FUTURE CIRCULAR COLLIDER
Expanding our Horizons

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

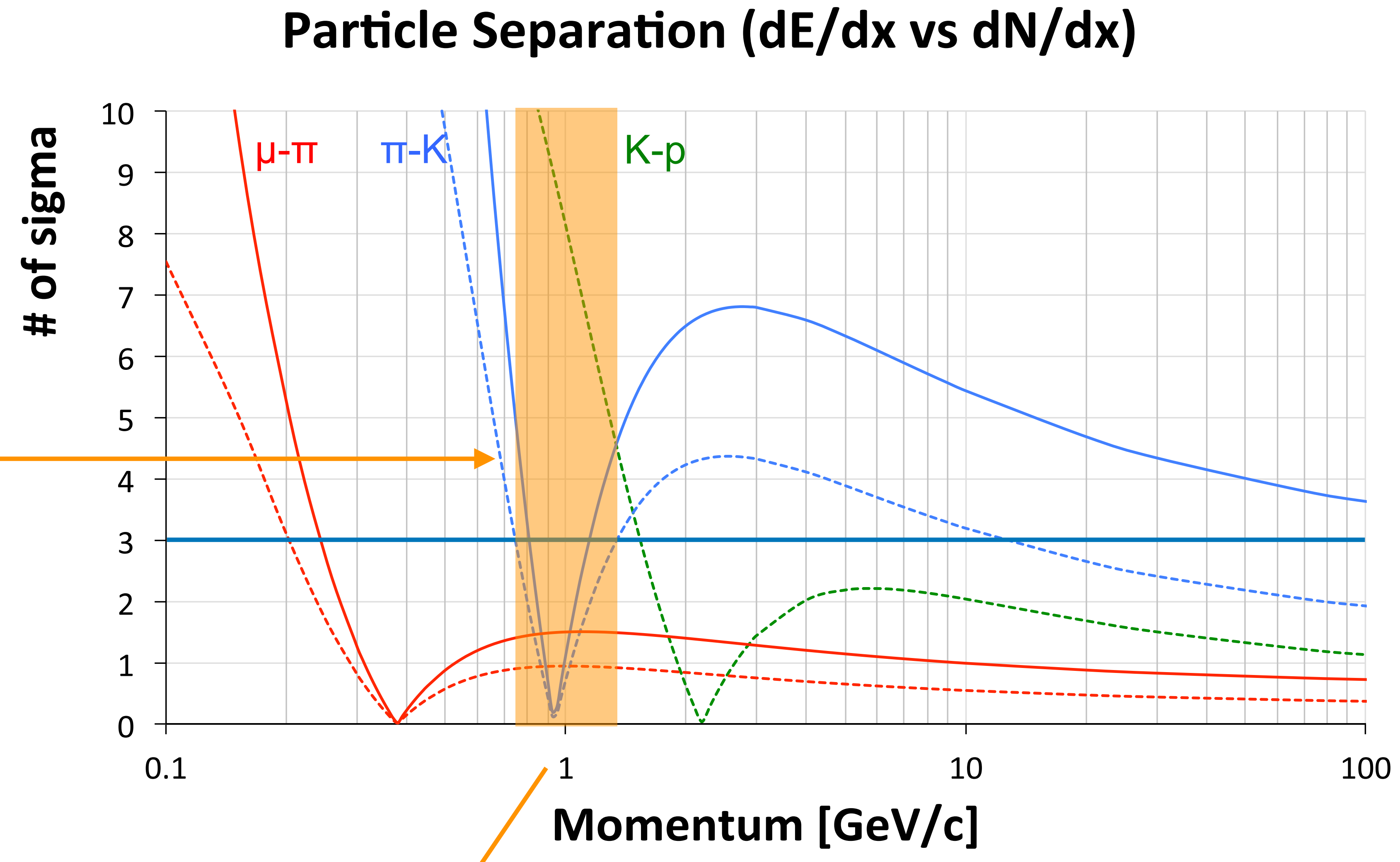
- For K-π separation, good performance in most of momentum spectrum, except for a region around 1 GeV/c

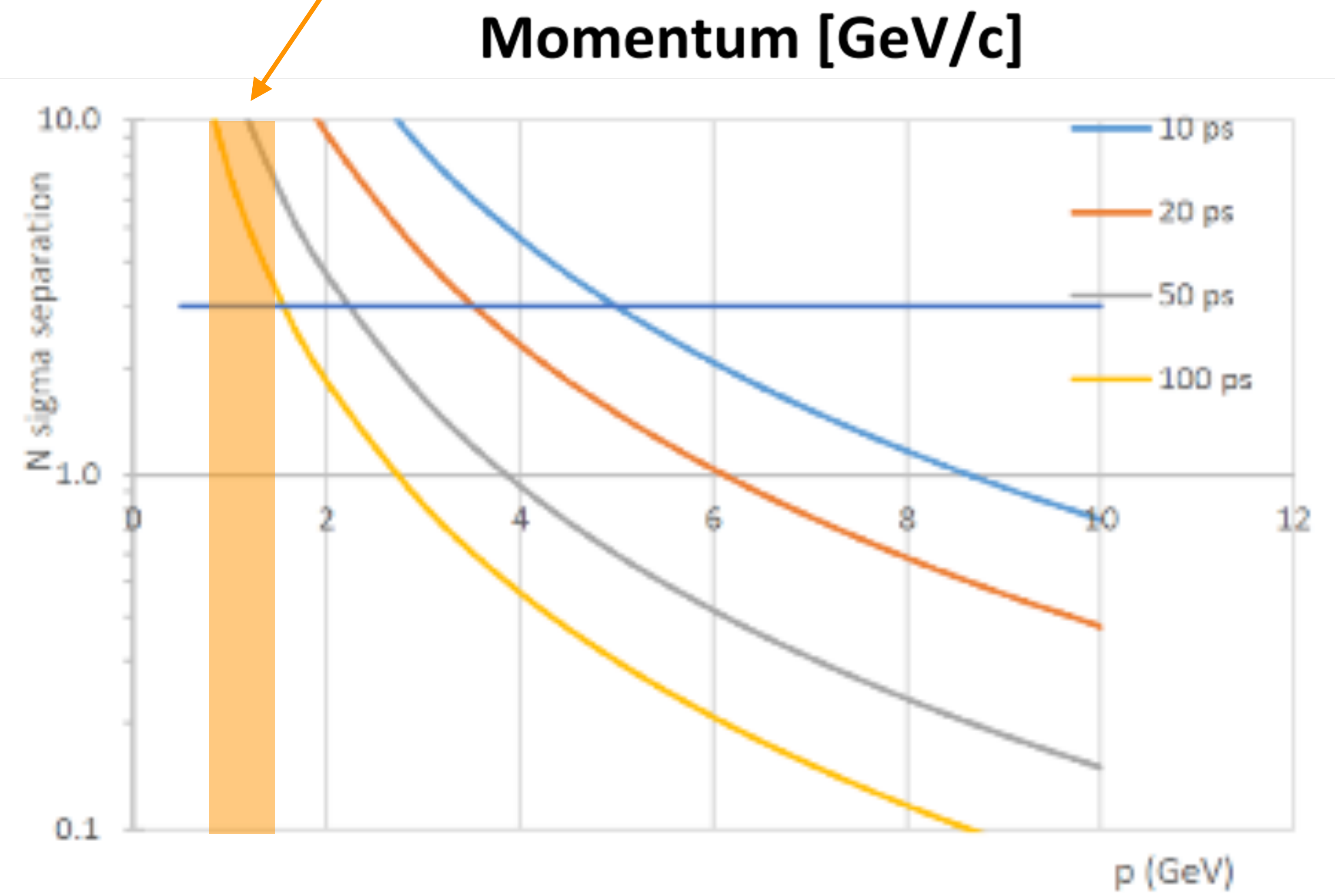
Complementary PID information could be granted by an external time-of-flight detector

