IMB-CNM Activities for the CMS High Luminosity Upgrade and ECFA DRDs

CMSUPG2 Project, 2026 Project Meeting

(PID2023-148418NB-C42, 01/09/2024-31/12/2027)

Zoom SIFCA. 30 July 2026

S. Hidalgo, J. Bravo, F. Dougados, R. Durá, P. Fernández, D. Flores, C. Fleta, M. Manna, X. Mas, A. Merlos, A. Moreno, J. Pallarés, J. Villegas

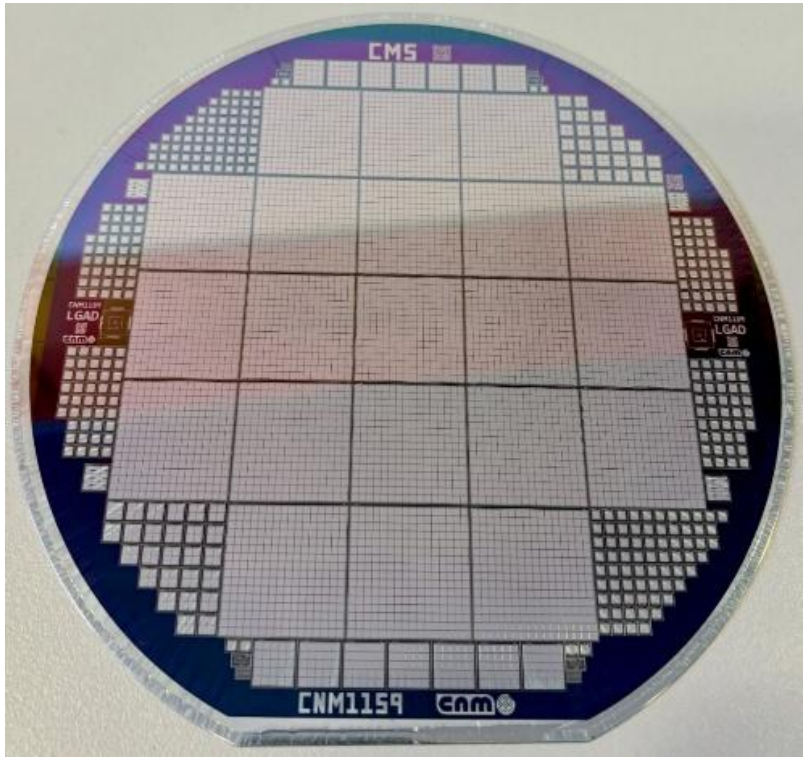
Outline

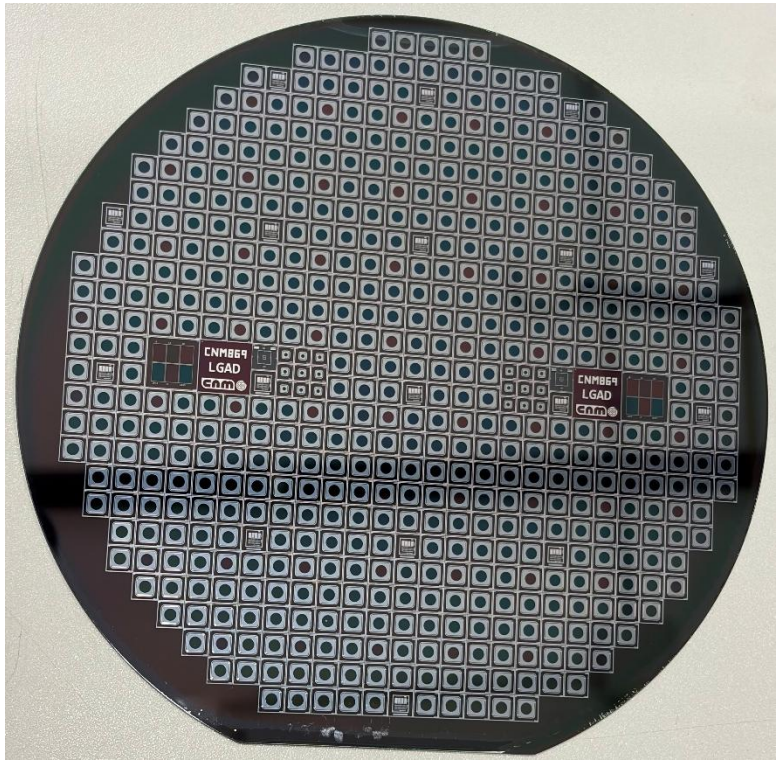
- **Subproject Objectives and Tasks**
  - **WP2. Sensor production, Module assembly, and Hybrid testing of the CMS ETL**
    - **Objective WP2.O1.** *Manufacturing and QC of LGAD sensors for the ETL detector*
      - ✓ **WP2.T1**: Pre-production and production of LGAD sensors
  - **WP3. R&D on solid state detectors for 4D tracking and extreme radiation environments inside the DRD3 collaboration**
    - **Objective WP3.O1.** *Development of 4D tracking detectors for precise timing and tracking based on the LGAD and 3D sensor architectures*
    - **Objective WP3.O2.** *Development of detectors for extreme fluence environments based on radiation hardened LGADs, 3D and SiC*
      - ✓ **WP3.T1.a**: Silicon. New Technologies for 4D Tracking and Extreme Fluence Environments
      - ✓ **WP3.T1.b**: SiC. New Technologies for 4D Tracking and Extreme Fluence Environments
      - ✓ **WP3.T2**: Si and SiC Detectors Characterization and POC Validation

- **Technologies Developed**
  - **LGAD.** *6DLG2v1, 6LG2v2, 6DLG2v2, 6DLG3v1, 6LG1v1, 6LG3v3*
  - **iLGAD.** *4TILG2v2, 4TILG3v2*
  - **nLGAD.** *4NLG1v2, 6NLG1v1*
  - **3D.** *43D1v2, 43D1v3, 43D1v4*
  - **PiN.** *6PN1v1, 6PN1v2, 6PN1v3, 6PN1v4*
  - **SiC.** *3µm & 50µm N-Type Diodes*

Subproject Objectives

- **WP2. Sensor production, Module assembly, and Hybrid testing of the CMS ETL**
  - **Objective WP2.O1.** *Manufacturing and QC of LGAD sensors for the ETL detector*
    - WP2.T1: Pre-production and production of LGAD sensors
      - ✓ LGADs fabrication compliant with the technical specifications established for the ETL sub-detector
      - ✓ Quality control process to ensure they meet the required specifications

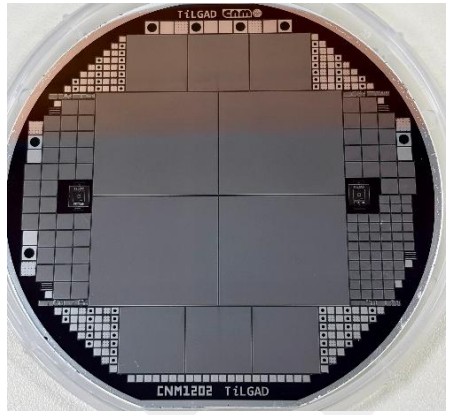




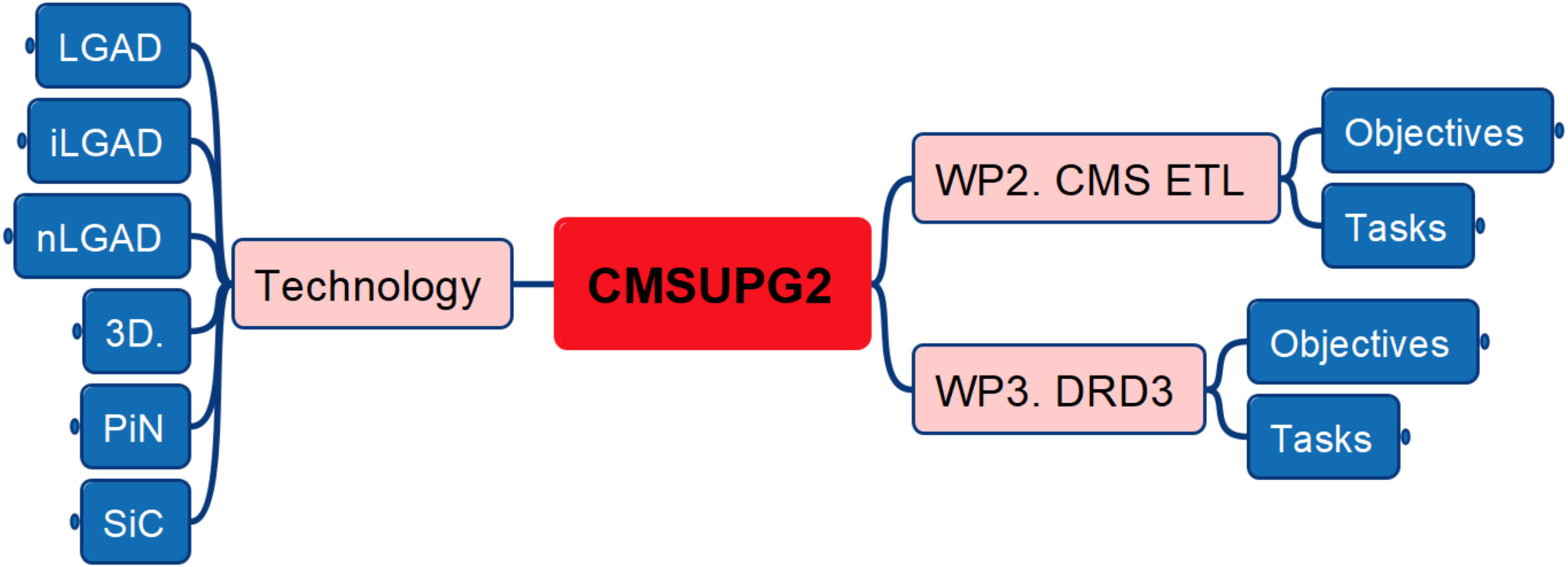
Subproject Objectives

- **WP3. R&D on solid state detectors for 4D tracking and extreme radiation environments inside the DRD3 collaboration**
  - **Objective WP3.O1.** *Development of 4D tracking detectors for precise timing and tracking based on the LGAD and 3D sensor architectures*
  - **Objective WP3.O2.** *Development of detectors for extreme fluence environments based on radiation hardened LGADs, 3D and SiC*

