

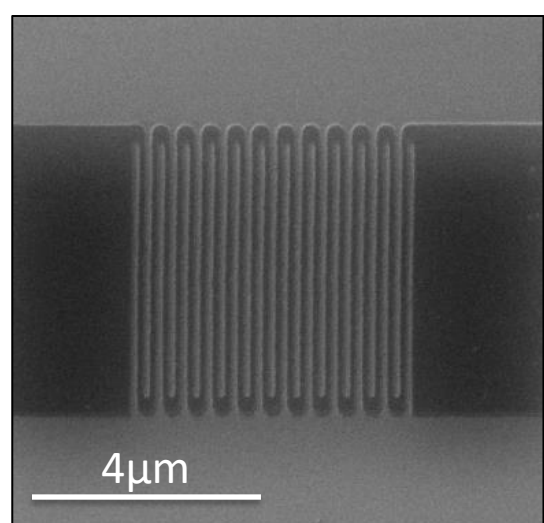
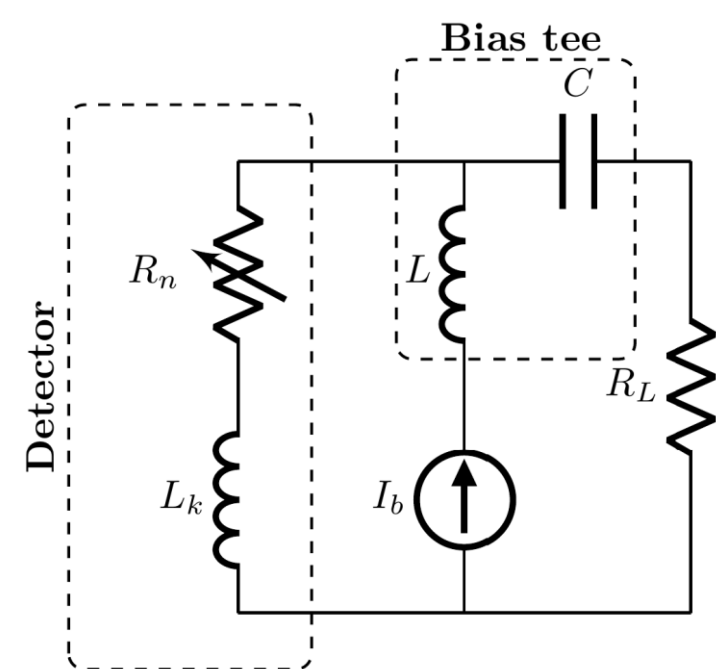
Photon-Number Resolution through SNSPD Pulse Analysis: The Role of Geometric Jitter

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Introduction

Superconducting nanowire single-photon detectors (SNSPDs) can encode photon-number information in the shape of their electrical pulses. Within the hot-spot model, the absorption of multiple photons modifies the pulse dynamics, with most photon-number information concentrated in the **rising edge**.



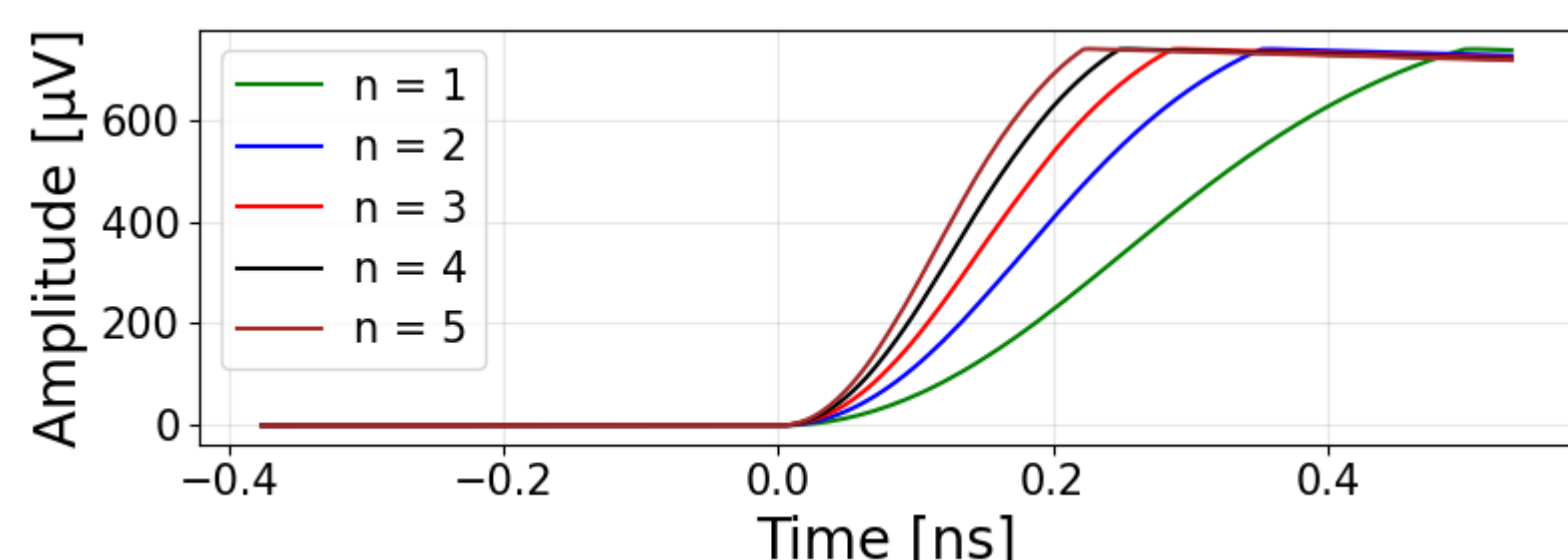
Extracting this information is complicated by noise and timing jitter, whose individual effects on photon-number resolution (PNR) remain unclear. Geometric jitter and electronic noise can themselves depend on photon number [3], motivating a systematic investigation of how these contributions influence detector performance.

