Istituto Nazionale di Fisica Nucleare
Sezione di Torino

Innovative Silicon Sensors

silicon sensors able to measure space and time

FAST TEAM

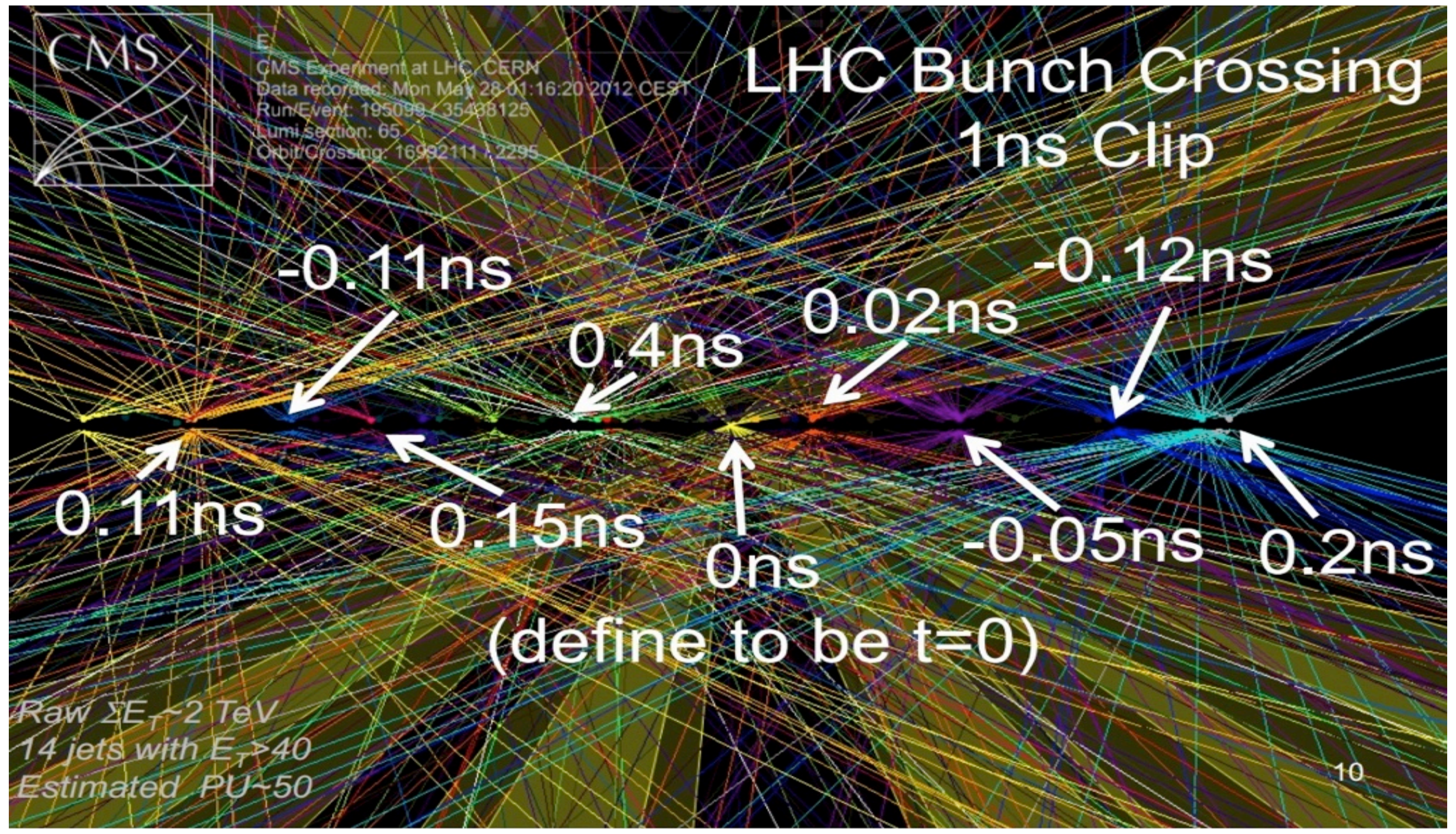
National Seminar on Innovative detectors (SNRI-VII) — 9 October 2023

Why is timing needed in the next generation of particle experiments?

