Classical analogy for the deflection of flux avalanches by a metallic layer

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LABORATORY OF PHYSICS OF NANOSTRUCTURED MATERIALS

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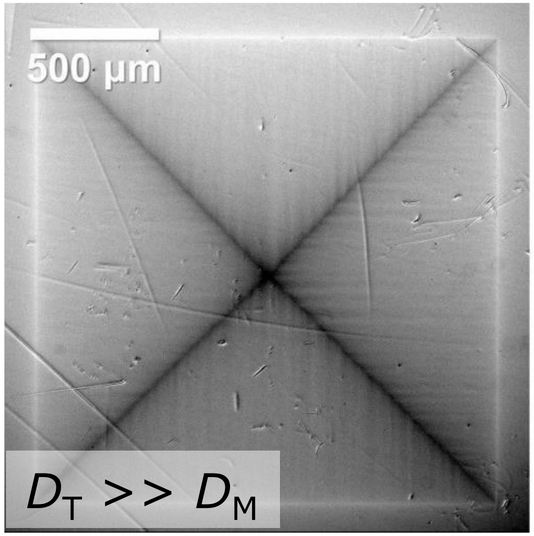
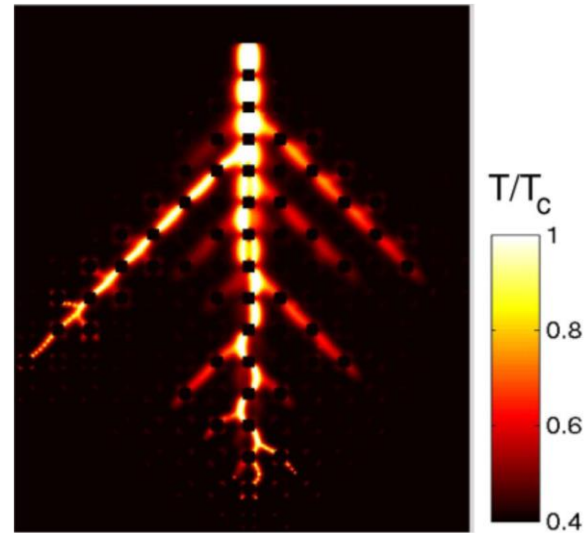
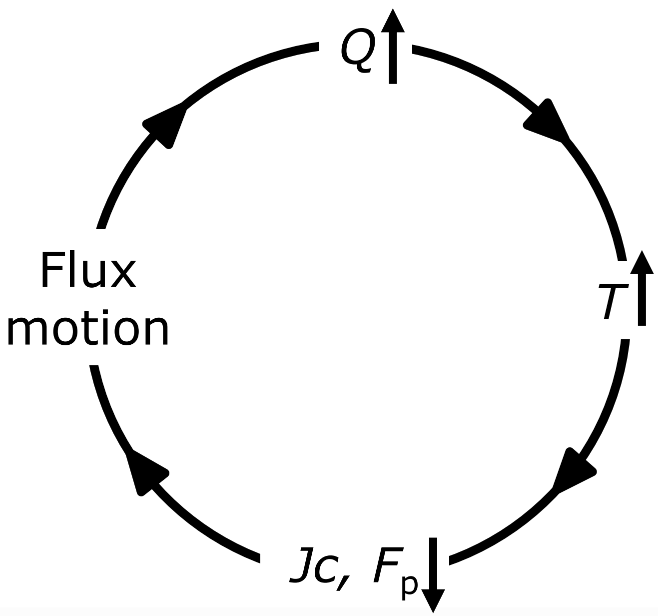
Magnetic flux avalanches







