Roma – Referee – 4 settembre 2023

International MUON Collider Collaboration

Tracking R&D plans (DRD3: LGAD - RSD - eXFlu) Simulation studies and R&D

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Valentina Sola, Marco Ferrero et al.

UFSD group

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PRIN: A Compensated Design of Thin Silicon Sensors for Extreme Fluences – **ComonSens**

PRIN: DC-RSD developments – **4D-Share** 2022KLK4LB

AIDA innova

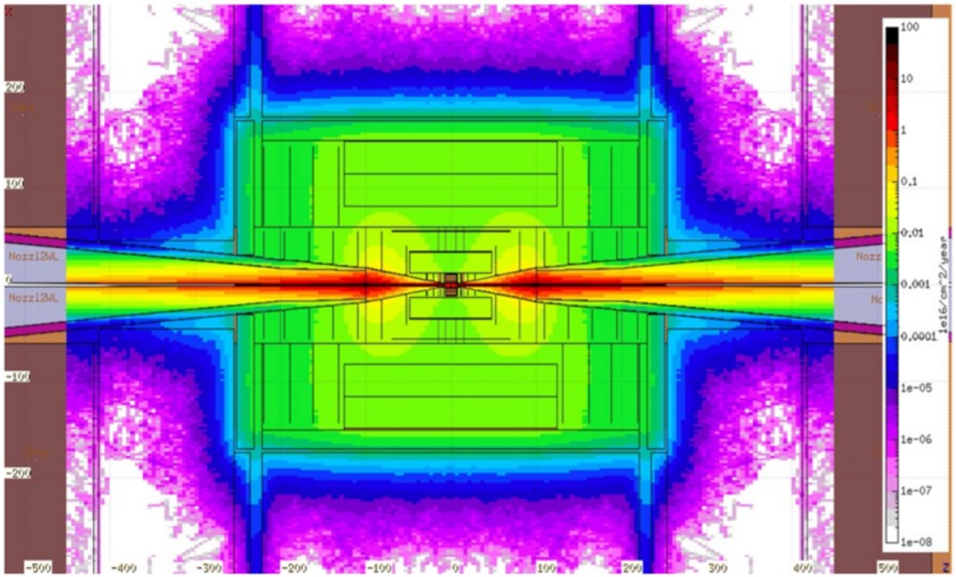
EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES

CSN5-4DSHARE

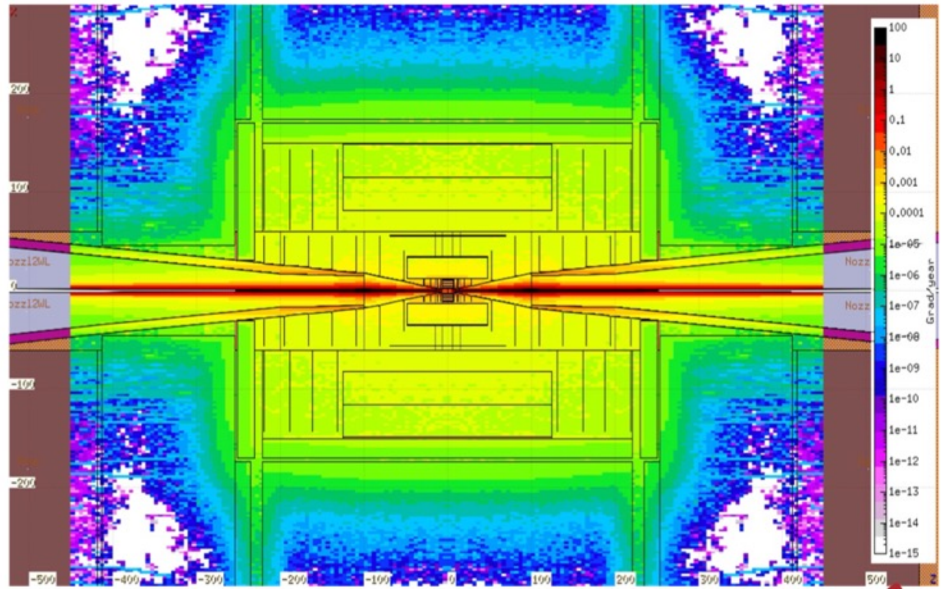
eXFlu

Radiation levels @ 1.5 TeV

1-MeV-neq fluence: one year (200 days) of operation



Total Ionizing Dose: one year (200 days) of operation

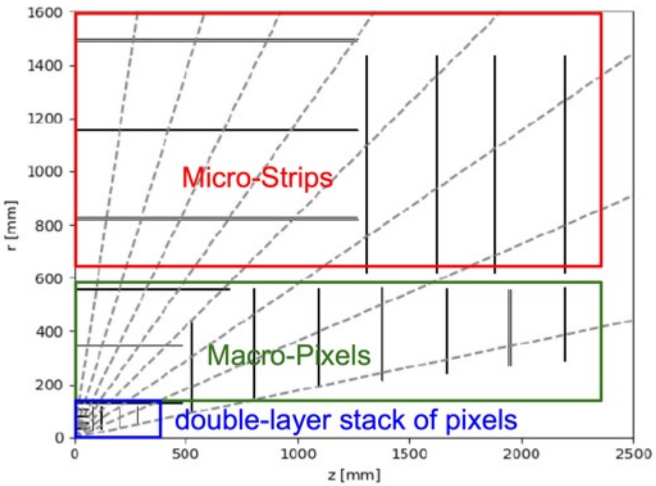


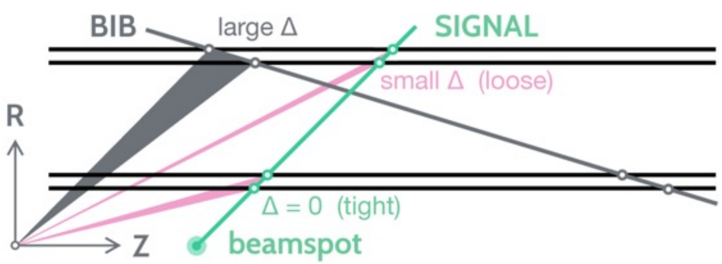
	Maximum Dose (Mrad)		Maximum Fluence (1 MeV-neq/cm^2)	
	R= 22 mm	R= 1500 mm	R= 22 mm	R= 1500 mm
Muon Collider	10	0.1	10^{15}	10^{14}
HL-LHC	100	0.1	10^{15}	10^{13}

Radiation hardness requirements are pretty similar to what expected at HL-LHC

Tracker layout: design requirements

Baseline tracking geometry



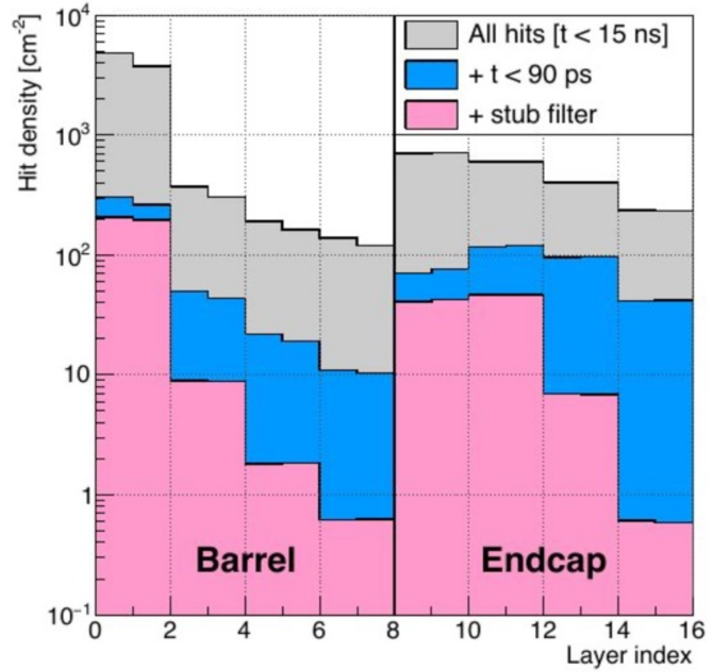


Detector Reference	Hit Density [mm^{-2}] MCD	ATLAS ITk	ALICE ITS3
Pixel Layer 0	3.68	0.643	0.85
Pixel Layer 1	0.51	0.022	0.51

