# Status of Lgad technology for timing applications

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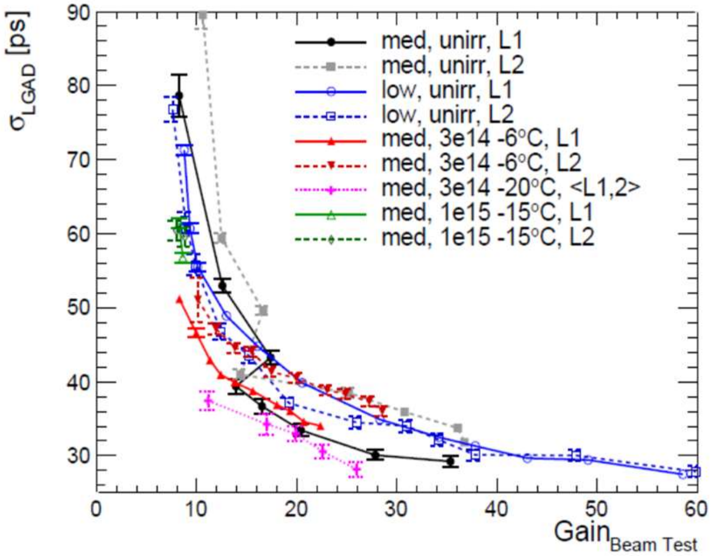
## *Summary*

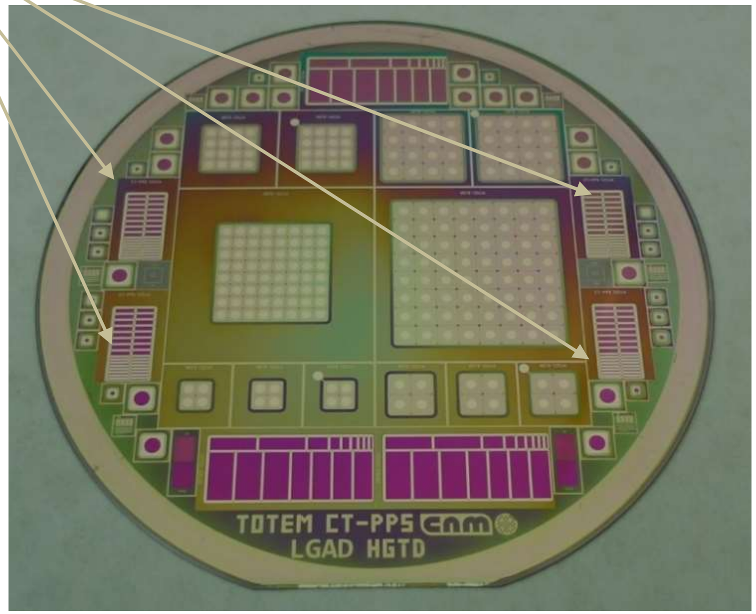
- **Status of LGAD for timing applications**
- **LGAD Radiation hardness strategy**
- **Gallium study**
- **First measurements on LGAD with Carbon spray**
- **HGTD on wafer to wafer bonding**
- **Future work within AIDA2020**

## *First 50 µm SOI Detectors (HGTD) presented in 2016*

- **LGAD HGTD Run** Basic Information:
  - ✓ **Cnm827** Mask Set
  - ✓ 50um thick SOI wafers
  - ✓ **8** Mask Levels




First LGAD installed in an experiment at CERN, CT-PPS




- Nicoló Cartigla et al., "Beam test results of a 16 ps timing system based on ultra-fast silicon detectors", https://arxiv.org/abs/1608.08681
- Joern Lange et al., Gain and time resolution of 50 um thin LGAD before and after irradiation, $12^{th}$ TREDI meeting, February 2017.


3

# *LGAD Radiation hardness strategy*

- **Previous studies demonstrated the LGAD gain reduction when fluence increases.**
  - ✓ **There is no gain for fluences higher than $2 \cdot 10^{15}$ $n_{eq}$ /$cm^2$**
  - ✓ **Boron removal effect**
  - ✓ **$B_s$ is displaced to an interstitial position and $B_i$ forms the complex $B_i$ - $O_i$ which is more energetically favourable.**

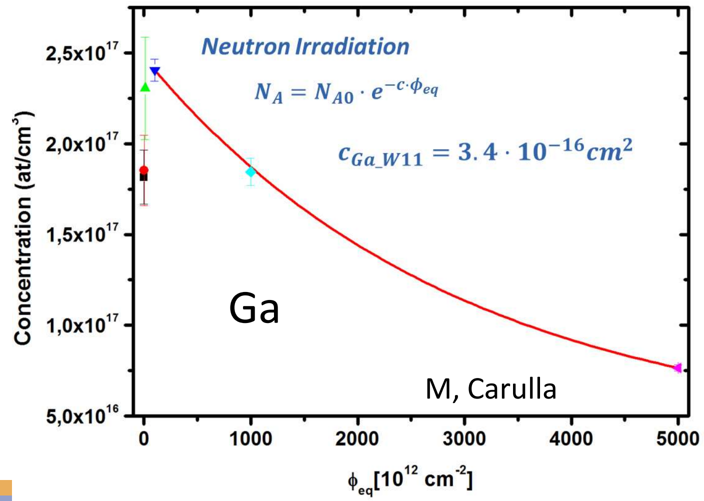
- **Fabrication of thin LGAD detectors in order to reduce the cross section of trapping due to radiation bulk damage.**
  - ✓ **SOI & Epitaxial substrates**

- **Use of Gallium as acceptor dopant for the LGAD multiplication layer.**
  - ✓ **Fabrication of Gallium p-i-n diodes to study the Gallium diffusion and the response to different neutron fluences.**
  - ✓ **Some references stands that carrier removal is drastically reduced in Gallium doped wafers meanwhile others affirm that the reduction is not that much. Furthermore Gallium introduces the electron trap level ( Ec-0.11 eV).**

- **Use of C to reduce the concentration of $O_i$ by introducing $C_s$. As a consequence, the amount of $B_i$ – $O_i$ complexes will be reduced. However $C_i$ – $O_i$ complex will increase, introducing the level $E_v$+0.36 eV that acts like a trap of holes.**

## *Preliminary Ga results*

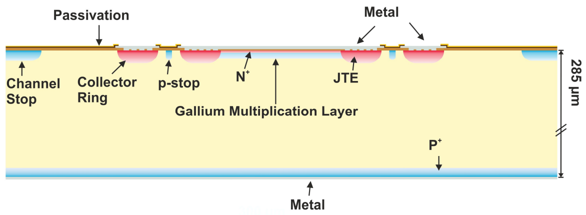
- Measure resistivity vs fluence to extract acceptor removal constant for neutrons. See M. Carulla´s Talk at the Trento Workshop 2017.
- Irradiations with electrons to compare with previous results. Undergoing.
- Detectors ready for neutron irradiation in Ljubljana.
- No **clear advantage** from using Ga, but results still very preliminary. We just measured the resistivity of the implant before and after irradiation but Gain depends on more factors .