Adiabatic conditions, $\Delta T = Q/C(\mathrm{T})$

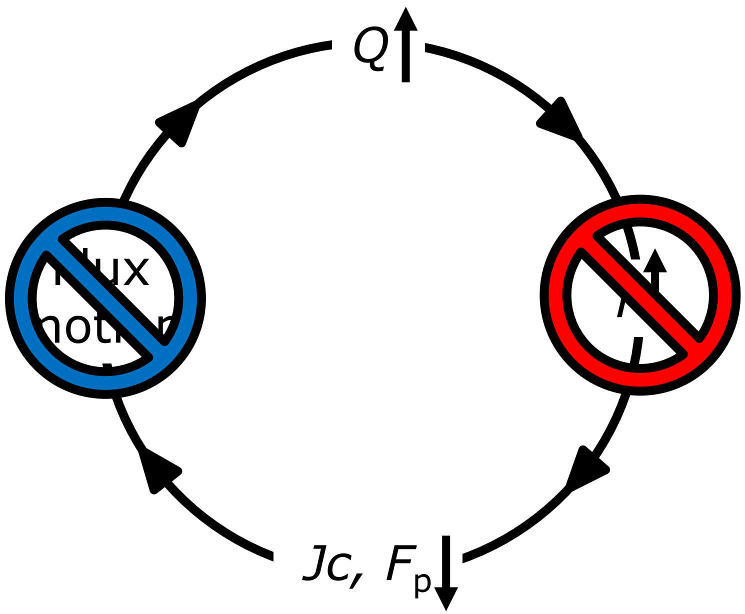
v>10 km/s > sound velocity 3 km/s

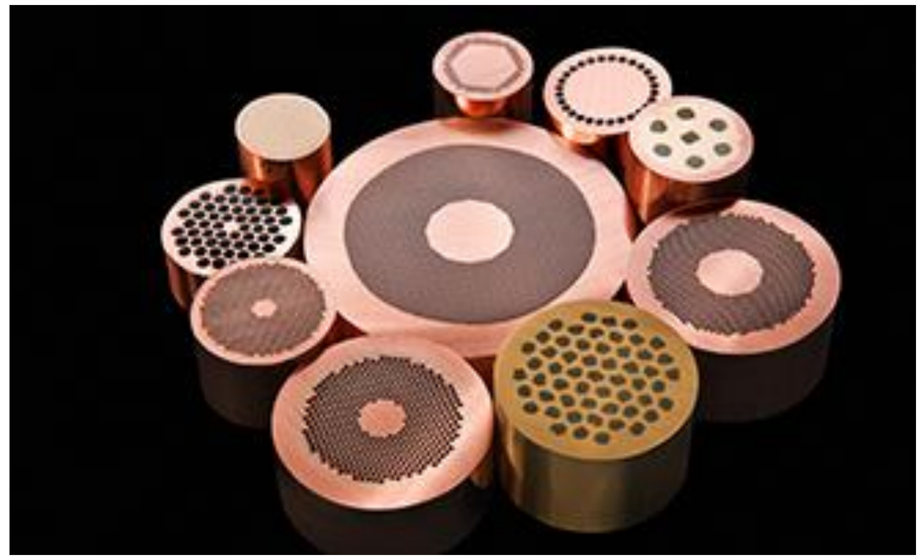
$v_{Abrikosov}$ << *1 km/ s*

$v_{kinematics}$ ~ *1-10 km/ s*

R. G. Mints and A. L. Rakhmanov, *Rev. Mod. Phys.* **53**, 551 (1981)

Cu coating of superconducting wires





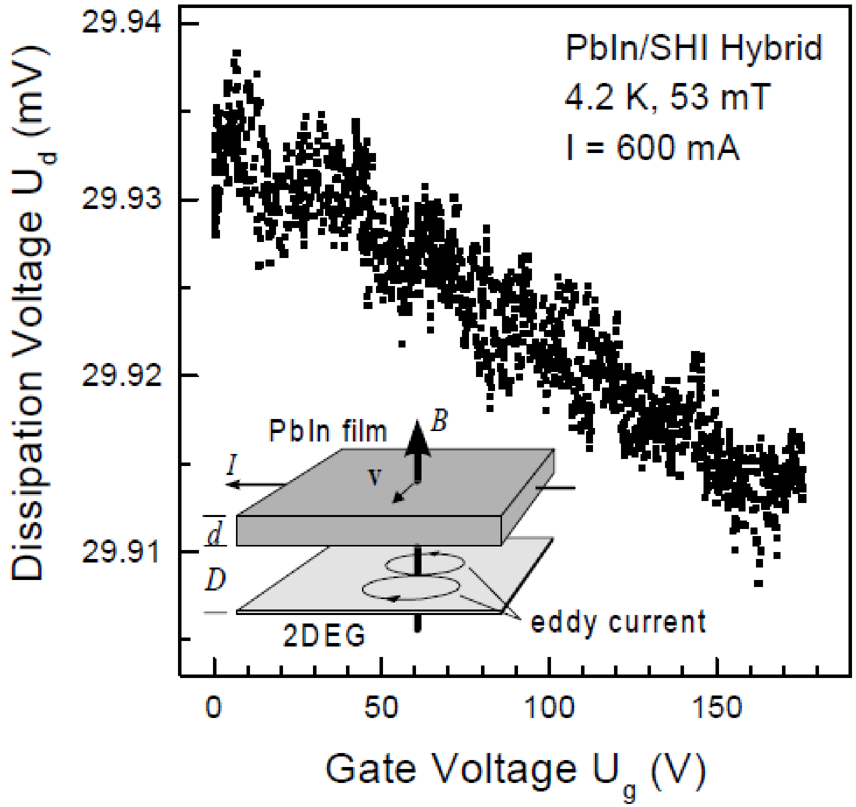
Better stability by reducing the speed of penetration of the flux jump

Thermal sink

Quench protection

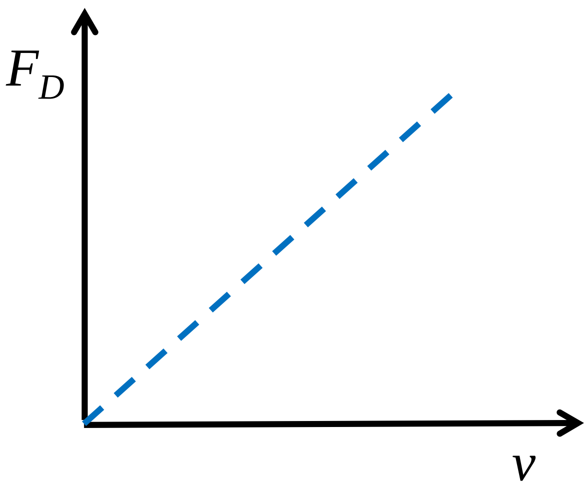
Harrison *et al.*, J. Low Temp. Phys. **18**, 1 (1975) | Larbalestier *et al.*, Nat. Mat. **13**, 375 (2014)

Magnetic braking of vortices in semiconductor/superconductor hybrids



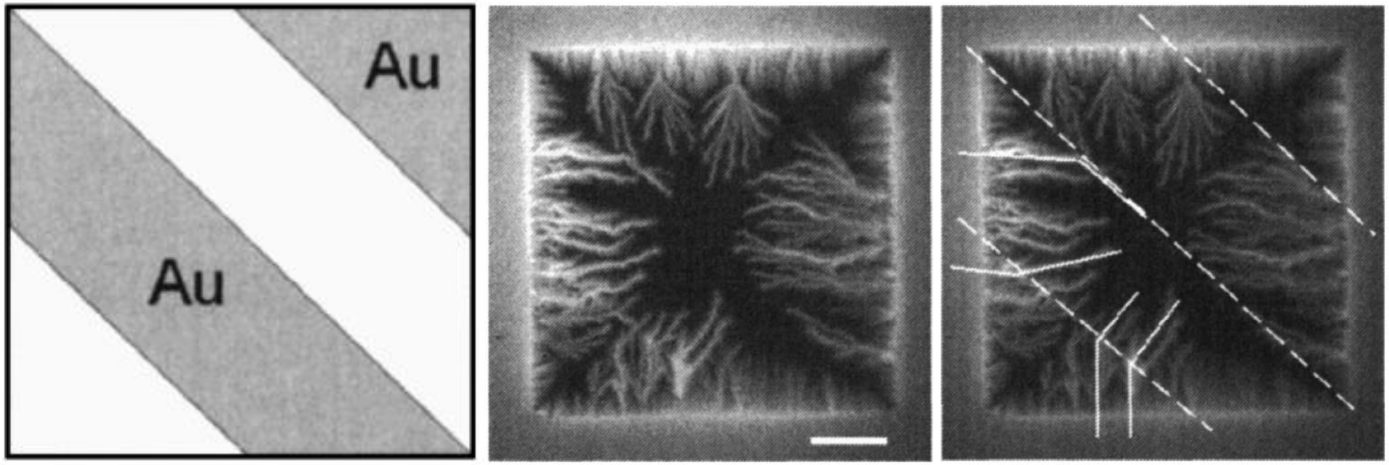
"significant additional damping of vortex motion caused by the eddy currents generated in the 2D electron gas"

$$\frac{F_D}{v} = \eta_T = \eta_{SC} + \eta_{2DEG} \approx \eta_{SC} + \frac{\sigma_{2DEG}}{\sigma_n d}$$



Danckwerts *et al.* (2000) *Phys. Rev. Lett.* **84,** 3702 | Baker and Rojo (2001) *Phys. Rev. B* 64, 14513

Deflection of flux avalanches

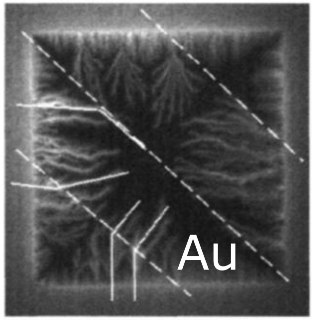


✓ The gold capping reduces the velocity v of the avalanches.

✓ Change of propagation direction depending on the incident angle.

