WELCOME TO THE WORKSHOP

Superconducting Devices for Quantum Optics and Quantum Simulations

Trento, 6-9 October 2025

Organising Committee:

Federica Mantegazzini, Iacopo Carusotto, Martina Esposito,
Nicolas Roch, Nicolò Crescini, Felix Ahrens

FONDAZIONE BRUNO KESSLER

ECT*
EUROPEAN CENTRE
FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS

Cavity QED in the optical domain

Interaction:

matter (atoms) ⇔ **light** (electromagentic fields)

CAVITY QED

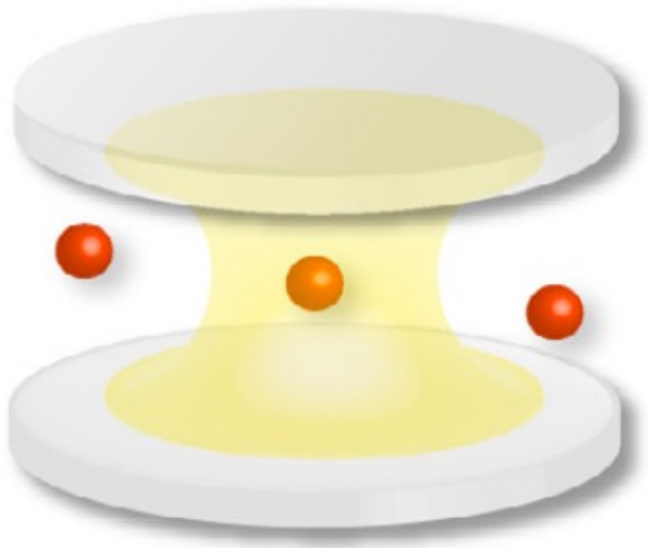

Figure from; *X. Gu, A.F. Kockum et al. Microwave photonics with superconducting quantum circuits, Physics Reports 718-719, 1-102, 2017*

“Standard approach”: with ***optical photons***

e.g. to study:

- Strong coupling
- Enhancement/suppression of spontaneous emission
- Soliton effects
- Novel sources
- Dynamic filters (for optical communication)
- …

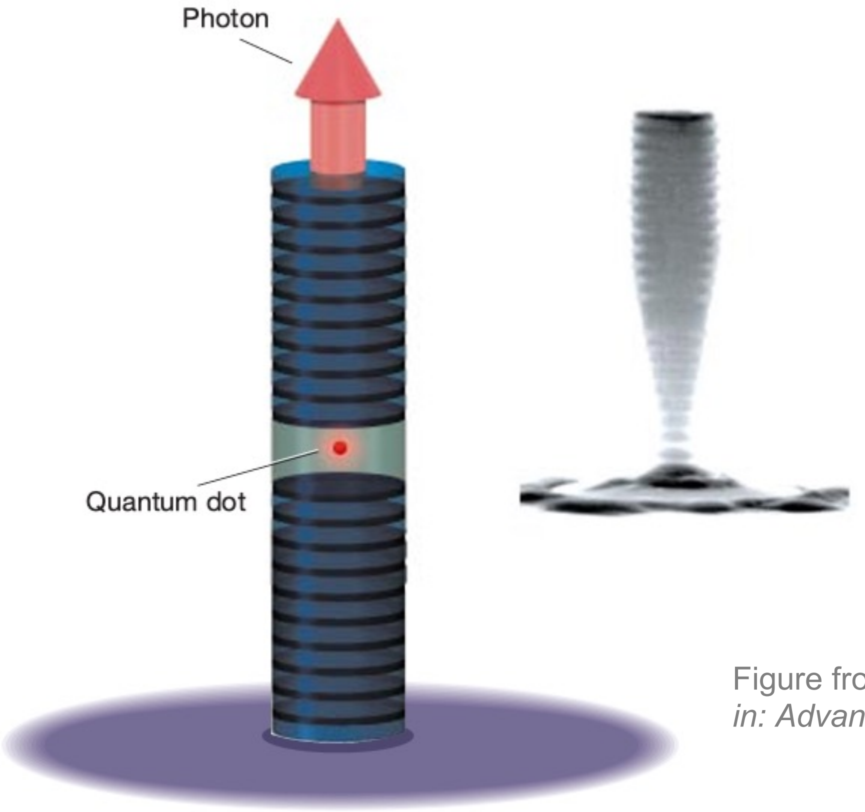

Figure from *K. Vahala (Ed.), Optical Microcavities, in: Advanced Series in Applied Physics, vol. 5, World Scientific, 2004*

Cavity QED in the optical domain

Interaction:

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CAVITY QED

“Standard approach”: with ***optical photons***

→ Advanced approaches to build microcavities

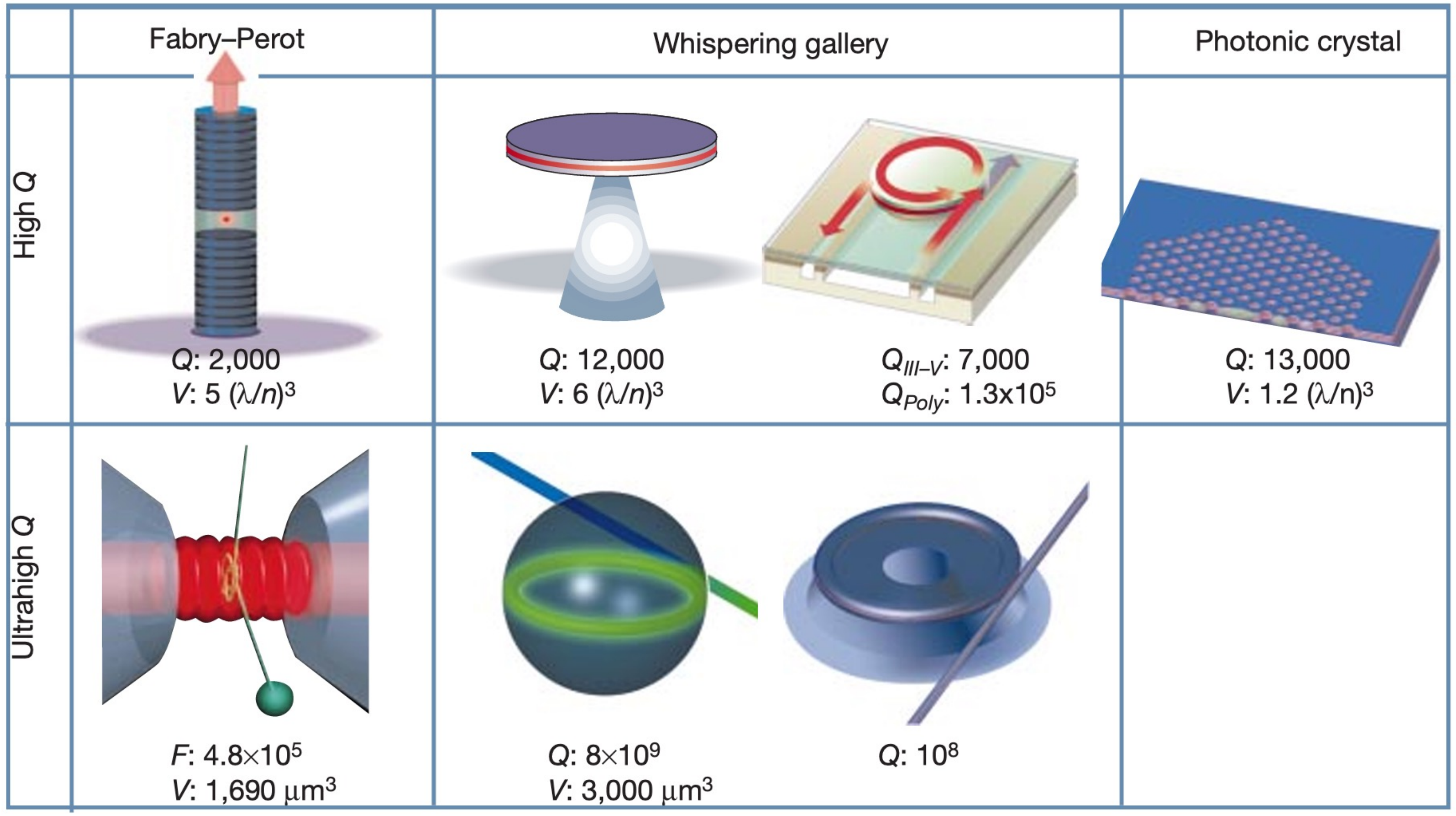

Figure from *K. Vahala (Ed.), Optical Microcavities,*
in: Advanced Series in Applied Physics, vol. 5, World Scientific, 2004

Recent developments of superconducting quantum circuits

1962: Brian D. Josephson predicts that a non-dissipative current can flow between two superconducting electrodes separated by non-superconducting barriers
→ **Josephson effect**

1980s: Experimental development of **superconducting quantum circuits**
→ test if ***macroscopic systems*** can behave ***quantum mechanically***

2000-now: Recent experimental development boosted by **quantum information processing**

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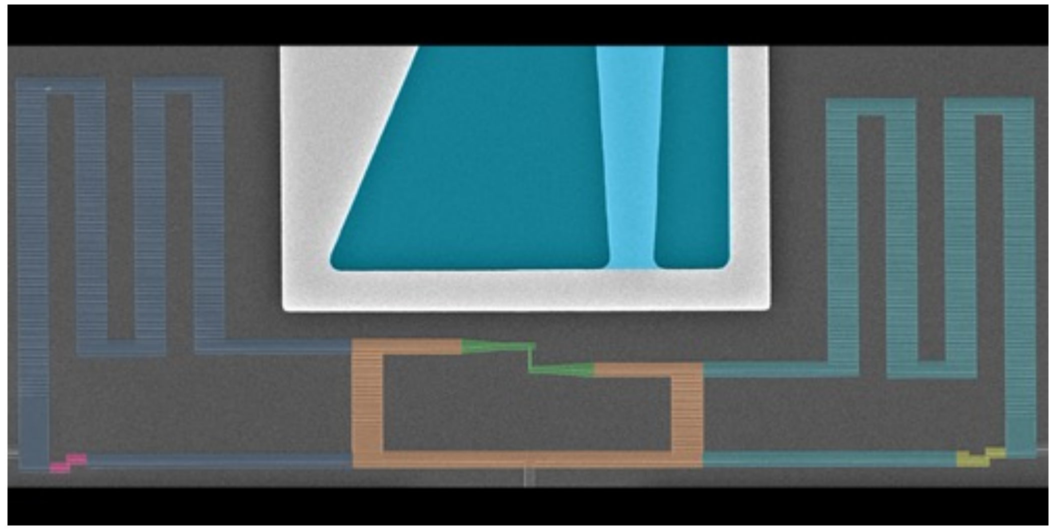
2000-now: Recent experimental development boosted by **quantum information processing**

Technological progresses

- **Design & architectures** →

- circuit design
- couplings
- systems architectures
- …



Two-qubit gate by inductive coupling of two fluxonium qubits

H. Zhang *et al.*, PRX Quantum 5, 020326, 2024

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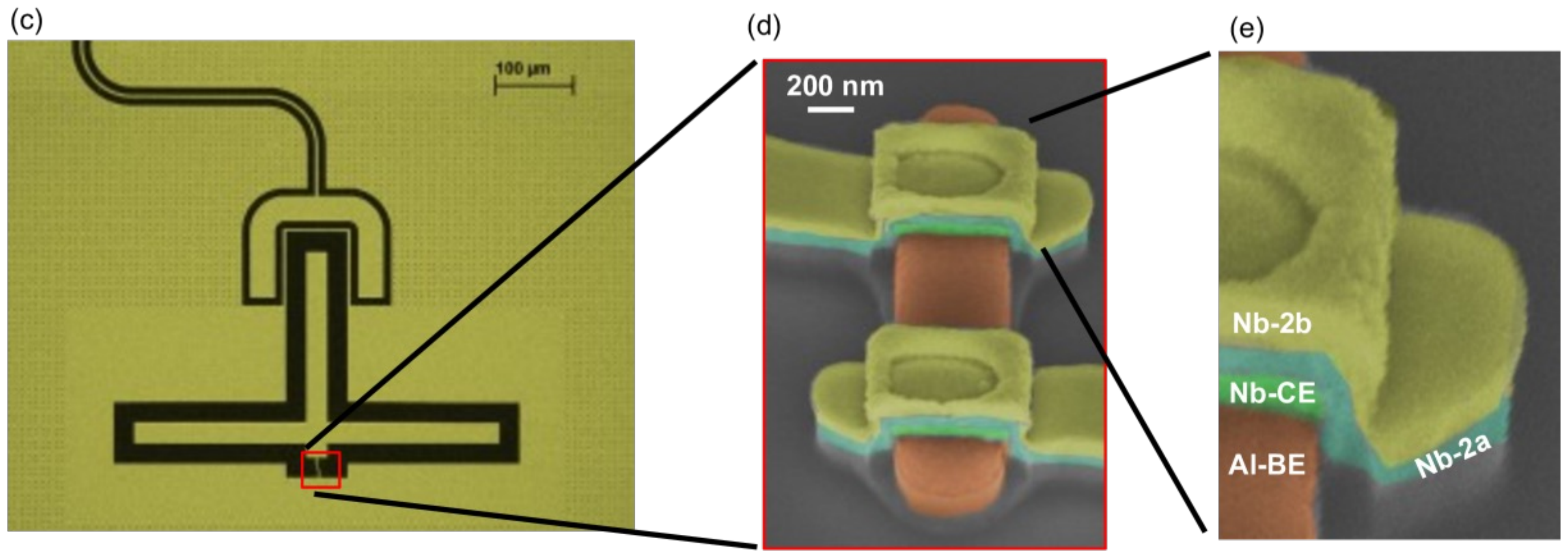
2000-now: Recent experimental development boosted by **quantum information processing**

