

Edge-TCT studies of irradiated HV-CMOS sensors and first test beam results with monolithic H35demo chips

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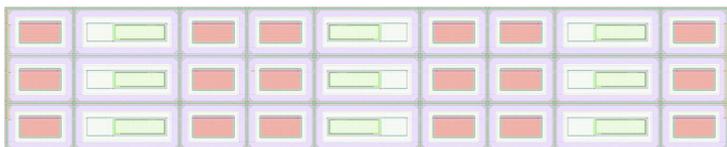
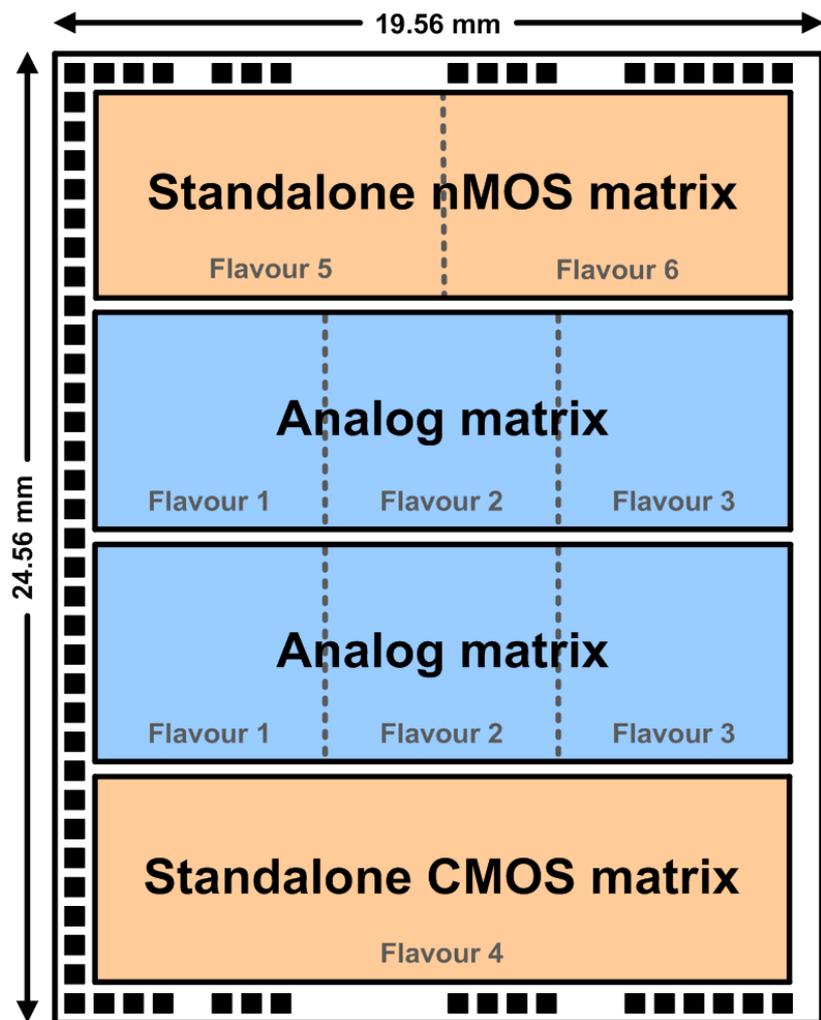
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TCT measurements and irradiations in collaboration with G. Kramberger and I. Mandić
Test beam measurements in collaboration with University of Geneva

The H35 Demonstrator

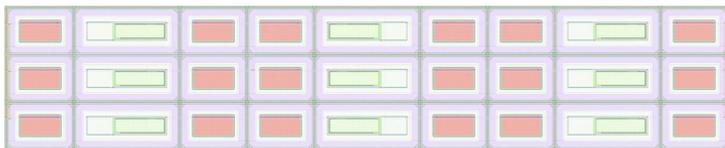
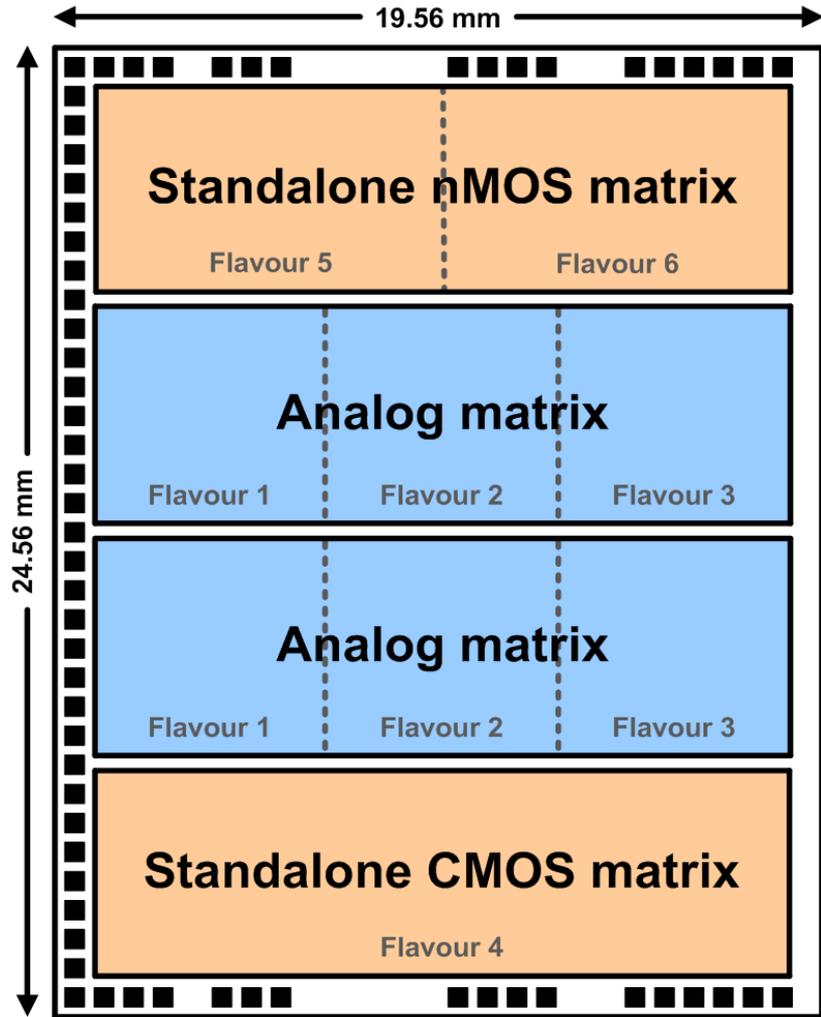


- AMS 0.35 μm High Voltage CMOS

- **Standalone nMOS matrix:**
 - Digital pixels with in-pixel nMOS comparator
 - Two flavors: with and without Time Walk (TW) compensation
- **Analog matrices (2 arrays):**
 - Different flavors in terms of gain and speed
 - To be Capacitive Coupled (CC) to FE-I4 readout chips
- **Standalone CMOS matrix:**
 - Analog pixels with off-pixel CMOS comparator
- Different ρ : 20–80–200–1000 Ωcm

+ test structures without electronics for TCT studies

The H35 Demonstrator

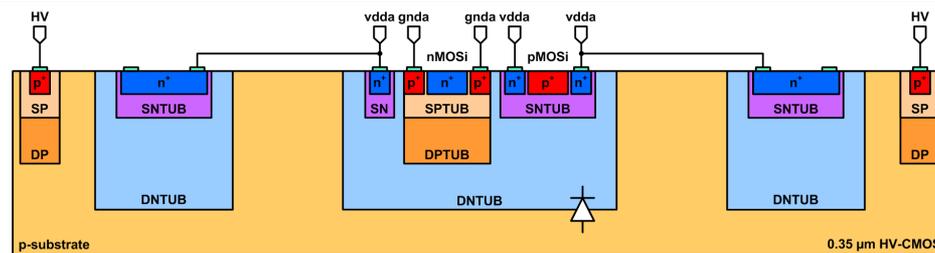


Edge-TCT studies of test structures

Sensor characterization

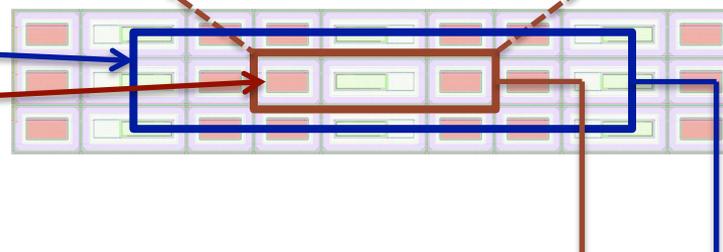
H35 pixel cell structure

- p-substrate + 3 deep n wells
 - Lower capacitance (noise, timing)
 - Reduce trapping
- Bias from the top -> single sided



