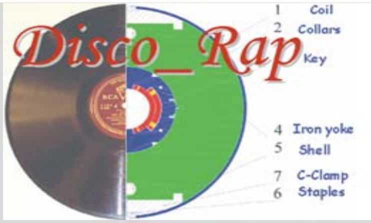


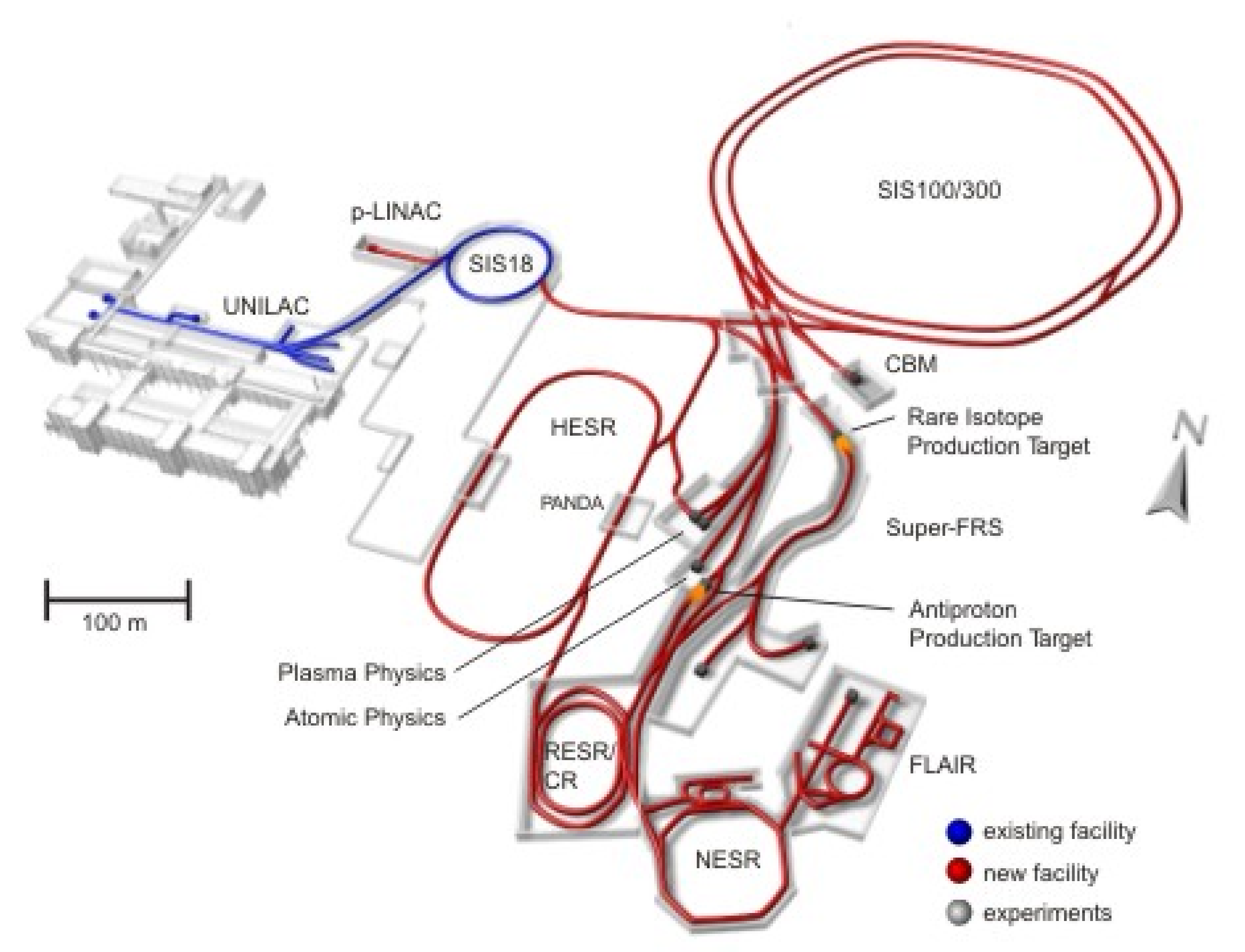
Pulsed magnets with curved shape for FAIR

