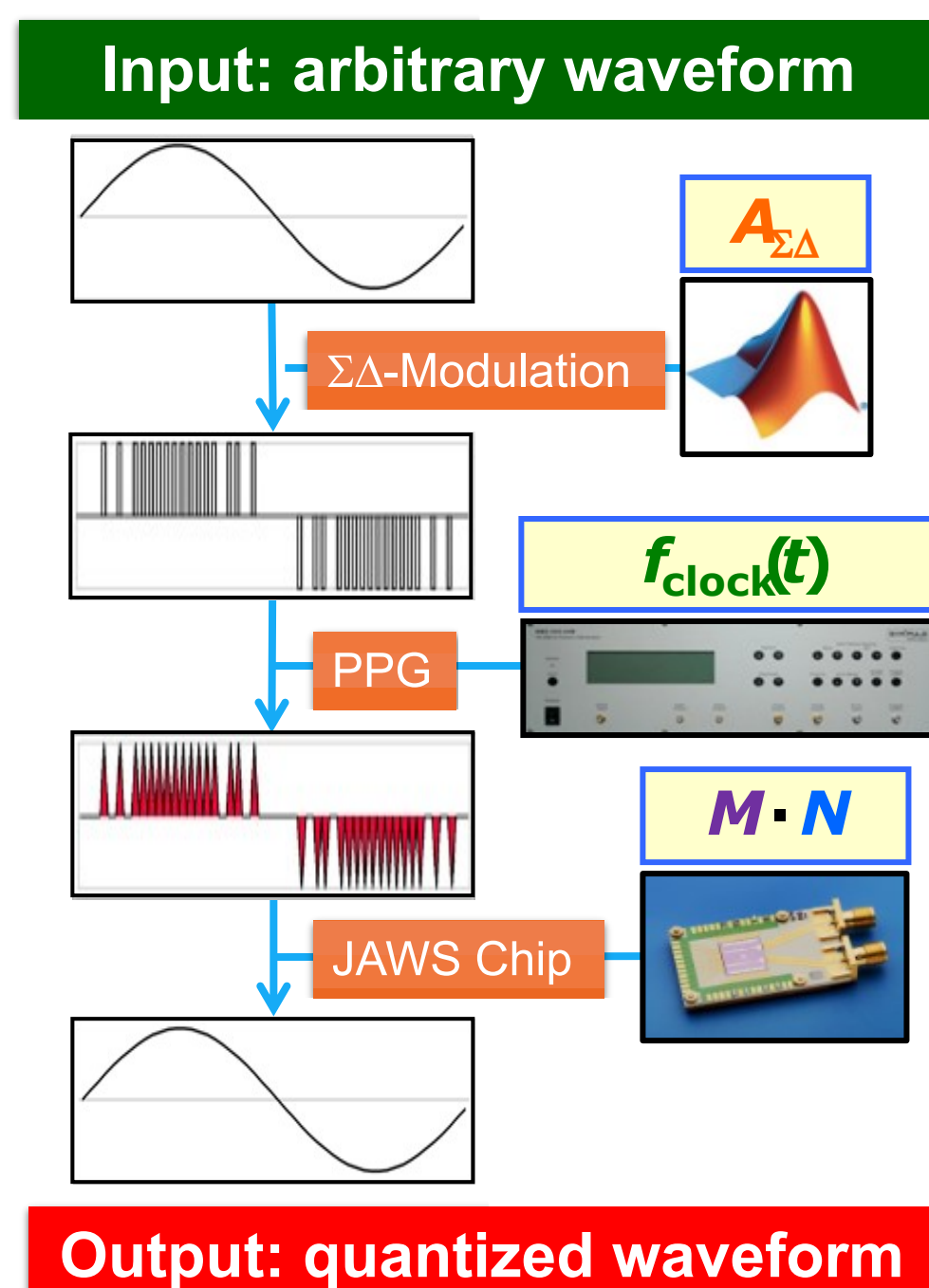
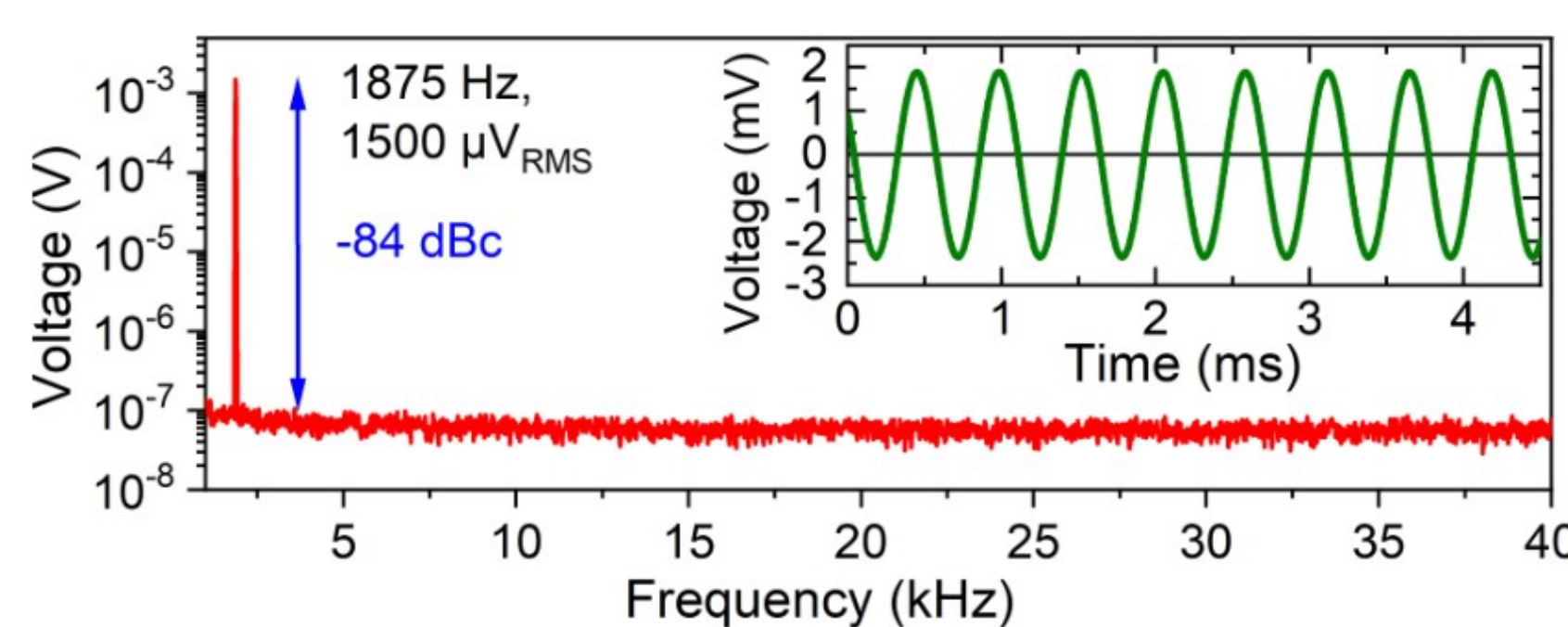