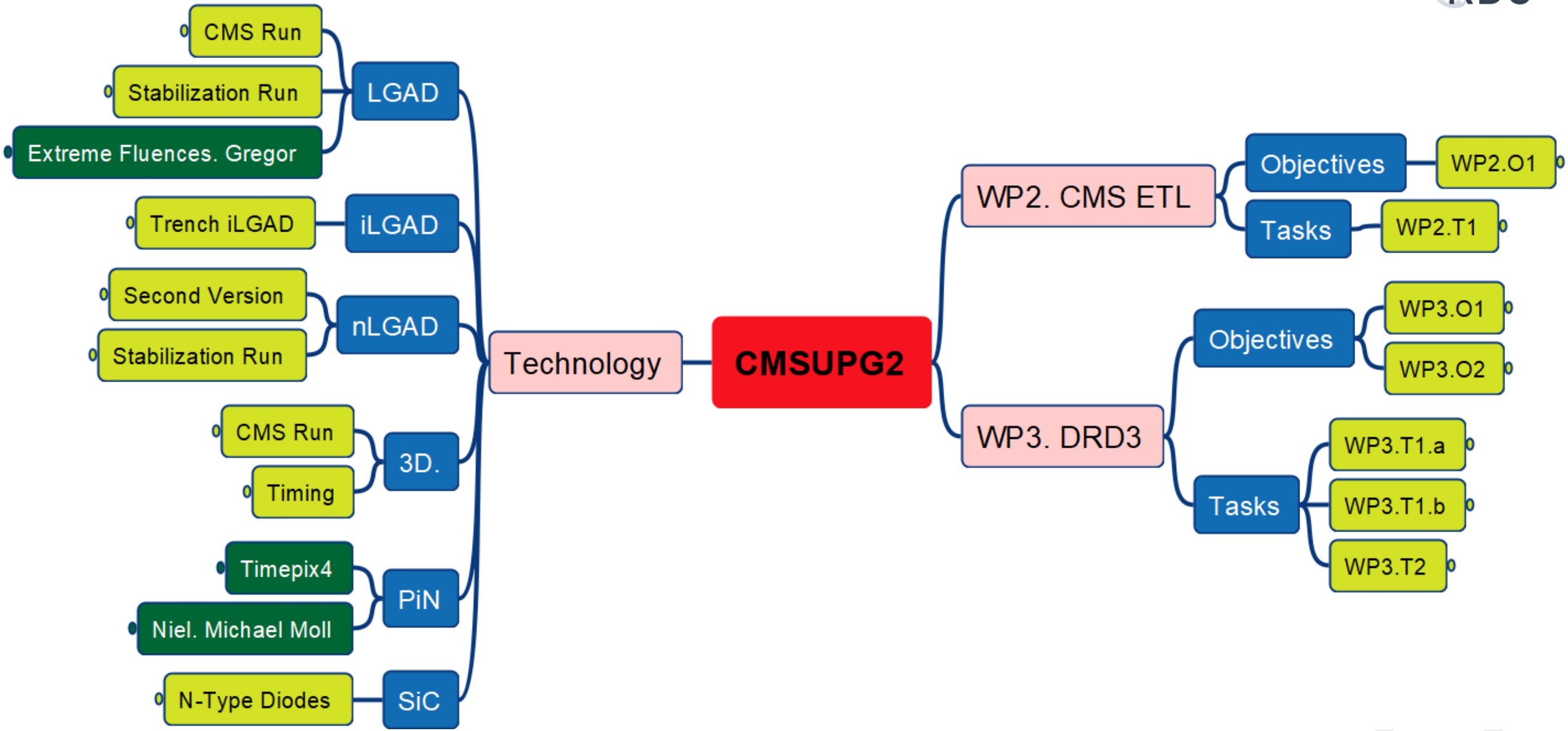
    - WP3.T1.a: New Technologies for 4D Tracking and Extreme Fluence Environments (Si Based)
    - WP3.T1.b: New Technologies for 4D Tracking and Extreme Fluence Environments (SiC Based)
      - ✓ Understand the limit of precision timing in sensors with and without internal multiplication
      - ✓ Develop pixel sensors with internal multiplication with 100% fill factor (iLGAD, Trench iLGAD)
      - ✓ Exploring the timing possibilities of pixelated sensors with higher radiation resistance (3D)
    - WP3.T2: Si and SiC Detectors Characterization and Proof of Concept Validation
      - ✓ Extend the capabilities of solid-state detector technologies (LGAD and 3D) to operate at extreme fluences (from 1×10^{16} to 5×10^{18} n_{eq} cm^{-2}) and evolve their design to cope with the highest possible fluence
      - ✓ Upgrading the simulation strategies for the extreme radiation damage
      - ✓ Use of wide bandgap semiconductors (SiC in particular) as radiation detectors



Subproject Objectives



Subproject Objectives

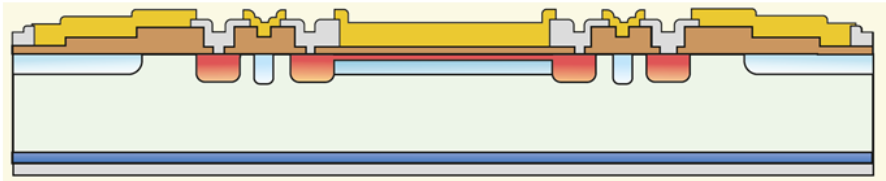
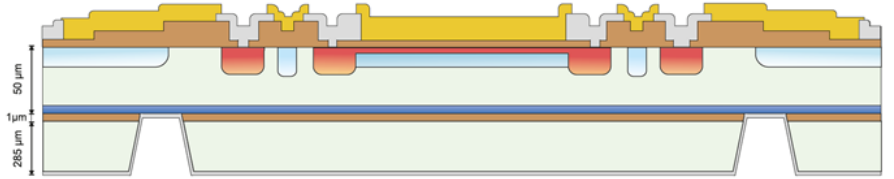
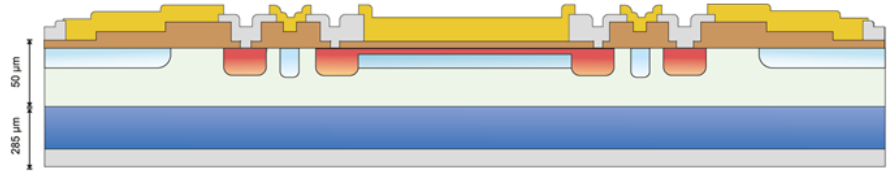
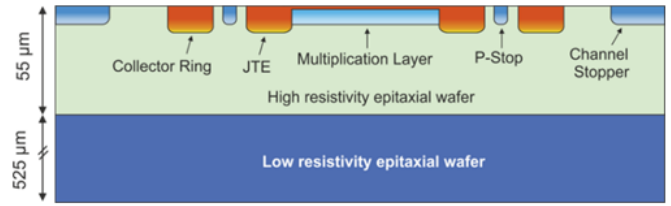


