Writing, reading and dissipationlessly transferring spin via charge

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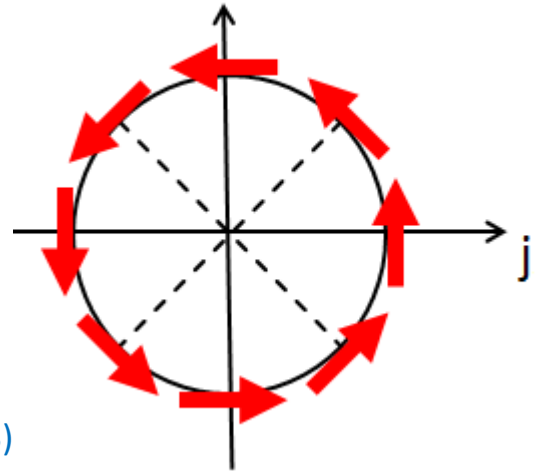
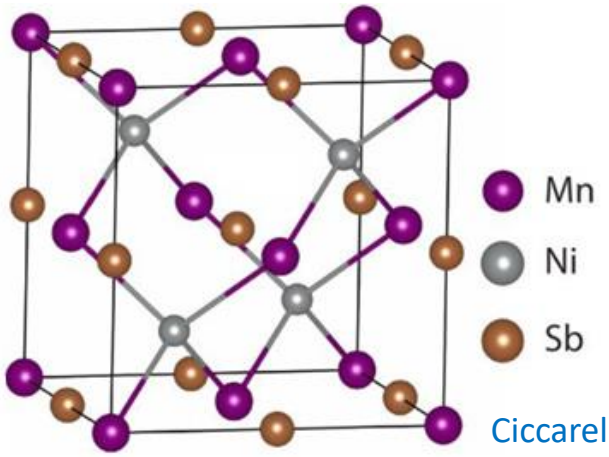
Nature Materials doi:10.1038/s41563-018-0058-9

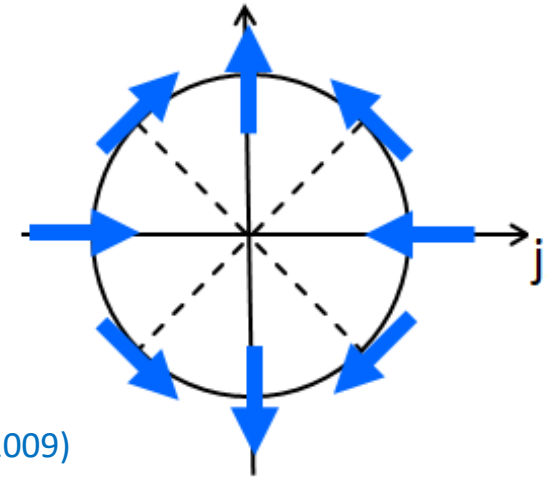
“Writing” magnetism via charge

$$H_{so} = \frac{e\hbar^2}{4m_e c^2}\boldsymbol{\sigma}\cdot[\mathbf{k}\times\boldsymbol{\nabla}V(\mathbf{r})] \xrightarrow[V(r)\neq V(-r)]{\text{INVERSION ASYMMETRY}} H_{so} \propto \boldsymbol{\sigma}\cdot\mathbf{B_{eff}}(\mathbf{k})$$



Garello et al., Nature Nanotech 18, 587 (2013)
Miron et al., Nature 476, 189 (2011)





Ciccarelli et al., Nature Physics 12, 855 (2016)
Chernyshov et al., Nature Phys. **5**, 656–659 (2009)

“Writing” magnetism via charge

$$H_{so} = \frac{e\hbar^2}{4m_e c^2}\boldsymbol{\sigma}\cdot[\mathbf{k}\times\boldsymbol{\nabla}V(\mathbf{r})]$$

INVERSION ASYMMETRY

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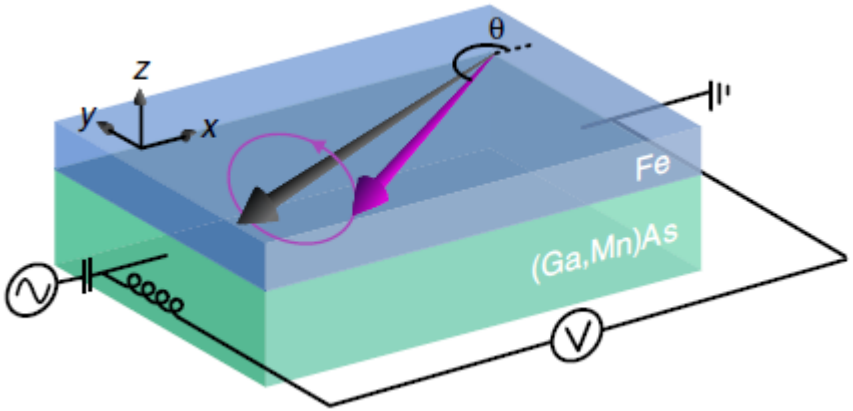
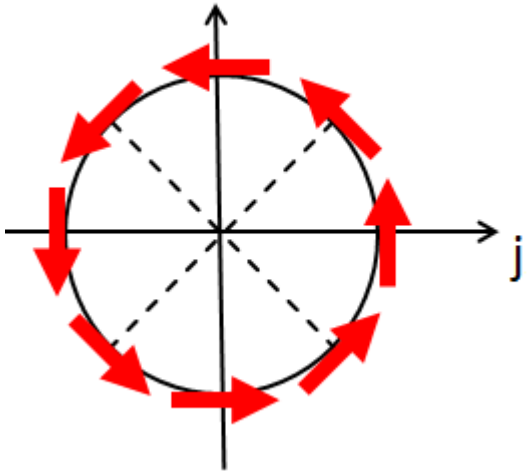
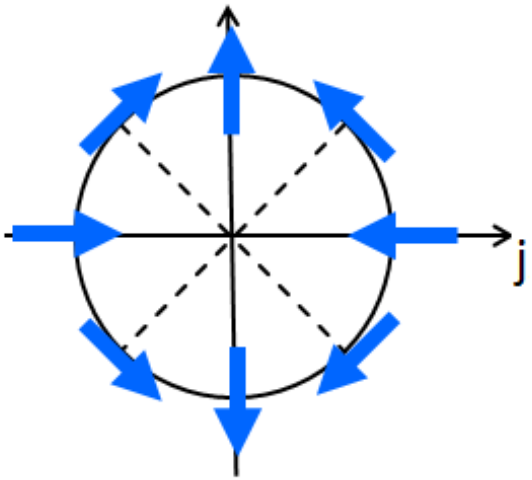




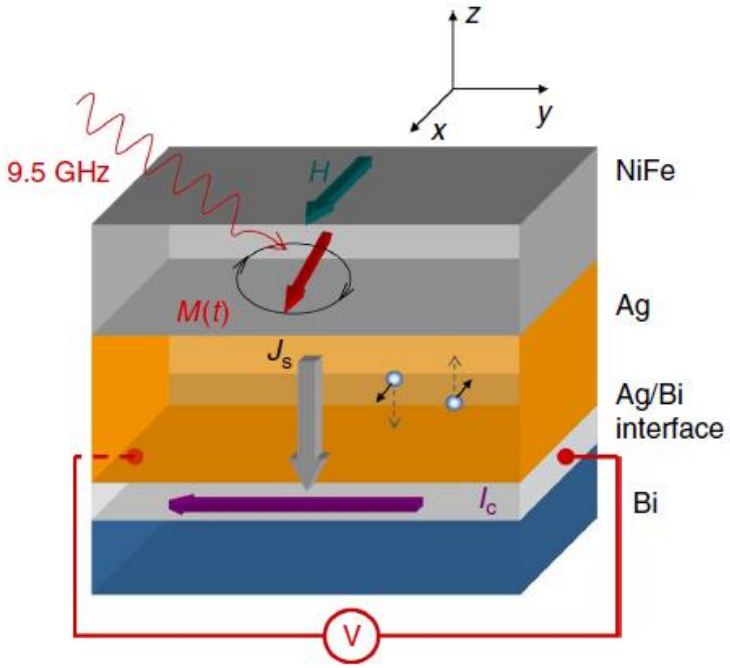
Chen et al., Nature Comm. 7, 13802 (2016)
Skinner et al., Nature Comm 6, 6730 (2014)



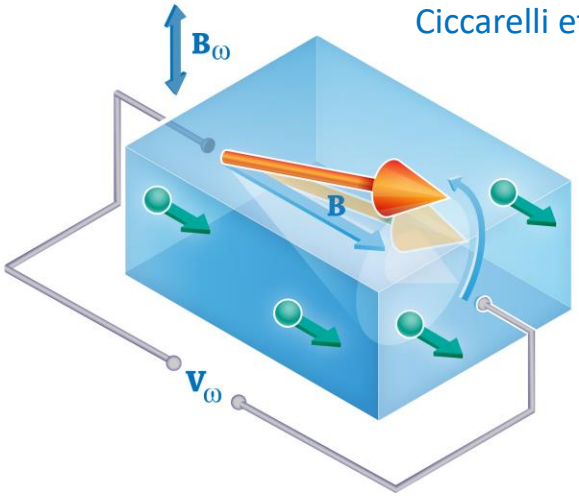
“Reading” magnetism via charge

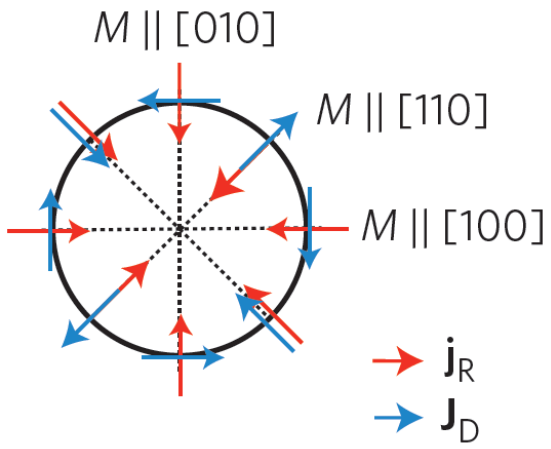
$$\begin{pmatrix} \hat{\chi} & \lambda\hat{\Lambda}_{so} \\ \eta\hat{\Lambda}_{so} & \hat{\sigma} \end{pmatrix} \begin{pmatrix} \mathbf{H}_{\mathrm{eff}}(t) \\ \mathbf{E}(\mathrm{t}) \end{pmatrix} = \begin{pmatrix} \mathbf{M}(\mathrm{t}) \\ \mathbf{J}(\mathrm{t}) \end{pmatrix}$$

