P4-RF
Baseline and alternative for WP9-Cryogenics

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HL-LHC - Technical Coordination Committee
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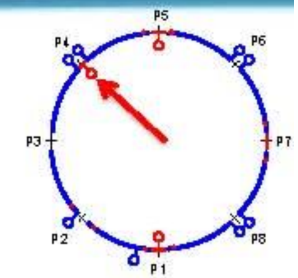
Content

- Intro to LHC-P4 Cryo baseline and alternative
- Cooling capacity requirements & perspectives
- Cryo-distribution
- Summary

LHC P4 Cryo Baseline

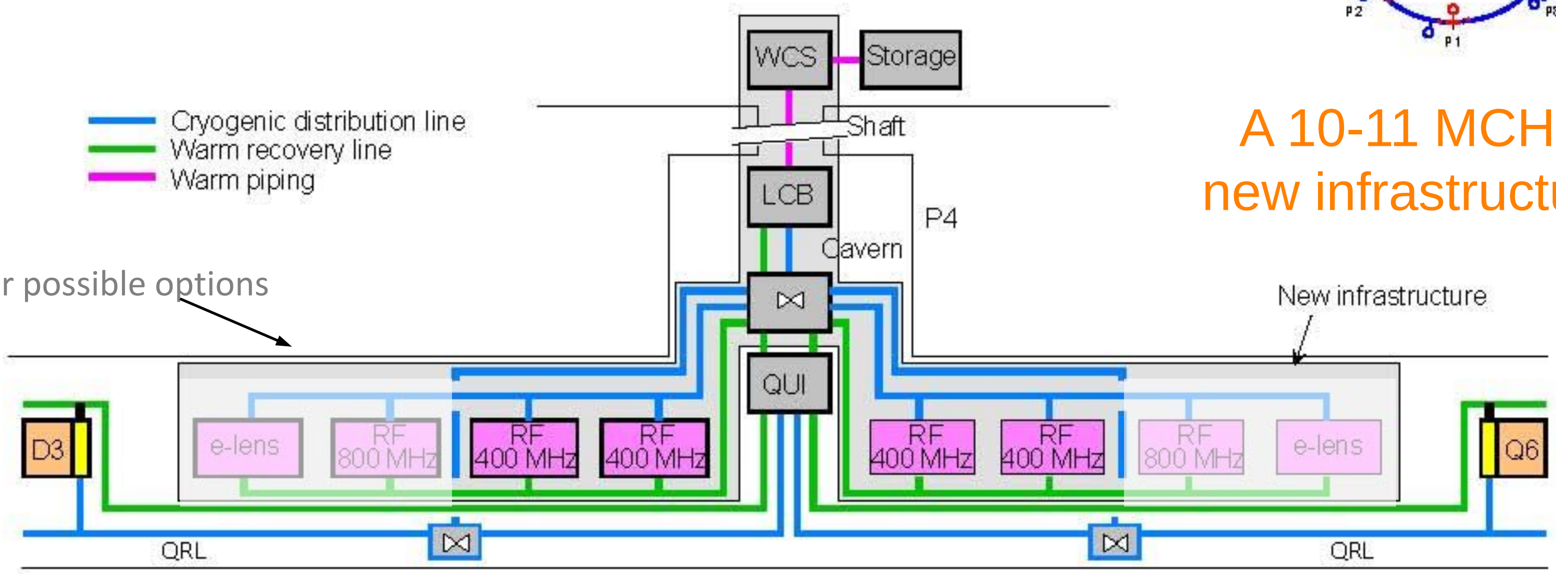
A dedicated refrigerator, valve box and cryolines

New cryogenic infrastructure at P4



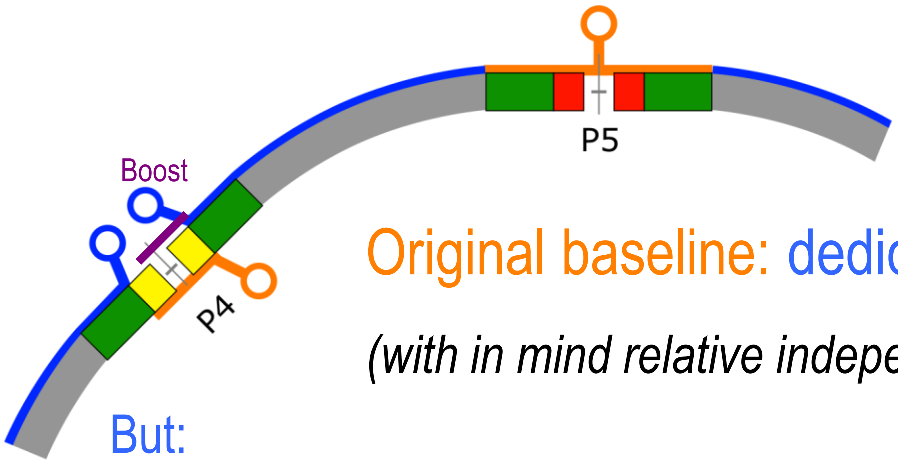
A 10-11 MCHF new infrastructure

So far possible options



- 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

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)

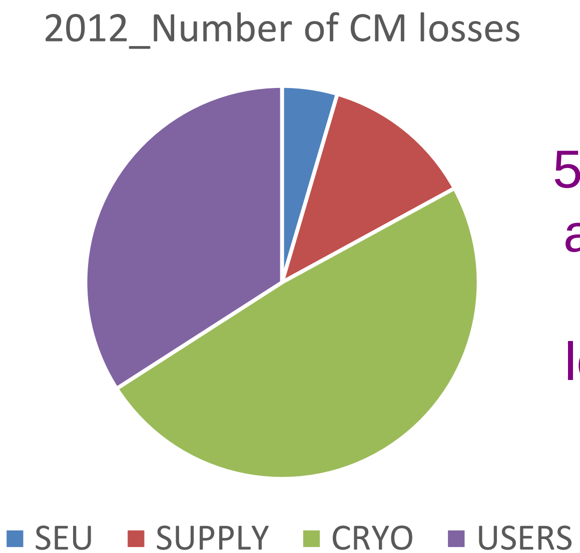
• Clear understanding at 4th_LARP_KEK_Nov'14 meeting that real gain for RF would be to test a module anytime during a LS, while Cryo would do maintenance

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

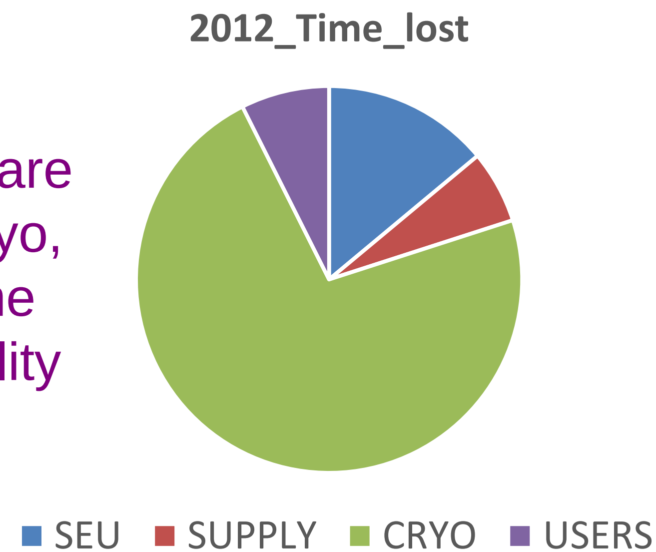
How much ? Anyway ! Concept !

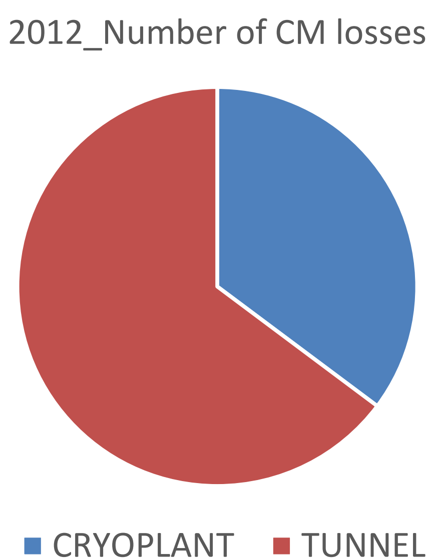
Cryo availability 2012

Similar for 2015



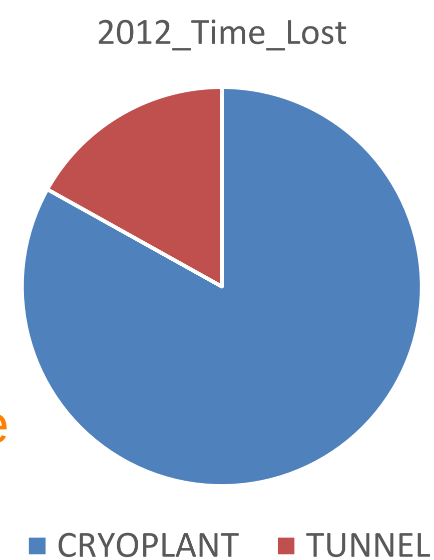
50% of failures are attributed to Cryo, 75% of the time lost for availability



