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LHC

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REFERENCE
LHC-LJ-EC-0054

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Date: 2024-10-01

ENGINEERING CHANGE REQUEST

Installation of the TWOCRYST Goniometers and Roman pot stations during YETS 24-25

BRIEF DESCRIPTION OF THE PROPOSED CHANGE(S):

TWOCRYST is a proof-of-principle to a potential future double-crystal based physics experiment in the LHC. TWOCRYST results must be gathered within the LHC Run 3. The required hardware shall be installed before the start of the 2025 run. The proposed TWOCRYST project hardware includes: one TCCS goniometer in vacuum cell A5R3.R; one TCCP goniometer for a long-bent crystal and a target in A4L3.R; and two Roman pot stations with two different detectors in A4L3.R. This setup is designed to address the TWOCRYST high-priority goals. This activity is within the scope of the Physics Beyond Colliders activity (LHC Fixed-Target WG).
The Optional installation of one scintillation detector mounted one top of the BPMW.4L3.B2 detailed in §3 will be the subject of a dedicated ECR in due course should the installation go ahead.

DOCUMENT PREPARED BY:	DOCUMENT CHECKED BY:	DOCUMENT APPROVED BY:
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DOCUMENT SENT FOR INFORMATION TO:

ATS Group Leaders, R2E, PBC-coordination.

SUMMARY OF THE ACTIONS TO BE UNDERTAKEN:

Opening of the vacuum pipe in sectors 5R3 (B2 only) and 4L3 (B1 and B2); installation of TCCS goniometer in sector 5R3, installation of TCCP goniometer and two Roman Pot stations in 4L3; bake-out and vacuum reconditioning; installation of 2 new BLMs; installation of secondary vacuum system for the Roman Pot Stations.

Note: When approved, an Engineering Change Request becomes an Engineering Change Order.

1. EXISTING SITUATION AND INTRODUCTION

TWOCRYST is a LHC machine experiment elaborated in the framework of the Physics Beyond Colliders study to collect crucial inputs for a novel future physics experiment under consideration, employing a double-crystal setup [1] to study magnetic and electric dipole moment of short-lived baryons like the Λ_c^+. TWOCRYST aims at demonstrating the proof-of-principle of the double-crystal setup and plans the installation in the LHC IR3 of two bent crystals to study, amongst others, the channelling efficiency of newly developed long bent crystals in the TeV range in the year 2025 [2]. The latter is crucial input to prepare a potential new LHC experiment that could be deployed in the HL-LHC era. This study is only possible at the LHC that gives access to the energy range of interest. A detailed proposal for such an experiment is currently under preparation by a proto-collaboration under the name ALADDIN (An LHC Apparatus for Direct Dipole moments INvestigation). Besides the channelling efficiency of the new bent crystals, TWOCRYST serves the purpose of gaining operational experience and validate performance estimates of such a setup.

The TWOCRYST setup involves two bent silicon crystals with distinct deflection properties: a 4mm crystal providing a 50 μrad deflection (Target Collimator Crystal for Splitting, TCCS) and a 70mm crystal delivering a 7 mrad deflection (Target Collimator Crystal for Precession, TCCP). While the former is identical to what is used in IR7 for beam collimation, the latter was never tested with hadron beam at the LHC energy range. Installed on LHC Beam 2, the TWOCRYST setup shall be used in dedicated Machine Development studies (MD), at energies of 450GeV, 1TeV, 3TeV, 5TeV and 6.8TeV, and at safe beam intensities for its initial phase. The setup will not be used in nominal physics operation with high intensity beams. The TWOCRYST activity was endorsed by the LHC Machine Committee (LMC) in July 2023.

2. REASON FOR THE CHANGE

2025 is the last year of LHC operation. The installation of the devices is crucial to complete the TWOCRYST physics program in the timeline required to demonstrate the feasibility of a future experiment in LHC Run 4. Failure to implement the devices will impede the success of both TWOCRYST and a future experiment.