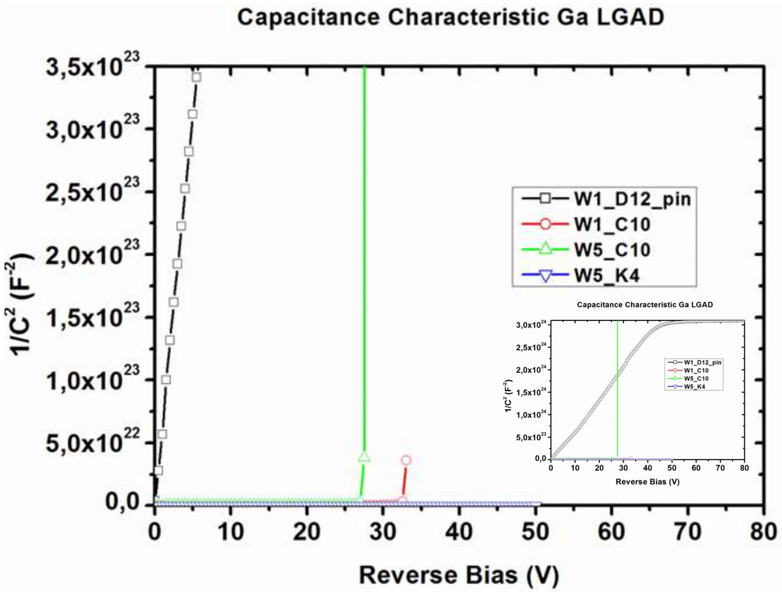


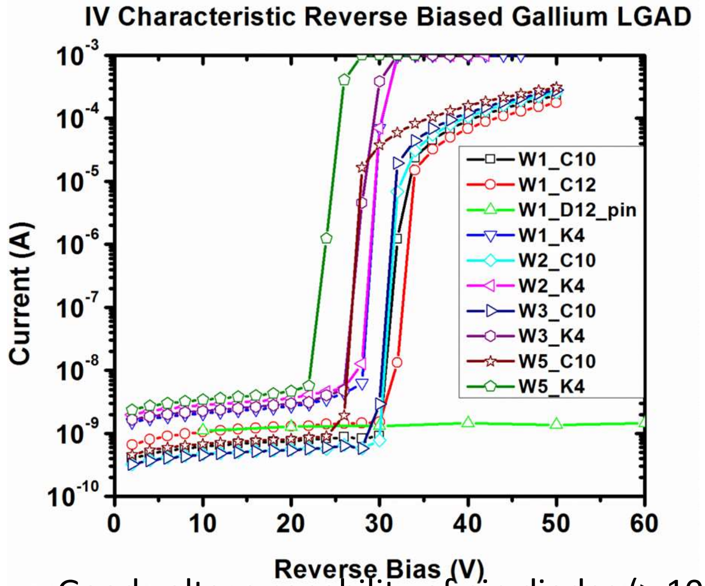
# *LGAD with Gallium multiplication layer*

**New technology:**

- ✓ 300 µm high resistivity p-type FZ wafers
- ✓ Gallium implant at multiplication layer
- ✓ 5 different implant doses
- ✓ LGAD with pad size 1.2x1.2 $mm^2$, 3.2x3.2 $mm^2$, 8.2x8.2 $mm^2$



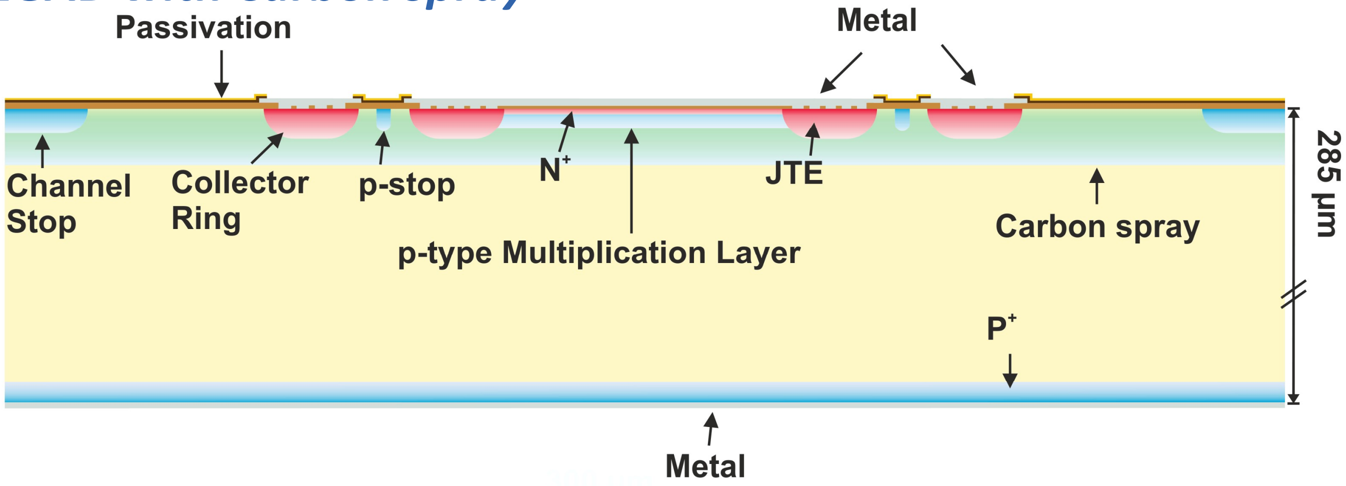

Good voltage capability of pin diodes (> 1000V)

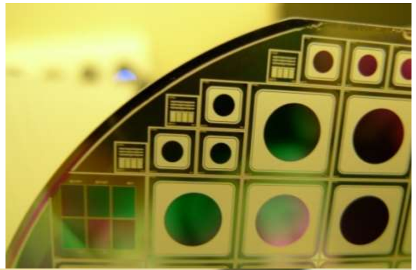
***LGAD with Ga breaks before multiplication layer has been depleted. Diffusion of Ga does not fit with simulation model.***

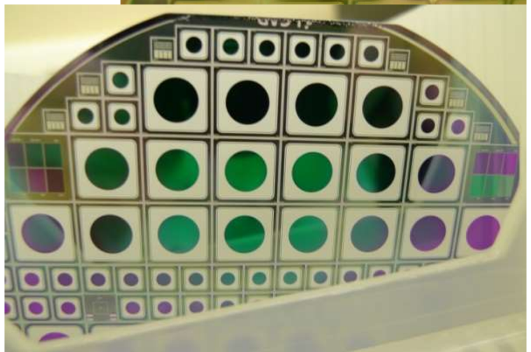
***We can still study acceptor removal and gain after irradiation.***