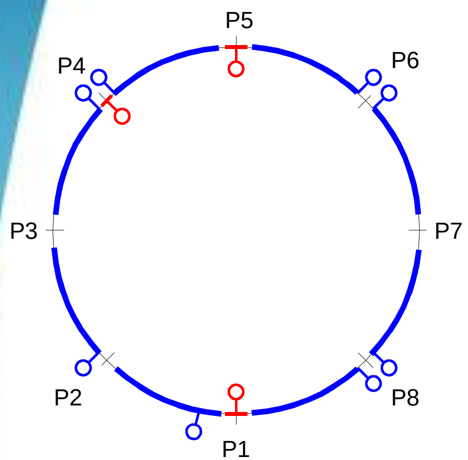


1/3rd of failures are for cryoplants, but leading to 5/6th of lost time

=> Worth limitating the number of cryoplants

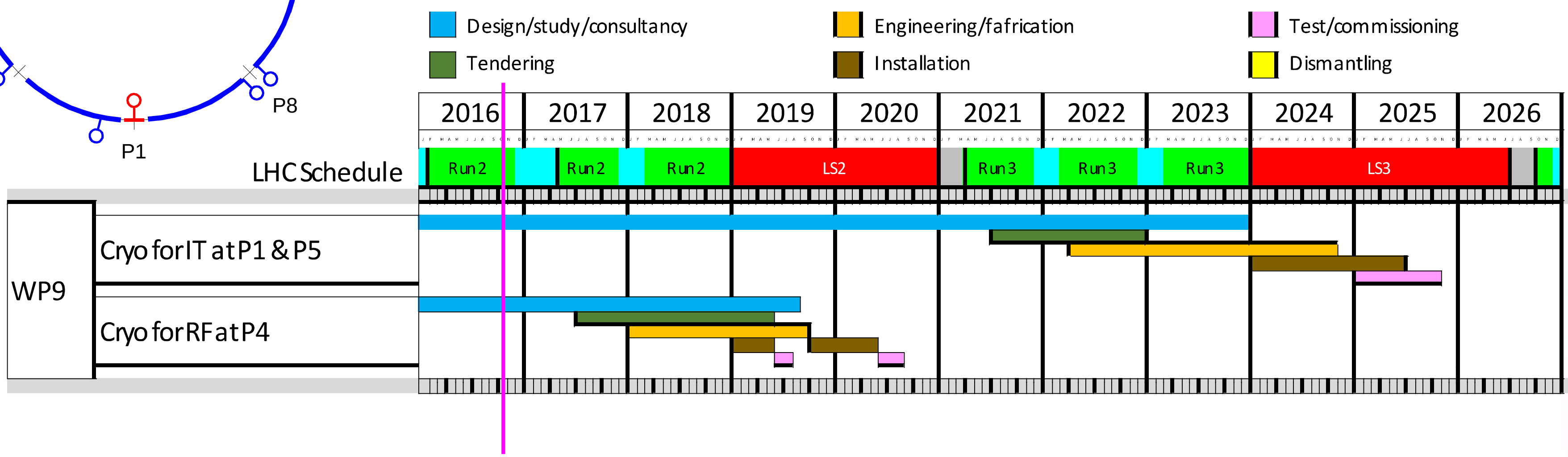


HL-LHC cryogenics master schedule



Major HL-LHC Cryo activities

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



Feedback for Upgrade feasibility: Done, OK

Cryodistribution studies: Aut' 16, *(on-going, not yet detailled)*

=> Decision baseline/alternative by end of 2016

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

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Cooling requirements for RF

Reference data: Chamonix'14

A: Cryogenic Table

Prelim Estimates

		Crab Cavities **(2K)**	400 MHz (4.5K)	800 MHz (4.5K)	200 MHz (4.5K)
Static (/cavity)		8	50 (?)	10	10
Dynamic (/cavity)	Cavity	3	25	15	5
	Other	4	10 (?)	10 (?)	10(?)
Total [W] (/Module)		~30 (2-cavities)	~340 (4-cavities)	~140 (4-cavities)	~100 (4-cavities)

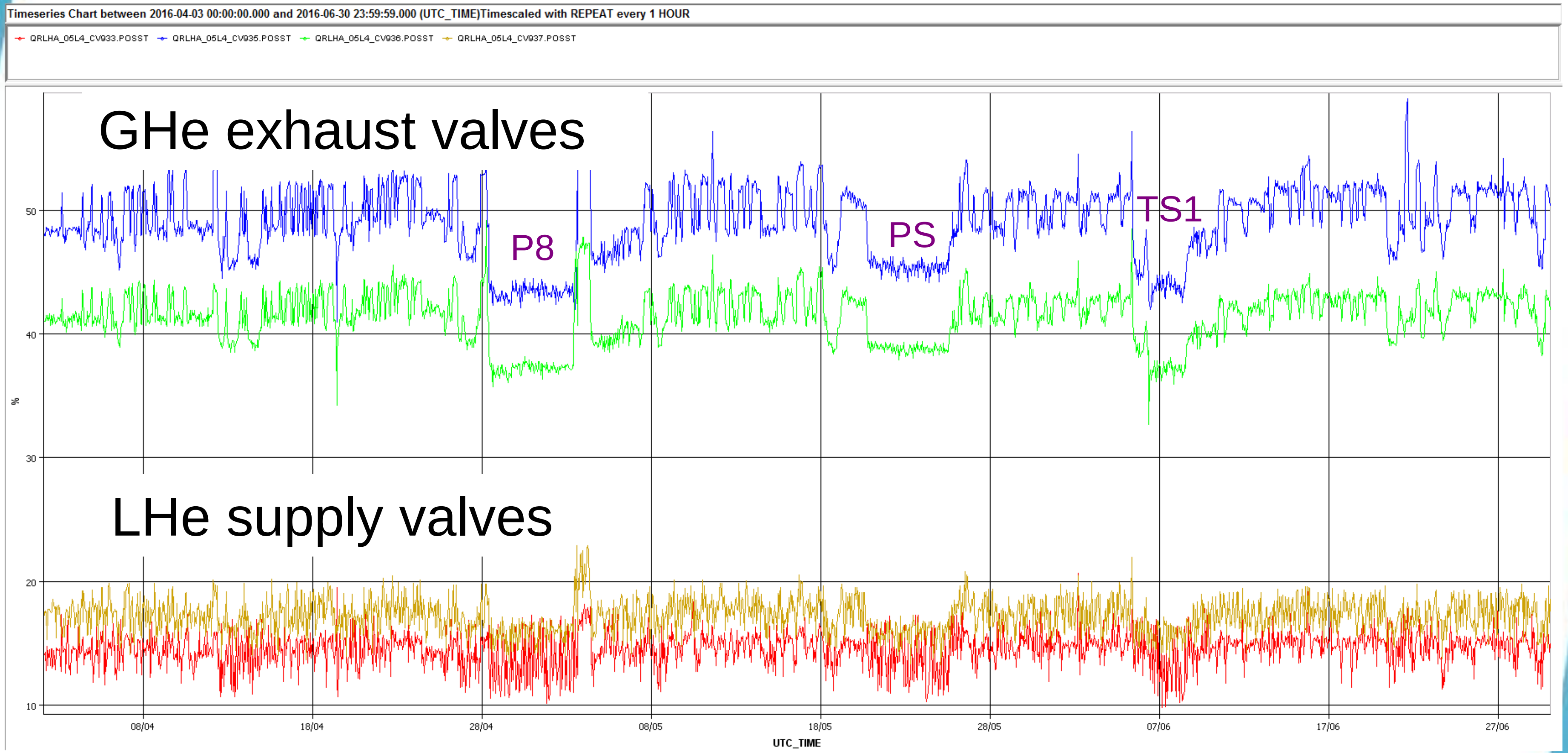
For sizing the cryo needs, multiply total in table by numbers below:

Crabs:	3.4 MV, total #: 32 →	Multiply x16
ACS-400:	2.0 MV, total #: 16 →	Multiply x4
800 MHz:	1.0 MV, total #: 10 →	Multiply x2.5
200 MHz:	1.5 MV, total #: 4 →	Multiply x1

But not always consistent guidelines concerning the influence of beam intensity ?

LHC RF cooling capacity

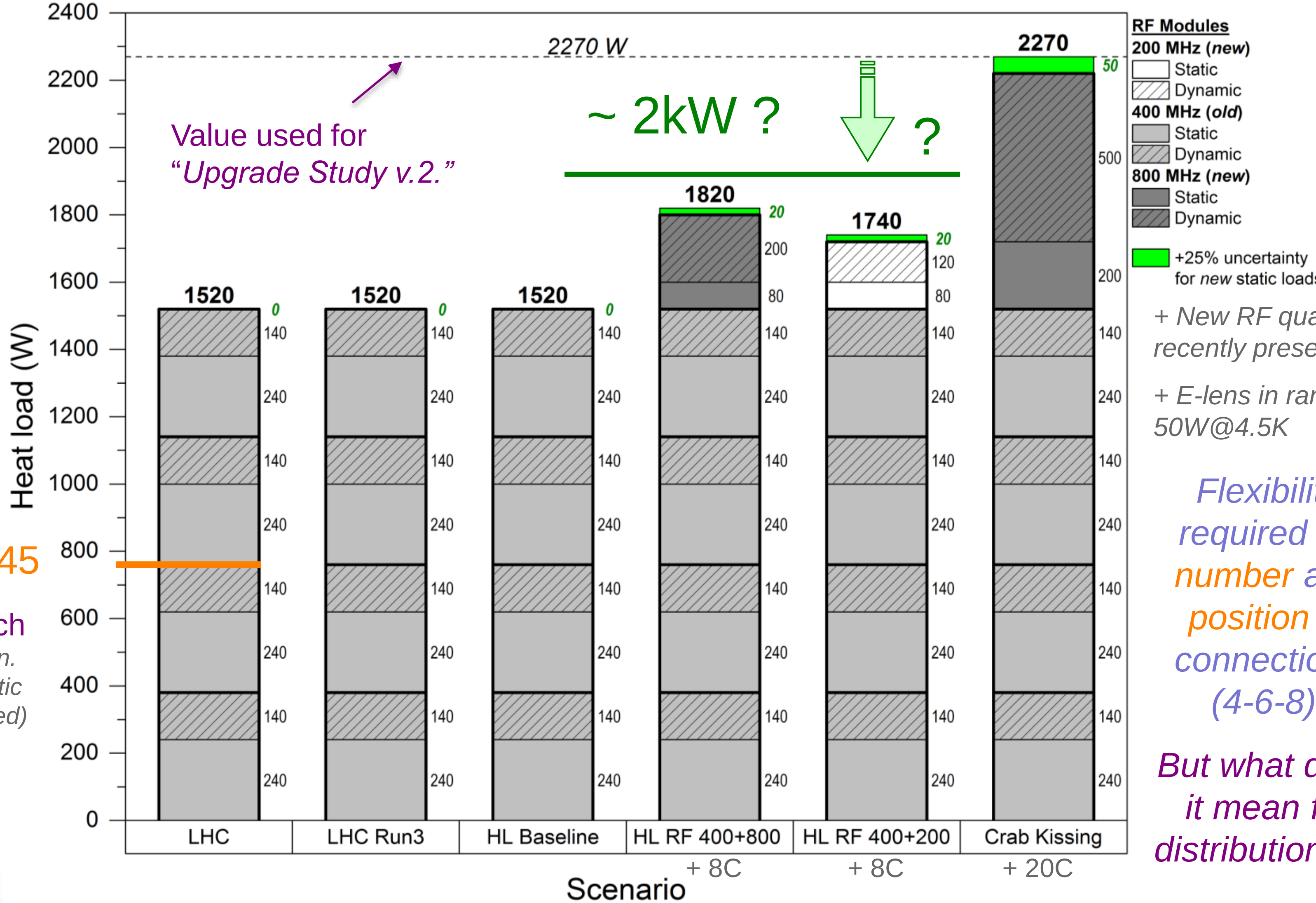
LHC intensity ramp-up 2016 (April-May-June)



=> We can conclude that cooling capacity is independent from beam intensity

Possible RF heat loads and configurations

Based on preliminary data Chamonix'14, and evolution since



34 - 45

760W each

140 W Dyn.
240 W Static
(as observed)

+ New RF quads recently presented,

+ E-lens in range of 50W@4.5K

Flexibility required for number and position of connections (4-6-8),

But what does it mean for distribution ?!?

