



# Timing and tracking with LGAD detectors

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# Time of flight for particle identification

The IDEA drift chamber is expected to provide PID information based on  $dE/dx$  measurement

- For  $K-\pi$  separation, good performance in most of momentum spectrum, except for a region around 1 GeV/c

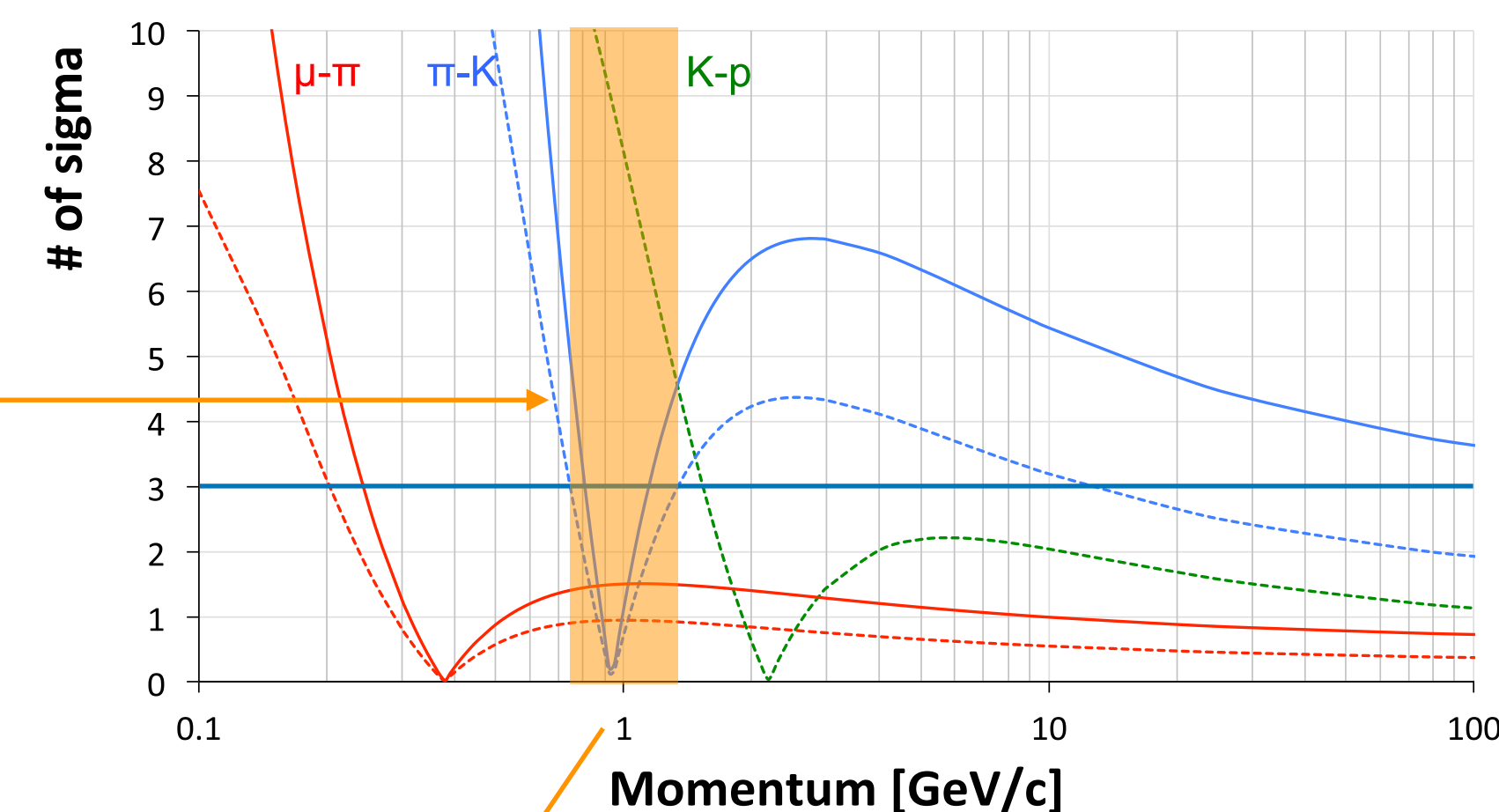
Complementary PID information could be granted by an external time-of-flight detector

- A resolution of few tens ps would allow good  $K-\pi$  separation in the “blind” region of  $dE/dx$

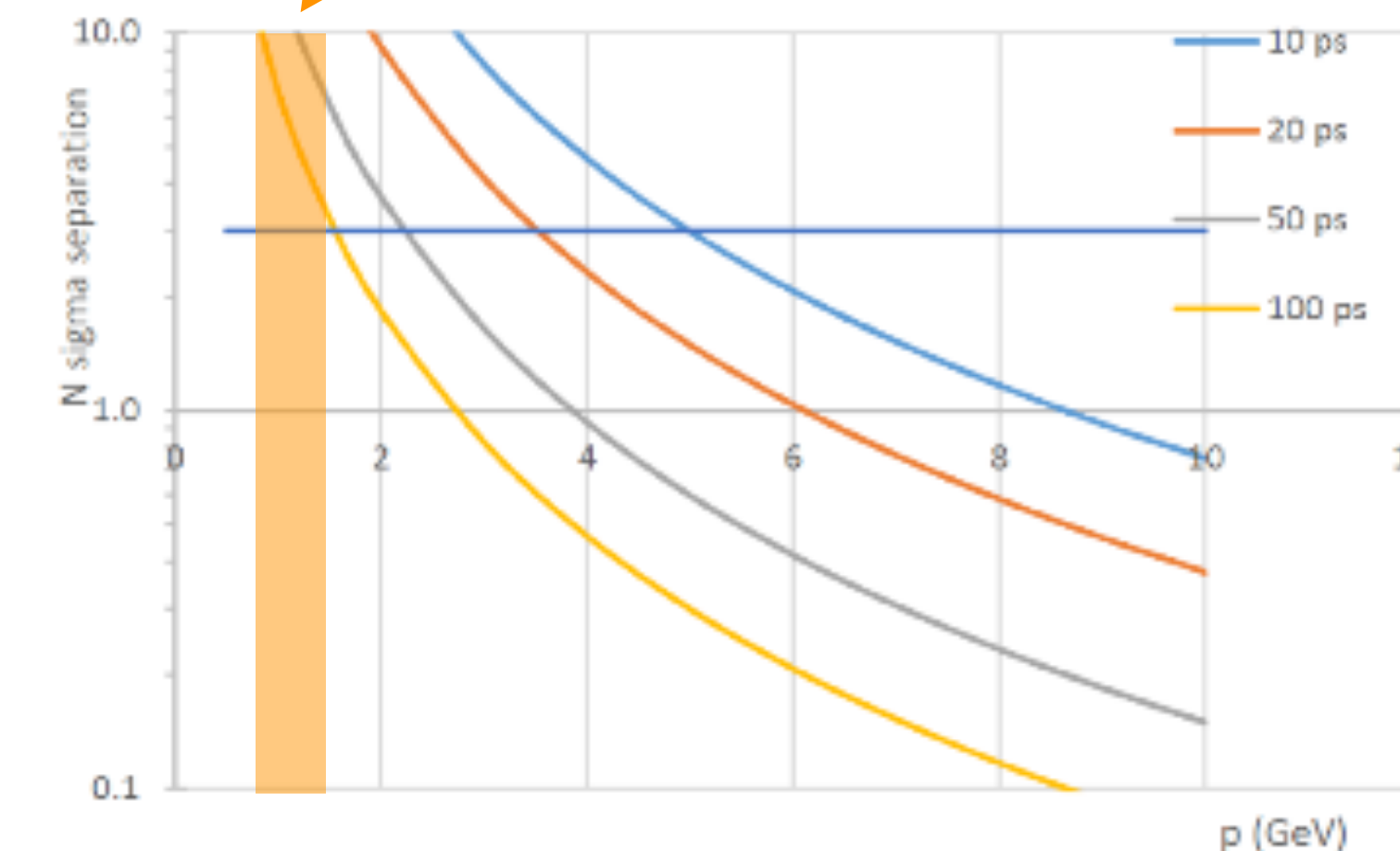
Timing information would also help relaxing requests on the vertex detector

- Larger integration time  $\Rightarrow$  less power  $\Rightarrow$  less material

Particle Separation ( $dE/dx$  vs  $dN/dx$ )