Technological Processes Developed

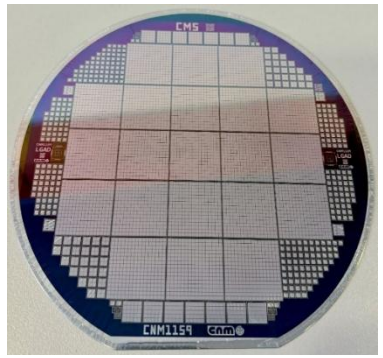
RDG Radiation Detectors Group

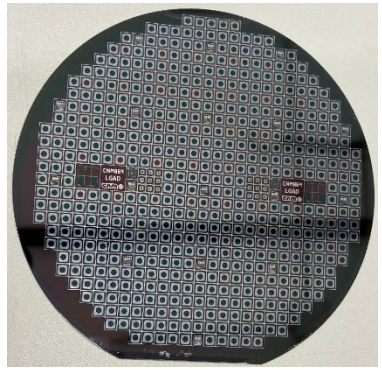
Acronyms for IMB-CNM Runs								
Run	PID	Acronym	Project(s)	Year	Description	Mask	Notes	
13002	CMSUPG	6LG3-v1	ATLAS and CMS experiments phase-II upgrade	2021	First version of carbonated LGAD on Epitaxial(3) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM869		
14002 15037	CMSUPG	4NLG1-v1	AIDAINNOVA	2022	First version of nLGAD on FZ(1) wafers of 4 inches (100 mm) diameter and 300 μm thickness.	CNM652		LGADs for Low Penetration Partiqules Detection
15246	CMSUPG TOMULGAD	6LG3-v2	ATLAS and CMS experiments phase-II upgrade	2022	Second version of carbonated LGAD on Epitaxial(3) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1023		
16421	CMSUPG	4TiLG2-v1	AIDAINNOVA	2023	First version Trench inverse LGAD on Si-Si(2) wafers of 4 inches (100 mm) diameter and 50 μm active thickness.	CNM1086		
16421	CMSUPG	4TiLG3-v1	AIDAINNOVA	2023	First version of Trench inverse LGAD on Epitaxial(3) wafers of 4 inches (100 mm) diameter.	CNM1086		
15973	CMSUPG TOMULGAD	6LG2-v1	ATLAS experiment phase-II upgrade	2023	First version of carbonated LGAD on Si-Si(2) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1139	Phosphorous	
16602	CMSUPG CMSUPG2	6DLG2-v1	CMS experiment phase-II upgrade	2024	First version of Deep profile carbonated LGAD on Si-Si(2) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1159	Phosphorous W1,W2,W3	High Phosphorous Diffusion STD Profile
16602	CMSUPG TOMULGAD PROTECT CMSUPG2	6LG2-v2	CMS experiment phase-II upgrade	2024	Second version of carbonated LGAD on Si-Si(2) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1159	Phosphorous W1,W2,W3	
16375	CMSUPG CMSUPG2	4NLG1-v2	AIDAINNOVA	2024	Second version of nLGAD on FZ(1) wafers of 4 inches (100 mm) diameter and 300 μm thickness.	CNM873		LGADs for Low Penetration Partiqules Detection
17941 18236	CMSUPG CMSUPG2	4TiLG2-v2	AIDAINNOVA	2024	Second version of Trench inverse LGAD on Si-Si(2) wafers of 4 inches (100 mm) diameter and 50 μm active thickness.	CNM1202		
17941 18236	CMSUPG CMSUPG2	4TiLG3-v2	AIDAINNOVA	2024	Second version of Trench inverse LGAD on Epitaxial(3) wafers of 4 inches (100 mm) diameter.	CNM1202		
16602 17591	CMSUPG CMSUPG2	6DLG2-v2	CMS experiment phase-II upgrade	2024	Second version of Deep profile carbonated LGAD on Si-Si(2) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1159	Arsenic W7,W8,W9	Spikes
16069	CMSUPG2	43D1-v3	3D Timing, Altiroc1, Medipix3	2024	First version of 3D Radiation Hard Timing Detectors	CNM987		3D-DS Timing
15534	RD50	6PN1-v1	PiN Timepix4, Timepix3	2024	First version of PiN Timepix3 Timepix4 on Thick(1) wafers of 6 inches (150 mm) diameter and 300 µm active thichness	CNM1084		PiN. Timepix4. Abraham
17958	CMSUPG PROTECT CMSUPG2	6DLG3-v1	CMS experiment phase-II upgrade	2025	First version of Deep profile carbonated LGAD on Epitaxial(3) wafers of 6 inches (150 mm) diameter and 50 μm active thickness.	CNM1159	Arsenic	16X16 Modules waiting for USTC IV Measurements
18399	CMSUPG2	6LG3-v3	CMS experiment phase-II upgrade	2025	Third version of carbonated LGAD on Epitaxial(3) wafers of 6 inches (150 mm) diameter and 50 µm active thichness	CNM869	Phosphorous	
16827 18111	CMSUPG CMSUPG2	43D1-v2	CMS experiment phase-II upgrade	2025	Second version of 3D on Thick(1) wafers of 4 inches (100 mm) diameter and 300 µm active thichness	CNM1125		3D CMS Preproduction
16069	CMSUPG2	43D1-v3	CMS experiment phase-II upgrade	2025	First version of 3D Timing on Thick(1) wafers of 4 inches (100 mm) diameter and 300 µm active thichness	CNM987		3D Tiiming
18245	CMSUPG2	43D1-v4	CMS experiment phase-II upgrade	2025	Second version of 3D Timing on Thick(1) wafers of 4 inches (100 mm) diameter and 300 µm active thichness	CNM1247		3D Tiiming
18111	CMSUPG2	43D1-v2	3D CMS	2025	First 3D run fabricated using "new" equipment (DRIE Sentech, Poly and the B/P doping process in Tempress Fournaces)	CNM1125		3D-SS 4 CROC
18245	CMSUPG2	43D1-v4	3D Timing, Timepix3	2025	Second version of 3D Radiation Hard Timing Detectors	CNM1247		3D-DS Timing
18177	RD50	6PN1-v2	PiN Timepix4, Timepix3	2025	Second version of PiN Timepix3 Timepix4 on Thick(1) wafers of 6 inches (150 mm) diameter and 300 µm active thichness	CNM1084		PiN. Timepix4. Abraham
18182	RD50	6PN1-v3	PiN 4 NIEL M. Moll	2025	First version of PiN for NIEL on Thick(1) wafers of 6 inches (150 mm) diameter and 300 µm active thichness	CNM869	+R16827	PiN. NIEL. Michael Moll
18399	CMSUPG2	6LG1-v1	CMS experiment phase-II upgrade	2026	First version of carbonated LGAD on Thick(1) wafers of 6 inches (150 mm) diameter and 300 µm active thichness	CNM869	Phosphorous	
18550	CMSUPG2	6NLG1-v1	LGADs for Low Penetration Partiqules Detection	2026	Third version of nLGAD on Thick(1) wafers of 6 inches (150 mm) diameter and 300 µm active thichness	CNM869		

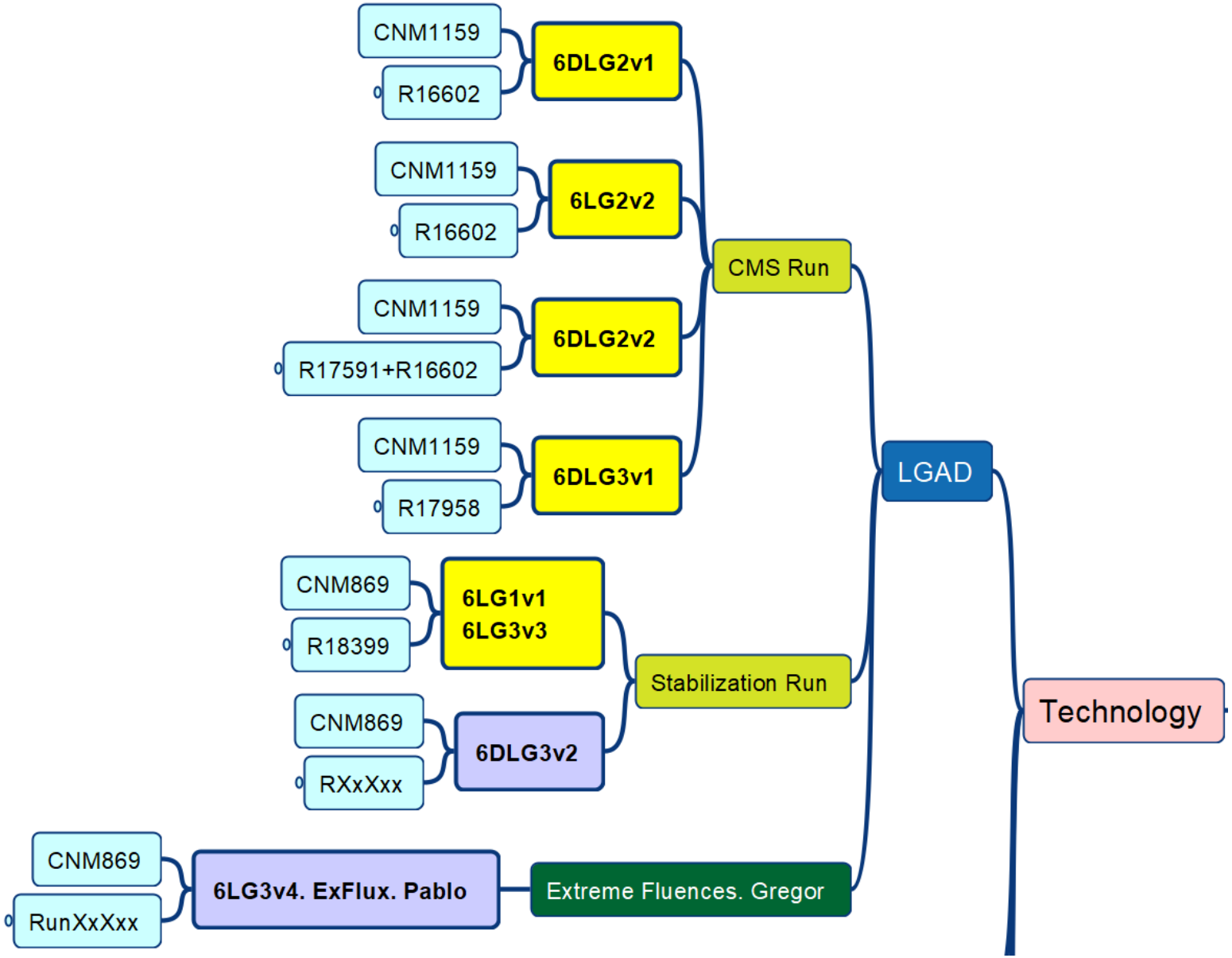
Technological Processes Developed

LGAD Generation	Wafer type	
6LG1	300 µm thick	
6LG4	50 µm SOI	
6LG2	50 µm Si-Si	
6LG3	55 µm epitaxial	

