Trends for a tracker of the next decades

(one or two?)

Run5, LHCb (and others)

- **Space resolution: O (10 μm)**
- **Radiation hardness: ≈ 10^{17} 1 MeV n_{eq}/cm^2 (sensors) and > 1 Grad (electronics)**
- **Time resolution: < 50 ps per pixel (also after irradiation), < 20 ps per track**
- **Real time track reconstruction algorithms and fast read-out (detector data throughput > 10 TB/s)**

→ Pixel size marginally reduce

→ High time resolution per pixel

→ Huge data throughput

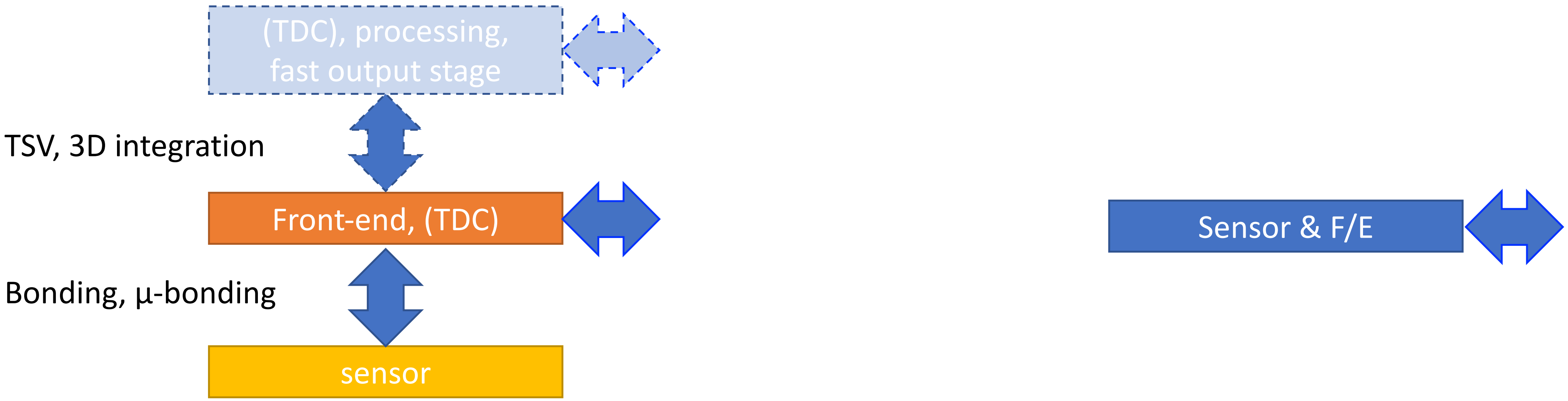
→ Higher event complexity → event pre-processing?

High density of functionalities (intelligence on detector), keep power consumption per pixel to a minimum (1.5-2W/cm^2), high system integration

→ System approach: the tracker as a whole

TimeSPOT (TIME and SPace real-time Operating Tracker) **conceived to address the requirements above.**

