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Shaping non-reciprocal caustic spin wave beams in magnetic films

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► To cite this version:

Vincent Vlaminck, Dinesh Wagle, Daniel Stoeffler, Matthieu Bailleul, Benjamin Jungfleisch, et al.. Shaping non-reciprocal caustic spin wave beams in magnetic films. colloque Louis Néel 2025, Jun 2025, Vogüé, Ardèche, France. 2025. ⟨hal-05132768⟩

HAL Id: hal-05132768

<https://hal.science/hal-05132768v1>

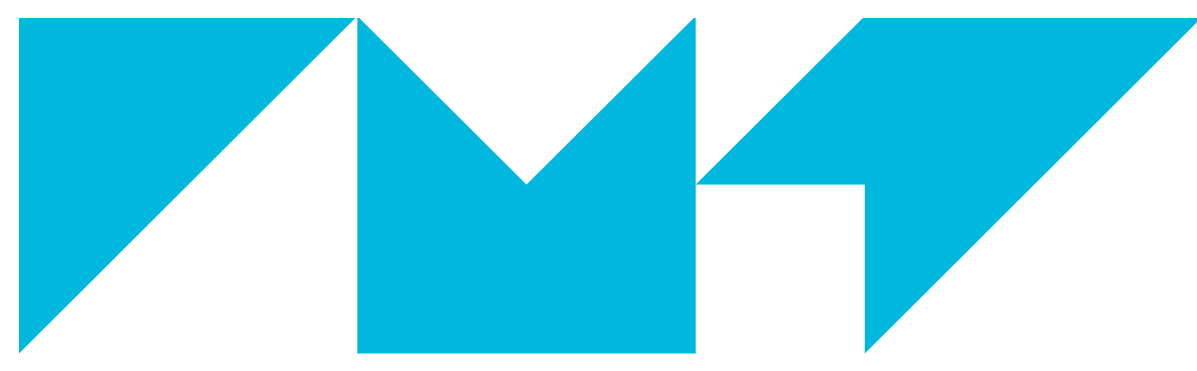
Submitted on 27 Jun 2025

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Shaping non-reciprocal caustic spin wave beams in magnetic films

Motivations

- ▶ **Non-reciprocal magnonic devices**
Miniaturizing isolator, circulator, delay lines
- ▶ **Shaping spin-wave beams in extended layer**
Development of magnon interferometric devices [1-3]
- ▶ **Diffraction model for in-plane modes**
Efficient tool to map the Near-Field Diffraction (NFD) patterns of any shape of spin-wave antennas [4]

NFD model for in-plane magnetized films

- ❖ **Kalinikos's approach to express $\vec{m}(u, v, t)$ [5,6]**

- **(ξ, η, ζ) SW propagation frame**

$$\vec{h}_d(\xi) = \int_{-\xi}^{\xi} \vec{G}_{xy}(\xi - \xi') \vec{m}(\xi') d\xi' = -\vec{N}_{dip} \vec{m} \Rightarrow \vec{N}_{dip}^{00} = \begin{pmatrix} 1-P & 0 \\ 0 & P \sin^2 \phi \end{pmatrix}$$

$$\vec{G}_{\xi\eta\zeta}(\xi - \xi') = \begin{pmatrix} G_p - \delta(\xi - \xi') & 0 & iG_Q \\ 0 & 0 & 0 \\ iG_Q & 0 & -G_p \end{pmatrix} \begin{matrix} \text{change of frame} \\ (\xi, \eta, \zeta) \Rightarrow (x, y, z) \end{matrix} \quad (P = 1 - \frac{1-e^{-kt}}{kt})$$

