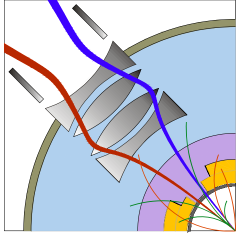
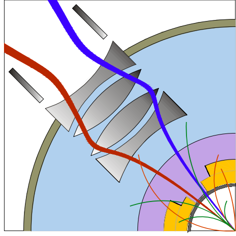


LHC Phase 1 upgrade: low β quadrupoles

Paolo Fessia

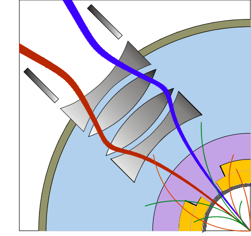
Insulation development: D. Tommasini, P Paolo Granieri, D. Richter
Magnetic Design: E. Todesco, F. Borgnolutti
Protection: N. Schwerg
Mechanic Design: F. Regis



Summary

- Approach to the problem and original planning
- The starting blocks
- The development of a new porous insulation and other efforts to be able to cope with thermal load
- The conceptual magnetic design
- The conceptual mechanical design
- The resulting coccept

The Approach to the problem



Guide-lines

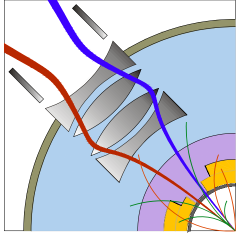
•Maximum use of material and components that have been purchased for the LHC construction, but not used
(this taking into account that we need to keep safety margins for the LHC exploitation).

•Use of existing tooling that can be modified, but in such a way to be fully operational for the original use (if needed for LHC).

•Exploitation of LHC magnets used and proved techniques, possibly limiting R&D efforts and reducing technological risks

SLHC-PP 2008 • 2011 PREPARATORY PHASE
LARGE HADRON COLLIDER UPGRADE

Magnet program planning as set in February 2008

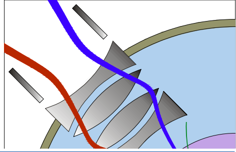


Phase	Task	Start	Completion
Model	Tooling installation	01/02/2008	01/02/2009
	Models construction	01/09/2008	01/07/2009
Prototype	Prototype and series tooling installation	01/02/2008	01/01/2010
	Prototypes construction	01/10/2009	01/09/2010
Series	Series production	01/10/2010	01/06/2012 Date of completion or delivery of last quadrupole. Production sequence optimized for installation and construction
Procurement	Specifications and invitation to tender for prototype and series components	01/02/2009	01/09/2009
	Delivery of components	01/10/2009	31/12/2011

