HL-LHC Baseline and Technical Coordination Committee summary

Markus Zerlauth – CERN
On behalf of the HL-LHC project

Genoa – October 7th to 10th - Indico

Outline

- TCC summary, main topics and decisions
- Layout and Baseline evolutions and statistics
- Main implemented HL-LHC baseline changes since annual meeting 2023
- Ongoing work / upcoming baseline changes
- Conclusions

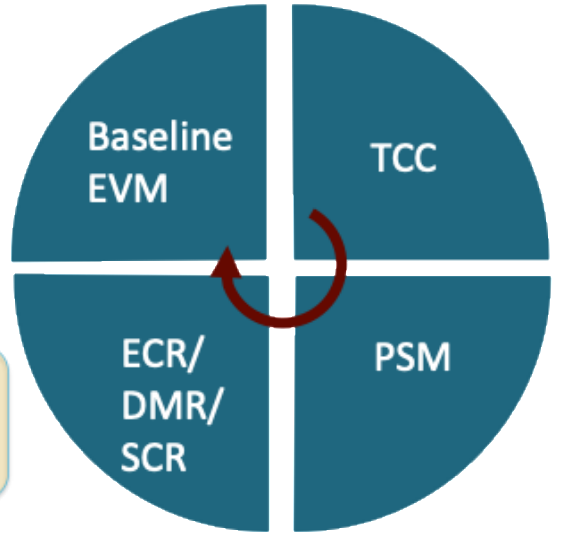
Outline

- TCC summary, main topics and decisions
- Layout and Baseline evolutions and statistics
- Main implemented HL-LHC baseline changes since annual meeting 2023
- Ongoing work / upcoming baseline changes
- Conclusions

Technical Coordination Committee (TCC)

- Technical Coordination Committee continued serving as an important forum to follow-up and approve the evolution of the project's technical baseline
- Organised on a bi-monthly basis with an average particiaption of ~ 35 people across project. >200 meeting to date, around 20 meetings held since last collaboration meeting in Vancouver
- Meetings today still in hybrid mode, in-turn allowing the regular participation of collaborators

Baseline EVM:
Implementation of changes in WP's Cost-to-completion



Technical Coordination Committee:
Technical assessment and decision on **scope changes** and consequences on schedule/cost

TCC Indico Link

Engineering Change request:
scope change assessment & approval
Decision Management Report:
Cost/schedule change

Schedule Change Request:
change impacting master schedule of WP/project

Project Steering meetings, per WP:
Assessment and decision on **budget changes** and **schedule changes**

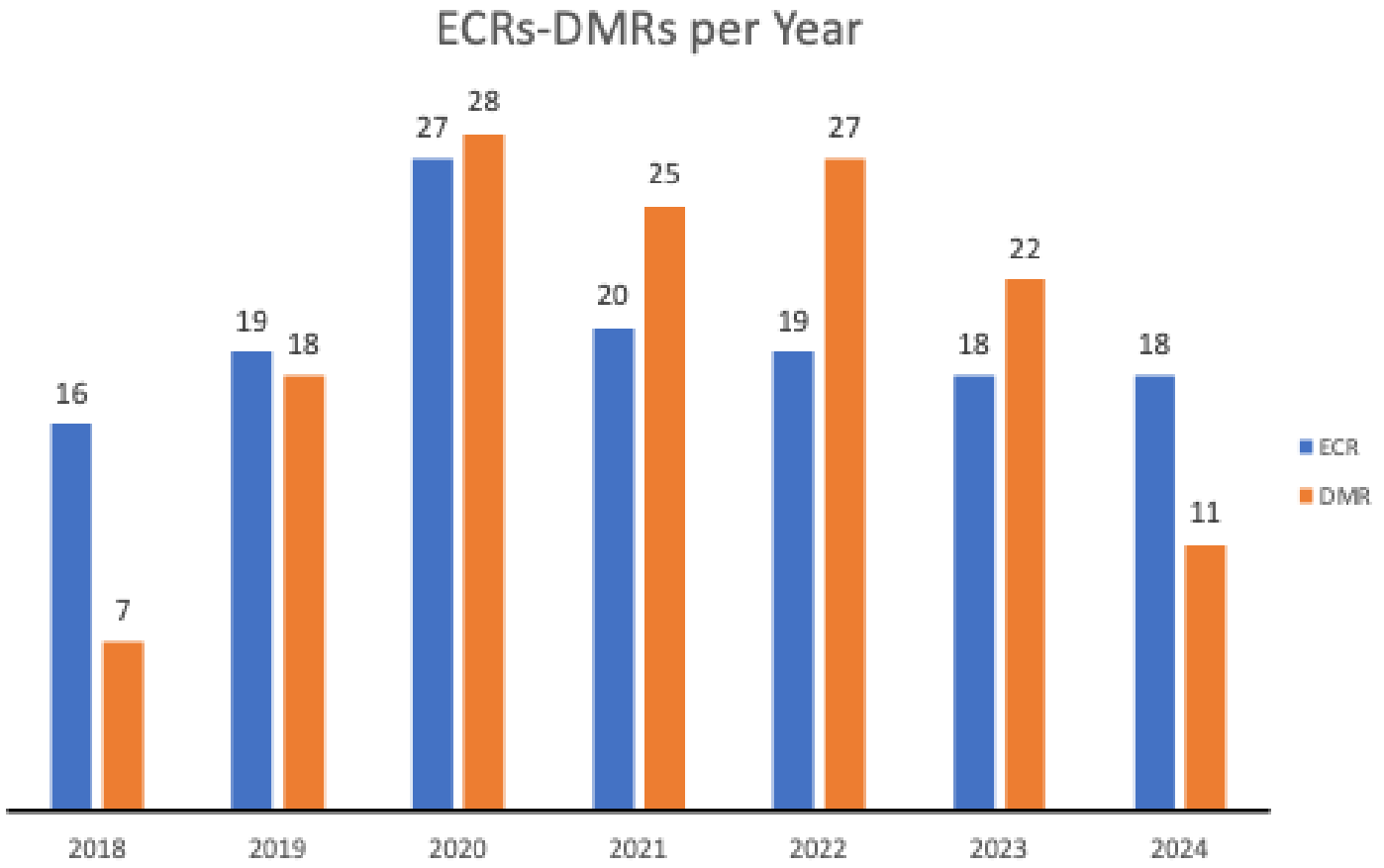
TCC topics and decisions since last annual meeting

- Crystal operation during the 2023 ion run
- Water cooled cables (LHC-DWWCF-EC-0002) and water treatment units (LHC-F-EC-0007)
- Radiation tests for general purpose cables + radiation tolerant cables
- Addition of 4th vertical core and Cable routing alternatives – LHC-K-EC-0064 and LHC-J-EC-0004
- Upgrade of Beam Energy Tracking System – LHC-MKCB-EC-0001
- 11T descoping LHC-LBH-EC-0002 + New IR7 optics to mitigate 11T
- Status of multi-channel FSI implementation for FRAS
- IT String Day '23
- 2nd stretched wire and additional alignment sensors for FRAS - LHC-GI-EC-0007
- Layout drawings for V1.7
- Crab cavities inter-module layout and status of BPTQR RF pick-up system
- Alignment of consolidation scope - LHC-_-EC-0047
- QXL routing in UR-UL galleries (and vault joint exclusions) – LHC-QXL-EC-0002
- Internal monitoring for MQXFBA/B + magnetic axis measurements
- PPS – Final LHC-XRP-EC-0020
- Modifications of Q4 and Q5 – LHC-QXLJ-EC-0001 and LHC-QI-EC-0010
- Collimator prototyping and choice of jaw material for TCSPM - LHC-TCSPM-EC-0002
- Operation in the HL-LHC era – physics days LHC-PM-ED-0002
- Edge welded bellow – lessons learned and follow-up
- Summary of warm powering ITS and SCT campaign in the IT String
- Update of radiation level specification in IR4, IR8 and UPS12,16

TCC topics and decisions since last annual meeting

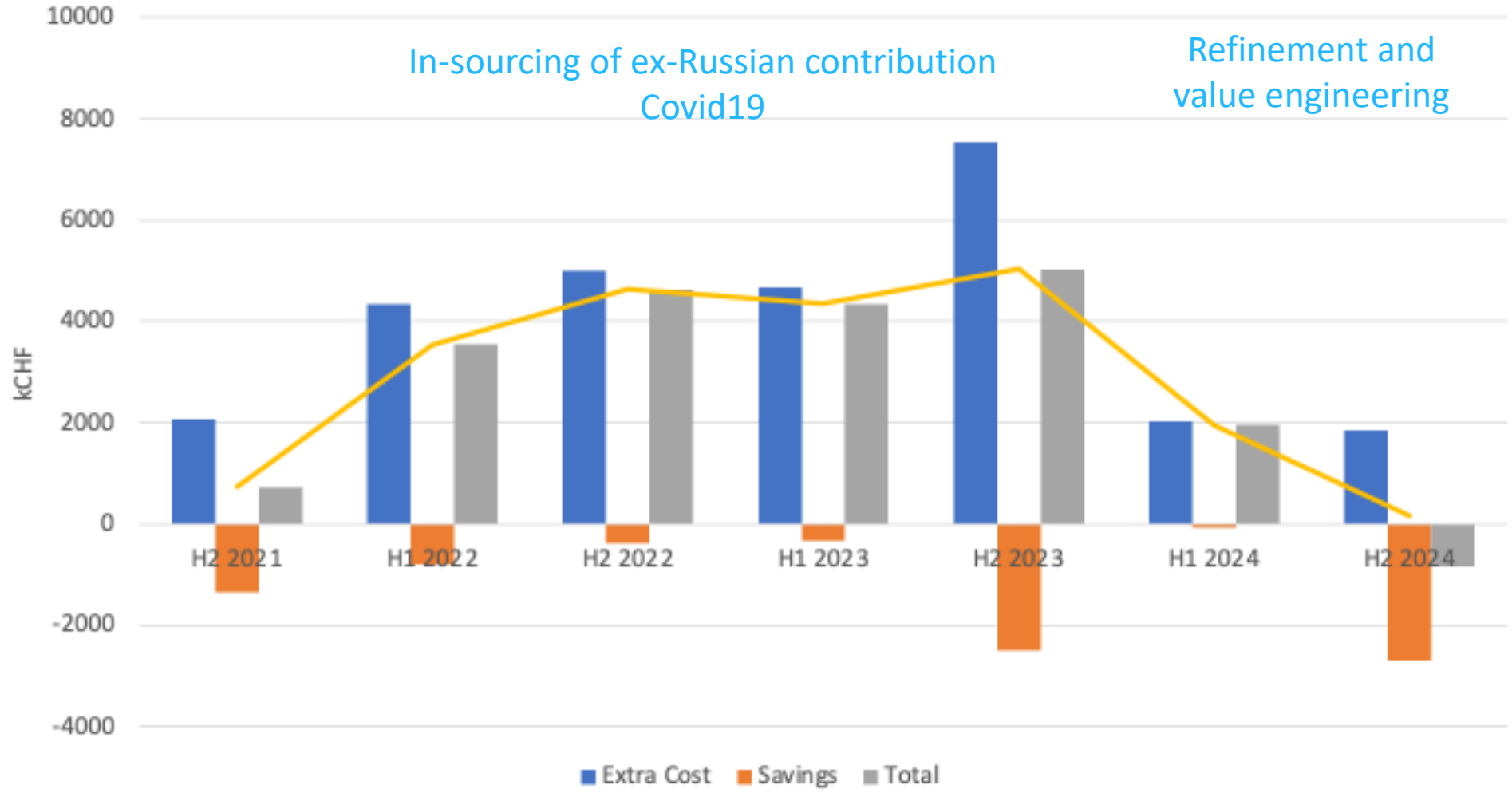
- ECR for modification of vertical line of QXL in surface and US cavern
- Transport in HL-LHC tunnel and measurement of transport height all along LHC tunnel – LHC-LBRD-EC-0001
- Redesign of MCBDR series front plate – LHC-MCBRD-EC-0003
- CDB rack positions in URs – LHC-RP-EC-0014
- Prototype RFD cryomodule repair towards installation in SPS
- Change of the Geometry and Coordinates of the Core in UL13/UL17/UL53/UL57 – LHC-HHT-EC-0002
- Installation of inner triplet in R5 and L5 due to limited height – LHC-HQ-EC-0001
- Results of powering tests for cold powering system prototype – reduction of T sensors for series
- Electrical supply of cryogenic compressors – LHC-QSCG-EC-0001
- Updated baseline planning of HL-LHC underground galleries
- Coating of BPMs for Q4/Q5 in IR1/IR5
- Use of UX65 as logistic platform – LHC-H-EC-0002
- Relocation of PIC outside of RRs – LHC-CIP-EC-0007
- Report of recent activities from MAB in view of IT string
- BLM IC sensitivity and layout for LSS in HL era
- Results from CA01 cold tests
- ECR for water cooling and compressed air pipes – LHC-F-EC-0008
- Operational experience with LESS demonstrator in LHC
- Commissioning of cryogenic system for the IT String - experience up to phase 1c and next steps
- Junction module design in Q4 area – ECR to come
- Return of experience from MKI cool installation and performance comparison

