CERN

HL-LHC Lay-out and integration

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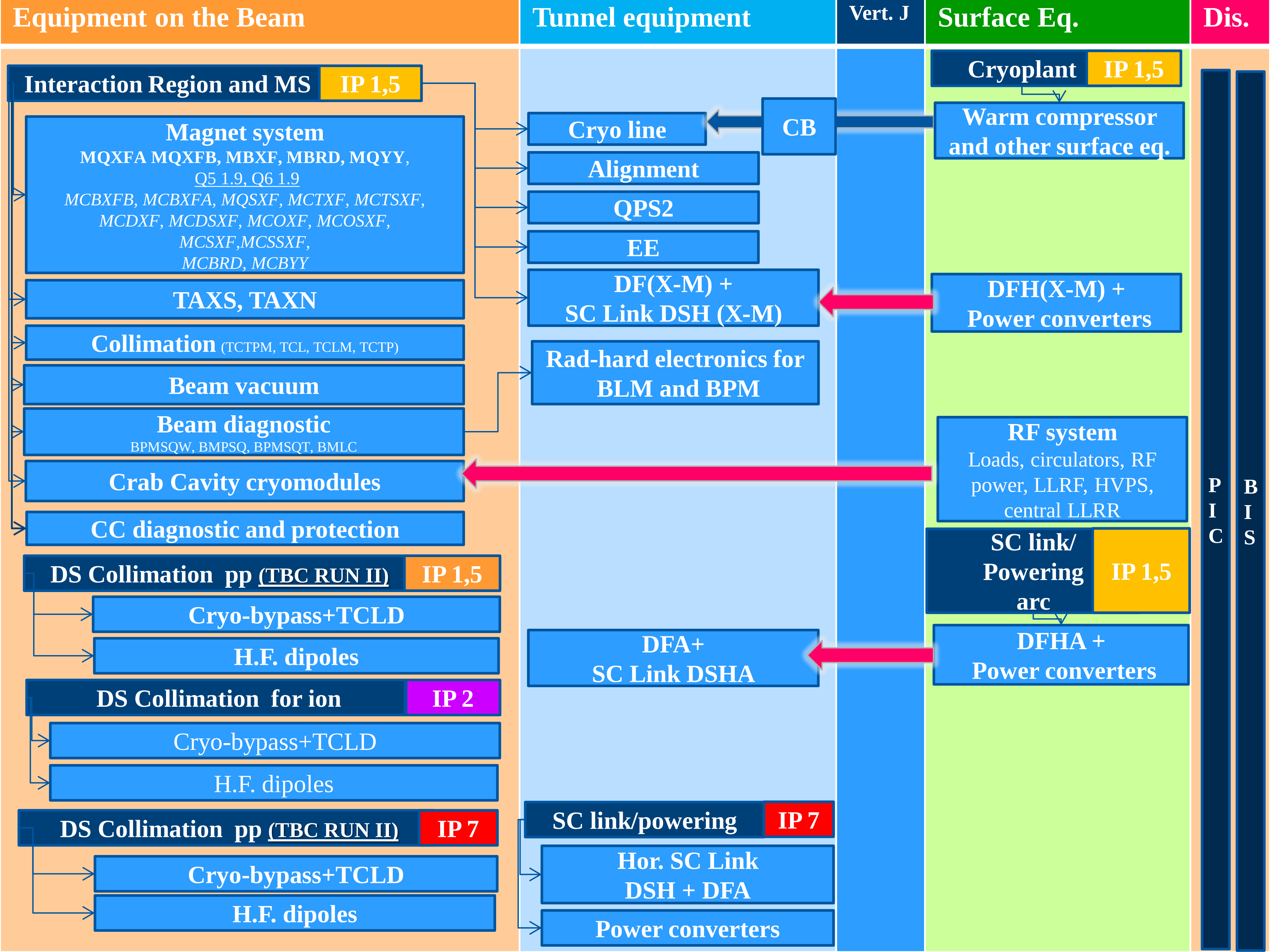
Integration studies by C. Collazos, J.P. Corso, C. Magnier.

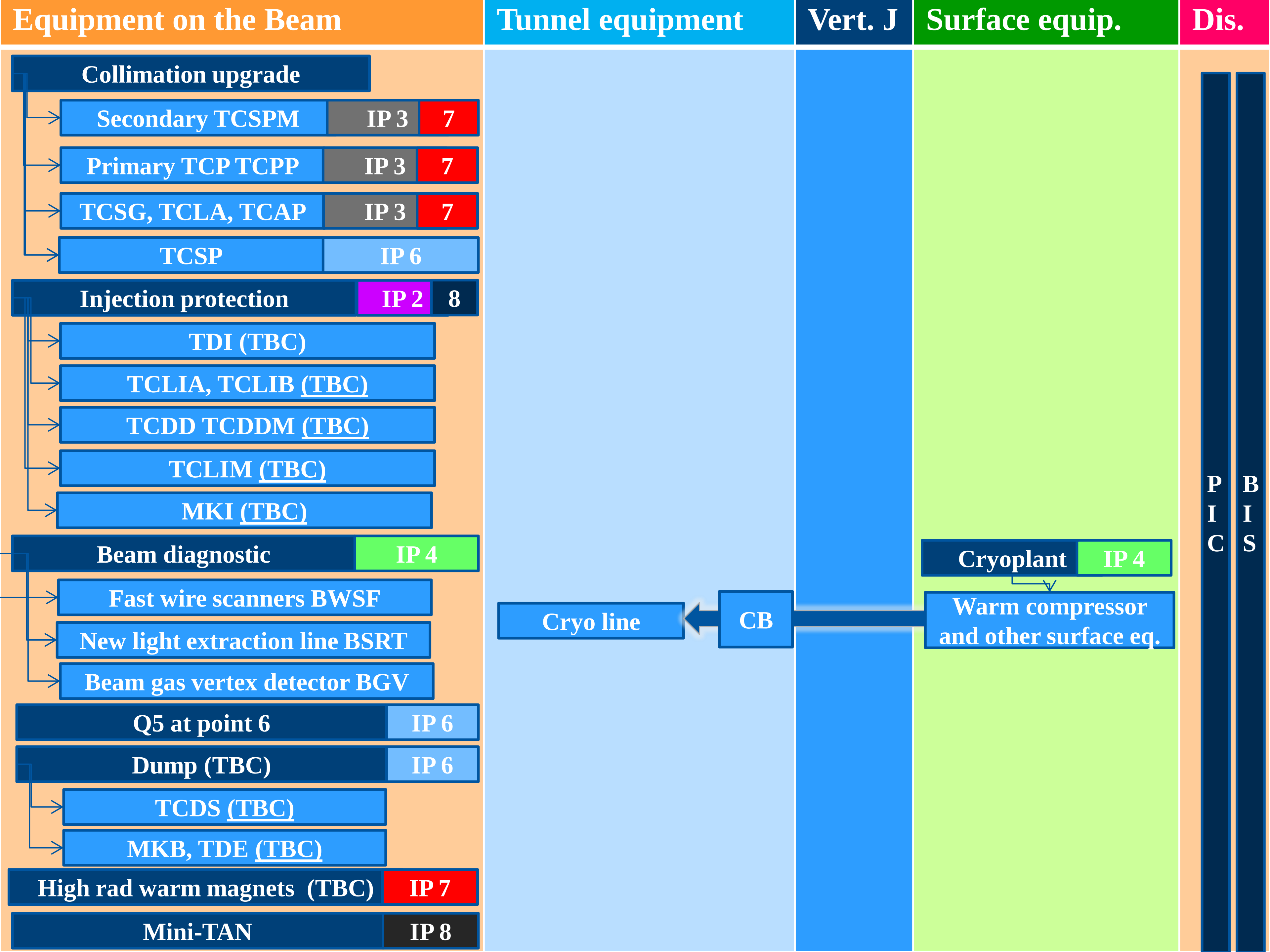
Presented by P. Fessia

Summary

- HL-LHC baseline and options
- IR 1-5 machine lay-out
- IR 1-5 system arrangement: baseline and option
- Other integration activities for HL
- Conclusions and next steps

HL-LHC BASELINE


Equipment on the Beam
Tunnel equipment
Vert. J
Surface Eq.
Dis.
Interaction Region and MS
IP 1,5
Magnet system
MQXFA MQXFB, MBXF, MBRD, MQYY,
Q5 1.9, Q6 1.9
MCBXFB, MCBXFA, MQSXF, MCTXF, MCTSXF,
MCDXF, MCDSXF, MCOXF, MCOSXF,
MCSXF,MCSSXF,
MCBRD, MCBYY
TAXS, TAXN
Collimation (TCTPM, TCL, TCLM, TCTP)
Beam vacuum
Beam diagnostic
BPMSQW, BMPSQ, BPMSQT, BMLC
Crab Cavity cryomodules
CC diagnostic and protection
DS Collimation pp (TBC RUN II)
IP 1,5
Cryo-bypass+TCLD
H.F. dipoles
DS Collimation for ion
IP 2
Cryo-bypass+TCLD
H.F. dipoles
DS Collimation pp (TBC RUN II)
IP 7
Cryo-bypass+TCLD
H.F. dipoles
Cryo line
CB
Alignment
QPS2
EE
DF(X-M) +
SC Link DSH (X-M)
Rad-hard electronics for
BLM and BPM
DFA+
SC Link DSHA
SC link/powering
IP 7
Hor. SC Link
DSH + DFA
Power converters
Cryoplant
IP 1,5
Warm compressor
and other surface eq.
DFH(X-M) +
Power converters
RF system
Loads, circulators, RF
power, LLRF, HVPS,
central LLRR
SC link/
Powering
arc
IP 1,5
DFHA +
Power converters
PIC
BIS


Equipment on the Beam
Tunnel equipment
Vert. J
Surface equip.
Dis.
Collimation upgrade
Secondary TCSPM IP 3 7
Primary TCP TCPP IP 3 7
TCSG, TCLA, TCAP IP 3 7
TCSP IP 6
Injection protection IP 2 8
TDI (TBC)
TCLIA, TCLIB (TBC)
TCDD TCDDM (TBC)
TCLIM (TBC)
MKI (TBC)
Beam diagnostic IP 4
Fast wire scanners BWSF
New light extraction line BSRT
Beam gas vertex detector BGV
Q5 at point 6 IP 6
Dump (TBC) IP 6
TCDS (TBC)
MKB, TDE (TBC)
High rad warm magnets (TBC) IP 7
Mini-TAN IP 8
Cryo line
CB
Cryoplant IP 4
Warm compressor and other surface eq.
PIC
BIS

HL-LHC OPTIONS

Equipment on the Beam	Tunnel equipment	Vert. J	Surface equipment	Dis.

