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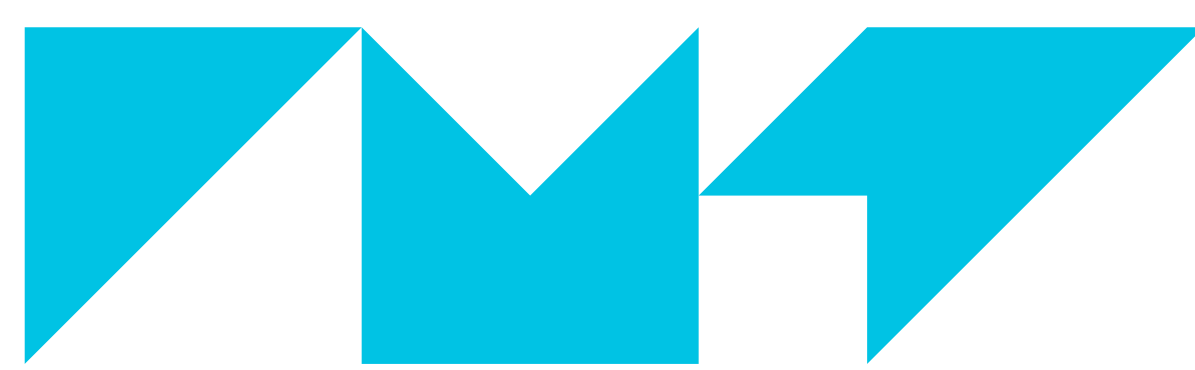
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# EXPERIMENTAL GENERATION OF CIRCULATING CAVITY MAGNON POLARITONS

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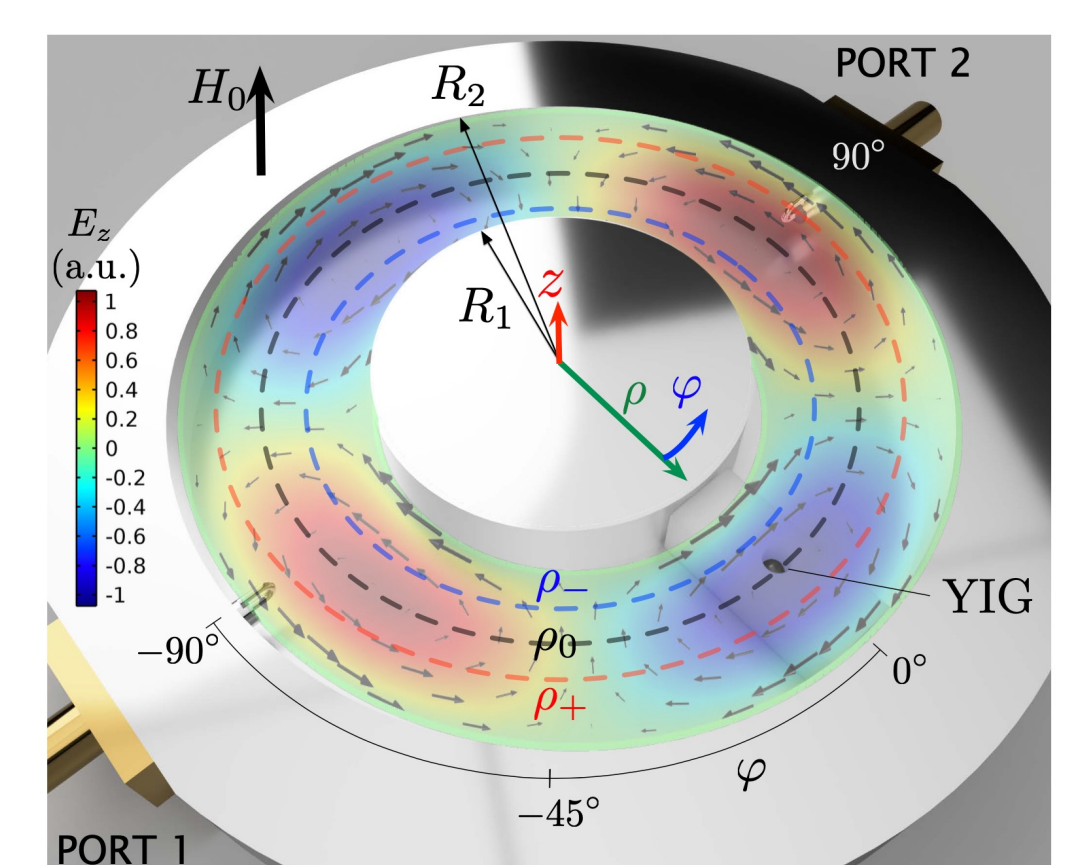
## INTRODUCTION

