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Dynamic Study of Field and Current Distribution in Multifilamentary YBCO Thin Films

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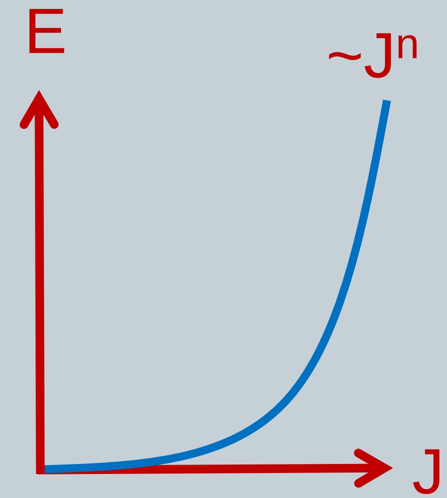
Motivation

- High-temperature superconductors (HTS) have many potential applications
- Most promising ones: $YBa_2Cu_3O_7$
  - Thin films
  - Very high aspect ratio (width/thickness): 1,000 – 10,000
  - AC losses still too high
  - Filamentarization
    - What is the dynamic?
- How can we predict their behavior?
  - Analytical models are too simplified
  - FEM
    - Numerically challenging
      - HTS have highly non-linear current-voltage relation
      - High aspect ratio (high number of FEM nodes)

The model (2-D)

- Faraday's law $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
- Non-linear resistivity for the superconductor
  - $\rho(J)=E_c/J_c\,|J/J_c|^{n-1}$
  - n=25-50
- Magnetic field components as state variables
  - J derived from H by differentiation
  - $E=\rho J$
- Transport current: integral constraint
- External field: boundary conditions
- Edge elements



Power losses in multifilamentary YBCO films

- Hysteresis losses

$$Q_h^{st} \approx I_c \cdot E_{\parallel} = I_c w_n B f$$

- Coupling losses

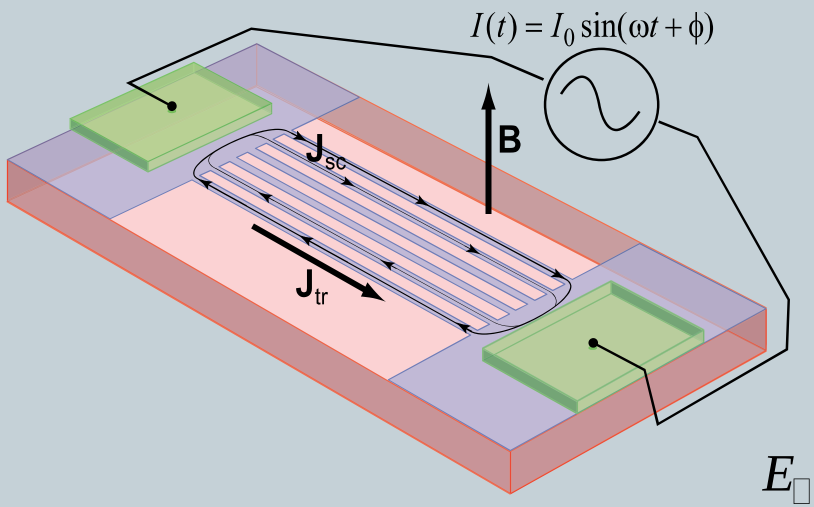
$$Q_n^{st} \propto \frac{\left|E_{\perp}\right|^2}{\rho} W d_n = 2\frac{(BfL)}{\rho} d_n W$$

- Total losses

$$Q = Q_h^{st} + Q_n^{st} \approx I w_n B f + 2\frac{(BfL)}{\rho} d_n W$$

- Loss reduction (high ρ)

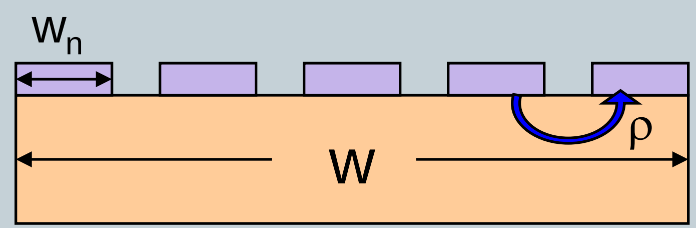
$$\frac{\left\langle Q^{st}\right\rangle_V}{\left\langle Q\right\rangle_V} \approx \frac{1}{N}$$



