Advancement and Innovation for Detectors at Accelerators

WP6 Summary

Hybrid Pixel Sensors for 4D Tracking and Interconnection Technologies

WP6 Indico meetings: https://indico.cern.ch/category/13504/

Anna Macchiolo, Claudia Gemme
On behalf of the WP6 group

AIDAInnova Third Annual Meeting 2024-03-20

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

WP6 Tasks and Task Leaders

- WP6 main focus:
  - Production of 3D and LGAD sensors both at FBK and CNM
    - Simulation to guide the design and interpret the results
    - Validation of sensors in laboratories and test beam
  - Develop interconnection techniques: Anisotropic Conductive Film (ACF) for single tiles, Wafer-to-Wafer for wafers

Objectives

Task 6.1. Coordination and Communication

See introductory section on page 29.

Task 6.2. Simulation and processing of common 3D and LGAD sensor productions

- Optimisation of processes for 3D and LGAD sensors for timing applications
- Simulations of various designs for 3D and LGAD sensors to compare and optimise the layout in terms of timing performance
- Simulations of surface and bulk radiation damage for 4D (tracking+timing) detectors toward more radiation tolerant solutions
- Processing of two common 3D sensor productions and two common LGAD productions by FBK/CNM
- Design and implementation of simulation software which is applicable to a large range of technologies and includes models for the description of effects from sensor level to readout electronics in semiconductor detectors

Task 6.3. Validation of common 3D and LGAD sensor productions

- Characterisation of the 3D sensors in terms of timing, radiation hardness, efficiency and uniformity via measurements in the laboratory and beam tests
- Characterisation of small pitch LGAD and inverse LGAD sensors (iLGADs) from the common production in terms of timing and efficiency via measurements in the laboratory and beam tests
- Feedback to the foundries for further process optimisation of 3D and LGAD sensors

Task 6.4. Development of interconnection technologies for future pixel detectors

- Development of suitable Anisotropic Conductive Films (ACF) material and die-to-die bonding process flows for small pixel pitches
- Production and post-processing of dedicated planar sensor wafers for ACF trials
- Test of the performance of sensor modules interconnected with ACF
- Production and test of ultra-thin assemblies interconnected with a wafer to wafer bonding technology
- Post-processing of sensor prototypes developed in Task 6.3

Task Leaders

T6.2
Gian Franco Dalla Betta
Giulio Pellegrini

T6.3
Gregor Kramberger
Ivan Vila

T6.4
Dominik Dannheim
Fabian Hügging

WP6 Milestones

Deliverable Number	Deliverable Title	Lead Beneficiary	Due Date (in months)	Means of verification
MS22	Wafer layout	FBK	18 ✅	Layout design file and report on the design choices, supported by simulations (Task 6.2)
MS23	Preliminary characterization of 3D and LGAD prototypes. Test set-up ready in the laboratories.	CSIC	23 ✅	Preliminary characterization on prototypes with the readout systems to be used with the final productions. (Task 6.3)
MS24	Completion of planar sensor productions for ACF	CNRS	18 ✅	Planar pixel sensor wafers delivered for interconnection tests (Task 6.4)
MS25	Availability of parts and definition of the technologies for wafer to wafer hybridization	UBONN	18 ✅	Wafers delivered to IZM and report on the technologies chosen for the interconnection (Task 6.4)

All Milestones achieved!

WP6 Deliverables

Deliverable Number	Deliverable Title	Lead Beneficiary	Type	Dissemination level	Due Date (in months)	comments
D6.1	Completion of common productions	CSIC	Report	Public	30 Oct 2023	Including preliminary char. at foundries
D6.2	Final validation of timing performance of common productions	INFN	Report	Public	46	Before and after irradiations
D6.3	Test of the final ultra-thin hybrid assemblies from wafer to wafer bonding	Bonn	Report	Public	44	Module functionality, interconnection yield and strength
D6.4	Validation of the ACF for large and small pitch assemblies	CERN	Report	Public	45	Small pixel sizes from 25 to 55 μm

- First Deliverable D6.1 was due in October 2023.
- Proposal is to submit the deliverable in **May 24** with the productions achieved so far:
    - FBK TI-LGAD, 3D (May 24); CNM iLGAD (RD50) and start of iLGAD production for AidaInnova

Task 6.2
Report from FBK

MS 22: M18 completed - wafer layouts
D6.1: due by Oct 2023 – completion of common production

M. Boscardin et al

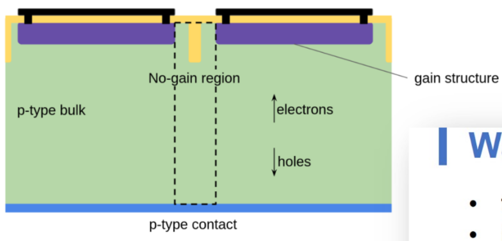
Trench-Isolated LGAD (TI-LGAD) in FBK

Reminder

Giovanni Paternoster
Matteo Centis Vignali
Maurizio Boscardin

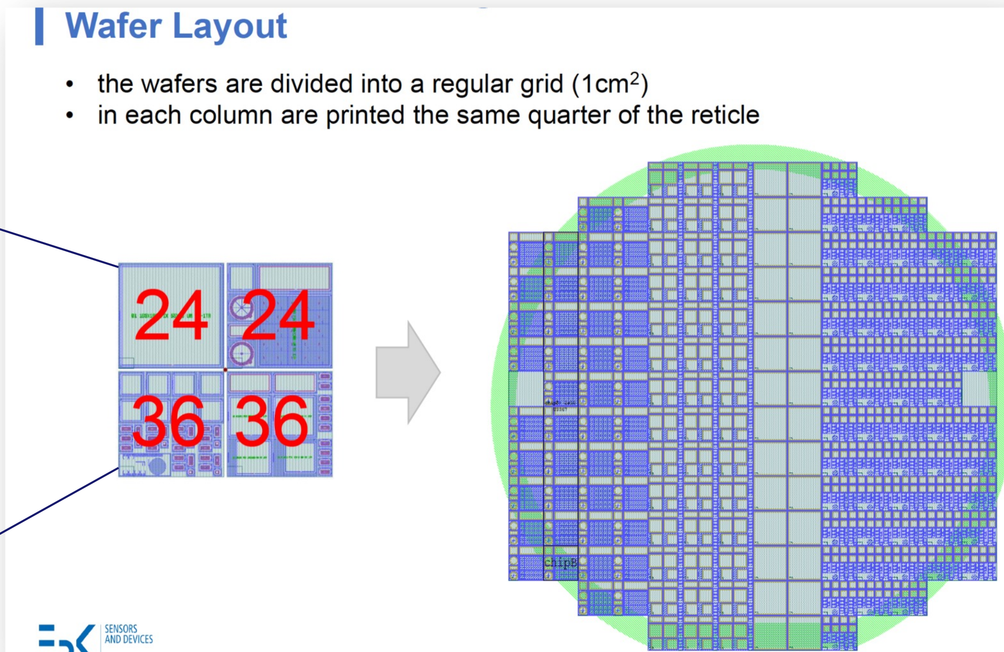
- The goal is to realize an LGAD compatible with small pitch (55micron or less) and with high fluences
  - Isolation made by trenches
  - Carbon co-implantation to increase radiationa hardness

- Previus exeperiece
  - Internal FBK batches
  - Batches in RD50



One full reticle (about 2x2 cm) in 4 quarter (about 1x1cm)
- Pixel & Strip
- PCM FBK
- 2x1 Test devices

In order to explore
- Pitch
- Border: 4 version
- Number of trenches : 1 or 2



Trench-Isolated LGAD (TI-LGAD) in FBK

Reminder

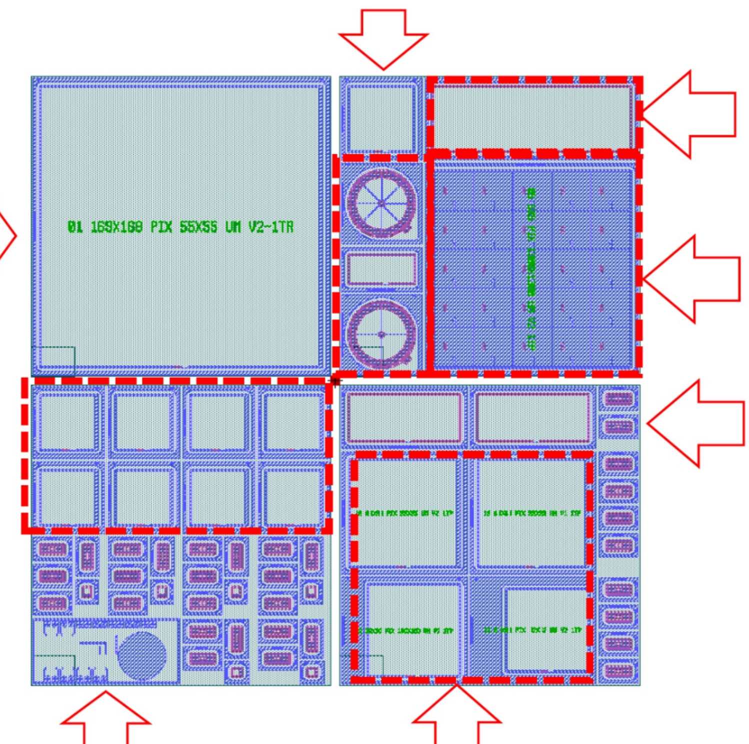
Giovanni Paternoster
Matteo Centis Vignali
'oscardin

Layout

50x50 pixels 42µm pitch

169x168 pixels
55 µm pitch

32x32 pixel, 55 um pitch
study of the border versions, with 1 or 2 trenches



Strip sensors

5x5 pixels
1300µm pitch

15 strip
100um pitch

Process Control Monitor Fbk

Pixel 100, 55, 42 um pitch
study of different sensor pitch and fill factor

Trench-Isolated LGAD (TI-LGAD) in FBK

Reminder

Process

- **12 wafers**
- **Main process**
  - 45 µm, D2 , P2 and «high diffusion»

Split on

- ✓ Wafer thickness
- ✓ With or without carbon (it's the first time that we use carbon on TiLGAD)
- ✓ Trench Depth
- ✓ Trench Process

Note : two wafer per «main» split

Table splits

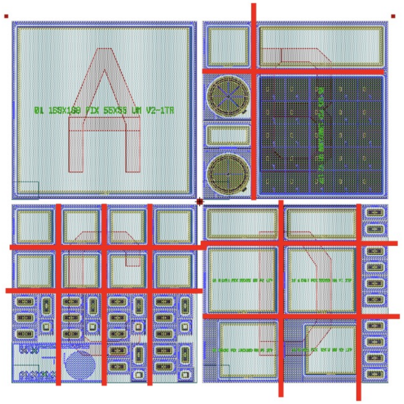
Wafer	Thickness	Carbon	Trench depth	Trench process
1	45	Y	D2	P2
2	45	Y	D2	P2
3	45	Y	D1	P2
4	45	Y	D1	P1
5	45	Y	D2	P1
6	45		D2	P2
7	45		D2	P2
8	45		D1	P1
9	55	Y	D3	P2
10	55	Y	D2	P2
11	55	Y	D2	P2
12	55		D2	P2

baseline ← (wafer 1)

Trench-Isolated LGAD (TI-LGAD) in FBK

Production completed in October.
Several tests run at wafer level in FBK to qualify the wafers. Then TM removed for dicing or hybridization.

Dicing method



Wafer1 (carbonated, baseline) diced

- parts being distributed to AIDAinnova Institutes
- parts (not irradiated and irradiated up to 2.5e15) tested in DESY on Feb 12-26

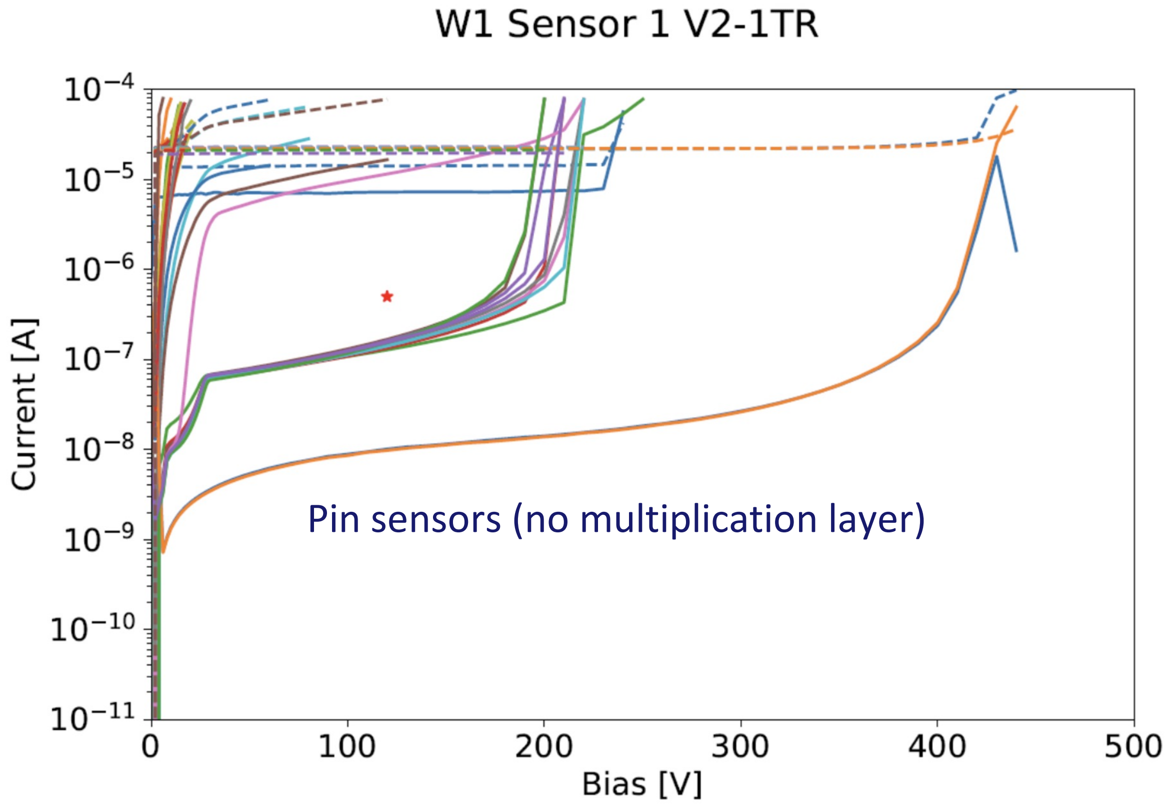
All the other wafers have temporary metal layer removed. Next:

- Two more wafers (W6 e W10) being diced to get parts, also for ACF hybridization.
- The other wafers to be sent to IZM for UBM and hybridization

Trench-Isolated LGAD (TI-LGAD) in FBK

Reminder

Example of IV for large sensors in W1.
The red dot represent the acceptance criteria. It is used to determine the yield.



