High Luminosity LHC

Cooling configuration in IR1 and IR5 based on the present layout

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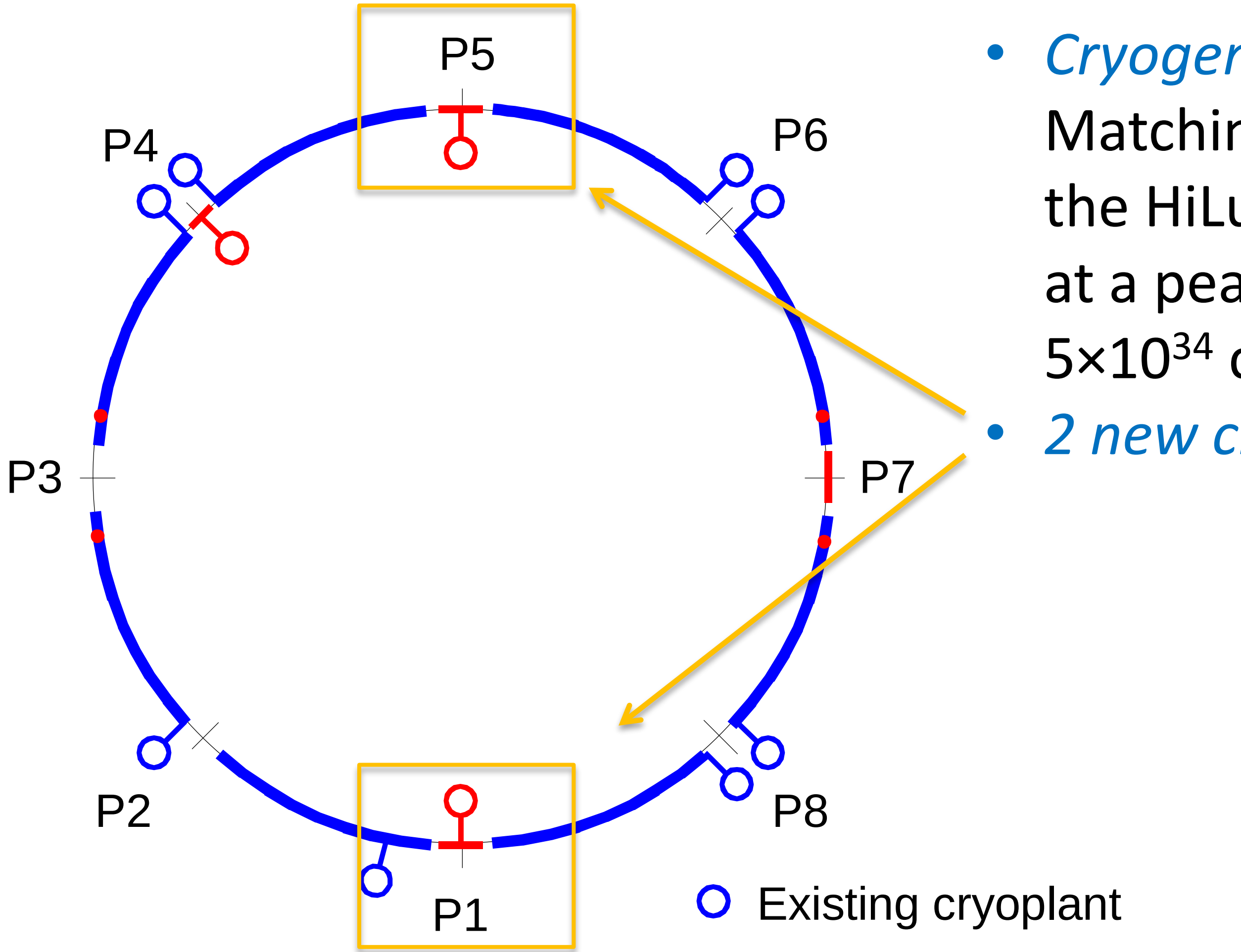
Overview

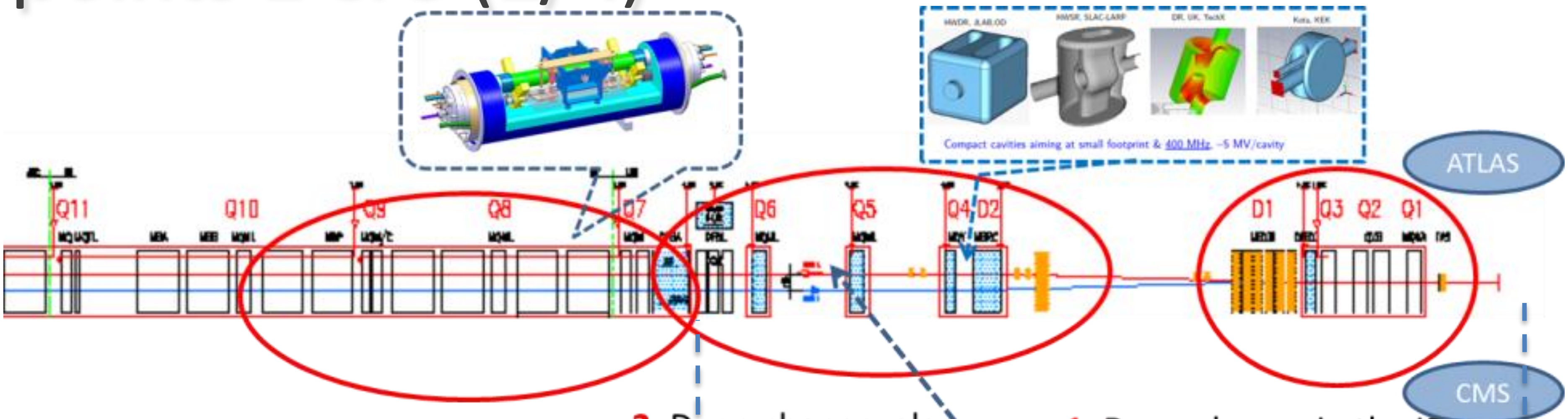
- Generic layout of cryogenic services
- Specifics for Q5 & Q6
- Specifics for D2, Q4 (- crab cavities)
- Specifics for D1 & IT

Generic layout of cryogenic services in points 1 & 5 (1/4)



