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

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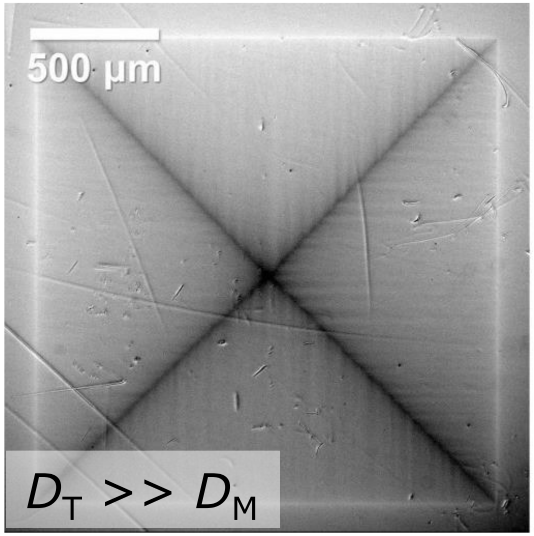
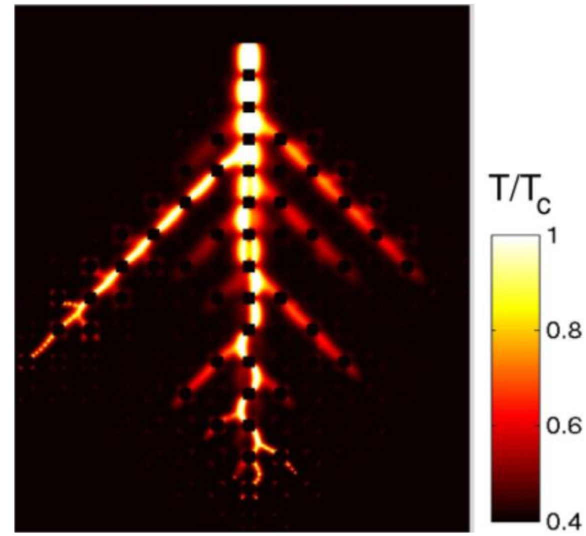
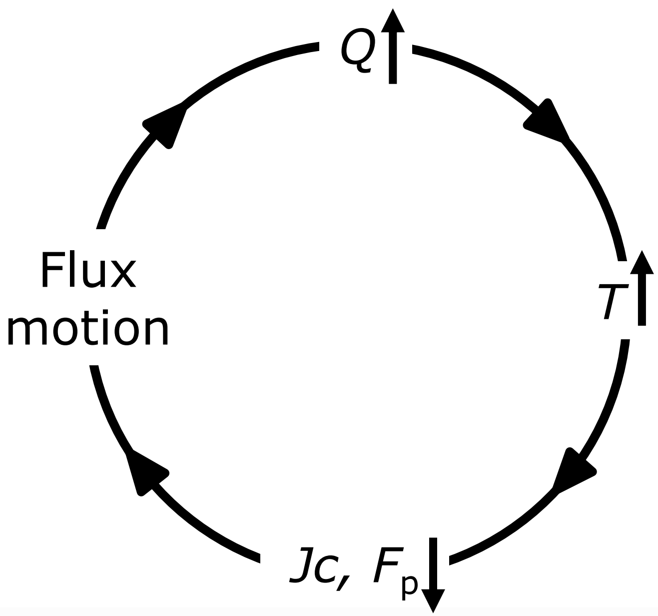
Magnetic flux avalanches







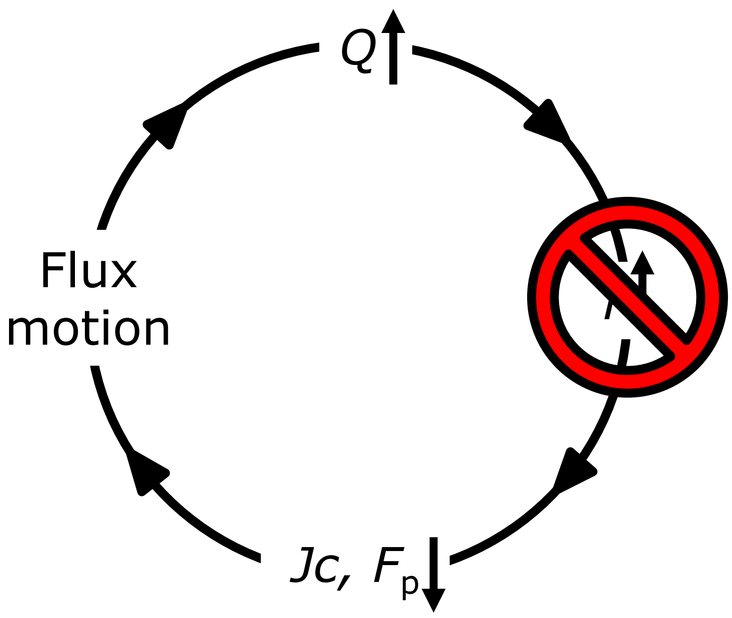
Heat transport by phonons can be ruled out → adiabatic conditions, hence $\Delta T = Q/C(\mathrm{T})$

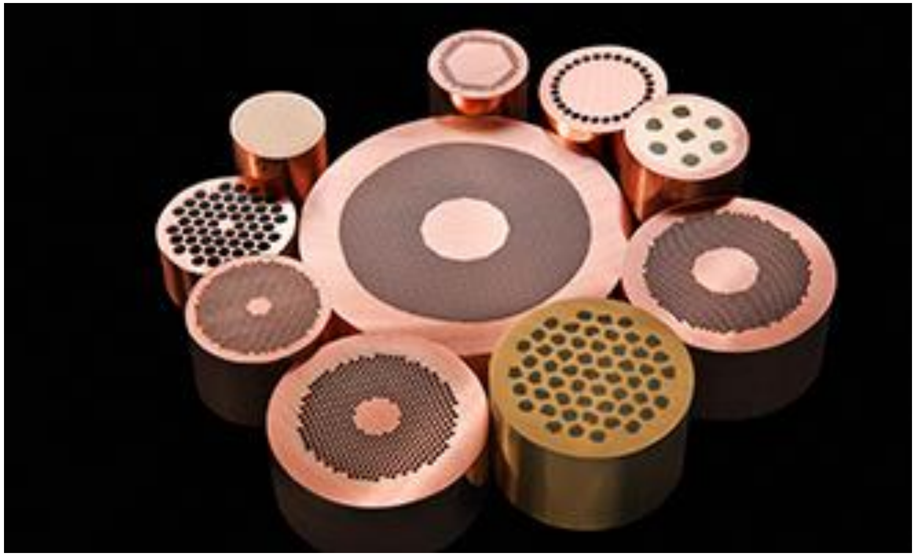
v~160 km/s >> sound velocity 7 km/s

$v_{Abrikosov}$ << 1 km/ s
$v_{kinematics}$ ~ 100 km/ s
$v_{josephson\text{-}vortex}$ ~ 10000 km/s

