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IMT Atlantique
Bretagne-Pays de la Loire
École Mines-Télécom



Spin Cavitronics System: From Strong to Ultra-Strong Coupling

Guillaume Bourcin^{1,2}, Vincent Vlaminck^{1,2}, Jeremy Bourhill³, Vincent Castel^{1,2}

¹Lab-STICC (UMR 6285), CNRS, France

²IMT Atlantique, Technopole Brest Iroise, 29200 Brest, France

³University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia

Introduction

Experimental study of ultra strong coupling (up to 60%) at room temperature with reconfigurable double re-entrant cavities and a millimetric YIG slab.

Currently used models no longer describe the observed hybridization between cavity photon and magnon above the strong coupling regime.

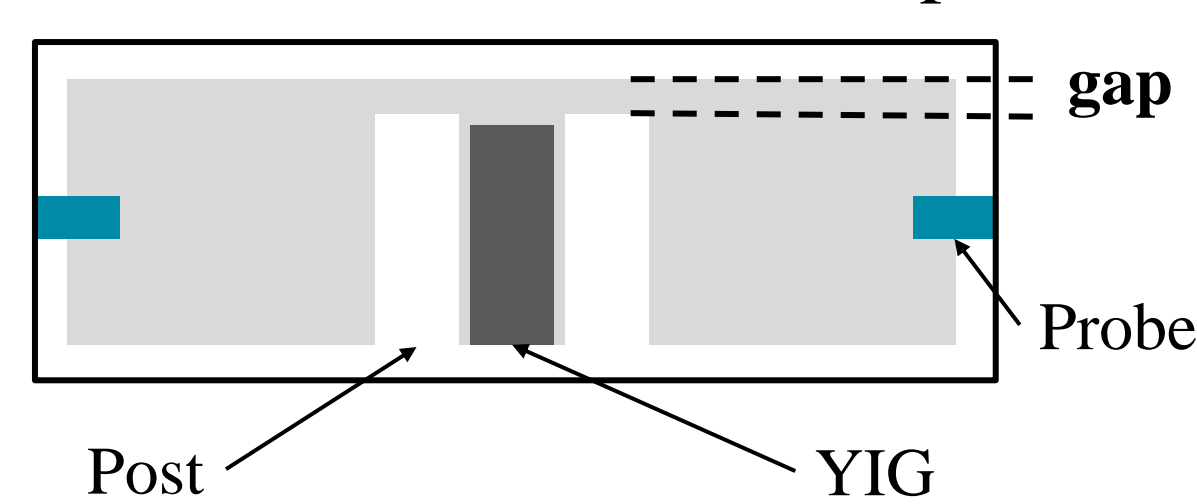
Advantages:

- ▶ Tunable (magnons and photons)
- ▶ Long coherence times (YIG)
- ▶ Ability to be coupled to other systems (e.g. qubits)

