Coordination of magnet circuits

Felix Rodriguez Mateos on behalf of the HL-LHC
Magnet Circuit Forum

HL-LHC Collaboration Meeting – 16th November 2016 - Paris

Table of contents

1. The Magnet Circuit Forum and recent work
2. Main open issues on circuit definitions
3. Documentation
4. Nomenclature
5. Outlook

The HL-LHC MCF (Magnet Circuit Forum)

One of the recommendations of the March 2016 review on HL-LHC Magnet Circuits was:

"… to realize close and regular interaction (communication) between the involved experts and work-packages. This could be possibly done by setting-up of a dedicated working group or by using existing structures to discuss circuit integration and protection on a regular basis and to identify the optimum scheme for each magnet circuit system."

Mandate

- The Magnet Circuit Forum (MCF) is the meeting where all aspects related to powering and protection of the HL-LHC circuits are discussed, in particular the ones pertaining to the optimization of circuit layouts and definition of protection means.
- Subjects in the agenda are defined in close collaboration with the relevant WPs.
- Interface aspects between systems are clarified through meetings at the forum. To this end, a documentation plan has to be developed and completed.
- The aim is to prepare a set of functional interface specifications that can be used as input for the design (technical specifications) of the different systems.
- Assessment on realistic failure scenarios and required mitigation strategies on a global basis is part of the activities of the MCF.
- The MCF is the meeting where aspects related to high voltage withstand levels are discussed and harmonized.
- The MCF reports regularly to TCC and takes up any relevant discussion within the domain of cold/warm powering and protection of the HL-LHC circuits in collaboration with the relevant WPs .

November 2016

- 08 Nov HL-MCF Meeting # 8 : Status on 11T Powering Scheme + Status on IT Circuit Layout
- 01 Nov HL-MCF Meeting # 7 : Modelling of the PC Output to the Magnetic Field + Nomenclature

October 2016

- 04 Oct HL-MCF Meeting # 6 : HL-LHC Matching Section Cold Powering + Disconnectors between the DFH and the Warm Cables

September 2016

- 20 Sep HL-MCF Meeting # 5 : HL-LHC Document Plan + Circuits Table V6 + Circuits Layout V1
- 13 Sep HL-MCF Meeting # 4 : Update on the Cold Powering of Q4/Q5/Q6 Correctors + IT Layout in the LHC

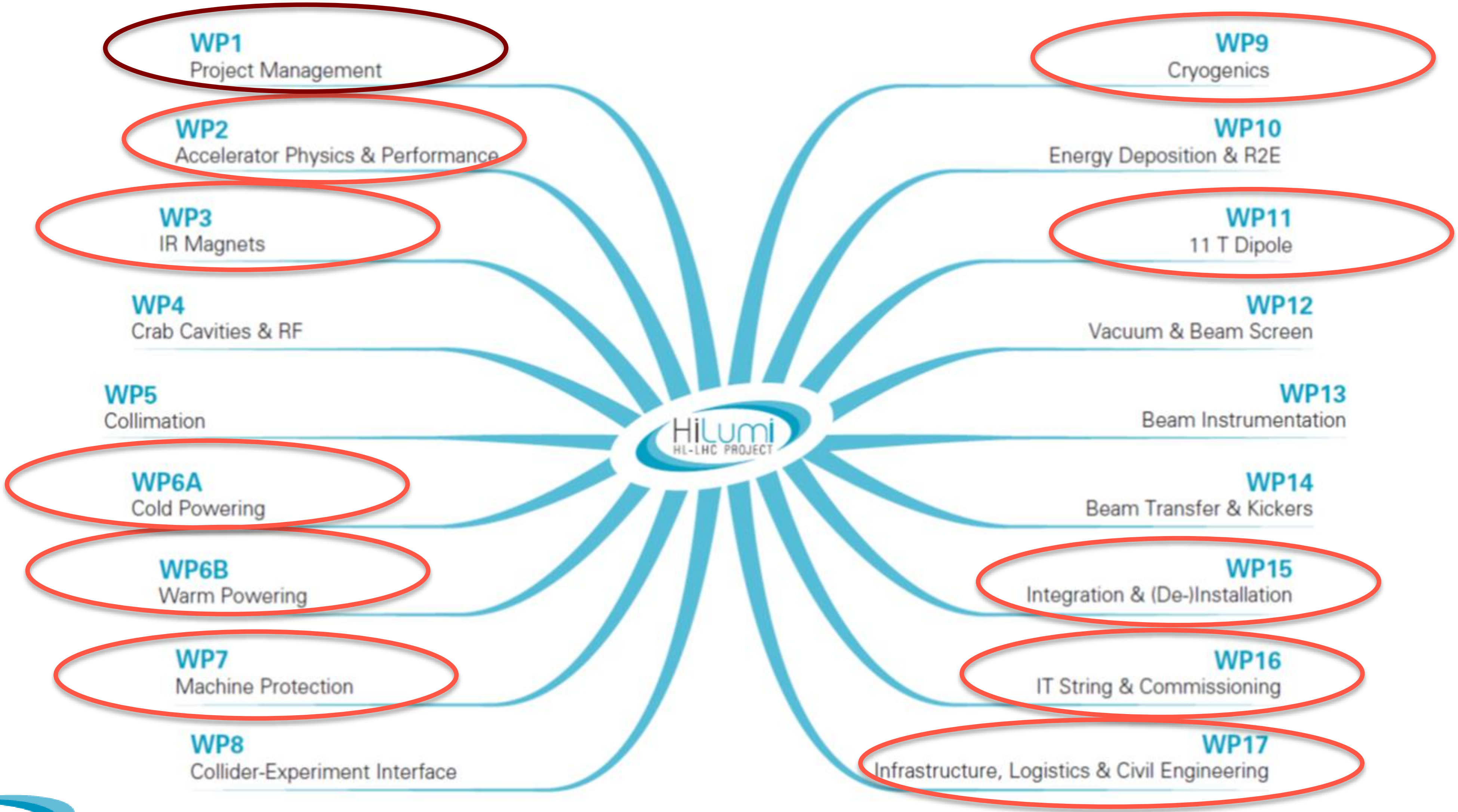
August 2016

- 09 Aug HL-MCF Meeting # 3 : 11T vs QXF Quench Protection Performance + Inner Triplet Powering and Protection Scheme
- 09 Aug HL-MCF Special Meeting # 1 : Q4/Q5/Q6 and correctors in HL-LHC

July 2016

- 26 Jul HL-MCF Meeting # 2 : Documentation Plan for the MCF + Update on High Voltage Withstand Levels
- 12 Jul HL-MCF Meeting # 1 : Forum Mandate + HL-LHC Re-baselining + QH vs EES for Correctors

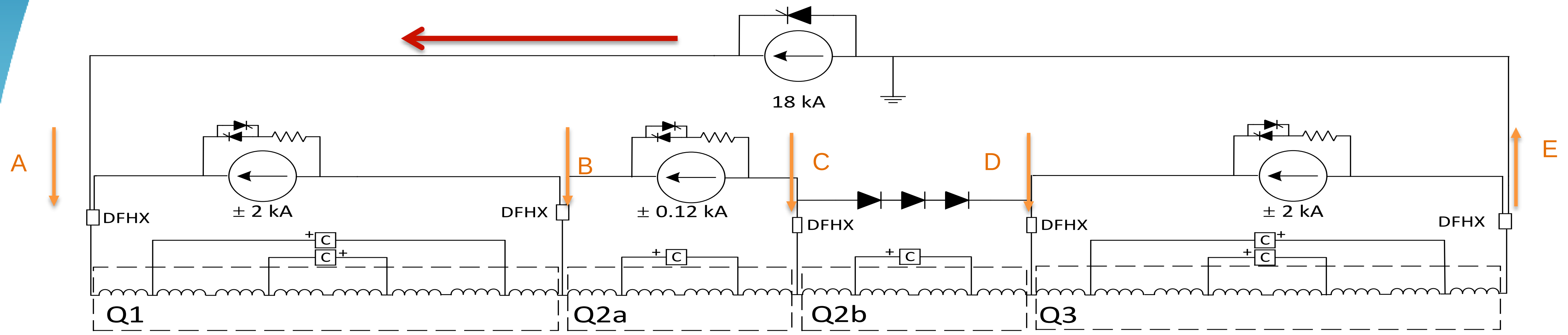
The players at MCF



Recent (major) activities of the MCF

- **Circuit definitions and design aspects**
  - **Inner triplet RQX circuit** ← E Ravaioli, H Thiesen, myself
  - **Powering of the correctors in Matching Section after re-baselining** ← A Ballarino
    - Simulations of the series connection of two MCBY magnets
- **Documentation**
  - **Reference Circuits Table (spreadsheet)**
  - **First version of circuit drawings**
  - Functional specifications in work
    - 11T circuit
    - High voltage withstand levels
- **Nomenclature**
  - **Agreement on circuit and power converter names**
- **Interfacing EN-EA for dose/fluence calculations** ← S Danzeca
  - Cold masses : 11T and RQX diodes
  - RRs for quench protection equipment
  - Tunnel in P7: quench heater discharge supplies (HDS) for 11T magnet, quench detectors and and HDS for neighboring magnets
- **Defining ramp and acceleration rates** ← D Gamba
- **Launching the concept of circuit separators**
  - Taken up by WP6b
- **Transfer functions V_{PC}-$B_{aperture}$ (ripple effect to beam)** ← M Martino

