MAGNET SESSION SUMMARY

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Acknowledgements: L. Bottura and all the speakers

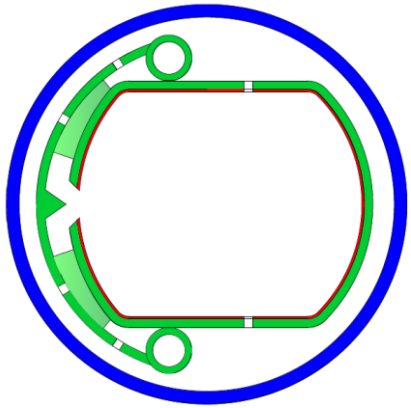
SOME REMARKS

- Design study in initial phase
  - Time not to close the door to ideas, but rather to explore
  - On the other hand …
    - Beam dynamics colleagues (and many others: vacuum, cryogenics, energy deposition …) need a baseline of magnets technology, lengths, field, transverse dimensions
    - Resources are limited, so when it comes to hardware few promising options should be tried (short models)

- Enthusiastic international team built in record time
  - Many labs contributed in US, Europe and Asia
  - Collaboration is fundamental to address the challenges
  - Synergy with Hi-Lumi giving very positive results
  - Massive presence of industry

APERTURE OF ARC MAGNETS

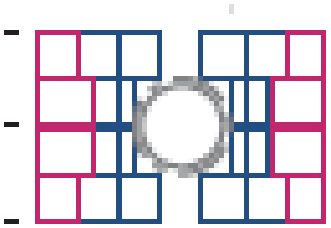
- Initial value was 40 mm → now it is 50 mm
  - Required for adding shielding
- 25% larger aperture has some beneficial effects
  - Solving the issues in magnet sc design for very small apertures
    - Quadrupoles become much less effective
    - Problems with curvature radius in the heads [G. L. Sabbi for main dipoles, C. Lorin for main quadrupole]
  - 25% more aperture gives 10% more conductor, so it is not a $ drama
- Space for shielding and beam screen allows heat removal
  - In principle, no need for open dipole design
  - Option explored by [P. McIntyre, R. Gupta]



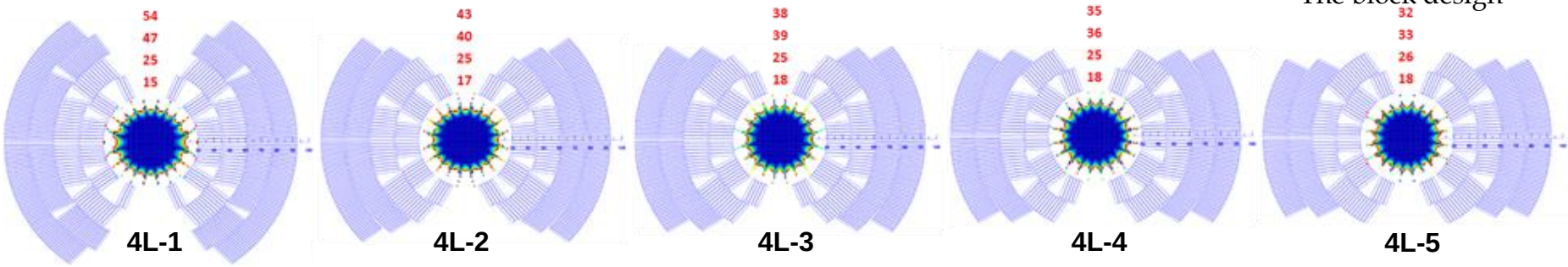
The beam screen design of [C. Garion]

DESIGN OF MAIN DIPOLE

- Block versus cos theta:
  - Similar efficiency between two design [J. van Nugteren]
  - Cos theta moves towards a block like shape [S. Zlobin]

