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Update on the FPF Facility technical studies

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Summary

The Forward Physics Facility (FPF) is a proposed new facility to house several new experiments at the CERN High Luminosity LHC (HL-LHC). The FPF is located such that the experiments can be aligned with the collision axis line of sight (LOS), a location which allows a wide variety interesting physics measurements and searches for new physics to be carried out. This document describes updates in technical studies related to the implementation of the FPF facility, covering civil engineering and integration studies.

Contents

1 Introduction

The Forward Physics Facility (FPF) [1, 2] is a proposed new facility to house several experiments in the very forward region of the IP1 LHC collisions during the HL-LHC. Technical studies related to the FPF have been carried out in the context of a dedicated working group as part of the CERN Physics Beyond Colliders (PBC) Study Group [3]. At the same time many physics sensitivity studies have been carried out, highlighting the broad and deep physics case for the proposed experiments at the FPF. The physics case covers searches for light, weakly coupled dark sector particles, studies of large samples of high energy neutrinos of all flavours and QCD measurements from probing very forward hadron production and deep inelastic scattering experiments with the high energy neutrino beam.

An overview of the technical FPF studies carried out by the PBC working group was documented in March 2023 [4]. Since then, the design of the FPF facility, and the proposed experiments has evolved. One of the experiments, Advanced SND (AdvSND) is no longer in the baseline plans, and more detailed designs of the other proposed experiments, including a more realistic description of the needed technical infrastructure has led to an update in the size and design of the FPF cavern. In parallel, a dedicated site investigation study was carried out to provide additional information for the civil engineering design and costing. Detailed integration studies related to the experiments, and associated infrastructure, in the facility have been carried out. This note summarizes the updates in the technical studies for the FPF facility, with a focus on the civil engineering, integration, and installation aspects of the project.

2 Civil Engineering Design Update

2.1 Overview

The Forward Physics Facility will comprise a large cavern, approximately 75m long and 11.8m internal width. An 84m deep access shaft will connect the facility with the surface. The FPF cavern will sit at a distance of 627m from the IP1 and at its closest point, will be 10m away from the LHC tunnel. The plan view of this arrangement can be seen in Figure 1.

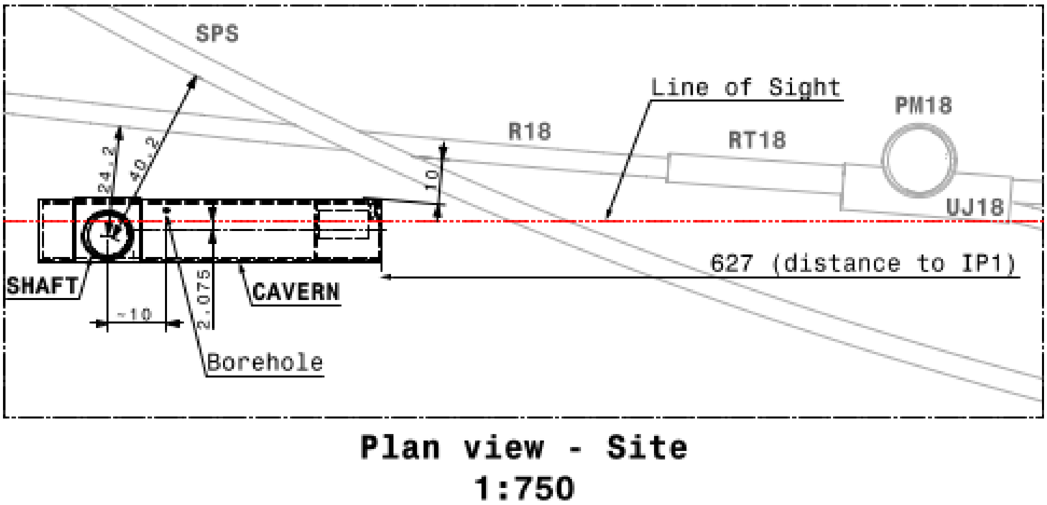


Figure 1: Situation plan of the underground facility with the proposed safety corridor inside the cavern

Above ground, the facility will include an access building, electrical building, and cooling and ventilation building.

2.2 Impact on SPS and HL–LHC operation

To allow the maximum flexibility in implemtning the FPF, the facility shaft and cavern may be excavated during beam operation in the nearby SPS and LHC tunnels. The study in [5] investigates the sensitivity of the SPS and HL–LHC rings to vibrations and static movements of the existing tunnels caused by construction activities, and the main results are briefly summarised here.

The study thoroughly investigates the impact of vibrations induced by civil engineering (CE) works near the HL-LHC. These vibrations can lead to oscillations in the beam orbit, reductions in luminosity, and potentially trigger beam dumps. The effect of these vibrations on the SPS is considered negligible due to the distance from the SPS tunnel as well as the lower sensitivity of the SPS optics to imperfections.

A network of ground motion sensors was installed to monitor and manage vibration levels before the HL–LHC civil engineering works was carried out before and during CERN Long Shutdown 2 (LS2). The data collected during HL-LHC civil engineering works provides a reference for setting vibration alarm thresholds for FPF-related activities. The primary excavation machinery anticipated for the FPF facility includes rock-breaker and road-header excavators. Rock breakers generate stronger vibrations but are more efficient for tunnel excavation. Expected vibration levels in the SPS and LHC tunnels during the FPF excavation are projected to remain close to the alarm threshold only near IP1. Vibrations of up to a factor of ten above the threshold may occur in adjacent tunnel sections but are considered manageable. The optics sensitivity of the HL-LHC near the FPF facility excavation area is about a factor of 10 smaller than in the triplet area (close to the IP), and three times greater than that of the SPS optics. Vibration levels and their associated impacts on orbit stability and luminosity production are expected to be comparable to those observed during the HL-LHC civil engineering works in the 2018 LHC run.

Historical data from similar projects suggest that tunnel movements of up to 1 mm can be expected in the vicinity of the FPF excavation works, affecting tunnel segments between 50 and 100 meters in length. Such movements are within tolerable limits and can be corrected with the available orbit correctors strength or, in the worst case in the SPS, with a one-day long beam-based alignment intervention.

Overall, no major disruptions to HL-LHC and SPS performance are expected during the FPF excavation works. However, specific actions are recommended, including detailed analysis of expected interference between tunnels, establishing vibration alarm procedures, including the possibility to switch to road-header excavators instead of rock breakers in case of too-high vibration levels, and scheduling ground compaction activities outside beam-time periods.

2.3 Site Investigation

To establish the subsurface conditions in which the facility will sit, site investigation works were carried out. A single core was drilled to the full depth of the proposed shaft, 100m deep, at the estimated location for the new shaft of 24m from LHC and 40m from SPS.

