FONDAZIONE BRUNO KESSLER

FUTURE BUILT ON KNOWLEDGE

SUPERCONDUCTING PLATFORM
Present and Future Capabilities

Federica Mantegazzini

13 FEBRUARY 2024, TRENTO

Quantum Architectures for Analogues and Theory Applications

Goal of this talk

Help to have a **base for discussion** between theoreticians and experimentalists

- Describe what we are able to (or learning to) develop ***now***
- Project the development for the next ***2-3 years***

Pinpoint
enabling superconducting technologies and circuits

What’s going on now

Ongoing projects at FBK:

- INFN DARTWARS, Qub-IT (2021/22-24), FBK ROLE: PARTNER, ACTIVITIES: QUANTUM-LIMITED TWPA & JPA FOR READ-OUT
- PNRR NQSTI (2023-26), FBK ROLE: PARTNER, ACTIVITIES: MULTI-QUBIT SYSTEMS
- HE Qu-Pilot (2023-26), FBK ROLE: PARTNER, ACTIVITIES: PILOT-LINE FOR SUPERCONDUCTING DEVICES
- MAECI Hy-QMS (2023-26), FBK ROLE: PARTNER , ACTIVITIES: SC DEVICES TO BE COUPLED TO MAGNETIC CANTILEVERS
- HE MiSS (2024-27), FBK ROLE: COORDINATOR, ACTIVITIES: KINETIC INDUCTANCE TWPA FOR MICROWAVE SQUEEZING

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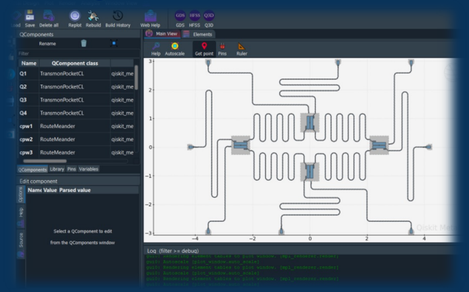
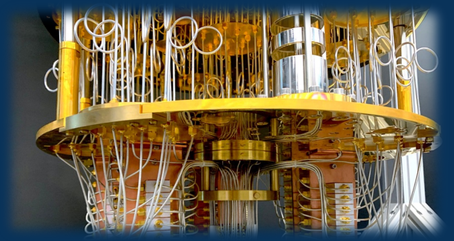
Design & Simulations



Microfabrication

Cryogenic measurements



➤ *NEW FBK CRYO LAB UNDER CONSTRUCTION*

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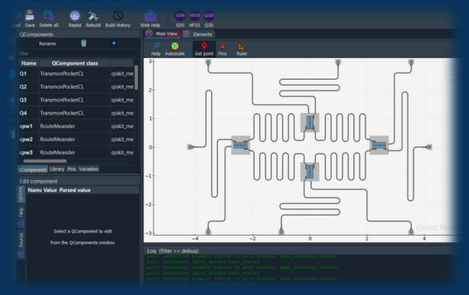

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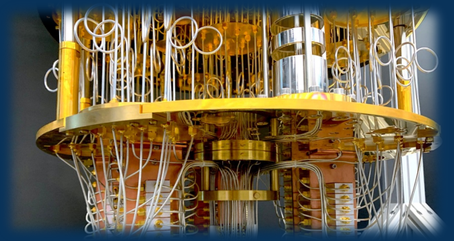


➤ *NEW FBK CRYO LAB UNDER CONSTRUCTION*

FBK team: Felix Ahrens, Nicolò Crescini, Alessandro Irace, Federica Mantegazzini, Benno Margesin

Other Trento experimentalists: Paolo Falferi, Renato Mezzena, Andrea Vinante

JOB ALERT

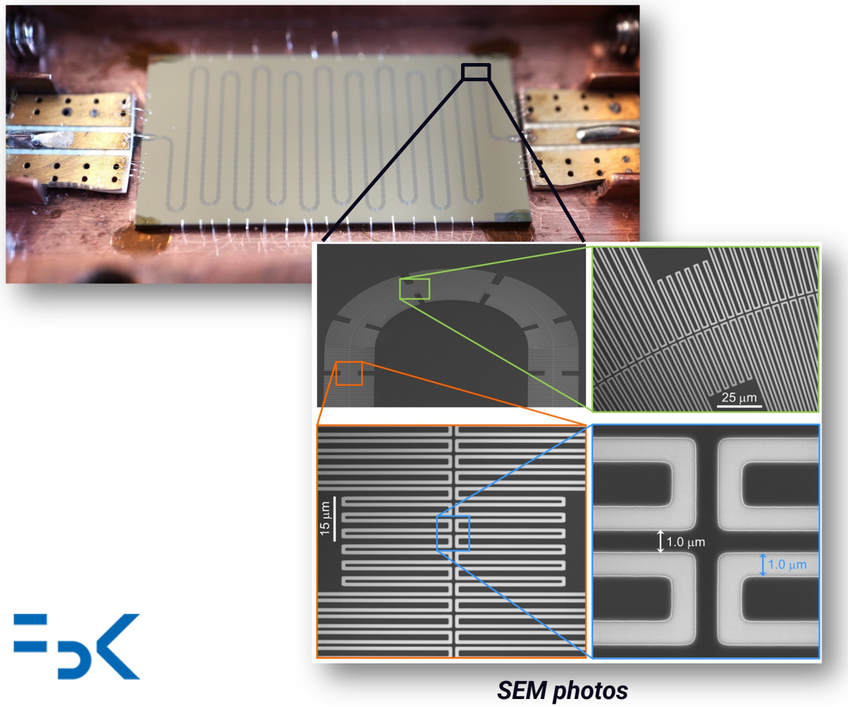
1 PHD, 1 RESEARCHER @FBK
1 POSTDOC @CNR-IFN

