DE LA RECHERCHE À L'INDUSTRIE

CERN-GSI Technical Coordination Meeting

13/02/2015

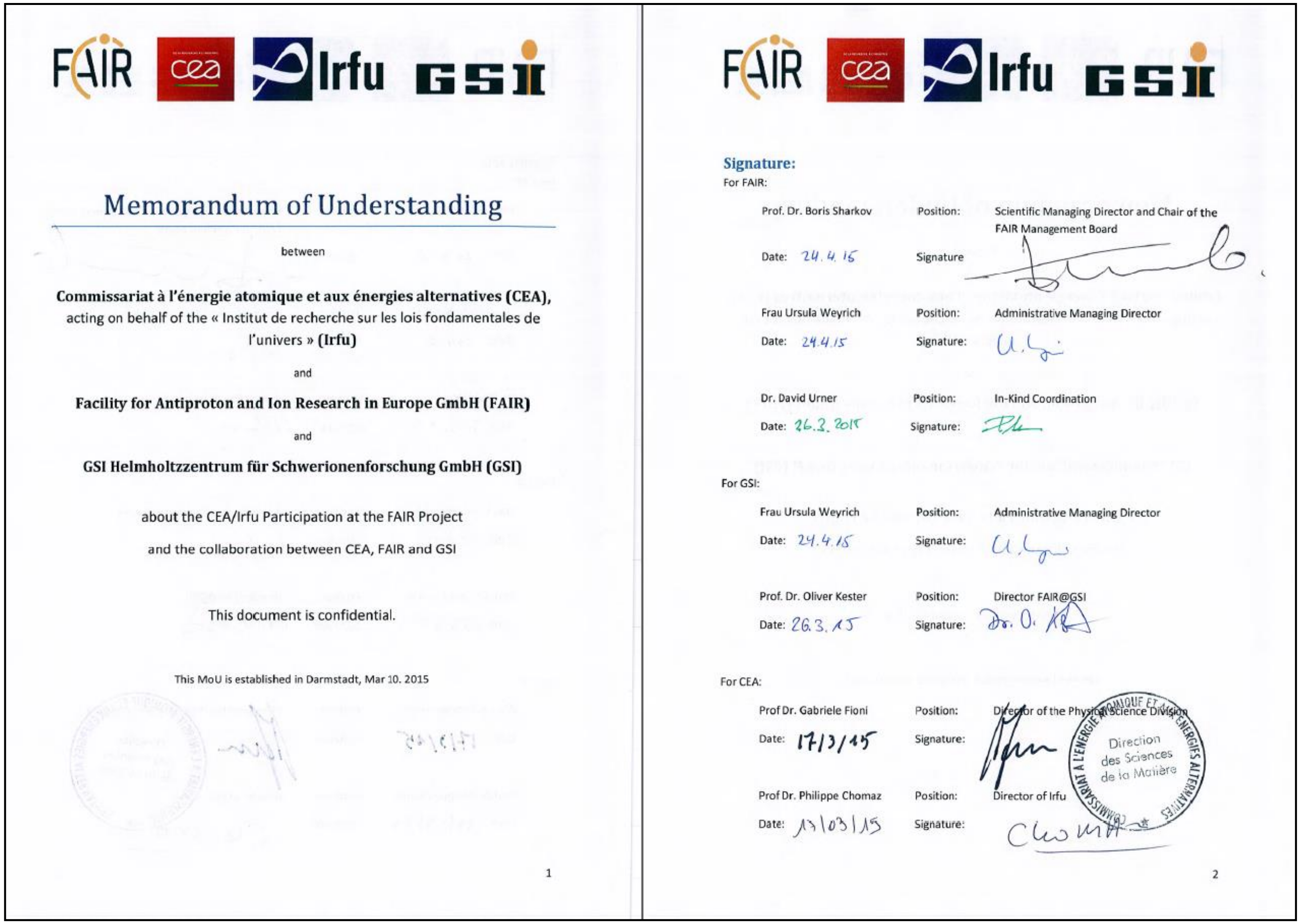
Super FRS dipole magnets status

Lionel Quettier

www.cea.fr

MoU Status

- MoU between CEA/Irfu and FAIR/GSI signed since April 24th to agree on the general SOW and responsibilities



Memorandum of Understanding

between

Commissariat à l'énergie atomique et aux énergies alternatives (CEA),
acting on behalf of the « Institut de recherche sur les lois fondamentales de l'univers » **(Irfu)**

and

Facility for Antiproton and Ion Research in Europe GmbH (FAIR)

and

GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI)

about the CEA/Irfu Participation at the FAIR Project

and the collaboration between CEA, FAIR and GSI

This document is confidential.

This MoU is established in Darmstadt, Mar 10. 2015

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Signature:

For FAIR:

Prof. Dr. Boris Sharkov Position: Scientific Managing Director and Chair of the FAIR Management Board
Date: 24. 4. 15 Signature

Frau Ursula Weyrich Position: Administrative Managing Director
Date: 24.4.15 Signature:

Dr. David Urner Position: In-Kind Coordination
Date: 26.3. 2015 Signature:

For GSI:

Frau Ursula Weyrich Position: Administrative Managing Director
Date: 24.4.15 Signature:

Prof. Dr. Oliver Kester Position: Director FAIR@GSI
Date: 26.3.15 Signature: Dr. O.

For CEA:

Prof Dr. Gabriele Fioni Position: Director of the Physical Science Division
Date: 17/3/15 Signature:

Direction des Sciences de la Matière

Prof Dr. Philippe Chomaz Position: Director of Irfu
Date: 13/03/15 Signature:

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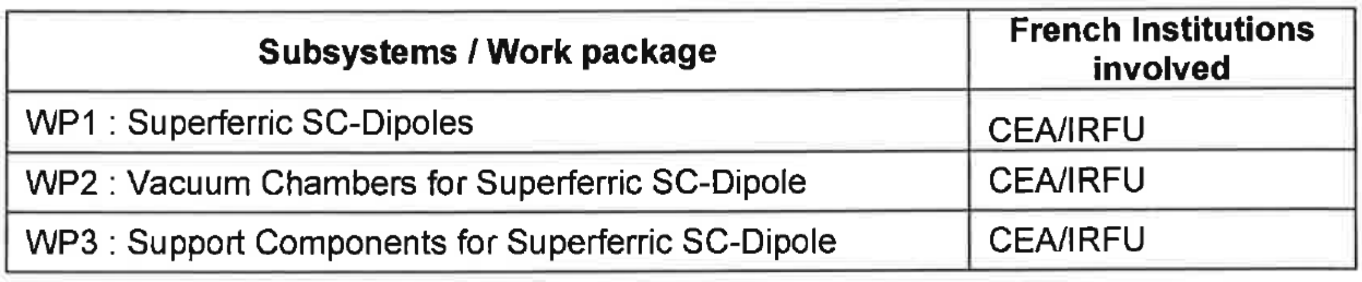
CONTRIBUTION CEA/Irfu

- **CEA is responsible for the delivery of all 24 superferric SC-dipole magnets**
  - 3 WPs

