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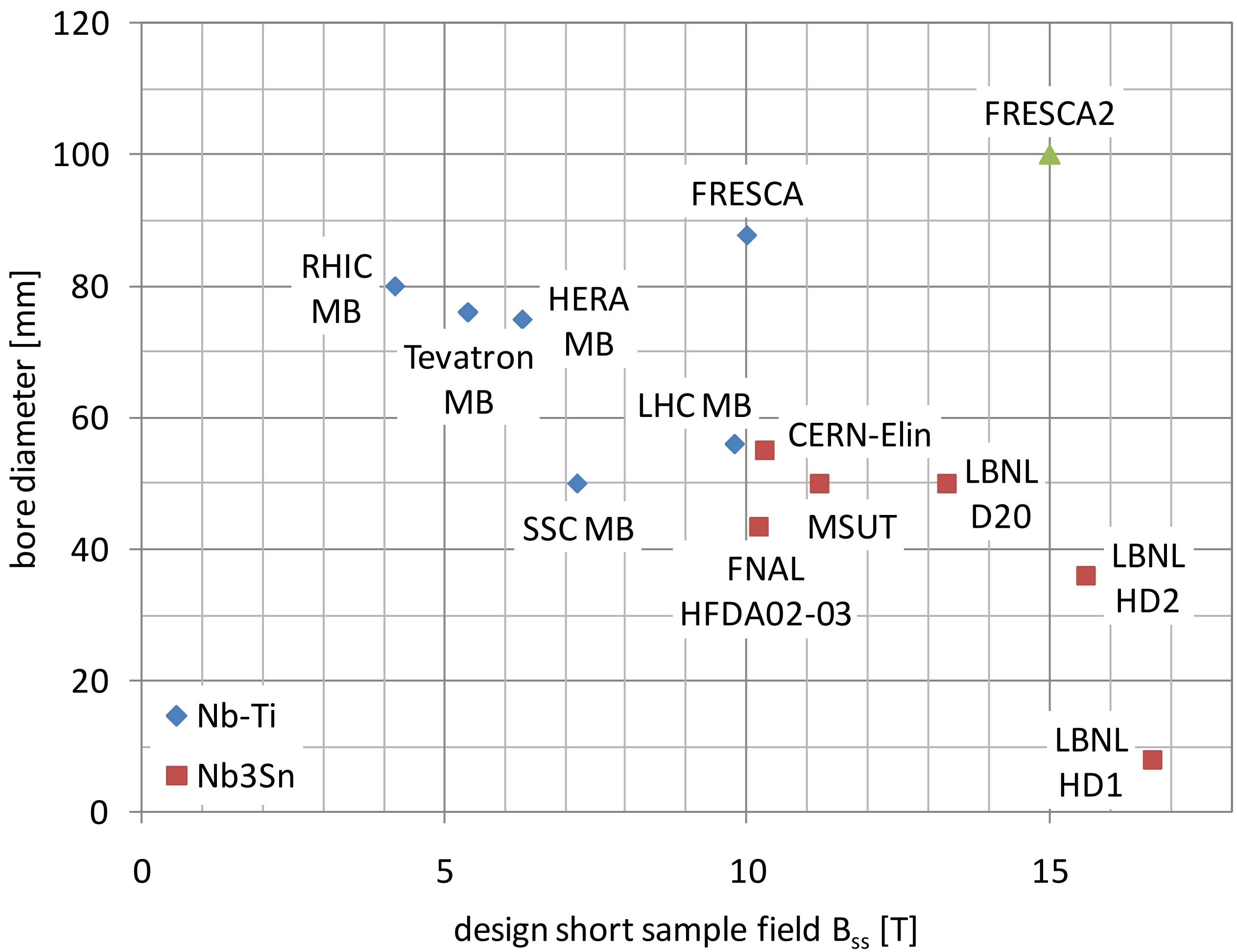
About the design of the FRESCA2 dipole (WP 7.3)

Attilio Milanese

Acknowledgements:

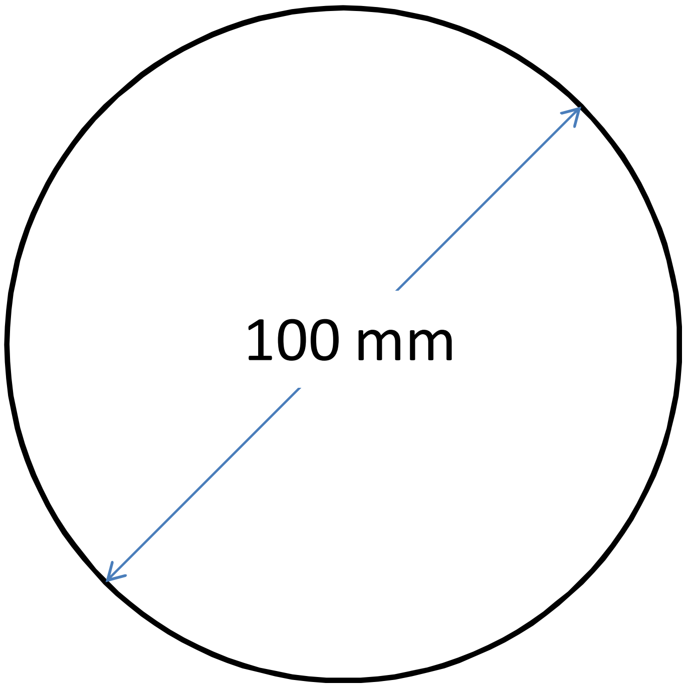
Gijs de Rijk, Ezio Todesco & other colleagues @ CERN
Paolo Ferracin, Shlomo Caspi @ LBNL
Pierre Manil & others @ CEA/Saclay

A map of dipoles



FRESCA = Facility for the Reception of Superconducting Cables

Conductor properties



Nb_3Sn strand, 1 mm diameter

J_c = 2500 A/mm² @ 12 T, 4.2 K
J_c = 1250 A/mm² @ 15 T, 4.2 K

Cu / non-Cu ratio = 1.25

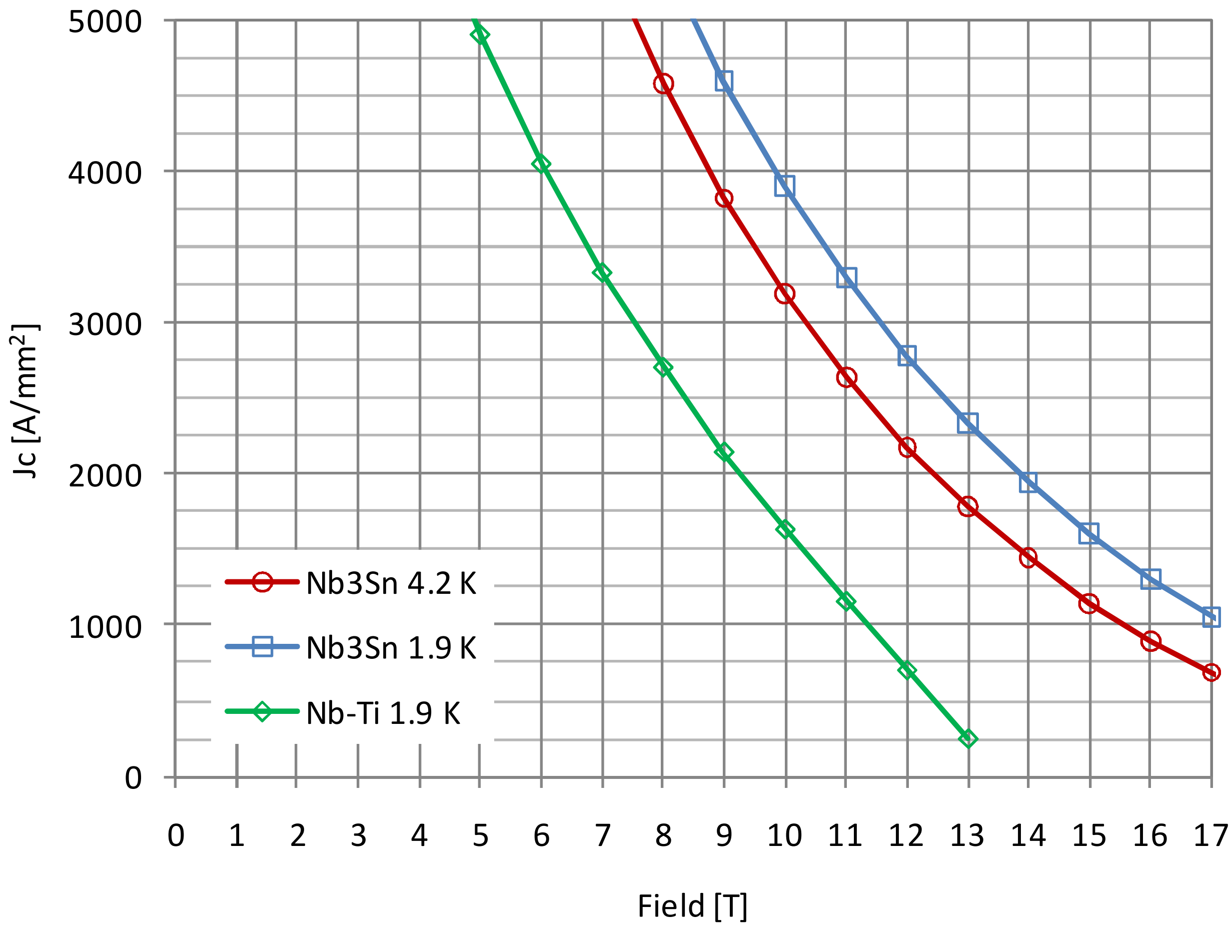
Rutherford cable

40 strands, no keystoning
21.4 x 1.82 mm (bare)
21.8 x 2.22 mm (with 0.2 mm insul.)