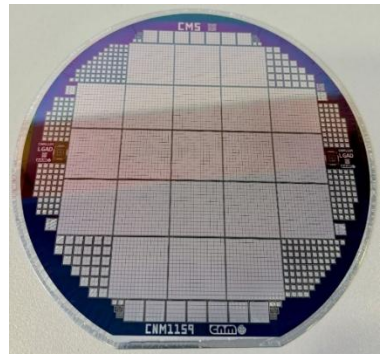
Subproject Objectives. Technologies. LGAD





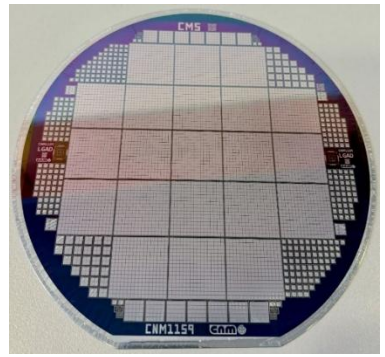


Subproject Objectives. Technologies. LGAD



- LGAD
  - Technology
    - CMS Run
      - 6DLG2v1
        - CNM1159
          - R16602
            - Wafers 1-3
              - Double Diffusion Overlap. Phosphorus diffused deep enough to partially neutralize boron
              - Passivation layers were deposited with Corial equipment (Bad quality oxide with charges)
              - Ileak High
              - Vgl Low
              - Vbr OK
            - N+ Phosphorous
              - High Energy Boron Implantation
            - Carbon All
      - 6LG2v2
        - CNM1159
          - R16602
            - Wafers 4-6
            - N+ Phosphorous
              - STD Profile
            - Carbon All
      - 6DLG2v2
        - CNM1159
          - R17591+R16602
            - Wafers 7-9
              - Spikes. Titanium layer was not deposited below the Al:Cu
            - N+ Arsenic
              - High Energy Boron Implantation (Lower than 6DLG2-v1)
            - Carbon All

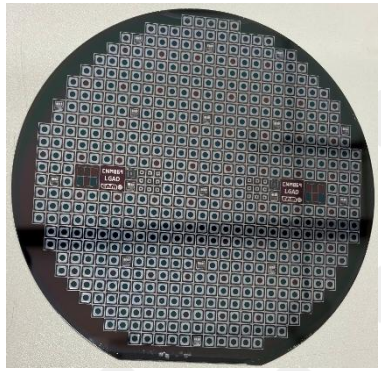
Subproject Objectives. Technologies. LGAD



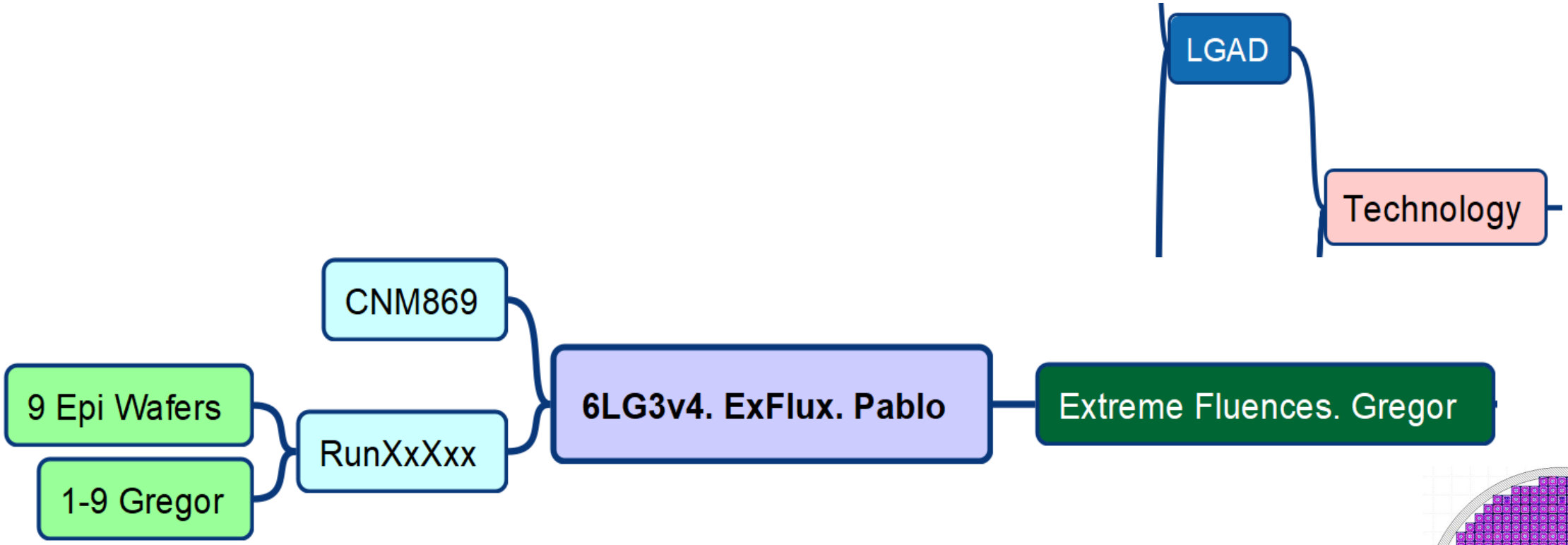
- Technology
  - LGAD
    - CMS Run
      - 6DLG3v1
        - CNM1159
          - 5 Wafers
            - Pad Devices. Low Yield
            - Ileak OK
            - Vgl OK
            - Vbr OK
            - Higher Ileak for LGAD with Carbon Implantation
            - Higher Gain for LGAD without Carbon Implantation
            - Higher Gain for Lower Ionization Density
            - Neutron Irradiation @ JSI (8e14, 1.5e15, 2.5e15)
            - IBIC & Tri-Alfa @CNA
            - Sr-90 & Cd-109 @IMB-CNM
            - 16x16 Modules Waiting for IV Characterization at USTC
        - R17958
          - N+ Arsenic
          - Carbon W1-3

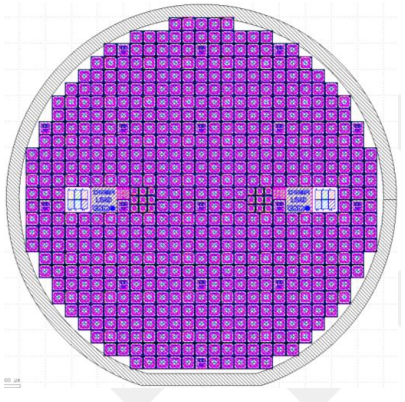
Subproject Objectives. Technologies. LGAD

- LGAD
  - Technology
    - Stabilization Run
      - 6LG1v1 6LG3v3
        - CNM869
        - R18399
          - 10 Epi + 2 Thick Wafers
            - Yield OK
            - Ileak Low
            - Vgl OK
            - Vbr OK
          - N+ Phosphorous
          - Carbon All
          - 1-3 Michael Moll
          - 4-6 Gregor
          - 7-10, 11-12 IMB-CNM
          - Diced and Sended to CERN & JSI
      - 6DLG3v2
        - CNM869
        - RXxXxx
          - 6 Wafers
          - N+ Arsenic
          - Carbon All