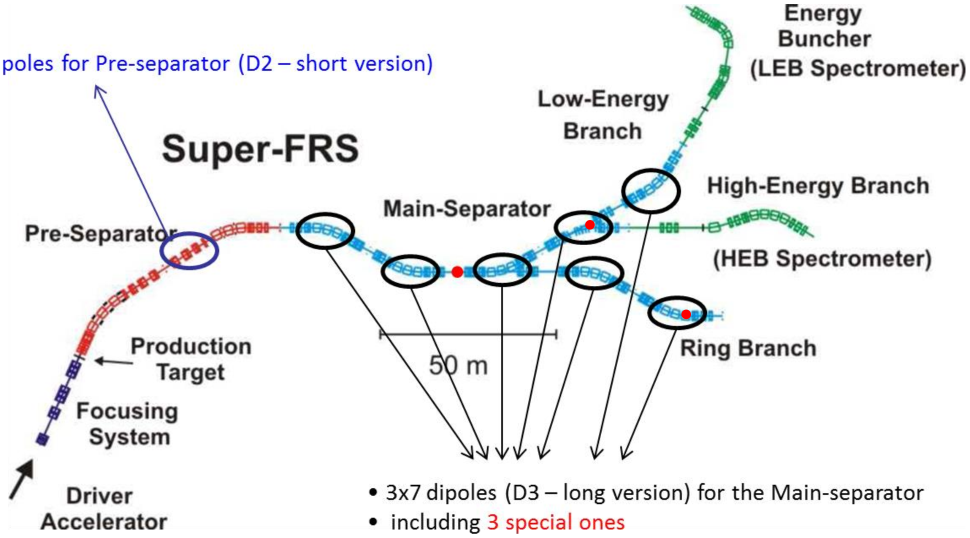


Subsystems / Work package	French Institutions involved
WP1 : Superferric SC-Dipoles	CEA/IRFU
WP2 : Vacuum Chambers for Superferric SC-Dipole	CEA/IRFU
WP3 : Support Components for Superferric SC-Dipole	CEA/IRFU

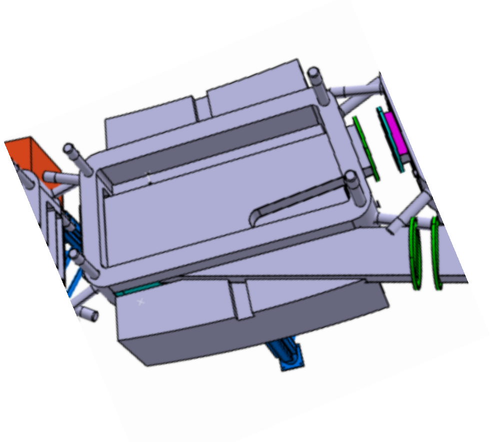
  - Management
  - Review of the existing design of the magnet
  - Functional specification and conceptual drawings production
  - Follow-up of the project including the production

DIPOLES FOR THE SUPER-FRS

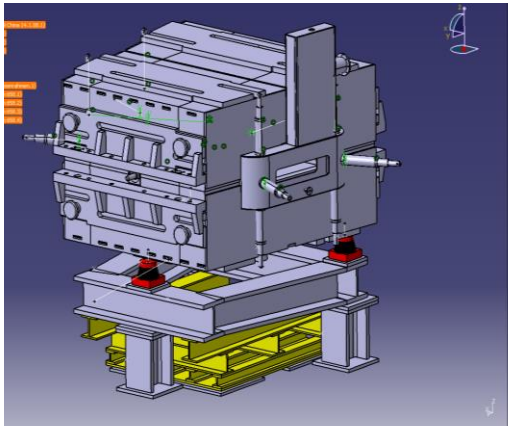
3 dipoles for Pre-separator (D2 – short version)



- 3x7 dipoles (D3 – long version) for the Main-separator
- including 3 special ones



Branched dipole



Dipole Type		D2	D3, standard	D3, branch
Number of dipoles		3	19	2
Deflection angle	degree	11	9,75	9,75
Bending radius	m	12,5	12,5	12,5
Effective length	mm	2400	2127	2127
Good field region (horizontal with sagitta)	mm	±190 ±29	±190 ±23	±190 ±23
Good field region (vertical)	mm	±70	±70	±70
Integral field quality (relative)		±3E-4	±3E-4	±3E-4

Tests of the prototype @ IMP

Min / Max dipole field	0,15 T / 1,6 T
Bending angle	**15°**
Curvature radius	8,125 m
Effective path length	2,126

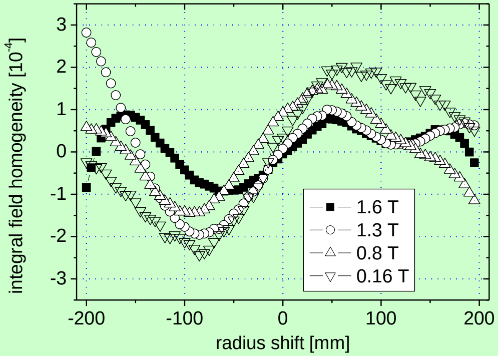
Magnetic flux:

B_{gap} = 1.6 T @ I = 232 A
(design value: I = 230 A)

Required field quality:

$DB/B = \pm 3\times10^{-4}$
(over ±190 mm, 5 mm steps)

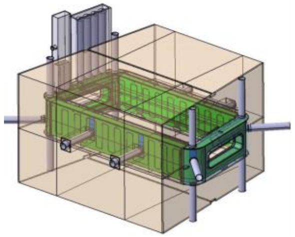
- field quality tests successful
- quench tests successful
- calculated: maximum hot spot ~100K, maximum coil to ground voltage ~300V
- stored energy ≈ 400 kJ
- inductance ≈ 15 H
- heat load @ 4.2 K: 6.8-8.1 W (0-232A)



