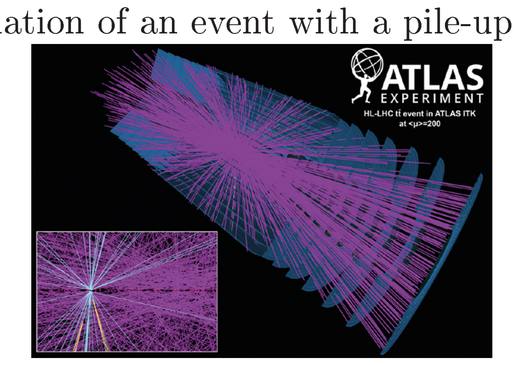
Characterization of Irradiated APDs for Picosecond Time Measurements

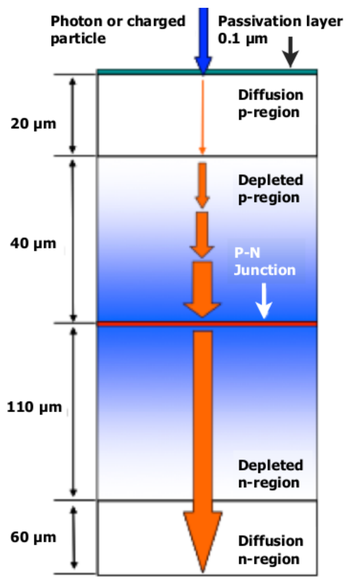
Introduction

Simulation of an event with a pile-up of 200



- High Luminosity LHC (2026 onward)
- Average pile-up of 200
- **Timing to reduce pile-up effects**
- Requirement: $\sigma_t = 30$ ps (1 MIP)
- Radiation hardness up to $\Phi_{eq} = 10^{15}$ cm^{-2}

Deep Diffused APDs



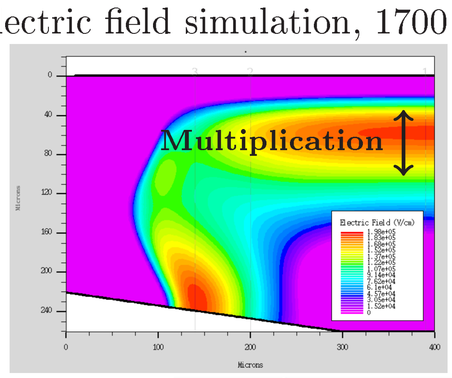
Avalanche Photo Diodes

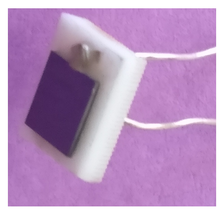
- Charge multiplication
- Gain: ≈ 500 at 1800 V
- Nominal active area: 2×2 mm^2
- Total thickness: 230-280 μm
- Produced by RMD [1]

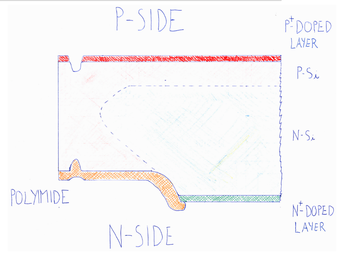
Irradiation

- JSI Ljubljana [2], reactor neutrons
- Up to 10^{15} 1 MeV neutrons cm^{-2} ($\Phi_{eq} = 10^{15}$ cm^{-2})

