International MUON Collider Collaboration

Tracker R&D

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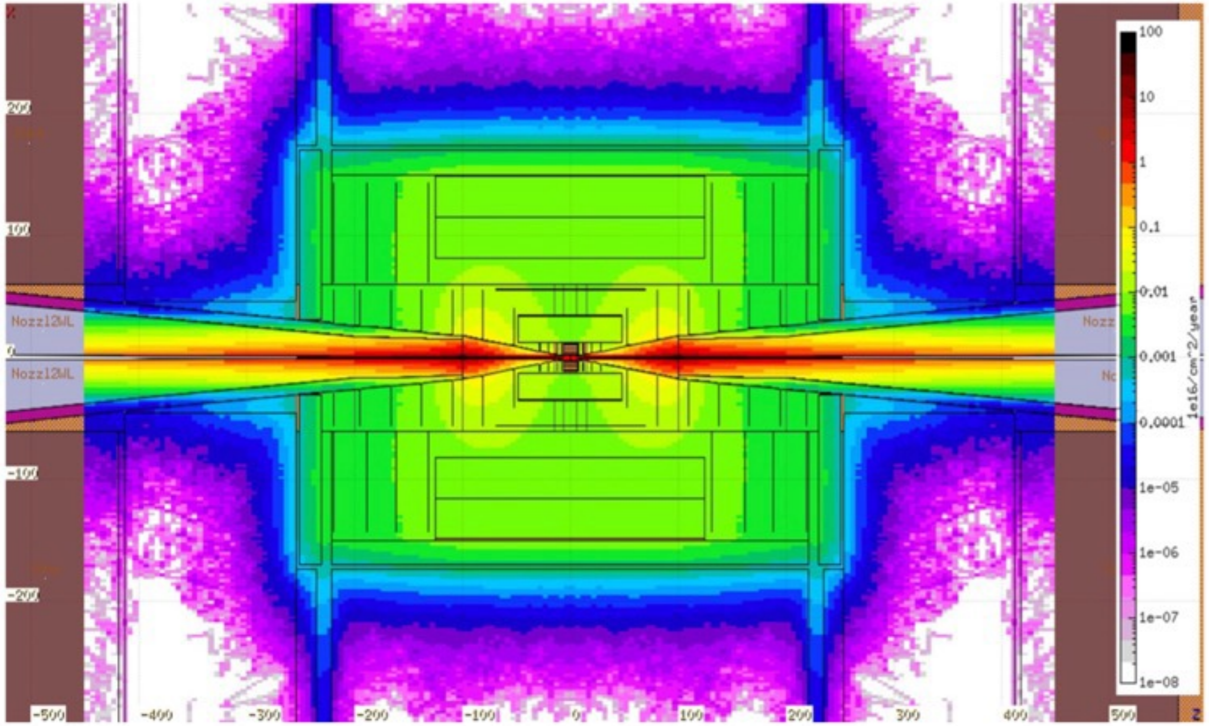
PRIN: A compensated Design of Thin Silicon Sensors For Extreme Fluences - **ComonSens**
PRIN: DC – RSD Developments - **4D-Share 2022KLK4LB**

