Spin transport in a conventional superconductor

Chiara Ciccarelli,
University of Cambridge

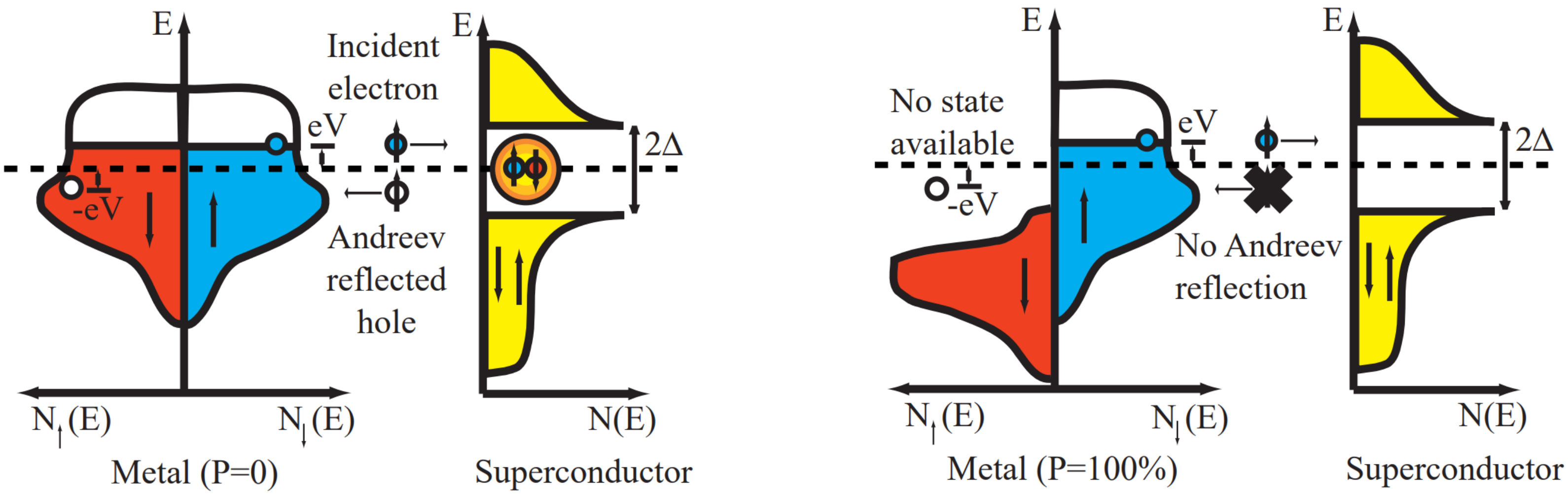
K.R. Jeon, J.W.A. Robinson, M. Blamire

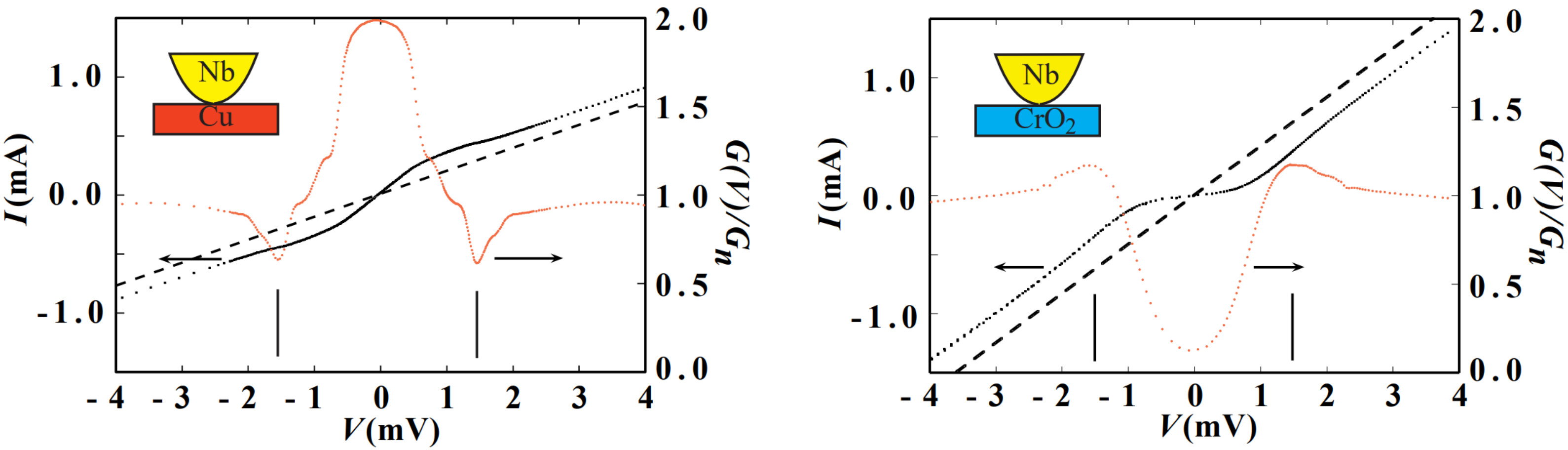
H. Kurebayashi

L.F. Cohen

X. Montiel,
M. Eschrig

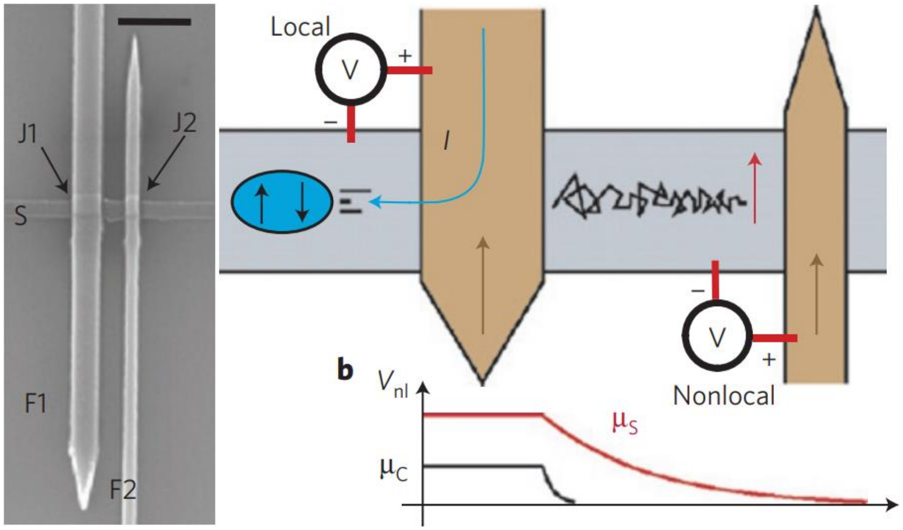
Spin transport BELOW the superconducting gap

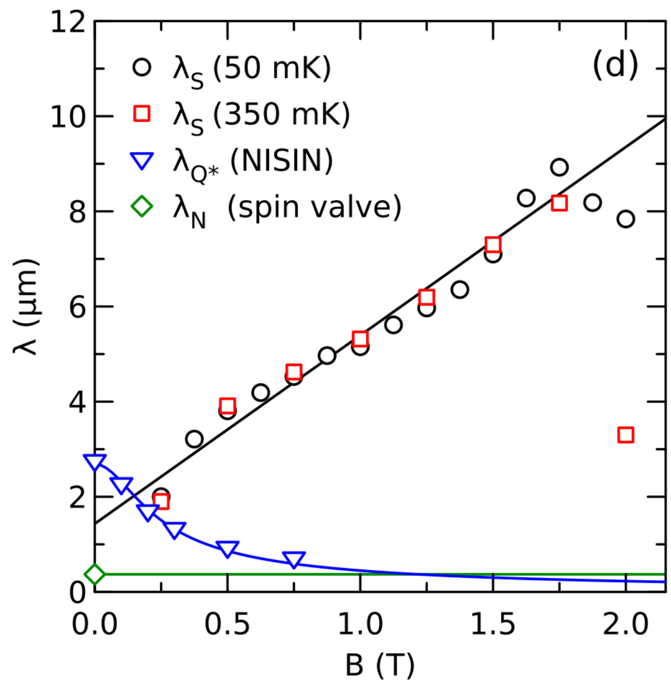




Science 282, 85 (1998)

Spin transport ABOVE the superconducting gap

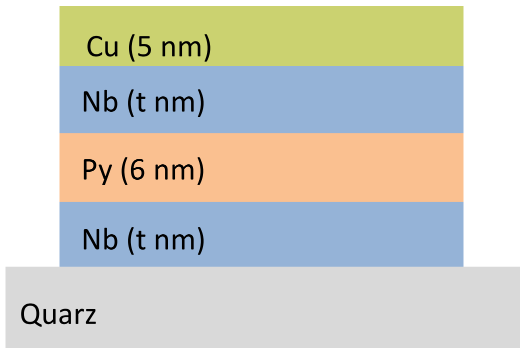


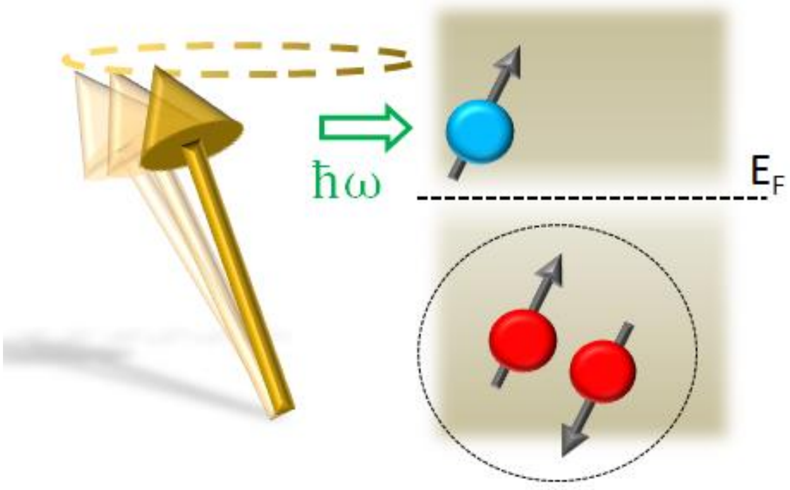


PRL 109, 207001 (2012)
Nature Physics 9, 84 (2013)

We measure spin-pumping in a superconductor

Layout 1





Nature Materials 17, 499 (2018)

We measure spin-pumping in a superconductor

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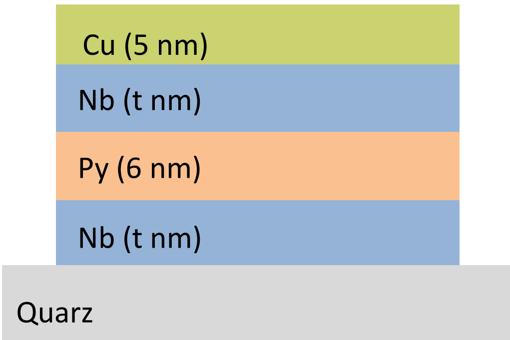
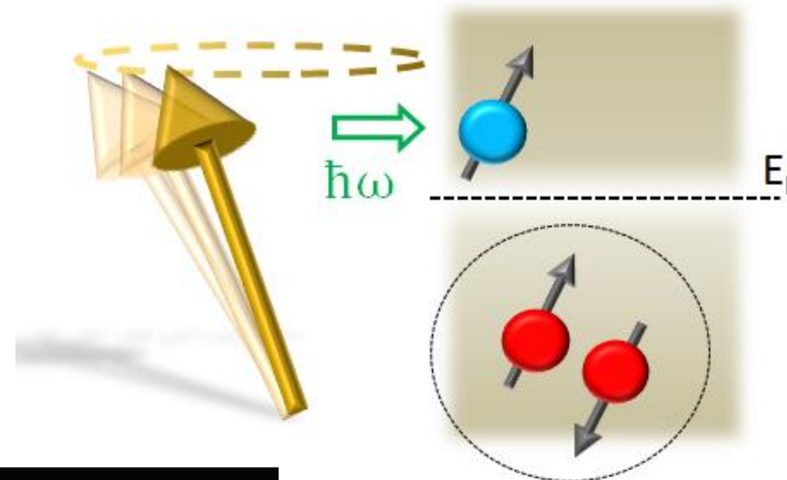
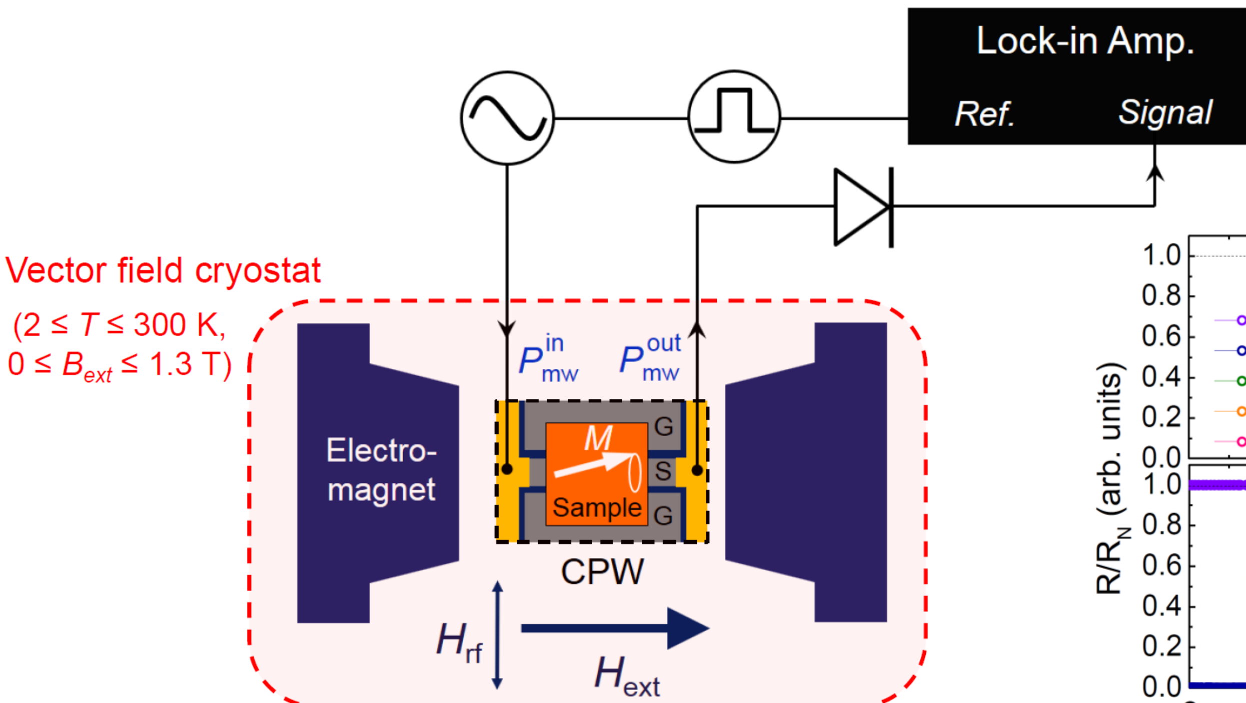
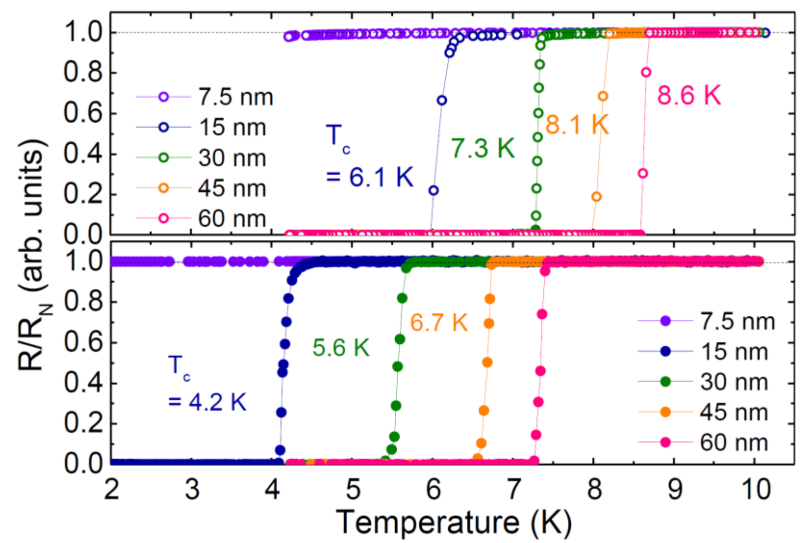
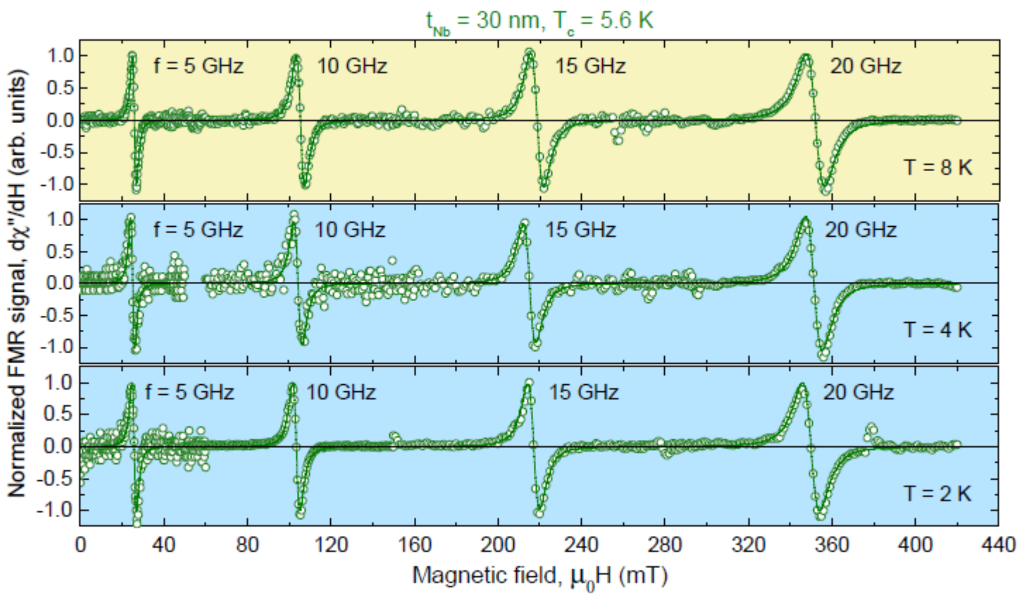