# *First measurements on LGAD with Carbon spray*

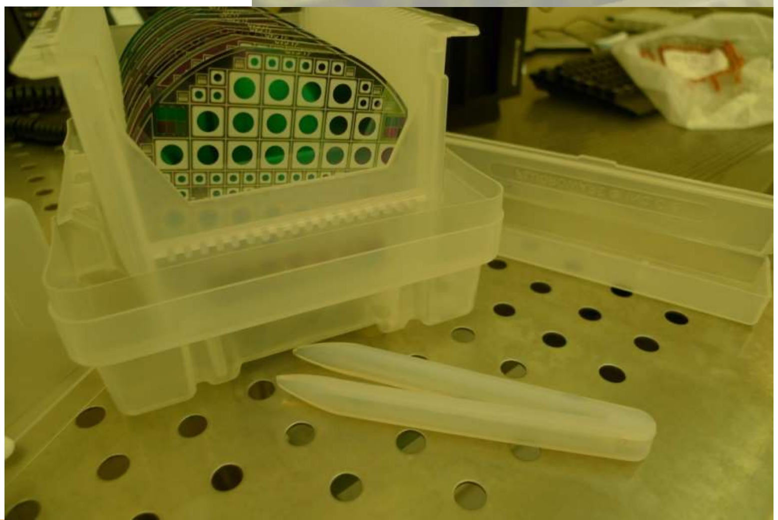
## *LGAD with Carbon spray*



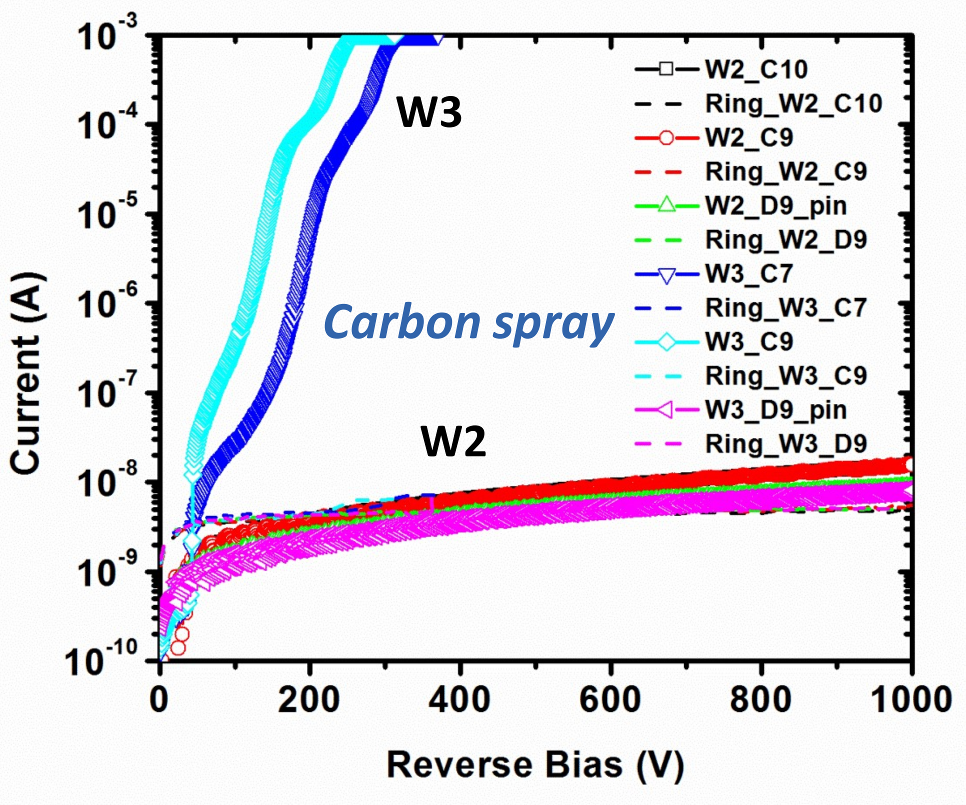


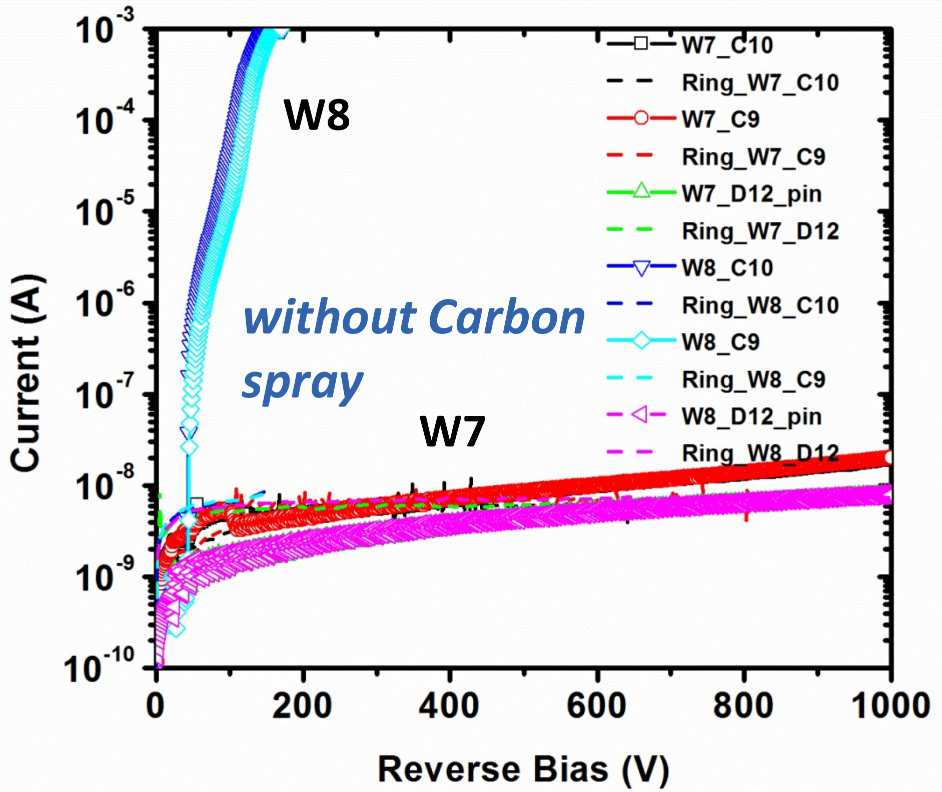
- 300 µm high resistivity p-type wafers
- 5 PWell Implantation Dose
  - ✓ Co-diffusion of Boron, Phosphorous and Carbon will introduce some difference in the final doping profile. Carbon can reduce the Boron and Phosphorus diffusion. Because that variation, 5 Pwell imp. Doses have been implanted.



