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Memo
Possible SPS Crab Cavity Installation Locations

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Abstract

This document this outlines the possible options for a crab cavity installation in the SPS. Issues discussed are the installation location, cryogenic concerns, and schedule issues. This document is meant to outline the options and help facilitate the decision process.

Contents

1 Introduction

The HL-LHC crab cavity project requires that crab cavities and their operation be validated with a proton beam before the approval for launching the final construction is given. To this end crab cavities are to be tested with beam in the SPS. The baseline planning is to launch crab cavity production for the HL-LHC begin at the start of LHC LS2, at which point it is expected that that at least one cavity prototype has been tested with beam in the SPS.

The SPS crab cavity installation consists of one 3m long cryo module containing 2 identical crab cavities. This cryomodule, along with some support infrastructure have to be installed into the SPS ring, mounted on a moveable table that can move the module in/out of the beam line. The transverse movement of the cryomodule is 510mm, and the connection of the cryomodule and bypass beam line is done with a simple Y-chamber. The present baseline design for the cryomodule and support table is shown in 1. The LxWxH envelope of this assembly is 10.7 x 3.4 x 2.5 meters

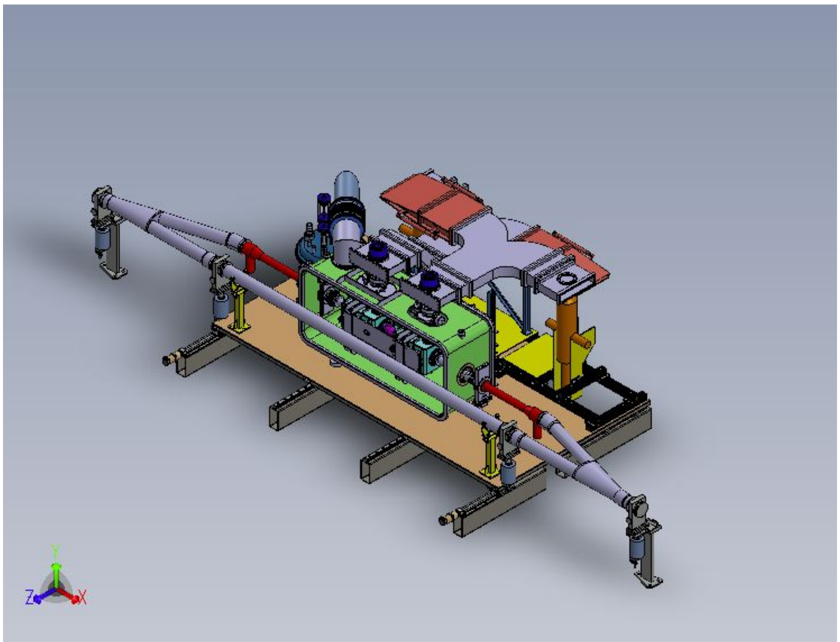


Figure 1: SPS crab cavity cryomodule and support table.

For operation this installation requires services in terms of

- RF power: Each cavity requires unto 50kW RF power at 400MHz
- Cryogenics: The required LHe liquefaction capacity is 2g/s
- Water: Distribution from the standard CV supply lines is sufficient

2 Requirements and Constraints

The location of the crab cavity installation in the SPS has not yet been finalised. The present baseline is that the crabs are installed in the LSS4 alcove, in the area that is presently occupied by the COLDEX experiment. COLDEX is an experiment that studies the properties of surface coatings (in particular the secondary electron yield) on beam pipes and beam screens. COLDEX is an installation that requires 4.5K cryogenics, and has an operational TCF20 coldbox with at liquefaction capacity of 0.7g/s installed across from the LSS4 alcove. Further, COLDEX has restarted operation in late 2014, and at present is scheduled to run at the LSS4 location until the end of 2016.

Present baseline:

- **Dec 2014-Dec 2016** COLDEX is operational. COLDEX removed from LSS4 in December 2016
- **EYETS 2107** Crab Cavity Installation
- **Mar 2017 - LS2 Start** Crab Cavity Validation Run: Test of two different cavity prototypes during the 2017and 2018 SPS run. Dedicated beam time is required
- **LS2** Removal of the Crab Cavity Installation from LSS4

Due to the possible continuation of the COLDEX programme beyond 2016, and suggestion to explore the possibility of having a 2nd independent cryogenics-equipped test facility for device tests with SPS beams, the question of whether there is actually a location in the SPS ring for such a test facility. If it existed it the new test site would be used for the crab cavity validation run, but after LS2 it could be superconducting RF would continue to be one of the main users of such a facility.

