Cost model

Daniel Schoerling

On behalf of the cost model task
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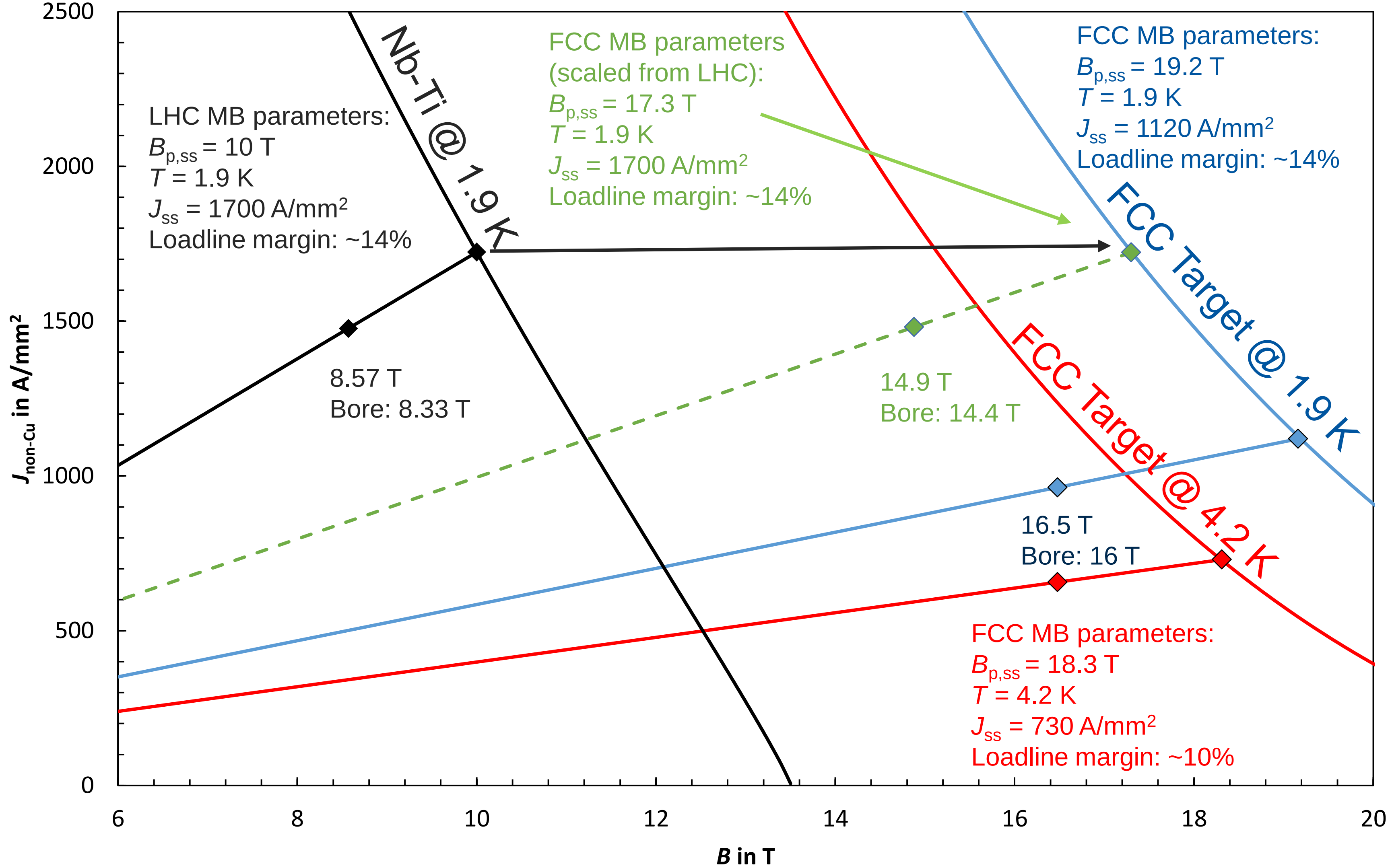
Introduction