Two *tracking religions*: Hybrid vs Monolithic



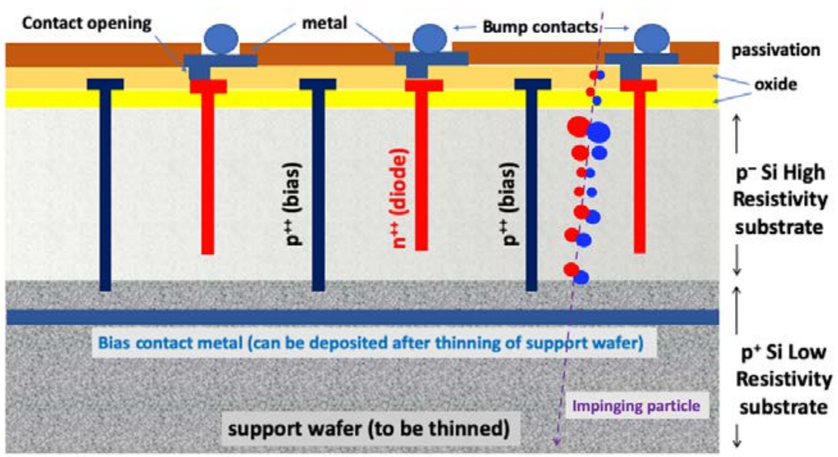
Benchmarks

Time resolution	High (<30 ps)
Space resolution	High (10 µm)
Power Consump.	High to moderate (<2 W/cm^2)
Material budget	Moderate (<0.5% X_0 , NA62 GTK)
Rad hardness	High (>10^{16} n_{eq}/cm^2, ATLAS 3D sensors)
Integration of funct.	Conceptually Maximum
Cost	High
Strength	Can maximize technology performance at each stage

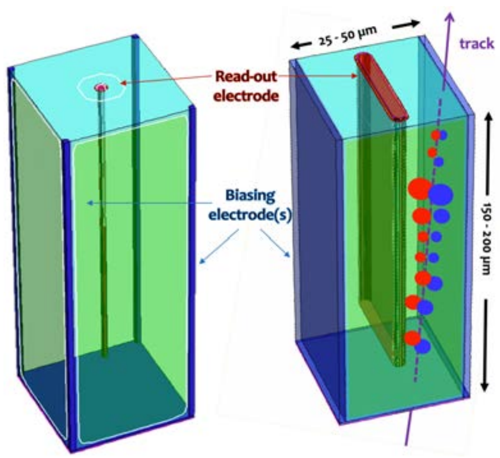
Time resolution	Poor (ns, but R&D ongoing, FastPix)
Space resolution	High (<10 µm)
Power Consump.	Moderate
Material budget	Conceptually Minimum
Rad hardness	Moderate (≈10^{15} n_{eq}/cm^2)
Integration of funct.	Modest
Cost	Moderate
Strength(s)	Conceptually elegant, can be accessible on large industrial scale

