# Optical Characterization of the Quantum Capacitance Detector (QCD)

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# Outline

## 1.- Introduction

- Proof-of-Concept of the QCD
- Dark NEP

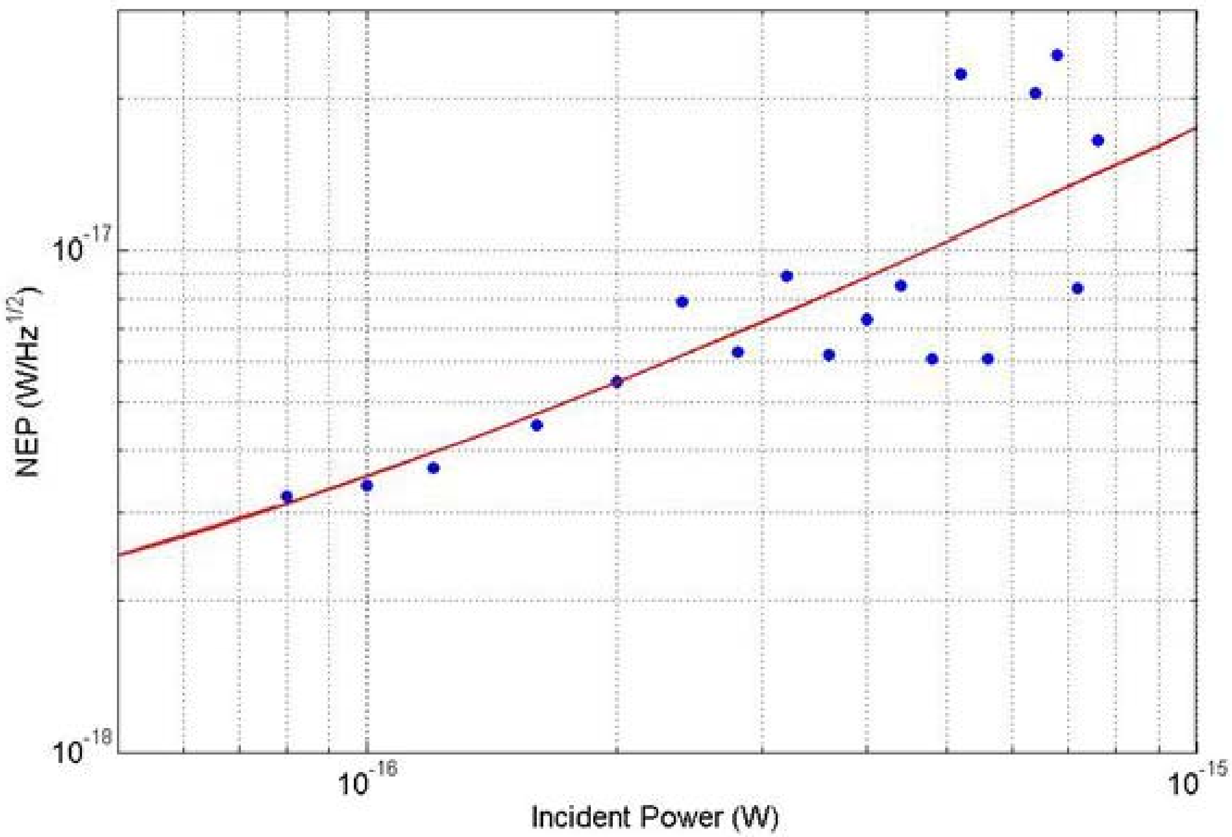
## 2.- Coupling Radiation to the QCD

- Optical System
- Experimental Setup

## 3.- Quantum Capacitance Detector Characterization

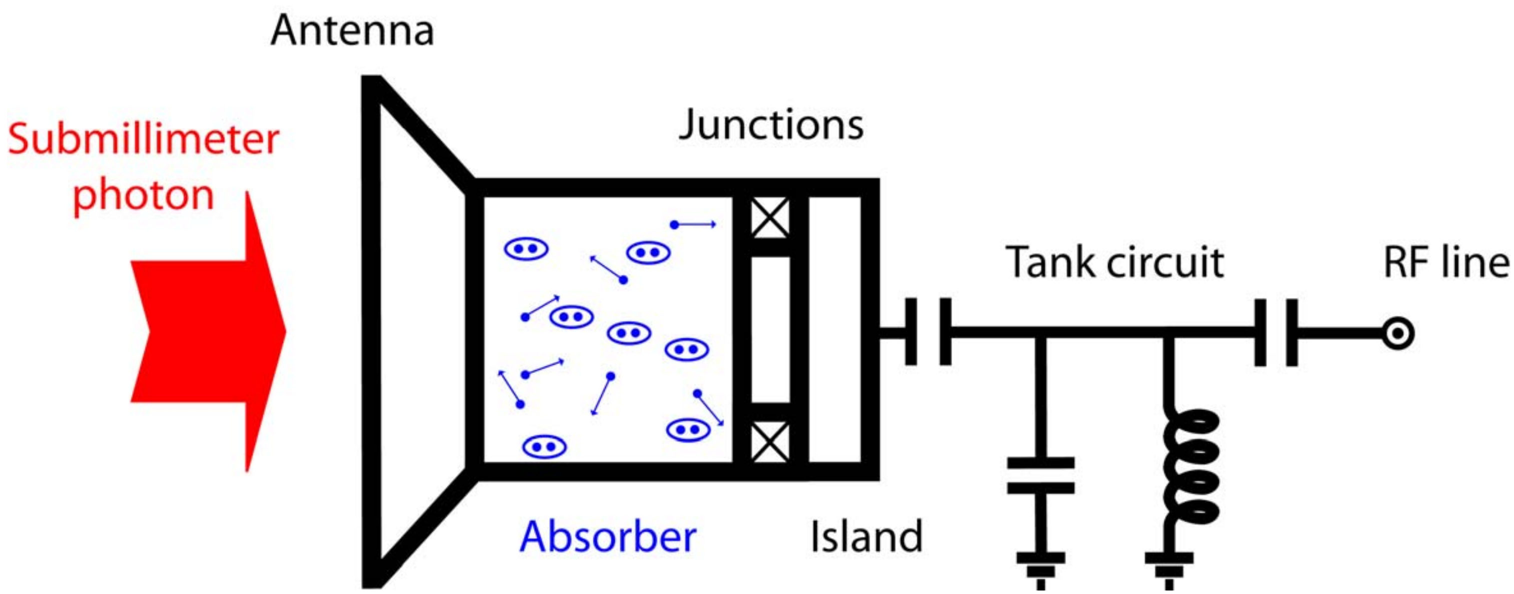
- Signal, noise and NEP
- Quantum Capacitance Trace
- Conclusions