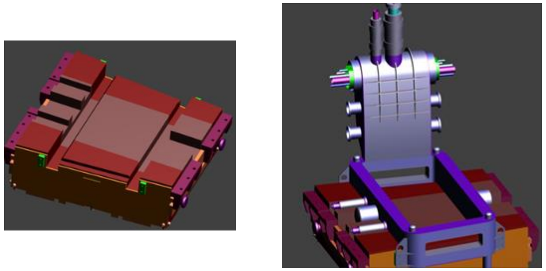
Design reviews and meetings

- Technical kick-off meeting January 2014
- Visit IMP April 2014

- 1st Review July 2014



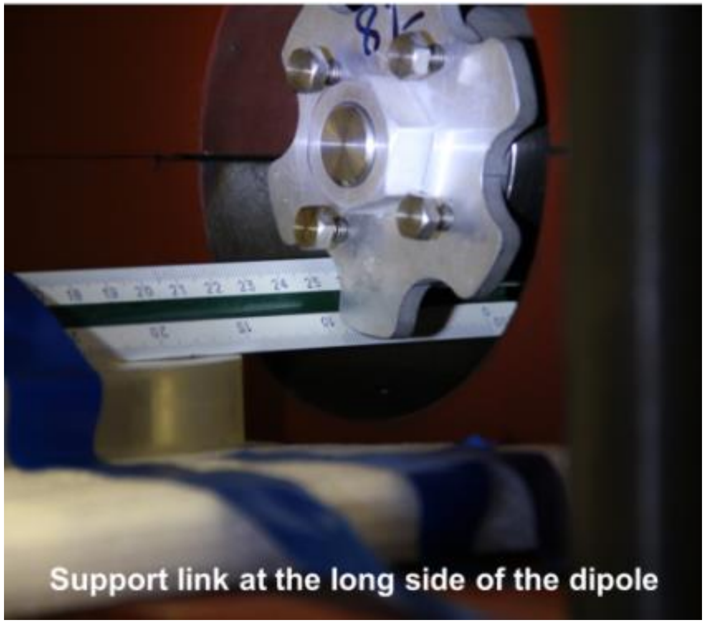
- 2nd Review Dec 2015



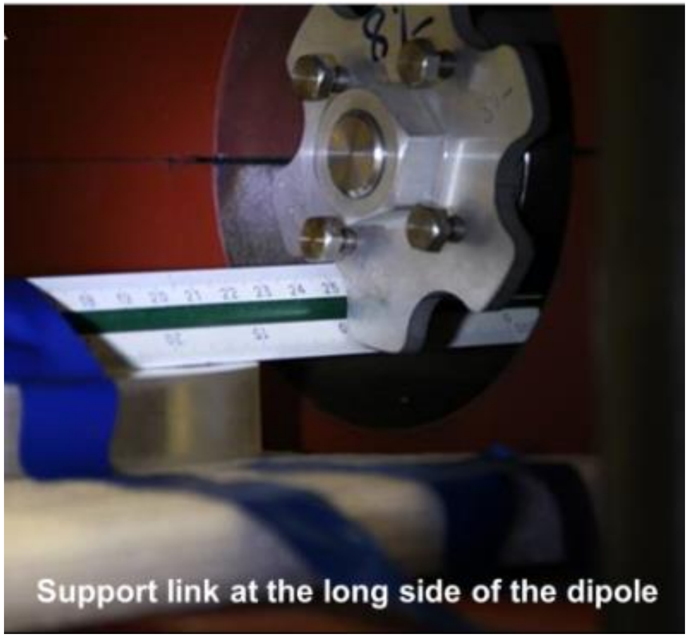
- Still updating the design based on the very last recommendations

Required modifications

- Motion of the cryostat observed during the tests

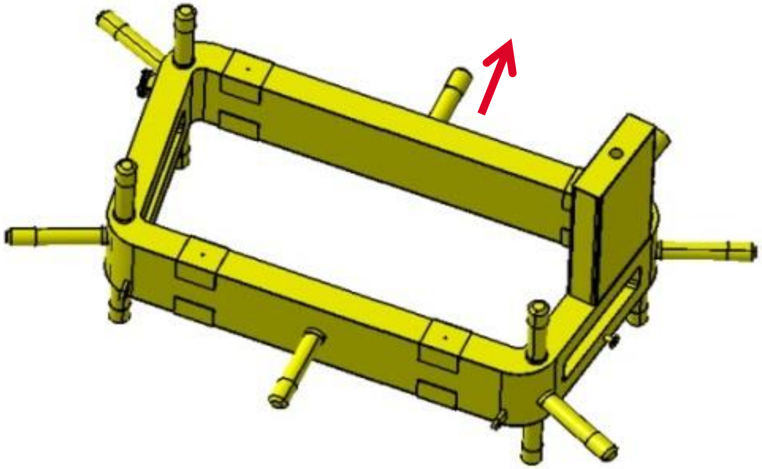


I = 0 A



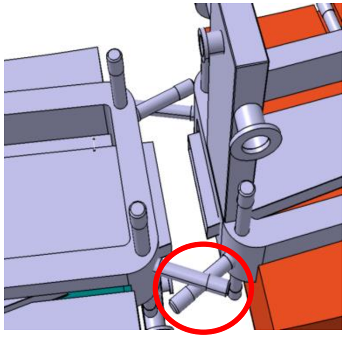
I = 278 A

Courtesy IMP

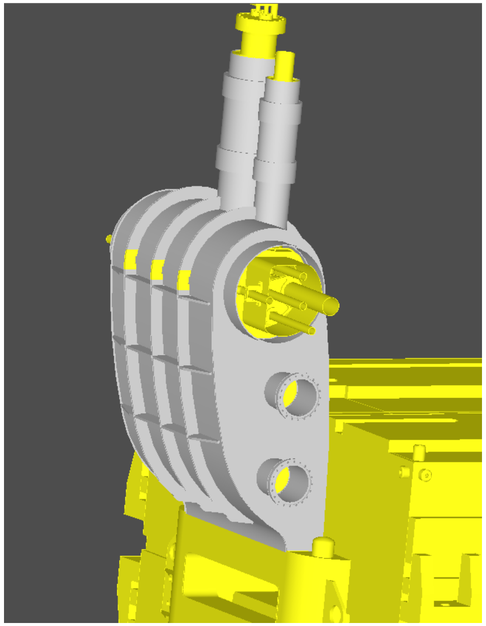


Required modifications

- Ensure the lack of physical interference between two successive magnets



- Design pressure of 20 bars vs 5 bars for the prototype



- Modifications of the interfaces and of the cryotower for the testing @ CERN and for the local cryogenics of the Super-FRS tunnel of FAIR:
  - DN 400 Flange
  - Voltages taps for the protection/instrumentation Fisher DEE107A015-130 (12 pins) / DEE 106A019-130 7pins)
  - Our design allows connecting the vacuum (2 ports DN160-CF) and the cryo from both sides

- Modifications on the magnet/yoke will be required for the branched dipole

Magnet design

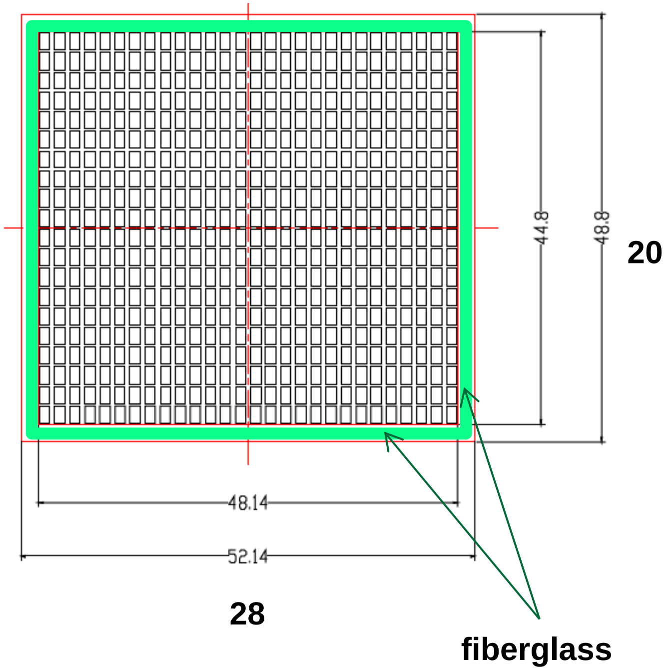
Conceptual design for version D3 (standard dipole - short version) – main parameters

Coil dimensions	1133 mm (medium length) x 2256 mm
Bending angle	**9,75°**
Curvature radius	12,5 m
Section size of coil	52.1×48.8 mm^2
Coil (per coil)	155 kg
Coil casing	755 kg
Cold mass	1065 kg
Thermal shield	155 kg
Vacuum vessel	650 kg
Vacuum vessel assembly	1870 kg
Yoke	46 tons
Overall mass	**47 tons**

Superconducting strands	NbTi
Dimension of conductor	1.43×2.23 mm^2
Number of Sc filaments	55
Ratio of Cu and NbTi	10.7
RRR of Cu in core wire	133
Number of turns	28 x 20 turns
Operating current	230 A
Central field @ 230 A	1,6 T
Peak field on the conductor @ 230 A	1,3 T
Inductance @ 230 A	18,3 H
Stored energy @ 230 A	484 kJ
Critical current density for wire @ 5 T @4,2 K	540 A
Length of conductor per coil	7,5 km
Ground insulation requirements and tests	3 kV

