Measurements on UFSD (thin LGAD)

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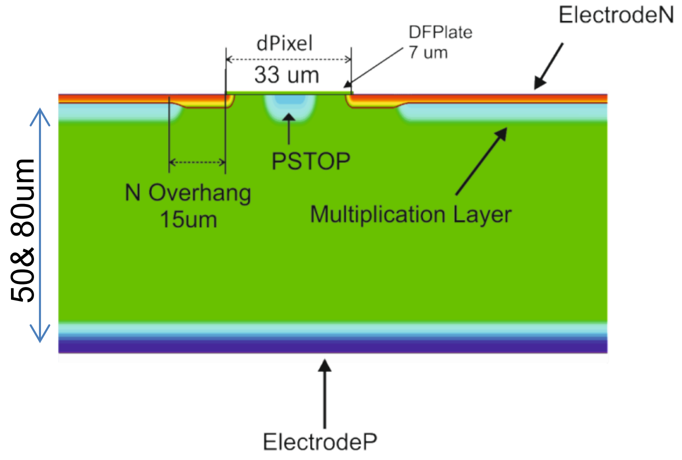
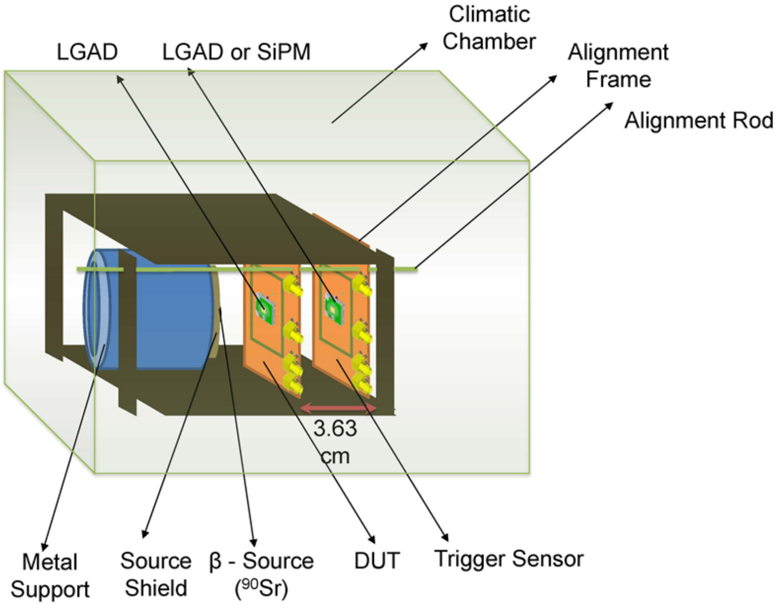
1. Issues for the use of LGAD
    a. Thickness
    b. Fill-factor -> Nicolo Cartiglia
    c. Effect of metal coverage on LGAD -> Nicolo Cartiglia

2. Post-rad measurements on HPK LGAD (neutrons)
    a. Bias voltage head room
    b. Timing resolution
    c. Rise time
    d. Landau fluctuations

3. WF2 simulations



^{90}Sr β Telescope, new beam tests: HGTD & US LGAD R&D



^{90}Sr β-source Set-up:
DUT LGAD between source and trigger plane
Trigger: either known LGAD or quartz/SiPM
Climatic chamber allows operation
between -30C and +20C

Beam Tests:
Torino/UCSC Summer 2016
HGTD CERN Fall 2016
US LGAD R&D group FNAL May 2017

LGAD tested:
CNM run 9088: 3 doping concentration, 1 mm pads, 2x2 arrays (2x2 and 3x3 mm^2)
HPK run ECX20840: 4 doping Concentrations, 1mm pads (3 GR configurations) , 2x2 arrays, 3x3 mm^2

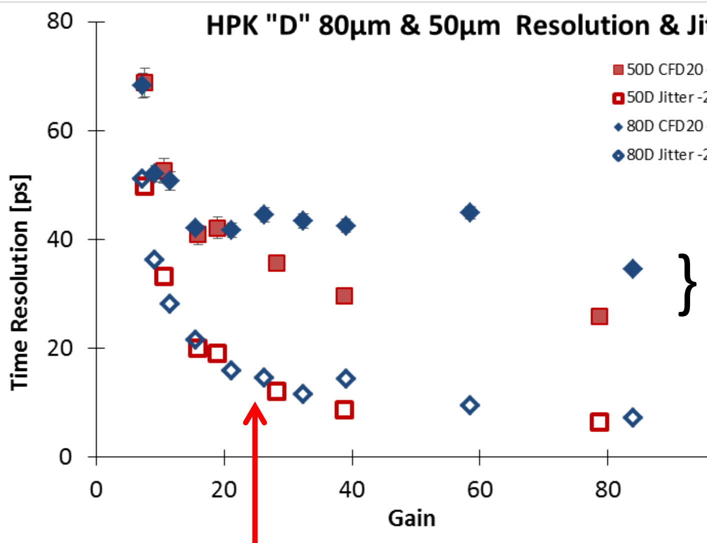
Timing Resolution for LGADs: Gain & Thickness