# Proof-of-concept of the QCD



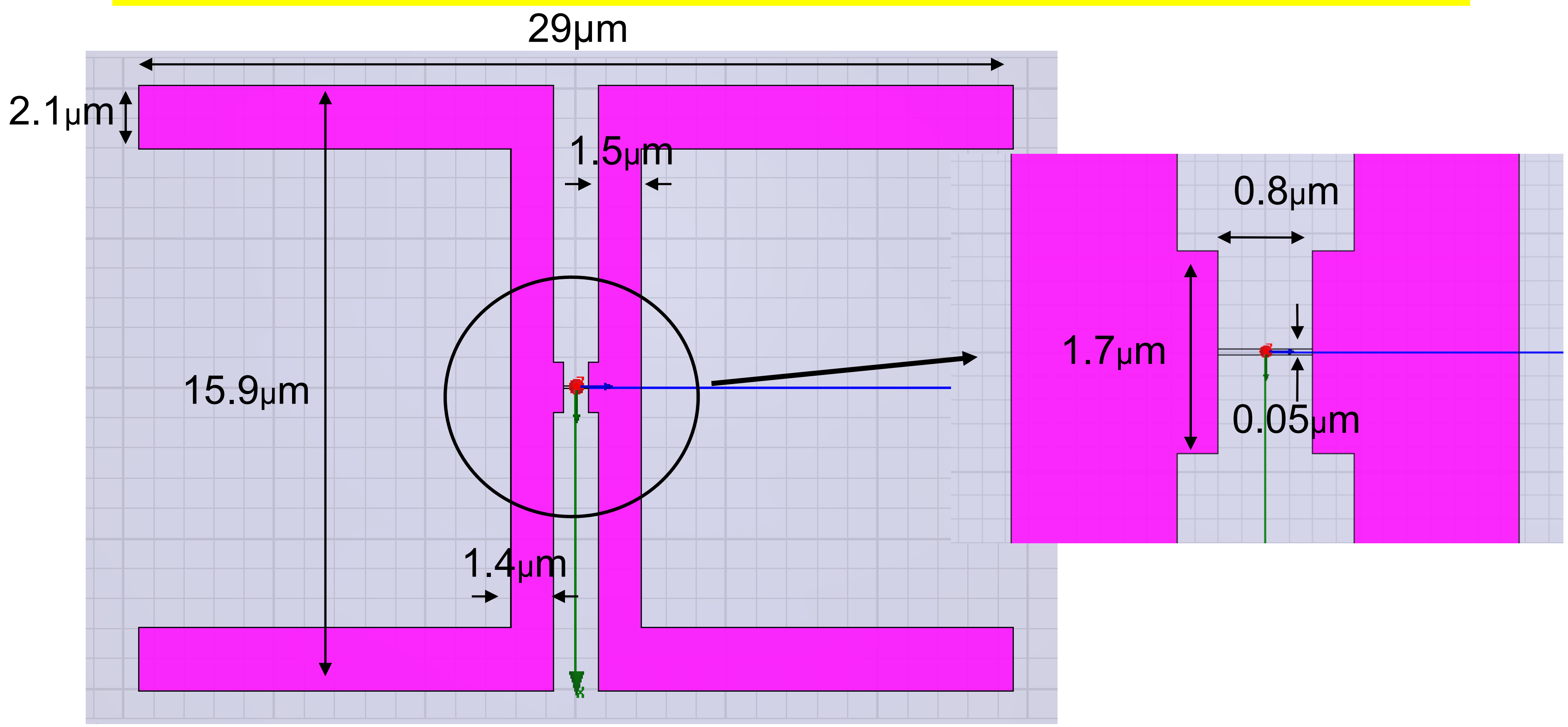

- Quasiparticles injected with a SIS junction
- NEP on the order of $10^{-18}$ W/Hz$^{1/2}$
- Large scalability
- Next step: couple light to the detector

# Detector Scheme




- Radiation is absorbed by the antenna which is coupled to the absorber
- Cooper-pairs are broken and quasiparticles tunnel through the junctions
- The quasiparticle density is proportional to the quasiparticle tunneling rate (our measurable quantity)

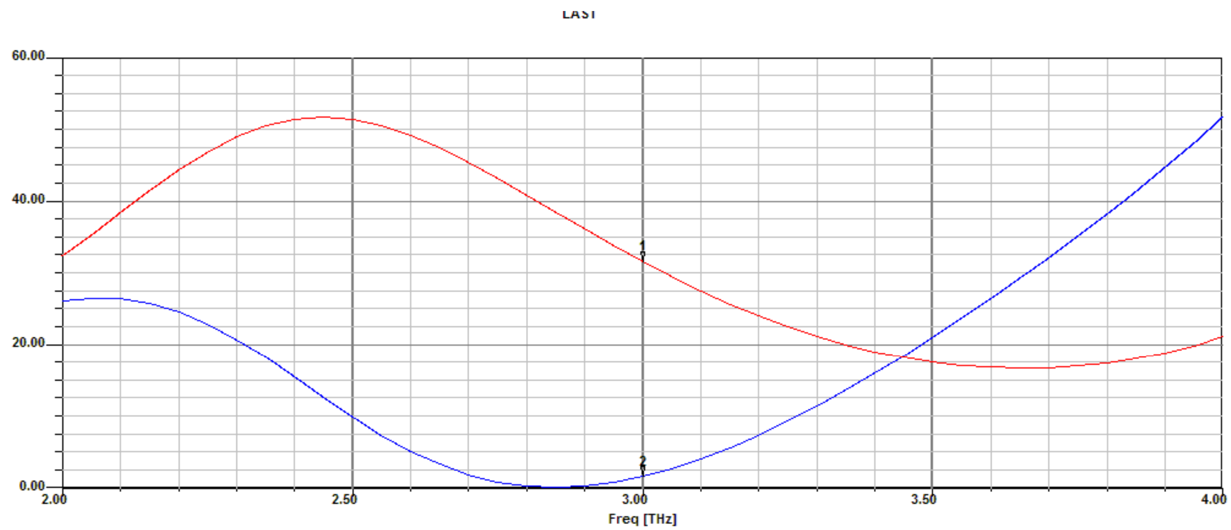
# Optical System (I)



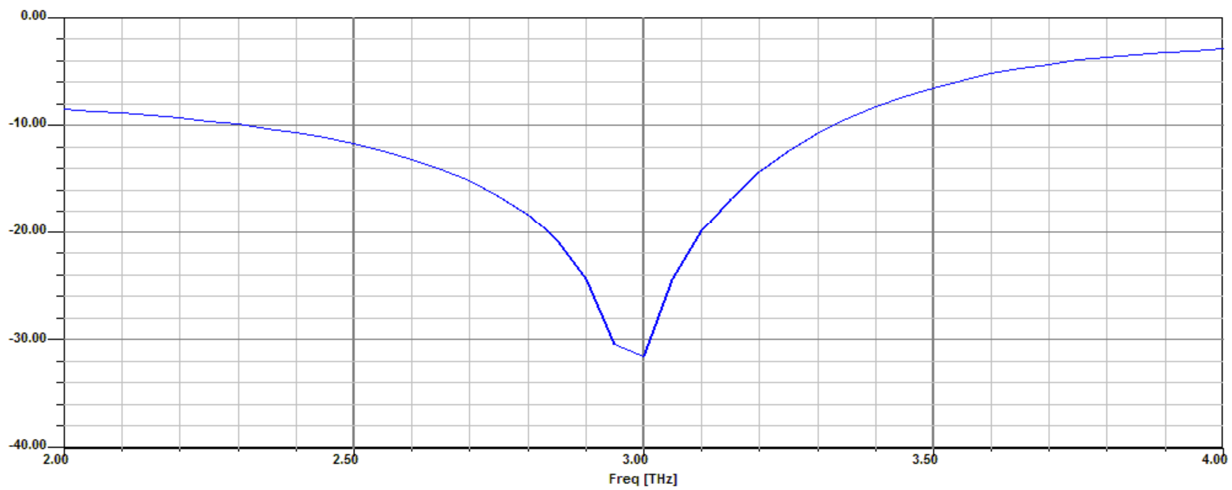

• Double-dipole antenna

• Frequency = 1.5THz (λ = 200μm)