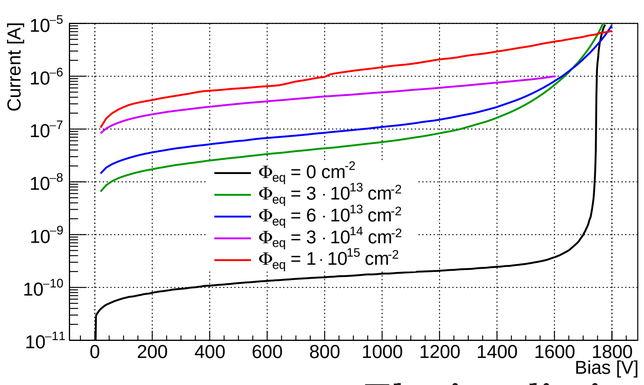
Electric field simulation, 1700 V







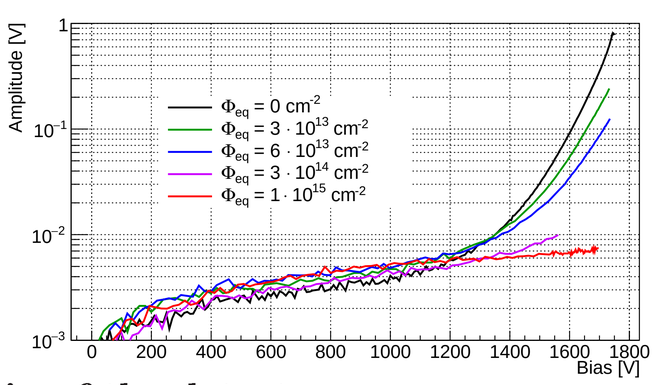
Signal Amplitude and Current Measurements



Left: current-voltage curves measured at -20°C

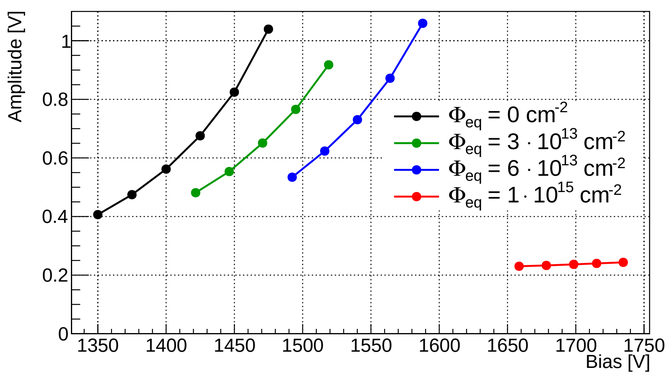
Right: signal amplitude versus voltage at -20°C

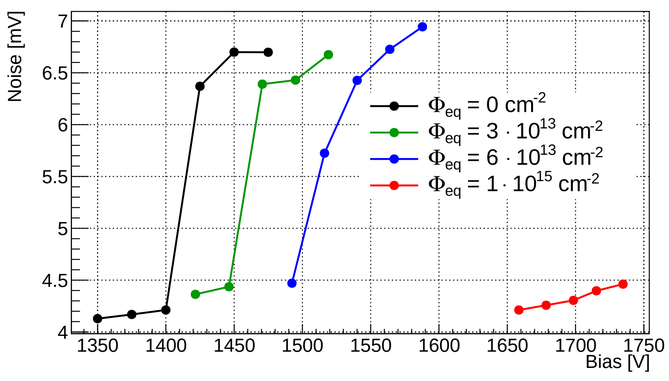
- IR laser: 200 ps pulse, 1064 nm
- 15 MIPs equivalent intensity
- 10 dB amplification

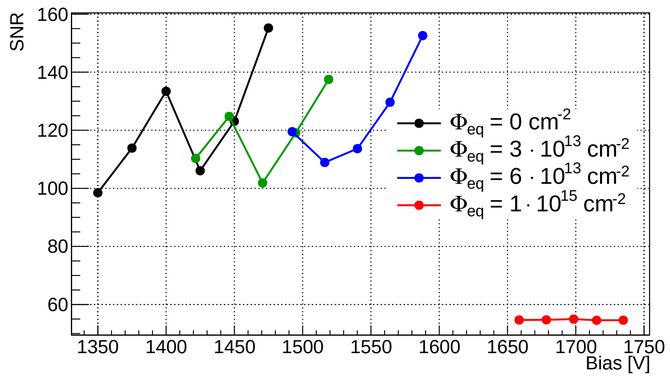


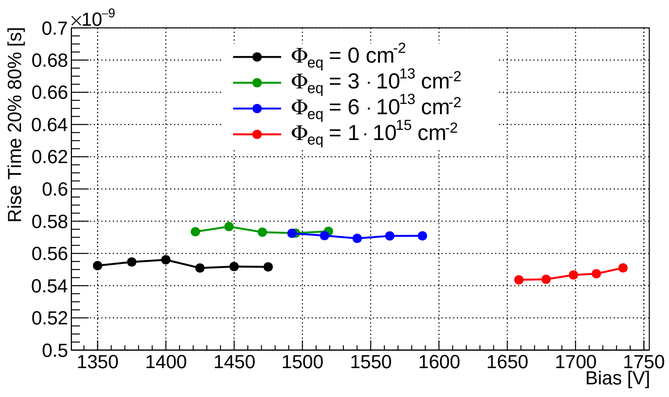
The irradiation increases the bulk generation current and reduces the gain of the detectors

