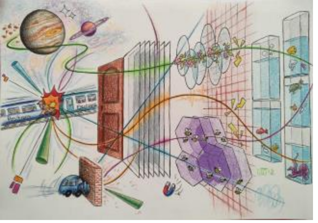

Milestones and costing of the near term strategic R&D

DRD3

DRD3 Community Workshop, CERN, 22-23 March 2023

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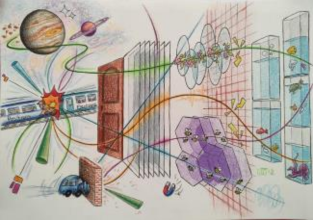
on behalf of the DRD3 proposal writing team



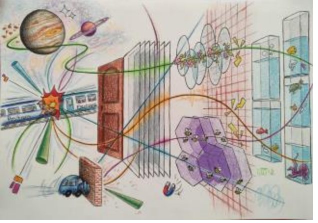
Proposal for RD& strategic program on Tracking sensors (excluding monolithics)

DRD3

Disclaimer 1: This proposal is based on our present vision of the strategic needs, it will evolve with time. It is a seed for discussion!

Disclaimer 2: Costing is a tentative exercise, number of sensor productions is indicative

Any feedback from the community is welcome!

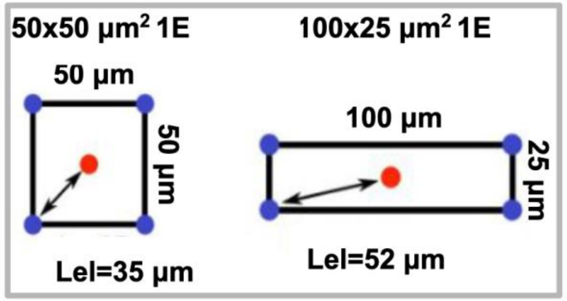


Reduction of pixel cell size for 3D sensors

MS 3.2.1

- Demonstration of the feasibility of the reduction of the pixel cell size for 3D sensors
  - Possible application for the replacement of the innermost pixel layer of ATLAS/CMS pixel systems
    - Geometry for Phase-2: 50x50 μm^2 or 25x100 μm^2.
- One replacement foreseen in Phase-3 (Run5 ~2035) where the use of 28 nm CMOS technology for the ASICs could allow for finer pixel sizes to improve hard scattering track reconstruction and pile-up rejection
  - ASIC pixel size possibly down to 30x30 μm^2 (No timing functionality included)

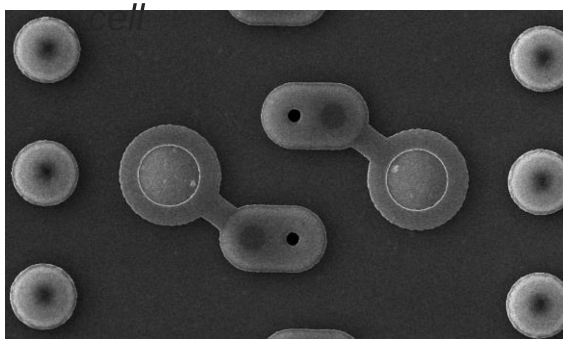
Inter-chip pixels in CROC quad



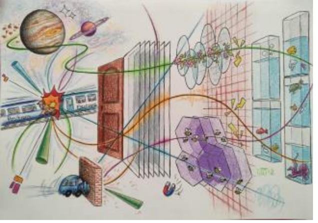
Deliverable

- **2024-2025:** Production of **3D sensor test-structures with reduced pixel sizes** with respect to the ones 50x50 μm^2 or 25x100 μm^2 presently adopted for ATLAS and CMS Phase-2 pixel systems.
  - Exploration of minimal size possible with columnar and trenched geometry.
  - Process optimization and module validation to determine radiation hardness.
- **2026-2028:** Production of **3D sensors with reduced pixel cells and larger total sizes,** to assess yield and validate interconnection technologies