Upgrade Study (v.2) of Refr. S4-5 for HL-LHC

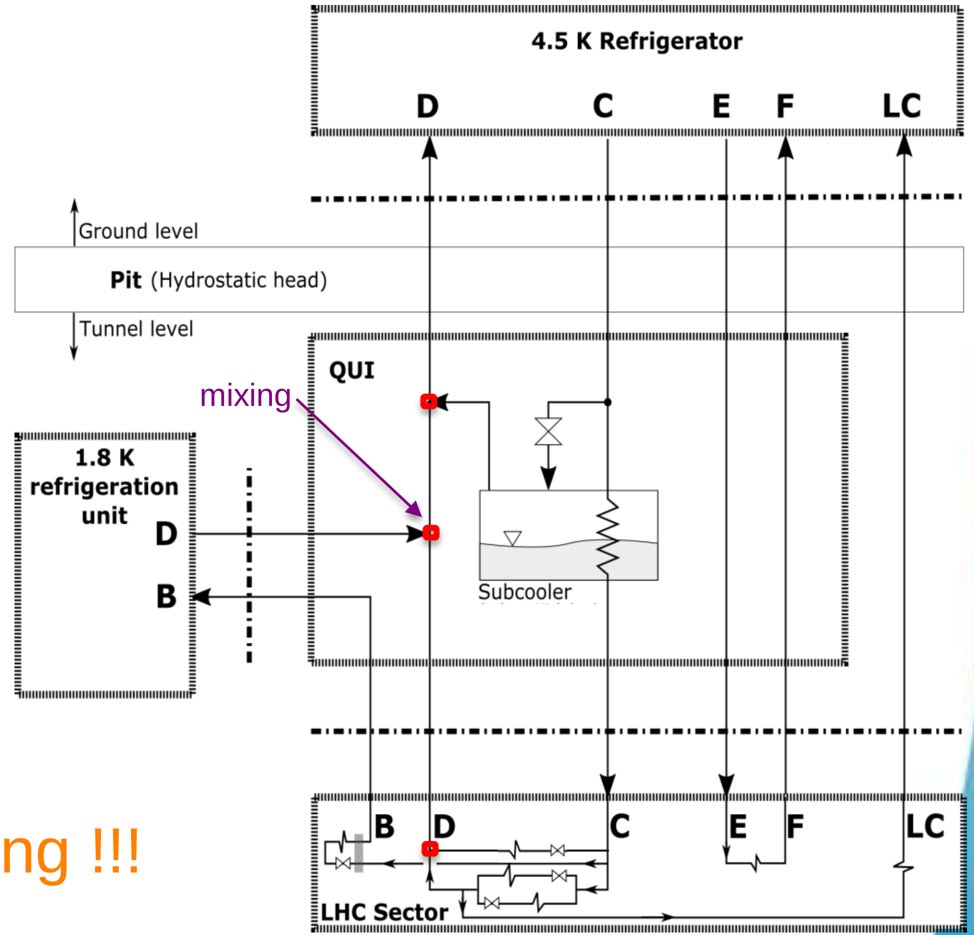
Refrigeration requirements in S4-5 [kW @4.5 K]

	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 → upgrade

Magnets (1.8 K) … others (aprox.) → ~0

* 2270 W RF load + 340.5 W (15%) operational margin



Main Difference w.r.t. LHC:

- **2.6 kW @4.5 K** for RF cavities is a dominant extra load.
- Penalty due to temperature mixing is equivalent to **2.2 kW @4.5 K**.

Mixing !!!

18kW@4.5K Refrigerator Upgrade, feasibility study

- Dedicated study purchased from manufacturer
  - Definition of needs and boundary conditions
  - Process study, with identification of major changes required
  - Budget estimate

- Very promising technical outcome (20Sept16)
  - Screw compressor (1, or 2 + Final Oil Removal System)
  - Turbines (5, or 6)
  - Possibly a Turbo-Brayton cooler to deal with thermal-shield load

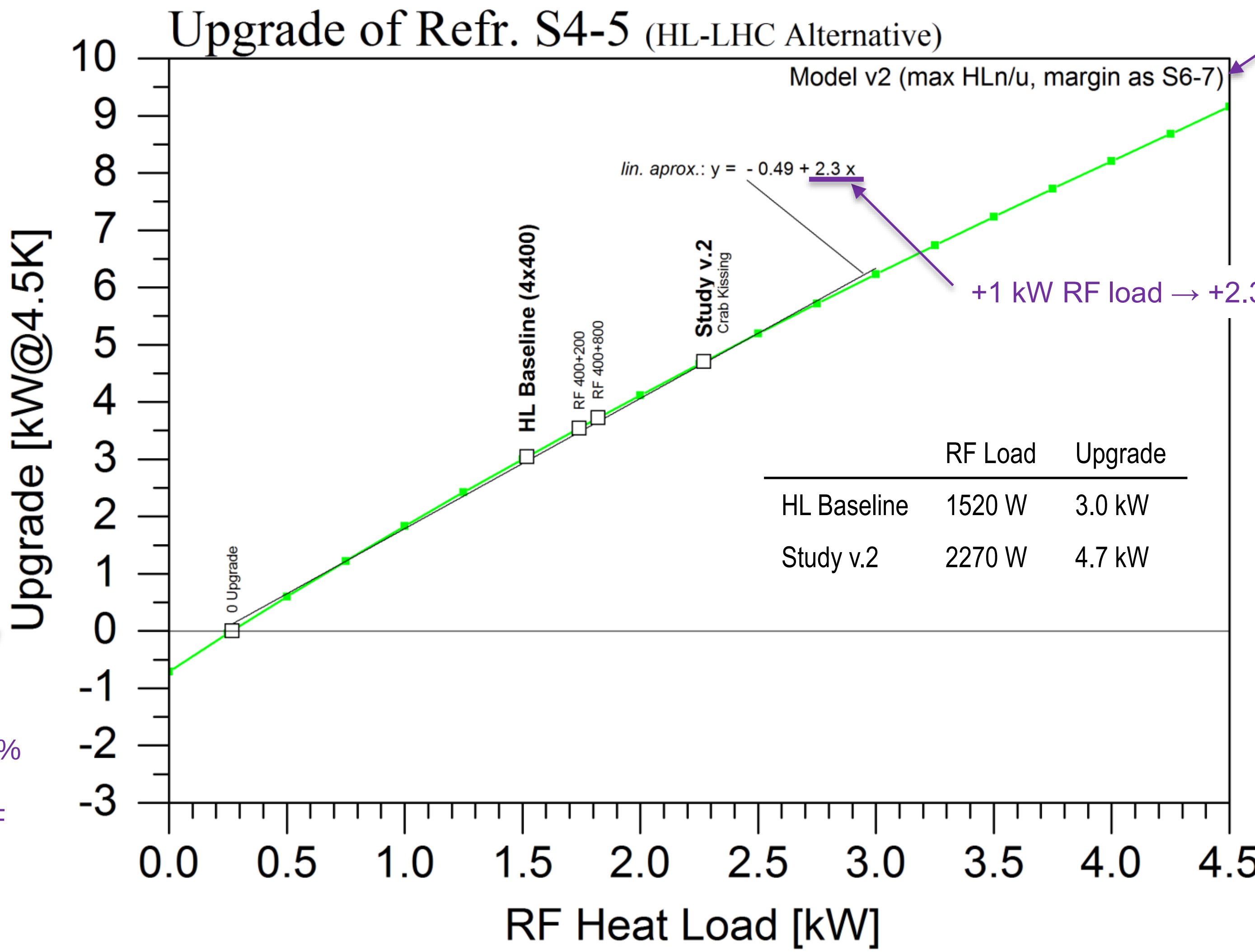
  => Significant cost reduction (1-2MCHF) if smaller upgrade envisaged

- Global picture with budget envelope presented (07Oct'16)
  - Same order of magnitude than a new cryoplant, if cost index w.r.t 1998 is confirmed (could be benchmarked with new 35g/s LHe plant for SM18 Q1-2017)

- Possibility to proceed with non-competitive tender, once! (IPT)