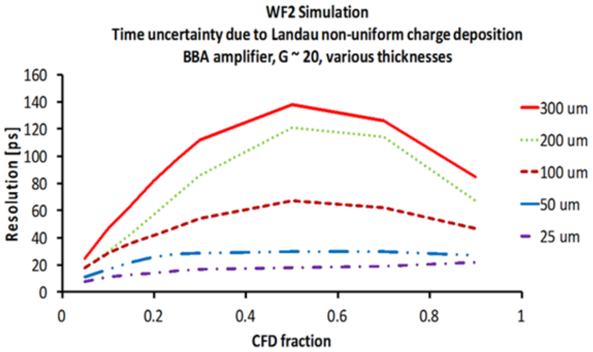
Two main contributions to the timing resolution: Jitter & Landau Fluctuations

$$\sigma_t^2 = \sigma_{TimeWalk}^2 + \sigma_{LandauNoise}^2 + \sigma_{Distortion}^2 + \sigma_{Jitter}^2 + \sigma_{TDC}^2$$

Jitter depends on gain, Landau fluctuations depend on LGAD thickness

Time walk reduced with the use of constant fraction discriminator (CFD ≈ 20%)





$$\sigma_{Jitter} = \frac{N}{dV/dt} \approx \frac{\mathbf{t_{rise}}}{\frac{\boldsymbol{S}}{\boldsymbol{N}}} \sim \mathbf{t_{rise}}\,\frac{\mathbf{N}}{\mathbf{G}}$$

Landau Fluctuations:
≈ 25 ps for 50 µm
vs.
≈ 35 ps for 80 µm.
Go thin!

Leakage Current vs Bias Voltage

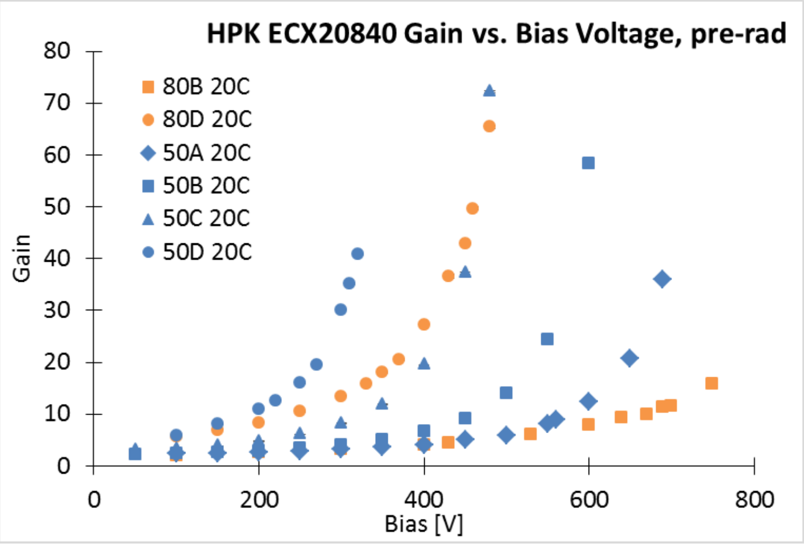
HPK manufactured four splits with doping concentration ~ 4% apart.

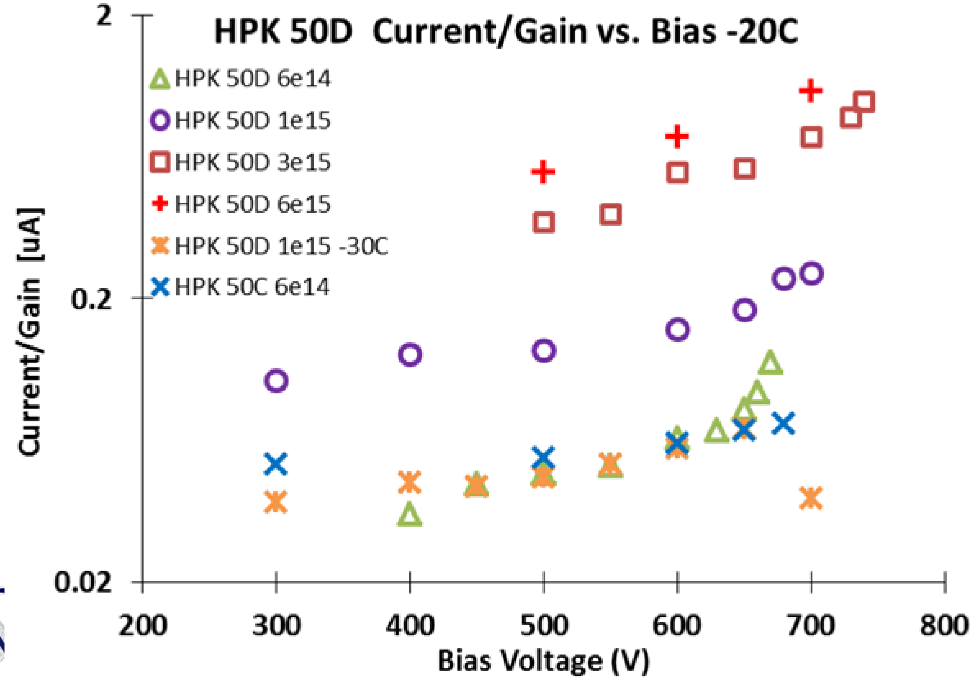
The radiation damage effect of “acceptor removal” favors high initial doping concentration.

