output's / different input charge.

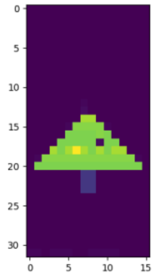
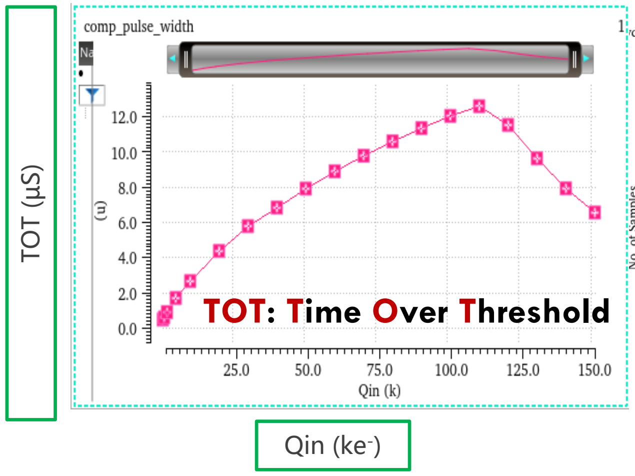
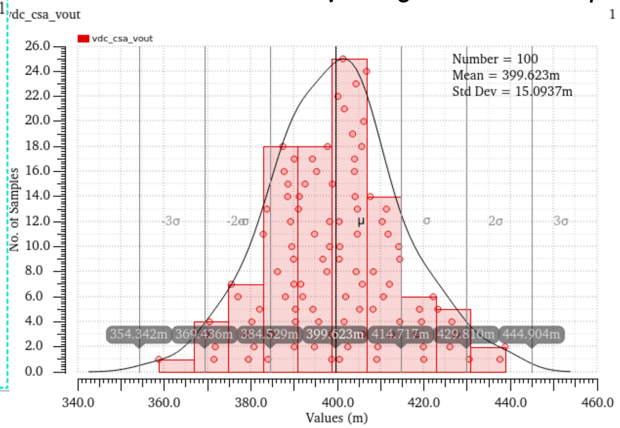


Image with digital readout test

Simulations



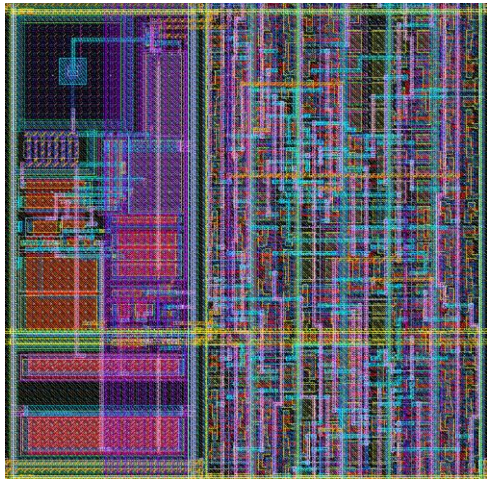
Monte Carlo simulation of voltage baseline of *CSA (Charge Sensitive Amplifier)* output



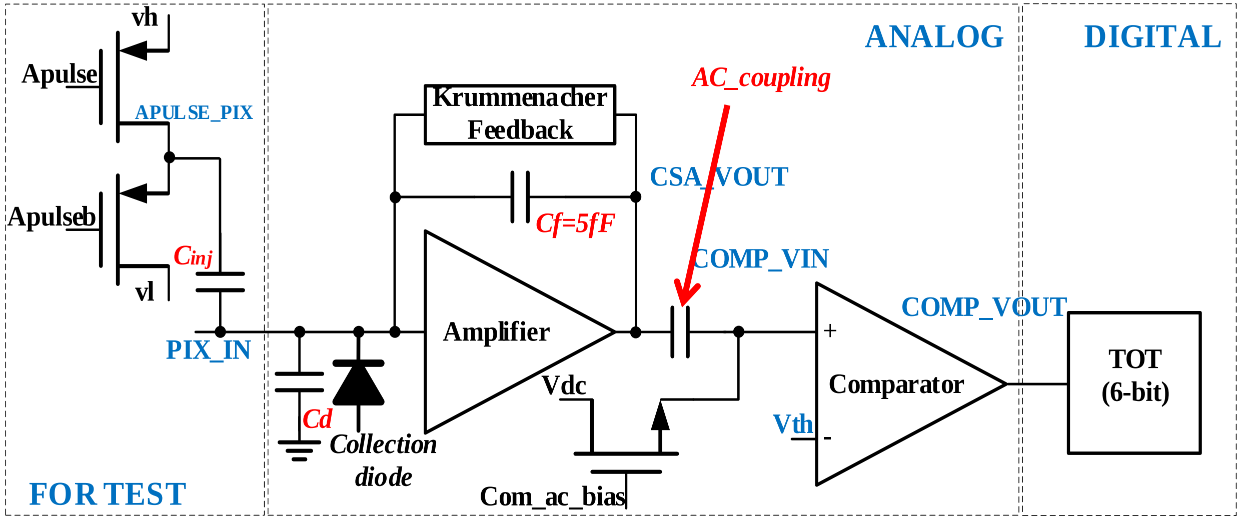
Limitations in TIIMM0 *(simulations)*:

1. **Maximum linear range is only 110ke-**
2. **The baseline spread of the Charge Sensitive Amplifier (CSA) output is large.**
3. **The dispersion of the pulse width of the CSA output is large**
4. **Undershoot problem in CSA output**

SENSOR'S OVERVIEW – TIIMM1 *(SECOND SUBMISSION – SIMULATION ONLY)*



TIIMM1 pixel cell 40 µm × 41.2 µm



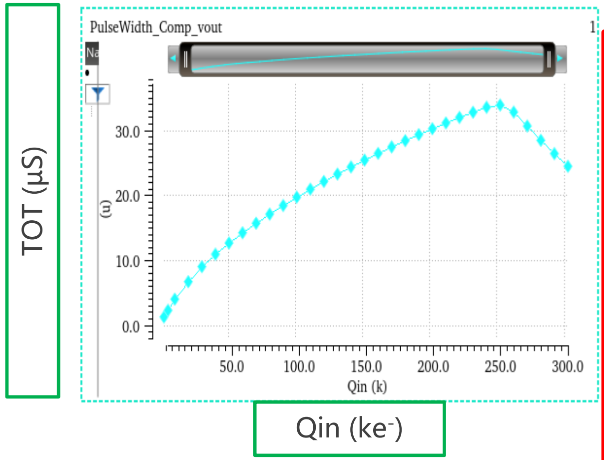
- **Spread of input comparator in TIIMM0**
  Mean: 400.22 mV
  Sigma: 15.1 mV

- **Spread of input comparator in TIIMM1**
  Mean: 400 mV
  Sigma: 1.11 µV

Optimization in TIIMM1:

1. Increase the Cf to have larger dynamic range.
2. AC coupling structure to fix the offset problem of the CSA output.
3. Optimization of the CSA to minimize dispersion of the pulse width.
4. Keep the digital readout structure.

