Intro to Low Gain Avalanche Detectors in High Energy Physics

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Acknowledgement

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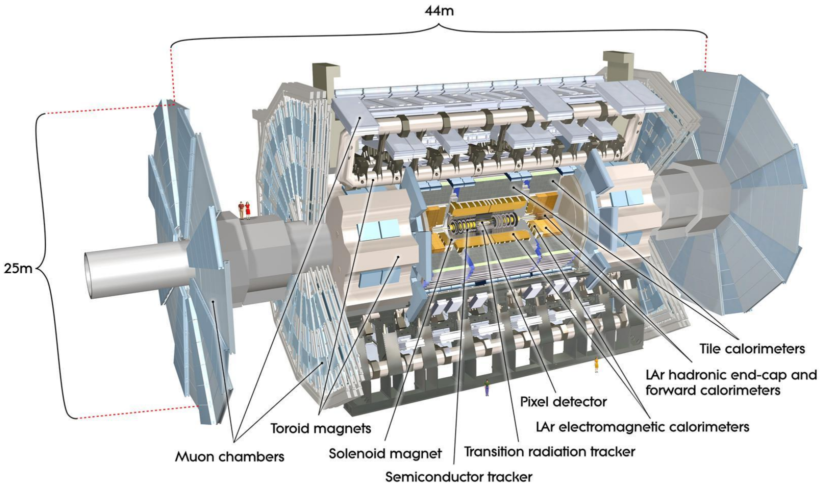
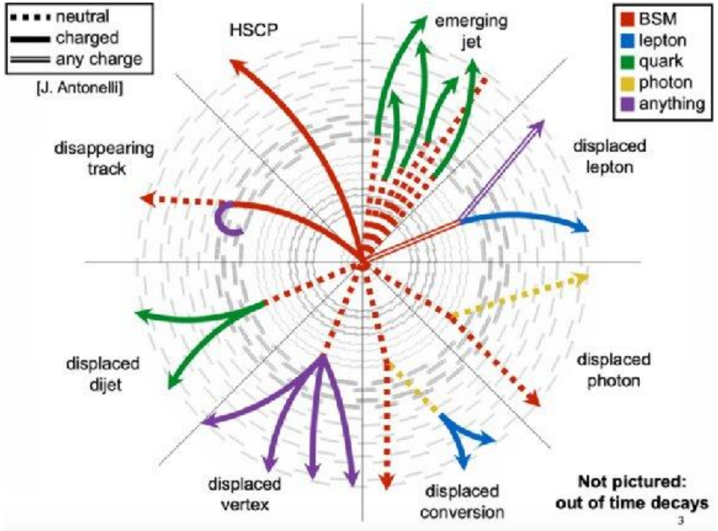
Silicon Detectors: LHC



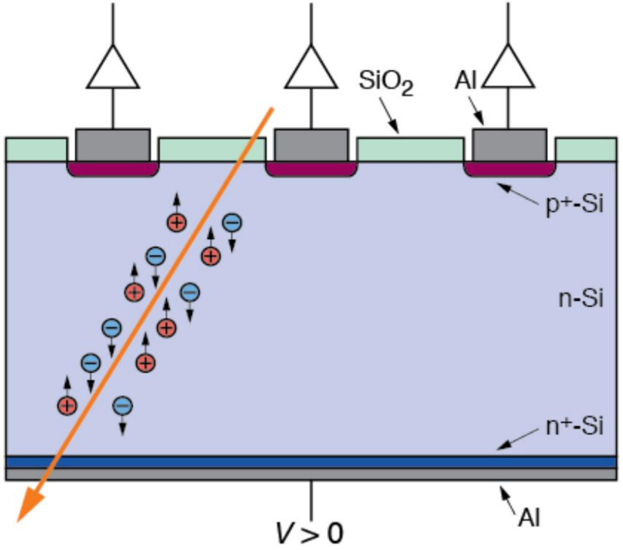
https://opendata.atlas.cern/docs/atlas/experiment/



