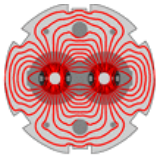
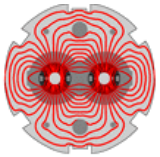


LARP

Nb_3Sn Quadrupole Designs

for

the LHC Upgrades



LARP

Context

- LARP is preparing Nb_3Sn quadrupoles for Phase 2 upgrade. Several series have already been designed and tested:

- SQ=> subscale quadrupole model with 90 T/m gradient and 110 mm aperture relying on racetrack and implementing alignment

- TQ => - 1-meter 90 mm aperture

- ~ 12 T peak field, ~ 200 T/m gradient

- The LQ series is under construction

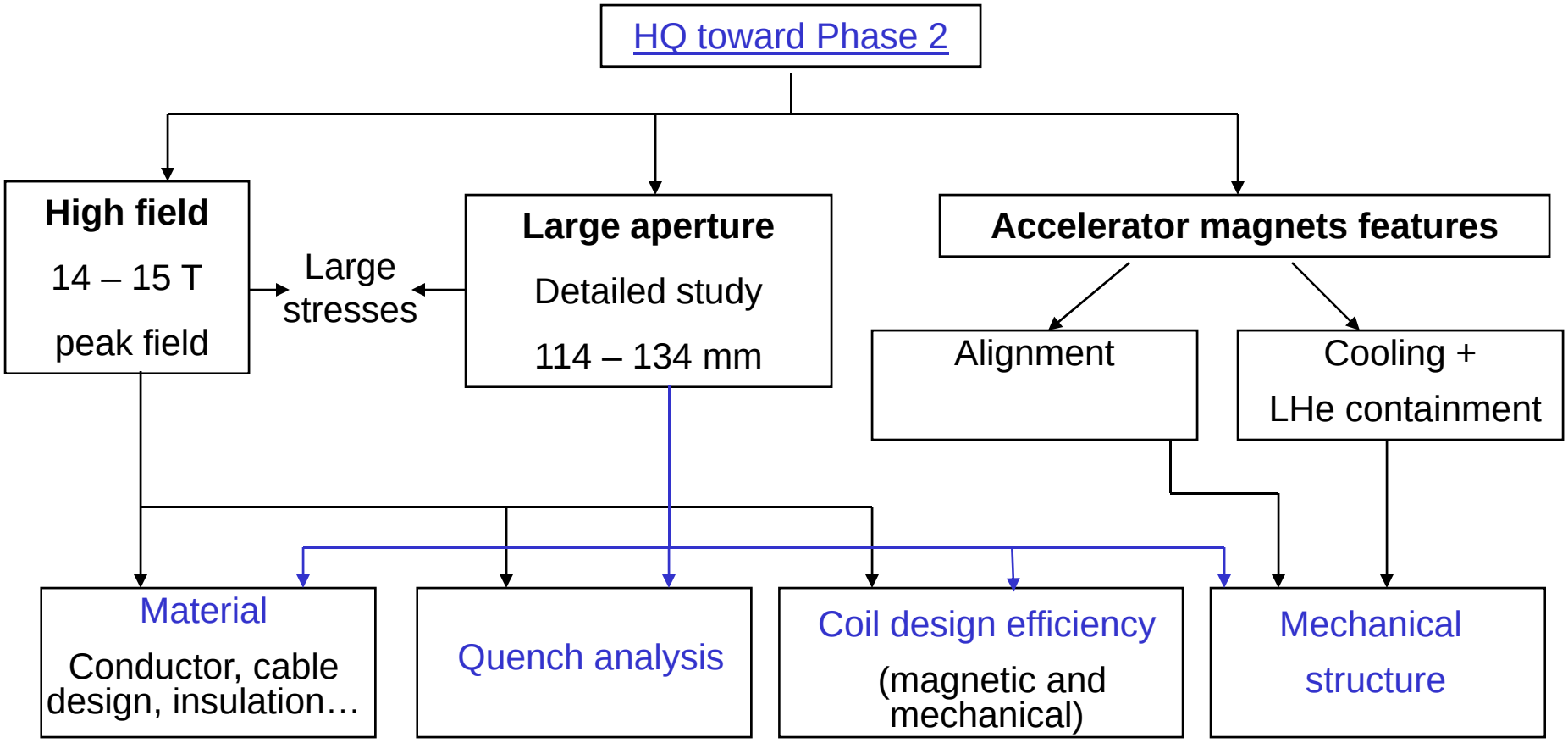
- LQ => scale up of TQ, 3.6 m long, 240 T/m short sample gradient at 4.5 K

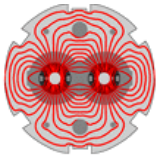
- **Next step: reaching 14 – 15 T peak field at 1.9 K with accelerator quality features for LHC luminosity upgrades**

- Large aperture, alignment (field quality), cooling

=> 1-meter model HQ: 110 / 140 mm aperture, 230 / 200 T/m gradient

HQ goals and R&D issues





LARP

HQ Design study

⇒ A range of apertures have been considered: from 110 mm to 140 mm

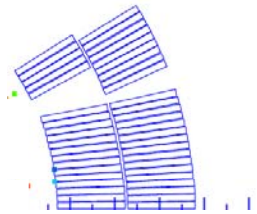
- detailed study of 114 mm and 134 mm

⇒ Several magnetic cross-sections have been compared in terms of:

- Gradient
- Peak field
- Field quality
- Pole angle (windability)
- Maximum stress in the coil for a given mechanical structure

⇒ Strong relation between the coil magnetic design and the mechanical stress distribution in the coil