- BBLR — IP 1,5
- Crab Cavity for crab kissing scheme — IP 1,5
- Other RF harmonic system — IP 4
  - Sub harmonic
  - Higher order hamonic
- ADT upgrade — IP 4
- Hollow e-lenses — IP 4
- Crystal collimation TECG — IP 7
- TAS — IP 8

W I C

F M C M

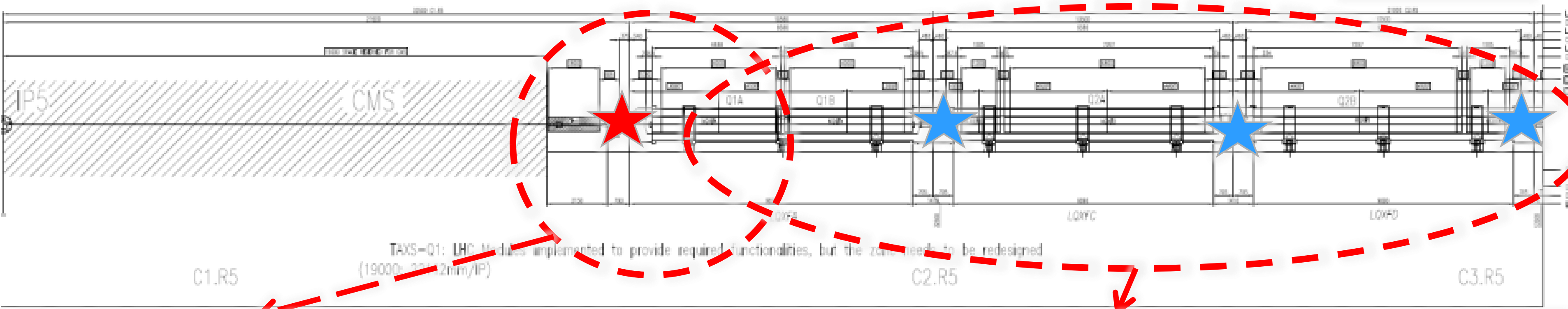
IR1 and IR5 according to approved plan LHCLSXHT0010 index A conforming to optics version HL-LHC V 1.1

New version next spring

LAY-OUT STATUS IN THE IR 1,5

IR1-IR5 TAXS→Q2B

★ BPM

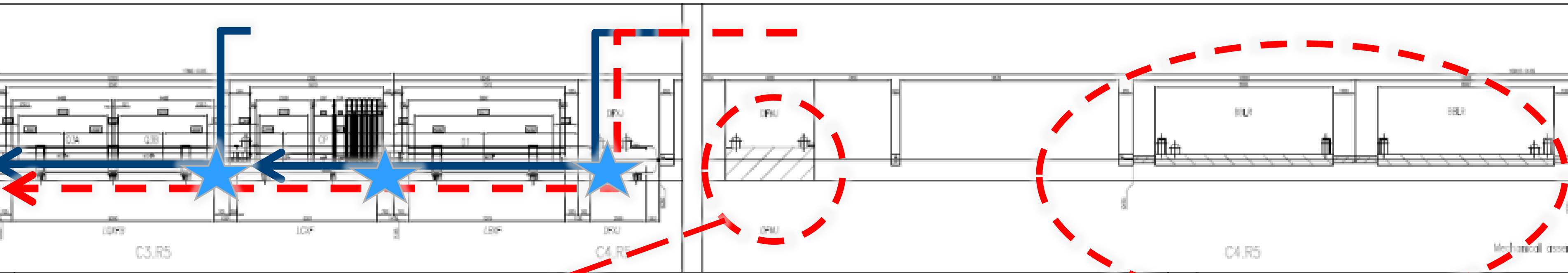


TAS to Q1 area under study, functionalities identified, but detailed equipment and assembly study recently started by WP12 (vacuum). Possibilities for BMP to be cold or part of the TAS could be discussed

New cryostat design required, possible need to use not standard shape (elliptical) and integrating system to manage vacuum and quench forces keeping interconnects of simple opening.
Under study by WP3

Initial equipment studies lead to a short TAS to Q1 area with more reduced access respect to the LHC. This is not compatible with future HL-LHC requirements
Higher radiation dose call for remote operation/redundancy and very high reliability.
The study of this area could require the shift of Q1 farther from IP

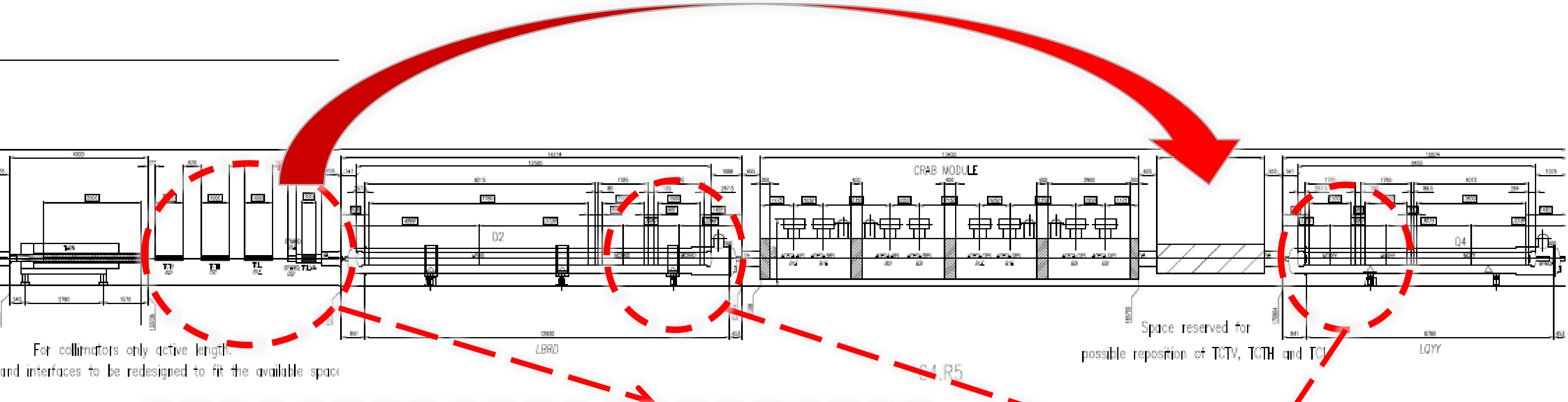
IR1-IR5 Q3→BBLR



DFM: terminal of the SC link for the Matching Sections

BBLR:
Space occupation allocated, but other position toward the IP possible.
HARDWARE NOT IN THE BASELINE AND UNITS NOT IN THE HL-LHC BUDGET

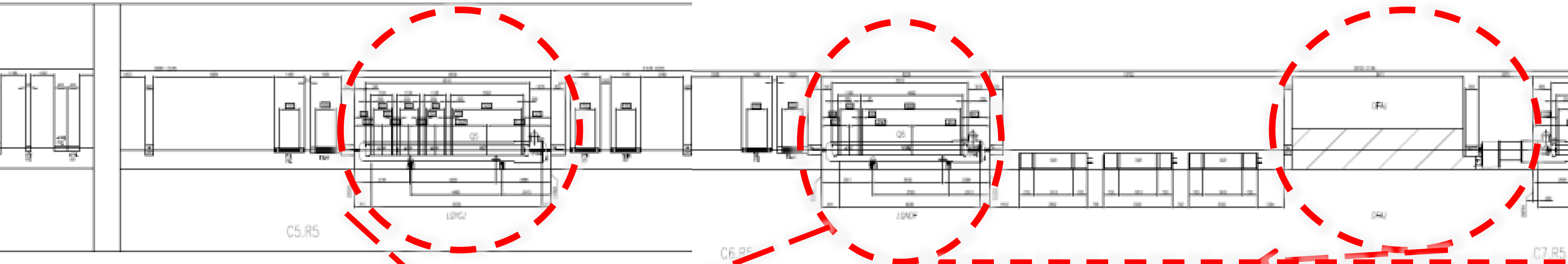
IR1-IR5 TAXN→Q4



TCT, TCL and BPMW and TCLM do not fit in the space between the TAXN and the D2. New Energy deposition simulations are being completed and should confirm the necessity of the mask. In any case it is needed to redesign the mechanical interfaces of the collimators (space, 5th axis and integrated protection design with the TAXN)

Orbit correctors in the Q4 and D2 are difficult challenges because of the large cross talk between the apertures. Final design could have impact on the lay-out

IR1-IR5 Q5→DFBA

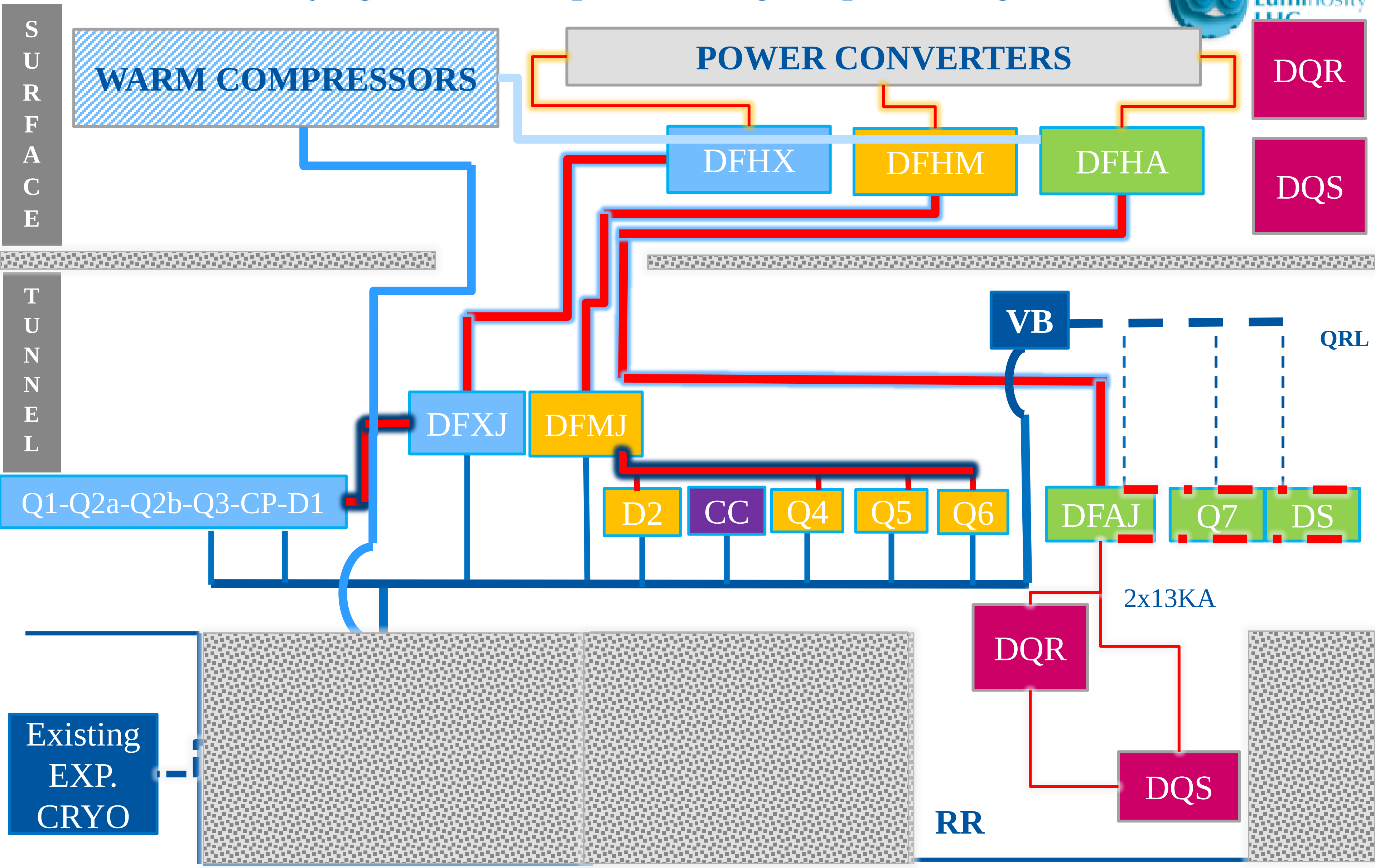


Q5 and Q6 are the LHC Q4 and Q5 modified to work at 1.9K.
Modifications, in order to optimize the work and the costs, requires the use of the magnets in IR1 in IR5 and vice-versa. In addition the Q4 can accept heat exchanger tube only over a section of the length, therefore cryogenic studies are needed