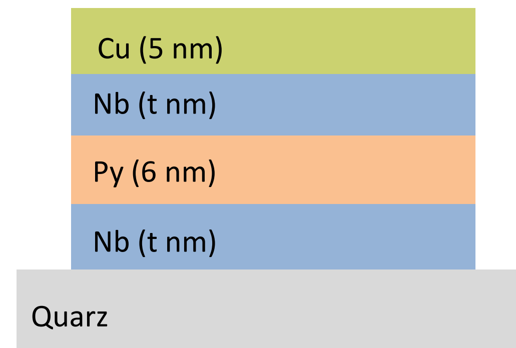


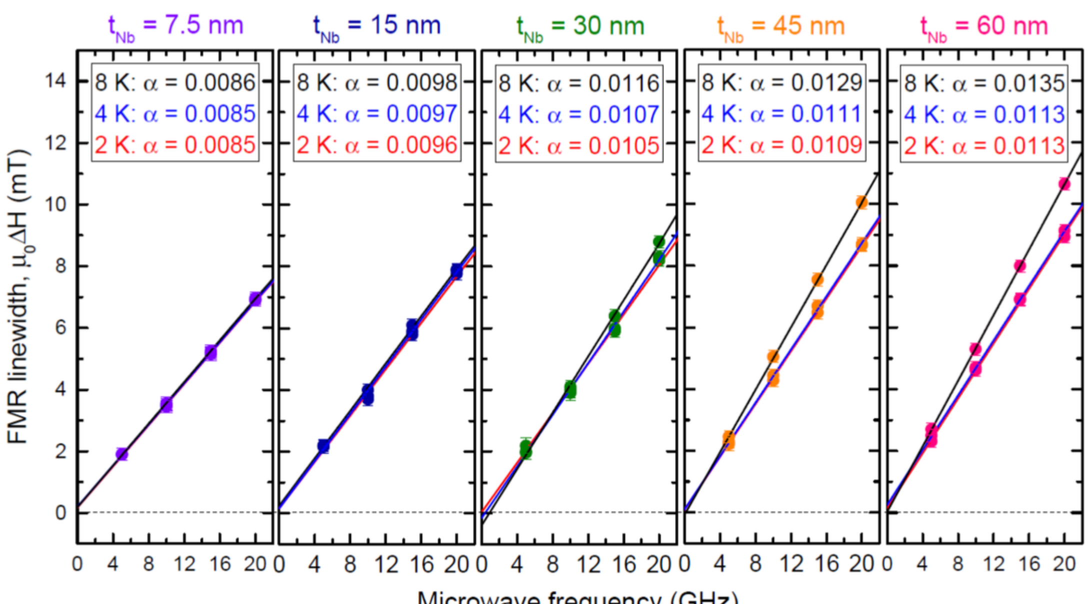


We estimate the spin through Nb from the FMR linewidth



Layout 1

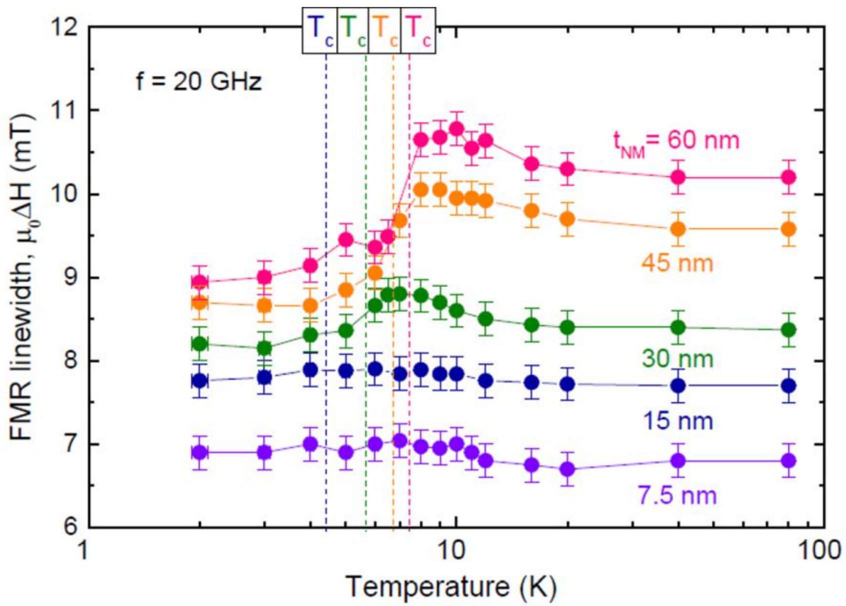


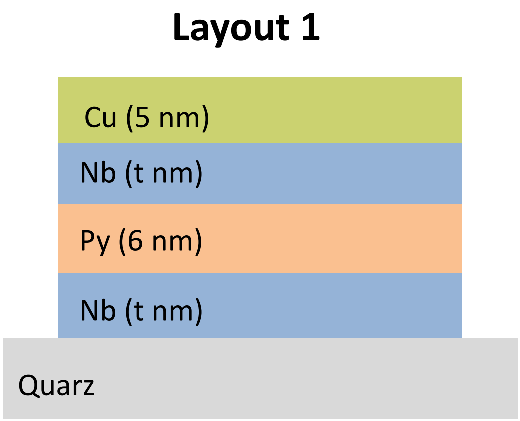


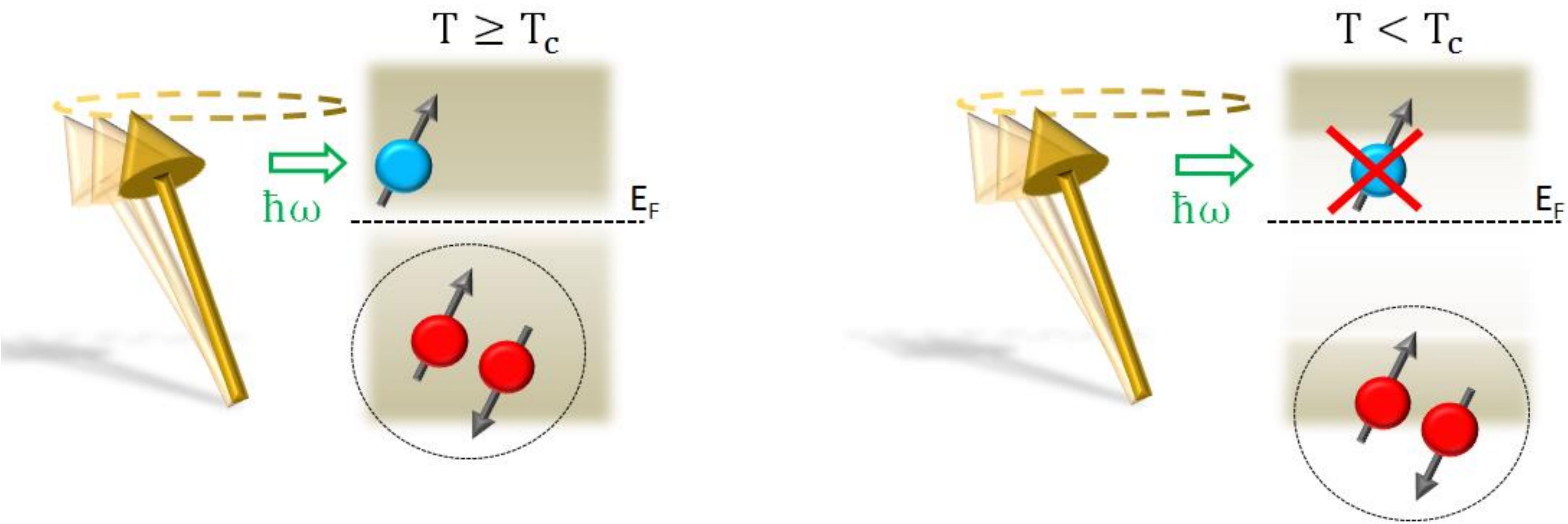
$$\mu_0 \Delta H(f) = \mu_0 \Delta H_0 + \frac{4\pi\alpha f}{\sqrt{3}\gamma}$$

Nature Materials 17, 499 (2018)

Damping has a sharp decrease below Tc







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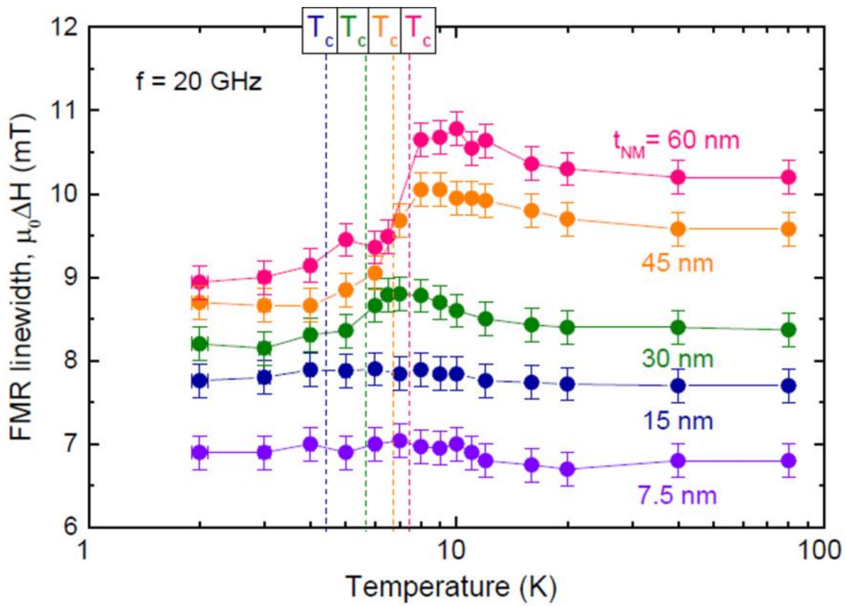
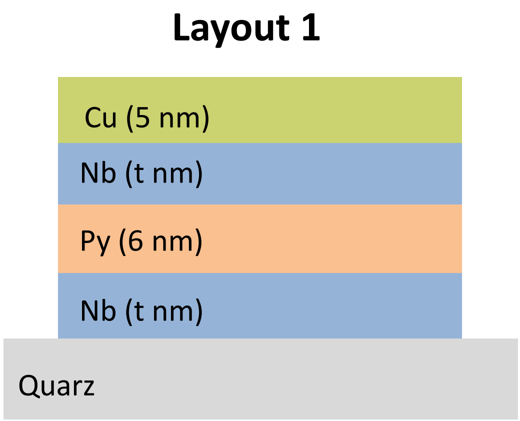
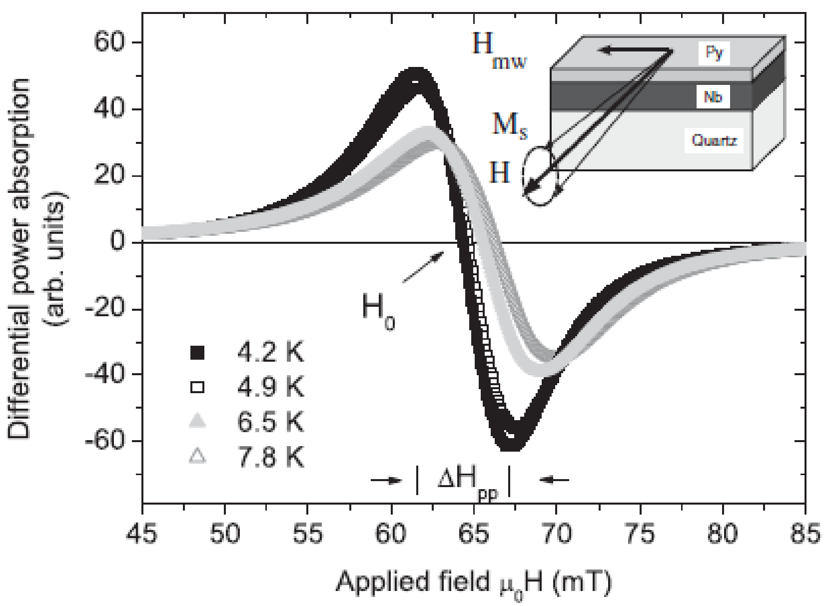
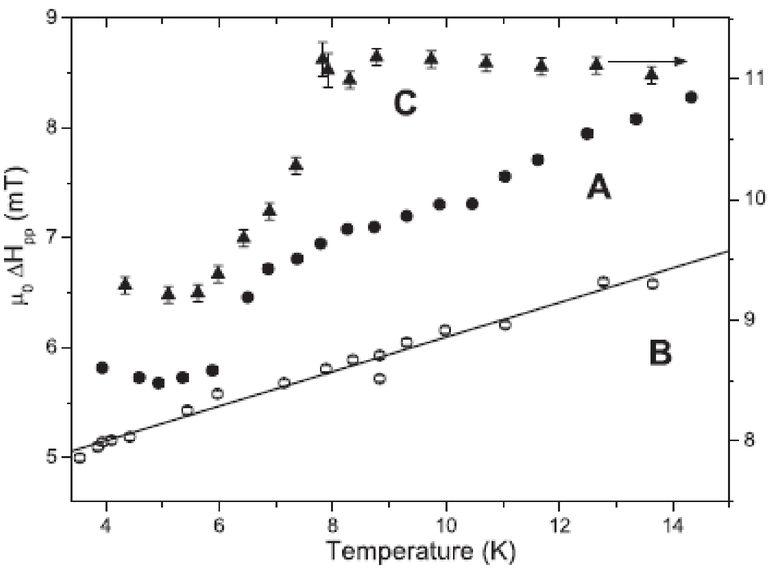