3. DETAILED DESCRIPTION

The TWOCRYST setup requires the installation of several new devices in LHC LSS3:

- A high-precision goniometer with a 50μrad crystal (TCCS), see Figure 1 showing the goniometer and Figure 2 showing the TCCS crystal. The goniometer was recovered from IR7 (former TCPCV.A6L7.B1, ST1727900), where it was used for crystal-based collimation in the vertical beam plane [3]. In a physics experiment, the crystal is needed to split off beam halo particles to a large amplitude onto a target. A very exact angular alignment is needed: the high-precision goniometer used for the TCCS provides an angular control below 1 μrad and a linear step size of 5 μrad. The design of the goniometer is such that a replacement chamber can be used to surround the circulating beam in high intensity operation, to avoid impedance related beam instabilities or undesired heating. The position (DCUM) of the device was specified based on beam dynamics simulations to be ideally in the range 6775 ± 2. The TCCS will be installed from DCUM 6773.72 to 6774.12 [4].

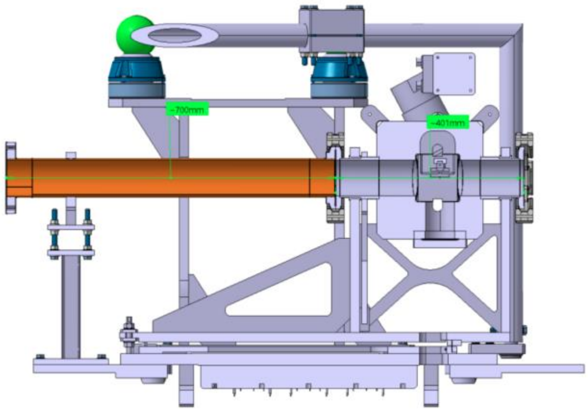


Figure 1 — TCCS Goniometer drawing. The tank containing the crystal is visible on the right hand side. Drawing ID ST172900.

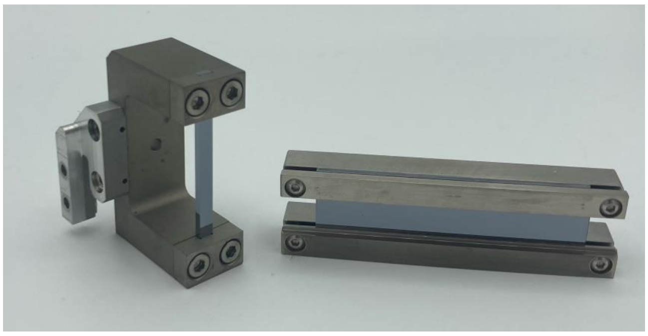
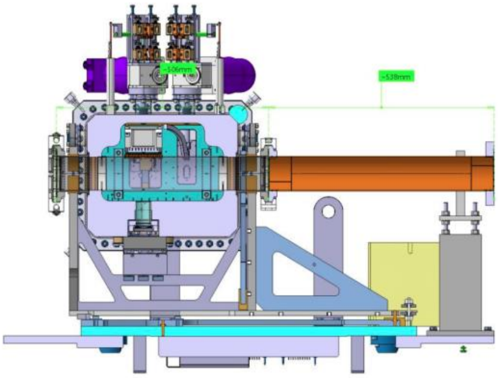


Figure 2 — TCCS crystal (left), TCCP crystal (right).

- A new high-precision goniometer holding the long TCCP crystal (7cm) with strong deflection (7mrad) with a movable integrated target (**TCCP**). The assembly was designed specifically for TWOCRYST (ID LHCTCCP_0003). It is designed to provide independent vertical linear motion of the TCCP crystal (see right hand side of Figure 2) and of a tungsten target 200μm upstream of the crystal. Additionally, it provides an angular precision of 1μrad for the alignment of the TCCP crystal. At the time of writing, the TCCP assembly is being constructed. The TCCP assembly is shown in Figure 3. The position (DCUM) of the device was specified based on beam dynamics simulations to be ideally in the range 6655 ± 2. The TCCP will eventually be installed from DCUM 6653.04 to 6653.55 [4]. Crystals and goniometer were designed and were/will be built based on the functional specifications defined by the BE-OP, BE-ABP and SY-STI [5].



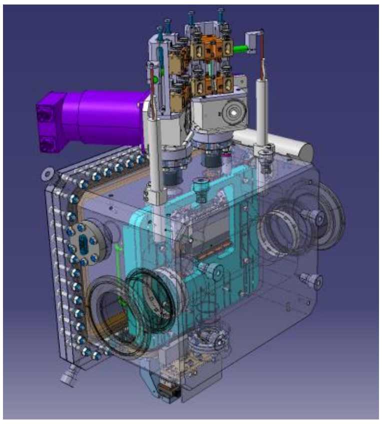


Figure 3 — TCCP assembly with target and TCCP crystal in the tank. Two RF bands were added to seal the gap between the inner beam pipe and the outer one, to reduce the impedance of the device. Drawing ID ST1756862.