Current focus: Devices

Devices

*Travelling Wave Parametric Amplifiers (**TWPA**s)*

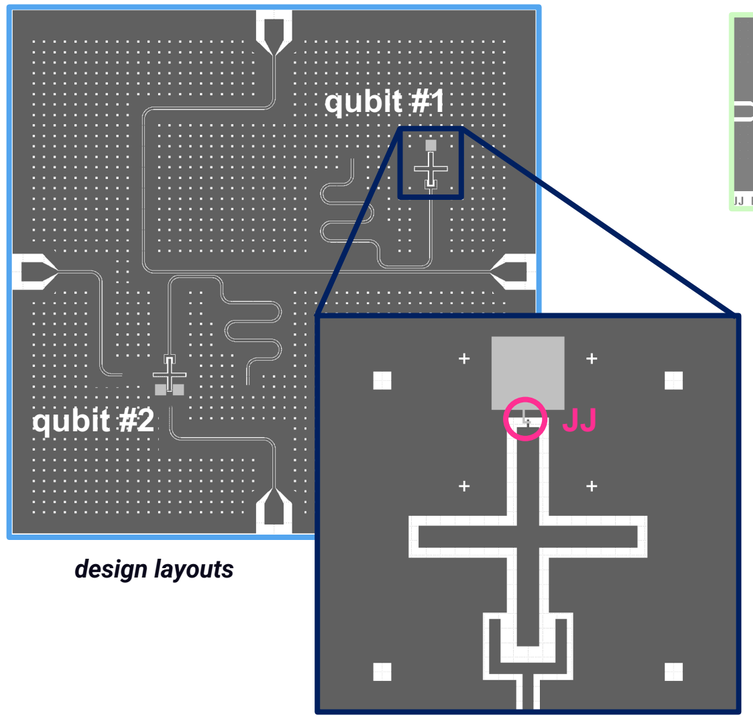
DARTWARS, MiSS, NQSTI



SEM photos

Superconducting qubits

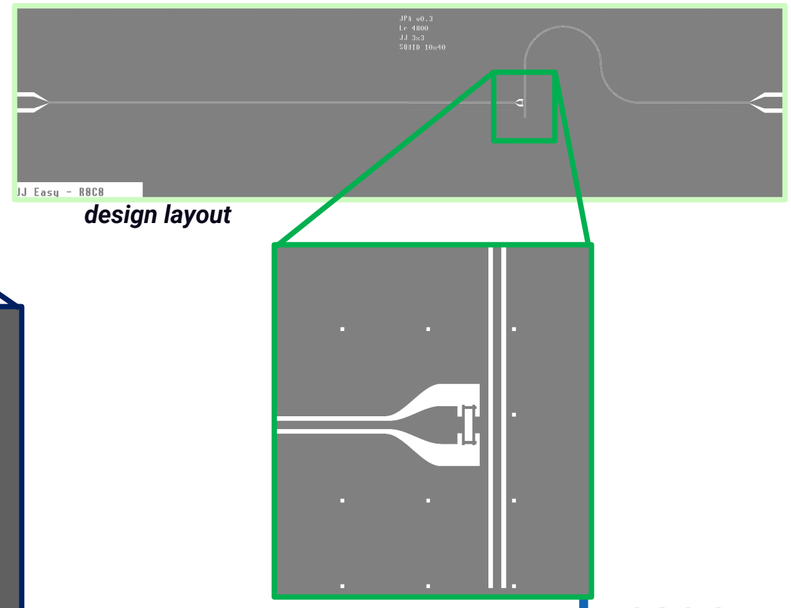
Qub-IT, NQSTI



design layouts

*Josephson Parametric Amplifiers (**JPA**s)*

Qub-IT, Hy-QMS



design layout

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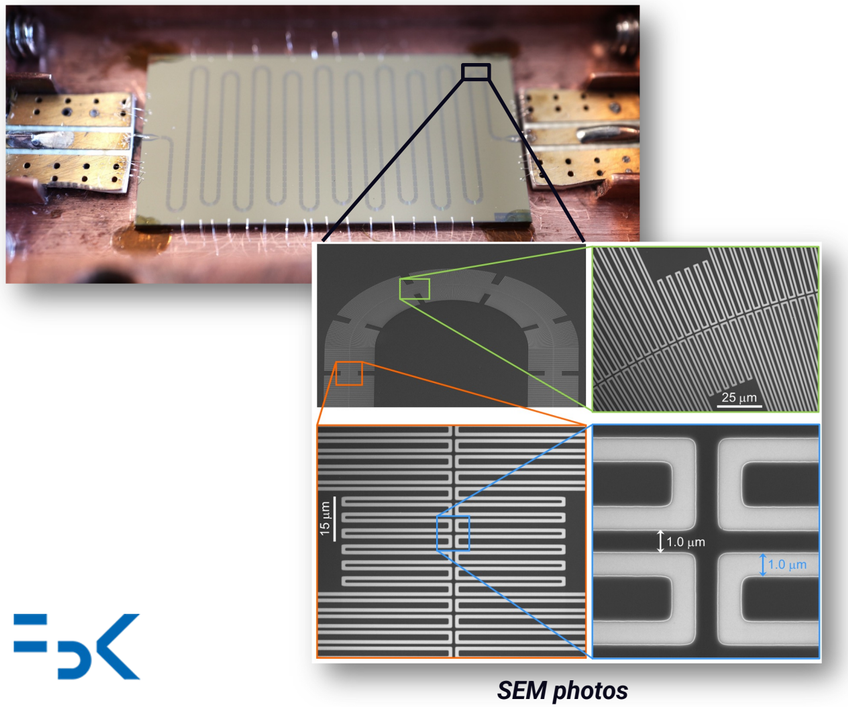
Current focus: Devices

Devices

*Travelling Wave Parametric Amplifiers (**TWPA**s)*

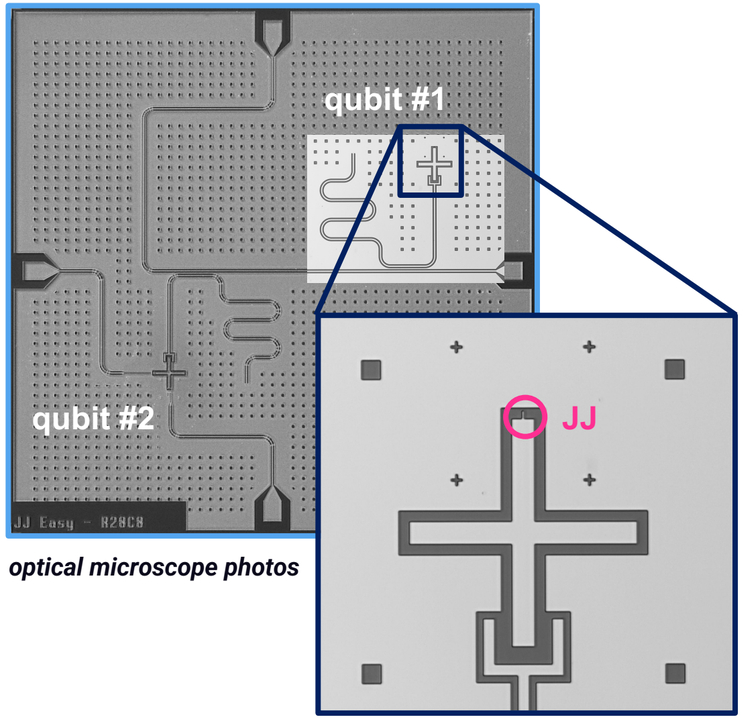
➤ **2ND GENERATION WILL BE MEASURED SOON**



