Busbars in the magnets and cryostats

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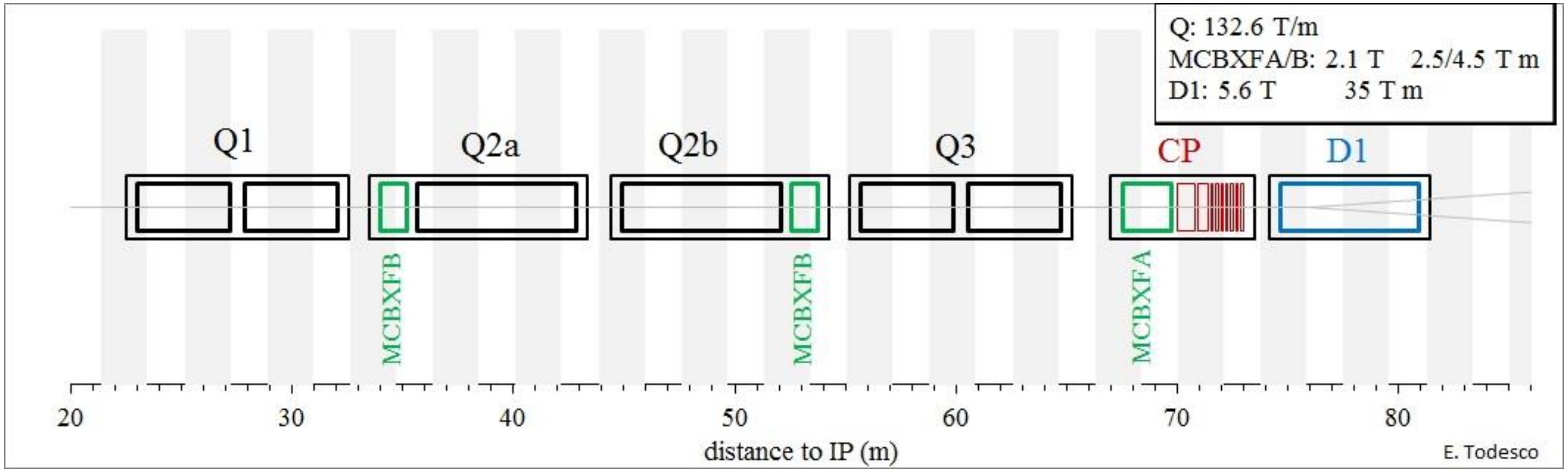
Review of cold powering system, 3 July 2017

CONTENTS

- IR magnets features and choices
- Baseline for busbars
- Further developments

OVERVIEW OF IR MAGNETS

- From Q1 to D1: 150 mm aperture
- Triplet: four magnets Nb_3Sn, current 16.4 kA, peak field 11.5 T
  - In series plus trim on each magnet
- Orbit correctors: three magnets, nested, Nb-Ti, current 1.4/1.6 kA
  - Independently powered (six circuits)
- High order correctors: 9 magnets, Nb-Ti superferric, 200/100 A
  - Indepentently powered
- D1: Nb-Ti, current 12 .0 kA, bore field 5.6 T



OVERVIEW OF IR MAGNETS

- Circuit baseline shown in F. Rodriguez Mateos talk

- Boundary conditions
  - Very tight longitudinal space – short distance between magnets means performance
  - Very tight transverse space – cold mass size at the limit of the cryostat size
  - Some magnets done by collaborations (Q1/Q3 by US-Hilumi AUP, D1 by KEK) – minimize interfaces, busbar crossing, etc.

- Four technical choices
  - A mixture of round and flat busbars
  - Some busbars inside the magnets, others in a parallel line
  - Quenching all magnets to protect the busbar
  - Keeping same design for Q1 and Q3 (reduce spares, flexibility in installation) at the cold mass level – Same for Q2a and Q2b

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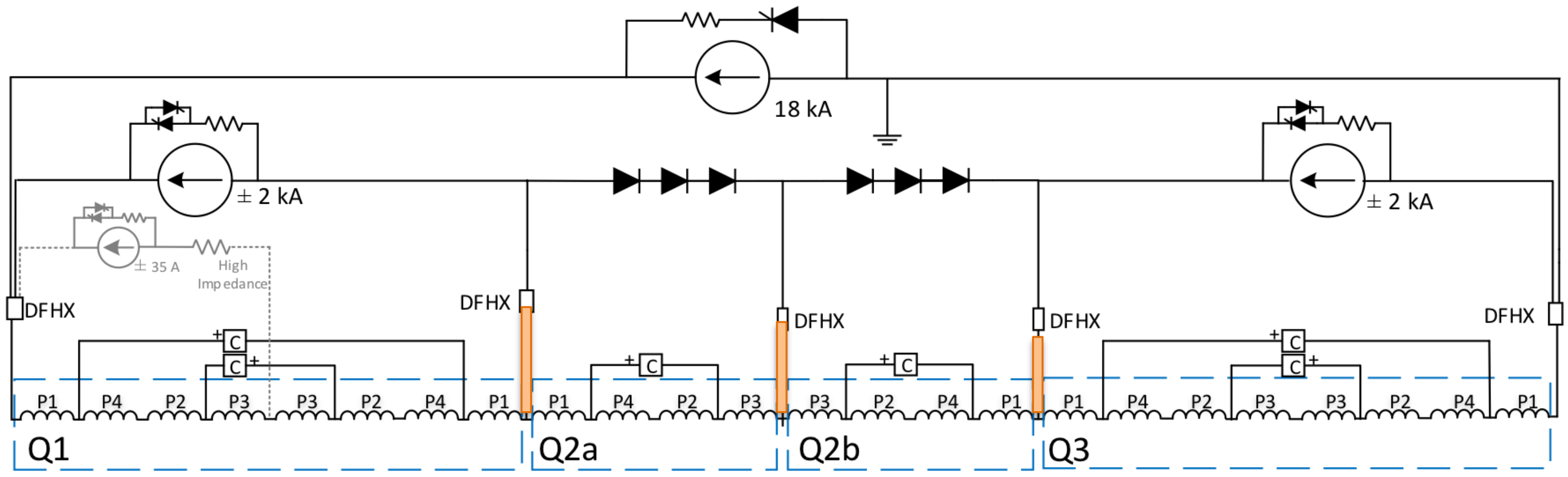
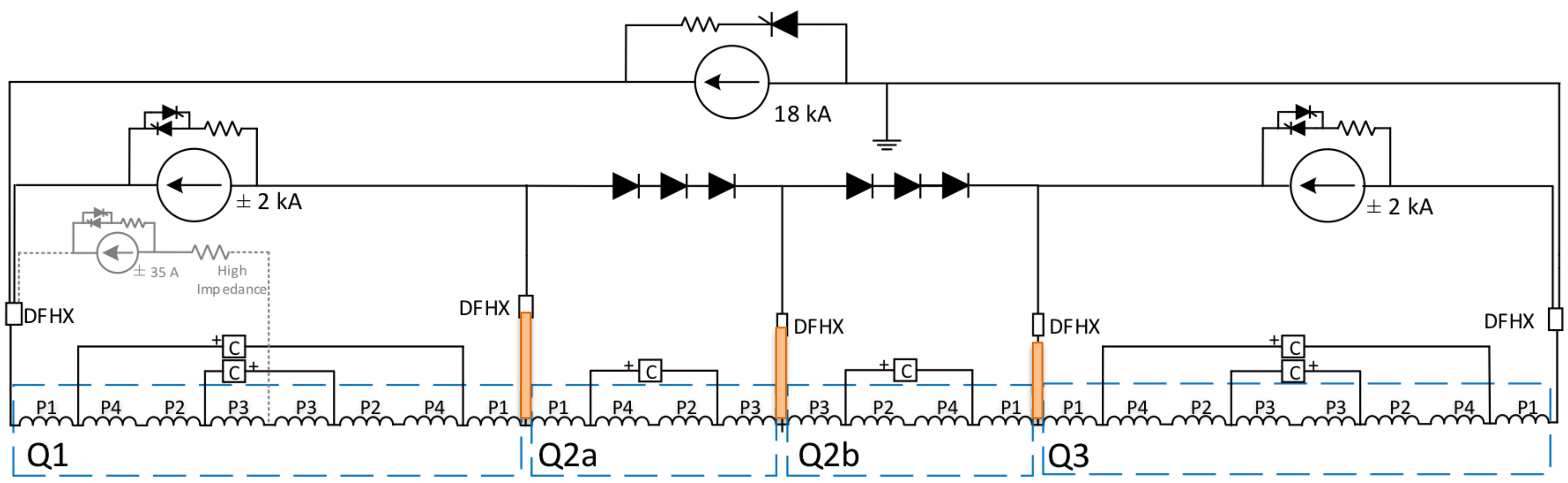
CIRCUIT BASELINE

- Triplet
  - One circuit rated at 18 kA plus trims (before we had two circuits, decision was taken in 2015/2016)
  - Three trims (2 kA rating needed) are rated at 7 kA to allow overcurrents during quench
  - Trim separating Q2a from Q2b not necessary for the beam dynamics, but needed for keeping the voltage to tolerable value



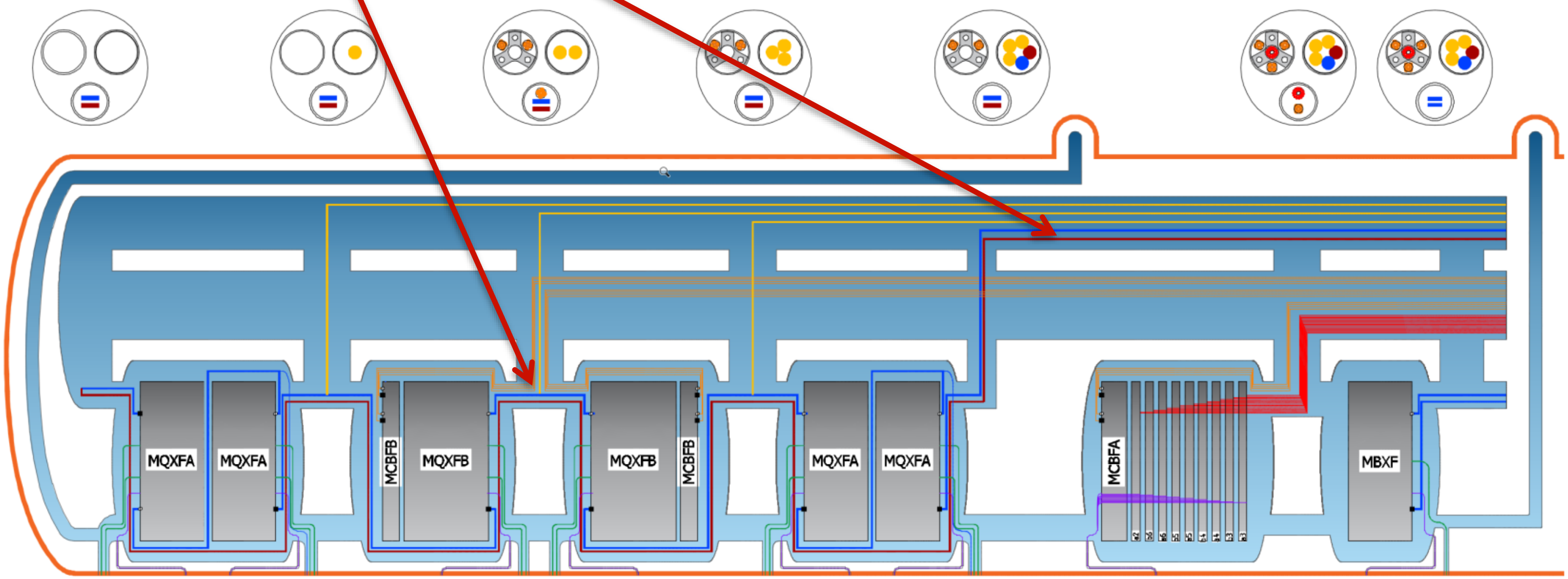
CIRCUIT BASELINE

- Triplet – «warm» diodes
  - Necessary to keep the voltages to tolerable values
  - Design will be compatible with the «cold» diode option



CIRCUIT BASELINE

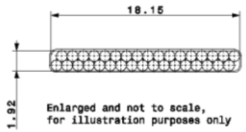
- Triplet 18 kA main busbar: a mix of flat and round
  - Flat busbars made of two Nb-Ti Rutherford cables inside the triplet, (see next slide)
  - In the parallel line bypassing D1 and the corrector package we will have a round busbar



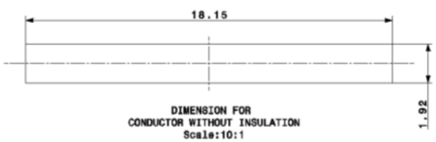
CIRCUIT BASELINE

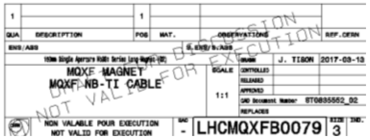
- Triplet 18 kA main busbar
  - Strand: Nb-Ti 1.065 mm diameter, 1.65 Cu/no Cu (LHC inner cable strand)
  - One cable made with 34 strands to have the same width of QXF cable
  - Flat busbar is a double cable (as the US cables used for Nb-Ti leads in the magnets)
  - Round busbar is a round cable with the same number and type of strands (to be developed)

  - Cu surface: 38 mm^2
  - Sc surface: 23 mm^2
  - Cable surface: 61 mm^2
  - 265 MIITs at 300 K
  - 200 MIITs at 200 K



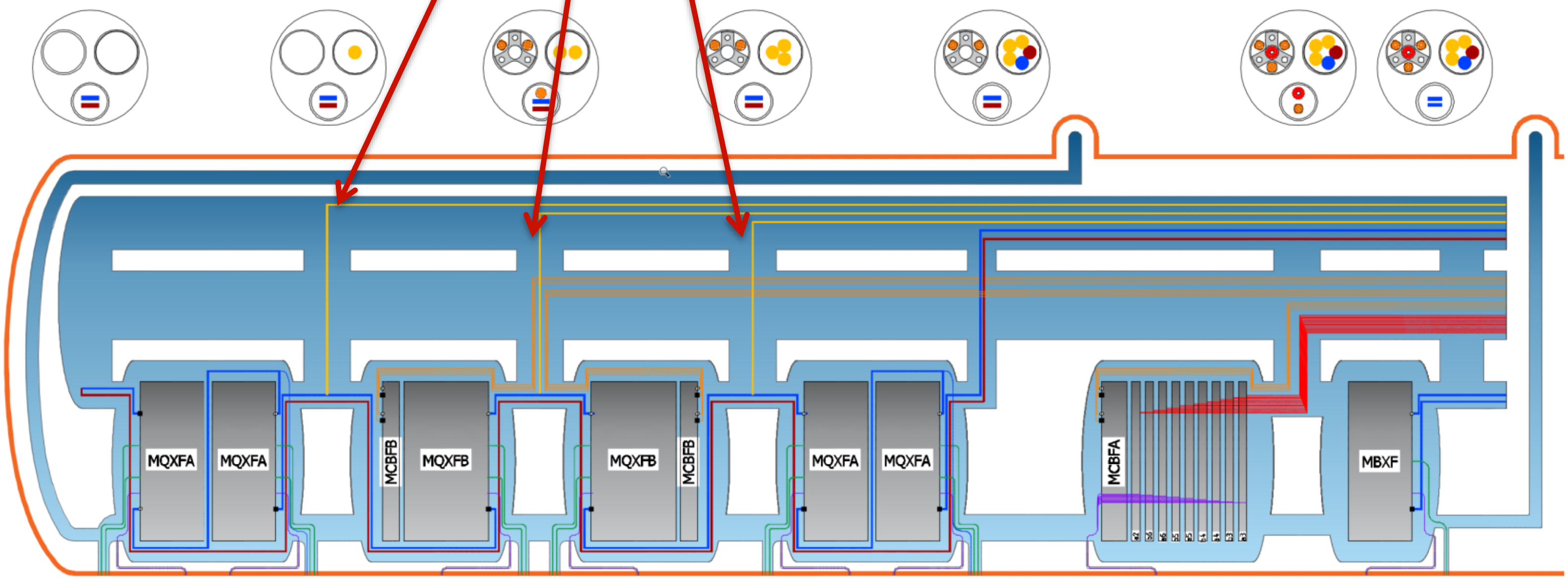
UNREACTED CABLE DIMENSIONS	
Strand Type	NbTi
Strand Diameter	1.066
Number of strands	34
Width	18.15 mm
Height	1.92 mm





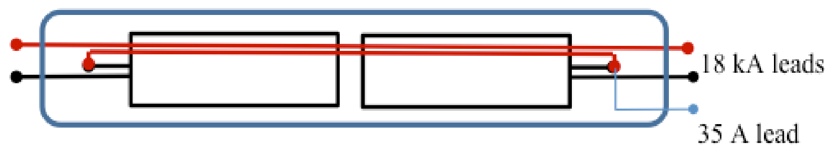
CIRCUIT BASELINE

- Triplet trim busbars
  - We consider a 18 kA round cable (to be developed)
  - Same used for the main along the corrector package and D1
  - Travelling through the parallel line and entering in the interconnection



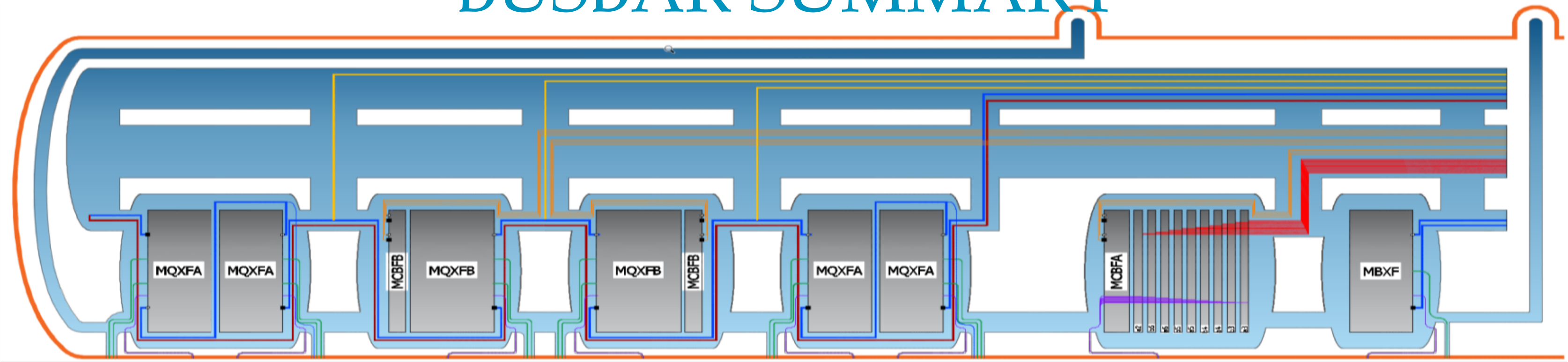
THE BUSBAR IN THE Q1/Q3

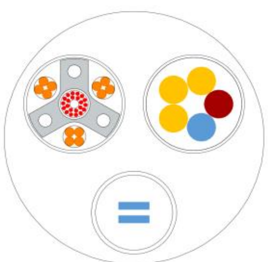
- Q1/Q3 are split in two magnets (made in US)
  - Bus bar cartridge goes through the cold mass, and one of the two busbars is spliced to the magnets on each side
  - This busbar is needed for mid 2019 (first US cold mass)



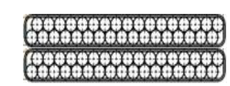
  - The busbar version for Q2 is needed for fall 2018

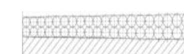
BUSBAR SUMMARY

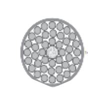


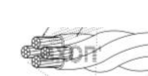


	I_{nom} (kA)	I_{ult} (kA) / I_{max} *	Busbar	Sc wire	Cu/Sc ratio	Bubar Cross Section	Stabilsation
IT Main Circuit inside the cold masses	16.5	17.82	***New***	34 NbTi wires type 01 LHC strand Ø1.065mm	1.6	18.15 x 1.92mm x2 with stab	Doubled cable Or same copper cross section
D1 Circuit	12	12.96	Present LHC 13kA cable	36 NbTi wires type 02 LHC strand Ø0.825mm	1.9	15.1 x 1.48mm X2 with stab	Doubled cable Or same copper cross section
IT Main Circuit along the cold masses	16.5	17.82	***New***	*To be devloped*			
Trim leads	2	2 / 6.8*					
Orbit Corrector	1.6 /1.47	1.73 /1.59	***New*** *or Present LHC 6kA cables*	*To be developed*			
High Order Correctors	0.182 /0.105	0.2 /0.12	Present LHC 600A cables	7 Cu wires Ø0.96 mm	9.5	42x600A wires in Ø16.7mm	N/A
CLIQ leads	2.8 (12Hz fast decay)		***New***	N/A	N/A	Ø5.14mm	Silver Platted copper



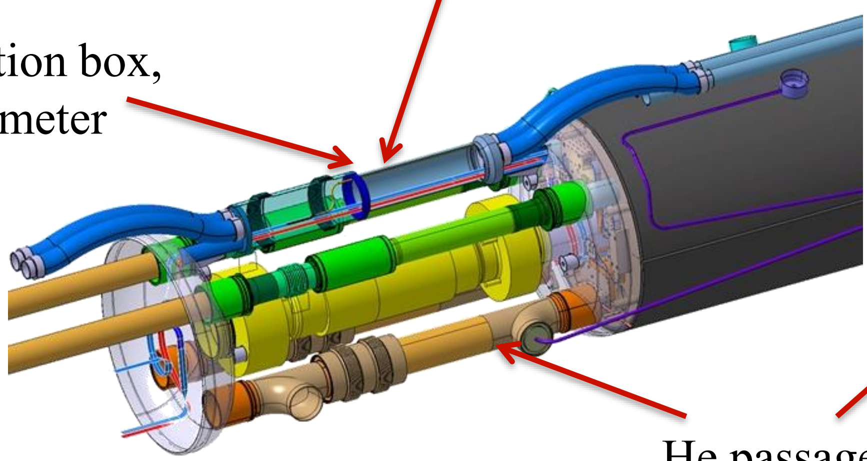


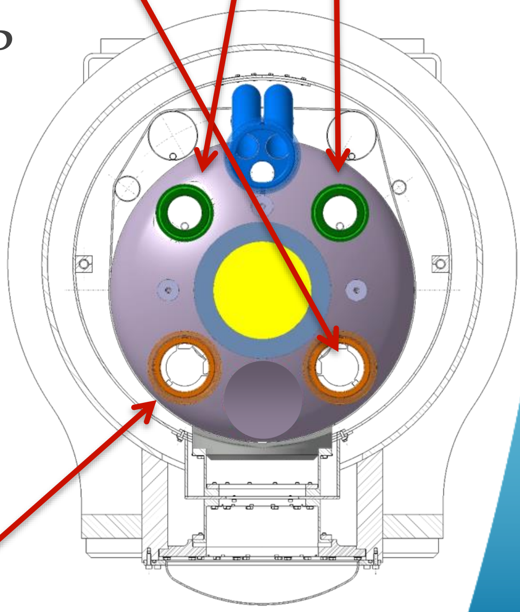




INTERCONNECTIONS AND PARALLEL LINES

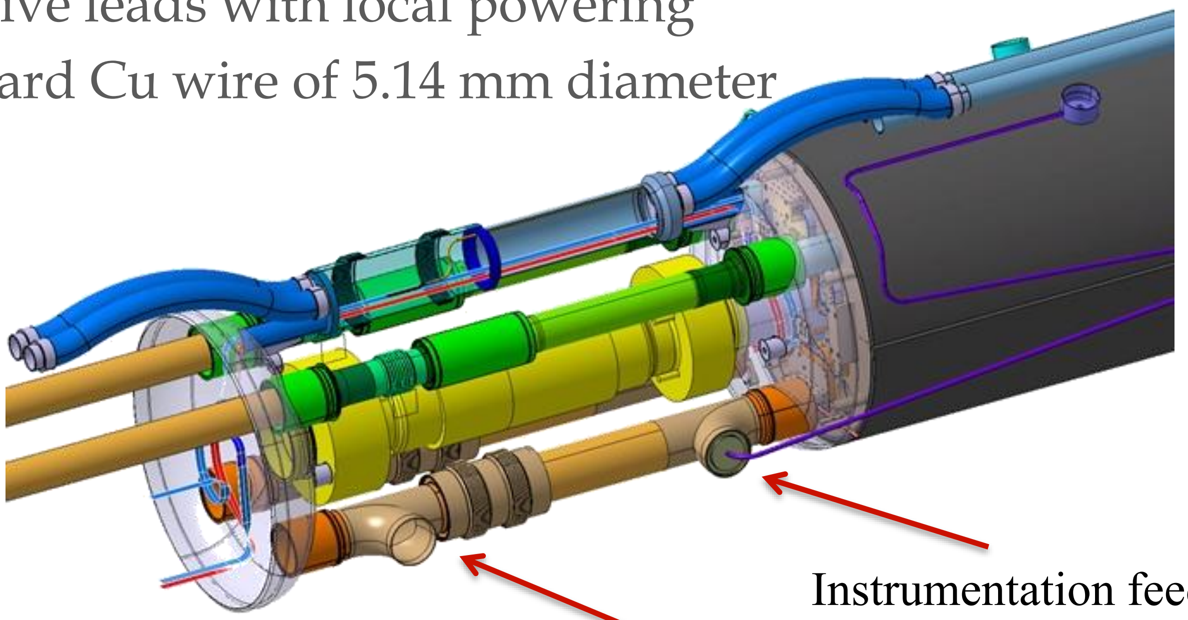
- The parallel line has a interconnection on the magnet axis
- Flat 18 kA main busbars (cartridge) go through one of the lower yoke holes
- Upper yoke holes used by heat exchanger
- Fourth hole used to carry through He
  - 150 mm^2 between triplet, 100 mm^2 D1 and CP





CIRCUIT BASELINE

- Triplet trim on Q1a (recent requirement, low current of 35 A)
  - Resistive lead with local powering
  - The same is put on Q3a to avoid symmetry breaking
- Triplet CLIQ leads (2 kA for short time ≈100 ms)
  - Resistive leads with local powering
  - Standard Cu wire of 5.14 mm diameter

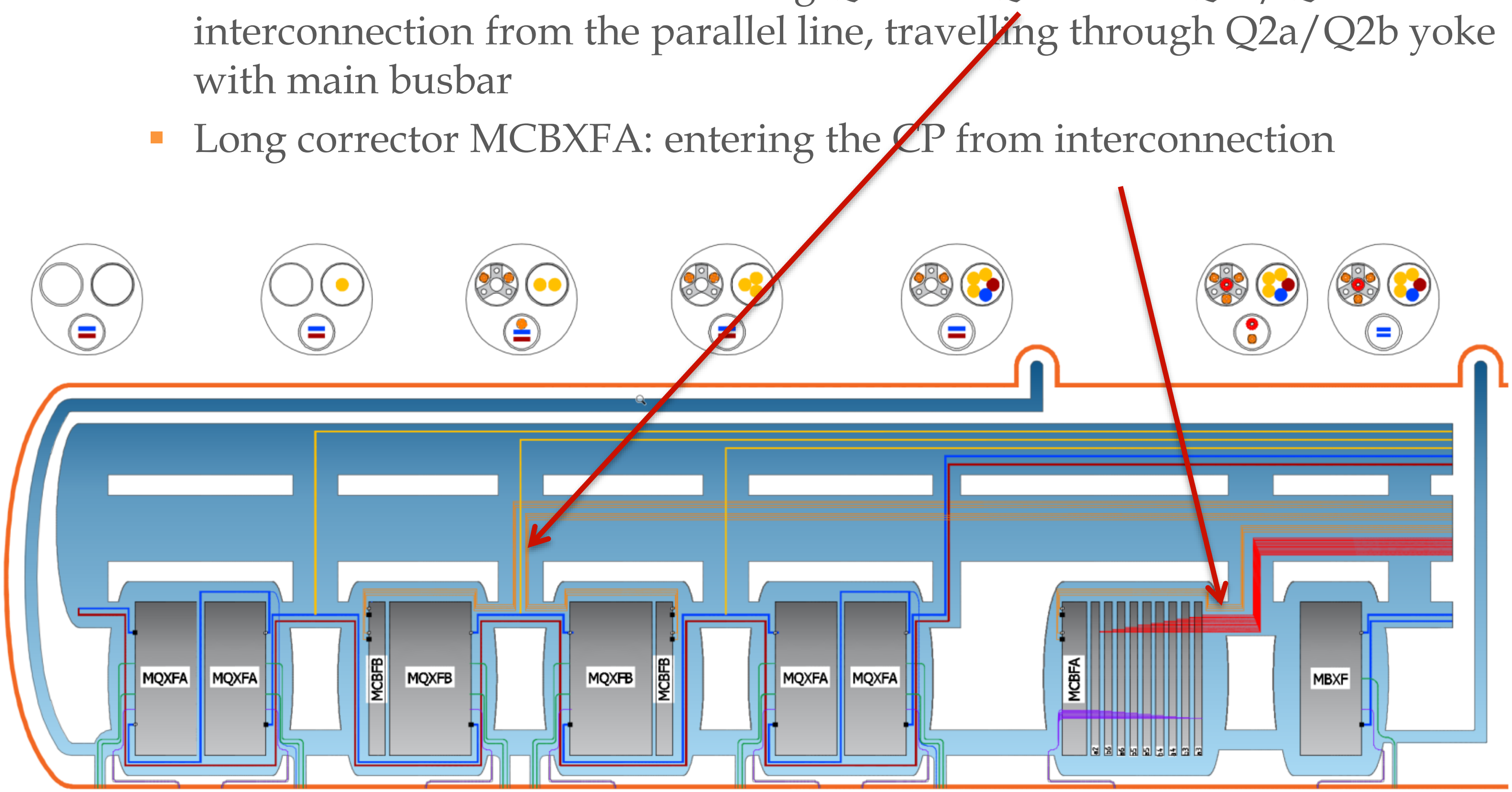


Instrumentation feedthrough

Q1 trim and CLIQ trim feedthrough

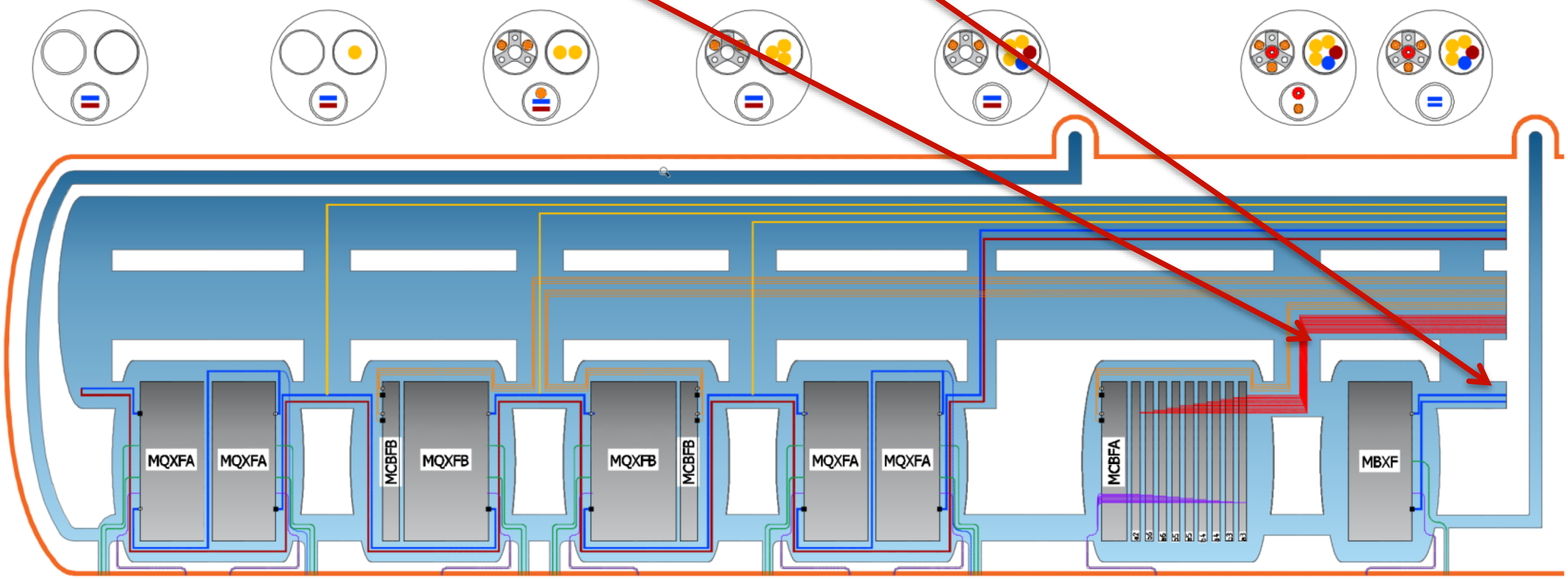
CIRCUIT BASELINE

- Orbit corrector busbars
  - These are 6 × 2 busbars rated at 2 kA
    - Short corrector MCBXFB: Entering Q2a and Q2b at the Q2a/Q2b interconnection from the parallel line, travelling through Q2a/Q2b yoke with main busbar
    - Long corrector MCBXFA: entering the CP from interconnection



CIRCUIT BASELINE

- D1 busbar
  - The 13 kA LHC busbar, entering at the level of D1
- High order corrector busbars
  - 600 A LHC busbars, entering at the level of the CP
  - No leads going through neither D1 nor the CP



18 kA CIRCUIT PROTECTION

- How to protect from busbar quench
- Threshold of 100 mV (from R. Denz)
- With a propagation velocity of 2 m/s, the threshold is reached in 200 ms (from L. Bottura)
  - Field is of the order of 1-2 T
  - Temperature margin of 6.0-6.5 K
  - This consumes 60 MIITs
- When quench is detected, heaters are fired
  - Time constant of the circuit with quenched magnets is of the order of 0.2 ms, 35 MIITs consumed
- With the 200 MIITs at 200 K, we consume less than 100 MIITs, so we are safe
  - A quench velocity of 1 m/s, 400 ms detection time would be also safe

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FUTHER DEVELOPMENTS

- Definition of 18 kA round busbars
- Definition of 2 kA corrector busbars (reusing 6 kA?)
- Topology of expansion loops
  - No space for lyra, pigtail needed
- Splices between round and flat cables
- Voltage taps number and position, instrumentation

CONCLUSIONS

- Busbar baseline has been outlined
  - Two flat 18 kA through the magnets (main circuit)
  - Three round trims also at 18 kA from interconnections
  - Parallel line to avoid crossing of corrector package and D1
  - Busbar protection requires quenching the triplet

- Some parts have to be developed
  - Round busbar geometry, round-flat splices, expansion loops, voltage taps