RT (*) cables terminations and routing to current leads according to baseline

D. De Luca, J-Cl. Guillaume

(*) RT = Room Temperature

Table of Contents

Table of Contents

Electrical Circuit…as per Baseline

Warm cabling is located between current leads and power converters

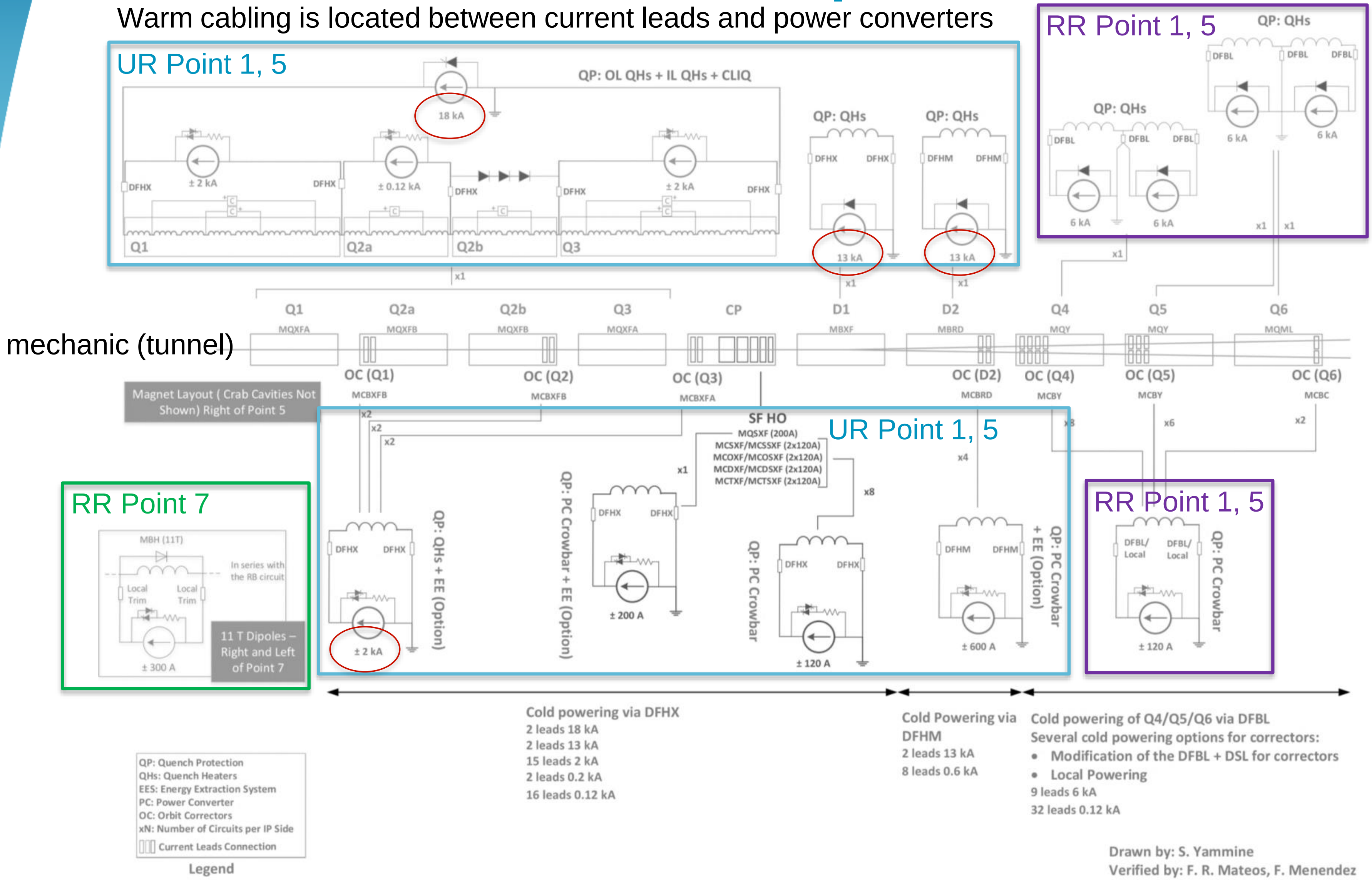

Table of Contents

- Electrical Circuit
- Cable Requirements
- Water Cooled Cables Specifications
- Installation Constraints
- Water Cooled Cable Layout
- Documentation
- Open Issues

Main Requirements…baseline

according to converter and DFH layout

	Circuits for HiLumi	Magnet Type	Number of circuits per IP side	Total number of circuits	I_nominal (7 TeV) [kA]	I_ultimate [kA]	I_cable [kA]	L per circuit [mH]	R per circuit [mΩ]	Power Converter Location	Cold Powering Feedbox	Cu section [mm2]	Length Warm Cables [m]	Nominal Total Cable Losses [kW]	Ultimate Total Cable Losses [kW]	Rated Total Cable Losses [kW]	Cable Type
Inner Triplet	Triplet Q1, Q2a, Q2b, Q3	MQXFA / MQFXB	1	4 (IR1/5)	16.5	17.82	18	255	0.264	UR	DFHX	2600	38	71.9	83.9	85.6	WCC
Inner Triplet	Trim Q1	-	1	4 (IR1/5)	2	2	2	69	1.44	UR	DFHX	500	40	5.8	5.8	5.8	WCC
Inner Triplet	Trim Q3	-	1	4 (IR1/5)	2	2	2	69	1.44	UR	DFHX	500	40	5.8	5.8	5.8	WCC
Inner Triplet	Trim Q2a	-	1	4 (IR1/5)	0.12	0.12	0.12	58.5	13.372	UR	DFHX	70	52	0.2	0.2	0.2	ACC
Inner Triplet	Orbit correctors Q2a/b - vertical	MCBXFB	2	8 (IR1/5)	1.6	1.73	2	59	1.512	UR	DFHX	500	42	7.8	9.2	12.2	WCC
Inner Triplet	Orbit correctors Q2a/b - horizontal	MCBXFB	2	8 (IR1/5)	1.47	1.59	2	135	1.656	UR	DFHX	500	46	7.2	8.4	13.4	WCC
Inner Triplet	Orbit correctors CP - vertical	MCBXFA	1	4 (IR1/5)	1.6	1.73	2	109	1.728	UR	DFHX	500	48	4.5	5.2	7	WCC
Inner Triplet	Orbit correctors CP - horizontal	MCBXFA	1	4 (IR1/5)	1.47	1.59	2	247	1.728	UR	DFHX	500	48	3.8	4.4	7	WCC
Inner Triplet	Superferric, order 2	MQSXF	1	4 (IR1/5)	0.182	0.2	0.2	1247	9.853	UR	DFHX	95	52	0.4	0.4	0.4	ACC
Inner Triplet	Superferric, order 3, normal and skew	MCSXF / MCSSXF	2	8 (IR1/5)	0.105	0.12	0.12	118	13.372	UR	DFHX	70	52	0.4	0.4	0.4	ACC
Inner Triplet	Superferric, order 4, normal and skew	MCOXF / MCOSXF	2	8 (IR1/5)	0.105	0.12	0.12	152	13.372	UR	DFHX	70	52	0.4	0.4	0.4	ACC
Inner Triplet	Superferric, order 5, normal and skew	MCDXF / MCDSXF	2	8 (IR1/5)	0.105	0.12	0.12	107	13.372	UR	DFHX	70	52	0.4	0.4	0.4	ACC
Inner Triplet	Superferric, order 6	MCTXF	1	4 (IR1/5)	0.105	0.12	0.12	229	13.372	UR	DFHX	70	52	0.2	0.2	0.2	ACC
Inner Triplet	Superferric, order 6, skew	MCTSXF	1	4 (IR1/5)	0.105	0.12	0.12	52	13.372	UR	DFHX	70	52	0.2	0.2	0.2	ACC
D1	Separation dipole D1	MBXF	1	4 (IR1/5)	12	12.96	13	27	0.27	UR	DFHX	2000	30	38.9	45.4	45.7	WCC
D2	Recombination dipole D2	MBRD	1	4 (IR1/5)	12	12.96	13	25	0.234	UR	DFHM	2000	26	33.7	39.4	39.6	WCC
D2	Orbit correctors D2	MCBRD	4	16 (IR1/5)	0.5	0.54	0.6	600	1.08	UR	DFHM	400	24	1.2	1.6	1.6	ACC
Q4	Individually powered quad Q4 (1.9K)	MQY	2	8 (IR1/5)	4.5	4.86	6	74	0.65	RR	DFBL	800	28.5	26.4	30.8	46.8	WCC
Q4	Orbit correctors Q4 (1.9K)	MCBY	8	32 (IR1/5)	0.088	0.1	0.12	5270	tdb	RR	DFBL/Local Powering						ACC
Q5	Individually powered quad Q5 (1.9K)	MQY	2	8 (IR1/5)	4.51	4.88	6	74	0.6	RR	DFBL	800	26.5	24.6	28.6	43.2	WCC
Q5	Orbit correctors Q5 (1.9K)	MCBY	6	24 (IR1/5)	0.072	0.08	0.12	5270	tdb	RR	DFBL/Local Powering						ACC
Q6	Individually powered quad Q6 (4.5K)	MQML	2	8 (IR1/5)	4.31	4.66	6	21	0.47	RR	DFBL	800	20.7	17.6	20.6	34	WCC
Q6	Orbit correctors Q6 (4.5K)	MCBC	2	8 (IR1/5)	0.08	0.09	0.12	2840	tdb	RR	Local Powering						ACC
11T	11T dipole, MBH	11T dipole, MBH	-	2 (IR7)	11.85	12.798	13	15734									
11T	Trim circuit	-	-	2 (IR7)	0.25	0.25		127.1	15	TZ76	Local Trim Powering	1200	1000	0.94			ACC