# First measurements on LGAD with Carbon spray

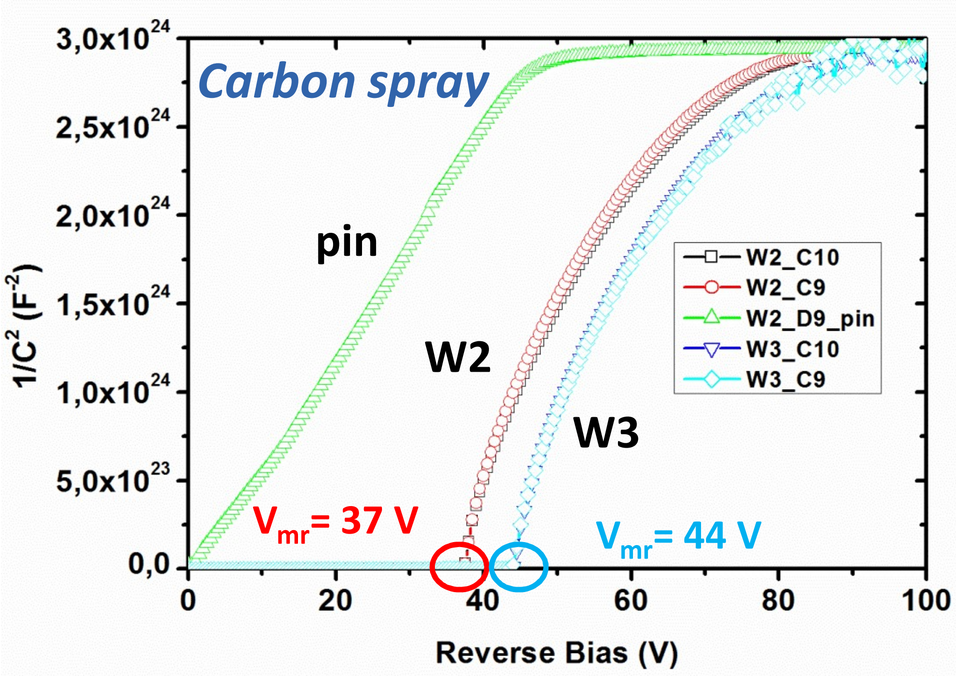
## Electrical characteristic of LGAD with Carbon spray

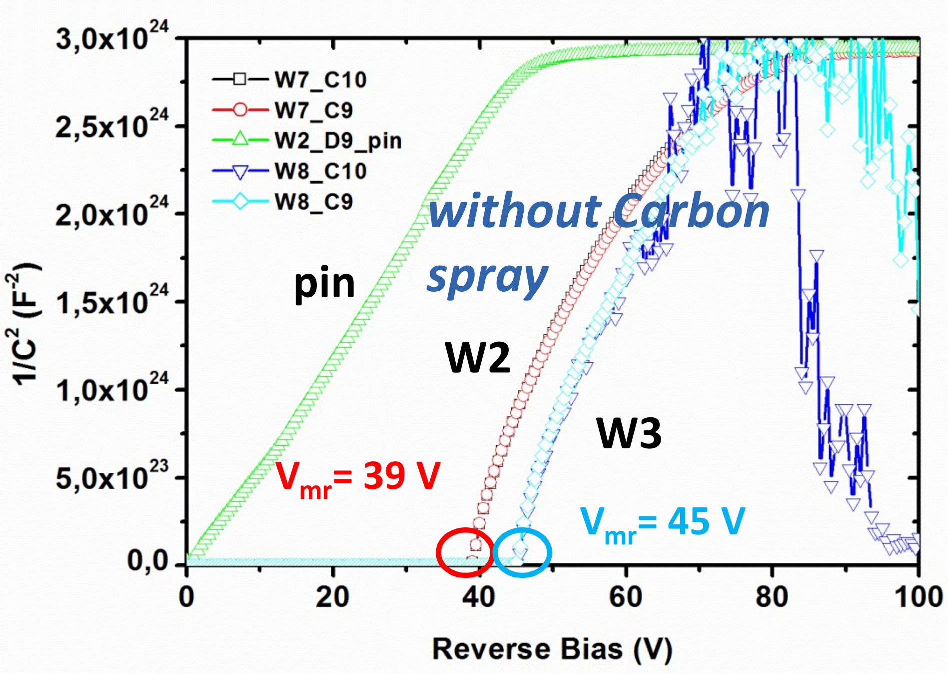


## First measurements on LGAD with Carbon spray

### Depletion voltage of the multiplication layer



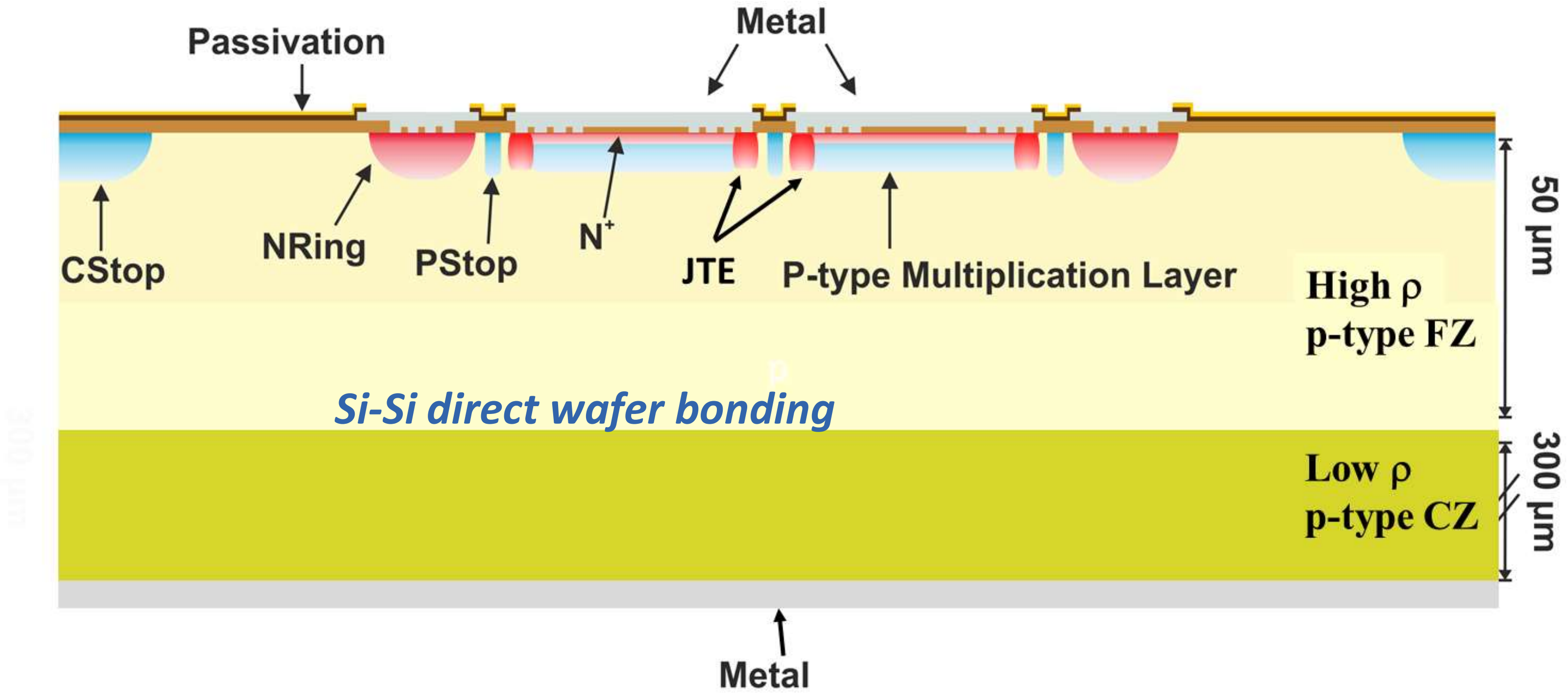




*As expected Carbon doesn't change the electrical characteristics of devices. Detectors already sent to Ljubljana for neutron irradiations and to CERN for proton irradiation.*