Cavity Design & Optimization

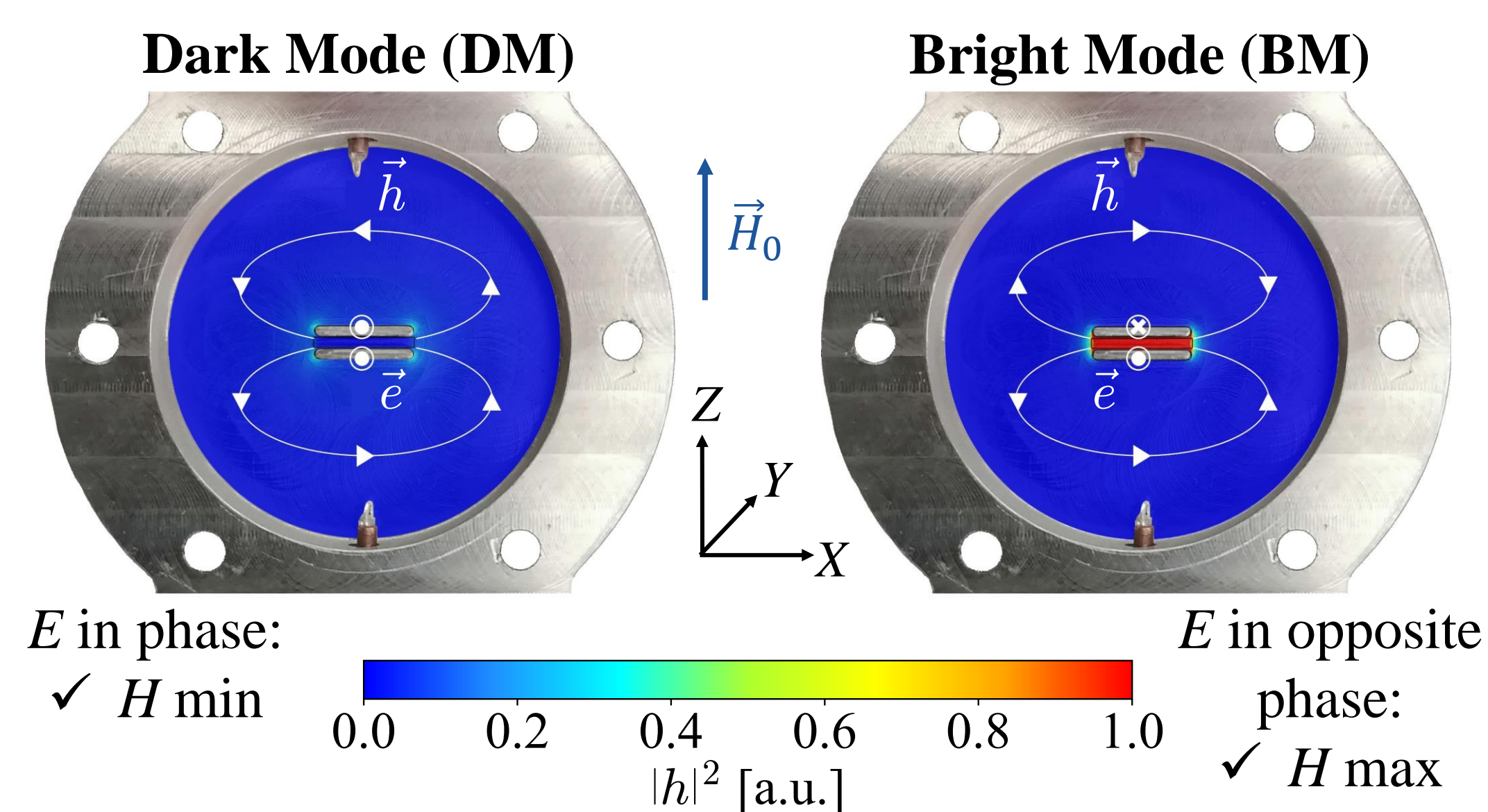
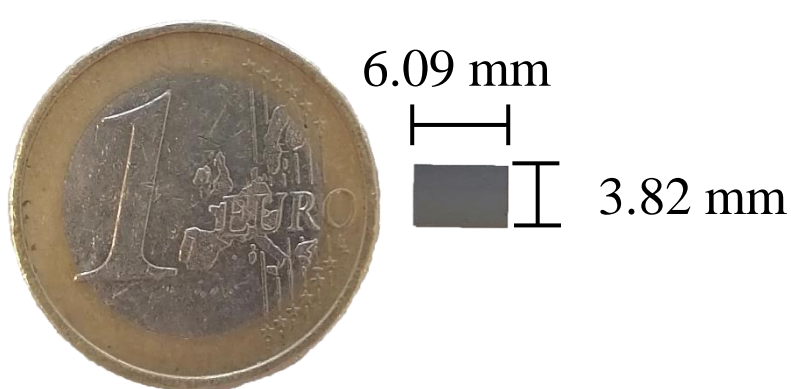
Double re-entrant cavity [1]:

- ▶ RF H -field in the YIG
- ▶ RF H and E -fields separated



Slab dimensions:

3.82×6.09×0.61 mm³



Coupling strength:

$$\frac{g}{2\pi} = \eta \sqrt{\omega} \frac{\gamma}{4\pi} \sqrt{\frac{\mu}{g_1 \mu_B}} \mu_0 \hbar n_s \quad \omega/2\pi: \text{Cavity frequency}$$

$$\eta: \text{Filling factor}$$



Optimisation:

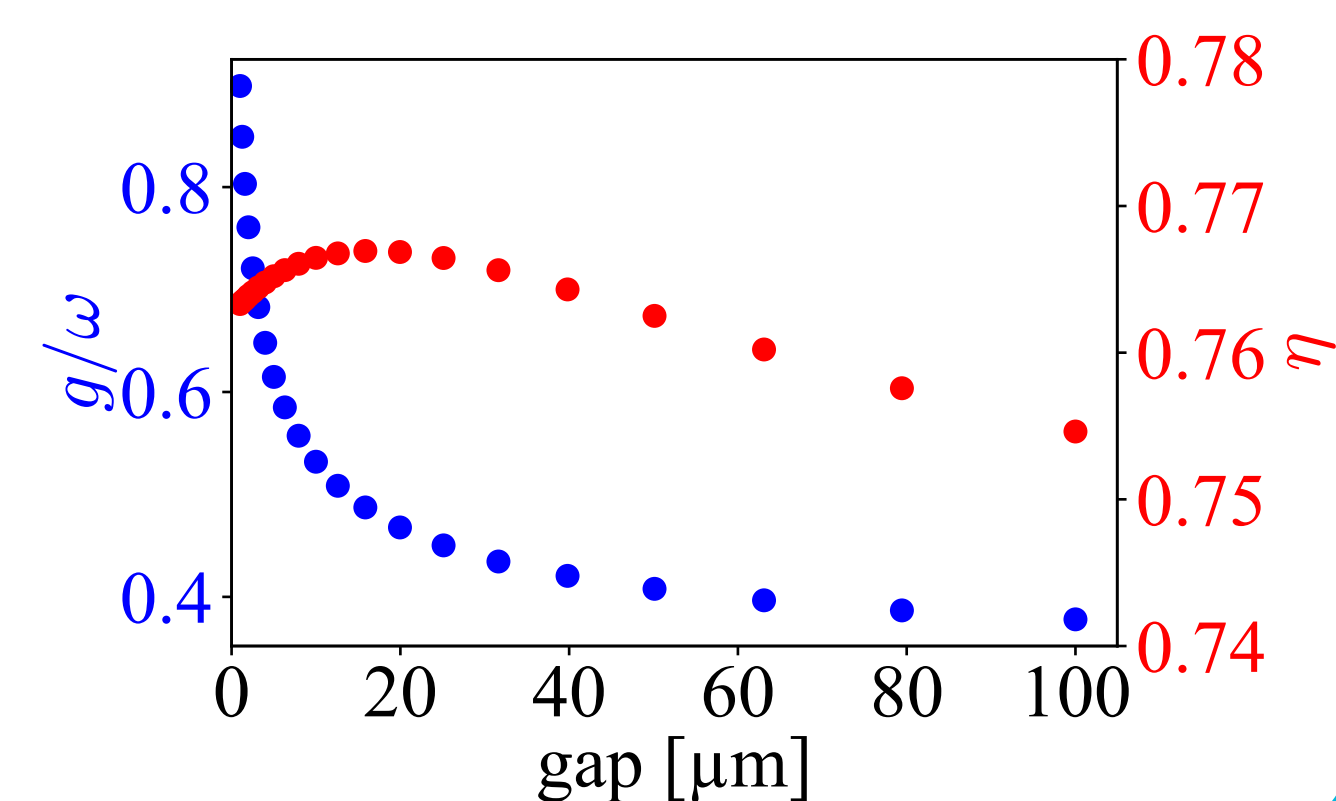
COMSOL simulation with EigenMode Solver:

- ▶ Maximize η

$$\eta = \sqrt{\frac{(\int_{V_m} \vec{h} \cdot \vec{e}_x dV)^2 + (\int_{V_m} \vec{h} \cdot \vec{e}_y dV)^2}{\int_{V_m} |\vec{h}|^2 dV}} \quad [2]$$

