WP9 Cryogenics for CC at P1-P5

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(HiLumi – CC review)

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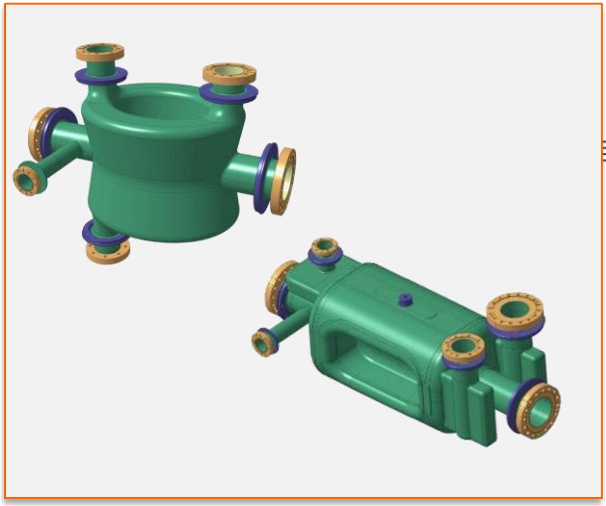
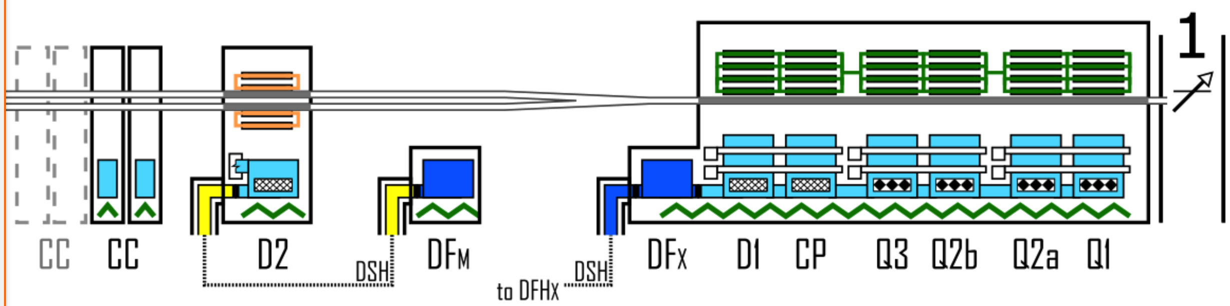
INTERFACES identification and definition

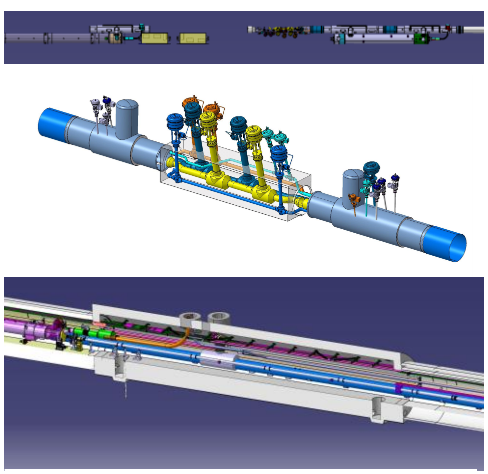
A large variety of cold masses, beam-screens and sc-links



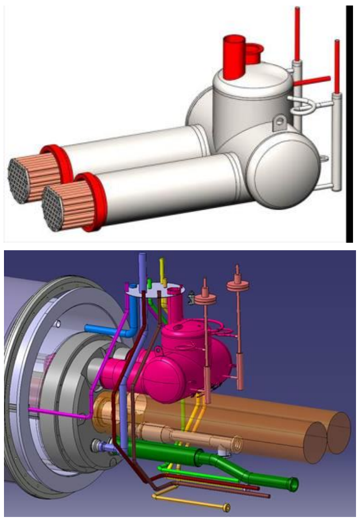


Heat extraction

validate technical choices in order to finalise design

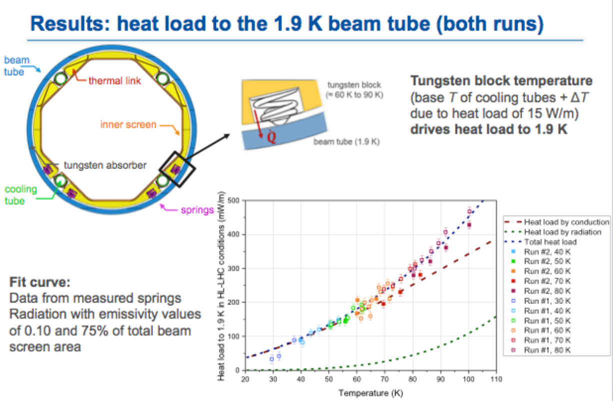


3D models for Cryo started this year!



D2 cooling heat exchanger collaboration with CEA-SBT

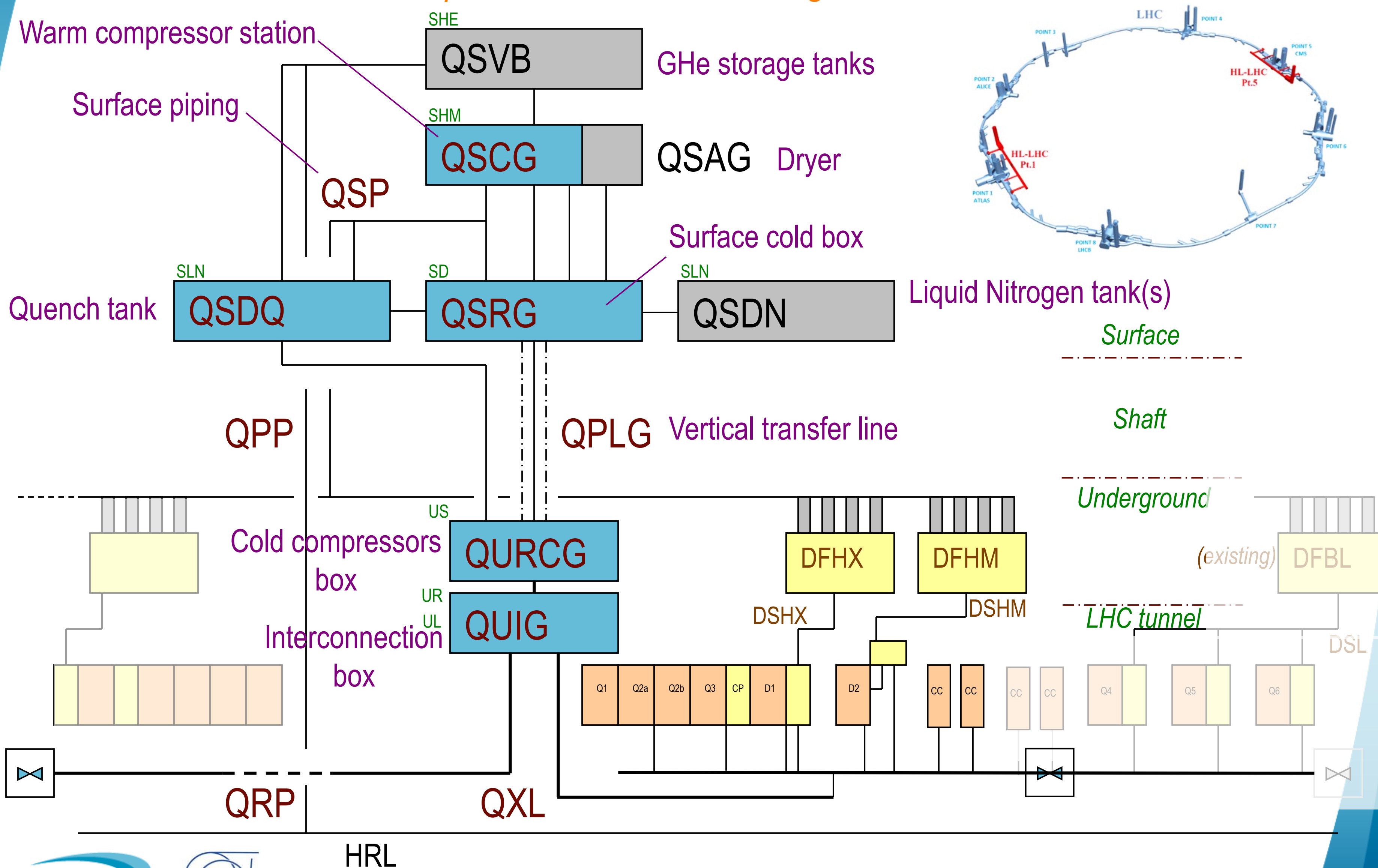
Un-shielded cryostats validated



Thermal behaviour of tungsten beam-screen validated at Cryolab, now looking for off-design modes