P.Fabbricatore

On behalf DISCORAP Collaboration

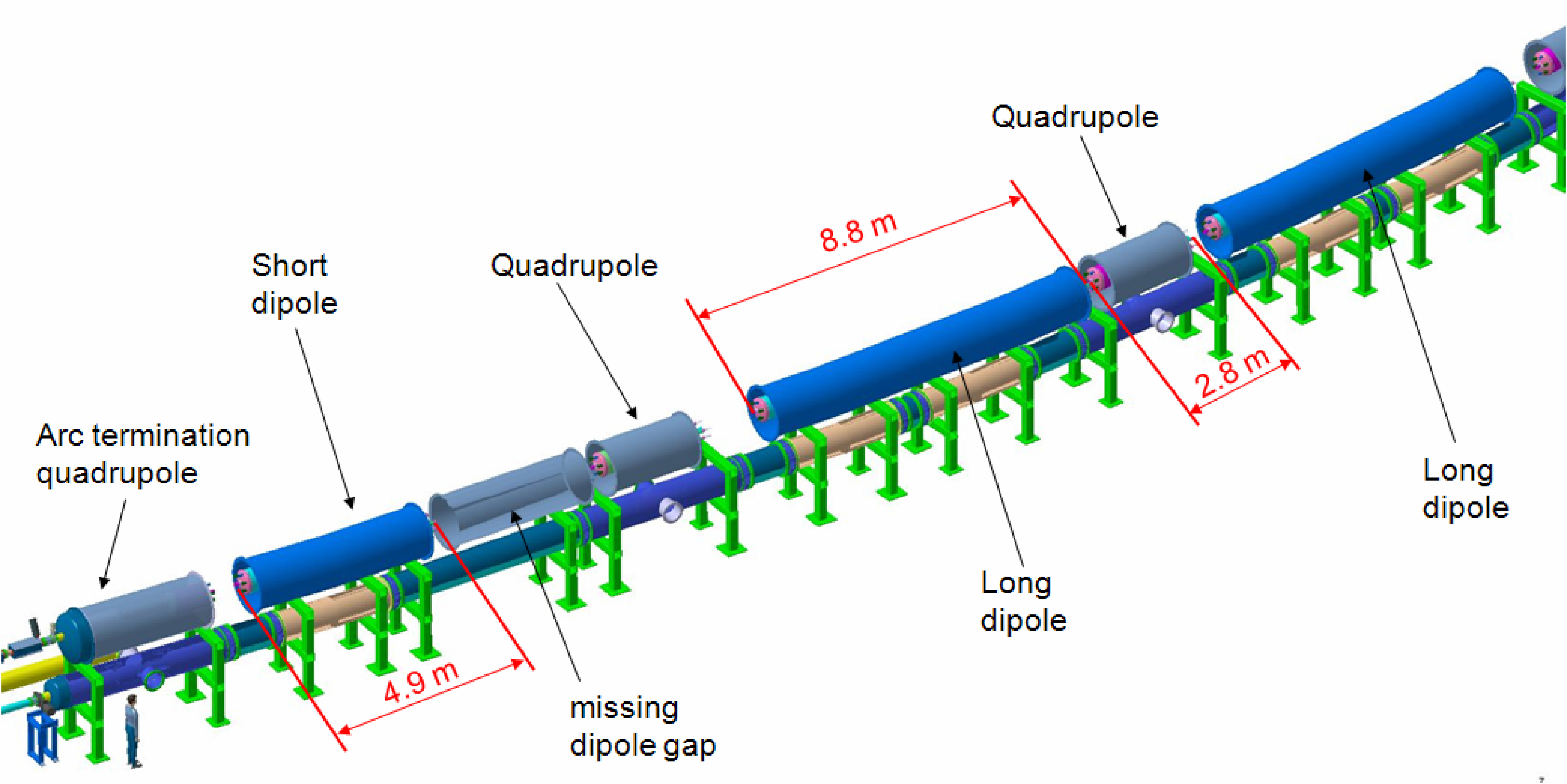
(INFN Frascati, Genova and Milano LASA)

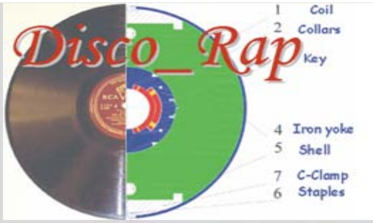
Facility for Antiproton and Ion Reasearch



48 long dipoles – Magnetic length 7.89 m
12 short dipoles – Magnetic length 3.94 m

SIS 300 arc cryostat stacked on top of SIS 100





Main characteristics of SIS300 dipoles (Short –Long)

Nominal field (T)	4.5
Ramp rate (T/s)	1
Radius of magnet geometrical curvature (m)	66 2/3
Magnetic length (m)	3.879 - 7.758
Bending angle (deg)	3 1/3 - 6 2/3
Coil aperture (mm)	100
Max temperature of supercritical He (K)	4.7

Criticity of SIS300 dipoles

	Aperture (mm)	B (T)	dB/dt (T/s)	Q (W/m)
LHC	53	8.34	0.0075	0.18
RHIC	80	3.5	0.07	0.35
SIS300	**100**	4.5	**1**	**<10**