Technological progresses

- Design & architectures
- **Microfabrication techniques** →

- materials (superconductors & dielectrics)
- layouts
- …



Josephson junctions with native aluminium oxide as a sidewall passivation layer

P. Sethi et al., arXiv:2504.03481, 2025

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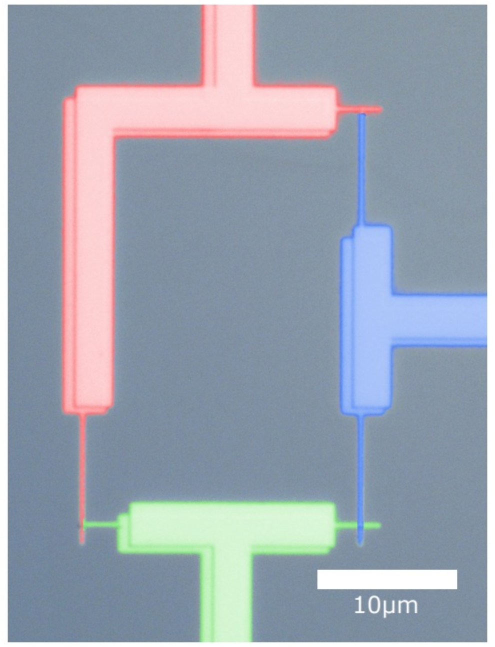
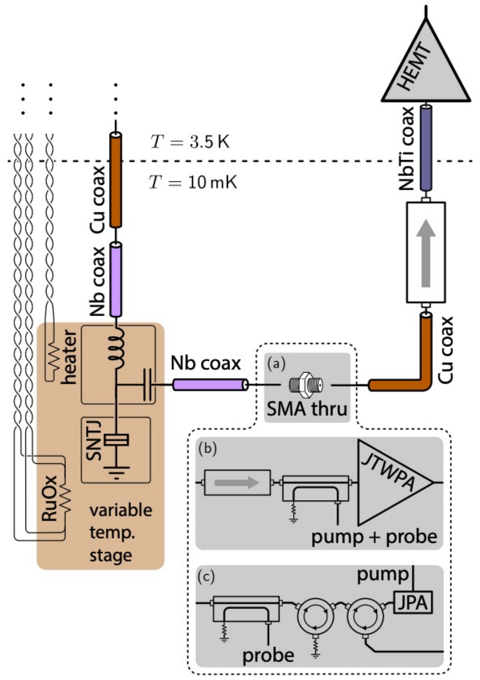
Technological progresses

- Design & architectures
- Microfabrication techniques
- **Cryogenic set-ups** →

- Standardisation
- Metrology protocols (calibration, noise sources, …)
- On-chip components
- …





R. Navaratna, et al. *Passive Superconducting Circulator on a Chip,* Phys. Rev. Lett. 130, 2023

M. Malnou, et al, *Low-noise cryogenic microwave amplifier characterization with a calibrated noise source.* Rev. Sci. Instrum, 95 (3), 2024

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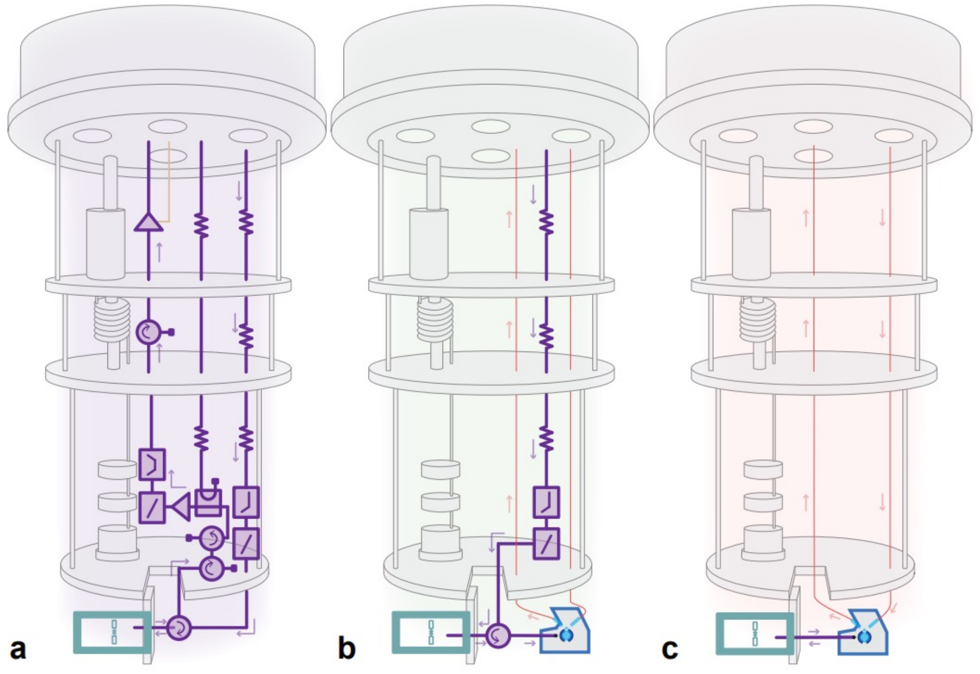
Technological progresses

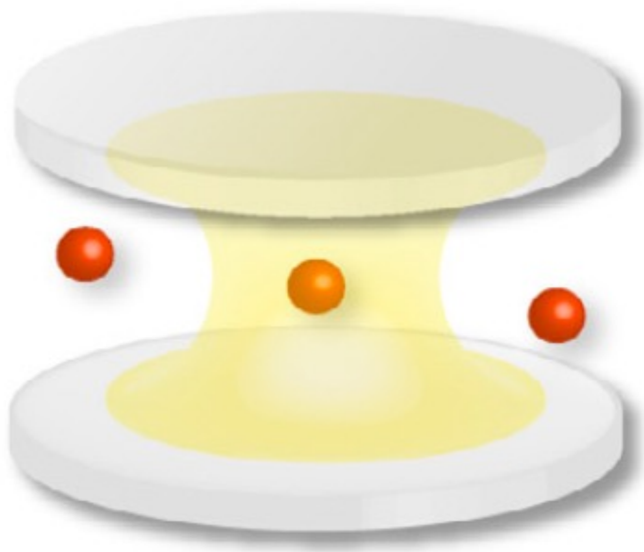
- Design & architectures
- Microfabrication techniques
- Cryogenic set-ups
- **Control & read-out** →

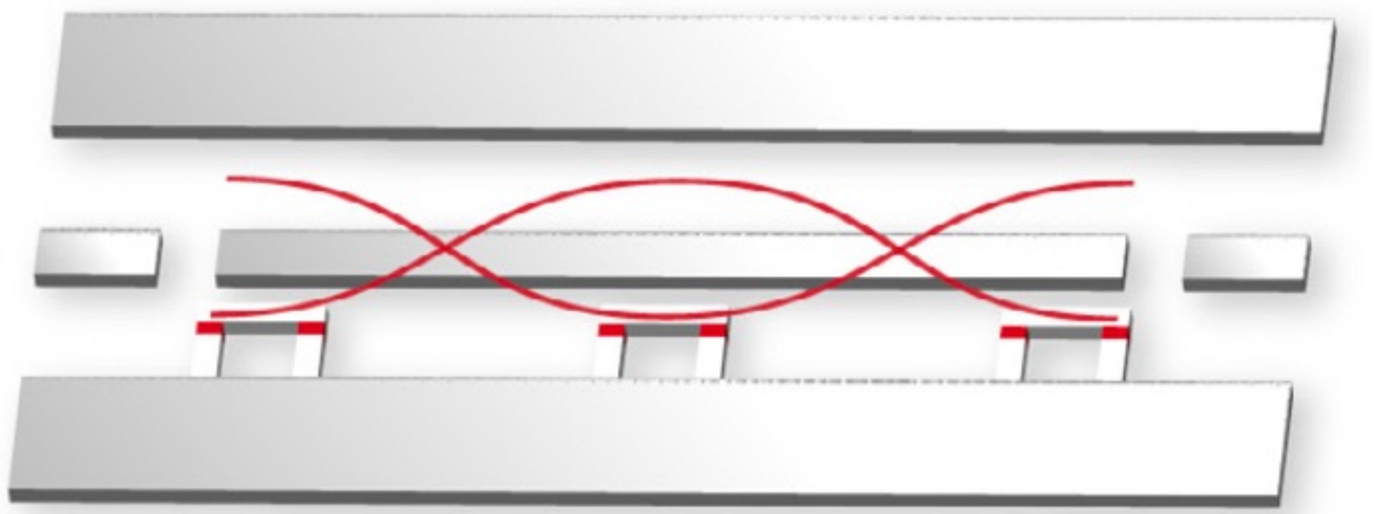
- FPGA-based systems towards fully digital control
- Quantum-limited amplifiers
- Hybrid optical-microwave systems
- …