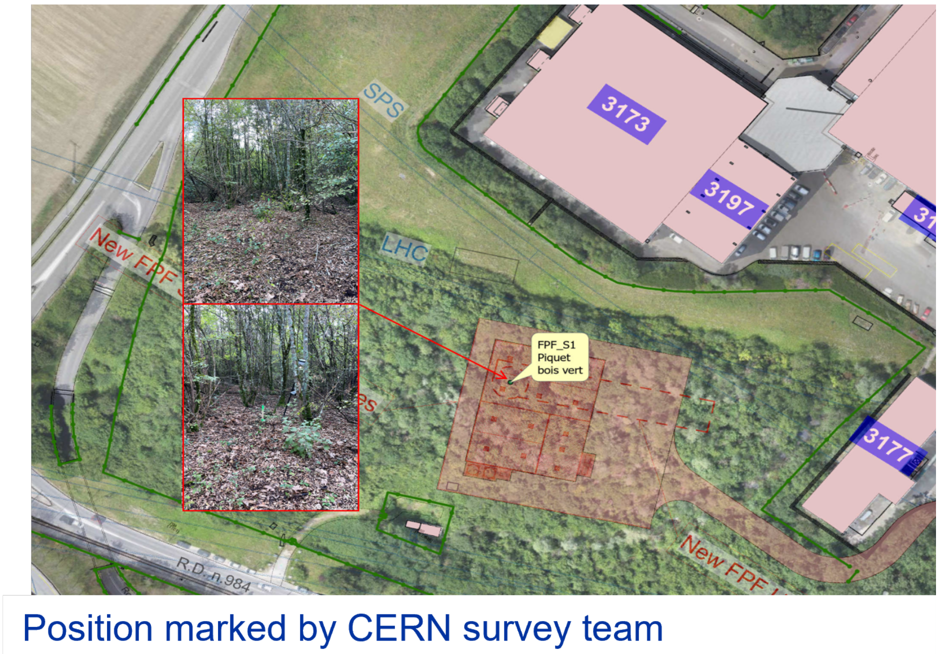


Figure 2: Position of core drilling location, marked in plan

The location of the core drilled was marked as shown in Figure 2. The works were carried out using a single drilling machine and once the core was drilled, it was divided into segments for transportation and analysis of the different ground types shown within it. The phases of this ground investigation are shown in Figure 3.

(a) Drilling machine in place (b) Works started (c) Core Samples

Figure 3: Site Investigation works: Extraction of Core Sample

The results of the site investigation were broadly positive, with favourable ground conditions noted and no water table identified. Some attention will still be needed to correctly manage the presence of hydrocarbons, fluoride and swelling potential on the site, but these can be addressed during the design phase. A full outline and interpretation of the site investigation works was given in a report by the Geotechnical consultants, GADZ [6]. These results were then contextualised into the rest of the FPF civil engineering proposed works in a report by Arup [7].

A more comprehensive overview of the results of the site investigation can be seen in Table 1.

Results	**Recommendations**
Ground found mostly competent for tunnelling purposes.	N/A
Signs of hydrocarbons were found in the soft sandstone at depths between 84m and 90m.	1) Excavation material contaminated with liquid hydrocarbons will require specific spoil management 2) Underground tunnels and works in contact with soils contaminated with hydrocarbons will require specialised waterproofing membrane
Foundations of the surface buildings will sit within competent moraine.	N/A
No water table has been identified. Overall the ground is not very permeable.	N/A
Vertical swelling test carried out showed a high swelling potential.	Swelling pressures to be considered during the design of the final lining
Slight elevation of fluoride levels shown in the existing backfill material.	Existing backfill material will need to be disposed of at appropriate facilities

Table 1: Site Investigation: Results and Recommendations

2.4 Design Updates

The design and sizing of the FPF cavern has undergone design development in recent months, to better accommodate the anticipated machinery and access to the facility. The dimensions and plan view shown in Figure 1 are the result of this process, giving the most up-to-date design.

This latest design was developed from an optioneering study to investigate the impact of an increase in the length of the cavern by 5 or 10m, and an increase in cavern radius by 1m. The key considerations in this study were the proximity of the FPF to the LHC and IP1, as well as the cost.

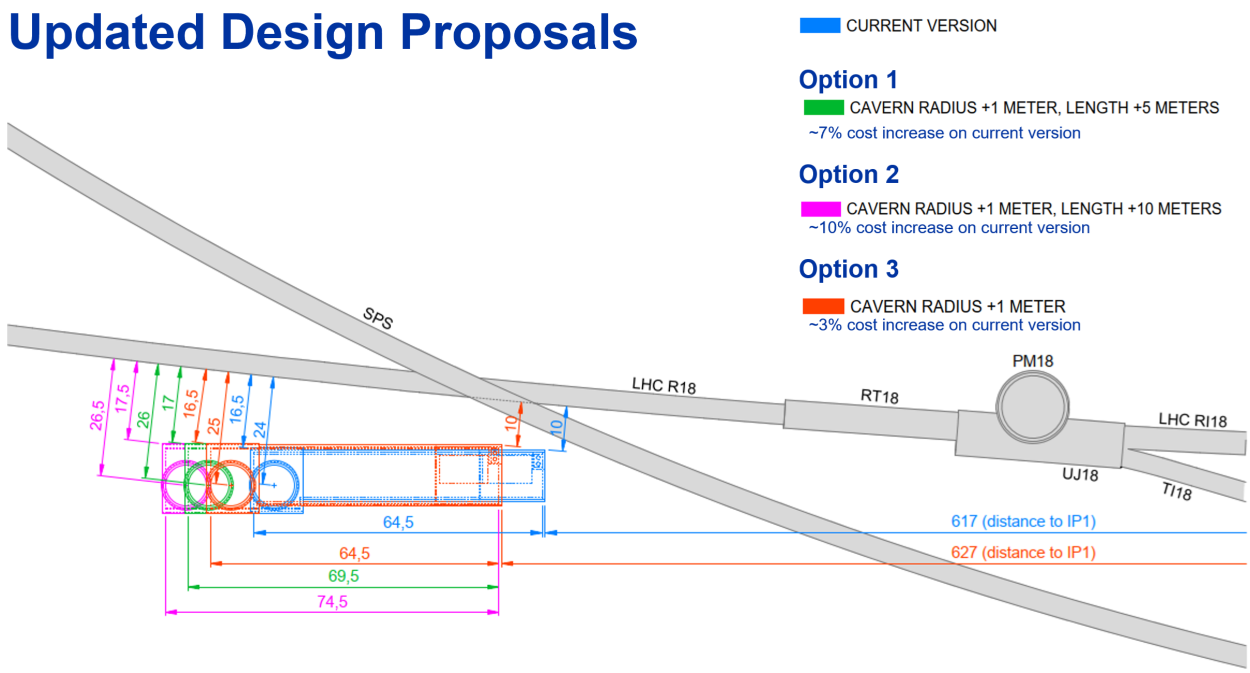
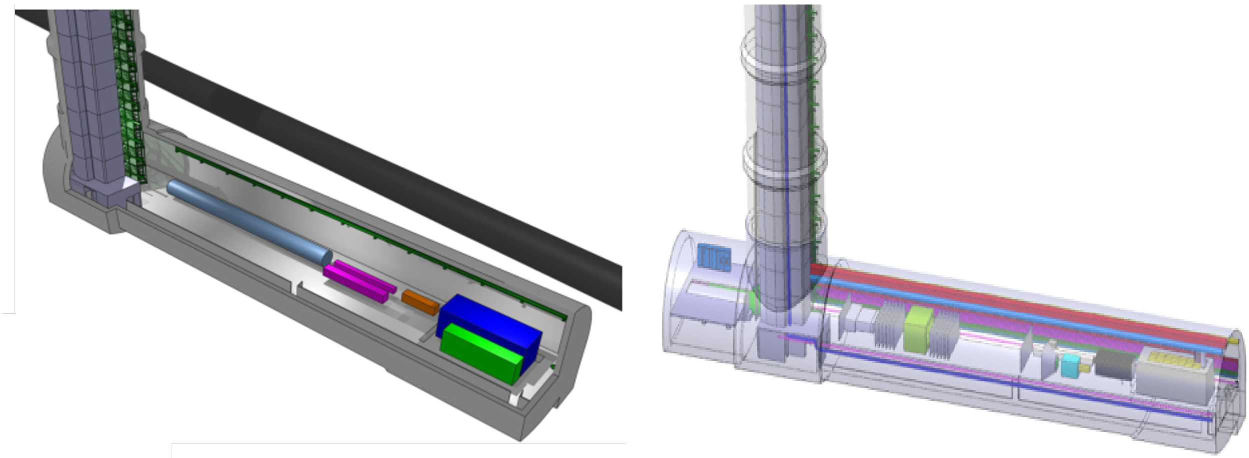


