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Ministero dell'Università e della Ricerca
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
NQSTI National Quantum Science and Technology Institute

Spoke 6 Quantum Integration

Quantum Collective States in Superconducting Qubit Networks – part B (5 qubits)

B. Ruggiero *MC* *E. Esposito* *MC* *C. Bonavolontà* *TD MC*

ISASI

M. Lisitskiy *MC* *V. Di Meo* *TD MC*

SPIN

G. Brida, L. Fasolo, E. Enrico

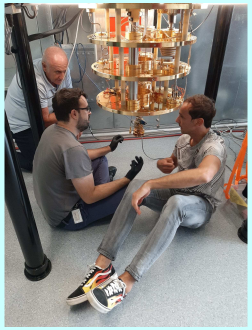
INRiM ISTITUTO NAZIONALE DI RICERCA METROLOGICA

P. Silvestrini

Università degli Studi della Campania Luigi Vanvitelli, Dipartimento di Matematica e Fisica

F. Romeo

Università degli Studi di Salerno, Dipartimento di Fisica E.R. Caianiello



Quantum Integration and Topology - INO, Firenze November 25h,

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PNRR Partenariato Esteso
NATIONAL QUANTUM SCIENCE AND TECHNOLOGY INSTITUTE "NQSTI"

Spoke 6 Quantum Integration - The Role of ISASI

Quantum Collective States in Superconducting Qubit Networks (SQN)

	Scientific Item	MIllestones		MC TI CNR	
6.3.3 Superconducting quantum networks	6.3.3.2 Demonstration of superconducting quantum networks topologies composed of interacting Josephson devices in 2D lattices.	M12-A6.3 M24-A6.3 M36-A6.3	CNR INFN	B. Ruggiero (CNR ISASI, NA) M. Lisitskiy (CNR-SPIN, NA), M. Salluzzo (CNR SPIN, NA), E. Esposito (CNR ISASI, NA), C. Gatti (INFN LNF)	

2023 - 2025

Quantum Integration 400 KEuro (Spoke 6 ISASI -Pozzuoli)

SQN Superconducting Qubit Network

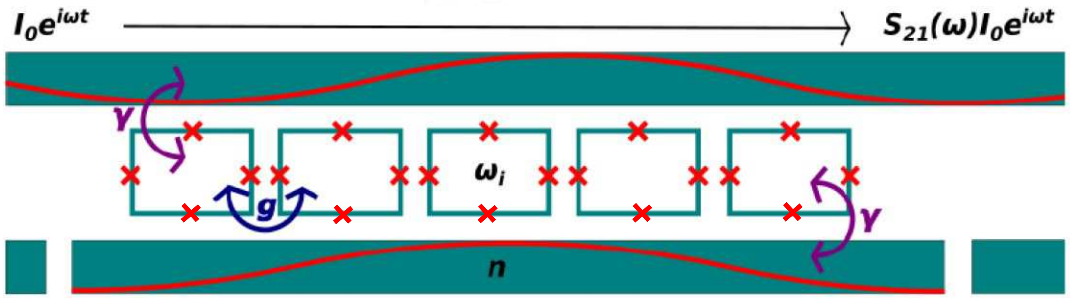
22 2024

ERGALAX

PHYSICAL REVIEW B **105**, 104516 (2022)

Quantum dynamics of disordered arrays of interacting superconducting qubits quantum collective states

M. V. Fistul,[1,2] O. Neyenhuys,[1] A. B. Bocaz,[1] M. Lisitskiy,[3] and I. M. Eremin[1]
[1]Theoretische Physik III, Ruhr-Universität Bochum, Bochum 44801, Germany
[2]National University of Science and Technology MISIS, Moscow 119049, Russia
[3]CNR-SPIN Institute of Superconductors, Innovative Materials and Devices, Pozzuoli, Naples 80078, Italy



$$\hat{H}_{\rm tot} = \hat{H}_{\rm SQA} - \alpha I(t)\sum_i \hat{\sigma}_i^z,$$

$$\hat{H}_{\rm SQA} = \hat{H}_{\rm qb} + \hat{H}_{\rm SR} + \hat{H}_{\rm LR} + \hat{H}_{\rm ph} + \hat{H}_{\rm qb-ph},$$

$$\hat{H}_{\rm qb} = \sum_{i=1}^{N}\left[\frac{\Delta_i}{2}\hat{\sigma}_i^x + \frac{\epsilon_i}{2}\hat{\sigma}_i^z\right.$$

e the coupling strength between qubits and the thransmission line
he current flowing along the transmission line

$\hat{a}^\dagger(\hat{a})$ are the creation (annihilation) photon ope

$$\hat{H}_{\rm SR} = g_{\rm SR}\sum_i \hat{\sigma}_i^z\hat{\sigma}_{i+1}^z,$$

$$\hat{H}_{\rm LR} = g_{\rm LR}\sum \left[\hat{\sigma}_i^x\hat{\sigma}_j^x + \hat{\sigma}_i^y\hat{\sigma}_j^y\right].$$

$$\hat{H}_{\rm ph} = \hbar\omega_0\hat{a}^\dagger\hat{a},$$

$$\hat{H}_{\rm qb-ph} = \gamma\sum_{i=1}^{N}\hat{\sigma}_i^z(\hat{a}^\dagger + \hat{a}),$$

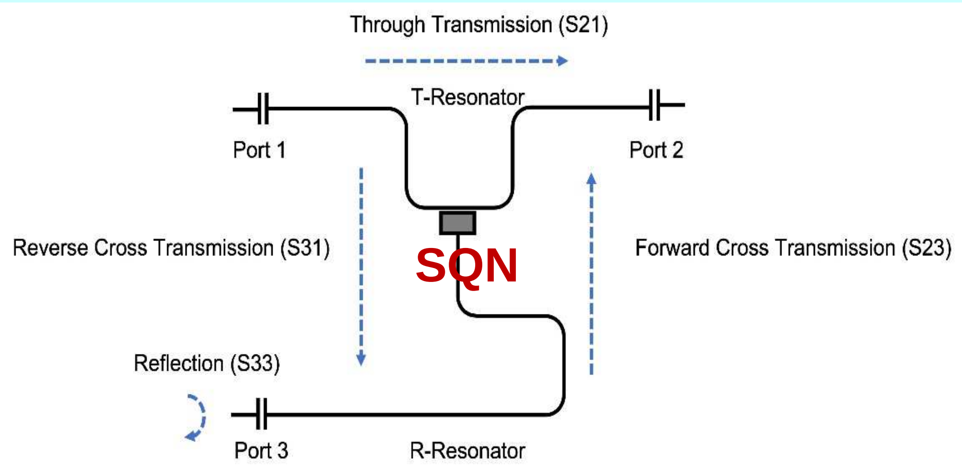
$$\Delta S_{21}(\omega) \simeq C(\omega).$$

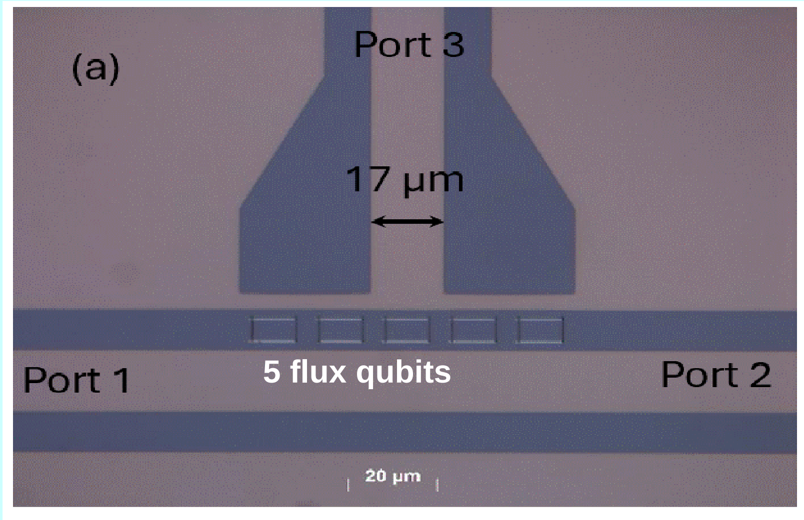
transmission coefficient

dynamic susceptibility,

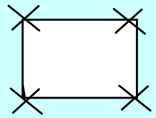
schematic of an SQN with five flux qubits coupled to the low-dissipative cavity and the transmission line is presented.
transmission line is used to establish an experimental setup for the measurements of S21