$$E_{\parallel} \approx B f w_n$$

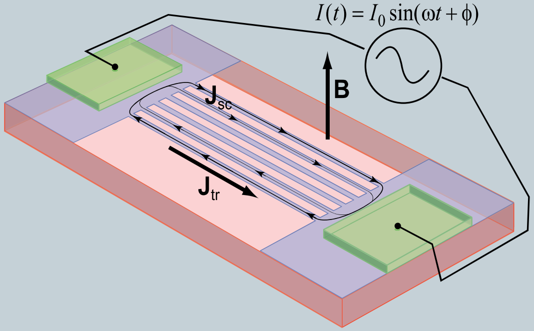
$$\left|E_{\perp}\right| \approx BfL$$

$$w_n = \frac{W}{N}$$

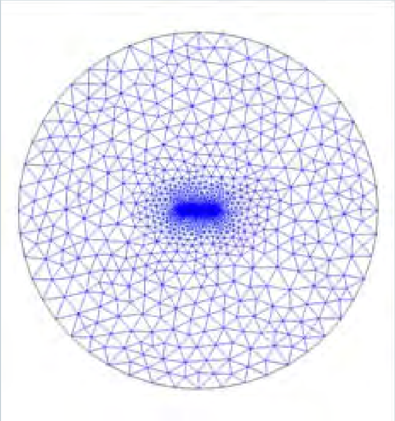


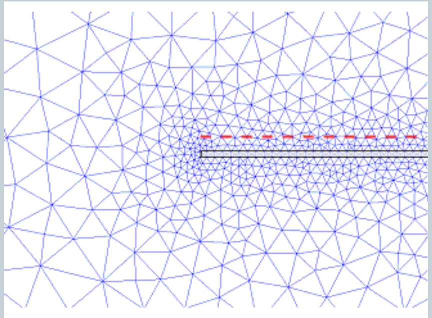
Geometry, mesh, physical parameters

- Simulation of 6 rectangular filaments
  - Dimensions: 120 μm x 300 nm
  - 60,000 mesh nodes
  - 90,000 degrees of freedom



- Magnetic field evaluated 1 μm above sample
  - As in experiments
- Physical parameters
  - $J_c = 3\ 10^{11}$ A/m^2
  - AC current: 8 A @ 1000 Hz
  - DC field 5 mT





Motivation for TRMOI

- TRMOI offers:
  - High spatial and temporal resolution (sub-μm, pico-second)
  - Dynamical study of the vortex movement
  - Qualitative and quantitative -> current density evolution
  - Manipulation of vortices

