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Findings of the Physics Beyond Colliders ECN3 Beam Delivery Task Force

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Summary

The ECN3 Beam Delivery Task Force was mandated by the PBC Study Group to assess the technical feasibility of increasing the proton beam intensity to the ECN3 hall of the North Area to satisfy the demands of a compelling set of PBC experimental physics proposals. This report summarises the findings of the Task Force that converge on a technically feasible solution with an implementation timeline that could exploit and build upon the investment already foreseen as part of Phase 1 of the NA-CONS project, and take the SPS complex into a new intensity frontier for Fixed Target physics in Run4.

Contents

Executive Summary

The Physics Beyond Colliders (PBC) ECN3 Beam Delivery Task Force (TF) was mandated to analyse the ECN3 intensity upgrade concerning beam delivery and related infrastructure, considering solutions compatible with the North Area Consolidation (NA-CONS) plans and the PBC Letters of Intent (LoI) received by the SPSC for exploitation of ECN3 from Run4 onwards. No showstopper has been identified to deliver the High Intensity (HI) beams requested in all PBC LoIs.

A solution based on a dedicated beam delivery scenario without beam splitting in TDC2 and without impacting the targets in TCC2 is recommended to avoid increasing dose rates in these critical areas. The dose rates from the beam-induced radioactivation of TDC2 and TCC2 are already critical and cannot be further increased without significant upgrades of the existing beam intercepting devices and beamline infrastructure, which are based on design techniques from the 1970s that are not ALARA compliant. The dedicated scenario meets the requirements of all PBC LoIs whilst continuing to service the other NA experiments and users in EHN1 and EHN2. It also reduces the scope of the work required during LS3 in TCC2 to prioritised consolidation items based on recent operational experience and equipment failures.

In order to avoid a significant upgrade of the T4 target and its associated XTAX, a solution has been identified whereby the T4 target is bypassed with a closed-trajectory, vertical magnetic bump on the dedicated cycles with beam into P42 to ECN3. In this way, the MTN magnets in the wobbling system of T4 can be kept powered in DC mode. The approach remains compatible with the T4 target intensity limitations and will significantly reduce beam loss and corresponding radioprotection constraints, while providing sufficient beam intensity to H6/H8 on SFTPRO cycles. A bumper magnet has been installed in TCC2 to demonstrate the concept in 2023.

The TF's investigations have found that the present understanding of the primary proton beam transmission from TCC2 to TCC8 is poor and needs to be urgently addressed to secure the HI future of ECN3. Recent beam measurements have highlighted an important discrepancy with the MADX optics model of TT20. It has motivated the advancement of magnetic measurements of the magnet types located on the primary beamlines up to ECN3. To further improve our understanding, many activities have already been advanced to the YETS22/23, including the installation of new beam instrumentation systems to facilitate studies with beam in 2023. A suspected aperture bottleneck in P42 has also been alleviated by the removal of the switching dipoles, no longer used between the P6 and P42 beamlines, with the latter undergoing survey to smooth alignment errors. Beam instrumentation often left in-beam during operation is now removed whenever possible, as well as vacuum pressures further improved to reduce beam loss. The understanding of the operational and failure limits of the existing NA beam intercepting devices has been increased with a dedicated FLUKA simulation campaign and thermomechanical studies. These have identified important machine protection and safety aspects that will be followed up in a future technical design phase. Radiation Protection (RP) studies have identified two areas with insufficient shielding between TCC2 and TCC8, at the EHN1 ramp and ECN3 bridge, which were addressed during 2022 operation. First mitigation measures have already been implemented and further improvements to the shielding of P42 have been proposed. With these implemented the

HI beam transfer from TCC2 to TCC8 is expected to be compliant with CERN's RP code.

The impact on the NA-CONS project was analysed in detail and synergies identified to minimise the cost and demand on resources when including the required upgrade of the primary beamlines and TCC8/ECN3. It is important to distinguish between upgrade requirements solely needed for HI operation, compared to additional consolidation needs linked to the operational deficiency or single-point failure of critical equipment observed during the last two years of operation. A timeline is proposed that prioritises the relevant consolidation work in TDC2 and TCC2 in NA-CONS Phase 1, but relaxes the demand for additional resources in LS3 by decoupling and staggering the work planned in TCC8/ECN3 to mostly after LS3. Importantly for the NA-CONS project, the advancement of the consolidation of BA82 from NA-CONS Phase 2 into LS3 can be avoided. The civil engineering work required in TCC8/ECN3 to house the upgraded HI facility is minimal and the reuse of existing, consolidated and upgraded infrastructure will come at a significantly reduced cost compared to the construction of a new underground experimental complex.