Sanchez et al., Nature Comm. 4, 2944 (2015)

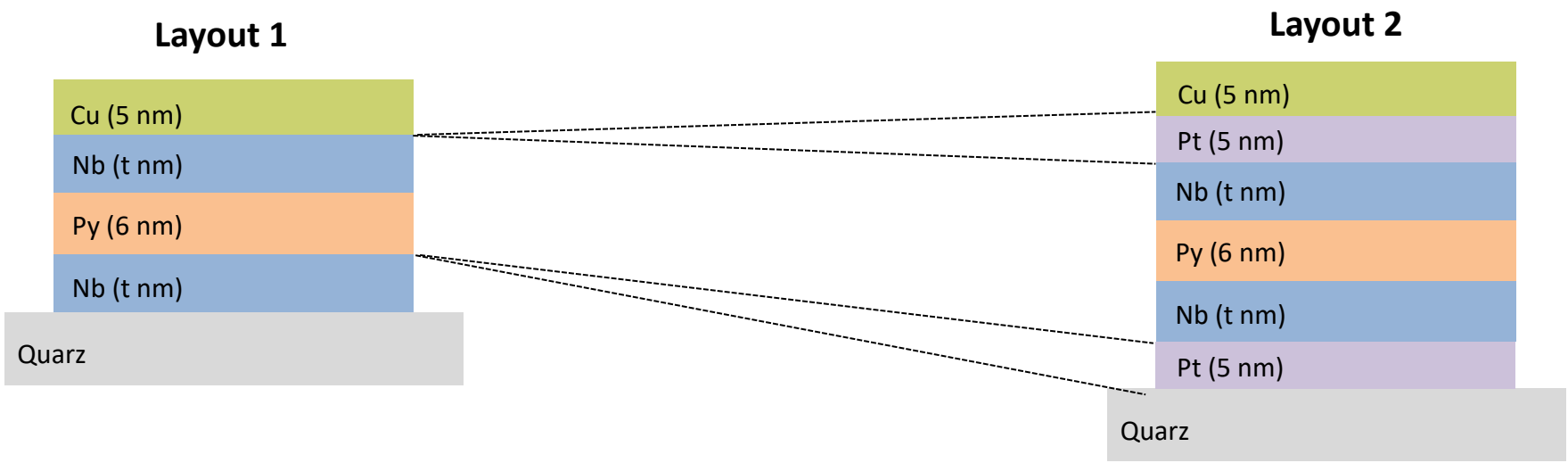


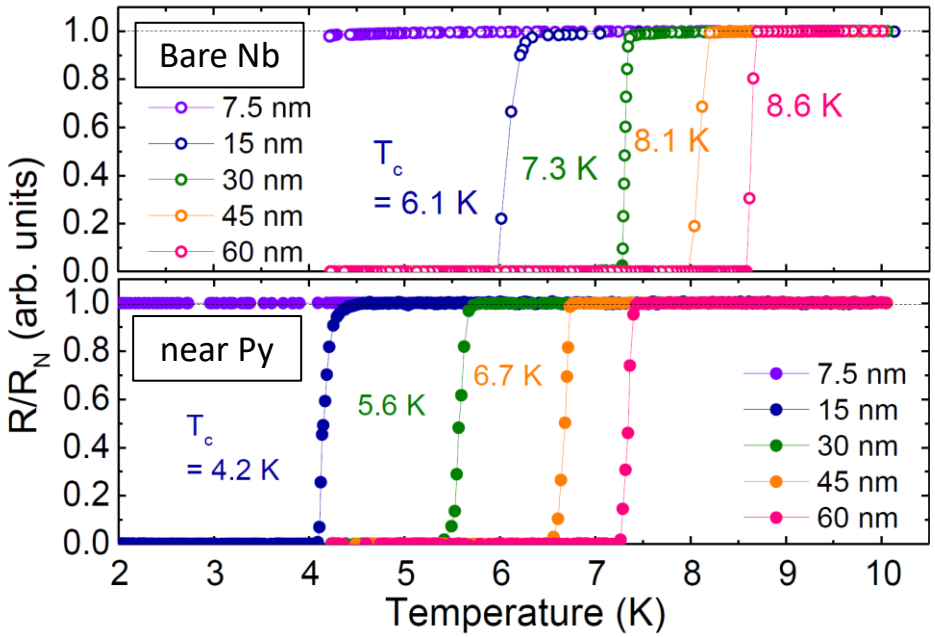
Ciccarelli et al., Nature Nanotech. 10, 50 (2015)

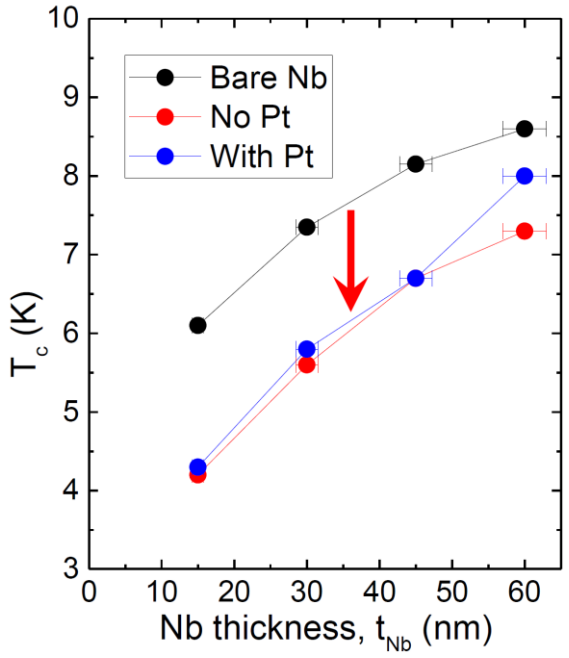




We measure FMR in two different structures







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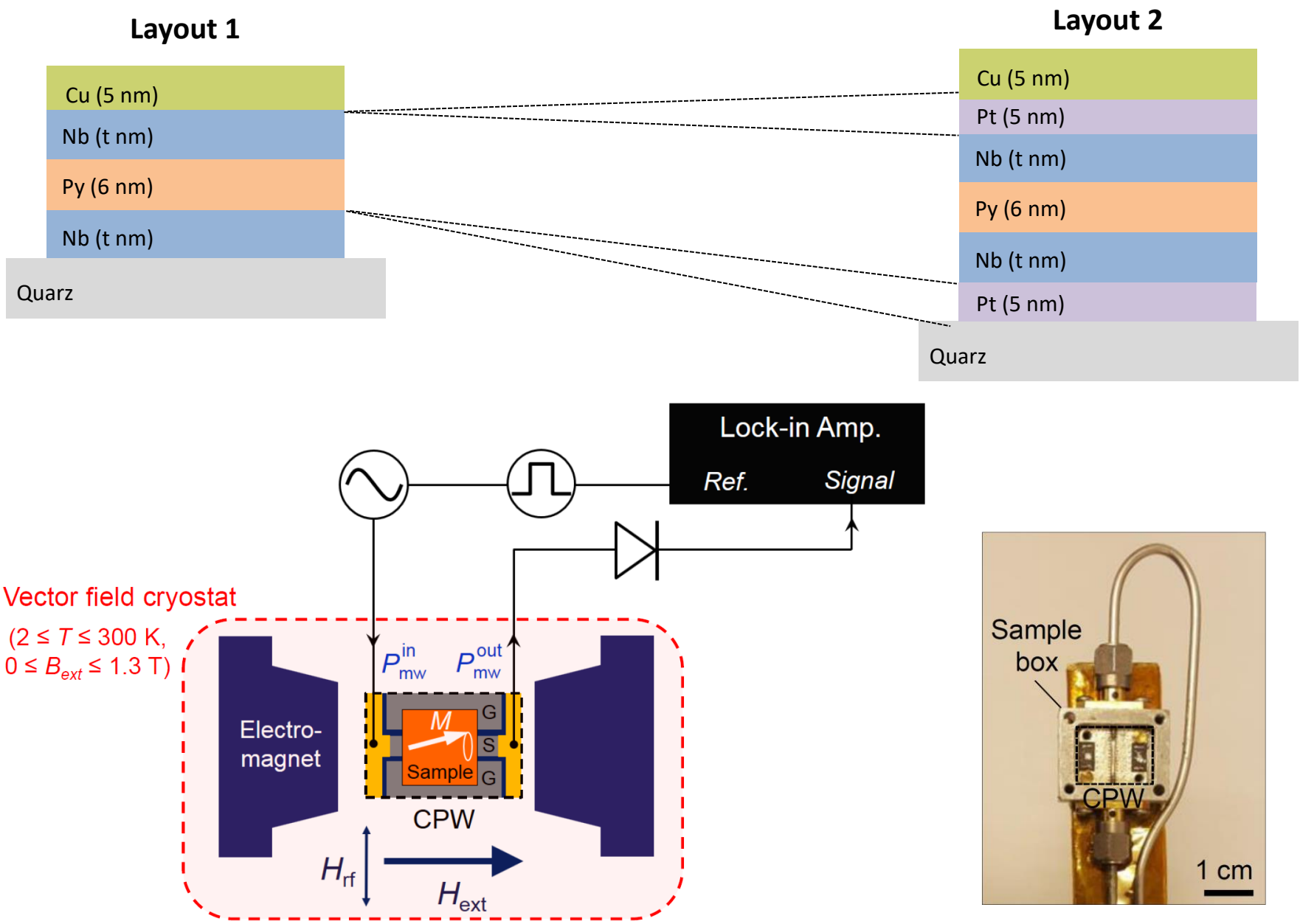
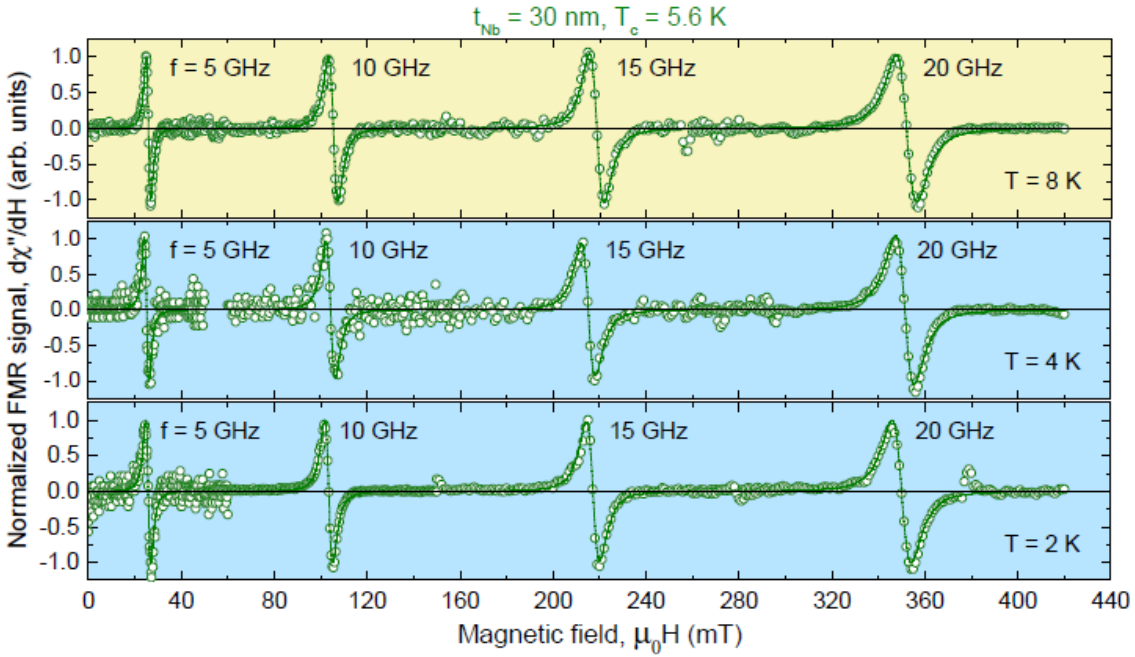
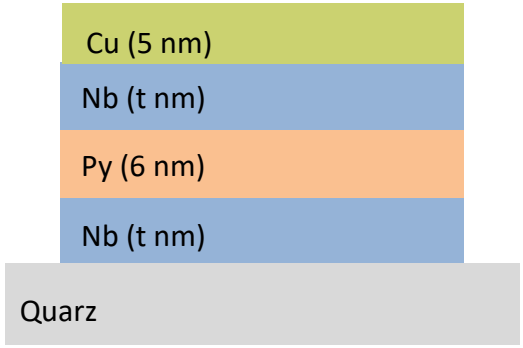
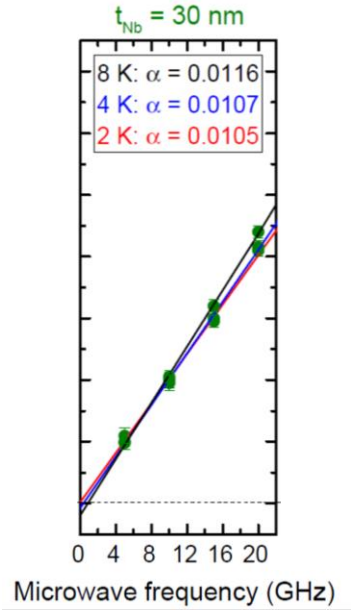


