Timing performance of thin Low-Gain Avalanche Detectors (LGADs)

Sofia Strazzi (University and INFN, Bologna)

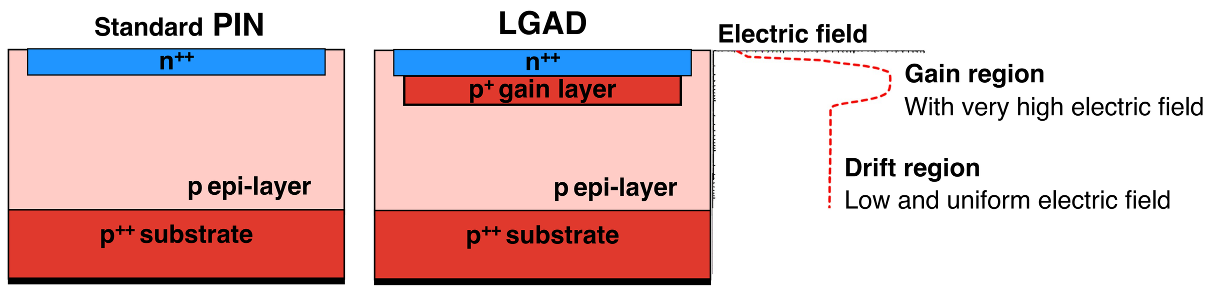
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

INFN Istituto Nazionale di Fisica Nucleare

INTRODUCTION

LOW GAIN AVALANCHE DETECTORS

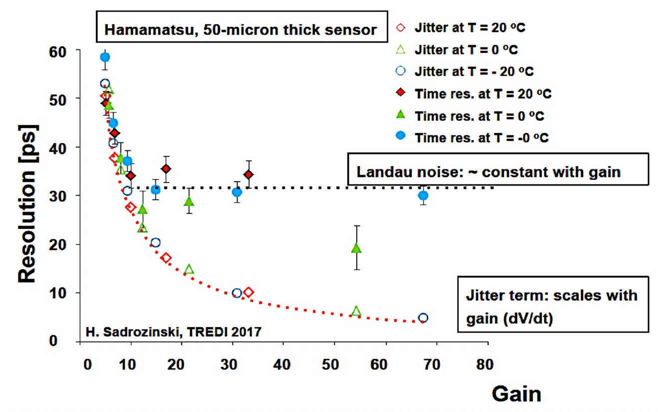
LGADs are silicon detectors used to **detect charged particles.**
→ They are an evolution of n-on-p (PIN) sensors, obtained by implanting an additional highly doped gain layer below the p-n junction.



Based on internal Low-gain (10-70) multiplication mechanism → Large and fast signals (in respect to sensors without gain layer) → Improved Signal to Noise ratio (S/N); **Excellent timing performance**

Extensively studied: most mature silicon detector technology for timing applications.

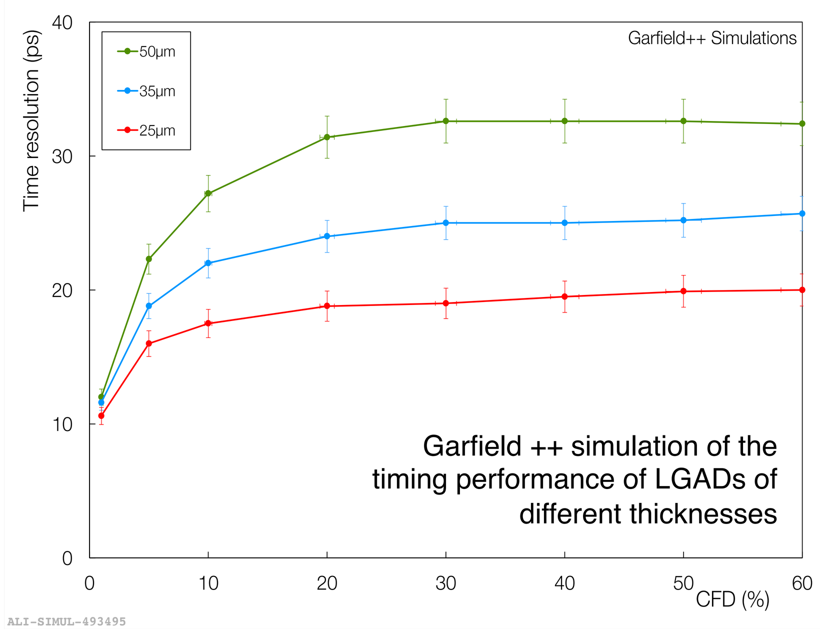
MOTIVATIONS



State of the art

50 µm thick LGAD: time resolution **~30 ps**

→ Already envisioned for the detector upgrades at the HL-LHC, both in ATLAS and CMS for 2026.



