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## Magnonic crystal in Heusler Based Co<sub>2</sub>MnSi thin films

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**Abstract:** Magnonic crystals are micro/nano-structured magnetic systems that can be used for passive microwave devices such as filters, waveguides, sensors etc.. The Heusler-based  $\text{Co}_2\text{MnSi}$  (CMS) alloy is considered as a promising material for magnonic applications due to its relatively high saturation magnetization and low Gilbert damping. Here, we demonstrated with micromagnetic simulations that its cubic crystal anisotropy allows microwave reconfigurable operations and filtering properties at zero bias field in a simple model consisting of a squared antidot magnonic crystal. We showed that a low amplitude (few mT) and ultra-short ( $\approx 1$  ns) initialization field can be used to recover different quasi-uniform remanent states that can couple or not to a microwave field. A first experimental demonstration of the reconfigurable operation at zero magnetic field has been observed by ferromagnetic resonance on a squared antidot lattice with square size 200 nm and spacing 600 nm.

## Spin waves and Magnonic crystals

Magnetization equilibrium position determined by  $\vec{H}_{eff}$

Landau-Lifshitz-Gilbert (LLG) Equation

$$\frac{d\vec{M}}{dt} = -\gamma\mu_0\vec{M} \times \vec{H}_{eff} + \frac{\alpha}{M_s} \left( \vec{M} \times \frac{d\vec{M}}{dt} \right)$$

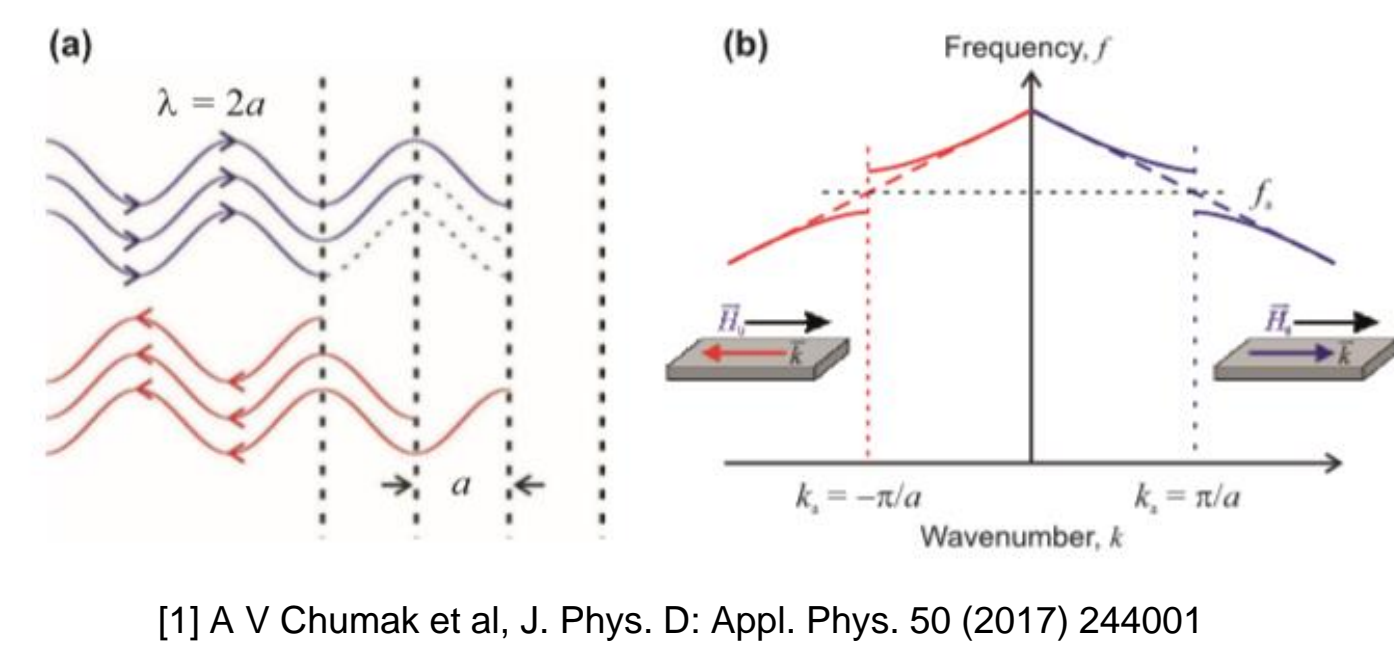
Precession  
Damping ( $\alpha = \text{Gilbert factor}$ )

**Spin waves (SW):** collective propagating precession of magnetic moments

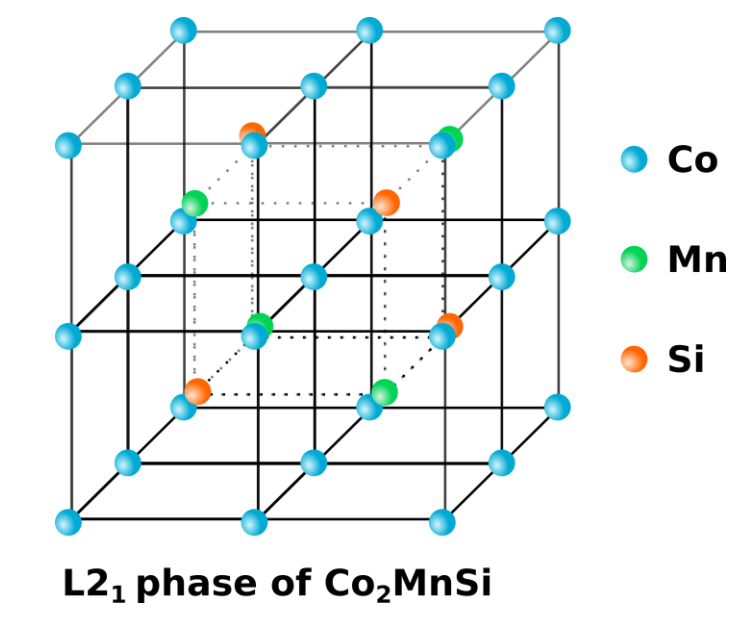
Amplitude  $\propto e^{-\frac{D}{L_{latt}}}$   
 $L_{latt} \propto \frac{1}{\alpha}$