Ac losses depend on **B** and **dB/dt**. The heat generated shall be efficiently removed for **avoiding premature quenching**. The ac losses shall be kept at a minimum level for keeping **the cryogenic costs at an acceptable level**

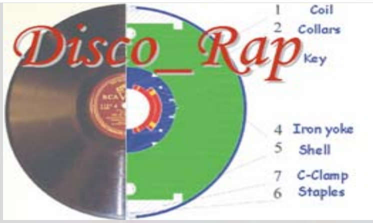
The curvature of R=66.667 m (sagitta 117 mm) produces a **significant manufacturing complexity** (consider that for reducing ac losses the conductor is quite stiff)

The magnets shall be cycled 10 million times → Design **optimised for fatigue loads**

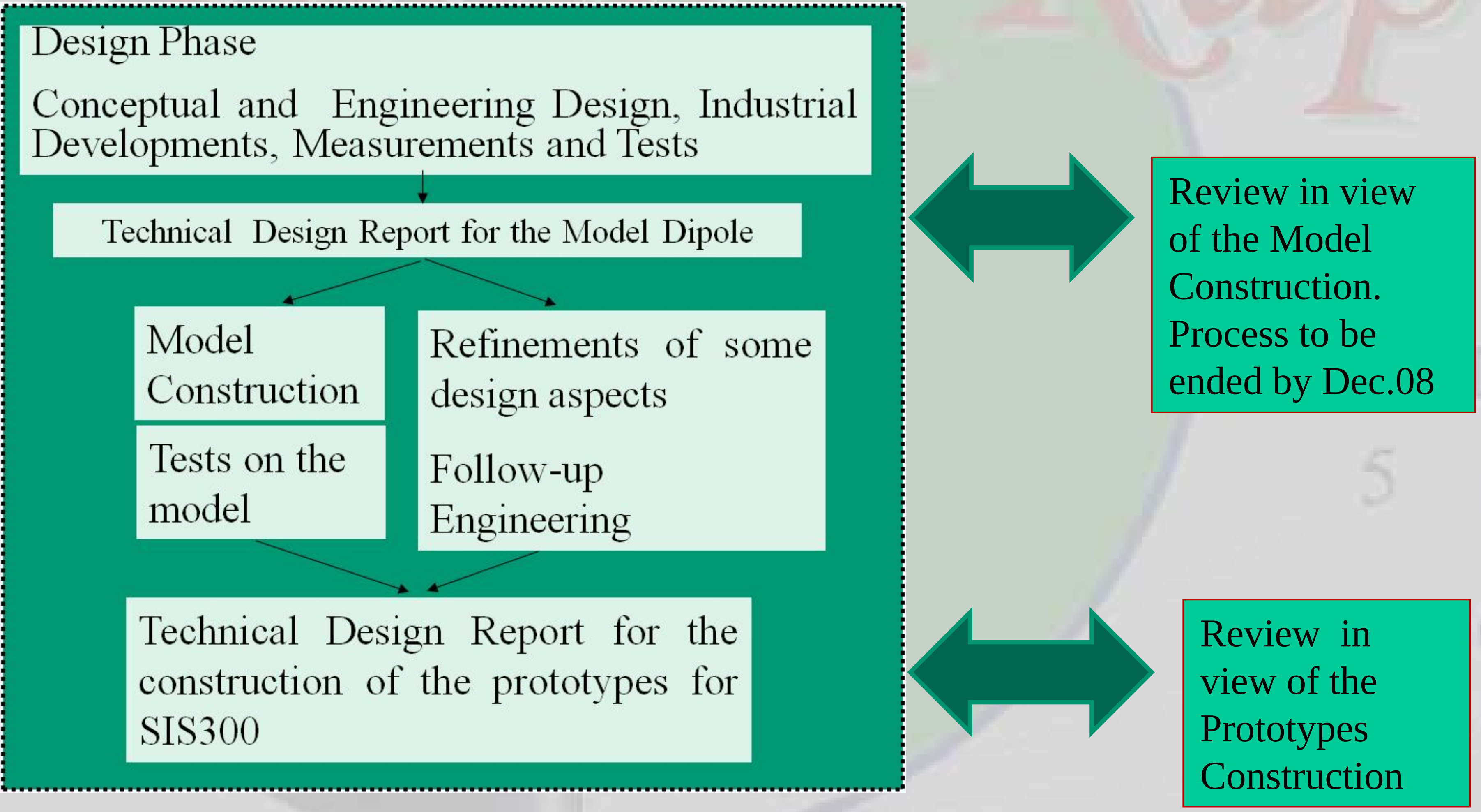
The R&D DISCORAP

The Italian National Institute of Nuclear Physics (INFN) is performing an R&D activity aimed to develop fast cycled superconducting dipole for FAIR SIS300.