Any location for such a new facility has several requirements:

- It must be possible to remotely switch the device under test in and out of the beam line within a short time period (20min max)
- The required longitudinal beam line space should be somewhere between 8 and 10 m. 2 x 2 m for the Y chamber transitions, and 4 to 6 m for the device under test.
- The installation must not have and impact on the SPS tunnel transport lane
- Radiation levels should be acceptably low
- Cryogenics supply of 4.5K Helium to the cryomodule installation is required, as the conversion to 2K Helium is to be done at the cryomodule installation.
- The distance to a gallery/cavern area where power an cryogenics infrastructure can be installed should ideally be as short as possible, with a target of lees than 50 m
- Accessible control space near the LLRF racks would be an advantage. This suggests that a control room either in an SPS experimental cavern or on the surface near the closest access shaft would be ideal.

If the cold box is moved to an accessible area, then the estimated footprint of the cryo services that would be required either on the surface or in an experimental cavern, is $\sim 40m^2$. Similarly, if the RF power is installed in a way to resemble as closely as possible the situation of the foreseen HL-LHC Crab RF power, then the Tetrode + High Voltage Power Supply + driver an controls, then the estimated footprint of the RF power installation is 32m^2. For the LLRF, There is not the need to have the LLRF as close as possible to the cavities, and as long as the LLRF racks can be within $O(100m)$ of the cavities there is no issue. This implies that the LLRF can easily be accommodated in a control room in a nearby experimental cavern or on the surface (as the SPS locations considered 30-40 m down).

3 Radiation Environment

It is desirable to have a location that has las-low-as-possible radiation levels, and as a measure of this residual dose rates from the RP 2014 survey of the SPS ring is considered. Figure 2 shows a zoom in around the SPS sextants where containing the long straight sections. The highlighted area indicates the typical locations of the alcoves or similar which could house a crab cavity installation. As can be seen, LSS1, and LSS2 are excluded as possible sites, due to high radiation levels. LSS3 would be the ideal followed by LSS4, and then LSS5 and LSS6 are similar and acceptable. It is worth noting that in comparison of 2014 to 2012 survey data, only LSS4 and LSS6 show a decrease of remnant activity in the highlighted region.

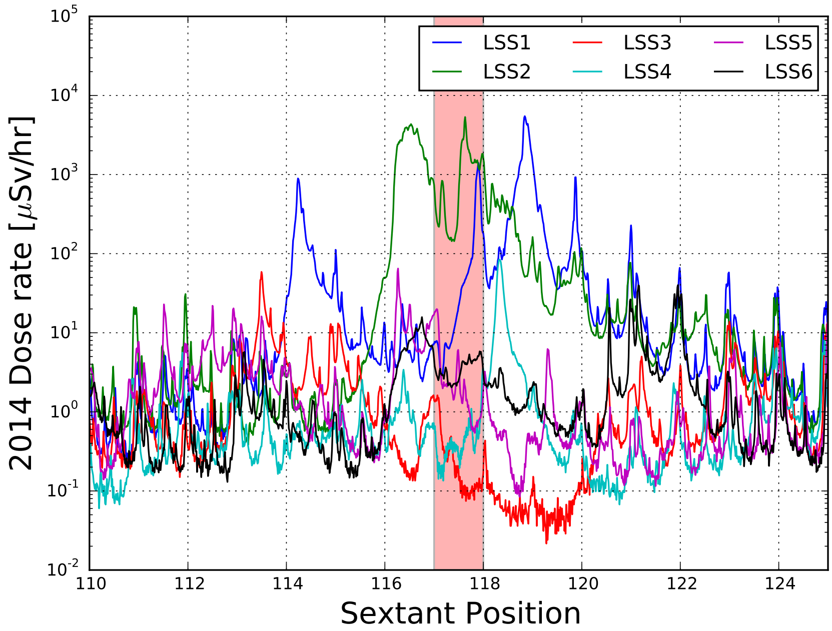


Figure 2: SPS RP survey from 2014 showing the residual dose rates as a function of SPS sextant number. The highlighted section indicates the typical straight section location of the SPS where the crabs cryomodule could be installed (if space is available).