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

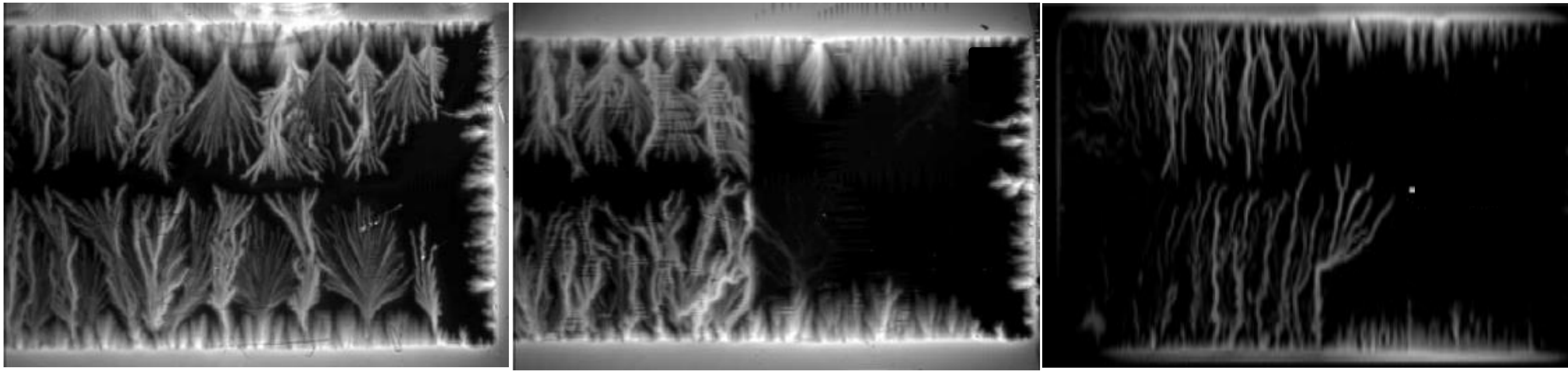
Cu coating of superconducting solenoids

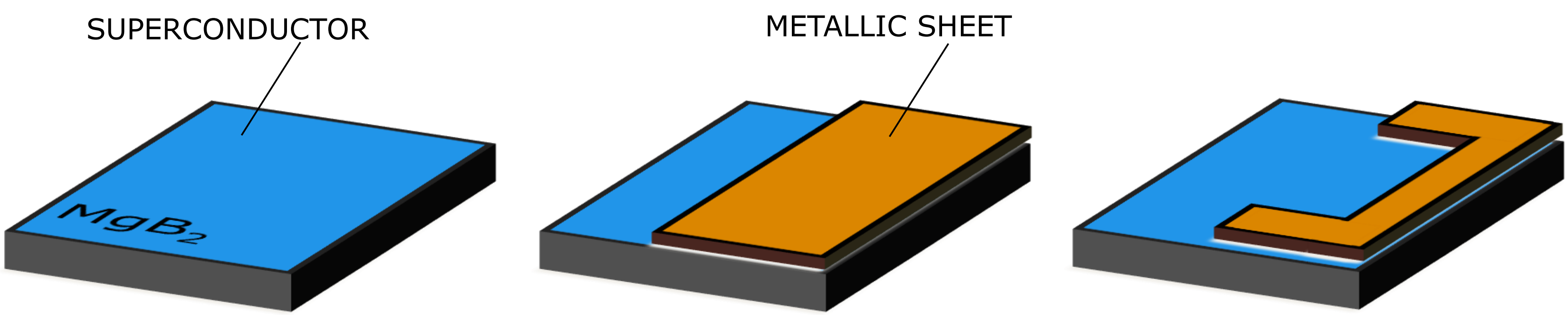




Kim Y B, Stephen M J and Parks R D 1969 *Superconductivity* vol 2

Suppression of flux avalanches

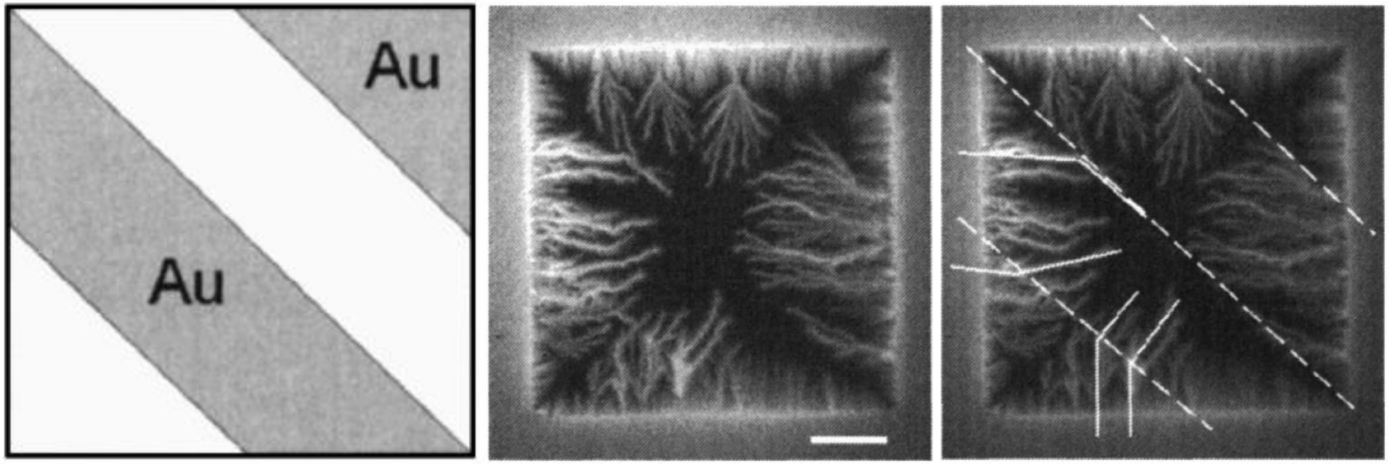




“The clear sensitivity of dendritic avalanches to the thickness of the gold layer suggests a thermal origin for the instability”