Parametric Study
RF heat load vs Upgrade

“Model v2, S6-7” used for *Upgrade Study v.2.*

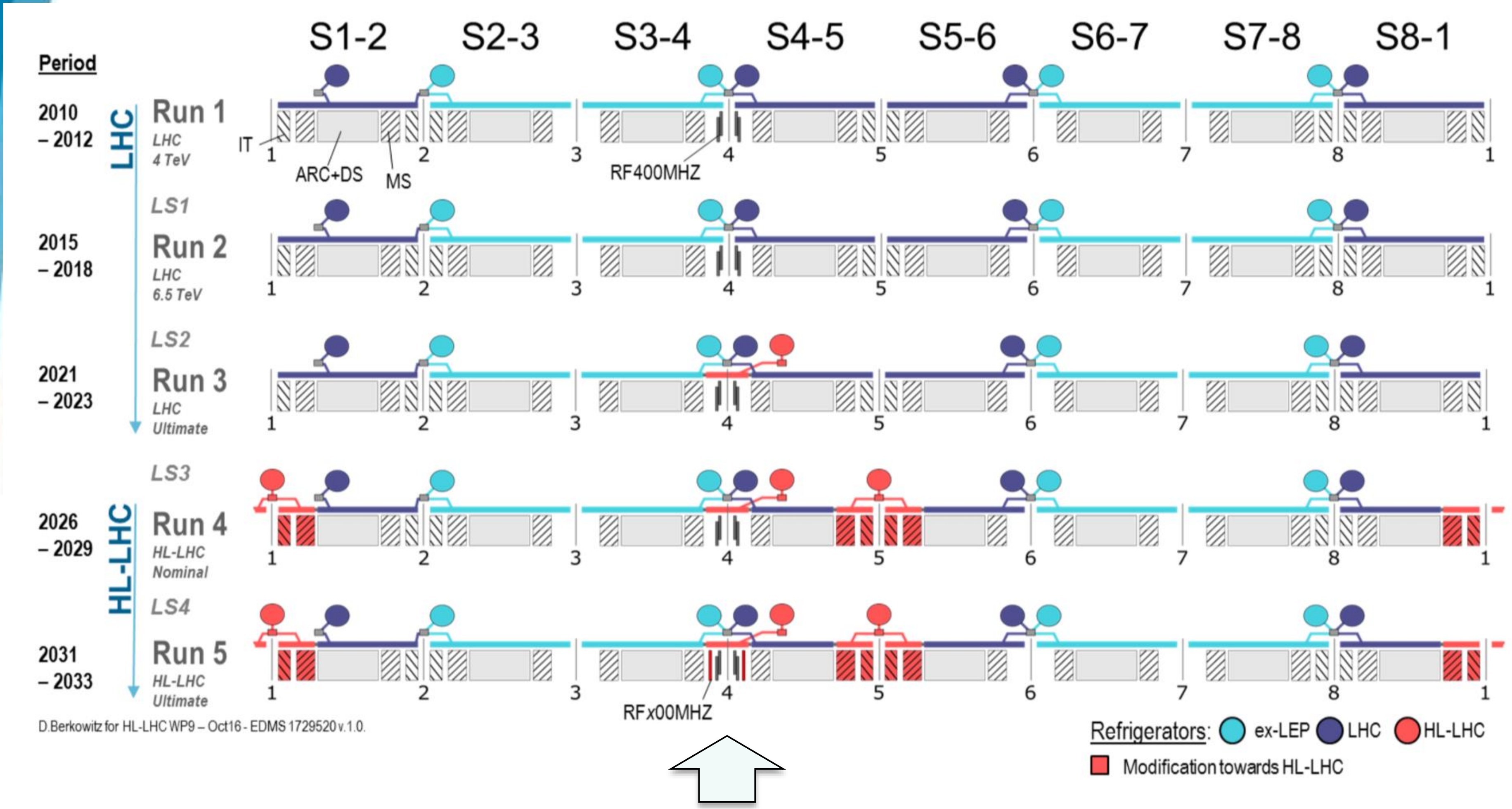


+1 kW RF load → +2.3 kW Upgrade

Includes +15% operational margin on RF heat loads.

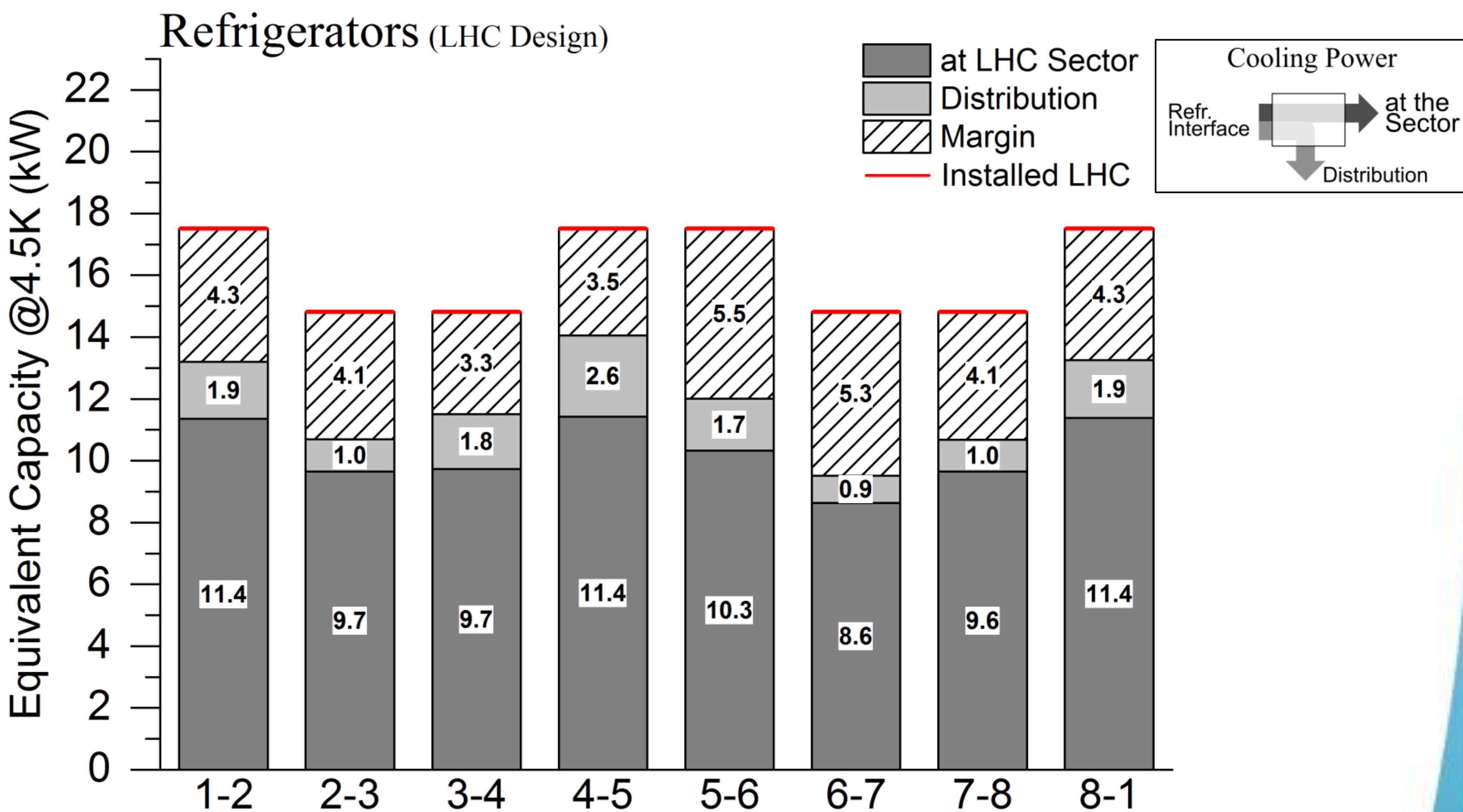
LHC Cryo-Configuration

(from Run1 to Run5)



Alternative Scenario
Upgrade of Refr. S4-5
for RUN3 onwards

Equivalent Refrigerator Capacity (LHC)



S3-4 & S4-5 incl. 760 W of RF load

Subcooler at QUI (high-load sectors only) and RF-loads lead to higher distribution losses due to *inefficient mixing*.

But heat loads will change for HiLumi (study on-going with WP2)

Equivalent Refrigerator Margins

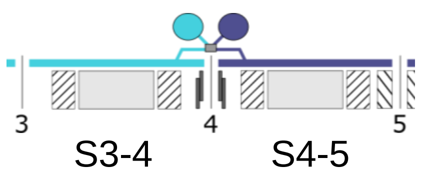
(For existing LHC refrigerators only)

Results based on our *model v.2* (new exercise with *v.3* ongoing)

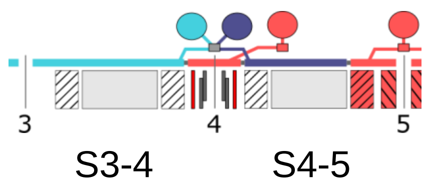
Refrigerators: ex-LEP, LHC, HL-LHC

Modification towards HL-LHC

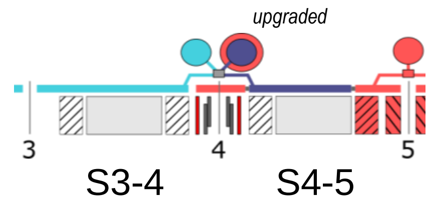
LHC (installed)

