Global Optimization of the Matching Section and Full Remote Alignment

- S. Claudet, P. Fessia: Matching Section Optimization Coordinators (WPLs of the WP9 and WP15)

- **For Full Remote Alignment**
- R. De Maria [WP2]
- R. Calaga (WPL), O. Capatina [WP4]
- A. Bertarelli, M. Calviani, L. Gentini, S. Gilardoni, I. Lamas, S. Redaelli (WPL) [WP5]
- V. Baglin (WPL), J. Hansen, R. Tavares [WP12]
- R. Jones, T. Lefevre [WP13]
- A. Herty, H. Mainaud Durand, A. Masi, M. Sosin [WP15.4]
- J. Uythoven, M. Zerlauth, J. Wenninger [Machine Protection]

- **Matching Section Optimization**
- R. De Maria, D. Gamba [WP2]
- D. Duarte, H. Prin, E. Todesco (WPL), A. Vande Craen [WP3]
- A. Ballarino (WPL), S. Claudet, V. Parma, A. Perin [WP6A]
- J-P. Burnet, M. Martino (WPL) [WP6b]
- D. Wollmann [WP7]
- J. Metselaar, M. Sisti [WP9]
- V. Baglin (WPL) [WP12]
- M. Amparo [WP15.1]

Summary

- Full Remote Alignment
  - Present baseline and new proposal
  - Alignment strategy and required stroke
  - Advantages
  - New possibilities for full Matching Section Optimization
- Matching Section Optimization
  - The magnet system simplifications
  - The QRL-QXL optimization
  - The Cold Powering
  - The Warm Powering
- Conclusions

Full Remote Alignment

Full Remote Alignment and Matching Section Optimization

Objectives

- Reduce dose to alignment team
- Cope with Experiment vs. machine misalignment in RUN IV after the machine and experiment installation completion
- Yearly correct ground motion drift without man intervention in the machine
- Provide tool to eliminate or at least minimize the residual alignment error using beam as reference
- Cope with unexpected source of misalignment avoiding losses in performance of physics time

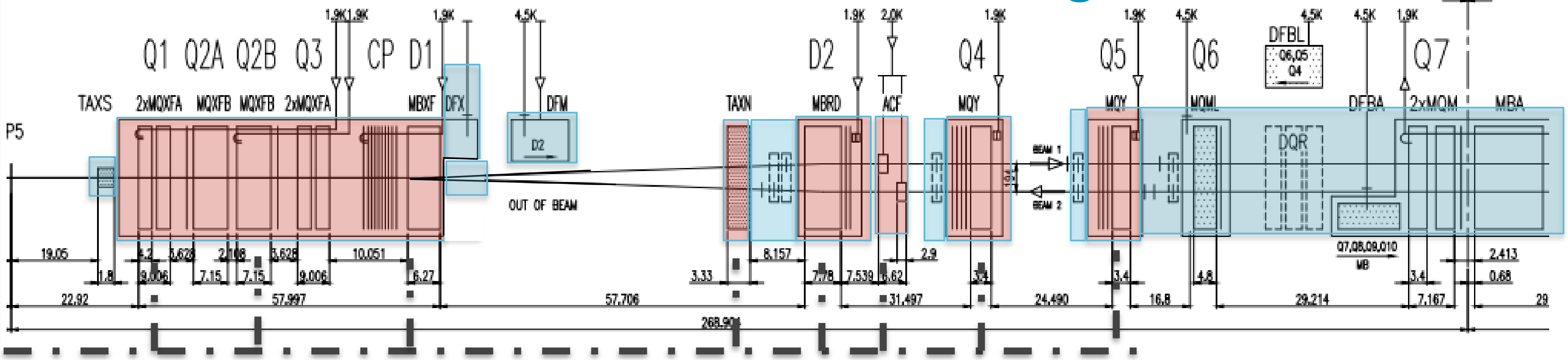
FRA

By products

- Gain aperture margin in various equipment
- Matching Section Optimization
- Reduce the requirement on the Matching Section orbit Corrector System
- Mitigate spurious orbit deviations in the triplet (simplifying non linear corrections)

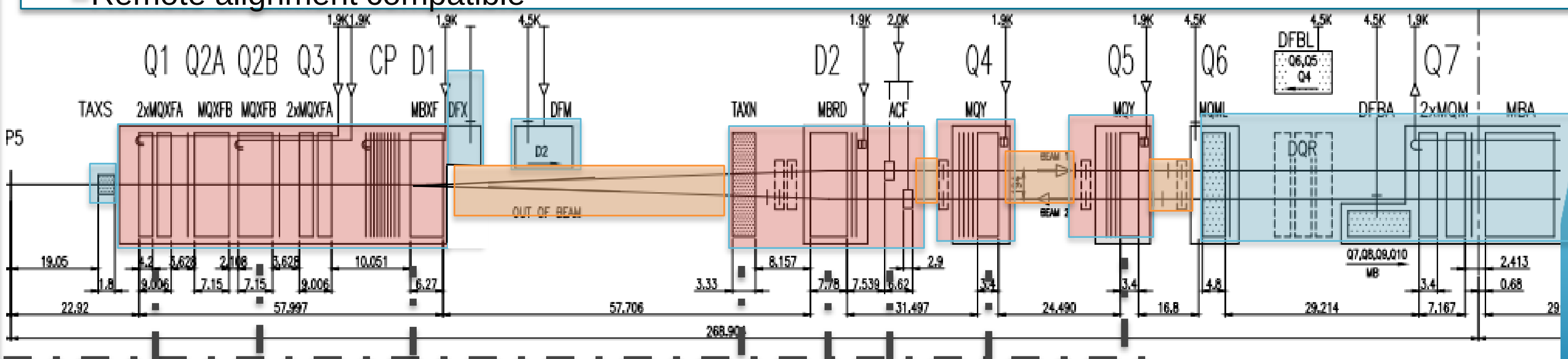
IP1 and IP5 HL-LHC
Synoptic of adjustment system <u>only</u>
Baseline vs Full Remote Alignment