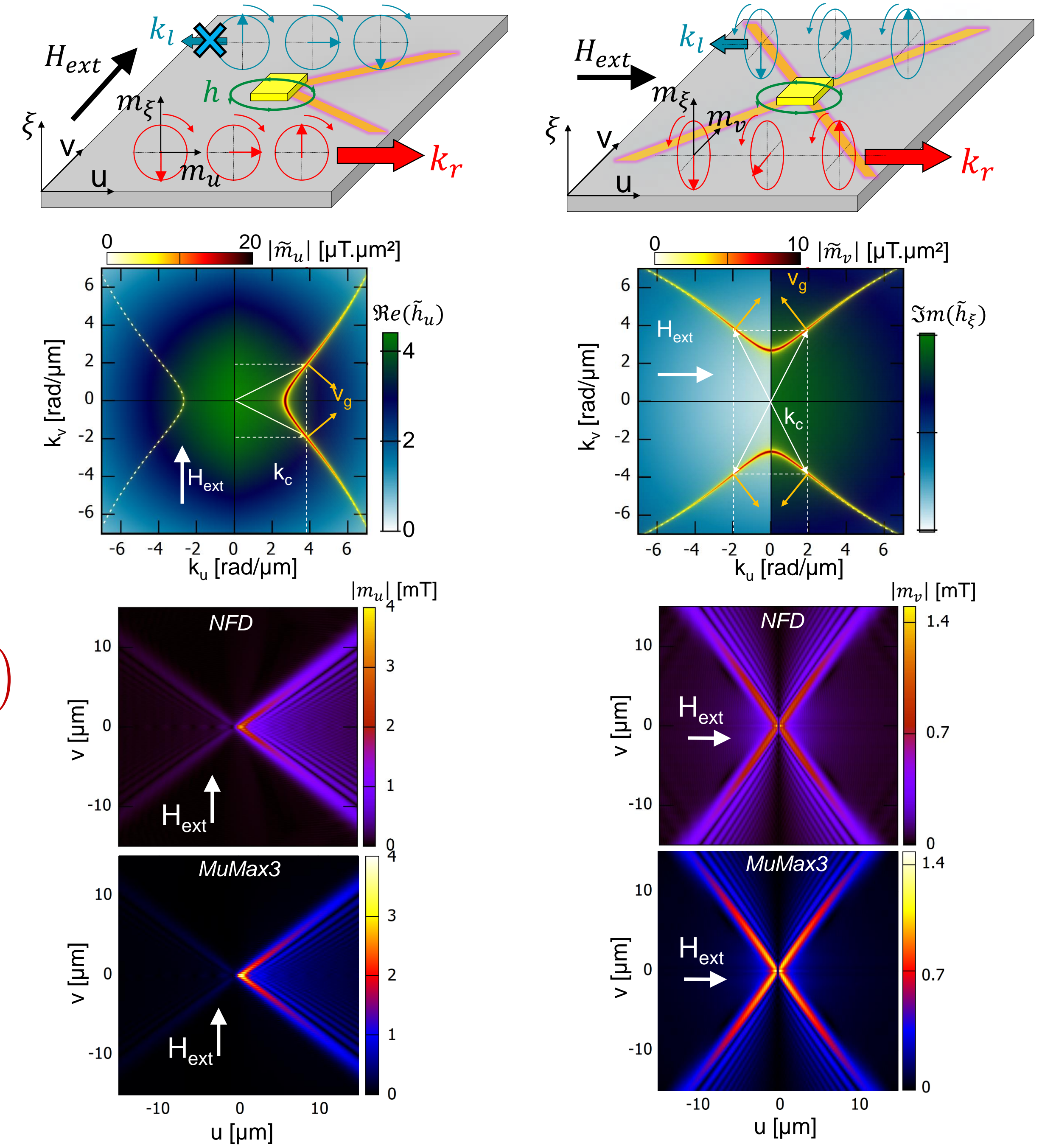
- **(x, y, z) $\vec{M}(\vec{r}, t)$ frame \Rightarrow Linearizing LLG**

$$\frac{1}{\omega_M} \begin{pmatrix} \Omega_k + i\alpha\omega + \omega_M \bar{N}_{d,xx}^{00} & -i\omega + \omega_M \bar{N}_{d,xy}^{00} \\ i\omega + \omega_M \bar{N}_{d,yx}^{00} & \Omega_k + i\alpha\omega + \omega_M \bar{N}_{d,yy}^{00} \end{pmatrix} \begin{pmatrix} m_x \\ m_y \end{pmatrix} = \begin{pmatrix} h_x \\ h_y \end{pmatrix}$$

- **(u, v, ξ) Lab frame - antenna orientation $\Rightarrow FFT^{-1}\{\vec{m}(\vec{k})\}$**

$$\vec{m}(u, v, t) = e^{i\omega t} \iint_{-\infty}^{+\infty} dk_u dk_v \vec{\chi}(k_u, k_v) \vec{h}_{exc} e^{-i\vec{k} \cdot \vec{r}}$$

"Point-like" excitation + $(h_{in}, h_{out}) \perp H_{ext} \Rightarrow$ Chiral Caustic Beams