filling factor κ = 0.289

Critical surface fit

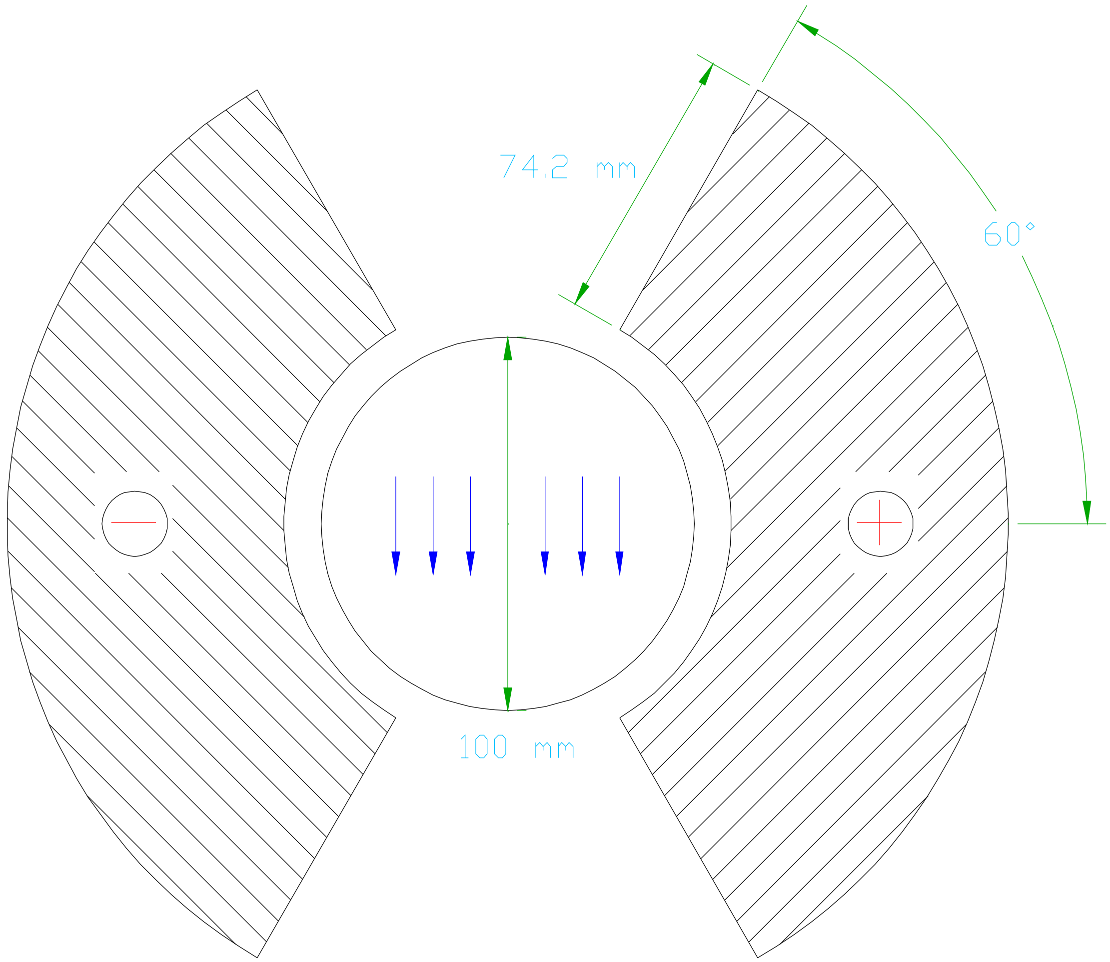
J_c = 2500*0.90 = 2250 A/mm^2 @ 12 T, 4.2 K
J_c = 1250*0.90 = 1125 A/mm^2 @ 15 T, 4.2 K



"extracted strand" J_c-fit with 10% degradation

Going from 4.2 K to 1.9 K in Nb_3Sn increases B_{ss} of about 8% or 1.1 T (in our case).

How much cable do we need?

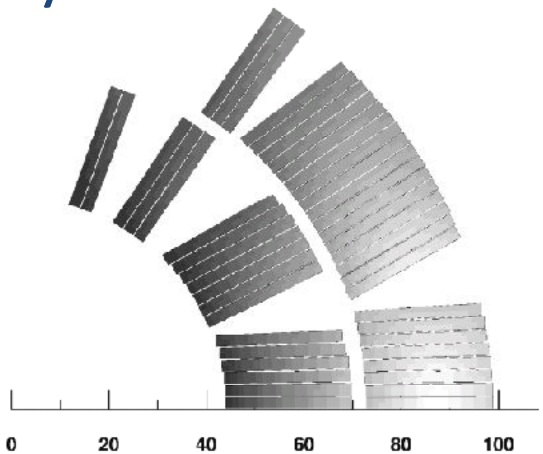


Using analytical scaling laws for the design of dipoles based on sector coils, we need about 150 turns (per pole).

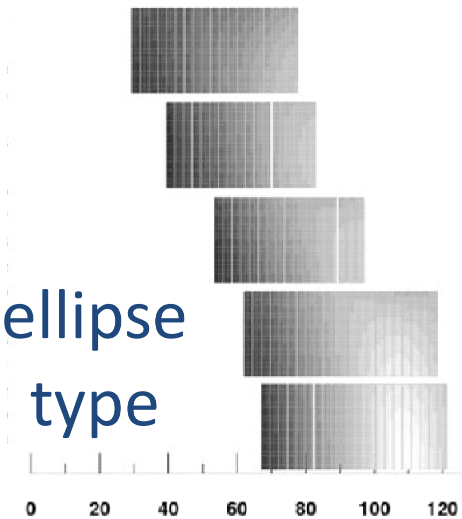
156 turns (per pole) have been chosen to start with.

How to use the cable?

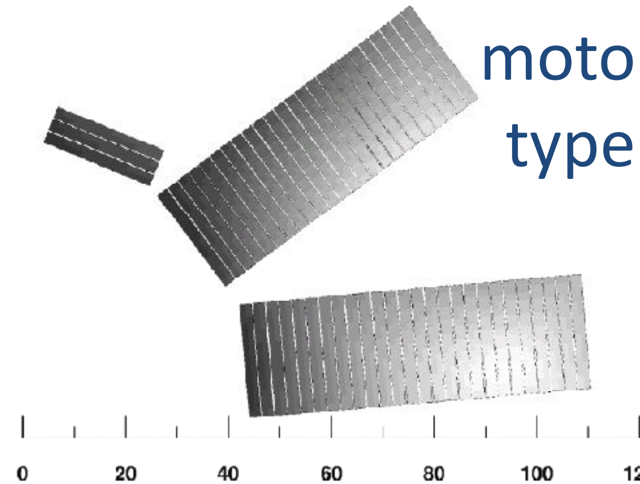
layered cos-θ



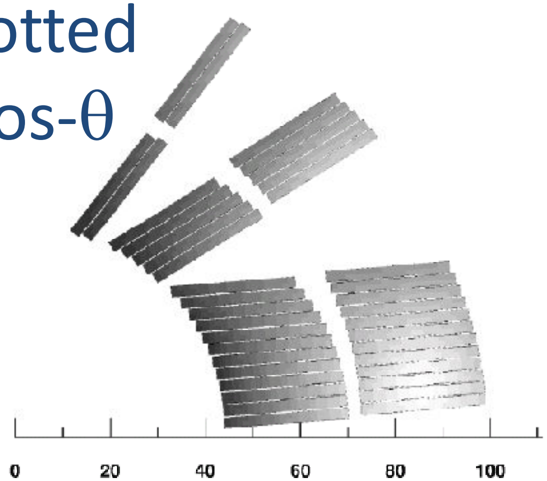
ellipse type



slotted motor type

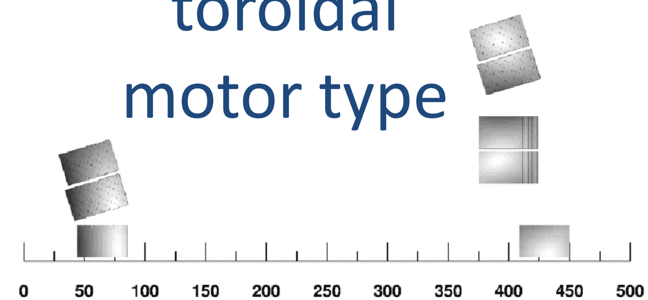


slotted cos-θ



common coil

toroidal motor type

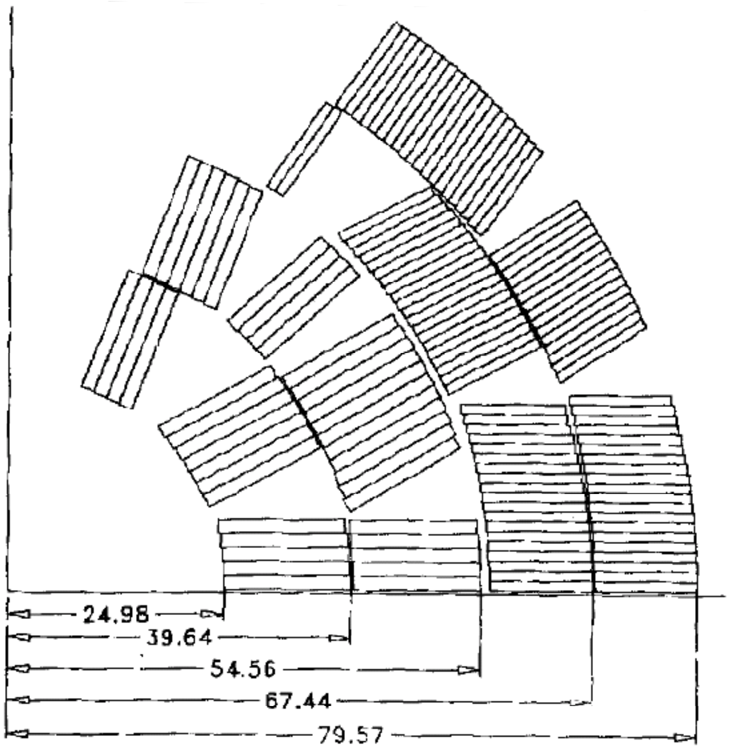


[Toral et al., NED, 2006]

