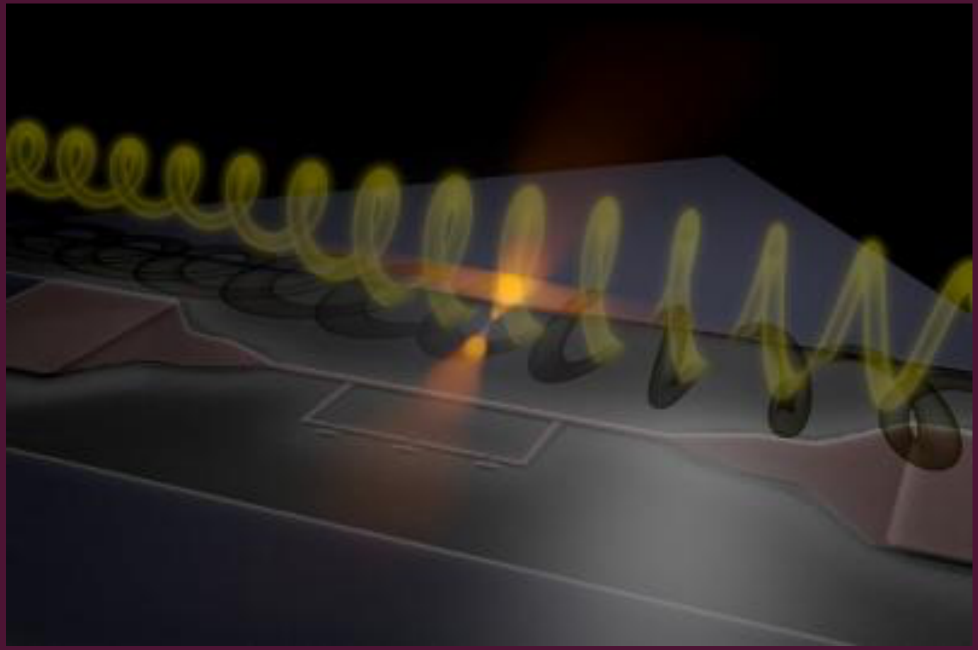
THE SIMP PROJECT: TOWARDS SINGLE MICROWAVE PHOTON DETECTION

CLAUDIO GATTI - LNF

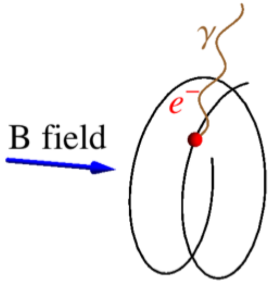


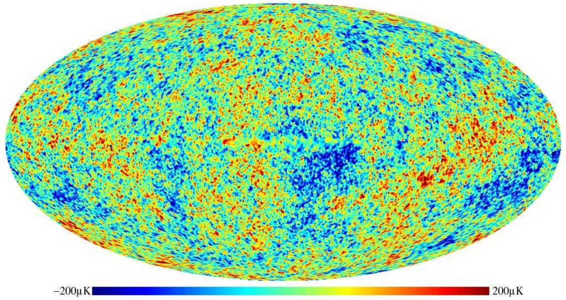
INTRODUCTION

- Detection of single photons in the microwave to terahertz regime has a large number of applications ranging from dark matter searches and astrophysics to quantum computing and homeland security