This activity, named DISCORAP (“Dipoli SuperCOnduttori RApidamente Pulsati”), born in the frame of HHH, started in 2006 in accordance with a specific INFN-FAIR Memorandum of Understanding signed by both institutions in December 2006. The aim is to have a complete cold mass model of the short dipole ready in 2009.



Synopsis of DISCORAP



Design Phase

Conceptual and Engineering Design, Industrial Developments, Measurements and Tests

Technical Design Report for the Model Dipole

Model Construction

Tests on the model

Refinements of some design aspects

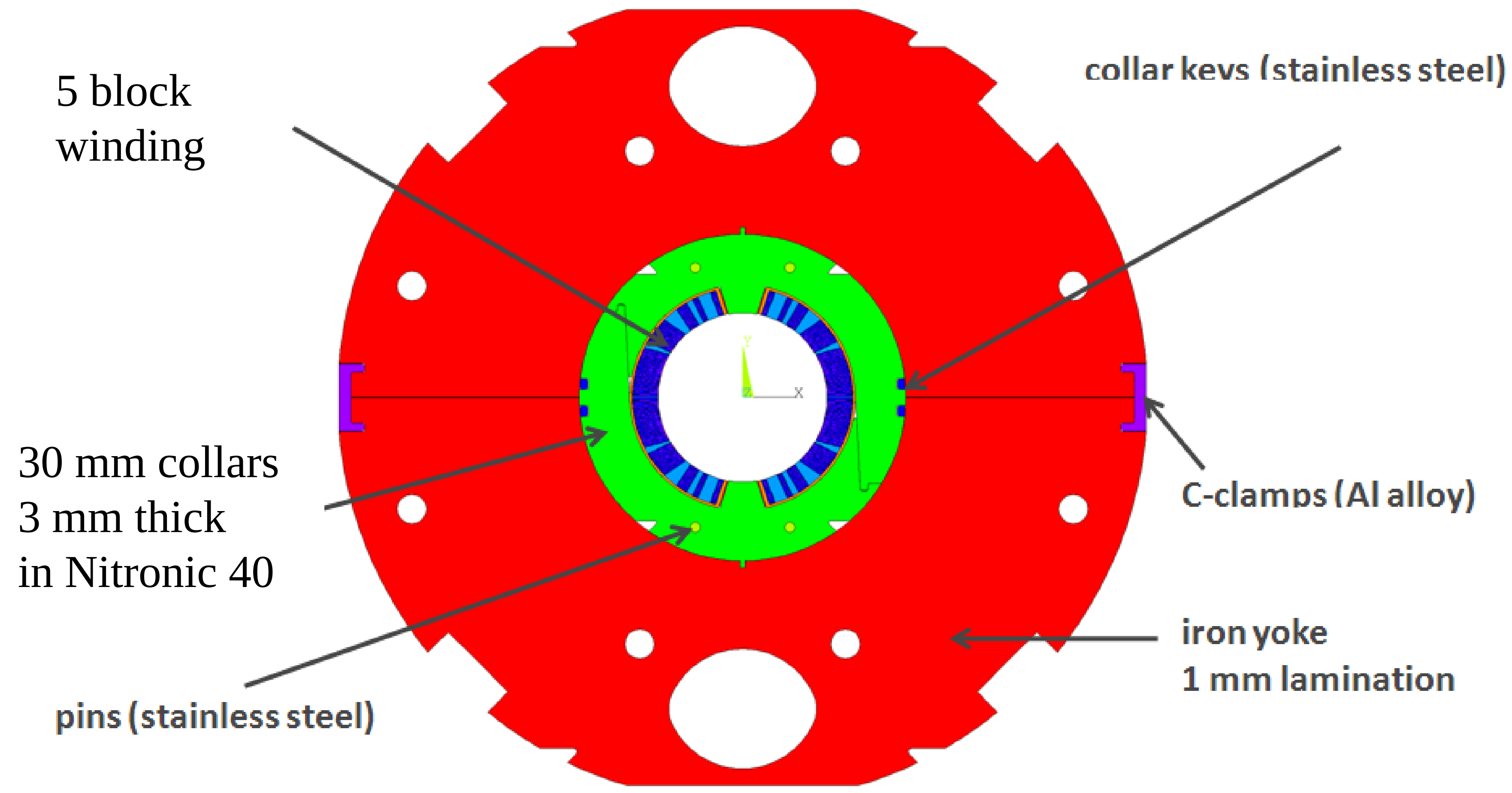
Follow-up Engineering

Technical Design Report for the construction of the prototypes for SIS300