Superconducting qubit network (SQN) with 5 flux qubits with 4 JJ



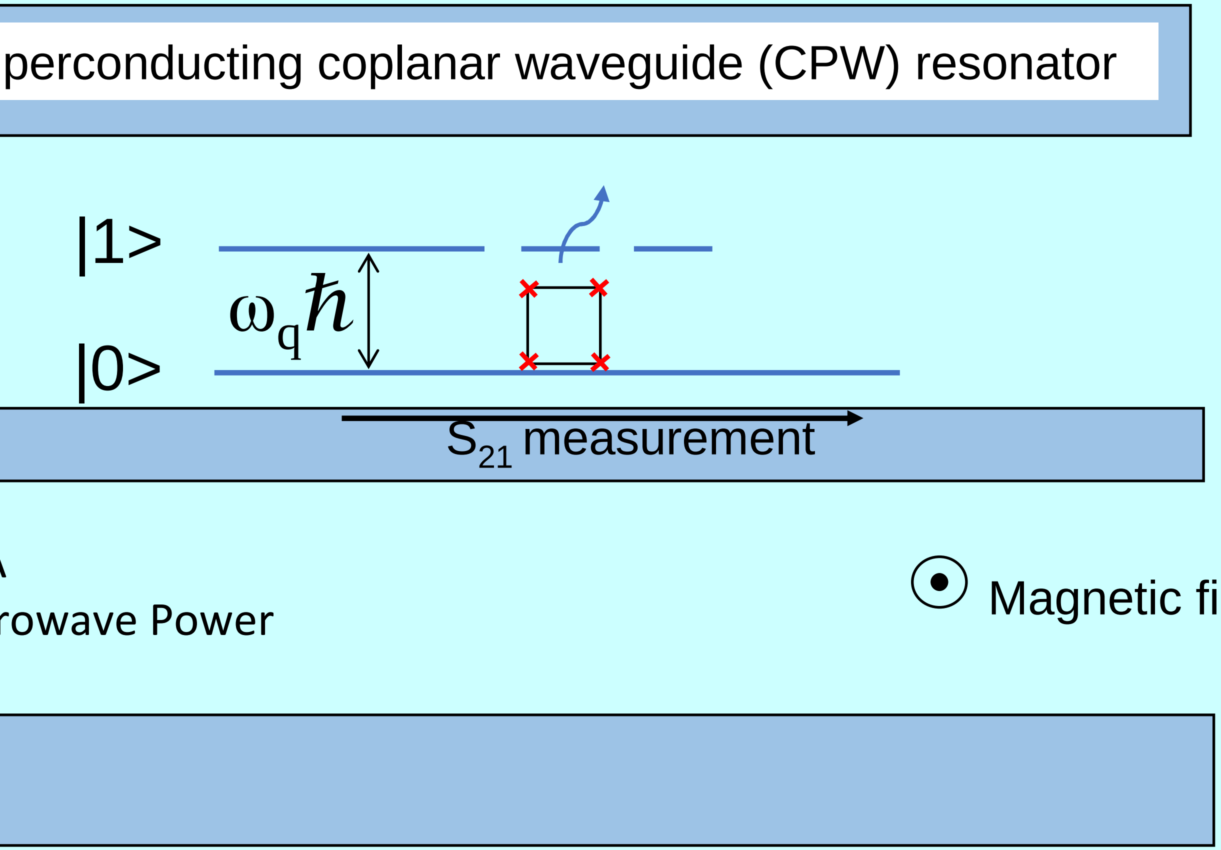


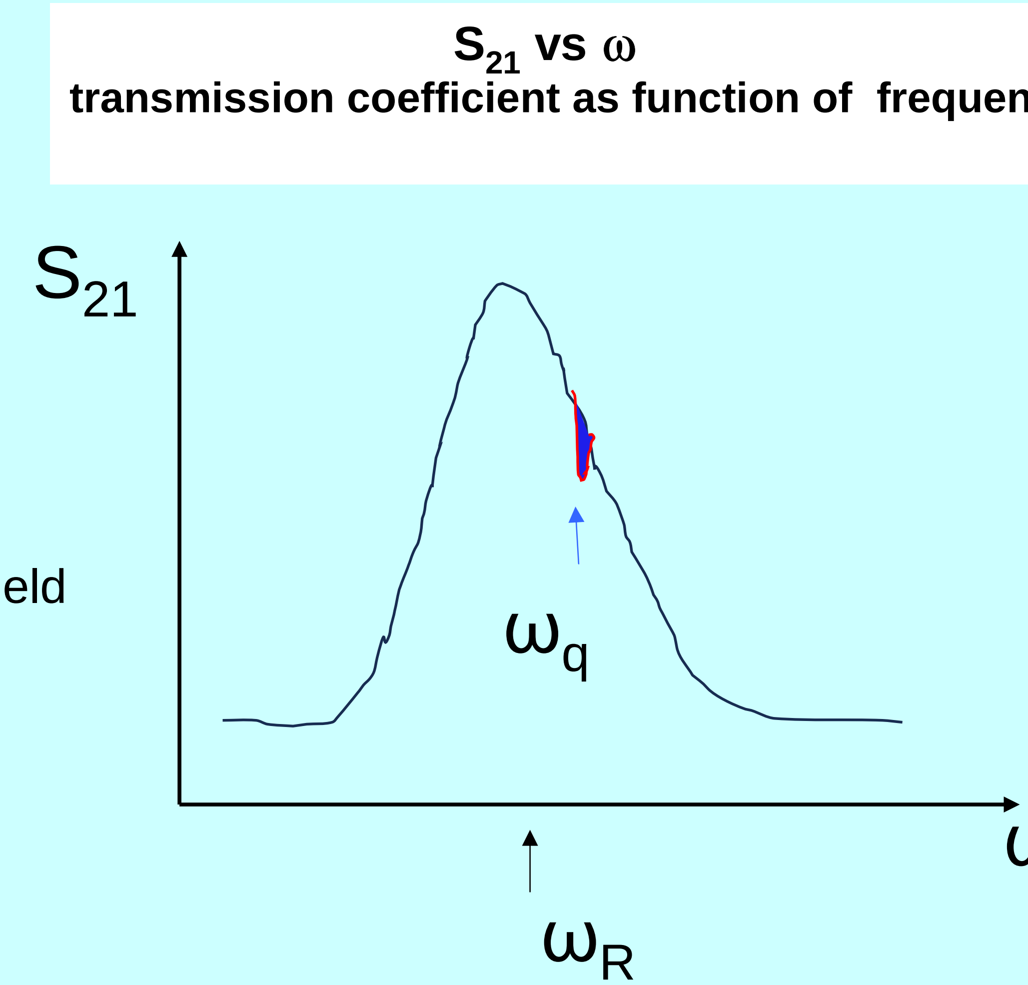
4 JJ flux qubits



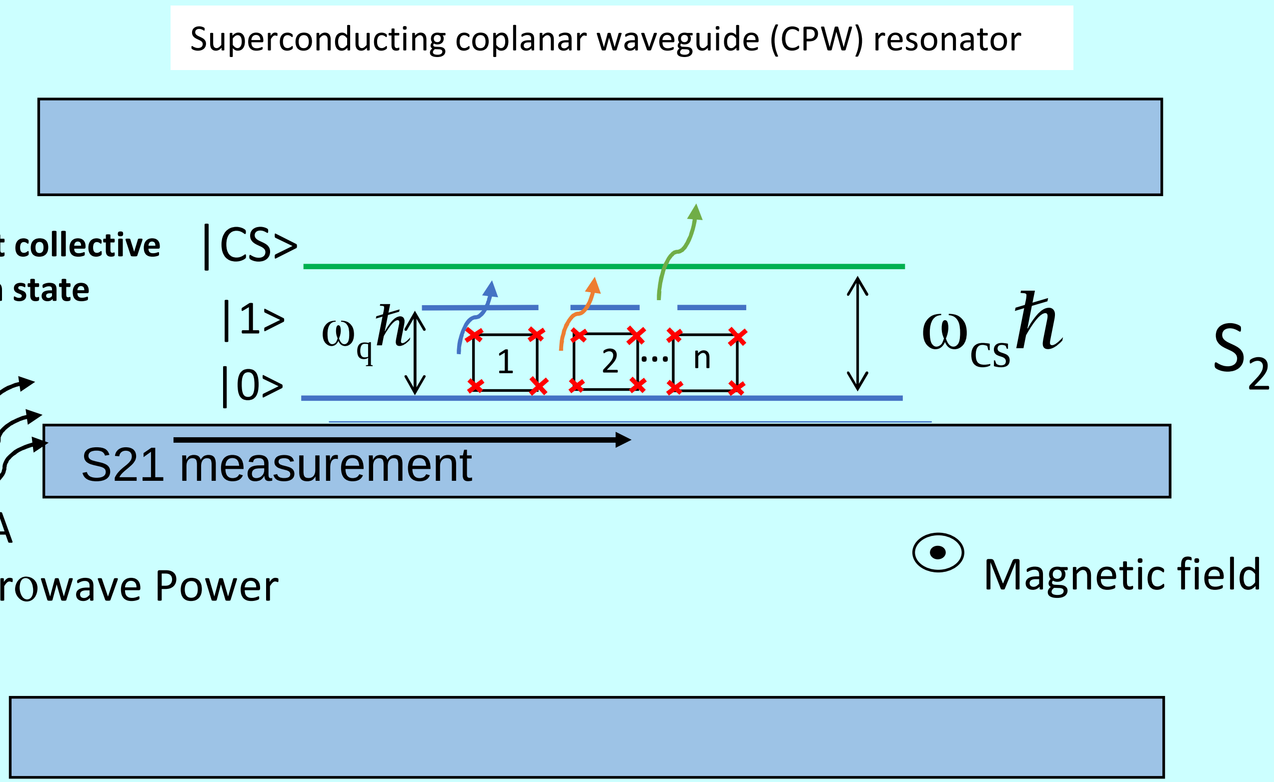
The transmission coefficient S_{21} vs frequency behaviour could present dips (absorption) when photons are exchanged in the resonant cavity.

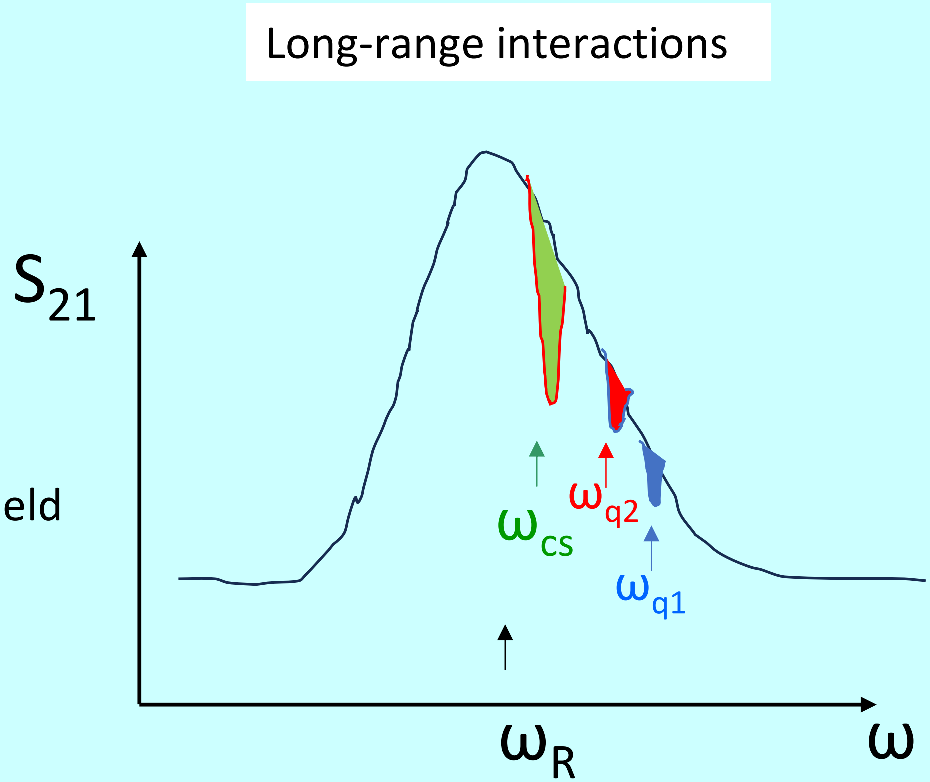
Nonlinear interactions between photons of energy level transitions in qubits and microwave power





Superconducting qubit network (SQN) with 5 flux qubits with 4 JJ