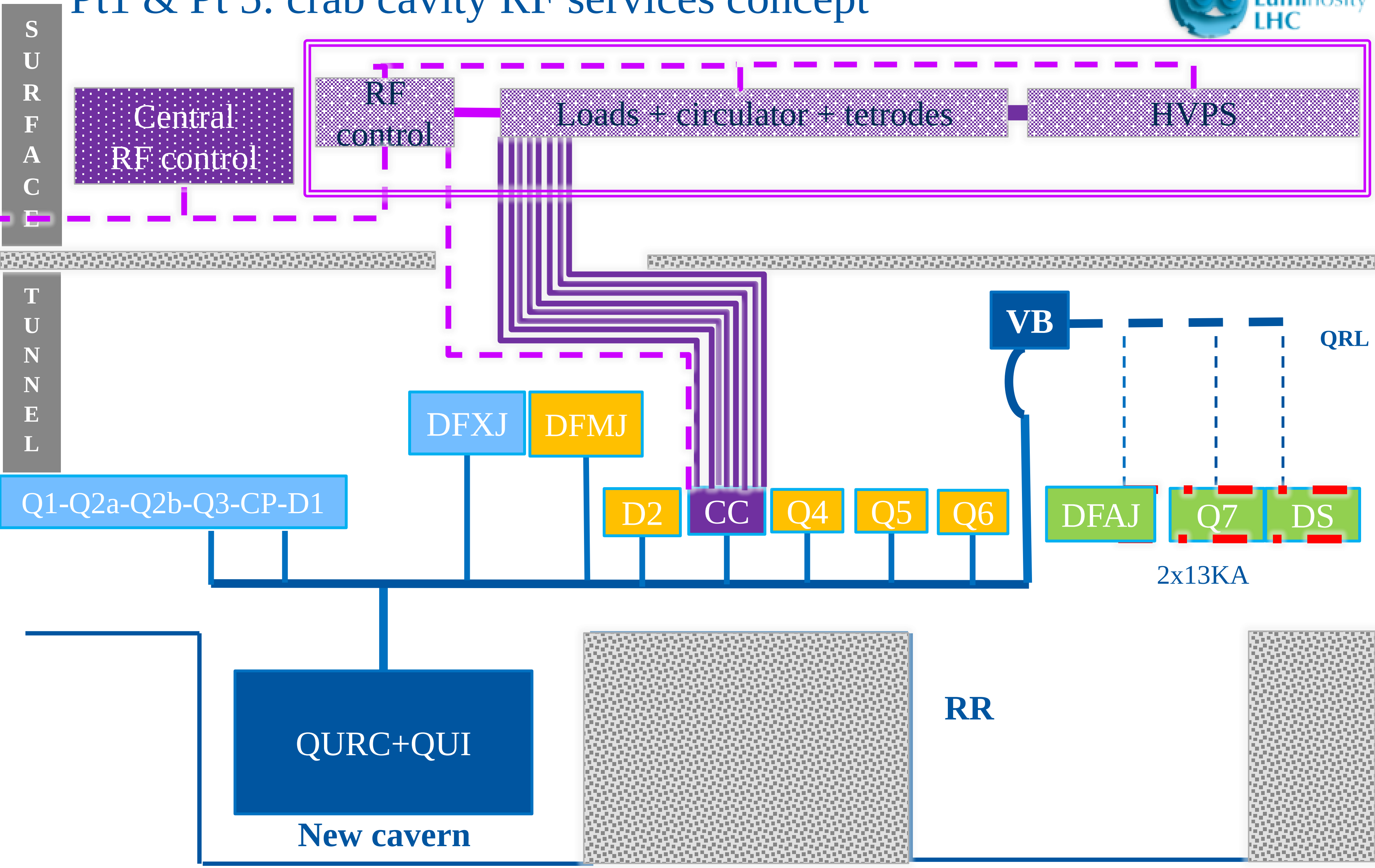
Present baseline features modification/change of the DFBA in a DFA being the terminal of a SC link feeding the 600 A and 6 kA circuits of the ARC. Possible other solution as the use of the radiation hard PC in the RR that would limit modifications and ease machine integration under evaluation

HL-LHC IR 1,5 MAIN SYSTEM DISTRIBUTION, BASELINE

Pt1 & Pt 5: cryogenic concept and magnet powering



Pt1 & Pt 5: crab cavity RF services concept



Space requirements baseline

High Luminosity LHC

Surface

- **Cryo installation** 1000 m^2
- **Power Converters and start of SC link** 700-900 m^2
- **Crab** 175 m^2 on each side
- **Central RF** 8m^2

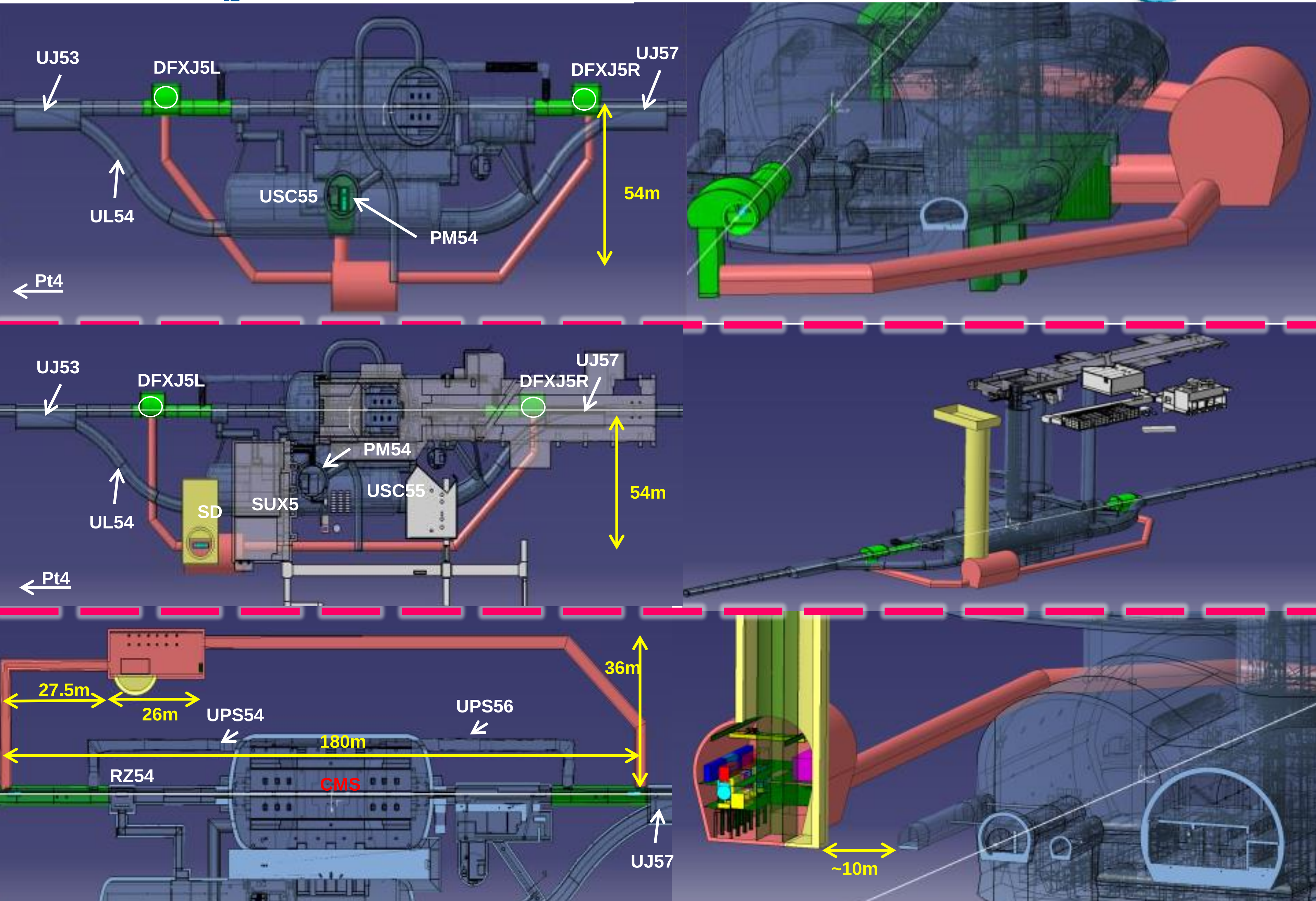
To surface

- **Cryogenic connection**
- **3 SC links each side (3 ducts or central shaft)**
- **CC Connection 4-8 ducts or shaft Each IP side**

Underground

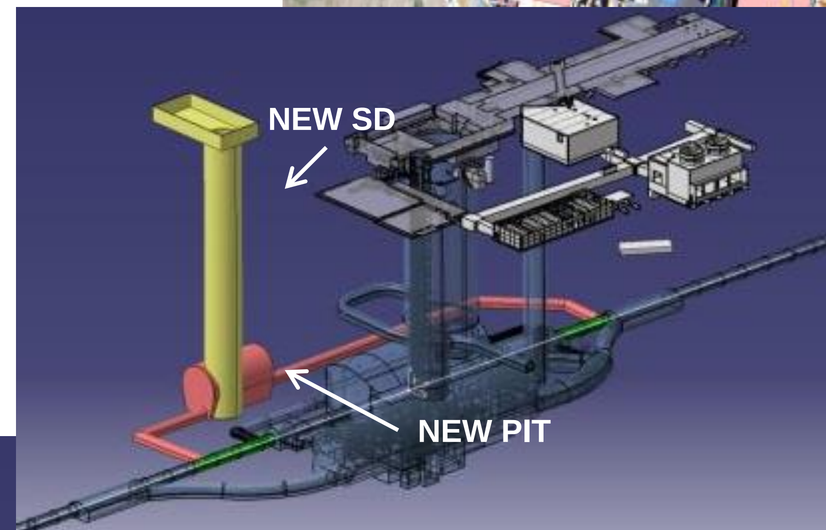
- Cold Box (QURC+QUI) cavern 250-350 m^2 4500-5000 m^3
- Connection from cold box to new QRL
- **Enlargement of LHC tunnel for loads and circulators**

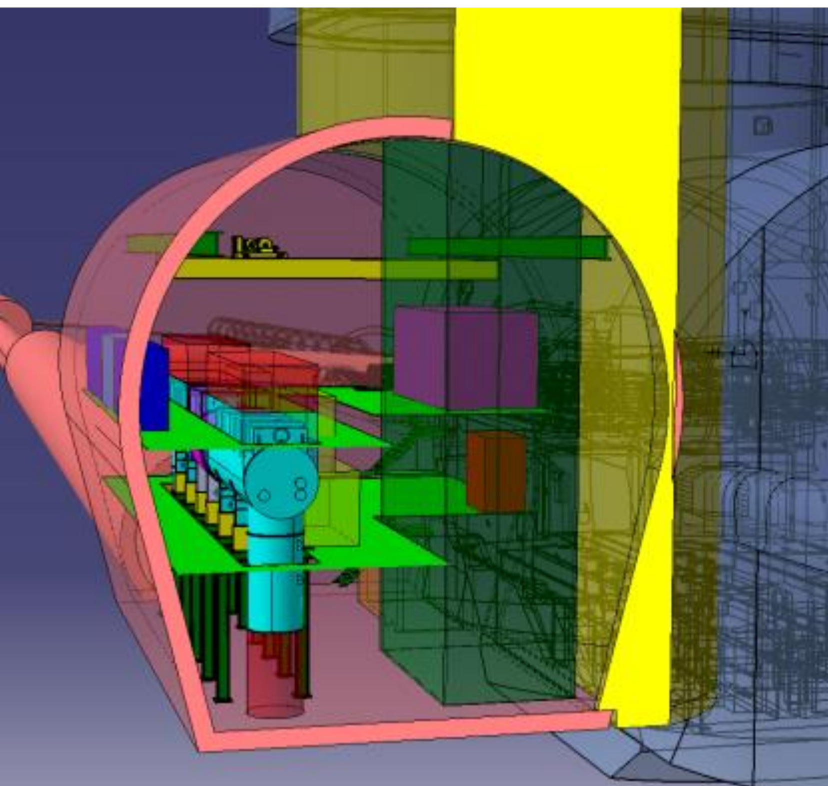
Various possibilities have been studied …