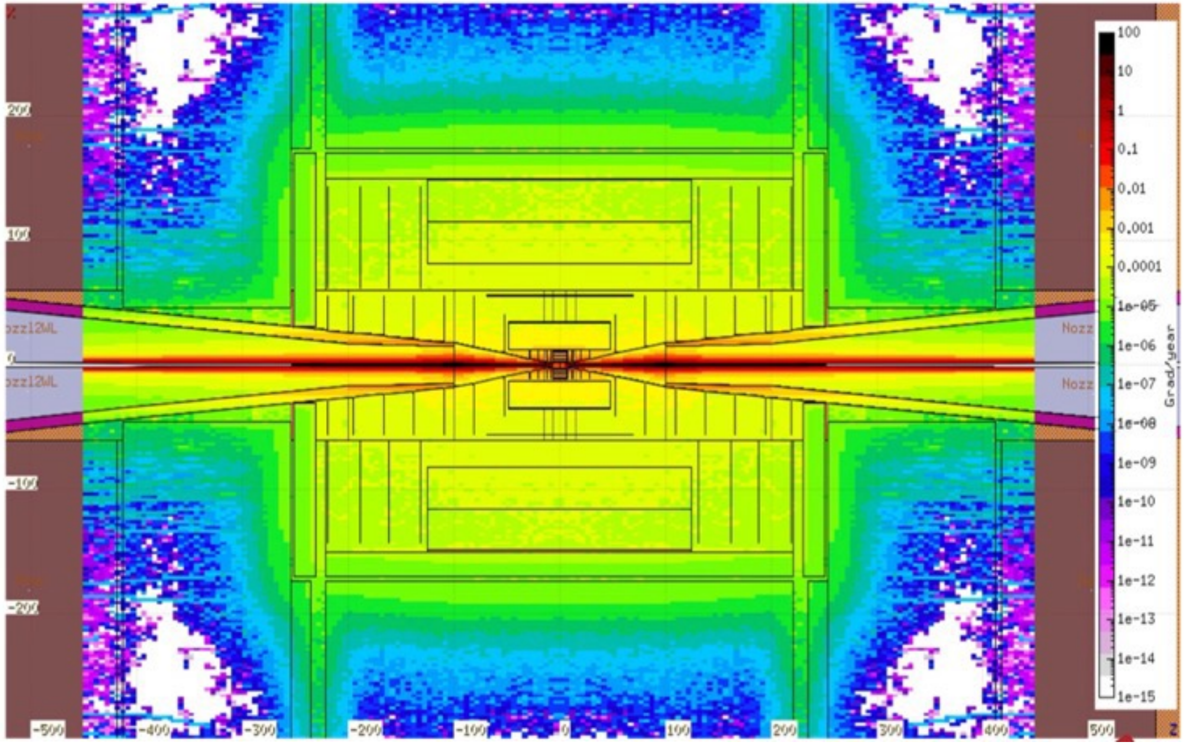
AIDA innova EURO-LABS EUROPEAN LABORATORIES FOR ACCELERATOR BASED SCIENCES CSN5-4DSHARE eXFlu

Radiation levels @1.5 TeV

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



Ionizing Dose: one year (200 days) of operation

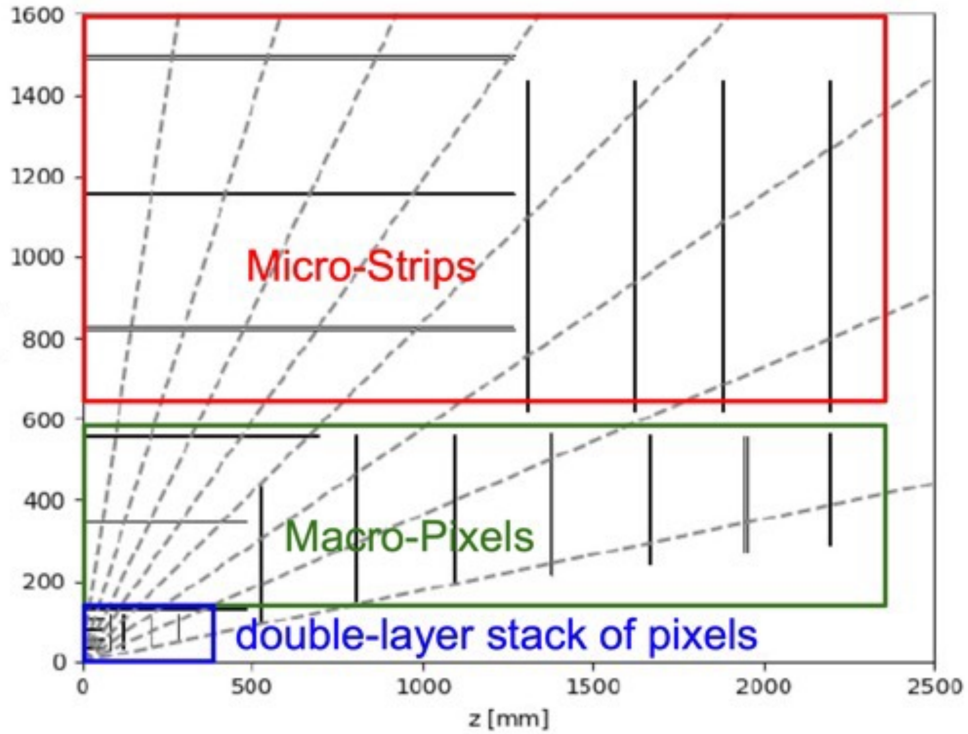


	Maximum Dose (Mrad)		Maximum Fluence (1 MeV-neq/cm^2)	
	R= 22 mm	R= 1500 mm	R= 22 mm	R= 1500 mm
Muon Collider	10	0.1	10^{15}	10^{14}
HL-LHC	100	0.1	10^{15}	10^{13}

