Design and simulation of single and coupled qubits towards tunability

QUART&T kickoff meeting

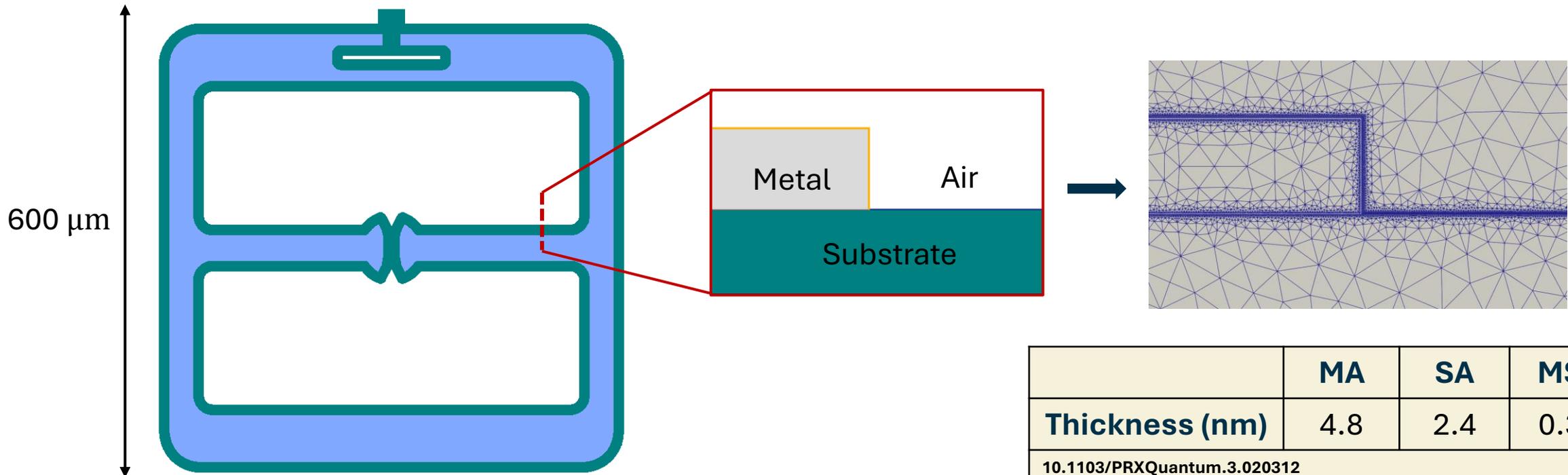Roberto Moretti – University of Milan Bicocca

Objectives

- A series of coplanar designs of increasing complexity to validate our control on modeling and simulating transmon qubit chips.

- Our past work (10.48550/arXiv.2409.05988) resulted in satisfactory agreement between the measured qubit properties and the ones extracted from quantization methods and FEM solvers, but T_1 and T_ϕ were limited.

- **Goal:** achieve a systematic improvement of **coherence** times, test the use of **Purcell filters** and implement **two-qubit gates**.

Improved TLS simulations

Two-level system (TLS) losses modeled with a hybrid 3D-2D approach, combining the precision of the full 3D geometry with the finer meshing of 2D.