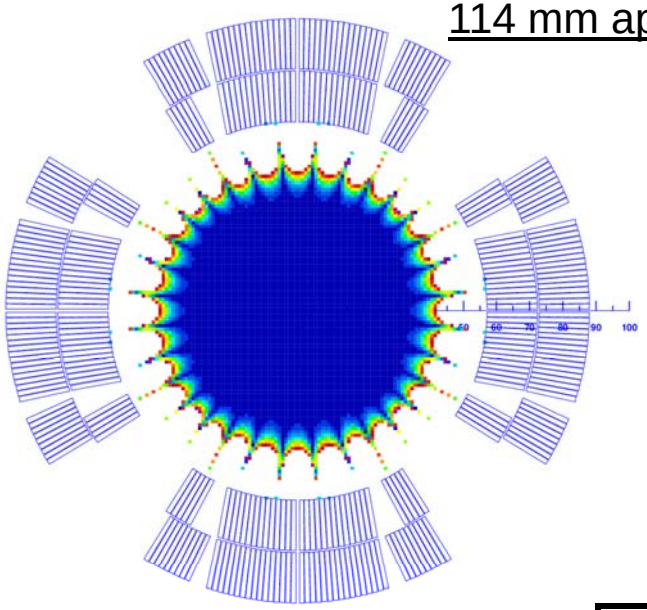
- Role of the Lorentz forces distribution between the 2 layers



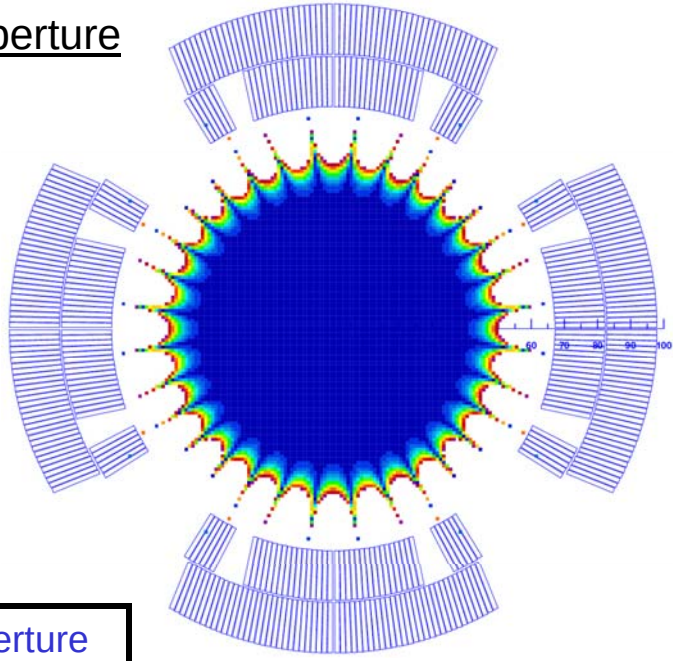
HQ magnetic cross-sections

Courtesy of V. Kashikhin

114 mm aperture



134 mm aperture



Cable parameters

15 mm wide

1.405 mm mid-thickness

0.11 mm insulation

Jc(12 T, 4.2 K) = 3000 A/mm²	114 mm aperture	134 mm aperture
Quench gradient at 1.9 K	234 T/m	201 T/m
Quench peak field at 1.9 K	15.39 T	15.66 T
Quench current at 1.9 K	19.18 kA	18.17 kA
F_θ Layer 1 / Layer 2	2.5 / 2.99 MN/m	2.7 / 3.4 MN/m
Stored energy	1.31 MJ/m	1.69 MJ/m

130 mm Aperture Quadrupoles for the LHC Luminosity Upgrade, F. Borgnolutti, E. Todesco, PAC07

Lorentz forces distribution and mechanical behavior

LARP

TQS (1-meter)

- 90 mm aperture
- 12 T peak field
- 240 T/m

- F_θ Layer 1 = -1.5 MN/m
- F_θ Layer 2 = -1.02 MN/m

LQS (3.6-meter)

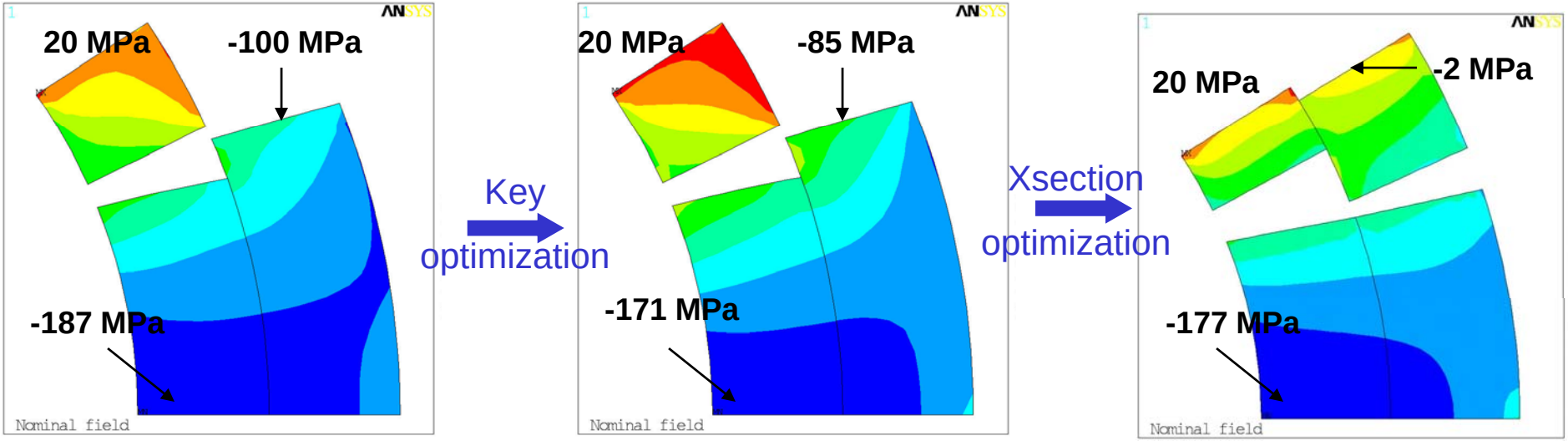
- 90 mm aperture
- 12 T peak field
- 240 T/m

