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## Design of the inductor of a superconducting machine with magnetized bulk HTS

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## Abstract

The development of cryo-magnets based on REBaCuO type superconductors that can generate up to 17 T requires the implementation of a magnetization system and therefore, it involves one or more coils around the superconducting materials. Currently, the most convenient way to magnetize a bulk High Temperature Superconductor (HTS) is to use a Pulsed Field Magnetization (PFM). It can generate strong magnetic fields while using a relatively compact and simple coil. Thus, bulk HTS can be directly magnetized, *in situ*, into the final application. In a previous work, we have studied and designed different coils in order to magnetize, using PFM, an inductor of a radial flux superconducting machine with one pair of poles. Each pole contains four HTS bulks that can be placed in a square or rectangular pattern. For a given primary source of energy, here a capacitor bank of 5 mF, the PFM process strongly depends on the inductance value of the coil used to magnetize because it defines the waveform of the current: the peak value and the time constant. The maximal magnetic field applied to the sample is in the range of 6 to 10 T, which is more than enough to consider magnetizing HTS bulks above 2 T. In this paper, the induced currents and trapped fields in HTS bulks are calculated by means of 3D numerical simulations, with taking into account saturated iron and the non-linear resistivity of HTS. Results are the maximal trapped magnetic flux density of each bulk HTS, and the estimated flux of the poles of the inductor.