- Computing EPRs on all surfaces, vacuum and substrate.
- Using 2D results to correct for Ansys Eigenmode EPR on customized-regions.
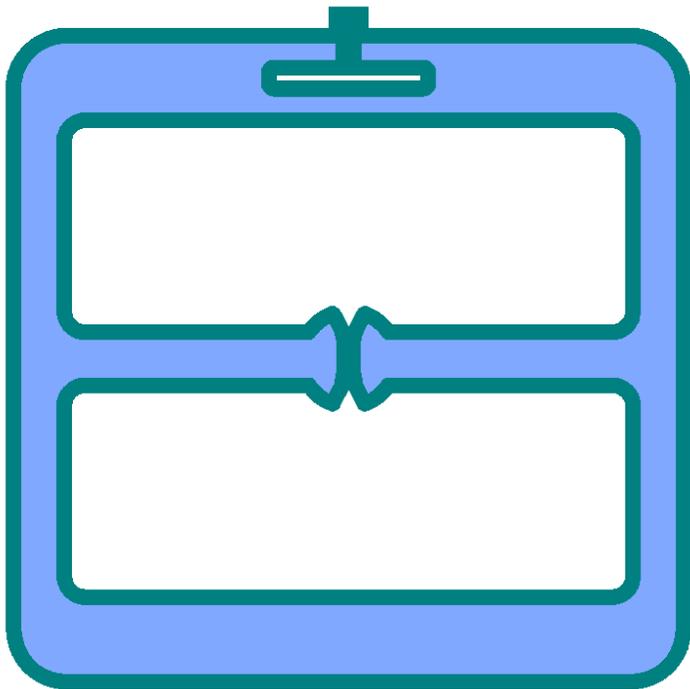- Engineering shapes to reduce **surface** EPR.

$$\frac{1}{T_{1\,TLS}} = \frac{\omega}{Q} = \omega \sum p_i \tan(\delta_i)$$

600 μm

Metal   Air

Substrate

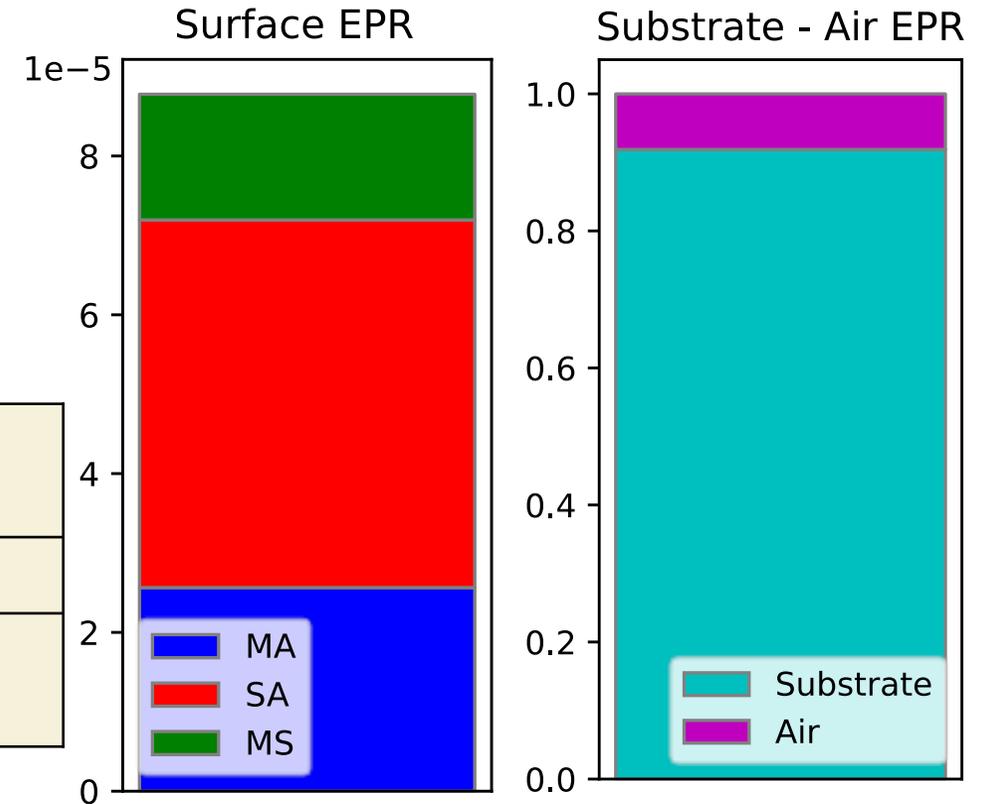|	MA	SA	MS
Thickness (nm)	4.8	2.4	0.3

Improved TLS simulations

- Bigger area and larger gaps lead to higher coherence time.
- **Surface loss decreases by a factor of 3.5** with respect to a standard x-mon.

