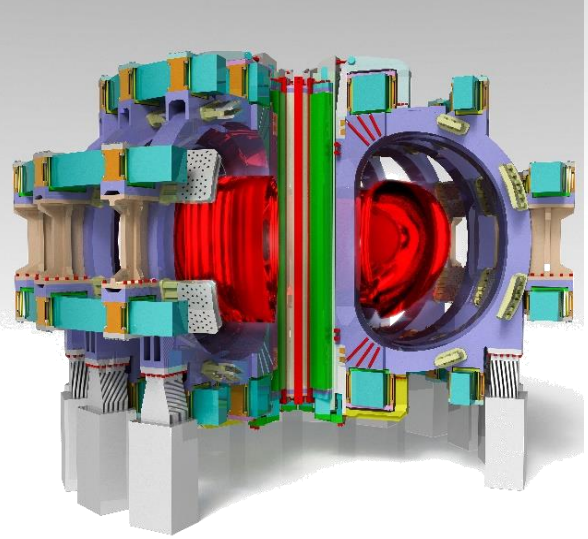
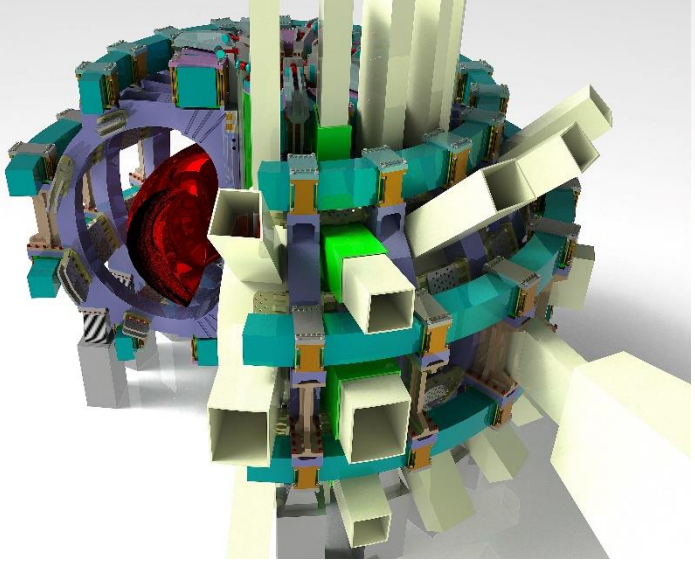
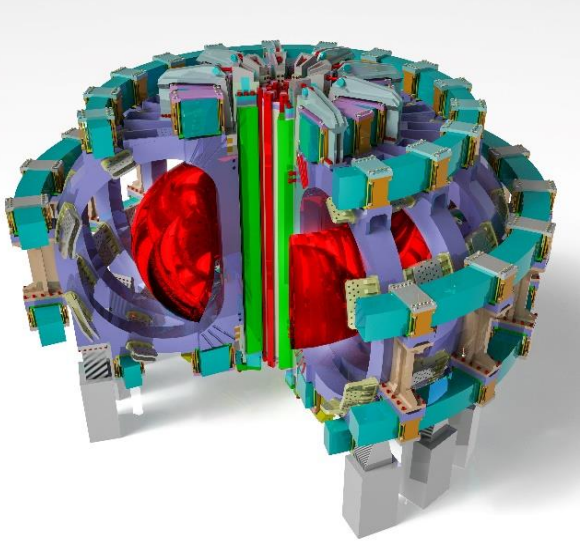




EUROfusion

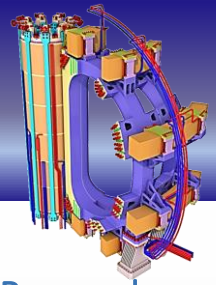
2020-22 Engineering Grants

Structural analyses of DEMO magnets

APPLICATION PROPOSAL

Candidate
Lorenzo Giannini

Mentor
Antonio della Corte



Candidate Résumé

Research and Work Experience

Jan 2019 **Structural analyst**, ICAS-Italian Consortium for Applied Superconductivity

- Design study and magneto-structural analyses of the DTT central solenoid
- Magnetic field evaluations for the operative plasma scenarios in normal and off-normal conditions
- Static stress and fatigue life assessment under different electromagnetic and thermal
- loading conditions of all main and support structures, for metallic and non-metallic components

Nov 2018 **Structural Analyst**, CREATE-Consorzio di Ricerca per l'Energia, l'Automazione e le Tecnologie dell'Elettromagnetismo

- Magneto structural analyses of the DTT central solenoid
- Definition and implementation of a parametric and multi-physical design optimization model for the CS layout

Miscellaneous & Education

Jun 2017 **Structural analyst**, ICAS-Italian Consortium for Applied Superconductivity

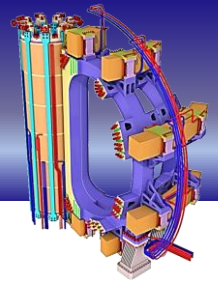
- Magneto structural analyses of the DEMO poloidal coil system
- PF#1-6 non-linear fully parametric 3D FEM model, magnetic field calculation for the operative plasma scenarios and static mechanical assessment under electromagnetic load conditions

Feb 2017 **MSc undergraduate intern,** ENEA-Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

- Internship done in conjunction with university of Rome "La Sapienza", oriented at developing Finite Element codes for structural analyses in tokamak applications.
- Bidimensional model for CICC steel jacket and mono-dimensional toroidal field coil model; derivation and validation of different equivalent loading conditions for a tokamak S/C cables.

Feb 2017 **BSc undergraduate intern,** ENEA-Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

- In-depth study of the superconducting magnet system of a tokamak fusion reactor
- Structural analysis of the DEMO toroidal magnet system via numerical simulations with thoroughly parametric 2D FEM models



Scheduled Activities

Report:

I. 1D, 2D static and fatigue analysis results

II. 3D static and fatigue analyses results, submodeling procedure, implementation of the new design criteria

III. Standard procedure for fusion magnets analyses

40% **Training/Knowledge sharing period**

30% **Review documentation**

33% **Report I [ASC Conference]**

- F4E ITER Departement (A. Portone)
- F4E JT-60SA Unit (E. Di Pietro)
- EPFL - SPC (P. Bruzzone)

80% **Training/Knowledge sharing period**

60% **Review of the design studies and design criteria**

66% **Report II [MT Conference]**

- NFRI (Kijung Jung)
- KIT (Klaus-Peter Weiss)