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

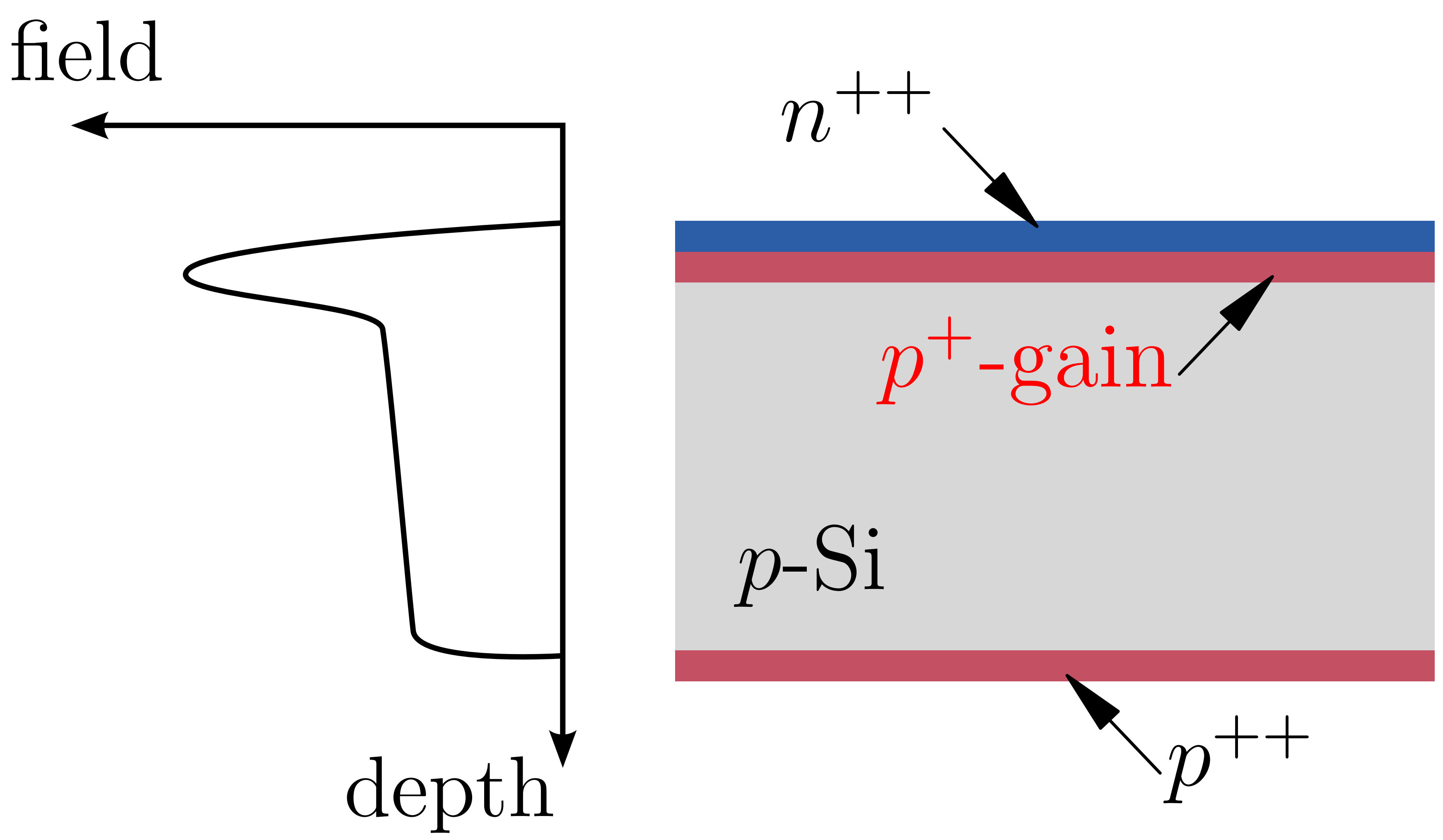
Timing information would also help relaxing requests on the vertex detector

- Larger integration time ⟹ less power ⟹ less material





Low Gain Avalanche Detectors

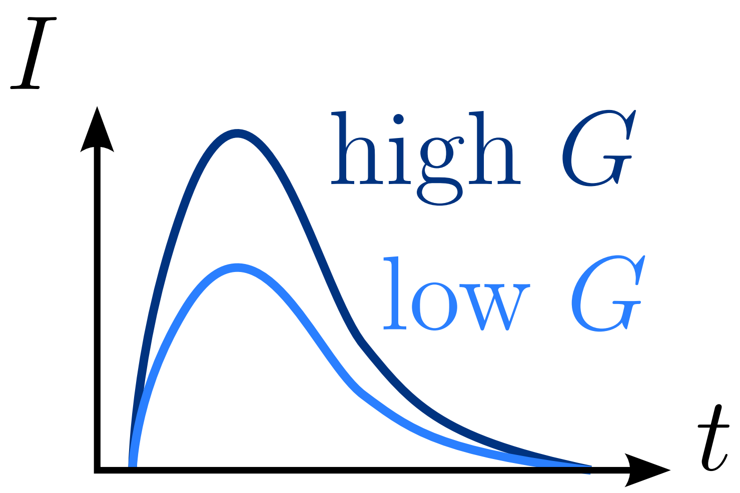


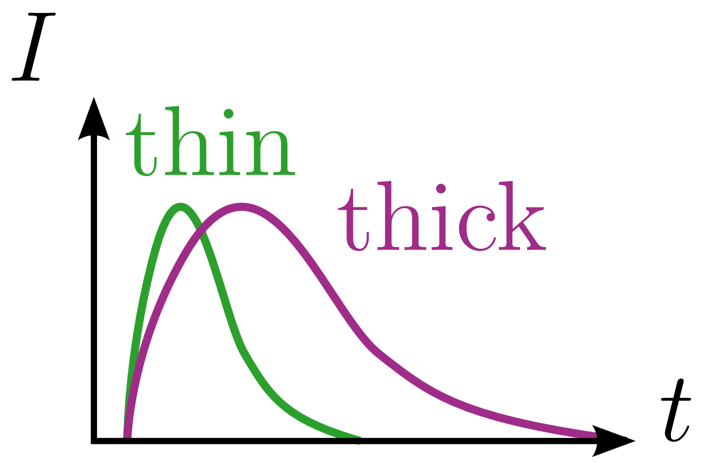
Low Gain Avalanche Detectors (LGAD) are reverse-bias, planar, silicon detectors, with an internal gain layer

- Usually *n*-in-*p* structure, with implanted p^+ layer
- High electric field (~300 kV/cm) in narrow region under the junction
- Moderate gain (~10) $\Longrightarrow$ 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 ~30 ps can be obtained