PRESENT SITUATION

the collisions are separated in space and time

Proton beam

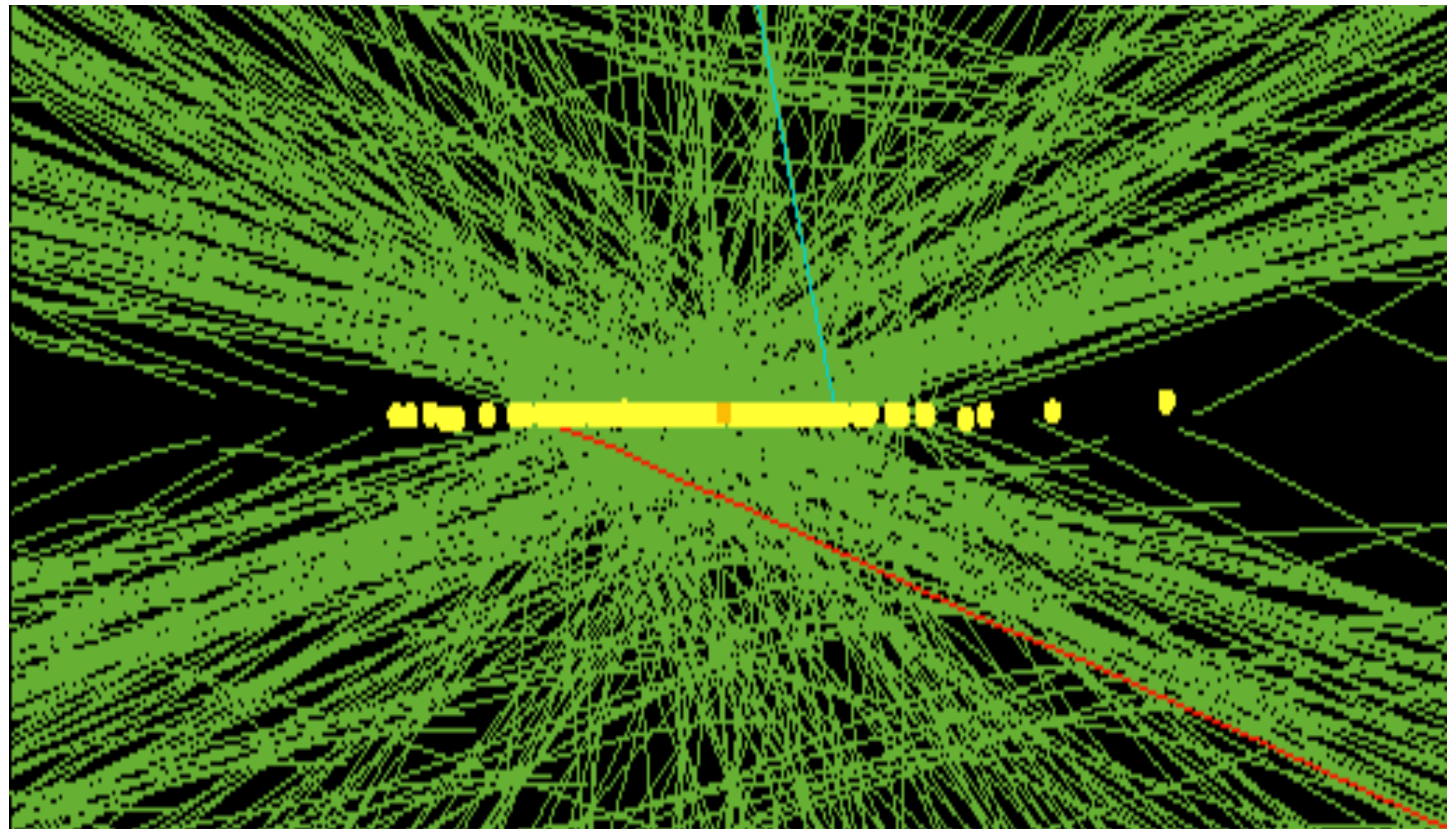


Proton beam

NEAR FUTURE SITUATION

the collisions are so dense that they overlap in space

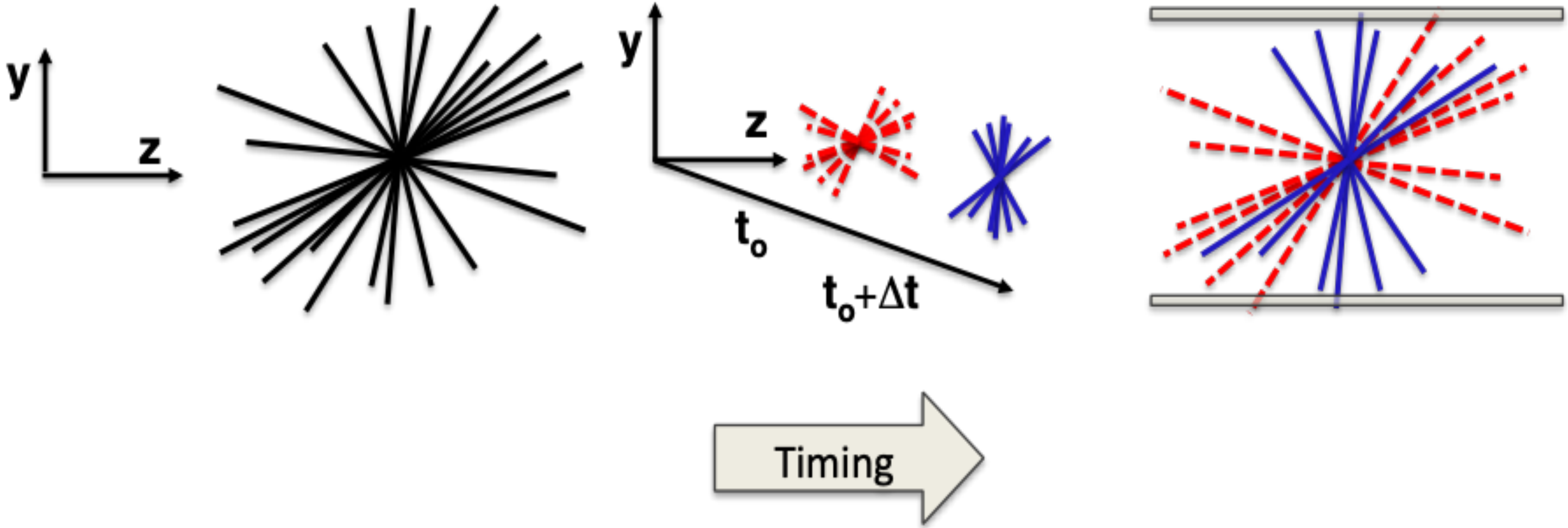
Proton beam



Proton beam

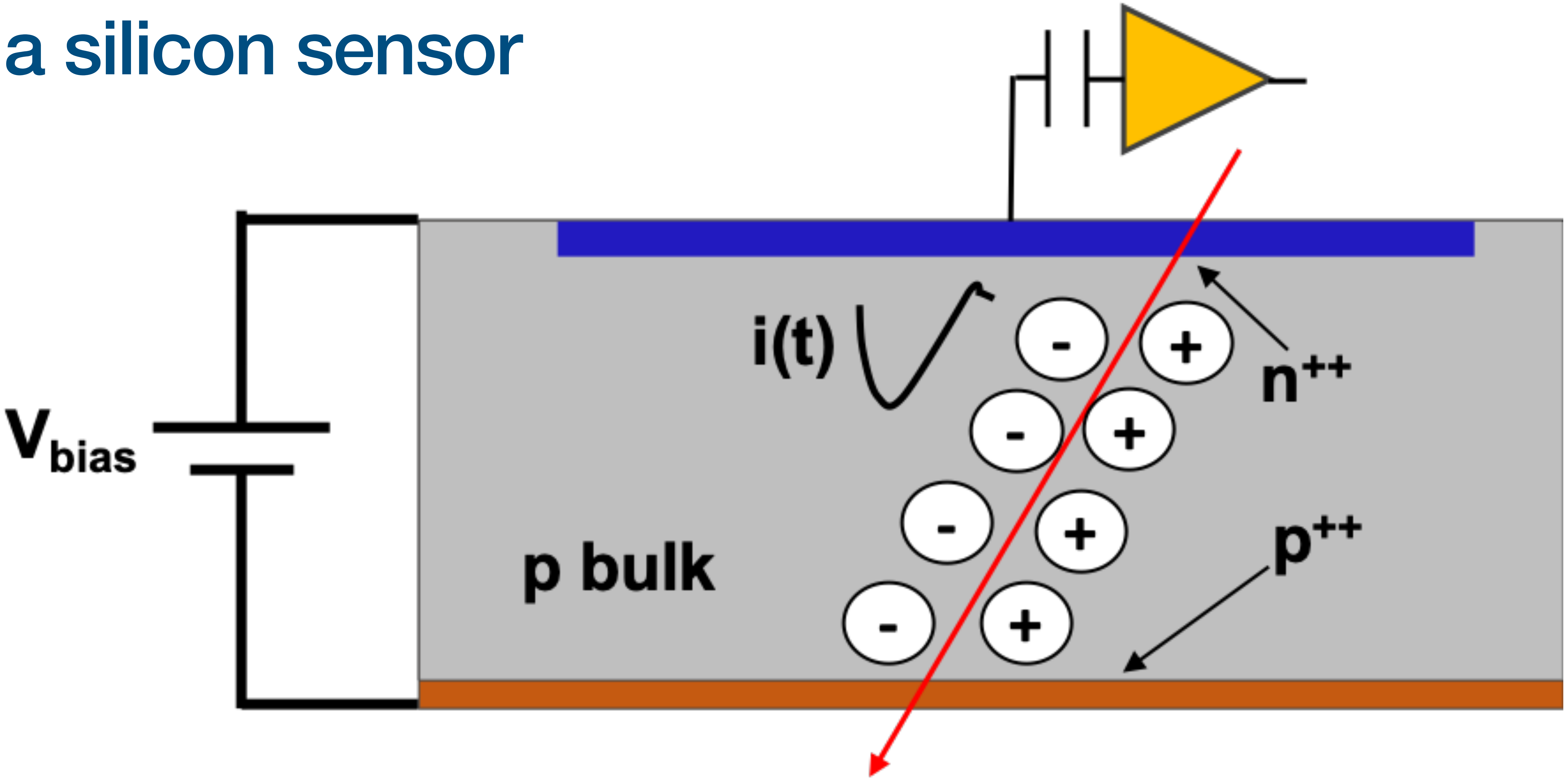
We can use the time of the interaction to separate events that are overlapping in space

One extra dimension: tracking in 4Dimension



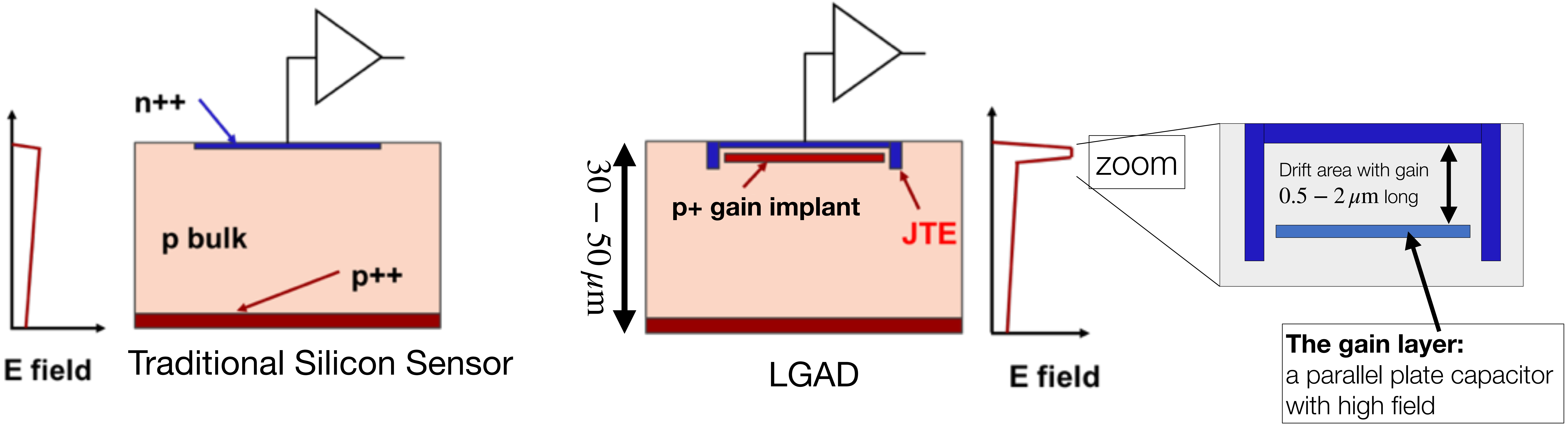
The introduction of timing allows separating collisions that happen in the same location

Basic operation of a silicon sensor



- A reverse bias voltage creates a depleted region inside the volume of the device
- A particle crosses the device and it create e/h pair
- The charge start moving into the depleted region under the effect of the electric field
- The motion of the charges induces a signal on the electrodes
- The signal ends when the charges reach the electrodes