After ¾ incident delayed of 6 months at least

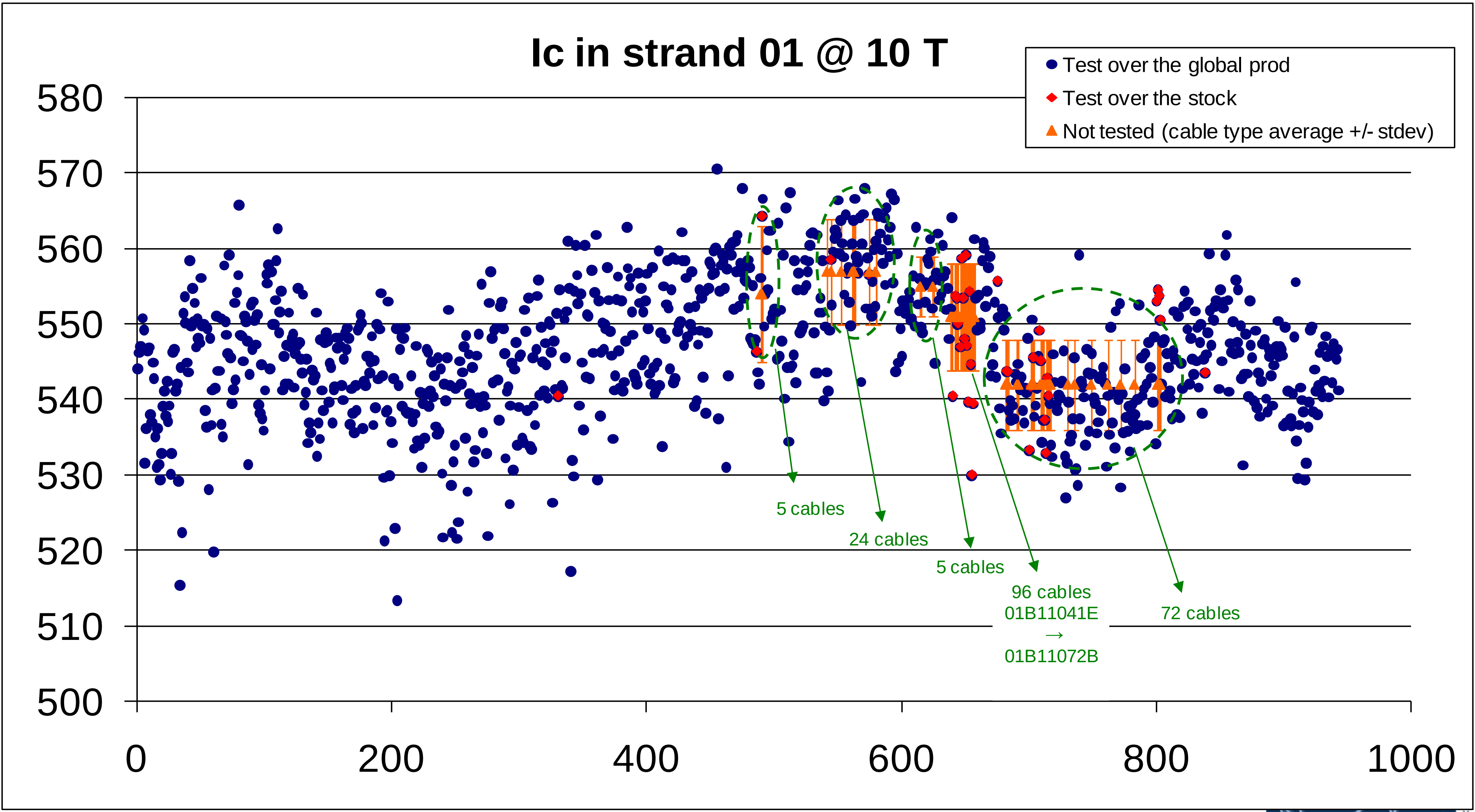
PREPARATORY PHASE

The starting blocks

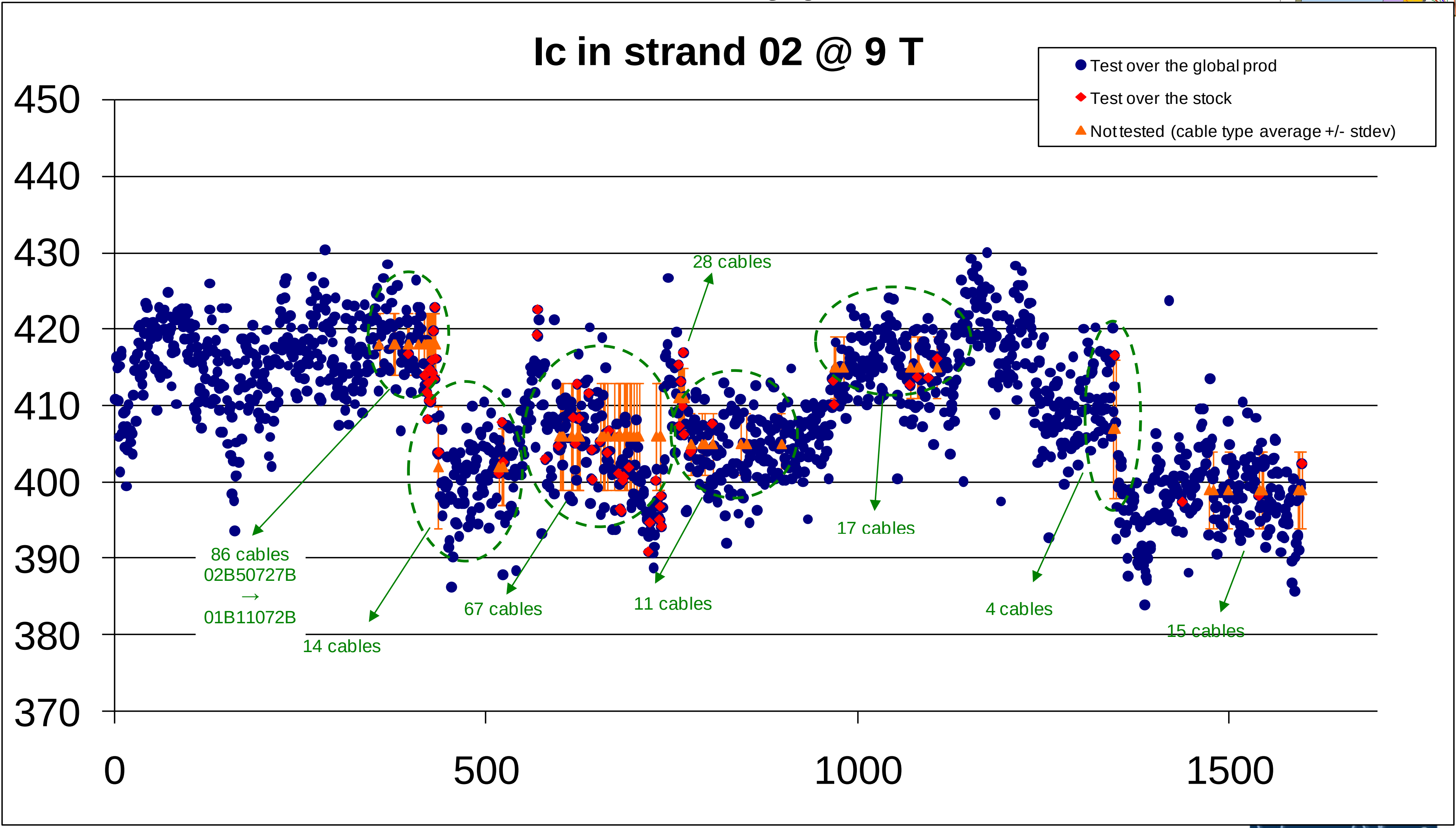


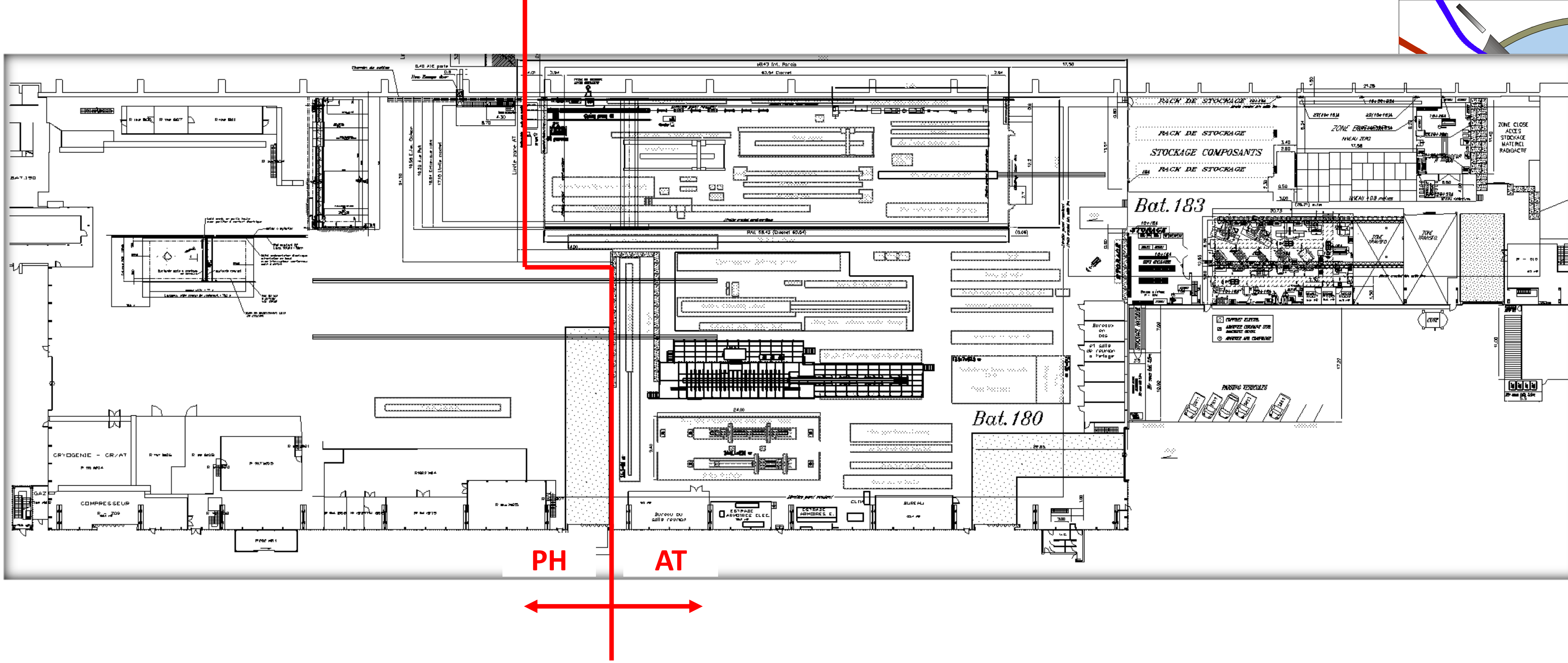
Material	Availability	Constraints on	Need of extra purchase
SC cables: LHC-MD inner and outer cable	205 inner U.L. (448 m) 172 outer U.L. (760 m)	Conductor distribution design	no
Steel for collars	136 ton YUS 130	Mechanical design	Ap. 120 mm-> need 106 ton
Iron for yoke laminations	262 ton Magnetil	Max outer diameter of cold mass. Probably mix of different iron lamination thicknesses	Need 700 ton-> decided to purchase all the needed material
MD tooling	Curing press Welding press	Max cold mass outer diameter, max coil length	Modification for flexible use