3D (MEMS) sensors

TimeSPOT
TIME and SPace real-time Operating Tracker

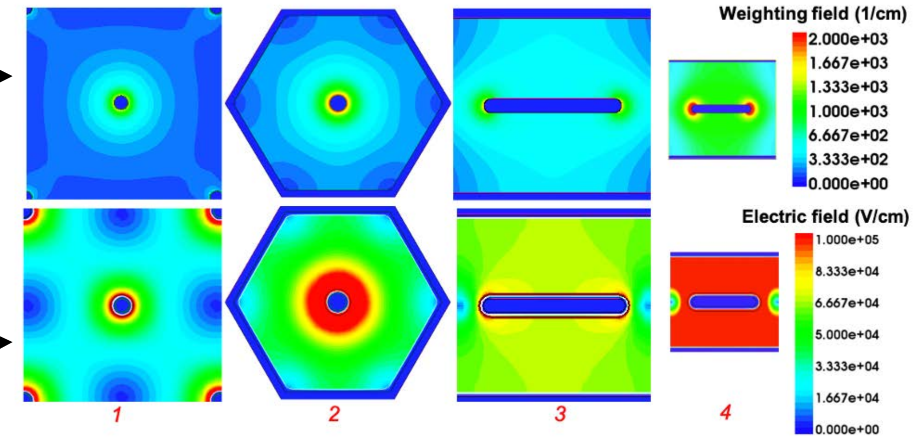


columns



trenches

$$i = qE_w \cdot v$$

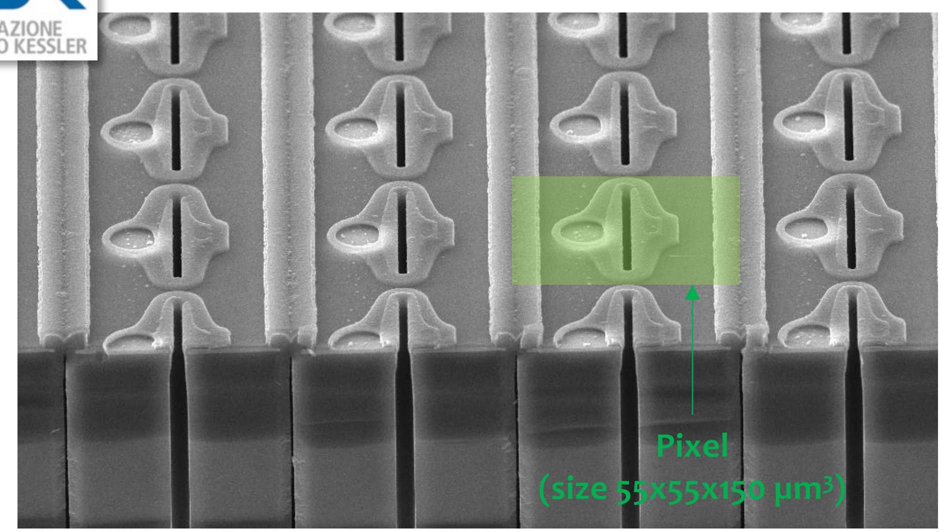


TCAD simulations. Vbias = – 150 V

1. Space resolution ≈ 10 µm.
2. Time resolution ≈ 20 ps at room temperature (not irradiated), dominated by F/E.
3. Radiation hardness ≈ 10^{17} n_{eq}/cm^2 (Columns).

Already demonstrated by experimental tests

FONDAZIONE BRUNO KESSLER



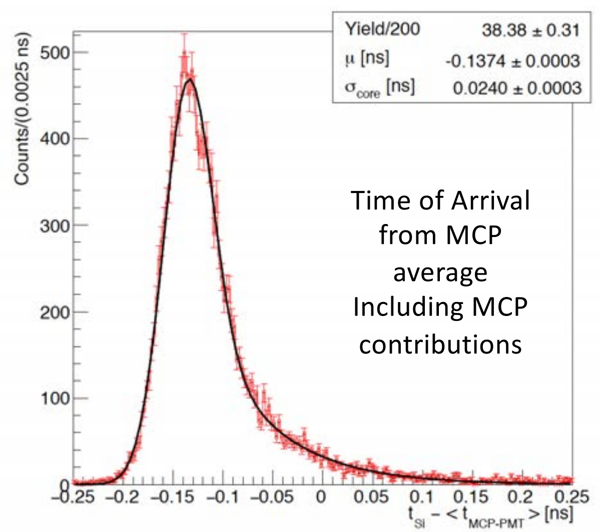
trench electrodes:
SEM image from TimeSPOT production batch#2 (Dec 2020)