SEM photos

Superconducting qubits

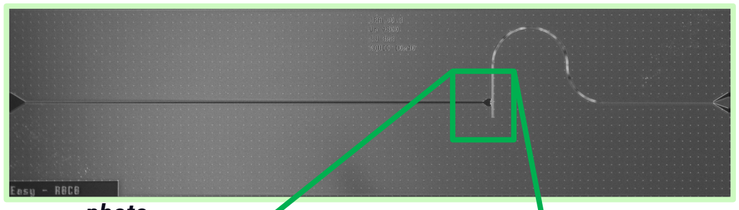
➤ **FIRST FABRICATION IS ONGOING!**



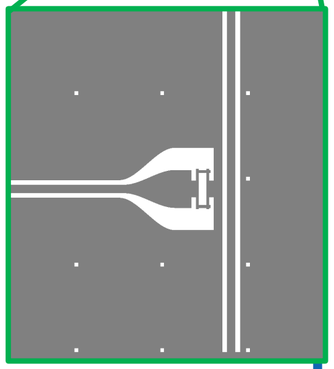
optical microscope photos

*Josephson Parametric Amplifiers (**JPA**s)*

➤ **2ND GENERATION IS BEGIN MICROFABRICATED**



photo



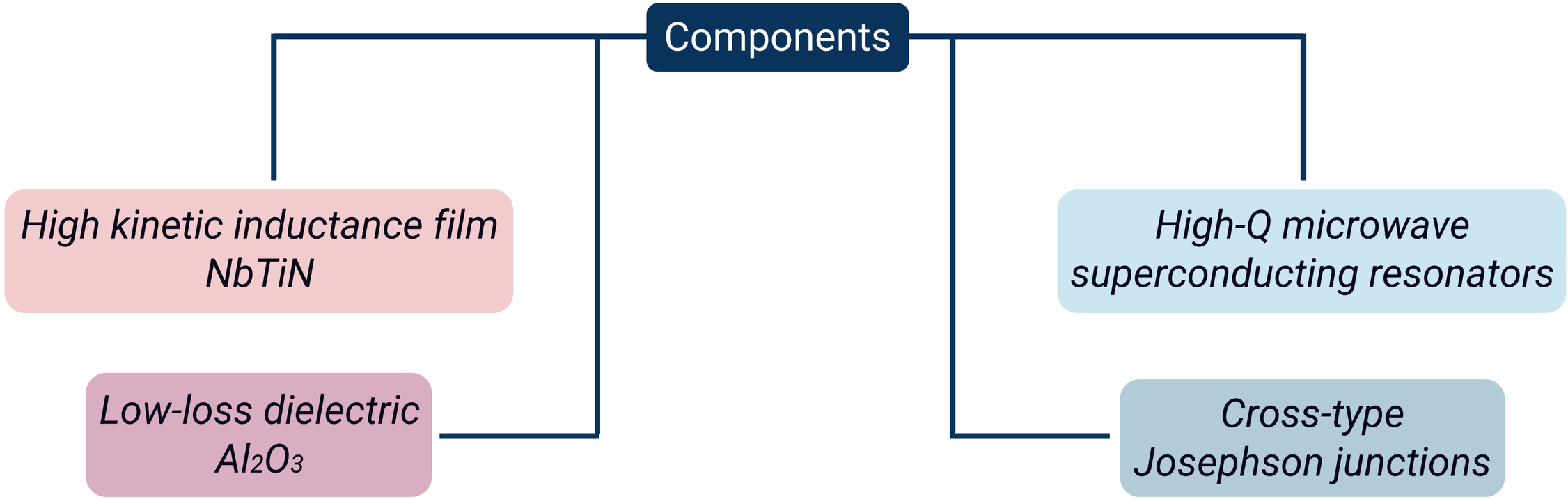
design layout

… and Components

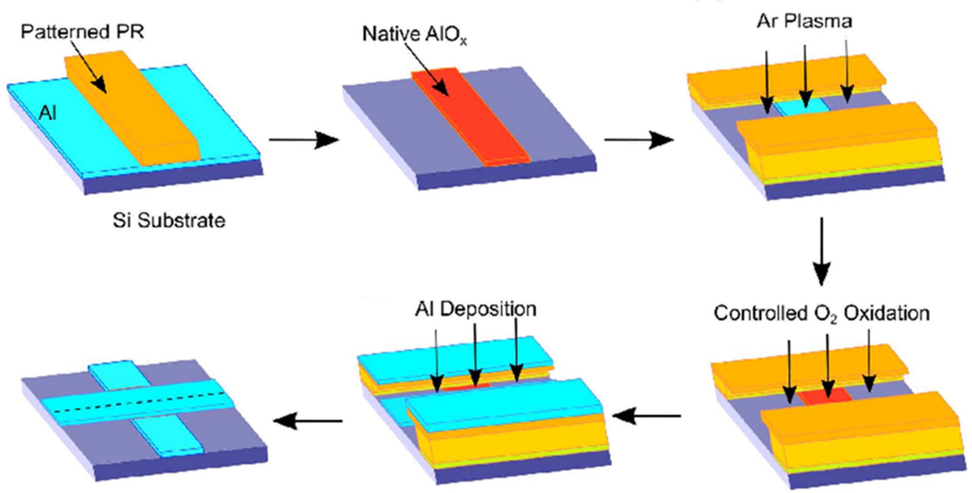
*Travelling Wave Parametric Amplifiers (**TWPA**s)*

Superconducting qubits

*Josephson Parametric Amplifiers (**JPA**s)*



Cross-type Al/AlOx/Al junctions at FBK

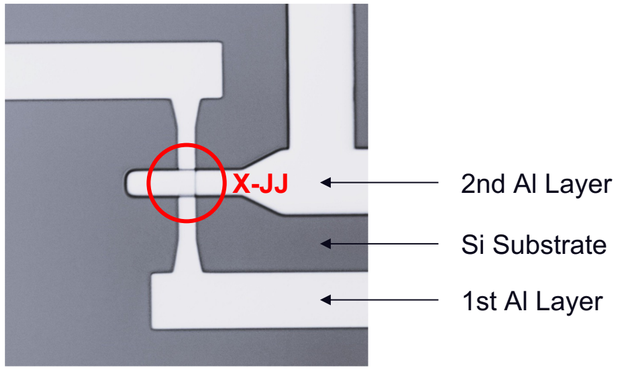


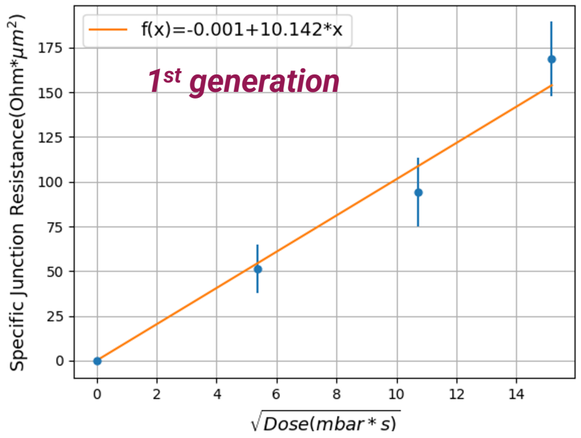
Advantages

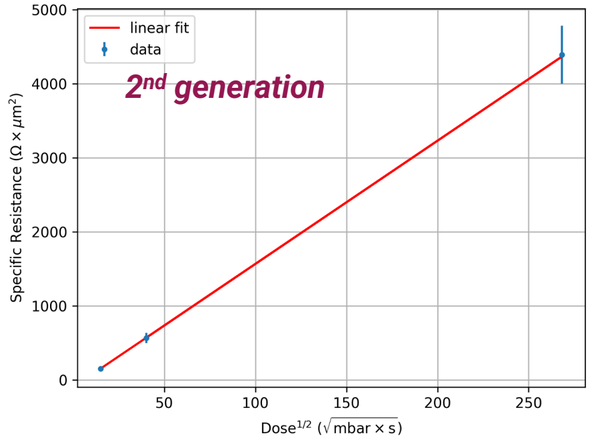
- High control on areas (and on junction parameters)
- Two-layers process

Challenge

- Develop an efficient Ar plasma cleaning
- Optimise the second lithographic step (lift-off)