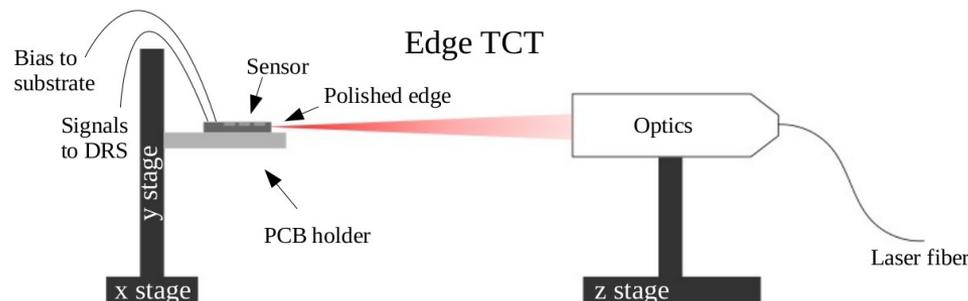
Characterization of H35 test structures:

- 3x3 pixel structures w/o electronics
- External pixels shorted together
- Separate readout of the central pixel
- $\rho = 80 \Omega\text{cm} - 200 \Omega\text{cm} - 1 \text{ k}\Omega\text{cm}$



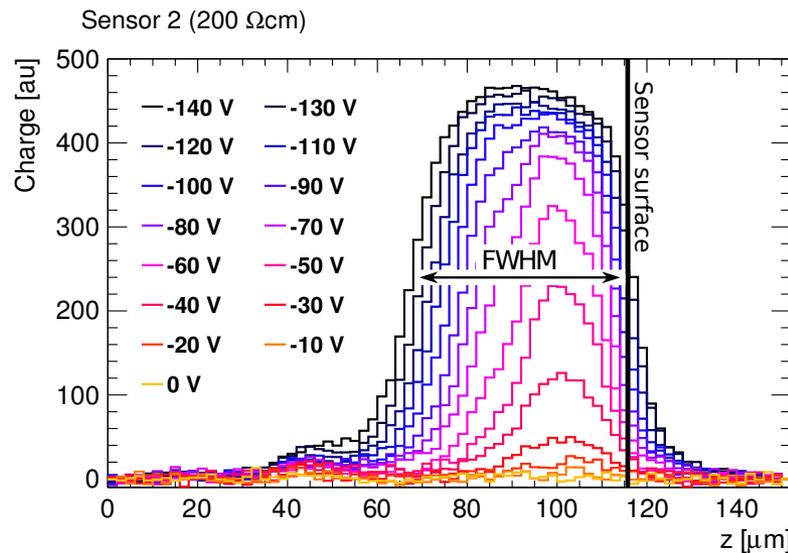
The Edge-TCT setup:

- Infra-red laser (1064 nm)
 - Beam spot about $10 \mu\text{m}$ FWHM
 - Pulses of about 500 ps
- Readout: DRS4 evaluation board
 - 700 MHz bandwidth
 - 5 GSPS
 - 200 ns sampling depth
 - Four channels: 1 × trigger, 1 × beam monitor, 2 × readout



Depletion: before irradiation

- Depletion depth is defined by the FWHM of the charge collection profile

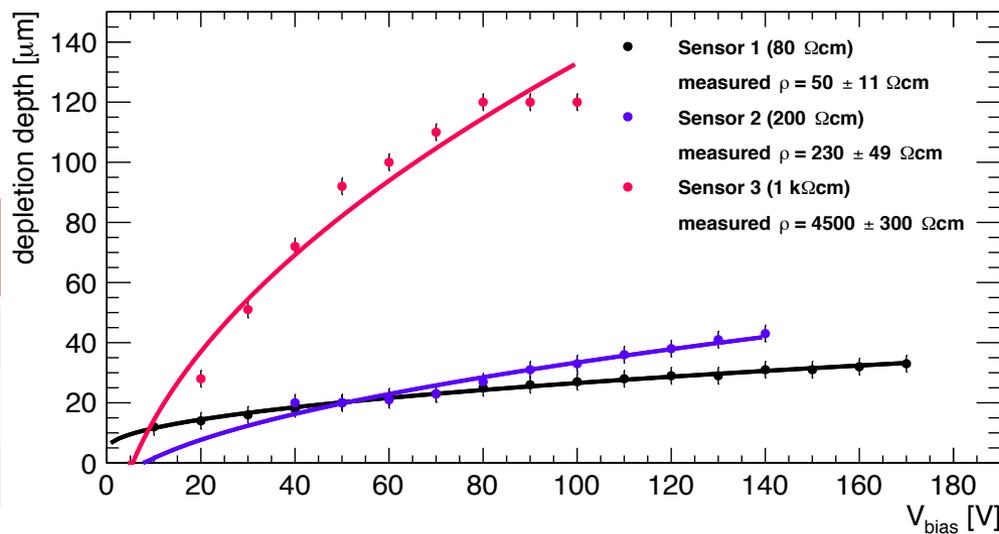


- Resistivity obtained fitting the depletion depth as a function of the bias voltages

$$d(V) = d_0 + \alpha \sqrt{\rho V}$$

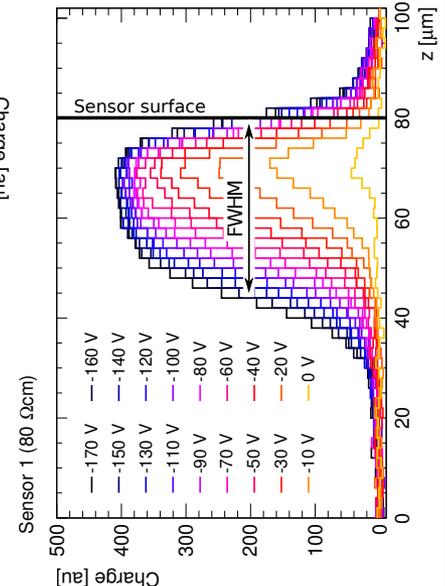
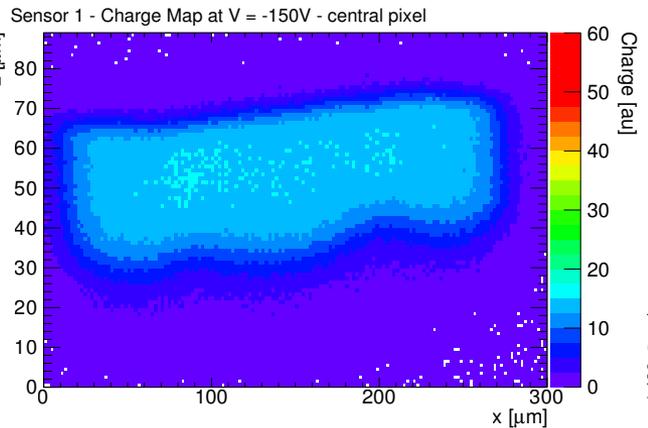
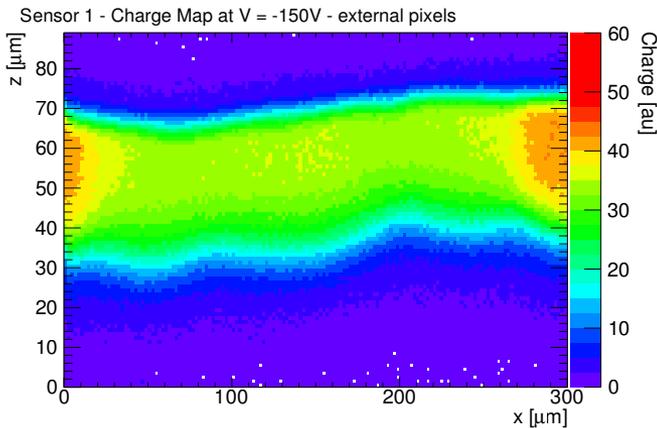
with $\alpha = \sqrt{2\epsilon\epsilon_0\mu}$

	ρ nominal	ρ measured
Sensor 1	80 Ω cm	50 \pm 11 Ω cm
Sensor 2	200 Ω cm	230 \pm 49 Ω cm
Sensor 3	1000 Ω cm	4500 \pm 300 Ω cm