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Cable Type Selection

- Based on the requirements shown before
- Taken into account the rated current of cables (I_{cable})
  - Constraints: decrease power losses to minimise heat dissipation
  - → If $I_{cable} \leq 600$ A → Standard air cooled cable (ACC)
  - → If $I_{cable} > 600$ A → Water cooled cable (WCC)

Intensity	Type
120 A	ACC
200 A	ACC
600 A	ACC
2 kA	WCC
13 kA	WCC
18 kA	WCC

Cable Section Selection

- ACC section selection: norm NF C 15-100 assuming
  - three cable layers (0.73 of $I_{cable\ r}$*)
  - $\geq$ 9 cables touching on cable ladders (0.78 of $I_{cable\ r}$*)
  - → Resulting factor of 0.57 of $I_{cable\ r}$*

- WCC section selection: technological constraints → LHC and other experiences at CERN
  - 500 mm^2 rated at 3.5 kA → 7 A/mm^2
  - 1300 mm^2 rated at 8 kA → 6.2 A/mm^2
  - 2000 mm^2 rated at 13 kA → 6.5 A/mm^2

* $I_{cable\ r}$: rated current of a single cable without taking into account installation reduction factors

Cable Proposal by EN-EL…baseline

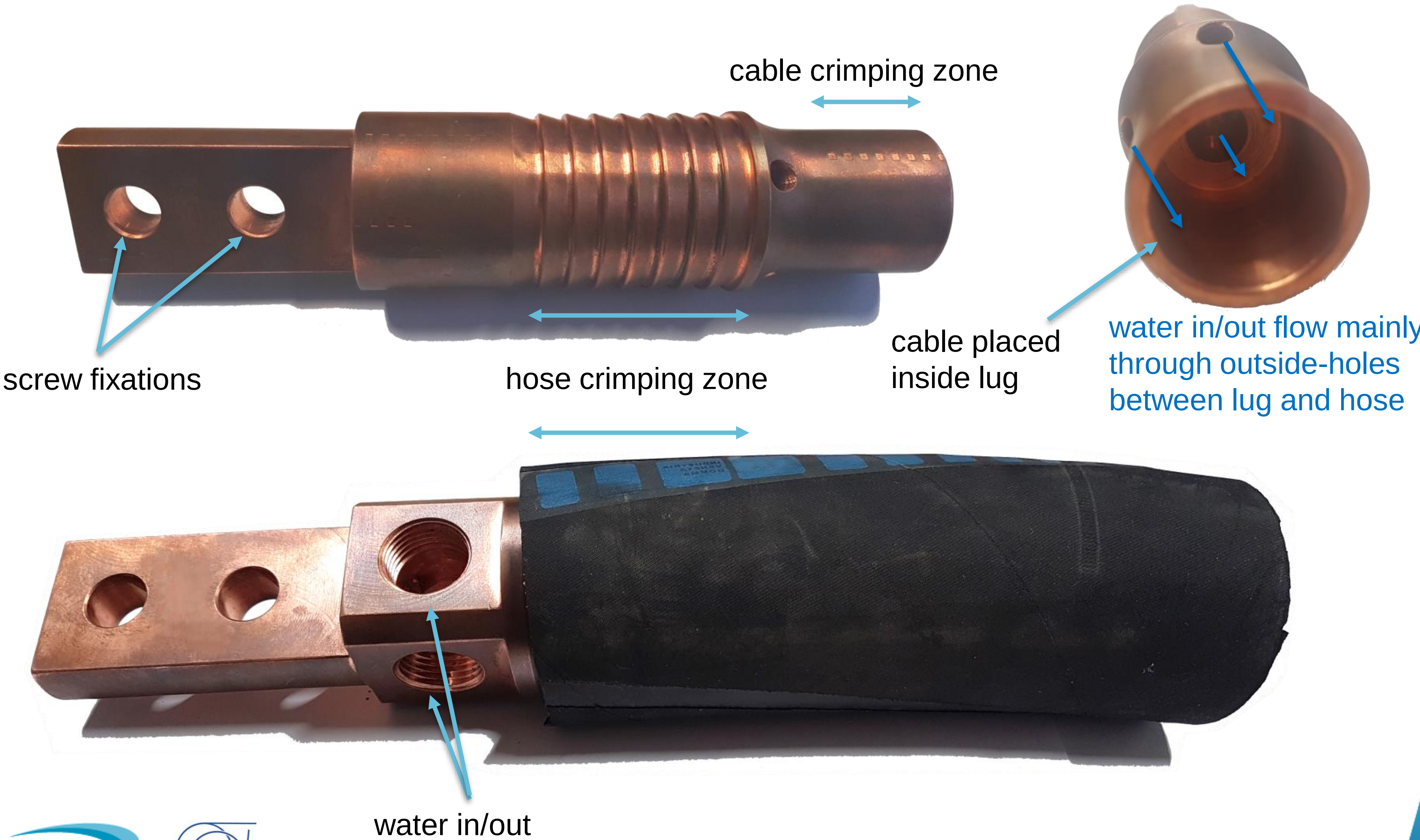
Intensity	Section [mm^2]	Type
120 A	70	ACC
200 A	95	ACC
600 A	400	ACC
2 kA	500	WCC
13 kA	2000	WCC
18 kA	2x1300	WCC