# Optical System (II)



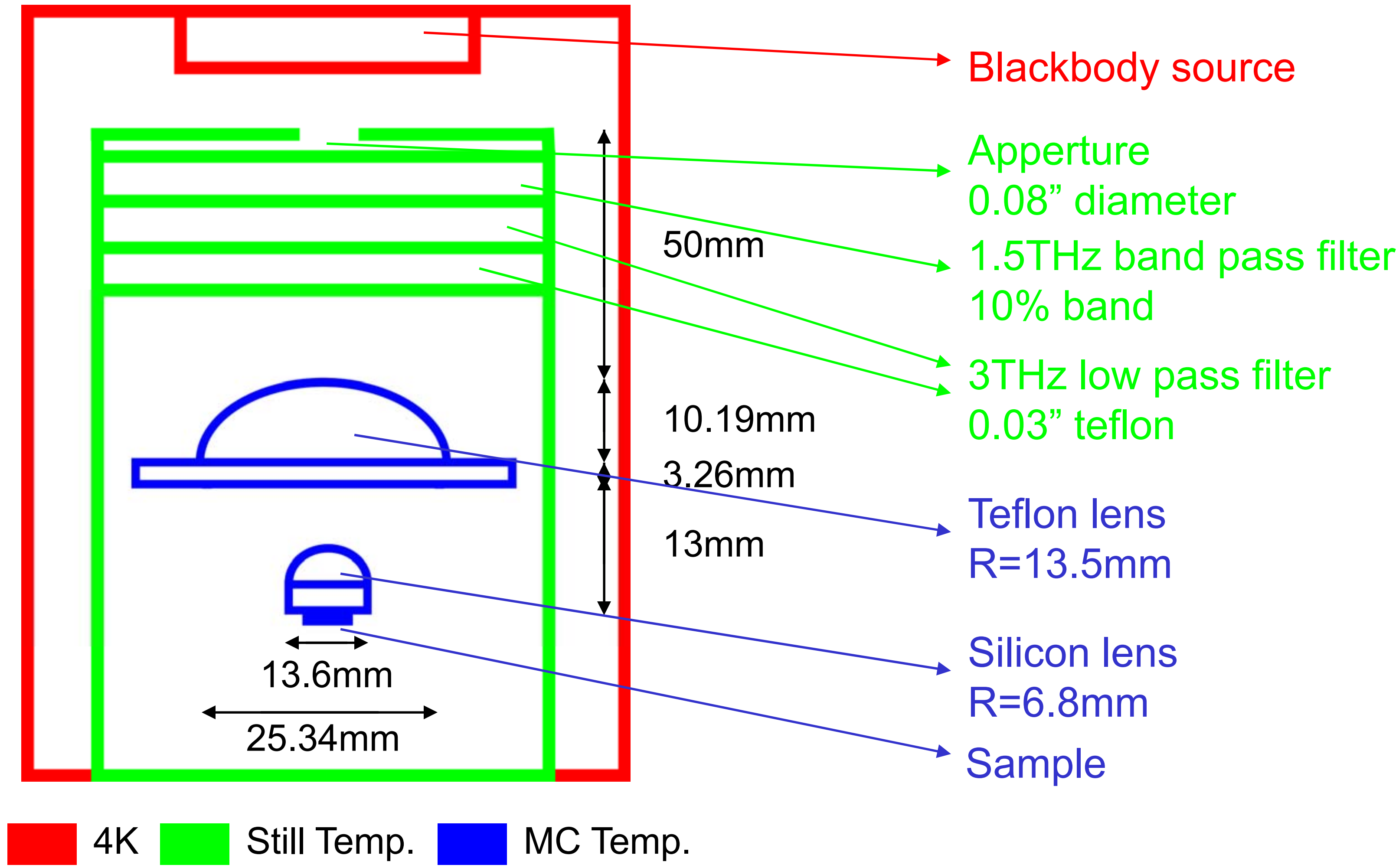

• Z = 32Ω



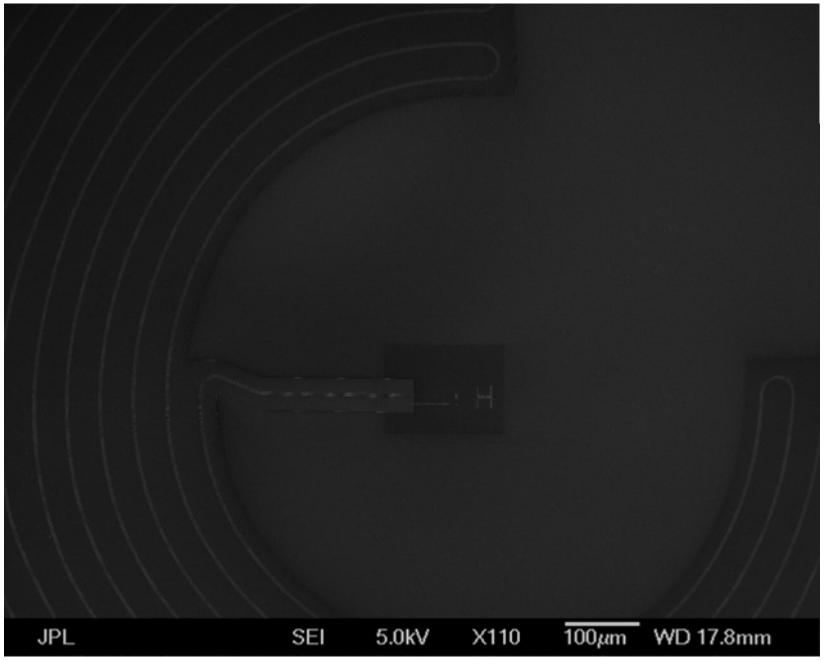

• Resonance @ 1.5 THz

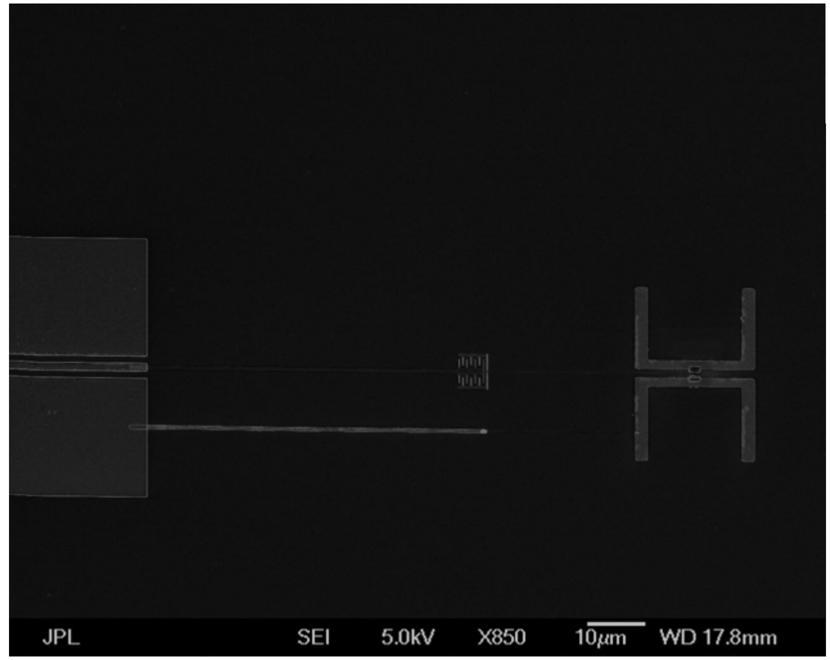
• 30% bandwidth

# Optical System (III)



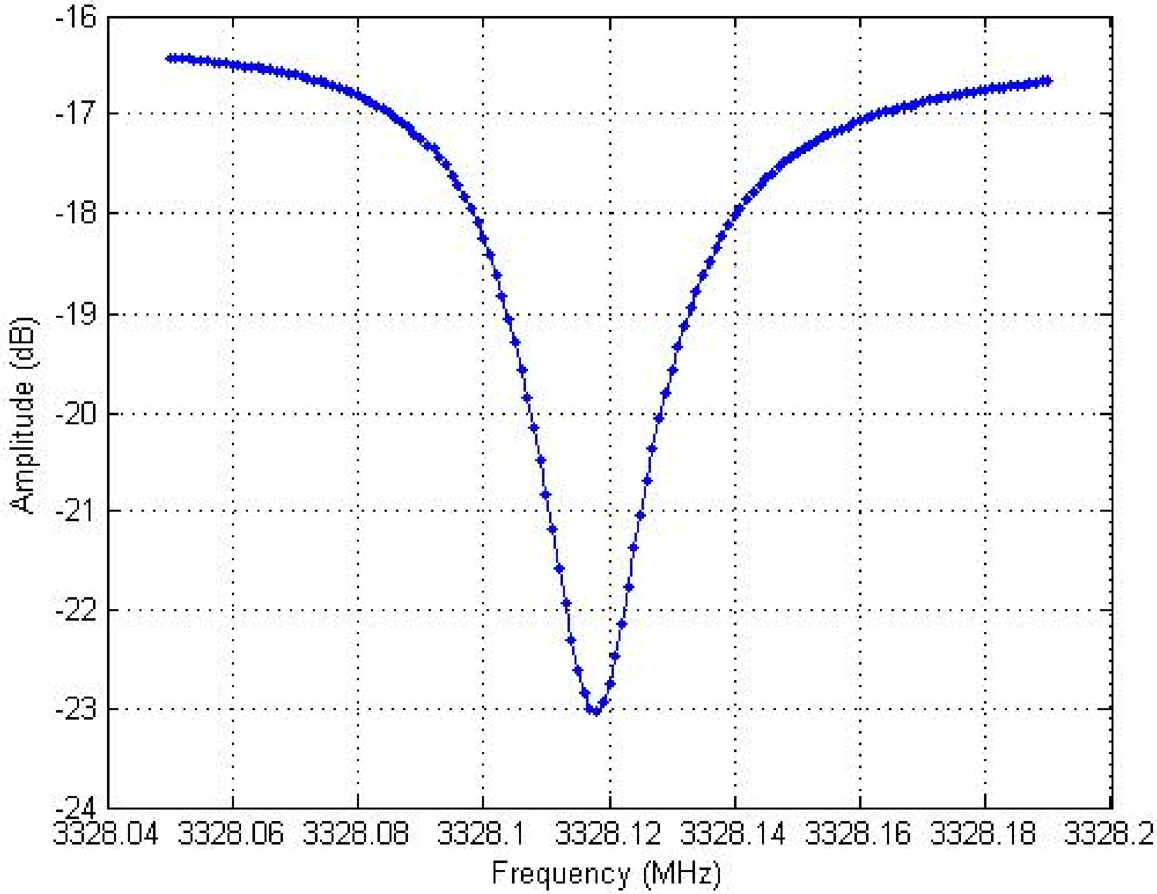