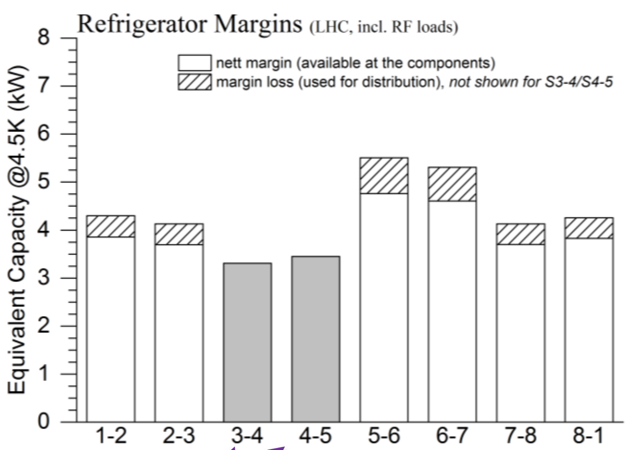


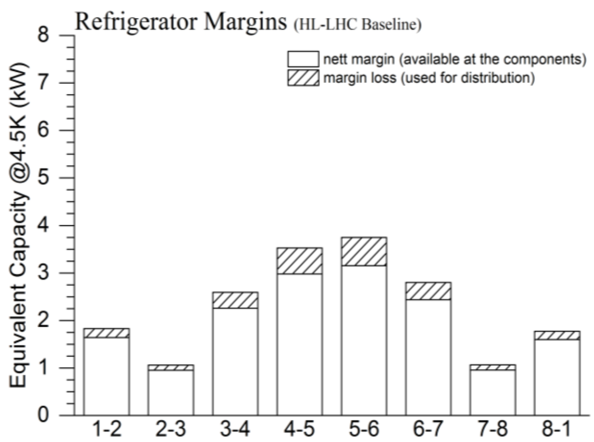
HL-LHC Baseline

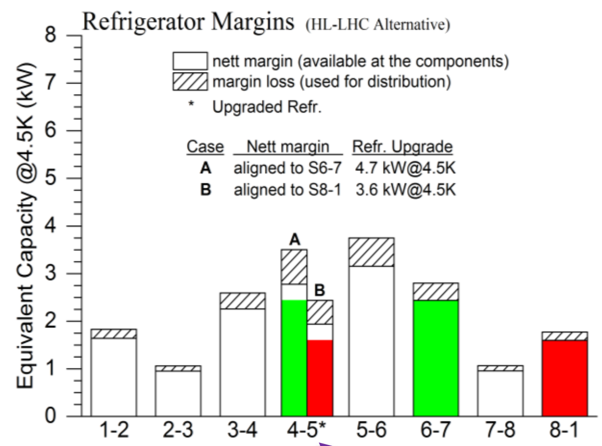


HL-LHC Alternative







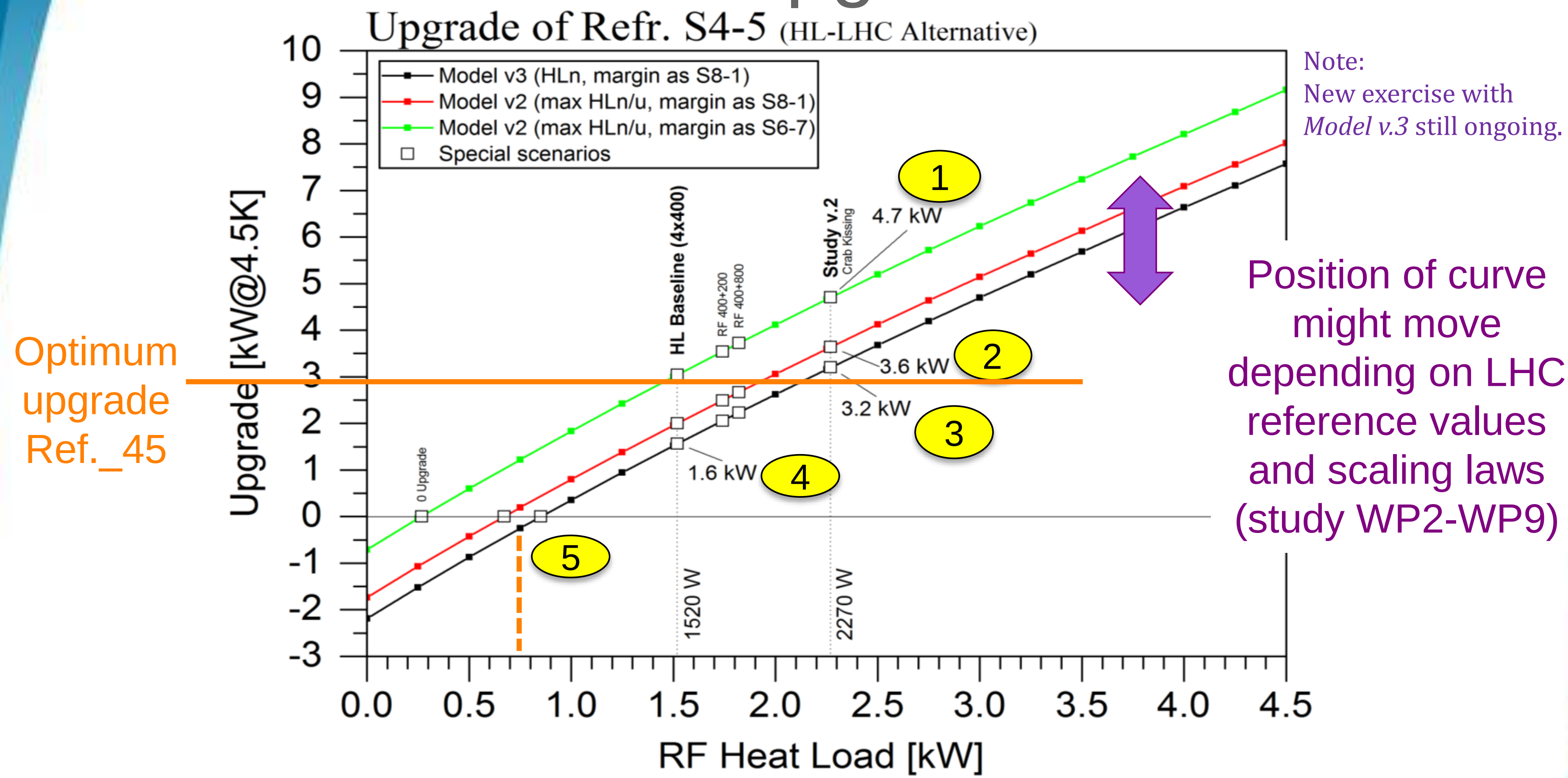


Shows the total margin (nett + loss)

Note: Here, the term "margin" implies an ideal "capacity transfer" between temperature levels. Although we know that this is only possible to a limited extend!

Includes +15% (340.5 W) operational margin on RF heat loads.

Evolution of the Upgrade estimation

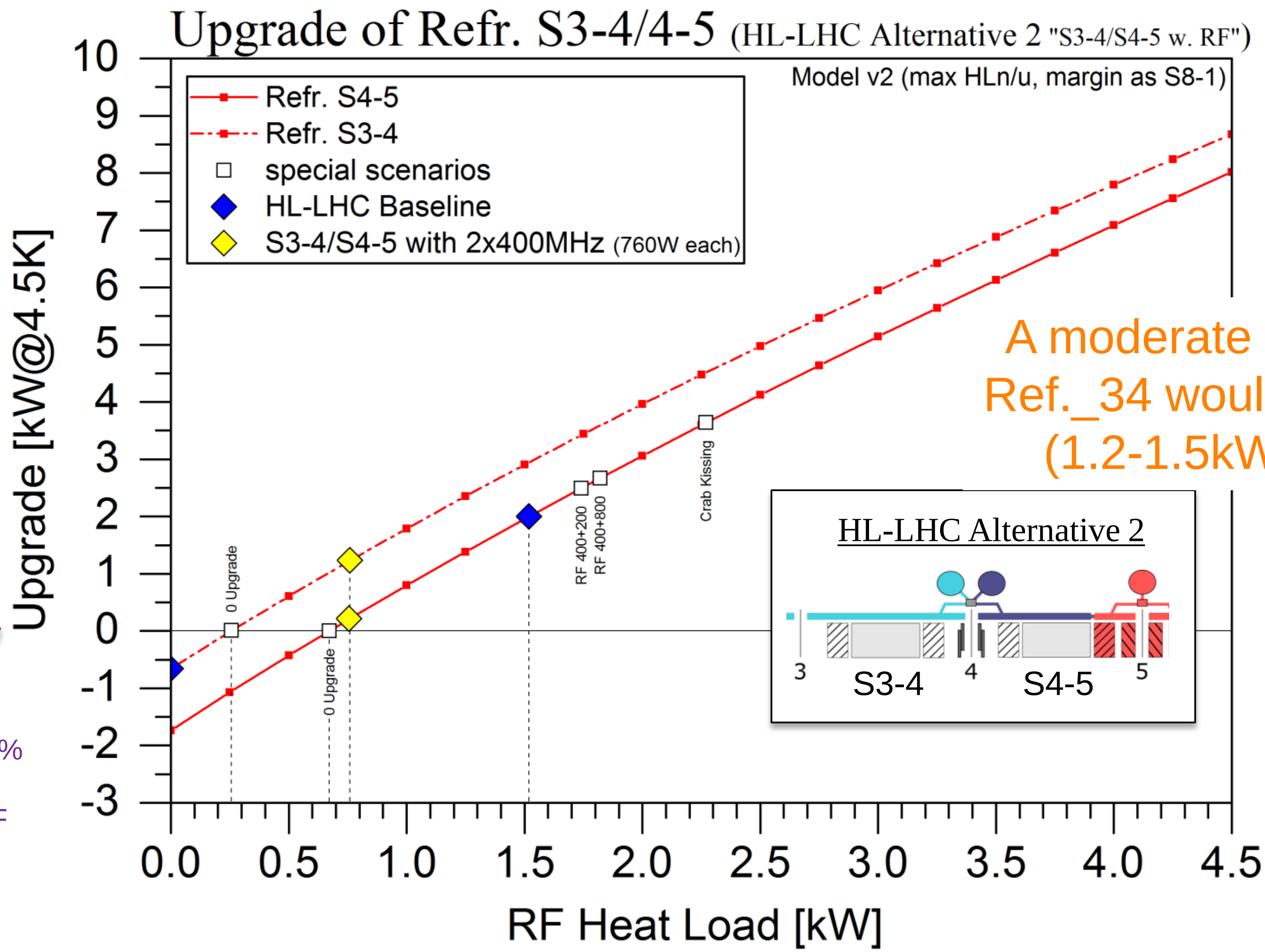


Note:
New exercise with
Model v.3 still ongoing.

	Path	Δ [kW]	Description
Margin (should be OK)	1→2	-1.1	Margin of S4-5 aligned to match S8-1 (margin from S6-7→S8-1)
Model being clarified	2→3	-0.4	Updated model. (model v.2→v.3)
RF load (to be decided)	3→4	-1.6	Estimation of RF heat loads reduced by 700 W (RF heat loads 2270 W→1520 W)
	Total	-3.1	Lower upgrade required (4.7 kW→1.6 kW)

Parametric Study
RF heat load vs Upgrade

(Model v2, S8-1)



A moderate upgrade of Ref._34 would do the job (1.2-1.5kW@4.5K)

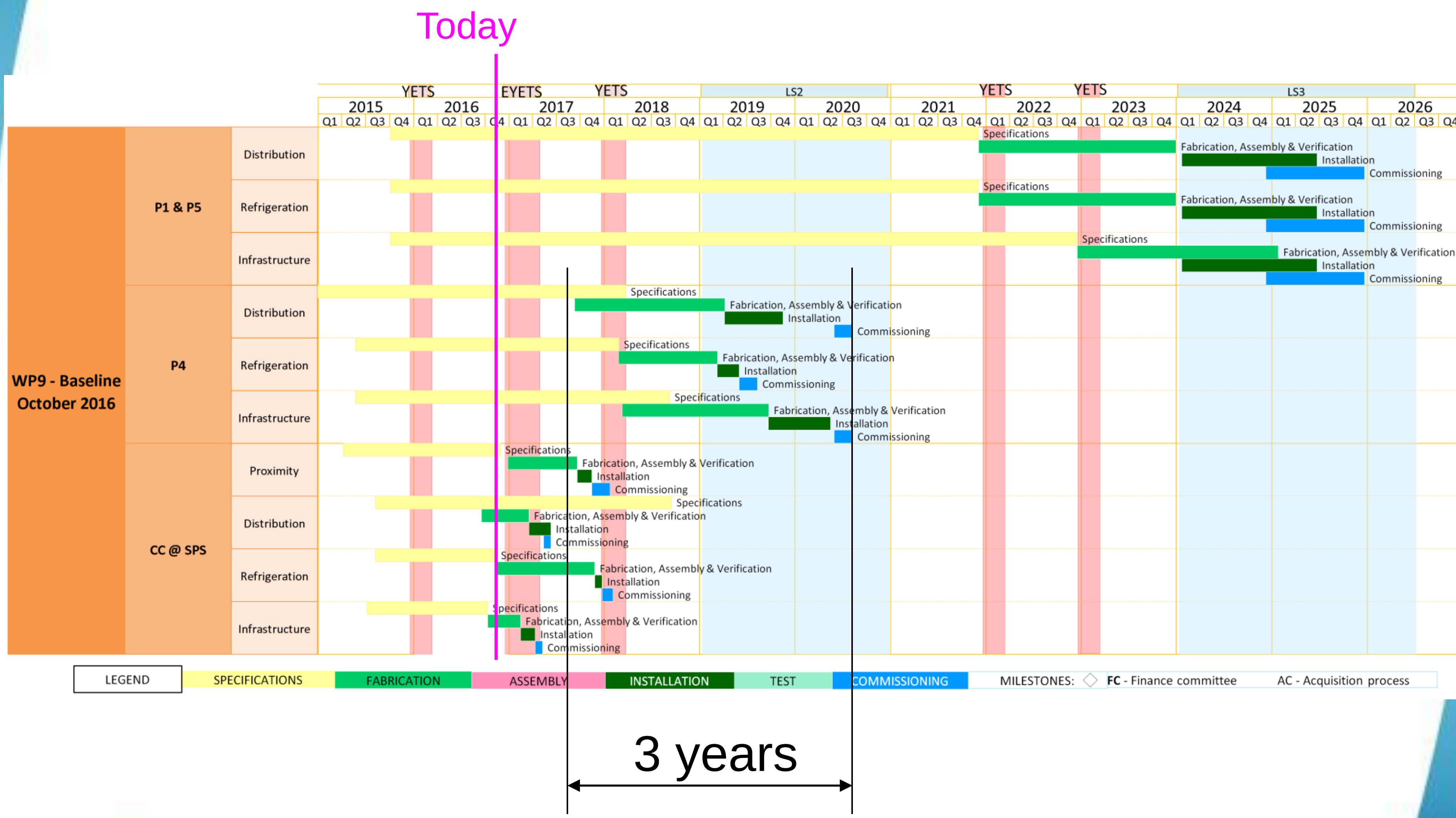
Includes +15% operational margin on RF heat loads.