It must be emphasised that the timeline is tight, hence demanding a timely decision on the go-ahead of the upgrade project in order to remain compatible for physics operation in Run4. A decision in time for the 2023 MTP exercise is particularly important to support the prerequisite studies needed already in 2023 to advance on the beam delivery aspects in parallel to the on-going experiment-specific decision process, and to ensure that the technical and engineering studies required to optimise NA-CONS Phase 1 can be completed before LS3. A decision endorsed by the CERN Research Board must be achieved before the end of 2023 to guarantee the start of a detailed TDR phase in 2024 for the target complex and the experiment-specific upgrades needed in TCC8/ECN3, which are also on the critical path.

1 Introduction

A diverse programme that is complementary to the energy frontier is an essential part of the European Particle Physics Strategy [1]. In terms of intensity, energy and infrastructure, the ECN3 underground cavern at CERN's SPS North Area (NA) offers unique opportunities for potential high-impact particle physics programmes that are complementary to the energy frontier and that are in line with the ESPPU 2020 recommendations. There is therefore a strong interest to fully exploit the SPS for Fixed Target (FT) physics, which has resulted in the PBC Study Group [2, 3] focusing on siting a future HI experimental facility in ECN3 of the NA.

The ECN3 underground cavern is part of the SPS NA complex [4]. It was designed in the 1970s as the high-intensity facility and was served by two beam lines. Since the approval of NA62, the beamline on the Jura side of the cavern was dismantled, which was at the time serving NA10, NA38, NA50 and NA60. The P42 beamline now serves to transport a primary proton beam to the T10 target, from which the K12 secondary beamline delivered the kaons initially to the NA48 experiment and now to NA62. An overview of the full flexibility of the complex is given in [5].

Locating a new HI facility in ECN3 has many advantages and, most importantly, makes upgraded or new physics experiments possible already after LS3 by exploiting synergies with the NA-CONS project at a reduced cost compared to constructing an additional new cavern [6]. With this in mind, and given that the NA-CONS project is already underway (most of the related infrastructure is now more than 40 years old), CERN must act quickly to guarantee a synergised approach with the NA-CONS project cost, scope and schedule in order not to miss this opportunity of implementing an HI FT physics facility at the CERN SPS in Run4.

1.1 Scope and mandate

Within the PBC Study Group, the ECN3 Beam Delivery TF [7, 8] was mandated to analyse the ECN3 intensity upgrade concerning beam delivery and related infrastructure, considering solutions compatible with consolidation plans and post-LS3 experimental scenarios. The investigations of the TF are summarised with brevity in this report to provide a first summary of the findings (scope, timeline, cost & resources) as input to the 2023 MTP exercise, with more detailed documentation to come as part of the PBC Study Group's final report *Post-LS3 Experimental Options in ECN3* to be published in summer 2023. This report summarises the technical solutions needed to realise the HI facility in LS3 and outlines an analysis of the first phase of the NA-CONS project that will lead to estimates for the required cost, scope and schedule of an updated project baseline. In particular, the TF was asked to:

- Identify and agree on the most relevant upgrade scenarios consistent with the intensity requirements of the ECN3 experimental proposals submitted to the SPSC, maintaining compatibility with post-LS3 NA users and experiments (EHN1/EHN2).

- Evaluate the required infrastructure modifications to the primary and secondary lines up to and including the TDC2/TCC2 areas and P42 transfer line.

- Consider an implementation in LS3 and highlight the impact on present NA-CONS consolidation project plans, including the impact of the experiment proposals on the consolidation plans for TCC8/ECN3.

The ECN3 Beam Delivery TF's investigations remain agnostic to the different PBC experimental requests. Nevertheless, in order to assess the specific impact on the NA-CONS project for the related infrastructure/services requirements in TCC8/ECN3, the conclusions of the BDF/SHiP and Conventional Beams (CB) Working Groups (WG) were used to understand the envelopes of the different experimental user requirements.

1.2 Considered experimental programmes

Several large and diverse user communities have well developed scientific proposals that require and would make use of a unique facility such as ECN3. Three collaborations have submitted LoIs to the SPSC for experiments in ECN3:

- BDF/SHiP [9] is a dedicated facility searching for Feebly Interacting Particles (FIPs), originally developed for a new dedicated underground cavern (ECN4). In this context a full engineering and infrastructure study has been performed for the target and experimental area complex from which many findings are applicable for the ECN3 evaluation [10]. The experimental programme also includes a neutrino detector and aims for an intensity of 4.0×10^{13} protons per pulse (ppp), giving 4.0×10^{19} Protons On Target (POT) per year for 5 years. The collaboration estimates that they could run up to 1.0×10^{21} POT before reaching the background limit.