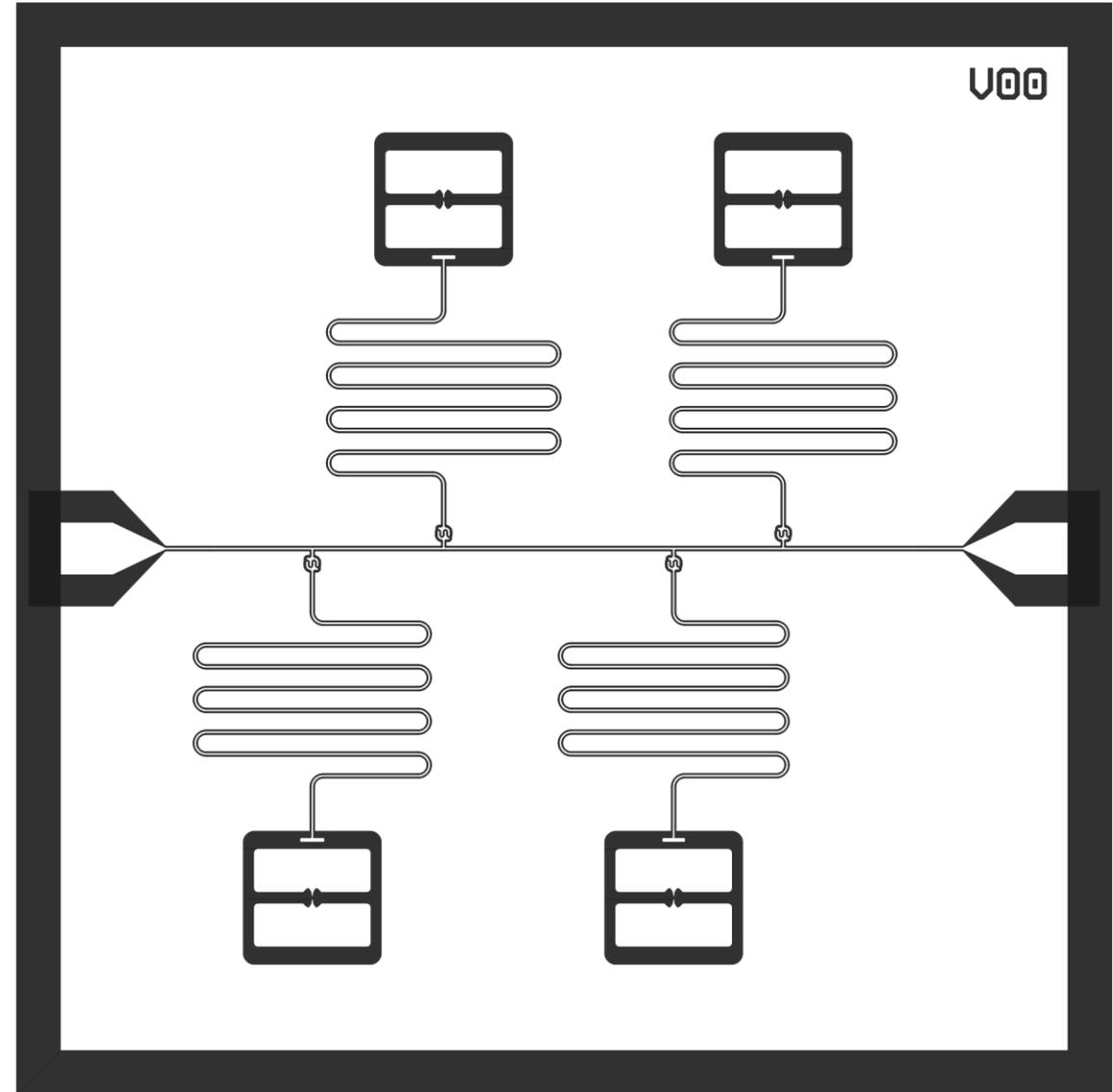| $f_{01} = 5.7$ GHz	Hybrid (MER)
$T_{1\,TLS}\,(\mu s)$	31.1
$\delta_{MA}, \delta_{SA}, \delta_{MS}, \delta_{substrate}$ as in **10.1103/PRXQuantum.3.020312** M. V. P. Altoé et al. (2022).	