## Radial flux superconducting machine with HTS bulks

### Cross-sectional drawing and 3D isometric view

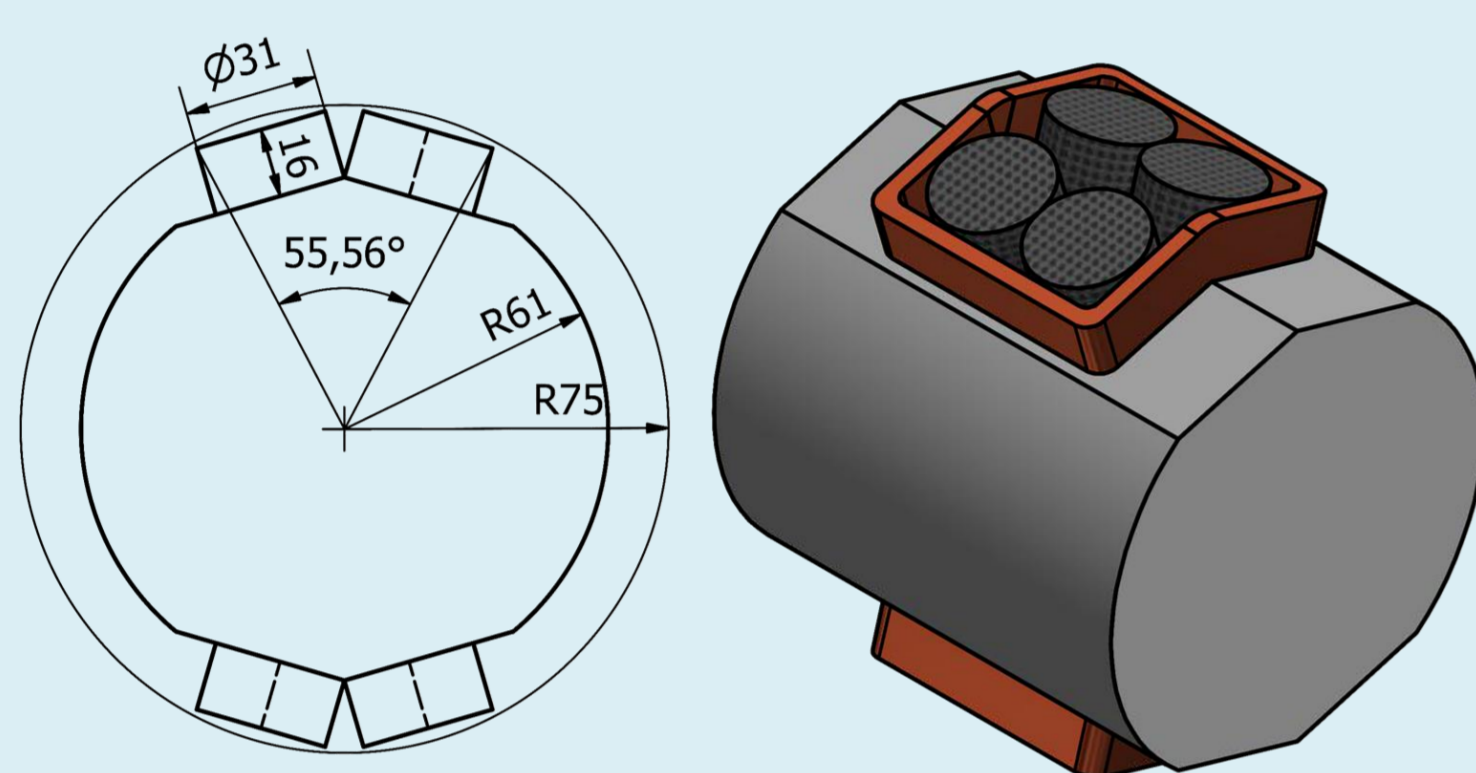
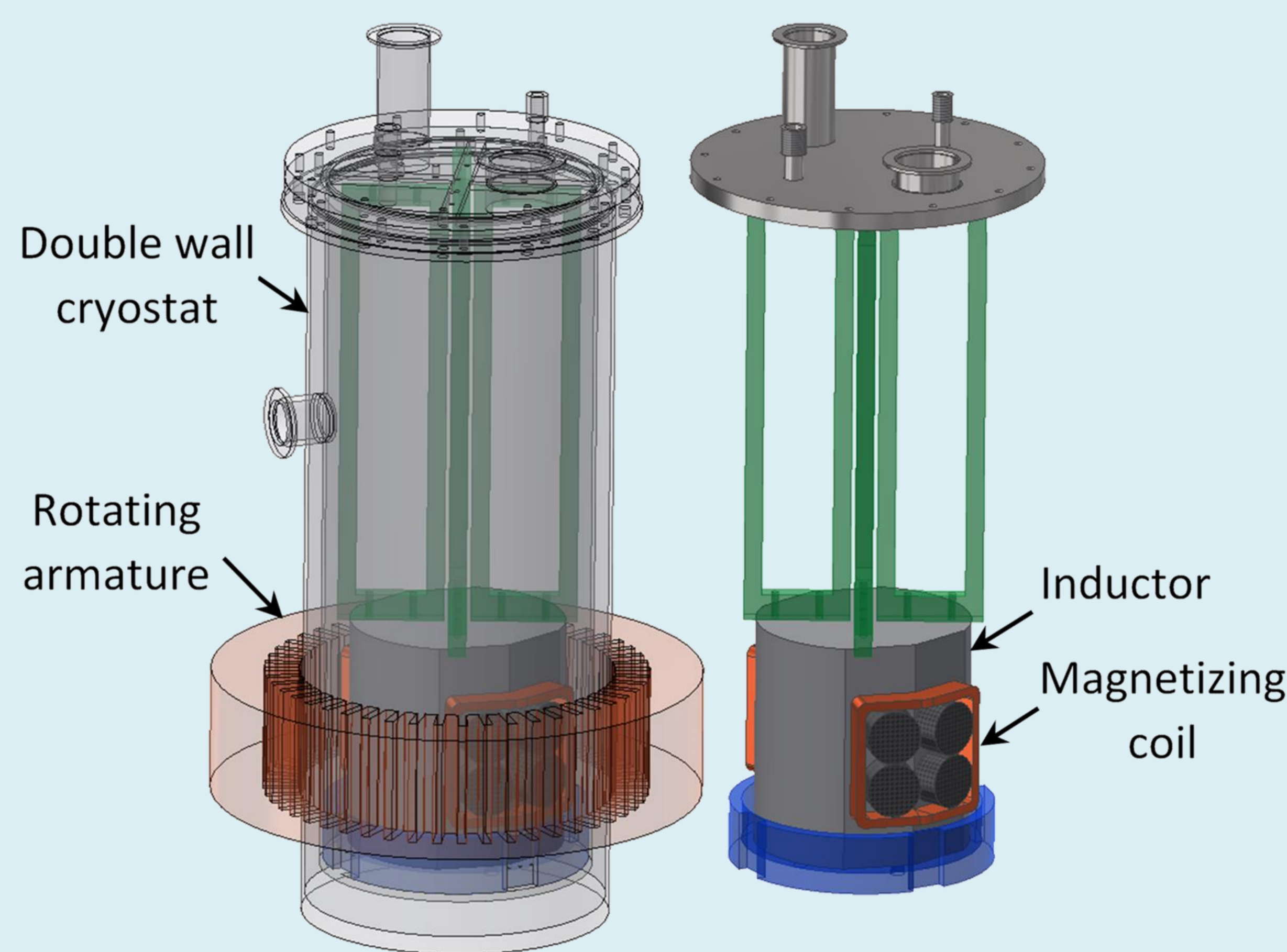