BASELINE



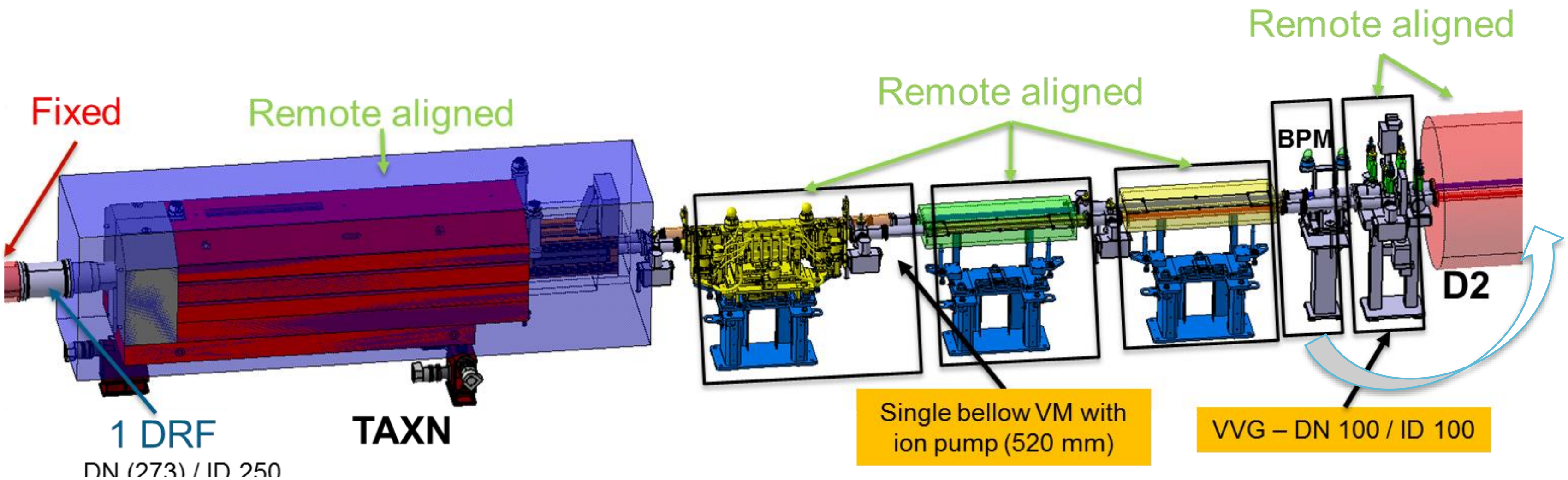
- Motorized adjustment system, remotely controlled : adjustment during run, from CCC
- Manual adjustment system: adjustment during LS,YETS,TS, personnel in the tunnel, access in front of element (special for TAXS)
- Remote alignment compatible

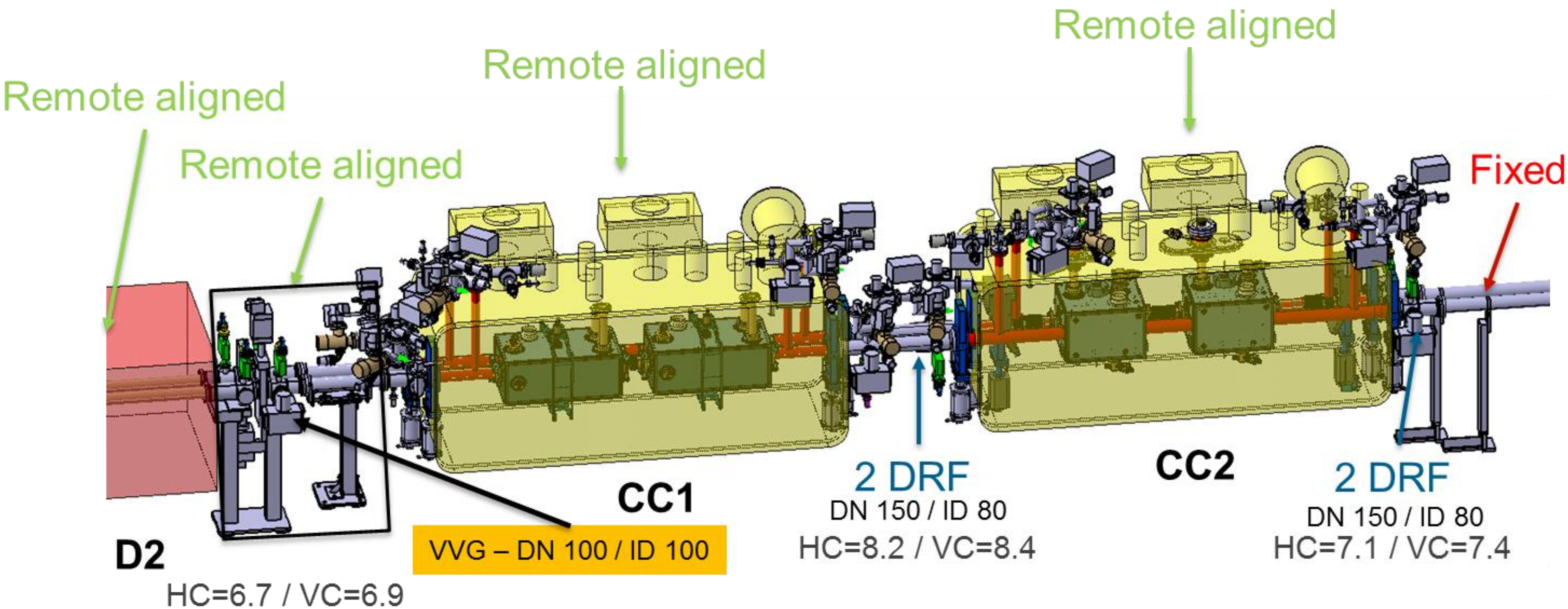
NEW PROP.



