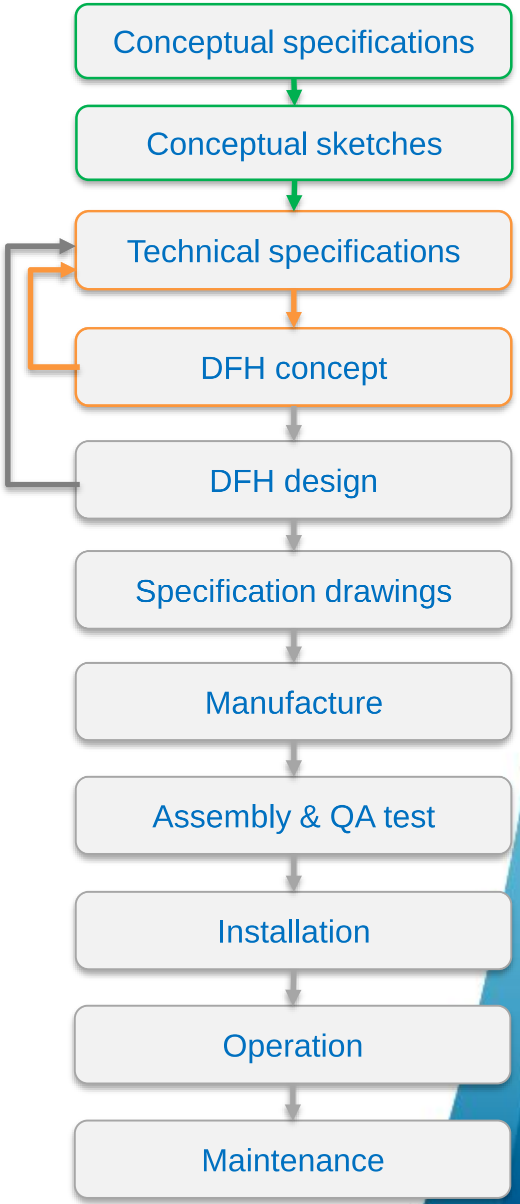
DFH-DFM meetings

- 7 Nov. #1: Conceptual Specifications
- 14 Nov. #2: DFHx : Layout & Splices
- 21 Nov. #3: Thermo-mechanical engineering
  - Thermal Contraction Strategy
  - Convective Heat Transfer : Fluid↔Splice

