Ultra-Fast Silicon Detectors for CMS Phase II upgrade

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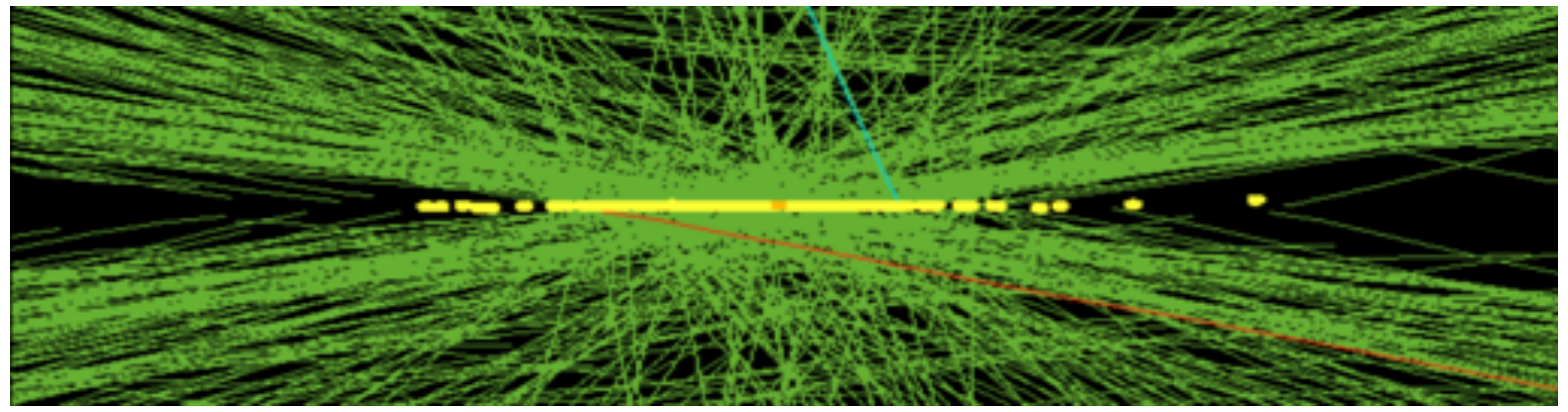
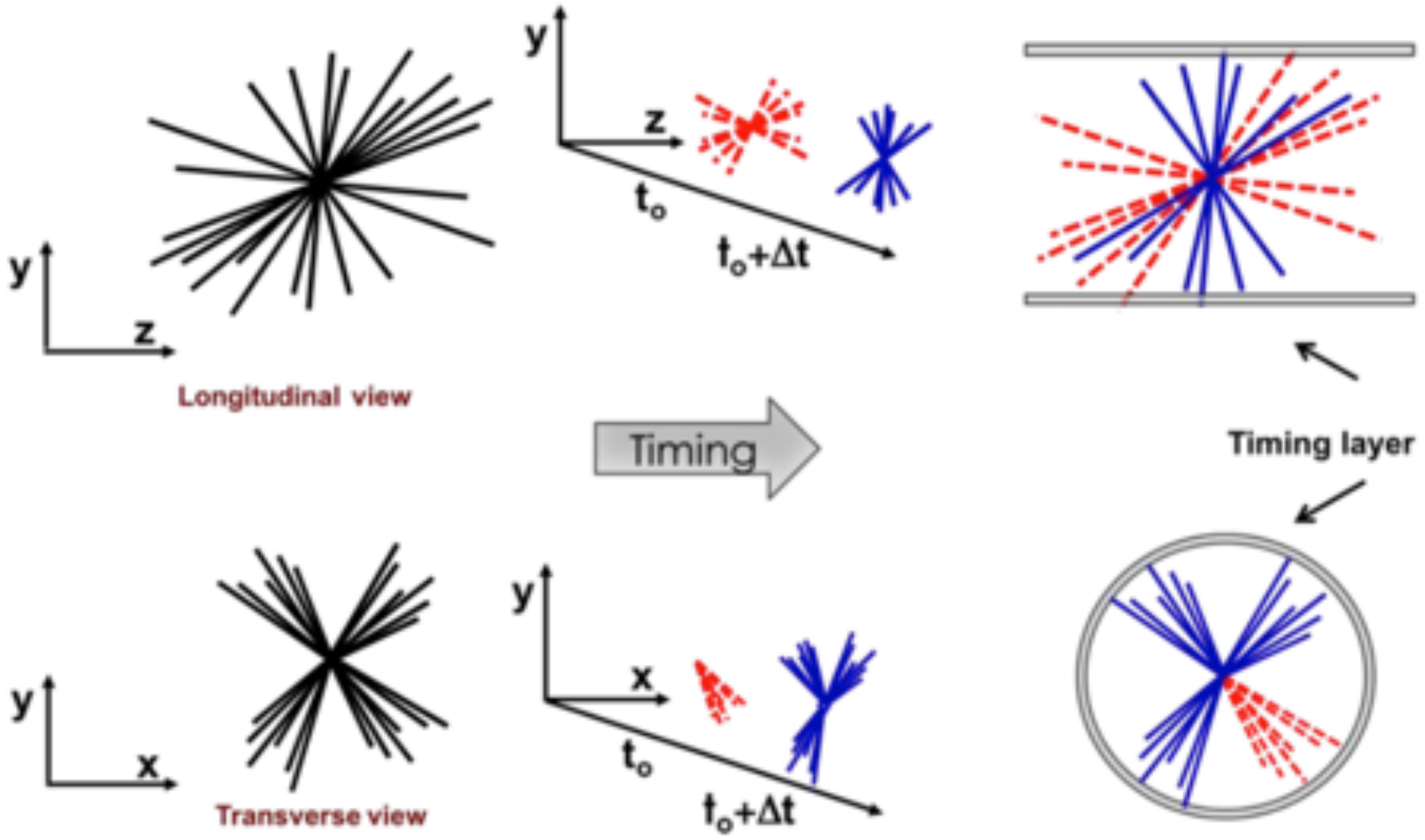
From LHC to High-Luminosity LHC





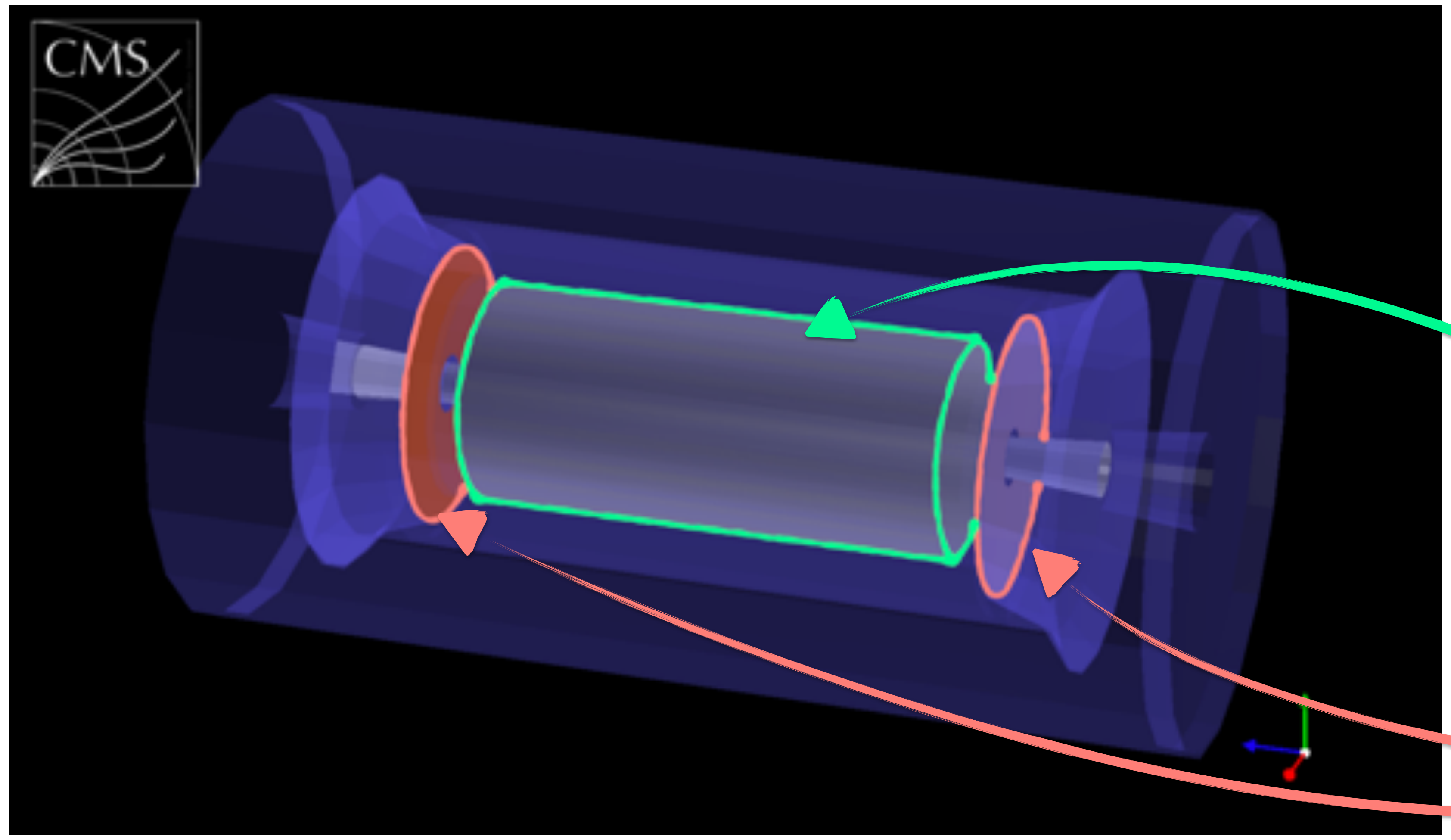
*At **High-Luminosity LHC (HL-LHC)** instantaneous luminosity will increase of a factor ~ 5*

