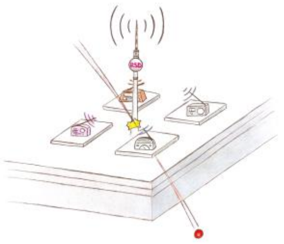
An R&D path for the muColl silicon tracker



- Request for the muColl tracker
- State of the art of LGAD-based 4D sensors
- Path forward for a muColl tracker based on UFSD_RSD

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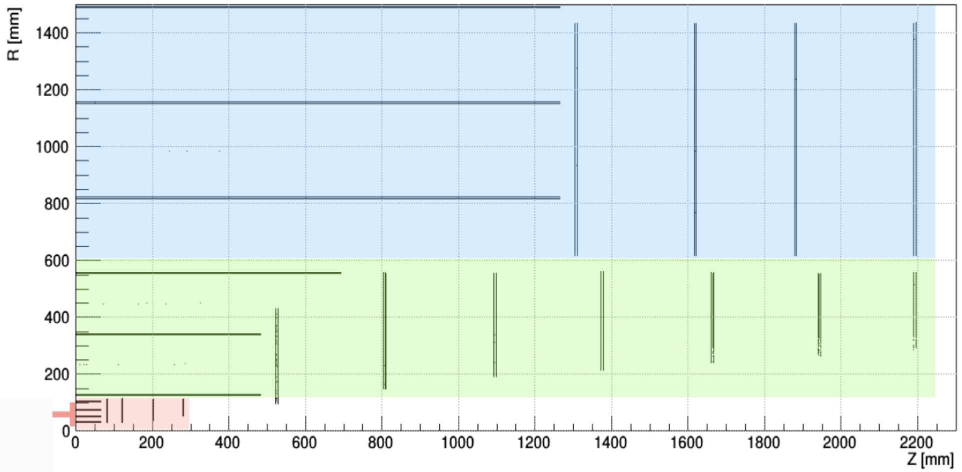
Setting the stage: resolution and occupancy

Silicon sensors with high spatial and timing resolution

- **Outer Tracker** $\sigma_\emptyset \sim 7\ \mu m, \sigma_z \sim 90\ \mu m\ \sigma_t \sim 60\ ps$ (strips)
- **Inner Tracker** $\sigma_\emptyset \sim 7\ \mu m, \sigma_z \sim 90\ \mu m\ \sigma_t \sim 60\ ps$ (macropixels)
- **Vertex Detector** $\sigma_\emptyset \sim 5\ \mu m, \sigma_z \sim 5\ \mu m\ \sigma_t \sim 30\ ps$ (pixel, 25x25 μm)
  - double layers with 2mm spacing
  - forward disks placed outside of the regions with highest BIB flux to minimize occupancy

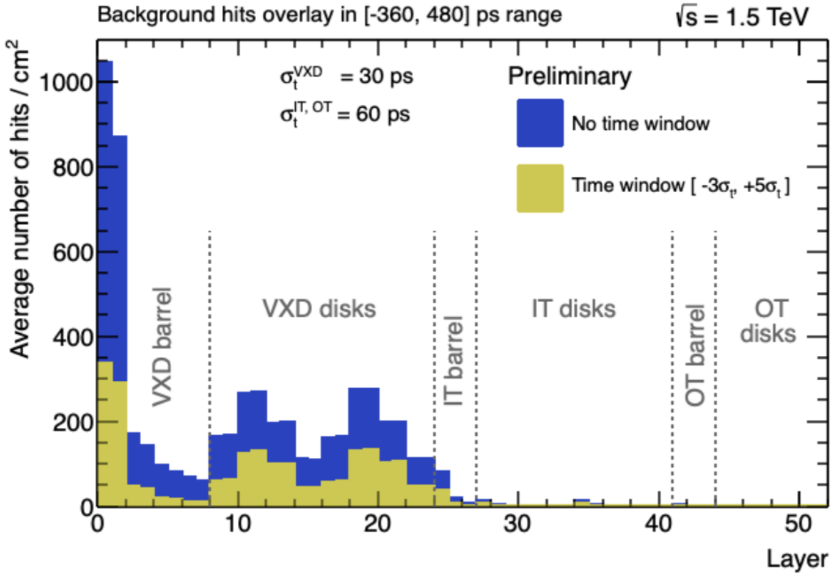


Fairly stringent requests for resolutions

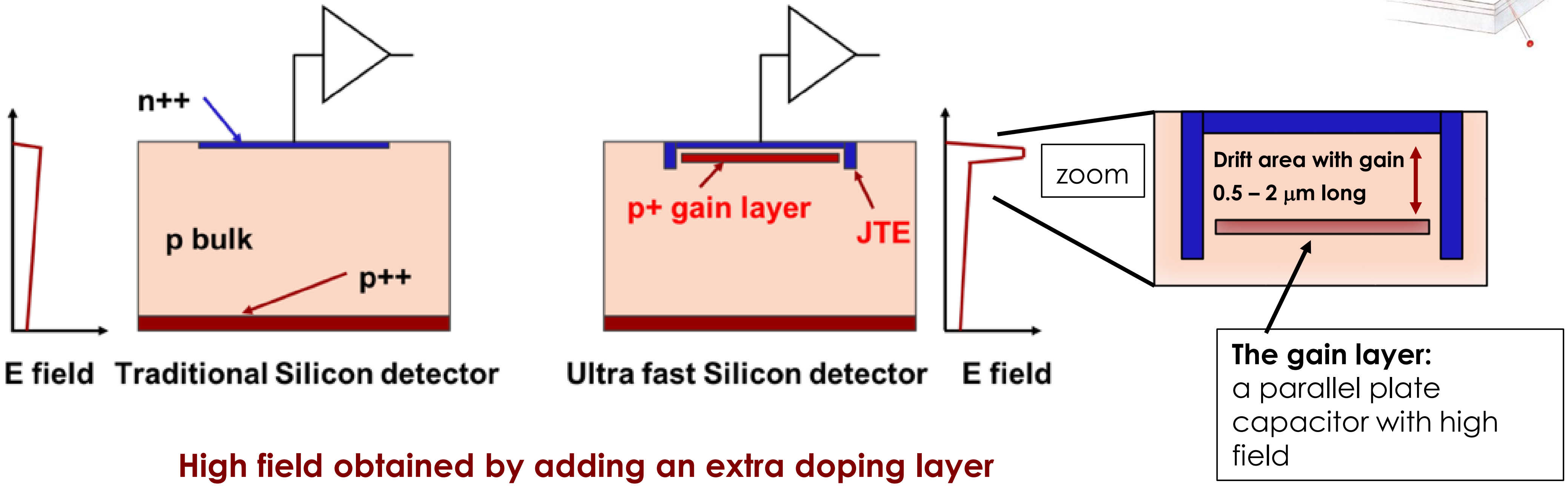
Very high occupancy in the vertex detector