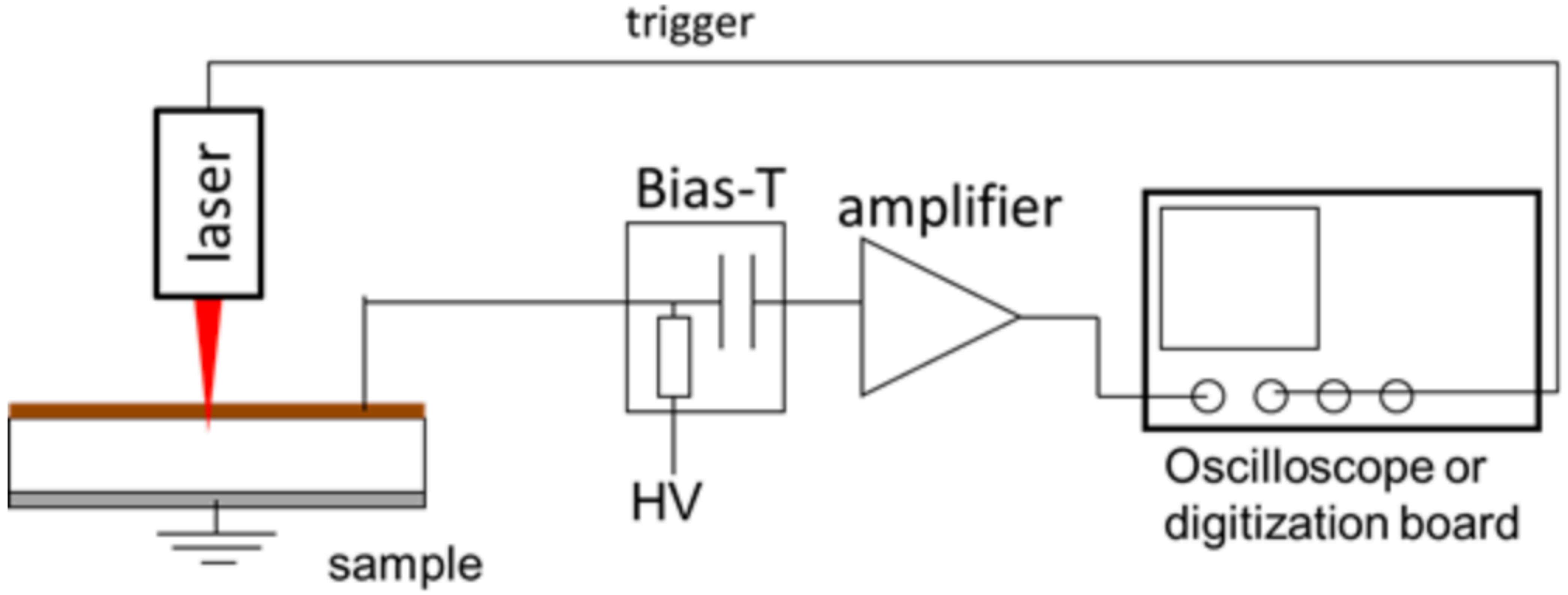
Key design innovation: low gain avalanche diode (LGAD)

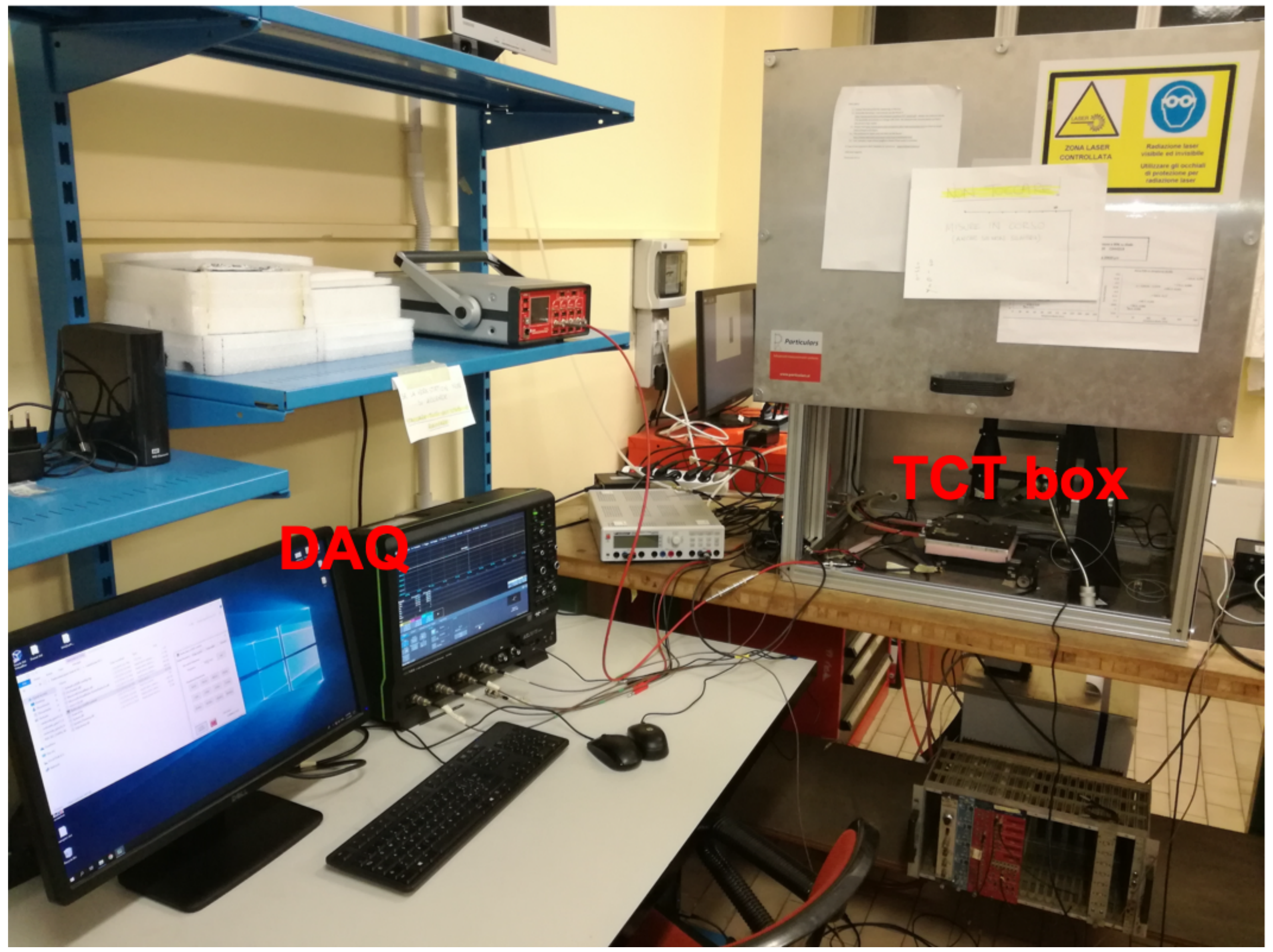


- In standard silicon sensors, the signal is small and it cannot be used to measure the time of the hit precisely.
- In LGAD, a moderately p-doped implant creates a volume of high field, where charge multiplication happens.
- The LGAD design yields a much larger signal that can be used to measure the time of the hit.