25x100 μm^2 3D pixel cell



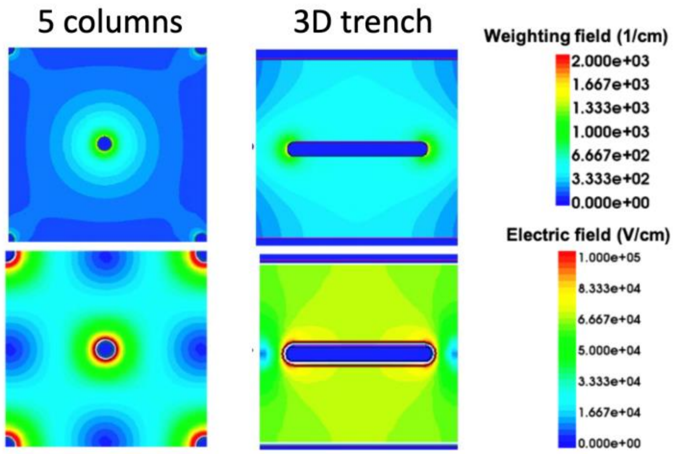
Cost of three 3D pixel productions with reduced cell size on 6” wafers: 80 kCHF x O(3) productions = 240 kCHF

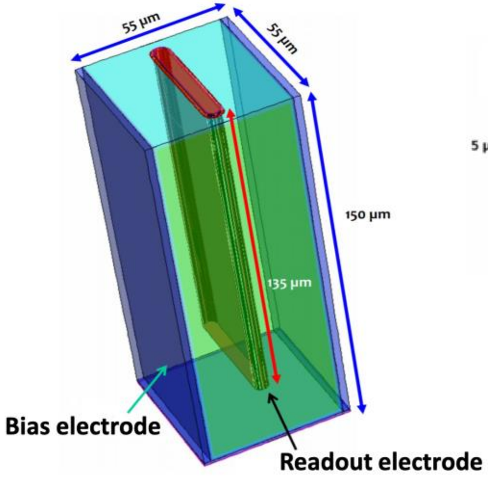


3D sensors for timing at HL-LHC

DRD3

- **MS 3.2.2** Demonstration of the feasibility of producing 3D sensors with a pixel size of 42 x 42 µm^2 or *55 x55* µm^2 , and a timing resolution around 50 ps per hit
  - Possible application for replacing the present VELO vertex detector at LHCb (Upgrade-II).
- Compare the performance in terms of timing properties and radiation hardness of columnar and trench 3D detectors. According to two different scenarios for the radius innermost layer, the radiation requirements span from 8×10^{15} n_{eq}/cm^2 to 8×10^{16} n_{eq}/cm^2, in the latter case implying the need for multiple replacements.



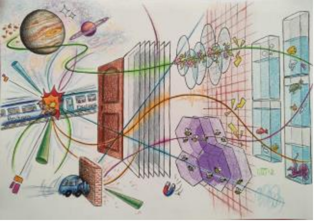


Deliverables:

2024-2025: Production of small matrices of pixelated **3D sensors** to be interconnected to the available **prototype read-out chips for 4D Tracking** (now being designed in 28 nm CMOS technologies). For the 3D sensors targeted to the VELO Upgrade-II 64 x 64 matrices with a pixel size of 42 x 42 µm^2 or 55 x55 µm^2 are foreseen.

2026-2028: Development of prototypes of **pixelated 3D devices with larger sensor sizes**, 1.5 cmx1.5 cm to 2 cm x 2cm, to be interconnected to read-out chips with final sizes for 4D applications at HL-LHC. Implementation of the best-performing 3D geometries among those explored in the prototype productions in 2024-2025

Cost of 3 (columnar)+3 (trenched) 3D pixel productions for timing on 6” wafers: 80 kCHF x O(6) runs = 480 kCHF



LGAD sensors for 4D Tracking at HL-LHC (I)

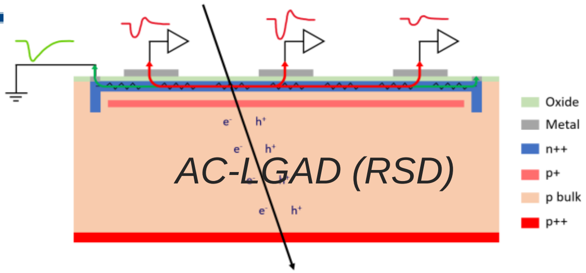
DRD3

- **MS 3.2.3** Demonstration of the feasibility of producing pixelated LGAD sensors to achieve a position resolution better than 10 μm, with a timing resolution of the order of 30 ps before irradiation. A possible application is the replacement of outer pixel layers or disks in the CMS/ATLAS pixel systems in Phase-3. The requested radiation tolerance is in the order of at least 3-5x10^{15} n_{eq}/cm^2.