Review in view of the Model Construction. Process to be ended by Dec.08

Review in view of the Prototypes Construction

Magnet layout



5 block winding

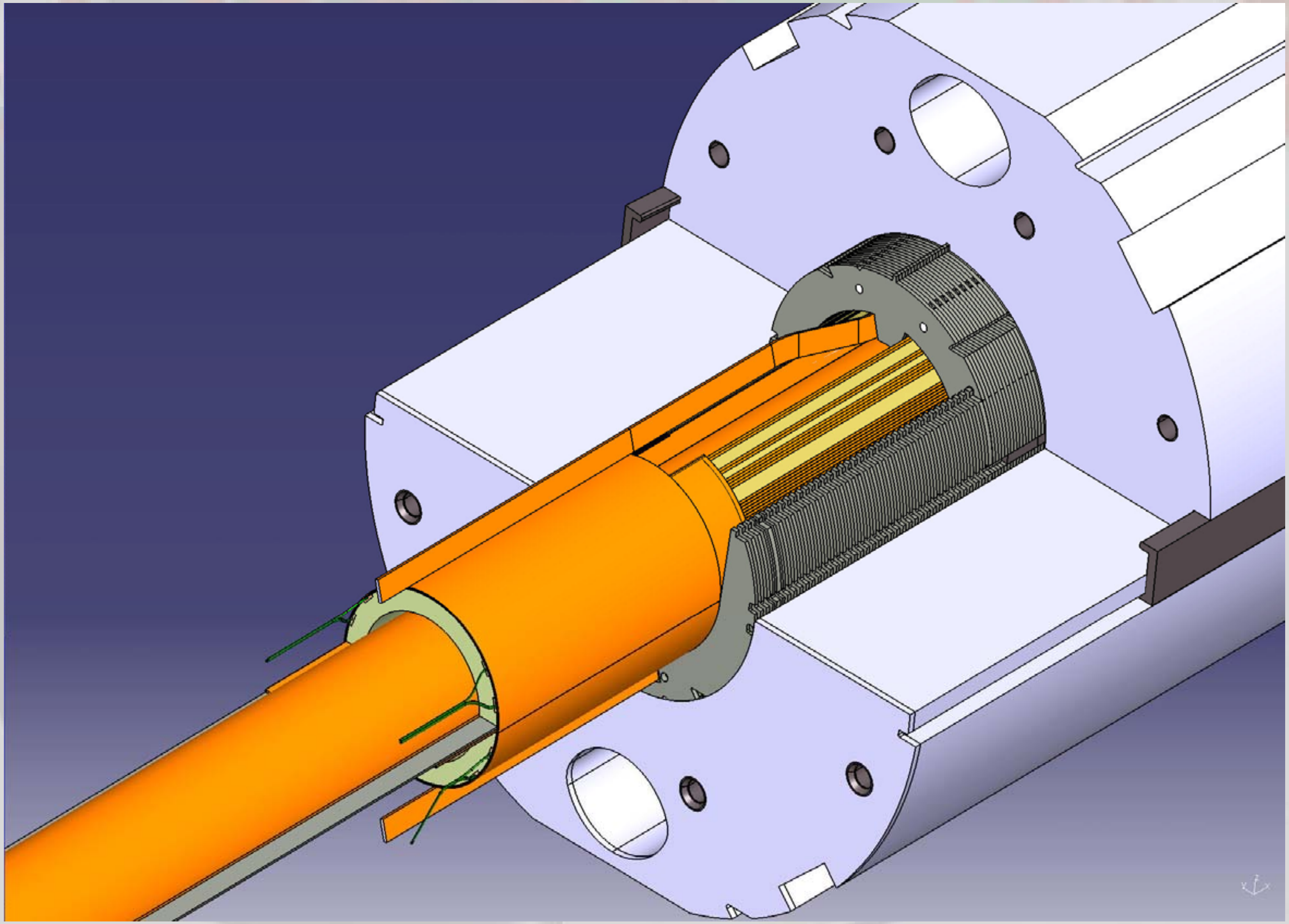
collar keys (stainless steel)

30 mm collars
3 mm thick
in Nitronic 40

C-clamps (Al alloy)

iron yoke
1 mm lamination

pins (stainless steel)



A VERY BASIC CHOICE: Curved winding

The starting assumption for the design was that the coil should be wound curved, because:

1) This solutions allows defining a curved geometry of the coil with no residual stresses;

2) Once cured, the coil can be handled in a simple and safe way for the following manufacturing operations (collaring, insertion in the iron yoke, …).