Show data from HPK 50D (i.e. 50um)

Neutron fluence steps:

0, 6e14 (CMS), 1e15, 2e15, 3e15 (HGTD), 6e15.



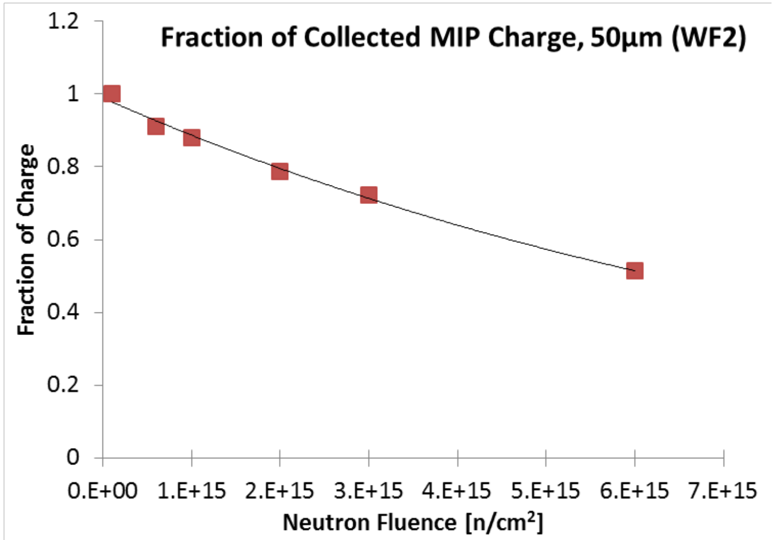


Leakage current determines the break-down voltage.

Leakage current is increased by gain.

Taking out the gain dependence indicates the expected fluence dependence.

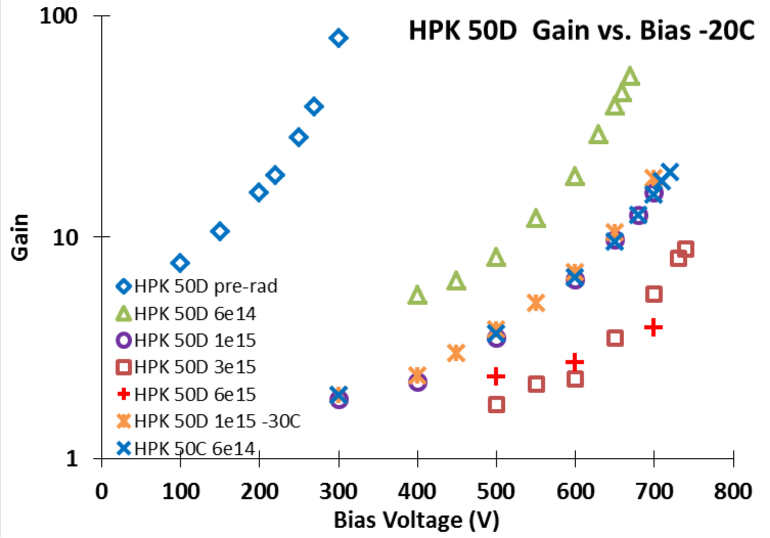
Gain = Collected Charge / No-gain charge



No-gain charge of MIP in 50µm LGAD is fluence dependent due to trapping:

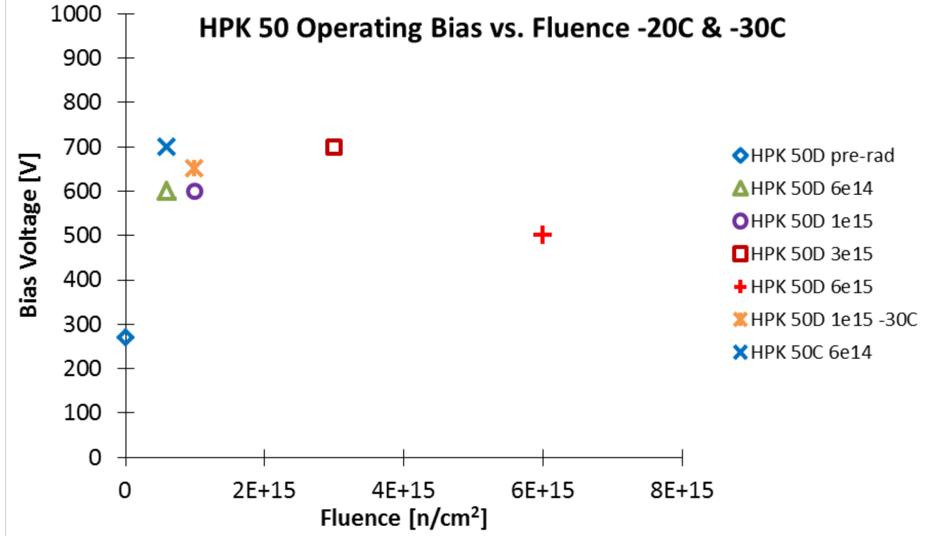
NGC = 0.51 fC, (3180 e^-) pre-rad

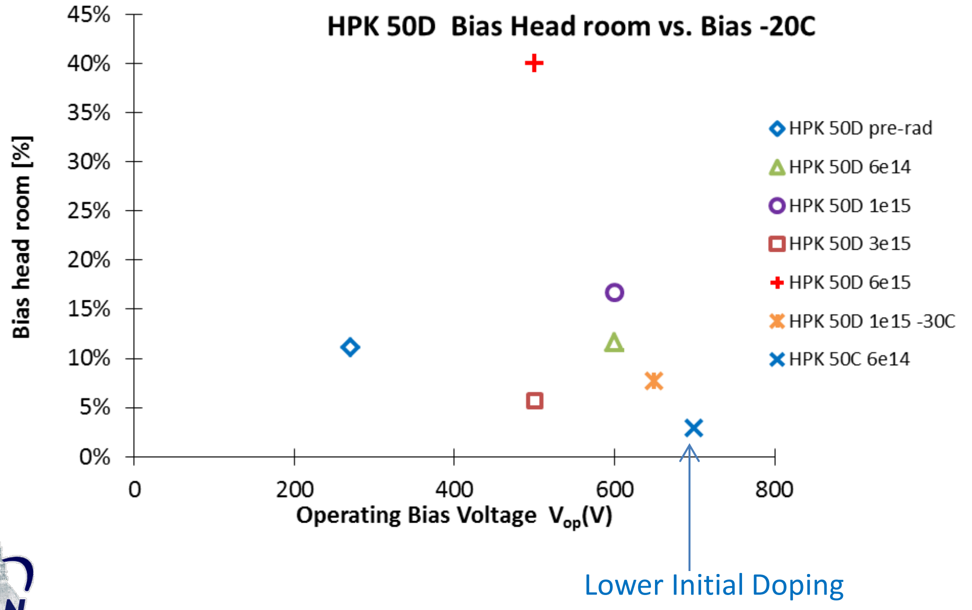
NGC = 0.26 fC, (1365 e^-) after neutron fluence of 6e15



Gain is fluence dependent, and dependents on the initial doping concentration.

Bias Voltage Headroom





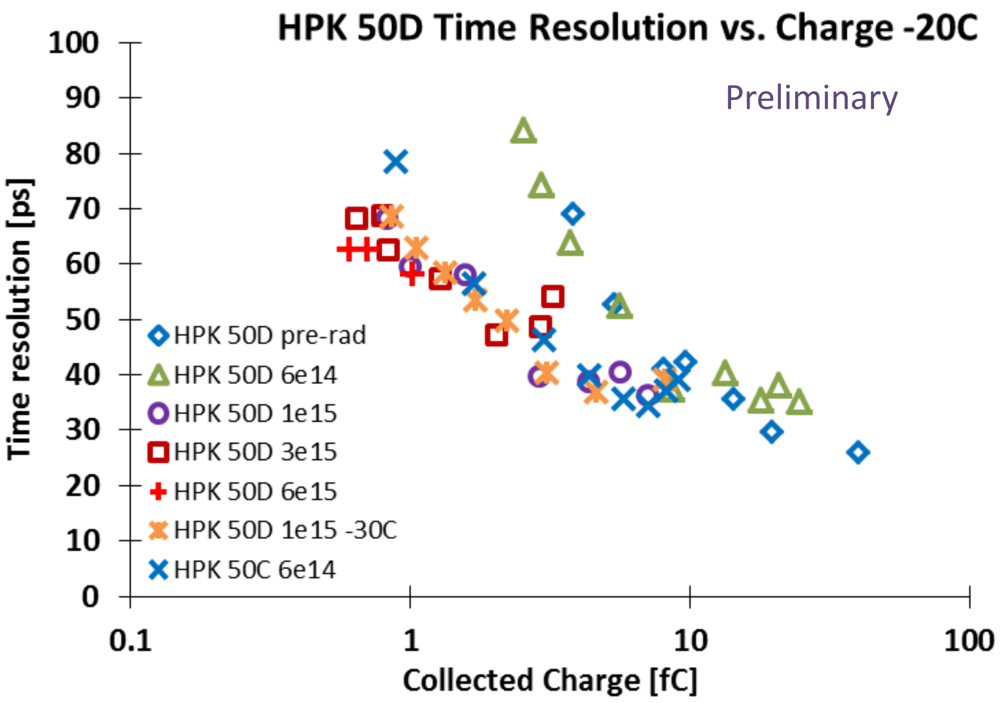
At fluences > 6e14 n/cm^2, bias voltage > 600-700V is required, quite constant.
Present limitation on bias reach:
Breakdown voltage is close to the oprtaing bias needed for sufficient gain.
(Risk of sensor damage and spurious noise/micro discharges close to breakdown)

