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Full 3D MultiPhysics Model of High Field PolyHelices Magnets

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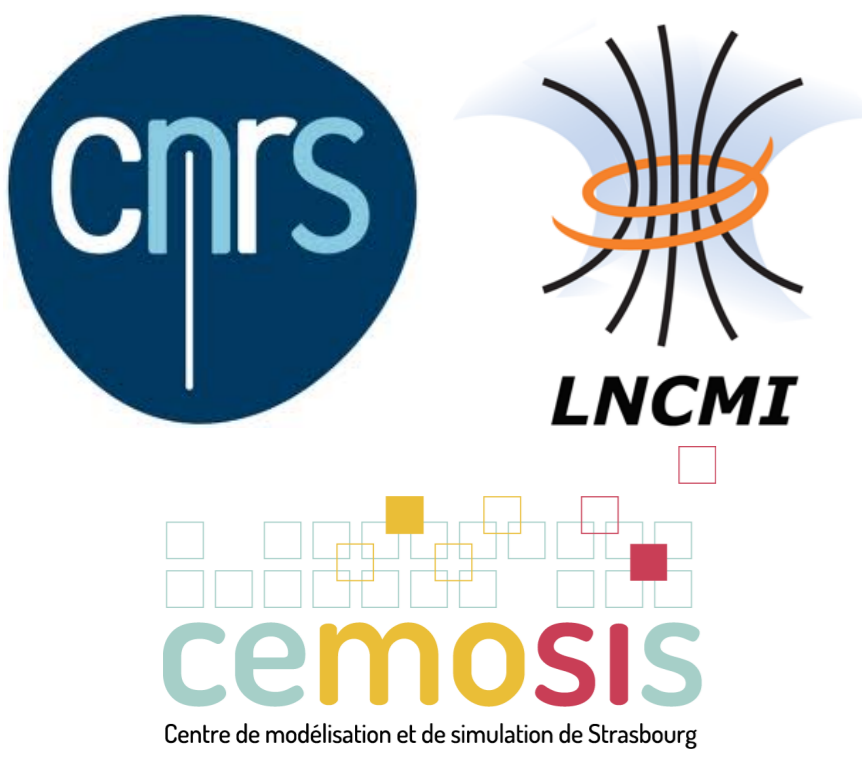
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Full 3D MultiPhysics Model of High Field PolyHelices Magnets

Cécile Daversin¹ Christophe Prud'homme¹ Christophe Trophime²

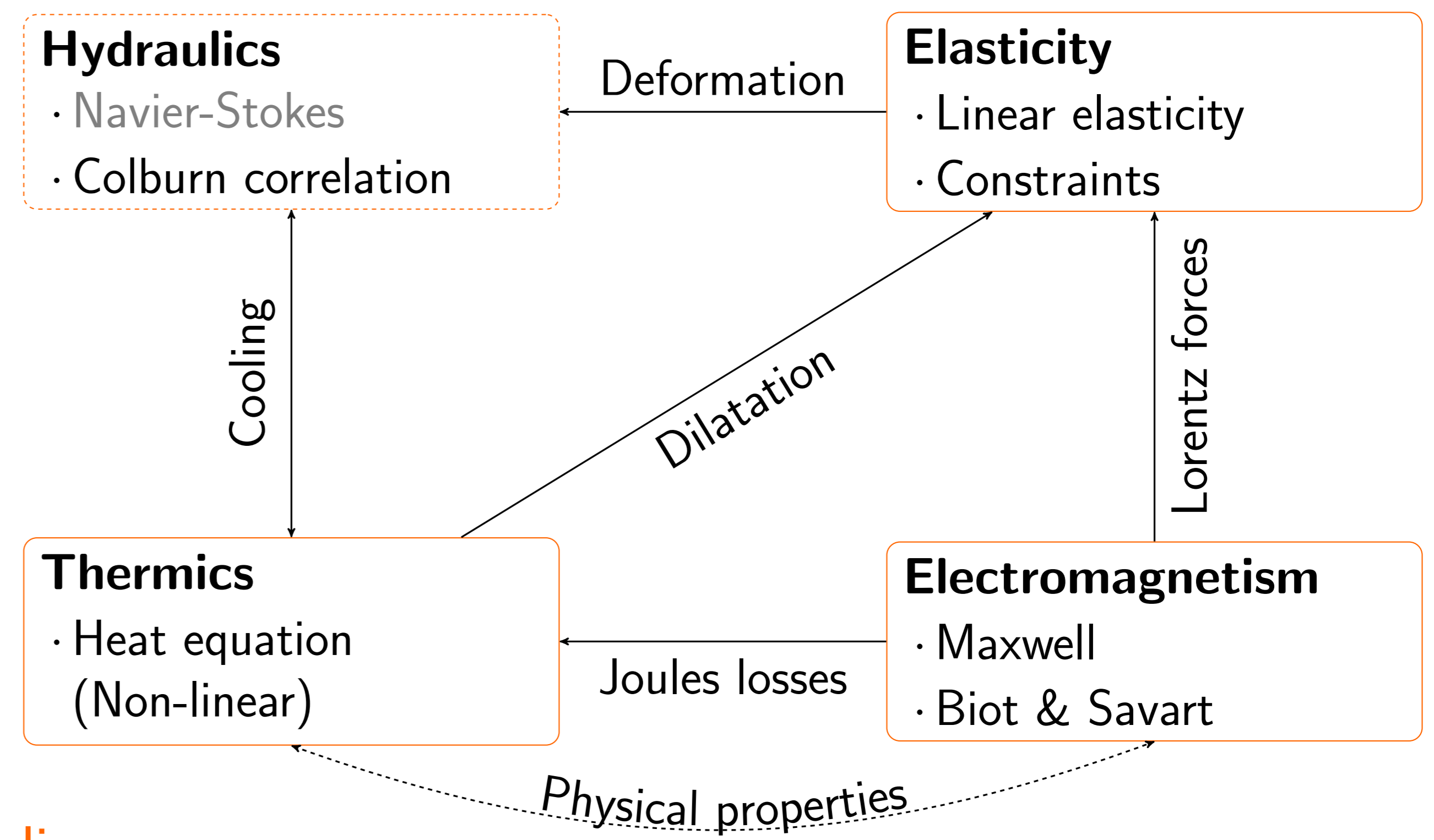
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Beyond 25 tesla... : Resistive high field Magnets

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

- 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
- $\sigma_0 = 52$ MS
- $Re \approx 500$ 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) :
— σ_0 : 6.85e-05 — V_D : 1.28e-01
— α : 4.54e-04 — h : 2.40e-01
— L : 9.21e-03 — T_w : 6.21e-01