Inner triplet's RQX circuit



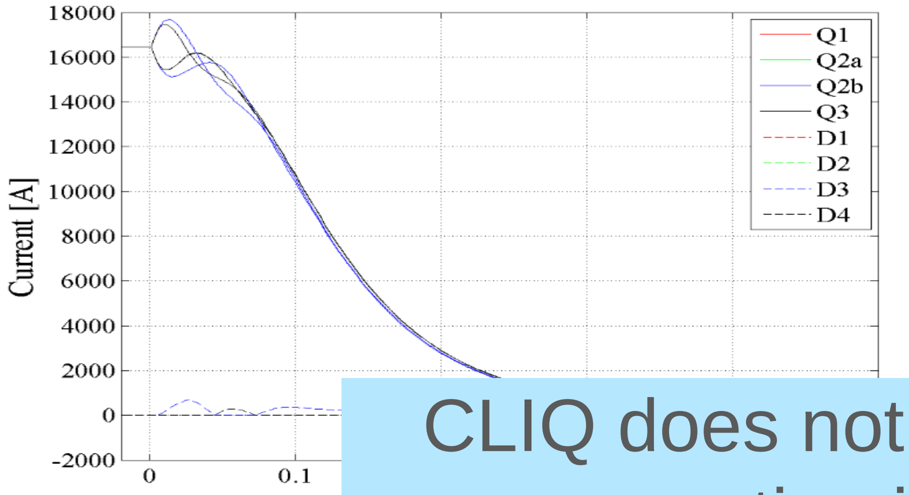
In a conservative scenario where one full magnet quenches by effect of beam, what will the currents be in the parallel paths? In other words, what will be the currents, loads and dI/dt seen by the bus bars, link and current leads?

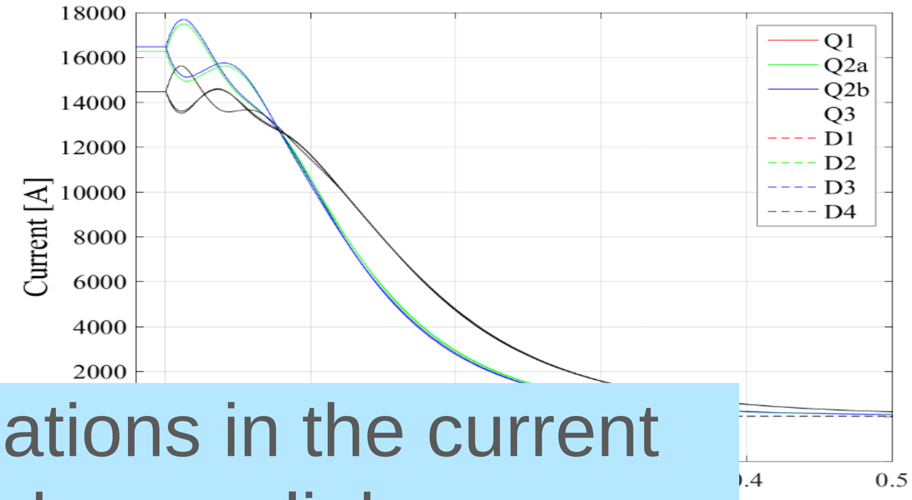
Simulation assumptions

- Q2b quenches suddenly and completely (4 poles)
- 15 ms detection and validation
- 1 ms CLIQ firing
- 5ms heater firing

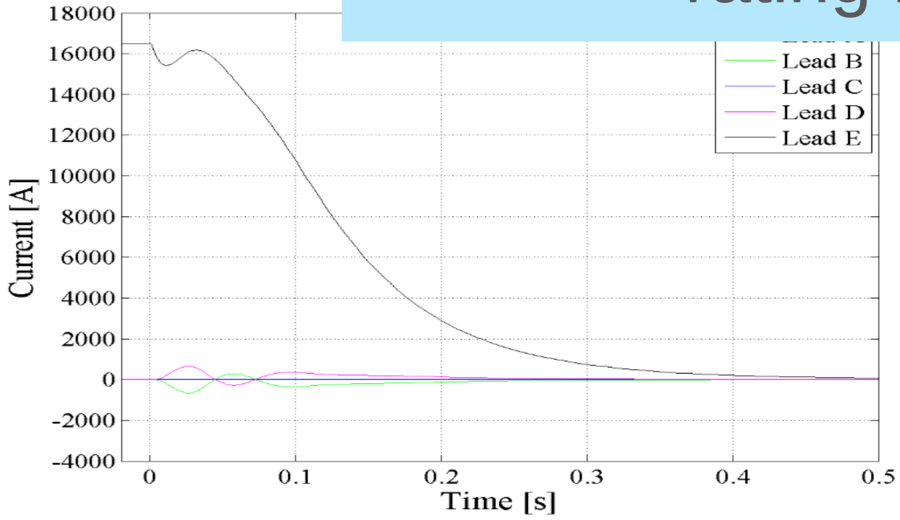
The nominal scenario

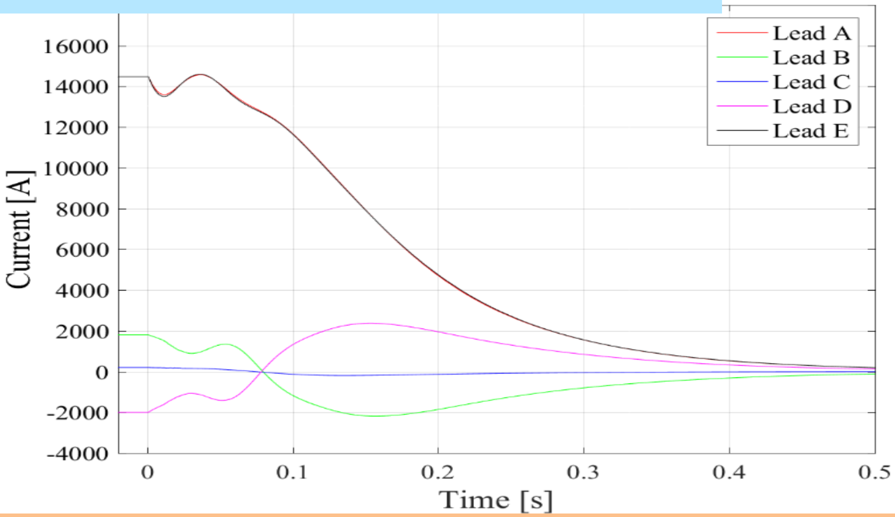
Emmanuele Ravaioli, LBNL





CLIQ does not have any implications in the current rating in s.c. leads, bus bars or link



