DARTWARS: status of WP3

(Andrea Vinante, Dec 1 2021, DARTWARS general meeting)

Working Package Number:	3	**Start Date or Starting Event**				
WP Package Title:	DTWKI Test and Characterization, and read out demonstration with microcalorimeters					
Participant short name:	LE	MIB	TIFPA			
Person/month per participant	10	18	41			
WP Leader	Andrea Vinante (TIFPA)					

Objectives: the goal of this WP is the full test and characterization of all the DTWKIs developed during the project and the demonstration of quantum limited noise read out with TESs and MIKDs.

Description of work

Prototype devices of the DTWKI developed in WP2 will be experimentally characterized at temperatures below 300 mK. A scheme of the measurement setup is reported in Figure 3. These measurements will provide feedback to the WP1 and WP2 in order to improve the design and the fabrication. TESs and MKIDs will be readout by coupling the resonator arrays to the TWPA input and their response will be studied with photon calibrations. Transmon qubits coupled to magnetostatic modes in Yttrium Iron Garnet (YIG) and read out by DTWKI will be tested at INFN-LE.

Tasks Description

Task 3.1: Set up of the experimental instrumentations (M1-M6)
Task 3.2: Experimental characterization of the performances of produced DTWKIs (M12-30);
Task 3.3: Test of produced DTWKIs and read out demonstration with detectors (M24-36);

Role of participants

- INFN-MIB and INFN-TIFPA will test and characterize the produced DTWKI amplifiers;
- INFN-MIB will perform the read out demonstration with TESs;
- INFN-MIB and INFN-TIFPA will perform the read out demonstration with MKIDs;

Deliverables

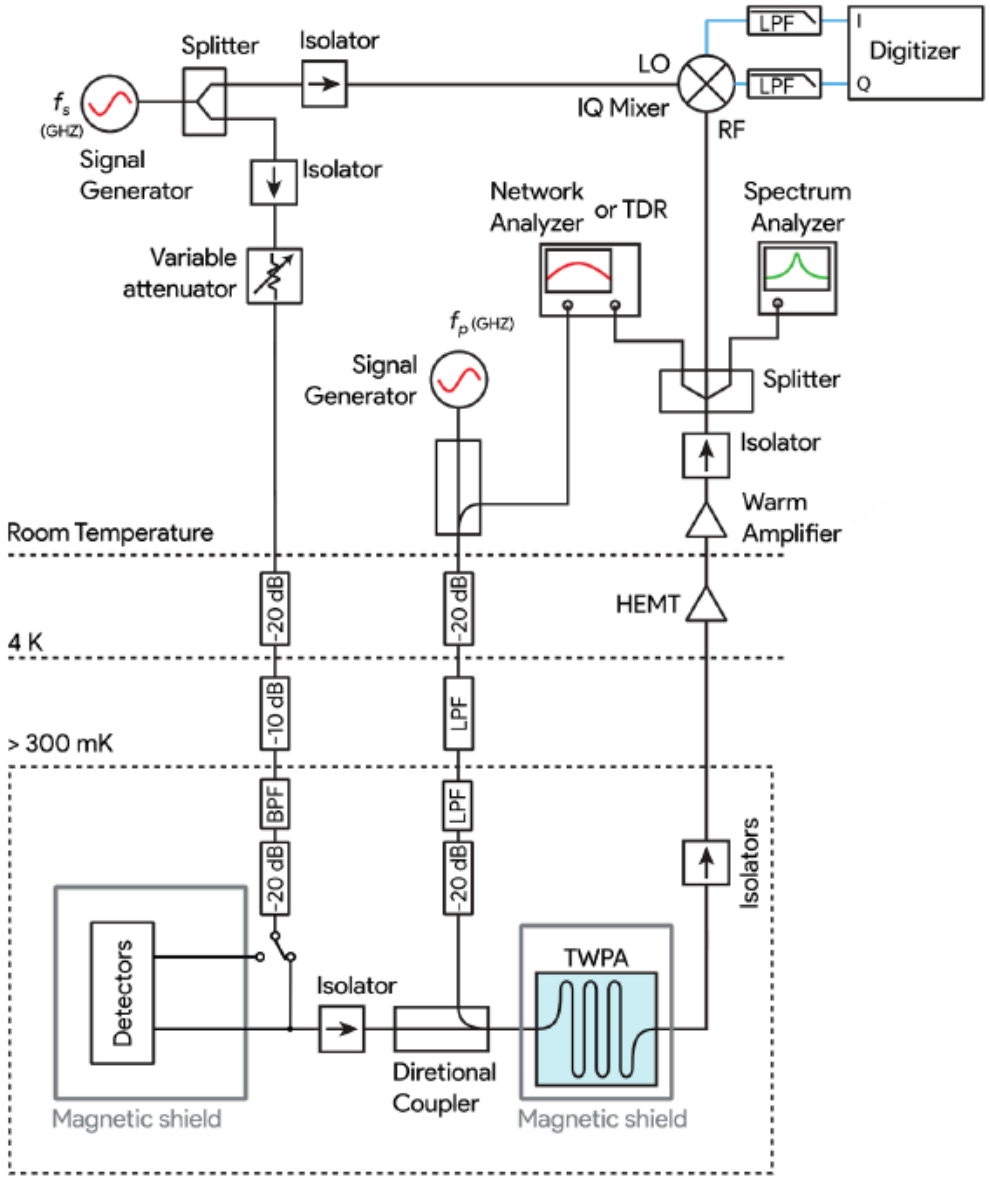
D3.1: Setup of the experimental instrumentations (M6)
D3.2: Report on the DTWKI characterization (M18/M30)
D3.3: Report on the on the read out demonstration with DTWKI (M36)

