Collected charge, gain and jitter measurements of unirradiated LGADs from Teledyne e2v

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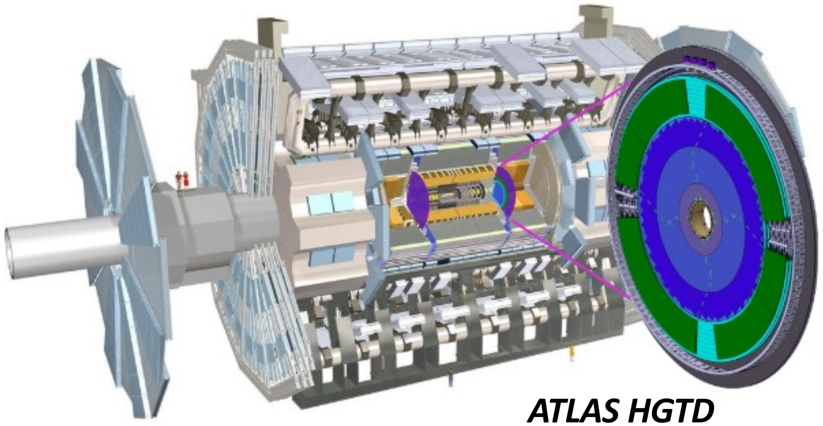
The Open University
TELEDYNE e2v Everywhereyoulook™

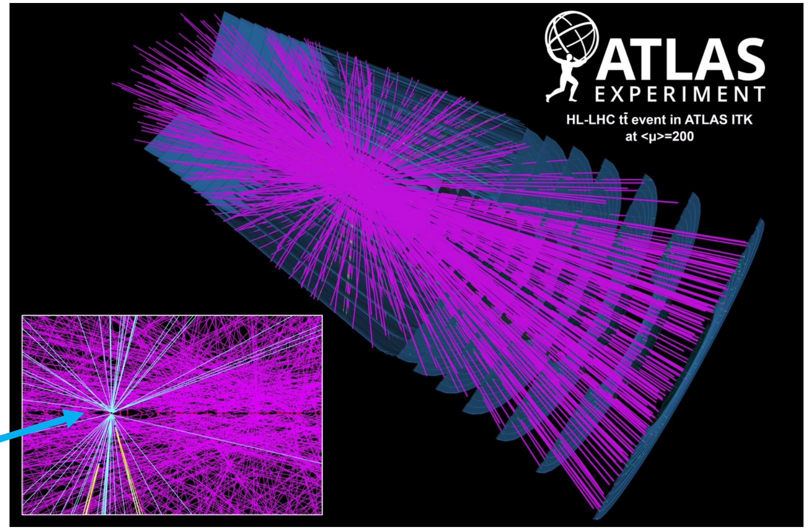
Outline

- Introduction: Ultra Fast Silicon Detectors
- Project overview: LGADs manufactured by Teledyne e2v
- Amplifier SPICE simulation
- Collected charge measurements
- Gain measurements
- Jitter measurements
- Future plans
- Summary

The need for Ultra Fast Silicon Detectors



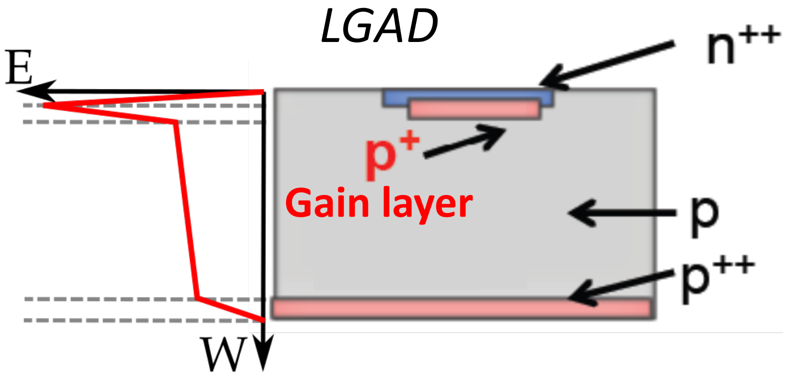
1 pp interaction amongst 200

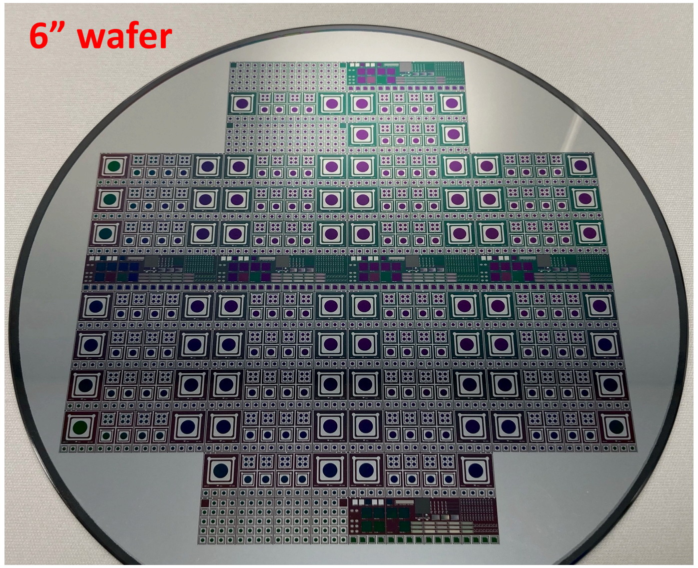


- Pile-up is one of the major challenges for tracking at the HL-LHC
- Timing information used to disentangle overlapping events
- ATLAS High-Granularity Timing Detector placed outside the ITk