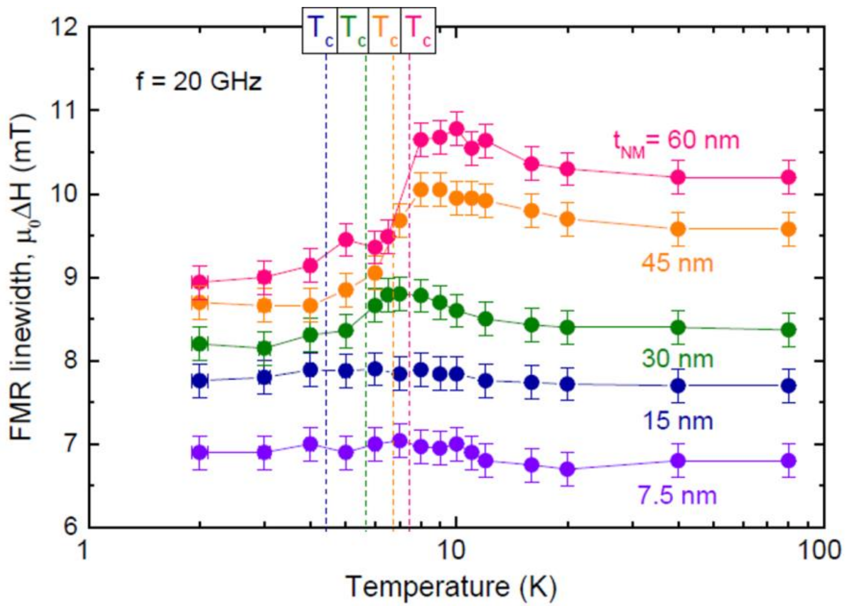


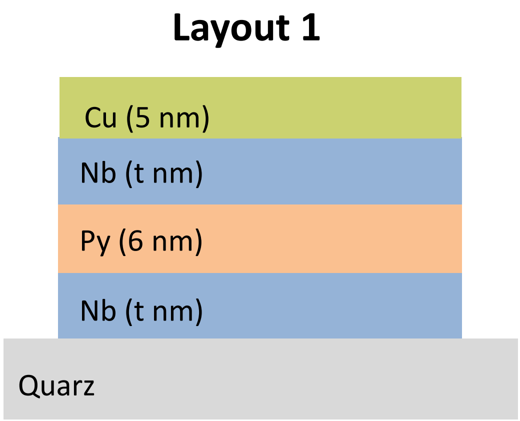


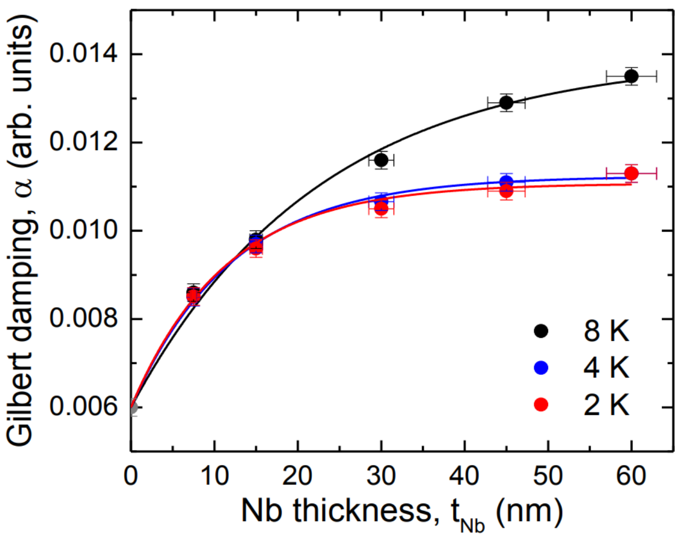


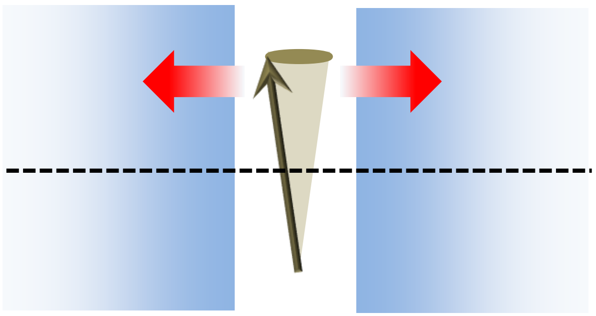
Phys. Rev. Lett. **100**, 047002 (2008)

Damping has a sharp decrease below Tc

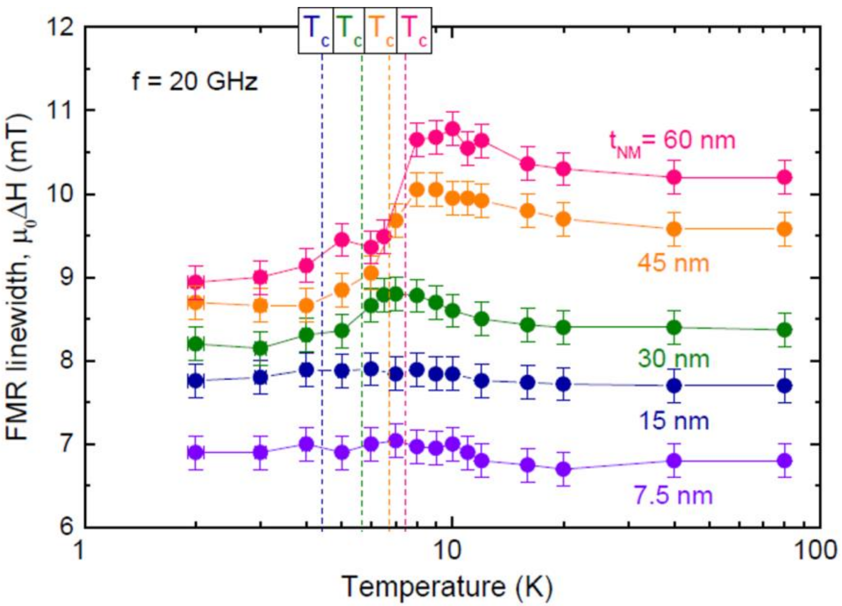


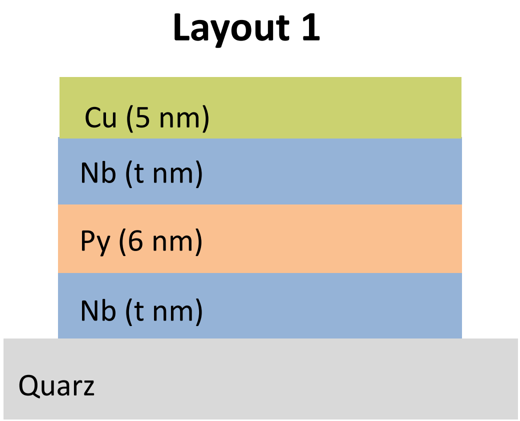


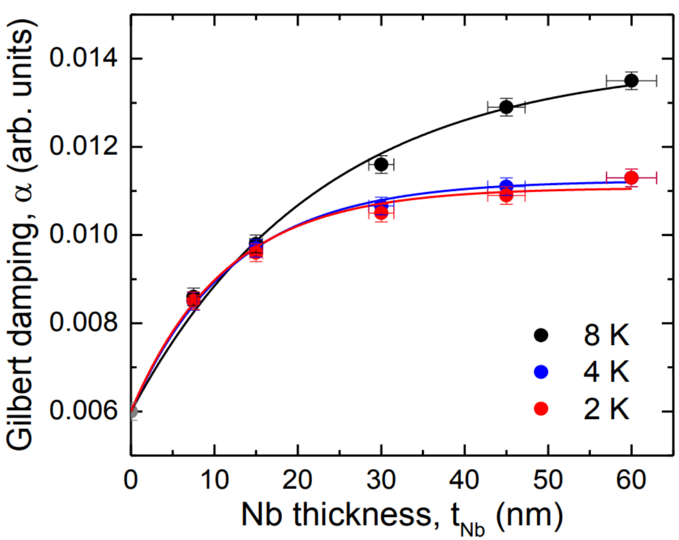


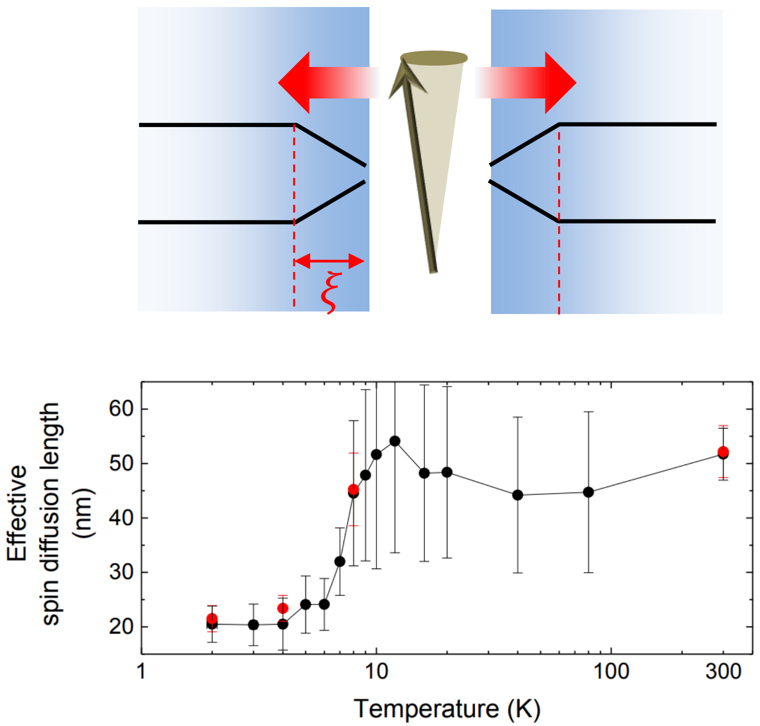


Damping has a sharp decrease below Tc

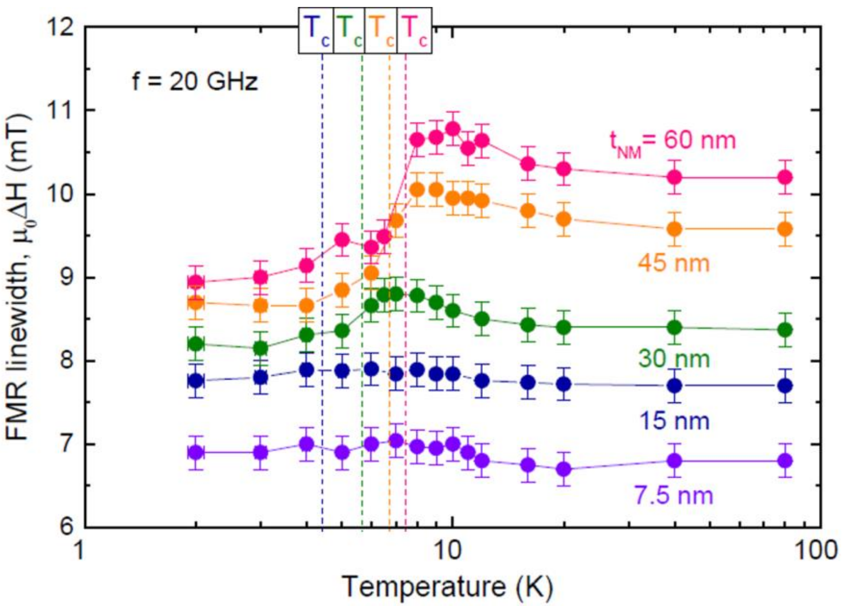




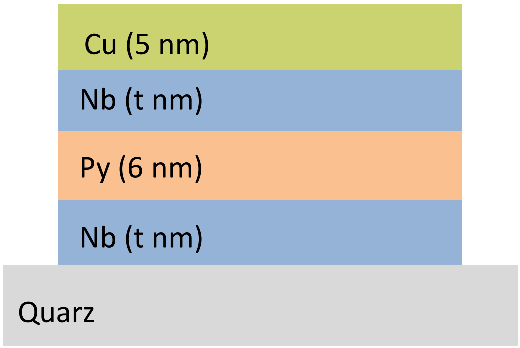


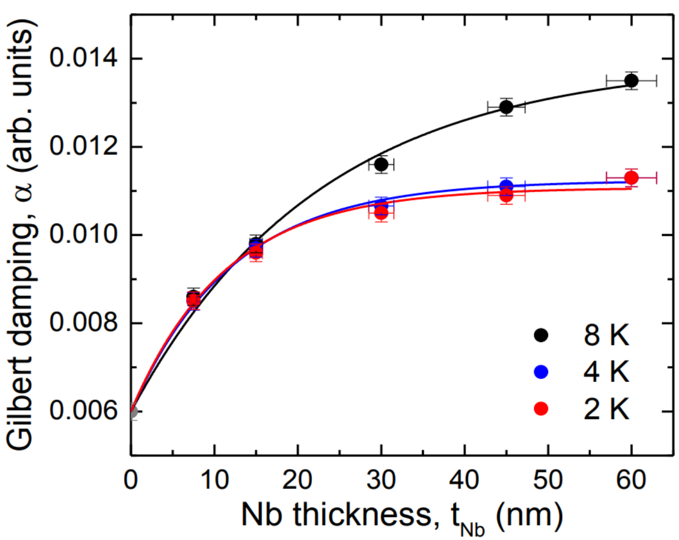


Damping has a sharp decrease below Tc

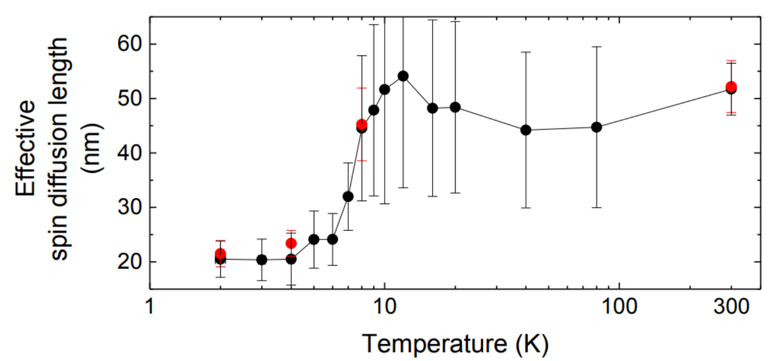


Layout 1

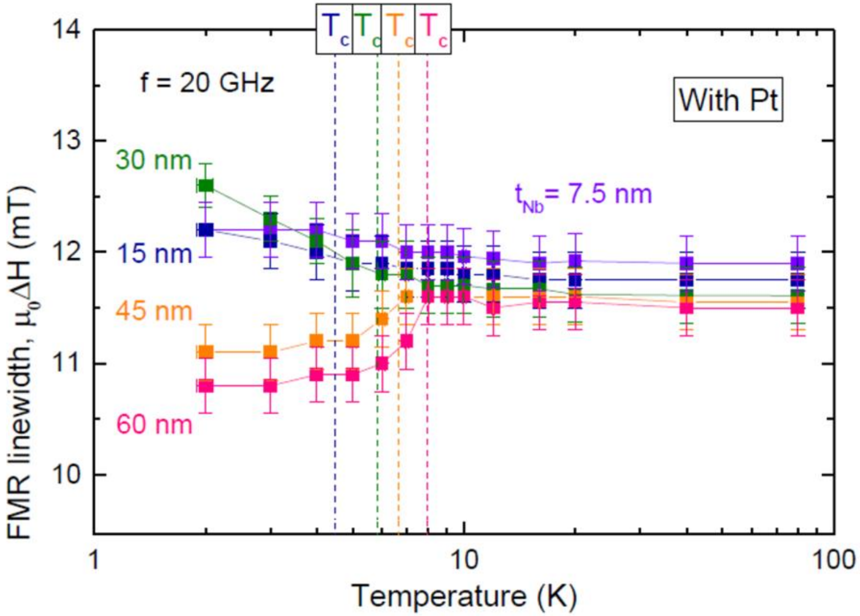


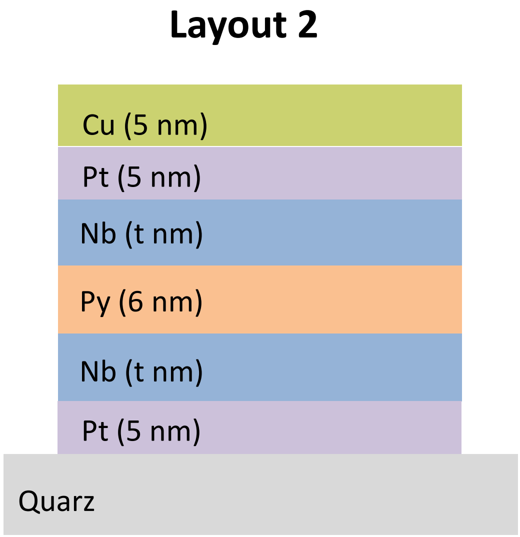


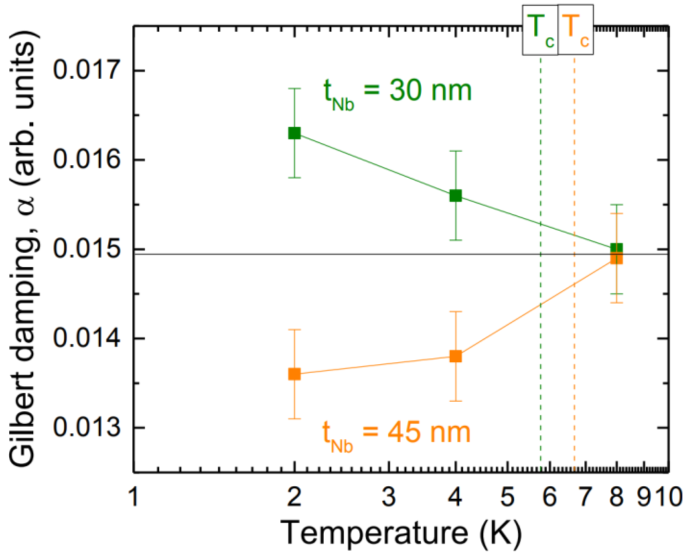
$$l_{QP}^{s} = \sqrt{D\left(\frac{1}{\tau_{AR}} + \frac{1}{\tau_{s}}\right)^{-1}} \sim 20 \text{ nm}$$



An unusual behavior is observed in the presence of Pt







[Nature Materials 17, 499 (2018)](#)