The main body of the coil is curved. The ends are straight

1) Straight winding → Bending →Curing

We have not found any satisfactory methods for bending an un-cured winding on its mandrel

2) Straight winding → Curing → Bending

$\Delta R/R=9.8\ 10^{-4}$ ←→ from -15 MPa to + 15 MPa permanent stress in the winding (Spring back effect). Not clear handling of this curved object (with not well defined deformed shape) during collaring operation.

3) Curved winding→ Curing

LOSSES AFFECTS THE DESIGN

Contribution to ac losses (ramping) 34 W (8.7 W/m)

Hysteresis	27 %	D_f=3.0 µm
Coupling Strand	8 %	CuMn- Twist 5 mm
Interstrand Ra+Rc	5 %	Cored cable
Total conductor	(40 %)	
Collars + Yoke eddy	9 %	3mm - 1mm
Yoke magn	24%	M600-100A
Beam pipe	13 %	
Collar-Keys-Pins	7 %	
Yoke-Keys-Pins	7 %	

A cored conductor

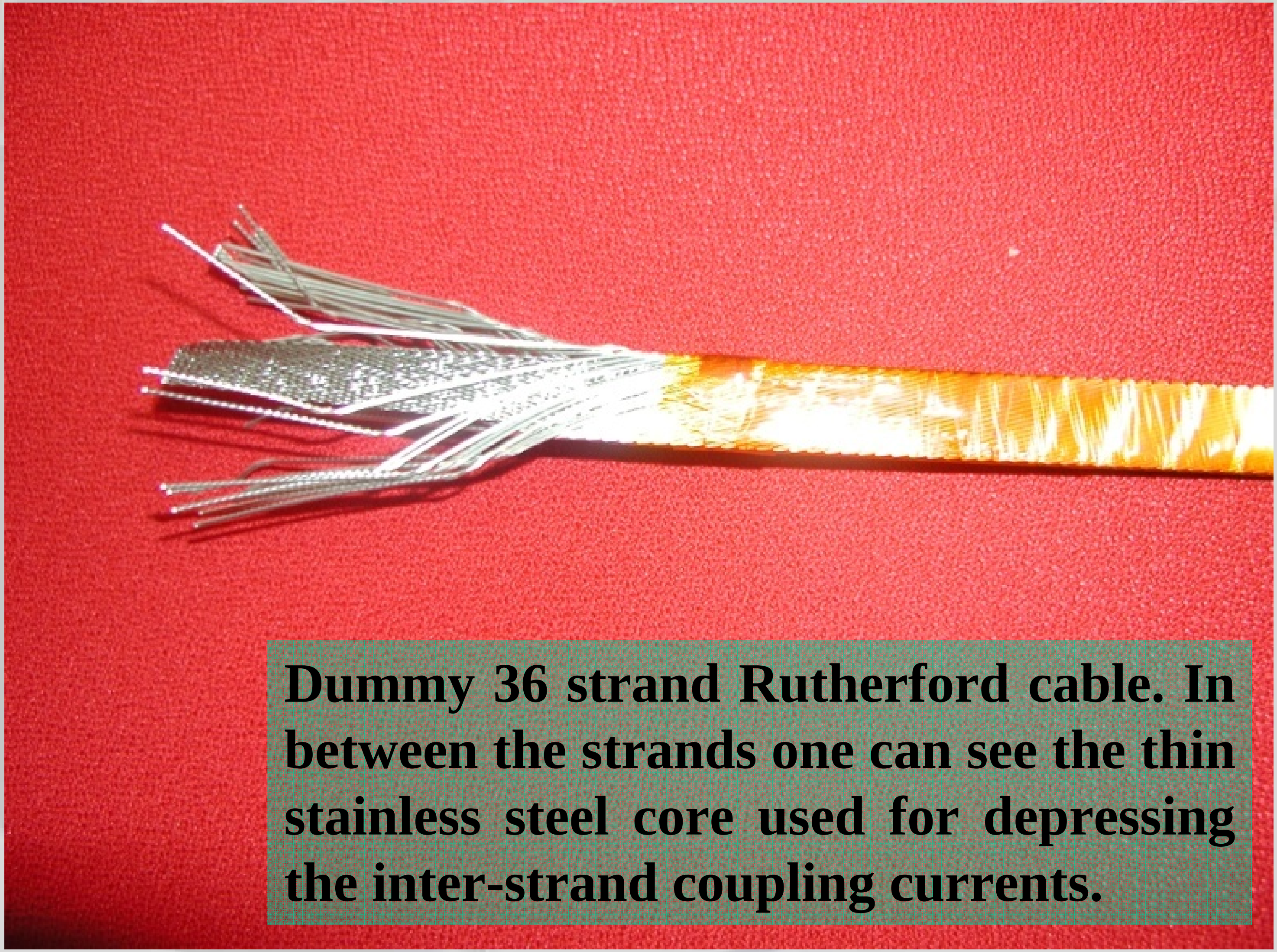
The conductor is based on a cored Rutherford cable with 36 strands (similar to the LHC dipole outer layer)