# Detector



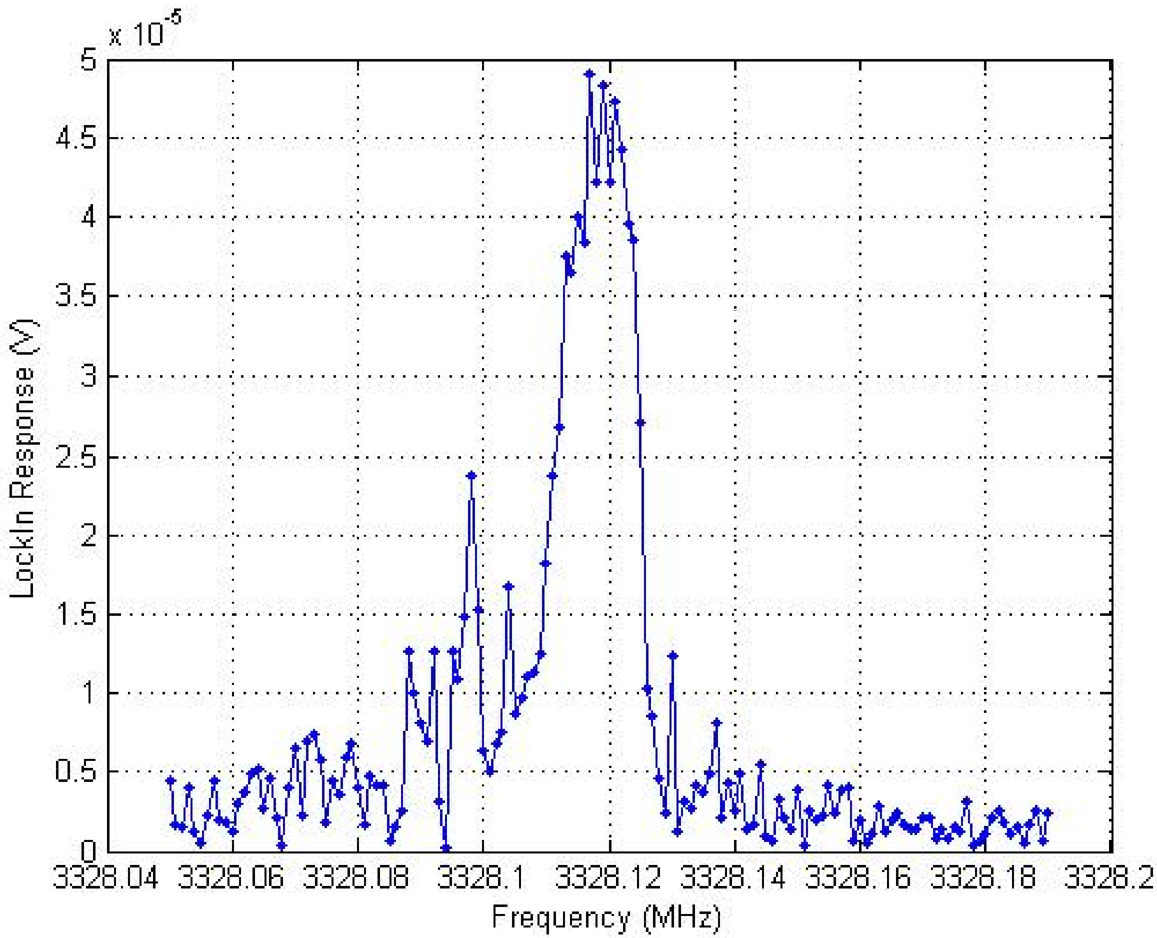

- Cooled down with a dilution refrigerator, experiments done at 100mK
- Nb λ/2 resonator, Au antenna with Al absorber with Nb plug for quasiparticle trapping
- QCD out of Al/AlOx/Al