100% **Training/Knowledge sharing period**

100% **Review of the models implemented**

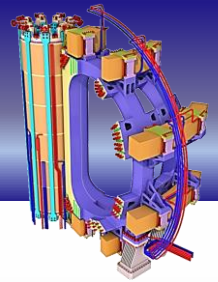
100% **Report III [SOFT Conference]**

- ITER Facilities
- JT-60SA Facilities

Final Report

2020 **2021** **2022**

Assessment - TFc system

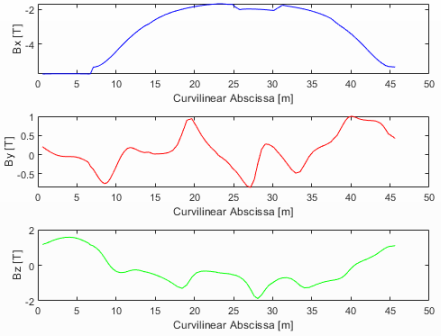


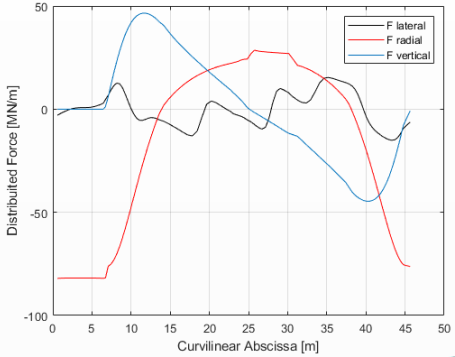
Visit to ITER department (F4E, A. Portone)

- Consolidates knowledge on Magneto-Structural FEA
- Review documentation past analyses on ITER

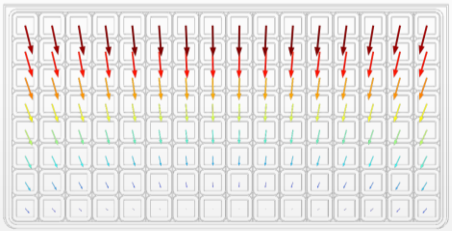
Actions - FEM analyses of the TF coil system

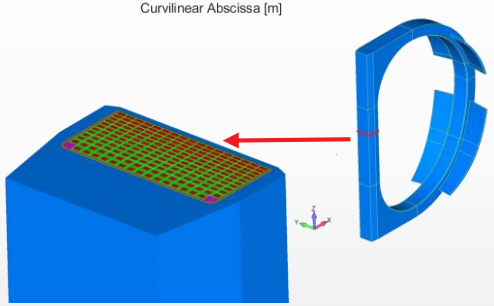
- 1D ideal representation of the TF centerline
- 2D model for of the most critical cross-section
- 3D modelling strategy for the PF and the TF coil