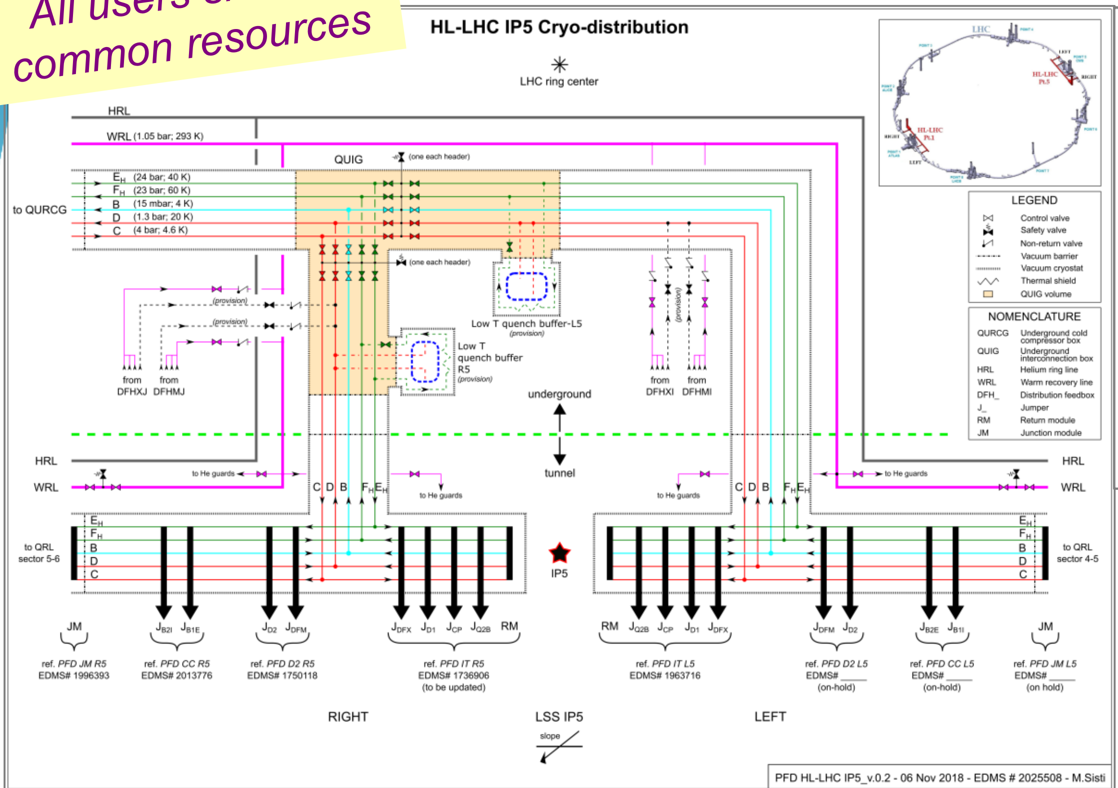
P1/P5 Cryogenic architecture

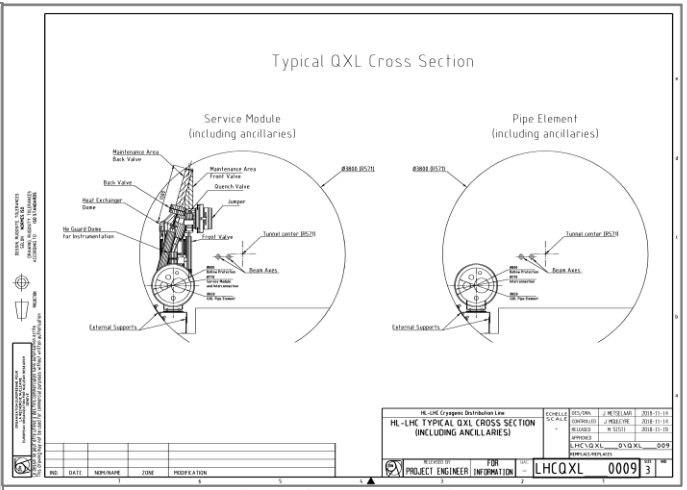
18 kW equivalent at 4.5 K, including 3 kW at 1.8 K

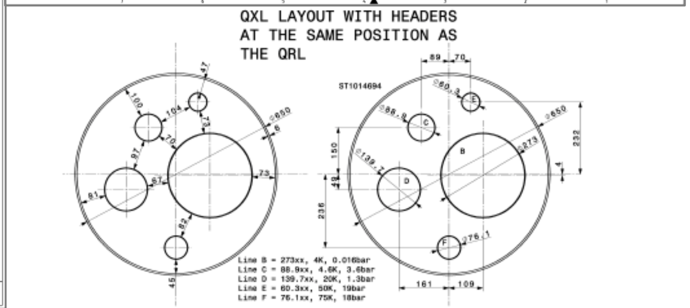


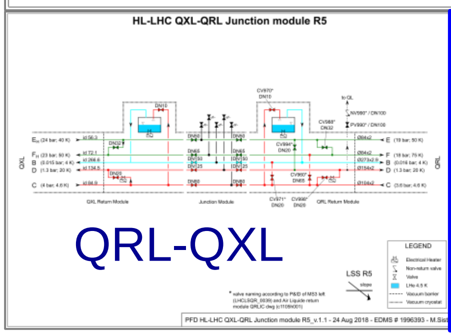
Cryo-distribution reference

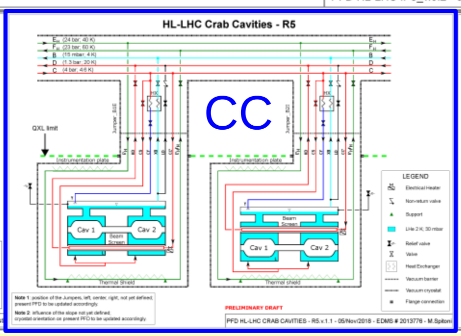
All users sharing common resources

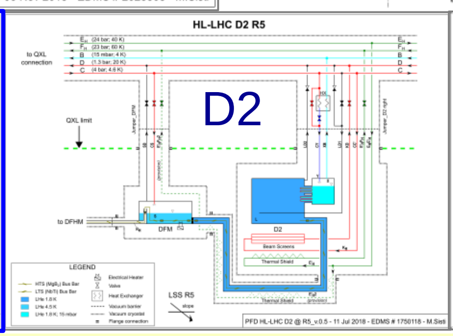


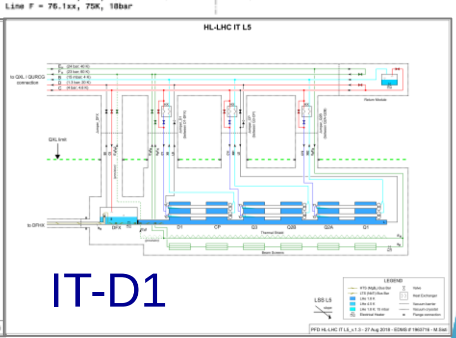












Reference established, optimised considering project requirements and CRG expertise

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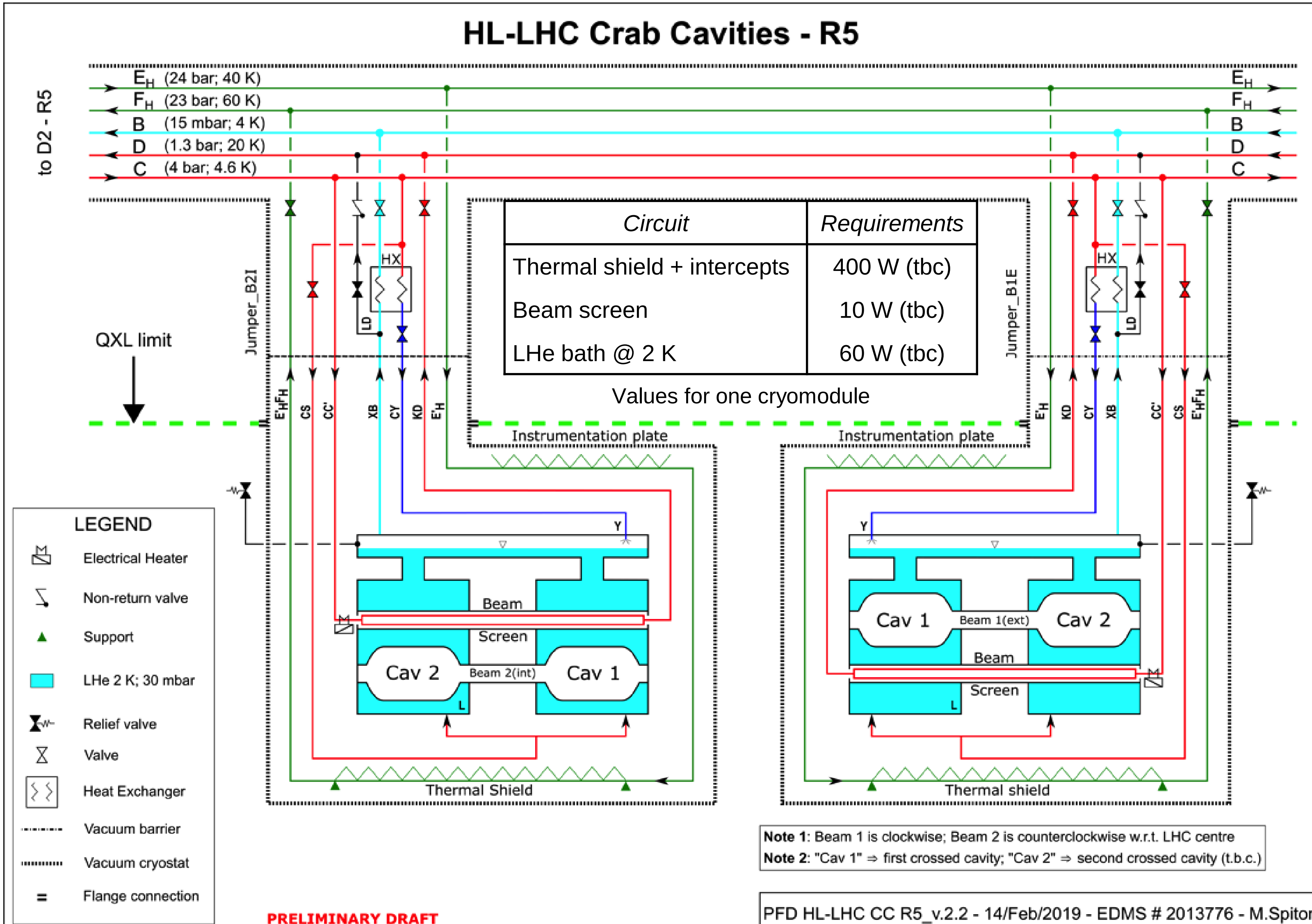
- Introduction to P1-P5 cryogenic aspects
- Main design parameters
- Possible independent thermal cycle
- Timelines
- Concluding remarks