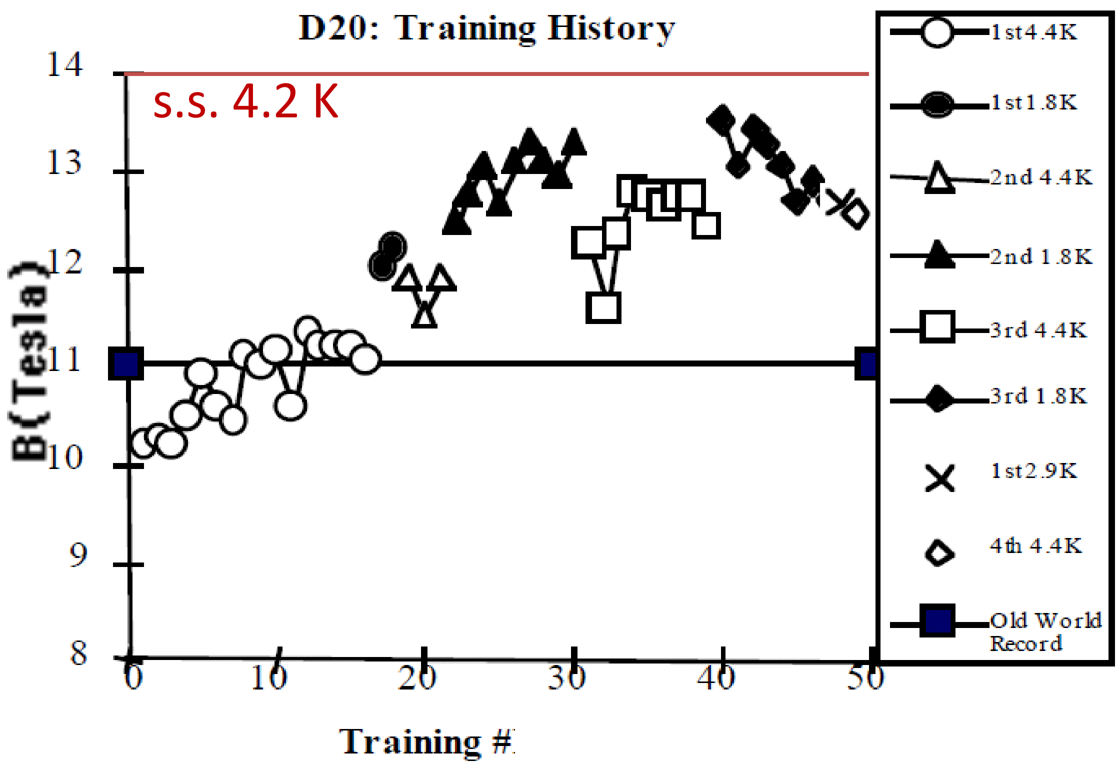
The cos-θ option

LBNL D20

(138 turns per pole)

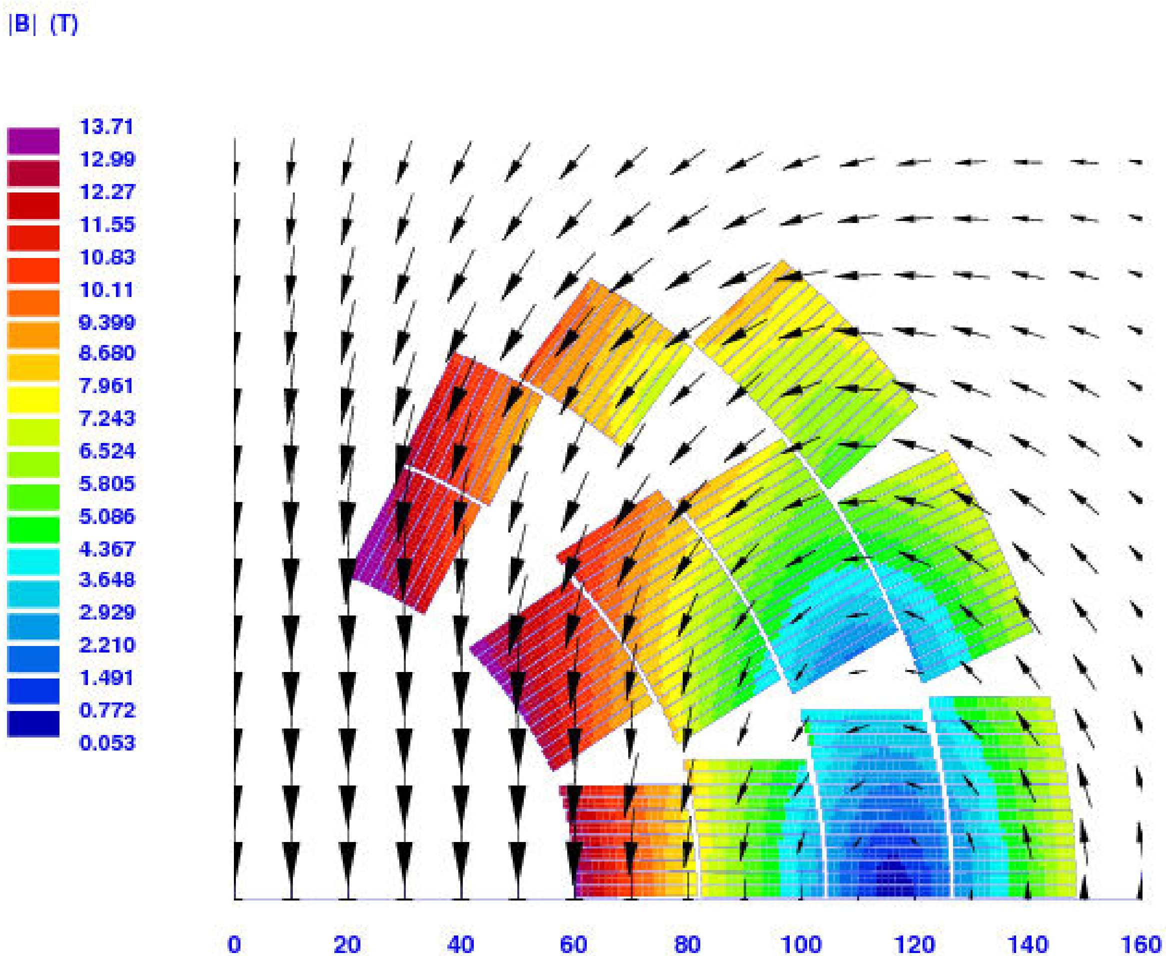


12.5 T / 14 T = 89%



The cos-θ option: a cross section

Baseline cos-θ with 4 layers (3-3-3-3)



156 turns

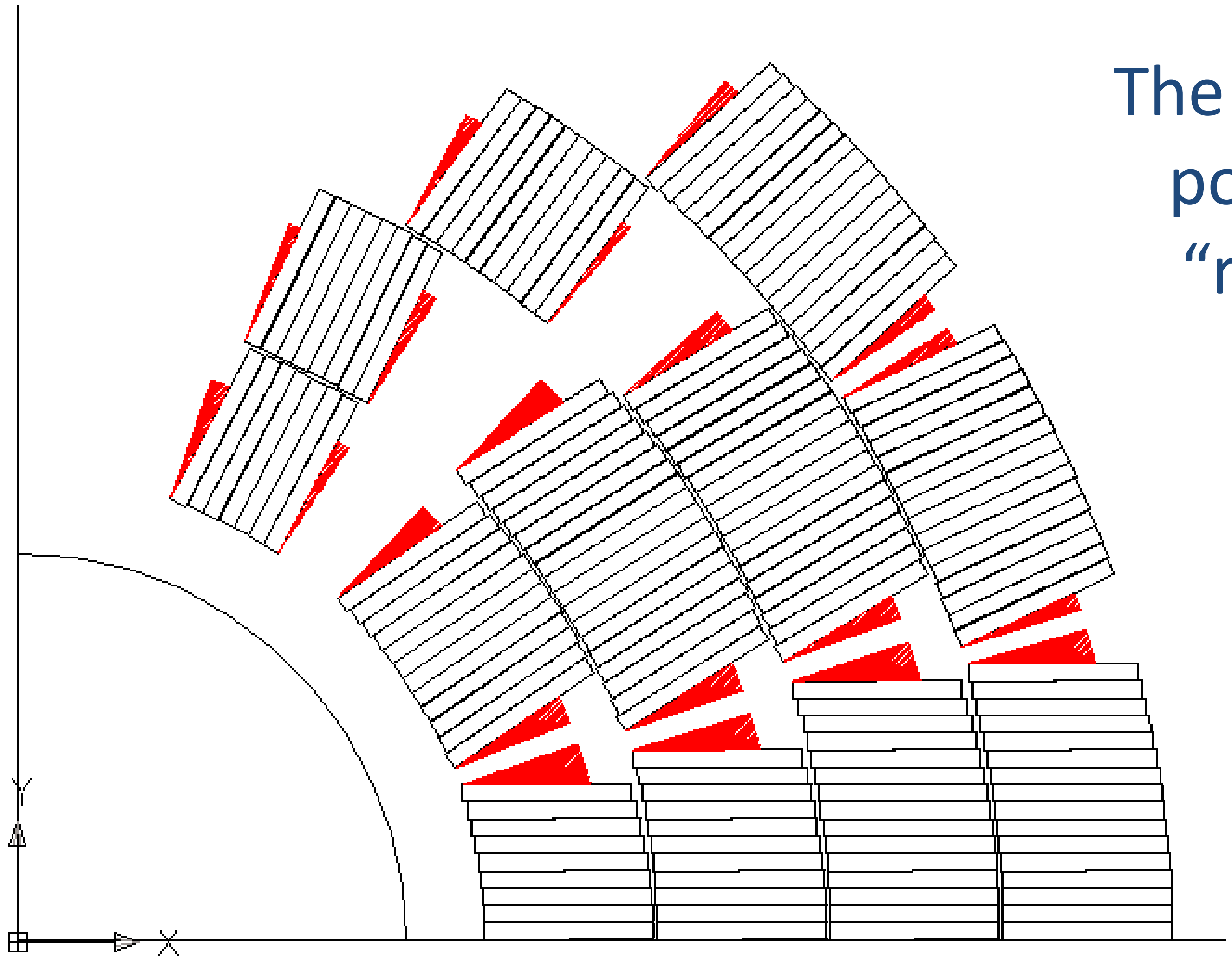
$B_{ss,\ 4.2\ K}$ = 14.57 T
$B_{ss,\ 1.9\ K}$ = 15.79 T
$I_{ss,\ 4.2\ K}$ = 14.6 kA

peak field / central field = 1.055

b_3 = 0.0
b_5 = 0.0
b_7 = 0.0

L = 41.7 mH/m
$E_{Bc = 13\ T}$ = 3.6 MJ/m
($E_{LHC\text{-}MB}$ = 0.5 MJ/m)