- Remarks
  - Standard ACC are well known at CERN
  - Further studies focused on WCC

Table of Contents

Introduction to WCC’s

Example: WCC lug, 500 mm² – FLOHE company



WCC Technologies

Cable bundle crimped on the lug:
WCC without spring (FLOHE, 2000mm^2)

Cable bundle braised on the lug:
WCC with spring (BRAR, 2000mm^2)

Main WCC Suppliers in Europe

- Three main suppliers in Europe
- Relevant information taken from suppliers catalogues
  - Suppliers usually provide cables with non-standard sections

<table>
<tr><th>FLOHE</th><th>BRAR</th><th>GECSA</th></tr>
<tr><td>Standard Sections [mm^2]</td><td>Standard Sections [mm^2]</td><td>Standard Sections [mm^2]</td></tr>
<tr><td>500</td><td>900</td><td>2500</td></tr>
<tr><td>800</td><td>1200</td><td rowspan="5">No cables below 2500 mm^2</td></tr>
<tr><td>1000</td><td>1500</td></tr>
<tr><td>1300</td><td>1800</td></tr>
<tr><td>2000</td><td>2100</td></tr>
</table>

WCC with cable bundle crimped on lug

WCC with cable bundle braised on lug

LHC WCC Specifications

Cross-section [mm^2]	Nominal current [kA]	Leakage current [μA/m]	DC voltage test level [kV]
500	3.5	10 @ 3.0 kV	3
800	6.0	20 @ 1.5 kV	3
1000	8.0	20 @ 1.5 kV	3
1300	8.0	30 @ 1.5 kV	3
2000	13.0	40 @ 3.0 kV	3

Normal usage	
Voltage level	500 V DC
Highest transitory voltage	500 V
Operating temperature (hose)	50 °C
Cooling water pressure in operation	16 bar
Rated pressure	24 bar
Water pressure drop	< 2 bar
Water speed	< 2.5 m/s
Maximum input water temperature	28 °C
Maximum delta T (water in/out)	15 K

LHC WCC Installation Example: DFBAK.5L6

6 kA
1000 mm²

13 kA
2000 mm²

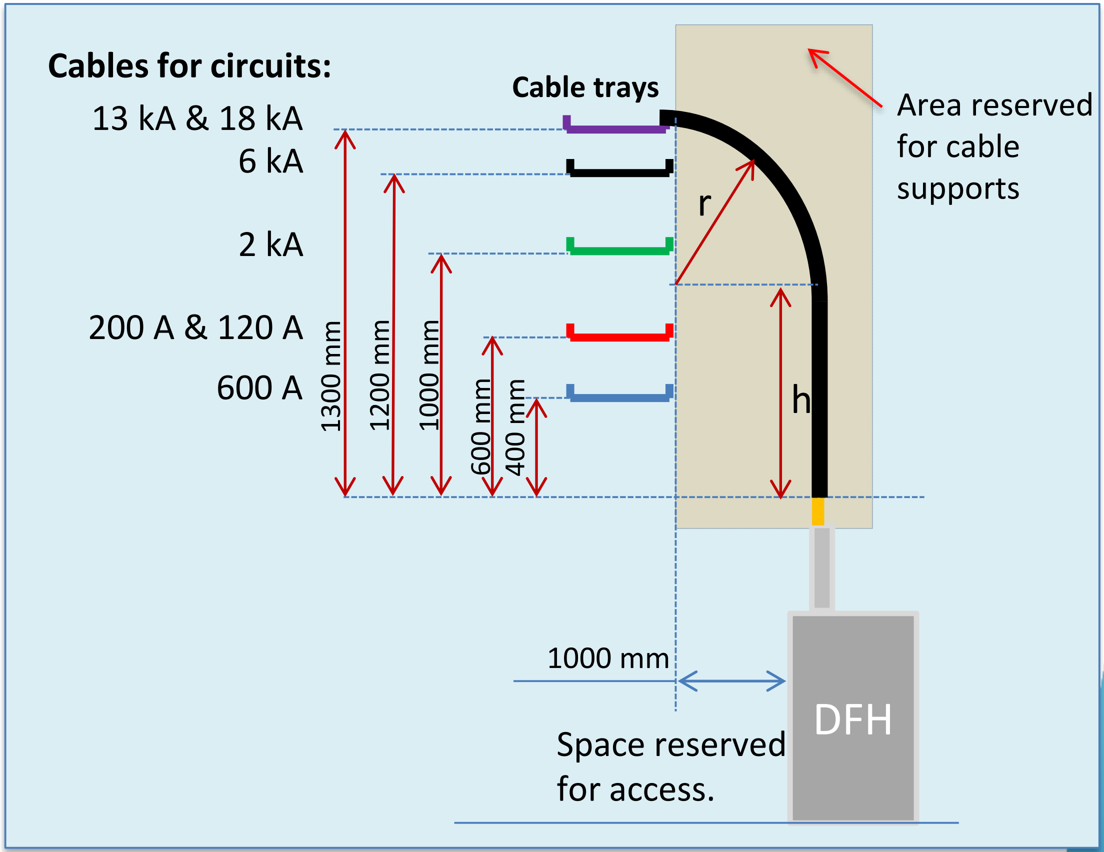
Table of Contents

- Electrical Circuit
- Cable Requirements
- Water Cooled Cables Specifications
- Installation Constraints
- Water Cooled Cable Layout
- Documentation
- Open Issues

Dimensional Constraints

Intensity	Section [mm²]	h [mm]	r [mm]	Ext. Diam. [mm]
18 kA	2x1300	500	800	2x95
13 kA	2000	500	800	115
6 kA	1000	500	700	95
2 kA	500	500	500	70
600 A	400	300	300	36
200 A	95	200	200	25
120 A	70	150	150	22

most significant constraints



Accessibility

- Accessibility to WCC support (installation & maintenance)
- Space needed for installation
  - Large bending radius
  - Manipulation of the cable
  - Demineralised water infrastructure