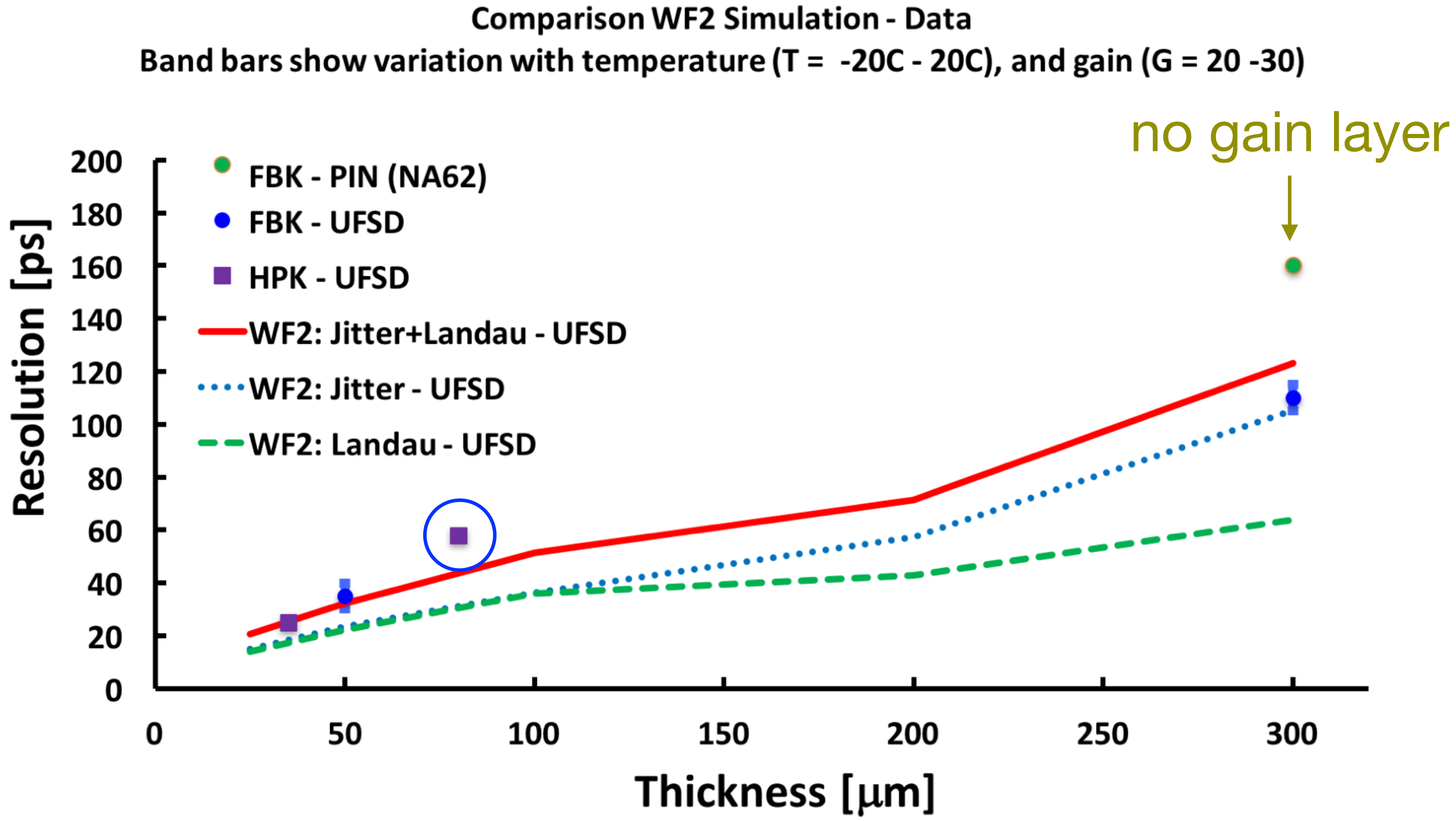


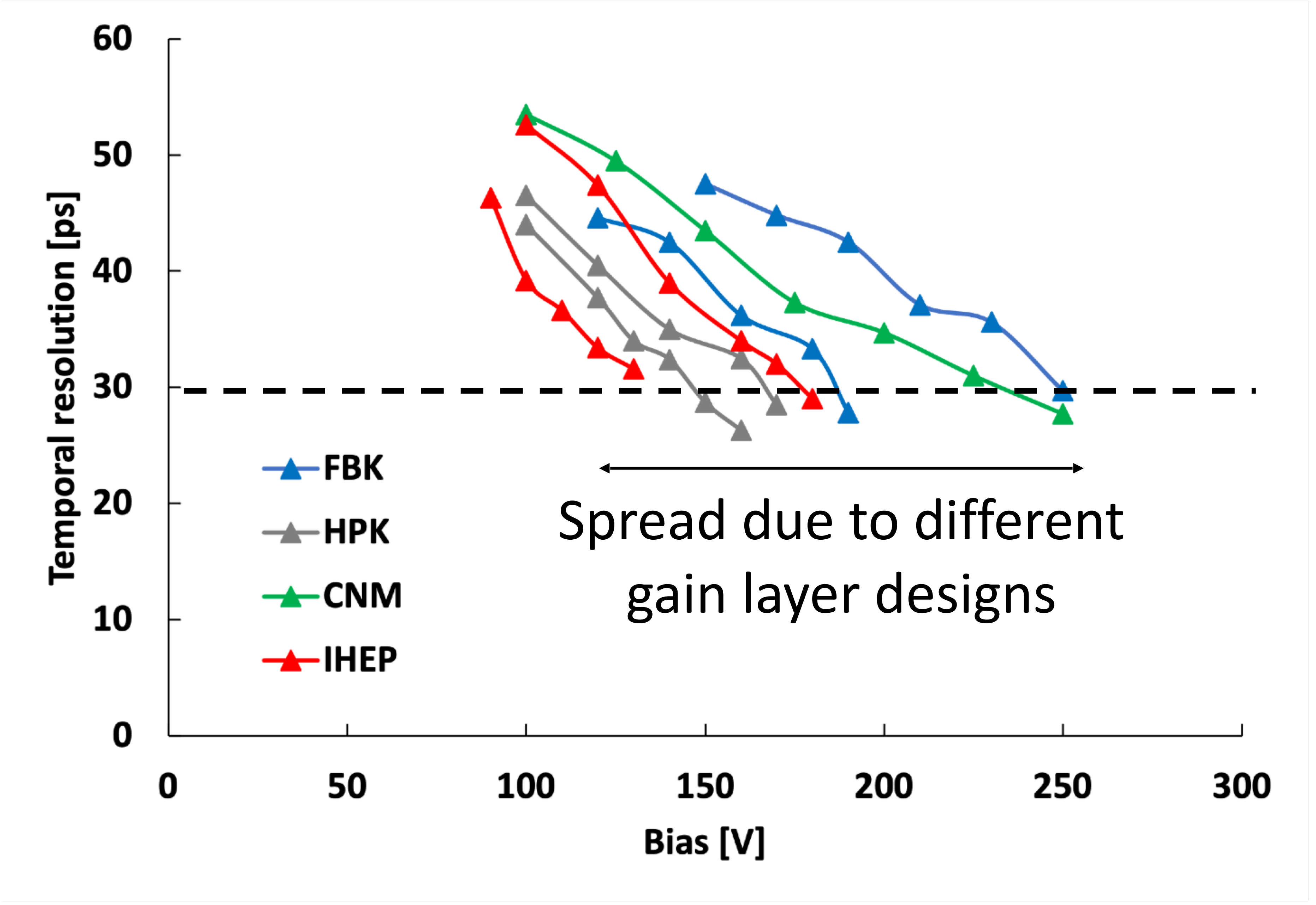


Time resolution of LGAD

Extensive studies have explored sensor configurations:

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



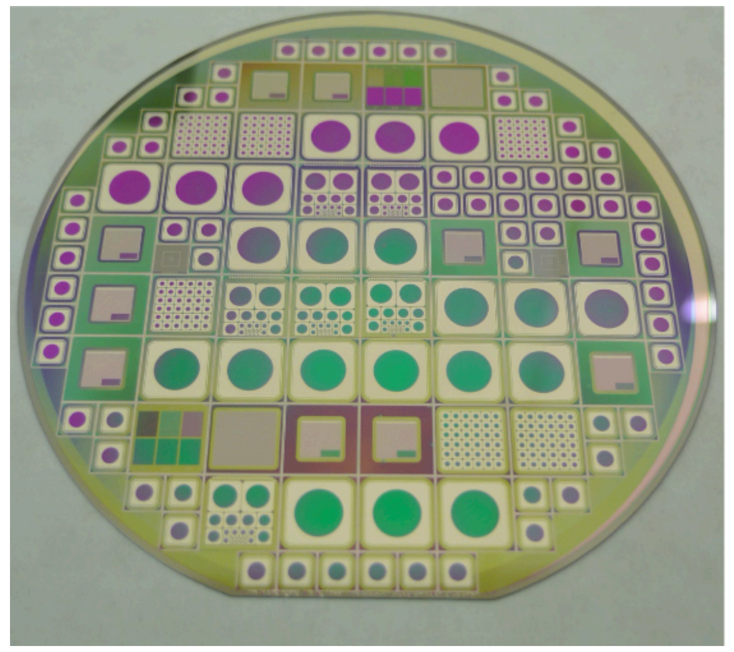


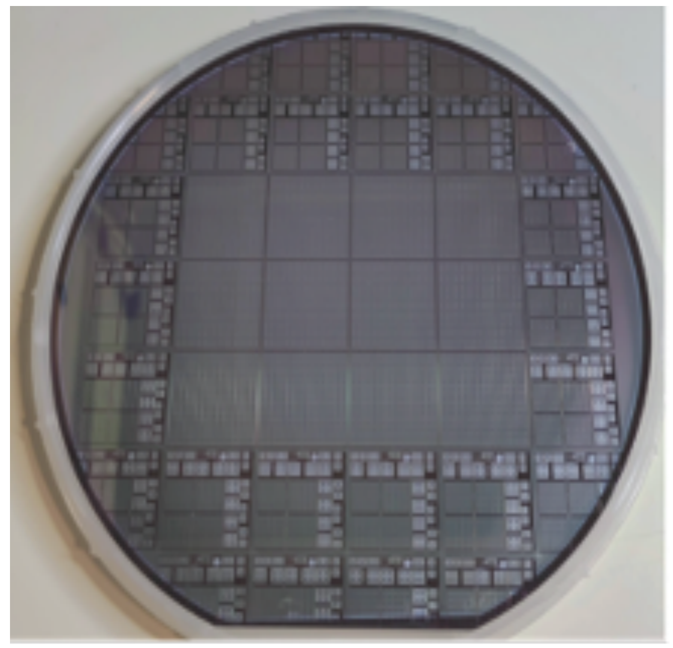
Current productions mostly focusing on 50-μ-thick sensors