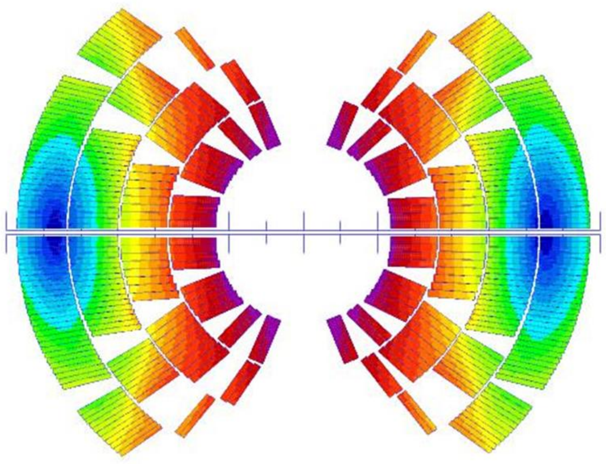
- The cost model is established within EuroCirCol, WP 5.3 and is accompanying the EuroCirCol study since the beginning.
- Members of WP 5.3 are CERN (coordination), CIEMAT (cost of parts), and CEA (cost of assembly) with help from other members of WP5
- The main target was to give strategic guidance to the main decisions and to provide some indication of the expected cost for the FCC magnet system (dominated by the dipole magnets)

Initial thoughts

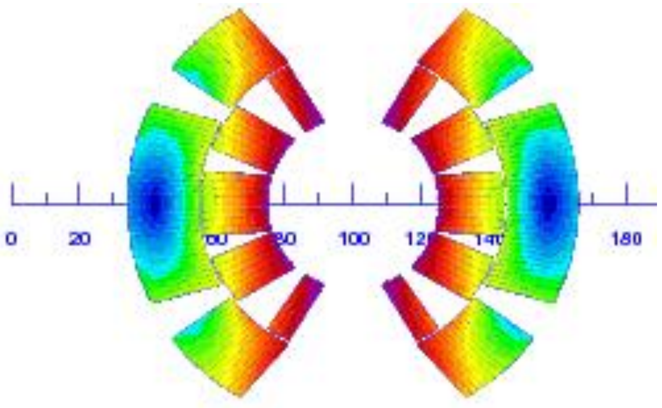


FCC Target is J_c(16 T, 4.2 K) = 1500 A/mm^2

The lower J_{eng} has a large impact



16 T magnet



14 T magnet

14T: ~40% less conductor
2 instead of 4 layers
Less than 15% decrease in field

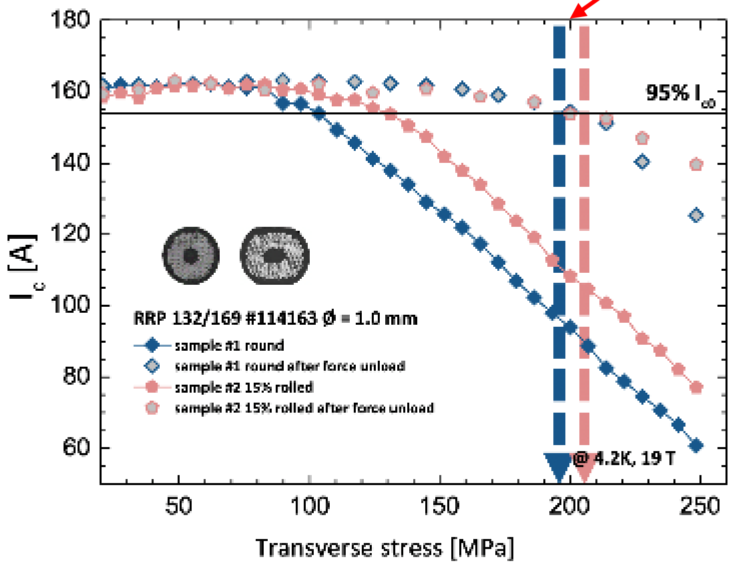
Large impact on :