4 Cryogenic Infrastructure Issues

In the original baseline, it was foreseen that the cryo cold box to be used was the TCF20 already installed at the LSS4 Alcove. This cold box has been re-commissioned for COLDEX operation with a liquefaction capacity of ∼1.0 grams/s per second. The present estimate for the crab cavity cryo requirement (based only on static losses) is a liquefaction capacity of 2.5 - 3 .0 grams/s baseline. As such the existing TCF20 is insufficient and needs to be replaced; a TCF50 would be at the limit of the required capacity, but the physical size is approximately twice that of the TCF20, and hence unfeasible for installation into the alcove area of an SPS LSS. This is especially the case if additional maintenance space is included in the required cold box space requirements.

As there is no cold box installed in the SPS with the required capacity, it is assumed that a new cryogenic installation is required. While the specifications of this new system are not to be defined here, it is assumed that the new cryogenics system be self-contained in the sense that the cold box is combined with a helium purifier, so that there is a closed helium circuit. This avoids the necessity of connecting the helium return line to the existing cryo network (which would require installation of a return line in sections of the SPS tunnel).

5 Locations Considered

Any possible location must be compatible with the above mentioned requirements and constraints. Given that the installation must allow for the cryomodule to be switched out of the beam line it is not possible to have an installation anywhere in the standard SPS tunnel, as this would imply a blocking of the SPS transport lane. Thus only the LSS sections are considered as possibilities. In the LSS sections there are both alcoves and in some places, experimental caverns. As noted above only LSS sections with acceptably low activation are considered, and the list of the possible locations is:

- **LSS1** Not considered due to radiation levels.
- **LSS2** Not considered due to radiation levels.
- **LSS3** Not possible: LSS space is completely occupied by SPS RF system.
- **LSS4**
  - **Alcove** Present baseline location. COLDEX installed in the alcove
  - **ECX4** Not possible: as incompatible with TT40 (LHC Beam 2) extraction.
- **LSS5**
  - **Alcove** Potential location .
  - **ECX5** Potential location.
- **LSS6** Possible location upstream of TI-12

An aerial view of each of the potential location is shown in Figure 3, with both beam line and tunnel (in blue) as well as existing surface building infra structure (in pink) indicated. In all cases the potential sites are within a relatively short distance from an access shaft. Typical depth of the SPS is 35 m, which makes the installation of services and control room on the service. feasible.

6 Possible Locations

To evaluate possible locations, on-site visits have been made to all potential locations and the pros and cons of each location evaluated. The evaluation was done in terms of available beam line space, feasibility of infrastructure installation, compatibility of with other programs and installations, and potential for a long term test facility installation.

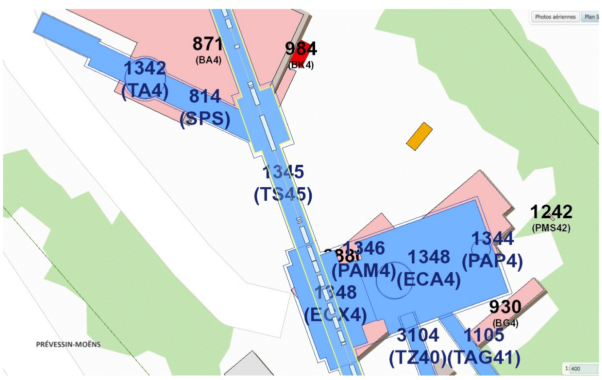
- **LSS4 Alcove**

  Pros:

  - Present Baseline Location: Preparations ongoing, Y-chamber conceptual design and impedance modelling done, existing cryo infrastructure and services refurbished and helium pumps installed in LS1.
  - ECX4 cavern is 35m away: LLRF to be located in ECA4 and there is the possibility of RF power and cryo coldbox to be installed in ECX4
  - Control room space allocated in ECA4
  - Alternative services installation: Possibility of relocation of cryo cold box to the surface with routing via the access shaft. Length of cable run is 100m.