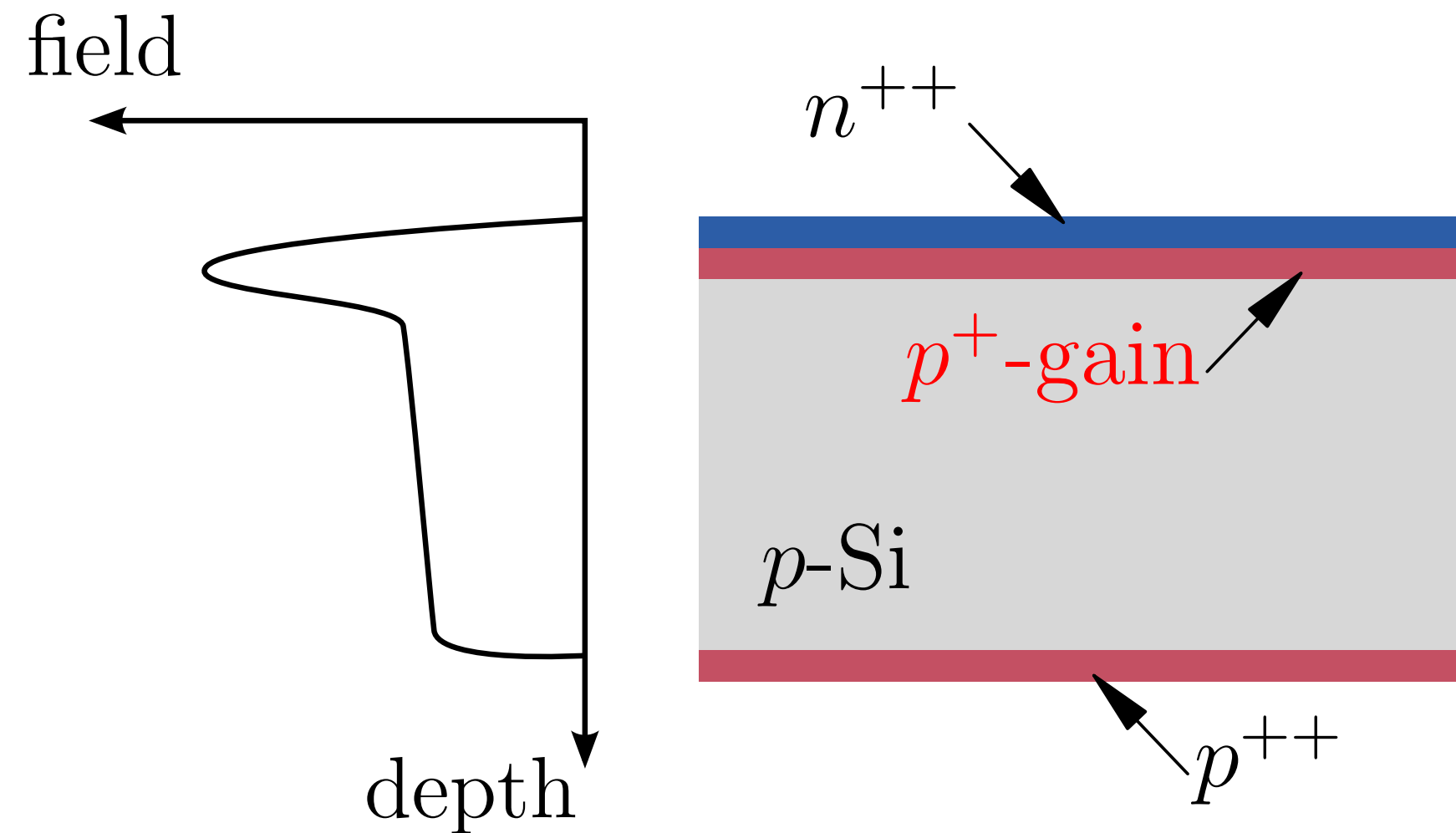


Momentum [GeV/c]





# Low Gain Avalanche Detectors

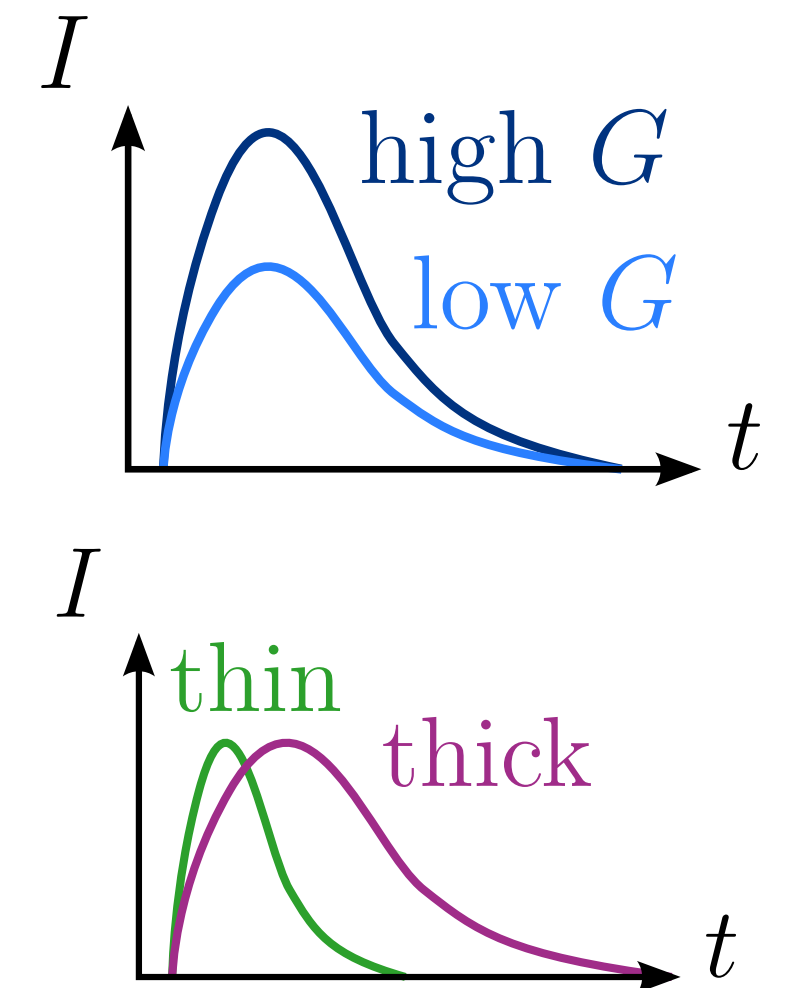


Low Gain Avalanche Detectors (LGAD) are reverse-bias, planar, silicon detectors, with an internal gain layer

- Usually  $n$ -in- $p$  structure, with implanted  $p^{+}$  layer
- High electric field ( $\sim 300$  kV/cm) in narrow region under the junction
- Moderate gain ( $\sim 10$ )  $\Rightarrow$  low noise, segmentation of readout pattern

The structure can be optimised for high precision timing (Ultra-Fast Silicon Detectors)

- higher gain, smaller thickness
- time resolution of  $\sim 30$  ps can be obtained

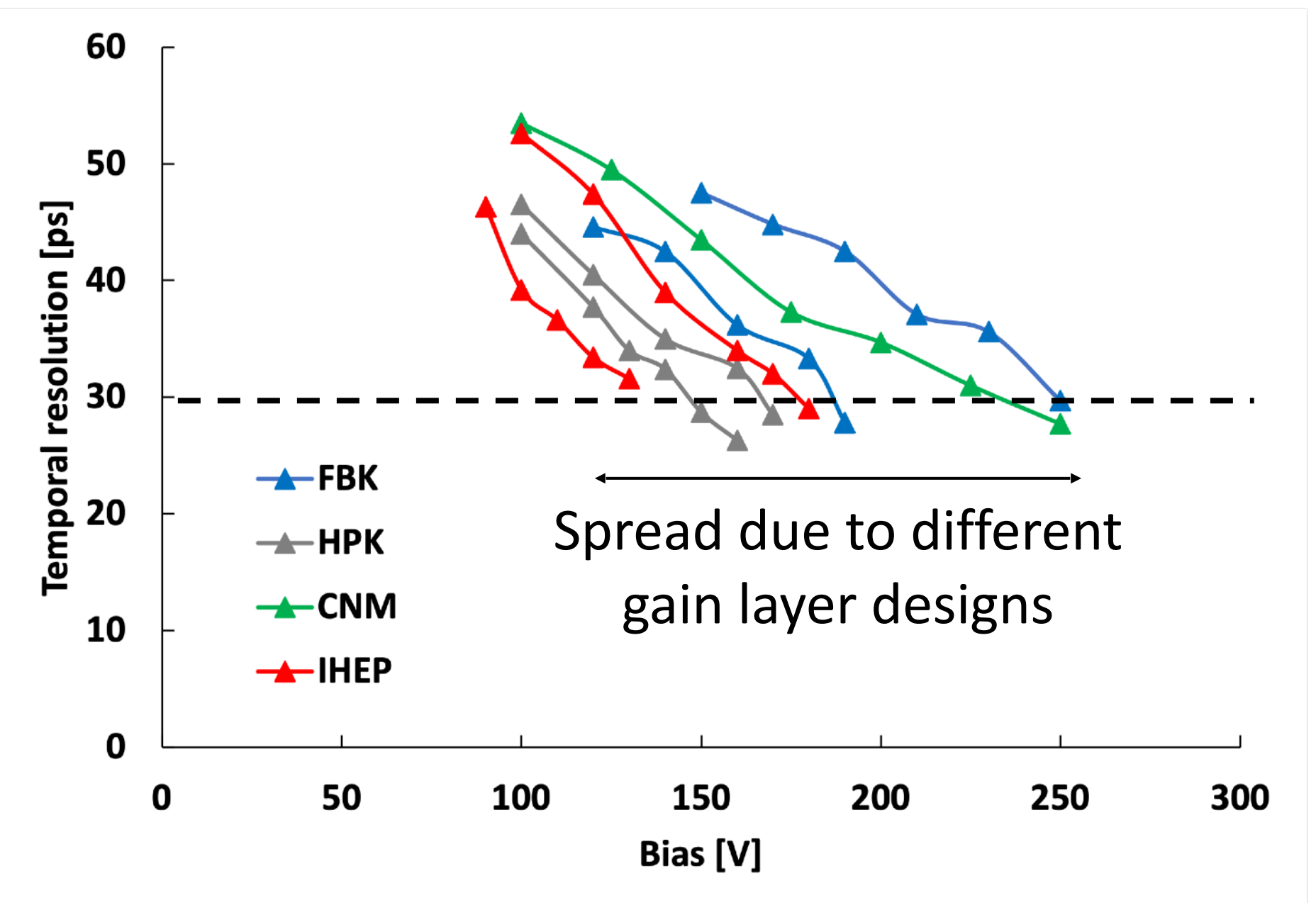
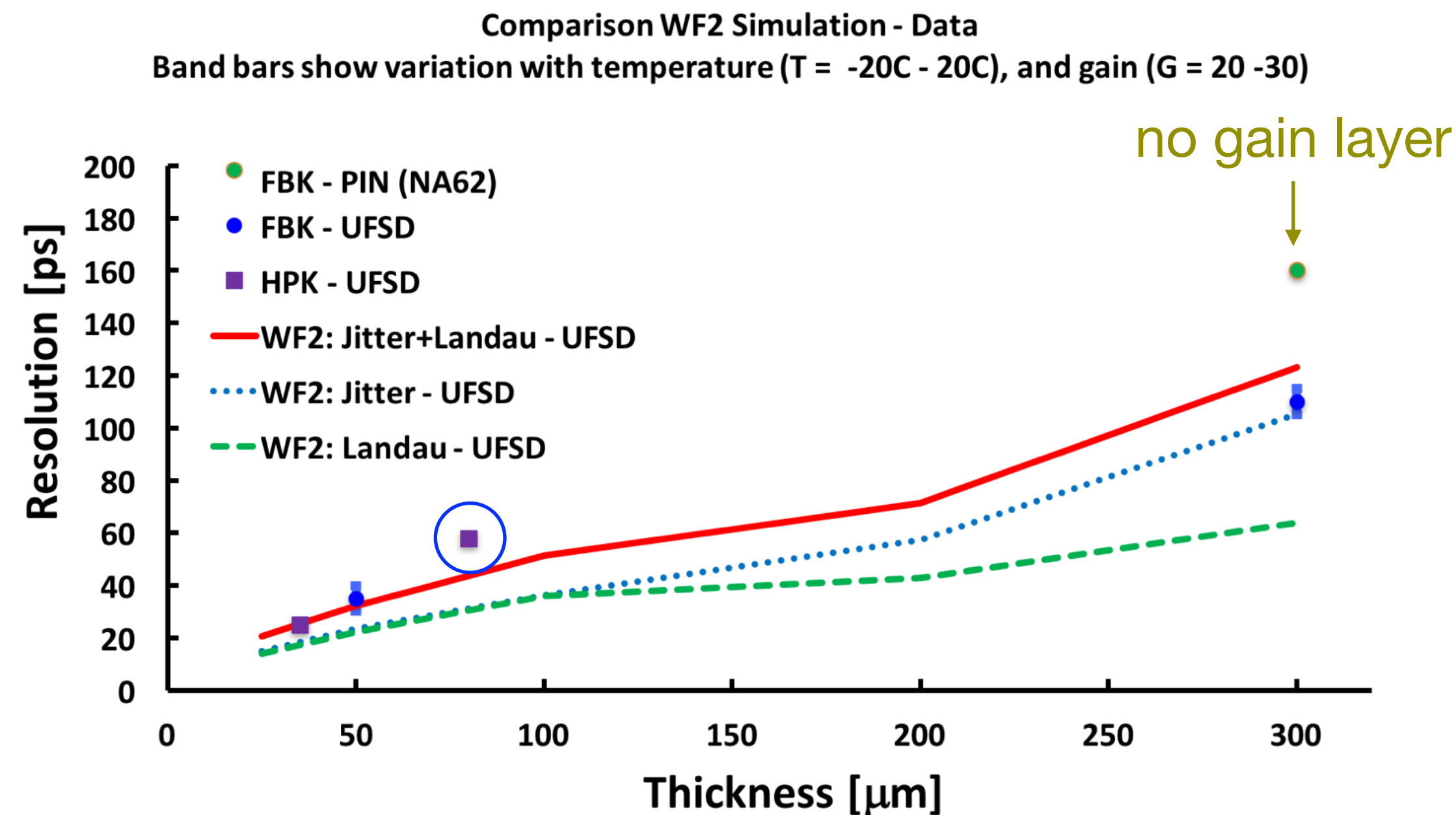