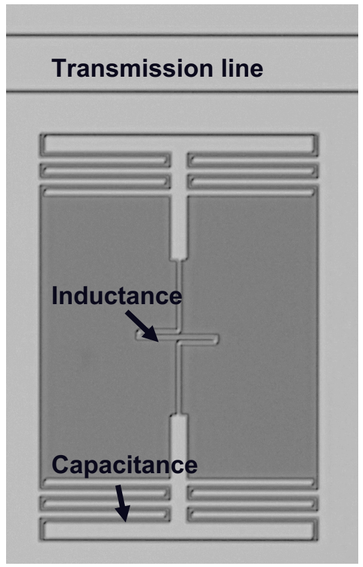




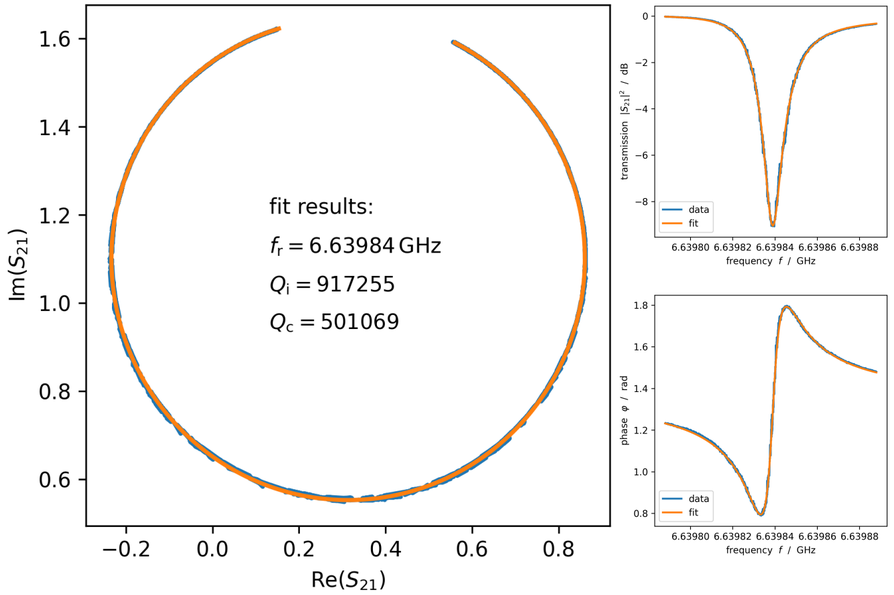
Parameter range: R_N up to 4k Ω·μm → I_C down to 70 nA·μm

Microwave resonators

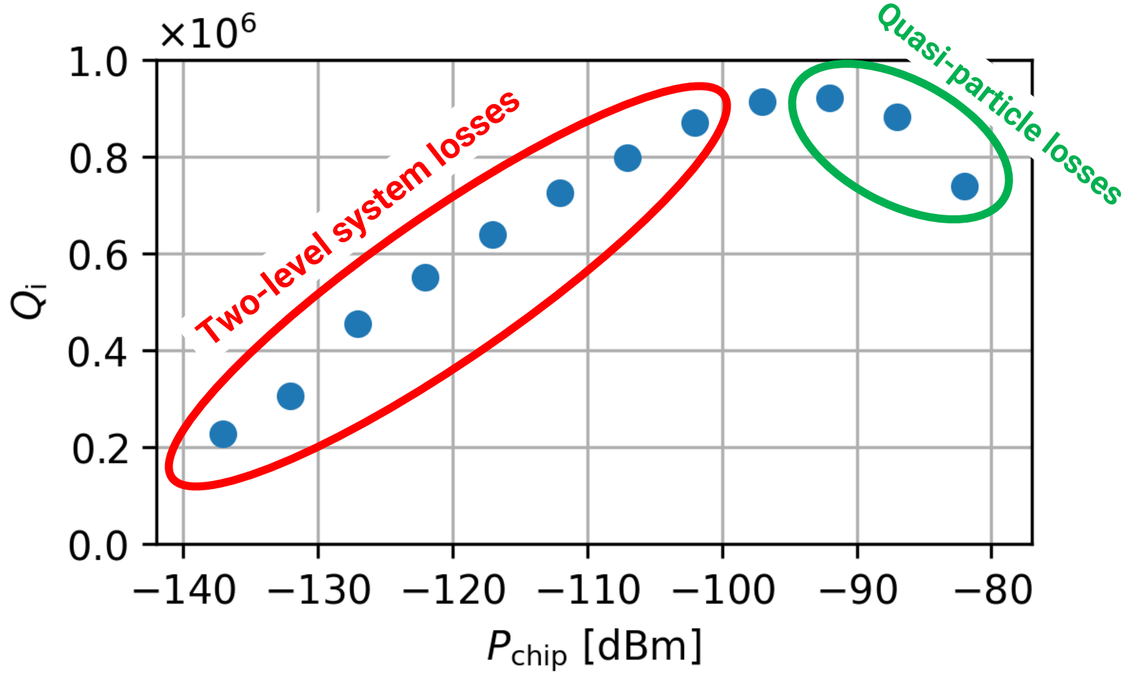
Lumped element resonator



Resonance fit in complex S_{21} plane



Power dependence of internal quality factor Q_i



Optimise:

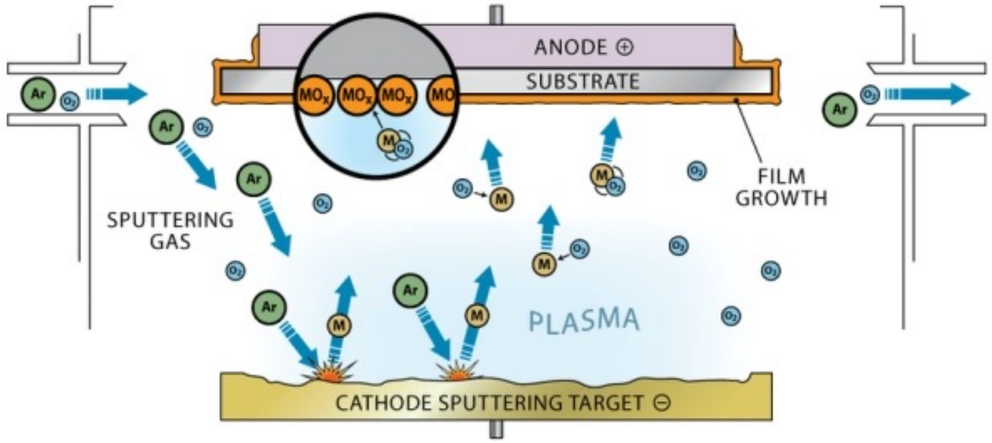
- material choice
- microfabrication process
- layouts and geometries

