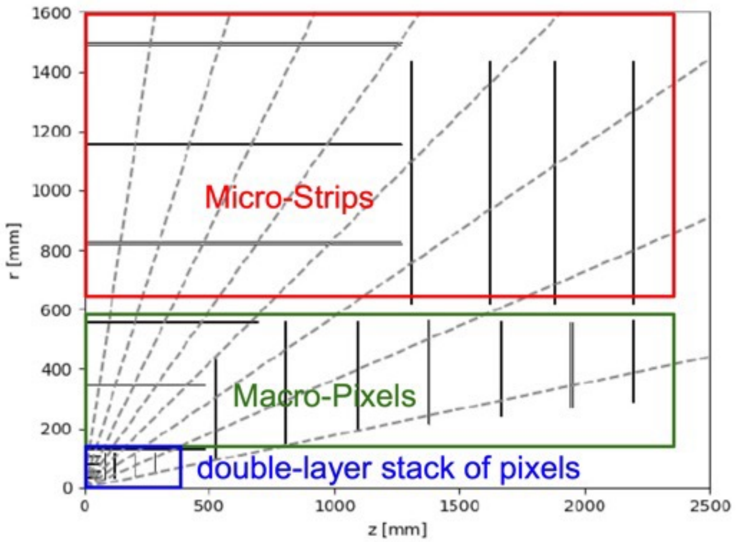
Detector R&D: tracking - LGAD (DRD3)

Marco Ferrero
INFN Torino

CSN5-4DSHARE

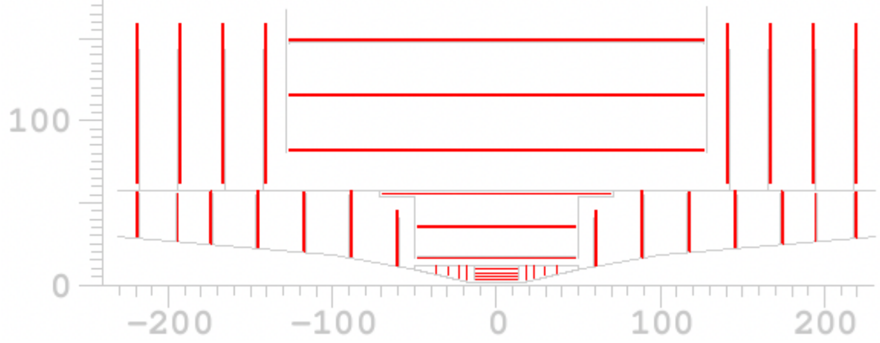
Tracker layout and sensors requirements

Original baseline tracking geometry and sensors requirements – design @ 3 TeV



	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	$5\,\mu m \times 5\,\mu m$	$7\,\mu m \times 90\,\mu m$	$7\,\mu m \times 90\,\mu m$

New design to be finalized@ 10 TeV: geometry and sensors requirements



Fairly stringent requests for resolutions

Very high occupancy in the vertex detector

To be combined with:

- As low as possible material budget
- As low as possible power consumption

Studies @ 10 TeV per bunch crossing

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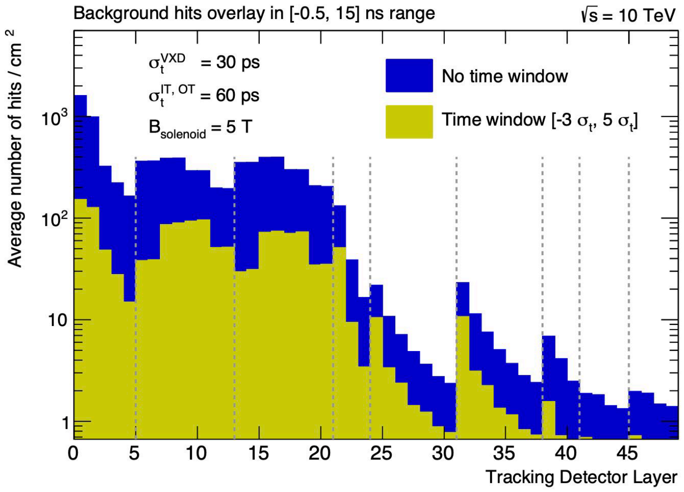
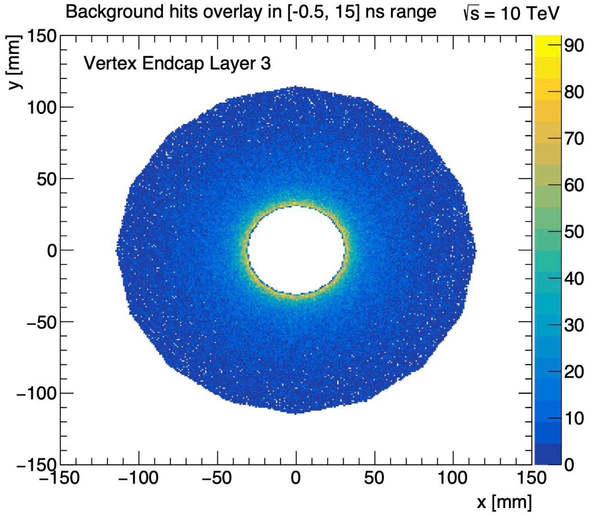
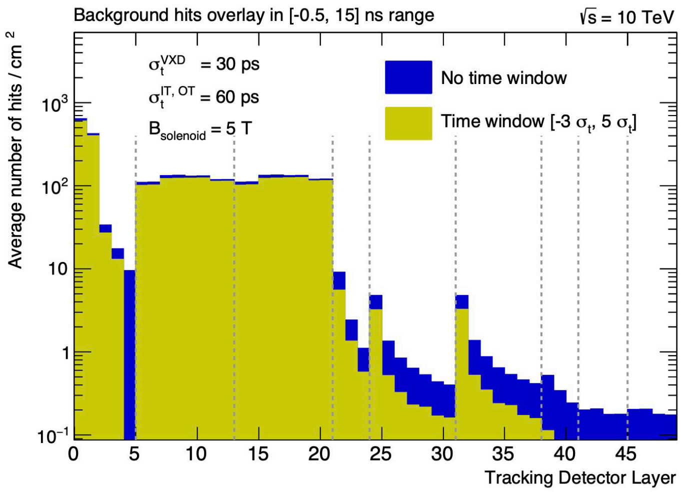
Timing crucial to reduce BIB

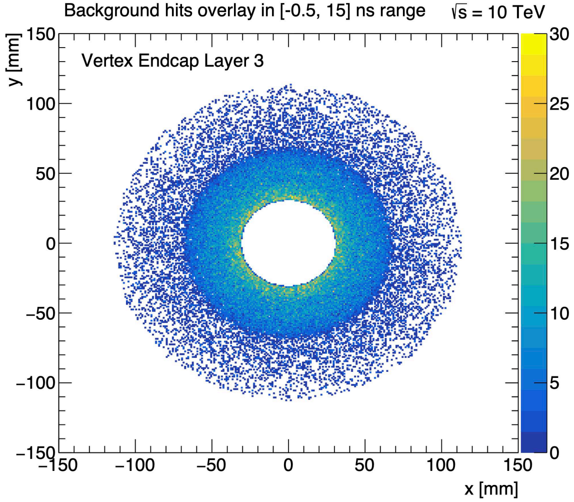
Beam Induced Background
(asynchronous, diffused)





Incoherent Pair Production
(synchronous, from IP)

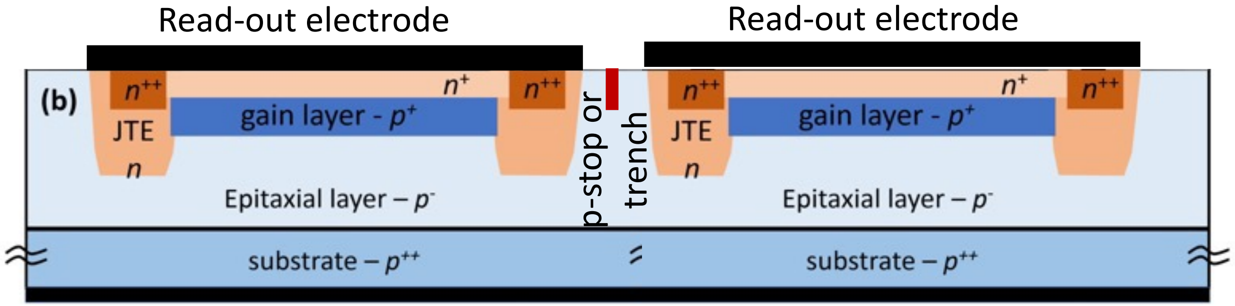




Incoherent pair production on-time

LGAD : a sensors technology candidate for the tracker

State of the art of LGAD technology
(technology chosen for CMS and ATLAS timing detectors)



Low Gain Avalanche Detectors (LGAD):