Consider "Headroom" = difference between breakdown voltage V_{BD} and operating bias V_{op} for "good resolution":
Bias Headroom = $(V_{BD} - V_{op}) / V_{op}$

Requirement: 10%? 20%?

High headroom for highest doping concentration since large noise reduces the optimal bias voltage
Low headroom for lower initial doping.

Timing resolution vs. gain



The timing resolution depends on the collected charge, i.e. gain.

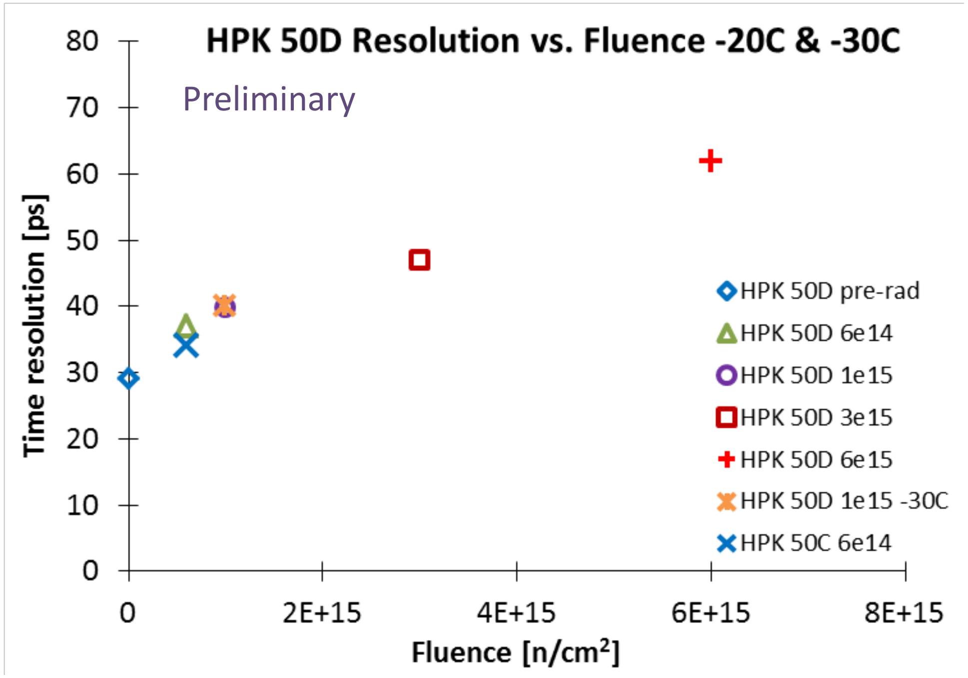
We see two distinct fluence dependences:

1. pre-rad up to 6e14: gain from multiplication layer
2. 1e15 and higher and for lower initial dopant: gain from bulk

Lowering temperature by only 10C helps only marginally.

Noise increase at large gain (i.e. bias) is limiting factor post-rad.

Timing resolution vs. fluence



Very good time resolution over large fluence range.
At 3e15 timing resolution is better than 50ps!