ECRs and DMRs since last Annual Meeting



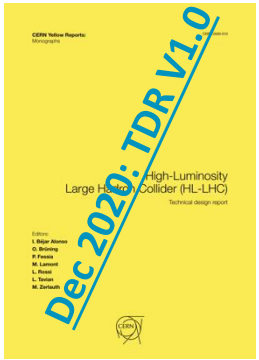
Courtesy: V. Guillen Humbria

(Bi-annual) cost impact of ECRs and DMRs



Courtesy: V. Guillen Humbria

Evolution of Project Baseline (Machine Layout Versions)



CSR'19

CSR'21

CSR'22

CSR'23

CSR'24

Start of LS3 – 1st of July 2026

2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

V1.5 November 2019
Small updates from V1.4
Optimization TAXN-D2 area

V1.6 June 2022
MQXFA/B – Update of
Magnetic length and offset
CC interchangeability, Space
reservation for FP, Change of
length TCLMB and TCLMC
Descope MS10, Addition of
electrical circuits

V1.7 October 2023
2nd HX for triplet magnets,
D1/D2 mechanical centers,
insertion of jacks and beam
instrumentation, detailed
apertures, automatic drawings

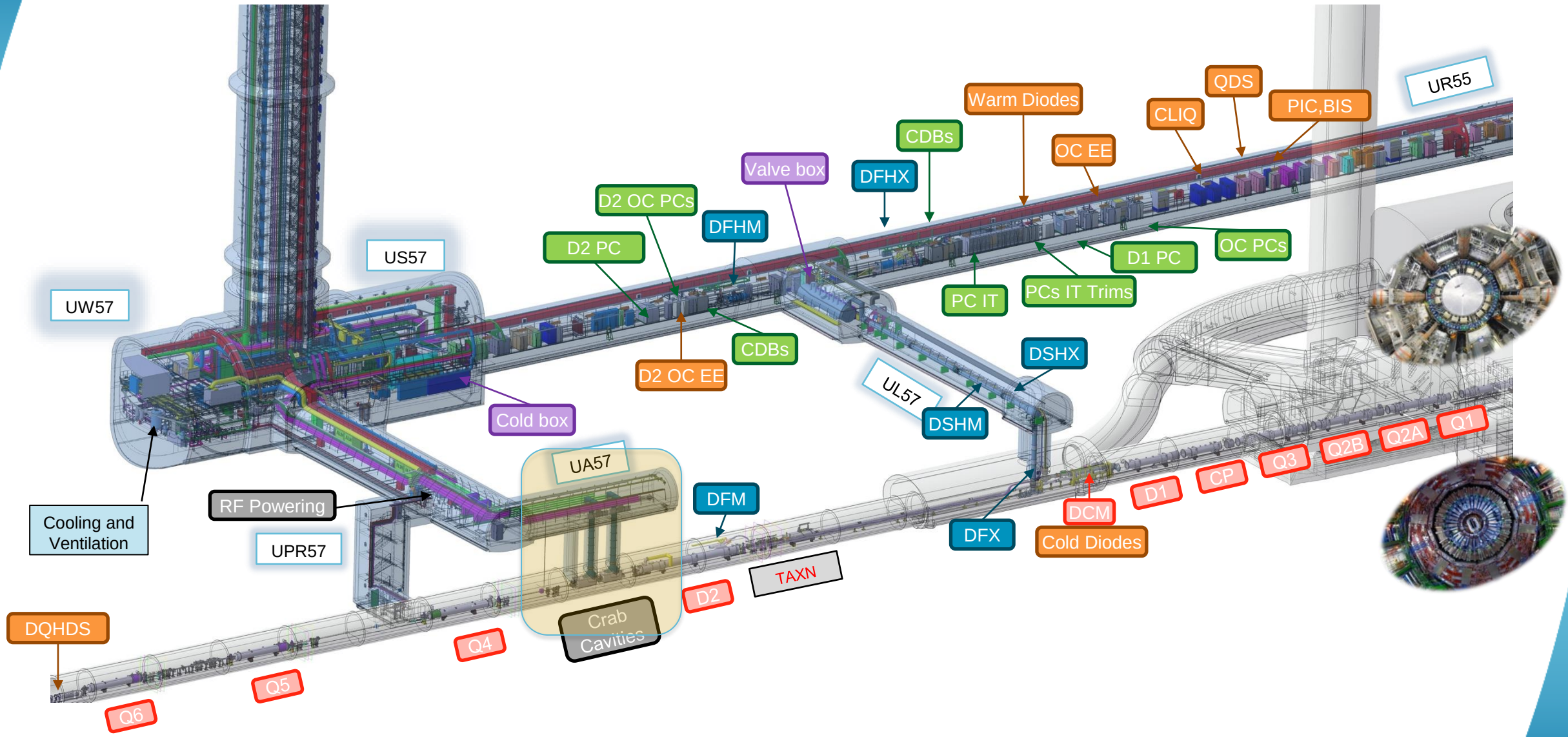
V1.8 July 2024
Modifications of Q4 and Q5,
new anchors and wedges, BPW
and BPTQR, CT-PPS2, TAXN/S
and D2 geometry

V1.9 September 2025 or directly
V2.0 February 2026 (final for LS3
installation)

Outline

- TCC summary, main topics and decisions
- Layout and Baseline evolutions and statistics
- Main implemented HL-LHC baseline changes since annual meeting 2023
- Ongoing work / upcoming baseline changes
- Conclusions

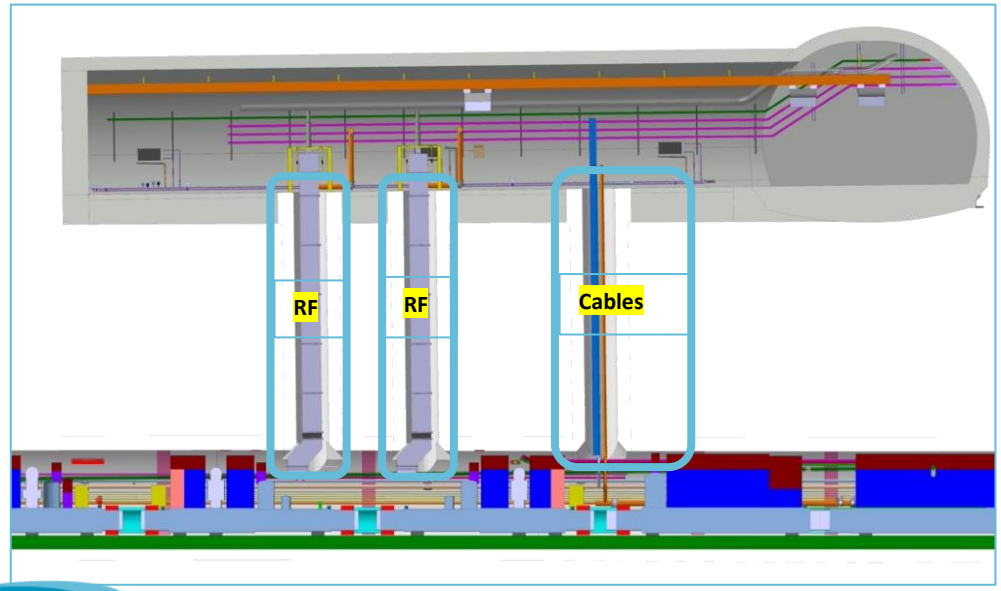
Addition of a 4th vertical core between UAs and tunnel

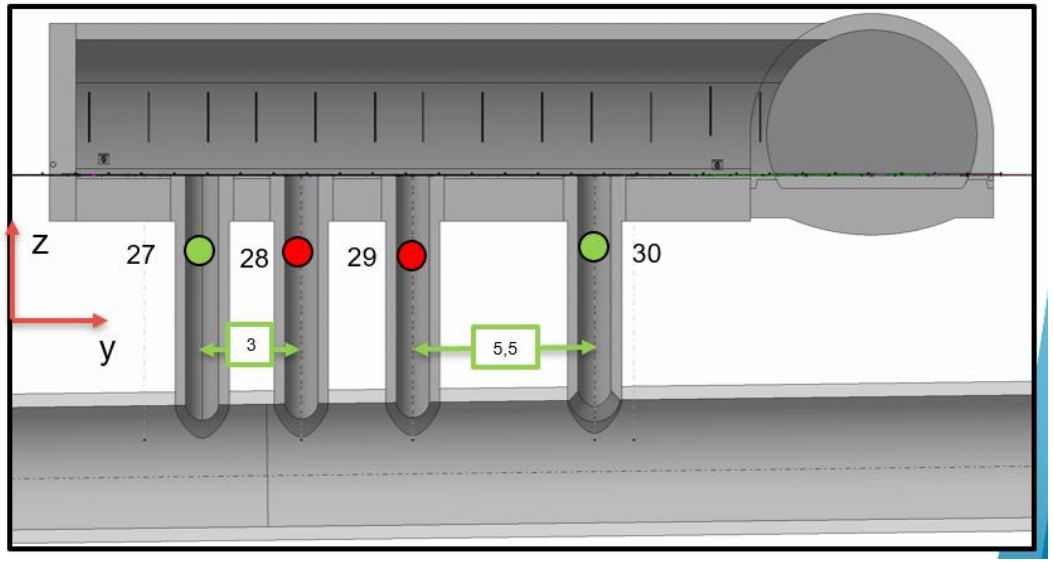


LHC-K-EC-0064

Addition of a 4th vertical core between UAs and tunnel

- Vertical cores used for passage of RF wave-guides towards CC cryomodules (UA), sc links (UL) as well as power/signal/instrumentation cabling between systems installed in new HL galleries and LHC tunnel
- Major difficulties to route required cable volume in front of the crab cavities, requiring complex re-routing from machine side to the transport side and back
- Cohabitation of cables with cryogenic and cooling more complicated as well as impossibility to separate cables with different functions (EMC impacts)
- Decision to add 4th core for the 4 UAs to solve integration issues, as well as to allow for some flexibility for future needs LHC-K-EC-0064. New baseline of 4 + 3 vertical cores per IP side.

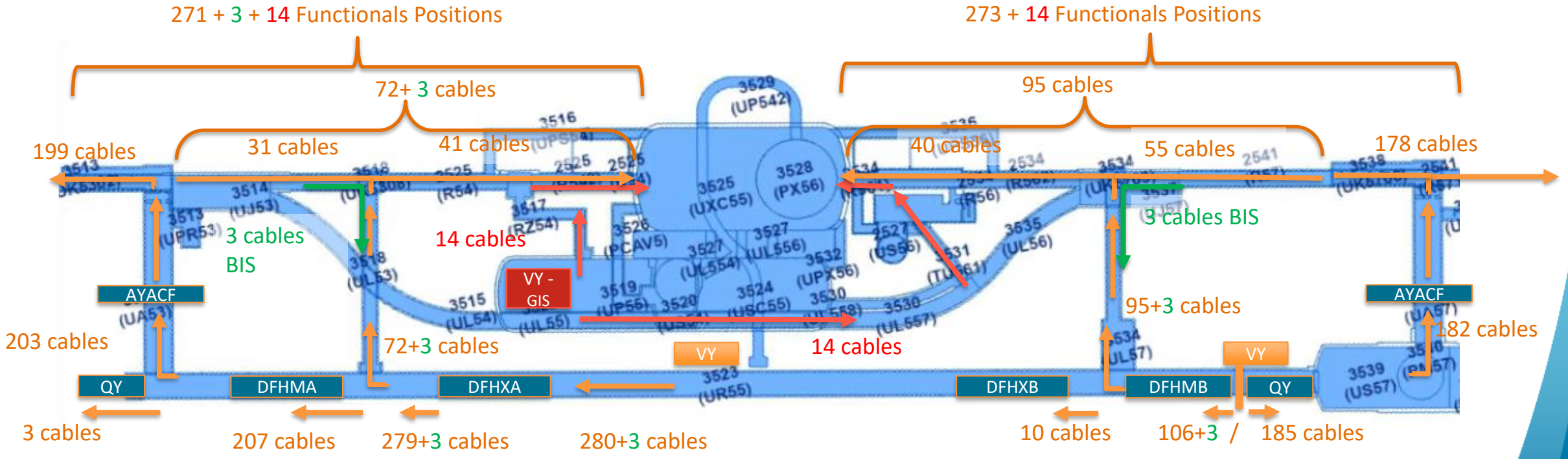




Previous (left) and new baseline (right), adding a 4th vertical core below the UAs