The cos-θ option: a cross section

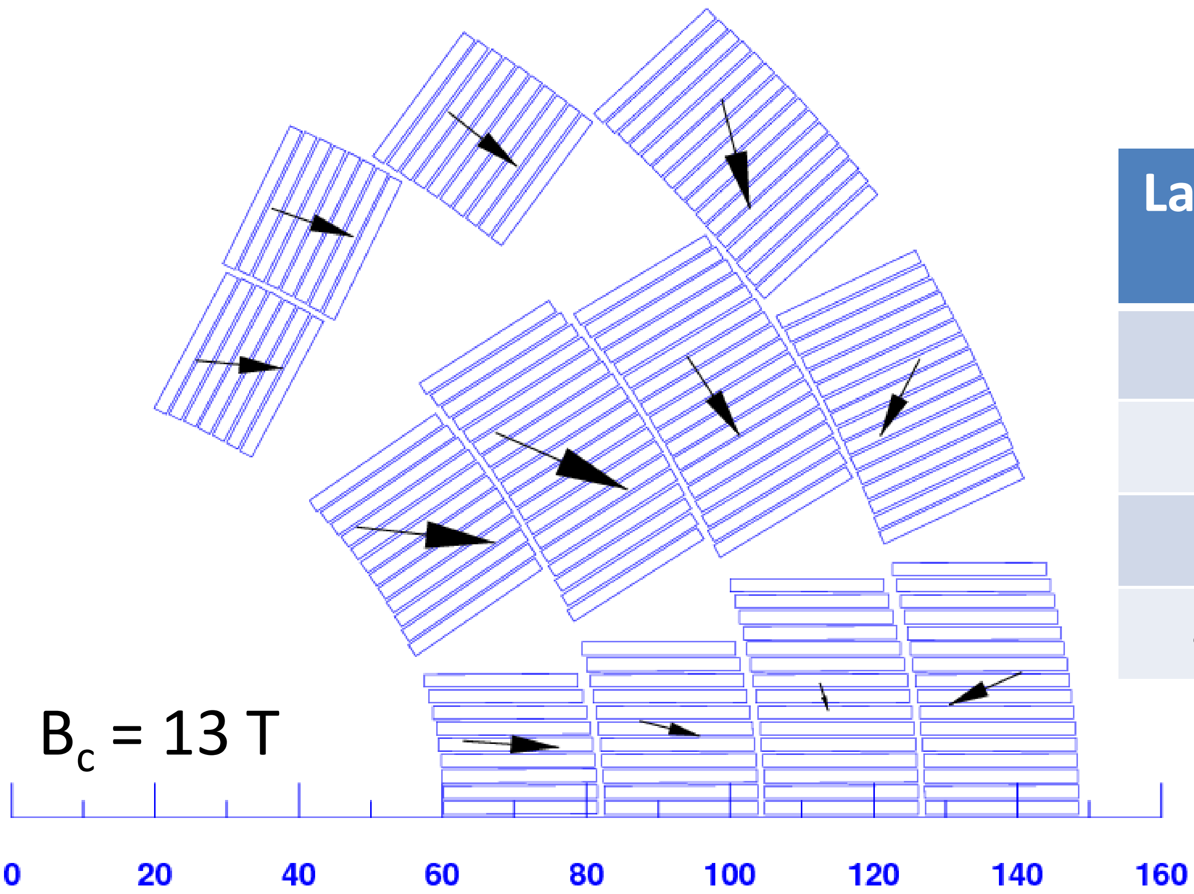


The blocks are positioned "radially".

Cos-θ: Lorentz forces and stresses

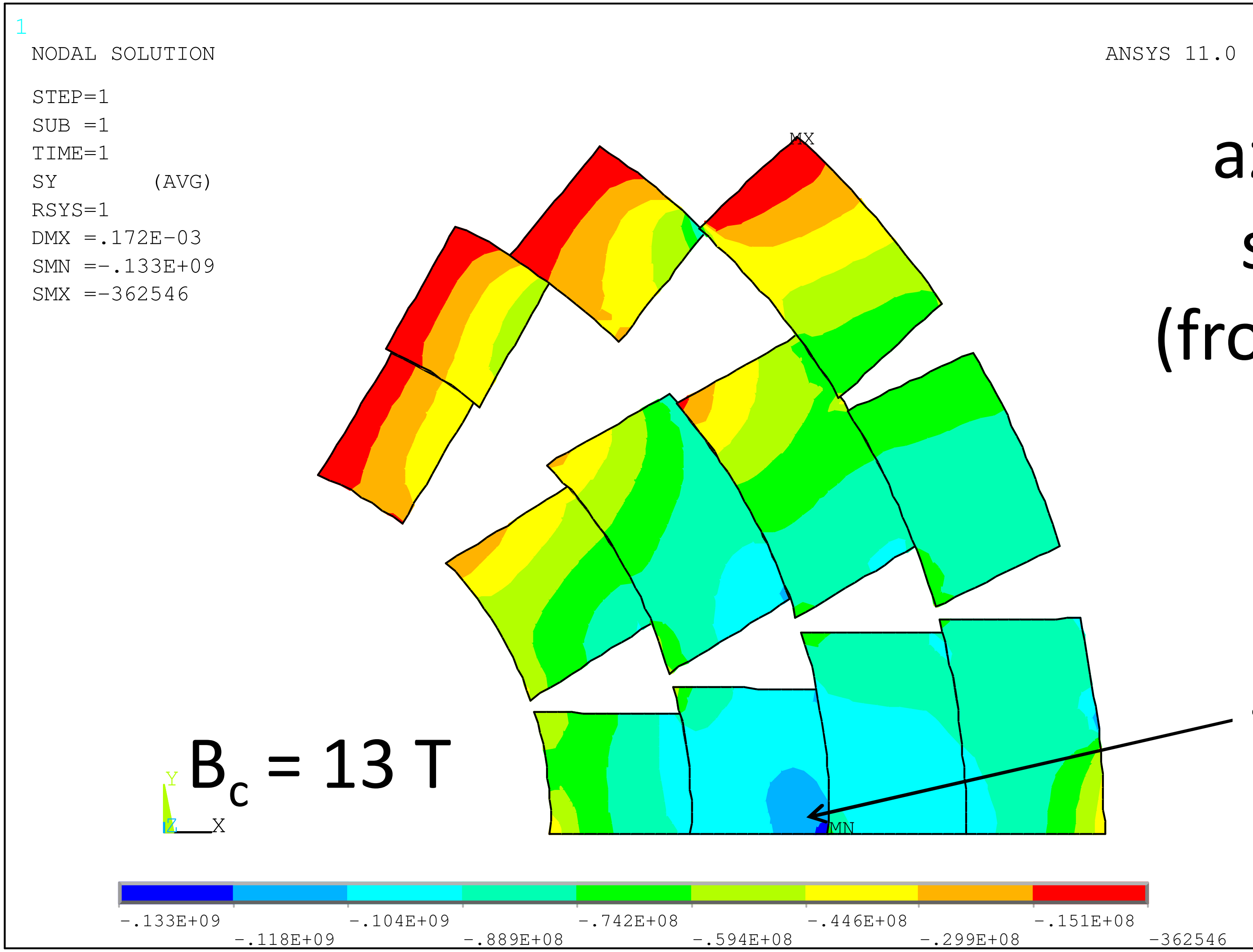
For the azimuthal stresses on the midplane

mean $\sigma_\theta \sim \Sigma F_\theta / w$



Layer	ΣF_θ [MN/m]	mean σ_θ [MPa]
1	2.40	110
2	2.85	131
3	2.66	122
4	2.19	101

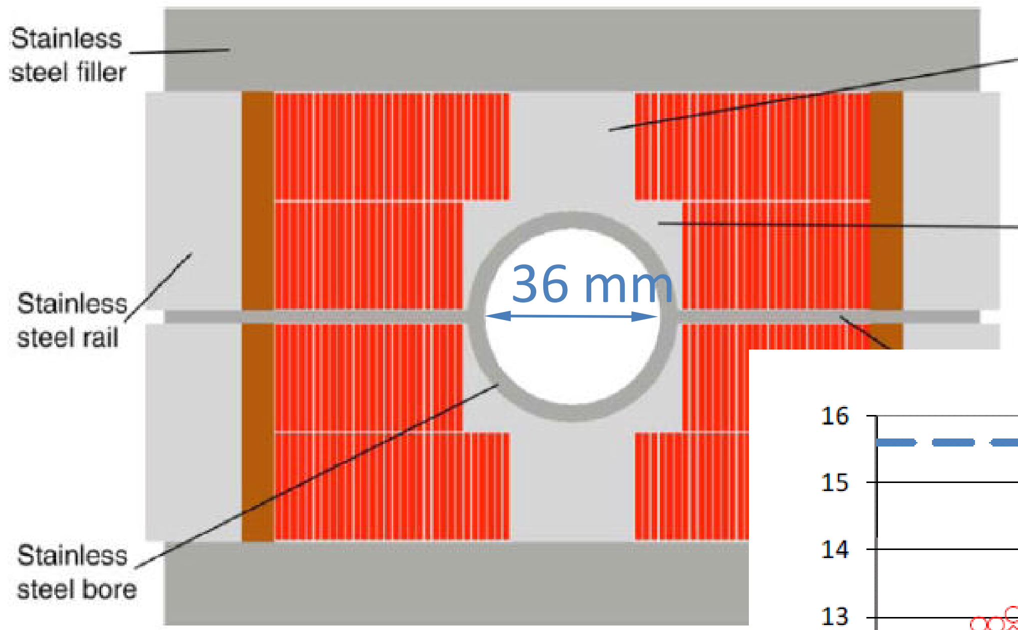
Cos-θ: preliminary FEM for stresses



azimuthal stresses (from Lorentz forces)