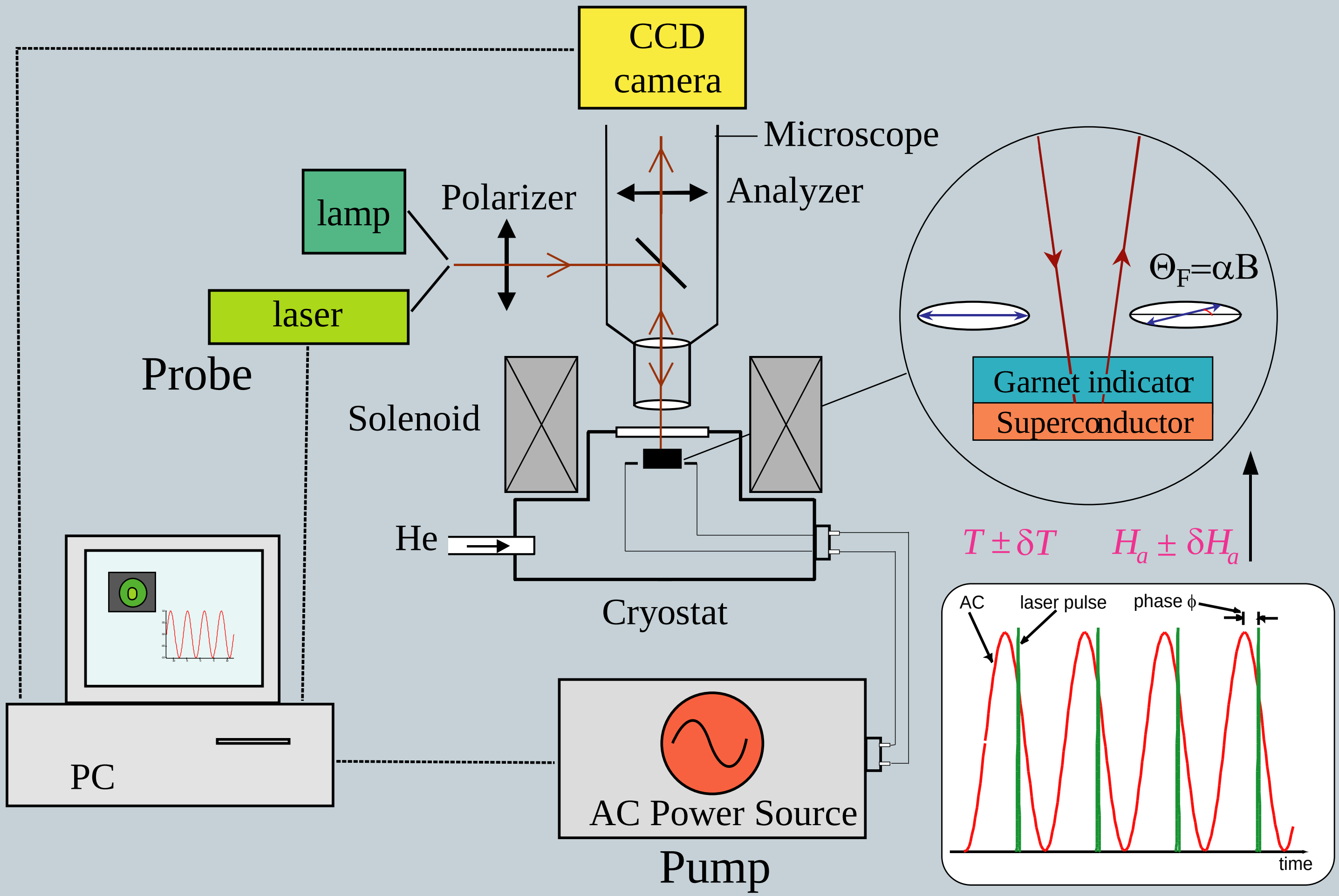
Bolz Europhys. Lett. 64,517 (2003)

Leidere PRL 93, 2642 (1993)

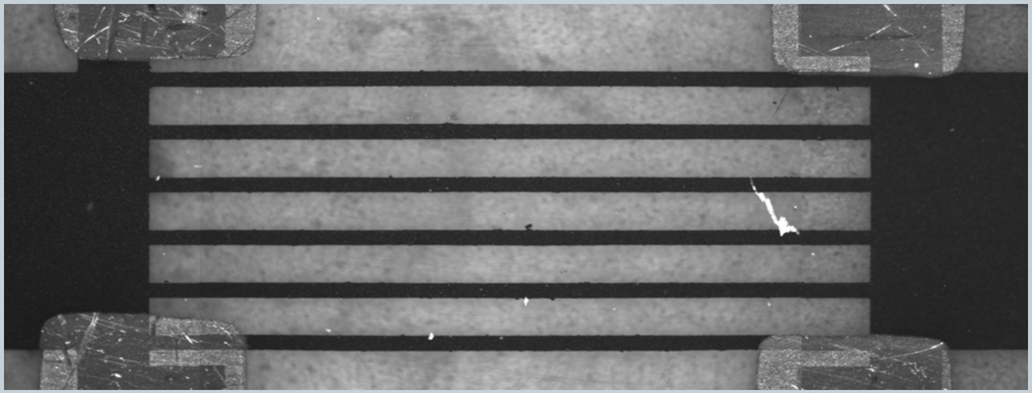
Johansen PRB 54, 16264 (1996)

Goa et al. APL 82, 79 (2003)