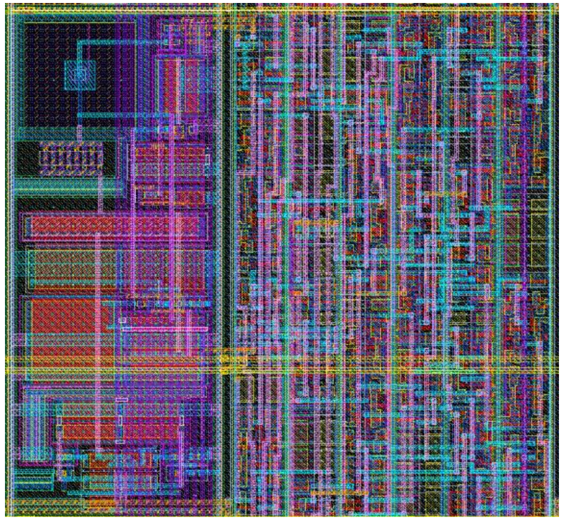
TOT: Time Over Threshold



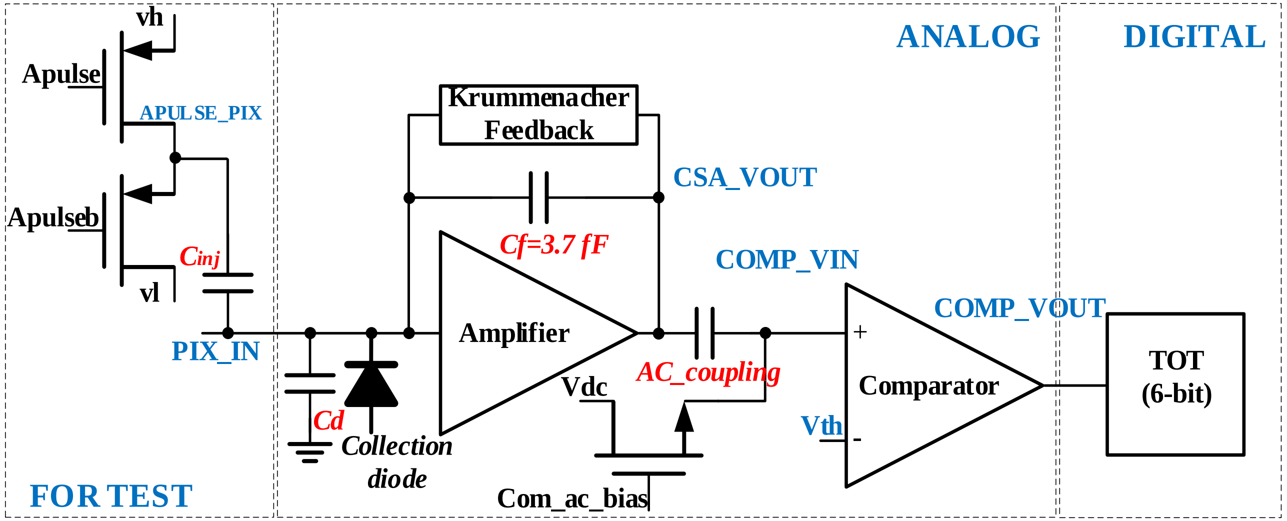
Limitations in TIIMM1:

1. Input dynamic range is greater than TIIMM0 but still limited to 250ke- (<10^3 MIPs)
2. undershoot problem in CSA output
3. The input offset *(mismatch and process)* of the comparator is still large (6mV).

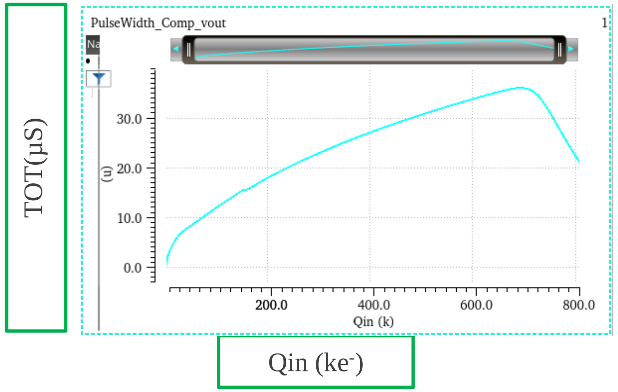
SENSOR'S OVERVIEW – TIIMM1B *(SECOND SUBMISSION – SIMULATIONS ONLY)*



TIIMM1B pixel cell



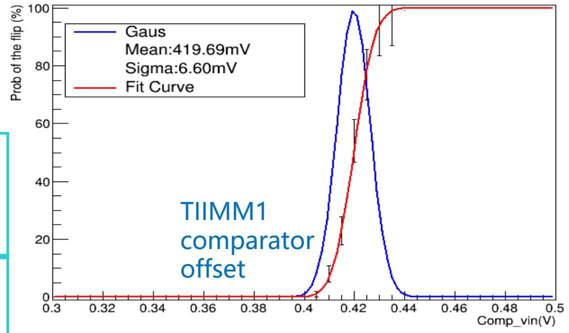
TOT: Time Over Threshold

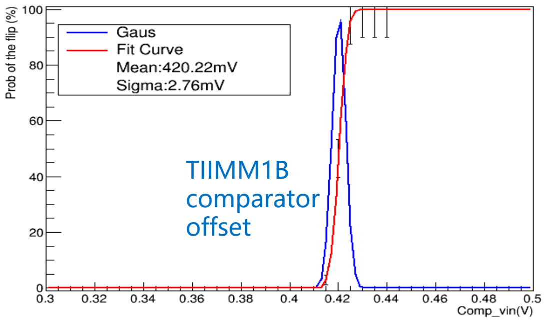


TIIMM1 vs TIIMM1B

- Amplifier structure optimized for larger input dynamic range
- New Comparator structure with less intrinsic input offset

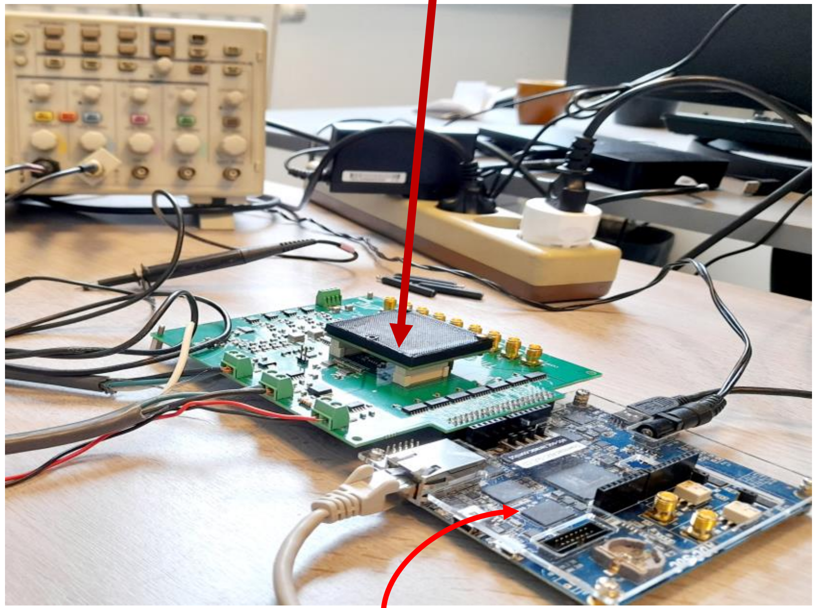
	TIIMM1	TIIMM1B
Range of TOT	Maximum at 250ke-	Maximum at 700ke-
Comparator input offset	6.6 mV	2.7 mV