Arnold, G., Werner, T., Sahu, R. *et al.* All-optical superconducting qubit readout. *Nat. Phys.* 21, 393–400, 2025

Circuit QED in the microwave domain





Figures from; *X. Gu, A.F. Kockum et al. Microwave photonics with superconducting quantum circuits, Physics Reports 718-719, 1-102, 2017*

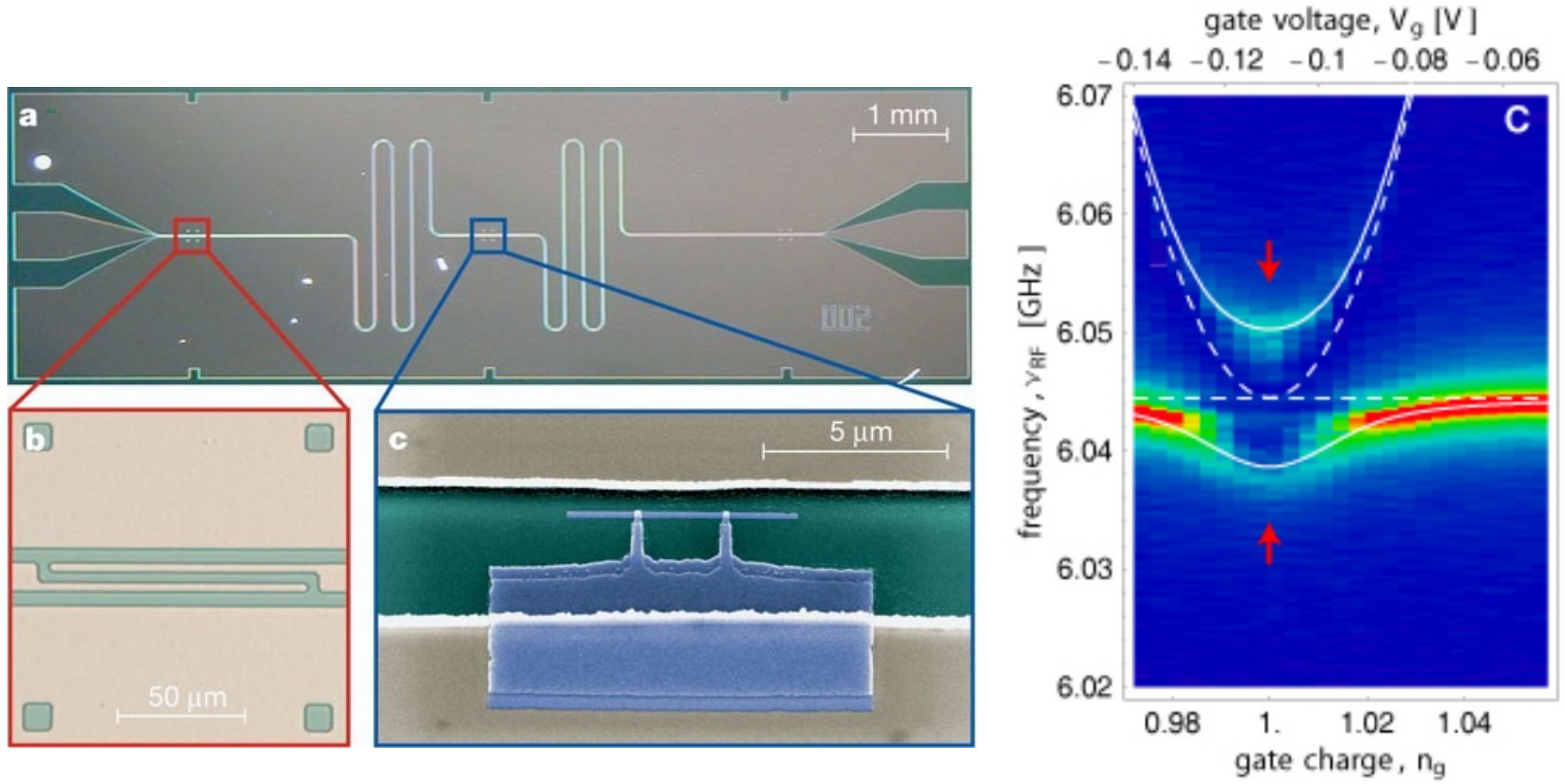
Optical (THz) ⟵	**ENERGY RANGE**	⟶ Microwave (GHz)
Neutral atoms / ions / quantum dots ⟵	**MATTER**	⟶ Superconducting qubit (artifical atom)
Fabry–Pérot cavity / fiber cavity ⟵	**ELECTROMAGNETIC FIELD**	⟶ Superconducting resonator (2D/3D)
Magnetic / electrical dipole ⟵	**COUPLING**	⟶ Inductor / capacitor

Circuit QED in the microwave domain

Many phenomena well-known in quantum optics have been demonstrated in the microwave domain using superconducting devices, e.g.:

- ☑ **Strong coupling** transmon – resonator ➔ vacuum Rabi splitting + Rabi oscillations
- ☑ **Jaynes–Cummings ladder** ➔ spectroscopy of dressed states
- ☑ **Squeezing** - with parametric amplifiers
- ☑ **Entanglement** and quantum state transfer
- ☑ **Photon Blockade**
- ☑ **Schrödinger cat states** ➔ bosonic codes

Wallraff *et al.*, *Nature* 2004
Fink *et al.*, *Nature* 2008
Eichler *et al.*, *Phys. Rev. Lett.* 2011
Esposito *Phys. Rev. Lett.* 2022
Kurpiers *et al.*, *Nature* 2018
Lang *et al.*, *Phys. Rev. Lett.* 2011
Ofek *et al.*, *Nature* 2016

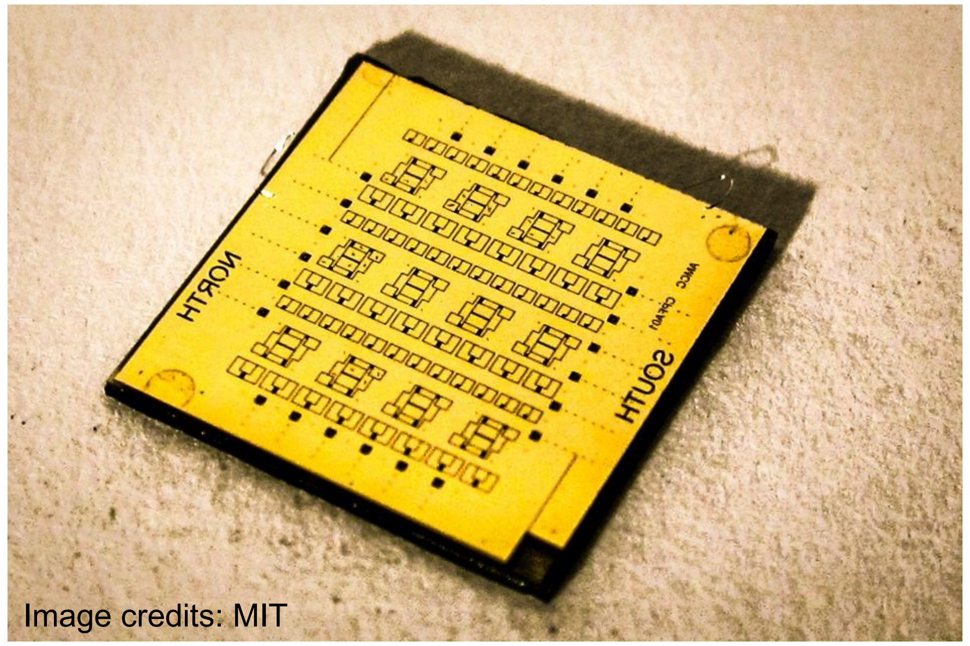


Wallraff, A., Schuster, D., Blais, A. *et al.* *Strong coupling of a single photon to a superconducting qubit using circuit quantum electrodynamics*. Nature 431, 162–167, 2004