M. Baziljevich, *Physica C* **369** (2002) 93–96; Choi *et al. Appl. Phys. Lett.* **87**, 152501 (2005)

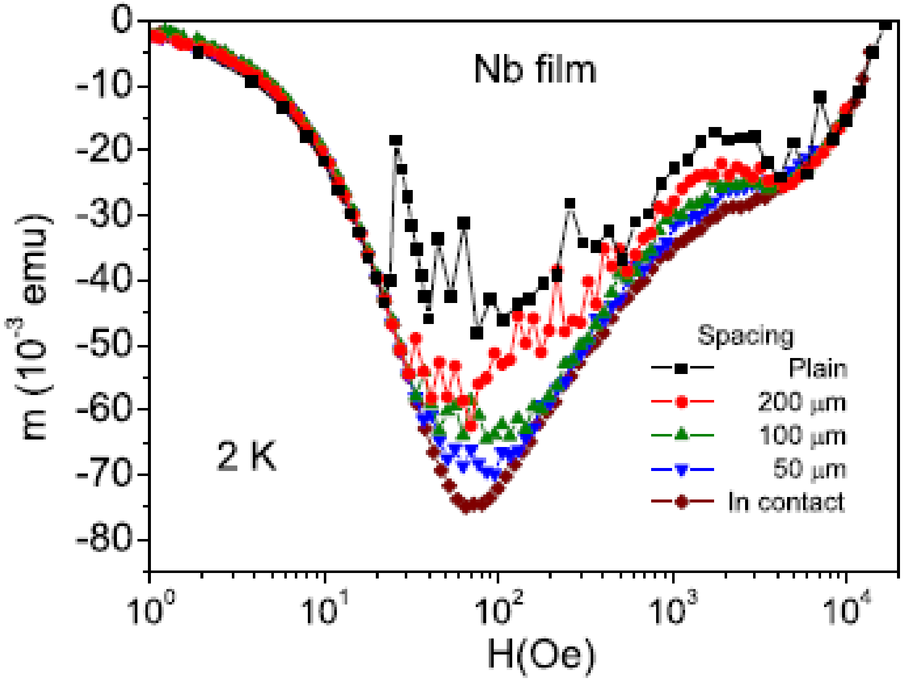
Deflection of flux avalanches

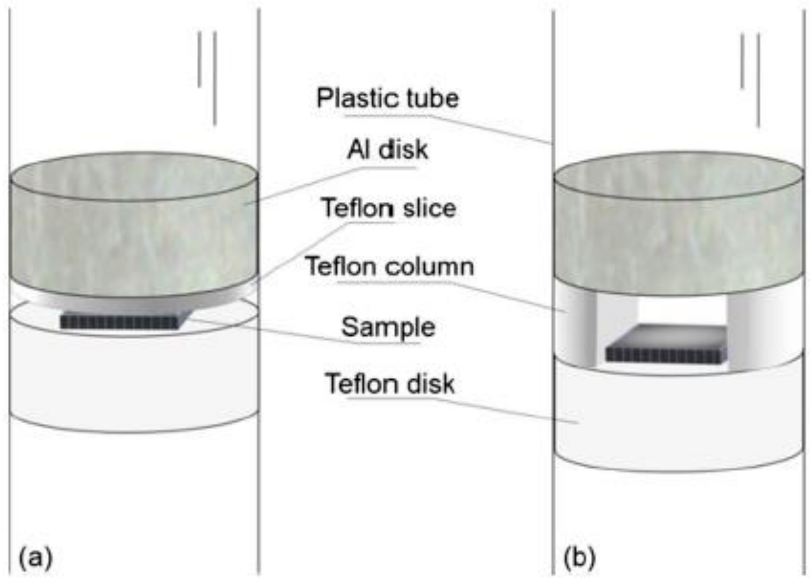


- ✓ Change of propagation direction depending on the incident angle.
- ✓ The gold capping reduces the velocity v of the avalanches.
- ✓The propagation of an avalanche gives rise to large electric fields according to Faraday’s law that cause high currents in the gold film.

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

Magnetic braking of flux avalanches

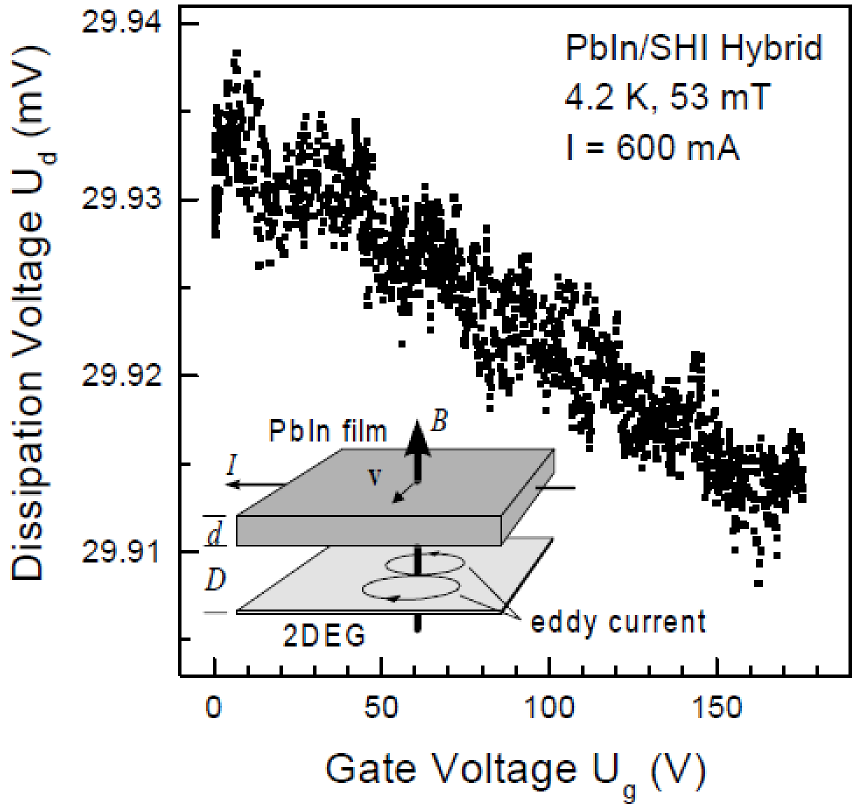




"Flux jumps are strongly suppressed when a metallic layer is located close—but not necessarily in contact. The effect is due to eddy currents induced in the metal preventing by electromagnetic braking large-scale vortex avalanches to develop."

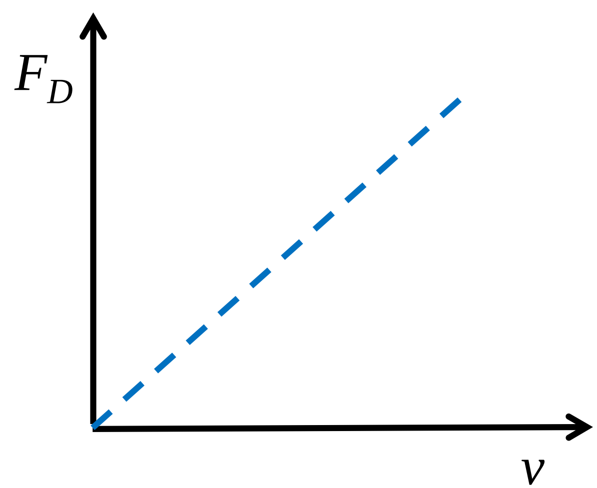
Colauto *et al.* (2010) *Appl. Phys. Lett.* **96**, 92512

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"

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

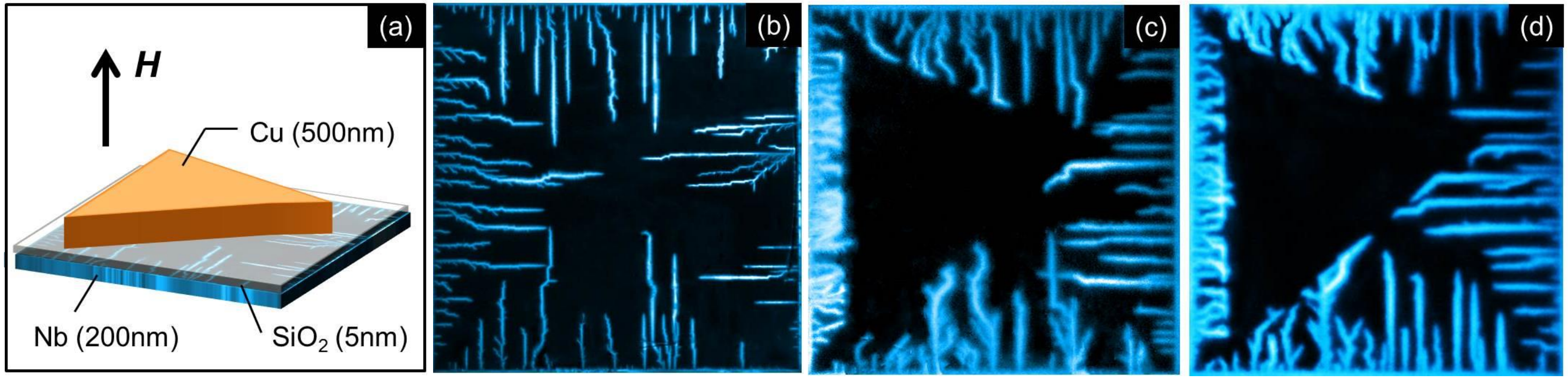


Danckwerts *et al.* (2000) *Phys. Rev. Lett.* **84,** 3702; Baker and Rojo (2001) *Phys. Rev. B* 64, 14513