- Two Roman Pot (RP) Stations to detect particles channelled by both crystals (TCCS and TCCP) simultaneously. The RP stations were already installed in LHC LSS1 and recovered from ATLAS-ALFA following the completion of its physics program after the successful 2023 run [6]. A new station mount was designed to account for the lower height of the beam pipe in LSS3, compared to LSS1 (a reduction of height of 15cm was necessary). Drawing ID ST1860748. The RP stations provide the possibility of mounting a 2D detector in a vertically movable Roman Pot, that can be moved in the direction of the beam. Two different detector types will be used in TWOCRYST, both with the aim of detecting channelled and double-channelled protons in the TWOCRYST MDs. The two detector types are described in the next bullet points.
- One Roman Pot station will be equipped with the TWOCRYST fiber tracker (TFT) detector. It is a 2D detector based with 1500 scintillating fibres arranged in 20 u/v detection planes, providing a spatial resolution of 30 μm [7]. It was provided to the TWOCRYST collaboration by the ATLAS-ALFA collaboration, after having been removed from LSS1, for the duration of the TWOCRYST activity.
- One Roman Pot station will be equipped with a 2D Silicon pixel detector (SPD) providing three 2D chips with 256x256 pixels each, with an active area of 1.6 x 4.2 cm. The detector package will consist in three layers of silicon sensors, inserted in a support structure made that will both provide mechanical support and thermic conductivity to help dissipate the heat. The heat produced in the operation of the detector is estimated to be lower than 40 W, and will be dissipated by an active cooling with a sealed Peltier element.
- To approach the detectors, close to the LHC beam, the Roman Pot is thinned down to about 200 μm in the dimension between the detector and the beam. This part is called the thin window. This feature is not strictly needed for the IR3 setup but was retained to minimize the new hardware to be built. To keep the thin window from bending, a secondary vacuum needs to be applied to the

detector volume. Since the bending of the thin window depends on pressure difference, the secondary vacuum pressure requirement is moderate: Some 10s of mBar. The design of the secondary vacuum system is illustrated in Figure 4 and described in detail in [8]. It will be based on two rotary vane pumps, which are frequently used in similar environments at CERN.

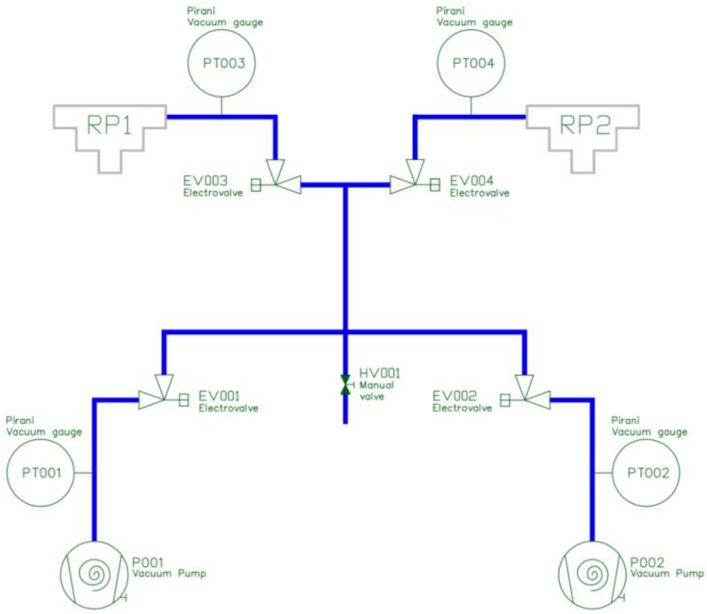


Figure 4 — Shared secondary vacuum system of the Roman Pot stations [8].

- Two BLMs – one BLM downstream of the TCCS and one downstream of the TCCP/RP stations. The DCUM of the one downstream of the TCCP/RP stations was optimized based on beam dynamics simulations and is ~6647.8m, see details in the BLM integration study EDMS 3129362.

The TWOCRYST activity is completed at the start of LS3 and all devices might be removed during LS3 if the MD goals are satisfactorily competed within Run 3.