We estimate the spin through Nb from the FMR linewidth



Layout 1





$$\mu_0 \Delta H(f) = \mu_0 \Delta H_0 + \frac{4\pi\alpha f}{\sqrt{3}\gamma}$$

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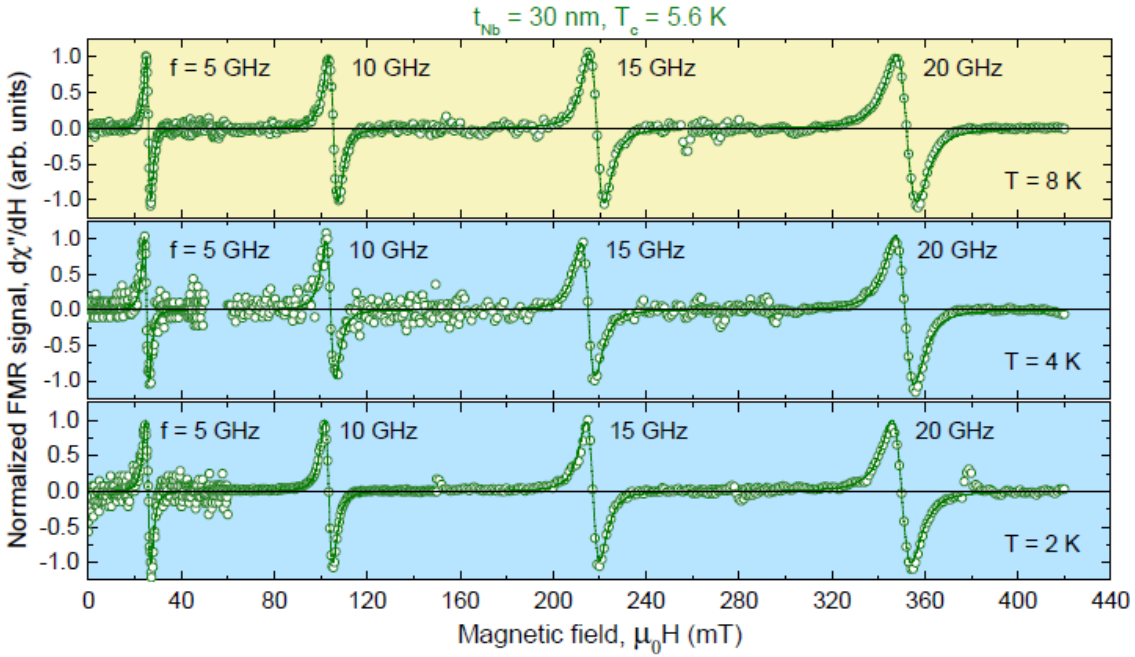

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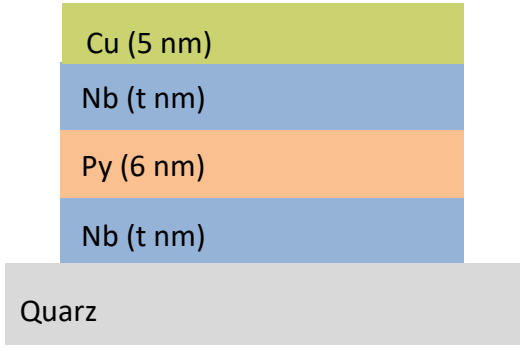

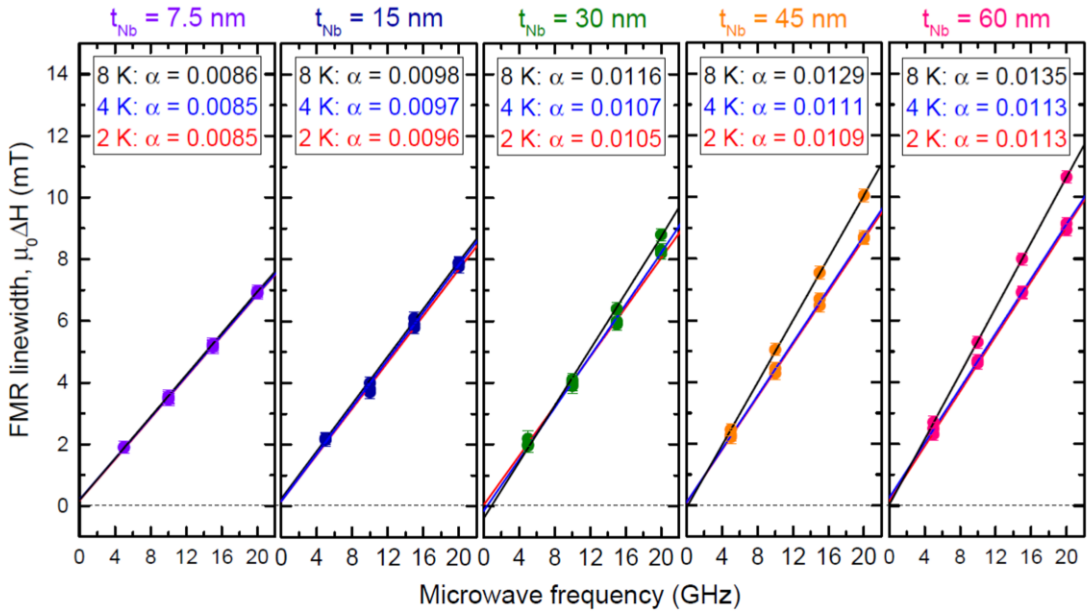

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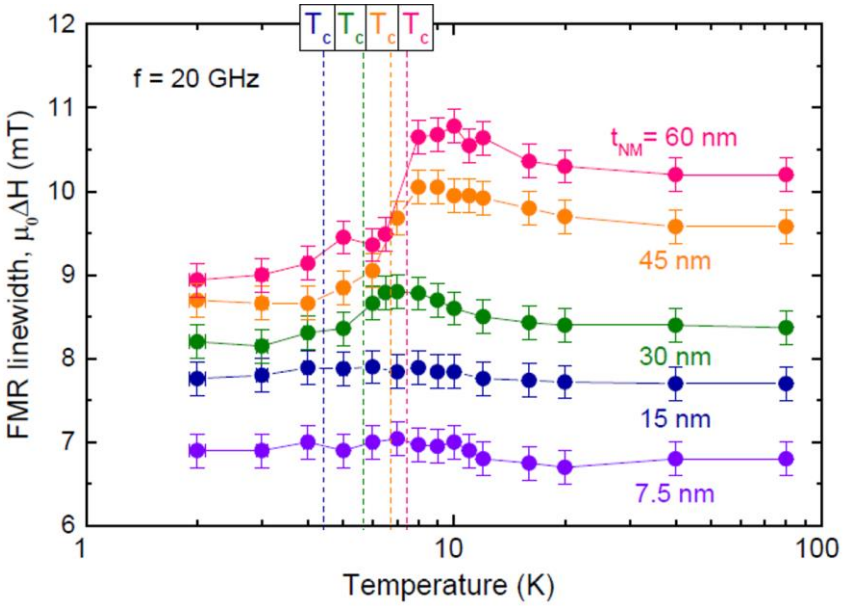
Damping has a sharp decrease below Tc