Axion searches

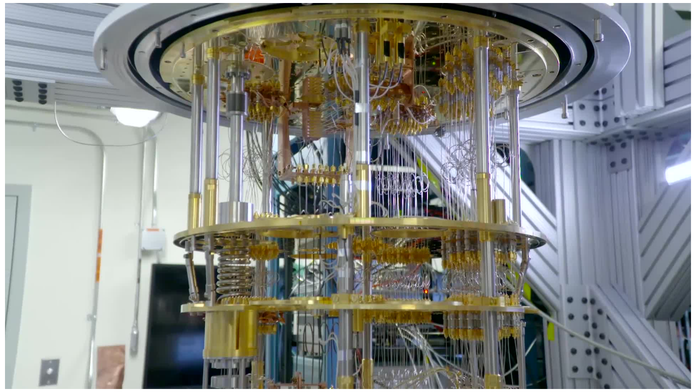
Neutrino mass



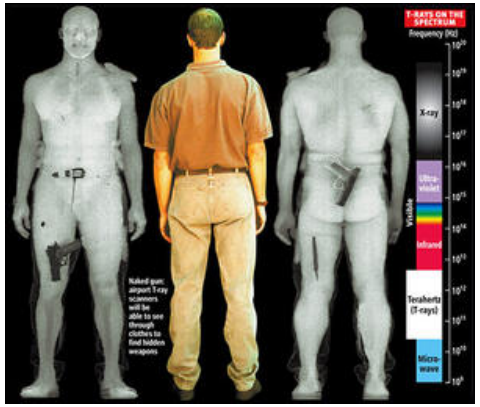


Cosmic Microwave Background

Quantum computers

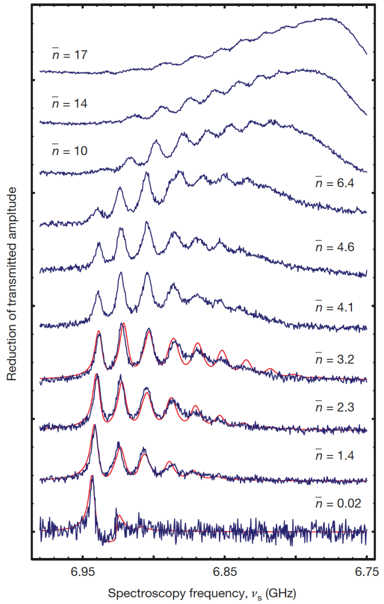


Homeland security



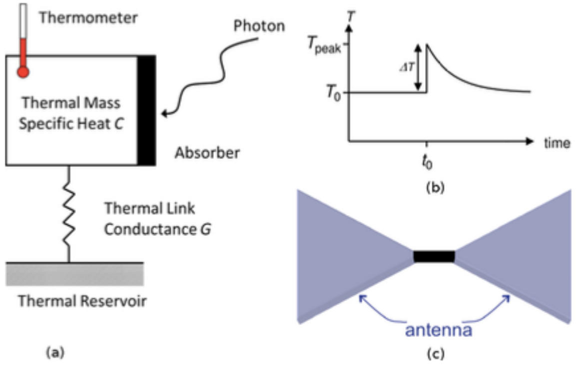
BACKGROUND

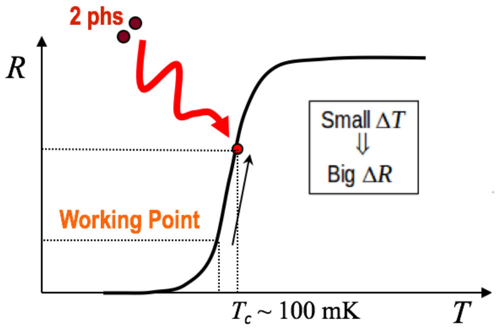
- In the last decade the development of nanotechnologies and of superconducting devices boosted the design of single photon detectors in the GHz to Thz frequency range.



Superconducting qubits
Schuster et al., NATURE Vol 445 (2007)

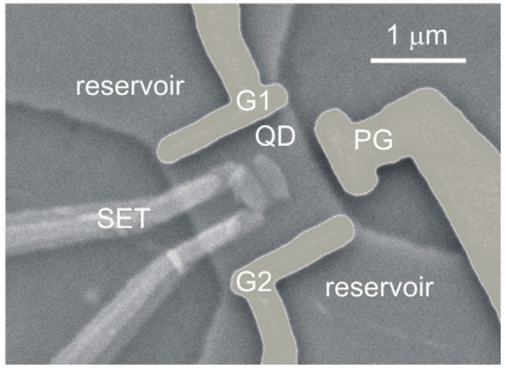
Graphene Bolometers
C.B. McKitterick arXiv:1210.5495





Transition Edge Sensors
Lolli et al, Sensors 2016, 16, 953

Quantum Dots
Hashiba Nanotechnology 21 (2010)



OBJECTIVES

- Development of SIngle Microwave Photon counters to strengthen INFN skills and technologies for Dark Matter searches, Neutrino Physics, Precision Physics and Astrophysics.
- Knowledge Sharing among Research Institutes
- Training of Young Physicists
- Technology Transfer
- Foster participation to National, European, and International Calls.

PARTNERS (COORDINATOR LNF)

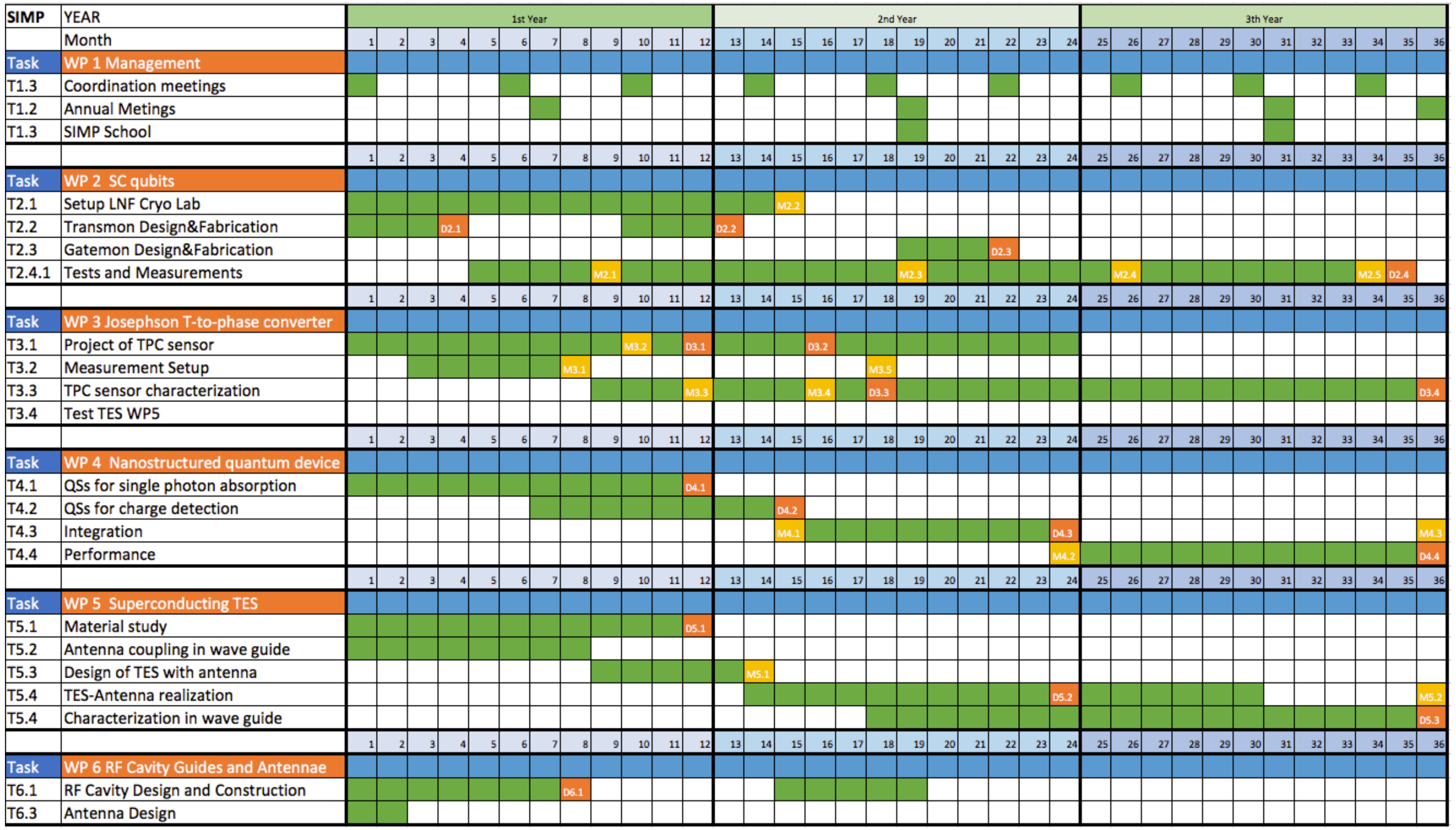
PROJECT DESCRIPTION

The SIMP project aims at reaching its main objective developing 4 different technologies (WP2 to WP5).