Depletion: before irradiation

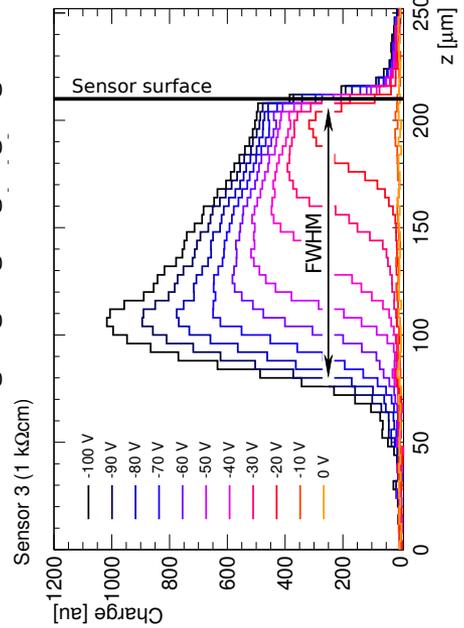
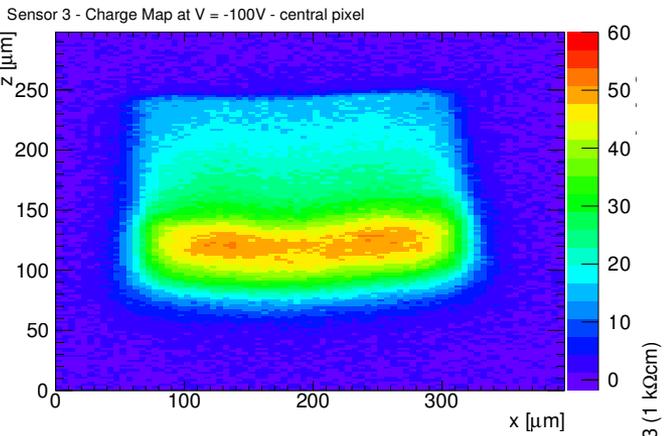
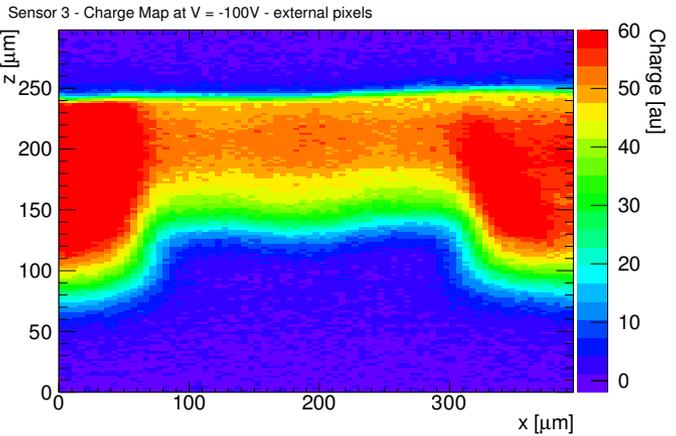
80 Ω cm



External pixels

Central pixel

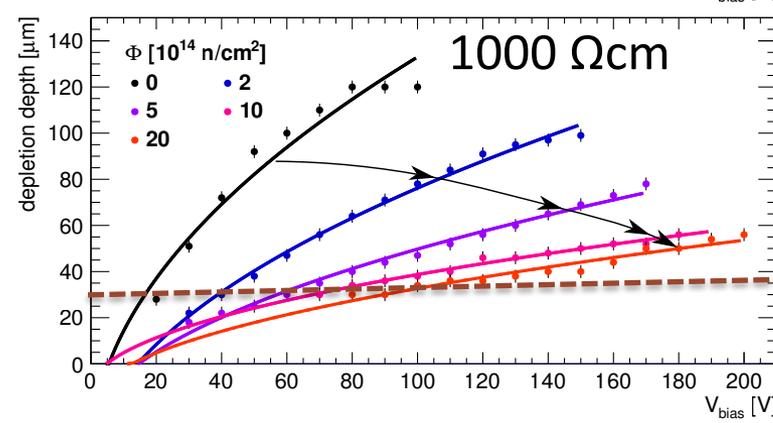
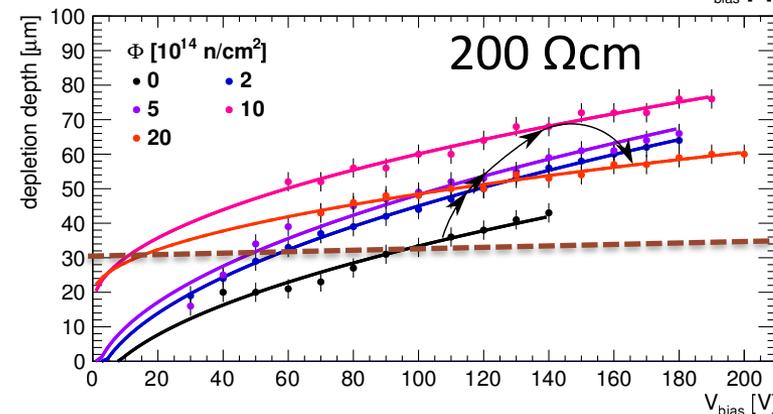
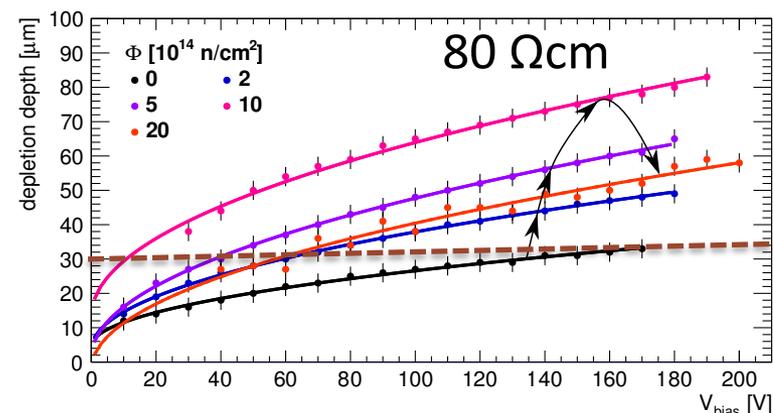
1000 Ω cm



When depletion gets larger of 100 μ m the central pixel starts to collect charge from the neighboring pixels

Depletion: after irradiation

- Irradiation at the TRIGA neutron reactor at JSI, Ljubljana:
 - Now: **2e14**, **5e14**, **10e14**, **20e14** $n_{eq}cm^{-2}$
 - Next steps: 5e15 and 1e16 $n_{eq}cm^{-2}$
- Acceptor removal effect visible for lower substrate resistivities which leads to an increase of the depletion depth after irradiation up to $2e15 n_{eq}cm^{-2}$
- Due to the low initial acceptor concentration in the 1000 Ωcm sample the creation of stable acceptors dominates and the depletion depth decreases after irradiation



Effective doping concentration

- Effective doping concentration obtained from:

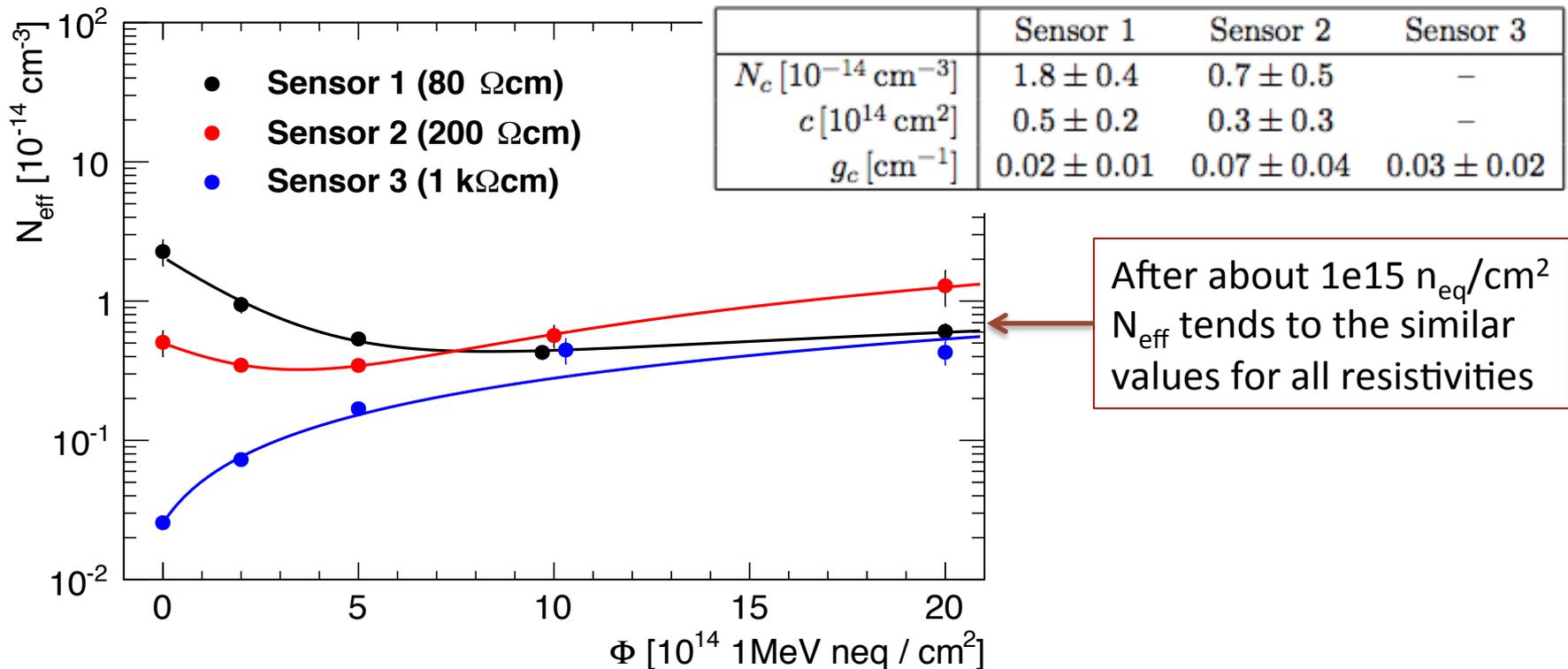
$$d(V) = d_0 + \alpha\sqrt{\rho V} = d_0 + \sqrt{\frac{2\epsilon\epsilon_0}{eN_{eff}}} V$$

$$N_{eff} = \underbrace{N_{eff0}}_{\text{Initial doping}} - \underbrace{N_c \cdot (1 - \exp(-c \cdot \Phi_{eq}))}_{\text{Acceptor removal}} + \underbrace{g_c \cdot \Phi_{eq}}_{\text{Acceptor introduction}}$$

Initial doping

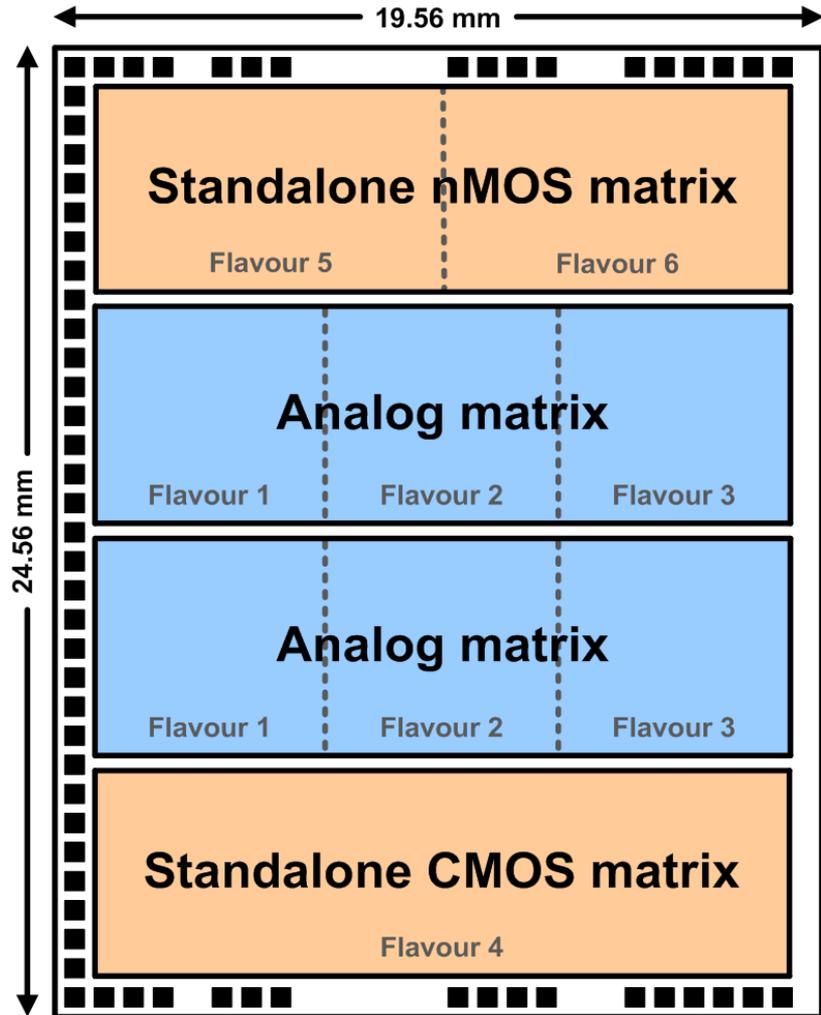
Acceptor removal

Acceptor introduction

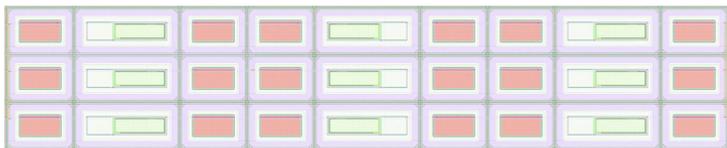


Results submitted to JINST, *E. Cavallaro et al.*, [arXiv:1611.04970](https://arxiv.org/abs/1611.04970)

The H35 Demonstrator



Test beam measurements of the standalone CMOS matrix



Standalone matrix readout

Adapter PCBs

- 1x H35 PCB
- 1x test signals
- 1x trigger board

Trigger board

- Trigger in
- Busy out
- RJ45



Xilinx ZC706 FPGA board

- Same as Caribou system

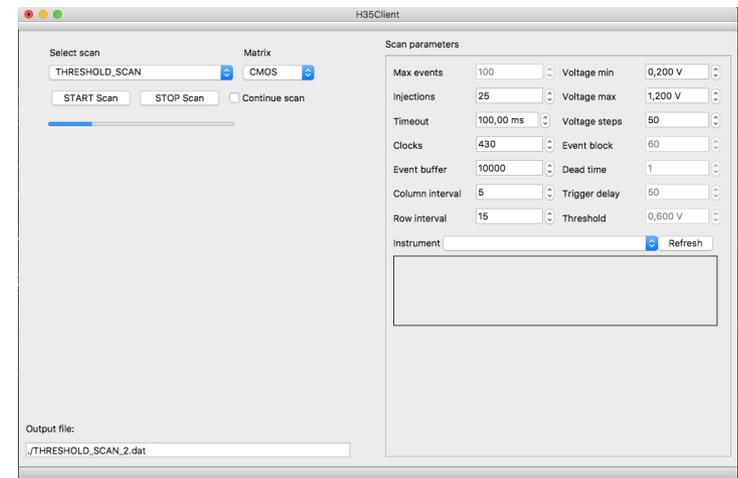
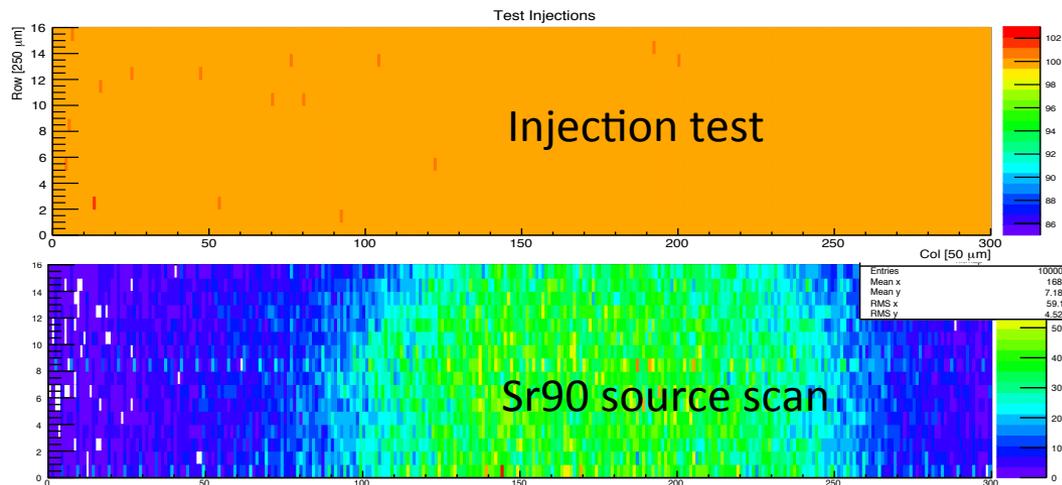
H35demo PCB