Gap dependence of the coupling strength

Posts dimensions:
6×4.2×0.6 mm³
Cavity radius: 12 mm



Study of the Transition SC/USC

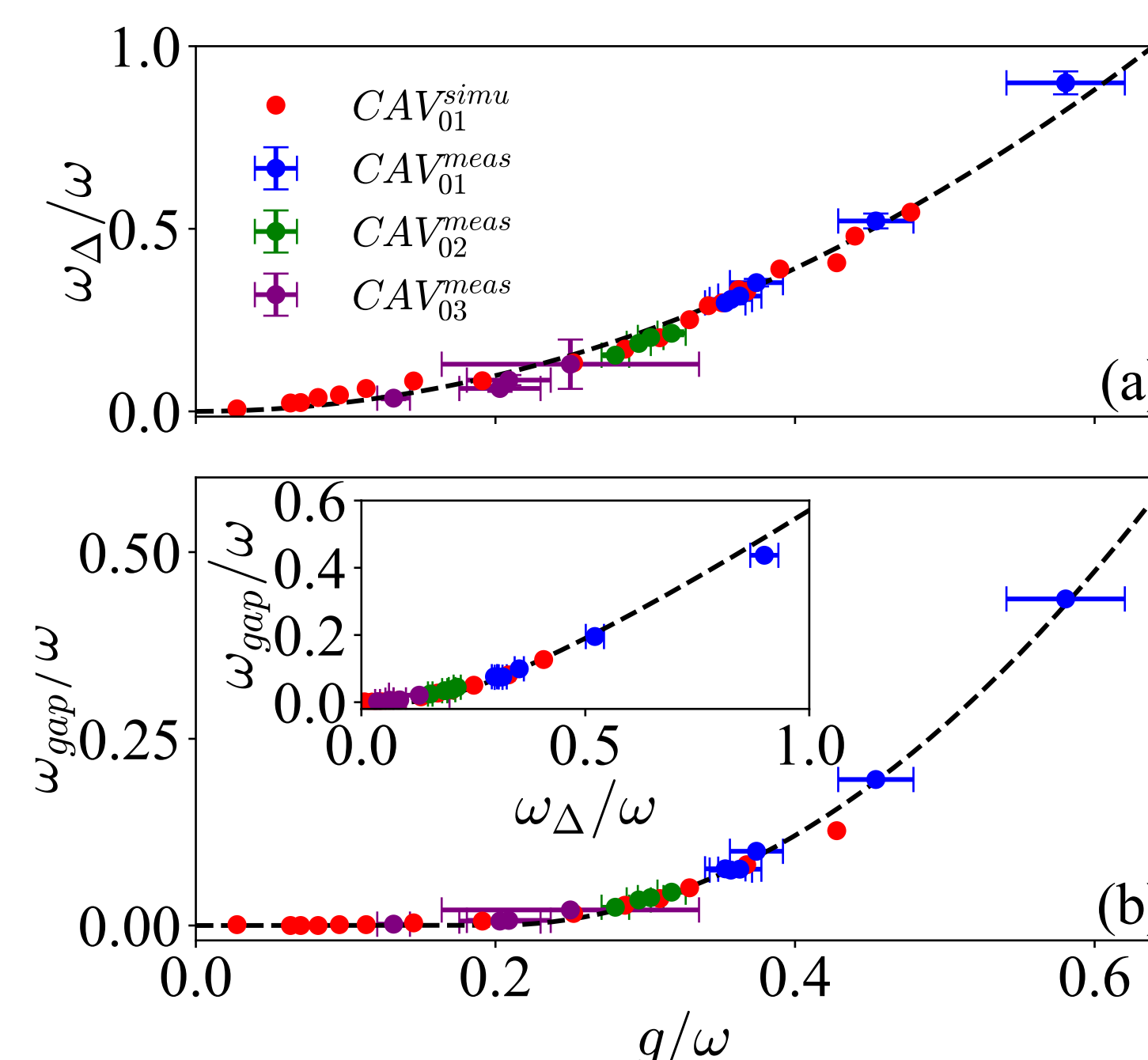
Reduce slab dimensions in simulations up to 1/5 with same aspect ratio allows to g/ω up to 2,7%.