- HIKE [11] proposes a comprehensive kaon physics programme. Phase 1 foresees an initial phase requesting 1.3×10^{13} ppp, resulting in 8.0×10^{18} POT/yr. This phase also includes running in beam dump mode to search for FIPs. Already this phase requires a full run between two Long Shutdowns (LS), more if an extended beam dump run is included. For Phase 2, HIKE plans a programme with a neutral kaon beam but still with a detector setup similar to Phase 1. This phase will require a new neutral beam line of 120 m length and again a full run between two LSs. Finally, the third phase, also called KLEVER, will require a 270 m long neutral kaon beam line and probably a 150 m extension of the ECN3 hall. For the beam dump mode and for Phases 2 and 3, HIKE requests 2.0×10^{13} ppp, corresponding to 1.2×10^{19} POT/yr. In this report, only the implications of Phases 1 and 2 are considered as this covers an operation period beyond LS5, when considering partly shared operation with SHADOWS (see next paragraph).

- SHADOWS [12] proposes an off-axis search for FIPs and can run in parallel with HIKE in beam dump mode. They must integrate the detector close to the dump (aiming at a large angular acceptance). A dedicated neutrino detector located downstream of the main detectors is also being developed. SHADOWS assumes 2.0×10^{13} ppp and 1.2×10^{19} POT/yr during 5 years.

Given the significant increase in requested beam intensity and in light of modern-day radioprotection and environment legislation, a new target complex design is assumed in TCC8 for the HI facility using ALARA principles for operation, maintenance and decommissioning [13].

2 Beam delivery scenarios

Two beam delivery scenarios, summarised schematically in Fig. 1, were considered for increasing the intensity to ECN3:

- **Shared:** identical to today's present-day operational scenario using cycles of type **SFTPRO**. The beam is split on Lambertson septa in TT20 and delivered simultaneously to all target stations in TCC2, with the splitting ratio adjusted to increase the intensity on T4 and towards the experimental target housed in TCC8.
- **Dedicated:** a new operational scenario where the beam is transported through TT20 and TCC2 and delivered exclusively onto the experimental target housed in TCC8 on a dedicated **SFTPRO** cycle.

The **dedicated scenario** assumes that the primary beam can be cleanly transported without splitting in TT20, bypassed around the TCC2 target stations and delivered onto new target system infrastructure housed in TCC8. No other NA experiment can receive beam when a dedicated ECN3 cycle is played, making proton sharing to the rest of the NA more challenging. The machine protection and safety aspects need to be considered when transporting high intensity beams through the existing accelerator infrastructure.

An increase of the beam intensity in the **shared scenario** would significantly impact the radiological situation at the splitters in TDC2 and existing targets in TCC2 to levels that would not be acceptable for such a facility being considered for construction today. An understanding of the thermomechanical limitations of the existing target infrastructure in TCC2 with the increase of intensity was part of the TF investigations.

