Optimizing single-turn coils for scientific applications beyond 100T

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High-field magnets for science

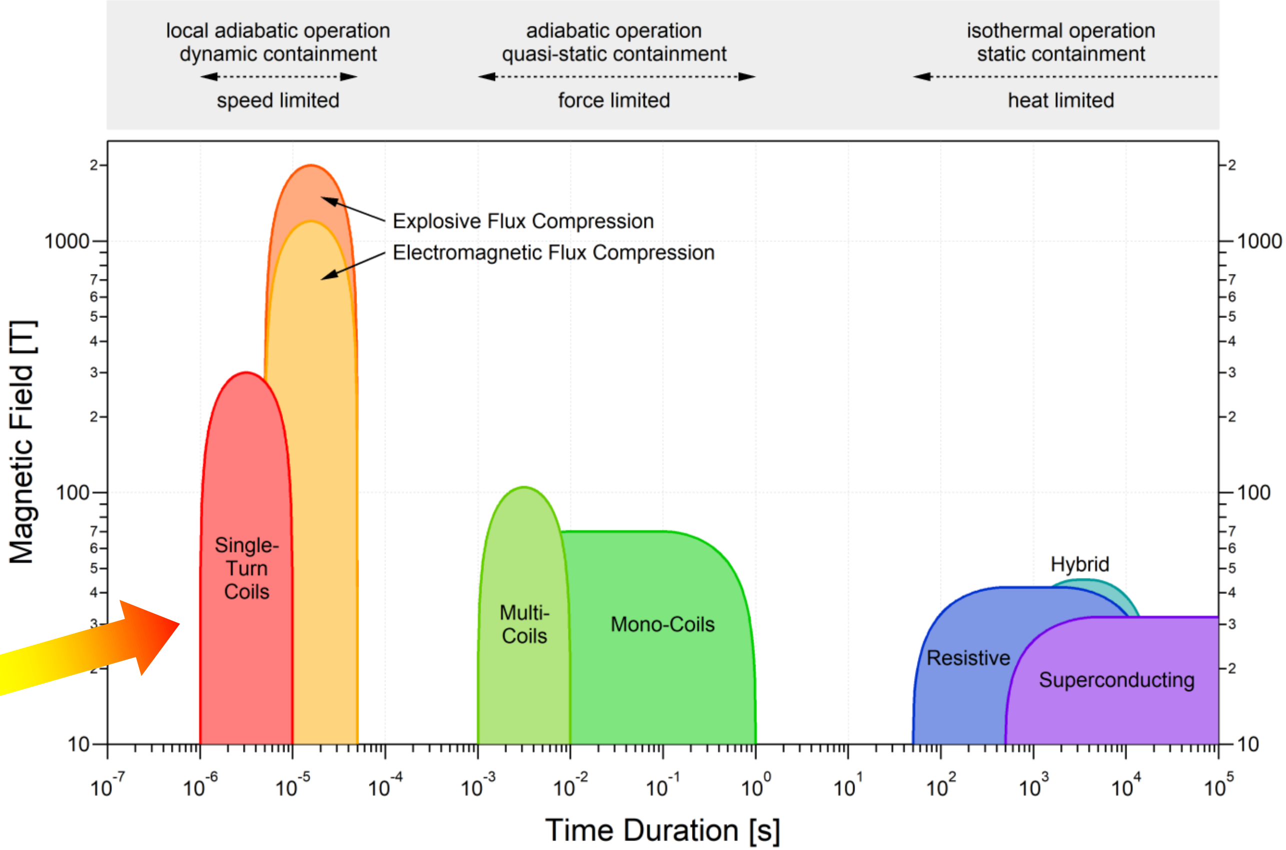
Currently, STC are the only available choice for measurements