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

Tracker layout and sensors requirements

Baseline tracking geometry

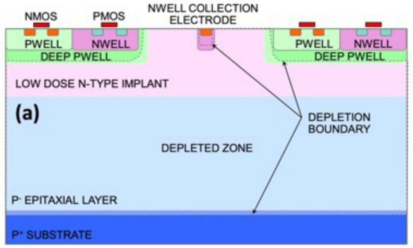


- Higher occupancies than LHC detectors are expected, but 100 kHz crossing rate (MuC with single bunch) vs 40 MHz (LHC)
- Occupancy up to 5k hit/cm^2 in time window of 15ns

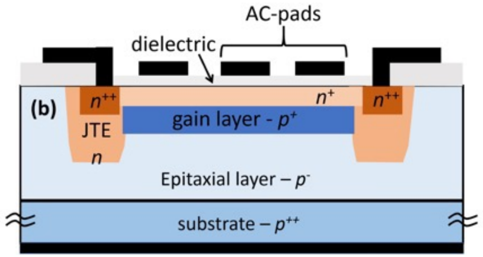
Sensors requirements

	Vertex Detector	Inner Tracker	Outer Tracker
Cell type	pixels	macropixels	microstrips
Cell Size	25 µm × 25 µm	50 µm × 1 mm	50 µm × 10 mm
Sensor Thickness	50 µm	100 µm	100 µm
Time Resolution	30 ps	60 ps	60 ps
Spatial Resolution	5 µm × 5 µm	7 µm × 90 µm	7 µm × 90 µm

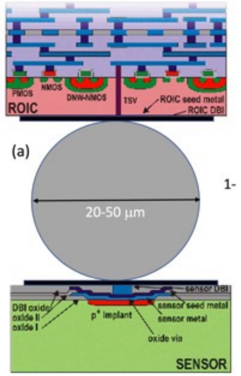
Sinergy with timing sensors development for HL-LHC



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

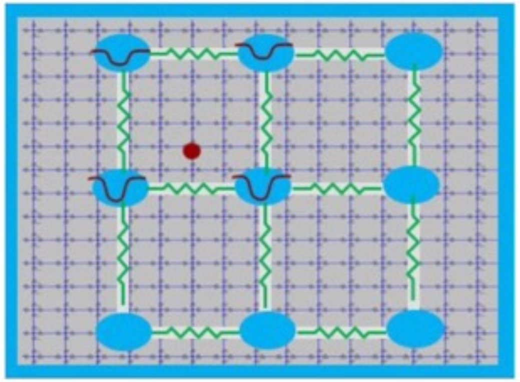


Hybrid small pixel devices: Fast timing (20-30 ps resolution)and good position resolution. Intrinsically radiation hard

LGAD sensors towards 4D tracking
AC-RSD → and DC-RSD

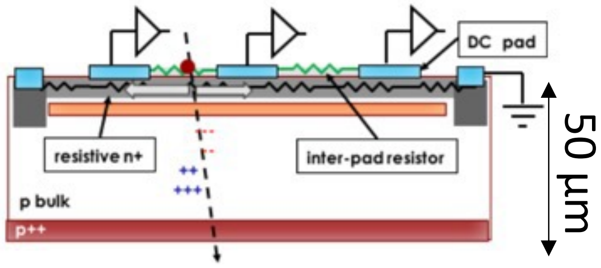
DC-coupled resistive readout in silicon sensors with internal gain: signal sharing for future 4D tracking