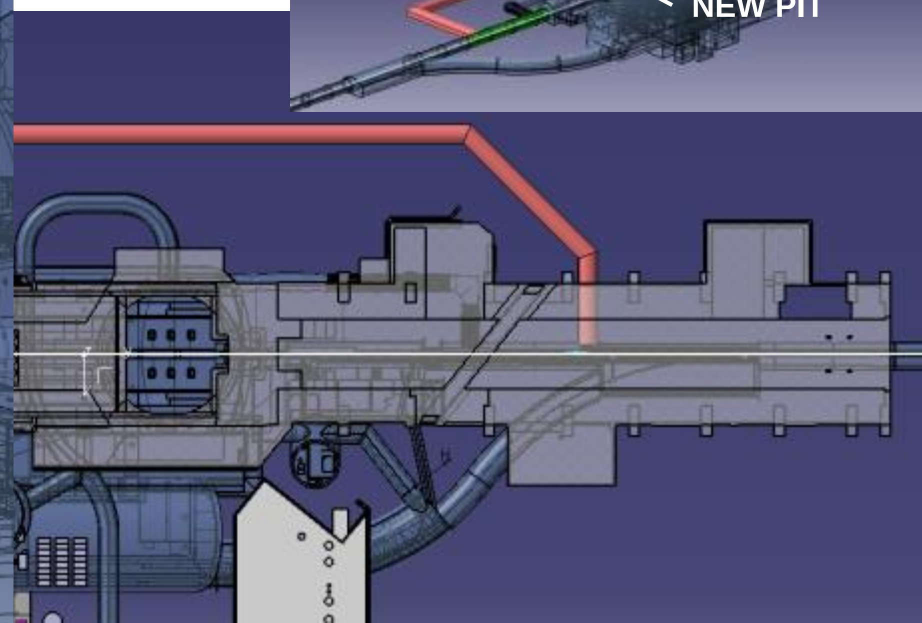


Baseline underground I: cryogenics

- Cavern for Cryogenics only
- Creating a new shaft
- Connection to machine tunnel: LHC machine side
- Floor of the cryo cavern same level of machine tunnel

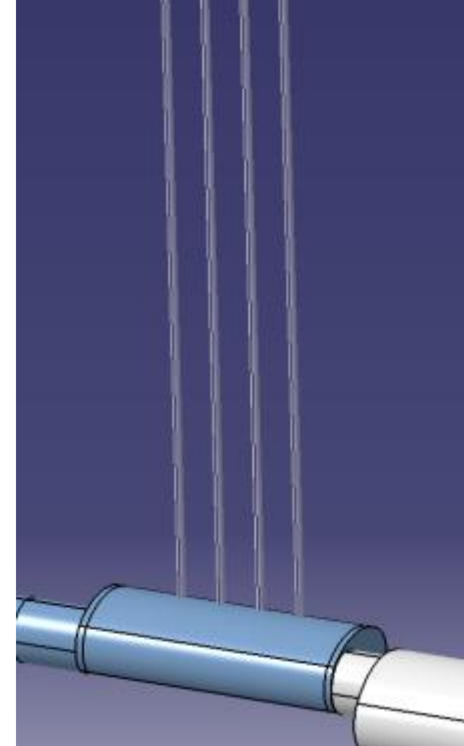


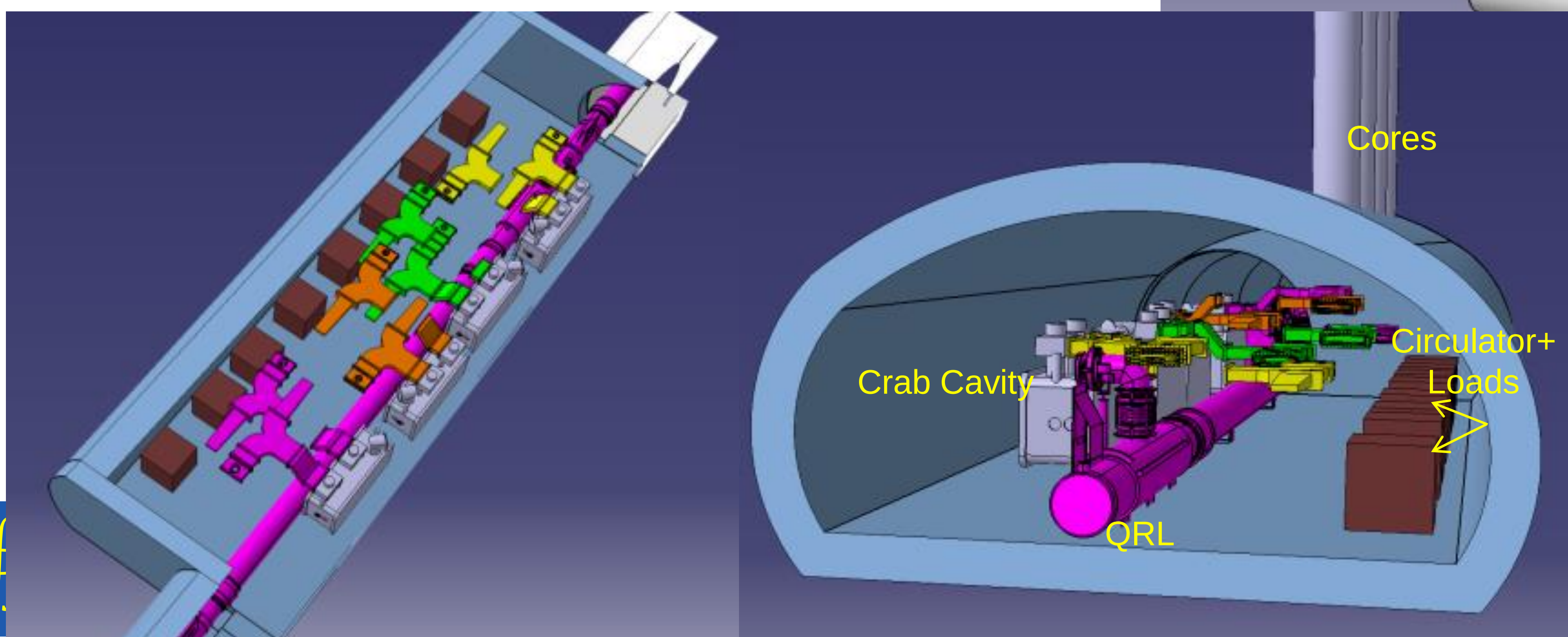




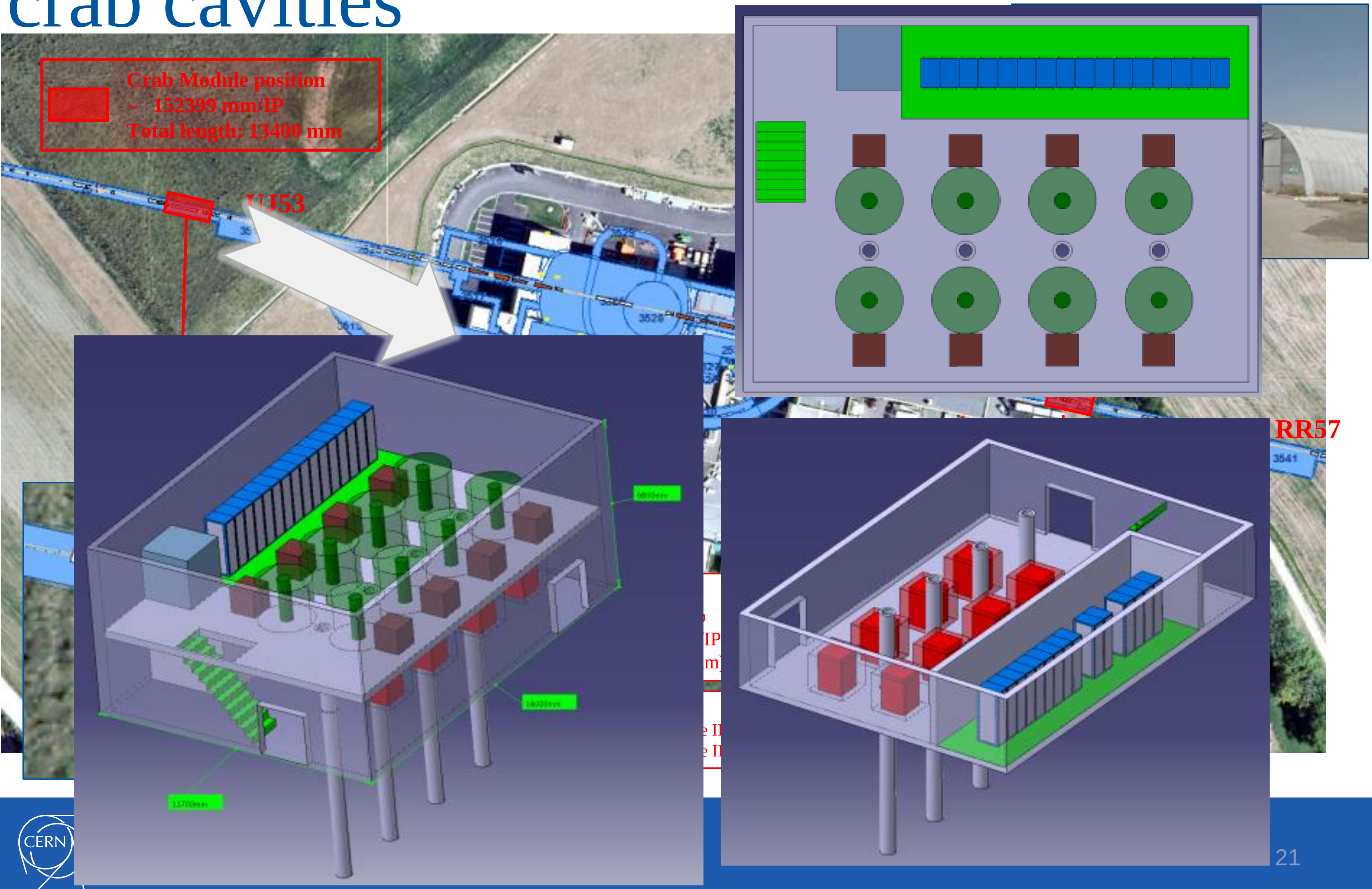
Baseline underground II: crab cavities

- Installation of loads and circulators underground to reduce coax diameter→ 2 coax in the same core
- Enlargement required to comply with limited precision of long vertical cores and to install loads and circulators