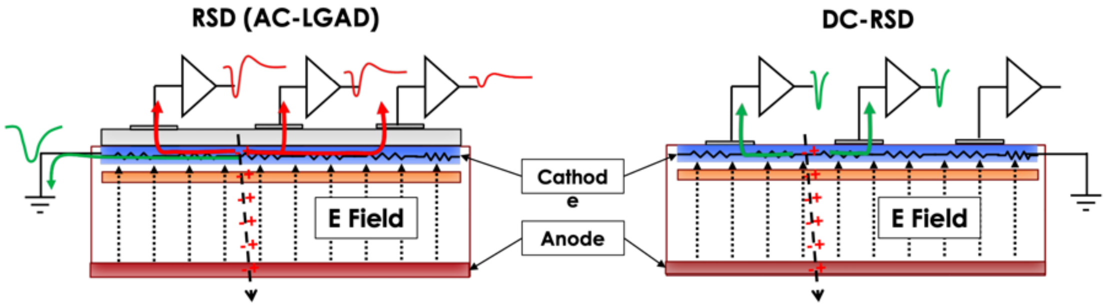
- Internal multiplication layer
- Large and fast signal (temporal resolution ~30 ps)
- Low active thickness (50 µm or less)
- moderate radiation hardness (up to 2-3·10^{15} n_{eq}/cm^2)
- Pixel isolation (p-stop implant or trench)

The two parallel lines of R&D on LGAD technology

Resistive silicon detector (RSD)

RSD based is functionality on the signal sharing between read-out pads via a resistive read-out electrode.

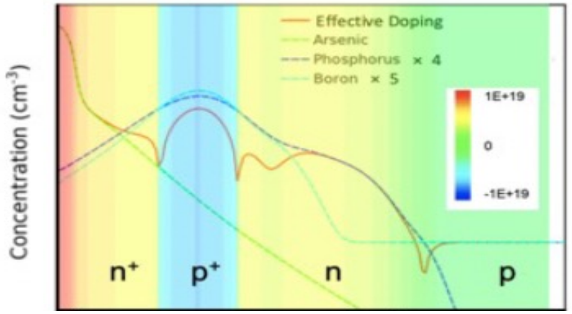
The signal sharing guarantees the reconstruction of the particle hit point with excellent precision.



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

Compensated-LGAD

Improvement of the multiplication layer design to cope with fluences exceeding 10^{16} n_{eq}/cm^2



A completely new tracker based on RSD (AC or DC couple)

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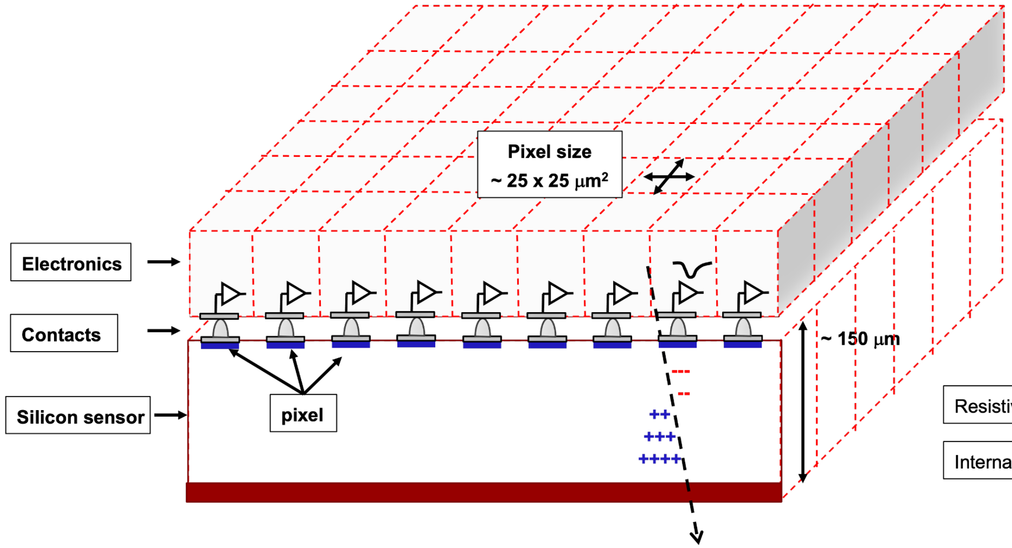
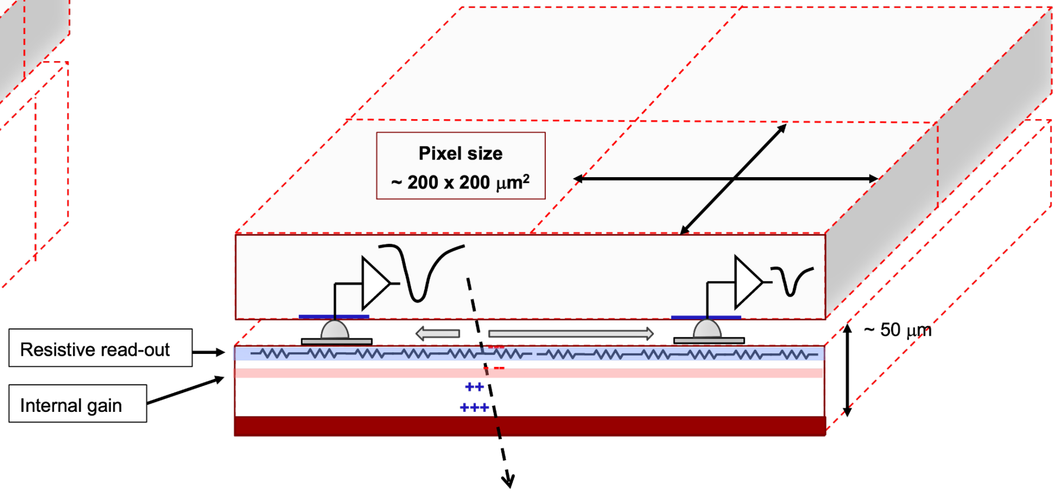
One of the candidate technology for the major part of the tracker