- ➢ 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



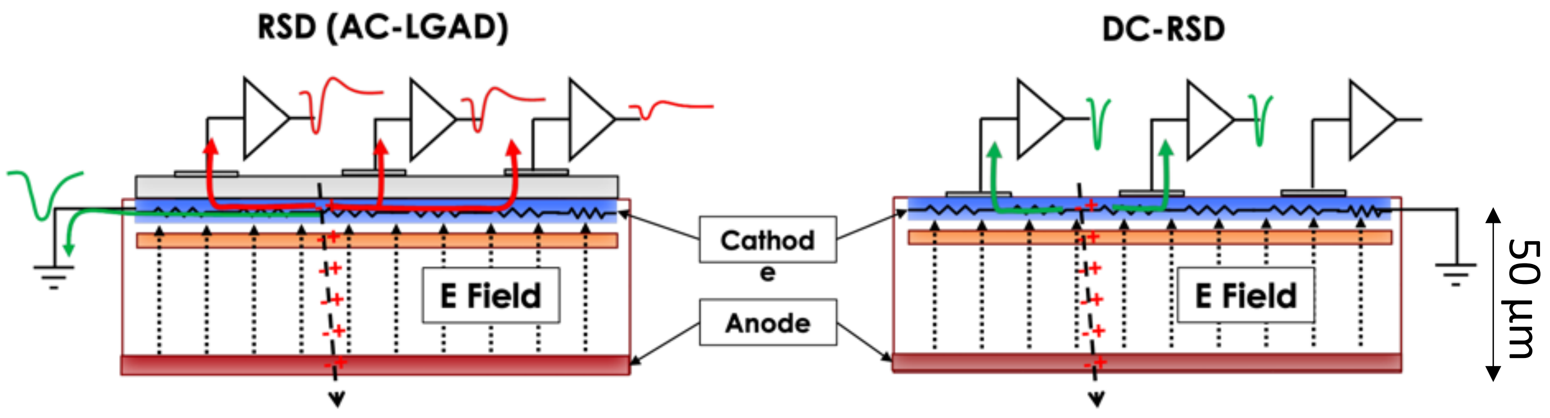
Current status and outlook of the project for 2024:

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 for the end of the year
4. The production should be ready for extensive testing in Q2/24 (with subsequent irradiation)



PRIN: DC – RSD Developments - 4D-Share 2022KLK4LB

LGAD sensors towards 4D tracking
From AC-RSD to DC-RSD



The design has been manufactured in several production by FBK, BNL and HPK

This design is presently under development by FBK
The main advantages of the DC-RSD design are:

- The ability to control the signal spread and
- Monopolar signal with temporal duration of few ns, rather than bipolar with long tail

Both features are fundamental to reduce the sensor occupancy

LGAD sensors towards 4D tracking -- AC- and DC-RSD

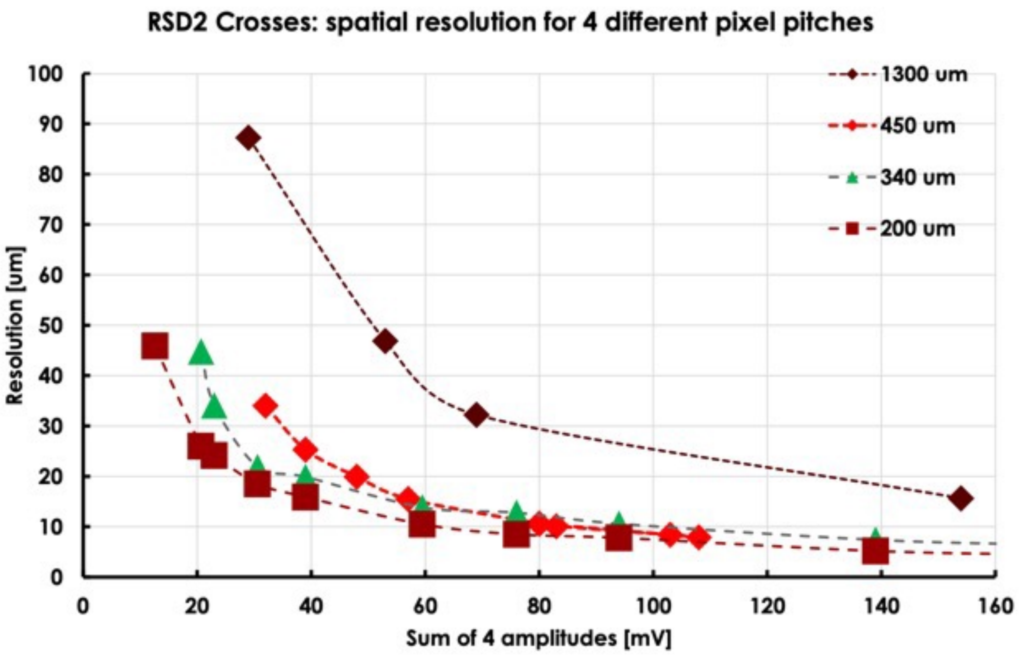
Extensive characterization of AC-RSD in laboratory