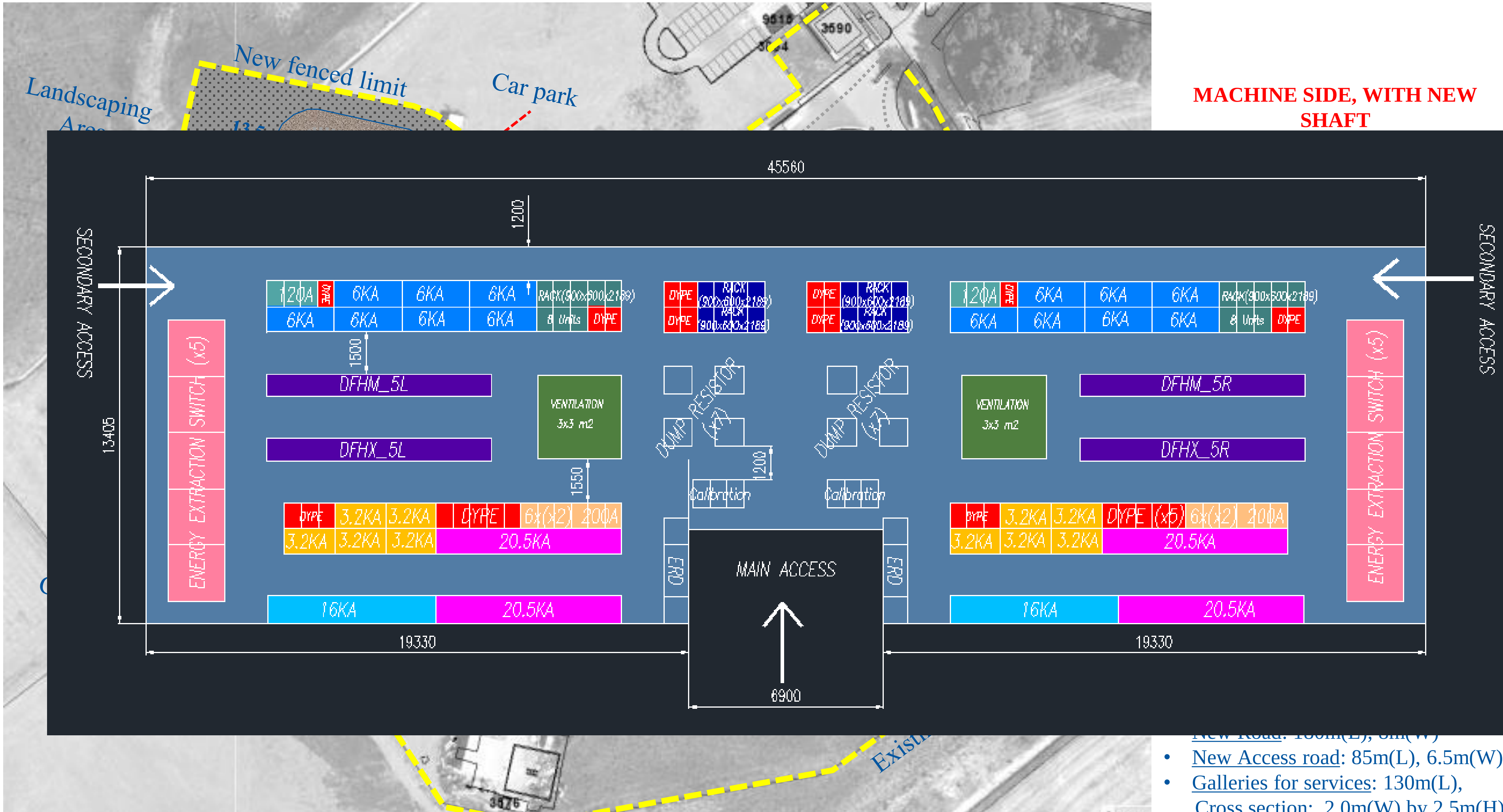




Baseline surface I: crab cavities



Baseline surface II:
all other equipment



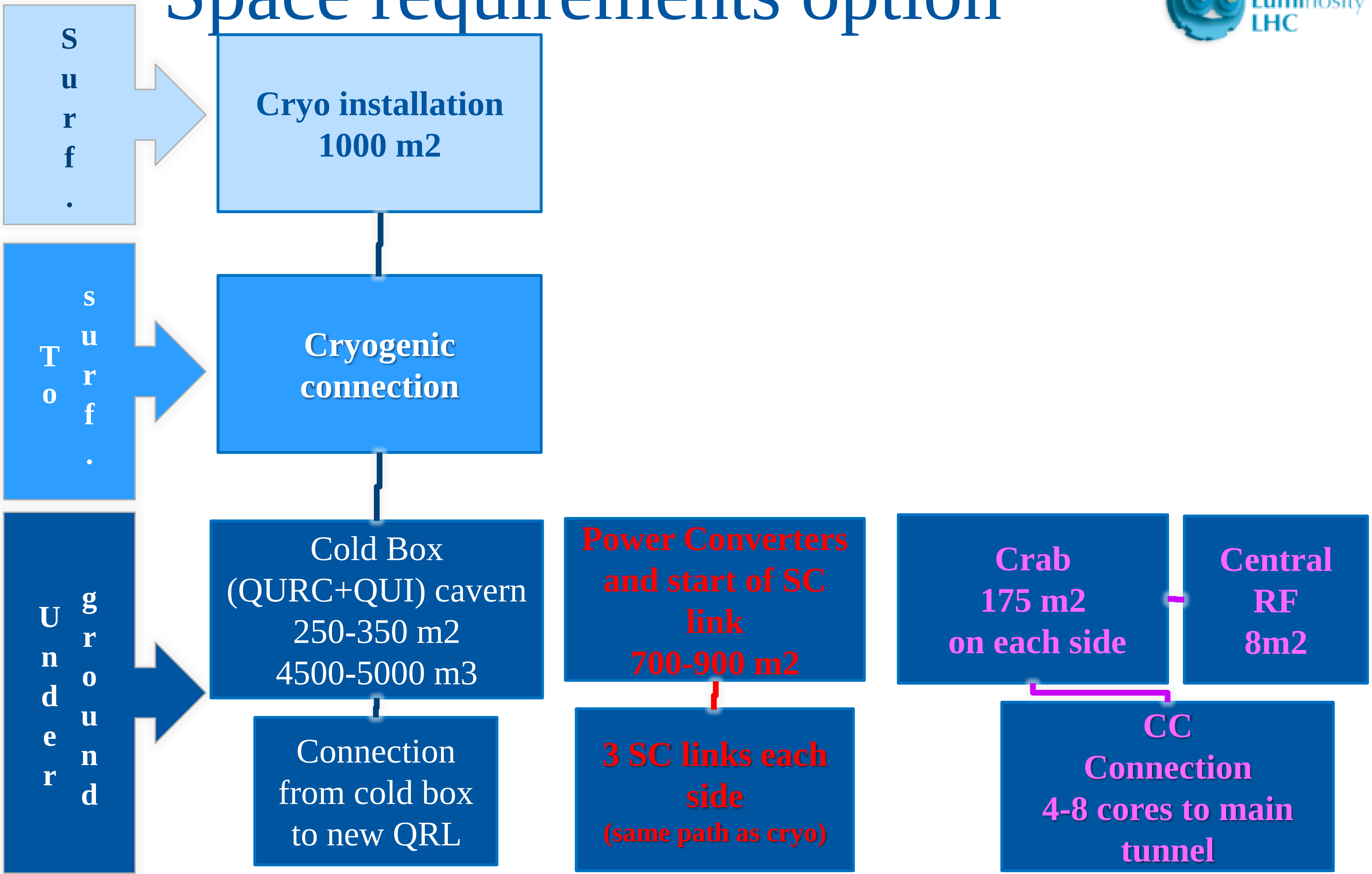
MACHINE SIDE, WITH NEW SHAFT

- New Road: 180m(L), 6m(W)
- New Access road: 85m(L), 6.5m(W)
- Galleries for services: 130m(L), Cross section: 2.0m(W) by 2.5m(H)
- Landscaping: 7'200m2

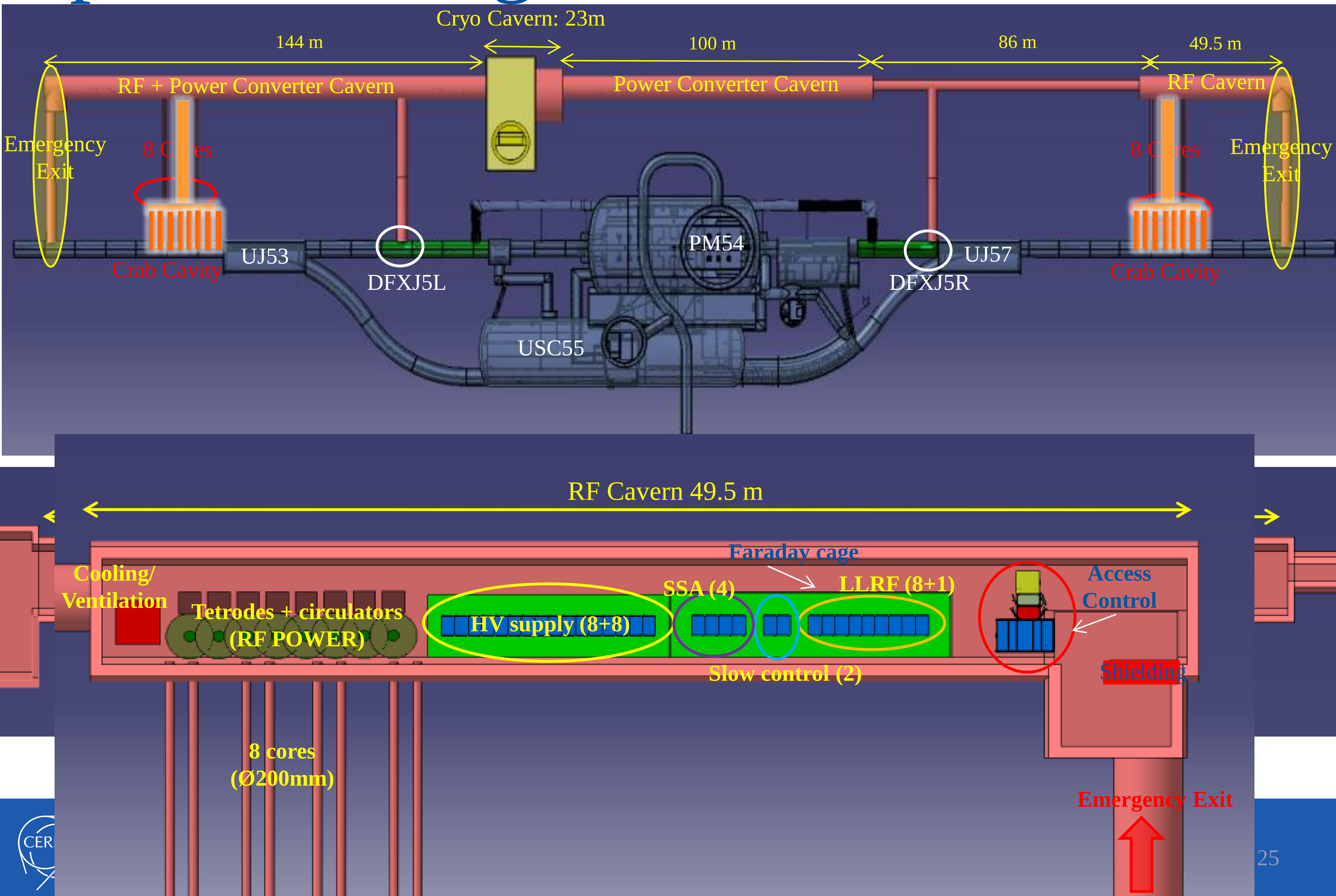
HL-LHC IR 1,5 MAIN SYSTEM DISTRIBUTION

OPTION

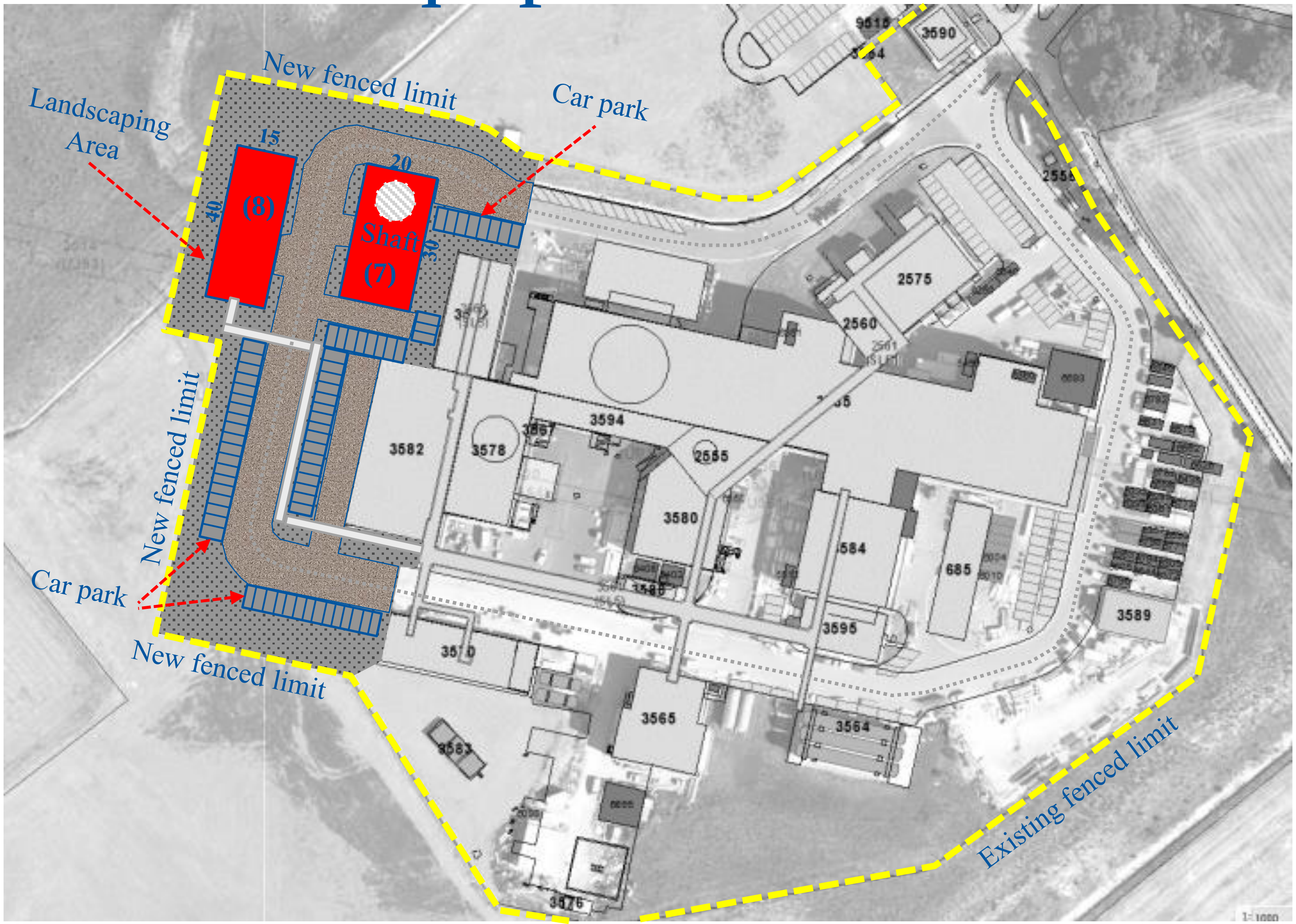
Space requirements option



Option: underground



Option surface: all other equipment



MACHINE SIDE, WITH NEW SHAFT + PC

7) SD (Steel)

- Dimension: 20 x 30 = 600m2
- Hmax = 12.0m
- Services (in;out): HV, water, SC Links ; ?
- Crane not costed (20t ?)