→ *140-200 proton-proton collisions for each bunch crossing (every 25 ns)*

*The **CMS experiment** aims to maintain its performances in the HL-LHC environment:*

→ *addition of a **timing information** needed to distinguish pile-up events overlaid in space but not in time*

→ *Creation of the new Minimum Ionizing Particle Timing Layer*



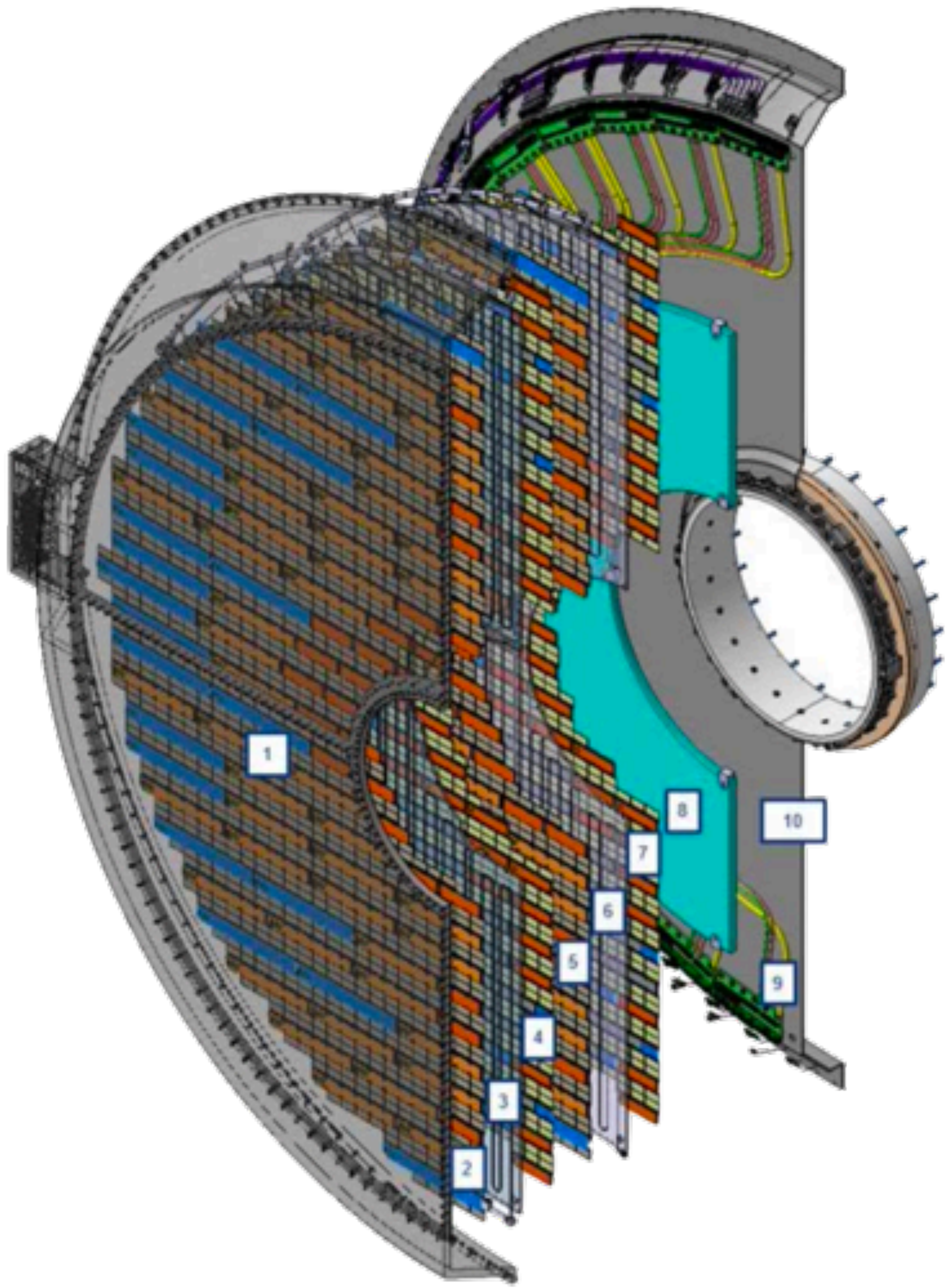
- ***4D tracking**: association of timing information to tracks*
- *Time resolution $\sigma_t \sim$* **30 ps**
- ***Barrel Timing Layer** (BTL): LYSO crystals + SiPMs*
- ***Endcap Timing Layer** (ETL): **Ultra-Fast Silicon Detectors***

The CMS Endcap Timing Layer

Two disks for each endcap covered with sensors on both sides

CMS requirements for ETL sensors:

- *excellent timing performance to reach* $\sigma_t \sim$ **30 ps** *with the whole detector*
- *large devices with excellent uniformity*
- *radiation hardness to withstand fluences up to* $\mathbf{1.7 \times 10^{15}\ n_{eq}/cm^2}$ *in the inner region*
- *narrow inactive area to allow each disk to have a fill-factor (ratio between active and total area) larger than 95%*



Ultra-Fast Silicon Detectors

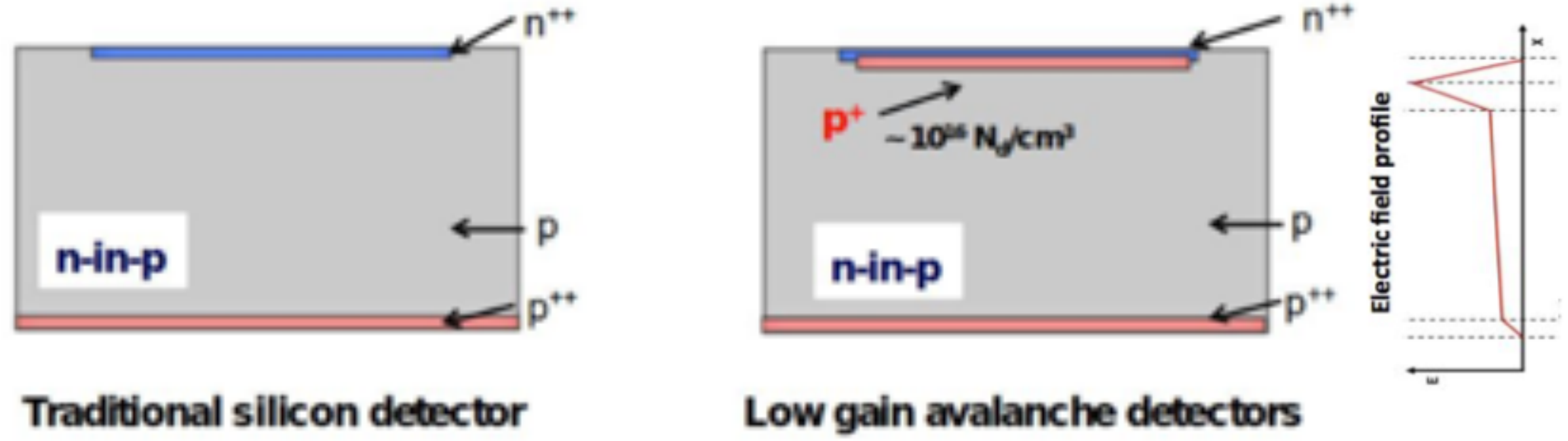
Ultra-Fast Silicon Detectors (UFSD) is a project born in **Torino** in collaboration with the **Fondazione Bruno Kessler** (FBK) and the **University of Trento**

The aim is to develop silicon sensors:

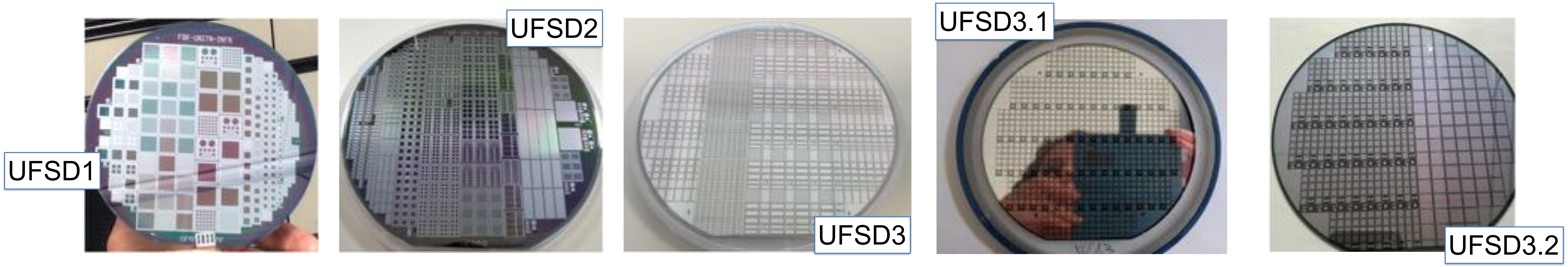
- Based on *Low-Gain Avalanche Diodes* (LGADs), silicon detectors with *moderate gain* (10-20)

  The thin highly-doped *gain layer* causes the generation of a high electric field near the p-n junction

  → *primary charges multiplication*



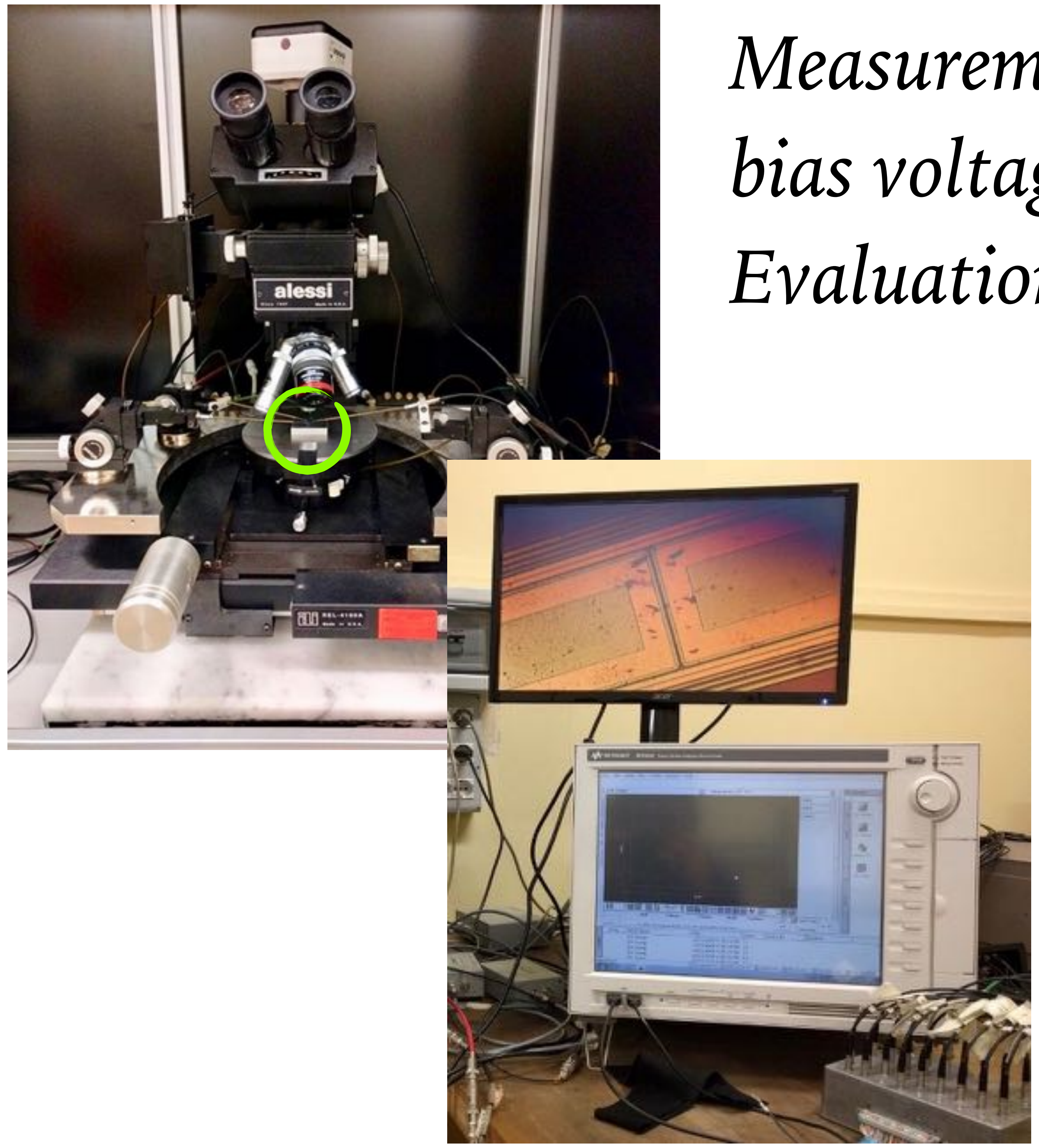
- *Optimized for timing measurements*
- *Radiation resistant*
- *Finely segmented*



Laboratory measurements

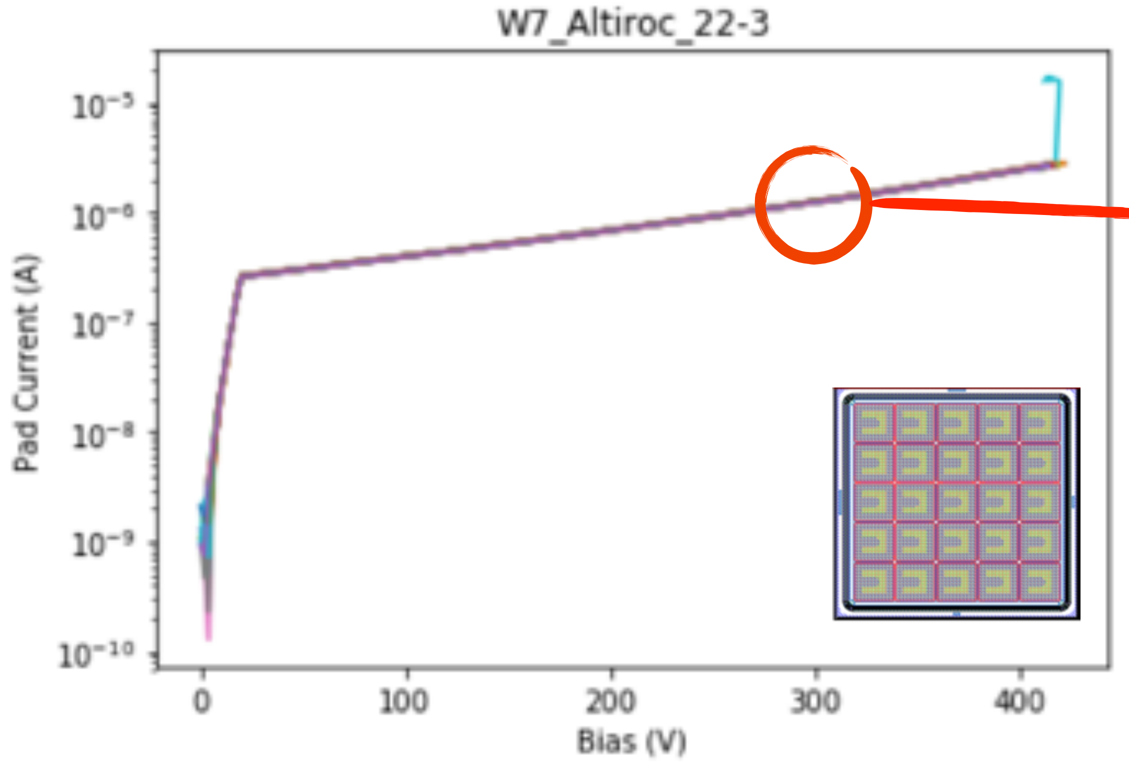
Ultra-Fast Silicon Detectors are tested with multiple setups and techniques before and after irradiation to verify they meet CMS requirements

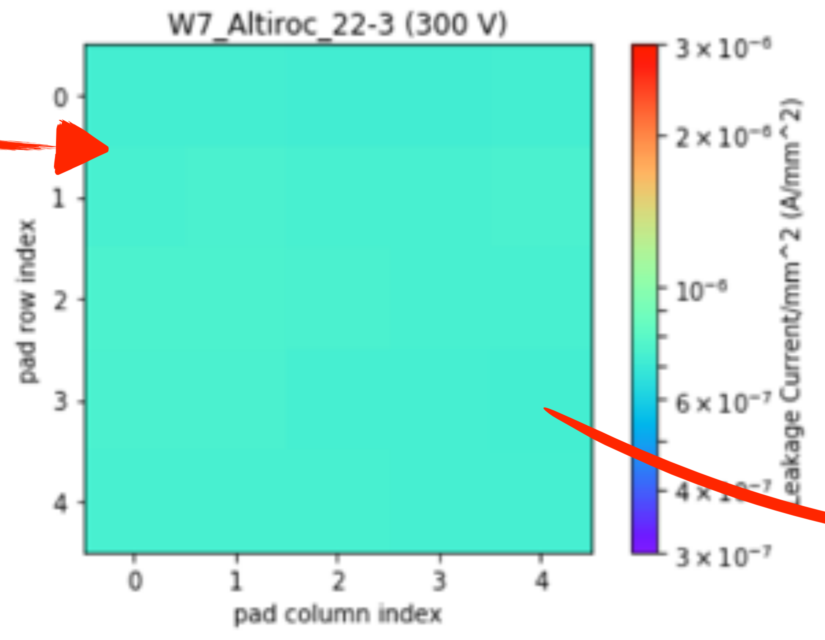
1 ***Static characterization**: do they work properly?*