Analysis:

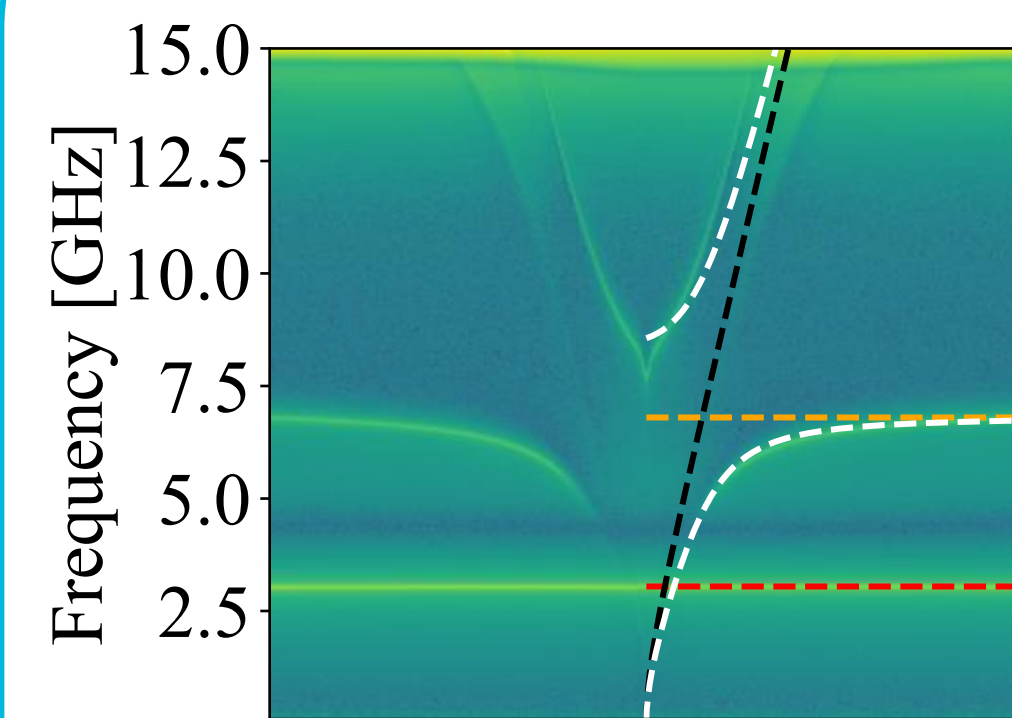
- ▶ ω_Δ is function to g^2/ω
- ▶ ω_Δ is negligible when $g/\omega < 0.1$

