Baseline and alternatives for WP9-Cryogenics,
- LHC-P4
- Back-up of LHC detectors

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HL - Technical Coordination Committee
July 7th, 2016

Content

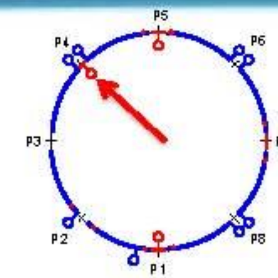
- LHC-P4: Cryo baseline and proposed alternative
- Cooling capacity and feasibility
- Cryo-distribution
- Summary

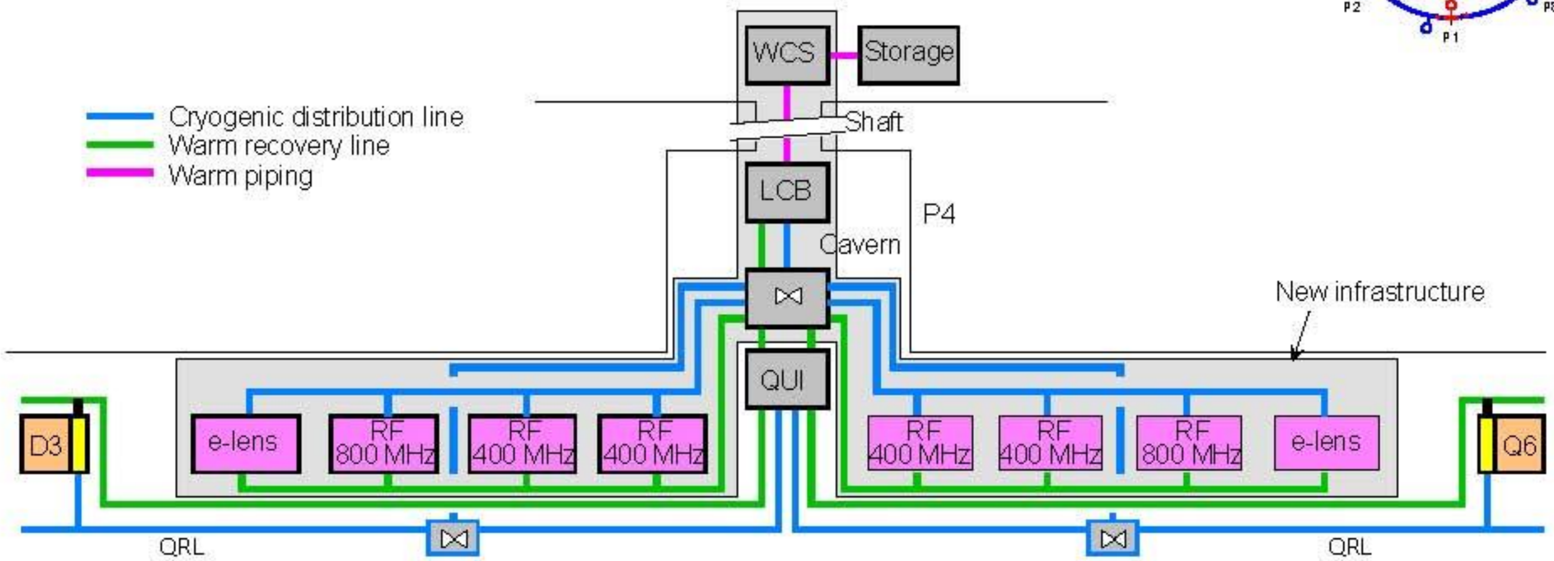
- Possible cryogenic back-up of detectors

LHC P4 Cryo Baseline

A dedicated refrigerator, valve box and cryolines

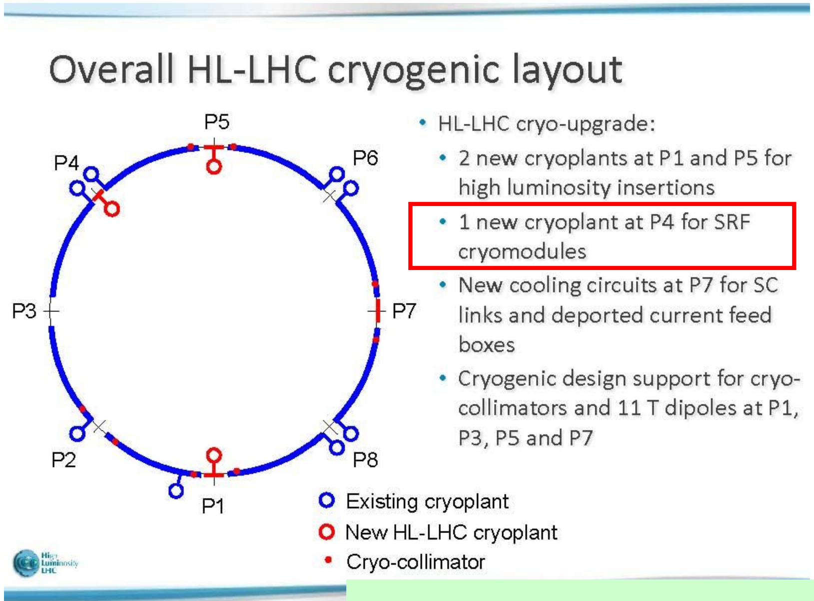
New cryogenic infrastructure at P4





- 1 warm compressor station (WCS) in noise insulated surface building
- 1 lower cold box (LCB) in UX45 cavern
- 1 valve box in UX45 cavern
- 2 main cryogenic distribution lines
- 2 interconnection lines with existing QRL service modules

Baseline so far



Cooling capacity:

- To align P4 on P6 (without RF loads)

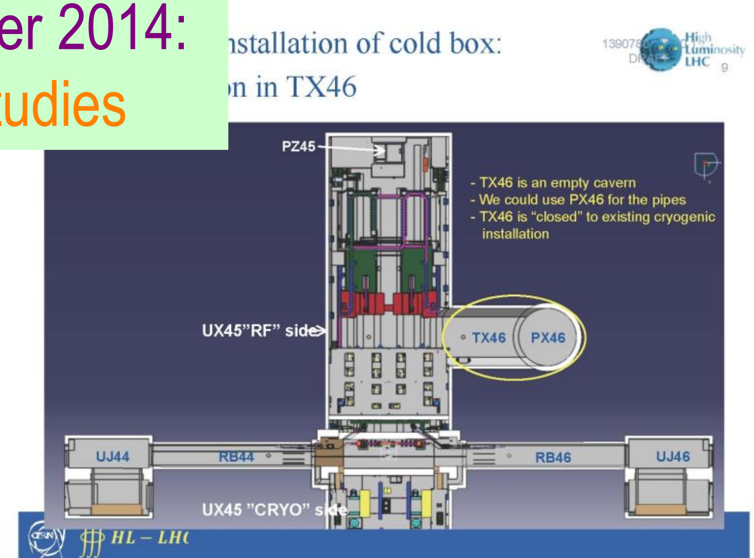
Flexibility:

- For specific RF tuning needs

(as part of the tentative to decouple the RF from Magnets following 2008 sector 34 incident, without specific requirement)

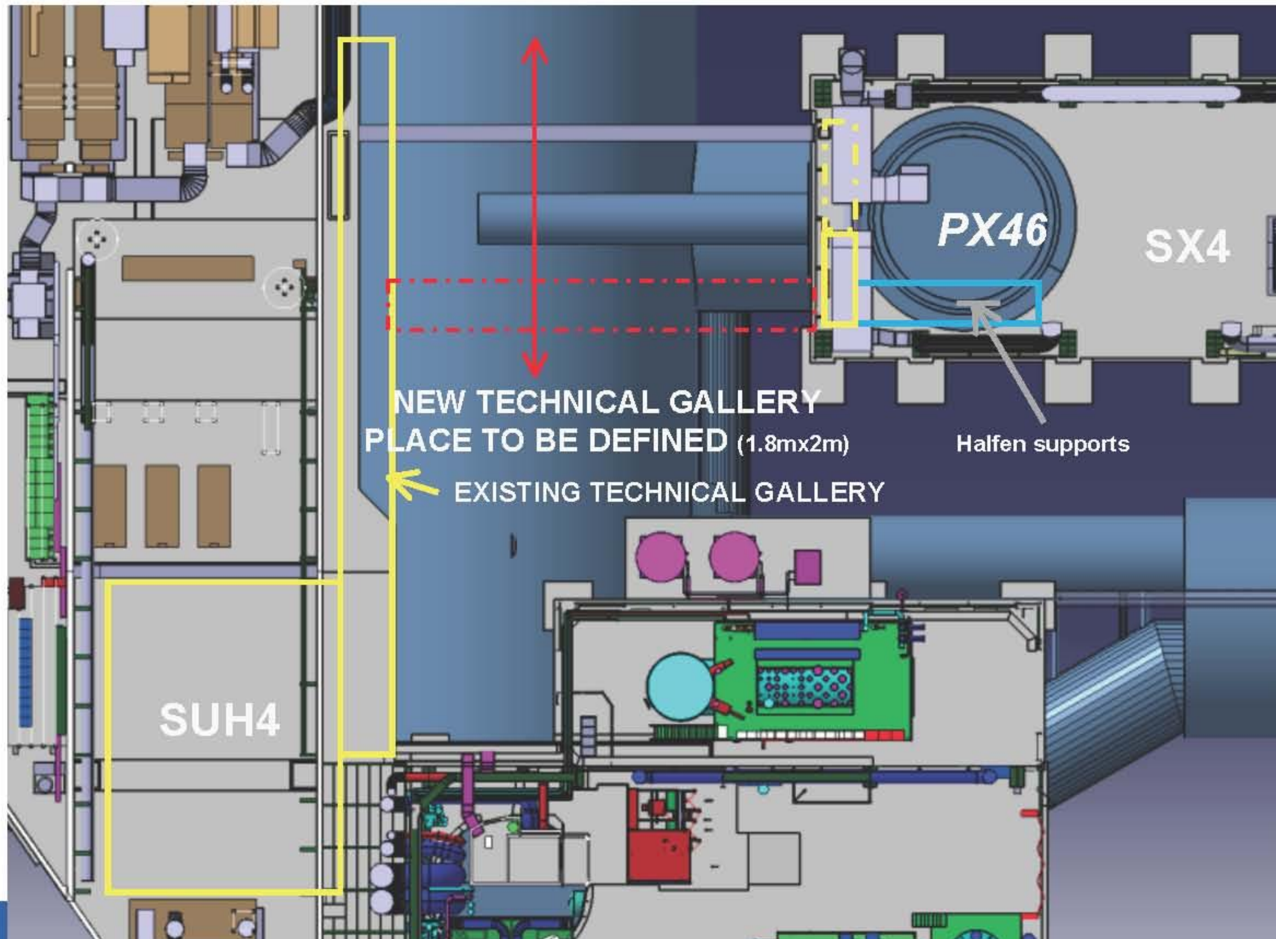
- In view of future "envisaged" sub-systems to be cooled at P4

Progress 1st semester 2014:
solid integration studies

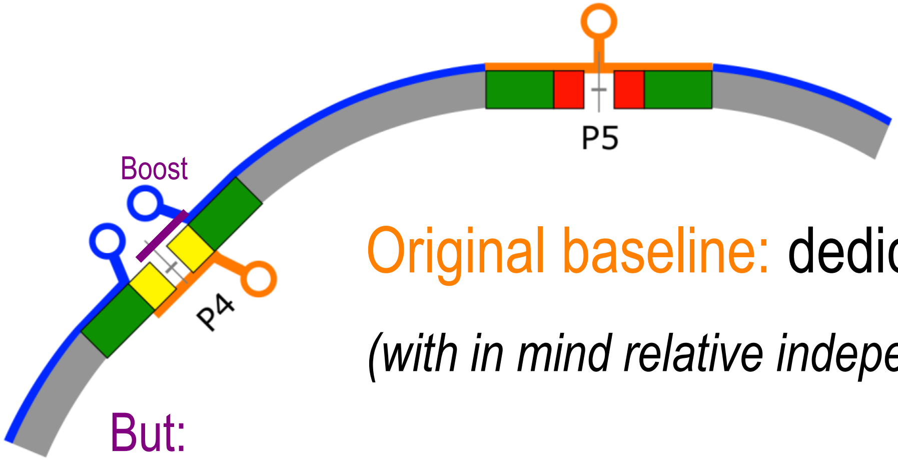


Cryogenics area

Results of integration studies for Cryogenic baseline for LHC-P4



P4 - RF Status and perspectives



Original baseline: dedicated 4.5K Refrigerator for RF

(with in mind relative independence from magnets operation/constraints)

But:

+ It does not work so bad for time being (RF never really late for beam commissioning)

- Availability for HL beam operation would be reduced with increased number of cryoplants to be operated simultaneously

• ideas summer 2014 to propose an upgradable refrigerator to match the RF needs (400MHz, then 800MHz as harmonic, switch to 200MHz with 400MHz as harmonic)

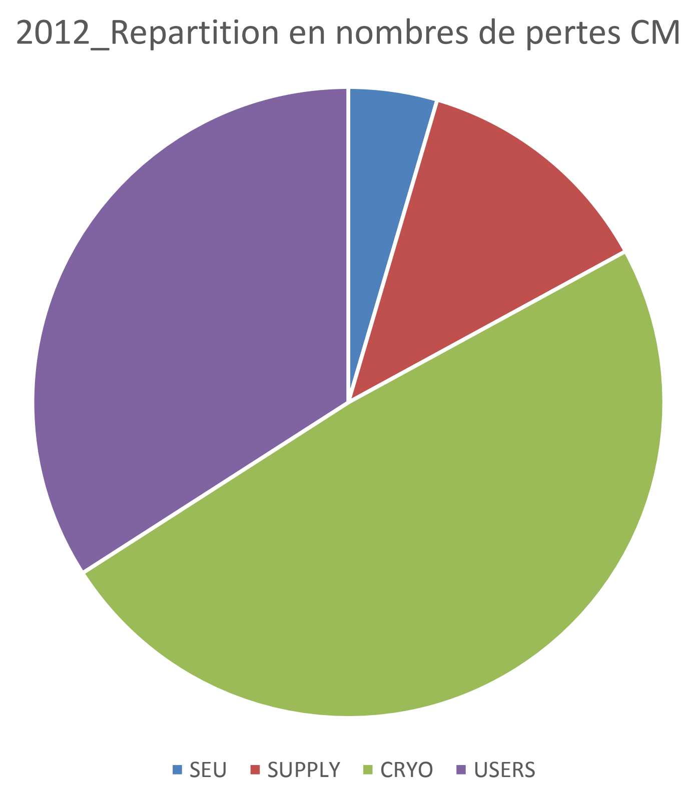
• Clear understanding at 4th_LARP_KEK_Nov'14 meeting that real gain for RF would be to test a module anytime during a LS, while Cryo would do maintenance

=> Proposal of alternative: Upgrade + corresponding distribution + mobile Refrigerator

How much ? Anyway ! Concept !