→ Cable installation to be done before placing DFH's

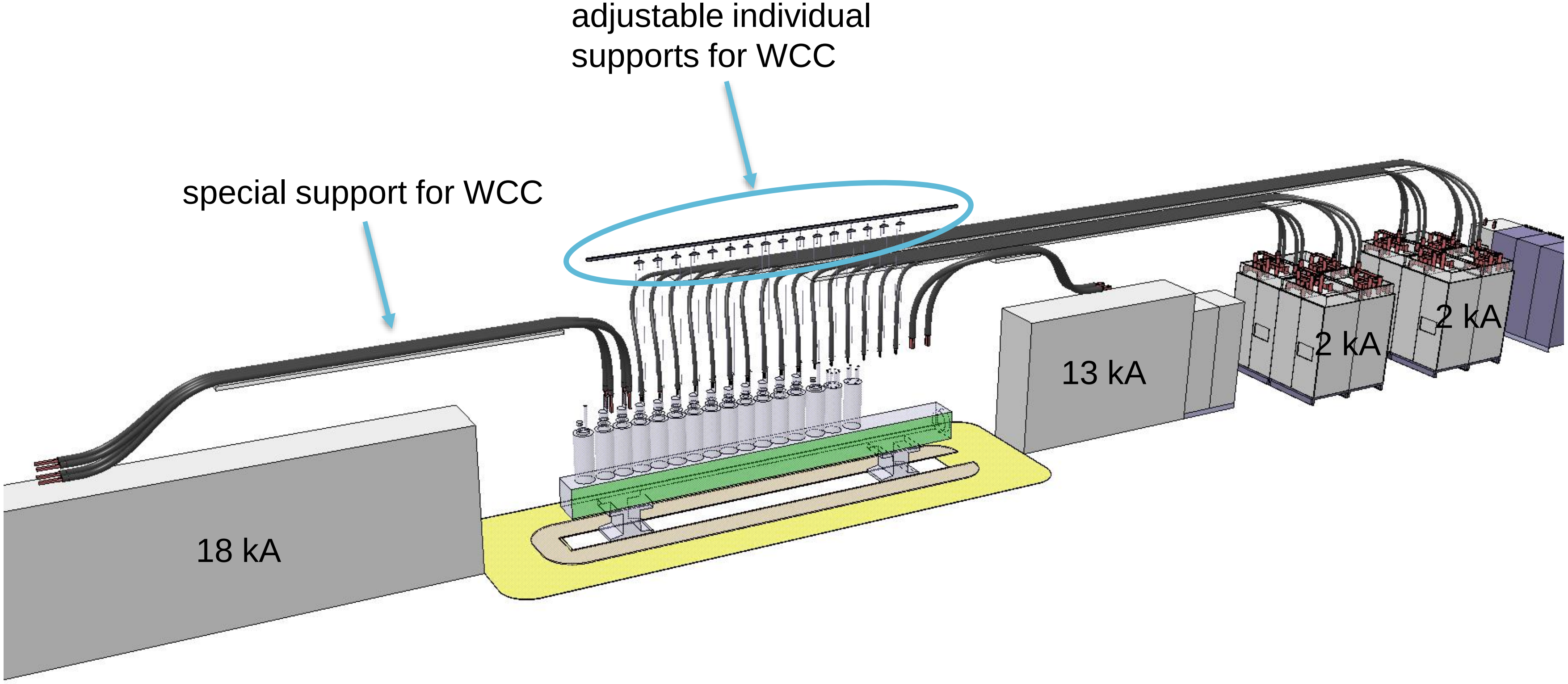
Mockup DFB (LHC installation)

Mockup power converters (LHC installation)

Table of Contents

Power Converter and DFHX Layout (1/2)

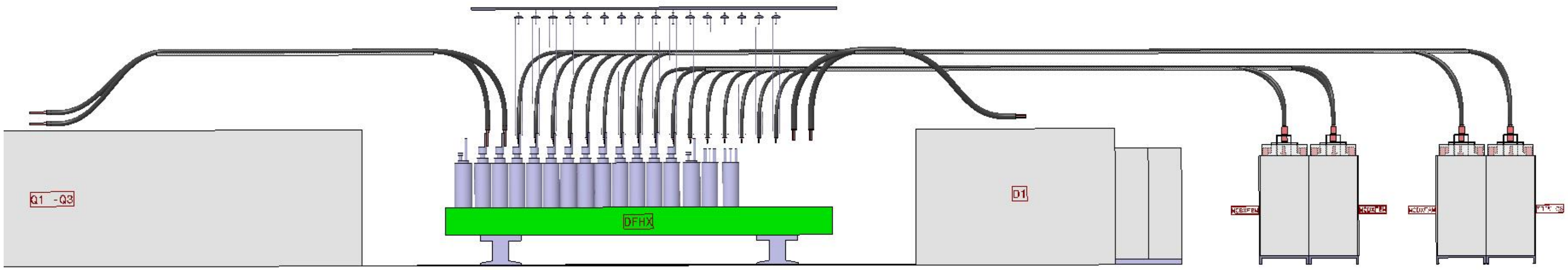
Layout only for WCC



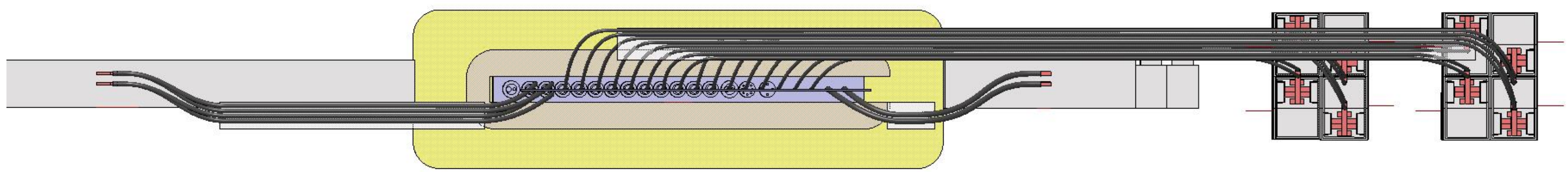
Proposed layout with max 2 cables per current lead

Power Converter and DFHX Layout (2/2)

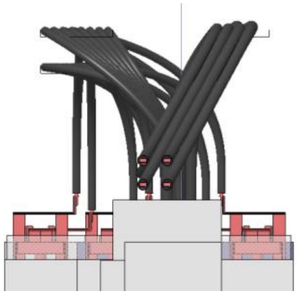
Front view



Top view



Side view



Cable tray positioning constraints:

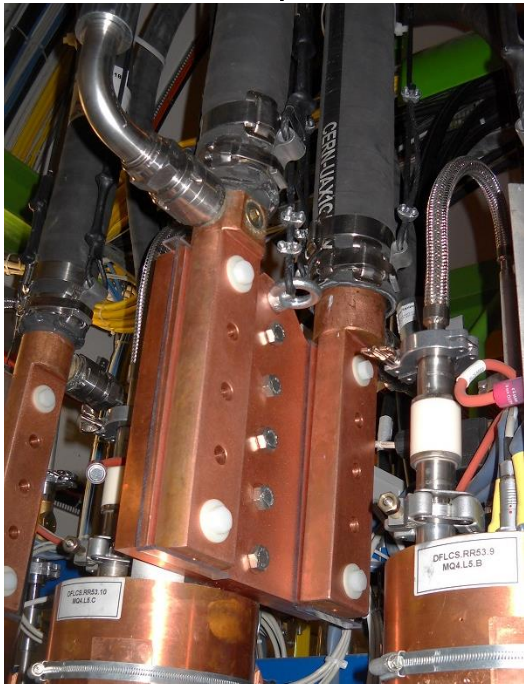
- Depending on converter/DFH alignment
- Maintain current leads accessible and removable (LHC)
- Cables shall not exert mechanical stress on the current leads when connected

→ cable trays are not aligned in order to fulfill the constraints

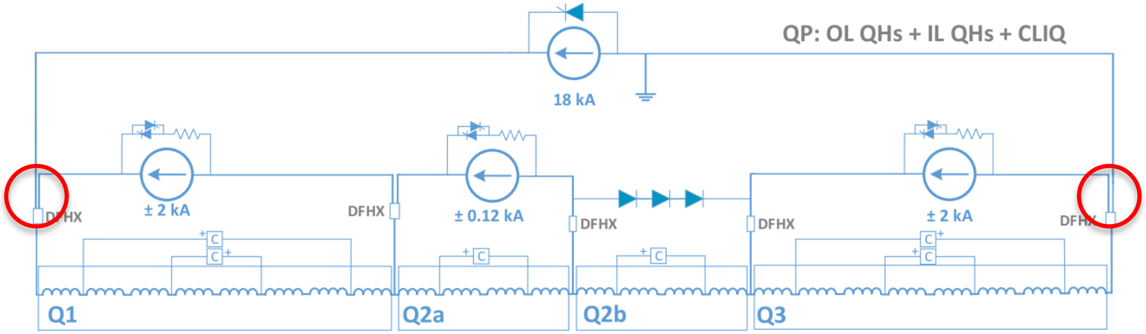
DFH Interface for 3 Cables

- 3 cables per current lead at DFHX
  - 2x1300 mm^2
  - 1x500 mm^2

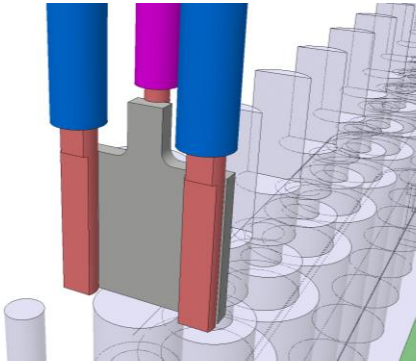
Applied solution for LHC TOTEM 2 cables per current lead