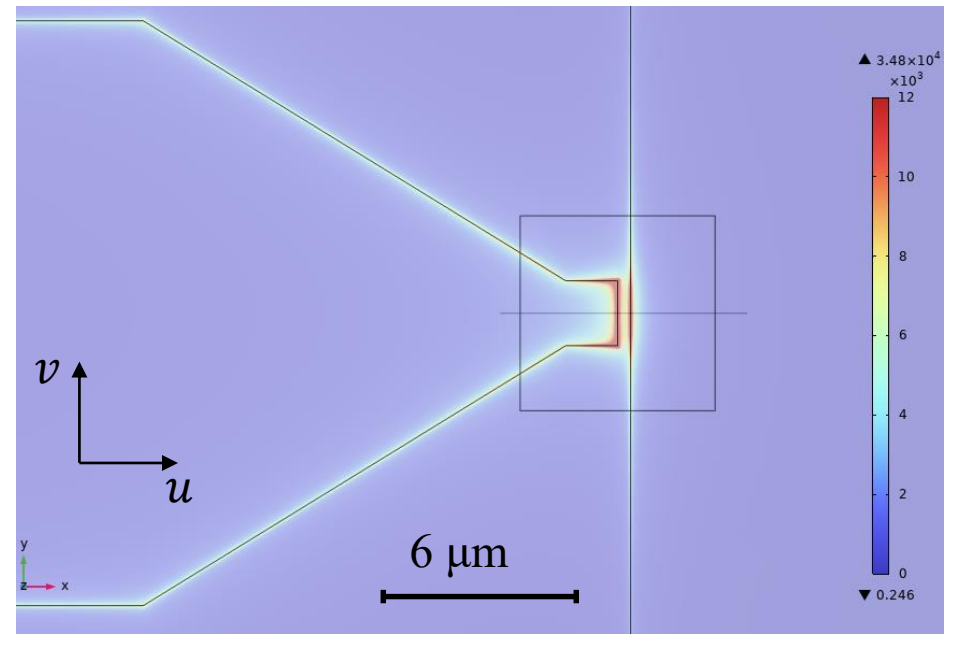
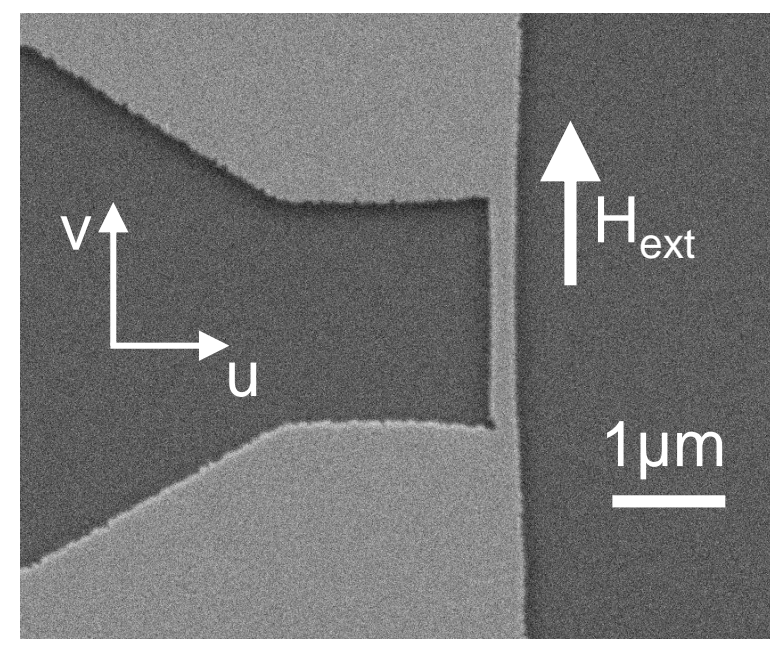