Cryo availability 2012

Similar for 2015

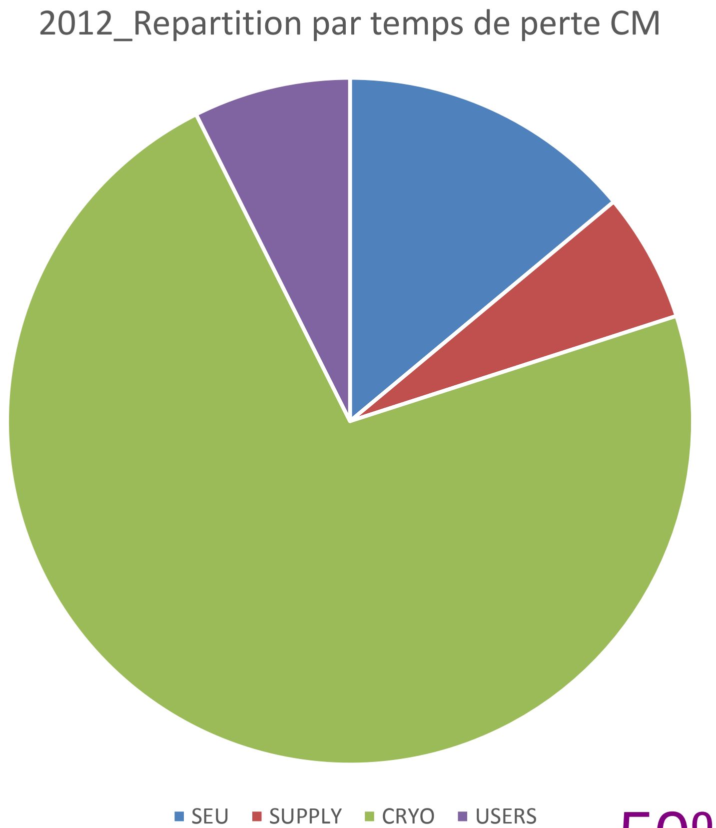


Nb pertes CM par categorie		
SEU	4	4.55%
SUPPLY	11	12.50%
CRYO	43	48.86%
USERS	30	34.09%
TOTAL	88	100.00%

CRYO: 50% of failures (numbers)

Cryo availability 2012

Similar for 2015

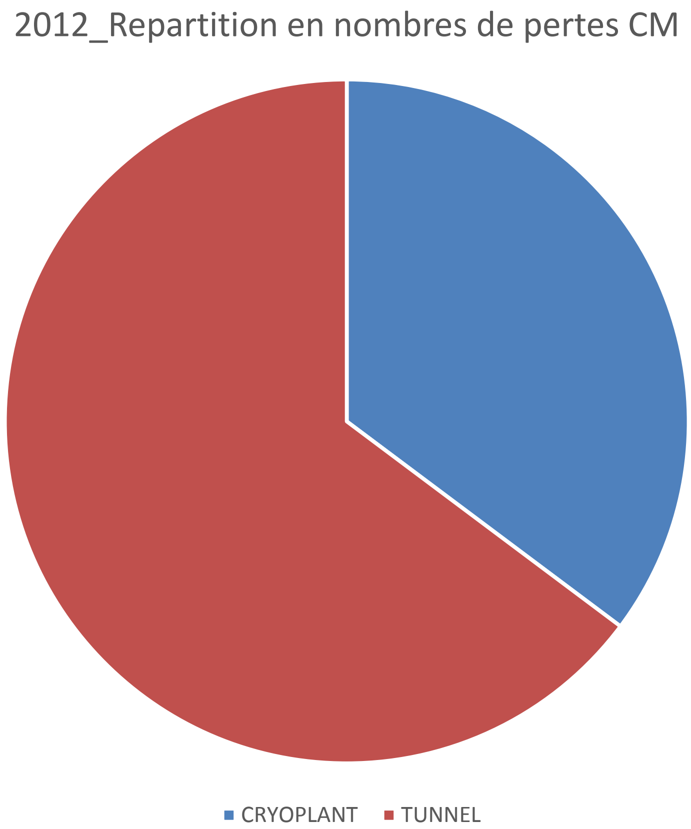


Temps perte CM par categorie		
SEU	48:21:40	13.96%
SUPPLY	21:03:13	6.08%
CRYO	251:16:43	72.55%
USERS	25:39:14	7.41%
TOTAL	346:20:50	100.00%

50% of failures are attributed to Cryo, 75% of the time lost for availability

Cryo availability 2012

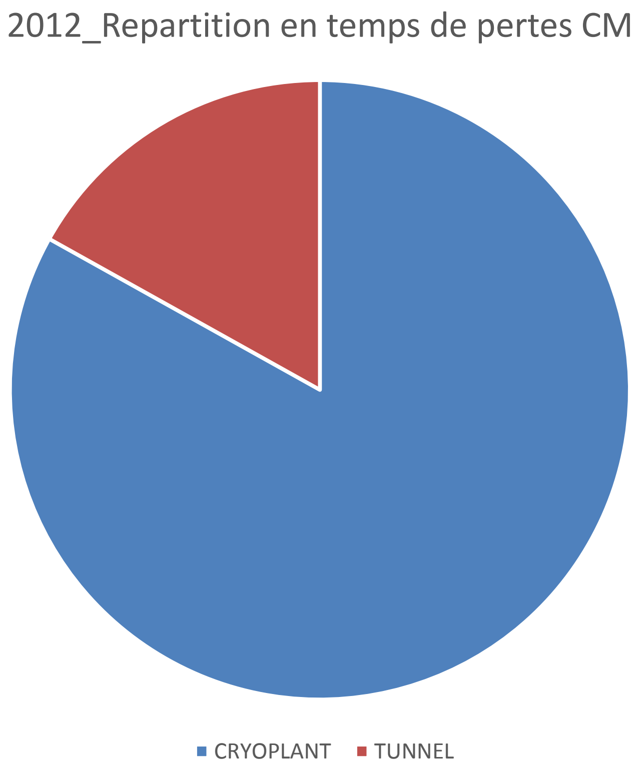
Similar for 2015



Nb pertes CM par type d'installations		
Cryoplant	31	35.23%
Tunnel	57	64.77%
TOTAL	88	100.00%

Mitigation to be studied for tunnel instrumentation,
Not more to be expected for HL
(same technology, same number of channels)

Cryo availability 2012



Similar for 2015

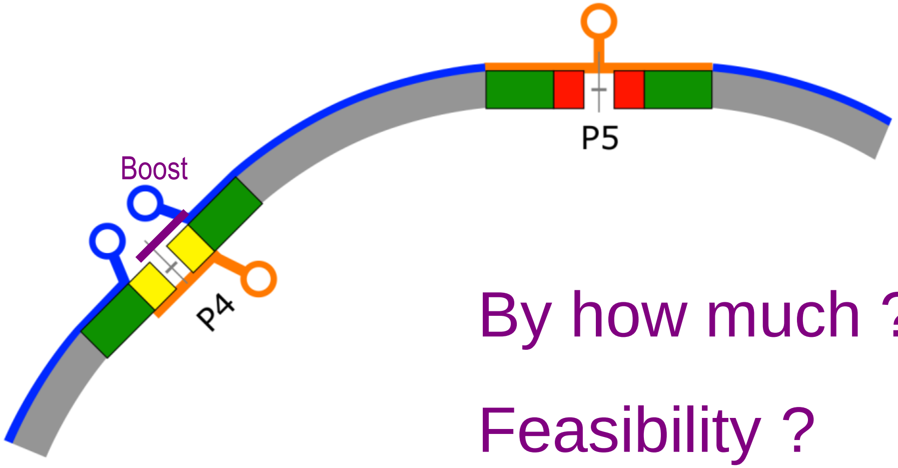
Temps perte CM par type d'installations		
Cryoplant	287:49:15	83.10%
Tunnel	58:31:35	16.90%
TOTAL	346:20:50	100.00%

Mitigation to be studied for tunnel instrumentation
(induced turnaround time)

With 1/3rd of failures for cryoplants leading to 5/6th of lost time, not nice perspective for HL-LHC: 11 cryoplants w.r.t 8 for LHC

=> Worth limiting the cryoplants to the strict minimum (10?)

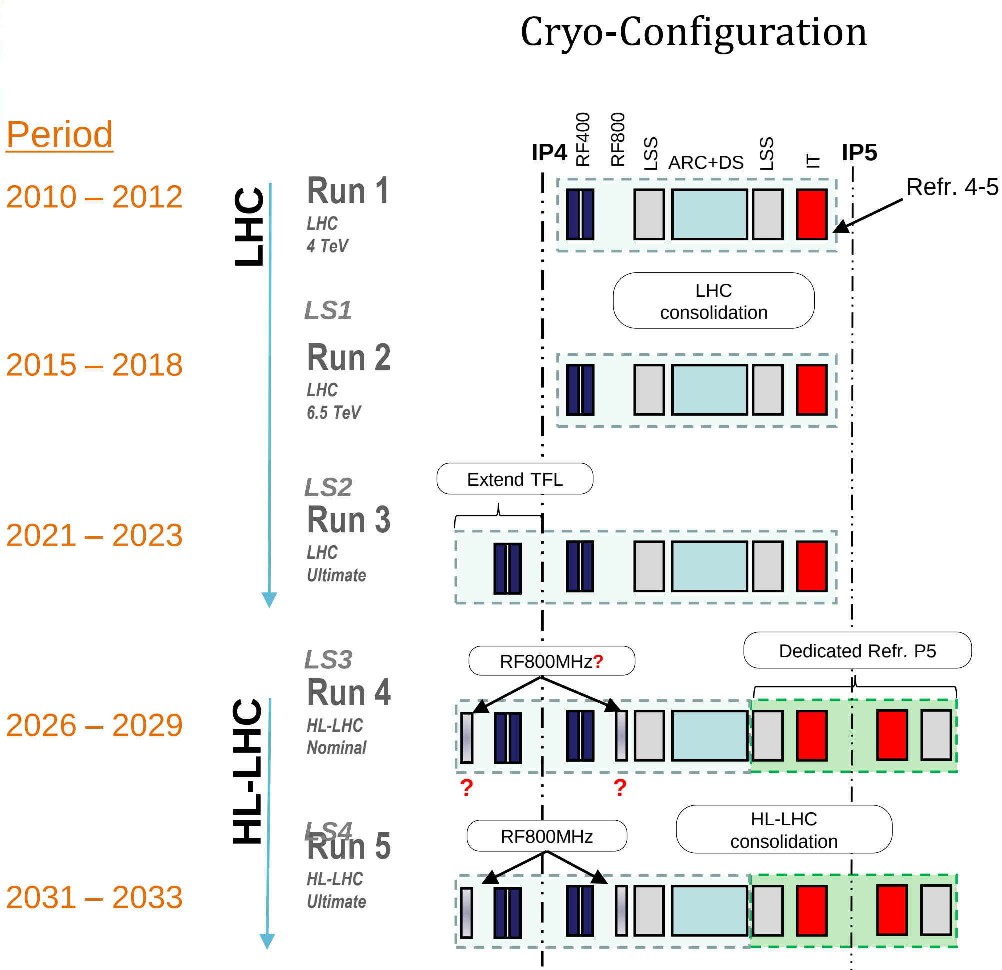
Upgrade existing 18kW cryoplant at P4



By how much ?

Feasibility ?

Cryo Configuration



760 W @4.5 K required for sector 4-5 for the RF cavities was <u>not</u> part of the refrigerator specifications. (Same for Sector 3-4)

LHC running almost at nominal conditions.

Extended transfer line allows refrigeration of the RF cavities „*left*“ of IP4.

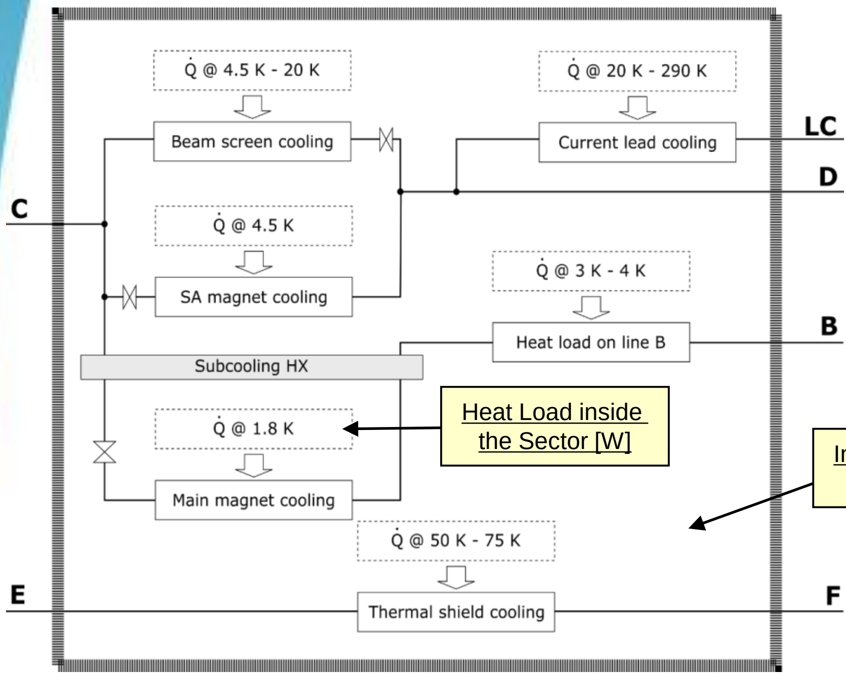
New dedicated refrigerator for the „long straight sections“ at IP5.

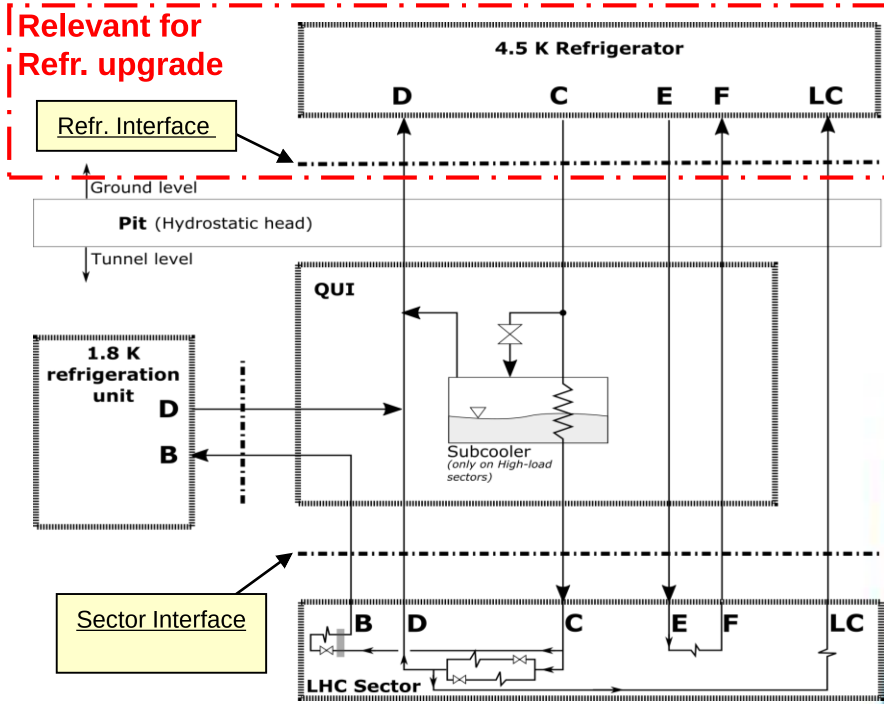
All RF cavities combined require **2610 W @4.5 K**. (including design coefficients)

Sector Refrigeration

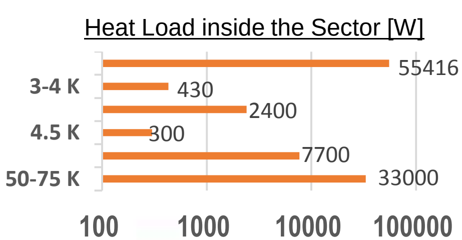
Flow-scheme **inside** the Sector

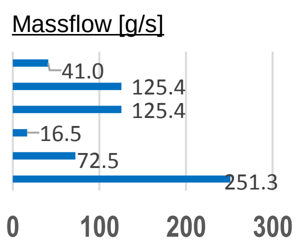
Flow-scheme of the overall refrigeration system