- External voltage regulators
- Sensor bias input
- Injection pulse input
- Analog signal output

H35demo chip

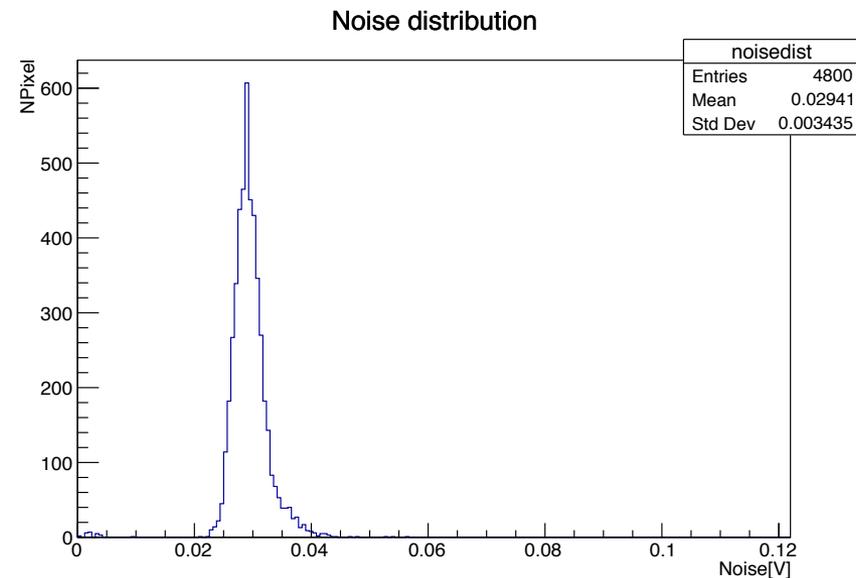
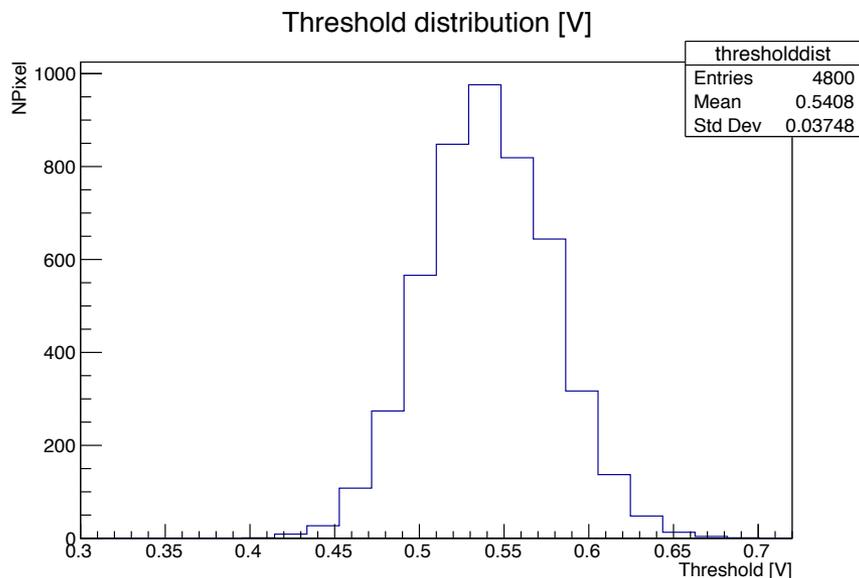
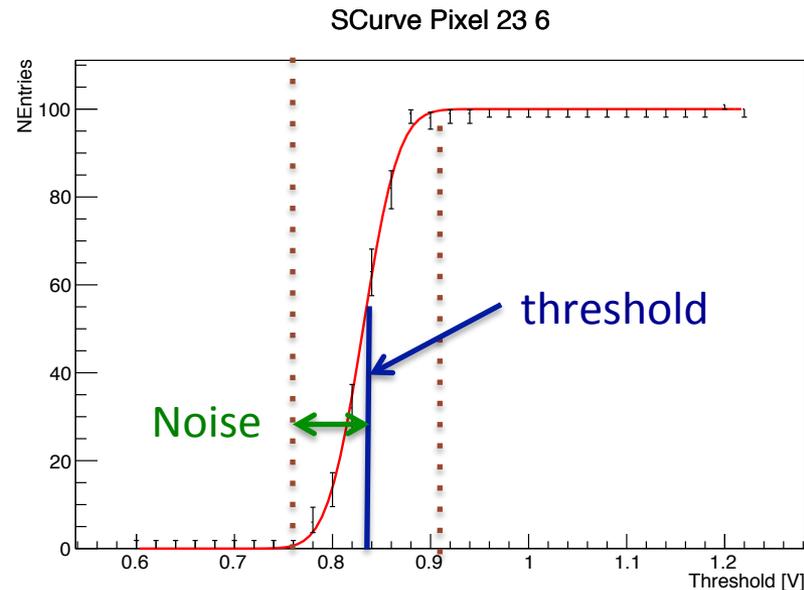
- Both CMOS and nMOS matrices wire-bonded

PCBs, FPGA firmware and steering software developed at IFAE



CMOS matrix: tuning

- The chip is tuned just with the global registers
- Calibration V to e⁻ still missing
- Nevertheless the threshold has a reasonable spread and the noise is about 9 sigma lower
 - Threshold: 0.54 ± 0.04 V
 - Noise: 0.030 ± 0.003 V