Process & Flow diagram for Crab Cavities



Circuit	*Requirements*
Thermal shield + intercepts	400 W (tbc)
Beam screen	10 W (tbc)
LHe bath @ 2 K	60 W (tbc)

Values for one cryomodule

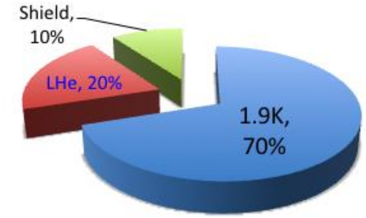
HL-LHC refrigeration capacity at Points 1 & 5

Preliminary global values, being revised

About ~~18kW~~ eq. @ 4.5K, including 3kW @ 1.8K
~15kW

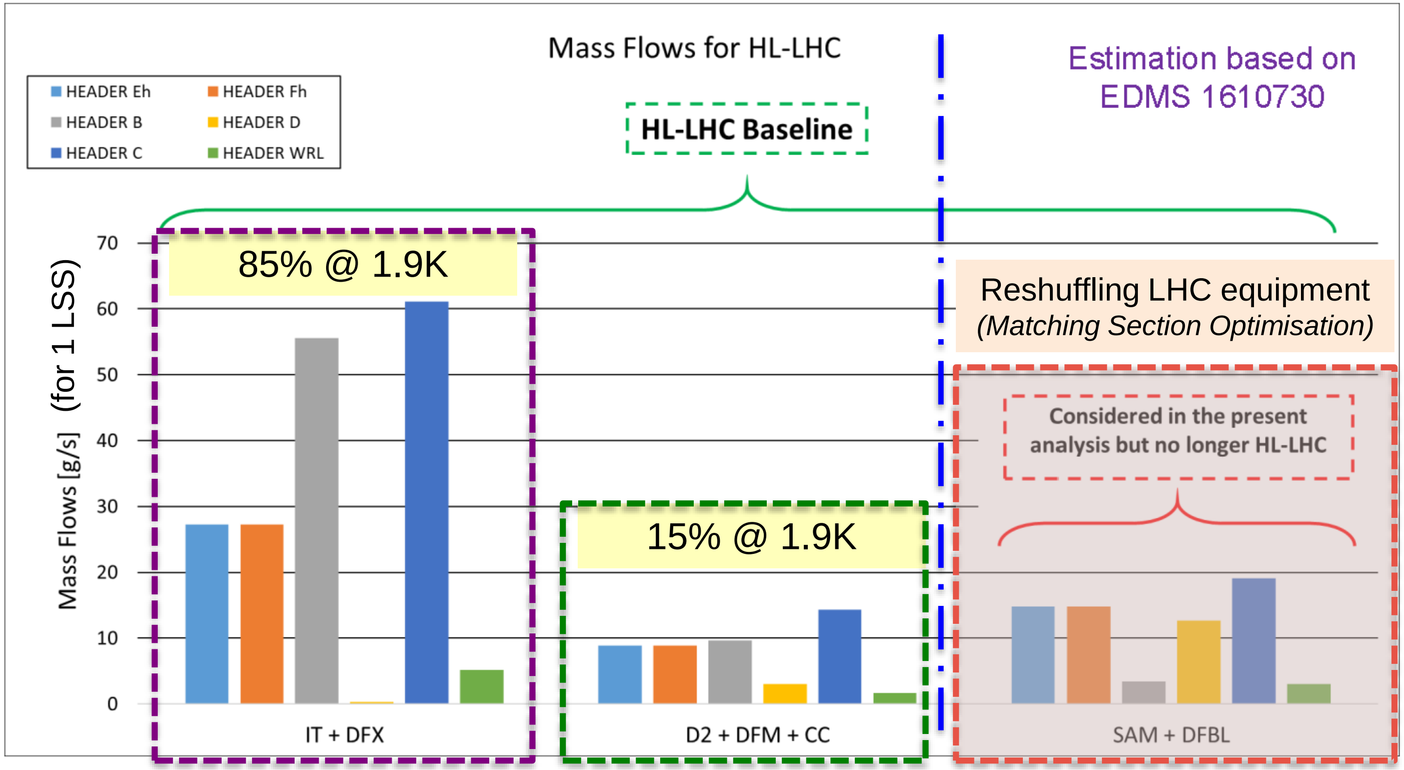
Temperature level	Cooling circuit	Specific heat load [W/m] (Static)	Capacity* / Point		Dynamic range
40-60 K	IT beam screen	16 (0)	3.2 kW	13 kW	~1.3
	Thermal shield	6 (6)	3.6 kW		
	Crab cavity	-	6 kW		
~~20-300 K~~ 4.5-300K	Current lead & SC link	-	~~40 g/s~~	~~40 g/s~~ 20 g/s	~2
4.5-20 K	MS beam screen	2 (0.1)	0.1 kW	0.1 kW	~20
1.9 – 2 K	Cold-mass (1.9 K)	14 (0.35)	2.6 kW	3 kW	~10
	Crab-cavity (2 K)	-	~~0.4 kW~~ 0.2 kW		

**: Including uncertainty and design capacity factor*



Remarks:
1- Crab cavities do not represent a large fraction
2- Large dynamic rage and pulsed heat loads

Mass flows for nominal operation mode



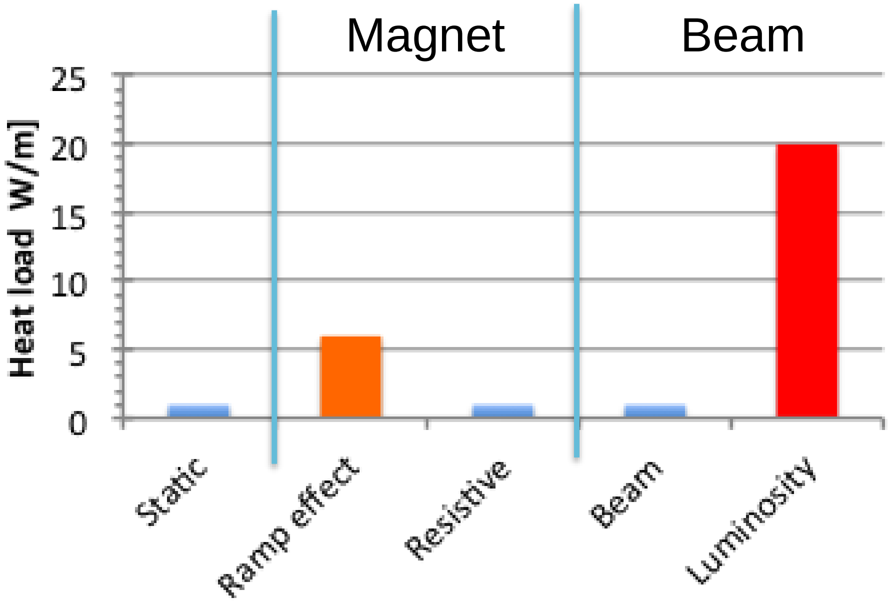
HEADER	Header Eh	Header Fh	Header B	Header D	Header C	Warm Recovery Line
Operating temperature [K]	40	60	4	20	4.6	300
Operating pressure [bar]	24	23	0.016	1.3	3.6	1.3
IT + DFX [g/s]	*27.3*	*27.3*	*55.6*	*0.4*	*61.1*	*5.2*
D2 + DFM + CC [g/s]	8.9	8.9	9.7	3.0	14.3	1.7
SAM + DFBL [g/s]	14.8	14.8	3.4	12.6	19.1	3.0
Total mass flow (LSS.L5 / R5) [g/s]	*51.0*	*51.0*	*68.7*	*16*	*94.5*	*9.9*
Gran Total (LSS.L5 + R5) [g/s]	*102*	*102*	*137.4*	*32*	*189*	*19.8*
Proposed mass flow [g/s]	**140**	**140**	**140**	**30**	**202**	**32**

Italic values are calculated

Introduction to heat loads per origin for triplets

Qualitative illustration (with not too bad orders of magnitude)

Important change in heat load for physics !!!
(well known for IT, but dominant user for HiLumi w.r.t LHC)



	Heat loads [W/m]
Static	1
Ramp effect	6
Resistive	1
Beam	1
Luminosity	20

Fluctuations (min/hours) in pumping line expected, however limited (max ~5mbar) to keep magnets at 1.9K

=> This will deserve specific strategy

(active control with heaters and feed-forward)