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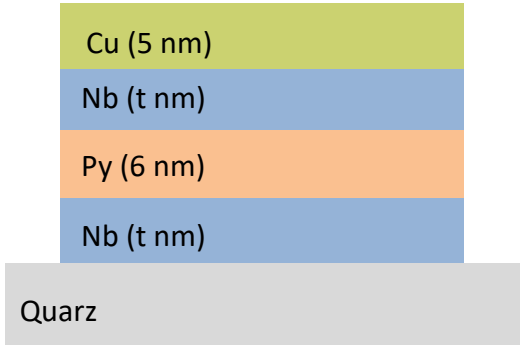

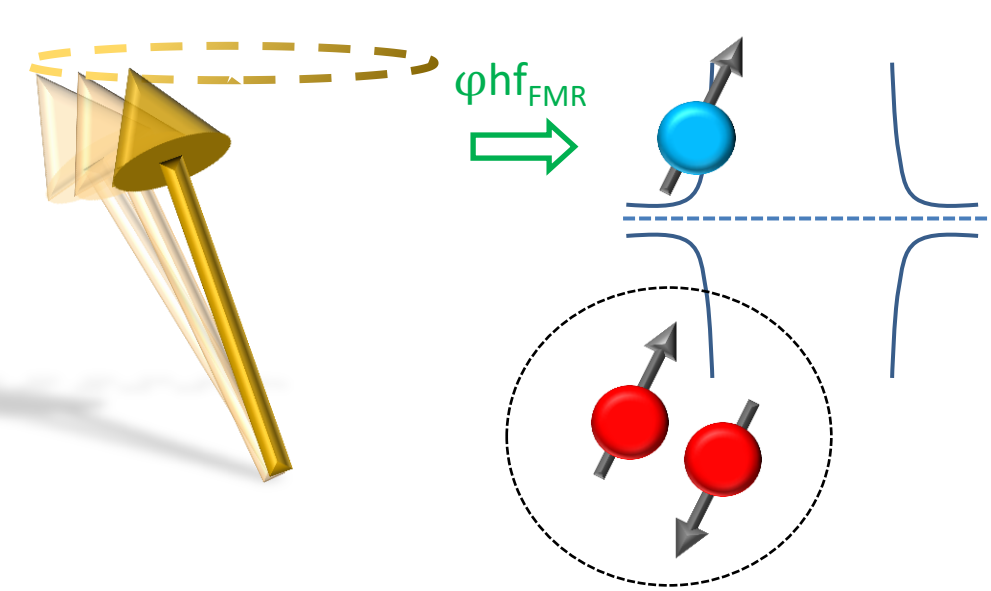

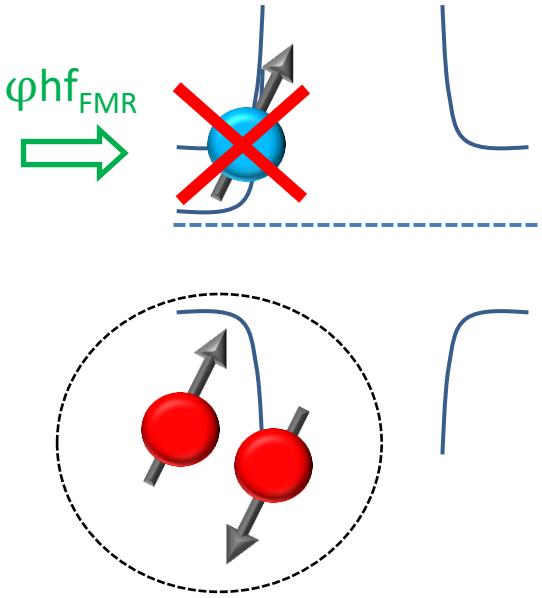

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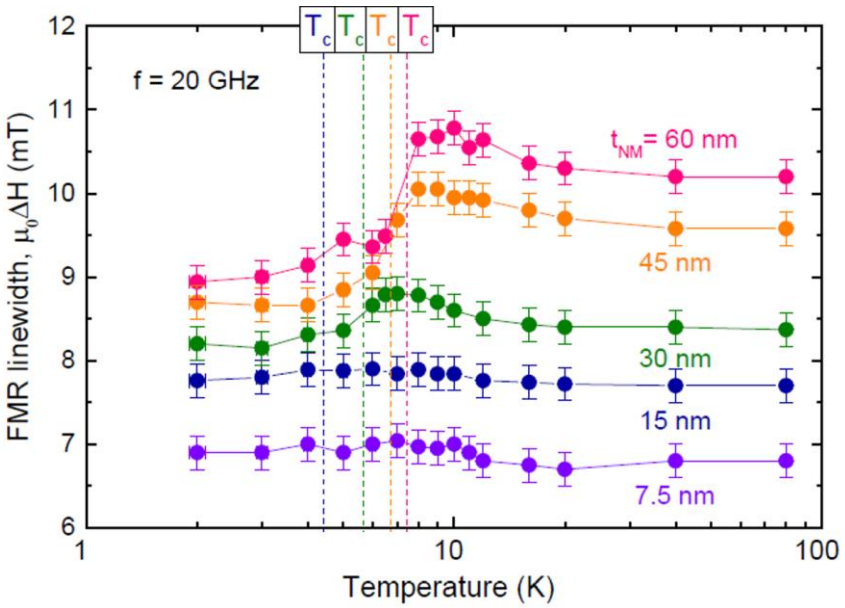

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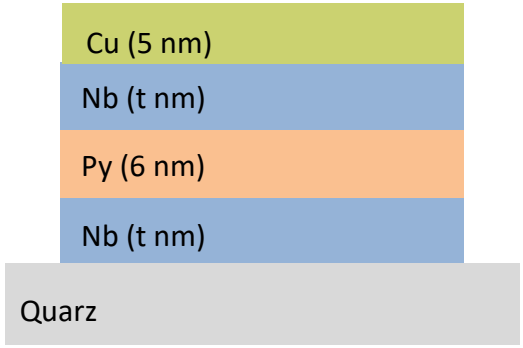

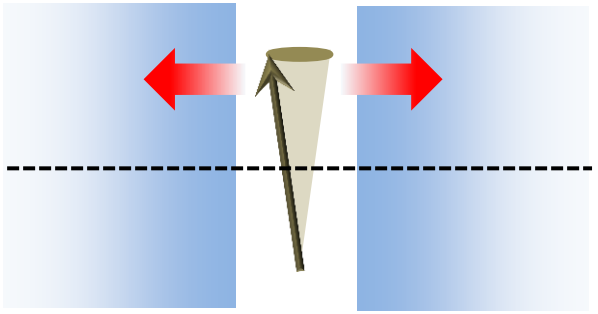

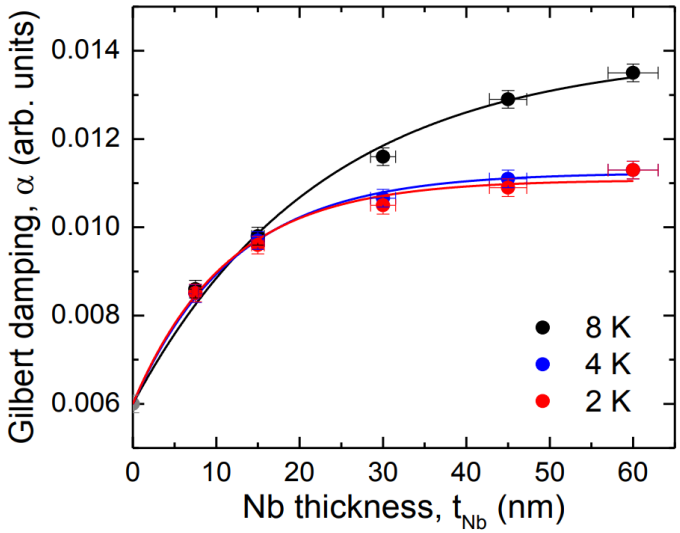

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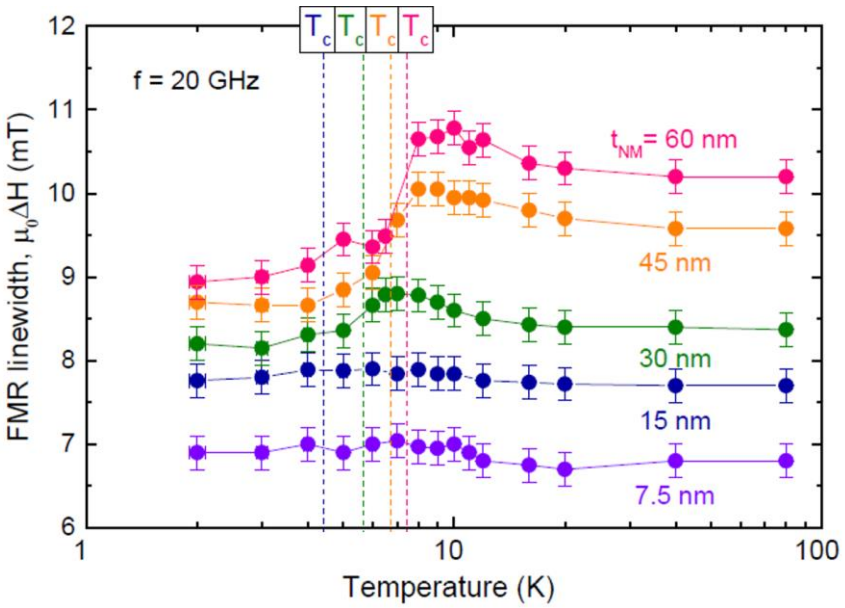