**Magnonic crystal (MC):** magnetic material with periodically modulated properties

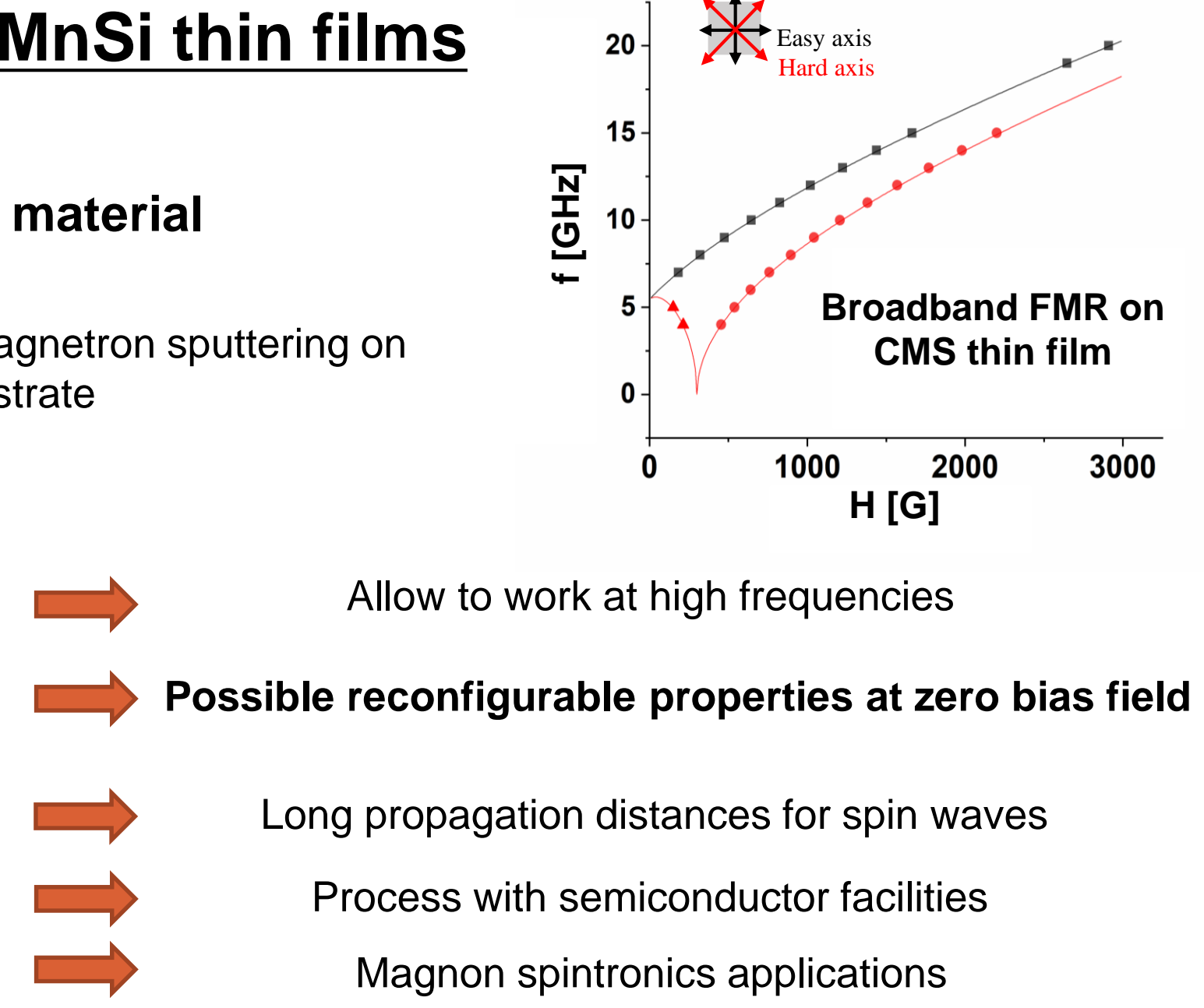
Creation of frequency band gaps in SW dispersion (analog to Bragg diffusion)



## Heusler-based $\text{Co}_2\text{MnSi}$ thin films



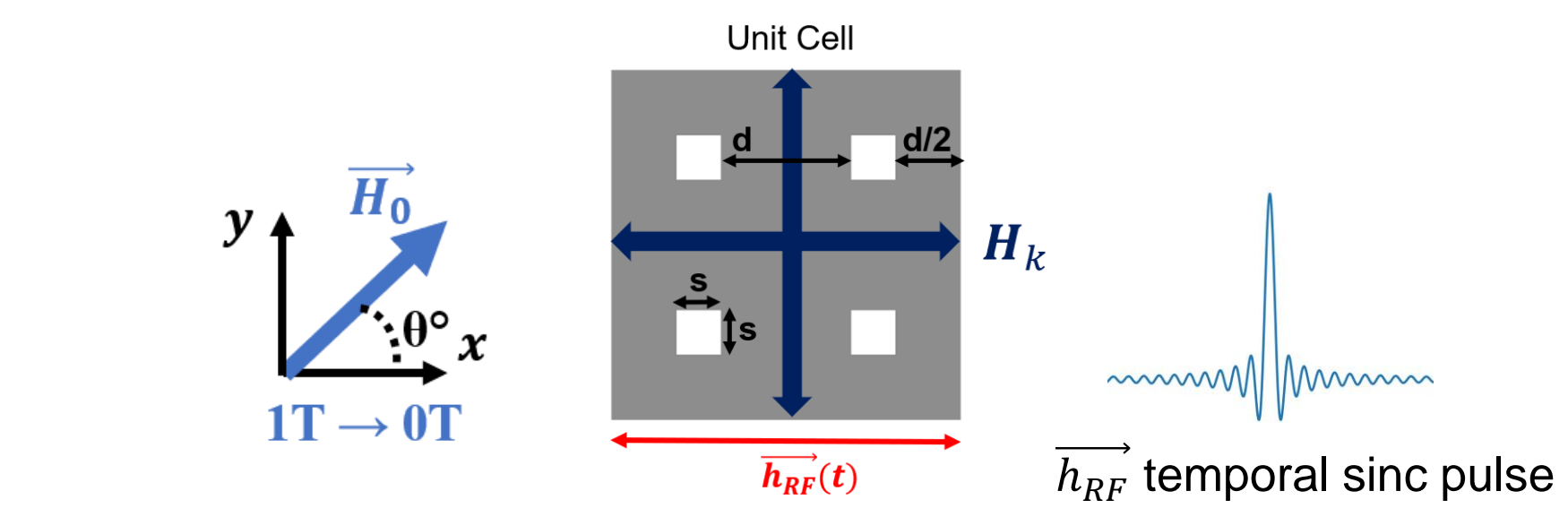
- Relatively high saturation magnetization ( $\mu_0 M_s \approx 1.37$ ) [2]
- Relatively high magnetocrystalline anisotropy ( $K_c \approx 10 \cdot 10^3$  to  $17 \cdot 10^3 \text{ J} \cdot \text{m}^{-3}$ ) [2]
- Very low Gilbert damping ( $2 \cdot 10^{-3}$  down to  $7 \cdot 10^{-4}$ )
- High Curie temperature ( $T_c \approx 860\text{K}$ )
- Spin polarization above 90%