Towards metrology for and with superconducting qubits

Quantum-accurate waveforms

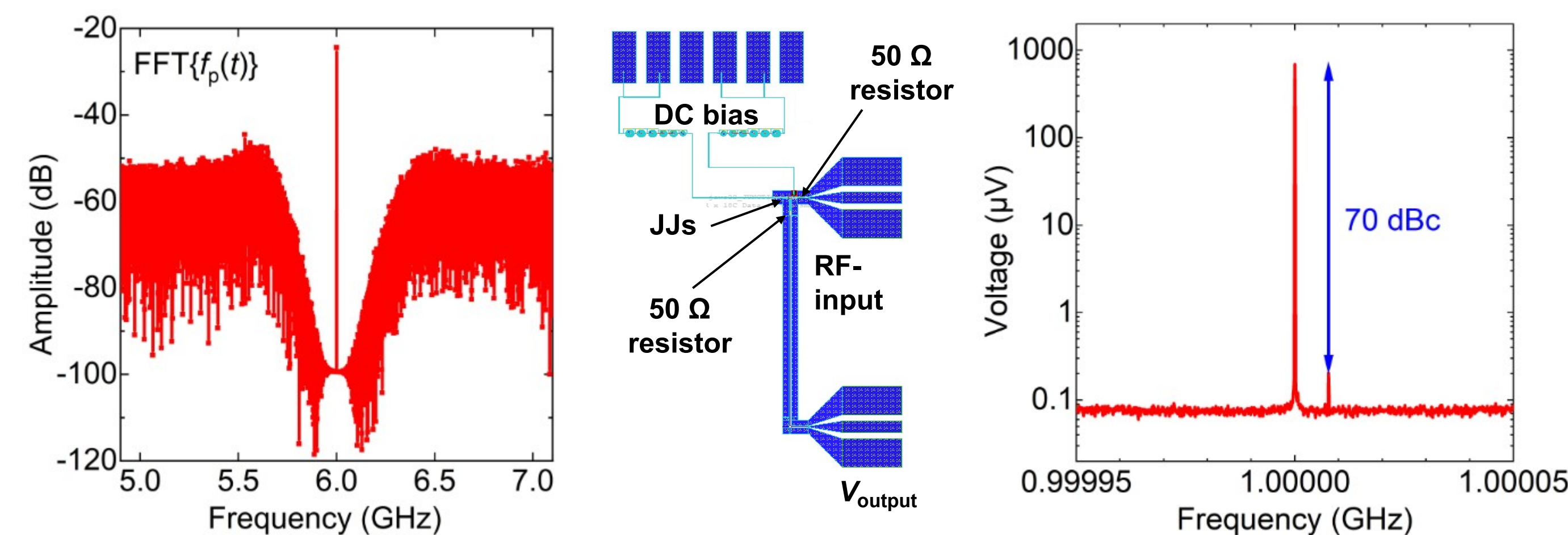
Josephson Arbitrary Waveform Synthesizer (JAWS)

- Josephson equation in pulse-mode operation
 $V_{AC}(t) = A_{\Sigma\Delta} \cdot M \cdot N \cdot h/(2e) \cdot f_{clock}(t)$
- Quantum accurate
- Spectrally pure waveforms (SNR > 120 dBc)
- No drift and low-noise
- Well established up to ~1 MHz
- Fabricated using SNS Josephson junctions