- F_θ Layer 1 = -1.5 MN/m
- F_θ Layer 2 = -1.02 MN/m

HQ (1-meter)

- 114 mm aperture
- 15 T peak field
- 230 T/m

- F_θ Layer 1 = -2.5 MN/m
- F_θ Layer 2 = -2.99 MN/m



=> Improvement of the cross-section to avoid layer 2 overloading

HQ Mechanical structure

Design concept and Guideline

Design concept

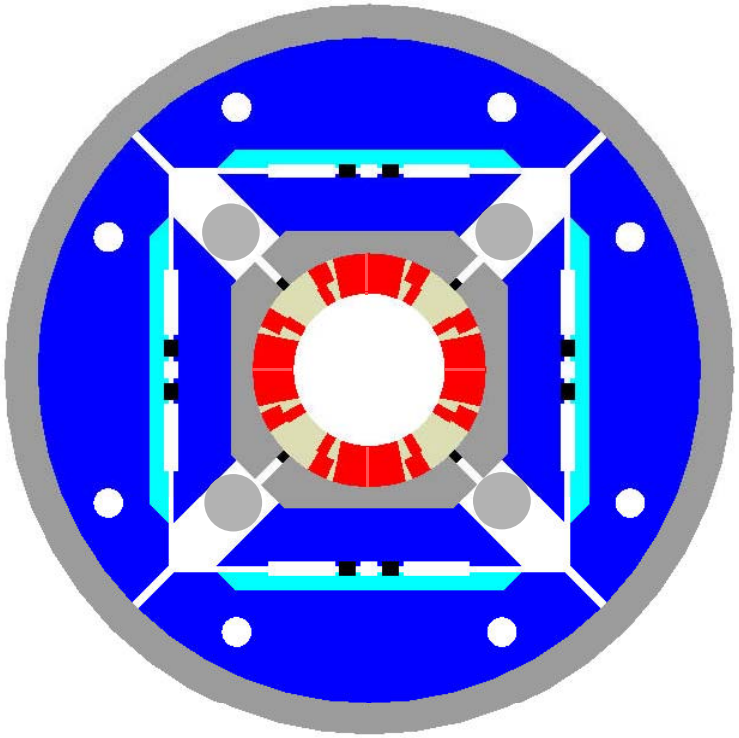
- Coil sub-assembly (coil + pad) at very low pre-stress
- Assembly at room temperature with keys and bladders
- Axial loading with axial rods
- Final pre-stress provided by an aluminum shell during cool-down

Guideline

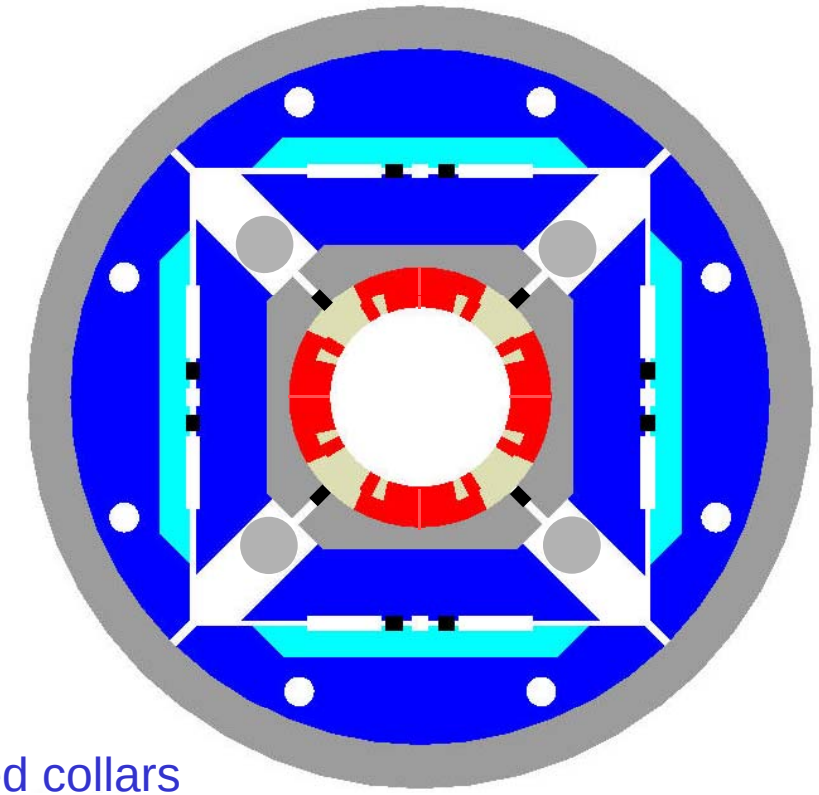
- Full contact between pole and coil at short sample (200 – 230 T/m)
- Optimization of the mechanical stress in the coil during bladder operation: bladder location
- Optimization of the mechanical stress in the coil after cool-down and during excitation: key location
- Alignment with gradual implementation