# *High Granularity Timing Detector (HGTD)*

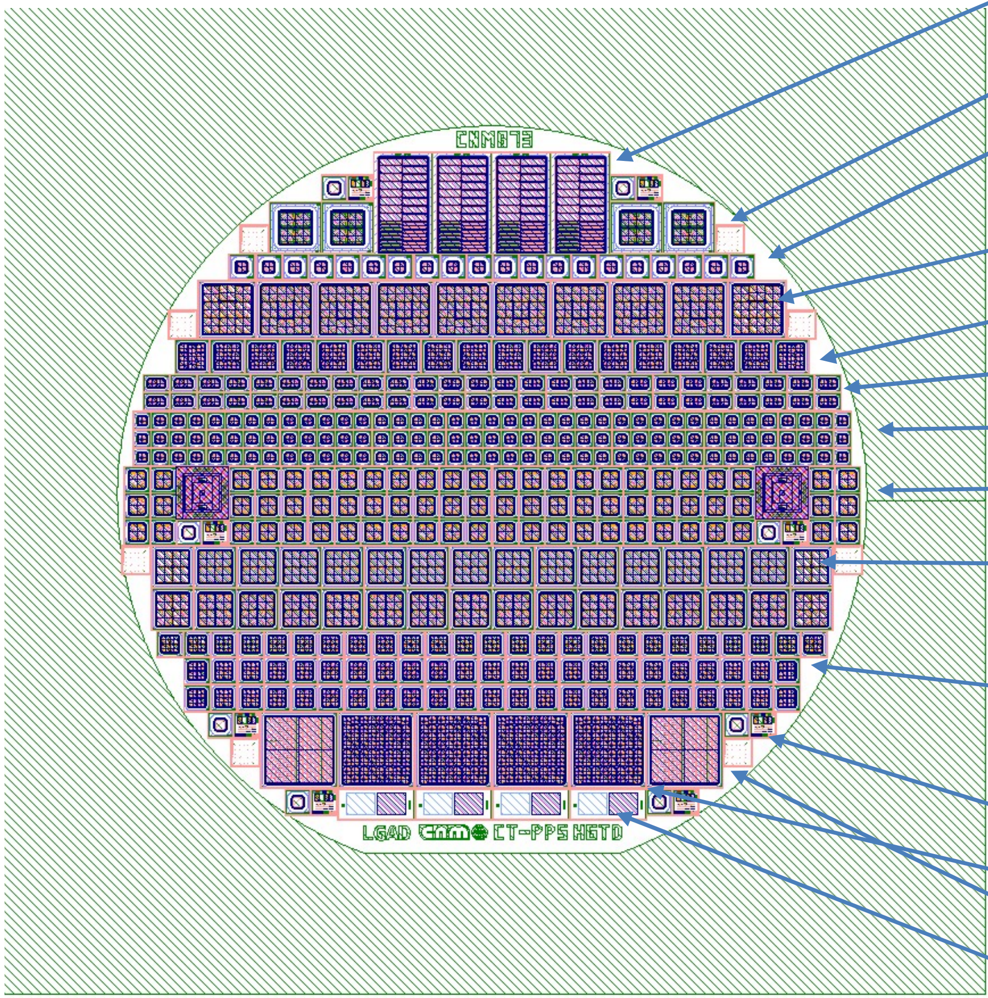
**HGTD technology:**

- ✓ Wafer to wafer bonding (1 mask step and process less than SOI wafers)
- ✓ 50 µm high resistivity p-type FZ wafer + 300 µm low resistivity p-type CZ wafer
- ✓ JTE in all structures
- ✓ Some wafers will be implanted with C spray.



# HGTD on wafer to wafer bonding

## New 4'' mask set up




- CT-PPS detectors (4)
- 2x2 matrix, 2x2 mm pads. 1000um edge (4)
- 1.2 mm LGAD diodes. 800um edge (18 lgad +2 pin)
- 3x3 matrix. 2mm pads (8 lgad +2 pin)
- 3x3 matrix. 1mm pads (16 lgad +2 pin)
- Epitaxial Lgad structures (TBD)
- 1 mm LGAD diodes. 500um edge (111 lgad + 6pin)
- 2 mm LGAD diodes. 500um edge (66 lgad + 6pin)
- 2x2 matrix, 2 mm pads. 500um edge (28 lgad + 4pin)
- 2x2 matrix, 1 mm pads. 500um edge (63 lgad + 8pin)
- AC coupled LGAD. 500um edge (2)
- 8x8 matrix, 1 mm pads. 500um edge (4)
- AltiRoc dummy structures (4)
- SIMS test structures (4)

# *Future work within AIDA2020*

Proposal for a Time detectors at CMS approved, Endcap front-end module with LGAD.

My opinion is that we should use this project to fabricate prototypes for this experiment.

Some geometries proposed by Nicoló Cartiglia from INFN Torino.

## Endcap front-end module with UFSD

**(Lot's of numbers from Joao's presentation)**

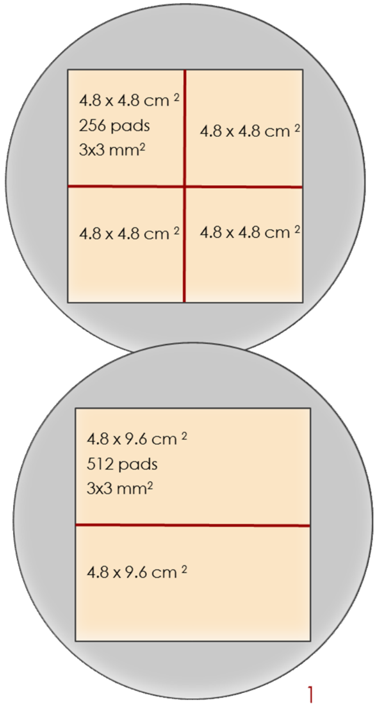
The sensor geometry is determined by the wafer size and by the pad dimension. The overall available silicon area in a 6 inch wafer is ~ 10x10 cm²