Higher occupancies than LHC detectors are expected but 100 kHz crossing rate (MuC with single bunch) vs 40 MHz (LHC)

- **Timing**: to suppress out-of-time BIB hits
- **Directional information**: BIB does not come from the interaction point
- **Energy depositions**: pulse shape analysis for rejecting soft component

BIB suppression at 1.5 TeV

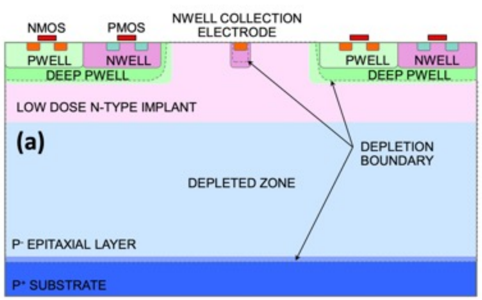


Sensors requirements

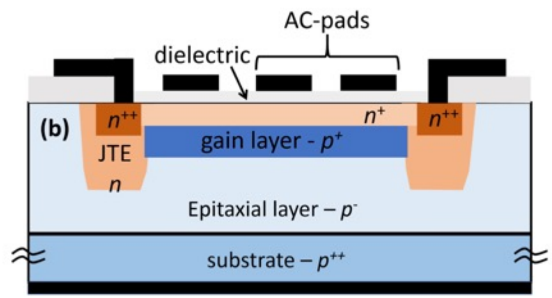
	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	$25\,\mu m \times 25\,\mu m$	$50\,\mu m \times 1\,mm$	$50\,\mu m \times 10\,mm$
Sensor Thickness	$50\,\mu m$	$100\,\mu m$	$100\,\mu m$
Time Resolution	30 ps	60 ps	60 ps
Spatial Resolution	$5\,\mu m \times 5\,\mu m$	$7\,\mu m \times 90\,\mu m$	$7\,\mu m \times 90\,\mu m$

Sinergy with timing sensors development for HL-LHC

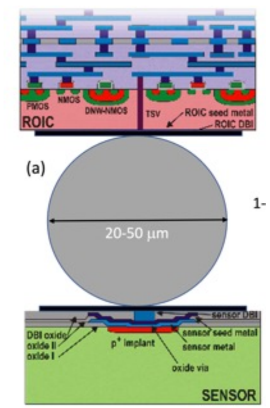
Promising technologies



Monolithic devices (CMOS):
Good timing and spacial resolution, radiation hardness to be improved

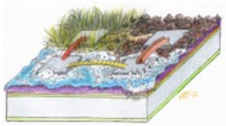


Low Gain Avalanche Detectors (LGAD):
Large and fast signal (20-30 ps resolution), moderate radiation hardness



Hybrid small pixel devices:
No gain but fast timing (20-30 ps resolution) and good position resolution.
Intrinsically radiation hard

LGAD sensors – DC-RSD

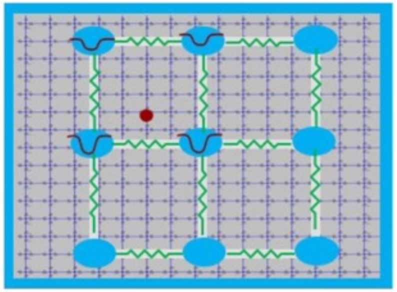


Sensori per Tracciamento in 4D

DC-coupled resistive readout in silicon sensors with internal gain: signal sharing for future 4D tracking

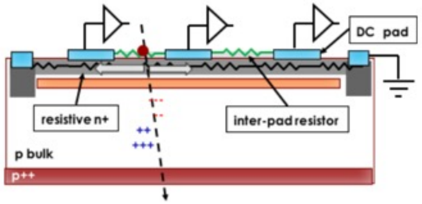
➢ Project goal: evolve the resistive AC-LGAD design, improving the performance and scalability to large devices
→ realization of DC-RSD sensors (DC-coupled Resistive Silicon Detectors)

➢ Key points: achieve controlled signal sharing in a predetermined number of pads and drain the device leakage current at every pixel



Current status and outlook of the project for 2024:

1. Completed first round of simulations for the device, using analytic modeling, SPICE and TCAD
2. Working on the process flow to manufacture DC-RSD: currently completing a few *short-loops* to acquire the necessary technical skills needed for DC-RSD
3. The first prototype run of DC-RSD should be submitted in summer
4. The production should be ready for extensive testing in Q1/24 (with subsequent irradiation)



LGAD sensors – eXFlu

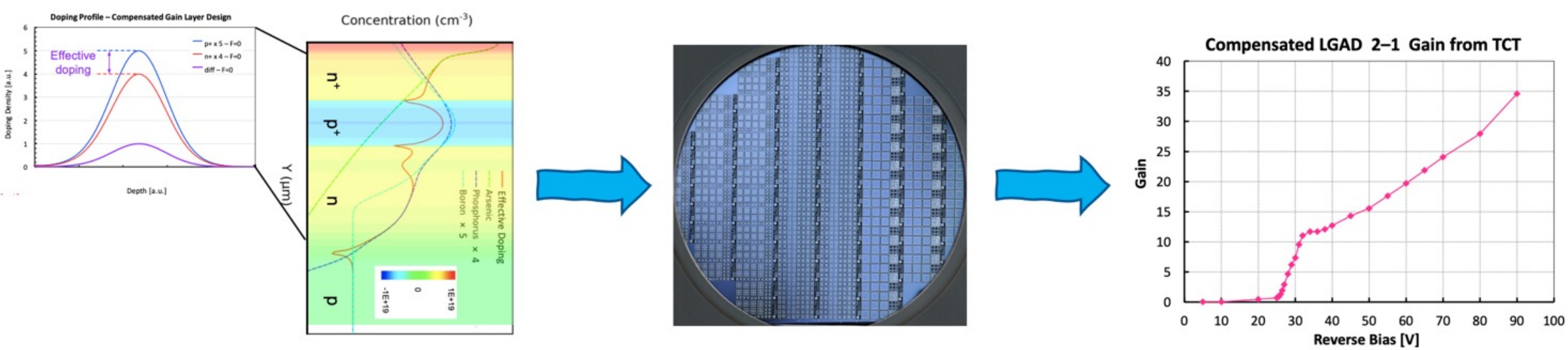
Sensori per Fluenze Estreme

Obbiettivo: Realizzare sensori sottili al silicio che operino fino a fluenze di 10^{17} n_{eq}/cm^2

- ➢ Misurare le **proprietà dei sensori al silicio** a fluenze superiori a 10^{16} n_{eq}/cm^2
- ➢ Disegnare e produrre **sensori planari con guadagno** in grado di operare a fluenze di $10^{16} – 10^{17}$ n_{eq}/cm^2

<u>Produzione di sensori al silicio</u>

- ▻ La prima produzione di sensori LGAD con *gain implant* p–n compensato
  → produzione di sensori completata a fine 2022, ora in fase di caratterizzazione e irraggiamento

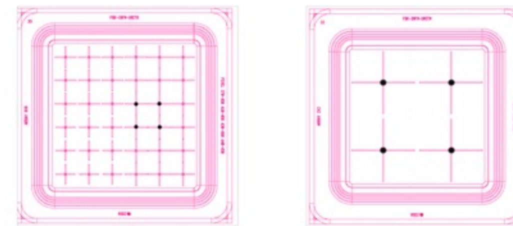


LGAD sensors design and production

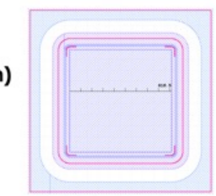
There is a strong coordinated effort – now in DRD3 to develop sensors by experts to:

- improve performances
- face high radiation environment

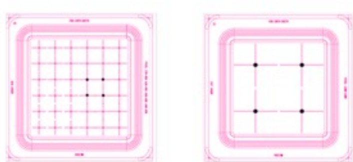
FBK-RSD2, two geometries
4 electrodes, 1300 x 1300 um^2
36 electrodes, 450 x 450 um^2