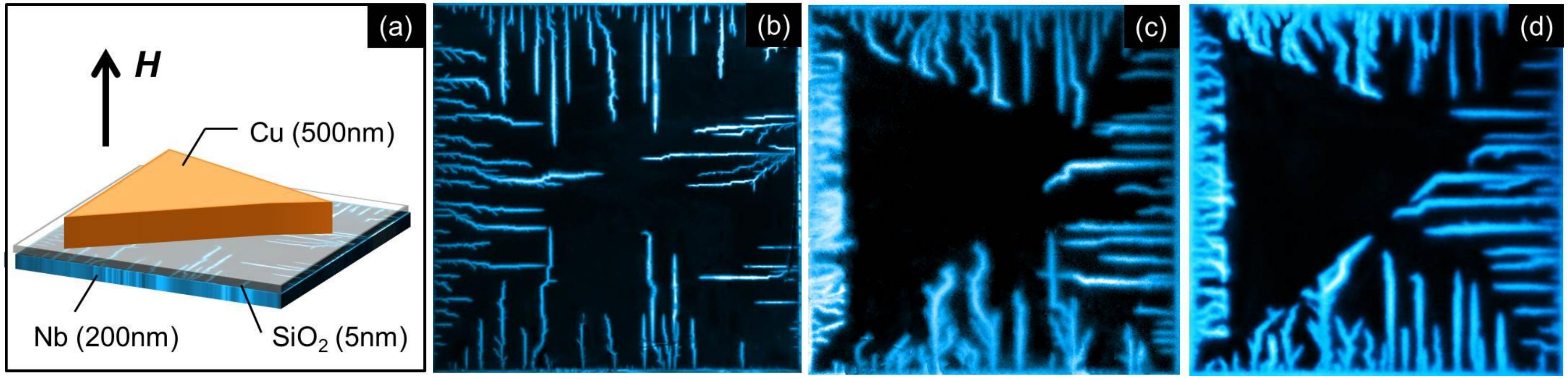
J Albrecht *et al.* (2005) *Appl. Phys. Lett.* **87** 182501

Open questions



- ✓ Is there a refraction like behavior of avalanches ?
- ✓ Is the extra vortex damping produced by the metallic layer constant ? $$\frac{F_D}{v} = \eta_{SC} + \eta_{metal}$$
- ✓ Can a single vortex also undergo deflection when entering the region covered by the metallic layer ?
- ✓ Does the metallic layer influences the vortex flow at lower velocities ?

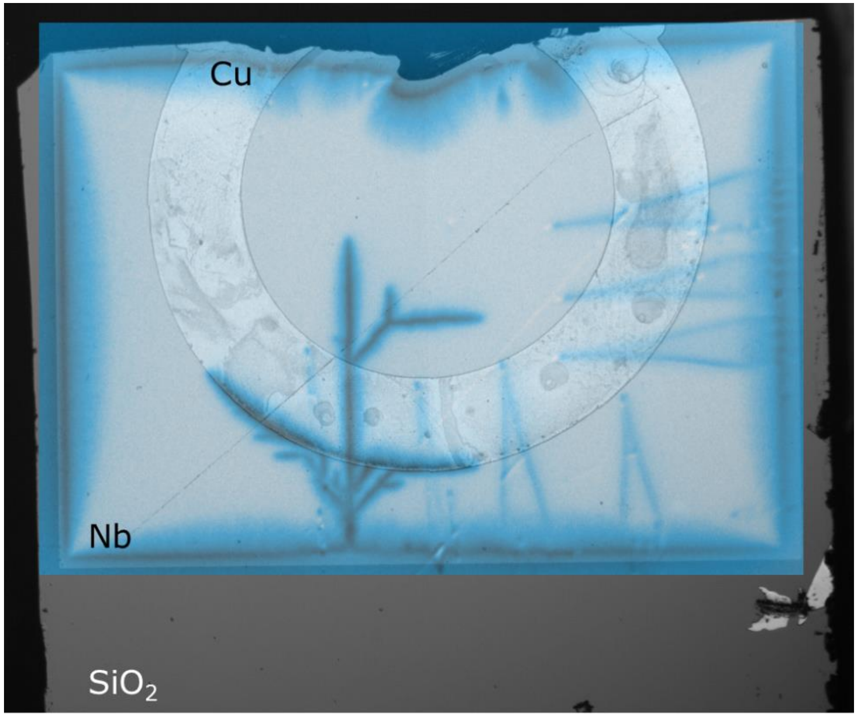
Avalanche exclusion

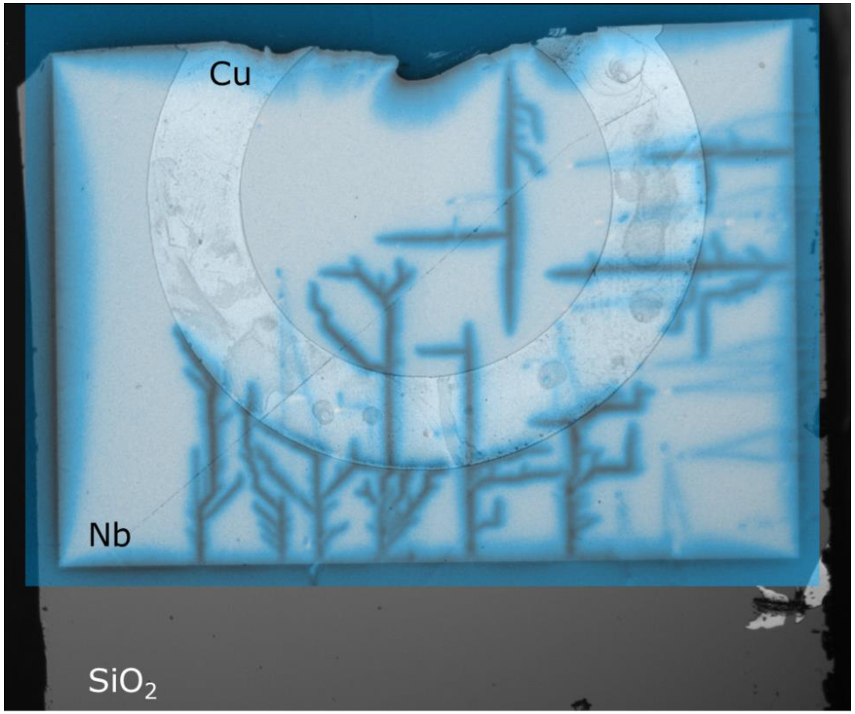


- ✓ No thermal shunt at the nucleation point of the avalanches
- ✓ Exclusion of flux avalanches by the Cu layer
- ✓ In the smooth (critical state) flux penetration regime, there is no difference between the sample with or without the Cu triangle