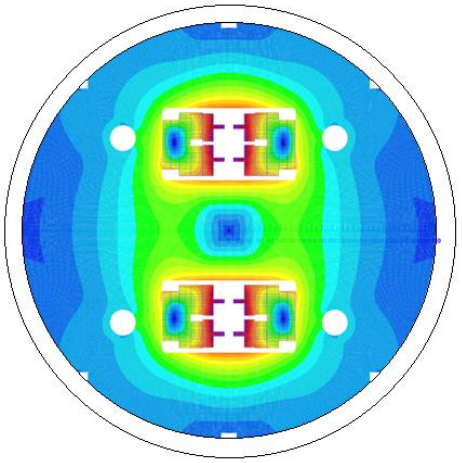


The block design



The origin of the species: from cos theta towards block

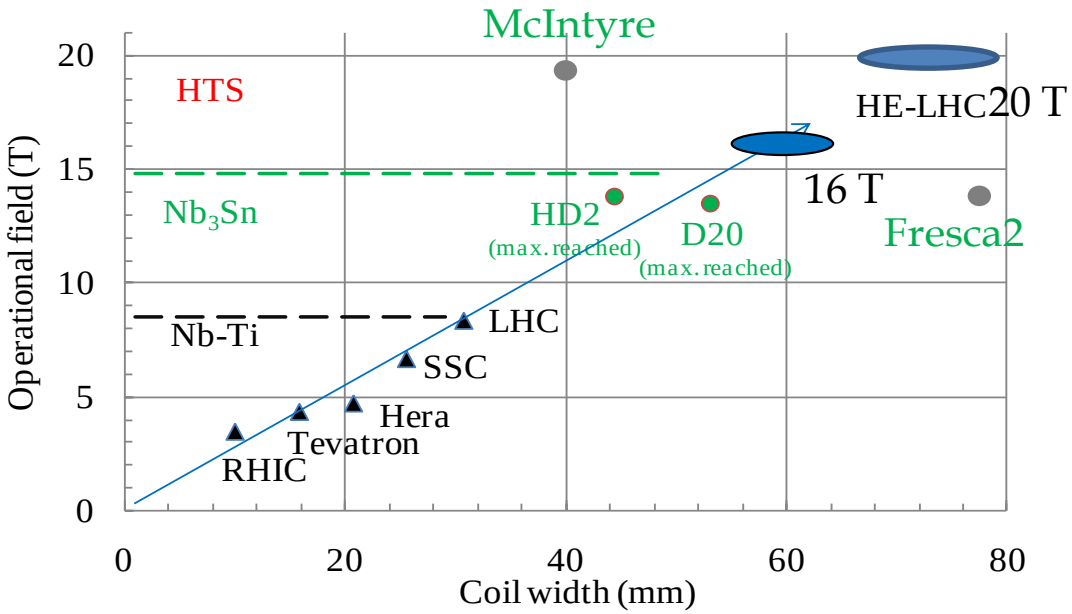
- Grading gives 25-40% saving
  - And using Nb-Ti another 10-15%
- Common coil layout at 20 T with HTS

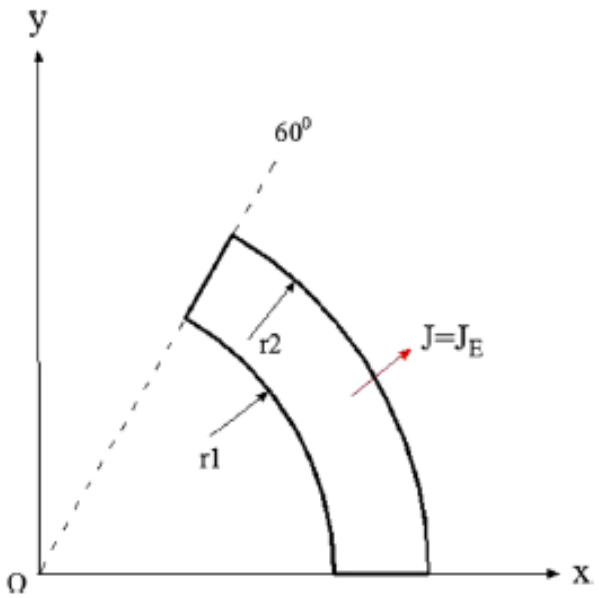


Common coil design [Q. Xu]