- **Circularly polarized unidirectional cavity magnon polaritons:** Experimental evidences
- **Hybrid system:** The chosen magnetic material is a YIG sphere loaded un a torus shaped cavity
- **Chirality:** In microwave guides and cavities it enables a chiral magnon-photon coupling because the polarization of the electromagnetic radiation metallic boundaries is locked to its orbital motion on “chiral” lines or planes: A magnet placed at these special lines breaks the degeneracy of counter-propagating waves and results unidirectional coupling.
- **We reveal** the chiral nature of the spectral energy and angular momentum flow by observing and modelling non-reciprocities of the microwave scattering matrix

## CAVITY DESIGN

### ► Torus-shaped microwave cavity:

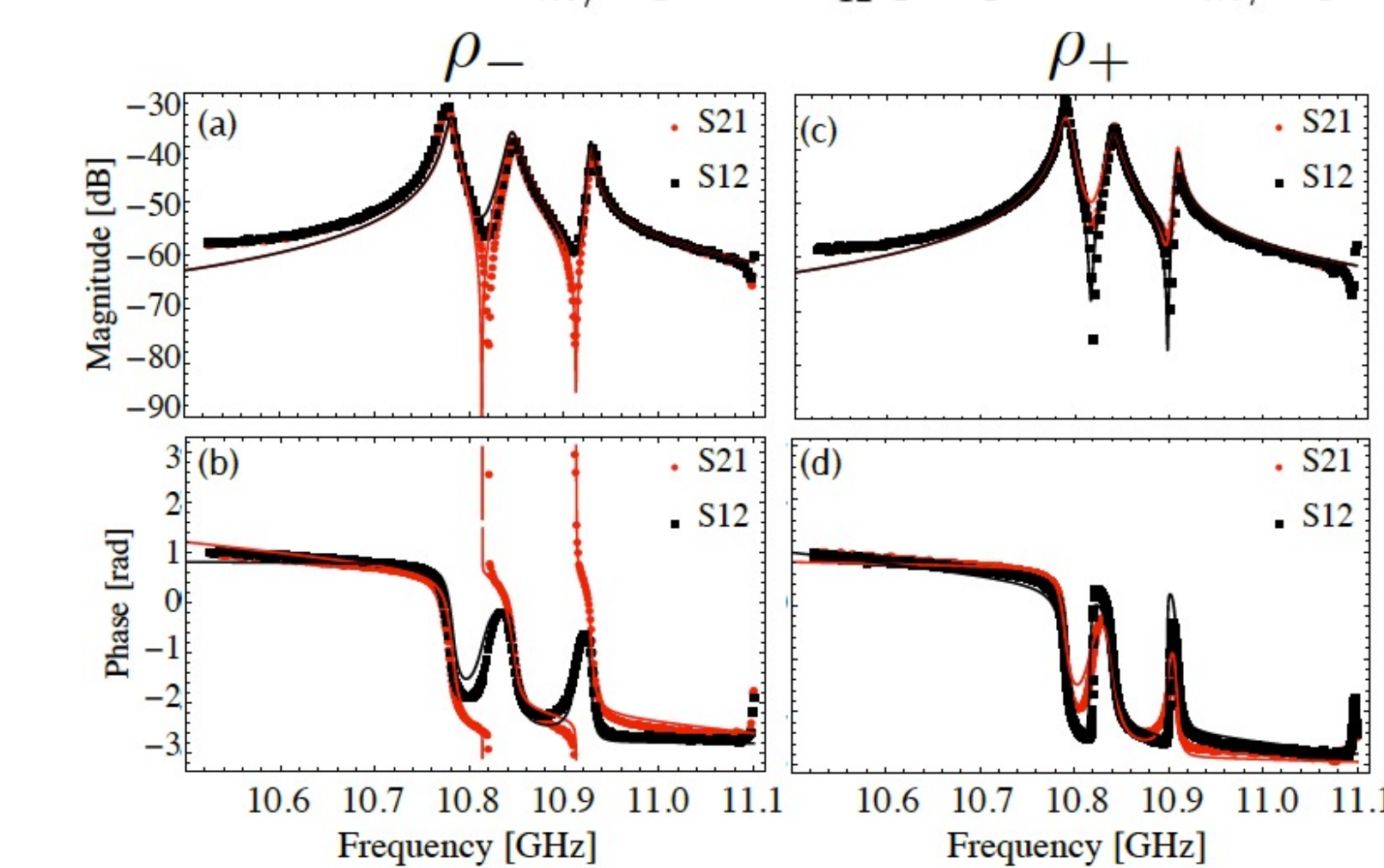
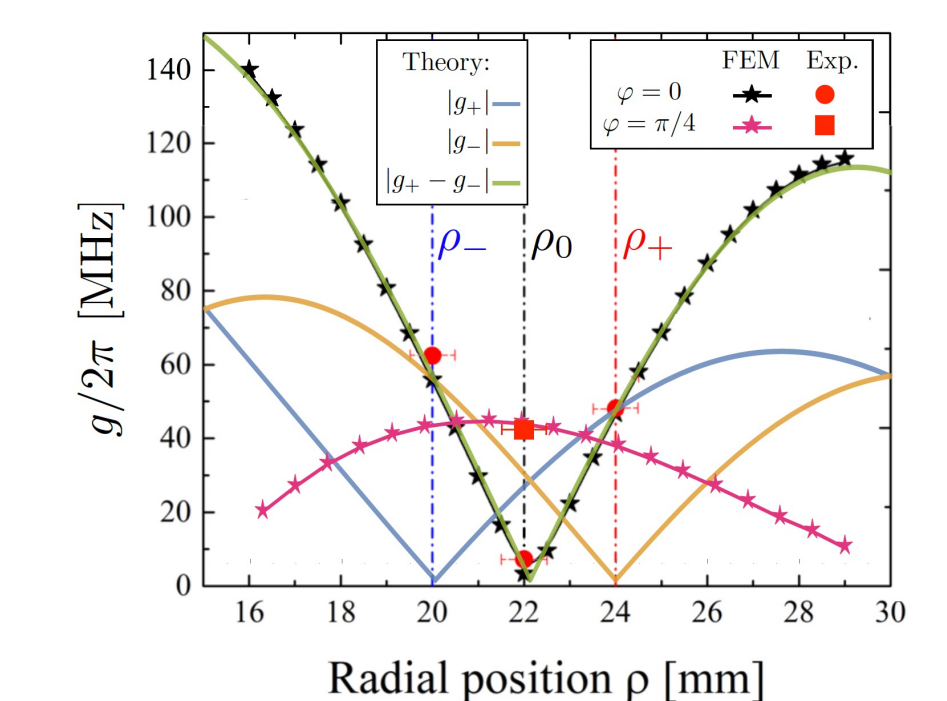
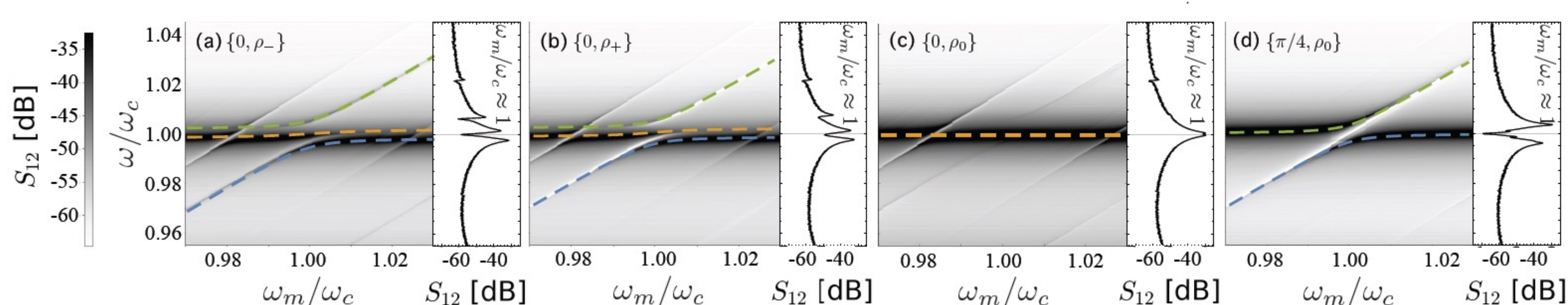
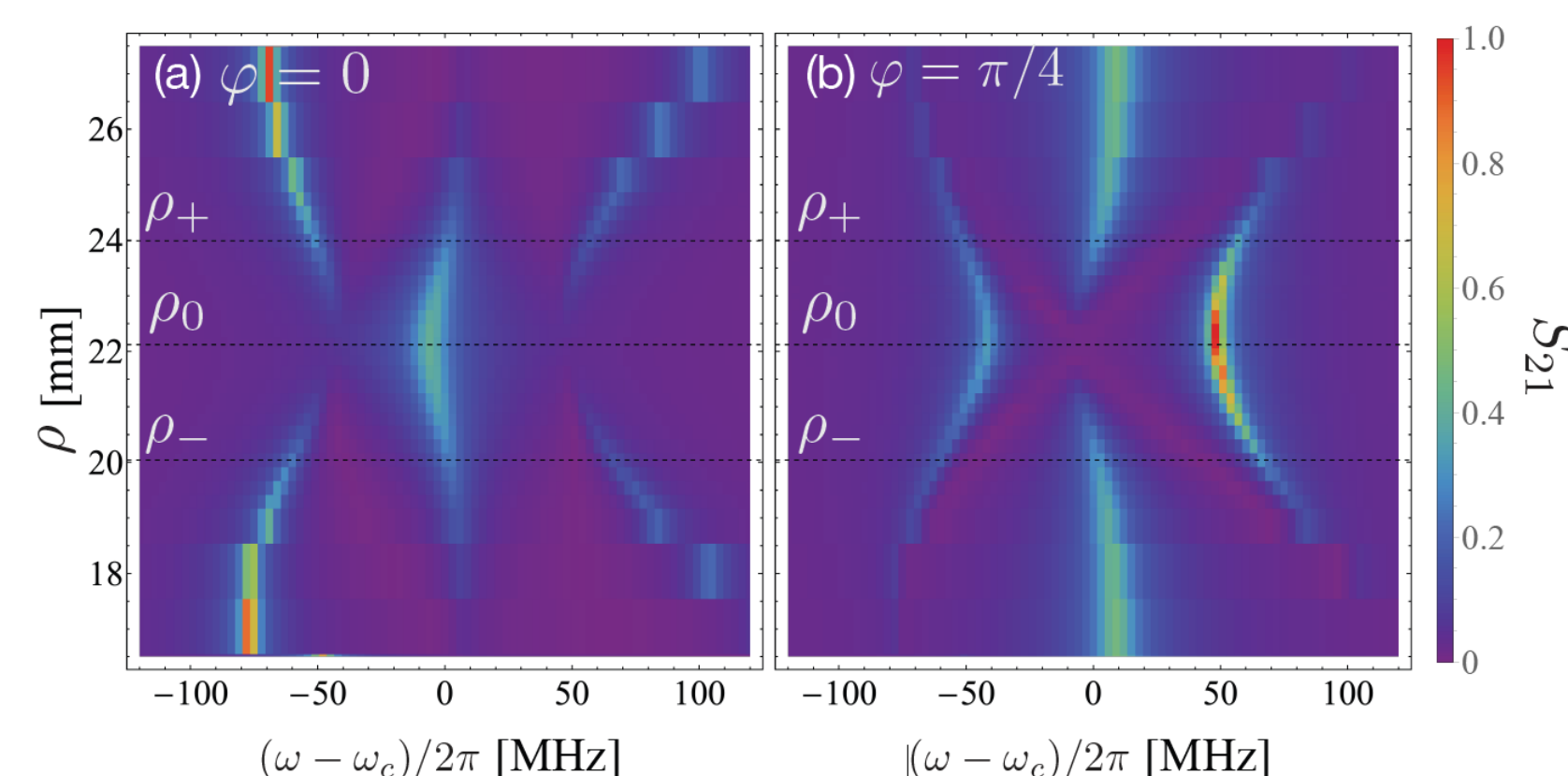
- Machined from high purity aluminium in two parts (lid and base). The inner and outer radii R1 (15 mm) and R2 (30 mm) and the height h (6 mm) [1]
- two magnetic loops around the radial axis at  $\varphi = \pm 90^\circ$  that couple to the  $H_\varphi$  component
- The second azimuthal harmonic of the TE mode of the cavity resonates at  $f_c = 10.8$  GHz with a quality factor  $Q = 775$ , which cc. responds to a bandwidth of 14 MHz
- Pure YIG sphere couples to a clockwise (cm,  $m > 0$ ) or counterclockwise (www,  $m < 0$ ) photon