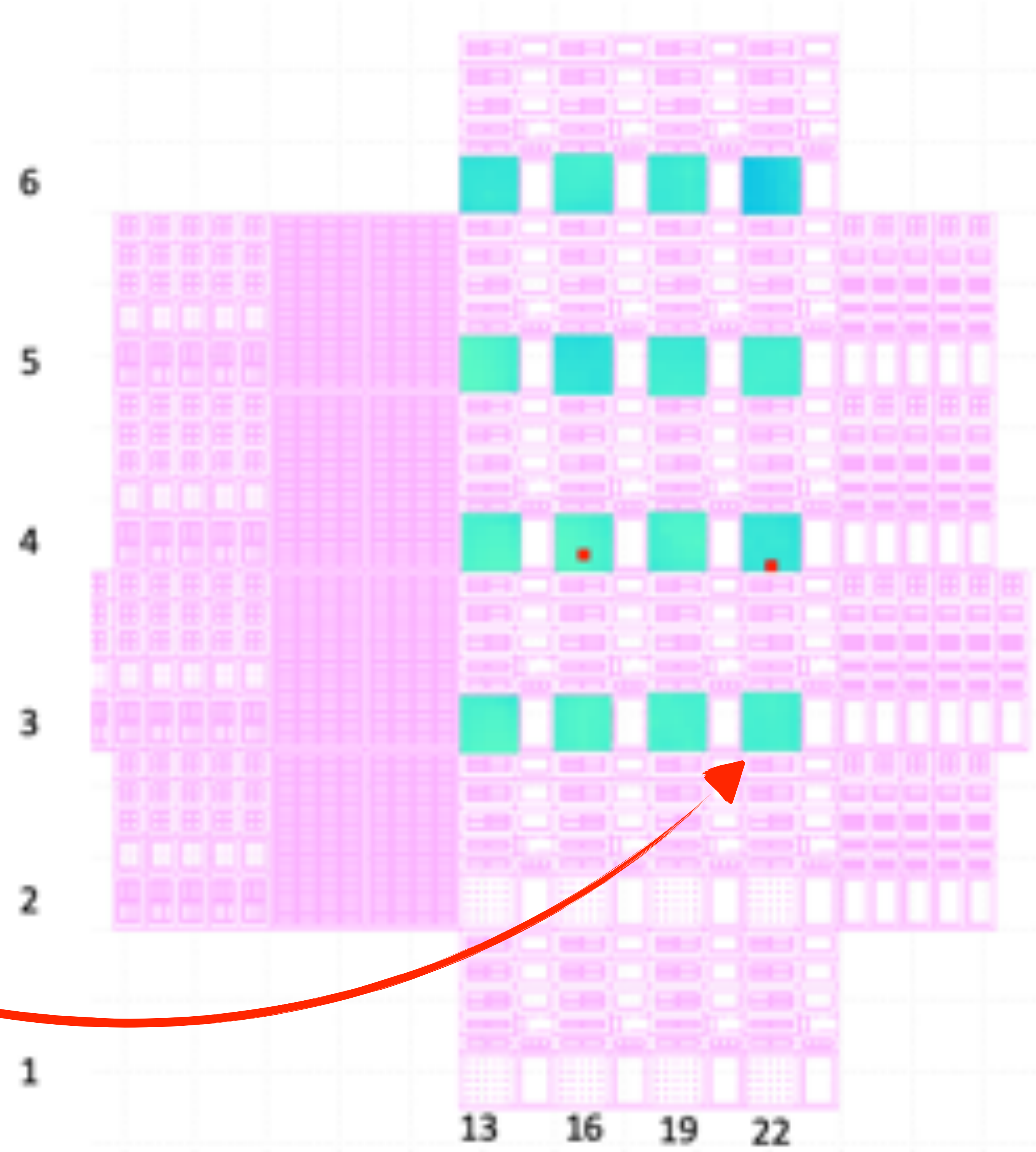


Measurements of current and capacitance as a function of bias voltage at probe stations

*Evaluation of production **yield** and **gain profile uniformity***







Laboratory measurements

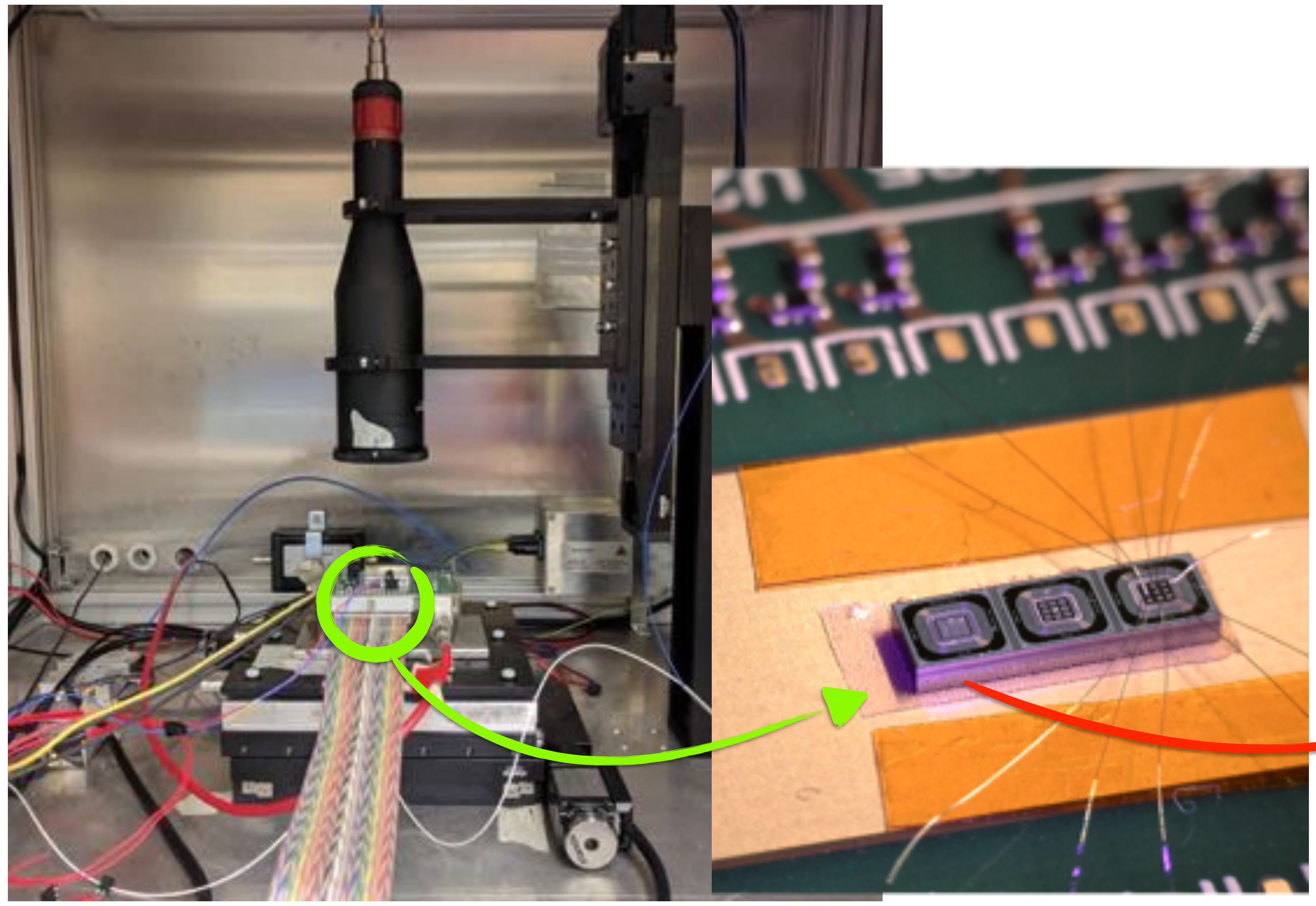
② Dinamic characterization: signals studies with the Transient Current Technique (TCT) setup