High kinetic inductance film

Magnetron sputtering deposition

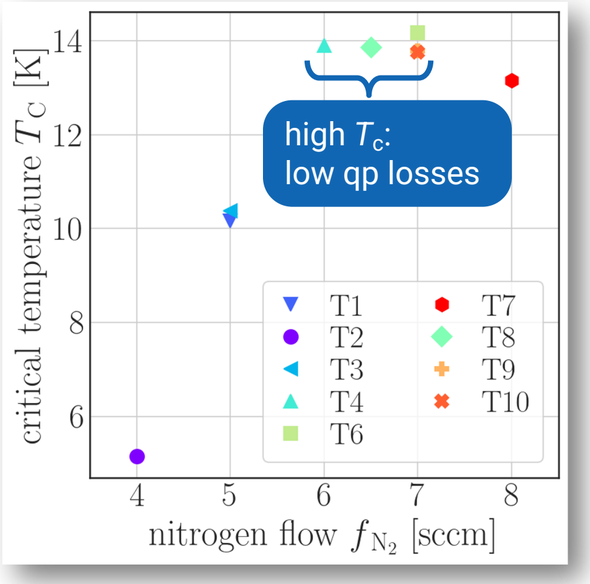
Nb80%Ti20% target + N_2 flow

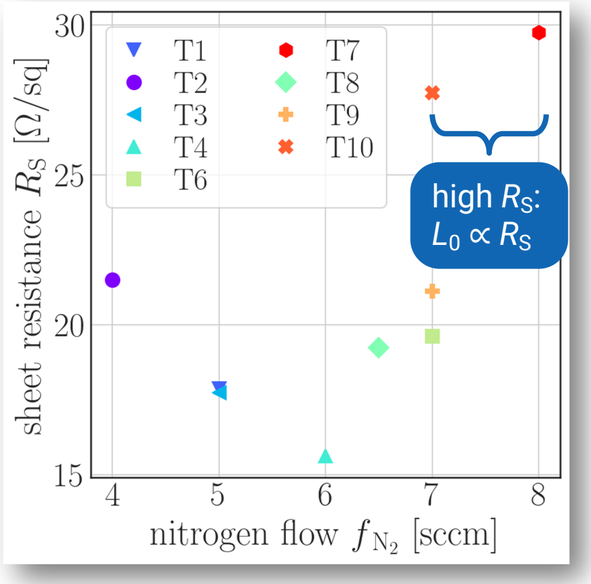
→ **NbTiN**

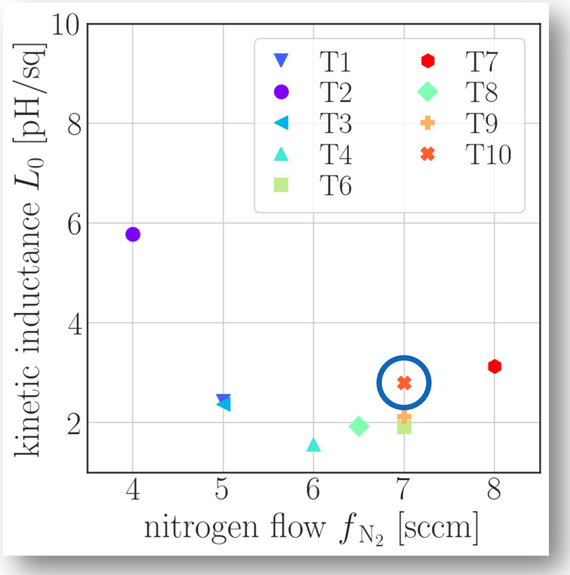


The film critical parameters (T_C, R_S, L_K) depend on the deposition process parameters

High kinetic inductance film







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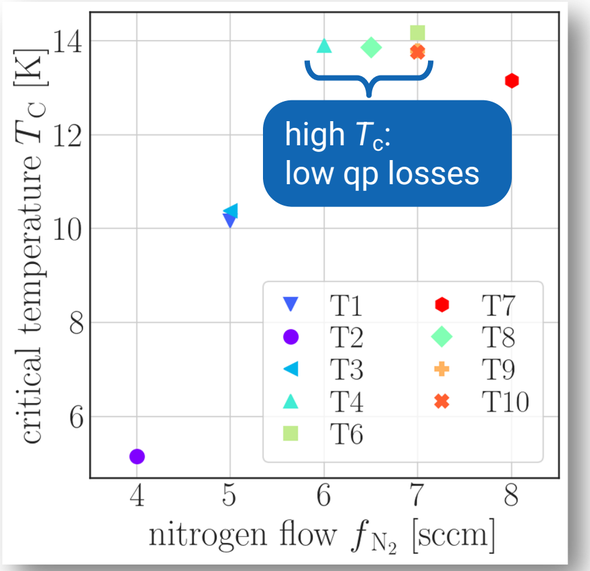
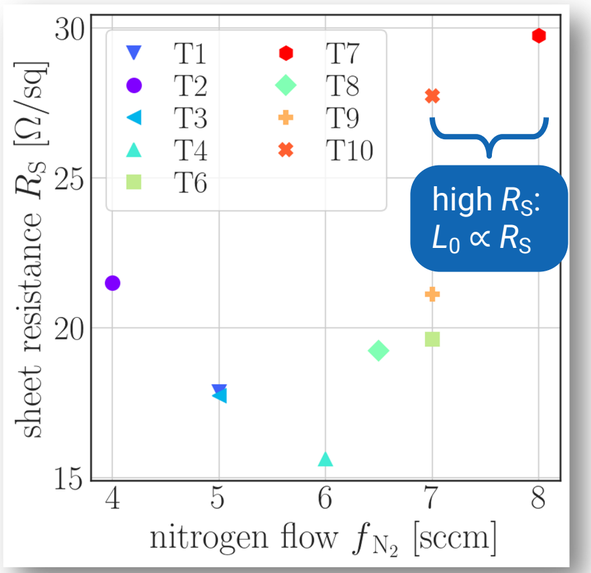
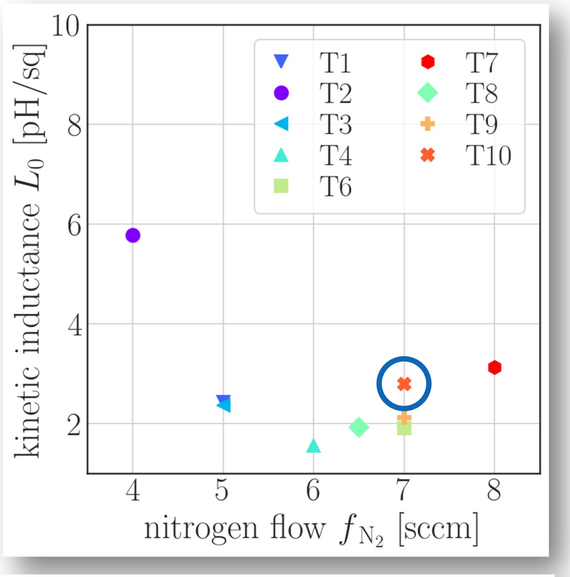
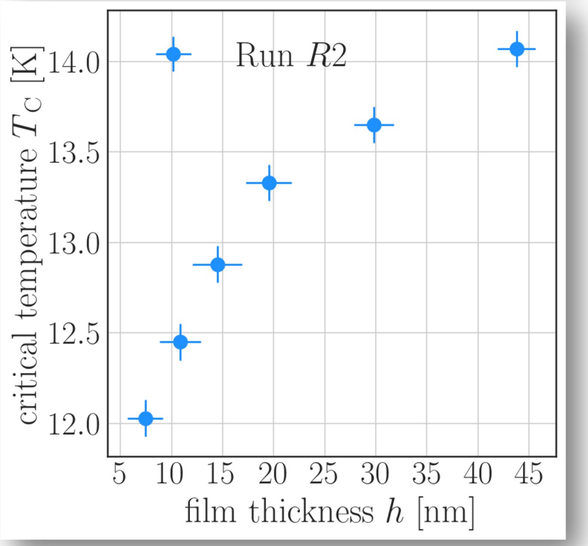
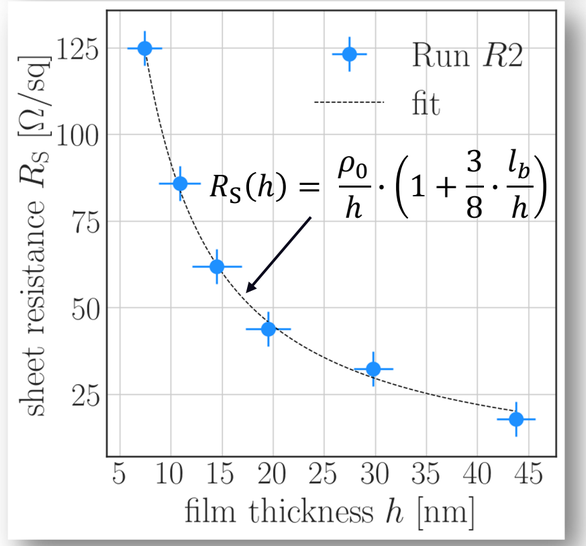
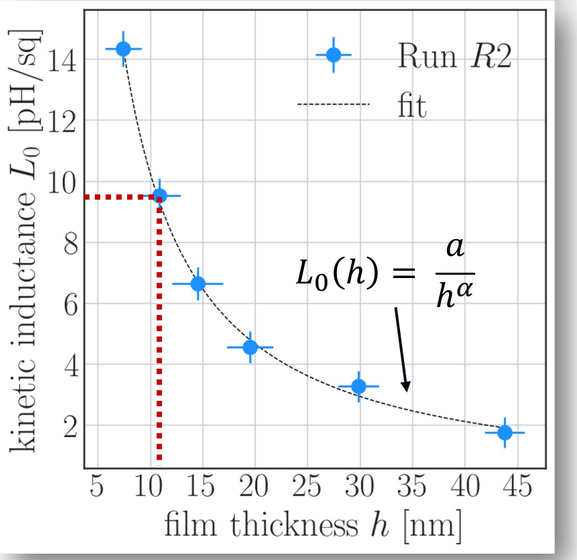