Selection of type 1 cable

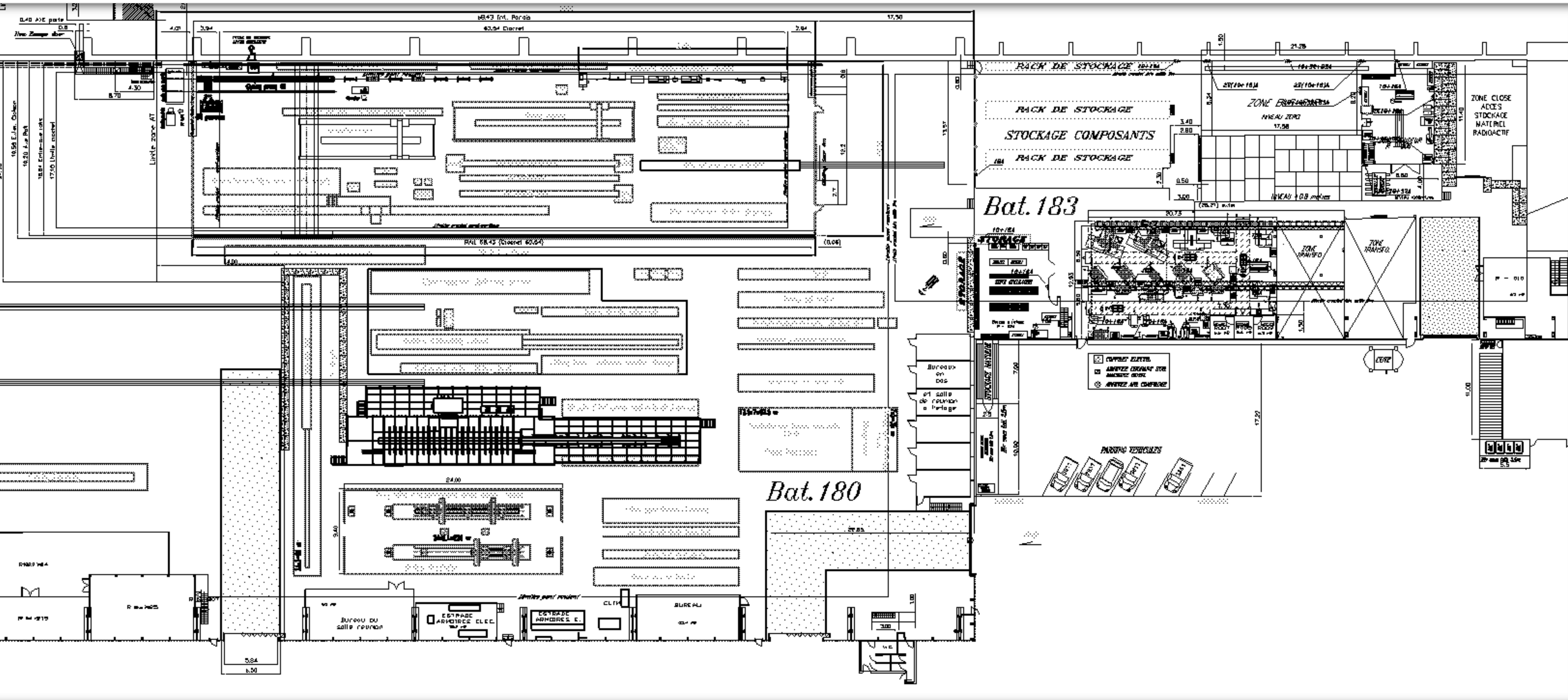


Selection of type 2 cable



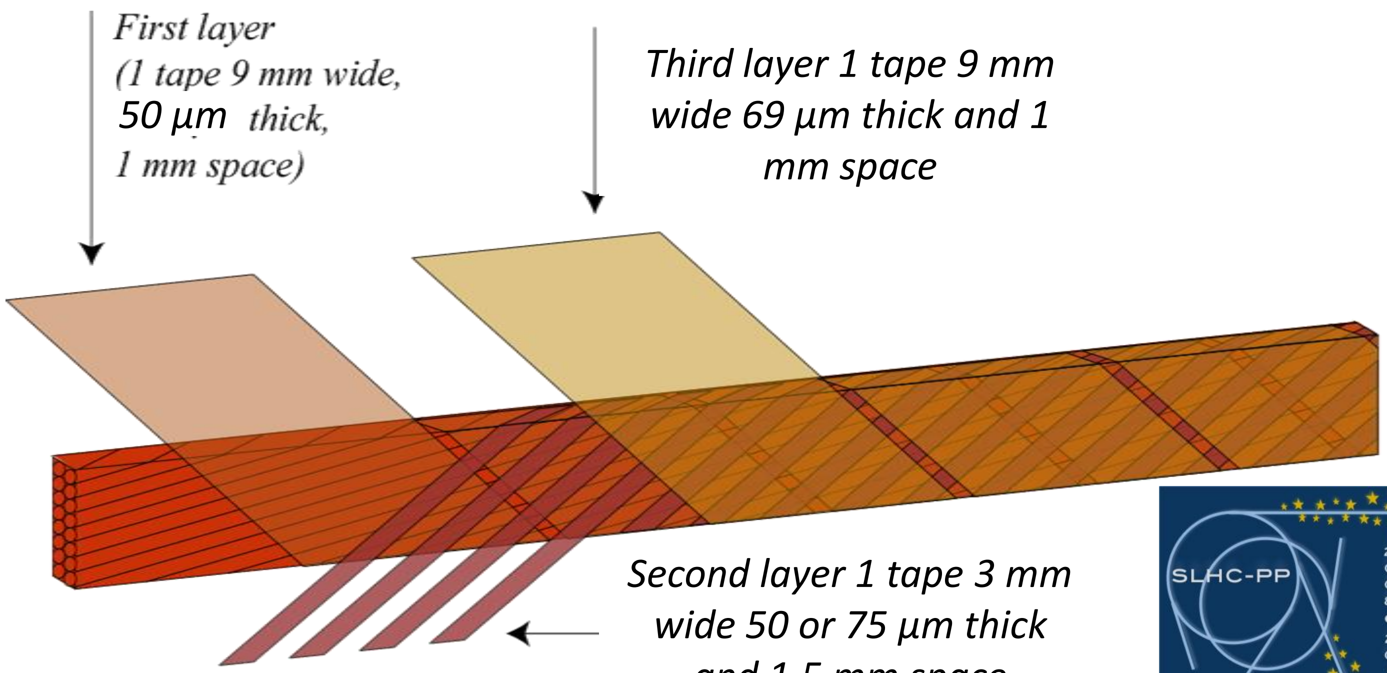


Bat. 183
Bat. 180
RACK DE STOCKAGE
STOCKAGE COMPOSANTS
RACK DE STOCKAGE
CRYOGENIE - CR/AT
COMPRESSEUR
PH
AT

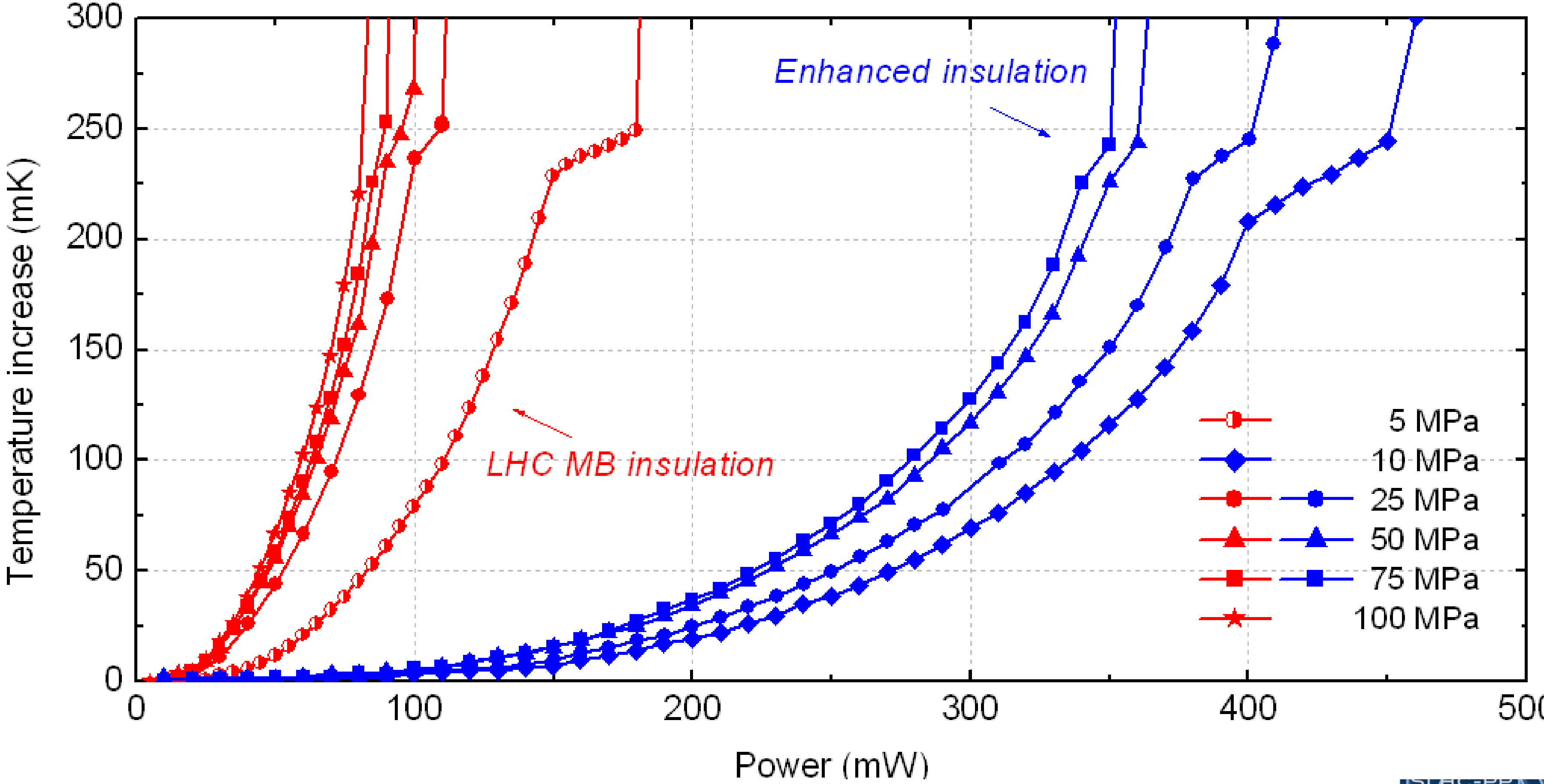

RACK DE STOCKAGE
STOCKAGE COMPOSANTS
RACK DE STOCKAGE
ZONE CLOSE ACCES STOCKAGE MATERIEL RADIOACTIF
Bat.183
STOCKAGE
ZONE TRANSFO.
PARKING VEHICULES
Bat.180

Development of new porous insulation topology: aim

- Provide adequate electrical insulation
- Increase the heat removal in order to better cope with the energy deposited by the I.P. debris
- E-modulus should be not be too much reduced and the coil should be creep stable
- Suitable to be industrialized:
  - Commercially available material
  - Use of Dipole recovered insulating machine



New results up to T λ



MQXC cross sections and iron yoke with heat exchanger(s)

Two possible solutions for heat exchanger proposed by the cryogenic team:

1) 2 heat exchanger in parallel inner diameter 71 mm (1st eval. wall thickness 2.5 mm). Hole diameter 80 mm
2) 1 heat exchanger inner diameter 100 mm (1st eval. wall thickness 3.5 mm). Hole diameter 110 mm

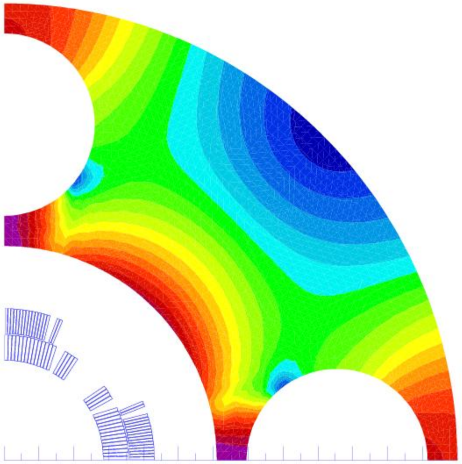
Both are large holes in the iron that affect transfer function and field quality

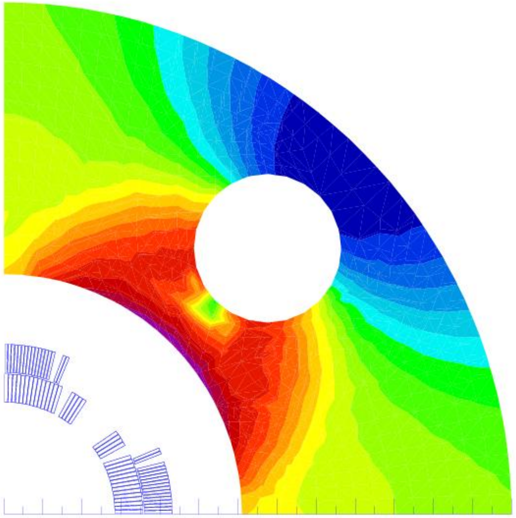
We can consider 2 possible configurations

1) Holes along the 2 mid-planes (larger effect on the transfer function)
2) Holes at 45 º