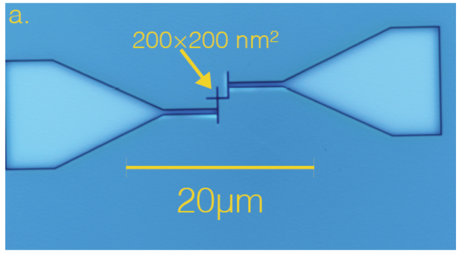
- WP1 Coordination and Dissemination (ALL)
- WP2 Super Conducting Qubits (LNF, CNR-IFN, CNR-NEST)
- WP3 Josephson Temperature to Phase Converter (CNR-NEST, INFN Pi)
- WP4 Nonostructured Quantum Device (INFN Pi, CNR-NEST)
- WP5 Transition Edge Sensors (INRIM, TIFPA, CNR-NEST)
- WP6 Resonant Cavities, WaveGuides and Antennae (LNF, INRIM, TIFPA)

PRELIMINARY GANTT, FTE AND BUDGET

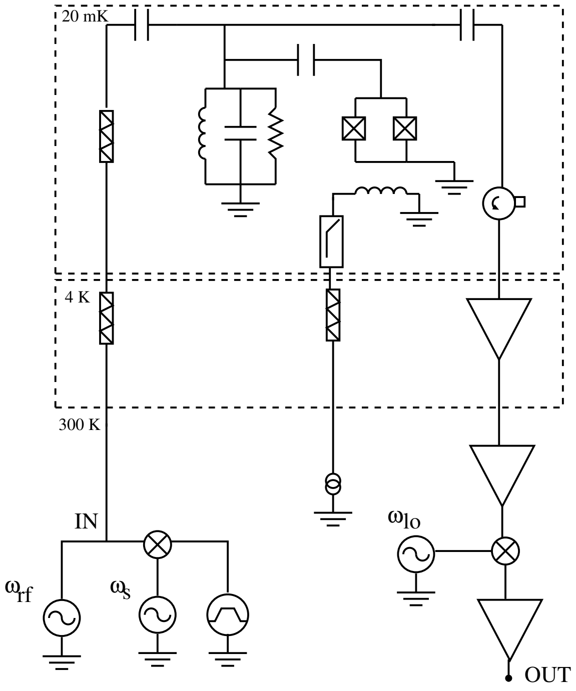
- 3 years project
- FTE 9.5
- Budget 0.8 - 1 M€
- 6-8 years AdR



WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



- Fabrication and test of superconducting qubits (Transmon and Gatemon)
- Coupling of qubit to 10 GHz resonant cavity at cryogenic temperature < 100 mK
- Readout of qubit state



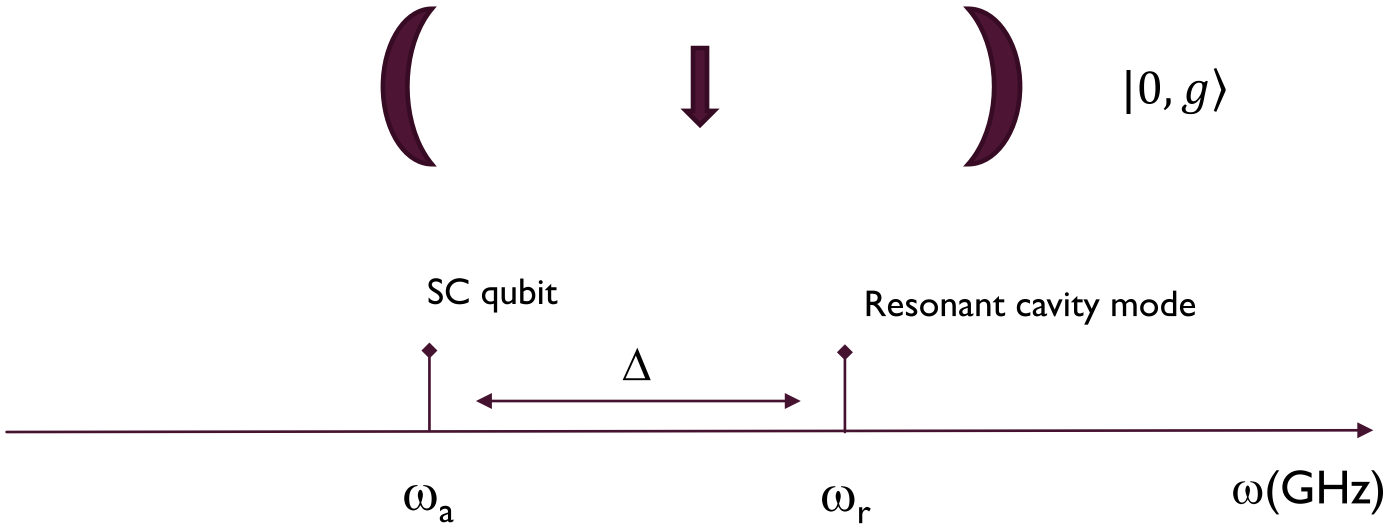
Dispersive Readout

The presence of a photon in the cavity with mode frequency ω_r induces a shift 2χ on the qubit frequency ω_a. Driving the qubit with a radiofrequency signal $\omega_s=\omega_a+2\chi$ a transition |g> → |e> is induced from its ground to the excited state. This transition happens only if there is a photon in the resonant cavity.

A qubit in the excited states induces in turn a shift in the cavity frequency. To test the qubit state a second radiofrequency signal with frequency $\omega_{rf}=\omega_r+\chi$ is sent to the cavity. The qubit state is inferred from the transmitted signal.