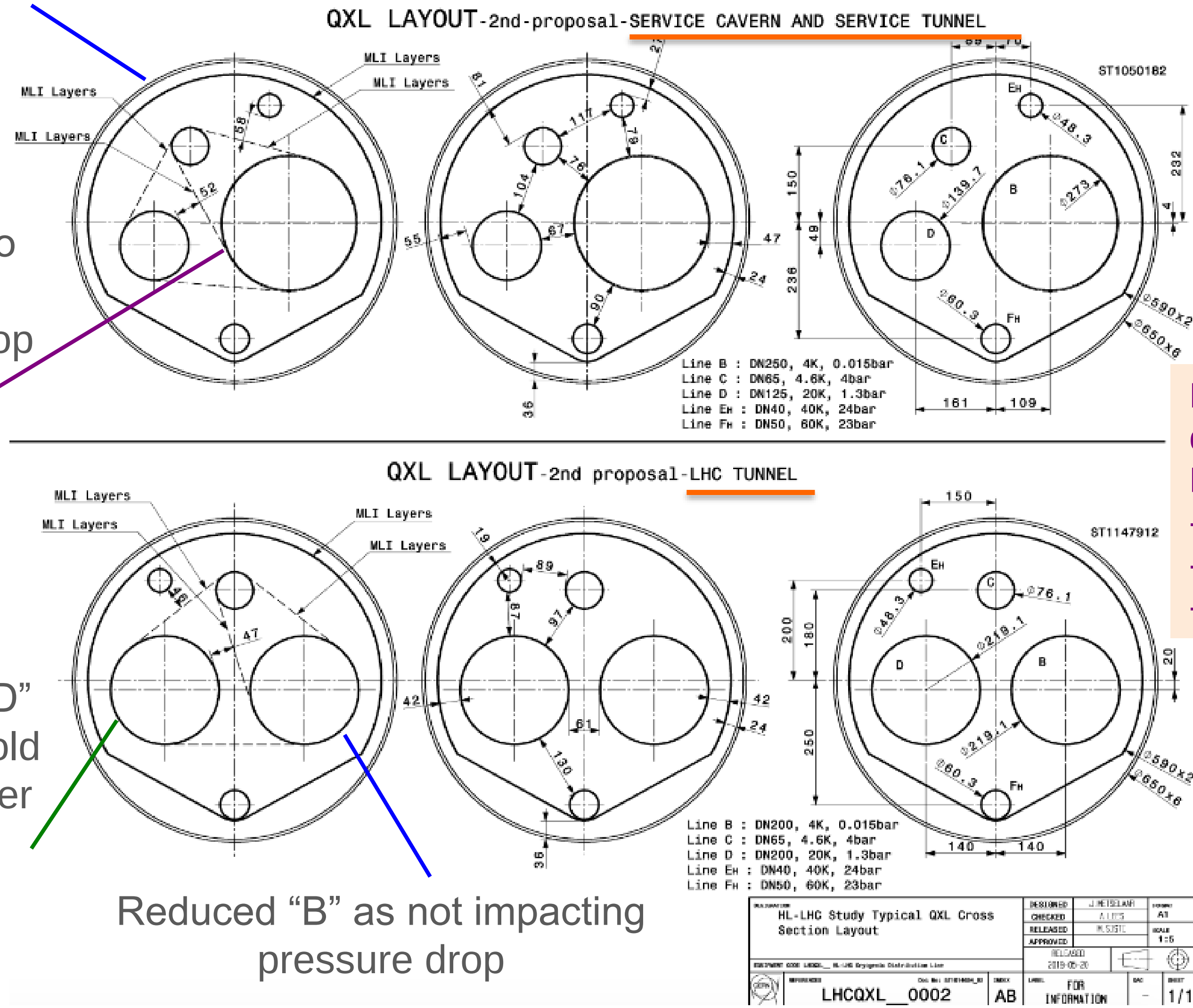
Independent pressure control required for crab cavities (foreseen anyway)

QXL latest dimensions

Constant outer diameter as boundary limit so far

Large “B” to match pressure drop criteria

Increased “D” to provide cold quench buffer for triplets



Reduced “B” as not impacting pressure drop

Design Pressures: defined (2016) EDMS#1573115:

- E,F: 25 Bar_abs
- B: 4 Bar_abs
- C,D: 20 Bar_abs

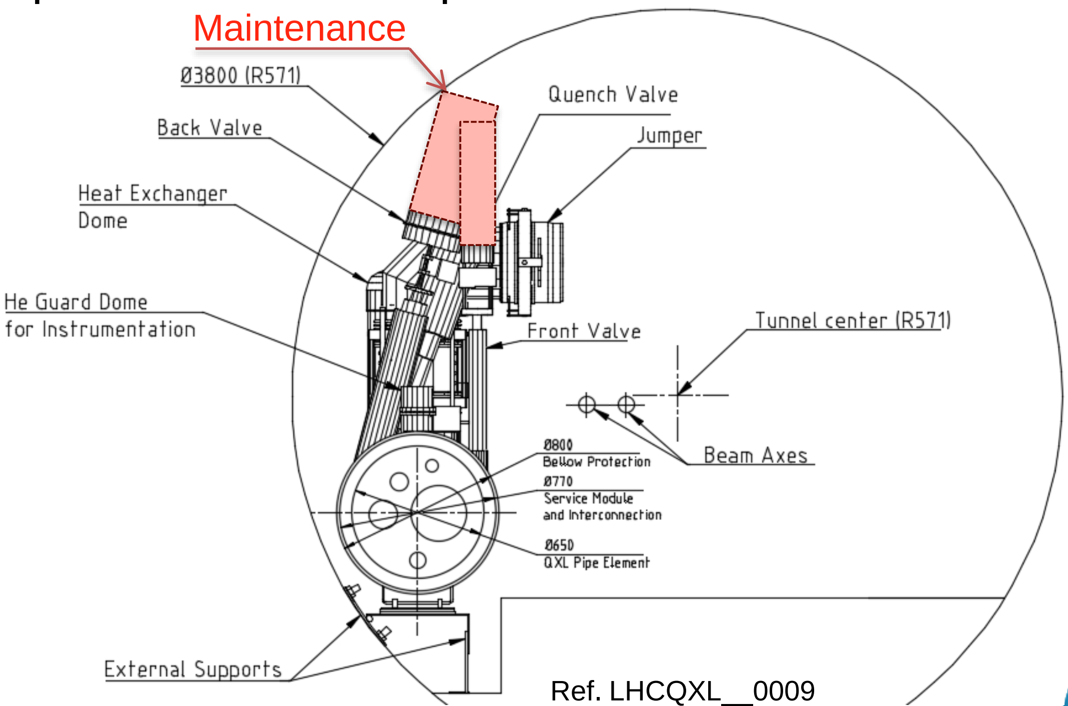
Design principles

Service Module (SM) for crab cavities:

- Based on LHC QRL design
- Valves (6) positioning and spacing
- Inner pipes routing w.r.t. to valves and jumper
- Space reservation for domes (heat exchanger and flow check valve)
- Space reservation for instrumentation (some of them under He guard)
- Space reservation for compressed air control panel

Additional constraints:

- Access for maintenance (even with platforms)
- ALARA principle for:
  - Total Ionizing Dose
  - 1 MeV n_{eq} fluence
  - Residual Dose Rate



Ref. LHCQXL__0009

Proposed solutions R5 (ref. LHCQXL__0011_v.AB)

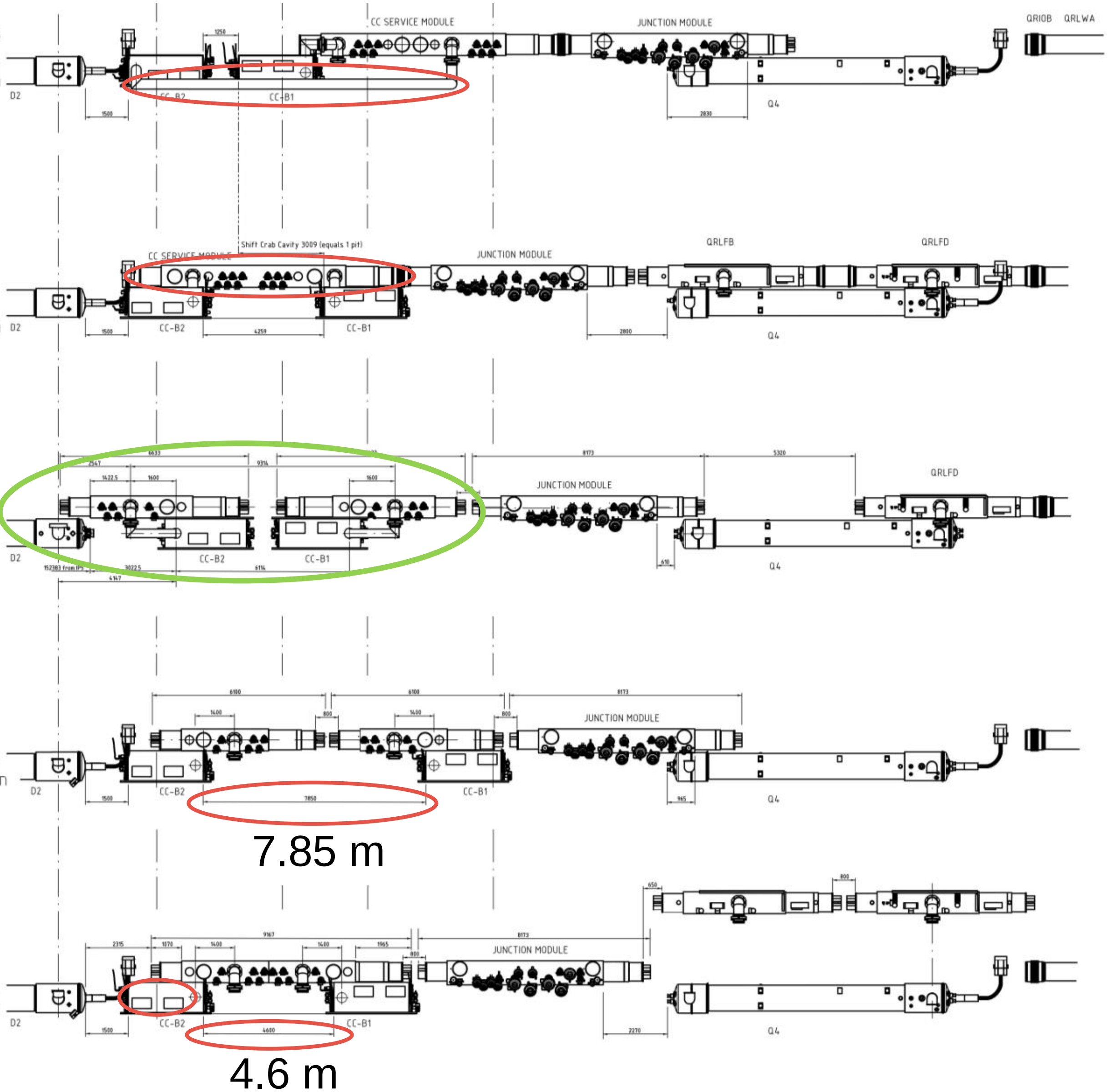
Solution 1: Crab Cavities in the baseline position, Service Module between CCs and Q4