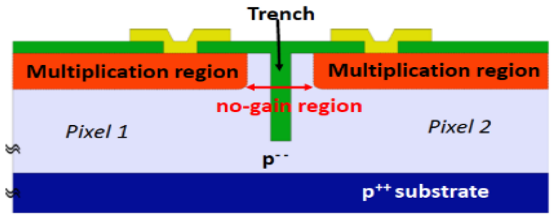
Deliverables:
2024-2025: Production of small matrices of pixelated **LGAD sensors** to be interconnected to the available **prototype read-out chips for 4D Tracking** (now being designed in 28 nm CMOS technologies).
The different LGAD technologies can achieve a spatial resolution of 10 μm with different pixel sizes. Notably RSDs could be able to reach this value with larger pixels, that would allow for a reduced power dissipation per area.

- Measurement of the effective LGAD fill factor before and after irradiation
- Compare the different LGAD technologies (TI-LGAD, RSD, I-LGADs, DJ-LGADs) in terms of:
  - Spatial and time resolution
  - Ultimate radiation hardness
  - Performance for not homogeneous fluence profile

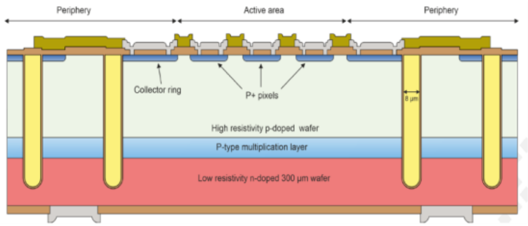
Cost of 12 LGAD pixel production (2x 4 technologies) on 6” and 8”wafers (2024-2026) :
60 kCHF x O(8) runs = 480 kCHF



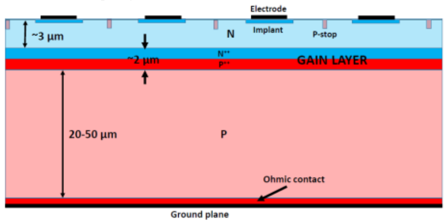
Trench Isolated LGAD

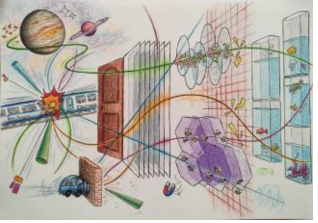


Inverse-LGAD (I-LGAD)



Deep junction LGAD

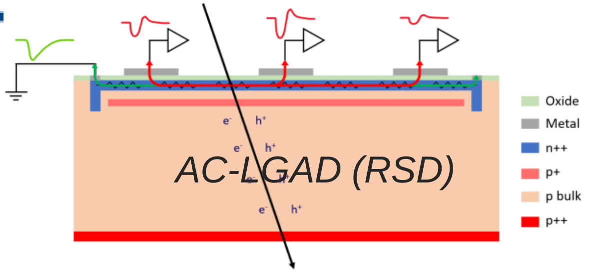




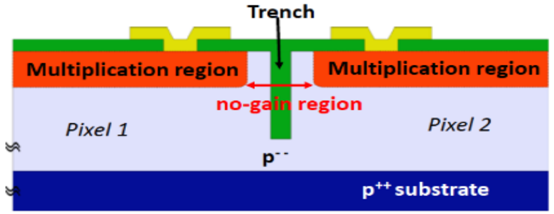
LGAD sensors for 4D Tracking at HL-LHC (II)

DRD3

- **MS 3.2.3** Demonstration of the feasibility of producing pixelated LGAD sensors to achieve a position resolution better than 10 µm, with a timing resolution of the order of 30 ps before irradiation. A possible application is the replacement of outer pixel layers or disks in the CMS/ATLAS pixel systems in Phase-3. The requested radiation tolerance is in the order of at least 3-5x10^{15} n_{eq}/cm^2.