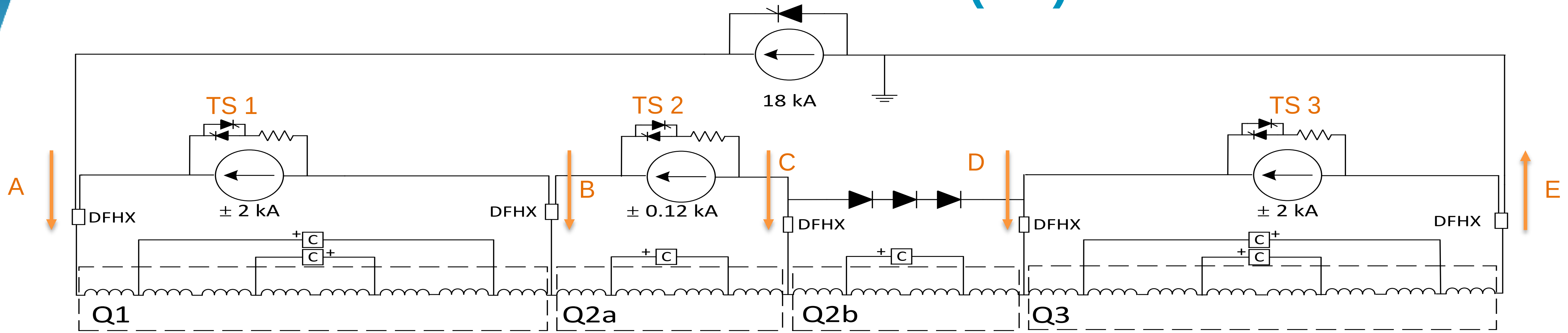


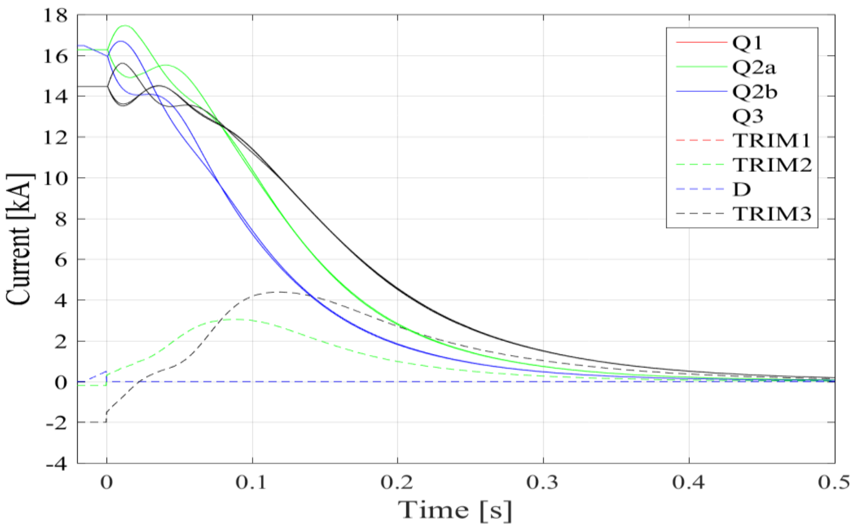
Quench at nominal current, with zero current in all trim power supplies

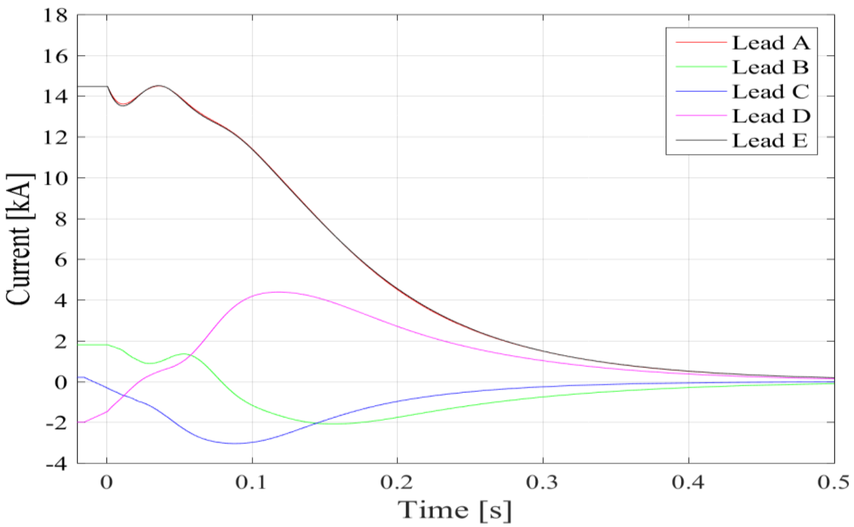
Quench at nominal current, with maximum currents in all trim power supplies

Conservative scenario (1/2)

Emmanuele Ravaioli, LBNL





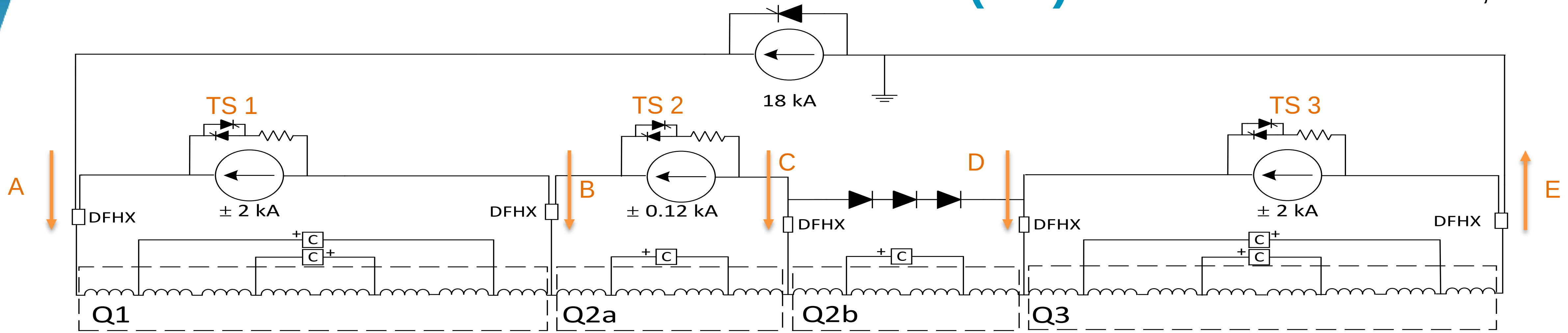


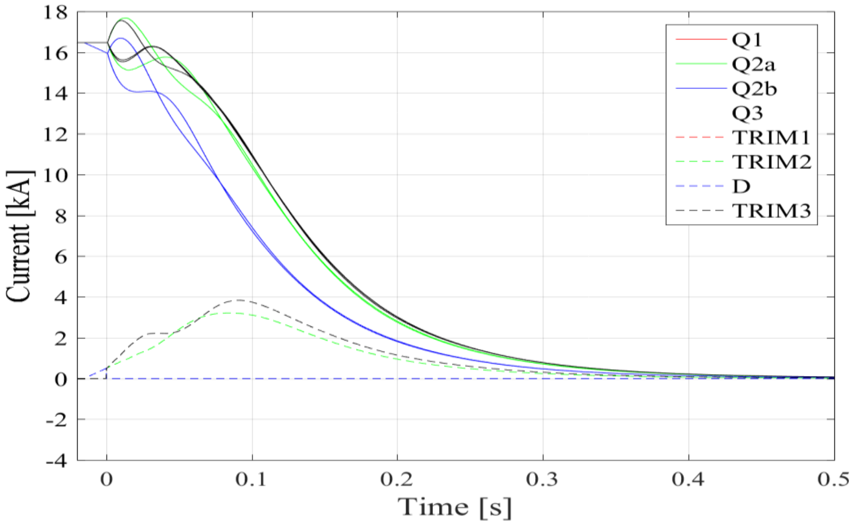
<u>Worst-case for Leads B and D, and for the three crowbars of the trim power supplies</u>

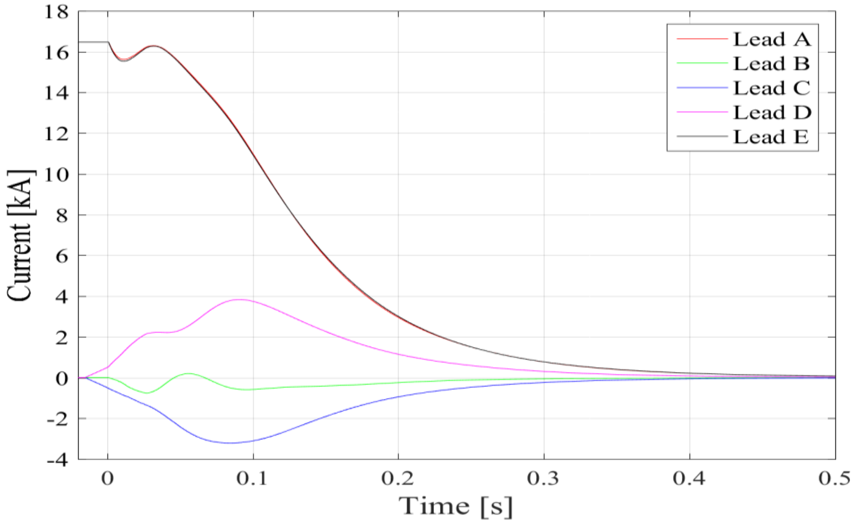
Initial currents: I_{MS}=16.5 kA, I_{TS1}=I_{TS3}=-2 kA, I_{TS2}=-0.12 kA. Quench of the entire Q2b coil (all four poles)

Conservative scenario (2/2)