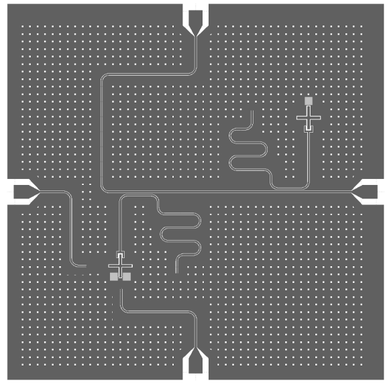




Combining the components to make devices

High-Q microwave superconducting resonators

Cross-type Josephson junctions



SUPERCONDUCTING QUBITS

Andrea Giachero's talk

JOSEPHSON PARAMETRIC AMPLIFIERS (JPA)

Exploitable for e.g.

- *Dynamic Casimir effect*
- *cQED experiments*

Combining the components to make devices

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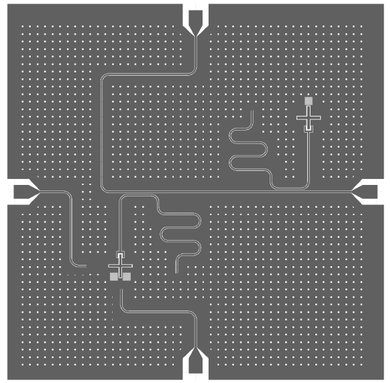
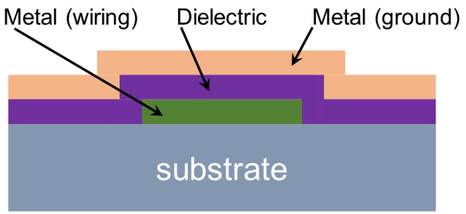
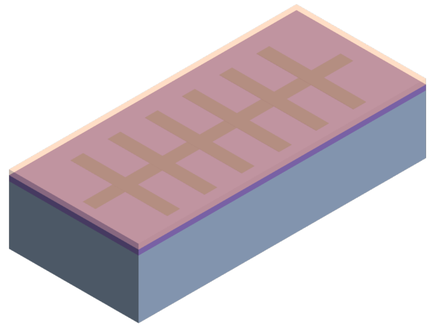
Cross-type Josephson junctions

High kinetic inductance film NbTiN

Low-loss dielectric Al_2O_3







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Exploitable for e.g.

- *Dynamic Casimir effect*
- *cQED experiments*

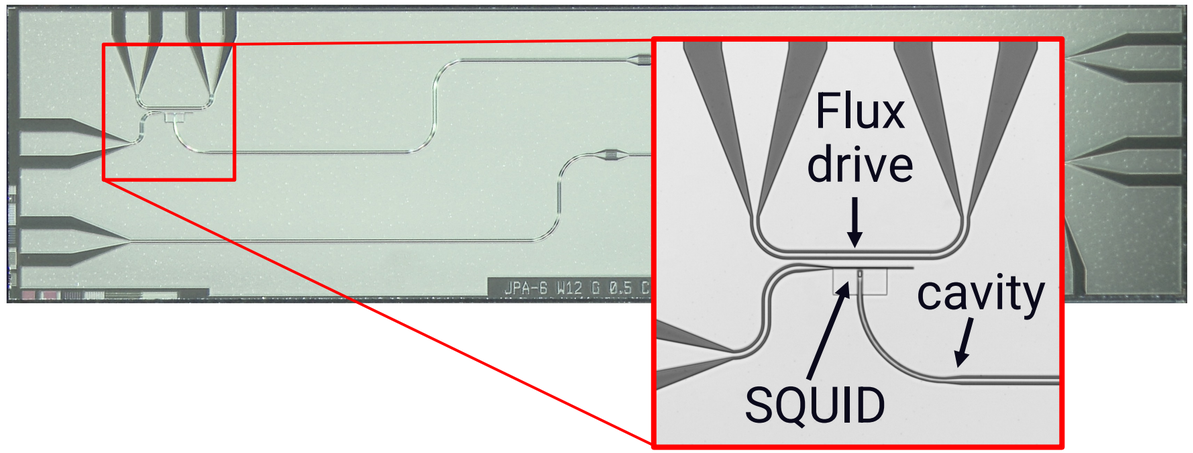
KINETIC INDUCTANCE TWPAs

Exploitable for e.g.

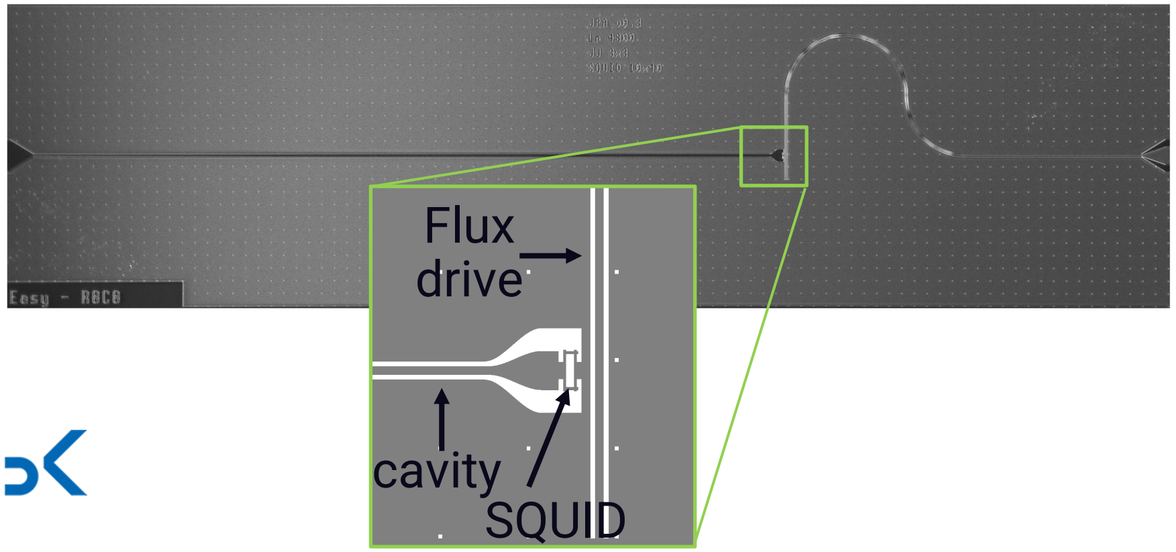
- *Quantum-limited amplification*
- *Generation of non-classical light (squeezing & entanglement)*