Teledyne e2v LGAD project

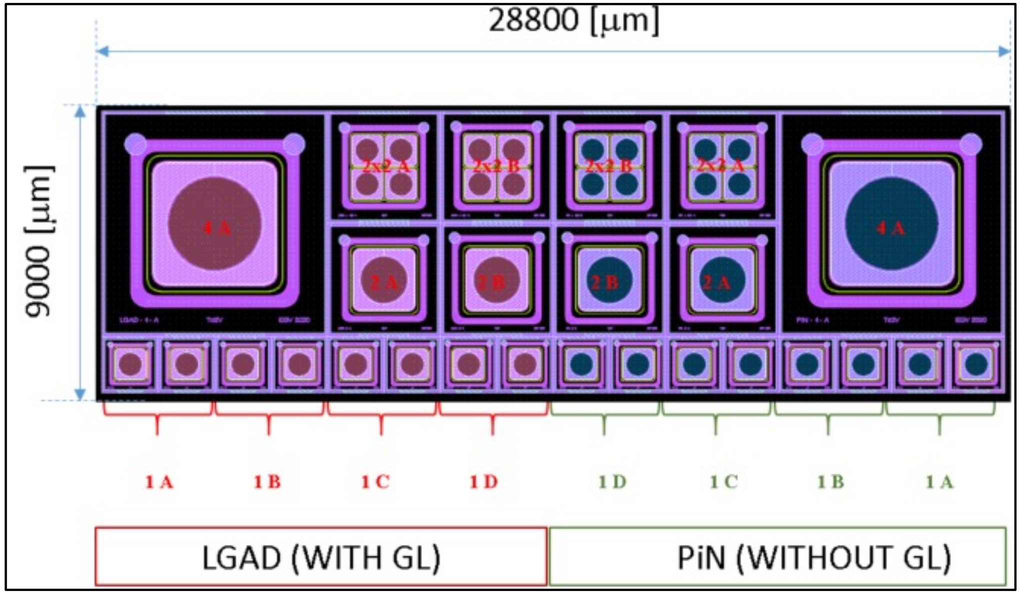
- LGAD: Low Gain Avalanche Detector
- Targeting track timing resolution of approx. 30-50 ps over detector lifetime
  - Time resolution benefits from high slew rate -> increased by introducing internal gain
  - Impact ionization in gain layer -> boron implantation (p^+)
- Pre-manufacture simulation done in TCAD
- University of Oxford, University of Birmingham, Open University, Rutherford Appleton Laboratory





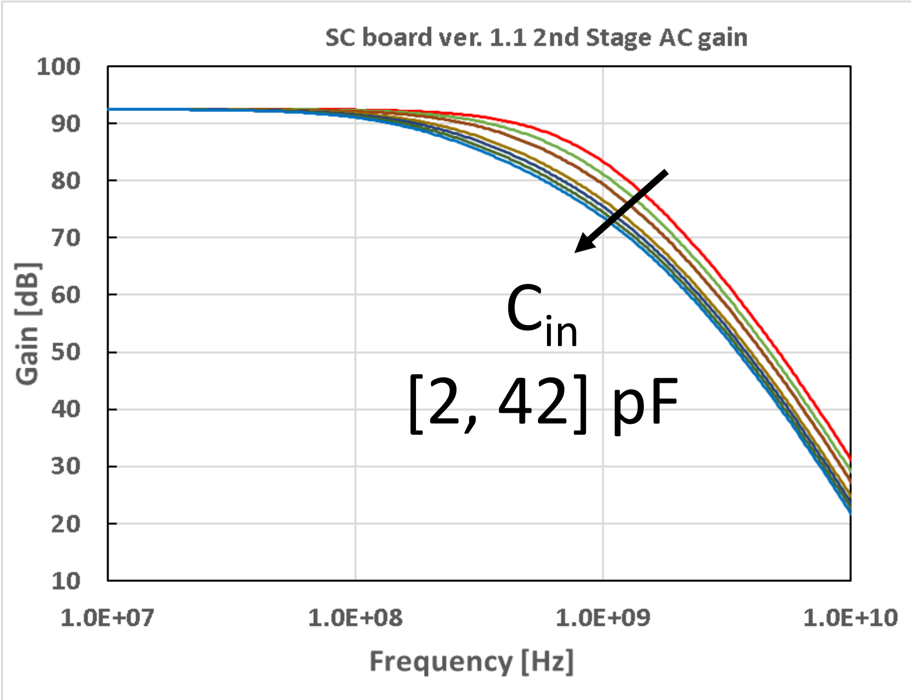
Teledyne e2v LGAD project

- Epitaxial layer: 50 um thick, high resistivity
- 8 different combinations of manufacturing parameters (only 3 shown below)
- Each field contains LGADs and PiN diodes of the same layout (4 mm, 2 mm, 1 mm)



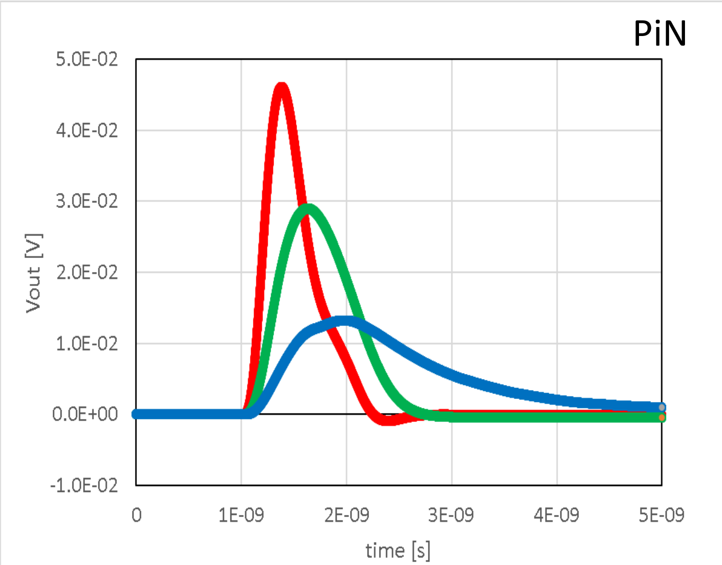
Charge gain measurement - amplification

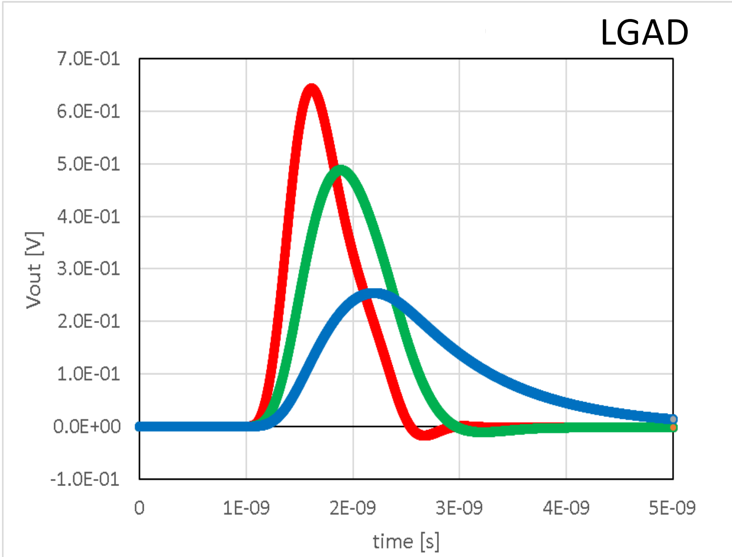
- *First stage amplifier:*
  Santa Cruz Readout v1.1
- *Second stage amplifier:*
  FEMTO HSA-X-2-40, 40 dB – 2GHz
- Impedance matched to 50 Ohm
- The combined effect of the chain of amplifiers simulated in SPICE
  - Estimate the gain of the chain
  - Gain: 92.5 dB or 42,170
    for 1mm devices with 2 pF capacitance
- Temperature is set to 25°C



SPICE – Transient current simulation of MIP signal

1st and 2nd stage amp. combined





Input capacitance:

1 mm ≈ 2 pF

2 mm ≈ 11 pF

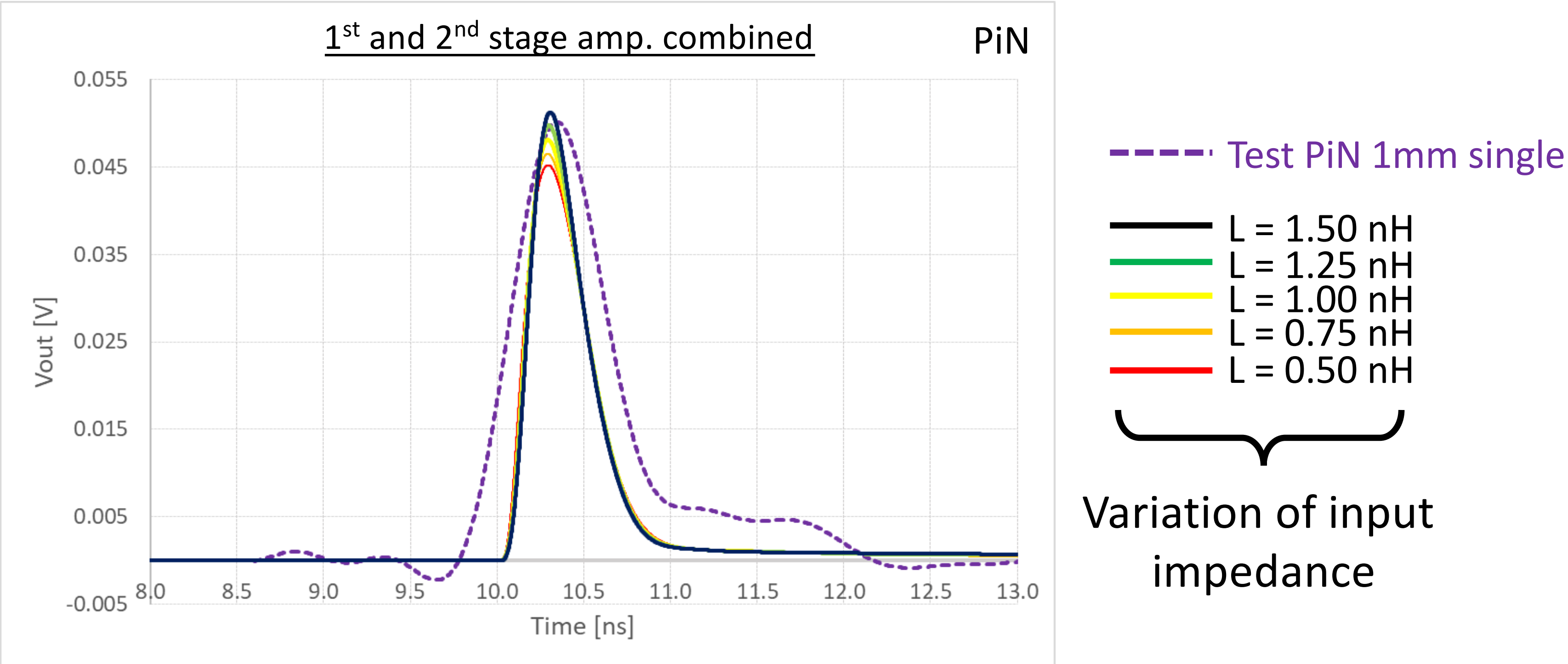
4 mm ≈ 42 pF

PiN signal: assuming saturated carrier velocity, peak current 1.5 uA with e^- collection time 300 ps, h^+ collection time 1 ns

LGAD signal: peak current 15 uA (10x of PIN signal)

SPICE – Transient current simulation

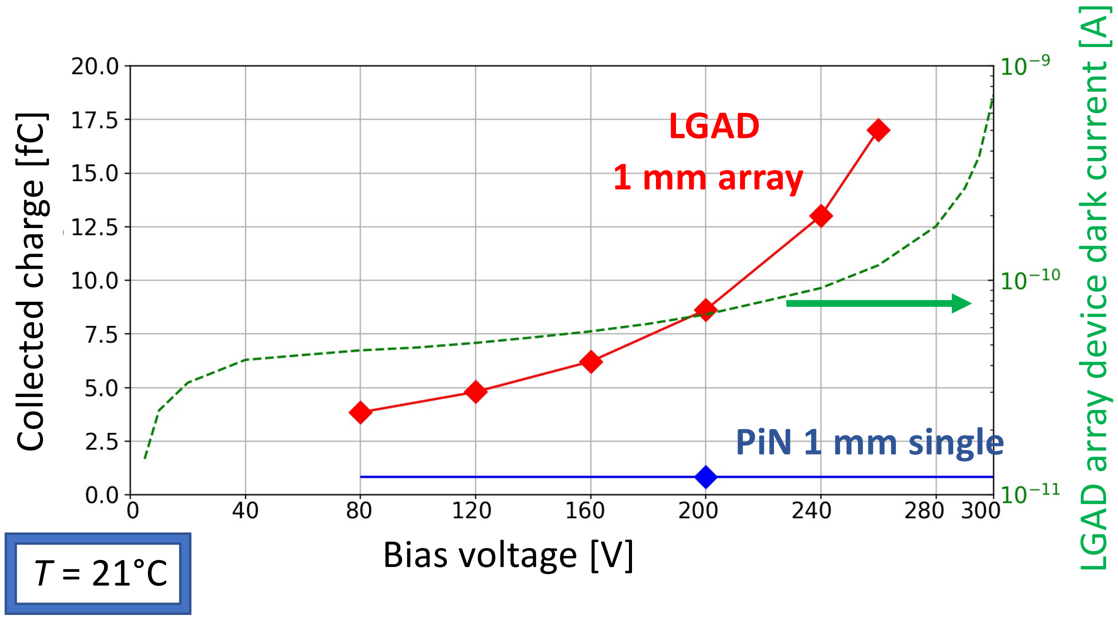
- PiN signal from TCAD simulation, input capacitance C_{in} = 2 pF
- Calibration of the laser to inject MIP-like amount of charge