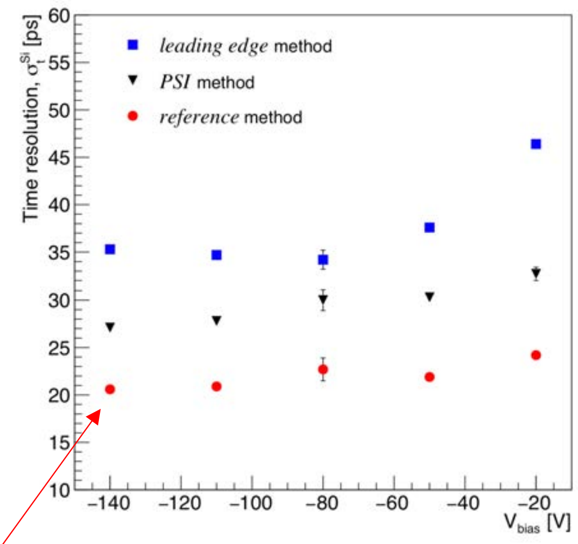
Results on 3D-trench pixels

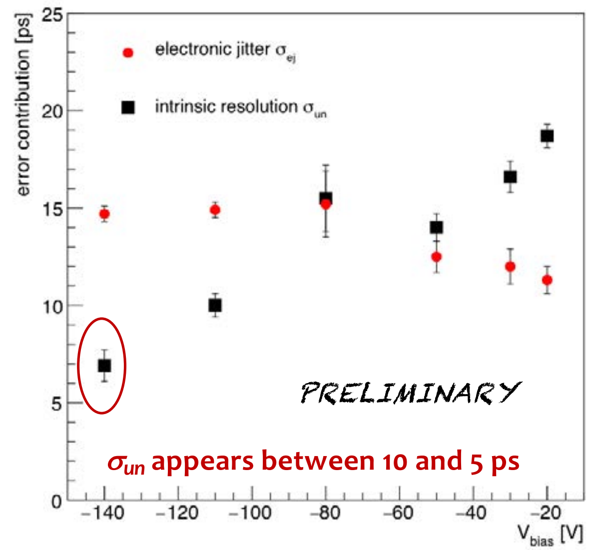
Time resolution of 3D-trench silicon pixels with MIPs (test-beam & lab) at room temperature

(**ref.** *Intrinsic time resolution of 3D-trench silicon pixels for charged particle detection*, 2020 JINST 15 P09029)

PSI πM1, π^+ beam, 270 MeV/c



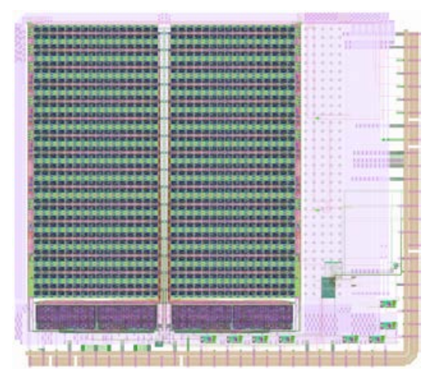




$\sigma_t \approx 20$ ps

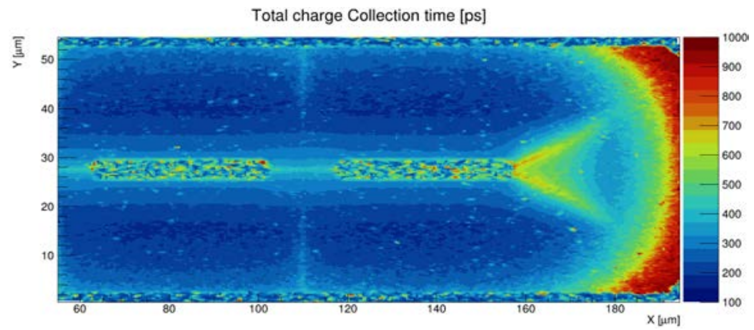
(after correction for MCP contribution)
confirmed in corresponding laboratory measurements
(with ^{90}Sr source)

The front-end electronics stage is crucial
Measurements made using Si-Ge discrete components
A 28-nm CMOS ASIC already developed and ready for tests