Synthesis for cooling capacity requirements

- There is no longer a need for 6kW@4.5K, that only a new dedicated refrigerator could handle
- With sector 45 relaxed from LSS5L, it is now demonstrated that an upgrade of Ref._Sect_45 providing 2.6kW@4.5K additional capacity for all RF needs would be possible (Alternative so far)
- Considering the situation of the capacity margins for the 8 sectors, there is a possibility to even reduce the cooling capacity requirements for P4 if we accept to align the margin of 45 on the one of 81 for instance
- Pushing the reasoning further, we could even consider not to touch the Ref._45 and only perform a moderate upgrade of Ref._34 (1.2-1.5kW@4.5K) , with feasibility to be checked asap !
- For “long term”, we should consider that time to deliver cryogenic capacity and distribution should not be longer than the time required to develop new RF modules ready for installation in LHC

With help of central team

WP9 – Cryogenics schedule



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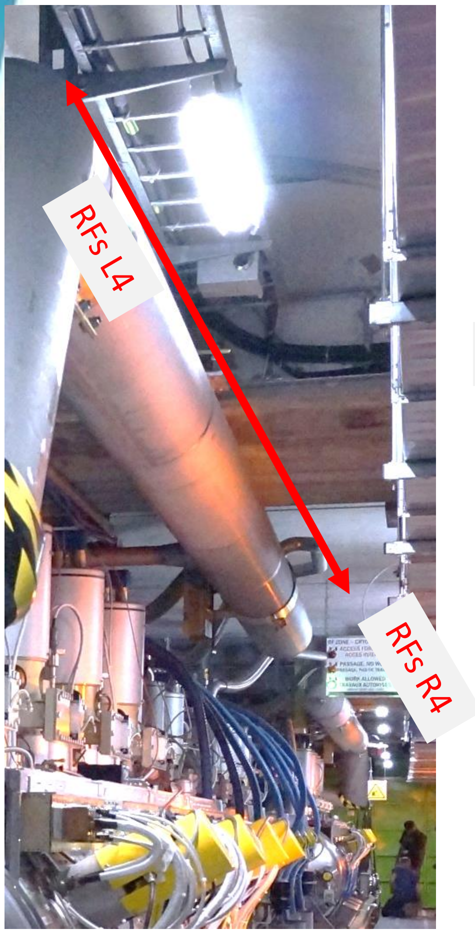
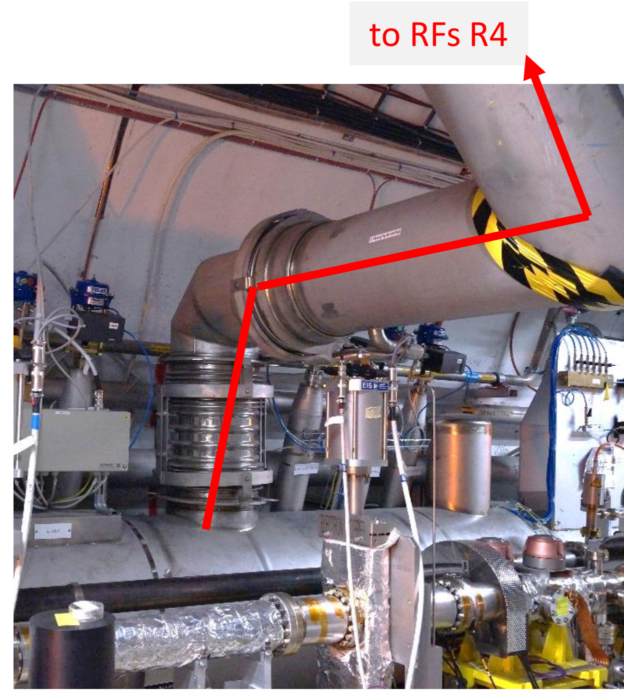
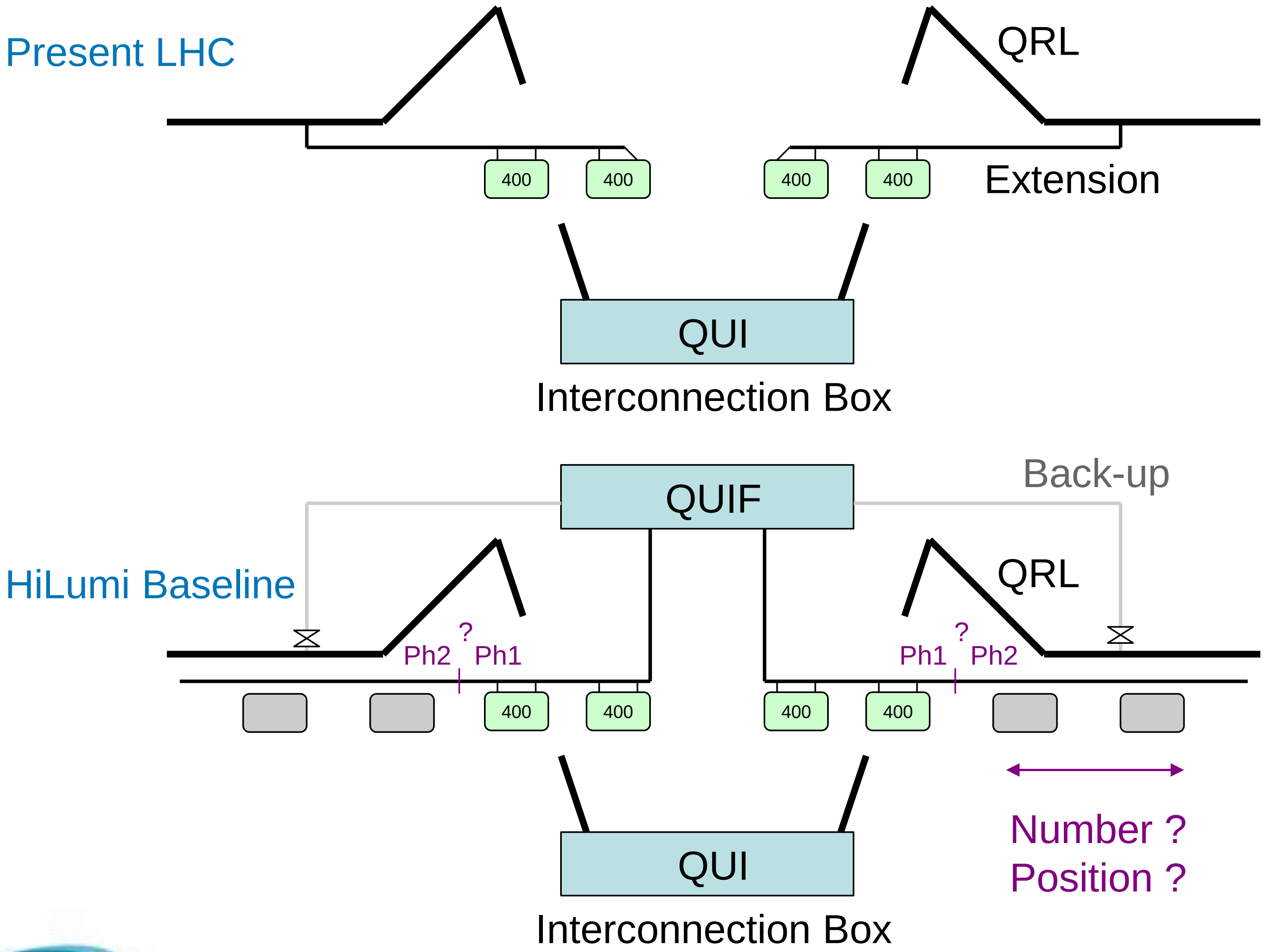
Present LHC P4-RF distribution line