HQ Mechanical structure based on LQ structure

114 mm aperture



134 mm aperture



- 550 mm outer diameter
- 25 mm Al shell
- 43 mm iron pad

- 15 mm Al bolted collars
- Iron pads
- Iron yoke
- 45 mm diameter axial rods

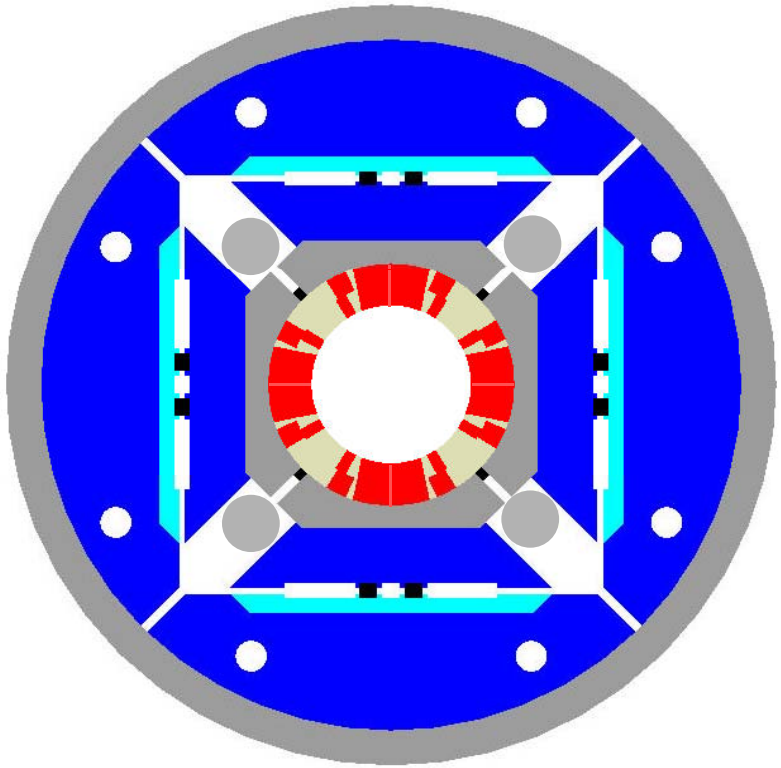
- 584 mm outer diameter
- 32 mm Al shell
- 53 mm iron pad

HQ – Mechanical Structure

114 mm aperture

Components

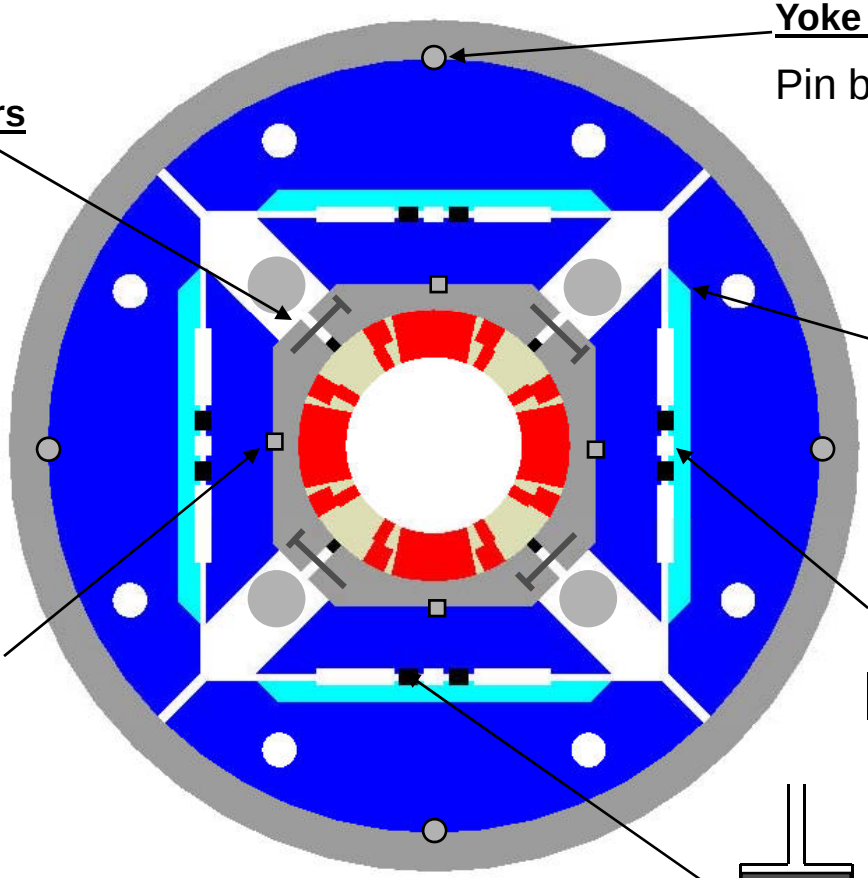
- Aluminum bolted collars
  - alignment feature
  - needs to remain in compression from assembly to operating conditions
  - intercept preload (~ 20 %)
- Iron pads and yoke
- Iron master => alignment
- 45 mm diameter axial rods => axial preload
- 25 mm aluminum shell => azimuthal preload
- Cooling area



Assembly

- 50 mm bladders located outside the key span
- 42 MPa pressure (550 + 50 microns clearance for 230 T/m)