8) WARM COMPRESSOR (Conc)

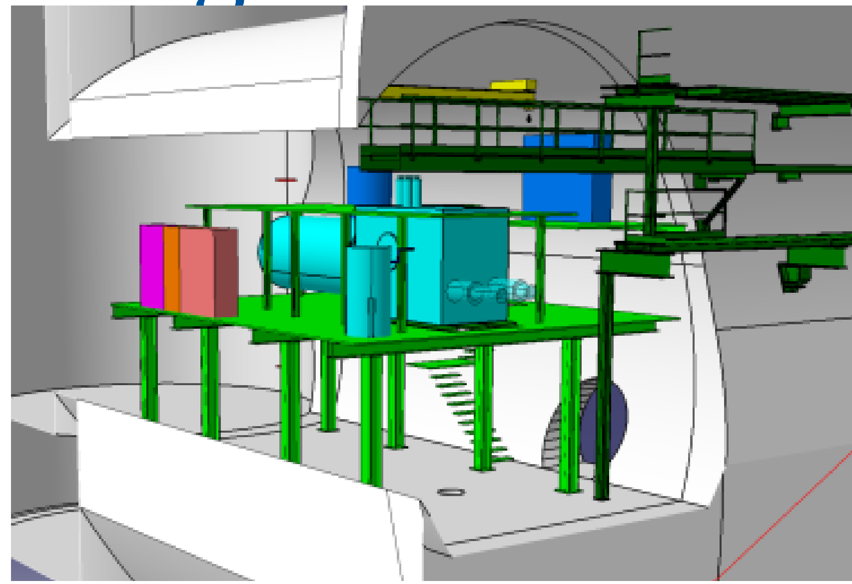
- Dimension: 15 x 40 = 600m2
- Hmax = 9m
- Services (in;out): HV, water, Cryo pipes ; ?
- 20t crane not costed

10) PARKING, ROADS, GALLERIES

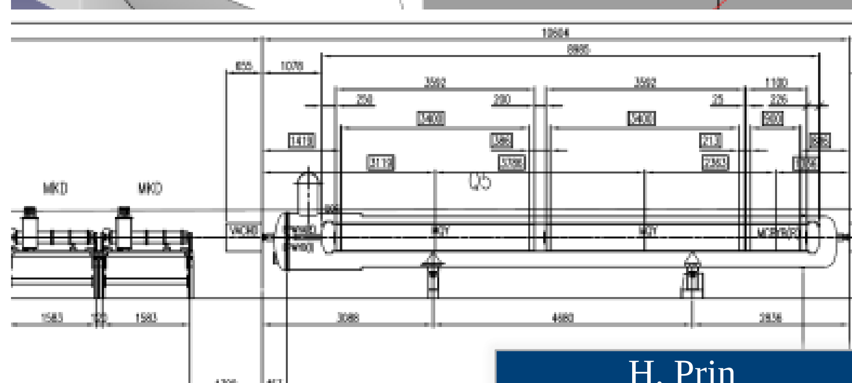
- Car Park: 20 places added
- New Road: 180m(L), 8m(W)
- New Access road: 70m(L), 6.5m(W)
- Galleries for services: 110m(L), Cross section2.0m(W) by 2.5m(H)
- Landscaping: 6,600m2

Other ongoing work for integration

- New RF dedicated cryogenic plant in IR4

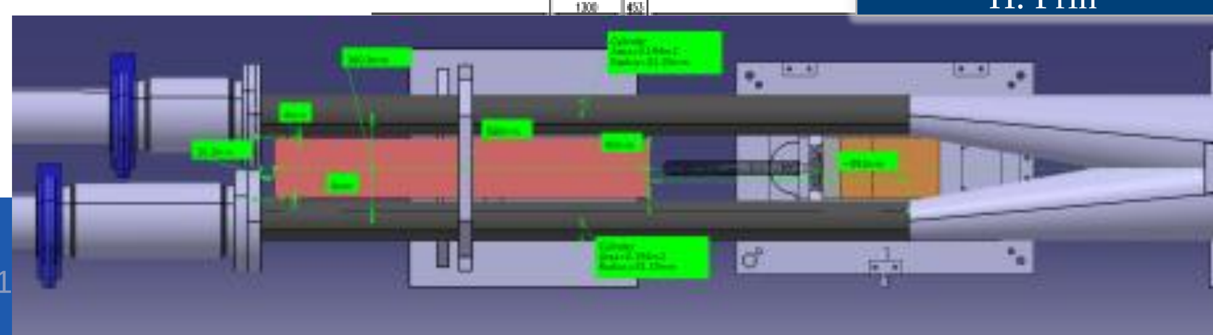


- Q5 in point 6



H. Prin

- TAN in point 8



Conclusions

- The Lay-out for IR1 and IR5 has been discussed putting in evidence the open issues and the new iteration should be prepared for next spring
- The baseline (and an option) proposal for the civil engineering and equipment installation in IR1 and IR5 has been shown. It will be used for detailed costing in the next weeks
- In the next months, the preparation of the cost and schedule review, and deepening the technical analysis of some solutions could bring important changes to the baseline and therefore to the integration plan
- Underground civil engineering infrastructure still need to be revised in term of radiation attenuation

Next spring shopping list first view…I

Major changes in the lay-out are probably required by the equipment design and the mechanical integration. This will need full validation and optimization from the whole project especially from optics (WP2).

In particular (here below possible values to be confirmed by the WPs in charge)

- The preliminary study of the TAS to Q1 region seems to indicate that it should be increased (+1000 mm ?)
- The interconnects length between magnet (Q1 to D1, 5 ICs) shall be increased. Today in the present lay-out we have allocated 810 mm. 925 mm are sure to be needed as today, but the inventory is not complete we need still to have better evaluation of the BPM mechanical length. Probably total of ≈ + 1000 mm on D1 position (+190/+200 on each interconnect)
- The interconnection length between the Q2a and Q2b could need further increase if phase separators have to be installed in that position (requires finalisation of the cryogenic/cryostat pipe scheme)
- The MQXF cold masses probably need more space for the interconnection box. Preliminary estimations are the following
  - + 400 mm for Q1 and Q3, total + 800 mm
  - + 200 mm for Q2a and Q2b, total + 400 mm

  This should also be linked to the final decisions of the bus bar routing (internal/external) and of the compensation system pre-design
- Possible changes in the MQXF design (passed cable review and upcoming magnet design review) that could impact the magnet length
- Confirmation of the lengths for D2 and Q4
- Finalization of the preliminary design and therefore lengths of the MCBRD (D2 correctors) and MCBYY (Q4 correctors)
- Definition of the option to be chosen for the collimators installation in the D2-Q4 area
- Revise of the needs of the TCLMA mask in front of D2 (see L. Esposito talk in this meeting)
- Tuning of length and position of the TAXN (see L. Esposito talk in this meeting)

Above modifications could possibly lead to a movement of D1 towards the arc of 4000 → 6000 mm and many other changes especially in D2 to Q4

- Q10 with extra sextupole if possible

Next spring shopping list first view…II

IR6:

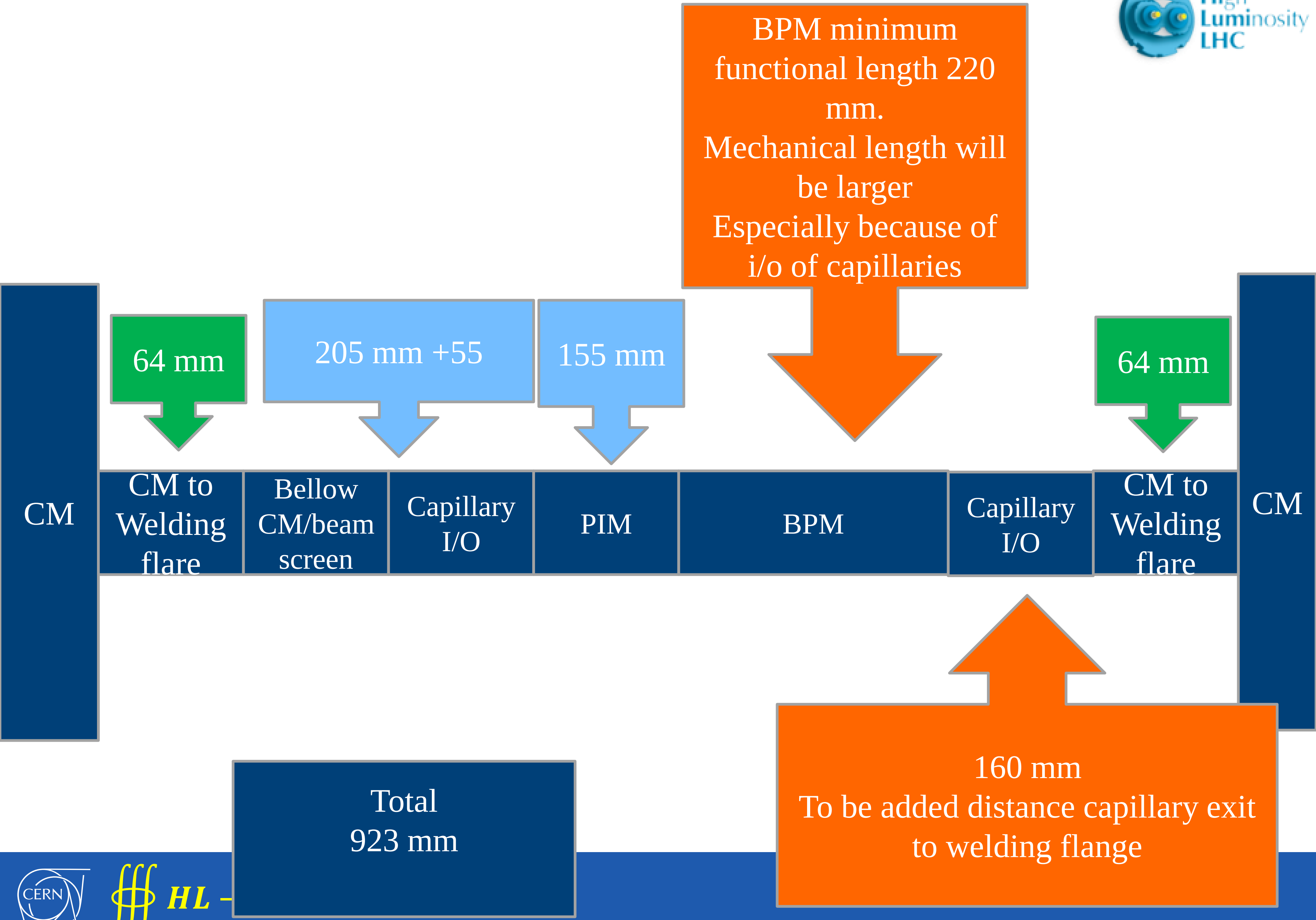
- New configuration with stronger Q5

IR4: 1st lay-out with

- Hollow e-lenses
- Other RF systems (200 MHz , 800 MHz)
- In case of need LHC crab cavity test
- Beam instrumentation requirements (BGV, BSRT light extraction line, fast wire scanners, …)