Standard tracker

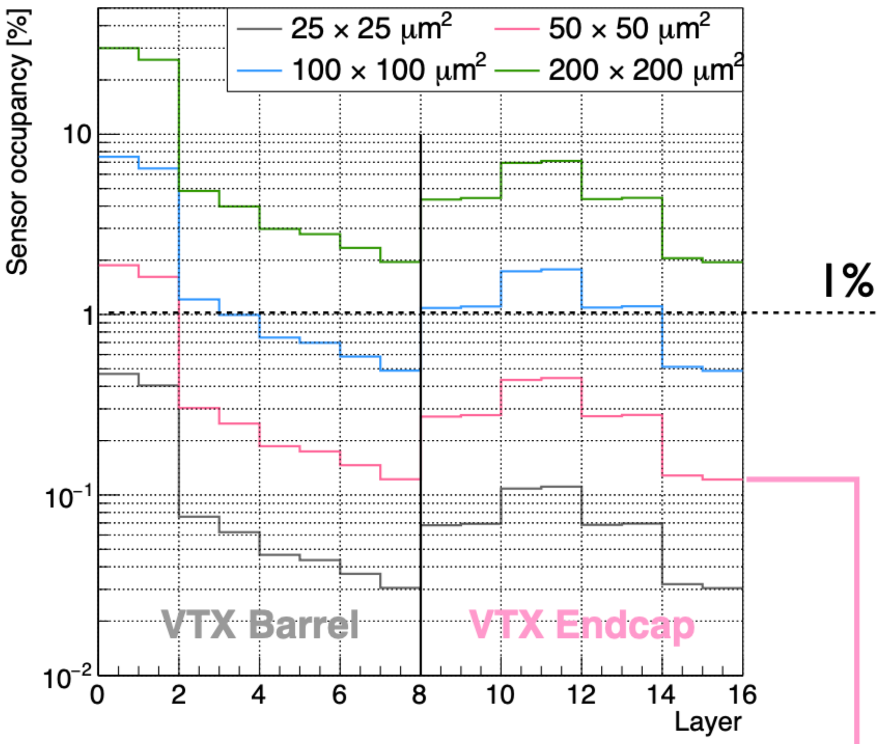


RSD-based tracker

The design of a tracker based on RSD is truly innovative:

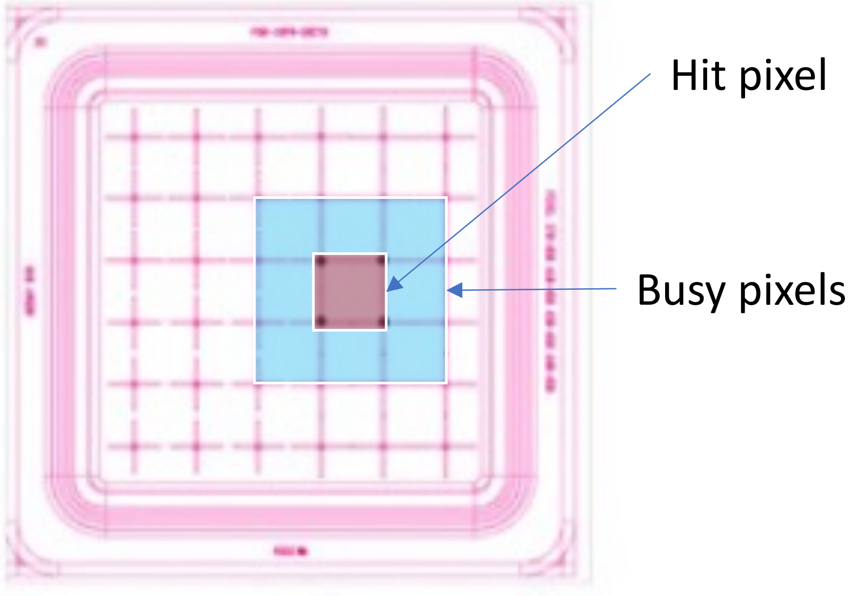
- It delivers ~ 20 -30 ps temporal resolution
- For the same spatial resolution, the number of pixel is reduced by 50-100
- The electronic circuitry can be easily accomodated
- The power consumption is much lower, it might even be air cooled (~ 0.1-0.2 W/cm²)
- The sensors can be really thin