TIIMM1B – First Functional test results *(single pixel)*

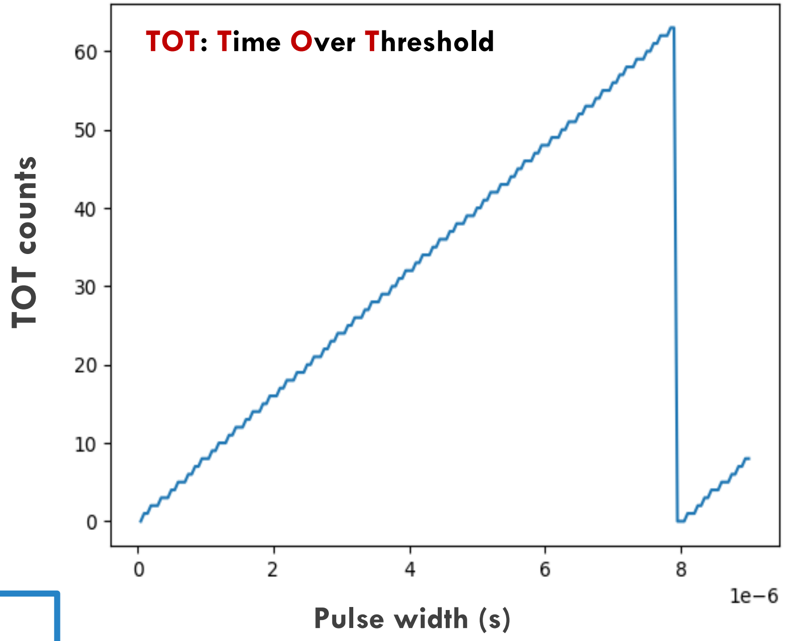
TIIMM1B Sensor covered



Setup:

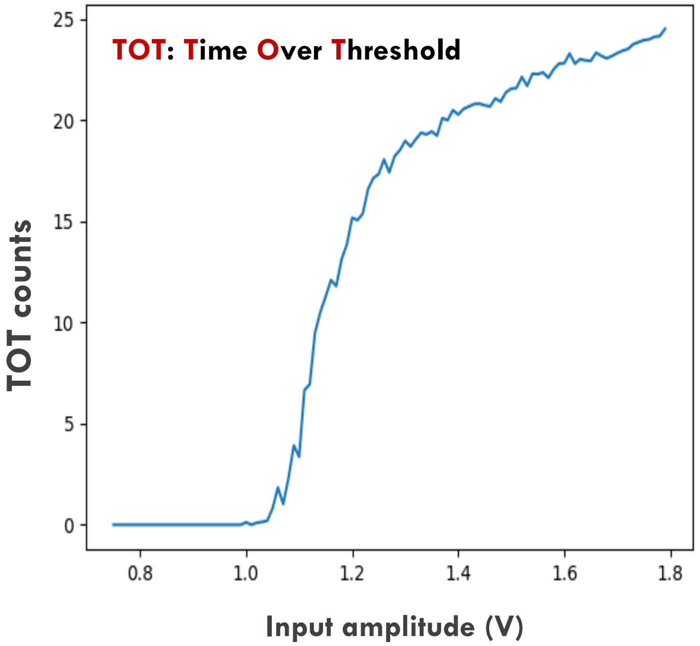
1. **ADC – SOC** (FPGA: Cyclone V with ARM- A9 running Linux)
2. **Automatic controlled Pulses generator**
3. **Sensor prototype wire bonded on custom board**
4. **monitoring ADC, biasing DACs, analog outputs readout**
5. **Full control acquisition system**

Digital part



- External digital pulse generator (hits emulator)
- TOT counting is correct (6bits)

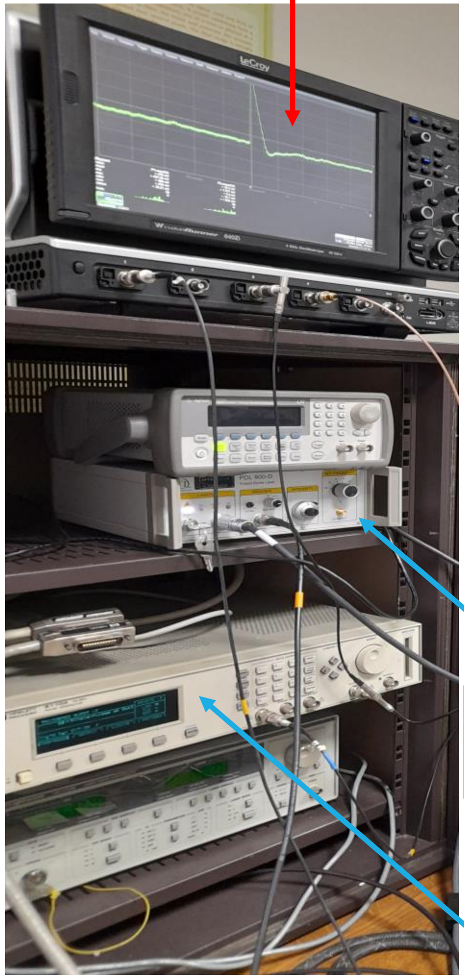
Full chain

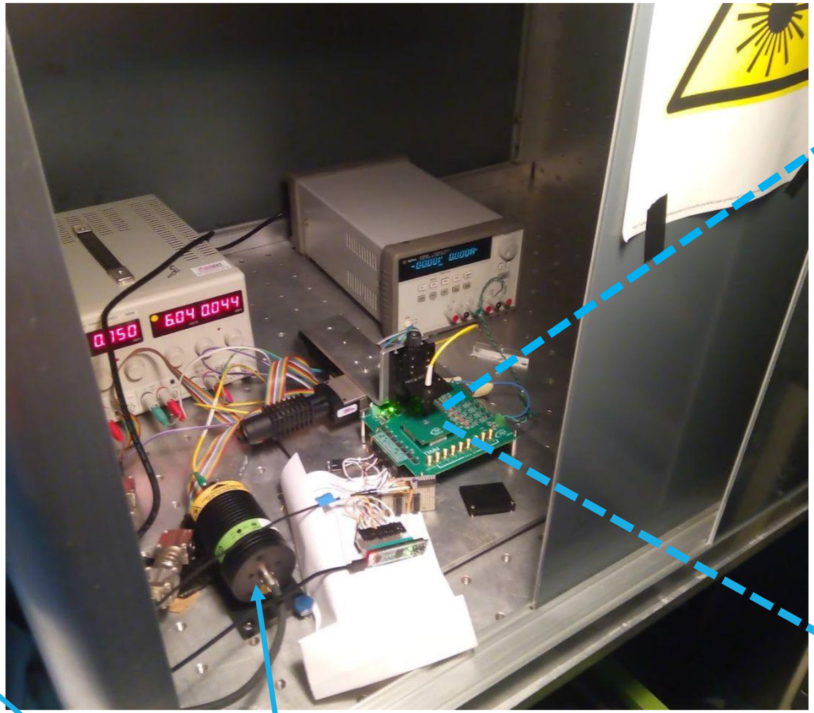


- Internal analog injection pulse (using parasitic capacitor)
- The full chain working