To be combined with:

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



First design innovation: low gain avalanche diode (LGAD)



High field obtained by adding an extra doping layer

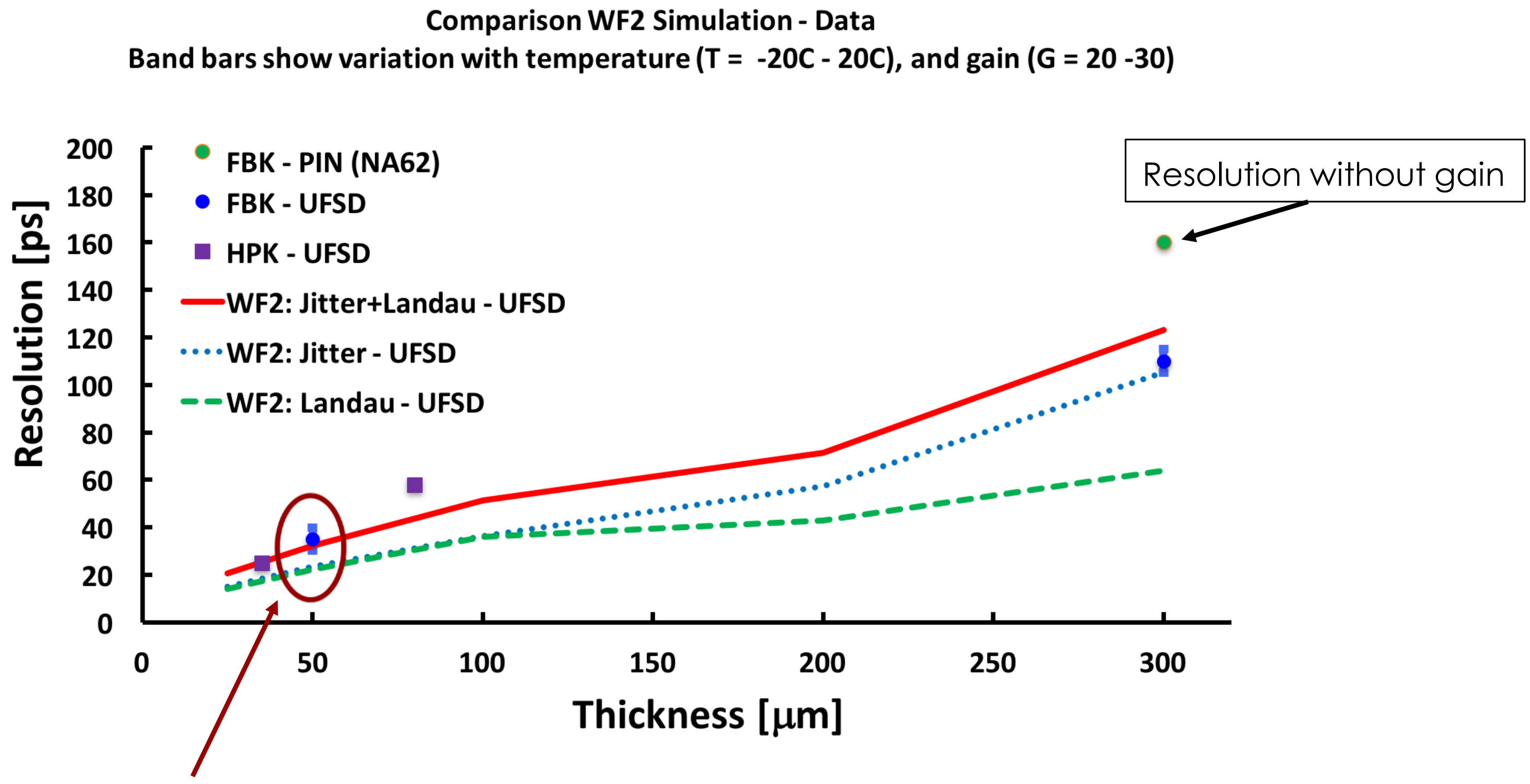
E ~ 300 kV/cm, closed to breakdown voltage

- The low-gain mechanism, obtained with a moderately doped p-implant, is the defining feature of the design.
- The low gain allows segmenting and keeping the shot noise below the electronic noise, since the leakage current is low.

Low gain is the key ingredient to good temporal resolution

LGAD optimized for timing are often called Ultra-Fast Silicon Detector (UFSD)

Summary of UFSD temporal resolution

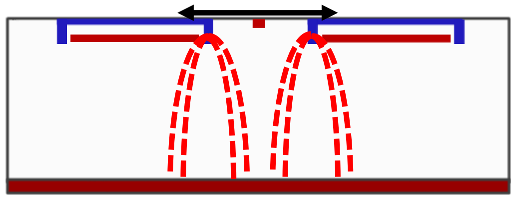


There are now hundreds of measurements on 45-55 µm-thick UFSDs

➔ Current sensor choice for the ATLAS and CMS timing layers

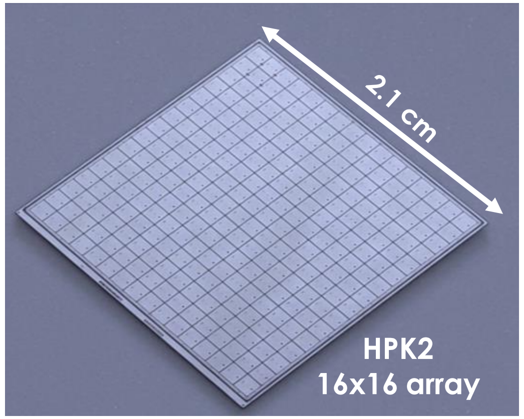
UFSD: State-of-the art

No gain area ~ 50 um

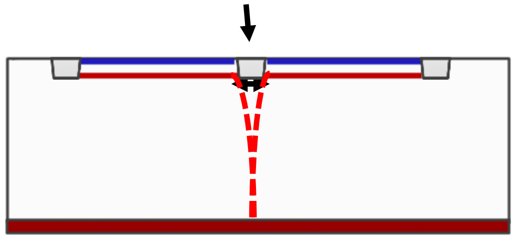


JTE + p-stop design

- CMS && ATLAS choice
- Not 100% fill factor
- Hit contained in a single pixel
- Very well tested
- High Occupancy OK
- Rate ~ 50-100 MHz
- Rad hardness ~ 2-3E15 n/cm2