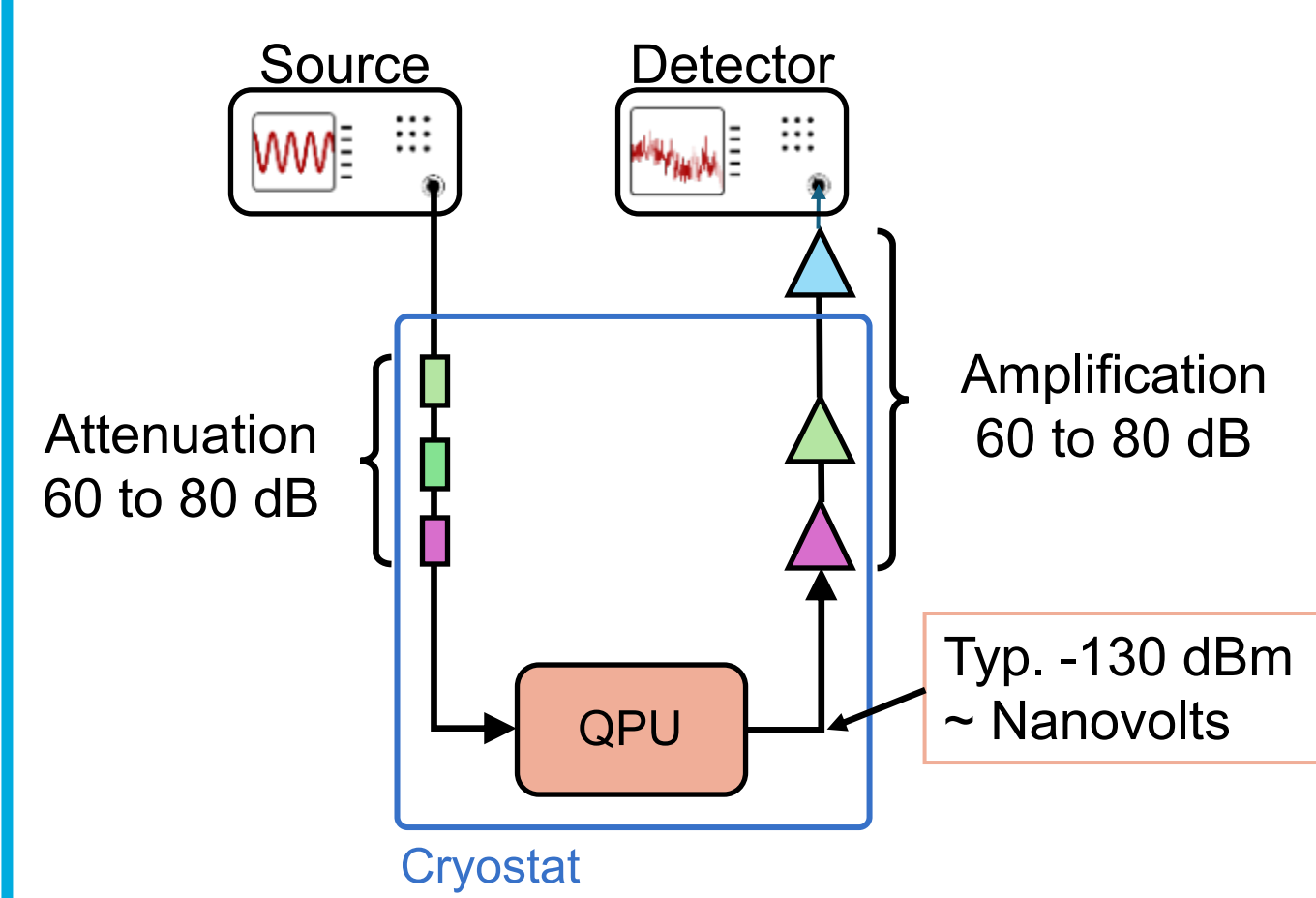
Approaching GHz frequencies

- Main problem: feedthrough of input signal to output.
- First realization focuses on lumped element design.



- Next realization: on-chip diplexers (band pass and band stop filters).

Superconducting parametric amplifiers

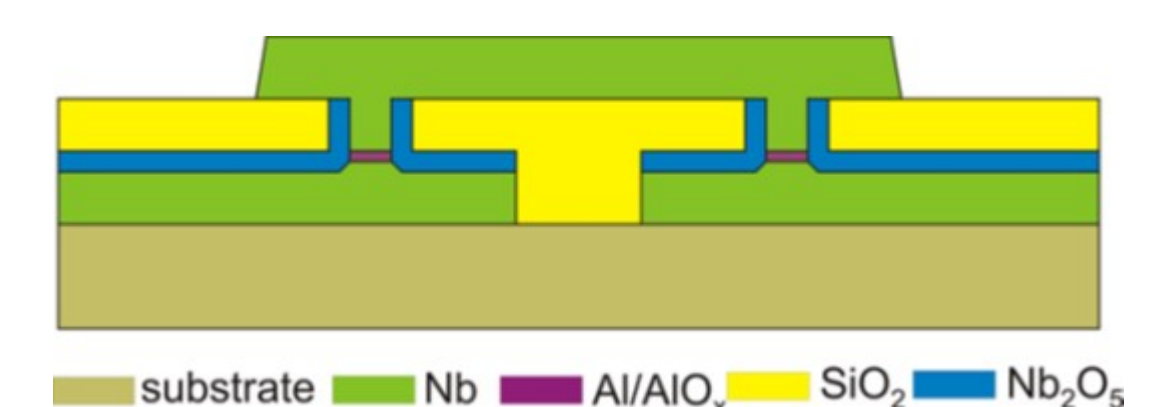


Femto-Watt readout signals of superconducting qubits must be amplified for further processing.