3.1 INTEGRATION

The official 3D differential layout drawings can be found in Smarteam under the following references: Smarteam ST1783887_2 (5R3), ST1783800_02 (4L3).

3.1.1 IR3 Vacuum Layout Modifications

The modifications to the vacuum layout are described in detail in EDMS document 3121958.

3.1.1.1 Vacuum layout modifications in A5R3

The differential layout for vacuum sector A5R3 is shown in Figure 5.

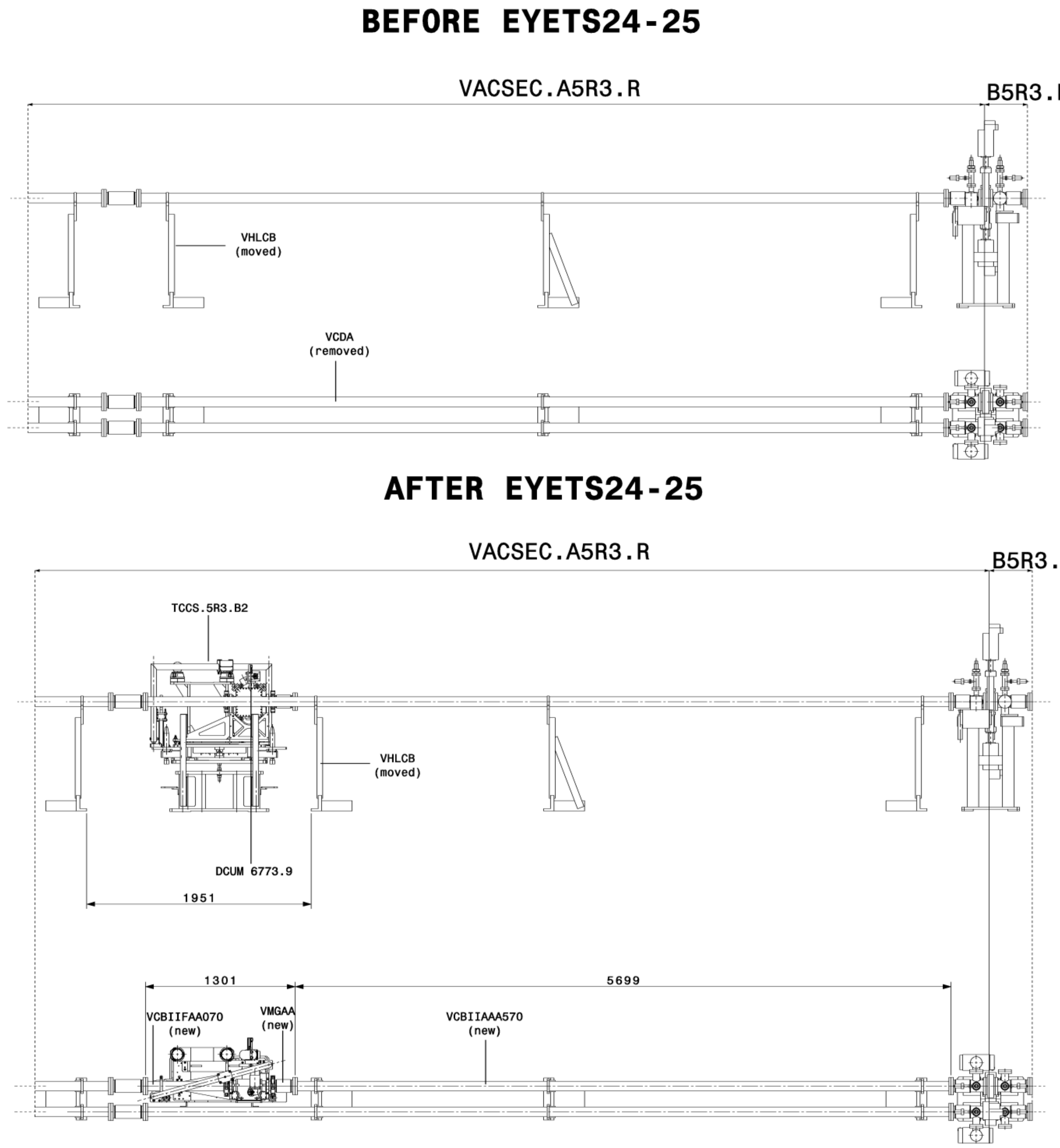


Figure 5 — Differential layout in vacuum sector A5R3, EDMS **3118297**, CERN CDD **LHCLJ 3U0048**, Smarteam **ST1783887_2.**

3.1.1.2 Vacuum layout modifications in A4L3

The differential layout for vacuum sector A4L3 is shown in Figure 6.