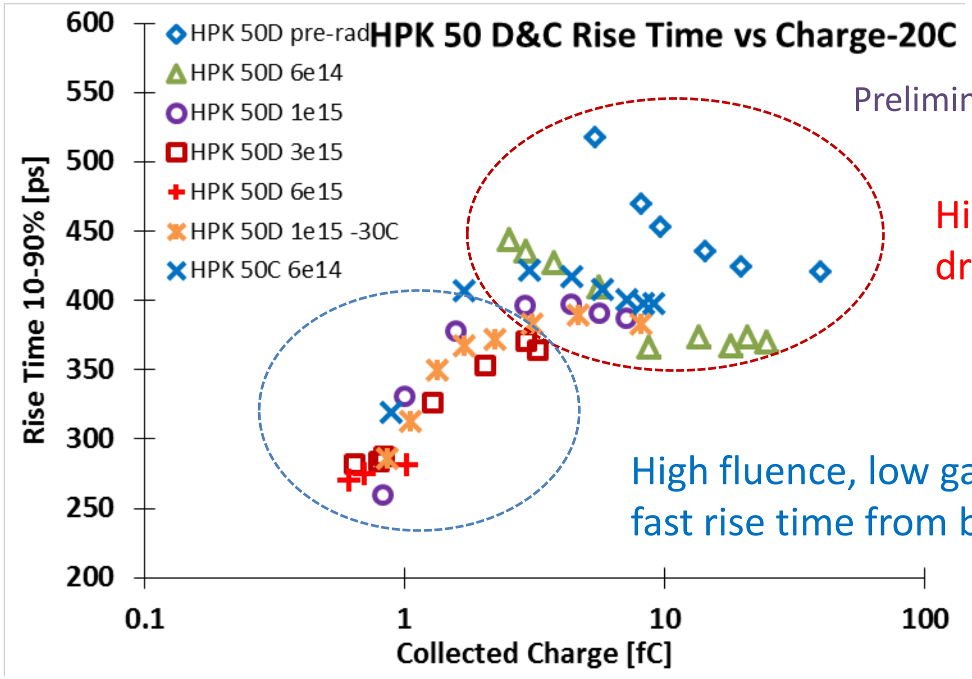
No difference -20C -> -30C?

Recall that gain at 3e15 is < 10
and at 6e15 is only 4.

Why can we still get good resolution at low gain (~ 4)?

$$\sigma_t^2 = \sigma_{LandauNoise}^2 + \sigma_{Jitter}^2$$

Post-rad Rise time -20C, neutron Irradiation



Preliminary

High gain (low fluence):
drift time limits rise time at low gain pre-rad

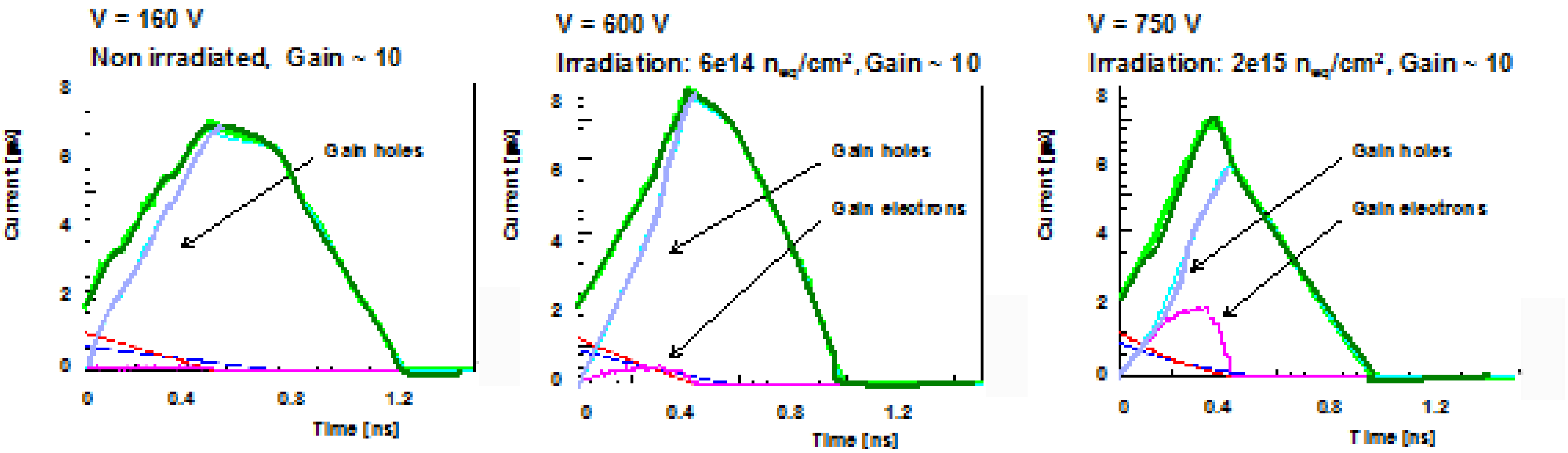
High fluence, low gain:
fast rise time from bulk multiplication!