- Quantity of conductor
- Number of coils
- Complexity of the assembly

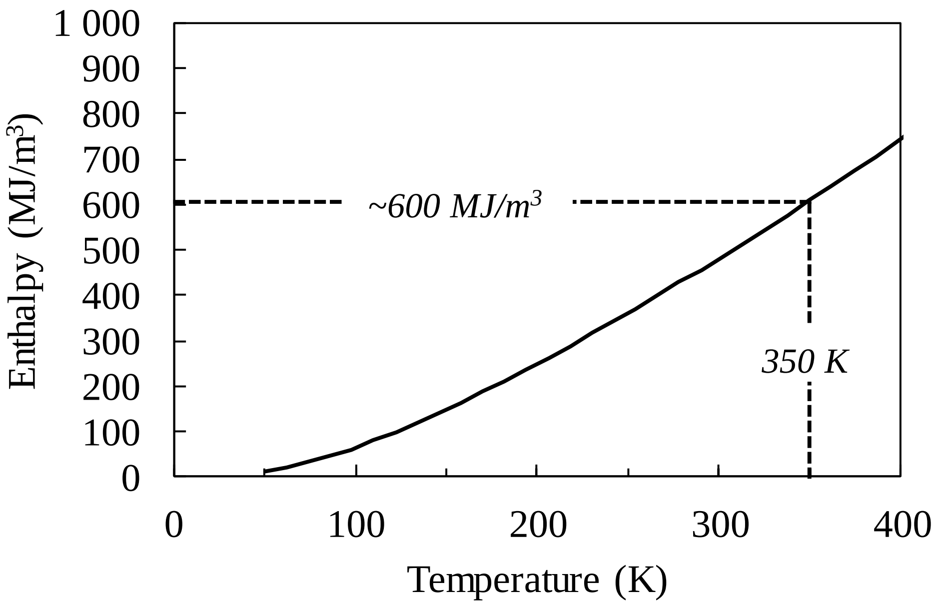
Margin and operating field

- For a high-field dipole of a given field *B* and aperture *r*, we find

$$\sigma \sim J \text{ and } E/V \sim J$$

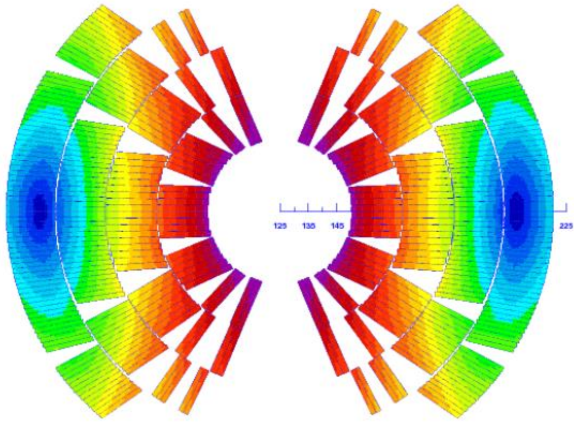


Wire Measurement @Univ. Geneve



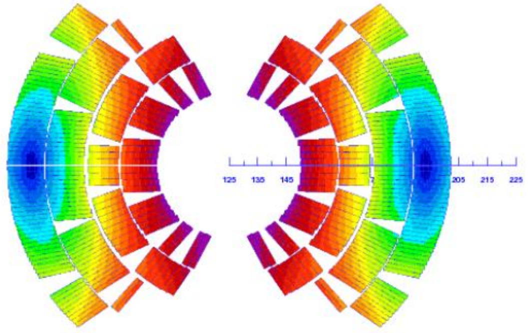
- The cost model asks for the largest *J*, the magnet designer (should) ask for the smallest *J* acceptable