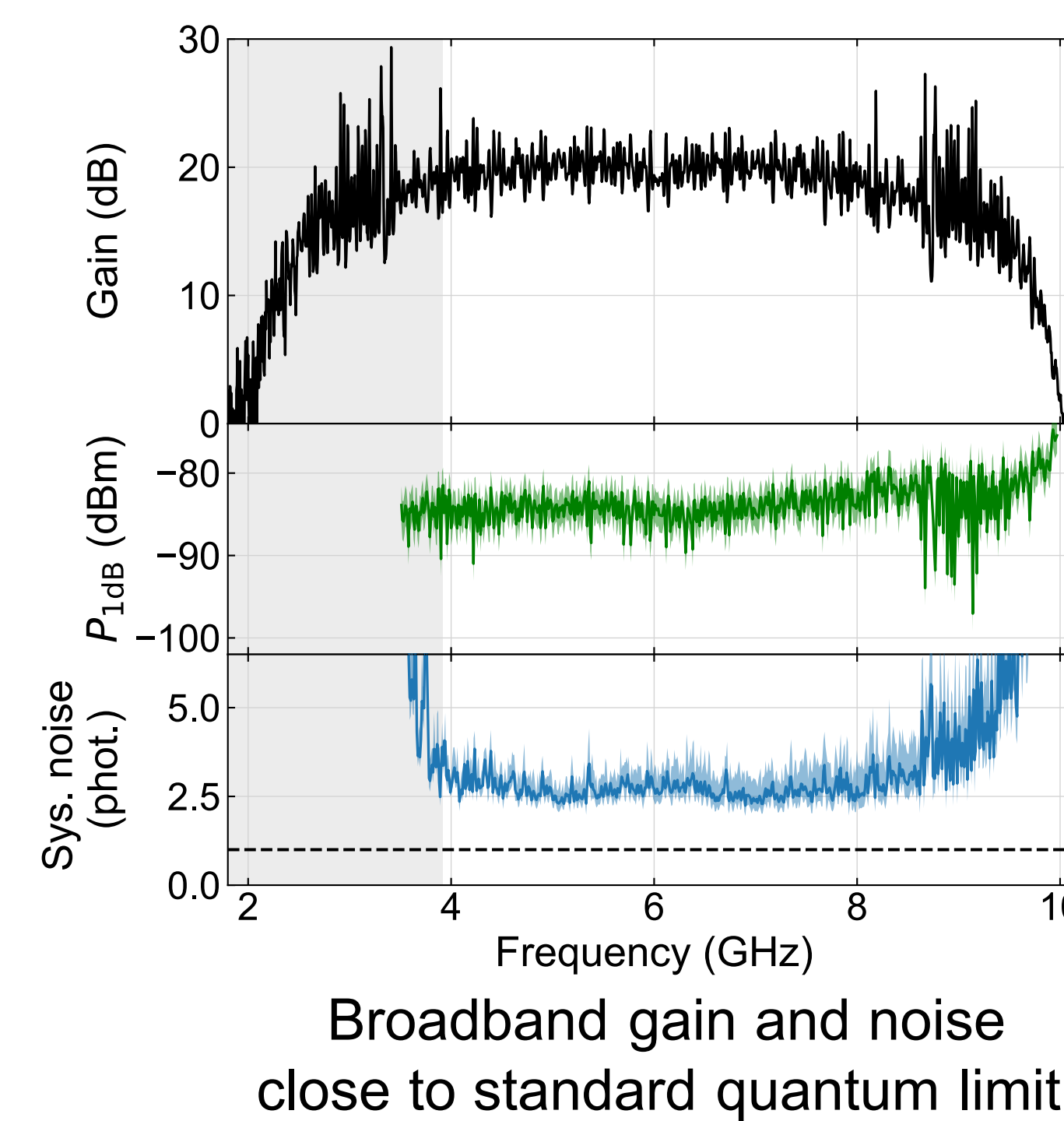
First amplifier governs total system noise:

$$T_{N,sys} = T_{N,1} + \frac{T_{N,2}}{G_1} + \frac{T_{N,3}}{G_1 G_2}$$

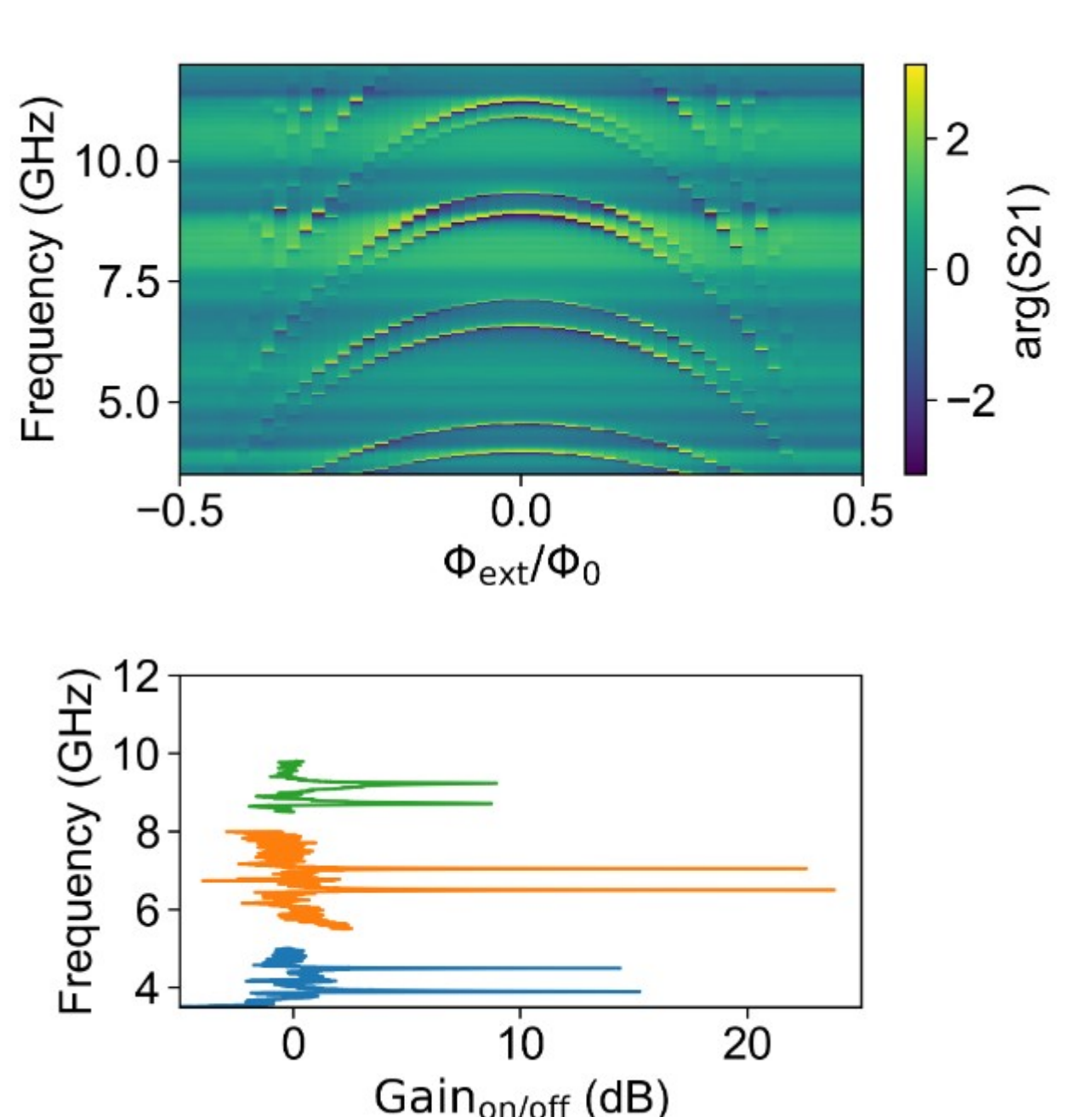
All devices fabricated in niobium-trilayer technology in PTB clean room.



