Fast and low power SiPM amplifier operating in a wide temperature range

Paolo Carniti[1][2], Claudio Gotti[1][2], Gianluigi Ezio Pessina[1][2], Davide Trotta[1][2]
[1] University of Milano-Bicocca
[2] INFN Milano-Bicocca

Amplifier schematic

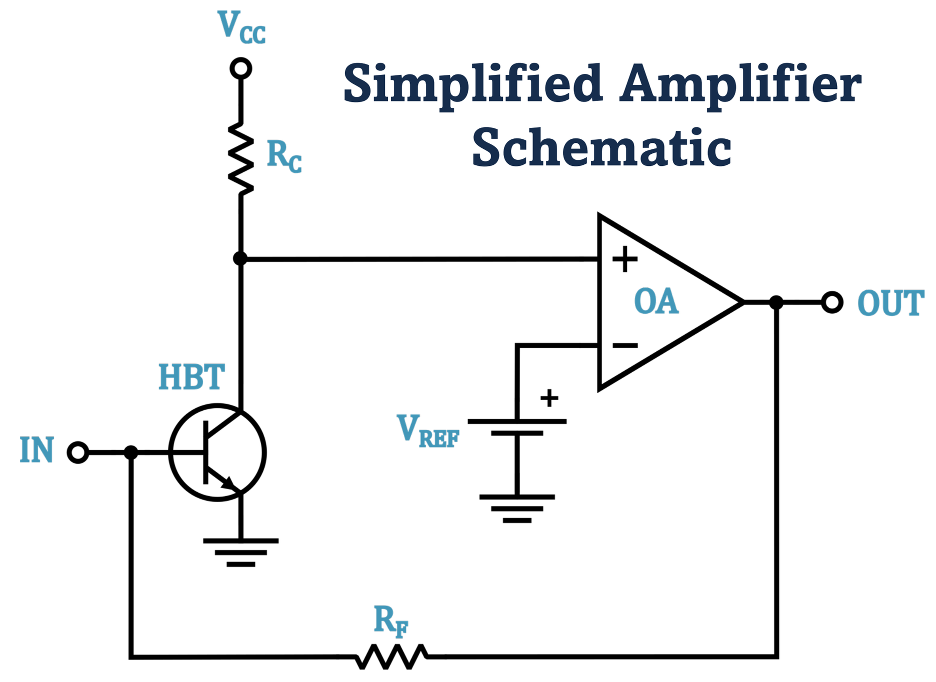
- Fast transimpedance signal amplifier for **SiPM (Silicon PhotoMultiplier) characterisation**.
- Study of **SiPM timing performance** in a wide temperature range (between ~ 80 K and ~ 300 K).
- **Low power consumption**: 135 mW @ ~ 300 K and 65 mW at @ ~ 80 K.
- **Layout** which aims at improving the amplifier speed and stability by minimising parasitic capacitance and using high-frequency dielectric.
- **Very low noise** $\left(< 0.4 - 1 \frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}\right)$ and **very fast response** (< 800 ps) result in **very low jitter**.