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

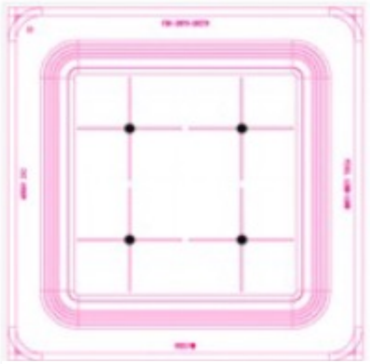
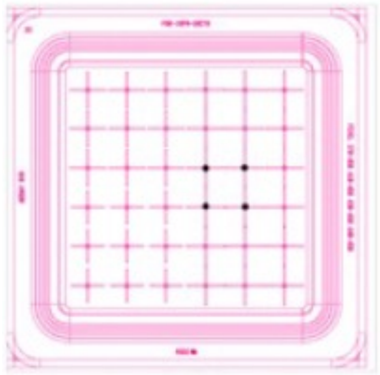


N. Cartiglia, INFN Torino. RD50, Tivat, 21/06/2023

Spatial resolution in RSD overcomes the limit of pitch/$\sqrt{12}$ from binary readout

Beam test campaign on-going

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

LGAD sensors for extreme fluences ($10^{16} – 10^{17}\ n_{eq}/cm^2$)

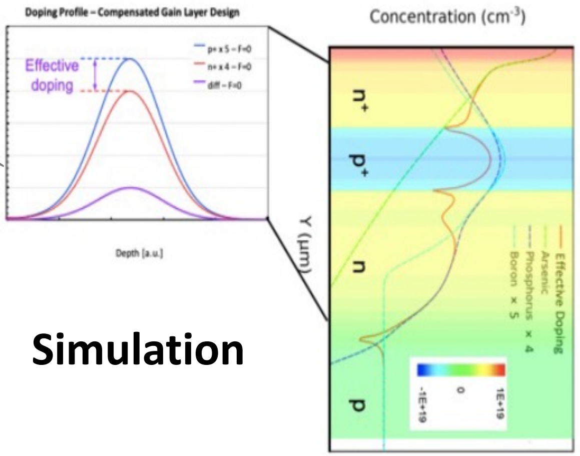
Sensori per Fluenze Estreme

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 $10^{16} – 10^{17}\ n_{eq}/cm^2$

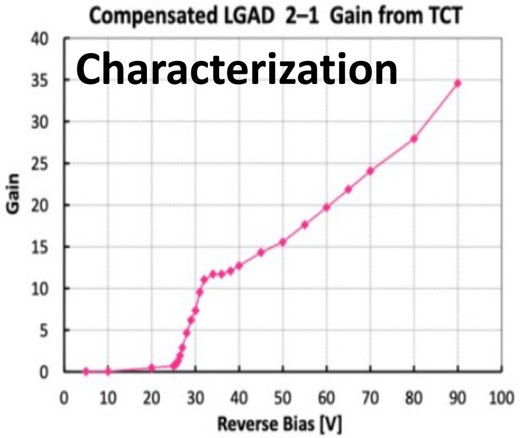
<u>Produzione di sensori al silicio</u>

- 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



Simulation

Production



First prototypes of compensated-LGAD Produced by FBK in EXFLU1 production and by HPK