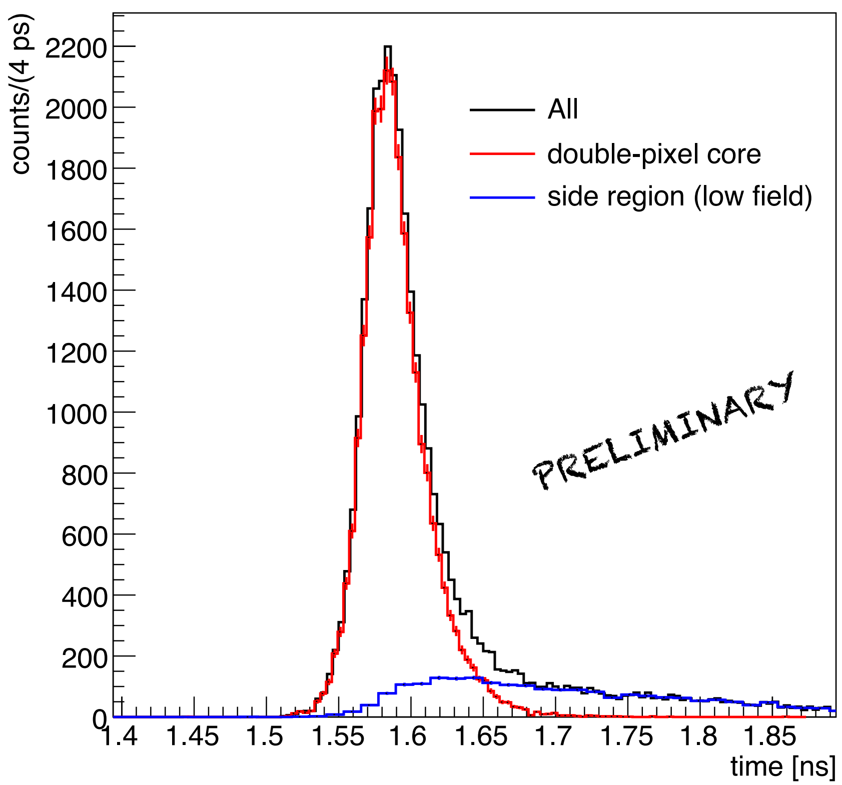
Insight: Tails in the ToA distribution

A consequence of 3D sensitivity to geometry



35k 270 MeV/c π^+ deposits

Simulation



After F/E convolution

Double pixel vs marginal area (≈ 21% of total area)

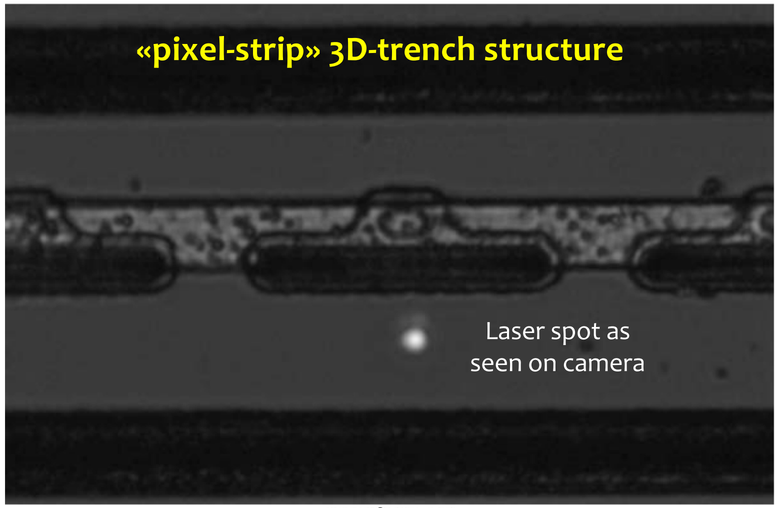
	Vbias [V]	σ_{core} [ps]	RMS [ps]	FWHM [ps]
Double pixel + marginal area		19.9±0.2	65.1±0.2	36
Double pixel	−50	18.8±0.2	27.0±0.1	36
Marginal area only			151±1	216
Double pixel + marginal area		17.8±0.2	61.4±0.2	36
Double pixel	−100	16.9±0.1	23.9±0.1	36
Marginal area only			103±1	180
Double pixel + marginal area		17.1±0.2	57.5±0.2	36
Double pixel	−150	16.7±0.1*	22.9±0.1	36
Marginal area only			87.3±0.7	156

***to be compared with experimental $\sigma_{t,core}$ = (18±0.2) ps**

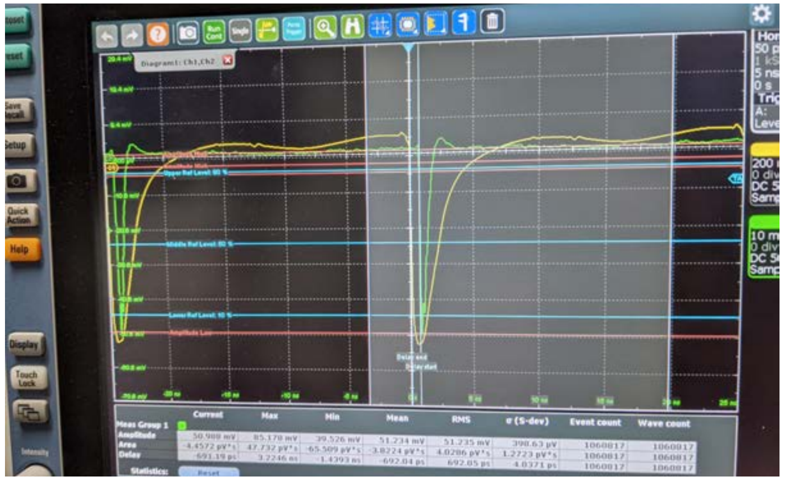
Tails
are not intrinsic but strictly depend on the particular geometry tested at the PSI test-beam

