Fast amplifier for SiPM characterization in a wide temperature range for the next RICH experiments

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SiPM characterization amplifier

- The next generation of RICH (Ring Imaging Cherenkov) detectors may use **SiPMs (Silicon PhotoMultipliers)** as photodetectors.
- SiPMs need to be **characterized with good timing resolution (tens of picoseconds) at different temperatures** to study the effects of radiation damage as a function of operating temperature (between ~ 80 K and ~ 300 K).
- Fast transimpedance signal amplifier for **SiPM characterization**.
- **Low power consumption, adequate for cryogenic operation**: 175 mW @ $\sim 300\ \mathrm{K}$ and 100 mW at @ $\sim 80\ \mathrm{K}$ per amplifier.
- **Very low noise** $\left(< 1 \frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}\right)$ and **very fast response** $(< 500\ \mathrm{ps})$ result in **very low jitter (high time resolution)**.

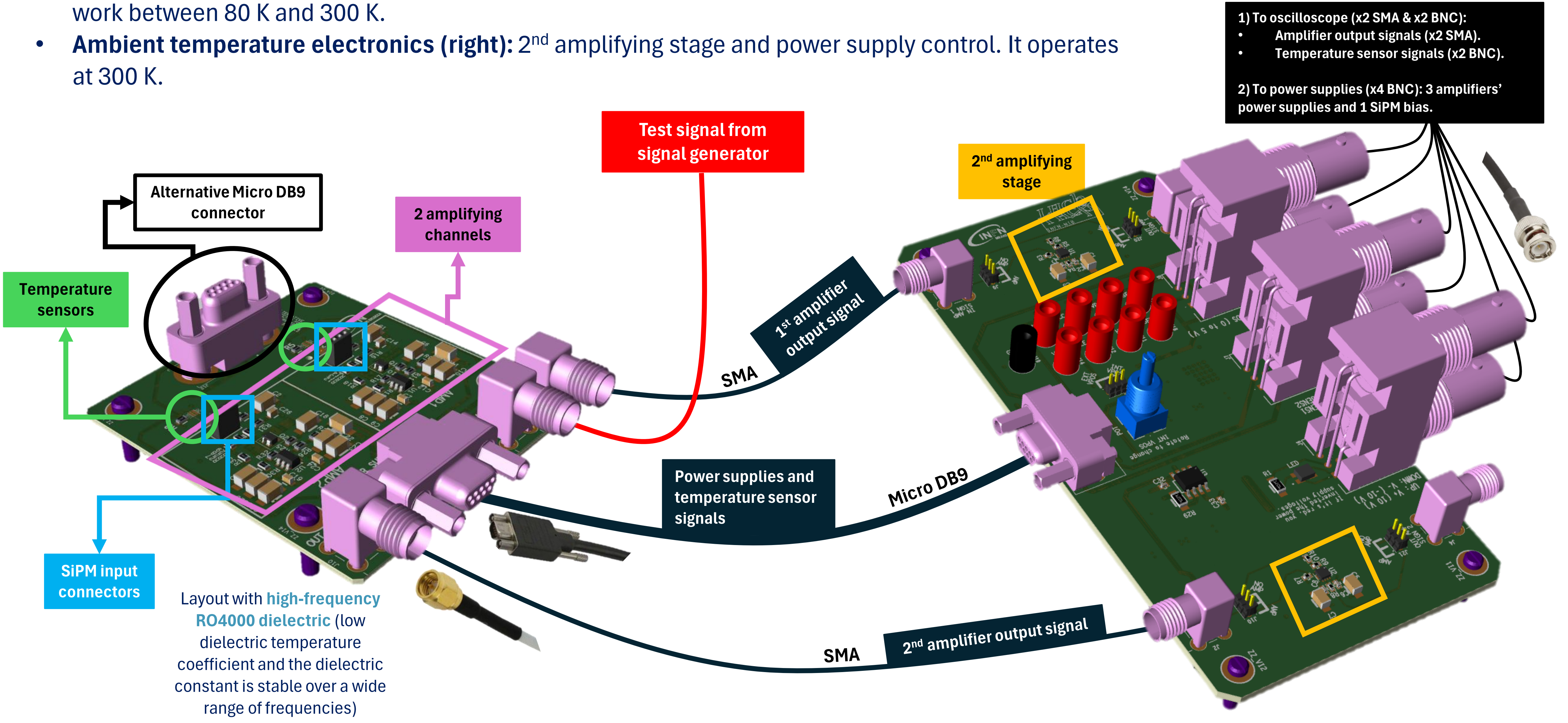
Electronics' jitter

$$\sigma_t = \frac{C}{Q_S}\sqrt{\frac{\overline{e_{amp}^2}}{f_{BW}}}$$

- $\overline{e_{amp}^2}$: input referred amplifier noise.
- f_{BW}: amplifier bandwith frequency.
- Q_S: charge produced by the source.
- C: constant.