<u>Full Remote Alignment applied to HL baseline optics not to optimized one</u>

Vacuum lay-out analysis and reconfiguration





Courtesy WP12 team

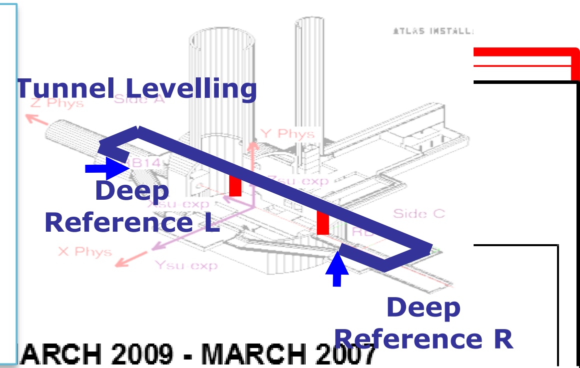
Possible alignment strategies with fully remote alignment

	Scheme 1: During operation or TS up 2.5 mm	Scheme 2: During TS Larger than 2.5 mm	Scheme 3: During YETS	Scheme 4: During LS 2 year RP cool down
Machine conditions	Machine operating conditions	Magnet cold but empty during movement	Magnet cold but empty during movement	Warm
Max stroke	+/- 2.5 mm	±10 mm (jack excursion other limits apply)	±10 mm (jack excursion other limits apply)	more
Time required per IP side Q1 to D1	30 min No access	60 min No access	60 min No access	
Time required per IP Q1 to Q5	30 min No access	2(L)+2(R) days Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)	2(L)+2(R) days Access for int. components. De-interconnection of the RF guides (from time point of view this fits into a TS)	
	CD: NA	CD: >12 mSv	CD: 2.8 mSv	CD:0.3 mSv
Time required per IP side Q1 to Q6	Not possible	2 TS TS1: measure Between TS1 and TS2 compute TS2 realign	Measurement, computation and re-alignment in the YETS	
	NA	CD: >13 mSv	CD: 3.2 mSv	CD:0.4 mSv

The needed stroke

The Survey team has linked the experiment cavern movement with the ones of the LSS

- For the vertical plane via the deep references (GITL) that are in machine tunnel for ATLAS and CMS
- For the radial plane via the GISB references points that are in the UPS survey galleries



	Δz [mm/y]	Δr [mm/y]	Observations
IP1	0.3	0.3	
IP5	0.2	0.2	Δz 0.7 mm/y locally at 150 m from IP where the “new” LHC civil engineering join the LEP tunnel

The proposed value of ± 2.5 mm would allow covering the movements from LS to LS with a safety factor at least 2 (vs. 0.3 mm) avoiding major realignment intervention during other time slots.

Yearly changes shall be much smaller in the range of 0.2/0.3 mm

This meets the requirement of the experiment that asks for the possibility to compensate +/-2 mm of IP shift and fits with the experimental vacuum system design and capability

In addition at LS3 partial overcompensation in the vertical plane (even in the assembly position of the inner tracker as proposed by CMS) could be applied on the base of the measurement that will be taken during LHC RUN III,

allowing to factorize in possible impact of the HL-LHC excavation that will have been completed in LS2

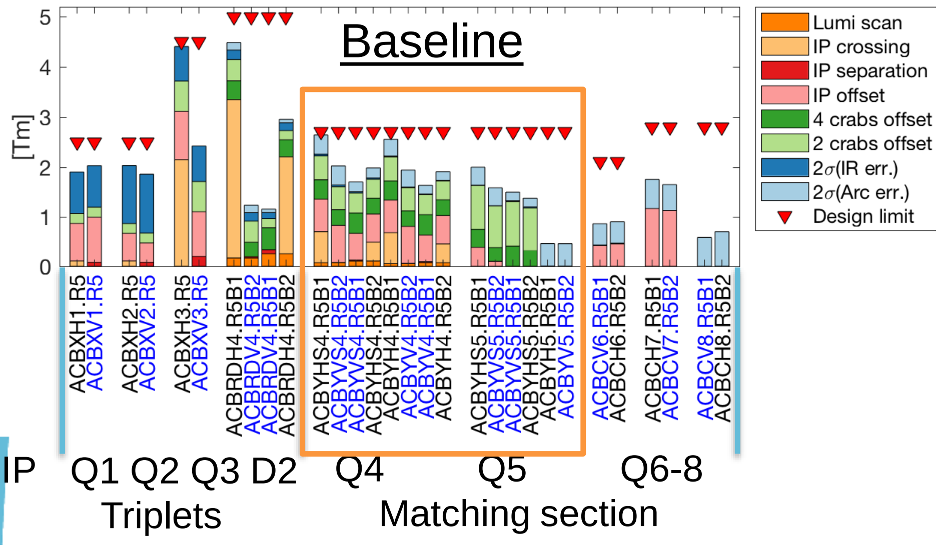
Courtesy WP15.4 team

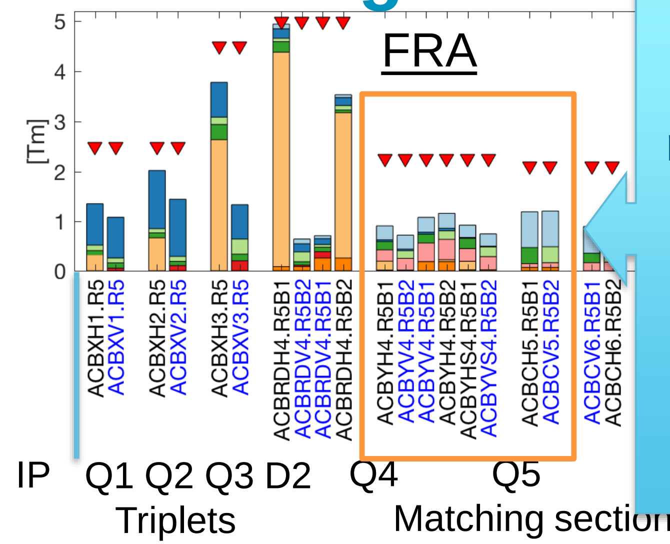
Machine Protection aspects discussed MPP 09/11/2018

- Interlocks
  - Interlocks shall be implemented to avoid that nearby elements move separately in dangerous way, putting at risk the mechanical integrity
  - Interlocks could be implemented to limit the maximum amplitude movement according to the machine status
  - Key-type interlocks shall be implemented to avoid that the machine can be moved in non-safe conditions

- Machine re-qualification is required after each movement. This would make of the end of the TS the most suitable moment to intervene.
- Integrating part of the Full Remote Alignment is the tracking and logging of the movement of the elements/interconnects. This is needed to know their exact position before applying any correction

Orbit corrector strength requirements and aperture without and with remote alignment





Increased corrector margin here applied already to reduce set of correctors

Right Point 5, H crossing.