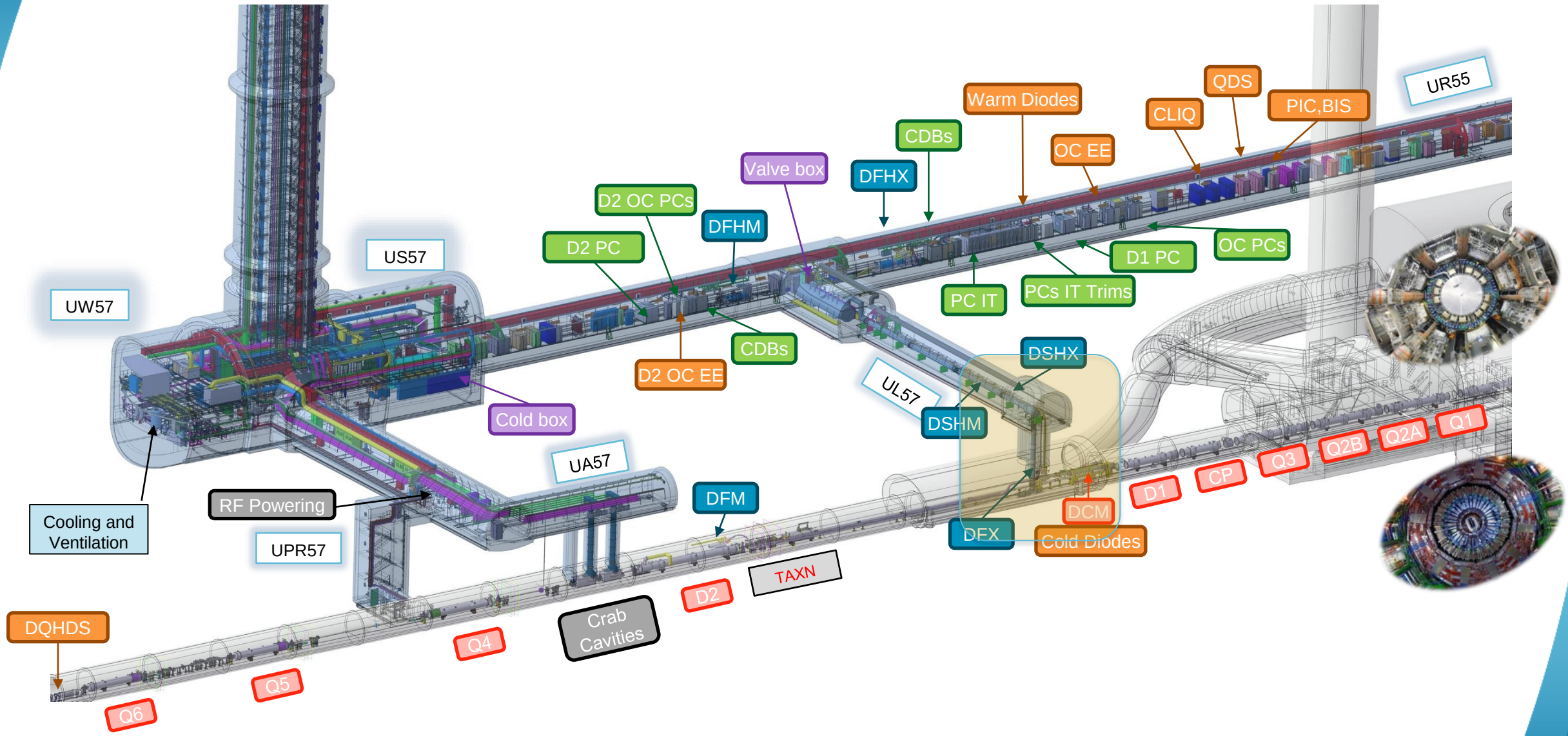
Optimisation of cable routing and rack integration

- Addition of 4th core allowed optimization of the cable routing and finding enough space for the cable trays and cable volume that shall be installed in the various tunnel sections (WP4, WP5, WP6a, WP15)
- Relocation of cryogenic and vacuum racks to optimize system layout and cable length (WP9, WP12)
- Minimisation of cable quantity in the DFX-crab cavity section of the tunnel, which is characterised by the highest level of radiation for cables in the LSS (past decision to use only general-purpose cables in LHC)



LHC-J-EC-0004

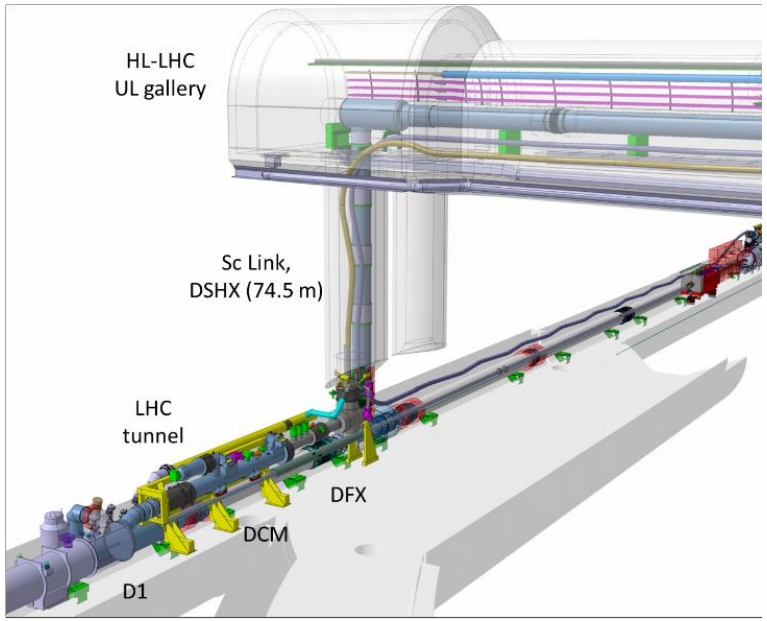
Addition of a 4th vertical core between UAs and tunnel

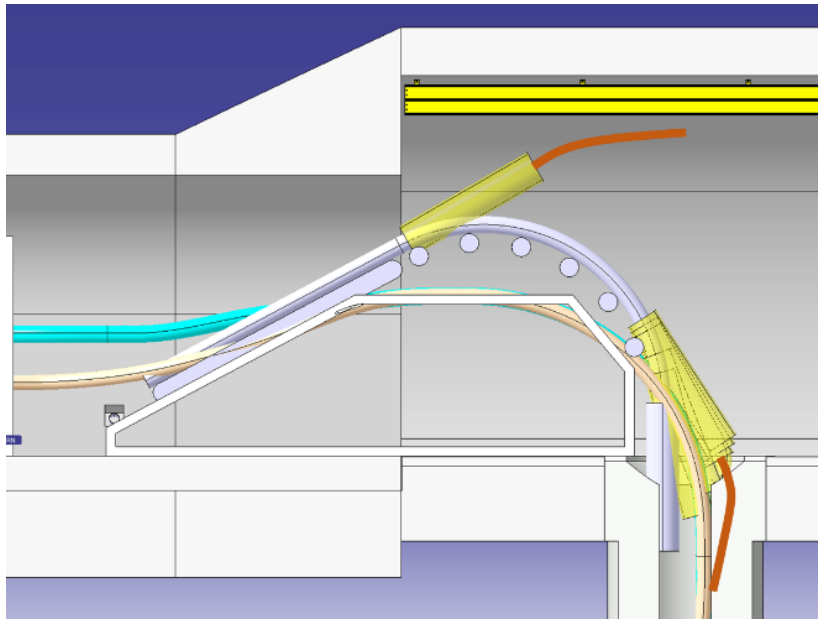


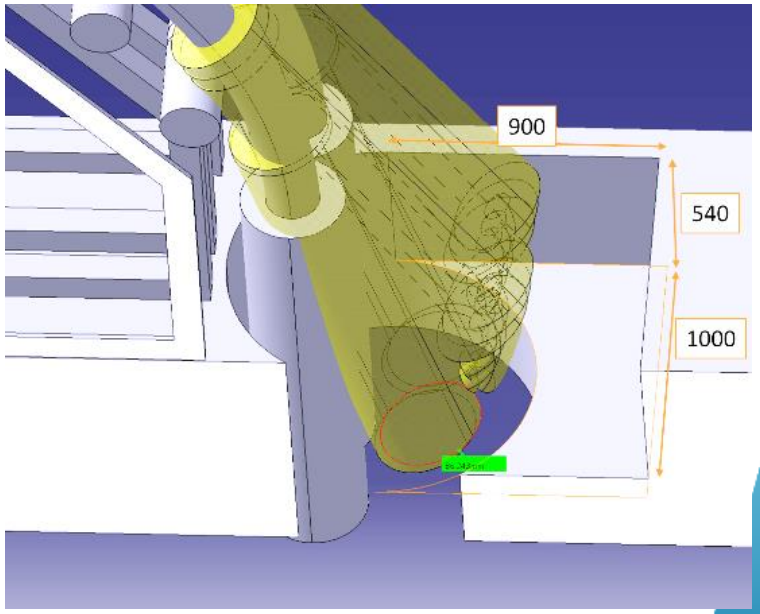
LHC-HHT-EC-0002

Change of the Geometry and Coordinates of the core in UL

- Compared to IT String installation, UL in tunnel features much lower height for installation of sc link
- Integration studies confirmed need for modified shape of reserved volume at the top of the core to allow the insertion of superconducting link for inner triplet (DSHX) and matching section magnets and (DSHM)
- Additional 50 mm displacement of the longitudinal position of the sc link core towards IP to align with final DFX position in tunnel LHC-HHT-EC-0002

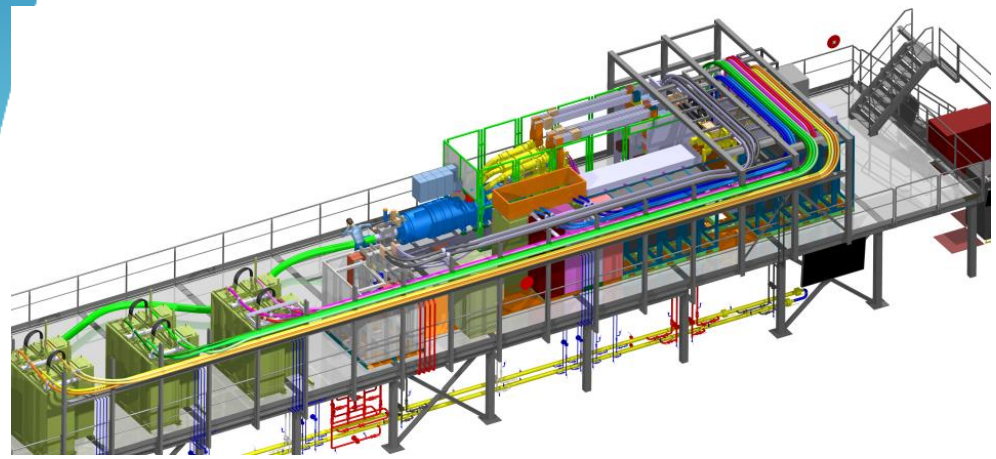






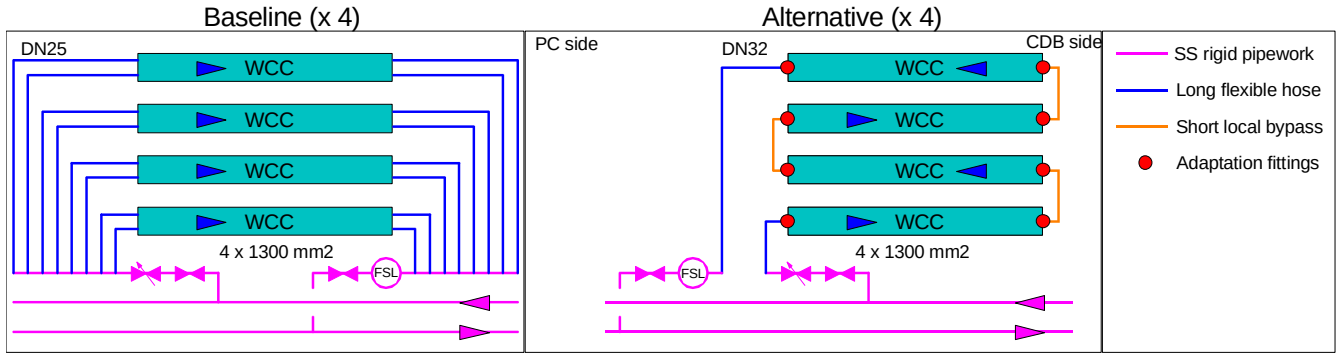
See A. Ballarino (Plenary Tue PM)