Chiral Caustic beams from a nanoconstriction

- ❖ **"DE-like" configuration ($\vec{h}_{in} \perp \vec{M}_{eq}$)**

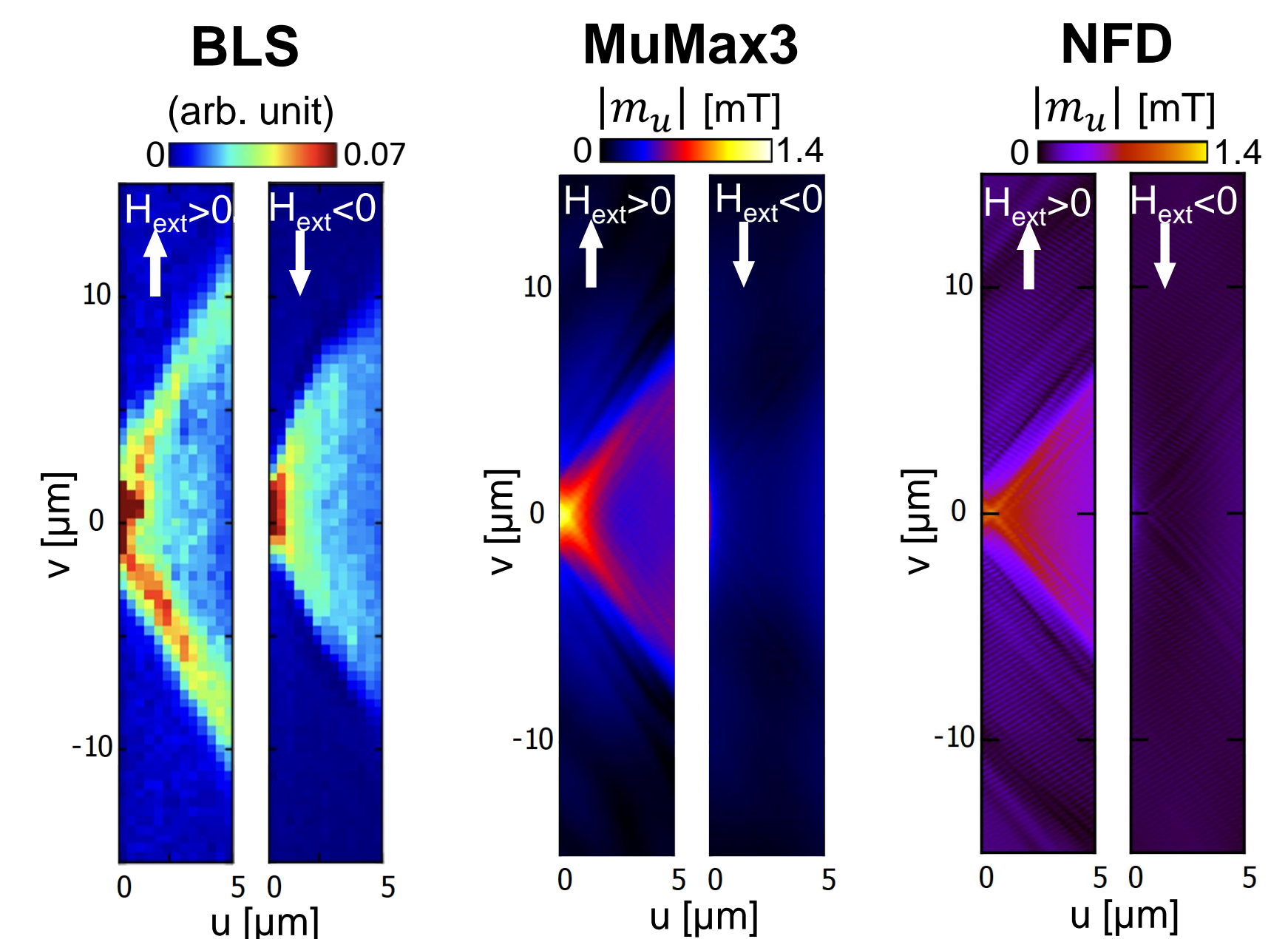
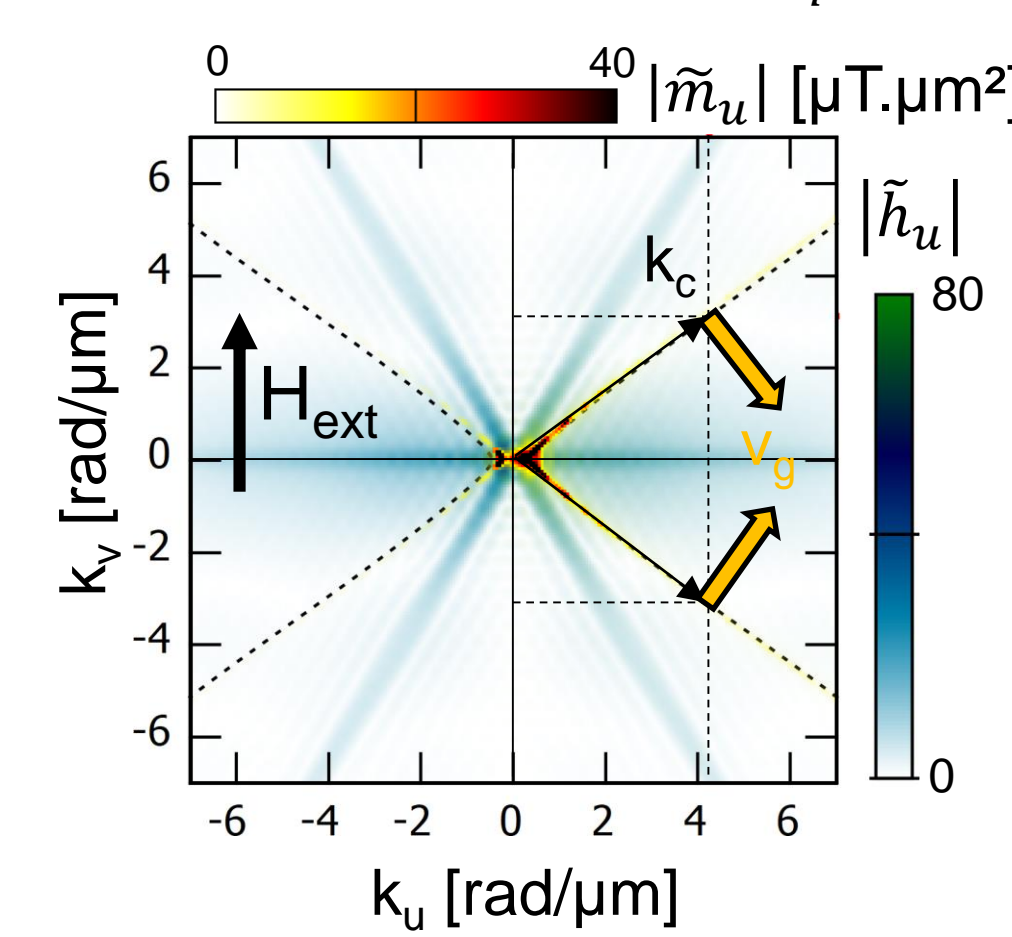
400 nm-wide
2 μ m-long constriction