- *Cryogenic layout* for new Matching Section (MS) for the HiLumi upgrade aimed at a peak luminosity of 5×10^{34} $cm^{-2}s^{-1}$ with leveling
- *2 new cryoplants* at P1 & P5

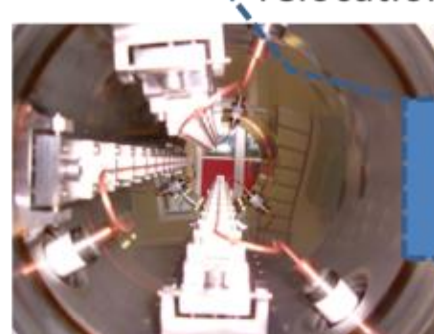
Generic layout of cryogenic services in points 1 & 5 (2/4)



1. Deep change in the IRs and interface to detectors; relocation of Power Supply

2. Deep change also matching section: Magnets, collimators and CC

3. For collimation we need to change also this part, DS in the continuous cryostat



4. LR BB compensation wires

Courtesy L. Rossi

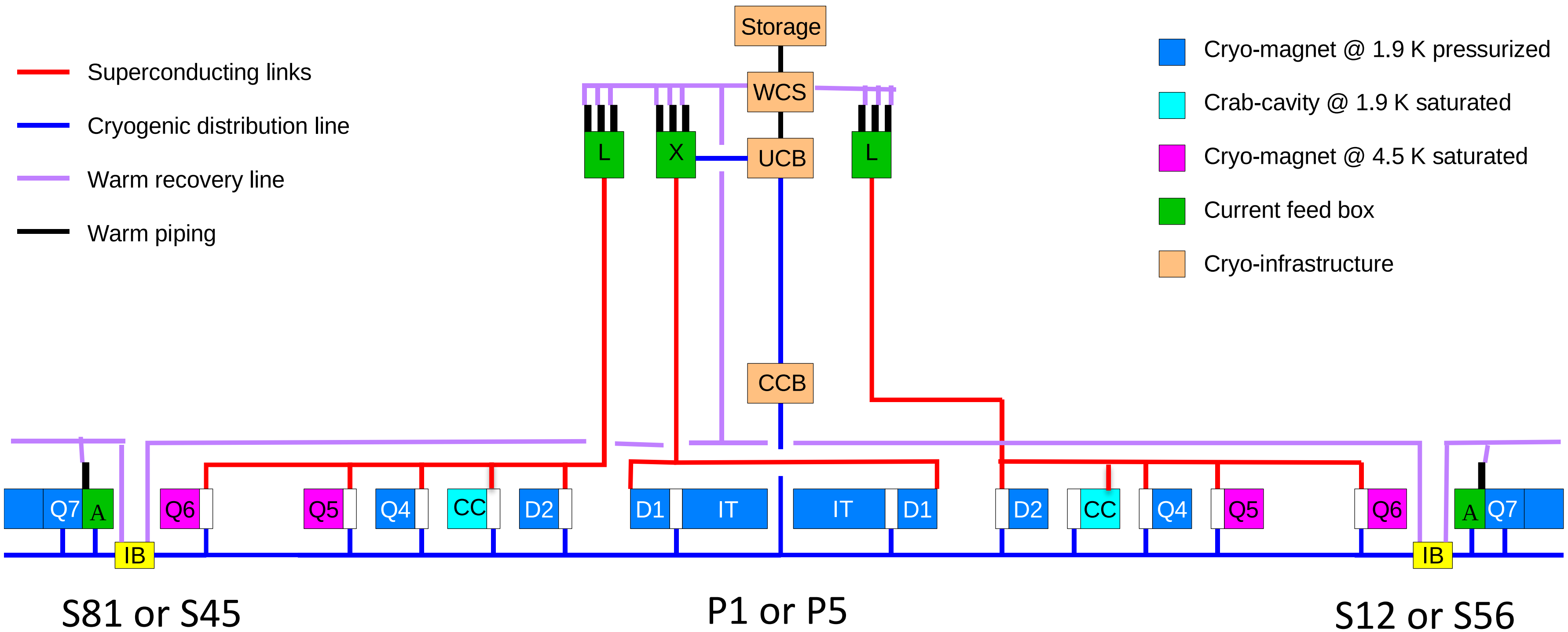
We will address the area from Q1 up to Q6 & DFBA

IR1/IR5 Baseline: New compared to Existing (3/4)

Item\cooled or powered by	New Plant @ IR on Surface	Existing Sector Cryoplants	New DFB: X @ Surface	Existing DFB: A @ Tunnel	New DFB: L @ Surface
IT&D1					
Matching Section					
Continuous Cryostat					

1. **MS, IT & D1** serviced by **New** cryoplants, continuous cryostat by existing ones *(+ independent warm-up/cool-down)*
2. Redundancy: **yes**, but level to be defined in detail later *(reduced luminosity operation or stand-by only)*
3. **All magnets** at **1.9 K** **except for Q5 & Q6 at 4.5**
4. **DFB-X** and **L** (servicing D1 & IT and MS) at **surface** *(# of links and DFBs to be optimized)*, **DFB-A** (servicing continuous cryostat) stays in **tunnel**