Occupancy



Low Occupancy must be ensured to avoid pile-up effects
50x50 μm pads would be sufficient for most of the VTX

Effective area for read out of a single hit is 3x3 pixels



Traditional trench-isolated LGADs could be more suitable mere suitable for VTX

LGAD sensors towards 4D tracking
AC- and DC-Resistive Silicon Detector (RSD)

Projects involved RSD technology development:

- **RSD** (Grant giovani Gruppo V - from 2019-2021):
  - Demonstrator of AC-LGAD based on resistive read-out for 4D tracking
- **4D-Share** (Call Gruppo V and PRIN2022 - from 2023 to 2025):
  - Expected 2 productions of DC-RSD sensors
  - 1 year post-doc starting in April 2023
- **RadHard AC-LGAD** (RD50/DRD3 common project - from 2024):
  - An AC-LGAD production with the purpose of investigating and extending the radiation hardness of the RSD technology
- **FAST3-Amplifier** (RD50/DRD3 common project - from 2024):
  - Development of a multichannel amplification boards based on FAST3 ASIC, optimized to readout multi-channel LGAD prototypes (optimal in laboratory and test beam activities).

LGAD sensors towards 4D tracking
AC- and DC-Resistive Silicon Detector (RSD)

The main goals of these projects:

- Evolve the resistivity AC-LGAD design towards a DC-RSD design (4D-Share)
  - Controlled signal sharing in a predetermined number of pads to operate the device in high occupancy environments
- Extend of the radiation resistance od RSD technology up to fluence of $3 \cdot 10^{15}$ n_{eq}/cm^2 (RadHard AC-LGAD project)

Outlook of the projects for the end of 2024 and 2025:

- The first DC-RSD batch is currently in production, it is expected in September 2024
- RadHard AC-LGAD production are expected for the end of 2025
  - The simulation of AC-LGAD including the Perugia radiation damage model is ongoing

AC-LGAD (RSD)
More significative experimental results

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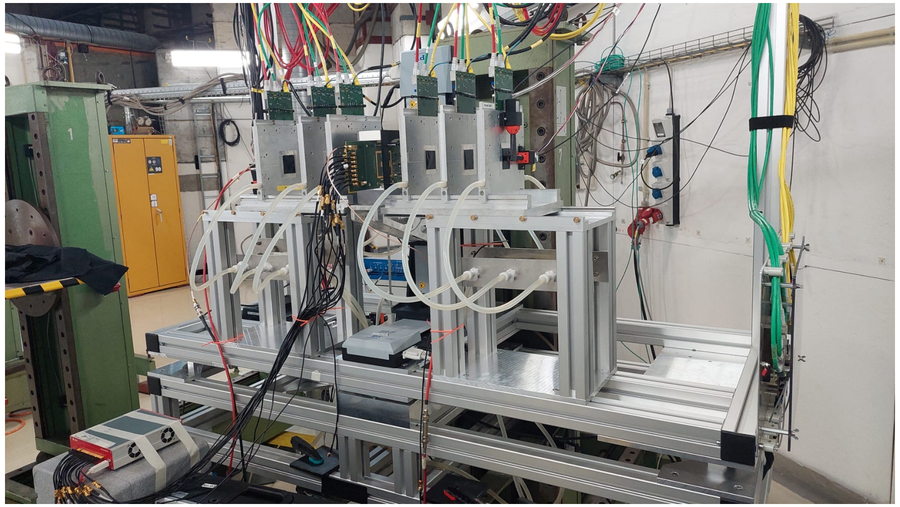
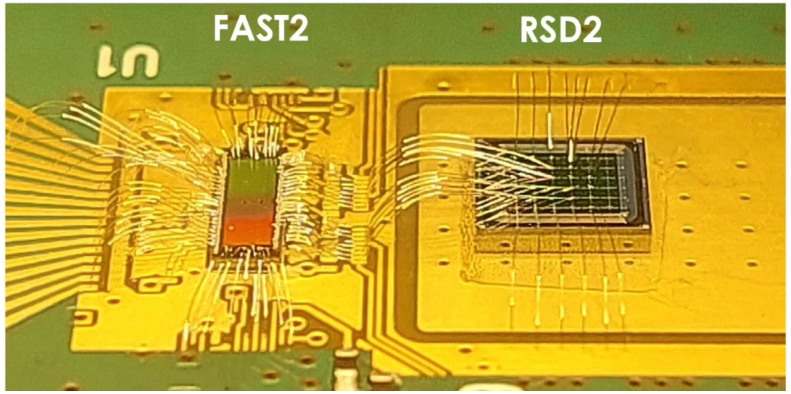
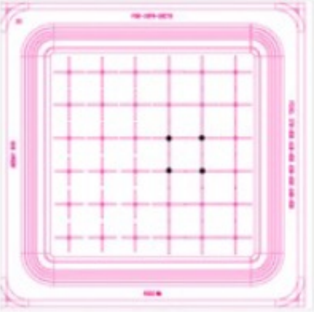
FBK-RSD2 sensor geometry tested in a beam test campaign in DESY