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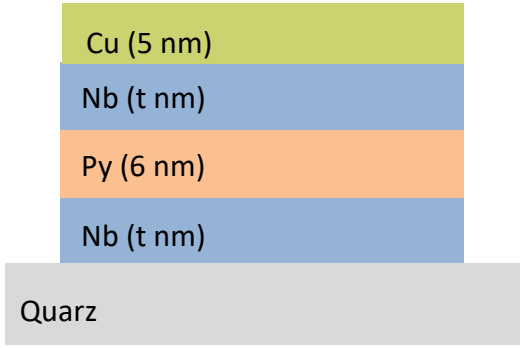

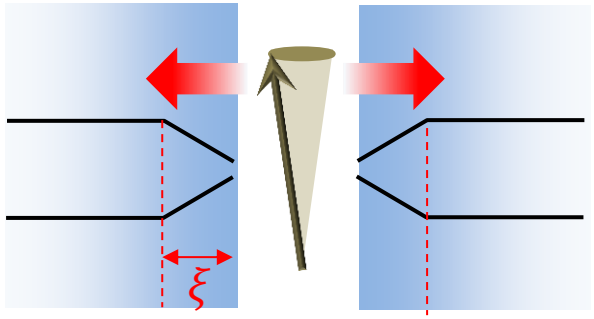

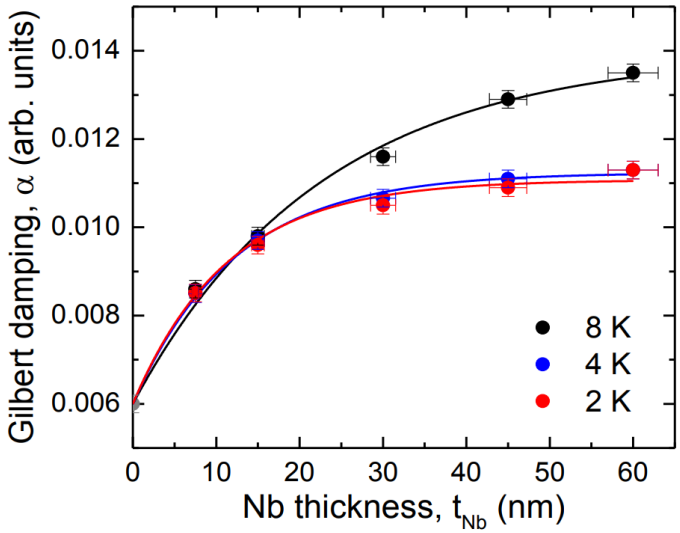

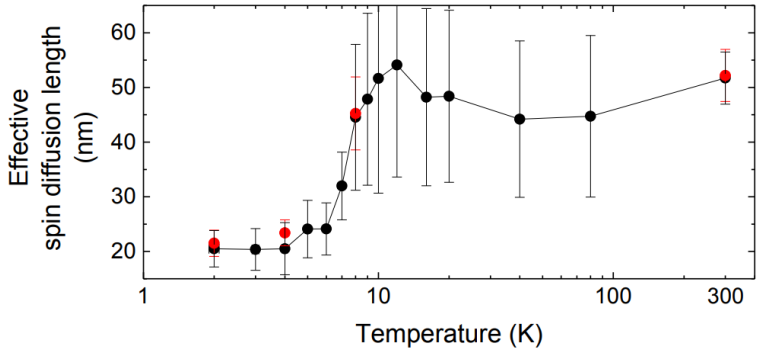

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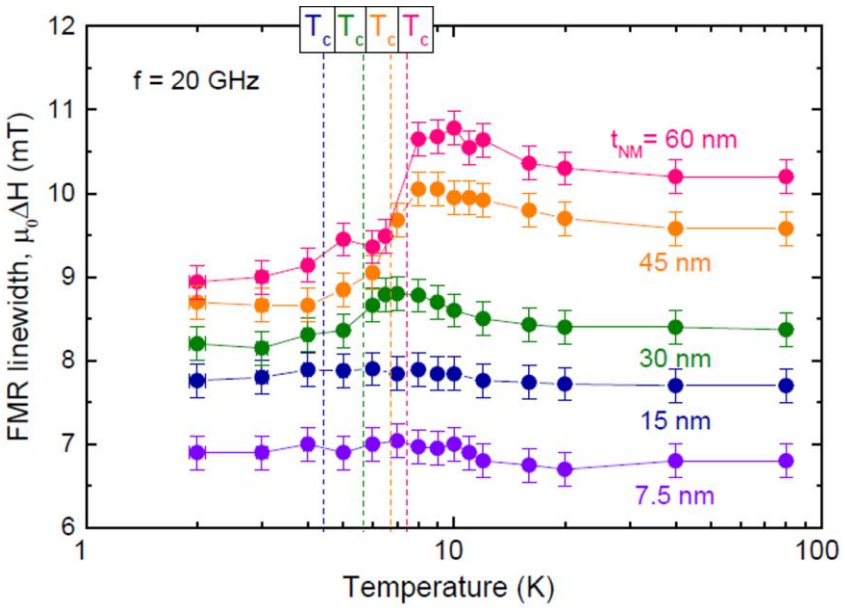

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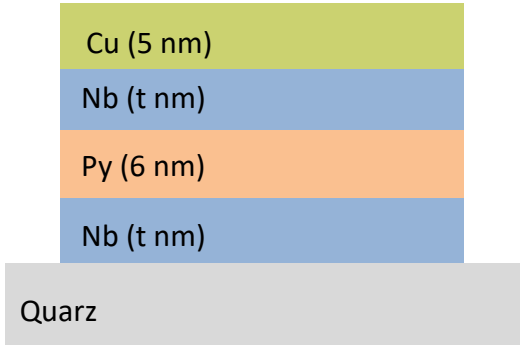
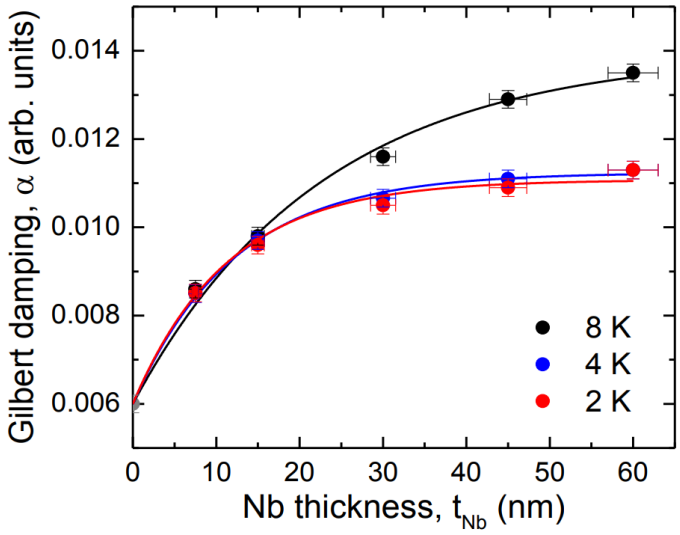
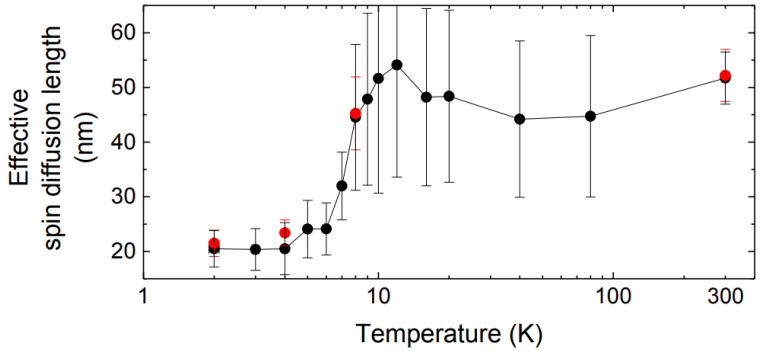




$$l_{QP}^{S} = \sqrt{D\left(\frac{1}{\tau_{AR}} + \frac{1}{\tau_s}\right)^{-1}} \sim 20 \text{ nm}$$



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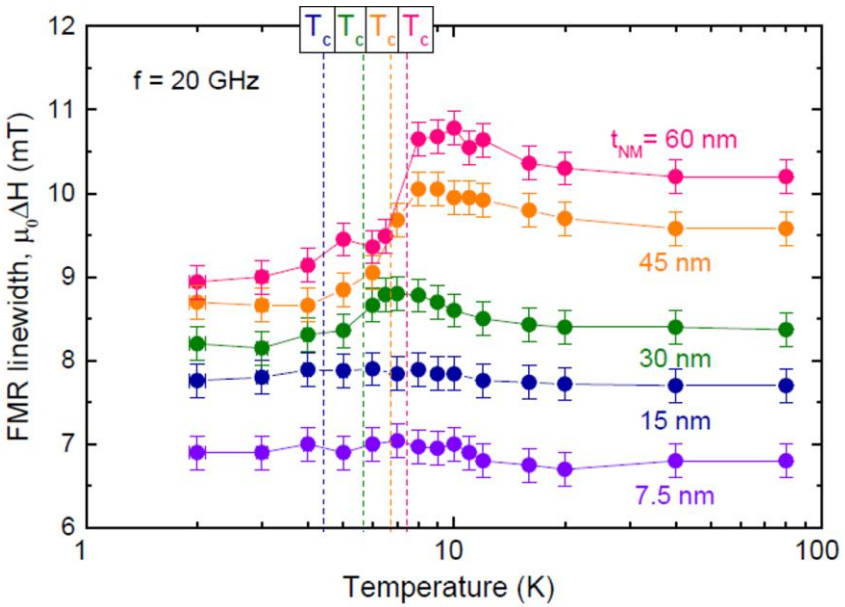

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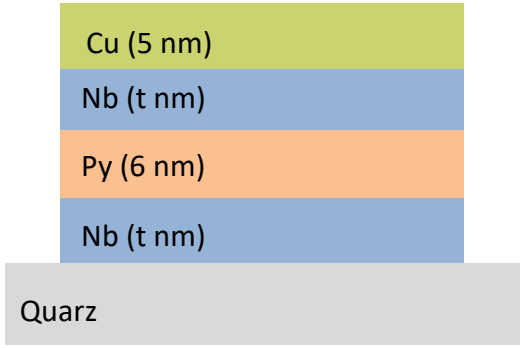