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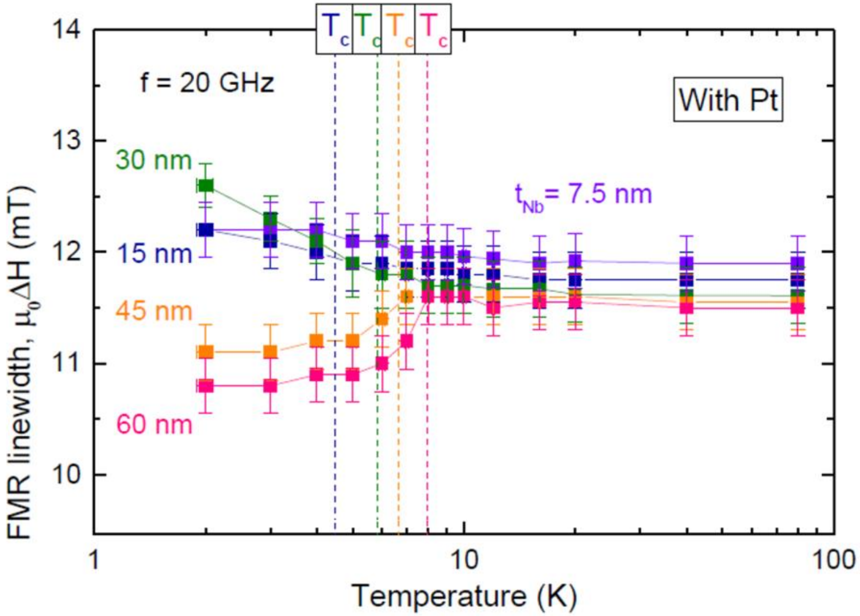
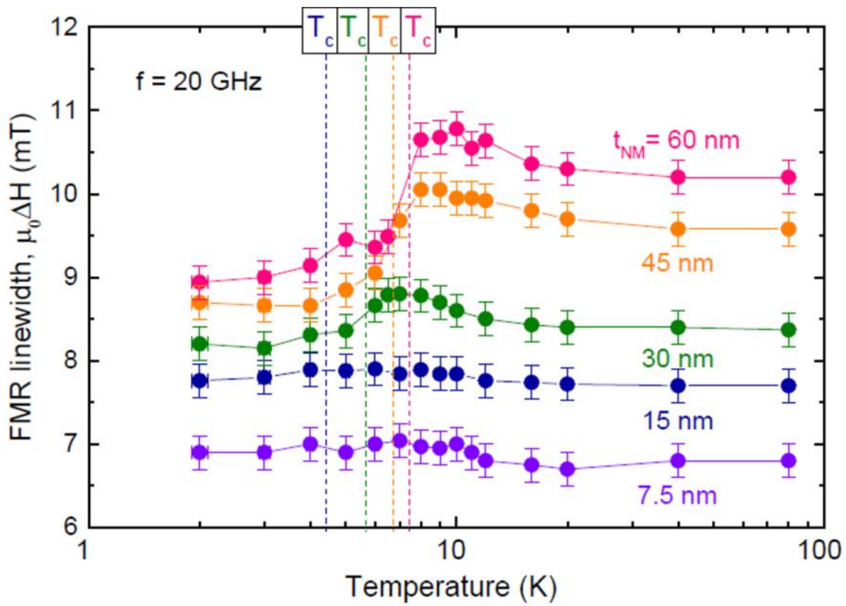
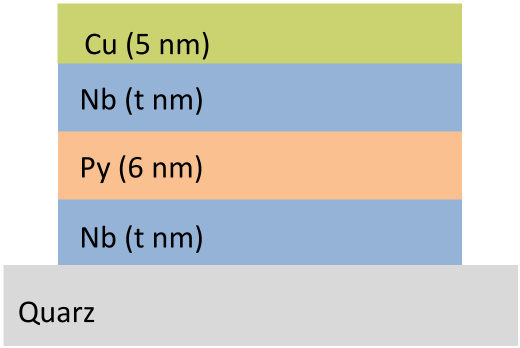


Layout 2

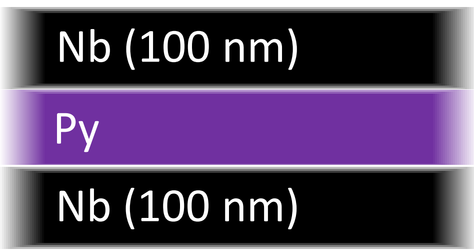


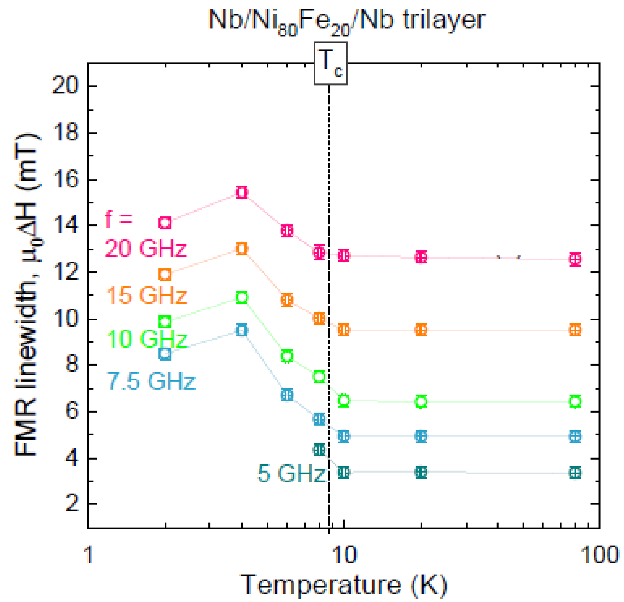
Layout 1

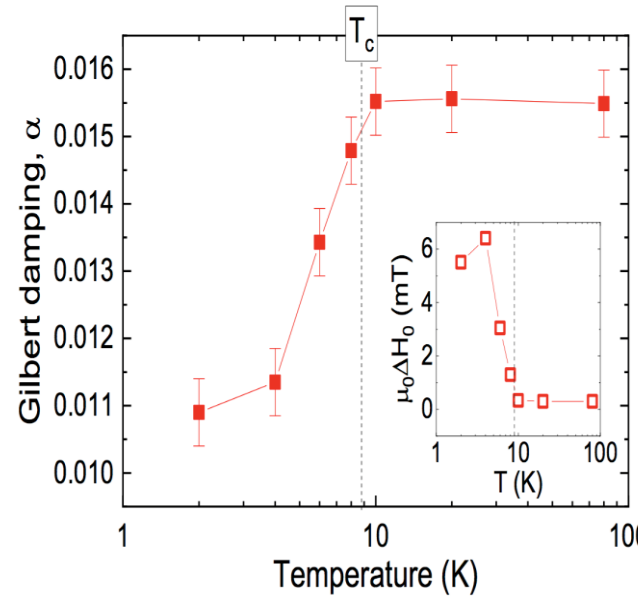


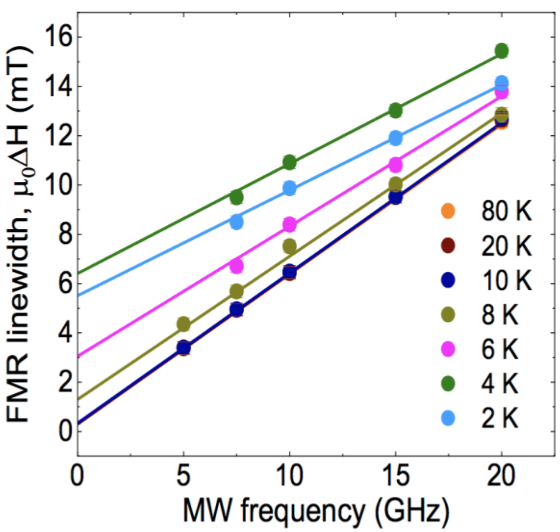
[Nature Materials 17, 499 (2018)]

Meissner screening



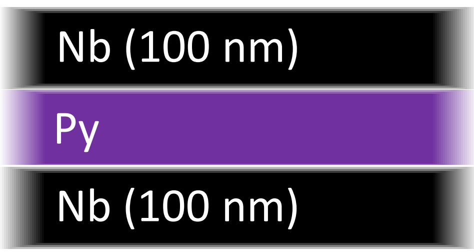


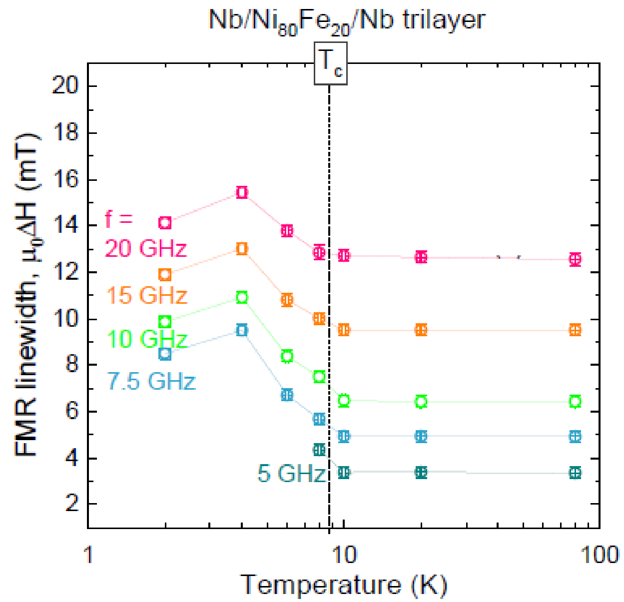


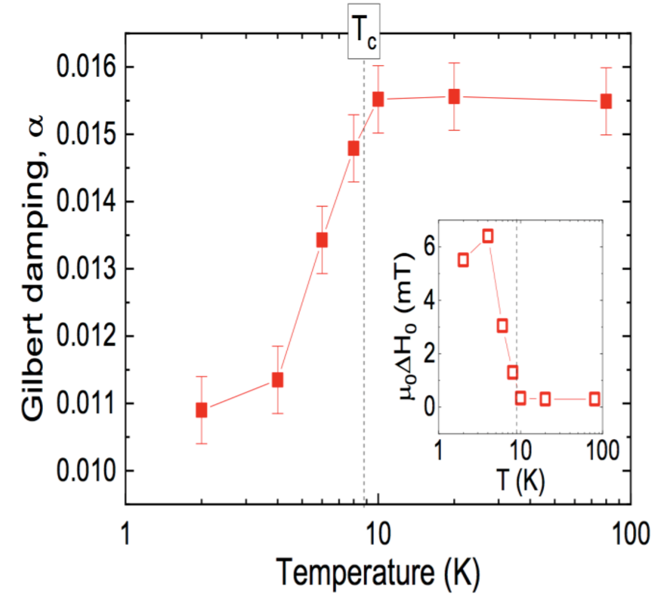


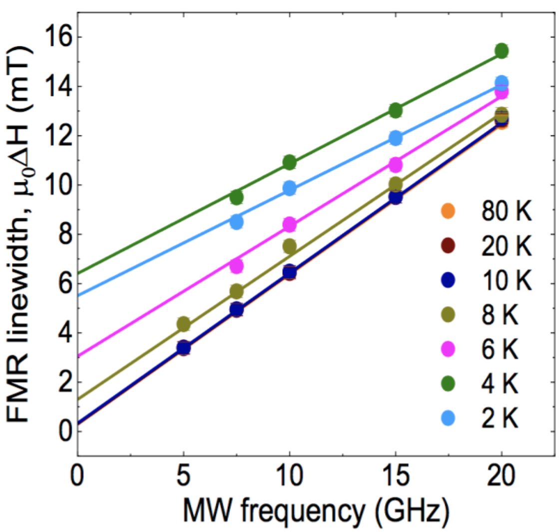
[Phys. Rev. Appl., 11, 014061 (2019)]

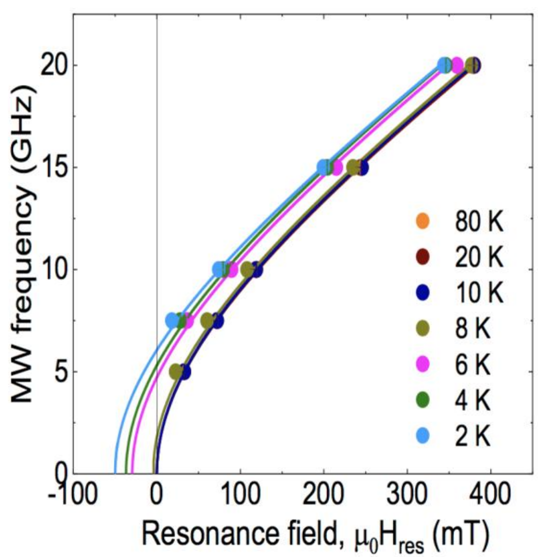
Meissner screening











$$f = \frac{\gamma}{2\pi}\sqrt{\mu_0(H_{res} + M_{eff} + \Delta H) \cdot \mu_0(H_{res} + \Delta H)}$$

Phys. Rev. Appl., 11, 014061 (2019)

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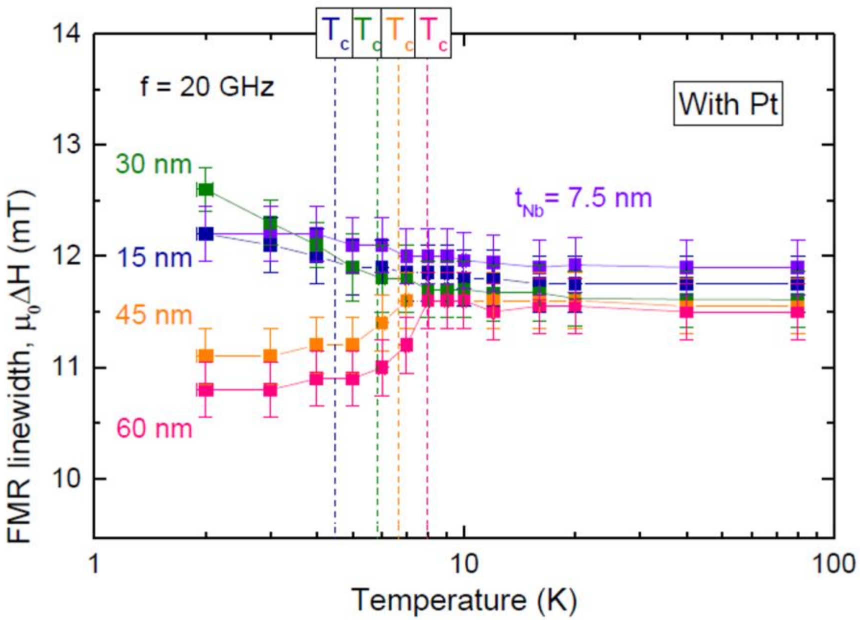
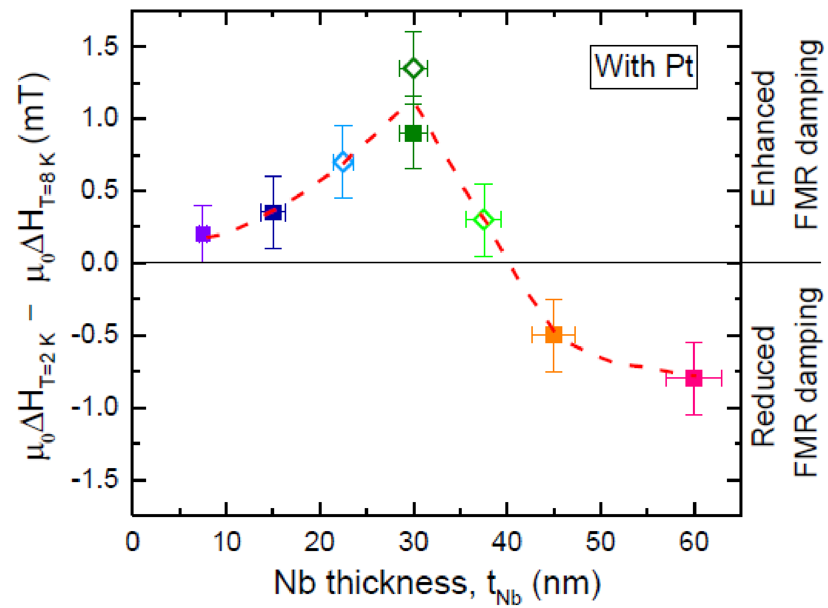
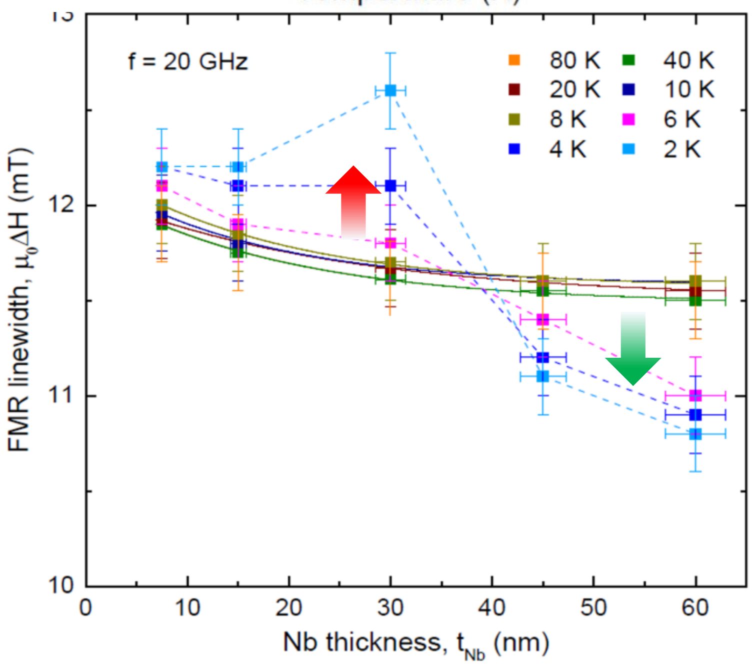
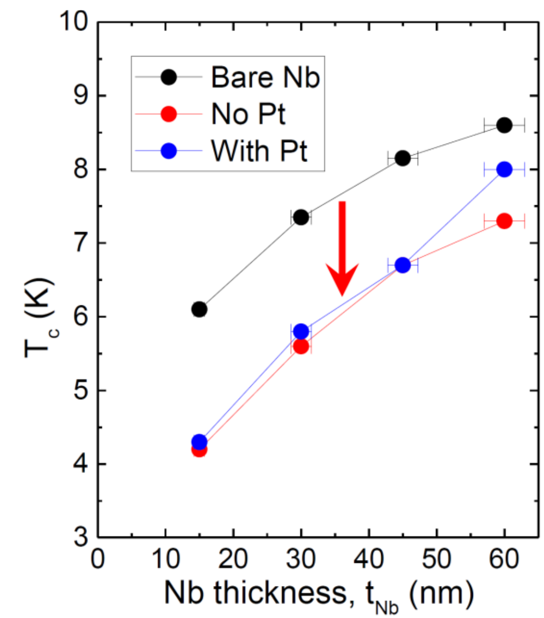
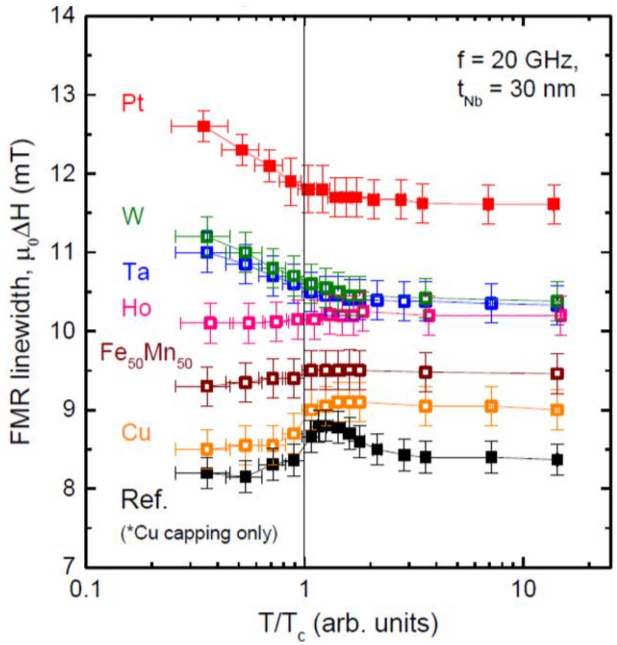