KI-TWPA not yet produced (still under design phase)

Outline

- Upgrade of setups (Trento, Milano, Lecce)
- Preliminary measurements on NbTiN thin films and test structures required to guide the design of the KI-TWPA devices

DARTWARS milestone dec-2021: (almost) all partners with a setup ready for quantum limited measurements



General setup (from the proposal)

- 2 input lines + 1 output line
- State-of-the-art HEMT amplifier ($kT_n/hf < G_{TWPA}$)
- Ultralow noise rf generators, VNA, Spectrum Analyzer
- Circulators, Couplers, Filters, Attenuators, Switches …

For WP3, the target frequency range is 4-8 GHz

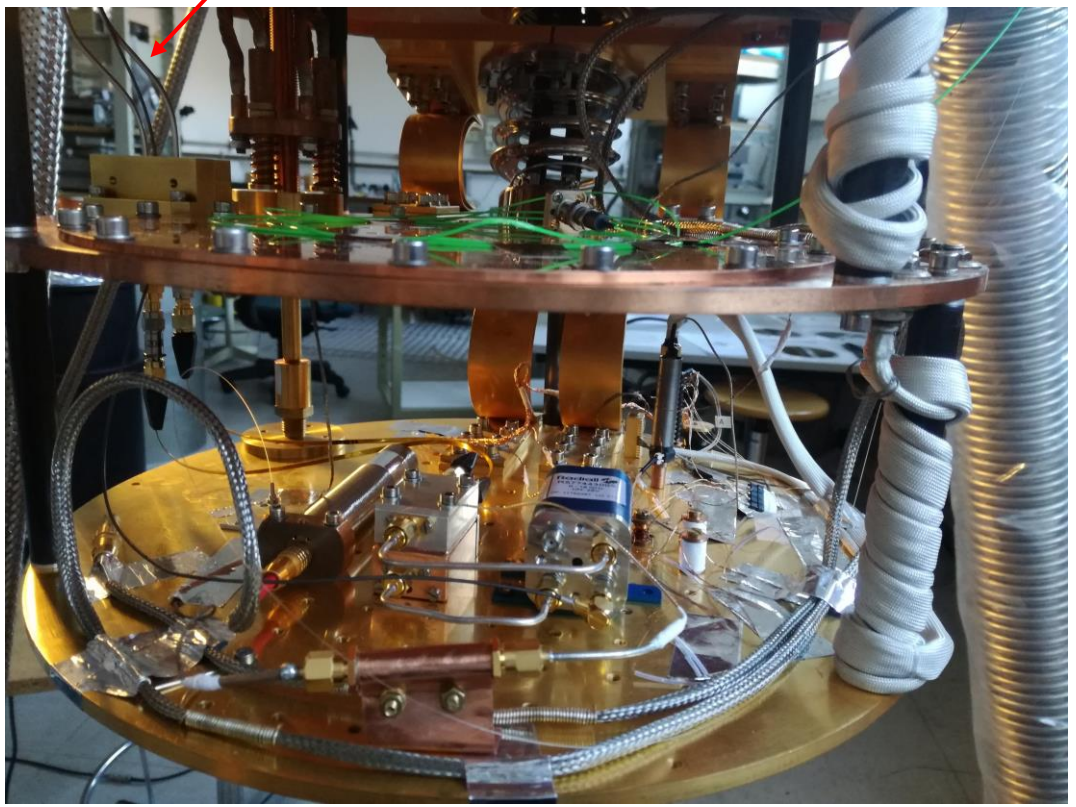
Partners active in WP3: MiB, Trento + Lecce

Setup in Trento: Upgrade

Before: cryostat equipped with microwave setup for readout of KIDs

- Dry dilution refrigerator T_0=20 mK
- 2 lines (1 input, 1 output)
- Wideband Low noise HEMT ($T_n \approx 5$ K)
- Low noise generator 5 GHz (-120 dBm)
- Spectrum Analyzer

3 coax lines (2 SS + 1 Nb)



Upgrade:

- 3rd line installed and tested
- Couplers, cryo-switches delivered
- Ultralow noise HEMT (LNF, $T_n \approx 1.5$ K) to be delivered
- Circulators/isolators/bias tees to be delivered
- VNA 20 GHz (CopperMountain C2220) delivered and tested
- Signal generator 20 GHz to be purchased beginning 2022 (DARTWARS + QUBIT)

Setup in Milano: upgrade (slide by E. Ferri)

The cryostat is equipped with a microwave set-up with a single input and single output coaxial

lines and a HEMT amplifier for reading the HOLMES detectors.

We are adding:

➢2 coax lines for the Pump thermalized with SparkPlug

➢1 coax line from cold plate to mixing chamber for noise characterization

The Cupron Nickel coax lines from 300 K to 4K, Nb line from 4K to MC plate, the bulked connectors for all plates, and the flange at 300 K are ready.