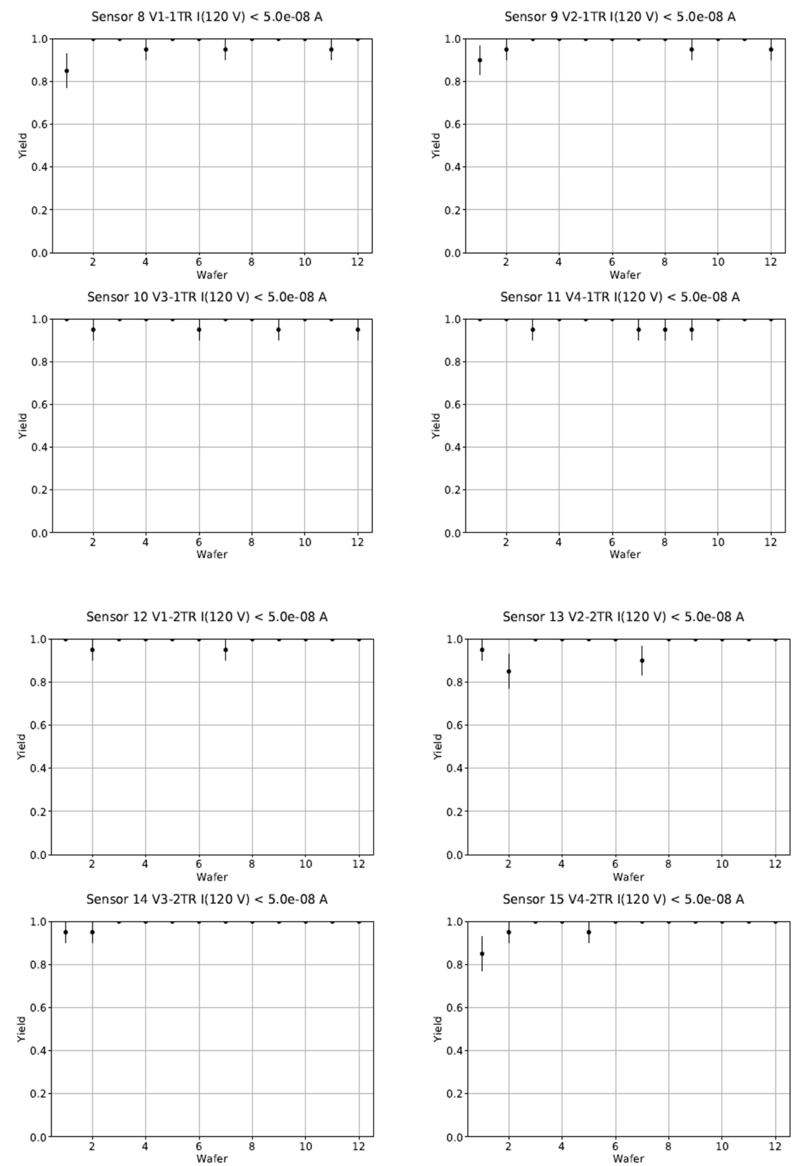
Trench-Isolated LGAD (TI-LGAD) in FBK

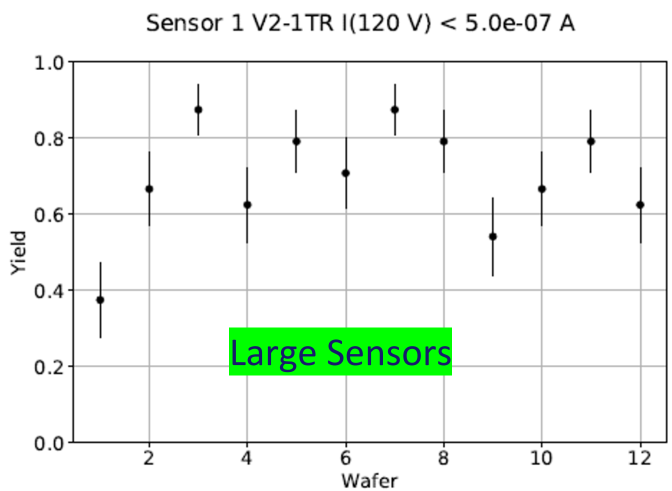
Update

Some examples of Wafer level measurements:

The yield calculation includes only sensors with gain:
Extremely high for small sensors, >60% for large sensors

Small Sensors





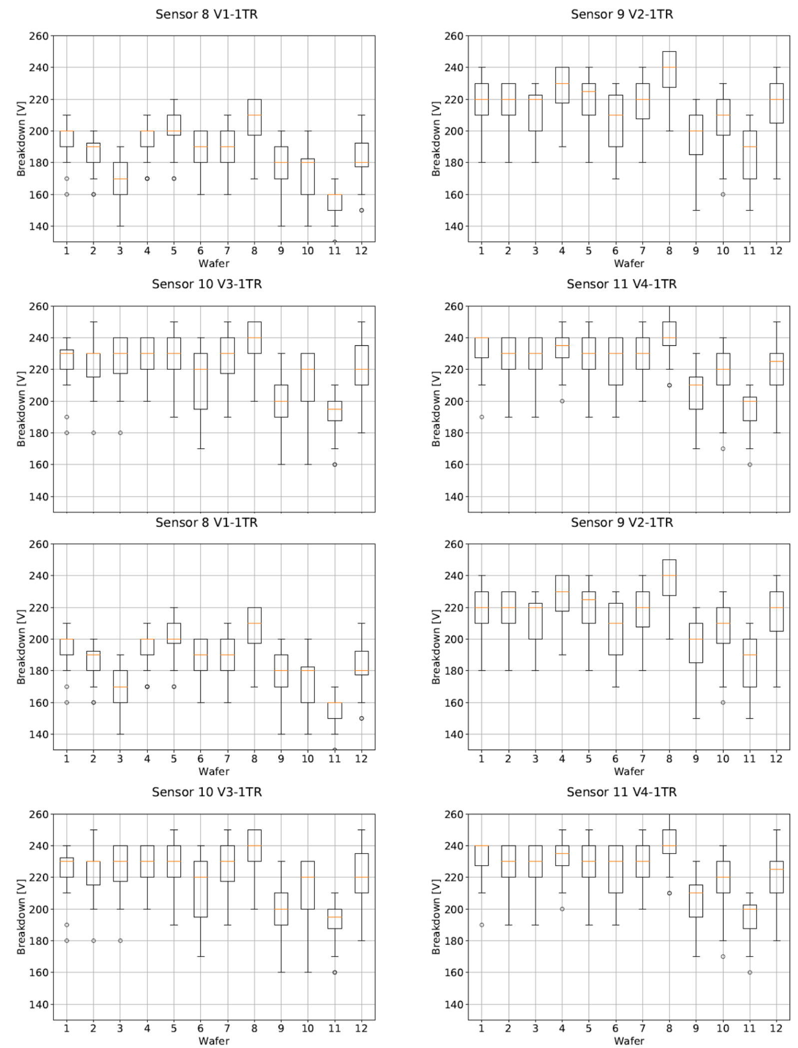
Trench-Isolated LGAD (TI-LGAD) in FBK

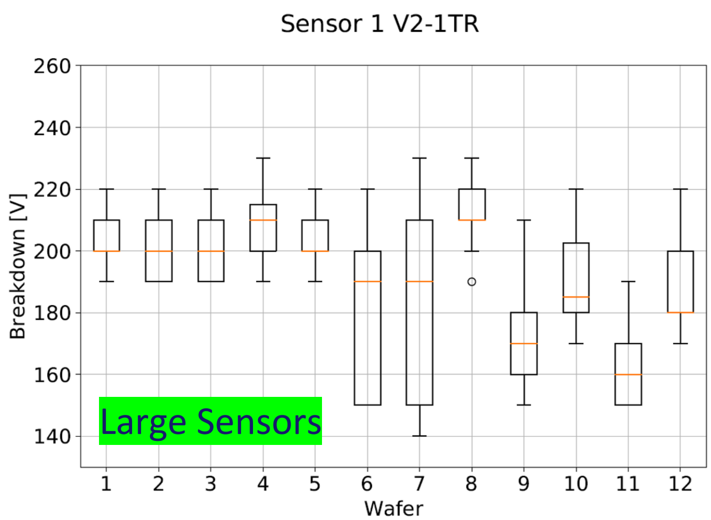
Update

Some examples of Wafer level measurements:

Breakdown voltage as expected

Small Sensors





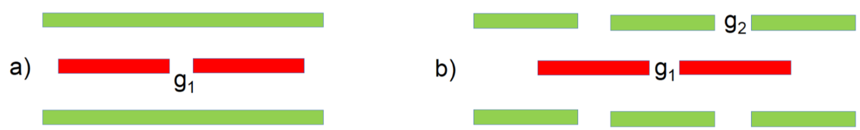
3D in FBK

Reminder

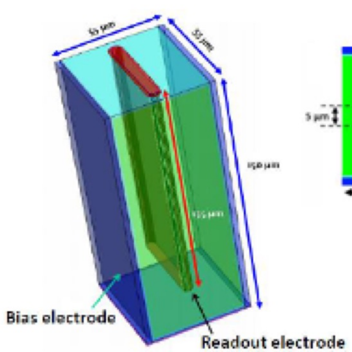
- Based on trench electrode
- Best performance for timing
- Develop in partnership with INFN Collaboration

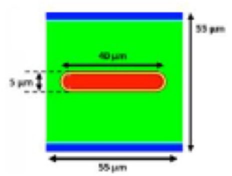
Laura Parellada Monreal
Sabina Ronchin
Maurizio Boscardin
G.F Dalla Betta

- 3D-trenched pixels only (no columns)
- Continuous ohmic trench (a) vs dashed ohmic trench (b)

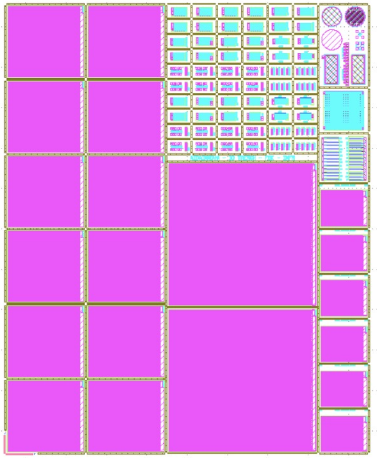


TimeSPoT





- **Pixel sensors (55 µm pitch)**
  - 32x32 pixels, multiplicity = 6 (3 std, 3 dashed)
  - 64x64 pixels, multiplicity = 12 (6 std, 6 dashed)
  - 128x128 pixels, multiplicity = 2 (1 std, 1 dashed)
- **Device test structures (55 µm pitch and 42 µm pitch, std and dashed)**
  - Groups of individual pixels
  - Strips
  - Diodes
- **Technological test structures**



Trench 3D in FBK

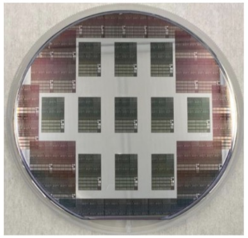
Update

Wafer Layout:

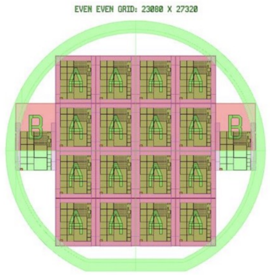
- 14 wafers with 18 DIE on wafer
- 4 wafers with 29 DIE to test high density yield.

Process Split:

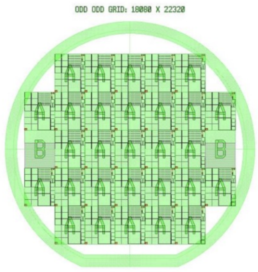
- 12 poly filling
- 6 BPSG filling



Old wafer layout
11 shot exposure

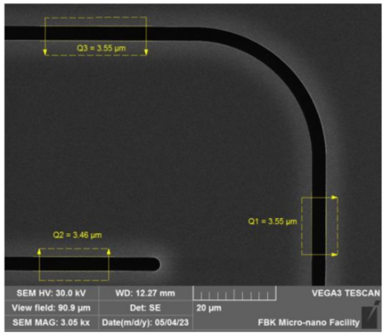


18 shot exposure



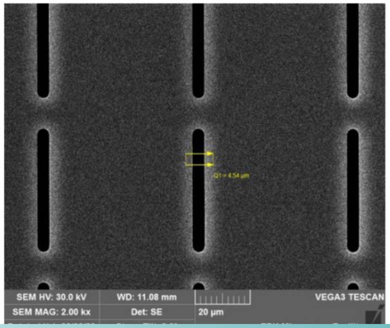
29 shot exposure

3D AIDA

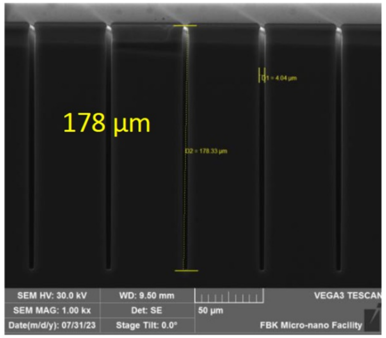


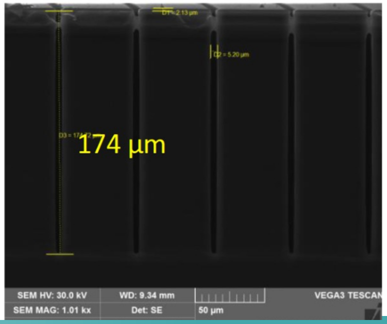
Long trenches:
3µm x ∞

Previous process:
trenches
4µm x ∞



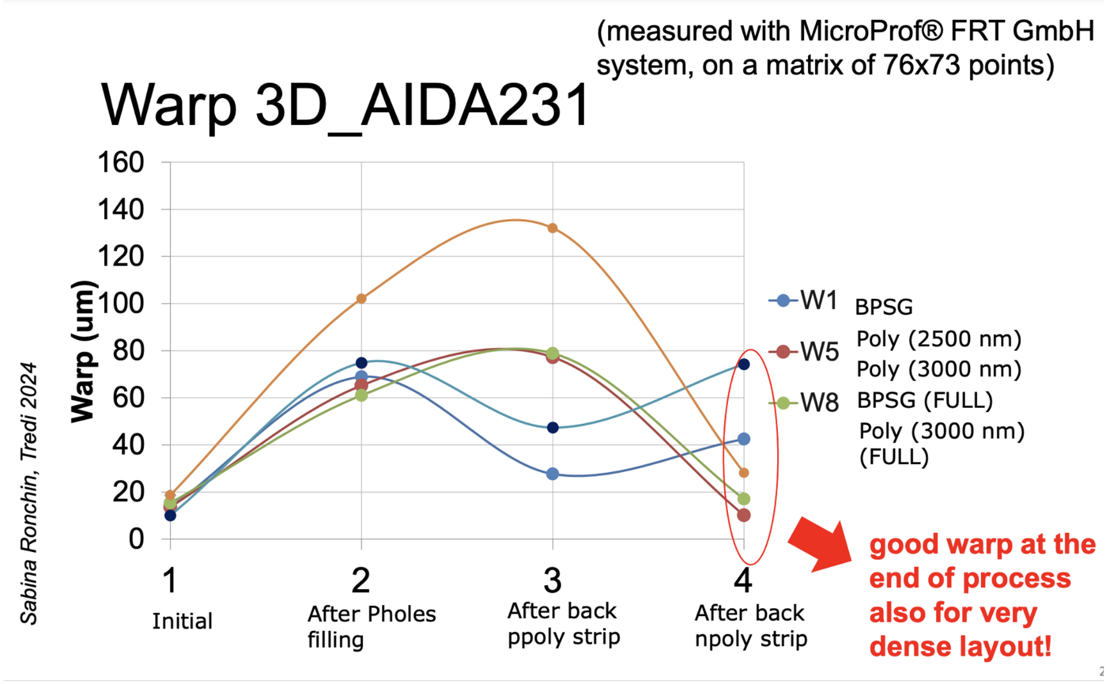
Short trenches:
4 µm x 40 µm





Short and narrow trenches to improve subsequent photolitographic process

Warp in acceptable range of values for all the process splits!