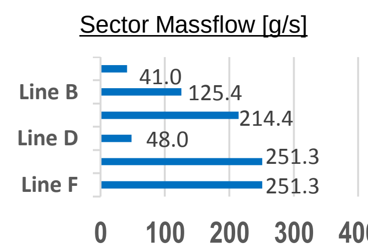


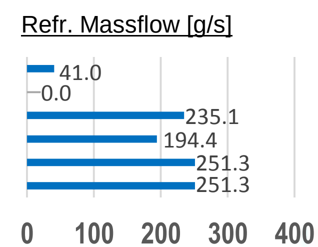


Values w.r.t. "LHC nominal Refrigeration" (LHC-ProjectNote-140) :

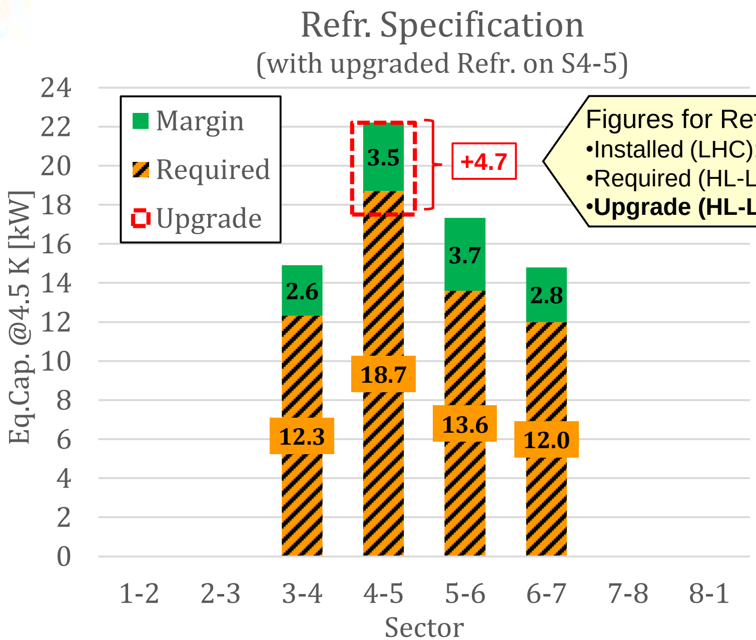




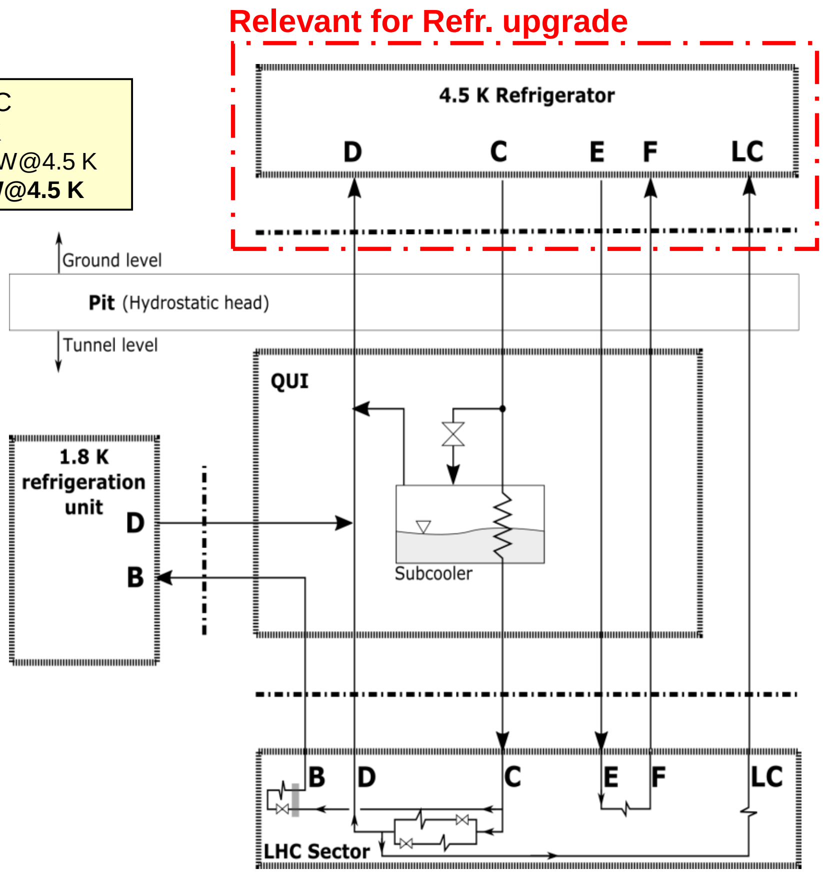




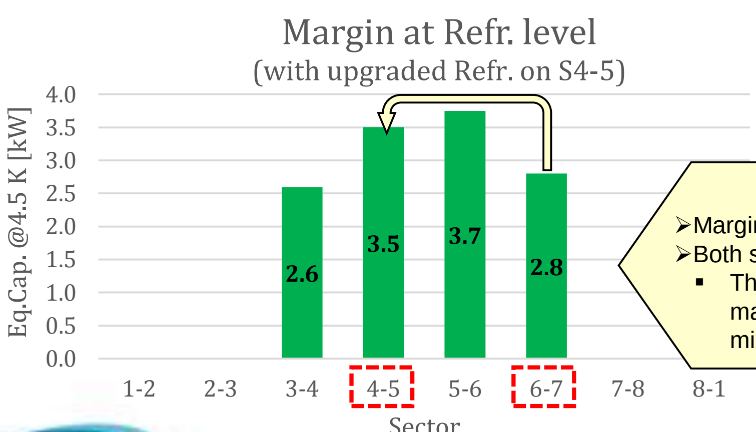
The HL-LHC Refrigerators



Figures for Refr. S4-5 HL-LHC
- Installed (LHC): 17.5 W@4.5 K
- Required (HL-LHC): 22.2 W@4.5 K
- **Upgrade (HL-LHC): 4.7 W@4.5 K**



Comparing Margins

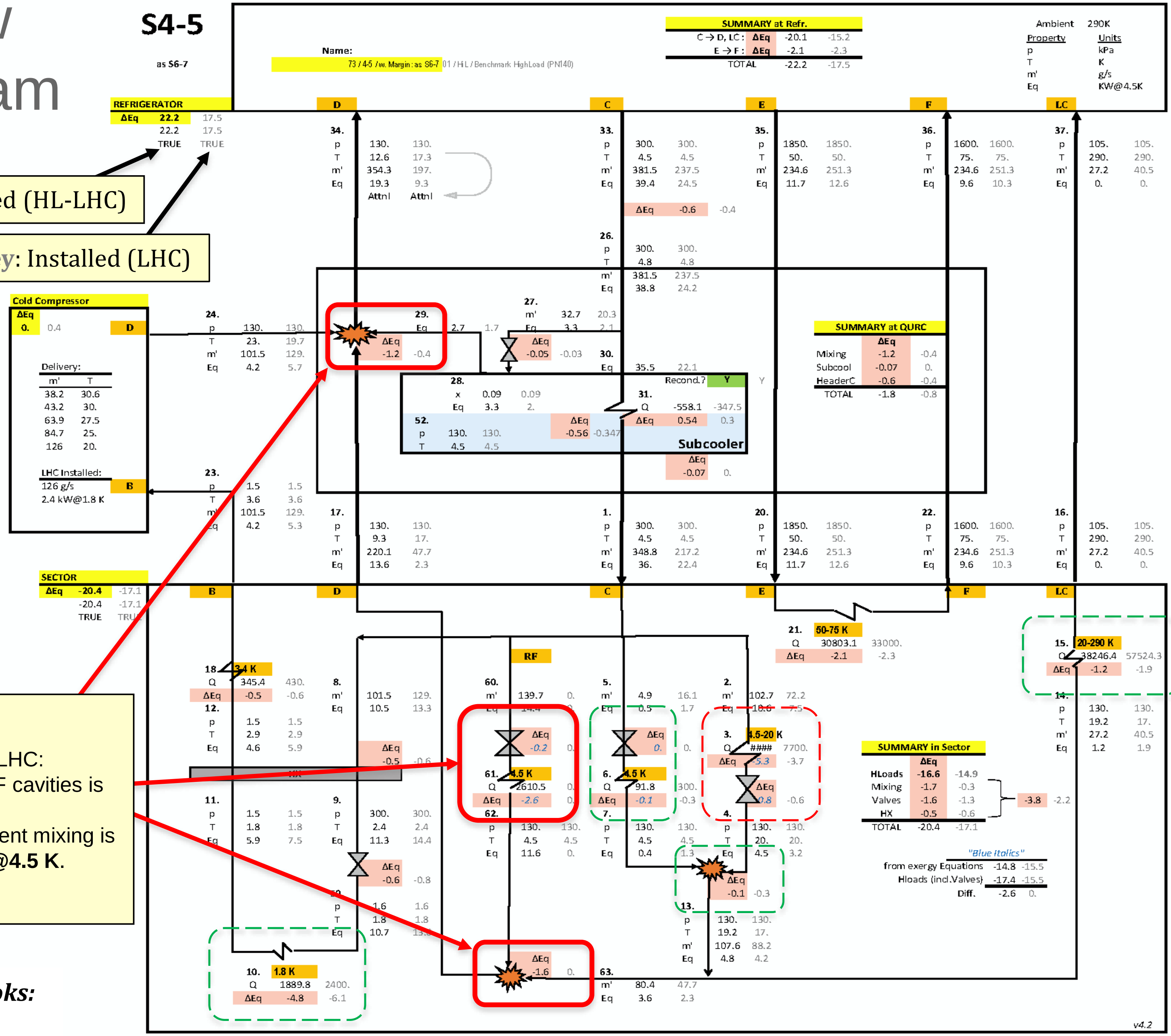


Sector S4-5 is leveled to S6-7
- Margins at S6-7 is used to define margins at S4-5.
- Both sectors have **the same** local margins.
  - The total margin is higher at S4-5 because it contains margins for RF cavities (including penalties from mixing flows).

Flow Diagram

Black: Required (HL-LHC)

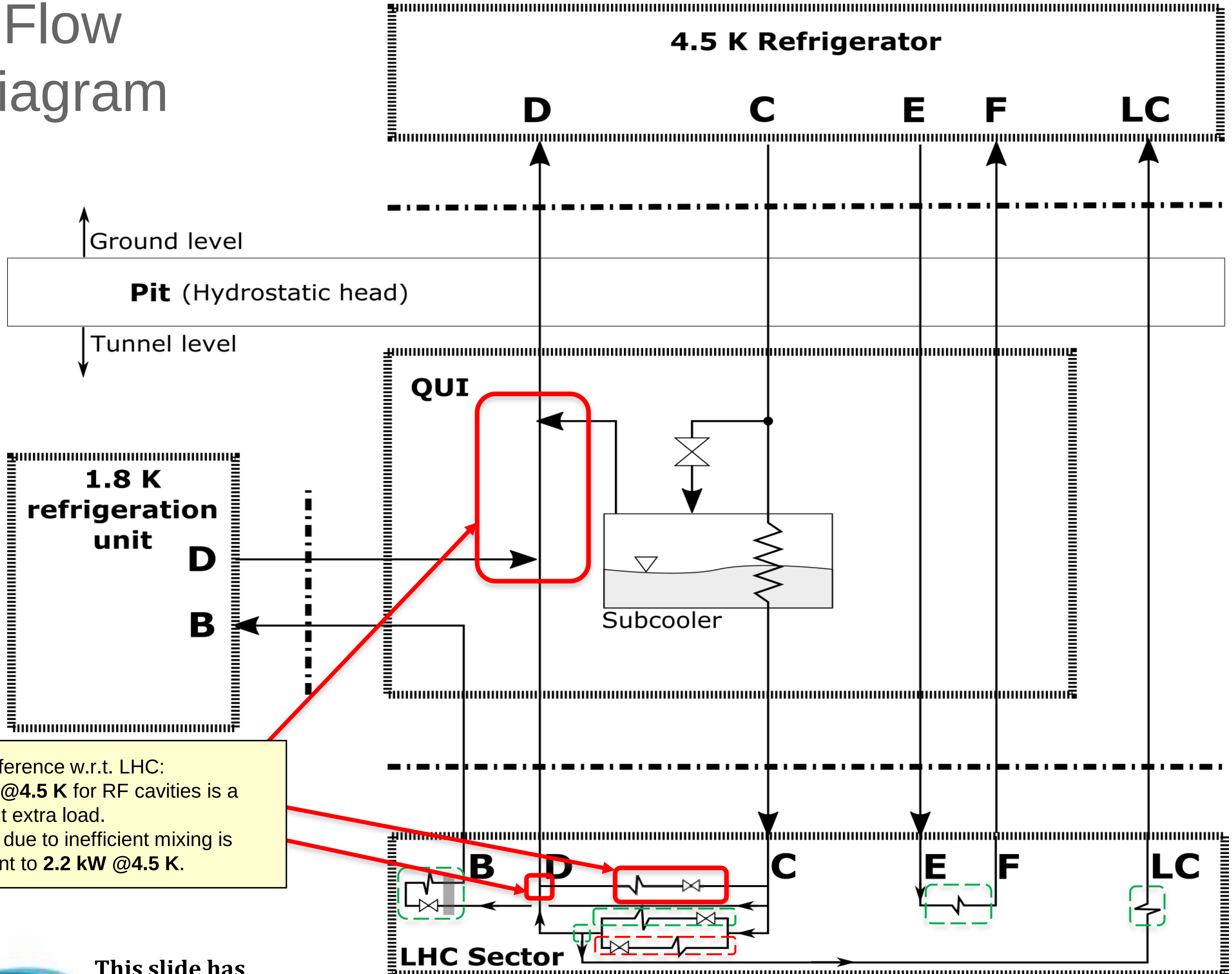
Grey: Installed (LHC)



Main Difference w.r.t. LHC:
- **2.6 kW @4.5 K** for RF cavities is a dominant extra load.
- Penalty due to inefficient mixing is equivalent to **2.2 kW @4.5 K**.

View inside our books:
Only for this meeting.
This slide will be **not** distributed!

Flow Diagram



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This slide has been edited for distribution.