TIIMM1B – FIRST LASER TESTS

Single pixel CSA output signal with 2 laser pulses





Pulsed Diode LASER

(Model LDH-P-C-N-1060)

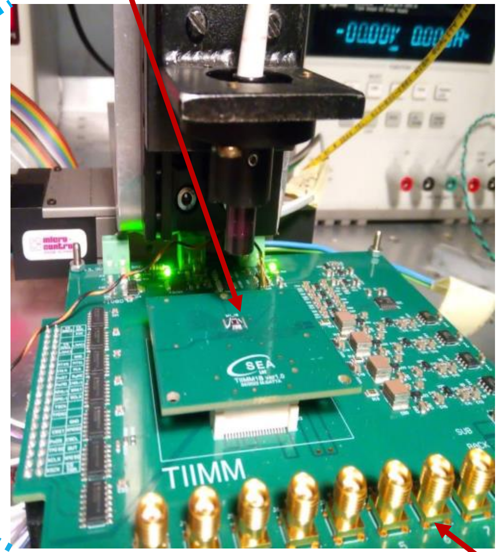
- Selectable repetition frequencies: 3.25 KHz to 80 MHz
- Wavelength *(average): 1061 nm*
- Peak power *(intensity): from 18 mW to 400 mW*
- *FWHM (time-width): 88 ps to 500 ps*

Pulse generator

(Model HP 811A)

- Width: 5 ns ; Period: 10 ns
- Amp: 2 V
- Leading-edge: 2ns ; Trailing-edge: 2ns

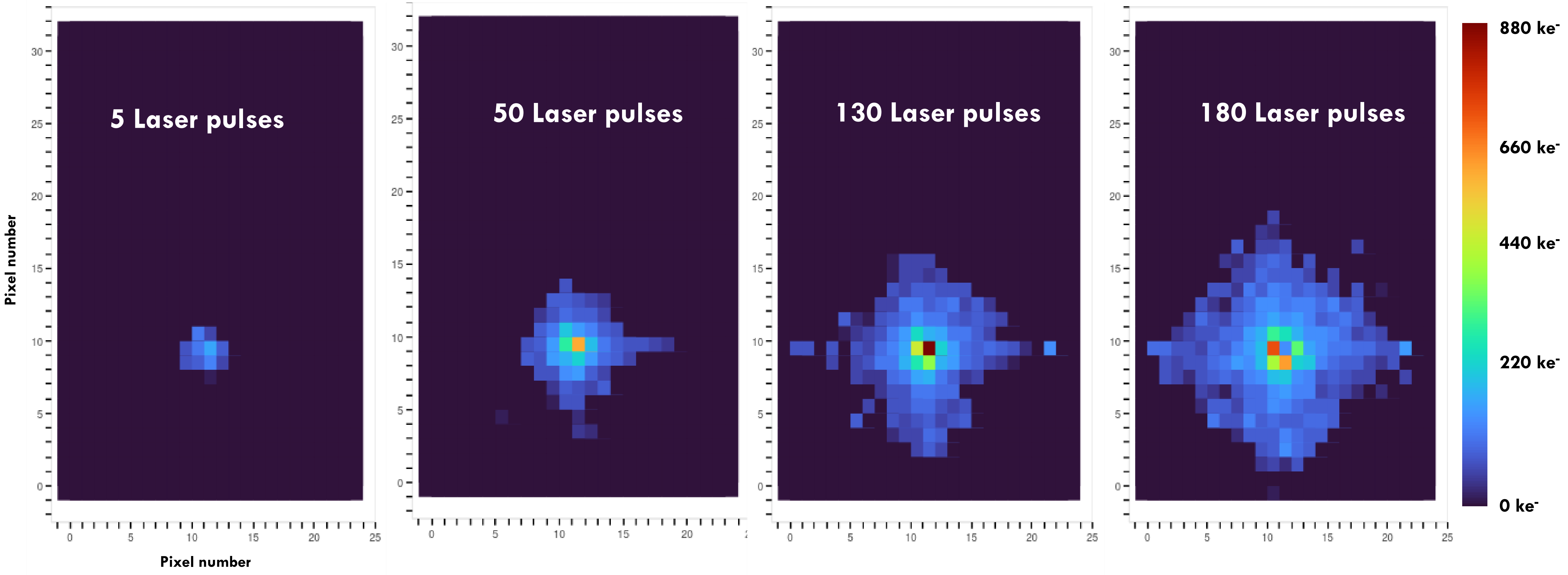
TIIMM1B sensor



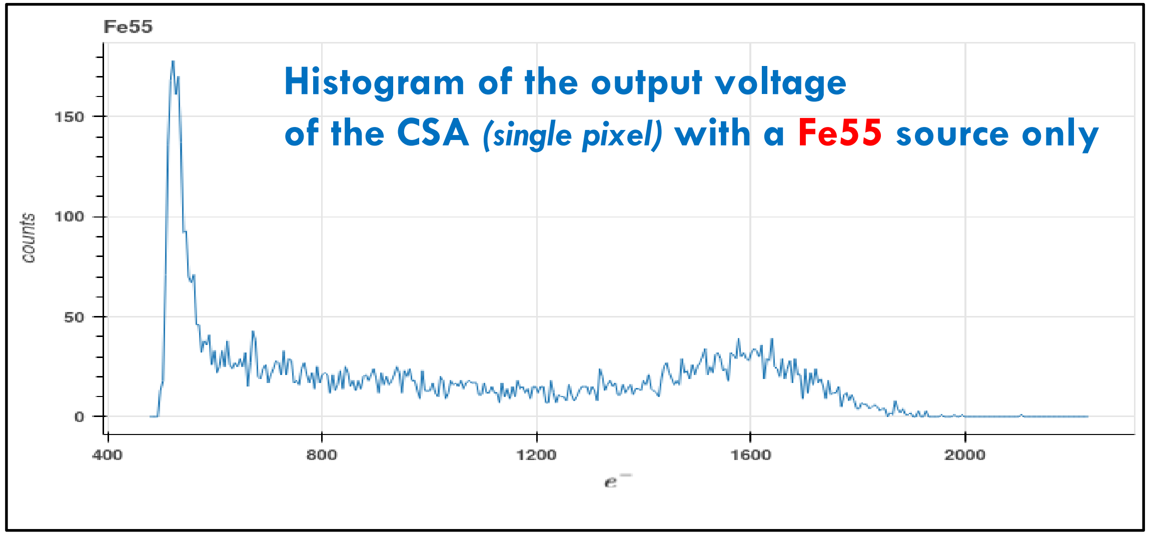
- We can move the laser spot in x/y direction with 1μm step precision
- We are able to inject charge in a single pixel
- Positioning and number of laser pulses are remotely controlled