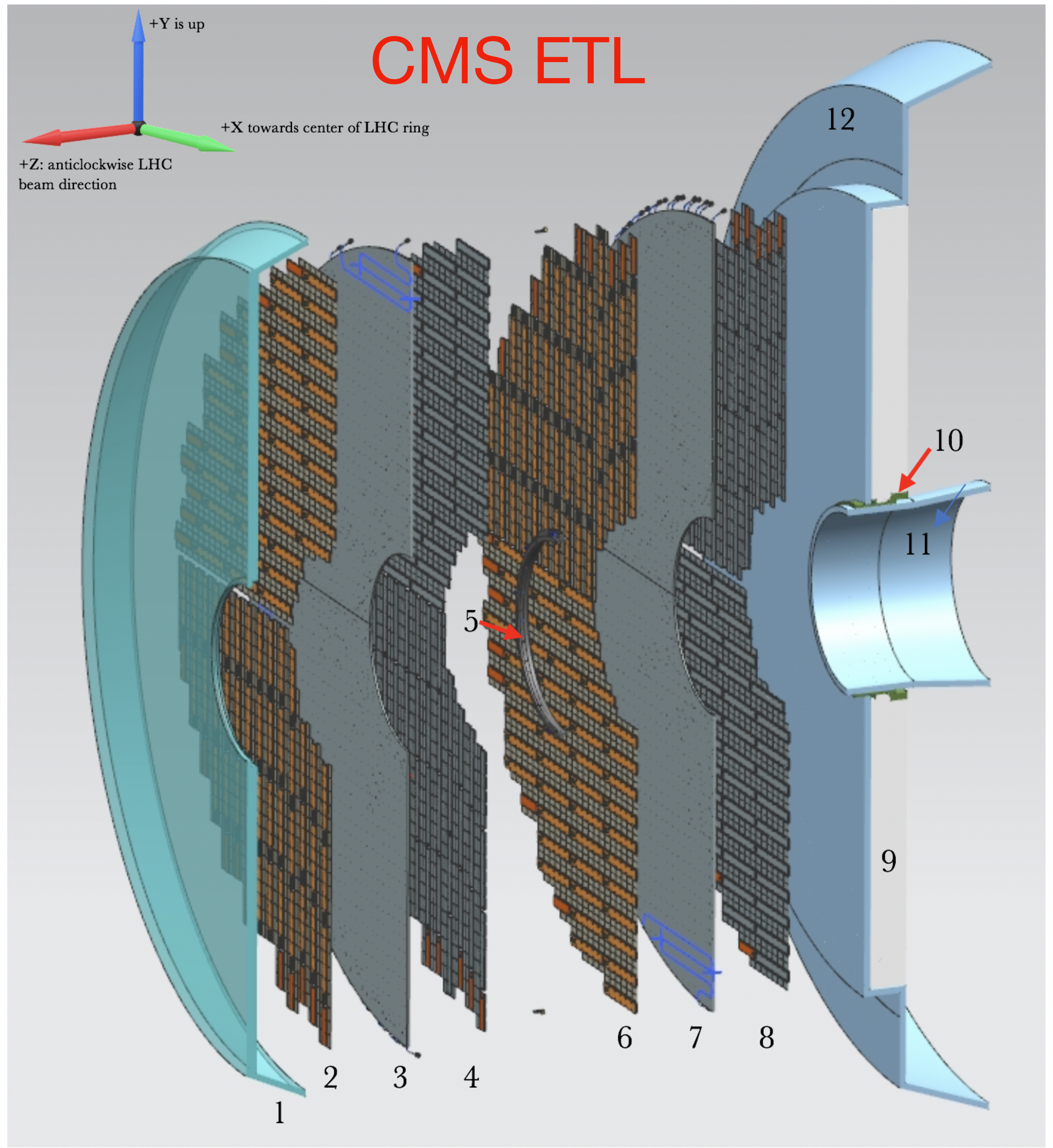
LGAD in HEP experiments

LGAD is now a mature technology

- Prototypes from foundries since 2014
- Several qualified manufacturers worldwide



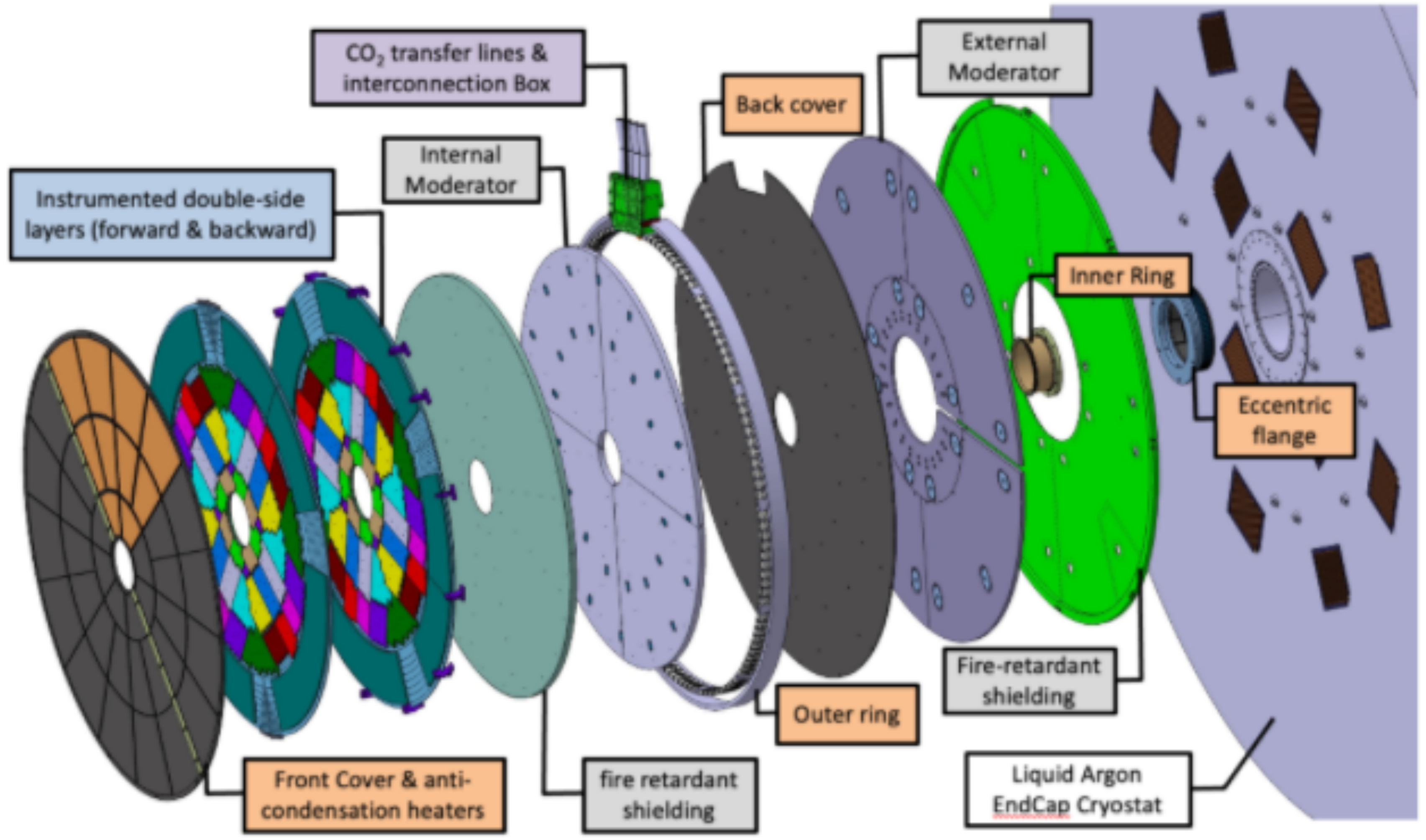




Both ATLAS and CMS include large LGAD-based timing detectors in their upgrade programs for HL-LHC