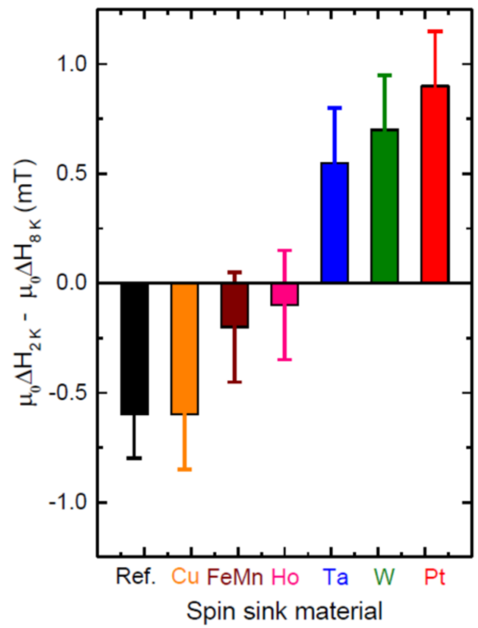






We substitute Pt with different metals





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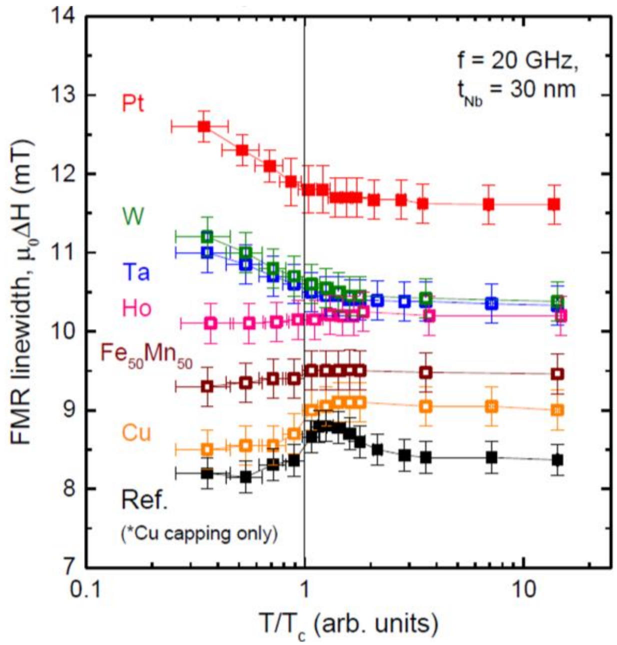
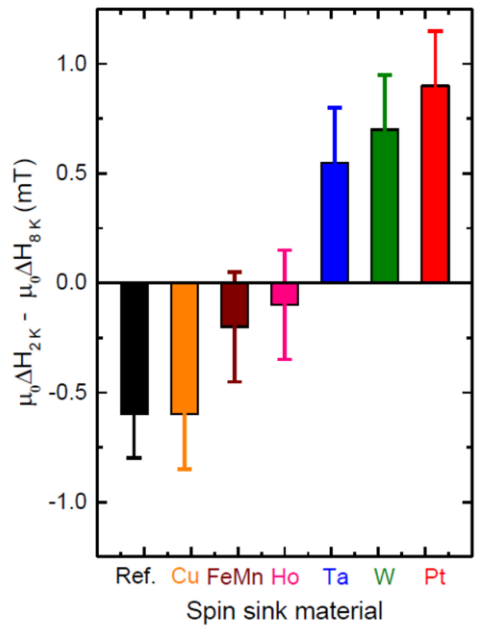
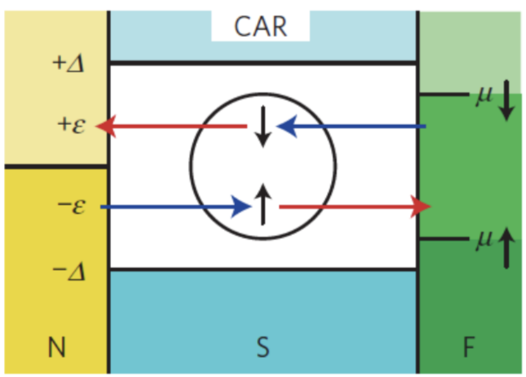
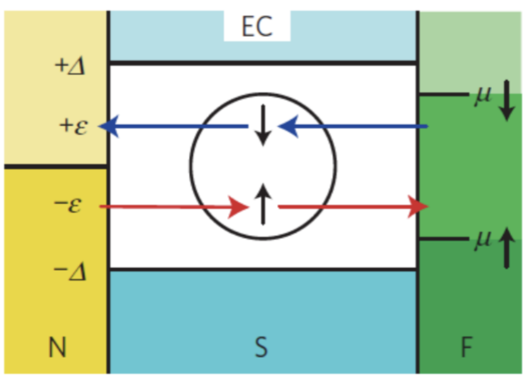
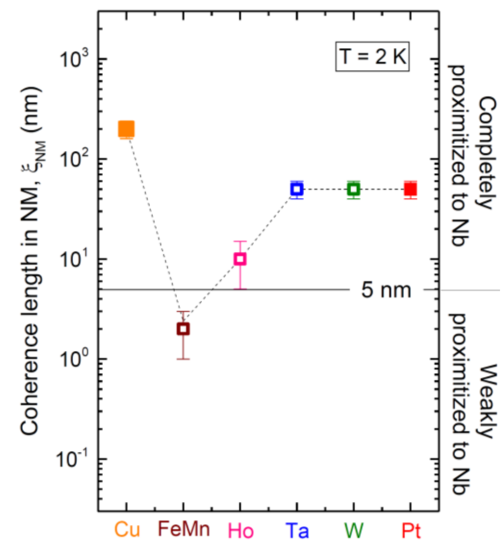




Quasiparticles-mediated spin-transfer



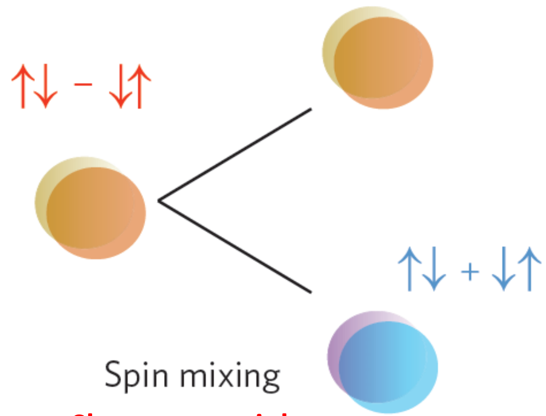




Nature Phys. 12, 57 (2015)
Nature Phys. 9, 84 (2013)

The role of Cooper pairs in mediating spin transport in Nb

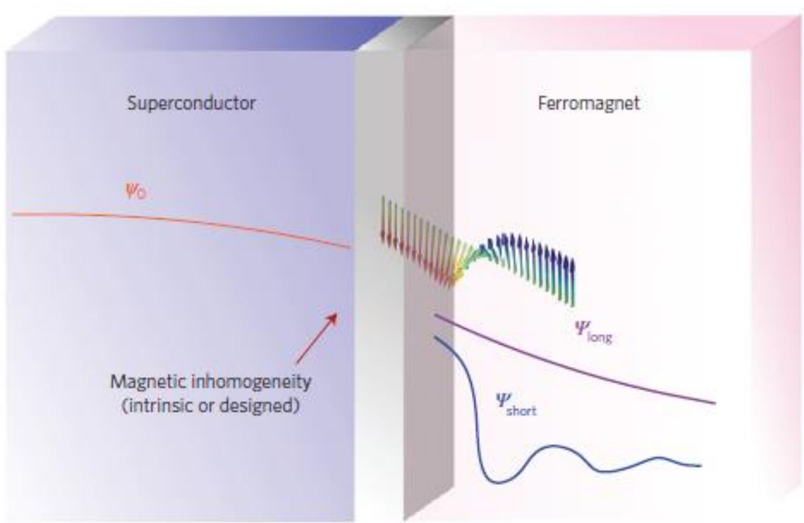
[Nature Physics 11, 307(2015)]



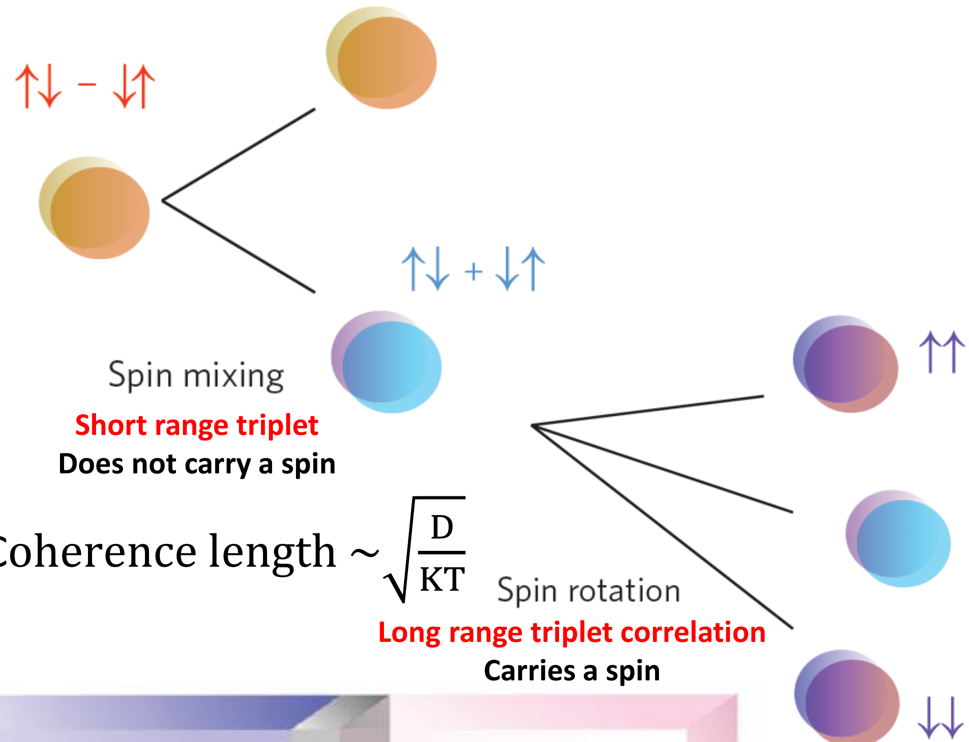
Short range triplet

Does not carry a spin

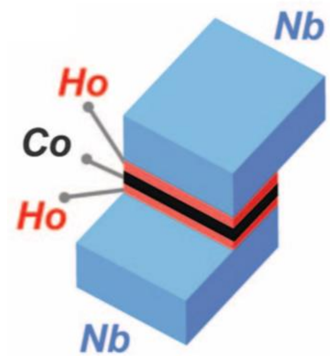
Coherence length $\sim \sqrt{\frac{D}{h_{ex}}}$