Garfield ++ simulation of the timing performance of LGADs of different thicknesses

Timing layers of future, more advanced high energy physics experiments **require even better time resolutions** (~20 ps). Looking at the simulations, **a thinner LGAD design** could match the requirements.

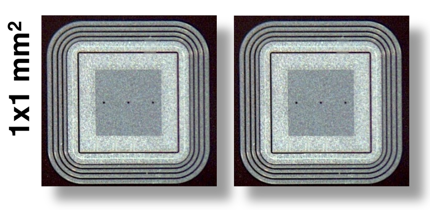
Many other applications:

- Positron Emission Tomography (**PET**): better image quality and lower dose on patients
- **Particle counting** and **hydrotherapy**: possibility to reach unprecedented rate capabilities
- **3D** and **robotic** vision: excellent precision in the reconstruction (few mm spatial resolution)

TESTED LGADs

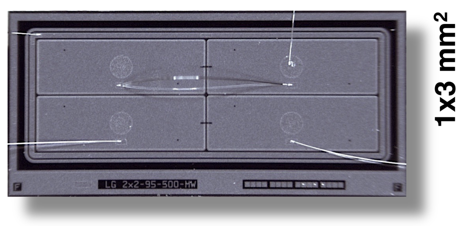
TESTED SENSORS

First very thin LGAD prototypes produced by Fondazione Bruno Kessler (FBK, Italy)



25 µm
35 µm
FBK single channel

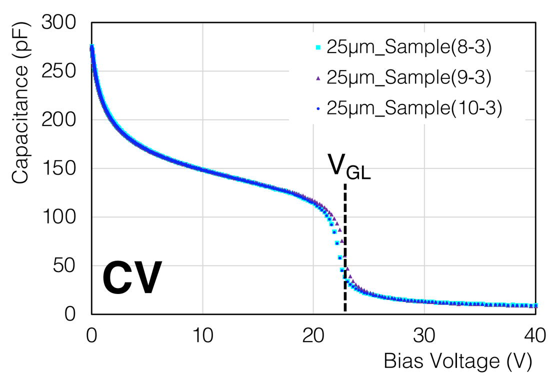
Reference **50 µm** HPK LGAD

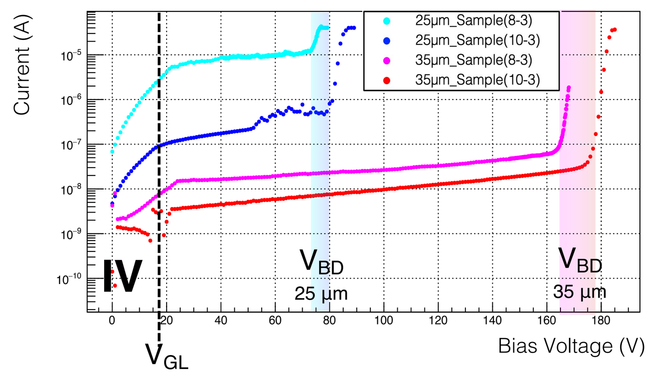


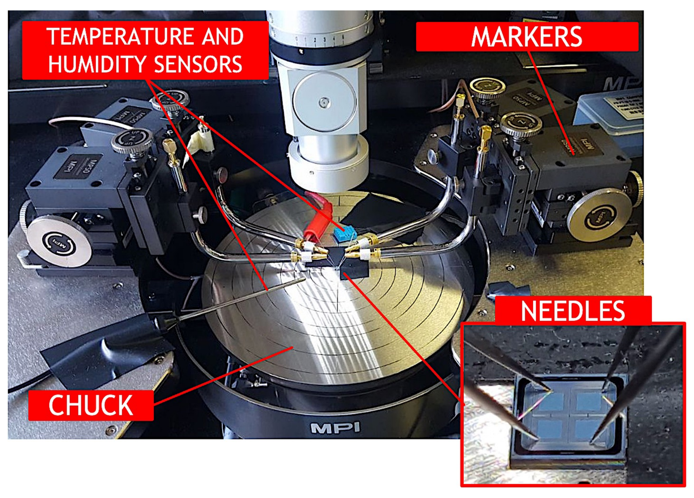
- **Comparison** with the thinner design
- **Validation** of setup and analysis technique