DESIGN OF MAIN DIPOLE

- Selection of the coil current density
  - Field=current density * width of the coil
  - Consensus that 400 A/mm^2 is a reasonable and feasible value
  - Coil width needed is 60 mm → two layers not enough

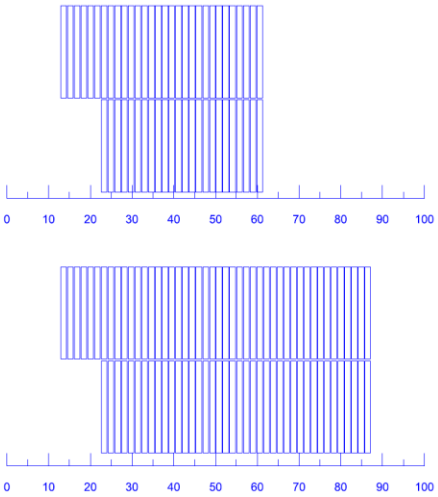




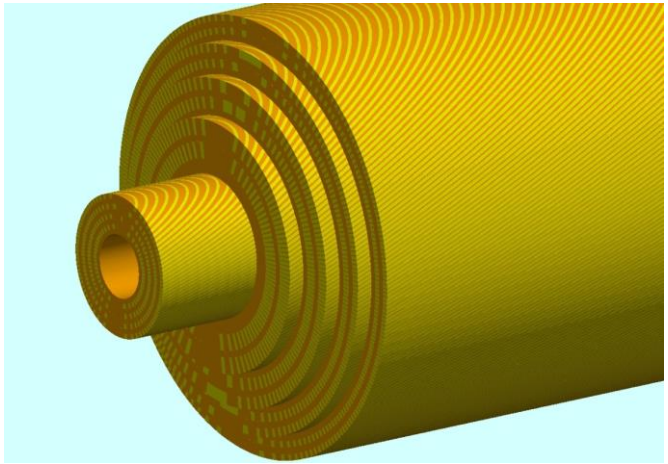
Field versus coil width [E. Todesco, L. Rossi, Malta 2011]

DESIGN OF MAIN DIPOLE

- A few, brave scientists try going beyond the 400 A/mm^2
  - G. L. Sabbi towards 500 A/mm^2 with block
  - S. Caspi towards 700-800 A/mm^2 with canted
    - Advantage: compact coil, lower price
    - Problem: stress, protection
  - It is an option for block, but is a must for canted (otherwise too expensive)



Compact, high current density lay out (top) [G. L. Sabbi]



Type	Non-Cu (%)	T (K)	B_{bore} (T)	$B_{conductor}$ (T)	J_{strand} (A/mm^2)	I_{cable} (A)
1-in-1	47	4.25	15.6	16.1	700	8100
1-in-1	60	**4.25**	16.3	16.9	732	8500
2-in-1	60	**4.25**	**16.7**	17.2	680	7820
1-in-1	60	**1.9**	17.9	18.5	803	9230
2-in-1	60	**1.9**	**18.2**	18.8	740	8510

The canted dipole concept and a guess of main parameters [S. Caspi]

DESIGN OF MAIN DIPOLE

- Margin and training
  - Usually one works at 80% of the maximum possible current (short sample) - this is a 20% margin
  - For the LHC, 20% margin corrresponds to 6.5 TeV

- Consensus on
  - Margin is expensive
  - Margin is needed
  - 20% is enough
  - Can we have less?