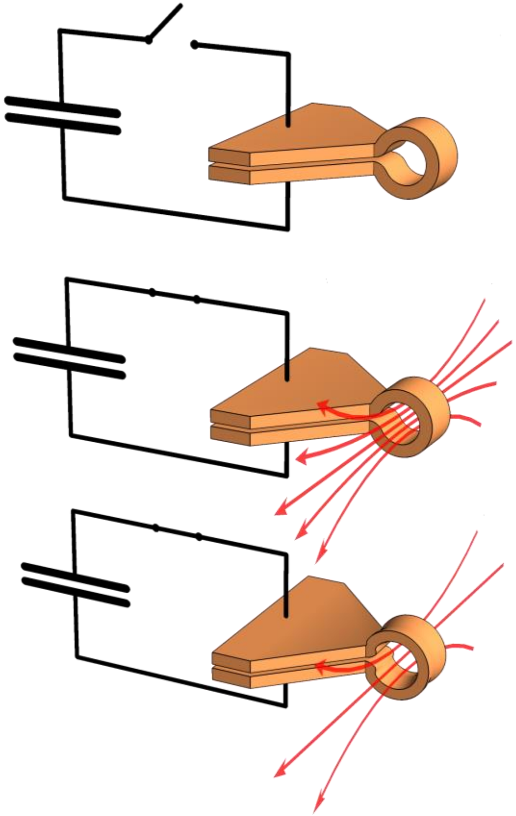
a) above 100 T

and

b) w/o sample destruction.

Coil destruction and µs-timescales cannot be avoided.





How STCs work:

Connect a simple disposable coil to a capacitor bank.

Electrical parameters determine the rise time of the field: impedance and capacitance.

Mechanical parameters determine the coil’s disintegration: coil mass and magnetic force.

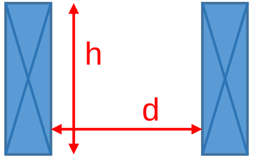
The circuit impedance can be adjusted to make the field rise faster than the coil disintegrates.

Good to know:

The outward acceleration of conductor fragments protects equipment in the bore (... at least up to 150 T).

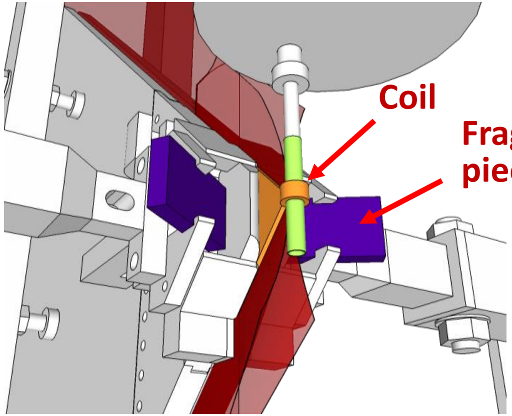
Why do we need a better understanding of the discharge dynamics of SC ?

Problem 1: STC typically feature a bore ratio of d/h=1, but the the value has never been systematically tested.*



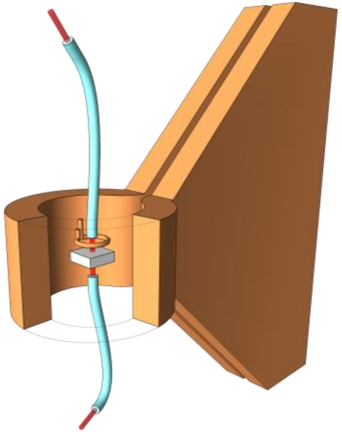
** unlike the conductor thickness, which represents a compromise between peak field, destructive effects and practical issues.*

Problem 2: Existing installations can produce 200 T in 10 mm. However, applications are mostly limited to 150 T to avoid destructive effects at higher fields.

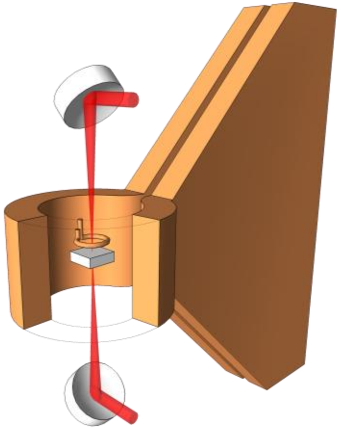


Established experimental techniques for measurements with STC

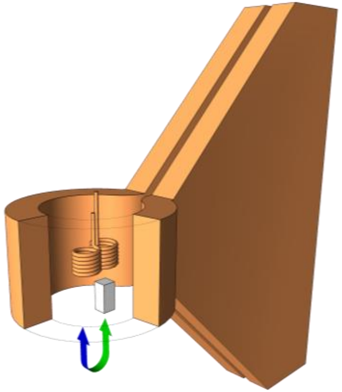
(at cryogenic temperatures)



VIS-NIR spectroscopy:
fibre-based magneto-transmission measurements with monochromatic sources.