# Resonance



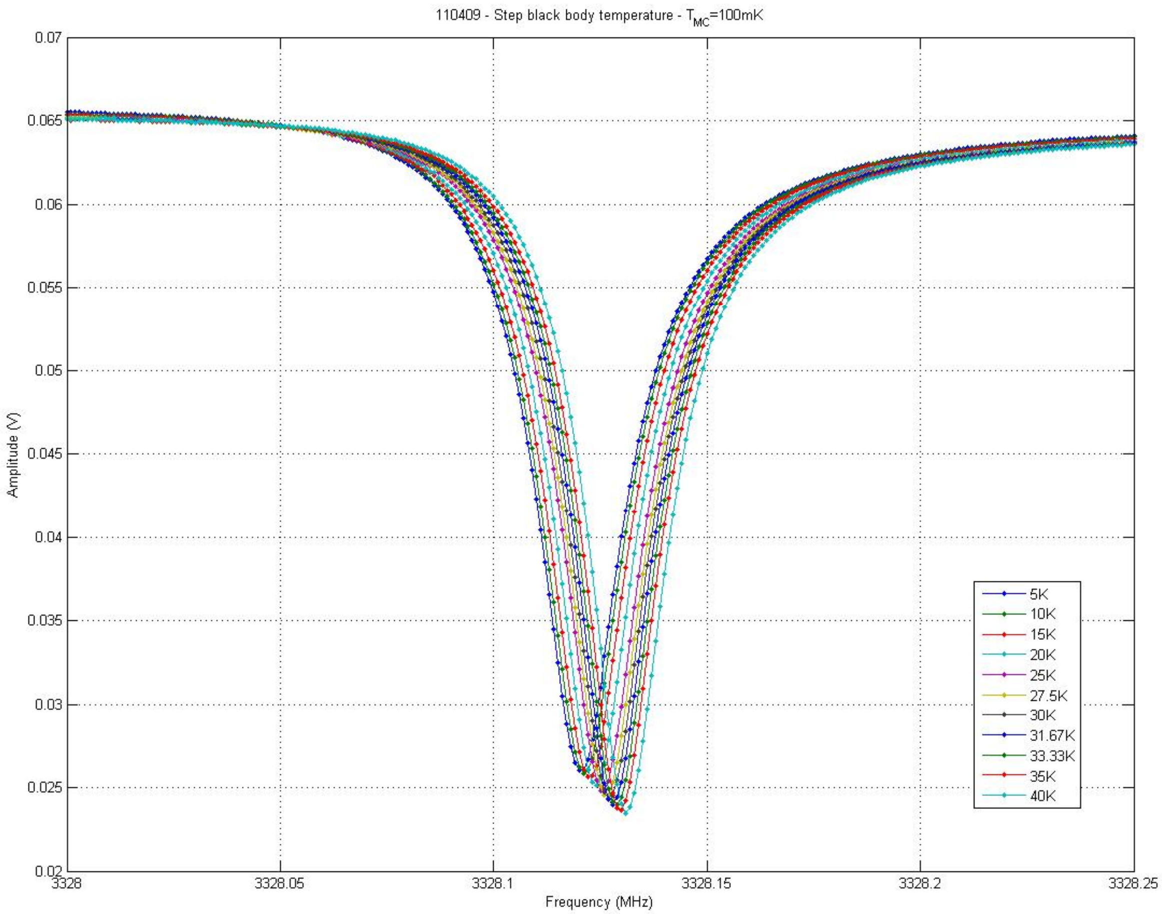

- Resonance frequency = 3.328118 GHz
- Q = 150000
- Peak depth = 6.5 dB

# Qubit signal



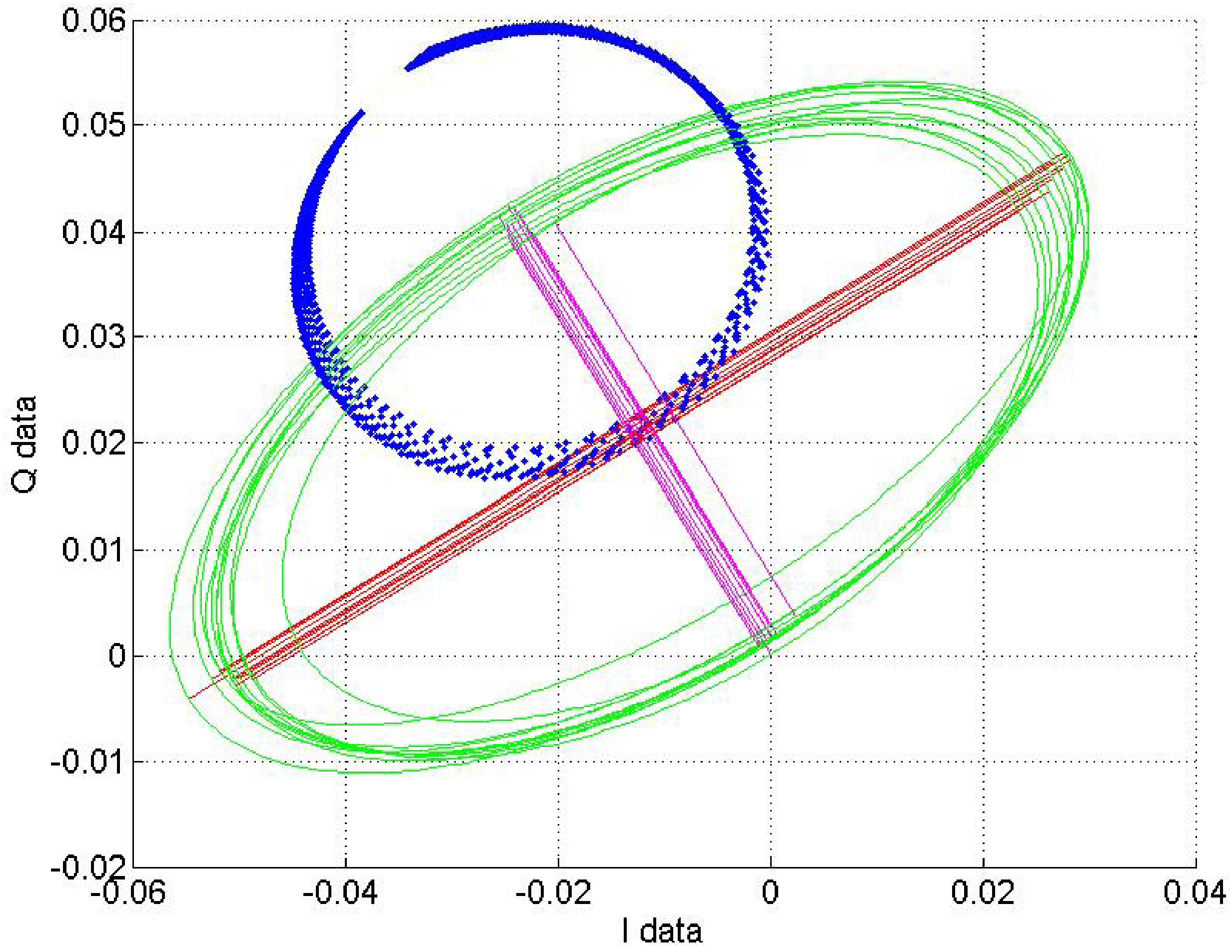

- Measured with a Lock-in amplifier technique
- Qubit biased with an AC tone at 25kHz

# Sending light to the QCD




- Step the blackbody temperature from 5 to 40K
- Resonance moves towards the right
- Consistent with a drop of the quantum capacitance signal