$$T_{1\,TLS}^{substrate} = 61\ \mu s$$

Surface EPR

- MA
- SA
- MS

Substrate - Air EPR

- Substrate
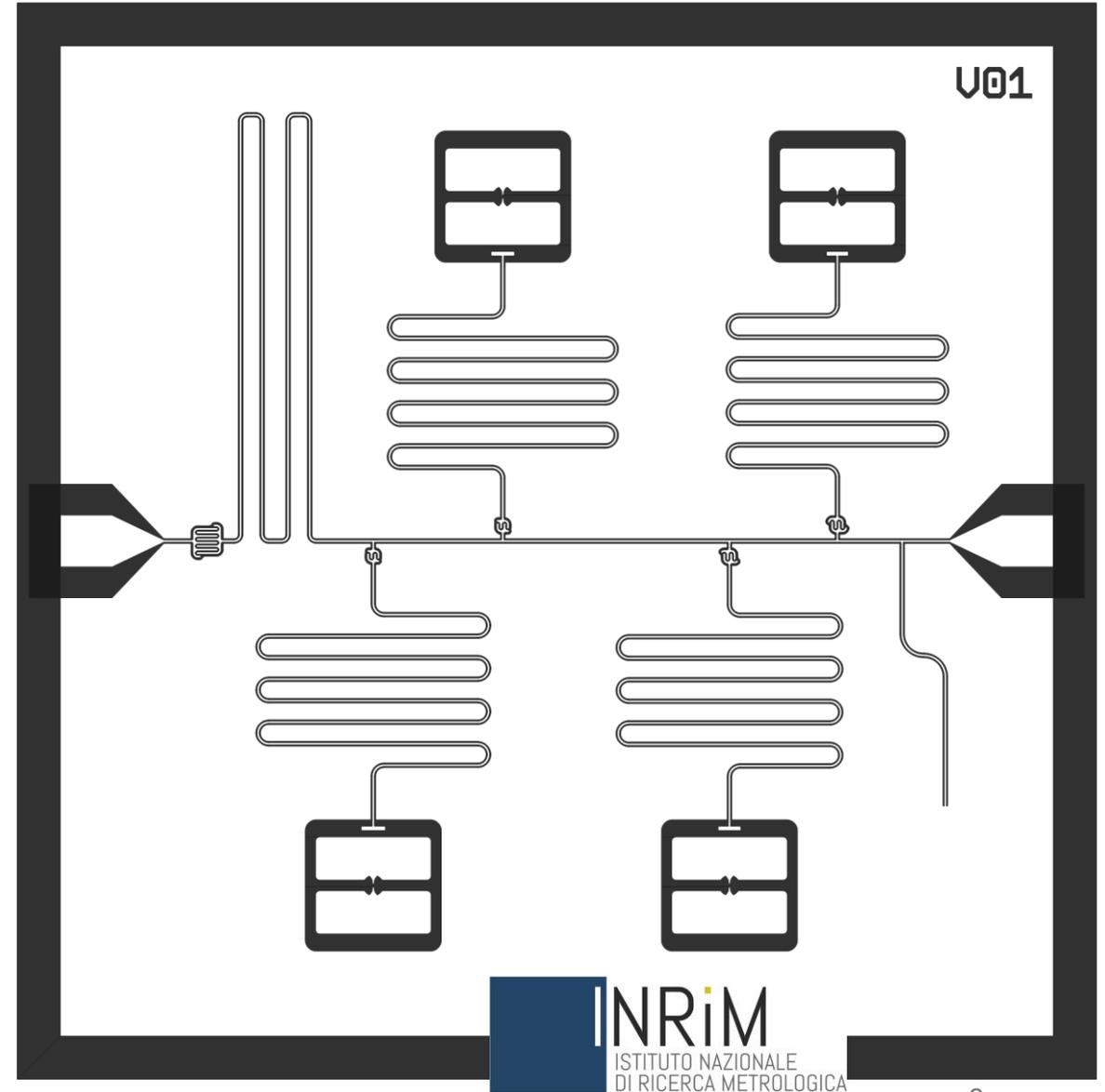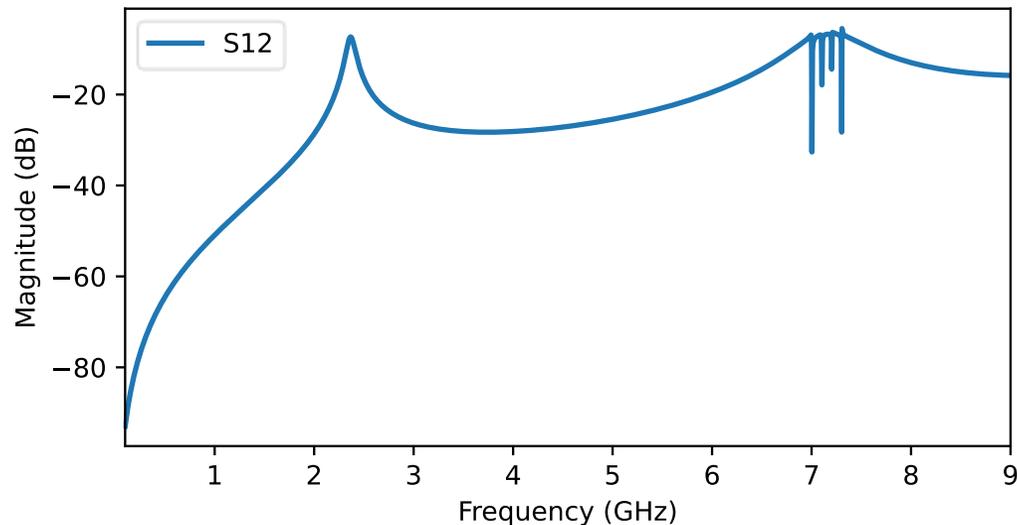- Air