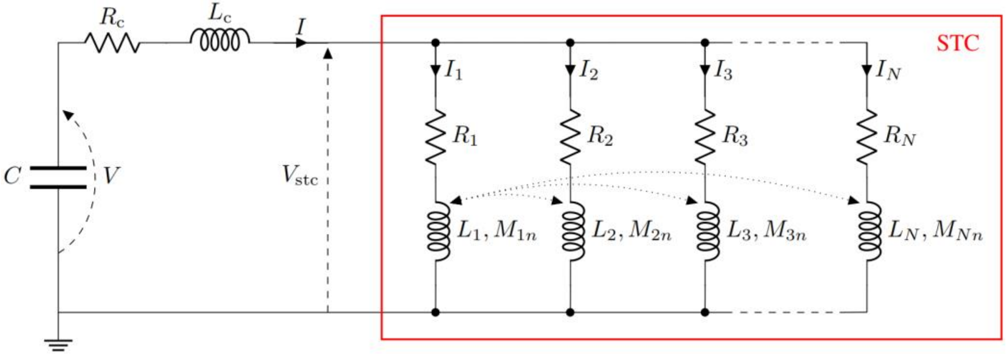


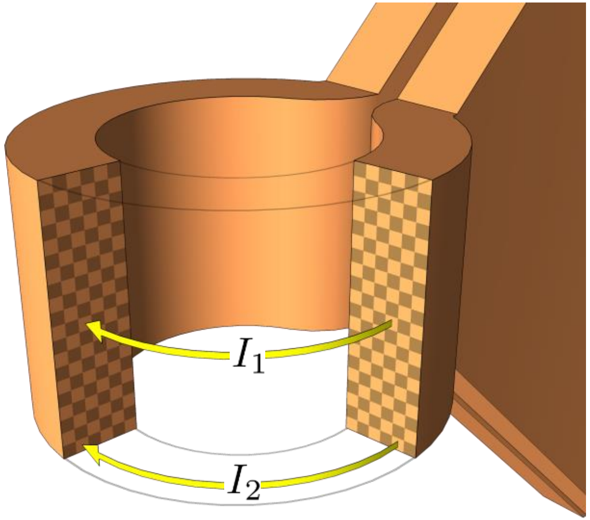
MIR spectroscopy:
free-beam optics with high-power MIR-lasers (CO, CO_2) and fast MCT detectors.



Magnetization:
dM/dt with compensated pick-up coils and background elimination by averaging alternate measurements.

Problem 3: homogeneity requirements of magnetization measurements





Electrical coupling of filaments (matrix equation)

$$\mathbf{I}(t+dt) = \mathbf{I}(t) + dt\,\mathbf{M}^{-1}(t)\left[\mathbf{V}(t) - \left(\dot{\mathbf{M}}(t) + \mathbf{R}(t)\right)\mathbf{I}(t)\right]$$

Local heating (1 simple equation per filament)

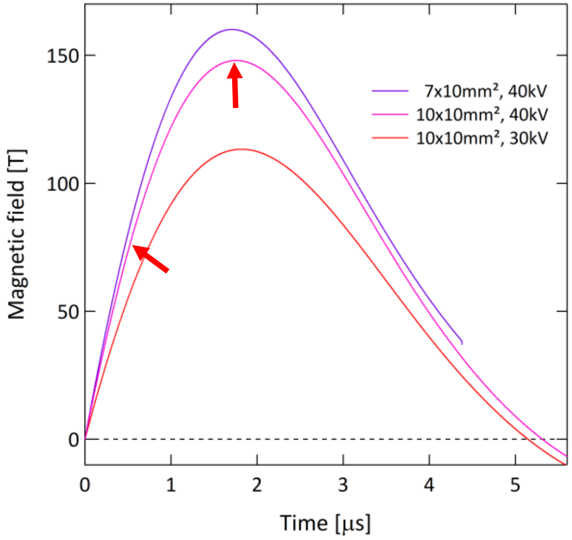
$$T(t+dt) = T(t) + dt\,\frac{j^2(t)\,\rho(t)}{D(t)\,C(t)}$$