The complete setup

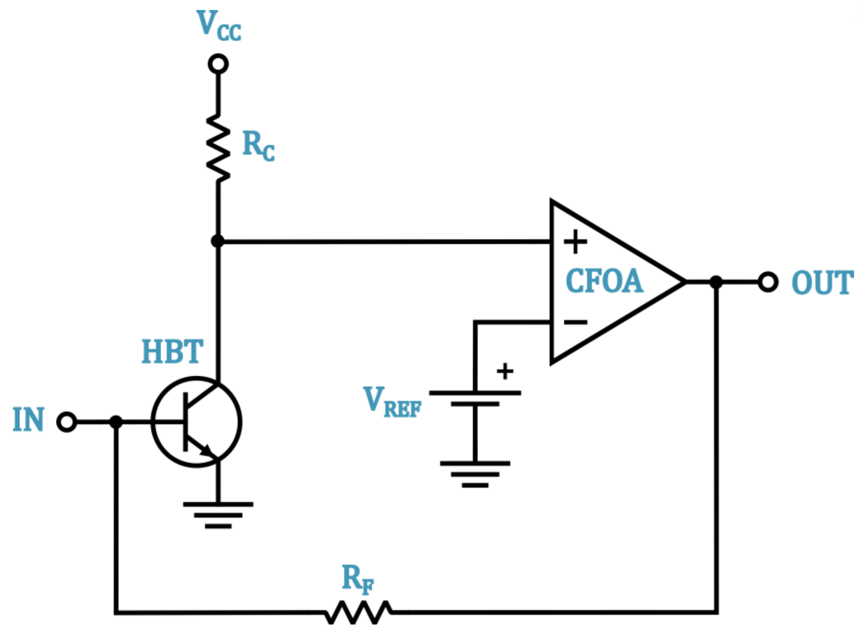
- **Cold electronics (left):** SiPM amplification (x2 channels), test signal and temperature sensor. It can work between 80 K and 300 K.
- **Ambient temperature electronics (right):** 2nd amplifying stage and power supply control. It operates at 300 K.



Simplified amplifier schematic

Amplifier summary (cold electronics):

- Low noise **HBT** (Heterojunction Bipolar Transistor).
- The transistor current is provided through resistor R_C.
- **Fast CFOA** (Current Feedback Operational Amplifier) that can also operate at cryogenic temperatures.
- The feedback path is closed by a feedback resistor R_F.
- Output signal:
  - Gain: 7500 Ω = 77.5 dB (Ω/Ω).
  - Bandwidth: ~ 1 GHz @ 300 K and ~ 700 MHz @ 80 K.
  - Input referred noise: $\sim 0.9 \frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}$ @ 300 K and $\sim 0.5 \frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}$ @ 80 K.



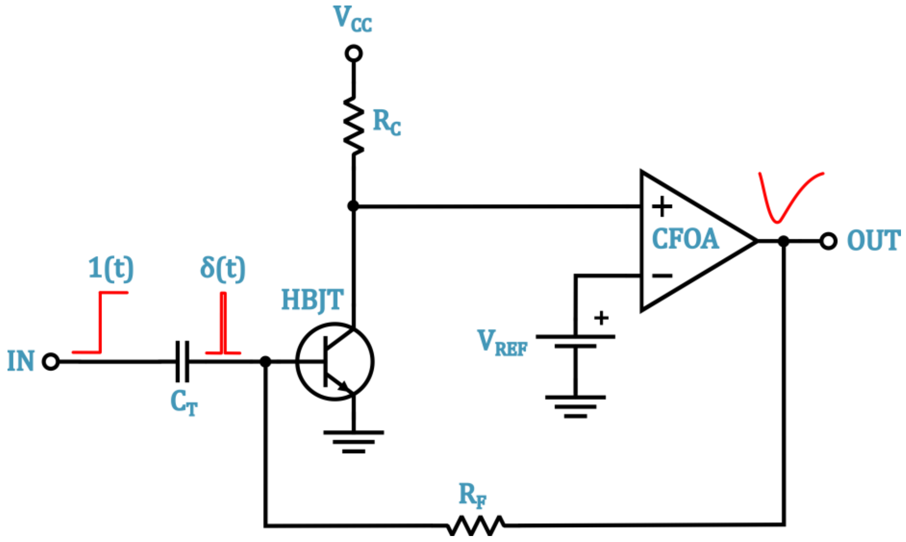
Feedback appropriately compensated

- The output signal is sent to the **ambient temperature board.**
- This output signal can be amplified by the **2nd stage amplifier**:
  - Large bandwidth: 3 GHz.
  - Gain: 3.5 V/V using a 50 Ω transmission line terminated on both ends.
- This second amplifying stage **can be bypassed**.