Solution 2: Crab Cavity B2 shifted, unique Service Module between CCs

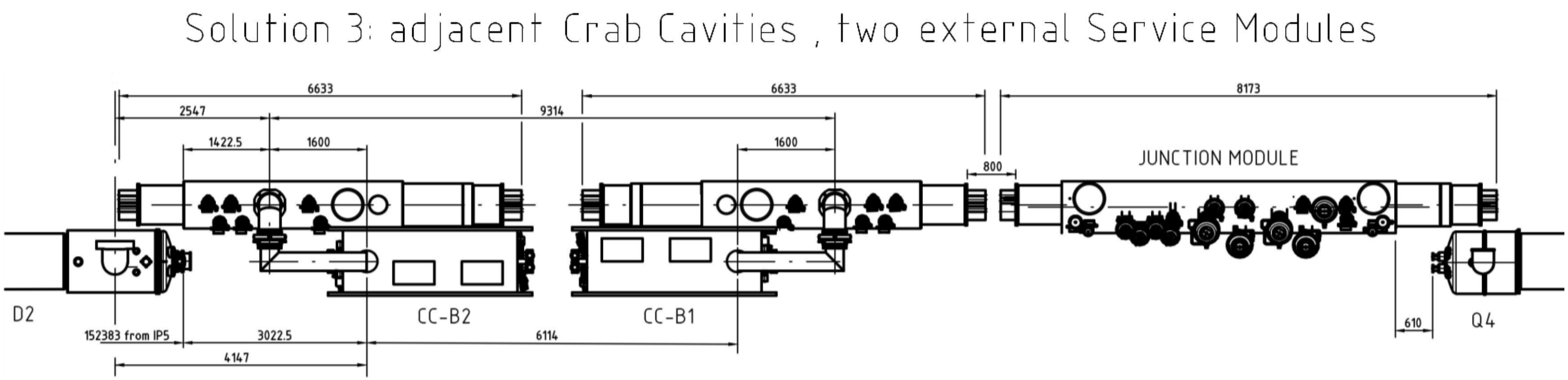
Solution 3: adjacent Crab Cavities , two external Service Modules

Solution 4: spaced Crab Cavities, two in-between Service Modules

Solution 5: spaced Crab Cavities, unique Service Module (optimized)

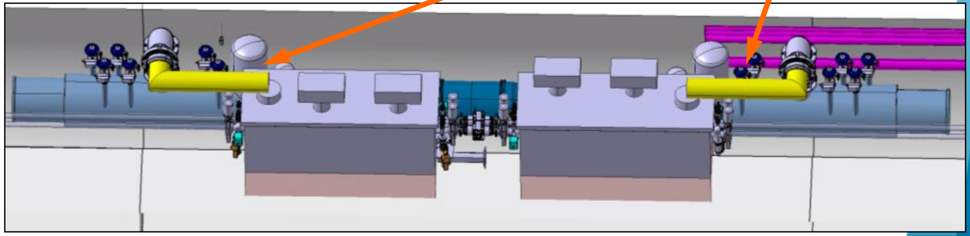


Selected configuration



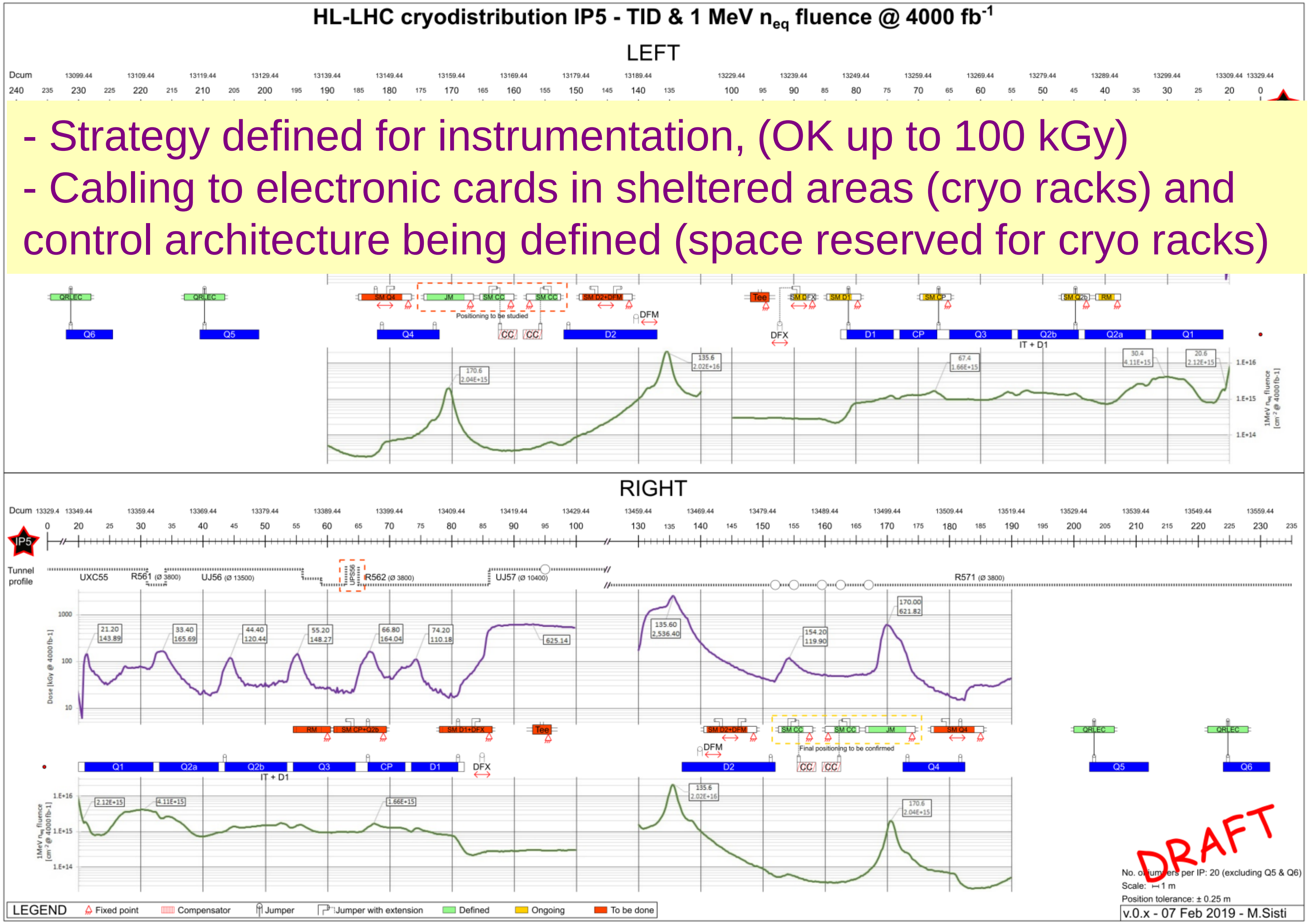
- Shifting from baseline position minimized (fulfilling the SM design principles)
- Distance between CC modules not depending from QXL
- No cryo-items behind waveguides
- Jumper extensions enabling CC module interchangeability
- Space reserved for the D2-DSL link crossing the SM
- Available space for platform (tbc)
- Impact on the QRL for Q4

Possible exchange P1-P5 would be done with associated extensions



QXL Cryoline integration and radiation constraints

- Strategy defined for instrumentation, (OK up to 100 kGy)
- Cabling to electronic cards in sheltered areas (cryo racks) and control architecture being defined (space reserved for cryo racks)