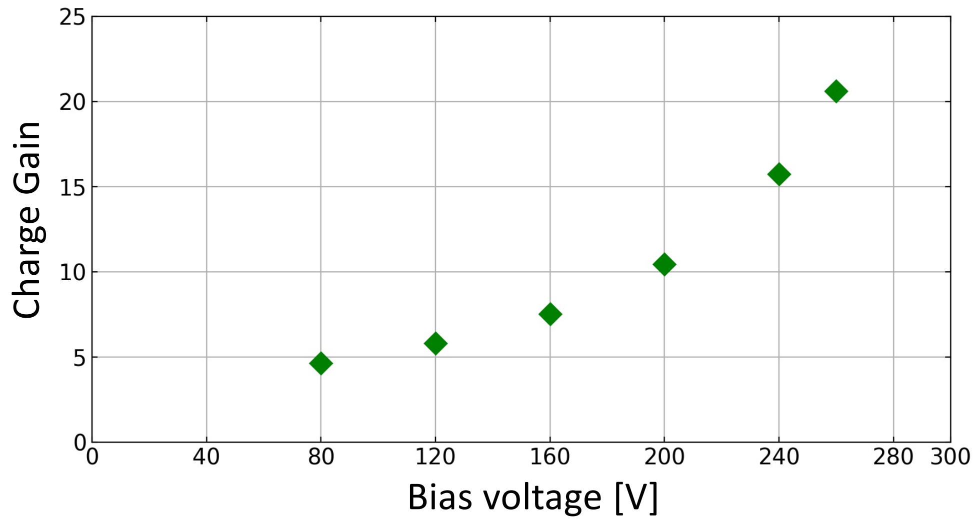


T = 21°C

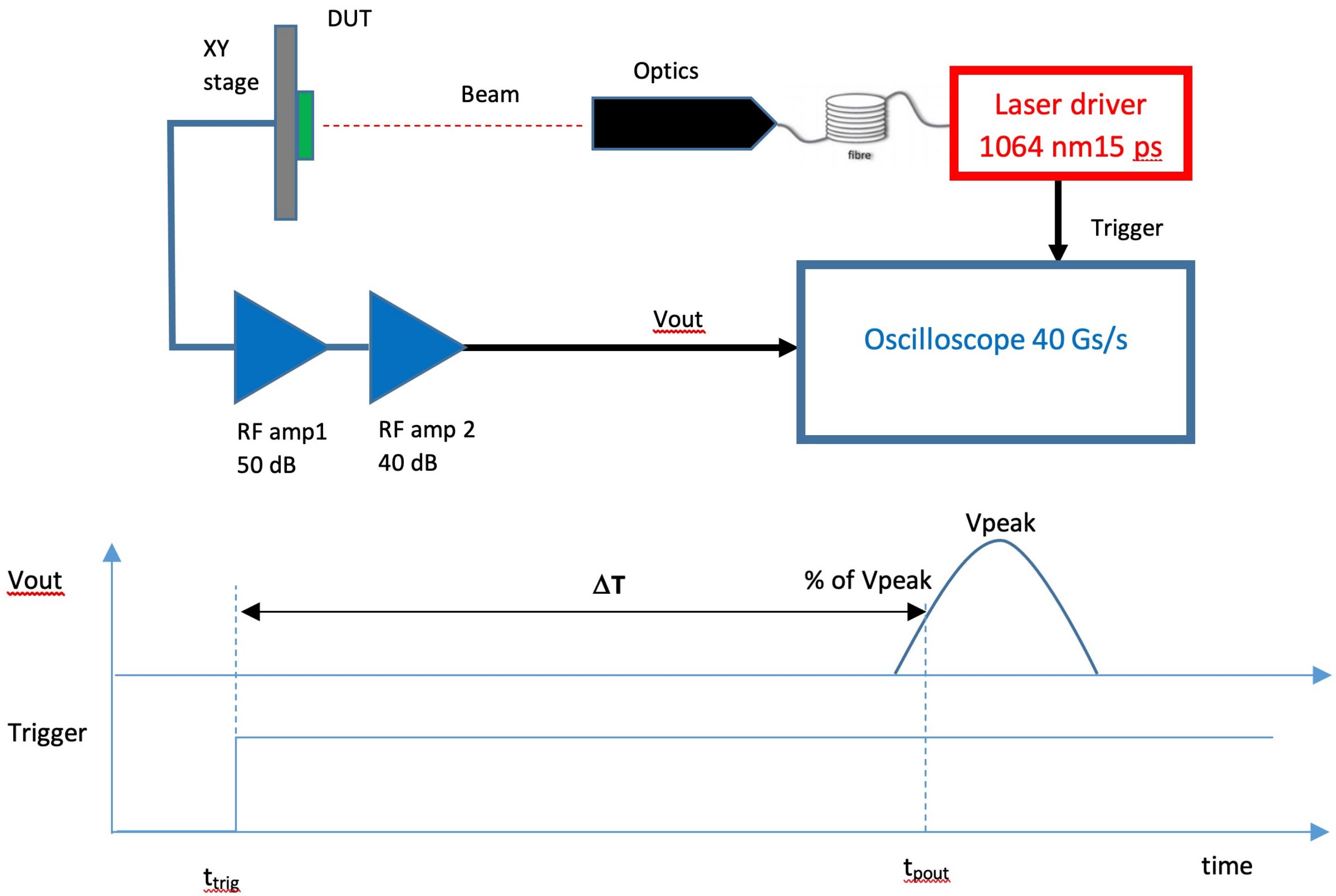
Charge collected and gain measurements – 1mm

- Conversion from the amplifier output to collected charge by estimating the gain of the chain of amplifiers from a SPICE simulation
  (92.5 dB or 42,170 for C_{in} of 2 pF – assumed constant up to 1.5 GHz)
- The charge gain - the ratio of the charge collected by LGAD and PiN



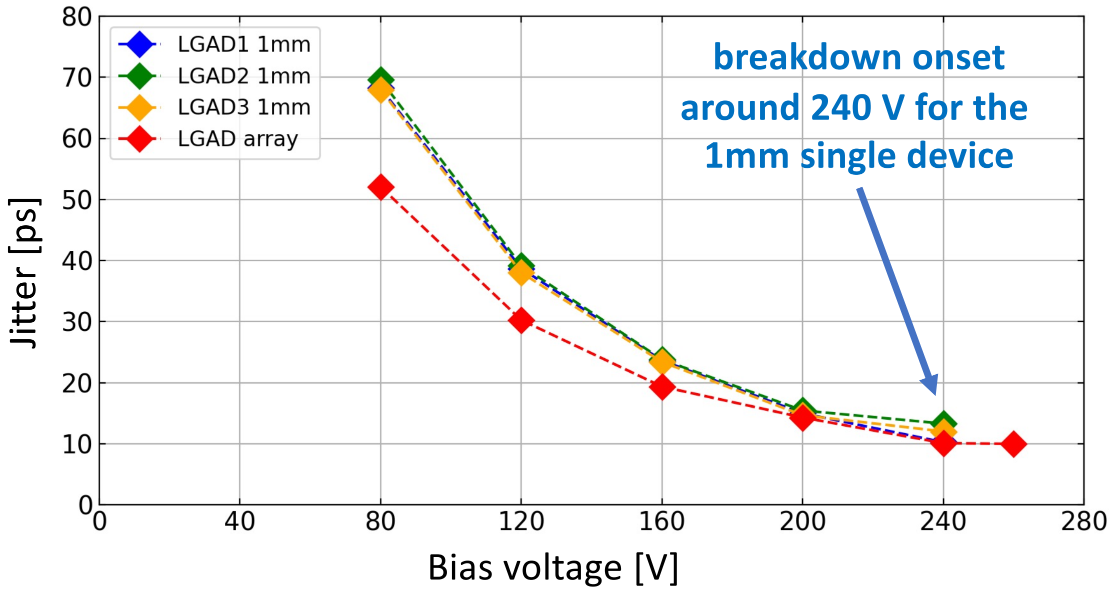


Jitter measurements - setup



Jitter measurements – 1mm LGAD (single and array)