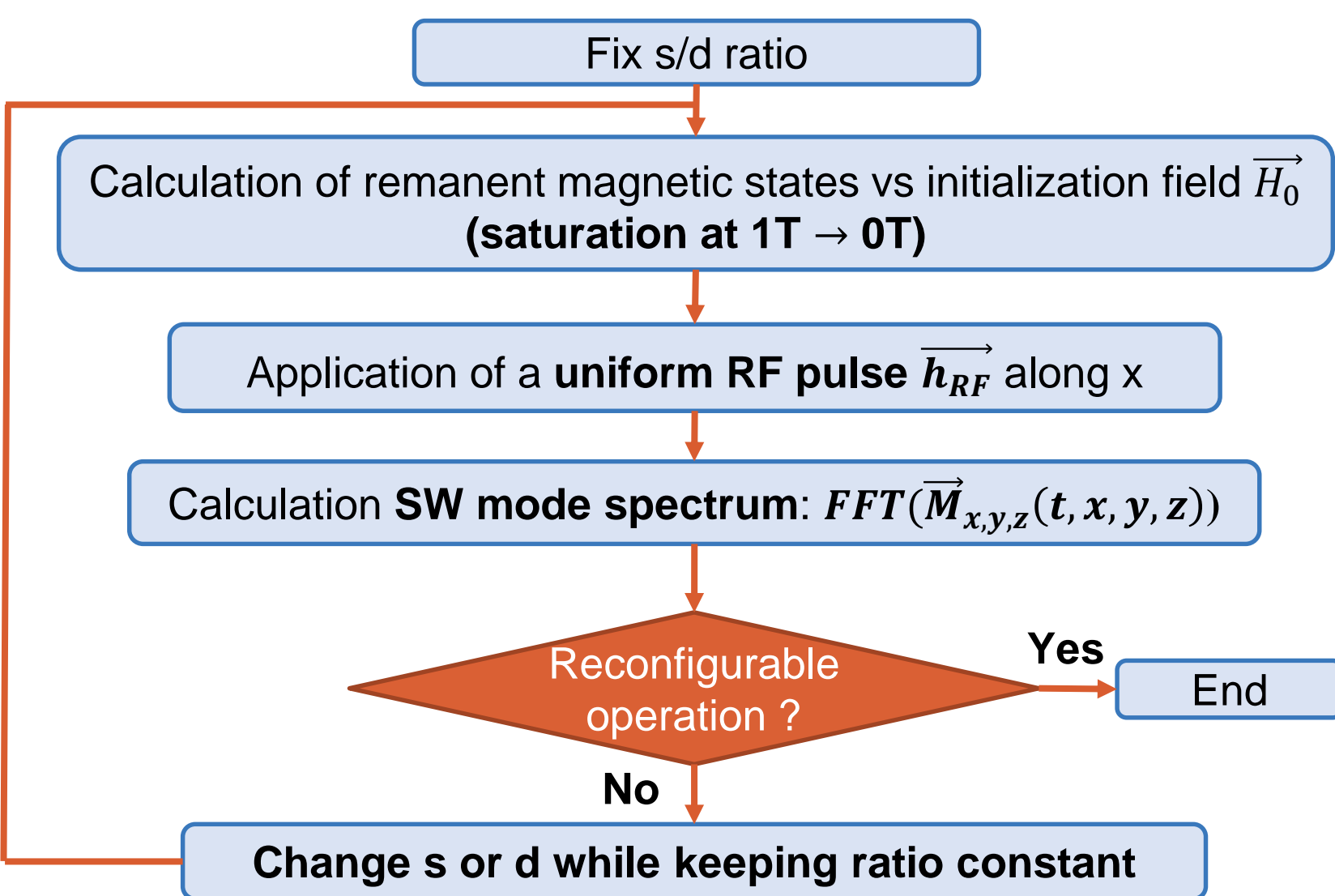
## Reconfigurable dynamic states in a CMS based magnonic crystal: A numerical study

**Objective:** Find quasi-uniform magnetic states at remanence

- Micromagnetic simulations performed with Mumax3
- Model system: a squared antidot lattice in a  $\text{Co}_2\text{MnSi}$  thin film of thickness 20nm
- Magnetic parameters:  $M_s = 1.26 \text{ mT}$ ,  $\gamma = 28.7 \text{ GHz} \cdot \text{T}^{-1}$ ,  $K_c = 17 \cdot 10^3 \text{ J} \cdot \text{m}^{-3}$ ,  $A = 18 \cdot 10^{-12} \text{ J} \cdot \text{m}^{-1}$  [2]