Figure 4: Optioneering Study for different Designs

Figure 4 shows the four options for the cavern design that were considered. The "Current Version" in this schematic was the baseline before the optioneering process began, which has now been superseded. As shown, the option with the greatest volumetric increase is Option 2, with an associated 10% increase in cost compared with the Current Version. In order to maintain the required 10m distance between the FPF and the LHC, all three options were moved 10m further away from IP1 as well. At the end of the optioneering study, Option 2 was selected since it offered the greatest increase in volume, for what was judged to be an appropriate increase in cost. Option 2 is the closest to the design which is shown in Figure 1.



(a) Before shaft move (b) After shaft move

Figure 5: Change in Design of Shaft

A further design development which has take place, is in the placement of the shaft. In Figure 4, the shaft is located at the far end of the facility, at the furthest point from IP1. This design has been updated such that the shaft will now be 10m closer to the IP1. The change in design is clearly shown in Figure 5.

Figure 5b is the design iteration which has been carried forward, and which has been represented in Figure 1.

2.5 Cost and Schedule Updates

Prior to the design optioneering task which was described in Section 2.4, a costing exercise was carried out using the "Current Version" shown in Figure 4. The results of this exercise are shown in Figure 6.

Since the previous cost exercise in 2021, the following updates have been incorporated:

- Access tunnel has been removed and safety corridor designed
- Previous costs were reviewed by external consultants, and adjusted according to advice
- Findings from the site investigation have been incorporated
- Inflation since last (2021) estimate

The previous cost estimate was 27.5MCHF. The Estimation Class used here is Class 4.

As previously mentioned, the updated cost estimate of 30MCHF does not include the design developments of increased cavern sizing. Another costing exercise was carried out separately, specifically covering the design optioneering which concluded that the chosen design (Option 2 in Figure 4) would be 10% more expensive than the baseline.

Ref.	Work Package	Cost [CHF]
1.	Underground Works	10,000,000.00
1.1	Preliminary activities	1,600,000.00
1.2	Access shaft	3,900,000.00
1.3	Experimental Cavern	4,500,000.00
2.	Surface Works	6,120,000.00
2.1	General items	640,000.00
2.2	Topsoil and earthworks	660,000.00
2.3	Roads and network	730,000.00
2.4	Buildings	4,090,000.00
2.4.1	Access building	2,000,000.00
2.4.2	Cooling and ventilation building	1,400,000.00
2.4.3	Electrical Building	490,000.00
2.4.5	External platforms	200,000.00
3.	General items	10,000,000.00
4.	Miscellaneous	4,000,000.00
	TOTAL CE WORKS	30,120,000.00

Figure 6: Costing Exercise (excluding recent design updates)

Alongside the costing exercise, a proposed civil engineering schedule has been developed whose key use is to illustrate the order of tasks and their estimated durations. The intention of this schedule is to assist in the integration of civil engineering works with other disciplines' programs.

Figure 7: Proposed Civil Engineering Schedule

Although the schedule shown in Figure 7 indicates the frozen design in early 2024, this is an estimate and the subsequent tasks will be shifted later according to the date when the design is frozen.

3 Integration

Detailed integration of the FPF experiments and the associated technical infrastructure into the FPF facility is ongoing. The effort has started by integrating the largest and most complex components, and has progressed adding in more detail. The integration work is continuing, and as more detailed design of the experiments and their associated requirements come available the model will be updated. The current status of the integration study is presented below.

Many aspects of the FPF design are similar to other underground facilities at CERN, and in many cases standard solutions are used, based on many years of previous experience at CERN, and the expertise of the CERN technical teams. This gives a confidence that the proposed solutions are realistic, and well thought through based on existing examples.

3.1 Experiments Baseline layout

In the FPF baseline design the cavern will house four proposed experiments: FLArE, FASERν2, FASER2 and FORMOSA. To maximise the physics reach the detectors are centered on the collision axis line-of-sight (LOS), which is 1.5 m from the cavern floor and 3.8 m from the closest side wall of the cavern, as shown in Figure 8. Note: the figure shows the nominal-LOS assuming no crossing angle in IP1, whereas for the default HL-LHC crossing angle of 250 μrad (half crossing) the LOS is pushed about 16.5 cm horizontally towards the right hand side. There is a possibility that the crossing plane would change to vertical after several years of HL-LHC running, which would move the LOS by 16.5 cm from the nominal LOS but in an up or down direction. Since 16.5 cm is small compared to the size of the experiments this change will not require realigning the experiments with the LOS, except perhaps in the case of FASERν2 where it may make sense to re-allign the detector and which would be relatively easy to do.

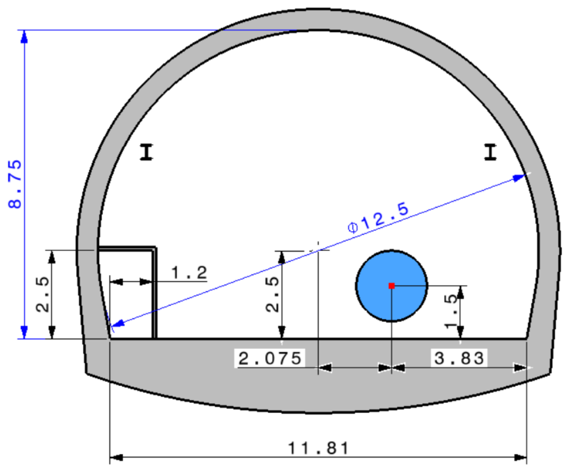


Figure 8: The FPF cavern cross section. The nominal LOS is shown as a red dot.