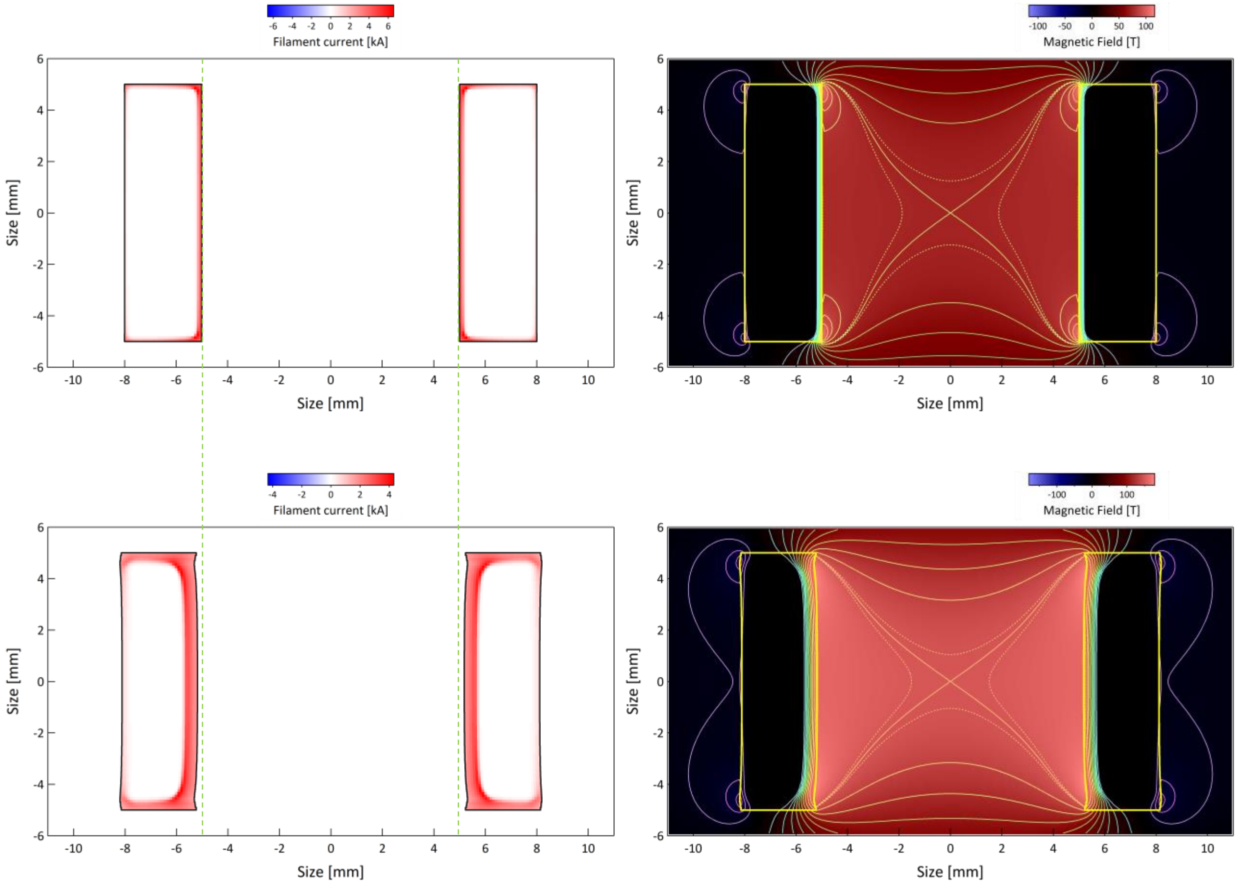
Displacement (1 simple equation per filament disc)