- Status and Timescale:
  - 18 wafers in production
  - To be completed by mid-May 2024 (was August '23) – Two additional months delay, they are due to trials for the optimization of the contacts and problems with the stepper machine
  - Testing will follow (program to be discussed to optimize the time). Temporary metal removal, and distribute single device.

Task 6.2
Report from CNM

MS 22: Due in M18, Completed - wafer layouts
D6.1: due by Oct 2023 – completion of common production

Current status of timing sensors runs at CNM

Update

Run	Description	Clean Room Step
15543	150 mm **Timepix4 PiN**, Si (300 µm), 6PN1. **AidaInnova WP3**	Production Completed (Waiting for UBM)
16020	150 mm **AC-LGAD**, Si (300 µm) and Si-Si (50/350 µm), 6LG4. **RD50**	Production Completed (Waiting for UBM)
16069	100 mm **3D-DS Timing**, Si (285 µm), 240 µm depth columns, 10 µm columns diameter. **RD50**	Production Completed (Electrical Characterization)
16421	100 mm **Timepix3 Trench iLGAD**, Epitaxial wafers, 4iLG3. Engineering Run. **RD50.** **AidaInnova WP6**	Production Completed (Electrical Characterization)
	100 mm **Timepix3 Trench iLGAD**, Si-Si wafers, 4iLG3. Engineering Run. **RD50.** **AidaInnova WP6**	Step 70/75 (Passivation)
-	100 mm **Timepix4 Trench iLGAD**, Epitaxial and Si-Si wafers, 4iLG3. **AidaInnova WP6**	Masks ordered Wafers available

CNM third generation Inverse LGAD (iLGAD)

Reminder

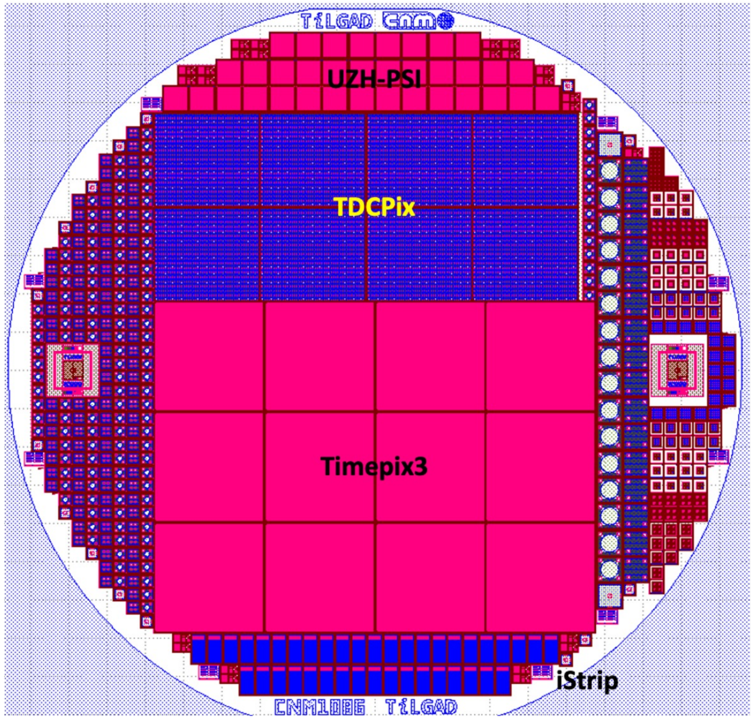
Run16421: 6 Wafers, 100 mm, CNM1086 Mask Set

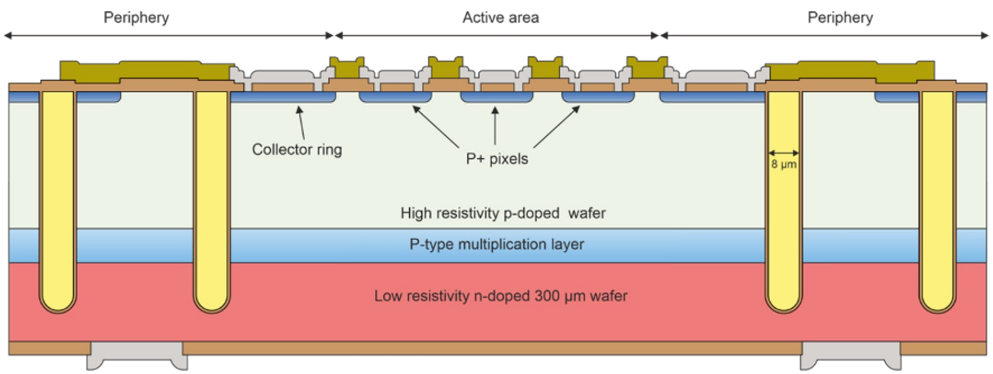
- **3 wafers: Epitaxial Wafers** (50/515 µm)
- **3 wafers: Si-Si Wafers** (50/350 µm)

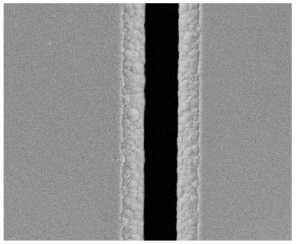
TimePix3. 55x55 µm pitch, 256x256 pixels: **12 devices**
TDCPix. 300x300 µm pitch, 40x45 pixels: **8 devices**
UZH-PSI. 100x100 µm pitch, 30x30 pixels: **36 devices**
iStrip. 80 µm pitch, 20 strips: **40 devices**
Pad and Nikhef Test Devices to fill the gaps

Considered as engineering run for the AidaInnova technology.

Wafer Layout







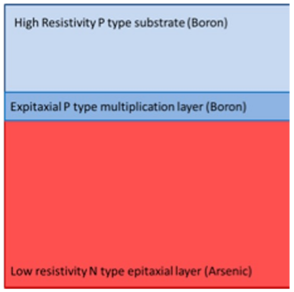
AIDA innova

Update

CNM third generation Inverse LGAD (iLGAD)

Run16421: 6 Wafers, 100 mm, CNM1086 Mask Set

- 3 wafers: **Epitaxial Wafers** (50/515 µm) → Fabrication simple and production faster, all implants except for front side done at wafer vendor → the doping of the multiplication layer is not very controlled
- 3 wafers: **Si-Si Wafers** (50/350 µm)



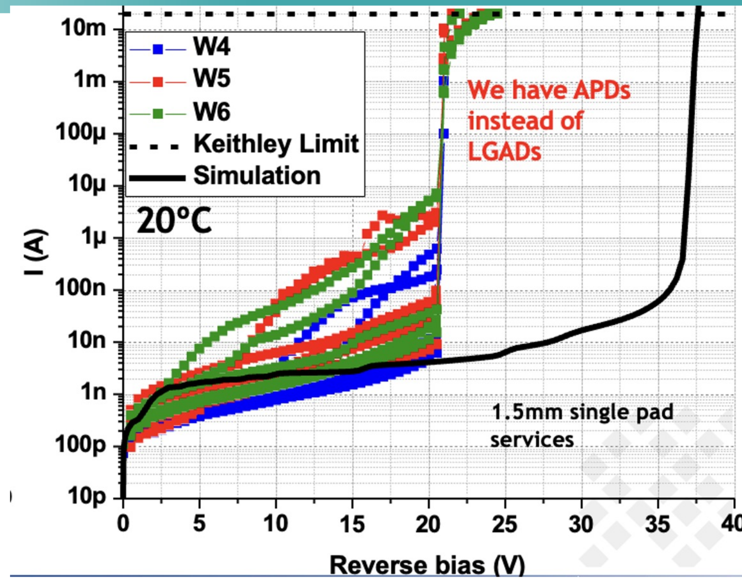
Epi wafers completed, Si-Si wafers in the last steps of the process →

It is very important to get samples for June to include them in SPS TB

Wafer	Wafer type	Boron Dose for multiplication layer (1/cm²)	Boron Energy for multiplication layer (keV)	Comments
1	Si-Si	3.7e14	150	Diffusion @ 1175°C for 3h (same as Epitaxial wafers 4, 5 & 6). **Preliminary IVs do not show APD behavior**. Fabrication about to finish (within 1 week).
2		3.9e14		
3		4.1e14		
4	Epitaxial	NA	NA	APDs obtained instead of LGADs. **Devices were irradiated @ JSI** with neutrons at fluences 8e13, 1e14, 2.5e14 & 5e14. Measurements ongoing.
5				
6				

CNM third generation Inverse LGAD (iLGAD)

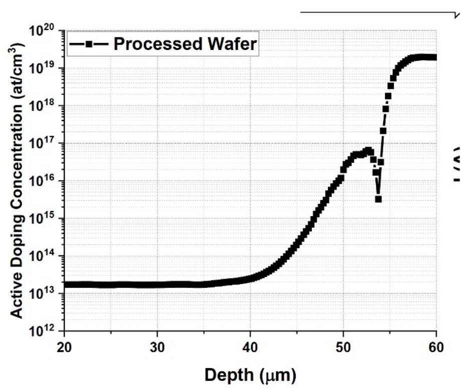
Update

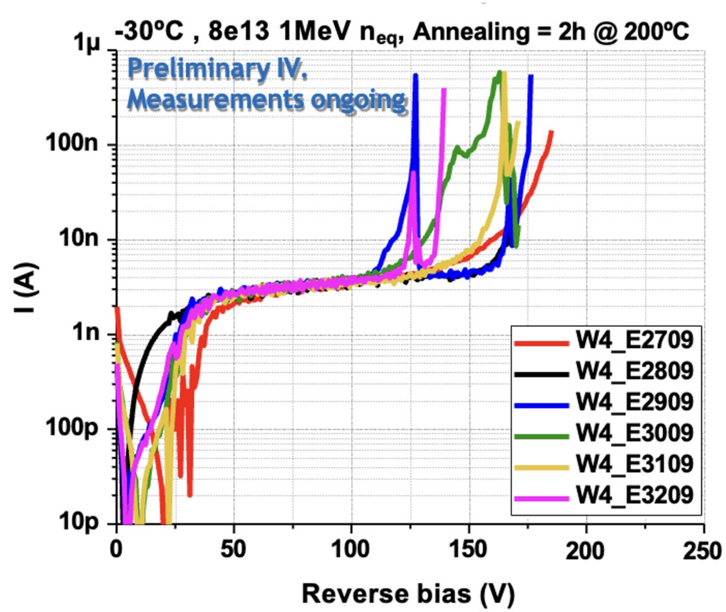


Run16421: Epitaxial Wafers

- Concerns about doping and resistivity of the procured wafers. Concentrations of multiplication layer were too large —> This explain the APD behaviour before irradiation (better after irradiation).
- CNM has now the instrumentation to measure the doping concentration before the process. **Thermal steps will be studied, and performed on the wafers BEFORE the process for the next run.**

Epitaxial Layer	Resistivity (Ohm.cm)	Doping Concentr. (at/cm³)
HR P-type substrate (specifications)	> 1000	< 1e13
HR P-type substrate (Processed wafer)	**800±20**	**1.7±0.1 (1e13)**
P-type mult (specifications)	0.39-0.53	3-4.8 (1e16)
P-type mult (Processed wafer)	**0.40±0.09**	**4.7±1.2 (1e16)**

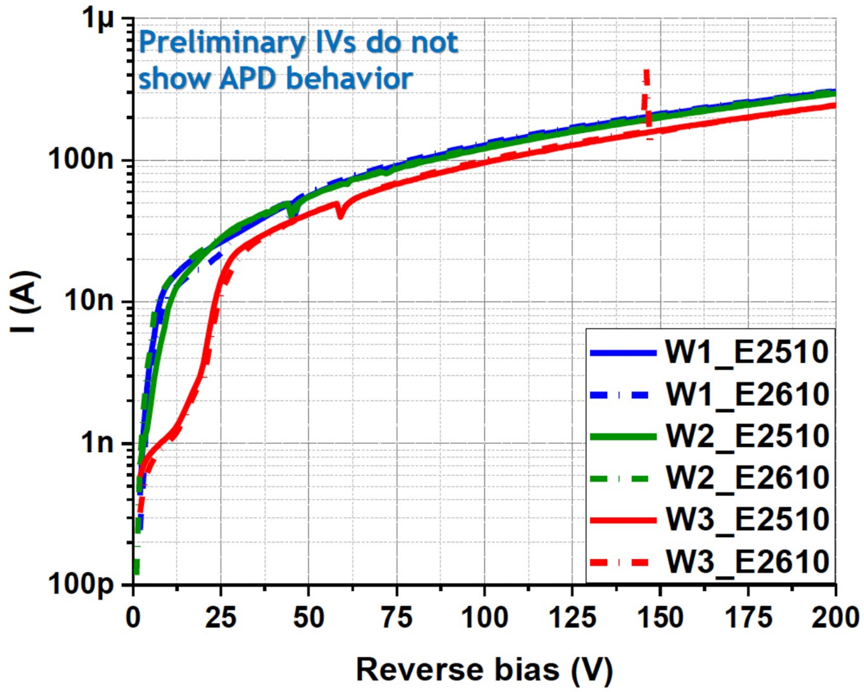


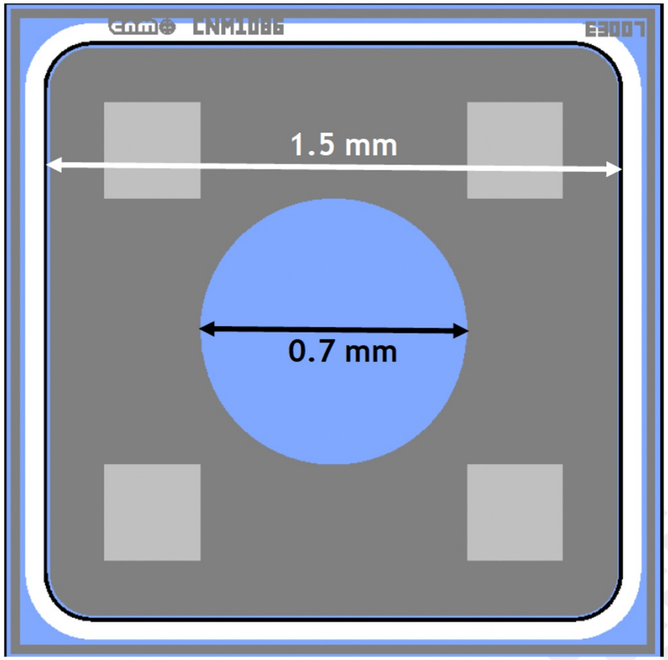


Update

Run16421: Si-Si Wafers

- Preliminary IVs do not show APD behavior.
  - **Measured at clean room after metallization, W3 may be the only wafer with sizeable gain**
  - Fabrication about to finish with passivation.