Electronics jitter

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

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

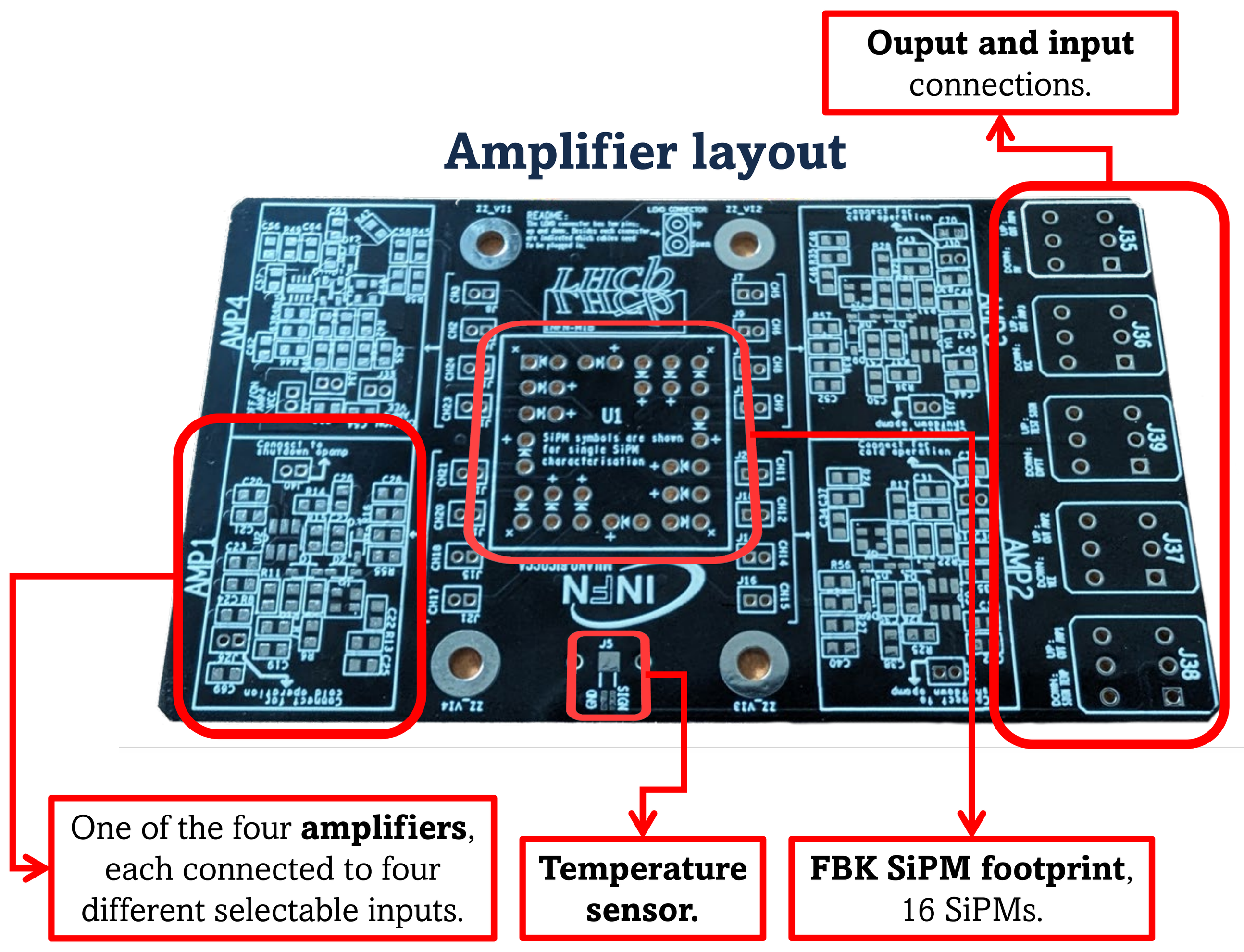
Simplified Amplifier Schematic



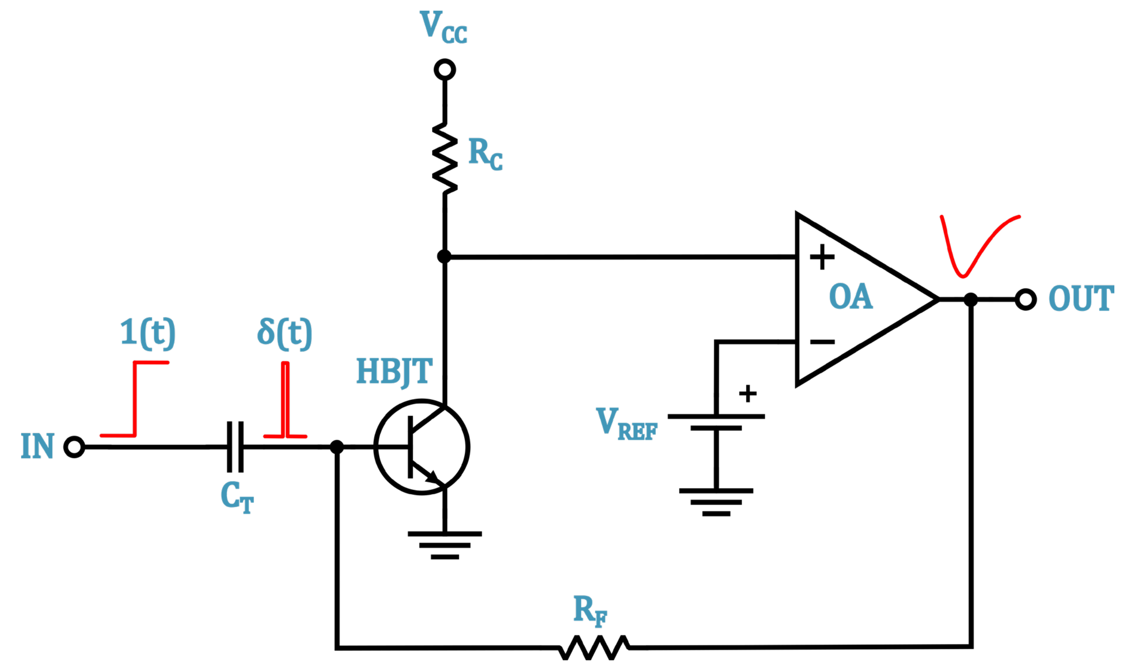
Amplifier made of a:

- Fast OA (Operational Amplifier) that can also operate at cryogenic temperatures.
- Low noise HBT (Heterojunction Bipolar Transistor).

Amplifier layout

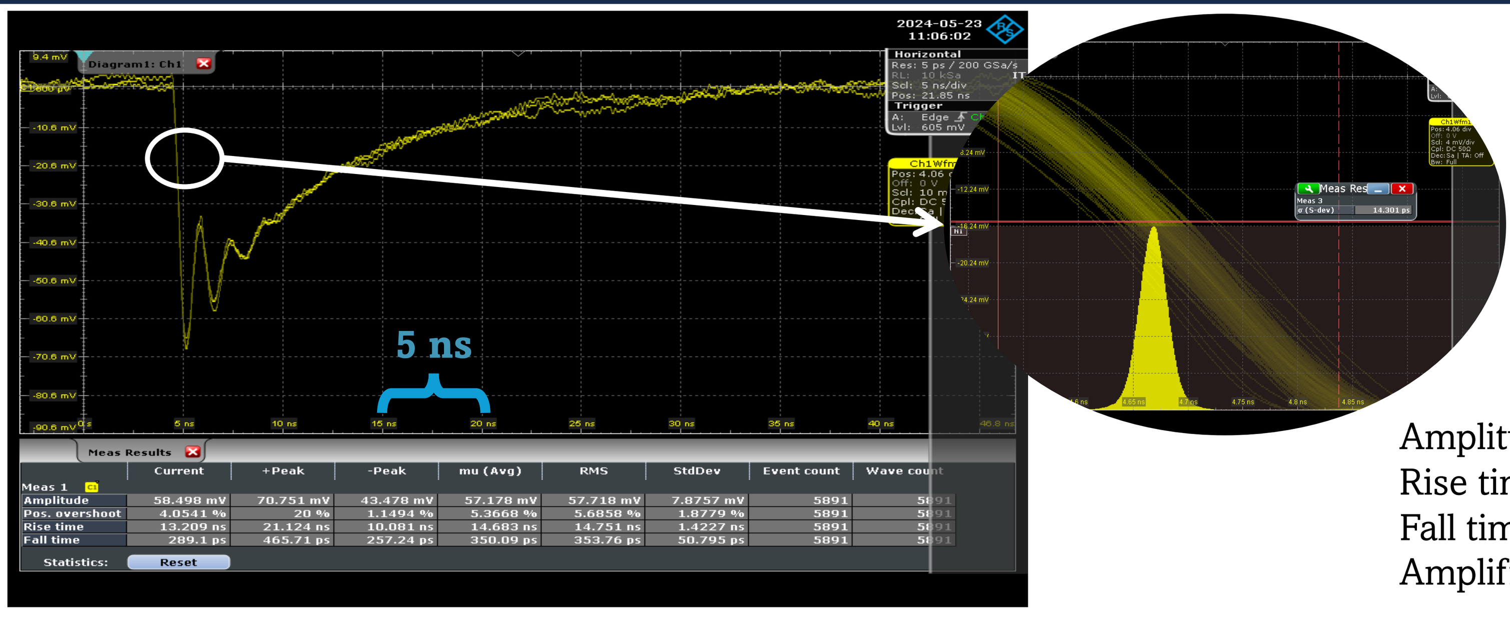


External input signal



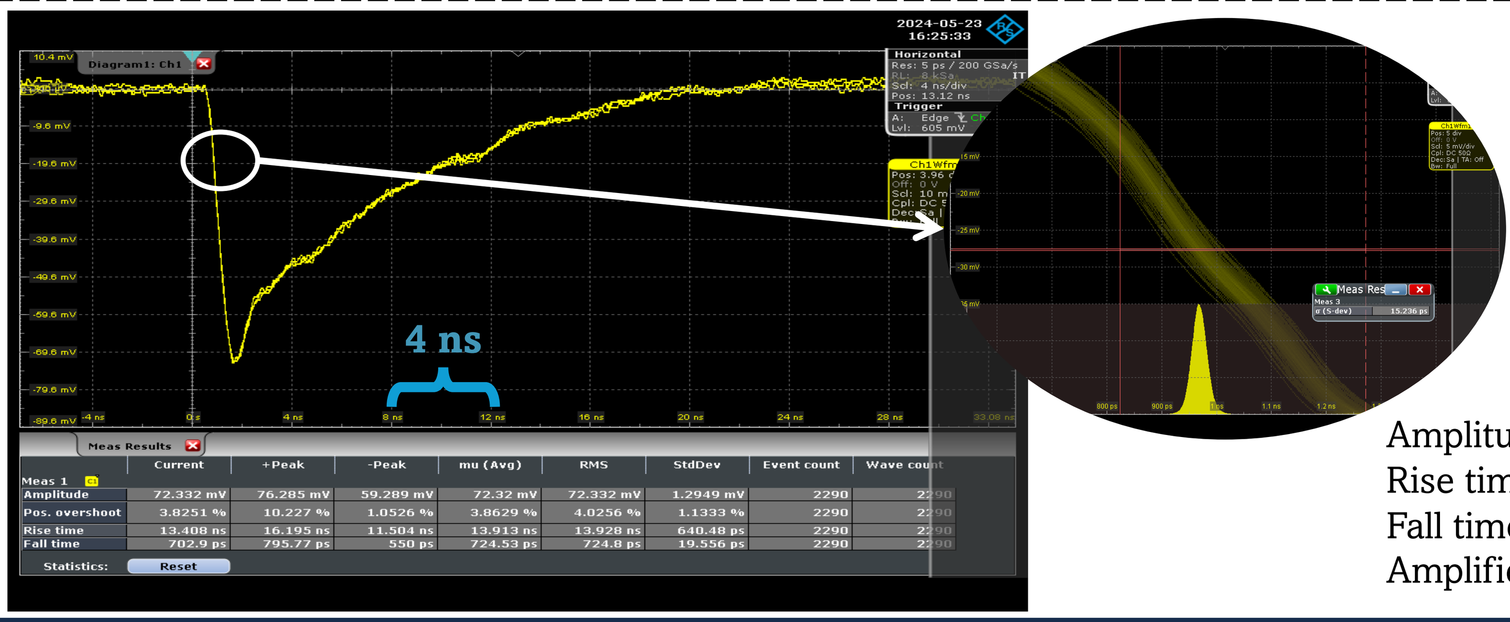
- **Step voltage input signal** (70 ps rise time).
- Voltage signal equal to **1 photon** signal (1.6 Me$^-$) generated by a 1.3mm x 1.3mm Hamamatus SiPM (S13360-1350) at 4 V_{OV}.
- The signal charges a **test capacitor** $C_T = 1$ pF.
- **~ δ(t)** input current signal.
- Instrument (oscilloscope) jitter: $\sigma_{t_{system}} \sim 10.4\ ps_{RMS}$. Therefore the **amplifier jitter** is $\sqrt{\sigma^2_{t_{measured}} - \sigma^2_{t_{system}}}$, with $\sigma_{t_{measured}}$ being a jitter measurement.

Ambient temperature (~ 300 K)



Amplitude: : ~ 57 mV.
Rise time: : ~ 14.6 ns.
Fall time: : ~ 350 ps.
Amplifier jitter: ~ 9.8 ps_{RMS}.