CHARACTERIZATION

The **electrical characterization** was done on the **bare prototypes** by performing current (IV) and capacitance (CV) measurements at different bias voltages using a **probe station.**







Many useful quantities could be extracted from the curves:

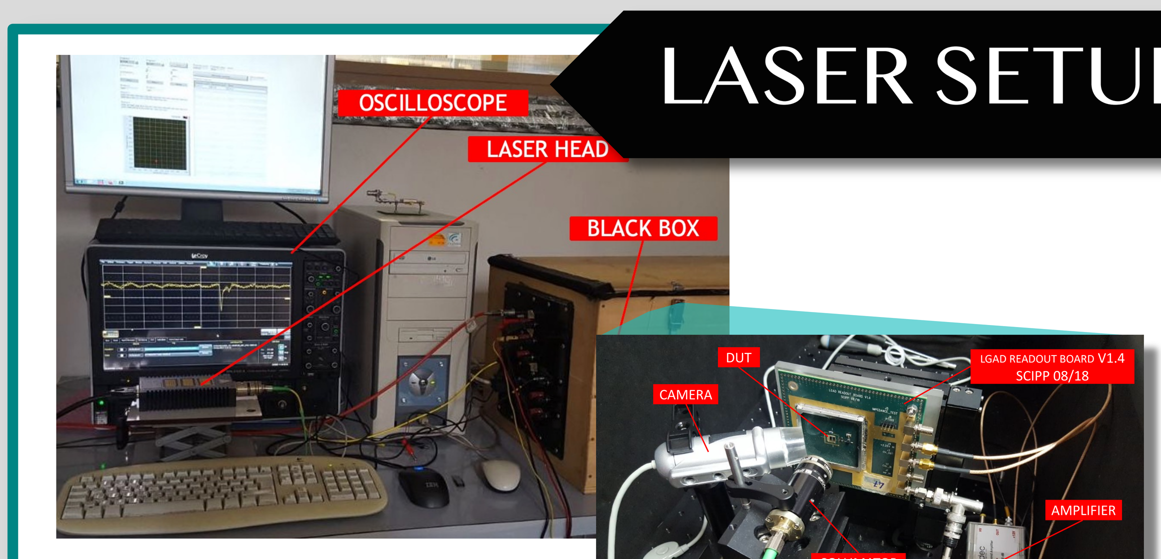
Capacitance-Voltage characteristics

- Voltage in which the gain layer depletes (V_{GL})
- Full sensor **depletion** voltage
- **Doping** profile and uniformity
- **Electric field**

Current-Voltage characteristics

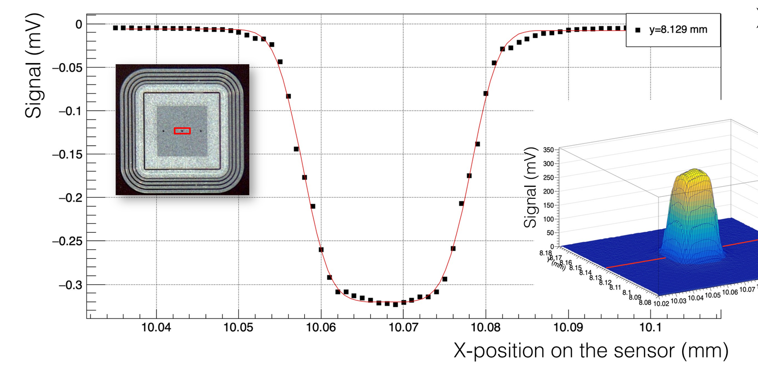
- Information on the voltage interval of **operation**
- breakdown voltage (V_{BD})
- Evaluation of the **layout** of the sensors

LASER SETUP

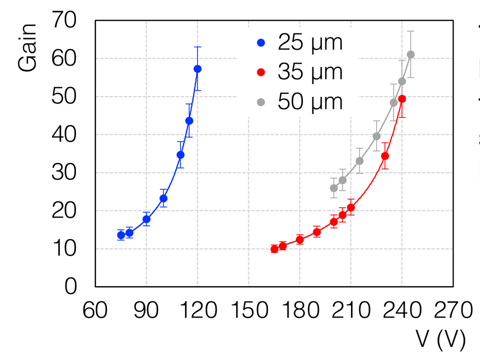


A preliminary performance study was done through a laser setup.