Final cross-section and operating current

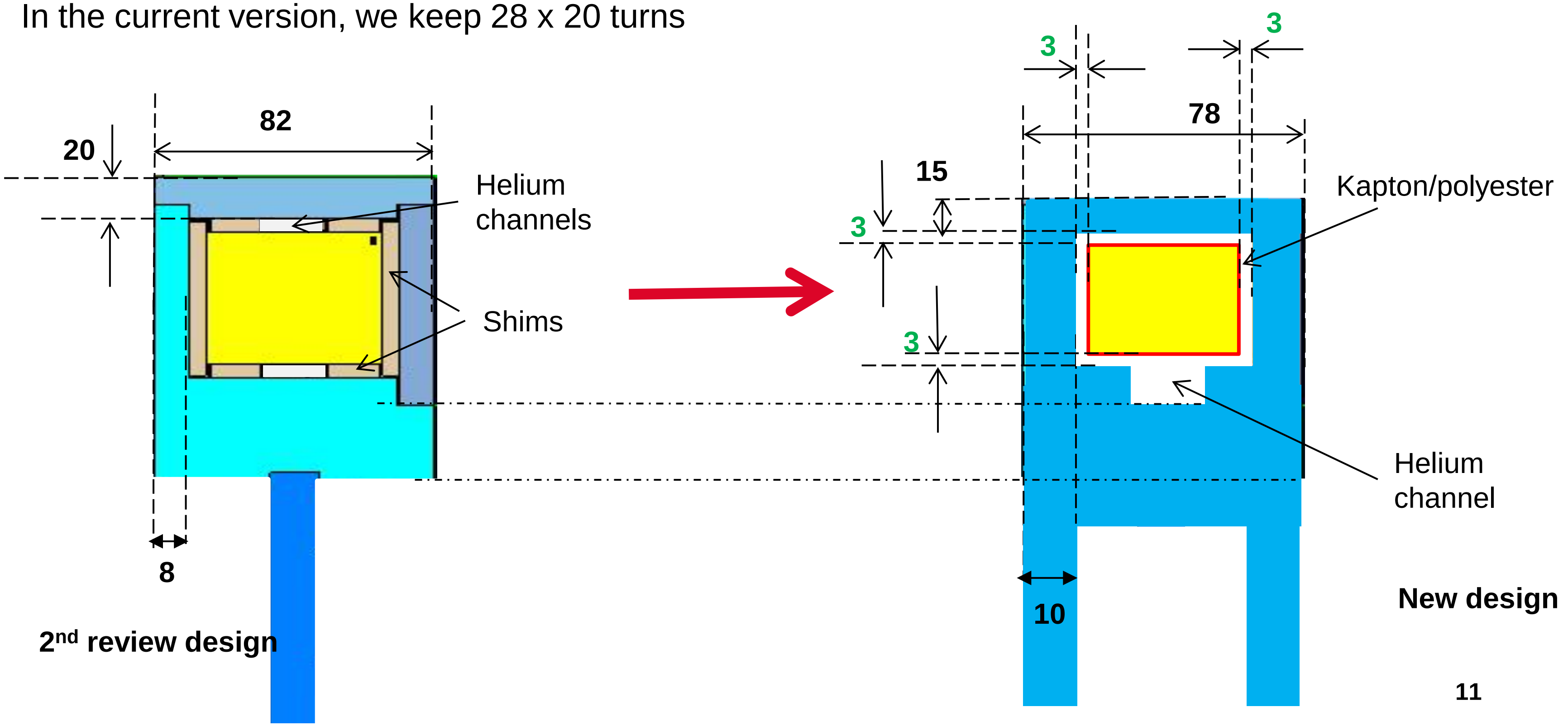
- Removal of 2 layers of the coil would be acceptable, as one would not increase the operating current to greater than 300 A.
- Final number to be decided during the preparation of the CAD model (we may need more space where the leads come into and out of the coils and it make will make construction a lot easier).



	560 turns (28 x 20)	540 turns (27 x 20)	520 turns (26x 20)
Current	I=230A	I=239A	I=248A
Dimensions	48 x 45	46 x 45	45 x 45
Overall dimensions with the 2mm fiberglass	52 x 49	50 x 49	49 x 49

New casing design

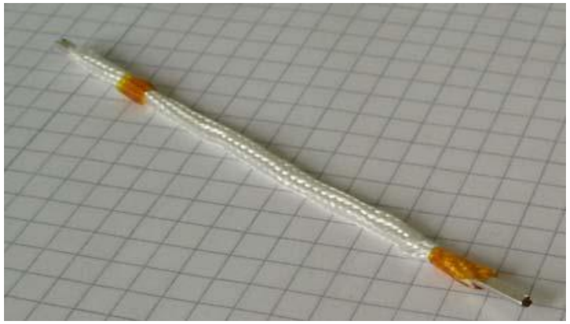
- ✓ Remove the shims (5mm each on side)
- ✓ Increase the casing side thickness from 8 to 10 mm reinforce the casing inertia
- ✓ Decrease the casing thickness from 82 to 78 mm
- ✓ Decrease the casing cover from 20 to 15 mm
- ✓ Keep the extra saved spaces for manufacturing tolerances, for assembly gaps of the impregnated coil into the casing, and for insertion of elastic steel shims to preload the coil
- ✓ Reinforcement of the electrical insulation with a kapton/polyester layer wrapped after impregnation
- ✓ Create a groove (20mm x 10mm) in the casing for cooling and for wetting the coil along the perimeter; design to be adapted based on the overpressure and cooling rate calculations
- ✓ In the current version, we keep 28 x 20 turns



Conductor

- Ic=660 A @ 4,2K @ 4T
- 0,715 mm diameter core wire
- PET insulation
- 70 µm filament diameter
- Twist pitch of 60mm

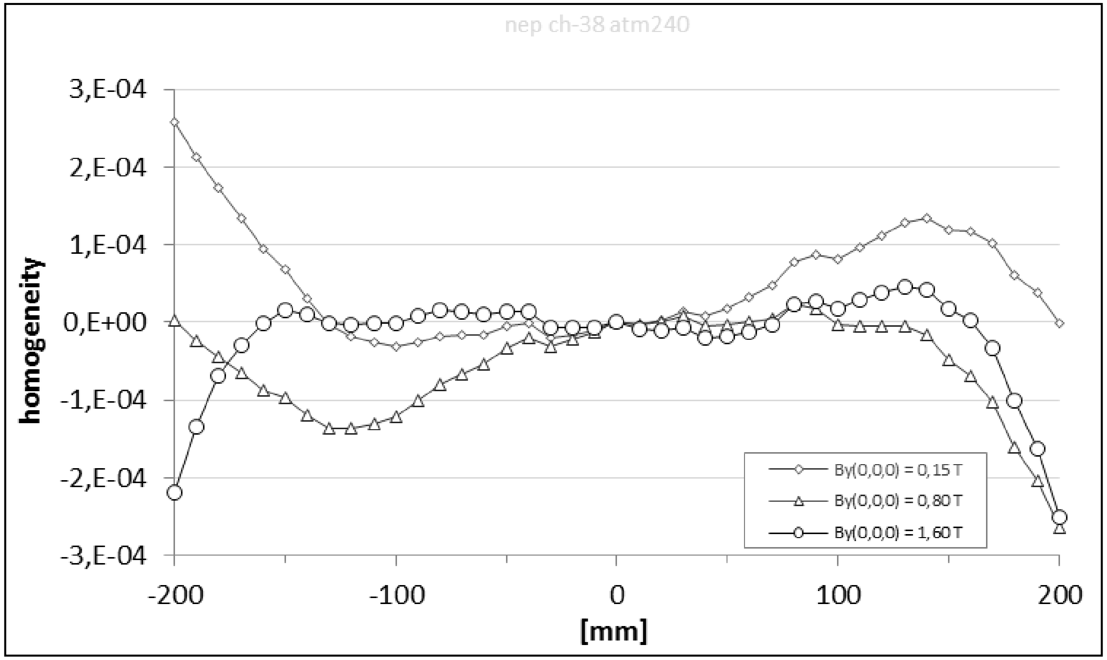
Superconducting strands	NbTi
Dimension of conductor	1.43×2.23 mm^2
Section size of coil	52.1×48.8mm^2
Ratio of Cu and NbTi	10.7
RRR of Cu in core wire	133