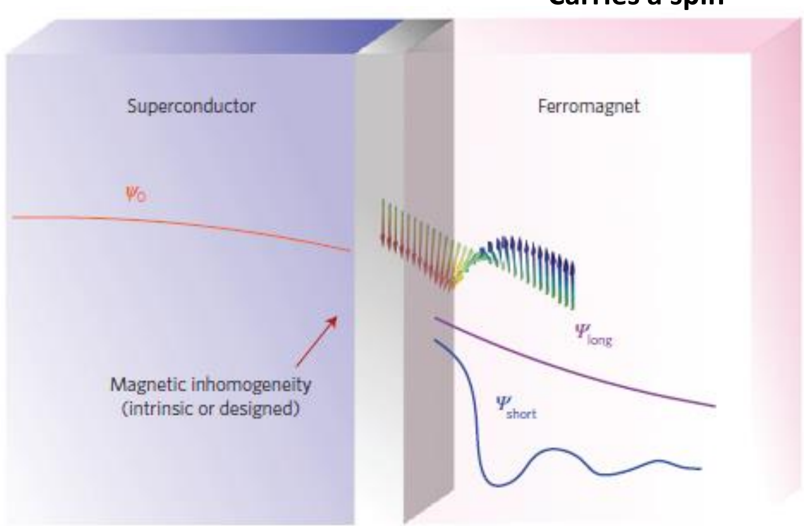
The Long-range triplet condensate

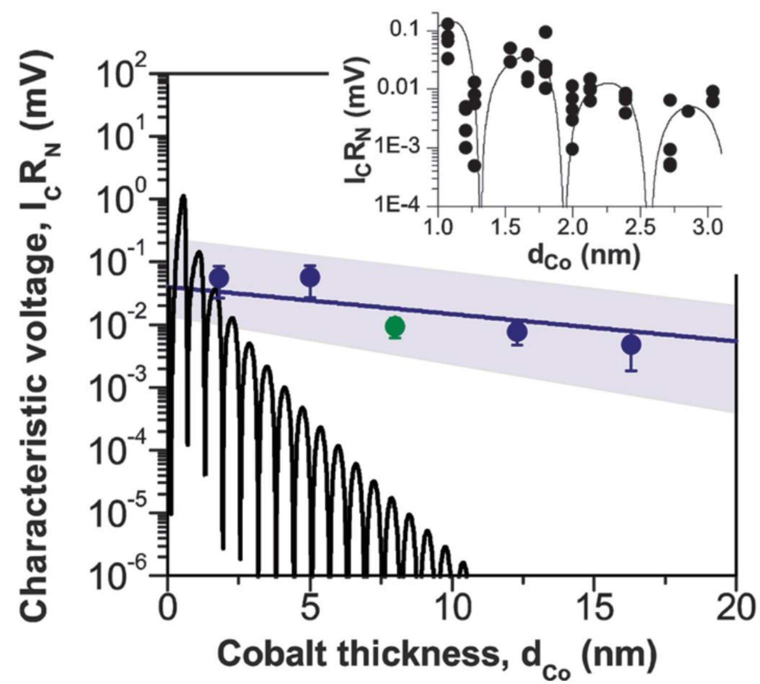


$$\text{Coherence length} \sim \sqrt{\frac{D}{KT}}$$

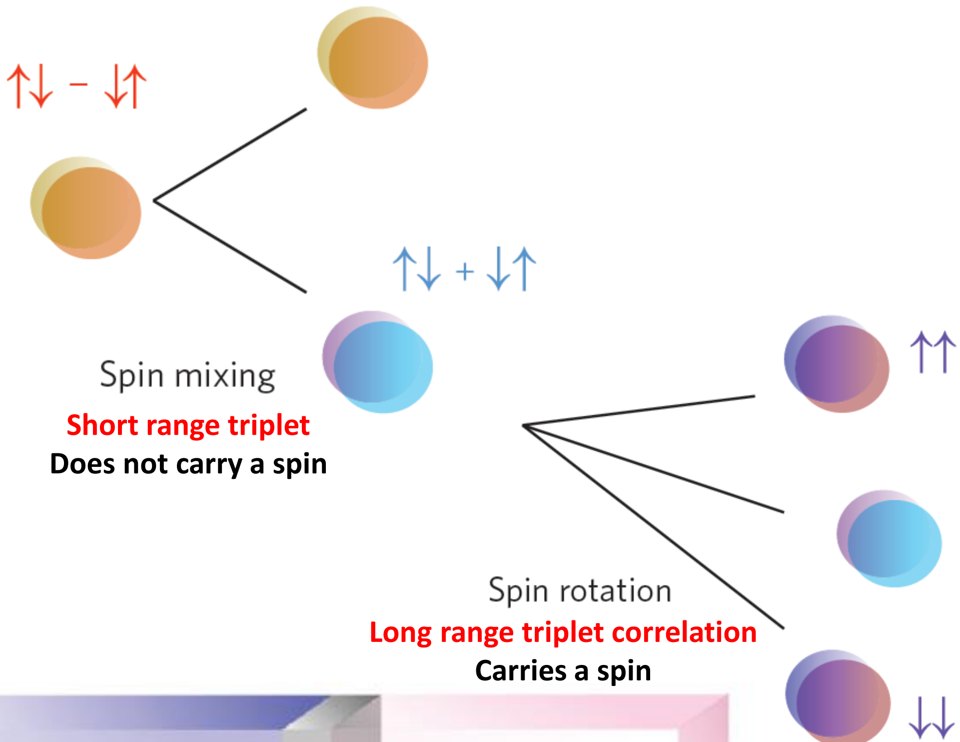


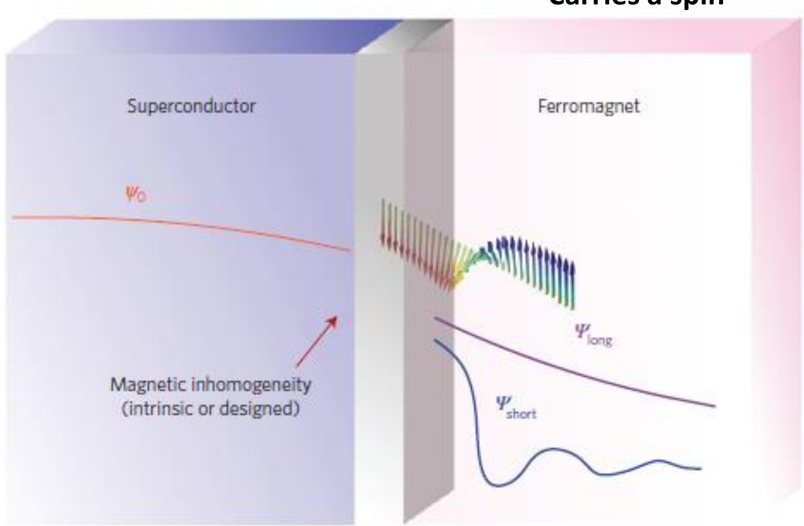
Science 329, 59 (2010)
PRB 89, 104505 (2014)
PRB 82, 060505 (2010)
PRL 104, 137002 (2010)
PRL 108, 127002 (2012)

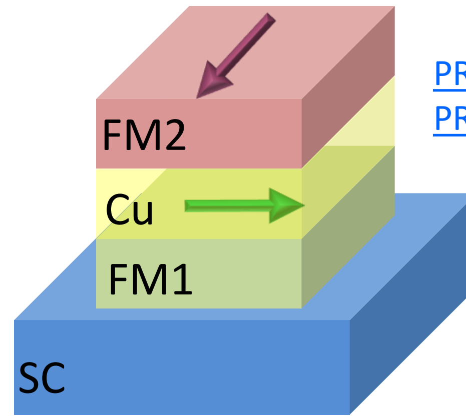




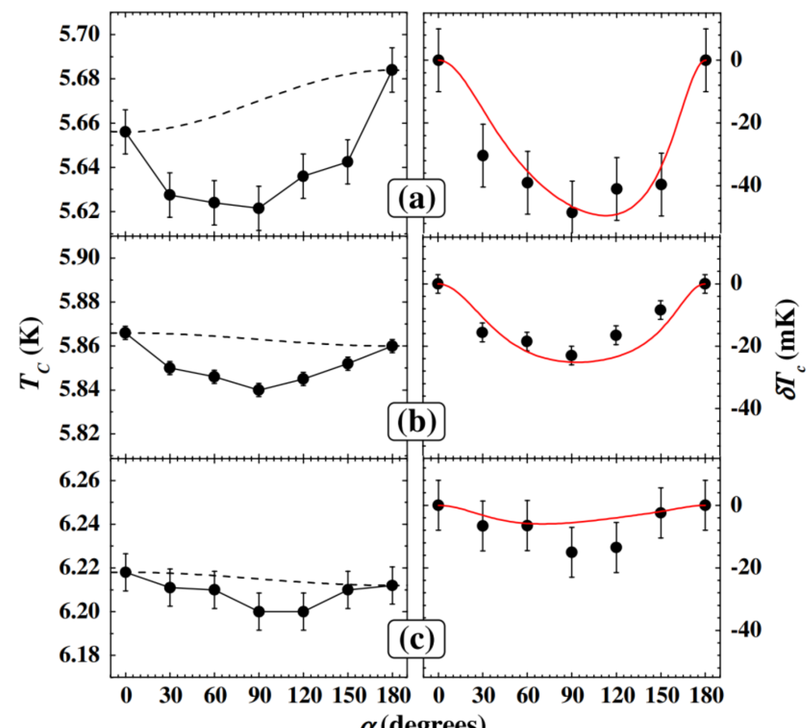
The Long-range triplet condensate





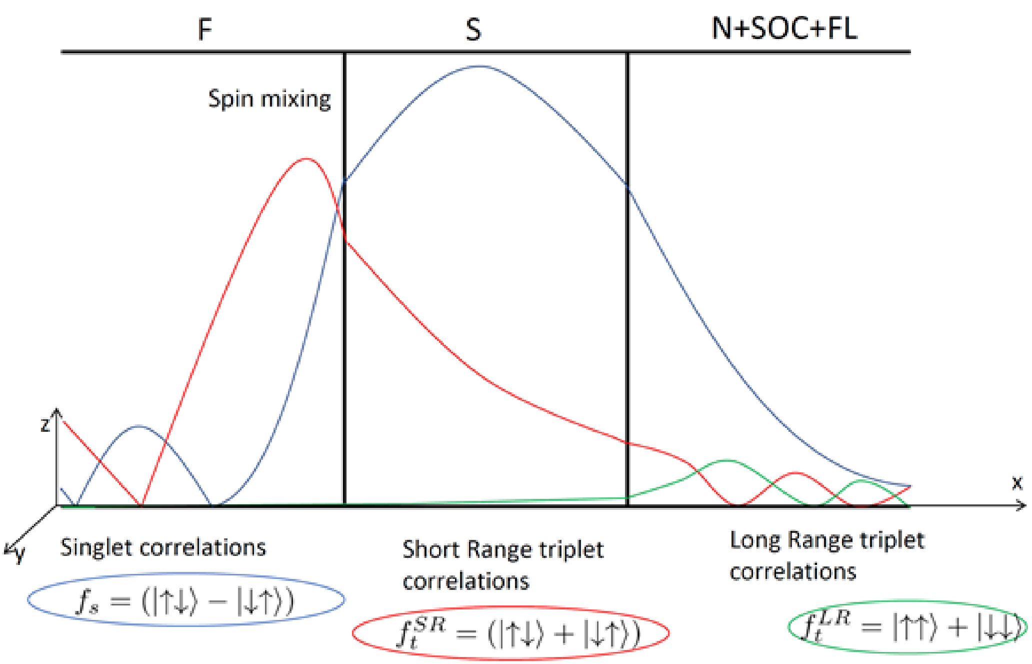


[PRL 109, 057005 (2012)]
[PRB 89, 140508 (2014)]



The role of Cooper pairs in mediating spin transport in Nb

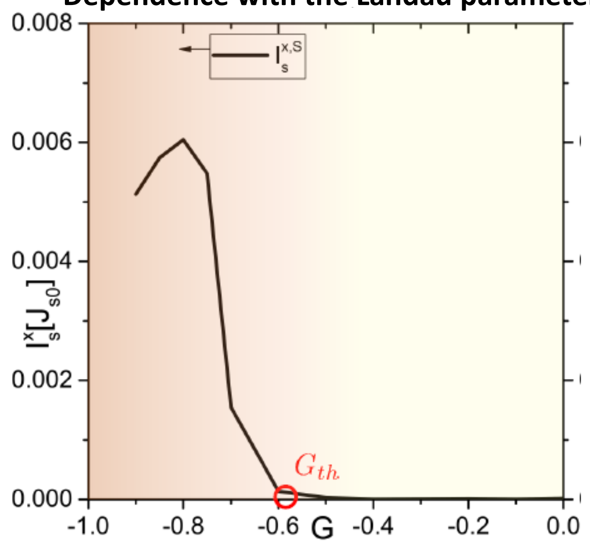
[Montiel, Eschrig, Phys. Rev. B 98, 104513 (2018)](#)
[PRB 89, 134517 (2014)](#)



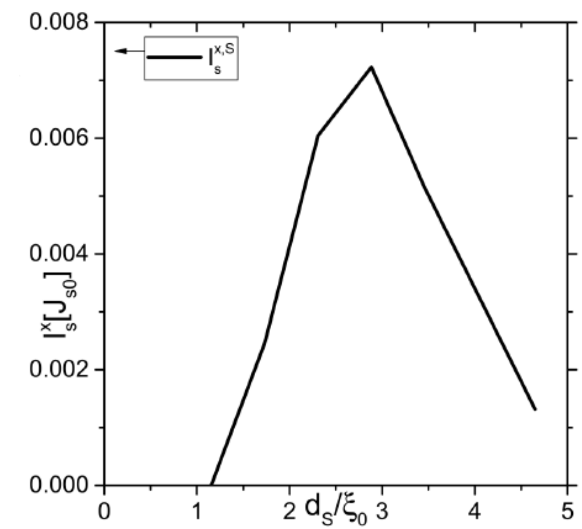
Pt, Ta, W have two characteristics:

- Spin-orbit coupled
- Close to a paramagnetic instability

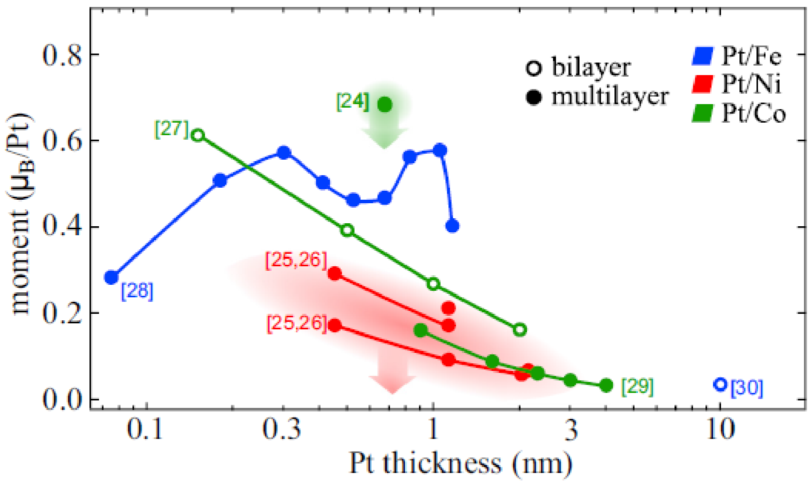
Dependence with the Landau parameter



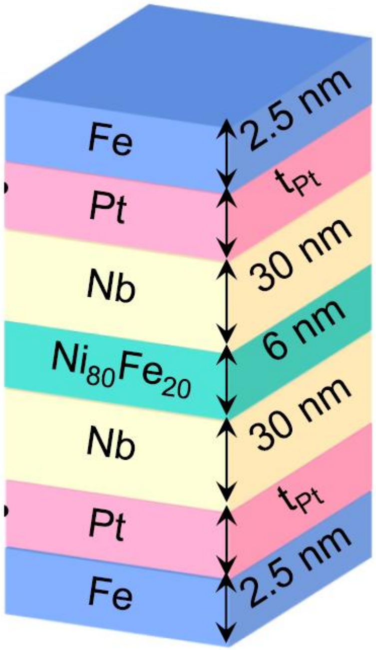
Dependence with the SC thickness

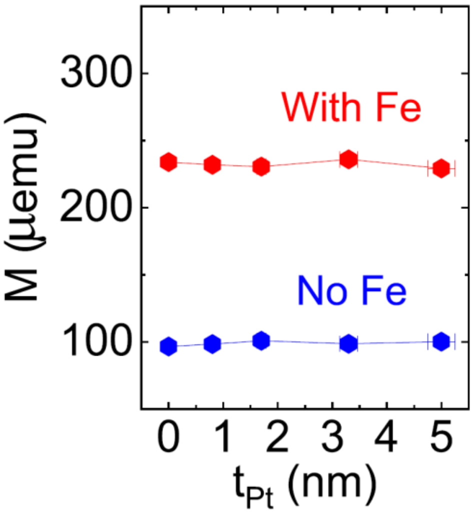


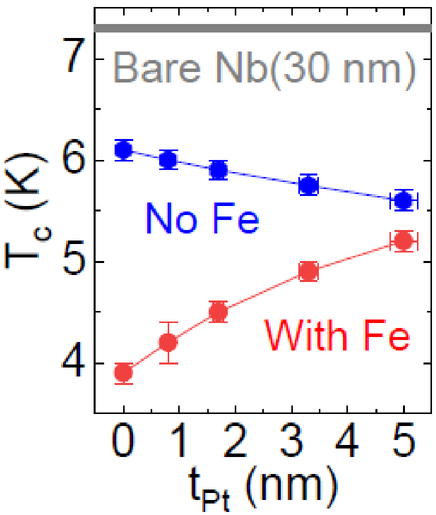
The role of the exchange in Pt

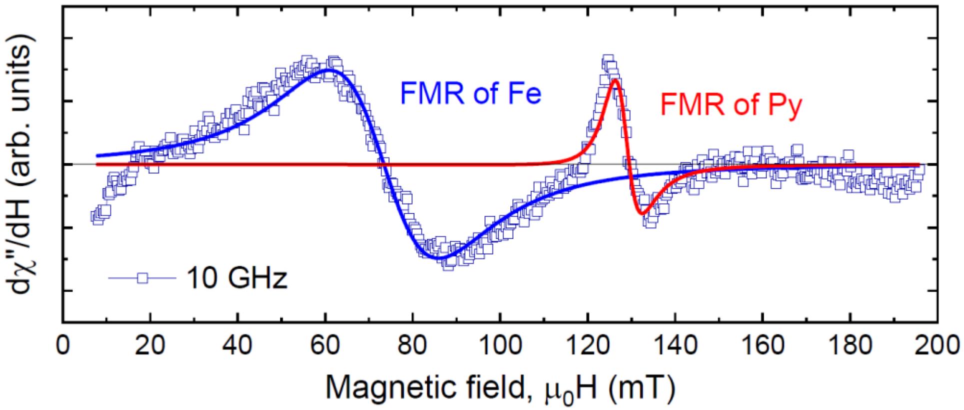


PRB **93**, 214440 (2016)