- Jitter - the spread (standard deviation) of time delay between 50 % of trigger signal amplitude and 50 % of LGAD signal amplitude
- Low pass filter applied at 1 GHz – no substantial change to the signal
- Unirradiated device; no subtraction of other contributions



Other contribution not subtracted (estimates)

Trigger jitter: $\sigma_{Trigger} \approx 1.5\ ps$

Laser pulse: $\sigma_{Laser} \approx 3.1\ ps$

SC amplifier: $\sigma_{Amp1} \approx 7.4\ ps$

T = 21°C

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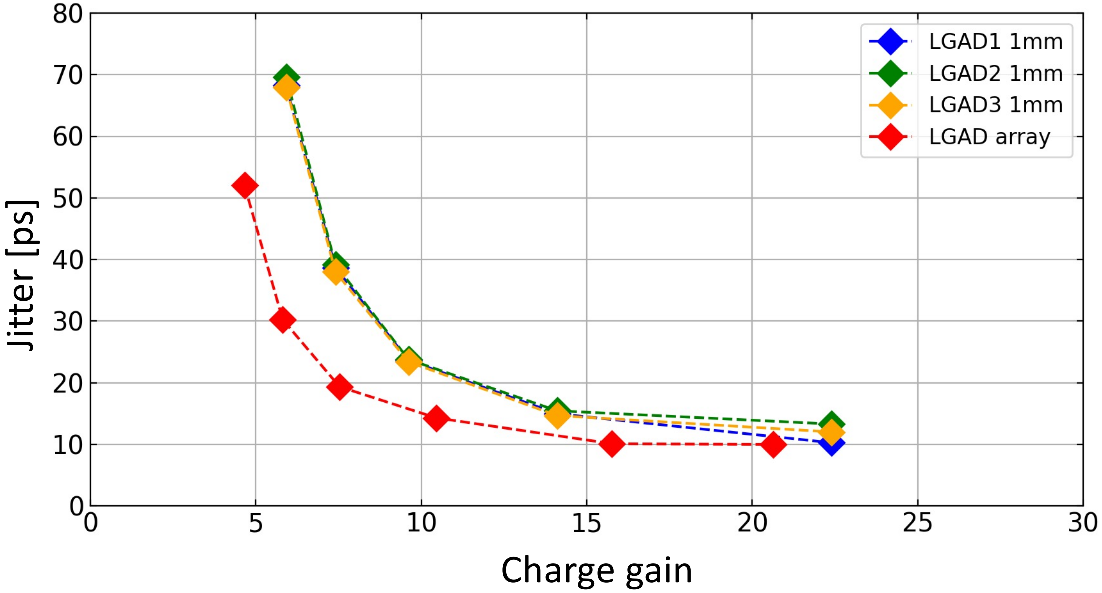

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Timing Measurement uncertainties

$$\sigma_{\Delta t}^2 = \sigma_{trig}^2 + \sigma_{Laser}^2 + \sigma_{DUT}^2 + \sigma_{Amp1}^2 + \sigma_{Amp2}^2 + \sigma_{TW}^2 + \sigma_{TDC}^2$$

- σ_{trig}^2: Jitter term of trigger output
- σ_{Laser}^2: Jitter term due to the laser pulse fluctuations
- σ_{DUT}^2: Intrinsic jitter of the DUT (+ distortion and Landau)
- $\sigma_{Amp1}^2 + \sigma_{Amp2}^2$: Jitter of the amplifiers
- σ_{TW}^2: Time-walk term
- σ_{TDC}^2: Time quantization noise of the scope

Timing Measurement uncertainties

Negligible according to the data sheet

$$\sigma_{\Delta t}^2 = \sigma_{trig}^2 + \sigma_{Laser}^2 + \sigma_{DUT}^2 + \sigma_{Amp1}^2 + \sigma_{Amp2}^2 + \sigma_{TW}^2 + \sigma_{TDC}^2$$

Jitter term of trigger output $\approx (\mathbf{1.5\ ps})^2$

Jitter term due to the laser pulse fluctuations $\approx (\mathbf{3.1\ ps})^2$

Intrinsic jitter of the DUT ~~(+ distortion and Landau)~~

Negligible

- **Firing on the same spot**
- **Using a monochromatic laser**

Jitter of the amplifiers

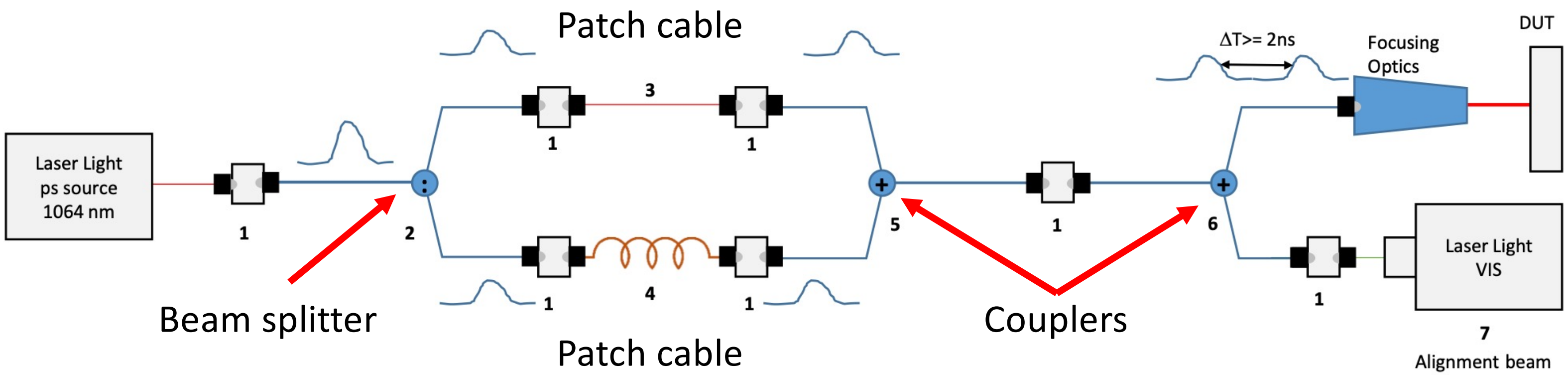
- **First stage $\approx (7.4\ ps)^2$**
- **Second stage negligible**