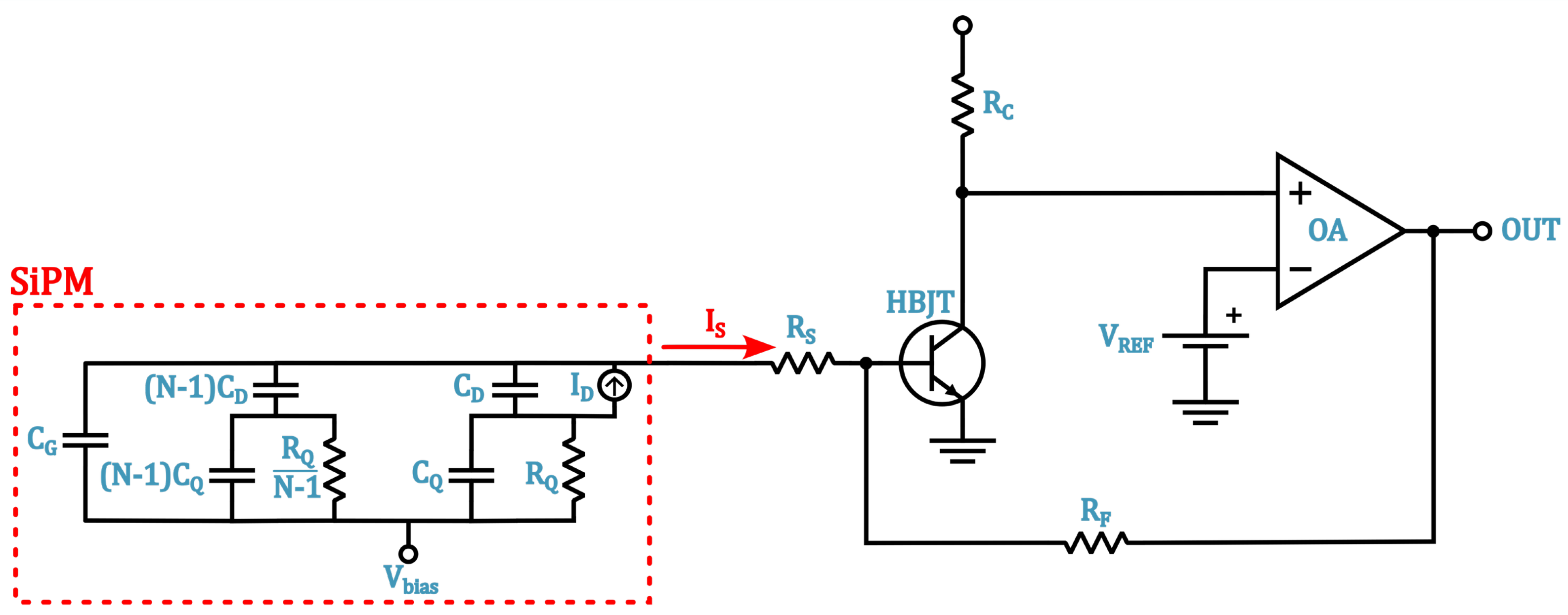
Cryogenic temperature (~ 77 K)



Amplitude: : ~ 72 mV.
Rise time: : ~ 13.9 ns.
Fall time: : ~ 700 ps.
Amplifier jitter: ~ 11.1 ps_{RMS}.

SiPM input signal

- The amplifier was tested with a **1.3mm x 1.3mm Hamamatsu SiPM** (S13360-1350).
- The photons were produced by a **405 nm laser** controlled by the **Hamamatsu PLP-10 pulser** (70 ps FWHM pulses)
- **Single photon jitter** measurements.
- **Low amplifier jitter**. It has low impact on SiPM jitter measurements: < 1% @ ~ 300 K and < 4% at @ ~ 80 K.
  - 300 K and 4 V_{OV}: 101.9 ps_{RMS} SiPM jitter (101.4 ps_{RMS} without the amplifier jitter contribution).
  - 80 K and 4 V_{OV}: 48.1 ps_{RMS} SiPM jitter (46.8 ps_{RMS} without the amplifier jitter contribution).