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

ATLAS HGTD



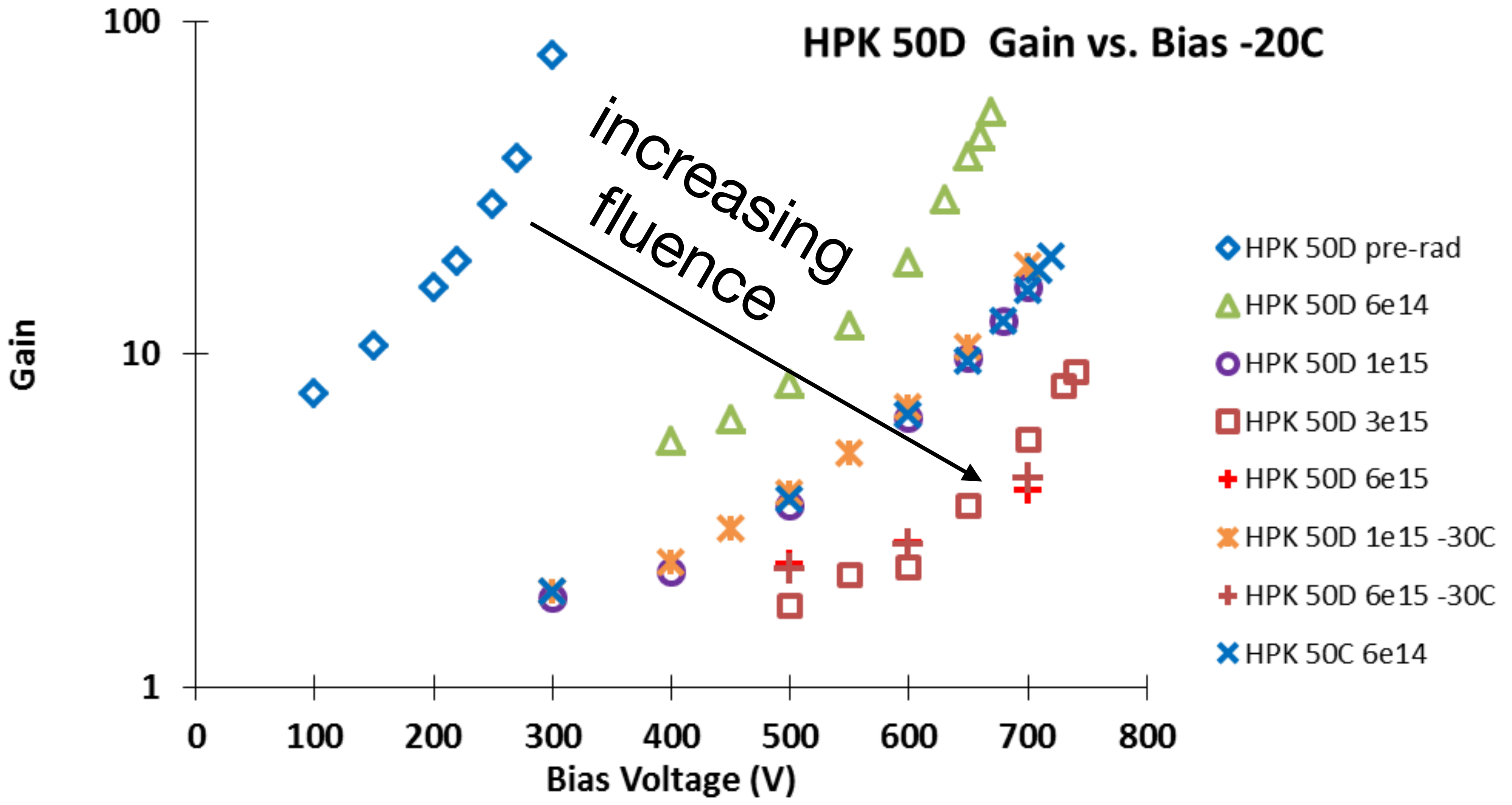
Radiation resistance

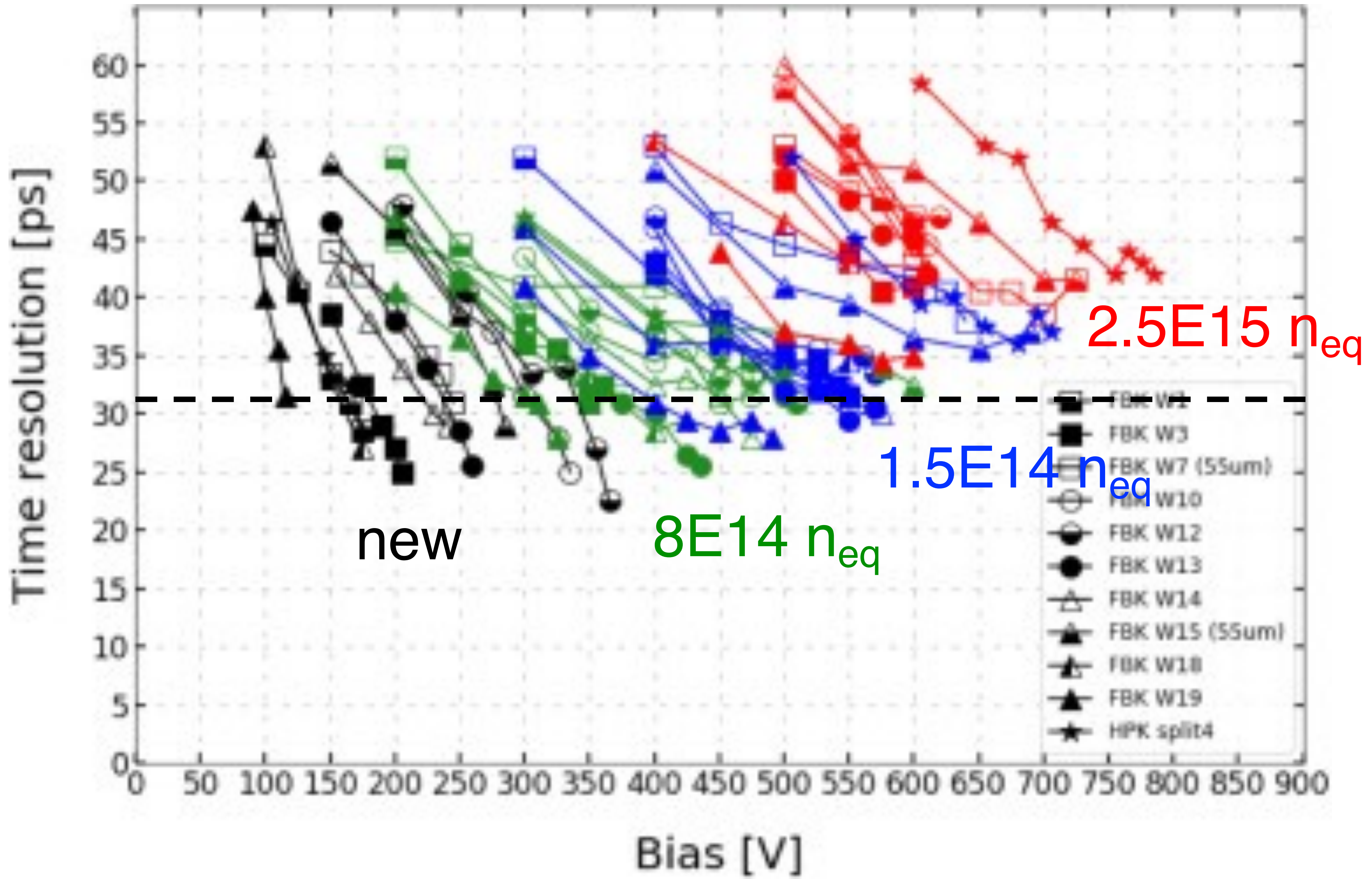
Main effect of radiation damage in LGAD is gain decrease