Let's suppose

- 6-inch wafers
- **2 PS sensor/wafer : 2* ( 4.8 x 9.6) cm²**

**For different pad sizes, the geometry will be changed accordingly**

**What overall geometry we assume? 0.3 – 1,1 m radius? ➔ 3.5 m2 area?**

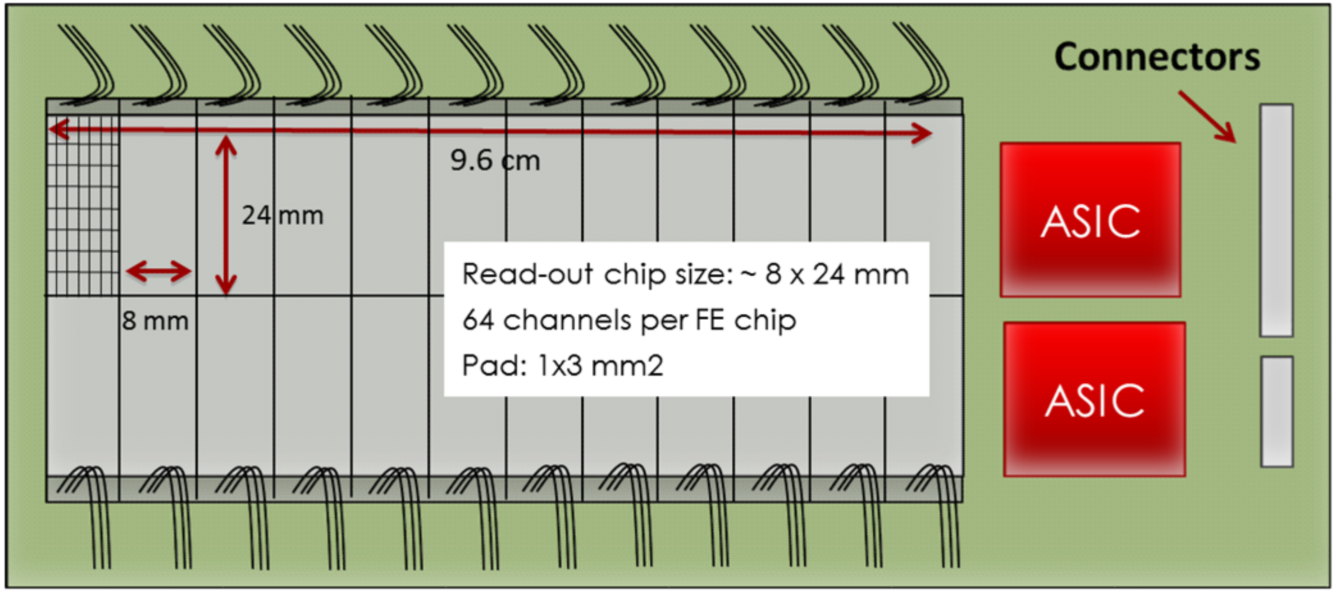



Nicolo Cartiglia, INFN, Torino

1

# Timing Module (TM) on PS geometry

Let's use the PS geometry (5x10 cm2) as baseline for our TM




**From physics**: what is the granularity? 1x1 mm2, 1x2 mm2, 1x3 mm2.

Shall we use hexagon to minimize the perimeter?

30 µm dead area

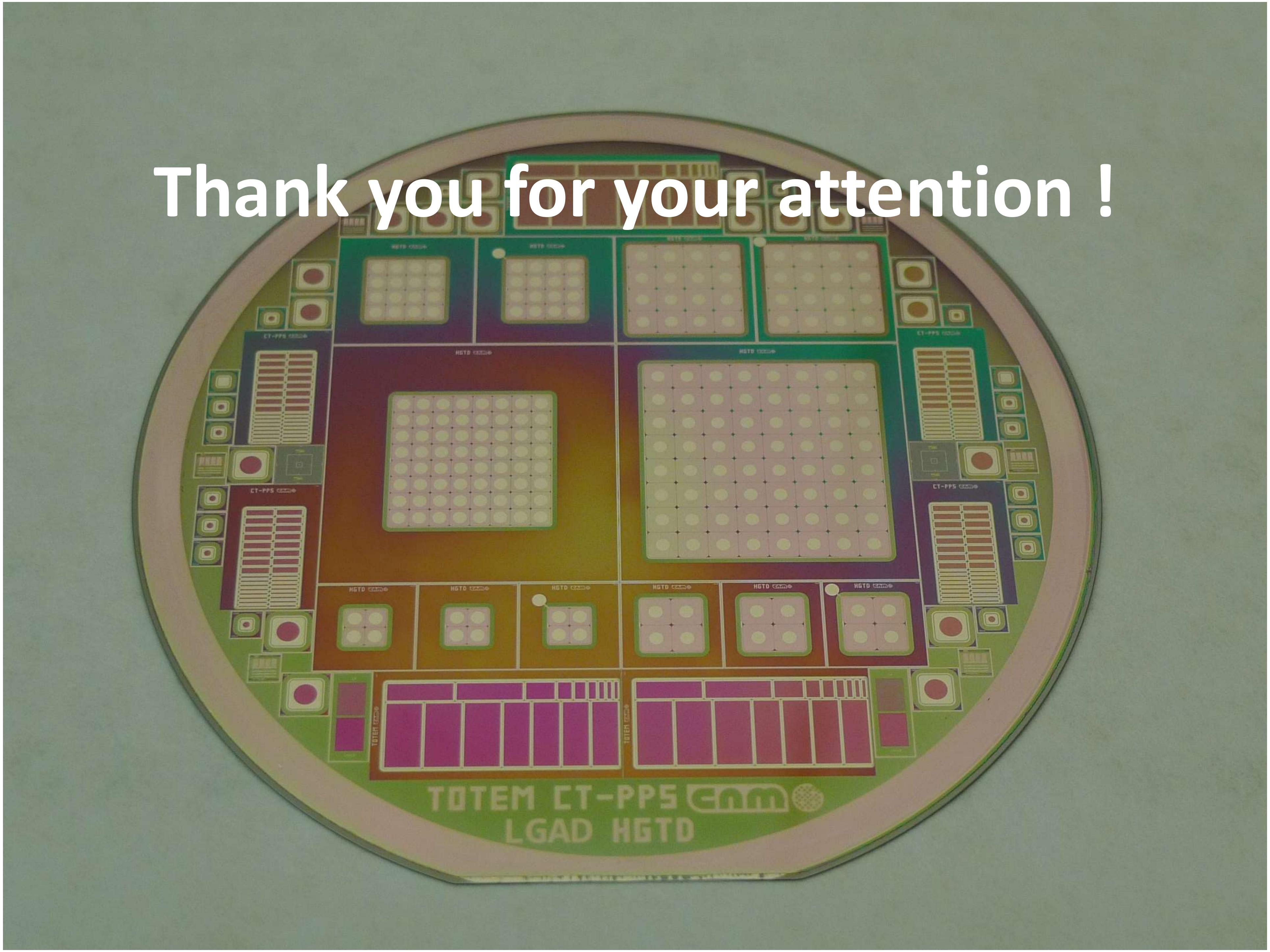

**Dead area:** 12% 9% 8% 9% 6%

Nicolo Cartiglia, INFN, Torino

# New mask for AIDA2020

- Include pixels with 1x2, 1x3 $mm^2$ geometries and **hexagons** of 2 and 3mm.
- Include pixels (1x1$mm^2$ and 2x2$mm^2$)compatible with the **AltiRoc** chip, 2x2 matrices.
- Include some **large** (Do we have FE electronics?) and small pixel matrixes.
- Include standard **pad** structures.
- Investigate different thicknesses for timing using as baseline 50um. Si-Si direct wafer bonding. **30um thick**?
- **Epitaxial** substrate may be an interesting option.
- **Radiation hardness** must be also addressed, target fluence 1E15n/$cm^2$ (for CMS).
- Open for discussion.