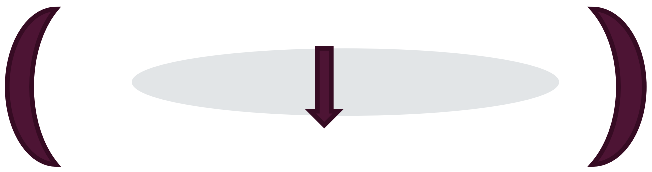
D.I.Schuster et al. "Resolving photon number states in superconducting circuits" Nature 445, p.515 (2007)

WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



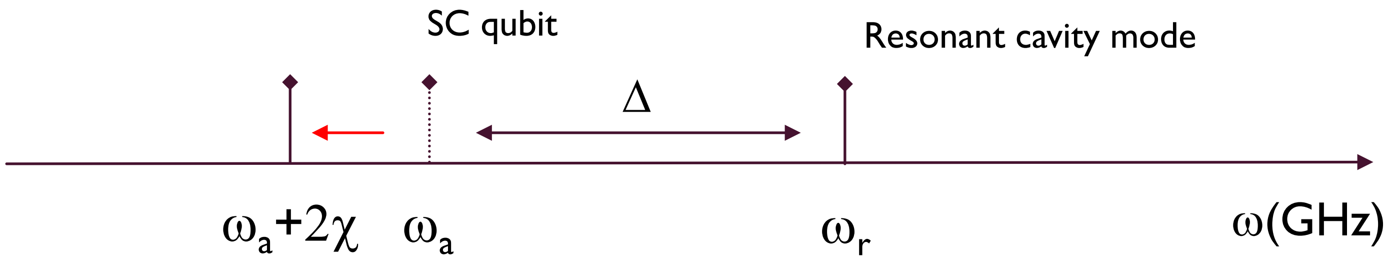
WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ

Stark Shift

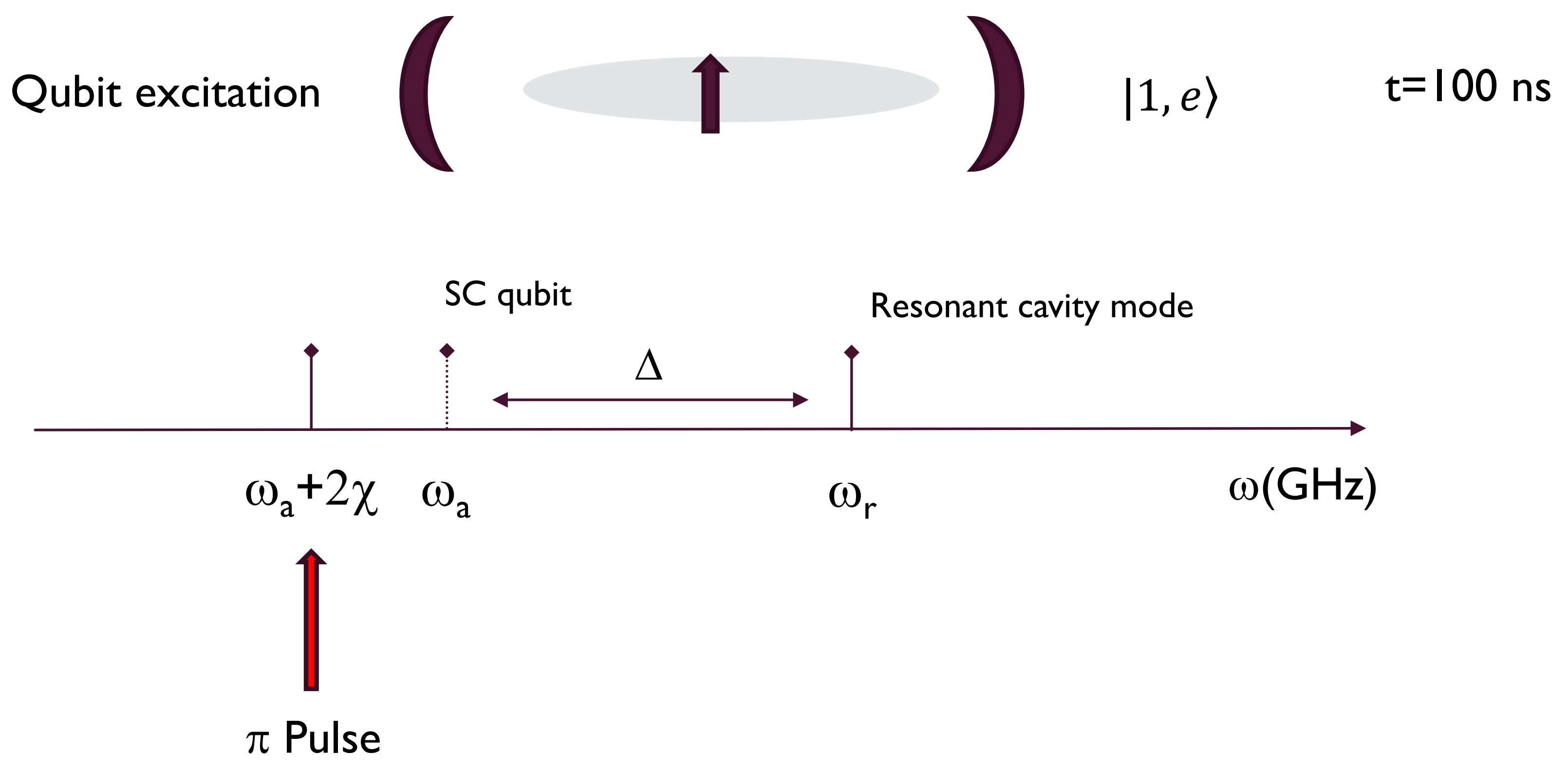


$|1, g\rangle$

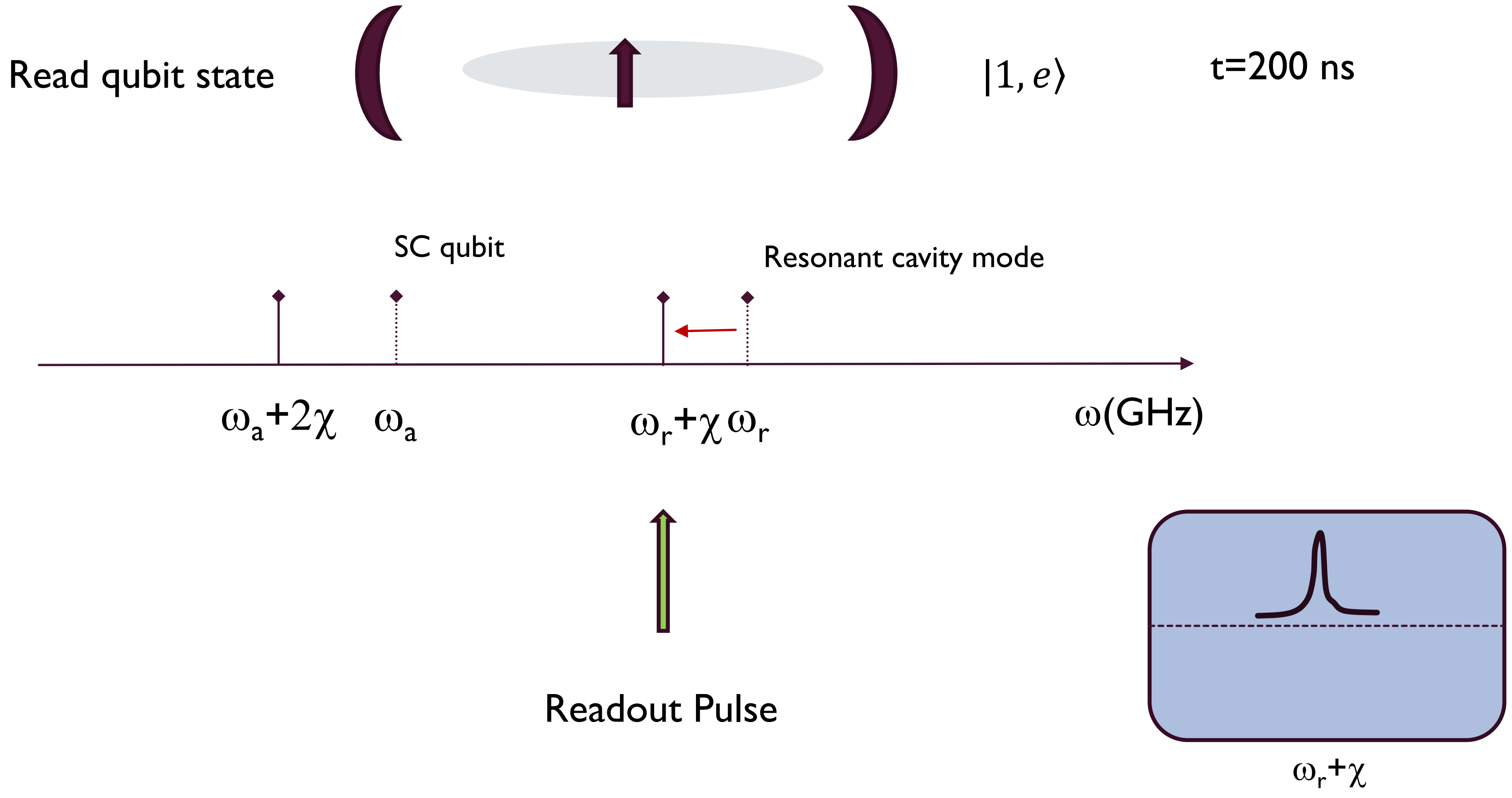
t=0



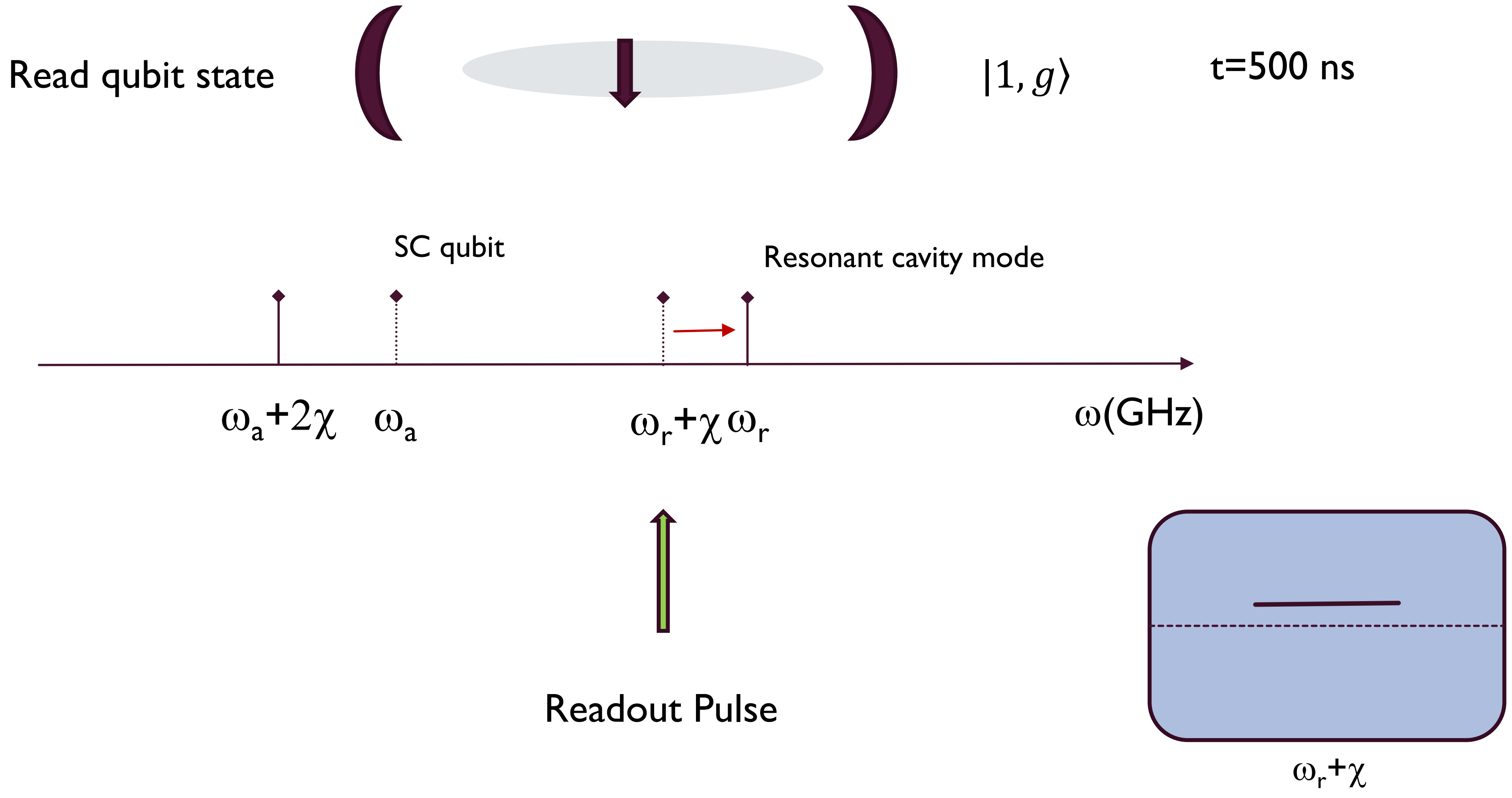
WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