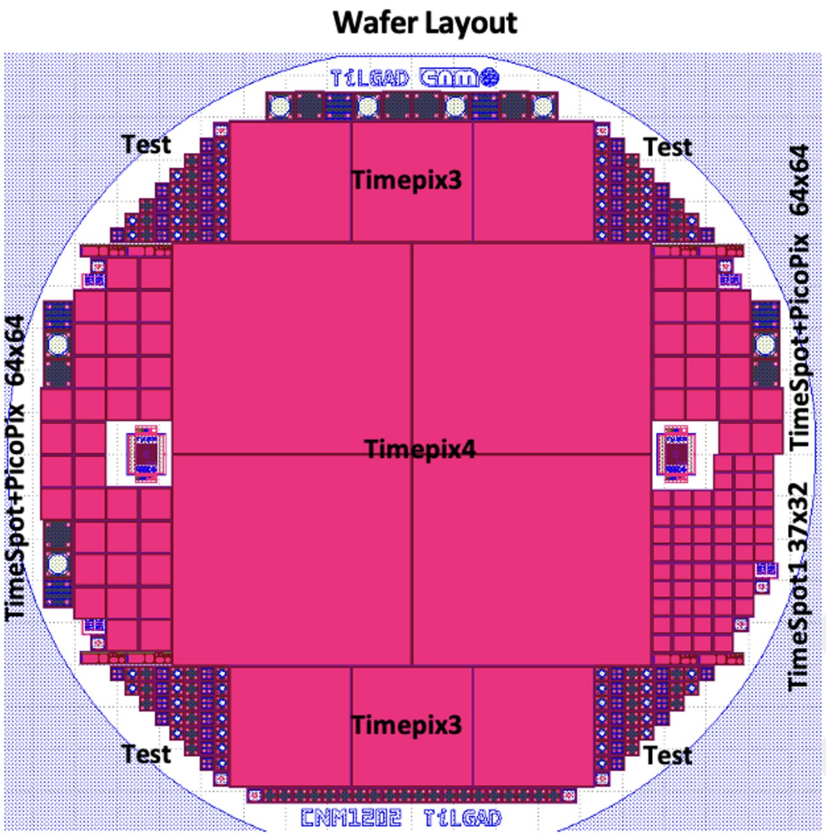
AIDAinnova WP6 CNM iLGAD production

Update

10 Wafers, 100 mm, CNM1202 Mask Set

- 4 wafers: **Epitaxial Wafers** (50/515 µm)
- 6 wafers: **Si-Si Wafers** (50/350 µm)

TimePix4. 55x55 µm pitch, 448x512 pixels: **4 devices**
TimePix3. 55x55 µm pitch, 256x256 pixels: **6 devices**
TimeSpot1. 55x55 µm pitch, 37x32 pixels: **53 devices**
TimeSpot,PicoPix.55x55 µm pitch, 64x64 pixels: **51 devices**
Test Devices to fill the gaps



Current status for the AidaInnova run:

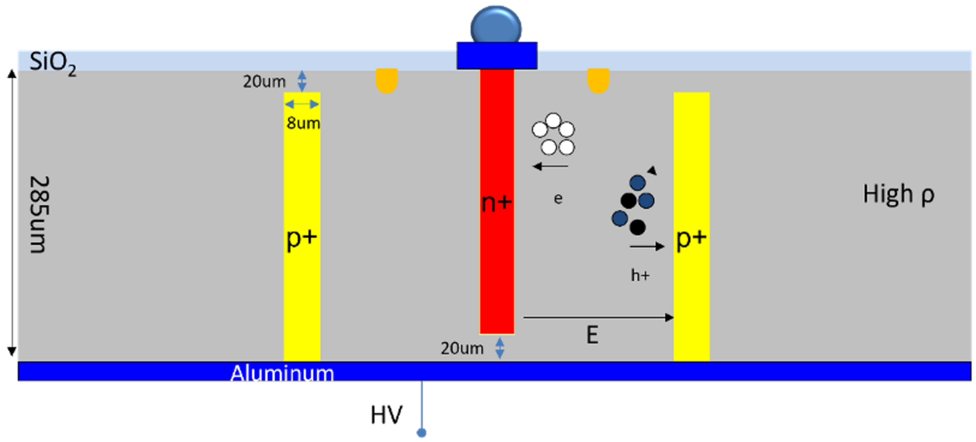
- Masks arrived last week.
- Wafers available.
- **Six months** are needed for its Production and electrical characterization→ by October ready to test.

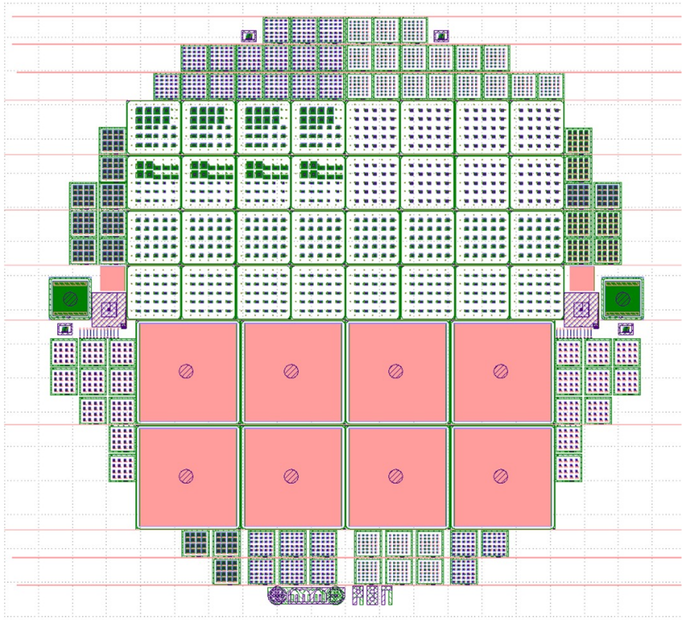
CNM 3D for timing

Update

Run16069: **3 Wafers,** 100 mm, CNM987 Mask Set → **Completed, few parts at Irradiation and TB.**

- **TimePix3.** 55x55 μm pitch, 256x256 pixels: 8 **devices.**
- **Altiroc 1.** 300x300 μm pitch, 40x45 pixels: 24 **devices.**

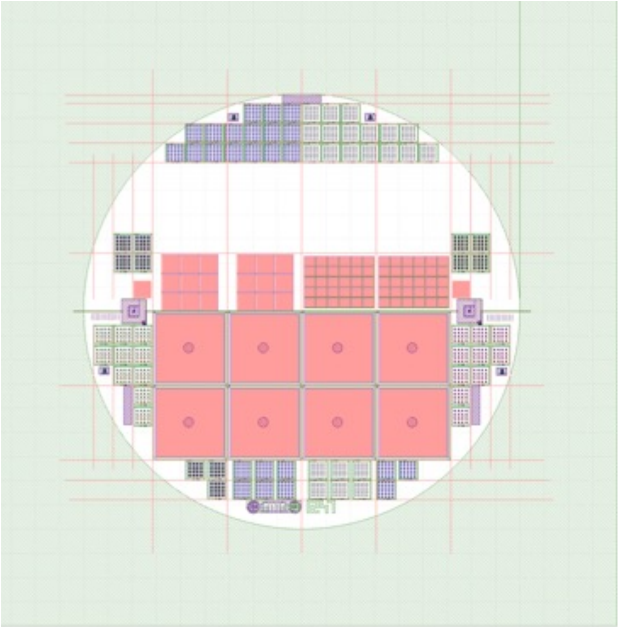


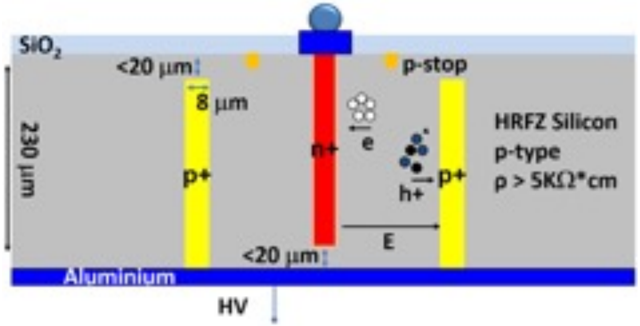


- Detectors irradiated with neutrons at different fluences
- Tested in the AIDAinnova DESY TB (data analysis will start soon)

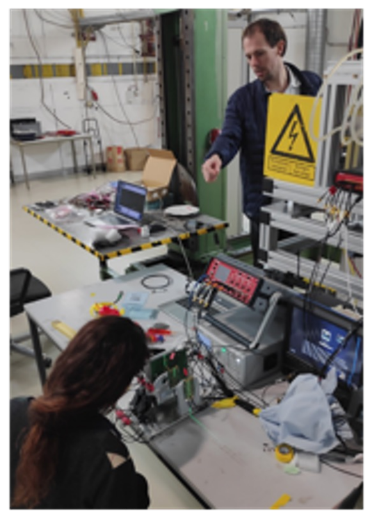
CNM AIDAinnova 3D production plans

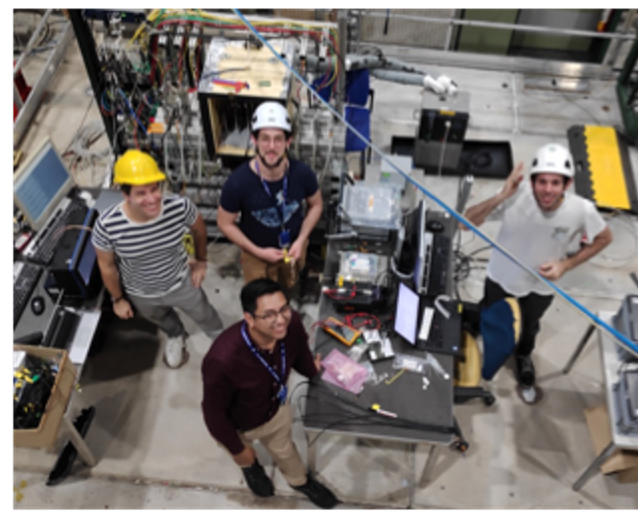
- Continue fabrication on 100 mm. Moving to 150 mm is desirable but too risky at this stage.
- Try to reduce holes diameter (= increase aspect ratio).
    - TimePix3. 55x55 µm pitch, 256x256 pixels: 8
    - TimeSpot1. 55x55 µm pitch, 37x32 pixels: 60
    - PicoPix+IGNITE (Timespot). 55x55 µm pitch, 64x64 pixels: 18 → PicoPix scope has changed
    - Different test structures
    - Space for LHCb type test structures. To be designed and agreed.





Task 6.3
Validation and
Test beam organization - I. Vila and G. Kramberger





WP6 Test beams

- **At CERN successful TB campaigns in 2023**, two weeks in June and one week in Aug, first results reported in Nov. RD50 meeting
- **In 2024**
  - Two weeks in Feb at DESY, and two weeks at CERN (5th June, September TBC)

What we should do for SPS in June (5-12.6.):

- Increase DAQ rate if possible to 100 Hz
- Include the new cold box (Vagelis/Aboud/Dominik are working on it)
- Make sure that software tools are ready for quick analysis

Get more people Find replacement for Matias !!

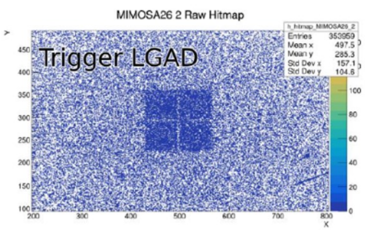
- Gather the samples from CNM and FBK that are tested before the TB
- This time the samples went from FBK – JSI irradiations – Mounting – DESY TB without being looked at beforehand. We can't always count on luck!

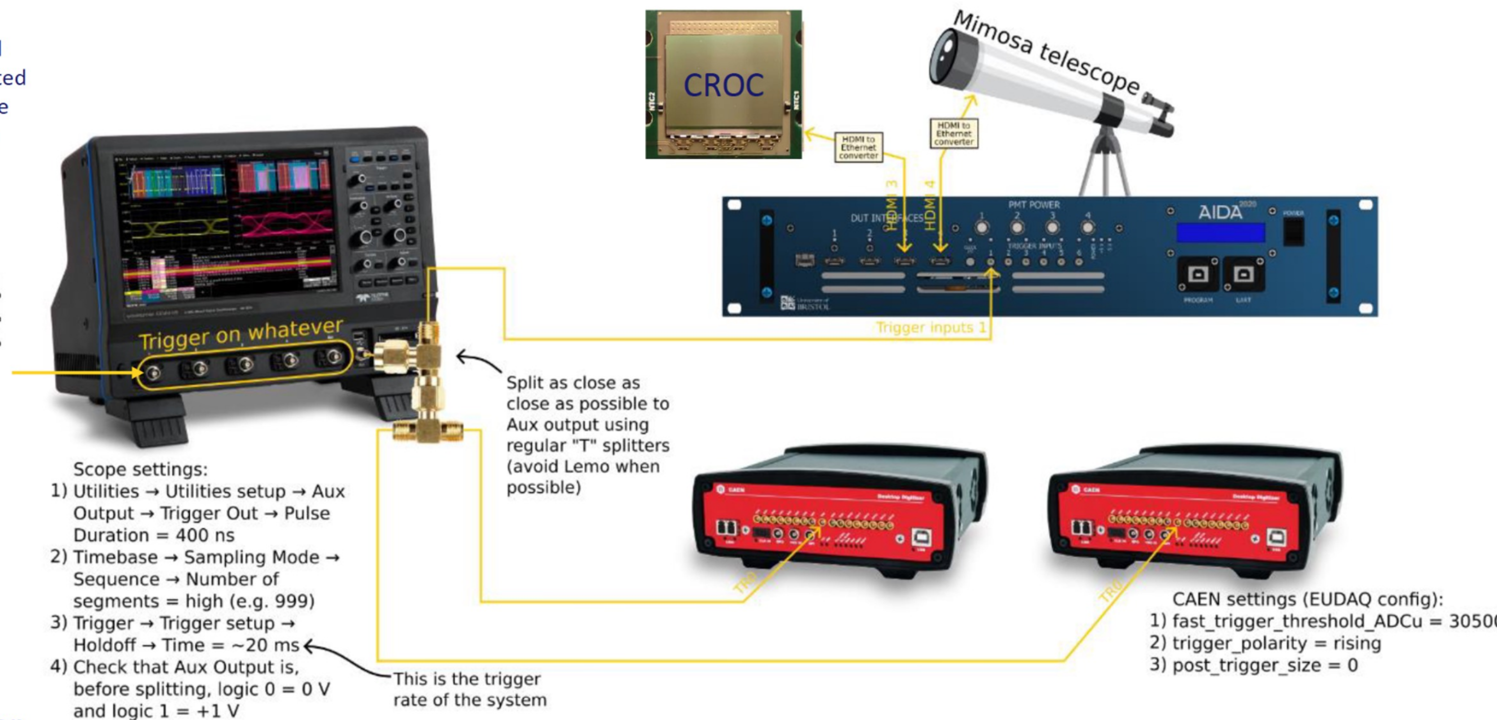
Test beam beam campaign Highlights

- Since the last AIDAInnova anual Meeting:
  - Two test beams at CERN (SPS) in June (two weeks) and September (one week)
  - One test beam at DESY in February (two weeks).
- Large involvement of the WP6 groups:
  - **CNM:** Oscar David Ferrer Naval, Neil Moffat
  - **IFCA:** Ivan Vila Alvarez, Andres Molina Ribagorda, Jordi Duarte Campderros, Efren Navarrete Ramos, Marcos Fernandez Garcia, Ruben Lopez Ruiz
  - **IJS**: Gregor Kramberger, Jernej Debevc
  - **INFN/ University of Torino:** Roberta Arcidiacono, Federico Siviero, Leonardo Lanteri, Luca Menzio, Roberto Mulargia, Valentina Sola, Marco Ferrero
  - **INFN Genova:** Claudia Gemme
  - **UZH:** Anna Macchiolo, Matias Senger, Parisa Rezaei Mainroodi, V. Gkougkousis
  - **CERN:** A. Rummler
- Major milestones:
  - Commission a fully-functional test beam set-up for 4D-tracking DUT characterization
  - Radiation tolerance study of the AIDAInnova TI-LGAD common production from FBK