Modification of the Water-Cooled cables cooling scheme

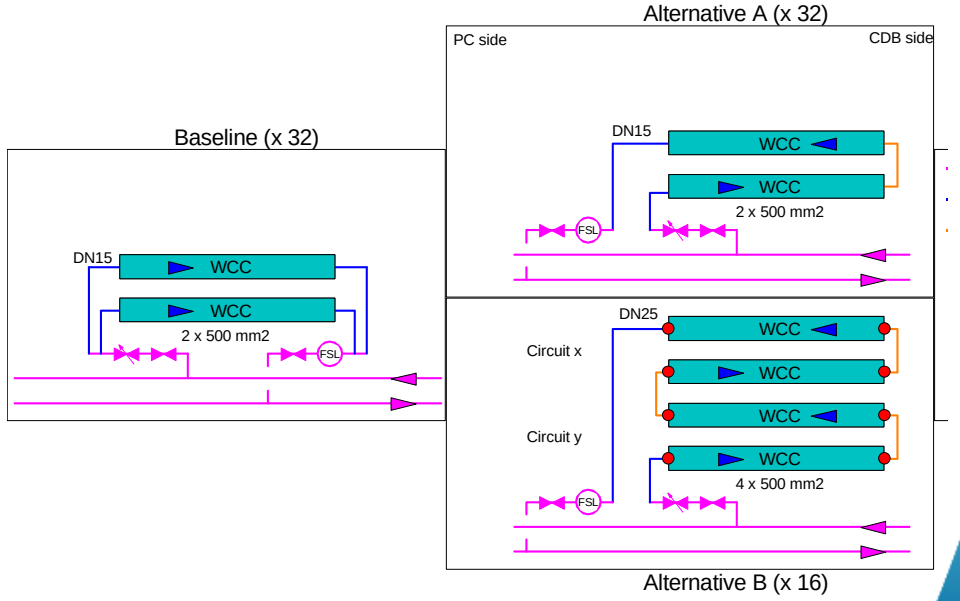


WCC at the IT String installation

- Water cooled cables (WCC) are used between power converters and Circuit Disconnector boxes
- Baseline cooling scheme foresaw indiviudal cooling circuits for each individual cable (up to 4 cables for 18kA circuit)
- Simulations and validation during Short Circuit Tests in IT String (two 2kA circuits) confirmed viability of serial cooling
- Adopted as baseline for all 2kA, 14kA and 18kA circuits, allowing considerable reduction of infrastructure LHC-DWWCF-EC-0002



Previous (left) and new baseline (right) for 18kA circuits



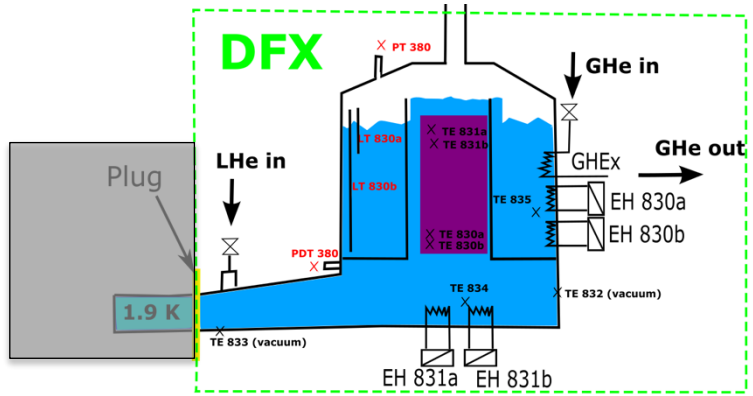
Previous (left) and new baseline (right) for 2kA circuits

See M. Bajko (Plenary Mon PM)

Reduction of temperature sensors for sc link

- sc link is cooled with gaseous He between 20-50K
- Temperature sensors all along sc cables and each splices to monitor and control He flow
  - current lead HEX: top & bottom
  - HTS – MgB_2 splice
  - DFHX gas inlet
  - DFHX gas return
  - DFX top & bottom, in liquid & on heaters
- All non-accessible sensors doubled in prototype system
- RoE of prototype systems during validation in SM18 confirms that sensors in one splice volume (containing several splices) show consistently same temperature
- Optimization and value engineering: for the series, 2 temperature sensors per splice volume retained instead of 2 per splice
  - 16 instead of 38 temperature sensors, reducing number of instrumentation cabling as well as controls electronics, process control logic…

DFHX/M side of sc link



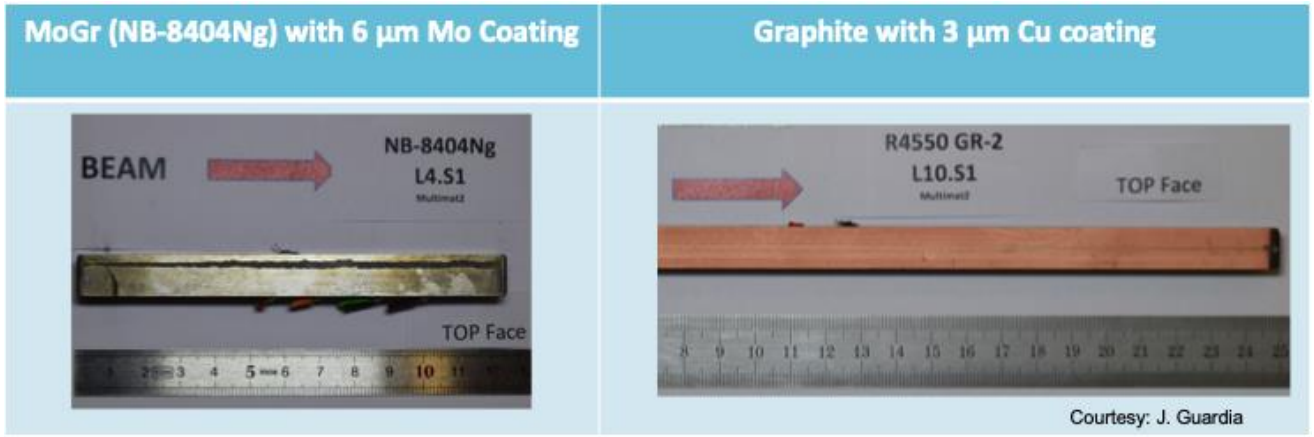
Liquid He boil off on DFX side

ECR in the writing…

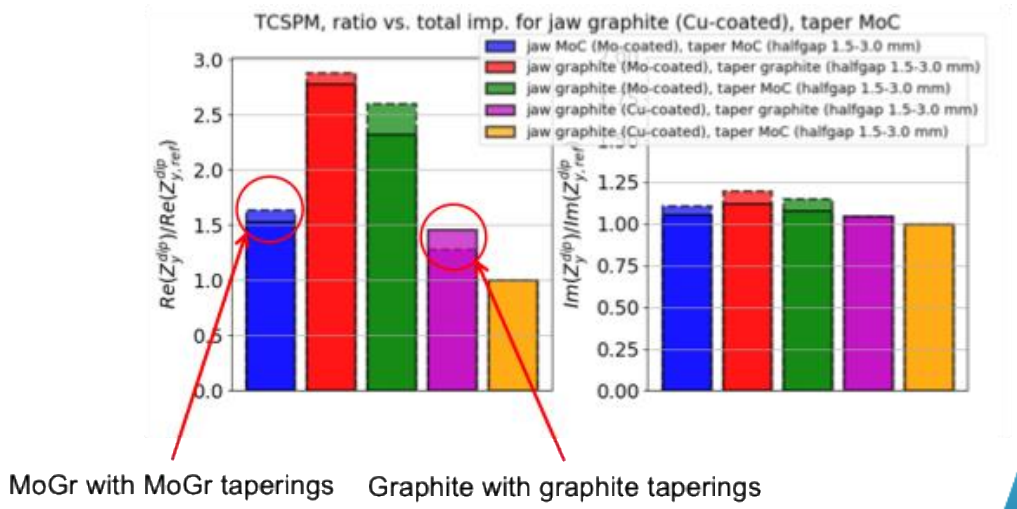
See A. Ballarino (Plenary Tue PM)

Change of Active Material for secondary Collimators

- 12 additional low impedance secondary collimators to be produced and installed during LS3 in IR7
  - 3 jaw materials studied MoGr (Mo Coating), Graphite (Mo Coating) and Graphite (Cu coating)
- Satisfactory beam impact tests performed in CERNs HighRadMat facility
- Impedance contribution studied in detail
  - Cu-coated graphite with graphite taperings is slightly better than Mo-coated MoGr with MoGr taperings
  - Cu-coated graphite taperings or MoGr taperings would further reduce RW impedance
- Decision: 12 TCSPM with Cu coated graphite jaws (taperings in graphite). Impedance measurements to accompany series production added (LHC-TCSPM-EC-0002)



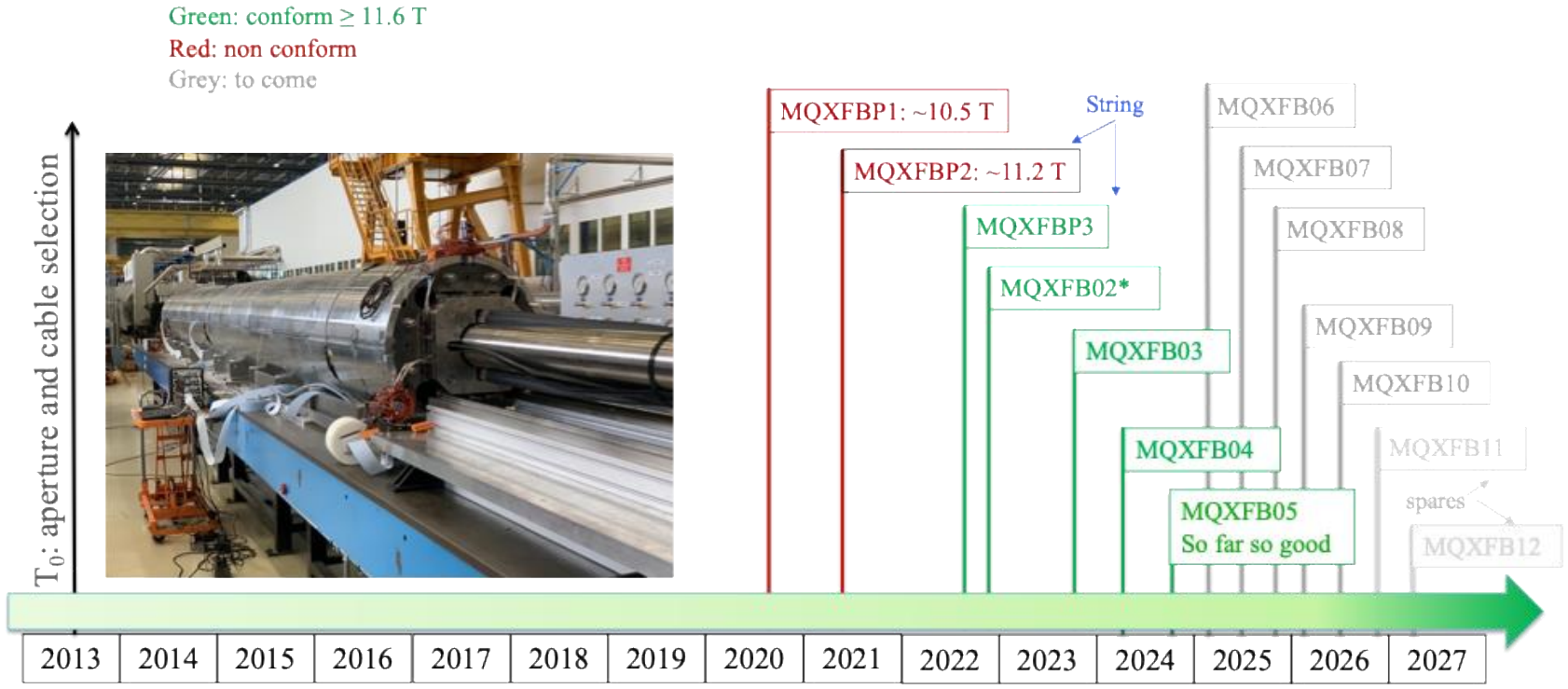
HighRadMat lasts results (Multimat 2) see Indico