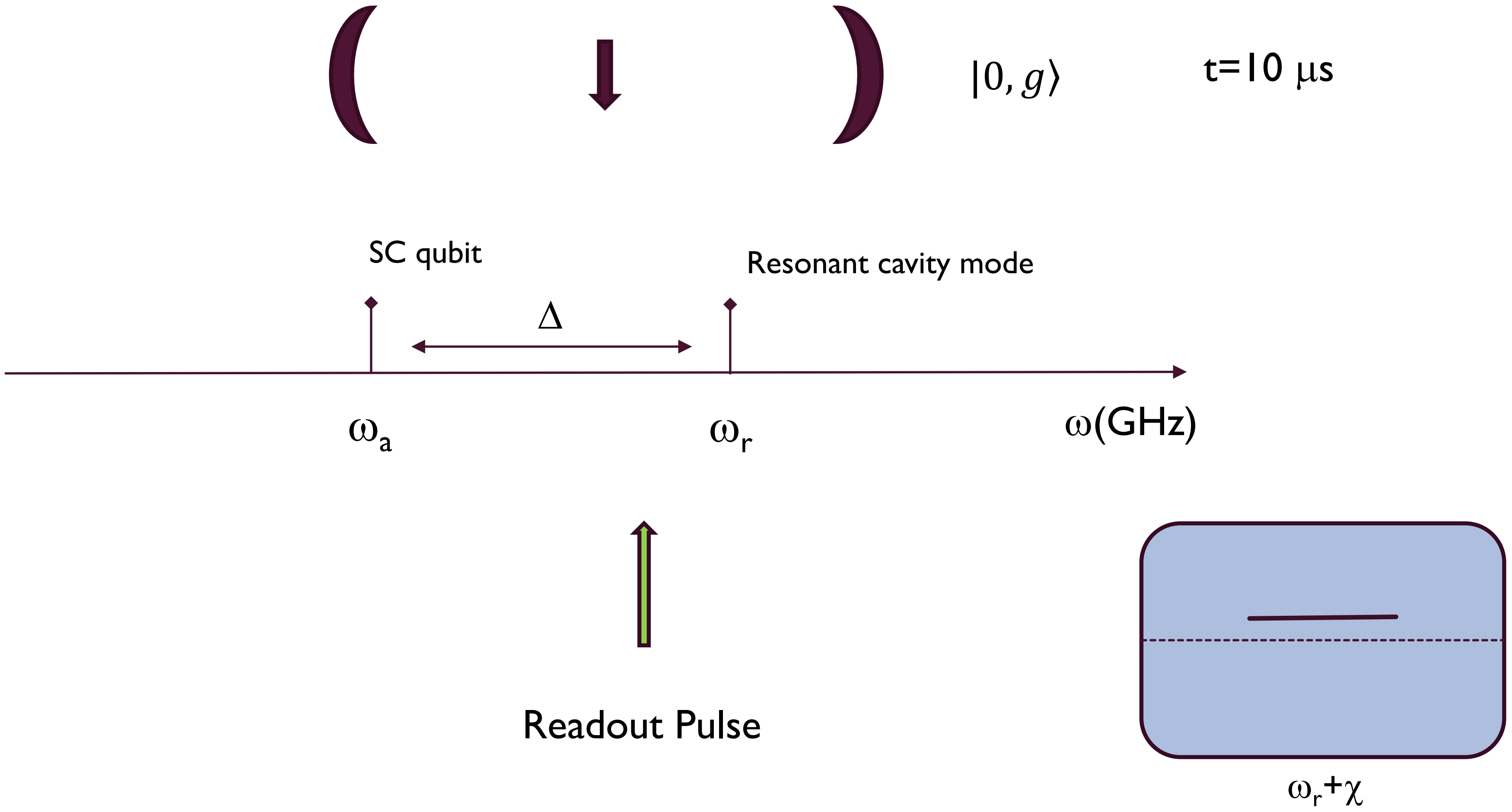
WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



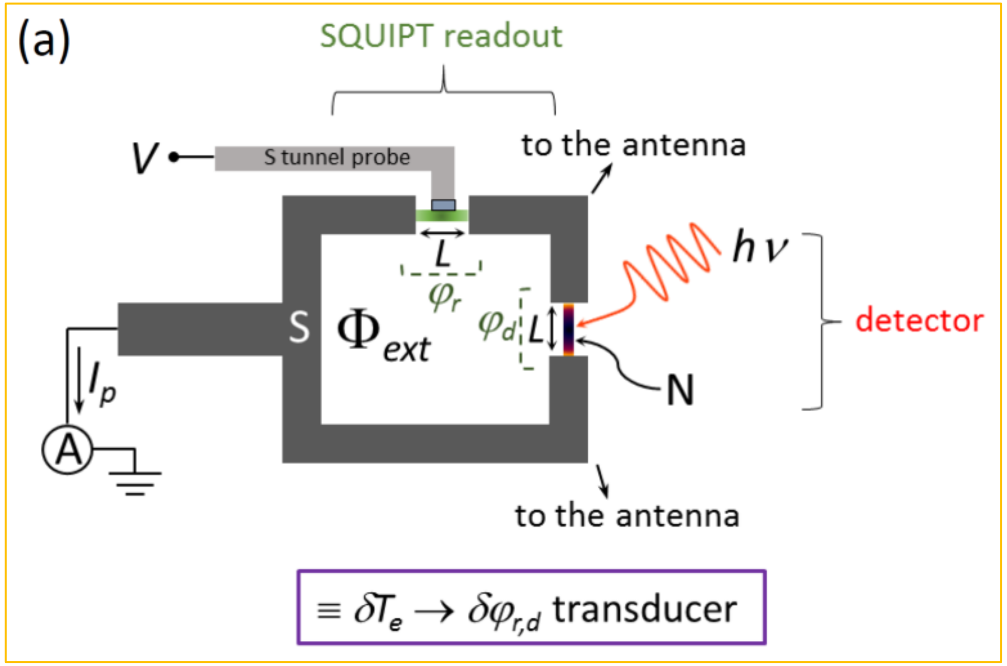
WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