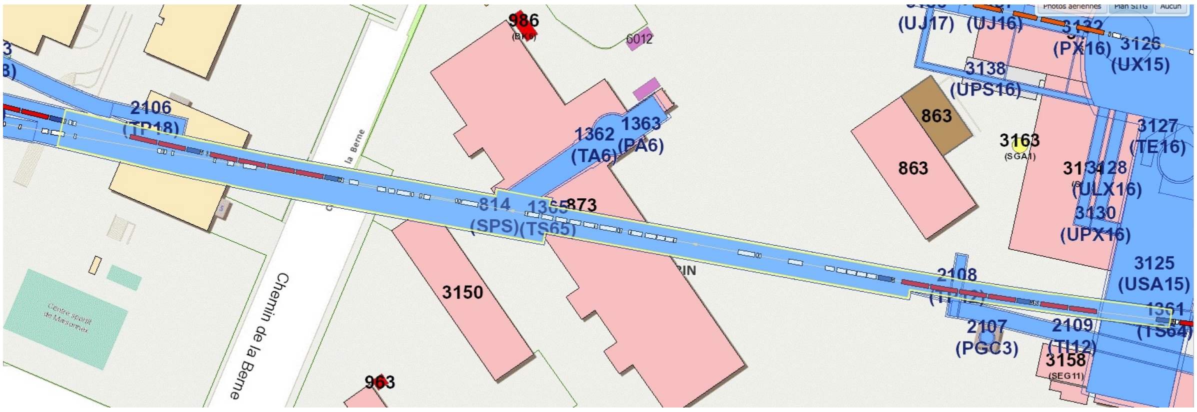
  Cons:

  - COLDEX is installed and will run until end of 2016, and may request continued operation past this date.
  - Cryogenic cold box is insufficient for crab cavity operation and needs to be replaced
  - Cryogenic return line is to North area via SPS Pt3
  - Difficult to install upgraded cold box installation in the alcove zone, due to insufficient available space in the .
  - Installation of cryogenic infrastructure in LSS4 can only take place during the 2016 YETS and or the 2017 EYTETS
- **LSS5 Alcove**



(a) LSS4

(b) LSS5



(c) LSS6

Figure 3: Breakdown of SPS LSS locations where a crab cavity installation could be installed. Tunnel and underground areas shown in blue, and surface buildings shown in pink. The possible locations for a crab cavity installation are where there is at least a 10m section of available beam line space in a section of tunnel that is larger than the standard arc sections.

Pros:

- Same spatial layout as LSS4 Alcove
- ECX5 and ECA5 cavern are only 35m away: Possibility of RF power and cryo cold to be installed in ECX5
- Control room space could be sited in ECA5 or on the surface in BA5
- Area in BA5 surface the ECA5 access shaft is presently only used for storage (components from ATLAS) next to ECASurface building

Cons:

- Space is presently occupied by Collimation and BI equipment.
- Like LSS4 Alcove there is insufficient space in the alcove area to install a cryo cold box of sufficient capacity. The cold box would have to be installed at a remote location (ECX5/ECA5 or surface) and helium supply lines installed.
- Existing CV water piping in the alcove encroaches more on the available space than in the LSS4 alcove, making the LSS5 alcove more restrictive than the LSS4 alcove. If the LSS5 alcove is to be considered, either the CV pipes would have to be rear-

ranged or the Crab Cavity table layout modified (i.e. displacement of the tetrodes to the ECX5/ECA5/Surface area

- Cable trays and service routes in the tunnel between the Alcove and ECX5/ECA5/Surface area are overcrowded, to the extent that it is unlikely that services could be routed from the ECX5 to the alcove (especially as cryogenics services would require a helium transfer line of 45cm diameter, and if the tetrodes were displaced to ECX5 or ECA5 two 30 cm RF coax lines would be needed.
- If the cryo and RF services are to be installed in the ECA5 or on the surface, then a solution needs to be found for passing the helium line RF power coax through the ECX5/ECA5 shielding.
- Any services installed in ECX5 or ECA5 would have to be done in compatibility with the proposed activities (cabling campaign, magnet coating facility, civil engineering for LIU) foreseen for LS2.

- **LSS5 ECX5**

  Pros:

  - Space on the passerelle of ECX5 is compatible with a cryomodule installation. This would require the extension of the passerelle by a platform on which the crab cryomodule could be installed.
  - There is amble space for the cryogenics and RF support infrastructure in ECX5, ECA5, or at the surface of the ECA5 pit shaft. It is assumed that a cold
  - If the cryo cold box is install in ECX5 or ECA5 then there is essentially no helium line routing in the tunnel. This assumes that the cryogenics cold box system is essentially a stand-alone system with its own helium purifier on the consists of a helium purifier.
  - Control room space could be assigned either in ECA4 or in BA5

  Cons:

  - A crab cavity installation in ECX5 would be in compatible with the LIU proposal for an external beam dump that is proposed for LSS5. If the new beam dump is approved, the civil engineering work is proposed to start in LS2. This means that any uses of ECX5 for crab cavity validation would be limited to beam time prior to LS2.