Oscillations on S_{21} indicate the interaction between qubit and resonant circuit.

Main resonant dip…………… is associated with COLLECTIVE QUANTUM STATE in SQN.

NQSTI
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Experiments on two Resonators with SQN with 5 flux qubits

T = 20

Brida and E. Enrico

23/24

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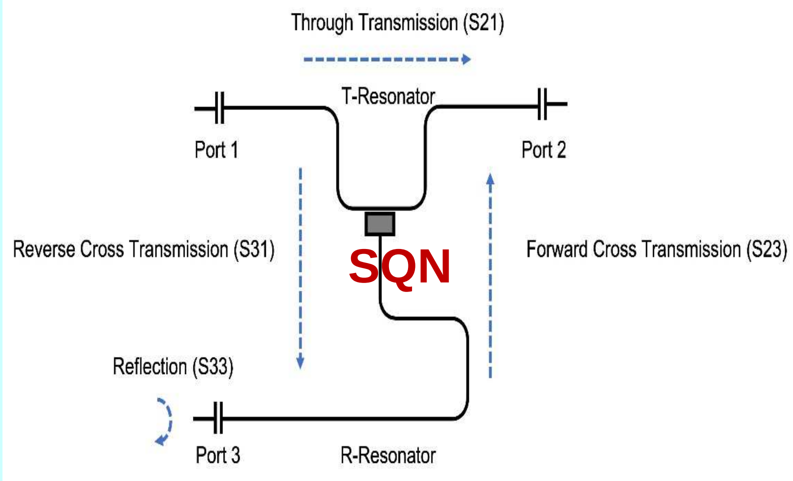
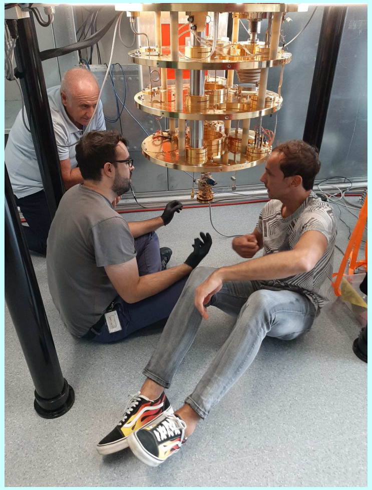
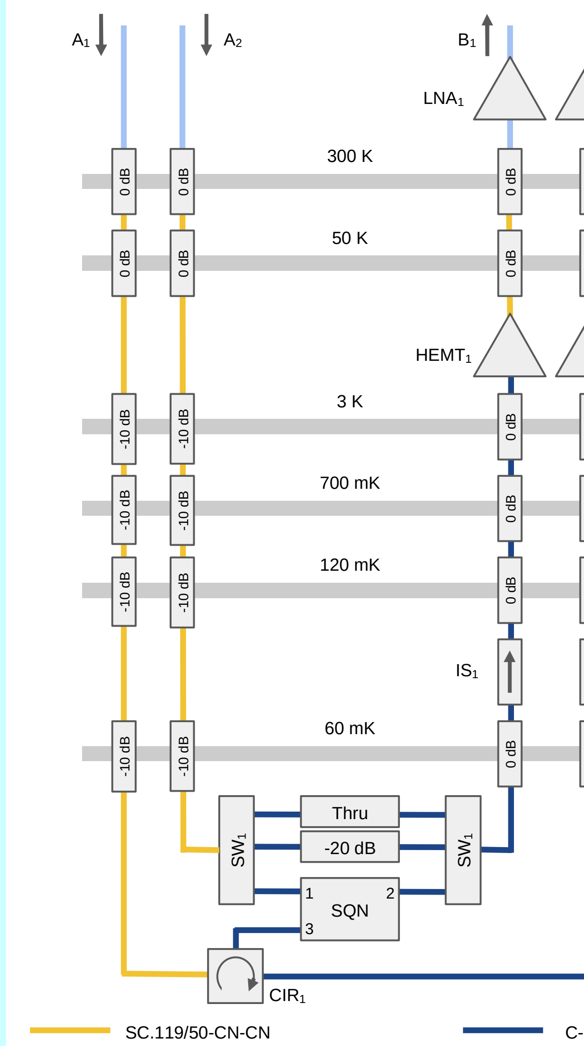
DI RICERCA METROLOGICA