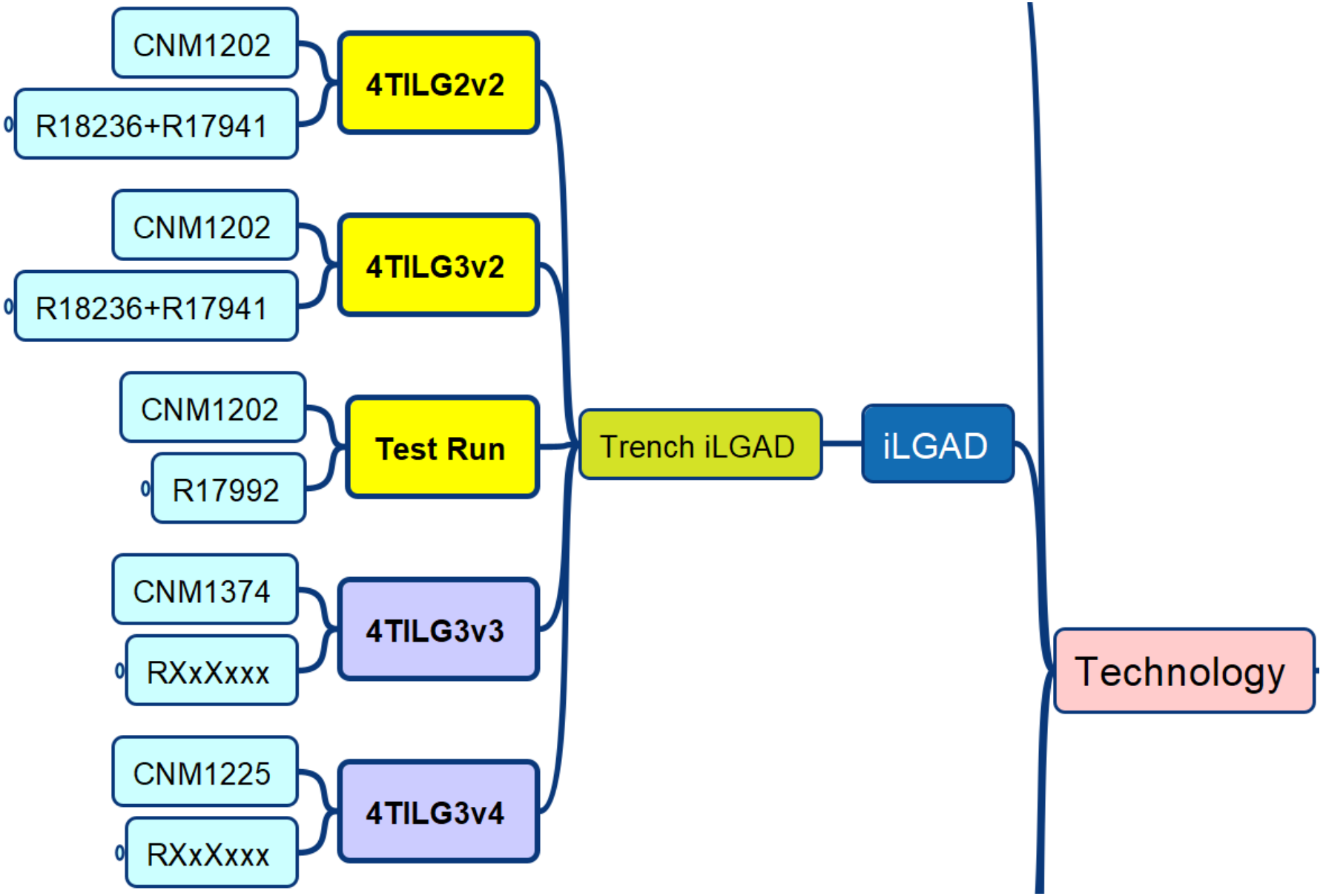


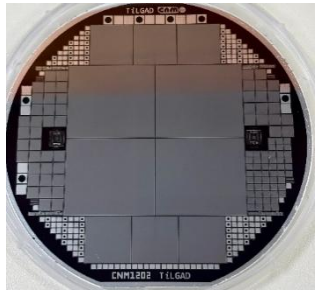
Subproject Objectives. Technologies. LGAD

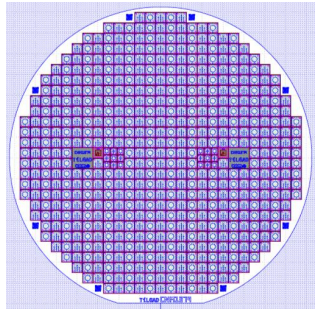


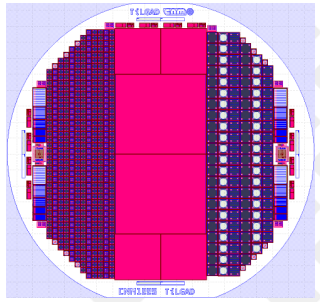


Subproject Objectives. Technologies. iLGAD

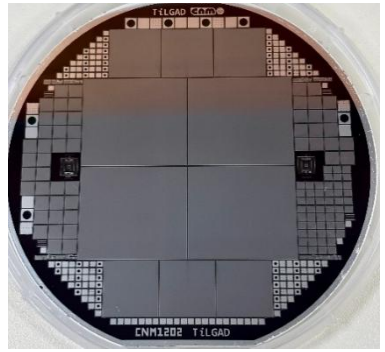






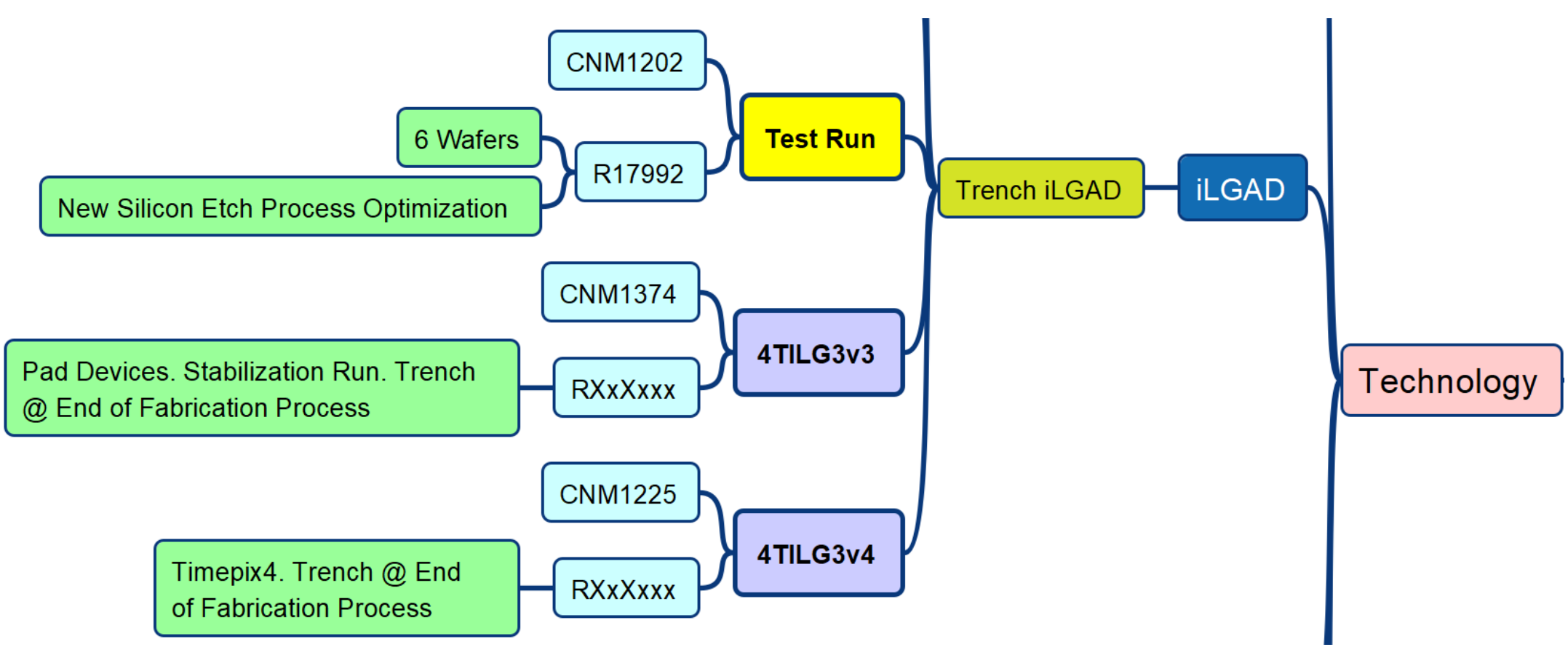


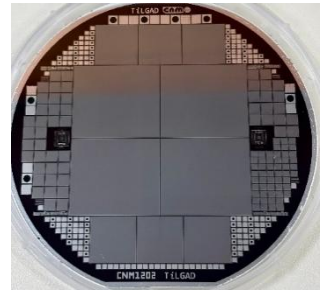
Subproject Objectives. iLGAD

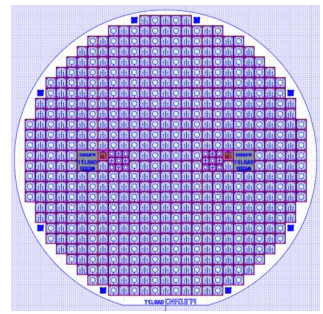


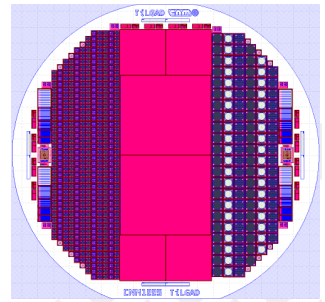
- Technology
  - iLGAD
    - Trench iLGAD
      - 4TILG2v2
        - CNM1202
        - R18236+R17941
          - 2 SiSi Wafers
            - APD Performance
            - Parasitic Capacitor at Trench Area
            - Ileak Low previous to Vbr
            - Vbr Low (20-22V)
            - Vgl Low
          - Timepix4
      - 4TILG3v2
        - CNM1202
        - R18236+R17941
          - 3 Epitaxial Wafers
            - APD Performance
            - Parasitic Capacitor at Trench Area
            - Ileak Low previous to Vbr
            - Vbr Low (38-40V)
            - Vgl Low
          - Timepix4