Test beam setup at SpS

UniGe cooling box with H35demo Capacitive
Coupled to ATLAS FE-I4 chips

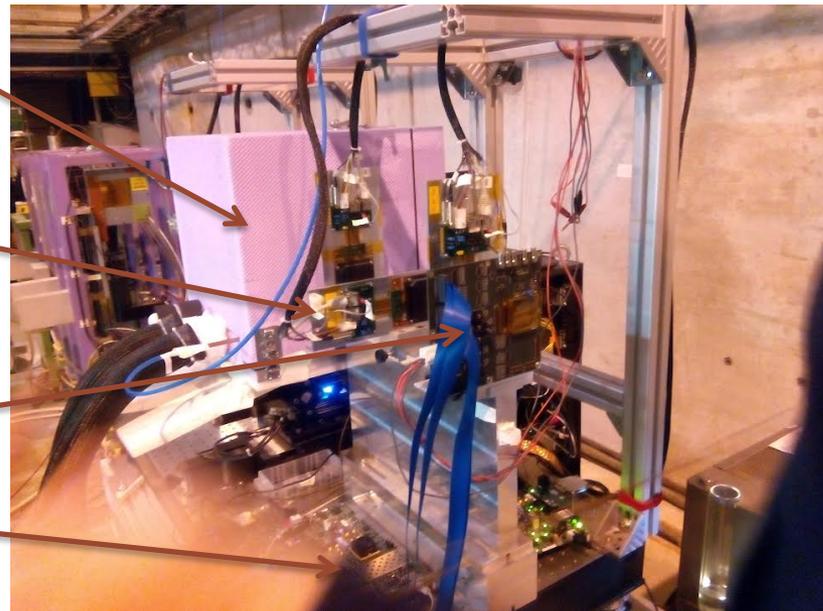
UniGe Telescope*

- 6x FE-I4 planes
- 2 planes rotated 90 degrees

H35demo PCB

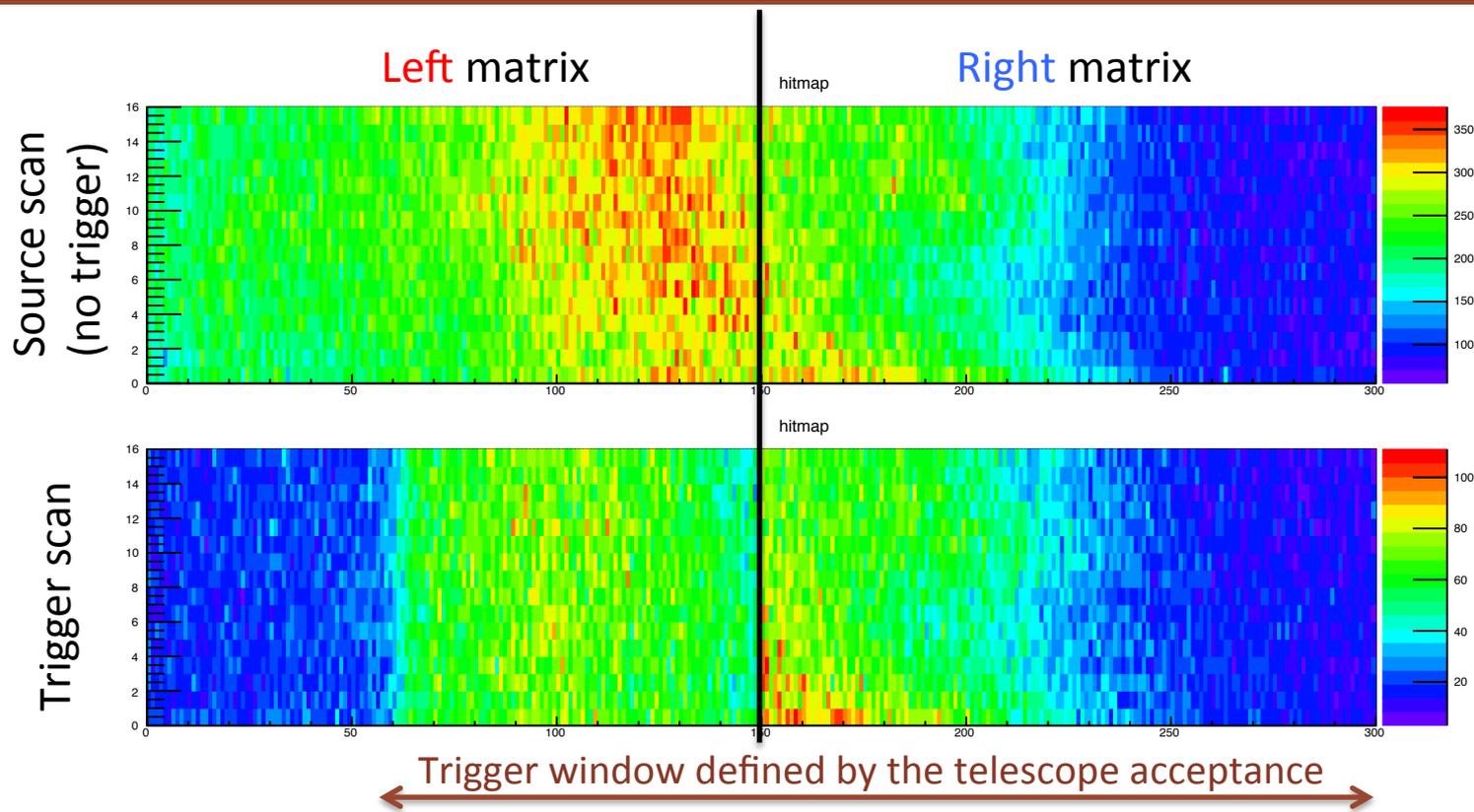
- CMOS matrix aligned in the beam

Xilinx board



- **Integration with the Geneva FE-I4 telescope (Trigger – busy scheme)**
 - Triggers from the telescope (RCE – HSIO based) reach the Xilinx FPGA board
 - Busy signal from the FPGA stops telescope DAQ until H35 is ready
 - Triggers (events) are written sequentially by the separate DAQs
- **De-synchronization problem**
 - Our trigger board sees less triggers than the telescope actually sent
 - A posteriori re-synchronization performed based on trigger time-stamp comparison

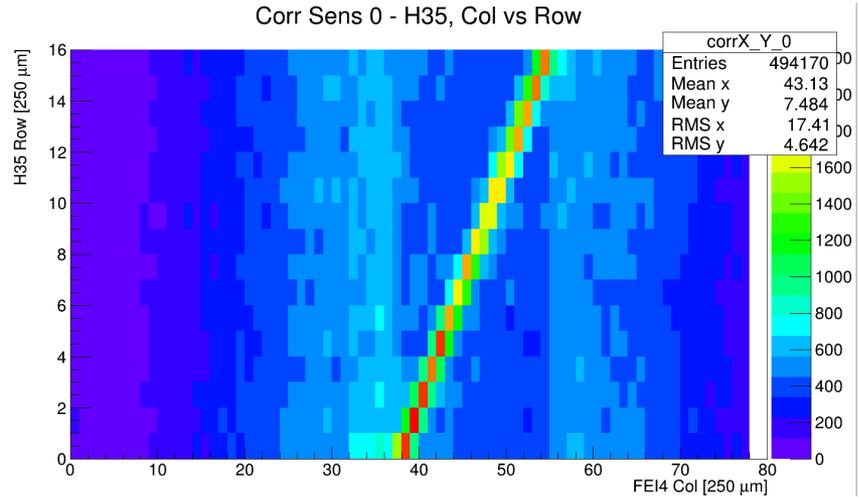
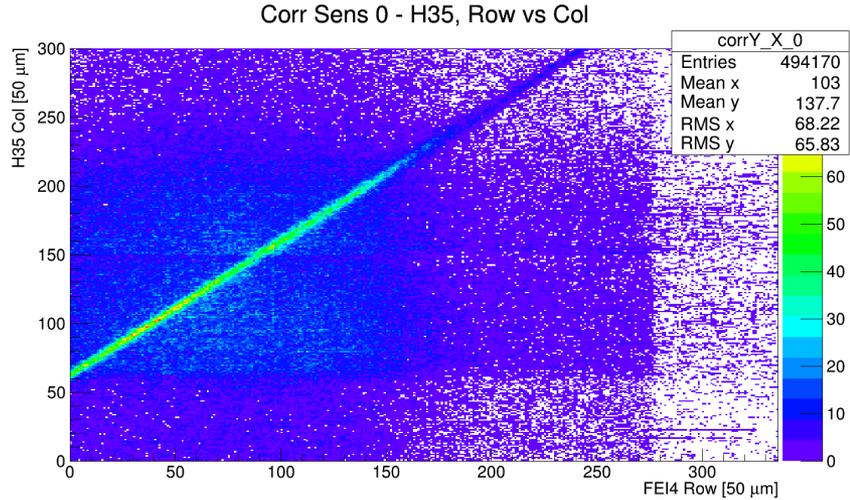
CMOS matrix: hitmaps



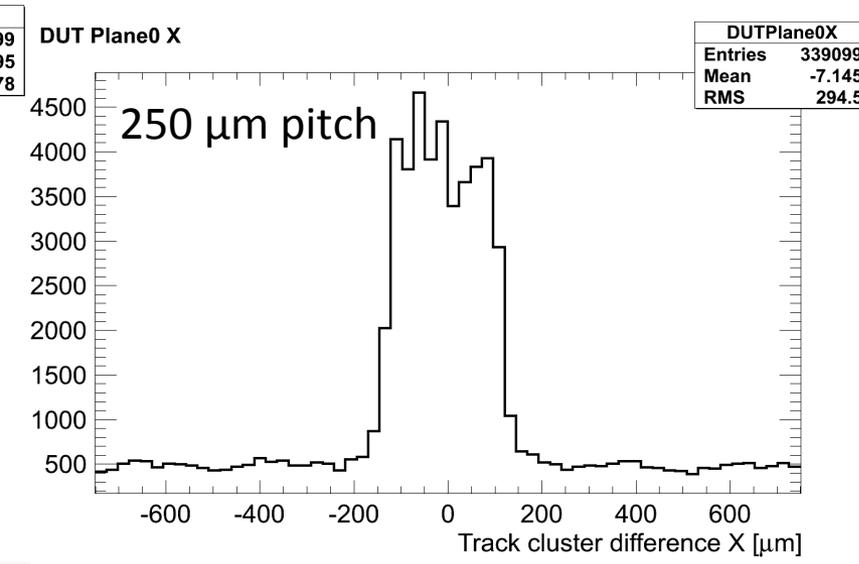
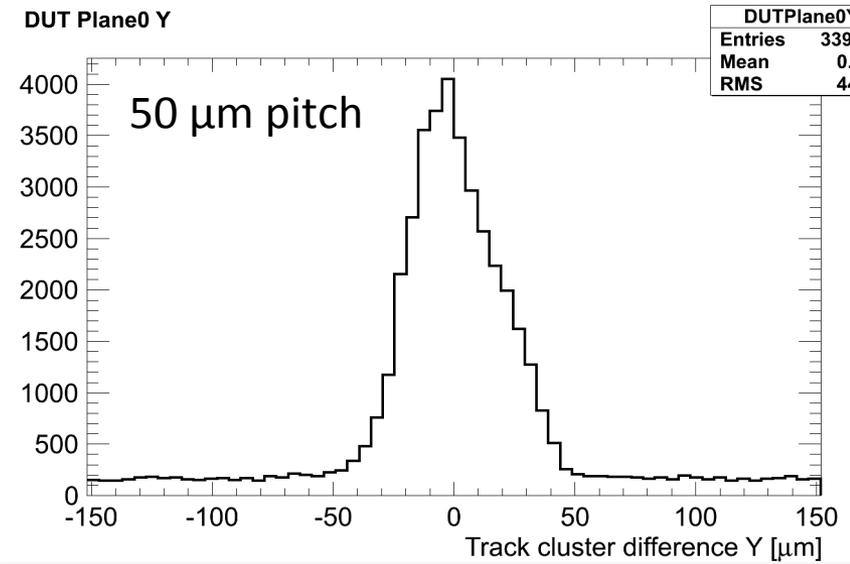
- Different behavior of the left and right part of the matrix
 - The two parts are read out on different lines
 - The data of the two arrives at the FPGA with different trigger delays
 - Timing properties still to be investigated