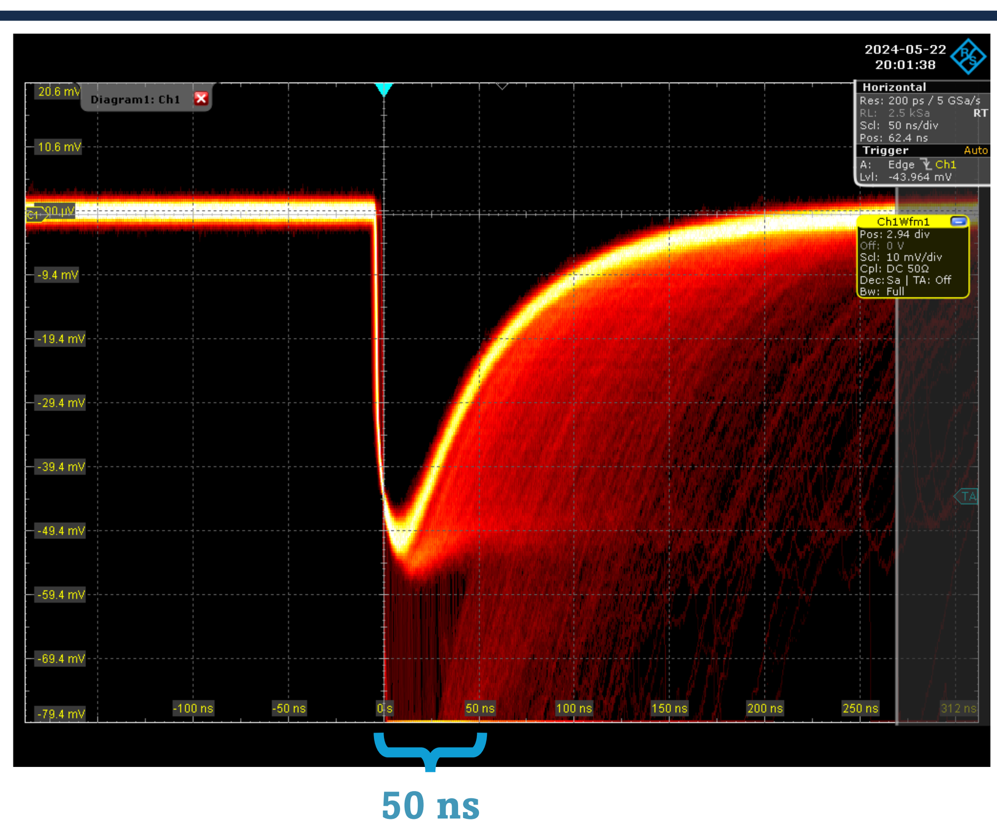


- $V_{OV} = V_{bias} - V_{br}$: overvoltage, with V_{br} being the breakdown voltage.
- C_D: single diode capacitance.
- I_D: avalanche current.
- C_D: diode capacitance.
- R_Q: quenching resistor.
- C_Q: quenching parasitic capacitance
- C_G: grid parasitic capacitance.
- $\tau_s = (C_D + C_Q)(R_Q +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

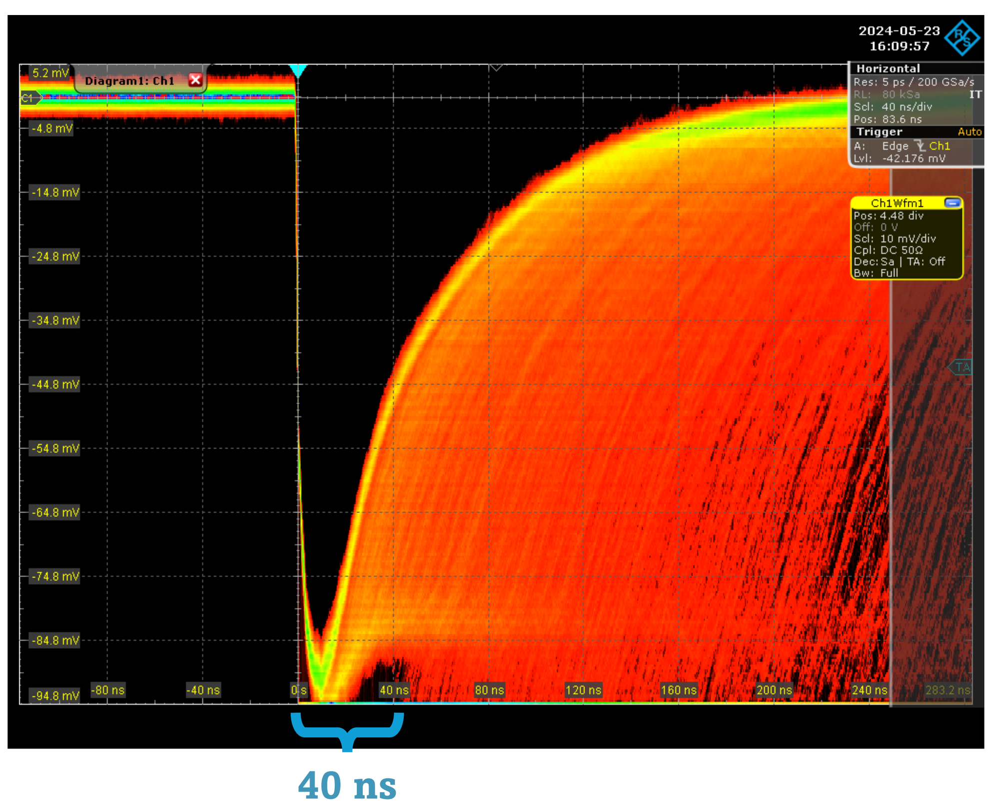
$$I_s = V_{OV}\left(C_Q\delta(t) + C_D\frac{e^{-t/\tau_s}}{\tau_s}\right)$$