This conductor is characterized by several features, chosen to provide low ac losses:

1) The filaments are small (down to 2.5 μm);

2) The matrix surrounding the filaments is made of CuMn;

3) The cable is cored using a thin stainless steel foil (25 μm) for cutting down the inter-strand coupling currents



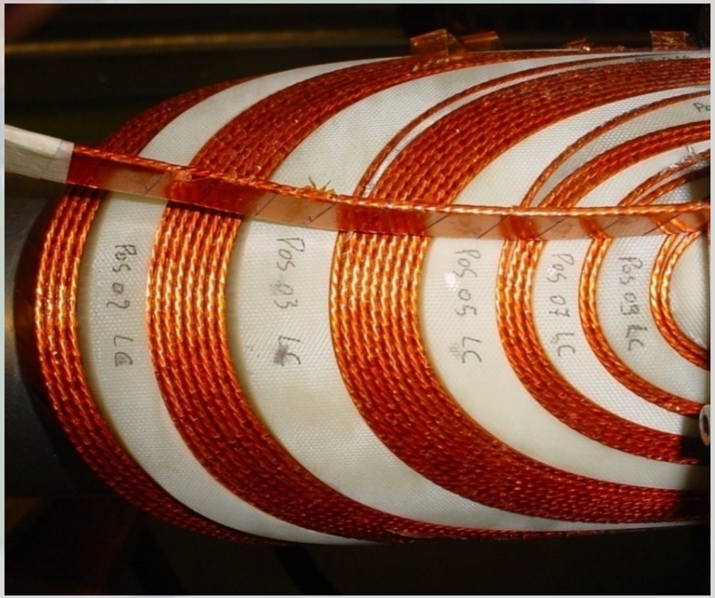
Dummy 36 strand Rutherford cable. In between the strands one can see the thin stainless steel core used for depressing the inter-strand coupling currents.

INDUSTRIAL R&D

The stainless steel core makes the conductor stiffer than a standard Rutherford cable, both causing more difficult winding operations and adding complexities to the already difficult curved winding. For this reason we launched, in parallel to the design, an industrial R&D, aimed at developing the winding techniques of a cored cable for a curved coil.

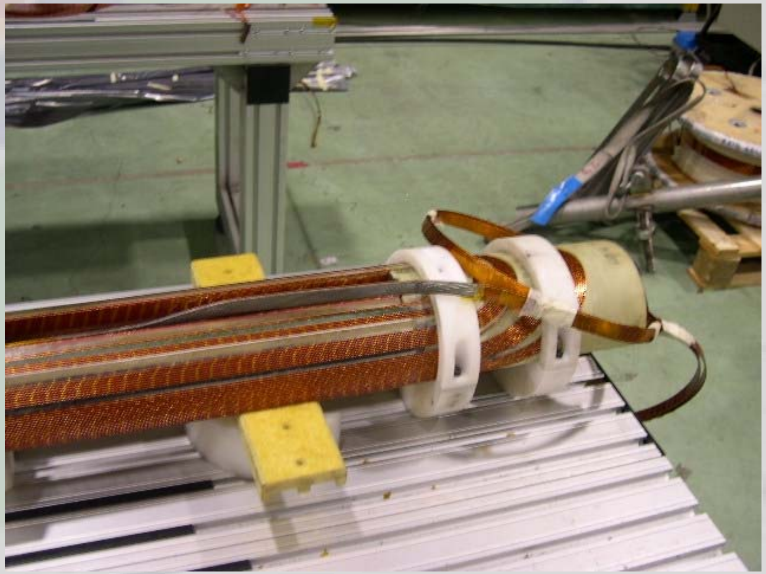
This activity held place at ASG Superconductors in Genova, under an INFN contract. A special winding machine was developed for winding a cored Rutherford cable on a curved mandrel.

Several winding tests were performed using first the LHC dipole outer layer



In a second step, the tests were carried out using the trial winding cored cable obtained by cabling the LHC dipole wire with a stainless steel insert .

An important milestone was then achieved with the successfully completion of a complete pole, proving the developed winding technology.