Crossing: ±295 μrad
Separation: ±0.75 mm
IP Offset: ±2.0 mm
Luminosity scan: ±100 μm
Crab knobs: ± 1-0.5 mm (baseline only)
Imperfection (2σ): from uniform distribution of mainly ±0.5 mm quad. Alignment and 0.5 mrad / 20 units dipole errors.

FRA:

- orbit bumps reduced at the crab cavities
- IP offset performed by alignment
- Limited crab beam adjustment still possible

	Base	FRA	Base	FRA
	Round β*=15 cm		Flat β*=7.5 cm	
TAXS	16.3	16.3	14.0	14.0
IT	12.0	13.1	11.8	12.7
TAXN	15.4	17.3	12.4	13.9
D2	15.5	18.6	12.9	14.7
Q4	14.5	18.3	10.4	13.0
Q5	24.8	28.2	17.6	19.9
Q6	25.5	25.9	18.0	19.3

Courtesy R. De Maria

Full Remote Alignment conclusion

- The deployment of the full remote alignment is feasible:
  - It satisfies the requirement and boundary conditions imposed by the experimental vacuum and experiment requirements
  - It can be made compliant with the Machine Protection requirements
  - All the systems between Q1 and Q5 can be made Full Remote Alignment compliant meaning
    - The vacuum system can be made Full Remote Alignment compliant with
      - Fix sections that provide sufficient aperture to move the beam inside in the ±2.5 mm range
      - Using when required Deformable RF bridge bellows
      - Having 2 sectors valves per IP side remotely moved on dedicated supports (total 8)
      - Having part of the vacuum system around the crab cavities fixed to the crab cavities and moved with them
      - Allowing to recover more sector valves from the LHC and allowing simplification in very tricky areas as the TAXN-D2
    - 5 collimators/masks per IP side will be equipped with their own dedicated alignment platforms (20 in total)
    - The equipment already foreseen on the triplet will be made more redundant and robust in order to be compliant with the requirement of a system that becomes an operational knob
  - The total cost the deployment is in the original ballpark figure presented at Chamonix 2018

WP	Scope Change [MCHF] vs HL baseline		Cost Change [MCHF] Vs HL baseline	
	Addition	Suppression	Increase	Decrease
WP2				
WP3				
WP4	0.02			
WP5	1.417			
WP6A				
WP6B				
WP7				
WP8				
WP9				
WP10				
WP11				
WP12	0.748			
WP13	0.044			
WP14				
WP15	4.814			
WP16				
WP17				
WP18				
WP12 previous CTC increase to be taken out		-1.7		
TOTAL by field	7.043	-1.7		
TOTAL	5.343			

Matching Section Optimization

The Matching Section Optimization

By products

FRA

Gain aperture margin in various equipment

Matching Section Optimization

Reduce the requirement on the Matching Section orbit Corrector System

Opportunities

Re-use present LHC Q4 and Q5 at 4.5 K

Re-optimize the cryogenic distribution reviewing the limits between QRL and QXL

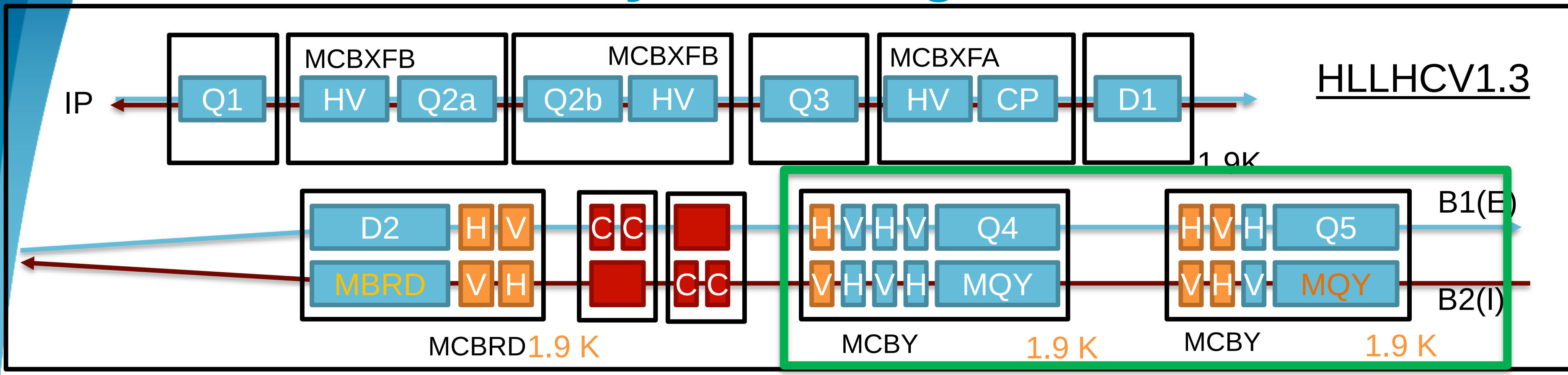
Review the capacity of the foreseen cryo plants at P1 and P5 (and also P4 sect 4-5)