We are assembling the stainless coax lines.

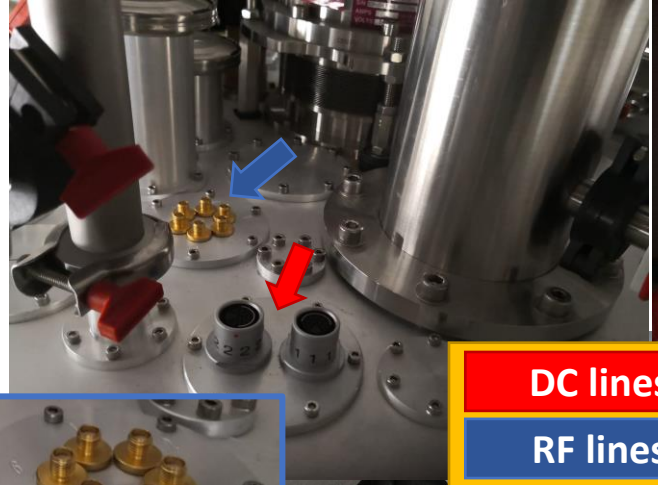
Circulators, bias-tees and directional couplers were procured.

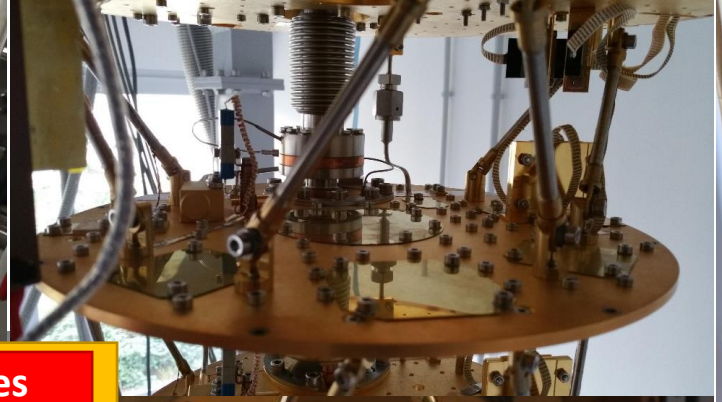
Front-end

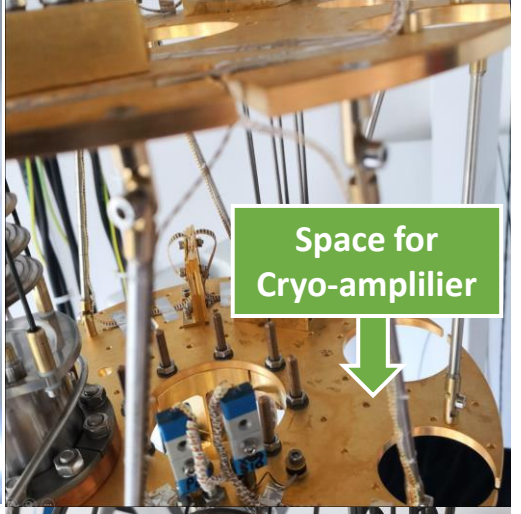
Instrumentation:

➢Rohde & Schwarz Signal generator 8 kHz – 20 GHz for the pump

➢Signal and Spectrum Analyzer up to 20 GHz – order at the beginning of 2022. The procedure to buy it is started in October.