See L. Giacomel (Parallel Tue PM)

MQXFB synoptic – towards completion of series production

- Following successful implementation of RoE from prototypes, all series magnets reached acceptance criteria
- Starting from MQXFB03 exclusively using new generation coils (without ceramic binder in outer layer)
- In order not interrupting coil and magnet production (quasi 100% yield in past 18 months) and to allow MQXFBP2 and P3 to remain in IT String, 2 more magnets added to baseline
- MQXFB03 - MQXFB10 to be installed in LHC (all using new generation coils), MQXFB11 (repaired MQXFB02) and MQXFB12 (new mechanical structure) to become operational spares - LHC-LQXFB-ED-0001



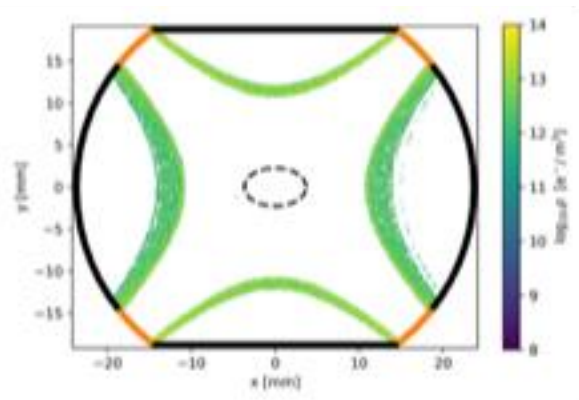
See E. Todesco (Plenary Mon AM)

Outline

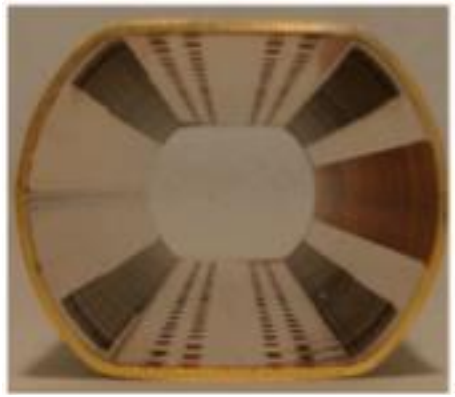
- TCC summary, main topics and decisions
- Layout and Baseline evolutions and statistics
- Main implemented HL-LHC baseline changes since annual meeting 2023
- Ongoing work / upcoming baseline changes
- Conclusions

E-cloud and heat loads

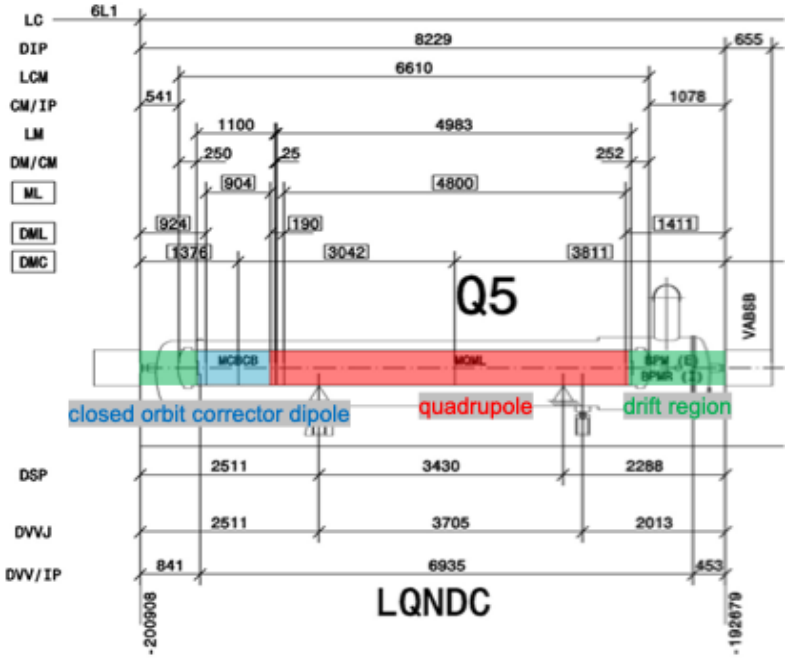
- Mitigation of e-cloud and resulting heat loads on cryogenic system and impact beam stability + transverse emittance remains one of the major challenges in reaching HL-LHC bunch intensities of 2.3E11 ppb.
- Beam Screen treatment project approved for LS3 (aC coating of ~20% of LHC arcs), hybrid beam schemes studied as fallback solution
- Continuous coating of IR1 and IR5 LSS (Q5-Q5) important for beam stability and as such part of HL baseline
  - Challenging for Q5 beam screens due to cryosorbers and Q4/Q5 BPMs due to activation
  - Alternative solutions studied to maintain baseline as much as possible -> Laser Engineering Surface Treatment



E'cloud simulation by
K. Paraschou



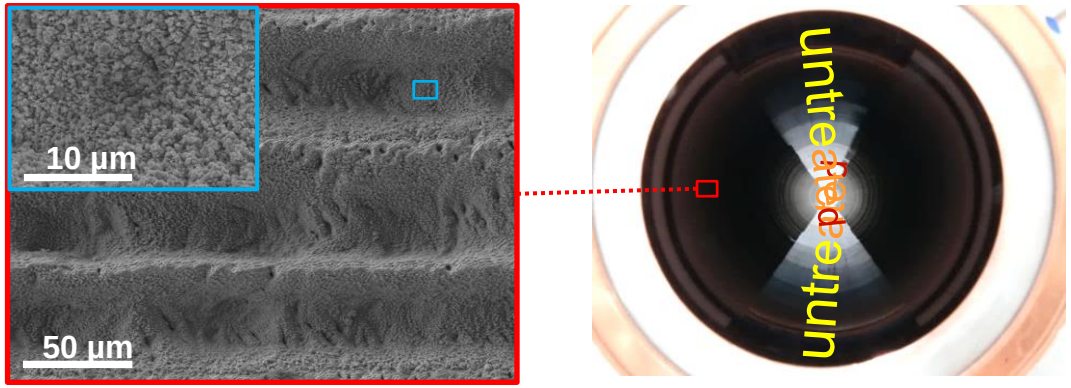
Selectively processed beam screen

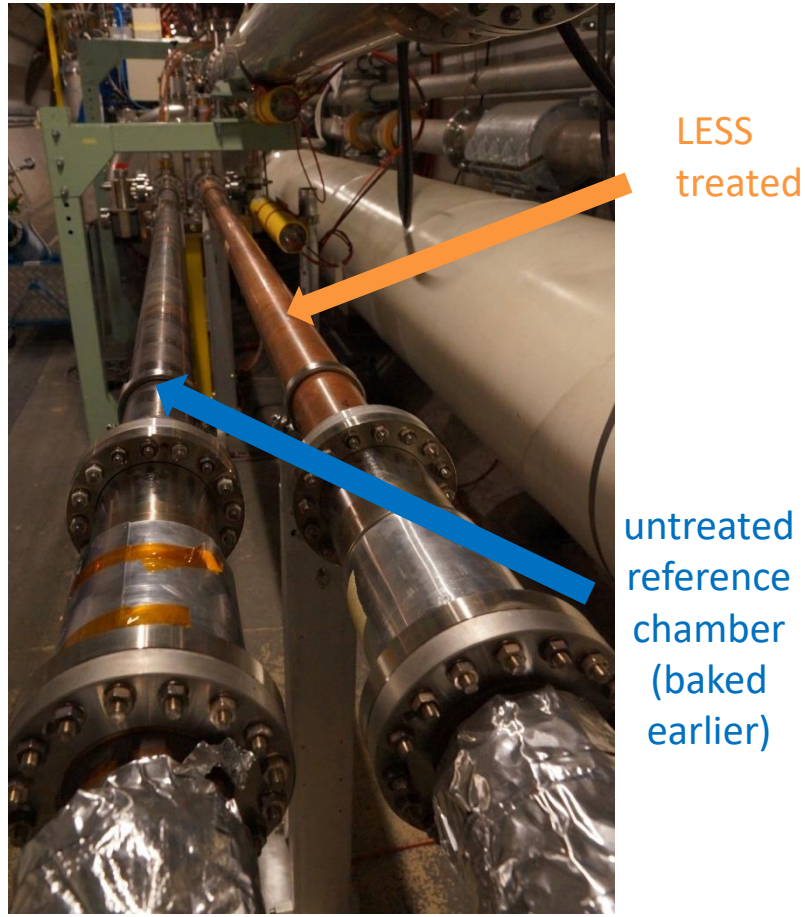


Acknowledgments: UK collaboration, M. Himmerlich et al

Laser-treated chamber for LHC validation

- 3.113 m test chambers installed in LSS6 in Nov' 2023 to validate operational behavior (focusing on beam interaction with dust particles)





- After almost 1 year of operation without impact on LHC availability, largest the dust particulate observed with diameter of d = 4-6 µm, factor 100 margin wrt to quench levels

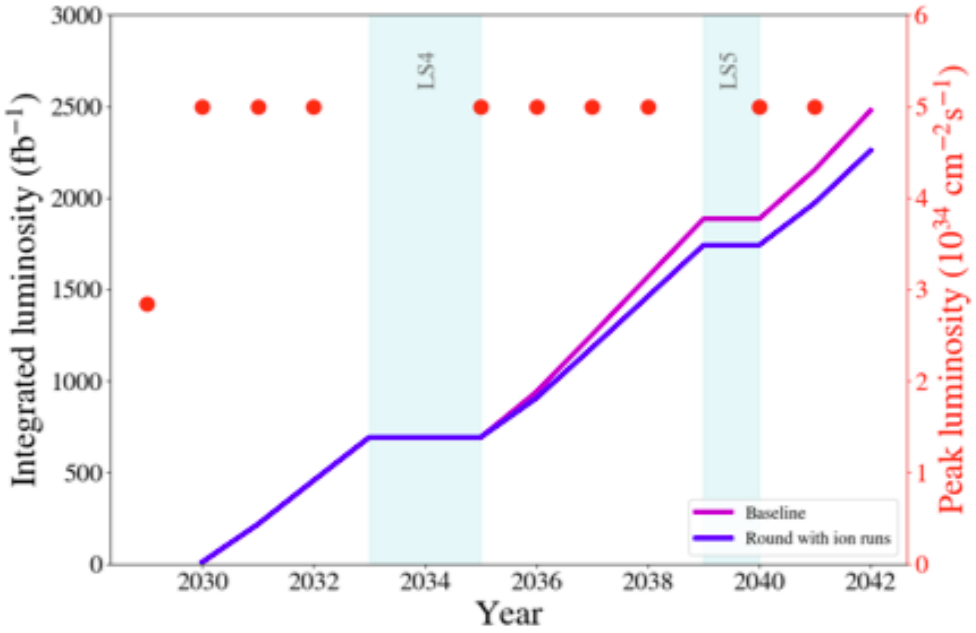
- Setup to be modified during YETS 2024/25 to complete validation program and prepare final decision for coating of Q5

LHC-VC-EC-0003, https://edms.cern.ch/document/2914342/1.0

Baseline parameters

- Recent operational experience in Run 3 (e-cloud) and descoping's (hollow e-lens, MKBH, 11T) triggered update and re-validation of the HL-LHC baseline parameter sets + optics variants (25ns 15cm round baseline, BCMS + 8b4e options)

- Mitigations for (partial) recovery being implemented / studied :
  - Beam screen treatment project (BST)
  - Flat optics (lower beta*) - BETS, MS@Q10, COLL jaw material, TCLM4 Mask in front of Q4 + potential swap of Xing planes already at start of Run 4
- First version of updated and more detailed breakdown of physics days in HL era for different scenarios released EDMS 2902691 (to be updated with new LS3 dates)