Time-walk term

Time quantization noise of the scope

Future tests

- Jitter measurements – elimination of the laser trigger component



- Test with the other produced wafers – variation of implant dose and energy
- Irradiation of the devices

Summary

- Response of PiN and LGAD unirradiated devices simulated in SPICE

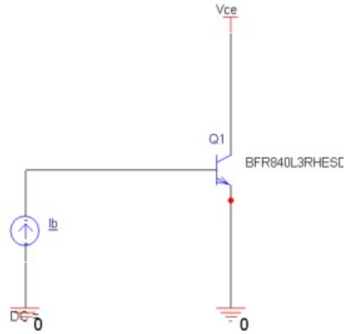
- Gain of the chain of amplifiers determined: 92.5 dB or 42,170

- Charge collection shows >15 fC charge collected for 1mm LGAD array device biased at >240 V (for unirradiated devices)

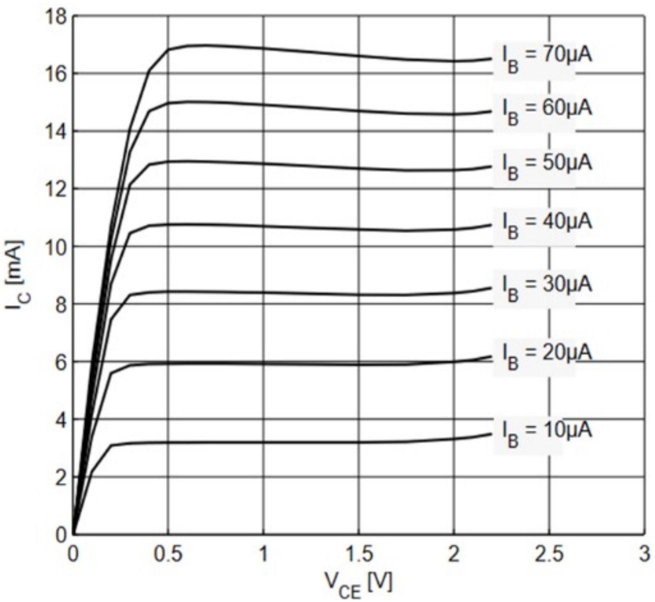
- 1mm LGAD array devices show jitter of <20 ps for bias >160 V

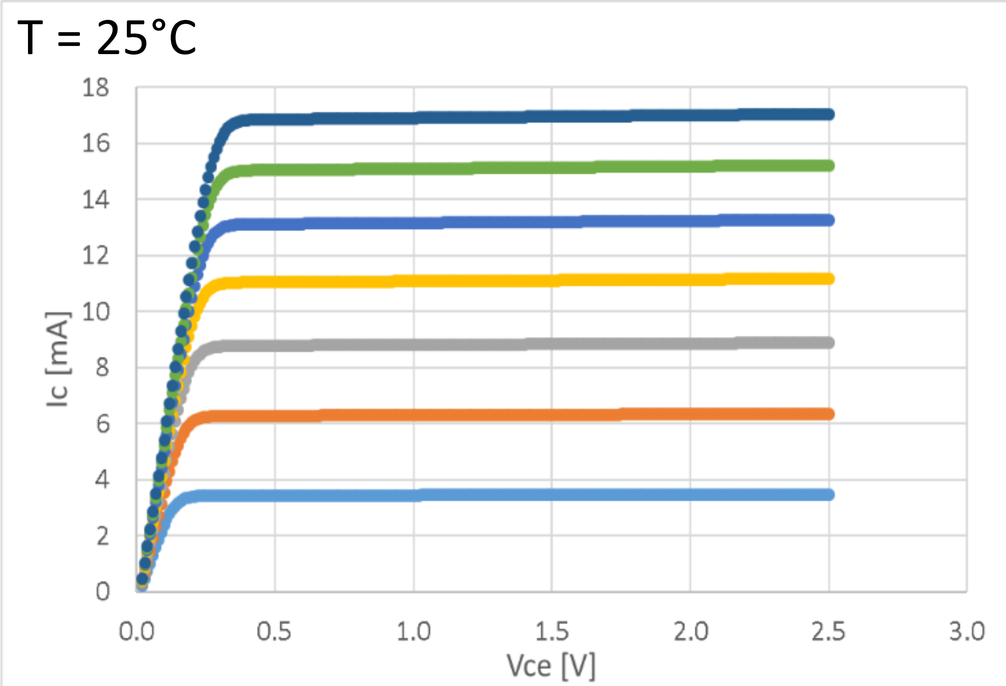
- Future improvements of laser optics setup should allow to refine jitter measurements – remove contributions from trigger and laser jitter

SPICE – DC Simulation of the SiGe NPN



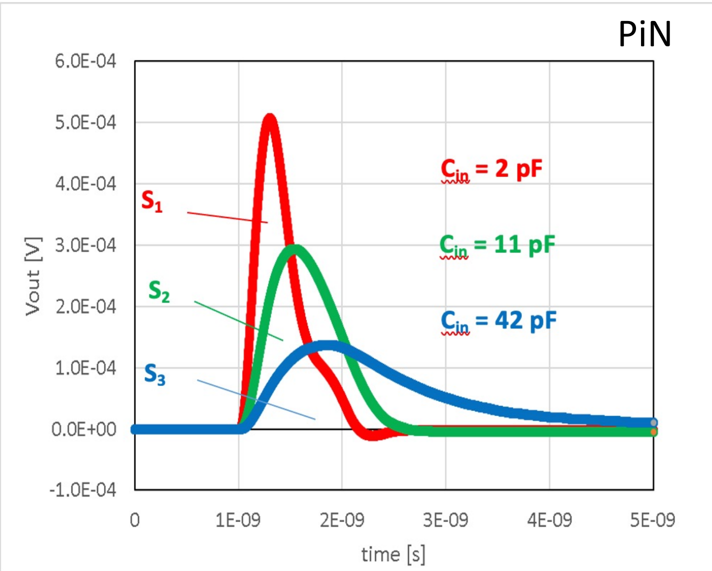
- SiGe NPN BFR840L3RHESD (Infineon)
- Compare SPICE predictions with typical DC curves reported in the design sheet