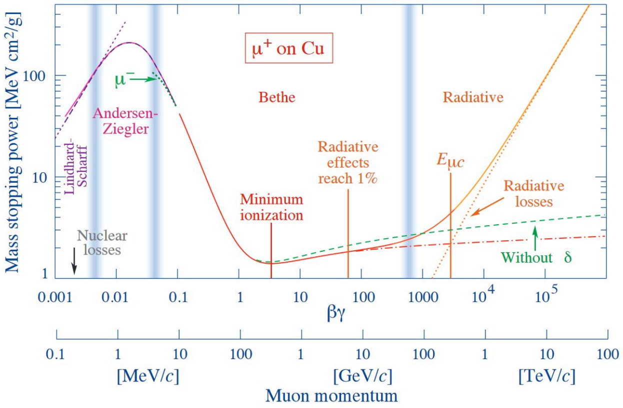
https://www.researchgate.net/publication/369617535_Searches_for_displaced_jets_at_the_LHC/figures?lo=1 v

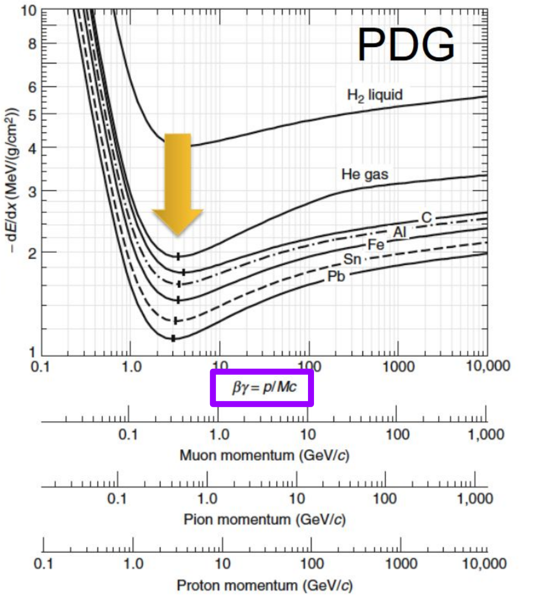
Silicon detectors are the innermost layer and are used for tracking and vertex identification.
In general, silicon detectors are thin as to not disturb the trajectory of particles.
Bruce covered silicon detectors in detail in his lecture

Silicon Detectors: Ionizing Radiation



https://indico.fnal.gov/event/54596/contributions/248572/attachments/158954/208808/Timing%20Detectors-v3.pdf