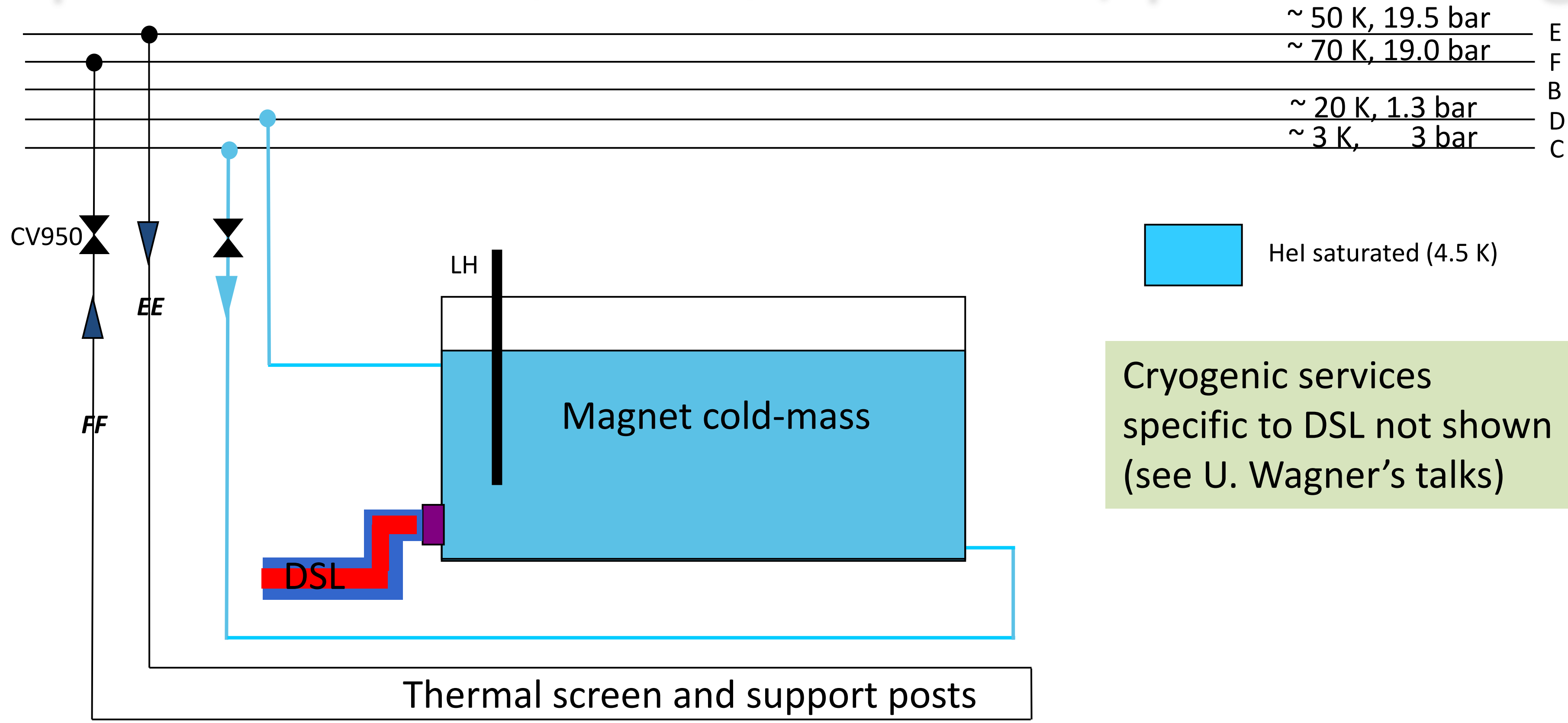
Baseline for P1 & P5 layout: Matching section cooled with inner triplet cryoplants (4/4)



Notes:

- Q5, Q6 at **4.5 K**,
- DFBA remains **in tunnel**, # of **superconducting links** and surface **DFB-boxes** to be optimized,
- level of cryogenic **redundancy (IB)** to be detailed
- **Space** requirements for **CCB** and **shaft-piping**

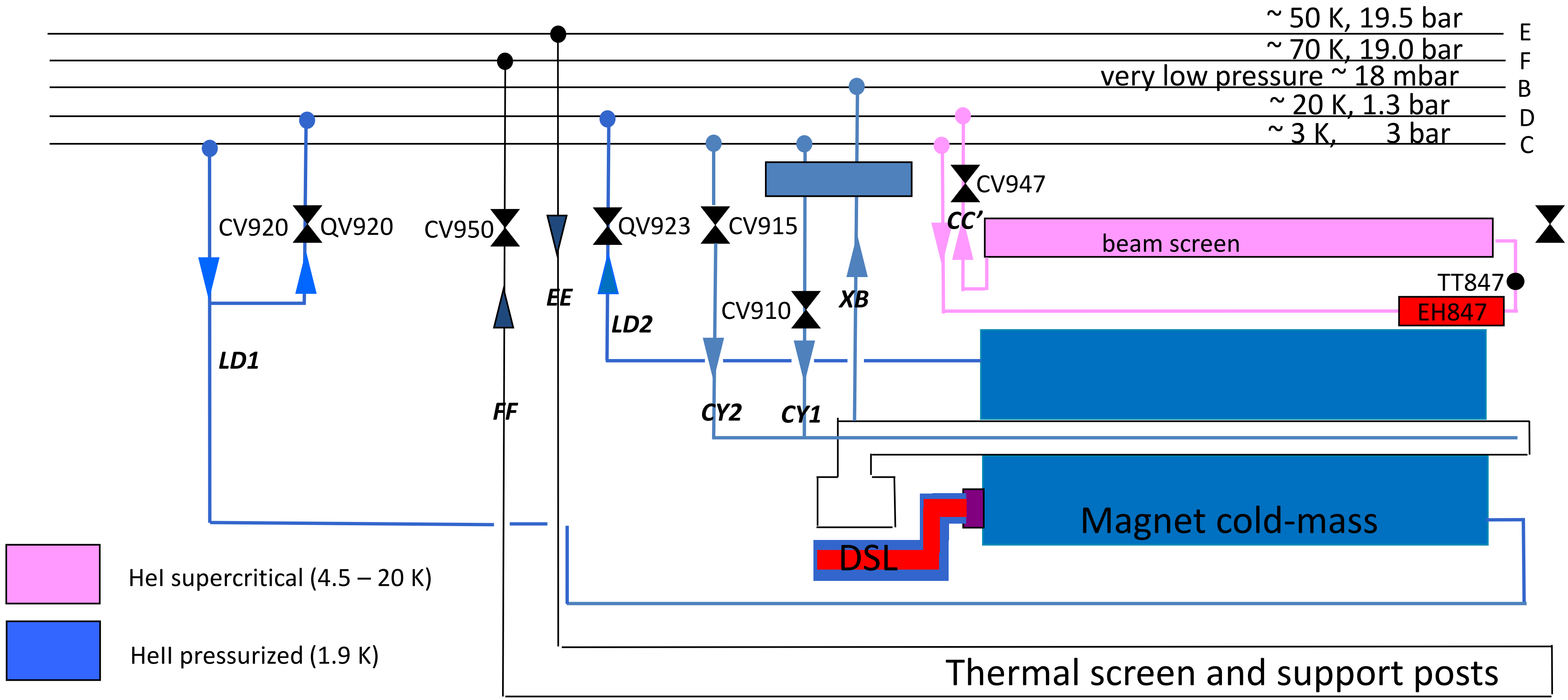
Specifics for Q5 & Q6 at 4.5 K, pool boiling