WP2 (LNF, CNR-IFN, CNR-NEST): SC QUBIT SIMP 10-100 GHZ



WP3 (INFN-PI, CNR-NEST): JOSEPHSON PHOTODETECTOR VIA T-PHASE CONVERSION 10 GHZ-THZ



F.Giazotto et al. arXiv:1703.05284

Radiation absorption ($h\nu$)

⇓

T_e enhancement in detector JJ

⇓

Suppression of circulating J current

⇓

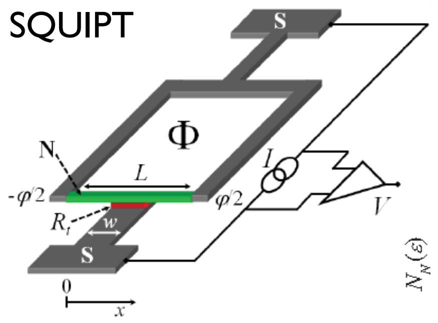
Variation of phase drop across the WLs

⇓

Modification of DOSs

⇓

SQUIPT readout
(Superconducting Quantum Interference Proximity Transistor)



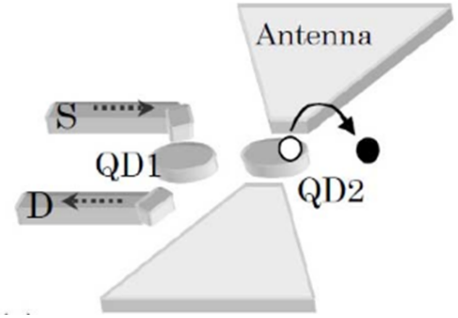
F.Giazotto et al. arXiv:0909.3806

$$NEP_{expected} \approx 10^{-22}\, W/\sqrt{Hz}$$

WP4 (INFN-PI, CNR-NEST): PHOTODETECTOR WITH NANOSTRUCTURED QUANTUM DEVICE 0.1THZ-1THZ

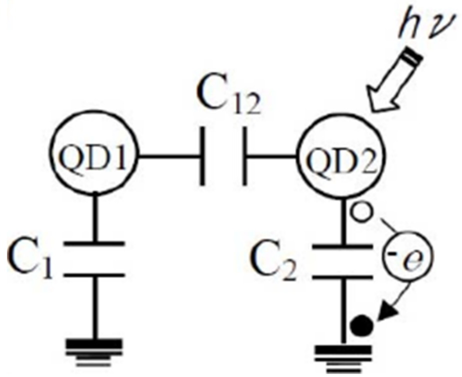
Quantum Dot Detectors

- QD2 coupled to an antenna act as an artificial atom
- QD1 act as a gate for a Single Electron Transistor. Capacitive coupling between QD1 and QD2 opens the SET gate



Typical values:

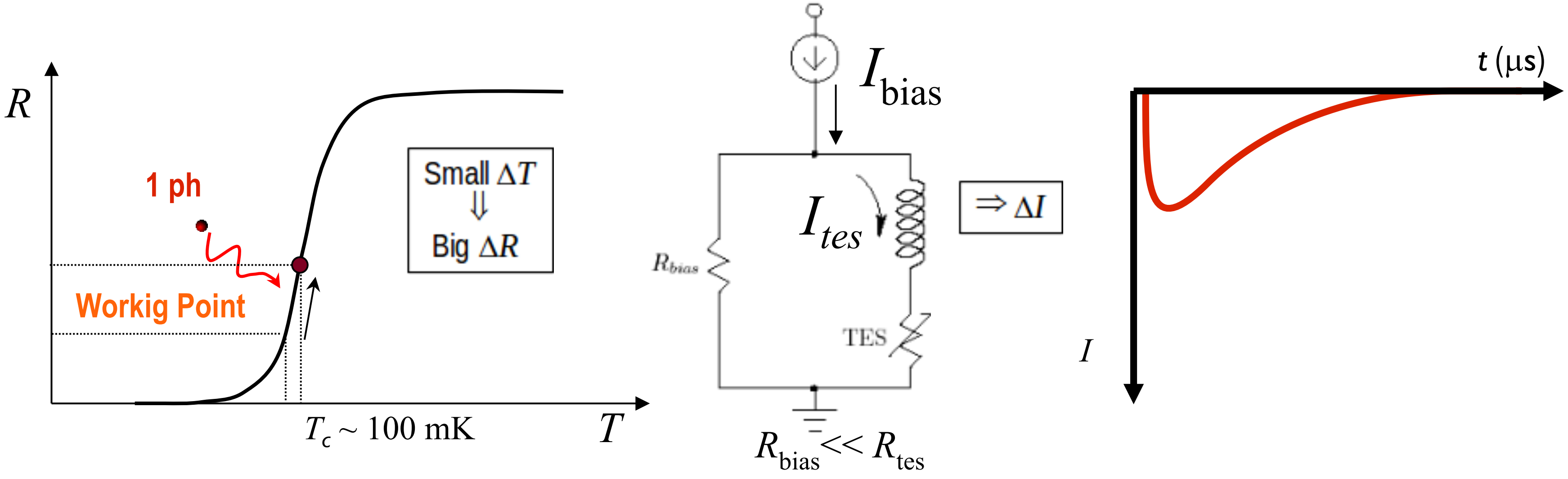
- C ≈0.1 fF
- $\Delta V = e/C = 1$ mV
- I=0.1 nA
- $\tau_{life} = 1$ ms
- $A = I\tau/e = 0.1$ nA 1 ms/1.6 10^{-19} C =5 10^{5}



$$NEP_{measured} \approx 10^{-20}\ W/\sqrt{Hz}$$

Komiyama "Single-Photon Detectors in the Terahertz Range" IEEE Journal Selected Topics In Quantum Electronics, Vol.17, No. 1 (2011)