Comsol simulation @ 5GHz

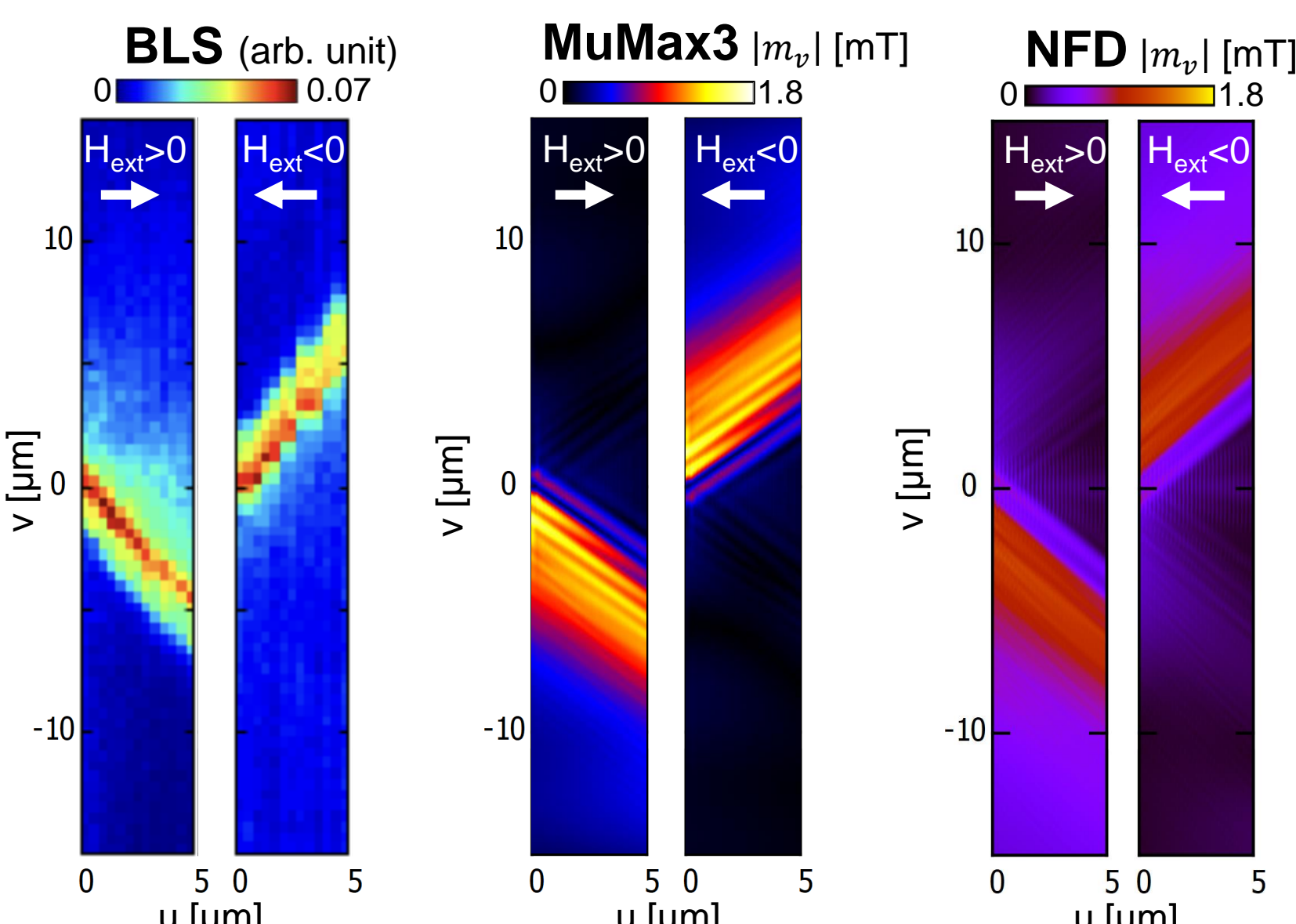


Concentrations of \vec{h} on the edges of the CPW, which extend further away from the constriction