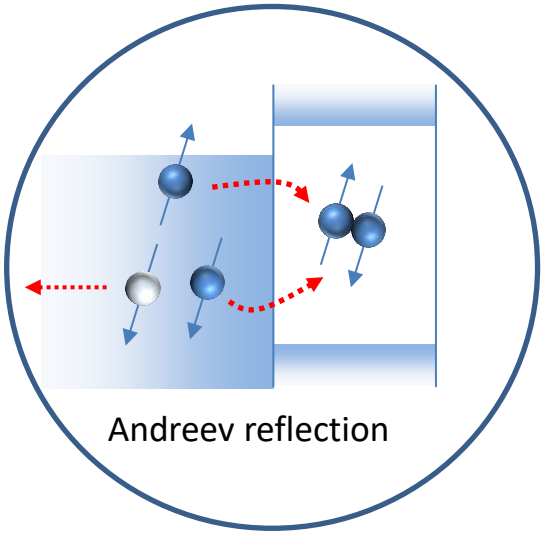

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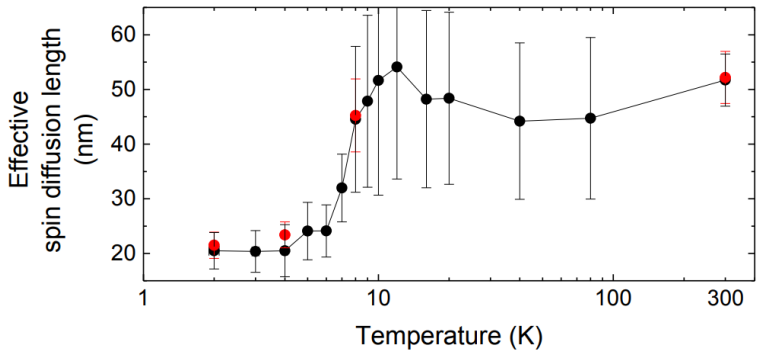

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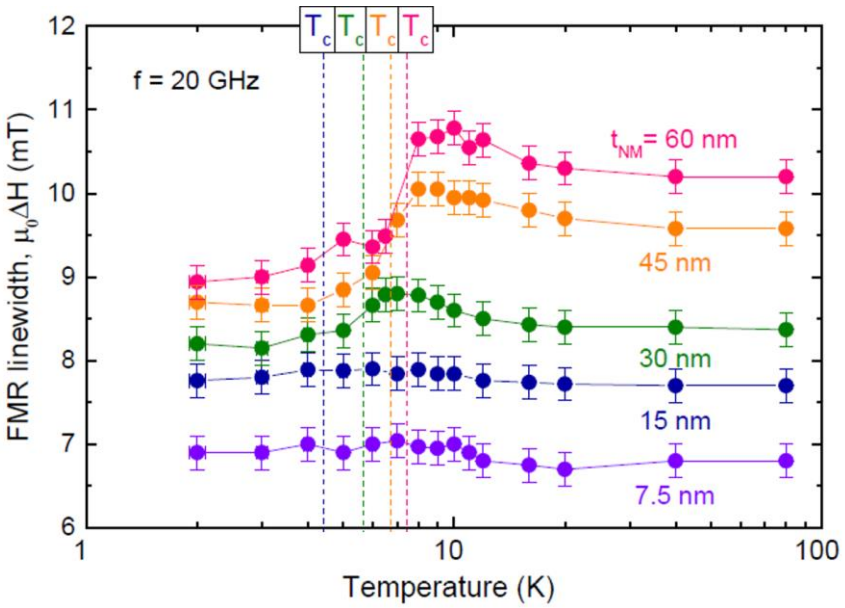

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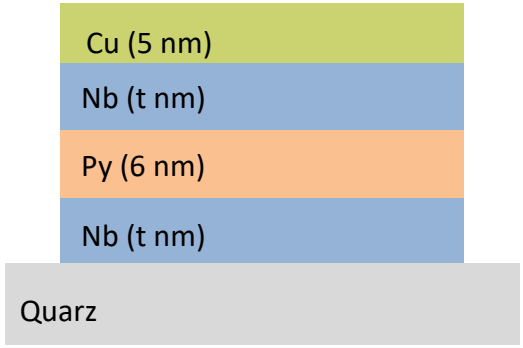

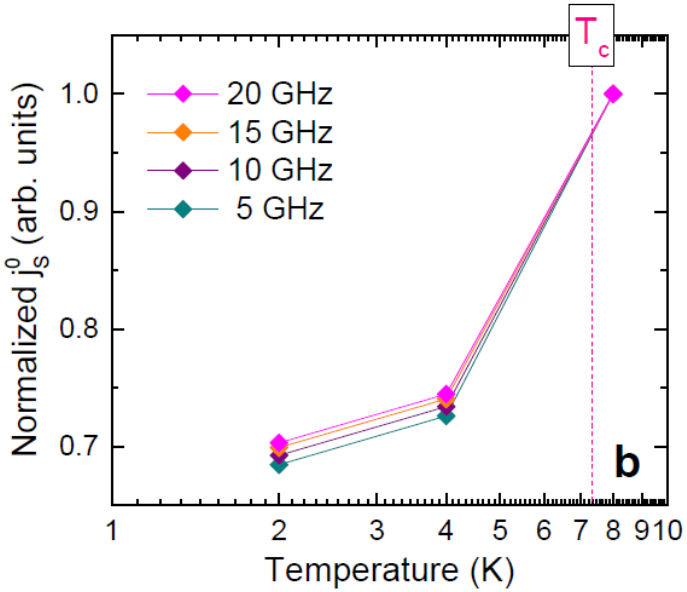

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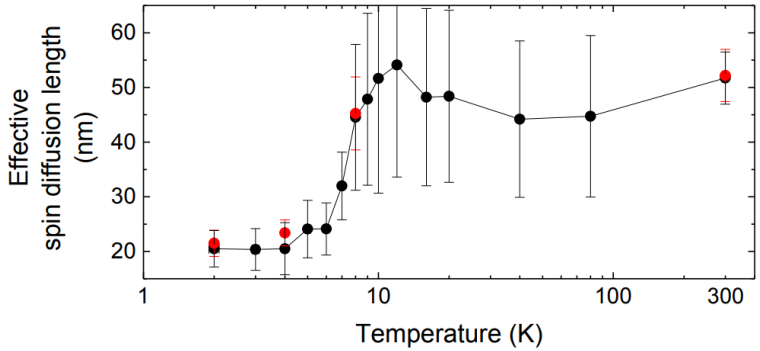
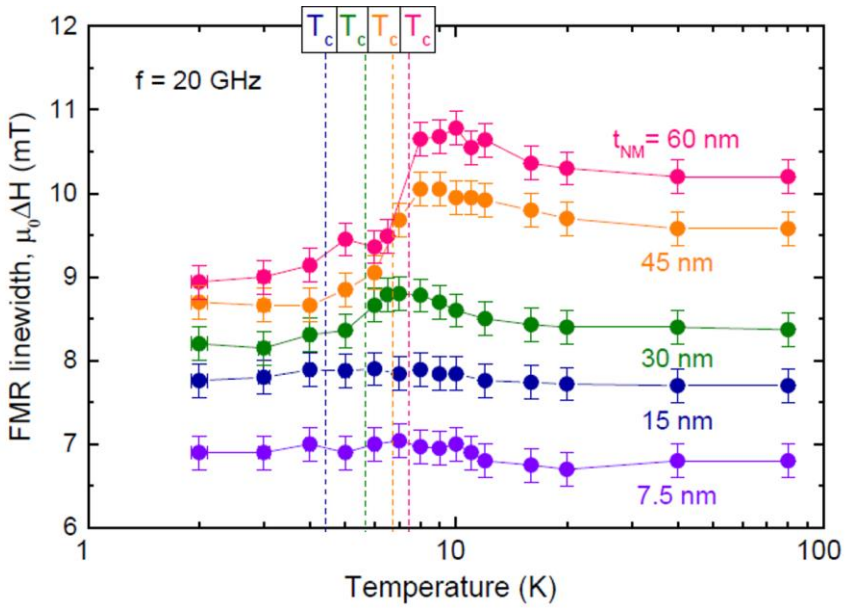
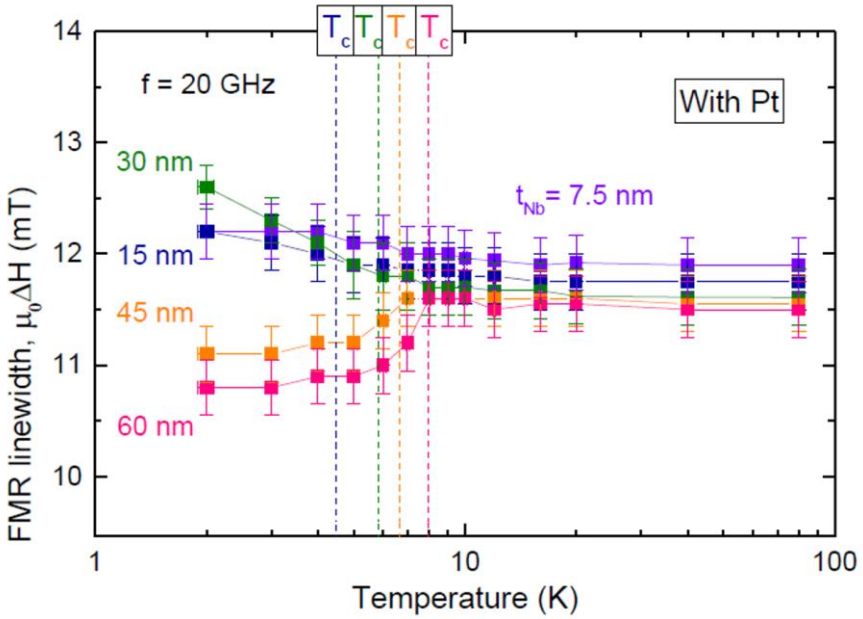