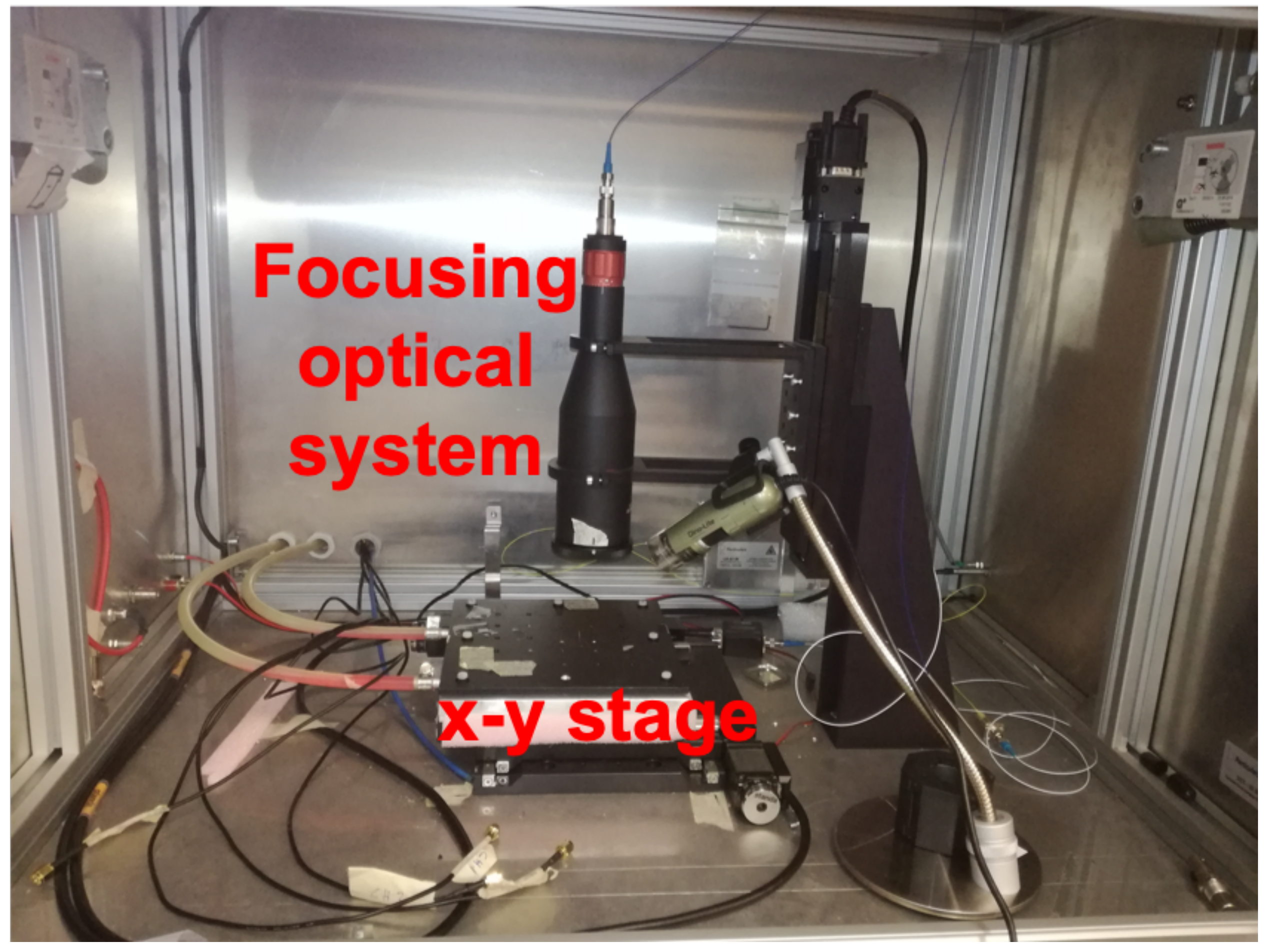
Low gain is the key ingredient to obtain good timing resolution.

Transient Current Technique (TCT) setup





TCT setup

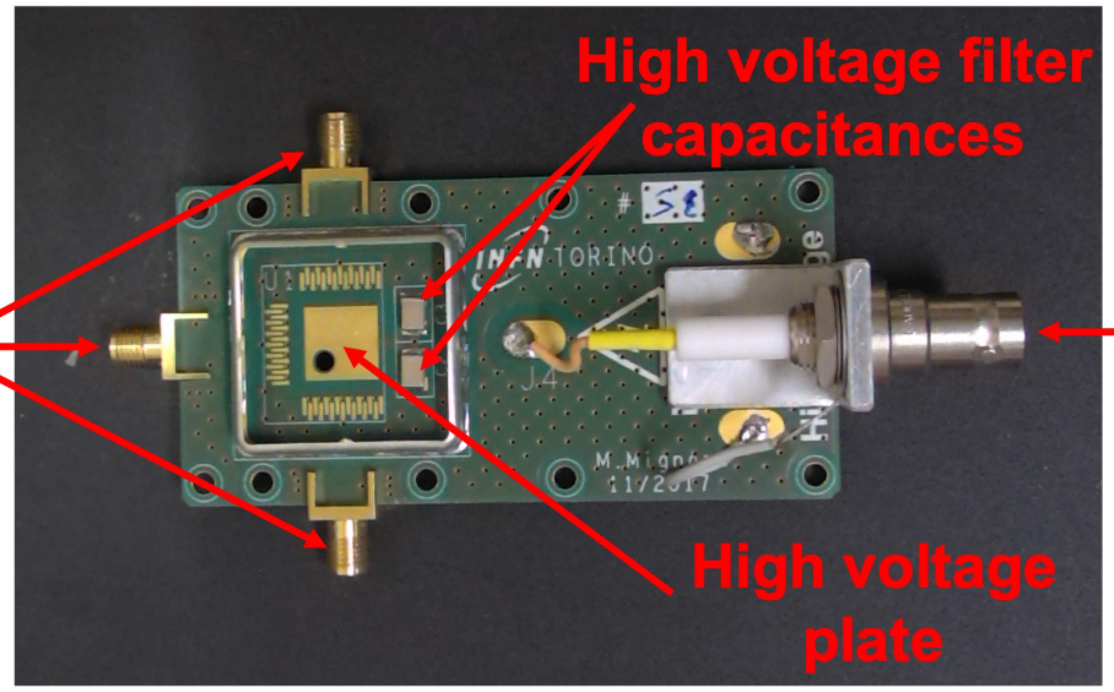


Measurements: Gain, Charge collection, Time resolution

Particulars TCT setup:

- IR pulsed laser ($\lambda = 1064\,\mu m$)
- Minimum laser spot of $10\,\mu m$
- Laser stability control
- x-y stage ($1\,\mu m$-precision)
- Cooling system
- Stage control and DAQ via LabView SW

PCB for sensor test



designed at the INFN Electronics Laboratory INFN in Turin

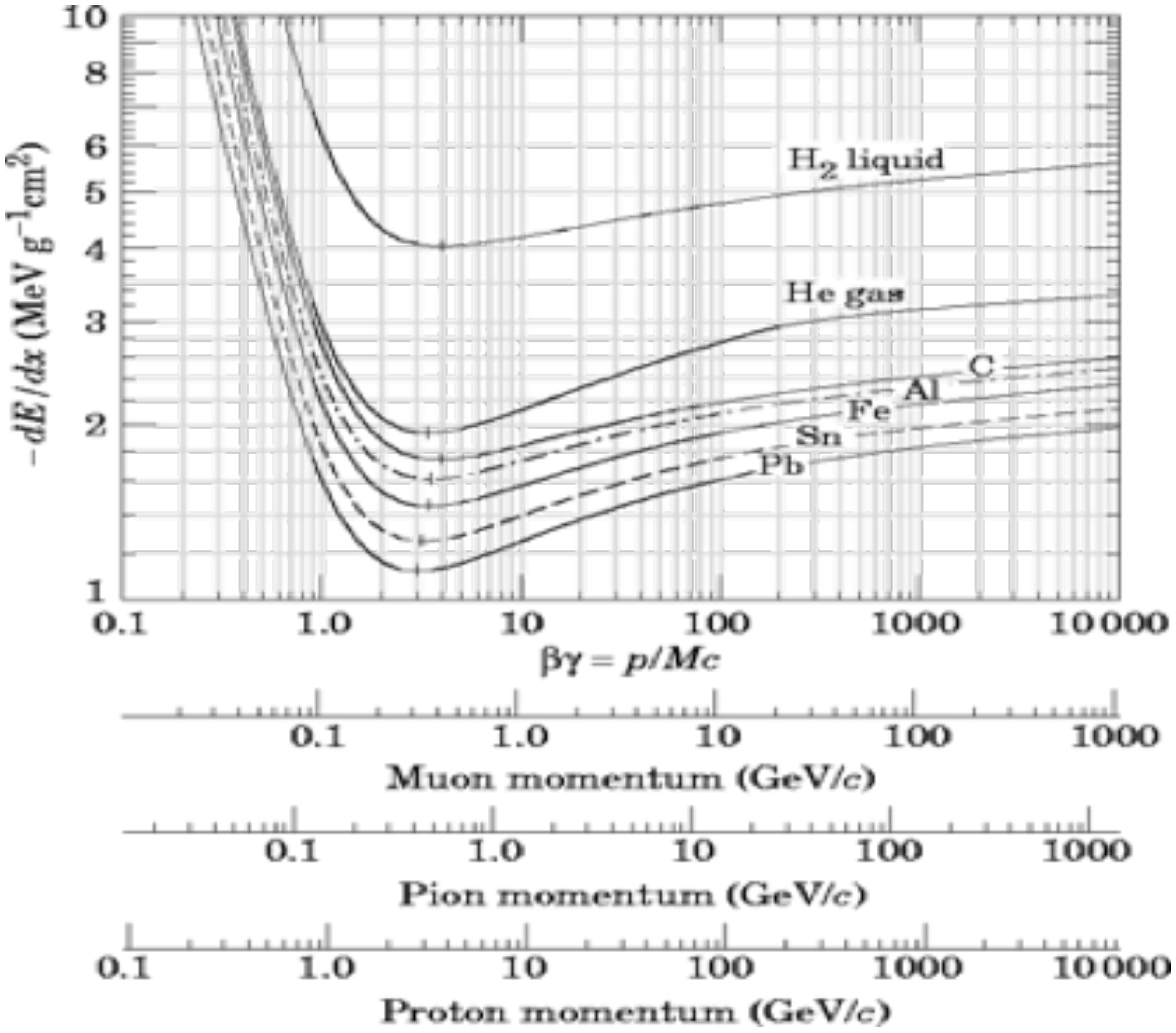
LASER system calibration

A Minimum Ionising Particle (MIP) loses $\sim 80\,\mathrm{keV}$ in $300\,\mu\mathrm{m}$ of silicon

The energy needed to create a electron-hole pair in silicon is $3.6\,\mathrm{eV}$

$$\frac{80\,\mathrm{keV}}{3.6\,\mathrm{eV}} = 22000 \text{ electron-hole pairs}$$

- ➡ 75 electron-hole pairs per $\mu\mathrm{m}$
- ➡ $0.5\,\mathrm{fC}$ in a $50\,\mu\mathrm{m}$ thickness



LASER system calibration

The LASER intensity must be regulated so that it releases the proper amount of charge in the active thickness of the sensor.

The calibration is performed using a sensor with no gain (PIN) and a reference diode for infrared light.