FBK-DC0 (in the ExFlu production)
4 electrodes, 900 x 900 um^2



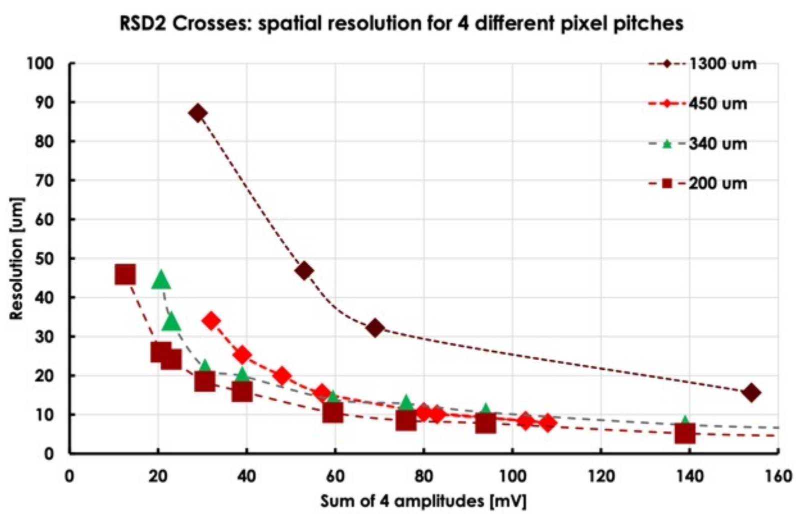
Study of RSD2: summary of past results (TCT)



$$x_i = x_{center} + k_x \frac{pitch}{2} * \frac{Q_3 + Q_4 - (Q_1+Q_2)}{Q_{tot}}$$

$$y_i = y_{center} + k_y \frac{pitch}{2} * \frac{Q_1 + Q_3 - (Q_2+Q_4)}{Q_{tot}}$$

- The hit position is obtained using charge imbalance
- The resolution is defined as the difference between the laser and the reconstructed position



N. Cartiglia, INFN Torino. RD50, Tivat, 21/06/2023

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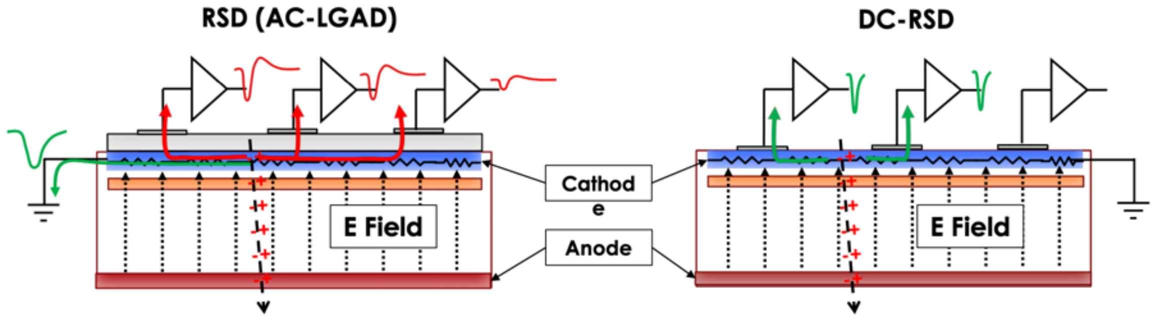
Lab tests
Irradiation
Test beam
Planned and on-going

LGAD sensors: RSD→DC-RSD and eXFlu

RSD vs DC-RSD



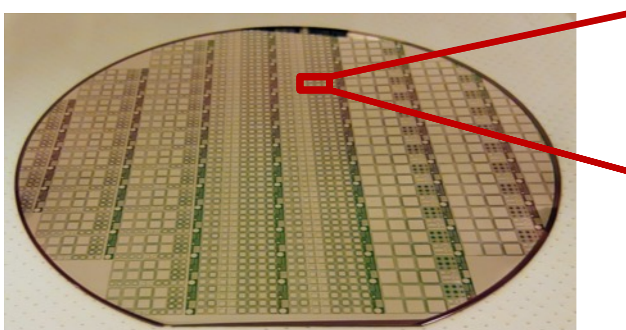
This design has been manufactured in several productions by FBK, BNL, and HPK

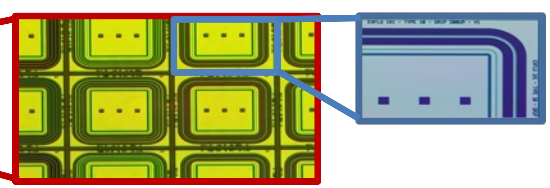
This design is presently under development by FBK
The main advantage of the DC-RSD design is the ability to control the signal spread