Chiral excitation \Rightarrow propagation only on the right-hand side of M_{eq}



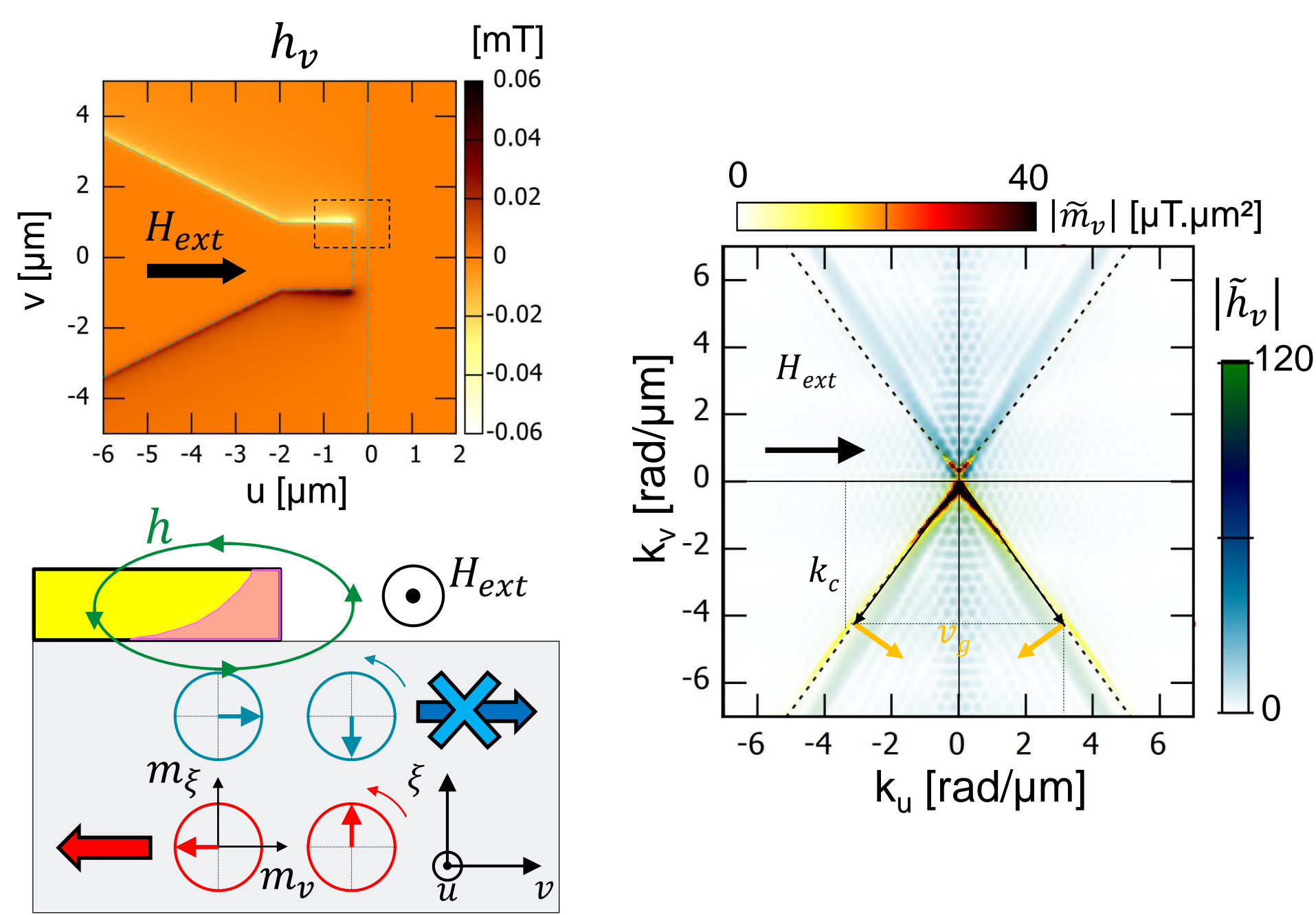
- ❖ **"BVW" configuration ($\vec{h}_{in} \parallel \vec{M}_{eq}$)**