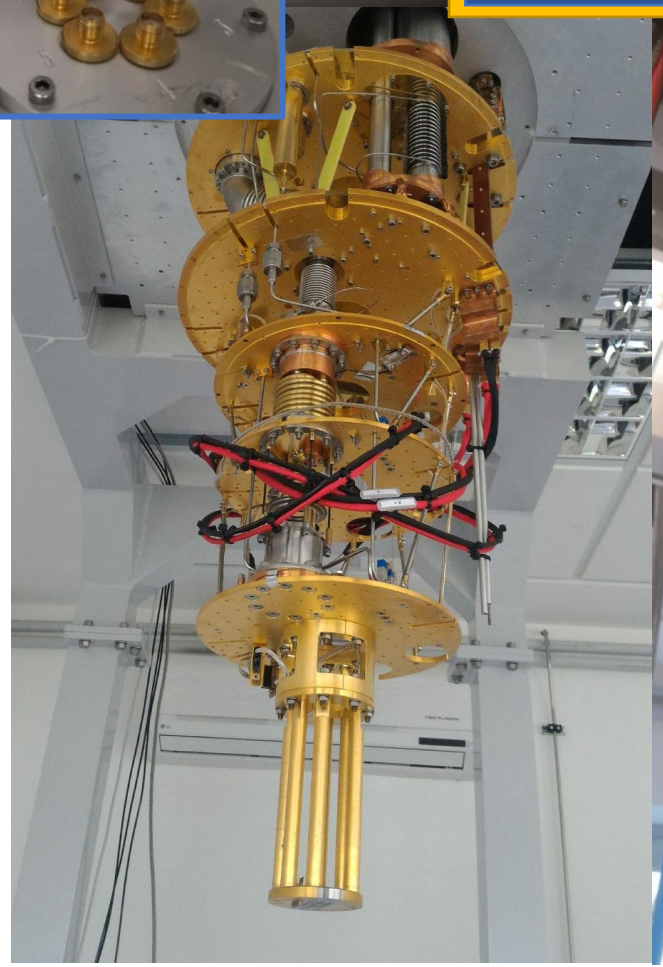


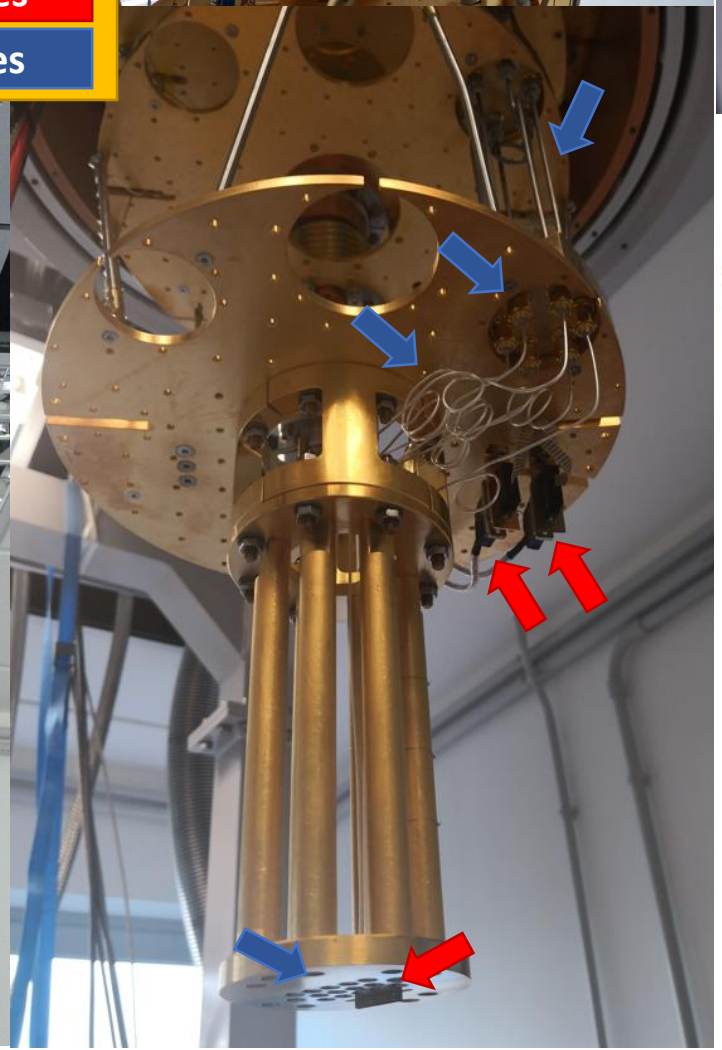


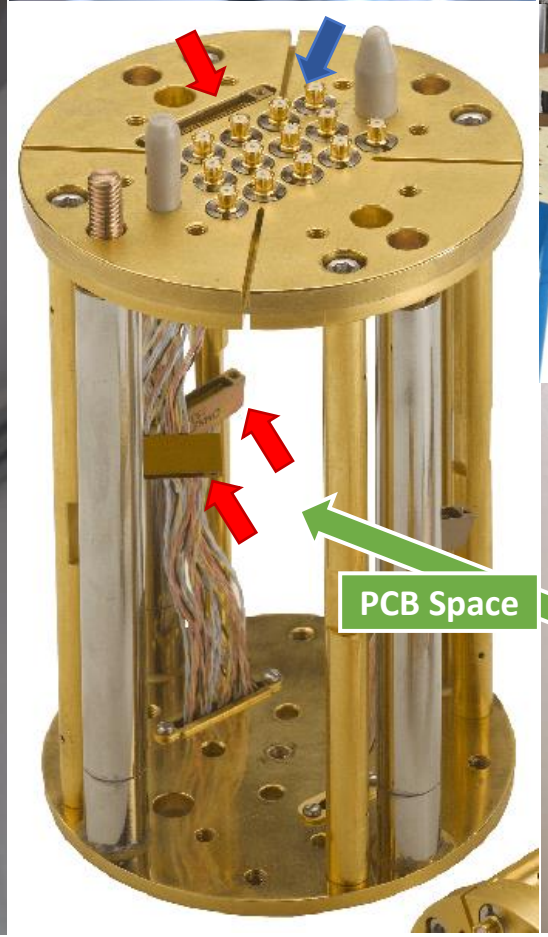


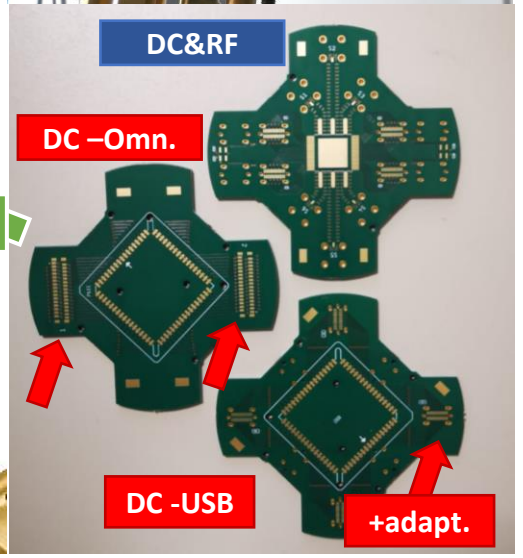
DC lines

RF lines