A new production of thin LGAD is now released by the FBK foundry ⇒ EXFLU1
different innovation strategies to extend the radiation tolerance up to the extreme fluences:

- carbon shield
- new guard ring design
- compensation
- thin substrates (15–45 µm)

6” Wafer





⇒ extensive testing campaign

RD_MUCOL: strategy and plan

STRATEGY:

- select the most promising sensor technology for the detector @ 3 and 10 TeV
  ⇒ new baseline design in 2-3 years
- simulation studies on detector performances
- participation to lab and test beam campaigns to optimize sensor/electronics design

PLAN:

- Contribute to the sensor read-out and set-up for laboratory and test-beam
- A new neo-laurea student will work almost full time for 1 year starting mid Sept.

2023

The TCT (second unit) was not ordered since it requires dedicated personnel. Instead:

- Four-Fold Programmable Logic Unit ⇒ in the lab
- RSD new electronics multichannel read-out boards ⇒ order to be finalized

RD_MUCOL: plan 2024++ – DRD3

PLAN:

- Contribute to the sensor read-out and set-up for laboratory and test-beam
- A new neo-laurea student will work almost full time for 1 year starting mid Sept.

2024

- 30 read-out boards single channel – timing characterization 6 keu
- 1 MCP-PMT – time measurement on test beam 15 keu
- 1 Newport x-y movement – axis 50 cm for test beam 25 keu
- Participation to lab measurements and test beams

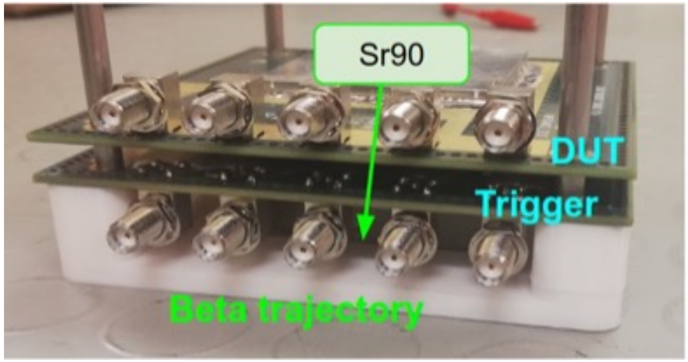
2025 ⇒ to be considered a possible contribution to sensor production

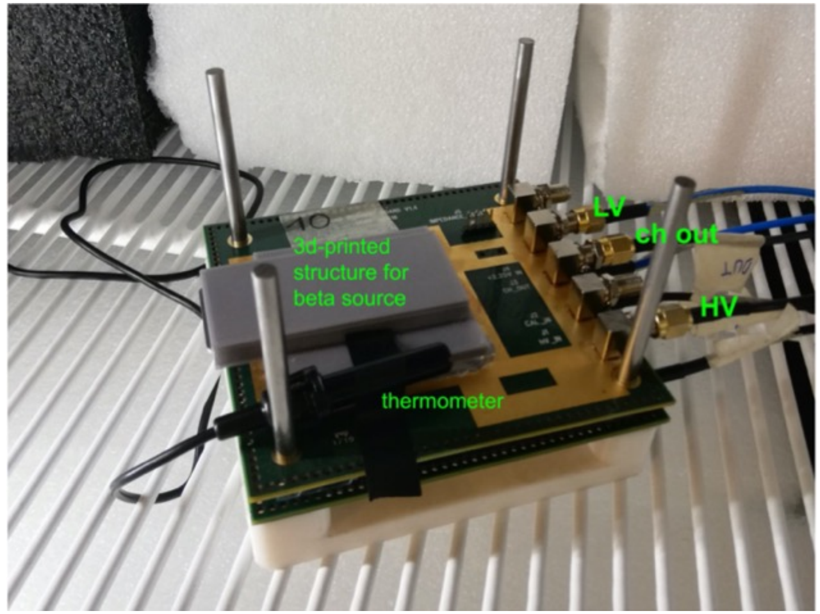
- Consumables ~ 25 keu
- Participation to lab measurements and test beams