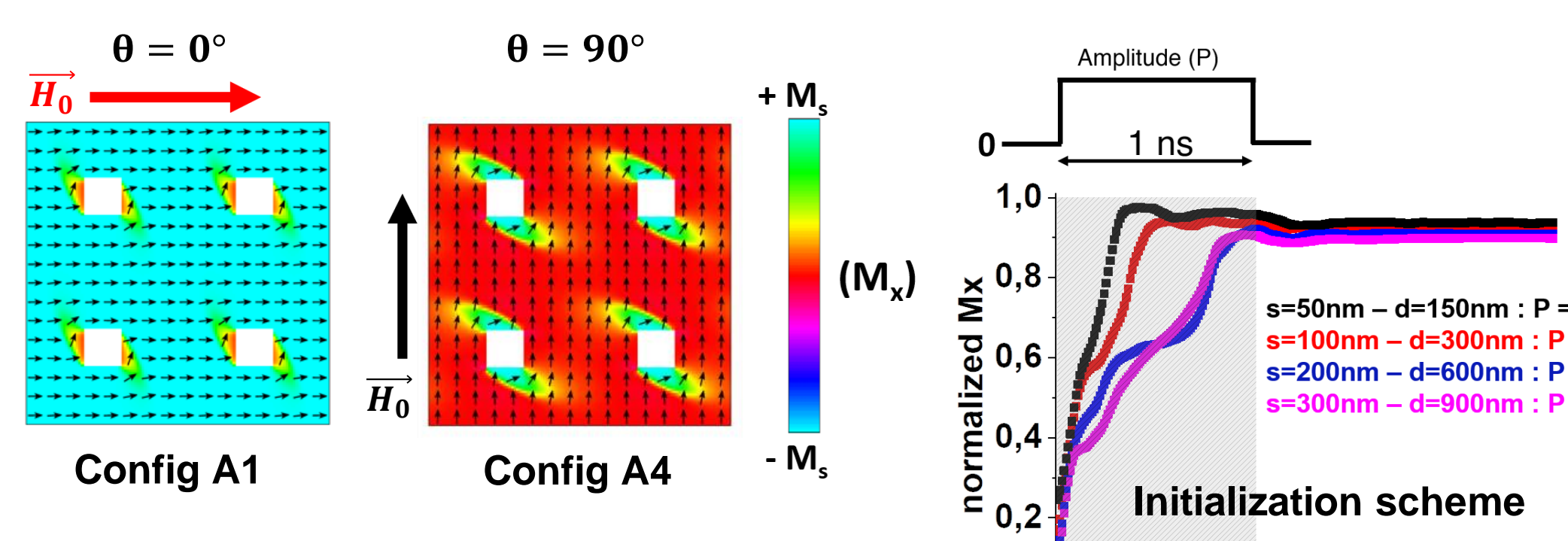


→ How we proceeded:



Result: Optimized reconfigurable states obtained for  $s/d \leq 1/3$

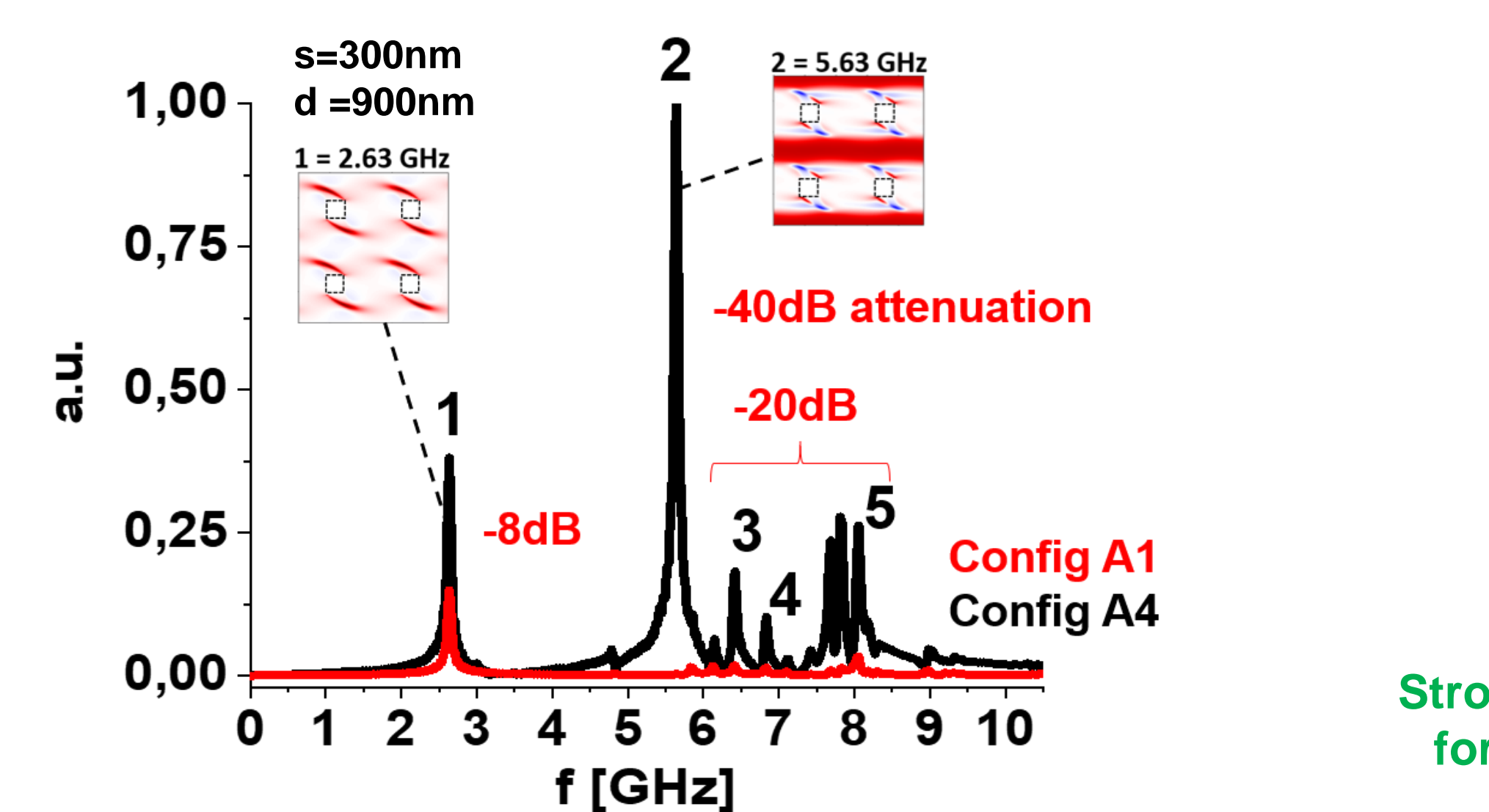
### Case 1 : CMS with cubic anisotropy



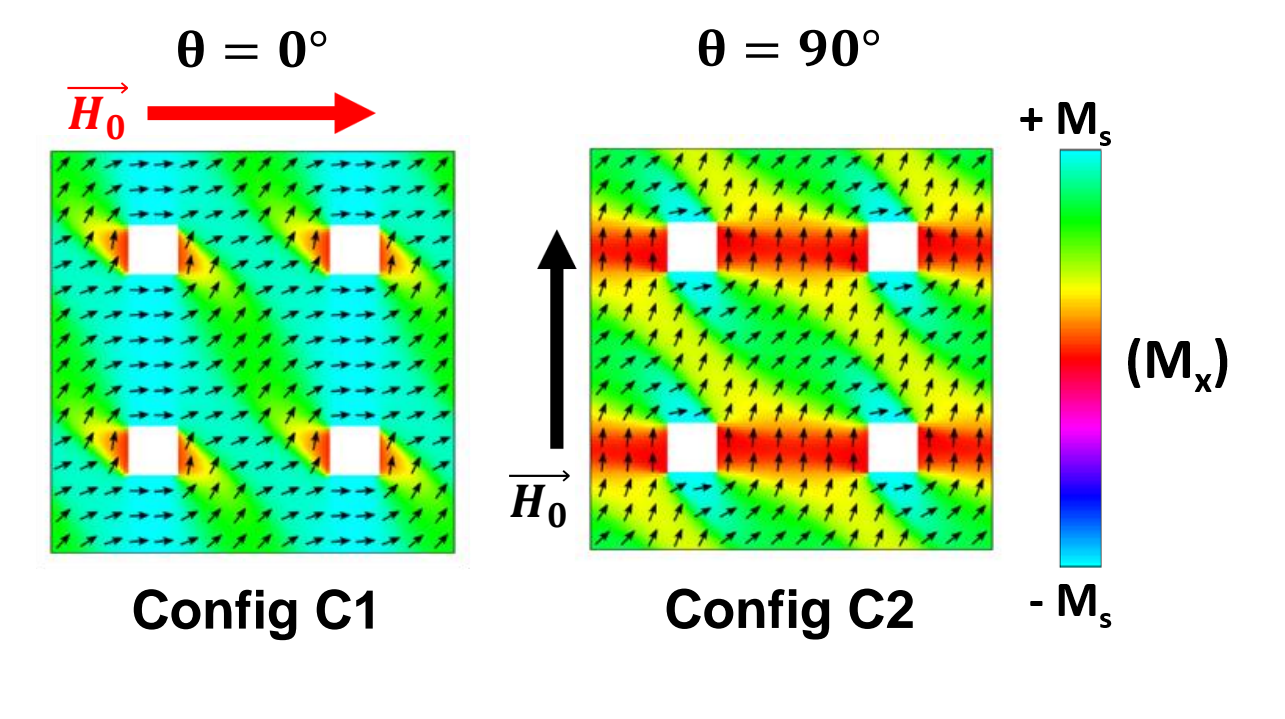
**Quasi-Uniform remanent states:**

- Switching times below 1.2ns
- Pulse amplitudes lower than 6 mT
- Decrease of s → decrease of amplitude field pulse