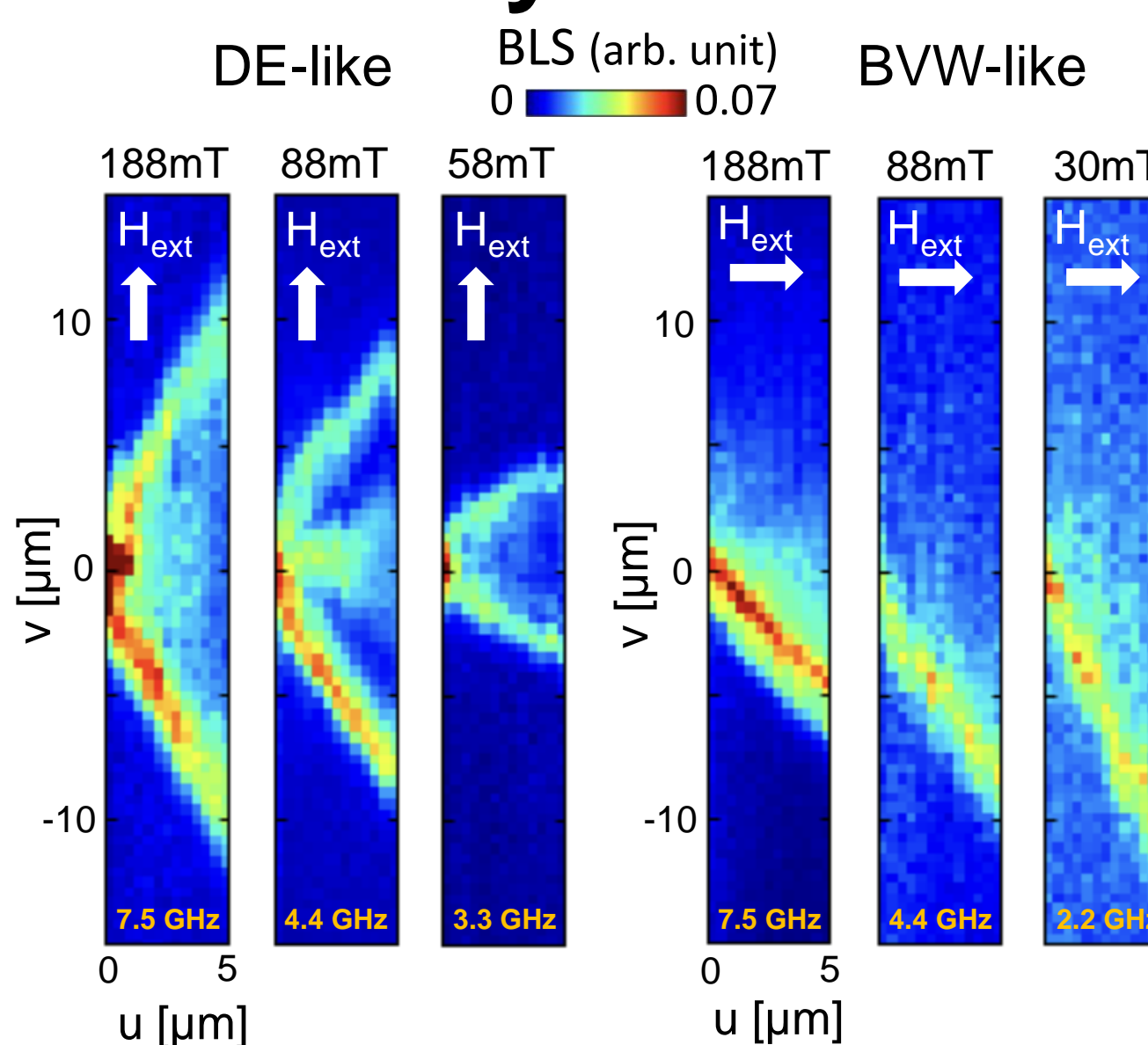
Single non-reciprocal beam upon reversal of H_{ext}