Contract ready for awarding

Magnetic design

- The 9.75° magnetic design is nearly completed.
- **Field integral value is 3.40 T*m**



Useable horizontal aperture	±190 mm
Useable vertical gap height	±70 mm
Integral field quality (relative) $\Delta\int \mathrm{Bdl}/\int \mathrm{Bdl}$	$\pm 3\text{x}10^{-4}$

Protection

New parameters

- Dump resistance 2.8 Ohm
- Time to detect the quench and open the switch : 60ms
- $V_{threshold}$: 0.6V

- Nominal case (110 % of nominal current)

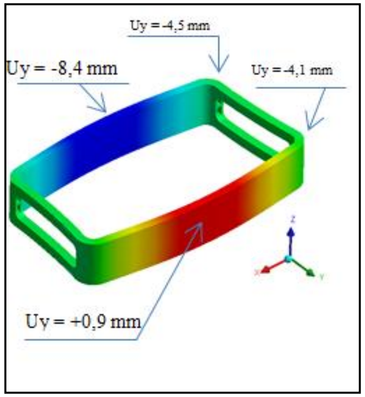
	t start quench (s)	t end quench (s)	Tmax (K)	% Total Energy
Bob 1	0	1,77	41	8
Bob 2	1,77	4,7	30	3
Dump resistor				89

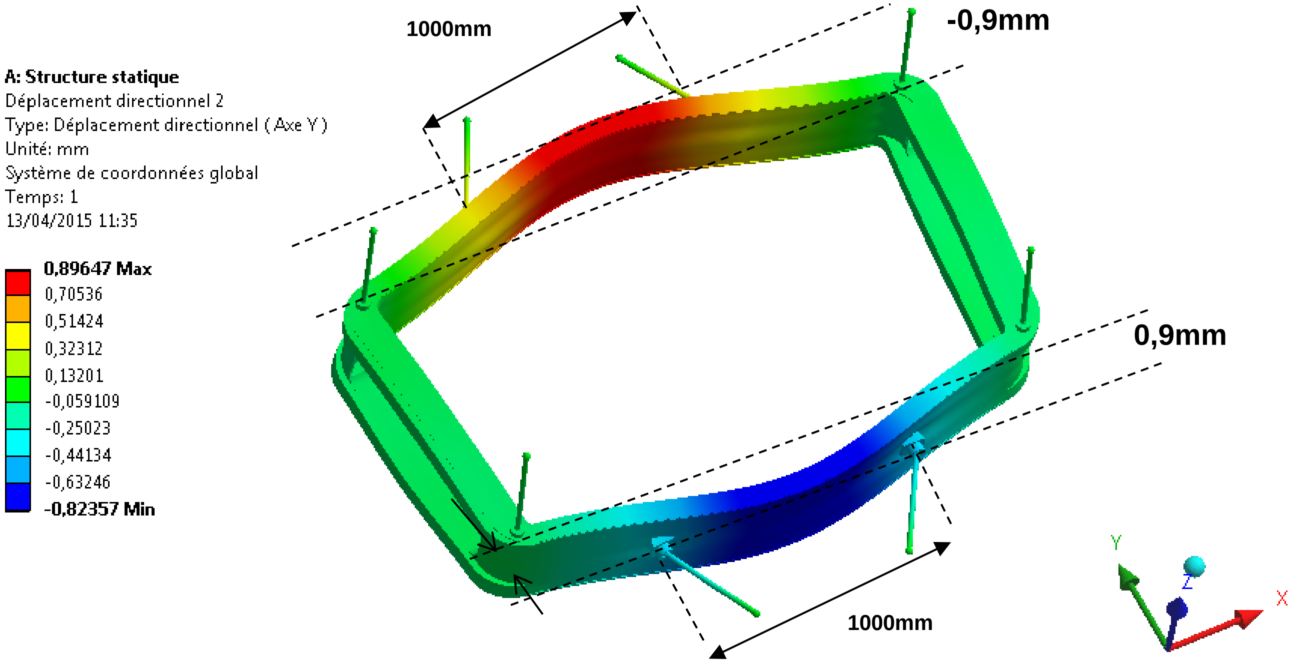
- Failure: all the energy dissipated in one coil :

	t start quench (s)	t end quench (s)	Tmax (K)	% Total Energy
Bob 1	0	1,59	**98**	100

Mechanical design
(only with magnetic forces)

IMP prototype





A: Structure statique
Déplacement directionnel 2
Type: Déplacement directionnel (Axe Y)
Unité: mm
Système de coordonnées global
Temps: 1
13/04/2015 11:35

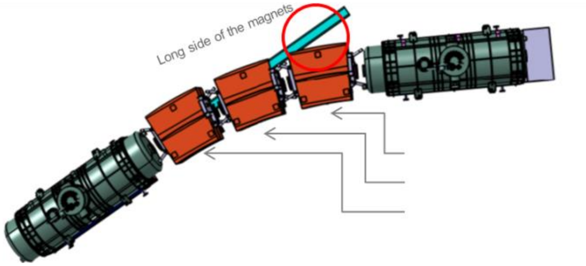
🟥	0,89647 Max
🟧	0,70536
🟨	0,51424
🟨	0,32312
🟩	0,13201
🟩	-0,059109
🟩	-0,25023
🟦	-0,44134
🟦	-0,63246
🟦	-0,82357 Min

Last modification:

- **Two tilted** cold to warm supports (20°) in the horizontal plan **on each side**

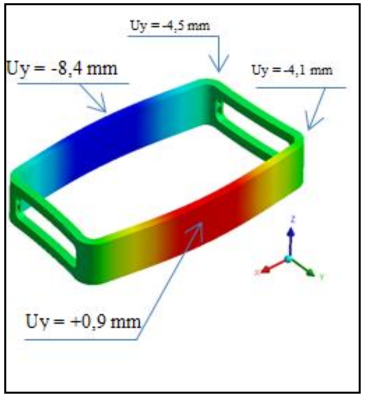
- Center to center distance optimized:
  to minimize the deflection of each side **(only 0,9mm!!!)**
  to have a symmetric coil deformation

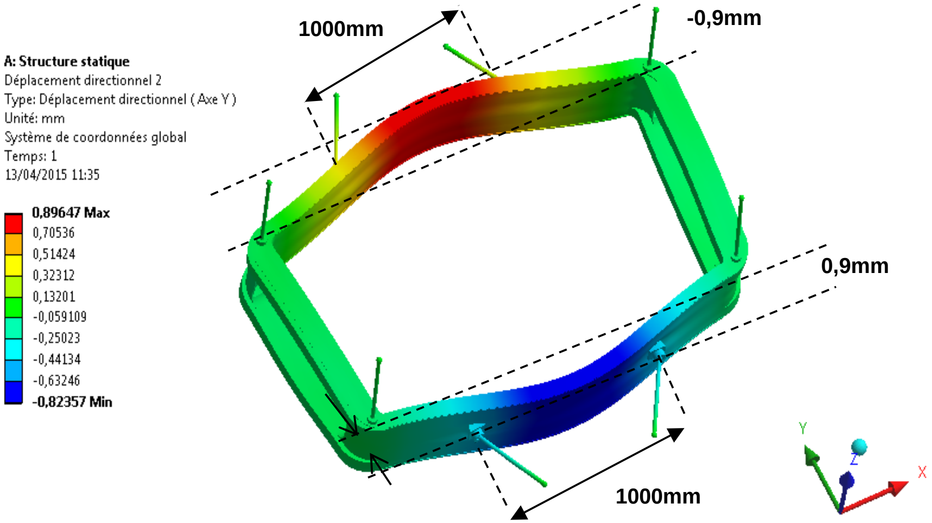
- Support length and location adjusted to avoid any problems for the VC at the branching