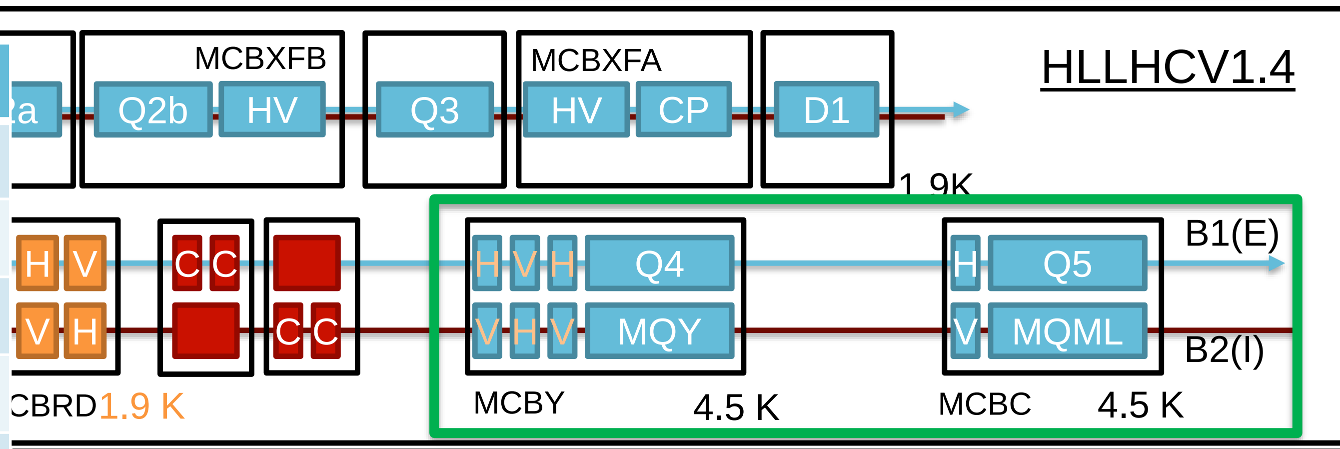
Reduce the number of circuits for the correctors, leading to a reduction of the number of associated Power Converters

Limit the modifications to the DSL: the superconducting link presently feeding the Matching Section from Q6 till D2

Relax the design requirements on the TCLX and TCTX, reduce aperture TAXN for improved protection

Layout changes





	Round	Flat
TAXS	16.3	14.0
Q1	17.4	15.9
Q23	13.1	12.7
D1	13.9	13.0
TAXN	18.0	14.0
D2	19.5	15.0
CRABS	28.3	20.1
Q4 Mask	19.3	13.6
Q5 Mask	21.0	14.9
Q6 Mask	26.5	18.9

Changes with respect to the baseline:
- Q4: reusing existing LHC Q4 cold mass (3 correctors instead of 4), no need of 1.9 K.
- Q5: reusing existing LHC Q5 cold mass (1 corrector instead of 3), no need of 1.9 K.
- Full deployment of remote alignment system to be used with safe beam.

Q5 Left and Right in IR1&5

- Moved of 10.5 m towards the DS
- Polarity remain the same
- Correctors have to act in the same plane
- Both beam screens rotated by 90º
- Temperature remains 4.5K
- ⇨ Jumper height to be checked if the QRL changes

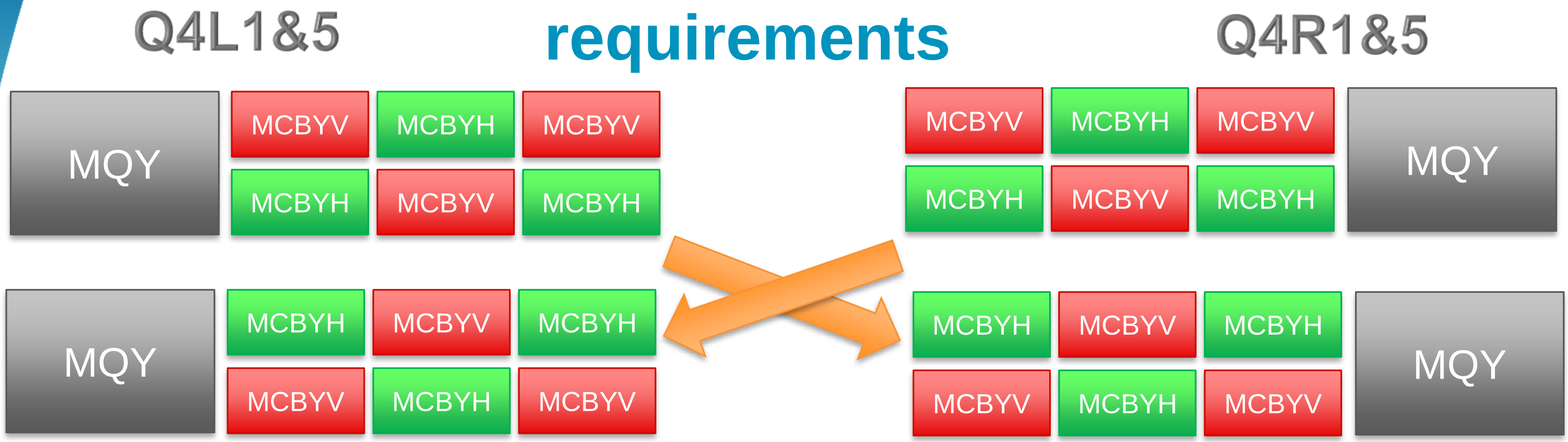
⇨ **Q5 will be reinstalled at their current location after beam screen rotation on surface**