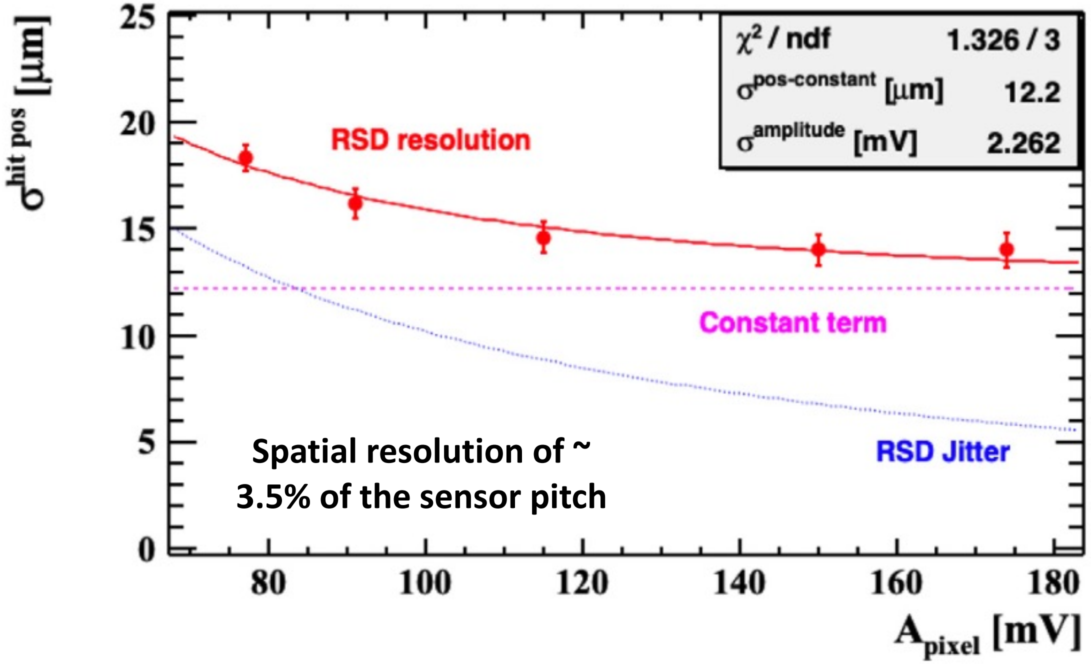






36 electrode
Pitch 450µm

Position Resolution as a function of the sum of the signal amplitudes seen by the electrodes at the 4 corners of the pixel



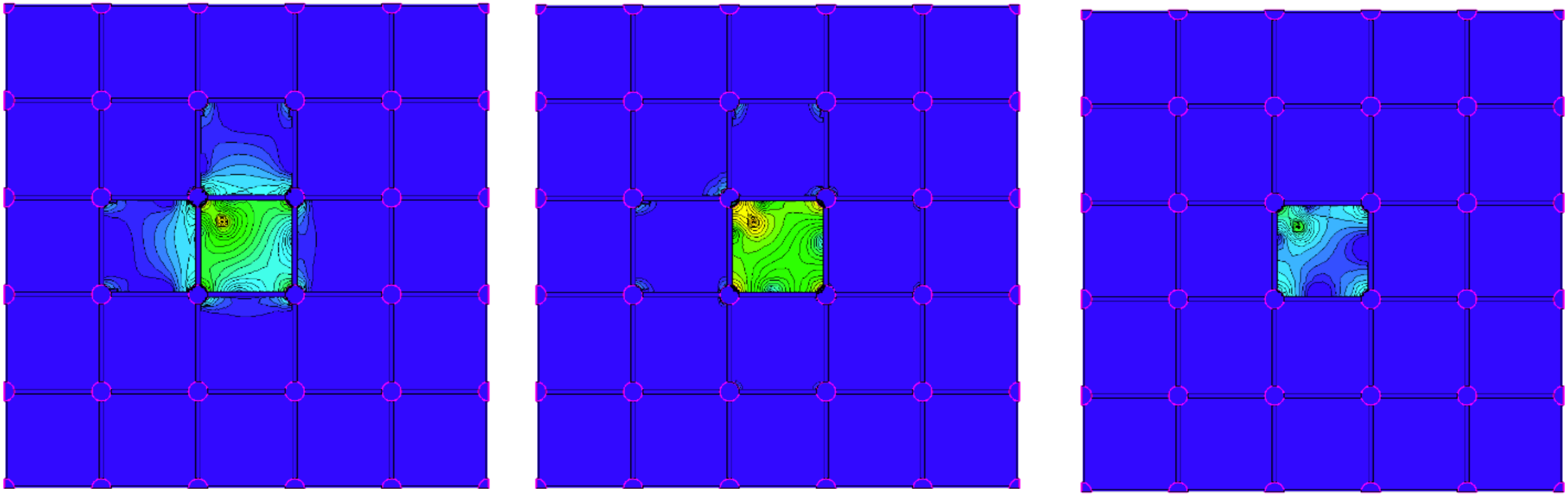
Charge imbalance has been used as reconstruction method