NR SPIN Pozzuoli

R ISASI Pozzuoli

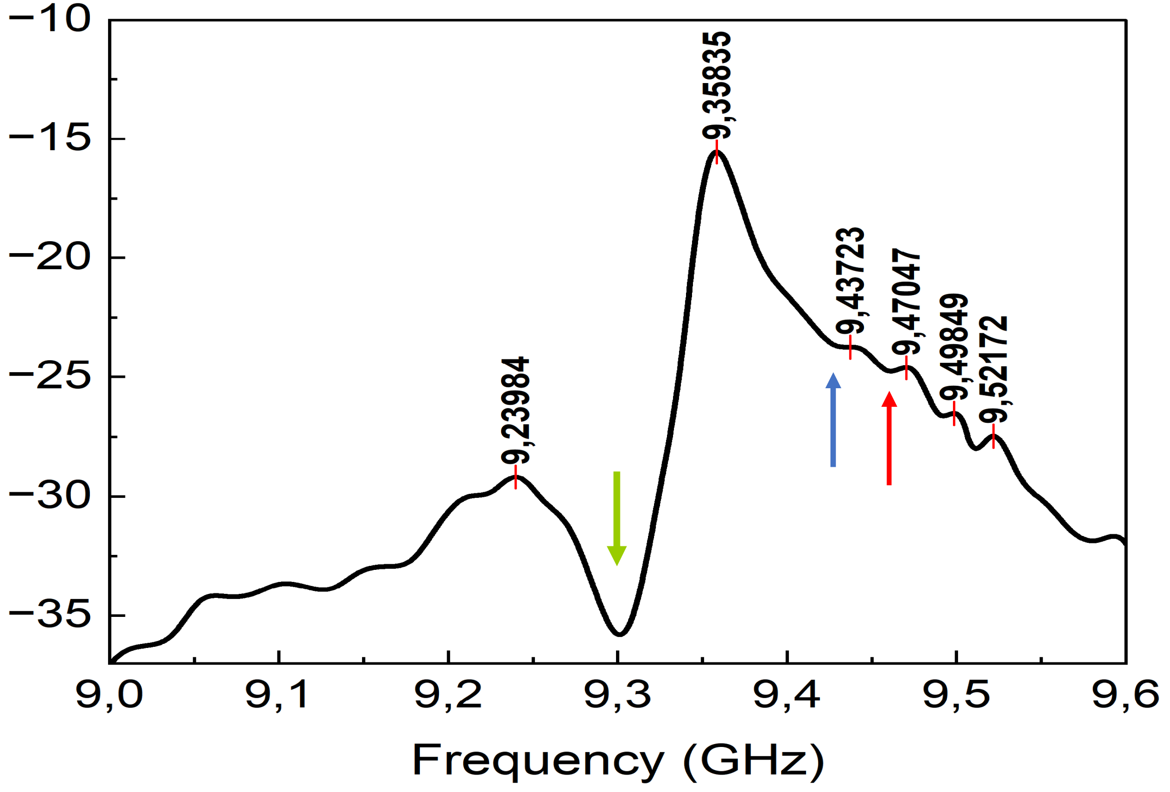


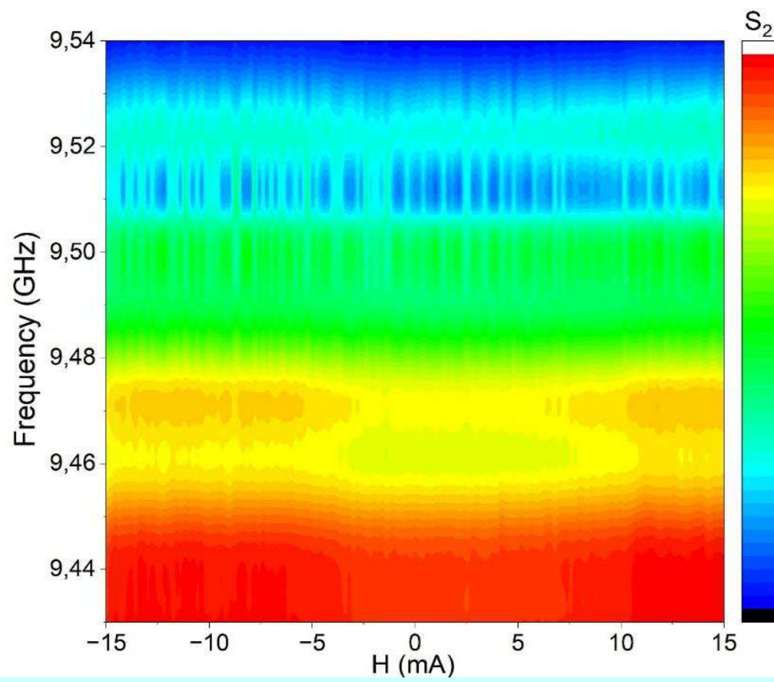


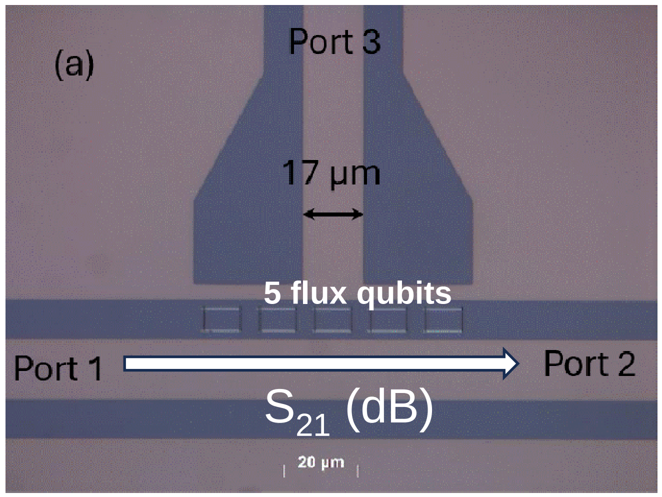


co, E.; Bonavolontà, C.; Brida, G.; Coda, G.; Il'Ichev, E.; Fasolo, L.; Fistoul, M.; Meda, A.; Oberto, L.; Oelsner, G.; Rajte
Ruggiero, B.; **Silvestrini, P.;** Valentino, M.; Vanacore, P.; **Lisitskiy, M.**
E TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY 34 (3), p. 1500306 (2023)