Extensive testing campaign on irradiated devices is on-going

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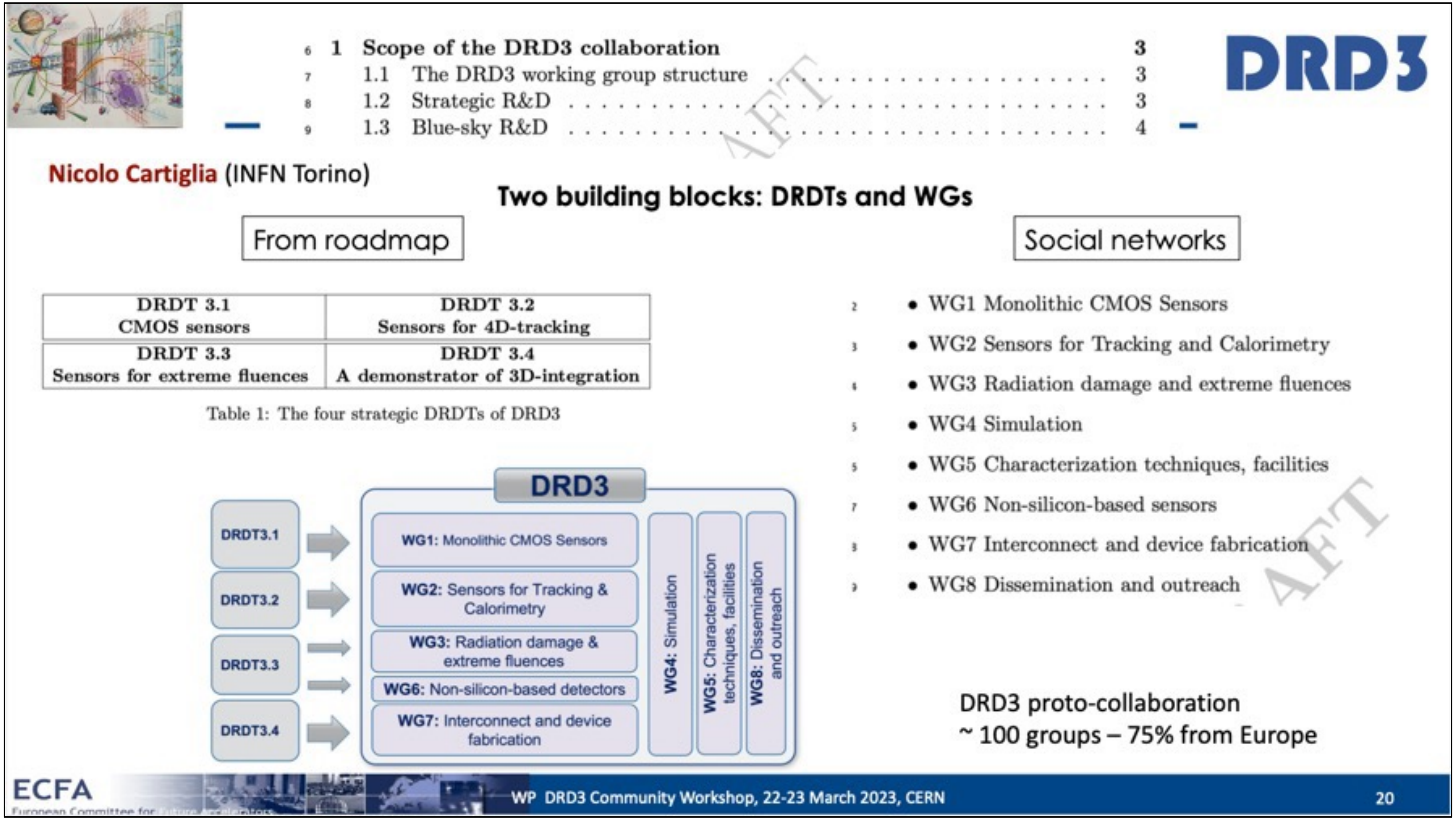
DRD3 Solid State Detector Program and Working Groups



- The most considerable interplay of DRD3 is with DRD7 (electronics), on the field of the DMAPS
- There is no DRD3 group that has expressed interest in silicon for calorimetry
- The plane to collaborate with industry in the same way we did in RD50

Outlook for the future

- Development of a reliable sensor technology requires a couple of sensors production (2-3 years)

DC-RSD

- First DC-RSD production will be ready for the Q2/2024
- A second DC-RSD batch is scheduled for the 2025