Emmanuele Ravaioli, LBNL





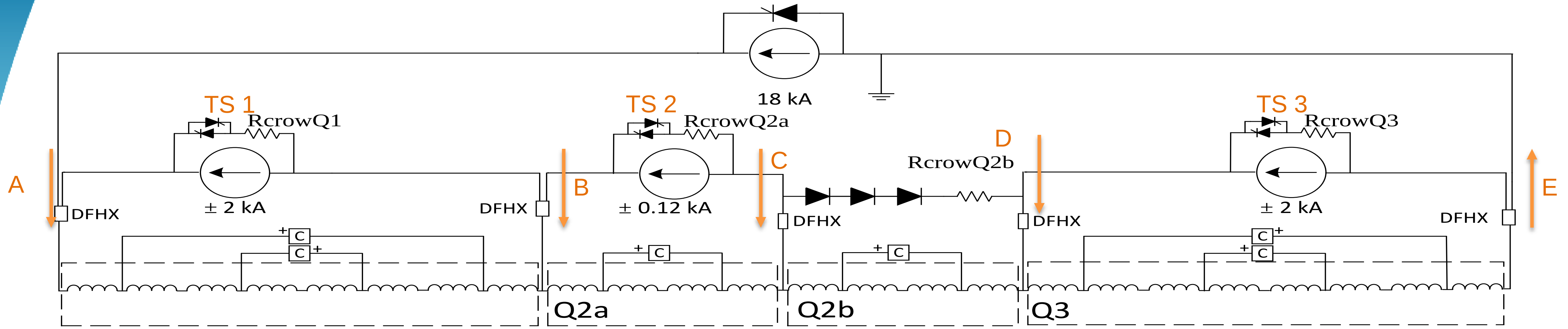


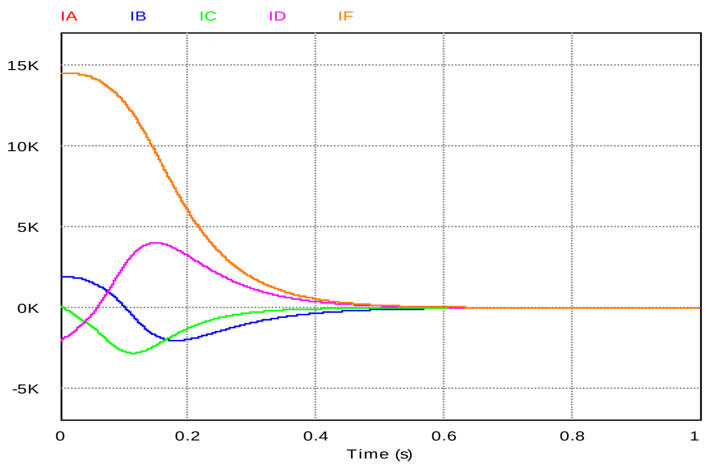
<u>Worst-case for Lead C</u>

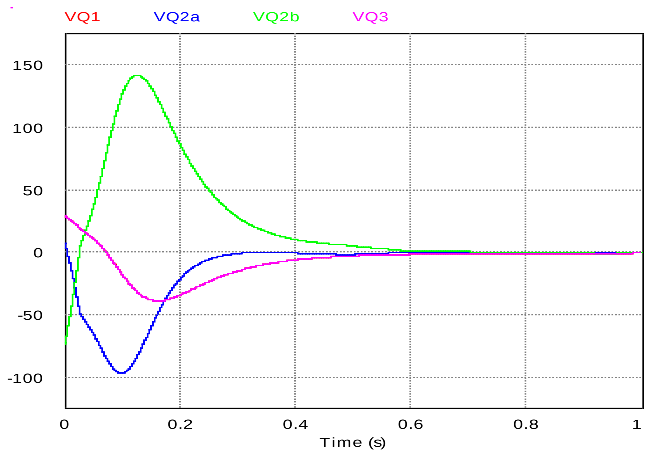
Initial currents: I_{MS}=16.5 kA, I_{TS1}= I_{TS2}=I_{TS3}=0. Quench of the entire Q2b coil (all four poles)

Adding resistances to the crowbars

Samer Yammine





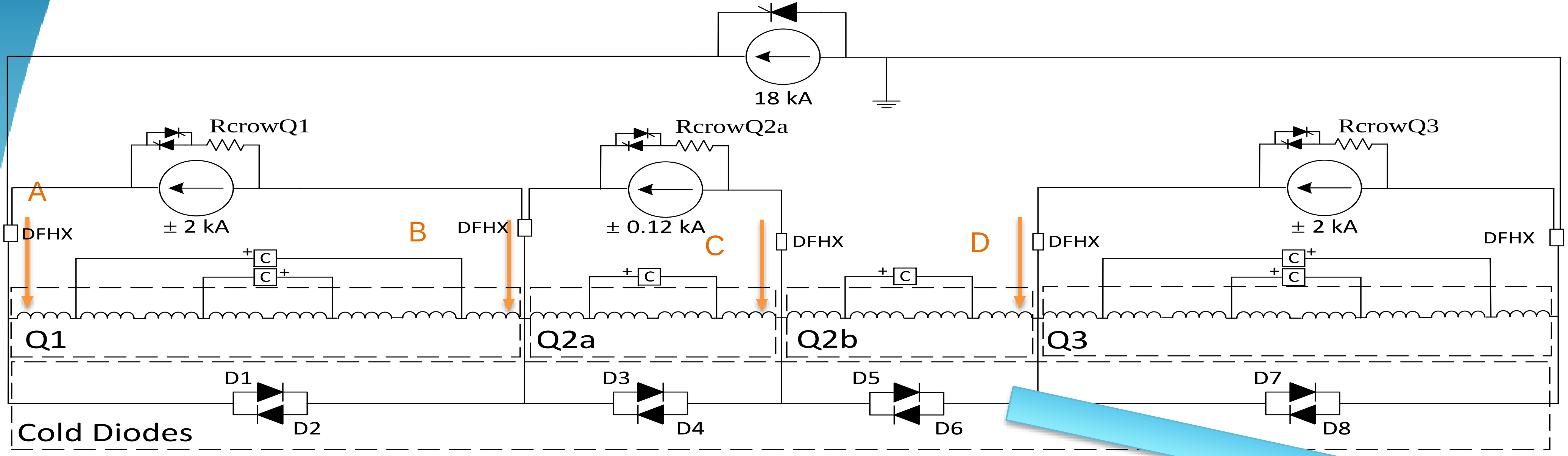


RcrowQ1 = 15 mΩ
RcrowQ2a = 80 mΩ
RcrowQ2b = 80 mΩ
RcrowQ3 = 15 mΩ

Maximum current decrease of less than 200A in the trim circuits → Low impact (MIITS and current peaks)

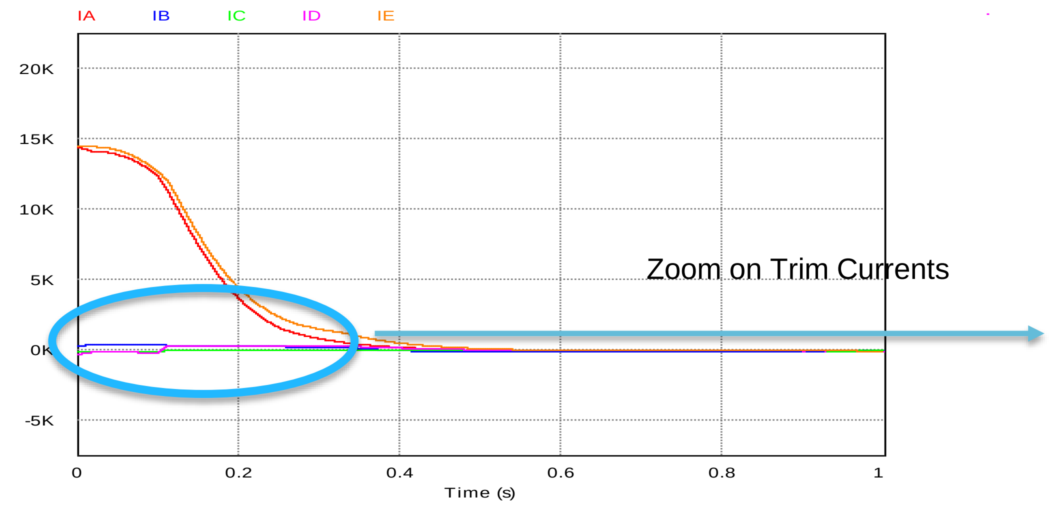
Adding crowbar resistances & cold diodes

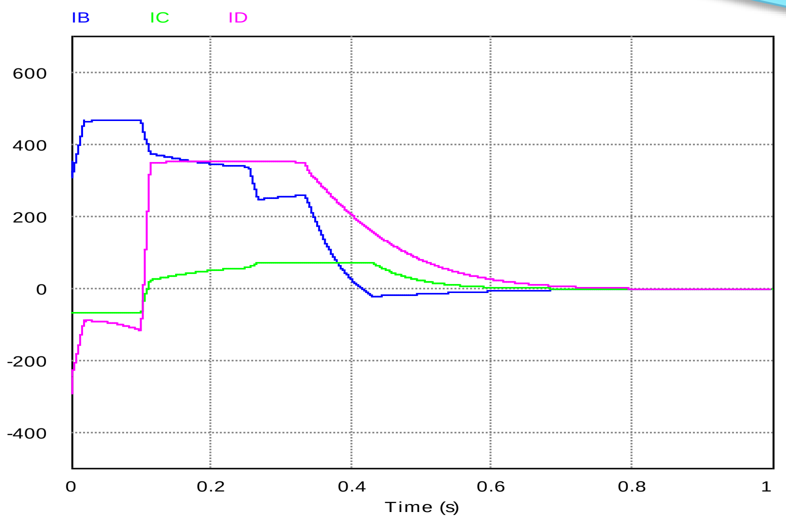
Samer Yammine



RcrowQ1 = 15 mΩ
RcrowQ2a = 80 mΩ
RcrowQ3 = 15 mΩ
Diode Vf = 6 V

But will cold diodes resist the radiation levels?