**On/off switching of SW modes!**

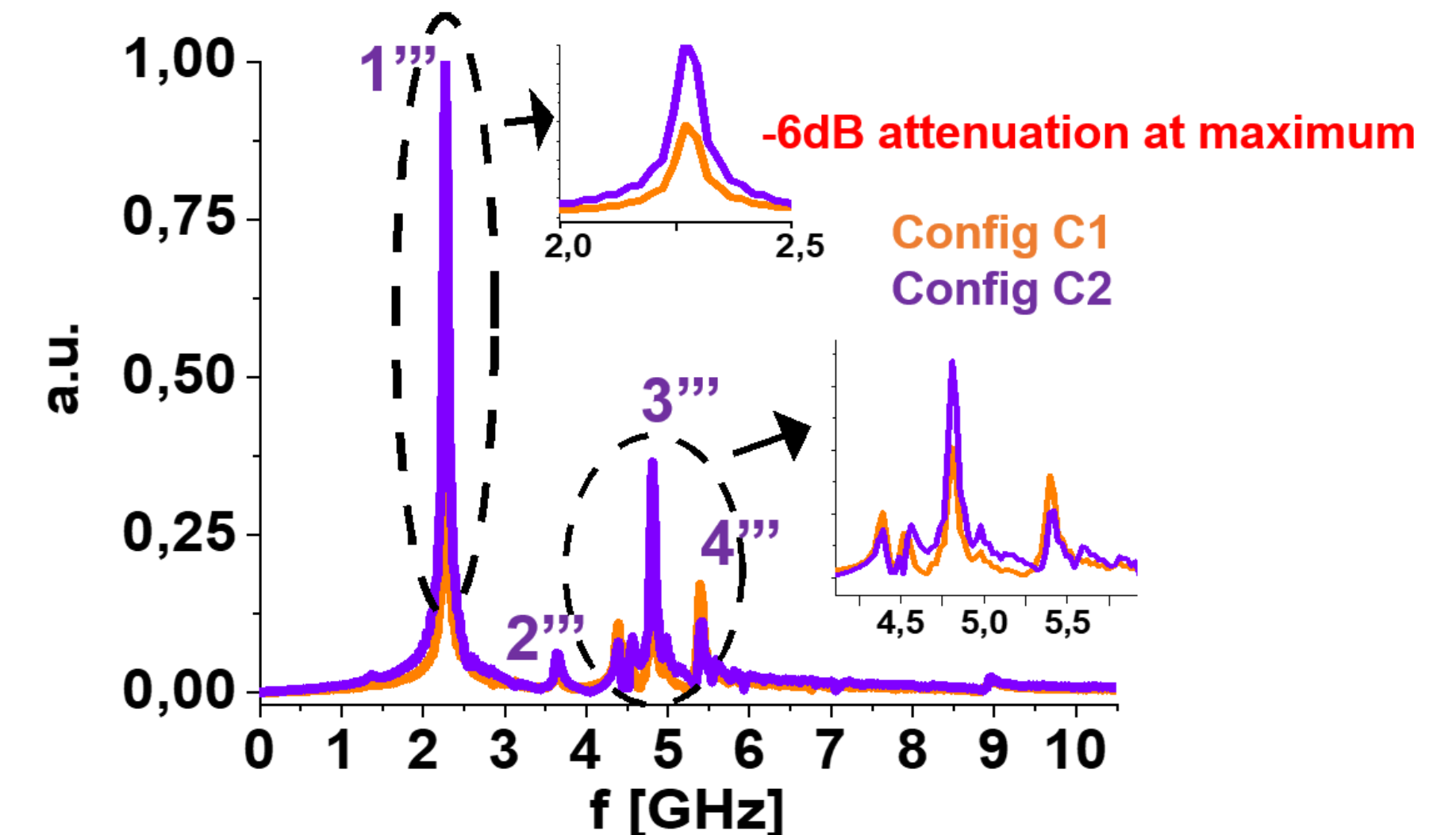


### Case 2: CMS with no anisotropy



**Non-uniform remanent states**

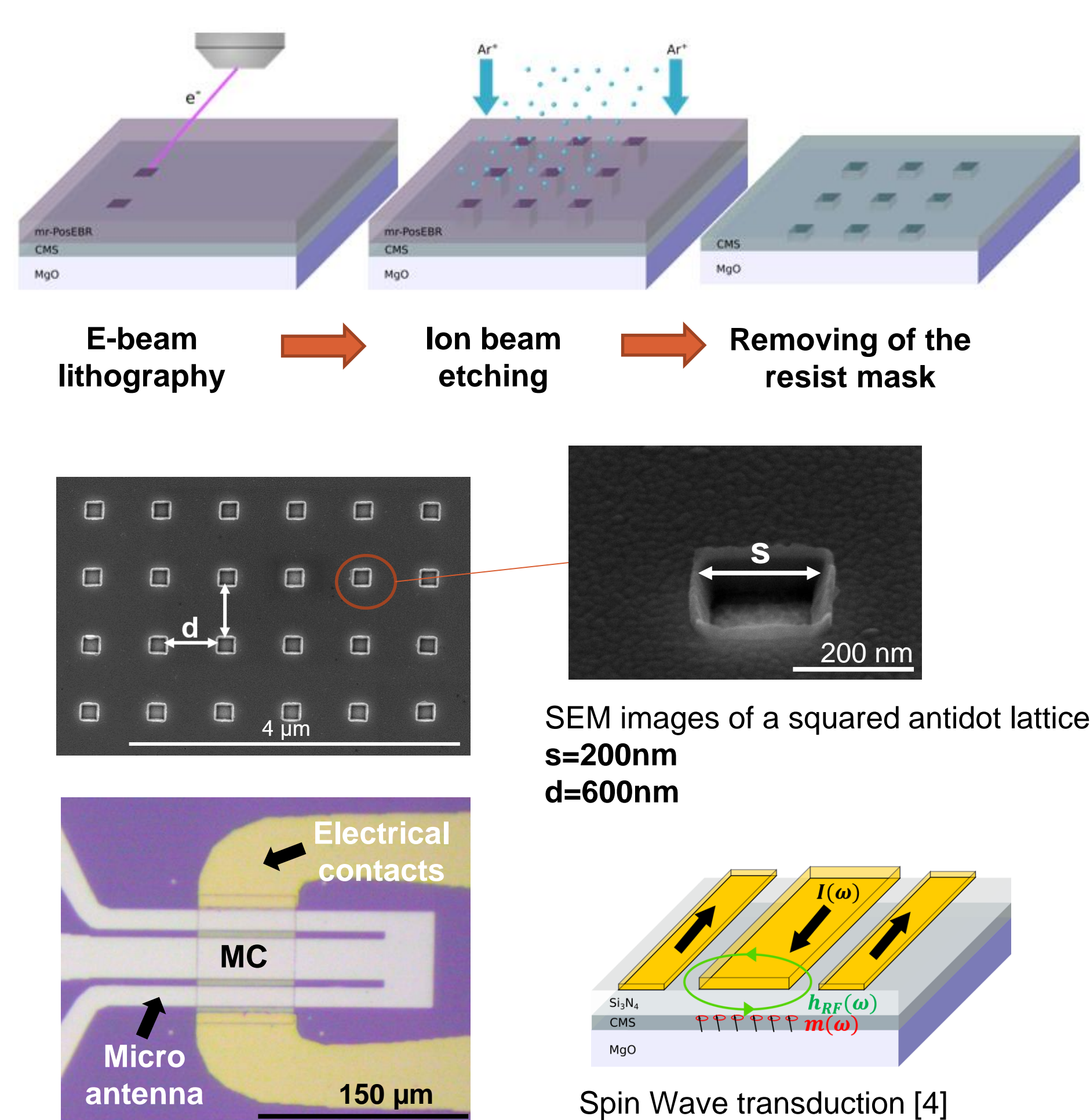
Very weak attenuation



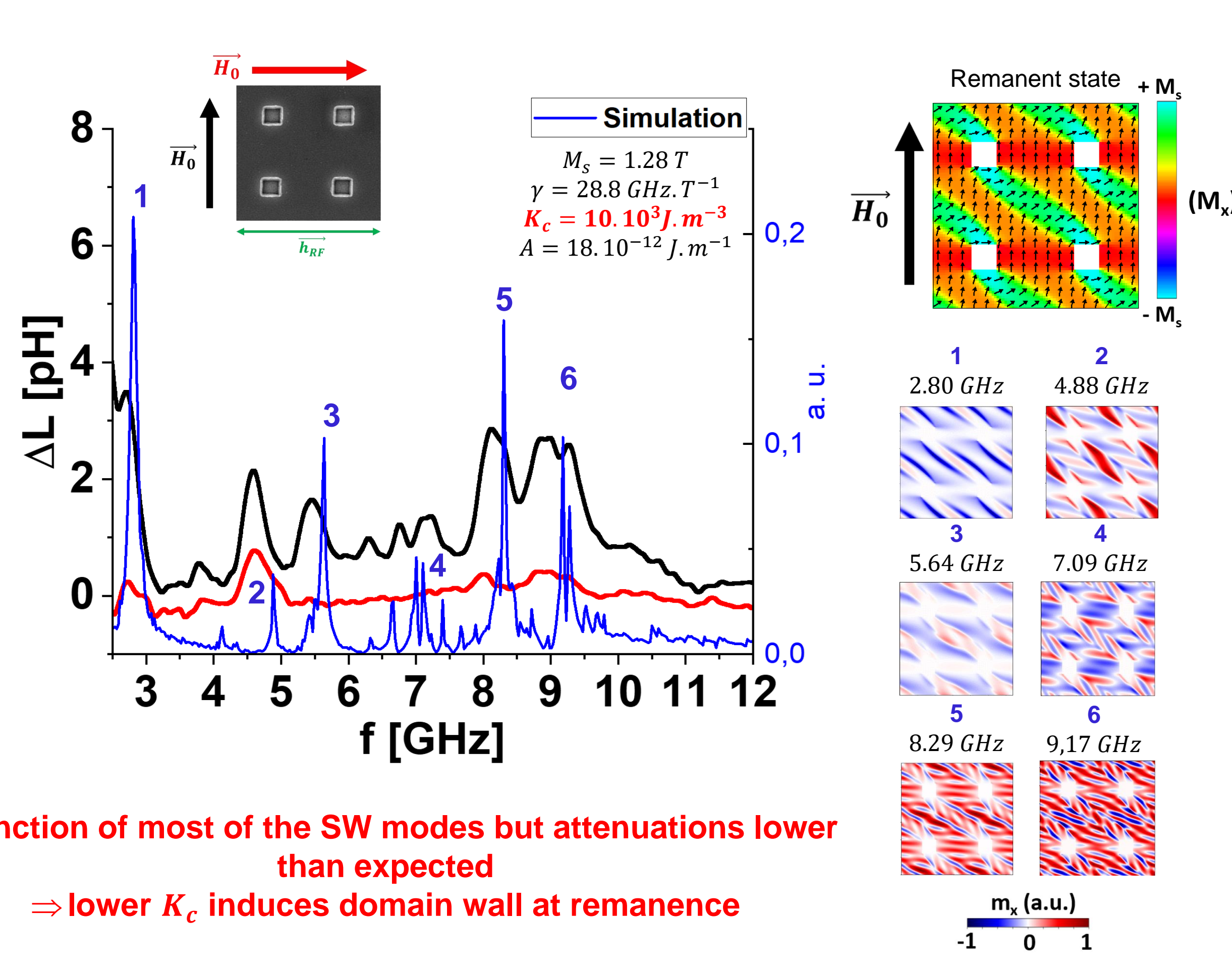
Strong cubic anisotropy such as with  $\text{Co}_2\text{MnSi}$  thin film is required for simple reconfiguration operation ([3] S. Manton et al., Phys. Rev. Applied 17, 044054 (2022))

## First experimental measurement of the reconfigurable operation (to be submitted)

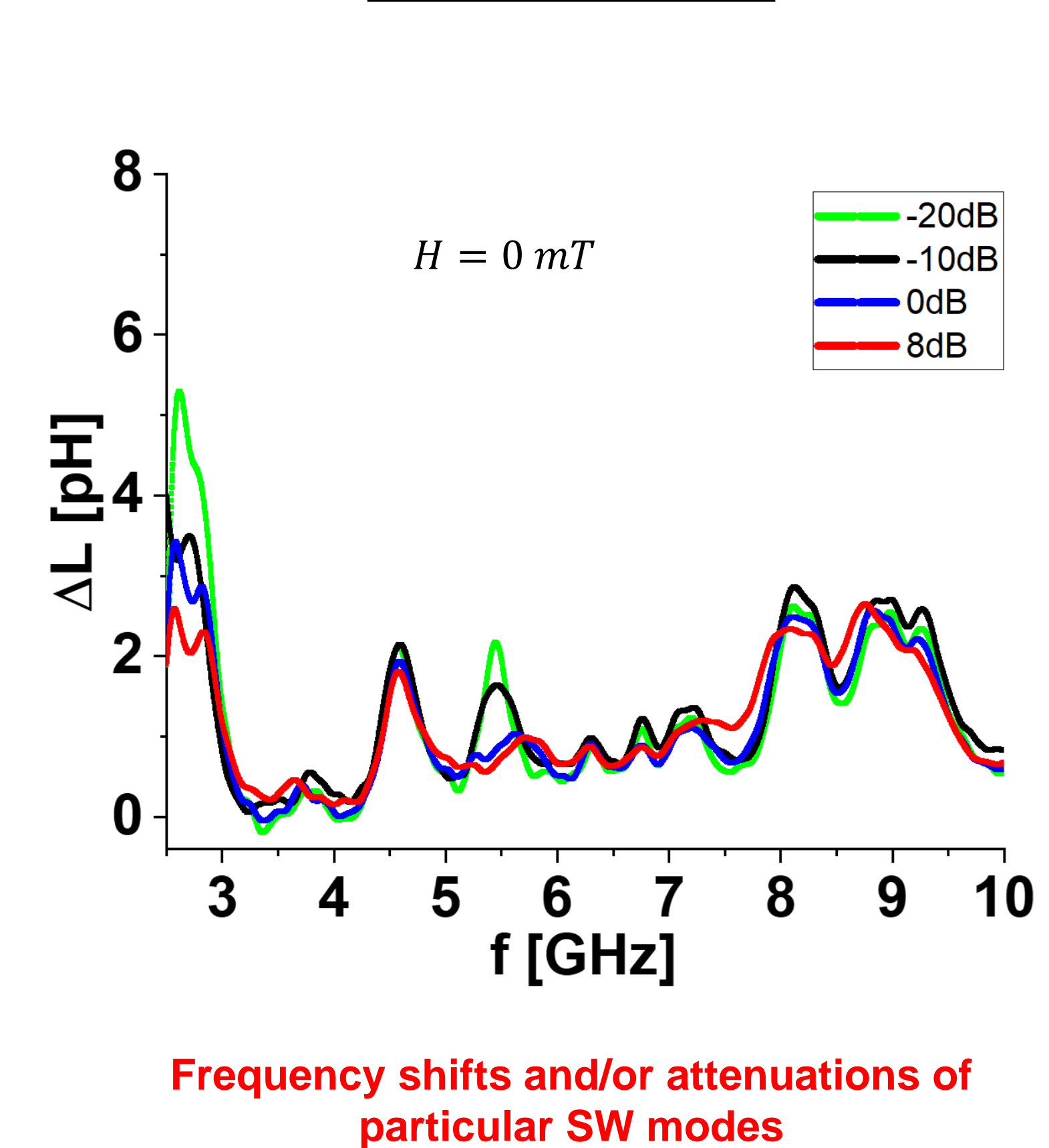
### Nanofabrication of the magnonic crystal



