The final cooling solenoids are part of the cooling system, in particular of the final cooling channel, which is constituted by several cells. At present, 14 cells are considered by IMCC. Each cell starts with a strong focusing final cooling solenoid enclosing the LH_2 absorber, which is followed by matching coils, energy-phase rotation rf cavities, and acceleration rf cavities. In total we need hence 14 final cooling solenoids.
The final cooling solenoids have been identified as the critical components of the final cooling section and for this reason our efforts have been focused to identify suitable designs for it. The main specifications used for the conceptual design are: 1) B ≥ 40 T, aperture $\boldsymbol{\phi} \geq$ 50 mm, field homogeneity 1 % over ˜ 0.5 m ; 2) 6 hrs energizing time, and 0.1 Units/s Persistency.
At present to reach static magnetic fields in excess of 40 T, only hybrid SC + resistive solenoids exist; however, these magnets have an unacceptable power consumption (>10 MW) for particle accelerator sustainability.
Regarding the all-superconducting option, solenoids reaching fields around 30 T in a bore up to 5 cm exist; they are hybrid in terms of the superconductor used: NbTi, Nb3Sn, ReBCO. All the mentioned solenoids are based on nested coils and present very large windings (radially): the outermost radius of the winding is larger than 25 cm. The reason for these large dimensions is that a solution to contain the hoop stresses is to dilute the current in large windings where blocks of turns are decoupled mechanically (nested coil). This design concept, applied to all SC solenoids, will be further investigated and perfected by ongoing projects that try to optimize it and to reach larger field values (see 40 T project at NHFML) While this design is suitable for user facilities, it is not clear it could satisfy the needs of the final cooling solenoids (cost, sizes, protection…).
For our conceptual design we decided to pursue another direction: compact, high Je ReBCO NI/MI windings made of a single block (no nested coils). Such a concept allowed S. Yoon and his team to reach 26.4 T in 35 mm bore solenoid; the estimated maximum hoop stress reached is 284 MPa. Because the hoop stress is proportional to B^2 and out target is a fields larger than 40 T, we decided to support radially the coil with stiff rings that also applies a precompression of 200 MPa at room temperature. Our FEM analysis showed that this precompression can be applied via shrink fitting and that the maximum stresses in the 6 cm thick coil, when energized to 40, is well below the conductor limits. The table below summarize the pro and cons of the different technology options to reach our field targets.

Technology	Pro's	Con's
Hybrid SC (LTS) + **resistive** Insulated Nested Coils	**Known technology** (TRL 9)	Large dimension and mass **Electric power** consumption
All SC, LTS + HTS Insulated Nested Coils	**Known design principles** Synergy with other fields of science application Can profit from development by others (e.g. NHMFL)	**Large dimension and mass** Developmental technology (TRL 6/7)
All SC**, HTS** Insulated Nested Coils	More compact than LTS/HTS Allows for operation at **higher temperature**	R&D at **low readiness** (TRL 4/5)
All SC, HTS **Non/Metal-insulated** Nested Coils	**Same** as **previous case** (row) **+** even **more compact,** with an **increased magnet stability** and **reduced risk** of **burning** the magnet. **Potential** of reaching even **larger fields** with **respect** to the **single coil** solution (next row). **Synergies** with **other fields of science** and **societal applications**. Can profit from development by others (e.g. NHMFL)	R&D at **low readiness** (TRL 3/4/5) **Ramping time**, **field stability** need, and **electro-mechanical** behavior during **fast transients** to be demonstrated
All SC, HTS Non/Metal-insulated **Single Coil** (No Nested)	**Same** as **previous case** (but the max. field potential) **+** even **more compact, with** a **lower risk** of **burning** the magnet**, simpler to protect, reduced number of** coils (one per pancake) and **joints**. Significant **cost/volume/weight reduction** for **20-40 T solenoids.**	**Same** as **previous option** (row) including TRLs + mechanical **precompression** (B>30 T) need **to be demonstrated**

We chose the all-HTS NI/MI Single Coil (pre-compressed) option because of its very high potential (for future particle accelerators and other societal applications) and because nobody is pursuing it (as far as we know).
The potential of a large coils' cost/mass/volume reduction and of operating at 20 K, makes this technology extremely attractable not only for the sustainability of medium/large particle accelerators but also for: Compact/Modular Fusion Reactor based on magnetic confinement, High Field Science, Nuclear Magnetic Resonance, Magnetic Resonance Imaging, Wind turbine generators.
From our conceptual design study, we can so far conclude that:

- The conductor critical current seems not to be a limiting factor for a all ReBCO 40-50 T solenoid with a 50 mm bore
- The proposed conceptual design shows the potential for developing a compact 40 T final cooling solenoid
- Two main criticalities have been identified:
  1) The electro-mechanical design → stresses on the conductor are very large
  2) The electrodynamics and protection of the magnet → complex transients to control
- CERN INFN, CEA, CNRS, PSI,UniGE, SOTON, UniTwente started to tackle these criticalities via modeling and experimental activities

The overall work plan, scheduling and resources have been defined and summarized in documents. If proven successful, this technology will have a huge relevance to Science and Society and for this reason we can count on several enthusiastic young researcher who strongly push the fast progresses of the project.