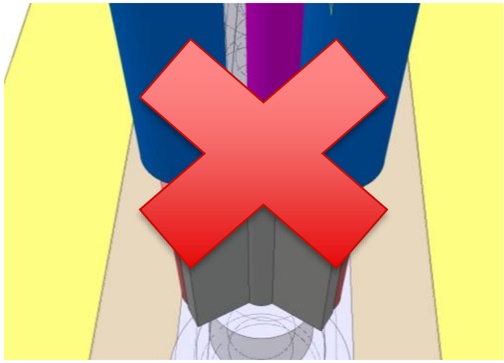
DFHX – 3 cables per current lead



HL-LHC: Solution 1



HL-LHC: Solution 2



Not to be used as discussed with Jerome Feiter

Current Lead Interface for WCC Cables

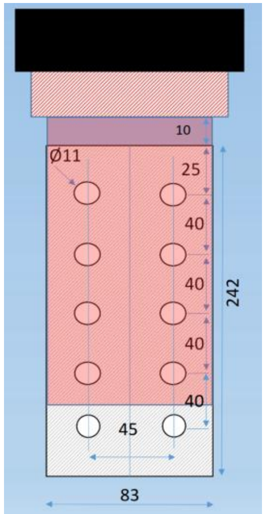
Constraint: Same Interface with Current Lead

- 13kA
  - WCC 1x2000 mm^2

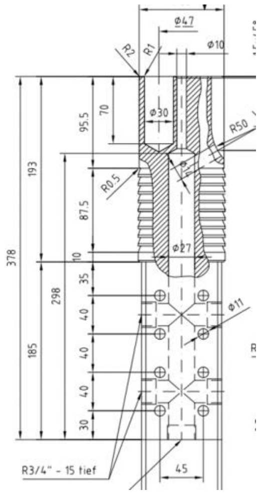
Current Lead dimensions (WxH)
83 x 242 mm

Current density
0.89 A/mm^2

S_{Lead} = 20086 mm^2

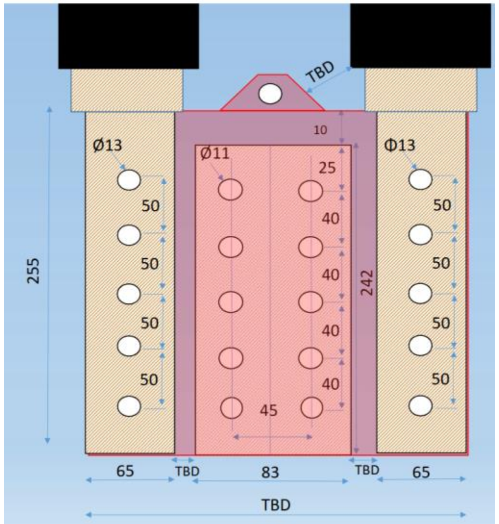


WCC 2000 mm² Lug
FHWI 2000C

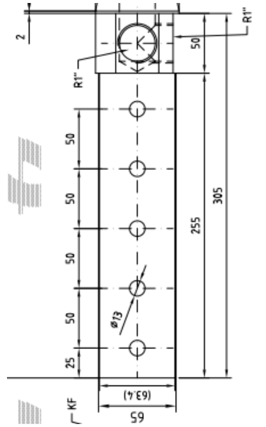


- 18kA
  - WCC 2x1300 mm^2

Proposed solutions to be confirmed after integration study



WCC 1300 mm² Lug
FAA 1300



HiLumi HL-LHC PROJECT

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Current Lead Interface for WCC Cables