Traveling-wave parametric amplifiers (TWPA)

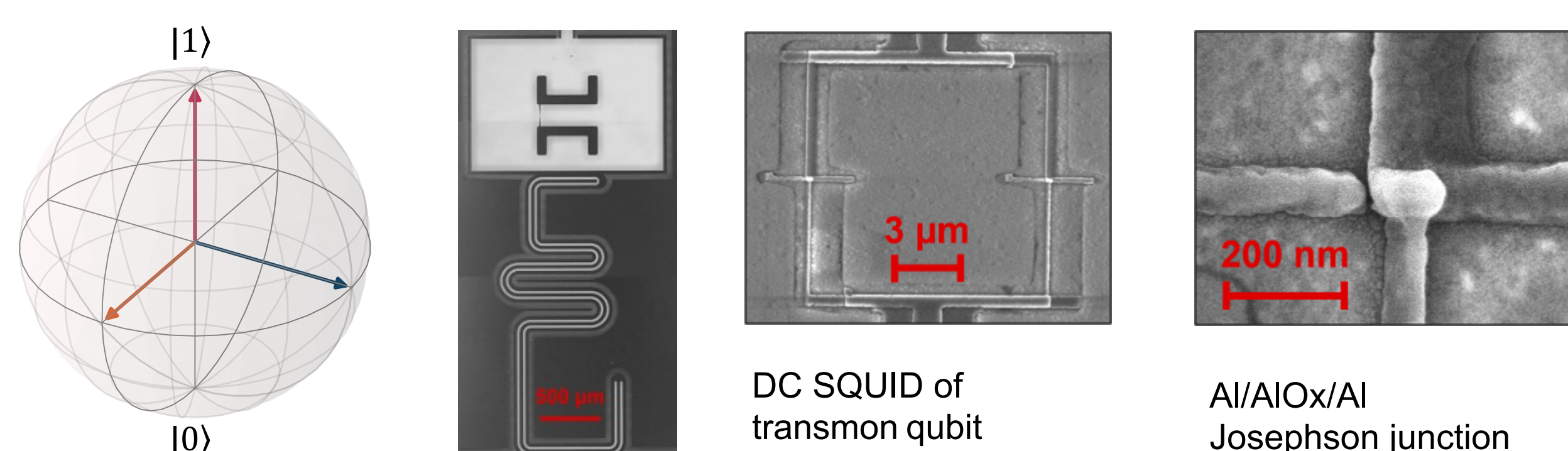


Resonant parametric amplifiers (DJJAA)