See N. Mounet et al, 199th HL-LHC TCC and S. Kostoglou, 288th WP2 meeting

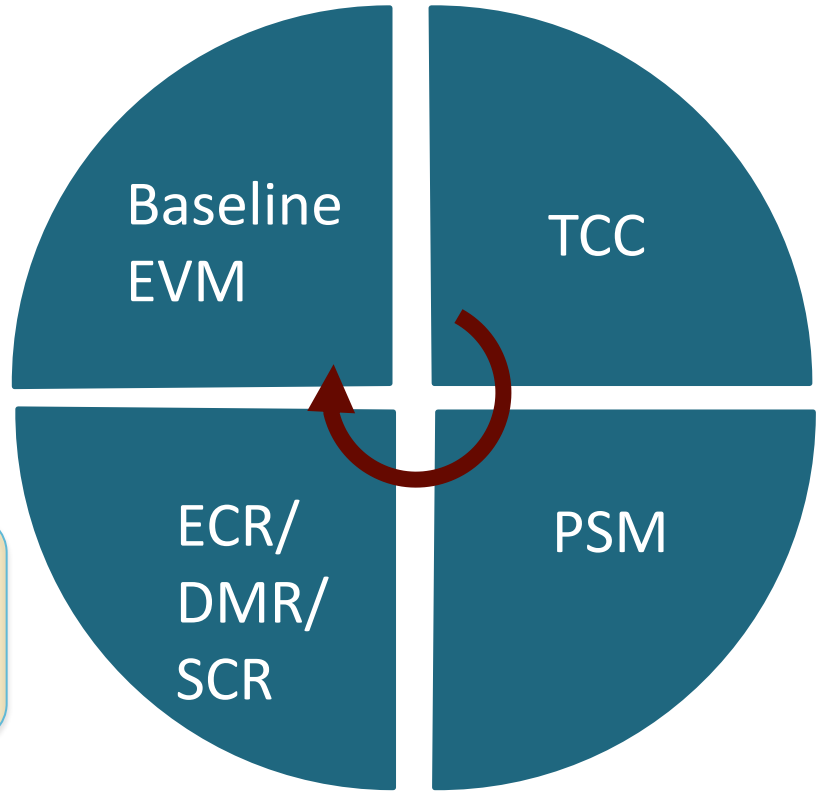
Conclusions

- One and a half years ahead of starting LS3, technical baseline has converged on all major aspects, focusing now on final details and value engineering
  - 18 Engineerig Change Requests (ECRs) + 11 Decision Management Reports (DMRs) approved
  - New Layout V1.8 approved in June 2024, final version V2.0 for LS3
- Update and re-validation of the baseline parameter set(s) in view of recent operational experience ongoing to confirm Run 4 start-up configuration
- Confirmation and further scrutiny of HL baseline to continue based on Run 3 experience and MD results (grateful for continued support by OP and Mgmt!)

Thank you for your attention!
Questions?

Managerial process

Baseline EVM:
Implementation of changes in WP's Cost-to-completion



Technical Coordination Committee:
Technical assessment and decision on **scope changes** and consequences on schedule/cost

Engineering Change request:
scope change assessment & approval
Decision Management Report:
Cost/schedule change

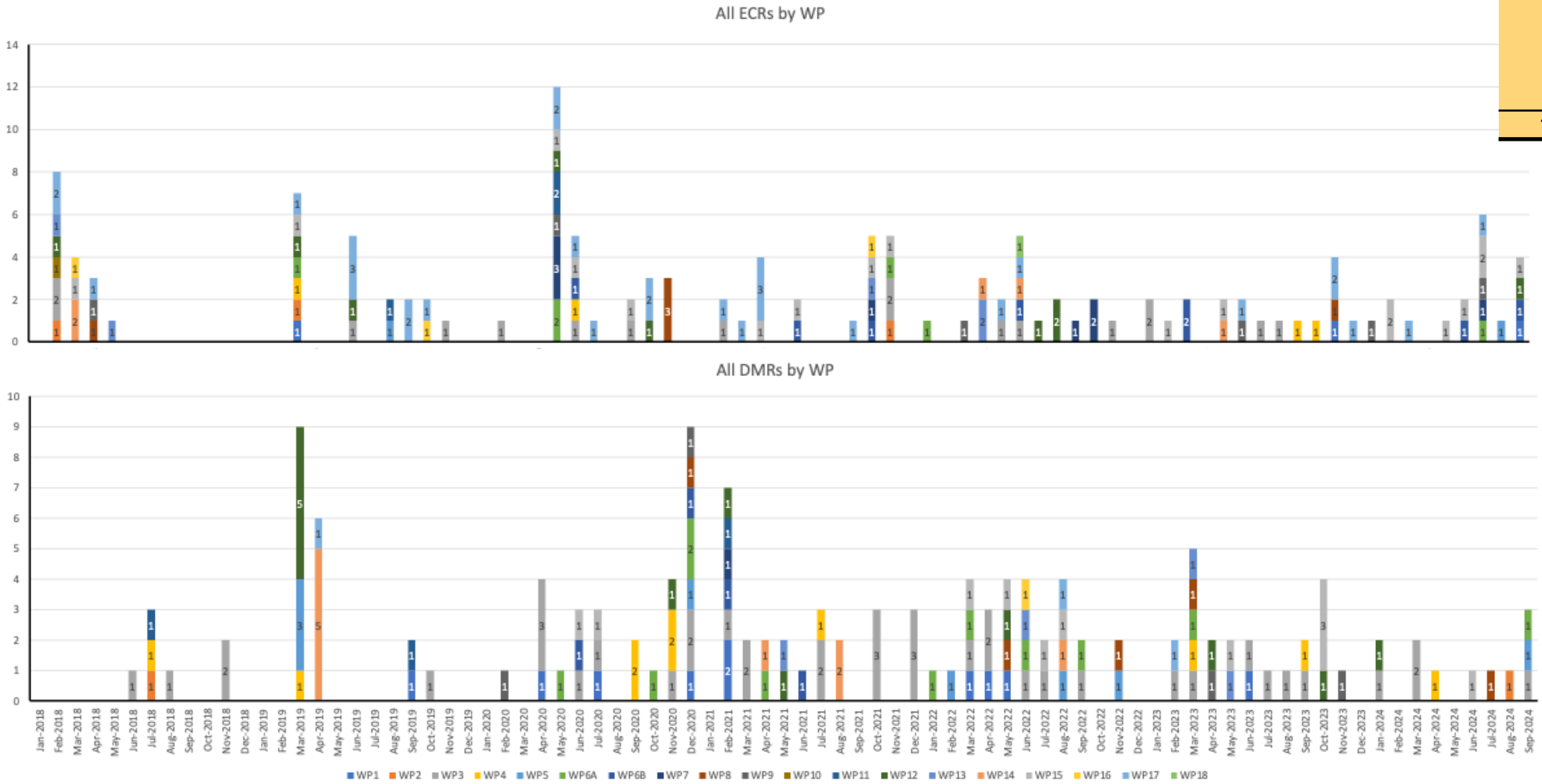
Schedule Change Request:
change impacting master schedule of WP/project

Project Steering meetings, per WP:
Assessment and decision on **budget changes** and **schedule changes**

Courtesy: G. Vandoni

ECRs and DMRs by WPs throughout the project

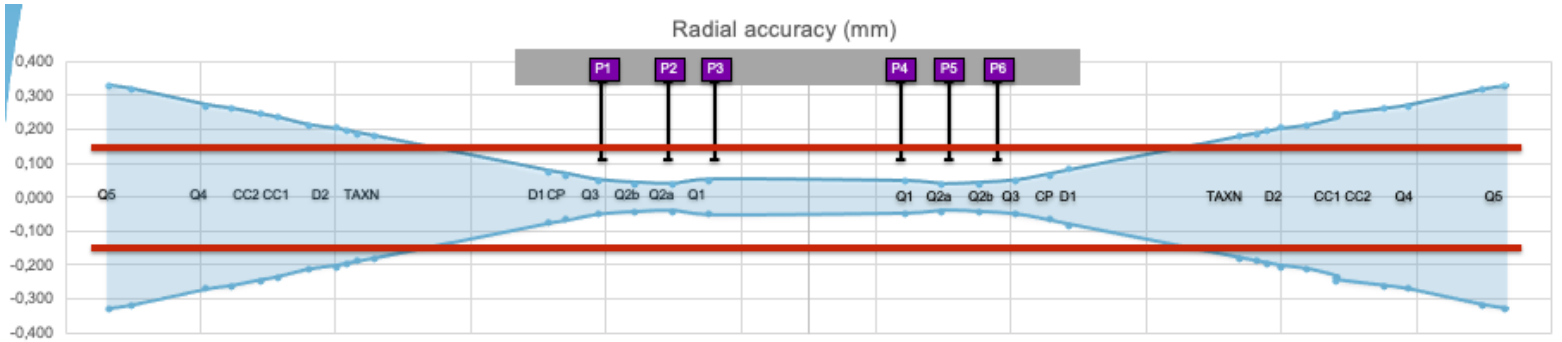
TOTALS	Qty
ECR	137
DMR	138
Total	275

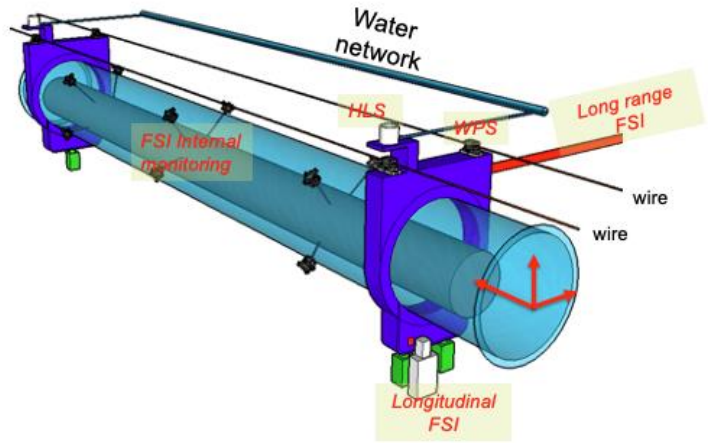


Courtesy: V. Guillen Humbria

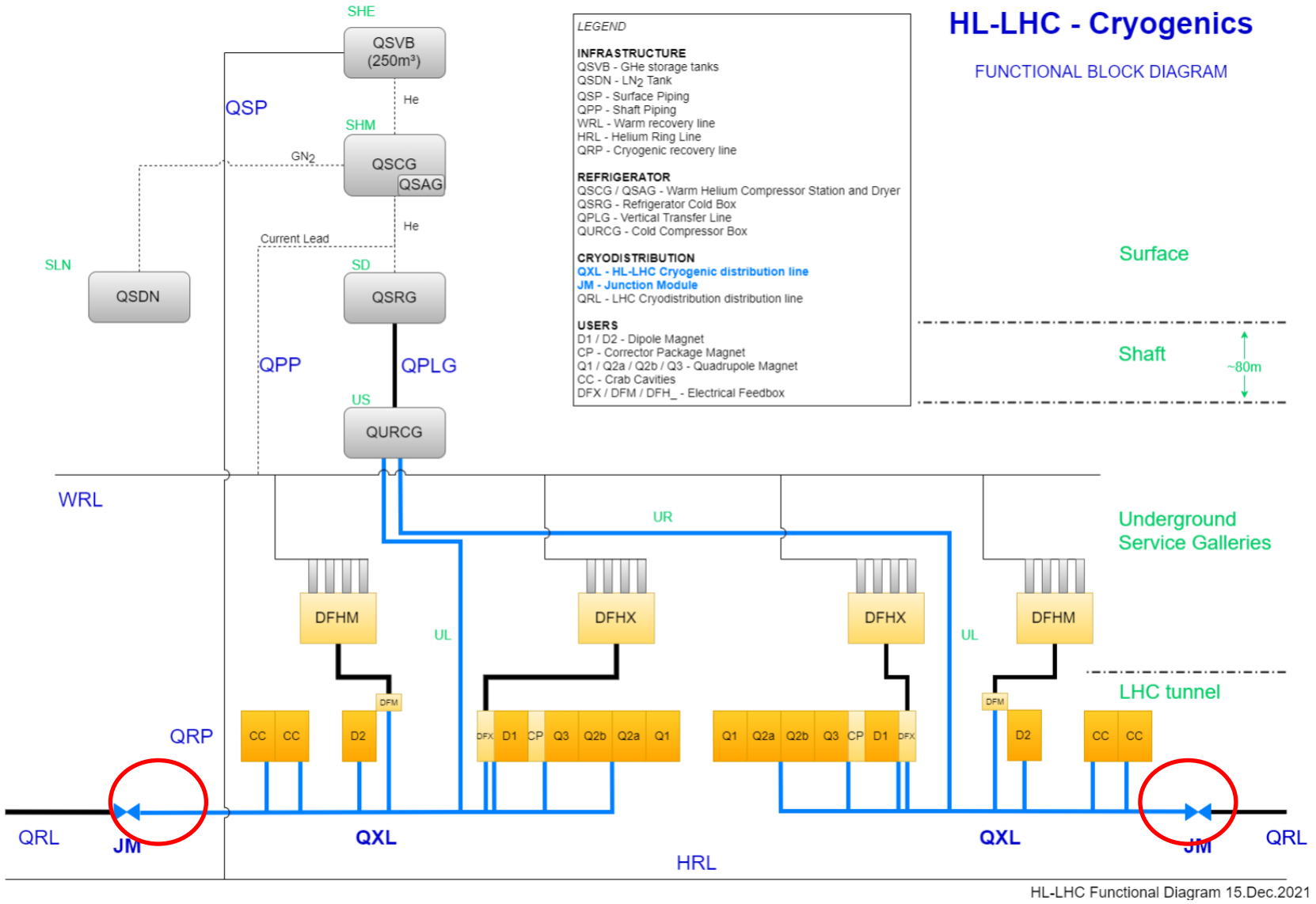
Additional sensors for Fully Remote Alignment (FRAS)