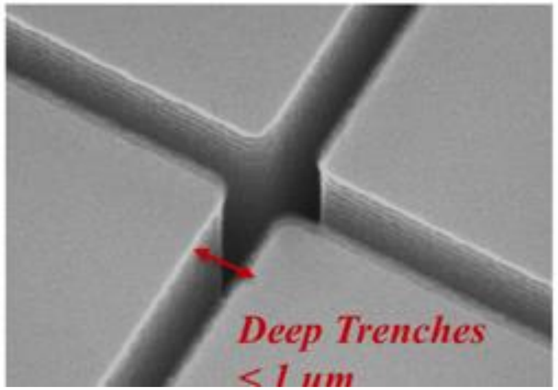


No gain area ~ 5 um



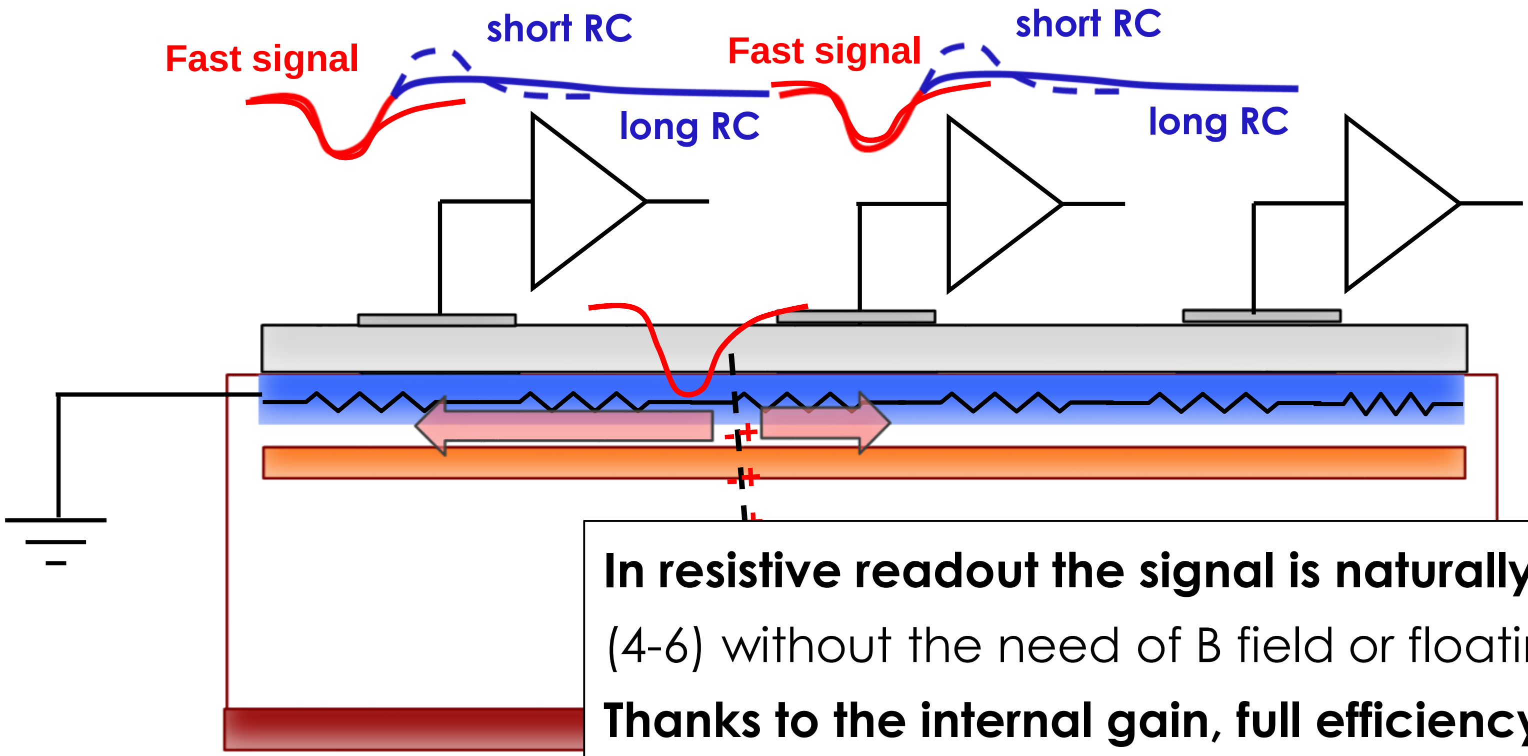
Trench-isolated design

- Almost 100% fill factor
- Hit contained in a single pixel
- Temporal resolution (50 μm) : 35-40 ps
- High Occupancy OK
- Rate ~ 50-100 MHz
- Rad hardness: ~ 1E15 n/cm2