Subproject Objectives. Technologies. iLGAD

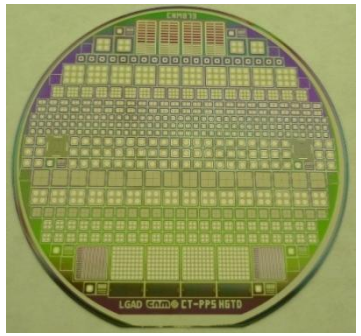


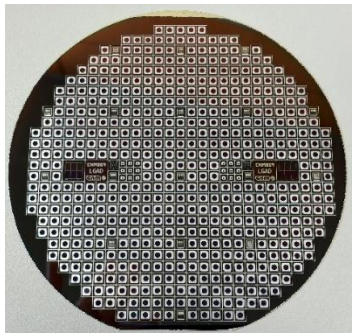






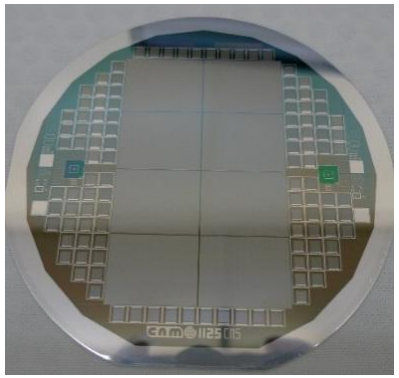
Subproject Objectives. nLGAD



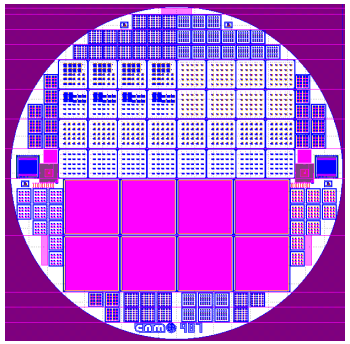


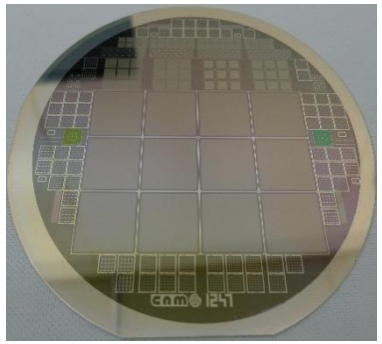
- Technology
  - nLGAD
    - Second Version
      - 4NLG1v2
        - R16375
          - 3 Thick Wafers
            - Gain Supression (decreases after protons and neutrons irradiation)
            - Ileak Low
            - Vgl OK
            - Vbr OK
        - CNM873
    - Stabilization Run
      - 6NLG1v1
        - R18550
          - 7 Thick Wafers
            - Ileak Low
            - Vgl OK
            - Vbr OK
        - CNM869

Subproject Objectives. 3D

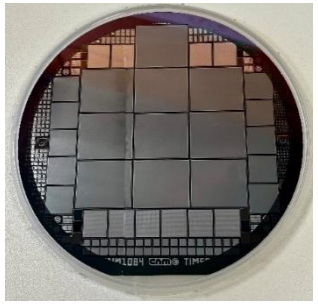


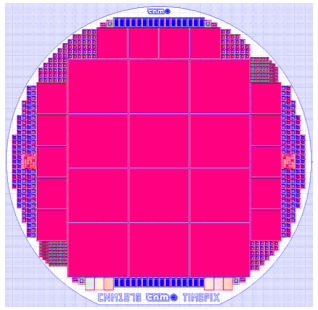
- Technology
  - 3D.
    - CMS Run
      - 43D1v2
        - CNM1125
        - R18111+R16827
          - 12 Wafers
            - Yield High
            - Ileak Low
            - Vbr OK
    - Timing
      - 43D1v3
        - CNM987
        - R16069
          - 4 Wafers
          - Ortogonal and Hexagonal Samples at IFCA and CNA for Characterization
            - Ortogonal design exhibits better timing performance than Hexagonal
      - 43D1v4
        - CNM1247
        - R18245
          - 5 Wafers
          - Timepix3. Ortogonal and Hexagonal Test Samples

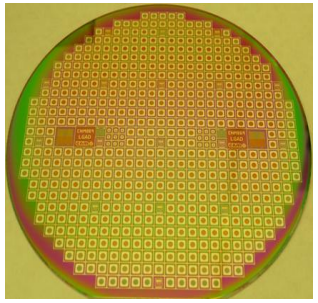




Subproject Objectives. PiN

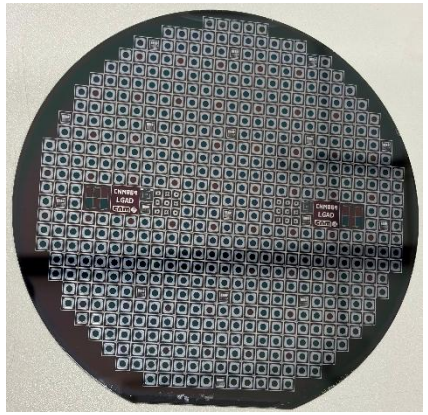




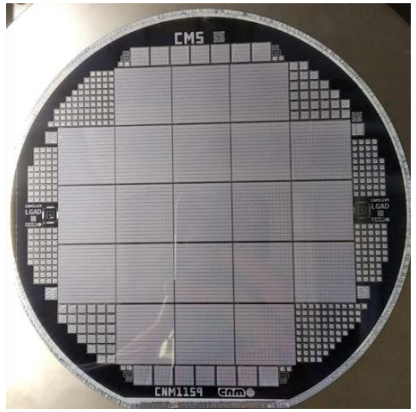


- Technology
  - PiN
    - Timepix4
      - **Timepix4 v1. 6PN1v1**
        - CNM1084
          - Mask set fabricated
        - R15534
          - 5 Wafers
          - Electrical and Technological Characterization
          - @NIKHEF, UBM and Flip-Chip at IZM
      - **Timepix4 v1. 6PN1v2**
        - CNM1084
        - R18177
          - 5 Wafers
          - Electrical and Technological Characterization
          - @IMB-CNM, Waiting for Abraham decission
      - **Timepix4 v2. 6PN1v4**
        - CNM1278
          - Mask set fabricated
          - Waiting for Abraham decission
    - Niel. Michael Moll
      - **6PN1v3**
        - CNM869
        - R18182+R17933+R17431
          - 10 Wafers
          - Electrical and Technological Characterization
          - Diced and Sended to CERN

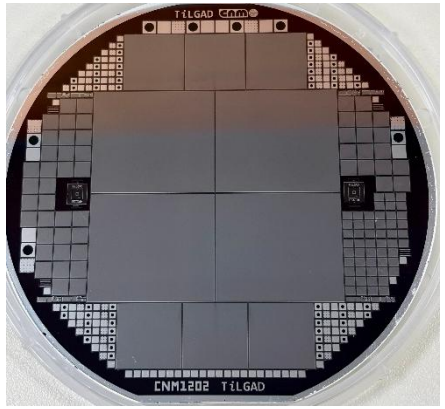
CMSUPG2 Technological Processes Developed



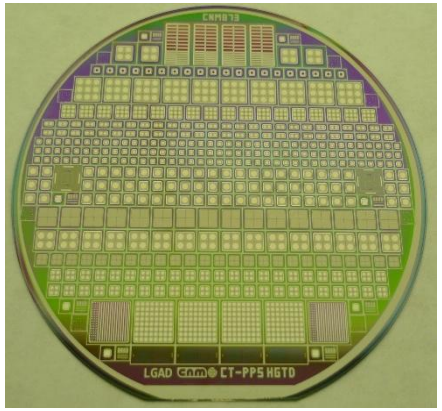
Oblea de 150 mm en la que se integran prototipos de detectores **LGAD** sobre substratos epitaxiales. Dispositivos **Pad** con **perfil original**. Tecnología **6LG3v3**



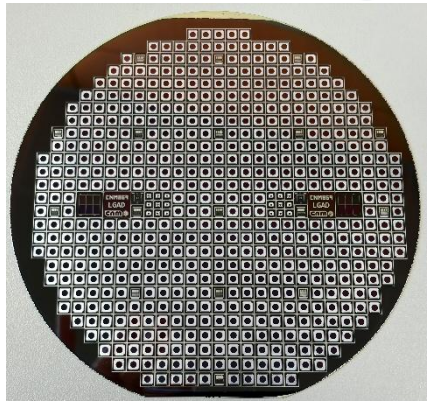
Oblea de 150 mm en la que se integran prototipos de detectores **LGAD** sobre substratos epitaxiales. Módulos **16x16** con **perfil profundo**. Tecnología **6DLG3v1**