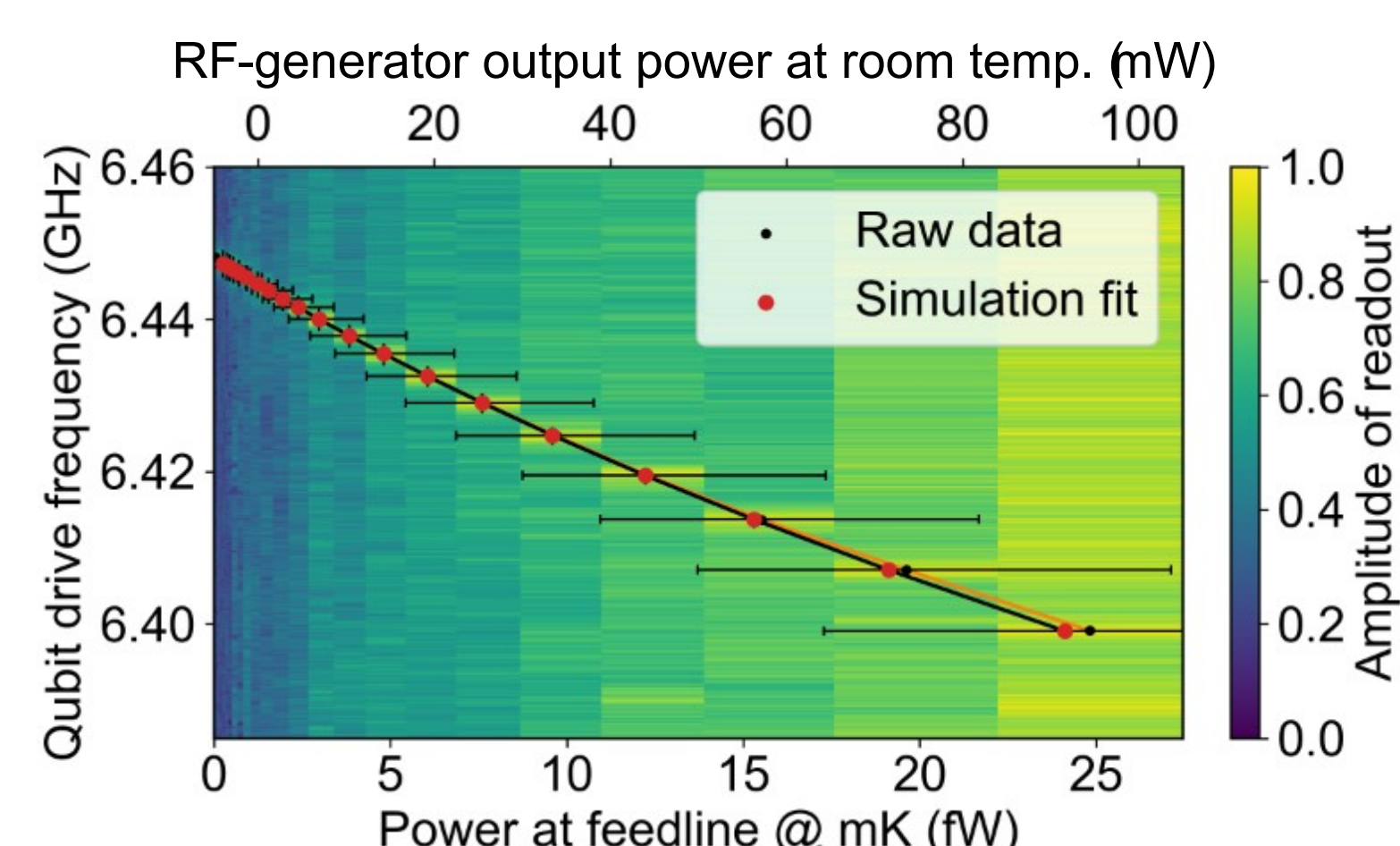
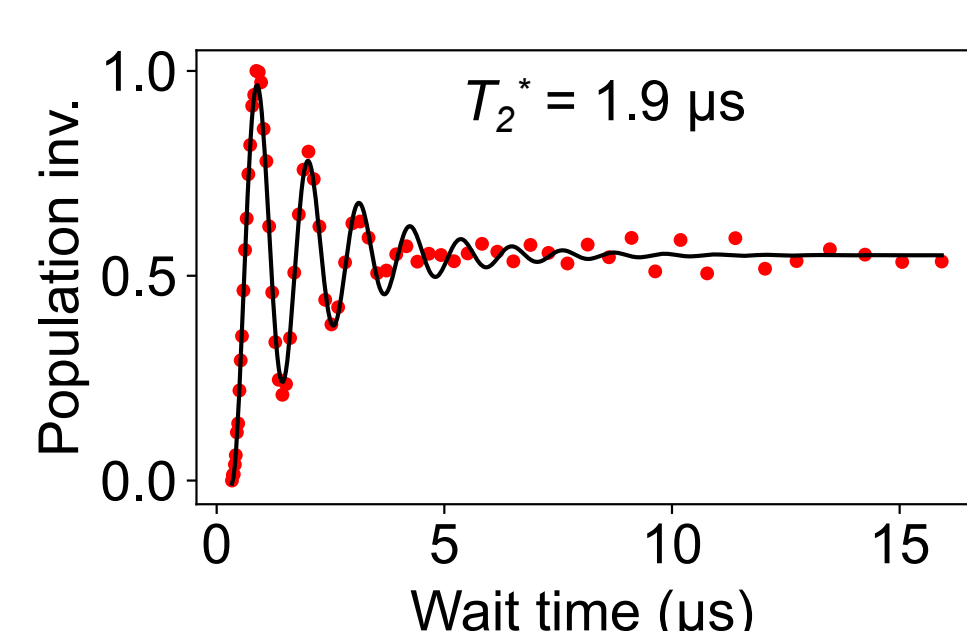
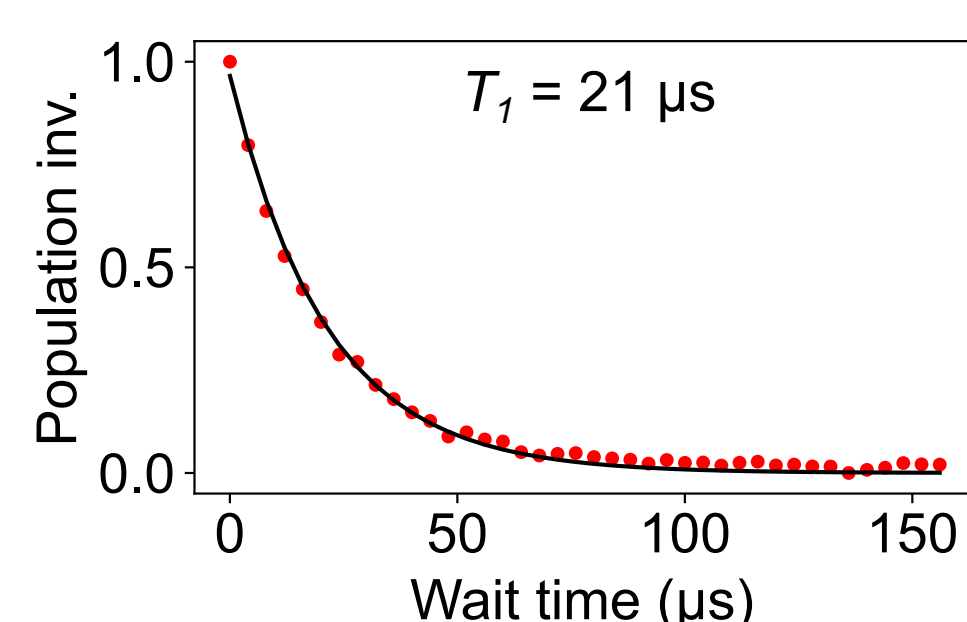


Quantum bits

Macroscopic inductors, capacitors and Josephson junctions are the building blocks of superconducting qubits.