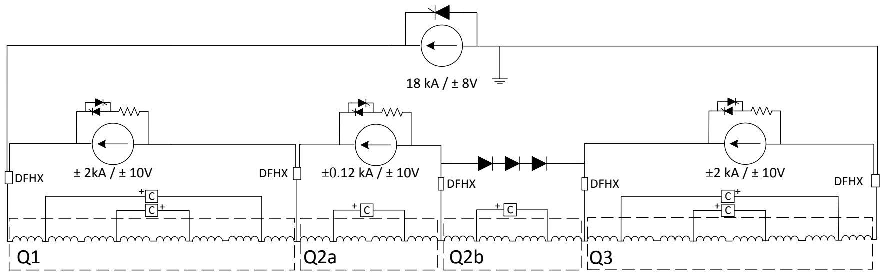
$I_C <= Vf/0.08\Omega <= 75A$
$I_B < 500$ A
$I_D < 400$ A

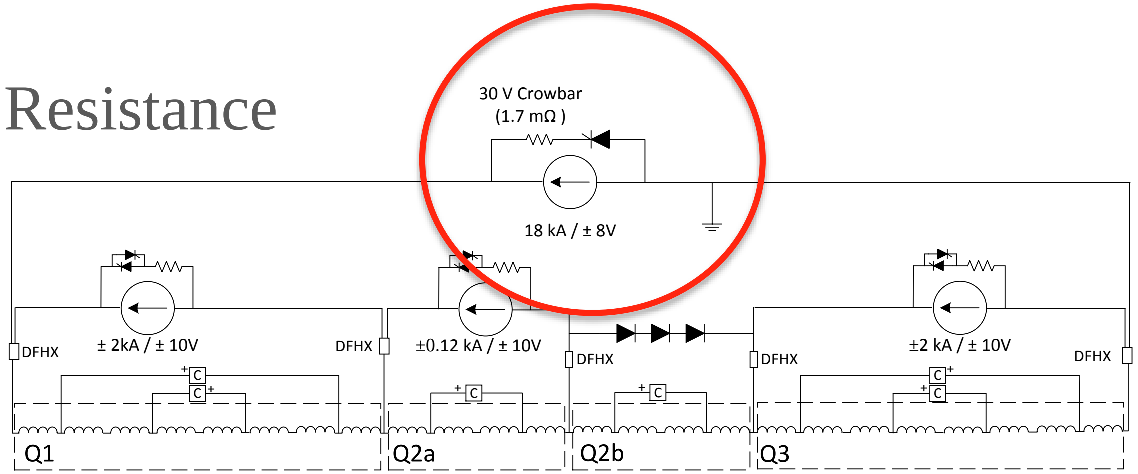
INTEGRATION ISSUES!

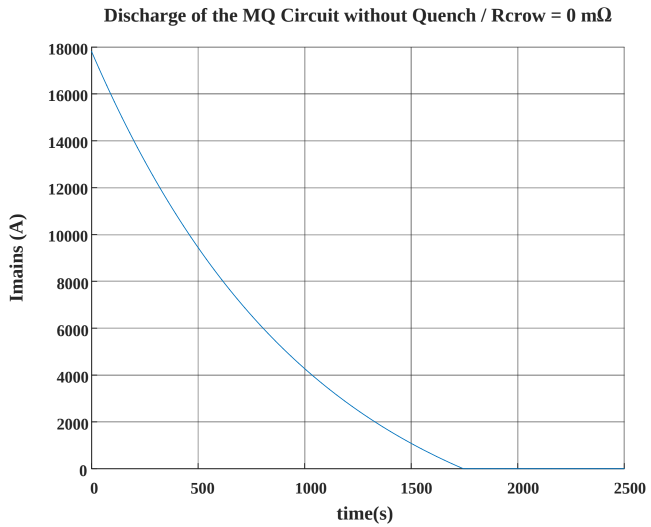
Hugues Thiesen

Optimizing in a global way

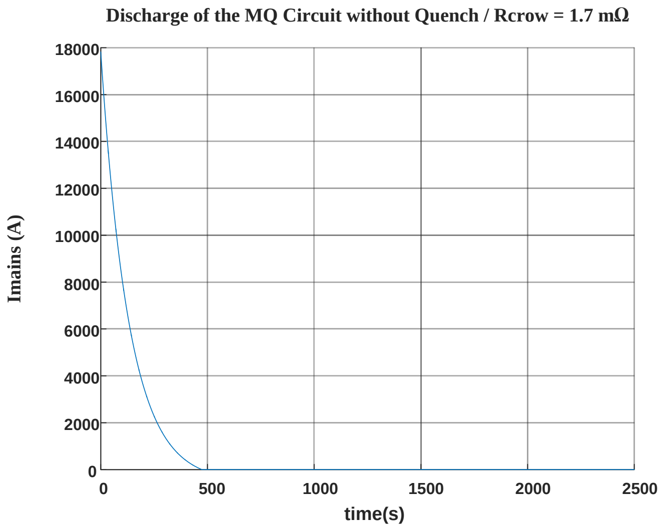
- Water Failure and Main Converter Crowbar Resistance







Introduction of 30 V Crowbar Resistance



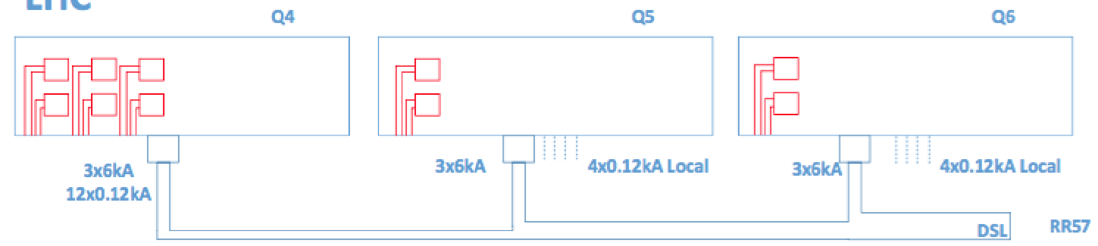
- Energy Dissipated in Free-Wheeling Thyristor = 11.5 MJ
- Energy Dissipated in DC Cables = 30 MJ → **ΔT = 86 °C in case of water failure**

- Energy Dissipated in Free-Wheeling Thyristor = 2.12 MJ
- Energy Dissipated in DC Cables = 5 MJ → **ΔT = 15 °C in case of water failure**
- **Energy Dissipated in Crowbar Resistance = 34 MJ**

Different solutions for the powering of the HL-LHC Matching Section circuits

Layout Right of Point 5

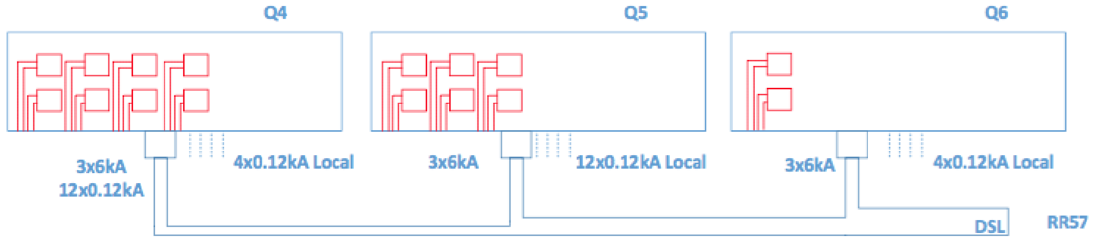
LHC



HL-LHC/Case1

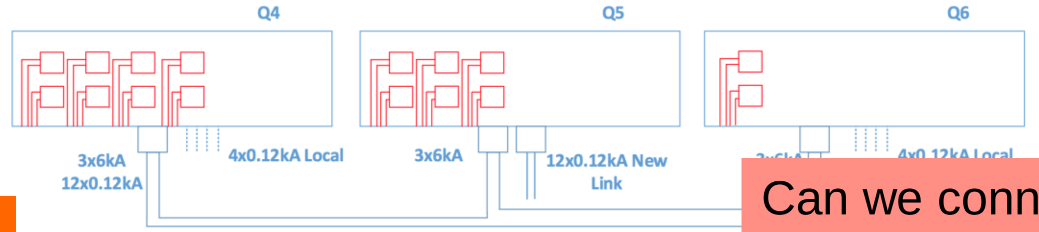
- Local powering for supplementary Q4 correctors
- Local Powering of Q5 correctors
- Q6 as LHC configuration

INTEGRATION ISSUES!