HQ – Alignment



Yoke / Shell alignment pin

Pin between the shell and the yoke

Aluminum bolted collars

Master / yoke alignment

Shape of the master

Pad / Yoke alignment key

Central key tight on the common edges

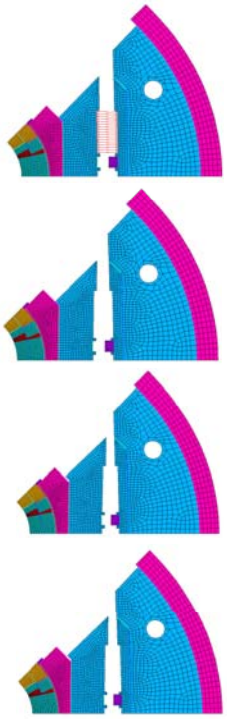
Collar / pad alignment key

Loading keys providing radial alignment

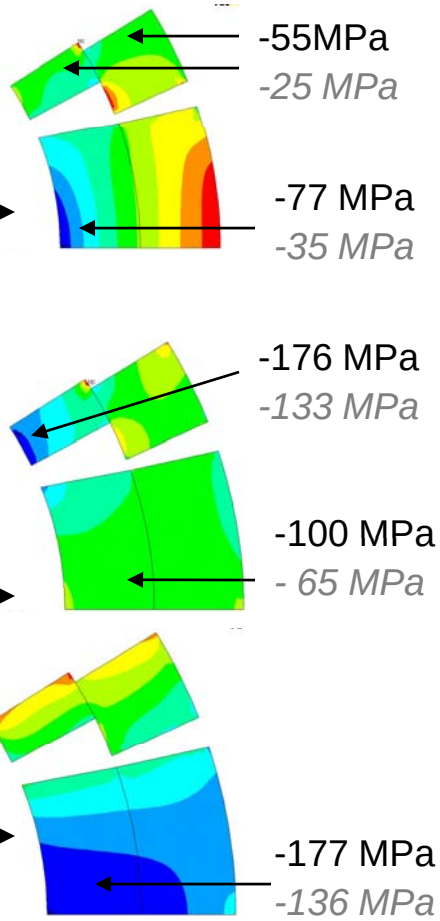
=> Can be implemented gradually

HQ – Mechanical analysis

Azimuthal stress in the coil for a 114 mm aperture



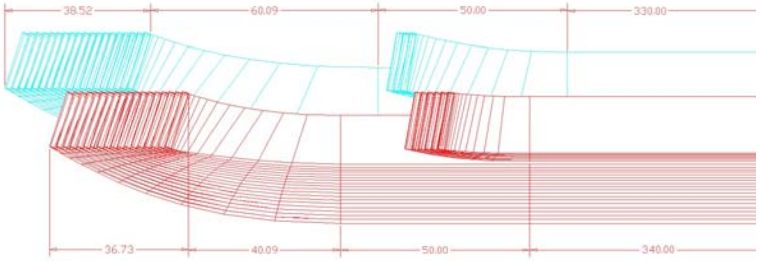
	Target 230 T/m	200 T/m
During bladder operation	-77 / -32 MPa	-35 / -15 MPa
With loading key	-83 / -18 MPa	-30 / -5 MPa
At 4.2 K	-176 / -15 MPa	-133 / 4 MPa
With Lorentz forces	-177 / 20 MPa	-136 / 20 MPa



=> Reasonable stresses in the coil even at short sample

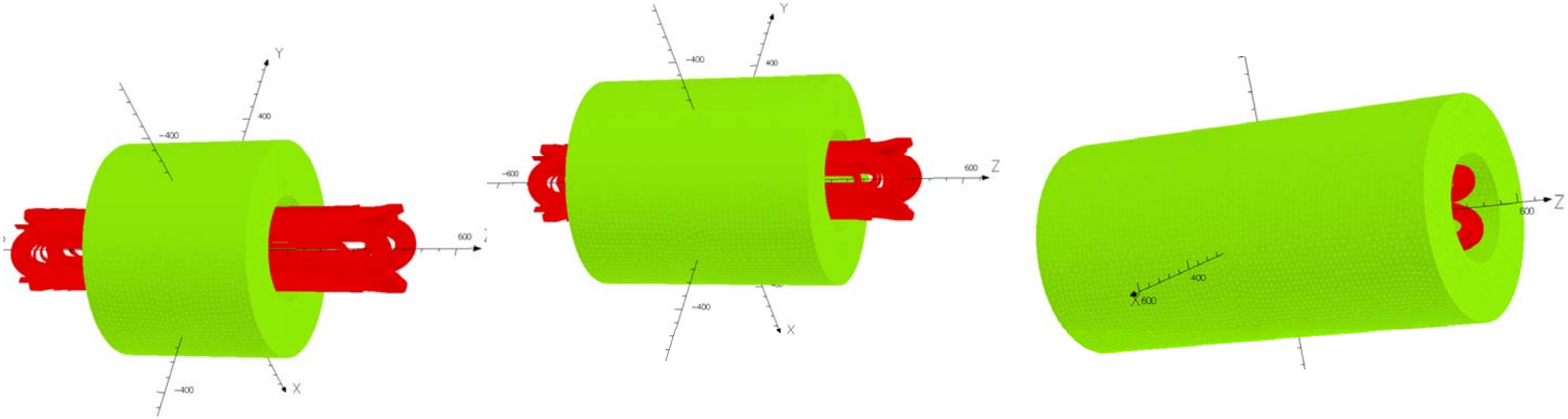
Work in Progress

Magnetic 3D



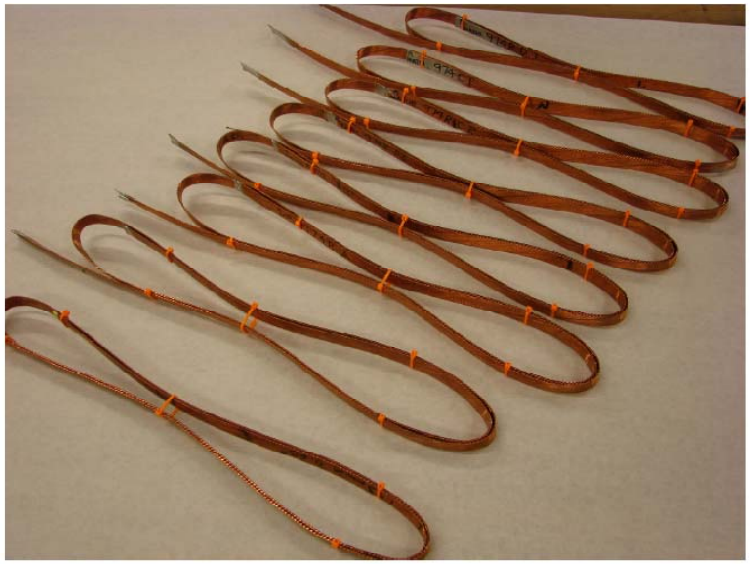
-**Study of coil-relative end position**