Synchronization and alignment

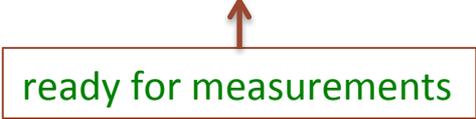
- Correlations between the hits in the H35 CMOS matrix and a telescope plane after re-synchronization of the events show the successful synchronization of the data



- Expected residual shape after alignment and tracking



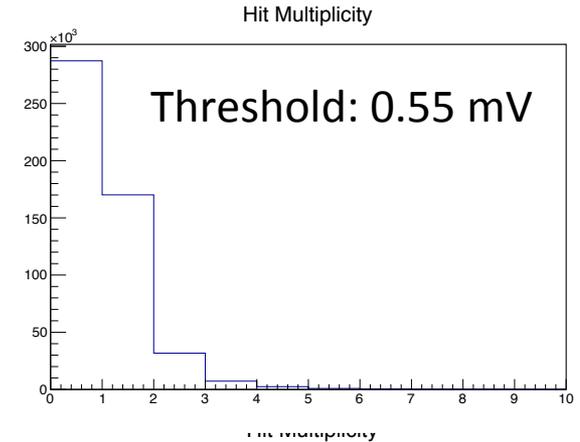
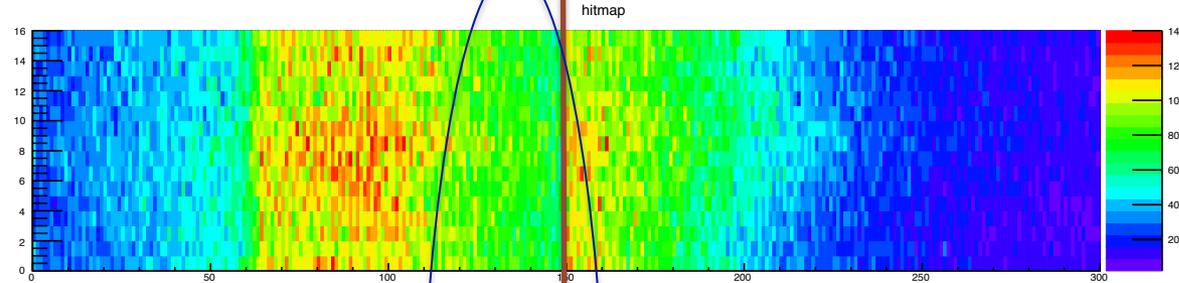
Conclusions

- Edge-TCT studies of the H35demo test structures with different resistivities
 - Acceptor removal effect increases the depletion depth for 80 and 200 Ωcm devices up to $1\text{e}15\text{ n}_{\text{eq}}\text{cm}^{-2}$ (It decreases again at $2\text{e}15\text{ n}_{\text{eq}}\text{cm}^{-2}$)
 - After $1\text{e}15\text{ n}_{\text{eq}}\text{cm}^{-2}$ the effective doping concentrations is similar for all tested resistivities
 - After this fluence a collection layer of at least $30\ \mu\text{m}$ is always achievable increasing the bias voltage over 100 V
 - Two more irradiation steps planned: **5e15** and $1\text{e}16\text{ n}_{\text{eq}}\text{cm}^{-2}$
- 
- Very first time of the H35 standalone matrices in a test beam
 - New readout system developed at IFAE + Geneva FE-I4 telescope
 - Re-synchronization of the data: good correlations and residuals
 - Data analysis ongoing to understand the difference between left and right matrix halves and calculate efficiencies

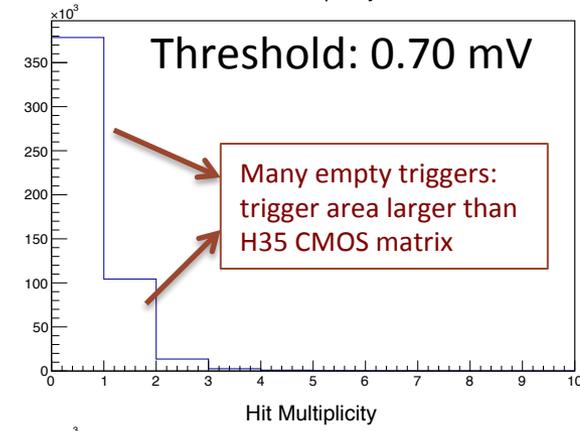
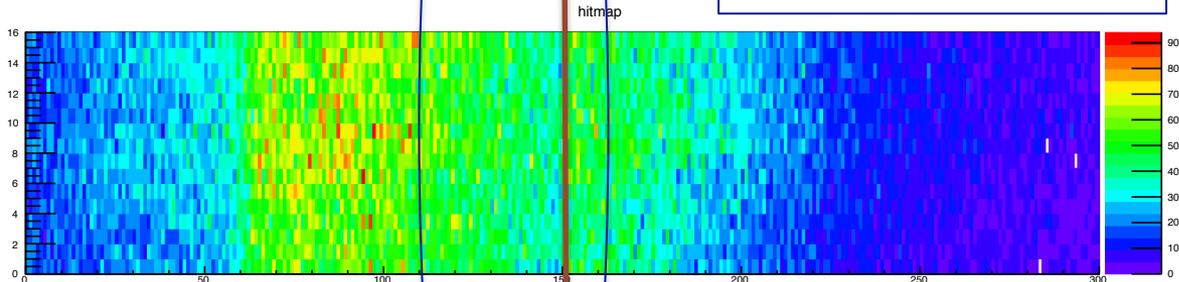
Backup

Raw Data example: HV=120 V

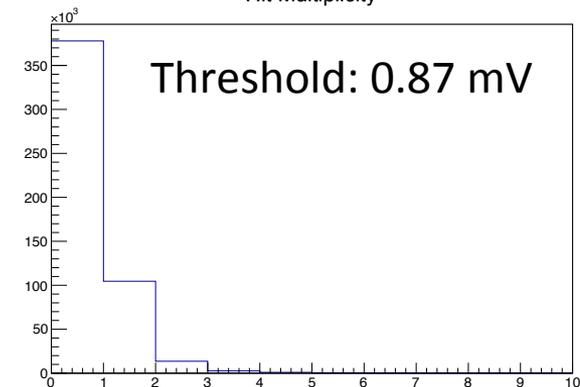
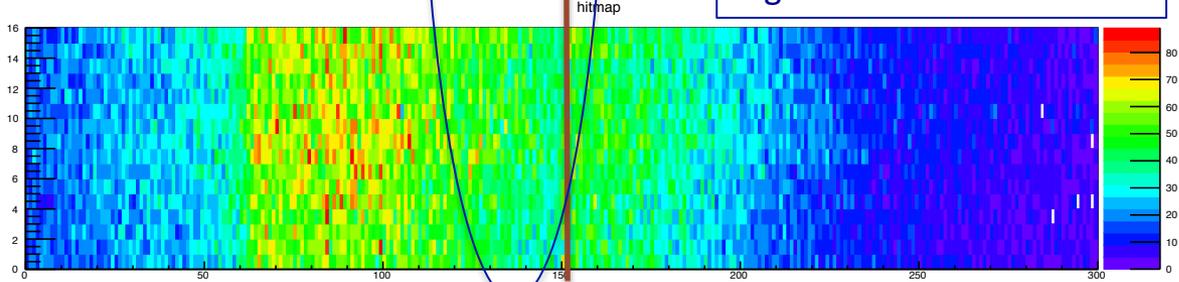
Threshold: 0.55 mV