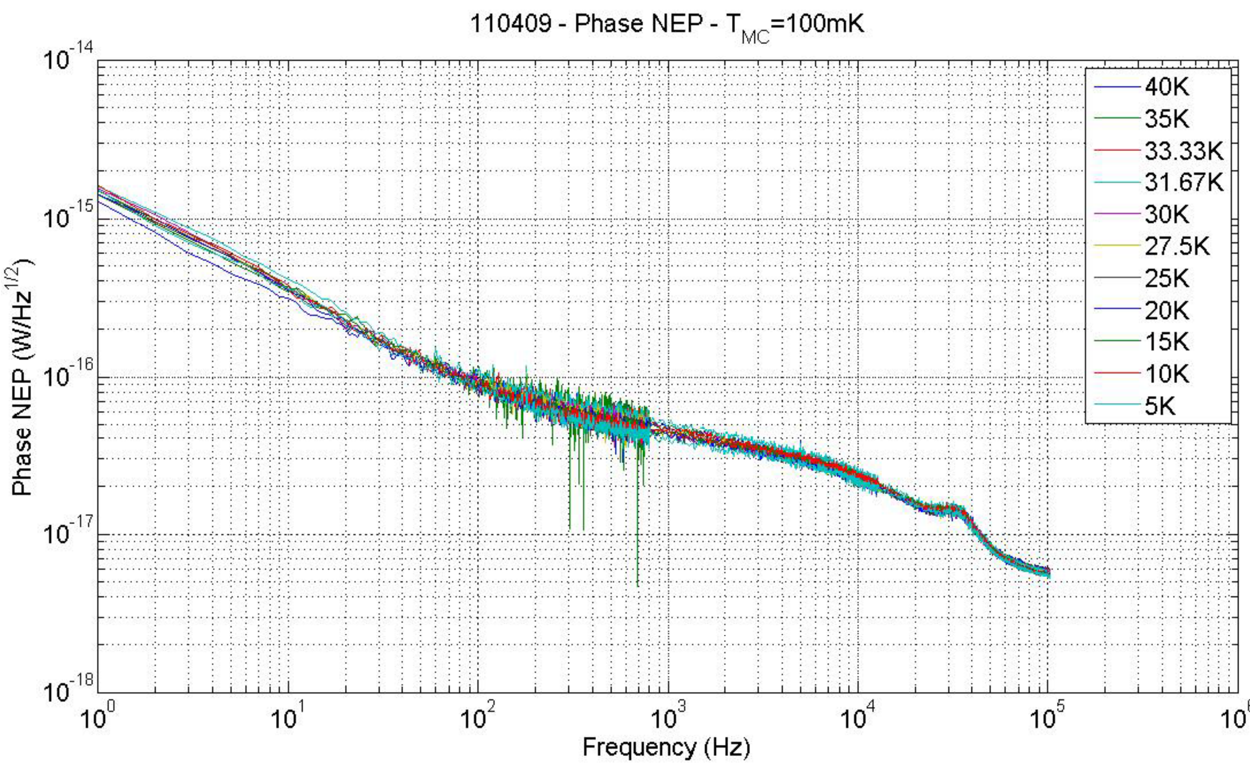
# Measuring the noise




- Noise measured with a spectrum analyzer at the resonance frequency
- Phase and amplitude noise measured for each temperature

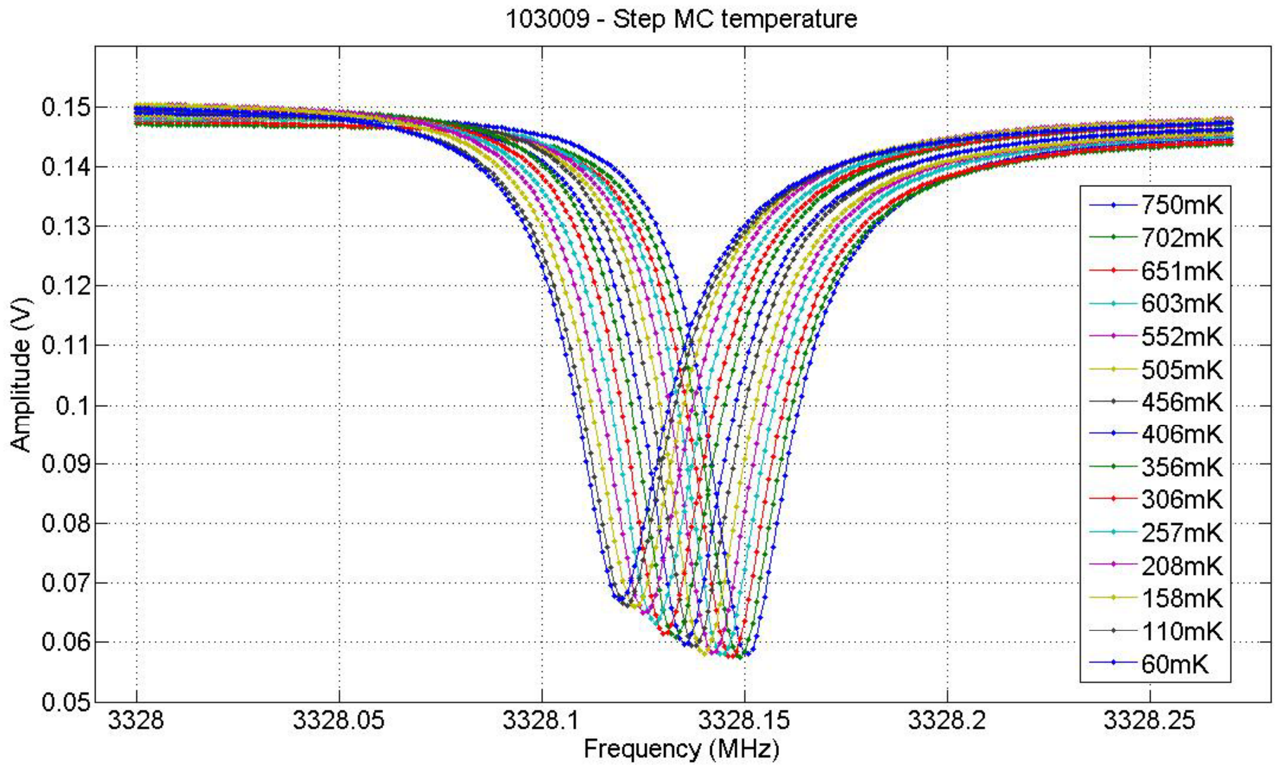
Ellipse of noise multiplied by 50 in the figure

# Phase NEP



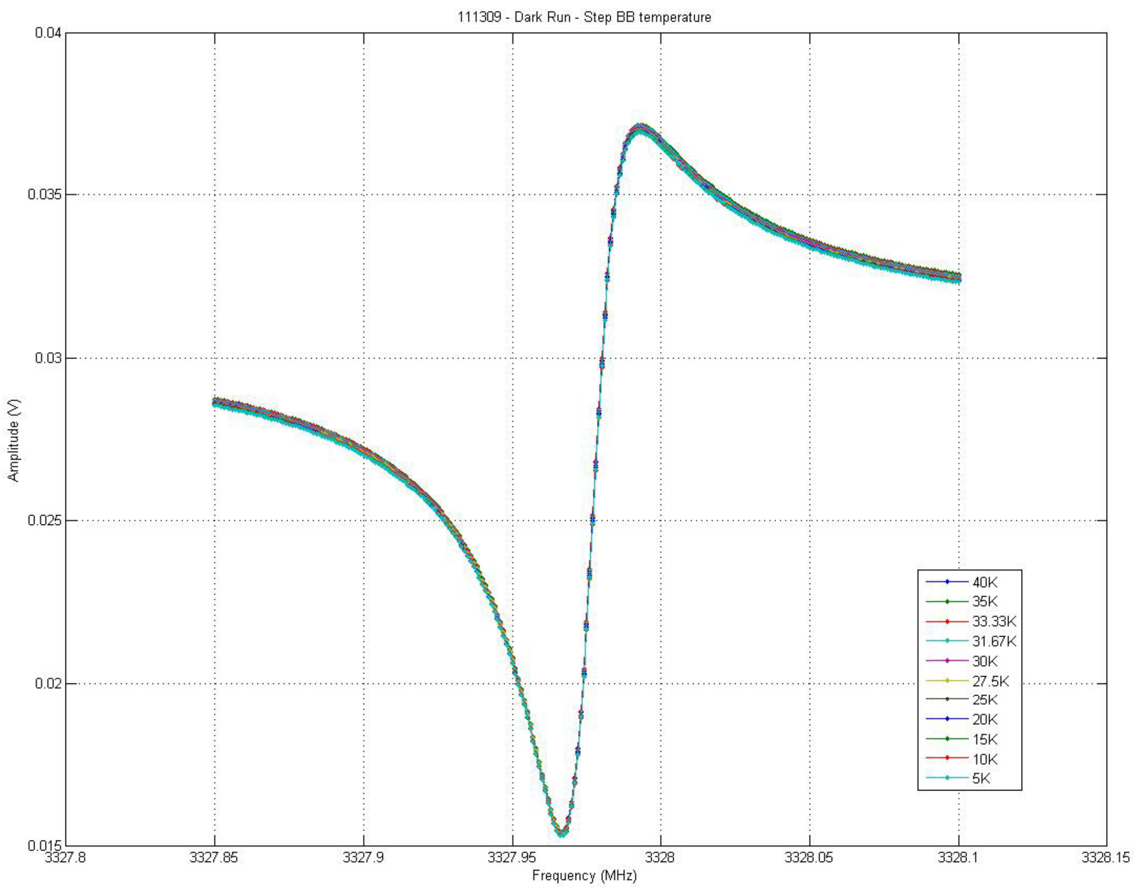

- Blackbody radiation couples to the detector in the single mode
- Filter bandwidth = 10%
- Transmission = 60%
- Resonance frequency shifts 400Hz/K
- NEP about $10^{-17}$ W/Hz$^{1/2}$