- To reach an maintain nominal beta*, the HL insertion region components need to be aligned with a radial accuracy of +-0.15 mm (1 σ) between two sides of Interaction Point (IP)
- Ensured by a system of stretched wires, water levelling systems & associated instrumentation and fully remote (motorized) alignment platforms/jacks
- Initial baseline was known to fall short of required alignment precision + reliability (see as well Review of HL Alignment and internal Metrology Aug ’19 + CSR’19 recommendation)
- Recent qualification of sensor accuracy and single components test stand confirmed new baseline proposal adding second stretched wire and updated distribution of alignment sensors
- Detailed ECR LHC-GI-EC-0007





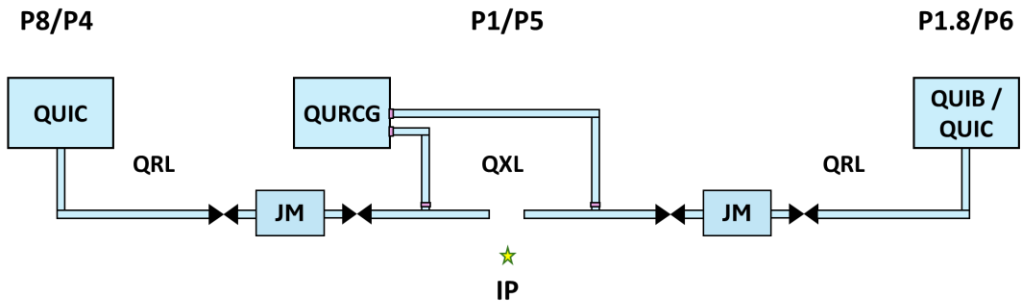
QXL – QRL junction module reconfiguration



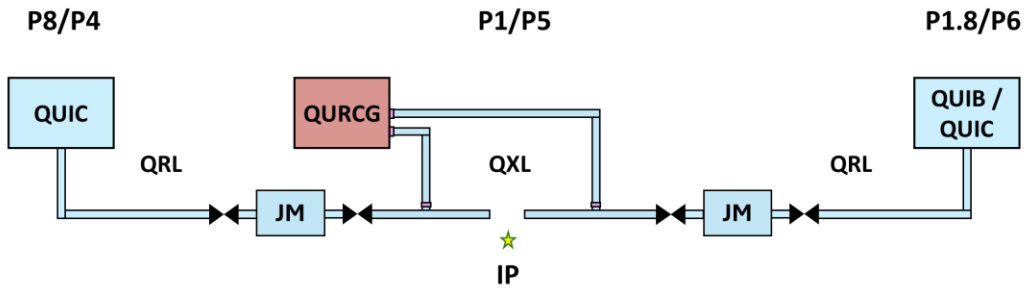
HL-LHC Functional Diagram 15.Dec.2021

QXL – QRL junction module reconfiguration

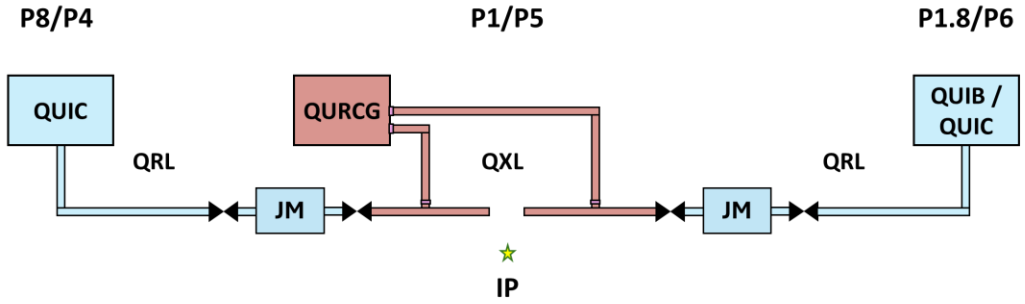
Nominal operation (HL-LHC)



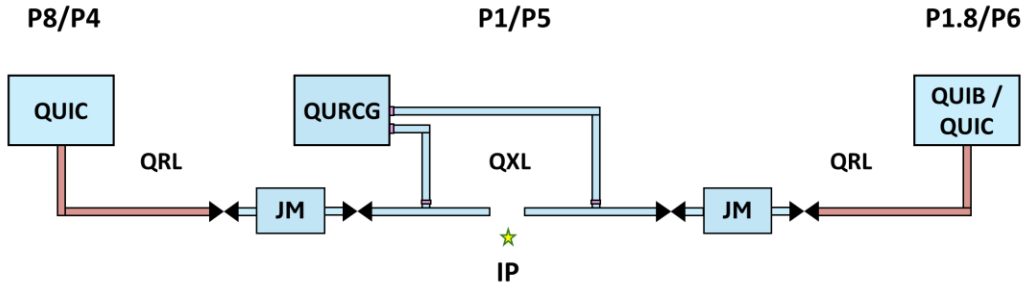
Degraded operation (LHC)



Cold stand-by / Maintenance



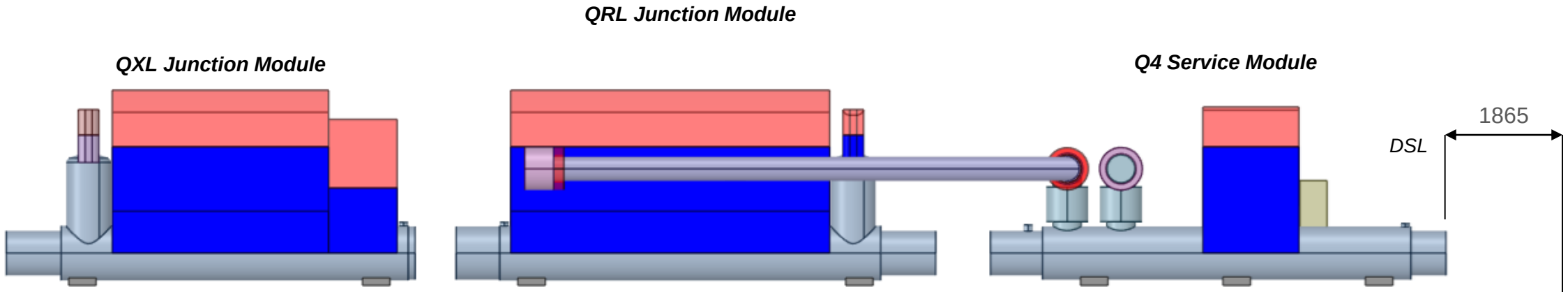
Maintenance / Cold stand-by



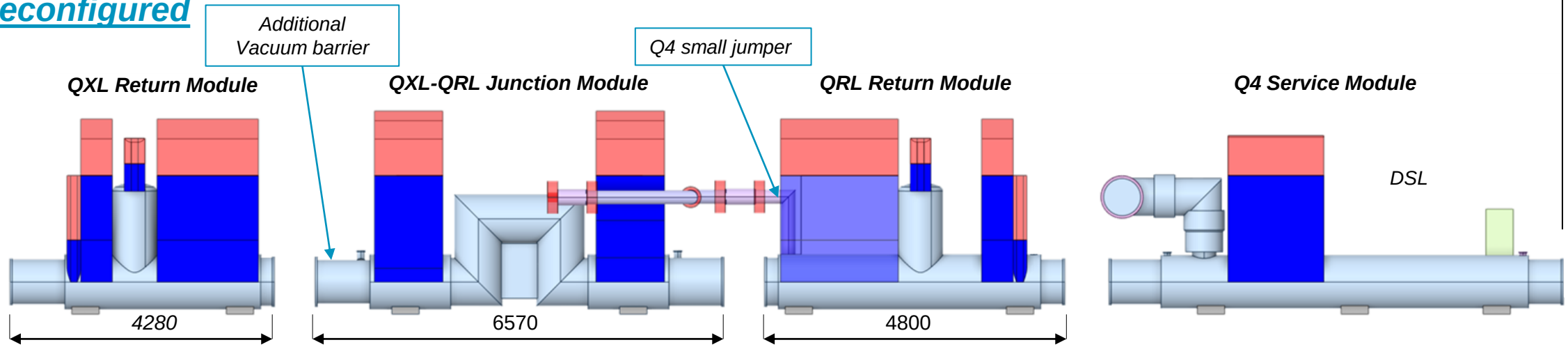
Junction module has an important role in allowing required Cold / warm configurations during HL lifetime

QXL – QRL junction module reconfiguration

Baseline

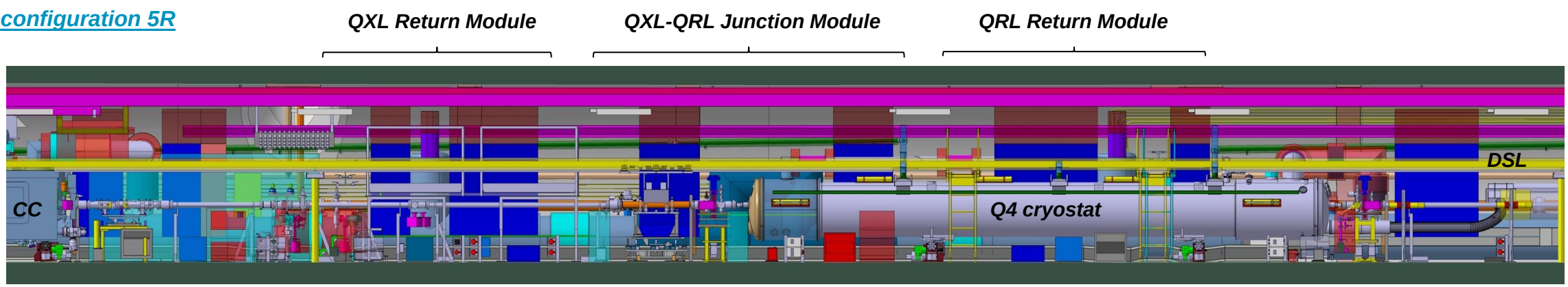


Reconfigured



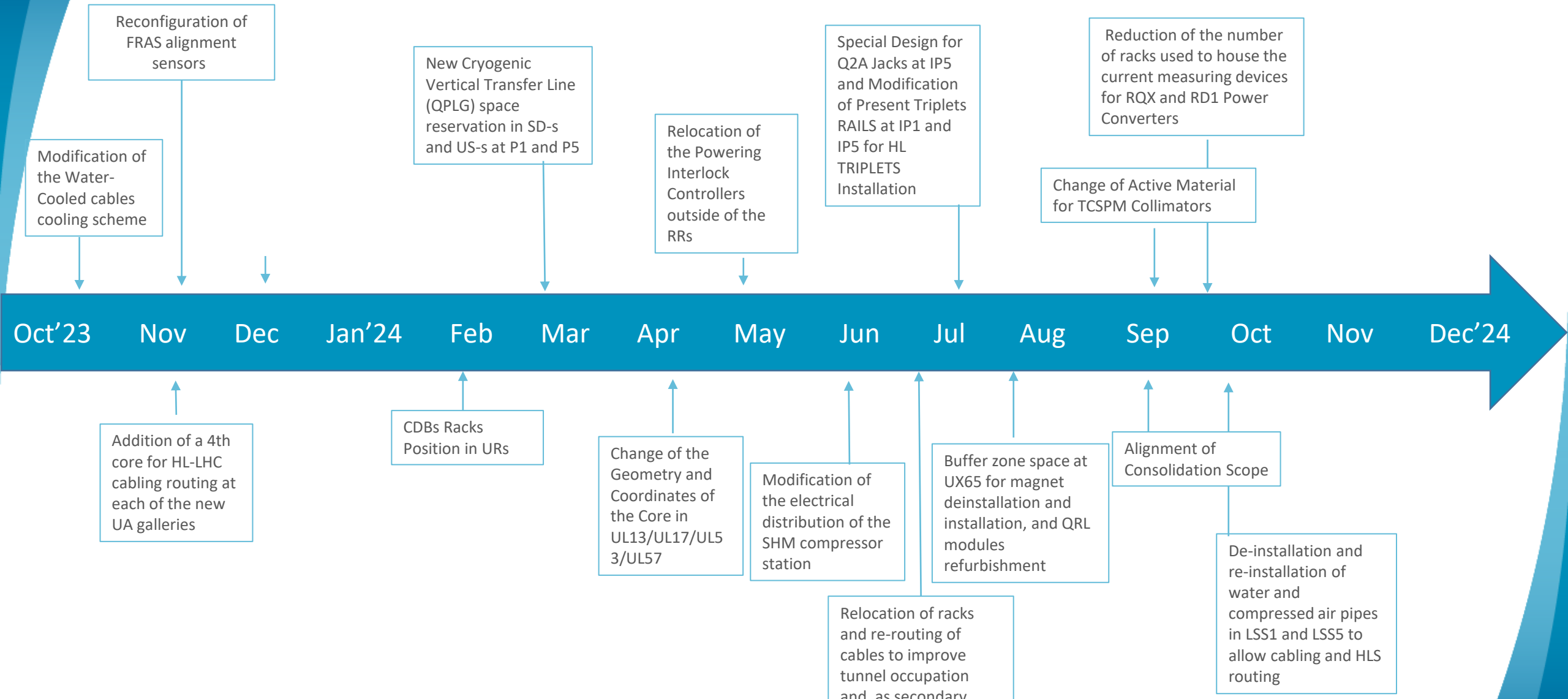
QXL – QRL junction module - Integration check