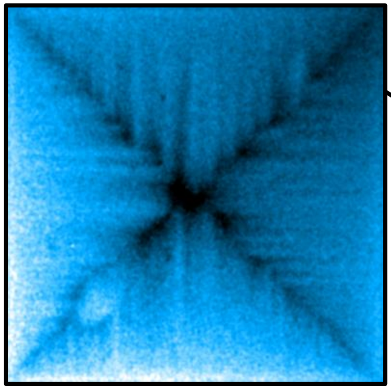
Research objectives

- ✓ What if the metallic layer is not covering the superconductor's borders ?
- ✓ May a single vortex also undergo deflection when entering the region covered by the metallic layer ?
- ✓ Can we think of a classical model mimicking the observed behavior ?

Avalanche exclusion

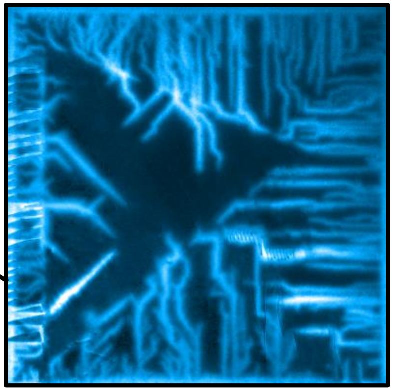


- ✓ No thermal shunt at the nucleation point of the avalanches
- ✓ Exclusion of flux avalanches by the Cu layer
- ✓ In the smooth (critical state) flux penetration regime, there is no difference between the sample with or without the Cu triangle