# Thermal behavior of the resonator



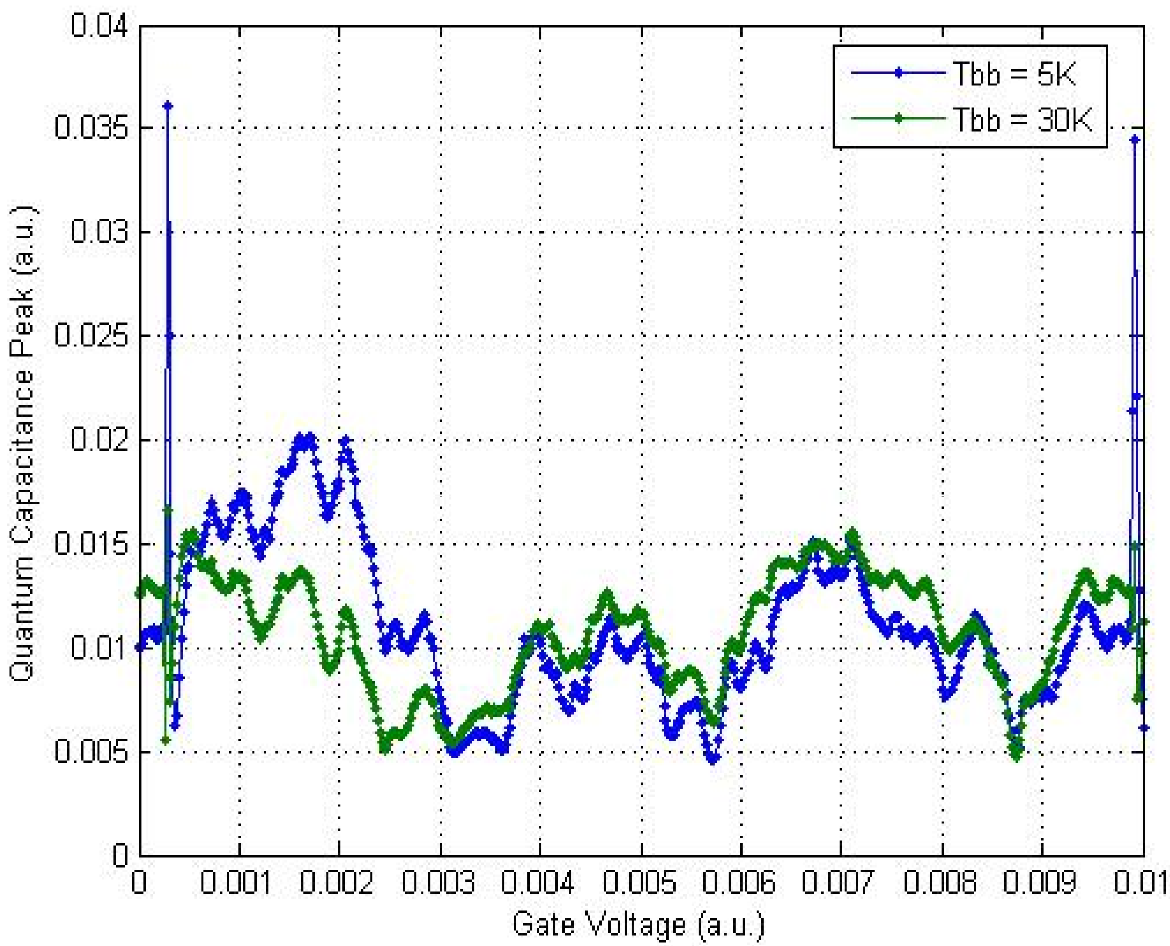

- Two level systems could be the cause of the frequency shift
- Step the mixing chamber temperature
- In order to get the same frequency shift, the mixing chamber should be at 300mK (too high!)

# Dark run



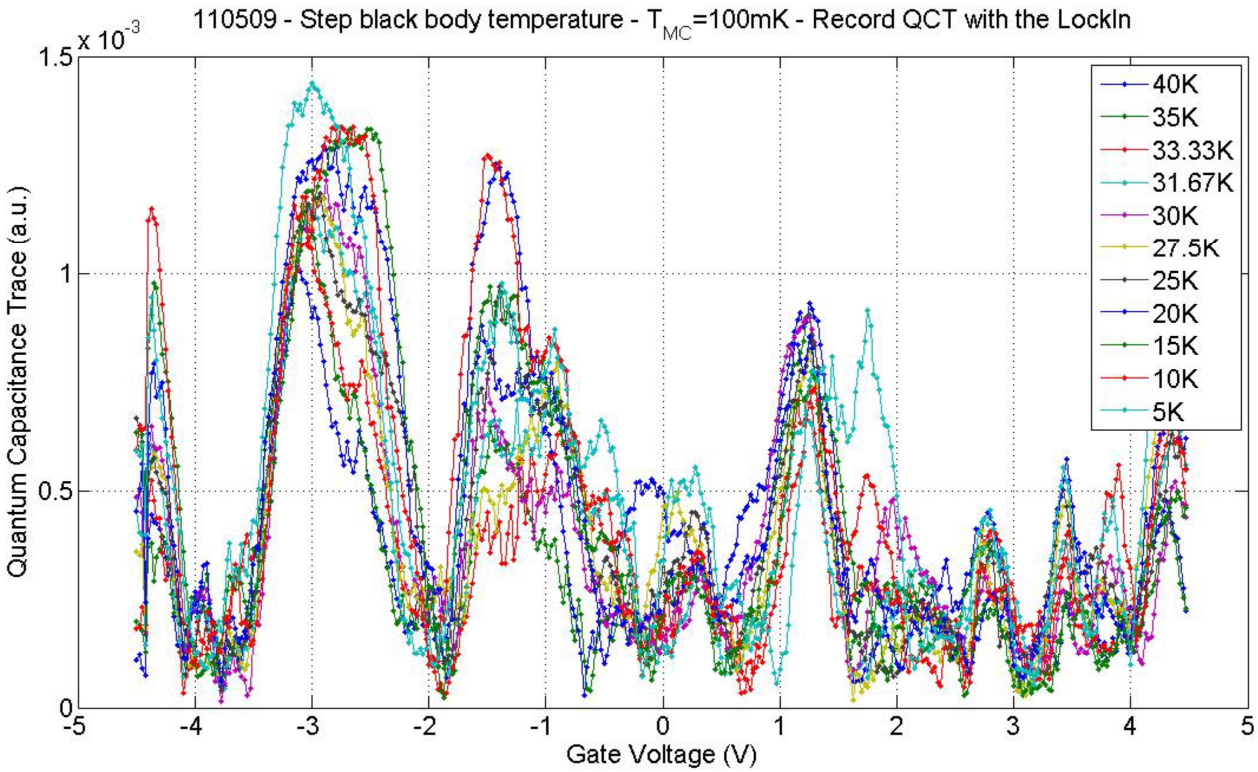

- Close all the windows to the experiment
- Step the blackbody temperature
- Resonance does NOT change at all
- Different shape due to magnetic flux trapped