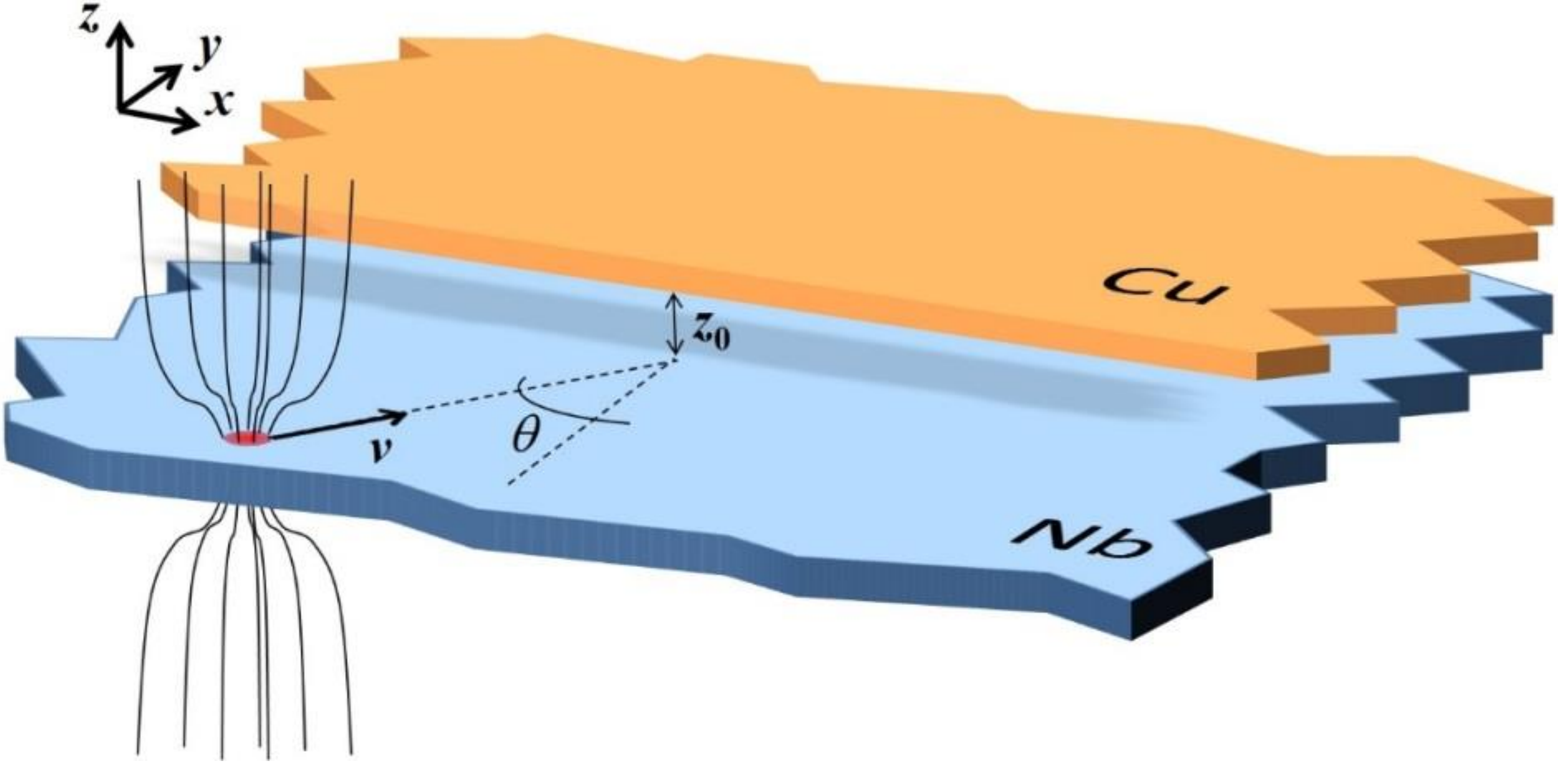
Brisbois *et al*., New Journal of Physics **16** (2014) 103003