- 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

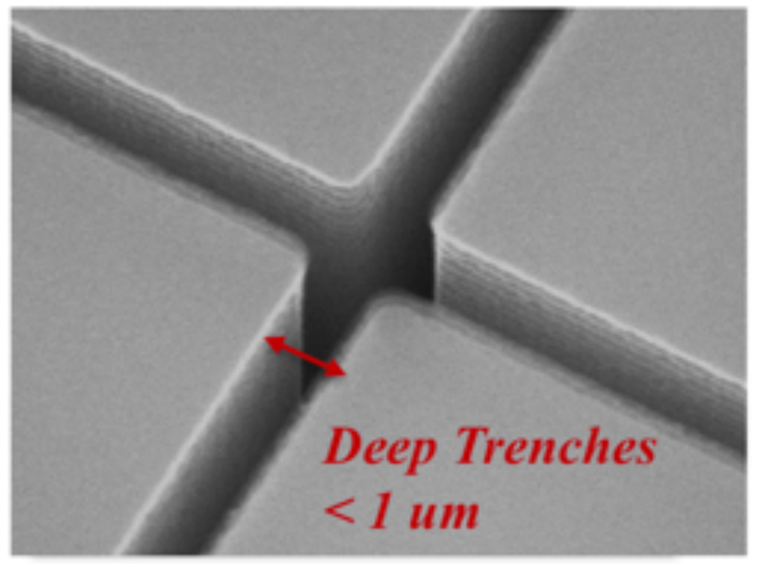




Geometrical efficiency

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

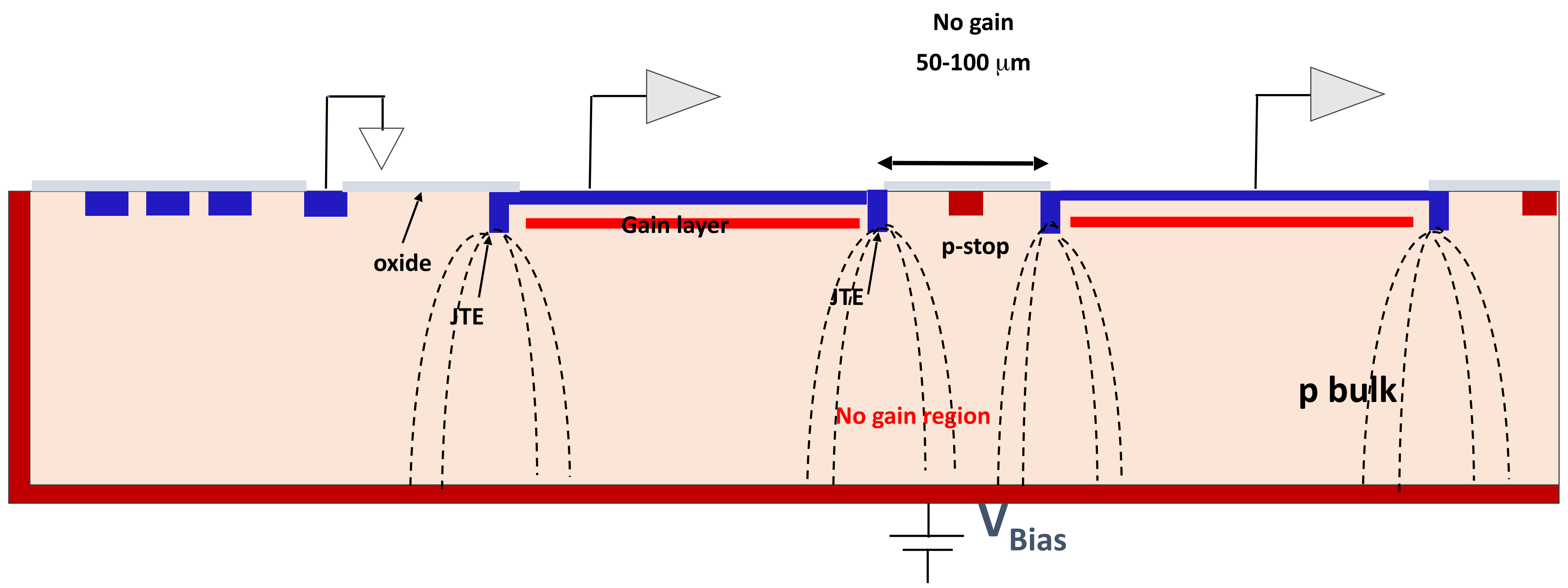
- ⟹ no-gain regions of 50-100 μm between adjacent pads
- ⟹ not suitable for small pixels



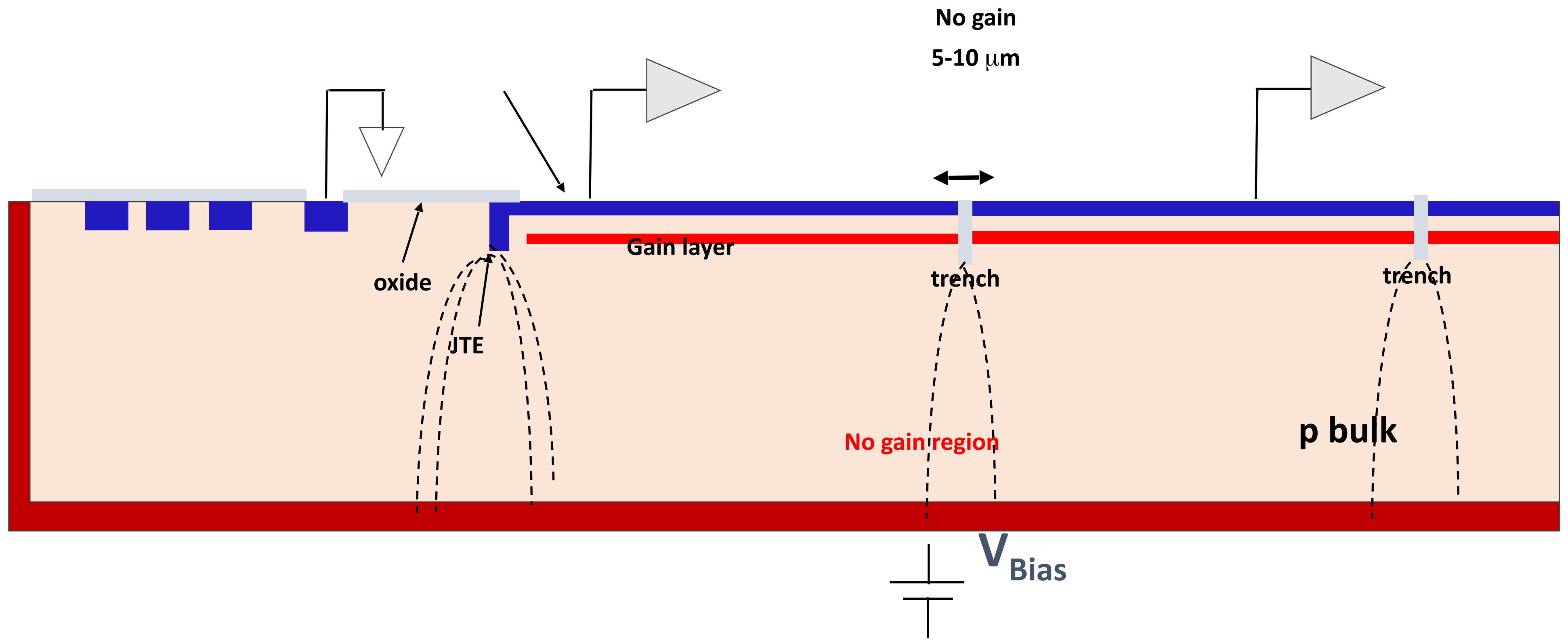
Fill factor can be significantly reduced by "digging" isolation trenches between pads