-**Study of iron field contribution**



=> Work in progress

HQ – Cable optimization



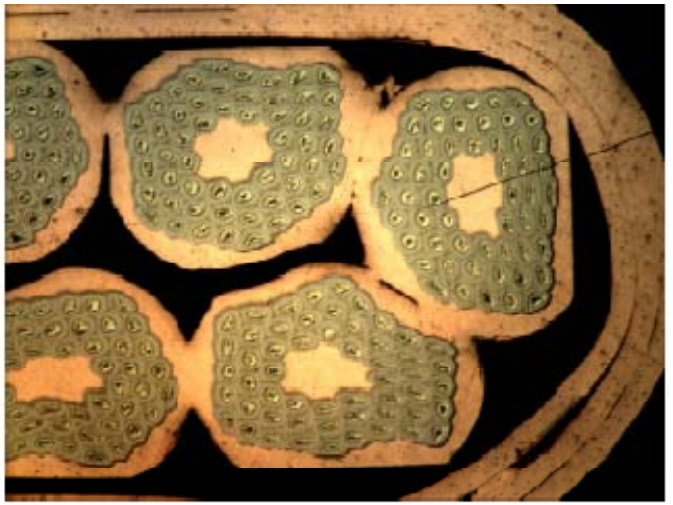
Test winding samples

Variation of the keystone angle, width, thickness…

Up to now, 8 cables evaluated

Micrographs analyzed for each sample

- Edge deformation – strand distortion
- Deformation of the sub-elements
- Barrier
- Size of the facets on the surface of the cable

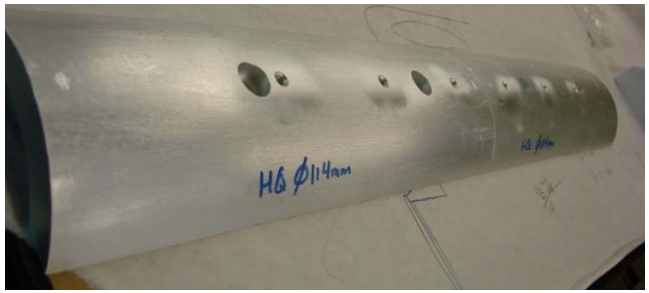


HQ – Cable optimization

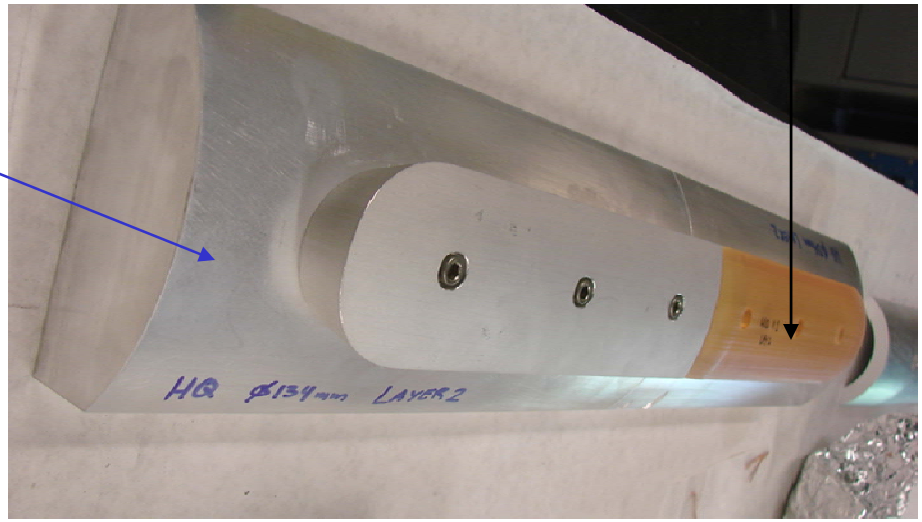
Winding tests

EDM part return end

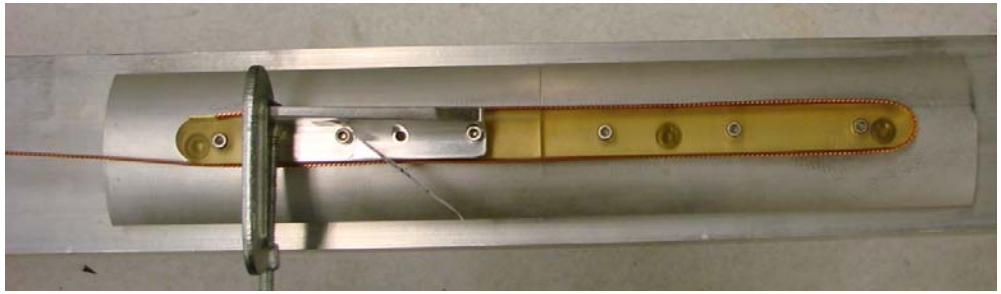
Rapid Prototype (RP) part lead end



114 mm aperture mandrel



134 mm aperture mandrel



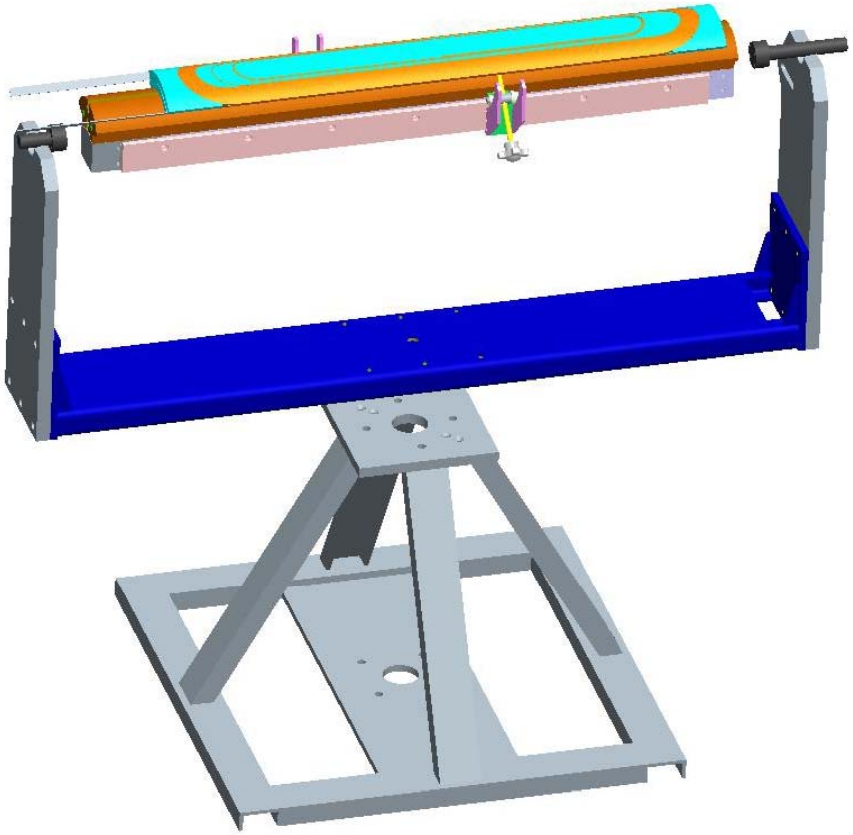
Ongoing tests:

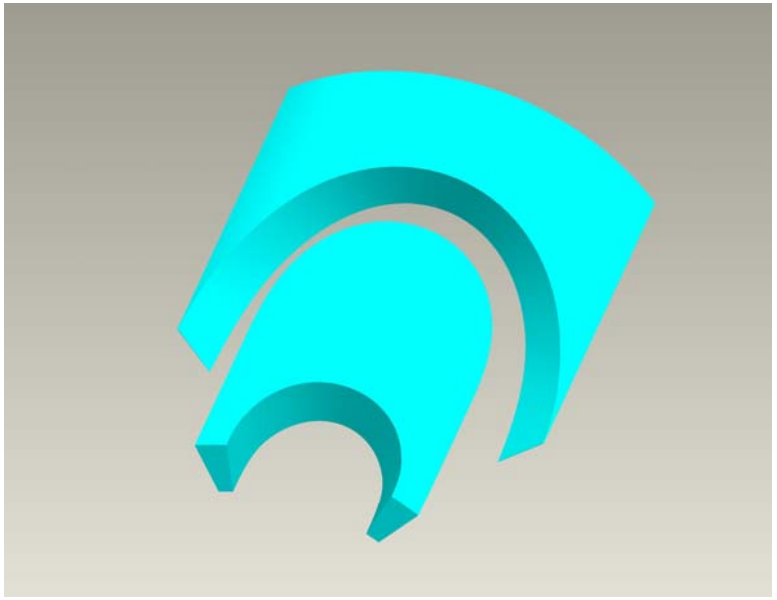
Winding tests on 114 mm mandrel with RP pole pieces