Cryogenic services specific to DSL not shown (see U. Wagner's talks)

No change with respect to present pool-boiling cooling
No beam screen foreseen
New connection type to DSL (superconducting link)
New QRL & jumper connection adaptation

Specifics for D2, Q4 (stand-alone @1.9)



LHC-ARC type cooling: *typical HX-size > 41 mm ID* (> 50 mm yoke hole) for ~17 W load
Actively cooled *beam screen foreseen* to keep load to 1.9 K low (if not increase HX-size)
New connection type to DSL (superconducting link)
New QRL & jumper connection adaptation

DSL services not shown (see U. Wagner's talks)

D1 & IT: heat loads

Total heat load (vertical crossing)

	10 cm gap in ICs		50 cm gap in ICs	
	Magnet cold mass	Beam screen	Magnet cold mass	Beam screen
	Power [W]			
Q1A + Q1B	100	175	100	170
Q2A + orbit corr.	95	60	100	65
Q2B + orbit corr.	115	80	120	80
Q3A + Q3B	140	80	140	80
CP	55	55	60	55
D1	90	60	90	60
Interconnects	20	140	20	105
Total	**615**	**650**	**630**	**615**

Courtesy L. S. ESPOSITO

Total values for horizontal crossing are about 10% lower

For sizing use:

Cold mass
710 W @ 1.9 K
(650 W ~ 1.0 W/m due to heavy beam screen)

Beam-screen & BLMs
683 W @5 K – 20 K /40 – 60 K = 12 W/m
(650+16+0.3 W/m image currents, excluding electron cloud)

1183 W or 21 W/m with 500 W electron cloud !

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Q2B + orbit corr.	115	80	120	80
Q3A + Q3B	140	80	140	80
CP	55	55	60	55
D1	[illegible]	60	90	60
Interconnects	20	[illegible]	20	105
Total	**615**	**650**	[illegible]	[illegible]

It'd better be suppressed! →

Courtesy L. S. ESPOSITO

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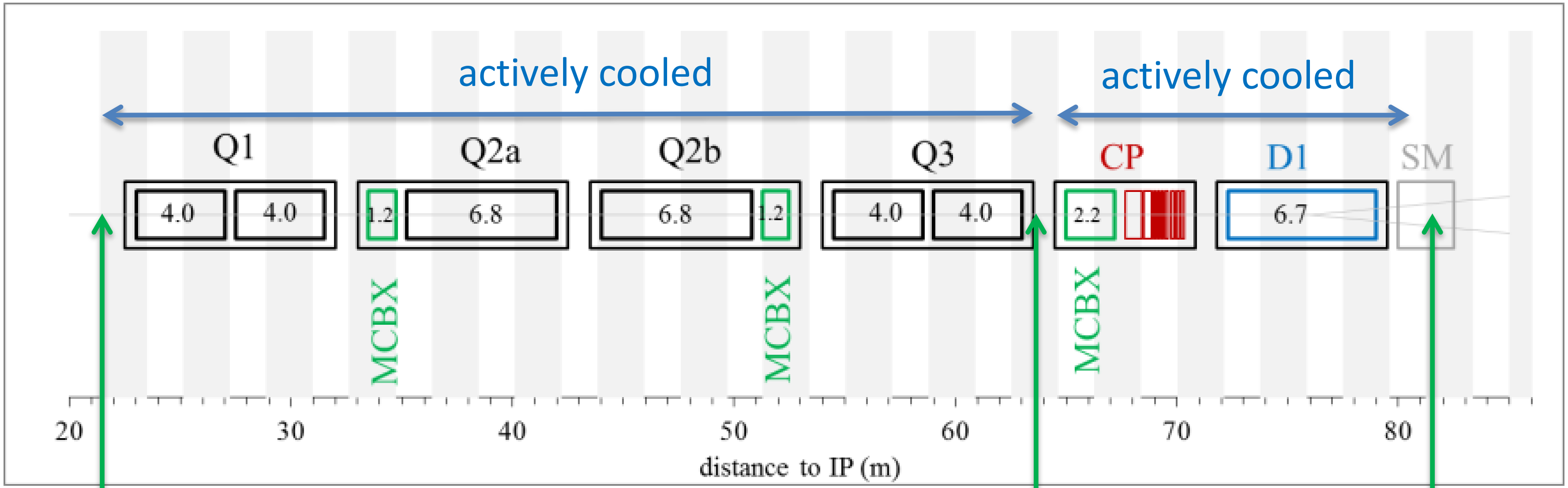
Placing of cryo-equipment considered (variant 4)



- Phase-separator &
- Piping entries/exits

- Phase-separator &
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- QRL-jumper

- SM &
- QRL-jumper
- Phase-separator
- Piping entries/exits

Q1,Q2a,Q2b,Q3: actively cooled for about 41 m, double-HXs needed
CP,D1 : actively cooled for about 16 m, double-HXs needed