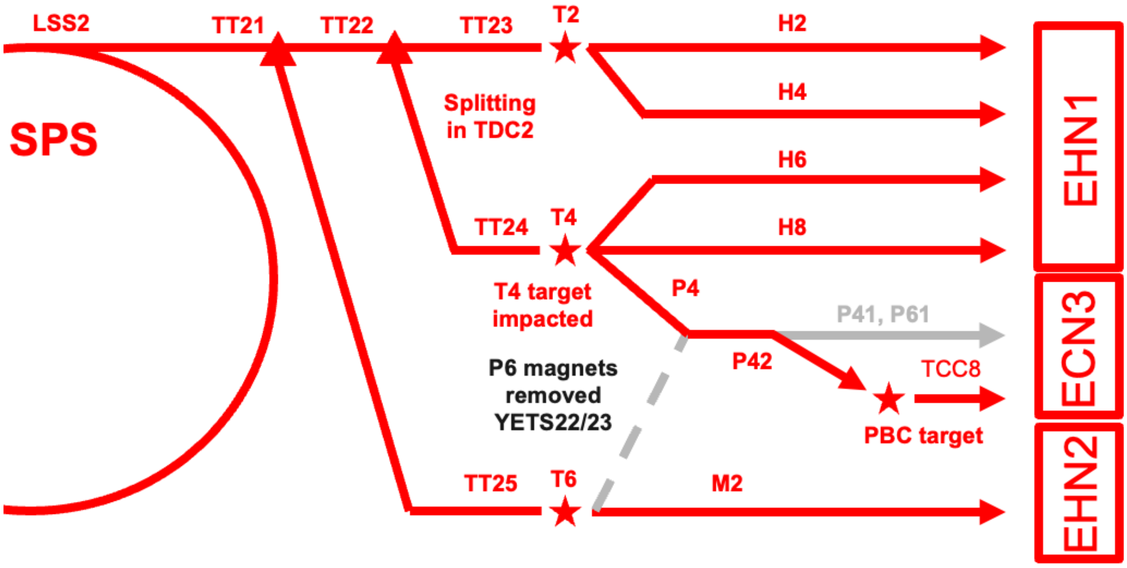
2.1 Constraints

2.1.1 Summary of beam requirements

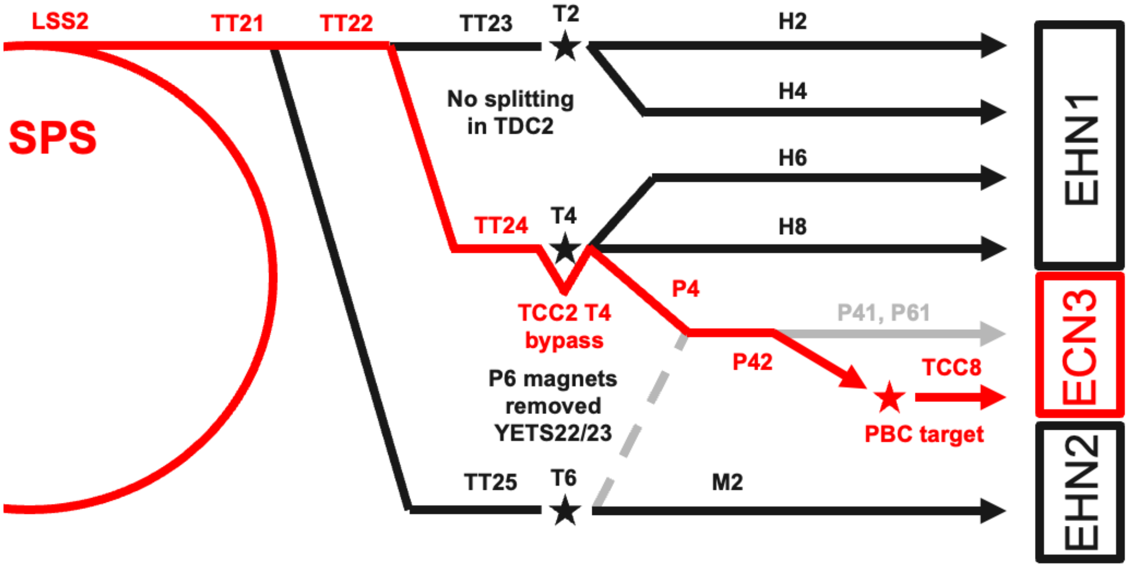
The experimental requirements were agreed through the PBC A&T Committee and communicated to the relevant CERN equipment groups via NA-CONS project management, and are consistent with the LoIs submitted to the SPSC, see [14, 15, 11, 12, 9] for a detailed explanation. The intensity, spill length and average proton flux requirements and limitations were translated into the two beam delivery scenarios collected in Table 1. The dedicated scenario is compatible with all LoIs submitted to the SPSC. The highest requested integrated intensity and shortest spills [9] was expressly only considered in the dedicated scenario because of the known constraints from proton sharing [16], in addition to the radiological and thermomechanical constraints of the existing infrastructure in TDC2 and TCC2.

2.1.2 General radiation protection constraints

The present-day NA beam operation poses several RP constraints that are already nowadays a challenge for operation and maintenance. Beside residual and prompt dose rate constraints,



(a) Shared ECN3 scenario (similar to today's operational scenario - SFTPRO)



(b) Dedicated ECN3 scenario

Figure 1: Schematic diagram of the two ECN3 beam delivery scenarios considered.

also activation of air and water have to be considered when operating such a facility.

Due to the nature of the slow extraction process and the need to serve multiple target stations simultaneously, significant radioactivation of beamline components occurs in the SPS LSS2 extraction straight, the TDC2 splitter area and TCC2 that hosts the target stations. These areas were designed and built in the 1970s when radioprotection regulations were less restrictive in comparison to today. Interventions in these areas are challenging due to the very high dose rates of some of the components and the lack of dedicated remote handling features, e.g. extraction septa in LSS2, splitter collimators and magnets in TDC2 and production targets and absorbers in TCC2. As a consequence, and in addition to the detailed preparation and optimisation work needed to reduce to a minimum the dose to

Table 1: Beam intensity and cycle constraints considered for the TF investigations [14].