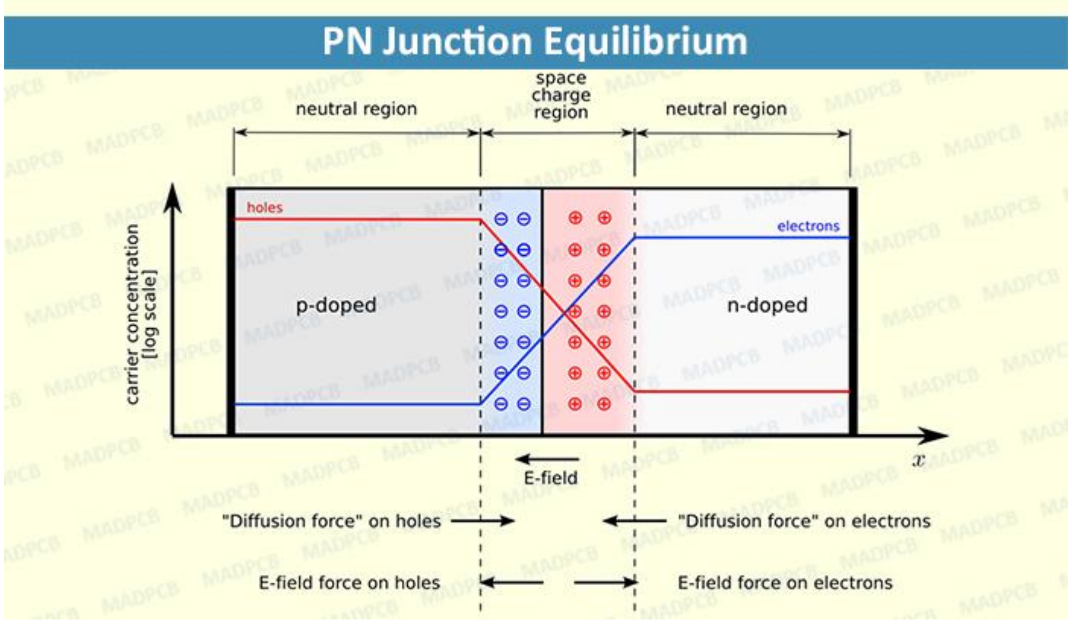


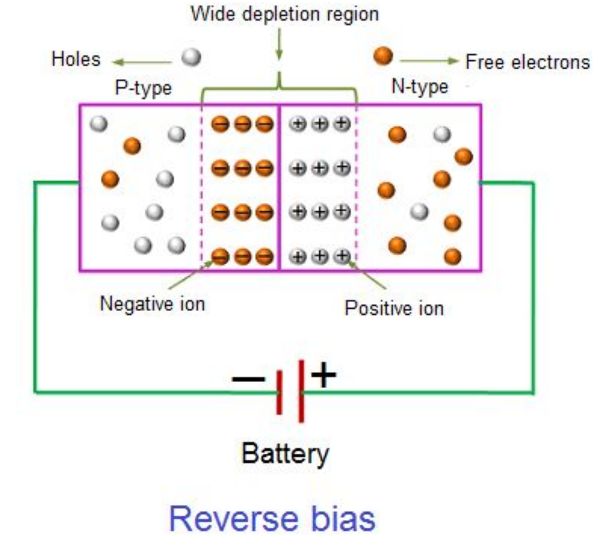


https://indico.cern.ch/event/387976/attachments/1124401/1605557/daniela_l2.pdf

When charged particles (ionizing radiation) go through a material they lose energy and in turn excite electron hole pairs in the material. This is true in semiconductors when the stopping power is governed by the Bethe-Bloch equation above. Most silicon detectors deal with minimum ionizing particles or MIPs. In contrast to calorimeters, trying to measure MIPs leads to dealing with small signals from sensors.