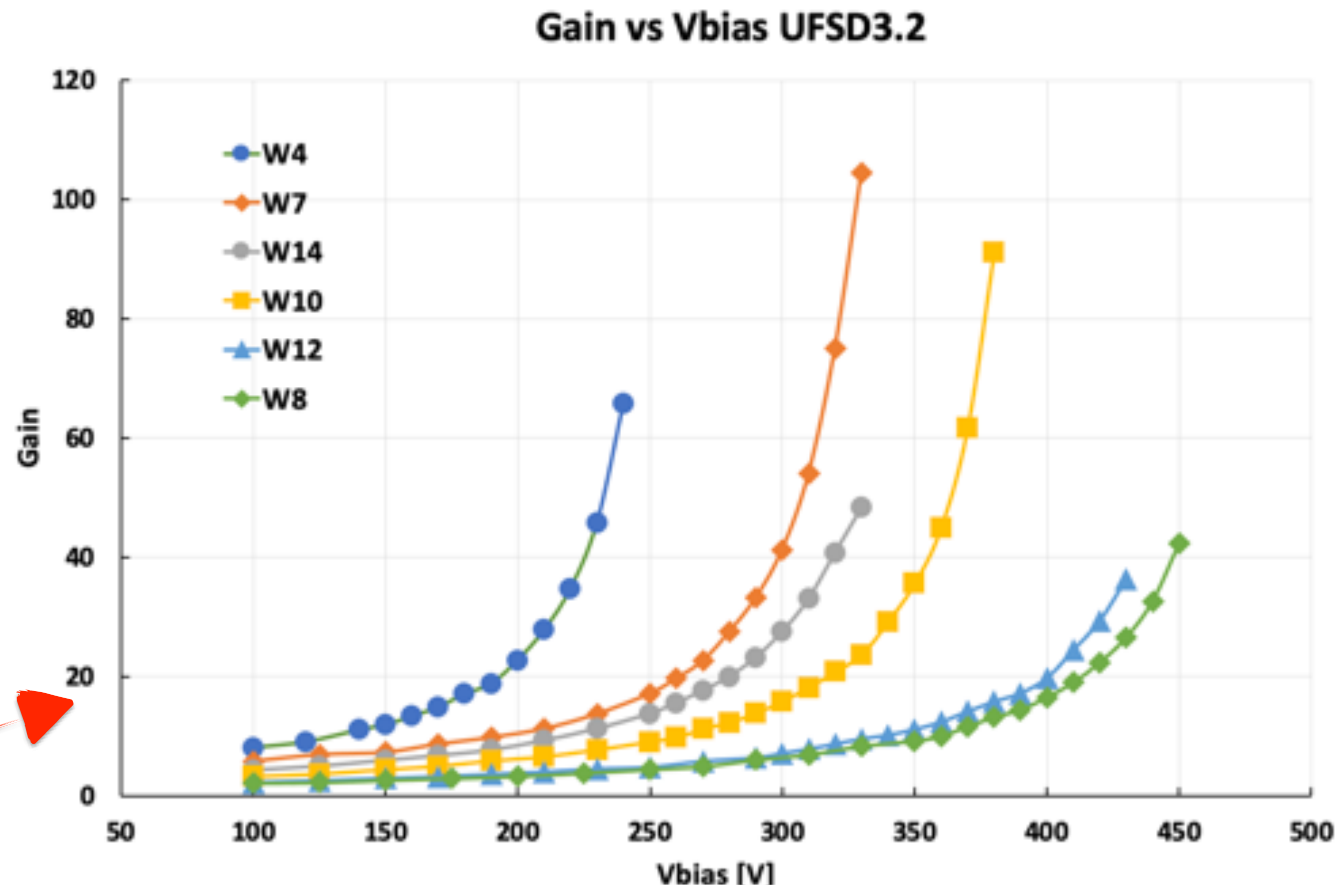
*The TCT exploit the **current signal** generated in silicon sensors by a laser to perform precision measurements*

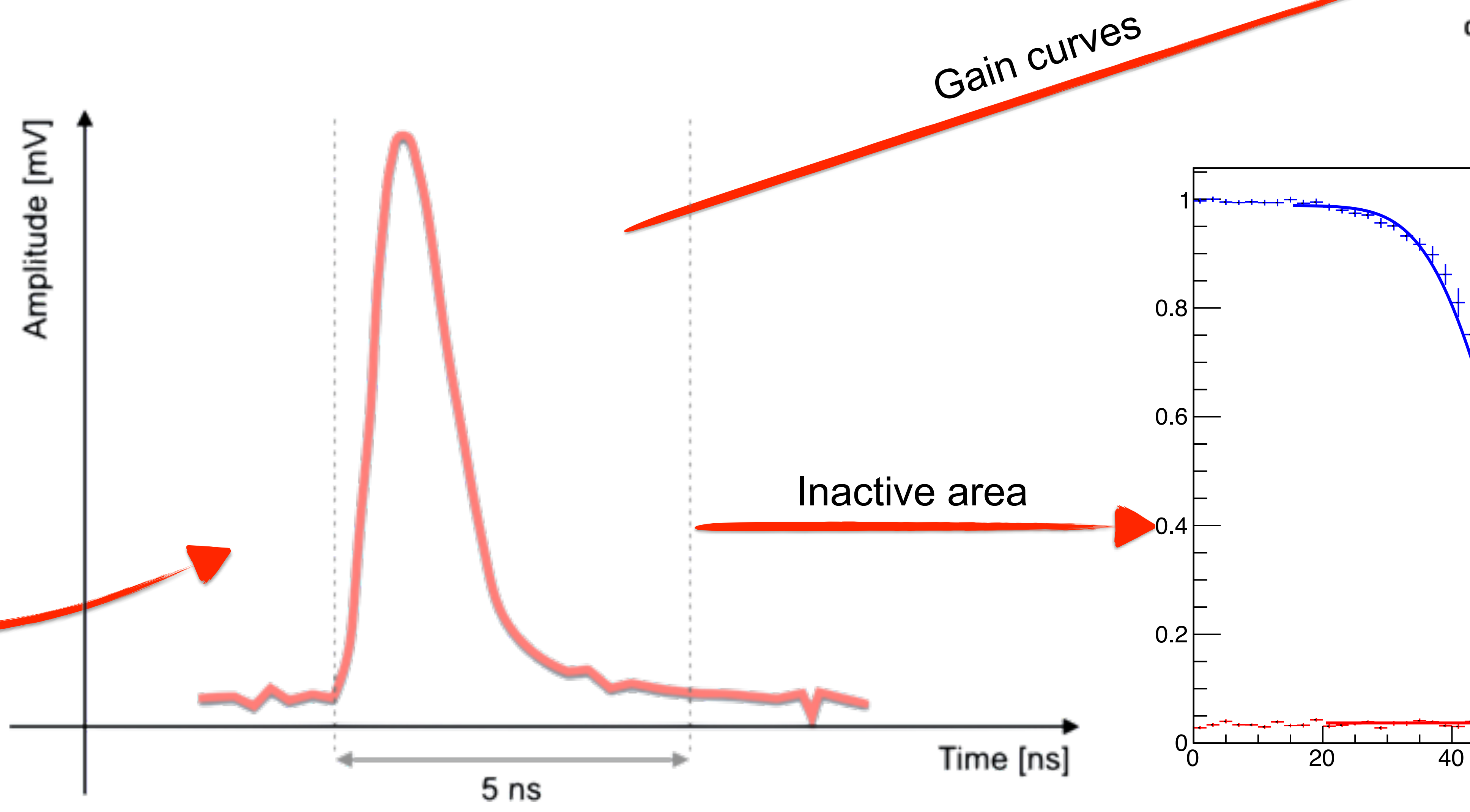
- *moving **stages with micrometrical precision***
- *optical system producing a **laser beam with minimum spot of** $\sim$ **10 μm***