Avalanche exclusion



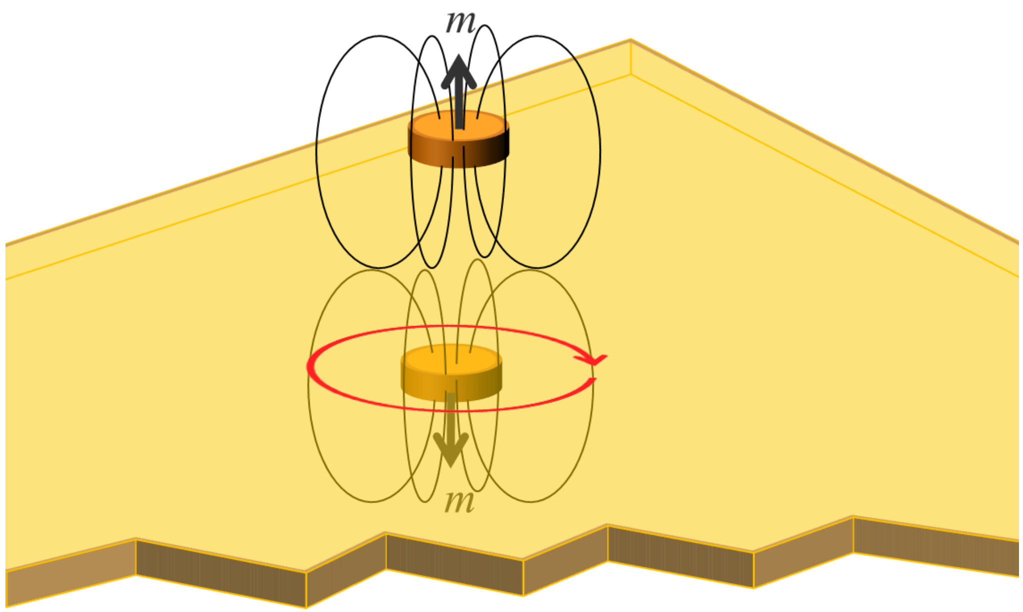


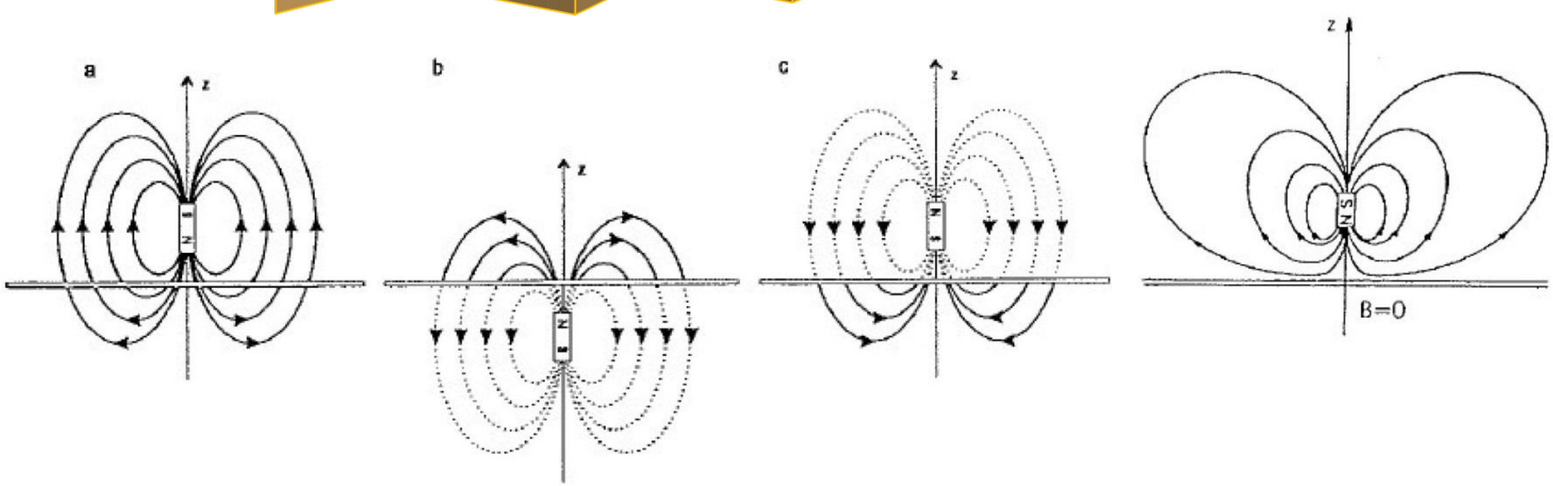
Classical model



Brisbois *et al*., New Journal of Physics **16** (2014) 103003

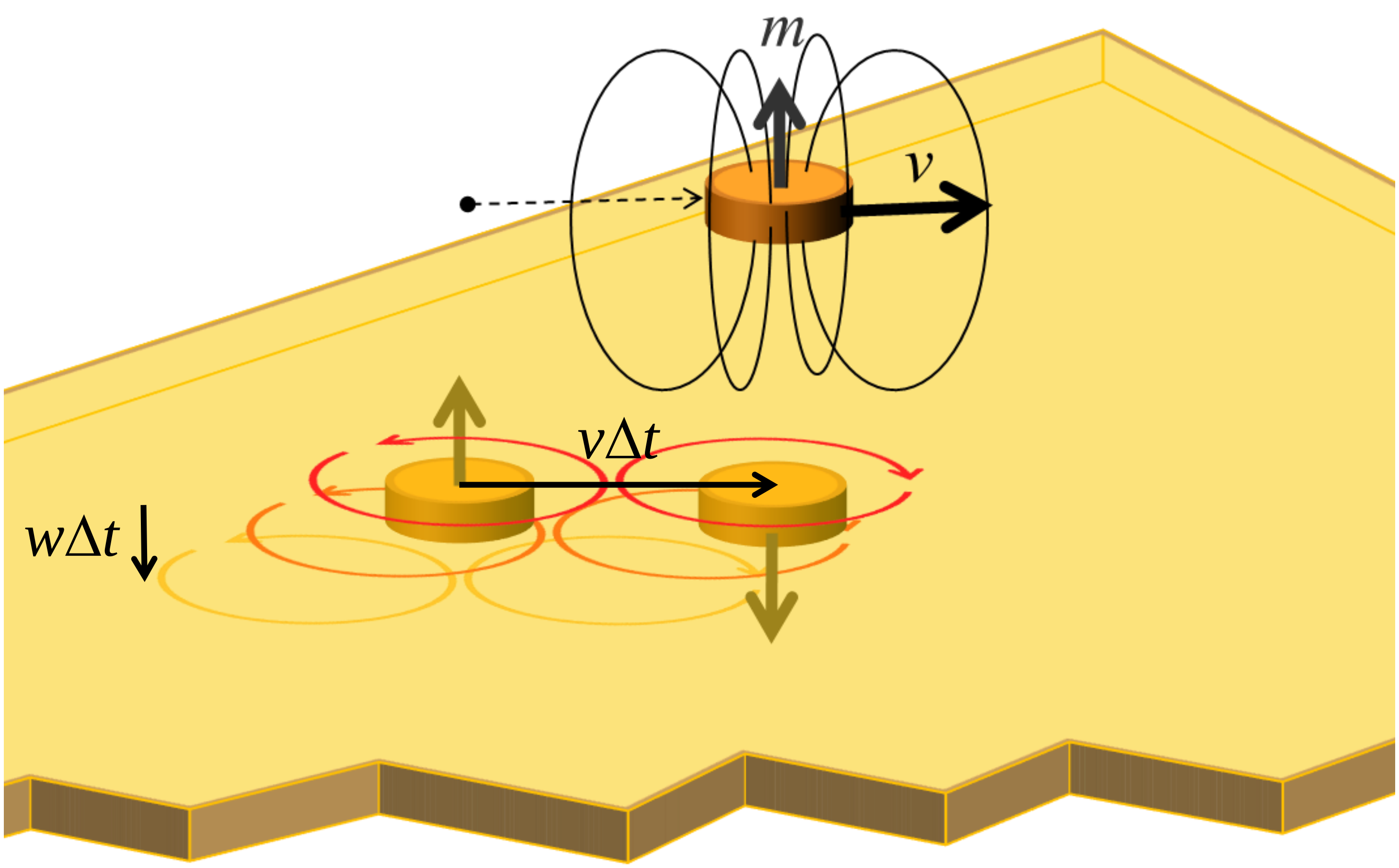
Eddy currents and image method





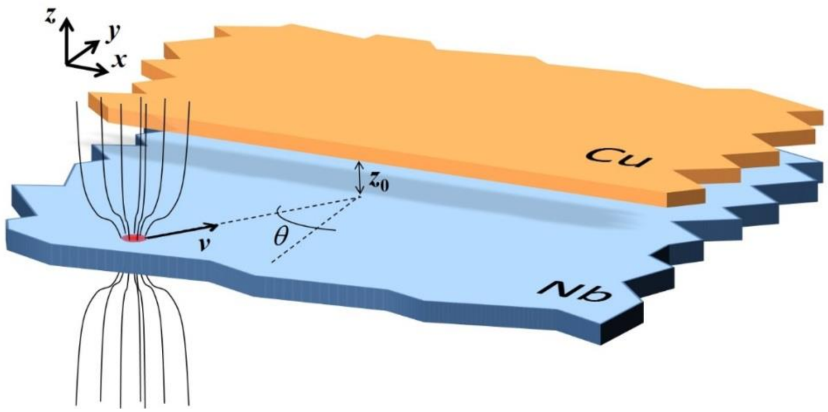
A magnetic dipole suddenly appears over a conducting plane