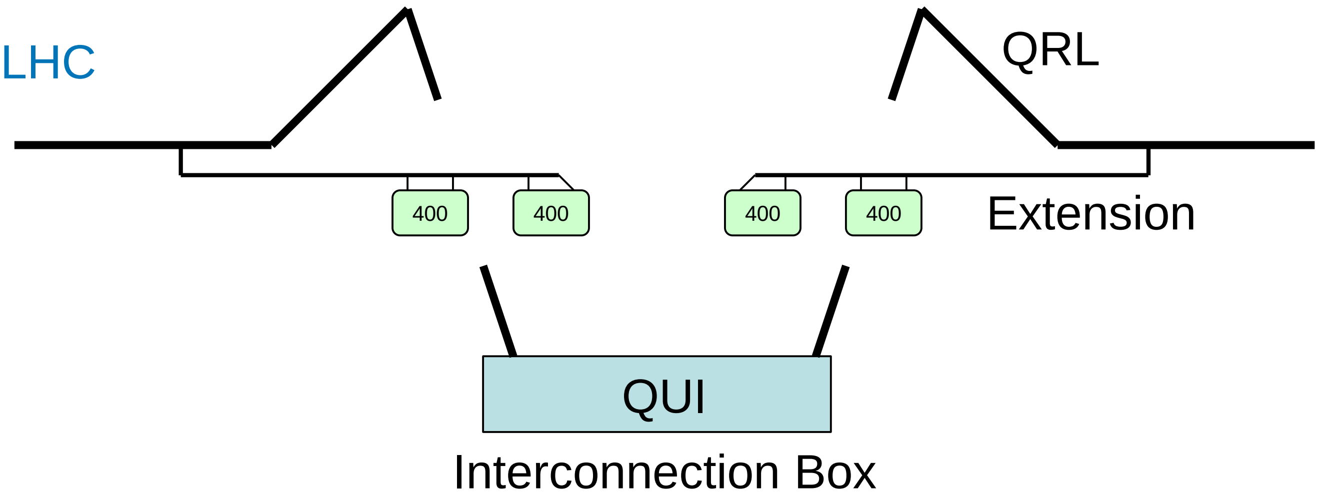
Connection to QRL and distribution along the existing and "future" RF zone (+e-lens!) to be looked at for present baseline and alternative scenario

Cryodistribution basic schematics (1/3)

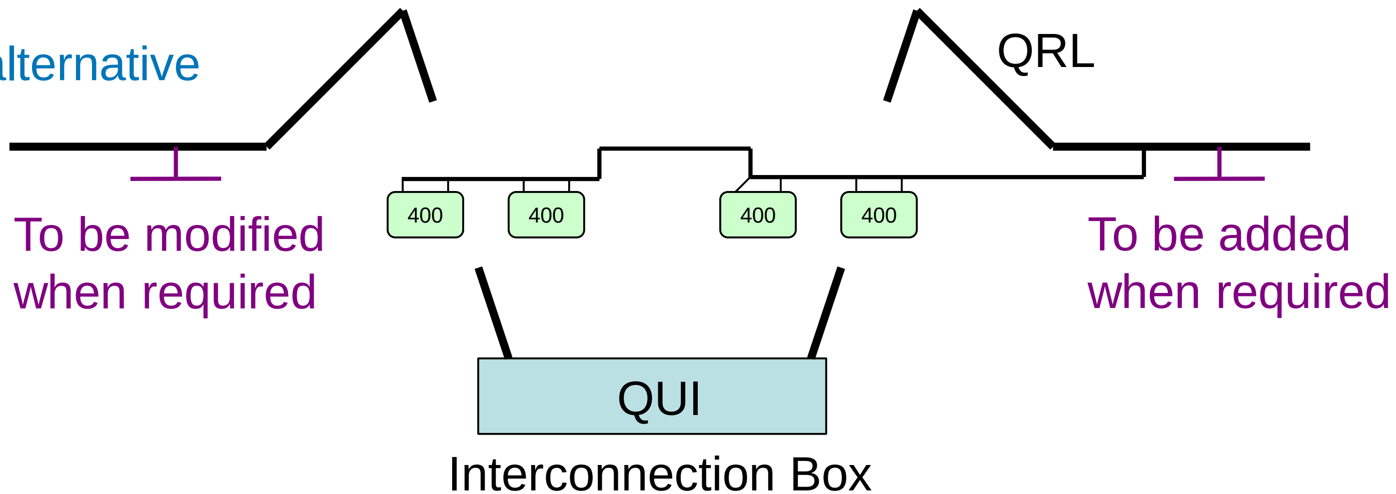


Cryodistribution basic schematics (2/3)

Present LHC

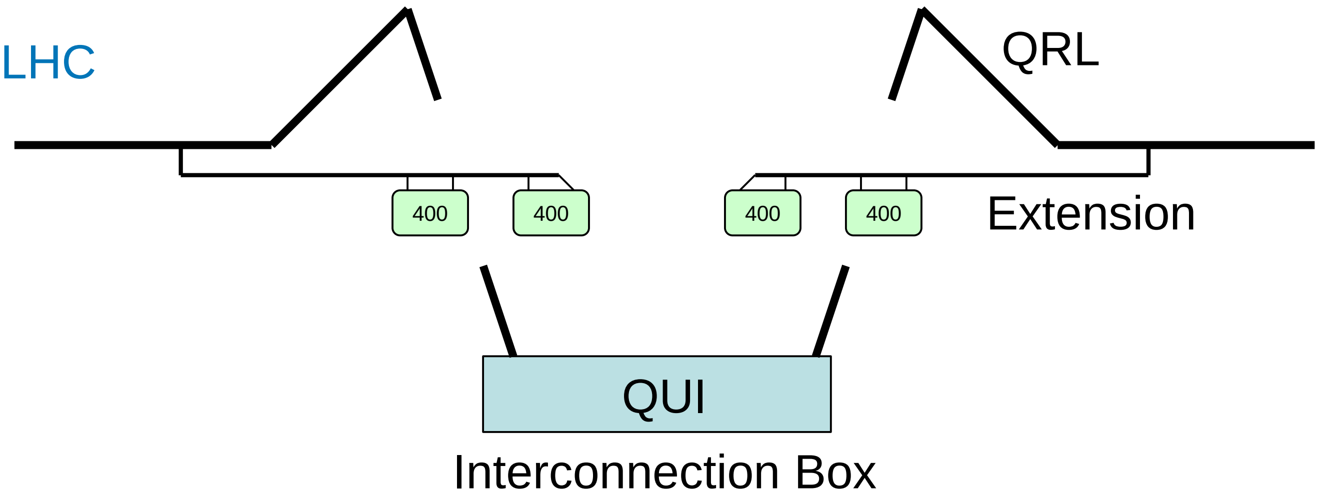


HiLumi alternative

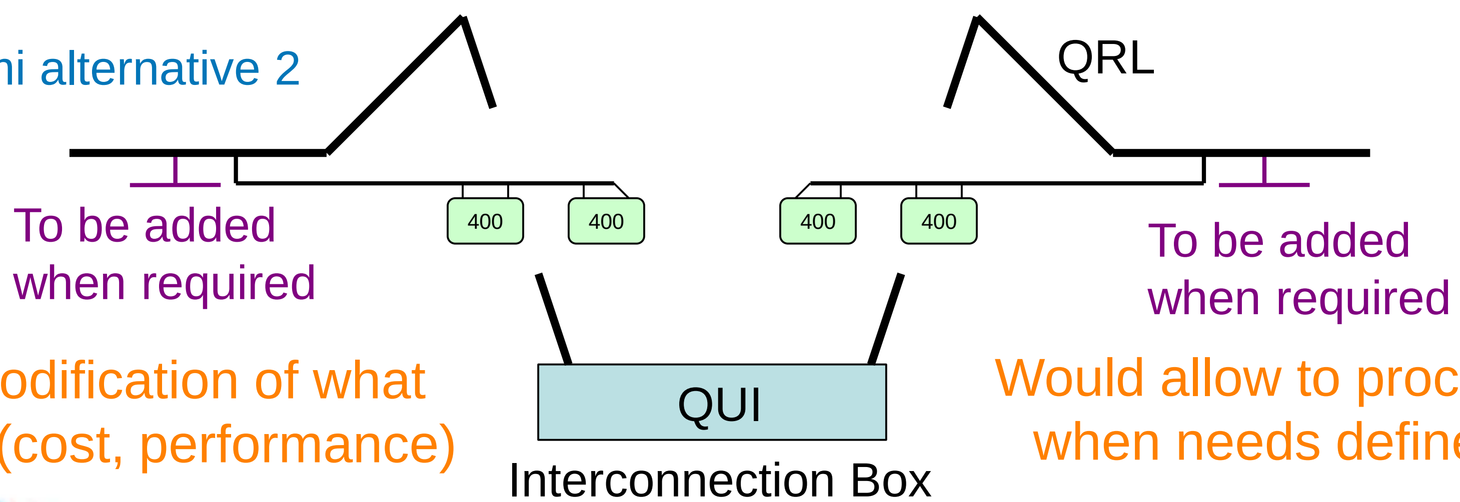


Cryodistribution basic schematics (3/3)

Present LHC



HiLumi alternative 2

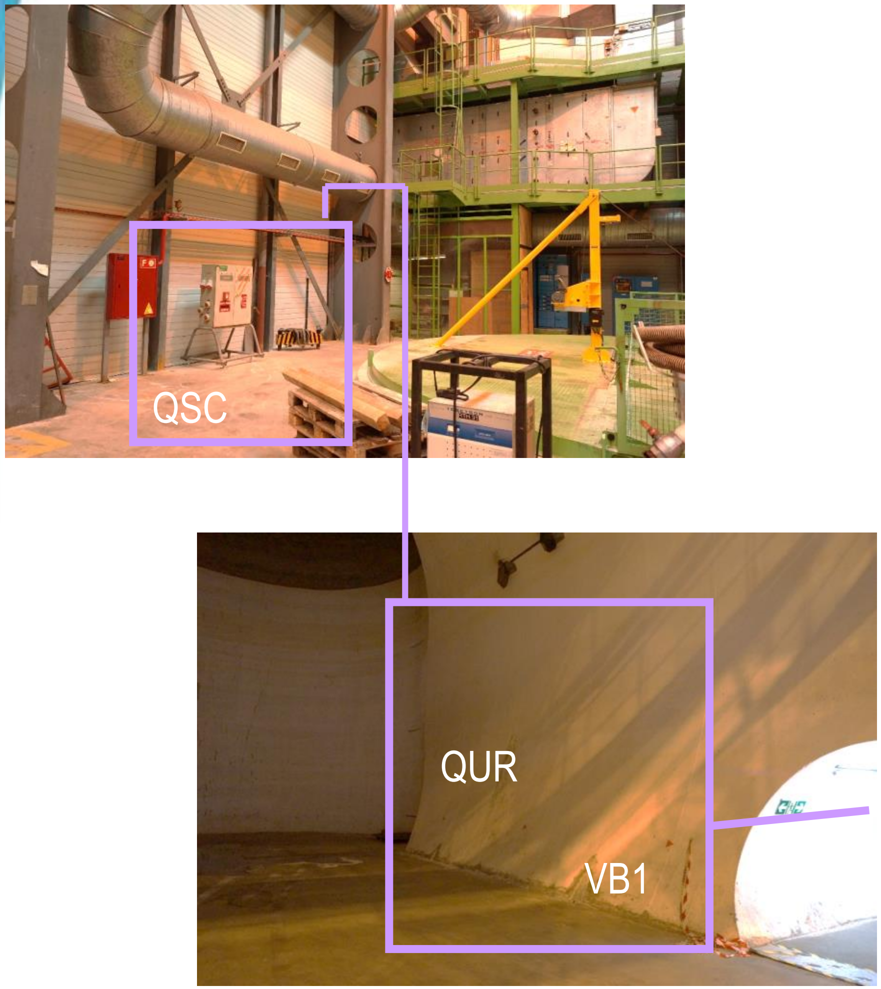


No modification of what works (cost, performance)