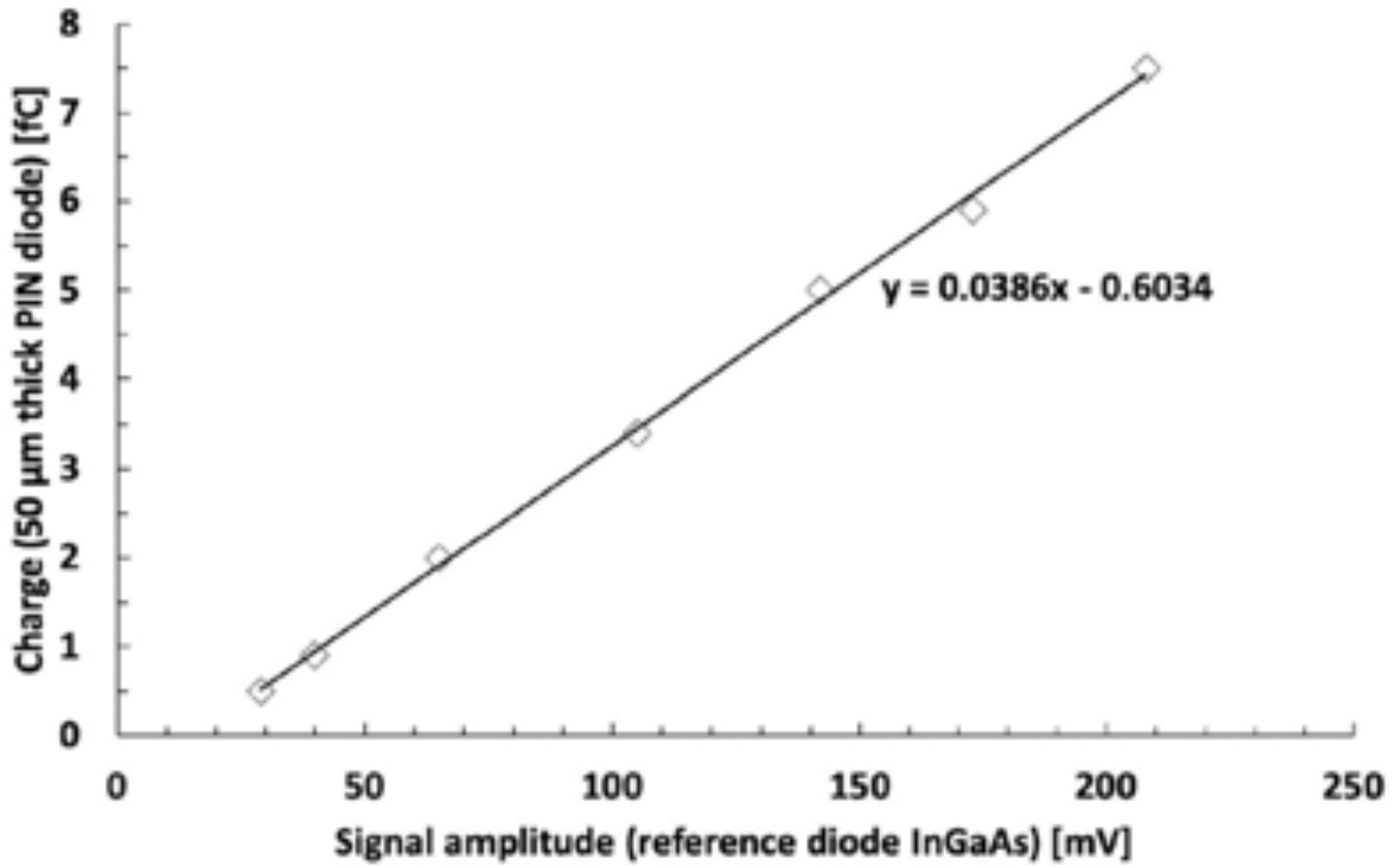
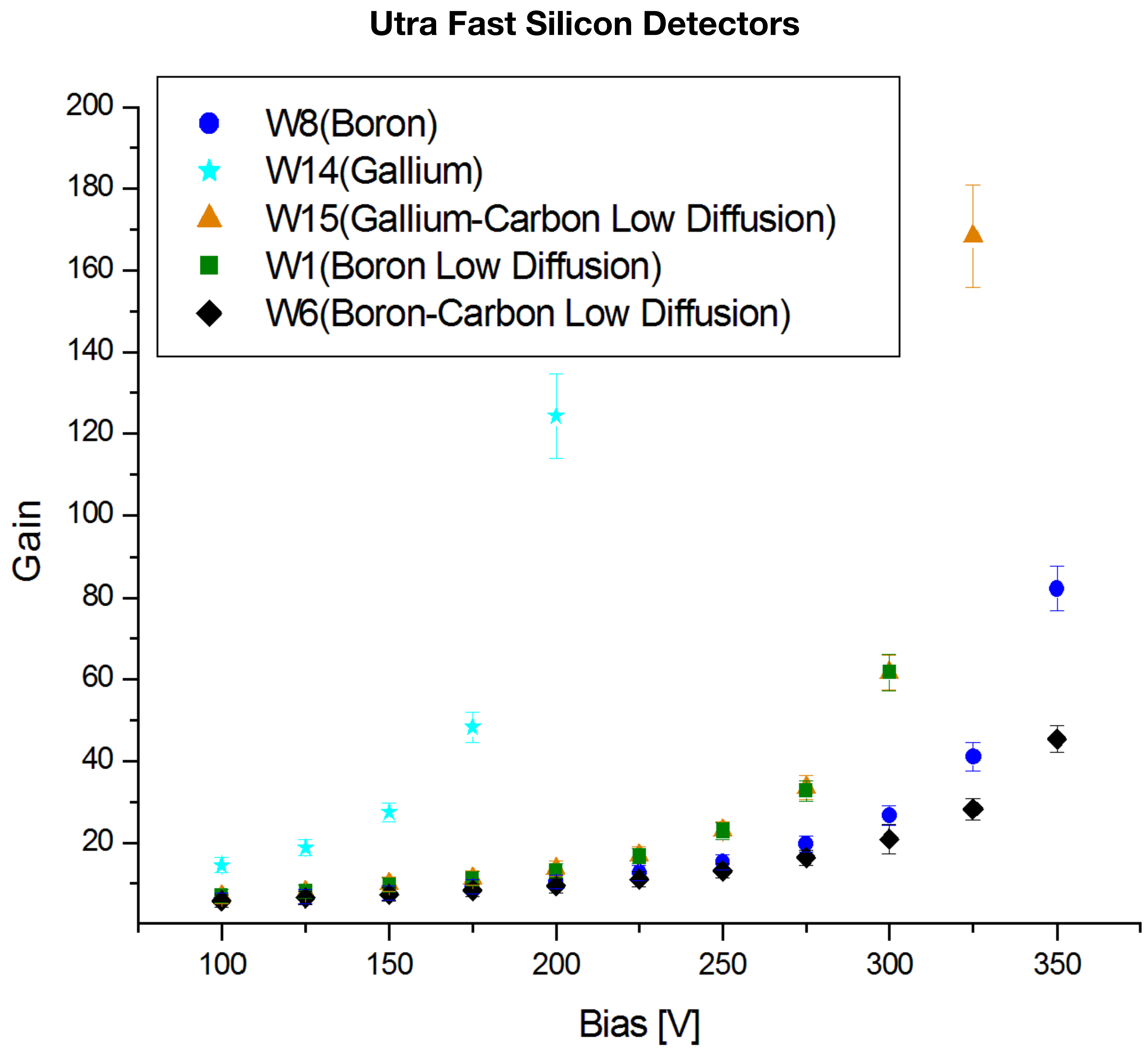


