High field magnets using the Nb$_3$Sn superconductor and a ceramic-based insulation.

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In the framework of LHC upgrades, big efforts have been provided to design accelerator magnets with the Nb3Sn superconducting alloy, in order to reach higher magnetic fields. The goal of the PhD work is to check the feasibility of a Nb3Sn high field magnet with a ceramic insulation. This innovative insulation has been developed by CEA Saclay. In high field magnets, the transverse compressive stress on the cables, due to Lorentz forces, can be higher than 150 MPa. Properties of Nb3Sn conductors are studied under pressure and magnetic field. The mechanic and magnetic behavior is finally incorporated in new methods of magnetic design.

- **Superconducting magnets for particle accelerators**
  - Discover new particles...
    - Increase the energy $E = \text{CBR}$
    - Increase $B > 12$ T (beam bending)
  - ...using superconductors.
    - R = 0 at low temperature
    - No electrical consumption, only cryogenics
    - High current density $\rightarrow$ compact
    - NbTi currently limited $\rightarrow$ use Nb3Sn
  - Constrained specifications

- **Magnetic design of the winding**
  - The winding shape must fulfill the specifications:
    - Central B
    - Field harmonics
    - Maximum forces
    - Operating margins
  - 3D magnetic design of an accelerator dipole
  - 2D magnetic design (cross section)

- **Nb3Sn manufacturing issues**
  - Heat treatment (650 °C, 100h) to form the superconducting alloy.
  - Nb3Sn very brittle after heat treatment $\rightarrow$ difficult handling
  - Electrical insulation needed for the coil $\rightarrow$ risky process

- **Improvements of the ceramic insulation**
  - Heat extraction: better than resins
  - Mechanical strength: lower than resins
  - High B, high current $\rightarrow$ high Lorentz forces
  - The insulation has to support high compressive stresses

- **Characterization of the electrical properties under stress**
  - 2 experiments:
    - Test the conductor with ceramic insulation, under pressure, in magnetic field
  - What stress limit to keep a high $J_c$?

- **Nb3Sn very sensitive to strain**

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**CERN**:
- 14 strands cable
- Current supply: 32 000 A
- Max. external field: 9 T
- Max. pressure: 50 MPa

**CEA**:
- 1 strand in its cable
- Current supply: 2000 A
- Max. external field: 11 T
- Max. pressure: 200 MPa