Design options in the 15-20 T range

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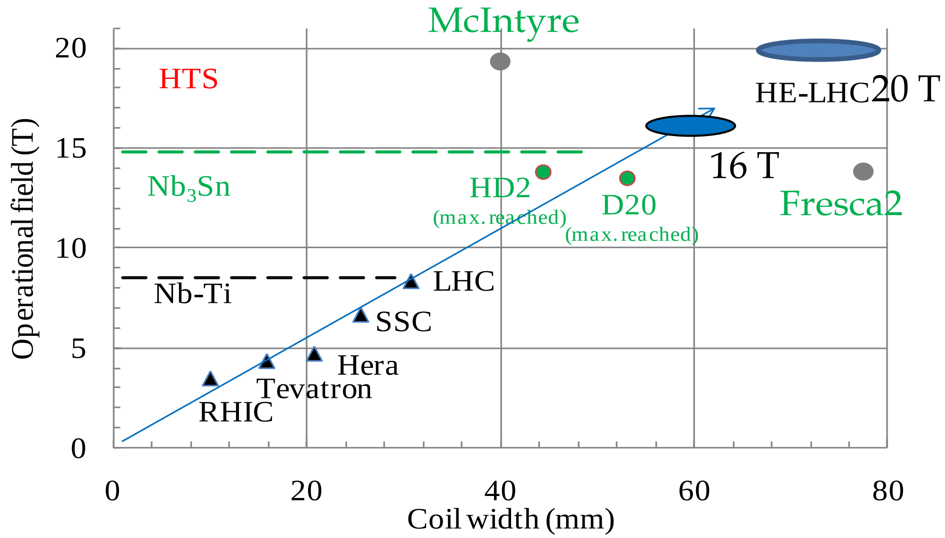
Acknowledgements: L. Bottura, G. De Rijk, P. Ferracin

Based on recently published paper
"Dipoles for High Energy LHC"
IEEE Trans. Appl. Supercond. 24 (2014) 4004346

Current density

- Operational current density
  - Of the order of j_o~400 A/mm² and j_{sc}~1200 A/mm²
    - Why not more? Two reasons: stress, protection
  - Example: D20 had j_o~550 A/mm² and j_{sc}~1600 A/mm² in outer layer → impossible to protect
- So ~80 mm coil width for 20 T, ~60 mm for 16 T
  - We had 30 mm in LHC - it's a large step

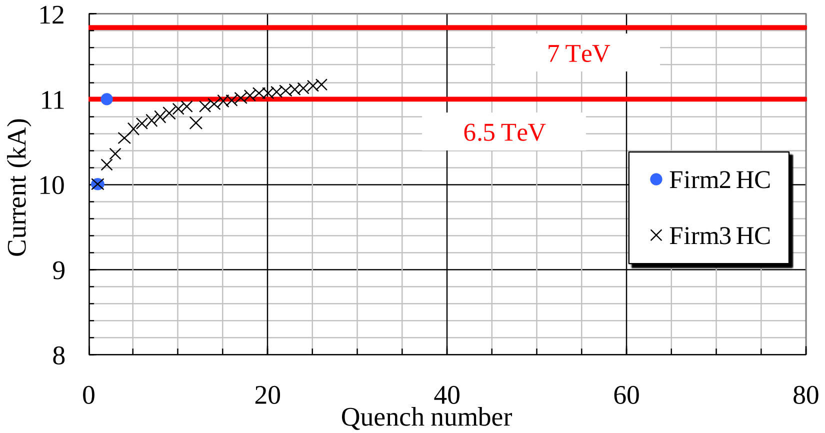


Field verus coil width in accelerator magnets and models

[E. Todesco, L. Rossi Malta workshop CERN 2011-003]

How much margin?