# Time resolution of LGAD

Extensive studies have explored sensor configurations:

- active thickness;
- gain layer doping, thickness, depth;
- pad isolation technology ( $p$ -stop,  $p$ -spray) and geometry;
- ...



Current productions mostly focusing on 50- $\mu$ -thick sensors

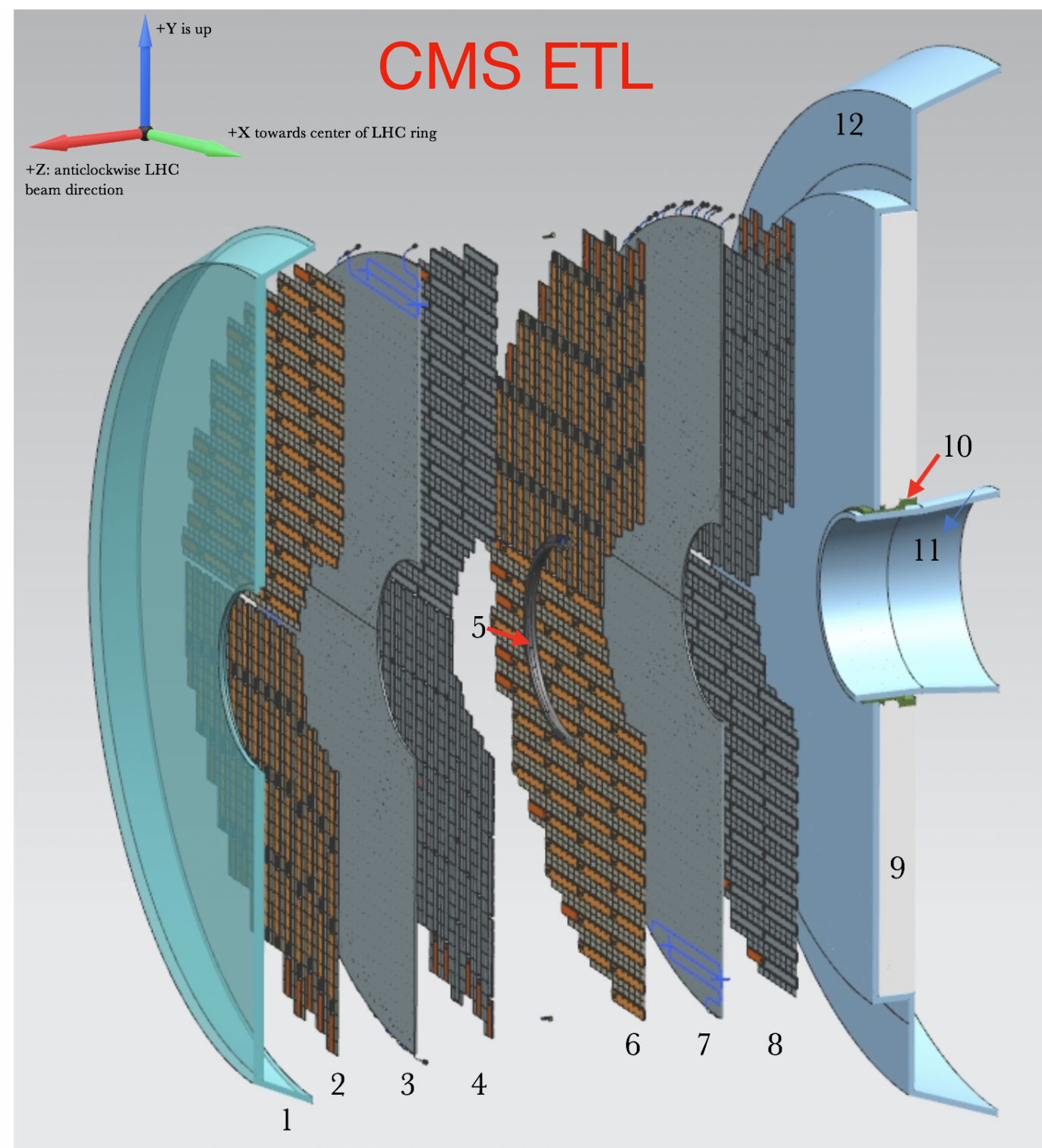
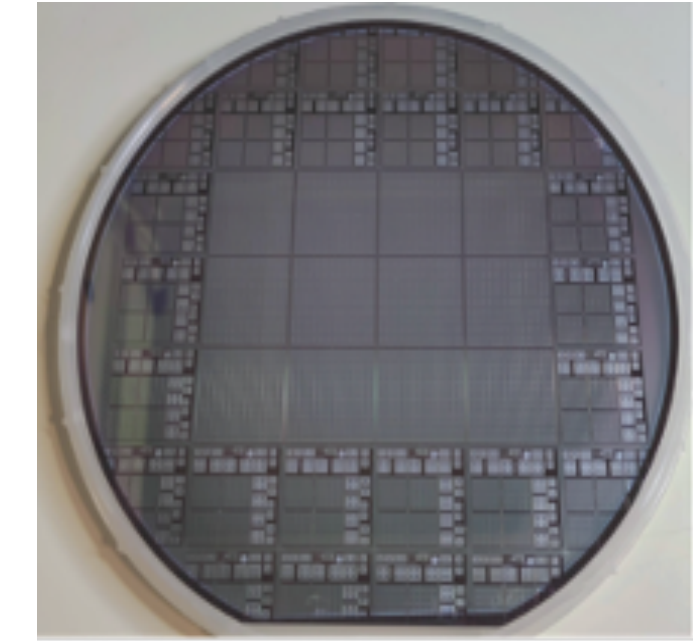
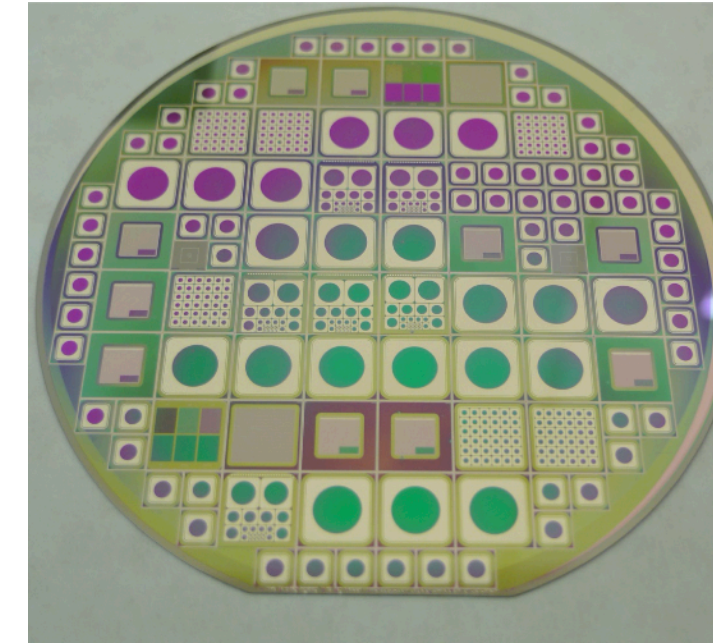