- Topics:
  - DFM: specifications & status



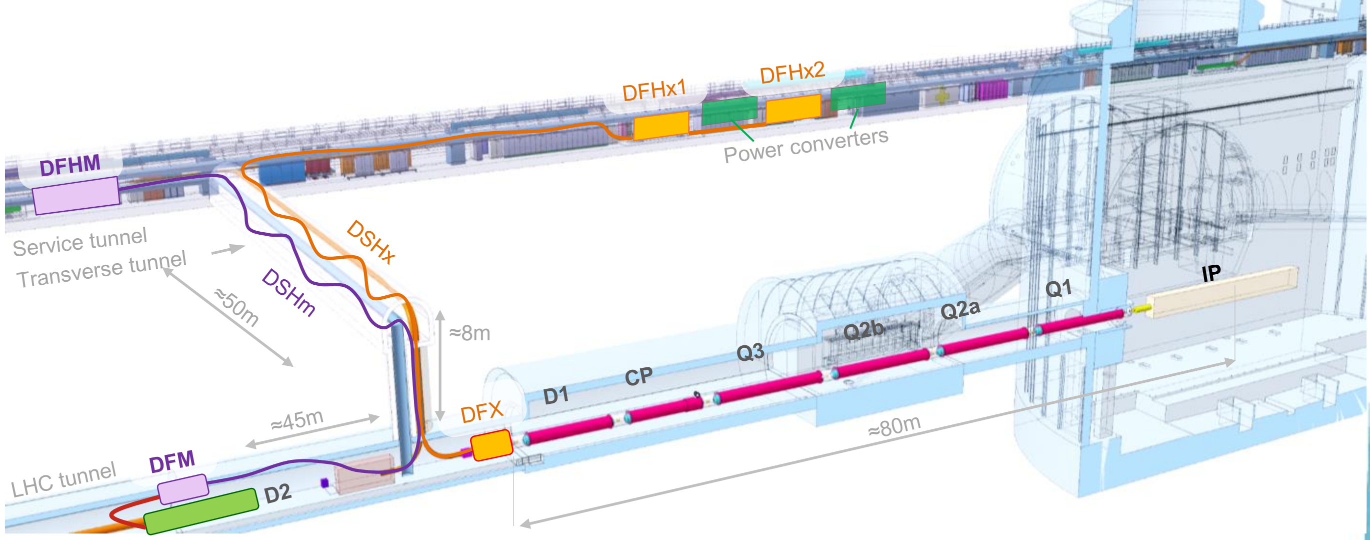
Overview

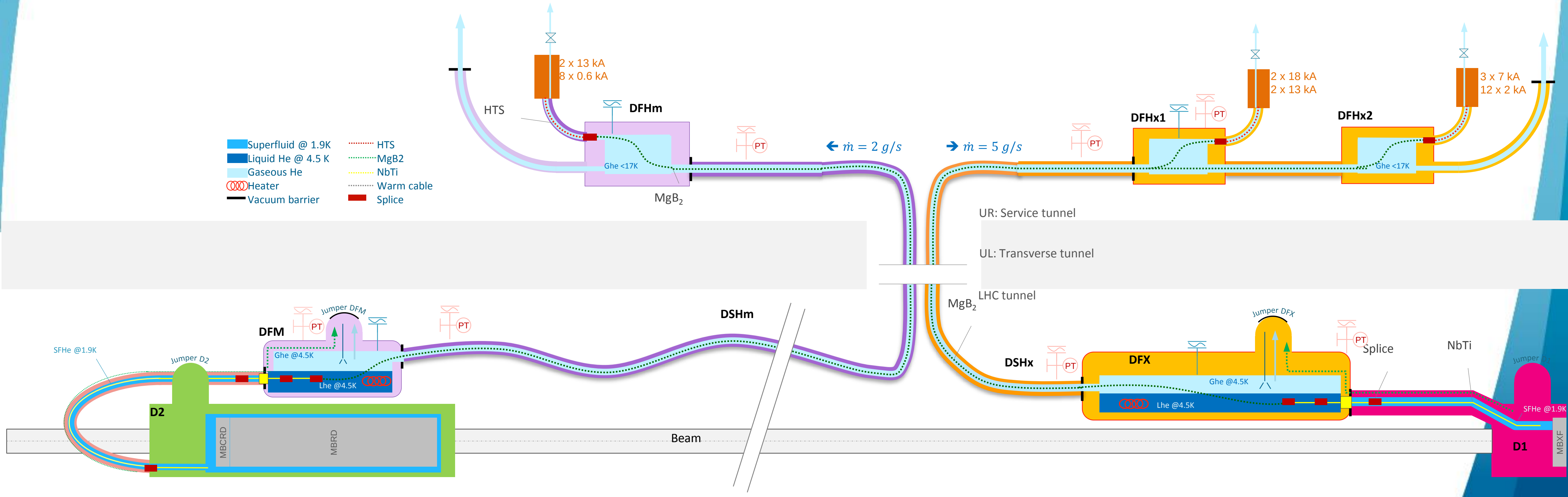
Each IP1 and IP5 sides equipped with 2 cold powering chains of cryostats

- Triplet insertion : DFHx – SC Link (DSH) – DFX
- Matching sections : DFHm – SC Link - DFM