# Quantum Capacitance Trace (I)



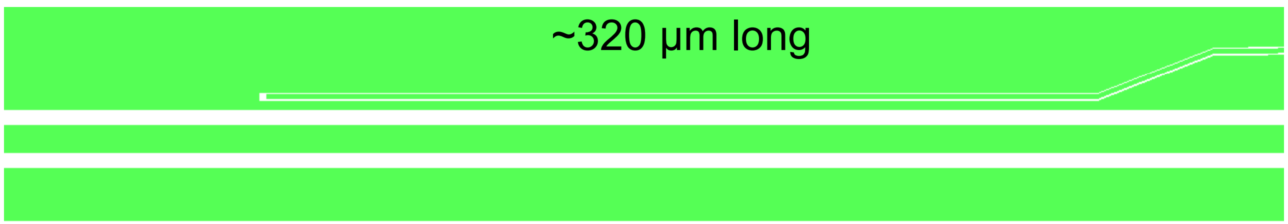

- Send a ramp to the gate and look at the signal with an oscilloscope
- No clear quantum capacitance peaks visible
- However, the signal drifts when an offset is applied to the ramp

# Quantum Capacitance Trace (II)

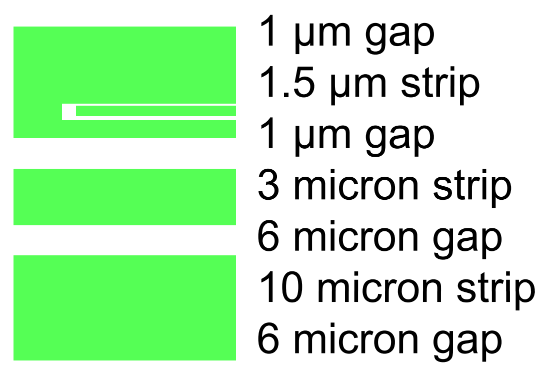


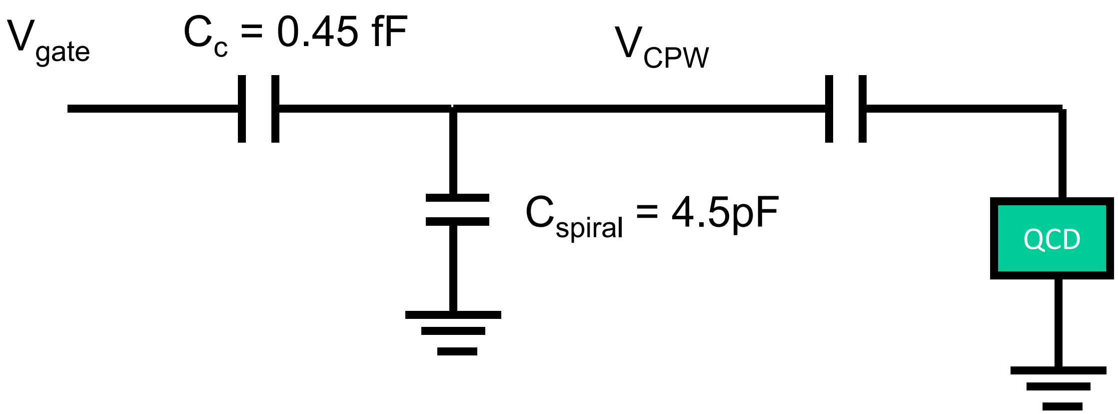

- Step the gate voltage and use a lock-in technique to look at the signal
- No clear quantum capacitance peaks visible.
- Step the blackbody temperature. Some peaks grew, some peaks decreased
- No clear conclusion can be drawn

# Quantum Capacitance Trace (III)



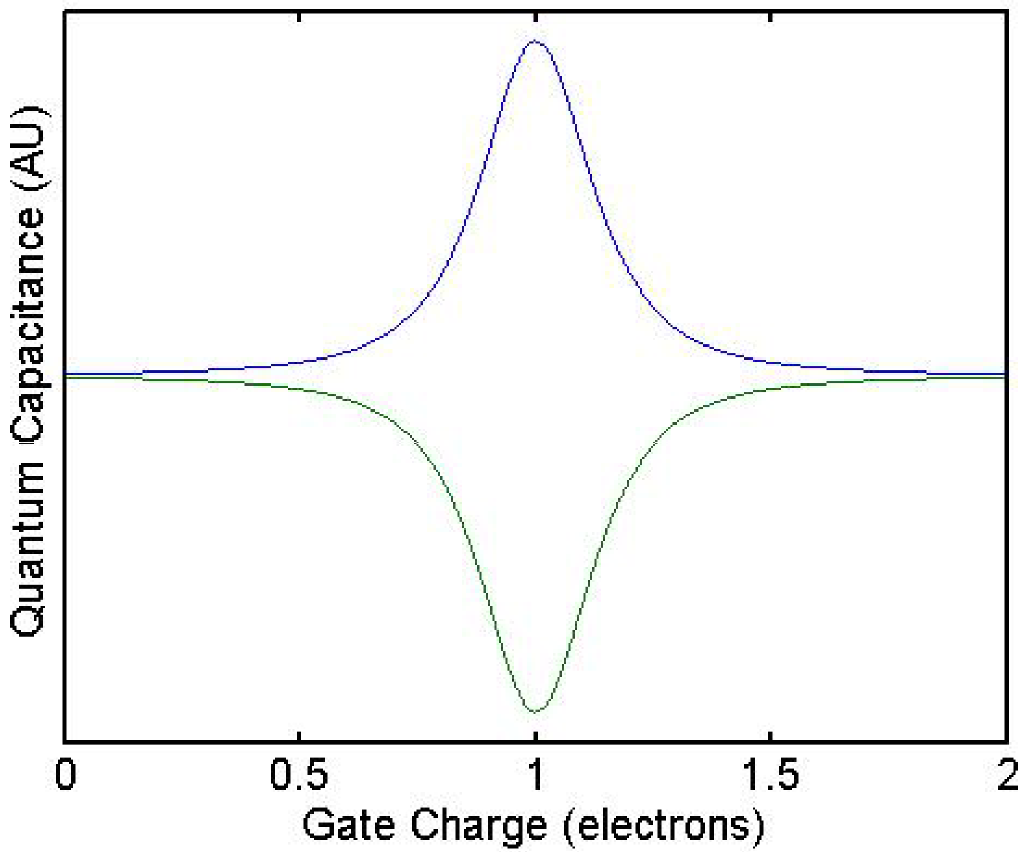

$C_c = 0.45$ fF




- Voltage divider
- $V_{CPW} = V_{gate}\ C_c / C_{spiral}$
- This is possibly the reason why we do not see a clear quantum capacitance trace

# Room for Improvement




- Adding an extra line for gating the qubit and biasing it at its degeneracy point
- Designing a new optimized optical system
- Coupling the QCD to a better quality resonator

# Conclusions

1.- Light has been coupled to the QCD

- Antenna couple radiation has been succesfully detected by the QCD
  - Response in both the phase and the amplitude

2.- Optical NEP in the order of $10^{-17}$ W/Hz$^{1/2}$ have been obtained for the phase signal

- Comparable to current detectors?

3.- Lots of room for improvement

- Separate gate line for the qubit
- Better optical system
- Better quality resonator