# LGAD in HEP experiments

LGAD is now a mature technology

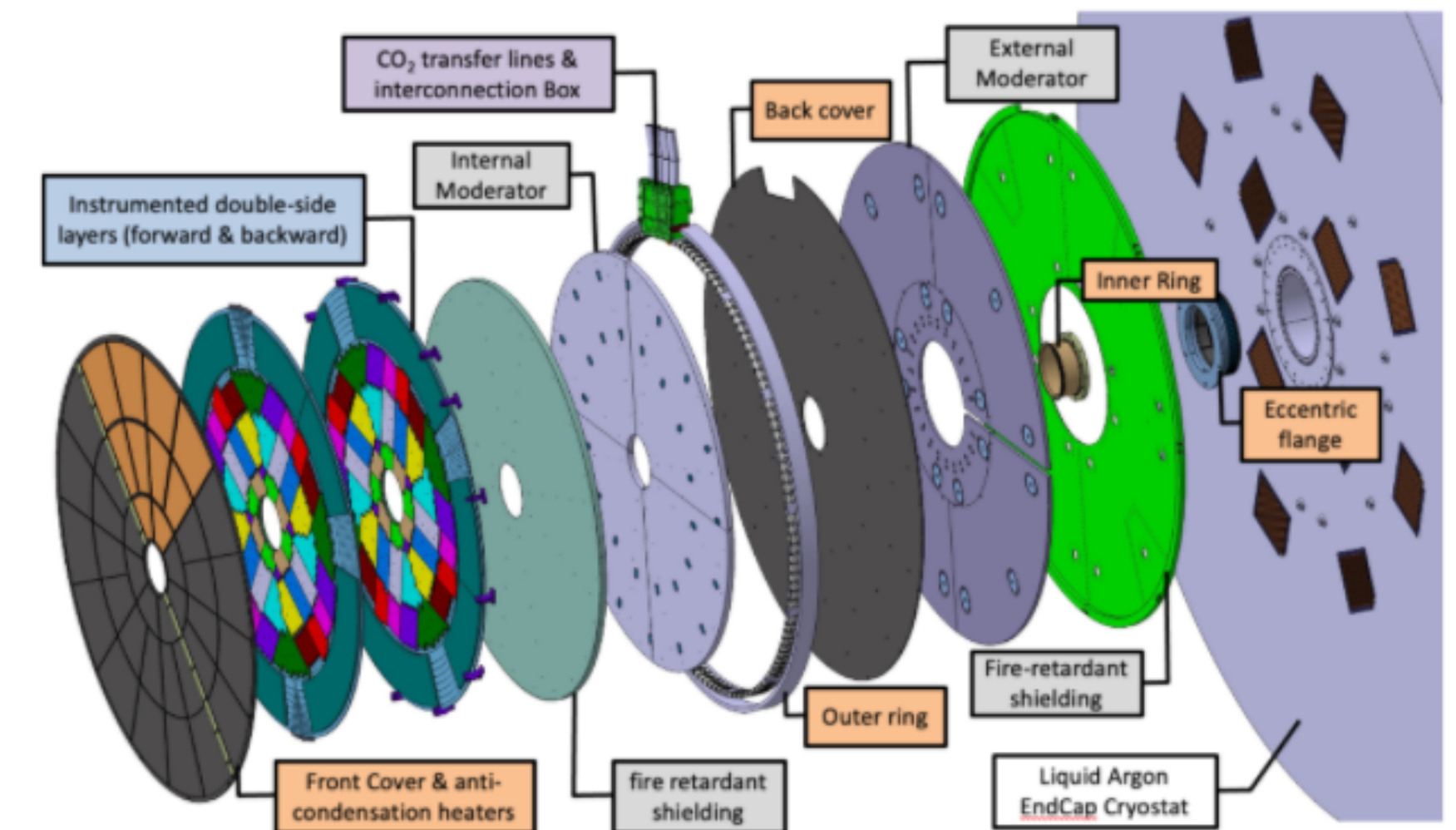
- Prototypes from foundries since 2014
- Several qualified manufacturers worldwide



Both ATLAS and CMS include large LGAD-based timing detectors in their upgrade programs for HL-LHC

- Detectors in pre-production phase
- Parallel development of dedicated front-end electronics

ATLAS HGTD







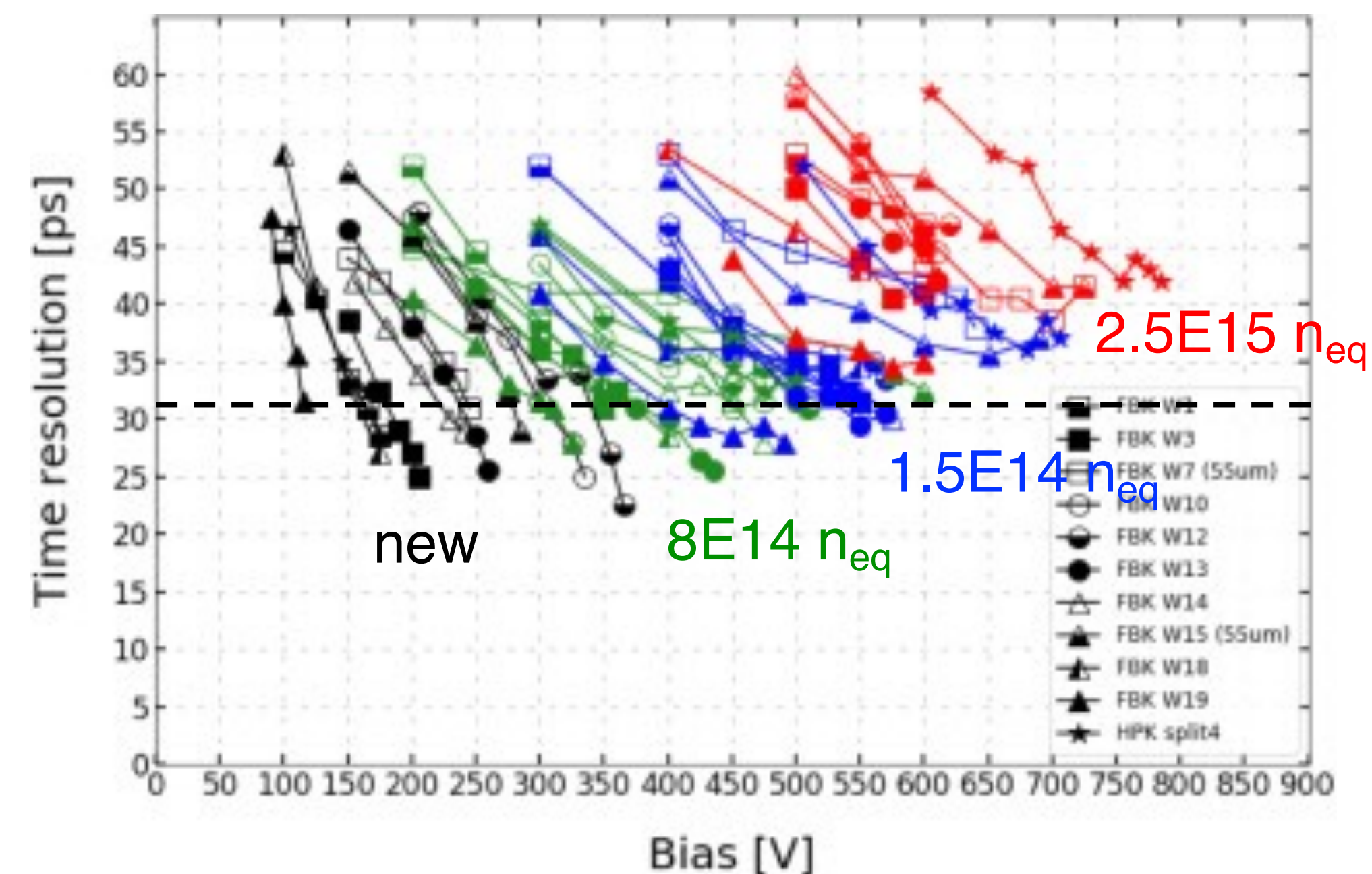
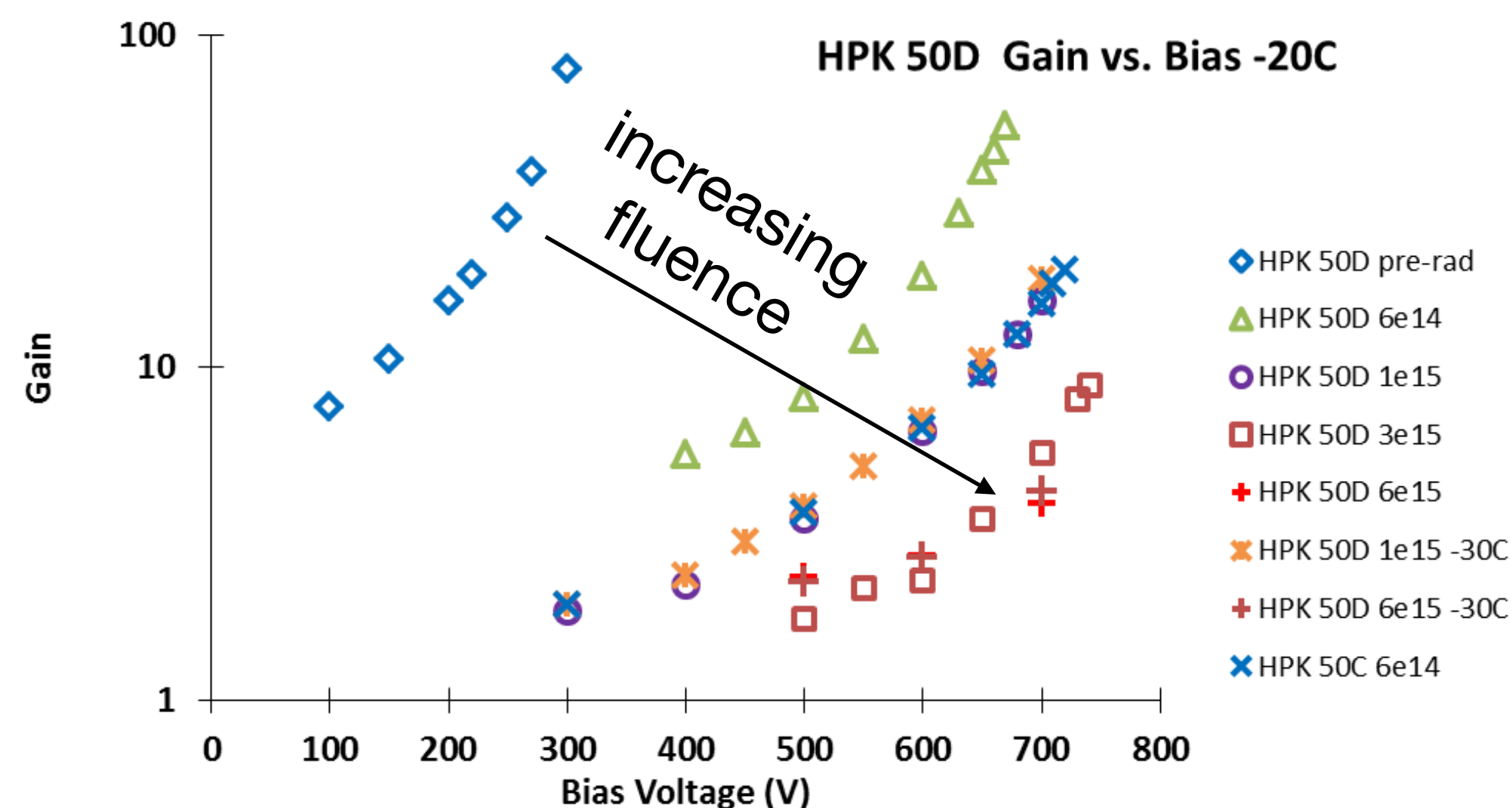
# Radiation resistance