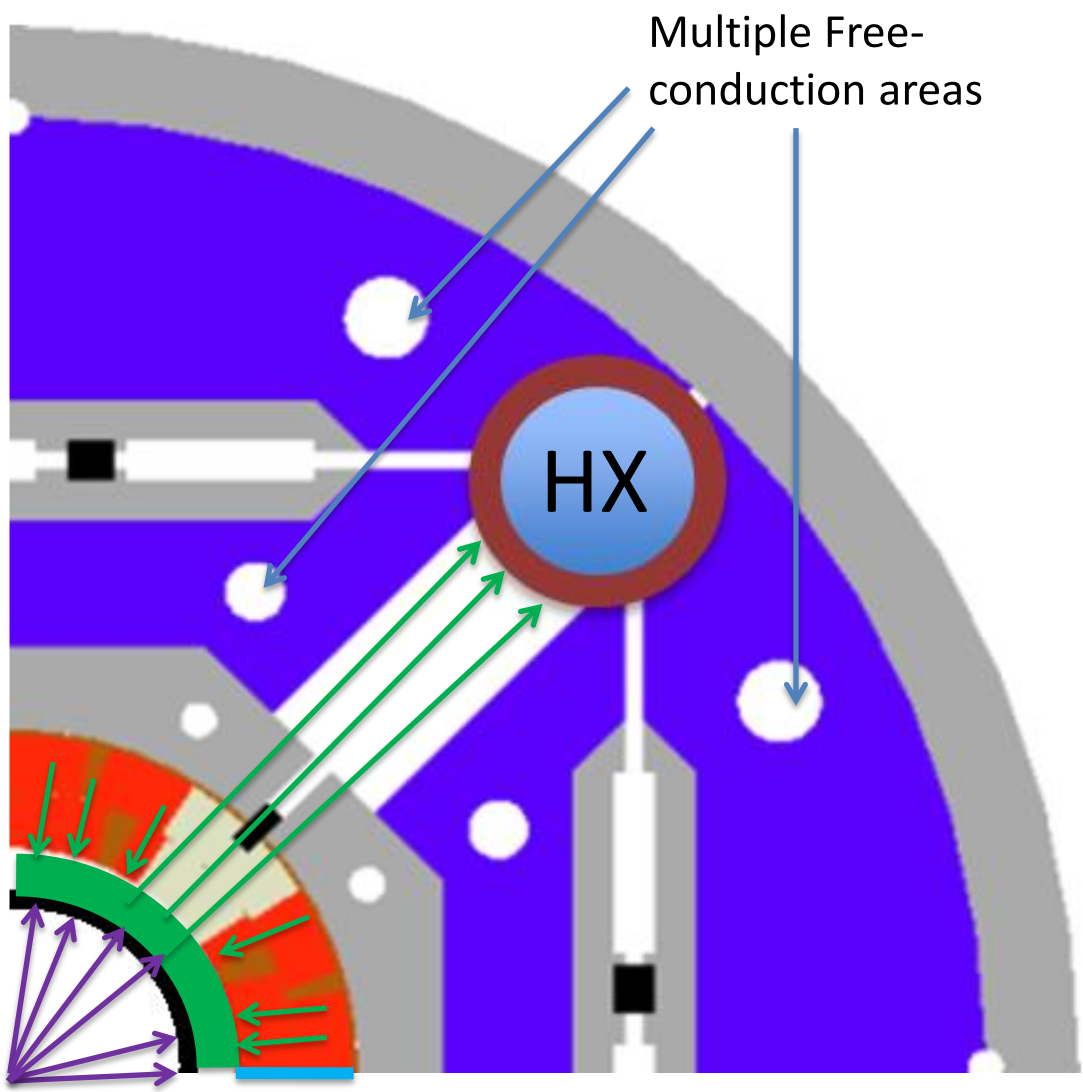
	Variant 1	Variant 2	Variant 3	Variant 4
Power limit (HX holes > 77 mm)	550 W (Q1-D1) $v_{vapour} \leq 7$ m/s	550 W (Q1-D1) $v_{vapour} \leq 7$ m/s	710 W D1 HX-Area	710 W D1 & CP HX-Area
Q1-Q3 HXs Q1-Q3 Free Area Q1-Q3 Cryostat Pumping line	2x77 mm holes ≥ 110 cm^2 97-100 mm	2x77 mm holes ≥ 110 cm^2 97-100 mm	2x77 mm holes ≥ 110 cm^2 97-100 mm	≥ 2x77 mm holes ≥ 110 cm^2 97-100 mm
CP HXs CP Free Area CP Cryostat Pumping line	none ≥ 300 cm^2 none	2x77 mm holes ≥ 130 cm^2 97-100 mm	none ≥ 85 cm^2 none	≥ 2x49 mm holes ≥ 85 cm^2 none
D1 HXs D1 Free Area D1 Cryostat Pumping line	none ≥ 300 cm^2 none	none ≥ 130 cm^2 none	≥ 2x77 mm holes ~ 85 cm^2 ~ X mm	≥ 2x49 mm holes ~ 85 cm^2 ~ X mm
Phase separator & piping entries/exits	1) Q1-end 2) Q3-CP	1) Q1-end 2) CP-D1	1) Q1-end 2) Q3-CP 3) CP-D1	1) Q1-end 2) Q3-CP
QRL-jumpers	Q3-CP SM	CP-D1 SM	Q3-CP SM	Q3-CP SM

Coil cooling principle

- Heat from the coil area (green) and heat from the beam pipe (purple) combine in the annular space between beam pipe and coil and escape radially through the magnet "pole" towards the cold source → *"pole, collar and yoke" need to be "open" :*
Calculations show that > 80 % of the heat is evacuated via the pole piece!

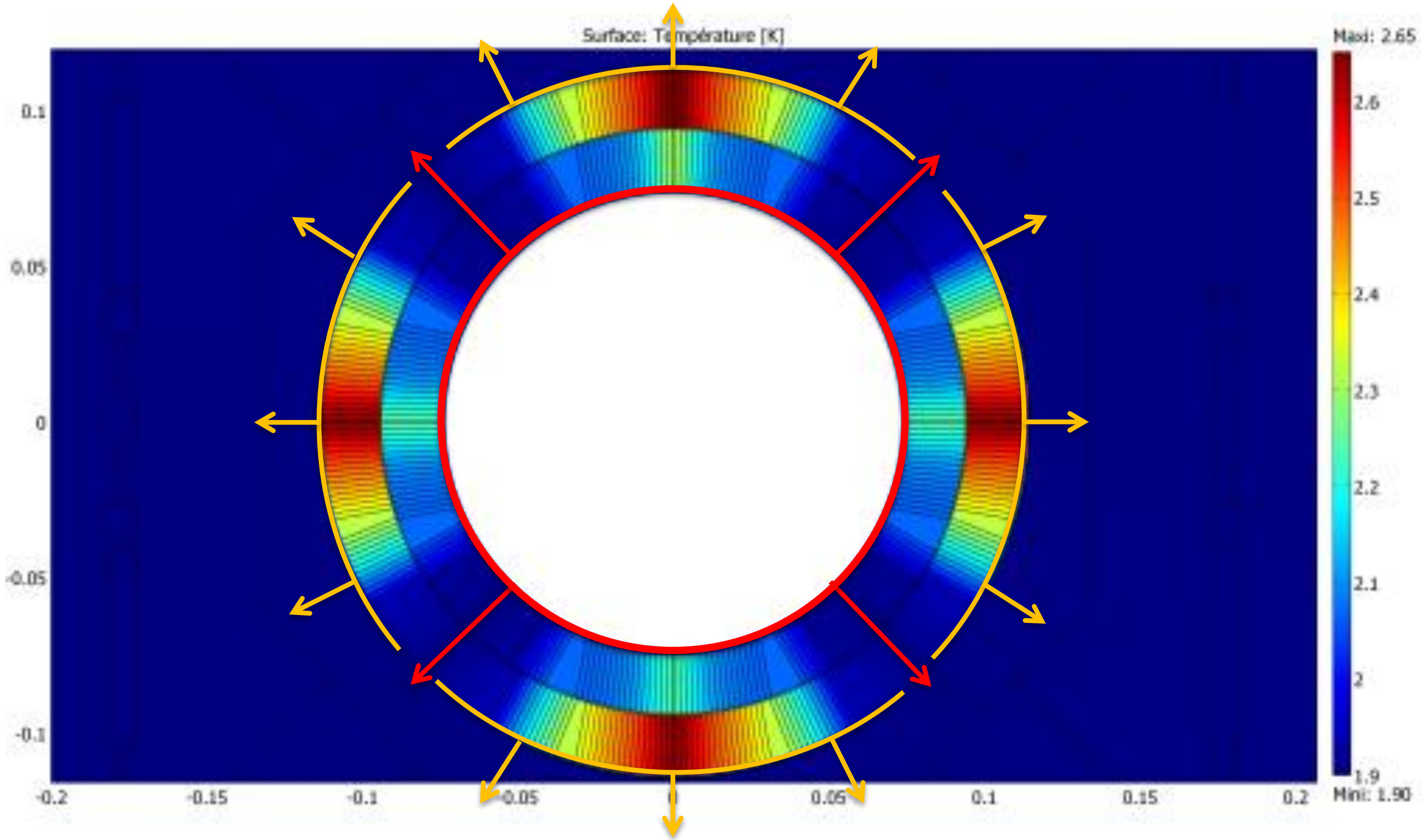
- Heat Conduction mechanism in the coil packs principally via the solids