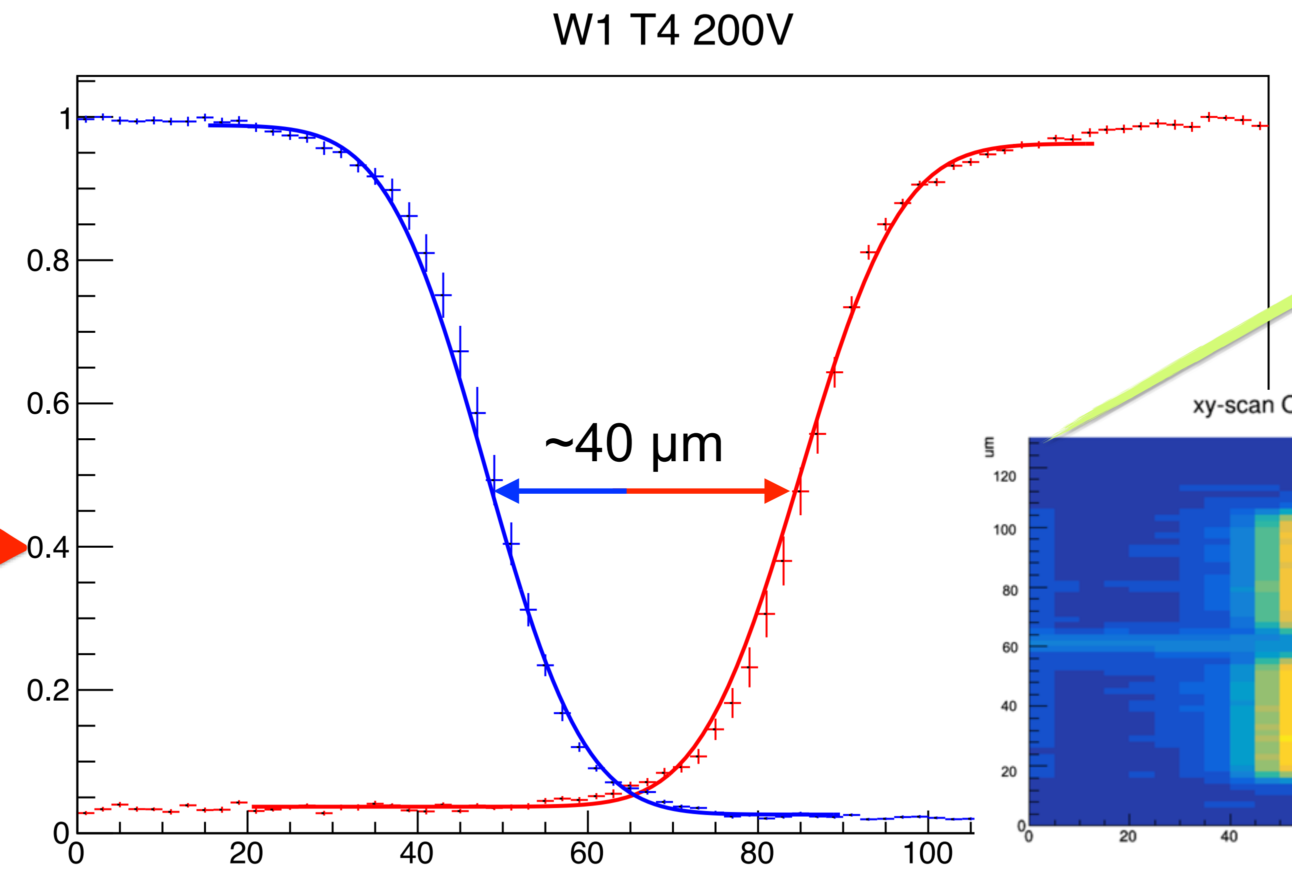
→ *We exactly know where the laser is shot on the device surface*

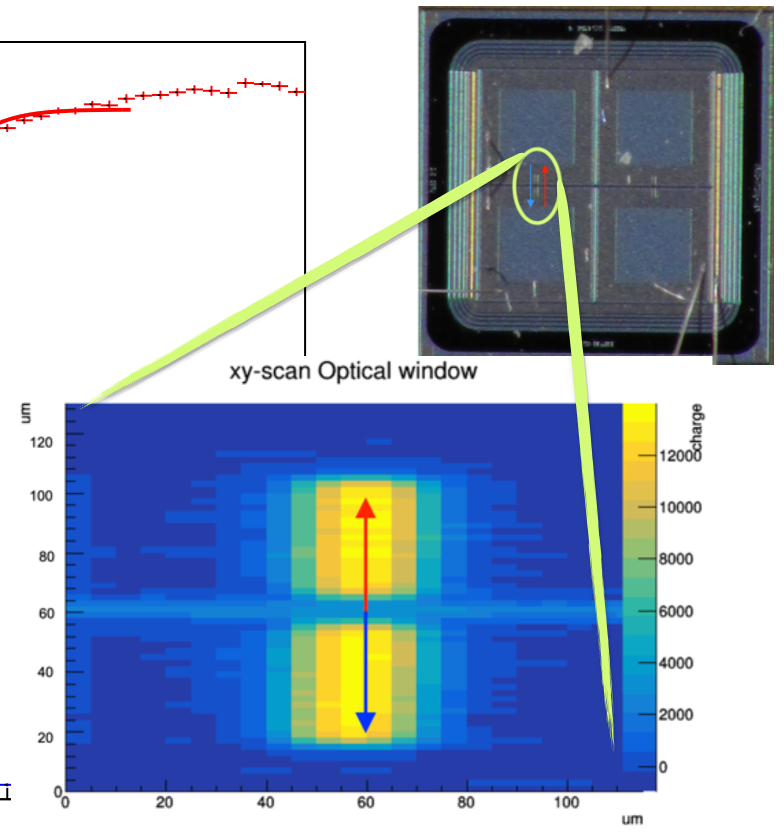
Used to measure gain curves, inactive area width, jitter and trapping