Main effect of radiation damage in LGAD is gain decrease

- Caused by acceptor removal in gain layer
- Can be balanced by raising the bias voltage up to breakdown or single event burnout conditions

Carbon implantation into the gain layer can slow down the gain decrease process

- Extensive tests conducted with different concentration values
- Optimised values can extend lifetime up to a factor 3





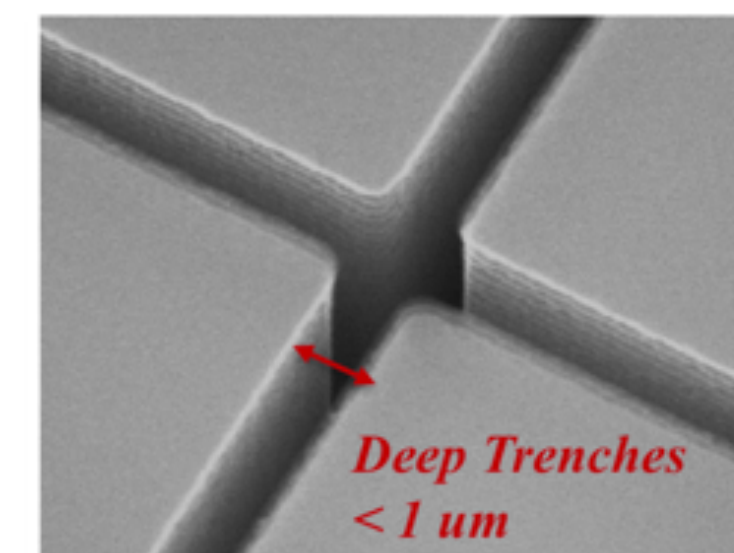
# Geometrical efficiency

Geometrical efficiency (“fill factor”) in LGAD is limited by the structures needed to separate readout electrodes

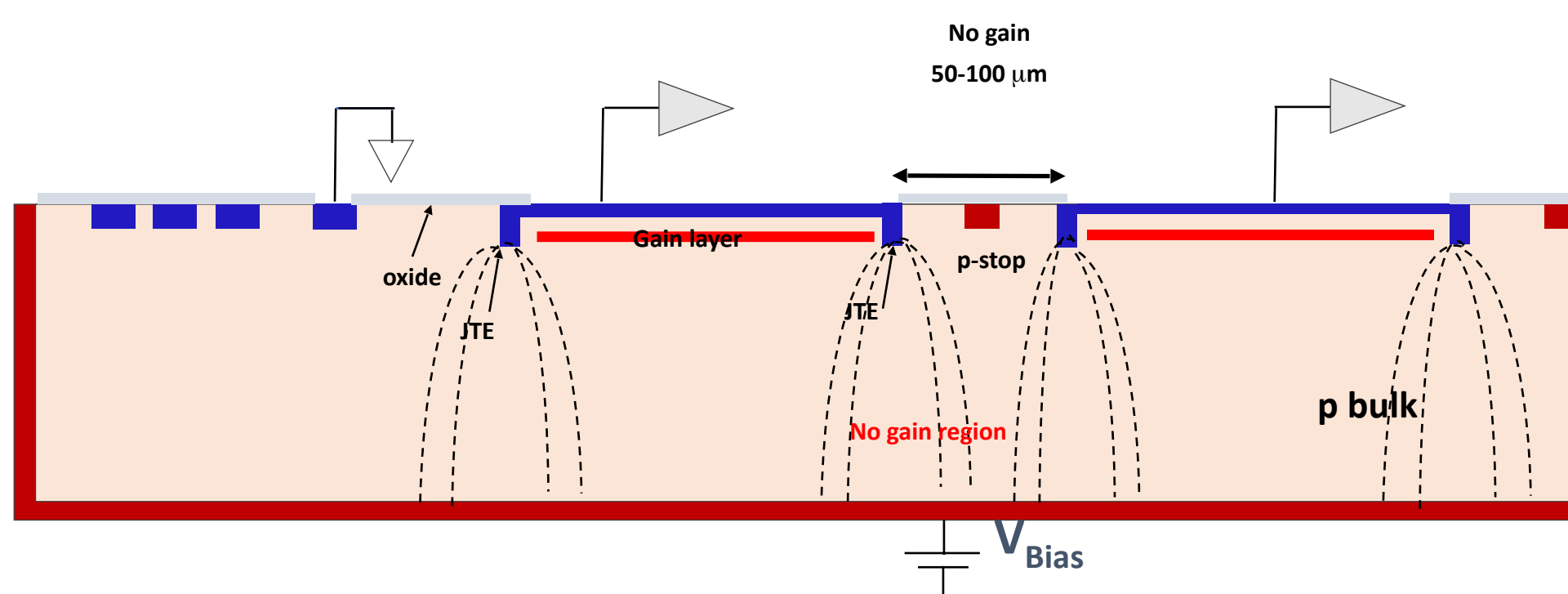
- $\Rightarrow$  no-gain regions of 50-100  $\mu\text{m}$  between adjacent pads
- $\Rightarrow$  not suitable for small pixels

Fill factor can be significantly reduced by “digging” isolation trenches between pads

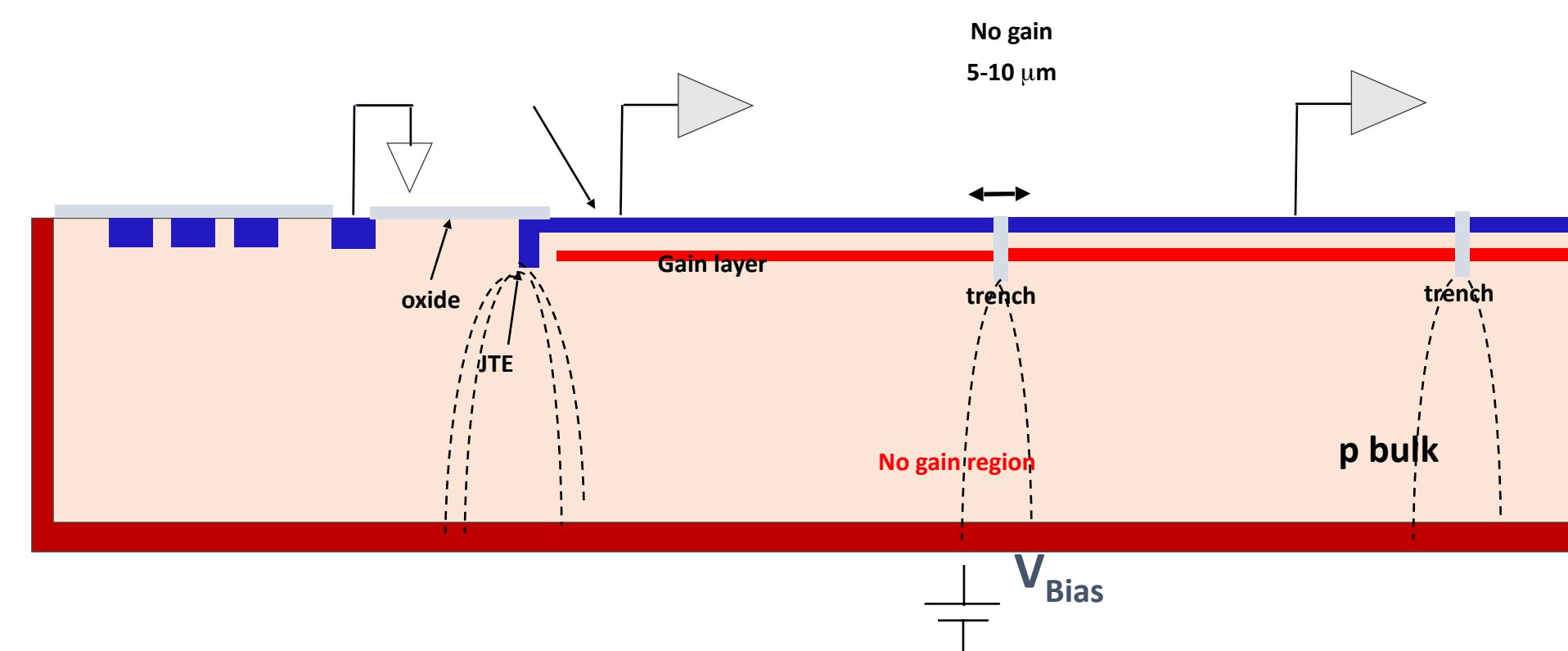
- $\Rightarrow$  no-gain regions of 5-10  $\mu\text{m}$  can be achieved