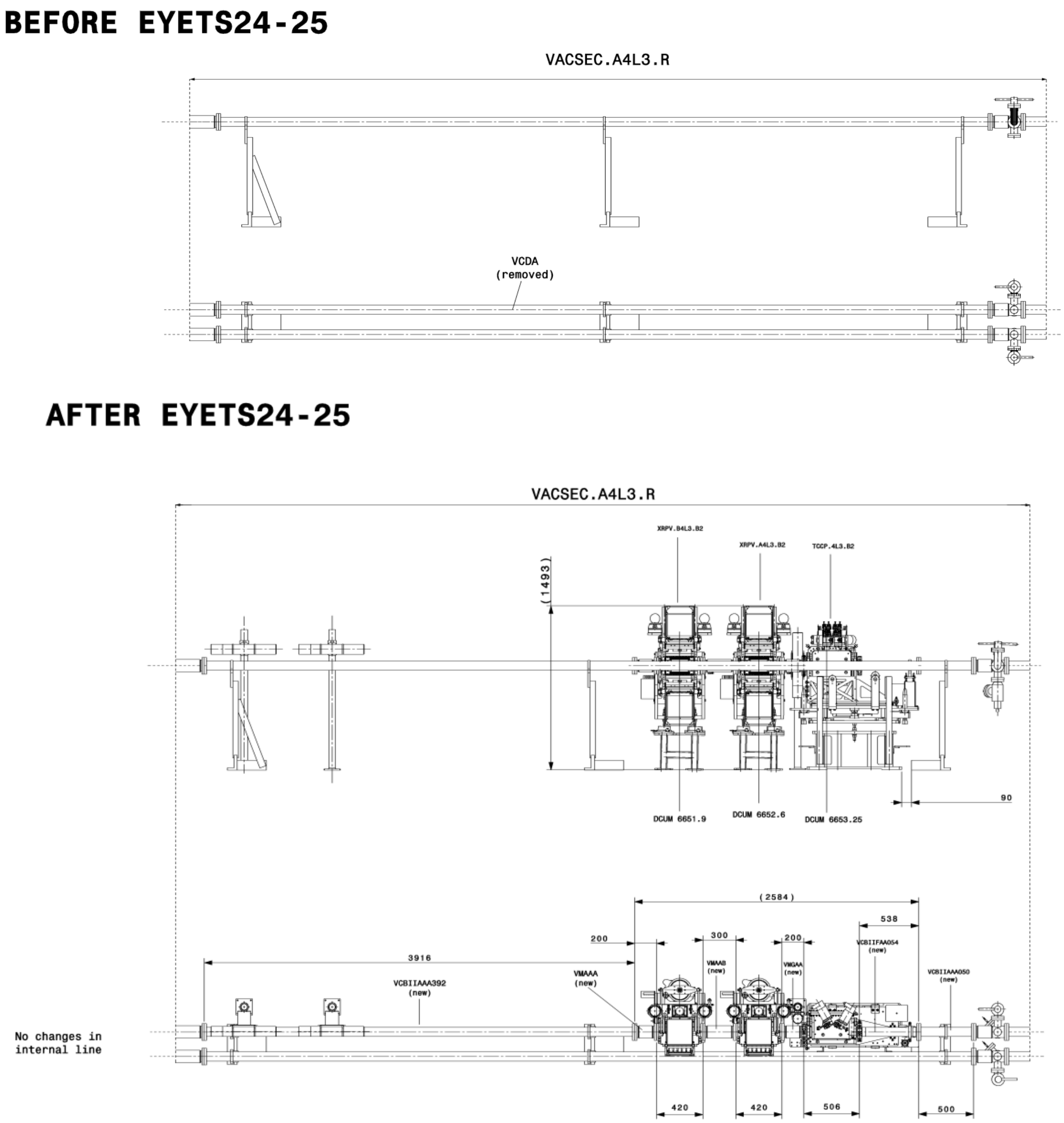


Figure 6 - Differential layout, EDMS **3105243**, CERN CDD **LHCLJ_3U0047**, Smarteam **ST1783800_02**

4. IMPACT ON ITEMS/SYSTEMS

Integration / Layout	The LHC layout database and the installation drawings must be modified in accordance with EDMS 3121958. A brief description is given in Chapter 3.
Collimation	Controls of the new devices must be integrated in the LHC OP system using the existing collimation controls.