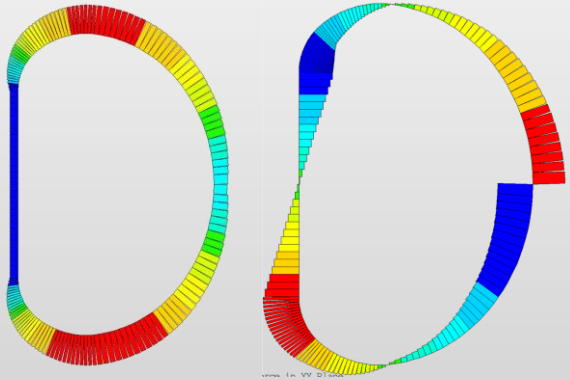


Evaluation of the EMAG field

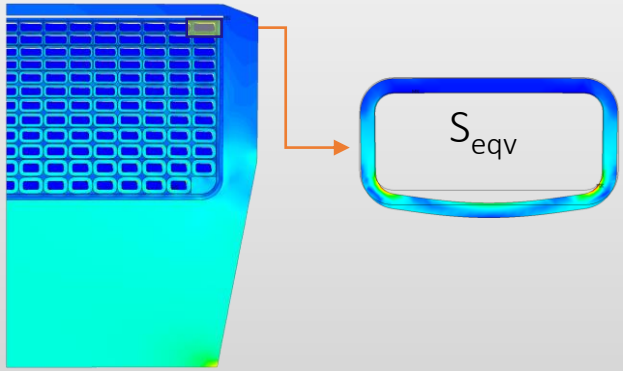




1D TF model

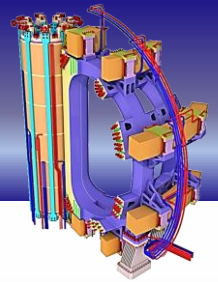


2D WP model



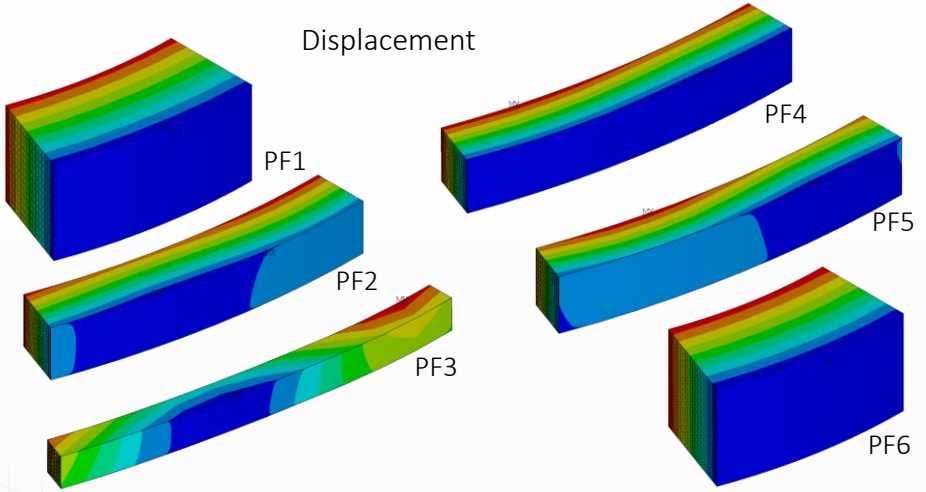
3D TF model

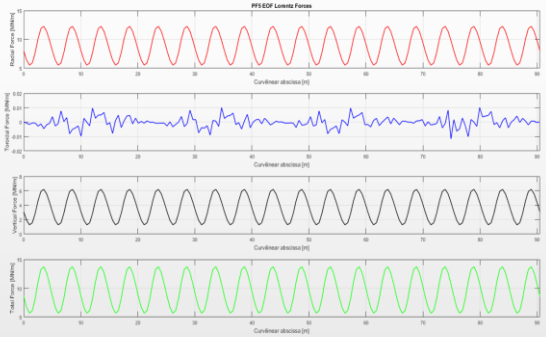
Assessment - PFc system

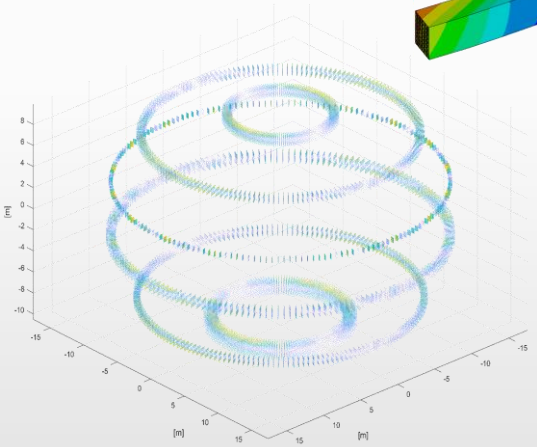


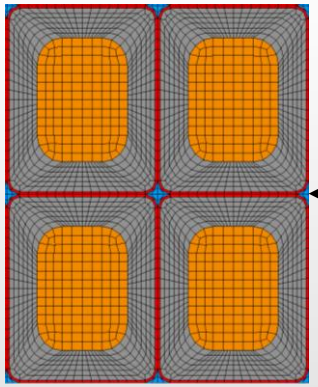
Actions - FEM analyses of the PF coil system

- Review of the modelling assumption for the PF system
- Magnetic field will be computed for each cable centroid in 180 cross-section of each PF
- Study of the effects of the in-plane and out-of-plane forces generated by the ripple in the magnetic field

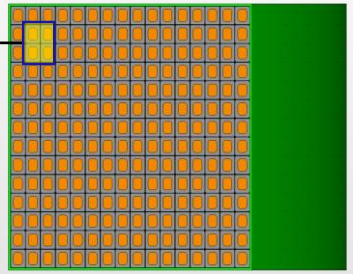


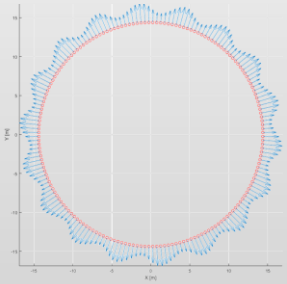




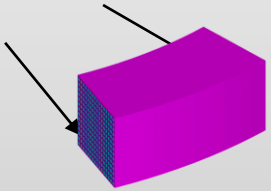


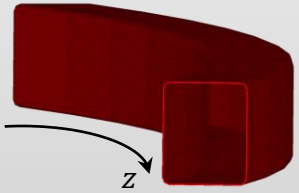
3D fully parametric and detailed model

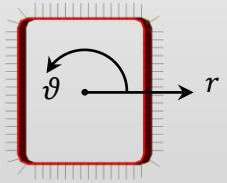




20° cyclic symmetry



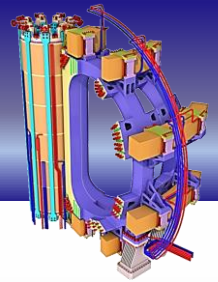




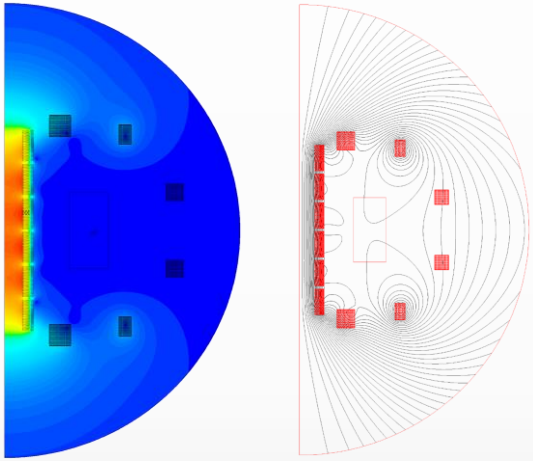
Orthotropic properties

r = through-thickness
ϑ = wrapping direction
z = coil direction

Electromagnetic assessment – CS



2D Fully Detail



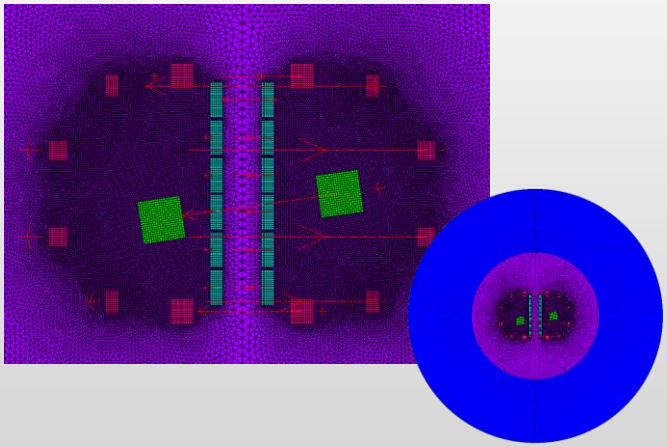
Visit to JT-60SA unit (F4E, E. Di Pietro)

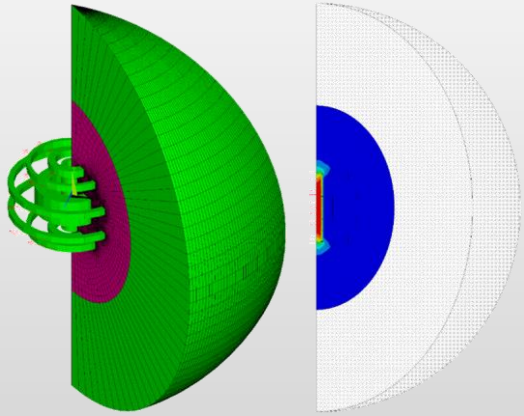
- Review documentation past analyses on JT-60SA
- Assessment of all normal and off-normal operative condition

Actions

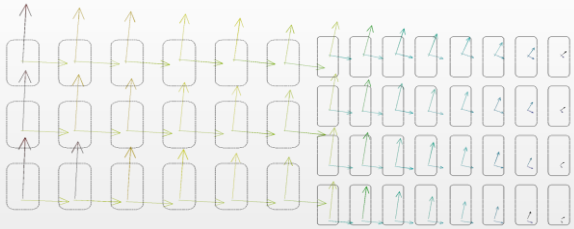
- The 2D and 3D FEM models will be implemented for the magnetostatic analyses of the CS and the evaluation of the magnetic field related to unconventional events:
  - Plasma disruption
  - Plasma Kink
  - Coil failure
  - Plasma tilting and offsetting
  - EQ event