ECN3 Scenario	**SPS p^+ Intensity** [ppp]	**ECN3 p^+ Intensity** [ppp]	**Spills (avg.)** [ECN3/day]	**Spill Length** [s]	**Repetition period** [s]
	[POT/yr]	[POT/yr]	[total NA/day]		
Dedicated[a]	$\leq 4.2 \times 10^{13}$	$\leq 4.0 \times 10^{13}$	$\lesssim 5000$	≥ 1.0	≥ 7.2
T4 bypass	$\leq 5 \times 10^{19}$	$\leq 4.0 \times 10^{19}$	$\lesssim 6250$		
Shared[b]	4.2×10^{13}	$\leq 2.0 \times 10^{13}$	~ 3000	≥ 4.5	≥ 14.4[c]
split in TT20	2.4×10^{19}	$\leq 1.2 \times 10^{19}$	~ 3000		

Limitations:

[a] Accidental beam impact scenarios requires checks of HW limits and corresponding interlocks

[b] RP impact of splitting in TDC2 and transmission in TCC2 is significant, thermo-mechanical limits of beam intercepting devices

[c] SPS mains RMS power: cycle length ≥ 10.8 s padded with an MD or degauss cycle: in the case of a 4.8 s flat-top this leads to a 10.8 s cycle length with a 3.6 s padding cycle.

personnel, significantly long cool-down times are needed before interventions.

In addition to high residual dose rates, prompt beam losses may also cause elevated dose rates in the areas of the NA that are accessible during beam operation. It must be ensured that in these areas the prompt dose rates do not exceed the applicable radiological area classification limits [17]. A few critical locations in the NA were identified, where already the present-day beam transfer provokes radiation levels close to or even exceeding the limit creating radiation alarms that interfere with beam operation. A detailed analysis was carried out during 2022 operation [18], triggering a number of immediate mitigation measures, on-going YETS improvements, as well as further modifications considered for early 2023 or kept for later optimisation.

In view of significantly increased beam intensities, adequate compensatory measures to reduce the residual and prompt dose rates are crucial to ensure unrestricted beam operation and maintainability of the NA in compliance with CERN's RP code [19] (see Section 3.4). If beam loss levels remain unchanged in the future, then air and water activation will also remain unchanged. However, if beam loss levels are to increase with the beam intensity, one has to study the development of air and water activation to satisfy legal and optimisation obligations in terms of radiation and environmental protection.

2.1.3 North Area operation and schedule

It is assumed that the needed upgrade or consolidation of the accelerator infrastructure upstream of TCC8 must be ready for operation after LS3 to avoid impacting other NA users, with LS3 starting in 2026 including an EYETS the year before. To achieve this goal, engineering studies must be completed before LS3 to keep compatibility with Phase I of NA-CONS and execution in LS3. For this reason and given the length of cool-down required in highly radioactive areas, major modifications in TDC2/TCC2 are (most likely) not compatible with LS3 constraints. An important requirement is the ability to decouple TCC8/ECN3 from the upstream accelerator infrastructure (access, cooling and ventilation, etc.) to allow 1 - 2 years to complete work in TCC8/ECN3 after LS3 and during Run4, whilst the rest of the NA is operational.

2.1.4 Accelerator operation at 4.0×10^{13} ppp

During the summer of 2022 and the month-long LHC downtime, the SPS demonstrated an impressively reliable period of operation at $\sim 4 \times 10^{13}$ ppp, when an exceptionally high proton flux was delivered for the experiments COMPASS, NA62, and NA64. Despite an improvement of normalised beam losses (per proton delivered on target) after LS2, unprecedented activation levels were measured in TDC2 and TCC2 during the Injector Technical Stop 2 [20]. The high activation was attributed and directly correlated to an extraction rate a factor of ~ 3 higher than typical for the NA. This remarkable period of HI operation marks an important milestone in pushing the limits of the CERN accelerator complex but highlights its consequences on the induced radioactivity in critical, high-loss areas. The TF recommends that the SFTPRO transmission throughout complex is reviewed and optimised during Run3 and well before LS3. Specific actions in view of a future HI facility in ECN3 include:

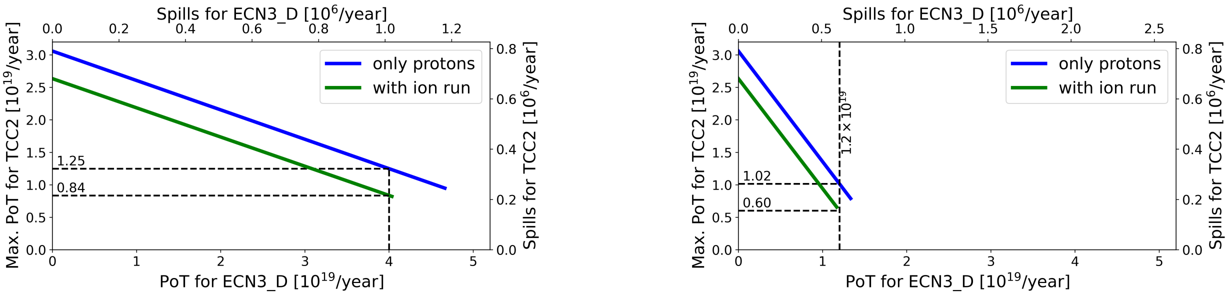
- Continued development of extraction beam loss reduction techniques (see Section 3.1.2);
- Development of instrumentation and procedures for accurate measurements of beam intensity and beam losses at extraction and in the transfer to the NA Targets (see Section 3.2.4);
- Developments to reduce beam loss across the complex, such as the barrier bucket in the PS to reduce extraction losses [21, 22].

2.1.5 Proton sharing

The sharing of protons throughout the accelerator complex and the rest of the NA with the operation of a HI facility in ECN3 was studied with realistic supercycle compositions, taking into account the RMS power limits of the SPS and NA circuits, over a 35 week operational year, assuming an 80% machine availability [16, 23].

The study demonstrates that up to 1.2×10^{19} POT/yr can be delivered to the targets in TCC2 (on SFTPRO) whilst satisfying all HI requests for PBC experiments with a **dedicated** ECN3 beam delivery scenario, as shown in Fig. 2, provided no ion run takes place, while 0.8×10^{19} POT/yr can be delivered in case an ion run (1 month) is included. This scenario provides a comfortable sharing between the other NA users. In particular, it will assure parallel operation of two FT experiments such as AMBER and NA64e, and is also compatible with the present view on other proposals for new experiments in the NA, which were mostly studied within PBC.

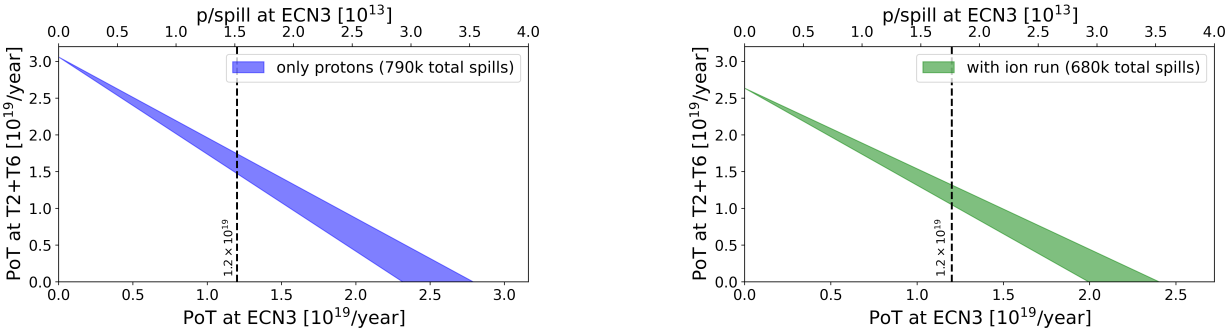
For the **shared** ECN3 scenario, more than 1.7×10^{13} ppp must impact the T4 target in order to achieve the requested POT delivered to ECN3, as shown in Fig. 3. Considering the presently uncertain transmission losses through the T4 target system and P42, this would bring the value up to 2×10^{13} ppp, leaving between 1.5×10^{19} and 1.8×10^{19} POT/yr for users other than ECN3 in the absence of an ion run. In the presence of an ion run 1.1×10^{19} to 1.3×10^{19} POT/yr would be available for users other than ECN3. The TF is working on various fronts to understand and optimise transmission through the T4 target system and P42 transfer line to TCC8.



(a) Dedicated ECN3 cycles (1.2 s flat-top), 4.0×10^{13} ppp entering TCC8 ($= 4 \times 10^{19}$ POT/yr).

(b) Dedicated ECN3 cycles (4.8 s flat-top), 2.0×10^{13} ppp entering TCC8 ($= 1.2 \times 10^{19}$ POT/yr).

Figure 2: Proton sharing for **dedicated** ECN3 beam delivery: POT delivered to the NA (TCC2) and ECN3



(a) Proton operation only.

(b) Including an ion run.

