The Technical Design Report (TDR) and the Detailed (functional) Specification of the CBM Superconducting Dipole

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CBM Dipole Conceptional Design Review

May 22-24 2017

GSI Darmstadt

CBM Dipole

- Design history
  - work by JINR, Dubna
- Technical Design Report (TDR) (October 2013)
  - by JINR and GSI
- Collaboration Contract with BINP, Novosibirsk for the design, prototyping, production, delivery and testing
  - Annex 3: Detailed Specification

Milestone	Work Description	Validation Criteria	Date
1.1 (M5)	Detailed work plan Quality Plan	Technical Specifications Consideration and approval of the Plan	12/2016
1.2 (A6)	Conceptual Design of the whole system and the components	Conceptual Design Review (CDR)	04/2017
1.3 (M6)	Technical Design of the whole system and the components	Preliminary Design Review (PDR)	09/2017
2.1 (M7)	Final design of the whole system (all documents, drawings necessary for the production)	Final Design Review (FDR), production approval	12/2017
2.2 (M9)	Manufacturing of all components	Assembly and test of the whole magnet at BINP Factory Acceptance Test passed	12/2019 (end of 2021)
2.3 (M10)	mechanical assembly and installation in CBM Cave Delivery and SAT of all components	Site Acceptance Test passed	06/2020
2.4 (M11)	Acceptance Test	Complete Magnet assembled and tested Ready for beam	12/2020

Design history

- CDR review 1/2012
- CDR review 6/2012
- TDR review 11/2012
- Travel to RIKEN/TDR update in 2013
- TDR final 10/2013
- BINP collaboration contract 10/2016

CDR review 1/2012

Main Dipole Parameters

Geometry

- Opening angle: ±25° vertically, ± 30° horizontally from the target
- Free aperture: 1.4 m x.1.4 m, no conical geometry!

Field

- Field integral within STS detector (along straight lines): 1 Tm
- Field integral variation over the whole relevant aperture along straight lines: ≤ 20%
- Fringe field downstream < 10 Gauss at a distance of 1.6m from target)

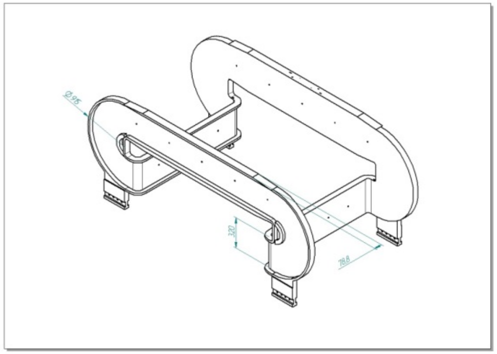
Operating conditions:

- 100% duty cycle, 3 months/year, 20 years
- No time restriction on the ramp
- Radiation damage (<10MG for organics): no problem

CDR review 1/2012

Design options

- Coil dominated versus iron dominated dipole
- Resistive vs. superferric
- Coil design
- Conductor
- Cooling method
- Materials/Mechanical support