$$x^{meas} = x_0 + \frac{pitch}{2} * \frac{(A_3 + A_4) - (A_1 + A_2)}{\Sigma_1^4 A_i}$$

$$y^{meas} = y_0 + \frac{pitch}{2} * \frac{(A_1 + A_3) - (A_2 + A_4)}{\Sigma_1^4 A_i},$$

DC-Resistive Silicon Detector (RSD)
More significative simulated results

TCAD simulation of 6x6 pixel matrix DC-RSD
(Time evolution of the charge density generated by the passage of a particle)



- Pixel isolation with trenches
- each read-out electrode shared between 4 pixels
- Hit position close the top-left electrode in the central pixel

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

Projects involved in LGAD for extreme fluence:

- **eXFlu** (Grant giovani Gruppo V - from 2020-2022):
  - Demonstrator of the compensated-LGAD technology
- **eXFlu-Innova** (AIDAinnova project from 2022 to 2025):
  - co-funding first prototype of compensated-LGAD and p-in-n LGAD, preparatory to the design of compensated-LGAD
  - 2 years post-doc starting in September 2023
- **ComonSens (**PRIN2022 - from 2023 to 2025):
  - co-funding of p-in-n LGAD preparatory to the design of compensated-LGAD
  - 2 years post-doc starting in July 2024
- **CompleX** (ERC - from 2024 to 2029):
  - Funding of 3 productions of Compensated LGAD for extreme fluences
- **Partial Activated Boron** (RD50/DRD3 common project - from 2024)

All ongoing project involve the INFN/CNR Perugia Groups and FBK

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

The main goal of these projects is to produce thin LGAD sensors able to operating up to fluence of 10^{17} n_{eq}/cm^2

- ➢ Simulation and design of a reliable and radiation hardness of multiplication layer based on compensation technology
- ➢ Design of the sensor termination structures able to operate above 10^{16} n_{eq}/cm^2
- ➢ Development of a radiation damage model for extreme fluences
- ➢ Measurements of silicon sensors properties irradiated over 10^{16} n_{eq}/cm^2

Outlook of the projects for the end of 2024 and 2025:

- ➢ A p-in-n LGAD production expected for the Q4/2024 – Q1/2025 (from eXFlu-innova and ComonSens projects)
  - Device simulations have been finalized
  - The design of the production layout is ongoing
- ➢ A compensated-LGAD production expected for the end of 2025