We prefer solution with 1 heat exchanger on the vertical mid plane because of

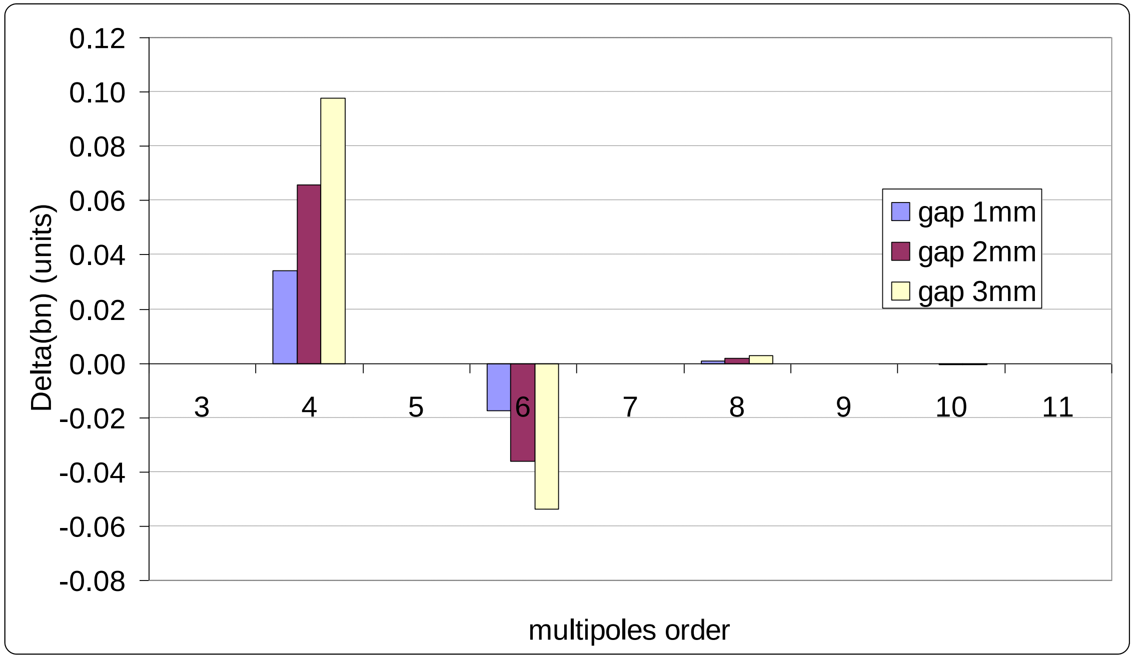
1) Simpler interconnect
2) Standardization of cold masses respect 1 heat exchanger at 45 º

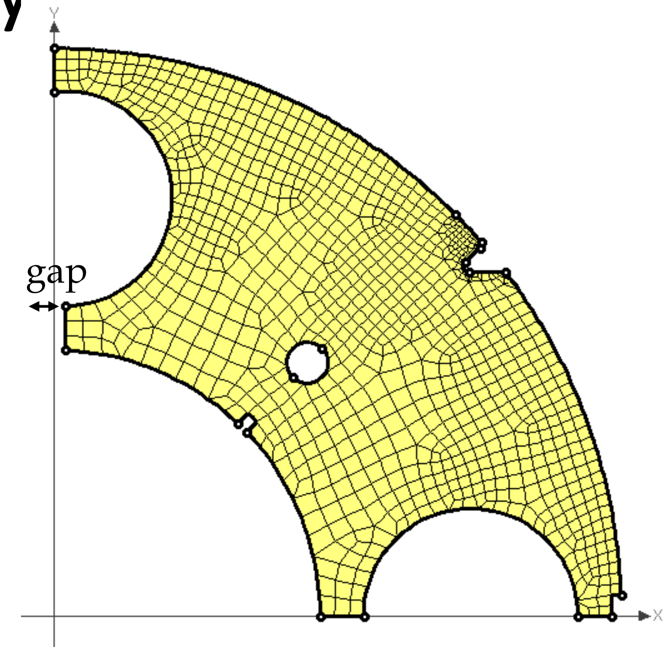




Effect of a slot in the iron on the magnetic field quality

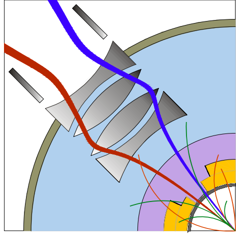
- Odd multipoles are not affected
- Only even multipoles b_4, b_6, b_8 and b_{10} are affected (multipole variation higher than 0.0001 unit)

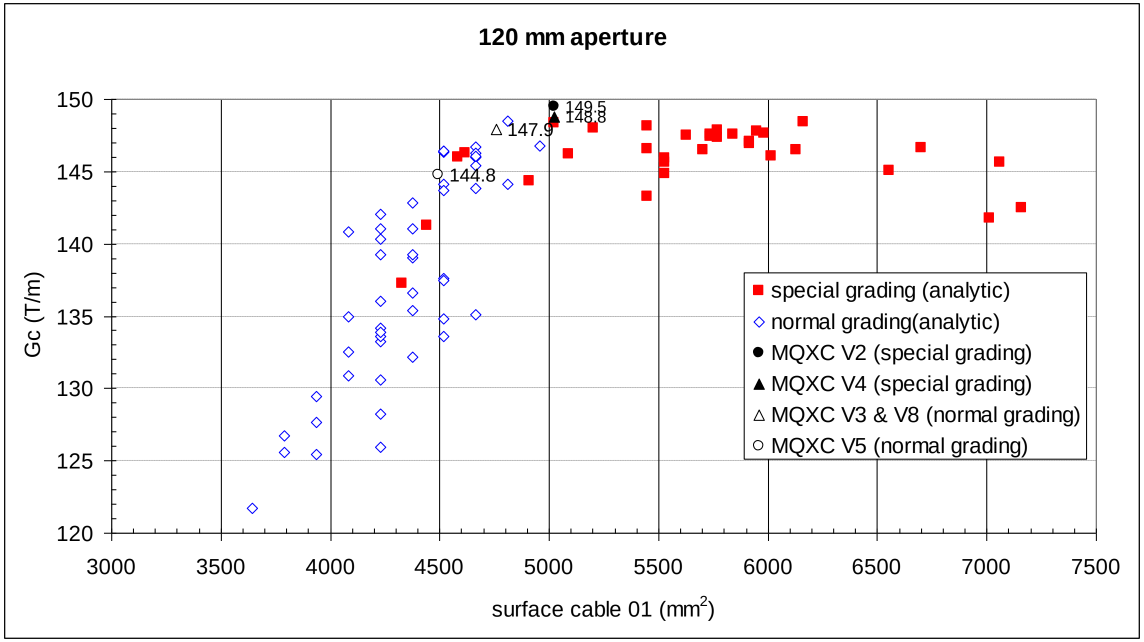


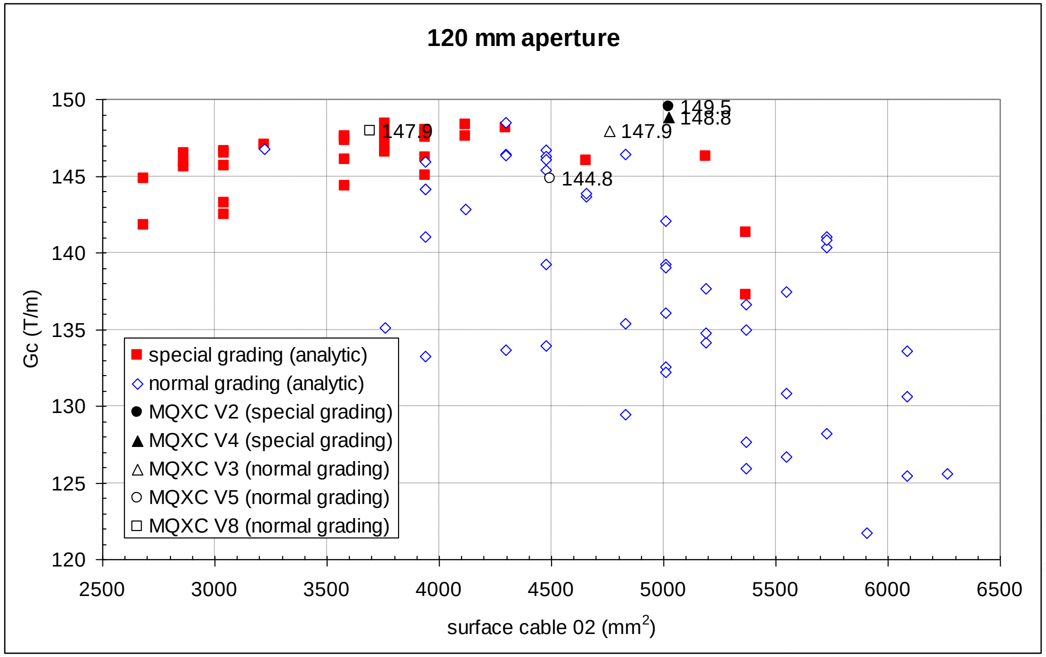


	gap 1mm	gap 2mm	gap 3mm
Δ b4	0.0340	0.0656	0.0978
Δ b6	-0.0174	-0.0362	-0.0536
Δ b8	0.0010	0.0020	0.0029
Δ b10	-0.0002	-0.0004	-0.0006