Different detectors configurations in the cavern have been studied to optimise the physics output and to minimise space requirements and costs. Since the FASER2 spectrometer will play an important role measuring the momentum and charge of muons produced in neutrino interactions in the FLArE and FASERν2 detectors, the distance to the spectrometer from these experiments should be minimized. For this reason the FORMOSA detector is placed downstream of FASER2 in the baseline layout, as shown in Figure 9, where the experiments are ordered from the most upstream as (1) FLArE, (2) FASERν2, (3) FASER2 and (4) FORMOSA.

An alternative option that has been considered is to place the FORMOSA detector slightly below the LOS in a dedicated trench under the FASER2 decay volume (which is empty space). This option is shown in Figure 10. It reduces the physics sensitivity of FORMOSA slightly, but could be considered if more space is needed in the cavern along the LOS.

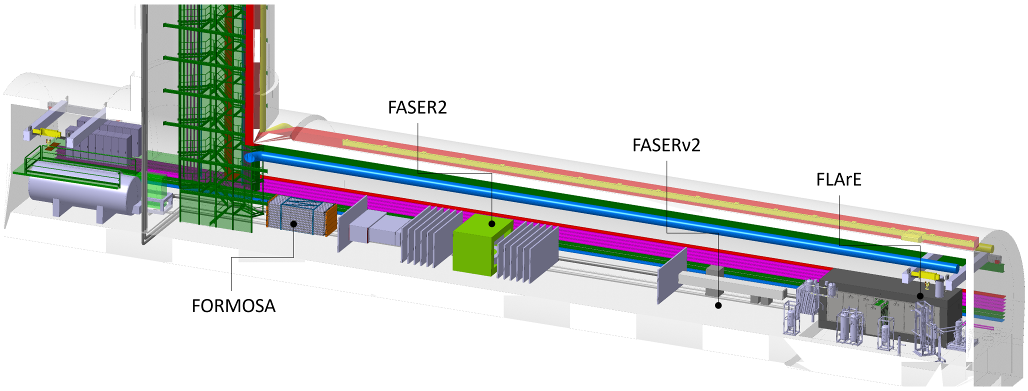


Figure 9: Baseline layout of experiments in the FPF cavern.

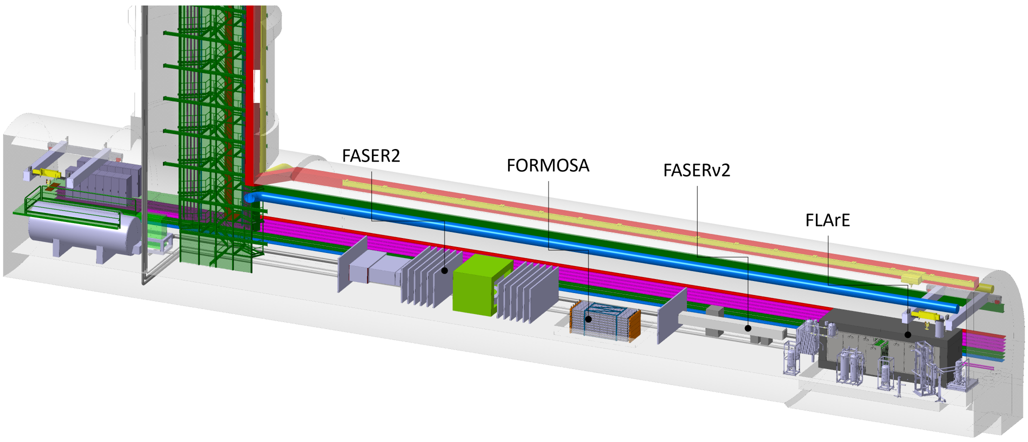


Figure 10: Alternative layour of the experiments in the FPF cavren, with FORMOSA under the FASER2 decay volume.

3.2 Experiments

Below, a short overview of the four experiments and related design solutions are presented. For each experiment, the relevant features effecting the global facility design and large technical infrastructure requirements are noted.

3.2.1 FLArE

The Forward Liquid Argon (LAr) based neutrino detector, FLArE, is an experiment based on a LAr TPC technology, ideally suited for detailed studies of high-energy neutrino interactions and searches for light dark matter scattering. FLArE is one of the largest detectors in the FPF, and requires careful safety risk assessments due to large volume of cryogenic liquids and the associated oxygen deficiency hazard (ODH) risk. Several features are foreseen to mitigate this risk:

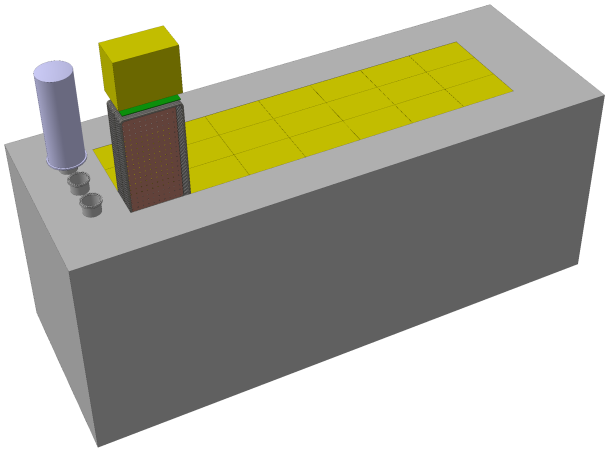
- A dedicated trench is integrated under the FLArE cryostat to catch any leaks of cold gasseous Argon;
- ODH detectors will be installed around FLArE and will trigger alarms as well as the dedicated Argon extraction system which is included in the design of the ventilation system (described in more detail in 3.3.2). As an additional precaution, personal ODH monitors will be required for people working in the cavern;
- The cryostat and cryogenics have been placed away from the main egress and the escape route. The facility design also includes an over-pressure safety corridor running along the side of the cavern, which will allow people to escape to the surface in the event of a gas leak or fire blocking their path to the lift area.

The FLArE detector includes a complex cryogenic system and related sub-equipment which is discussed in more detail in 3.3.3. The installation of the TPCs into the cryostat is a significant engineering challenge, with an initial solution considered based on vertical installation. More recently a revised design using horizontal installation has been developed and is the current baseline solution. The two options are shown in Figure 11. An additional integration challenge relates to finding a compact and safe solution to bring argon in the cavern.