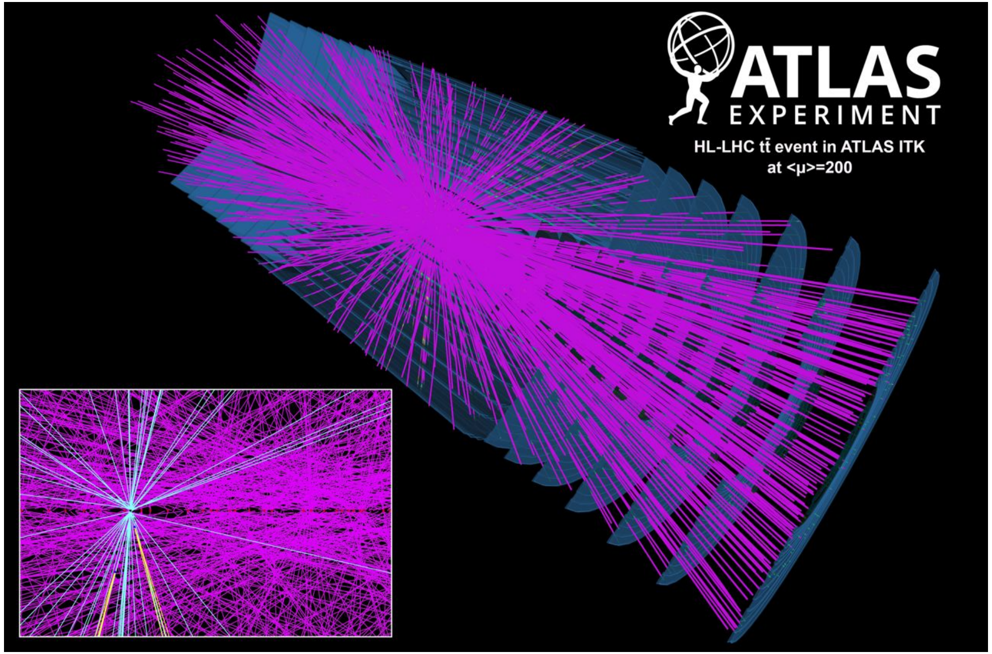
Traditional Silicon Detectors





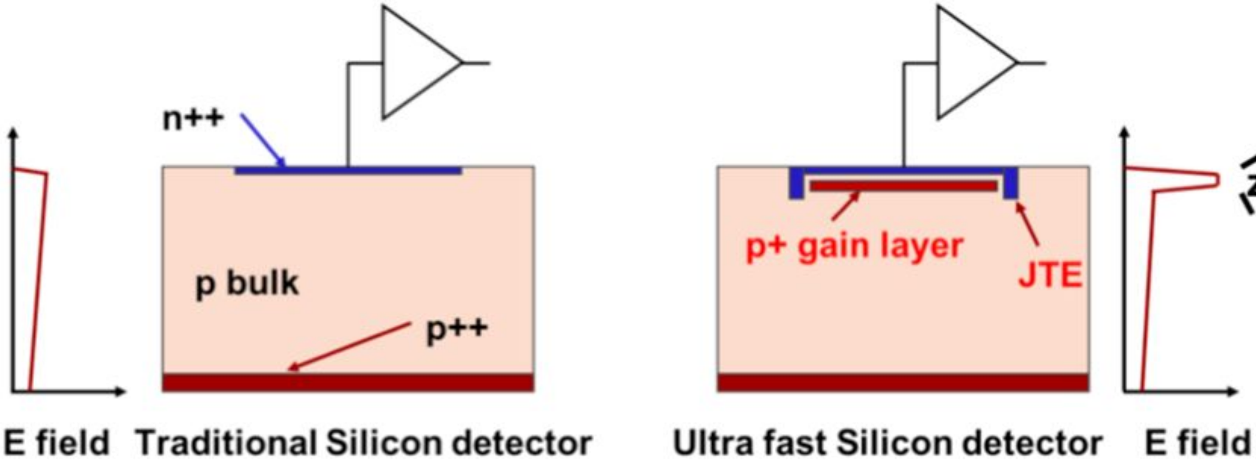
Traditional silicon detectors are essentially reverse biased semiconductors. When ionizing radiation hits the depletion region, electron hole pairs create a current, which is collected and can be measured as a voltage at an electrode.

Problem: High Luminosity



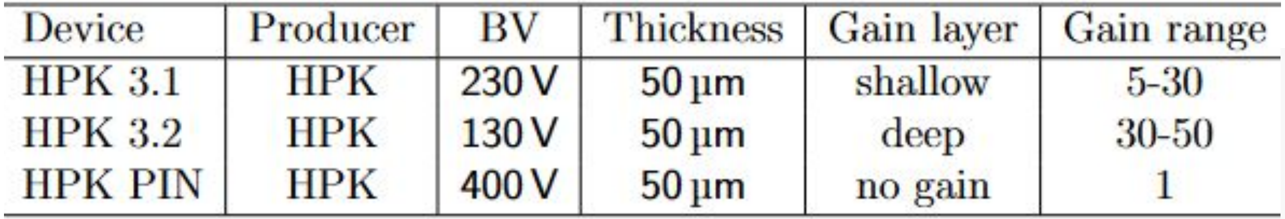
How do we do tracking in high luminosity and pileup environment if all we have is a position measurement?

Solution: Add Timing → LGAD



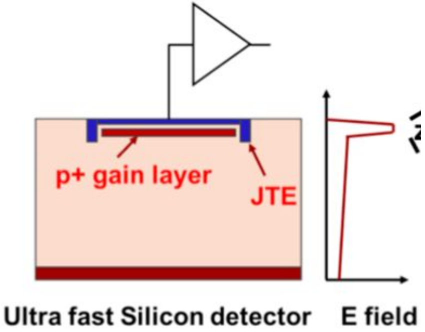
Unlike standard silicon detectors, DC Low Gain Avalanche Detectors (DC-LGADs) have an internal gain layer allowing even very small signals to be read out. In fact, the HL-LHC will be read out by DC-LGADs in timing layers within both the CMS and ATLAS experiments.
Since LGAD amplification only occurs in the thin gain layer, effectively all electrons/signal travel for a short period of time, leading to excellent uniformity and time resolution (~30 ps).