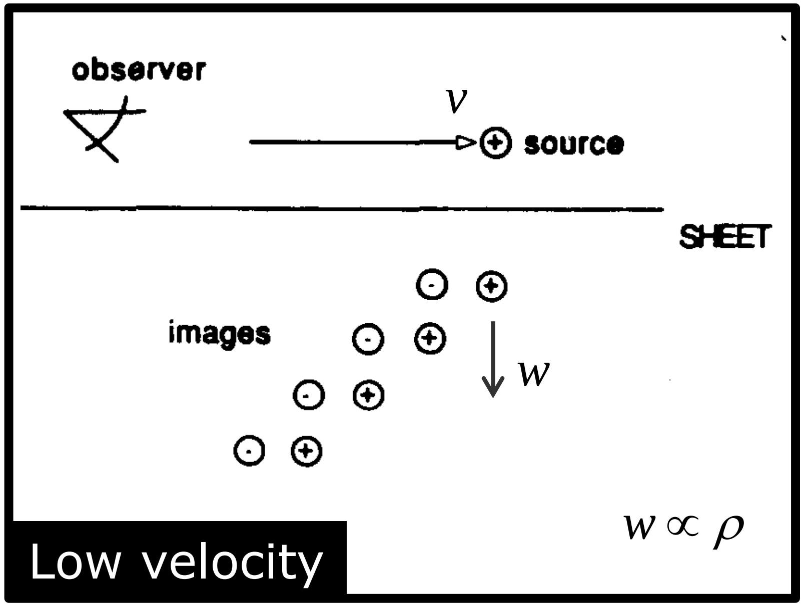
Eddy currents and image method

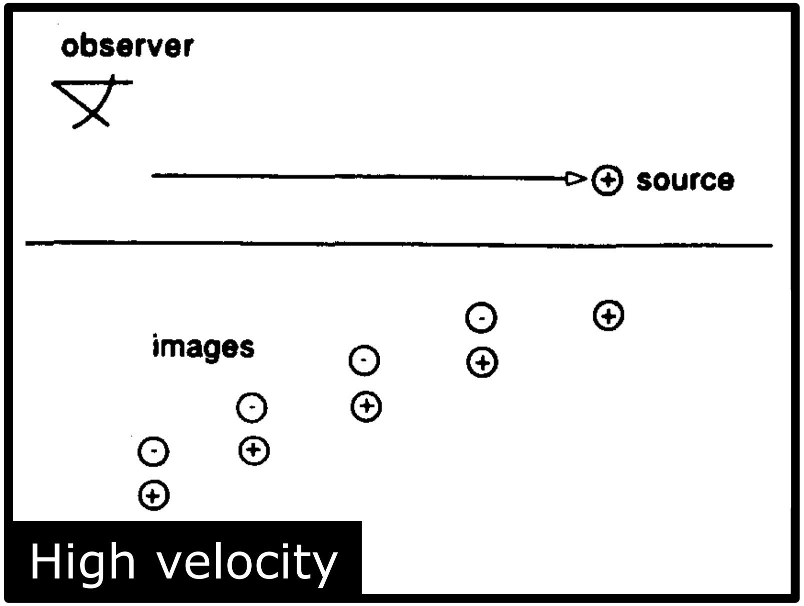


$w \propto \rho$

Classical model

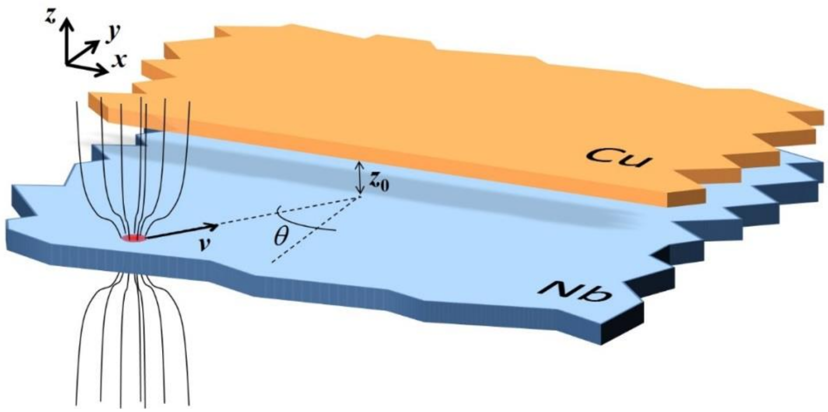






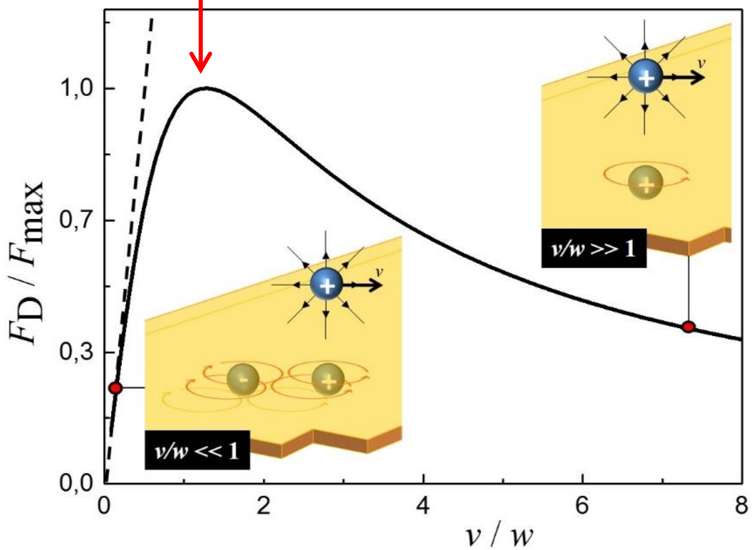
T.D. Rossing and J.R. Hull, *Phys. Teach.* **29** 552 (1991) | W.M.Saslow, *Am J. Phys.* **60**, 693 (1992)

Classical model

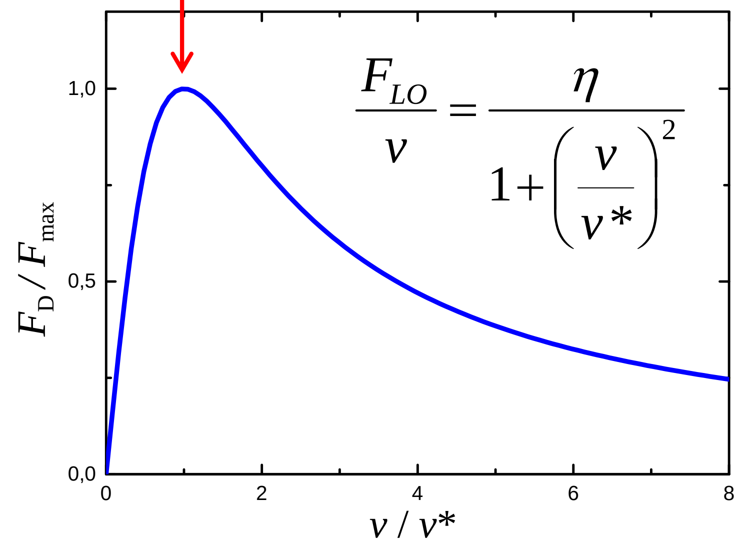


$$F_D = \frac{\mu_0 q^2}{16\pi z_0^2}\frac{w}{v}\left(1 - \frac{w}{\sqrt{v^2 + w^2}}\right)$$