HL-LHC/Case2

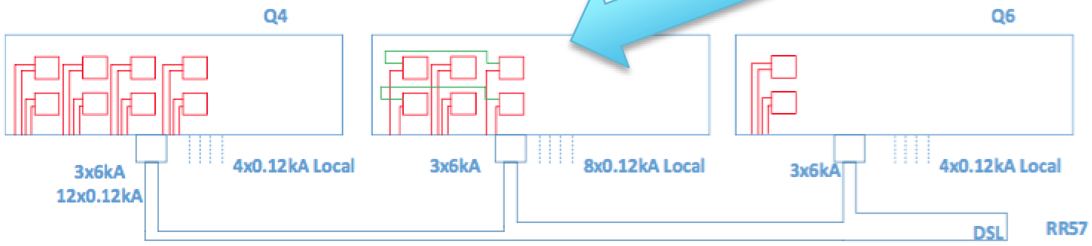
- Local powering for supplementary Q4 correctors
- New SC Link + Leads in RR for Q5 correctors
- Q6 as LHC configuration



Can we connect two MCBYs in series?

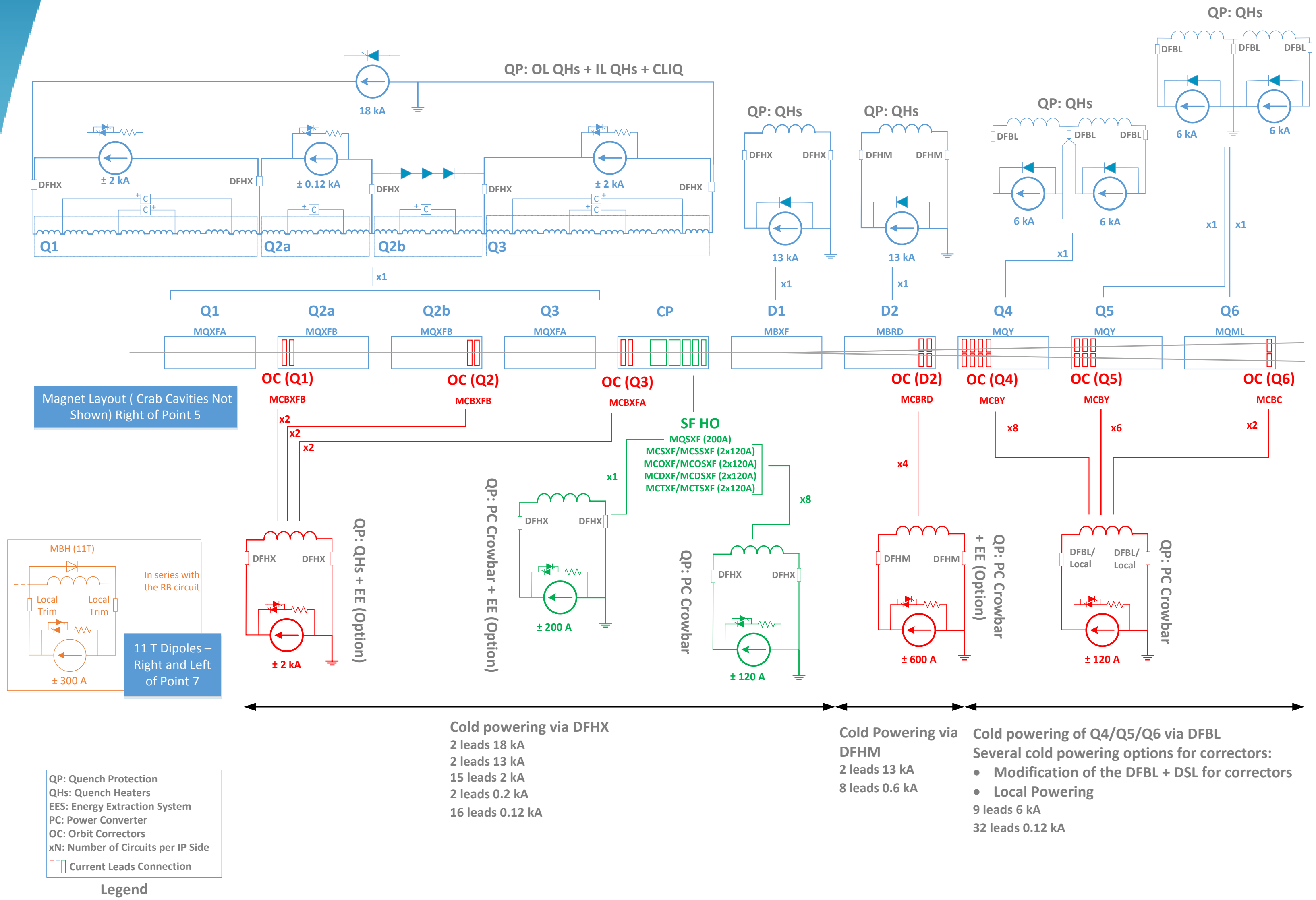
HL-LHC/Case5 – Q5 Correctors Series Connection

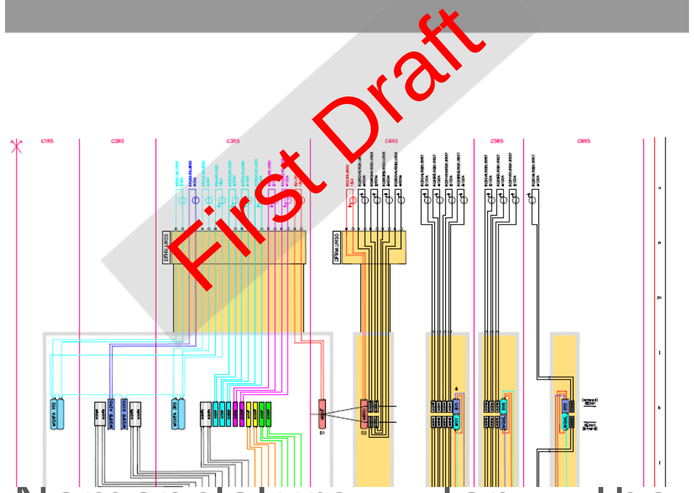
- Local powering of supplementary Q4 correctors
- Local Powering of Q5 correctors (Series Connection)
- Q6 as LHC configuration



Amalia Ballarino, Samer Yammine

Circuit Layouts and Database





- Nomenclature for the circuits has been prepared and submitted to TCC
- A substantial effort has been deployed over the last months in order to have a **reference Circuits Table** with all parameters related to the circuits