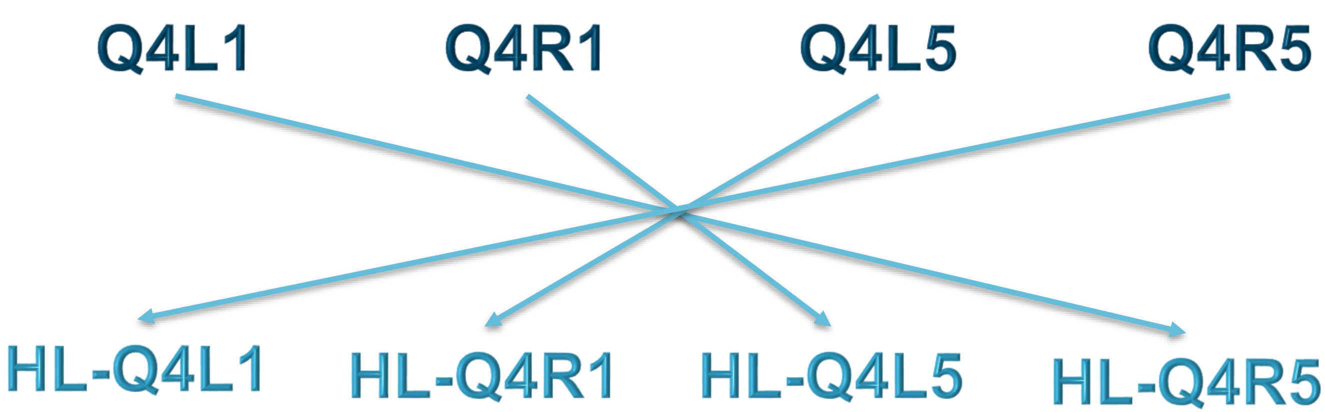
Q4 Left and Right in IR1&5

- Moved by 10.5 m towards the DS
- Polarity remain the same
- All correctors have to act in the perpendicular planes
- Correctors positions better in the IP side
- One beam screen rotated by 90º (VV⇨HV)
- Temperature remains 4.5K
- Cryogenic distribution to be adapted (Semi-standalone ⇨ Standalone)

Courtesy H. Prin

Fulfilling Q4 Optics requirements



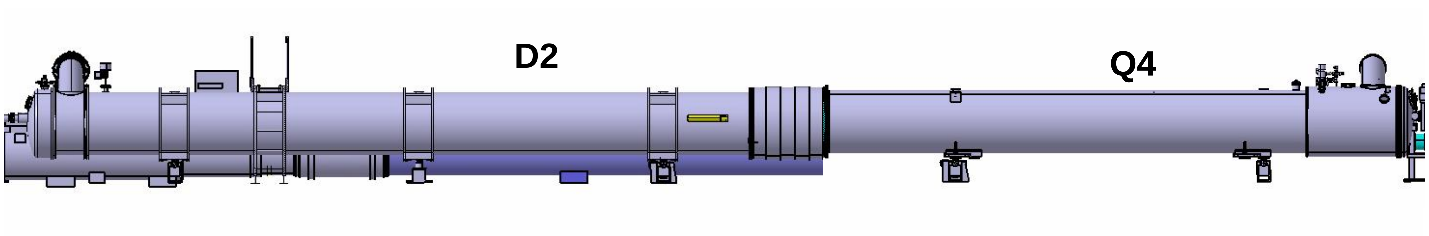


⇨ **Allowing to have level gauges and Temp sensors in the highest side**

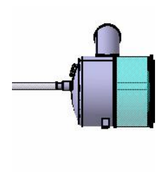
Courtesy H. Prin

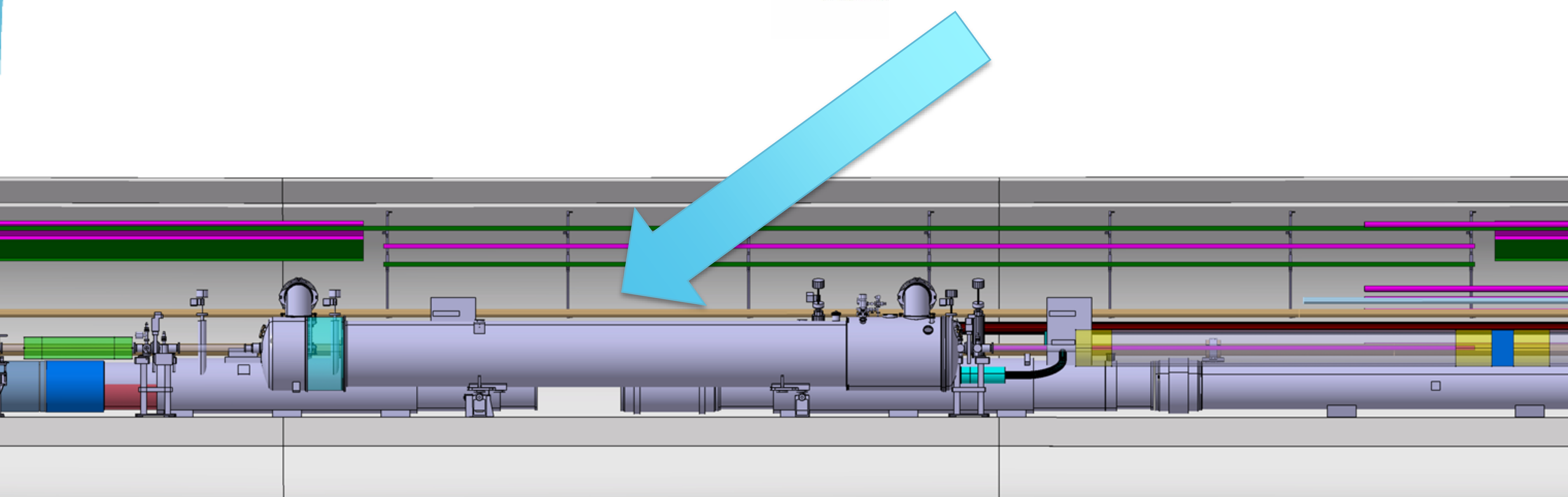
From D2 – Q4 (LHC) to Q4 (HL-LHC)

LHC



HL-LHC





Courtesy D. Duarte

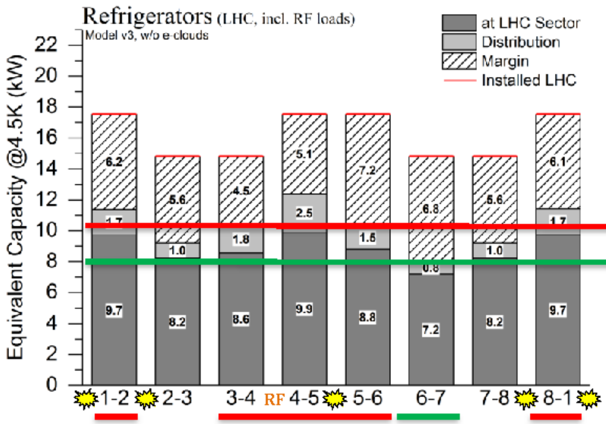
Cooling capacity: is it enough?