~0,1 km/s

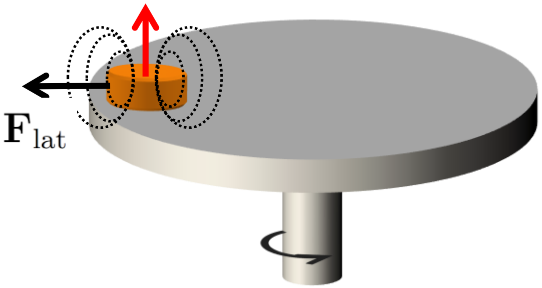


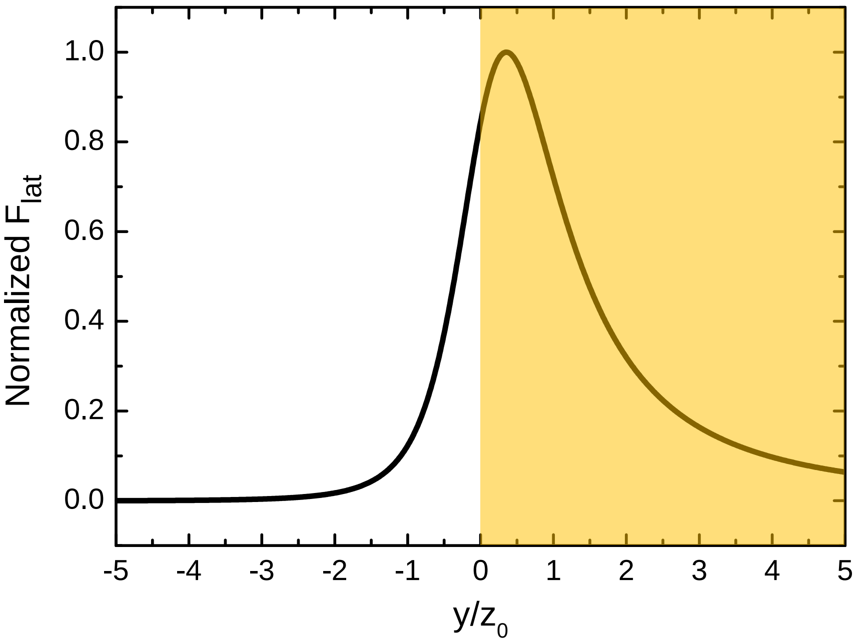
~1 km/s



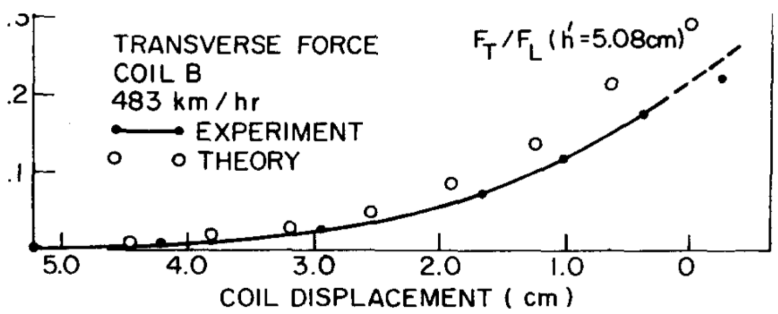
Brisbois *et al*., New Journal of Physics **16**, 103003 (2014) | W.M.Saslow, *Am J. Phys.* **60**, 693 (1992)

Boundary effect



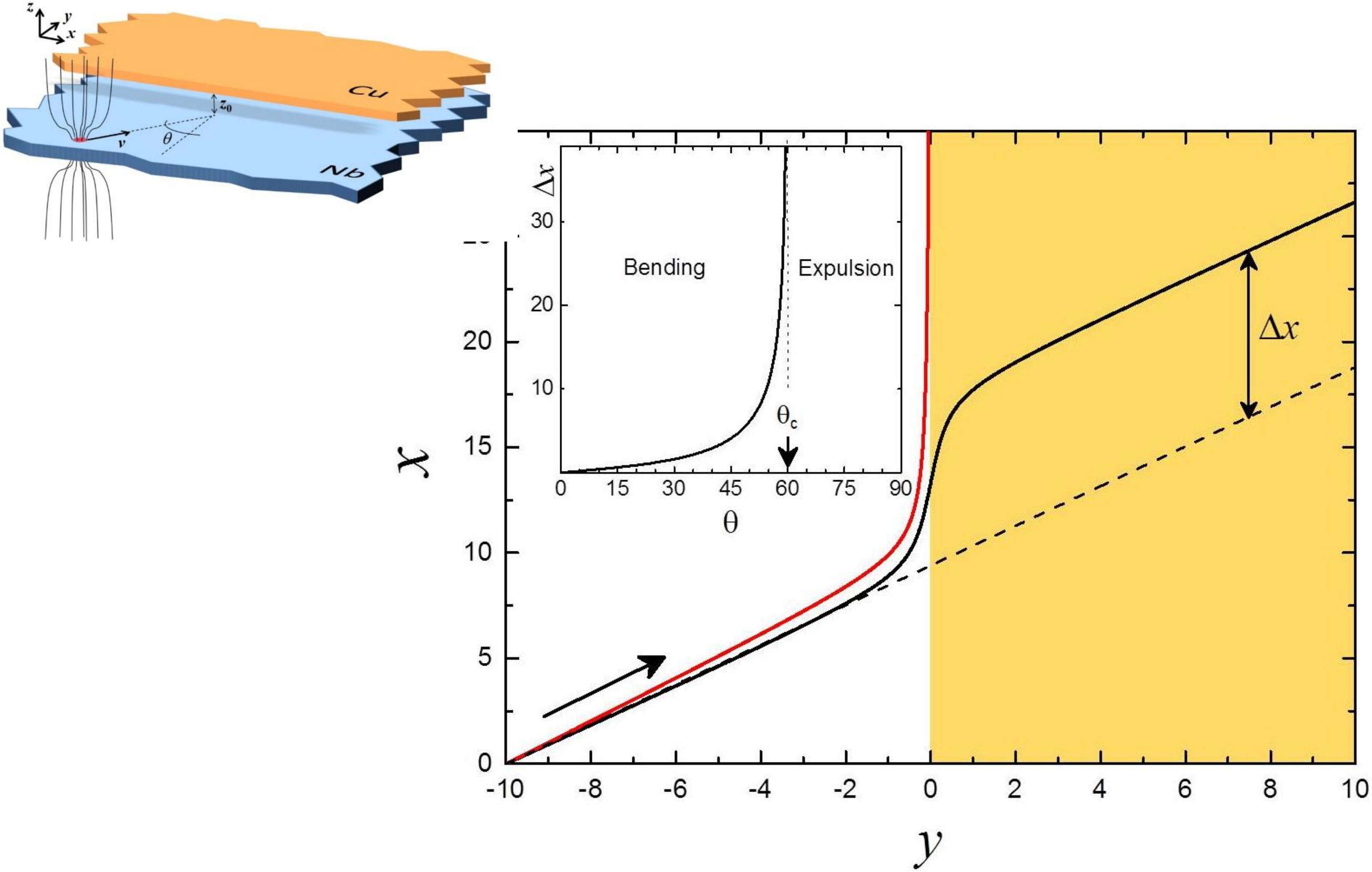


$$\mathbf{F}_{\text{lat}} = -C_{\text{m}} \left(\frac{1}{y^2 + z_0^2} + \frac{y}{(y^2 + z_0^2)^{3/2}} \right) \hat{y}.$$



Borcherts R H and Davis L C 1972 *J. Appl. Phys.* **43** 2418 | Davis L C and Reitz J R 1971 *J. Appl. Phys.* **42** 4119