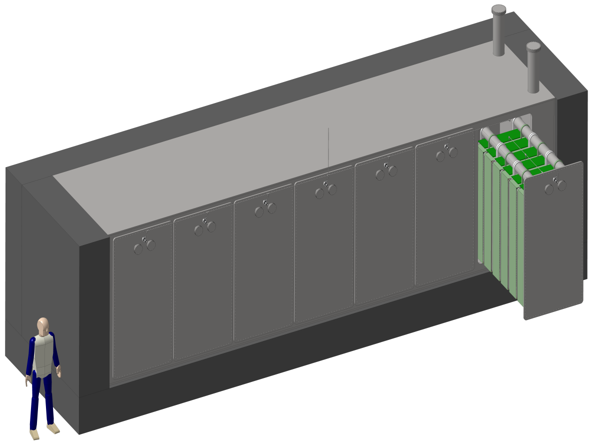
3.2.2 FASERν2

FASERν2 is a 20-tonne emulsion/tungsten neutrino detector located on the LOS. It is placed in front of FASER2, so as the spectrometer can be used to reconstruct the momentum and charge of muons produced in neutrino interactions in FASERν2. The FASERν2 design is informed by the experience running with the current 1-tonne FASERν detector currently running in TI12.

The emulsion in the detector needs to be replaced periodically, which will require relevant handling tooling, with different options under study. In addition, a precise alignment between the emulsion films needs to be kept while the detector is in place, which can be achieved by applying a large pressure. Tests are ongoing to study different ways to achieve this. Finally, to ensure good performance of the emulsion films during a long exposure time the full detector is kept in a temperature controlled box, operating at around 10 degrees. Design studies are ongoing on all of the above areas, however these do not have a large impact on the global FPF facility design, or introduce additional large technical infrastructure into the facility. A 3D model of the FASERν2 detector is shown in Figure 12.



(a) Vertical installation of the TPCs into the FLArE cryostat.



(b) Horizontal installation of the TPCs into the FLArE cryostat.

Figure 11: FLArE

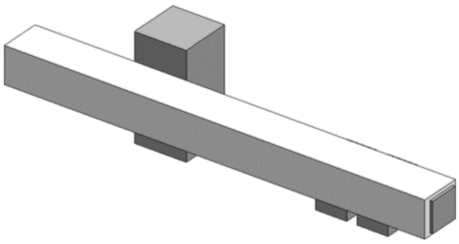


Figure 12: FASERnu2 detector

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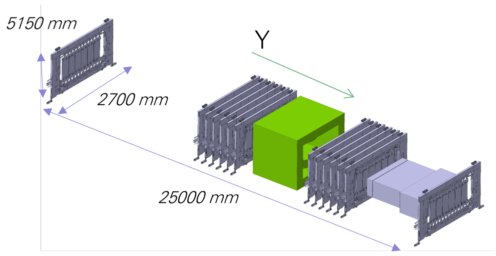
3.2.3 FASER2

The ForwArd SEaRch experiment2, FASER2, is designed to search for BSM particles and to measure the momentum and charge of muons from neutrino interactions in upstream experiments. It consists of a 10m long decay volume, and a large-volume tracking spectrometer, as can be seen in Figure 13.

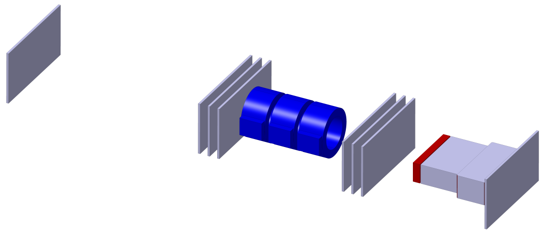
The most challenging aspect of the detector is the large area air-core superconducting magnet, which should have a bending power of greater than 2 T.m over a transverse area of at least 1.6m x 1.6m. Two possible solutions for this magnet are under study, with discussions with multiple companies for the conceptual designs ongoing:

- The first solution is to use a custom-built superconducting dipole based on the design of the SAMURAI experiment magnet, although with lower magnetic field. In this case the cryogenics can be delivered by commercially available cryo-coolers and the largest single piece to transport into the facility is the cryostated superconducting coil.
- The second solution would be to use commercially available crystal-puller magnets which are available fully integrated with their cryogenic system. Here the full magnet would be transported into the facility as a single piece.

Integration models of the experiment with both magnet options are shown in Figures 13a and 13b. Using the SAMURAI type magnet is considered the current baseline. The main integration challenge relates to the transport of the magnets coils or complete magnets into the cavern due to their large dimensions, which has been studied ands hown to be possible (see section 4).



(a) FASER2 with a SAMURAI-type magnet



(b) FASER2 with a crystal-puller magnet

Figure 13: FASER2 detector

3.2.4 FORMOSA

The FORMOSA experiment is designed to search for milli-charged particles and will be constructed of plastic scintillators. In the baseline layout it is situated as the most upstream of the FPF experiments. The detector is fairly simple and does not present any significant integration challenges, or require large technical infrastructure. The 3D model of FORMOSA can be seen in Figure 14

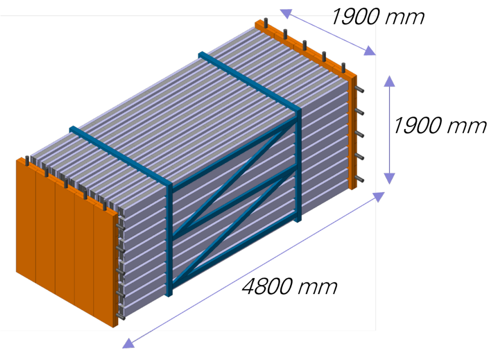


Figure 14: FORMOSA detector

3.3 Integration of services

The experiments in the FPF need to be supported by essential services. Integration studies collecting the requirements from a civil engineering constructions, cooling and ventilation, electrical, transport, survey services equipment, cryogenic system etc. are ongoing. The current status of the integration of the services is described in more detail below.

3.3.1 Electrical equipment

The electrical services currently considered in the integration model include cable trays and electrical racks (as shown in Figure 15). The current study is based on a very preliminary estimate of the needed electrical equipment, power and cables, and will be updated once the full requirements from the experiments become clear. The study shows, however, that there is sufficient room for this equipment in the baseline FPF design.

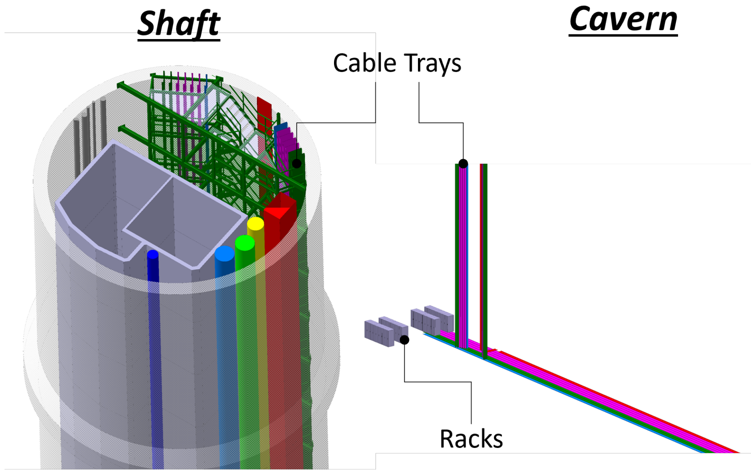


Figure 15: Electrical service

3.3.2 Ventilation

A preliminary conceptual design of the FPF ventilation system was discussed in [8].This design has now been included into the integration model of the baseline FPF facility. The proposed preliminary design is shown in Figure 16, and includes four separate systems:

- A normal ventilation system is represented by air supply and extraction. The ducts have diameters of 700 mm and aimed to 10000 m3/h. The air supply is distributed along the cavern and is extracted at the upper part of the shaft.
- A duct for pressurisation with the diameter of 400 mm is running from the surface to the cavern. The duct is housed in the special designed safety corridor, used as emergency escape route, and in the pressurized concrete module which includes the pressurized lift and stairwell.