Circuits Table V6

Working version is available from the MCF sharepoint

	Circuits for HiLumi	Magnet Type	Number of circuits per IP side	Total number of circuits	I_nominal (7 TeV) [kA]	I_ultimate [kA]	L per circuit [mH]	R per circuit [mΩ]	Collaborations
Inner Triplet	Triplet Q1, Q2a, Q2b, Q3	MQXFA / MQFXB	1	4 (IR1/5)	16.5	17.82	255	0.3	US-HiLumi
	Trim Q1	-	1	4 (IR1/5)	2	-	69	2.09	-
	Trim Q3	-	1	4 (IR1/5)	2	-	69	2.16	-
	Trim Q2a	-	1	4 (IR1/5)	0.12	-	58.5	7.2	-
	Orbit correctors Q2a/b - vertical	MCBXFB	2	8 (IR1/5)	1.6	1.73	59	2.31	Ciemat
	Orbit correctors Q2a/b - horizontal	MCBXFB	2	8 (IR1/5)	1.47	1.59	135	2.38	Ciemat
	Orbit correctors CP - vertical	MCBXFA	1	4 (IR1/5)	1.6	1.73	109	2.52	Ciemat
	Orbit correctors CP - horizontal	MCBXFA	1	4 (IR1/5)	1.47	1.59	247	2.6	Ciemat
	Superferric, order 2	MQSXF	1	4 (IR1/5)	0.182	0.2	1247	5.31	INFN
	Superferric, order 3, normal and skew	MCSXF / MCSSXF	2	8 (IR1/5)	0.105	0.12	118	7.2	INFN
	Superferric, order 4, normal and skew	MCOXF / MCOSXF	2	8 (IR1/5)	0.105	0.12	152	7.2	INFN
	Superferric, order 5, normal and skew	MCDXF / MCDSXF	2	8 (IR1/5)	0.105	0.12	107	7.2	INFN
	Superferric, order 6	MCTXF	1	4 (IR1/5)	0.105	0.12	229	7.2	INFN
	Superferric, order 6, skew	MCTSXF	1	4 (IR1/5)	0.105	0.12	52	7.2	INFN
D1	Separation dipole D1	MBXF	1	4 (IR1/5)	12	12.96	27	0.4	KEK
D2	Recombination dipole D2	MBRD	1	4 (IR1/5)	12	12.96	25	0.33	INFN
	Orbit correctors D2	MCBRD	4	16 (IR1/5)	0.5	0.54	600	1.08	CERN
Q4	Individually powered quad Q4 (1.9K)	MQY	2	8 (IR1/5)	4.5	4.86	74	0.65	CERN
	Orbit correctors Q4 (1.9K)	MCBY	8	32 (IR1/5)	0.088	0.1	5270	tdb	CERN
Q5	Individually powered quad Q5 (1.9K)	MQY	2	8 (IR1/5)	4.51	4.88	74	0.6	CERN
	Orbit correctors Q5 (1.9K)	MCBY	6	24 (IR1/5)	0.072	0.08	5270	tdb	CERN
Q6	Individually powered quad Q6 (4.5K)	MQML	2	8 (IR1/5)	4.31	4.66	21	0.47	CERN
	Orbit correctors Q6 (4.5K)	MCBC	2	8 (IR1/5)	0.08	0.09	2840	tdb	CERN

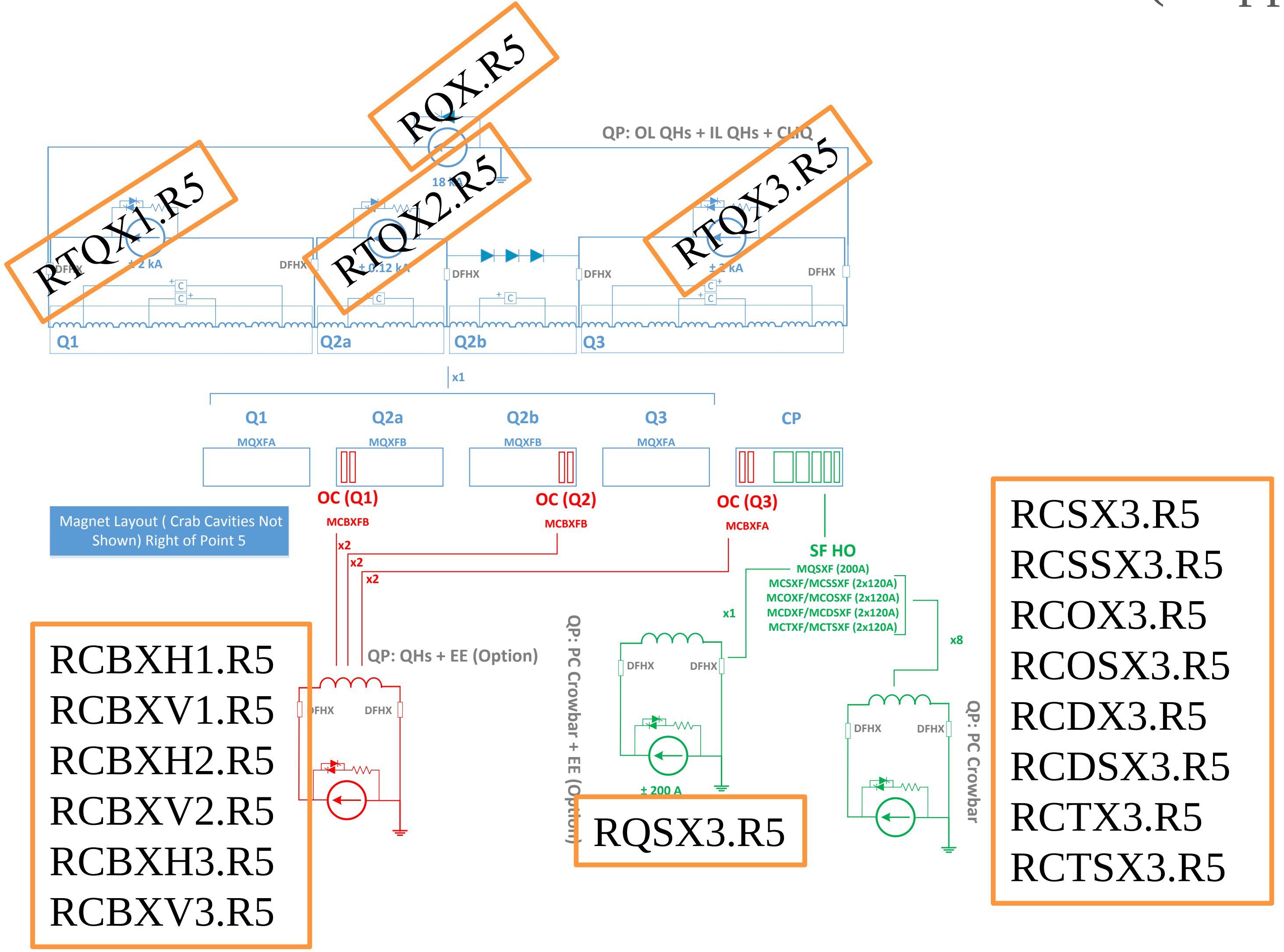
Circuits - WP3 | Circuits - WP11 | Beam Dynamics - WP2 | Cold Po... | ...oltage

Interlinked Sheets for different WPs

Circuits - WP3 | Circuits - WP11 | Beam Dynamics - WP2 | Cold Powering - WP6a | Power Converters - WP6b | **Protection - WP7** | Infrastructure - WP17 | DC Test Voltage

Nomenclature

- R + Optical Function + . + Machine Position + Beam Number (if applicable)



Inner Triplet Circuit + Orbit & HO Correctors

Samer Yammine for the MCF Meeting No.7 - 01/11/2016

Felix Rodriguez Mateos, TE/MPE

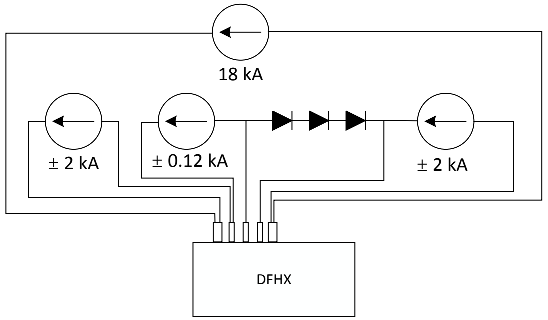
Outlook

- The work towards definition of magnet circuits intensively profits from the Magnet Circuit Forum where representatives of the involved WPs and activities are present
- The baseline of the HL-LHC magnet circuits . . .
  - has seen modifications in 2016 following the Circuits Review and re-baselining
  - is properly documented in TDR
- The baseline has some issues pending:
  - Rating of cold powering components in RQX circuit
    - Radiation dose/fluence for cold diodes
  - Powering scheme of matching section correctors
    - Series connection of MCBY
- Protection tests during model/prototype test campaigns are fundamental to confirm the choices
- Documentation has to accelerate now, especially with respect to 11T powering and protection and high voltage withstand levels for all circuit components
- Circuit Schemes work will continue in full swing until completion