Gradient respect cable used in the cross section



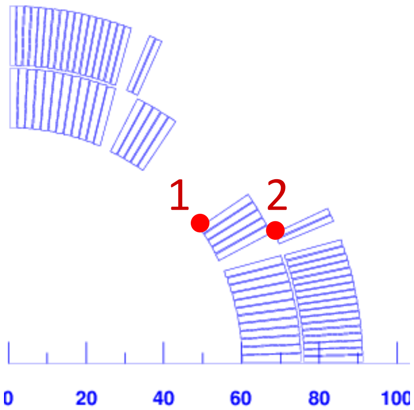




Proposed Coil Cross-Section

- Coil blocks features

Block Nº	Nb Cond	r (mm)	φ (º)	γ (º)	cable type
1	12	60.00	0.2101	0.000	Cable 01
2	5	60.00	25.728	27.757	Cable 01
3	17	75.92	0.1849	0.000	Cable 02
4	2	75.92	23.501	22.762	Cable 02



MQXC V24

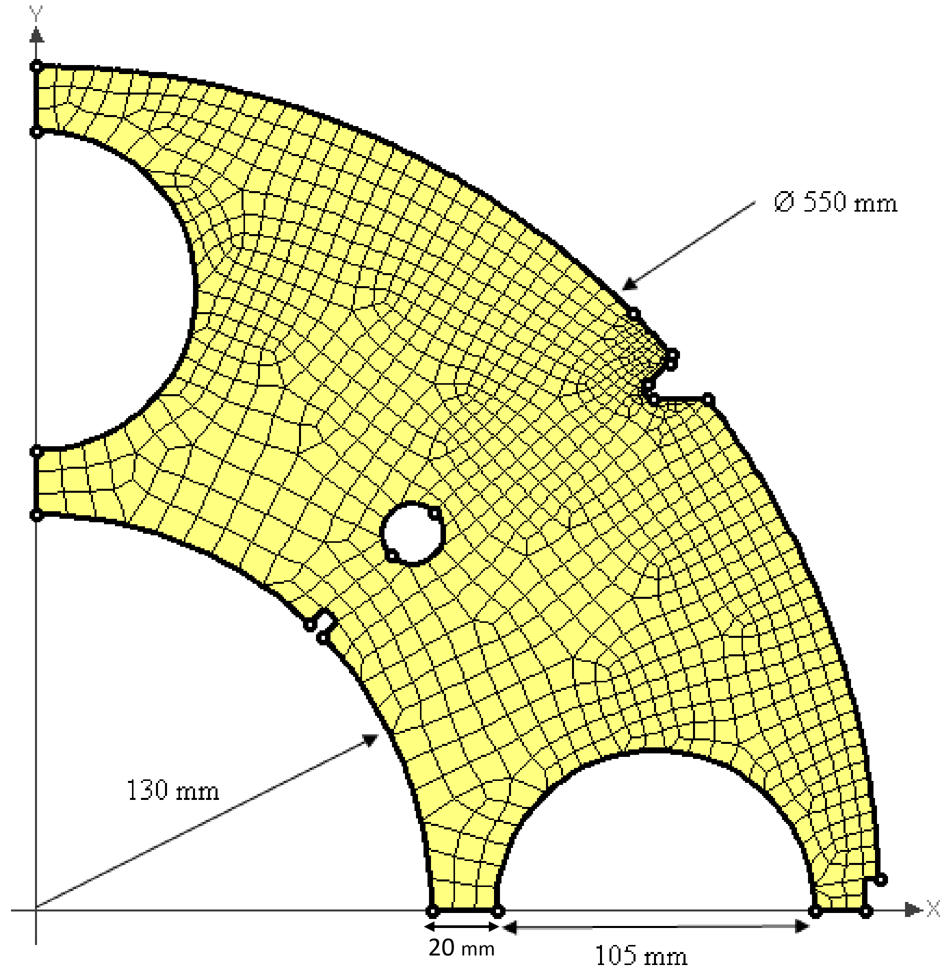
- Angular position of the point 1 & 2

  (mechanical requirement: angles < 41º)

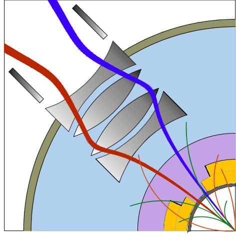
  - Point 1: ~35º
  - Point 2: ~26º

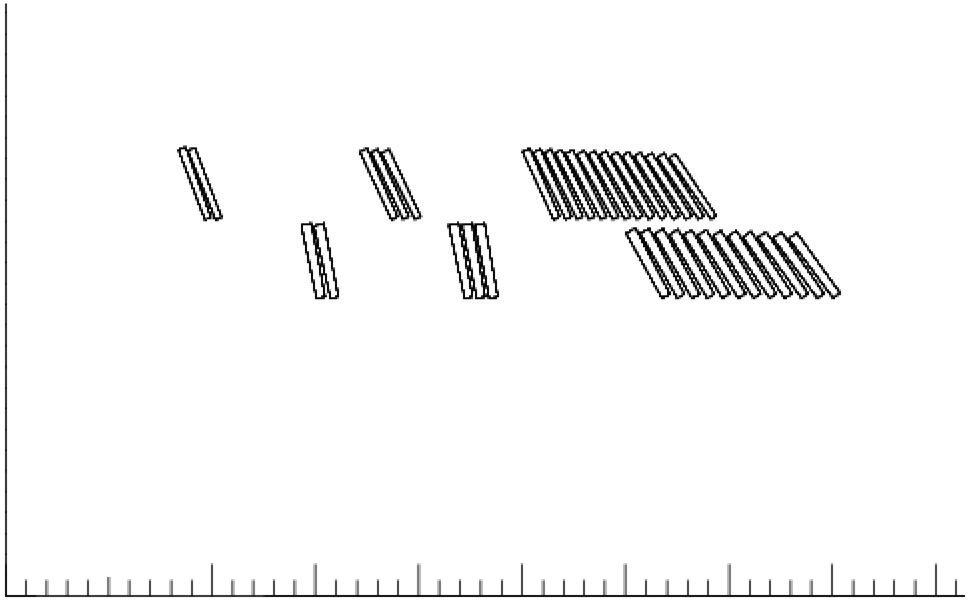
Iron Yoke Dimensions

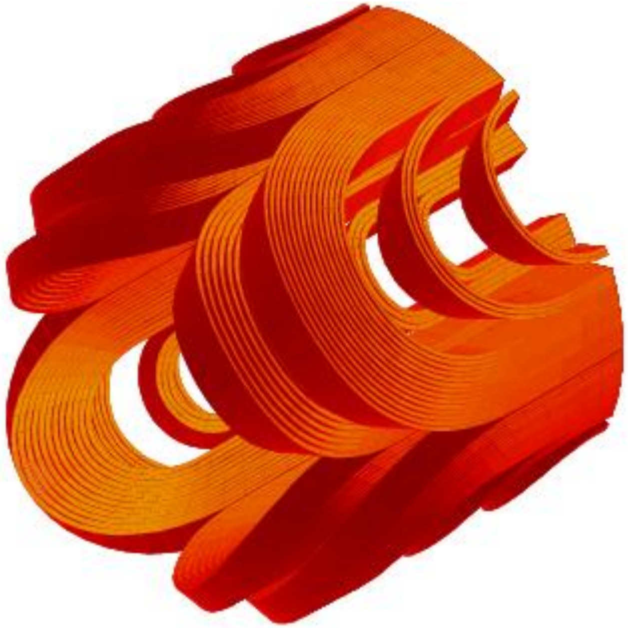
- Distance between coil outer radius and iron inner radius is of ~ 38.6 mm.
- He holes are radialy centered. this lefts about 20 mm of matter on each side.
- The small hole (Ø 20.5 mm) is used for the rods. It can be moved somewhere else because its impact on the multipoles is low.