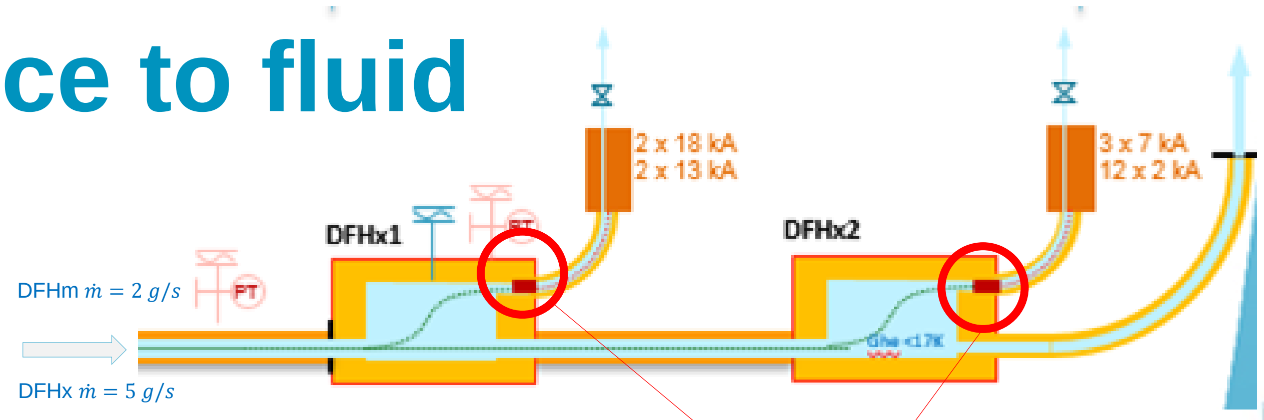
DFX/DFM basic functions:

- Electrical interface between SC Link and superconducting magnets
- Supply cryogenics to the SCLink



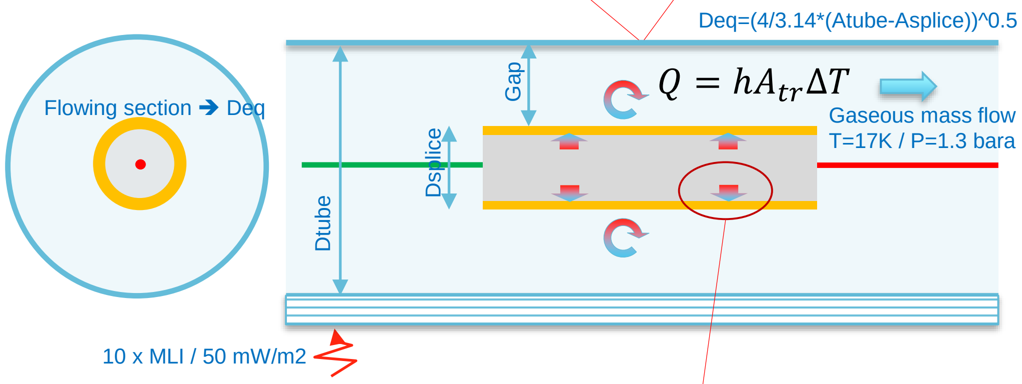


Heat transfer from source to fluid



- Objective:
  - $T_{MgB2\ cable}$ & $T_{MgB2\ splice}$ < 20 K

- Heat sources:
  - Static:
    - Heat loads to He vessel (conduction/radiation)
    - Ghe flow + MLI ➔ $T_{fluid} \approx T_{vessel\ walls}$
  - Dynamic:
    - Transverse current through resistive material (Monel, REBCO tape) within splice (see meeting#2)
    - Values from Jerome F meeting #2

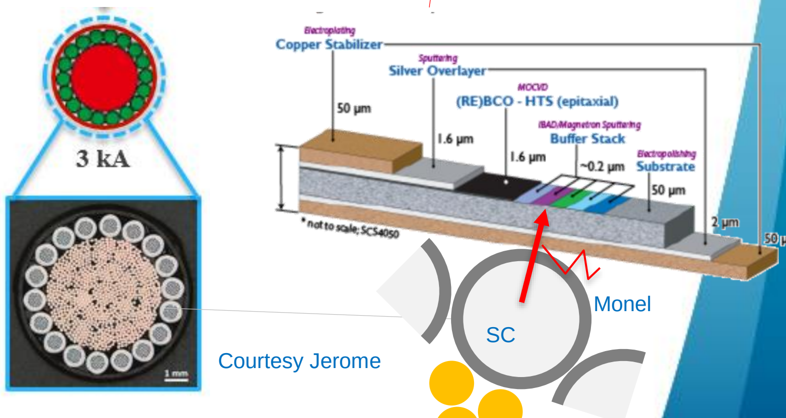


- Heat extraction:
  - Convective heat transfer between splice surfaces and fluid
  - ➔ design to improve heat transfer