BLM	Two BLMs will be installed as agreed with the SY/BI team. One BLM detector in 5R3 and one in 4L3. Details in https://its.cern.ch/jira/browse/BIBML-2879 In 5R3 there are BLM channels and cables available for the installation. In 4L3 there are no BLM channels/cables available. The plan is to disconnect and use a BLM previously assigned to an empty collimation slot. Agreed between SY/BI and BE/ABP. Channel name is BLMEI.04L3.B2E10_TCSM.4L3.B2. BLM database must be updated, and BLM signal must be integrated into the BLM fixed display and NXCALS. Available channels will be identified by the SY-BI team. SY-BI support needed for mounting/dismounting of the BLMs.

4.1 IMPACT ON UTILITIES AND SERVICES

Raw water:	Not needed.
Demineralized water:	Demineralized water needed for the cooling of the Peltier used for the SPD.
Compressed air:	No compressed air needed.
Electricity, cable pulling (power, signal, optical fibres…):	Six 220V power plugs close to Roman Pot stations. One 400V AC power supply for the secondary vacuum (3 phase, 16A) needed at the rack location **VY15**. RQF2764736 One 400V AC power supply for the secondary vacuum (3 phase, 16A) needed at the rack location **VY17**. RQF2764736 One power cable (230V monophase 16A) needed to go to rack **PYMR01** in UJ33/U0. RQF2775901 Motion controls will re-use the cabling of the TCSM slots TCSM.A4L3.B2 and TCSM.C5R3.B2.
DEC/DIC:	**Cables**: RQF2632571 RQF2764736 RQF2775901 **Optical fibres**: RQF2602015
Racks (name and location):	New racks could not be installed in UJ33. TWOCRYST has agreed with rack owners of partially occupied racks to use their following existing rack space in UJ33: **Secondary vacuum electronics in VY15** **TFT electronics in VY17** Rack owner / technical contact: Gregory Pigny (TE-VSC) **SPD electronics in PYMR01**

	Rack owner Daniel Perrin (HSE-RP), technical contact Jeremy Rosset-Lanchet **SPD electronics in MYWIC01** Rack owner / technical contact Richard Mompo (TE-MPE)
Vacuum (bake outs, sectorization…):	Vacuum sectors A5R3.R and A4L3.R must be vented and 2 7-meter NEG vacuum chambers removed to introduce: The TCCS (sector A5R3.R) and the TCCP plus two RP stations (sector A4L3.R), and the surrounding vacuum elements required. Bake-out elements must be installed followed by the reconditioning of the sectors (NEG activation) for a total of 3.5 weeks per sector. Due to the RP station dimensions and the tunnel geometry, one 7m long vacuum chamber for B1 needs to be removed in cell A4L3.R to move the Roman Pot Stations into position. In cell A5R3.R, the device can be lifted across the B1 beam pipe and only the B2 beam pipe needs to be opened.
Special transport/ handling:	New vacuum chambers (L=5700 and 3916mm) should be transported from IR2 or IR4 due to the limited room available on IR3 lift. Handling and transport procedure of the RP stations will be communicated to the transport team. Transportation of RP stations can be done via elevator on a pallet. The RP stations were installed in the LHC before and are classified as radioactive and must be handled as such. They will need to be transported from the lab space in Prevessin to IR3. TFT and adjacent equipment is classified as radioactive and must be transported from the laboratory space (304/1-004) to LSS3 accordingly. SPD needs slow transport from VELO laboratory (Meyrin site). It is fragile and correct orientation must be maintained. TCCS and TCCP stations must be transported as TCPC crystal collimator goniometers -> Detailed description in the TCPC Installation Procedure 2644146 v.1. The TCCS station was in the LHC tunnel before and is classified as radioactive.
Temporary storage of conventional/radioactive components:	No temporary storage needed.
Alignment and positioning:	Alignment / survey needed in line with requirements applied to crystal collimators (TCPC) in the past for the TCCS and TCCP. BE-GM support with laser tracker during crystal alignment needed. BE-GM support needed for the alignment and calibration of the RP stations in the LHC tunnel.
Scaffolding:	Not needed.
Controls:	Identical to existing crystal collimators (for TCCS) and to existing RP stations. For the TCCP – motion interlocks identical to the existing standard collimators.
GSM/WIFI networks:	Not needed.