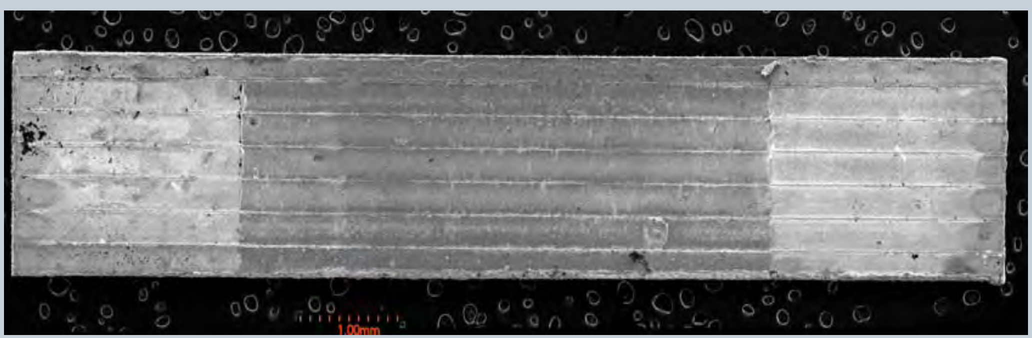
Experimental setup

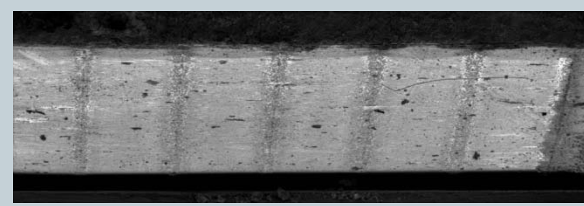


Multifilamentary YBCO Samples



YBCO thin film 250-300nm thick. 6 filaments obtained using etching.