Circuit QED in the microwave domain

Main advantages of superconducting artificial atoms:

- High control and tunable design
- Artificial engineering of interaction with electromagnetic fields



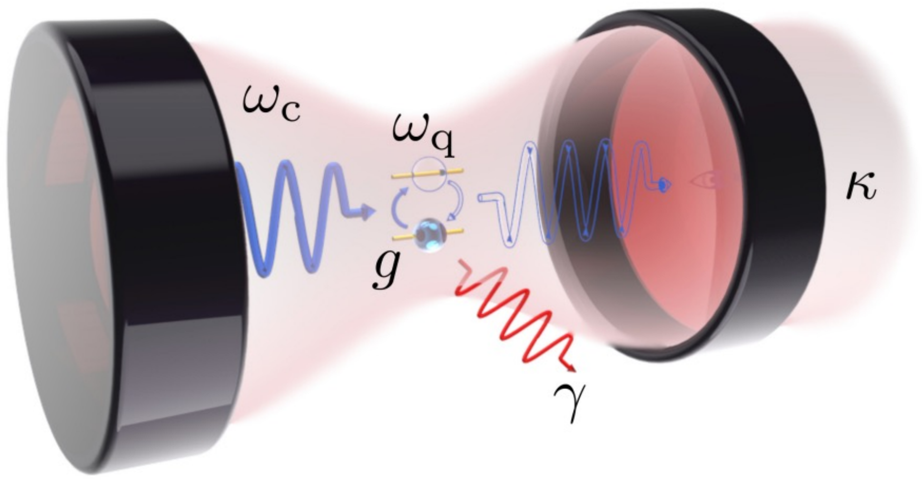
Access to new parameter ranges

Possibility of **demonstrate phenomena that cannot be observed in atomic / quantum optics**

e.g. ***ultrastrong coupling***

=

coupling strength comparable to transition frequencies



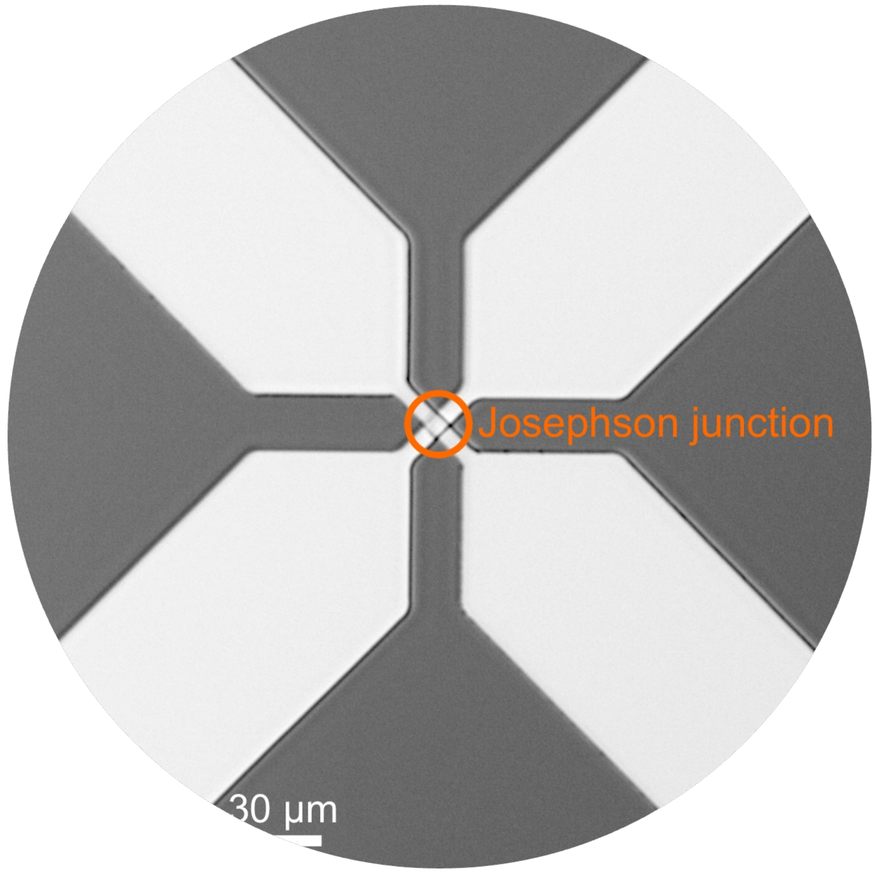
Ultrastrong coupling:
$g/\omega_c \gtrsim 0.1$

Frisk Kockum, A., Miranowicz, A., De Liberato, S. et al.
Ultrastrong coupling between light and matter, Nat Rev Phys 1, 19–40, 2019

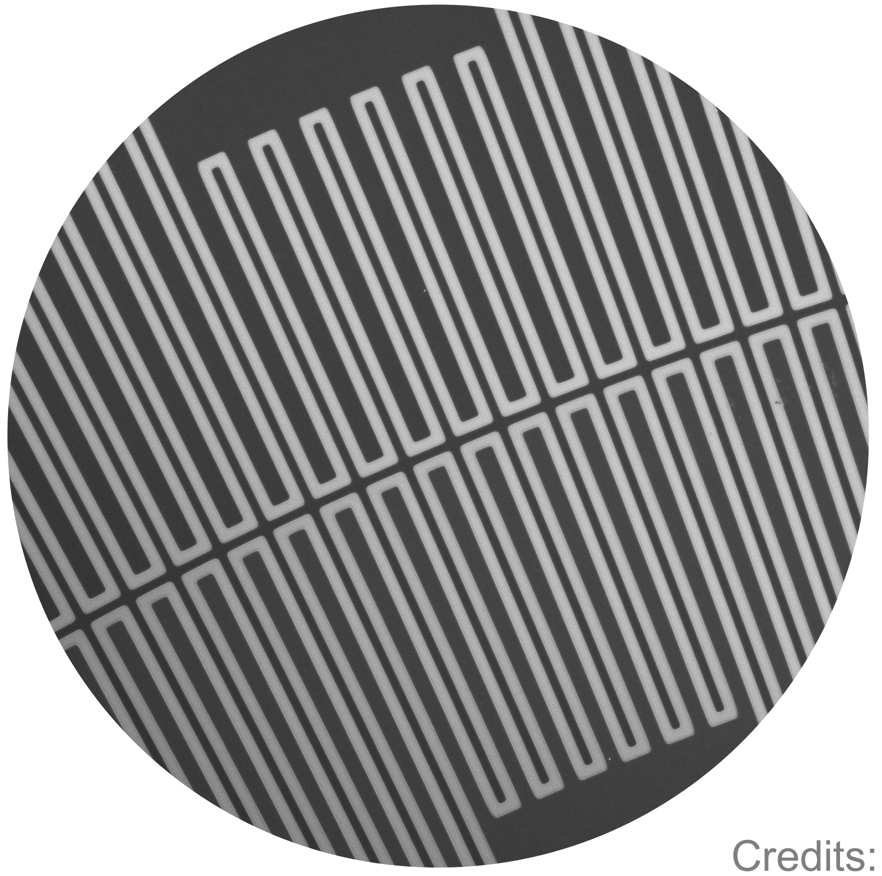
Circuit building blocks

Superconducting building blocks:

Josephson junctions



High-kinetic inductance circuits



Credits: FBK

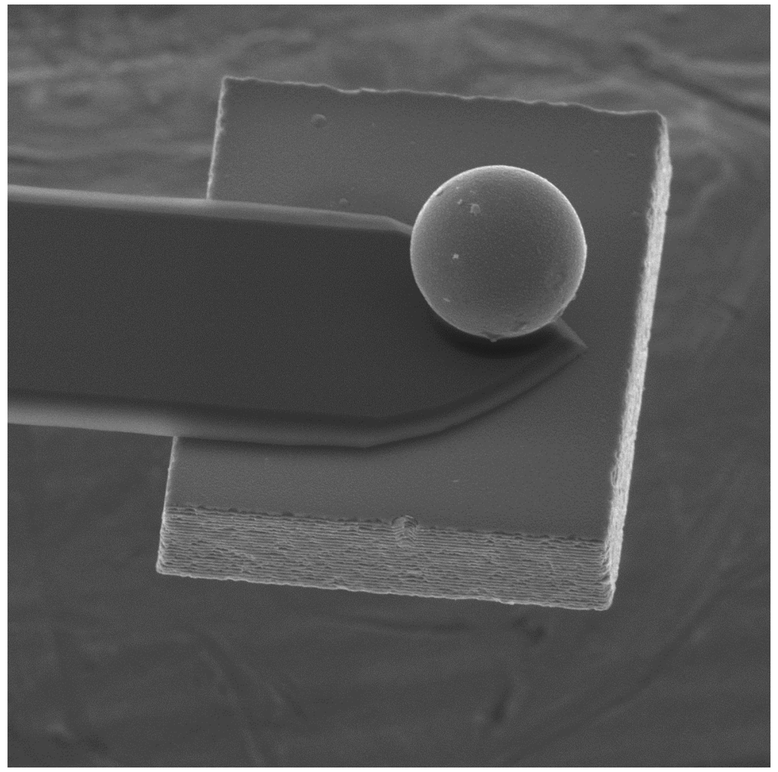
<u>Additionally:</u>

- High-*Q* microwave resonators
- Lumped and parallel plate capacitors
- …

Other approaches:

Hybrid systems

- superconductor + semiconductor (e.g. quantum dots)
- superconductor + magnetomechanical elements (e.g. cantilever, levitating particles, …)



Credits: A. Vinante

Key challenges today

Issues: → Solutions:

Limited systems
(size & architectures)

Scaling up

Advanced coupled multi-qubit architectures,
quantum fields in advanced waveguides, …

➔ to investigate:

- complex quantum manipulation
- generation of quantum states (e.g. squeezing)
- quantum information processing
- generation of quantum fluids of light
- ….

Key challenges today

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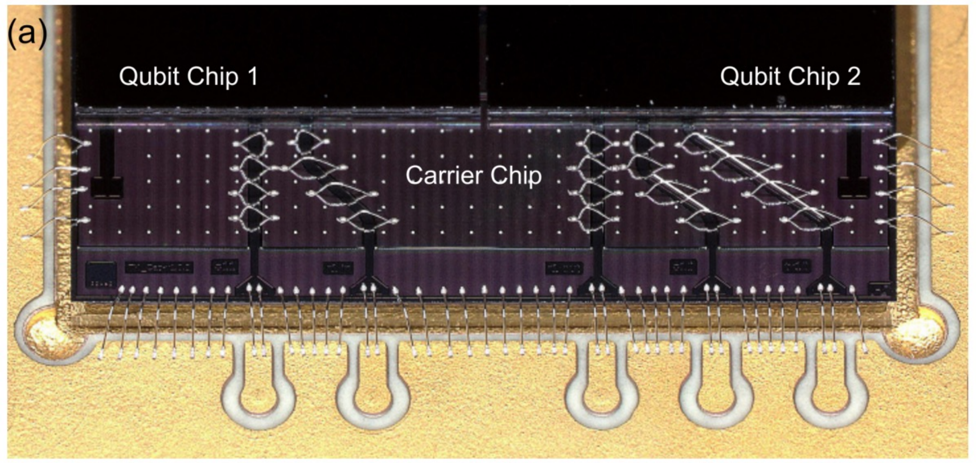
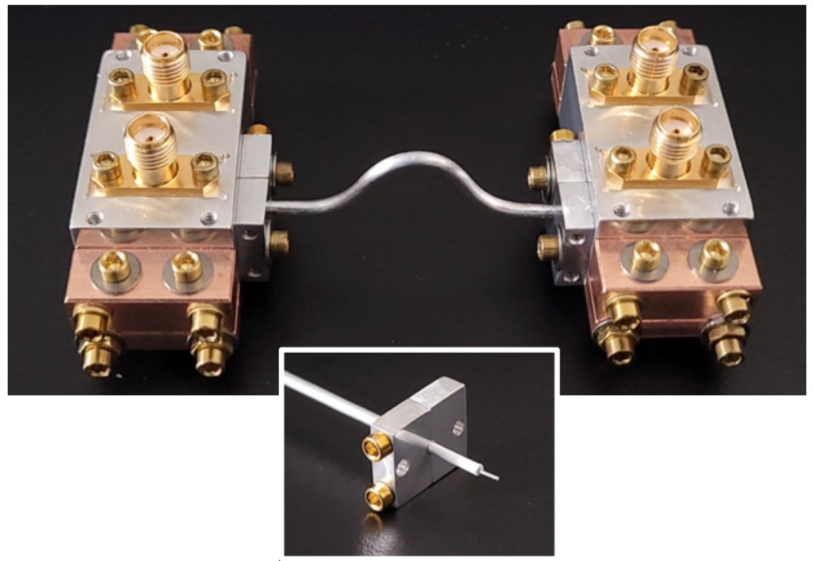
"Lego-approach"
➔ modular networks

M. Field, A. Q. Chen *et al.* Modular superconducting-qubit architecture with a multichip tunable coupler, *Phys. Rev. Applied* 21, 054063, 2024





Mollenhauer, M., Irfan, A., Cao, X. *et al.* A high-efficiency elementary networ k of interchangeable superconducting qubit devices. *Nat Electron* 8, 610–619, 2025

Key challenges today

Issues: → Solutions:

Limited systems
(size & architectures)