Figure 4.11 Example of a TCT calibration curve: relationship between the signal charge in a 50 µm-thick PIN diode and the signal amplitude in the reference diode (InGaAs) when using and IR laser.

Gain measurement versus bias $G(V)$



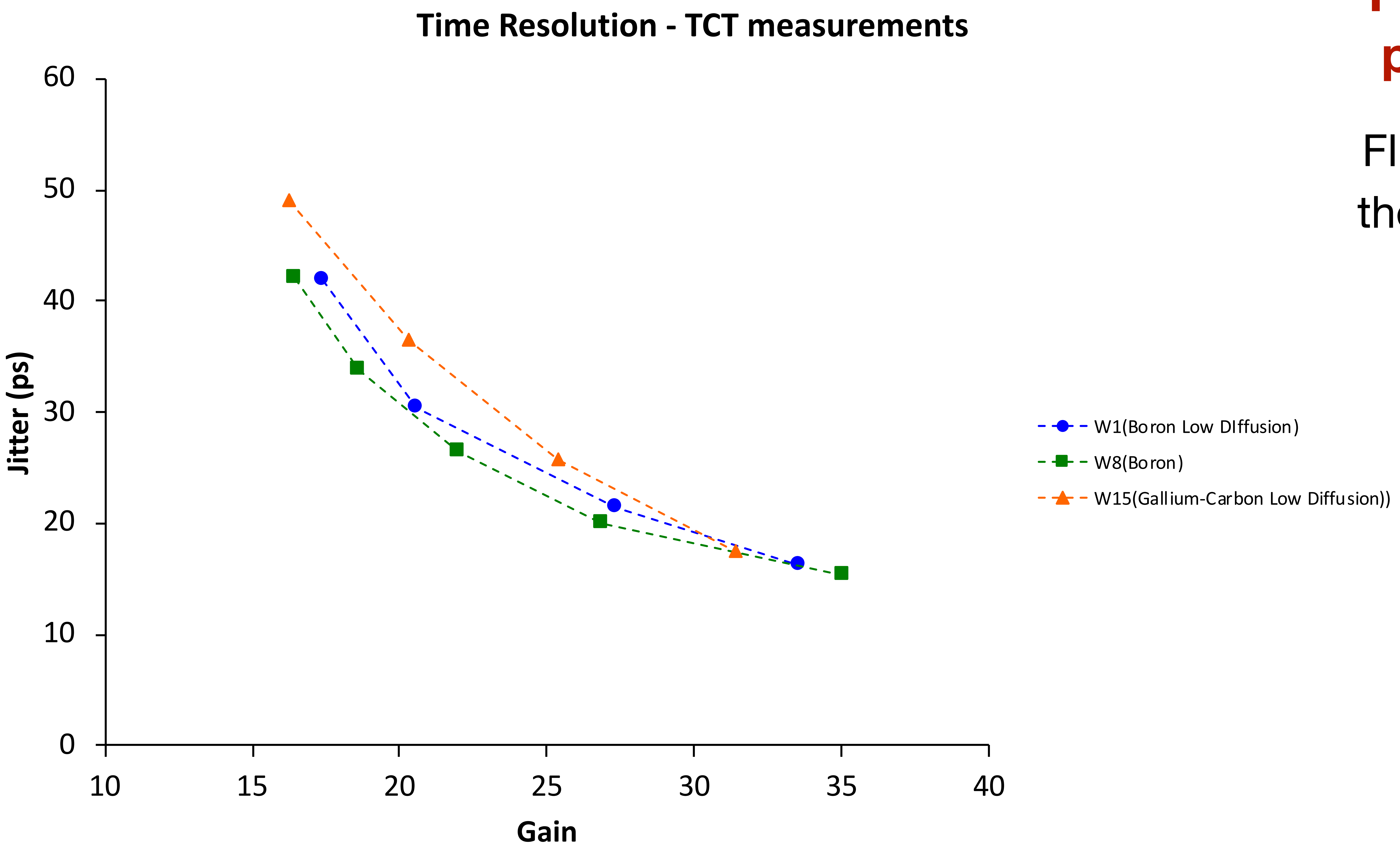
The charge multiplication is dependent on the electric field intensity.

$$[\text{Gain}] = \frac{[\text{Signal Area}_{\text{LGAD}}]}{[\text{Signal Area}_{\text{PIN}}]} \qquad G = \frac{Q_{LGAD}}{Q_{PIN}}$$

$$[\text{charge}] = \frac{[\text{Signal Area}]}{[\text{Input Resistance}]} = \frac{\text{mV} \cdot \text{ns}}{\Omega}$$

$$\text{Wb} = \text{V} \cdot \text{s}$$

Jitter measurement versus Bias $\sigma_t(V)$



First indication of the timing performance of the sensor.

Fluctuation of the measurement of the time at level $t_{x\%}$ with respect to a trigger signal (laser).

$$\sigma_{t\,,Jitter} = \frac{N}{\frac{dV}{dt}}$$

⚠ Simplified version

asd