Performed tests

- Tests were performed with both the test and SiPM signals.

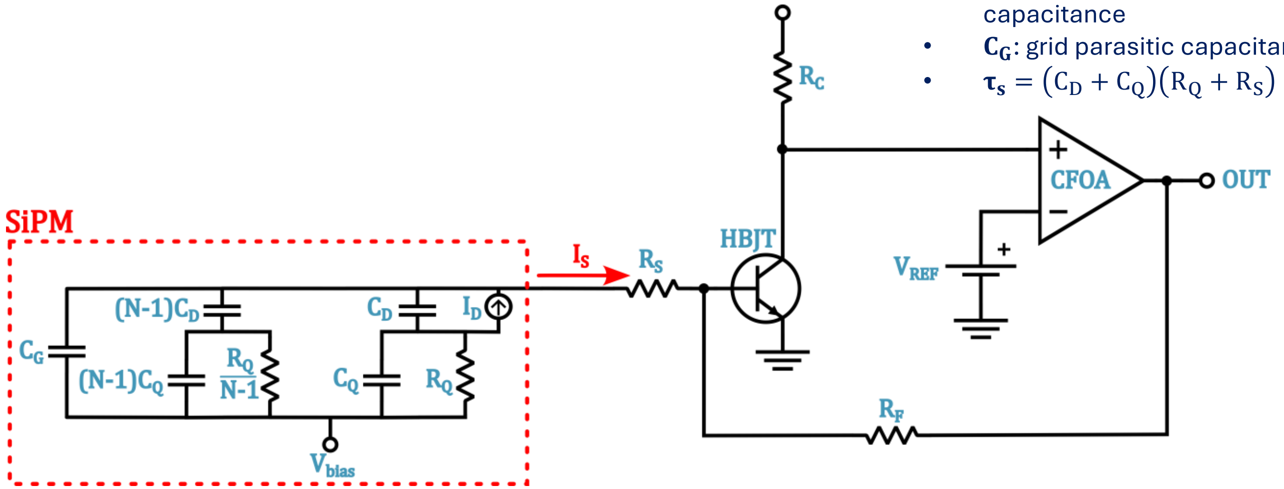
Test signal



- Step voltage charges a test capacitor C_T.
- **Dirac delta-like current signal** into the amplifier to test the amplifier capabilities.
- Measurement of rise time, fall time and amplifier's contribution to the jitter.

SiPM signal

- $V_{OV} = V_{bias} - V_{br}$: overdrive voltage, with V_{br} being the breakdown voltage.
- C_D: single diode capacitance
- I_D: avalanche current
- C_D: diode capacitance
- R_Q: quenching resistor
- C_Q: quenching parasitic capacitance
- C_G: grid parasitic capacitance
- $\tau_s = (C_D + C_Q)(R_Q + R_S)$

