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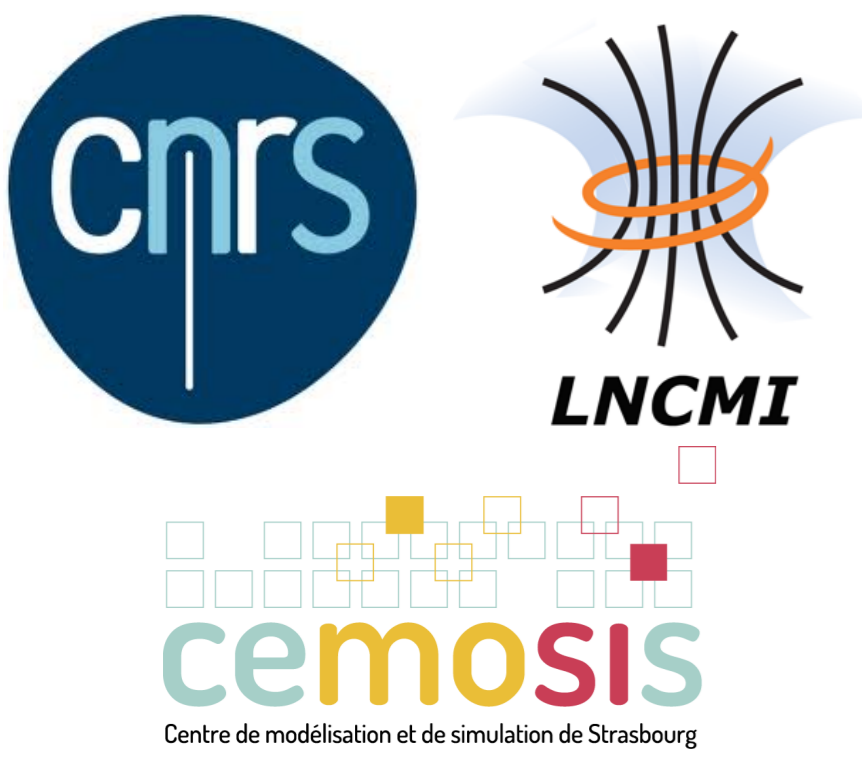
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# Full 3D MultiPhysics Model of High Field PolyHelices Magnets

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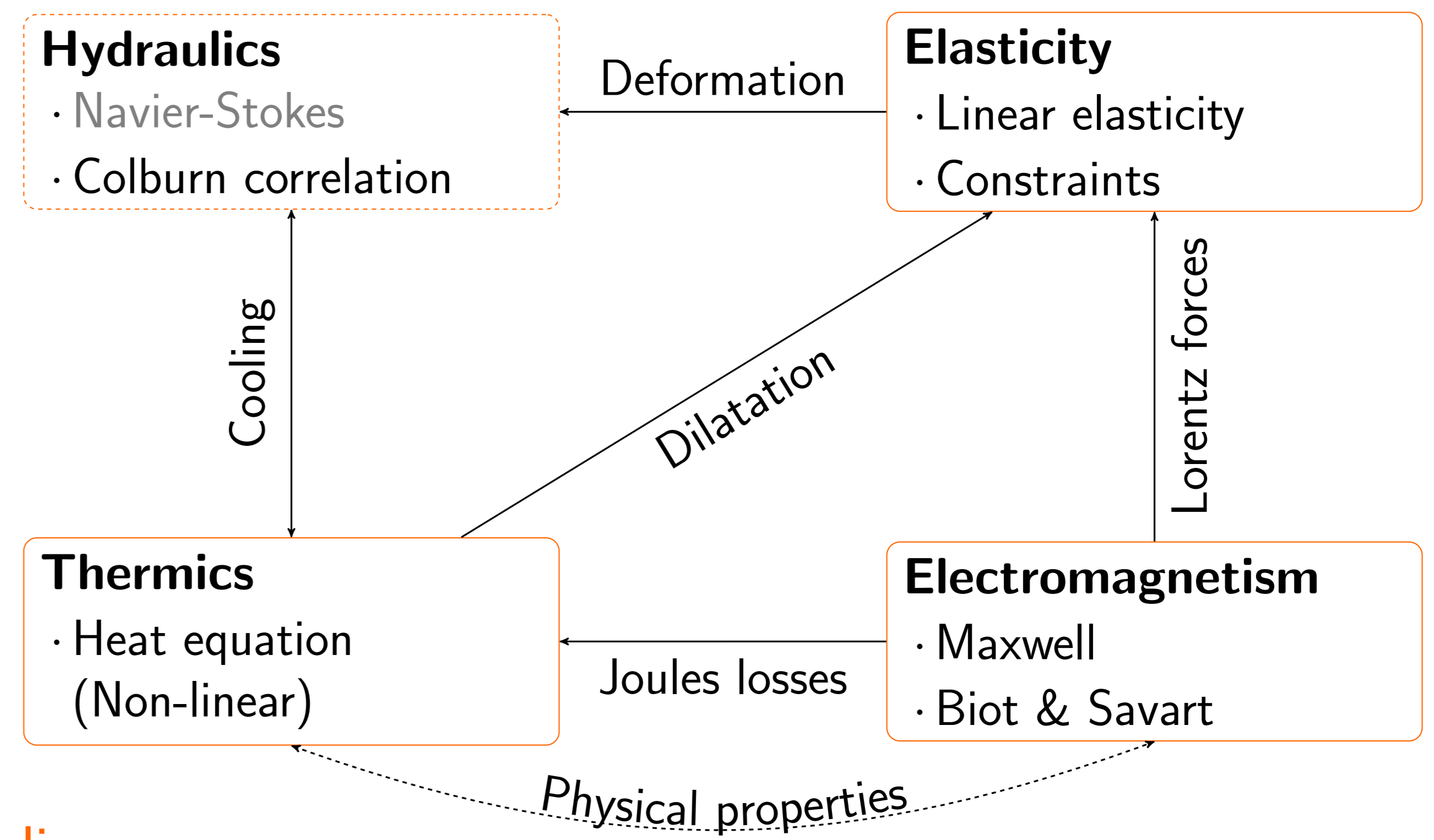
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### Beyond 25 tesla... : Resistive high field Magnets