$$r(t+2dt) = r(t+dt) + dt\,v(t) + dt^2\,\frac{\Delta F}{\Delta m}$$

STC discharge simulations based on Nakao's filamentary approach

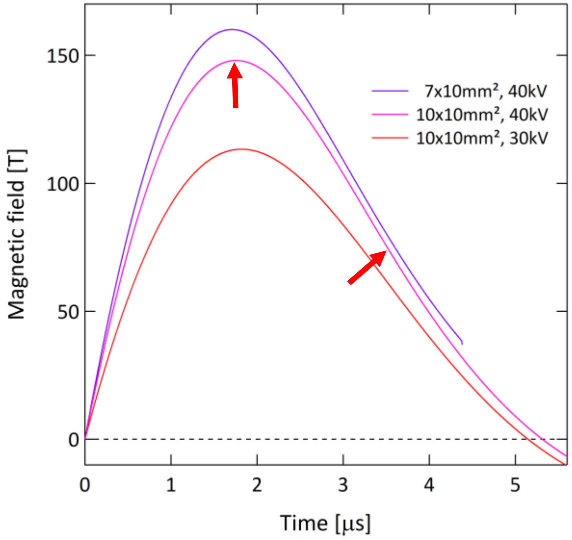
Field & current on the up-sweep and at B_{max}

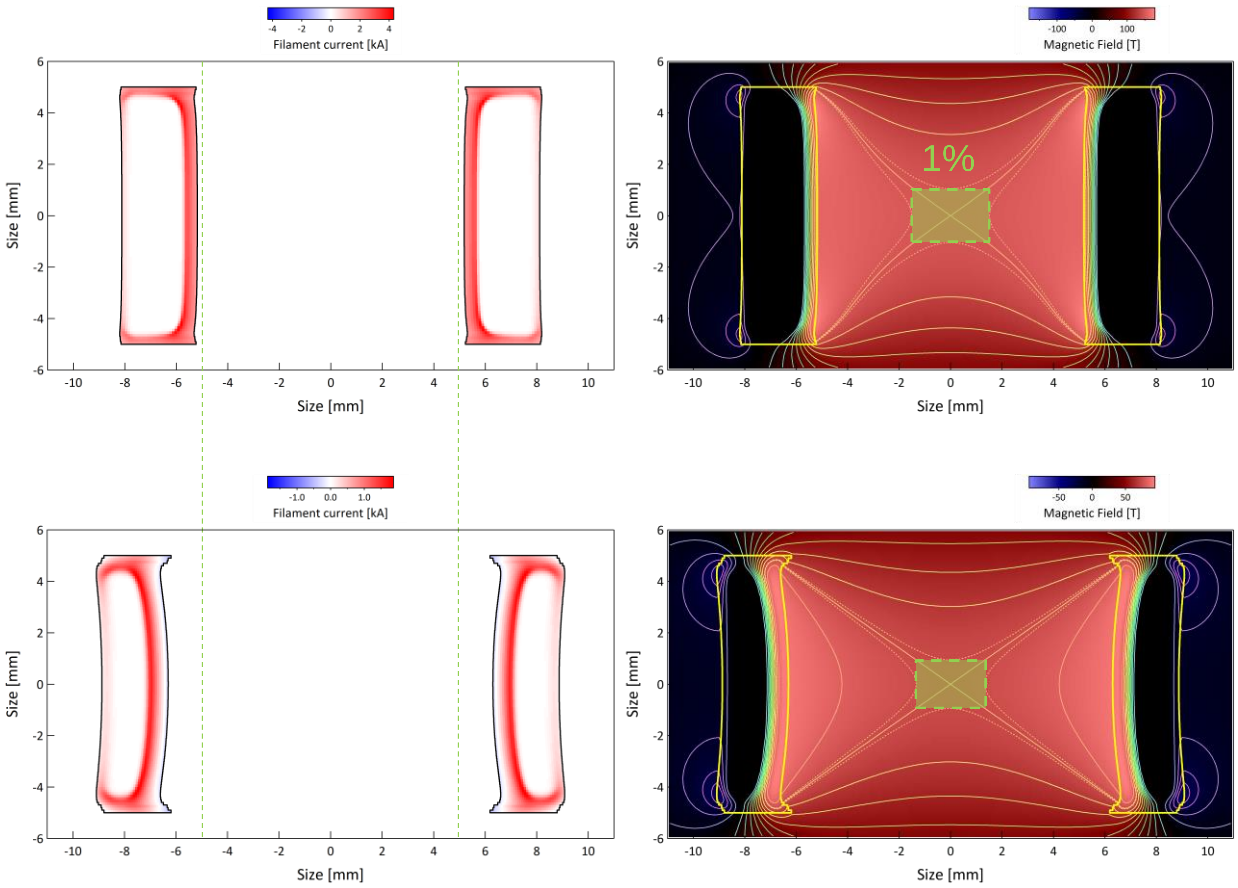




Negligible coil expansion up to peak field ; the current distribution reflects the effect of magnetic diffusion.

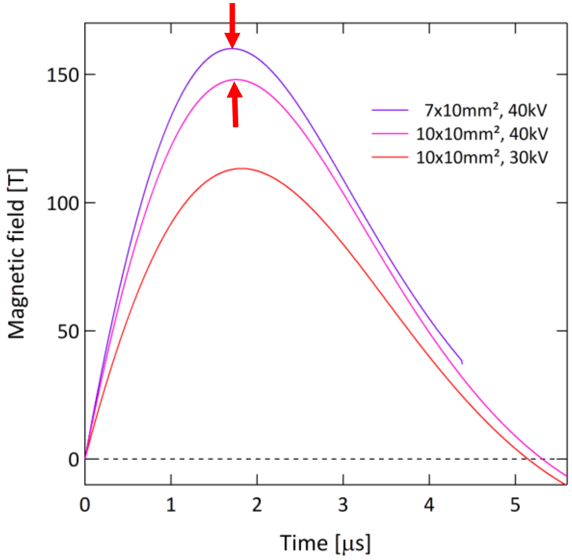
Field & current on the down-sweep and at B_{max}

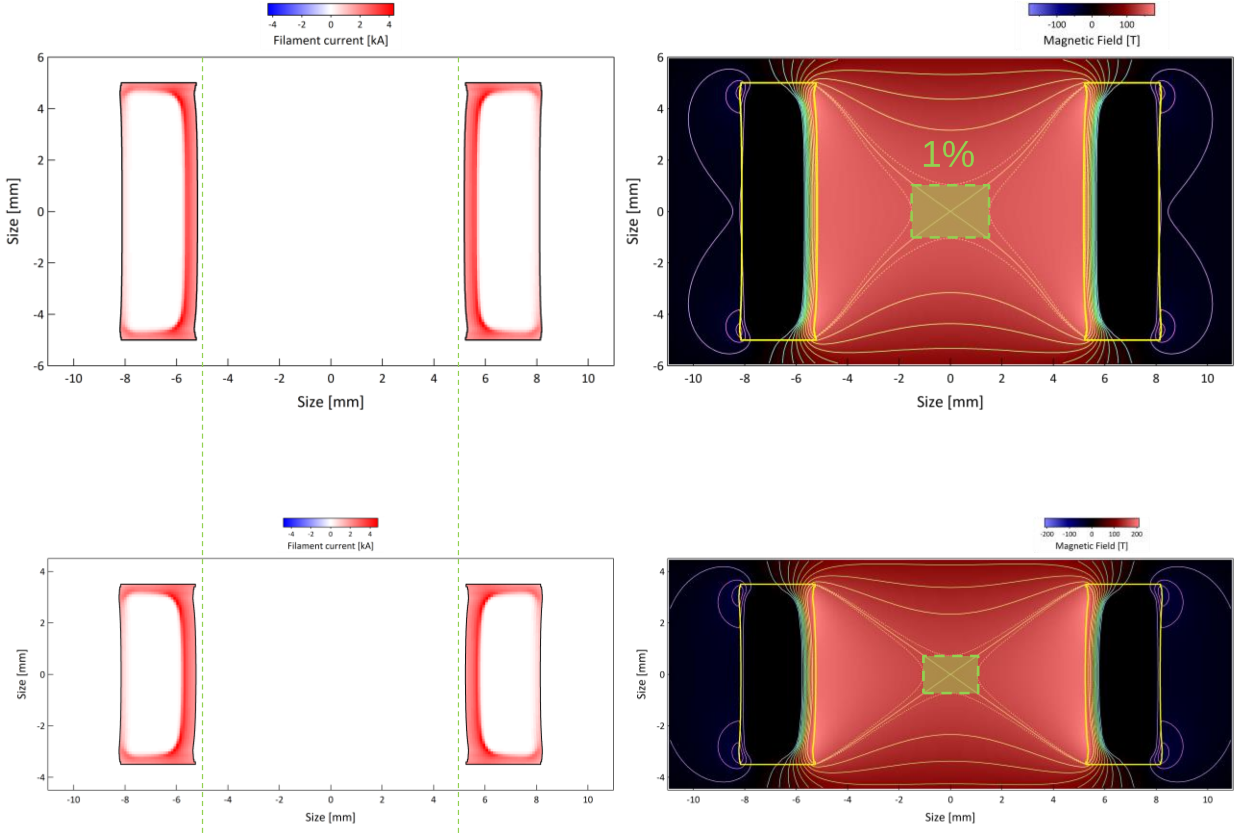




Homogeneity in 10mm coils is surprisingly good: less than 1% deviation in a 1.5mm sphere.

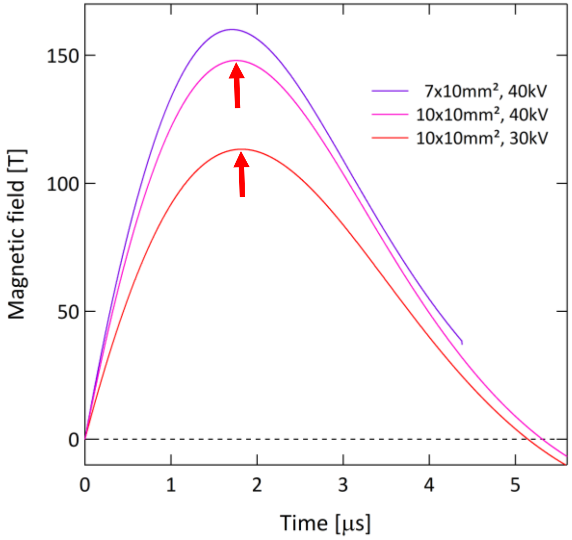
Field & current at B_{max} in coils with 7 and 10 mm width

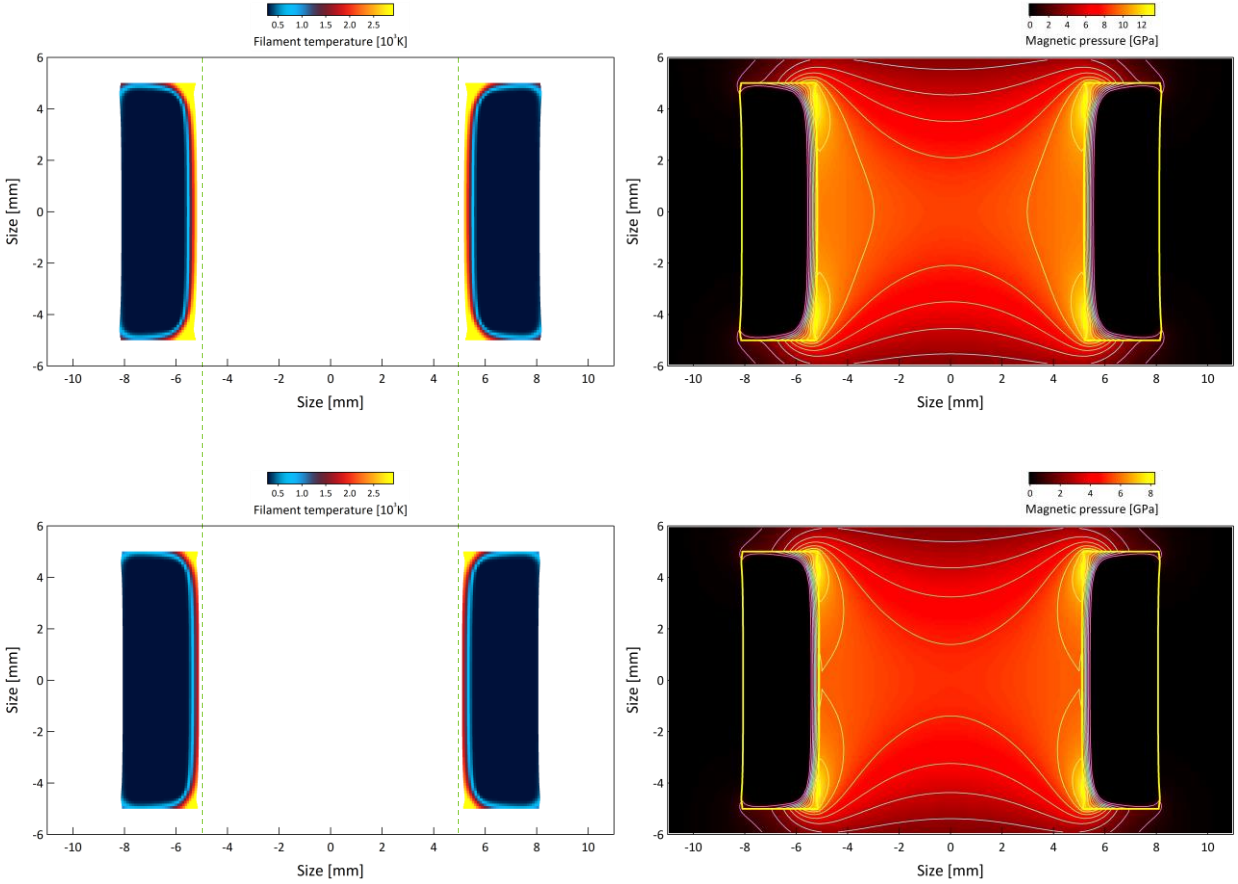




Flat coils may give several % more field with tolerable effect on homogeneity.

Temperature & pressure at B_{max} for 30 and 40 kV



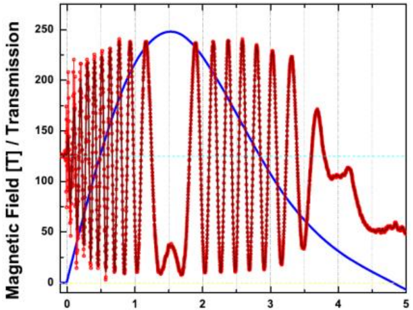


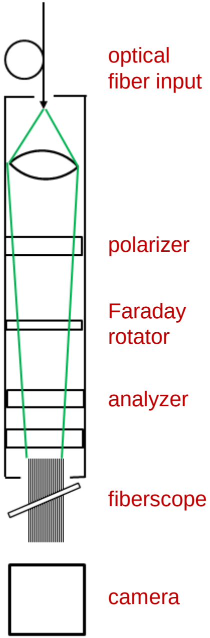
Overheating gives rise to explosive sublimation when magnetic pressure is released > destruction in the bore.

Future projects
(towards a 200 T standard for scientific applications)

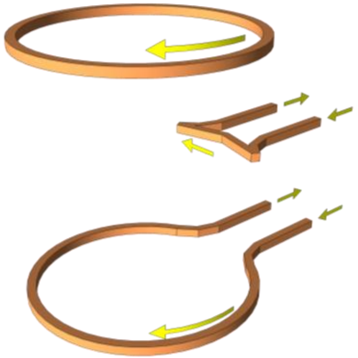
Project 2: improve simulations (structured coils, material properties, mechanics ...)

Project 1: Faraday rotation imaging of field homogeneity





Project 3: Quasi-3d feed-gap simulation using polygonal filaments



sum over all segments; direction of segment; distance from segment end points; segment length

$$\mathbf{A}(\mathbf{r}) = \frac{\mu_0 I}{4\pi} \sum_{n=1}^{N} \mathbf{e}_{n,n+1} \ln\left[\frac{|\mathbf{r}-\mathbf{r}_n| + |\mathbf{r}-\mathbf{r}_{n+1}| + |\mathbf{r}_{n+1}-\mathbf{r}_n|}{|\mathbf{r}-\mathbf{r}_n| + |\mathbf{r}-\mathbf{r}_{n+1}| - |\mathbf{r}_{n+1}-\mathbf{r}_n|}\right]$$