Here, we analyze the rising edges of simulated electrical pulses to quantify how geometric jitter affects the photon-number-resolving capability of SNSPDs.

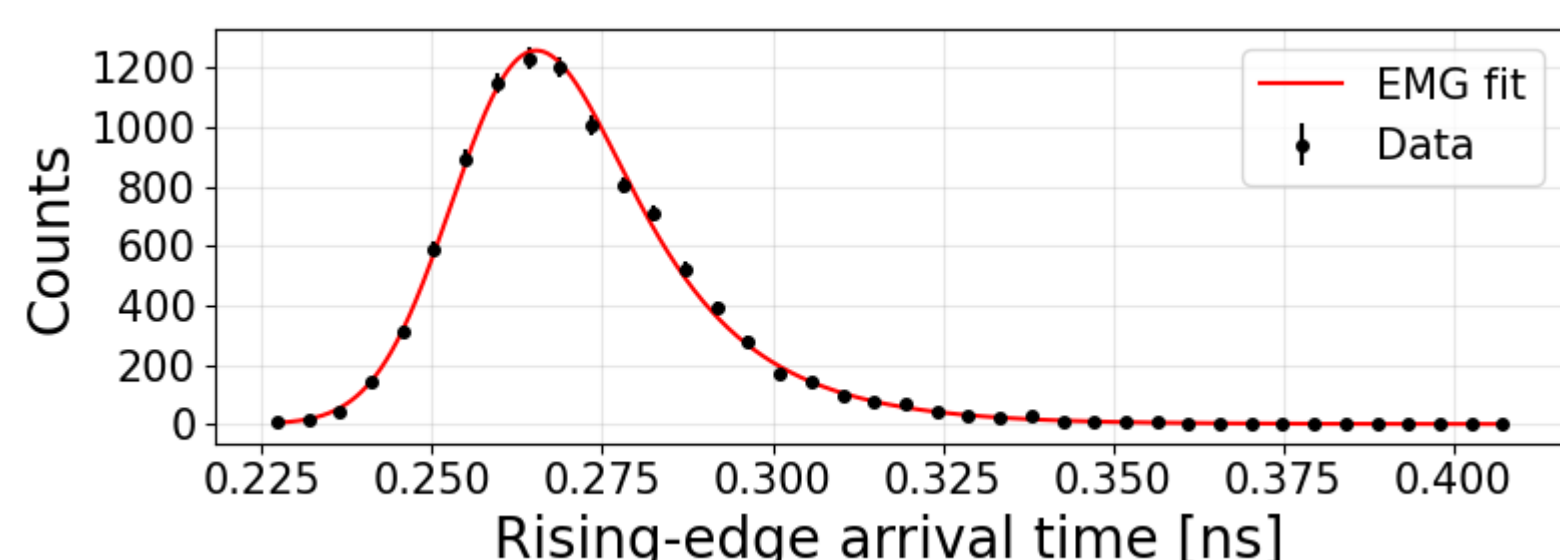
Modelling photon-number-dependent pulses

SNSPD electrical pulses are simulated using a multi-hotspot model [1] for a niobium nitride nanowire with a kinetic inductance of 500 nH, length of 0.95 mm, width of 100 nm, and thickness of 4 nm. The detector is biased at $I_b = 18 \mu\text{A}$, 90% of the critical current.