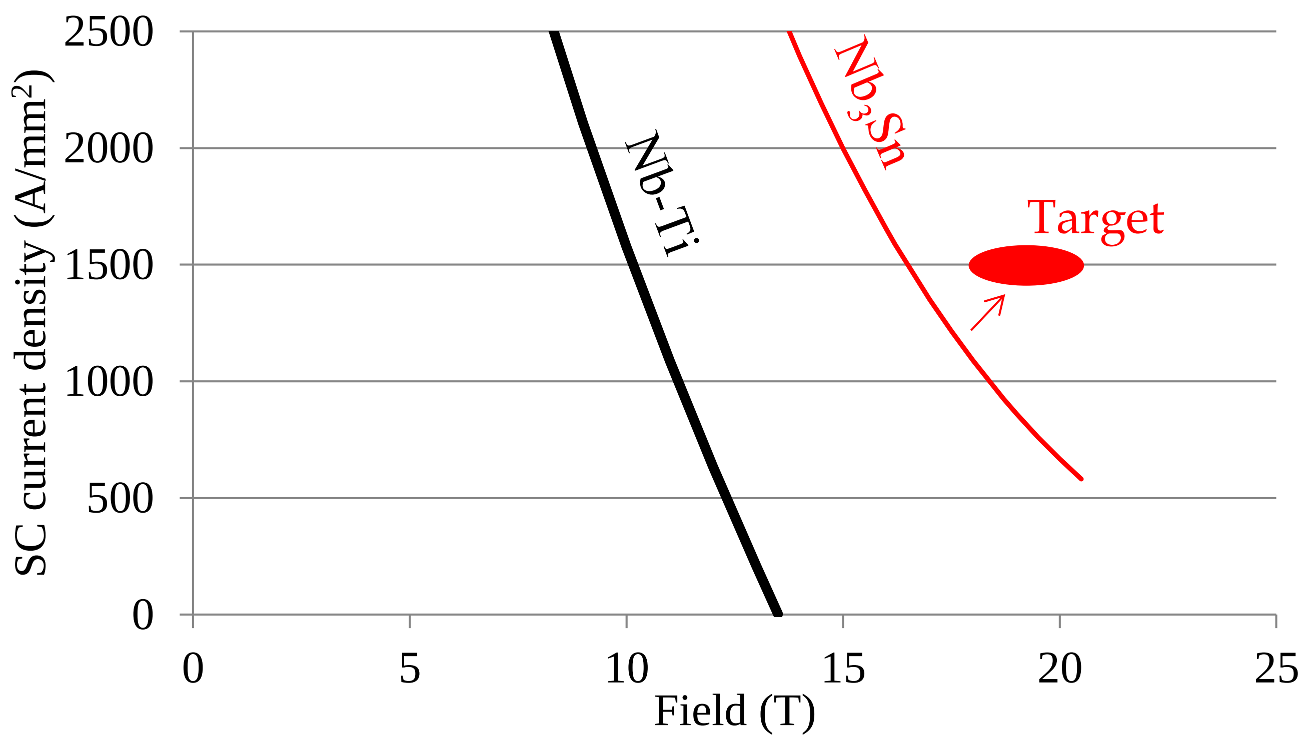
- 20% margin means that a 16 T magnet is designed for 20 T
  - Is 4 T margin too much ? This is the Tevatron dipole …
  - Should we take the margin in T and not in %?
- Experience with LHC at 7 TeV will be crucial
  - LHC dipole at 7 TeV are at 86% of the loadline – 14% margin
  - One sector was pushed to 6.6 TeV with 25 quenches, corresponding to 20% margin for the LHC dipoles
  - Was this an accident due to Firm3 magnets or is it a common feature?



