WP3 busbars

E. Todesco, H. Prin

With contributions from
A. Ballarino, L. Bottura, F. Rodriguez Mateos, V. Parma

10 May 2017

CONTENTS

- Short overview of IR magnets
- Baseline for busbars
- Open ponts and options

OVERVIEW OF IR MAGNETS

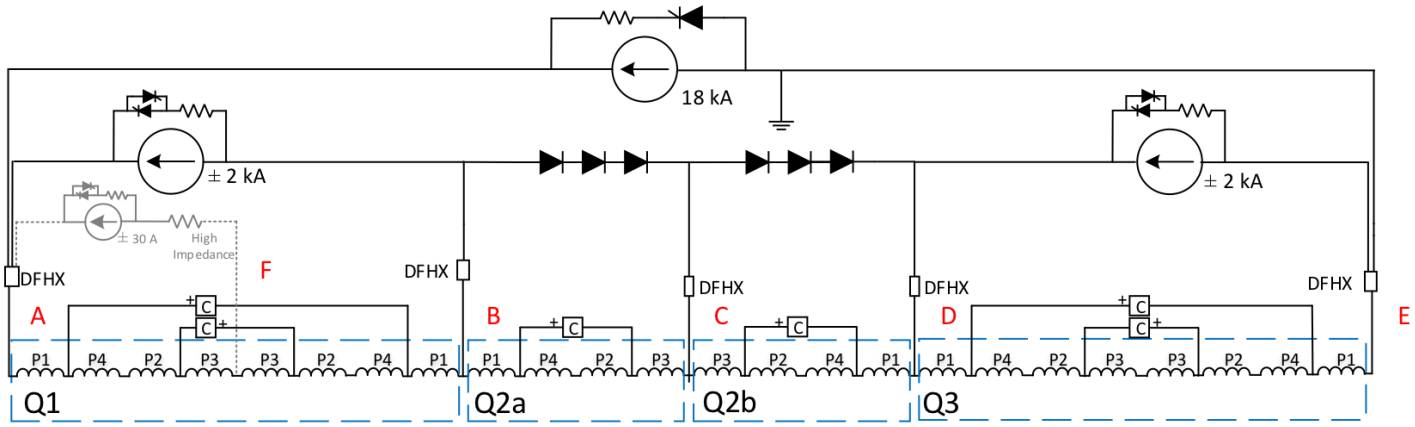
- Bla bla bla

CONTENTS

- Short overview of IR magnets
- Baseline for busbars
- Open ponts and options

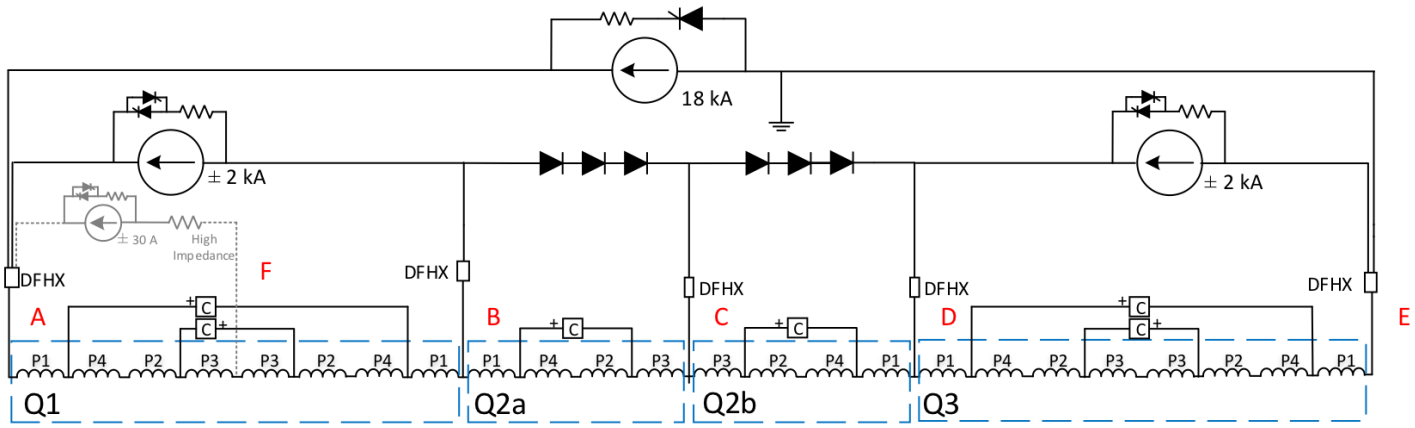
CIRCUIT BASELINE

- Triplet
  - One circuit rated at 18 kA plus trims (decision in 2016 after review)
  - Three trims (2 kA 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

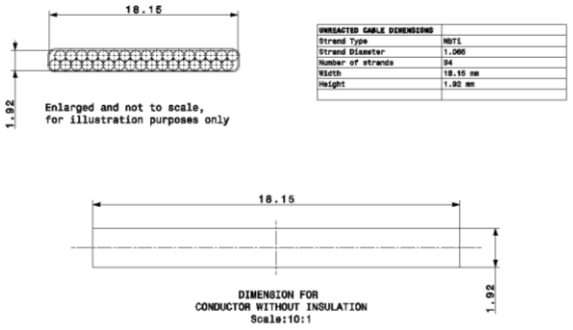
- Triplet - warm diodes
  - Necessary to keep the voltages to tolerable values
  - Design will be compatible with the cold diode option (space left in front on DFX)
  - For this reason the trim circuits from DFX to the magnets are 18 kA cables

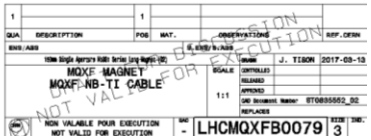


CIRCUIT BASELINE

- Triplet 18 kA main busbar
  - One busbar made of two Nb-Ti Rutherford cables
- Plus/minus busbar going though the triplet in the hole not used by heat exchanger
  - 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
  - Busbar is a double cable (as the US cables used for Nb-Ti leads in the magnets)

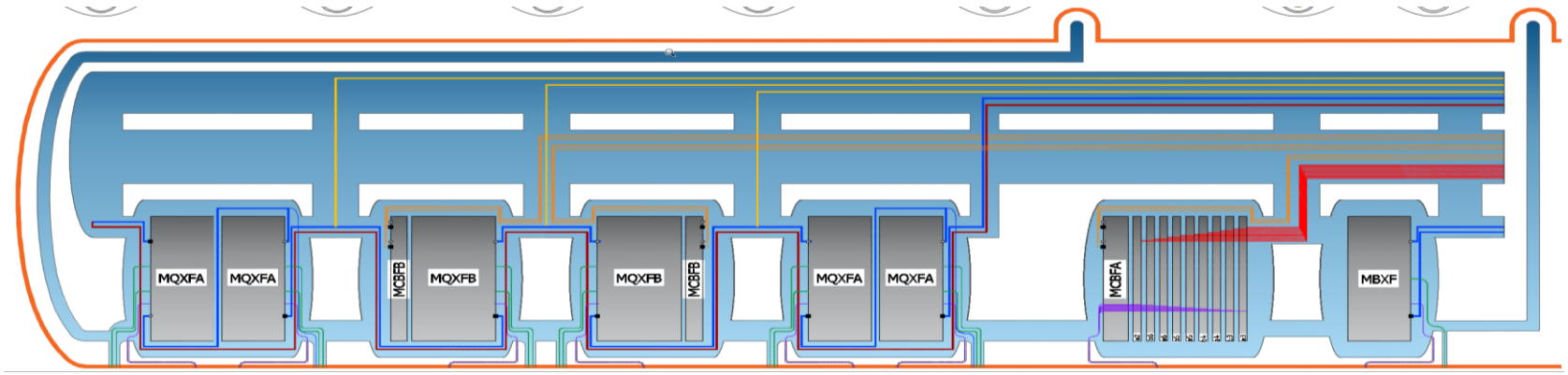
  - Cu surface: 38 mm^2
  - Sc surface: 23 mm^2
  - Cable surface: 61 mm^2
  - 265 MIITs at 300 K
  - 200 MIITs at 200 K



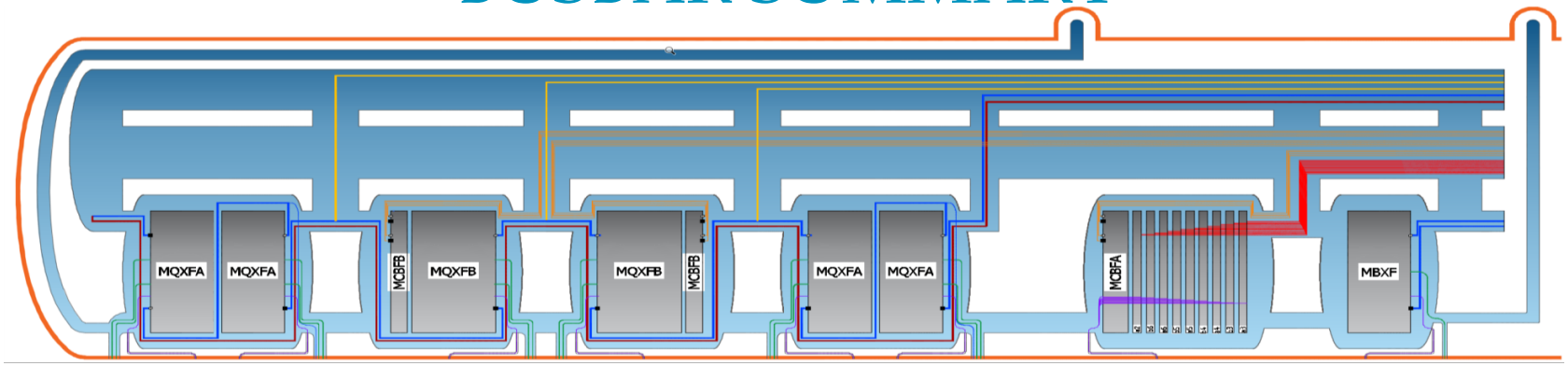


CIRCUIT BASELINE

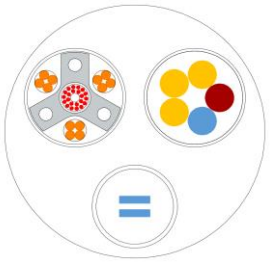
- Triplet trim busbars
  - One round busbar made of same number of strands of the two Nb-Ti Rutherford cables (design to be made)
  - Travelling through the parallel line and splice in the interconnection

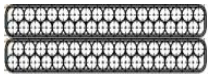


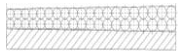
BUSBAR SUMMARY



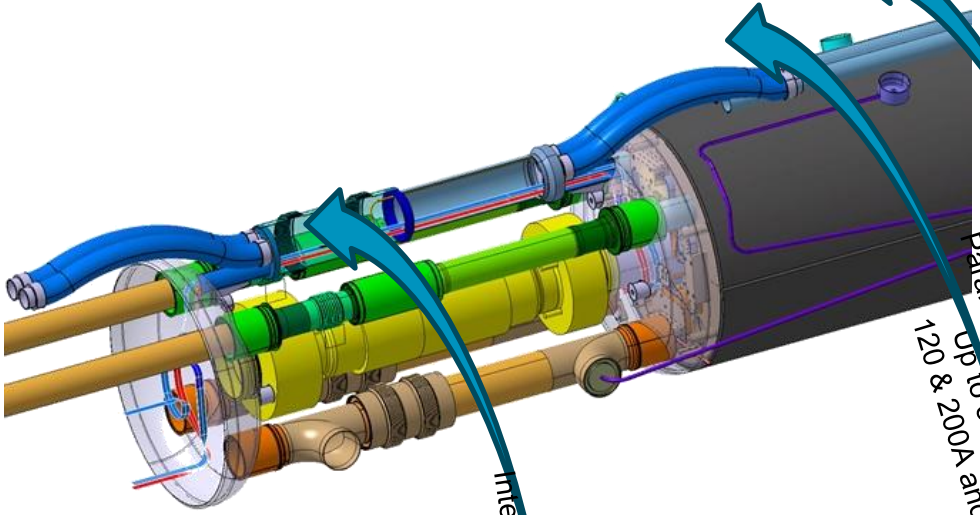
	I_{nom} (kA)	I_{ult} (kA) / I_{max} *	Busbar	Sc wire	Cu/Sc ratio	Bubar Cross Section	Stabilsation
IT Main Circuit inside the cold masses	16.5	17.82	***New***	34 NbTi wires type 01 LHC strand Ø1.065mm	1.6	18.15 x 1.92mm x2 with stab	Doubled cable Or same copper cross section
D1 Circuit	12	12.96	Present 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***	*Under development*			
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	2.8						Silver Platted

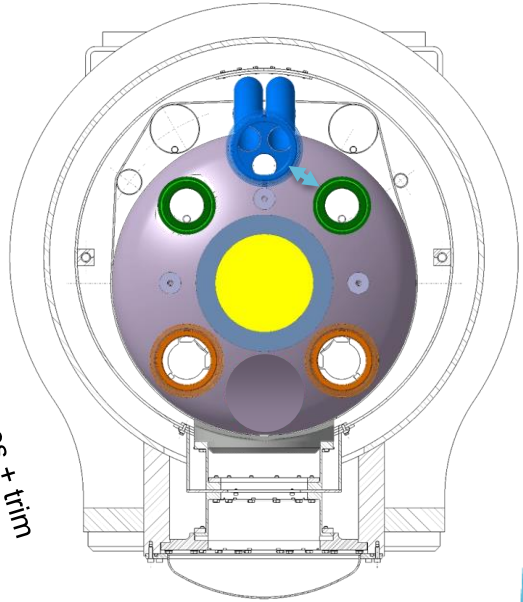






INTERCONNECTION AND PARALLEL LINES

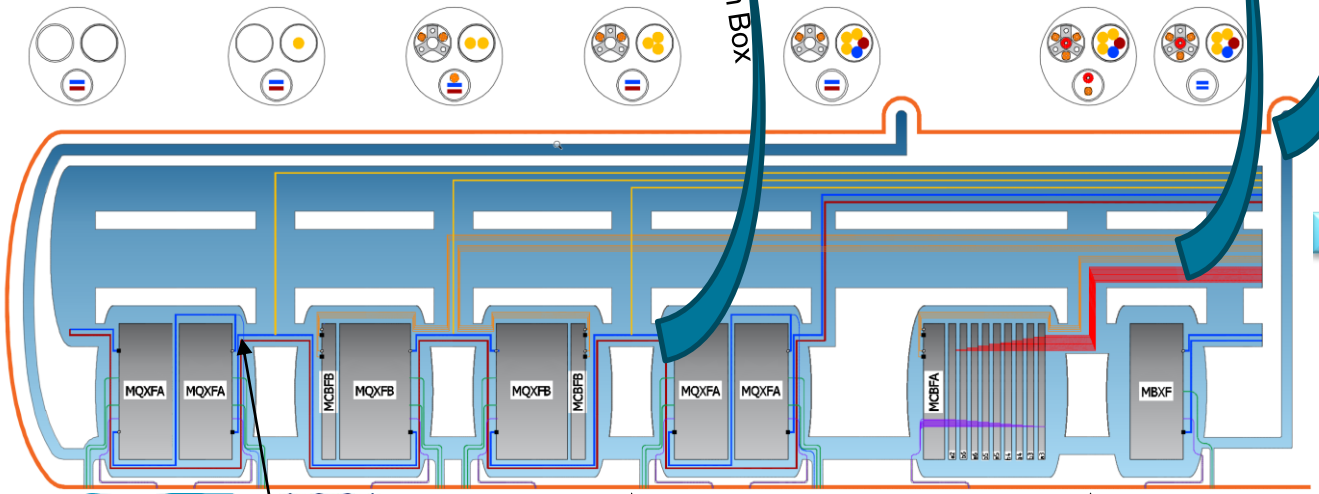




Busbars Interconnection Box

Parallel line for corrector buses
Up to 30 busbars
120 & 200A and 2kA

Parallel line for main buses + trim
Up to 5 busbars
18kA



To DFX

See Y. Leclercq slides

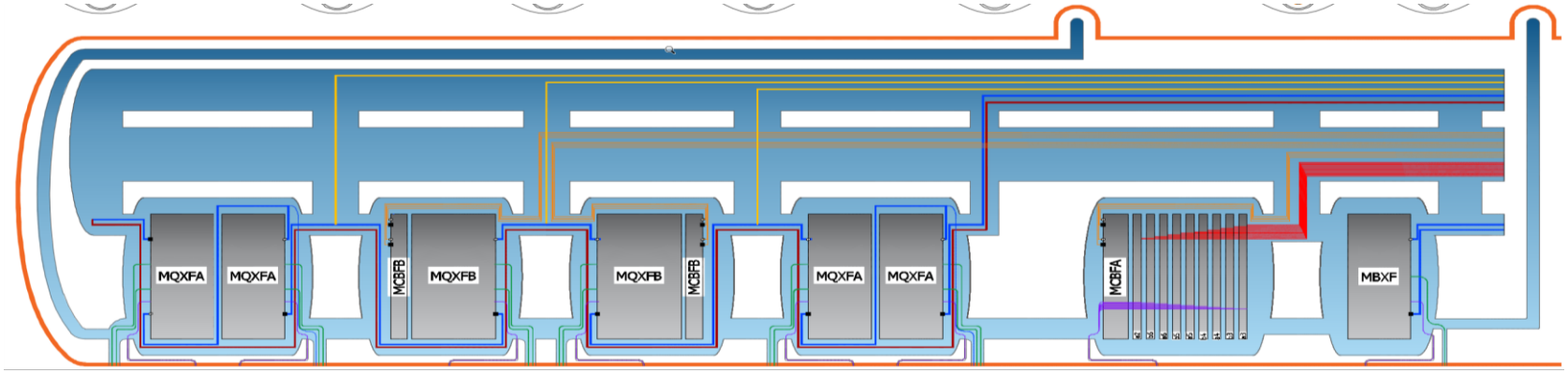
Local restrictions to guide

Free longitudinal area 150cm^2

Free longitudinal area 100cm^2

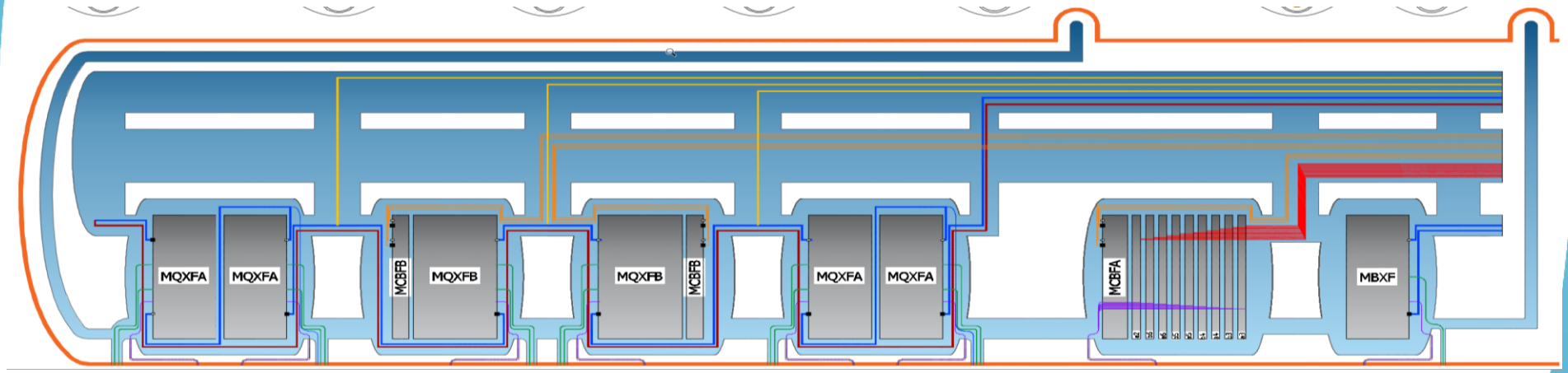
CIRCUIT BASELINE

- Triplet trim on Q1a
  - Resistive lead with local powering
  - The same is put on Q3a to avoind symmetry breaking
- Triplet CLIQ leads
  - Resistive leads with local powering



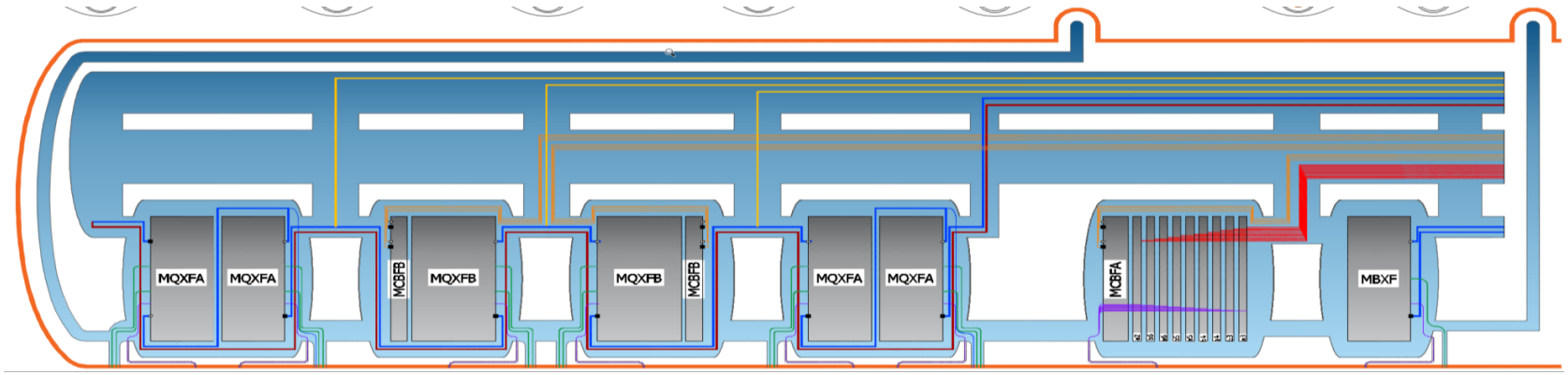
CIRCUIT BASELINE

- Orbit corrector busbars
  - These are 6*2 busbars rated at 2 kA
  - Entering Q2a and Q2b at the interconnection



CIRCUIT BASELINE

- D1 busbar
  - The 13 kA LHC busbar, entering at the level of D1
- HO corrector busbars
  - 600 A LHC busbars, enetring 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

FUTHER STUDIES

- Definition of round cable
- Topology of expansion loops
- Splices between round and flat cable
- Voltage taps nomber and position

CONTENTS

- Short overview of IR magnets
- Baseline for busbars
- Options

THE COLD DIODE OPTION

- We are considering the option of having cold diodes operating at 1.9 K in each quadrupole
  - Problem: radiation level
  - Validation of the solution will be available only in one two years
  - We want adopt a busbar compatible with this option (reccomendation of the internal review)
  - The cold diodes would be placed between DFX and D1, above beam line
  - To keep this option possible, 7 kA trims inside the magnets are at 18 kA, and space is kept free for installation

BUSBAR PROTECTION WITHOUT TRIPLET QUENCH

- If a quench in the busbar is detected, all the triplet should quench (as today in the LHC triplet)

- To avoid this, 18 kA busbars should be compatible with a 100 s time constant
  - This implies having 400 mm^2 of Cu, i.e. a cross-section of 2*2 cm
  - This cannot be integrated in the parallel line, so this option is excluded

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 still to be finalized
  - Round busbar geometry, round-flat splices, expansion loops, voltage taps
- Design compatible with cold diodes, if they are proved to be compatible with radiation levels

APPENDIX: STRAND QUANTITY

- 100 km of strand needed for the triplet busbars

		Length		Prototype	Magnets	Spares	
Inner busbars	Q1	12	2	1	4	1	144
Inner busbars	Q2a	10	2	1	4	1	120
Inner busbars	Q2a	10	2	1	4	1	120
Inner busbars	Q3	12	2	1	4	1	144
	CP D1	15	2	1	4		150
Trim 1		50	1	1	4		250
Trim 2		40	1	1	4		200
Trim 3		30	1	1	4		150
Total length (m)							1278
Total strand (km)							96

APPENDIX TRIPLET PROTECTION

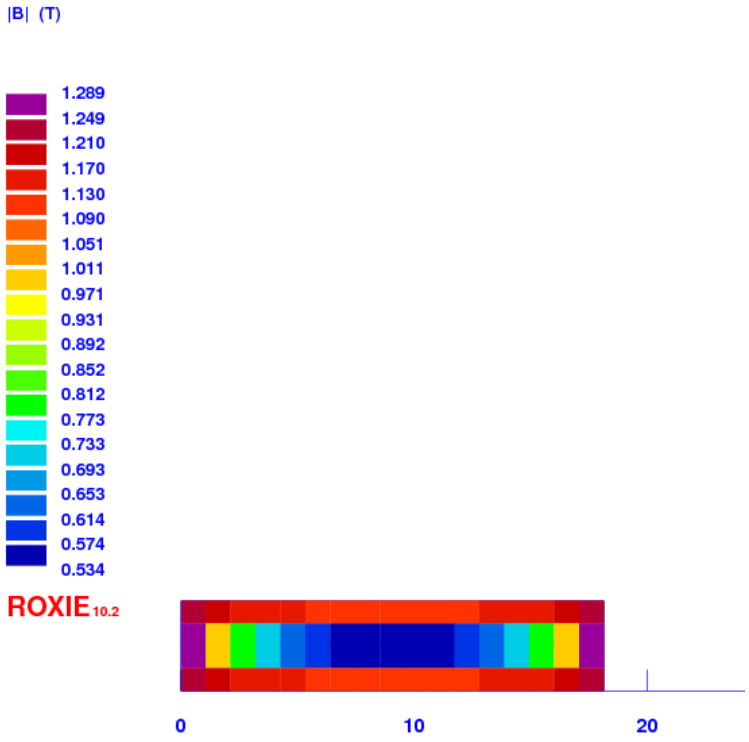
- Scaling from the MIITs of the LHC cable (45 MIITs for 300 K and 28 strands) one obtains
  - 45*(34*2/28)^2 = 265 MIITs at 300 K
  - Safe values not to be exceeded is 200 MIITs (200 K)
- Assuming a quench propagation of 2 m/s
  - Voltage threshold of 100 mV
    - Current of 17.7 kA
    - Needed resistance of 6 μΩ
    - Resistivity of 6 10^{-10} Ω m, Cu section of 38 mm^2
    - Resistance/m is 16 μΩ/m
    - About 0.4 m need to be quenched, so 200 ms detection time
    - 60 MIITs of detection
  - Plus the 30 MIITs of the quench – large margin

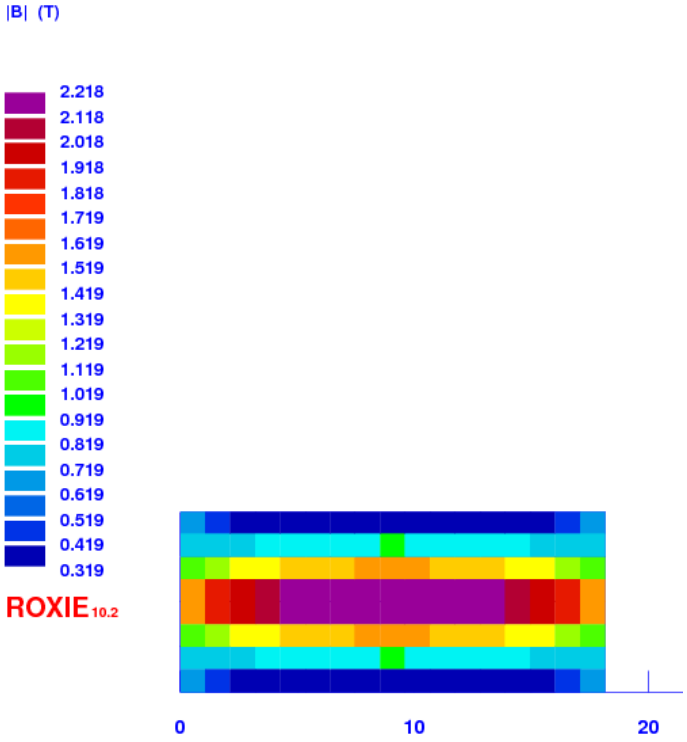
APPENDIX: FIELD IN THE BUSBAR

- For the main, at ultimate one has 17.7 kA
  - Taking a circle with 5 mm radius, field is 0.7 T
  - So peak field for coupled cables is of the order of 1.5 T
  - Current density in the sc is 770 A/mm^2
  - Temperature margin of the order of 6 K (1.5 T) to 6.5 K (0 T)
- Quench velocity
  - Scales with J and $1/\sqrt{(T_{cs}-T_{op})}$
  - We have J=300 A/mm^2 and $T_{cs}-T_{op} =$ 6 K, so w.r.t. LHC dipoles (10 m/s) about 1/3 quench velocity, so I would use 3 m/s
  - Estimate from Luca (multiphysics code) 2 m/s

APPENDIX: FIELD IN THE BUSBAR

- Field in the busbar
  - 1.2 T single busbar, 2.2 T for double





Peak field in the busbars, one busbar (left) and two positive/negative busbars (right)
(S. Izquierdo Bermudez)