2026 ⇒ to be considered a possible contribution to sensor production

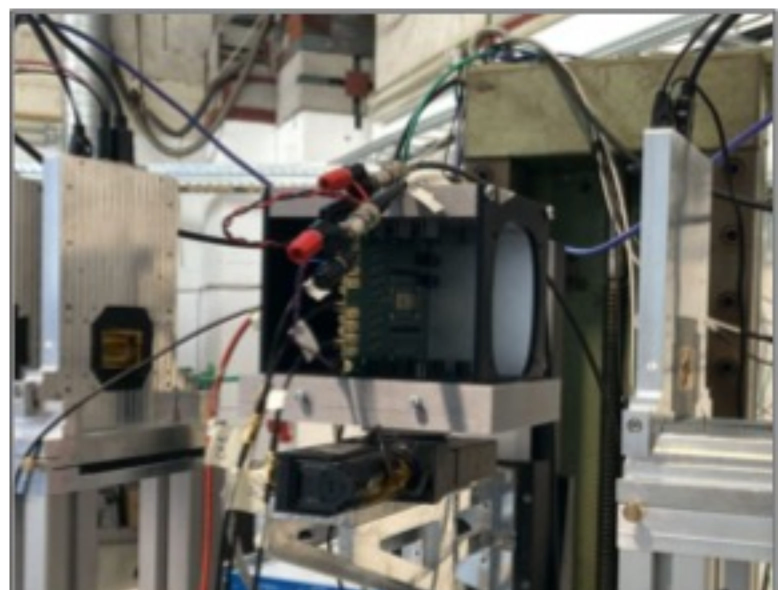
- Consumables ~ 25 keu
- Participation to lab measurements and test beams

Single channel read-out board





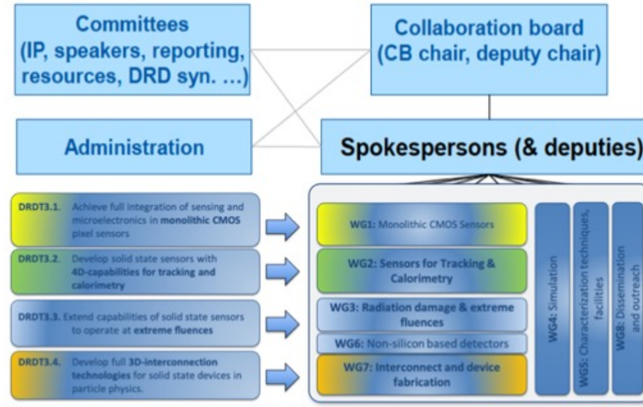
Test beam set-up



DRD3

DRD3 Solid State Detectors program & community building status

conveners: **Nicolo Cartiglia**, Giulio Pellegrini, 484 people registered



Organized in 8 working groups to develop the R&D program

- WG1 : Monolithic CMOS sensors
- WG2 : sensors for tracking and calorimetry (Hybrid, LGADs)
- WG3 : radiation damage and ultrahigh fluence
- WG5 : characterization techniques, facilities
- WG6 : non silicon based detectors
- WG7 : Interconnect and device fabrication
- WG8 : dissemination and outreach

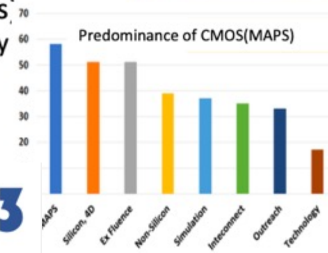
Survey to assess community interests

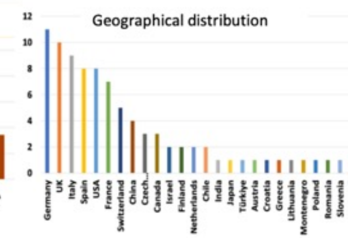
- 88 contributions presented at 1st community meeting

Planning of technology Work Packages (deliverable/milestones)

- on-going mapping of needs and aspirations of the community

DRD3 proposal draft beginning of June





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1.1 The DRD3 working group structure 3
1.2 Strategic R&D 3
1.3 Blue-sky R&D 4