- The margin range of 20%-10% should be explored [L. Bottura, G. L. Sabbi, S. Zlobin, S. Caspi, …]

CONDUCTOR

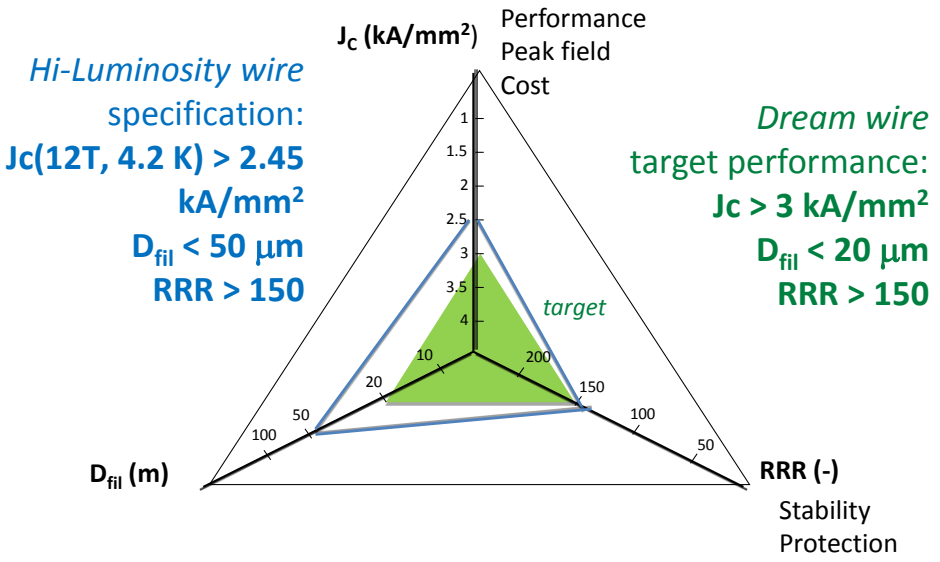
«Ask and it will be given to you» [Mt., 7.7]

«Share the burden» [S. Gourlay, yesterday]

- The golden triangle of Luca and Amalia [ASC 2014]
  - 60% smaller filament (20 μm instead of 50 μm)
  - 50% more j_c at 15 T
  - RRR is OK

Wire diameter	mm	**≤ 1**
Non-Cu Jc (16 T, 4.2 K)	A/mm²	**≥ 1500**
μoΔM(1 T, 4.2 K)	mT	**≤ 150**
σ(μoΔM) (1 T, 4.2 K)	%	**≤ 4.5**
Deff	μm	**≤ 20**
RRR	-	**≥ 150**
Unit length	km	**≥ 5**

Nb_3Sn specification for Hi-Lumi LHC



+ Mechanical properties

CONDUCTOR

- If I had only one wish, I would ask $$$ (less)
  - Cost presented by [L. Cooley]
  - Present cost of Nb_3Sn is a showstopper to the project
  - Cost should be well below 1000 $/kg (Lucio set a target of 800 in Malta)

- If I had a second one: lengths
  - We need kms! This is crucial
- Several talks from manufacturers
  - Eager to take the challenge
- Consensus on
  - Best j_c available today is a must
    - And a 50% increase asked gives 40% reduction of conductor
  - RRR>150 for stability

Visual metaphor for future FCC strand!

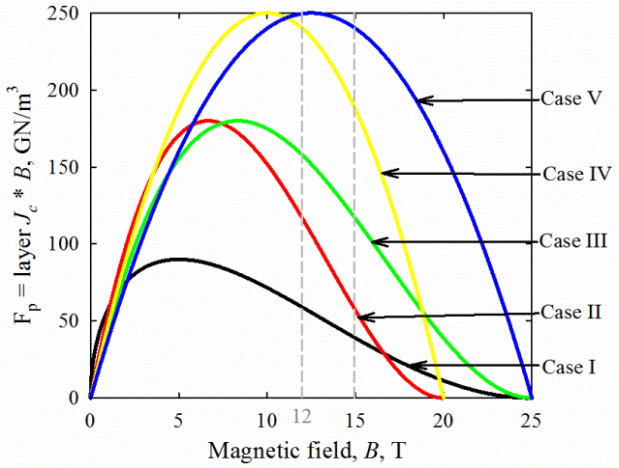
Future FCC conductor [M. B. Field, OST]