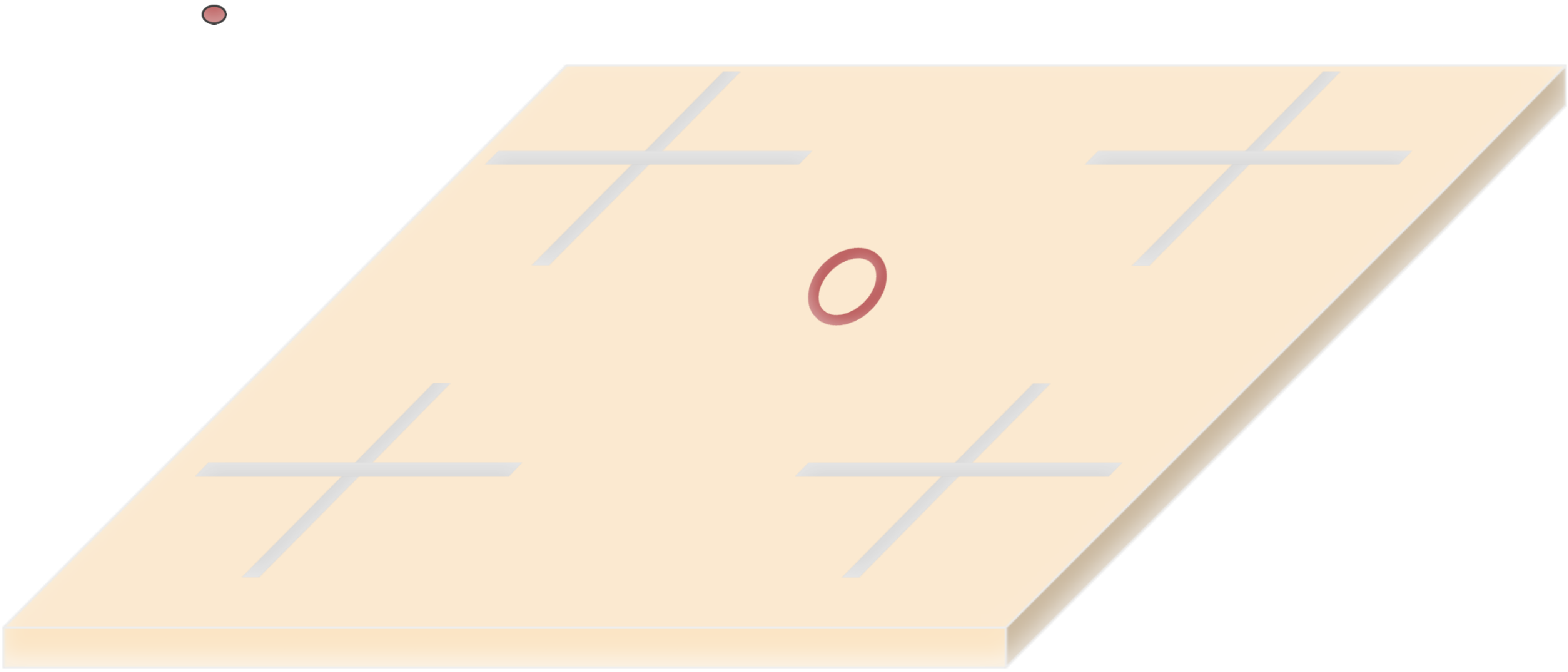
Second design innovation: resistive read-out

- **The signal is formed on the n+ electrode ==> no signal on the AC pads**
- **The AC pads offer the smallest impedance to ground for the fast signal**
- **The signal discharges to ground**

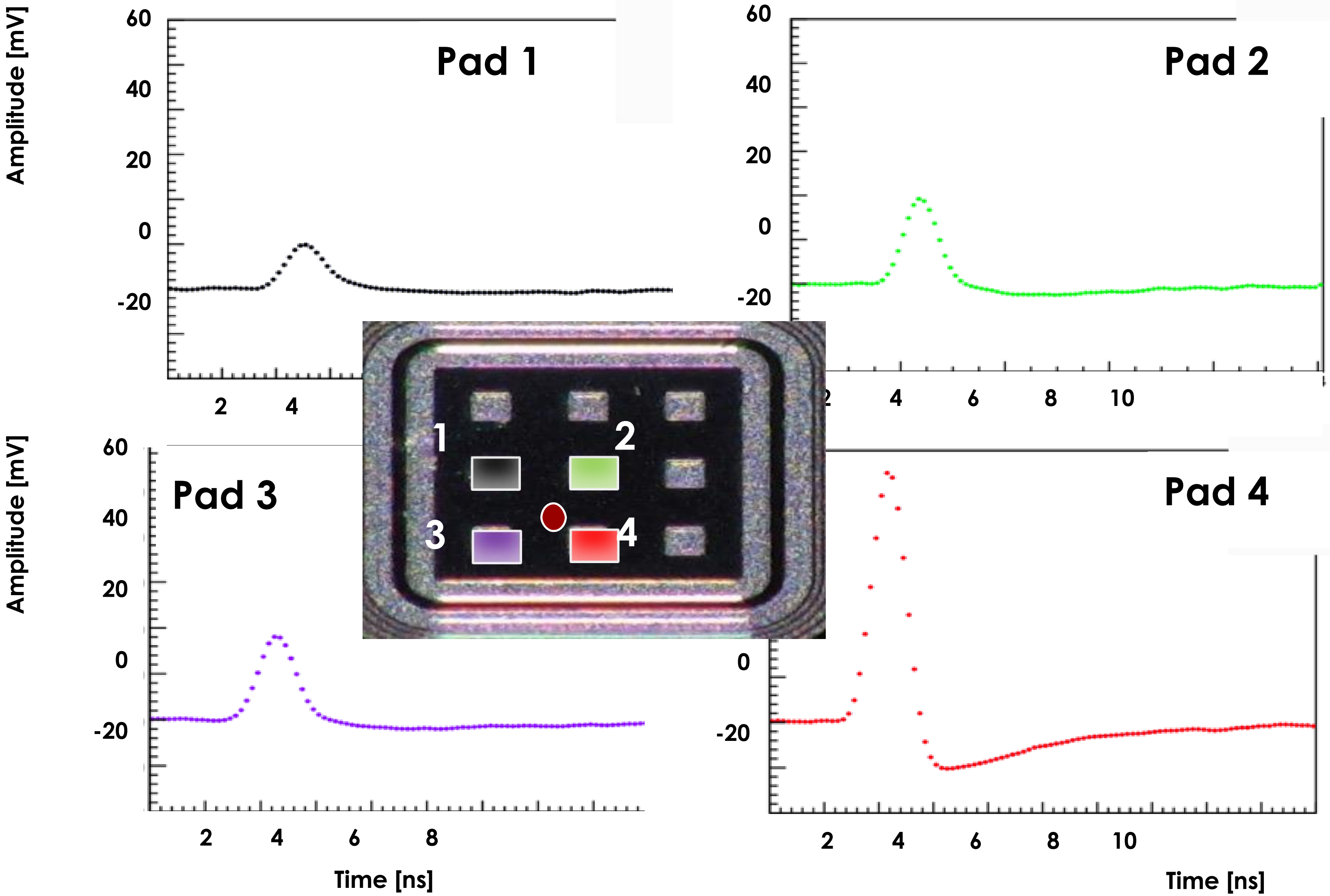


In resistive readout the signal is naturally shared among pads
(4-6) without the need of B field or floating pads
Thanks to the internal gain, full efficiency even with sharing
Results presented here are from the FBK RSD2 production