Dissipated power in DFH splices

R design factor	1.5	Resistance			Dissipated power			
					Per splice		Per DFH	
	Quantity	Current	Nominal	Design	Nominal	Design	Nominal	Design
DFHx	[-]	[kA]	[nΩ]	[nΩ]	[W]	[W]	[W]	[W]
	2	6x3	10	15	0.54	0.8	1.08	1.6
	2	6x2.2	10	15	0.28	0.4	0.56	0.8
	3	7	6	9	0.29	0.4	0.88	1.3
	12	2	12	18	0.05	0.1	0.58	0.9
						Total	3.10	4.65
DFHm	[-]	[kA]	[nΩ]	[nΩ]	[W]	[W]	[W]	[W]
	2	13	2	3	0.34	0.51	0.68	1.01
	8	0.6	12	18	0.00	0.01	0.03	0.05
						Total	0.71	1.07

Note: 18kA separated in to 6x3kA splices



Courtesy Jerome

Joule effect through resistive material during current transfer between superconductors

Convective heat transfer: first approach

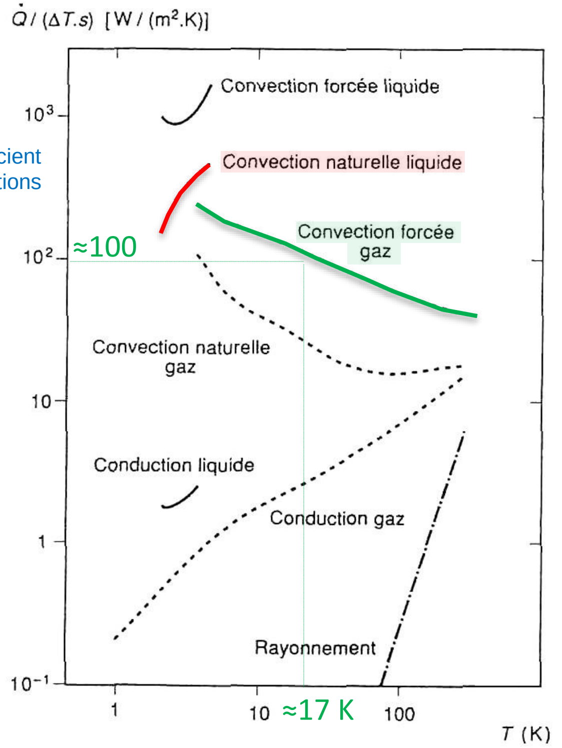
- Equilibrium $Q = hA_{tr}\Delta T$:
  - Q: transferred heat = dissipated heat in the splice
  - Atr: exposed area to flowing fluid
  - ΔT=$T_{fluid} - T_{surface}$
  - h: convective heat transfer coefficient, depends on:
    - Fluid properties (P, T, Cp, u) ≈ constant
    - Mass flow Qm
    - Geometry (flow area, ε) ➔ flow properties (Re, Pr, Nu)

- Order of magnitudes
  - Literature
  - Analytical calculations:
    - Between 0.1 and 5 g/s of He @ 1.3 bara & 17K, “efficient” heat exchanges require “small” flowing area
    - >Ø200 diameter, turbulent flow requires high mass flows

- ➔ Flowing area must be reduced around splices to offer the proper turbulent flow leading to efficient convective heat transfer