Set-up arrangement

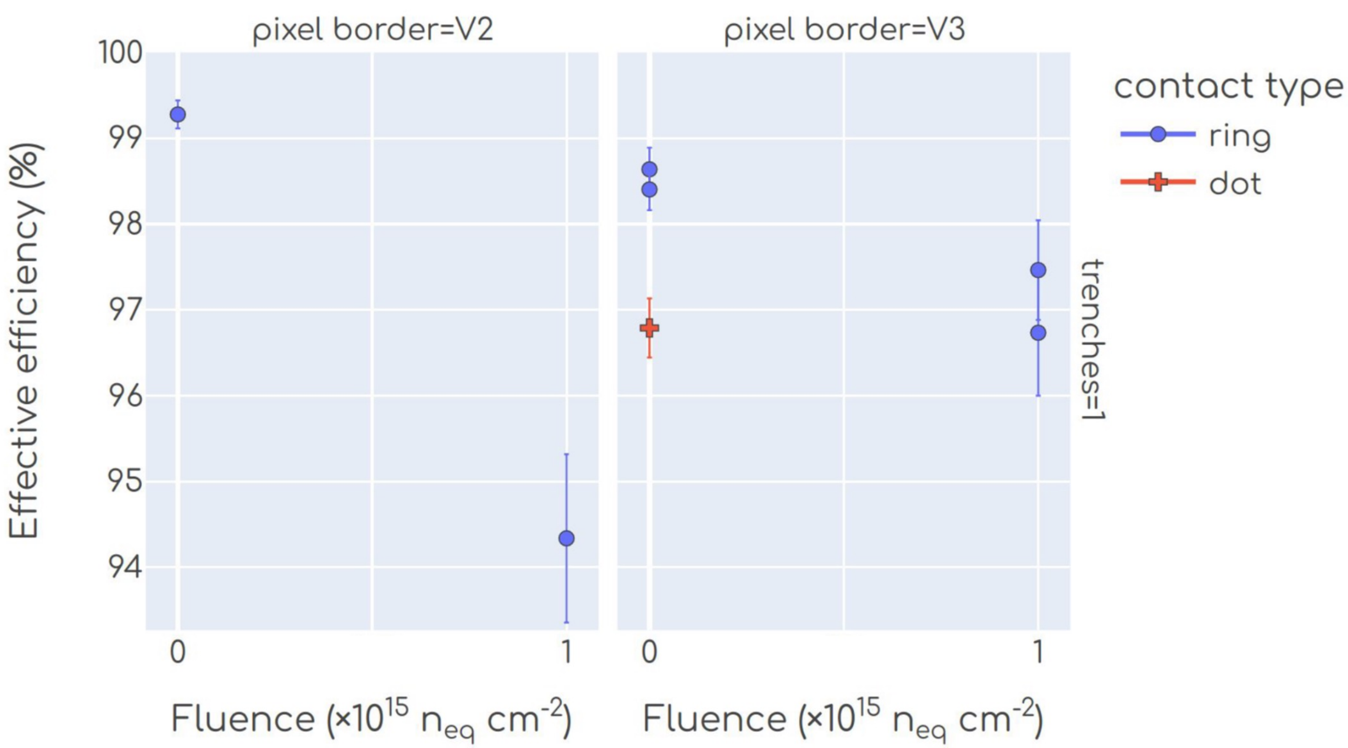
For alignment, each DUT is removed from the CAEN digitizer and connected to the inputs of the oscilloscope. The whole system is then triggered from the DUT and we can observe its shadow in the telescope planes.





Adapted from M. Senger

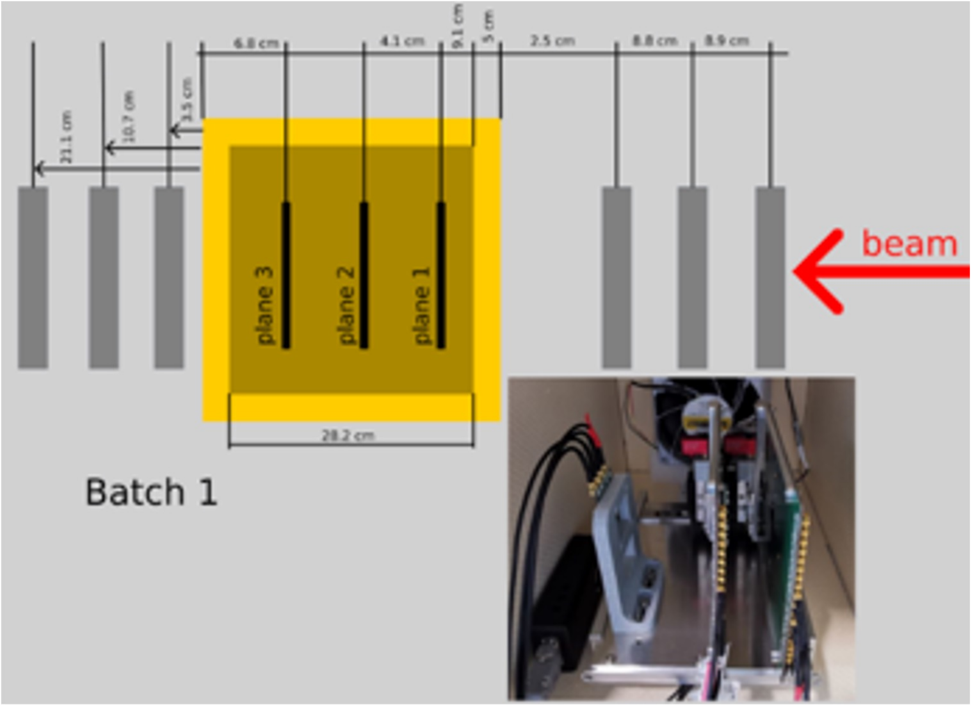
Results from SPS Test-beam



- Before irradiation, inefficiency is due to effective inter-pixel distance (no-gain area)
- After irradiation, gain loss contributes to inefficiency, as for standard LGADs
- Lower efficiency of V2 after irradiation probably due to noise induced by a value of HV close to breakdown→ see results of DESY TB in next slide

The february TB @ DESY

- AIDAinnova TI-LGAD before and after irradiation up to 2.5E15 n_{eq}/cm^2
- CNM RD50 3D timing sensor
- CNM RD50 3D timing sensor non irradiated
- BNL AC17 non irradiated - square
- BNL AC15 non irradiated – triangular



Special thanks:

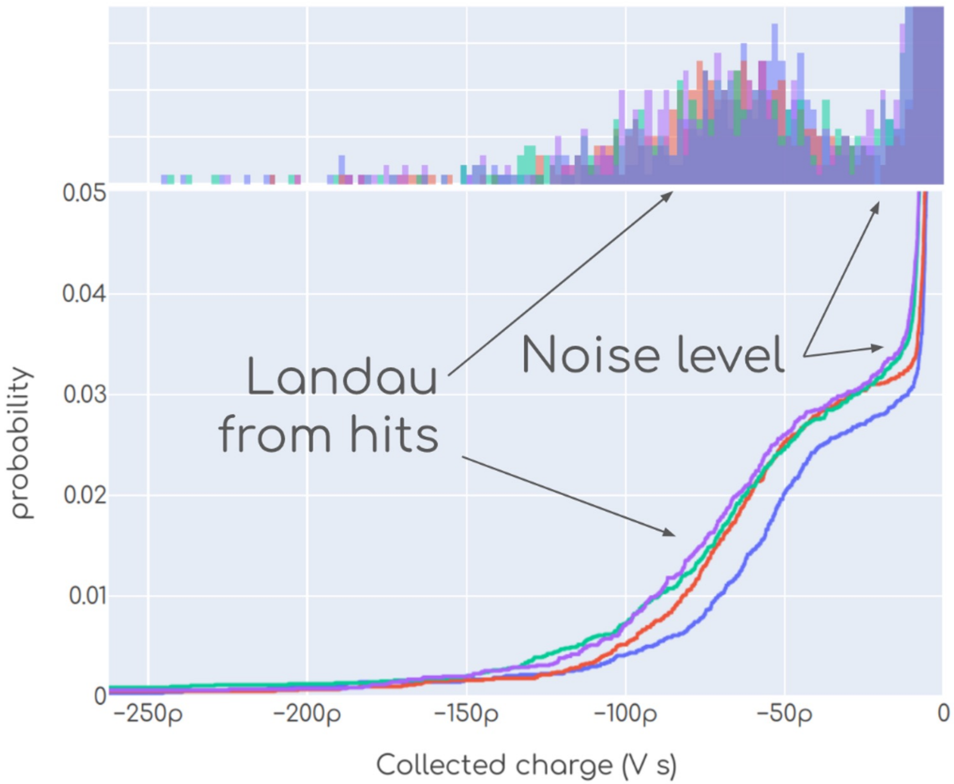
- LHCb-Velo group for lending us the equipment.
- Uni-HH group for Chiller and cold finger
- DESY TB coordinators for being super helpful.

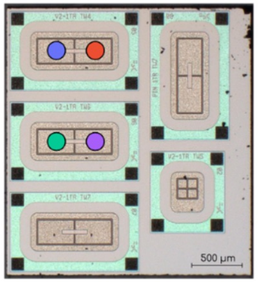
Cold operation for irradiated sensors – we reached -22C to -25C with two different T sensors

First look at DESY test-beam

TI-LGAD w/carbon, irradiated to 25e14 n_{eq} cm^{-2}

Bias voltage = 650 V, T = -25 °C





Clear separation between Landau and noise ✅

Sensor still works at the highest fluence 👏

Task 6.2
Simulations
F. Moscatelli et al, Slides

TCAD simulation of LGAD devices

In collaboration with INFN Torino: calibration/extension of the previously developed models by comparing the simulation findings with measurements carried out on different classes of LGAD detectors.

Comparison with experimental data, before and after irradiation; good agreement of measurements and simulations

"PerugiaModDoping"

- **Torino analytical parameterizations**
  - **Gain Layer** (Acceptor Removal)
  - **Bulk** (Acceptor Creation/Damage Saturation)
- **"New UNIPG"** TCAD Radiation Damage Model

Surface damage (+ Q_{ox})

Type	Energy (eV)	Band width (eV)	Conc. (cm^{-2})
Acceptor	$E_C \leq E_T \leq E_C$-0.56	0.56	$D_{IT} = D_{IT}(\Phi)$
Donor	$E_V \leq E_T \leq E_V$+0.6	0.60	$D_{IT} = D_{IT}(\Phi)$

Bulk damage

Type	Energy (eV)	η (cm^{-1})	σ_n (cm^2)	σ_h (cm^2)
Donor	E_C - 0.23	0.006	2.3×10^{-14}	2.3×10^{-15}
Acceptor	E_C - 0.42	1.6	1×10^{-15}	1×10^{-14}
Acceptor	E_C - 0.46	0.9	7×10^{-14}	7×10^{-13}

TCAD simulation of 3D sensors

- In collaboration with the University of Trento: validation of the previously developed model by comparing simulations to post irradiation measurements on 3D diodes
  - Two models considered do not reproduce satisfactorily data

✓ Post-irr.