# Thank you for your attention !



# RD50 Institutes Participating in the LGAD development

1. CNM Barcelona, G. Pellegrini
2. Liverpool University, Gianluigi Casse
3. UC Santa Cruz, Hartmut Sadrozinki
4. IFCA Santander, Ivan Vila
5. University of Glasgow, R. Bates
6. INFN Florence, Mara Bruzzi
7. INFN Torino, N. Cartiglia
8. CERN, M. Moll
9. Jozef Stefan Institute, G. Kramberger
10. IFAE Barcelona, S. Grinstein
11. LPNHE Paris, Giovanni Calderini
12. LAL Orsay, Abdenour Lounis

CERN RD50

*http://rd50.web.cern.ch/rd50/*

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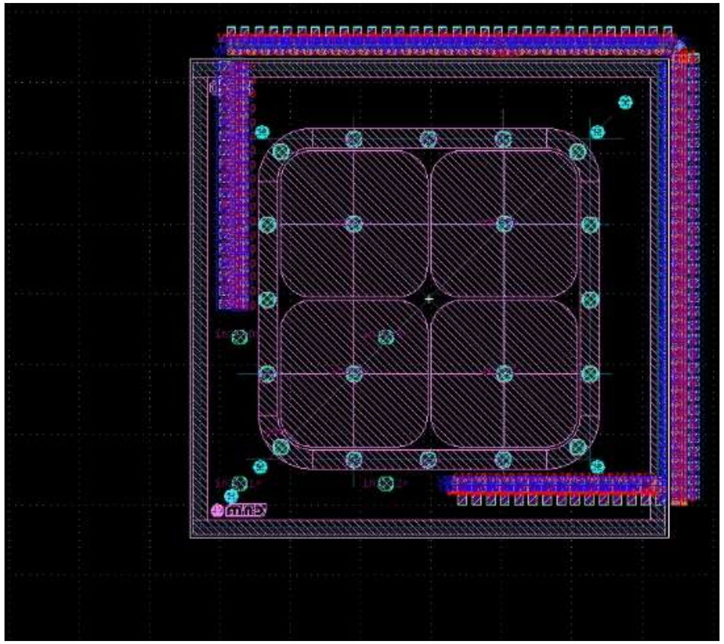
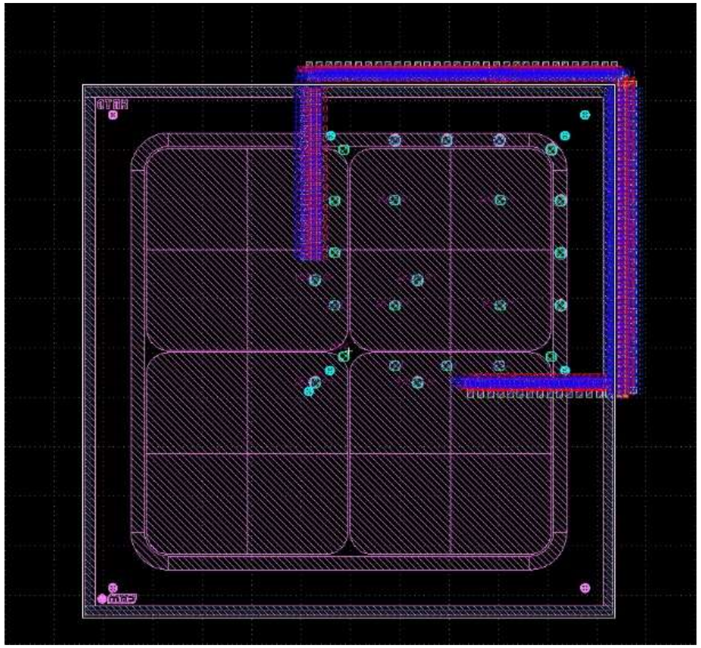
AIDA 2020