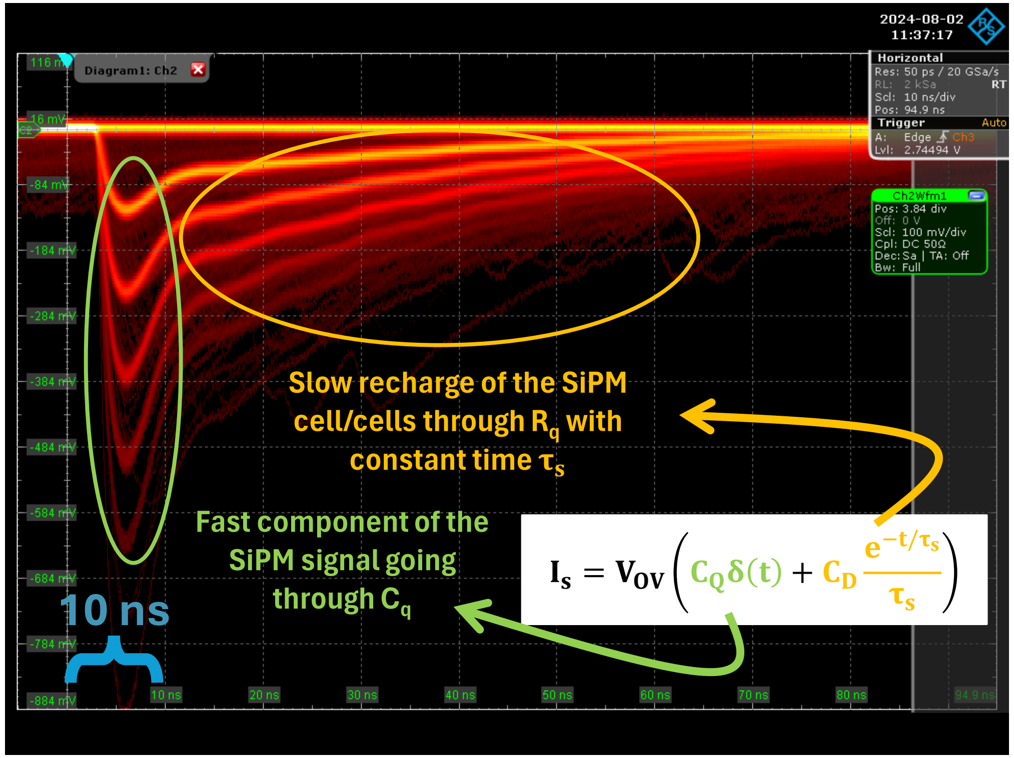


- **SiPM signal** fed into the amplifier through R_s = 50 Ω.
- Measurement of parameters such as rise time, fall time and jitter due to both the SiPM and amplifier (amplifier's jitter and fall time are negligible).

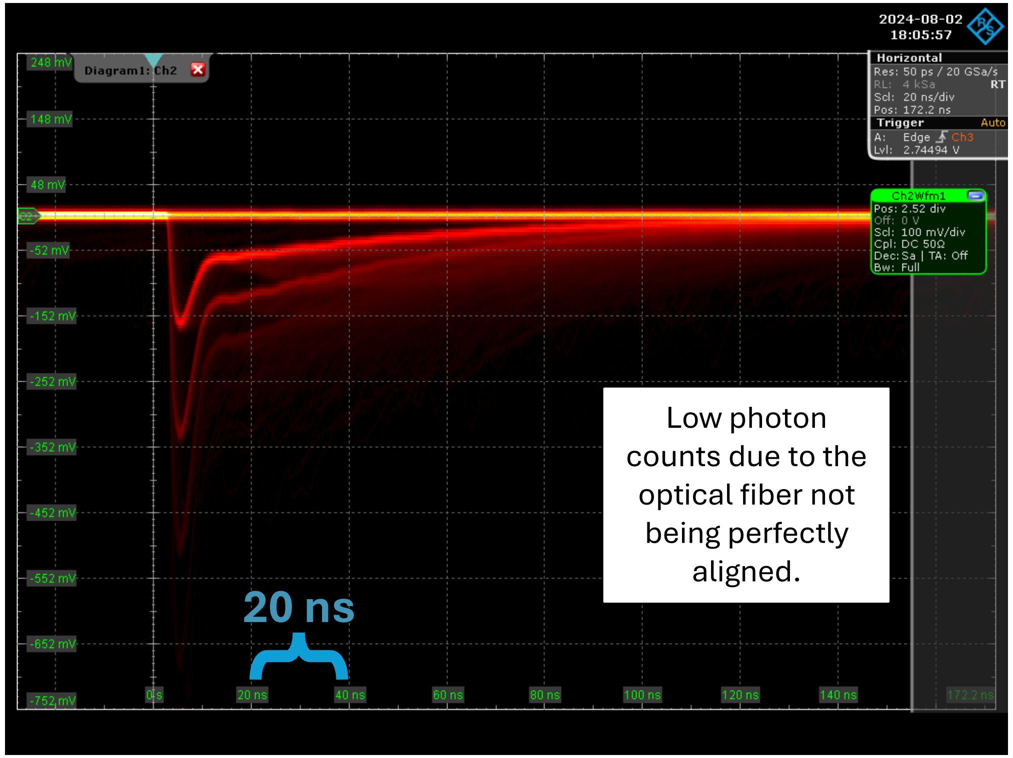
Amplifier response to a SiPM signal

- The **SiPM signal** can be written as $I_s = V_{OV}\left(C_Q\delta(t) + C_D\frac{e^{-t/\tau_s}}{\tau_s}\right)$.
- The amplifier was tested with a **1.3mm x 1.3mm Hamamatus SiPM** (S13360-1350).
- The photons were produced by a **405 nm laser** controlled by the **Hamamatsu PLP-10 pulser** (70 ps FWHM pulses).
- Here are shown the oscilloscope screenshots of **photon counting measurements** with the SiPMs operated at 3 V_{OV}.