Training of one LHC sector in 2008

Superconductor properties

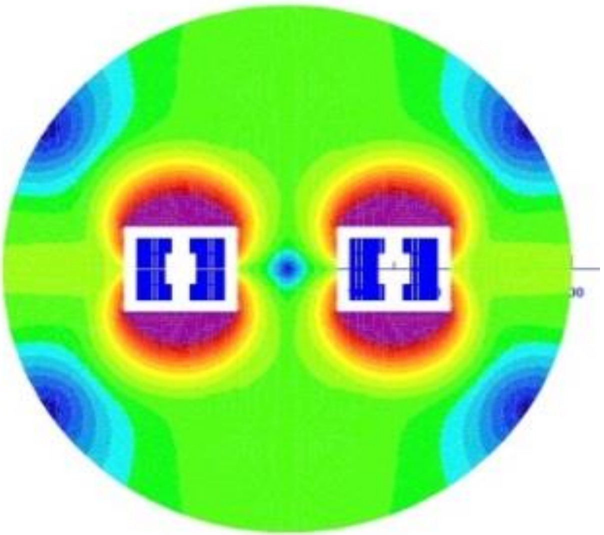
- Asking for j_{sc}~1200 A/mm^2 at 16 T operational, with 20% margin we need j_{sc}~1500 A/mm^2 at ~20 T
  - Today this value is reached for 16.5 T, not enough
  - Performance should be pushed in this direction



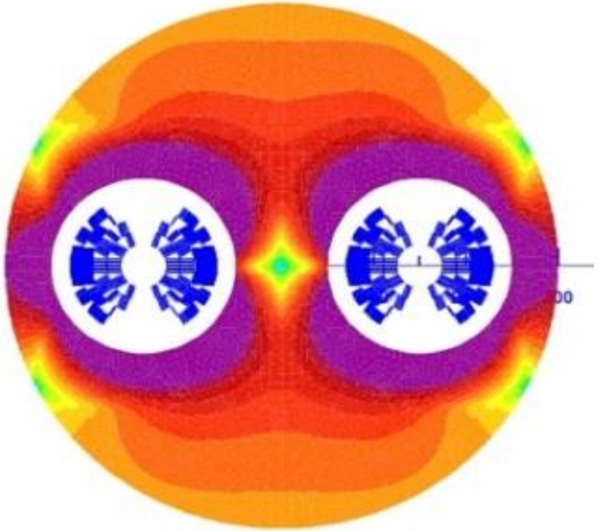
Critical surface of Nb-Ti, Nb3Sn and target for a 16 T magnet

BLOCK AND COS THETA

- Cos theta
  - Wide experience, design is more effective, easy heads
    - In progress: 11 T, QXF (~12 T peak field in operational conditions)
- Block
  - One can completely fill the available space, very little experience, difficulties in the head transition
    - In progress: FrescaII (~15 T field with 20% margin)



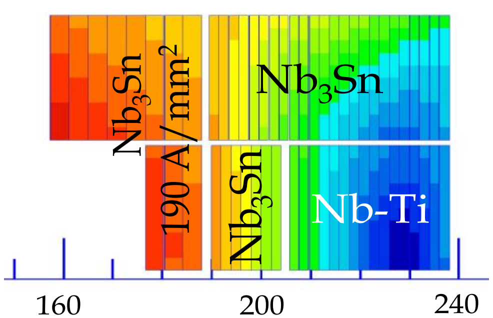
HD2 dressed as HE LHC magnet



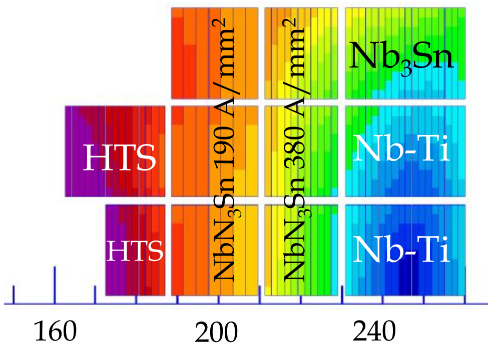
D20 dressed as HE LHC magnet

Grading

- There is a trade off between complexity and price
  - Mastering coil fabrication with different materials
    - Lower performance (and lower cost) material in low field region
  - Mastering internal splice technology
- Examples (just to give an order of magnitude)
  - 15 T: grading allows saving ~20% of the cost
  - 20 T: grading allows saving ~15% of the cost