F. Moscatelli – AIDAinnova 3rd Annual meeting

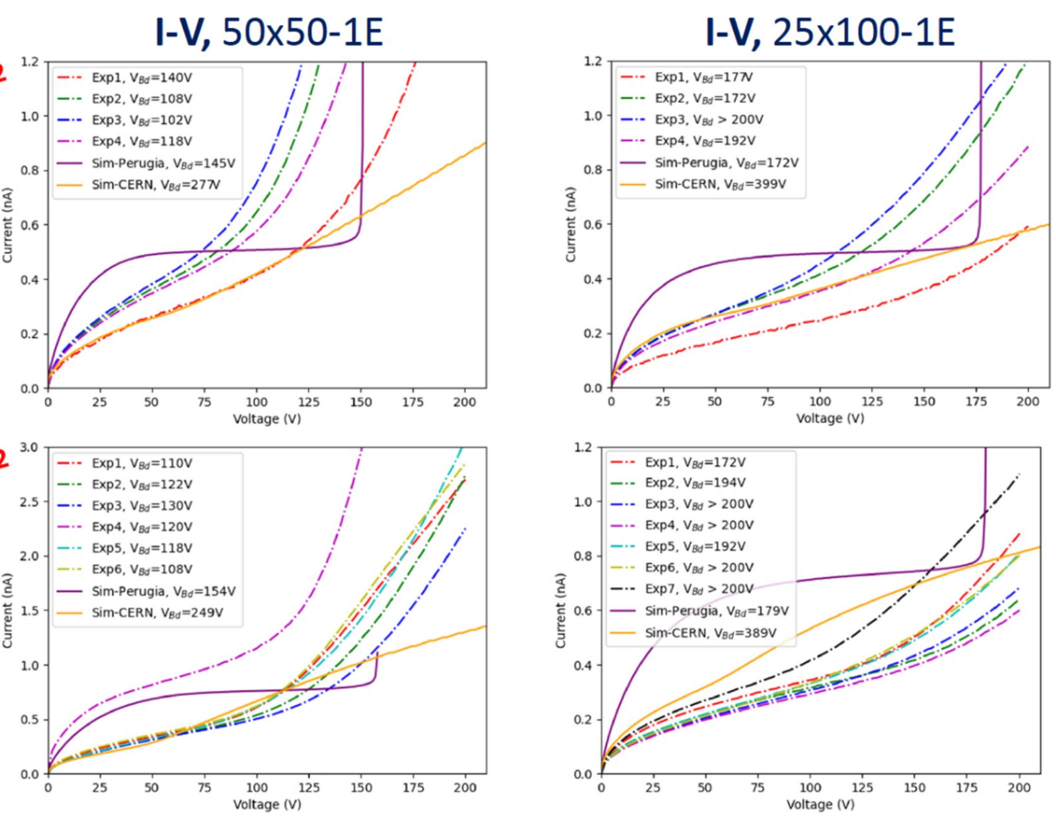
1,0E16 n_{eq}/cm^2

Calculated Damage Rate at V_b=100V, T=20°C

Structure	α^* Experiment (10^{-17}A/cm)	α^* Perugia Model (10^{-17}A/cm)	α^* CERN Model (10^{-17}A/cm)
50×50-1E	6.92±1.14	5.92	4.90
25×100-1E	4.25±0.91	5.74	4.22

1,5E16 n_{eq}/cm^2

Structure	α^* Experiment (10^{-17}A/cm)	α^* Perugia Model (10^{-17}A/cm)	α^* CERN Model (10^{-17}A/cm)
50×50-1E	4.41± 0.36	5.91	5.14
25×100-1E	3.87±0.43	5.54	4.09

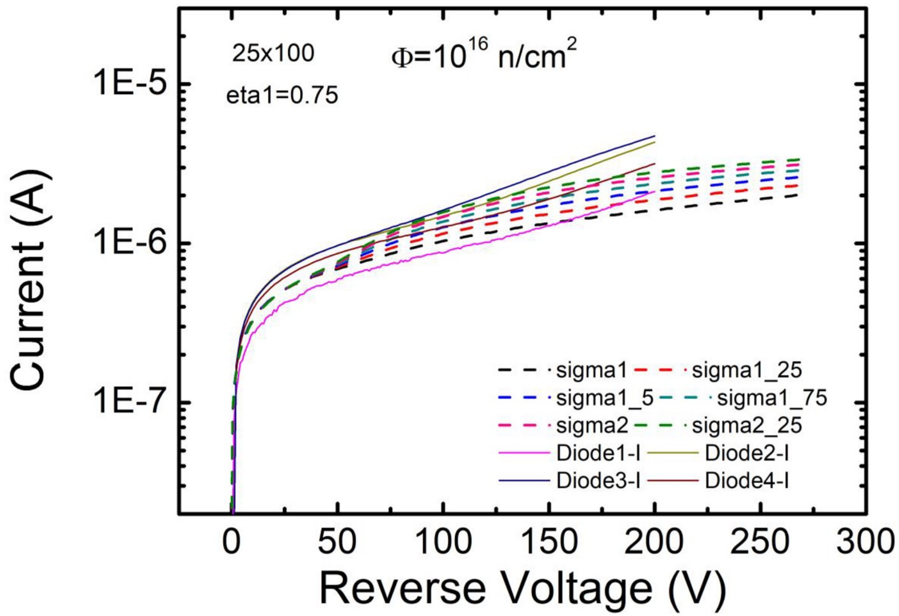


Optimization of the model

Table 2
Parameters of the proposed radiation damage model. The energy levels are given with respect to the valence band (E_V) or the conduction band (E_C). The model is intended to be used in conjunction with the Van Overstraeten–De Man avalanche model.

Defect number	Type	Energy level [eV]	σ_e [cm^{-2}]	σ_h [cm^{-2}]	η [cm^{-1}]
1	Donor	$E_V + 0.48$	2×10^{-14}	1×10^{-14}	4
2	Acceptor	$E_C - 0.525$	5×10^{-15}	1×10^{-14}	0.75
3	Acceptor	$E_V + 0.90$	1×10^{-16}	1×10^{-16}	36

Effect of the variation of the capture x-section for the acceptor levels



New measurements in Perugia on 3D detectors and test structures in the range 1-2.5×10^{16} n_{eq}/cm^2

→ **Optimize parameters in simulations to compare with experimental data.**

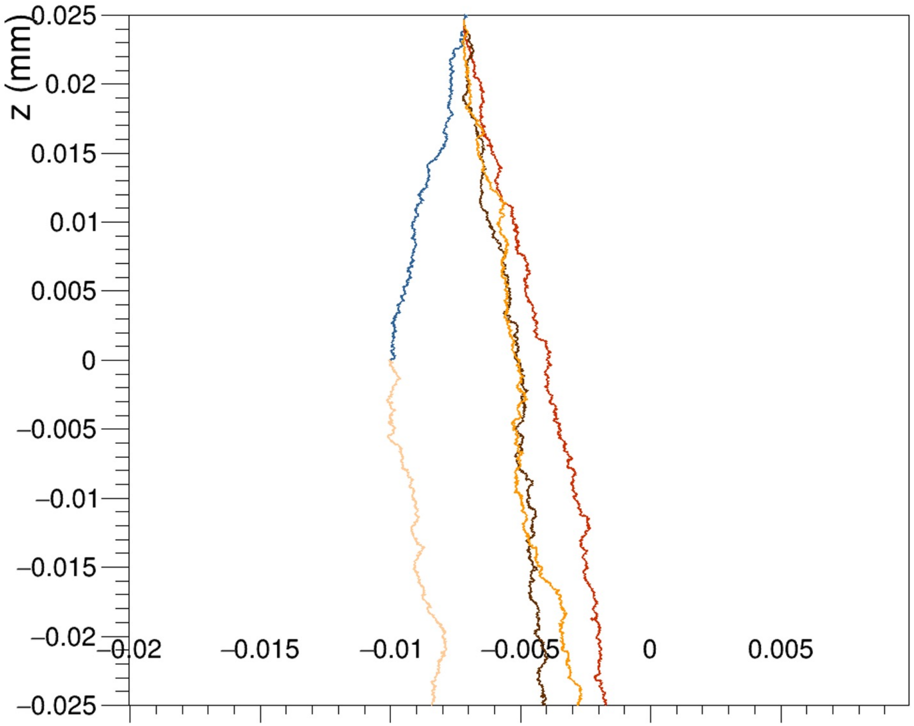
To measure: DC behavior and laser response of 3D and trenched-3D detectors, before and after irradiation(up to the fluence of 2,5E16neq/cm2)

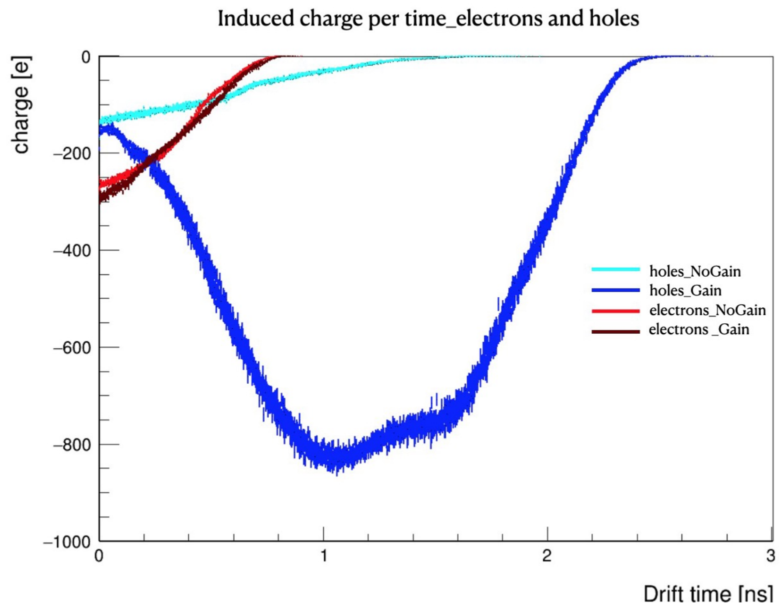
Task 6.2
AllPix Squared Simulations
Lennart Huth al, Slides

TCAD simulation of LGAD devices

Implemented mechanism of Impact Ionization: generation of secondary carriers in high electric field, relevant for LGAD devices

- Per step of the propagation, calculate …
    - local gain as a function of electric field
    - number of generated charge carriers stochastically per carrier in a group of carriers



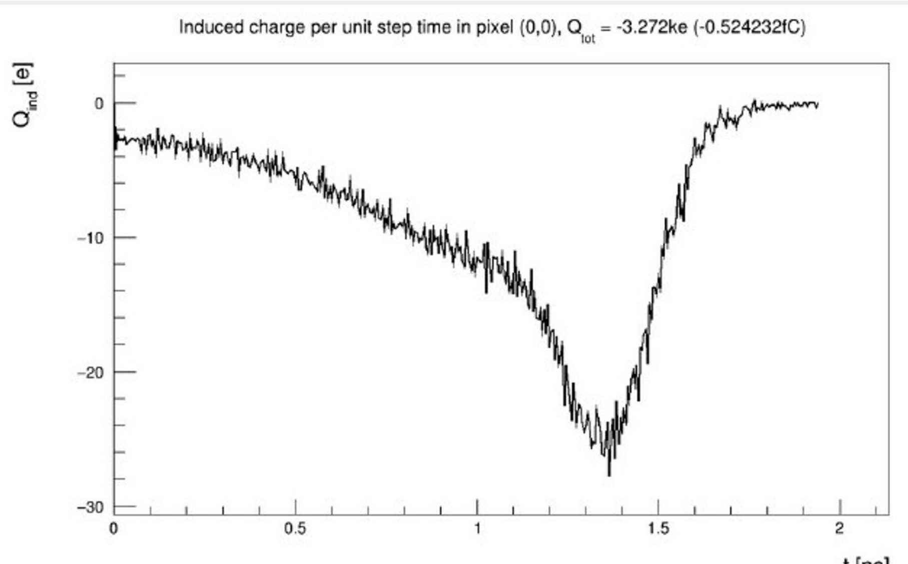


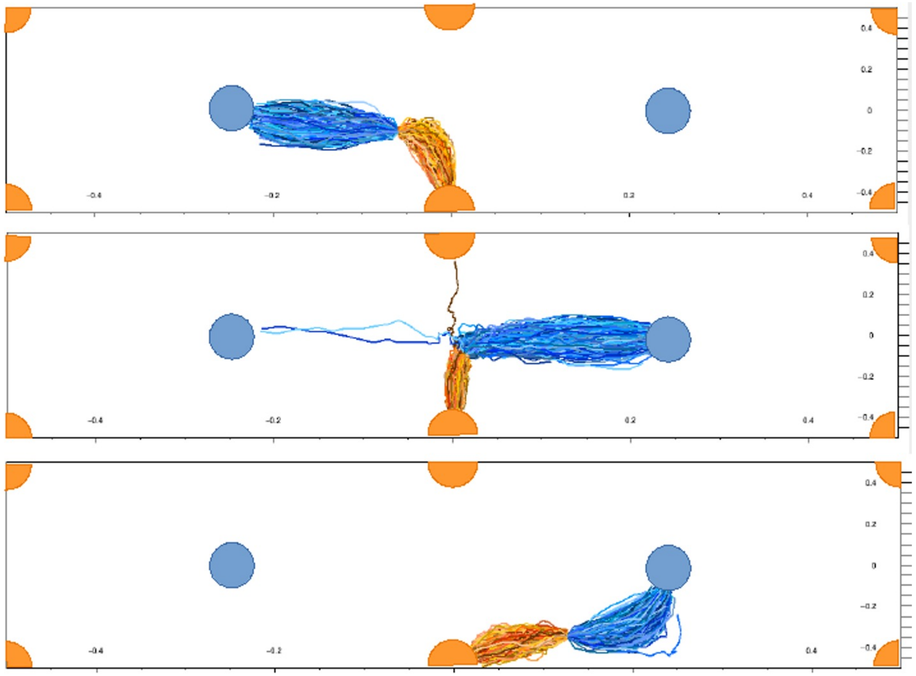
TCAD simulation of LGAD devices

Implemented 3D sensor geometry

First simulations with ATLAS 3D sensor geometry
- Two central front-side columns (collect charge)
- Six ohmic backside contact columns
- Charge collection & sharing as expected

- Pulses from transient simulation





Task 6.4
Interconnections: Anisotropic Conductive Films

Dr Ahmet Lale, Haripriya Bangaru

Anisotropic Conductive Adhesive

- **A**nisotropic **C**onductive **F**ilm/**P**aste (or **N**on-conductive)

  ACF/ACP or **NCF/NCP**

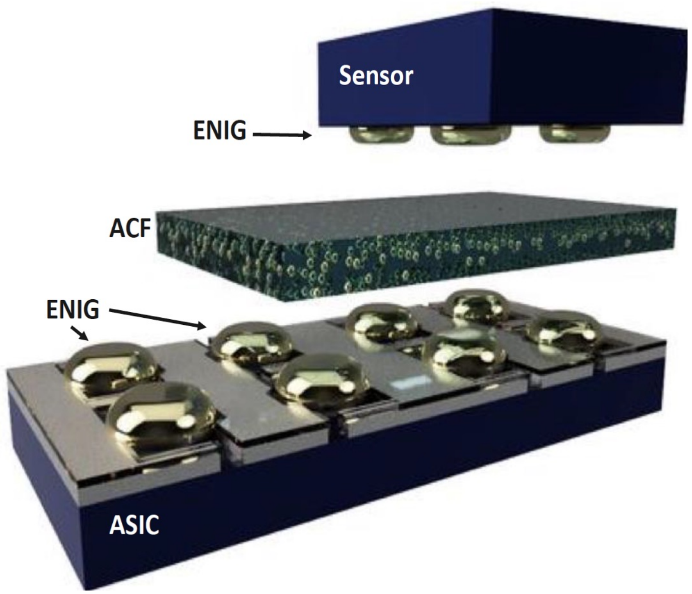
- Widely used for display production as strips --> transfer to small pitch area applications

- Thermo-compression bonding process

- Anisotropic / Vertical electrical connection via compressed conductive particles or direct contact of metal pads
- Permanent mechanical bonding

- Specific topology

  ENIG as Under Bump Metallisation (UBM)



Preparation
- Electrical testing
- Visual inspection

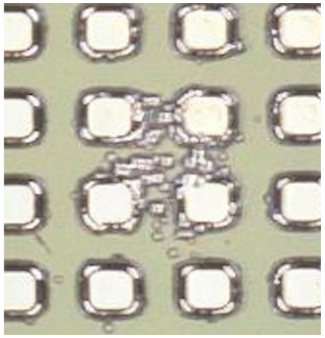
→ **ENIG (UBM)**
- Nickel growth
- Pad topology