- Metrology for superconducting qubits to aid future hardware development, e.g. elucidate further sources of decoherence, frequency fluctuations, ...
- Metrology with superconducting qubits to harness their potential as quantum sensors, e.g. power sensing, parametric amplifier characterization,



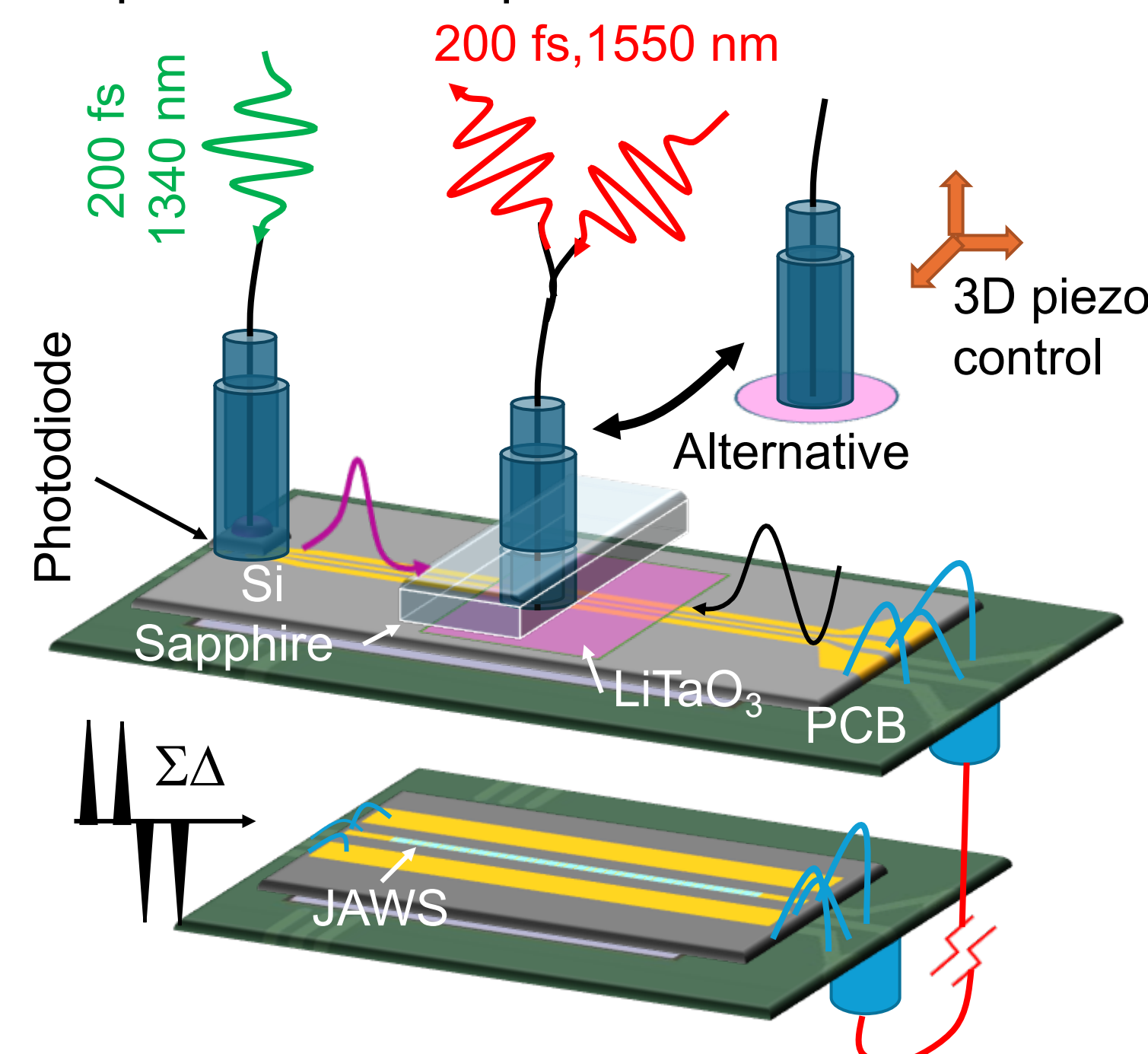
Establishing a microwave power sensing technique including uncertainties for Milli-Kelvin temperatures.