The **rise time scales with photon number as $1/\sqrt{n}$** [1].



Photon-arrival times are sampled from an exponentially modified Gaussian distribution [3]:



We set $\tau = 15$ ps, characterizing the vortex-related jitter, and the RMS electronic noise to $1.5 \mu\text{V}$ – typical values for high-performance SNSPDs.

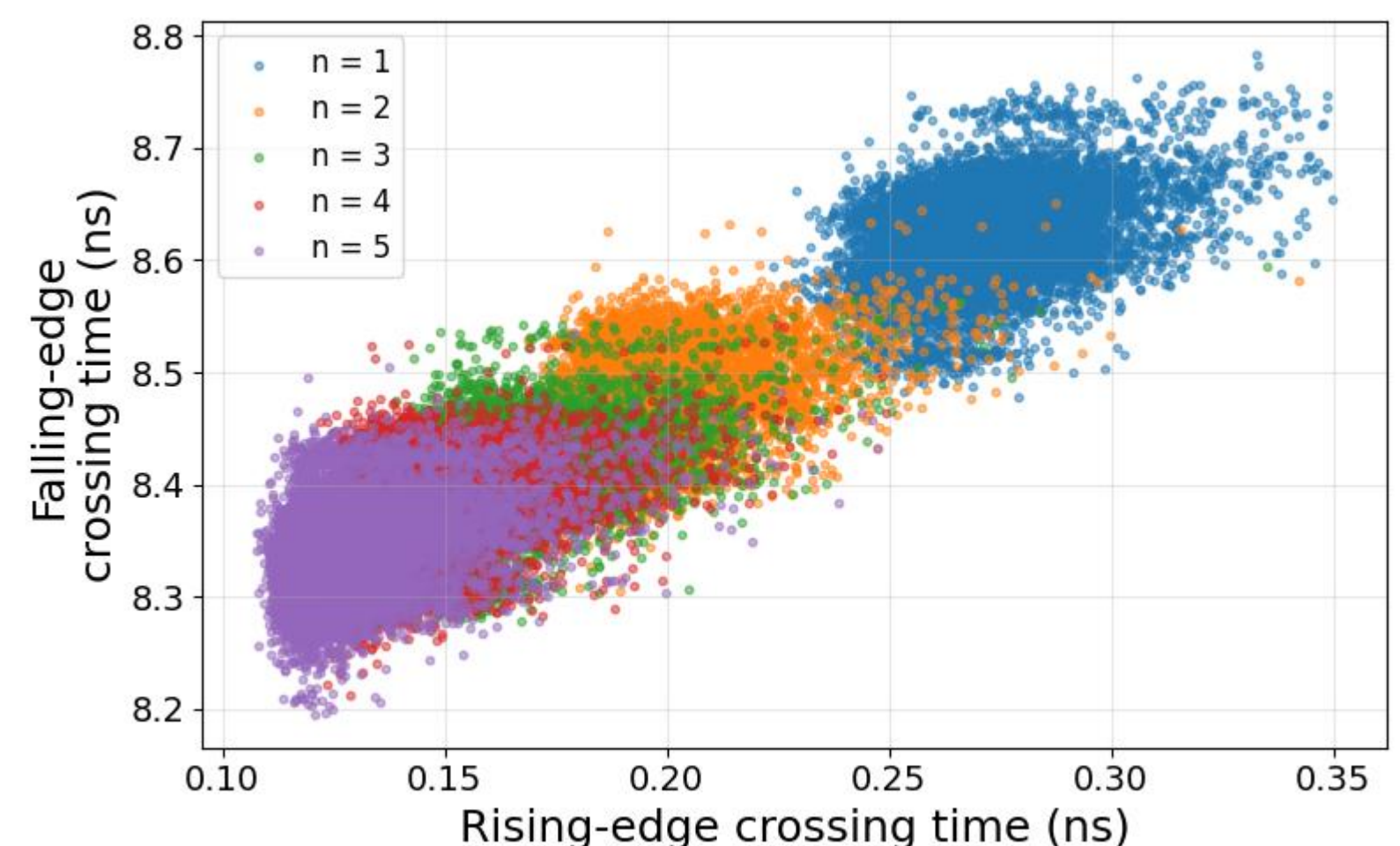
Geometrical jitter scales with photon number according to [3]