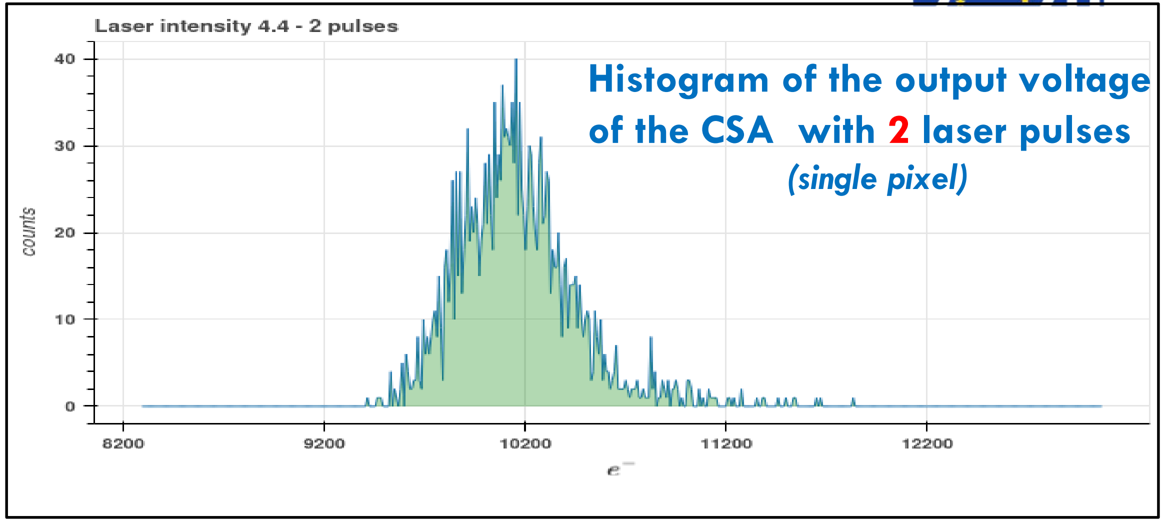
8 analog outputs to perform different measurements with the oscilloscope

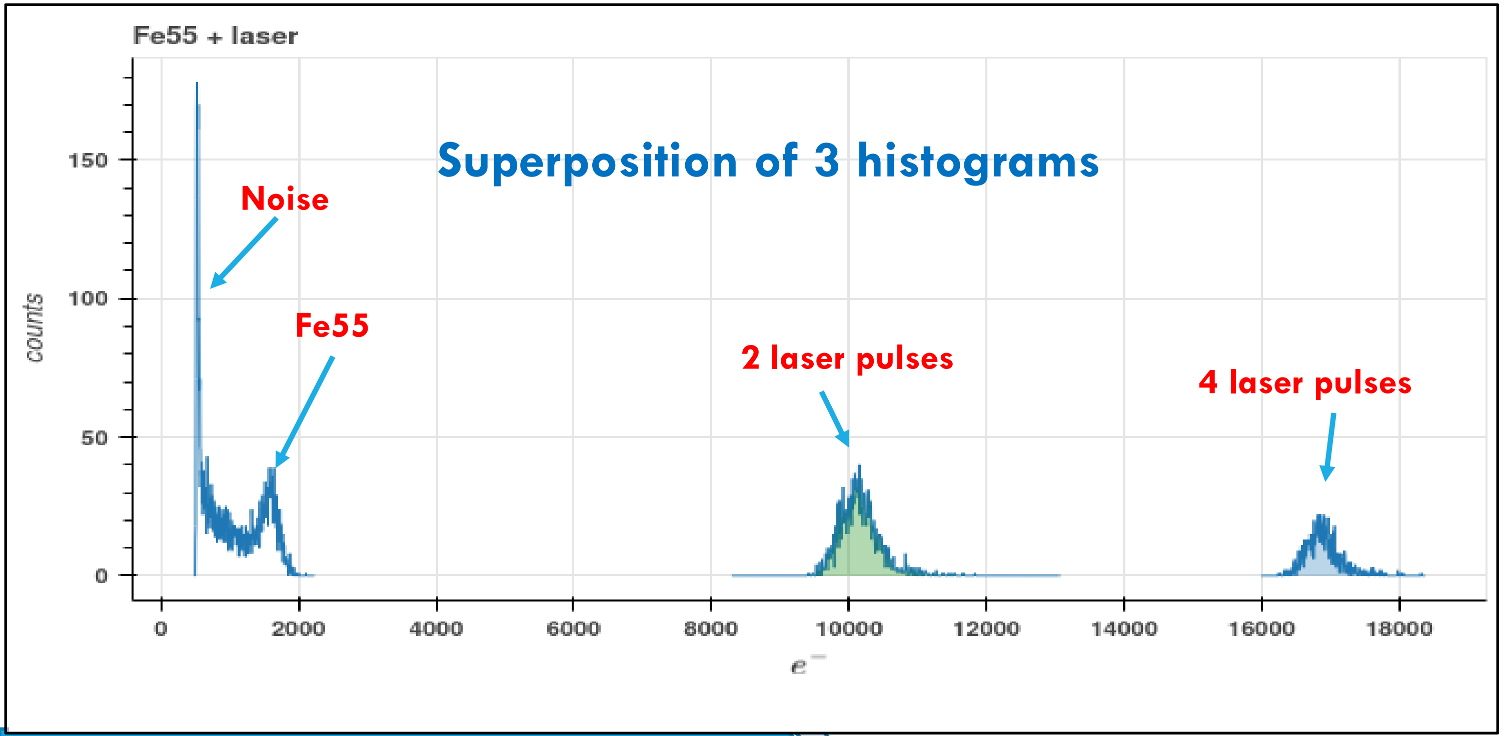
TIIMM1B – FIRST LASER TESTS - FULL MATRIX HEAT MAP