- ➔ Design A_{flow} to ↑Re ➔ ↑h ➔ ↑Q

Convective heat transfer coefficient for various helium conditions



Typical analytical estimation of convective heat transfer

Thermal Convection

$$Q = hA_{tr}\Delta T$$

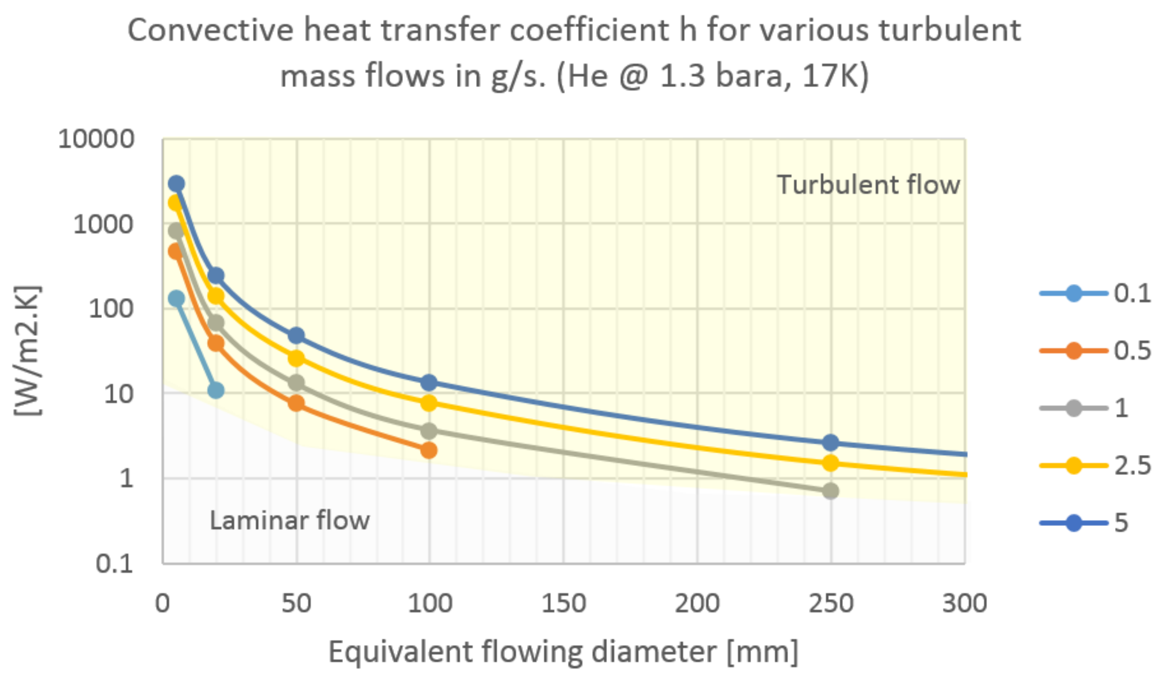
$Re = \frac{4Q_m}{\pi d \mu}$ $Pr = \frac{Cp.\mu}{k}$

Inputs		Unit
Qm	1.00E-03	[kg/s]
d	2.00E-02	[m]
The	17	[K]
Phe	1.3	[bara]
Cp	*5.30E+03*	*[J/kg/K]*
μ	*3.24E-06*	*[Pa.s]*
k	*2.38E-02*	*[W/m/K]*
ρ	*3.70E+00*	*[kg/m3]*
Pr	*7.22E-01*	*[-]*
Flow:	**Turbulent**	
Re	**2.0E+04**	**[-]**