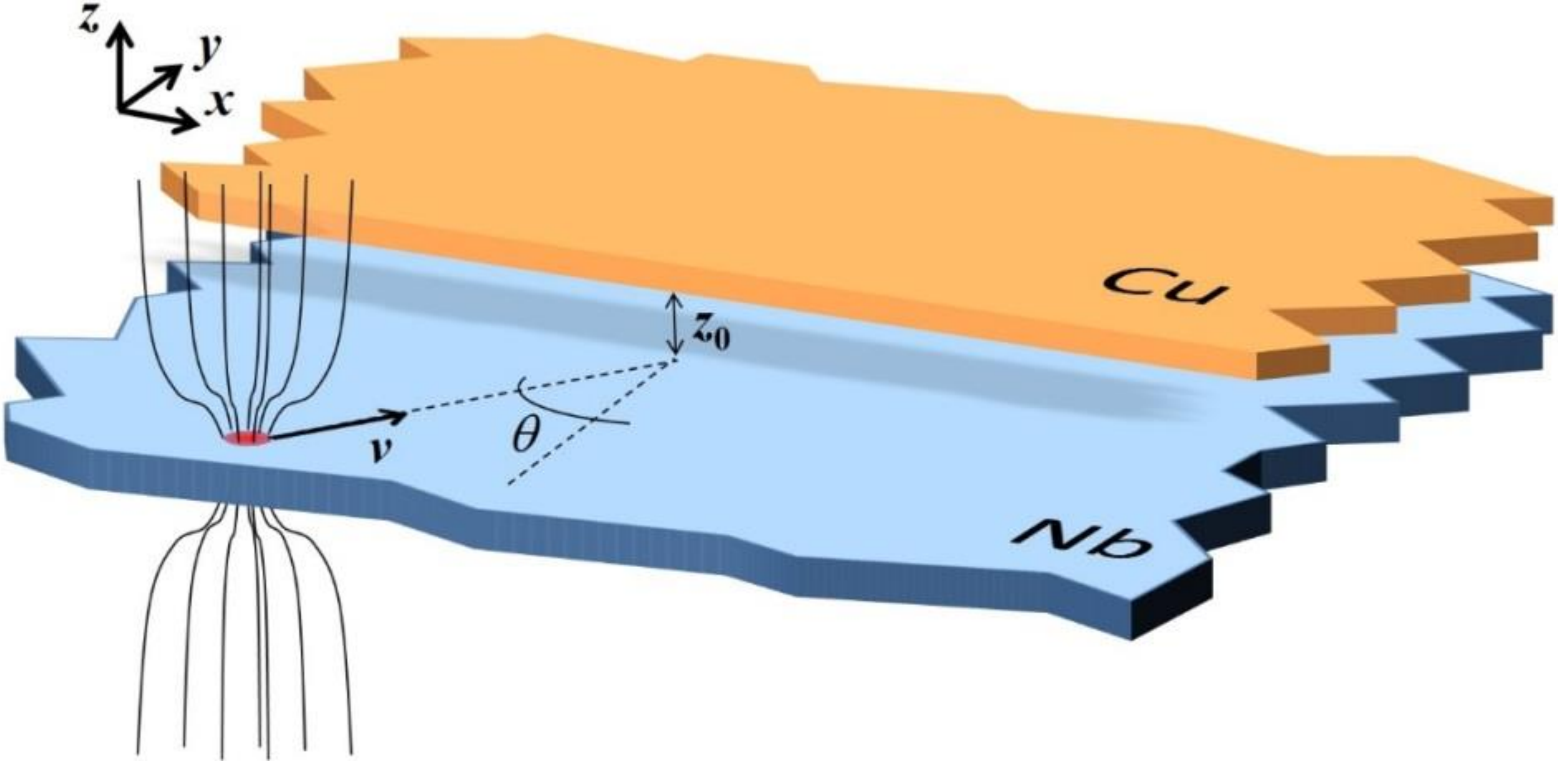
ZFC 7K, 15 Oe

ZFC 2.5K, 20 Oe



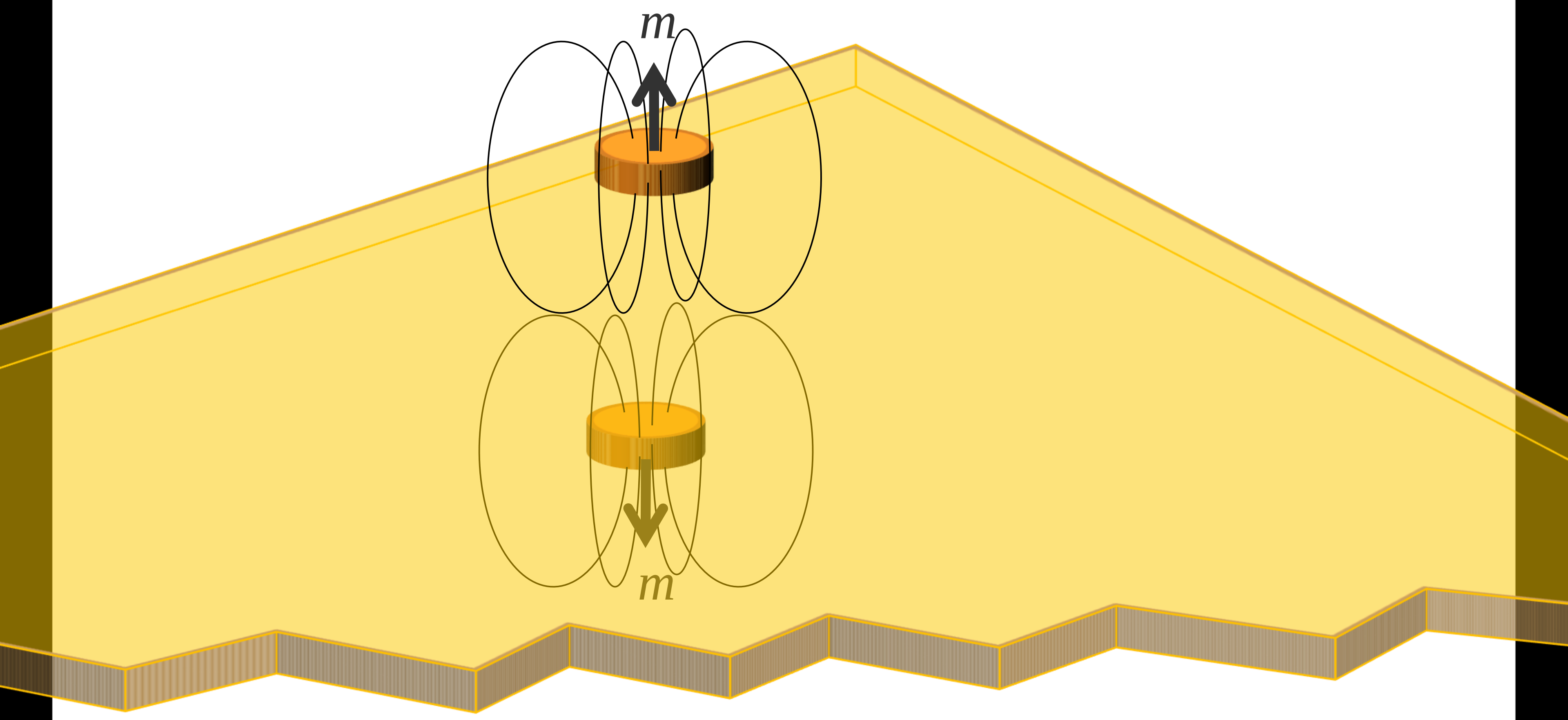
Brisbois *et al.* arXiv:1408.2420v1

Classical model



Brisbois *et al.* arXiv:1408.2420v1

Eddy currents and image method



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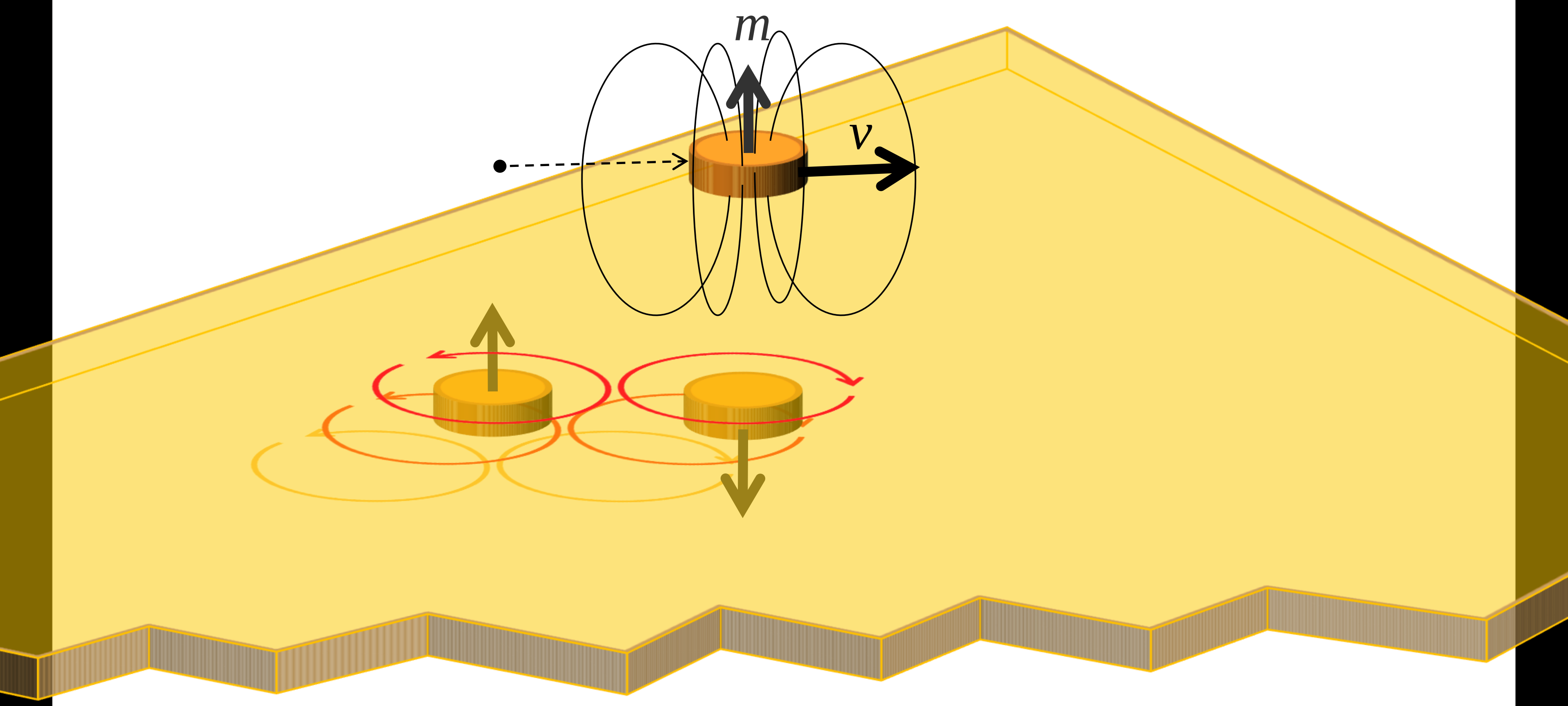
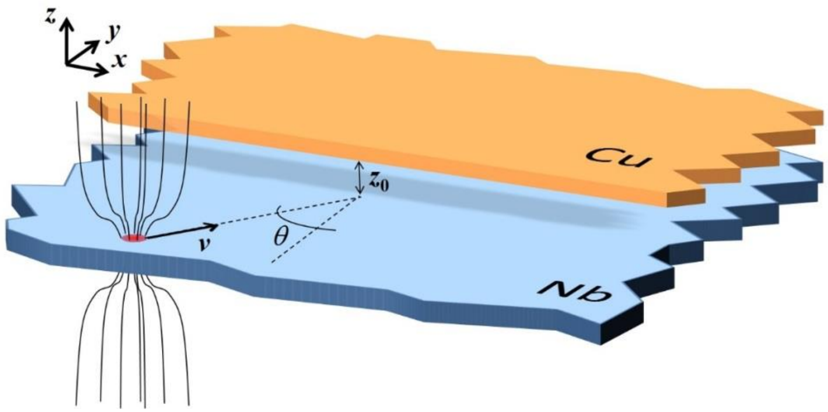
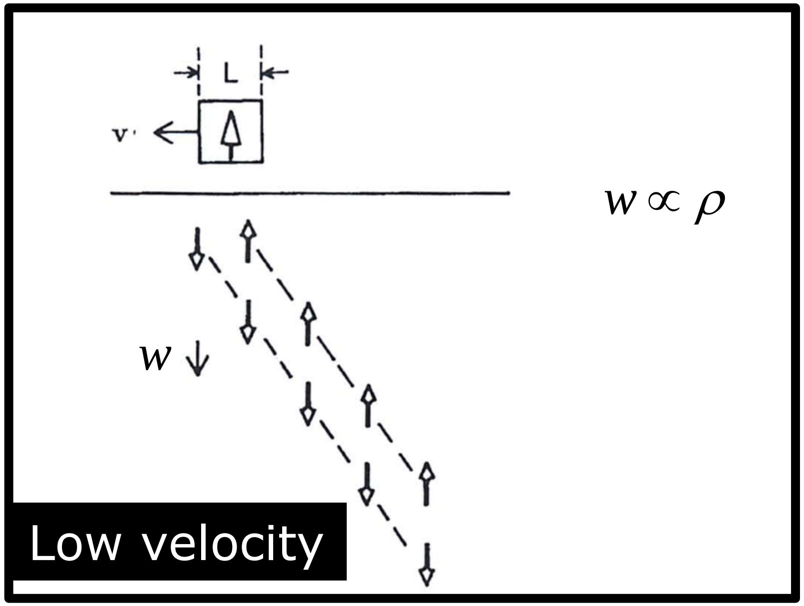
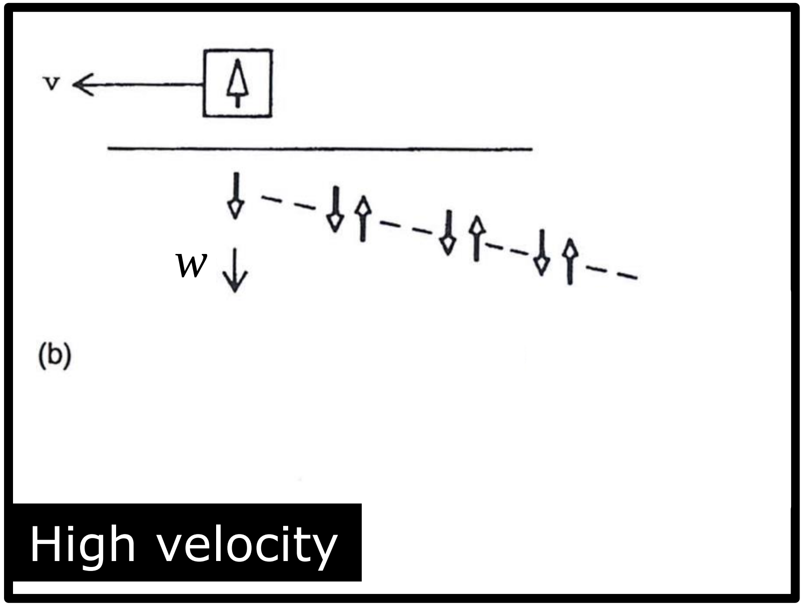