3D Homogenised

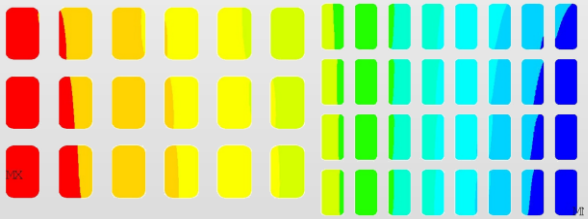


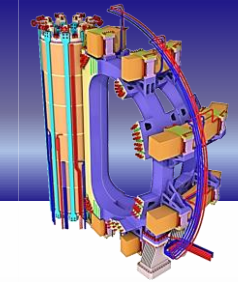


Lorentz force field



Magnetic field gradient



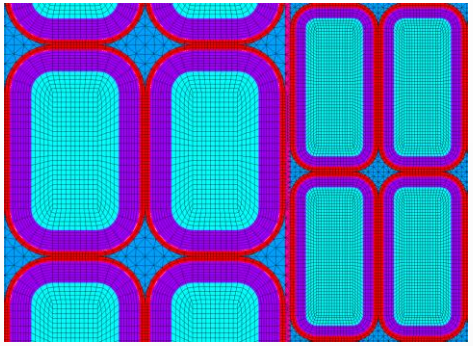


Modeling Strategies

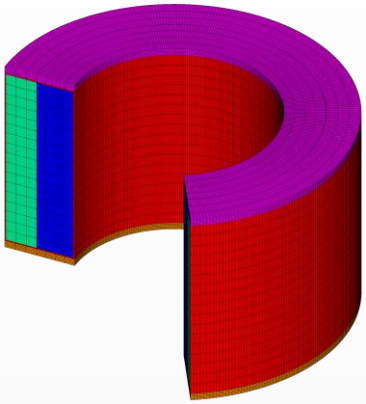
Actions

- Electromagnetic, static Structural and Fatigue assessments and dedicated strength criteria for insulation and steel
- In-depth analysis will be done via 2D structural and thoroughly parametric model
- Implementation of 3D modelling and submodeling procedure for the local investigation of the most stressed

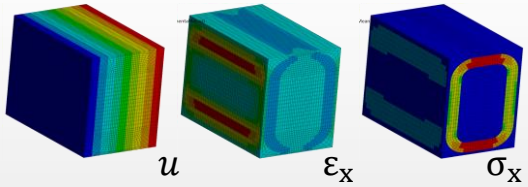
2D fully detailed model



3D homogenised model



Orthotropic properties definition

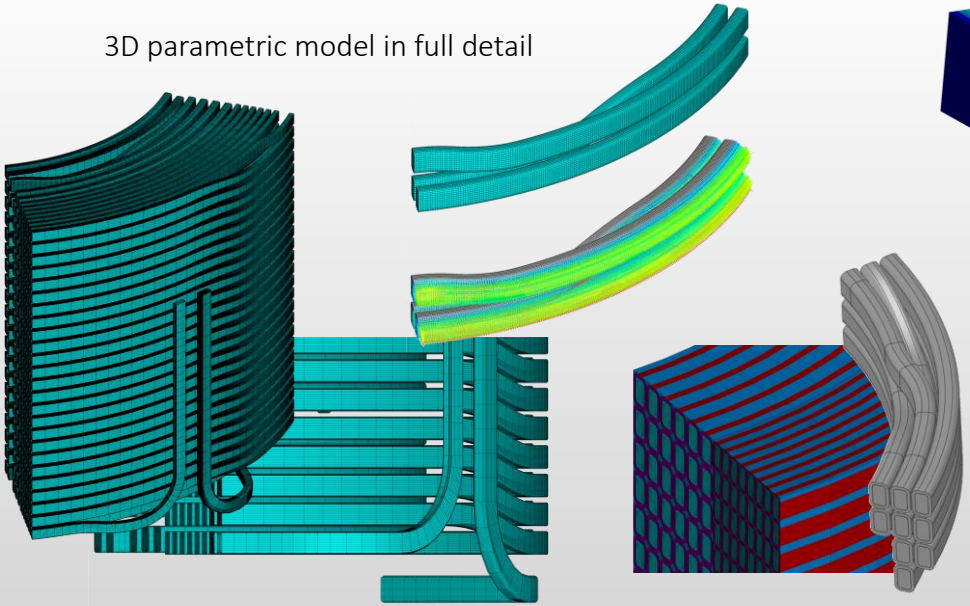


$$C_{11} = \frac{\langle \sigma_x \rangle}{\langle \varepsilon_x \rangle}$$

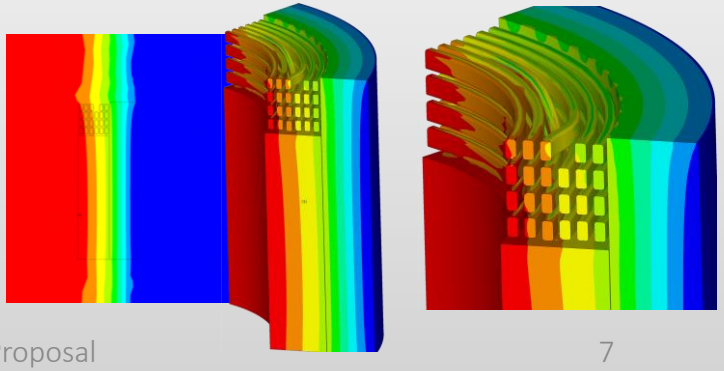
$$\langle \varepsilon_x \rangle = \frac{1}{V} \sum_{i=1}^{N} \varepsilon_{x,i} V_i$$