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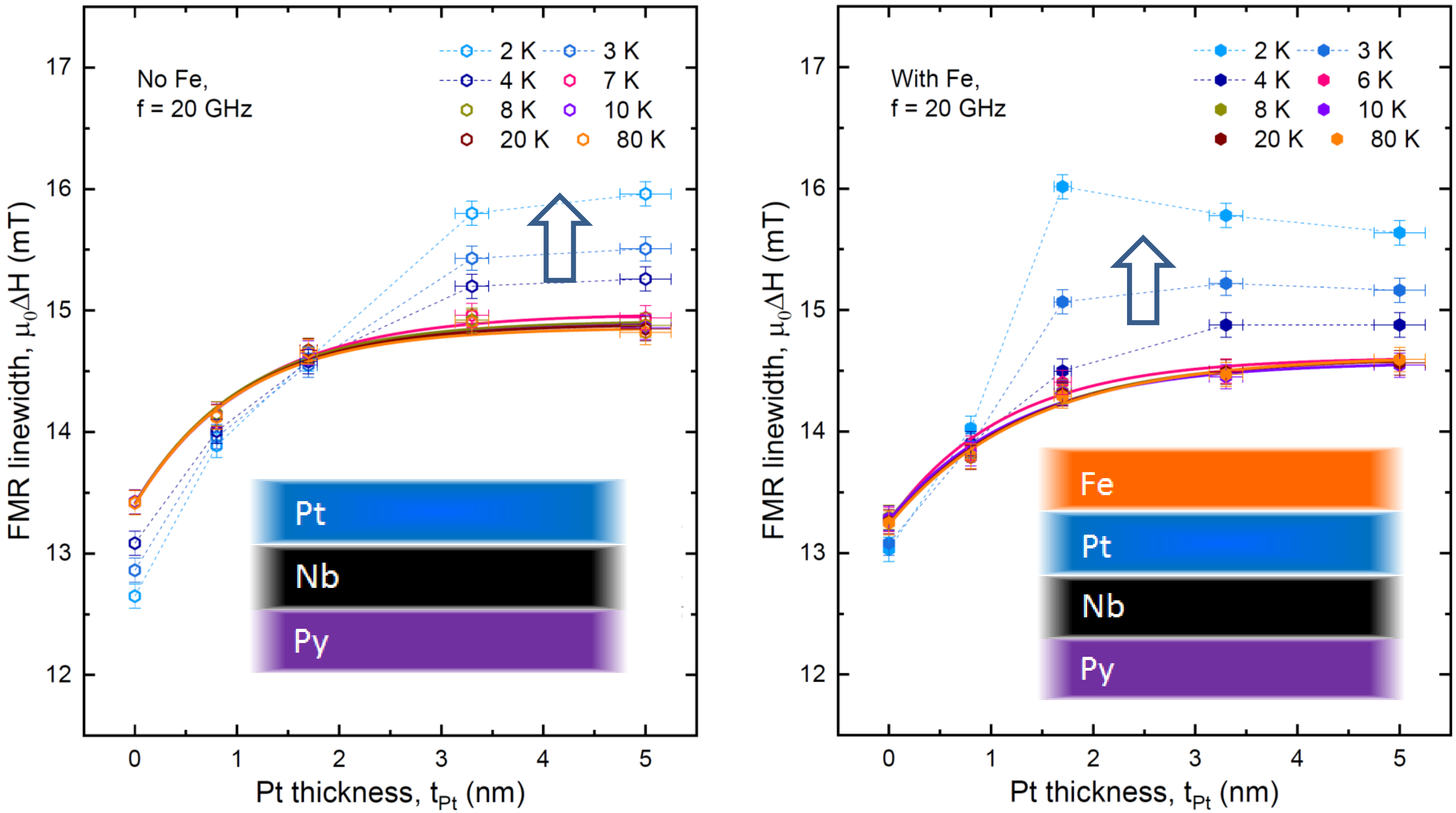
The role of the exchange in Pt



Phys. Rev. B 99, 024507 (2019)

Abrikosov vortex nucleation in an OP field

[Phys. Rev. B 99, 144503 (2019)](#)

$$[\mathrm{A_k}, [\mathrm{A_k}, h^a\sigma^a]] \sim$$

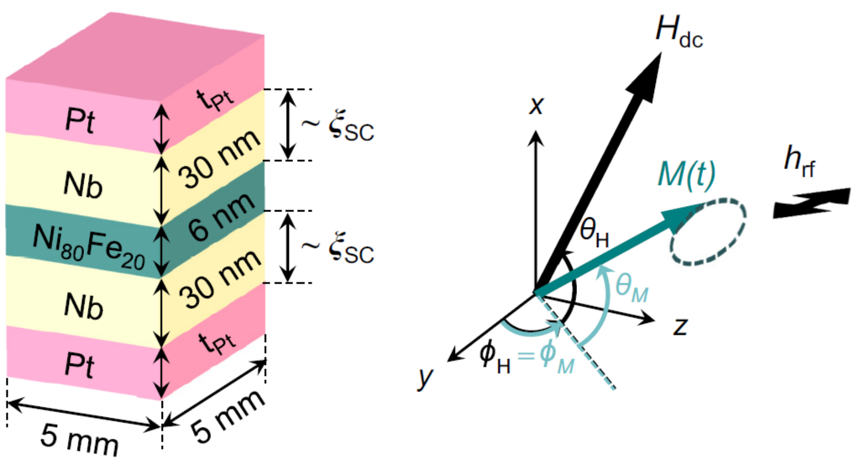
$$A_x = 0$$

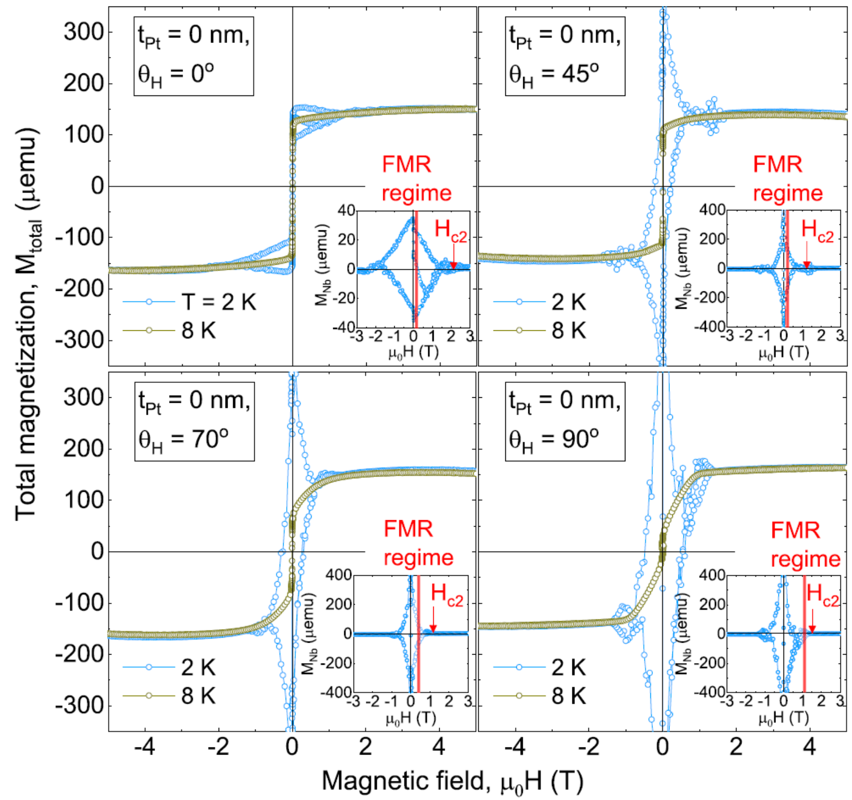
$$A_y = -\beta_D\sigma^y + \alpha_R\sigma^z$$

$$A_z = \beta_D\sigma^z - \alpha_R\sigma^y$$

$$\sim \alpha^2 (h^a\sigma^a + h^x\sigma^x)$$

[PRB 89, 134517 (2014)](#)

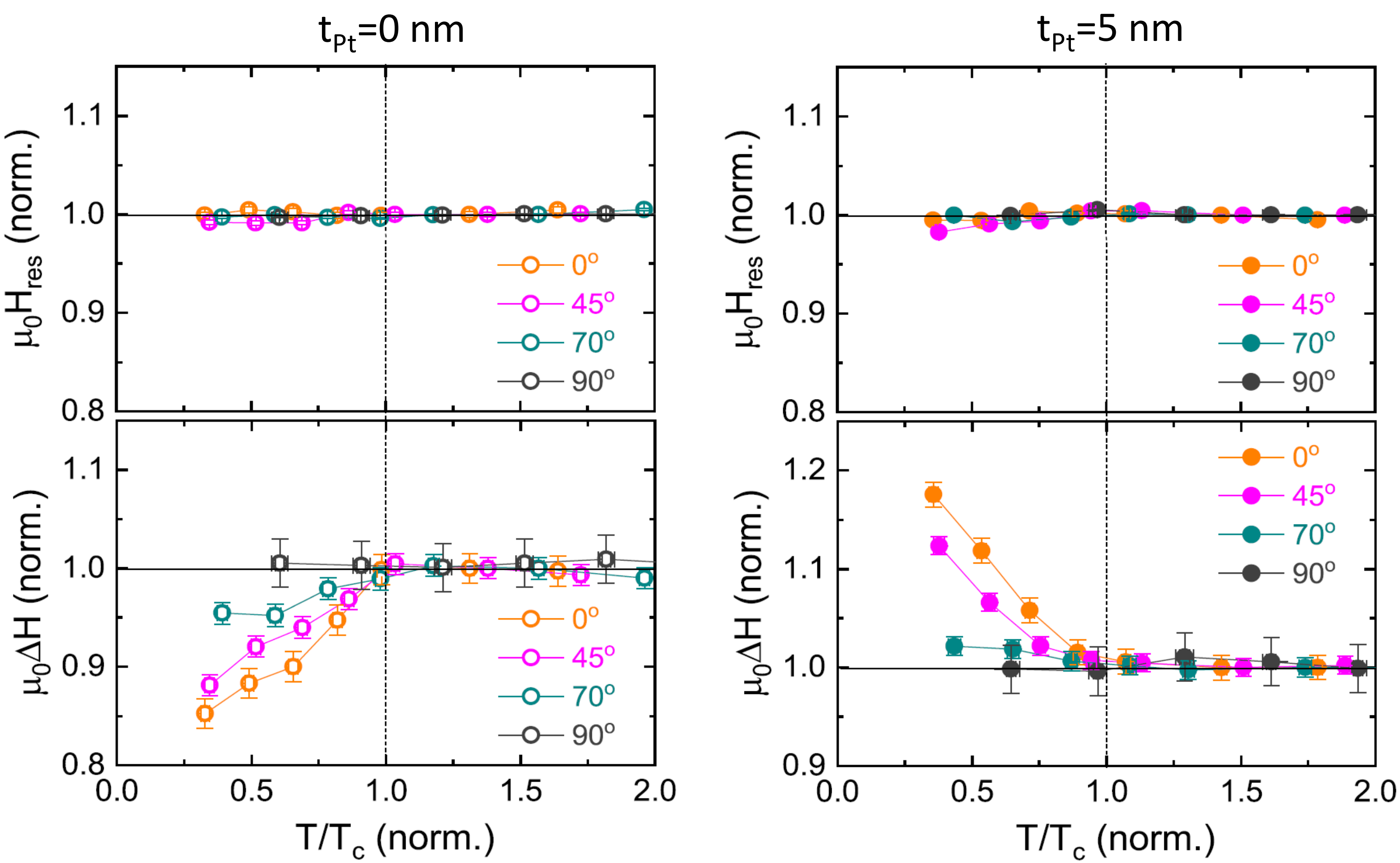




$$V_{sc}^{mea} \sim 1 - \frac{H_{res}(\theta_H)}{H_{c2}(\theta_H)}$$

	No Pt			With Pt		
θ_H	V_{SC}^{cal} [%]	V_{SC}^{mea} [%]	2Δ [meV]	V_{SC}^{cal} [%]	V_{SC}^{mea} [%]	2Δ [meV]
0°	100	95 ± 2	1.65	100	94 ± 2	1.51
45°	96	91 ± 3	1.57	95	90 ± 3	1.42
70°	86	72 ± 5	1.14	84	70 ± 4	1.12
90°	37	20 ± 8	0.81	30	19 ± 6	0.72

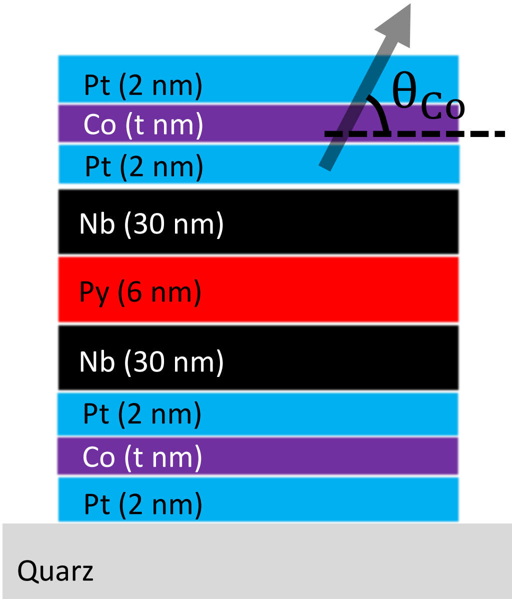
Abrikosov vortex nucleation in an OP field

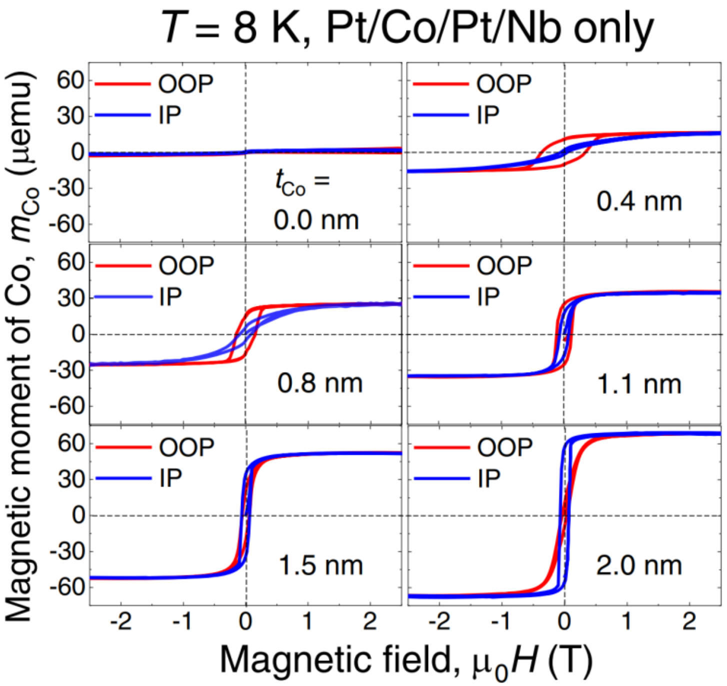


Phys. Rev. B 99, 144503 (2019)

Angular dependence is in agreement with Rashba SOC

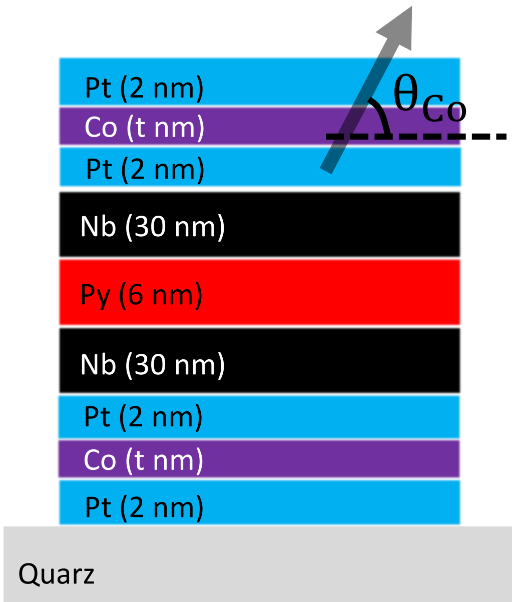
Phys. Rev. X 10, 031020 (2020)

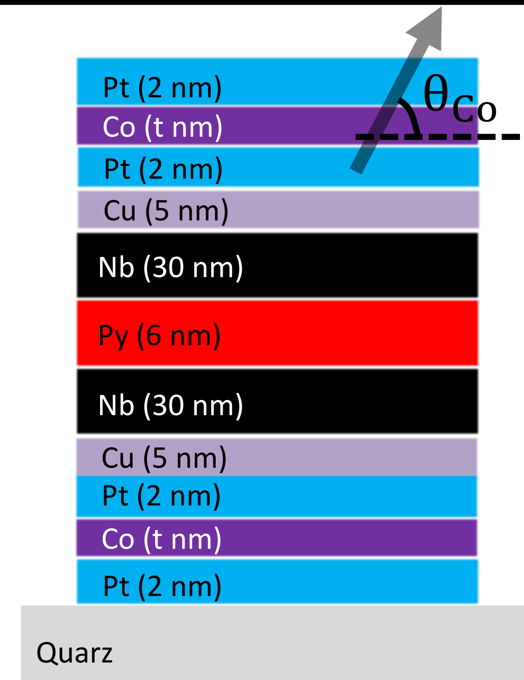


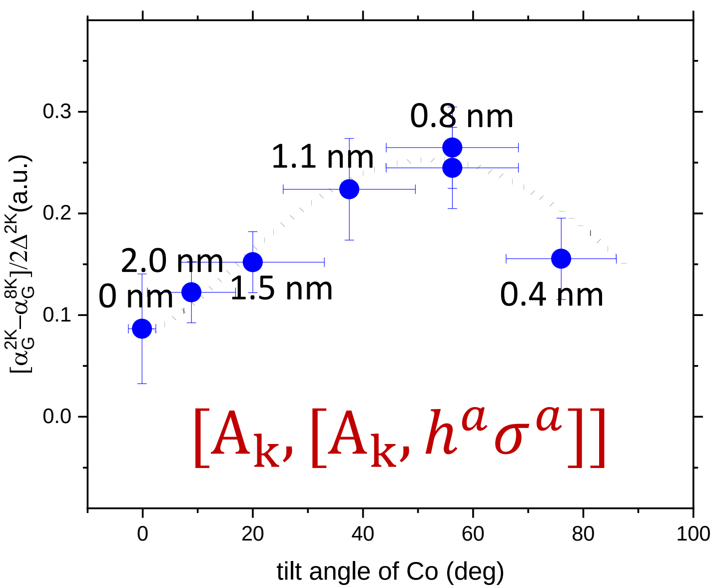


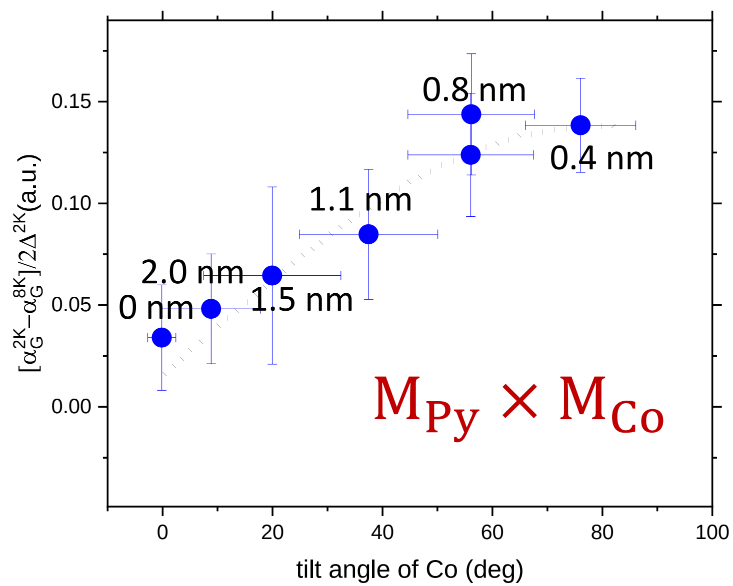
Angular dependence is in agreement with Rashba SOC