✓ SC: converges to the standard Dicke model

✓ It exists a forbidden gap in USC



Measurements & Modelling

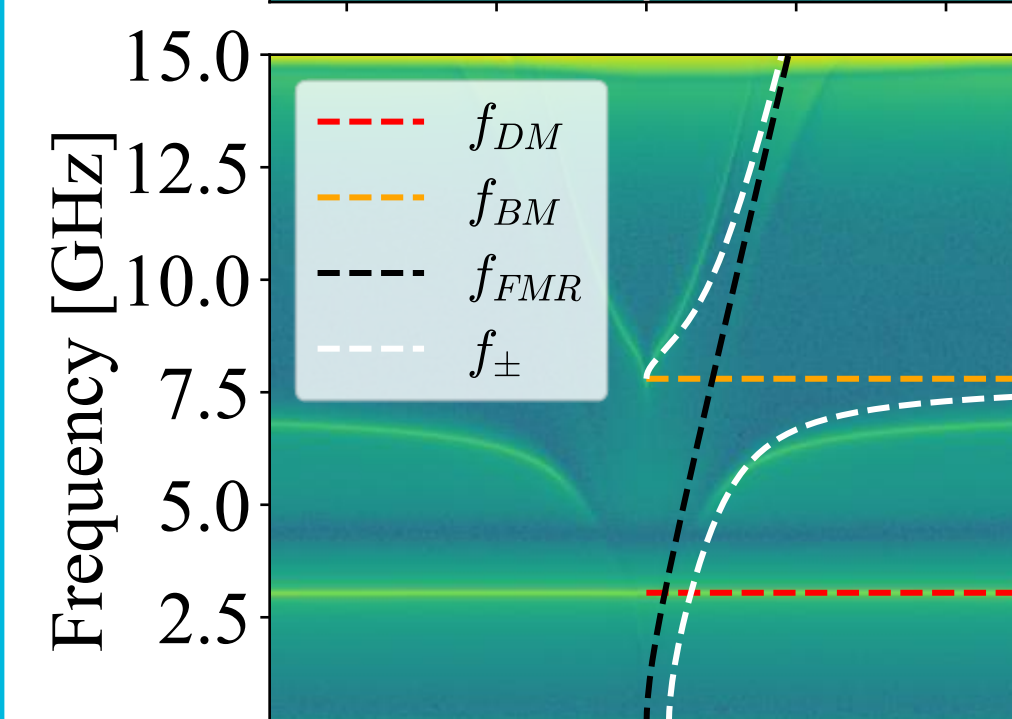


Hopfield model:

$$\hbar \omega_c \hat{a}^\dagger \hat{a} + \hbar \omega_m \hat{b}^\dagger \hat{b} + \hbar g (\hat{a}^\dagger + \hat{a})(\hat{b}^\dagger + \hat{b}) + \hbar D (\hat{a}^\dagger + \hat{a})^2$$

Eigenmodes:

$$2\omega_{\pm}^2 = \omega^2 + \omega_m^2 + 4g^2 \pm \sqrt{(\omega^2 - \omega_m^2 + 4g^2)^2 + 16g^2\omega\omega_m}$$

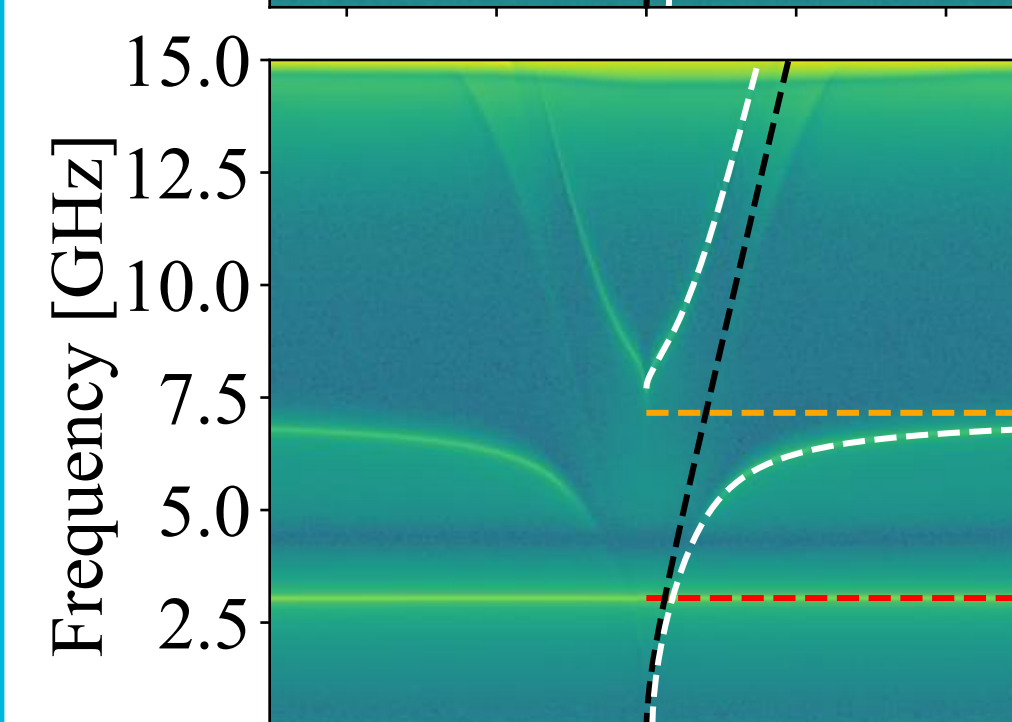


Dicke model:

$$\hbar \omega_c \hat{a}^\dagger \hat{a} + \hbar \omega_m \hat{b}^\dagger \hat{b} + \hbar g (\hat{a}^\dagger + \hat{a})(\hat{b}^\dagger + \hat{b})$$