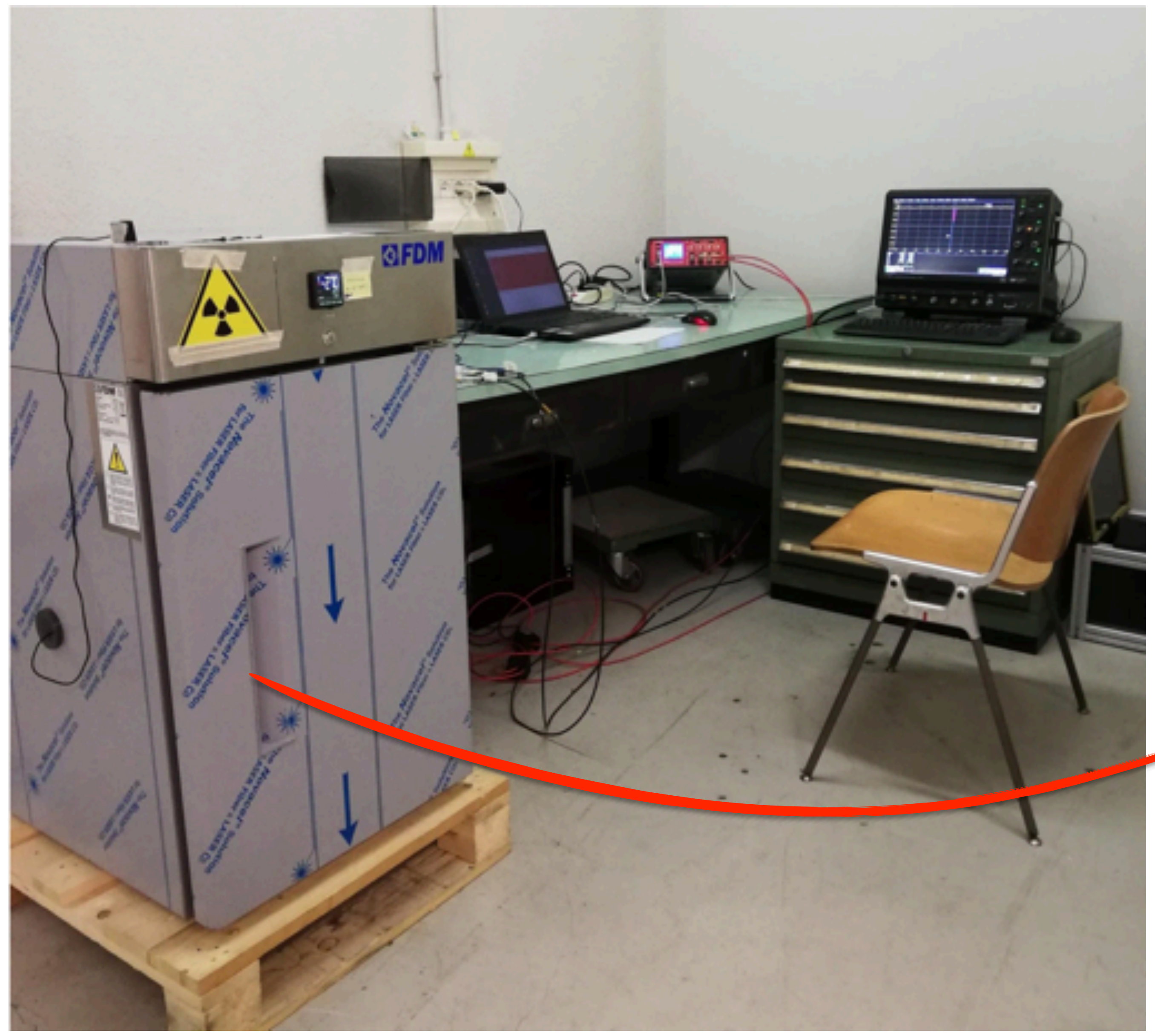
Laboratory measurements

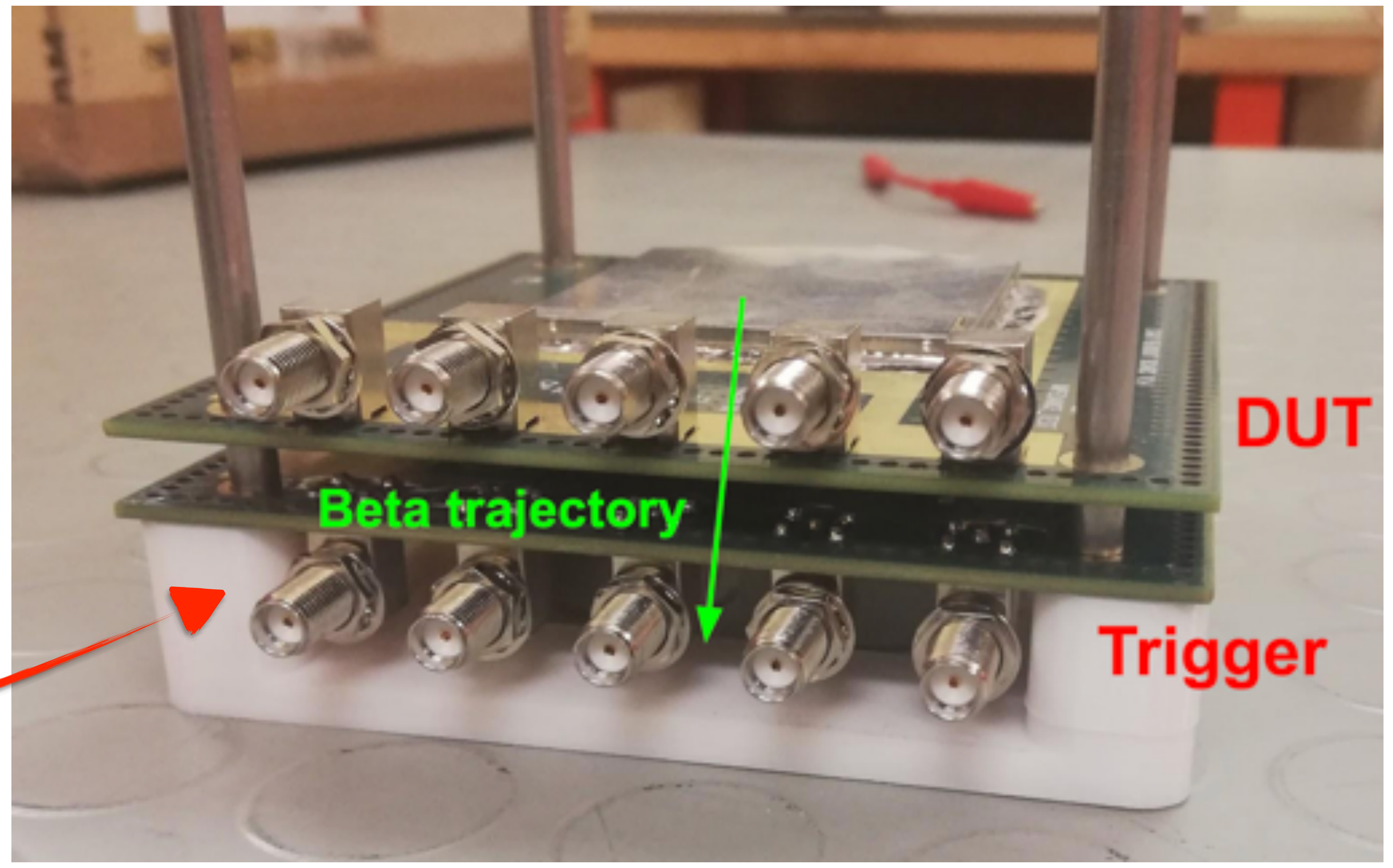
③ ***Dinamic characterization***: *signals studies with* ***beta source***

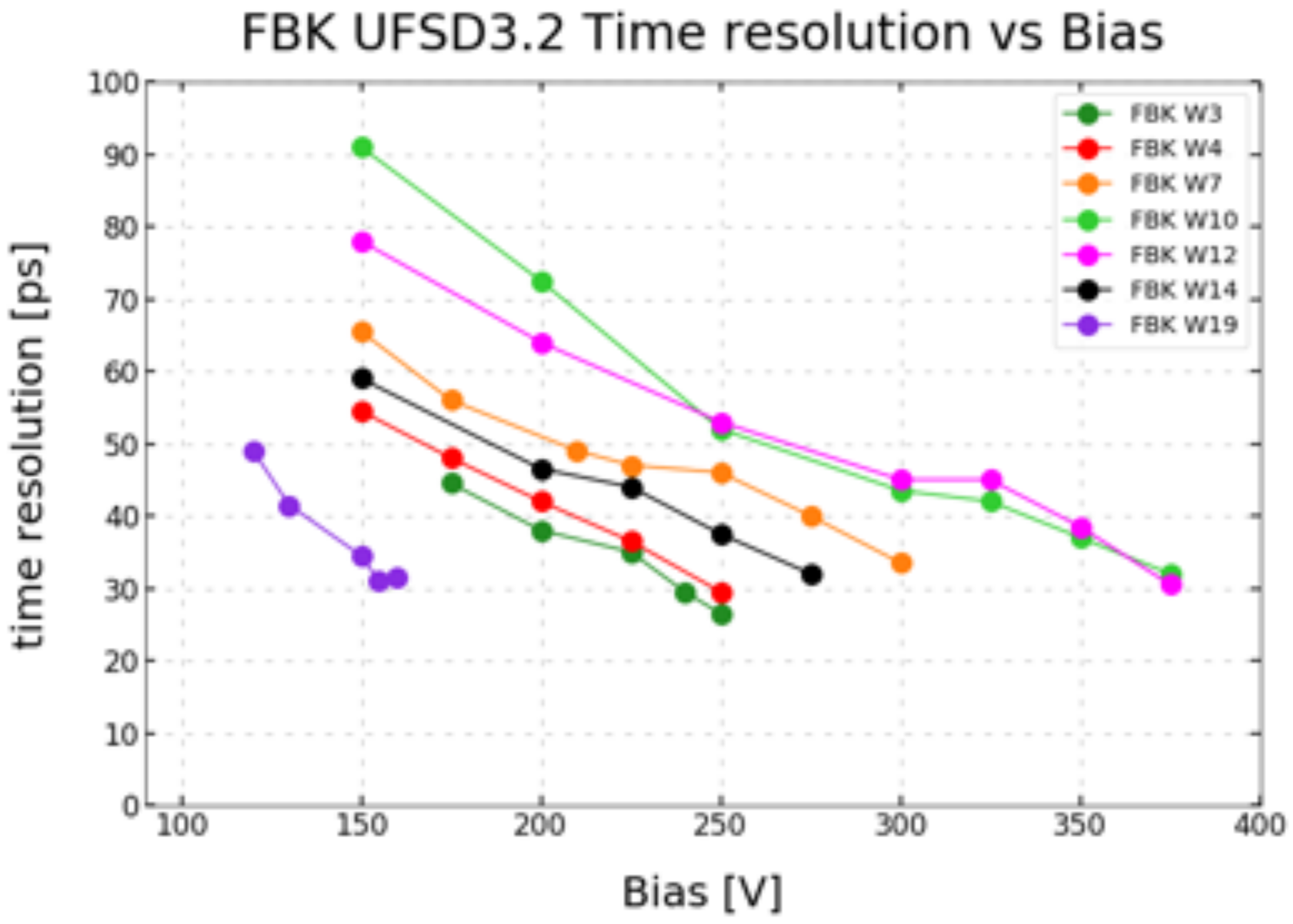
Exploitation of ***Minimum Ionizing Particle*** *emitted isotropically by a* ***Sr90 source***