$Nu = \alpha Re^{0.8} Pr^n$

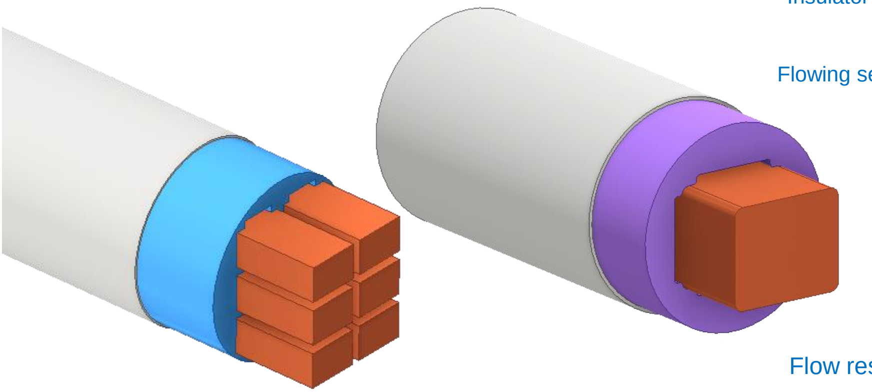
Valid for turbulent flow only

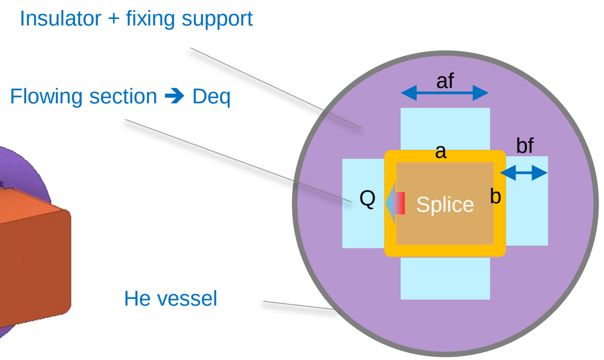
Input		Unit
Gas {α=0.023, n(cool;heat)=(0.3,0.4)}		
Liq {α=0.027, n=0.33}		
α/n	0.023	0.3
Nu	*5.68E+01*	*[-]*
$h = Nu\frac{k}{d}$	**6.75E+01**	[W/m2/K]
Atr	8.40E-02	[m2]
ΔT	3	[K]
T increase	3.21E+00	[K]
Q	**1.70E+01**	**[W]**



Inputs for design

- Design approach proposal: Maintain splices in electrical insulating supports
  - ➔ control flow area & provide holding and fixations
  - 1 or several splices per flowing tube

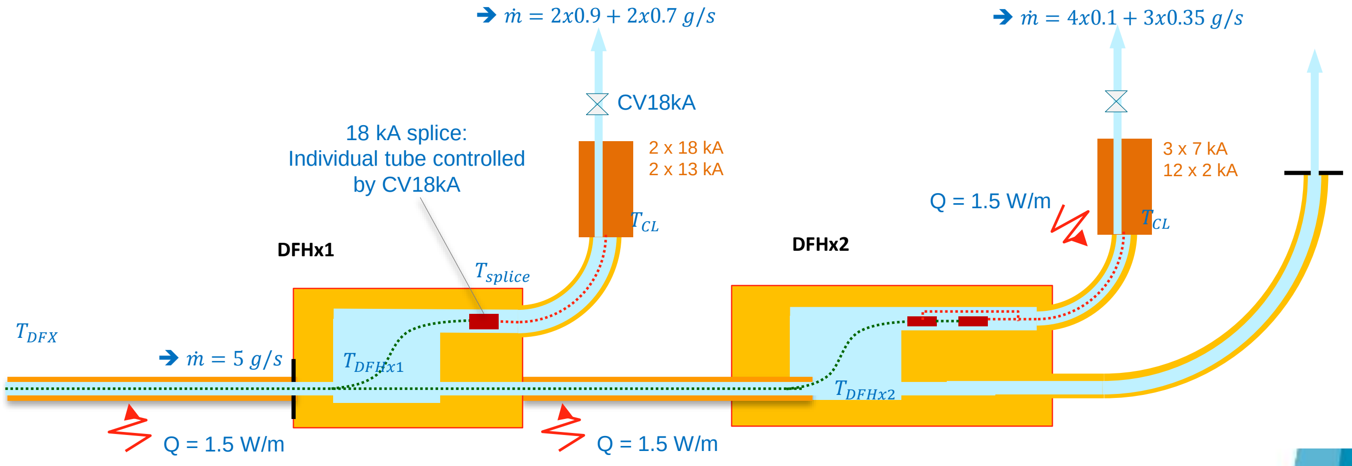




Flow restriction + splice support principle

- Is the current leads mass flow sufficient to cool splices ? (first approach: individual tube / splice(s))
  - Current leads 0.05g/s/kA ➔ 5 g/s
  - Heat loads SCLink 1.5W/m ➔ $T_{DFHx1} = 10.1\ K$
  - 18 kA splices: 0.9 g/s @ 10.1K ➔ $T_{18kA\ splice} < 12$ K
  - Heat loads interlink 1.5 W/m ➔ $T_{DFHx2} = 11.5\ K$
  - 2 kA splices: 0.2 g/s @ 11.5K ➔ $T_{2kA\ splice} < 12$ K
  - 7 kA splices: 0.35 g/s @ 11.5K ➔ $T_{18kA\ splice} < 13$ K

- What if :
  - $\boldsymbol{R_{Splice}}$↗ to 20nΩ, T_{splice}=17K
  - $\boldsymbol{\dot{m}_{CL}}$↘ due to lower T_{CL}; for half mass flow, $\Delta T_{splice} + 1K$