## EXPERIMENTAL RESULTS

### ► Simulation:

- We calculate the microwave-induced dynamics of the Kittel mode by solving the coupled Maxwell and linearized Landau-Lifshitz-Gilbert (LLG) equation in the frequency domain in the macrospin by an electromagnetic FEM
- Simulated microwave transmission amplitudes for  $m = 2$  TE mode of the torus cavity as a function of the radial sphere position along (a)  $\varphi = 0^\circ$  and (b)  $\varphi = 45^\circ$  and  $H_0 = 0.3895$  T tuned such tha  $\omega_m \approx \omega_c$



- The  $\rho_-$  case can be modelled by swapping cw terms with ccw terms and changing the sign of B because transmission paths S21 and S12 have been effectively swapped. Hence given all other parameters are equal in amplitude, the difference in the phase shifts observable for the two radial positions is caused by the slightly stronger coupling at  $\rho_-$ .

$$S = D_{ccw} [-A_{ccw} - i\omega I]^{-1} B_{ccw} + \zeta D_{cw} [-A_{cw} - i\omega I]^{-1} B_{cw}$$

$$A_{cw} = \begin{pmatrix} -i\omega_{cw} - \frac{\kappa_0}{2} & ig \\ ig & -i\omega_m - \frac{\kappa_0}{2} \end{pmatrix},$$

$$B_{cw} = \sqrt{\frac{\kappa_{cw}}{2}} \begin{pmatrix} 1 & e^{i\alpha_{cw}} \\ 0 & 0 \end{pmatrix},$$

$$A_{ccw} = -i\omega_{ccw} - \frac{\kappa_0}{2}, B_{ccw} = \sqrt{\frac{\kappa_{ccw}}{2}} \begin{pmatrix} 1 & e^{i\alpha_{ccw}} \\ 0 & 0 \end{pmatrix},$$

$$D_X = -CB_X^T, C = \begin{pmatrix} \sqrt{1-\xi} & \sqrt{\xi} \\ i\sqrt{\xi} & \sqrt{1-\xi} \end{pmatrix},$$

$$\zeta = \begin{pmatrix} e^{i\beta} & 0 \\ 0 & e^{-i\beta} \end{pmatrix}.$$

## CONCLUSION & PERSPECTIVES

### ► Thermal control of mode hybridization

- Our observation of non-reciprocity in the scattering matrices of both two- and three-port torus cavities are a direct proof of microwave circulation, i.e. unidirectional nature of the magnon polariton modes over macroscopic distances, which is induced by a relatively very small magnetic load.
- The experimental results agree very well with finite calculations of the coupled Landau Lifshitz and Maxwell equations and can be understood by a three-mode input-output model

## REFERENCES

[1] W. Yu, T. Yu, and G. E. W. Bauer, Phys. Rev. B 102, 064416 (2020)

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