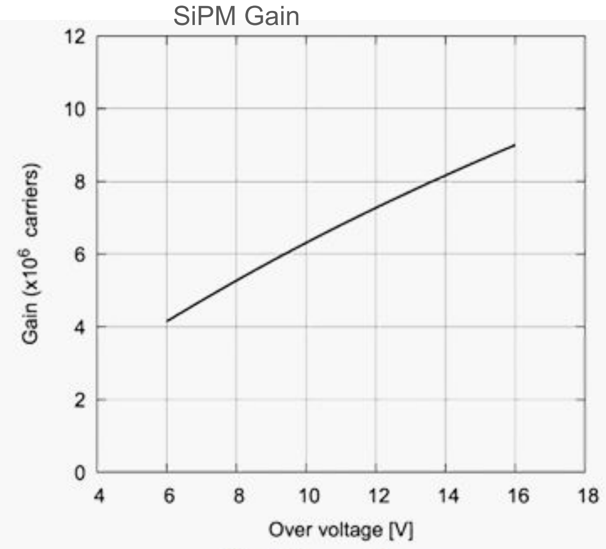
Why LGADs and not SiPMs?



Device	Producer	BV	Thickness	Gain layer	Gain range
HPK 3.1	HPK	230 V	50 µm	shallow	5-30
HPK 3.2	HPK	130 V	50 µm	deep	30-50
HPK PIN	HPK	400 V	50 µm	no gain	1