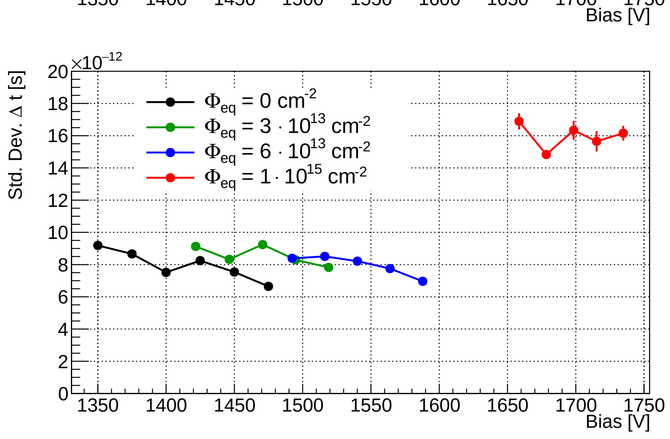
Time Resolution Measurements

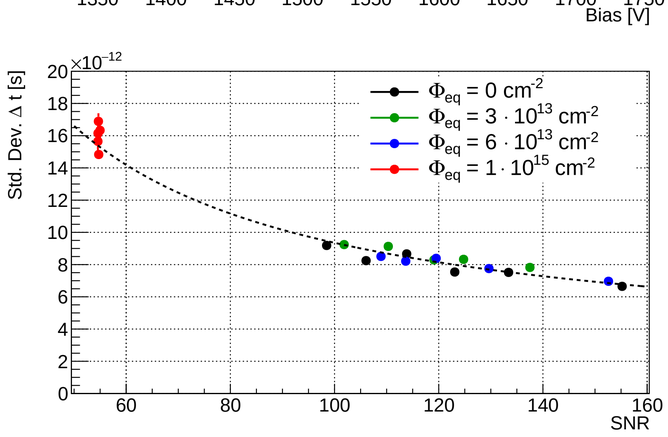












Experimental Setup

- IR laser: 200 ps pulse, 1064 nm
- 15 MIPs equivalent intensity
- -20°C
- 40 dB amplification
- 1500 waveforms per point
- **Time reference resolution: $\sigma_t = 4.2 \pm 0.1$ ps**
- Sensor irradiated to $\Phi_{eq} = 3 \cdot 10^{14}$ cm^{-2} could not be measured due to its breakdown behavior
- Sensor irradiated to $\Phi_{eq} = 10^{15}$ cm^{-2} shows "dark pulses" that affect the measurements
- Events with "dark pulses" were removed

Amplitude

- Limited to 1 V by amplifier
- Up to $\Phi_{eq} = 6 \cdot 10^{13}$ cm^{-2}: restored by increasing bias

Noise

- Standard deviation of the baseline signal
- Affected by multiplication effects

Rise time

- Not much affected by irradiation: variation within 6%

Time resolution (15 MIPs)

- $\sigma_{\Delta t} = 6.7 \pm 0.1$ ps before irradiation
  $\rightarrow \sigma_t = 5.2 \pm 0.2$ ps reference resolution subtracted
- Varies as a function of SNR (Signal to Noise Ratio)
- Up to $\Phi_{eq} = 6 \cdot 10^{13}$ cm^{-2}: restored by increasing bias

Conclusions & Outlook

- The performance of deep diffused APDs is not degraded at least up to $\Phi_{eq} = 6 \cdot 10^{13}$ cm^{-2}
- At a fluence of $\Phi_{eq} = 10^{15}$ cm^{-2} "dark pulses" with a frequency around 3 MHz are observed
- Further studies, including beam tests, and improvements of the measurement setup are foreseen

Bibliography

[1] http://rmdinc.com/

[2] L. Snoj et al., Applied Radiation and Isotopes, Volume 70, Issue 3, pp. 483-488, 2012.

M. Centis Vignali[1*], R. Dalal[2], M. Gallinaro[1,3], B. Harrop[4], G. Jain[2], C. Lu[4], M. McClish[5], K. T. McDonald[4], M. Moll[1], F. M. Newcomer[6], S. Otero Ugobono[1,7], S. White[1,8]

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