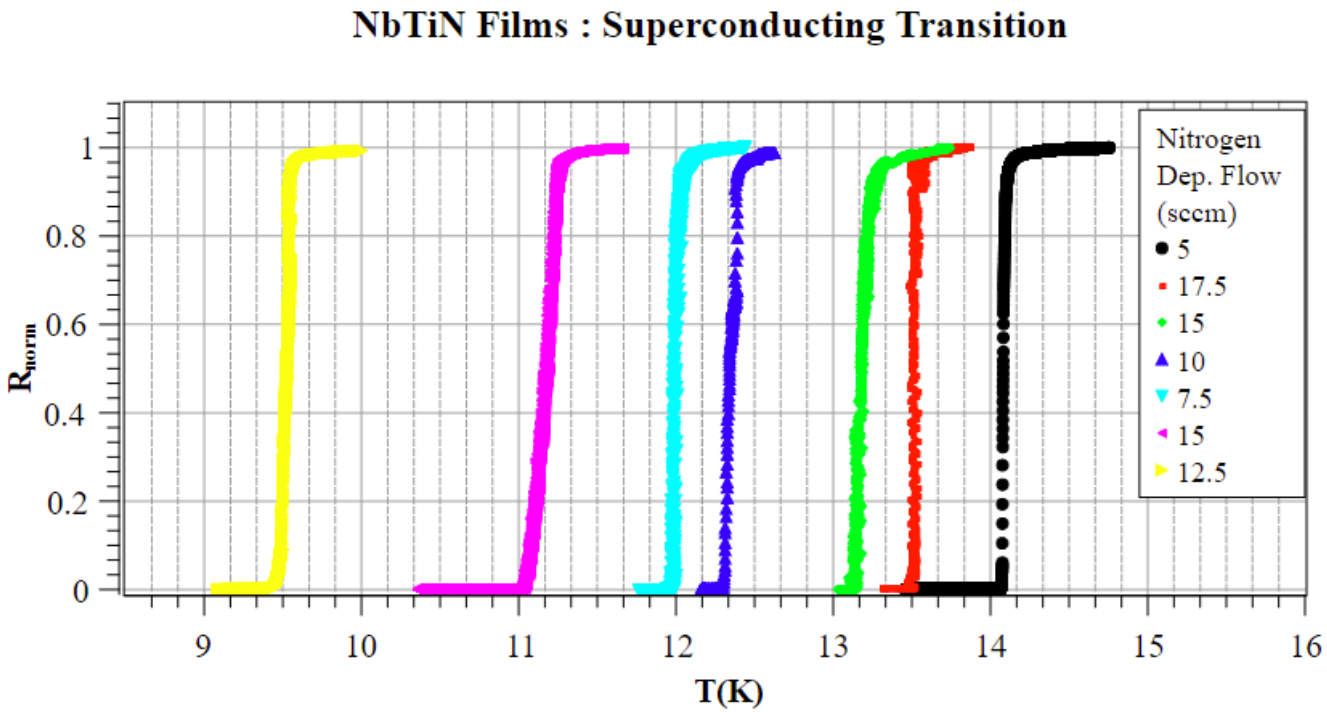




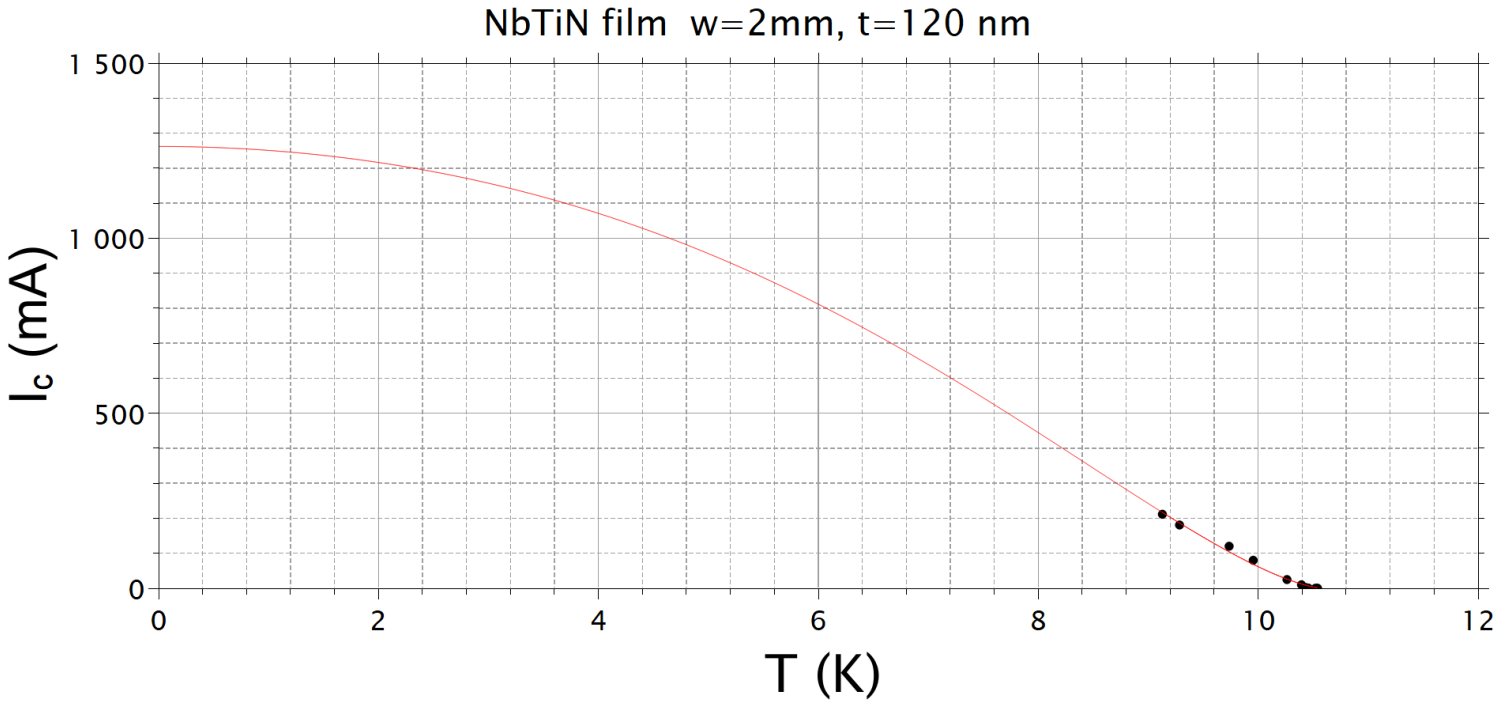
Preliminary Measurements on NbTiN Films and Test Structures (to provide feedback to FBK fabrication process)