Target *J* in comparison to target J_c



HL-LHC strand

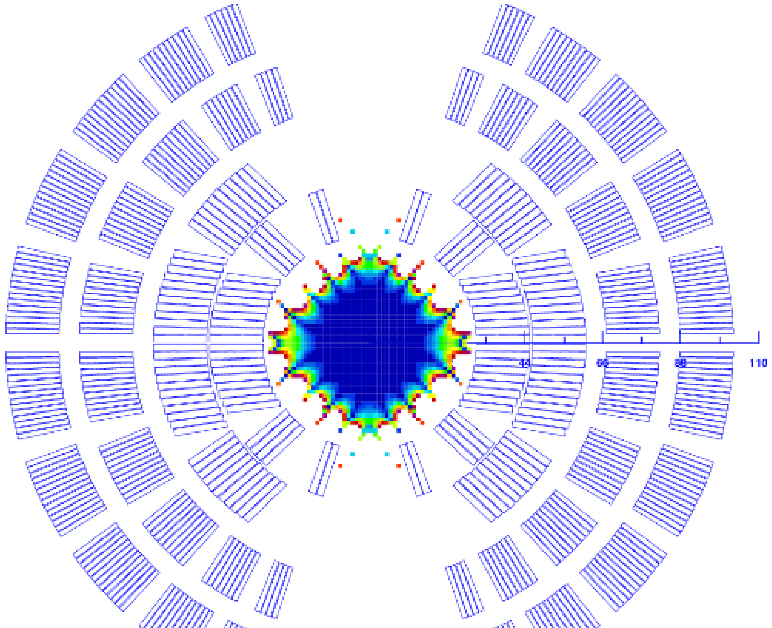
(J_c = 1000 A/mm^2 at 4.2 K, 16 T)



FCC target strand

(J_c = 1500 A/mm^2 at 4.2 K, 16 T)

- The current baseline design would profit from a further increase of J_c beyond the target parameters to go from a Cu/Non-Cu ratio of 0.8 to 1. Using this gain to further decrease the coil size seems difficult, due to mechanical limitations.
- On the other hand, a lower *J* makes stress management and protection easier. As an alternative, ideas distributing the conductor over larger volumes, are in some way similar to a decrease of *J*, with the additional feature of introducing a distributed support system.



A.V. Zlobin et al.

Target J_c

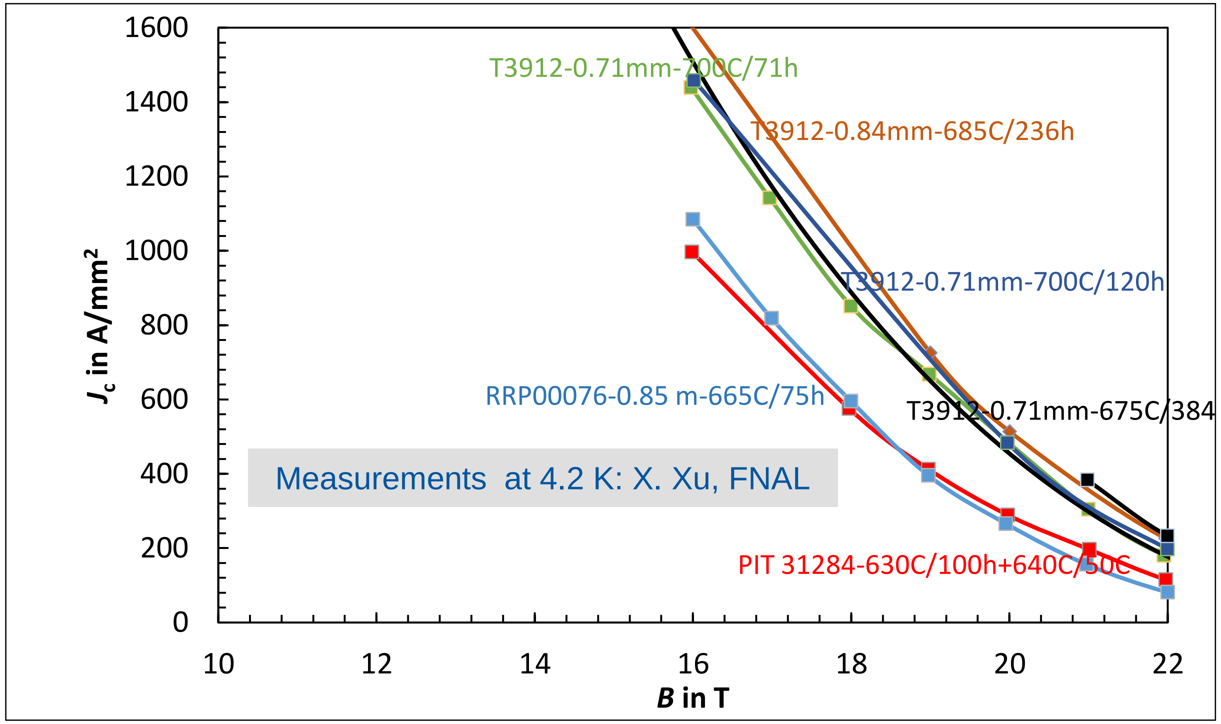
- The conductor program is broadening the supplier base and working towards reaching the main target parameter (J_c)
- Recent results with Artificial Pinning Center (APC) are very promising, achieving at a laboratory level the FCC target of J_c(16T, 4.2K) ~ 1500 A/mm^2
- Industrialization and cost-reduction is yet to come