- A duct of smoke extraction is measured 1000 mm by 700 mm and has to withstand fire temperatures. The duct is running from the cavern to the surface.
- A duct of argon extraction is 600 mm diameter and is served to evacuate any possible gas Argon leaks. The duct has a starting point close to the FLArE experiment which represents the highest risk for the Argon leaks in the FPF cavern.

For the further study a possibility to combine smoke and Argon extraction will be investigated. The above-mentioned dimension of the ventilation system are approximate and still can be changed.

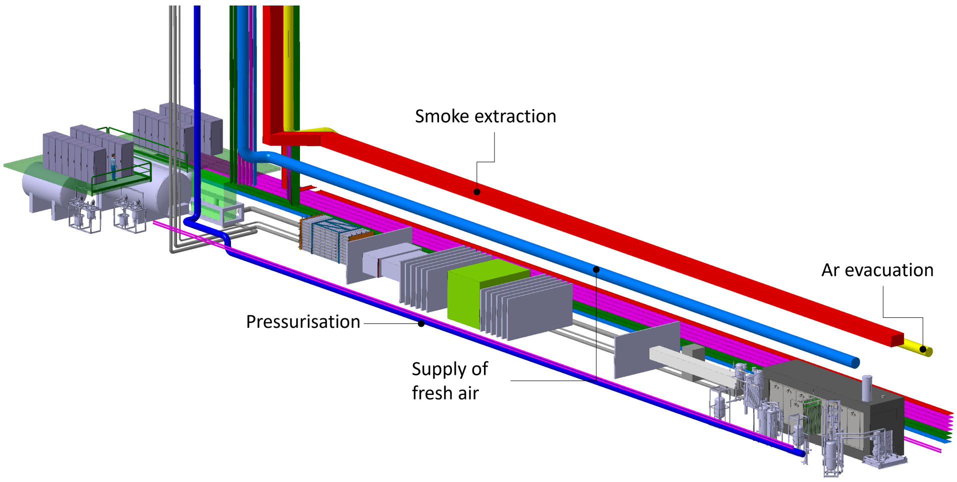


Figure 16: Cooling and Ventilation

3.3.3 Cryogenic system

The FLArE experiment in the FPF requires a complex cryogenic system. There is a lot of experience at CERN in operating large cryogenic systems for liquid nobel-gas detectors, for example the proto-DUNE detector and the ATLAS experiment LAr calorimeter (which as the FPF experiments is deep underground at the level of the LHC machine). The system is currently being designed, however, the FPF integration model already includes the most significant cryogenic equipment including two storage tanks for the liquid Argon and Nitrogen, a Turbo-Brayton cryogenic cooling unit, as well as piping for transporting cryogenic liquids from the surface into the cavern, and within the cavern. Figure 17 shows the main cryogenic system components in the cavern. Initial requirements for cryogenic system are:

- Pipe for Gas Ar OUT - 30 cm.
- Pipe for Gar Ar IN - 10 cm.
- Pipe for liquid N_2 - 20 cm (vacuum jacket included).
- Pipe for liquid Ar - 20 cm (vacuum jacket included).

Two dewars on the surface of 50 m^3 and 10 m^3 for liquid Ar and N_2 accordingly have to be integrated.

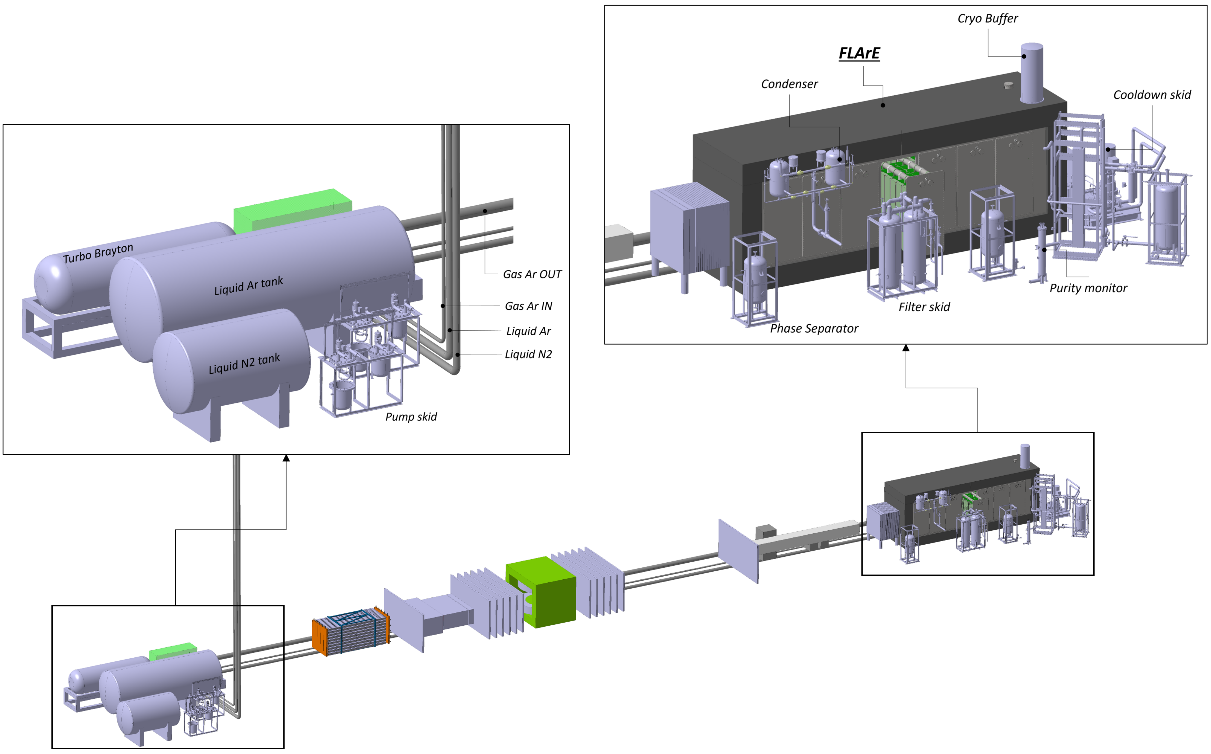


Figure 17: Cryogenic system

4 Transport and installation

Transport and handling considerations form an important element in the facility design. All experimental equipment have to be able to be transported to its location, either already assembled or in parts to be assembled in the experimental hall. Therefore it is essential to check the transport path and foresee compatible transport means such as rails, cranes etc. Furthermore, it is important that the needed transport paths are not blocked after the construction of the infrastructure and the installation of the experiments.