TABLE I  
SOME GEOMETRICAL PARAMETERS OF THE MOTOR

Symbol	Quantity	Value
$R_{cyl}$	radius of the ferromagnetic cylinder of the inductor	61 mm
$R_{ind}$	overall radius of the inductor including the HTS bulks	74 mm
$e_1$	mechanical air gap between the inductor and the cryostat	1 mm
$R_{int}$	inner radius of the cryostat	75 mm
$e_2$	overall thickness of the cryostat	12 mm
$R_{out}$	outer radius of the cryostat	87 mm
$e_3$	mechanical air gap between the armature and the cryostat	2 mm
$R_{arm}$	inner radius of the armature	89 mm
$e_4$	total air gap between the inductor and the armature	15 mm
$L_{arm}$	active length of the armature	70 mm

### Preliminary design of the whole structure

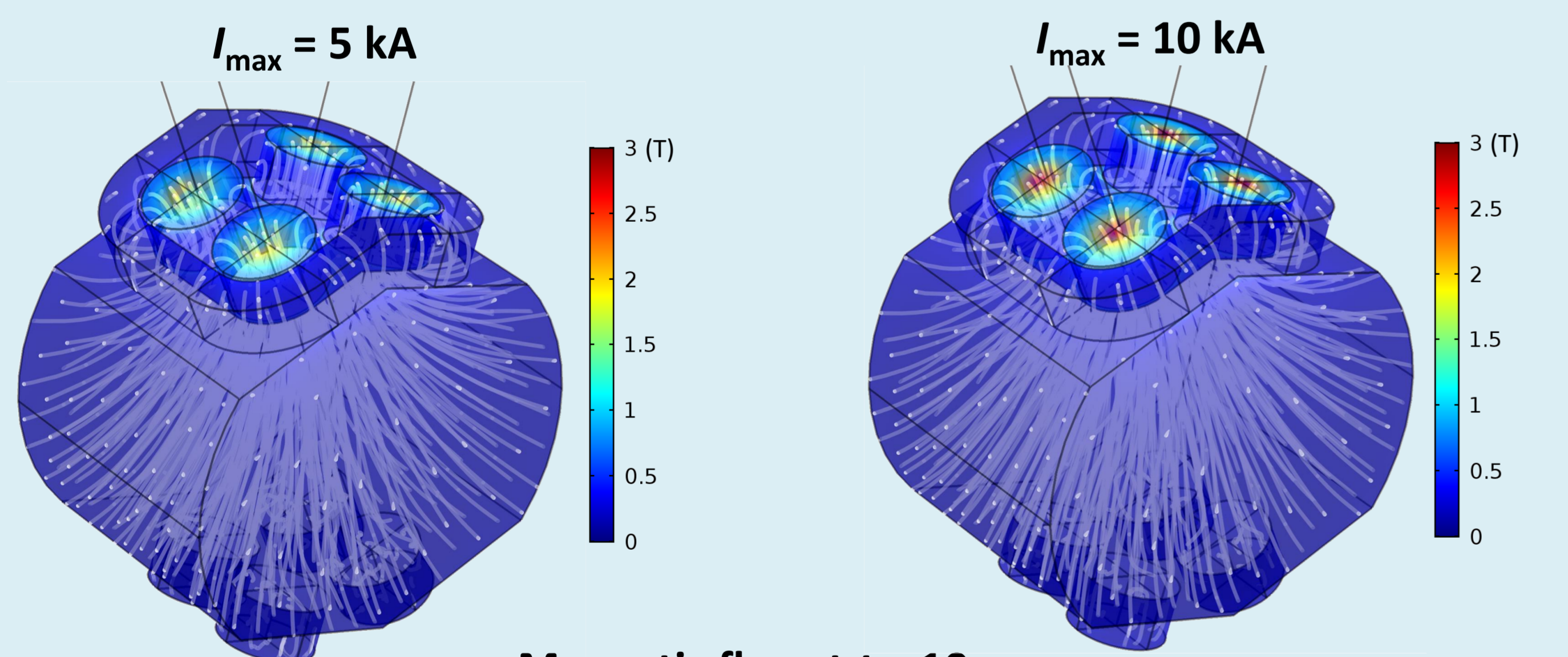