$$\langle \sigma_x \rangle = \frac{1}{V} \sum_{i=1}^{N} \sigma_{x,i} V_i$$

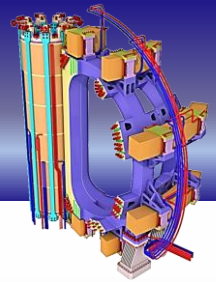
3D parametric model in full detail

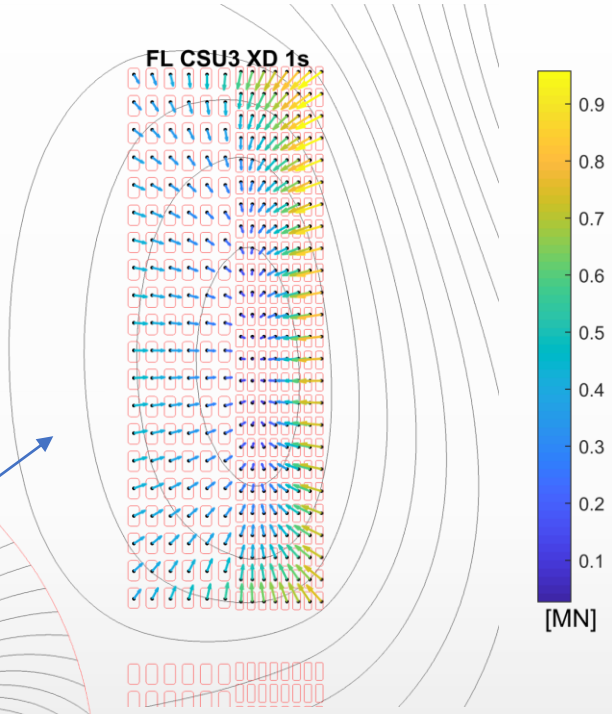


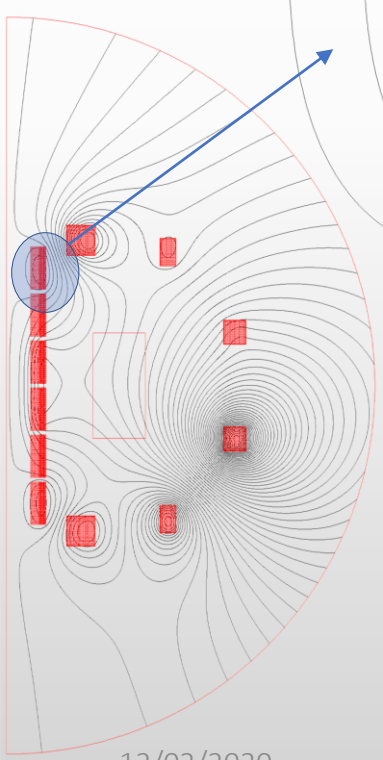
3D submodeling procedure

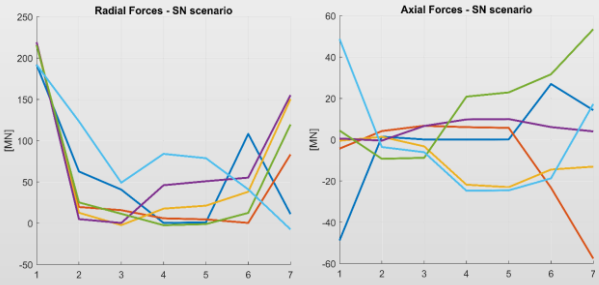


EMAG load conditions



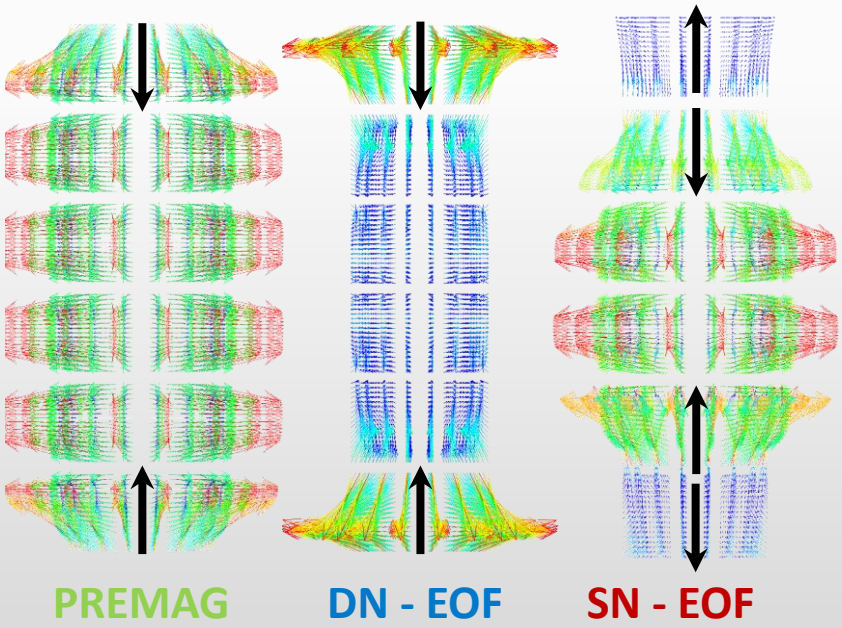




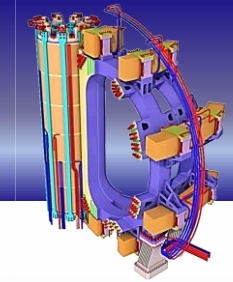


Actions

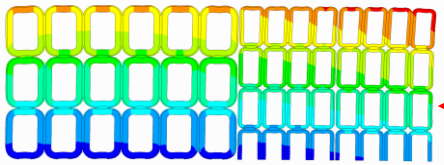
- All the defined plasma scenarios will be evaluated for several time instants
- Completing the electromagnetic assessment of the machine all the needed inputs will be collect, splitting the internal actions by the external ones



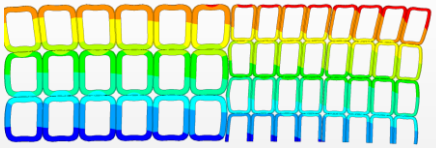
Static and fatigue assessment



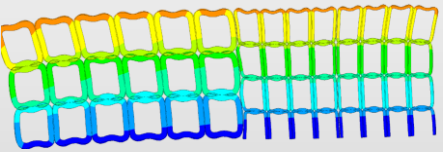
U_{sum}(1. Preload)



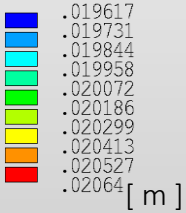
U_{sum}(2. Cooldown)