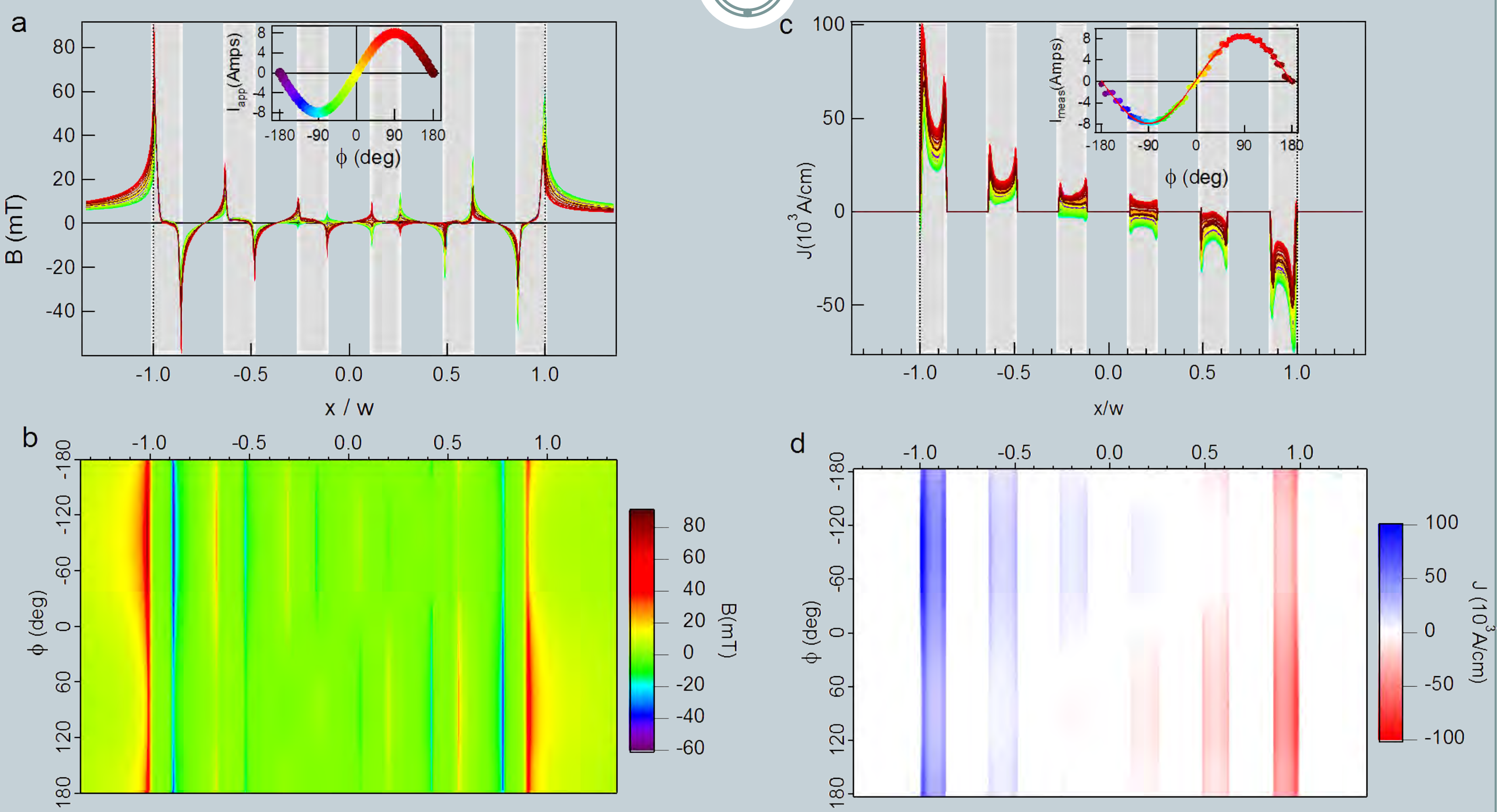




YBCO thin film 1-3 mm thick. 7 filaments obtained using laser processing.