Figure 3: Proton sharing for **shared** ECN3 beam delivery (4.8 s flat-top): POT at NA (TCC2: T2 + T6) depends on the assumed transmission through T4 target system (75 - 95%)

It is important to point out that the integrated TCC2 POT for the **dedicated** ECN3 beam delivery scenario was computed to maximise the flux to TCC2, i.e. today's SFTPRO cycle accelerating 4.2×10^{13} ppp with a 4.8 s flat-top. For some existing NA users this might be problematic due to instantaneous rate limitations. A careful scheduling of rate-limited NA experiments exploiting longer cycles with a flat-top of 9.6 s would help optimise beam delivery and alleviate this problem. The study demonstrated that up to 0.8×10^{19} POT/yr can be delivered to TCC2 on SFTPRO cycles with a 9.6 s flat-top in parallel to dedicated ECN3 cycles, provided no ion run takes place, while 0.6×10^{19} POT/yr can be delivered in case an ion run (1 month) is included in the operational year. The TF recommends that a WG is established to survey NA users to understand the rate limitations and to what extent better scheduling, improvements in spill quality or even improvements in detector and readout technology could improve data taking.

To reduce the already wide scope of beam delivery and cycle options, so far the TF's investigations of an hybrid cycle (dedicated and SFTPRO on the same cycle) was not yet addressed in detail. However, it is important to point out that hybrid cycles are now conceptually possible with PPM (Pulse-to-Pulse Modulation[1]) converters in TT20 and the ability to stop and start the slow extraction by manipulating the tune [24]. In view of increasing the proton throughput to the NA in the future, the TF recommends that a hybrid, multi-user cycle with an intensity higher than 4.2×10^{13} ppp is investigated.

2.1.6 Energy consumption with HI Operation in ECN3

The energy consumption of the SPS main magnets and the NA magnets depends on the cycle composition. It therefore depends on the operational scenario and the corresponding SPS cycle composition. These elements are among the main contributors to the overall SPS and NA energy consumption during beam operation, representing more than 40 % and almost 15 % of the total, respectively. Supplying beam to a HI facility in ECN3 will not change the power consumption significantly with respect to recent years. For 2022 the total energy consumption of the SPS main magnets was $\sim$ 170 GWh and the estimated difference for all the ECN3 beam delivery scenarios considered (with 1.2 to 9.6 s flat-top) is small and no larger than $\sim$ 10 %, see [23].

2.2 Preferred beam delivery scenario

The preferred beam delivery scenario is a mixed super-cycle with the present-day SFTPRO cycles for EHN1 and EHN2 along with dedicated high-intensity cycles for ECN3. As described above, the dedicated cycles will be delivered without splitting in TT20 and bypassing the present T4 target before being transported along P4/P42 to TCC8. This approach remains compatible with T4 target intensity limitations and will significantly reduce beam loss and corresponding RP constraints, while providing sufficient intensity for the other NA experiments and test beam users. Furthermore, a significant upgrade of the T4 target and XTAX complex is avoided when an LS3 implementation timeline is already challenging; an upgrade would likely require a complete consolidation of TCC2 which is highly demanding considering the already limited resource availability.

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[1] Pulse-to-Pulse Modulation refers to the capability of a parameter of an accelerator device (e.g. current in a magnet) to be set differently depending on the user/destination being played. In this case, different settings must be played on the dedicated ECN3 cycles to those played on the operational SFTPRO cycles.

2.2.1 TCC2 target bypass and P42 dump

The bypass of the T6 target system in TCC2 was ruled out because of the need to design and manufacture a laminated version of the MTN dipole magnet located on the P6 beam line. The MTN dipoles deflect the beam back from the T6 target towards P42 and would need to be laminated in order to maintain EHN2 operation. In addition, there were other challenges in reviving the P6 line, which was last operated for NA60. The production of large aperture, laminated MTN magnets (capable of pulsing) would undoubtedly cost many MCHF and have an undefined lead-time with significant R&D required.

Instead, it is proposed to bypass the T4 target station with a closed, vertical magnetic bump. The MTN magnets in the wobbling system of T4 (that allow for a momentum selection of the secondary beam produced in the T4 target for H6/H8) can be kept powered in DC mode and the beam transported into P42 to ECN3 on dedicated cycles, whilst still providing beam to H6/H8 on SFTPRO cycles. The drawback with this approach is that the fraction of beam that does not interact with the T4 target on the SFTPRO cycle will still enter P42, as it does today for NA62 in ECN3. To ease the situation, the beam entering P42 can be reduced in intensity on the SFTPRO cycle by reducing the primary beam intensity and increasing the target length (up to 500 mm, according to the H6/H8 experimental programme). It is foreseen to transport the beam played on the SFTPRO cycles to the target in TCC8, which would boost the POT in ECN3 by a small amount. For this reason, the dedicated optics in TT20 was matched to the same optics in P42 as used on SFTPRO.