- ⟹ no-gain regions of 5-10 μm can be achieved

"Standard" LGAD



Trench-Isolated LGAD



Resistive Silicon Detectors

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

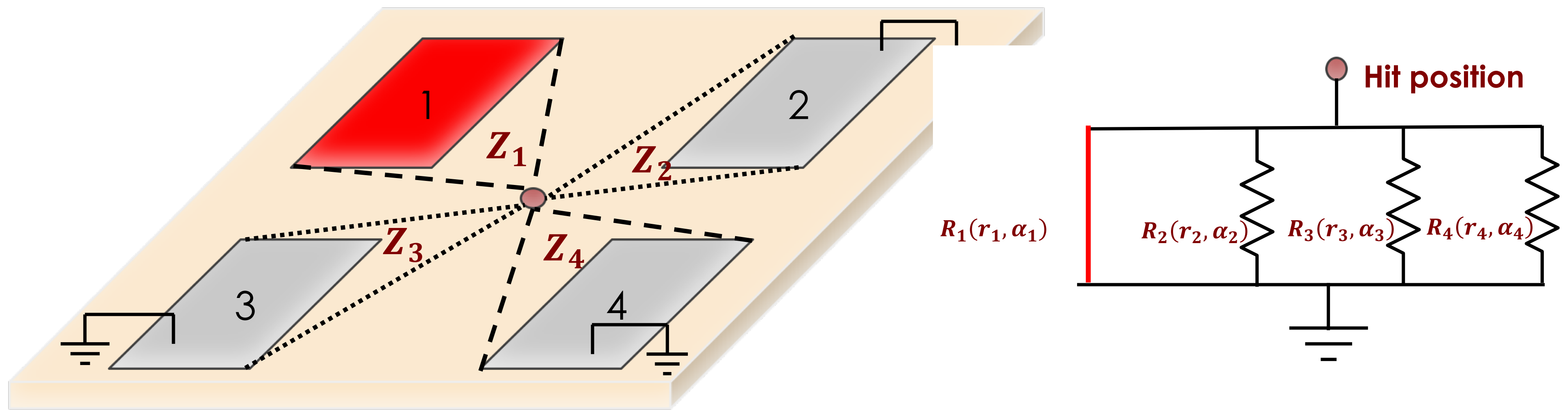
- readout geometry decoupled from electric field

A resistive layer is needed as a charge collection path

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

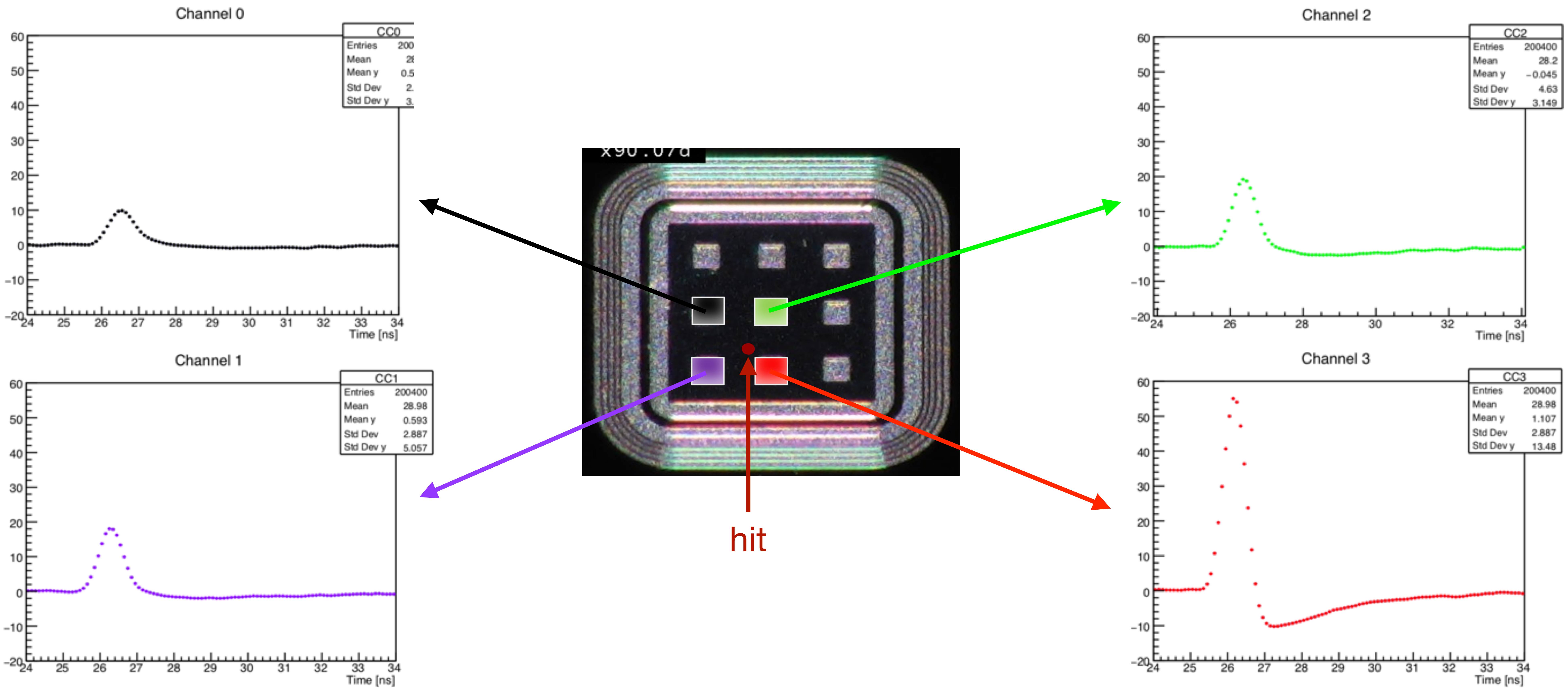
$\Longrightarrow$ concetto simile a rivelatori a gas tipo RPC

Hit reconstruction in RSD



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

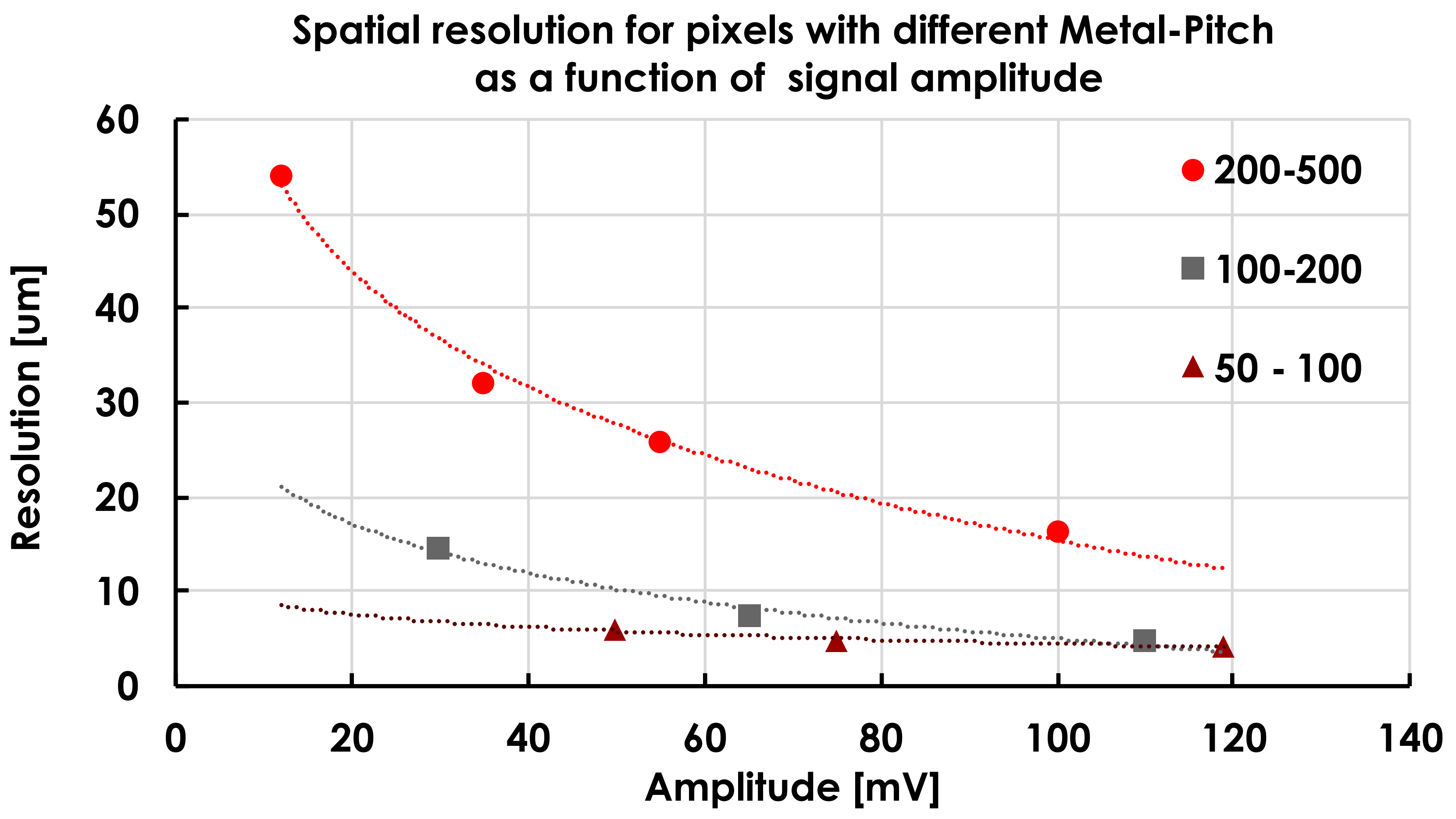
Resistive layer causes signal to be shared among nearby electrodes