CONDUCTOR

- Some questions still open
  - Do we really need 20 μm filament?
    - Efforts to be carried out on persistent current, instabilities, etc
    - Interesting results on field quality in main dipole, that looks nice even with thick filaments [S. Izquierdo] but for D1 is critical [T. Nakamoto]
  - HL-LHC magnets will have 50 μm filament size, will be a good test for instabilities

- US effort to explore the ultimate limits in Nb_3Sn current density:

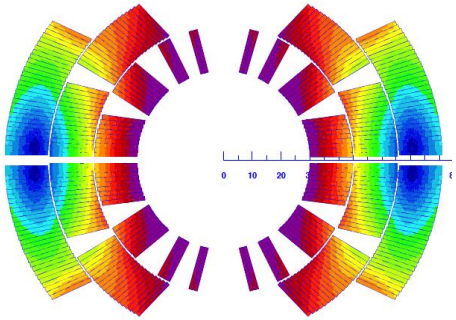
The outlook is impressive …



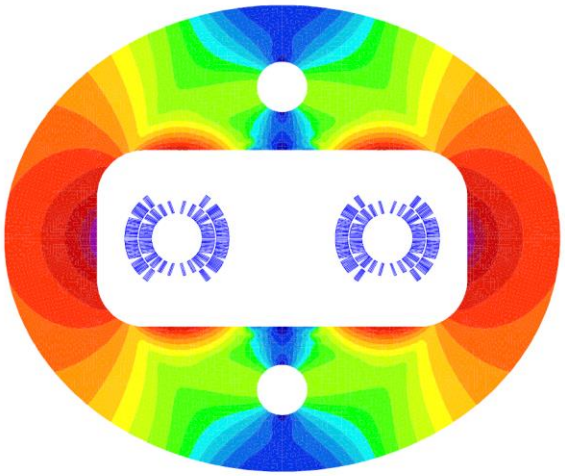
Improving the pinning in Nb3Sn [D. Larbalestier]

OTHER MAGNETS

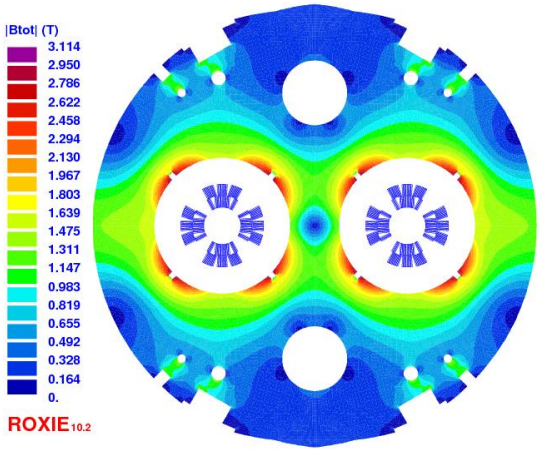
- Guideline: strong synergy with HL LHC
  - Magnets with similar level of difficulty as in HL-LHC
    - Peak fields of 10-13 T
    - Conceptual design in progress, first layout seems reasonable



D1 coil [T. Nakamoto]



D2 cross-section [P. Fabbricatore]



Q4 cross-section [C. Lorin]

- Next target: correctors!
  - We must be sure to have no showstoppers due to 7* more energy

CONCLUSIONS AND SOME QUESTIONS

- Very fast advancement towards a baseline for the lattice
  - Convergence on many parameters and main features of the 16 T dipole
  - Many programs progressing to answer many issues
- Design: reducing cost and complexity
  - Are 500 A/mm^2 ok ? And 700-800 ?
  - Can we reduce the 20% margin?
- Conductor
  - How to reduce price?
  - How to get to 5-km lengths ?
- Technology
  - Explore materials that can withstand 150 MGy
  - Explore how to manufacture coils with different conductors