“Standard” LGAD



Trench-Isolated LGAD





# Resistive Silicon Detectors

Full geometrical efficiency can be restored in AC-coupled LGADs (AC-LGAD)

- readout geometry decoupled from electric field

A resistive layer is needed as a charge collection path

- $\Rightarrow$  similar concept to gas detectors such as RPCs

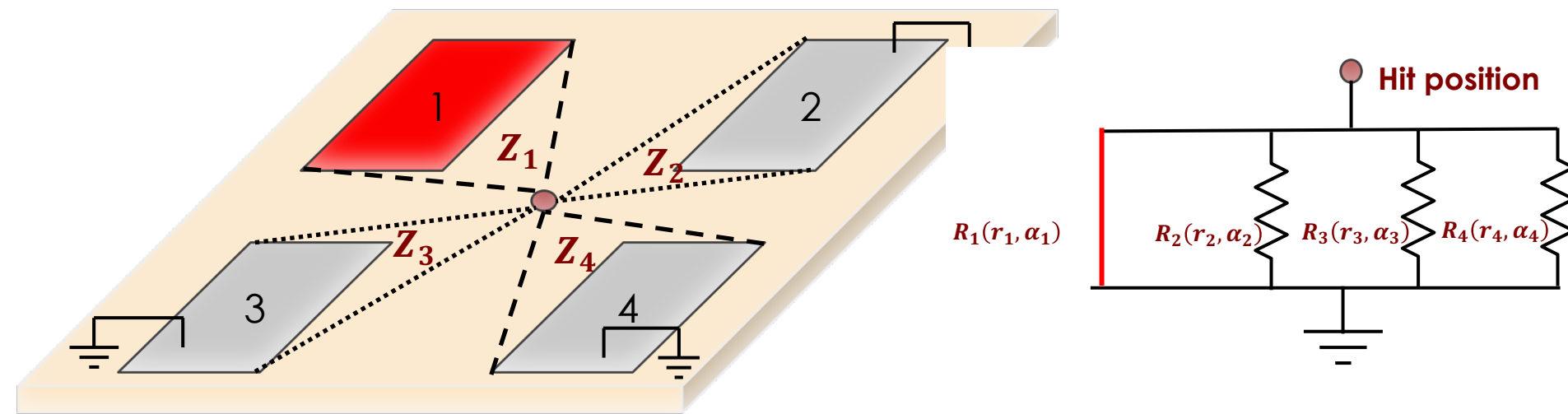


$\Rightarrow$  concetto simile a rivelatori a gas tipo RPC



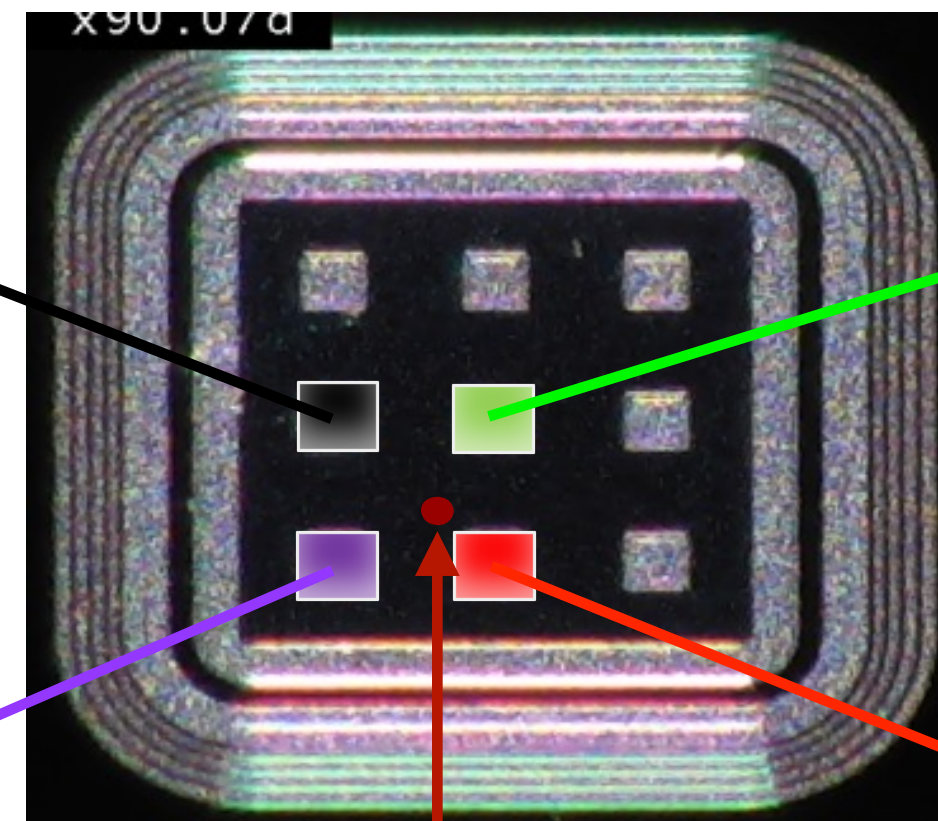
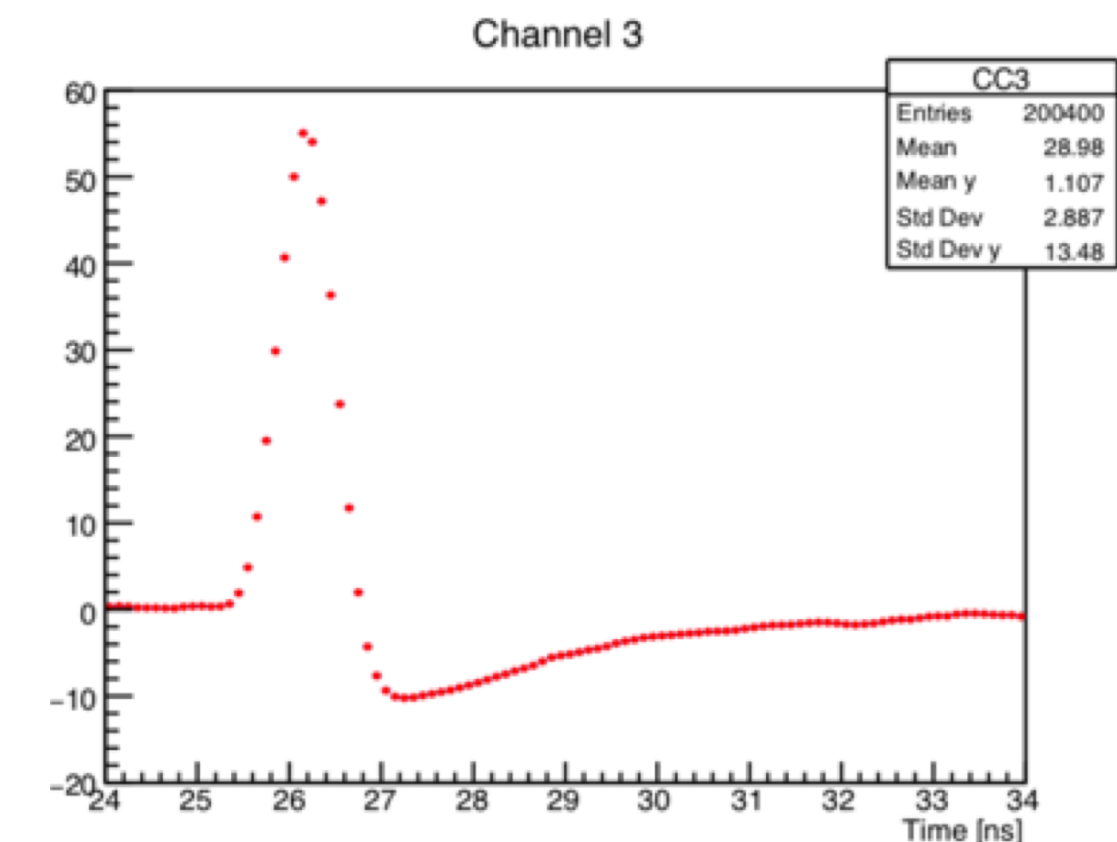
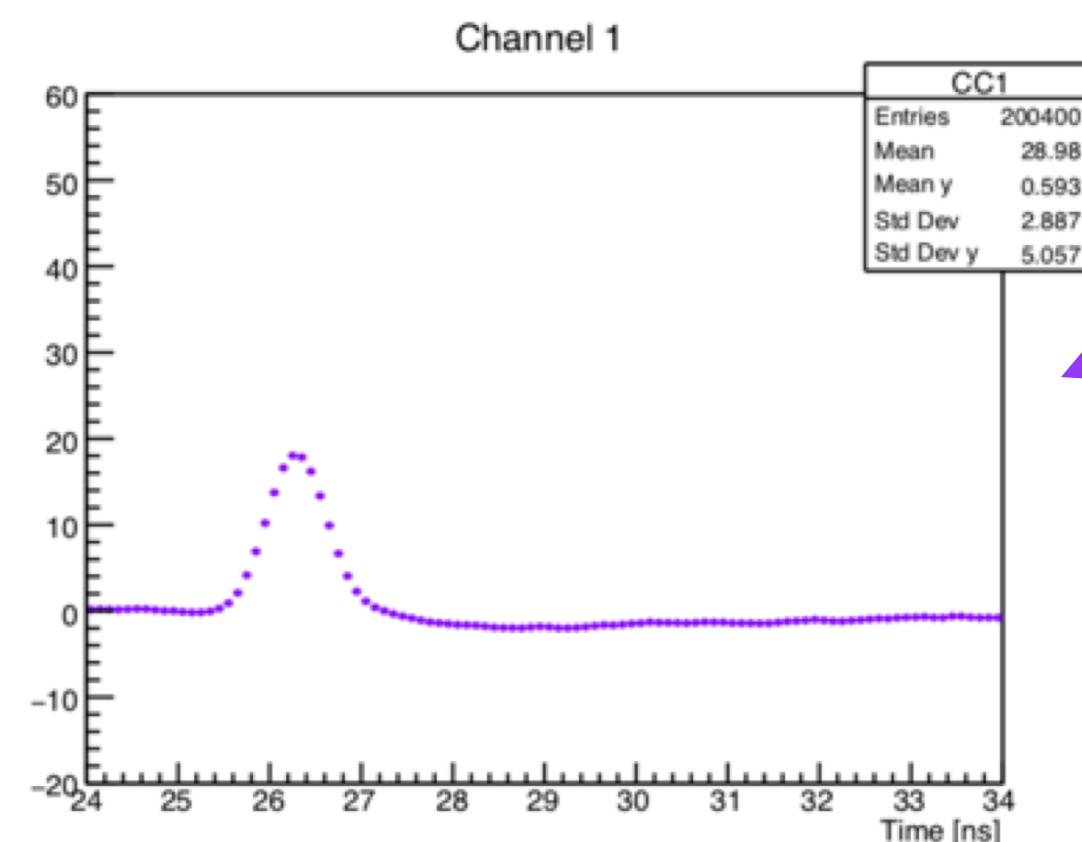
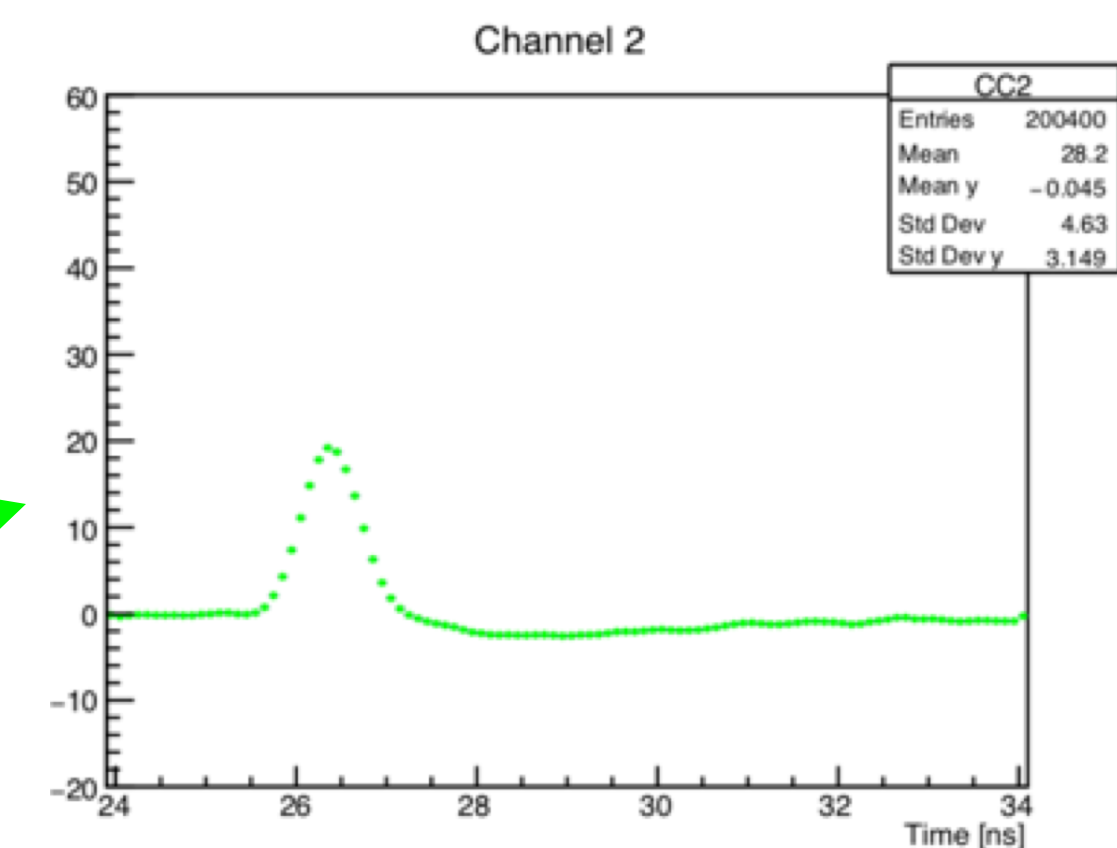
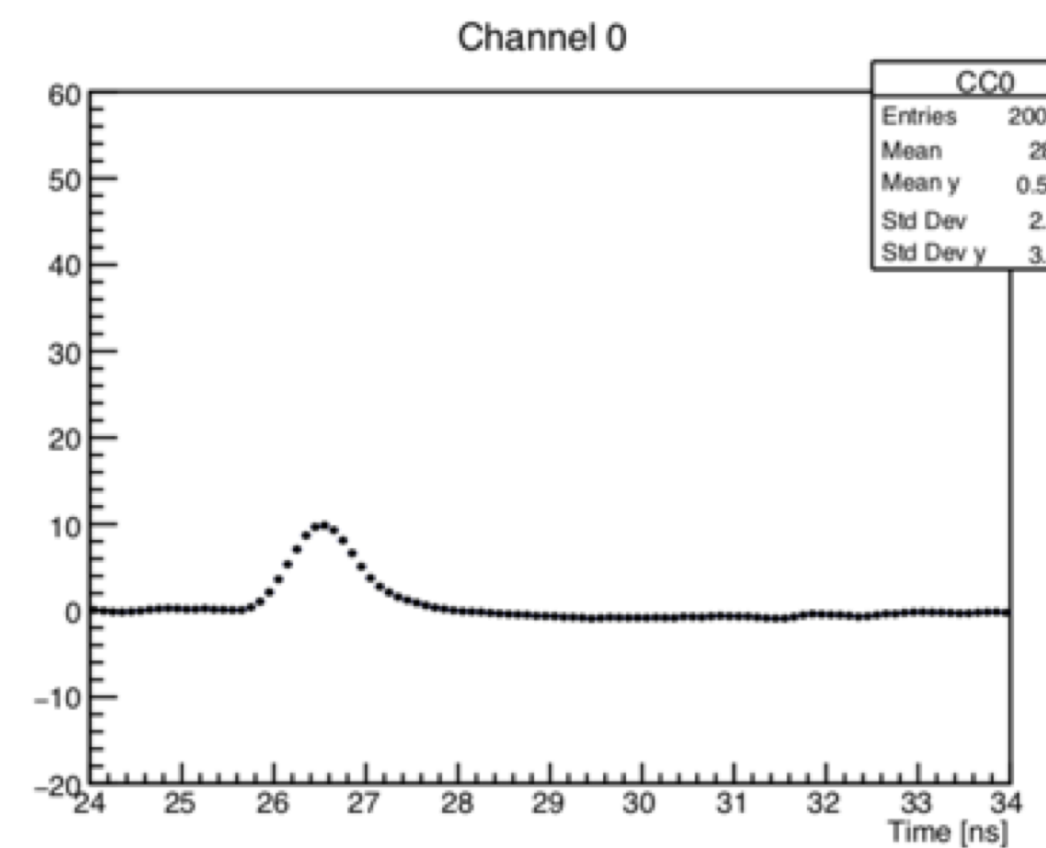