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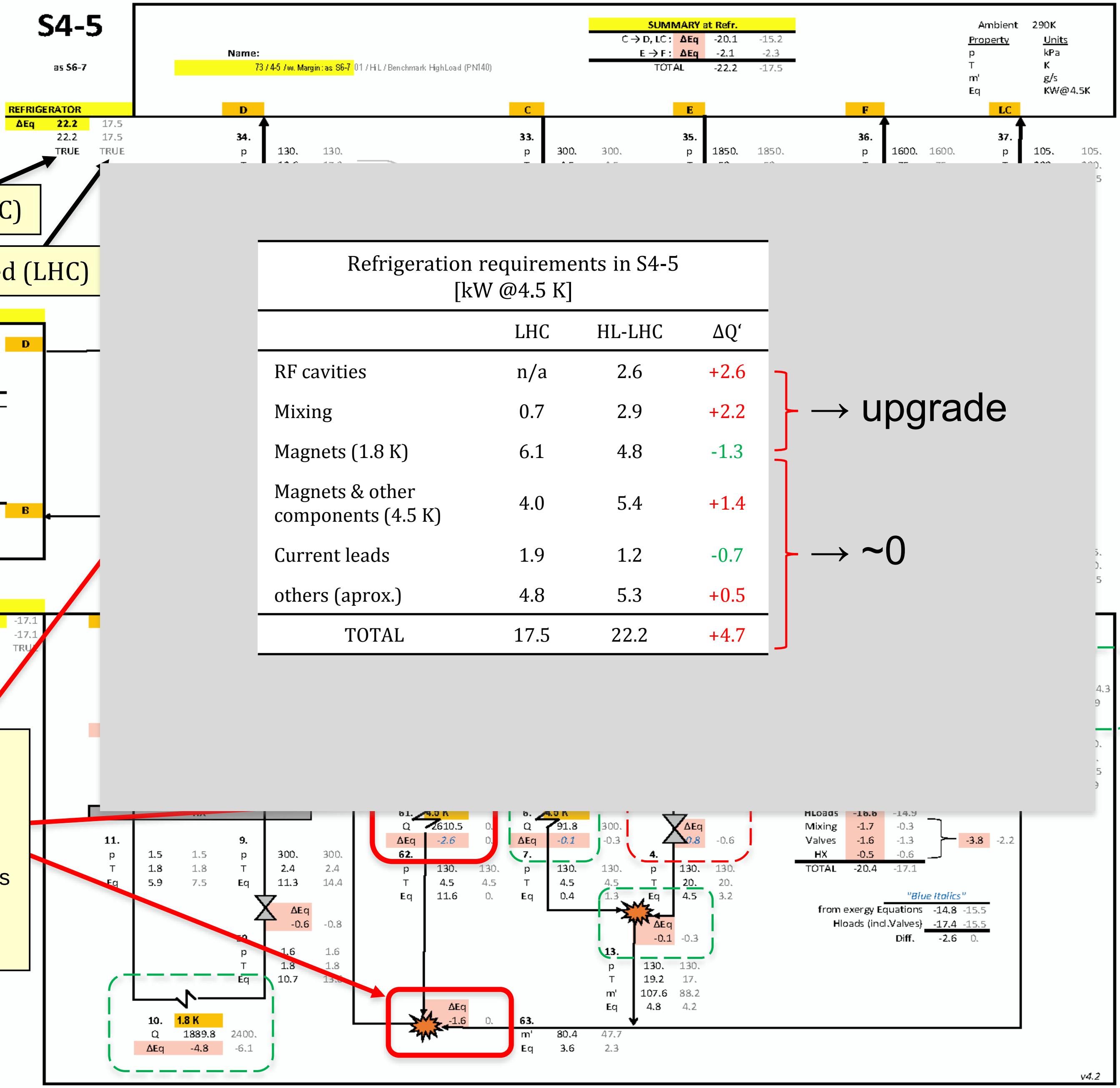

Black: Required (HL-LHC)

Grey: Installed (LHC)

Refrigeration requirements in S4-5 [kW @4.5 K]	LHC	HL-LHC	ΔQ'
RF cavities	n/a	2.6	+2.6
Mixing	0.7	2.9	+2.2
Magnets (1.8 K)	6.1	4.8	-1.3
Magnets & other components (4.5 K)	4.0	5.4	+1.4
Current leads	1.9	1.2	-0.7
others (aprox.)	4.8	5.3	+0.5
TOTAL	17.5	22.2	+4.7

RF cavities, Mixing, Magnets (1.8 K) → upgrade

Magnets & other components (4.5 K), Current leads, others → ~0

Main Difference w.r.t. LHC:
- **2.6 kW @4.5 K** for RF cavities is a dominant extra load.
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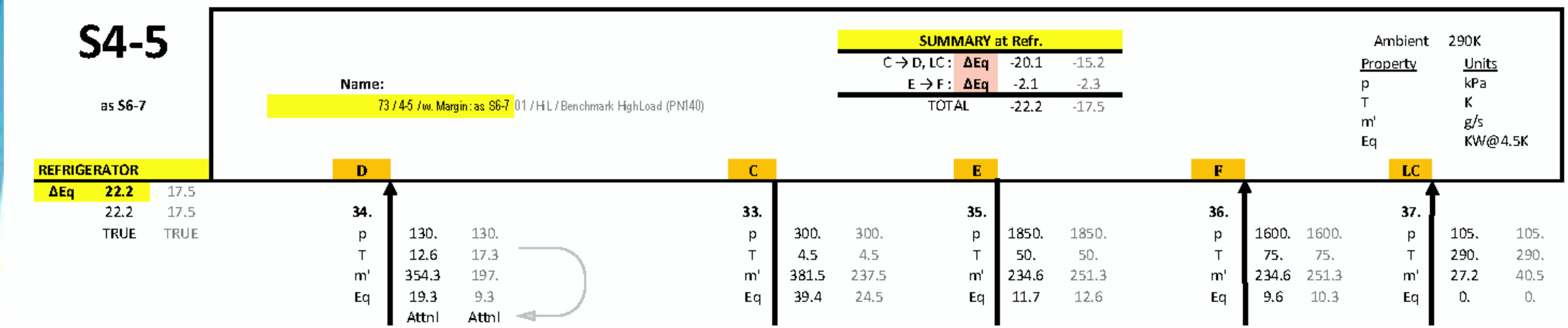
Flow Diagram



Capacity at sector level

LHC (installed)

Temperature level	50-75 K [W]	4.6-20 K [W]	4.5 K [W]	1.8 K [W]	3-4 K [W]	20-280 K [g/s]
Heat load	33000	7700	300	2400	430	41

HL-LHC (required)

Temperature level	50-75 K [W]	4.6-20 K [W]	4.5 K [W]	1.8 K [W]	3-4 K [W]	20-280 K [g/s]
Heat load	30803	10954	2703*	1890	345	27.2

* 2611 W correspond to RF cavities.

Interface to refrigerator S4-5

Line		C	D	E	F	LC
Temperature	K	4.5	20	50	75	290
Pressure	bar	3.0	1.25	18.5	n/a	1.25
Flow	g/s	235	194	n/a	n/a	41

Line		C	D	E	F	LC
Temperature	K	4.5	12.6	50	75	290
Pressure	bar	3.0	1.3	18.5	16.0	1.1
Flow	g/s	381.5	354.3	234.6	234.6	27.2

Equivalent capacity @4.5 K: 22.2 kW
(+ 4.7 kW with respect to installed capacity)

Our request for quotation

Feasibility study for an upgrade of a 18kW@4.5K Refrigerator

Feasibility study and deliverables:

We would like to ask you to perform a feasibility study evaluating the necessary changes to be made on the existing equipment. For this the following documents should be provided:

1. a T,s diagram of the upgraded refrigerator providing the required capacity
2. the corresponding Process & Flow diagram
3. a description of the technical modifications required, including the list of items or sub-systems that would need to be replaced, with corresponding new performance and dimensions.

In particular, the oil removal system and heat exchangers would have to be checked

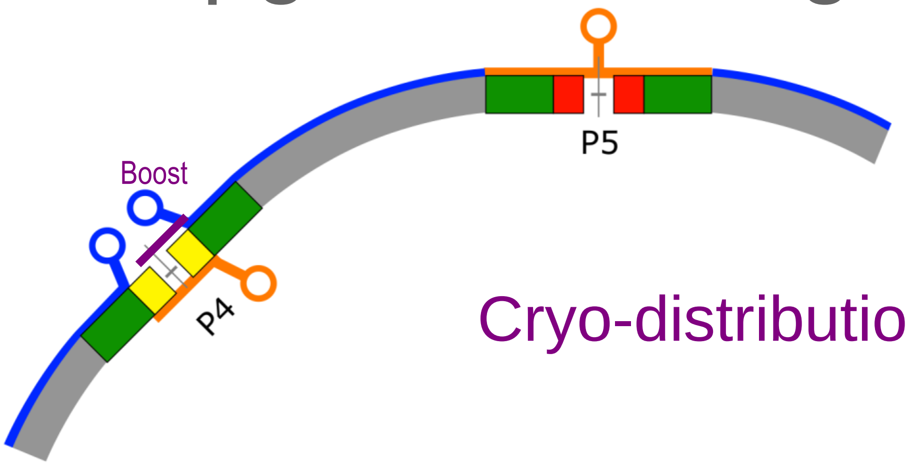
4. Variants: on our side, we are investigating possibilities to avoid degrading so much the distribution efficiency due to mixing. Any suggestion in this domain would be welcome, as well as maximum cooling capacity compatible with existing oil removal system or aluminium heat exchangers, while corresponding hypothesis on the ratio amongst cooling capacities at various temperatures.