$$\sigma_{\text{geom}, n} = \frac{\sigma_{\text{geom}, 1}}{n^{0.75}}$$

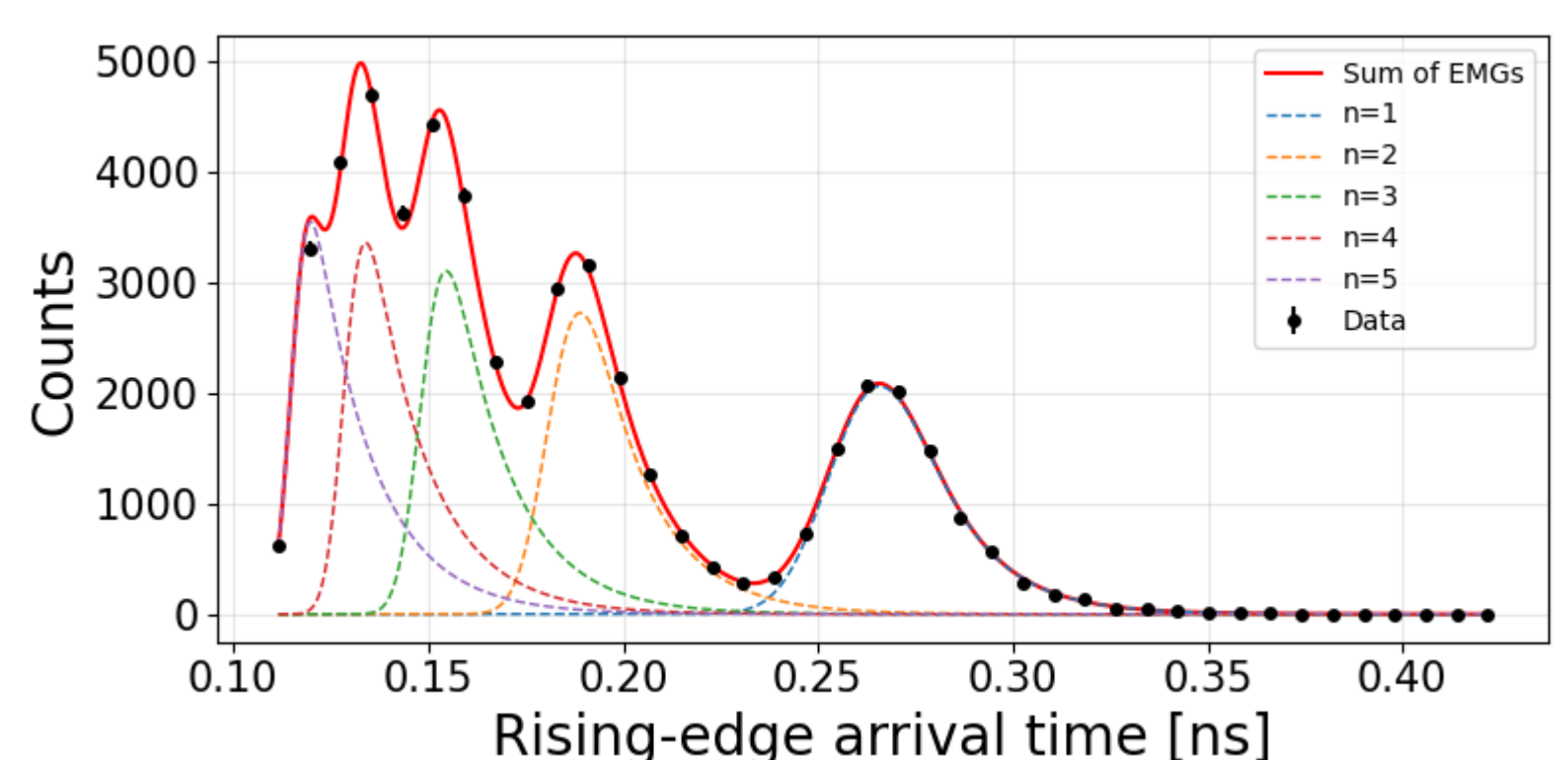
For each photon number n , we generate **10000 random traces** for subsequent rising-edge analysis.

Result & Discussion

The arrival time of each pulse is defined by its rising-edge crossing of a $350 \mu\text{V}$ threshold (50% of peak voltage).