Setup for quick characterization of FBK films

- Small vacuum chamber fitting in a liquid He transport dewar
  Heater and Thermometer for temperature control in 4.2 – 15 K range
- Superconducting transition measured with standard 4-wire
- Fast measurement time (~1 hour).
  Useful to provide quick feedback to FBK without need for the dilution refry



Critical current (field) measurements



Reliable only for low currents

Self-heating significant for high currents (tends to underestimate I_c)

«Optimistic» extrapolation to zero temperature with Ginzburg-Landau prediction modified for thin films:

$$I_c = I_{c0}(1-t^2)(1-t^4)^{1/2} \qquad t = \frac{T}{T_{c0}}$$

Estimations: I_{c0}≈0.5-1 MA/cm^2 (NbTiN)
I_{c0}≈10 MA/cm^2 (Nb)

New NbTiN thin films (20 nm) + test structures (resonators)

Goal: determine all material parameters relevant to the design of KI-TWPA

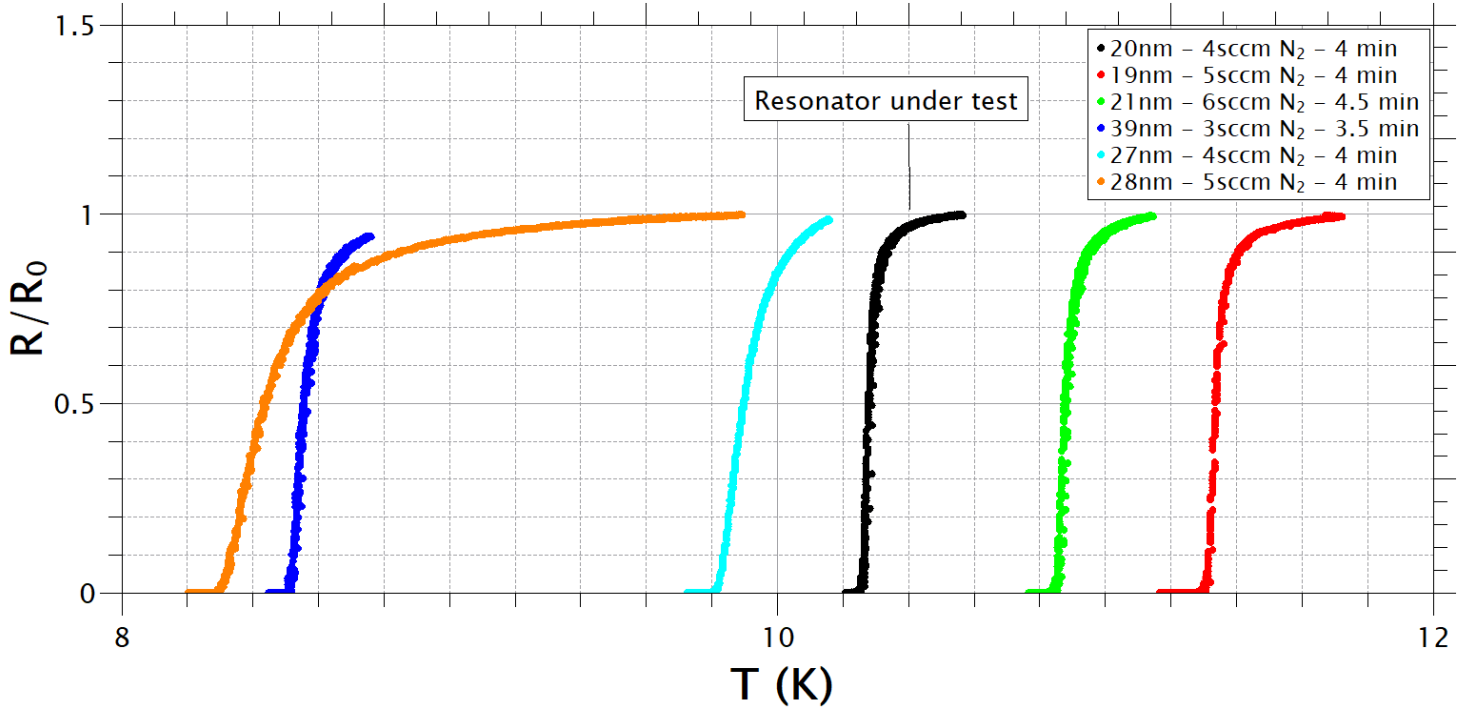
- Transition Temperature T_c
- Kinetic inductance (per square) L_k
- Dissipation/quality factor Q
- Nonlinearity

