Measurement of Magnetisation Losses of Roebel Cable Samples at Southampton

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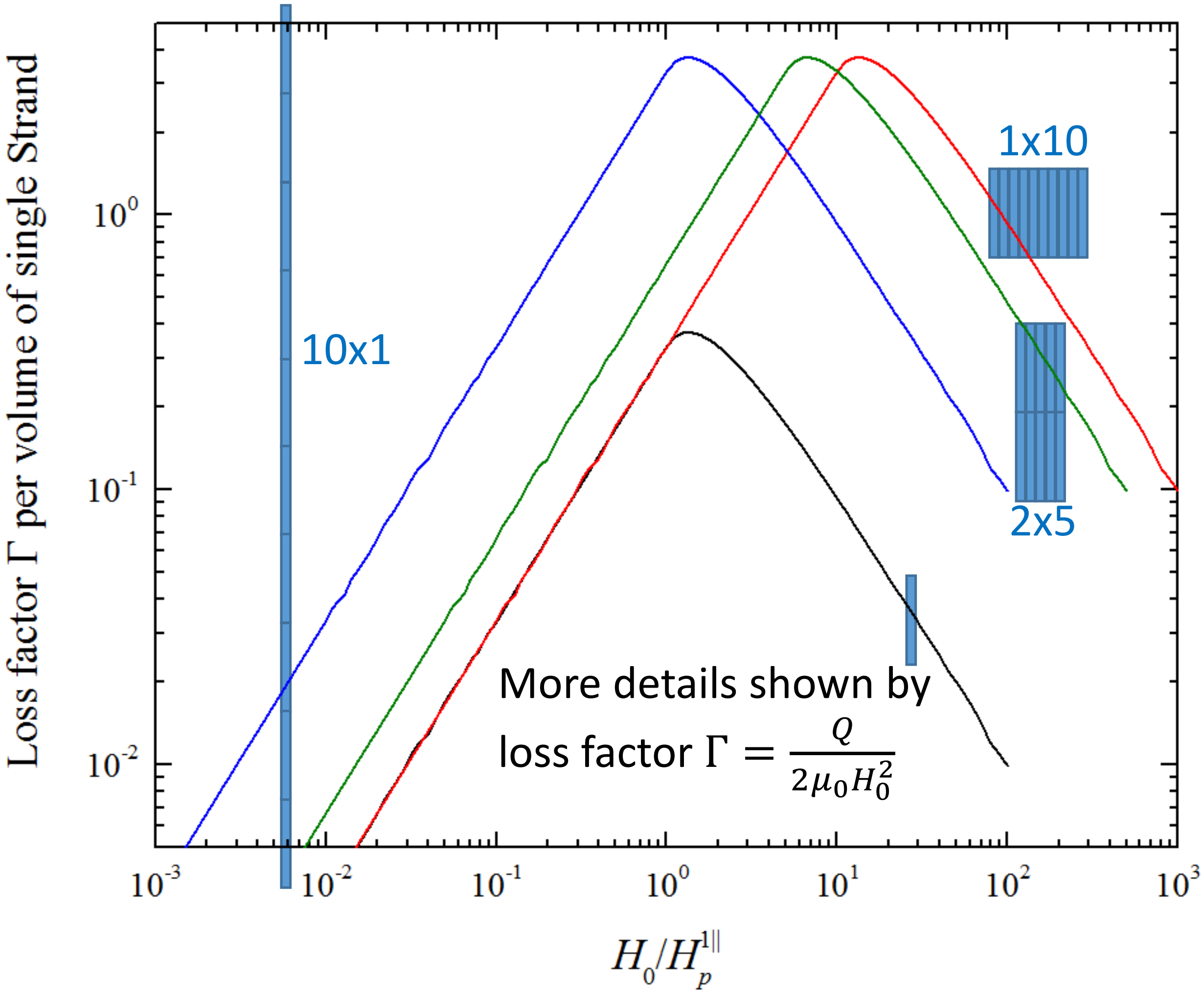
Assemblies of thin strips in parallel field



Single tape as (infinite) slab:

$$H_p^{1\parallel} = J_c \frac{d}{2} = \frac{I_c}{2w}$$

Loss per unit volume at $H_p^{1\parallel}$:

$$Q_{1\parallel}(H_p^{1\parallel}) = \frac{2}{3}\mu_0 (H_p^{1\parallel})^2$$

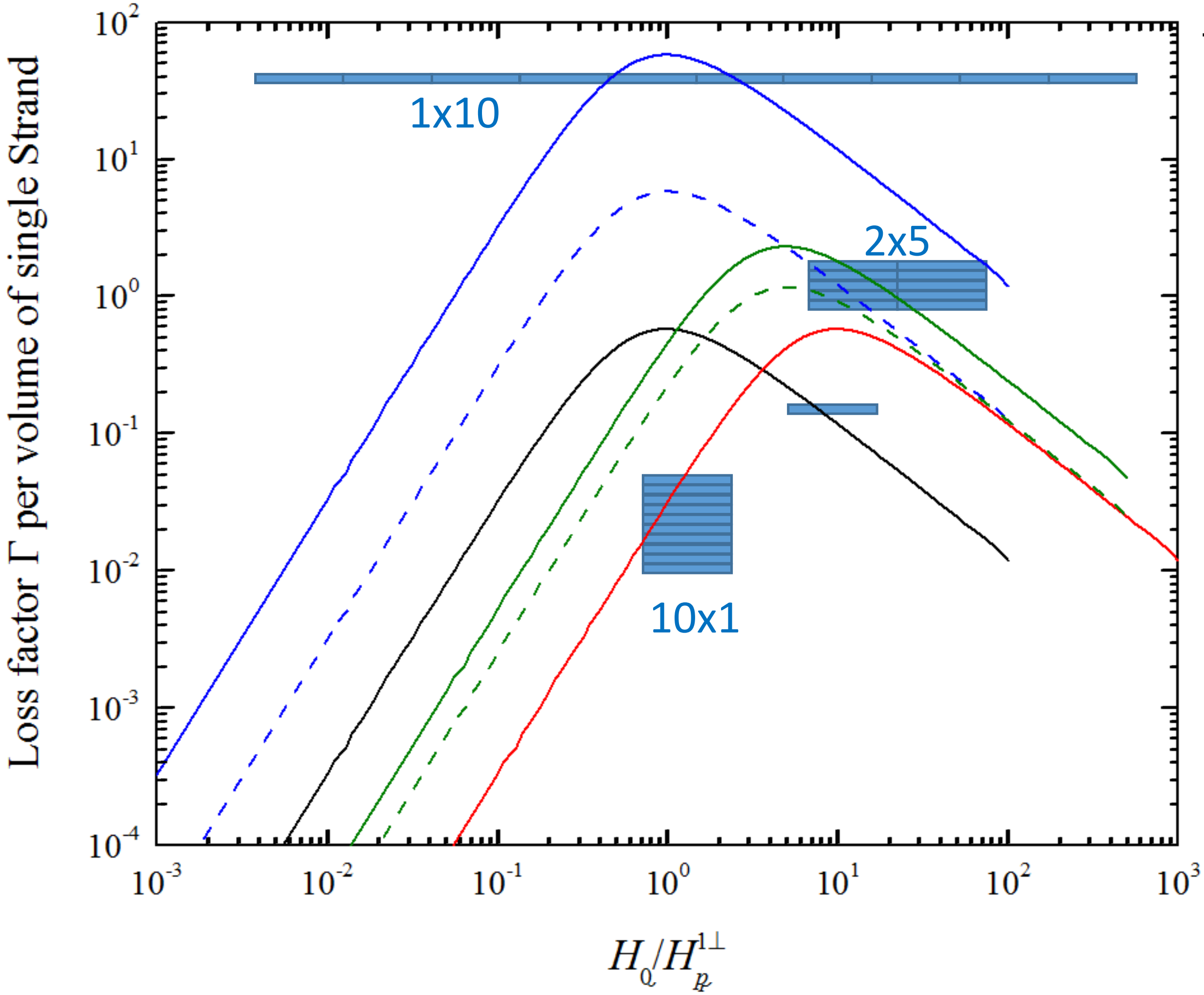
$$= \frac{1}{6}\mu_0 \left(\frac{I_c}{w}\right)^2$$

Loss per unit length at $H_p^{1\parallel}$:

$$q_{1\parallel}(H_p^{1\parallel}) = \frac{1}{6}\mu_0 \frac{I_c^2}{w} d$$

- *N* uncoupled tape assembly is the same as a stack inline to the field, lowest losses (Nq_1)
- *nxm* (stack of *n* inline x stack of *m* transverse) gives ($m^2 n q_1$) with transverse coupling
- Overall loss is small as d/w~1/5000

Assemblies of thin strips in perpendicular field



Single tape as a thin (Norris) strip:

$$H_p^{1\perp} = \frac{5 I_c}{2\pi w} = \frac{5}{2\pi} J_c d = \frac{5}{\pi} H_p^{1||}$$

Loss per unit volume at $H_p^{1\perp}$:

$$Q_{1\perp}(H_p^{1\perp}) = 0.6 \frac{w}{d} \mu_0 (H_p^{1\perp})^2 = \frac{15}{4\pi^2} \mu_0 \frac{w}{d} \left(\frac{I_c}{w}\right)^2$$

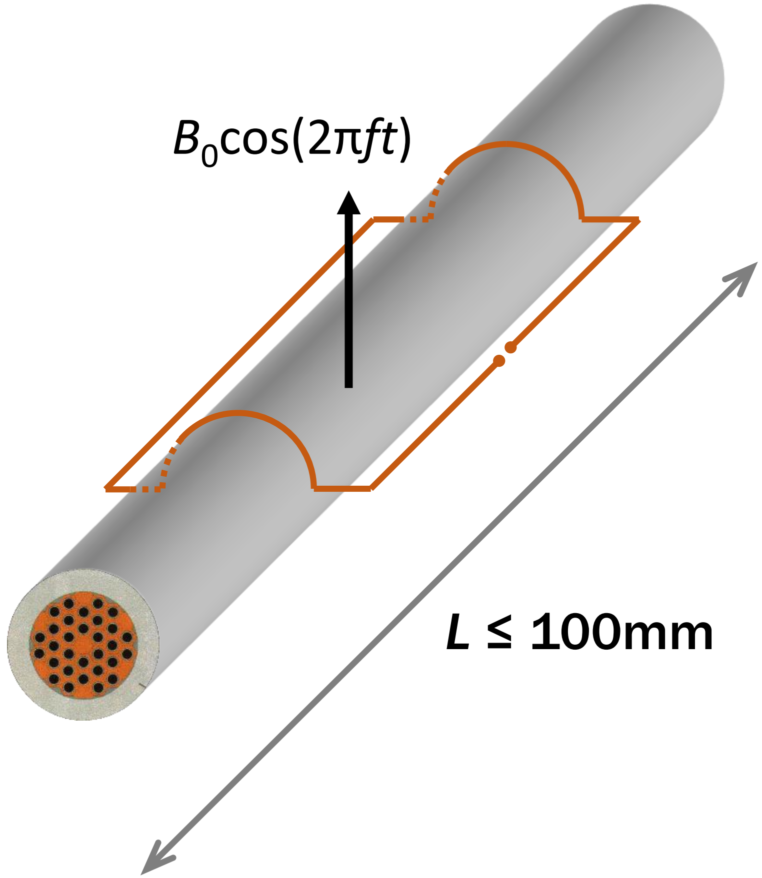
Loss per unit length at $H_p^{1\perp}$:

$$q_{1\perp}(H_p^{1\perp}) = \frac{15}{4\pi^2} \mu_0 I_c^2$$

- *N* uncoupled tape assembly has the lowest losses (Nq_1)
- *nxm* (stack of *n* inline x stack of *m* transverse) gives ($m^2 n q_1$) with transverse uncoupling
- Overall loss per unit length finite, independent of *d*

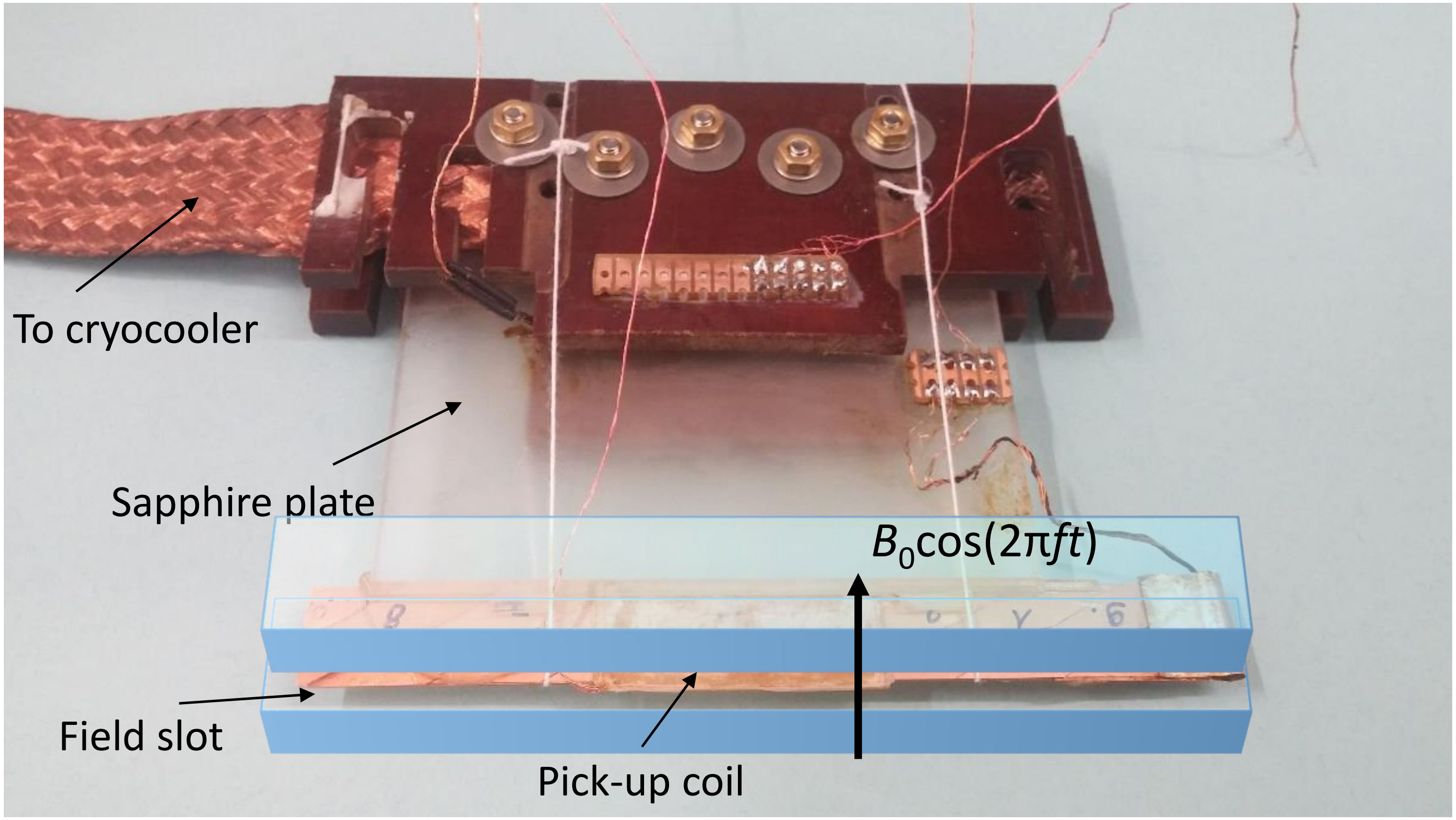
Methods

- **Applied sinusoidal field**
  - $B_0 \leq 0.2$ T
  - 5Hz ≤ f ≤ 2kHz
- **Measurements**
  - 3K ≤ T ≤ 100K
  - Single-turn saddle pick-up coil
  - Sample length L ≤ 100mm

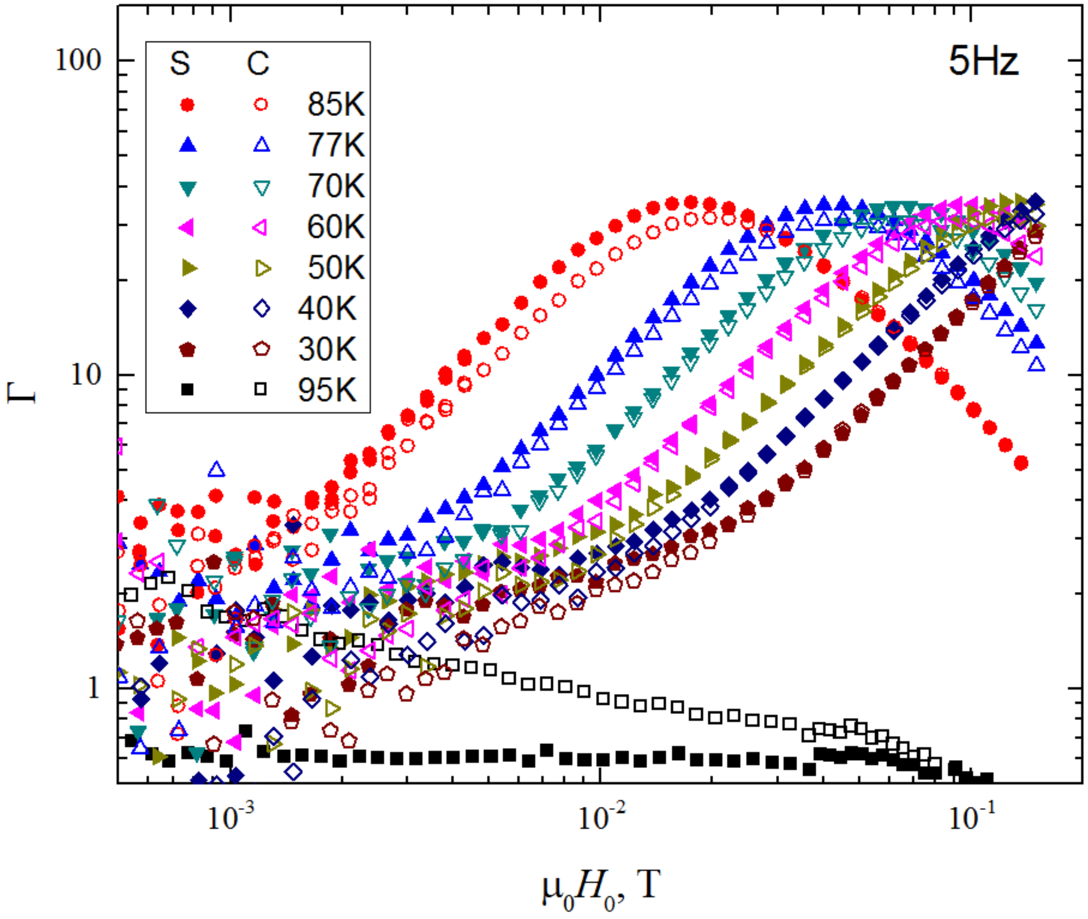


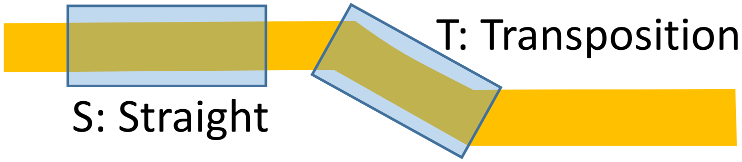
- **Strength**: Wide frequency range for detailed probing of the coupling current: *essential for twisted filaments.*
- **Limitation**: No DC field
- **Mitigation**: Extended range of temperature

Sample Mounting



Single Tape Strand (1)



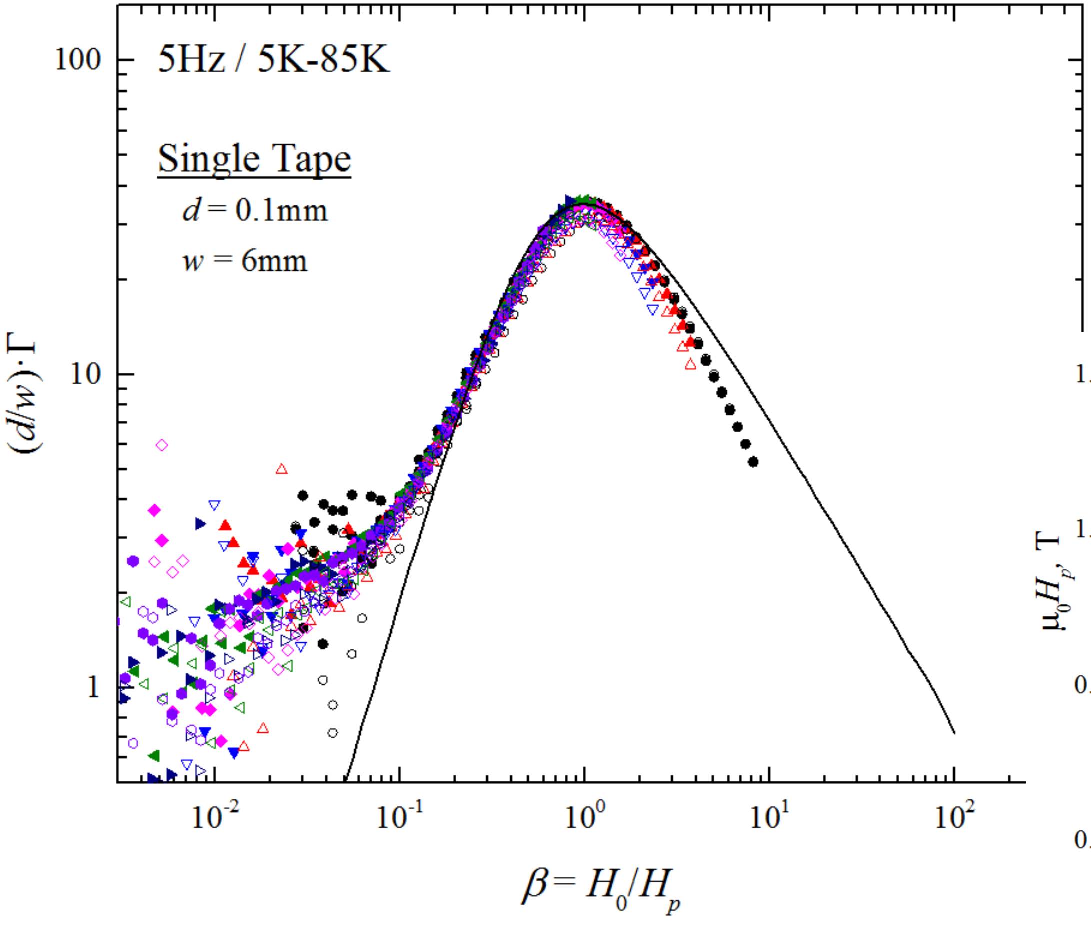


<u>Loss factor broadly as expected:</u>

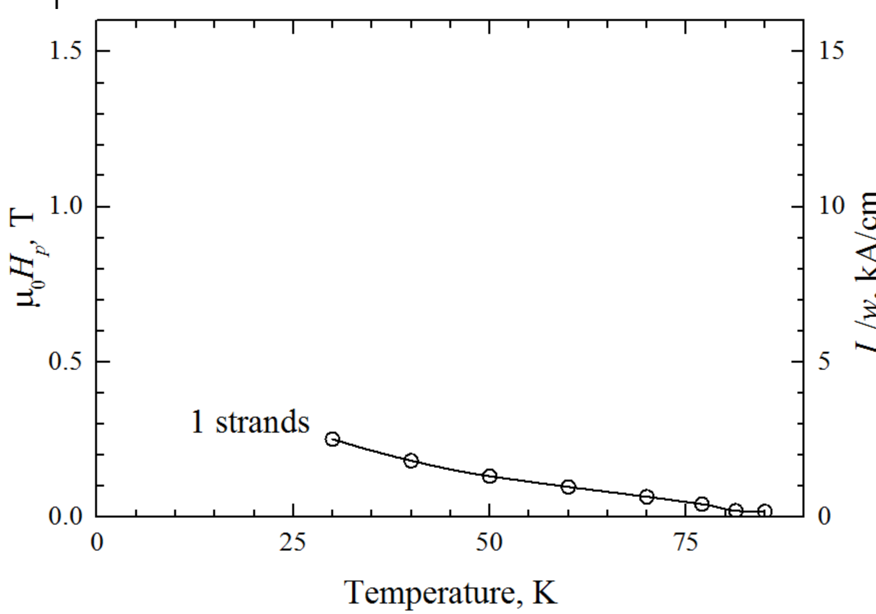
For $H_0 < H_p$, $H_0^{3.x}$,
not exactly H_0^4 of Norris Strip but close.

Slight separation between the corner and straight sections at high temperatures

Single Tape Strand(2)



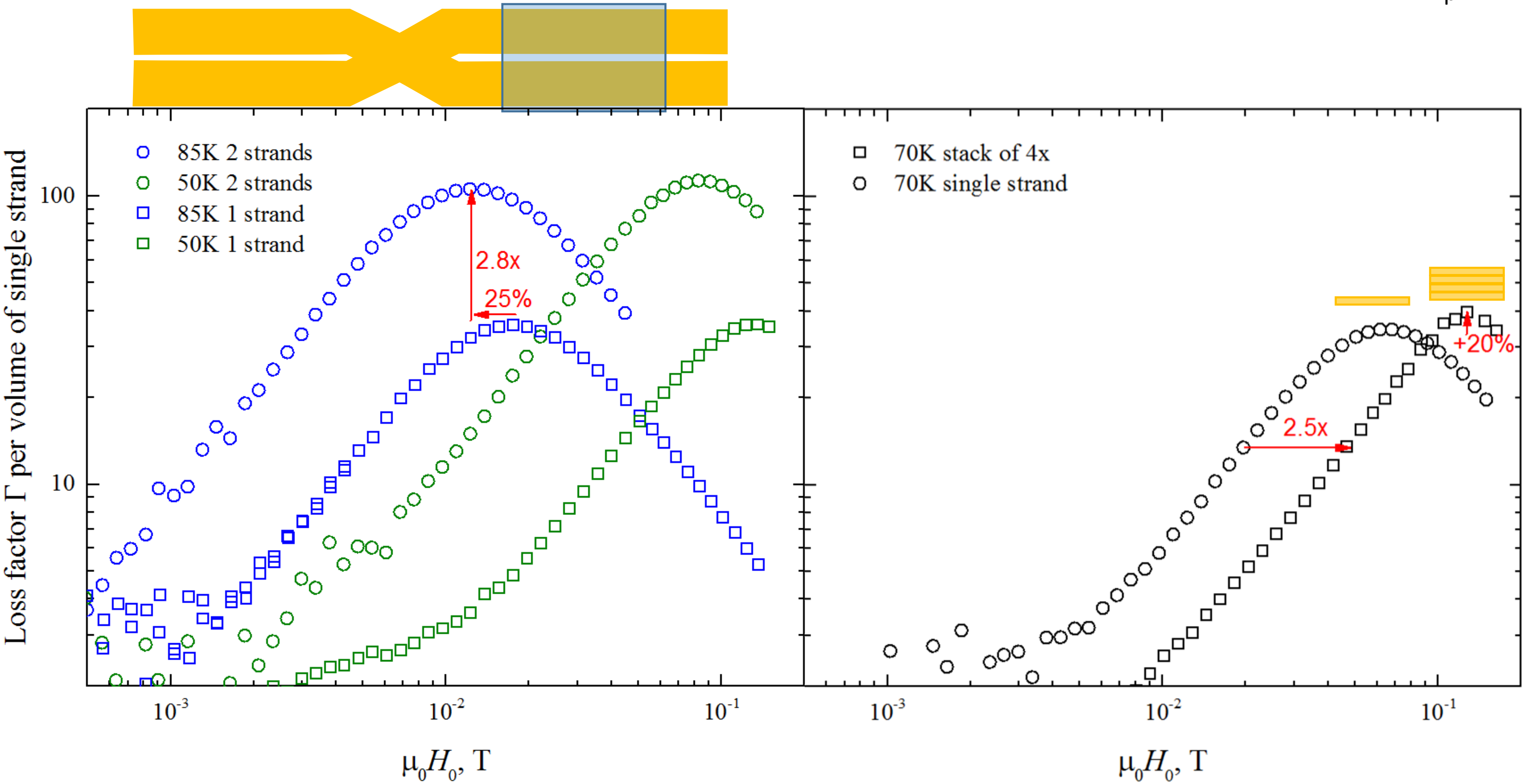
The loss factor scales well with the full penetration field H_p for all temperatures, implying $I_C\ (T)$ is largely consistent with specification



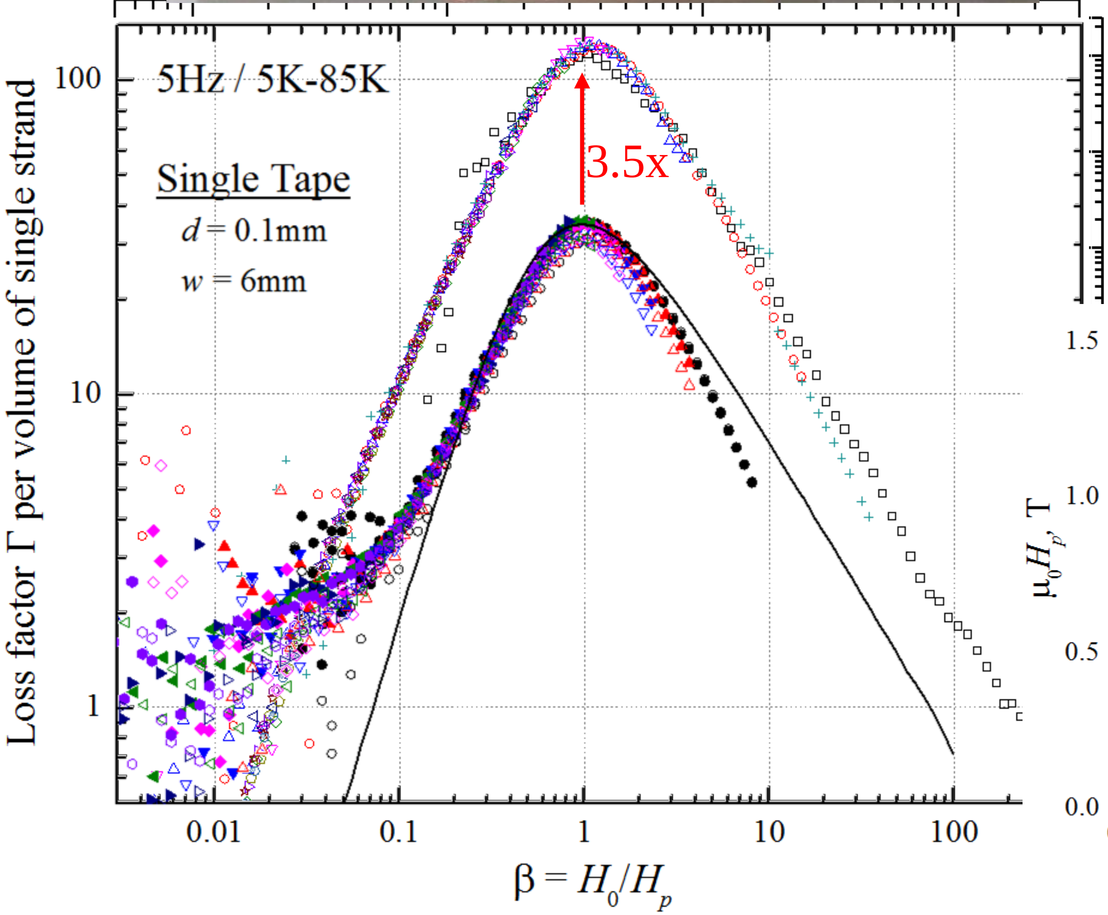
Simple tape assemblies

2 strands side by side: less than full coupling?

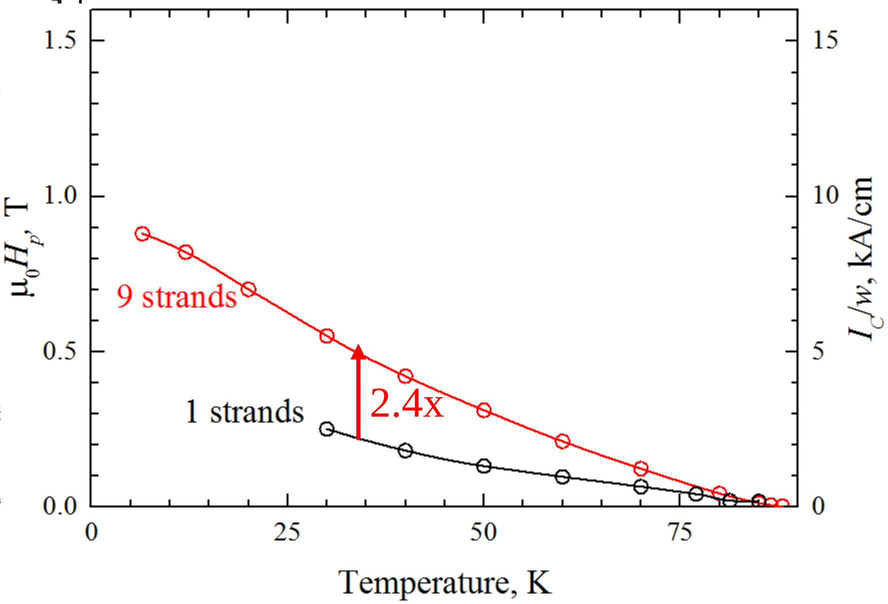
Stack of 4 strands: less than expected H_p



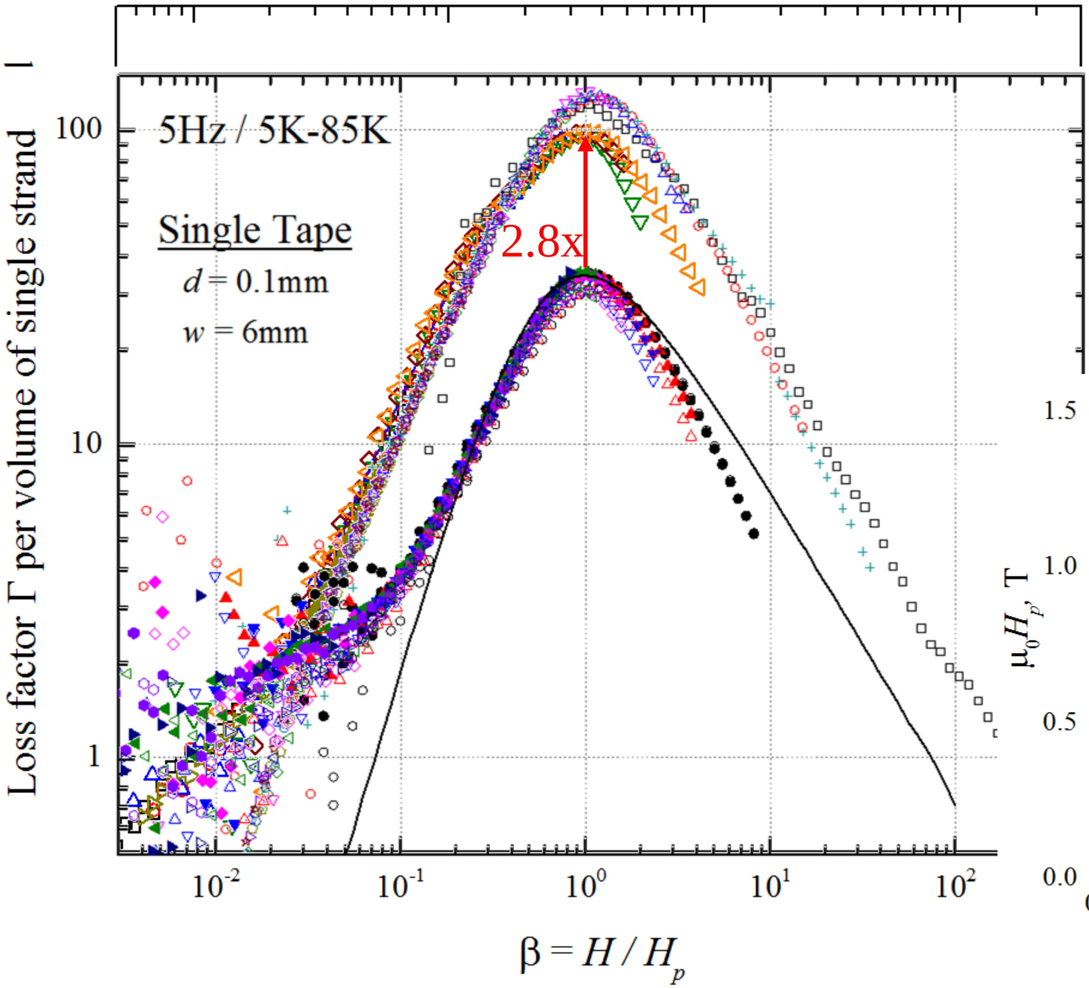
9 Strands Roebel Sample (KIT)



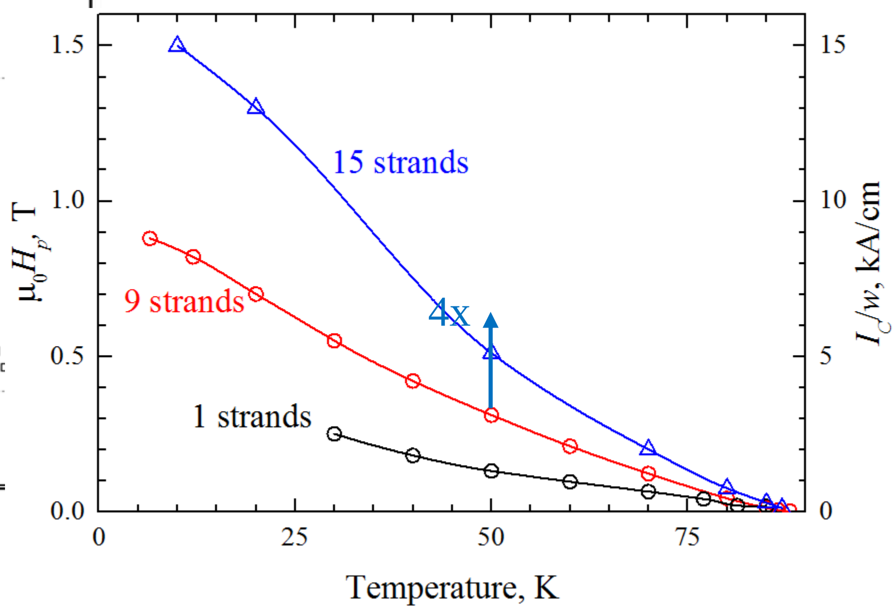
- Saturation field at 2.4x$H_p^{1\perp}$, instead of the expected ~4x (finite thickness?)
- Scaling with H_0/H_p is maintained
- Peak loss factor at 3.5xΓ_1 less than the expected 4x for full coupling