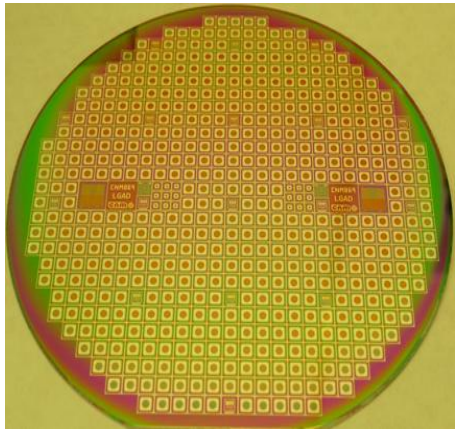
Oblea de 100 mm en la que se integran prototipos de detectores **Trench iLGAD** con diseño **Timepix4. Primera Generación**. Tecnologías **4TILG2v2** y **4TILG3v2**



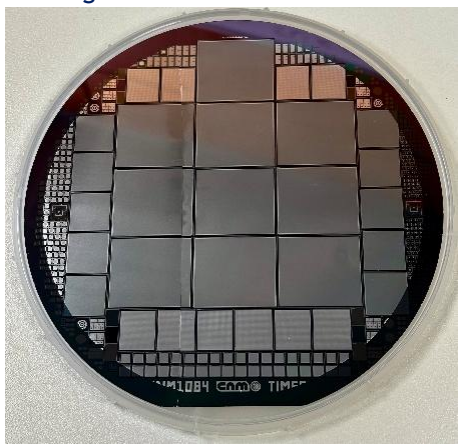
Oblea de 100 mm en la que se integran prototipos de detectores **nLGAD. Segunda Generación.** Tecnología **4NLG1v2**



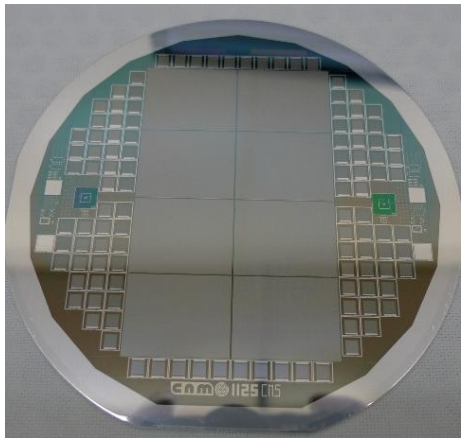
Oblea de 150 mm en la que se integran prototipos de detectores **nLGAD. Tercera Generación.** Tecnología **6NLG1v1**



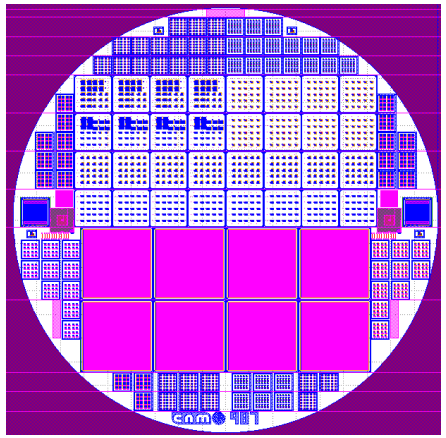
Oblea de 150 mm en la que se integran prototipos de detectores **PiN para RD50**. Tecnología **6PN1v3**



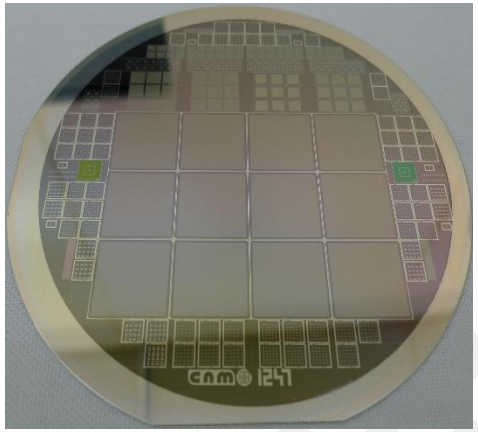
Oblea de 150 mm en la que se integran prototipos de detectores **PiN** con diseño **Timepix4. Primera y Segunda Generación**. Tecnologías **6PN1v1** y **6PN1v2**



Oblea de 100 mm en la que se integran prototipos de detectores **3D Single Side** compatibles con **CMSROC**. Tecnología **43D1v2**



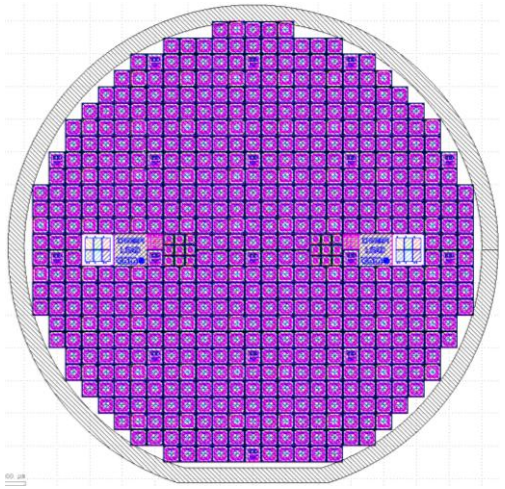
Oblea de 100 mm en la que se integran la primera generación de detectores **3D Single Side** para aplicaciones de **Timing**. Tecnología **43D1v3**



Oblea de 100 mm en la que se integran la segunda generación de detectores **3D Single Side** para aplicaciones de **Timing**. Tecnología **43D1v4**

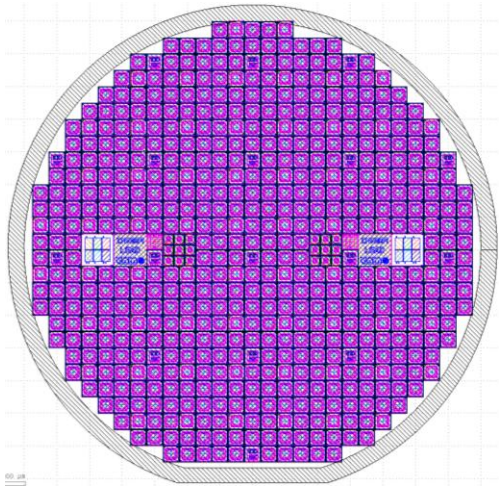
CMSUPG2 Technological Processes Developed

- **IMB-CNM Clean Room Status**
  - The clean room **will be closed for four months from October 2026**



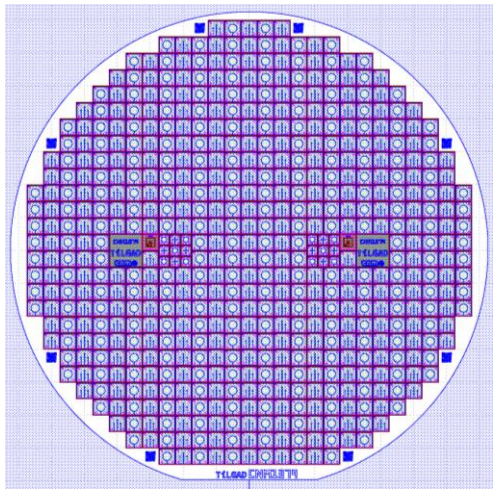
Oblea de 150 mm en la que se integraran prototipos de detectores **LGAD** para **RD50 ExFlux**. Tecnología **6LG3v4**

High priority run. It will begin as soon as the SB is up again. **October 2027?**



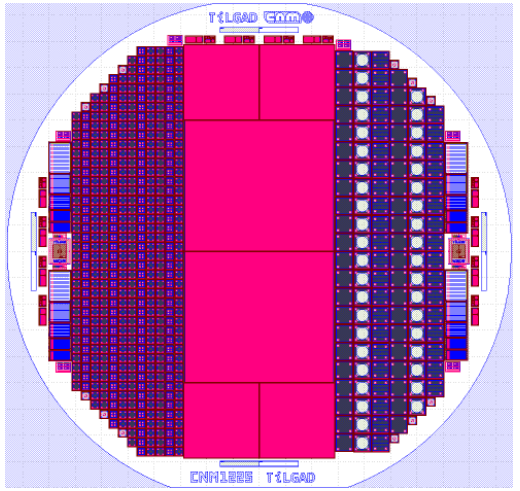
Oblea de 150 mm en la que se integraran prototipos de detectores **LGAD** sobre substratos epitaxiales. Dispositivos **Pad** con **perfil profundo**. Tecnología **6DLG3v2**

High priority run. It will begin as soon as the SB is up again. **November 2027?**



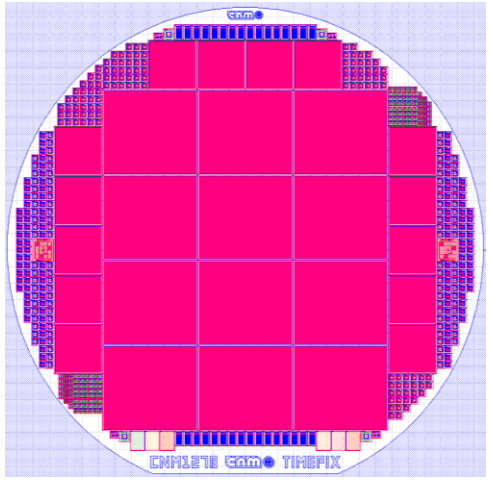
Oblea de 100 mm en la que se integraran prototipos de detectores **Trench iLGAD** con diseño **Single Pad. Segunda Generación**. Tecnología 4**TILG3v3**