Assumptions:
Non insulation between splice & flow
Homogeneous temperature in the splice
CL: Independent cryostat for 18kA & 13 kA / Common 4-in-1 cryostat for 2kA (3-in-1 for 7kA)

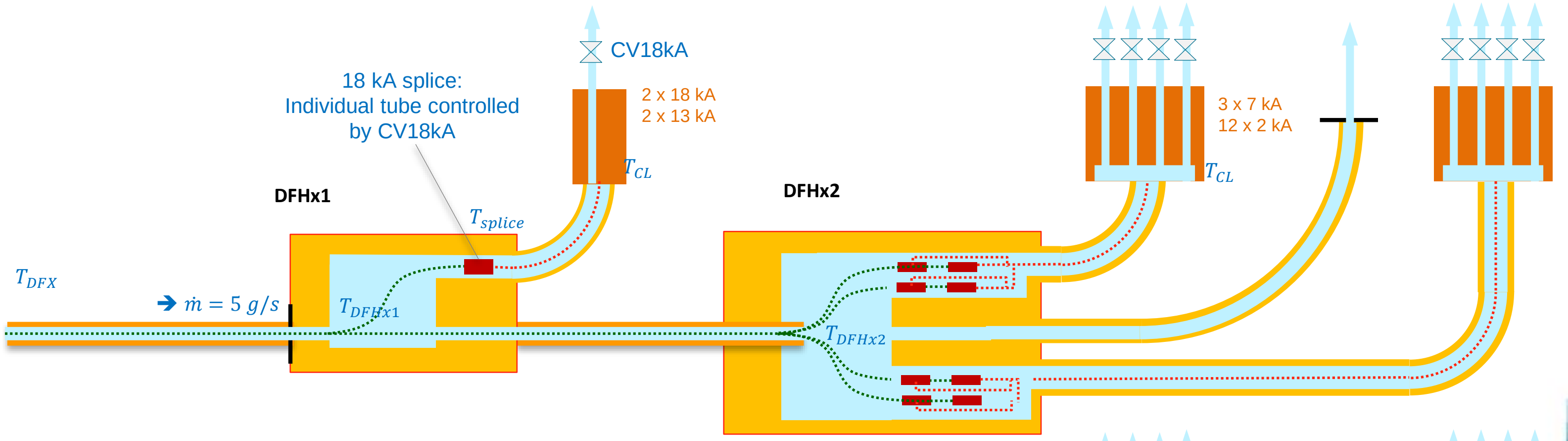
$Q = \dot{m}\ Cp\ \Delta T \qquad Q = hA_{tr}\Delta T$

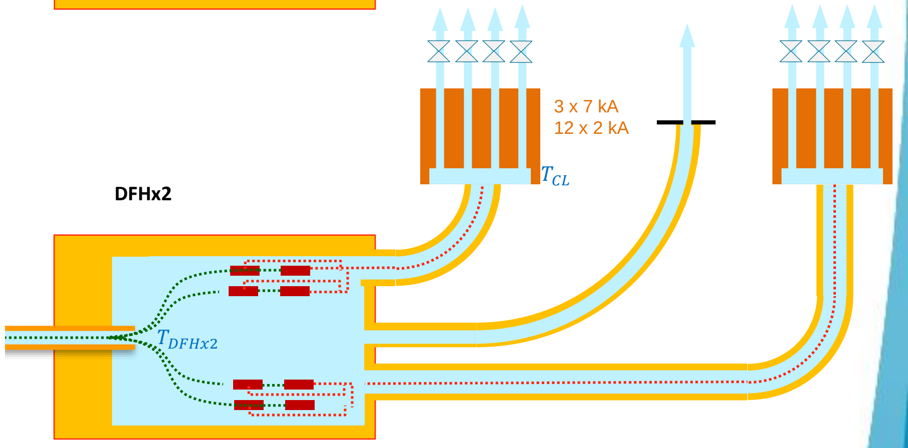
Temperature of splices for CL nominal flow and 5mm gap around splices for flow area