Classical model

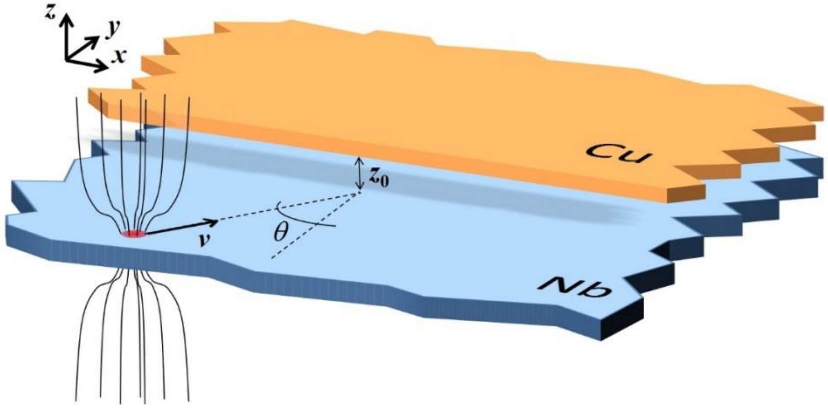






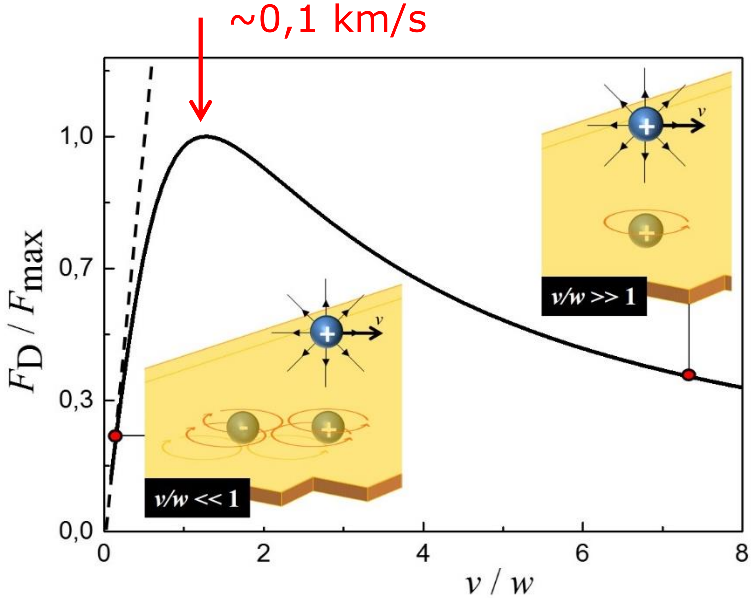
Rossing T D and Hull J R 1991 *Phys. Teach.* **29** 552-562 | W.M.Saslow, *Am J. Phys.* **60**, 693 (1992)

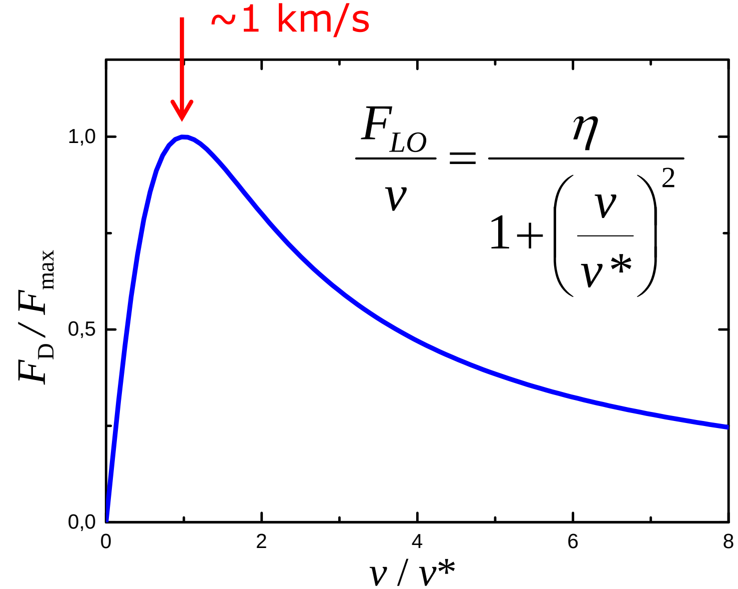
Classical model



$$F_L = (\mu_0 q^2 / 16\pi z_0^2)\left[1 - w/(v^2 + w^2)^{1/2}\right]$$

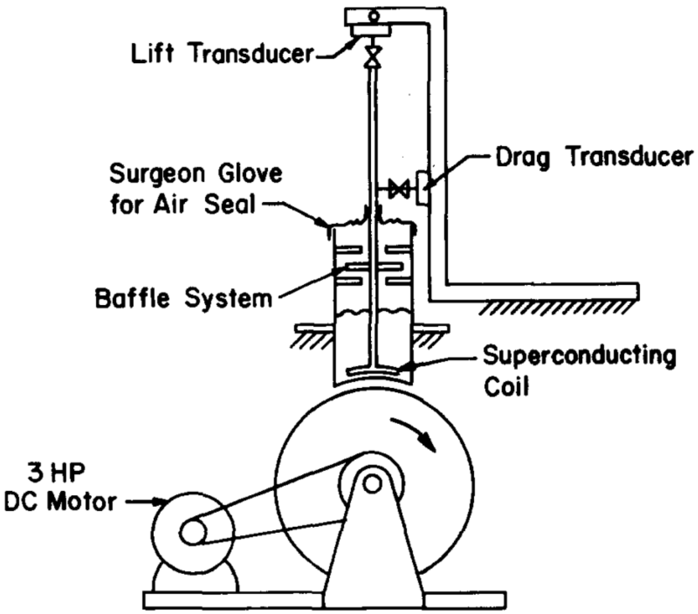
$$F_D = (w/v)\,F_L$$

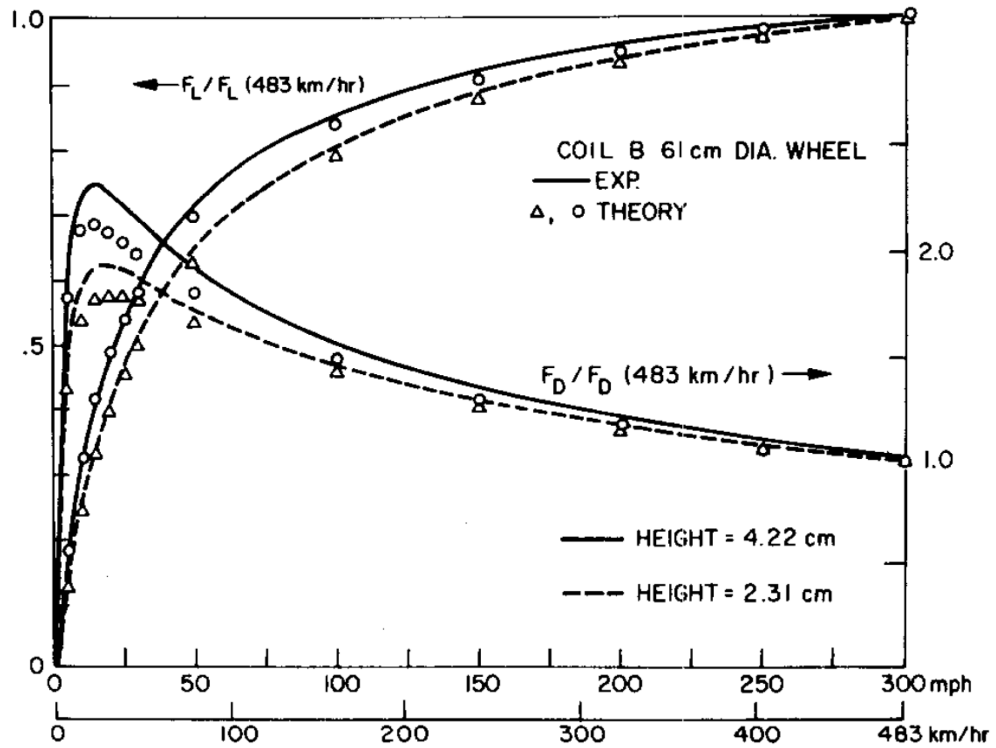




Brisbois *et al.* arXiv:1408.2420v1 W.M.Saslow, *Am J. Phys.* **60**, 693 (1992)

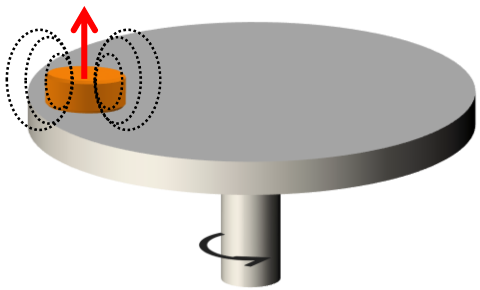
Classical model

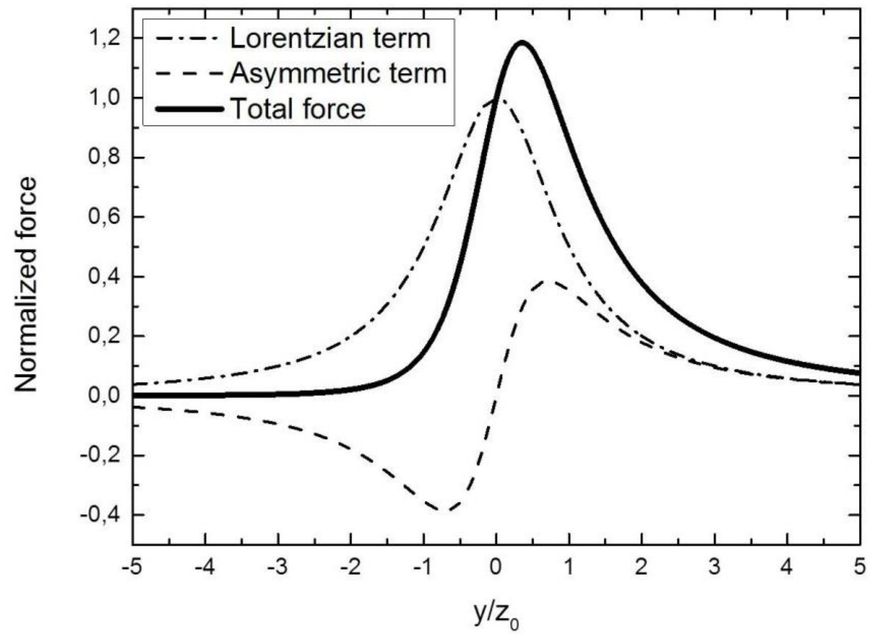




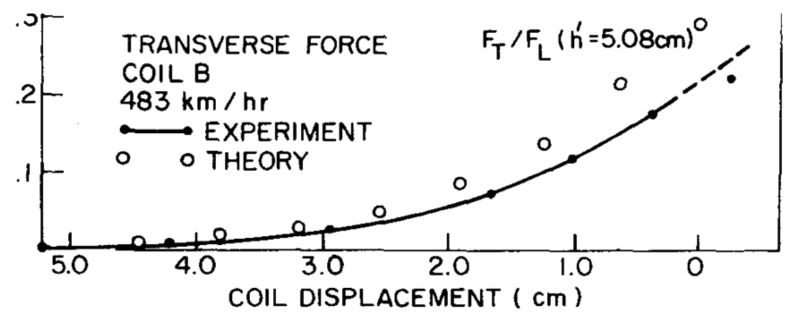
Borcherts R H and Davis L C 1972 *J. Appl. Phys.* **43** 2418

Boundary effect



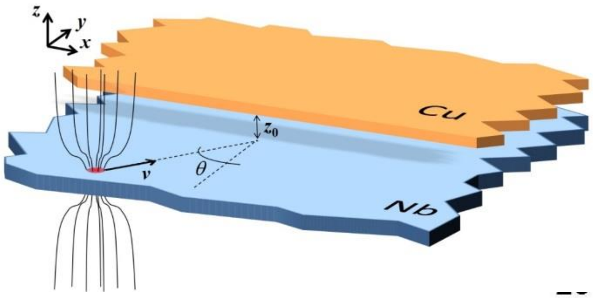


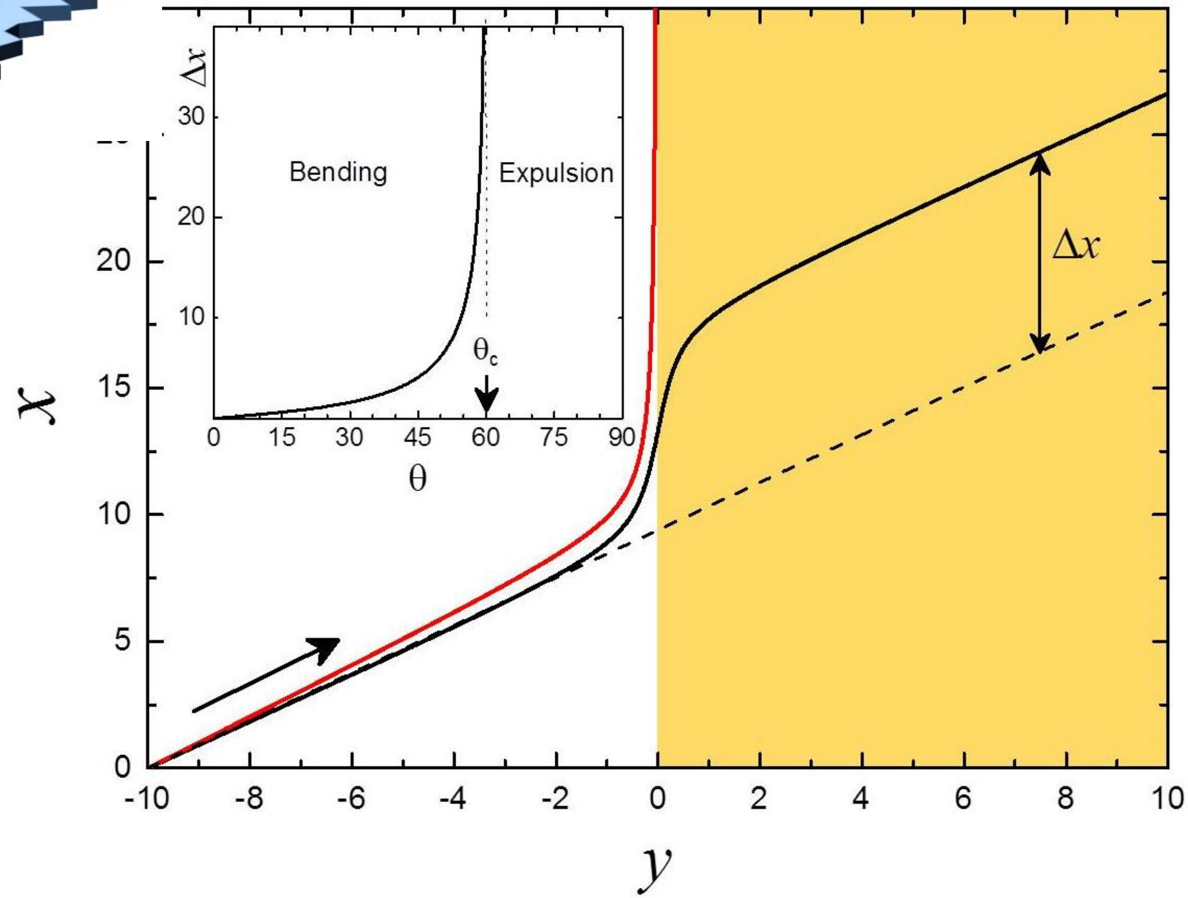
$$\mathbf{F}_{\mathrm{lat}} = -C_{\mathrm{m}} \left(\frac{1}{y^2 + z_0^2} + \frac{y}{(y^2 + z_0^2)^{3/2}} \right) \hat{y}.$$



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

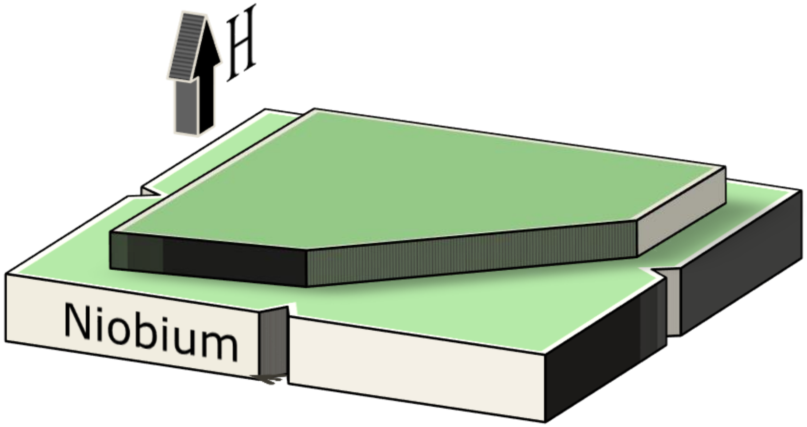


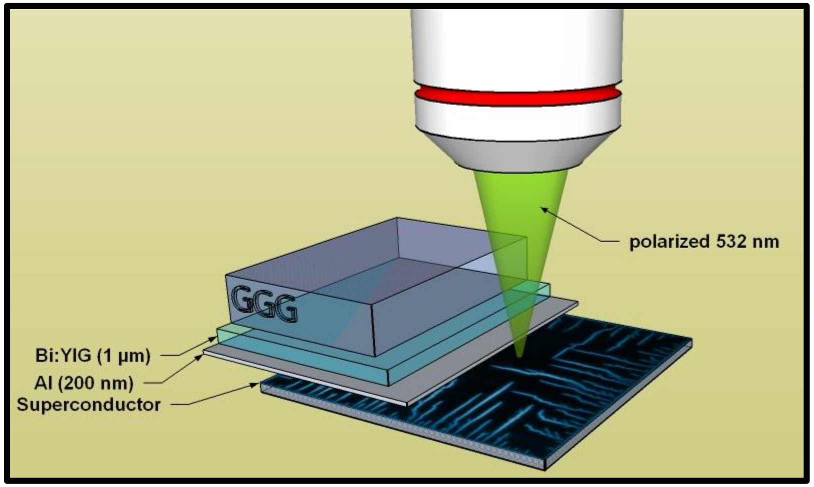


Brisbois *et al.* arXiv:1408.2420v1

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 200nm. Does this mirror influence the measurements?
- ✓ Next step: what about replacing the Cu layer by a superconducting film?
- ✓ How LO instabilities are affected by a metallic layer?





Brisbois *et al.* arXiv:1408.2420v1

Thank you

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Supplementary slides