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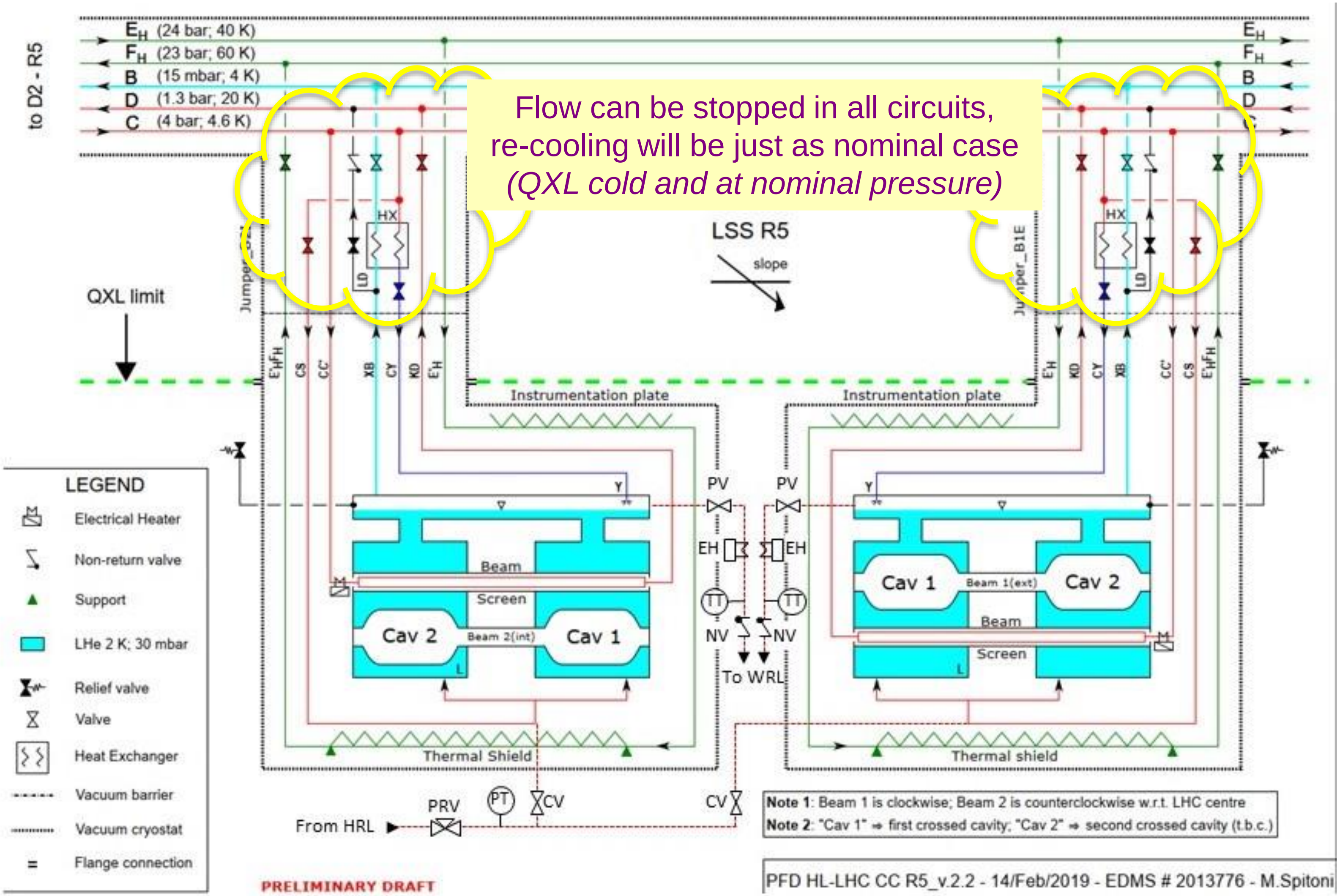
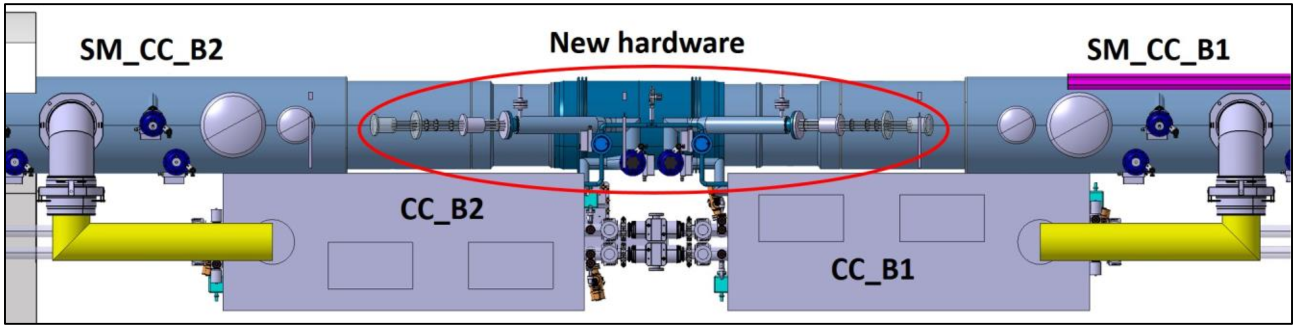
Independent warm-up & cool-down

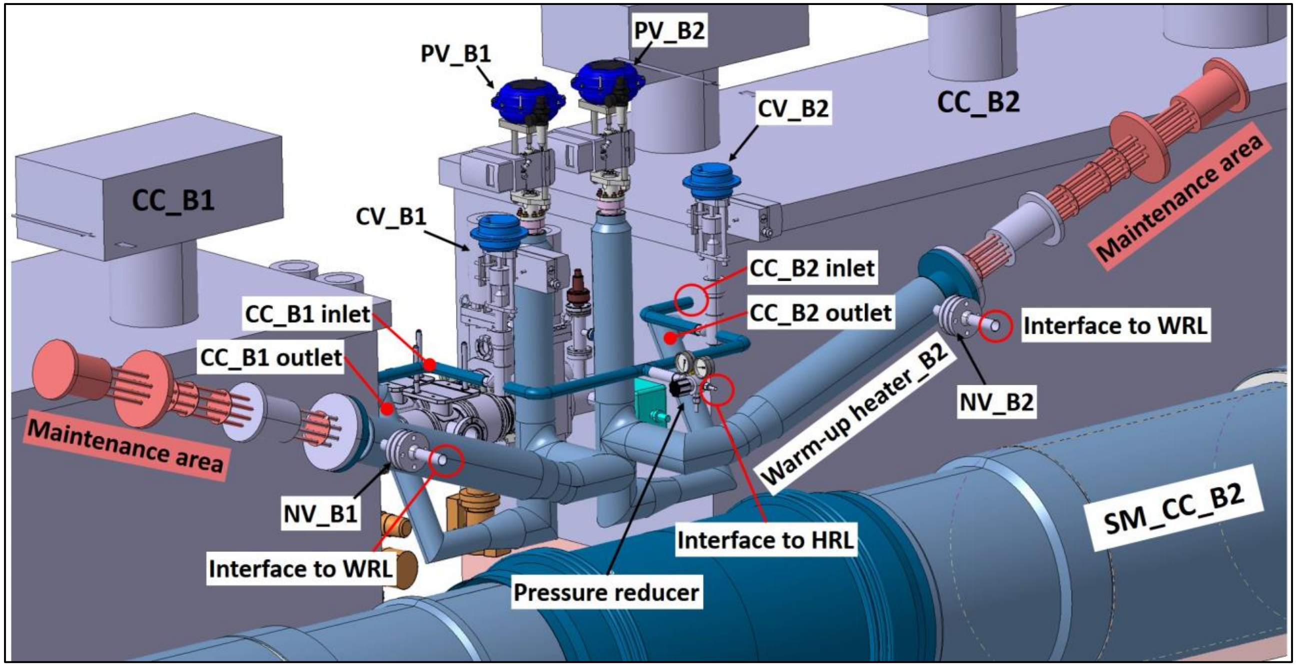
Additional equipment only required for warm-up



Preliminary study to define space



If it is finally decided, then it will have to be properly integrated



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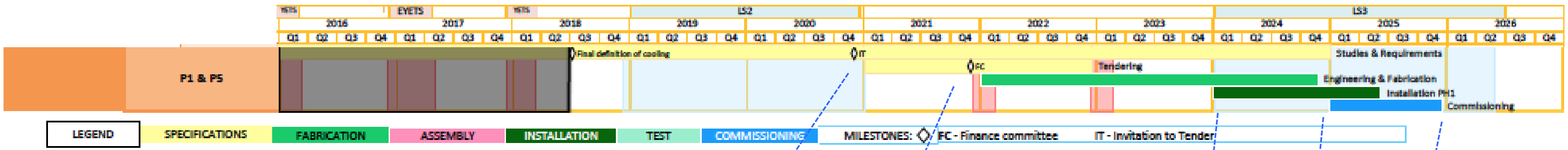
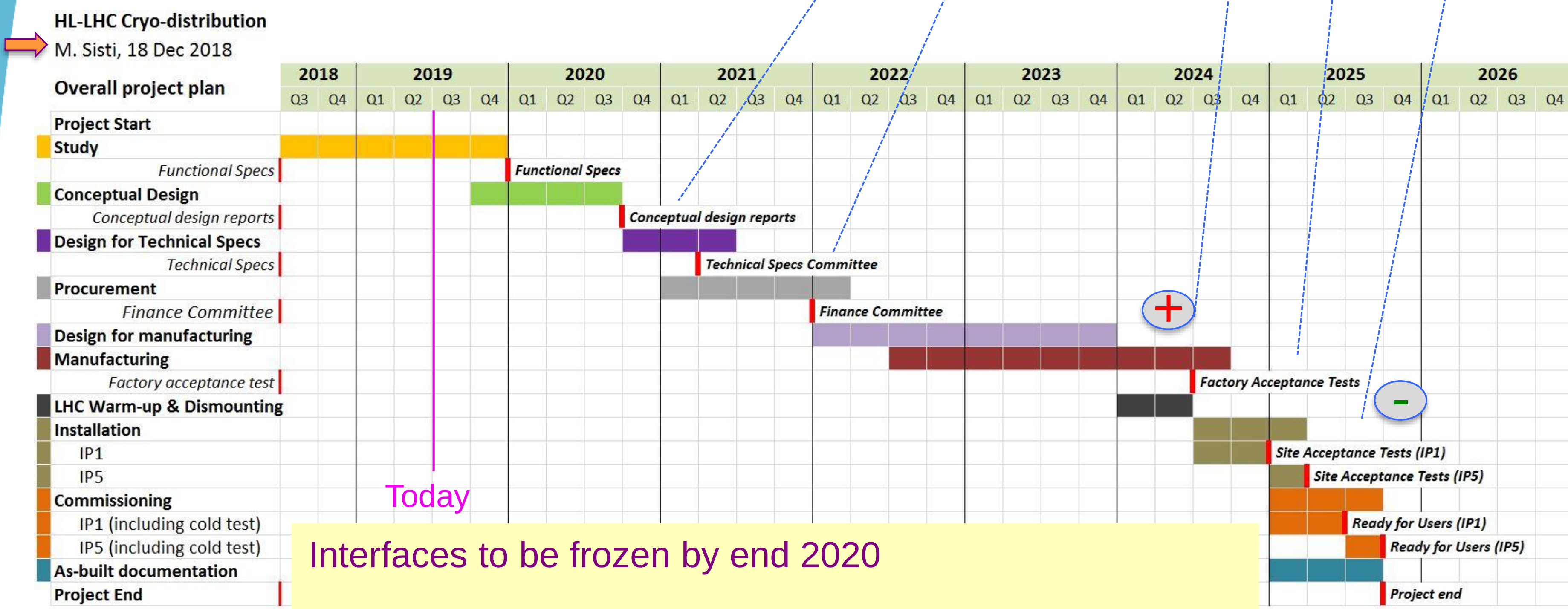
Project plans Refrigeration-Distribution