A preliminary transport study has been performed to ensure that the space reservation is correct and that the installation of the largest components will be possible. Integrating the required equipment in the facility allows to have a rough estimation of the space and dimensions of the transport zones, which will be needed to choose the transport/handling equipment and to define the sequence of the installation. The largest and heaviest components that need to be transported into the cavern as a single piece have been identified and a simplified simulation of their transport carried out.

For the simplified transport study, the facility is broken down into four transport zones, as shown in Figure 18:

- Zone 1 - Surface Building;
- Zone 2 - Shaft;
- Zone 3 - Start of the Cavern (closer to the IP1);
- Zone 4 - End of the Cavern (further from IP1).

4.1 Equipment

The largest equipment are identified and listed in the table shown in Figure 20. The list is preliminary and will be adjusted and supplemented with refined designs of the experiments. Challenges related to the transport of the largest equipment also depends on the assembly sequence, which will be provided by each detector collaboration in the future.

4.2 Transport capacities

Based on the equipment dimensions and weight, the handling group at CERN (EN-HE) proposes a corresponding solution for the transport means with required crane capacities and movement range. A preliminary list of the required crane capacities and movement range is shown in Figure 21. Transport zones 1 and 2 are covered by the same crane which will operate in the surface building and will be used to lower equipment into the cavern, as shown in Figure 19a. Zone 3 requires more flexibility for the movement and installation therefore a crane and a monorail hoist are integrated, as shown in Figure 20. Zone 4 houses auxiliary equipment, which will also need to be covered by a crane.

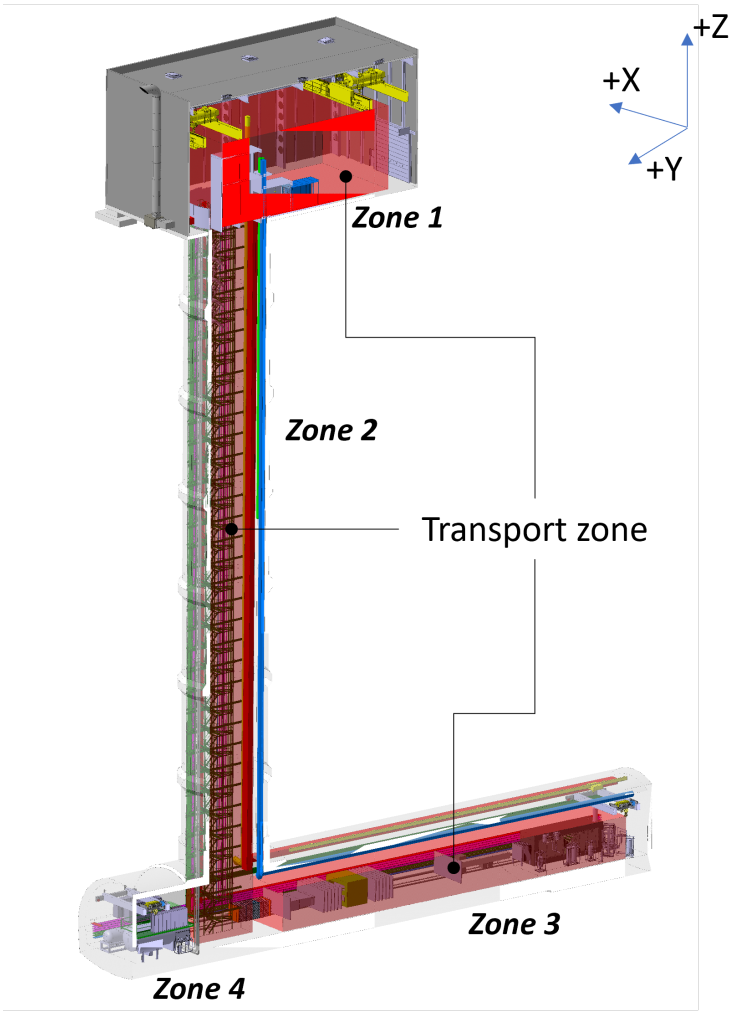


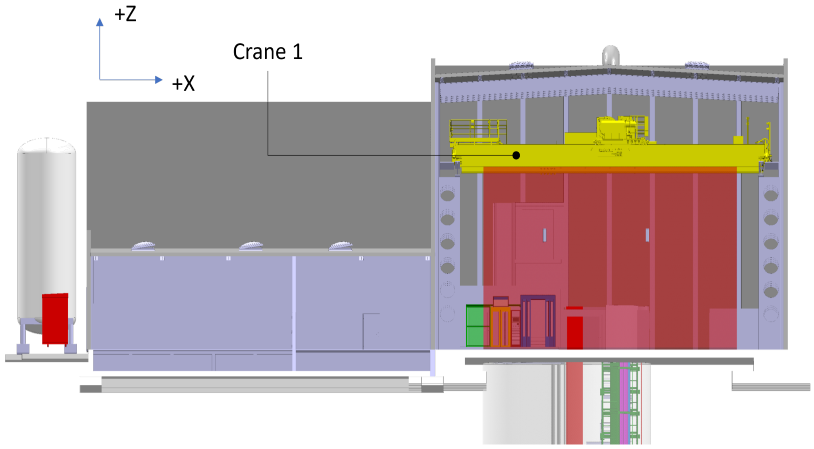
Figure 18: Transport zone

4.3 Transport study - Turbo-Brayton system

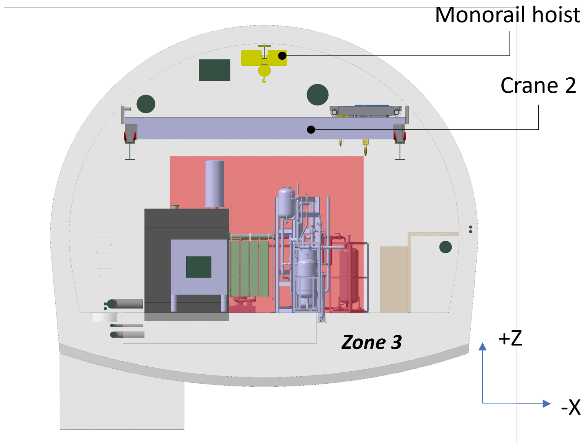
As an example the transport study related to the installation of the Turbo-Brayton cryogenic system is described in more detail here. The Turbo-Brayton system is one of the largest pieces of equipment that needs to be transported into the cavern in one piece. The dimensions and a picture of this item can be seen in Figure 22).

Figure 23 shows the preliminary study carried out to demonstrate that the Turbo-Brayton unit can be transported into the cavern with the existing facility design and handling infrastructure. Considering the dimensions of the Turbo-Brayton unit, the only possibility to move the equipment into the cavern through the shaft is in an inclined position rotated by about 60 degrees. The critical path is then the transition between the shaft and the cavern - to pass from the inclined position to the horizontal one which can be achieved by combination of +Z/-Z and +Y/-Y movements. Thus the Turbo-Brayton cooling unit can be brought down and installed at its final position.