- Longitudinal extraction via the annular space is in superfluid helium, with T close to T_λ and with magnets up to 7 m long not reliable → *"pole, collar and yoke" need to be "open"*



≥ 1.5 mm annular space

Heat flow distribution - no helium channel in the mid-plane



85 % through the helium channels in the pole

15 % through the external insulation

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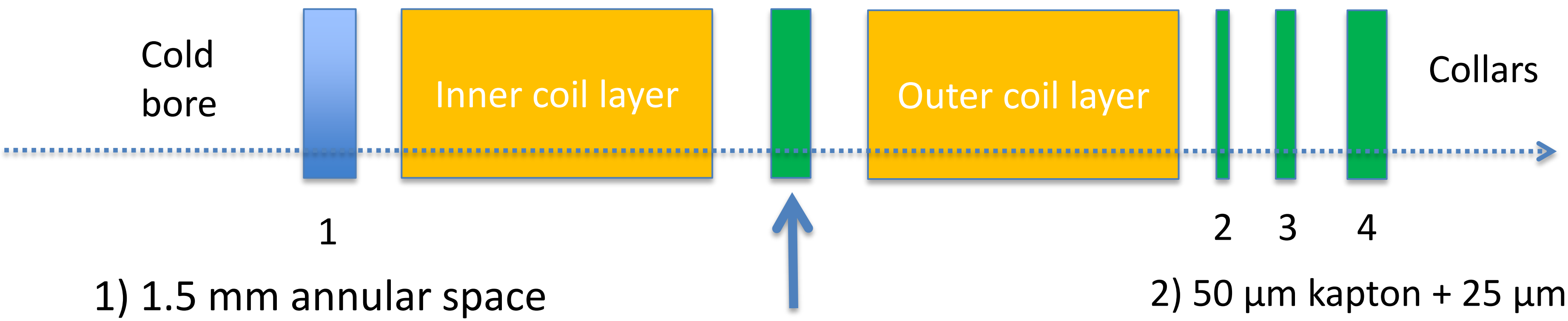
Coil magnet configuration assumed for calculations



1) 1.5 mm annular space

0.5 mm G-10

2) 50 µm kapton + 25 µm stainless steel 50 % filled
3) 200 µm G-10
4) 0.5 mm kapton

- Cable: 0.15 mm G-10 insulated
- 2-3-4 have been homogenized to form one mono layer
- Lack of some material thermal properties: need to be measured

Model will be changed to evaluate impact of partial blocking of inner layer by additional quench heaters (this is a thermally very bad location!) : work in progress

Criticality analysis

	T_{max} (K) (position)	Lowest T margin (K) (position)
HX - 2.05 K – no He channel in the mid-plane – collars/yoke open	2.75 (mid-plane)	4.18 (pole)
HX - 2.05 K – no He channel in the mid-plane – collars/yoke closed	2.76 (mid-plane)	4.17 (pole)
HX – 1.9 K – no He channel in the mid-plane – collars/yoke closed	2.66 (mid-plane)	4.3 (pole)
HX - 2.05 K – He channel in the mid-plane – collars/yoke open	2.47 (~± 20° axis)	4.18 (pole)
HX - 2.05 K – He channel in the mid-plane – collars/yoke closed	2.47 (~± 20° axis)	4.17 (pole)
HX – 1.9 K – He channel in the mid-plane – collars/yoke closed	2.36 (~± 20° axis)	4.3 (pole)

All results scale ~ linearly with bath temperature
Lowest T-margin always at the pole
No real criticality for yoke and collar packing

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Saturation analysis with regards to peak power deposition

8 mm diameter holes in the pole piece

Hole spacing (mm / equivalent %)	Saturation (W/m)	Peak power deposition (mW/cm^3)	T-margin (K) position	Safety factor regards to nominal
284 mm – 0.6 %	33.3	8	4.1 (pole)	2
129 mm – 1.28 %	66.5	16	4.06 (pole)	4
78.9 mm – 2.1 %	99.6	24	4.01 (pole)	6
54.2 mm – 3.05 %	132.9	32	3.81 (mid-plane/inner coil)	8
39.7 mm – 4.16 %	166	40	3.52 (mid-plane/inner coil)	10
30.2 mm – 5.47 %	199.3	48	3.25 (mid-plane/inner coil)	12

- **Hole spacing**: spacing between the center of 2 consecutive holes
- **Equivalent %**: percentage open in the pole piece with regards to the surface of the pole piece on the annular space side