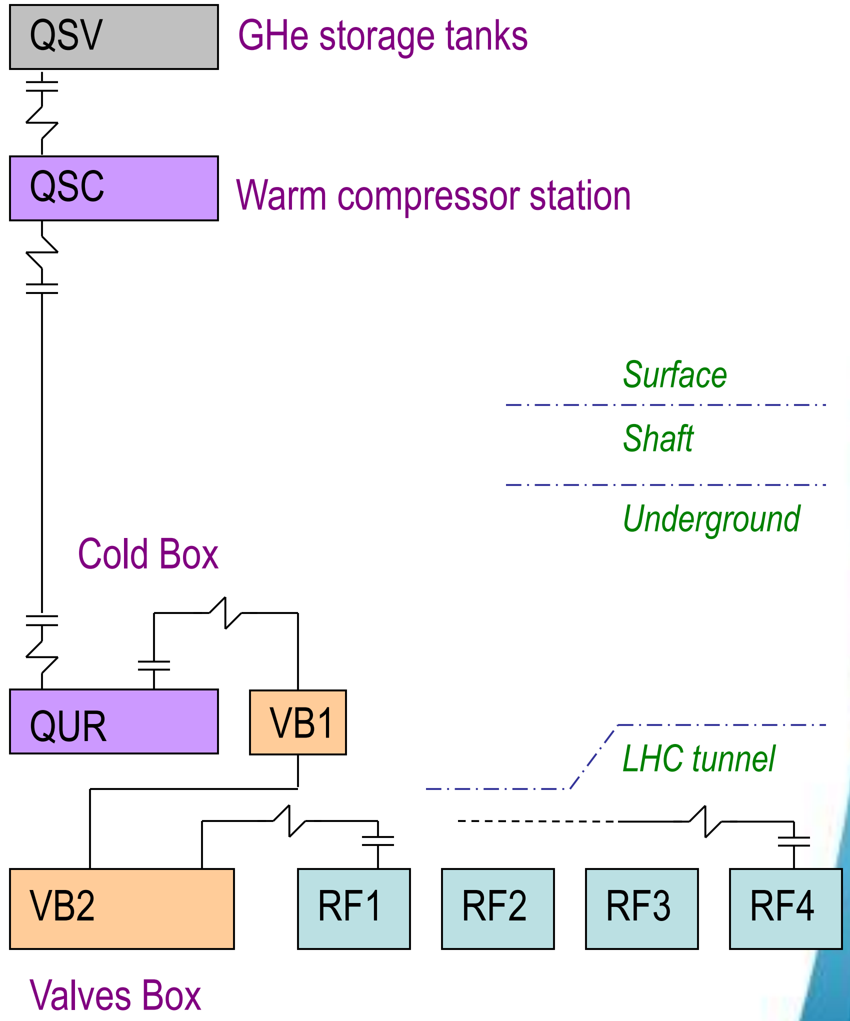
Would allow to proceed when needs defined

RF tests refrigeration concept

Simplified infrastructure w.r.t baseline



LHC-P4 during Long Shutdowns



Summary table

Refrigeration	Cryogenic Distribution	
New 3kW Refrigerator	New lines Ph1 for 400MHz Ph2 others	Baseline *cost index ?!?* (11 MCHF)
Upgrade 45 4.7kW@4.5K (2.3kW for RF)	New line for 400MHz The rest when needed	Alternative 1 Up. Ref._45 (9-10 MCHF)
Upgrade 45 3.0kW@4.5K (1.5kW for RF)	New line for 400MHz The rest when needed	Alt. 1 optim. Up. Ref._45 (7-8 MCHF)
Upgrade 34 * 1.5kW@4.5K (2.3kW for RF)	As is for 400MHz The rest when needed	Alternative 2 Up. Ref._34 (5-6 MCHF)

** Feasibility to be checked*

Summary

- With cooling requirements for P4-RF between 1.5 to 2.5 kW@4.5K, an upgrade of one existing cryoplant and cryodistribution would be possible, with moderate cost savings while keeping open possibilities for future decisions
- In the coming months, we will have a better picture of heat loads values (beam induced) on all sectors for HiLumi beams, but we will have to wait some years before we can identify the type of RF option that might be needed
- For work to be done at LS2:
  - We could implement the baseline, but total capacity, and cryo-distribution interfaces to be defined …
  - Proceed with alternative 1 – Upgrade 45 (or it's variant) together with redoing the distribution line for 400MHz cavities
  - Develop further alternative 2 – Upgrade 34, with no modification of existing cryo-distribution, unless a clear requirement is expressed

AVAILABILITY COST FLEXIBILITY

Cryo Configuration

Cryo-Configuration

Period

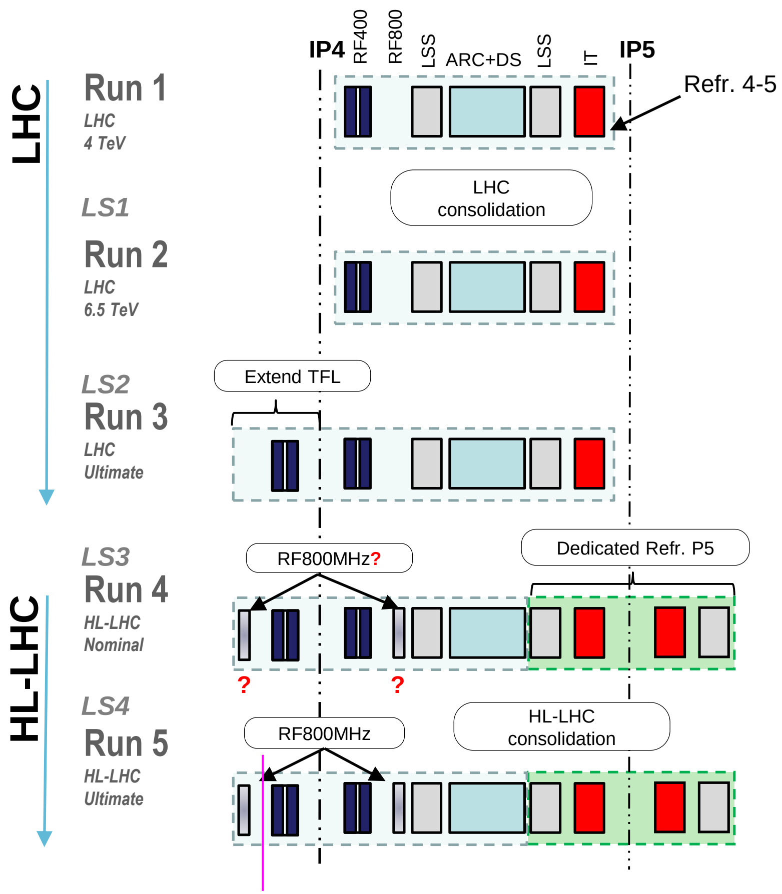
2010 – 2012

2015 – 2018

2021 – 2023

2026 – 2029

2031 – 2033



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

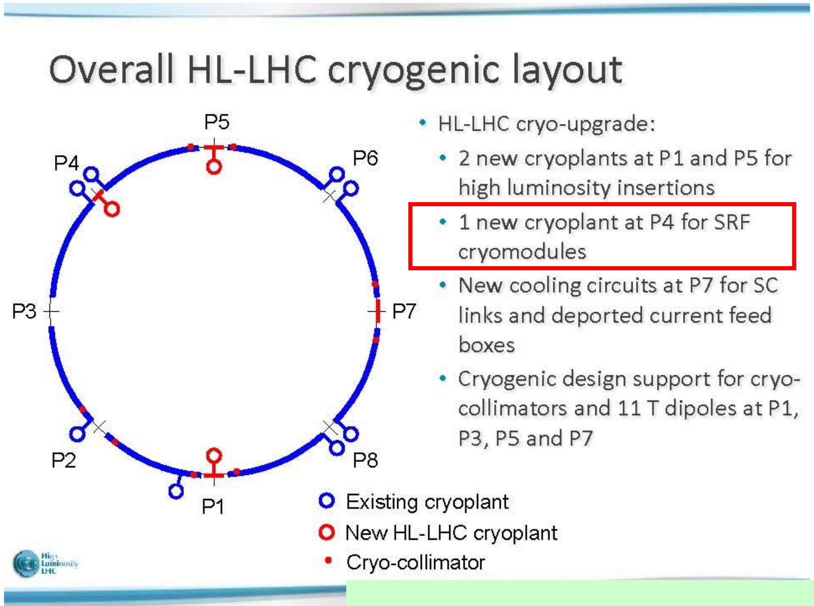
LHC running almost at nominal conditions.

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)

Baseline so far



Cooling capacity:

- To align P4 on P6 (without RF loads)

Flexibility:

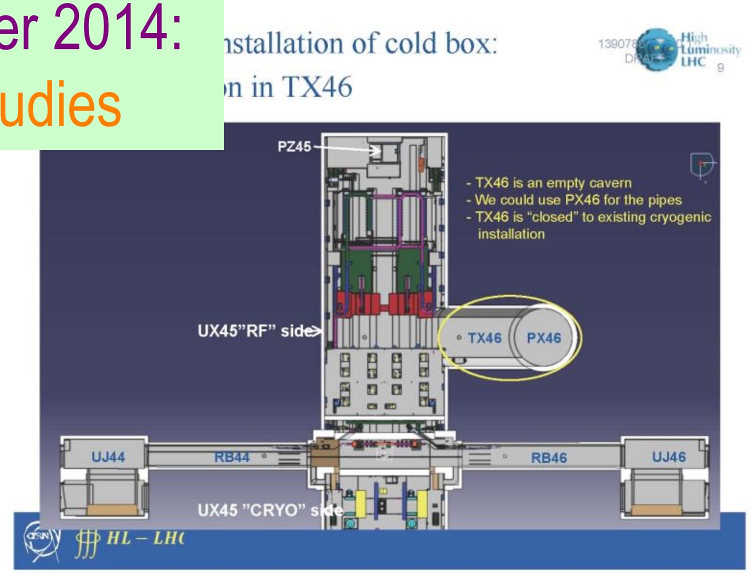
- For specific RF tuning needs

(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