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

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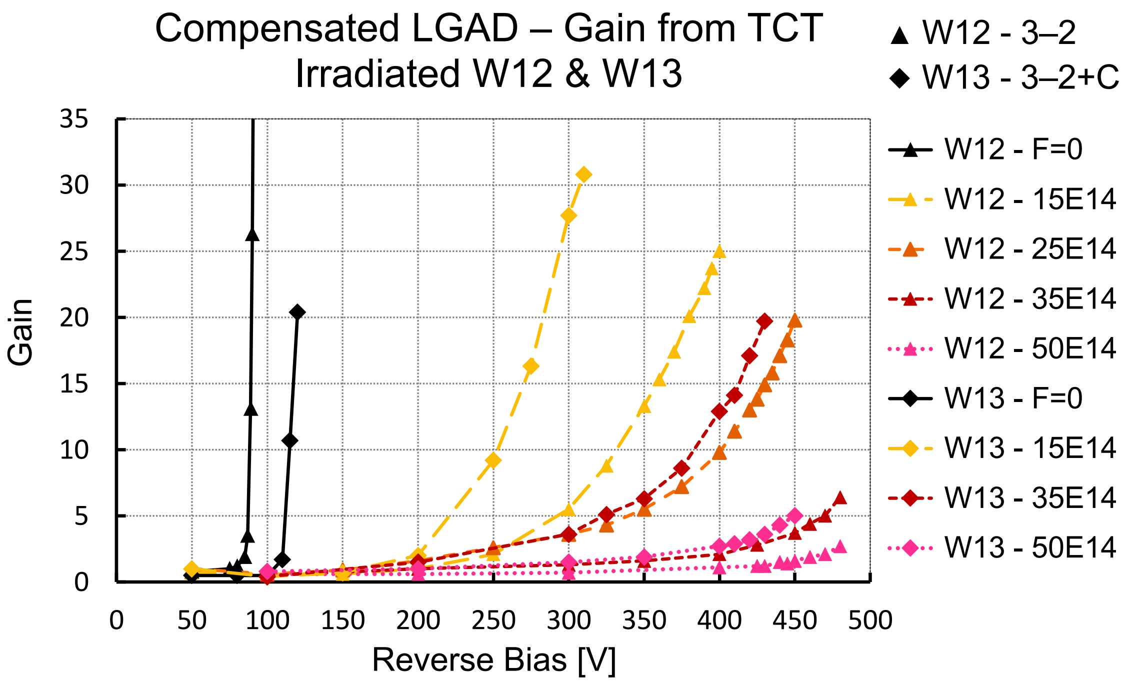
eXFlu-batch
Demonstrator of Compensated-LGAD technology delivered in 2022

An extensive characterization with pulsed IR laser was conducted in laboratory on irradiated compensated-LGAD



For the first time an LGAD irradiated at $5 \cdot 10^{15}$ provide 10 fC of charge

Conclusion and outlook for 2024 and 2025

Sensor batches expected in 2024 and 2025:

- DC-RSD in Q4/2024
- p-in-n LGAD in Q4/2024 – Q1/2025
- First CompleX batch in Q4/2025
- Partial Activated Boron in Q4/2025
- RadHard AC-LGAD in Q4/2025

- Extensive laboratory testing campaigns to select most promising sensor design and layout
- Several beam test campaign are and will be scheduled at the end of 2024 and in 2025, at DESY and CERN facilities

DESY TEST BEAM.

DESY 2 Test Beam Schedule 2024 - Status from 22/JUL/2024

DESY 2 Test Beam Coordinators: Ralf Diener, Norbert Meyners, Marcel Stanitzki

Startdate	Week	TB21	T	TB22	T	TB241	T	TB24	T
09.12.2024	50	LHCb-MightyPix	X	DCRSD	X			CMS ETL ETROC	X
16.12.2024	51	LHCb-MightyPix	X	Telescope-Dev	X			EXFLU	
23.12.2024	52	Shutdown		Shutdown		Shutdown		Shutdown	

Backup

Matching UFSD-RSD capabilities to the muColl requests

		cell size	sensor thickness	time resolution	spatial resolution	number of cells
VXD	B	25 μm × 25 μm pixels	50 μm	30 ps	5 μm × 5 μm	729M
	E	25 μm × 25 μm pixels	50 μm	30 ps	5 μm × 5 μm	462M
IT	B	50 μm × 1 mm macropixels	100 μm	60 ps	7 μm × 90 μm	164M
	E	50 μm × 1 mm macropixels	100 μm	60 ps	7 μm × 90 μm	127M
OT	B	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	117M
	E	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	56M

High occupancy and levels.

TI-LGAD can be used up to 1-2E15 n/cm^2

R&D in radiation harness needed to cover the full radiation field

Low occupancy and radiation levels. Ideal for macro-pixels.

Pixel size, spatial, and temporal resolutions are a perfect fit for present RSD technology

RSD will strongly reduce the number of pixels

Very Low-occupancy and radiation levels. Long strips do not provide accurate temporal resolution.

Propose to replace it with RSD macro pads

Conclusions

UFSD and RSD offer very good combined spatial and temporal performances

These designs are a good fit to the need of the muColl design

		cell size	sensor thickness	time resolution	spatial resolution	number of cells
VXD	B	25 μm × 25 μm pixels	50 μm	30 ps	5 μm × 5 μm	729M
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OT	B	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	117M
	E	50 μm × 10 mm microstrips	100 μm	60 ps	7 μm × 90 μm	56M

Proposed detector

Cell size	Number of cells	Thickness	Detector
To be decided		50 um	**TI_LGAD**
200 um x 2 mm	1/8 # of present design	50 um	**RSD**
200 um x 2 mm	Similar to the present design	50 um	**RSD**

Very difficult (impossible?) to achieve good timing with strips

Better to use macro-pads?

In Torino we are continuing the development of TI-LGAD and RSD for applications to the muColl tracker