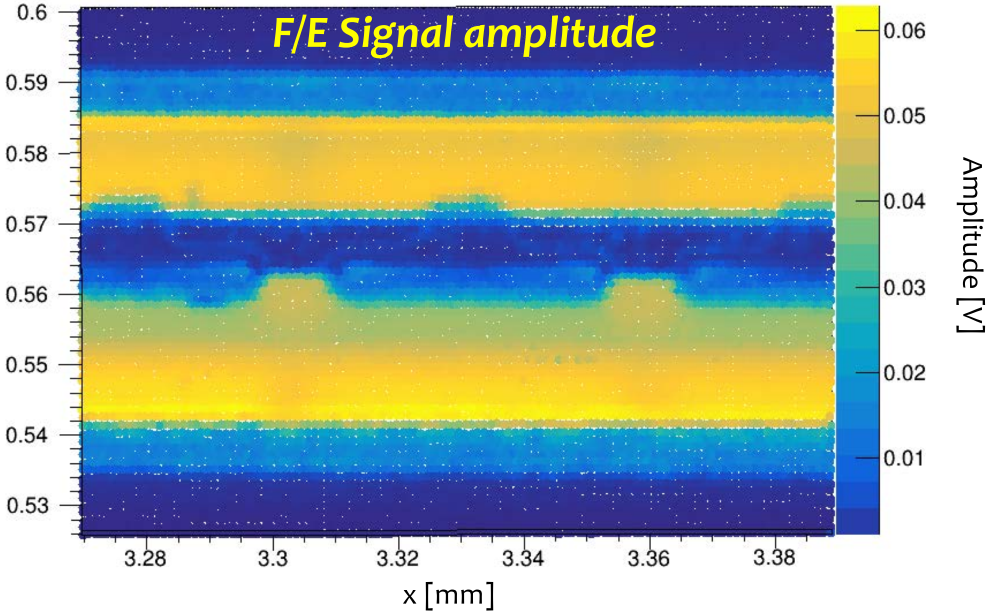
Laser pixel scan

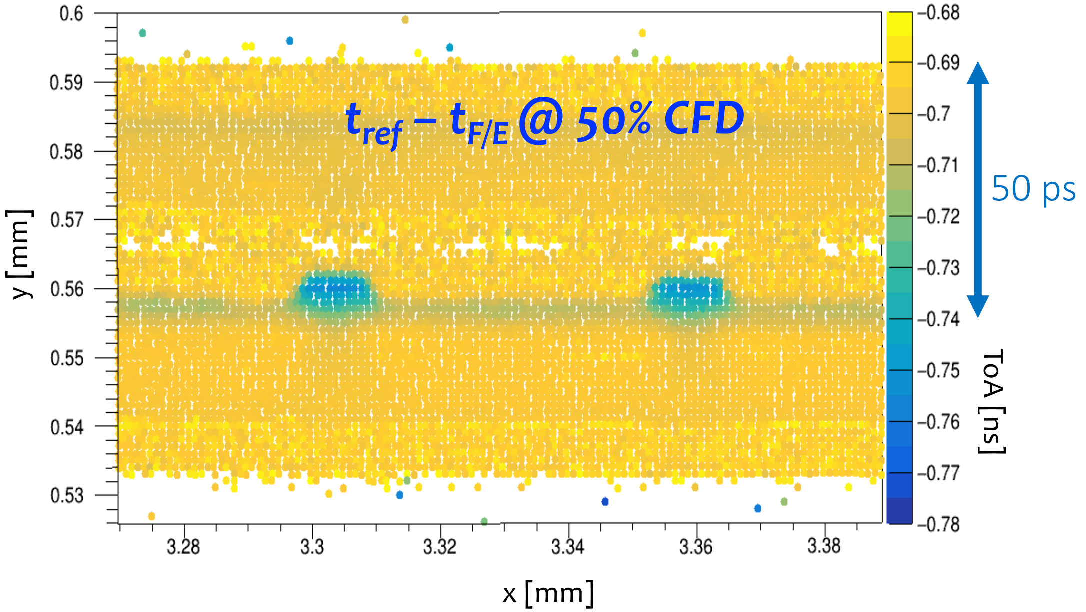
A measurement of the intrinsic sensor response