Film thickness reduced from ~100 nm to ~20 nm in order to enhance L_k

Measurements ongoing this week: preview of preliminary results

Transition temperature

Simultaneous measurements of 6 thin films in the dilution refrigerator



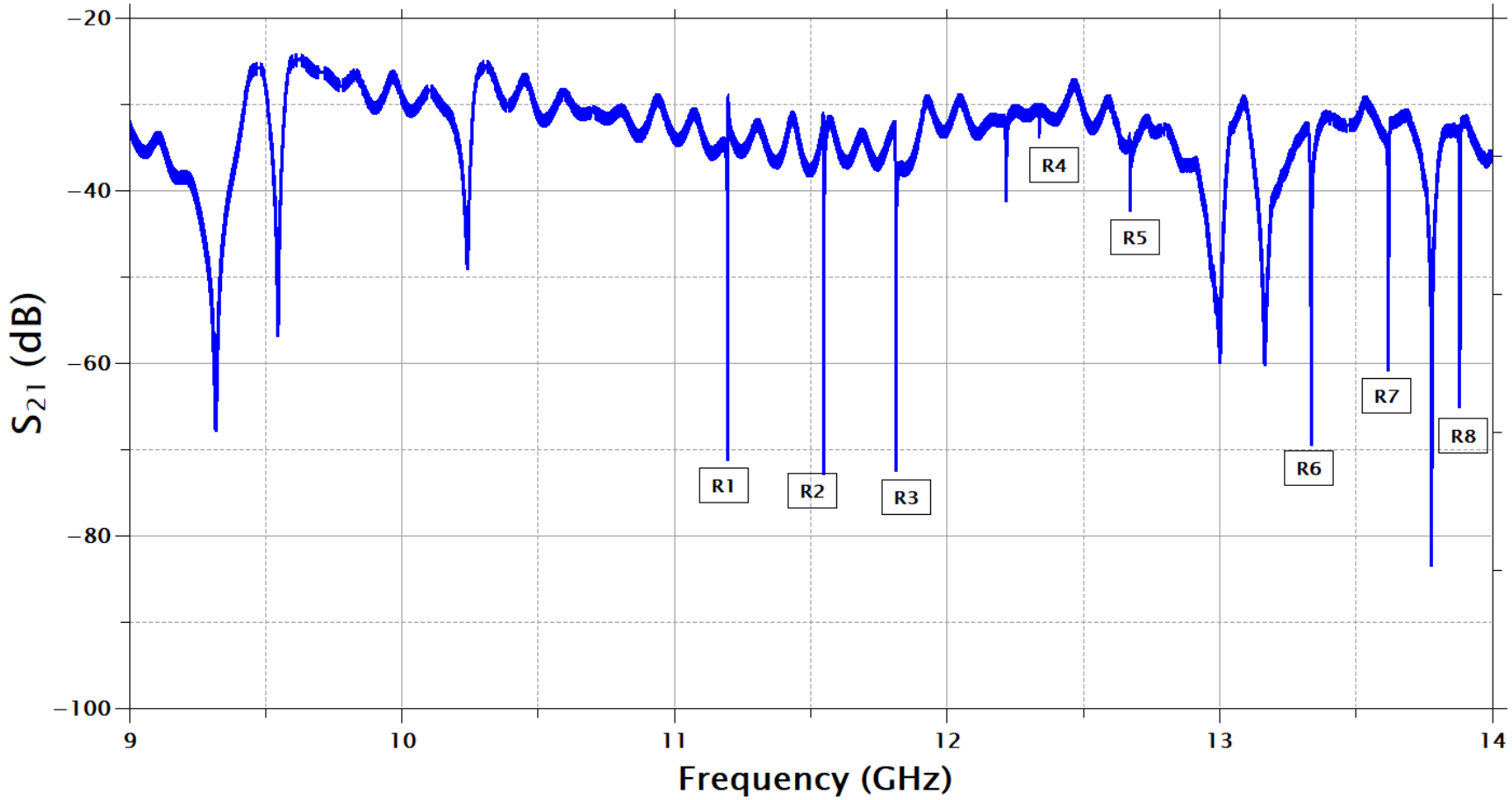
$T_c \sim (10 \pm 1.5)$ K

Estimation of Kinetic inductance for the selected resonator film:

$$L_K = \frac{\hbar}{1.76\pi k_B T_c} R_n \approx 4.5 \text{ pH/}\square$$

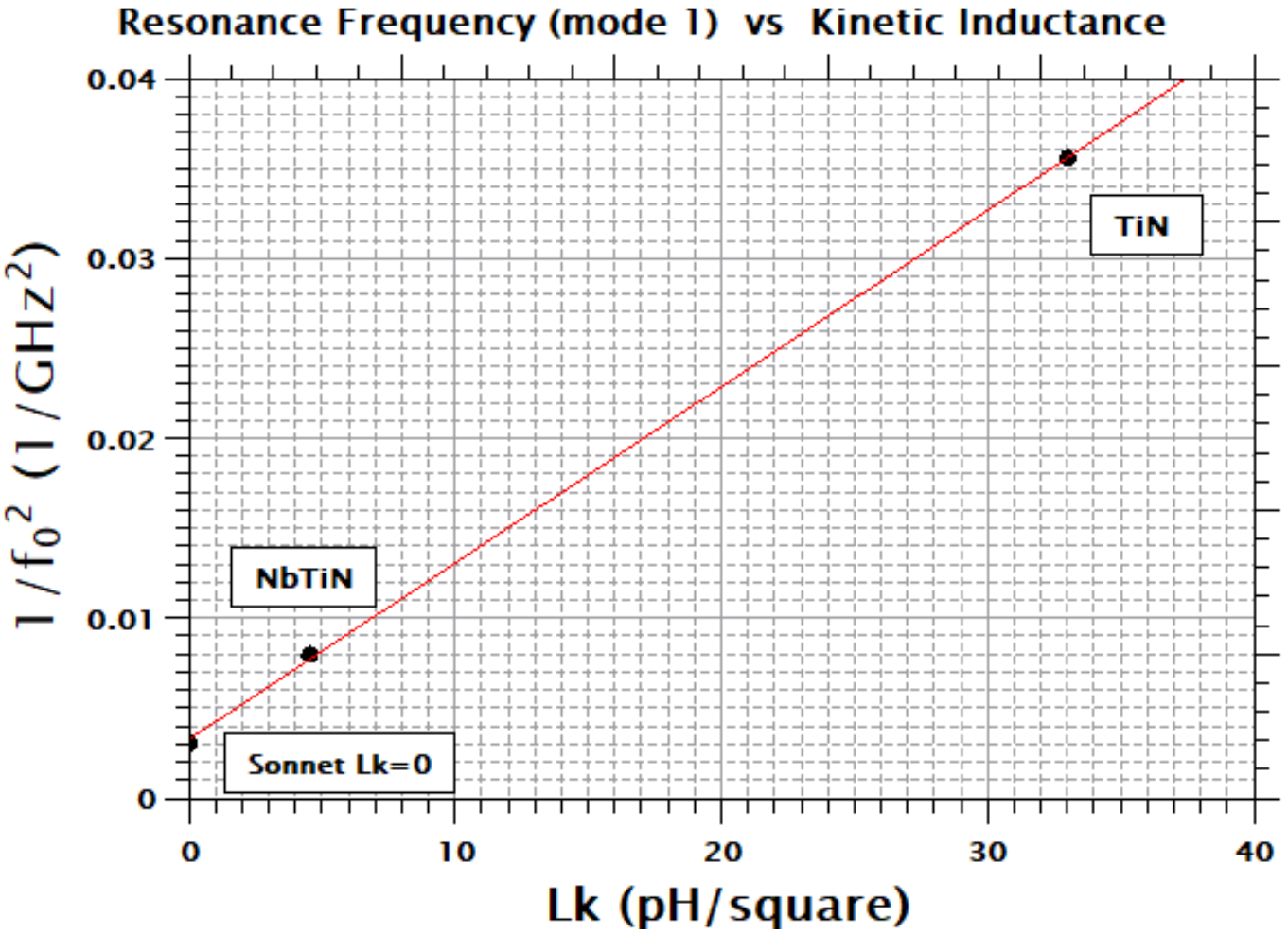
Resonator test chip

- Re-used a mask from past fabrication of TiN Kinetic Inductance Detectors (KIDs)
- 8 KIDs on the same chip & feedline simultaneously detected by the VNA
- KIDs distinguished from spurious peaks by frequency shift vs T



Kinetic Inductance vs Resonance frequency

- Comparison of resonance frequency with past measurements on TiN (same mask)
- L_k=33 pH/□ from Sonnet simulations in TiN



$$\frac{1}{{f_0}^2} \propto (L_{geom} + Lk)$$

Estimation of L_k is consistent!

Preliminary conclusions for the new ~20 nm films

- $T_c \approx (10 \pm 1.5)$ K

- L_k=4.5 pH/□ for selected chip film (less resistive),
  but factor up to 5 larger predicted for the other (more resistive) films

$L_k \approx$5-20 pH/□

(values comparable with fabrication in NIST)

- Preliminary estimations for internal dissipation: $Q_{int} \approx 1 \times 10^5$

  Work in progress!

- Nonlinearity: still to be investigated