RSD principle of operation in motion



Example of signal sharing



50-mm thick RSD, Gain ~ 20

The laser is shot at the position of the red dot: the signal is seen in 4 pads

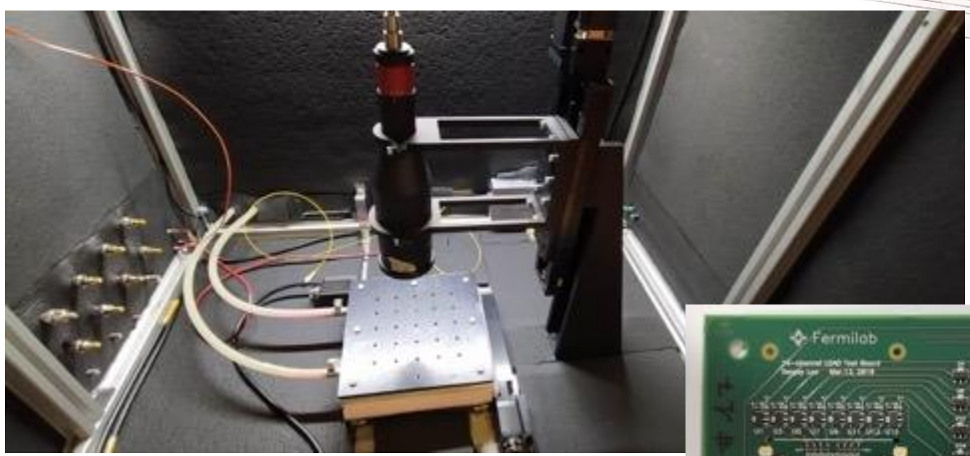
Experimental set-up

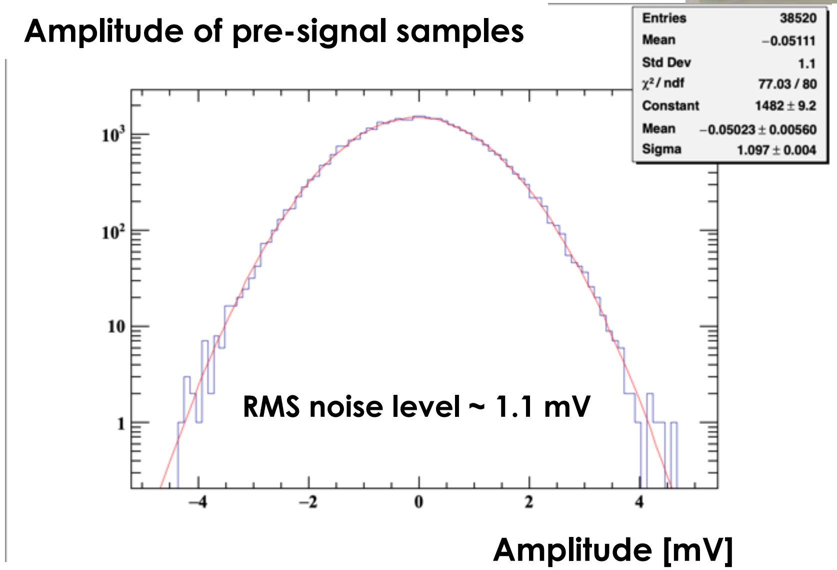
The **Particulars TCT laser setup** has been used:

- IR laser generates a signal in the RSD,
- simulating the passage of a MIP
- laser spot size ~ 8 μm
- Laser temporal precision: ~ 8 ps
- movable x-y stage provides reference positions of the laser shots, precision: σ_{Laser}~ 2 μm

Sensors are read out with 16-ch fast analogue board, developed at FNAL

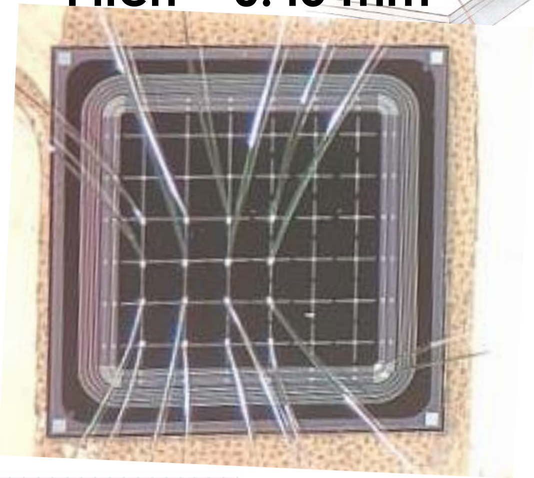
The signals are recorded with16-ch CAEN Digitizer (5 Gs)





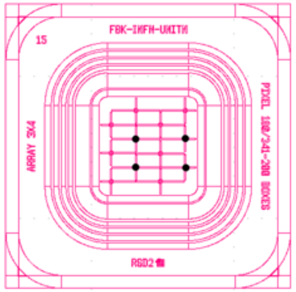
RSD2 structures used in this analysis (FBK - RSD2 production)

Pitch = 0.45 mm

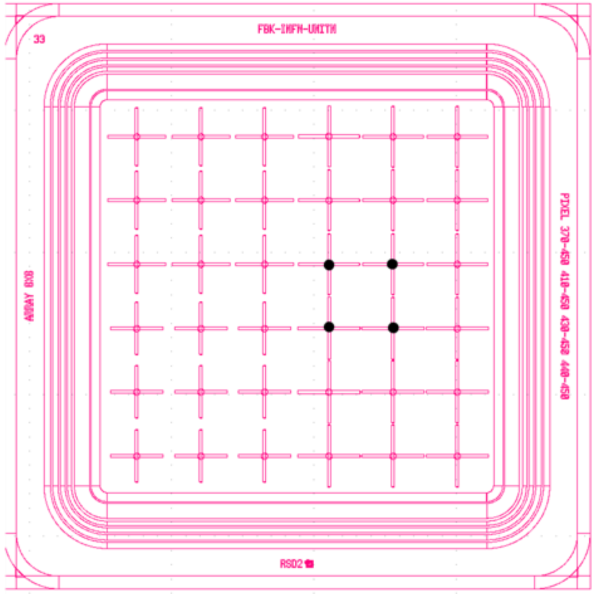


In this study, the perfomance of sensors with electrodes shaped as crosses is presented.