Decoherence

Scaling up

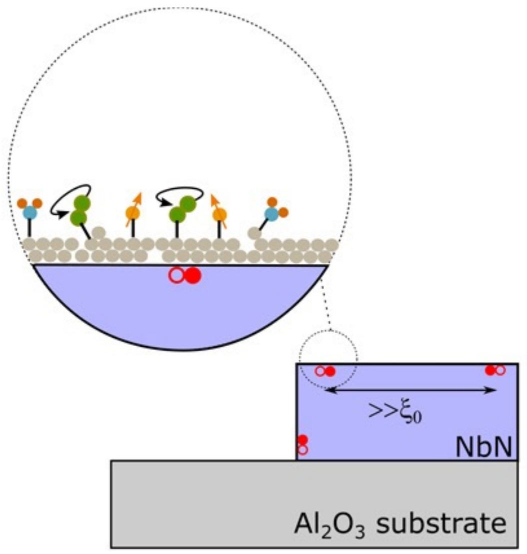
Reduce losses & environmental interference

Advanced coupled multi-qubit architectures, quantum fields in advanced waveguides, …

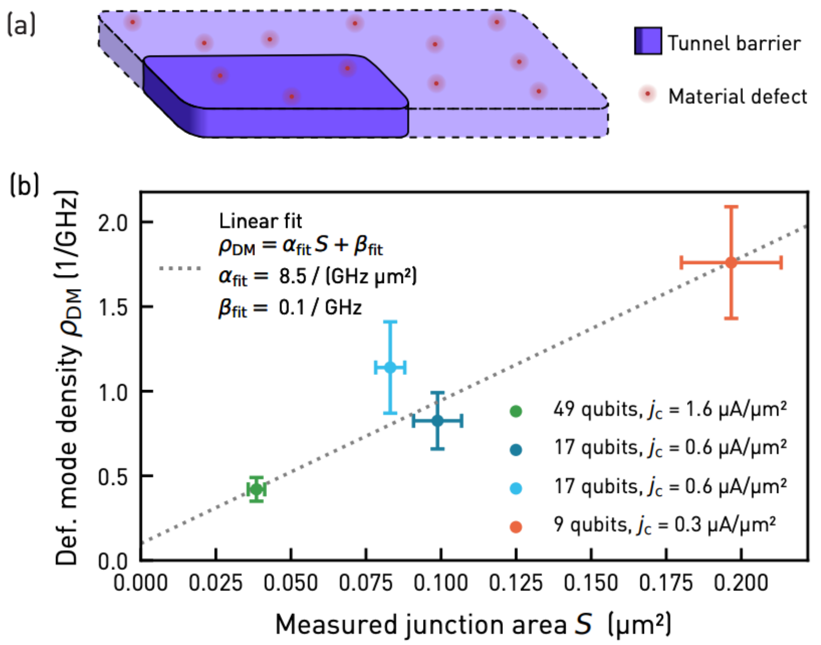
➔ to investigate:

- complex quantum manipulation
- generation of quantum states (e.g. squeezing)
- quantum information processing
- generation of quantum fluids of light
- ….

- **Theoretical models**
- **Experimental efforts**



S.E. de Graaf et al., *Two-level systems in superconducting quantum devices due to trapped quasiparticles*. Sci. Adv.6, 2020



D. Colao Zanuz, Q. Ficheux et al., *Mitigating losses of superconducting qubits strongly coupled to defect modes*, Phys. Rev. Applied 23, 044054, 2025

Ingredients for microwave quantum optics

Know-how and expertise from **different fields**

EXPERIMENTAL FIELDS

- Cryogenics & Low temperature physics
- RF engineering
- Circuit design
- Microfabrication

THEORETICAL FIELDS

- Quantum optics
- Superconductivity
- Open quantum systems
- Many-body physics
- Quantum information

APPLICATION FIELDS

Quantum computing
Quantum communication & cryptography
Quantum sensing
Quantum simulations, e.g. for nuclear physics
Detectors for particle physics
…

→ Different communities coming together!

Spirit of this workshop

Bringing together **experimental** and **theoretical** communities

Explore the **links** between **fundamental physics** (quantum optics)
and **applications**, mainly for quantum simulations and quantum sensing

Address the **recent developments** and discuss **new ideas**

Foster exchange with the **new generations** of scientists

Invited talks

Speaker	Title	Session
Miles Blencowe	*Quantum Solitons in SNAIL TWPAs*	Mon 6 Oct 9:00
Sorin Paraoanu	*Two-photon Landau-Zener effect*	Mon 6 Oct 14:00
Quentin Ficheux	*Building a parity-protected superconducting qubit*	Mon 6 Oct 15:50
Simone Gasparinetti	*Real-time detection of correlated quasiparticle tunneling events in a multi-qubit superconducting device*	Tue 7 Oct at 9:00
Cristiano Ciuti	*Recent theoretical advances on multi-mode circuit QED*	Tue 7 Oct 10:50
Mikko Möttönen	*Microwave quantum optics using a millikelvin bolometer*	Tue 7 Oct 14:00
Denis Basko	*Photonic bath overheating in superconducting circuits*	Wed 8 Oct 9:00
Alexis Coissard	*Fabrication of negative index Josephson metamaterials*	Wed 8 Oct 10:50
Emanuele Enrico	*Programmable Microwave Cluster States via Josephson Metamaterials*	Wed 8 Oct 14:00
Gianluigi Catelani	*Improved modeling of superconducting devices*	Wed 8 Oct 15:50
Gerhard Kirchmair	*Hot Schrödinger cat states*	Thu 9 Oct 9:00
Pasquale Scarlino	*Harnessing high kinetic inductance for multimode quantum electrodynamics and microwave photodetection*	Thu 9 Oct 10:50

Agenda and practical information

Mon 6 Oct		Tue 7 Oct		Wed 8 Oct		Thu 9 Oct	
Welcomes	9:00-9:20	**Simone Gasparinetti** *Real-time detection of correlated quasiparticle tunneling events in a multi-qubit superconducting device*	9:00-9:50	**Denis Basko**, *Photonic bath overheating in superconducting circuits*	9:00-9:50	**Gerhard Kirchmair**, *Hot Schrödinger cat states*	9:00-9:50
Introductory talk by organisers	9:20-10:00	**Benjamin Remez**, *Optical Spectroscopy of Andreev Bound States*	9:50-10:20	**Alexander Poddubny**, *Subradiant Correlations in Driven-Dissipative Waveguide QED*	9:50-10:20	**Marco Paradina**, *Cat qubit stabilization with a DC-biased Josephson junction*	9:50-10:20
Miles Blencowe, *Quantum Solitons in SNAIL TWPAs*	10:00-10:50	Break	10:20-10:50	Break	10:20-10:50	Break	10:20-10:50
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Tanjung Krisnanda, *Advancing control and measurements in bosonic circuit quantum electrodynamics*	11:20-11:50	**Alexander Schnell**, *Quantum simulation for open systems: State engineering and theory challenges*	11:40-12:10	**Giulio Cappelli**, *A negative index Josephson metamaterial: wave-mixing and beyond*	11:40-12:10	**Alexandre Le Boité,** *Non-linearity driven topology via spontaneous symmetry breaking*	11:40-12:10
Jeffrey Yao *Non-equilibrium phase transition in interacting 1D spin lattice*	11:50-12:20	Lunch	12:10-13:10	Lunch	12:10-13:10	Lunch	12:10-13:30
Lunch	12:20-13:20	Coffee and free discussions	13:10-14:00	Coffee and free discussions + **optional visit to the labs**	13:10-14:00	Coffee and free discussions	13:30-14:00
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Jérôme Esteve, *Tunneling in a high impedance environment: simulating the boundary Sine-Gordon model*	14:50-15:20	Break	15:20-15:50	Break	15:20-15:50	Break	15:00-15:30
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Shelender Kumar, *Plasma modes in fluxonium qubit*	16:40-17:10	Short break	16:50-17:10	**Kilian Seibold,** *Manifestations of flow topology in quantum driven-dissipative systems*	17:10-17:40	**Andrea Vinante** *Ultrafast Meissner-levitated microrotor*	16:30-17:00
Valentina Brosco, *Quantum devices based on Twisted Cuprate Heterostructures*	17:10-17:30	**Enrico Bogoni** *Front-induced frequency shifting of mIcrowave pulses*	17:10-17:40	Poster session and aperitif	17:40-19:30	Conclusion and open discussion	17:00-18:00
Poster session and aperitif	17:30-19:30	Social dinner	20:00				