# Hit reconstruction in RSD



$$S_i(\alpha_i, r_i) = \frac{\alpha_i \ln(r_i)}{\sum_1^n \alpha_i \ln(r_i)}$$

Resistive layer causes signal to be shared among nearby electrodes



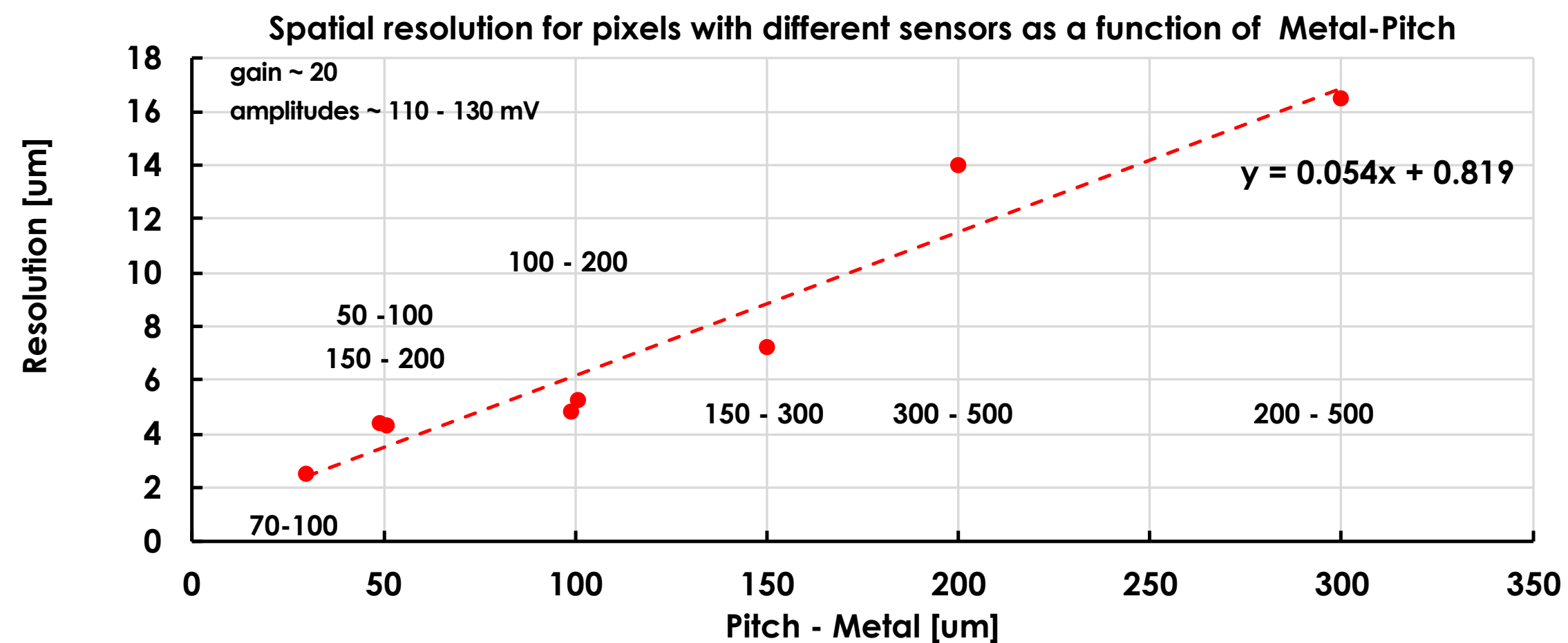
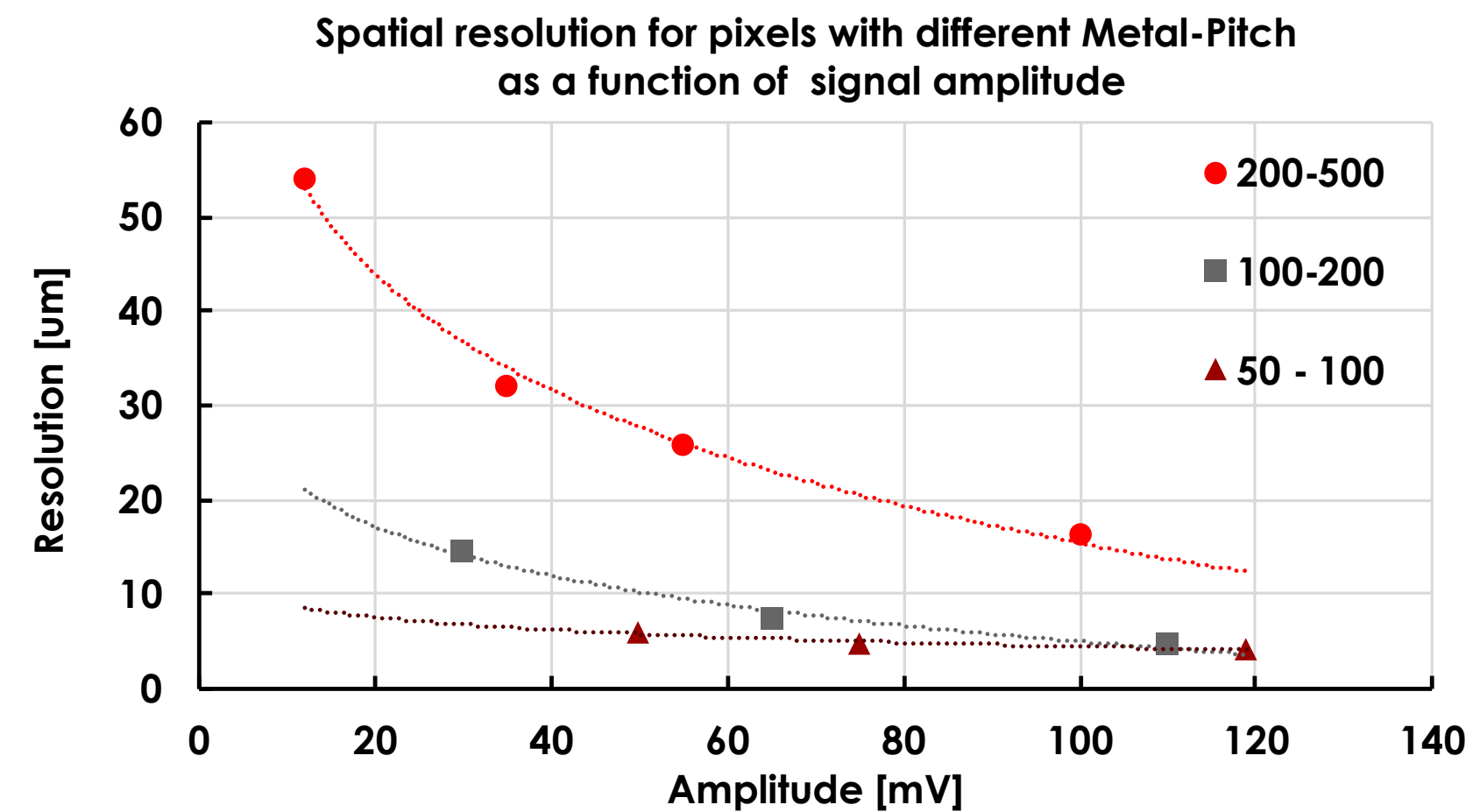
hit



# Space resolution in RSD

Achievable space resolution depends on several factors

- channel pitch;
- electrode geometry;
- electronics noise;
- signal digitisation;
- reconstruction algorithm;
- ...



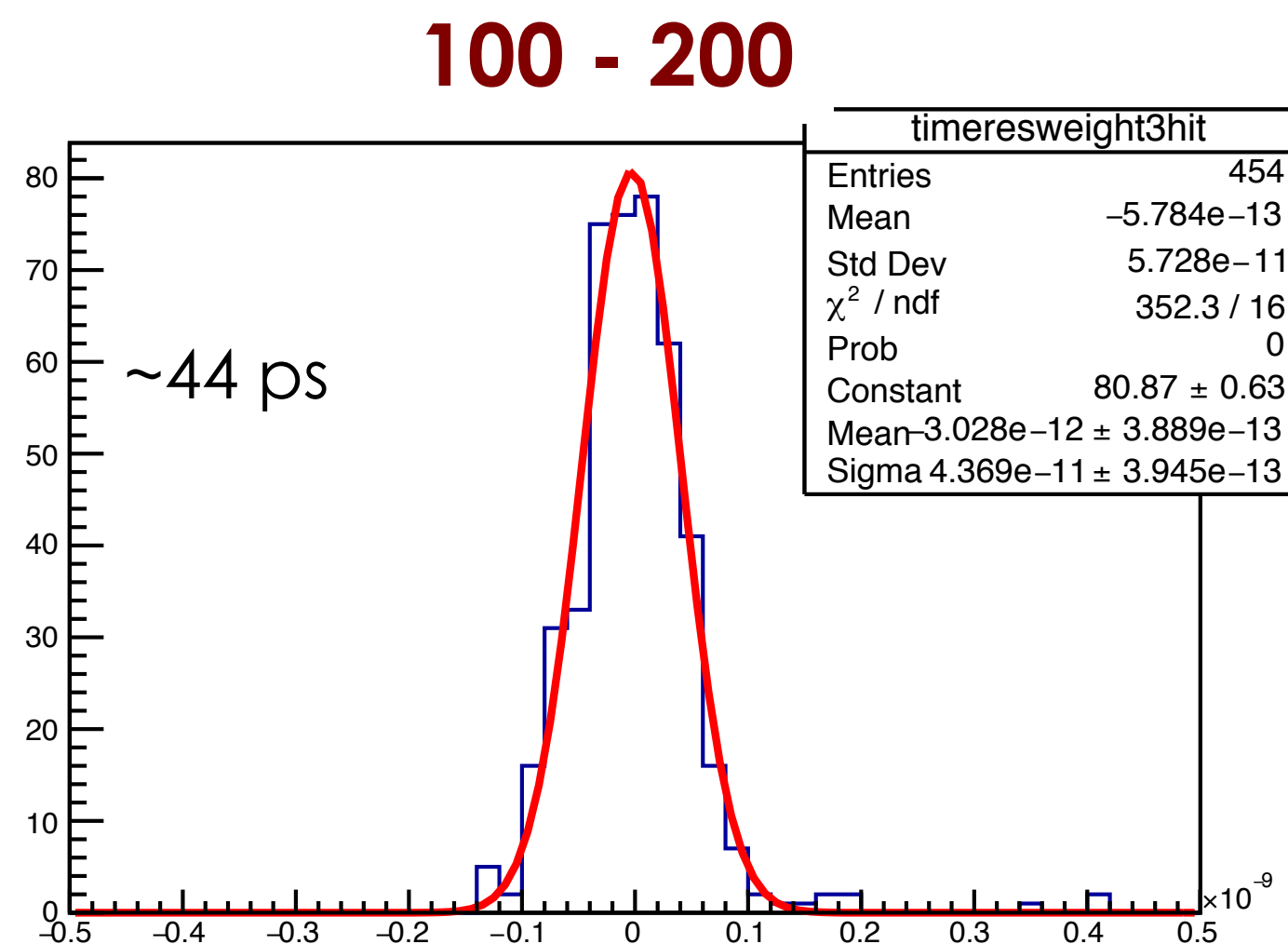
Resolution of up to **3%** of electrode pitch can be achieved



# Time resolution in RSD

RSD preserve the excellent timing performance of other LGAD sensors

- combined measurement from shared signals;
- additional contribution from propagation delay;
- very good uniformity observed on active area



Beam tests on sensors from first productions demonstrated **40-45 ps** resolution achievable (~20 ps from laser tests)

Realistic performances also depend on readout electronics



# LGAD studies for FCC-ee

Activity started at INFN Genova to investigate the potential of a space-time detector for IDEA based on LGAD technology

Studies on detector simulation, including benchmark channels:

- requirement on detector performance and geometry (granularity);
- possible benefits from use of RSD  $\Rightarrow$  optimisation of electrode geometry

Tests on LGAD sensors from recent productions, in collaboration with INFN Torino:

- set-up for laboratory characterisation of different structures;
- participation at beam tests