→ **ACF bonding**
- Lamination
- Flip-chip bonding

→ **Testing**
- Cross-section
- Electrical, source and Test-beam measurement

Optimization of the ENIG plating

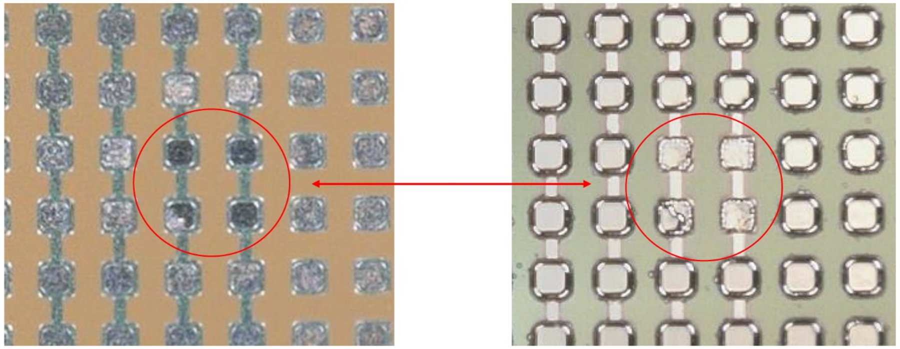
- Uniformity of nickel bump height across the chips
- Improve nickel deposition on chip edges
- Reduce eliminate over-plating phenomenon: plating on areas that should not be plated
- Enhance deposition reproducibility from one chip to another
- ENIG on smaller pads with a lower pitch →higher connection density as in Timepix3



Clusters of overplating

Before nickel plating, (After zinc plating)

After nickel plating

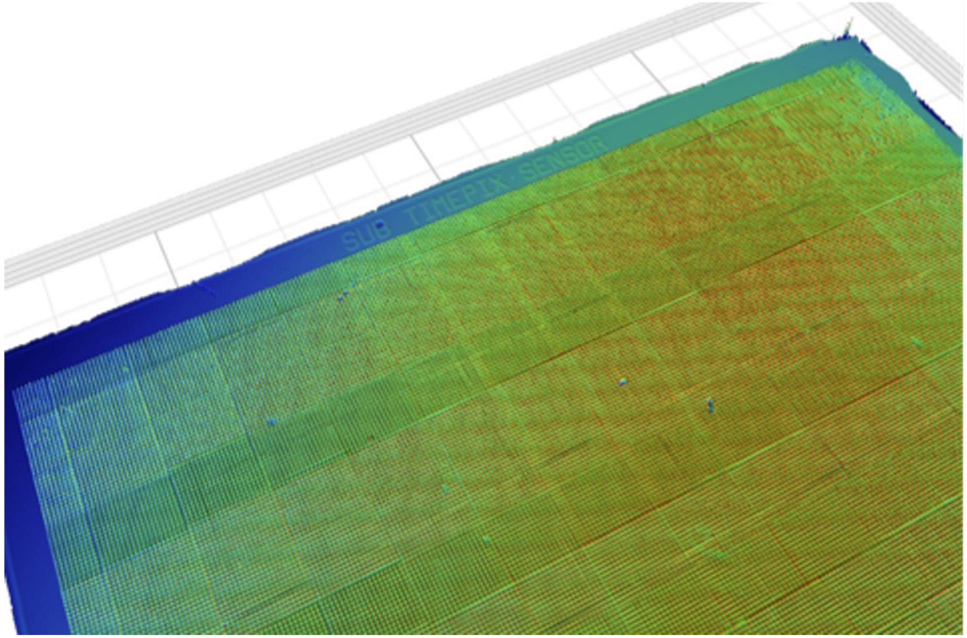


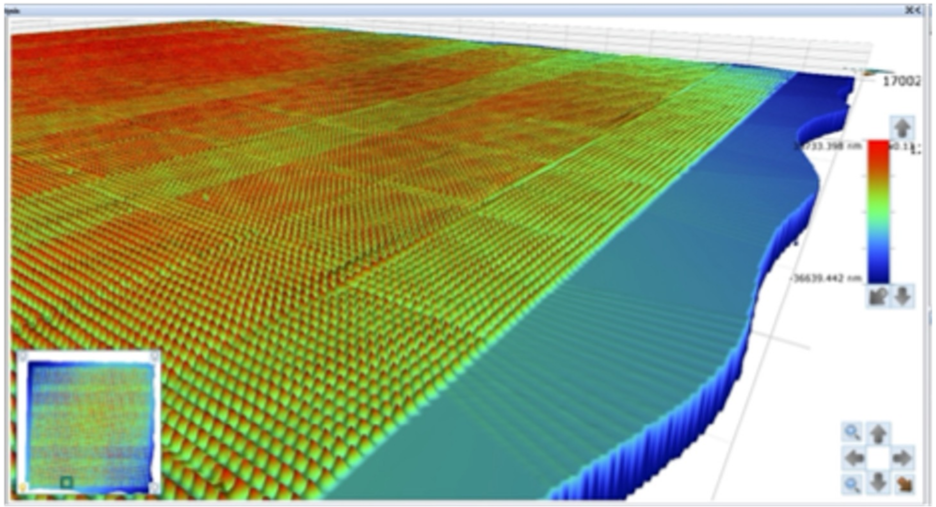
Improve Zinc deposition that is the step before the nickel plating

Enig results

- New equipment available at Campus Biotech for characterizing all nickel bumps on a chip, allows for quick identification of problematic areas, if any.
    - High bump height 10.5 µm
    - Good ENIG homogeneity with a variation of only 0.5µm (except for the first 2 rows on each edge).
    - Very few defects, approximately 98% of 65 536 pads are compliant.

Bruker Contour optical profilometer (at Campus Biotech)





Task 6.4
Interconnections: Wafer-to-Wafer

Thin hybrid pixel detectors with W2W

Update

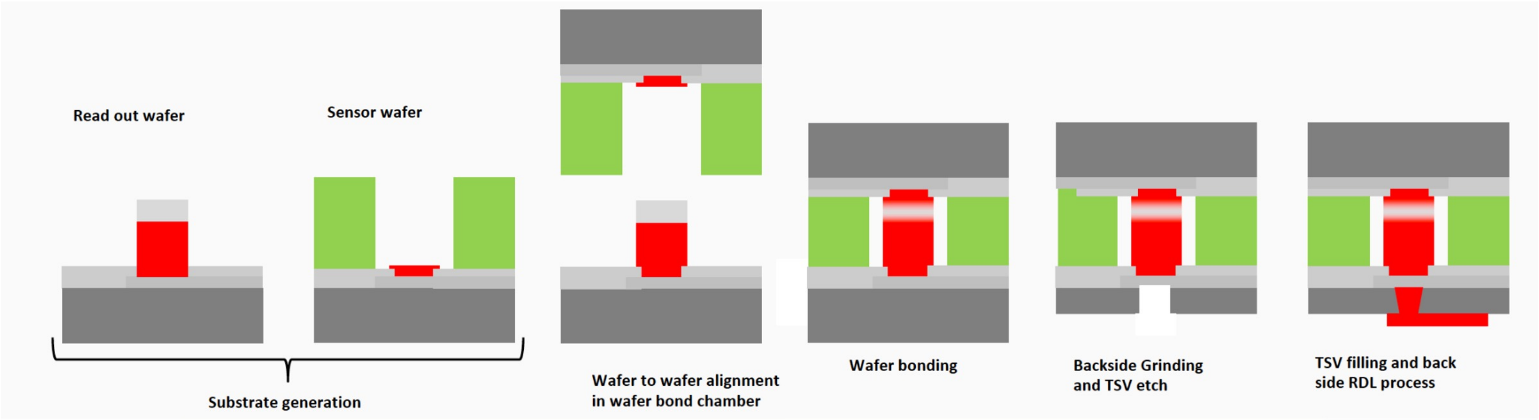
WP1: Design development and manufacturing of process qualification wafer, design preparation of functional TIMEPIX3 and DMAPS sensor wafer

– 1.1 Definition of technological approach for ultra-thin low-mass hybrid pixel detectors

– 1.2 Process qualification design including test structures

– 1.3 Fabrication of process development wafers → wafers with daisy chains available

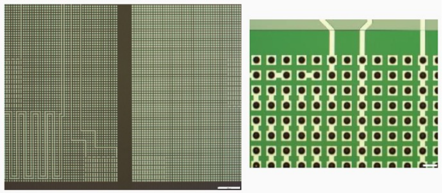
– 1.4 Design and mask preparation for TIMEPIX3 readout electronics and DMAPS active sensor wafer



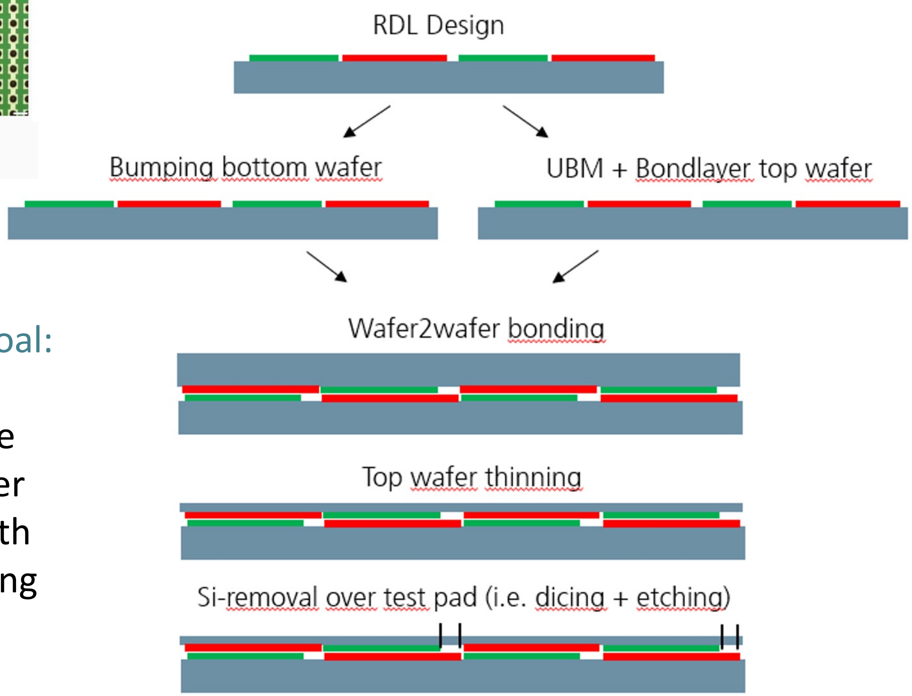
Process status- Daisy chains setup

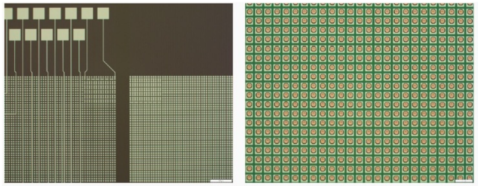
Update

W2W bonding setup bottom wafer:



Bottom wafer with Cu-SnAg pillar

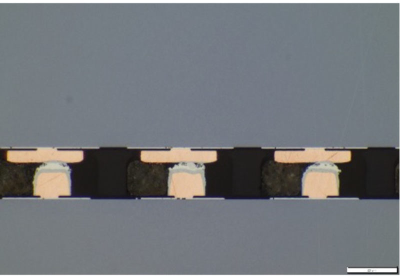




Top wafer with Cu-Pad and polymer layer

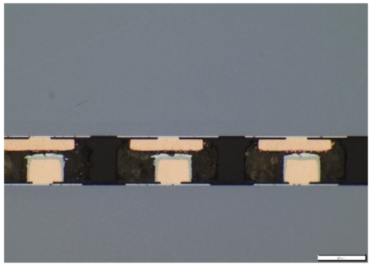
Process Development Goal:

Evaluation of a bonding material that enables the combination of a polymer glue bonding process with the Cu-SnAg pillar bonding process



Left: slightly connected pillars, solder transfer to Cu pad (top) visible

Right: gap between pillar and pad, no solder transfer to Cu pad (top) visible



Status and next steps

Preparations for W2W with Timepix3 and passive CMOS sensor well progressing

− Timepix3 wafers available and ready for W2W bonding

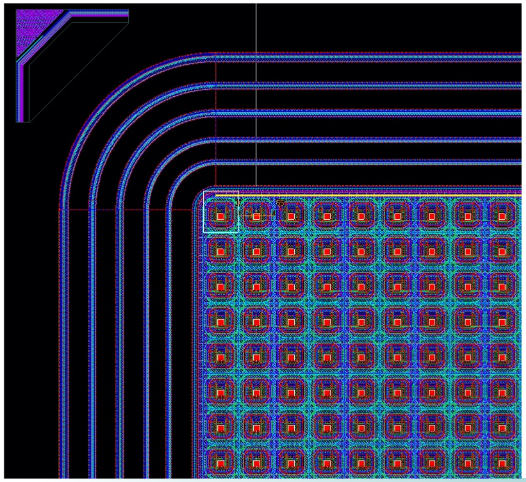
− Sensor wafer design finished and processing about to start, could be available by end of summer

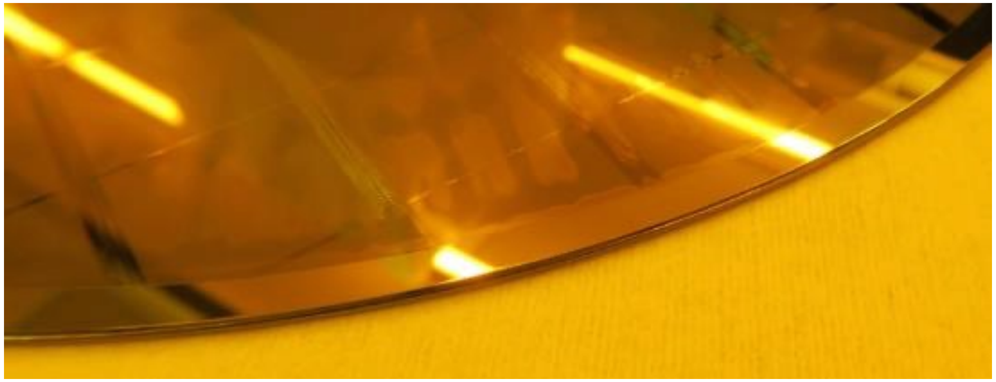
− W2W bonding process setup with daisy chain at IZM well advanced but still some optimizations needed

Next steps:

− Finishing W2W process setup and optimization including electrical test results on daisy chain wafers

− Processing of passive CMOS sensor wafer designed for W2W bonding with Timepix3 wafers





Additional slides

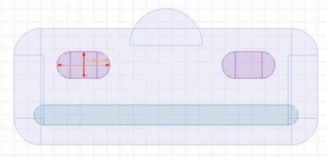
Trench 3D in FBK

Update

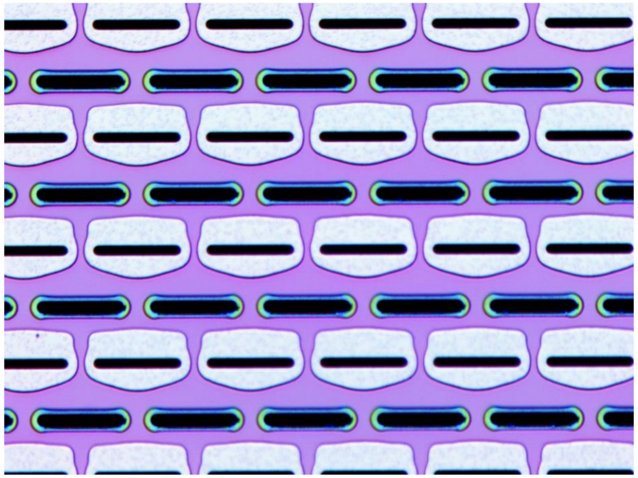
One reason for delay is the optimization of the contact.
Moreover the stepper is now down.