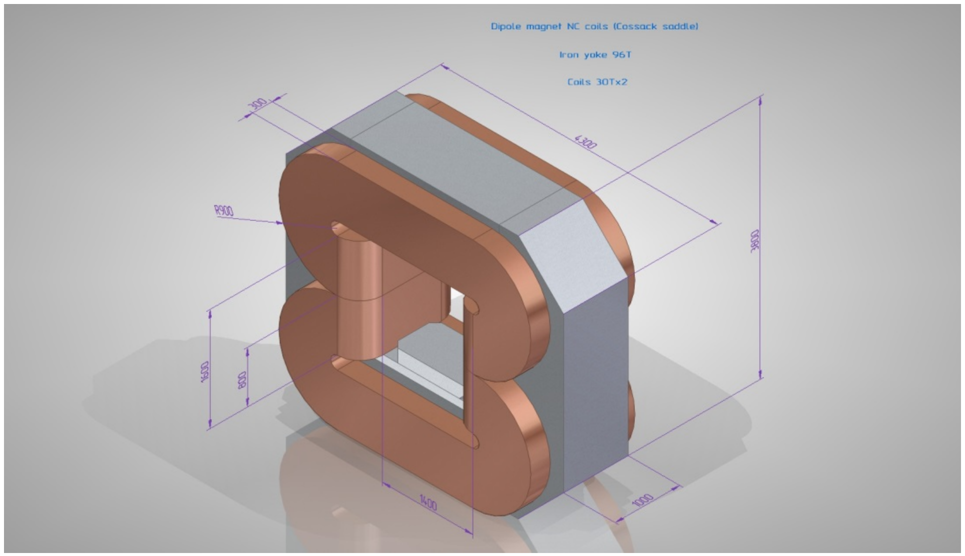
Cossack saddle type

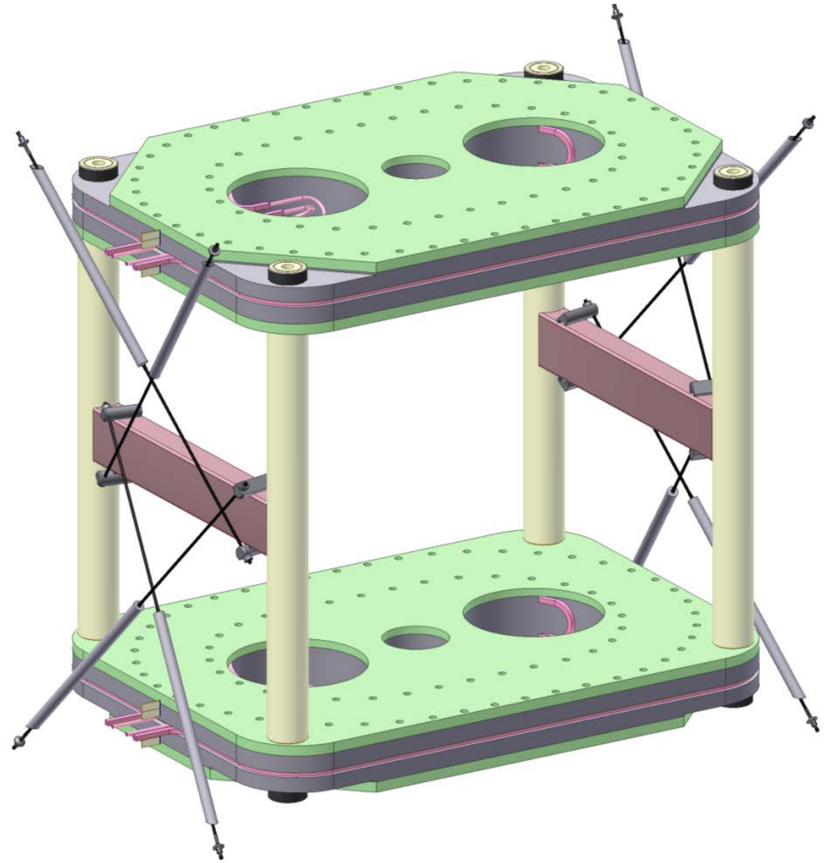
CDR Review 1/2012

From minutes: Conclusions and recommendations

- The committee believes that the superferric design is the best solution for the CBM dipole. However it proposes a comparison with the resistive option...
- The committee (dismissed a saddle coil and) recommends a more 'simple' coil (similar to a racetrack coil) for a superferric magnet
- H-type dipole with race track coils has to be optimized. That was considered as the baseline option to be pursued.
- A commercially available conductor should be chosen, if at all possible. It must have enough copper stabilizer to stay within the allowed hot spot temperature and coil voltage during a quench without heaters.
- No specific recommendations about the mentioned cooling methods (thermosyphon via channels, radiator embedded in the coil casing, direct or indirect cooling,...) were given.

CDR Review 6/2012





Type of coils	Current N*I	Power
Cossack saddle	760 kA	1,5MW
SF racetrack	1700 kA	~35kW

CDR Review 6/2012

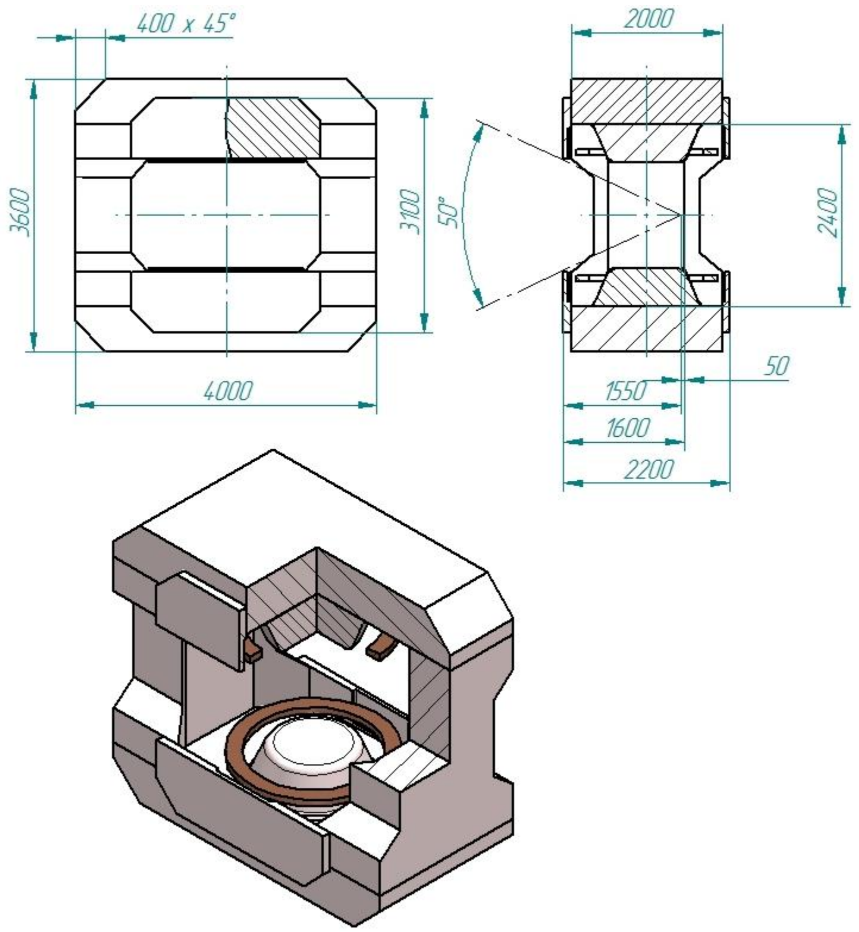
Conclusion and recommendations

- The committee recognizes that the horizontal aperture was increased since the last meeting from 1.4m to 1.8m, which lead to a lot of additional work.
- It became obvious during the meeting that a resistive version has to be dismissed due to too excessive power consumption. A superferric design is clearly the best choice.
- The presented WF-version with 1.6m aperture fulfils all requests. It has the advantages of a relatively simple and reliable coil support structure and of one compact cryostat. All forces are compensated within the cold mass. ....
- However, regarding the large forces on the coil, the committee recommends to investigate also the H-type version, which will reduce the ampereturns and the field in the coil and will consequently reduce forces and stored energy and increase margins. Saturation of the iron in superferric magnets is not as large a problem as in resistive magnets. It only requires more amp-turns....

CDR Review 6/2012

- As a first preliminary choice the ATLAS solenoid conductor was chosen. In principle an operating current of 7600 A is possible (single magnet, leads are available, the length of the supply cables are less than 100m). However, a more conventional conductor (with an operating current of some hundred amps) will be more economical and more vendors will be capable of manufacturing it. This will also reduce winding R&D requirements as technology required for large conductor requires significant development. This solution must be investigated...
- The number of turns is determined by the quench voltage. Therefore in parallel with the conductor design quench calculations have to be done, which deliver the quench voltage and the hot spot temperature.....

Magnet report 10/2012



first H-type design

Samurai dipole magnet (H-type)
RIKEN, Japan, 2012

Magnet report 10/2012

Parameter	WF type	H type
Magnetomotive force	1,52MAT/coil	0,92MAT/coil
Magnetic field	6,8T	3,5T-4,8T
Magnetic field in coil	6,78T	2,8T-3,3T
Magnetic field in yoke	2,8T	2,46T
Sum Forces ,Z	~400tons	~220-260tons
Sum Forces,Y	~260tons	~90tons
Sum Forces ,X	~350tons	~90tons
Current density max	167A/mm2	65A/mm2
Stored energy	10MJ	4MJ
Yoke weight	~120tons	~150tons
Working aperture	1,4x1,8m	1,4x2,5m
Magnet dimensions	4,12x4,8x1m	3,6x4x2m

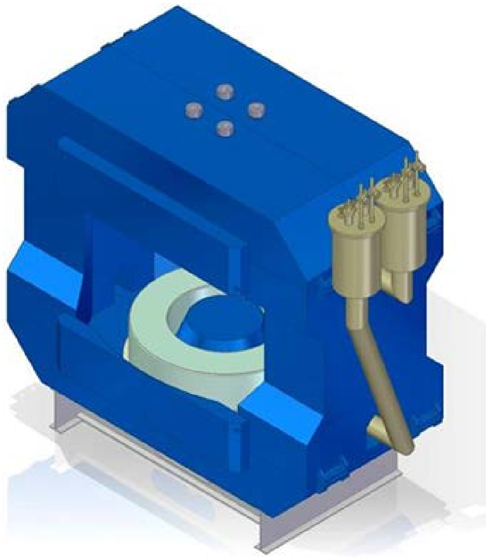
Conclusions: currents, forces, coil field and stored energy are lower for the H- type dipole!!

Review 11/2012

- “We agreed on the following design: We will build a superferric dipole of the H-type with cylindrical potted coils in 2 separate cryostats. The coil will be potted (not cryogenically stable), the protection scheme will include a dump resistor.”
  - -> TDR

Technical Design Report (TDR)
October 2013

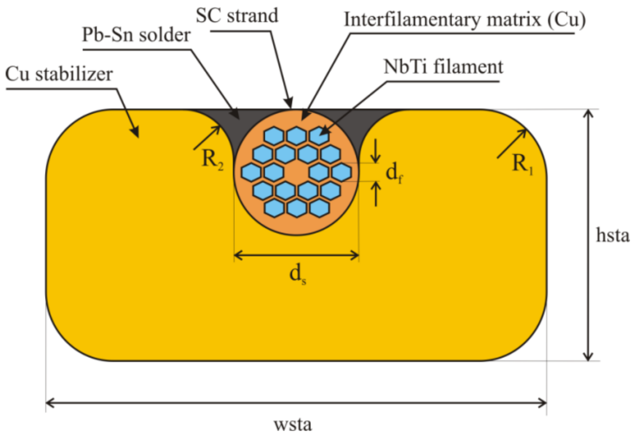
Main design principles



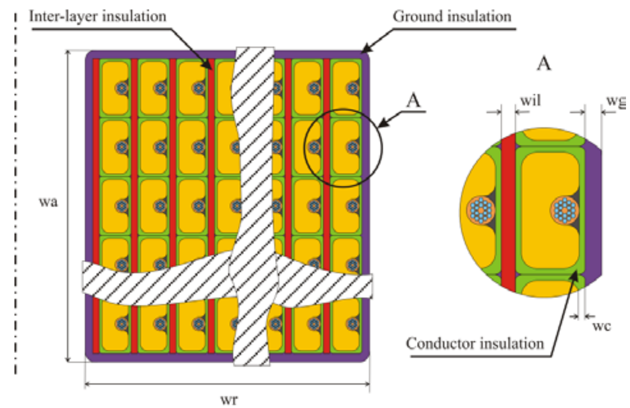
- Warm iron yoke (huge vertical and horizontal balks)
- Warm round (tapered) poles
- Removable field clamps
- cylindrical NbTi coils wound on cylindrical bobbin , cooled with LHe
- Thermal shield cooled with Helium gas (50-80K)
- Two independent cold masses and cryostats
- Vertical forces transferred from the coil to the cryostat and finally to the yoke
- Normal conducting leads

Challenges:

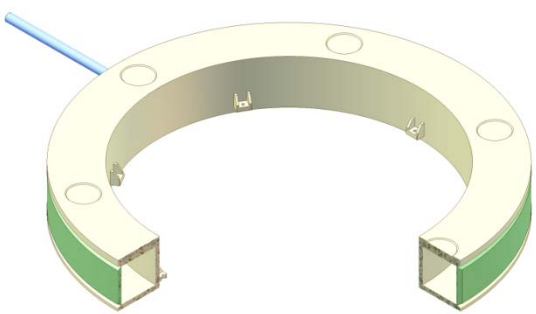
- stored energy: 5.2 MJ
- forces of the order of 300 tons



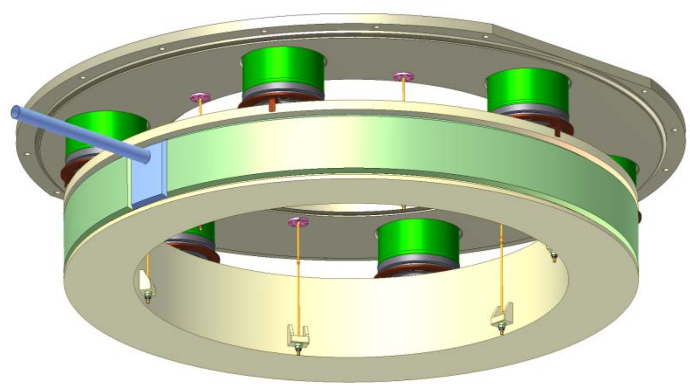
CMS strand, ‚wire in channel‘ with copper as stabilizer



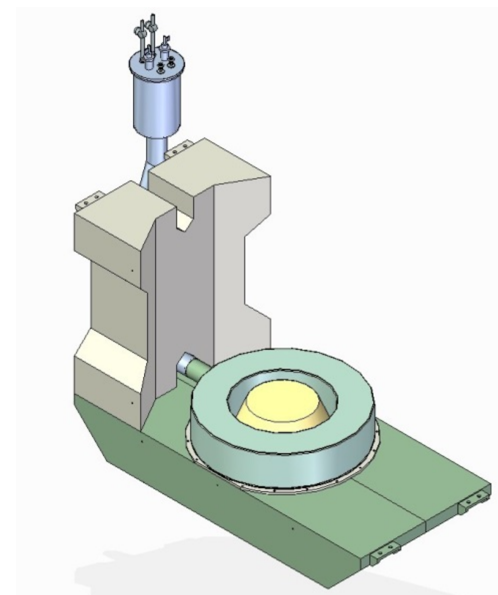
coil



coil case



cryostat with support struts and tie rods



lower coil in the yoke

CBM Dipole Detailed Specification

- Annex 3 to the collaboration contract (Magnet and Power Converter)

- Functional specification
  - main parameters
  - main procedures
  - interfaces
  - rules, regulations, technical guidelines...

mandatory!!

- but within this framework
  - freedom of the contractor
  - responsibility of the contractor

Main Parameters (mandatory)

Geometry

- Opening angle: ±25° vertically, ± 30° horizontally from the target
- Free aperture: 1.44 m vertically x 1.8 m horizontally, no conical geometry
- Distance target- magnet core end: 1m (STS detector must fit in)
- Total length: 1.5 m
- Space upstream of the magnet: <1 m

Field

- Field integral within STS detector (along straight lines): 0,972 Tm --> max. Field ≈ 1 T, depending on the magnet length
- Field integral variation over the whole opening angle along straight lines: ≤ 20% (± 10%)
- Fringe field downstream < reasonable value of the order of 50 to 100 Gauss at a distance of 1.6 m from the target (RICH only)

more

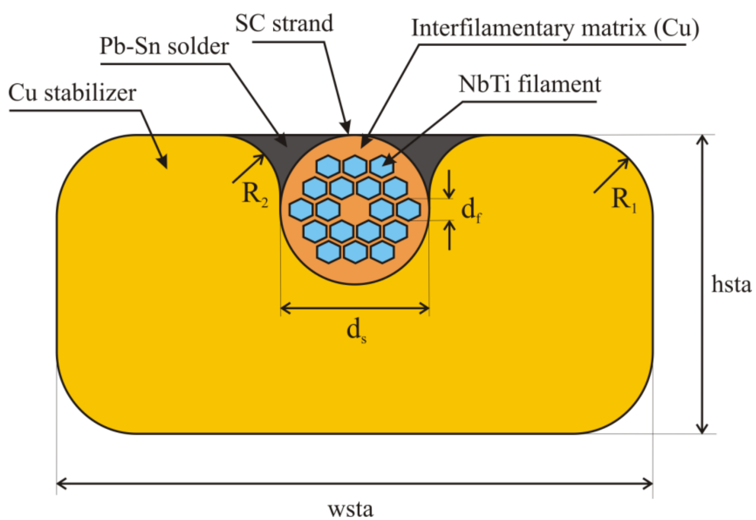
Conductor

- Material: NbTi,
- Copper to superconductor ratio: > 9.1
- Filament size: less than 60 µm
- Insulation: The conductor insulation consists of 2x 0.05 mm polyimide tape and 2 x 0.1 mm glassfiber material (tape or braid), in total 0.3 mm.
- The nominal current should be less than 50% of the critical current at 4.5K along the load line

  $I_n/I_{loadmax} < 0.5$
- The nominal current should be less than 30% of the critical current at the max. coil field at nominal current:

  $I_n/I_c(4.5K,B_m) < 0.3$

TDR example

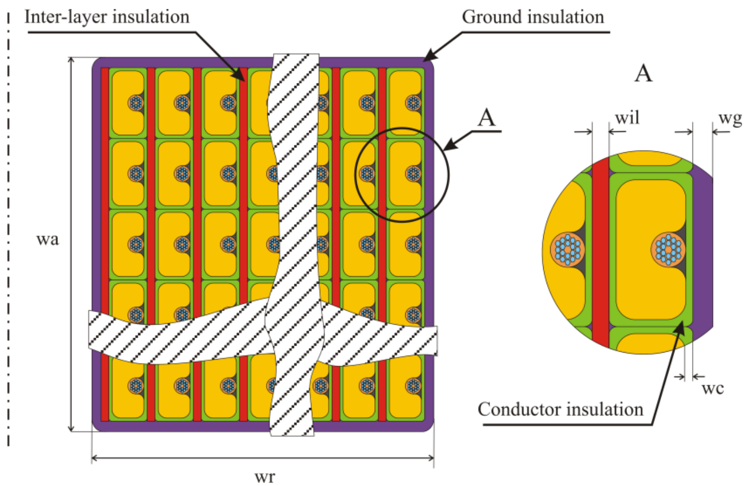


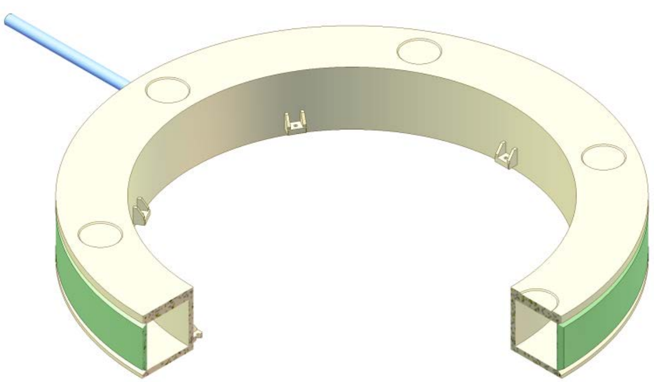
Coil and coil case

interlayer insulation (mm)	0.3
ground insulation thickness (mm)	2

Material coil case	Stainless steel 316LN
Design pressure coil case	20 bar

TDR example

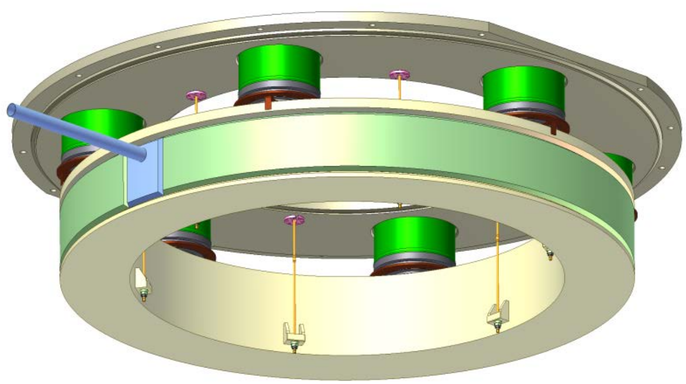




Cryostat and heat loads

- Cryostat deformation < 0.1 mm
- Heat load per cryostat < 11W at 4.5K (SAMURAI much better!)
- Heat load per cryostat < 45W at 80K
- He liquefaction for the leads < 0,15 g/s

TDR example



Cryogenics

4.9.1 Functional and technical design requirements for the CBM FB and BB

Technical Guidelines:

F-TG-K-50.1e_Cryogenic_Operation_Parameter

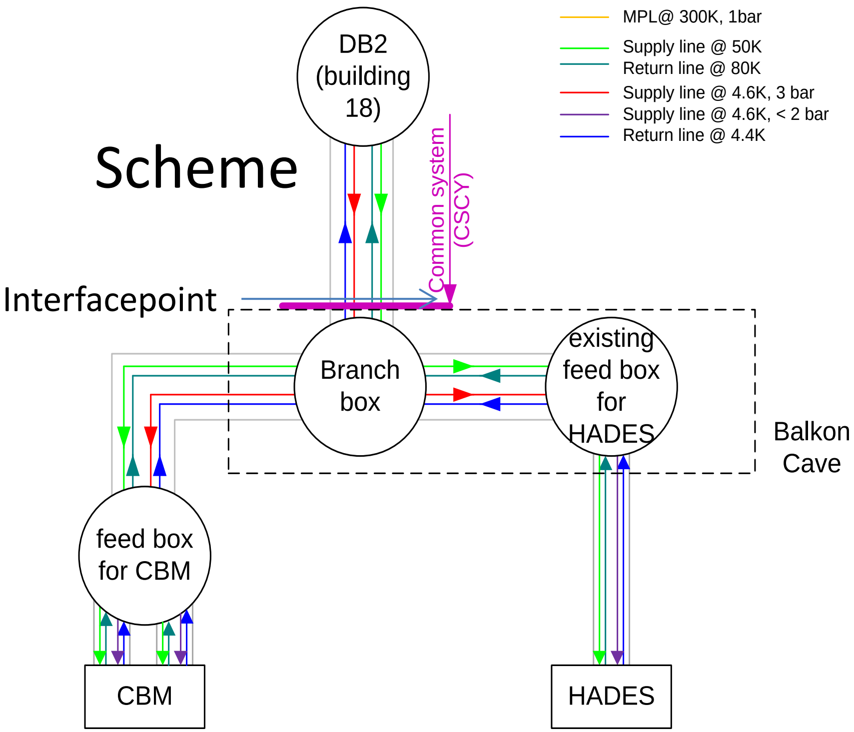
F-TG-K-3.76e_ Instrumentation of FAIR cryogenic cooling

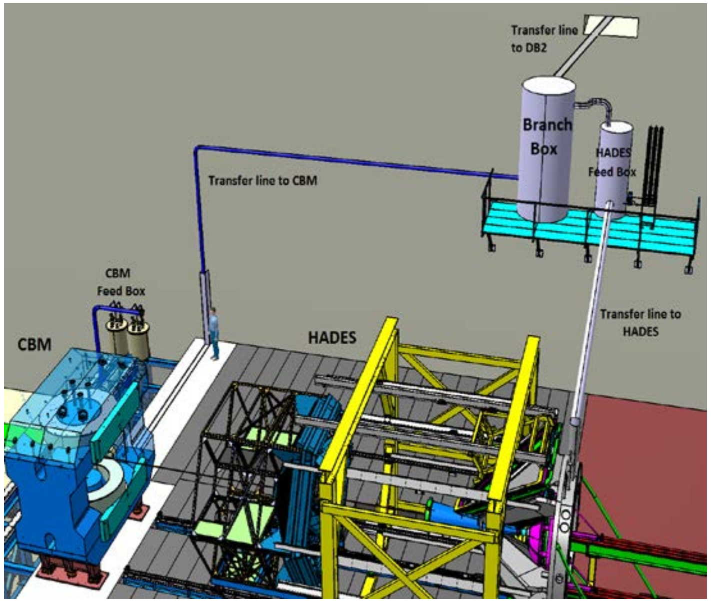
All helium lines have to be designed for a maximum pressure of 20 bar*.

etc..........

etc..........

Scheme





Quench detection and protection

without external dump resistor:

- maximum quench voltage < 1500 V
- maximum hot spot temperature < 120 K

to make the magnet self-protecting!

However, a Quench Detection and Protection circuit together with an external dump resistor will be used!

Alignment

during magnet production:

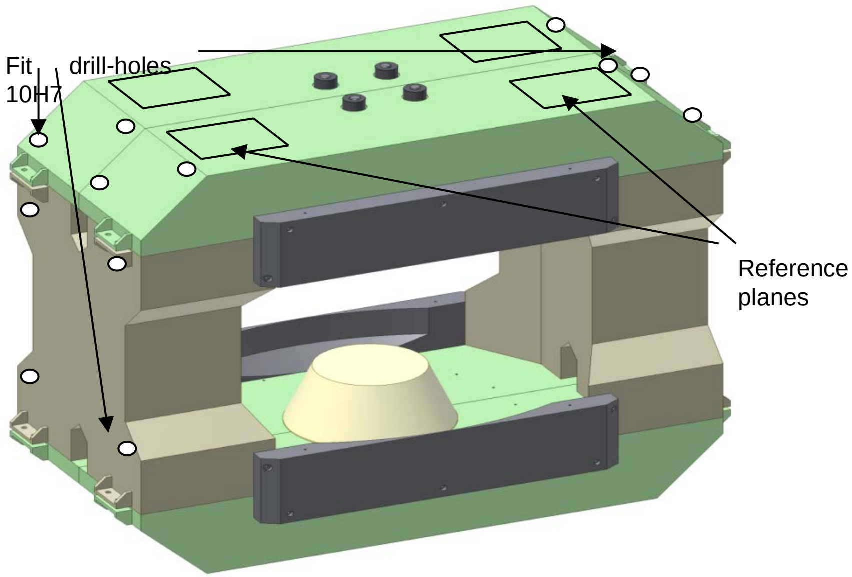
references: planes, fit drill-holes and grooves

after installation at the final place:

fiducials: sockets and removable targets

Stand and feet

- Independent horizontal (x,y) and vertical (z) movement
- 3 jacks for vertical alignment, supporting a base plate
- 3 x-y alignment tables, mounted on the base plate
- Alignment range: ±20 mm in x,y,z



Summary

- CBM Dipole - Design history
- CBM Dipole – as described in the TDR of October 2013
- CBM Dipole – detailed specification (Annex 3 of the contract)
  - functional specification for
    - the magnet including feedbox and branchbox
    - the Power Converter including QD/QP system

  - It is the mandatory basis for the design work of the contractor.
  - The existing design - as given in the TDR- is only one option.