Threshold: 0.70 mV

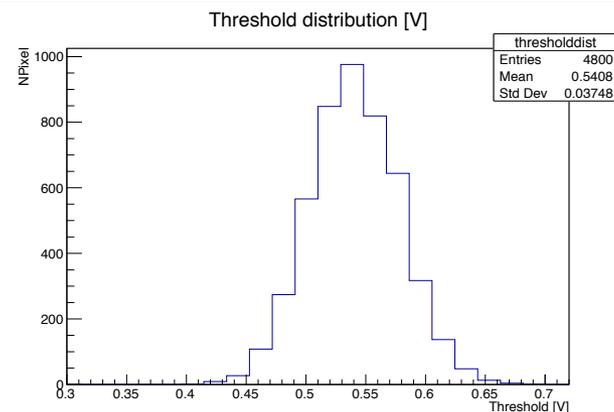
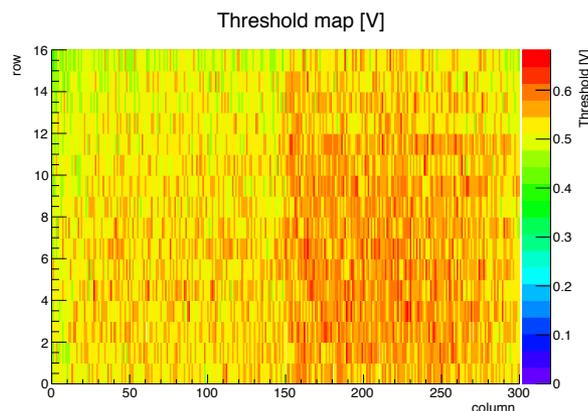


Threshold: 0.87 mV

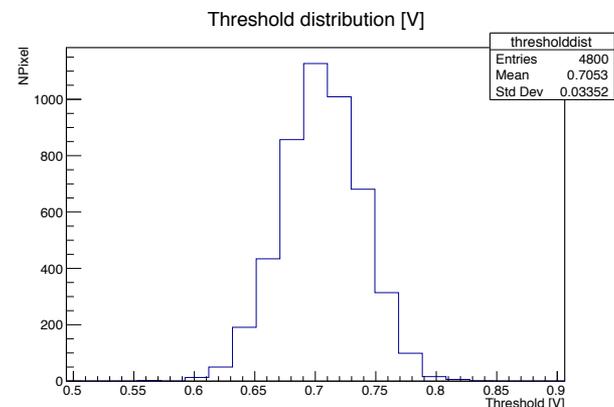
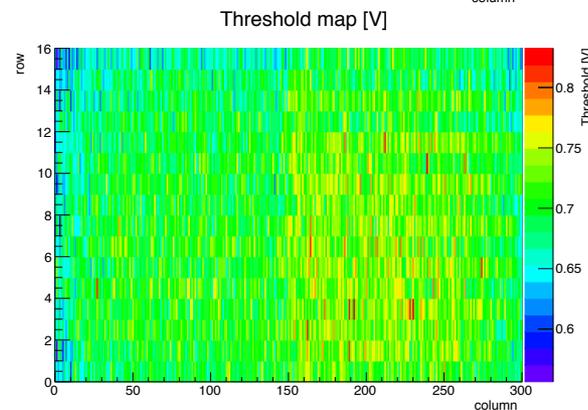


Threshold distributions

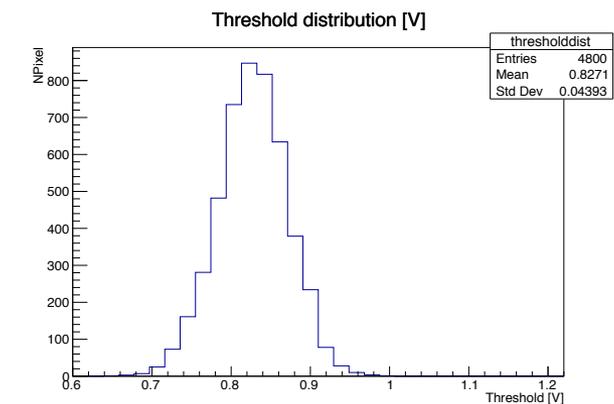
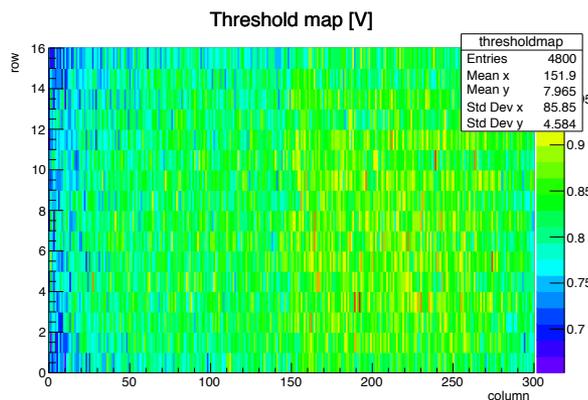
nThPix value = 1.66 V
Threshold = 0.55 mV
Std. Dev. = 0.04 mV



nThPix value = 1.80 V
Threshold = 0.71 mV
Std. Dev. = 0.03 mV



nThPix value = 2.00 V
Threshold = 0.83 mV
Std. Dev. = 0.04 mV

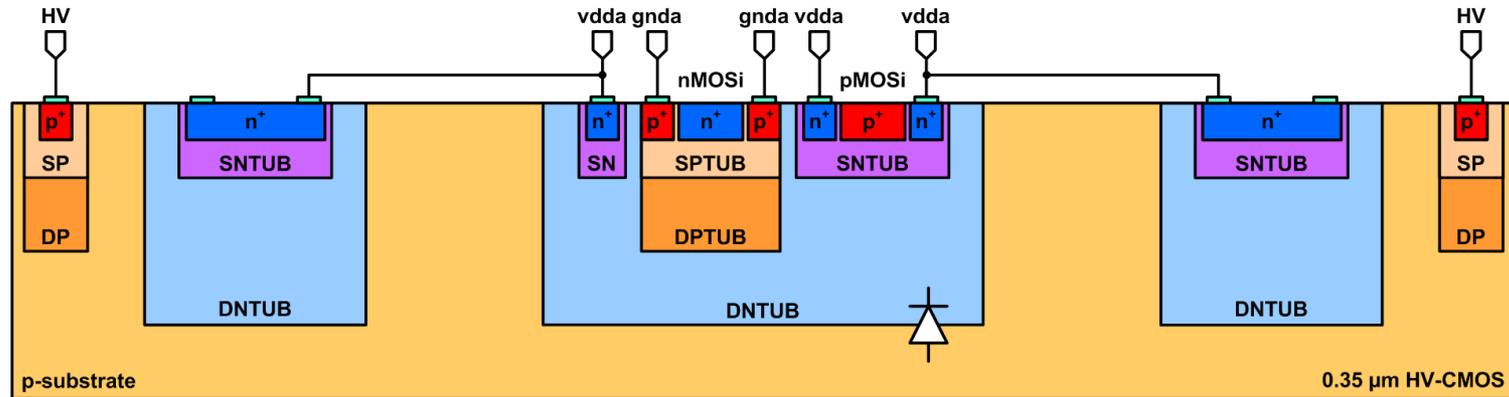


Summary of collected data

HV	THR	EVENTS
50	0.55 mV	1 M
50	0.70 mV	1 M
50	0.85 mV	1 M
100	0.55 mV	1 M
100	0.70 mV	1 M
100	0.85 mV	1 M
120	0.55 mV	1 M
120	0.70 mV	1 M
120	0.85 mV	1 M

Combinations of 3 thresholds and 3 bias voltages

H35 pixel



- DNTUB: Deep N well
- DPTUB: Deep P well
- DP/DN: Deep P/N
- SP/N: Shallow P/B
- SNTUP: Shallow N well
- SPTUP: Shallow P well