WP9-Cryogenics, PSM-20Dec'18, S. Claudet



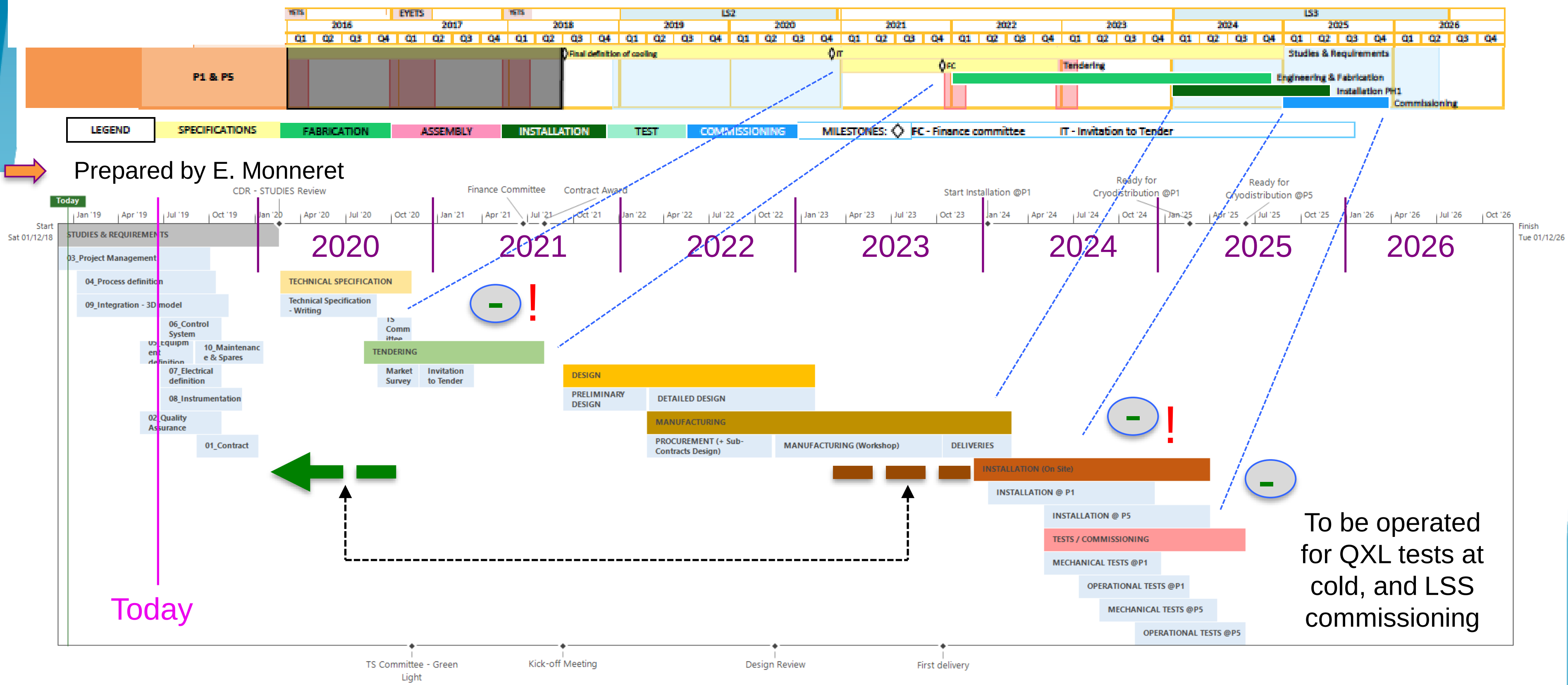


Interfaces to be frozen by end 2020

Used now to discuss for LS3 (ready to install, P1 w.r.t P5)

Project plans Refrigeration-Distribution

WP9-Cryogenics, PSM-20Dec'18, S. Claudet



Cooling capacity and interfaces to be frozen by end 2020

Possible to anticipate delivery in 2023 (surface only),
it would require to freeze heat loads at the end of 2019 (why not, risky?)

Concluding remarks

- Crab Cavities have been considered since beginning of studies for P1-P5, with common resources shared amongst users (capacity, transients, interface)
- Integration consolidated for baseline, with preliminary envelope for additional equipment in case “independent warm-up & cool-down” would be desired
- 18 months ahead from “freezing” interfaces and capacity for tendering main cryo-distribution and refrigerators for P1-P5

Thank you for your attention !

Complements
(if needed)

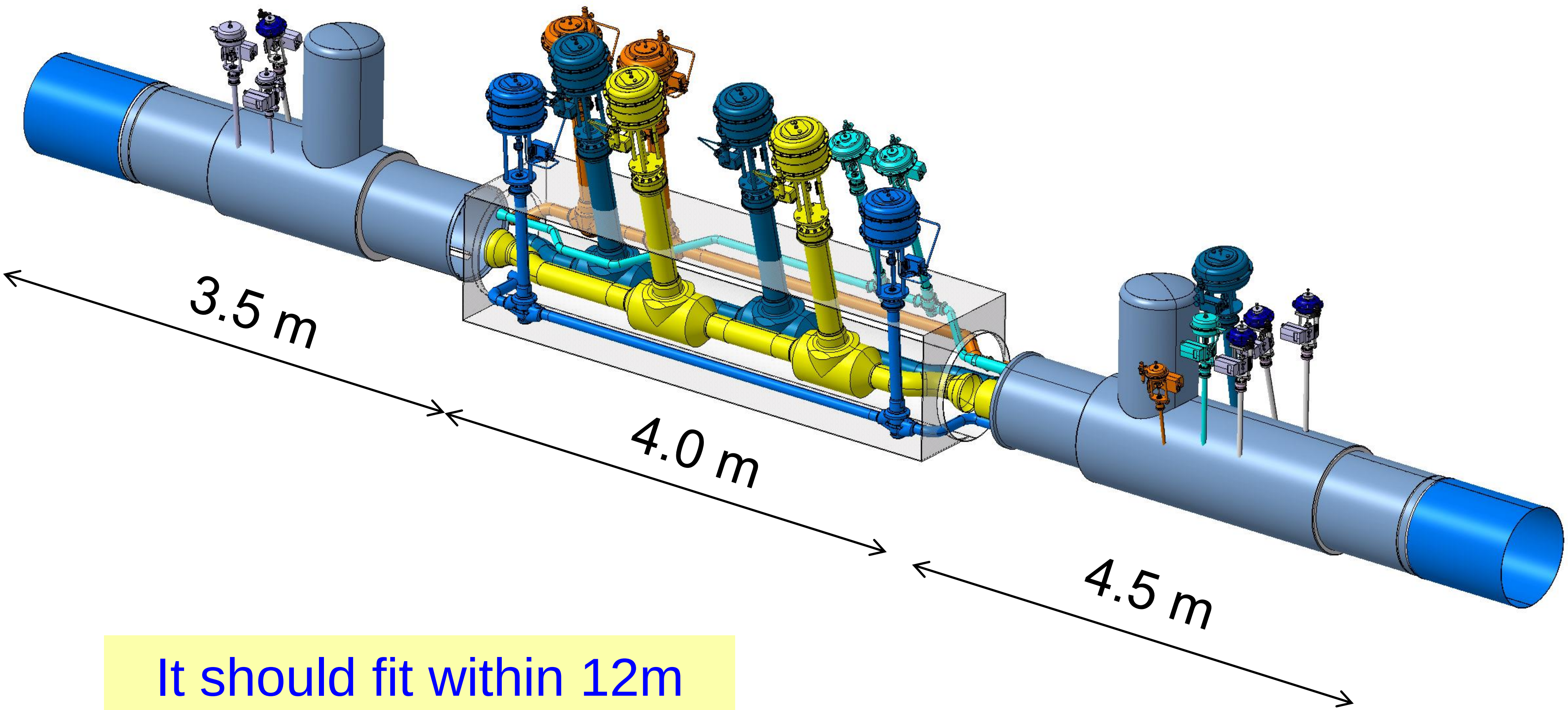
WG2, Summary results

	Thermal shield (Eh - Fh)	Header B	Header C	Header D
LHC (mm)	80 - 80	267	100	150
Higher DN		**Not yet started Directly affects QXL vacuum jacket** DN 300 @ caverns? (damping reasons)	**Study started Maximum increase → to be investigated** DN 100/125 ? (damping reasons)	DN 200 @ LSS_ (quench buffer)
Baseline HL-LHC (DN)	50 - 65	250	80	125
Lower DN	DN 40 - DN 50 (ΔP reasons) **No changes for the time being**	DN 200 @ LSS_ (encumbrance)	DN 65 (conservative) DN 50 (ΔP reasons)	~~Could be decreased (ok for ΔP) (not ok quench)~~

On-going work on damping effects for C (close to a baseline) and B (not much hope with "short" QXL w.r.t QRL 180m3)

Junction module QRL-QXL

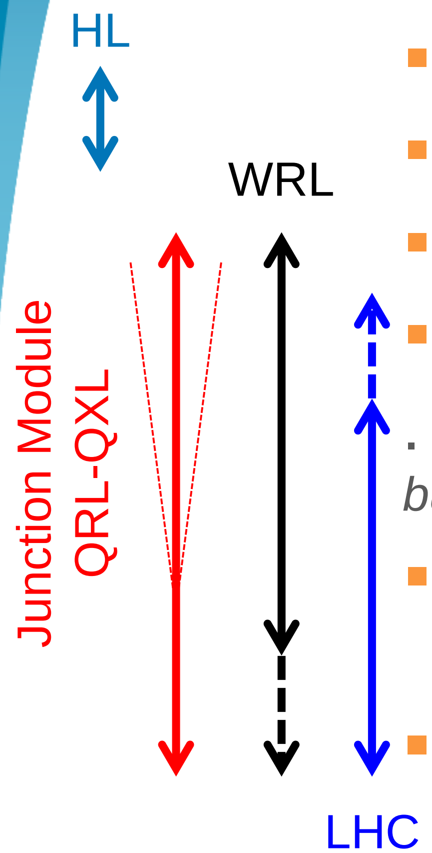
Work on-going



It should fit within 12m

Possible modes and implications, as identified so far for HiLumi

Decreasing requirements in cooling capacity



- Ultimate Luminosity (HL)
- Nominal Luminosity (HL)
- Nominal Luminosity (LHC)
- Low Luminosity / Intensity
- . Powering conditions to 7TeV, *(maybe pilots or few bunches)*
- Injection stand-by (He preservation in magnets, ELQA, maybe pilots or few bunches at injection)
- Magnets @20K