Telescope with ***trigger + DUT*** *inside an environmental chamber*

Measurements of ***charge***, ***gain*** *and* ***time resolution***

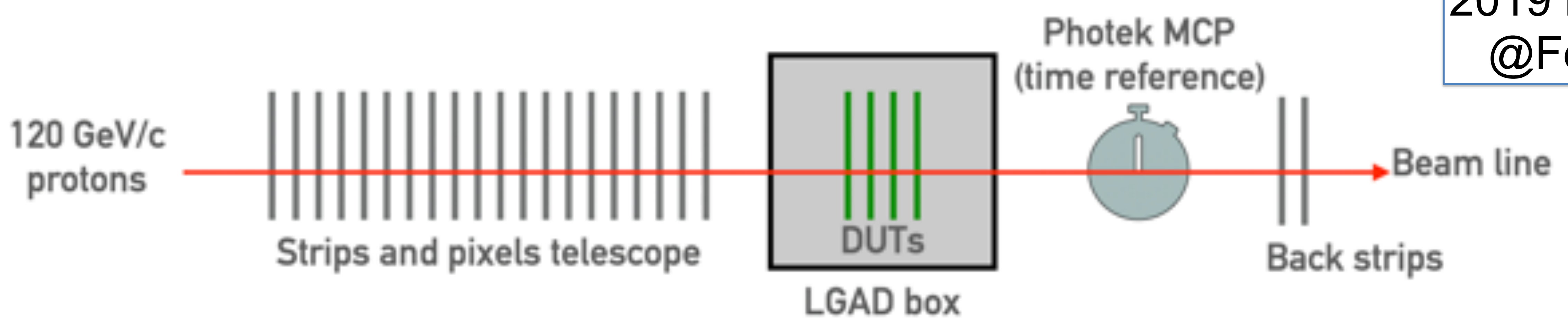




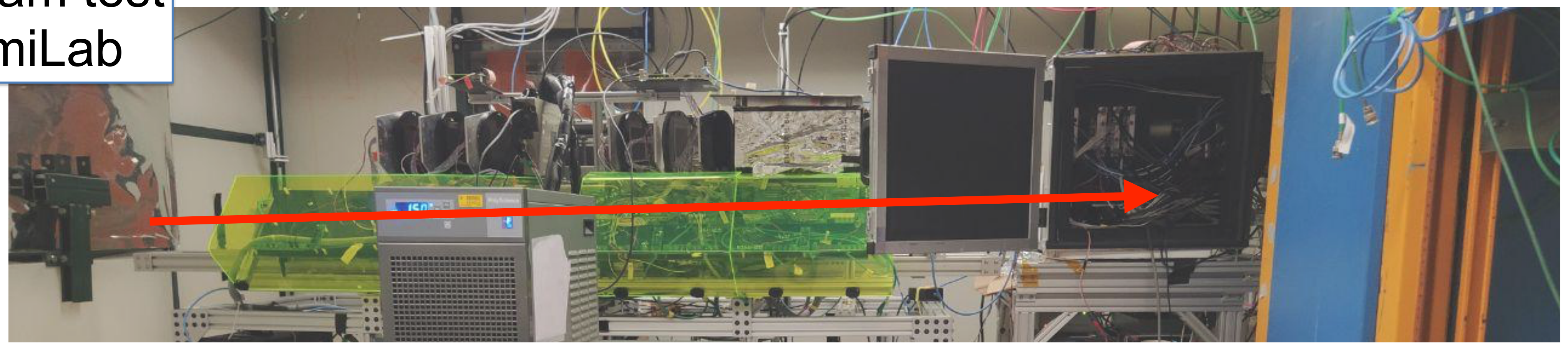


Laboratory measurements

4 Beam tests



2019 beam test @FermiLab

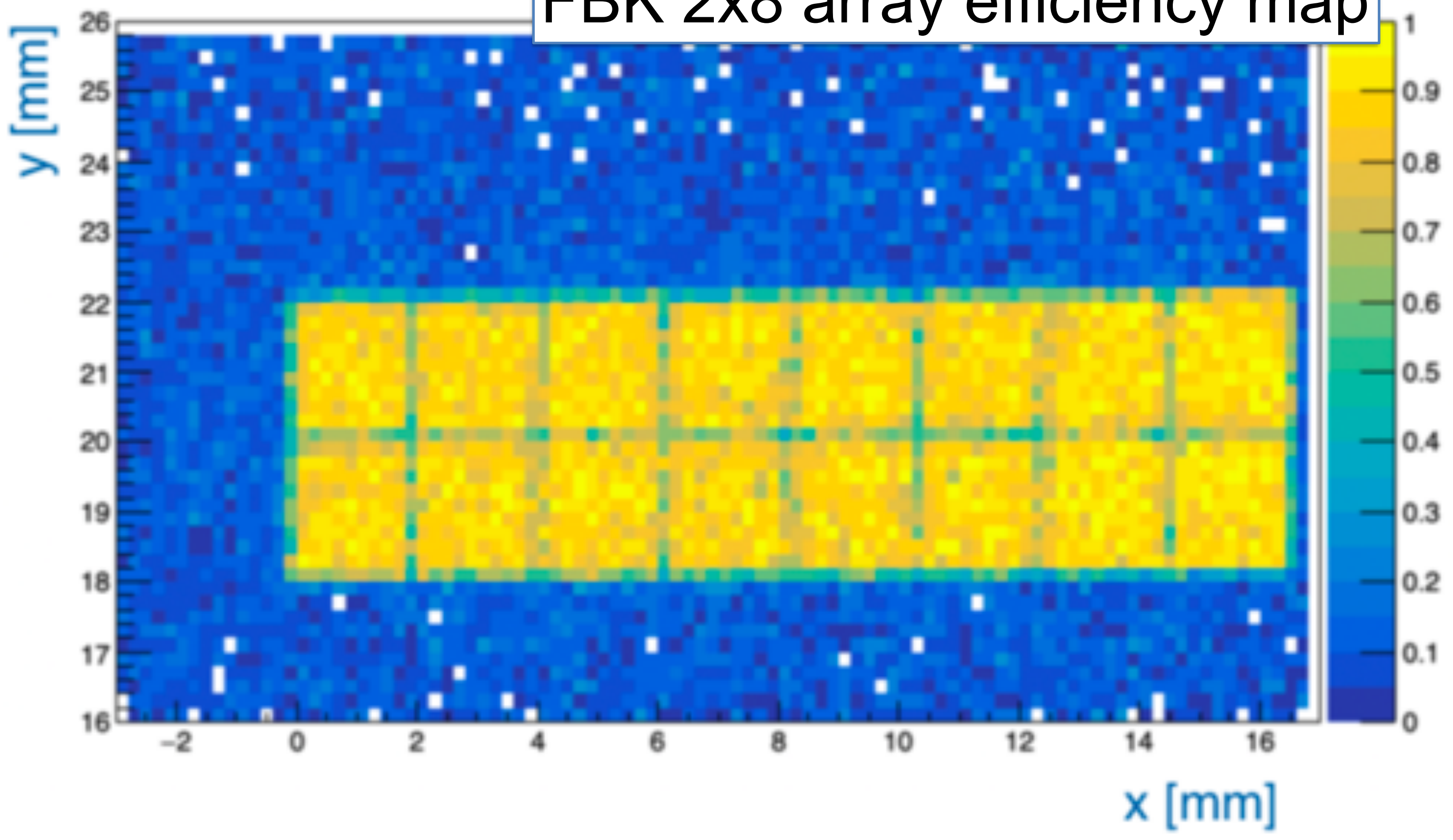


Test with ***beams of Minimum Ionizing Particles*** *in dedicated laboratory (CERN, FNAL)*

Measurements of ***efficiency****,* ***gain****,* ***inactive area*** *and* ***spatial and temporal resolutions***

Setups provided with ***tracking telescopes*** *for hit reconstruction and fast detectors used as* ***reference in timing measurements***

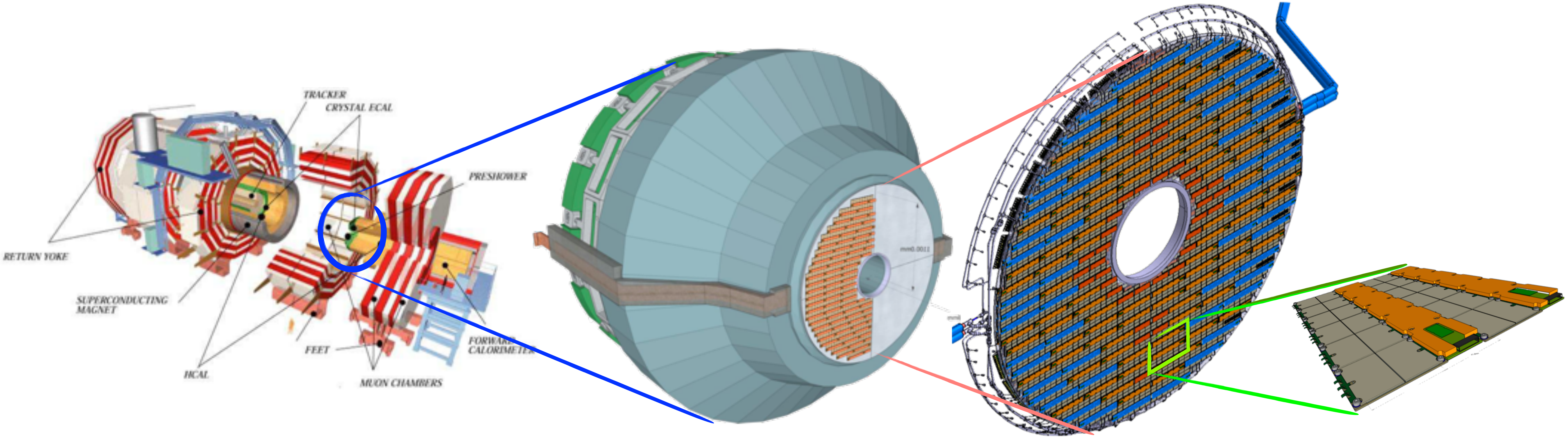
FBK 2x8 array efficiency map



Endcap Timing Layer in CMS software environment

The CMS Minimum Ionizing Particle Timing Layer is a ***brand new detector*** *that will be installed in the experiment in 2026*

→ *It has been necessary to* ***implement the detector geometry inside the CMS software environment*** *(CMSSW) for simulations and future analysis*



UFSD

Acknowledgements

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INFN Istituto Nazionale di Fisica Nucleare

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