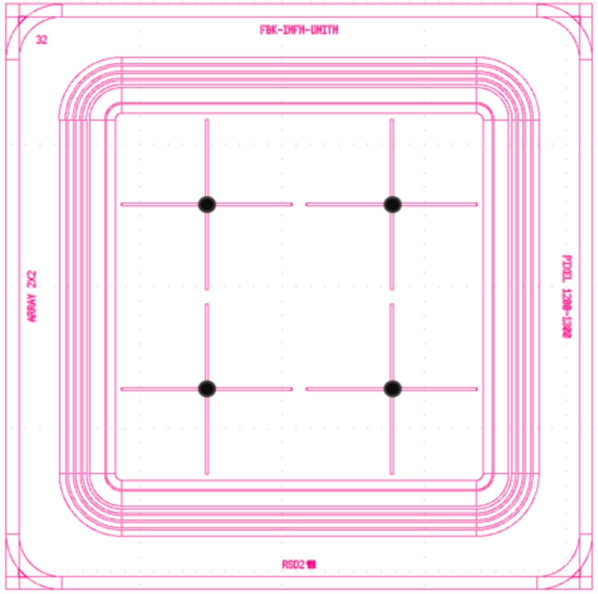
4 different dimensions: 200, 340, 450, and 1300 μm



(A)
200 x 340 μm²



(B)
Pitch = 450 μm



(C)
Pitch = 1300 μm

RSD position resolution (FBK RSD2 production)

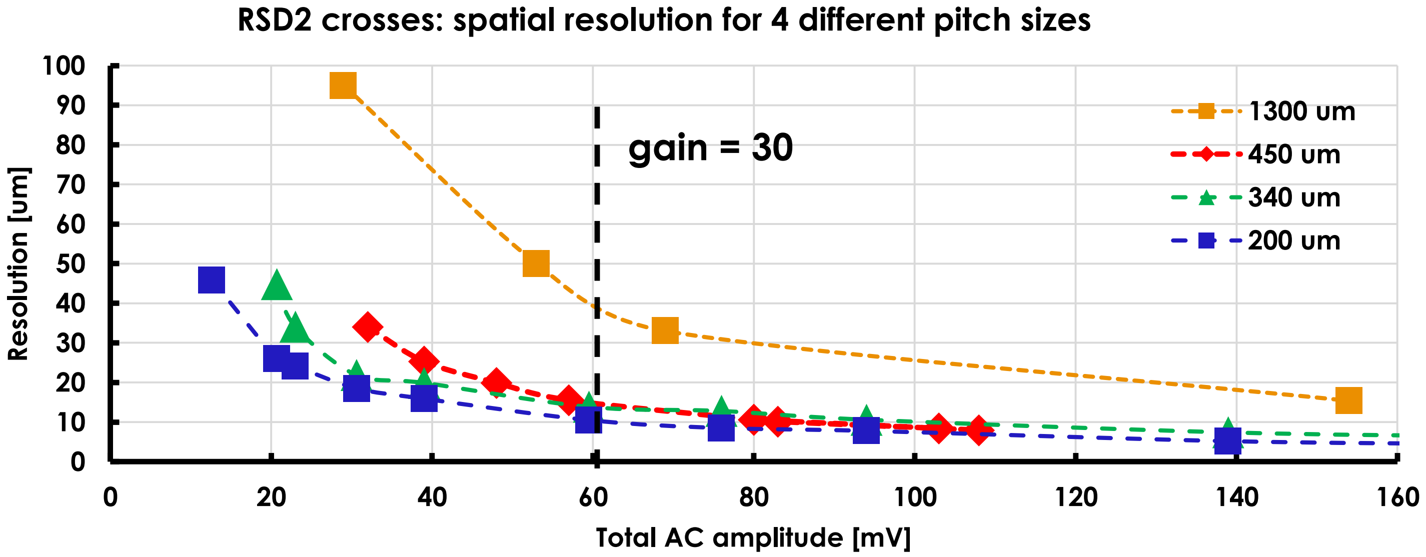
RSDs at gain = 30 achieve a spatial resolution of about 2-3% of the pitch size:

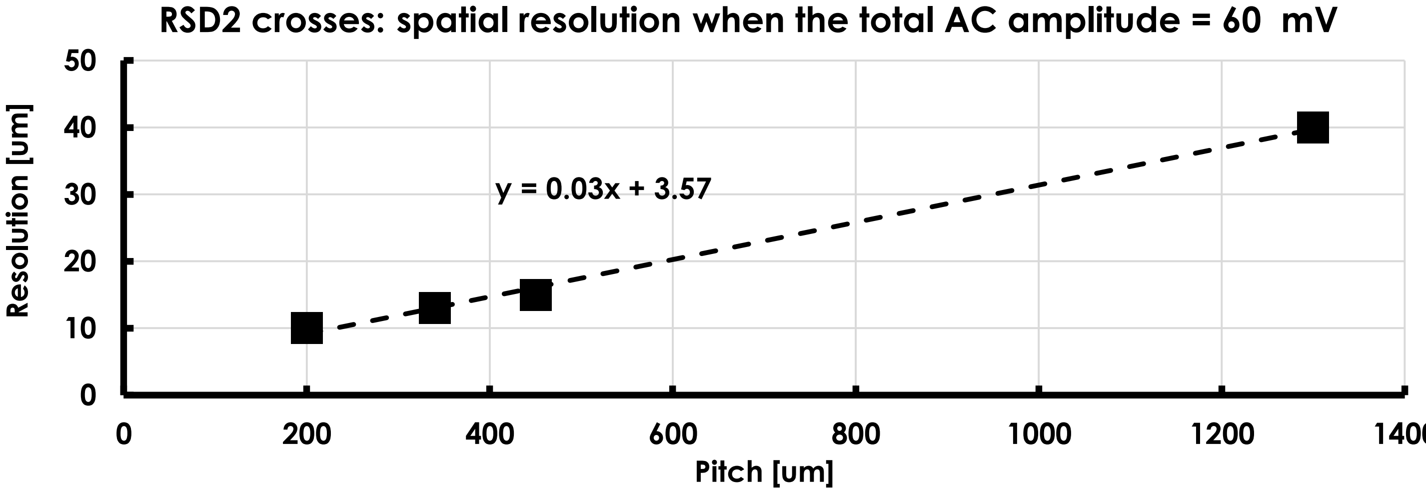
RSD:

- **1300 x 1300 mm^2: $\sigma_x \sim 30$ μm**
- **450 x 450 mm^2: $\sigma_x \sim 5$ μm**

Compared to a standard pixel

- **1300 x 1300 mm^2: $\sigma_x \sim 920$ μm**
- **450 x 450 mm^2: $\sigma_x \sim 320$ μm**

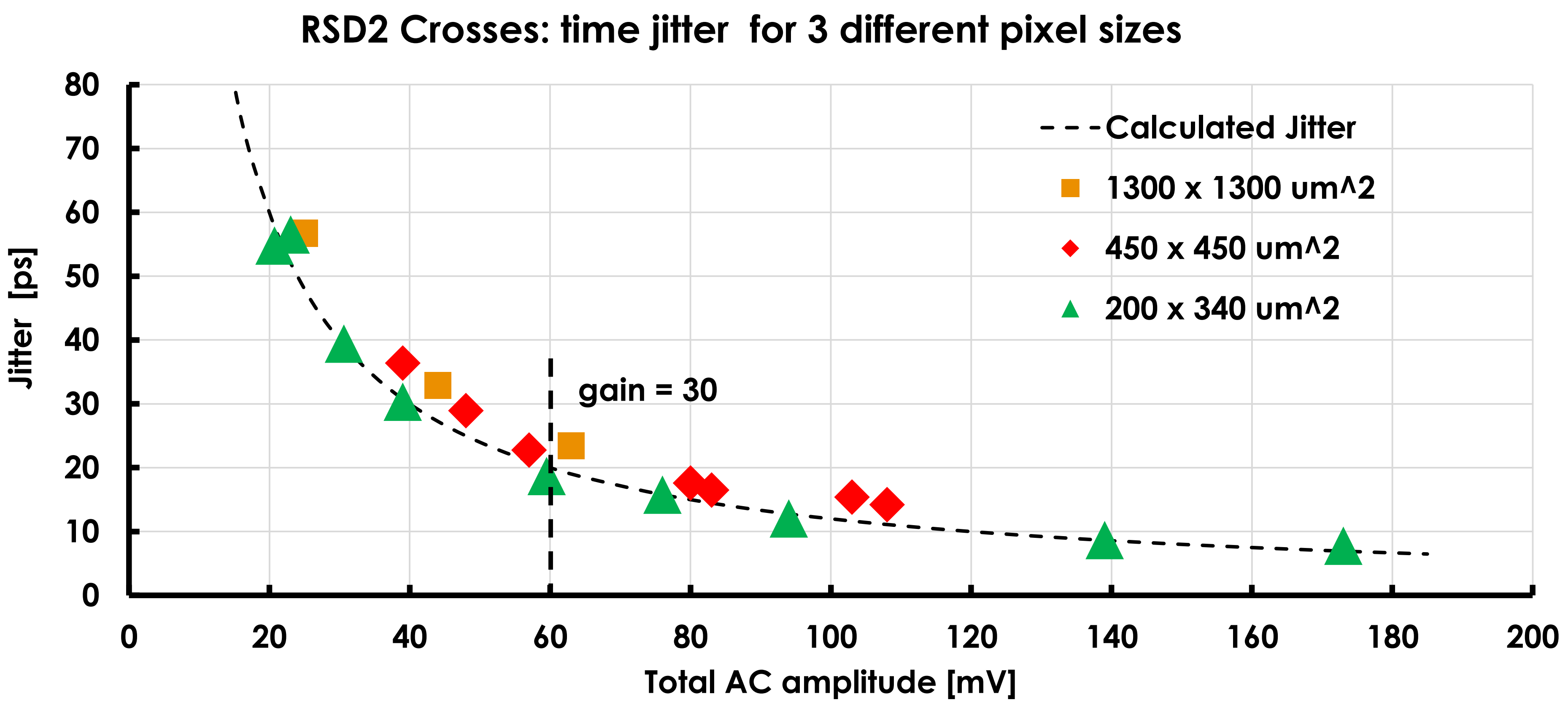




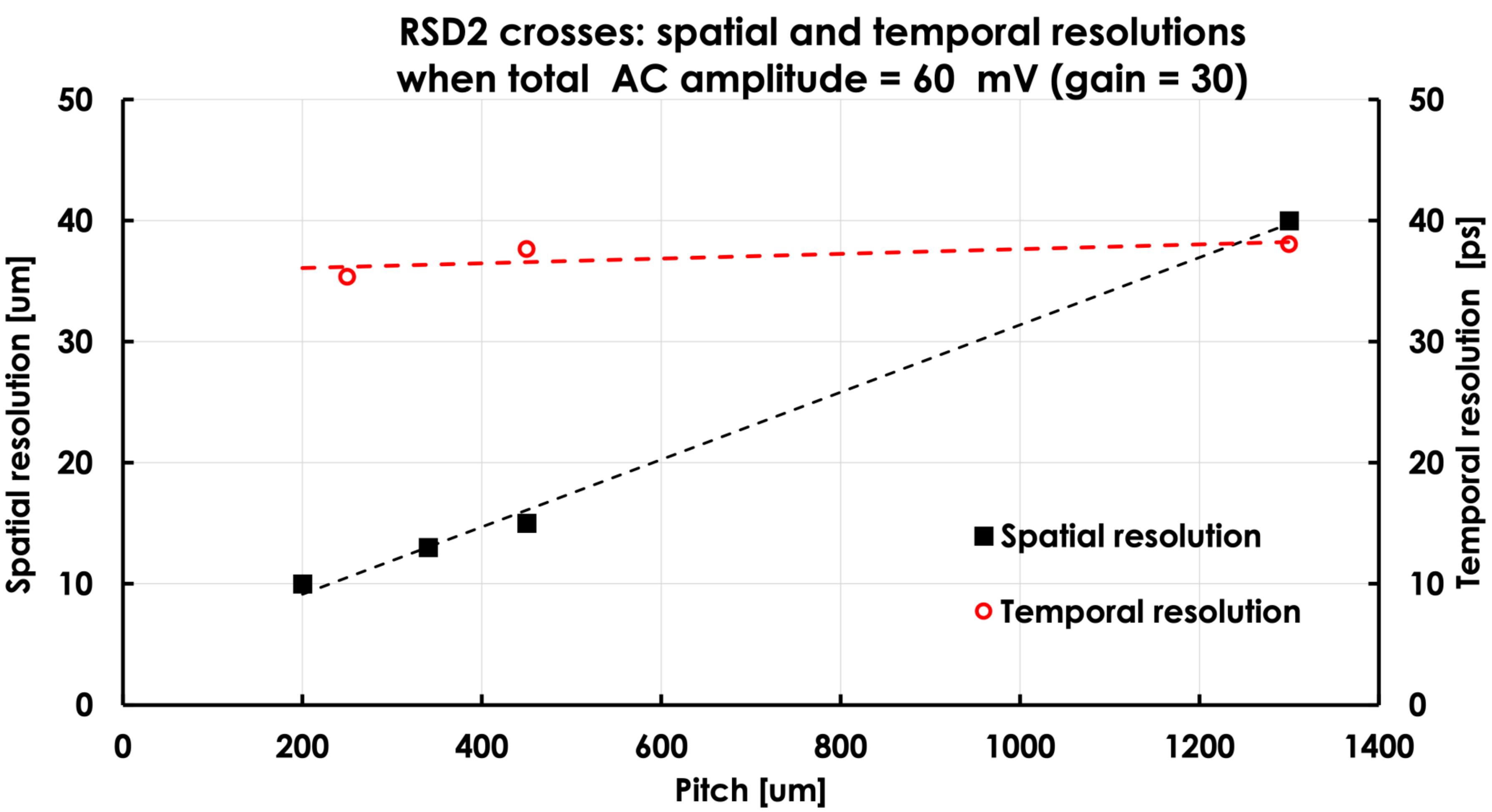
RSD temporal resolution (FBK RSD2 production)

The resolution depends mostly upon the signal size and **weakly on the pixel size**