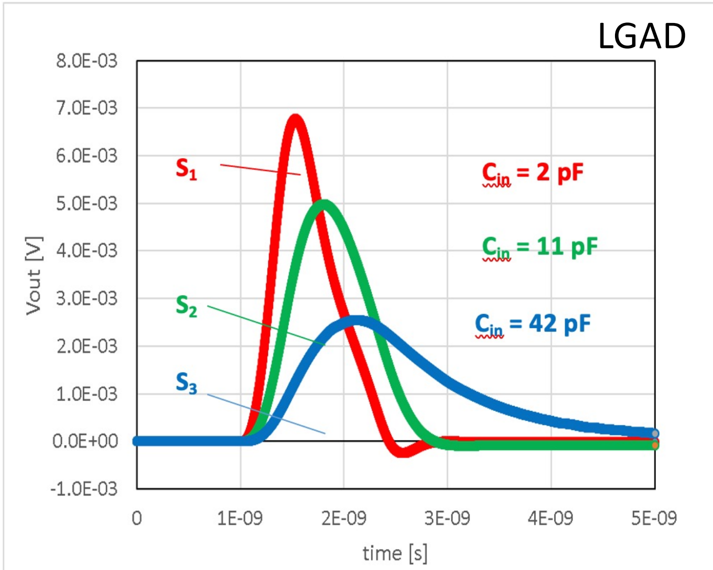




SPICE – Transient current simulation

1st stage only





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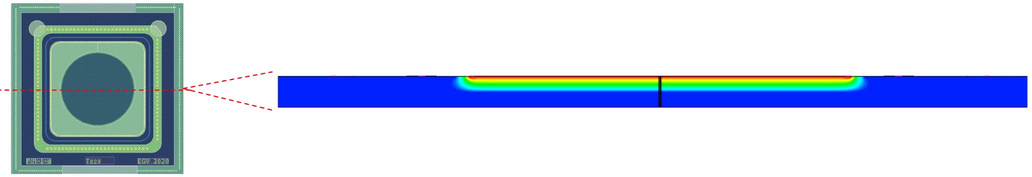
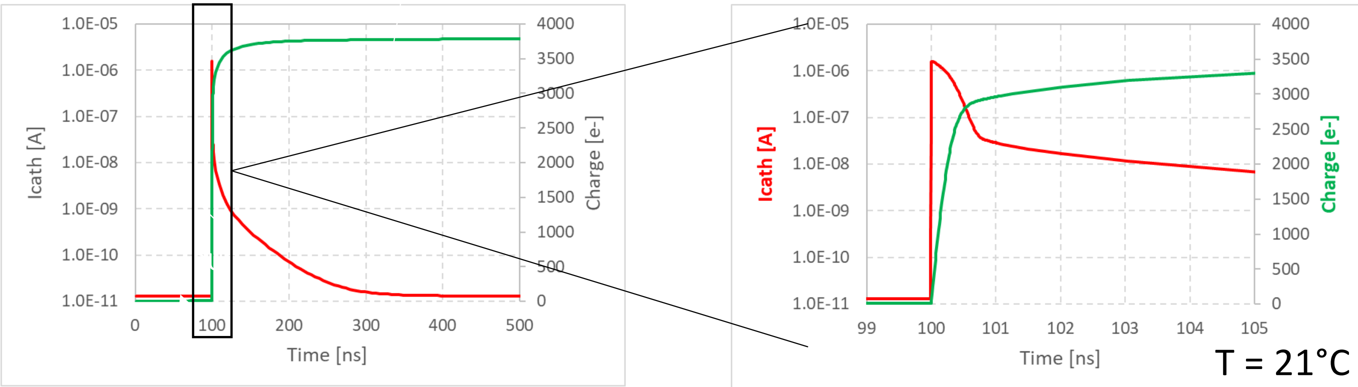
TCAD simulation for PiN(MIP)