- Average of 500 waveforms for each position to remove the electronic noise and then perform the signal **amplitude** and **Time of Arrival** measurements
- Scan step 1 µm
- Sensor bias **100 V**

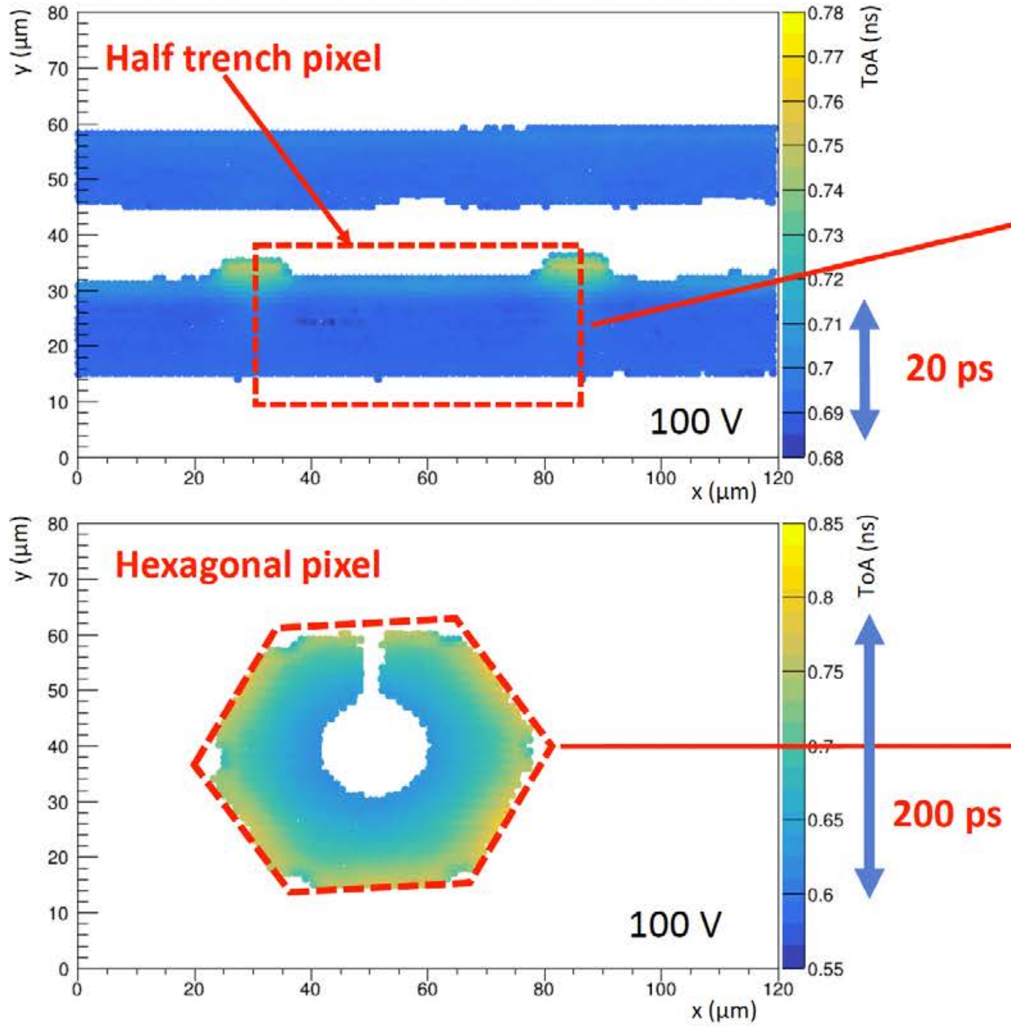




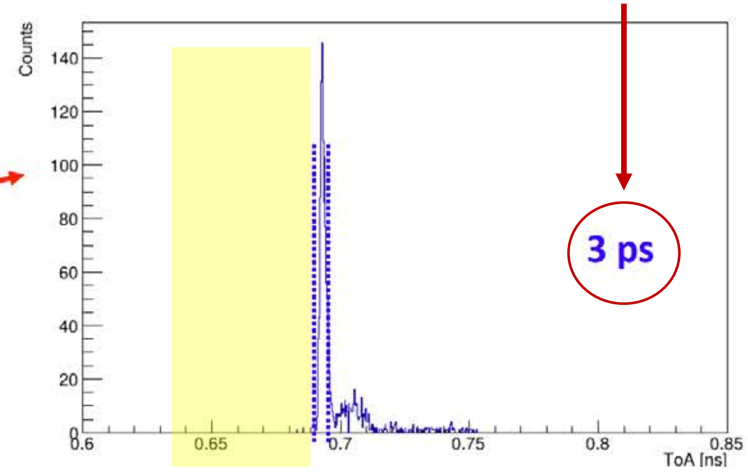


Geometry comparison: 3D-trench vs 3D-hexagonal

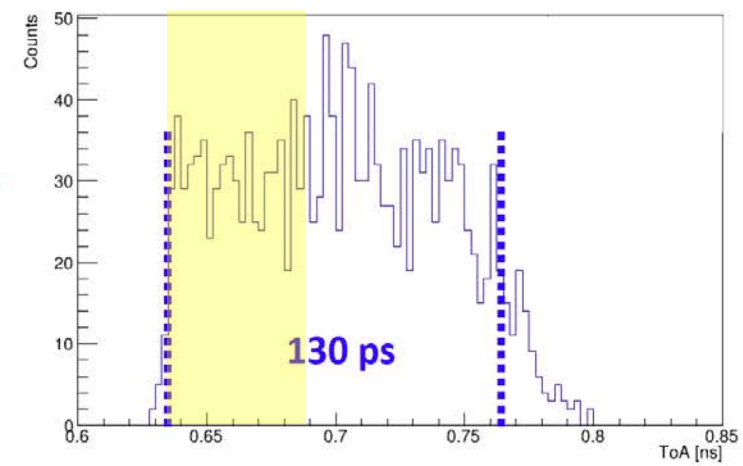
and extreme intrinsic speed of 3D-trench



A first experimental look at σ_{un}



Signals arrive later but almost alla synchronous
→ much better time resolution



Alcune considerazioni su costi di R&D e di produzione
Sensori ed elettronica

- La comunità HEP può avere scarso impatto sul mercato mondiale della sensoristica e della μ-elettronica
- I costi di sviluppo e produzione crescono enormemente a causa della scala relativamente piccola della nostra comunità
- Andare all'R&D sulla grande scala (necessario per l'equipaggiamento degli apparati) richiede vari passi di Engineering Run su grande area e ad alto costo (1 M€/run)

→ Per quanto riguarda la μ-elettronica massimizzare la massa critica (dentro l'INFN e oltre), con pochi sviluppi general purpose

→ Per quanto riguarda la sensoristica a stato solido: difficile decifrare il futuro. Riguardo al breve termine creare dei centri di sviluppo e produzione proprietari della HEP (@INFN?!?), stile FBK-CNM ma che funzionino (cfr. Stanford, BNL…)