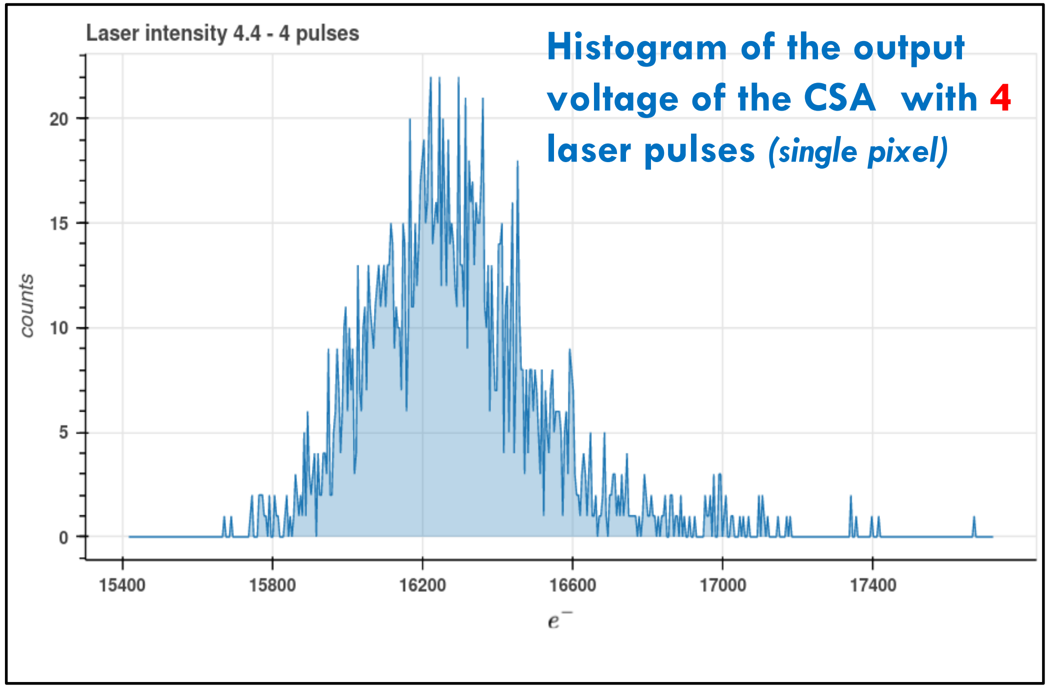


TIIMM1B – CSA output preliminary tests with Fe55 source - Calibration



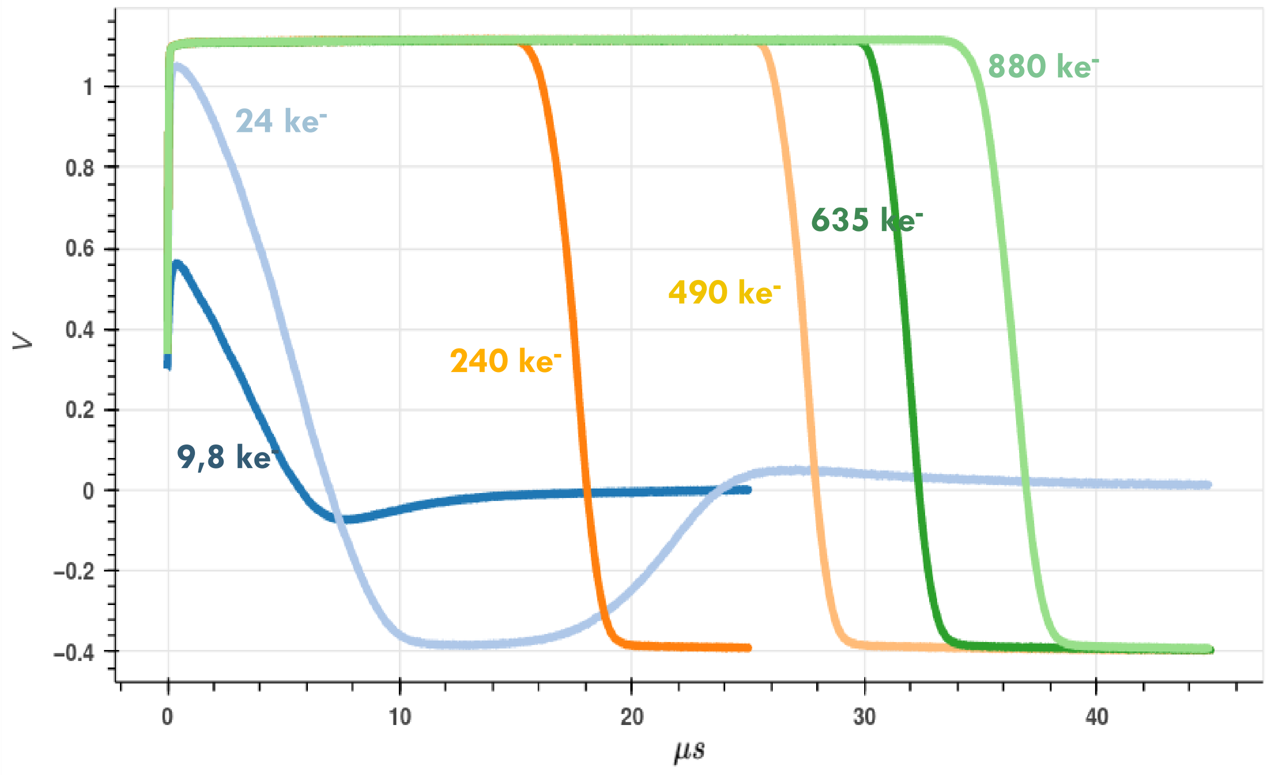


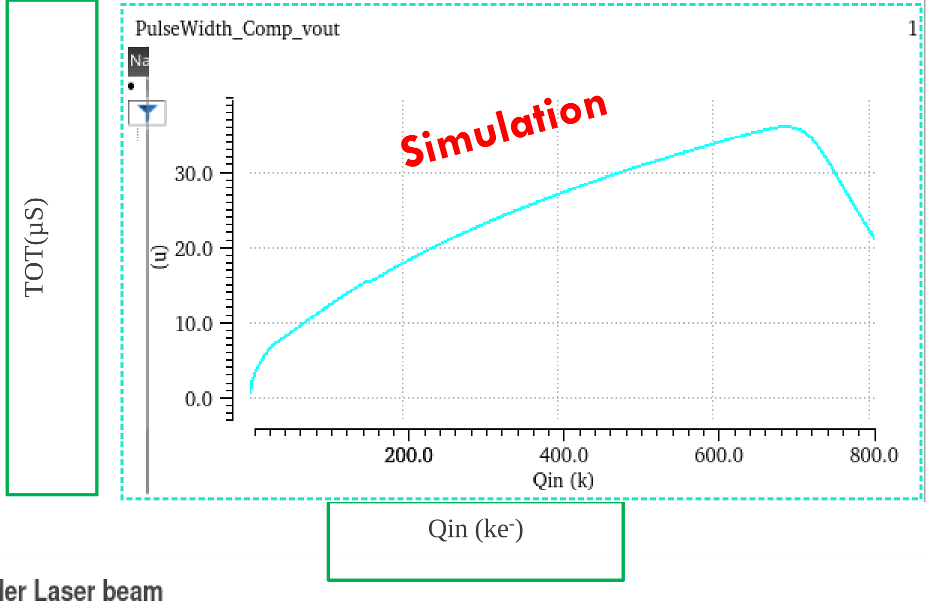


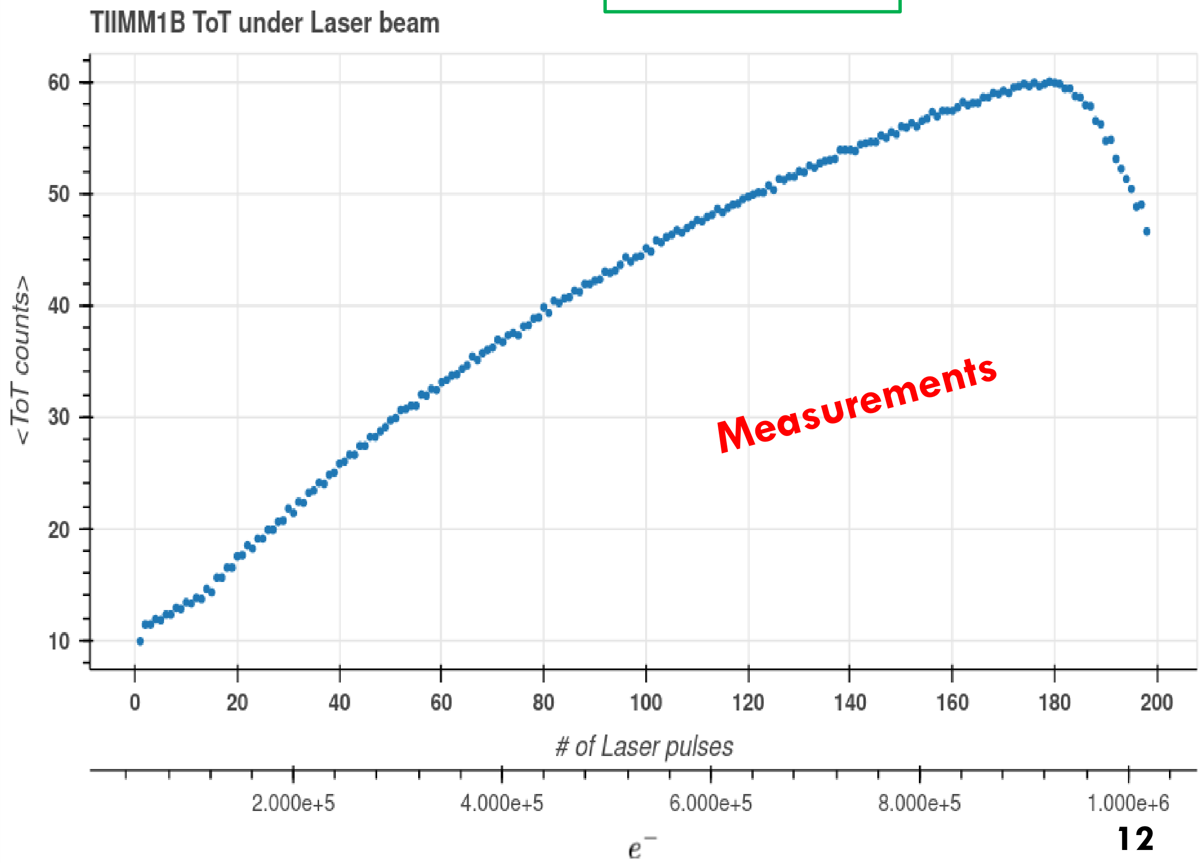


TIIMM1B – FIRST LASER TESTS ENERGY LOSS MEASUREMENT (SINGLE PIXEL TOT)

Charge Sensitive Amplifier output voltage *(oscilloscope)*