Color plot

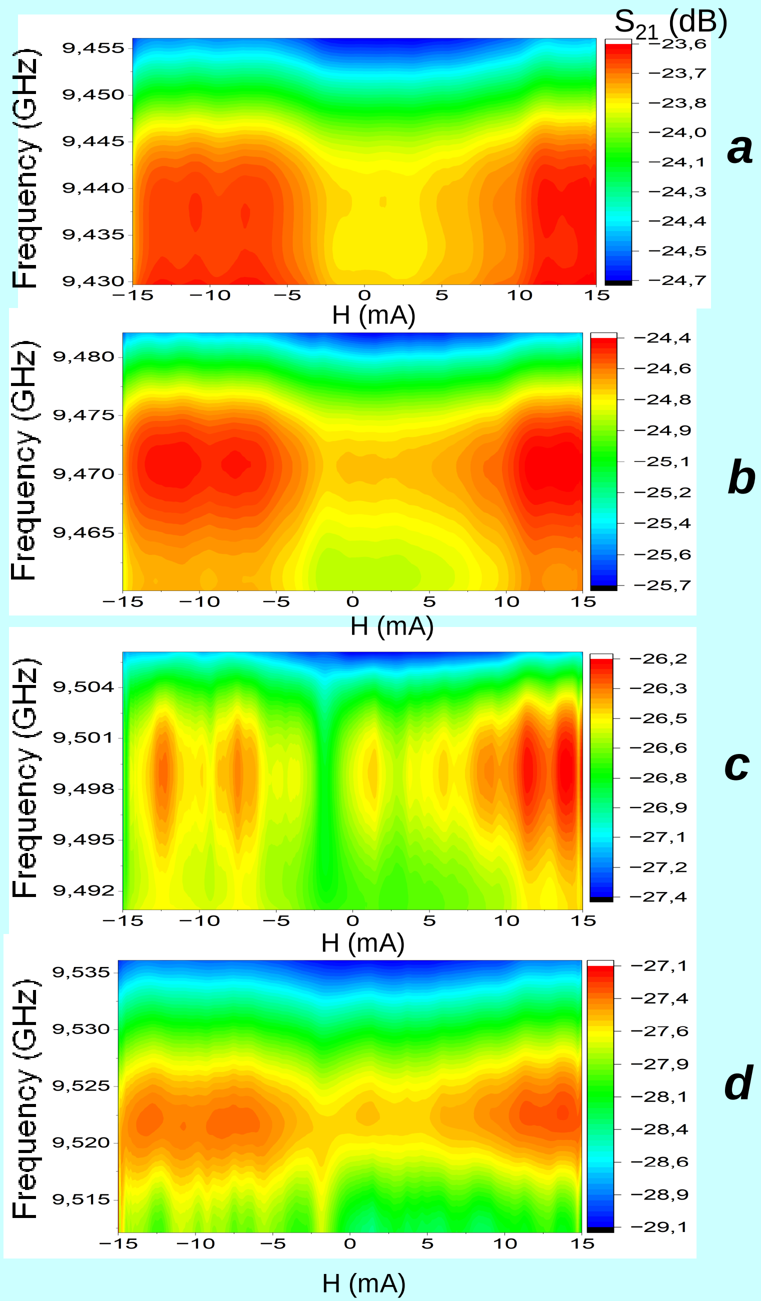


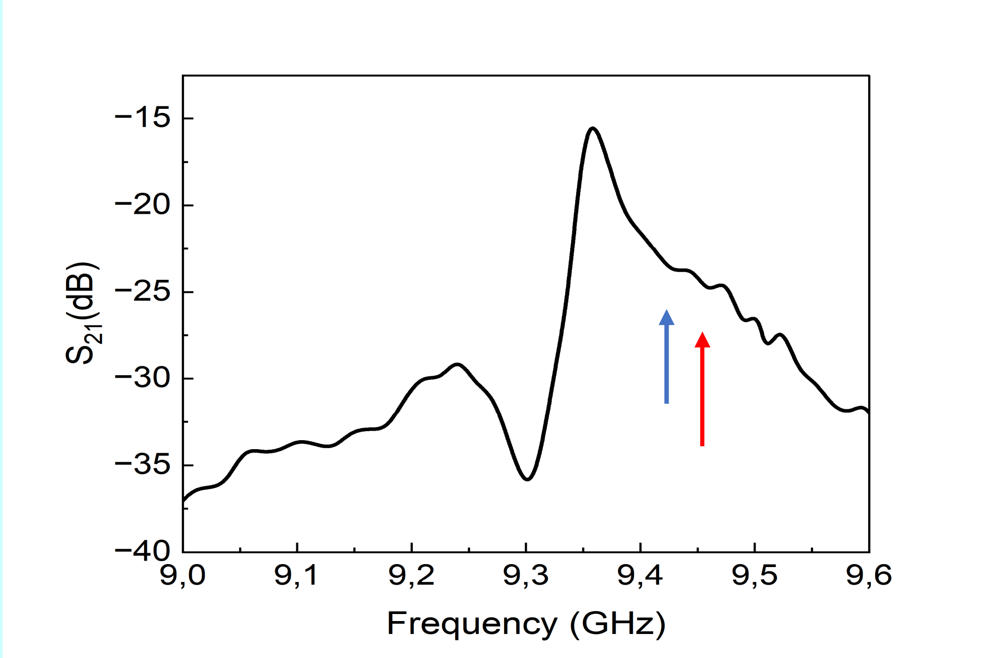




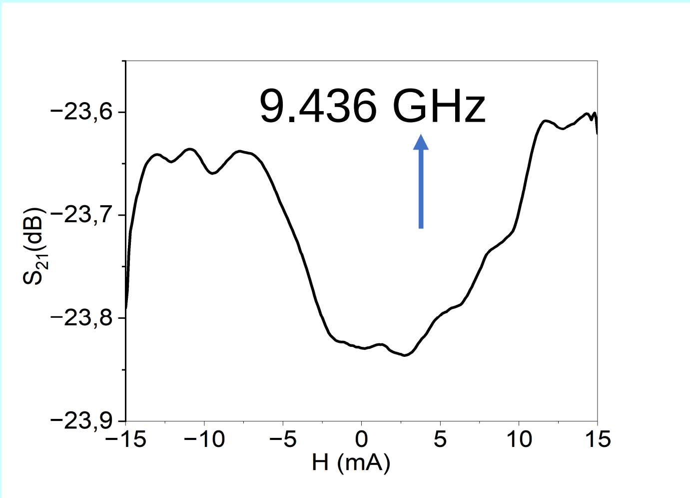
transmission measurements of S21 versus frequency demonstrate the ence of **number of resonant dips.**

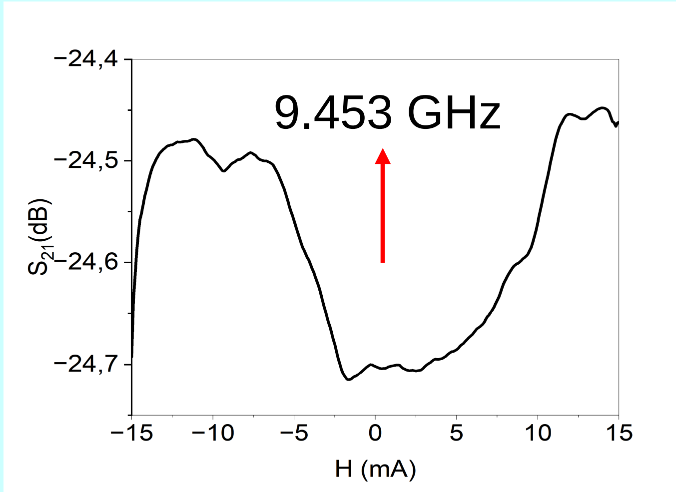
esonant dips as function of external magnetic field



