High current warm busbars for the HL-LHC circuits – Boundary conditions and design

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- How are they designed?
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- Validation of the Design
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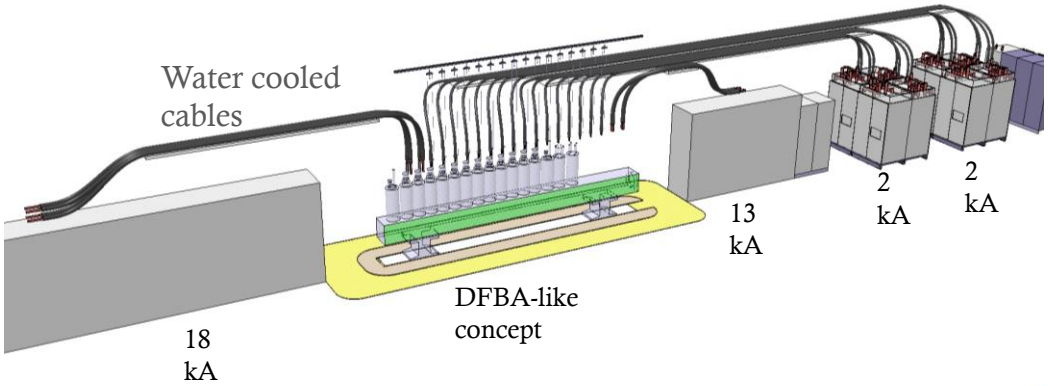
Why do we need High Current Busbars?

Circuit disconnector boxes

- LHC: direct connection between the WCC from the PC to the Current leads.
- Problems due to direct connection
  1. Difficulty yearly intervention for ElQA tests.
  2. DFBA area is crowded due to several connections- cryogenics, water and cooling etc
  3. Risks and hazards for people and possibility of mechanical damage to current leads.

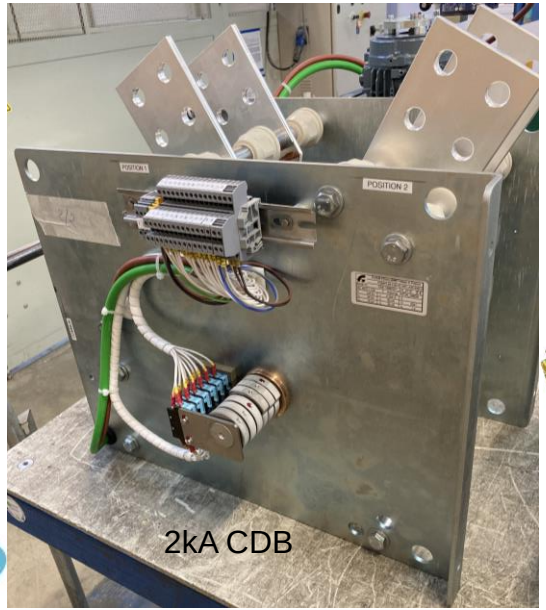
DFBA.L6

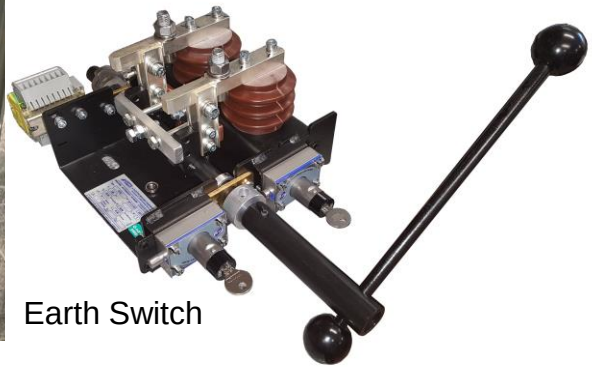


Courtesy of JC. Guillaume, L. Sburlino

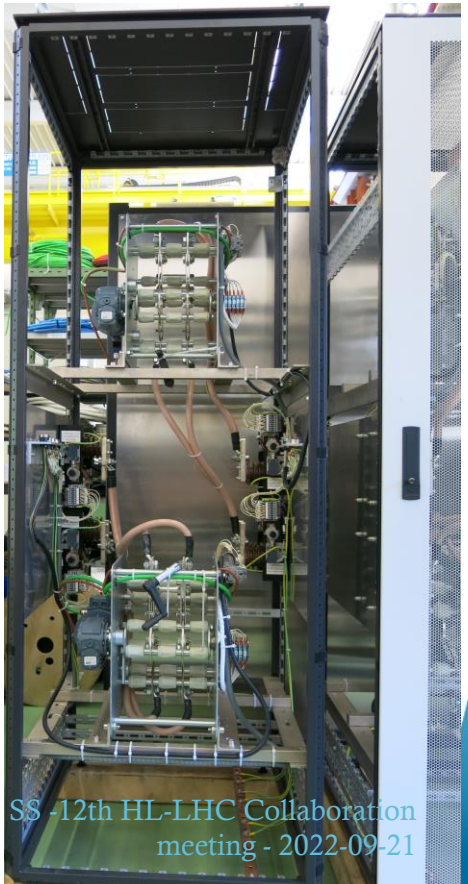
Circuit disconnector boxes

- For HL-LHC : Circuit Disconnector Boxes (CDB) have been added to:
  1. Safety for personnel
  2. Enables ElQA test
  3. Protects the current leads from wear and tear.
  4. Drastically decreases connection-reconnection time

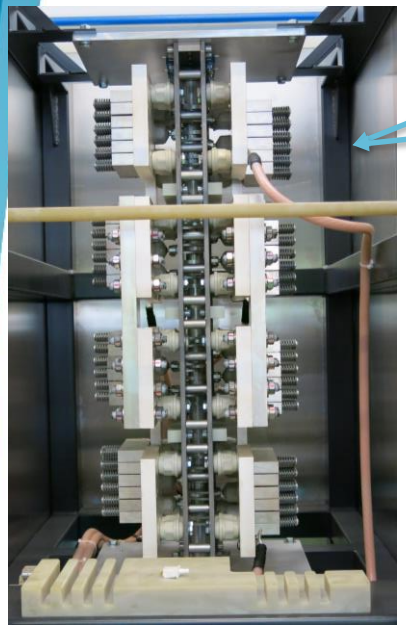

2kA CDB


Earth Switch

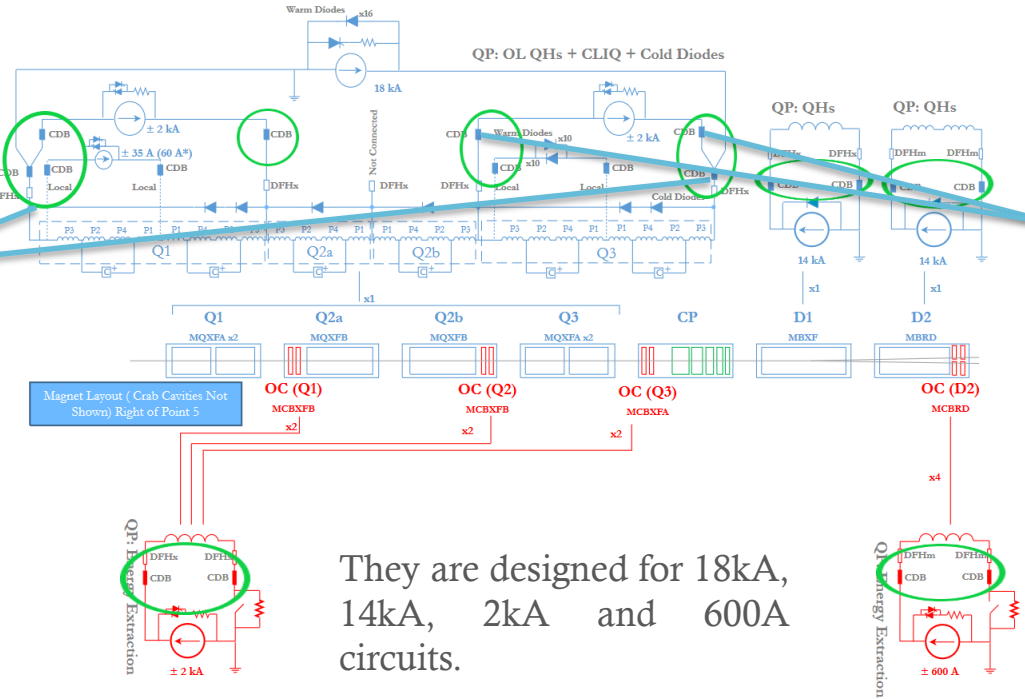
CDB racks



Circuits with Circuit disconnector boxes



18kA CDB

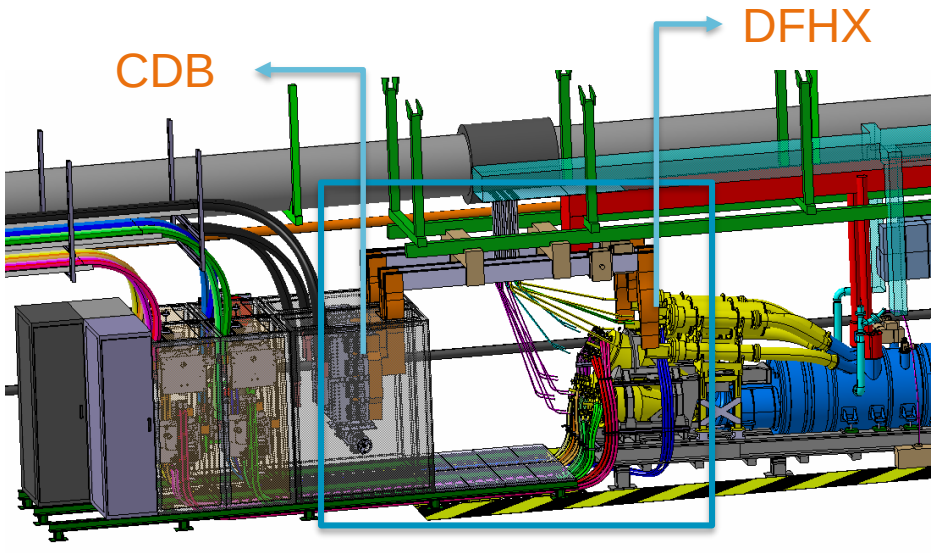


They are designed for 18kA, 14kA, 2kA and 600A circuits.

2kA CDB rack

High Current Busbars connection

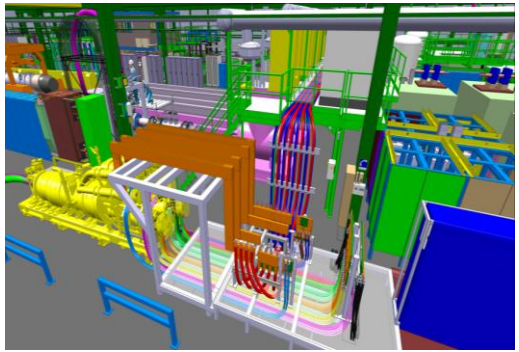
- High Current (HC) warm Busbars are proposed for connecting CDB to DFHX/M in inner triplet (RQX) and Dipole (RD1 and RD2) circuits. HC busbars is an interface between WCC and DFH for RQX, D1 and D2 circuits.
- The lower current CDB are connected by ACC to DFHX/M.



Connection of busbar

Installation of the High Current Busbars

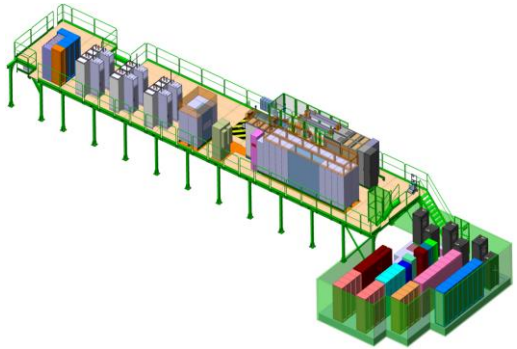
- Deliverables are split into 3 stages :



Test Bench F2 / Cluster F

Prototype and Design Validation

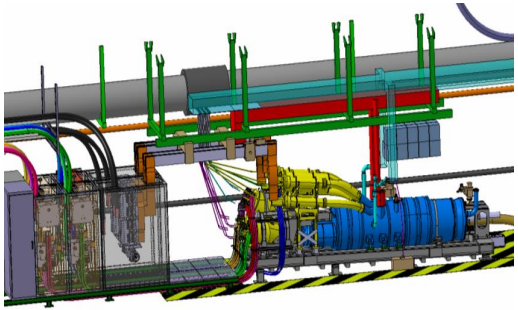
- Used for validating the electrical mechanical and thermal interfaces.
- To respect the cost and schedule- Water cooling plates used are non-isolated



HL-LHC IT String

Pre-series

- Additional validation of the isolated water cooling plates.
- Busbars will be re-used in the HL-LHC after String test operation



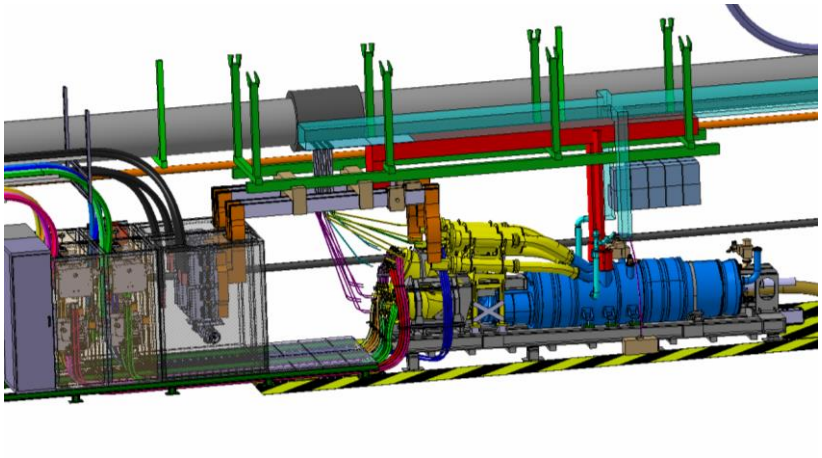
HL-LHC DFHX/DFHM

Series

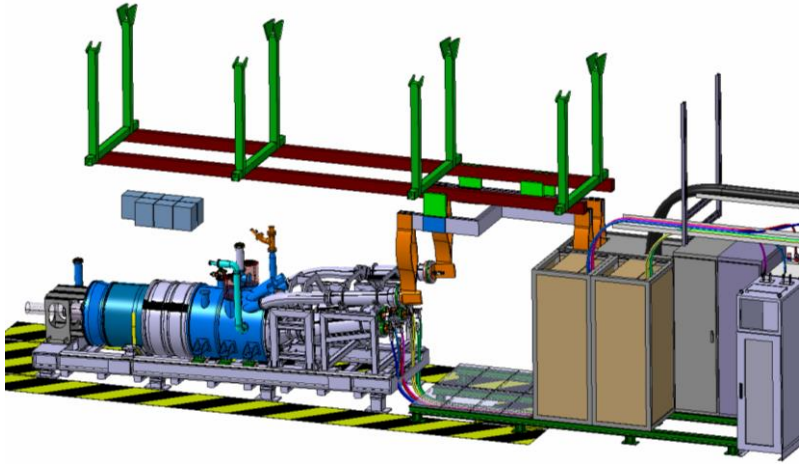
- Based on the experience from the HL-LHC IT String and Cluster F, the series bus bars will be installed in the HL-LHC.

Types of High Current Busbars

- Due to configurations of the DFHX and the DFHM, two Busbar types are needed in the machine



DFHX Cluster (RQX & RD1)

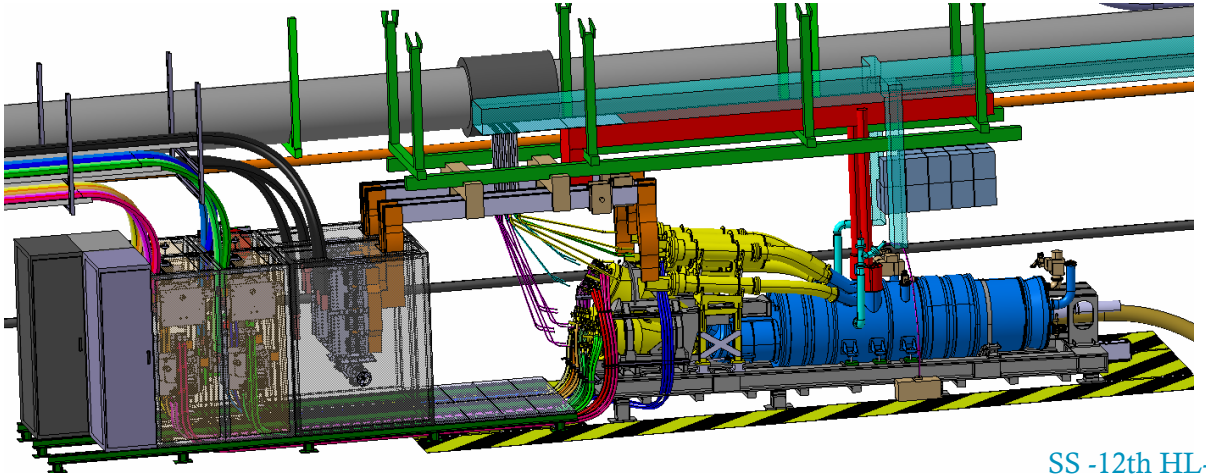


DFHM Cluster (RD2)

How are they designed?

Design criteria

- Design of the high current busbars was done by accounting for different criteria and boundary conditions, such as :
  - Connection with the CDBs and the DFHs
  - Current rating of the circuits
  - Power dissipation in the current lead heads and in air

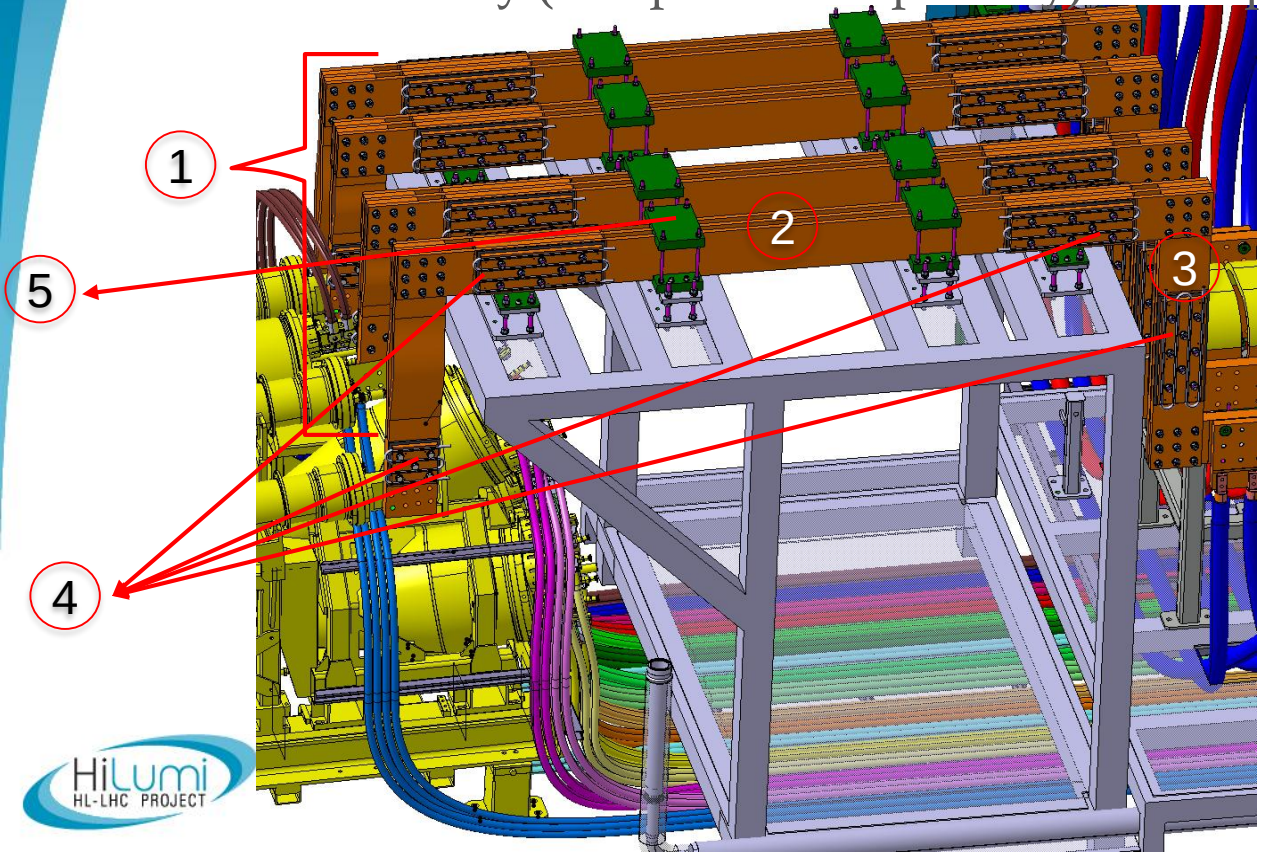


Boundary Conditions of the High Current Busbars

- The main bus-bar design constraints are the following
  - DC current: 18 kA for the RQX circuits and 14 kA for the RD1 and RD2 circuits
  - Earth leakage current at 1.1 kV: < 0.1 μA for full circuit (two polarities)
  - Power losses in water: < 6 kW for full circuit (two polarities)
  - Power losses in air: < 2.3 kW for full circuit (two polarities)
  - Power injected per CL: < 100 W
  - Bus-bar temperature: < 70 °C

Elements in the High Current busbars

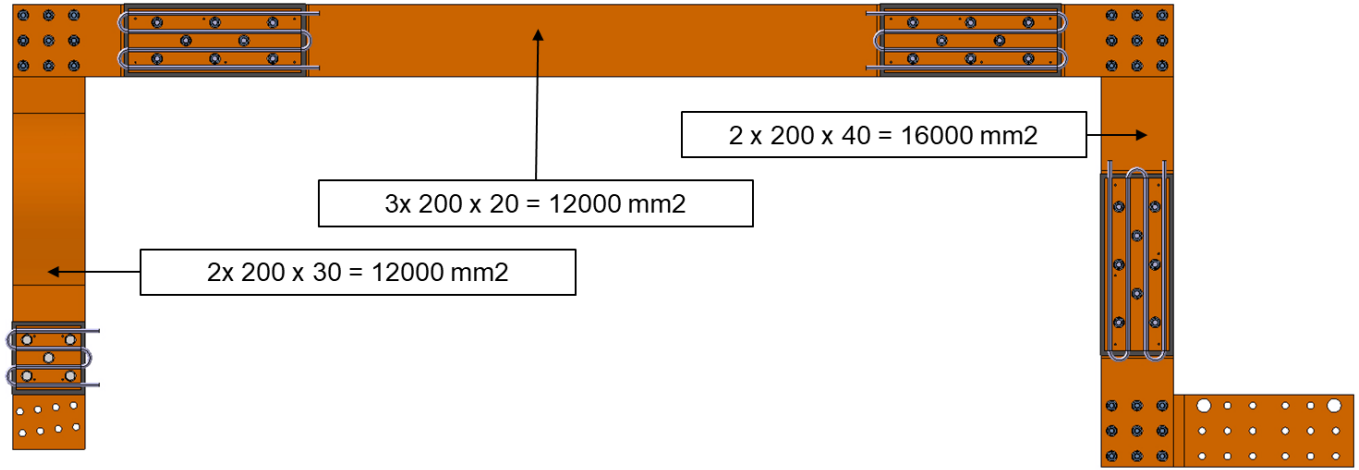
- Bus-bar assembly (one per circuit polarity) is composed of 5 sections



1: Flexible connection to CL (Length depending on CL position)
2: Horizontal connection 3140 mm
3: Vertical connections to CDB
1280 mm
4: Water-cooling plates
5: Busbar support (design depending on location)

Dimensions of the High Current DC Busbars

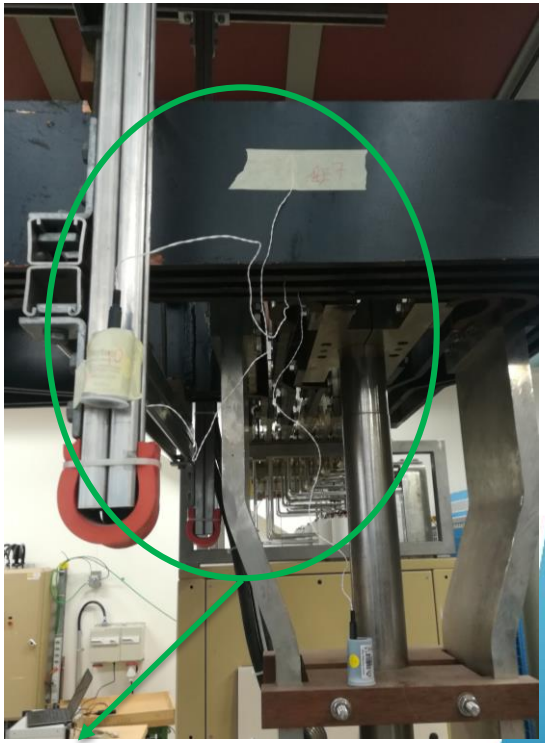
- The cross section of copper required is defined at a base of 12000 mm2 based benchmarking on analytical calculations and benchmarking at CERN installations



Thermal Performance of the High Current DC Bus-bars

- A replica of copper busbars present in Hall P at CERN were tested to understand the heating effect of 18kAs.

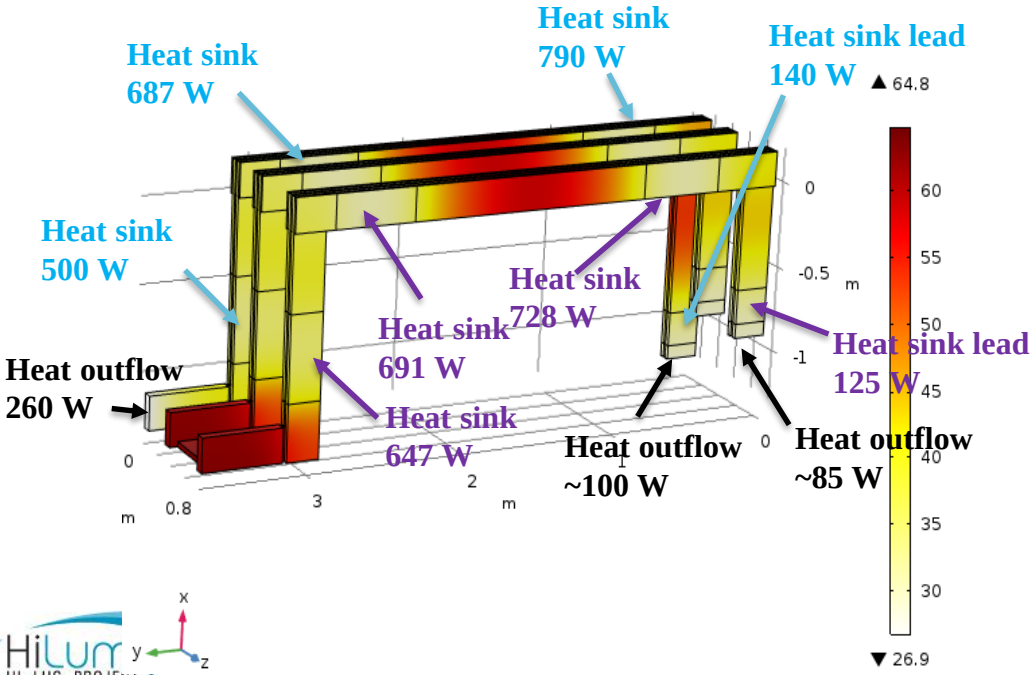
Busbars



Temperature sensors

Thermal Performance of the High Current DC Bus-bars

- Model of the busbar designed for Cluster F2 was simulated to define the cooling configurations.



Simulation realized by J. Fleiter (TE-MSC)

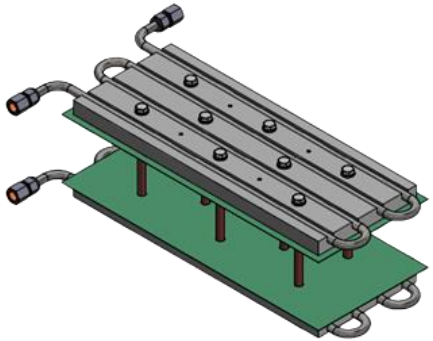
- **Heat flow at CL < 100 W**
- **Tmax < 65 °C**
- **P_water per circuit < 4.5 kW**
- **P_air per circuit < 2 kW**
- **Simulated results show the necessity of water cooling plates at 4 positions for each busbar assembly.**

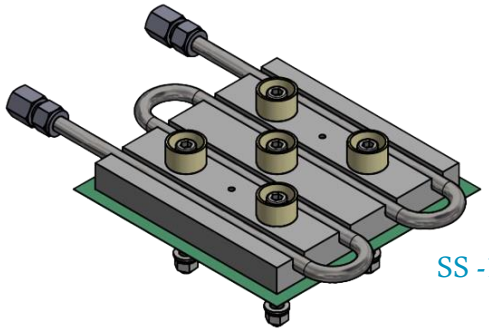
Design of the Water Cooling Plates

Requirement from Water cooling plates

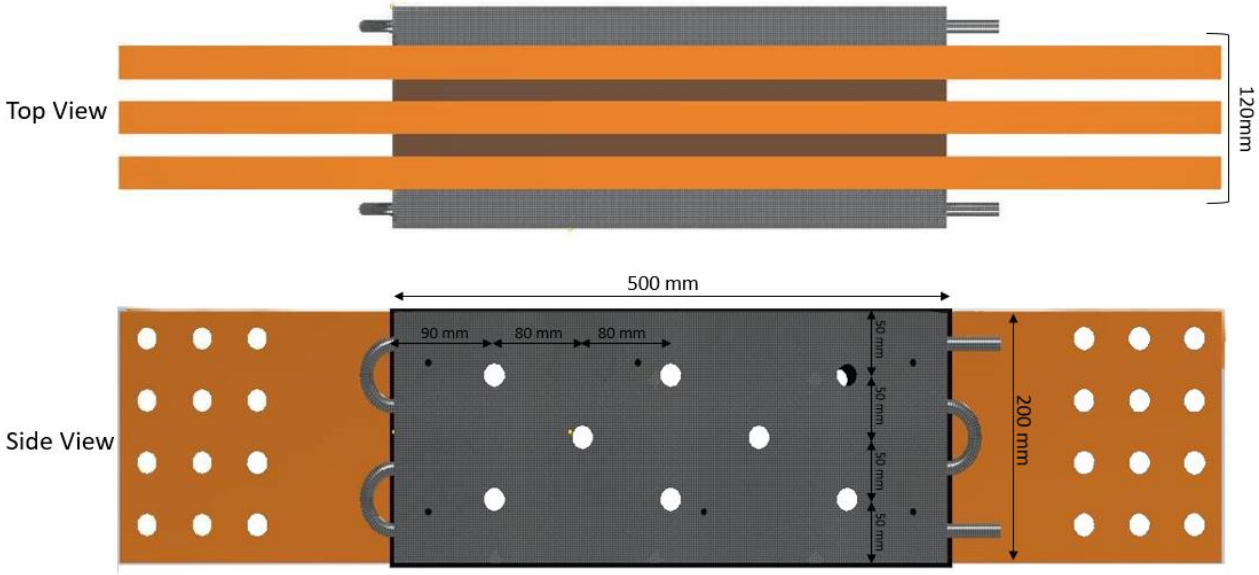
- **3 long** and **1 short** water-cooling plate assemblies are used per busbar assembly.
- The plates are designed for the water-cooling parameters:

Parameter	Value
Maximum inlet water temperature	27 °C
Maximum outlet temperature	37 °C
Maximum operating pressure	16 bars
Nominal water flow rate	16 l/min





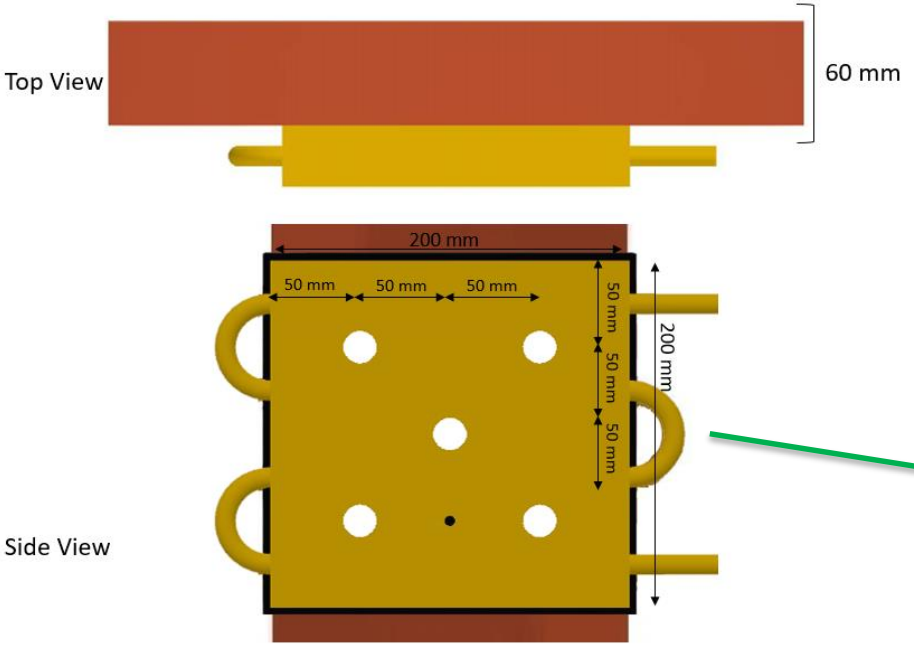
Design of Water Cooling Plates

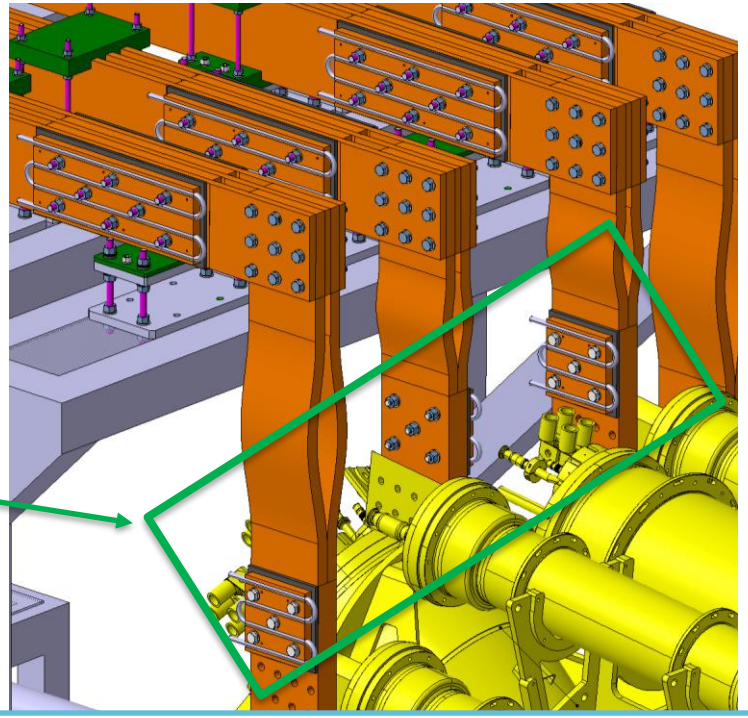


Maximum thermal resistance between bus bar and water = 15K/kW

Power to be dissipated per cooling plate = 1.5 kW

Design of Water Cooling Plates





Maximum thermal resistance between bus bar and water = 20 K/kW

Power to be dissipated per cooling plate = 0.75 kW

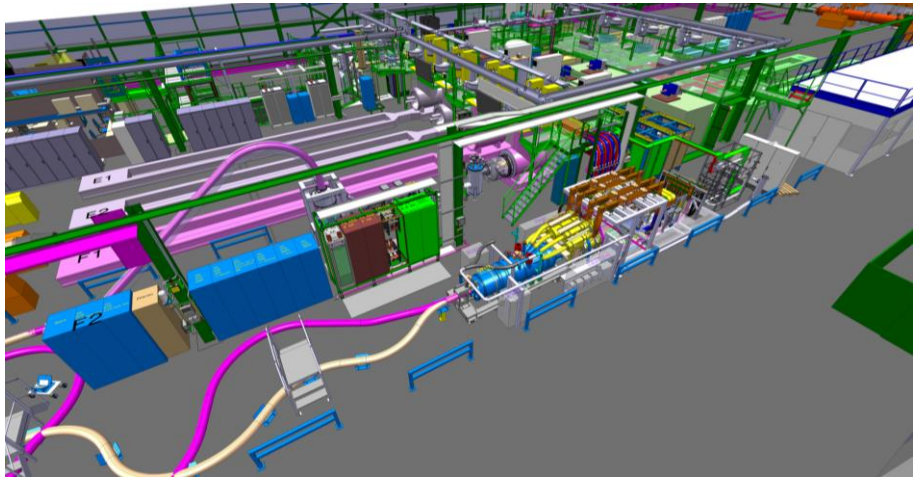
Design of Water Cooling Plates

- The Water cooling plates for IT string require electrical insulation.
- The insulation layer must:
  - Comply with specified thermal resistance
  - Provide a resistance of >110GΩ for 1.1kV DC
- Insulation material such as Kapton, Si and Fiber glass combinations have been studied to provide a sturdy insulation between water cooling plates and HC busbar.

Validation of the Design

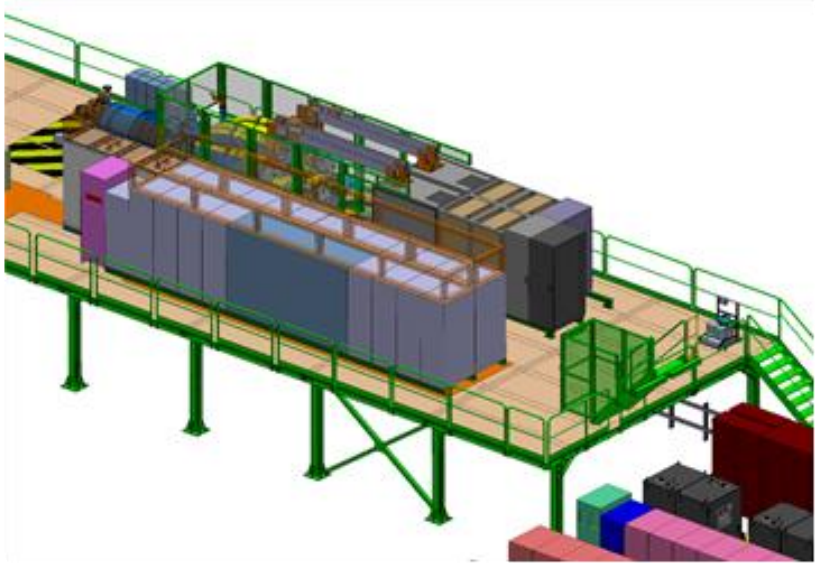
First Validation in Bench F2

- Bench F2 (2022)
  - Dedicated test bench for HL-LHC SC link is used to validate the thermal and mechanical aspects of the busbar.
  - To respect the cost and schedule, water cooling plates used are non-isolated
  - Thermal performance is broadly validated, and mechanical and electrical interfaces are validated in an identical manner to the machine



Final Validation at the HL-LHC IT String

- String HL-LHC (2023-2025)
  - Validate RQX and RD1 bus-bar in operational conditions (machine configuration, CDB connections and isolated WCPs)
  - Thermal performance is fully validated, similar to the machine.



Conclusions

Conclusions

- The purpose and design of High current busbars has been presented .
- The design and project distribution of the High Current DC bus-bars is now well defined.
- The details have been drafted and approved under the ECR LHC-DWD-EC-0001
- The next step would be to validate the testing and results from Cluster F test bench.

Thank you for your attention