Typical photon signal

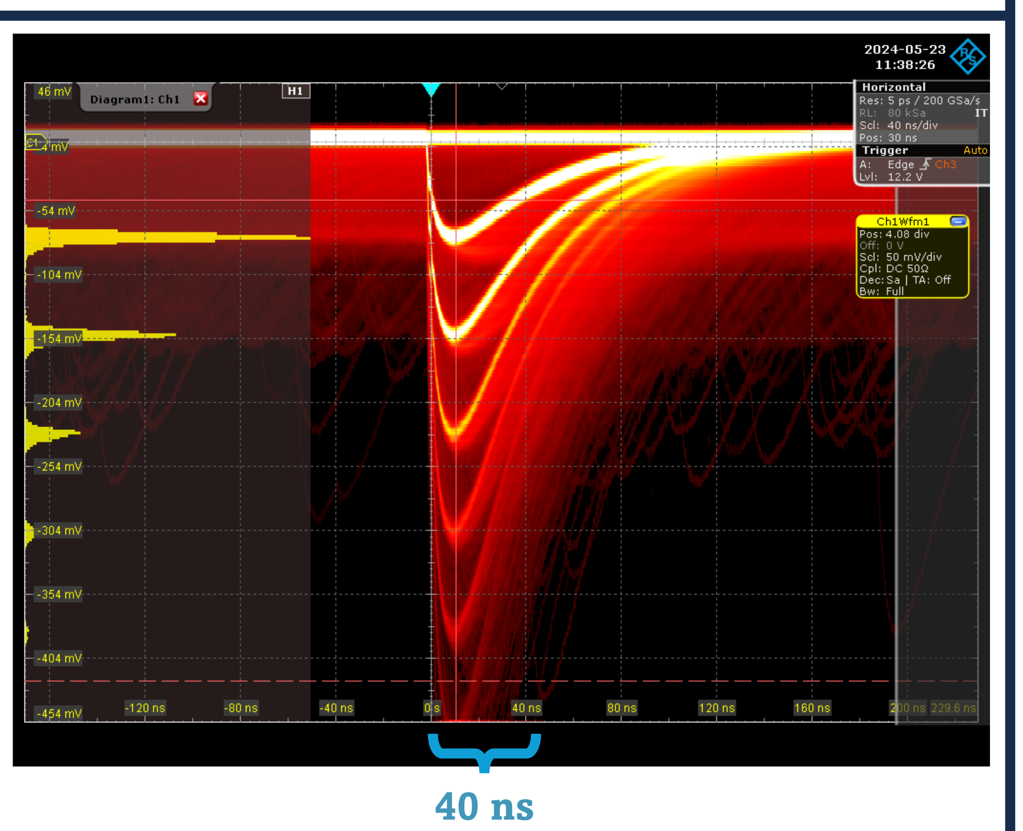
Ambient temperature (~ 300 K)