From our request on 4th May 2016
Clarification meeting held mid Jun'16

Presentation of results: Beg. Sept'16

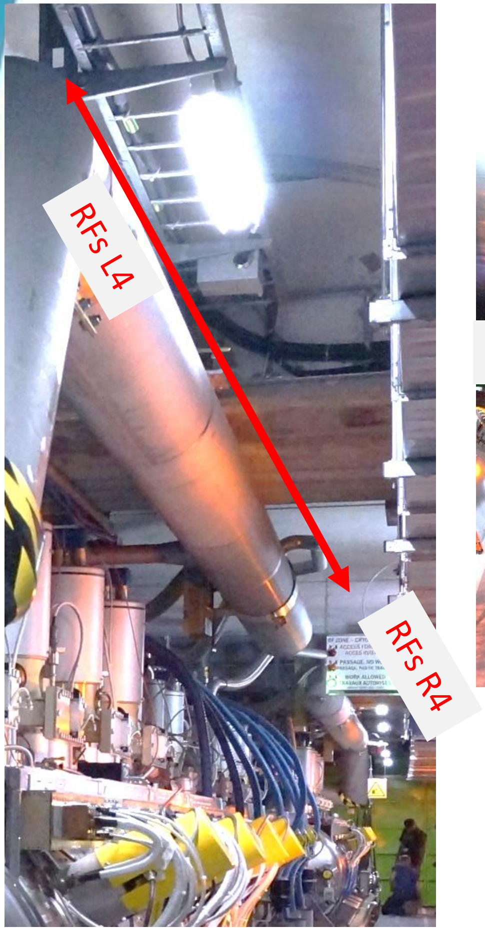
Final Report: 30Sept'16

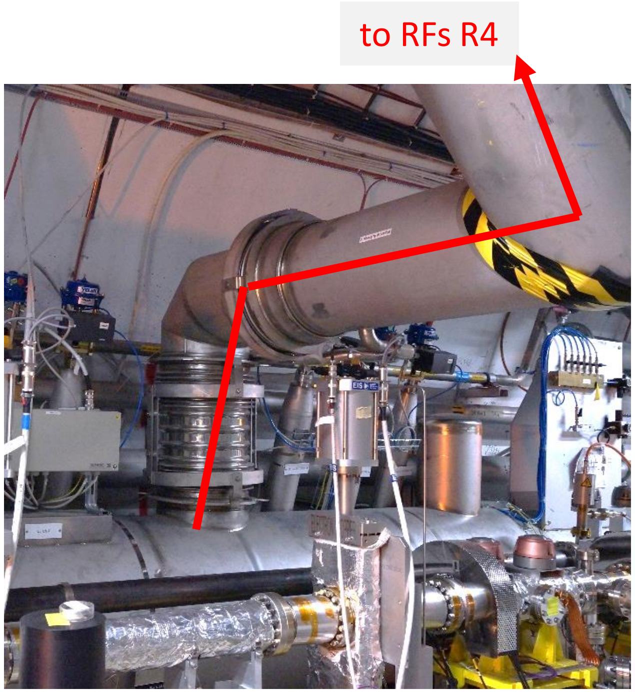
Upgrade existing 18kW cryoplant at P4



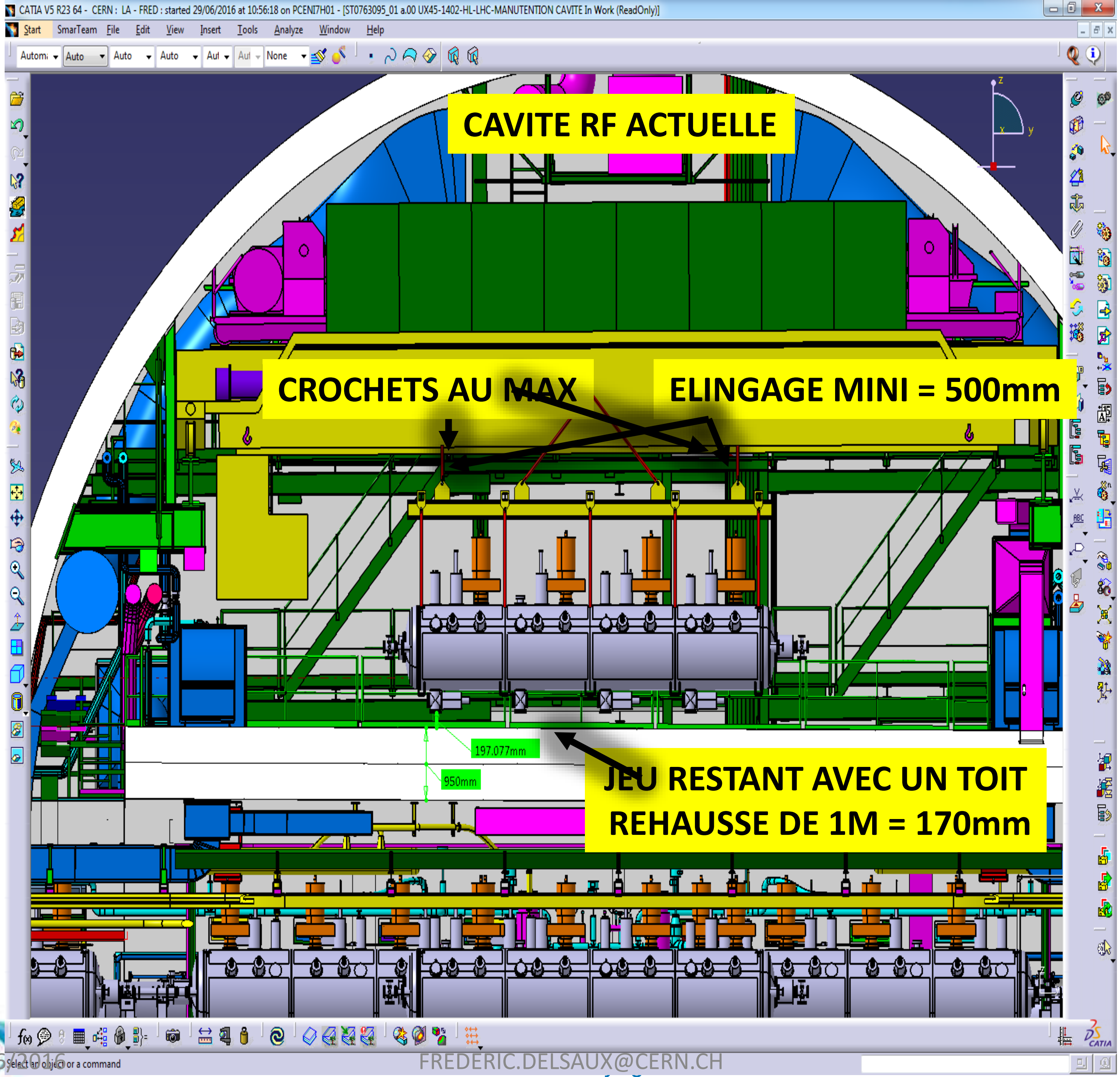
Cryo-distribution aspects

P4-RF distribution line

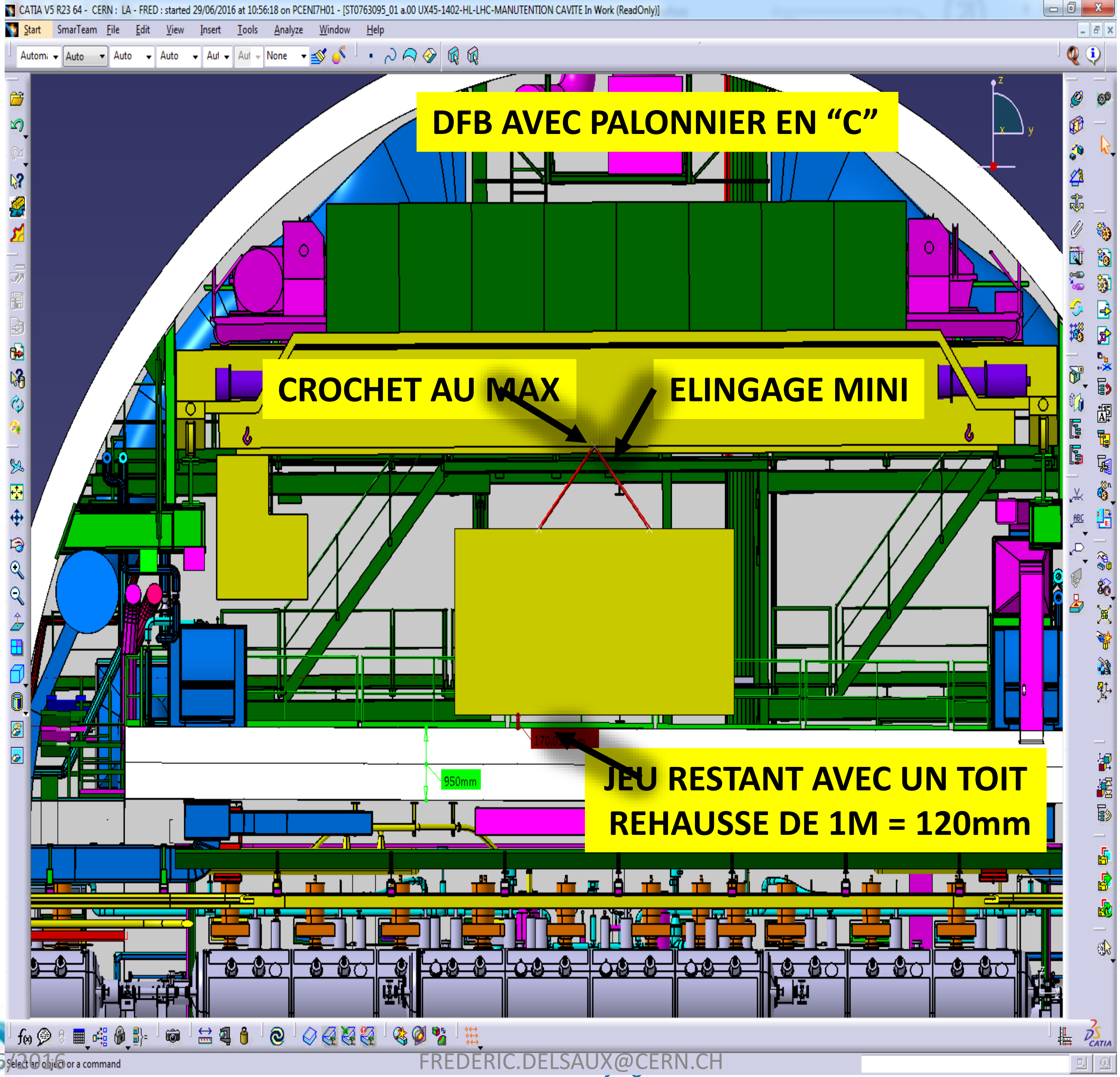


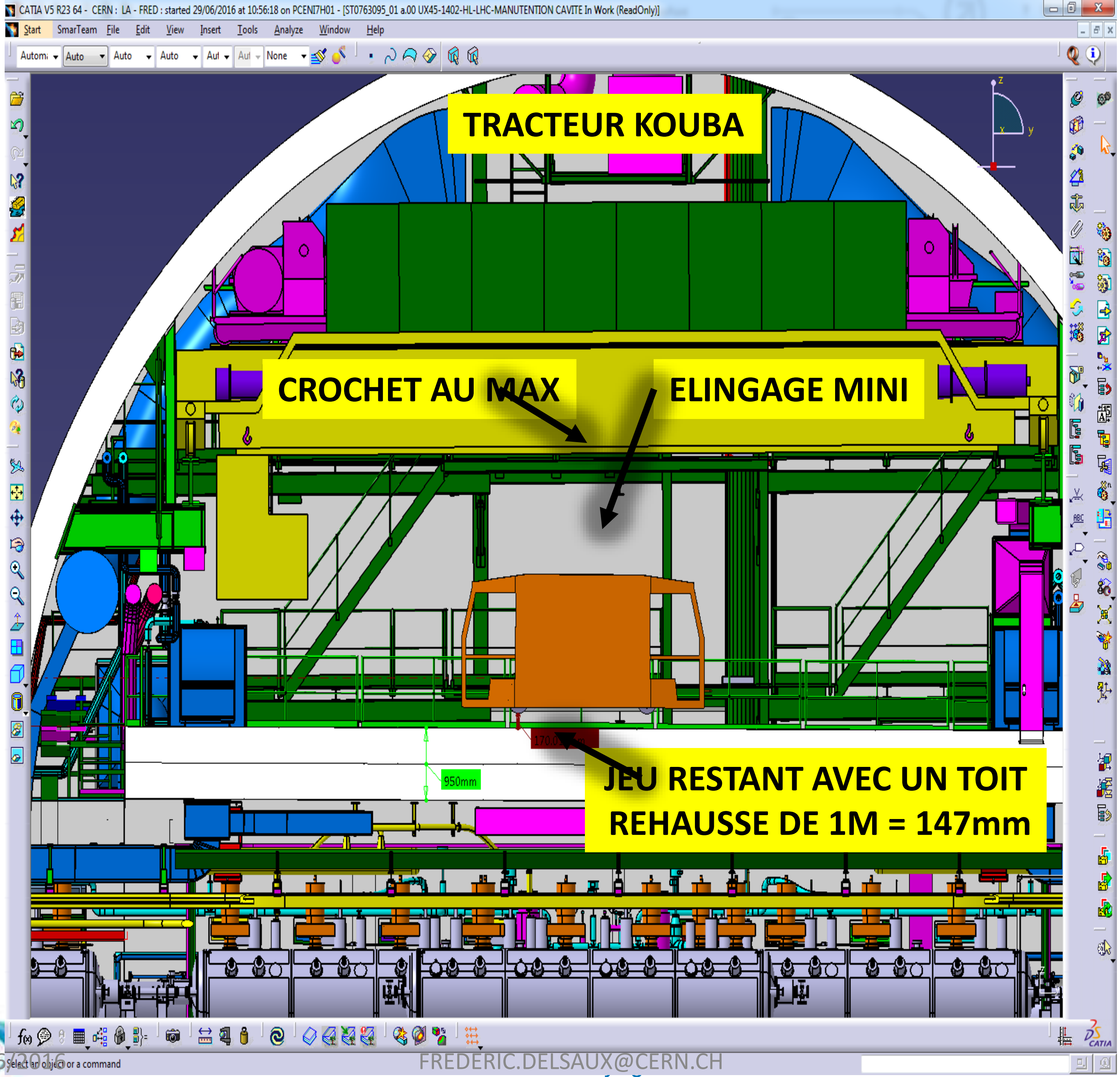


Connection to QRL and distribution along the existing and “future” RF zone (+e-lens!) to be looked at for present baseline and alternative scenario


CATIA V5 R23 64 - CERN : LA - FRED : started 29/06/2016 at 10:56:18 on PCENI7H01 - [ST0763095_01 a.00 UX45-1402-HL-LHC-MANUTENTION CAVITE In Work (ReadOnly)]
Start SmarTeam File Edit View Insert Tools Analyze Window Help
CAVITE RF ACTUELLE
CROCHETS AU MAX
ELINGAGE MINI = 500mm
197.077mm
950mm
JEU RESTANT AVEC UN TOIT REHAUSSE DE 1M = 170mm
Select an object or a command