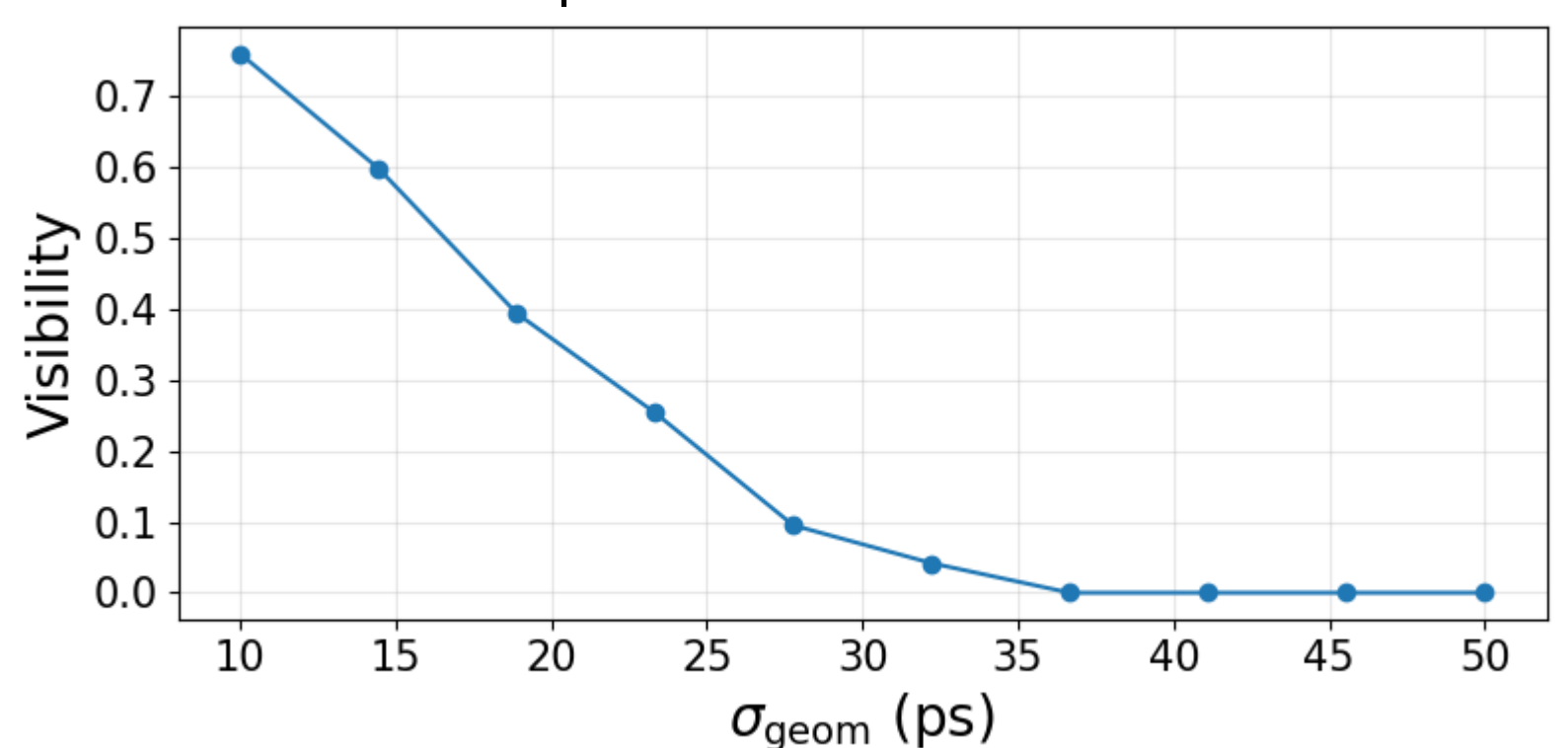
The resulting arrival-time histogram is fitted with a sum of exponentially modified Gaussian distributions.



To quantify the separation between single-photon and multiphoton events, we define the **visibility** as

$$V_{12} = \frac{C_{\text{max}} - C_{\text{min}}}{C_{\text{max}} + C_{\text{min}}}$$

Where C_{max} , C_{min} corresponds to the local maxima and minima between the fitted first and second peak.



Conclusions

Under the simulated conditions, the single-photon peak visibility decreases monotonically with increasing geometric jitter and become unresolved at approximately $\sigma_{\text{geom}, 1} = 35$ ps.

Building on studies of kinetic inductance and PNR performance [2,4], future work should connect detector geometry and readout characteristics to pulse rise time, intrinsic jitter, and geometric jitter. This would help identify **detector and readout parameters that jointly optimize photon-number resolution**.

[1] Phys. Rev. Appl. **12**, 034020 (2019)

[2] Opt. Express **33**, 41869 (2025)

[3] APL Photonics **10**, 086113 (2025)

[4] Appl. Phys. Lett. **109**, 152601 (2016)