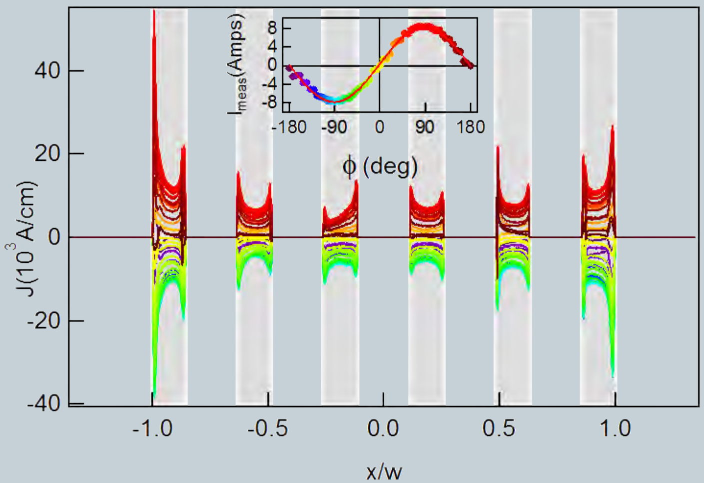
Experimental observation

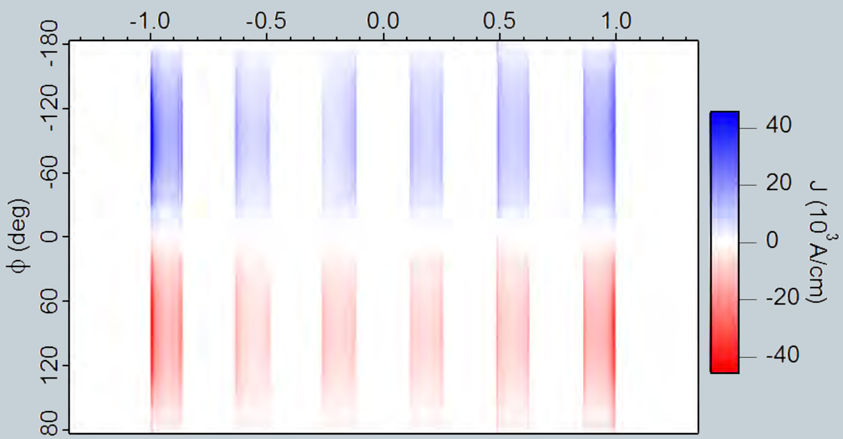
TRMOI field and current profiles

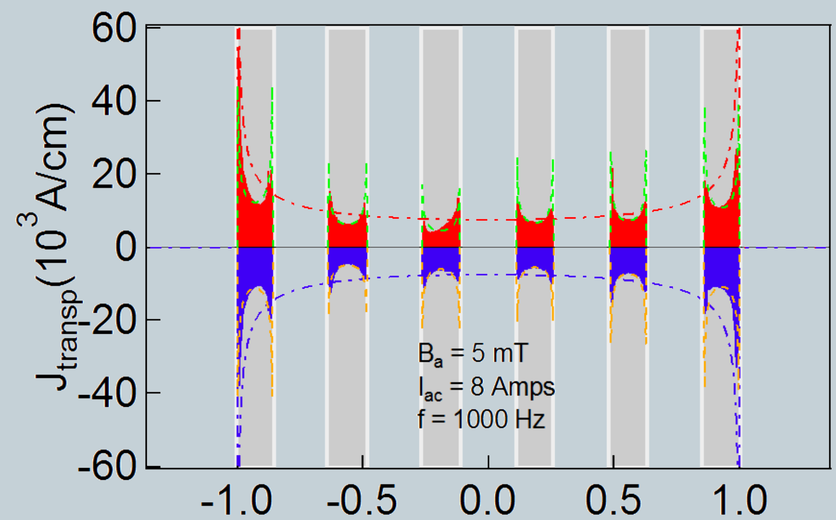


T=40K H_a=5mT I=8A f=1000Hz

Transport current per filament

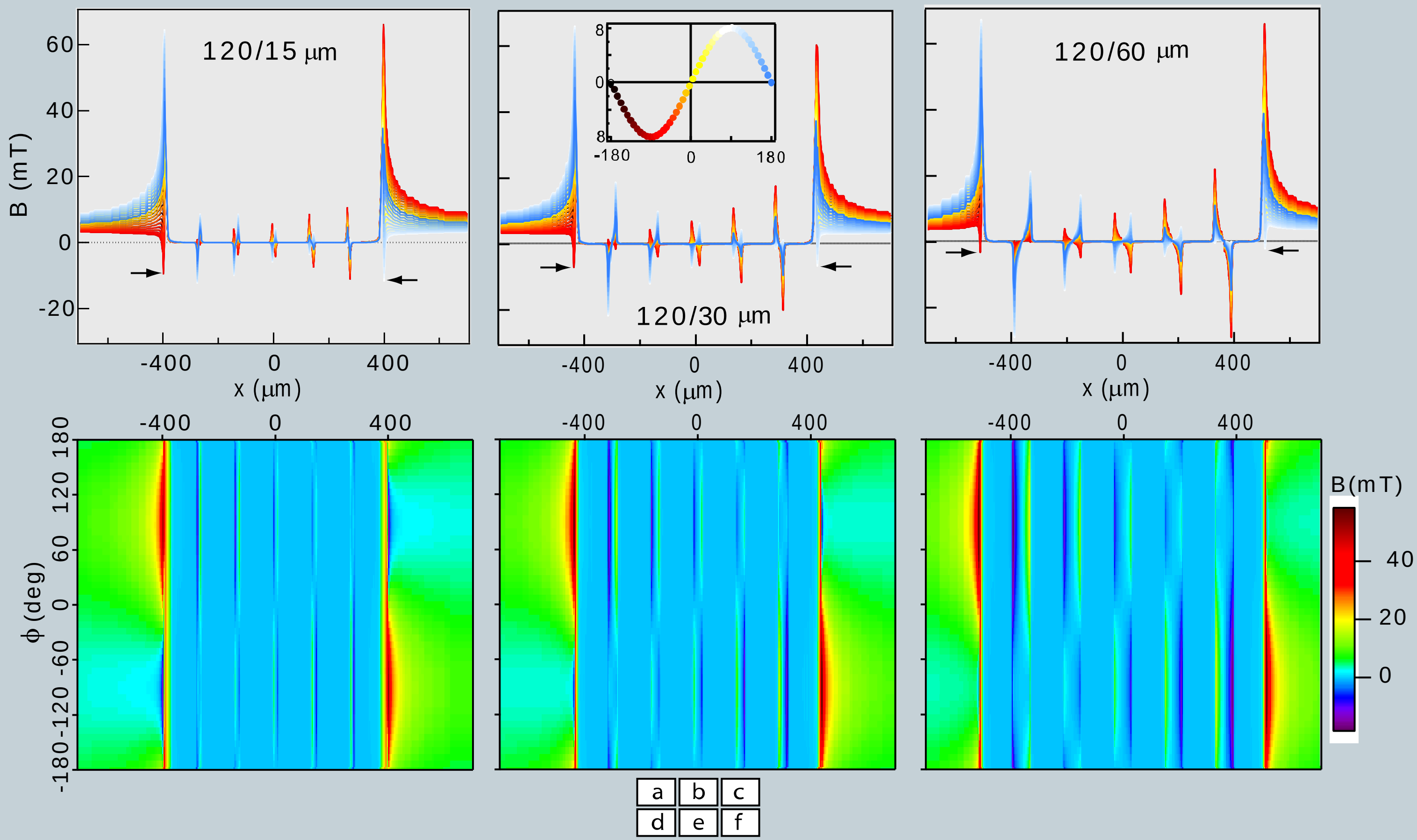