15 Strands Roebel Sample with Epoxy impregnation (CERN)

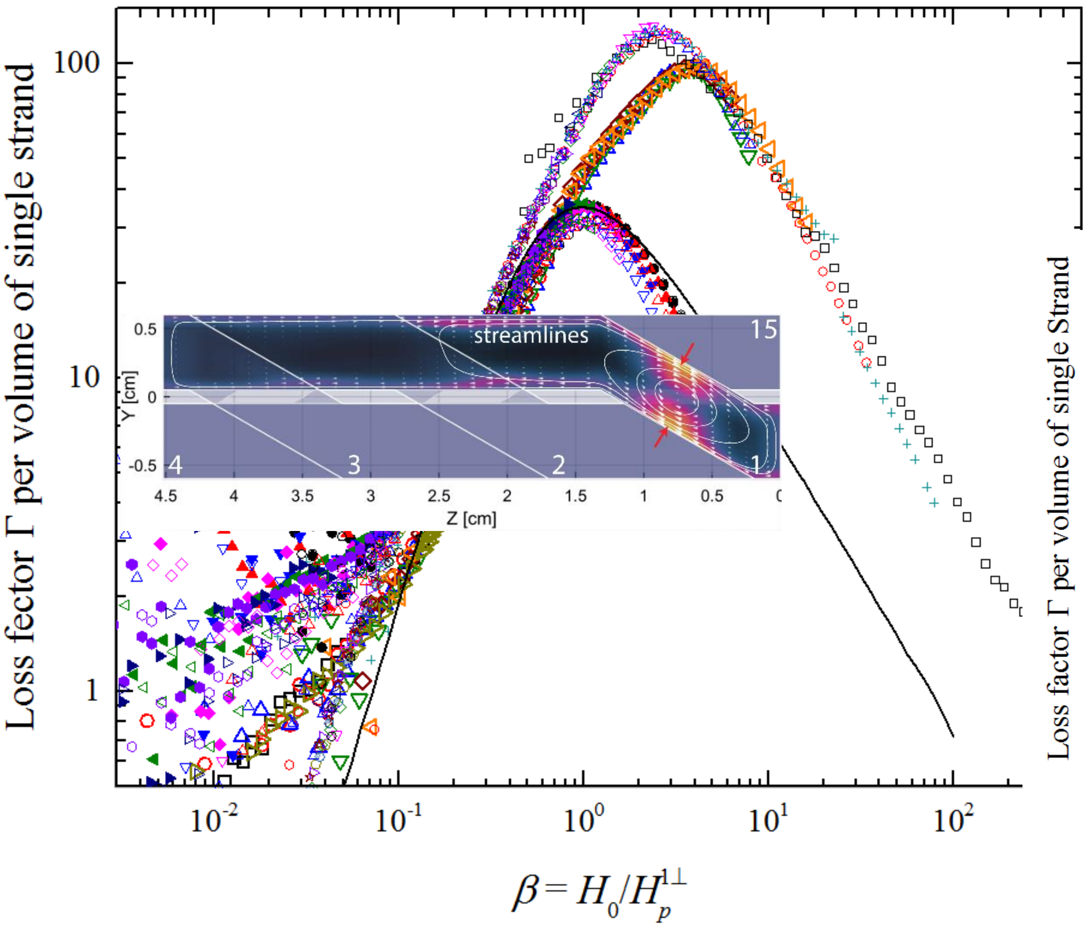


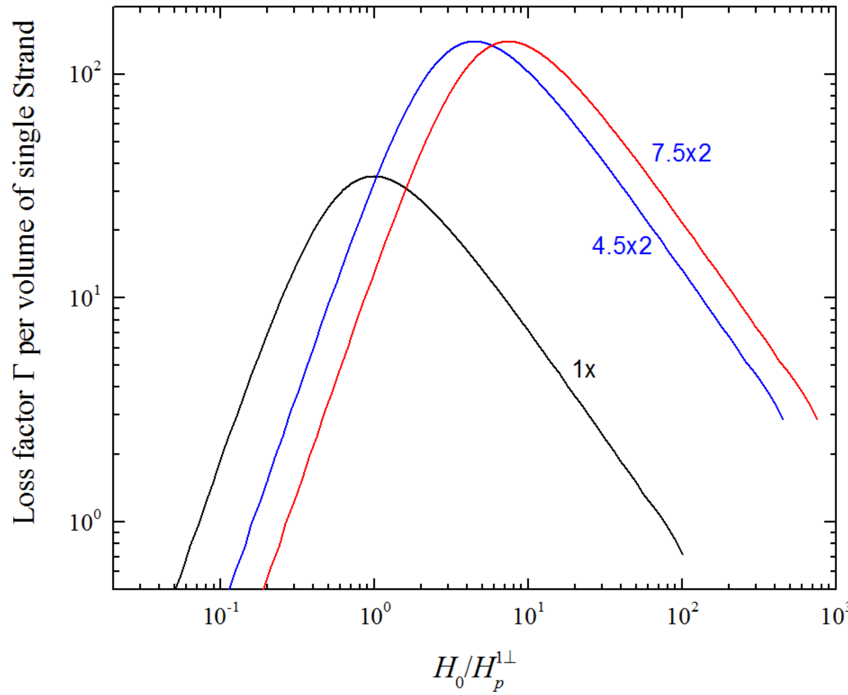
- Saturation field is only 4 times of that of single tape, instead of the expected ~7-8x (finite thickness?)
- A kink at lower field (~$H_p^{1\perp}$)…
- Scaling with H_0/H_p is maintained
- Peak loss factor at 2.8xΓ_1, further reduction of coupling?



Loss Factor wrt Single Tape $H_p^{1\perp}$

- Not exactly as fully coupled *nxm*, but qualitatively consistent with the simple strips model
- The kinks in impregnated cable indicating single tape saturation





Conclusions

1. Losses are dominated by the hysteresis of superconductor assemblies in Roebel
2. Single tape behaves as Norris' strip, independent of different temperatures, scales with H_0/H_p as expected;
3. Simple assemblies of isolated tapes are coupled, i.e. as a monolithic conductor, but not quite fully.
4. Roebel samples with/without epoxy impregantion behave as two coupled bundles of in-line tape stacks. The saturation fields of the bundles increases linearly with the number of tapes, as expected.
5. Epoxy impregnated Roebel is less coupled and the strand in transposition seemed uncoupled.