Proposed design target

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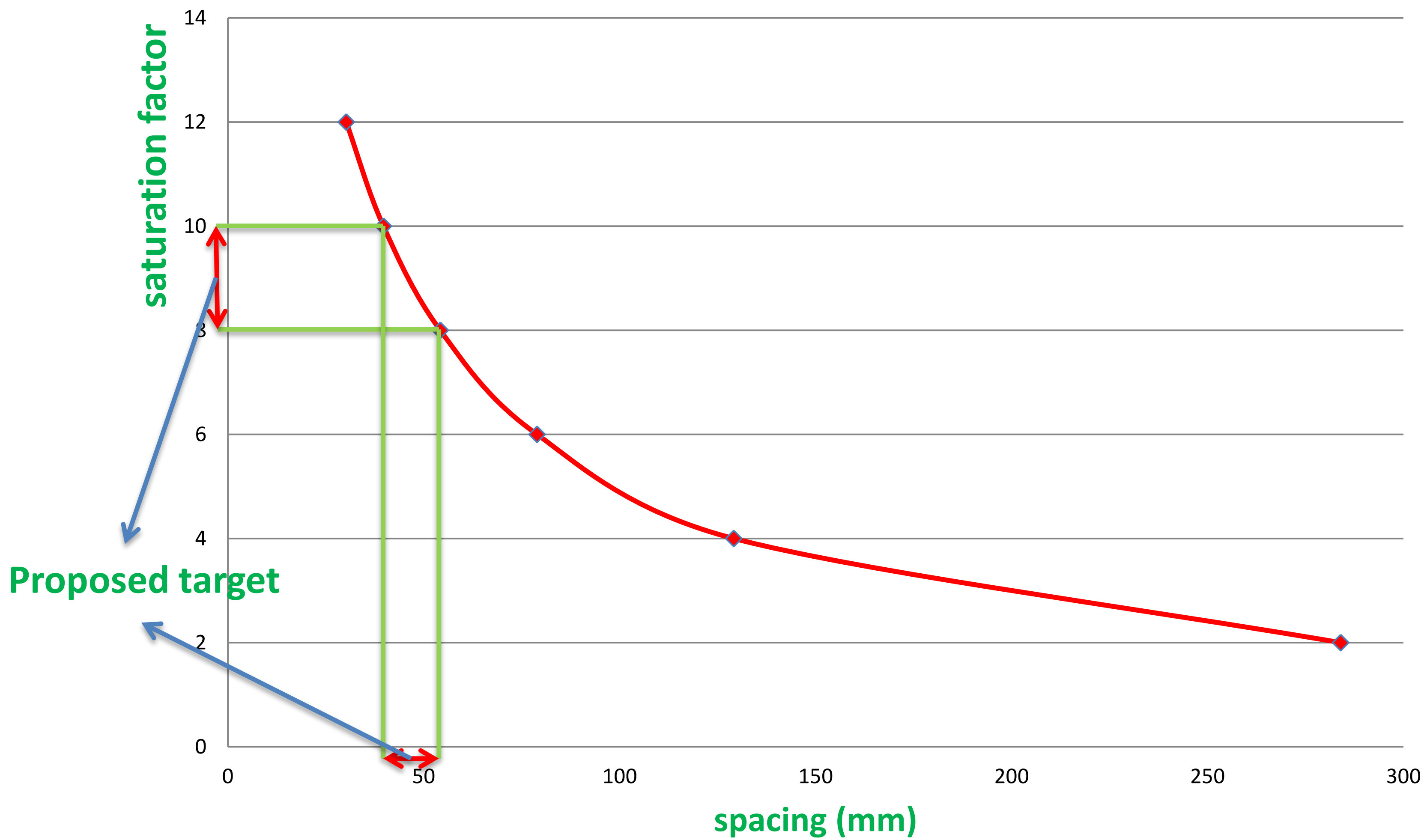
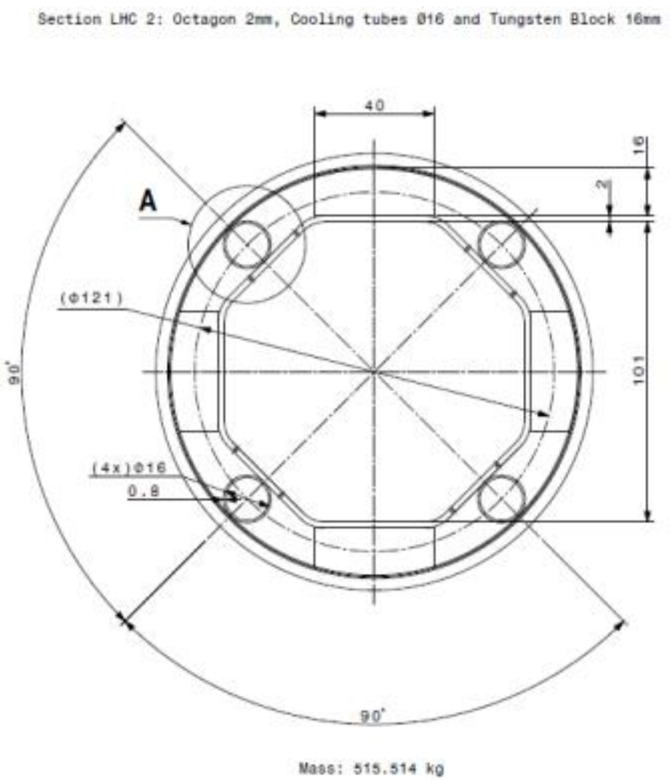
Safety factor – spacing graph