Similar studies show that all the components considered in Figure 20 can be transported



(a) FPF Surface Building



(b) FPF Cavern

Figure 19: Transport means

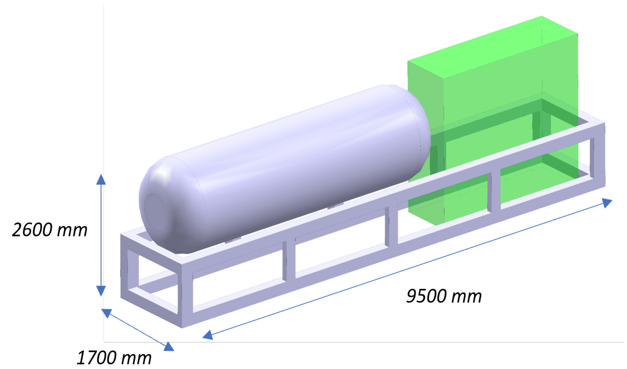
into the cavern with the current design, with the exception of the large Ar tank, which is too big to fit down the transport area of the shaft. One possibility is that this tank could be transported into the cavern before the stairs have been installed in the shaft, or a smaller tank could be used.

Name	Weight estimation	Dimensions	System
Turbo-Brayton	Full 15 t	9.5 m x 2.6 m x 1.7 m	Cryogenics
Ar Storage tank	Empty – 13.9 t Full Ar – 57.8 t	Diam. 2.8 m, L = 7.7 m	Cryogenics
FLArE module	1 t	1.2 m x 2.3 m x 2.2 m	Detector
FASER2 Samurai magnet coil	1.8 t	Diam. 3 m, h = 0.5 m	Detector
FASER2 Crystall puller magnet	9 t	Diam. 2.4 m, H = 1.25 m	Detector

Figure 20: The largest equipment

Crane	Capacity	Range
Surface Building – Zone 1		
Crane 1	25 t	X 15280 mm Y 24000 mm Z 96800 mm
SHAFT – Zone 2		
Crane 1	25 t	X Y Z 96800 mm
CAVERN – Zone 3 & 4		
Monorail hoist	10 t	X 0 mm Y 55450 mm Z 7650 mm
Crane 2	25 t	X 5300 mm Y 50000 mm Z 5400 mm
Crane 3	15 t	X 5300 mm Y 5000 mm Z 5400 mm

Figure 21: Transport capacities



(a) Turbo-Brayton cryogenic systems (simplified model)

(b) Turbo-Brayton cryogenic systems (detailed model)

Figure 22: Turbo-Brayton cryogenic systems

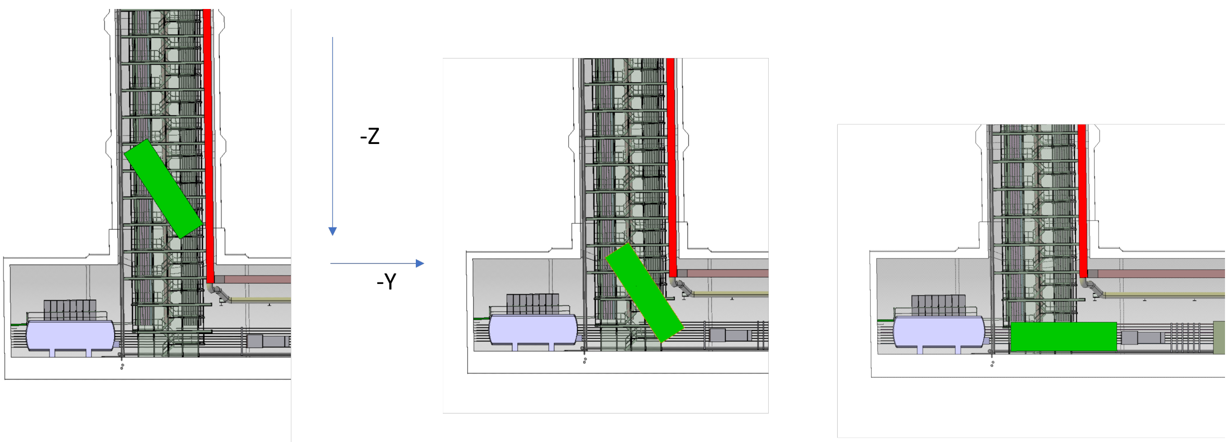


Figure 23: Transport exercise for TBF

5 Summary

Progress on technical studies related to the implementation of the Forward Physics Facility design, as well as related to the inputs for the proposed experiments design has been described. On the civil engineering side the updates include an updated design, large enough to house the needed technical infrastructure for the experiments; the analysis of the site investigation works carried out in spring 2023; an updated costing; and studies on the effect of the civil engineering works on operation of the SPS and HL-LHC. Significant progress has also been made on integration of the proposed experiments and the associated technical infrastructure into the facility, which is documented, including studies on installing the largest and most complex pieces needed in the cavern.

The FPF project will continue to evolve towards a conceptual design to be included in a "Letter of Intent" submitted to the European Strategy in early 2025. Although this current document presents a coherent and realistic design, it represents a snapshot of the technical FPF studies carried out within the PBC working group.

Further studies to optimize the facility layout to maximize the global physics output are ongoing. The outcome of these studies may lead to changes in the experiments and related infrastructure, possibly leading to a refined facility design, as is natural at this stage of such projects.

References

[1] J. L. Feng *et al.*, "The Forward Physics Facility at the High-Luminosity LHC," *J. Phys. G*, vol. 50, no. 3, p. 030501, 2023.

[2] L. A. Anchordoqui *et al.*, "The Forward Physics Facility: Sites, experiments, and physics potential," *Phys. Rept.*, vol. 968, pp. 1–50, 2022.

[3] "Physics Beyond Colliders Study Group," https://pbc.web.cern.ch/.

[4] J. Boyd *et al.*, "Update on the FPF Facility technical studies," "https://cds.cern.ch/record/2851822", 2023.

[5] D. Gamba *et al.*, "Impact of Vibration to HL-LHC Performance During the FPF Facility Construction," "https://cds.cern.ch/record/XX", 2024.

[6] GADZ SA, "Forward Physics Facility (FPF) Reconnaissances Geotechniques," Tech. Rep. EDMS 2910442, 2023. [Online]. Available: https://edms.cern.ch/document/2910442/1

[7] Arup, "CERN Forward Physics Facility (FPF) – FPF Soil investigation Interpretation Report," Tech. Rep. EDMS 3102950, 2023. [Online]. Available: https://edms.cern.ch/document/3102950/1

[8] G. Peon, "Ventilation Installations for the Forward Physics Facility (FPF)," Tech. Rep. EDMS 2801032, 2022. [Online]. Available: https://edms.cern.ch/document/2801032/1