# Overlapping the detectors with the Artiroc



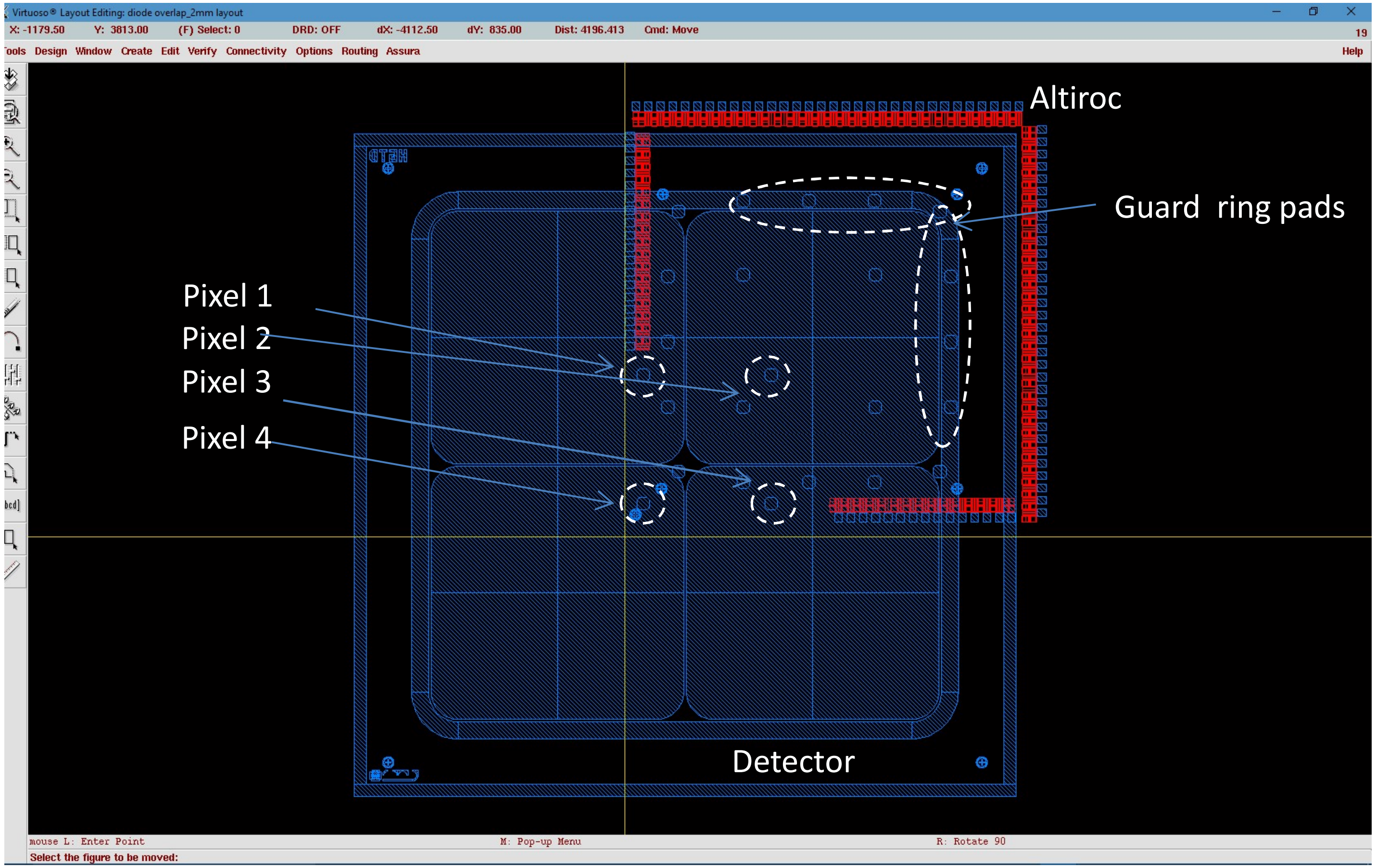
1mm pads



2mm pads

Details in next page

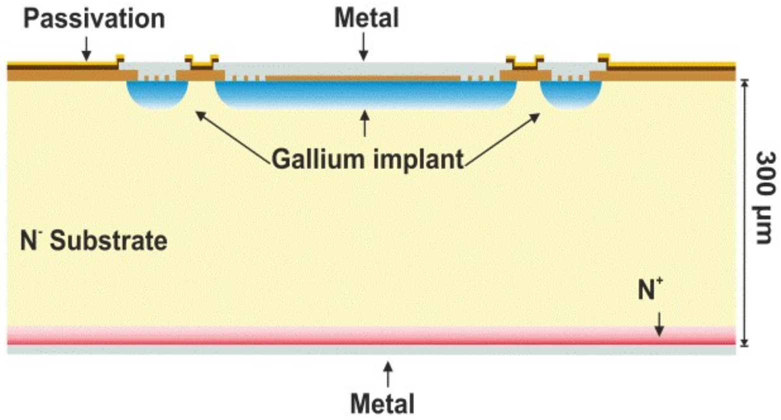
# Flip chip with Altiroc (2mm pads)




Only the pads highlighted in white will be bonded to the chip.
The others pads will not be opened at the detector surface. The surface is passivated with nitride to avoid shorts.

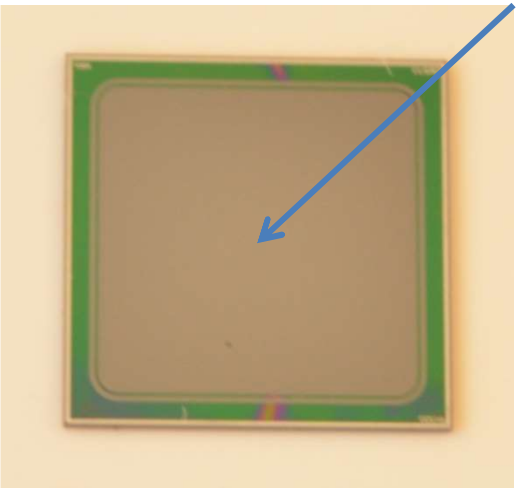
## *Gallium Doping*

- **p-i-n diodes on high resistivity n-type float zone substrates ($P^+/N^{--}/N^+$)**
- **Gallium or Boron implantation**
- **PAD design with implant area of 8.2x8.2mm²**



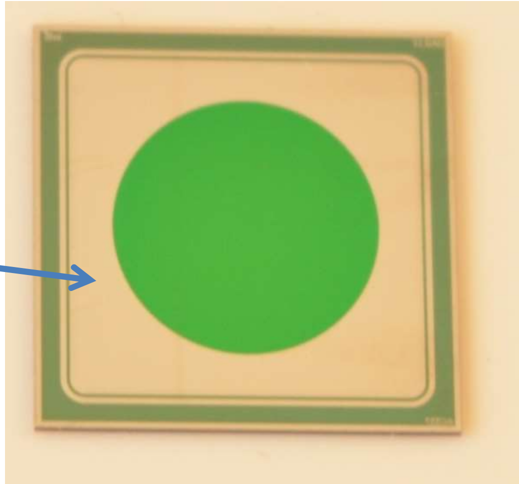

***30 samples without passivation and metal***

***30 Samples***



***Sheet resistance measurements***

***IV and CV measurements***



# *Definition of Ga doping profile*

## *Optimization of Silvaco Gallium diffusion simulation*

- **Simulation was adjusted to reproduce the same peak and junction depth of gallium**
- **Tuning of segregation and transport coefficients**

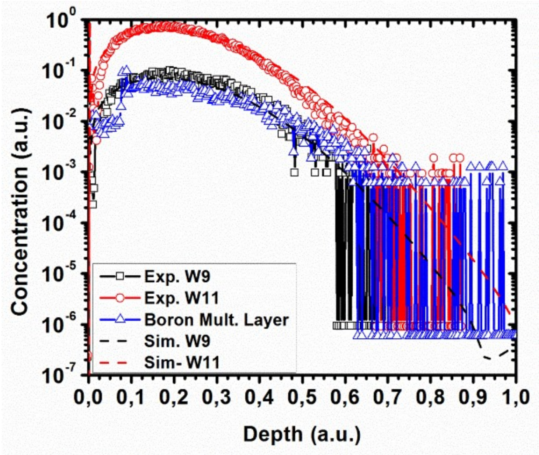
**Simulated sheet resistance:**

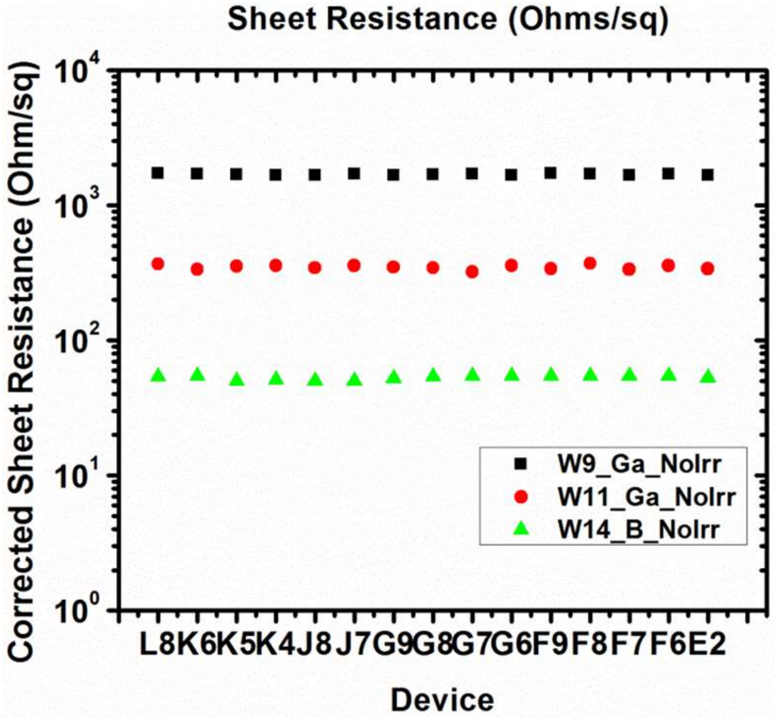
- **Imp. Dose 1e14 atoms/cm² (W9) :**

  **R□ = 1540 Ω/□**

- **Imp. Dose 1e15 atoms/cm² (W11):**

  **R□ = 314 Ω/□**




Experimental sheet resistance