Important : we shall try to introduce all changes in IR1 and IR5 in one go in order to make the iteration process the most effective as possible

ANNEX


BPM minimum functional length 220 mm.
Mechanical length will be larger
Especially because of i/o of capillaries
64 mm
205 mm +55
155 mm
64 mm
CM
CM to Welding flare
Bellow CM/beam screen
Capillary I/O
PIM
BPM
Capillary I/O
CM to Welding flare
CM
Total
923 mm
160 mm
To be added distance capillary exit to welding flange

SPACE REQUIREMENT SYSTEM BY SYSTEM

CRAB CAVITIES

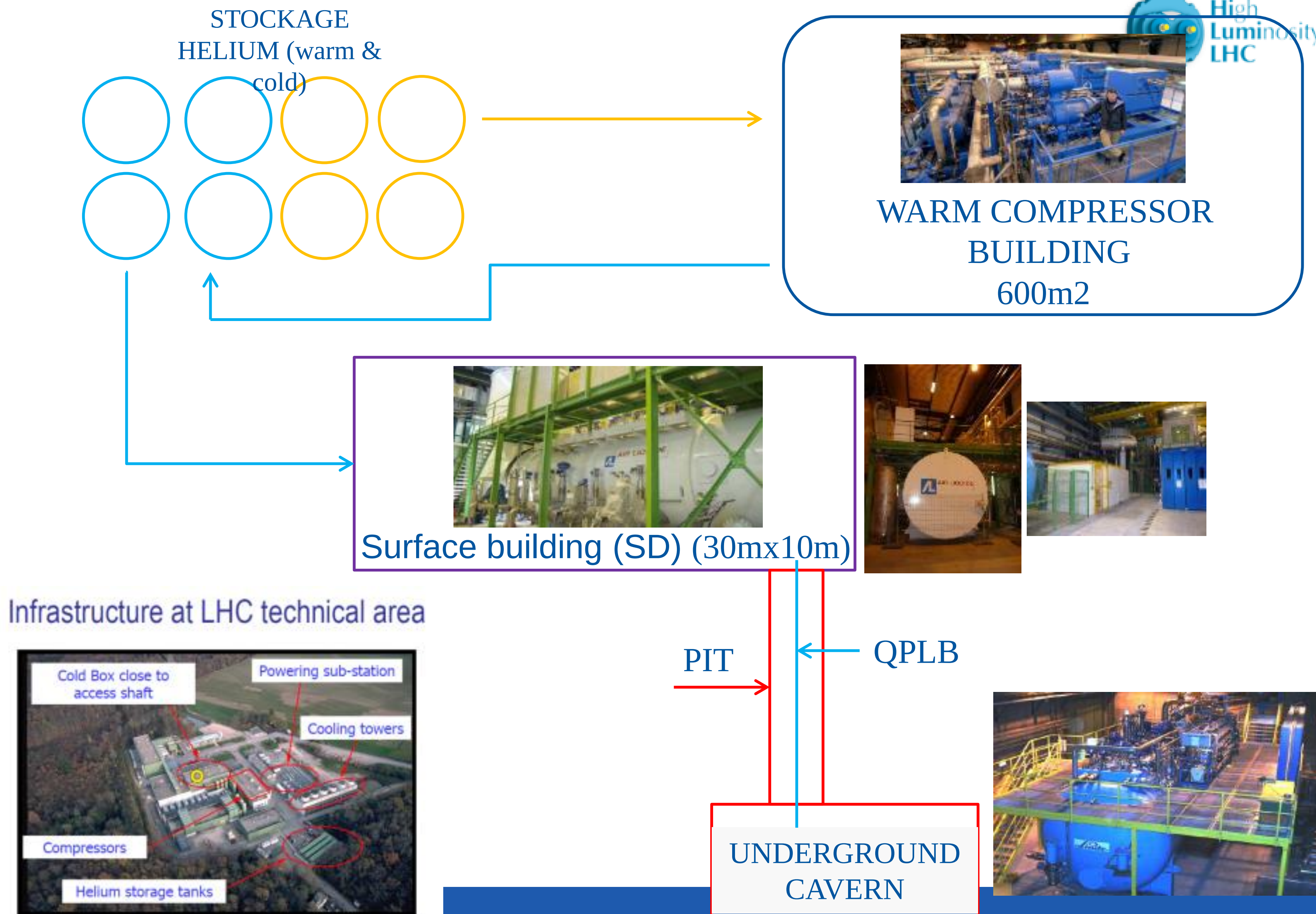
Crab cavities

	Requirement	Area	Baseline/Option
RF power (2×IP)	2×[3×14] m	2×42 m^2	Underground/surface
LLRF racks (2×IP)	2×[(5.6+4.4+7)×3.8] m	2×65 m^2	Underground/surface
LLRF central racks(1×IP)	2×3.8 m	8 m^2	Underground/surface
HVPS (2×IP)	2×[4×16] m	2×65 m^2	Surface

Remark

LLRF requires Electromagnetic shielding and it is radiation sensitive

CRYOGENICS



Illustrations : Serge Claudet (CRG)

Cryogenics

Cryogenic system	Where		
Warm compressor	Surface	Area	700 m^2
		Crane	20 t
		Type	Noise insulated
Surface SD building	Surface	Area	$30\times10=300$ m^2
		Crane	5 t
Cold Compressor	Underground	Volume	200 m^3
		Surface	0 m^2
		Crane	2 t

Remark

The electronics for the magnetic bearings of the cold compressor is radiation sensitive and maximum distance from its control electronics to the compressor is

50 m

COLD POWERING

Cold powering Circuits Q1 to D1

Q1 to D1 (for each IP side)

circuits connected to the DFHX

C.M.	Circuit / magnet	Op. current [kA]	PC current rating [kA]	N of circuits	N. of 19” racks /PC	Total racks/ Circuit type
Q1-Q3	MQXF	17.5	20	1	10	10
	trim MQXF Q3	±2	±3.2	1	3	3
Q2A-Q2B	MQXF	17.5	20	1	10	10
	trim MQXF Q2	±0.3	±0.8	1	0.5	0.5
	MCBXB	±2.5	±3.2	4	3	12
CP	MCBXA	±2.5	±3.2	2	3	6
	MQSXF	0.182	0.2	1	0.5	0.5
	MCTXF	0.17-0.2	0.2	1	0.5	0.5
	MCTSXF	0.17-0.2	0.2	1	0.5	0.5
	MCDXF	0.193	0.2	1	0.5	0.5
	MCDSXF	0.193	0.2	1	0.5	0.5
	MCOXF	0.17-0.2	0.2	1	0.5	0.5
	MCOSXF	0.17-0.2	0.2	1	0.5	0.5
	MCSXF	0.17-0.2	0.2	1	0.5	0.5
	MCSSXF	0.17-0.2	0.2	1	0.5	0.5
D1	MBXF	11.8	16	1	9	9

Space needed

circuits connected to the DFHX

Total racks	55
Installation surface [m²]	40
Access/manipulation surface [m²]	43
Linear installation extension [m]	35
Height [m]	2.6
Installation volume [m³]	100
Cooling water flow rate [l/min]	305

Cold powering Circuits D2 to Q6

D2 to Q6 (for each IP side)						
Circuits connected to the DFHM						
C.M.	**Circuit / magnet**	**Op. current [kA]**	**PC current rating [kA]**	**N. of circuits**	**N. of 19” racks /PC**	**Total/ circuit type**
D2	MBRD	12.4	16	1	9	9
	MCBRD	±3	±4	4	4	16
Q4	MQYY	16.1	20	2	10	20
	MCBYY	±3	±4	4	4	16
Q5	MCBY	0.088	±0.12	6	0.25	1.5
	MQY	4.2	8	2	4	8
Q6	MCBC	0.1	±0.12	2	0.25	0.5
	MQML	5.39	8	2	4	8

Space needed	
Circuits connected to the DFHM	
Total racks	79
Installation surface [m^2]	56
Access/manipulation surface [m^2]	60
Linear installation extension [m]	50
Height [m]	2.6
Installation volume [m^3]	145
Cooling water flow rate [l/min]	400

Cold powering arc

Continuous cryostat presently fed from DFBA
(for each IP side)

Circuits connected to the DFHA				
Magnet	PC current rating [kA]	N. of circuits	N. of 19" racks /PC	Total/ circuit type
MQT	±0.6	2	0.5	1
MQS	±0.6	2	0.5	1
MQTL	±0.6	2	0.5	1
MQT	±0.6	2	0.5	1
MSS	±0.6	2	0.5	1
MO	±0.6	4	0.5	2
MQM	6	4	4	16
MQML	6	4	4	16
D11 T trim	±0.6	2	0.5	1

Space needed

Circuits connected to the DFHA	
Total racks	38
Installation surface [m^2]	27
Access/manipulation surface [m^2]	29
Linear installation extension [m]	25
Height [m]	2.6
Installation volume [m^3]	68
Cooling water flow rate [l/min]	NA

Space becoming free in RR by DFHM related PC	
Racks removed	34
Installation surface made available	24
Linear installation extension [m]	22

Spare Power Converters

High Luminosity LHC

Q1 to D1 (for each IP side)			
"DFHX"			
N. spare	PC current rating [kA]	N. Circuit served	N. of 19" racks
1	20	2	10
1	16	1	9
1	±3.2	7	3
1	±0.8	1	0.5
1	0.4	10	0.5

D2 to Q6 (for each IP side)			
"DFHM"			
N. spare	**PC current rating [kA]**	**N. Circuit served**	**N. of 19" racks**
1	20	2	10
1	8	4	3
1	±4	4	0.5
1	±0.12	8	0.5

Cont. cryostat (for each IP side)			
"DFHA"			
N. spare	**PC current rating [kA]**	**N. Circuit served**	**N. of 19" racks**
Total 5 racks			

Q1 to Q6 (for each IP side)			
DFHX+ DFHM spares			
N. spare	PC current rating [kA]	N. Circuit served	N. of 19" racks
1	20	5	10
1	8	4	3
1	±4	12	0.5
1	0.4	10	0.5
1	±0.12	8	0.25

Q1 to Q6 (for each IP side)	
DFHX+ DFHM spares	
Installation surface [m^2]	10
Access/manipulation surface [m^2]	12
Linear installation extension [m]	9
Height [m]	2.6
Installation volume [m^3]	18
Cooling water flow rate [l/min]	100

Quench detection, Q.H. powering

Q1 to D1 (for each IP side)				
circuits connected to the DFHX				
C.M.	Circuit	DQS	Q.H.	Total racks
Q1-Q3	MQXF	1	2	1.5
	trim MQXF Q3	1	NA	0.5
Q2A-Q2B	MQXF	1	2	1.5
	trim MQXF Q2	1	NA	0.5
	MCBXB	4	Not def	2
CP	MCBXA	2	1	1.5
	MQSXF	1	0	0.5
	MCTXF	1	0	0.5
	MCTSXF	1	0	0.5
	MCDXF	1	0	0.5
	MCDSXF	1	0	0.5
	MCOXF	1	0	0.5
	MCOSXF	1	0	0.5
	MCSXF	1	0	0.5
	MCSSXF	1	0	0.5
D1	MBXF	1	1	0.5