An unusual behavior is observed in the presence of Pt





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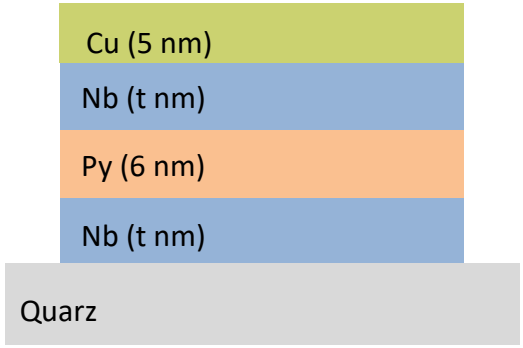

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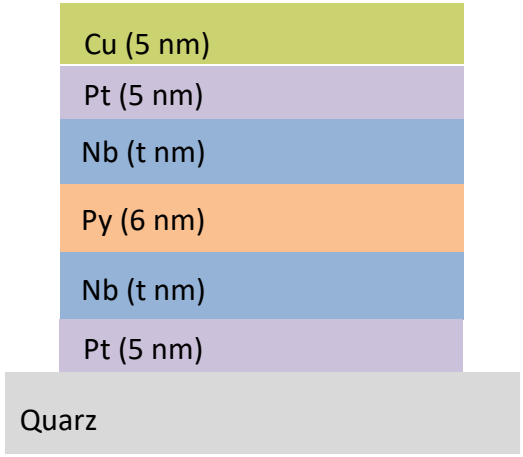

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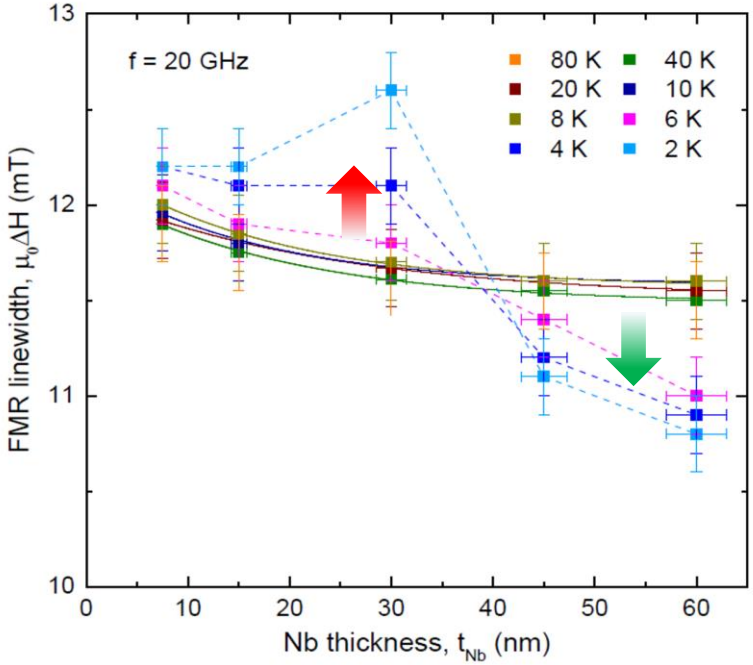
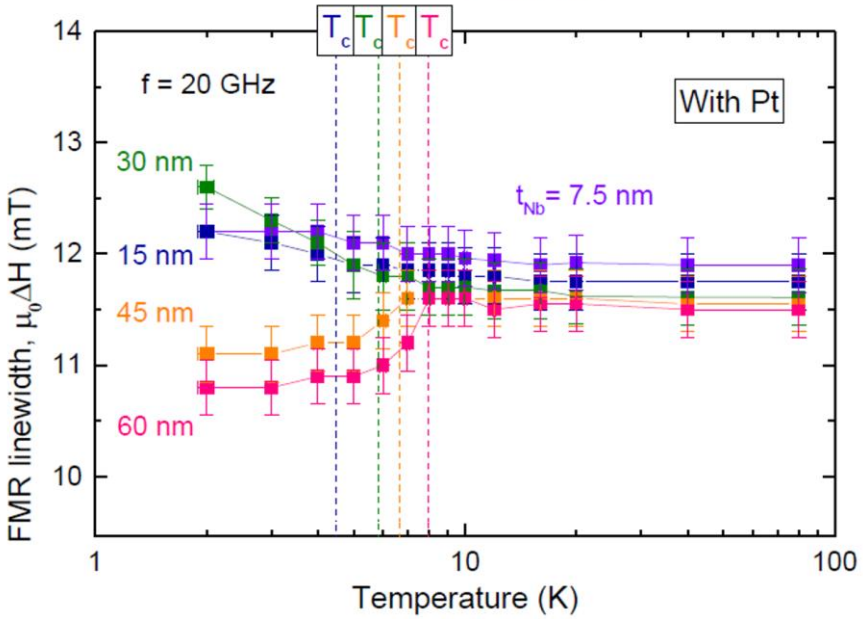
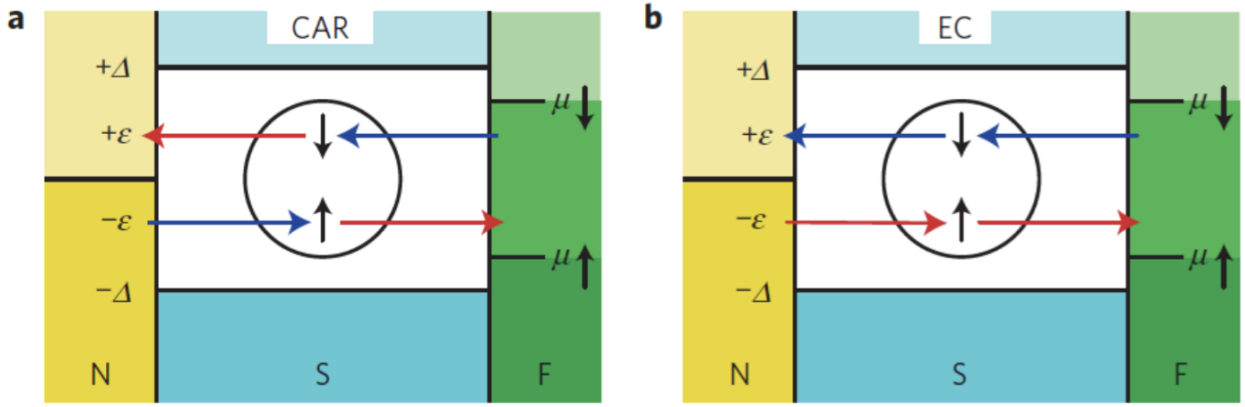




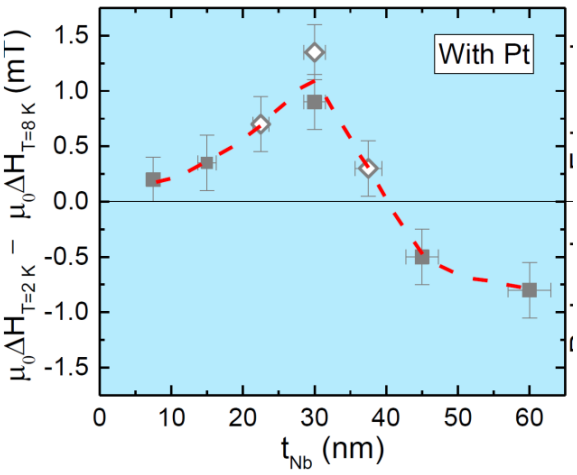
Layout 2

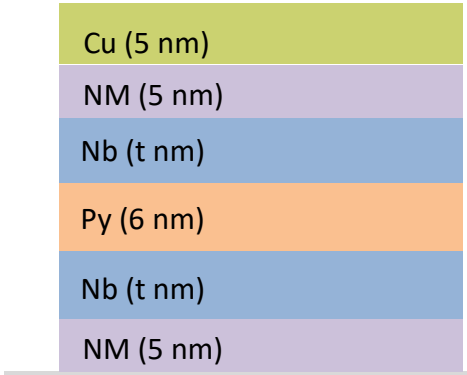
Spin must be carried by Cooper pairs

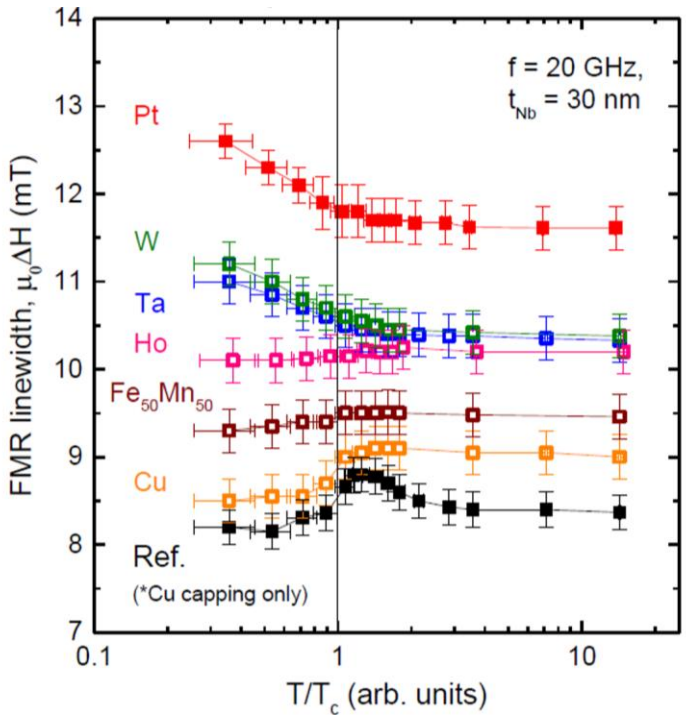
Flokstra et al., Nature Phyysics 12, 57 (2015)