PRELIMINARY RESULTS

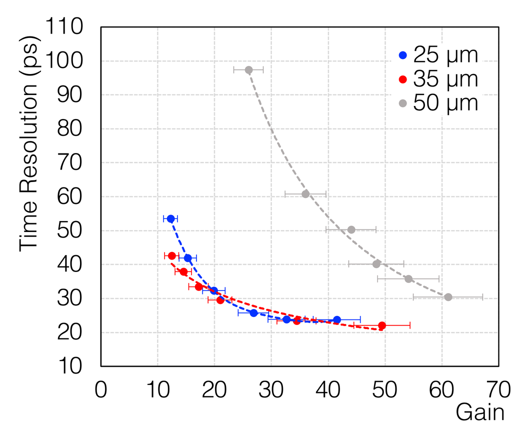


- Evaluation of the light-sensitive areas in terms of:
  - Efficiency
  - Uniformity
- Extraction of windows and laser spot dimensions



The **gain** of the sensors was extracted by **comparing** the signal obtained in the LGAD and in a **sensor** with the same layout, but **without the gain layer**.

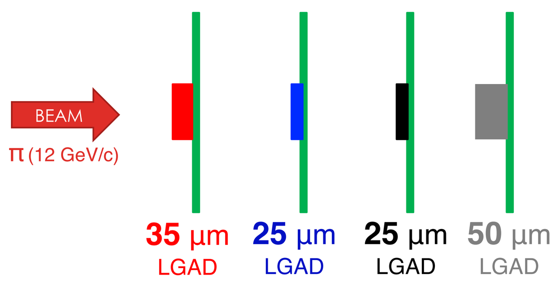
Preliminary results on the **timing performance** were obtained with the laser light intensity tuned to **reproduce** the energy deposition of **a MIP** in the detector. The time resolution was extracted by applying the **CFD method.**

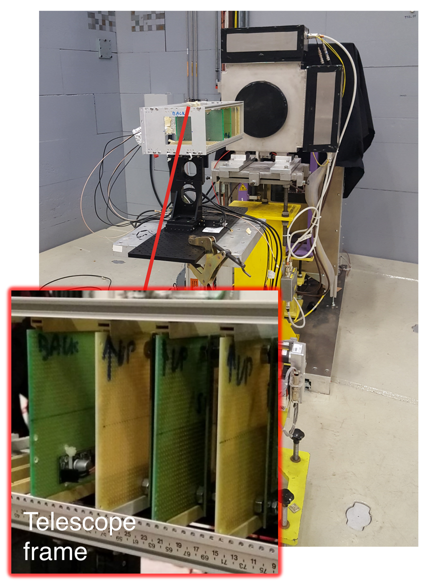


TEST BEAM

SETUP

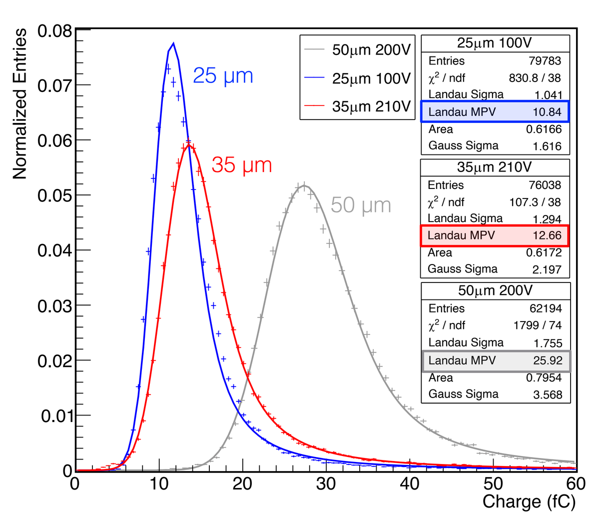
The setup was designed to use up to **four sample boards,** aligned back-to-back, in a telescope frame.





CHARGE DISTRIBUTION

Charge distributions for a similar gain (G~23)



A fit is done with a convolution of:

- **Landau** (signal shape)
- **Gaussian** (noise distribution)

functions to extract the charge MPV.