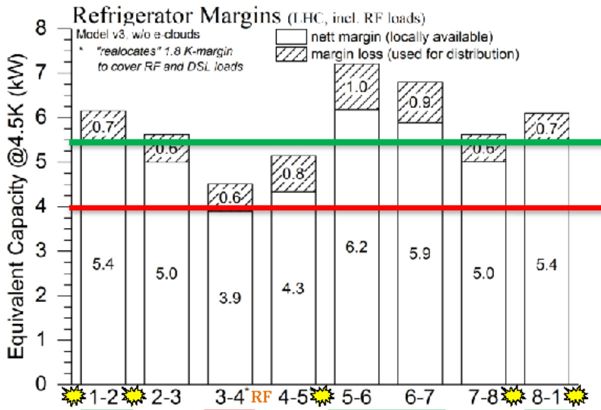
w/o e-clouds!

Refrigerator Assessment

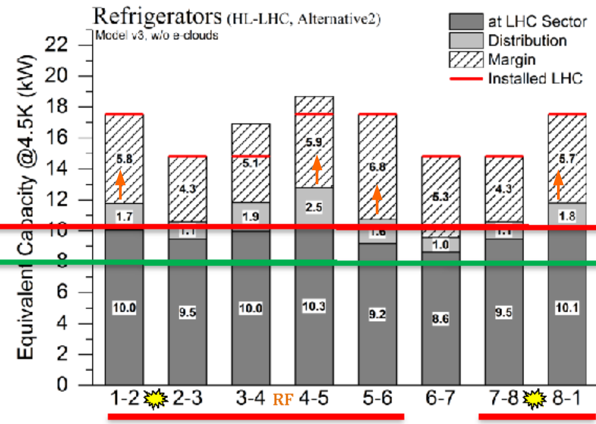
Results based on *model v.3*, for existing LHC refrigerators only

LHC



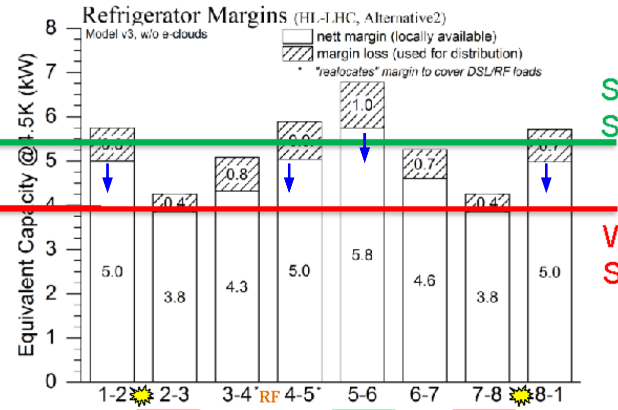


HL-LHC



High Load

Low Load



Strong Sector

Weak Sector

Cooling capacity for SAM's & DFBL to come from main sector Refrigerators
(~0.5kW_eq@4.5K)

Cooling capacity margins will be aligned on other sectors
(5-6 higher as no IT nor RF)

No "weak point/sector" created with this alternative

QRL / QXL optimisation in Right of 5

QXL-QRL
Junction
Module

HL-LHC Baseline layout

Present LHC machine and QRL layout

1

3

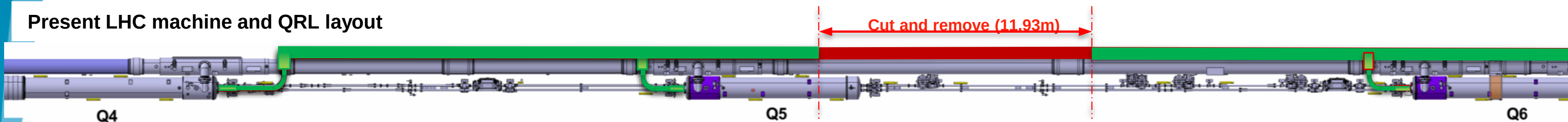
Warm powering simplification

		Baseline	Optimized approach
Q4	Quadrupole	MQY	MQY
		1X HCRPHRA R2E-LHC4-6-8kA+08V	1 X HCRPHRA R2E-LHC4-6-8kA+08V
	Correctors	8 MCBY	6 MCBY
		8 X HCRPLBC R2E-HL-LHC120A-10V	6 X HCRPLBC R2E-HL-LHC120A-10V
Q5	Quadrupole	MQY	MQML
		1 X HCRPHSB R2E-LHC4-6-8kA+08V	1 X HCRPHSB R2E-LHC4-6-8kA+08V
	Correctors	6 MCBY	2 MCBC
		6 X HCRPLBC R2E-HL-LHC120A-10V	2 X HCRPLBC R2E-HL-LHC120A-10V
Q6	Quadrupole	MQML	MQML
		1 X HCRPHSB R2E-LHC4-6-8kA+08V	1 X HCRPHSB R2E-LHC4-6-8kA+08V
	Correctors	2 MCBC	2 MCBC
		2 X HCRPLBC R2E-HL-LHC120A-10V	2 X HCRPLBC R2E-HL-LHC120A-10V