Cryogenics:	Not needed.
Contractor(s):	None
Surface building(s):	No
Integration:	For TCCS - Integration C5R3 - Integration 3D Models: ST1783887_01 v.a.00 & ST1887938_01 v.a.00 - Differential Drawings: LHCLJ_3U0048 v.0 - 3D Models: ST1727900_01 v.A.00, ST1773749_01 v.a.00 & ST1870053_01 v.a.00 For TCCP plus Roman Pot Stations - Integration C4L3 - Integration 3D Models: ST1783800_01 v.a.03 & ST1876357_01 v.a.01 - Differential Drawings: LHCLJ_3U0047 v.0 - 3D Models: ST1876375_01 v.a.00, ST1783792_01 v.a.01, ST1756862_01 v.a.00 & ST1870079_01 v.a.00 Drawings for the individual devices to be installed: - TCCS.5R3.B2: ST1727900 - TCCP.4L3.B2: ST1756862 - XRPV.A4L3.B2 and XRPV.B4L3.B2: ST1860748
Others:	No

5. IMPACT ON COST, SCHEDULE AND PERFORMANCE

5.1 IMPACT ON COST

Detailed breakdown of the change cost:	Cost covered by the TWOCRYST project (within PBC).
Budget code:	PBC / TWOCRYST 61701

5.2 IMPACT ON SCHEDULE

Proposed installation schedule:	EYETS 2024/2025
Proposed test schedule (if applicable):	
Estimated duration:	TE/VSC: 3.5 weeks of work per vacuum sector, including: Venting, layout modifications, installation of the bakeout, NEG activation and final commissioning. SY/STI: 2 weeks needed, in collaboration with BE/CEM, GM, can partially overlap with TE/VSC.
Urgency:	High

Flexibility of scheduling:	Installation must be completed in EYETS 2024/2025.

5.3 IMPACT ON PERFORMANCE

Mechanical aperture:	The mechanical apertures corresponding to the transverse apertures in parking are 40mm (radius, circular aperture) for all new devices installed (TCCS, TCCP, RP stations). This is identical to the dimensions of the surrounding beam pipes.
Impedance:	All devices will operate with low-intensity beams only. Impedance simulations were conducted to assess the impact of impedance on heating, as well as on the transverse and longitudinal dynamics during nominal LHC operation with high intensity beam, when they are retracted to "parking" position and are far from the beam. For the TCCS, the established concept of a replacement chamber was applied. In the case of the TCCP, detailed simulations resulted in design optimization by adding two RF bands to bridge the gap between the inner and outer beam pipes. The Roman Pots, installed without issue until 2023, had undergone detailed impedance studies beforehand. External cooling is not needed for either of the devices. The devices were approved for their intended use and scope by the Impedance Working Group (#91) on September 20, 2024. The devices are planned to be removed in LS3, thus the approval from the Impedance Working Group is only valid until LS3.
Optics/MADX	New functional positions need to be inserted/modified in the layout database and acc-models-lhc repository updated. No impact on machine optics.
Electron cloud (NEG coating, solenoid…)	No particular e-cloud effects expected
Insulation (enamelled flange, grounding…)	No change.
Vacuum performance:	TE-VSC will perform vacuum acceptance tests on each component to assess vacuum compatibility prior to any assembly/installation within the LHC vacuum environment based on EDMS 1752123. In case of not conformities, the components could be rejected and not being installed.
R2E impact on performance and availability:	Hardware is not critical for LHC performance or safety. TWOCRYST informed/contacted R2E project lead and awaits assessment.
Others:	

6. IMPACT ON OPERATIONAL SAFETY

6.1 ÉLÉMENT(S) IMPORTANT(S) DE SECURITÉ

Requirement	Yes	No	Comments
EIS-Access		x	
EIS-Beam		x	
EIS-Machine		x	

6.2 OTHER OPERATIONAL SAFETY ASPECTS

What are the hazards introduced by the hardware?	Standard materials and design. No new hazards introduced. Procedures to protect from moving parts will be established in analogy to existing crystal collimators and RPs.
Could the change affect existing risk mitigation measures?	No.
What risk mitigation measures have to be put in place?	N/A
Safety documentation to update after the modification	N/A
Define the need for training or information after the change	N/A