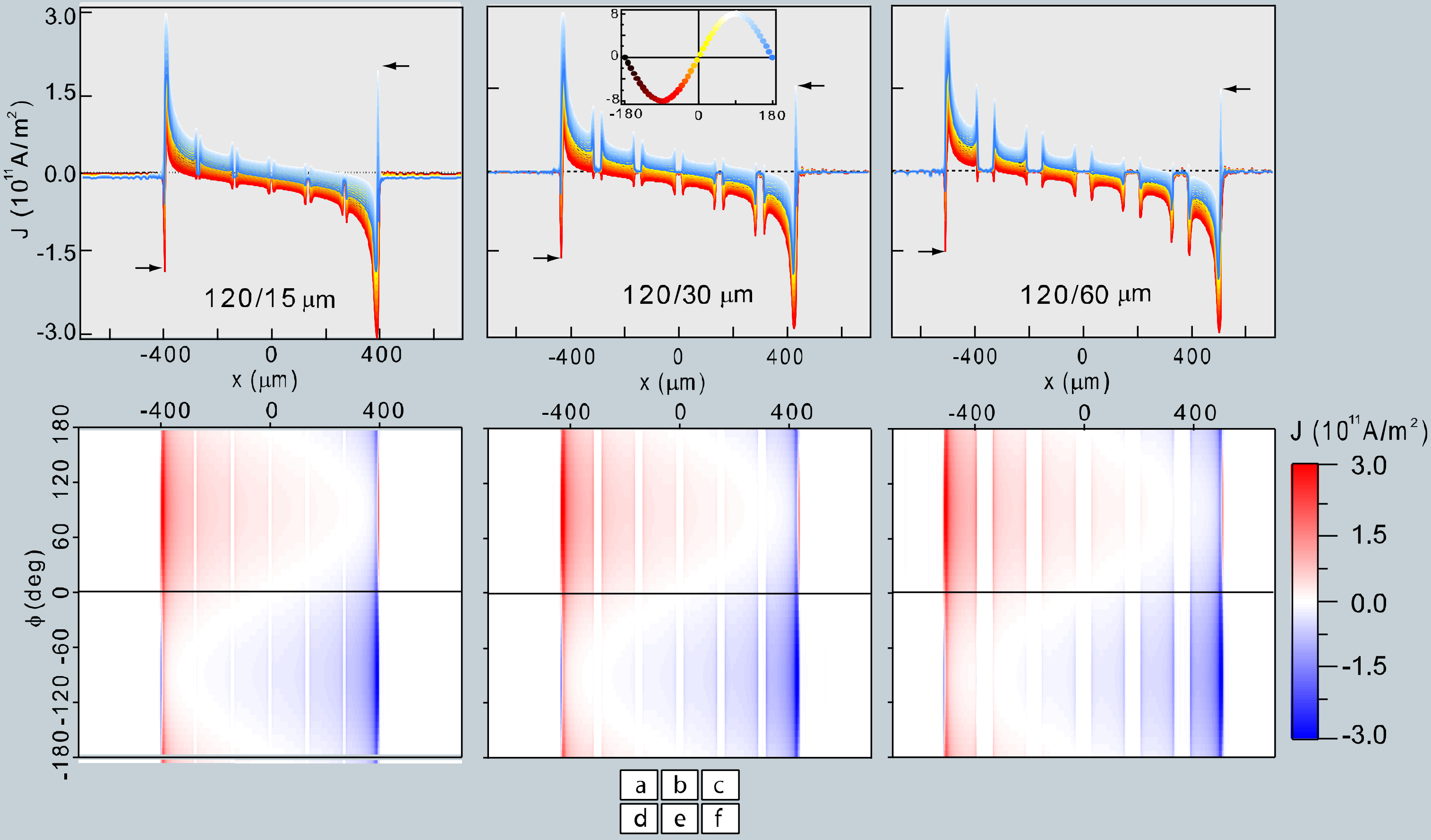


Filaments	Pos Int Current (A	Pos Current Fit (A)	Neg Int Current (A	Neg Current Fit (A
Filament#1	-1.93	2.50	2.30	-2.30
Filament#2	-0.88	1.39	1.15	-1.10
Filament#3	-1.01	1.00	0.86	-1.32
Filament#4	-0.89	1.40	1.07	-1.39
Filament#5	-1.10	1.50	1.18	-1.50
Filament#6	-1.84	2.20	1.80	-2.20