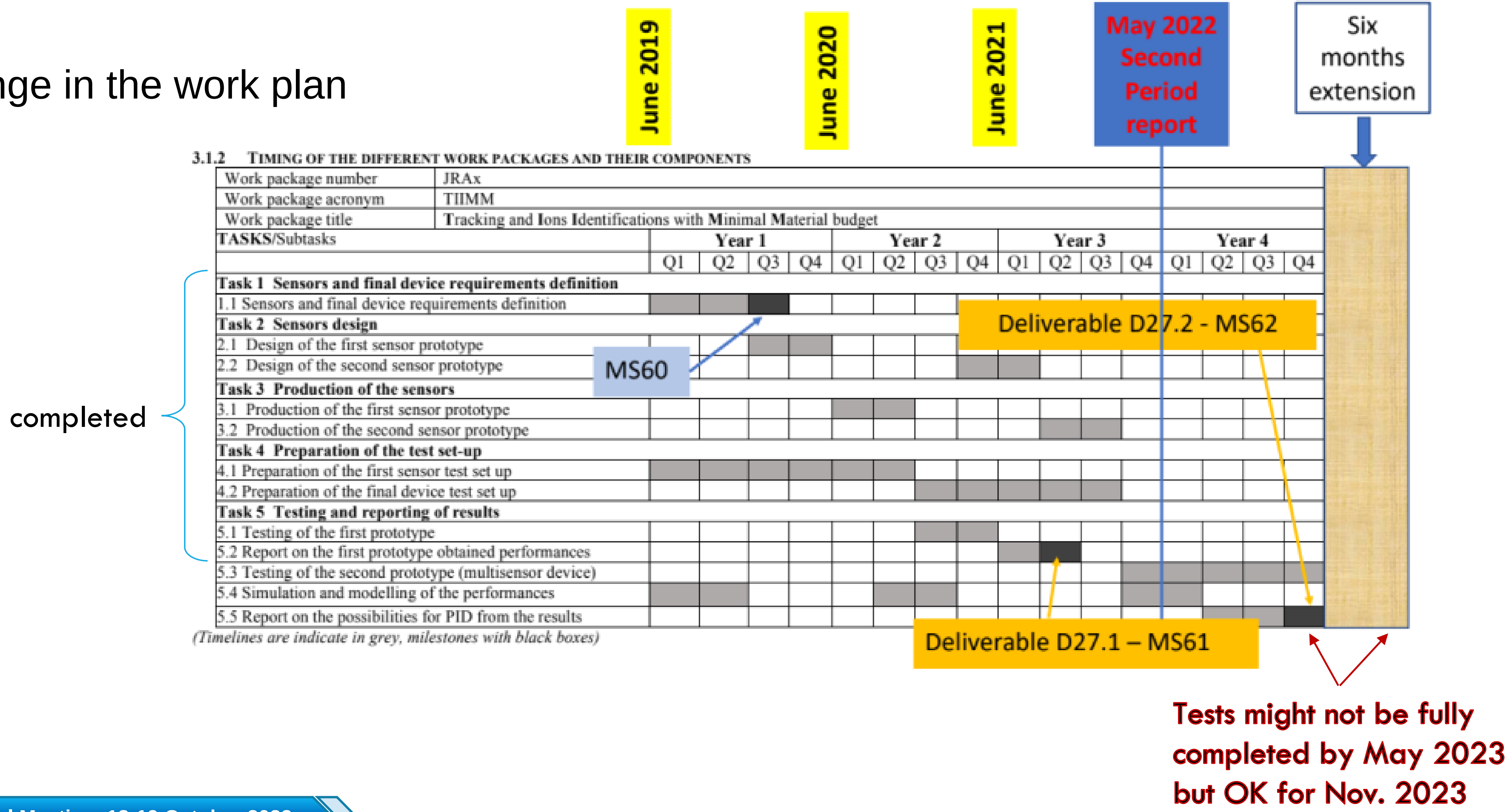




Range of measured charges on single pixel: ~ [500e⁻ , 900Ke⁻]

STATUS ON THE WORK PLAN

No change in the work plan



3.1.2 TIMING OF THE DIFFERENT WORK PACKAGES AND THEIR COMPONENTS

Work package number	JRAx
Work package acronym	TIIMM
Work package title	Tracking and Ions Identifications with Minimal Material budget