### Reconfigurable dynamic states at remanence

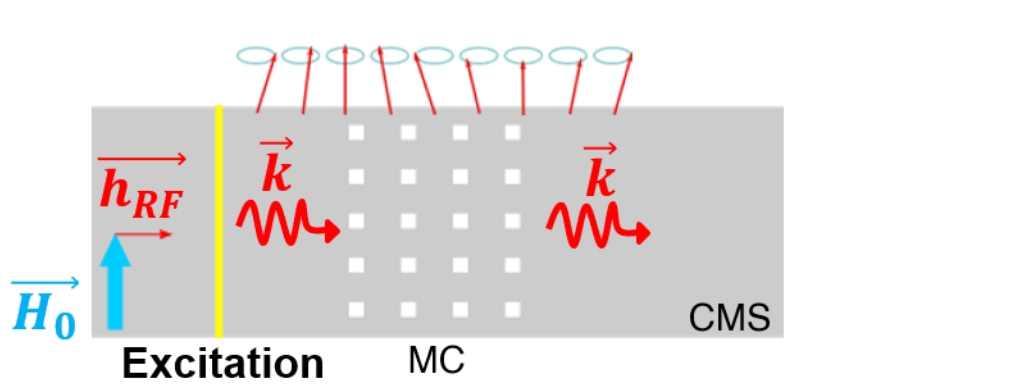


### Nonlinear effects

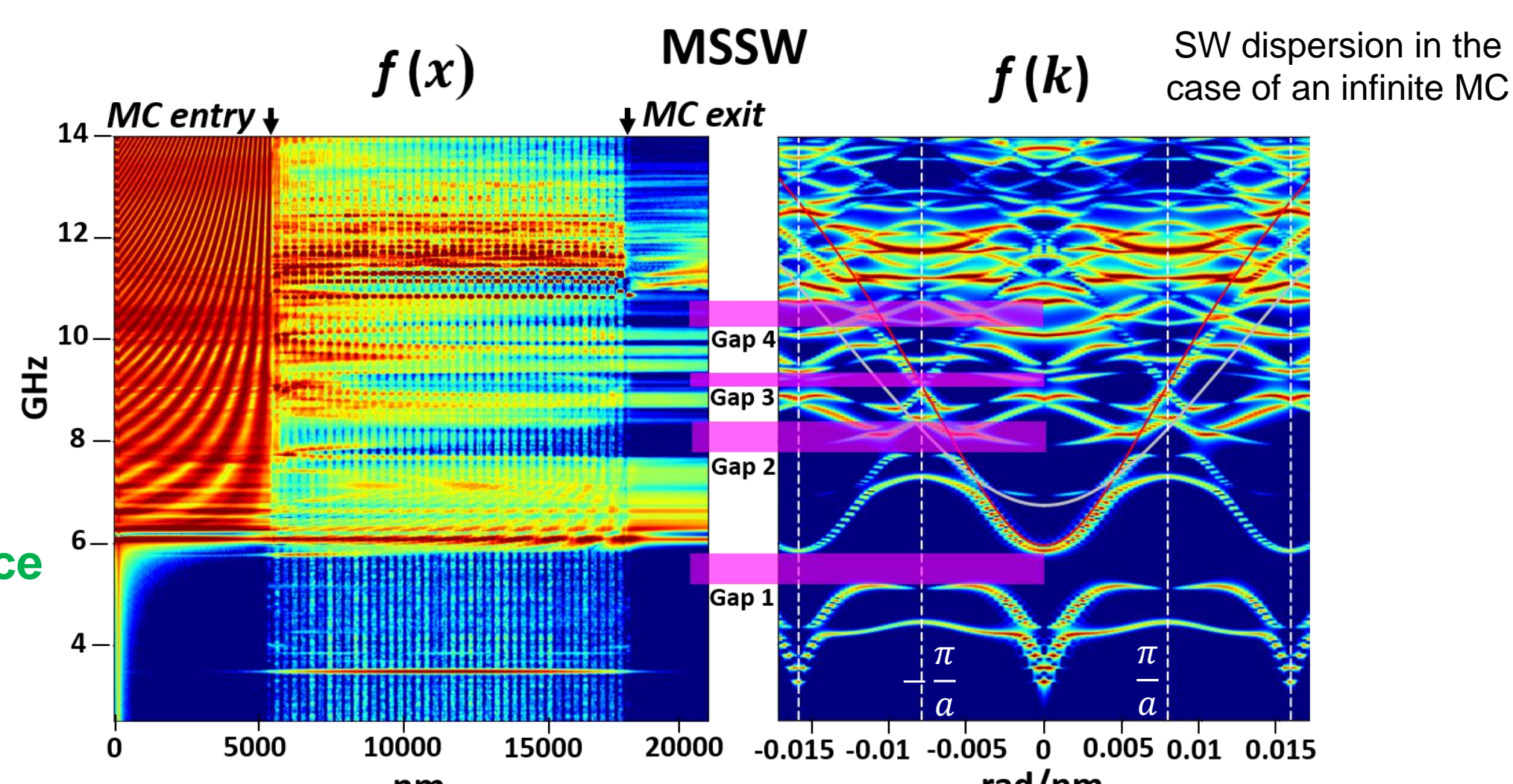


## Filtering properties at remanence in a CMS based magnonic crystal [3]

Application of a localized microwave excitation  $\vec{h}_{RF}$  to excite propagating SW towards the MC



Frequency band gaps generation at remanence for Magneto Surface Spin Waves (MSSW) in cubic crystal  $\text{Co}_2\text{MnSi}$



## Perspectives:

- Fabrication of a similar device with different s and d in order to compensate the lower  $K_c$  obtained
- Measurements of the filtering applications at remanence with Magneto Surface Spin Waves (MSSW)
- Measurements of FMR and propagating SW modes with varying electrical currents through the MC

References:

- [1] A. V. Chumak et al., J. Phys. D: Appl. Phys. 50, 244001 (2017)
- [2] I. Abdallah et al., J. Phys. D: Appl. Phys. 50, 035003 (2017)
- [3] S. Manton et al., Phys. Rev. Applied 17, 044054 (2022)
- [4] V. Vlaminck et al., Phys. Rev. B 81, 014425 (2010)

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