- **LSS6**

  Pros:

  - Possible location: 15m space between the SPS.QDA.61710 and SPS.TPSG.61773
  - The tunnel in this section is enlarged so that is essentially an extented alcove, and there is sufficient space for the installation of crab cavity support table, Y-chamber switching, and cryomodule.
  - The space behind the beam line is not used by any other system.
  - The location is 70m away from the bottom of the closest access shaft, and then an additional 35m to the top of the access shaft.
  - The only beam extraction occuring in LSS6 is the fast extraction for HiRadMat, and so radiation does rates are expected to reduce with time.

  Cons:

  - There is no experimental cavern near by, so either the infrastructure is located on next to the crab installation or it is moved to the surface.
  - Space will have to be found for an on-surface control room. Combined with the relocation of service infrastructure to the surface, an estimated surface area of XX m^2 is required.
  - The conceptual design of the cryomodule support table infringe on the SPS transport lane.

Using the conceptual design of the crab cavity installation foreseen for LSS4, Figures 4, 5, and 6 show a simple visualisation of what could be achieved. Note that in Figures 5, and 6, the green an orange box represents a TCF50 cryo cold box, which would be capable of providing the required capacity.

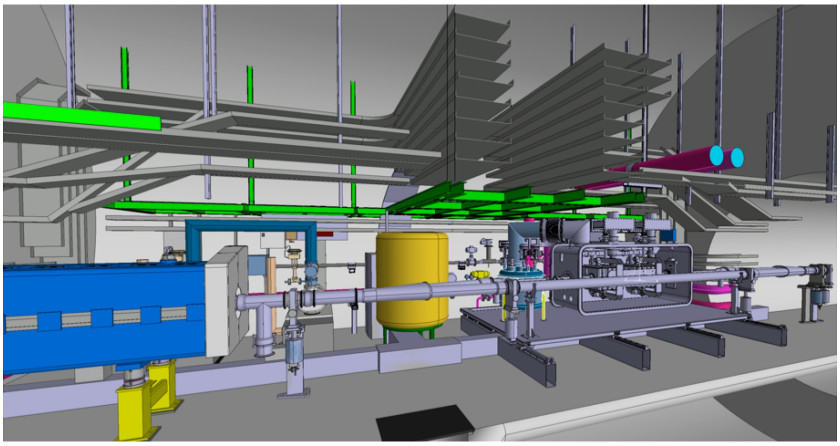


Figure 4: Baseline LSS4 Alcove installation. Shown in grey is the crab cavity cryomodule and support table.

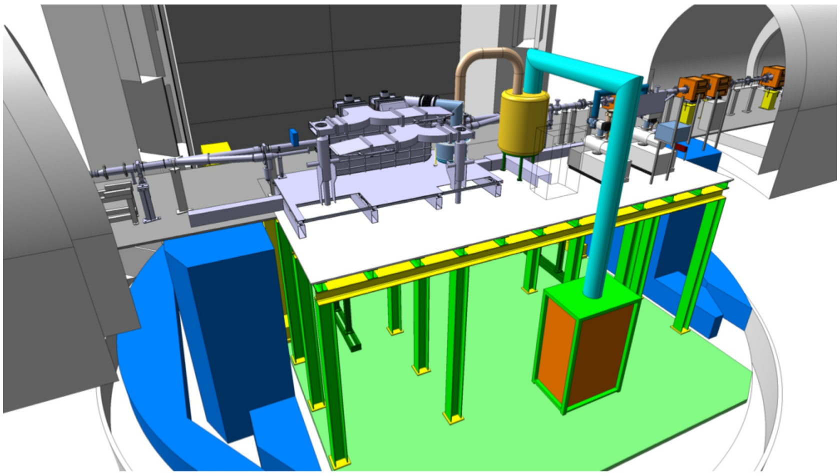
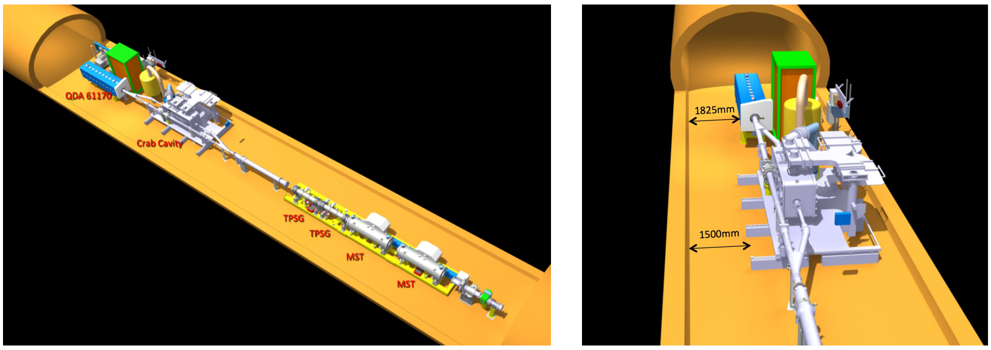


Figure 5: LSS5 ECX5 installation. Shown in grey is the crab cavity cryomodule and support table.