Vortex trajectories



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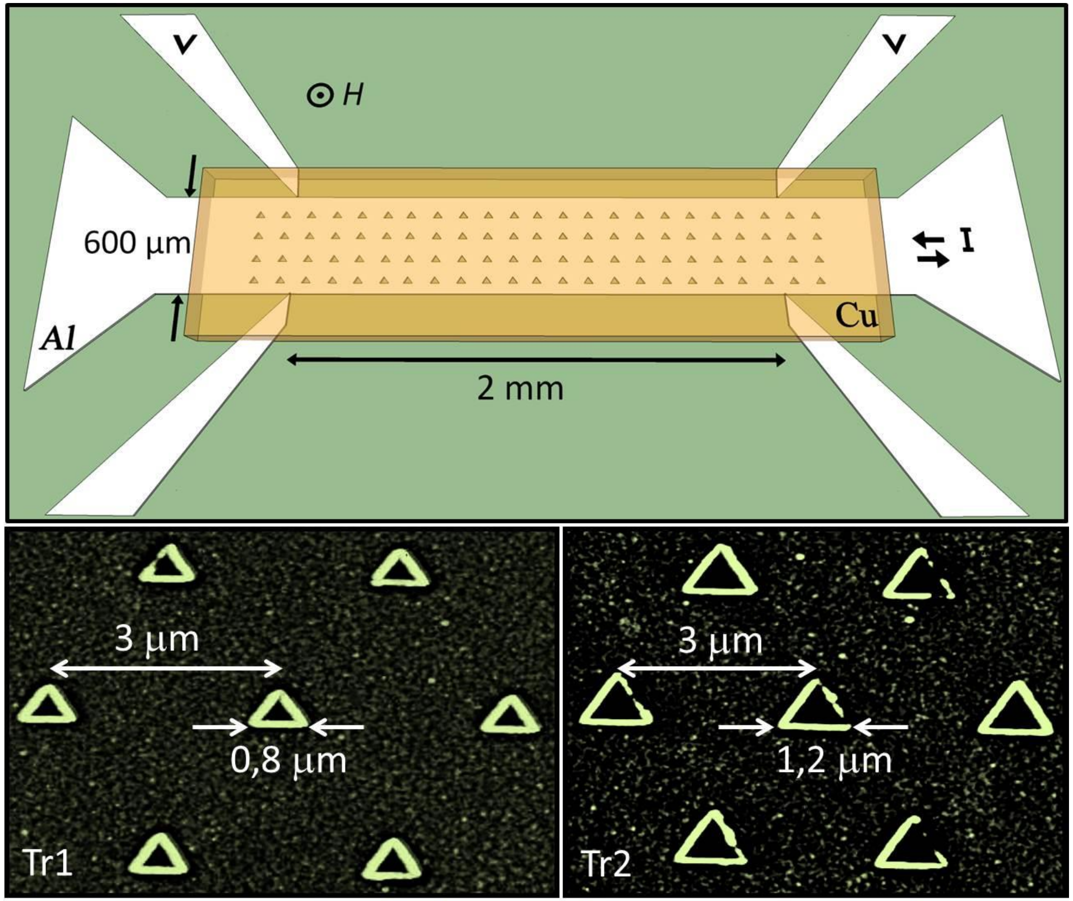
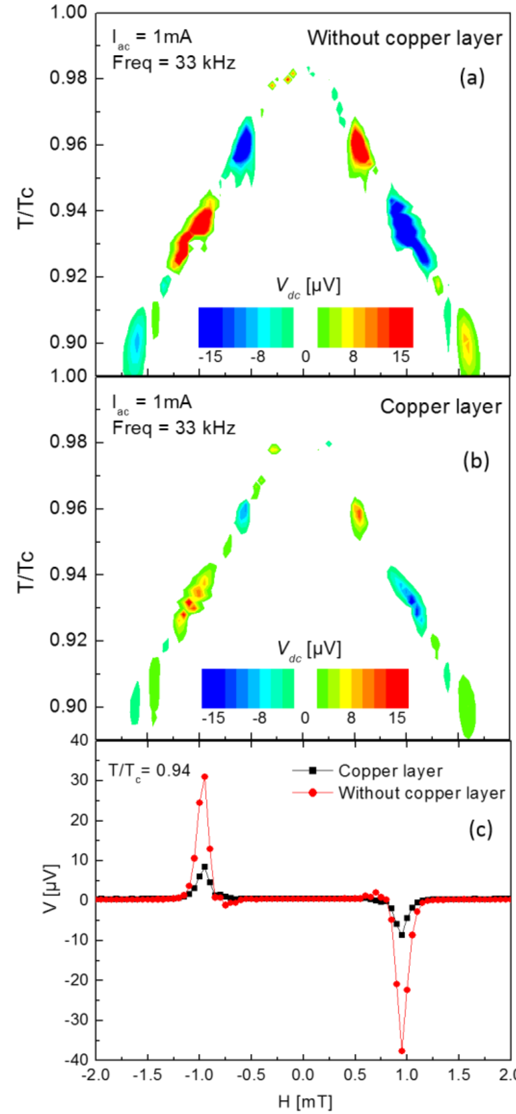
Damping of ratchet motion



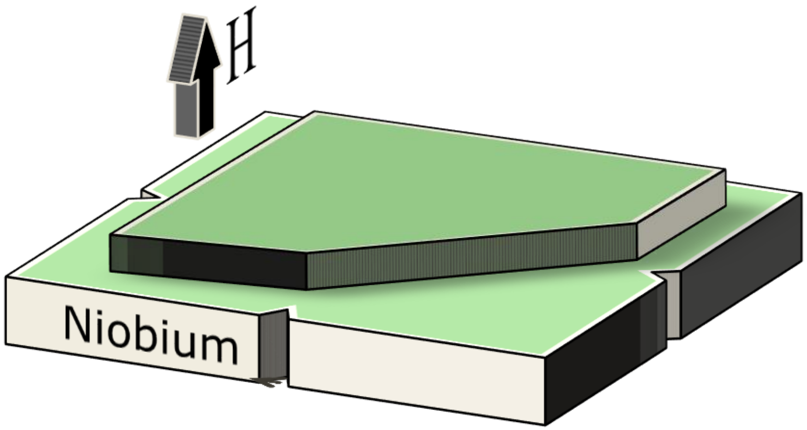


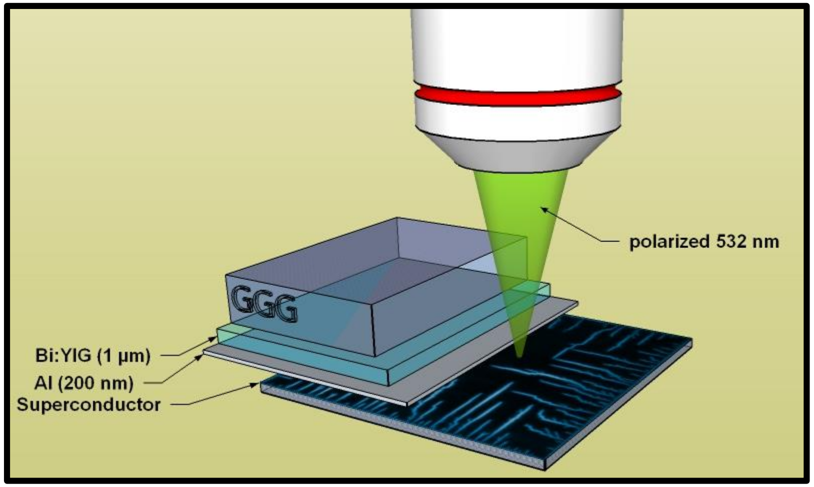
$$\eta v = (J - J_c)\Phi_0$$

Adami *et al*., unpublished.

Conclusion

- ✓ We are able to explain in classical terms the deflection of magnetic flux by a conducting layer
- ✓ Our classical analogy suggests a non-monotonous $F_{\mathrm{D}}(v)$ relation
- ✓ Typical MOI experiments need an Al mirror of about 100nm. Does this mirror influence the measurements? and the cold finger?
- ✓ The metallic layer affects the effective vortex ratchet
- ✓ Next step: what about replacing the Cu layer by a superconducting film?





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Thank you

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