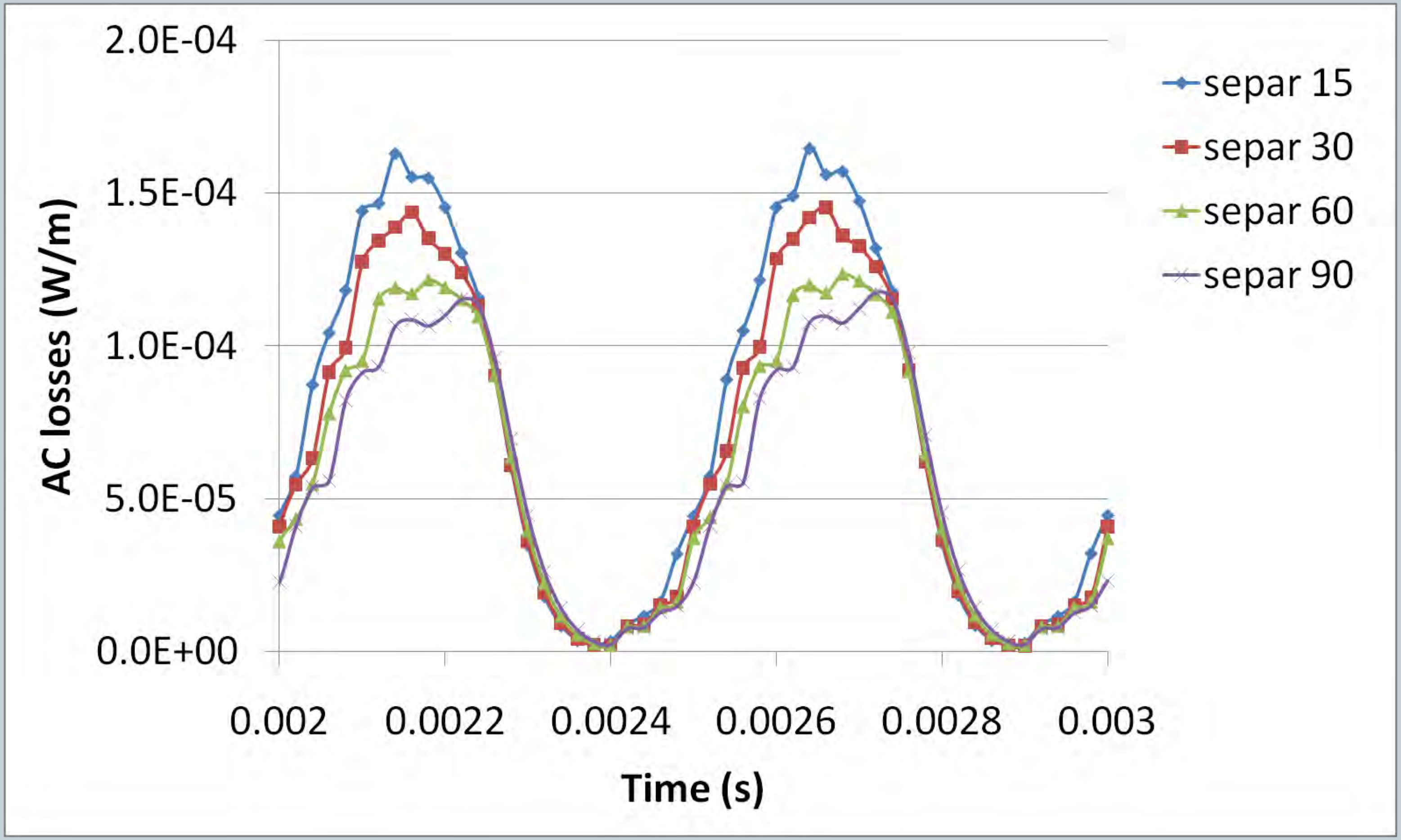
Magnetic field profiles



Current density profiles



AC losses



2.0E-04
1.5E-04
1.0E-04
5.0E-05
0.0E+00
AC losses (W/m)
0.002
0.0022
0.0024
0.0026
0.0028
0.003
Time (s)
separ 15
separ 30
separ 60
separ 90

Conclusions

- Performed TRMOI measurements on YBCO multi-filamentary films
- Developed FEM model in Comsol for studying current density and field profiles in HTS
  - Very good agreement with measurements
- Used model to study influence of inter-filament distance (“magnetic coupling”)
  - Current/field profiles and AC losses change
- Model will be used to optimize geometry