Josephson Parametric Amplifiers

1st generation Josephson Parametric Amplifier @ FBK

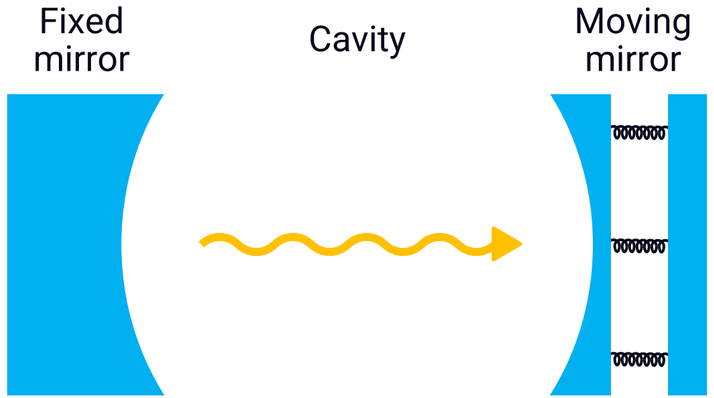


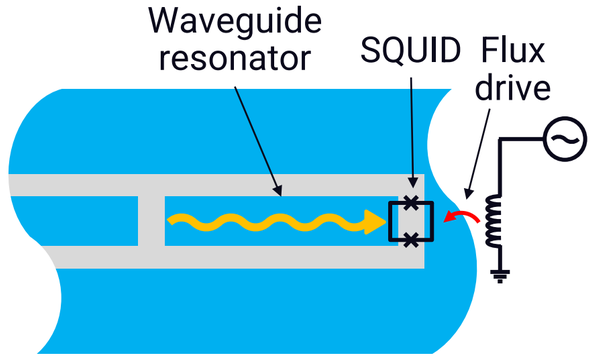
2nd generation Josephson Parametric Amplifier @ FBK



Dynamic Casimir effect

Creation of real photons out of the quantum vacuum by changing the boundary conditions rapidly





SQUID ≈ magnetic flux tunable inductance

C.M. Wilson *et al. Nature* **479**, 376–379 (2011)

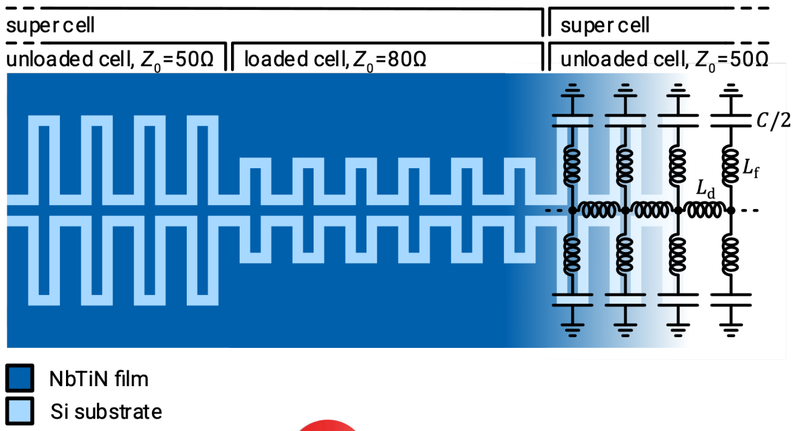
Kinetic Inductance TWPAs

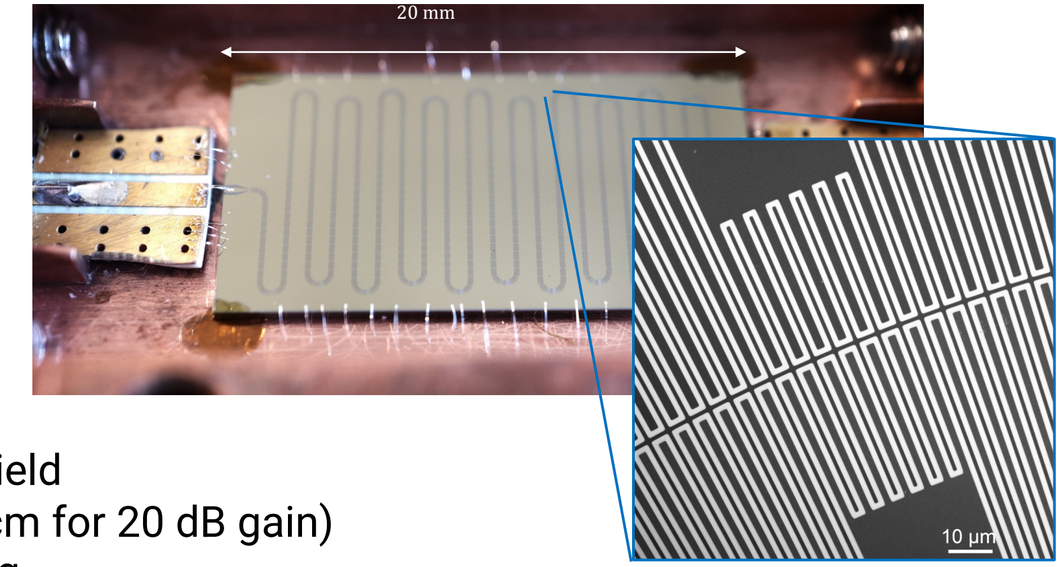
DARTWARS
Detector Array Readout with Traveling Wave AmplifieRS

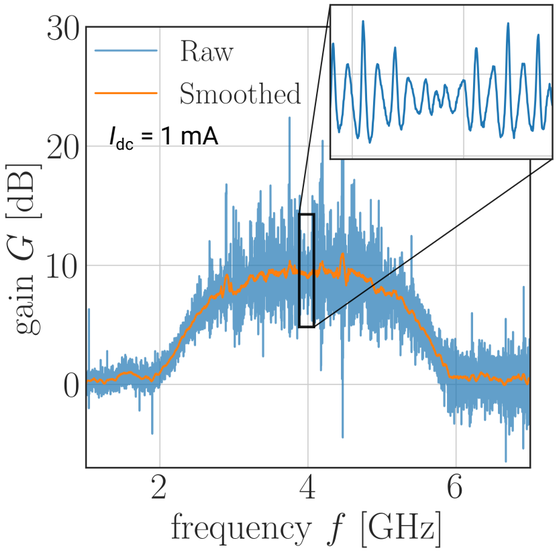
CSN5 Ricerca Tecnologica

MARIE CURIE ACTIONS

1st generation: CPW geometry







- Low fabrication yield
- Long device (33 cm for 20 dB gain)
- Difficult grounding