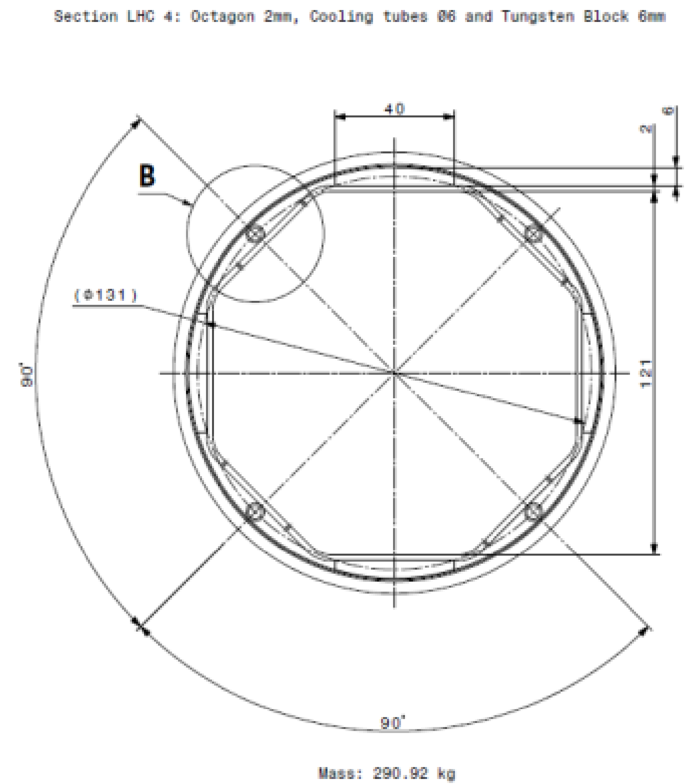
8 mm diameter holes in the pole piece



Beam-screens with 16 mm & 6 mm Tungsten



Q1, 515 kg, 4 x 14.4 mm ID



Q2-D1, 291 kg, 4 x 4.4 mm ID

Courtesy R. Kersevan

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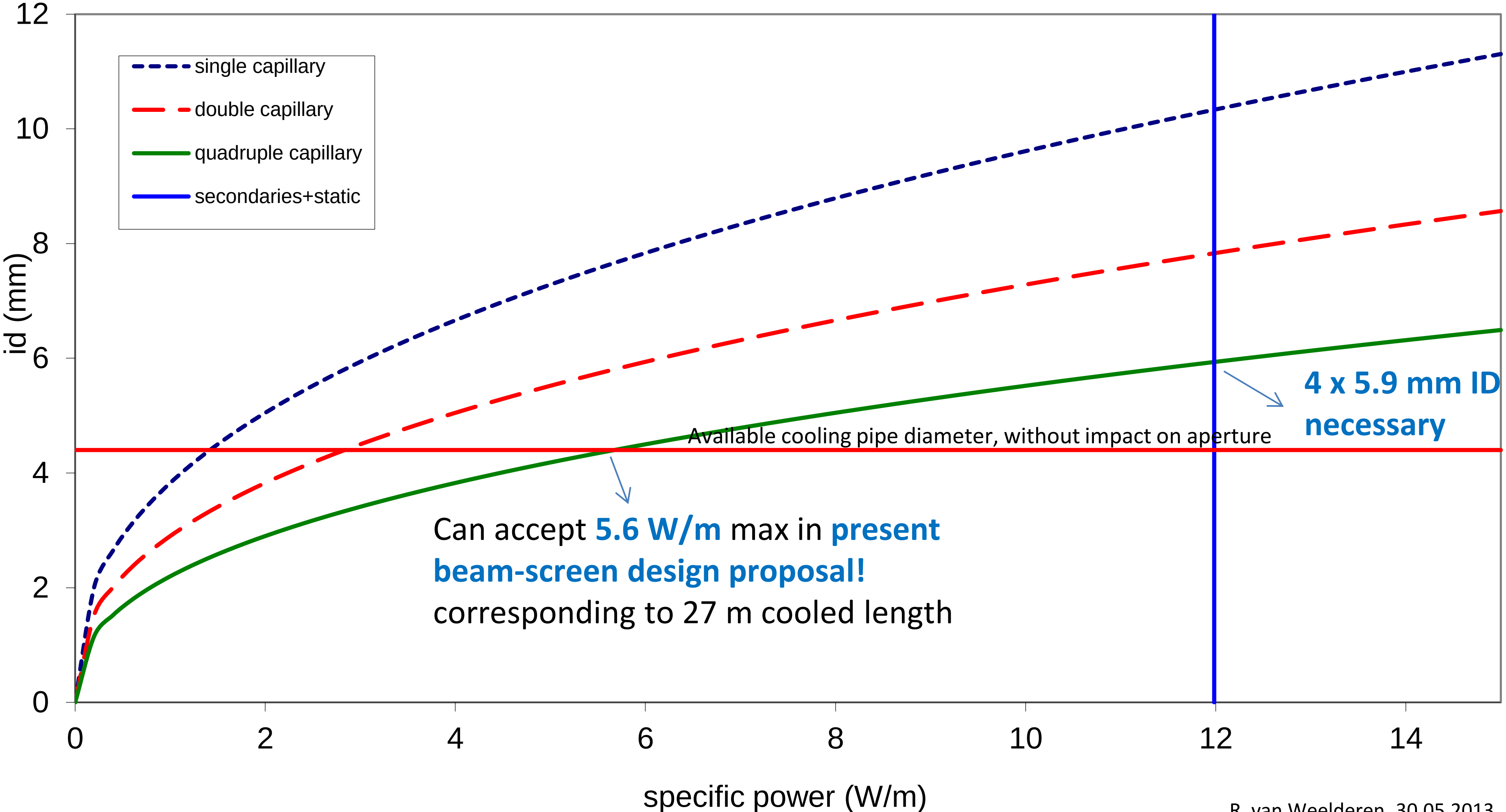
HiLumi Q2-D1 beam screen & BLM cooling capillary inner diameters (Q1 at 4 x 14.4 mm)
secondaries+static: L=57 m, Q=683 W (650 W secondaries+16 W+0.3 W/m estimate of image current,
excluding 500 W electron cloud = 12 W/m
5 K - 20 K



R. van Weelderen, 30.05.2013

Have to split beam-screen & BLM cooling between (Q1 – Q3) & (CP – D1)
Cryogenically working 40 K – 60 K would be better
Cooling possibility at these T-levels under investigation

Conclusions

- **MS, IT & D1** serviced by new cryoplants, continuous cryostat by existing ones *(+ independent warm-up/cool-down)*
- Redundancy level to be defined in detail later *(reduced luminosity operation or stand-by only)*
- **DFBs** servicing D1 & IT and MS at **surface**, **DFB-A** (servicing continuous cryostat) stays in **tunnel**
- Cryogenic design requirements for IT being implemented in cold-mass design (quench heaters implementation critical)
- Beam-screens & BLMs cooling on the limit, 40 K – 60 K option being considered