SENSORS for EXTREME FLUENCES

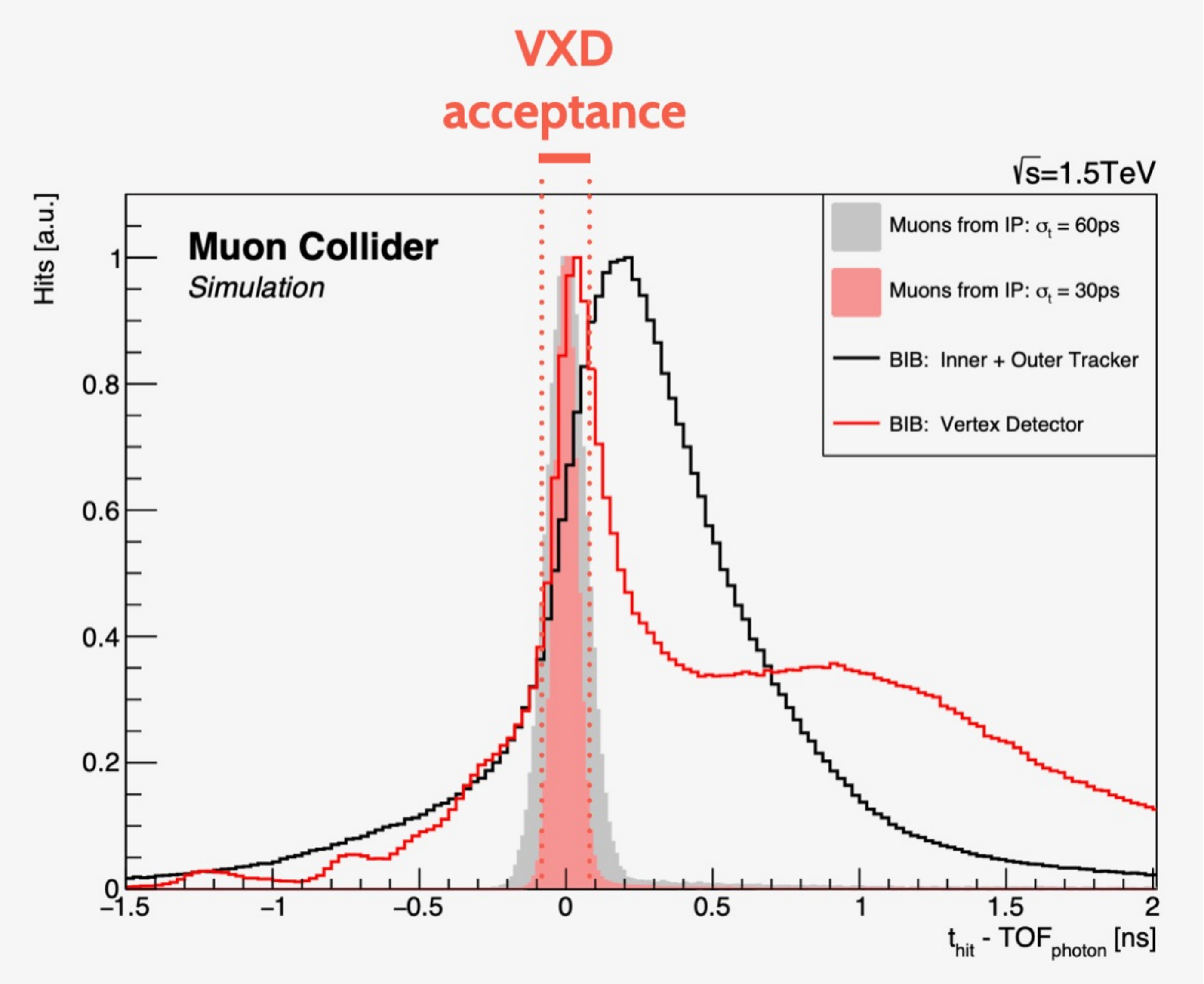
- The characterization of the first batch of Compensated-LGAD is on-going
- A second production is scheduled for the end of 2024

It is reasonable to have target prototypes in 2026, after 3 years of R&D

- Characterization results are an important input for realistic digitization in the physics and detector simulation

Backup

Occupancy



VXD
acceptance
√s=1.5TeV
Muon Collider
Simulation
Muons from IP: σt = 60ps
Muons from IP: σt = 30ps
BIB: Inner + Outer Tracker
BIB: Vertex Detector
Hits [a.u.]
t_hit - TOF_photon [ns]
0
0.2
0.4
0.6
0.8
1
−1.5
−1
−0.5
0
0.5
1
1.5
2