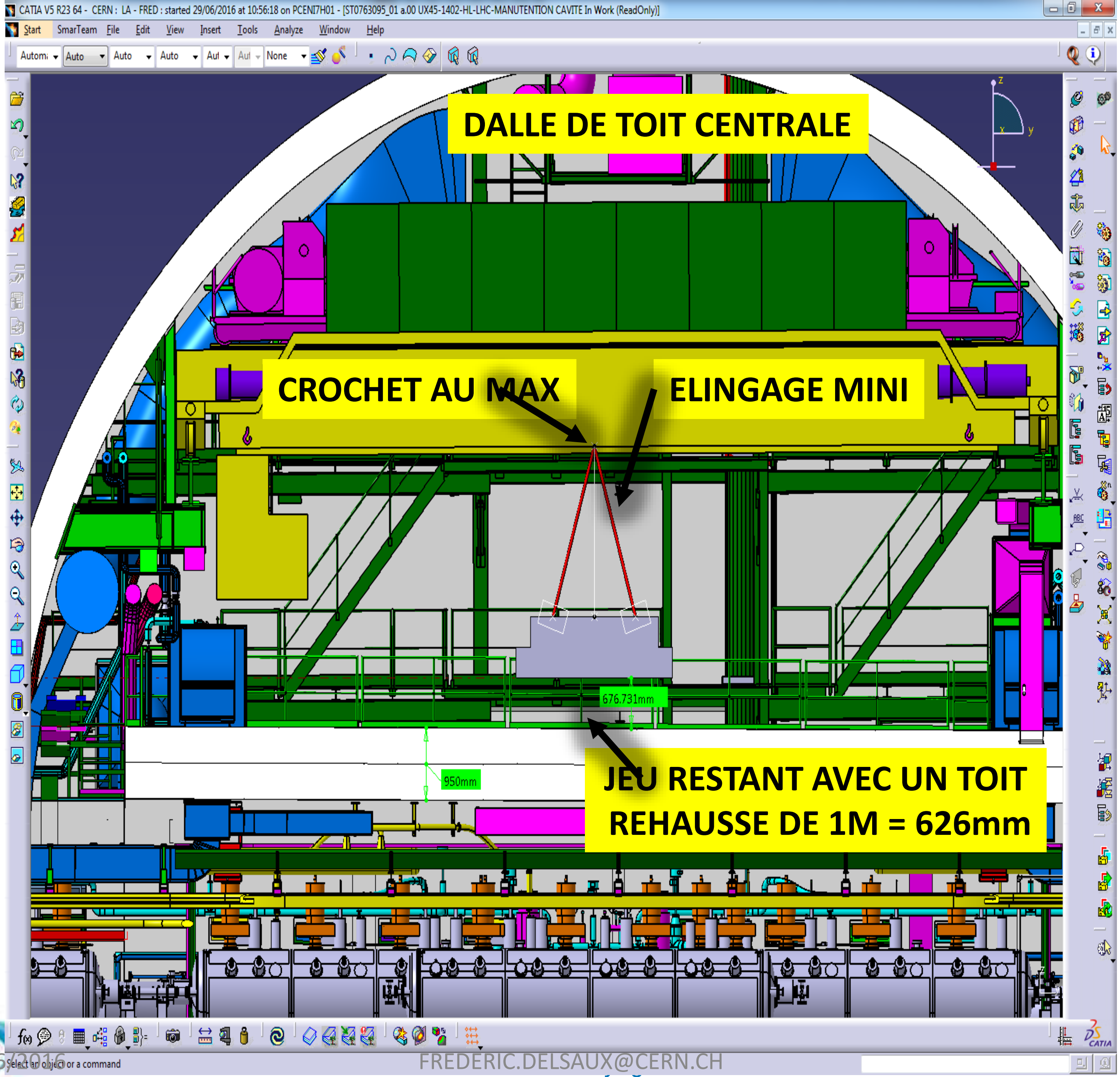
22

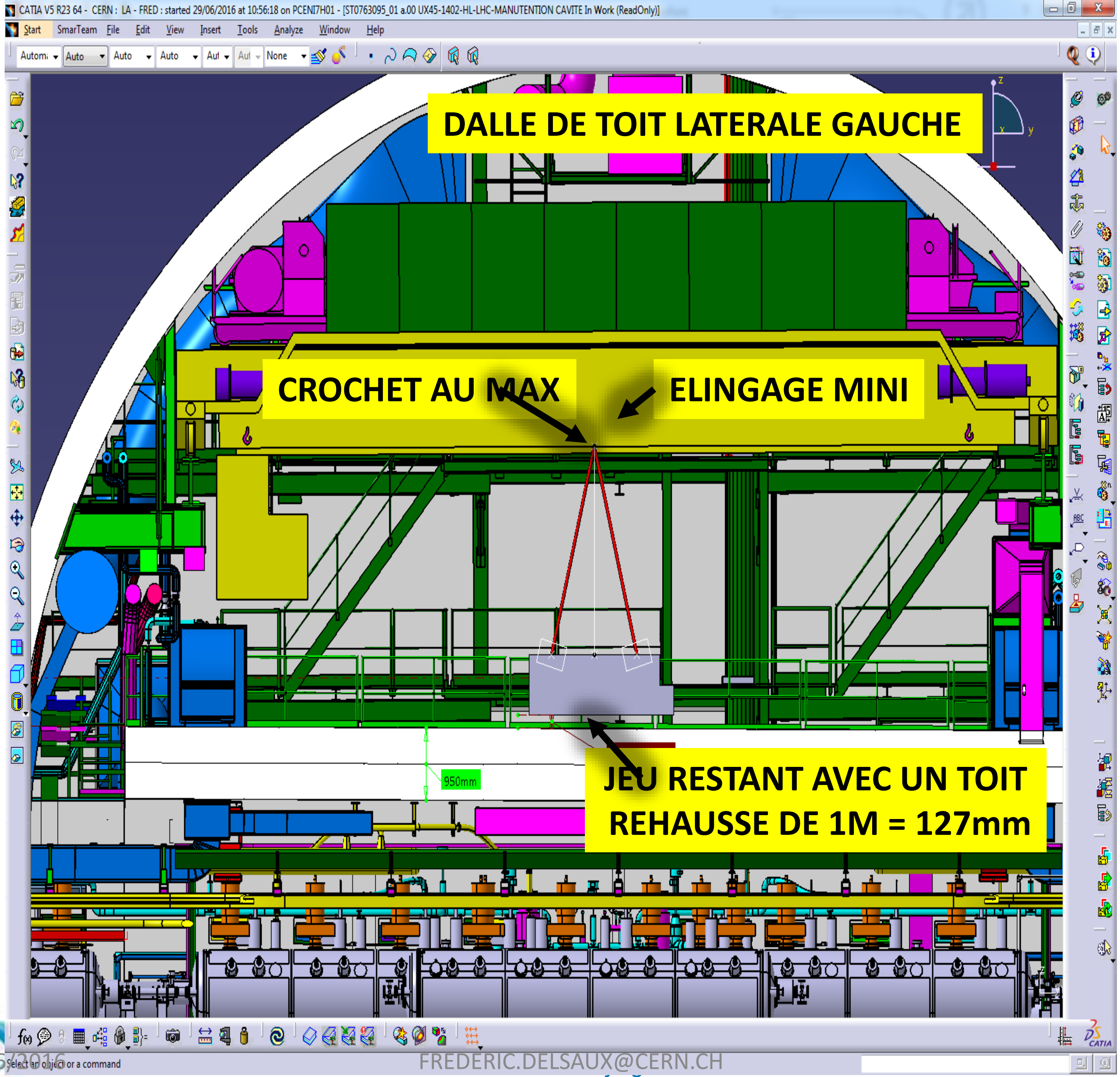

DFB AVEC PALONNIER EN "C"
CROCHET AU MAX
ELINGAGE MINI
950mm
JEU RESTANT AVEC UN TOIT REHAUSSE DE 1M = 120mm



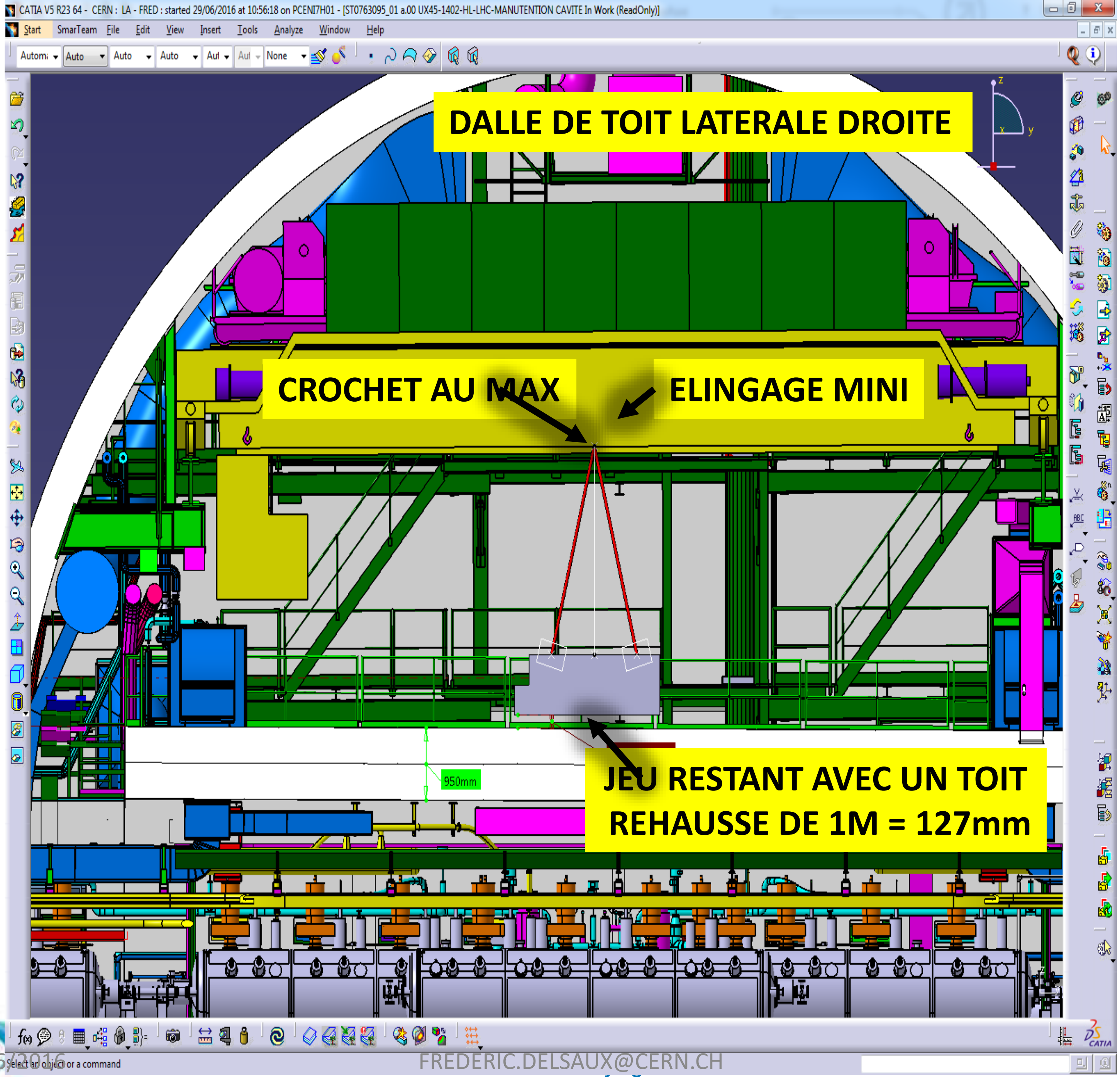
TRACTEUR KOUBA
CROCHET AU MAX
ELINGAGE MINI
950mm
JEU RESTANT AVEC UN TOIT REHAUSSE DE 1M = 147mm

24


CATIA V5 R23 64 - CERN : LA - FRED : started 29/06/2016 at 10:56:18 on PCENI7H01 - [ST0763095_01 a.00 UX45-1402-HL-LHC-MANUTENTION CAVITE In Work (ReadOnly)]
Start SmarTeam File Edit View Insert Tools Analyze Window Help
DALLE DE TOIT CENTRALE
CROCHET AU MAX
ELINGAGE MINI
676.731mm
950mm
JEU RESTANT AVEC UN TOIT REHAUSSE DE 1M = 626mm
Select an object or a command


DALLE DE TOIT LATERALE GAUCHE
CROCHET AU MAX
ELINGAGE MINI
950mm
JEU RESTANT AVEC UN TOIT
REHAUSSE DE 1M = 127mm

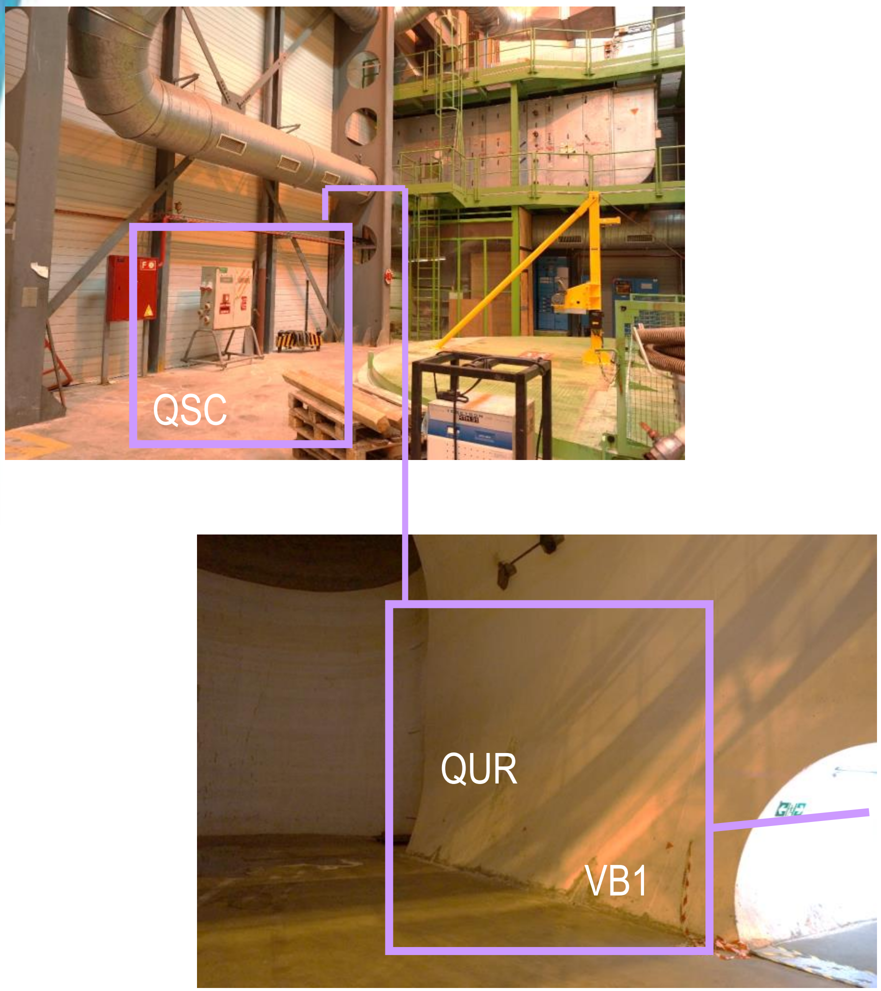
26

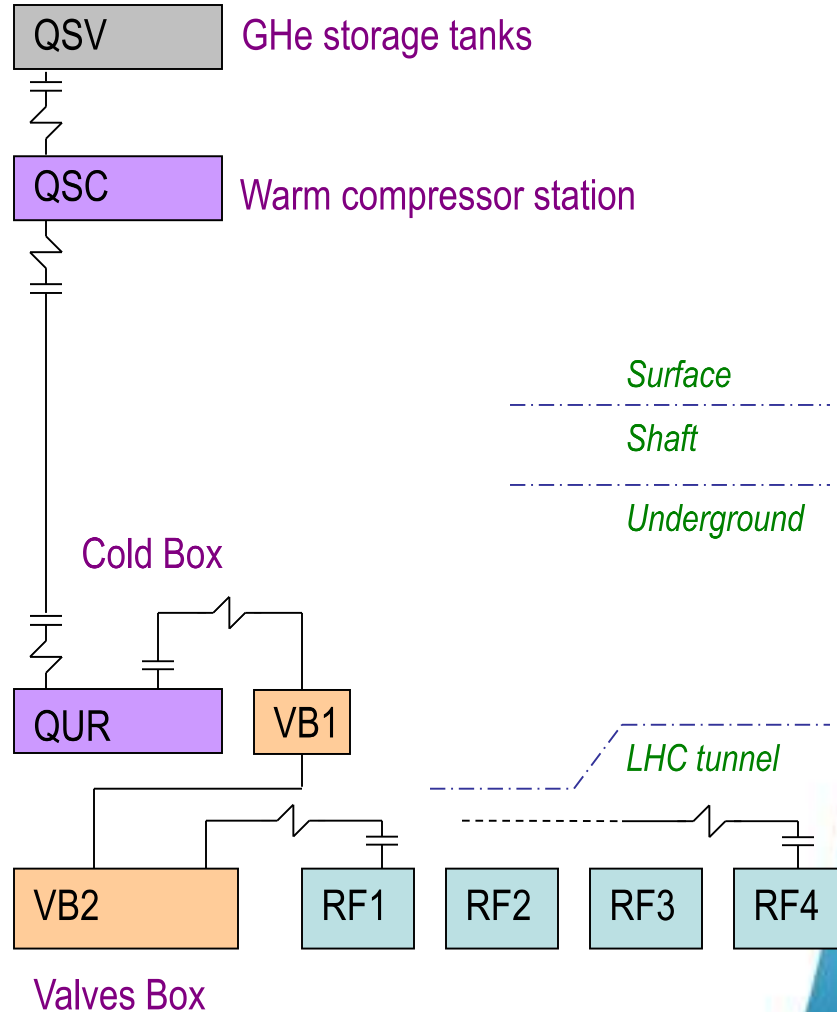

DALLE DE TOIT LATERALE DROITE
CROCHET AU MAX
ELINGAGE MINI
950mm
JEU RESTANT AVEC UN TOIT REHAUSSE DE 1M = 127mm
Select an object or a command

RF tests refrigeration concept

Simplified infrastructure w.r.t baseline

LHC-P4 during Long Shutdowns

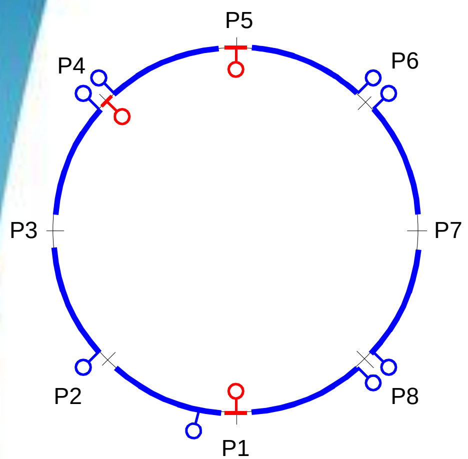


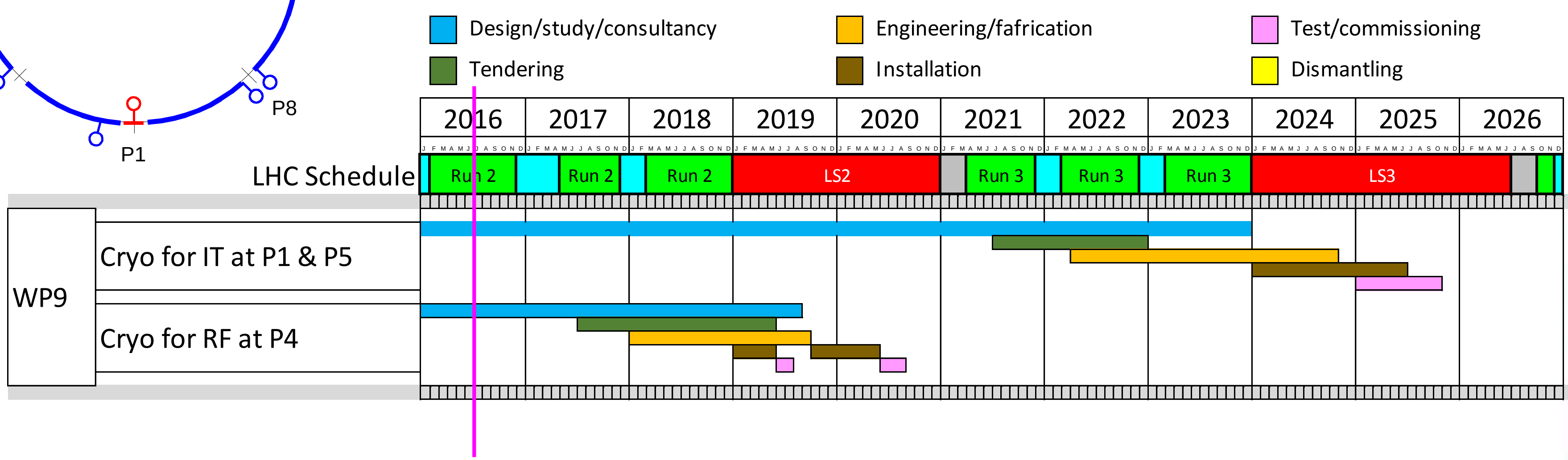


HL-LHC cryogenics master schedule

Major HL-LHC Cryo activities

(SPS-BA6 on tracks, in parallel with SM18 activities)