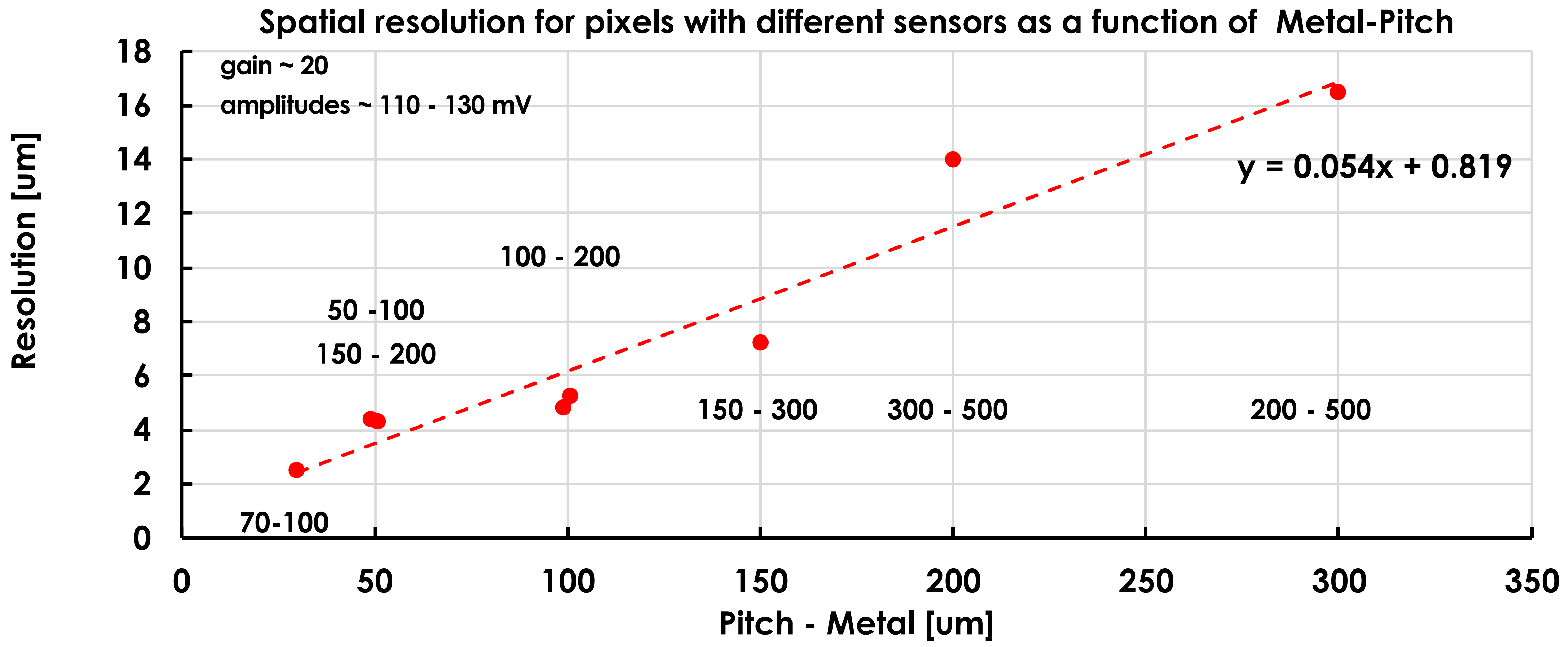


Space resolution in RSD

Achievable space resolution depends on several factors

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



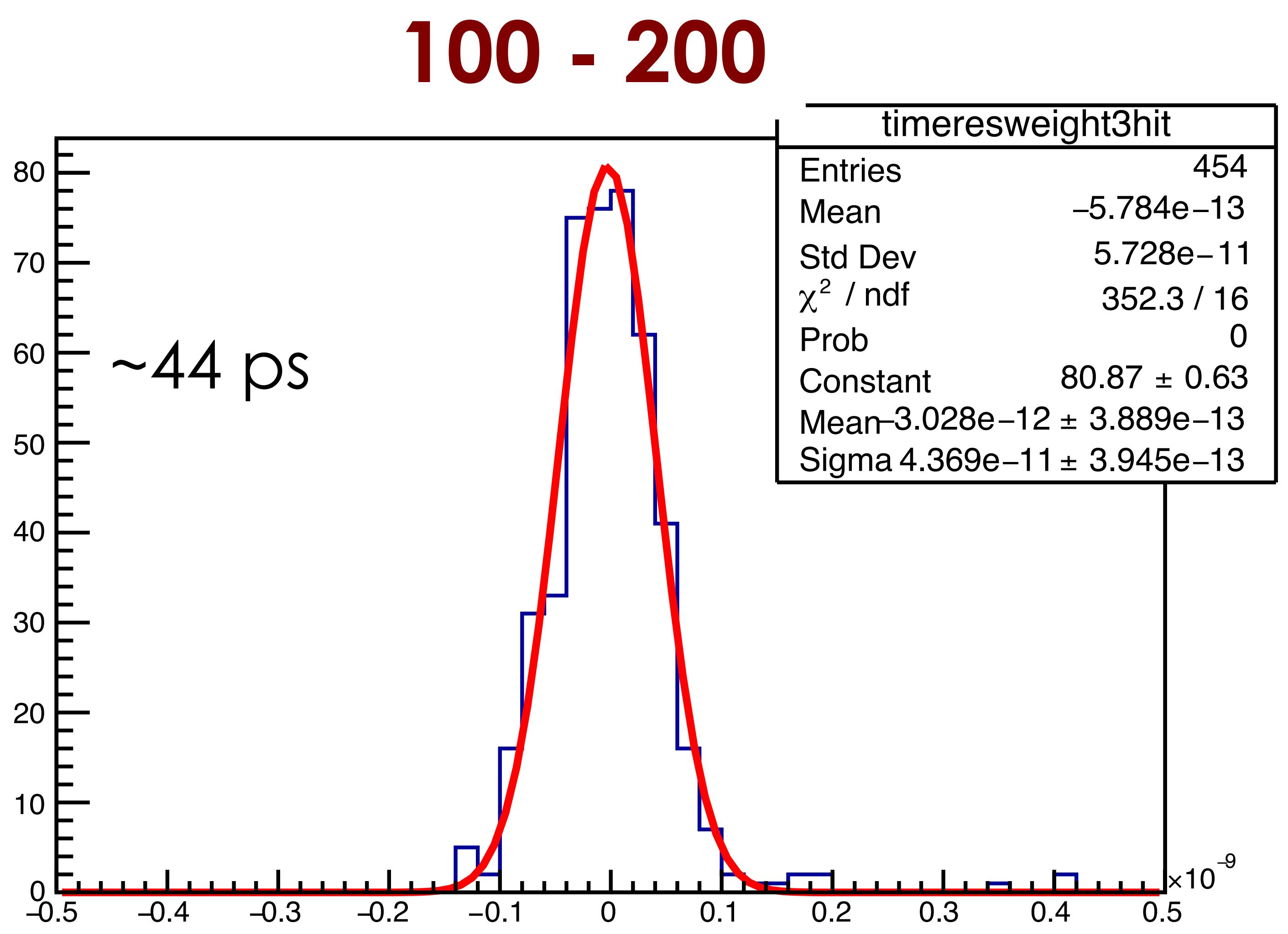


Resolution of up to 3% of electrode pitch can be achieved

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 $\Longrightarrow$ 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