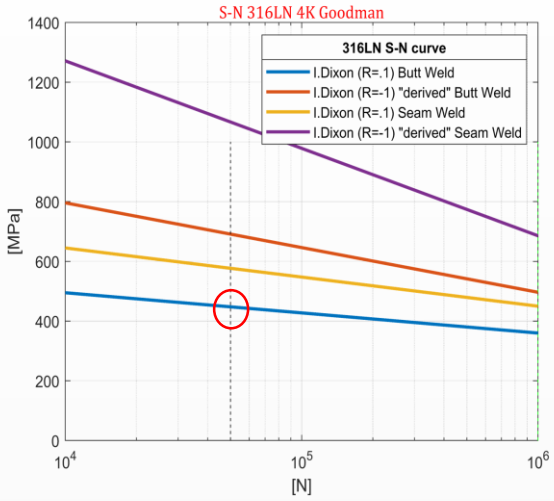


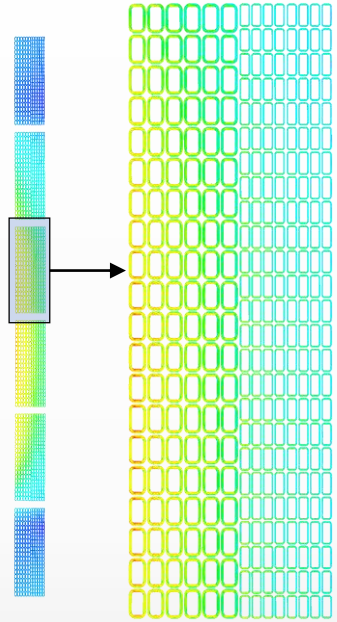
U_{sum}(3. Energisation)



«Deformed shape x100»

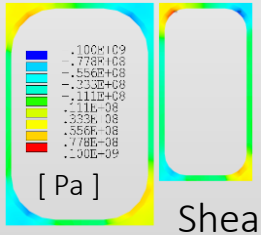




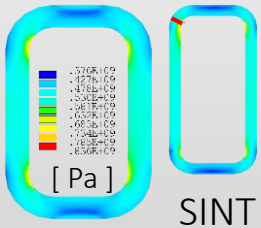


Actions

- Static structural 2D and 3D analyses
- A critical stress cycle will be defined in order to perform the fatigue assessment via SN approach and crack growth

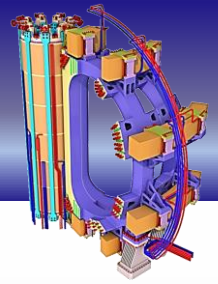


Shear XY



SINT

Dedicated strength criteria

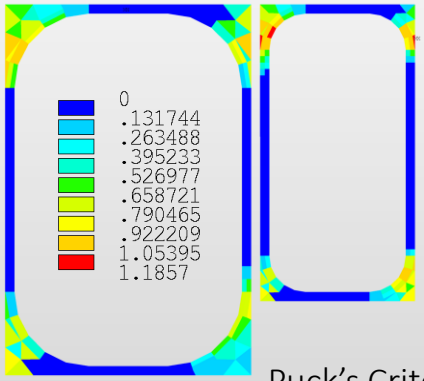


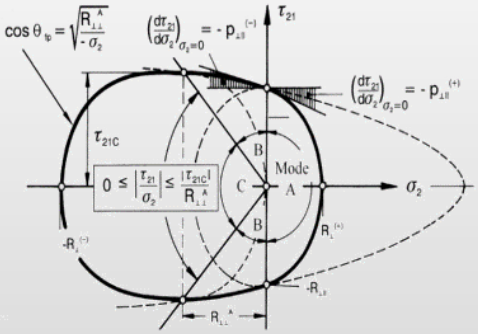
Visit to KIT (K.P. Weiss)

- Experimental campaign aimed at verifying the predictions of the classical and non-standard failure criteria for the insulation materials in fusion magnet applications

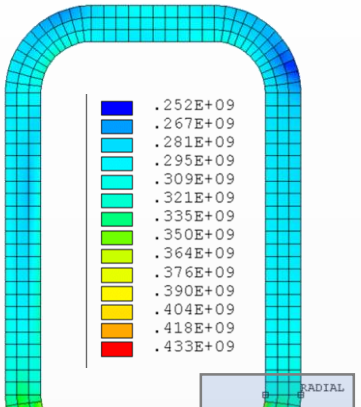
Activities

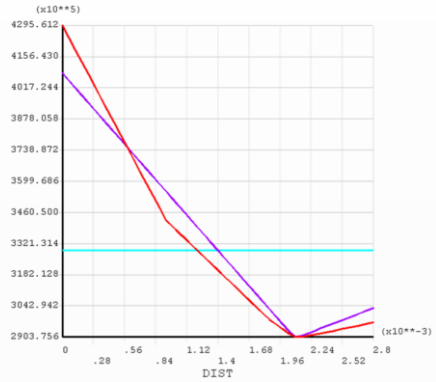
- Revision of the ITER design criteria for Metallic components
- Study and implementation of classical and innovative strength criteria for the analysis of the shear stress on the turn insulation

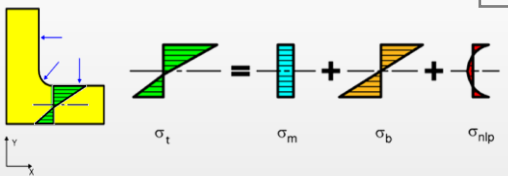


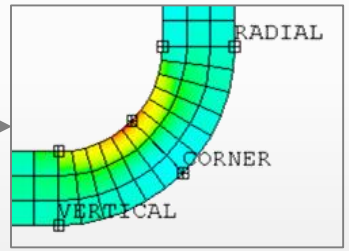


Puck's Criterion









Membrane

(Avarege between each stress componet along the SCL)

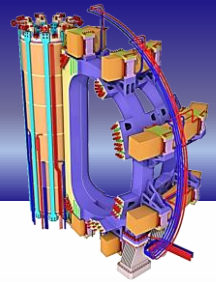
$$\sigma_{\theta m} = \frac{\int_0^t \sigma_\theta \, dx}{t} = \frac{1}{t}\frac{\Delta x}{3}\left(\sigma_{\theta_1} + 4\left(\sigma_{\theta_2} + \sigma_{\theta_4}\right) + \sigma_{\theta_5} + 2\,\sigma_{\theta_3}\right)$$

Bending

(Linearly variable portion of each component along the SCL)