=> The maximum reasonably possible

Bonus *(only 1st year)*

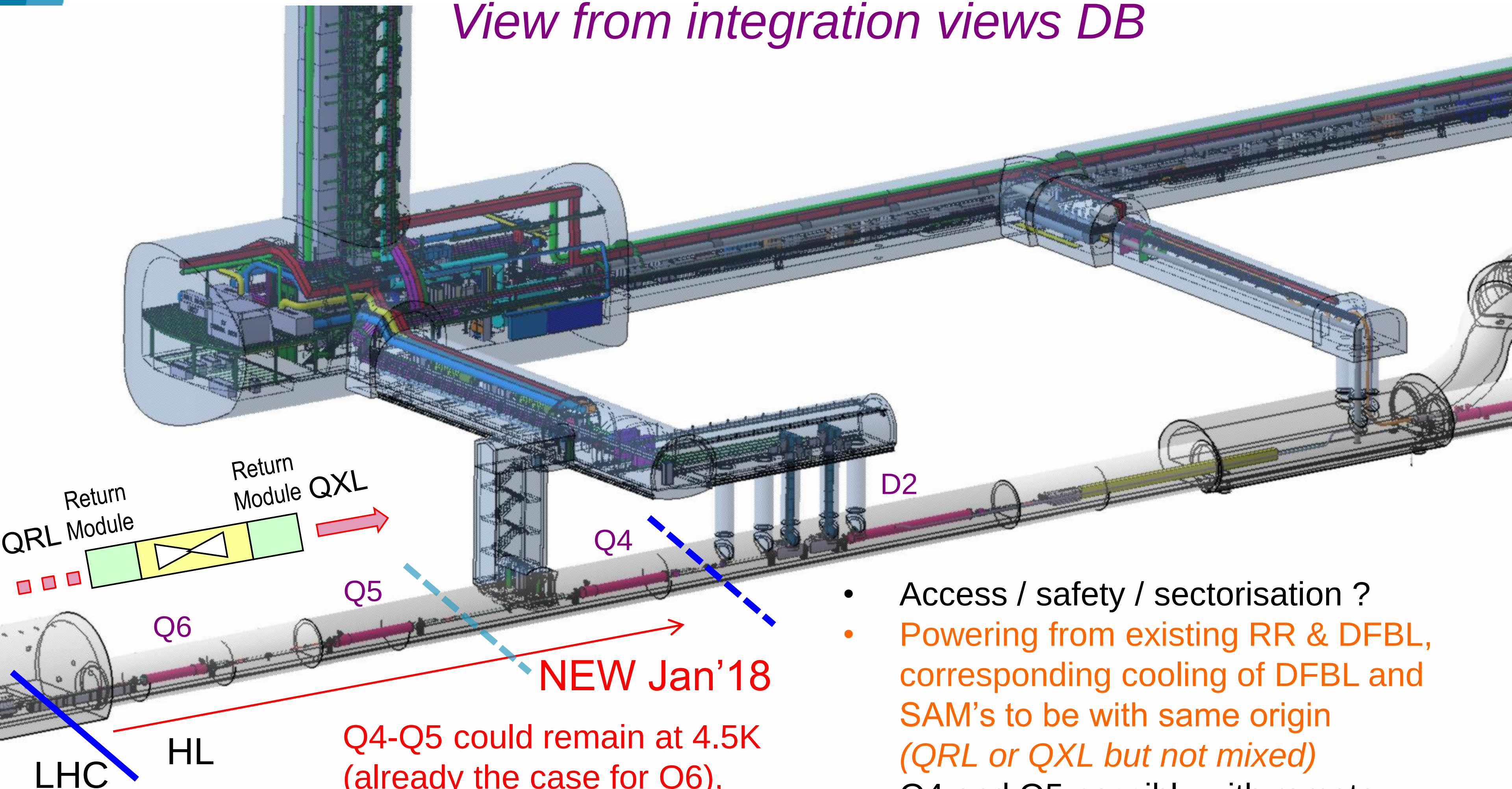
Desired *(1 wk)*

Mandatory *(few wks)*

=> Junction Module and bridge between WRL's recommended
=> Corresponding cooling capacities and impact on size/cost/volume to be further investigated

Cooling P1/P5 SAM's

View from integration views DB



Present limit for QRL/QXL

Q4-Q5 could remain at 4.5K (already the case for Q6), *and moved towards the arc by 10-11m*

- Access / safety / sectorisation ?
- Powering from existing RR & DFBL, corresponding cooling of DFBL and SAM's to be with same origin *(QRL or QXL but not mixed)*
- Q4 and Q5 possibly with remote alignment, compatible with QRL ?
- 3D models to be implemented and then integrated (Q2-2018 for CRG)

1st Evaluation of Heat Loads

EDMS NO. 1610730 | REV. 1.0 | VALIDITY RELEASED
REFERENCE : -

Table 3. Heat load table for mayor components on the magnet side of HL-LHC LSS.R5.

1000 W

1200 W

Component Length [m] (thermal shield)	Q1 10.140 (10.640)	Q2A 9.785	Q2B 9.785	Q3 10.140	CP 6.016	D1 7.370	Intercon. 5.800 (5 units *)	DFX 2.435 (2.935)	DFM 4.000	D2 13.025 (14.025)	CC 4 module units †	Q4 9.062 (10.062)	Q5 8.010 (9.010)	Q6 6.610 (7.610)
Cold Mass														
Temperature [K]	1.9	1.9	1.9	1.9	1.9	1.9	1.9	4.5	4.5	1.9	2	1.9	1.9	1.9
Total Heat Load [W]	185.9	147.6	186.7	195.4	90.2	120.4	65.5	1.7	tbd	55.0	123.8	14.4	11.3	4.0
Avg. Heat Load [W/m]	18.34	15.08	19.08	19.27	15.00	16.33	6.13	0.72	tbd	4.22	30.94 W pu	1.59	1.42	0.60
Data: Static [W/m]	*0.82*	*0.83*	*0.83*	*0.82*	*0.87*	*0.83*	*0.13*	*0.72*	tbd	*0.28*	12.5 W pu	*0.29*	*0.32*	*0.36*
Data: Resistive [W/m]	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	-	tbd	tbd	tbd
Data: Beam Induced [W/m]	*0.16*	*0.05*	*0.06*	*0.11*	tbd	*0.17*	tbd	tbd	-	*0.10*	0.5 W pu	*0.19*	*0.23*	*0.24*
Data: Collision Induced [W/m]	*17.36*	*14.21*	*18.19*	*18.34*	*14.13*	*15.33*	*6 W pu*	tbd	tbd	*3.84*	0.34 W pu	*1.10*	*0.87*	tbd
Data: RF Induced [W/m]	-	-	-	-	-	-	-	-	-	-	17.6 W pu	-	-	-
Beam Screen														
Temperature [K]	40-60	40-60	40-60	40-60	40-60	40-60	40-60	tbd	-	4.5-20	-	4.5-20	4.5-20	4.5-20
Total Heat Load [W]	271.1	118.9	158.2	161.2	107.4	117.9	110.0	1.3	-	16.7	-	21.7	14.3	3.0
Avg. Heat Load [W/m]	26.74	12.15	16.17	15.90	17.85	16.00	22 W pu	0.55	-	1.28	-	2.40	1.79	0.45
Data: Static [W/m]	*0.14*	*0.14*	*0.14*	*0.14*	*0.23*	*0.19*	-	*0.55*	-	*0.00*	-	*0.15*	*0.17*	*0.21*
Data: Resistive [W/m]	tbd	tbd	tbd	tbd	tbd	tbd	tbd	tbd	-	tbd	-	tbd	tbd	tbd
Data: Beam Induced [W/m]	*1.25*	*0.25*	*0.39*	*0.67*	*tbd*	*1.29*	*tbd*	tbd	-	*1.08*	-	*2.08*	*1.60*	*0.24*
Data: Collision Induced [W/m]	*25.35*	*11.75*	*15.64*	*15.09*	*17.62*	*14.52*	*22 W pu*	tbd	-	*0.20*	-	*0.17*	*0.02*	tbd
Thermal Shield														
Temperature [K]	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	40-60	80	40-60	40-60	40-60
Total Heat Load [W]	56.6	53.2	53.2	54.3	33.8	38.2	18.6	24.1	tbd	68.1	1528.0	48.1	44.7	40.2
Avg. Heat Load [W/m]	5.32	5.44	5.44	5.36	5.63	5.18	3.21	8.21	tbd	4.85	382 W pu	4.78	4.96	5.28
Data: Static [W/m]	*5.32*	*5.44*	*5.44*	*5.36*	*5.63*	*5.18*	*3.21*	*8.21*	tbd	*4.85*	252 W pu	*4.78*	*4.96*	*5.28*
Data: RF Induced [W/m]	-	-	-	-	-	-	-	-	-	-	130 W pu	-	-	-

Maturity level of the source data: estimated = *italic*; calculated = normal; measured = underlined.
tbd = to be defined; "-" = not applicable; W pu = Watts per unit.
* Length of each interconnection unit is 1 m, except between Q3-CP which is 1.8 m.
† A module unit contains 2 crab cavities.

Heat loads to be revisited as well for CC (1.9K, thermal shield, Beam-Screen)