High priority run. It will begin as soon as the SB is up again. **September 2027?**



Oblea de 100 mm en la que se integraran prototipos de detectores **Trench iLGAD** con diseño **Timepix4. Segunda Generación**. Tecnología 4**TILG3v4**

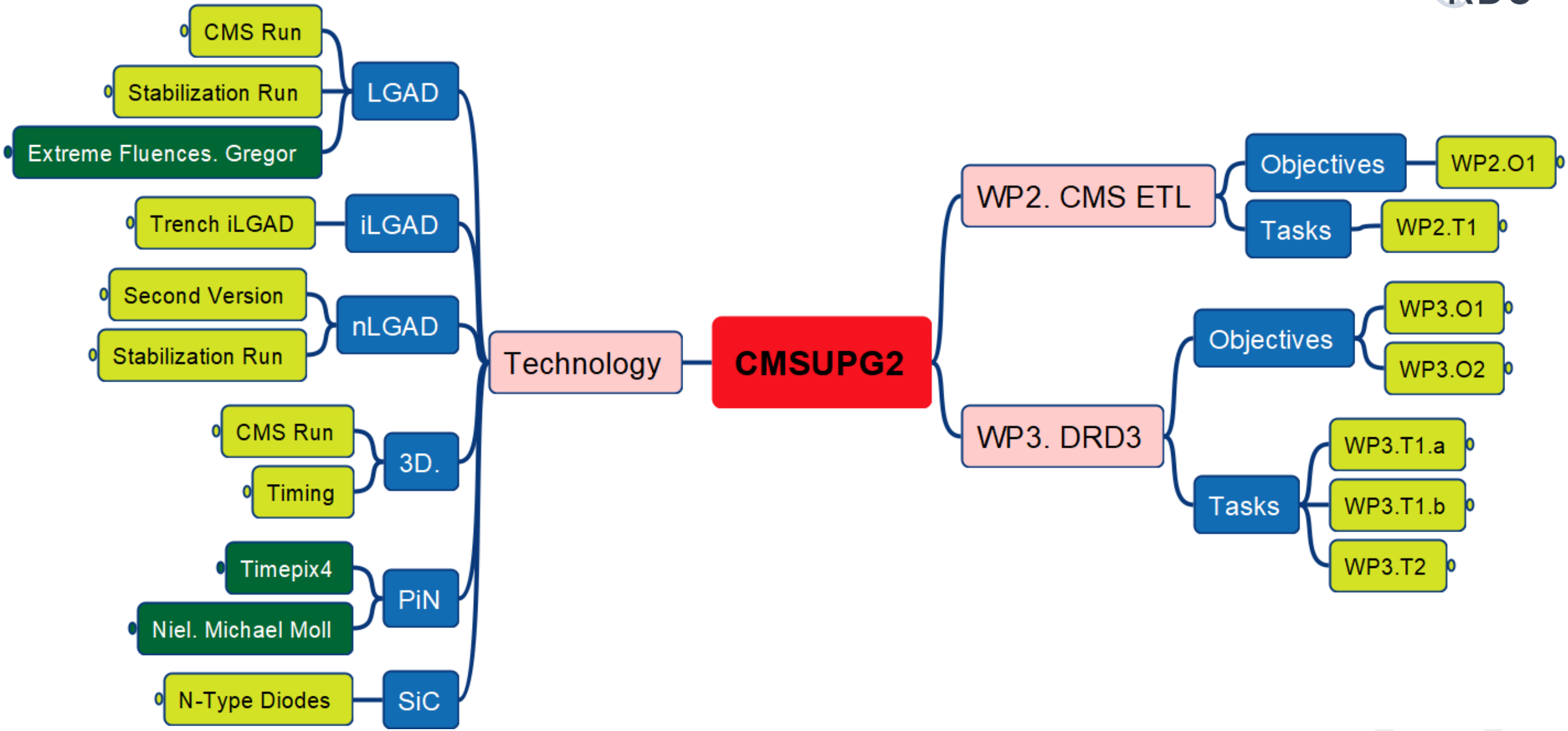
It will begin once the results of the 4TILGv3 run have been analysed



Oblea de 150 mm en la que se integraran prototipos de detectores **PiN** con diseño **Timepix4. Tercera Generación**. Tecnología **6PN1v4**

It has yet to be decided when it will begin. Discussions with IGFAE, NIKHEF and IFCA

Subproject Objectives



Publications

1. C. Lasaosa, J. Duarte-Campderros, M. Fernandez, G. Gomez, I. Vila, S. Hidalgo, G. Pellegrini. “The influence of pixel cell layout on the timing performance of 3D sensors”. Journal of Instrumentation. ISSN: 1748-0221. Vol. 20, nº C06080, 27 June 2025. https://doi.org/10.1088/1748-0221/20/06/C06080. Open Access. **Colaboración entre PID2023-148418NB-C41 y PID2023-148418NB-C42**
2. V. Kraus, M. Biveinyte, M. Fernandez, S. Hidalgo, M. Moll, J. Villegas, M. Wiehe. “Investigating irradiation effects and space charge sign inversion in n-type Low Gain Avalanche Detectors”. Nuclear Instruments and Methods in Physics Research A: Accelerators, Spectrometers, Detectors and Associated Equipment. ISSN: 0168-9002. Vol. 1080, June 2025. https://doi.org/10.1016/j.nima.2025.170763. Open Access. **Colaboración entre PID2023-148418NB-C41 y PID2023-148418NB-C42**
3. J. Villegas, F. Dougados, C. Torres, P. Fernandez-Martinez, M.C. Jimenez-Ramos, S. Hidalgo. “The Effects of High-Energy Carbon Co-Doping on IMB-CNM LGAD Fabrication and Performance”. Sensors. ISSN: 1424-8220. Vol. 25, 5571, 6 September 2025. https://doi.org/10.3390/s25175571. Open Access. **Colaboración entre PID2023-148418NB-C42 y PID2023-148418NB-C44**
4. M. Manojlovic, A. Crnjac, N. Moffat, J. Villegas, I. Pintille, E. Cabruja, G. Pellegrini, S. Hidalgo. “Gain Response and Ion Beam-Induced Donor Removal in nLGAD Detector: Global Gain Quenching”. IEEE Sensors Journal, Vol. 25, No. 24, 15 December 2025. ISSN: ISSN: 1530-437X (Print), 1558-1748 (Online). https://doi.org/10.1109/jsen.2025.3624206. Open Access
5. V. Kraus, M. Fernandez, S. Hidalgo, M. Moll, J. Villegas. “Studies on the effect of low-fluence proton and neutron irradiation on n-type LGADs”. Nuclear Instruments and Methods in Physics Research A: Accelerators, Spectrometers, Detectors and Associated Equipment. ISSN: 0168-9002. Vol. 1083, March 2026. https://doi.org/10.1016/j.nima.2025.171138. Open Access. **Colaboración entre PID2023-148418NB-C41 y PID2023-148418NB-C42**
6. J. Villegas, V. Kraus, F. Dougados, M. Moll, S. Hidalgo. “Gain suppression studies on nLGAD detectors”. Nuclear Instruments and Methods in Physics Research A: Accelerators, Spectrometers, Detectors and Associated Equipment. ISSN: 0168-9002. Vol. 1083, March 2026. https://doi.org/10.1016/j.nima.2025.171164. Open Access. **Colaboración entre PID2023-148418NB-C41 y PID2023-148418NB-C44**
7. E. Navarrete-Ramos, J. Villegas, J. Duarte-Campderros, M. Fernandez, A. Gomez-Carrera, G. Gomez, J. Gonzalez, S. Hidalgo, R. Jaramillo, P. Martinez Ruiz del Arbol, A. Merlos, C. Quintana, I. Vila. “Effects of neutron irradiation on LGADs with broad multiplication layer and varied carbon-enriched doses: A study on timing performance and gain deterioration”. Nuclear Instruments and Methods in Physics Research A: Accelerators, Spectrometers, Detectors and Associated Equipment. ISSN: 0168-9002. Vol. 1085, May 2026. https://doi.org/10.1016/j.nima.2026.171305. Open Access. **Colaboración entre PID2023-148418NB-C41 y PID2023-148418NB-C42**
8. J. Villegas, C. Torres, M. Rodriguez-Ramos, S. Hidalgo, J. Garcia-Lopez, M.C. Jimenez-Ramos. “Impact of Gain Suppression in LGADs on Energy Resolution for Charged Ion Spectrometry”. IEEE Sensors Journal, Vol. xx, No. xx, xx October 2026. ISSN: ISSN: 1530-437X (Print), 1558-1748 (Online). https://doi.org/10.1109/jsen.2026.3624206. Open Access. **Colaboración entre PID2023-148418NB-C42 y PID2023-148418NB-C44**

Thank you for your attention!

Acknowledgements

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