Main development goals:

- **J_c (16T, 4.2 K) > 1500 A/mm^2**
- 50% higher than HL-LHC

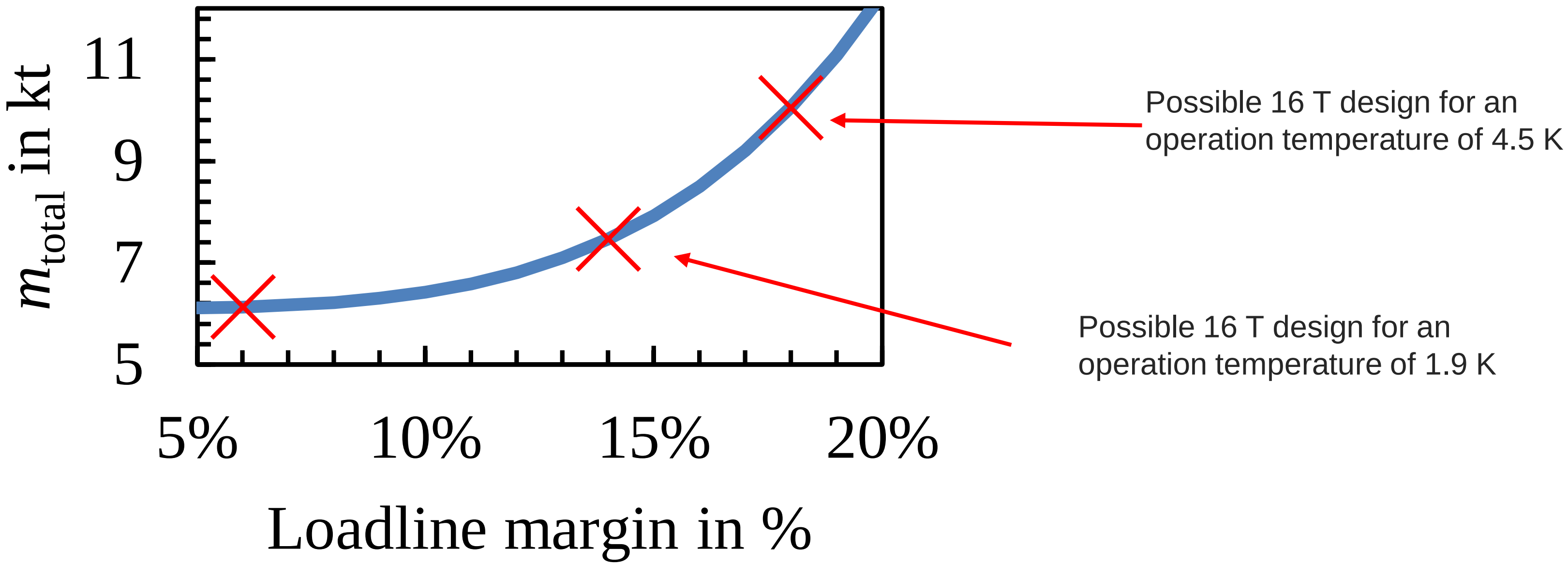
Global cooperation:

- CERN/KEK/Tohoku/JASTEC/Furukawa
- CERN/Bochvar High-tec. Res. Inst
- CERN/KAT
- CERN/Bruker
- T.U. Vienna, Geneve U., U. Twente,
- Florida S.U. - Appl. Superc. Center
- US-DOE-MDP, Fermilab



Operating temperature

- At the time of the start of the construction for LHC the Nb_3Sn technology at 4.2 K was in competition with Nb-Ti technology at 1.9 K for the MBs. At that time, it turned out that cryogenic systems at 1.9 K are easier to realize and less expensive than making Nb_3Sn magnets (a statement still true today looking at the experience until now).
- This historic view may explain, why initially an operating temperature at 4.5 K was proposed for FCC. However, and again, it turned out that a cryogenic system at 1.9 K is more cost efficient and technically more appealing than operating magnets at 4.5 K. Furthermore, it is also advantageous for the vacuum system.



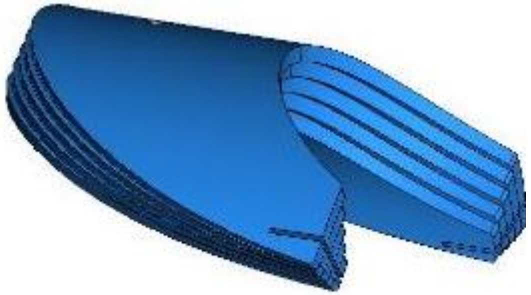
Cost of magnets

How can one credibly estimate the cost of an object never designed nor produced?

- We decided to follow a two-fold approach
  - Scaling from LHC
  - Work on the cost reduction of the parts and assembly
- Conductor cost: Mainly processing cost, see conductor session
- Assembly cost: See talk of UoTampere;
- Parts cost: Large optimization potential with industry, no (major) issue expected to reduce cost largely compared to HL-LHC and to obtain the parts in industry.

Conductor cost:	0.7 MEUR/magnet
Assembly cost:	0.6 MEUR/magnet
Parts cost:	0.5 MEUR/magnet
Total cost:	**1.8 MEUR/magnet**

Courtesy: Sintex, Denamrk



Courtesy: A. Ijspeert

Some personal remarks

- The difference between a 14 T and a 16 T magnet is very large, in terms of quantity of conductor needed, number of coils, and complexity of the construction. Though, on paper, a 16 T magnet is possible and is costing about twice the cost of a LHC magnet for twice the field. Achieving such a construction on a large series may be extremely difficult. I believe that considering a two-layers 14 T magnet would be much more cost-effective and reduce the complexity.
- The conductor program is giving very promising results, however a strong cost reduction is essential to make a large production economically feasible.
- The dipole magnet reaching so far the highest field (Fresca2) features a low current density (*J*), the opposite of a cost efficient accelerator magnet design promoted by the cost model. The battle between a cost-efficient magnet and a reliable magnet design can only be solved by building prototype magnets.
- All different design options (common-coil, cos-theta and block) have their specific features, in my opinion only a serious model program can deliver an answer which design is best (and this answer will be valid only for a certain field range, which should be re-defined)!

Main publications related to the cost model

D. Schoerling et al.,“Strategy for superconducting magnet development for a future hadron-hadron circular collider at CERN.” EPS-HEP, 2015, Proceedings of Science.

D. Schoerling et al., Considerations on a cost model for high-field dipole arc magnets for FCC, IEEE Transactions on Applied Superconductivity, vol. 27, No. 4, June 2017.

D. Schoerling et al., The 16 T dipole development program for FCC and HE-LHC, IEEE Transactions on Applied Superconductivity, 2019, DOI: 10.1109/TASC.2019.2900556.