Mechanical design
(only with magnetic forces)

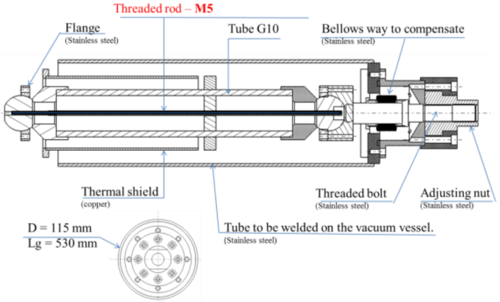
IMP prototype





- No need of additional stoppers to handle displacements along the beam axis; the system is stable
- No influence of the side holes inside the yoke on the integral field homogeneity
- Vertical and short side cold to warm supports are in tension
- Long side cold to warm supports are in compression

But design from MSU can only work on tension:



- **We are re-designing a new cold to warm support**
- Complete mechanical analysis will be done including vacuum, cooldown, magnetic forces weight and test pressure of 28 bars

Design pressure

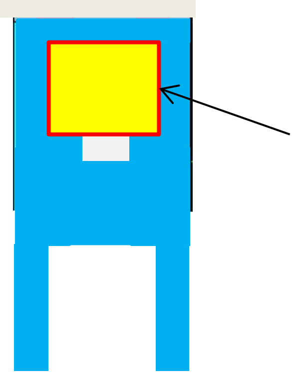
Design pressure of 20 bars

- TUV indicated a factor 1.43 must be used for our calculation (ie a test pressure of 28 bars)
- The casing should not be affected by 1.43, but the cryotower is more tricky.
- Some of the welds in the piping must be strengthened and some plates thickened
- Because of the DN 400 flange, we need several stiffeners to improve the rigidity of the tower.

Pressure increase in case of quench

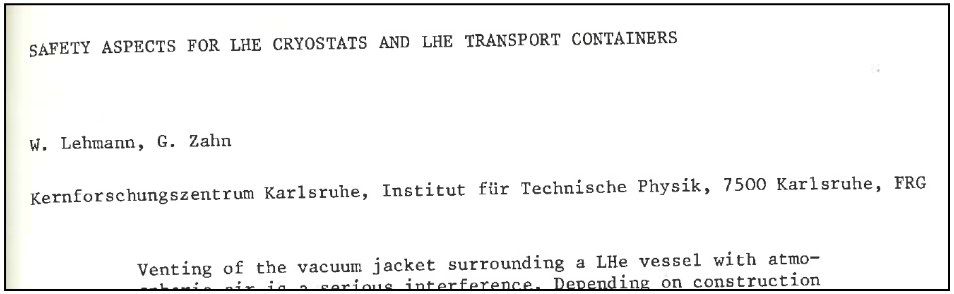
No singularity – one continous groove around the coil perimeter
4 channels in parallel, L=half perimeter of one coil (**L=3,3m**)

Rectangular Channel of 20mm x 10mm :	Equivalent hydraulic diameter **13,3mm**
Square Channel of 20mm x 20mm :	Equivalent hydraulic diameter 20mm



We assume there is helium only inside the channel, there is no helium around the coil (perfect contact coil/casing)

We only consider the loss of vacuum, ie 4 W/cm²
(Lehman data, assuming there is no superinsulation; if SI, we should consider 0,6W/cm²)



SAFETY ASPECTS FOR LHE CRYOSTATS AND LHE TRANSPORT CONTAINERS

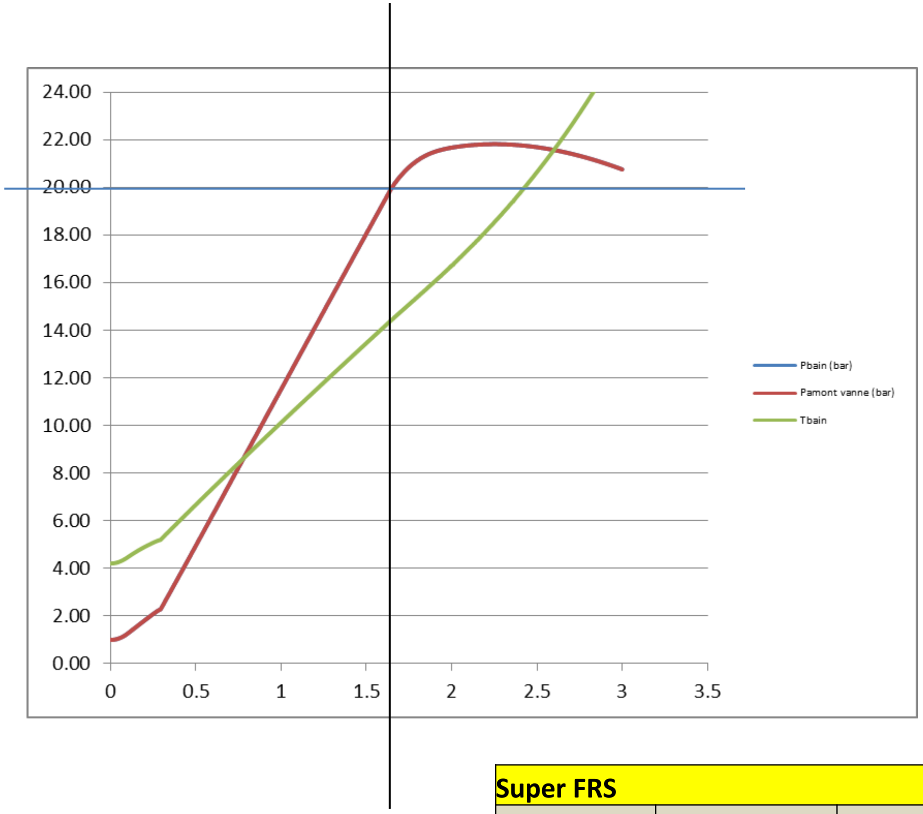
W. Lehmann, G. Zahn

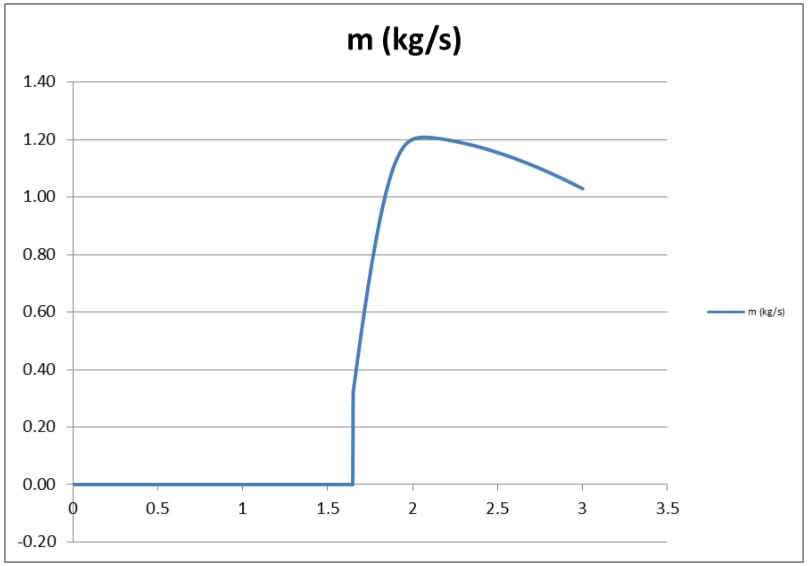
Kernforschungszentrum Karlsruhe, Institut für Technische Physik, 7500 Karlsruhe, FRG