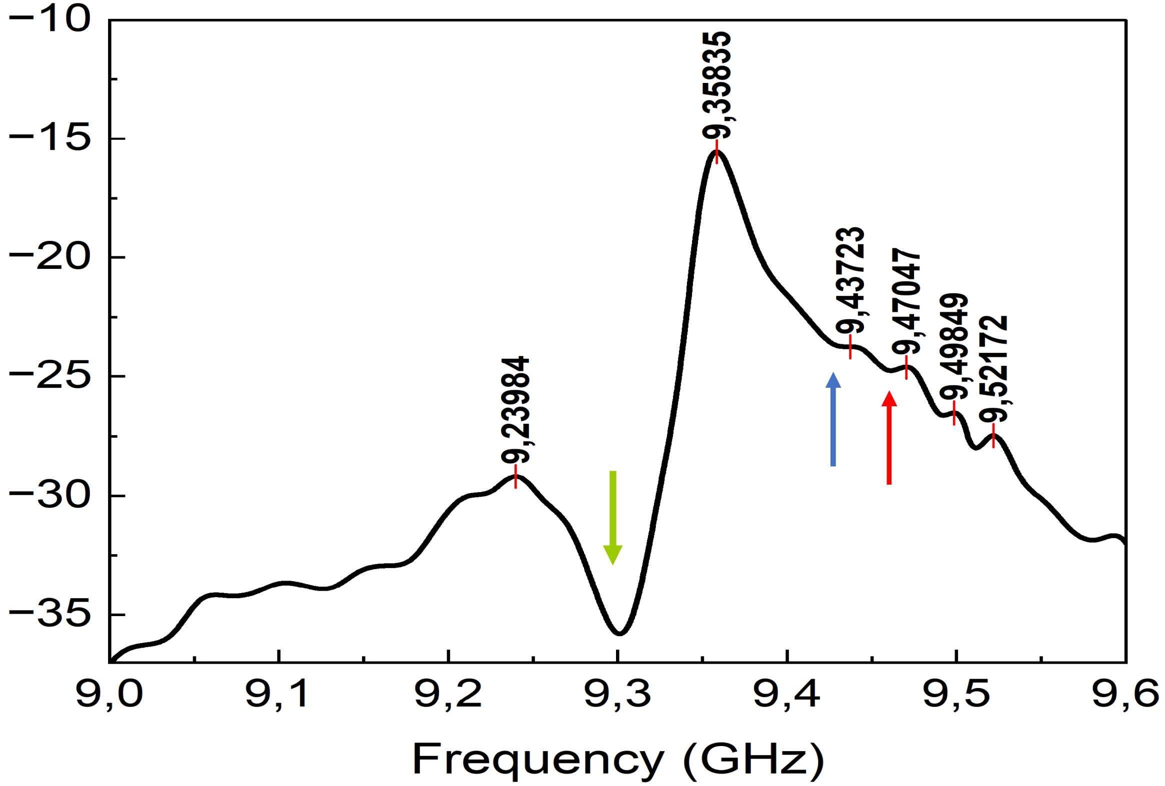


Periodic dependence of resonant dipsas function of the esternal magnetic field is associated with the excitation of single qubits

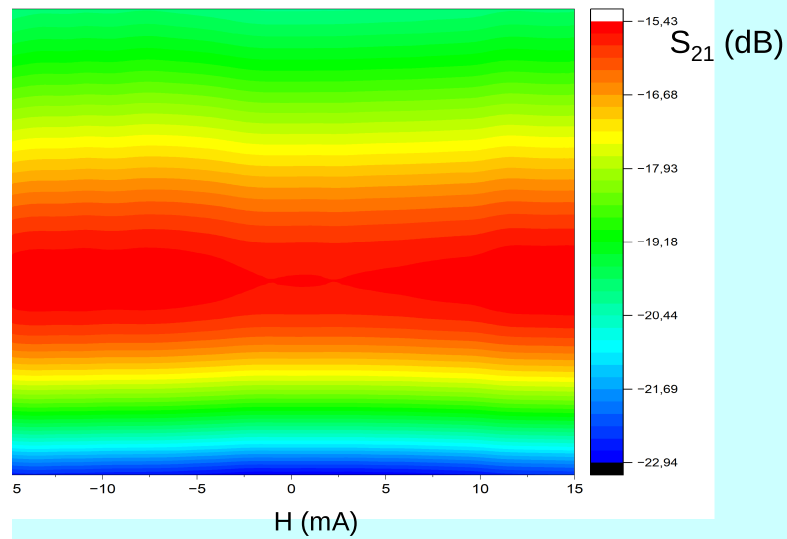


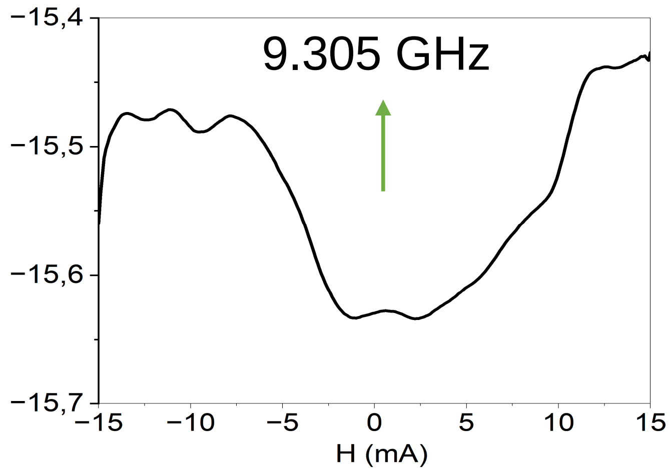


3 terminal SQN with 5 flux qubits



Color map S21 main resonance 9,305 GHz,





://nqsti.it/research-highlights March 27th, 2024

The main resonant dip in $S_{21}(\omega)$ dependence and its periodic magnetic field oscillation indicate the presence of a strong long-range interaction between qubits leading to the quantum collective state

I25-M 36 Spoke 6 ISASI Fabrication a) and Measurements b) (Cross SQN)

a) EBL ISASI CNR

SQN with 5 flux Qubit with 4 Josephson Junction

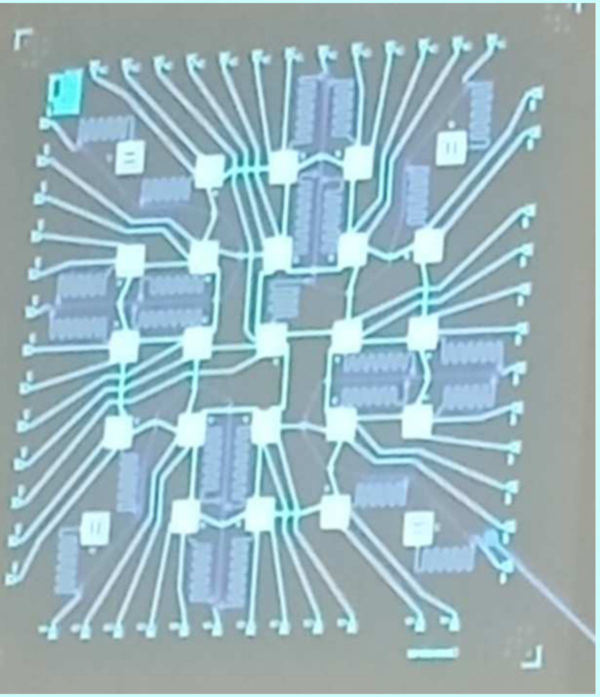
Area JJ =0.2x0.5 μm²

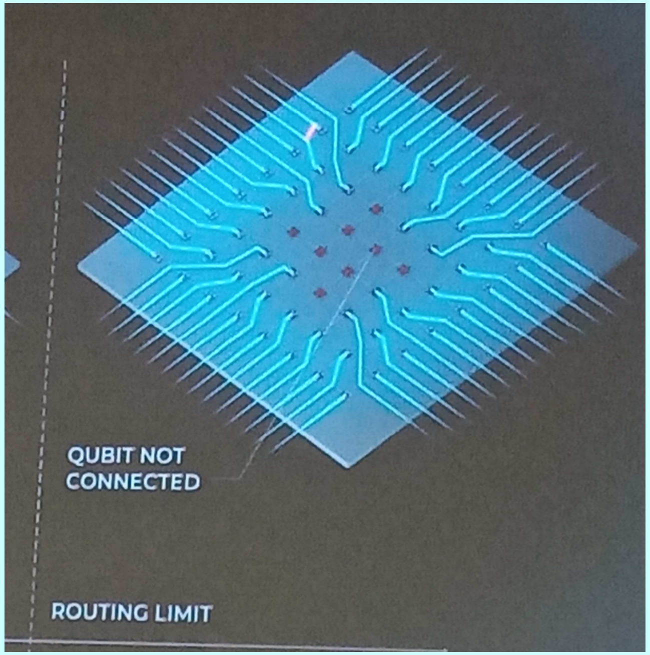
ADR Helium Free Cryostat T= 50 mK
SPIN/ISASI Pozzuoli CNR