7 Schedule Issues

The installation schedule plays an important aspect in the selection criteria, as access to the SPS tunnel is limited to shutdowns and technical stops. For access into the SPS before LS2 the only substantial periods of access are the 2015-2016 Year End Technical stop (YETS), the 2016-2017 Extended Year End Technical Stop (EYETS), and the 2017-2018 Year End Technical stop (YETS). YETS correspond to 5 weeks and EYETS 12 weeks of SPS access. Given that LS2 is scheduled to start in mid 2018, and that the crab cavities are to be validated with beam prior to the start of LS2, the 2015-2016 YETS and 2016-2017 EYETS must be used for installing the required infrastructure. The EYETS is also seen as the time slot in which the first crab cryo module is to be installed in the SPS.



(a) Proposed LSS6 location

(b) Transport lane constraints

Figure 6: Proposed LSS6 for a crab cavity test site. As shown in (a), the crab cavity cryomodule is installed between QDA61170 and the TPSG collimators. As can be seen in (a), there is sufficient space for both RF power (tetrodes+ circulators+ loads) and cryogenics cold box, if it is decided to install these inters in the tunnel close to the cryomodule. However, as can be seen from (b,) the conceptual design of the support table does infringe on the transport lane, and so would need to be modified. Also, the implicit constraint is that the cryo module must be in the out of beam position whenever there is an access into LSS6.

Scheduling is further complicated by the need for compatibility with other users and equipment teams In particular:

- **LSS4**
  - COLDEX in operation until end of SPS running in 2016. No new crab related infrastructure can be installed in LSS4 until after COLDEX is removed.
- **LSS5**
  - If the LIU beam dump project is approved, then Civil engineering is expected to start in LS2
  - An extensive cabling capping in LSS5 is expected to start in LS2
  - If approved, ECA5 is to be used as a magnet coating facility in LS2, and so it is assumed any crab related activity in ECA5 would be limited in the time leading up to LS2
- **LSS6**
  - No known constraint either before or after LS2.

8 Summary

In summary, there are several possible locations for a cryogenic crab cavity testing facility in the SPS, but none are without issues. Of the SPS long straight sections, which are the only feasible section in the SPS in which to install a test facility, only LSS4, LSS5, and LSS6 are to be realistically considered.

If not for the incompatibility with the LIU external beam dump proposal, the LSS5 ECX5 location would be ideal, especially considering that the ECA5 area could be used for infrastructure and control room. If this location is unavailable then the next preference is for LSS6, as there is space for the installation and infrastructure in the tunnel, and no incompatibility with other users or experiments. LSS4 is the least likely location, despite being the present baseline, due both to the predilection of COLDEX for the LSS4 alcove, and the lack of capacity of the existing cryo system installed in LSS4.

Location	Beamline Space	Cold Box Space	Compatible with Others
LSS4 Alcove	Yes	No	No: COLDEX till end of 2016
LSS5 Alcove	Yes*[1]	No	Maybe: Collimation, BI
LSS5 ECX5	Yes	Yes	No: LIU external beam dump
LSS6	Yes*[2]	Yes	Yes

Table 1: Summary of possible locations. *[1] Refers to the point that CV piping would have to be reorganised to allow the crab installation to be installed, and *[2] refers to the point that the crab cryomdule support table design has to be modified to avoid infringement on the SPS transport lane.

In all locations considered, it is assumed tag a "self-contained" cryo system will be installed, with cold box and helium purifier on the rerun line, so that the cryogenics is a stand-alone system. As to whether the new cold box is installed down stairs in the SPS tunnel or experimental cavern, or on the surface, this recommendation for this decision should come from Cryogenics, but they have noted that a solution that allowed access to the cold box when the SPS is with beam would be preferred. This suggest that an on surface installation is preferred if the cost and time of helium line routing is not prohibitive.

Similarly the RF power would prefer to Pre-amps and tetrodes on the surface, both for access and as it would match more closely with the foreseen RF-Power installation for the HL-LHC.

Lastly, of all the locations, LSS6 seems the most compatible location for a short term and long term test facility, simply because there seem to be no conflicts with other projects or installed experiments.