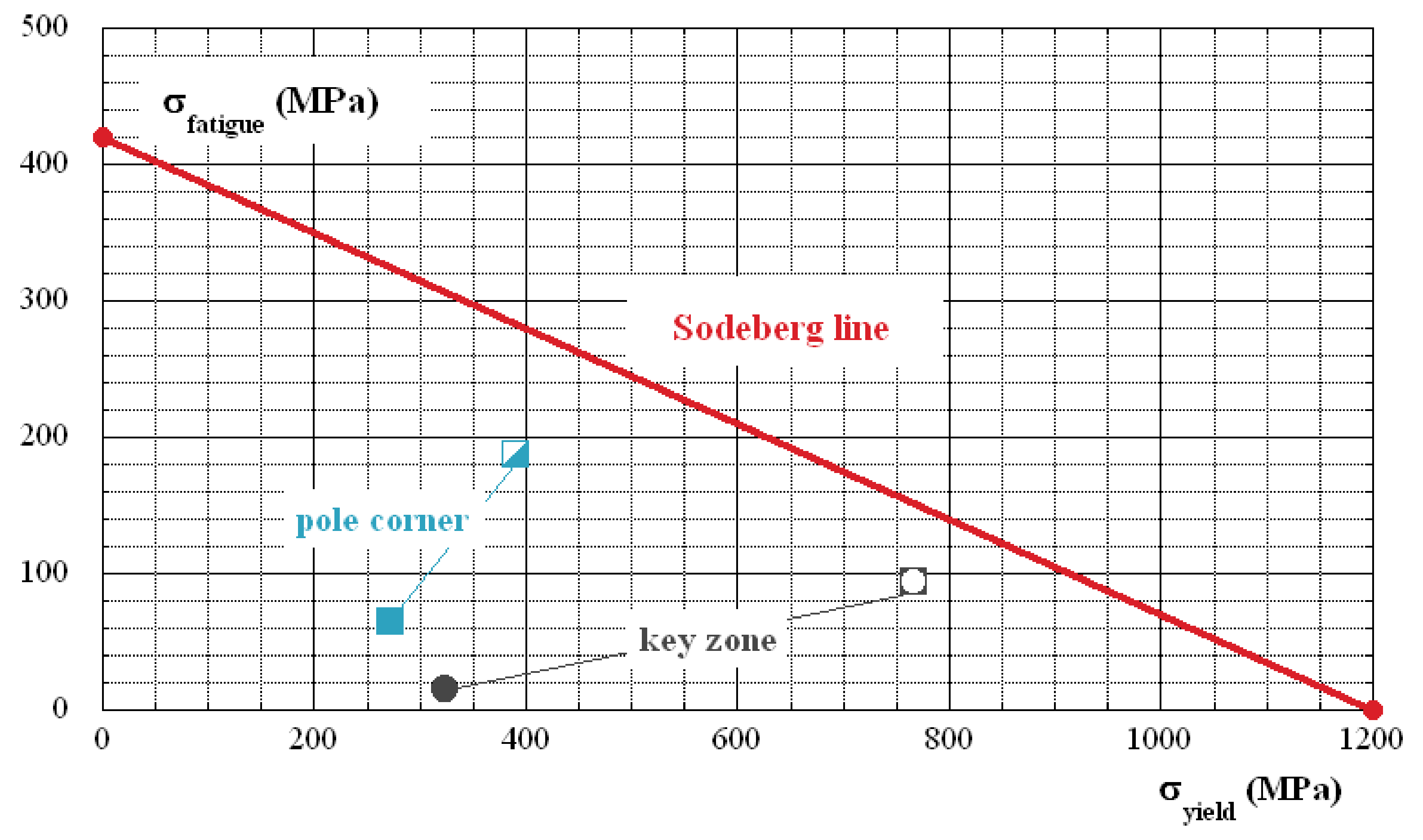


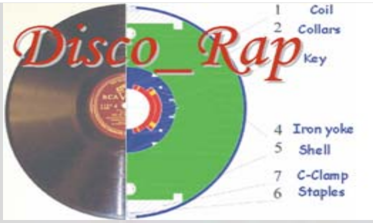
Fatigue load

The magnets shall be cycled 10 million times, consequently the design shall be optimised in view of severe fatigue loads. Radiation effects may even weaken the material with respect mechanical and electrical strength.

→ Mechanical design optimization to be checked through experimental results on the model

Our recipe: Stress as low as possible





Concluding Remarks

After TDR we are now entering into the construction phase. Other design choices were of course possible, but we considered fundamental to define a credible design, build the model and test is as soon as possible, rather than try to optimize a design before constructing something.

Any developments can only be based only on verified (or not verified) hypotheses.

Thank you for your attention