DRD3

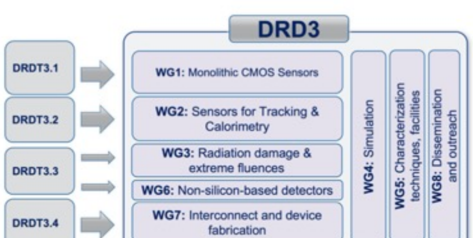
Nicolo Cartiglia (INFN Torino)

Two building blocks: DRDTs and WGs

From roadmap

DRDT 3.1 CMOS sensors	DRDT 3.2 Sensors for 4D-tracking
DRDT 3.3 Sensors for extreme fluences	DRDT 3.4 A demonstrator of 3D-integration

Table 1: The four strategic DRDTs of DRD3



Social networks

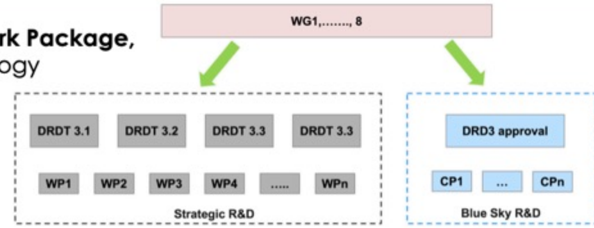
- WG1 Monolithic CMOS Sensors
- WG2 Sensors for Tracking and Calorimetry
- WG3 Radiation damage and extreme fluences
- WG4 Simulation
- WG5 Characterization techniques, facilities
- WG6 Non-silicon-based sensors
- WG7 Interconnect and device fabrication
- WG8 Dissemination and outreach

DRD3 proto-collaboration
~ 100 groups – 75% from Europe

DRD3

Implementation of the DRD3 mandate

Strategic R&D via Work Package, identified by technology



Projects to be defined by the community

Blue sky R&D via common project, approved by the DRD3

Work package	Goal
WP 3.1: TPSCo 65 nm	
WP 3.2: TowerJazz 180 nm	
WP 3.3: LFoundry 150 nm	
WP 3.4: TSI 180 nm	
WP 3.5: LFoundry 110 nm	
WP 3.6: IHP 130 nm	
WP 3.7 3D sensors	
WP 3.8 LGAD	
WP 3.9: Wide bandgap (SiC, GaN)	
WP 3.10: Diamond	
WP 3.11: Silicon	

Table 2: DRD3 work packages

DRDT:	3.1 DMAPS						3.2 4D Tracking		3.3 Extreme Fluence			3.4 Intercon.	
Workpackage:	TPSCo 65 nm	TowerJazz 180 nm	LFoundry 150 nm	TSI 180 nm	LFoundry 110 nm	IHP 130 nm	3D	LGAD	Silicon	Diamond	Wide Bandgap		3D-integration
MS Description													
1.1 Spatial resolution: specification of 3 μm position resolution													
1.2 Timing resolution: specification of 20 ps timing precision													
1.3 Readout architectures for 100 MHz/cm^2													
1.4 Radiation tolerance: specification of 10^{16} n_{eq}/cm^2 NIEL and 500 MRad.													
2.1: Reduction of pixel cell size for 3D sensors							X						
2.2 3D sensors for timing (50 × 50 um, < 50 ps)							X						
2.3 LGAD for 4D tracking < 10 um, < 30 ps, wafer 6" and 8"								X					
2.4 RSD for ToF (Large area, < 30 um, < 30 ps								X					
3.1 Build up data sets on radiation-induced defect formation in WBG materials										x	x		
3.2 Develop silicon radiation damage models based on measured point and cluster defects									x				
3.3 Provide measurements and detector radiation damage models for radiation levels faced in HL-LHC operation							x	x	x	x	x		
3.4 Measure and model the properties of silicon and WBG sensors in the fluence range 10^{16} to $10^{18} n_{eq}cm^{-2}$										x	x		

Table 18: Mapping of DRDTs, WPs, and Milestones

DRAFT

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41 11.4 Funding presently available in the RD50 collaboration 33

Shortly, we will send a **new questionnaire to the community.**
This questionnaire will ask to indicate to which Milestones each group is interested and with what resources.

- The most considerable interplay is with DRD7 (electronics), on the field of DMAPS
- Presently, there is no DRD3 group that has expressed interest in silicon for calorimetry. We still need to develop this field
- Industry: the present plan is to collaborate with industry in the same way we did in RD50