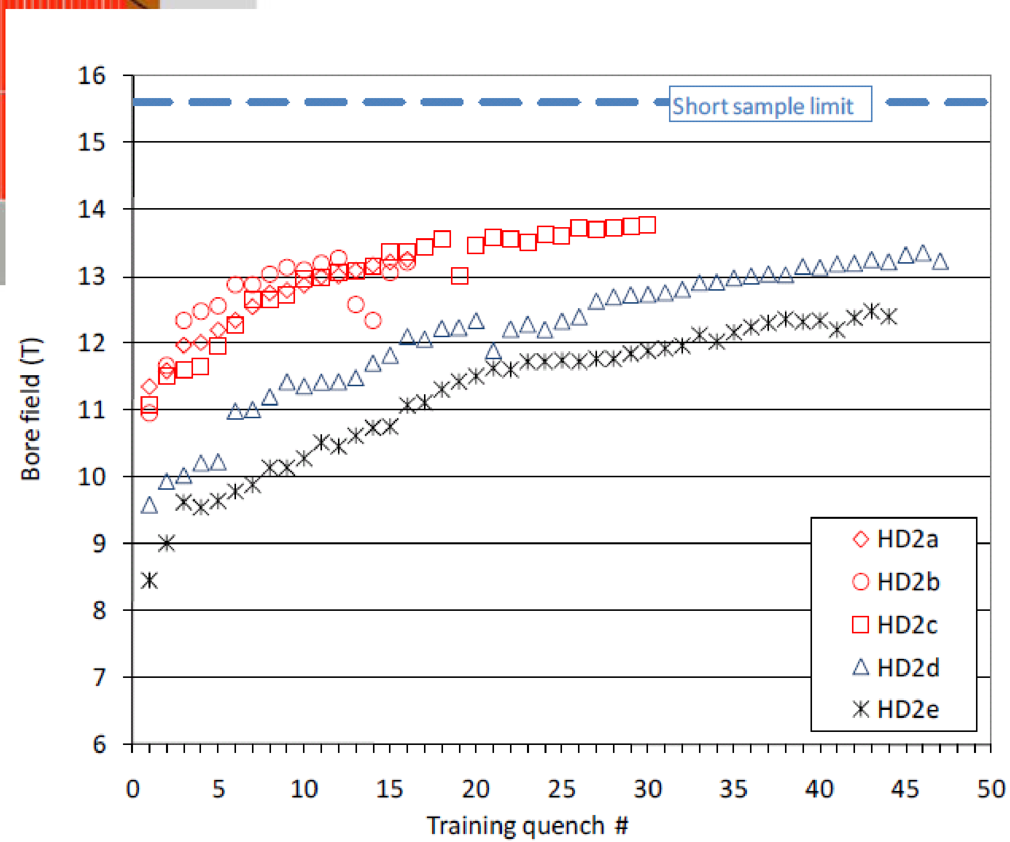
-130 MPa

The blocks option



LBNL HD2

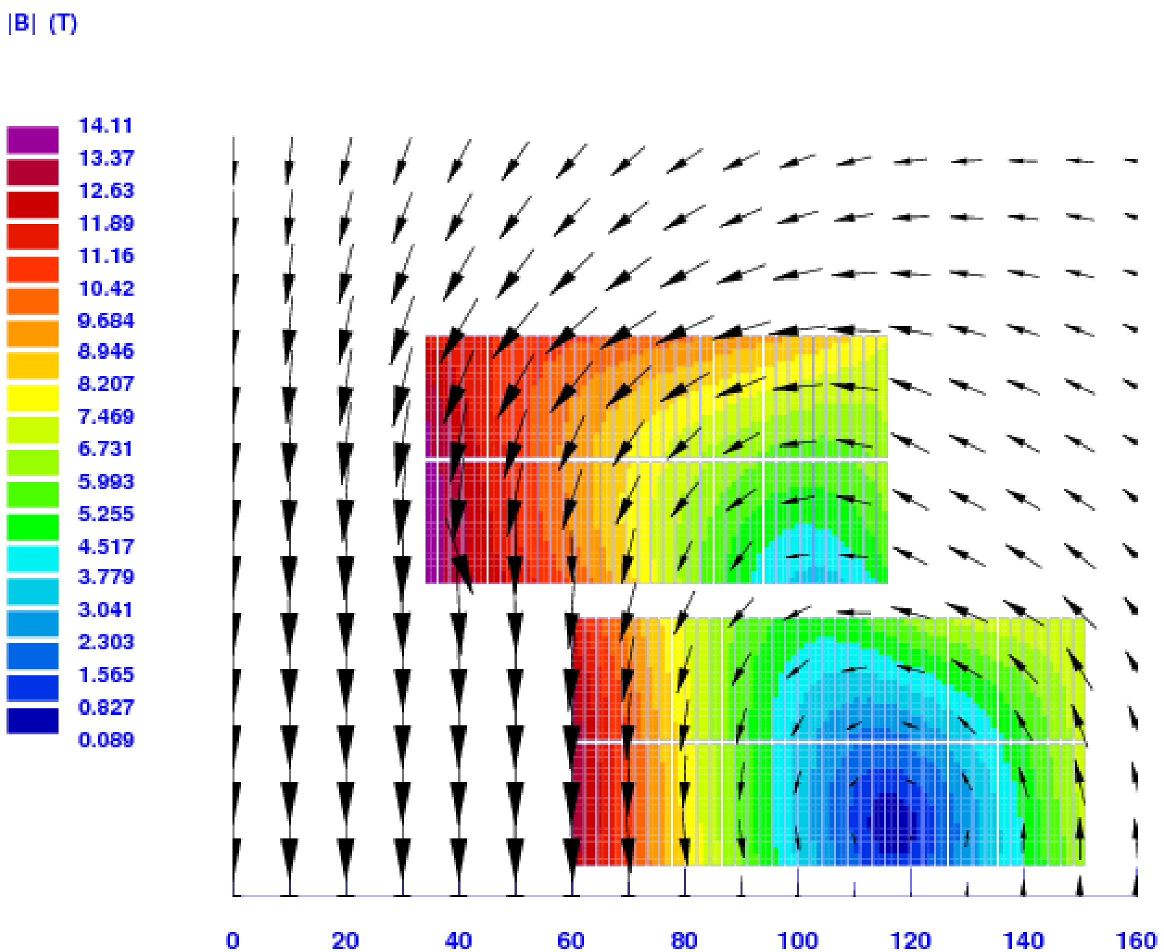
(61 turns per pole)



13.8 T / 15.6 T = 88%

Blocks: a cross section

baseline 41-41-37-37



156 turns

$B_{ss,\ 4.2\ K}$ = 14.18 T
$B_{ss,\ 1.9\ K}$ = 15.37 T
$I_{ss,\ 4.2\ K}$ = 14.6 kA

Peak field / central field = 1.086

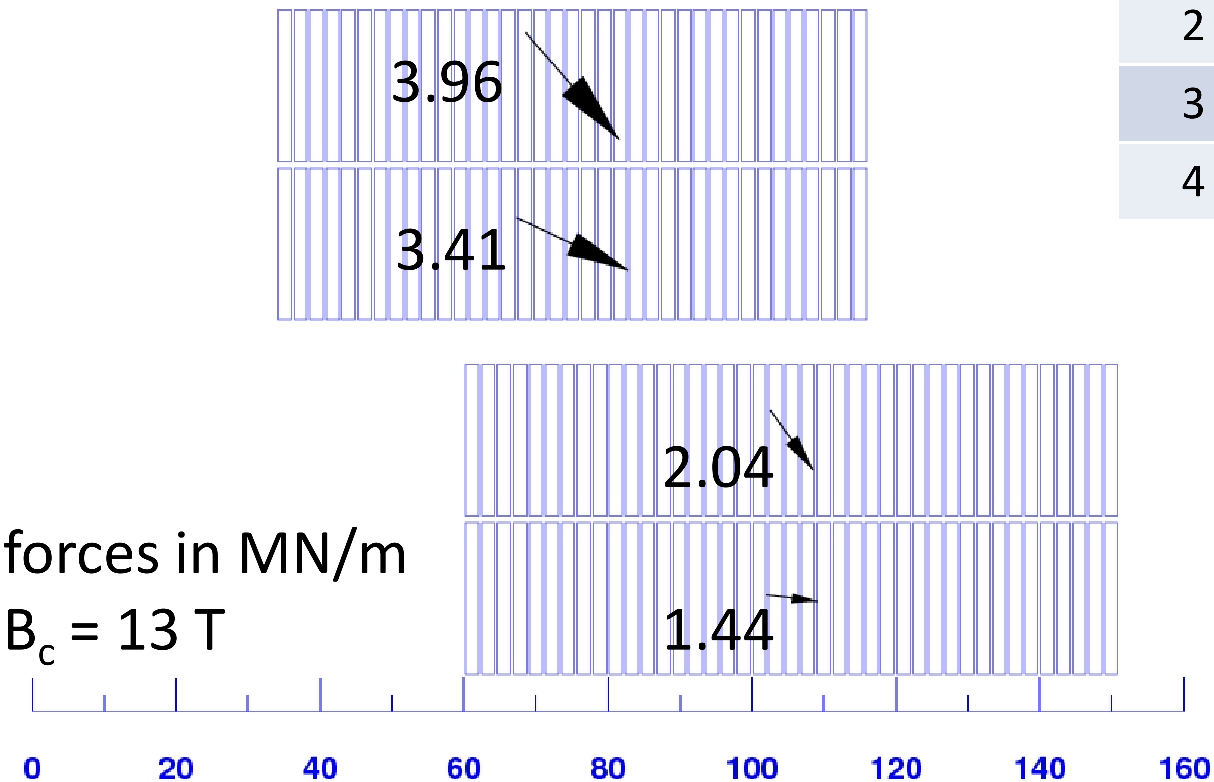
b_3 = 0.0
b_5 = 0.0
b_7 = 1.8

L = 42.2 mH/m
$E_{Bc\ =\ 13\ T}$ = 3.8 MJ/m
($E_{LHC\text{-}MB}$ = 0.5 MJ/m)