Work in progress

Winding Table

Initial parametric design of coil and spacers for both layers

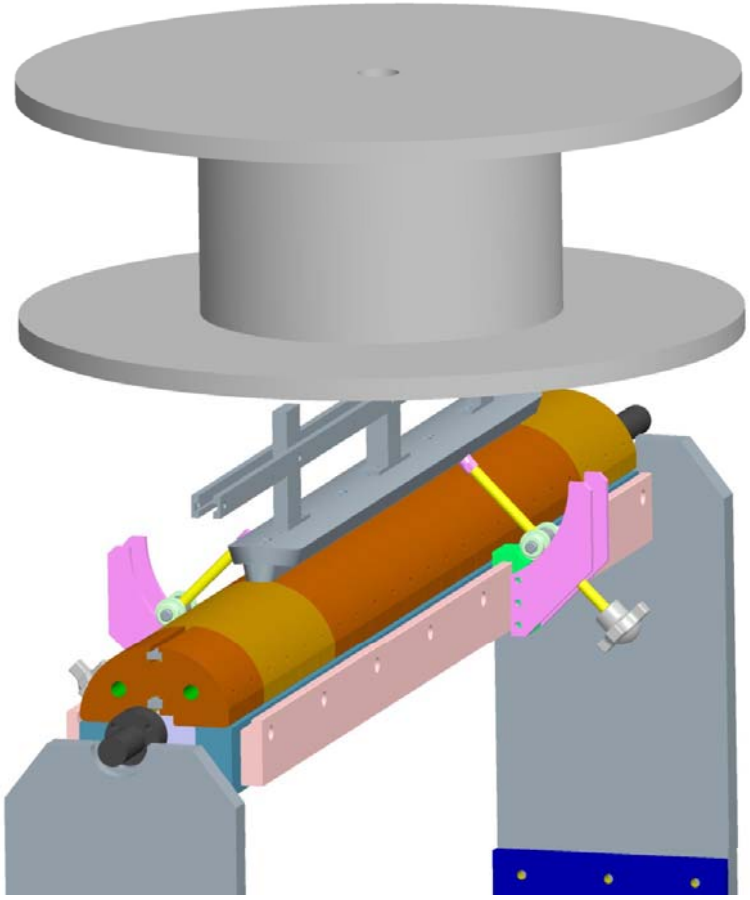




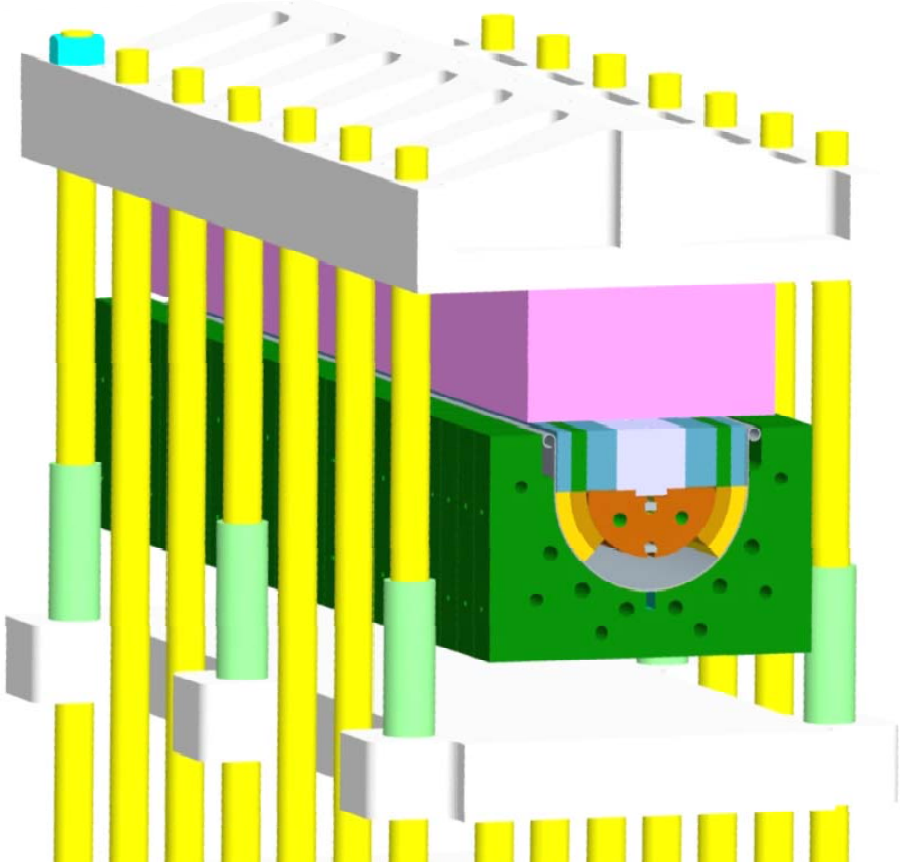
Work in progress

Tooling design

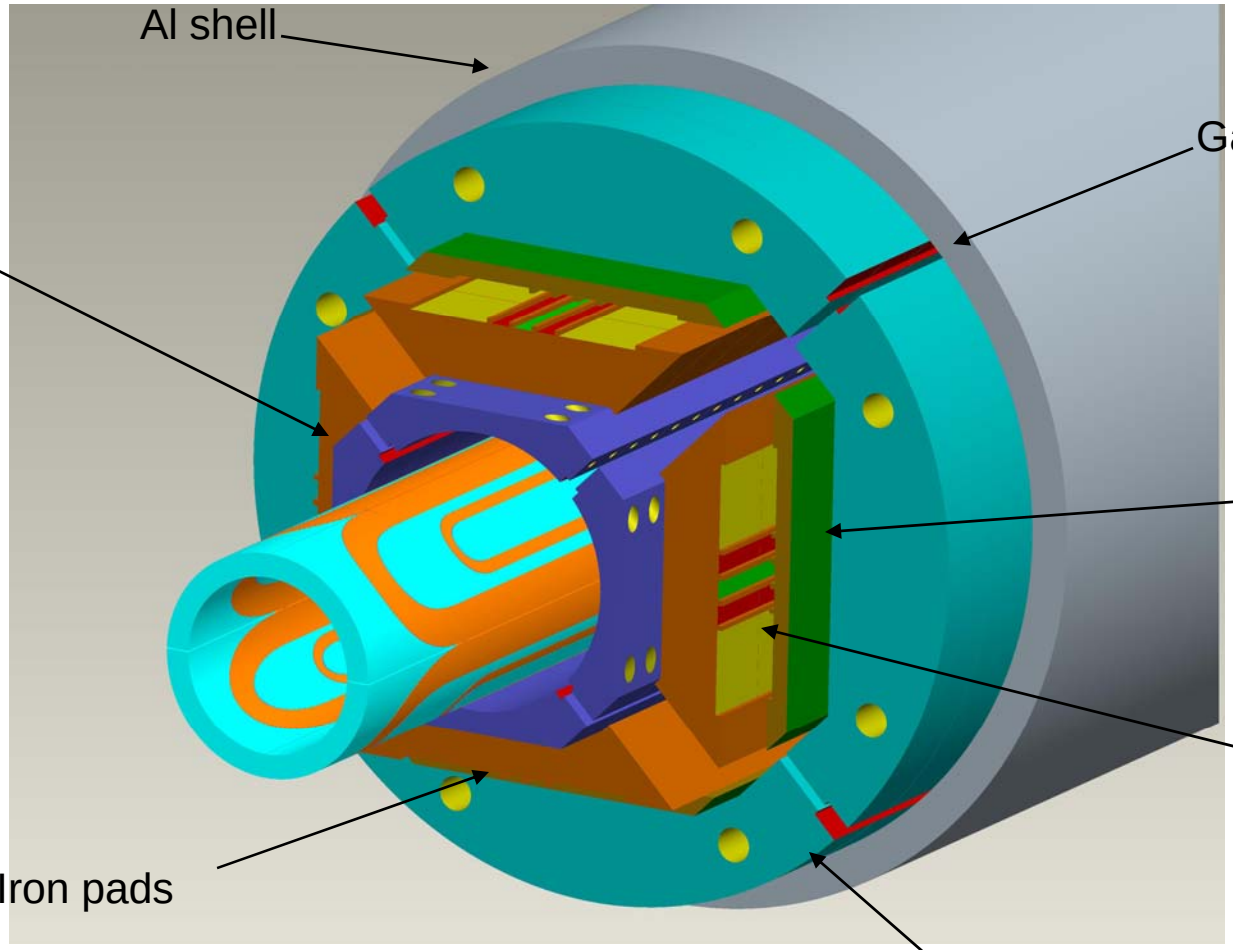
Winding tooling



Curing tooling



HQ – CAD Model


Al shell
Bolted collars
Gap keys slot
Iron master
Loading keys slot
Iron pads
Iron yoke

LARP

Summary

⇒ A range of apertures have been considered: from 110 mm to 140 mm

- detailed study of 114 mm and 134 mm

⇒ Optimization of the cable in progress => iteration on the magnetic cross-section

⇒ For each aperture, a mechanical structure is under study in order to provide:

- ⇒ support up to the short sample limit of the magnet
- ⇒ alignment
- ⇒ cooling

⇒ Tooling design is in progress, End parts design under study

⇒ 3D computations have been started