https://arxiv.org/pdf/2405.02550

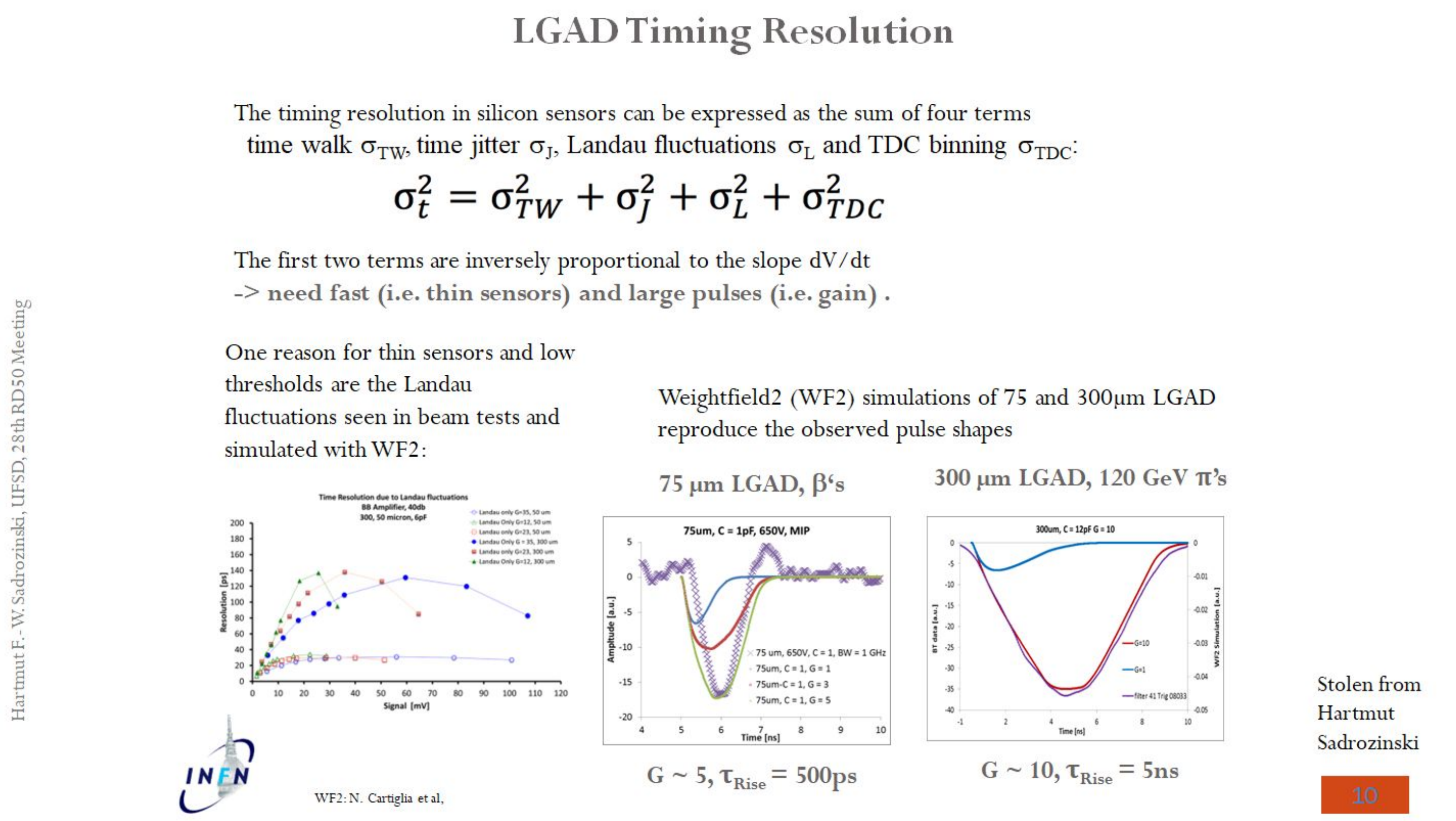




$V_{OB} = V_{Bias} - V_{Breakdown}$

Since impact ionization gain only occurs for electrons passing through the gain layer, gain is much lower compared to SiPMs and a runaway avalanche mode does not occur. This leads to a faster recovery time.

Timing Resolution



LGAD Timing Resolution

The timing resolution in silicon sensors can be expressed as the sum of four terms time walk σ_{TW}, time jitter σ_J, Landau fluctuations σ_L and TDC binning σ_{TDC}:

$$\sigma_t^2 = \sigma_{TW}^2 + \sigma_J^2 + \sigma_L^2 + \sigma_{TDC}^2$$

The first two terms are inversely proportional to the slope dV/dt
-> **need fast (i.e. thin sensors) and large pulses (i.e. gain) .**

One reason for thin sensors and low thresholds are the Landau fluctuations seen in beam tests and simulated with WF2:

Weightfield2 (WF2) simulations of 75 and 300μm LGAD reproduce the observed pulse shapes