Uncoupled test qubits

- Big-sized doublepads (gap area: 630x600 um).

- Idea: minimize the Energy Participation Ratio (EPR) on the oxide surfaces, hence the TLS losses.

- 4 qubits, targeting 4-4.4 GHz. Large resonator detuning (3 GHz).

- Dispersive (multiplexed) readout through lambda/2 resonator, ensuring purely capacitive coupling between resonator and feedline.

Just been fabrcated at INRiM

Purcell filtered uncoupled qubits

- This variant adds a 1.2 GHz-wide Purcell filter in a 'feedline-resonator' architecture.

- The filter is dimensioned so that the $\frac{3}{4}\lambda$ mode is centered in the readout resonator frequencies.

- We expect faster readout pulses and a higher Purcell-limited T1.

Bus-coupled qubits

- Two large double-pads qubits coupled via lambda/2 resonator. The exchange rate is known analytically.

- This architecture is **fully-fixed** in frequency and allows to implement Cross-Resonance gates.

$<\sigma_z>$
Target

Control in $|0\rangle$

Control in $|1\rangle$

Time [ns]

Soon fabricated at NIST

V00

UNIMIB

Conclusions

- A new yield of quantum devices is soon to be characterised.

- Aims: increased coherence, Purcell protection, implementing two-qubit gates.

- Further steps will depend on the measurement outcome.

- More complex design will additionally feature tunable coupling schemes (see next talk from Alessandro Cattaneo).