Kinetic Inductance TWPAs

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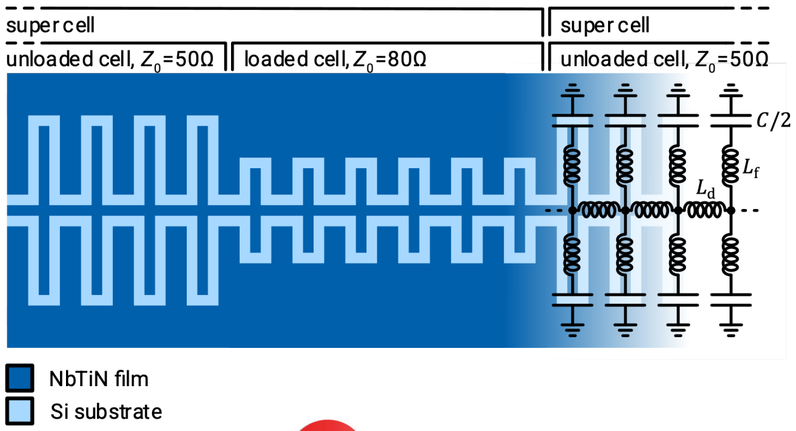
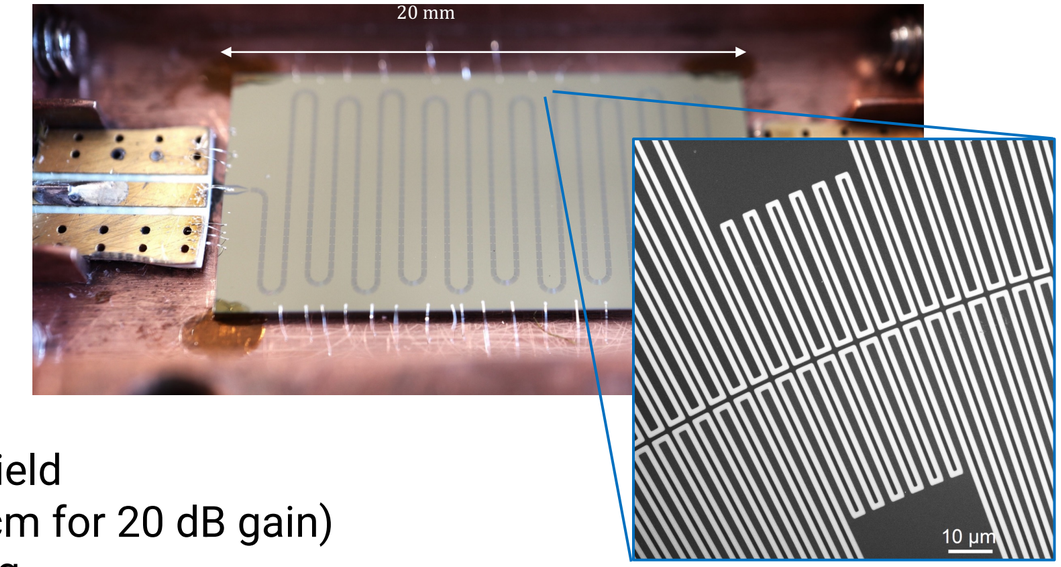
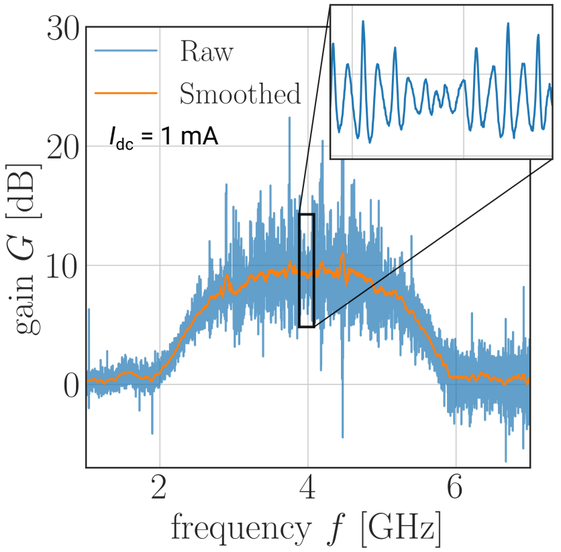
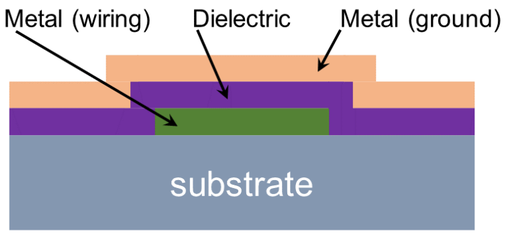


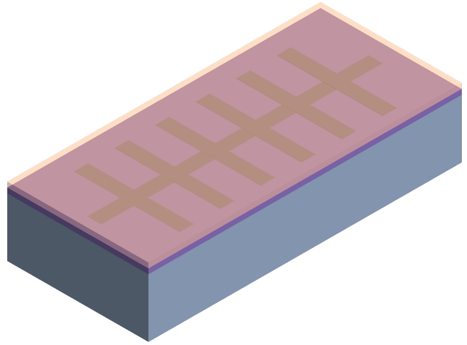




- Low fabrication yield
- Long device (33 cm for 20 dB gain)
- Difficult grounding

2nd generation: inverted microstrip geometry





- High fabrication yield
- Shorter device
- Easy grounding
- More compact device

CHALLENGES

- Low-loss dielectric film
- Increase L_K

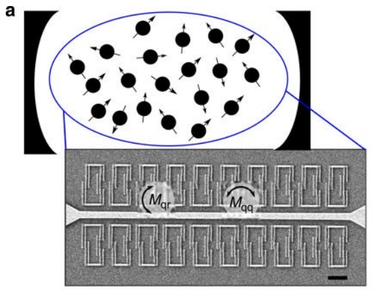
Kinetic Inductance TWPAs (and Josephson TWPAs)

DARTWARS
Detector Array Readout with Traveling Wave AmplifieRS

CSN5 Ricerca Tecnologica

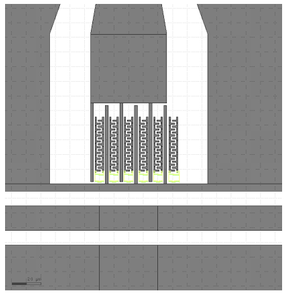
MARIE CURIE ACTIONS

METAMATERIALS



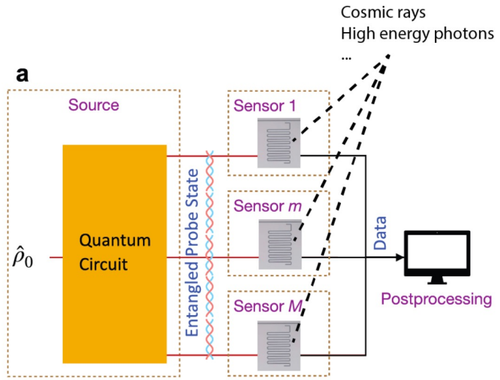
Implementation of a quantum metamaterial using superconducting qubits

https://www.nature.com/articles/ncomms6146



Supergalax project

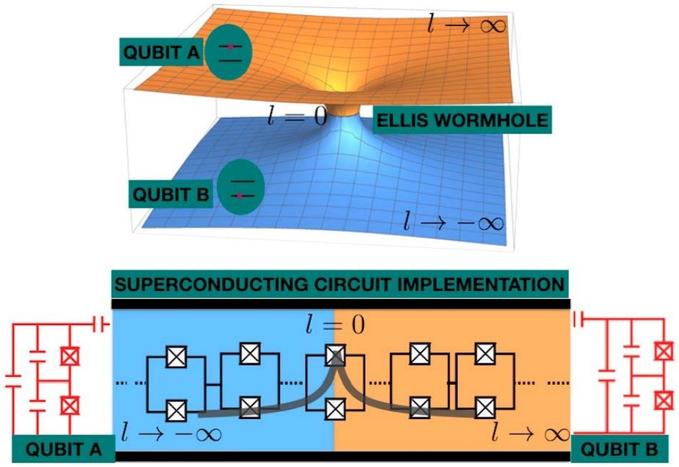
MICROWAVE SQUEEZING



Distributed Quantum Sensing using multi-mode broadband microwave squeezing

MiSS project

ENTANGLEMENT



Entangling Superconducting Qubits through an Analogue Wormhole

https://doi.org/10.3390/universe6090149