Blocks: Lorentz forces and stresses

baseline 41-41-37-37

Block	F_x [MN/m]	$\sigma_{hor,\,ave} = F_x/w$ [MPa]
1	1.43	65
2	1.19	54
3	3.08	141
4	2.60	119



forces in MN/m

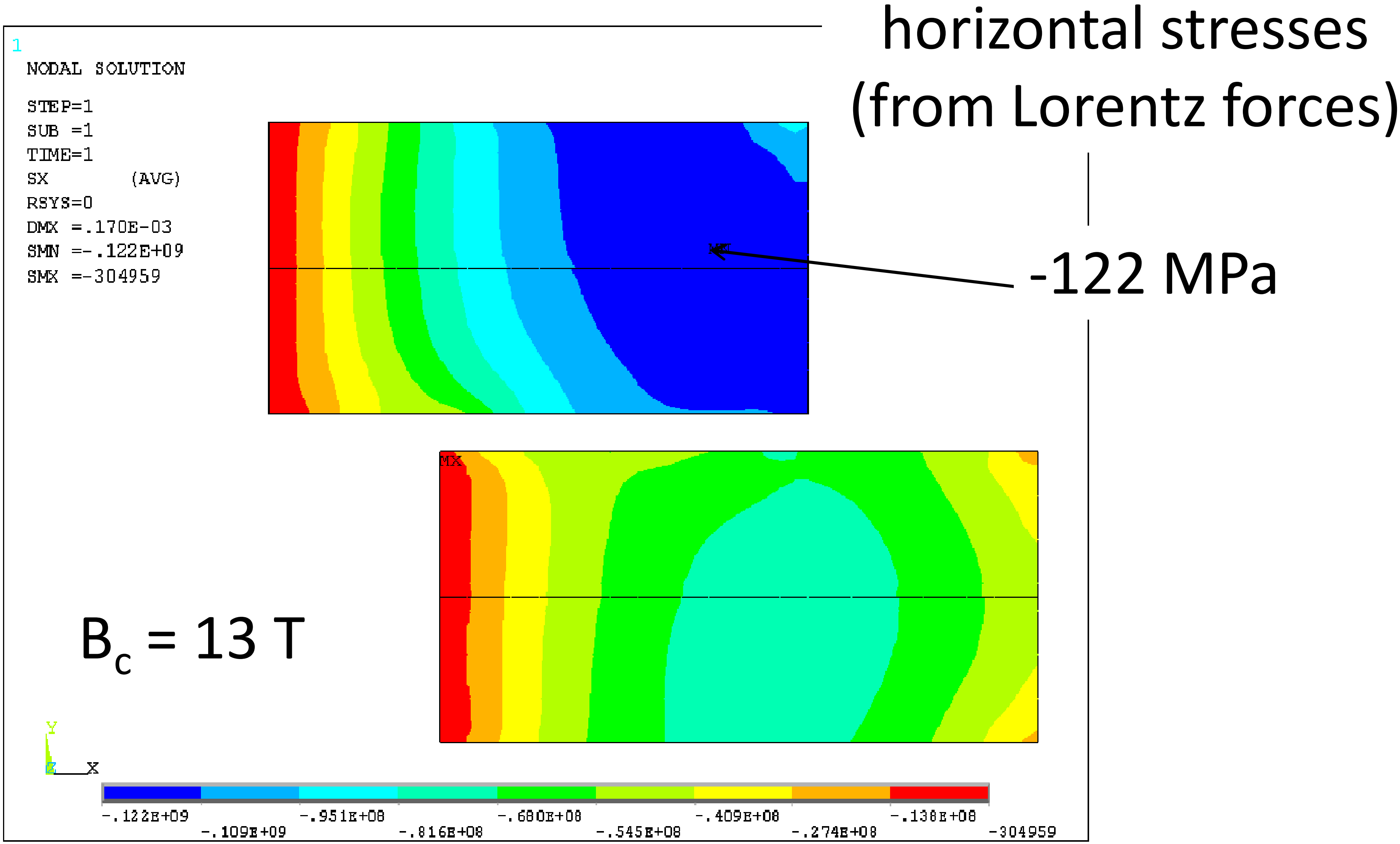
B_c = 13 T

HD2 @ short sample (4.2 K)

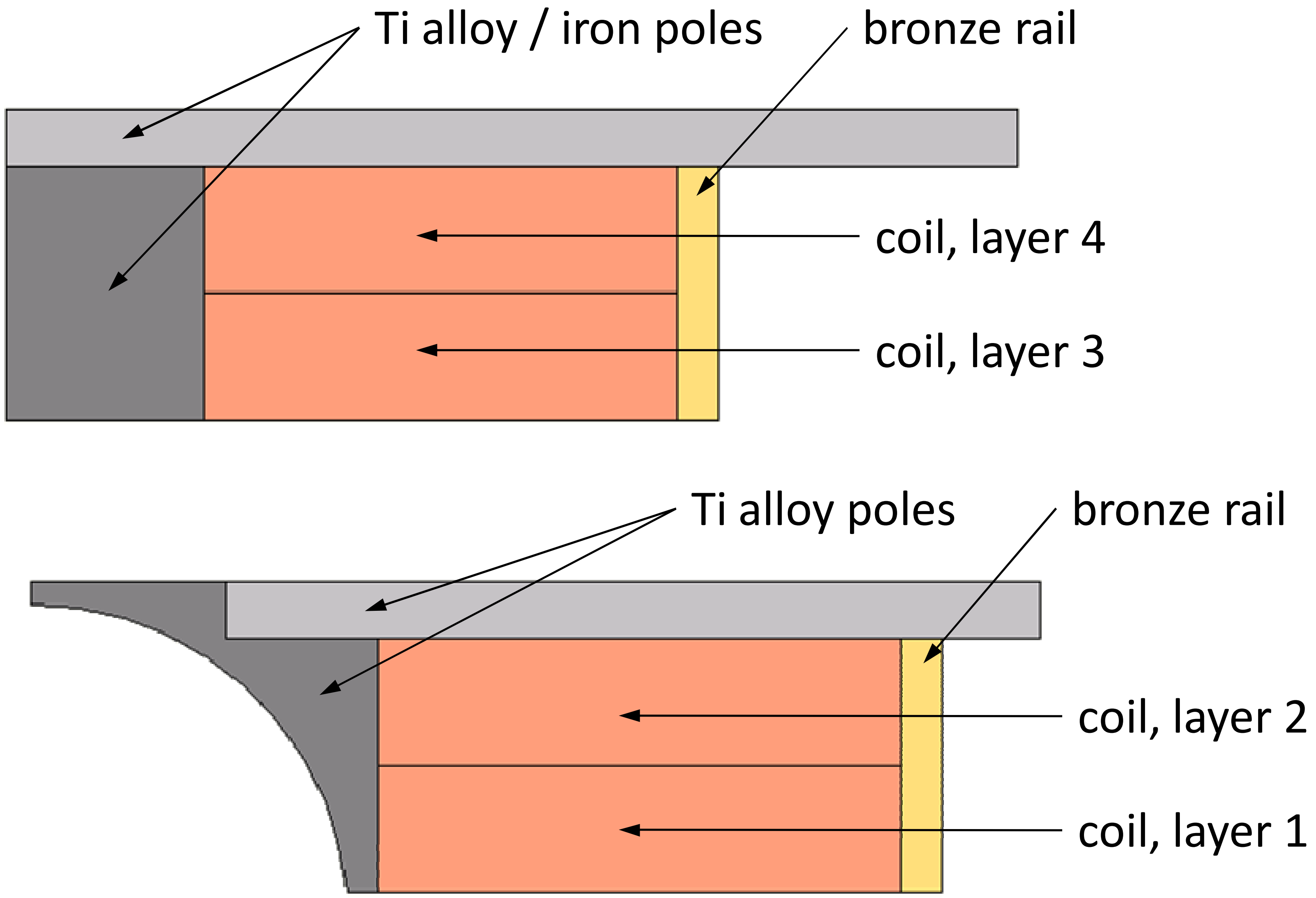
(B_{ss} = 15.0 T, 17.3 kA)