75 μm LGAD, β's

300 μm LGAD, 120 GeV π's

G ~ 5, τ_{Rise} = 500ps

G ~ 10, τ_{Rise} = 5ns

WF2: N. Cartiglia et al,

Hartmut F.- W. Sadrozinski, UFSD, 28th RD50 Meeting

Stolen from Hartmut Sadrozinski

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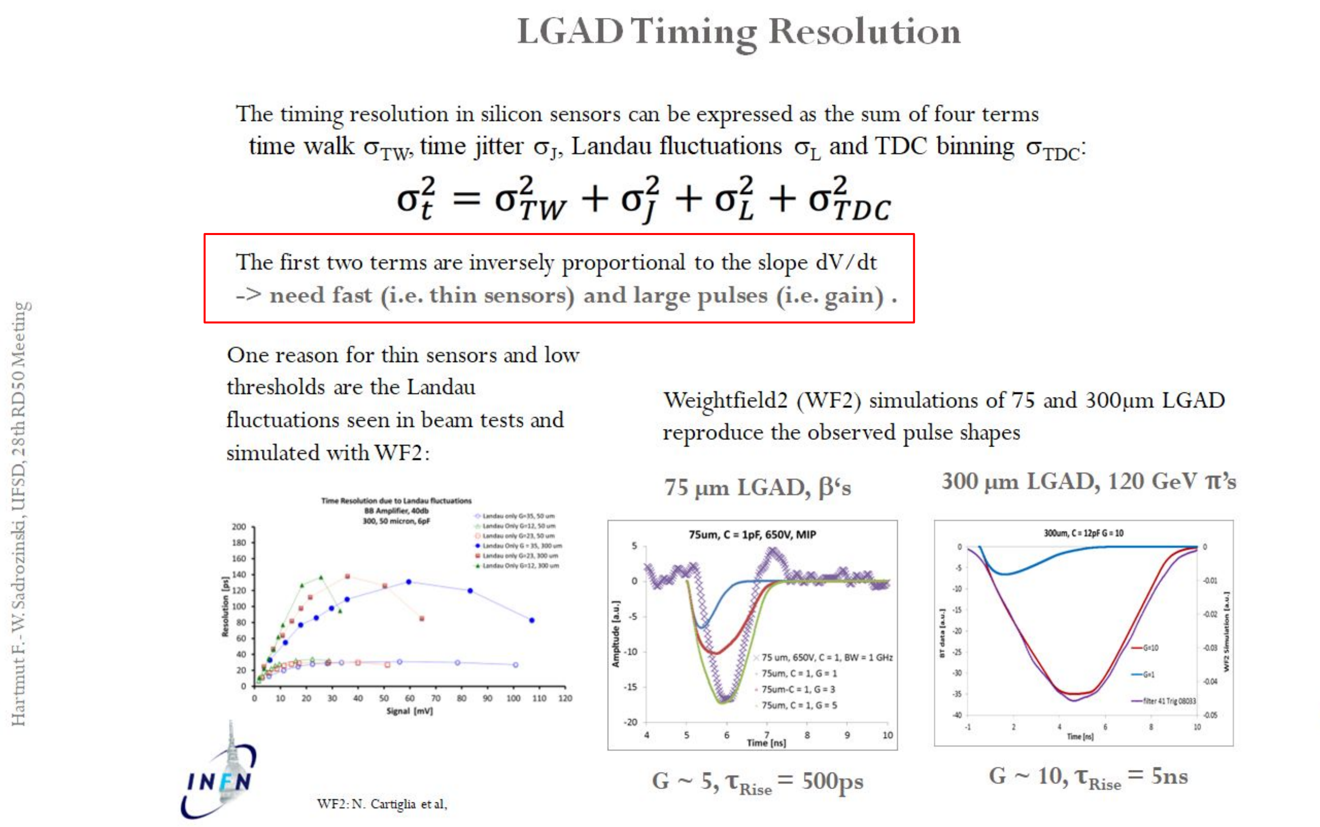
Timing Resolution



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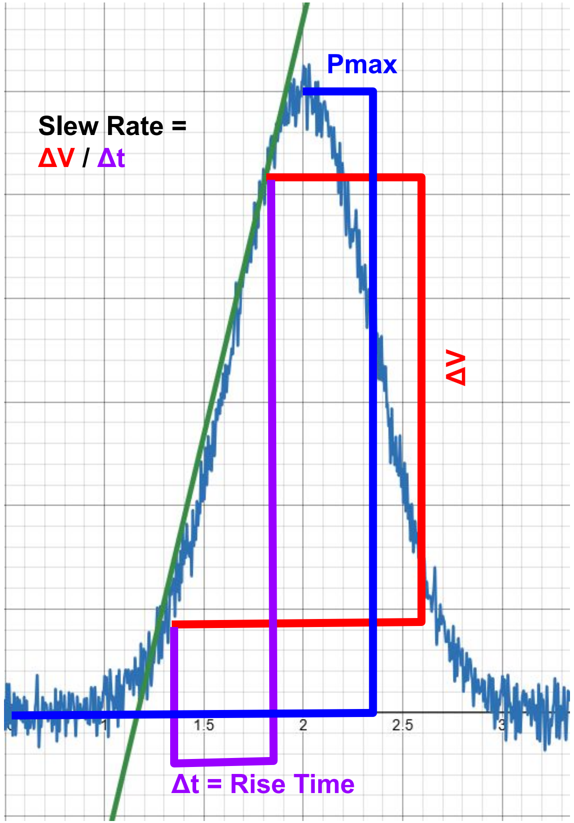
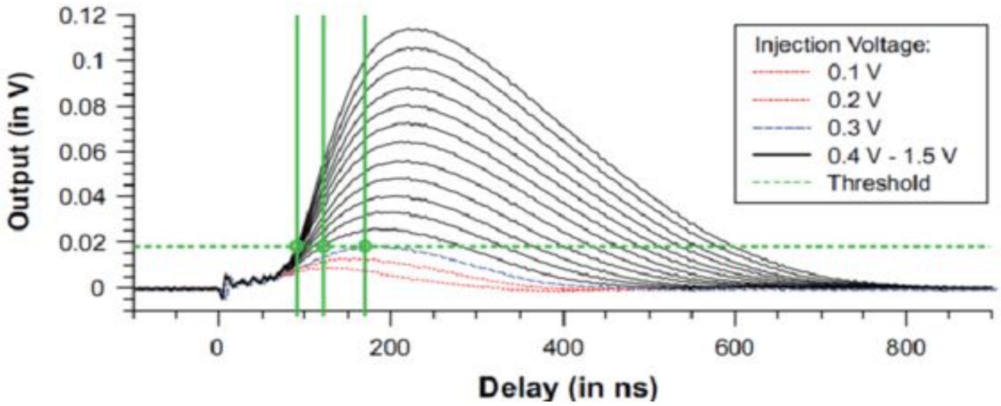
Time Jitter and Time Walk