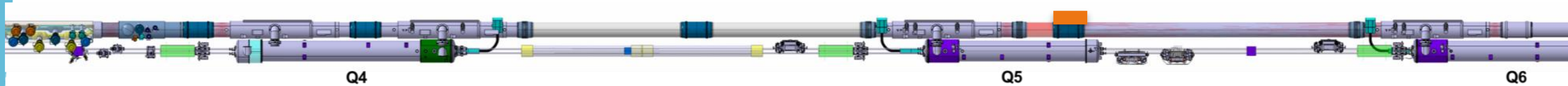
Courtesy M. Martino

DSL optimisation in Right of 5

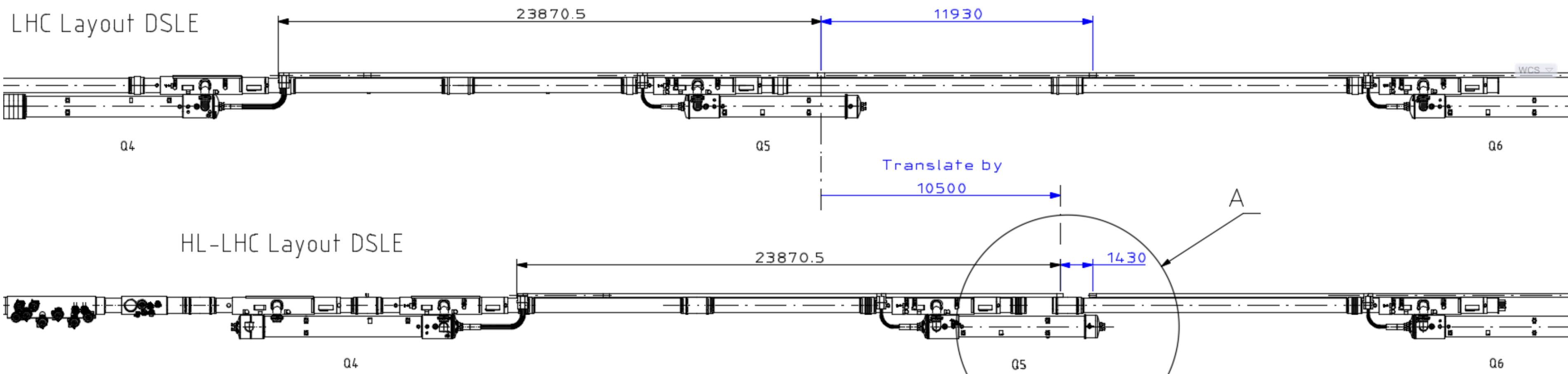
Present LHC machine and QRL layout



HL-LHC Matching Section Optimization layout



LHCDSLE_00



Conclusion
Matching Section Optimization

- A re-optimization of the Matching Section is Point 1 and Point 5 is possible and it would lead to
  - Magnet system:
    - Re-use of the LHC Q5 units with minor modifications
    - Re-use of the LHC Q4 units: jumper shall be turned and second jumper shall added to recover D2 jumper functionality and minimize interventions
  - Cryogenic system
    - The present QRL can be modified in order to cryogenically feed the Q4 and Q5 in their new optical positions (collaboration between optics and cryogenics it has been instrumental to find the best solution that has also opened optimization opportunities on the DSL modifications)
    - The return module between the QRL and QXL can be integrated in a new positon thanks to the suppression of the options for the second batch of crab cavities. Junction module still requires further optimization
    - The cryo plant power shall be adapted to the new configuration: decrease in the power installed in P1 and P5. P4 capacity for Sector 4-5 needs to be re-evaluated if needed
  - Warm powering
    - As corrector circuits are suppressed the corresponding Power Converters are not necessary any more
  - Cold powering
    - The DSL modification can be significantly reduced and the fact of keeping the distance between Q4→Q5 fixed from LHC to HL-LHC would allow to rigidly translate those segments of the system
- The above listed actions allow to reduce the linked costs

WP	Scope Change [MCHF] vs HL baseline		Cost Change [MCHF] Vs HL baseline	
	Addition	Suppression	Increase	Decrease
WP2				
WP3	0.665	-6.946		
WP4				
WP5				
WP6A	0.516	-1		
WP6B		-0.666		
WP7				
WP8				
WP9	1.5	-4.25		
WP10				
WP11				
WP12	0	0		
WP13				
WP14				
WP15		-0.159		
WP16				
WP17				
WP18				
TOTAL by field	2.681	-13.021		
TOTAL	-10.34			

Conclusions

- The Full Remote Alignment
  - Can be deployed
  - It will be beneficial to reduce radiation to personnel
  - It will increase the window for machine optimization (larger margin in aperture margin and lower β^* reach)
  - Less pressure on orbit corrector system
  - Higher machine flexibility and reduced reaction time
  - It opens the possibility to re-optimize the Matching Section
- The Matching Section can be re-optimized
  - Reducing the amount of work to be performed and the extension of the LHC machine modifications
  - It simplifies the design of few elements as i.e. the collimators
- The combination of the two actions make possible a sizable saving for the HL-LHC project of 4.997 MCHF
- Until very recently the saving was 6 MCHF but the analysis of the cryo connection to the crab cavity demonstrated the very high complexity of the area leading to the need to build also new service modules for the Q4. For this reason 1 MCHF has been added to take care of those elements

Next steps

- After endorsement from TCC we introduce in the bassline
  - The Full Remote Alignment
  - The Matching Section Optimisation
- We will document this with
  - Phase I:
    - HL-ECR with the description and in attachment the related detailed table costs
    - Implement the cost + and cost – in the new future budget baseline
  - Phase II:
    - Prepare a functional specification of the Full Remote Alignment covering
      - Functionalities
      - Interfaces between WP/groups and equipment
      - MPP related matters
    - Person to be identified in the WP15.4
- Working towards the lay-out
  - We need to modify completely the full LSS1 and LSS5 lay-out especially vacuum
  - Collimation and vacuum team are optimizing the TAXN-D2 area
  - The proposal of reducing the TAXN aperture is being discussed
  - The full crab cavity area shall be reviewed to make possible their installations
- Honestly I do not think we will have all the data ready before end of February therefore We hop to have the drawings ready for May
- In addition we need to put in place an action to homogenize as maximum the solutions adopted for supports taking into account standardization and the real needs for radiation resistance