D2 to Q6 (for each IP side)				
Circuits connected to the DFHM				
C.M.	Magnet	DQS	Q.H.	Total racks
D2	MBRD	1	1	1
	MCBRD	4	Not def	2
Q4	MQYY	2	1	1.5
	MCBYY	4	Not def	2
Q5	MCBY	6	0	3
	MQY	2	1	1
Q6	MCBC	2	0	1
	MQML	2	1	1

Plus 0.5 rack for each SC link itself

Space needed SC link included		
	DFHX related	DFHM related
Total racks	14	14
Installation surface [m²]	9	9
Access/manipulation surface [m²]	11	11
Linear installation extension [m]	9	9
Height [m]	1.8	1.8
Installation volume [m³]	25	25

Quench extraction

Quench extraction system main equipment modules		
Equipment	Dimensions [m]	remark
Energy extraction switch	2×2×2 [L×W×H]	Solid state based switches best guess for dimension 20 kA
Dump resistor	1×1×1 [L×W×H]	Cooled dump resistor with water to coolant heat exchanger. Best guess dimension for 10 MJ

Quench extraction number and volume approximation		
Equipment	No of units	Volume best guess on the base of energies and current
Energy extraction switch	5	2×[2×2×2]+3×[2×2×1]
Dump resistor	7	4×[1×1×1]+3×[0.5×0.5×0.5]

Quench extraction 1st guess installation surface and volume		
Equipment	Surface including access [m^2]	Volume [m^3]
Energy extraction switch	42	30
Dump resistor	20	5

Cold Powering volume and surface total needs

Q1 to D1 (for each IP side) including DFHX and DFHM						
	Q1 to D1	D2 to Q6	Spare PC Q1 to Q6	QDS	QEE	total
Installation surface [m²]	52	68	10	18	25	173
Access/manipulation surface [m²]	56	73	12	22	37	200
Linear installation extension [m]	46	61	9	18	14	148
Installation volume [m³]	120	164	18	50	35	387
Cooling water flow rate [l/min]	305	400	100	NA	NA	810

DFH (X M A)	
Length [m]	11
Width [m]	0.95
Height [m]	1800
Installation surface [m²]	11
Access surface [m²]	13
Installation volume [m³]	19

Arc including DFHA	
Installation surface [m²]	37
Access/manipulation surface [m²]	41
Linear installation extension [m]	35
Installation volume [m³]	86

Summary per IP

Maximum in surface

	Crab cavities	Cryogenics	Cold Powering	Total
Installation area on surface	2×172 m^2 + 8 m^2	1000 m^2	2×450 m^2	2244 m^2
Installation area underground		150 m^2		150 m^2

Maximum in tunnel

	Crab cavities	Cryogenics	Cold Powering	Total
Installation area on surface	2×65 m^2	1000 m^2		1130 m^2
Installation area underground	2×107 m^2 + 8 m^2	150 m^2	2×450 m^2	1280 m^2

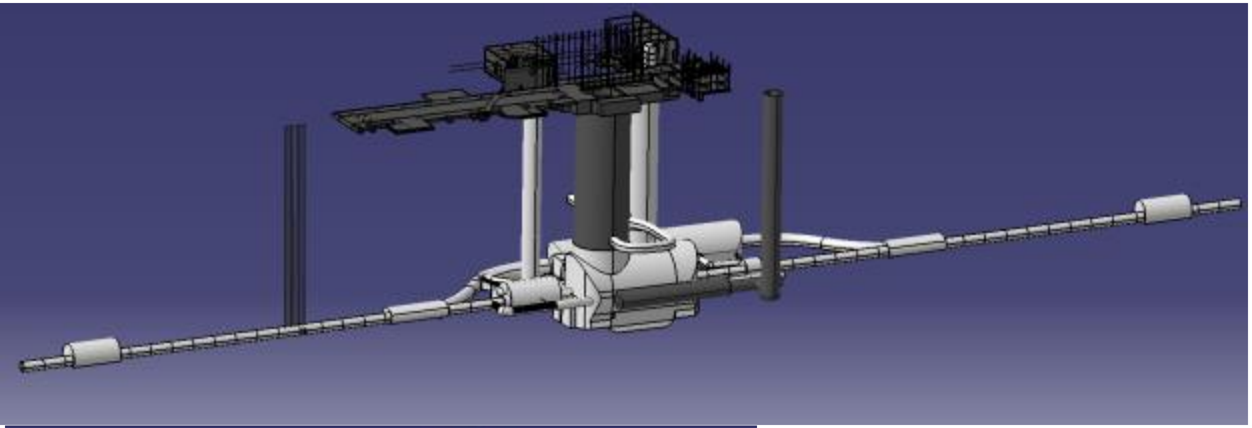
DFHA in RR

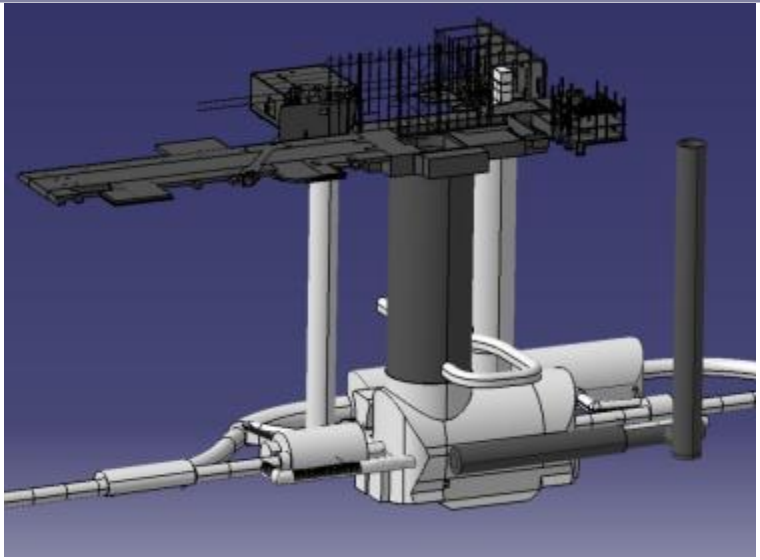
	Crab cavities	Cryogenics	Cold Powering	Total
Installation area on surface	2×172 m^2 + 8 m^2	1000 m^2	2×372 m^2	2096 m^2
Installation area underground		150 m^2	2×88 m^2 (RR)	150+176 m^2

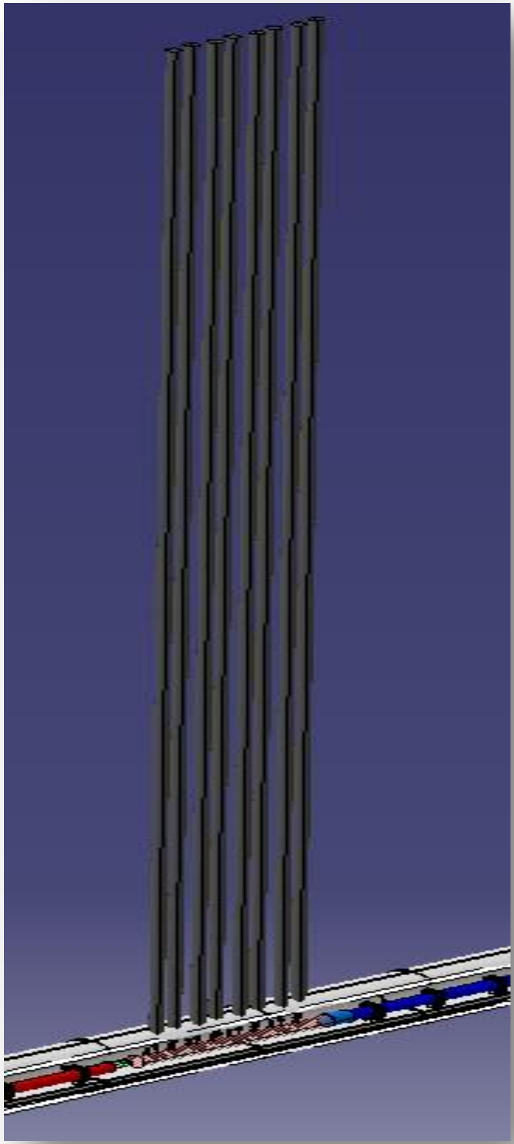
DFHA + QDS in RR

	Crab cavities	Cryogenics	Cold Powering	Total
Installation area on surface	2×172 m^2 + 8 m^2	1000 m^2	2×332 m^2	2016 m^2
Installation area underground		150 m^2	2×128 m^2 (RR)	150+256 m^2

Option B2: short service tunnel







Option comparisons

		Option A1 **CP:** service tunnel **RF:** service tunnel **New pit**	**Option A2** **CP:** surface **RF:** service tunnel **New pit**	**Option B1** **CP:** surface **RF:** surface **New pit**	**Option B2** **CP:** surface **RF:** surface **Extension**	**Option B1** **CP:** surface **RF:** surface **New pit**	**Option B2** **CP:** surface **RF:** surface **Extension**
		SC link to the DFHA				No SC link to the DFHA	
S	**Central building CRY**	1000 m^2	1000+900 m^2 ***1900 m^2***	1000+900+8 m^2 ***1908 m^2***	1000+900+8 m^2 ***1908 m^2***	1000+644+8 m^2 ***1652 m^2***	1000+280+8 m^2 ***1288 m^2***
		Cryo	Cryo + CP (X+M+A)	Cryo + CP (X+M+A) + LLRF	Cryo + CP (X+M+A) + LLRF	Cryo + CP (X+M) + LLRF	Cryo + CP (X+M) + LLRF
S	**Crab buildings CL and CR**			***175 m^2 +175 m^2***	***175 m^2 +175 m^2***	***175 m^2 +175 m^2***	***175 m^2 +175 m^2***
U	**Underground Extension**				***150 m^2***		***150 m^2***
					plus connection to LHC machine		plus connection to LHC machine
U	**RR**					2×128 m^2	2×128 m^2
U	**Service Tunnel**	2×(175+450) + 8 + 150 m^2 ***2×625+150 m^2***	2×(175) + 8 + 150 m^2 ***2×175+150 m^2***	***150 m^2***		***150 m^2***	
		RF+CP+LLRF+ Cbox	RF + LLRF + Cbox	Cbox		Cbox	
U	**Vertical**	New PIT	New PIT	New PIT	PM54	New PIT	PM54

Option comparisons I

	Option A1 CP: service tunnel RF: service tunnel New pit	Option A2 CP: surface RF: service tunnel New pit	Option B1 CP: surface RF: surface New pit	Option B2 CP: surface RF: surface Extension	Option B1 CP: surface RF: surface New pit	Option B2 CP: surface RF: surface Extension
	SC link to the DFHA				No SC link to the DFHA	
Access Crab	-	-	+	+	+	+
Access PC	-	+	+	+	+	+
Access QDS	-	+	+	+	+	+
Access QEE	-	+	+	+	+	+
Radio shielding PC	+	+	++	++	+	+
Radio shielding	+	+	+	+	+	+
Civil work impact on planning	Limited Connection to machine tunnel	Limited Connection to machine tunnel	Limited Crab connection	Important Common pit use	Limited Crab connection	Important Common pit use
Tunnel installation complexity	Very high	High	Mild	Mild	Easiest	Easy
Integration complexity	Difficult Cryo to SC link	Difficult Cryo to SC link	Mild	Mild	Easiest No SC link to DFBA	Easy No SC link to DFBA
Equipment simplification	Very high (only hor. SC link)	None	None	None	4 SC link less probably the most complex to install and integrate no modif. of	4 SC link less probably the most complex to install and integrate no modif. of DFBA

Option comparisons II

	Option A1 CP: service tunnel RF: service tunnel New pit	Option A2 CP: surface RF: service tunnel New pit	Option B1 CP: surface RF: surface New pit	Option B2 CP: surface RF: surface Extension	Option B1 CP: surface RF: surface New pit	Option B2 CP: surface RF: surface Extension
	SC link to the DFHA				No SC link to the DFHA	
Extension of underground civil work	+++	+++	++	+	++	+
Service underground installation	++++	+++	++	++	+	+