Optoelectronic detection technique

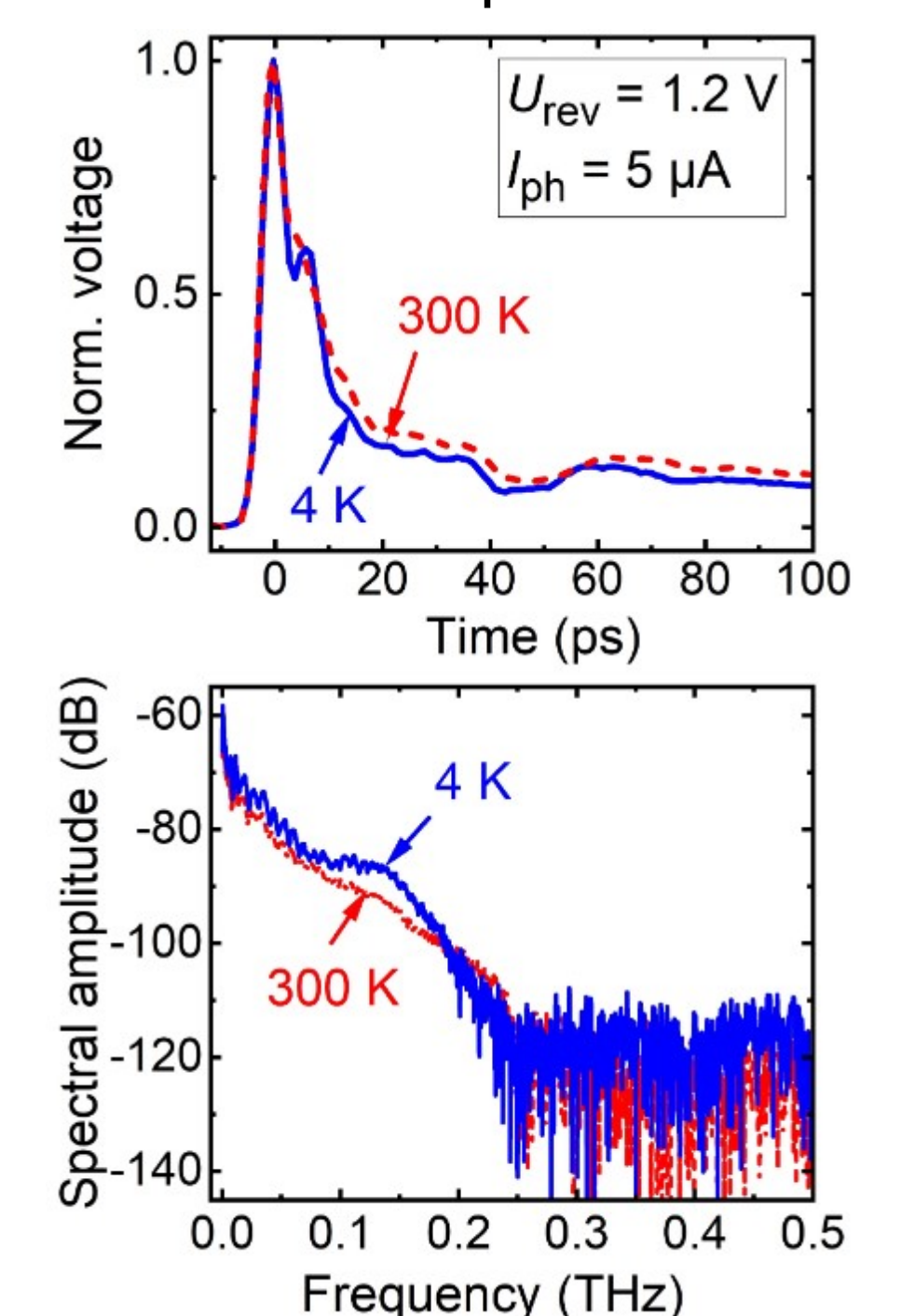
Cryogenic high-frequency measurements

- Standard approach: vector network analysers (S parameters)
- Our alternative approach: optoelectronic techniques based on fs lasers
→ Enhanced bandwidth, in-situ probing, reduced heat insertion

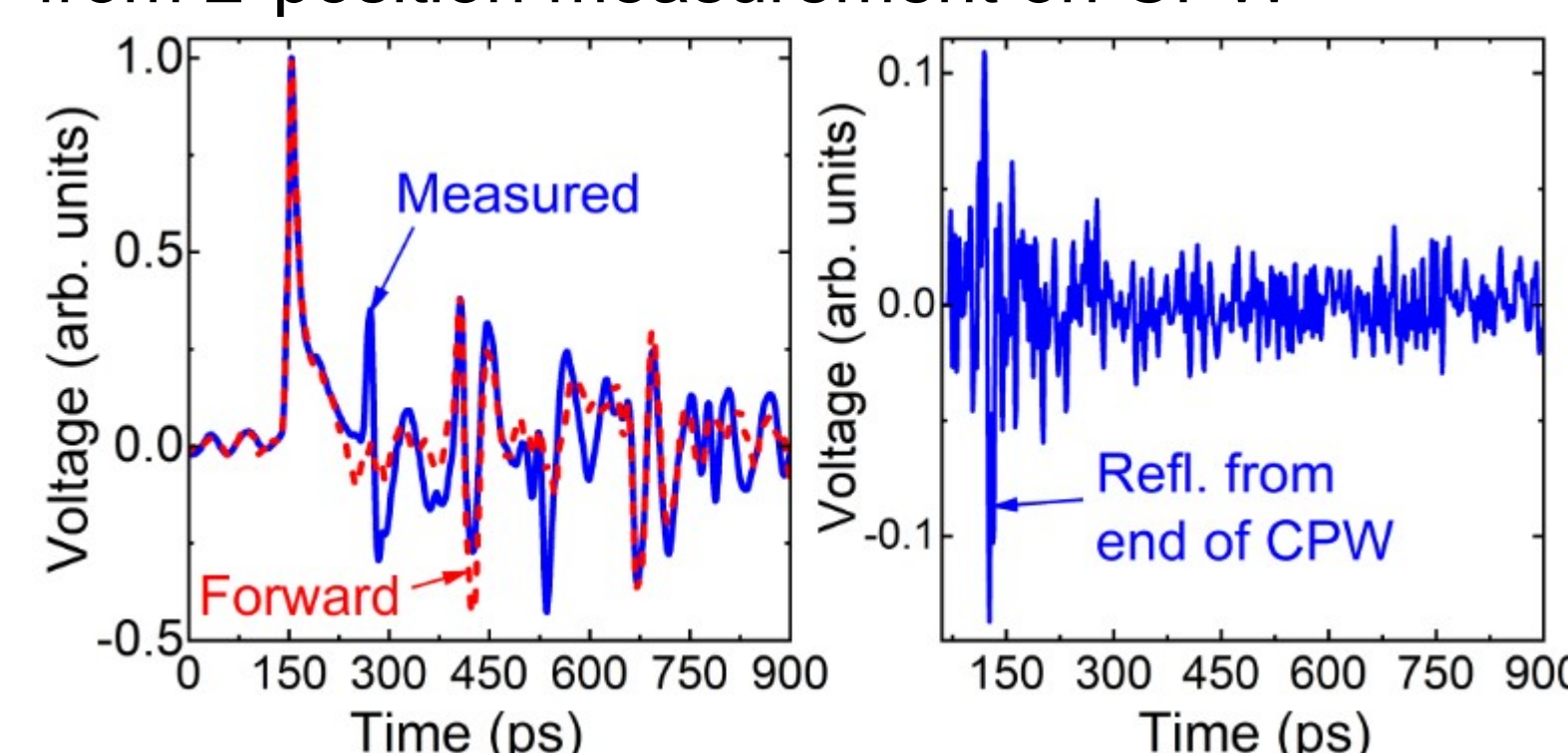
Experimental setup



Characterization of photodiodes



Extraction of el. reflection coefficient (S11) from 2-position measurement on CPW



Direct sampling of JAWS output