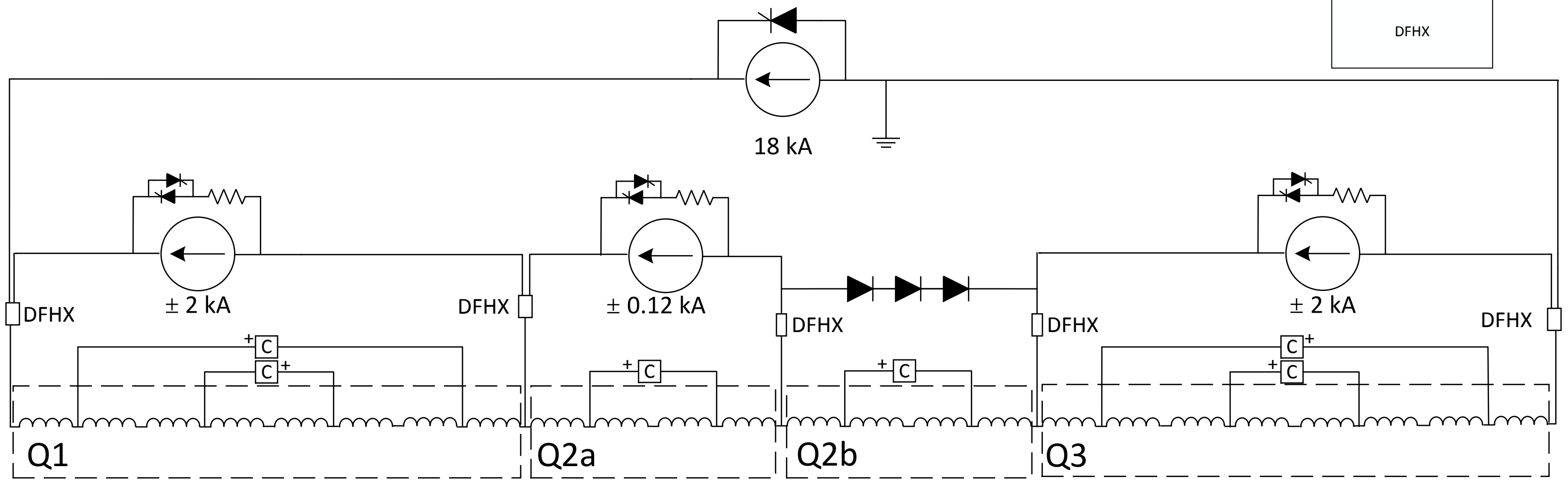
Thanks for your attention

Many thanks to all of those who participate to the Forum activities, to those who help keeping work efficient and those who promote the fruitful exchanges

Inner Triplet and Correctors

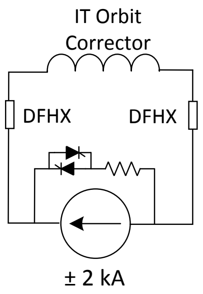


- 1 Circuit per IP side
- Power Converters:
  - 1 x18 kA 2 quadrants
  - 2 x 2 kA 4 quadrants
  - 1 x 0.12 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 18 kA leads
  - 3 x 2 kA leads (over currents due to failure scenarios are not taken into account)
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Outer layer quench heaters
  - CLIQ
  - Inner layer quench heaters
- Open Issues:
  - Overcurrent simulations
  - Cold powering rating



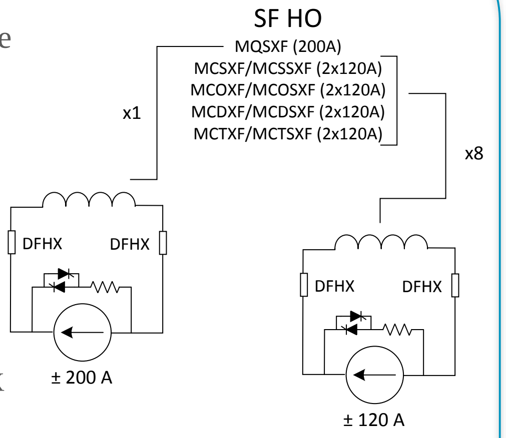
IT Orbit Correctors

- 6 Circuits per IP side
- Power Converters:
  - 6 x 2 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 12 x 2 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Quench heaters (baseline)
  - Energy extraction (Possibility)



Superferric High Order Correctors

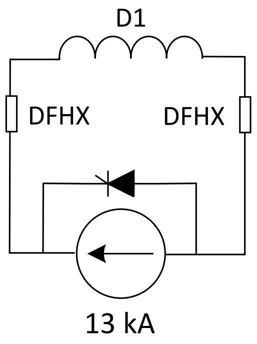
- 9 Circuits per IP side
- Power Converters:
  - 1 x 0.2 kA 4 quadrants
  - 8 x 0.12 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 0.2 kA lead
  - 16 x 0.12 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - PC crowbar



D1, D2 and Correctors; 11 Tesla Dipole

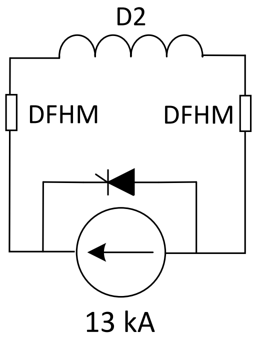
D1

- 1 Circuit per IP side
- Power Converters:
  - 1 x 13 kA 1 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 13 kA leads
  - Feedbox: DFHX @ UR
- Quench Protection:
  - Quench heaters



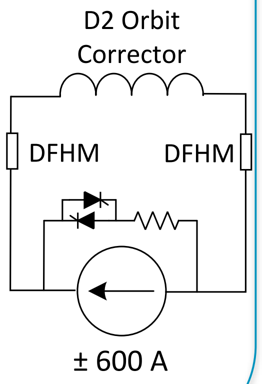
D2

- 1 Circuit per IP side
- Power Converters:
  - 1 x 13 kA 1 quadrants
  - Location: UR
- Cold Powering:
  - 2 x 13 kA leads
  - Feedbox: DFHM @ UR
- Quench Protection:
  - Quench heaters



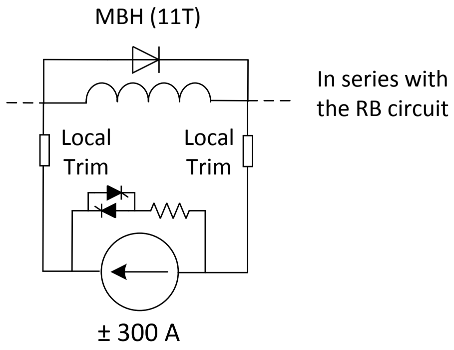
D2 Orbit Correctors

- 4 Circuit per IP side
- Power Converters:
  - 4 x 0.6 kA 4 quadrants
  - Location: UR
- Cold Powering:
  - 8 x 0.6 kA leads
  - Feedbox: DFHM @ UR
- Quench Protection:
  - PC Crowbar



11 Tesla Dipole

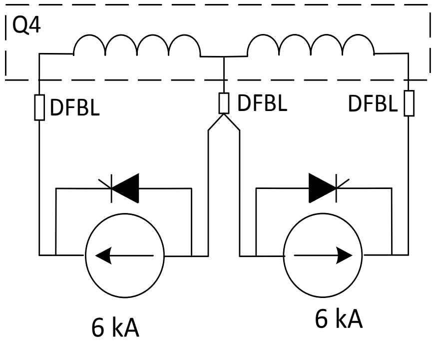
- Power Converters:
  - One power converter per circuit rated at ± 300 A
- Cold Powering:
  - Copper cables will be placed between the power converters placed in the TZ76 or RR and the local current leads of 11T trim.
- Quench Protection:
  - Quench heaters
  - Existing RB EE



Quadrupoles Q4, Q5 and Q6 and Correctors

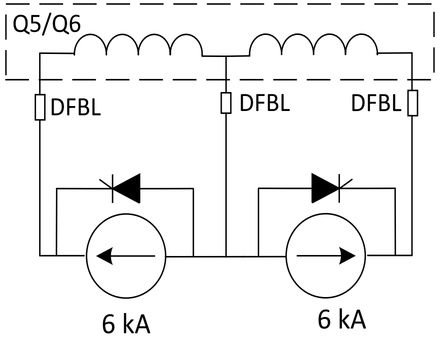
Q4

- 2 Circuit per IP side
- Power Converters:
  - 2 x 6 kA 1 quadrants
  - Location: RR
- Cold Powering:
  - 3 x 6 kA leads
  - Feedbox: DFBL @ RR
- Quench Protection:
  - Quench heaters



Q5/Q6

- 2 Circuit per IP side
- Power Converters:
  - 2 x 6 kA 1 quadrants
  - Location: RR
- Cold Powering:
  - 3 x 6 kA leads
  - Feedbox: DFBL @ RR
- Quench Protection:
  - Quench heaters



Q4 orbit corrector

- 8 Circuit per IP side
- Power Converters:
  - 8 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 16 x 0.12 kA leads
  - Feedbox: DFBL @ RR
  - Local powering (tbc)
- Quench Protection:
  - PC Crowbar

Q5 orbit corrector

- 6 Circuit per IP side
- Power Converters:
  - 6 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 12 x 0.12 kA leads
  - Feedbox: DFBL @ RR
  - Local powering (tbc)
- Quench Protection:
  - PC Crowbar

Q6 orbit corrector

- 2 Circuit per IP side
- Power Converters:
  - 2 x 0.12 kA 4 quadrants
  - Location: RR
- Cold Powering:
  - 4 x 0.12 kA leads
  - Local Powering
- Quench Protection:
  - PC Crowbar