Bl	Fx [MN/m]	Fy [MN/m]
1	2.30	-0.40
2	3.30	-2.20

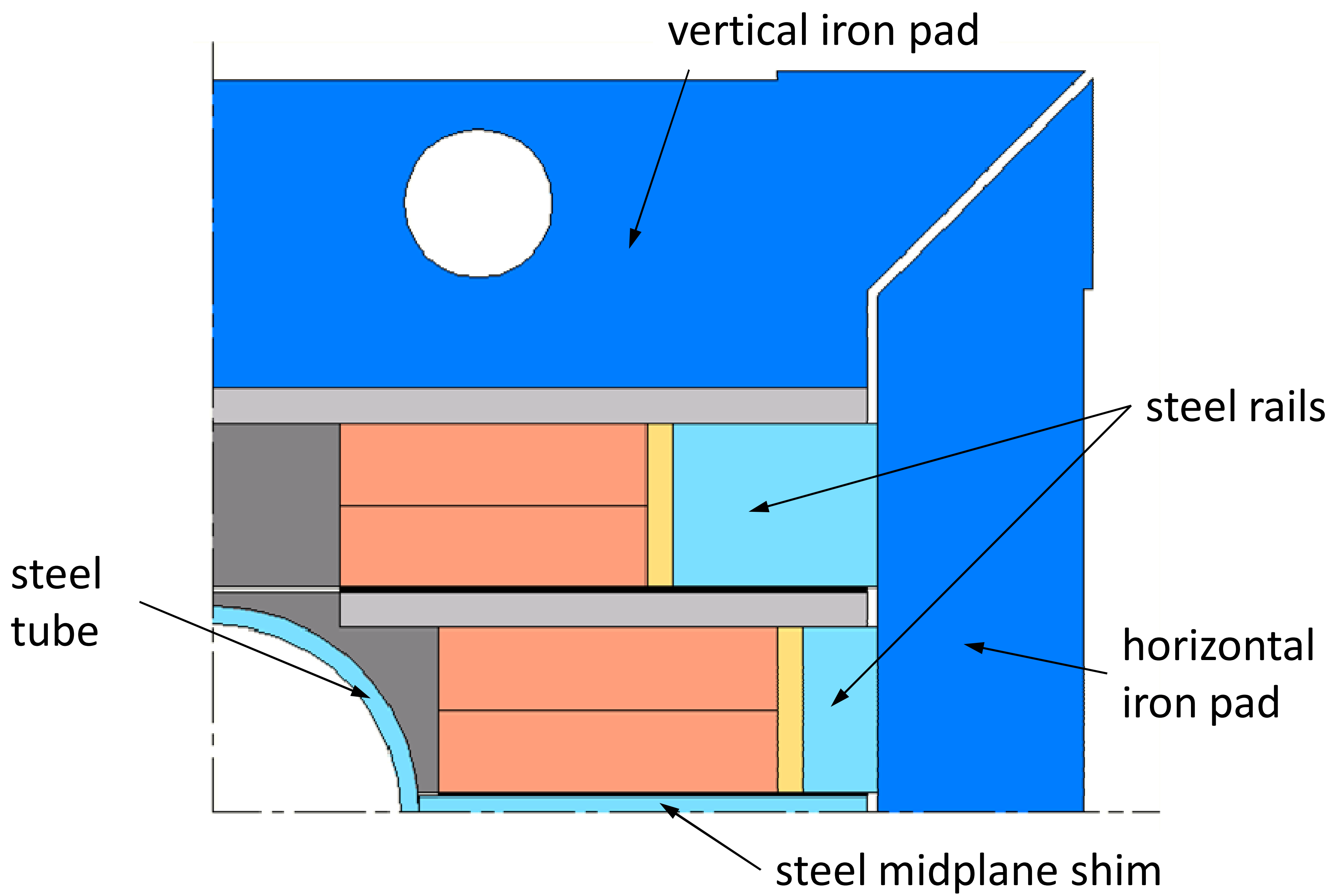
Blocks: preliminary FEM for stresses



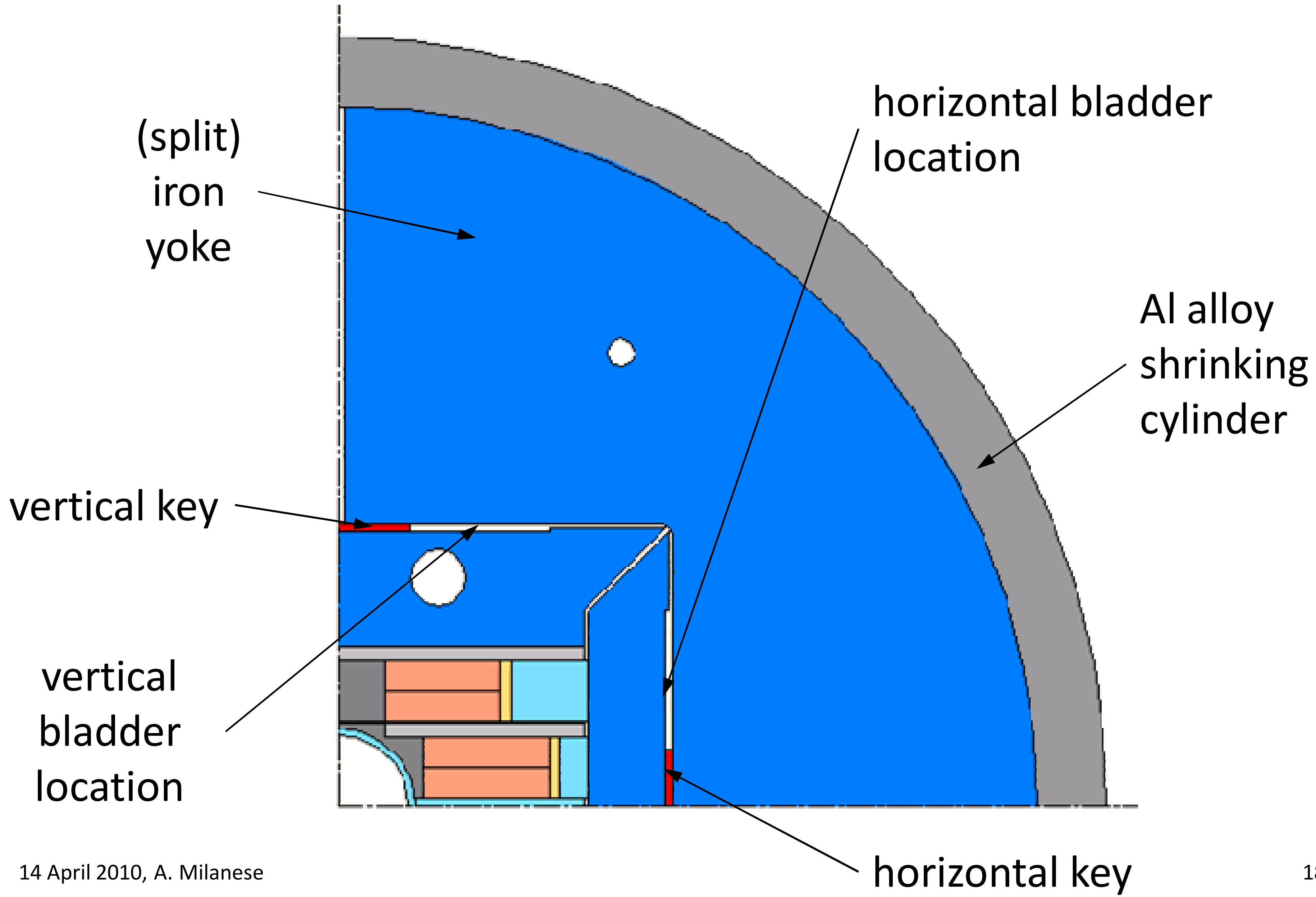
Blocks: ideas for the structure (2d)



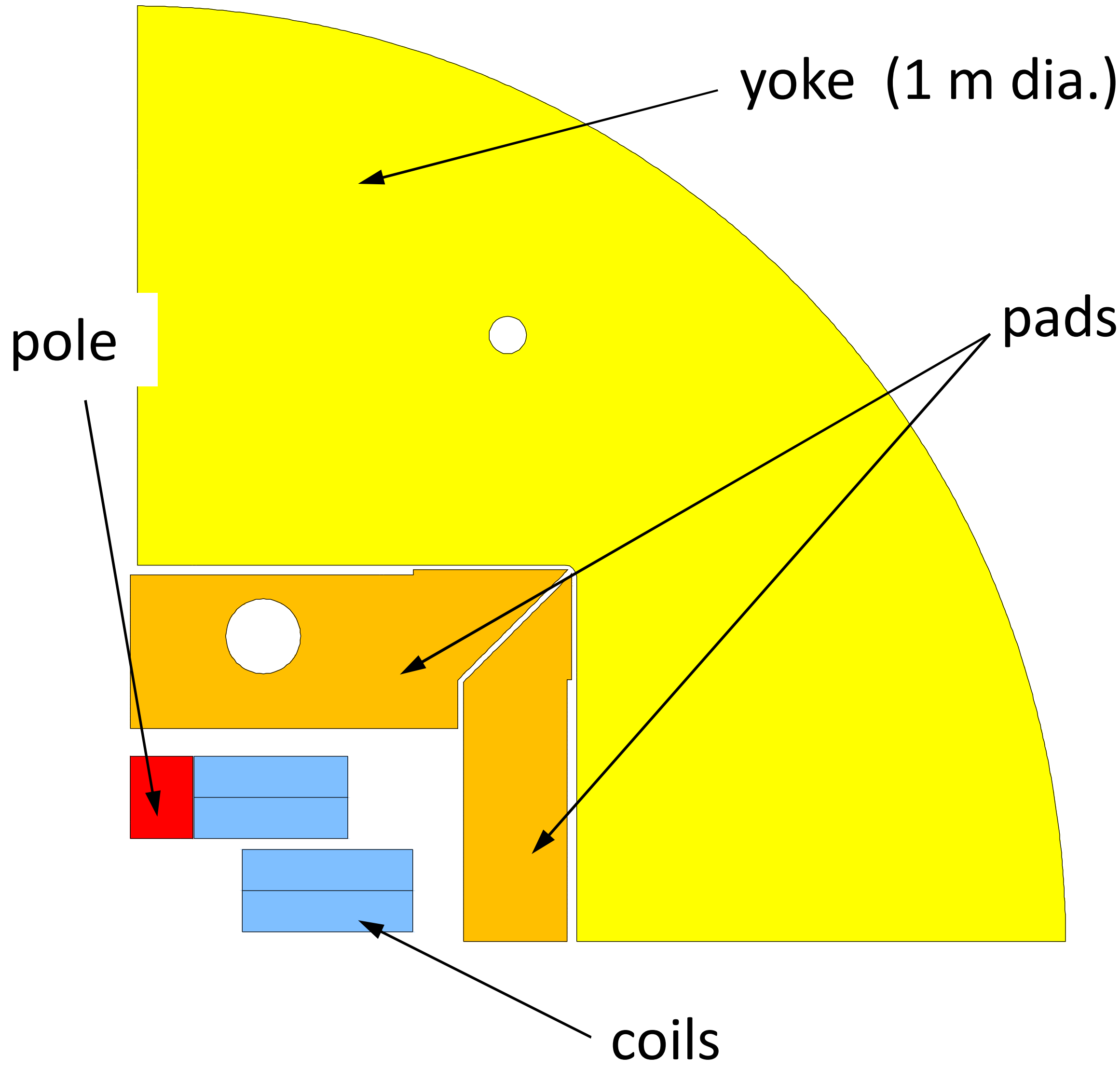
Blocks: ideas for the structure (2d)