- 2kA
  - WCC 500 mm^2

Current Lead dimensions (WxH)
40 x 76 mm

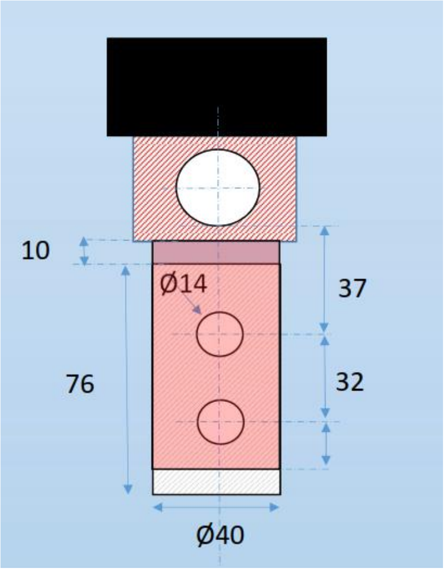
Current density
0.76 A/mm^2

$S_{Lead} = 3040\ mm^2$

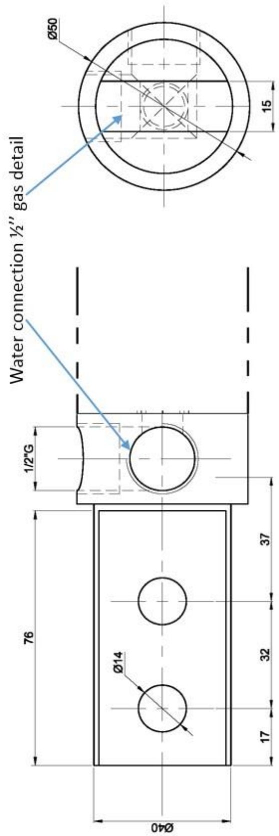
Contact Surface
40 x 66 mm

$S_{contact} = 2640\ mm^2$

Proposed solutions to be confirmed after integration study



WCC 500 mm^2 Lug water entrance ½" GAS



Current Lead Interface for WCC Cables

WCC not on the same plane

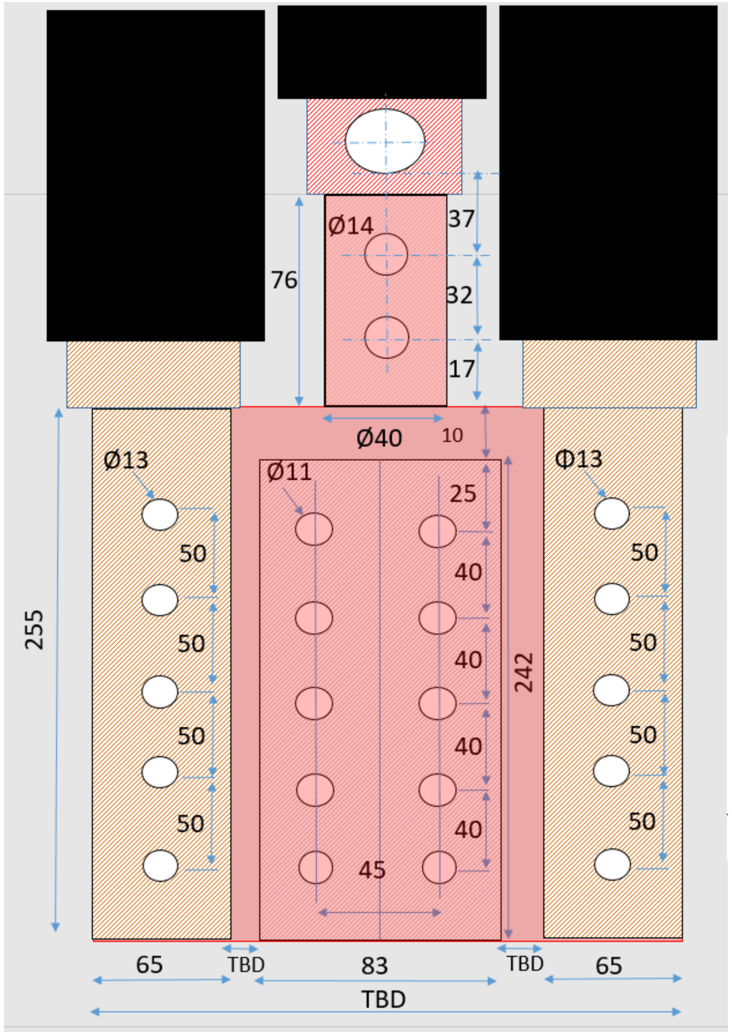
- 18kA + 2kA (TRIM)
  - WCC 2x1300 mm^2 +1x500 mm^2

Current Lead dimensions (WxH)
83 x 242 mm

Current density
0.89 A/mm^2

S_{Lead} = 20086 mm^2

Proposed solutions to be confirmed after integration study



Current Leads / Converters
Arrival of cables on equipment

- I – Vertical on Current Leads

- Requires Suspension / Supports to avoid stress on current lead

- II – Vertical on Converter Bus Bar

- Dedicated Cable tray
- Support (avoid damage of the hose)

Current Leads / Converters Interface for WCC Cables

- III – Horizontal on Converter busbar

- Less stress on bus bar
- Cable need space on Converter side
- No Suspension / Support from top
- Plates between Converter and cables

- IV - Inclined on current Leads

- Reduce stress on current leads
- Suspension / Support
- Reduce space between Current lead and vault
- Possible Angle 30º

Table of Contents

- Electrical Circuit
- Cable Requirements
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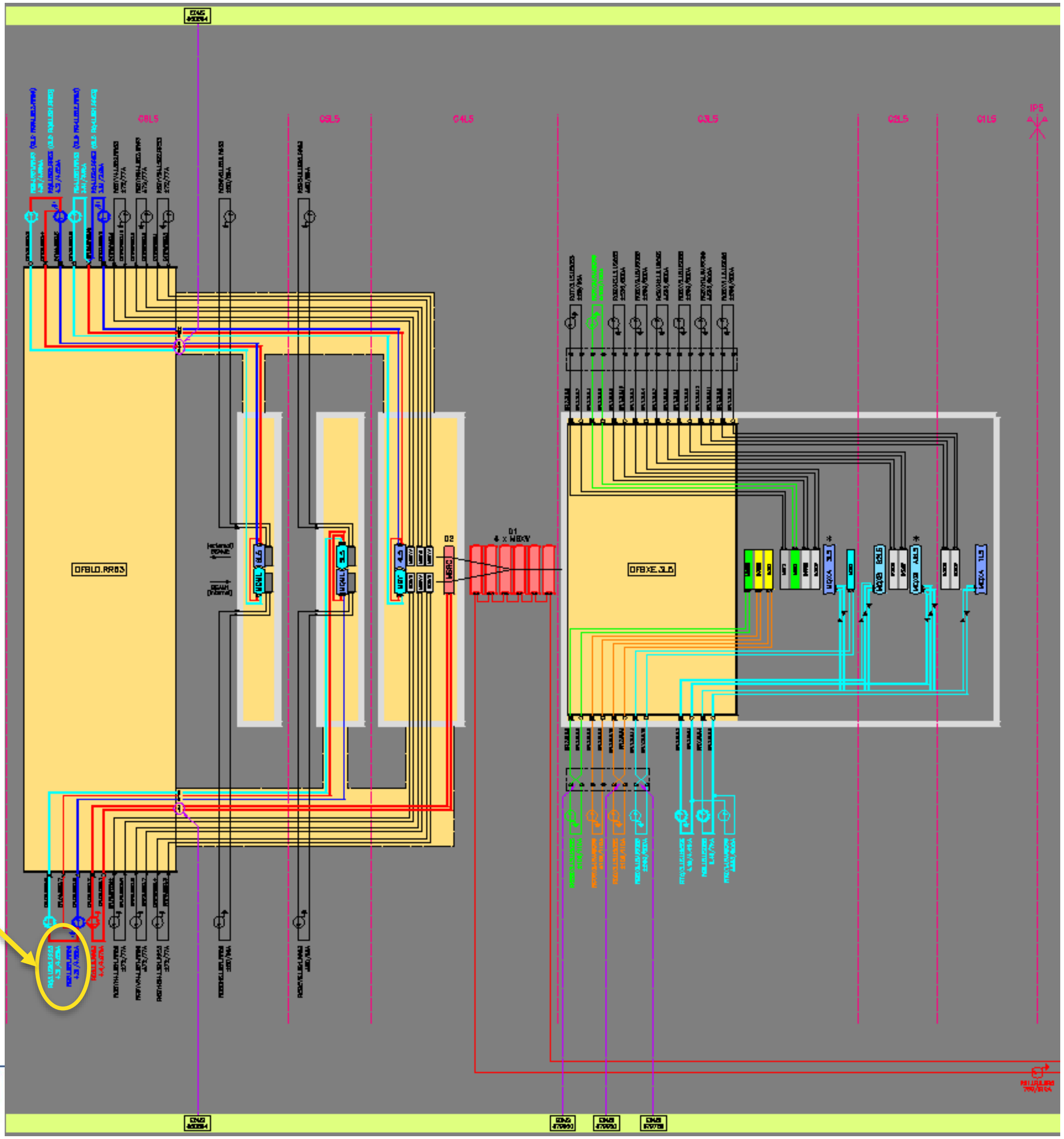
- Open Issues