### Description

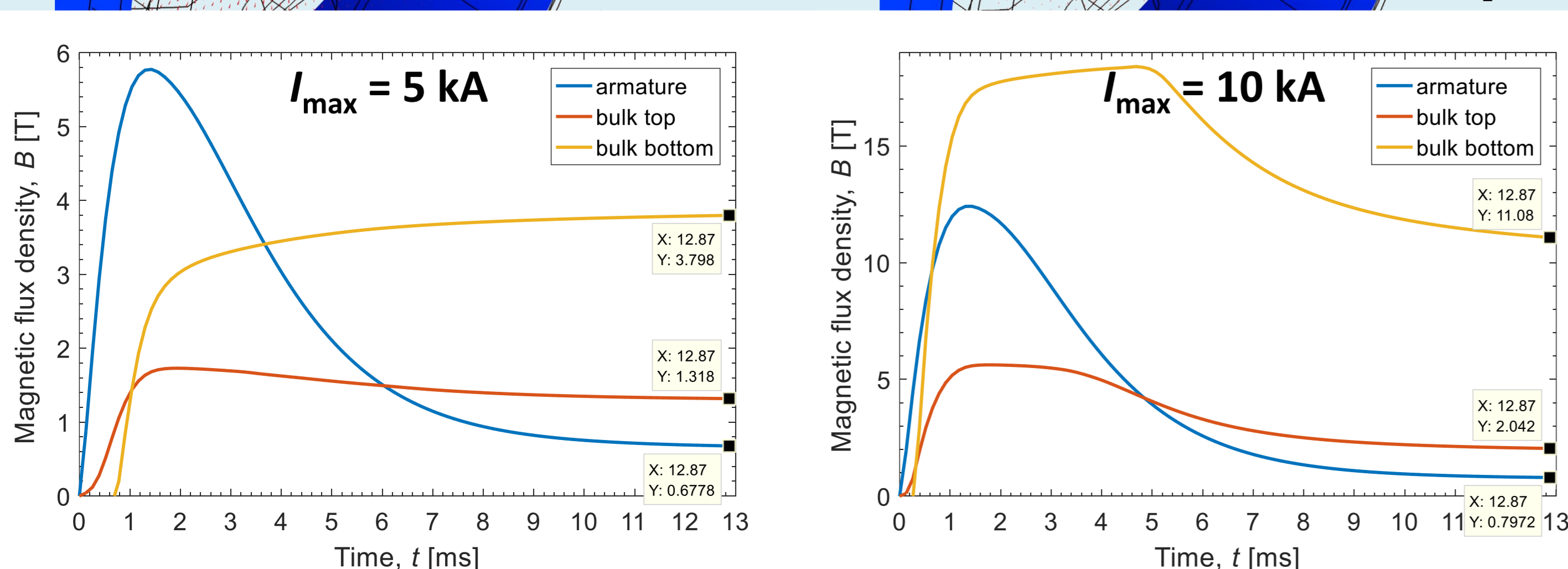
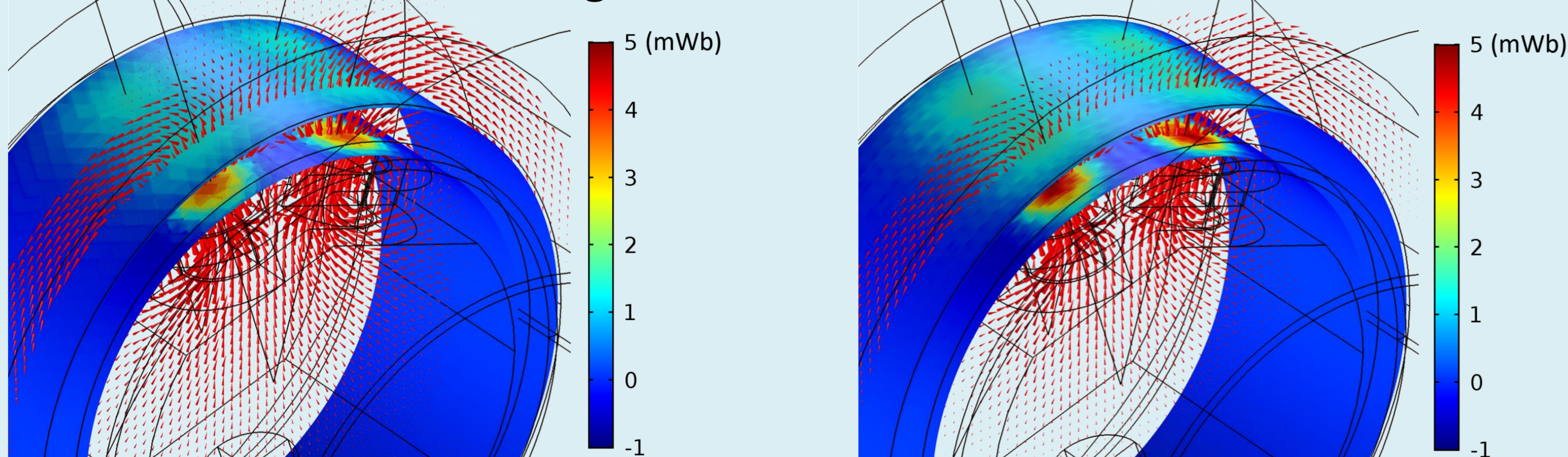
- ✓ The rotating machine, shown on the left side, has the particularity to have an inductor part mounted inside a stationary cryostat and a rotating armature outside the cryostat.
- ✓ The inductor will consist of one-pole pair, each pole contains four HTS bulks to be magnetized, mounted on a square pattern. We planned to use melt textured (RE)BCO bulks of 31 mm of diameter. The typical trapped magnetic flux density of one bulk with a PFM process is 700 mT @ 77 K.
- ✓ Several cooling systems are being considered:
  - Liquid Nitrogen,
  - A cryocooler placed on the lower part of the cryostat,
  - Frozen Nitrogen,
  - Liquid Helium,
  - In transient stage with Helium gaz.