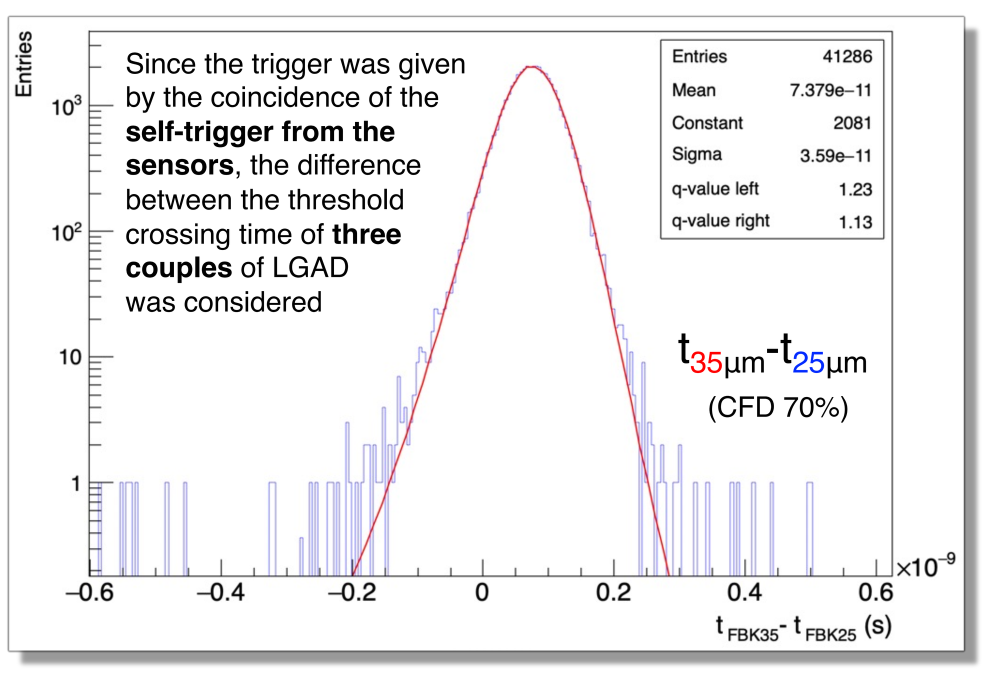
→ the **MPV increases** both as a function of **thickness** and of **voltage**

→ All the values are in **accordance with the ideal** ones

RESULTS

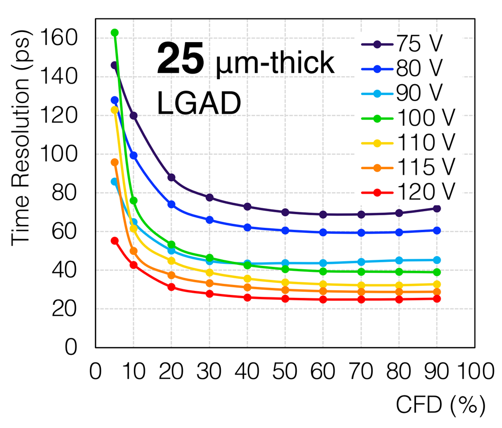
DATA ANALYSIS

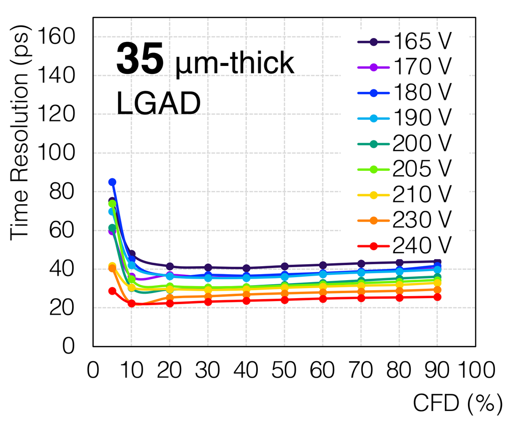
The time resolution was evaluated by applying the **Constant Fraction Discrimination** (CFD) technique to minimize the time slewing effect.



Each distribution was fitted with an **asymmetric q-Gaussian** function.