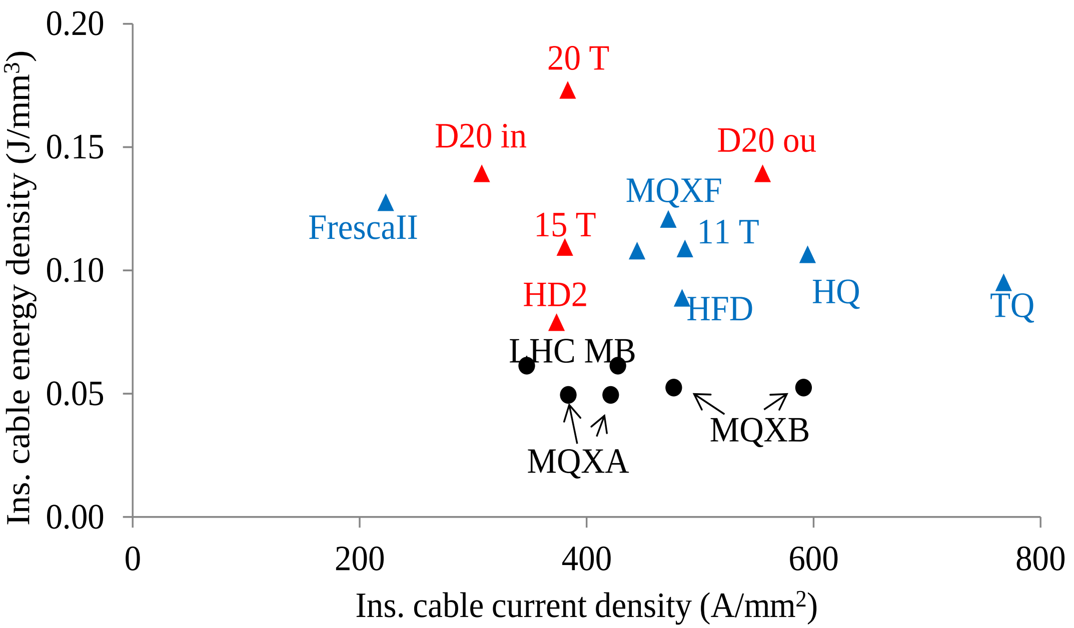
Coil sketch of a 15 T magnet with grading



Coil sketch of a 20 T magnet with grading

PROTECTION

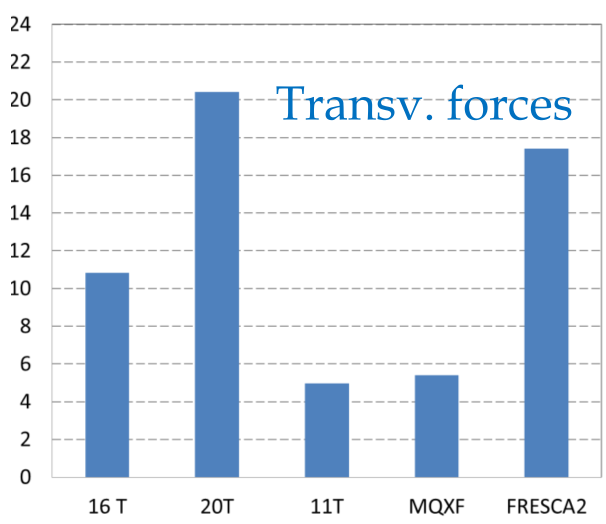
- Energy density is also a critical parameter
  - 0.05-0.06 J/mm^3 in Nb-Ti
  - 0.10-0.12 J/mm^3 in Nb_3Sn current projects (QXF, 11 T)
  - The 16 T is in the same range, the 20 T is 50% larger
- With these reasonable current densities, protection looks viable