Eigenmodes:

$$2\omega_{\pm}^2 = \omega^2 + \omega_m^2 \pm \sqrt{(\omega^2 - \omega_m^2)^2 + 16g^2\omega\omega_m}$$



Modified Dicke model:

Following [3] and [4], it was also necessary to modify standard model:

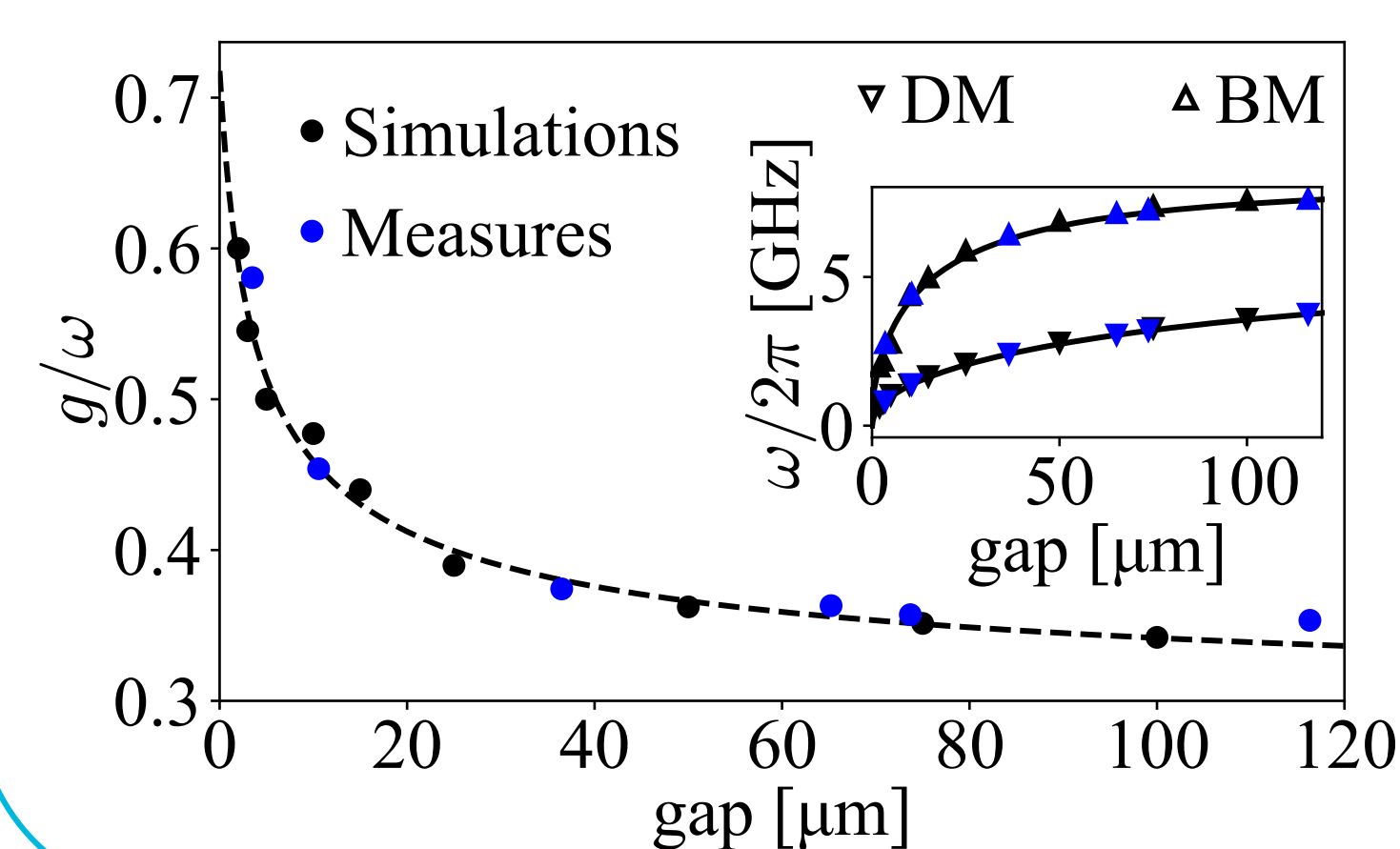
$$\omega_{MD}^\pm = \omega_D^\pm(\omega_m \rightarrow \omega_m + \omega_\Delta)$$

- ✗ Standard model can not be used
- ✓ Adding a frequency shift to the Dicke model works

Measurements & Simulations

COMSOL simulation with Frequency Domain Solver:

- S -parameters extraction through static H -field sweep.
- Including Polder tensor permeability, excitation probes, cavity electric losses, and demagnetizing field [5].