Time Walk

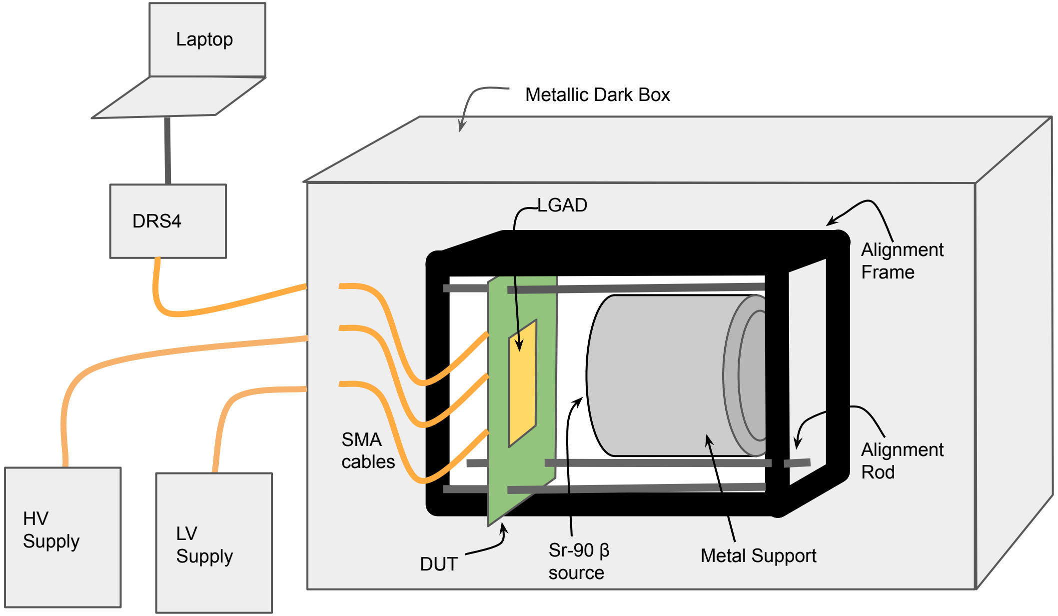


https://www.researchgate.net/figure/Time-walk-on-signals-of-different-amplitudes-22_fig2_335588052

$$Jitter = \frac{RiseTime}{SNR} = \frac{RMS_{Noise}}{SlewRate}$$

Time jitter is a deviation in timing due to noise shifting the waveform earlier/later than if there was no noise. Time walk is a shift in signal timing due to different pulse heights reaching threshold at different times.

LGAD Lab Setup



Looking at the jitter component of LGAD timing resolution by determining an average slew rate. Groups will be hooking up the experiment in the first section and doing analysis in the second. Ideally have a method of running jupyter notebooks installed on your computer (Jupyter-lab or Visual Studio Code with extensions).