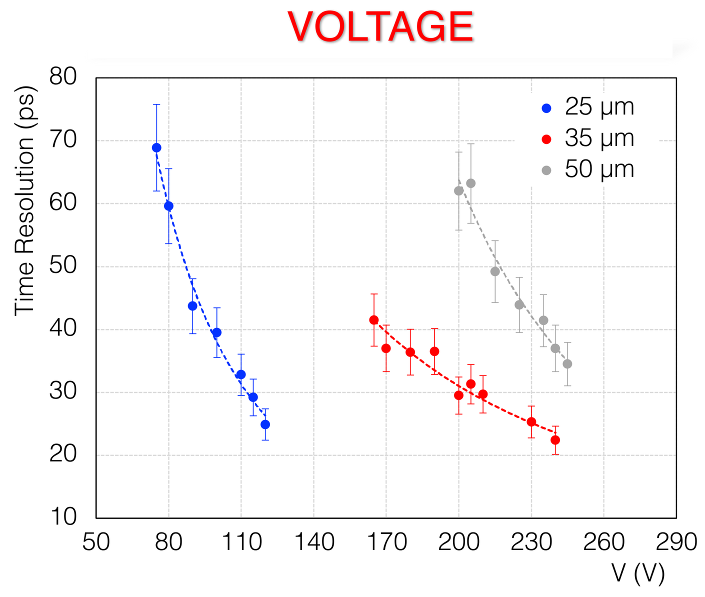
The **sigma extracted** from the fit has then been used to obtain the **final time resolution** of the three sensors at a certain voltage and CFD.

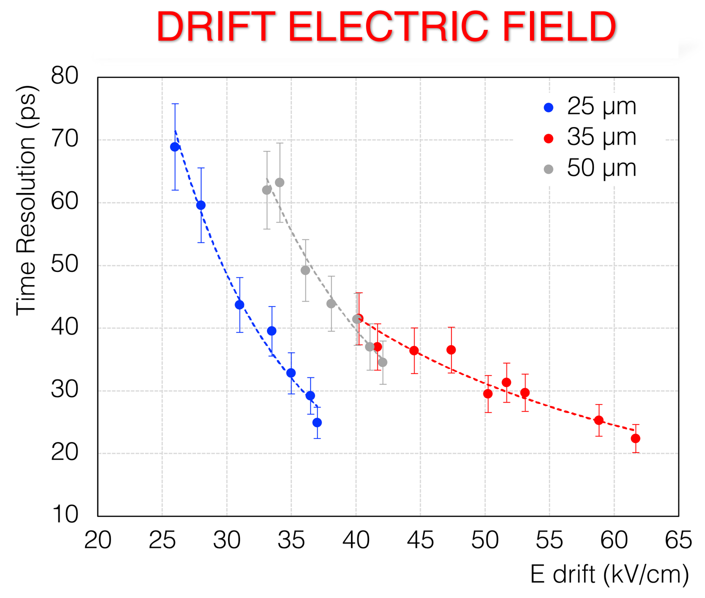


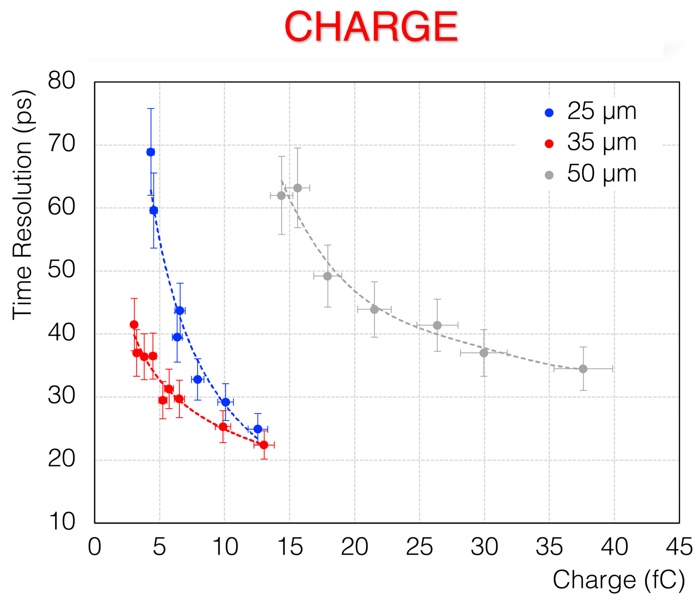


TIME RESOLUTION

The time resolution for a fixed CFD (the one that minimizes the time resolution) is reported as a function of different quantities:







Reference **50 µm** LGAD: The reference standard LGAD reached a time resolution of ~**34 ps** in line with the expectations
→ Validation of experimental setup and analysis procedure

35 µm LGAD: **~22 ps** at 240V (Gain ~49)
The measured time resolution is totally in agreement with MC simulations

25 µm LGAD: **~25 ps** at 120V (Gain ~57)
Time resolution is slightly worse than simulations, probably due to the non-optimized wafer production

Both results demonstrated the expectations of **improved time resolution with thinner LGAD detectors**