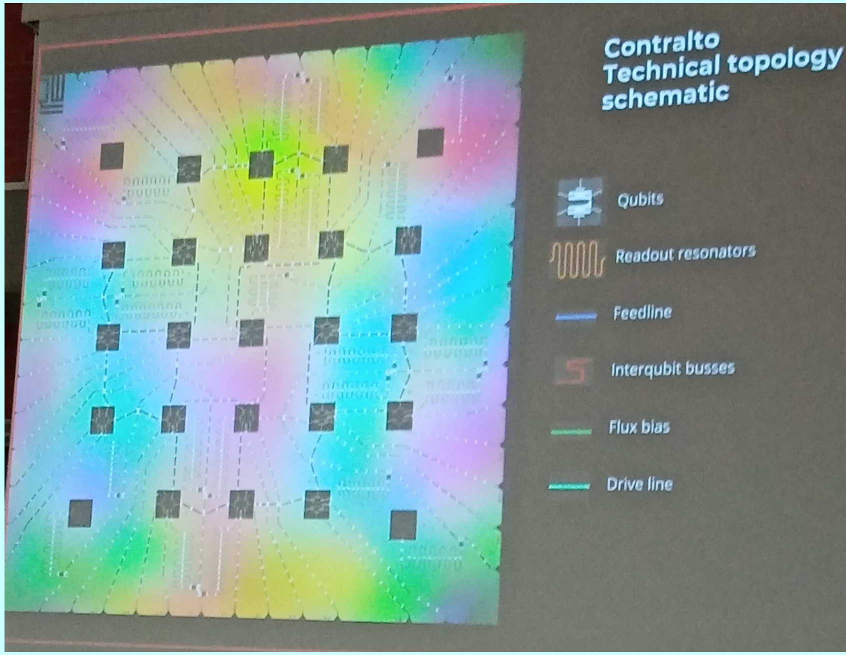
ological Corrections in realising qubit chip

QC Companies

QuantumWare

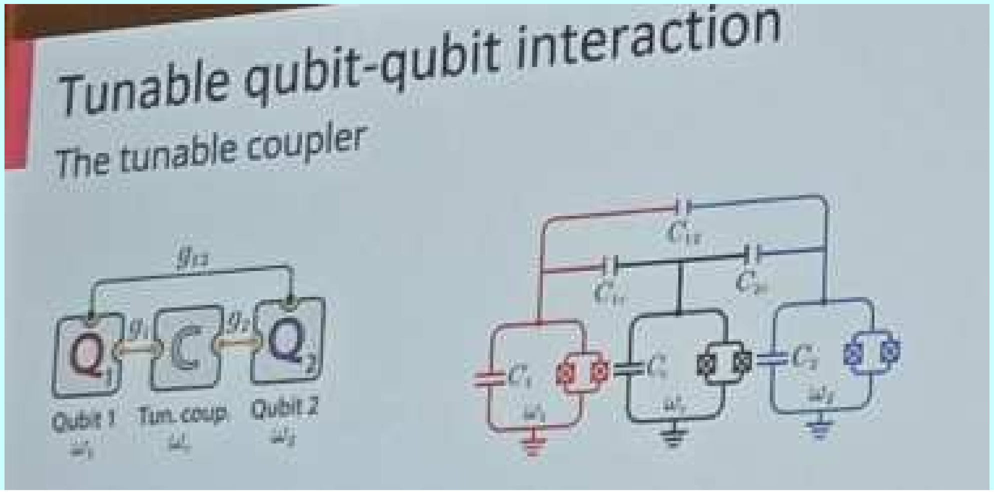






Rigetti

ubit/qubit Interaction

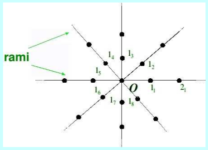


Topology-induced Qubit/Qubit configurations ...!!

Experiments: ISASI/Tor Verga

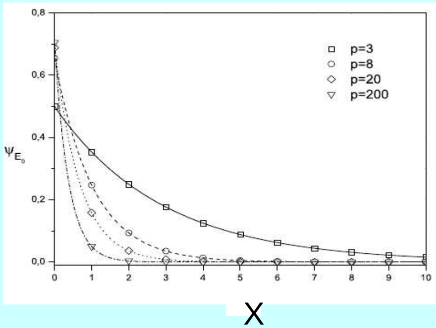
Andrea Trombettoni /Paolo Silvestrini

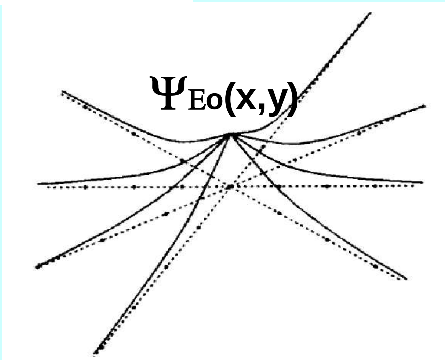
Topology-Induced Spatial Bose-Einstein Condensation in Inhomogeneous Josephson Arrays (JJ STAR NETWORK)

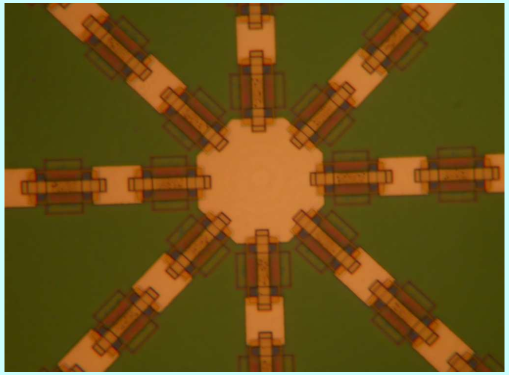


$$\psi^{star}_{E_0}(x,y) = \sqrt{\frac{p-2}{2p-2}}e^{-\frac{x}{\xi}}$$

$$\xi = \frac{2}{\log(p-1)}$$

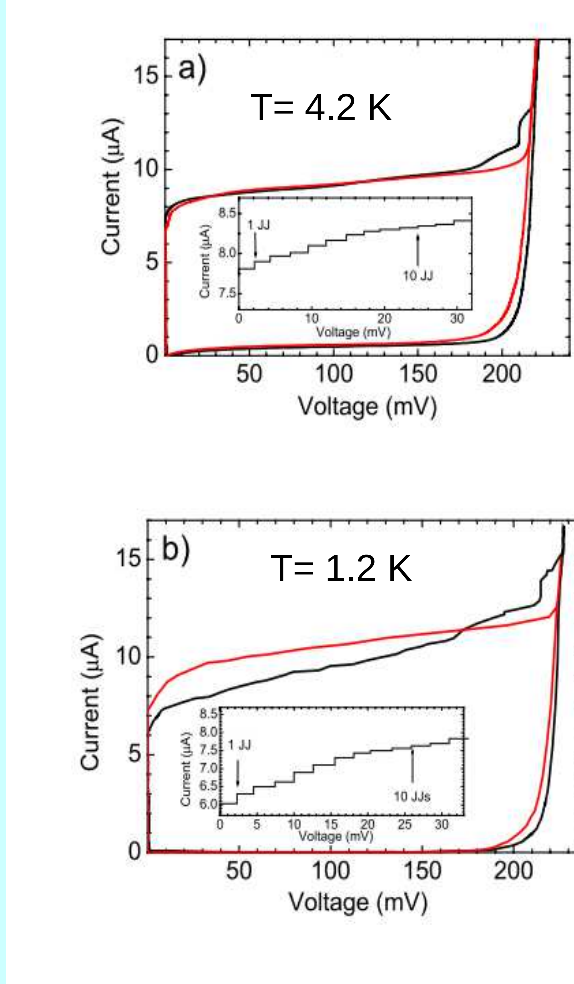






JJ STAR NETWORK

SN (black)
RN (red)



odano, **A. Trombettoni**, **P. Silvestrini**, R. Russo, **B. Ruggiero**
omogeneous superconductivity in comb-shaped Josephson junction networks
v Journal of Physics 8, 327 (2006).

ilvestrini, R. Russo , V. Corato , **B. Ruggiero, A. Trombrettoni……..**
ology-induced critical current enhancement in Josephson networks.
sics Letters A370, 499 (2007).