Long. cooled Helices    Radial. Helices

up to 30 kA,  
up to 24 MW,  
water cooled 30 m/s,  
pressure drop 25 bars  
up to 36 tesla (34 mm)



## High field magnets modeling process

### Optimization (2D axi) under constraints

Find  $\{j_i\}$  s.t.

$$\begin{cases} \sum_i B_i(0,0) j_i \text{ is max} \\ P < P_{max} \\ T < T_{max} \\ r_j B(r_i) < \sigma_{max} \end{cases}$$

**FEEL++** : Finite Element Embedded Library in C++  
[www.feelpp.org](http://www.feelpp.org)

- High order elements, high order meshes
- Seamless parallel computing
- Large scale parallel linear and non-linear solvers

### Optimization → Geometry → Mesh

From longitudinally cooled helices ...

Automatic process

... to radially cooled ones

### Resistive part of future Hybrid Magnet

- PolyHelix magnet · 14 helices
- Material : Cu5Ag
- $\sigma_0 = 52 \text{ MS}$
- $Re \approx 500 \text{ MPa}$

Temperature along X, Stress along X

### Numerical/Experimental Validations

- Exp : Pick up coil measurements
- 2D Axi : Analytical axisymetrical calculation
- 3D : Biot & Savart 3D calculation from current density  $j$

## Towards a finer analysis

### Improve model efficiency

Standard 14 helices insert :  $6.4 \cdot 10^6$  tetras,  $10^6$  nodes  
FE computational time : 32 procs  $\approx$  20 min

- Electro-thermal (8 Picard iterations) : 631 s  
Potential :  $\approx$  60 s  
Temperature :  $\approx$  18 s
- Magnetostatic (2D axi) : 575 s
- Elasticity (Linear) : 83 s
- Yield strength : 20 s

Magnetic field

### Reduced Basis Method

$u^N(\mu) \approx u^N(\mu)$  : linear combination of FEM solutions

$$W^N = \text{span}\{\xi_i \equiv u^N(\mu_i)\}_{i=1}^N \rightarrow u^N(\mu) = \sum_{i=1}^N u_i^N(\mu) \xi_i$$

RB approximation space

10  $\leq N \leq$  100

Computational time gain factor  $\approx$  150

### Parametric studies - Bitter magnet (Hybrid)

Mean temperature (C) vs Current density ( $A \cdot m^{-2}$ )

$j = 65 \cdot 10^6 A \cdot m^{-2}$

Increase current density  $j$  on Bitter  
→ Max( $j$ ) without damages ?  
40 C° to 60 C° : + 1 Tesla

### Sensitivity Analysis - Radially cooled helix

$\sigma_0 \in [50, 2.10^6] (S \cdot m^{-1})$   
 $\alpha \in [3, 3.10^{-3}; 3, 5.10^{-3}] (K^{-1})$   
 $L \in [2, 5.10^{-8}; 2, 9.10^{-8}]$   
 $U \in [0.14; 0.15] (V)$  Intensity  $\approx$  25kA  
 $h \in [70000; 90000] (W \cdot m^{-2} \cdot K^{-1})$   
 $T_w \in [293, 313] (K)$

Quantiles :  
 $q(\gamma)$  such that  $P(Y < q(\gamma)) > \gamma$   
99.0 quantile = 380 K = 107 C  
80.0 quantile = 377.5 K = 104.5 C

Sensitivity indices (Sobol) :  
—  $\sigma_0$  : 6.85e-05    —  $V_D$  : 1.28e-01  
—  $\alpha$  : 4.54e-04    —  $h$  : 2.40e-01  
—  $L$  : 9.21e-03    —  $T_w$  : 6.21e-01