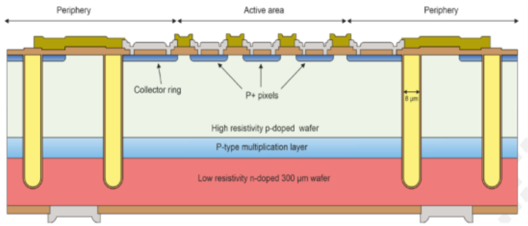


Trench Isolated LGAD



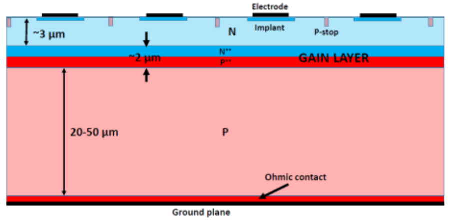
Deliverables:
2026-2028: Implementation of the best performing LGAD technologies among those explored in the prototype productions in 2024-2025.
Development of prototypes of **pixelated LGAD devices with larger sensor sizes**, 1.5 cmx1.5 cm to 2 cm x 2cm, to be interconnected to read-out chips with final sizes for 4D applications at HL-LHC.

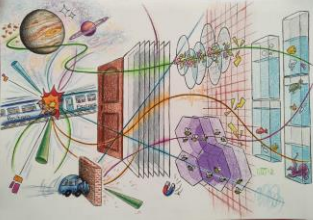
Inverse-LGAD (I-LGAD)



Cost of 4 LGAD pixel production (2x 2 technologies) on 6" and 8"wafers (2027-2028) :
60 kCHF x O(4) runs=240 kCHF

Deep junction LGAD





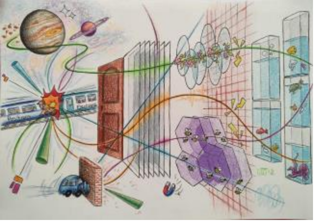
LGAD sensors for Time of Flight applications

DRD3

- **MS 3.2.4** Demonstration of the feasibility of producing LGADs for particle identification (Time of Flight).
  - Possible applications at ALICE 3 (Run5), Belle2, Electron Ion collider (Tracking+TOF@ePIC) >2031) and Future Lepton collider (>2040).
  - In all these cases, larger surfaces (several m^2) have to be covered with respect to vertex detectors.
  - Yield and reproducibility of the process have to be demonstrated while radiation hardness is less of a problem in these experiments with respect to HL-LHC applications.
- In the case of the Electron Ion Collider, a spatial resolution around 30 µm and timing resolution better than 30 ps are required. An area up to 13 m^2 has to be instrumented. In case RSD are used, pad size of 0.5 mm could be implemented.
- For experiments at FCC-ee, a time of flight detector could be placed as the most external tracking layer (silicon wrapper), with a surface of around 100 m^2, time resolution better than 30 ps, and spatial resolution around 10 (90) µm (r-φ, z).

Deliverables:
2024-2026: Production of **LGAD (RSD) sensors with large size for Tracking/Time of Flight applications** to demonstrate yield and doping homogeneity. Study of spatial and time resolution as a function of the pixel size.
2027-2028: Structures produced with vendors capable of large area productions, to demonstrate the industrialization of the process.

Cost of O(2) RSD pixel productions on 6"/8" wafers (2024-2026): 60 kCHFx 2 productions=120kCHF
Cost of O(1) RSD pixel productions on 8" wafers (2027-2028): 60-80 kCHF



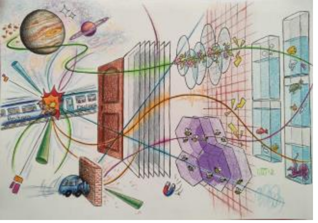
Total DRD3.2 costing for Tracking detectors

DRD3

Only for DRD3.2:

- 3D and LGAD sensor productions (O(24) runs) distributed over several foundries: 1.4-1.8 MCHF
- Hybridization costs (”standard” flip-chipping technology) ~ 30-50 kCHF per run: 0.7-1.2 MCHF → synergies with DRD3.7 (*Interconnect technologies*)
- Characterization costs (irradiations) ~ 10-15 kCHF per run: 0.25-0.35 kCHF

Total (excluding ASICs): 2.2 - 3.2 MCHF



Milestones and experiments timeline

DRD3

	LS4 (2033-2034), LS5?	LS4 (2033-2034)	LS4 (2033-2034) or LS5 (2039)	LS4 (2033-2034) for ALICE and >2031 for EIC
MS 3.2.1	Reduction of 3D sensors pixel cell size *(ATLAS/CMS innermost pixel layer replacement)*			
MS 3.2.2		3D sensors with timing *(VELO Upgrade-II)*		
MS 3.2.3			LGADs for 4D timing *(ATLAS/CMS outer pixel layers and/or disks replacement)*	
MS 3.2.4				LGADs for ToF layers (*ALICE TOF and EIC 3+1 4D)*