Feedback for Upgrade feasibility: End Sept'16

Cryodistribution studies: Aut'16

=> Decision baseline/alternative by end of 2016

=> Specification work 2017-Q2, contracts by end'2017

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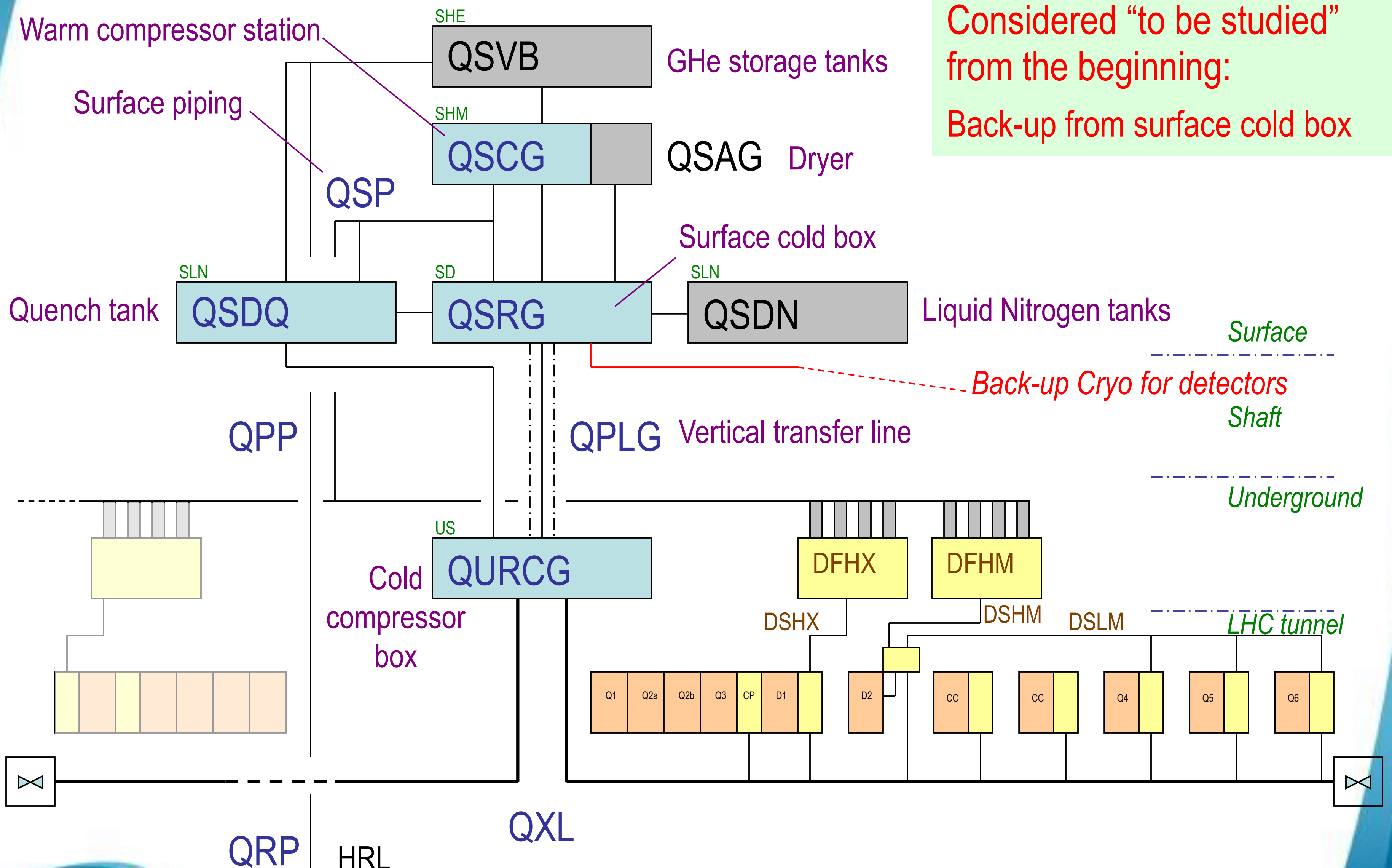
- Possible cryogenic back-up of detectors

P1/P5 Cryogenic architecture



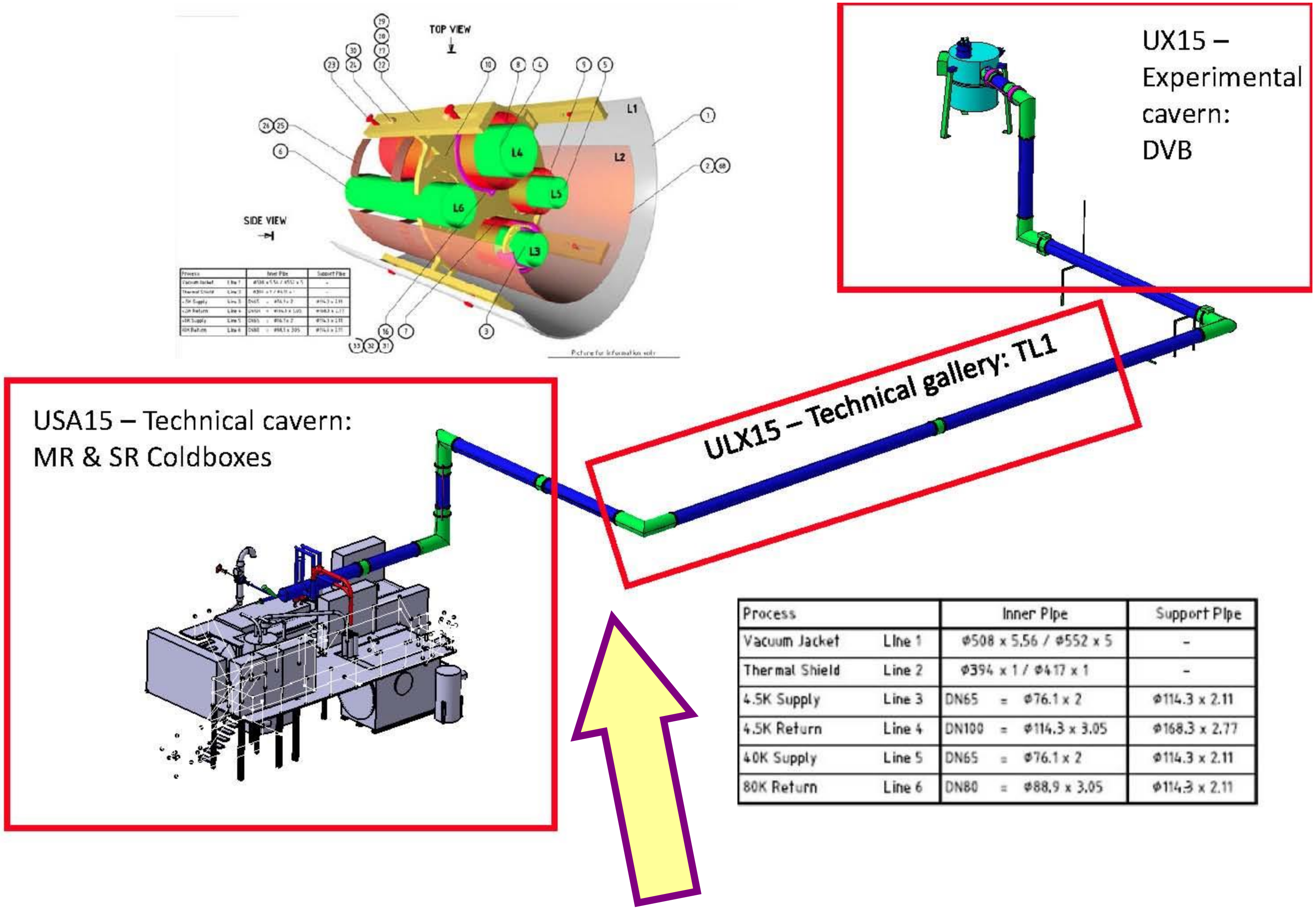
Considered "to be studied" from the beginning:

Back-up from surface cold box

Our basic approach

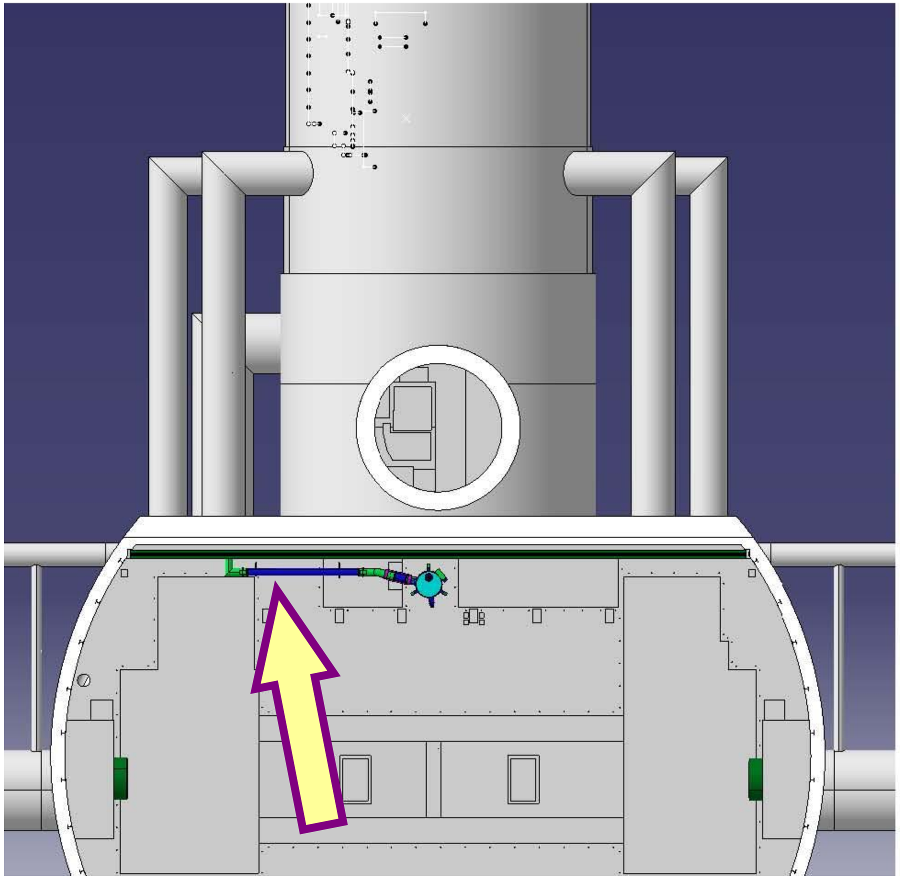
- Cooling capacity:
  - So far no additional cooling capacity foreseen, if back-up required, HL-LHC would be operated at reduced luminosity for some time
  - *Marginal additional capacity could be evaluated of desired*
- Feeding line:
  - 1st evaluation surface to shaft in experimental environment
  - 2nd from QURCG and HL underground infra to detectors
- Feasibility and cost estimate:
  - Preliminary feasibility studies for Cryo, Civil Eng. & integration
  - Costs (orders of magnitude) to be presented at HL/detectors EC June 1st
- Possible cost effective alternatives ?
  - Always check if the 1st idea was the right one and is cost effective !
- Decision:
  - Obviously at management level (HL + detectors)

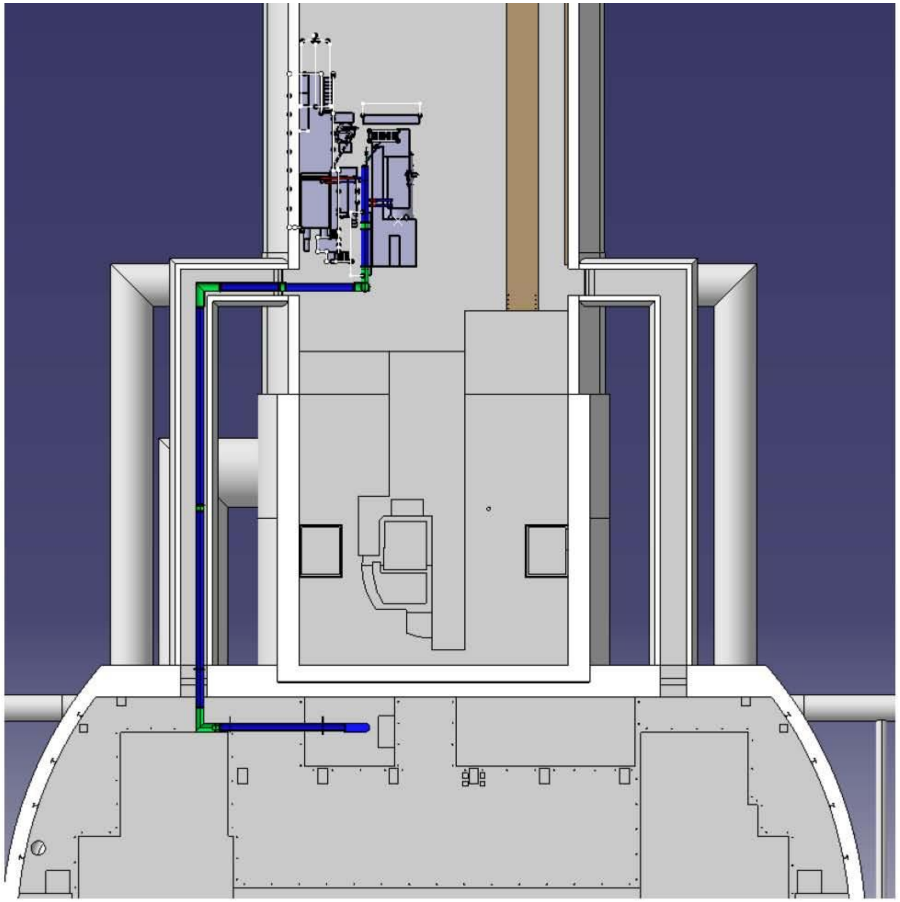
P1 Cryo underground



Process		Inner Pipe	Support Pipe
Vacuum Jacket	Line 1	ø508 x 5.56 / ø552 x 5	-
Thermal Shield	Line 2	ø394 x 1 / ø417 x 1	-
4.5K Supply	Line 3	DN65 = ø76.1 x 2	ø114.3 x 2.11
4.5K Return	Line 4	DN100 = ø114.3 x 3.05	ø168.3 x 2.77
40K Supply	Line 5	DN65 = ø76.1 x 2	ø114.3 x 2.11
80K Return	Line 6	DN80 = ø88.9 x 3.05	ø114.3 x 2.11