## 3D numerical modeling

### Magnetic flux density distribution at $t = 10\tau$



### Magnetic flux at $t = 10\tau$



## Modelling Framework

The conductor used for the coil is a copper foil of 0.2 mm thickness and 12 mm high, insulated using Kapton tape 25  $\mu$ m. The coil consists of 28 turns. The coil current is assumed to be known and imposed as :

$$i(t) = I_{max} \frac{t}{\tau} \exp\left(1 - \frac{t}{\tau}\right) \text{ with } I_{max} = \{5; 10\} \text{ kA and } \tau = 1.3 \text{ ms}$$

The iron parts being saturated,  $\mu_r = 10$  has been considered

### H-formulation with non-linear resistivity

$$\nabla \times \mathbf{E} = -\frac{\partial(\mu_0 \mu_r \mathbf{H})}{\partial t} \text{ and } \nabla \times \mathbf{H} = \mathbf{J} + \mathbf{J}_s, \text{ with } \mathbf{J}_s \text{ the current density applied in the coil}$$

$$\text{In the HTS bulk: } \mathbf{E} = \rho(\mathbf{J})\mathbf{J} \text{ with } \rho(\mathbf{J}) = \left(\frac{E_c}{J_c} \left(\frac{\|\mathbf{J}\|}{J_c}\right)^{n-1} + \rho_0\right) \text{ and } \rho_0 = 10^{-14} \Omega \cdot \text{m}$$

$$J_c = 200 \text{ A/mm}^2 \text{ and } n = 21$$

## Conclusion & perspectives

- ✓ A 3D non linear problem of a HTS machine has been simulated using H-formulation in COMSOL,
- ✓ A trapped magnetic flux density of 2 T are achieved on the top surface of the HTS bulks,
- ✓ The maximal magnetic flux at the stator radius is around 1.5 mWb,
- ✓ This leads to 21 mWb/m (per active length of the machine), which is comparable to others machines,
- ✓ Thermal and magnetic dependencies of HTS bulks have to be taken into account,
- ✓ Other configurations have to be studied in order to increase the magnetic flux.