7. WORKSITE SAFETY

7.1 ORGANISATION

Requirement	Yes	No	Comments
IMPACT – VIC:	X		
Operational radiation protection (surveys, DIMR…):	X		A common WDP should be validated by RP for each step of the installation: mechanical, installation, bake-out and NEG activation, commissioning, drilling, detector integration...
Radioactive storage of material:	X		The 2 7-meter NEG vacuum chambers removed from the vacuum sectors will be temporarily stored in the tunnel PZ33 (towards the QRL) until LS3.

Requirement	Yes	No	Comments
Radioactive waste:	x		Yes, bolts, gaskets.
Non-radioactive waste:		x	No waste expected.
Fire risk/permit (IS41) (welding, grinding…):		x	None.
Alarms deactivation/activation (IS37):		x	
Electrical lockout:		x	SPD: no electrical lockout required. (Possibly in the alcove if required by BE/CEM. To be confirmed)
Others:		x	

7.2 REGULATORY INSPECTIONS AND TESTS

Requirement	Yes	No	Responsible Group	Comments
HSE inspection of pressurised equipment:				
Pressure/leak tests:	X		TE/VSC	Helium leak test of the crystal collimators and Roman Pots before and after bake-out cycle is performed.
HSE inspection of electrical equipment:				
Electrical tests:				
Others:				

7.3 PARTICULAR RISKS

Requirement	Yes	No	Comments
Hazardous substances (chemicals, gas, asbestos…):		x	N/A
Work at height:		x	N/A
Confined space working:		x	
Noise:		x	
Cryogenic risks:		x	
Industrial X-ray (*tirs radio*):	x		X-ray on Warm Modules after bake-out cycle

Ionizing radiation risks (radioactive components):	x		TFT detector and RP stations are radioactive, and transport will be requested via TREC. The Peltier contains Bismuth which can be transformed into Po-210 in the high radiation environment of the LHC. The quantities are estimated to be very low (potential effective dose << 100 μSv in a very pessimistic intake scenario). It was agreed with the HSE team to use a sealed Peltier to limit the radiation risk, discuss the manipulation with HSE-RP in advance and ensure traceability of the equipment for future disposal. Full documention in EDMS 3133281.
Others:			

8. FOLLOW-UP OF ACTIONS BY THE TECHNICAL COORDINATION

Action	Done	Date	Comments
Carry out site activities:			
Carry out tests:			
Update layout drawings:			
Update equipment drawings:			
Update layout database:			
Update naming database:			
Update optics (MADX)			
Update procedures for maintenance and operations			
Update Safety File according to EDMS document 1177755:			
Others:			

9. REFERENCES

[1] Achille Stocchi et al., “Measuring magnetic moments with bended crystal”, PBC kick-off meeting, CERN, 06.09.2016.

[2] Pascal Hermes et. al, “TWOCRYST, a proof-of-principle for a double-crystal based FT experiment at the LHC”, Presentation at the Physics Beyond Colliders Annual Workshop 2024, 25.03.2024.

[3] Stefano Redaelli et. Al, “Crystal collimation of heavy-ion beams”, Published at IPAC 2024, Nashville, TN, USA.

[4] Cesar Vazquez Pelaez, "VACUUM LAYOUT EXCHANGE FOR THE TWOCRYST PROJECT", EDMS 3121958, [2024].

[5] Q. Demassieux, K. Dewhurst, A. Fomin, P. Hermes, D. Mirarchi, S. Redaelli, R. Seidenbinder, "Functional Specification - [TCCS/TCCP] FUNCTIONAL AND OPERATIONAL CONDITIONS FOR THE DOUBLE-CRYSTAL SETUP IN THE LHC IR3", EDMS 2883108.

[6] P. Hermes, S. Redaelli, (BE-ABP) M. Milovanovic, M. Trzebinski, "Deinstallation of the ATLAS/ALFA RP Station", ECR, EDMS 2914324.

[7] Sune Jakobsen, "Commissioning of the Absolute Luminosity For ATLAS detector at the LHC", CERN-THESIS-2013-230.

[8] Sune Jakobsen, "Control System for vacuum and environment monitoring for the TWOCRYST", EDMS 3119438.