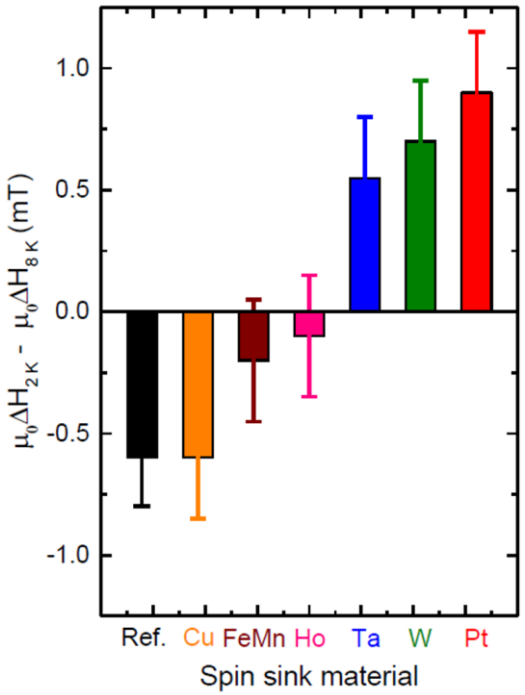


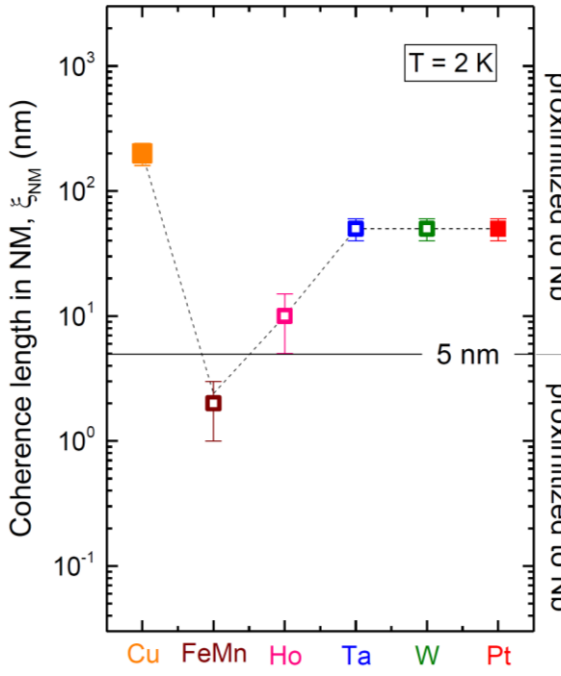
Cooper pairs cannot be in a singlet state





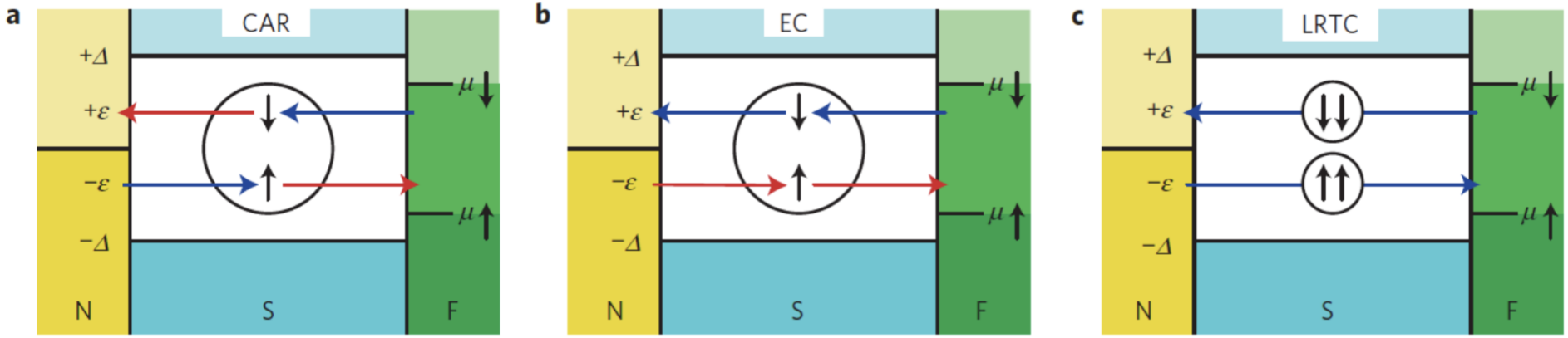






Spin must be carried by Cooper pairs

Flokstra et al., Nature Phyysics 12, 57 (2015)



At a ferromagnet/superconductor interface

- Short range triplets and singlets $\sim\sqrt{\frac{D}{h_{ex}}}$
- Long range triplets $\sim\sqrt{\frac{D}{KT}}$

Jacobsent et al., PRB 92, 024510 (2015)
Bergeret et al., PRB 89, 134517 (2014)

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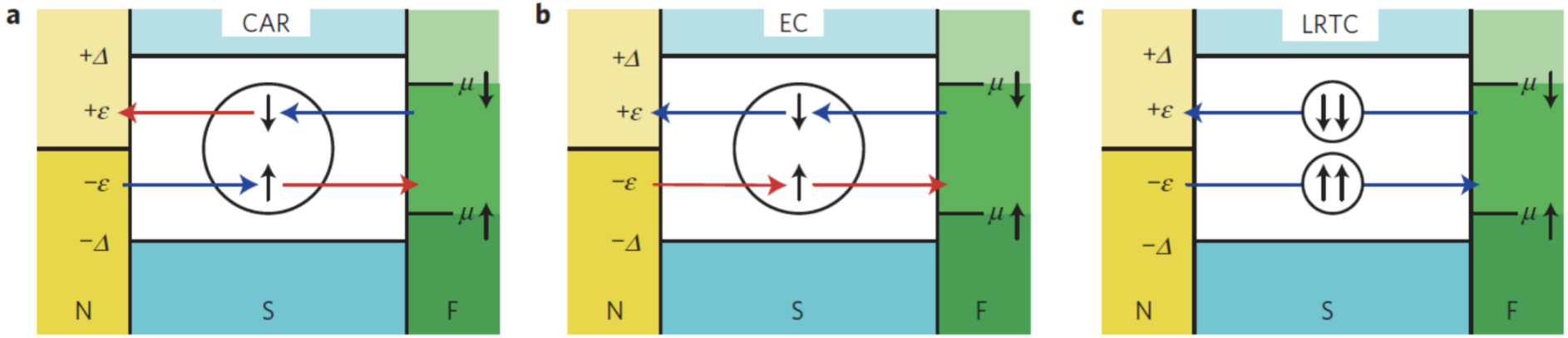

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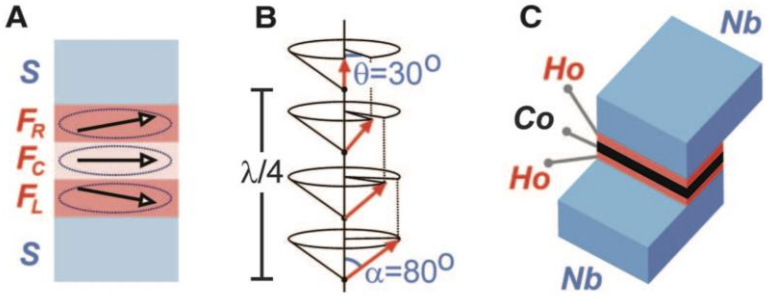
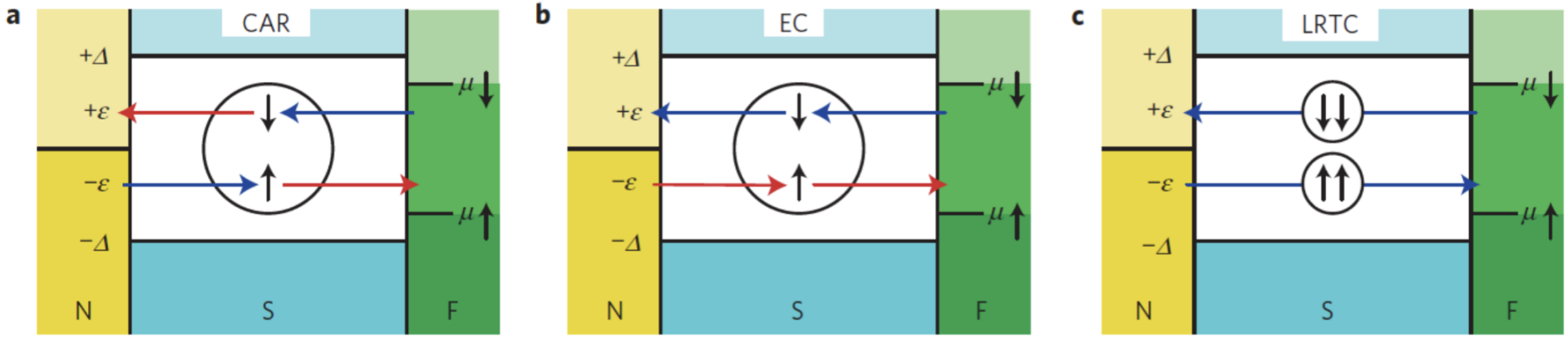


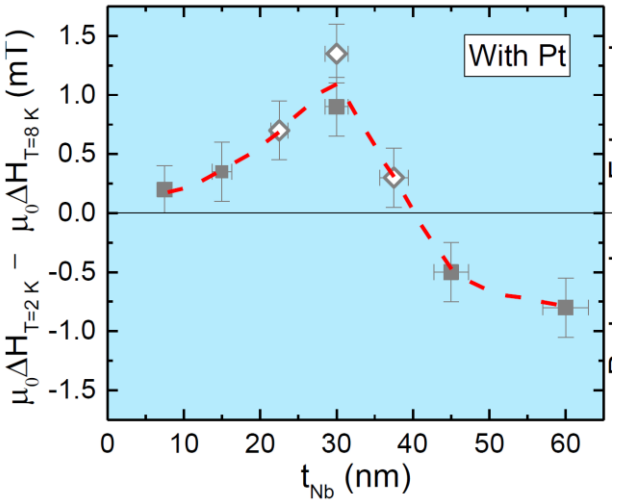
Jacobsent et al., PRB 92, 024510 (2015)
Bergeret et al., PRB 89, 134517 (2014)

Khaire et al., PRL 104, 137002 (2010)
Robinson et al., Science 329, 59 (2010)
Leskin et al., PRL 109, 057005 (2012)

Spin must be carried by Cooper pairs in a triplet state

Flokstra et al., Nature Phyysics 12, 57 (2015)





Conclusions

- Spin transfer in a BCS superconductor can be mediated by Cooper pairs in a triplet state.

- These Cooper pairs propagate to longer distances than quasiparticles and do not dissipate energy.

- The crucial ingredient to generate triplet Cooper pairs seems to be the Rashba SO field.

Nature Materials doi:10.1038/s41563-018-0058-9

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