For fluence 6e15:

$$\sigma_{Jitter} \approx \frac{\mathbf{t_{rise}}}{\frac{S}{N}} = 270\mathrm{ps}/4$$

Advantage of irradiated LGAD II: Shorter Rise time

-20C, neutron Irradiation



V = 160 V
Non irradiated, Gain ~ 10

V = 600 V
Irradiation: 6e14 n_{eq}/cm^2, Gain ~ 10

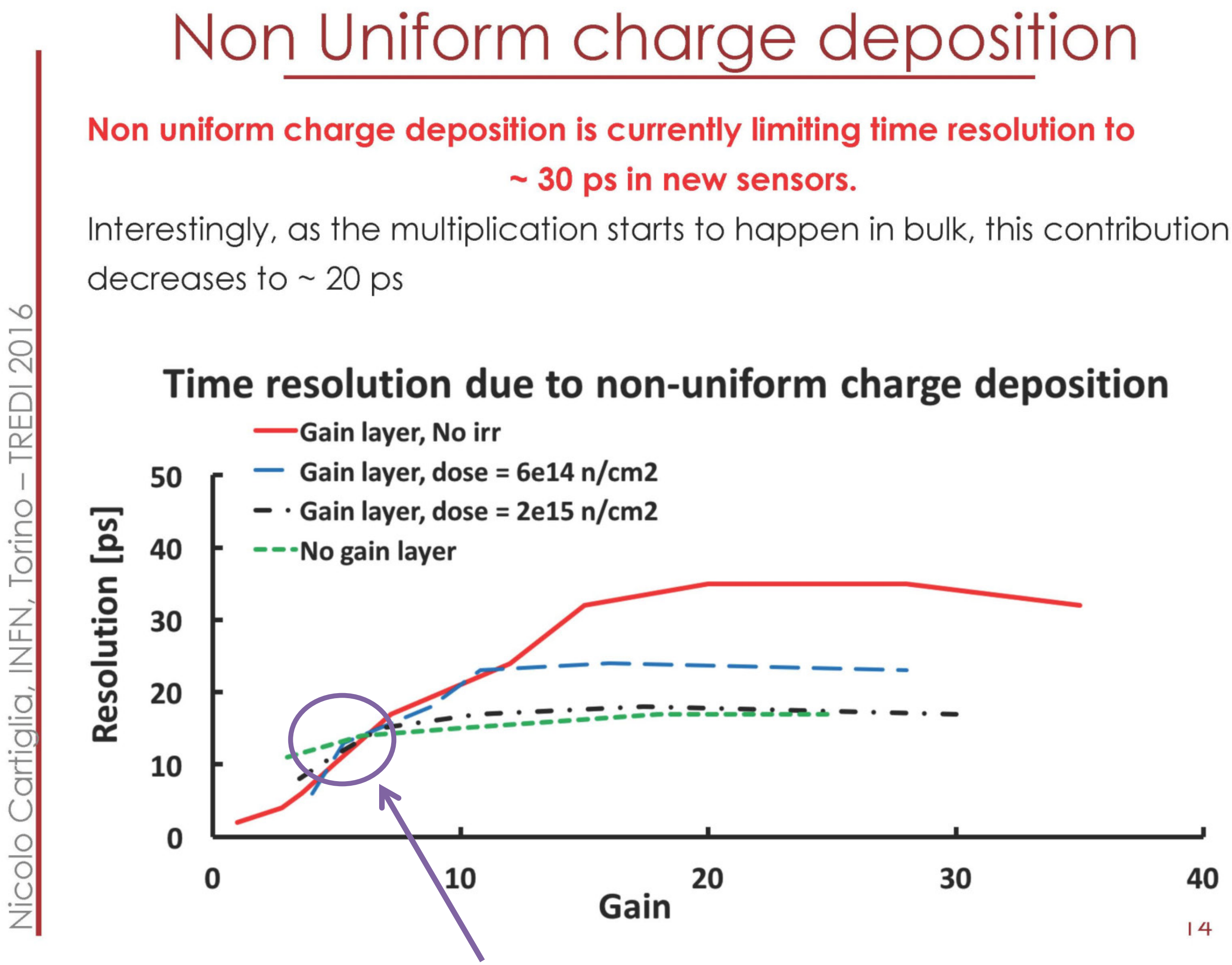
V = 750 V
Irradiation: 2e15 n_{eq}/cm^2, Gain ~ 10

arxiv 1704.08666
Figure 33: Simulated combined effect of charge trapping and initial acceptor removal on the UFSD output pulse.

“Compared to thick no-gain sensors….., in UFSD the overall changes with radiation are fairly mild, indicating the possibility of performing accurate timing even after high values of fluence. Notably, the overall signal length decreases slightly due to trapping, and the rise time becomes shorter since the current plateau due to holes current disappears.” …. and the electrons from bulk appear which are early.

Advantage of irradiated LGAD I: Reduced Landau

-20C, neutron Irradiation



Non Uniform charge deposition

Non uniform charge deposition is currently limiting time resolution to ~ 30 ps in new sensors.