Gap dependence of the coupling strength

✓ COMSOL model confirmed

Conclusion

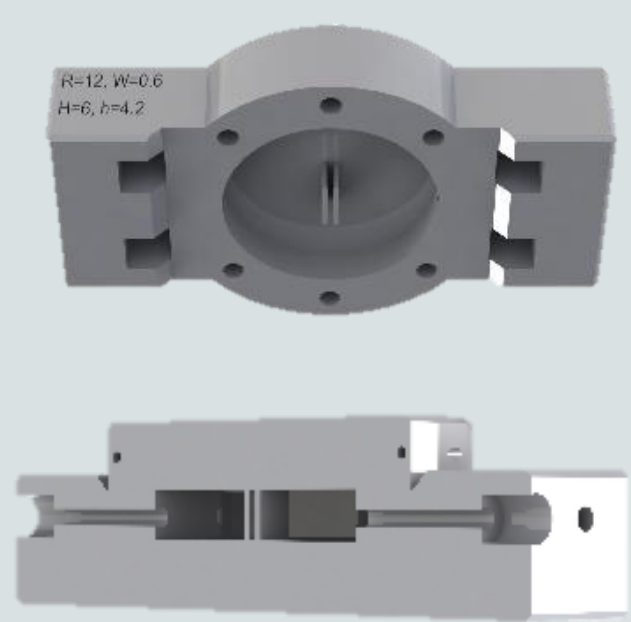
- ✓ USC reached in a double re-entrant cavity
- ✓ Cavity tunable in frequency
- ✓ Adding ω_Δ in the Dicke Model: It is needed a new Hamiltonian

Applications potentials:

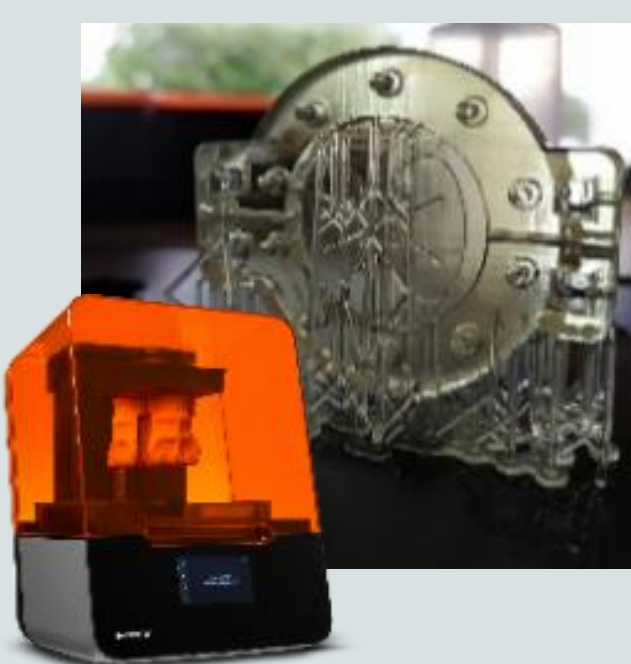
- ▶ Information transfert
- ▶ Sensors (dark matter, magnetometry...)
- ▶ RF components (insulators, circulators...)

Designing steps

SolidWorks



3D printing



Metalization



Machining



References

- [1] Phys. Rev. Applied 2, 054002 (2014)
- [2] Journal of Applied Physics 128, 073904 (2020)
- [3] Phys. Rev. B 101, 075301 (2020)
- [4] Phys. Rev. Applied 16, 034029 (2021)
- [5] Journal of Applied Physics 36, 1579 (1965)