	Qty	Geometry a	b	L	af	bf	Calcs. Parameters Atr	Aflow	Deq	Mass flow per CL	per splice	Coef. h	Heat load Q design	DT		Mass flow DFX	Heat Load SCLink	Temp. T-DFHx1	Mass flow DFHx2	Heat Load Interlink	Temp. T-DFHx2	Tsplice	Mass flow HTS	Heat Load Flex HTS	Temp. T-HTS	T-CL	Temp. T-return
	[-]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm2]	[mm2]	[mm]	[g/s]	[g/s]	[W/m2.K]	[W]	[K]		[g/s]	[W]	[K]	[g/s]	[W]	[K]	[K]	[g/s]	[W]	[K]	[K]	[K]
18 kA splice	2	70	60	300	50	5	33000	1000	35.7	0.9	0.9	25	0.8	1.0	➔	5.35	150	10.1	2.3	15.0	11.4	11.1	0.9	7.5	10.3	12.0	11.9
13 kA splice	2	70	60	300	50	5	33000	1000	35.7	0.65	0.65	17	0.4	0.7								10.8	0.65		10.2	12.5	
2 kA splice	12	30	20	300	20	5	15000	400	22.6	0.1	0.2	15	0.1	0.4								11.9	0.4		11.5	15.3	
7 kA splice	7	45	20	300	35	5	24000	700	29.9	0.35	0.35	14	0.4	1.2								12.6	1.05		11.7	13.1	

Inputs for design

- 1st conceptual design proposal:
  - 18 kA splices:
    - In series with Current leads
    - Individual flowing tube
      - ➔ standard sleeve system
      - ➔ local flow increase in case
      - ➔ individual protection of splices
  - 2 kA / 7 kA splices:
    - 2 options

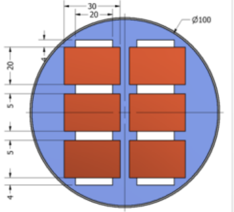




	DFHx2 Option #1	DFHx2 Option #2
Increase of mass flow if required	Through Current leads	Through return line
Mass flow control	Control flow through parallel lines at current leads outlet	CL mass flow independent from splice cooling
Flow control at splice level	Divide 1 mass flow into 4 splices	Divide 1 mass flow into 15 splices ➔ How to ensure by geometry parallel flows around splices ?

Convective heat transfer at DDFH splice Demo1

- 6 sub-splices 20x30x200mm
- Flowing section: 720 mm², Deq = 30 mm
- Area in contact with fluid: 12 x 20 x 200 =48 000 mm²
- Dissipated heat:
  - R=10nΩ, 6 x I=3kA
  - Each sub-splice: P=0.9 W / Total=5.4W
- Convective heat transfer:
  - Assumption: homogeneous T in splices bulk parts.



Mass flow	T_{GHE}	P	h	ΔP	ΔT	T_{splice}
[g/s]	[K]	[bara]	[W/m².K]	[mbar]	[K]	[K]
1	17	1.3	32.5	< 1 mbar	3.5	20.5
5	17	1.3	118	< 1 mbar	0.95	18.0
5	300	1.3	NA	< 1 mbar	NA	NA

Thermal Convection

$$Q = hA_{tr}\Delta T$$

$$Re = \frac{4Q_m}{\pi d\mu} \qquad Pr = \frac{Cp.\mu}{k}$$

Inputs		Unit
Qm	5.00E-03	[kg/s]
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μ	3.24E-06	[Pa.s]
k	2.38E-02	[W/m/K]
ρ	3.70E+00	[kg/m3]
Pr	7.22E-01	[-]
Flow:	Turbulent	
Re	**6.6E+04**	**[-]**

$$Nu = \alpha Re^{0.8} Pr^{n}$$

Valid for turbulent flow only

Input	✔	Unit
5 Gas (α=0.023, n(cool;heat)=(0.3,0.4))		
Liq (α=0.027, n=0.33)		
α/n	0.023	0.3
Nu	1.49E+02	[-]
$h = Nu\frac{k}{d}$	1.18E+02	[W/m2/K]
Atr	8.00E-03	[m2]
ΔT	1	[K]
Tincrease	3.56E-02	[K]
Q	**9.43E-01**	**[W]**

- Next steps:
  - Check mechanical feasibility
  - Validate physical accesses to cables/splices
  - DFHx2 : parallel flow control ?
  - Validate design approach with DEMO1