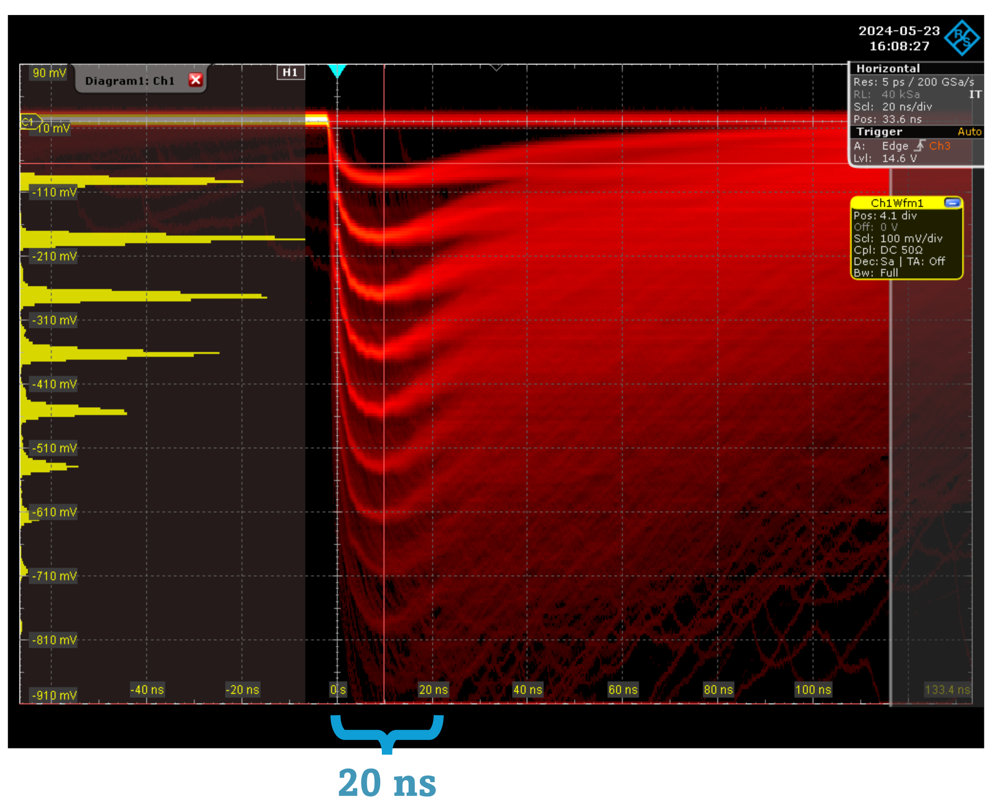


Cryogenic temperature (~ 77 K)

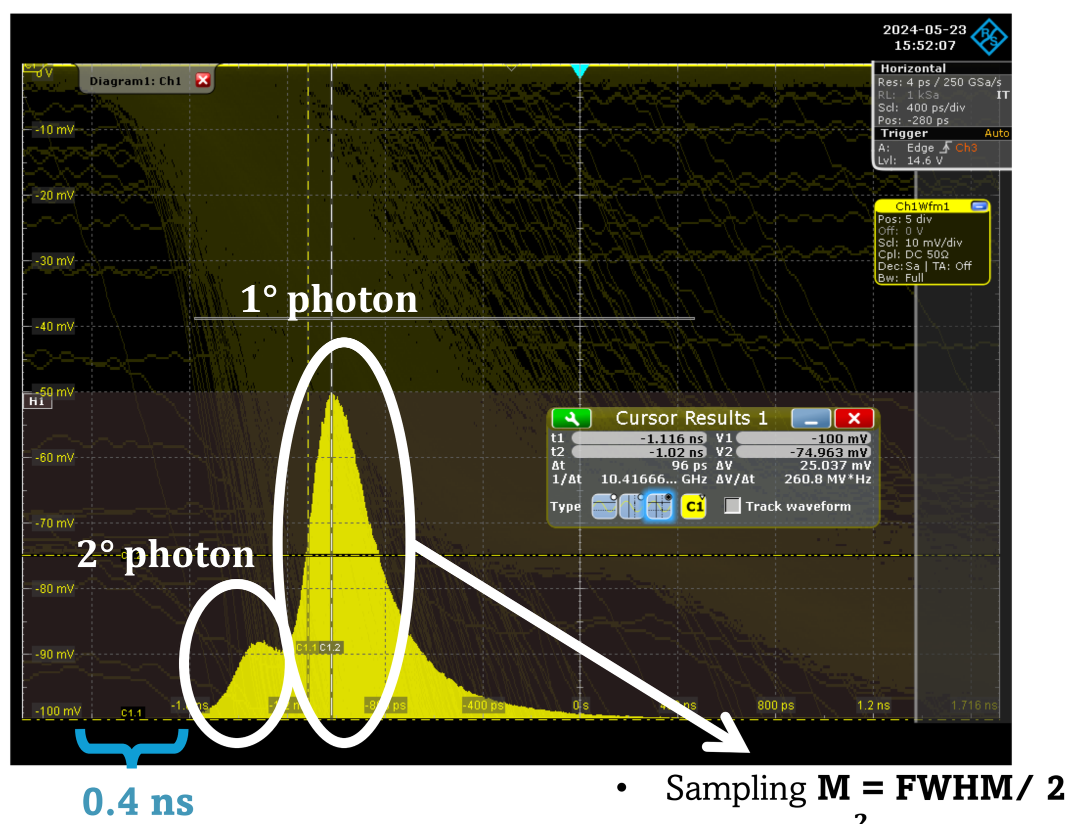


Photon counting





SiPM jitter measurements



- Sampling **M = FWHM/ 2**
- $\sigma_t \cong M \cdot \frac{2}{2\sqrt{2\ln(2)}}$

SiPM jitter measurments (preliminary results)