Reconfiguration 5R

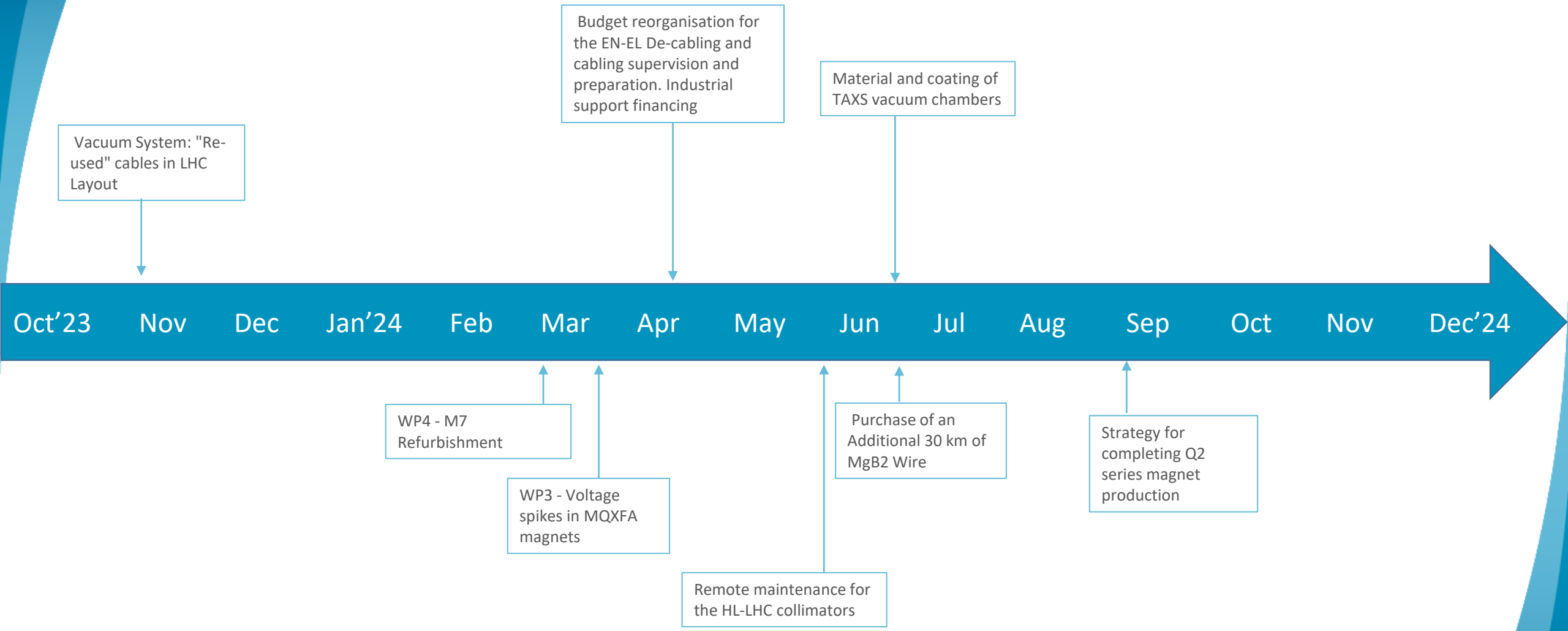


- Extremely dense area, several integration issues had/have to be resolved
  - Sectorization valves maintenance
  - Improve access for maintenance
  - Impact on cables length
  - Review localisation of the racks under the machine for vacuum and WP15
- Several changes are under agreement with equipment teams (magnet, vacuum, C&V)
  - Junction Modules sub-assemblies
  - Q4 Service Module layout
  - Additional vacuum equipment
  - Compressed air valves position to be shifted along the tunnel
  - Cooling water pipes manifolds position to be shifted along the tunnel

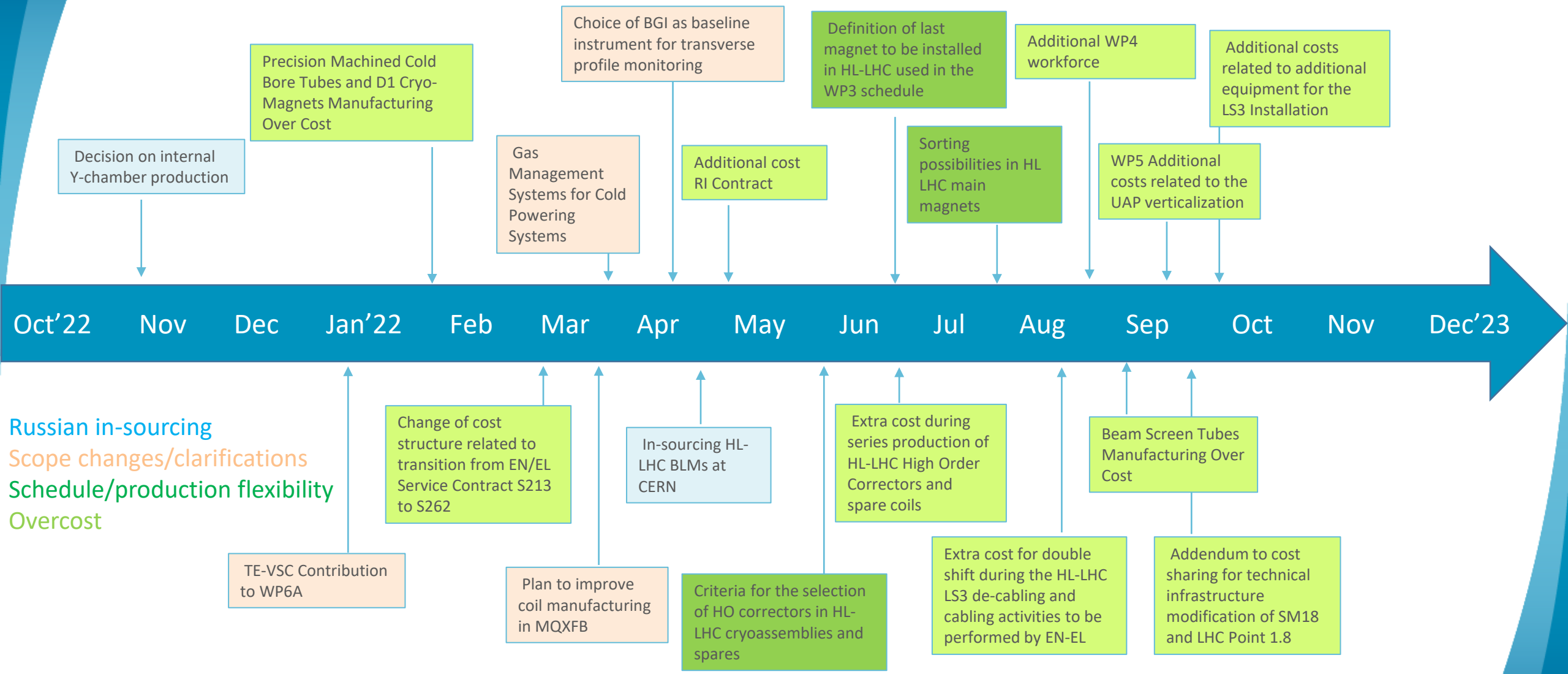
HL-LHC Baseline Changes (via ECRs/TCC)



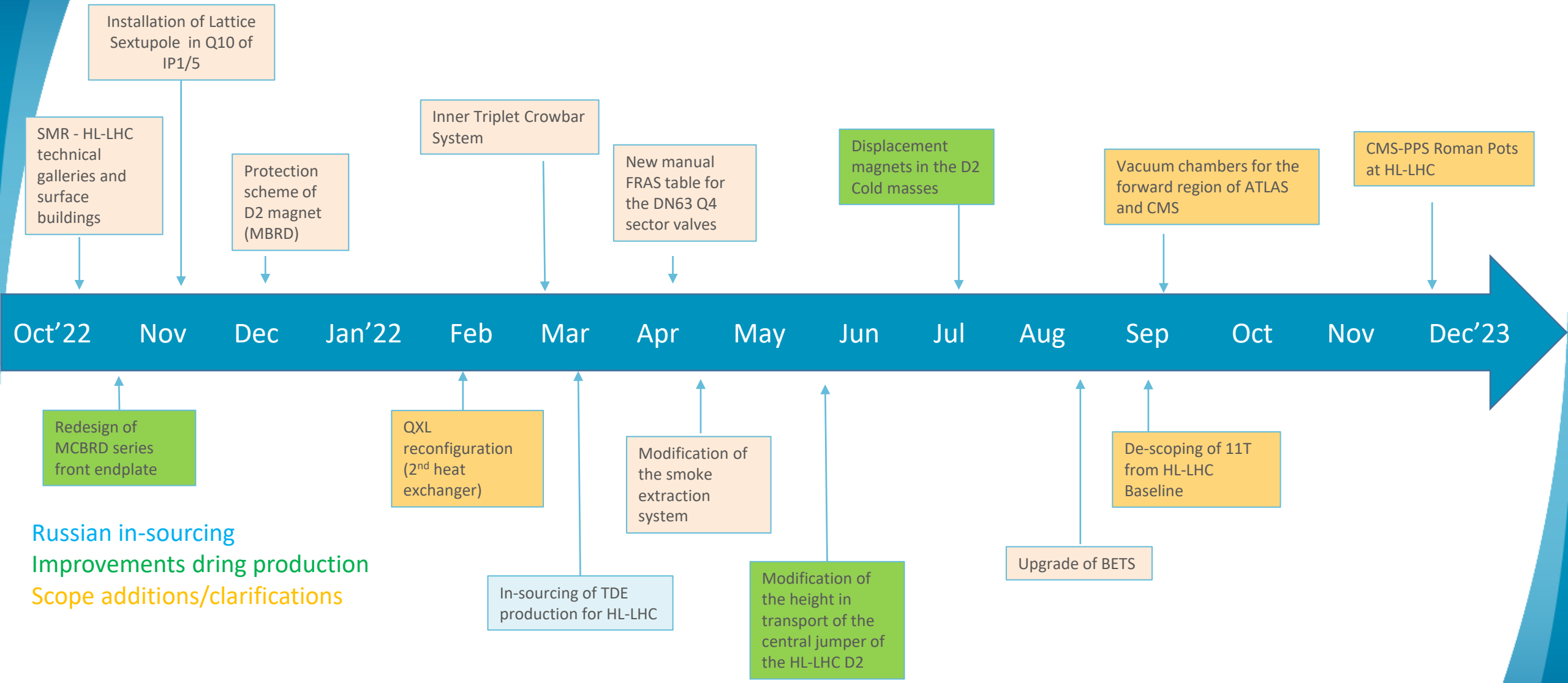
HL-LHC Baseline Changes (via DMRs/TCC)



HL-LHC Baseline Changes (via DMRs/TCC)



HL-LHC Baseline Changes (via ECRs/TCC)



Russian in-sourcing
Improvements dring production
Scope additions/clarifications