N-Poly Litho Optimization & Contact lithography

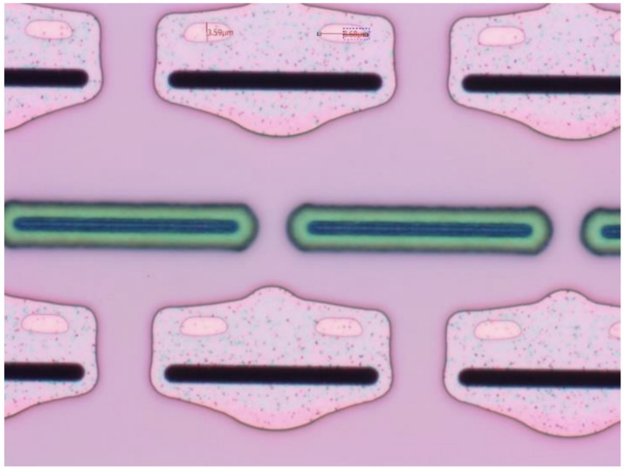
Designed pixel layout



Poly Definition



Contact Definition



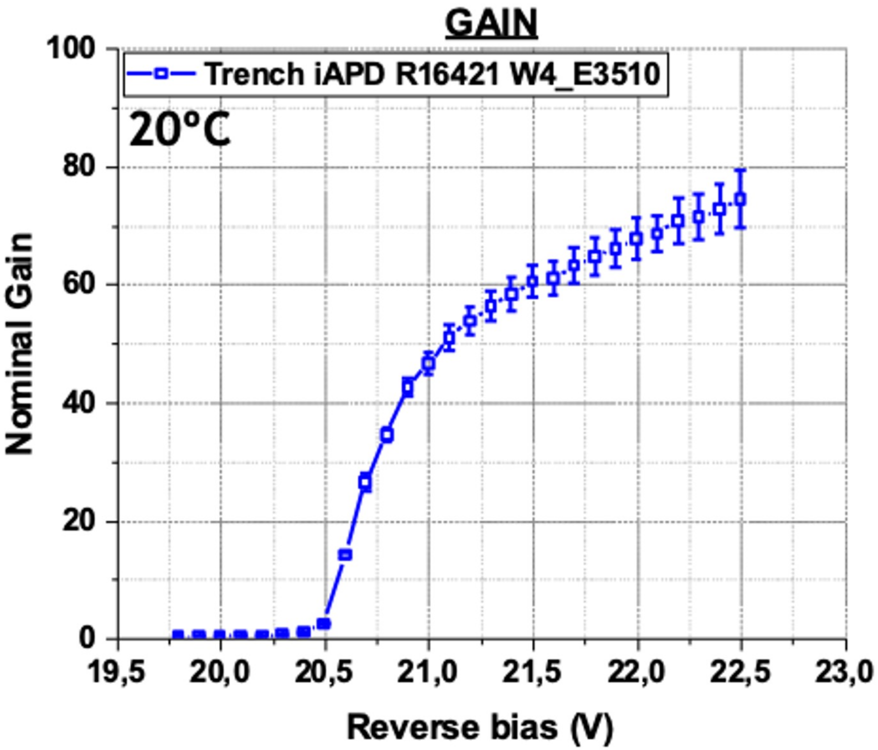
Sabina Ronchin, Tredi 2024

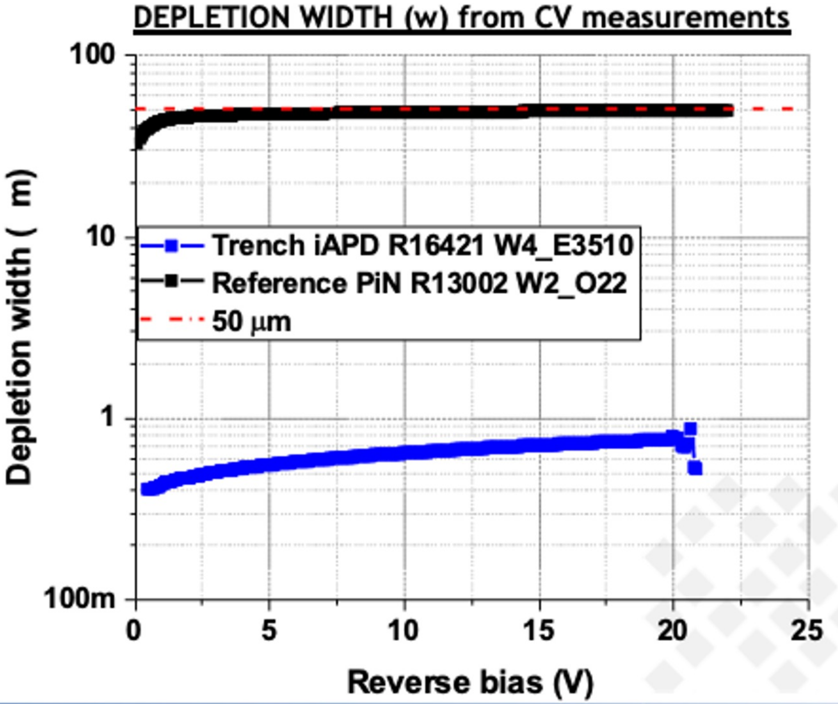
We had to accept a slight deformation, obtaining really nice frog!

→ Contact from 4x8 to 3.5x8.7 → **Ok for device!!**

iLGAD - SEN EPI

1064 nm TCT IR Light, **10000 waveforms per V point**
Max intensity of the laser, 1kHz

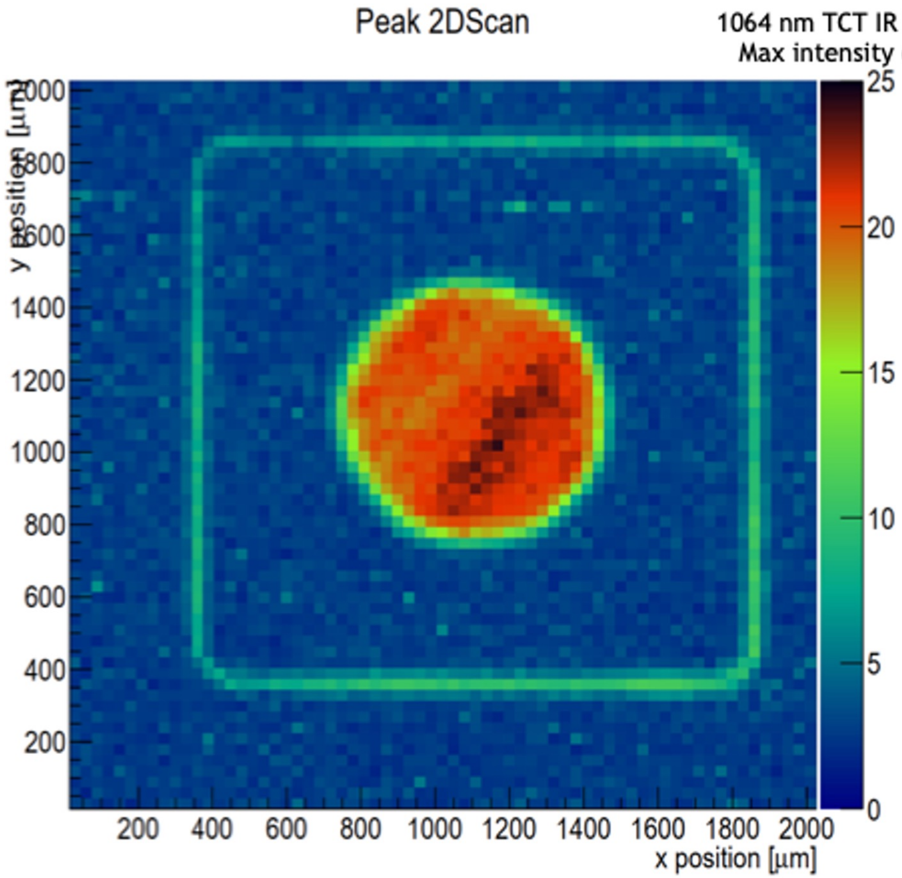


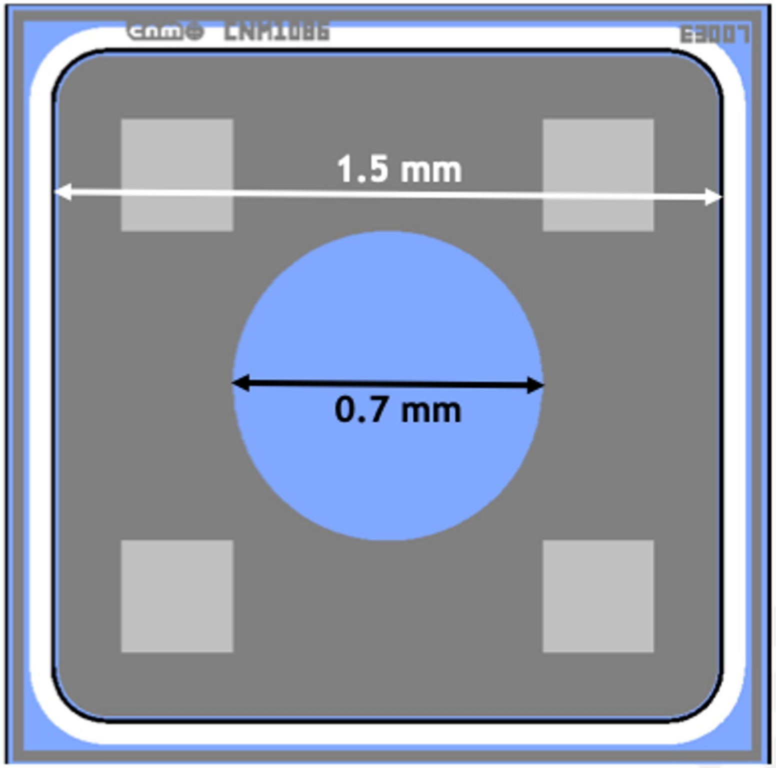


To BACKUP

iLGAD - SEN EPI - laser

1064 nm TCT IR Light, 20.5 V, 20°C
Max intensity of the laser, 1kHz

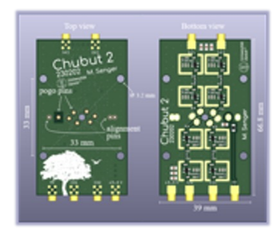




Test beam setup and commissioning: Major challenges

Characterization of the 4D-tracking DUTs requires:

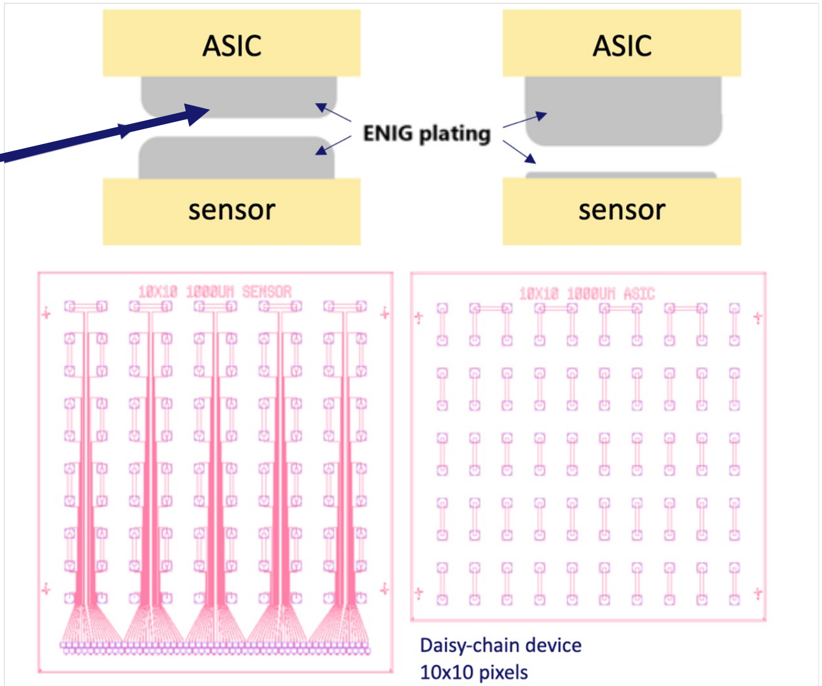
- Precision Tracking:
  - AIDA-type telescope (MIMOSA 26 CMOS sensors) for high-resolution track reconstruction.
  - MIMOSA 26 pixels sized 18.4 $\mu m \times$ 18.4 μm, in 1152 columns and 576 rows, covering an active area of 21.2×10.6 mm → binary resolution of 5.3 μm
  - SLOW read out MIMOSA 26 with a rolling-shutter, for correlated double sampling and zero suppression on-chip → integration time equals 115.2 μs, 8680 frames to be read out per second
  - FAST read out using CROC sensors pixel sized 50 $\mu m \times$ 50 μm → Allows for determining the DUT absolute efficiency.
  - Digitizer, CROC producer integrated into EUDAQ2.
- Precision Timing:
  - No dedicated read out ASIC available.
  - No dedicated time reference device.
  - **Discrete front-end electronics (CHUBUT-2) as preamp and shapper.**
  - Fast waveform digitizer (DRS4 ASIC):
    - Analog bandwidth 500MHz, 5Gs/s, 16 channels.
- Trigger logic, rates, latency and dataset sizes:
  - Small area DUTs (pixel size) → small trigger acceptance
  - CAEN digitizer fixed acquisition time window → TLU2 trigger latency too large.
  - Dedicated Lecroy DSO WR8104 for implementing a low latency trigger logic.
- Mechanics and cooling:
  - Chiller with high power cooling required to achieve -25 C as operating point (at SPS just -12 C)
  - Somewhat cumbersome operation of supporting linear stages.
  - Fine alignment of DUT done with piezo electric stages



ACF performance with Daisy-chain structures

Chain devices from the FBK production:

- 12 chains tested in total
- Two types of ENIG plating investigated
- ACA Anisotropic Conductive Adhesive bonded (Araldite 2011 with 5% content of 20 µm particles) for large parts as an alternative to films on small parts.
- Electrical 4-wire resistance measurements



Daisy-chain device
10x10 pixels
1000 µm pitch
~150 µm pad size

Reliability studies ongoing, in particular aging in climate chamber:

- Temperature ramp at 7.5°C per minute, kept for 10 minutes at min/max with 20 cycles
- Standard cycle -40 °C to 80 °C and harsher cycle -60 °C to 120 °C

Preliminary resistivity results very promising (200 mOhm difference)!