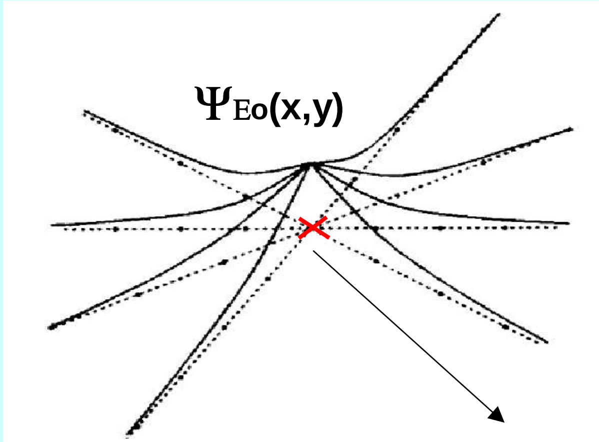
omeo et al. **Journal of Phys. 33, 045401 (2021)**

The observed phenomena evidence n surprising behavior of transport prop in superconducting Josephson juncti Network

F. Romeo et al. May 2024

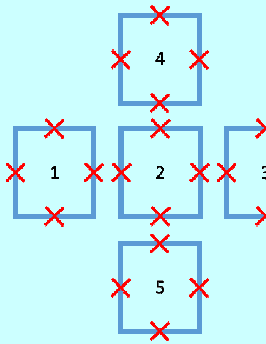
Modeling Superconducting Qubit Networks with 5 flux qubit

SQN topology effects

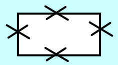


JJ STAR NETWORK

Cross SQN

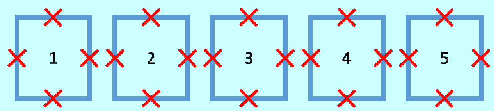


Josephson Junctions → 4 JJ Flux Qubit

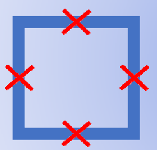


JJ Flux Qubit Effective Hamiltonian

Linear SQN



Qubit effective Hamiltonian



$$\widehat{H}_{eff} = -\epsilon(f)\,\sigma_z - \Delta\,\sigma_x$$

$$f = \frac{\Phi}{\Phi_0}$$

$$\epsilon(f) = I_s\Phi_0\left(f - \frac{1}{2}\right)$$

1990-1999 ELQ, MQT, RMQT ICIB CNR

L REVIEW B VOLUME 54, NUMBER 2 1 JULY 1996-II

Resonant macroscopic quantum tunneling in SQUID systems

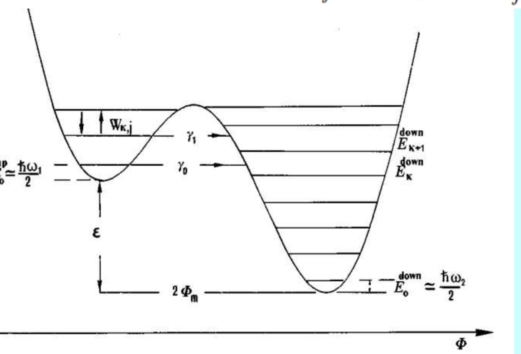
Paolo Silvestrini, Berardo Ruggiero, and Yuri N. Ovchinnikov*
Istituto di Cibernetica del C.N.R., I-80072, Arco Felice, Napoli, Italy

(Received 29 January 1996)

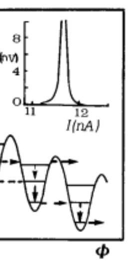
Nb

30 mK=T<Tcros

$$\Gamma(K) = \frac{dI}{dt}\frac{1}{\Delta I}\frac{P(K)}{\sum_{j=1}^{K_{max}} P(j) - \sum_{j=1}^{K} P(j)}.$$



1. Sketch of the potential $U(\Phi)$ describing the SQUID s in a quantum picture.



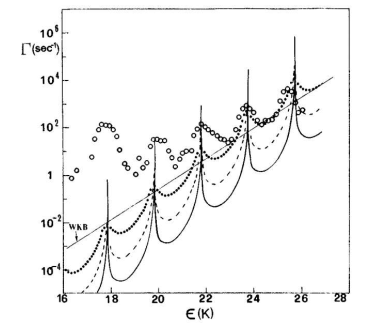
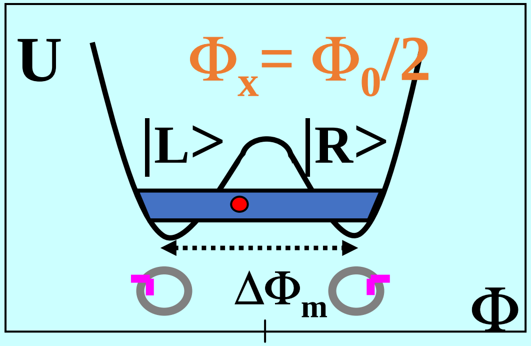
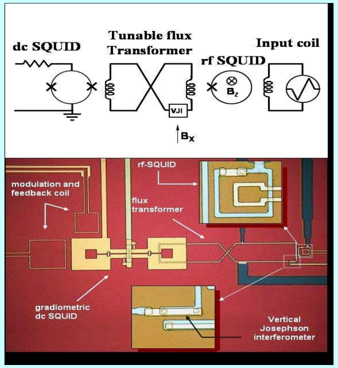
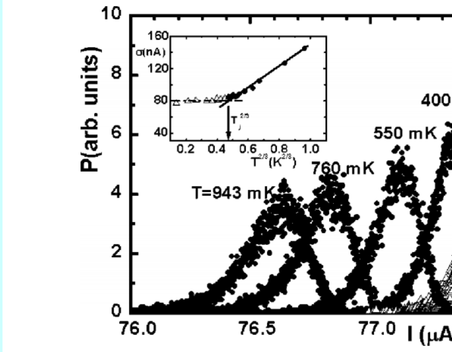


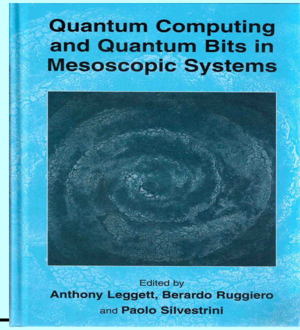
FIG. 2. Escape rate Γ vs ε. Open circles are data from Ref. 9, while three different values of resistance have been considered for the theoretical curves: $R/R_Q=100$ (solid line), $R/R_Q=10$ (dashed line); $R/R_Q=1$ (solid points); $R_Q=6.45$ kΩ. For all the curves $L=210$ pH, $C=80$ pF, and $\Delta U_0=16.3$ K.

B) 2000-2013 MQC Group ICIB CNR









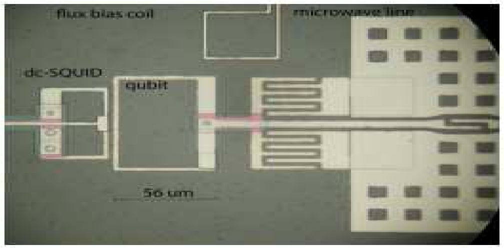
Nb rf-SQUID as a qubi

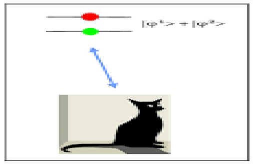
20 mK=T<Tcro

C) 2014-2018 MQC in phase qubits

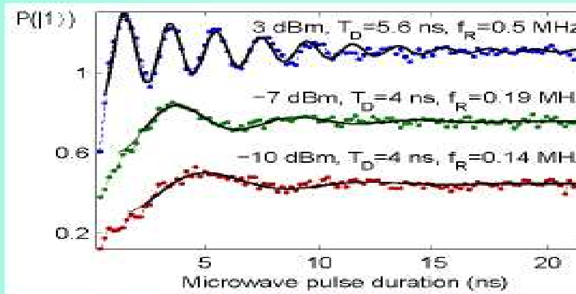
NbN based superconducting Josephson phase qubit with AlN tunnel barrier
M.P. Lisitskiy, et al IEEE Trans on Superc. pp.1-3 (2017)

Nb





❑ Rabi oscillations



Rabi oscillations are measured varying the duration of the reson microwave pulse $\Delta t_{\mu W}$. The me decay time is about of 3-5 ns.