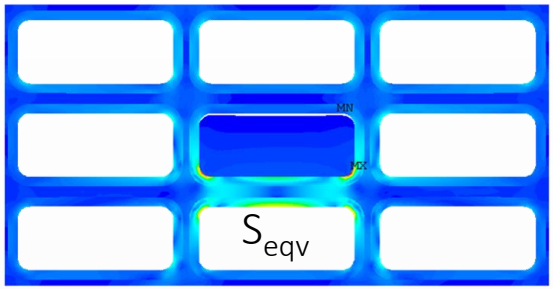
$$\sigma_{\theta b} = \frac{6\int_0^t \sigma_\theta\left(\frac{t}{2} - x\right) dx}{t^2} = \frac{6}{t^2}\frac{\Delta x}{3}\left(\sigma_{\theta_1}\frac{t}{2} + 4\left(\sigma_{\theta_2}\frac{t}{4} - \sigma_{\theta_4}\frac{t}{4}\right) - \sigma_{\theta_5}\frac{t}{2}\right)$$

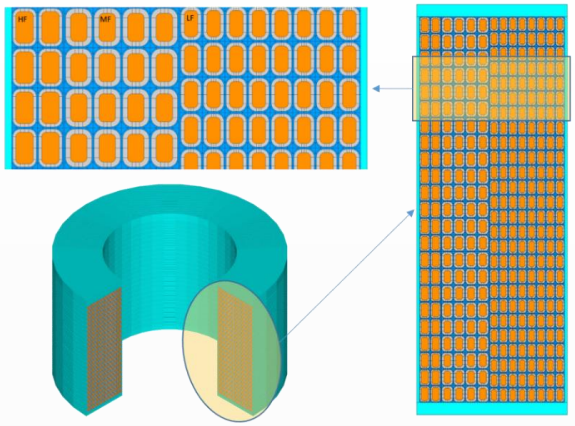
Design exploration



Visit to SPC (P. Bruzzone)

- Analyse the possible design solutions for the WP of the DEMO magnets





Actions

- Definition of a parametric code for the poloidal magnets as a design exploration algorithm for testing and comparing different layout proposal

Coil Parameters (Hcoil, Re, Ri, Iop, Winding Solution, n° modules, n° sub-modules, n° layers, n° turns, MA/m)

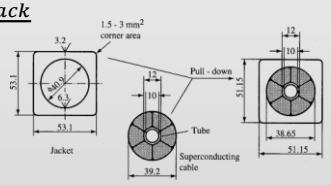
S/C Parameters (n_{wire}(Cu), n_{wire}(Nb_3Sn), d_{wire}(Nb_3Sn), cos(theta), twist pitch, Void Fraction, Aspect Ratio, Jacket thickness)

To minimise

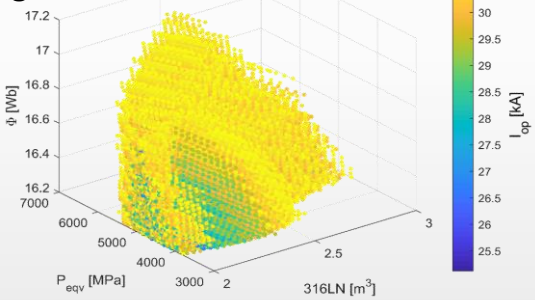
$$P_{eqv} = \frac{I\, n_{cables}\, 2\pi\, R_m\, B\, H_{stack}}{V}$$

To maximise

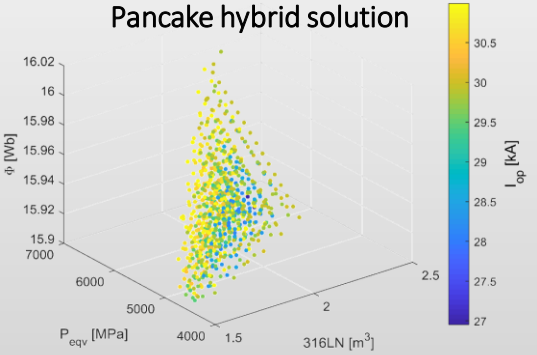
$$\Phi = \frac{\left(R_e^2 + R_i^2 + R_e R_i\right) B\, \pi}{3}$$

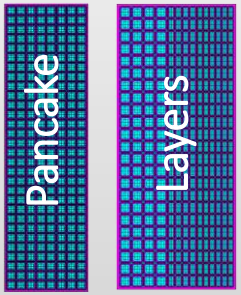


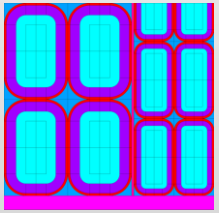
Layers solution



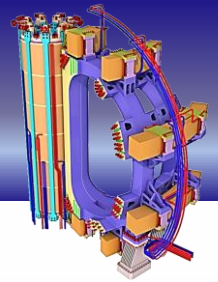
Pancake hybrid solution







Assessment – support structures

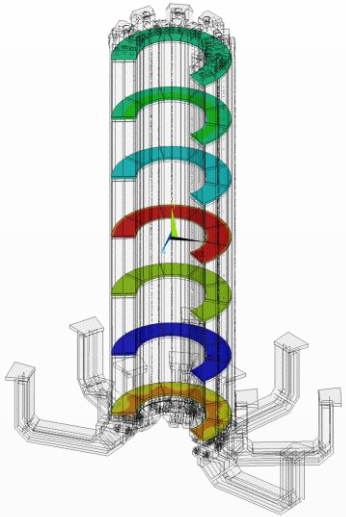


Visit at the NFRI laboratories (K. Jung)

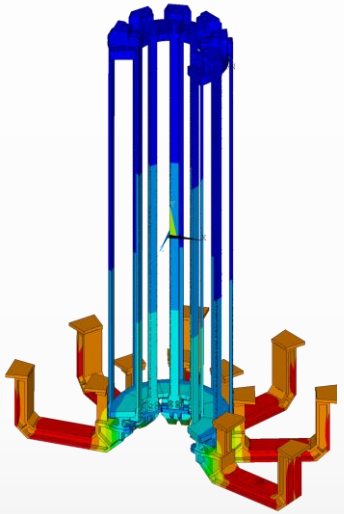
- The aim is to compare the electromagnetic and structural analyses reviewed for ITER and JT-60SA with the data collected for the KSTAR device and with the designer team of the project

Actions

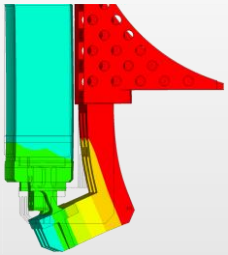
- Analyses of the terminations and electrical connections
- Review of the preload study and design solutions
- Structural assessment of the support and auxiliary structures