SiPM signal response (300 K, 3 Vov)

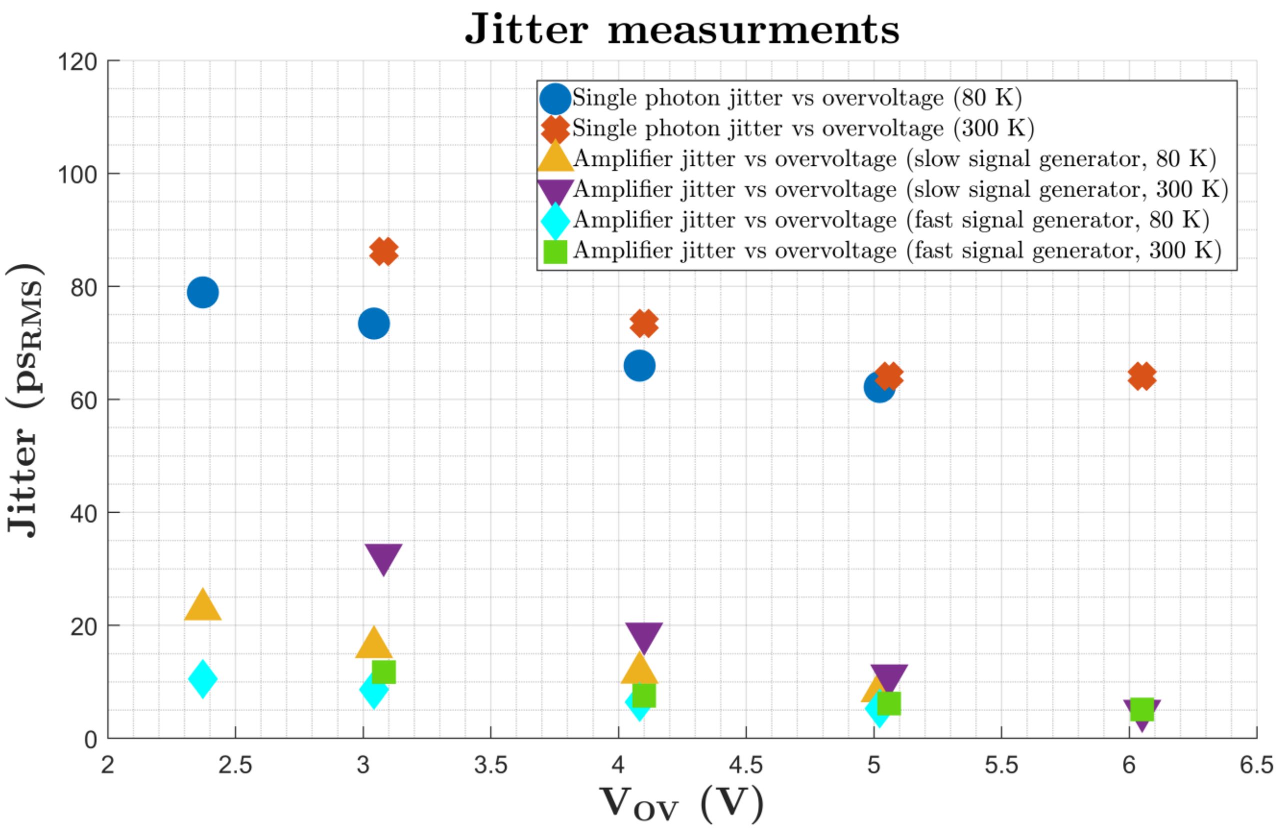


SiPM signal response (80 K, 3 Vov)



Jitter measurements summary

- Measurement of the amplifier (amplifier jitter) and SiPM+amplifier (single photon jitter) jitter contributions.
- Jitter contributions from the **signal generator**, **oscilloscope** and **laser pulses** have been subtracted.
- This plot summarizes all the results for the SiPM and amplifier jitter measurements



- The **amplifier jitter** was measured with:
  1. **Fast signal generator** to simulate an ideal input signal with negligible rise time.
  2. **Slow signal generator** simulates the real rise time of a SiPM input signal → slower signal means higher jitter.
- Amplifier jitter measured with an **input step voltage amplitude** equal to the amplitude of single-photon SiPM signals at different V_{OV} → more amplitude (higher V_{OV}) means less jitter.

Thanks for the attention!