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POSTER SESSIONS & APERITIF

Today
starting at 17:30

Wednesday
starting at 17:40

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OPTIONAL VISIT TO THE LABS
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Introductory talk by [illegible]	9:20-10:00	**Benjamin Remez**, *Optical Spectroscopy of Andreev Bound States*	9:50-10:20	**Alexander Poddubny**, *Subradiant Correlations in Driven-Dissipative Waveguide QED*	9:50-10:20	**Marco Paradina**, *Cat qubit stabilization with a DC-biased Josephson junction*	9:50-10:20
Miles Blencowe, *Quantum Solitons in [illegible] TWPAs*	10:00-10:50	Break	10:20-10:50	Break	10:20-10:50	Break	10:20-10:50
Break	10:50-11:20	**Cristiano Ciuti**, *Recent theoretical advances on multi-mode circuit QED*	10:50-11:40	**Alexis Coissard** *Fabrication of negative index Josephson metamaterials*	10:50-11:40	**Pasquale Scarlino** *Harnessing High Kinetic Inductance for Multimode Quantum Electrodynamics and Microwave Photodetection*	10:50-11:40
Tanjung Krisnanda, *Advancing control and measurements in bosonic circuit quantum electrodynamics*	11:20-11:50	**Alexander Schnell**, *Quantum simulation for open systems: State engineering and theory challenges*	11:40-12:10	**Giulio Cappelli**, *A negative index Josephson metamaterial: wave-mixing and beyond*	11:40-12:10	**Alexandre Le Boité**, *Non-linearity driven topology via spontaneous symmetry breaking*	11:40-12:10
Jeffrey Yao *Non-equilibrium phase transition in interacting 1D spin lattice*	11:50-12:20	Lunch	12:10-13:10	Lunch	12:10-13:10	Lunch	12:10-13:30
Lunch	12:20-13:20	Coffee and free discussions	13:10-14:00	Coffee and free discussions + **optional visit to the labs**	13:10-14:00	Coffee and free discussions	13:30-14:00
Coffee and free discussions	13:20-14:00	**Mikko Möttönen**, *Microwave quantum optics using a millikelvin bolometer*	14:00-14:50	**Emanuele Enrico**, *Programmable Microwave Cluster States via Josephson Metamaterials*	14:00-14:50	**Asian Selvakumaran**, *Towards an all-optical single photon detector*	14:00-14:30
Sorin Paraoanu, *Two-photon Landau-Zener effect*	14:00-14:50	**Gerbold Ménard**, *Time-resolved sensing of electromagnetic fields with single electron interferometry*	14:50-15:20	**Isita Chatterjee** *Three wave mixing squeezing in a SNAIL Traveling Wave Parametric Amplifier with alternating flux polarity*	14:50-15:20	**Ognjen Stanisavljević** *Neural-network-based design and implementation of fast and robust quantum gates*	14:30-15:00
Jérôme Esteve, *Tunneling in a high impedance environment: simulating the boundary Sine-Gordon model*	14:50-15:20	Break	15:20-15:50	Break	15:20-15:50	Break	15:00-15:30
Break	15:20-15:50	**Alberto Tabarelli de Fatis**, *Adiabatic generation of a Tonks-Girardeau gas of photons in superconducting waveguides*	15:50-16:20	**Gianluigi Catelani** *Improved modeling of superconducting devices*	15:50-16:40	**Joan Agusti**, *Non-Markovian thermal reservoirs for autonomous entanglement distribution*	15:30-16:00
Quentin Ficheux *Building a parity-protected superconducting qubit*	15:50-16:40	**Tomas Levy-Yeyati**, *Two photon control quantum gates in circuit QED*	16:20-16:50	**Luca Giacomelli**, *Exact Duality at Low Energy in a Josephson Tunnel Junction Coupled to a Transmission Line*	16:40-17:10	**Gianluca Rastelli**, *Circuit Quantum Electrodynamics with Semiconductor Quantum Dots*	16:00-16:30
Shelender Kumar, *Plasma modes in fluxonium qubit*	16:40-17:10	Short break	16:50-17:10	**Kilian Seibold**, *Manifestations of flow topology in quantum driven-dissipative systems*	17:10-17:40	**Andrea Vinante** *Ultrafast Meissner-levitated microrotor*	16:30-17:00
Valentina Brosco, *Quantum devices based on Twisted Cuprate Heterostructures*	17:10-17:30	**Enrico Bogoni** *Front-induced frequency shifting of mIcrowave pulses*	17:10-17:40	Poster session and aperitif	17:40-19:30	Conclusion and open discussion	17:00-18:00
Poster session and aperitif	17:30-19:30	Social dinner	20:00				

Agenda and practical information

SOCIAL DINNER
<u>Tue at 20:00</u>
Restaurant *Il Simposio*
Via Rosmini 19

Mon 6 Oct	
Welcomes	9:00-9:20
[illegible]	9:20-10:00
[illegible]	10:00-10:50
[illegible]	[illegible]
[illegible] *bosonic circuit quantum electrodynamics*	11:20-11:50
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Tue 7 Oct	
Simone Gasparinetti *Real-time detection of correlated quasiparticle tunneling events in a multi-qubit superconducting device*	9:00-9:50
Benjamin Remez, *Optical Spectroscopy of Andreev Bound States*	9:50-10:20
Break	10:20-10:50
Cristiano Ciuti, *Recent theoretical advances on multi-mode circuit QED*	10:50-11:40
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Enrico Bogoni *Front-induced frequency shifting of mIcrowave pulses*	17:10-17:40
Social dinner	20:00

Wed 8 Oct	
Denis Basko, *Photonic bath overheating in superconducting circuits*	9:00-9:50
Alexander Poddubny, *Subradiant Correlations in Driven-Dissipative Waveguide QED*	9:50-10:20
Break	10:20-10:50
Alexis Coissard *Fabrication of negative index Josephson metamaterials*	10:50-11:40
Giulio Cappelli, *A negative index Josephson metamaterial: wave-mixing and beyond*	11:40-12:10
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Thu 9 Oct	
Gerhard Kirchmair, *Hot Schrödinger cat states*	9:00-9:50
Marco Paradina, *Cat qubit stabilization with a DC-biased Josephson junction*	9:50-10:20
Break	10:20-10:50
Pasquale Scarlino *Harnessing High Kinetic Inductance for Multimode Quantum Electrodynamics and Microwave Photodetection*	10:50-11:40
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Conclusion and open discussion	17:00-18:00

Enjoy the workshop!

Organising Committee:

Federica Mantegazzini, Iacopo Carusotto, Martina Esposito,
Nicolas Roch, Nicolò Crescini, Felix Ahrens

My contact:
fmantegazzini@fbk.eu

FONDAZIONE BRUNO KESSLER

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EUROPEAN CENTRE
FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS