Busbars for Q1 to D1 magnets

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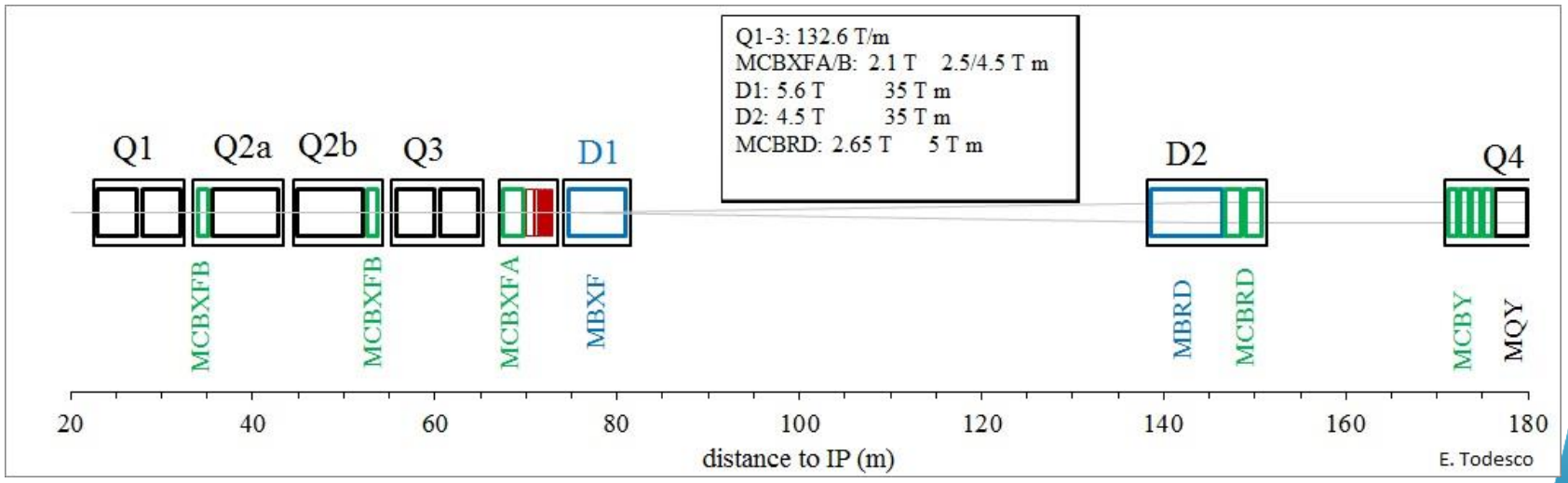
OVERVIEW

- Busbar system for Q1 to D1 magnets linked to DFX
  - Q1/Q2/Q3 18 kA (one) main circuit
  - Q1/Q2/Q3 (three) trims
  - D1 circuit (one)
  - MCBXFA/B 2 kA circuit (six)
    - Above quantities are per IP side
  - Note that the so called « 2 kA » will never see more than 1.75 kA



PROTECTION STRATEGY

- Energy extraction were removed long time ago (2015) with the exception of MCBXFA

- 18 kA
  - In case of quench detection in a magnet, the whole string of magnets is quenched via CLIQ and outer layer heaters
  - In case of quench detection in a busbar, the whole string of magnets is quenched via CLIQ and outer layer heaters
- 13 kA
  - In case of quench detection in D1, the magnet is quenched via outer layer heaters
  - In case of quench detection in D1 busbar, the magnet is quenched via outer layer heaters
- 2 kA
  - In case of MCBXFB quench, the magnet is protected via energy extraction on the crowbar and via quench propagation in the magnet. We assume a 30 mΩ crowbar.
  - In case of quench of the MCBXFB busbar or magnet lead, the busbar or magnet lead is protected via energy extraction on the crowbar.
  - In case of MCBXFA quench, the magnet is protected via energy extraction on a 0.3 Ω external dump resistor.
  - In case of quench of the MCBXFA busbar of magnet lead, the busbar or the magnet lead are protected via energy extraction on a 0.3 Ω external dump resistor.

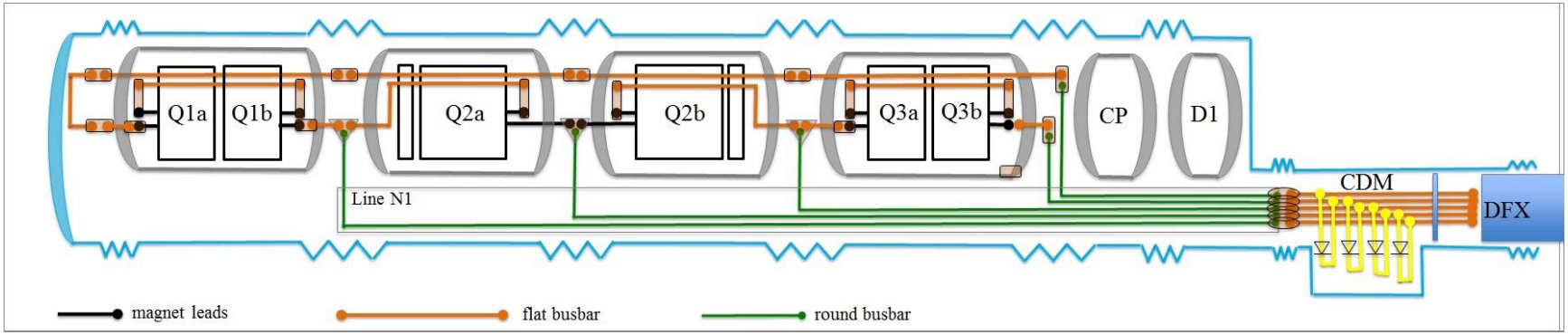
SPECIFICATION

- Most relevant numbers
  - Quench load given by protection strategy (not including detection)
  - Temperature margin : 5 K
  - Hotspot: 150 K

Parameter	(units)	Triplet	D1	MCBXFA/B
Design current	(kA)	18.0	13.0	1.73
Operating temperature	(K)	1.9	1.9	1.9
Quench integral	(MA^2 s)	30	29	0.27/6.0
Equivalent time constant	**(s)**	**0.17**	**0.35**	**0.17/4.0**
Minimum temperature margin	(K)	5	5	5
Voltage test: RT at acceptance[1]	(V)	4600	4000	4600
Voltage test: RT in the cold mass[2]	(V)	3800	2800	3700
Test voltage at 1.9 K	(V)	1900	1400	2300
Maximum leakage current	(mA)	10	10	10
Joint resistance (per joint)	(nW)	1	1	3
Maximum hot spot temperature	(K)	150	150	150
Maximum dI/dt	(kA/s)	90	36	15
Number of thermal cycles	(-)	50	50	50
Number of triplet magnet quenches	(-)	150	150	150
Maximum envelope internal busbars	(mm x mm)	30×30[3] 19×8.2[4]	NA	NA
Maximum envelope round busbars (diameter)	(mm)	45 Ø[5] 15 Ø[6]	10	5
Minimum curvature radius magnet leads	(mm)	50	50	50
Minimum curvature radius round busbars	(mm)	70	70	50
Thermal shrinkage (from RT to operation)	(%)	0.3	0.3	0.3

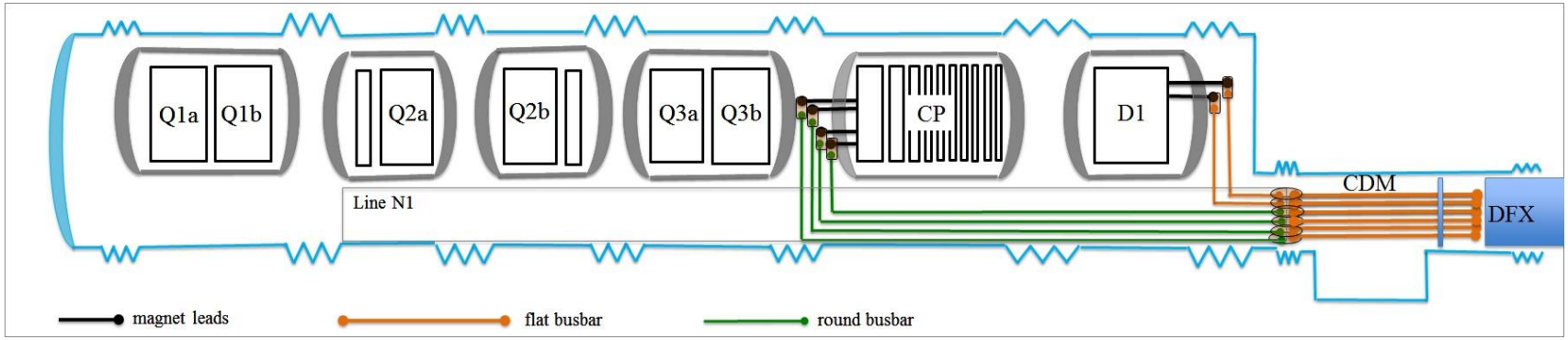
CONCEPTUAL DESIGN

- Main circuit and 18 kA trims
  - Magnet leads in Nb-Ti
  - One internal busbar going through Q1 Q2 Q3 based on flat cable
  - Round cable for trims
  - Flat cable for CDM (Cold Diode Module) and passage through lambda plate
  - Trims in the N1 line
  - Passage through D1 and CP avoided through the N line also for the main
  - End return module to avoid breaking symmetry between Q1 and Q3



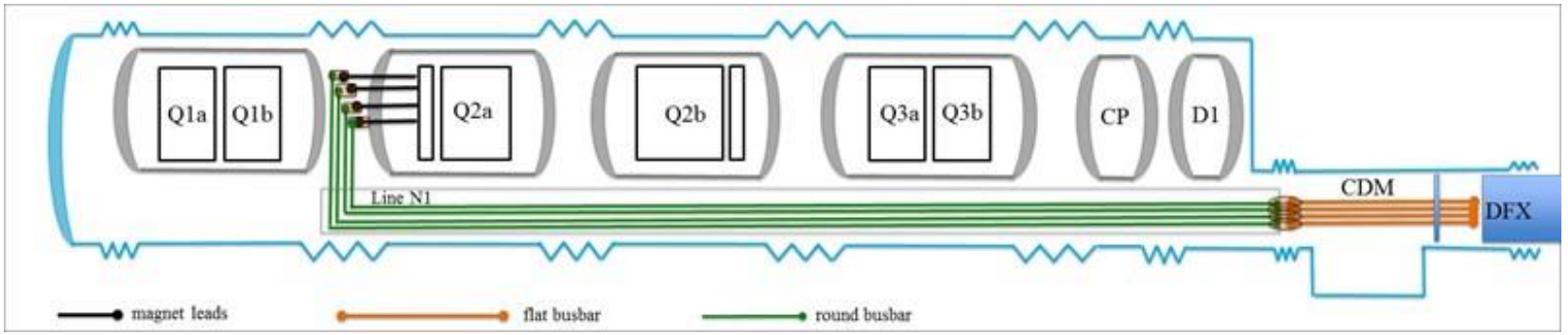
CONCEPTUAL DESIGN

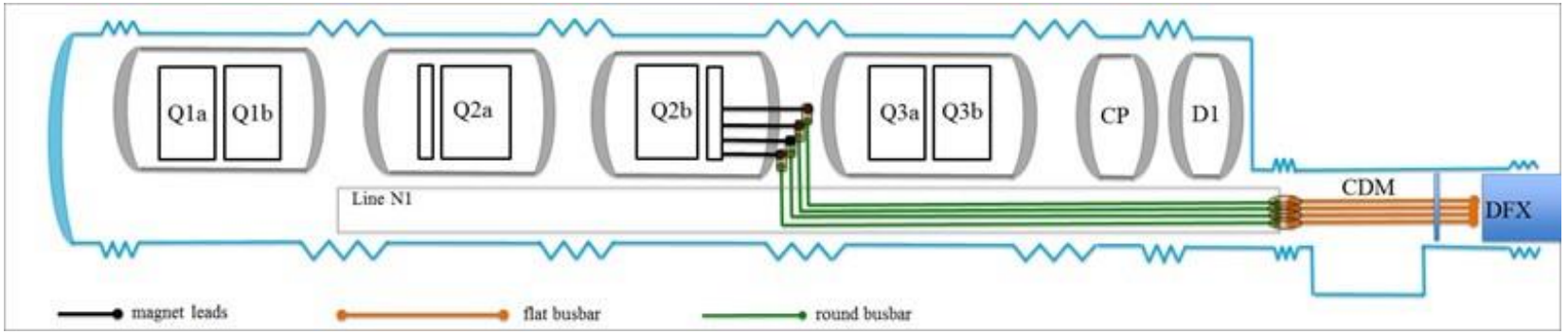
- 12 kA circuit
  - Magnet leads in Nb-Ti
  - Same cable for magnet leads, busbars going out of the cold mass, and through CDM



CONCEPTUAL DESIGN

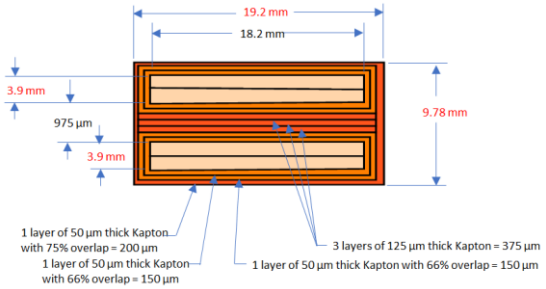
- 2 kA circuit MCBXFB
  - No need of internal busbar
  - Magnet leads (flat cable)
  - Round busbar in the N line





PROPOSAL

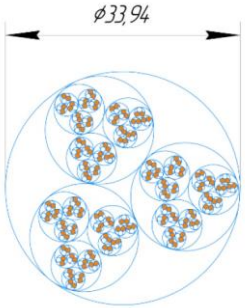
- 18 kA flat busbar
  - Double cable of magnet lead



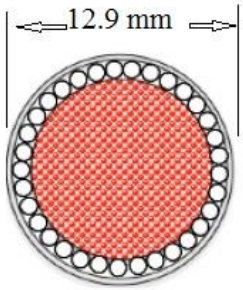
18 kA internal busbar (M. Baldini et al.)

Type	N. Strands	Strand dimension	Cu/no_Cu	Cu surf.	Sc surf.
	(adim)	(mm)	(adim)	(mm^2)	(mm^2)
18 kA flat busbar	17×2×2	1.065[1]	1.65	22.8	37.7
Needed				33	12

- 18 kA round busbar
  - Under development in VKINP
  - Two options



Option 1 (V. Vitaly et al.)



Option 2 (L. Bottura)

Type	N. Strands	Strand dimension	Cu/no_Cu	Cu surf.	Sc surf.
	(adim)	(mm)	(adim)	(mm^2)	(mm^2)
18 kA round busbar option 1	36 72	1.065 1.065	1.65 ∞	20 64	12
18 kA round busbar option 2	34 1	1.065 10.37	1.65 ∞	19 83	11.5
Needed				33	12

PROPOSAL

- 13 kA flat busbar
  - Nb-Ti cable with 1.5 mm thick copper conductor, same width

Type	N. Strands	Strand dimension	Cu/no_Cu	Cu surf.	Sc surf.
	(adim)	(mm)	(adim)	(mm^2)	(mm^2)
13 kA flat busbar - Double cable	18×2×2	0.825	1.95	51	13
13 kA flat busbar – Single cable plus Cu	18×2 Cu	0.825 15.1×1.5	1.95 ∞	25.4 22	6.5 0
Needed				28	7

- 2 kA flat busbar
  - Nb-Ti cable with 1.5 mm thick copper conductor, same width

Type	N. Strands	Strand dimension	Cu/no_Cu	Cu surf.	Sc surf.
	(adim)	(mm)	(adim)	(mm^2)	(mm^2)
One 1.7 cable and one rectangular Cu cable	9×2 (Nb-Ti) 1 (Cu)	0.48[1] 4.35×1.5	1.75 ∞	2.08 6.5	1.18 0
Needed				8	0.5

- 2 kA round busbar
  - The 6 kA of the LHC is ok

Type	N. Strands	Strand dimension	Cu/no_Cu	Cu surf.	Sc surf.
	(adim)	(mm)	(adim)	(mm^2)	(mm^2)
LHC 6 kA round busbar	11 (Nb-Ti) 9 (Cu)	0.85[1]	1.38 ∞	3.62 5.10	3.62 0
Needed				8	0.5

CONCLUSIONS AND FUTURE ROADMAP

- Specifications for the busbar are available
  - Main parameters are 5 K temperature margin and 150 K maximum hotspot
- Layout has been agreed
  - Internal busbar only for the 18 kA
  - 18 kA trims will use the same busbar as the mains
- Quantities and schedule are baselined
  - The US AUP shall make the 18 kA internal busbar
- Protection verified
  - Three documents by M. Mentink on EDMS
    - https://edms.cern.ch/document/2052319 (MQXF)
    - https://edms.cern.ch/document/2052325 (MCBXF)
    - https://edms.cern.ch/document/2061856/ (D1)
  - Internal busbar for MQXF verified by M. Baldini
- Next steps
  - Cross-check of quench stopper in the full system
  - Definition of splices between round and flat cables