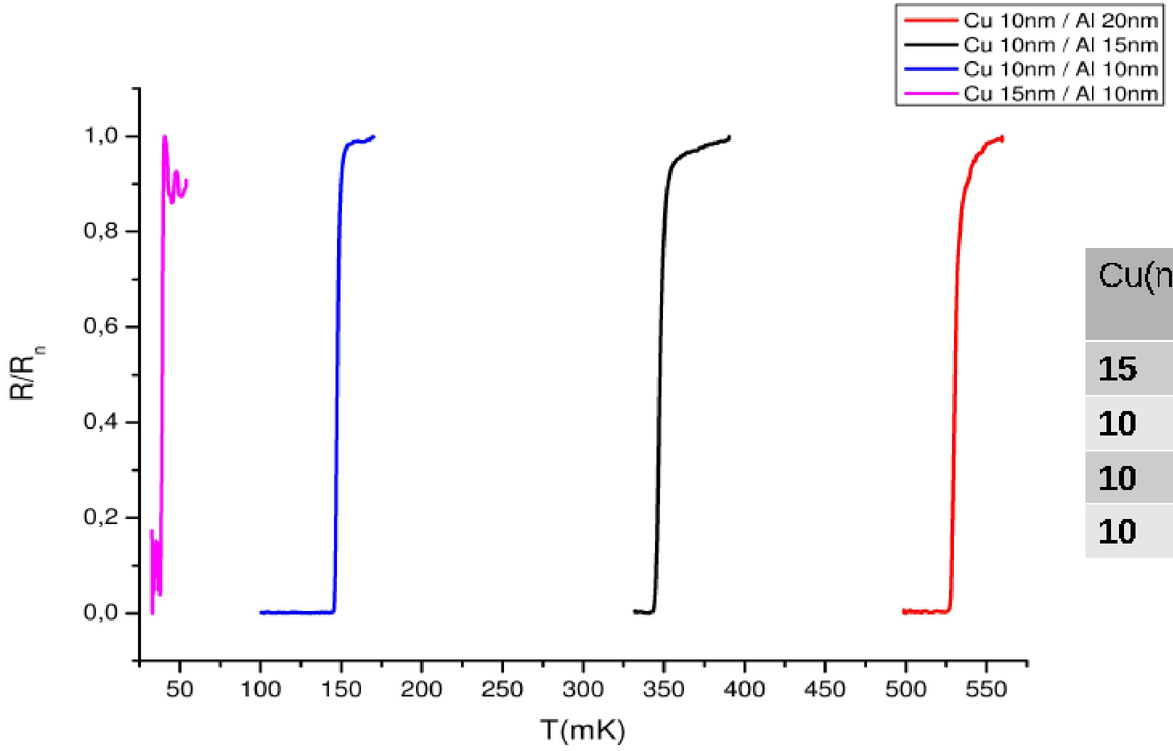
WP5 (TIFPA, CNR-NEST, INRIM TO,…): TES SINGLE PHOTON DETECTOR 50 GHZ



ΔT ⇨ ΔR @ Voltage bias ⇨ ΔI

WP5 (TIFPA, CNR-NEST, INRIM TO,…): TES SINGLE PHOTON DETECTOR 50 GHZ

Tc of Cu/Al bilayers



alpha=MAX(T/R dR/dT)

Cu(nm)	Al(nm)	Tc (mK)	Rn (ohm)	alpha
15	**10**	40	70	100
10	**10**	147	165	420
10	**15**	347	115	500
10	**20**	530	75	900

STAX R&D in GRV

LNF UNIT

- Claudio Gatti 50% (Coordination, RF setup, Test & Measurements) (+ Quax 50%)
- Daniele Di Gioacchino 50% (Experimental setup, Test & Measurements) (+ Quax 50%)
- Carlo Ligi 29% (Operation of Diluition Refrigerators, Test & Measurement) (+ Quax 20%)
- Luca Foggetta 30% (Operation of Diluition Refrigerators, Test & Measurement)
- Bruno Buonomo 30% (Test & Measurement, Setup of Qubit Fabrication)
- David Alesini 10% (Resonant Cavity Design, Simulation, RF Setup) (+ Quax 15%)
- Sandro Gallo 10% (Resonant Cavity Design, RF Setup)

RELATION WITH QUAX AND OTHER INFN ACTIVITY

- Single photon counting of GHz photons would boost the sensitivity of axion searches, Quax included
- The Quax-LNF group is involved in SIMP
- G.Lamanna (Quax-LNF) is part of INFN-Pi Unit
- P. Falferi (Quax-Tn) is in the TIFPA Unit
- First results of the STAX R&D on TES for axion detection (approved last year in CSN V) will continue in WP 5 (ongoing discussion with CSN V if the projects formally merged or other similar solution) (Involved CNR-NEST and INFN-Pi)

REQUESTS

To CSN V

- About 150-200 k€ (Wave function generator 20 GHz, Spectrum Analyzer, amplifiers, mixers, circulators, digitizer, thermometers, chiller, resonant cavity construction, cryogenic gas, travel, 2 years AdR)

To LNF

- New Cryo Lab in Nautilus Area
- Nautilus He Liquefactor and Technician for operation (0.2 FTE)
- Cryogenic Technician (0.5 FTE)
- Mechanical Designer DA (0.1 FTE) for resonant cavity technical design
- People interested in building this new activity

CONCLUSION

Since 1990 an increasing number of papers were published on single photon detectors (SPD) driven by reasearch in Quantum Information. A strong effort was put also in SPD in the sub-THz regime. To face new and old challenges of fundamental physics (Axions, Light Dark Matter, CMB, Neutrinos), we must look to these technologies.