Venting of the vacuum jacket surrounding a LHe vessel with atmo-

Given the casing surface, this leads to **120kW**

Pressure increase in case of quench


Opening of the safety valve



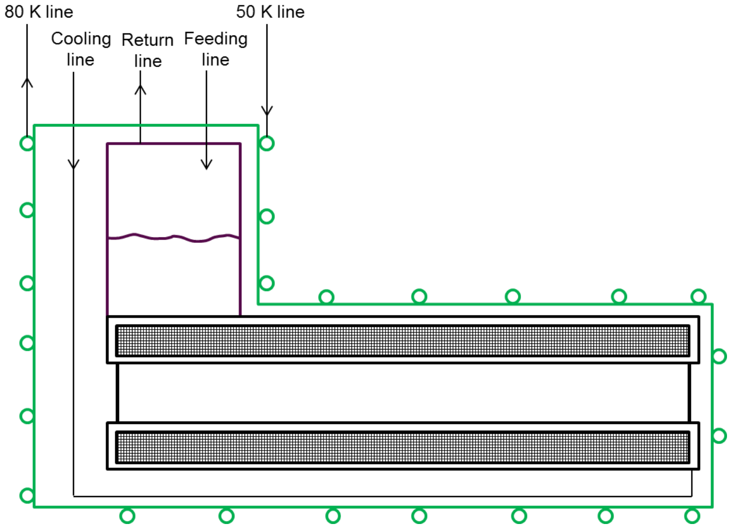
Disk diameter
19 mm

Super FRS					
Hydraulic channel mm	Pressure mbar	T K	Mass flow g/s	L m	Dp mbar
13,33	20000	15	**300,00**	3,3	**3449,31**

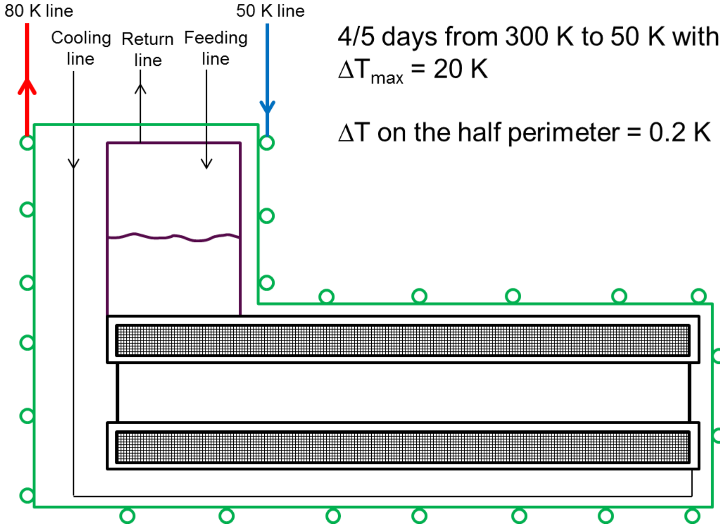
With 22 bars (Standards give MAP=design pressure + 10%), we reach **25,5 bars**
No problem for the casing from a mechanical point of view

Cooldown

Scheme



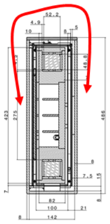
Thermal shield



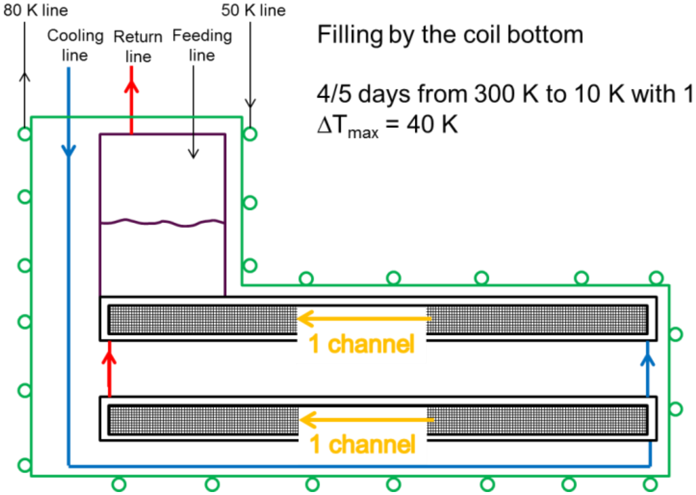
4/5 days from 300 K to 50 K with 1 g/s

ΔT_{max} = 20 K

ΔT on the half perimeter = 0.2 K



Cold mass



Filling by the coil bottom

4/5 days from 300 K to 10 K with 1.5 g/s

ΔT_{max} = 40 K

- Still need to perform dynamic calculations to establish the cool down rates for the coil and the heat shields and confirm the current size of the groove (20mm x 10mm) is acceptable.

Current leads

Discussion with Mark & Wedell A/S.

Main requirements (draft spec based on the spec for the multiplets) have been defined

- Design pressure of 20 bars
- Burnout–proof design
- Electrical insulation
- Overall dimensions
- Interfaces for sensors and connections

Preparation of a draft CAD model to be implemented into the magnet model

instrumentation

First list of sensors:

- 10 voltages taps for quench detection

- Temperature sensors (Cernox):
  - cold mass
  - thermal shield (one near the windows - worst cooling area)
  - in/out tubes
  - helium filling tube
  - Two thermocouples on the cold mass, two more T sensors for the preproduction magnet

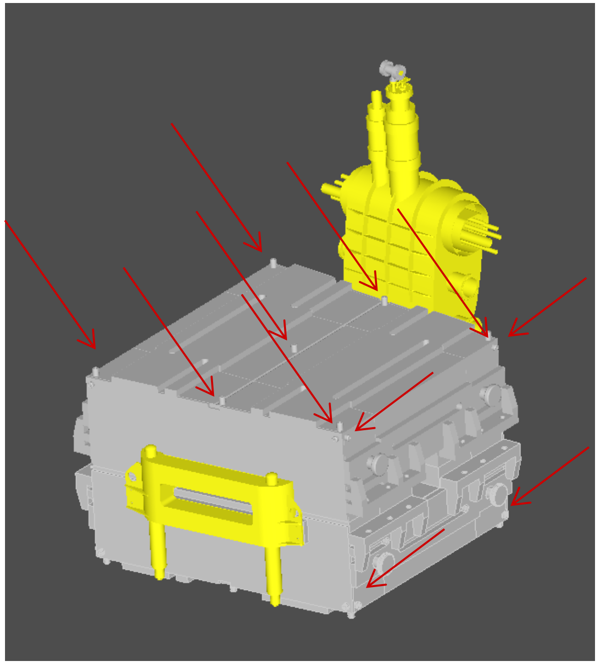
- Strain gauges on the supports and if possible on the wedges used to adjust the location of the cryostat respect with the yoke (at least on the preprod magnet)