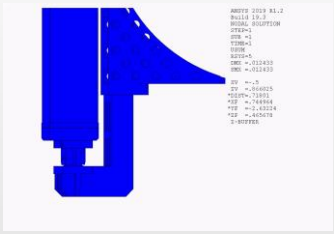


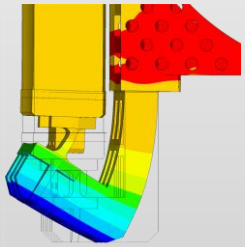
Support structure

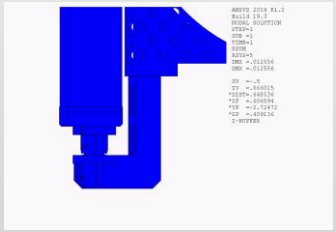


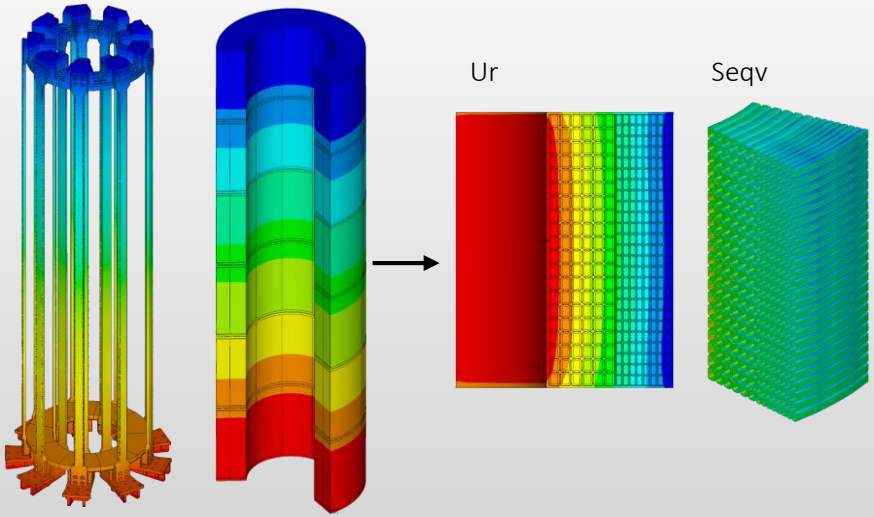
Displacement

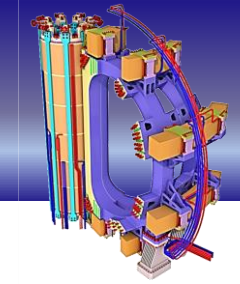








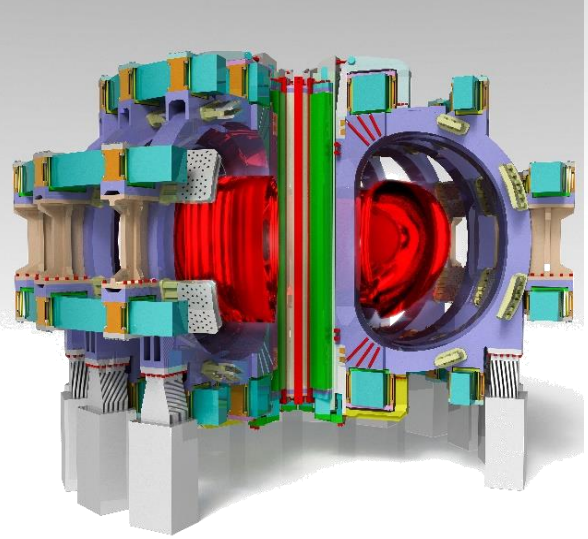
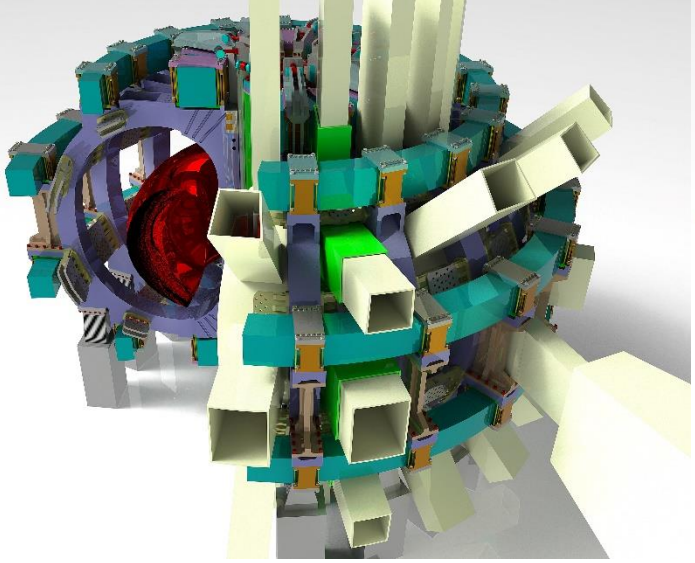
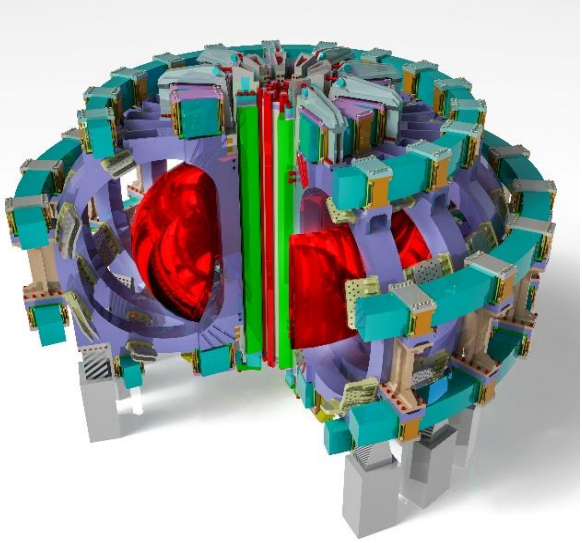




In conclusion

A **final report** will be drafted, intended as a guideline document which encompasses and critically selects the essential aspects of fusion magnet mechanics:

- Standardisation of the Magneto-Structural modelling procedure for 1D, 2D and 3D static and fatigue analyses
- Revision/implementation of new and classical design criteria, materials and technical solutions
- Innovative design proposal for the three DEMO main magnetic systems

EUROfusion

2020-22 Engineering Grants
Position ref.EEG-2020/02

APPLICATION PROPOSAL

Candidate
Lorenzo Giannini

Mentor
Antonio della Corte