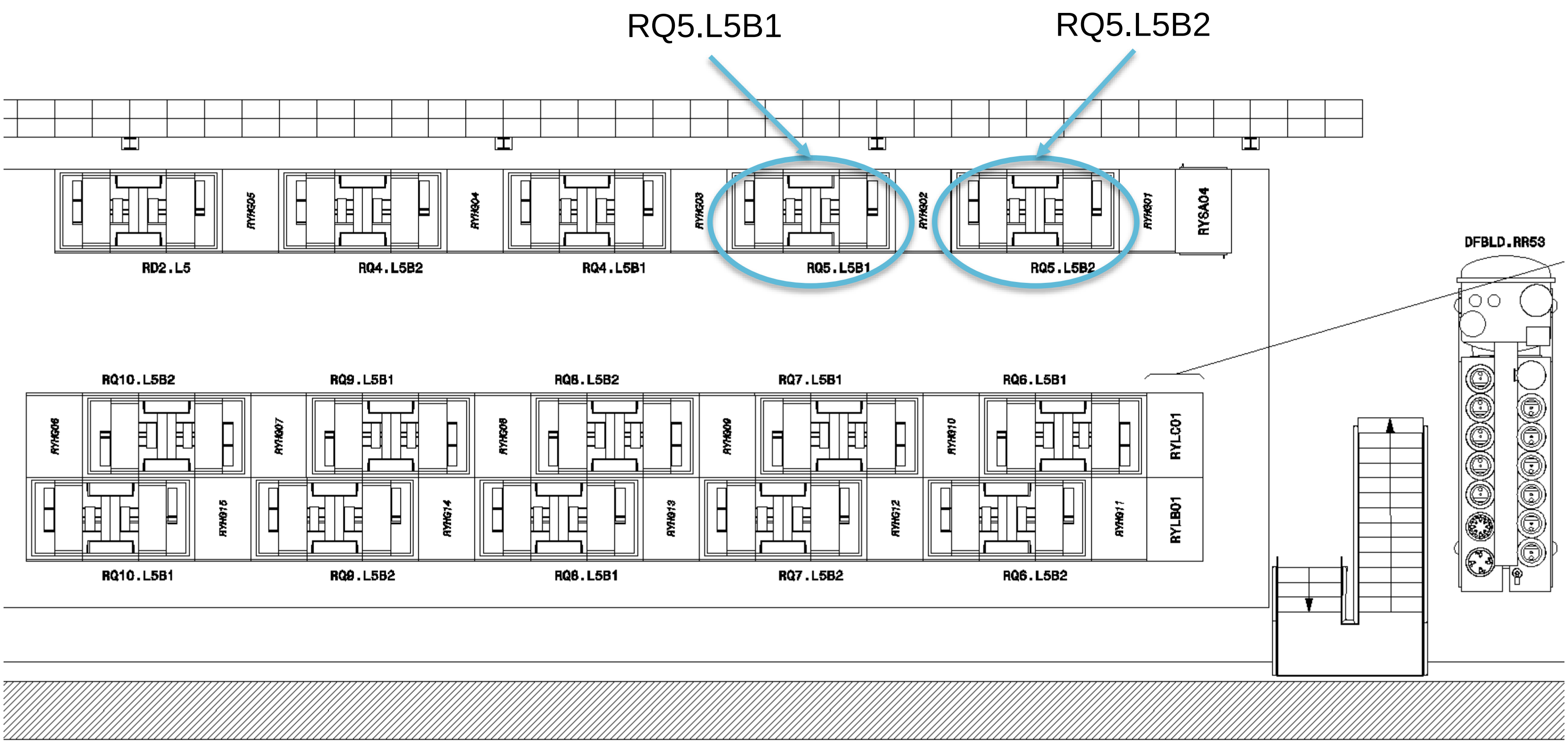
LHC DC-Scheme Example: Point 5 Left

HL-LHC DC scheme ongoing



RQ5.L5B1
RQ5.L5B2

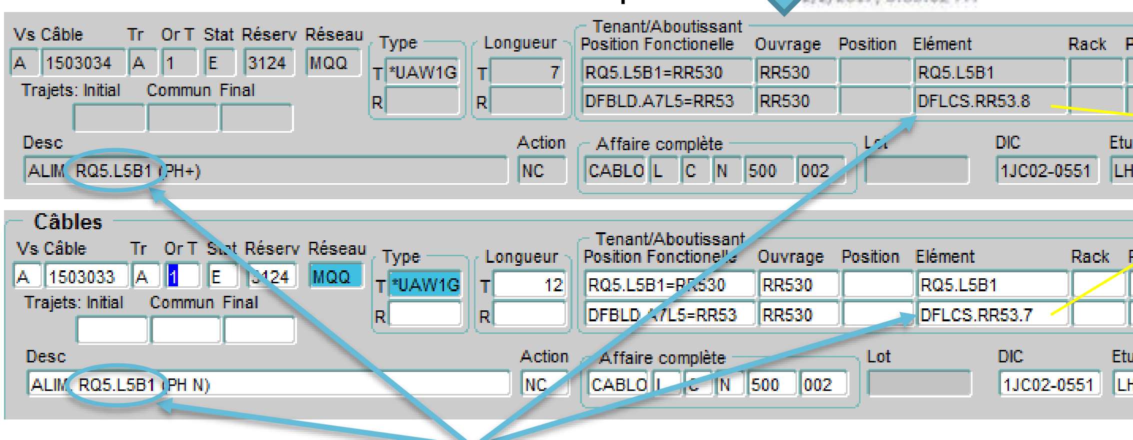
LHC Equipment Layout Example: RR53

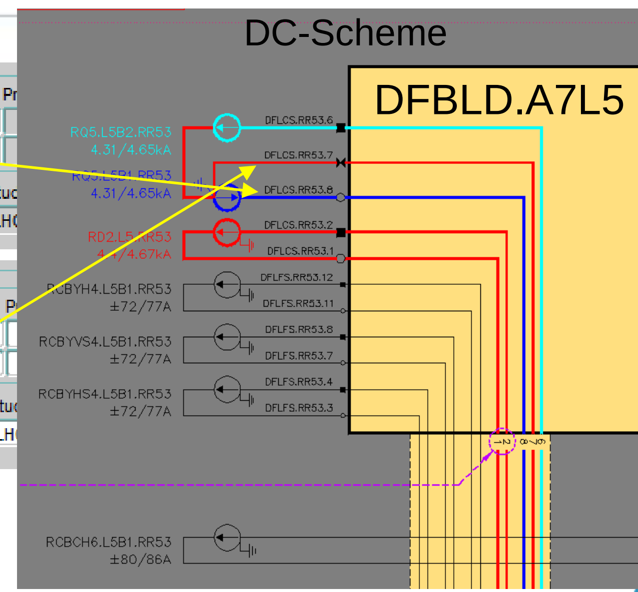


Existing Relation between Databases: Example of 2 Cables Installed at LHC RQ5.L5

Technical database – Layout Database

Database for installations – Cablothèque





Elements (circuit names) make link between databases

Table of Contents

- Electrical Circuit
- Cable Requirements
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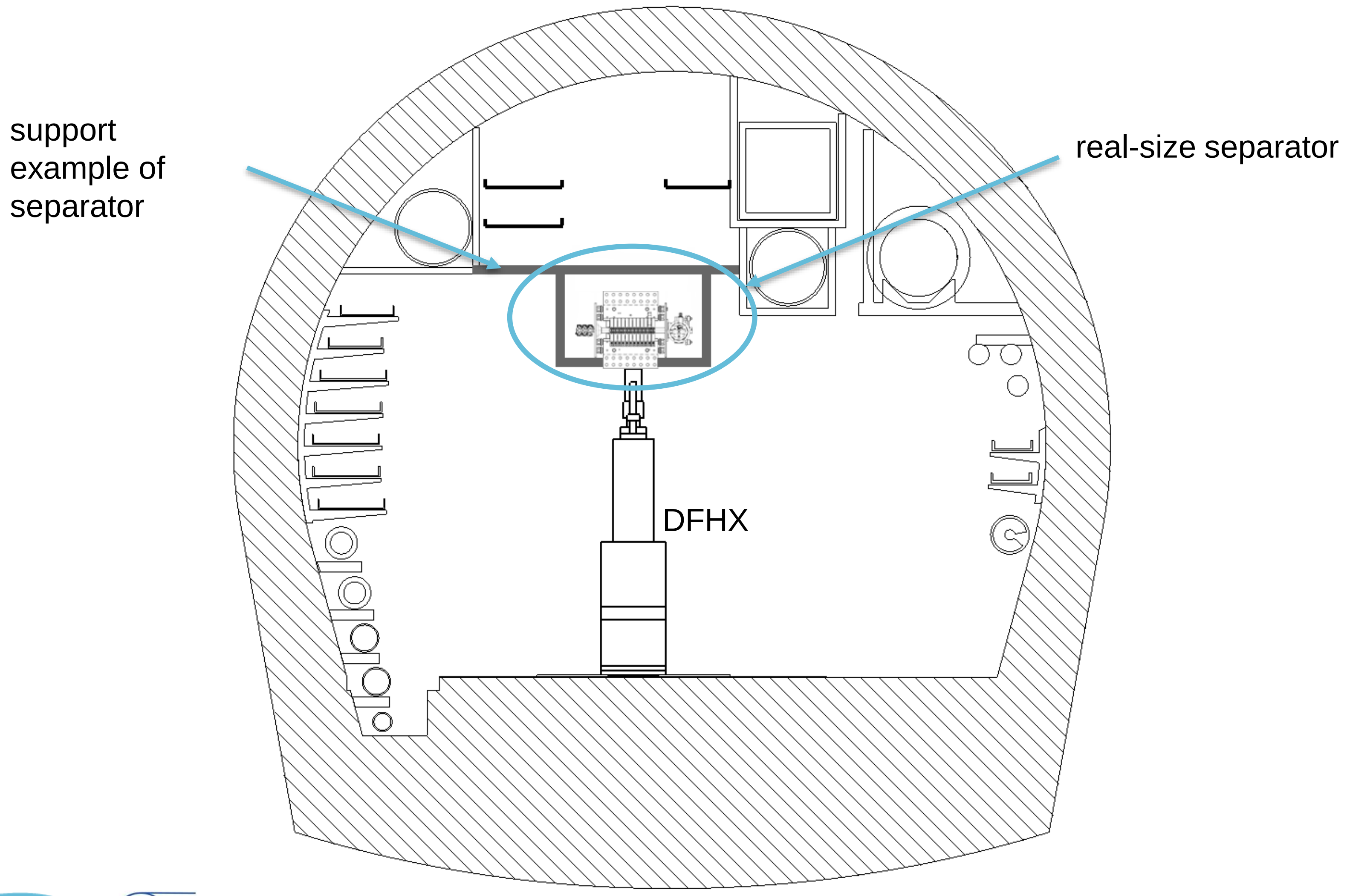
Open Issues

- Sections Optimised?
  - Cables adapted to electrical circuit parameters ?
  - Current profile ?
  - Other constraints ?
- Position and size of DFH’s?
  - For further studies on cabling → details on DFH’s and power converters necessary (exact position, connection technology)
- Separator (Disconnector) ?

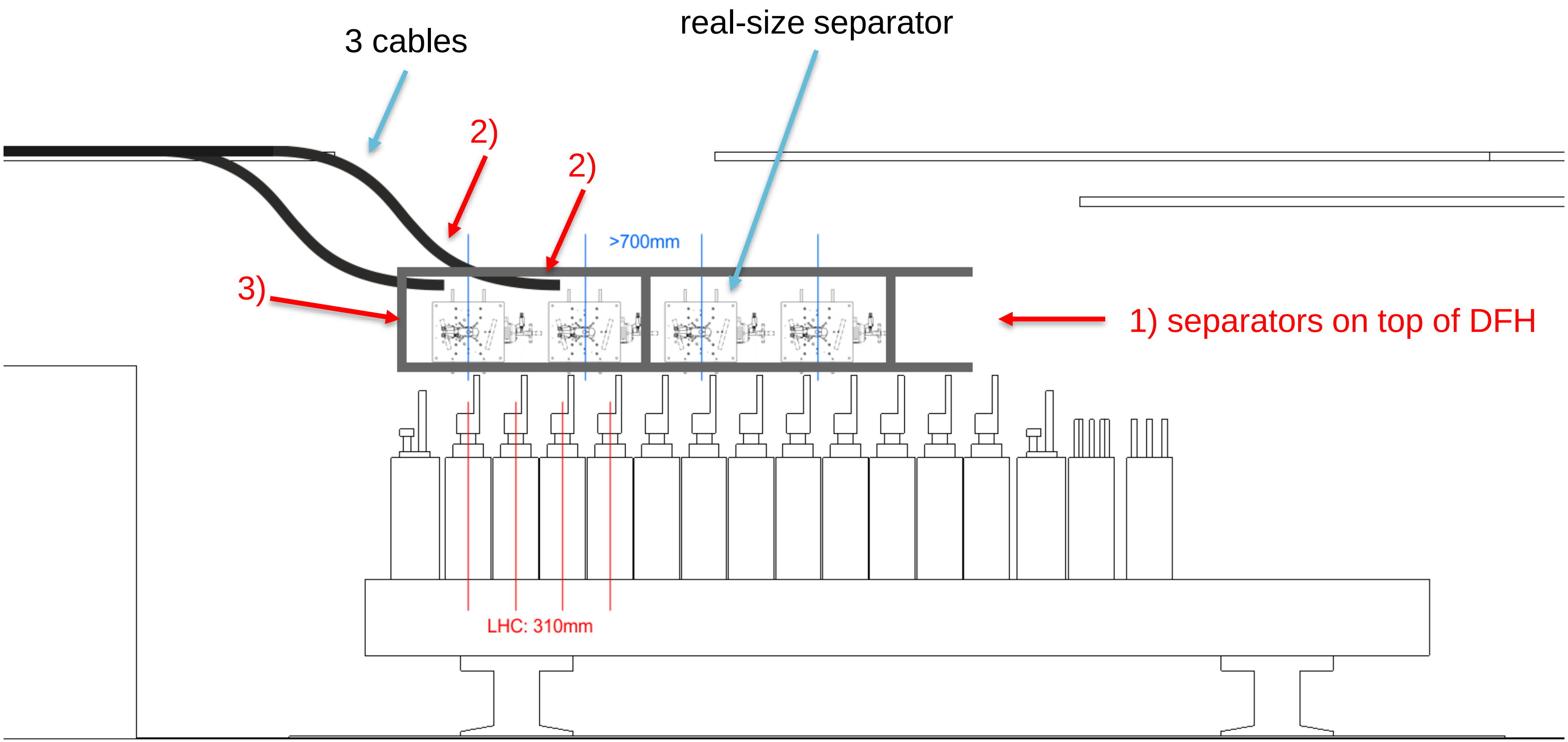
First Attempt of Separator Location (1/2)

HL-LHC UR-section



First Attempt of Separator Location (2/2)

Possible to locate separators on top of current leads?



Open Questions (?)

1) Decision about circuit separators
   - Are they needed?
   - What model, which size (technical specifications)
   - Adaptation to cable connection constraints: Interfaces/adaptation of standard model?
   - For commissioning of DC-circuits – short-circuit test: How to integrate separator in the test?
2) How to connect WCC's to separator?
   - Allowable weight of cables on separator?
   - Space for WCC & water flexibles sufficient?
   - Accessibility to WCC guaranteed during and after installation?
3) How to support/fix separator?
   - Possible conflict with WCC accessibility?

Thank you for your attention!

Additional Slides

Cable Bending Radius Dependence

- External diameter
- Hose thickness
- Hose material and constitution
- Applied water pressure
- Cable section
- Wire section
- Way of winding wires to a bunch
- Winding step (distance per turn of wire/bunch)
- Technology: spring/no spring