Blocks: ideas for the structure (2d)



Iron effect in blocks design



BEM-FEM, LHC iron (with saturation)

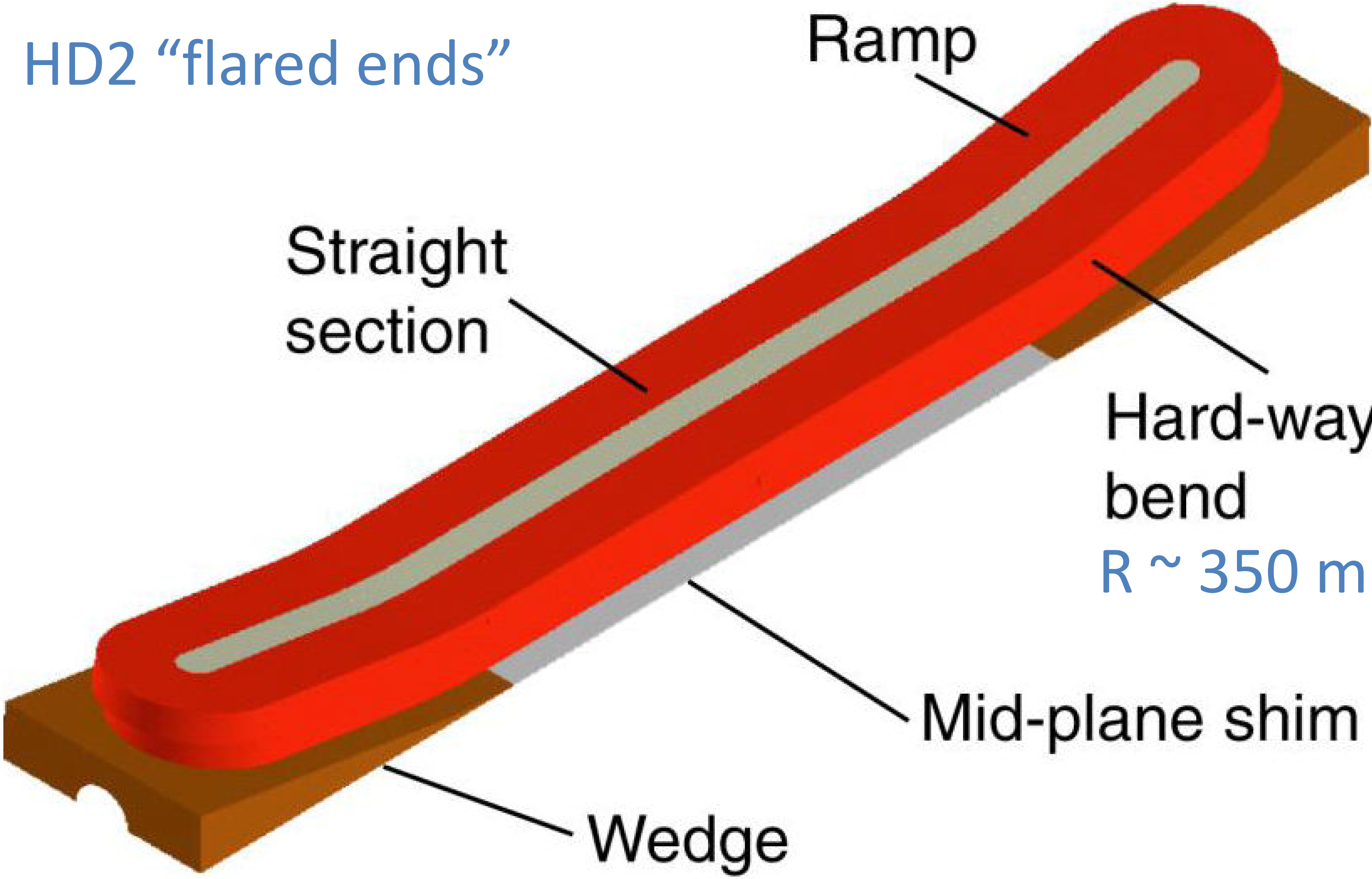
Short sample @ 4.2 K

- no iron: 14.2 T
- pads: 14.4 T
- pads and yoke: 14.8 T
- pole: 15.1 T
- pole, pads
  & yoke: 15.7 T

Stray field with no iron is about 150 mT at 1 m from the bore (B_c = 15).

Blocks: ideas for the ends

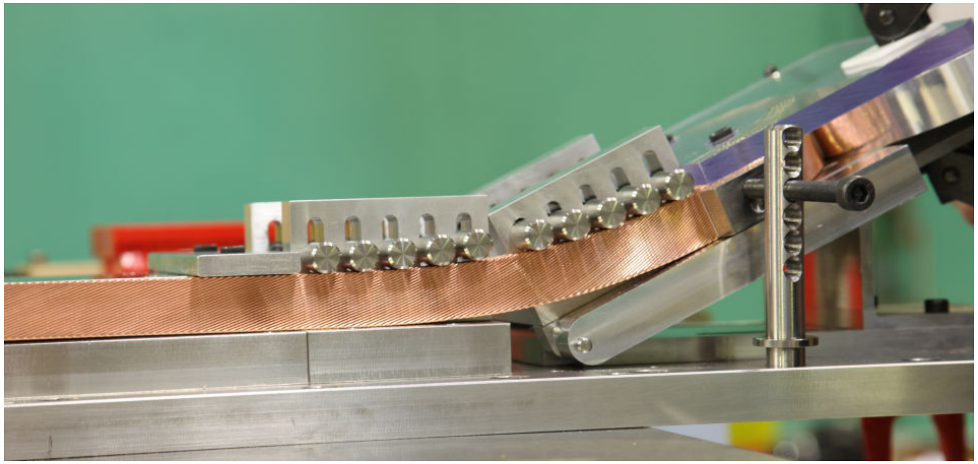
HD2 "flared ends"



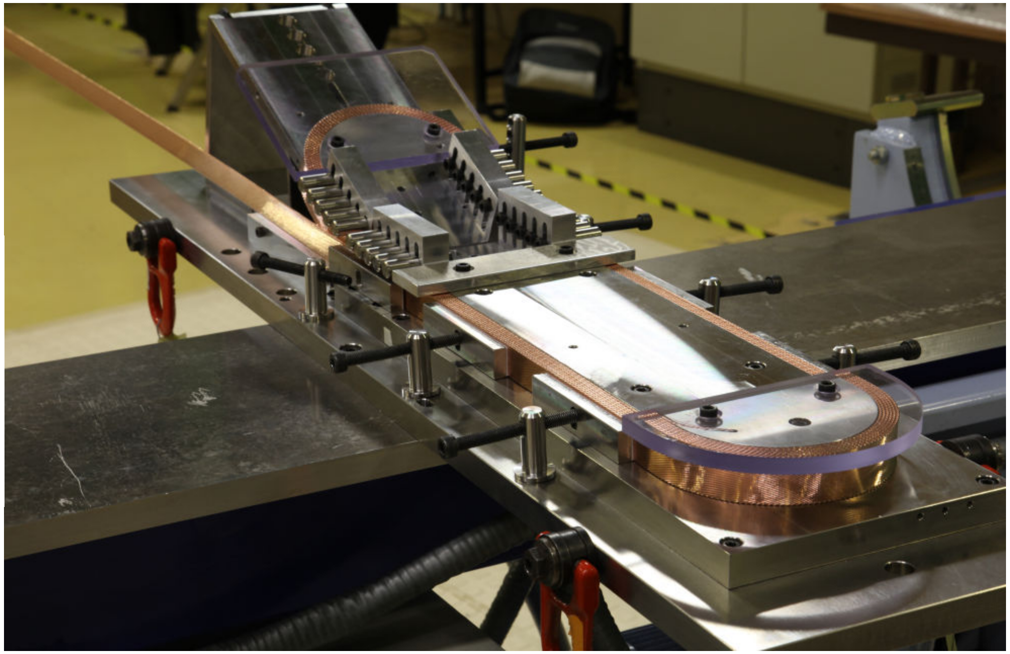
R ~ 350 mm

10° angle

Blocks: ideas for the ends



A first proof-of-concept winding test has been performed with copper cable in March 2010.



The result is that such an end design looks feasible.

Conclusion

- preliminary analyses for a 13 T, 100 mm bore Nb_3Sn dipole magnet have been concluded
- two layouts have been proposed: cos-θ and blocks
- proof-of-concept winding tests for flared ends (blocks design) have been performed
- the choice of the layout is planned for beginning of May
- detail magnetic and mechanical design will then follow (2d and 3d)

Thank you.