Chiral coupling due to a significant h_v at the corner of the constriction

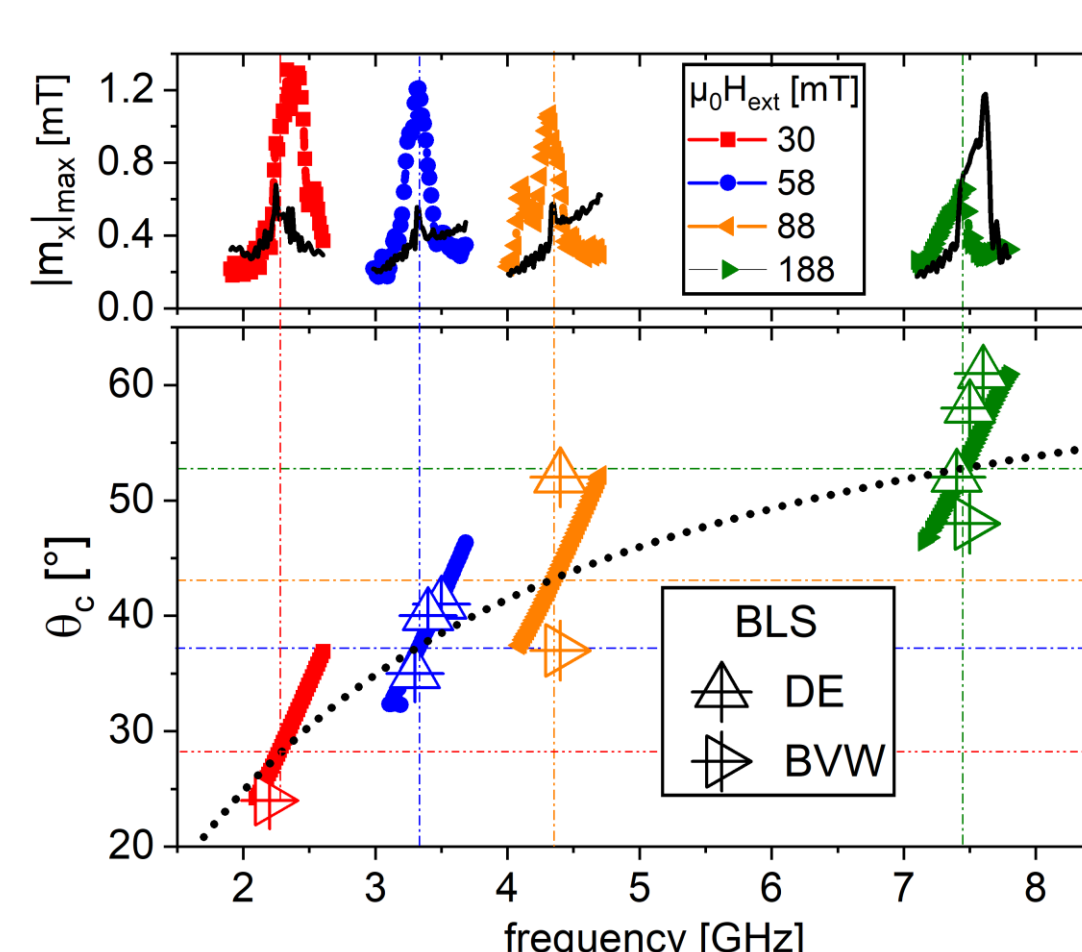
Good agreement with MuMax and NFD
BLS slightly thinner than simulations
 \Rightarrow difficulty to assess microwave field



Steerability of Caustics



Caustic amplitude peaks right around FMR field-frequency



Beam steered toward equilibrium direction as f increases
 \Rightarrow good agreement with theoretical $\theta_c = \frac{\pi}{2} - v_g / H_{ext}$

Conclusions

- ▶ **NFD model: excellent agreement with MuMax3**
 \Rightarrow Efficient method to study spin wave beamforming
- ▶ **Experimental demonstration of a direct excitation of non-reciprocal caustic beams**
- ▶ **Non-reciprocity governed by chiral coupling**
 \Rightarrow combination of h_{in}, h_{out} both transverse to H_{ext}
- ▶ **Beamforming related to constriction shapes & sizes**
- ▶ **Steerable single beam throughout frequency range**

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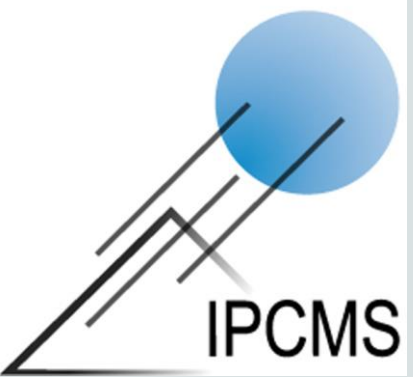
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Fundings

anr[®] agence nationale
de la recherche
MagFunc/ANR-20-CE91-0005

FA
CE
Thomas Jefferson
Funds
Magnon Interferometry

FRANCE
2030
PROGRAMME
DE RECHERCHE
SPINTRONIQUE

PEPR SPIN SWING
ANR-22-EXSP-0004

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