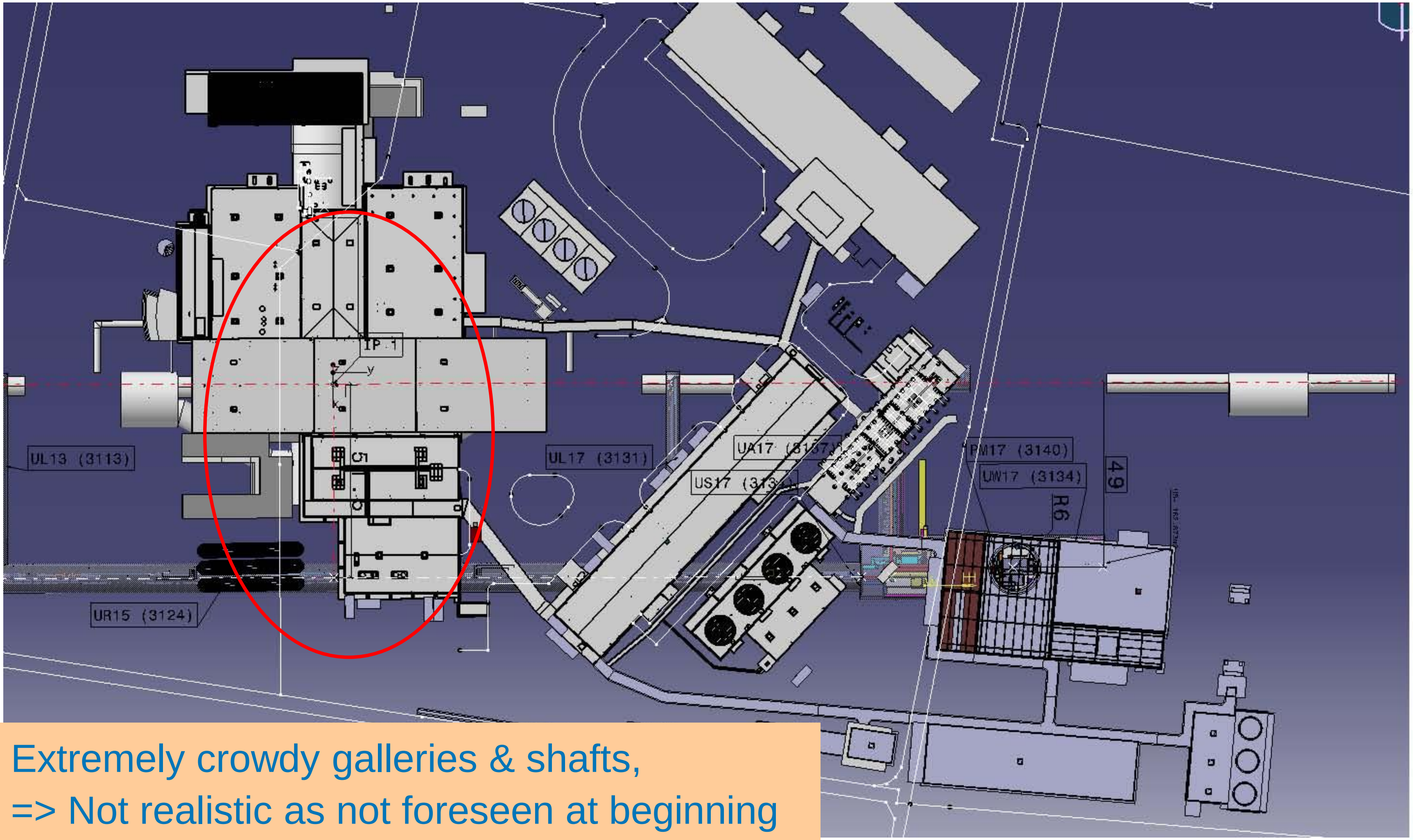
P1 Cryo underground as installed





Routing at the surface

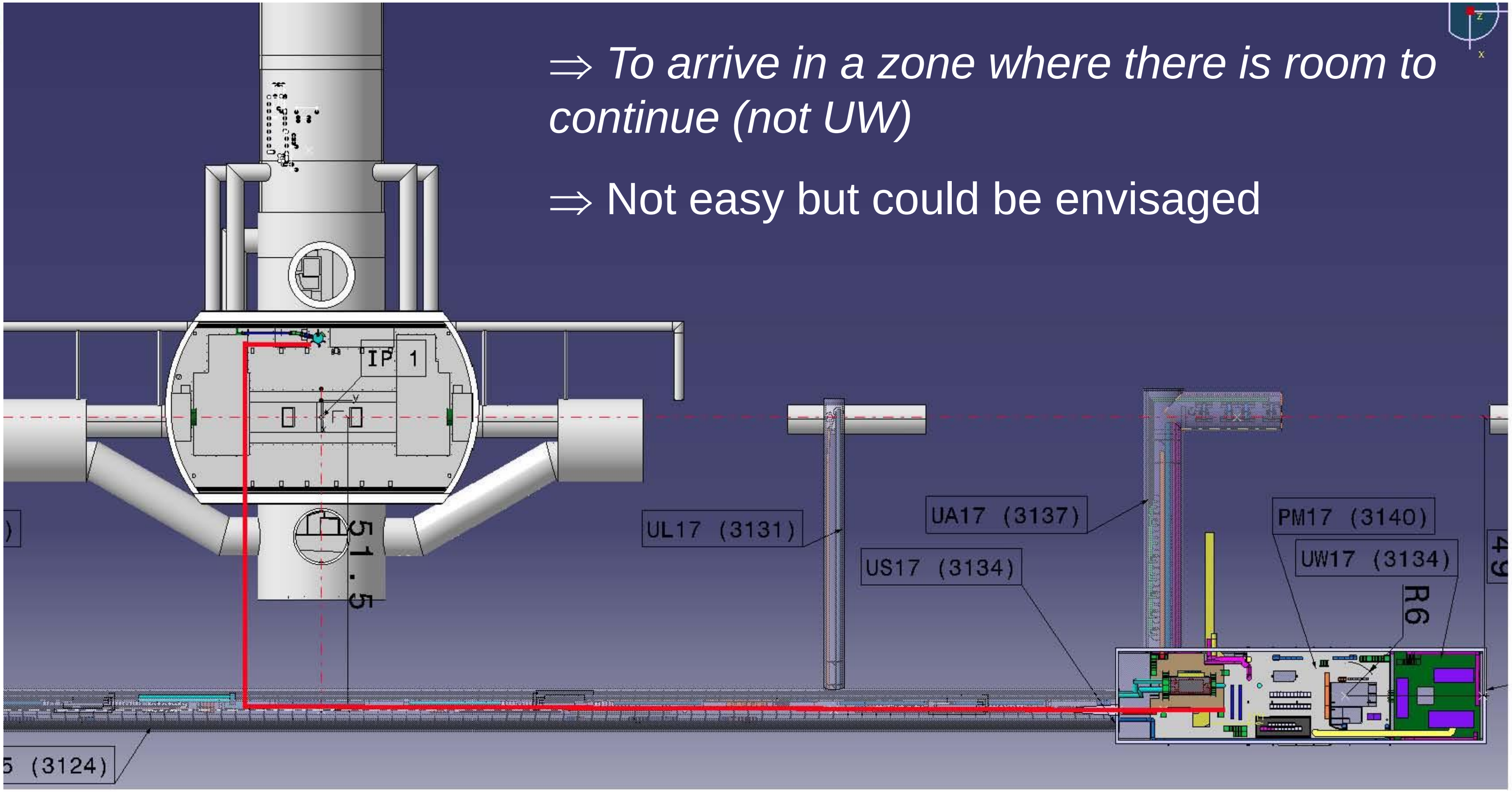
New cryogenic line DN400 considered at this stage



Extremely crowdy galleries & shafts,
=> Not realistic as not foreseen at beginning

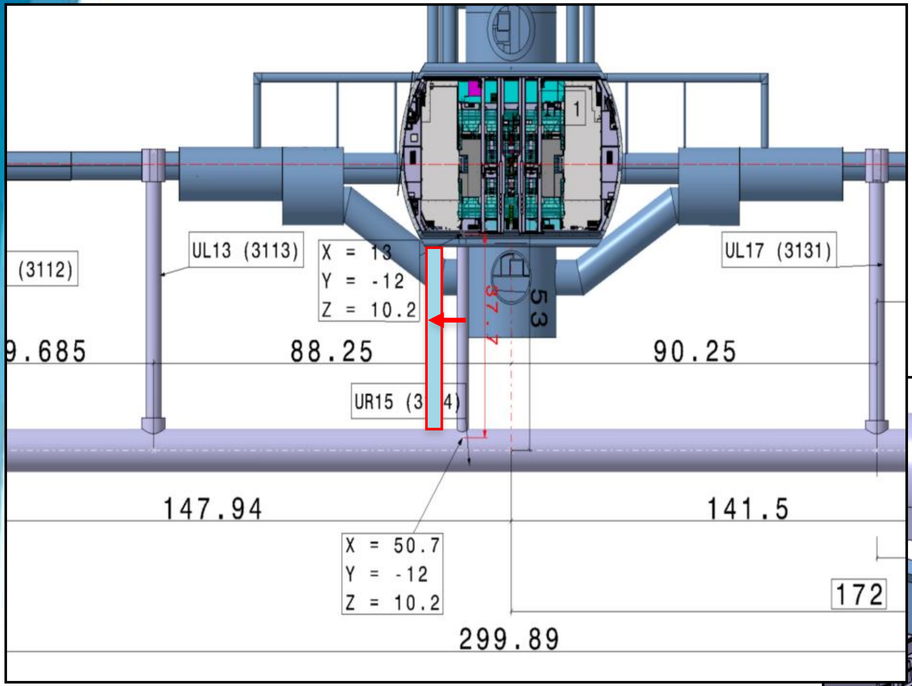
Routing underground

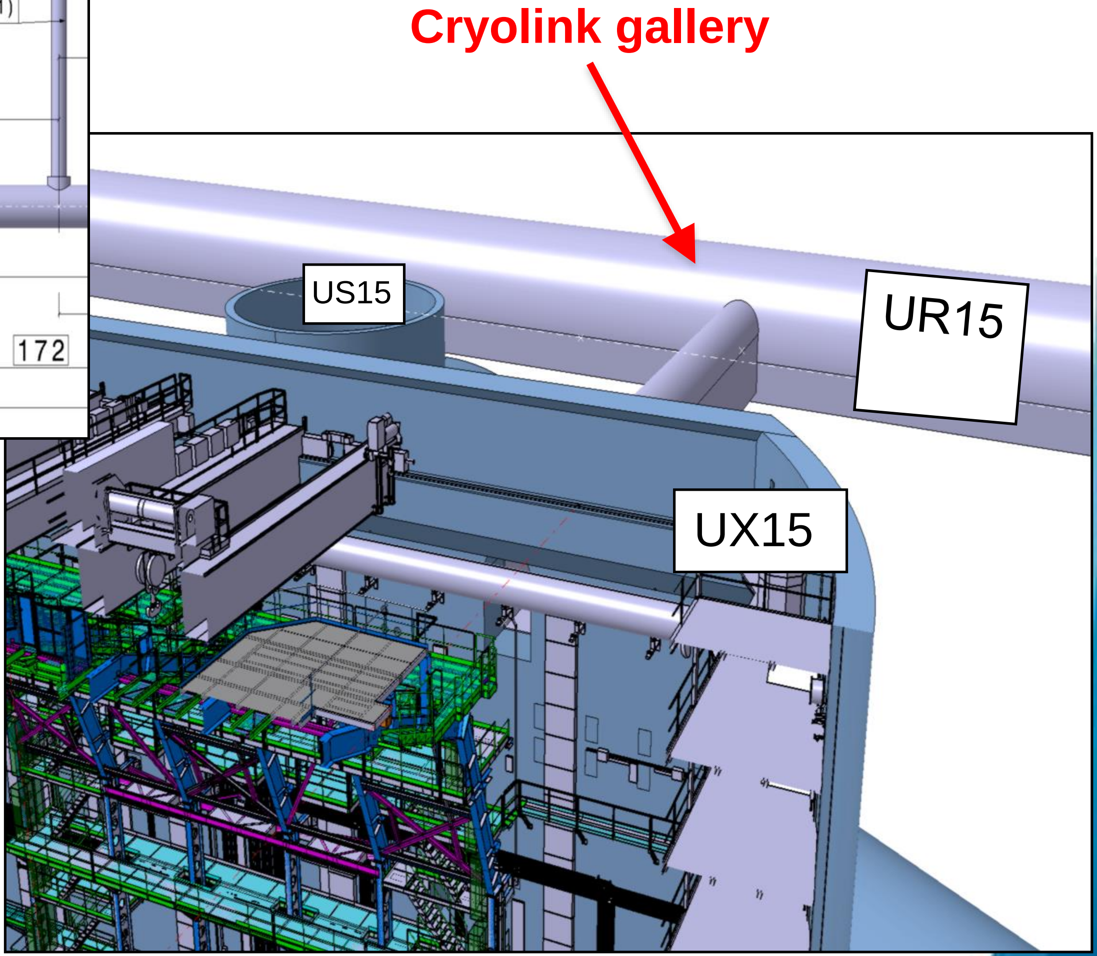
New cryogenic line DN400 considered at this stage



Transferline line length from underground coldbox to proximity cryogenics in UX15: 220m

Point 1

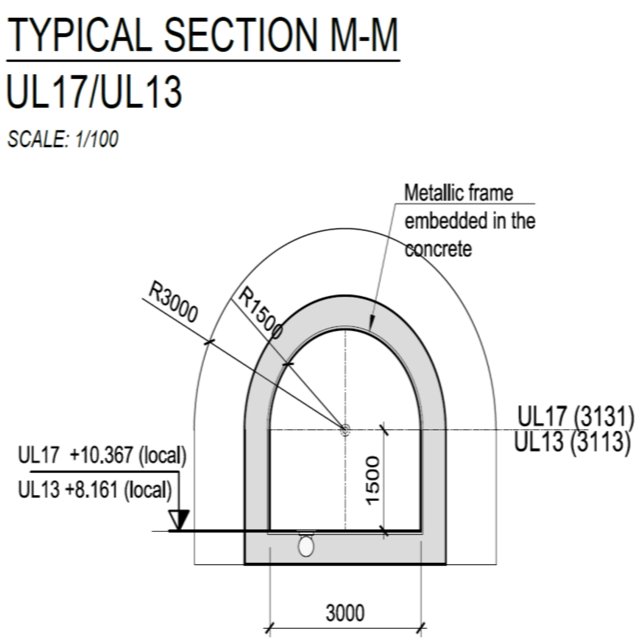


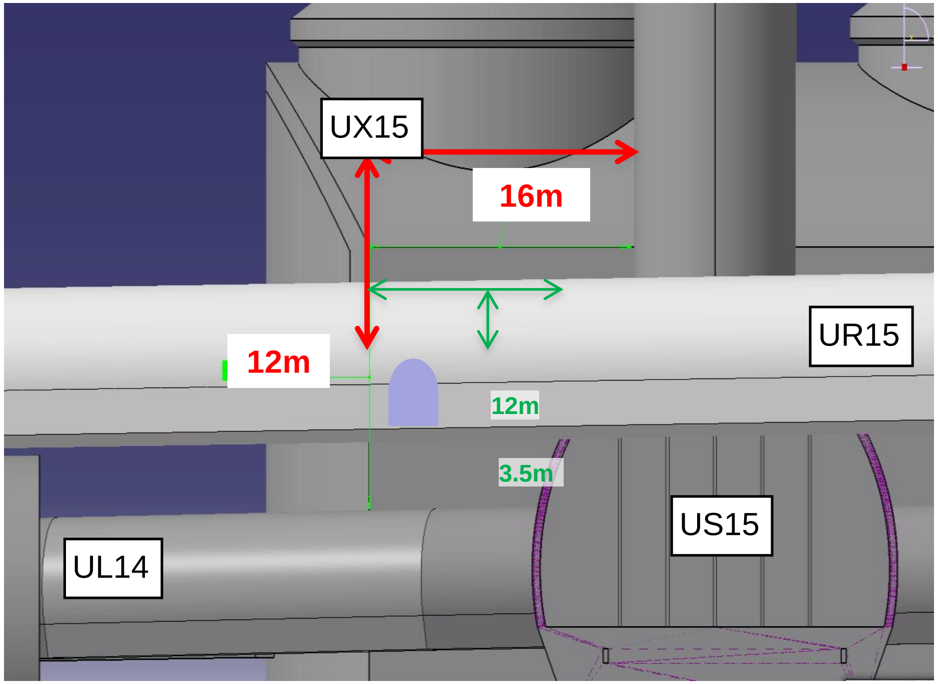


Cryolink to be positioned as far away as possible from US15 to ensure technical and geometric feasibility.

Formal integration, P. Fessia & S. Maridor
Study by SMB-CE, P. Mattelaer & Co

Point 1





Formal integration, P. Fessia & S. Maridor
Study by SMB-CE, P. Mattelaer & Co

Summary

5th LIU/HL-LHC Executive Cttee June 1st, 2016

- Surface option:
  - Not realistic for a DN400 like cryoline at this stage

  if it would have been possible, most likely 250m of DN500 (2 x 125m)

- Underground:
  - Not easy but it appears feasible for Cryo, (with add. Resource)
  - Cost effective integration and civil works basically evaluated

  should not induce safety/ventilation issues,provided tightness realistic

- Feasibility and cost estimate:
  - About + 6 MCHF (Cryo 4.5 MCHF and CE 1.2 to 1.6 MCHF)

- Possible cost effective alternatives ?
  - What else could be envisaged for less than 4 MCHF ?
  - Spare cold box ? Add. 1st stage HX and 80K adsorbers ? Spares?

- Decision:
  - *LHC Compressors: decision for "cold" spares + 3-4 days to repair*
  - Not to be further considered, but alternatives to be evaluated now