Phys. Rev. X 10, 031020 (2020)

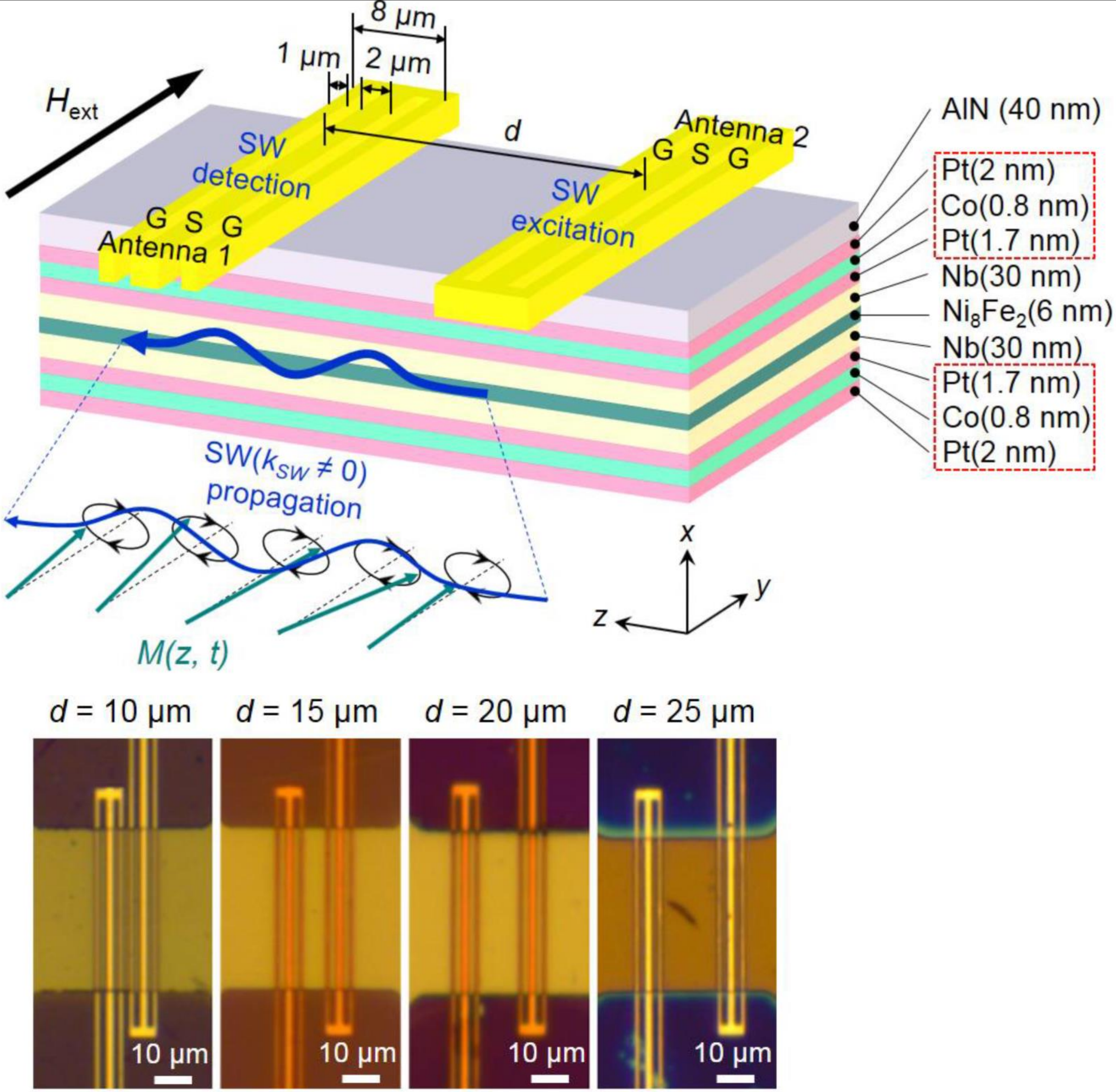






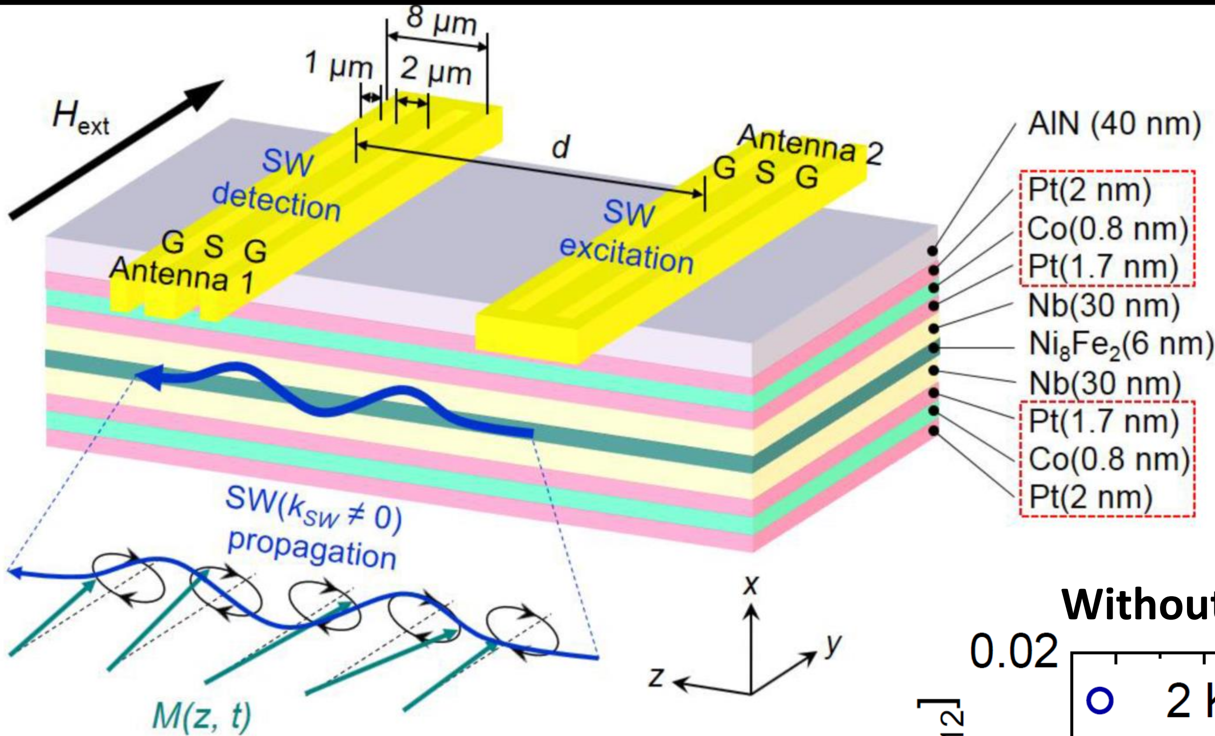


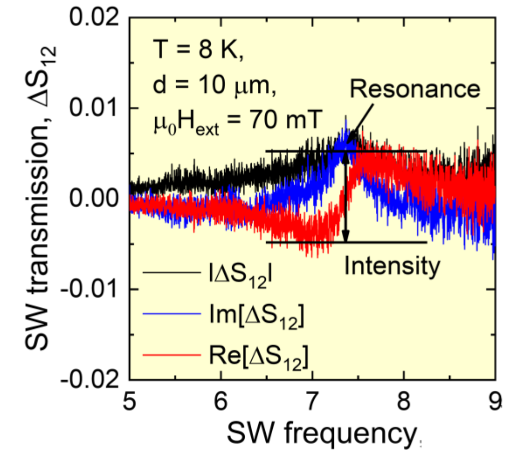
Tunable spin-wave propagation by the triplet CPs

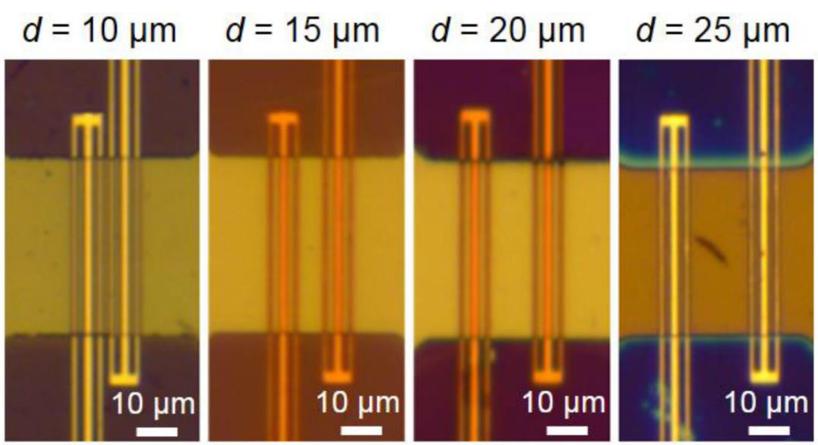


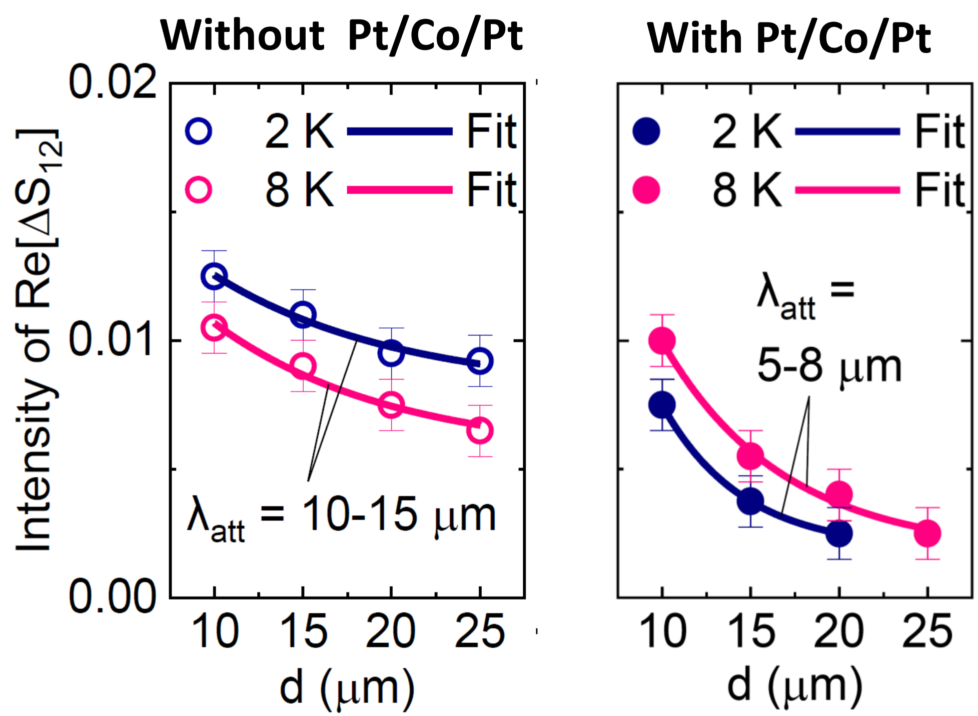
[Phys. Rev. X 10, 031020 (2020)]

Tunable spin-wave propagation by the triplet CPs









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Conclusions

- Pure spin is efficiently pumped in superconducting Nb when it is interfaced by a heavy metal
- The spin pumping efficiency is increased when the Pt internal exchange field is increased by proximity to a ferromagnet
- The angular dependence of the effect points towards Rashba SOC for generating long-range equal spin states

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Phys. Rev. Appl., **11**, 014061 (2019)
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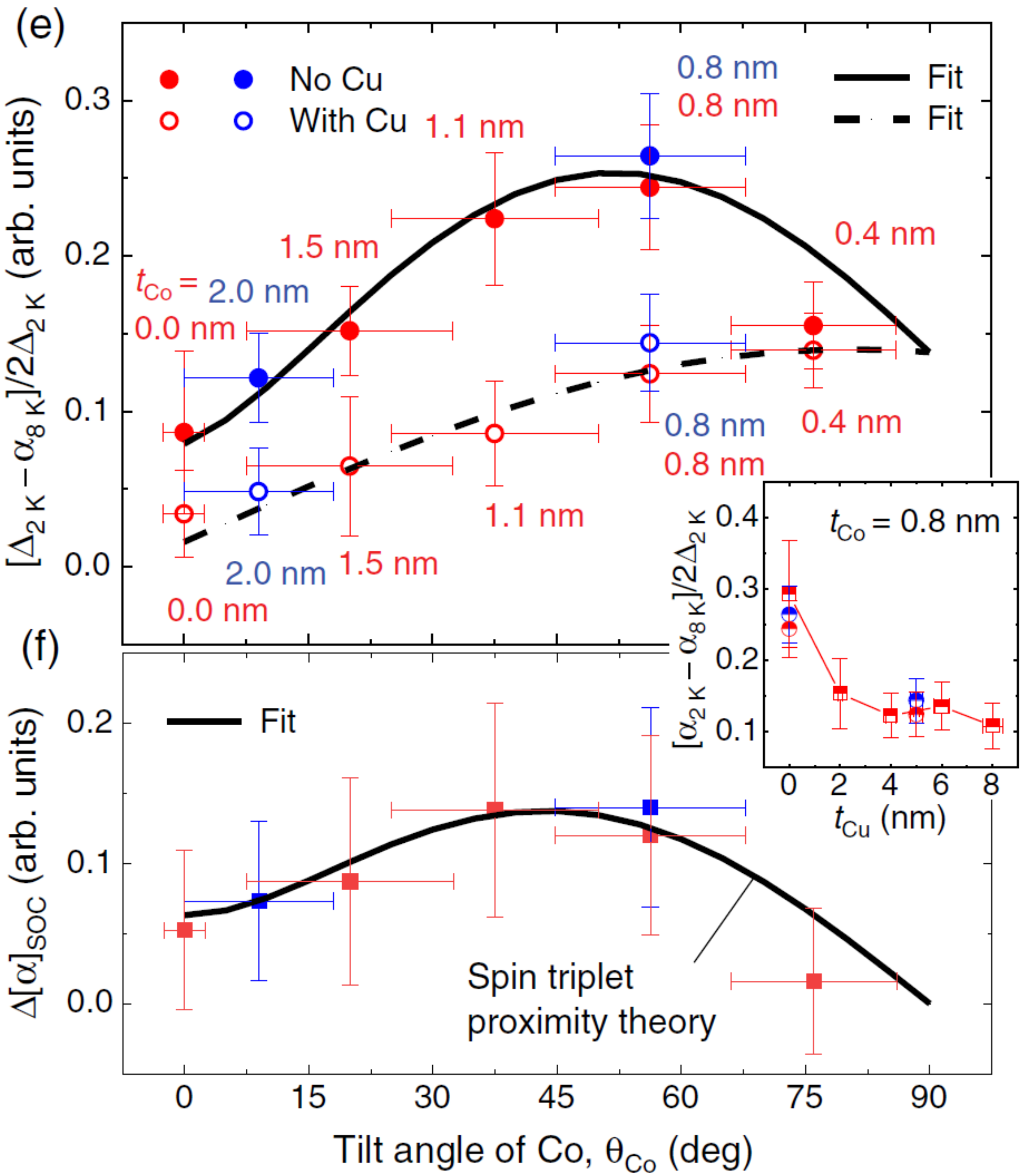
Phys. Rev. X 10, 031020 (2020)
Phys. Rev. B 99, 144503 (2019)



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