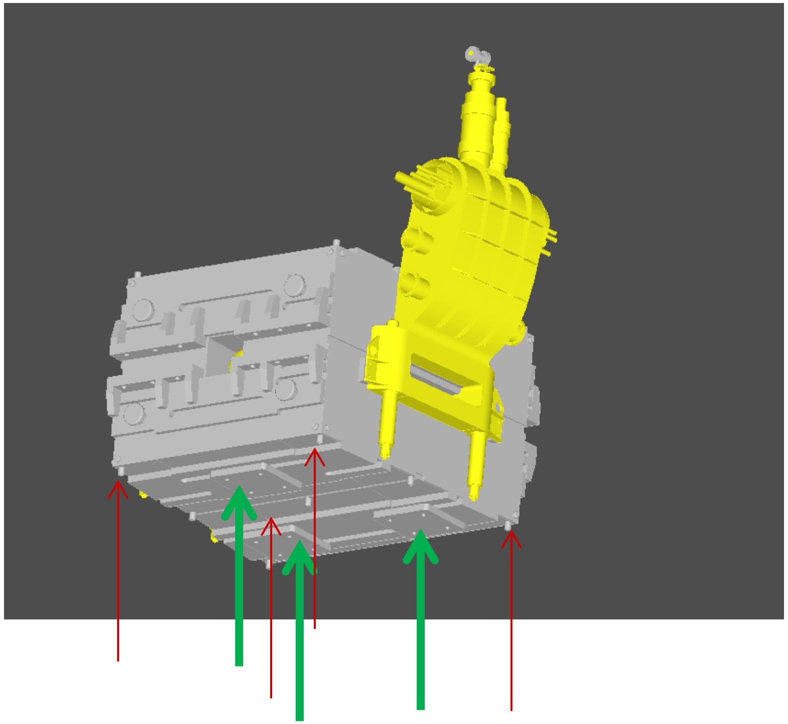
- Vacuum gauge inside the cryostat

- Pressure sensor on top of the helium bath

What is needed for the MCS? What about the redundancy?
Possibility of replacing damaged sensors?

Survey and alignment





- We added **some pads for the attachment** of the supports on the yoke
- **Alignment and survey points** have been added at relevant locations based on the requirements provided by GSI

CAD model

- Ready to start the final CAD model and the assembly procedure, including the comments from the last review

- Choice of materials according to the radiation resistance of components to be installed in the magnets

- Design the yoke so that it can be relatively easy to replace the chamfer pieces.
  Include tapped through holes to facilitate unsticking the pieces when they are magnetized.

- Regardless of the method for positioning the coils (slider or links), we are ready to generate a complete plan linking the assembly procedure to cooling, positioning, to mapping and establishing that coil positioning does not change with thermal and magnetic cycling.

Next steps

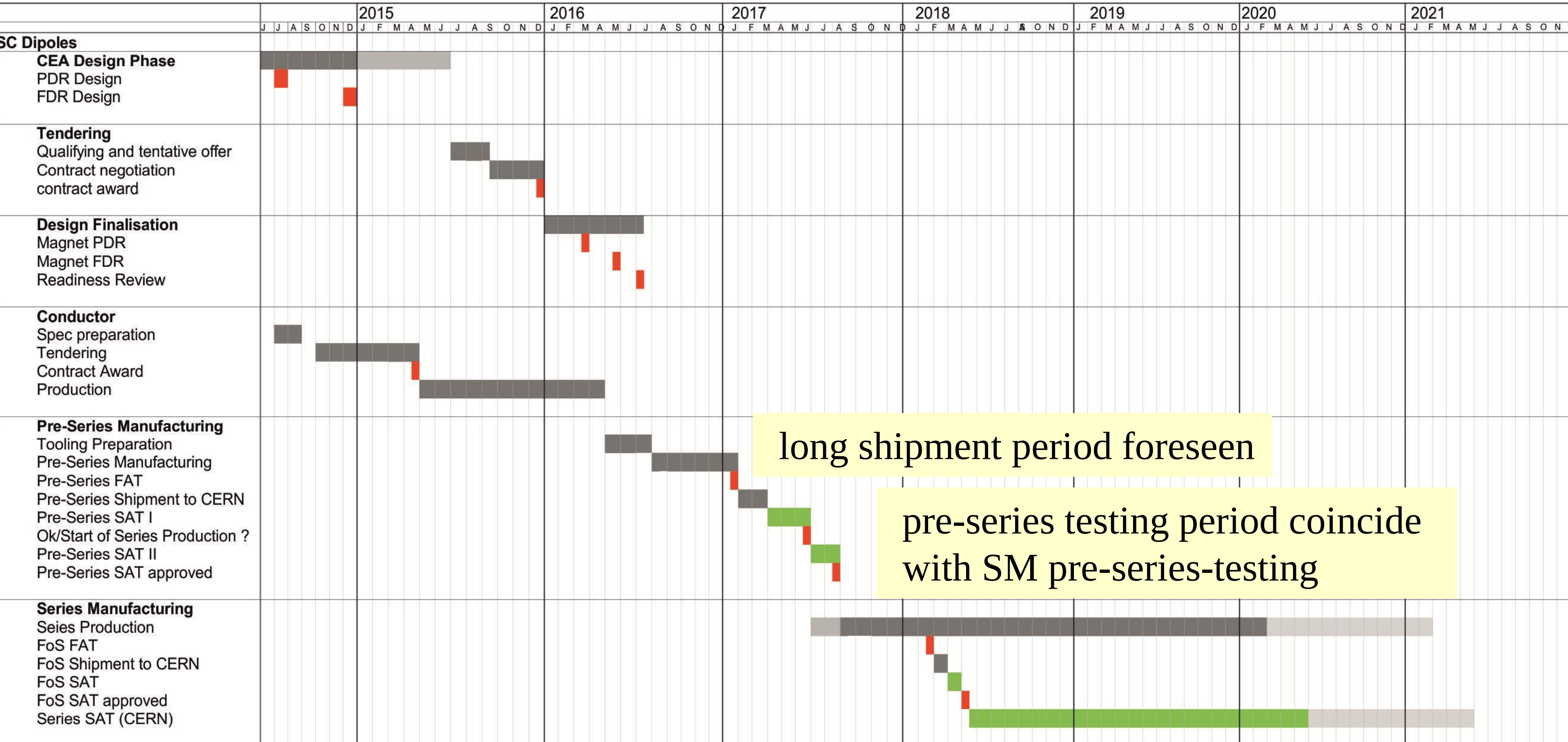
- Open points:
    - Constrains on the usable materials
    - Design factor for the shipping loads
    - Details on the VC flanges

- Next steps:
    - Design new cold to warm supports and complete the mechanical analysis with the new design
    - Evaluate the cooldown time for the new configuration; adjust the casing groove dimensions if required
    - Verify that the M&W lead design meets our requirement (dimensions, pressure and electrical insulation)
    - Compute the forces in the thermal shield in case of quench
    - Based on the mechanical analysis results, adjust the number of turn/layer if more assembly gaps are needed
    - Update the CAD model and prepare associated drawings
    - Evaluate the magnetic forces for the 11° version and verify that it is possible to use the same concepts developed for 9,75° version
    - Start the preparation of the specifications
    - Start the design of the branched magnet

Schedule – as presented during the last MAC

- ✓ Pre-bidder information meetings Q4/2014
- ✓ Tendering of SC wire, ready for awarding
- ➢ Design finalization, preparation of documents
- ➢ Tender by FAIR: Q3/2015
- FAT Pre-Series: Q1/2017
- SAT Series: Q2/2018 – Q2/2020

- **Very optimistic**
- **Strongly depends on the ongoing discussions between CEA and FAIR/GSI**



long shipment period foreseen

pre-series testing period coincide with SM pre-series-testing