PiN 1mm



PiN 1mm V_{bias} = 200 V

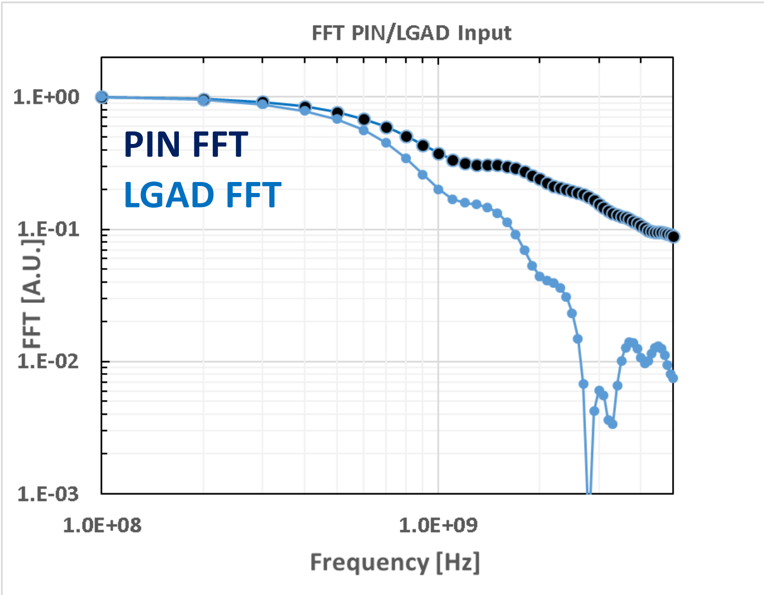


MIP transient current and collected charge for PiN diode at V_{bias} = 200 V

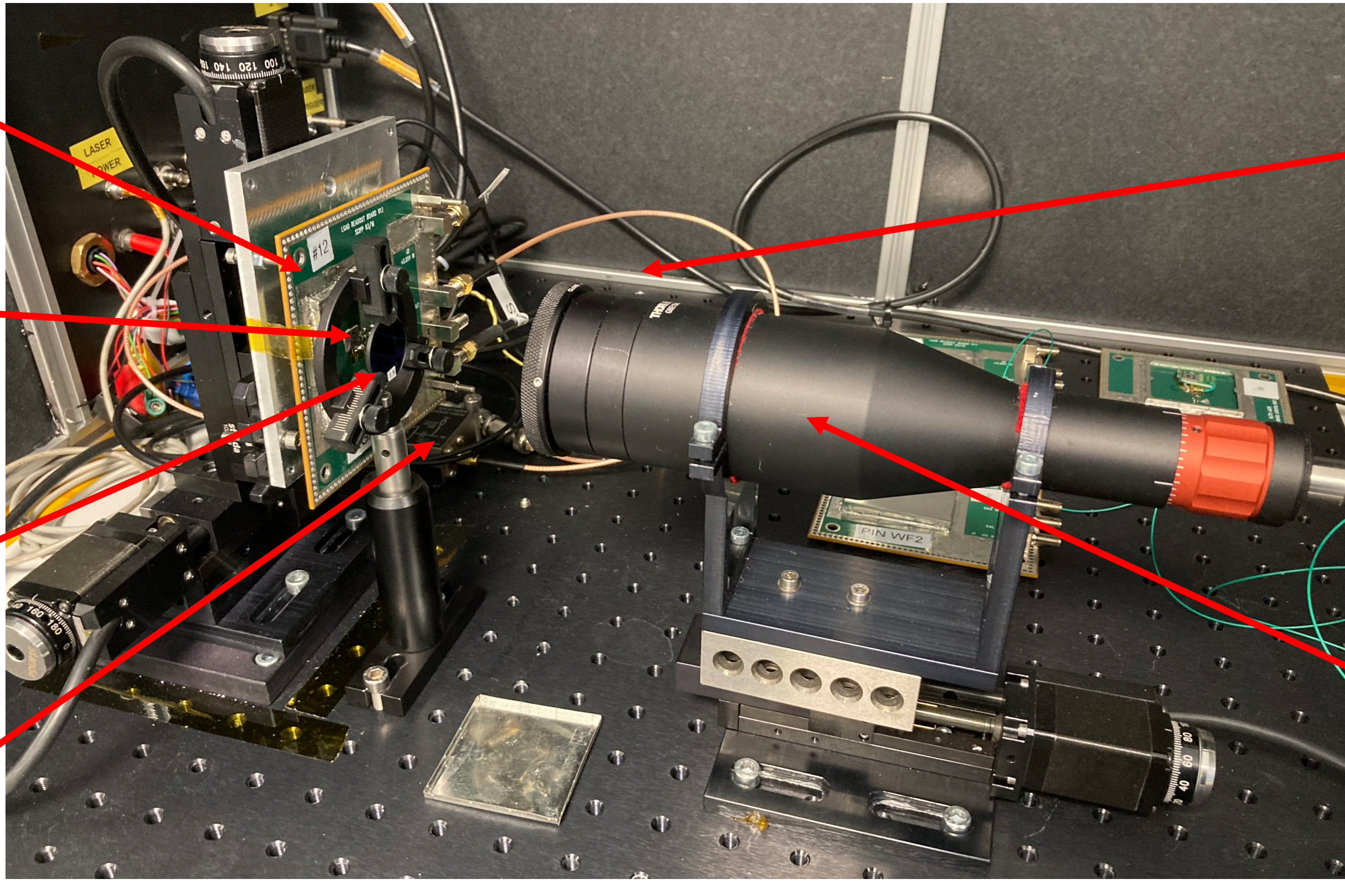
- MIP : MPV [300 um] ~ 72 e/h pair/um
- Central hit
- Time resolution [t_0 , t_0+1ns] : 100 fs
- Implement the current waveform [t_0, t_0 + 5 ns] into SPICE simulation of RF amplifier
- TCAD estimated collected charge at 5 ns = 3303 e- (eqv. 0.53 [fC])

Normalized PiN and LGAD (MIP) FFT of current signal

- Comparison the FFT of the PiN and LGAD signals, normalized to their maximum magnitude



Charge collection and jitter - laser setup



Santa Cruz v1.1
(1st stage amp)

LGAD/PiN
device

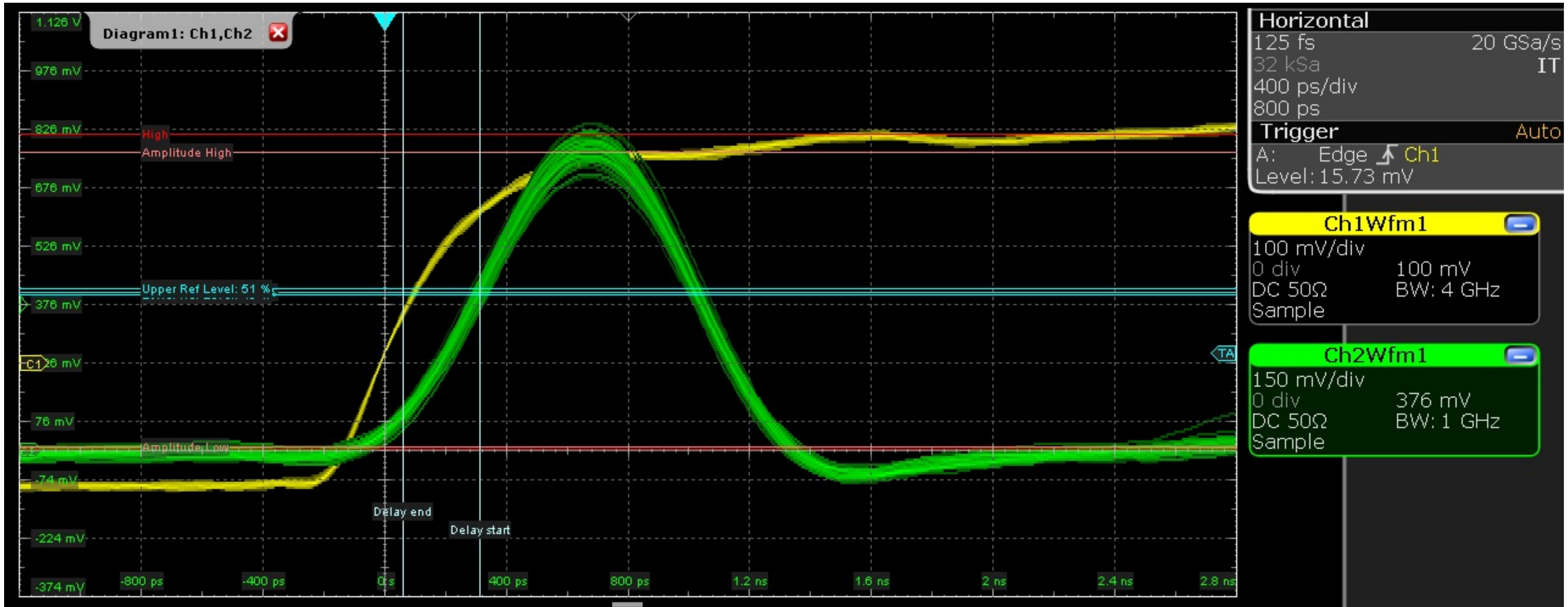
ND filter

FEMTO 40dB
(2nd stage amp)

QD Laser
1064 nm
(behind)

Laser Optics

1mm LGAD array signal – 240 V bias



	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Meas Group 1								
Delay	-253.25 ps	-56.337 ps	-273.76 ps	-232.57 ps	232.79 ps	10.087 ps	30458	30458
Meas Group 2								
Low	9.8933 mV	137.36 mV	-76.075 mV	-6.4623 mV	10.271 mV	7.9831 mV	30458	30458
Amplitude	755.93 mV	975.3 mV	664.03 mV	781.75 mV	782.2 mV	26.727 mV	30458	30458
Area	531.33 pV*s	1.1405 nV*s	444.15 pV*s	548.53 pV*s	549.37 pV*s	30.33 pV*s	30458	30458
Meas Group 3								
Slew rate rising	1.5 V/ns	1.933 V/ns	500.31 V/µs	1.521 V/ns	1.524 V/ns	86.028 V/µs	30458	30458