TASKS/Subtasks	Year 1				Year 2				Year 3				Year 4			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 Sensors and final device requirements definition																
1.1 Sensors and final device requirements definition																
Task 2 Sensors design																
2.1 Design of the first sensor prototype																
2.2 Design of the second sensor prototype																
Task 3 Production of the sensors																
3.1 Production of the first sensor prototype																
3.2 Production of the second sensor prototype																
Task 4 Preparation of the test set-up																
4.1 Preparation of the first sensor test set up																
4.2 Preparation of the final device test set up																
Task 5 Testing and reporting of results																
5.1 Testing of the first prototype																
5.2 Report on the first prototype obtained performances																
5.3 Testing of the second prototype (multisensor device)																
5.4 Simulation and modelling of the performances																
5.5 Report on the possibilities for PID from the results																

(Timelines are indicate in grey, milestones with black boxes)

CONCLUSIONS & EXTENSION BEYOND NOVEMBER 2023

Current results of second prototypes are very promising

- Continue in-lab test
- Beam tests with ions planned in first half of 2023

Possibility to extend the scope of our WP

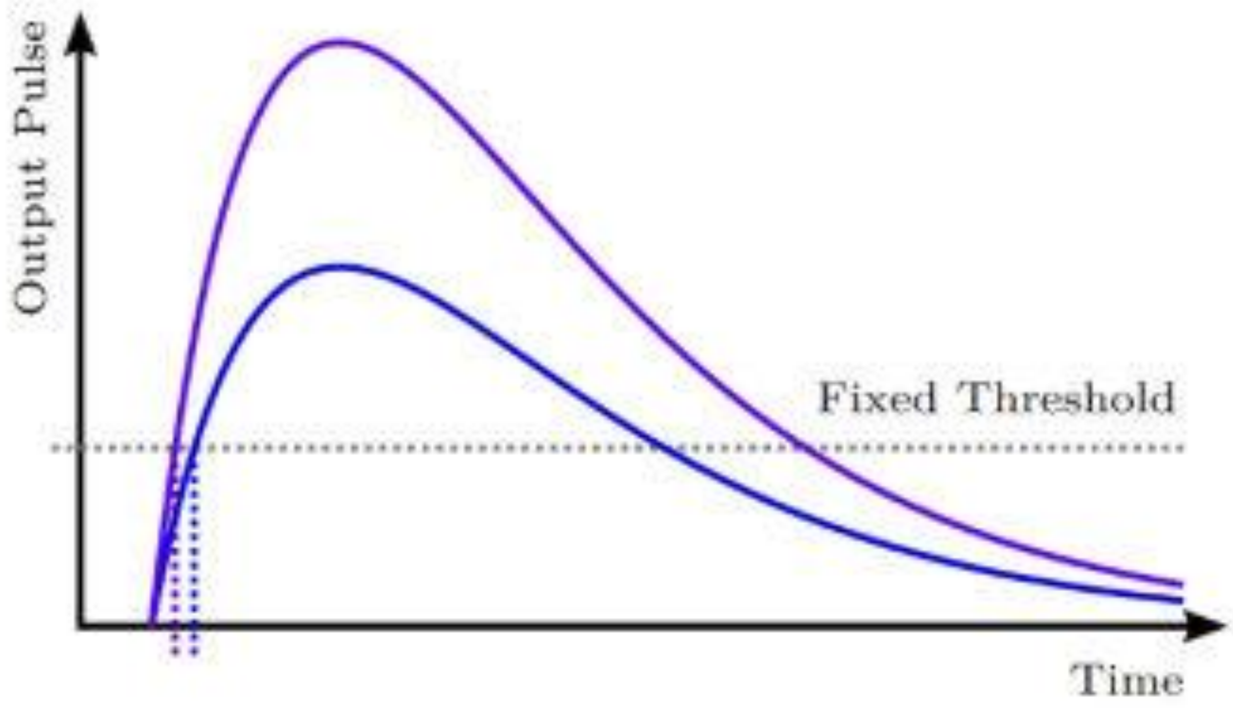
- Combine the pixel front-end developed within TIIMM with a **faster** scalable matrix digital read-out
- Third prototype, still small area (~ 5 x 5 mm^2), but otherwise almost complete sensor / usage in experiment

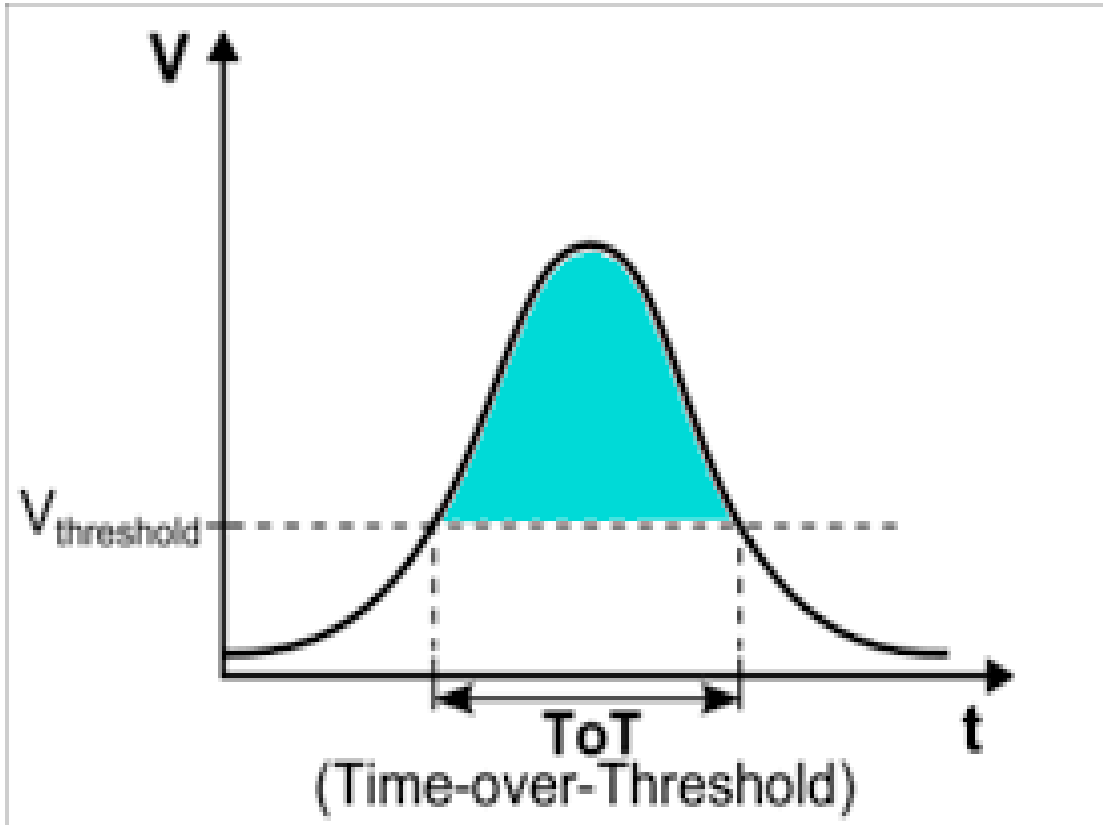
Schedule

- Third prototype design can be achieved within current project but not with delivery and tests.
- Fabrication and Tests would require an additional 6-12 months

THANKS

Backup


Output Pulse
Fixed Threshold
Time


V
$V_{threshold}$
t
ToT
(Time-over-Threshold)