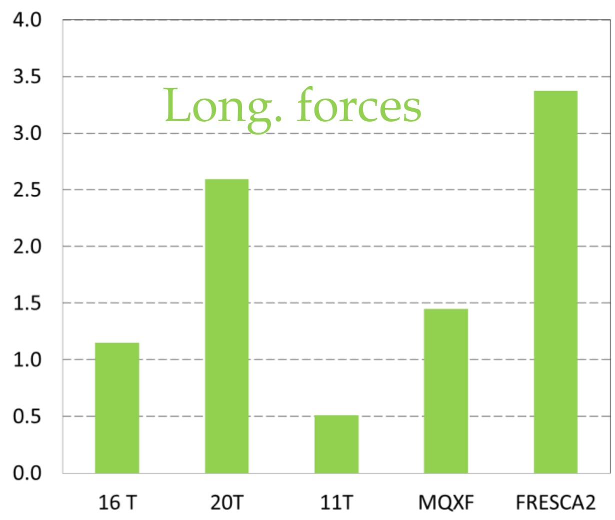


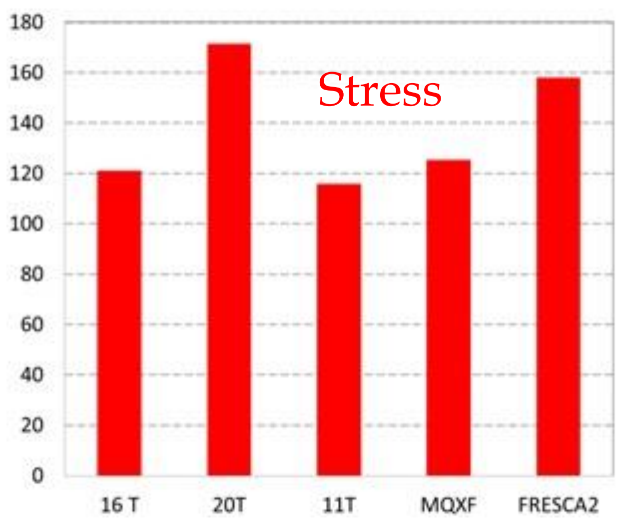
Energy density versus current density for accelerator magnets and models
[E. Todesco, et al., IEEE TAS 24 (2014) 4004346]

Structure and Stress

- Estimates from P. Ferracin, based on scaling laws [P. Fessia et al., IEEE TAS **17** (2007)]
- Stress in the conductor:
  - 16 T at the level of QXF (120 MPa)
  - 20 T at the level of FrescaII at ?? T
- Forces in the structure
  - At the level of FrescaII







SUMMARY

- Margin is a big unknown: is 20% too much?
  - LHC will give us precious information
- Hi-Lumi magnets will prove the technology for 16 T dipole
  - 11 T, inner triplet, FrescaII have features that are essential to prove the level of field, forces, stress
- Main directions to follow
  - Superconductor
    - Aiming at 1500 A/mm^2 at 18-20 T in Nb_3Sn
  - Current density: reduce the HiLumi values (QXF, 11 T) of overall current density from 500 A/mm^2 to 400 A/mm^2
    - Needed to master stress, protection
  - To reduce the cost
    - Mastering splice technique and grading to reduce cost
    - Mastering hybrid coil technique
  - Pursuing the block option to keep an alternative to cos theta

SUMMARY

	16 T magnet		
	11 T	QXF	FrescaII
Field at 80% of short sample	11	12	15
Coild width	half	half	25% more
Stress	same	same	30% more
Transv. Forces	half	half	50% larger
Long. Forces	half	50% larger	3.5 times
Current density	20% larger	20% larger	half
Two in one	Yes	No	No
Dipole	Yes	No	Yes
Nb_3Sn grading	No	No	No
Hybrid Nb_3Sn / Nb-Ti	No	No	No

	20 T magnet		
	11 T	QXF	FrescaII
Field at 80% of short sample	11	12	15
Coild width	< half	< half	same
Stress	25% less	25% less	same
Transv. Forces	4 times	4 times	same
Long. Forces	one fifth	half	25% more
Current density	20% larger	20% larger	half
Two in one	Yes	No	No
Dipole	Yes	No	Yes
Nb_3Sn grading	No	No	No
Hybrid Nb_3Sn / HTS	No	No	Yes (with HTS insert)
Hybrid Nb_3Sn / Nb-Ti	No	No	No

- Most fields covered by present programs
  - Grading and hybrid need more