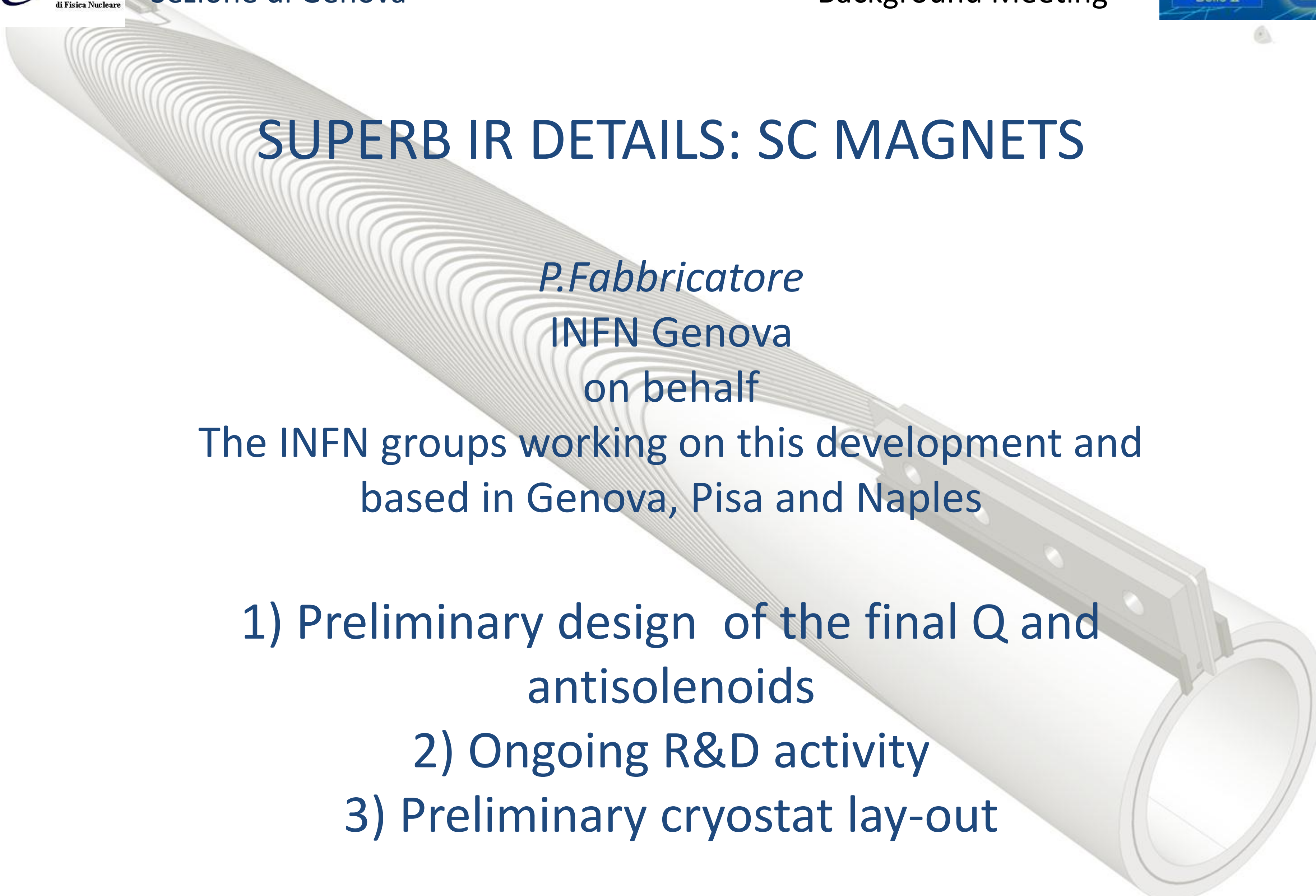
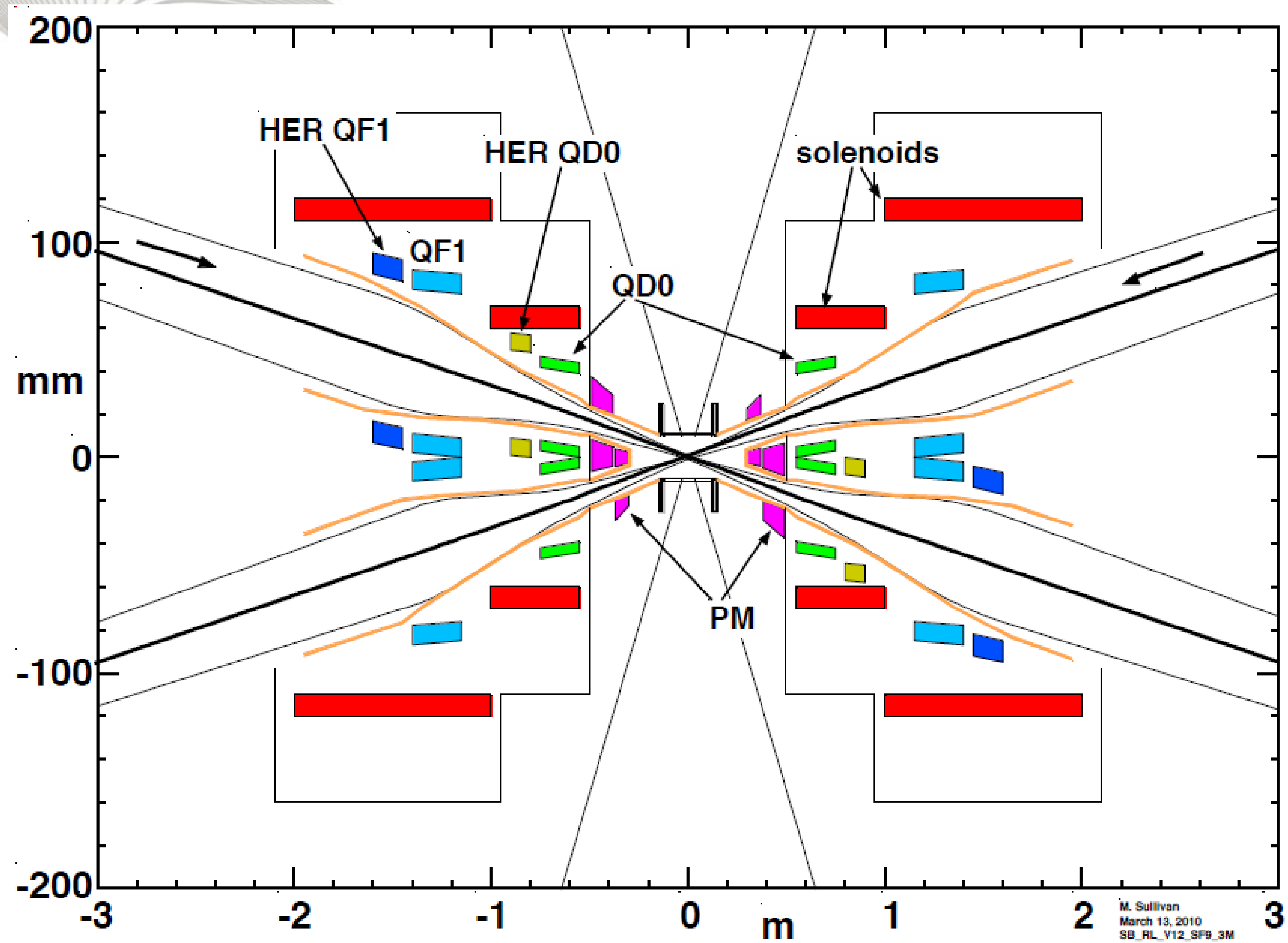


SUPERB IR DETAILS: SC MAGNETS

P.Fabbricatore
INFN Genova
on behalf
The INFN groups working on this development and based in Genova, Pisa and Naples

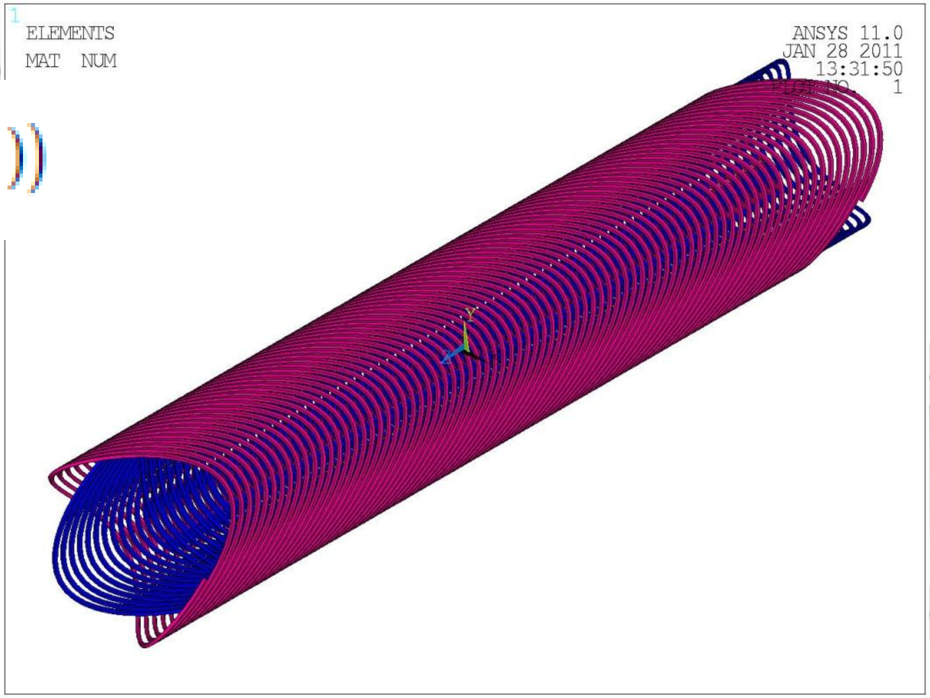
1) Preliminary design of the final Q and antisolenoids
2) Ongoing R&D activity
3) Preliminary cryostat lay-out

We are developing the magnets of the IR on the basis of the IR design made by M.Sullivan

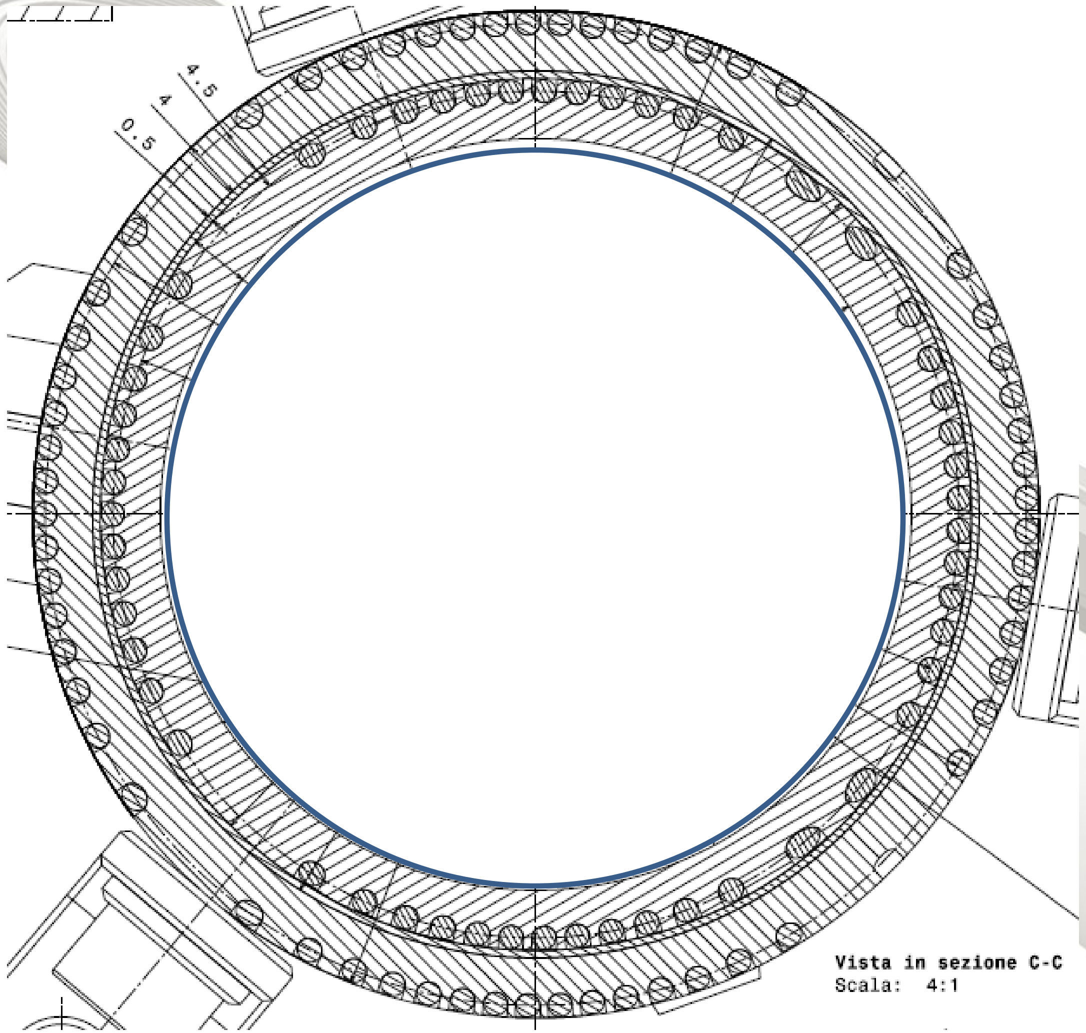


The quadrupoles are done according the double helix principle. This lay-out allows to modulate the winding introducing suitable multipole corrections. The overall structure is compact and the effect of coil ends on field quality is minimal (wrt more conventional designs)

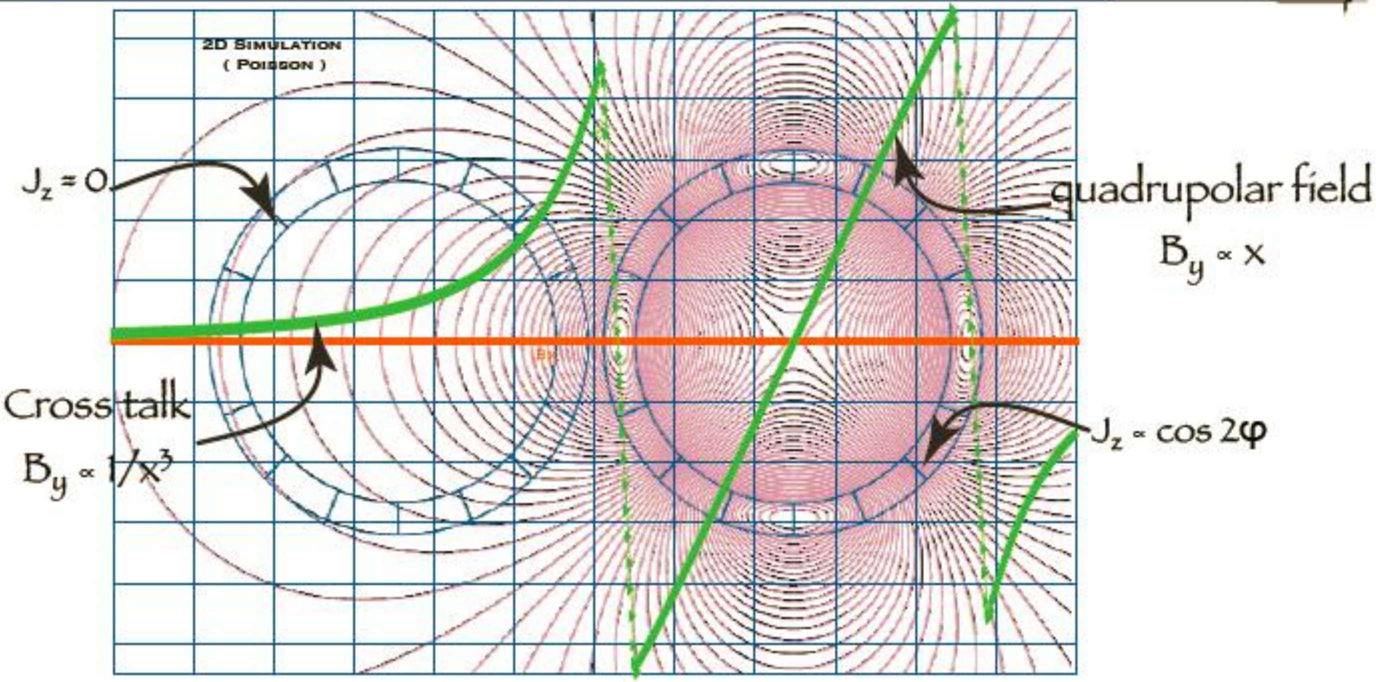
$$z(\theta)=\frac{h\theta}{2\pi}+A_0\left(\sin\theta+\varepsilon_2\sin\left(2\theta+\phi_2\right)\right)$$



Cross section of a (pure) quadrupole



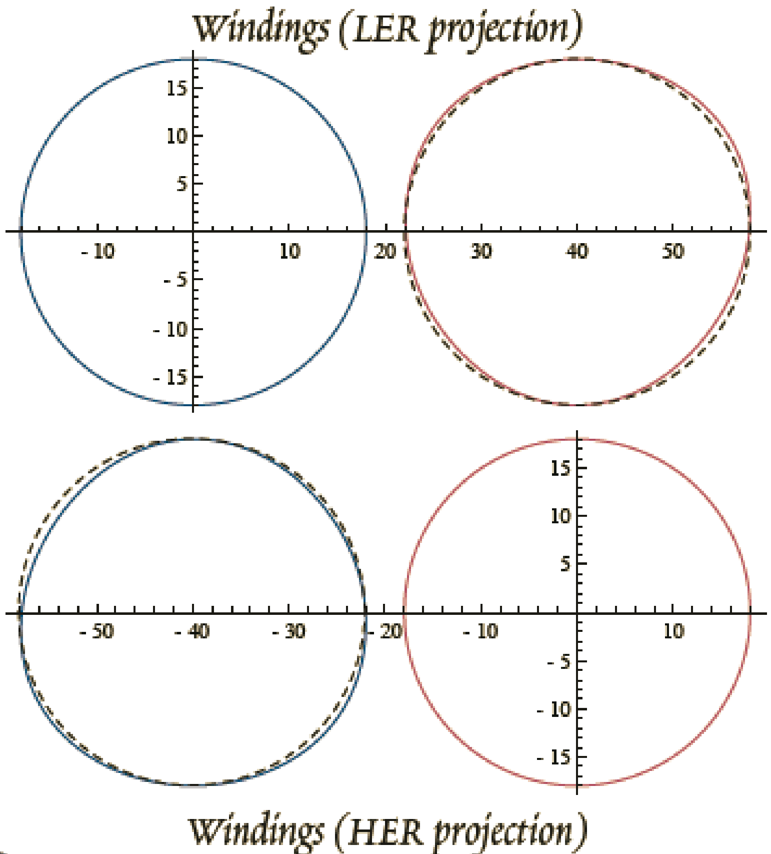
Cross Talk Compensation

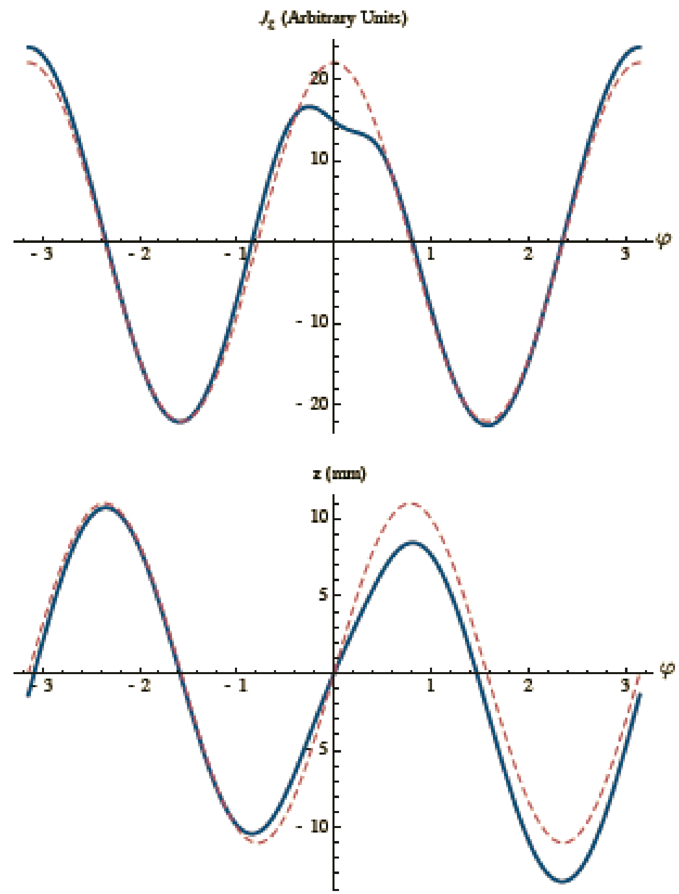


- Idea: exploit the superposition principle to design the coil shape in such a way that the integrated beam kick is a linear function of the displacement from the reference orbit

E.Paoloni

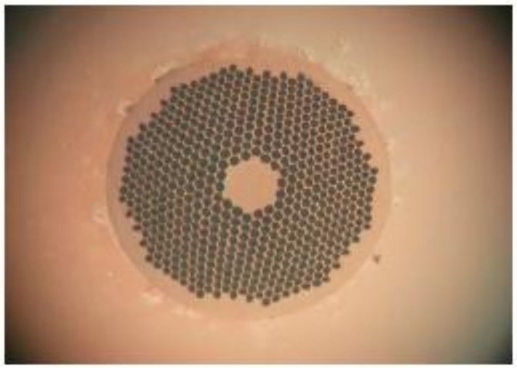
Compensated Winding Shape





E.Paoloni

The superconducting wire

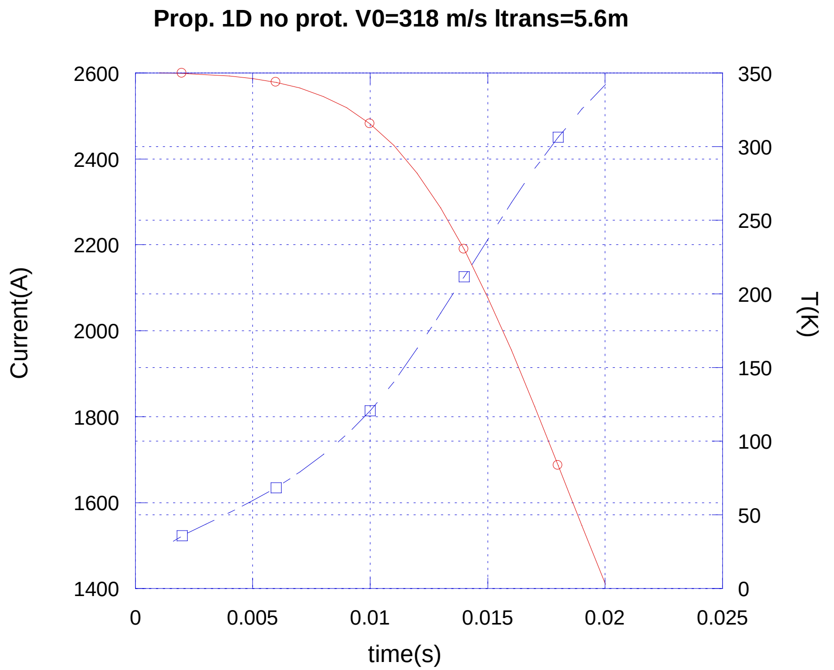


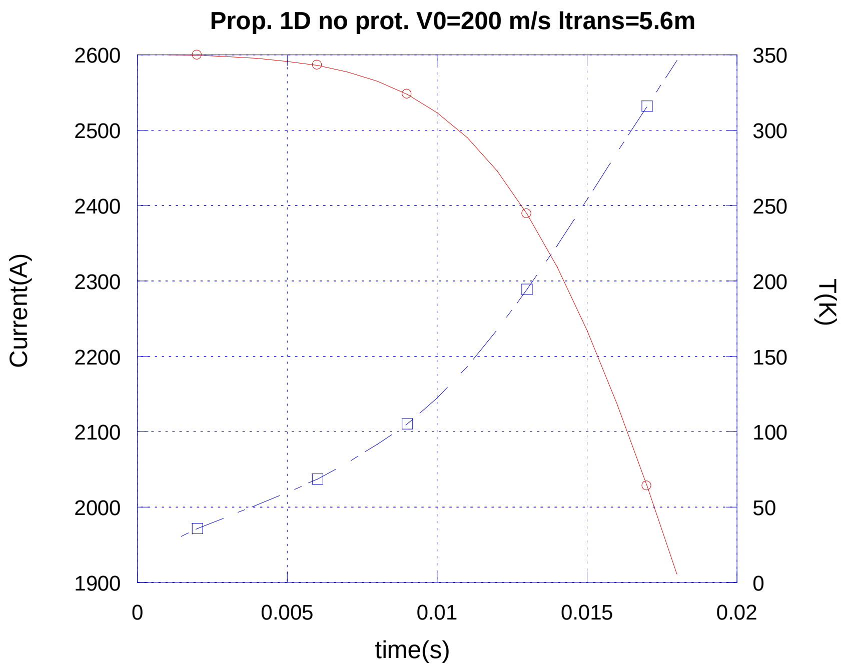
Preliminarly the sc wire chosen for these coils if a NbTi multifilamentary wire already involved in CMS conductor. The diameter is 1.28 mm; the Cu/SC ratio is 1.1

Item	Sample	B	K	Ic(K)	Ic(4.2)
Critical Current (A)	Head	4T	4,255	2435	2 475
	Head	5T	4,255	2001	2 039
	Head	6T	4,255	1573	1 608
	Head	7T	4,255	1172	1 205
Retained Ic (A)		5T	4,2	2001	2 039

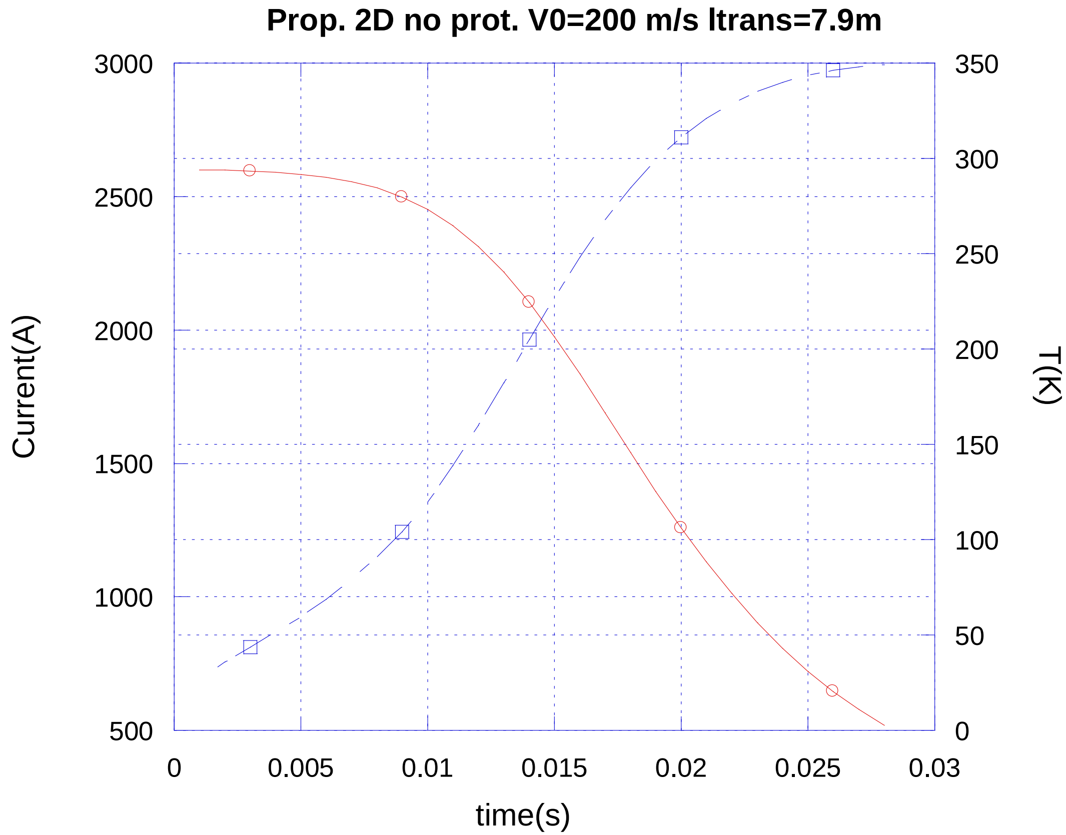
Quench issues

Simple quench simulations indicate potential problems (The problem!) This is due to the high current density in the wire: $2kA/mm^2$ (5 times the one in LHC dipoles)





Quench propagation in 2 directions help, but the basic problem remain of excessive local



Mitigation

In facts quench scenario is better because:

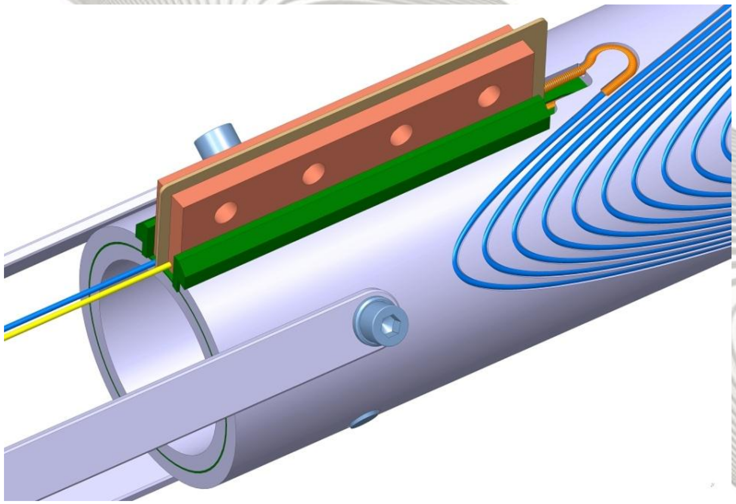
1) As current decay, the eddy current induced in the mandrel will heat up the coil (quench back) better distributing the temperature increase; induced currents also dissipates energy in the mandrel reducing the amount of energy dissipated in the winding.

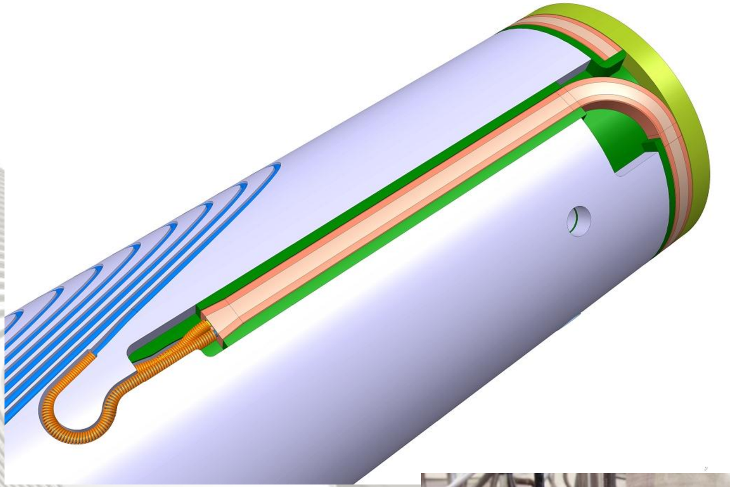
2) ac losses in the sc wire help in quenching larger regions.

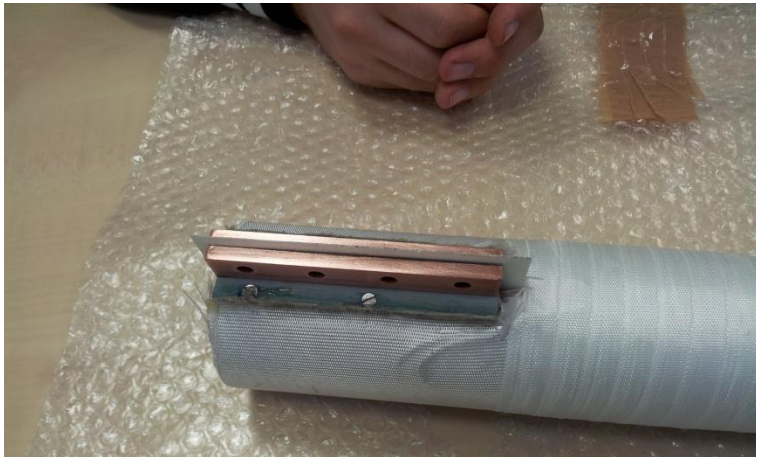
→ A test of the model is crucial for understanding these issues.

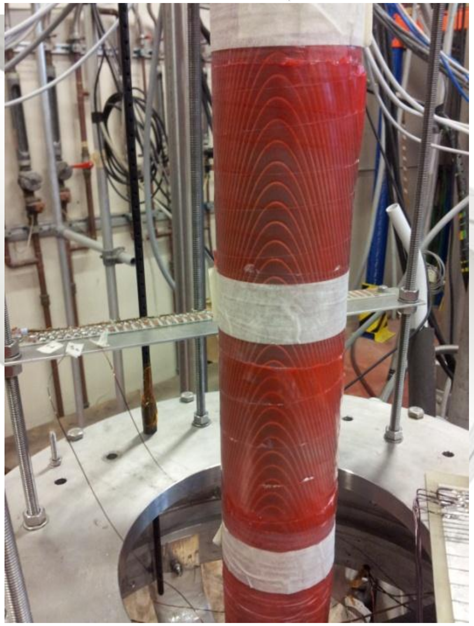
Construction of a model coil for addressing quench issues

The coil has been constructed at ASG Superconductors and was successfully tested at 4.2 K at INFN.



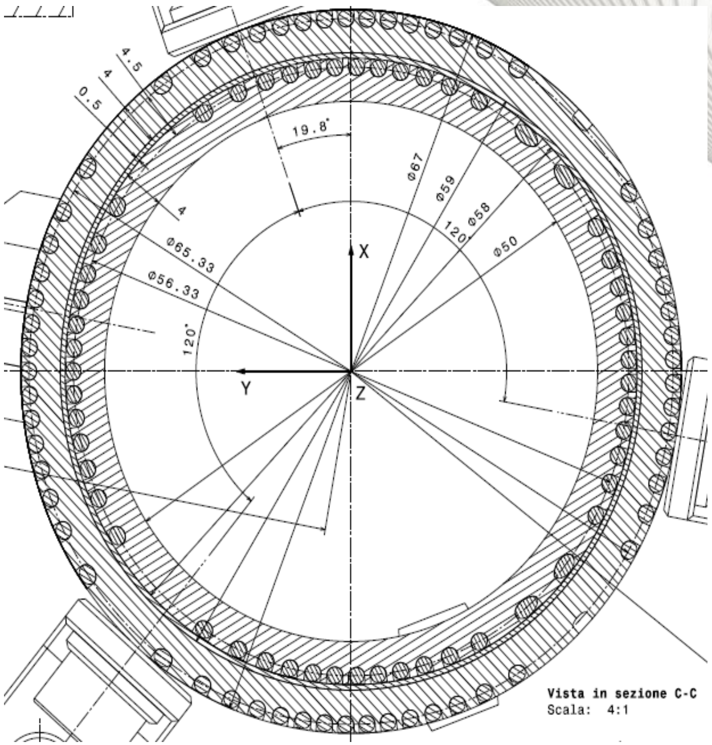


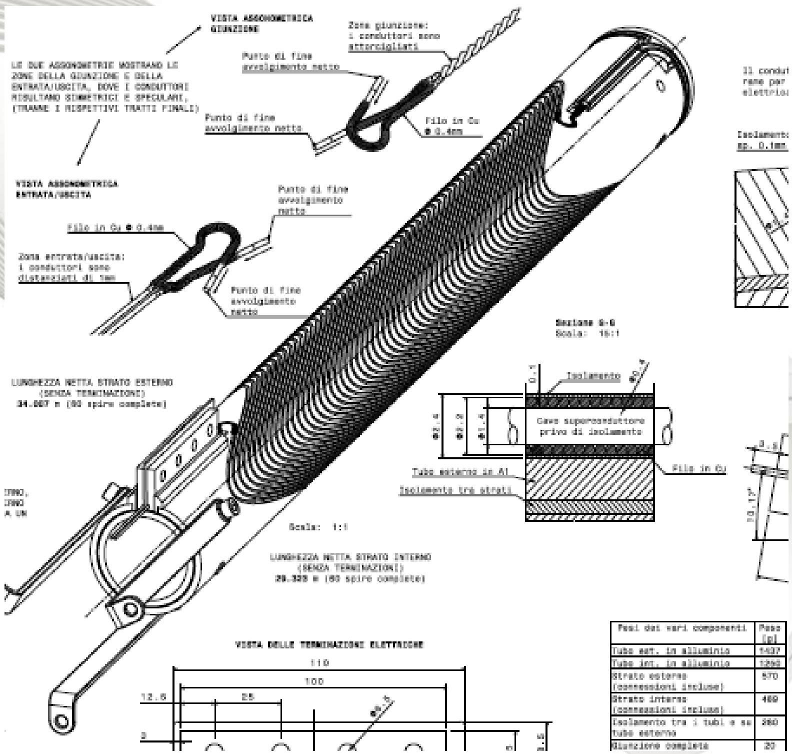




The model

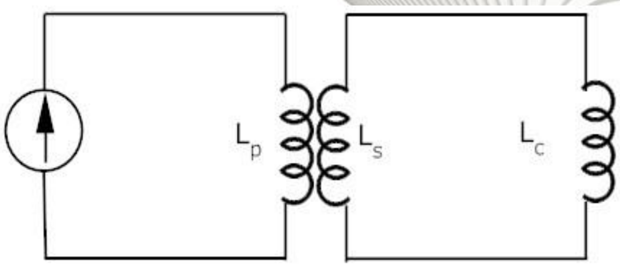
With 60 turns this coil generates a gradient of 50 T/m at 2600 A
The stored energy is 1.1 kJ (2 times QD0). The current density is the same of QD0





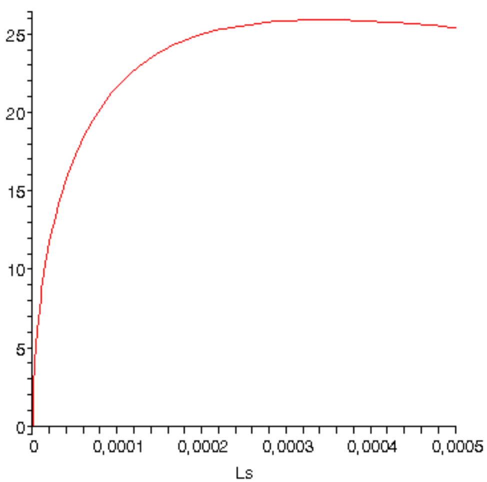
For limiting quench problems …

…we used a transformer system for charging the model so to limit the energy which in case of in case of quench can be dissipated as heat (1150 J)



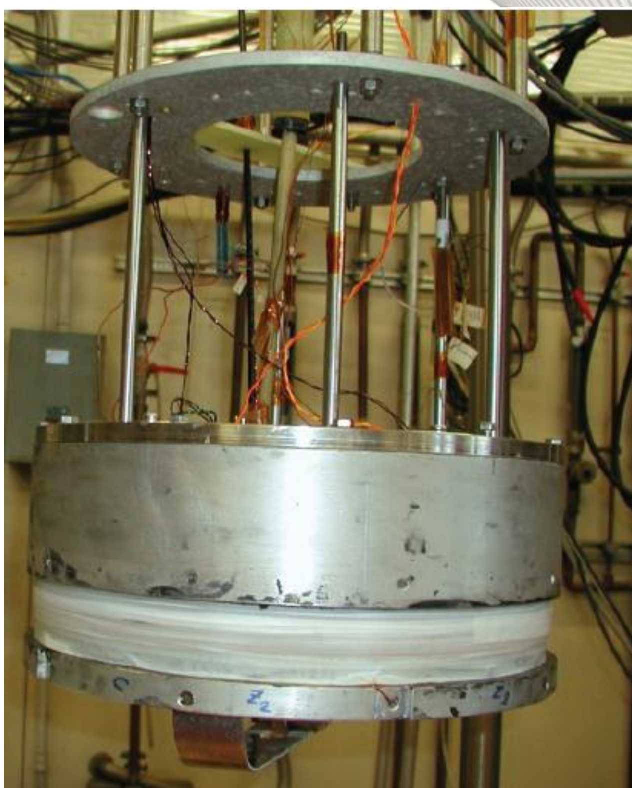
$$\alpha = \frac{I_s(t)}{I_p(t) - I_{p0}} = \frac{M}{L_s + L_c} = \frac{k\left(L_p L_s\right)^{\frac{1}{2}}}{L_s + L_c}$$

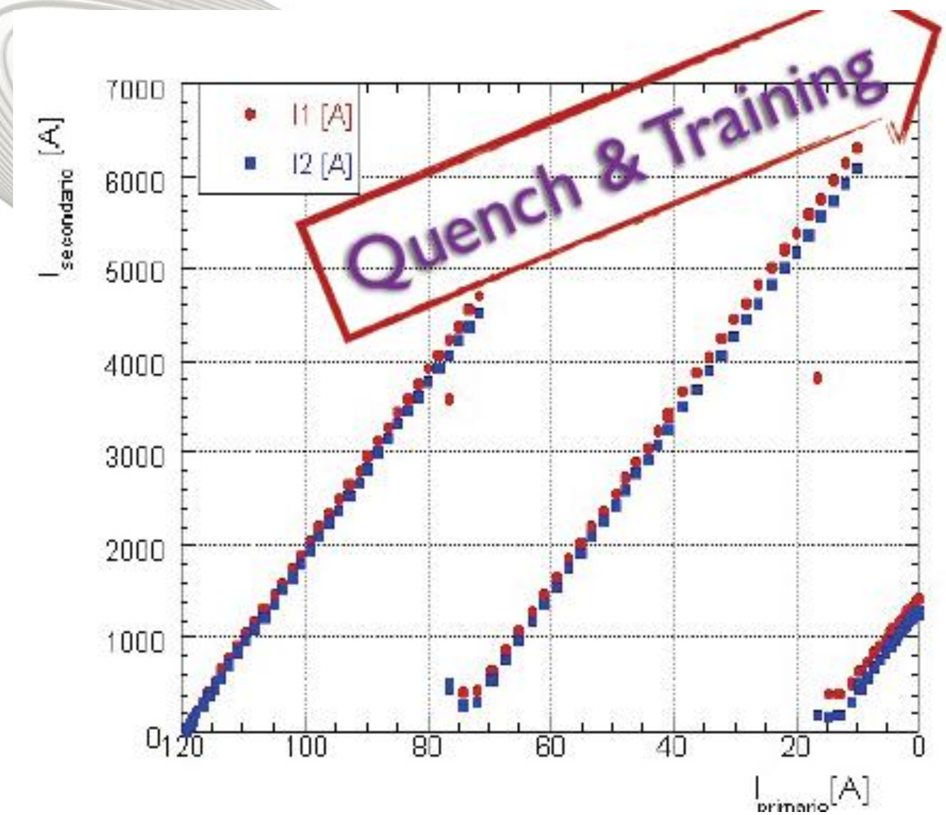
As primary we use a large magnet we have in lab L_p=6H ; L_c= 330 μH



The ideal current transformer ratio is for Ls=Lc, but the energy would double. Using a reduced secondary inductance L_s=90 mH the current transformer ratio is still acceptable. In order to fast dump the current and extract energy from the coil, a heater is placed in the secondary winding

The secondary was built and tested. It is done by a bi-filar wire of the same type involved for the quadrupole. In a single wire current up to 3000 A was induced. After quench the sc conditions were soon restored in the wire. Very good and promising result!





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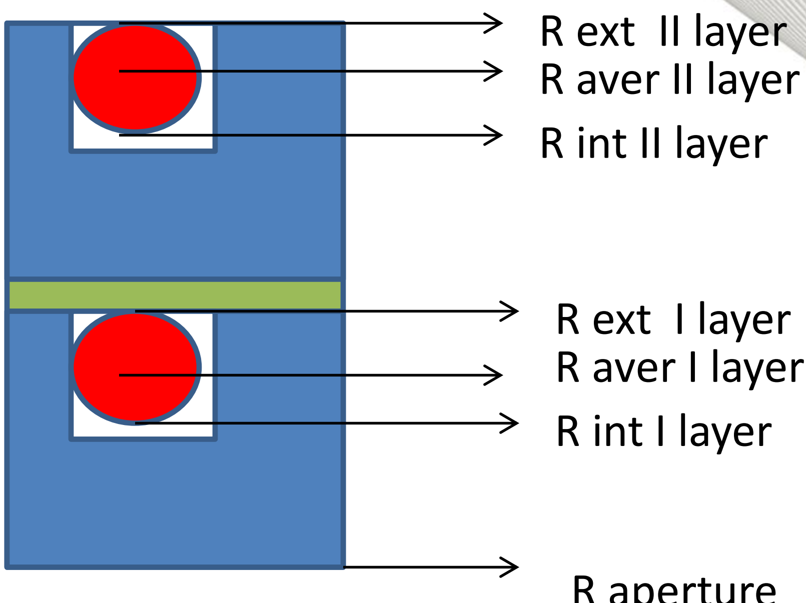
Sezione di Genova

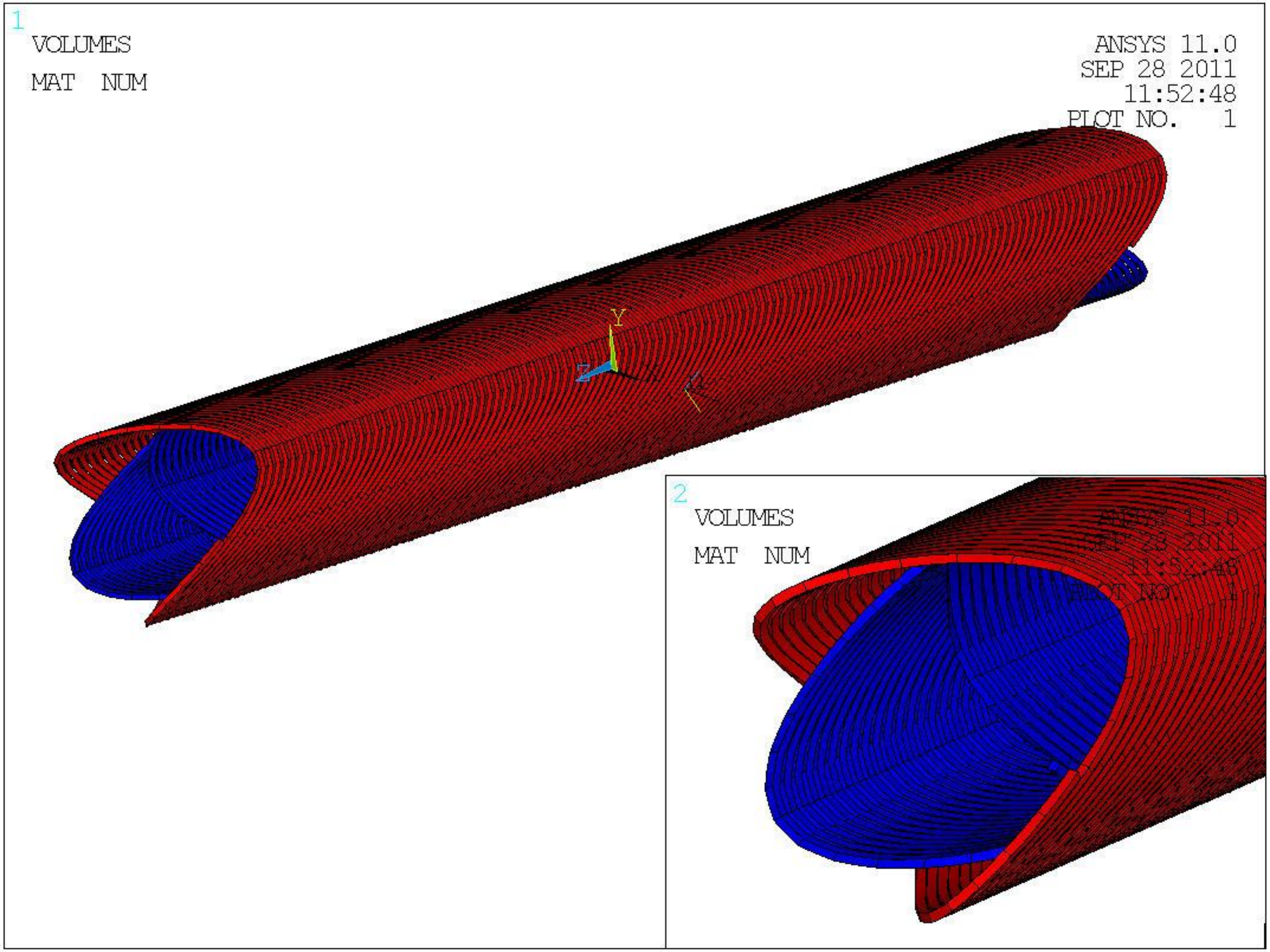
The model was successfully tested; it was fed with a current of 2750 A. The limitation seems to be of mechanical nature (mechanical disturbances). Further test are planned for better investigate this aspect.

Moving towards an updated design

- The tests gave indications that high current could be involved (2750 A) →
- We are developing a design with angles of 35° and high current. With respect the model we also reduced the thickness of each layer down to 2.5 mm (4 mm used for the model). The pitch is the minimum one (turns touch each other)
- The wire is the CMS one with formvar (Φ 1.28 + 0.08= 1.36 mm) or a Nb_3Sn wire Φ 1.20 + 0.14= 1.34 mm



R ext I layer	R aperture + 2.5 mm
Gap	0.5 mm
R ext II layer	R aperture + 5.5 mm
Cave hosting wire	1.4 mm x 1.4 mm

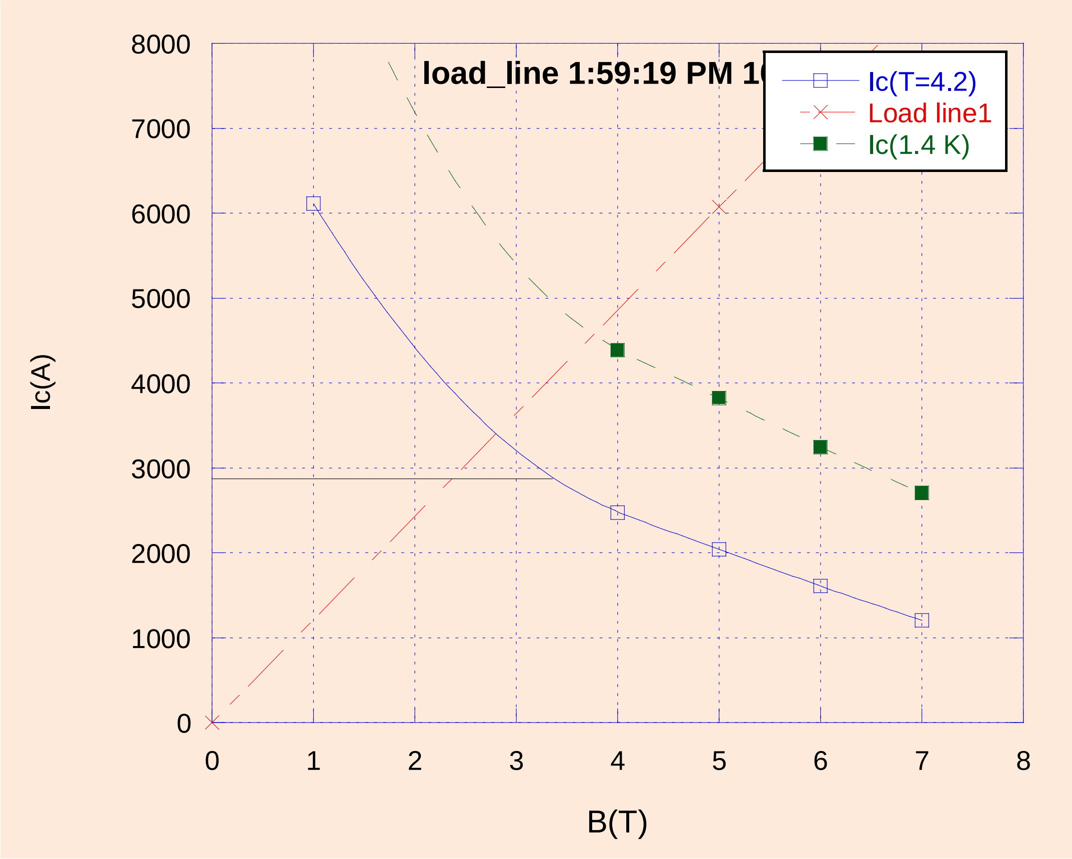

1
VOLUMES
MAT NUM
ANSYS 11.0
SEP 28 2011
11:52:48
PLOT NO. 1
Y
Z
X
2
VOLUMES
MAT NUM

Main characteristics of all magnets last version (not yet frozen)

	QD0	QD0H	QF1	QF1H	Large Solenoid	Small solenoid
Magnetic lenght (m)	0.30	0.15	0.40	0.25		
Gradient (T/m) or Field(T)	97.088	72.810	40.870	38.049	1.5	1.5
Aperture (mm)	35.00	50.00	73.00	78.00	240	140
Inner radius of inner layer	18.65	26.15	37.65	40.15	120	70
Outer radius of inner layer	20.00	27.50	39.00	41.50		
Inner radius of outer ayer	21.65	29.15	40.65	43.15		
Outer radius of outer layer	23.00	30.50	42.00	44.50	130	80
Outer radius including insul.	23.10	30.60	42.10	44.60		
Num. of turns (2 layers)	256	128	340	212	960	680
Pitch (mm)	2.35	2.35	2.35	2.35	-	-
Calculated mag. lenght (m)	0.301	0.150	0.400	0.249		
Current (A)	2733	2794	2208	2185	1050	950
Axial.lenght inner layer (m)	0.326	0.186	0.450	0.304	0.84	0.595
Axial.lenght outer layer (m)	0.330	0.190	0.455	0.308		
Axial length (m)	0.350	0.210	0.465	0.318	0.85	0.6
Total wire lenght (m)	46	31	117	77	754	320
Stored Energy (J)	563	567	1923	1332	35320	7300
Peak field (T)	2.2	2.3	1.9	1.9		
Inductance (mH)	0.15	0.15	0.79	0.56	64.07	16.18
E/m (J/g)	1.07	1.58	1.44	1.50		

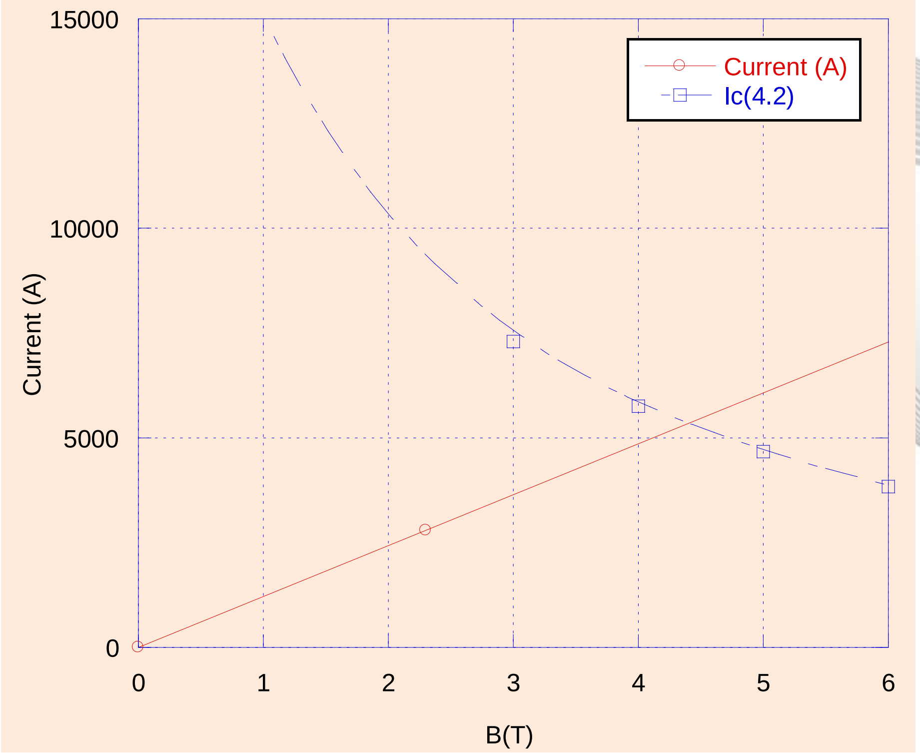
Margins (QD0H) with NbTi technology

At T=4.2K the margin on the current is 70% ←→ ΔT =1.2K)
At T=1.9 K the margin on current is 42% ←→ ΔT =3.7 K

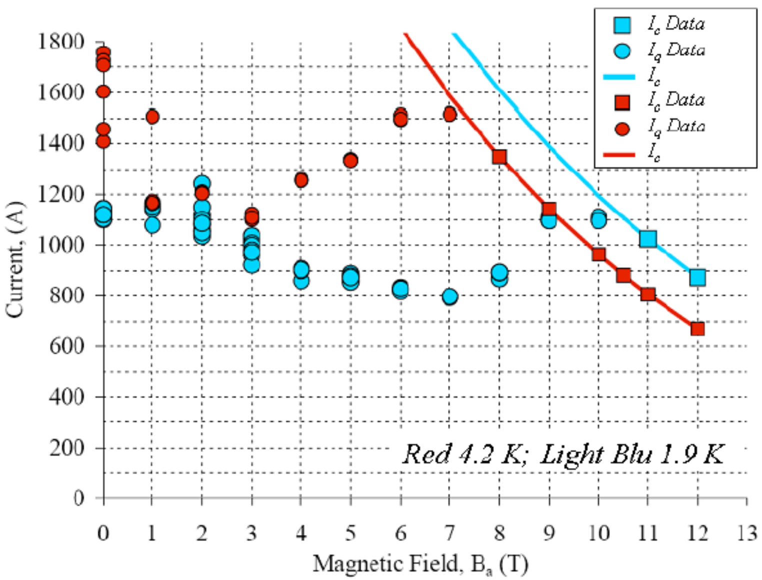


Margins (QD0H) with Nb_3Sn technology

Involving Nb3Sn (much more difficult technology) we could operate with a larger margin, but limitations can arise due to thermo-magnetic instabilities at low fields.



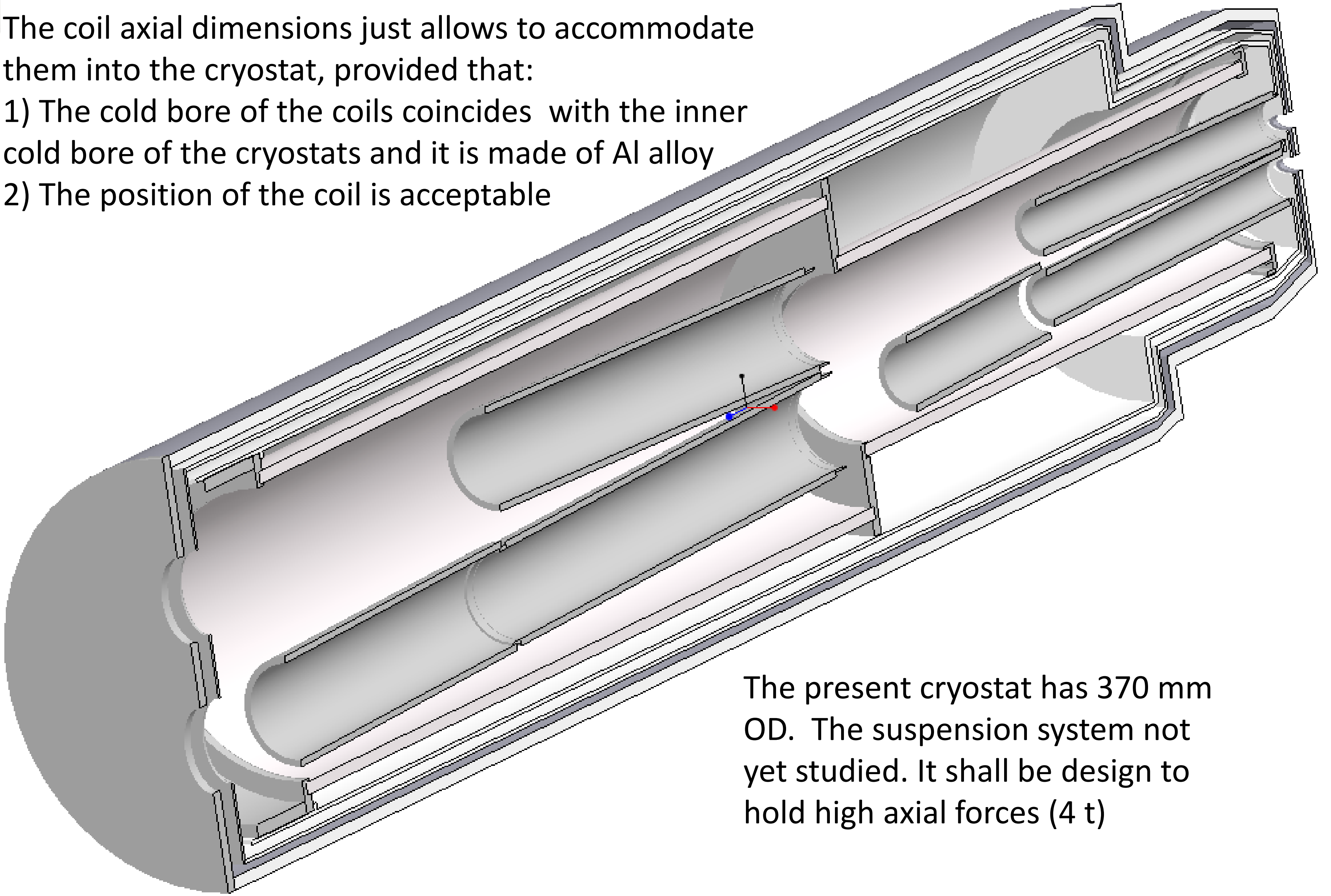
Fermilab studies



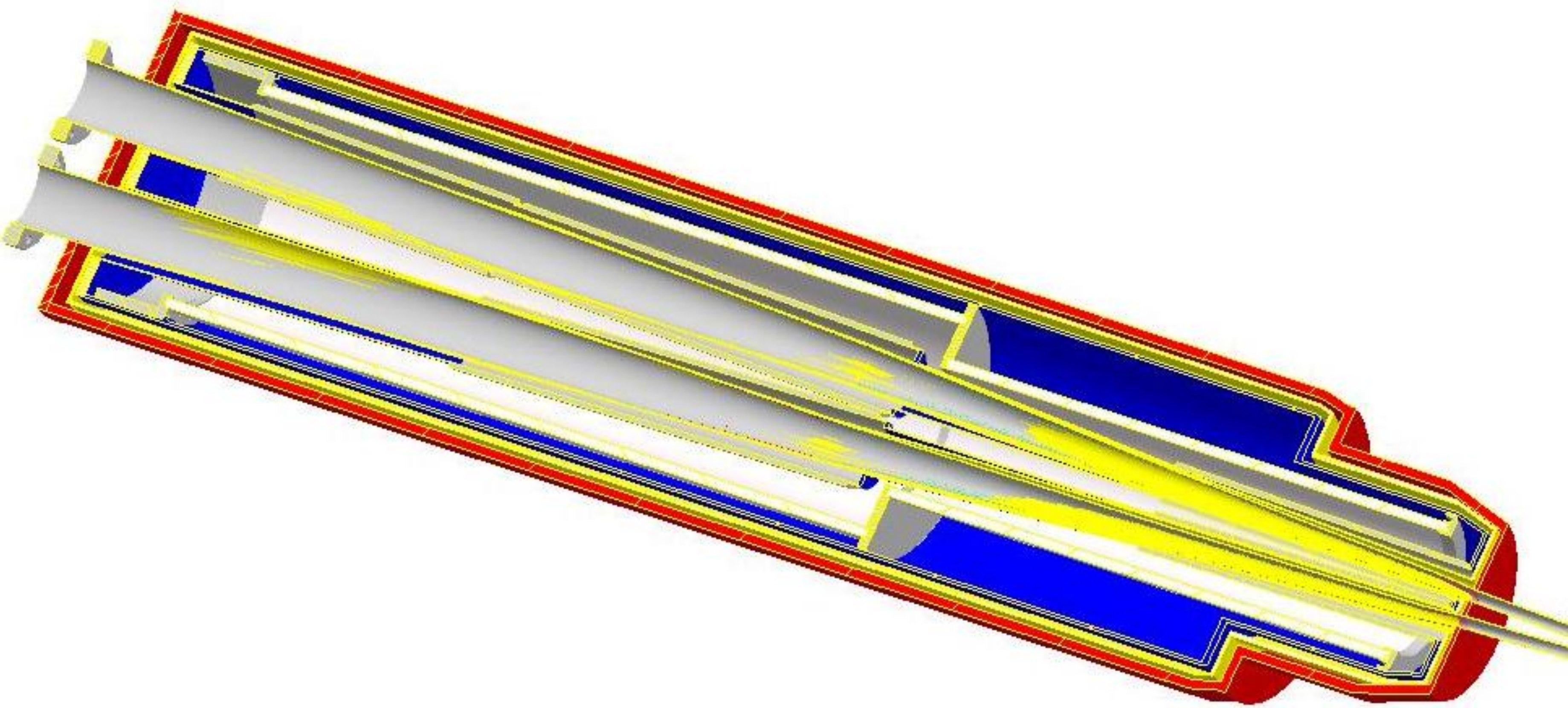
It would be better operating at higher temperature (Supercritical helium) or using a wire 1.2 mm diameter but lower Ic

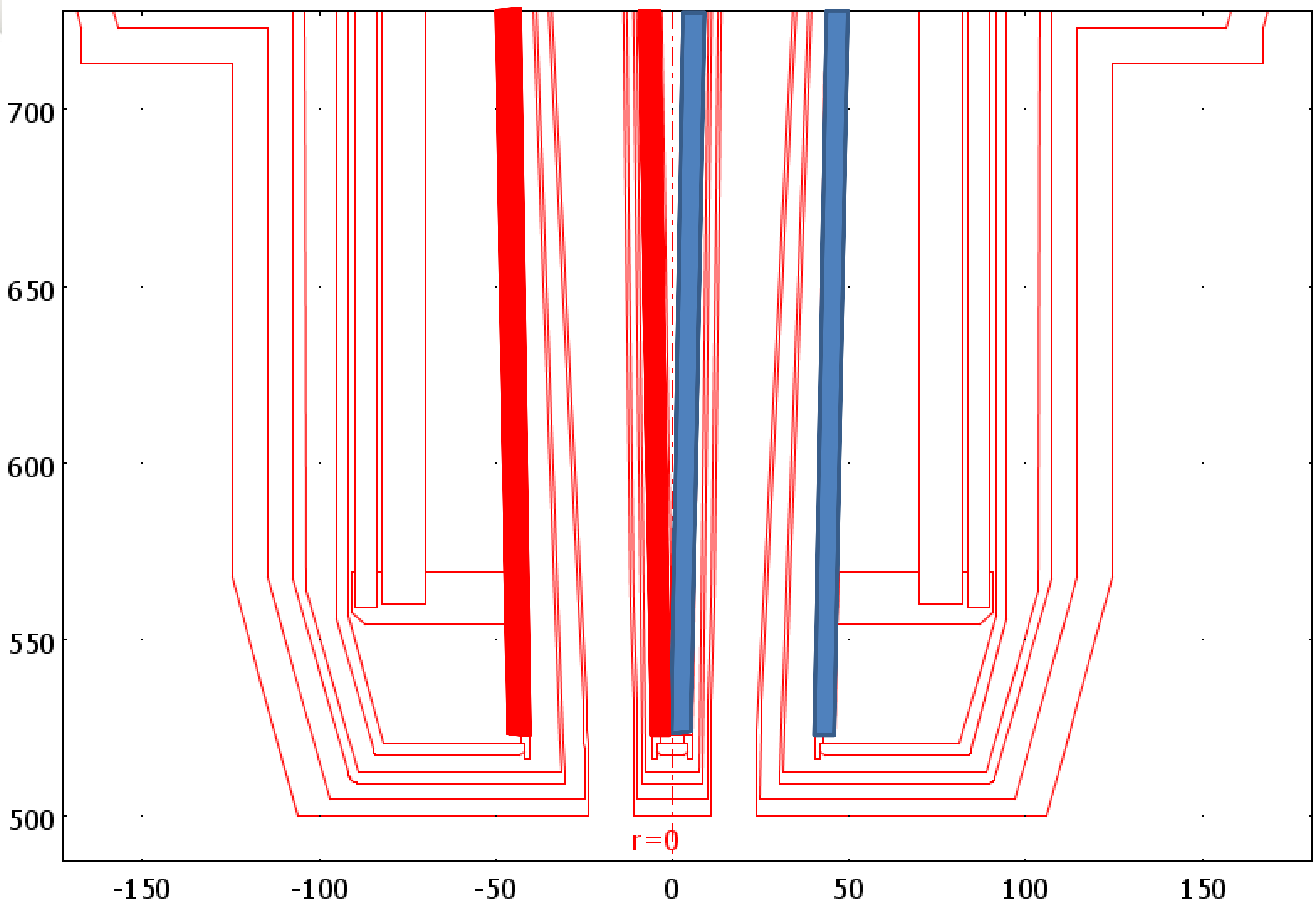
The coil axial dimensions just allows to accommodate them into the cryostat, provided that:

1) The cold bore of the coils coincides with the inner cold bore of the cryostats and it is made of Al alloy
2) The position of the coil is acceptable



The present cryostat has 370 mm OD. The suspension system not yet studied. It shall be design to hold high axial forces (4 t)

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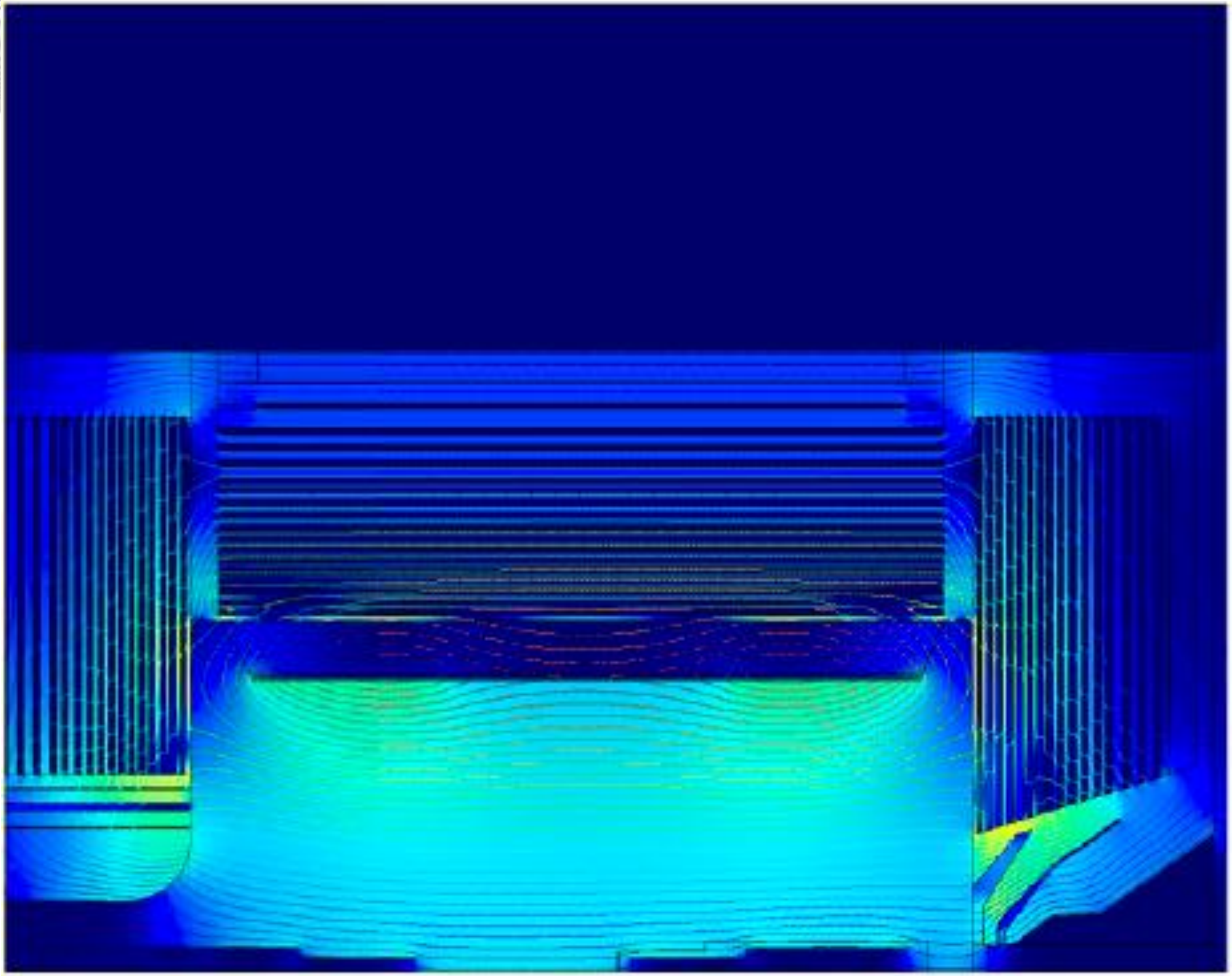
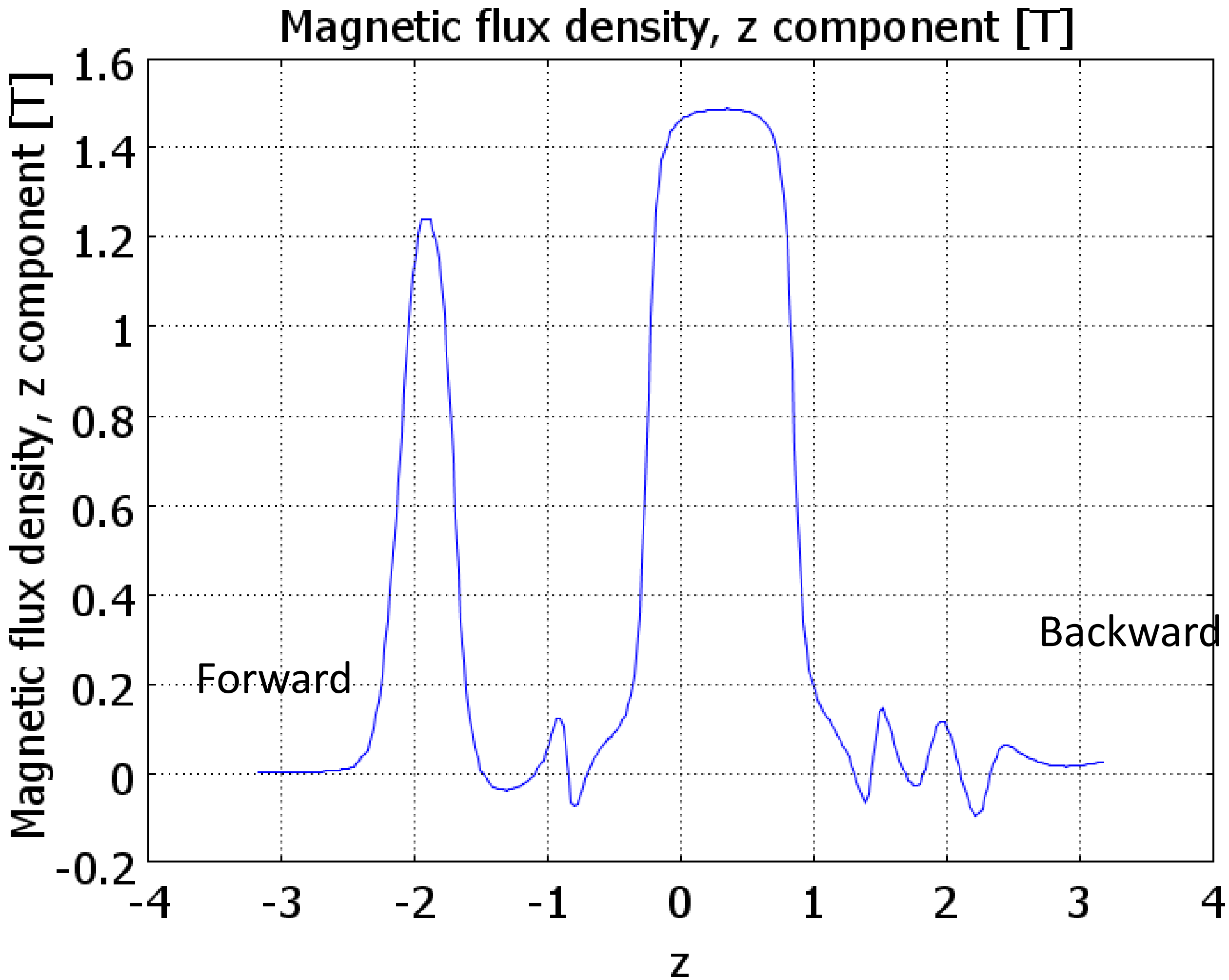
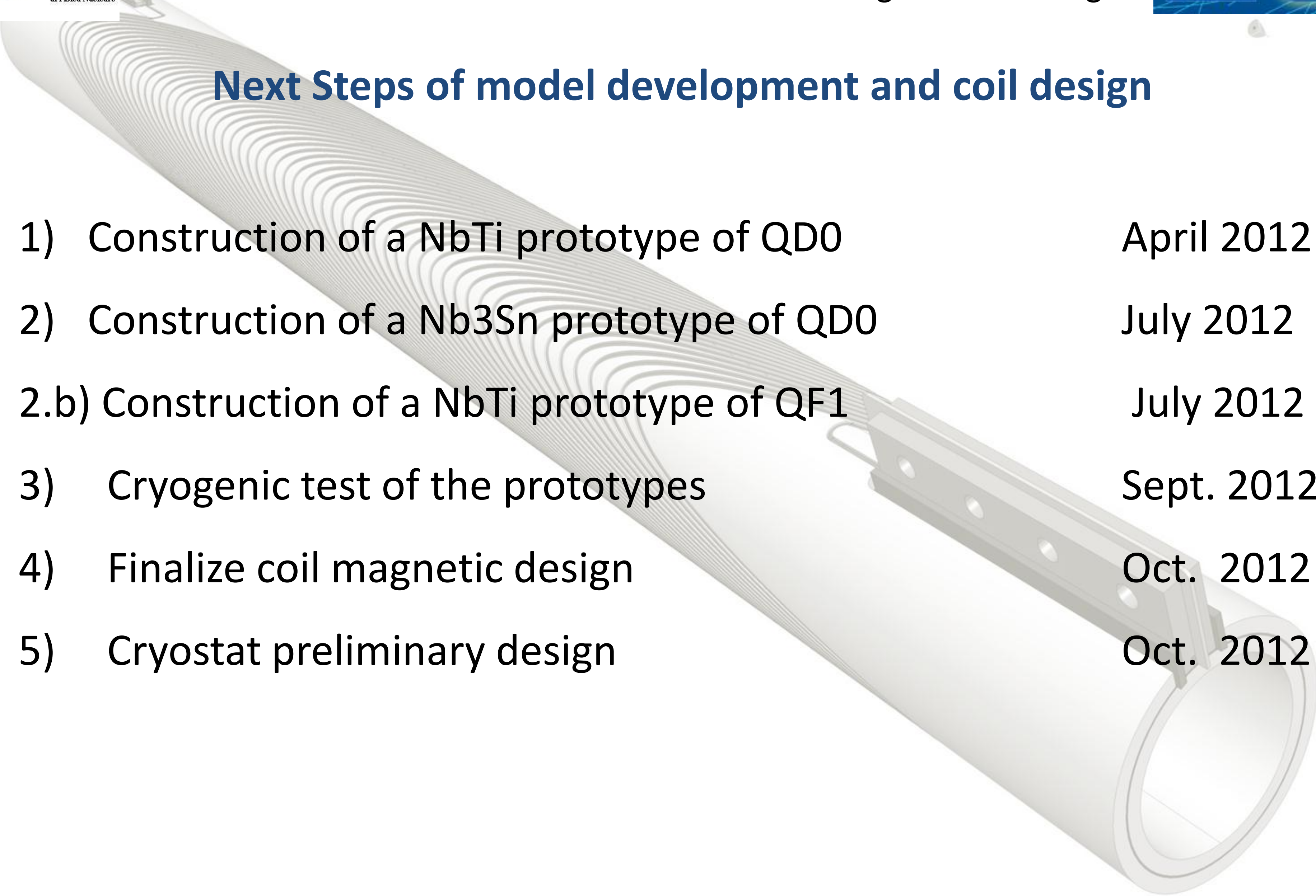
600
550
500
r=0
-150
-100
-50
0
50
100
150




Magnetic flux density, z component [T]
Magnetic flux density, z component [T]
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-4
-3
-2
-1
0
1
2
3
4
z
Forward
Backward

Next Steps of model development and coil design



1)	Construction of a NbTi prototype of QD0	April 2012
2)	Construction of a Nb3Sn prototype of QD0	July 2012
2.b)	Construction of a NbTi prototype of QF1	July 2012
3)	Cryogenic test of the prototypes	Sept. 2012
4)	Finalize coil magnetic design	Oct. 2012
5)	Cryostat preliminary design	Oct. 2012