Interestingly, as the multiplication starts to happen in bulk, this contribution decreases to ~ 20 ps

Time resolution due to non-uniform charge deposition

Nicolo Cartiglia, INFN, Torino – TREDI 2016

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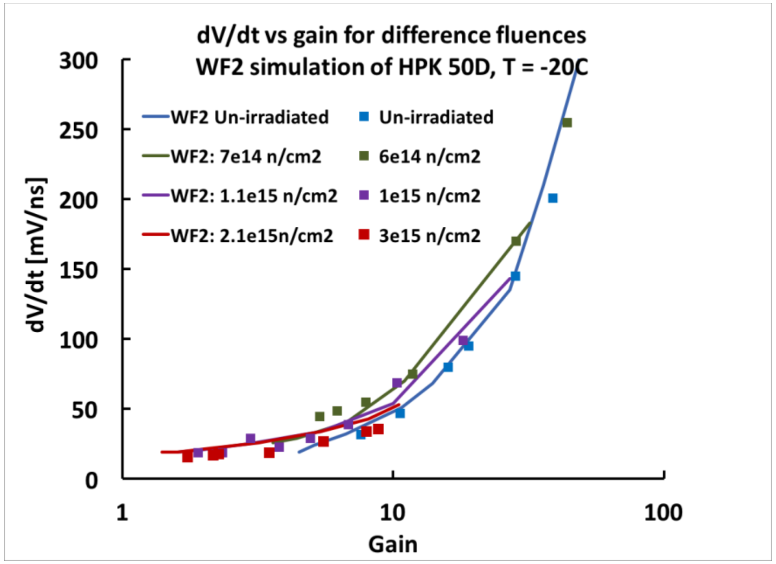
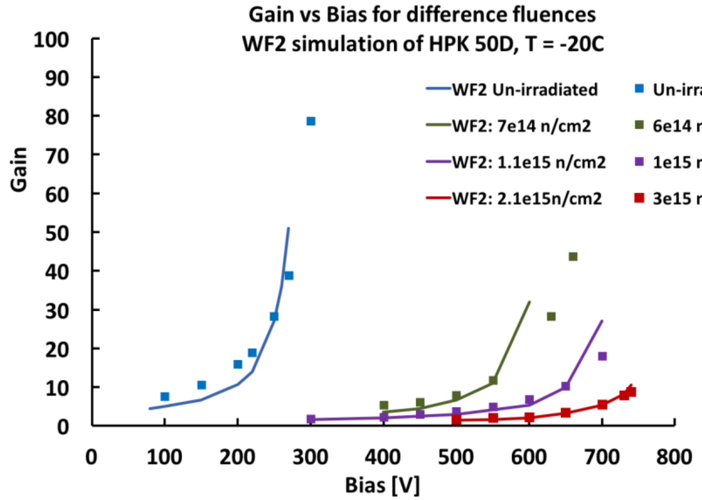
Nicolo Cartiglia, TREDI 2017.

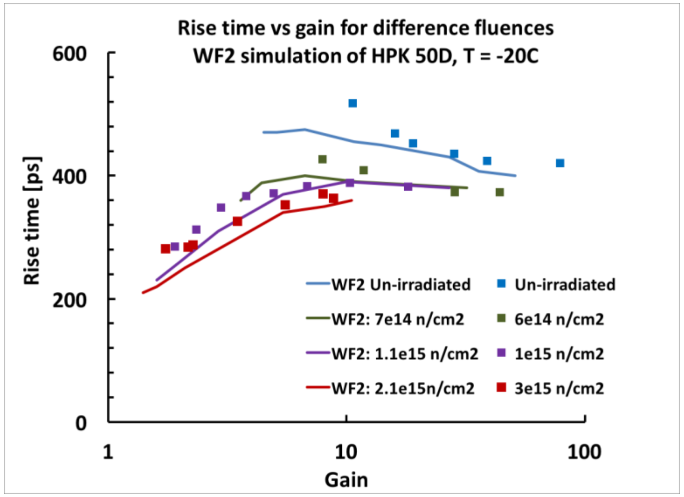
The Landau fluctuations are reduced too!

WF2 Simulation of UFSD Performance

-20C, neutron Irradiation 0, 6e14, 1e15, 2e15, 3e15 n/cm²







Hartmut F.-W. Sadrozinski, "Measurements on thin LGAD", RD50 2017

Conclusions

- We have now copious data on the performance of LGADs from two suppliers
- We are starting to investigate how we would use LGAD in a real experiment (ATLAS & CMS)
  - Optimal thickness
  - Head room in bias voltage

- Radiation campaign of HPK LGAD with neutron fluence up to 6e15 n/cm^2
  - Lower rise time and Landau fluctuation are favorable at the highest fluence
  - Gain up to 10 (4) and timing resolution of 50 (60) ps measured at fluences of 3e15 (6e15) n/cm^2, respectively.

- Measurements in β-source and beam tests are complementary

- The sometimes surprising properties of LGAD are well predicted or explained by Weightfield 2.

- **Thanks to the organizers for a stimulating RD50 meeting in Krakow!**

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HGTD and LGAD R&D beam test crews

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