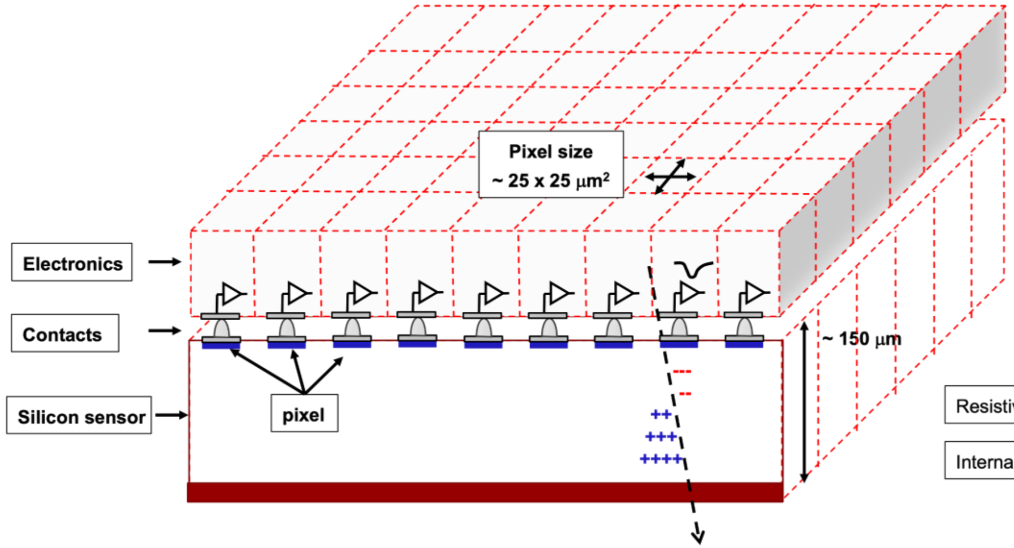
RSDs at gain = 30 achieve a temporal jitter of about 20 ps



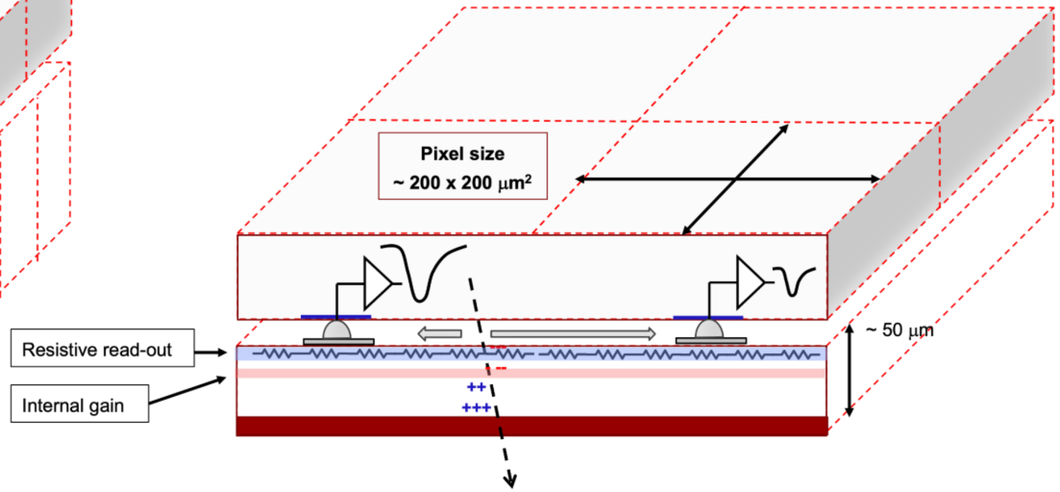
RSD2 performance summary



Final goal of RSD R&D: a completely new 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/cm^2)
- The sensors can be really thin

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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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