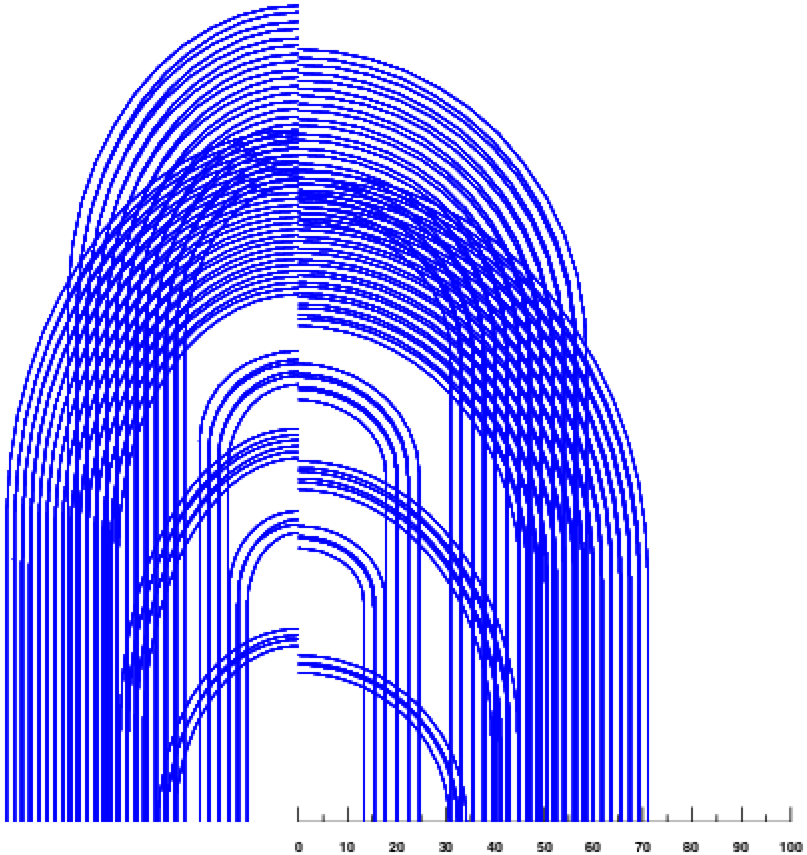


NCS head design



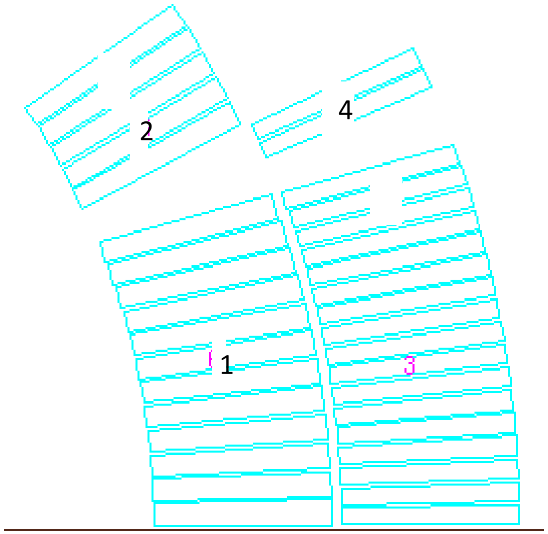




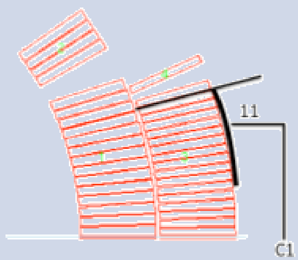
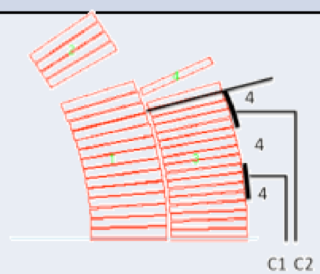
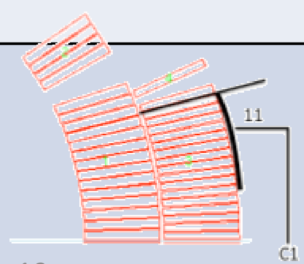


Peak field in the head, 30 mm of coil more and a lot more of margin in the head

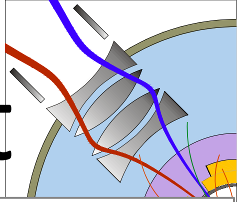
			straight part	head	B peak	ss field	% ss cur
no Iron Yoke	cable 01	BS1	6.5	6.6	cb01		
		BS2	7.3	7.4	**7.4**	9.6	77
	cable 02	BS3	5.7	6.1	cb02		
		BS4	6.1	6.4	**6.4**	8.4	75
unsat Yoke	cable 01	BS1	7.3	7.3	cb01		
		BS2	8.1	8.1	**8.1**	9.9	82
	cable 02	BS3	6.4	6.7	cb02		
		BS4	6.8	7.2	**7.2**	8.8	82
real Yoke	cable 01	BS1	7.1	7.2	cb01		
		BS2	7.9	8.0	8.00	9.8	81
	cable 02	BS3	6.6	6.6	cb02		
		BS4	6.6	7.0	7.03	8.7	81

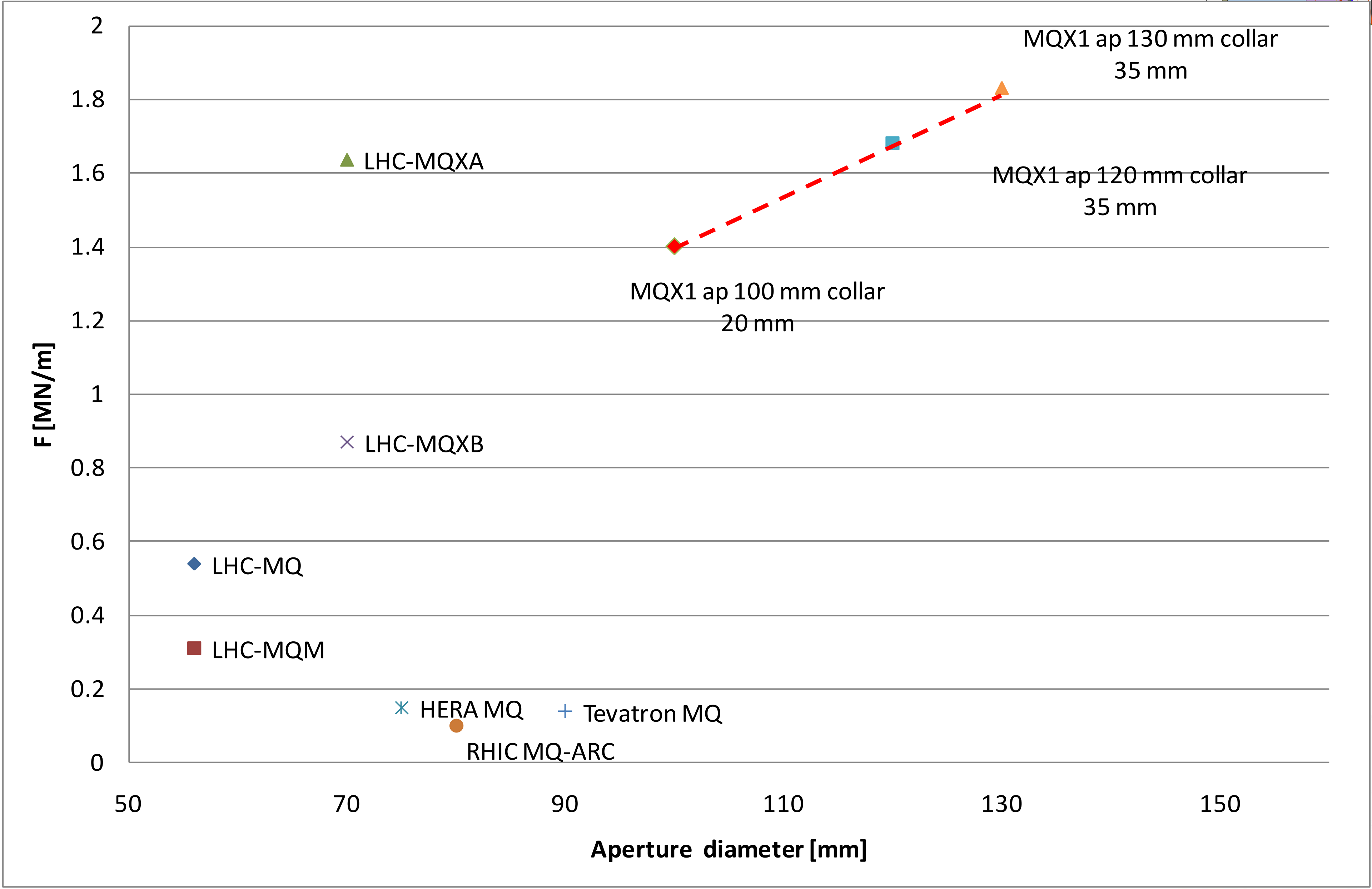


Protection Study

		Nominal Current		Half Current		
Setup		**T peak**	**MIITs**	**T peak**	**MIITs**	
Dump resistor 40 mOhm, 10 ms delay		117	33.6	--	--	
		157	33.3	78	23.0	
	20ms extra delay	157	36.4	78	23.7	Hot spot in outer layer
	only half of the heaters	220	38.1	103	27.5	
		180	35.2	86	24.5	
	20ms extra delay	217	38.0	104	27.6	
	only half of the heaters	221	43.4	102	30.8	
	+ Dump Resistor	118	29.4	50	15.2	Hot spot close to heater
	+ Dump Resistor, half of heaters	136	29.8	--	--	Heater failure uncritical

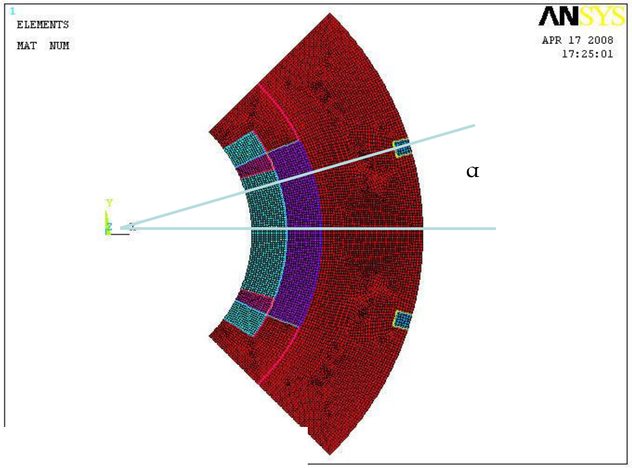
Forces in few quads per octant

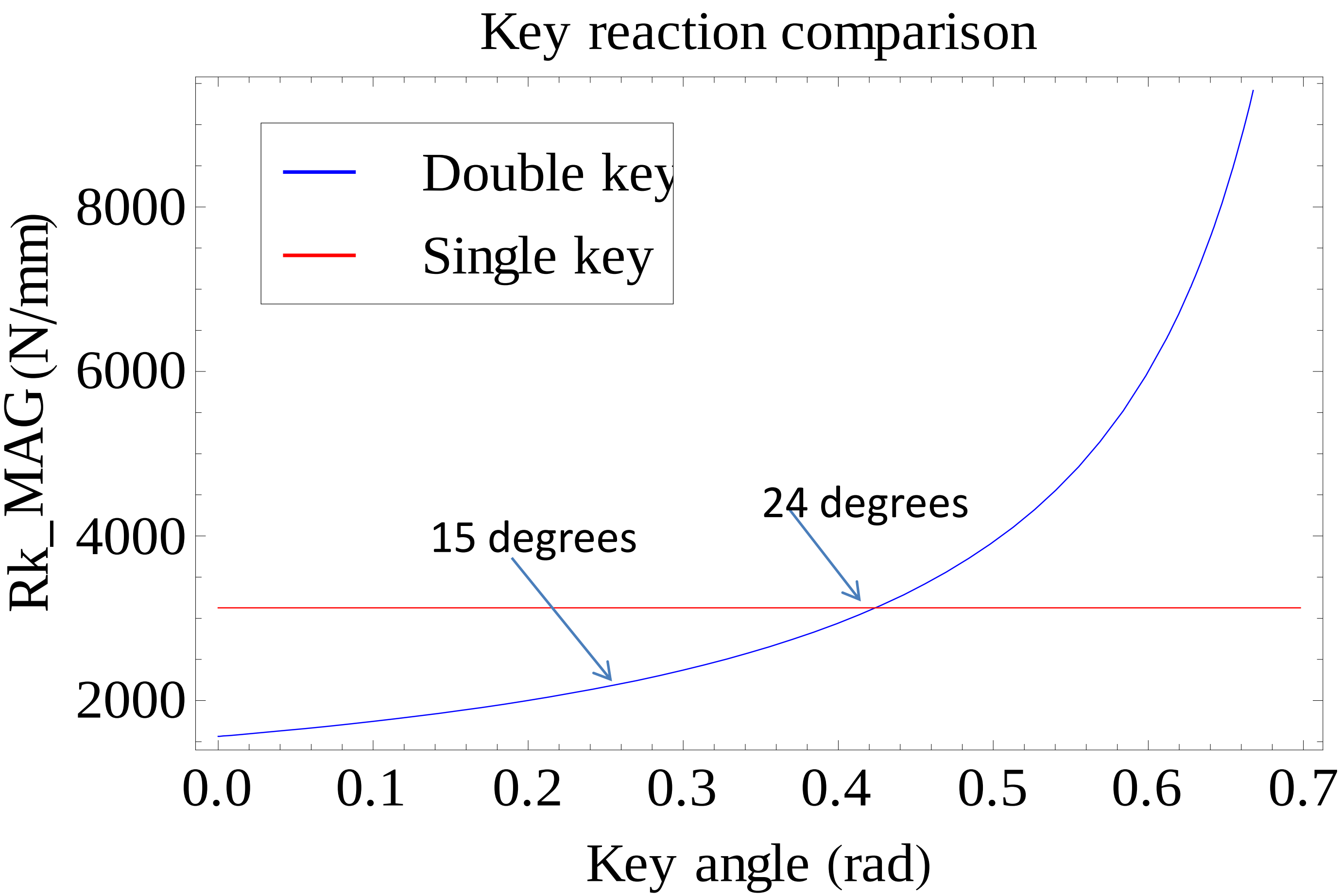




Key layout analysis

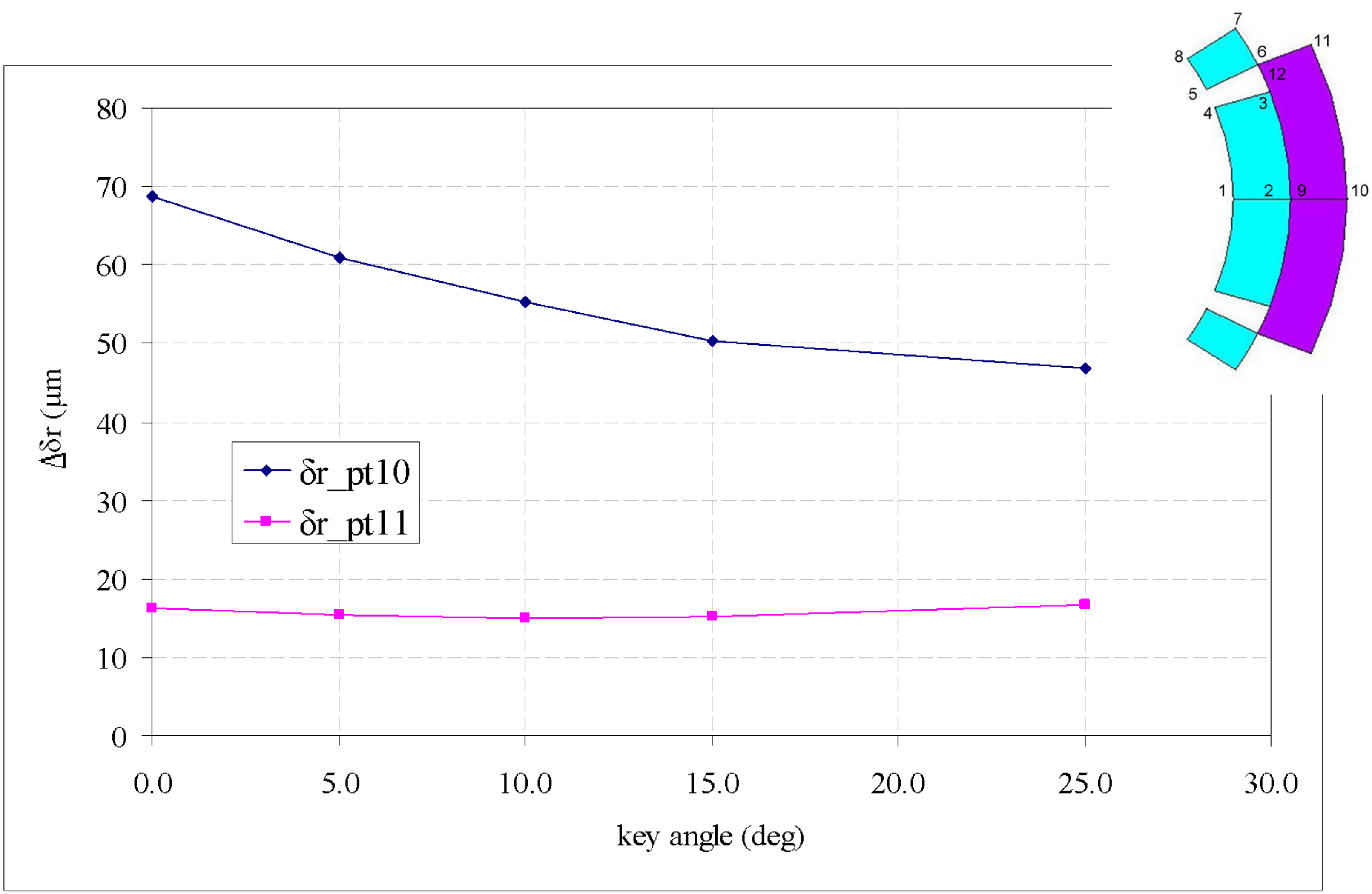
Forces repartition on keys according to
1key or 2key layout per quadrant structure



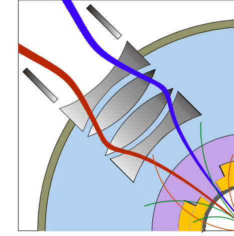


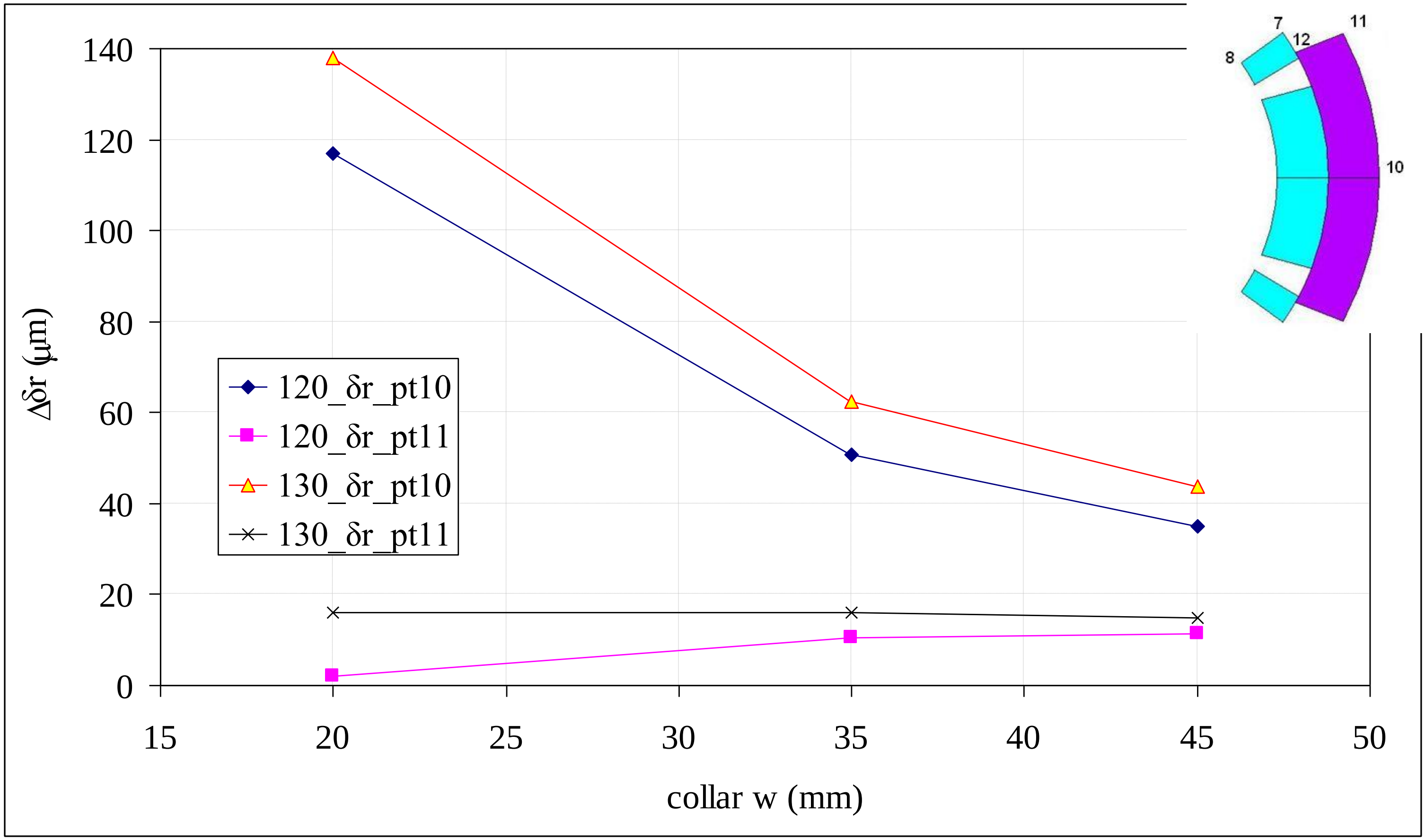
Key layout analysis

- Coil radial displacement in function of the angular distance between keys

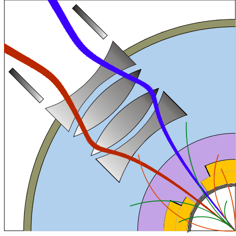


FE analysis – radial displacement

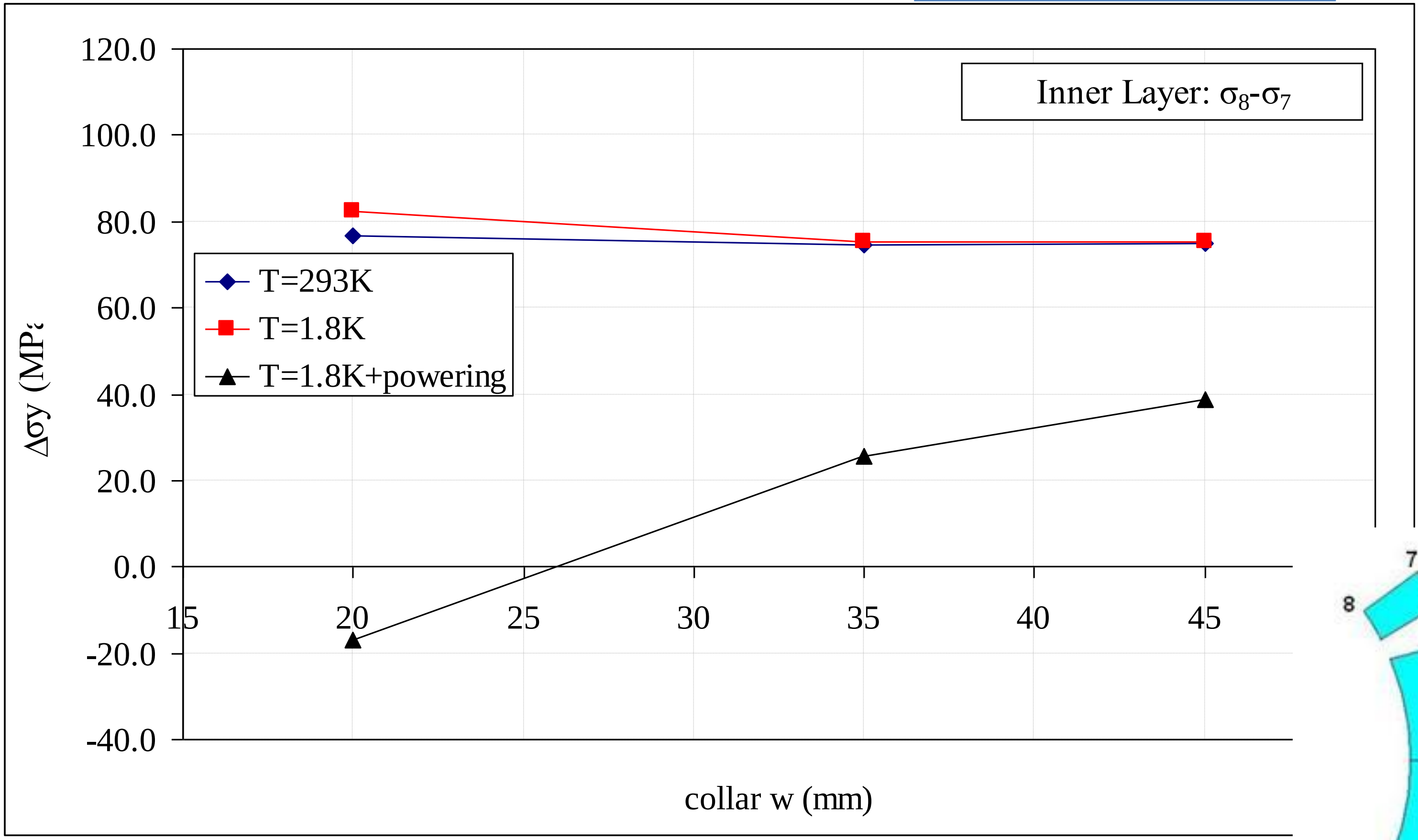


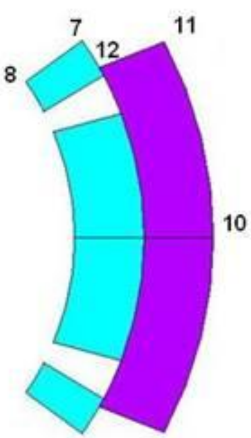


FE analysis – bending effect

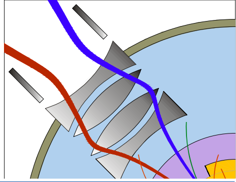


∅=120mm I.L.



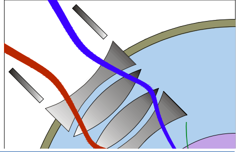


Magnet and cold mass concept



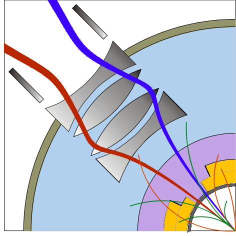
	Solution	Remarks
Coil	2 layers independently cured with a splice and layer jump	Best use of available SC material. Re-use of LHC MB experience for layer jump
Collar	Thick self standing collars	Reduce cost of fine- blanking for collars and yoke due to mechanical de-coupling. Reduced influence of cold mass assembly on field quality a part from iron saturation and alignment
Yoke	1 Lamination to make the yoke	Reduce cost of fine blanking for yoke
Cylinder	10 mm thick shells not contributing to mechanical efforts. No pre-stress	Possibility to use other steels then 316 LN
Cylinder weld	No stress in the cylinder and therefore reduced stress in the weld	It is leak tight weld for which whatever weld process can be chosen and for which we can release acceptance criteria

Magnet and cold mass concept



	Solution	Remarks
Ground insulation	Same scheme as MQ or MB ground insulation with 4 layers of 0.125 polyimide. Double G.I. on mid plane to provide handle for field quality and increase insulation between 1^{st} and 2^{nd} layer (as MB)	
Q. H.	Use of intermediate G.I. foil between coil and Q.H. Use of connection without omegas	Increase reliability
Heat exchanger position	1 large internal heat exchanger 100 mm i.d. 110 mm hole in yoke. Position vertical mid plane. Available He volume for control from 95 cm^2 to 285 cm^2	Allows interchangeability of magnets
Cold mass support	Possibly 2 feet. With 10 m long cold masses with cylinder 10 mm thick a 1^{st} estimation gives a max deflection of -0.35 mm with an average of -0.16 mm. This is the preferred choice for the moment for the cryostat design	

927 installation for model



180 installation for model and prototype