During Run4 not all power converters downstream of TCC2 will be capable of pulsing in PPM-mode (those located in BA81), however, after LS4 all magnets and power converters in P42 will be PPM-compatible and the two different users SFTPRO and dedicated ECN3 could be optimised independently. A dump located in the P42 beamline could be used before LS4 if the transmission of the SFTPRO beam causes issues. The P42 dump is discussed in more detail in Section 3.3.5.

3 Beam delivery implementation

3.1 SPS extraction

3.1.1 Electrostatic septa

The LS3 timeline for implementation of the HI upgrade is too short to realise advanced crystal technology to replace the electrostatic septa, which will remain the workhorse of the SPS slow extraction system for many years to come. The consolidation of the septa is already planned and funded in ACC-CONS during LS3 and ready for Run4, with a far longer-term R&D objective to replace the septa with crystals. In parallel, PBC funding is supporting R&D for the development of a low-density version of the septa with an improved anode straightness, which could possibly be implemented into the consolidated tanks.

3.1.2 Extraction beam loss reduction

A factor of ~ 4 reduction is needed to facilitate the upgrade without impact on the present day radiological situation in LSS2. R&D on the LS3 timeline is focused on beam loss reduction techniques that significantly improve the efficiency of the present electrostatic slow extraction system [25, 26, 27].

The required extraction beam loss reduction factor can be achieved with the crystal shadowing technique developed at CERN [28]. With PBC funding support, up to a factor of 2 has already been demonstrated at the SPS with beam tests of prototype local and non-local shadowing systems installed in LSS2 and LSS4, respectively. In the latter case, the system performance is presently limited by the installation of a non-optimised crystal due to the termination of the crystal R&D collaboration with Saint Petersburg Nuclear Physics Institute (PNPI) after the Russian invasion of Ukraine. The phase-space folding technique [29] can be combined with the crystal shadowing technique to boost the loss reduction close to a factor ~ 4, although it cannot be combined effectively in the shared mode of operation because the larger emittance of the folded beam will increase the beam lost in the TT20 splitting process [30]. It is therefore vital to support funding for the DEvelopment of CRYstals for Collimation and Beam Extraction (DECRYCE) project [31] aiming at developing state-of-the-art crystals in-house at CERN. In particular, the DECRYCE project should target the production of a 1.8 mm thick, single crystal to be installed in the non-local system in LSS4 on the timeline of LS3, which would be capable of achieving a factor 4 loss reduction.

3.2 Dedicated beam optics

The optics in TT20 was rematched to provide a dedicated beam to ECN3 by transmitting it unsplit through the two TT20 Lambertson septa [32]. The magnets in the P42 line will not have PPM functionality before LS4 and so these magnet strengths were left unchanged from SFTPRO operation. Similarly, a non-laminated and non-PPM magnet in the TT22 line (QSLD.2201) was also maintained at its SFTPRO setting. These dedicated optics were designed so that two existing bumper magnets could be used in combination with a newly installed magnet for the vertical bypass around the T4 target. To help this further, the vertical beam size at the T4 target was reduced to $\sigma = 0.2$ mm. The beam size at the T10 target is $\sigma = 0.21$ mm both horizontally and vertically. Beam sizes at key locations throughout the TT20 and P42 transfer lines are given in [32]. It is recommended to use the largest T4 XTAX setting of 40 mm $\times$ 20 mm to accommodate the large beam divergence at the T4 target. With this XTAX configuration, an unsplit beam should be transported to the T10 target without losses.

Measurements of the beam size at the T4 target were time consuming due to the need to perform BBS or BSP scans at each quadrupole setting [33] and the need for a ‘single-shot’ profile measurement at this critical location was highlighted. Quadrupole scans showed that the horizontal beam focus at the T4 target was upstream of its expected location and the vertical focus was downstream. Kick response measurements highlighted similar discrepancies between the MADX model and the beamline as those observed for the operational Q-split optics, described next in Section 3.2.1. A significant effort is needed in 2023 to understand the optics discrepancies observed in TT20.

3.2.1 TT20 optics discrepancy

The SPS historically used the so-called Q-split mode of operation to allow extractions from both LSS6 (West Area) and LSS2 (NA) during the same SFTPRO flat top. Such a methodology consists in locally perturbing the SPS phase advance in the extraction plane to rotate and present the beam identically at the two different extraction systems. This results in a different presentation of the slow extracted beam in LSS2 compared to today.

Presently, two set of optics exist for TT20: (i) Q-split and (ii) non Q-split, where each is matched using the different initial conditions from LSS2 mentioned above and obtained from particle tracking in the ring [34]. In 2018, and again in 2021, the non Q-split optics was tested in operation. In 2021, the optics resulted in very poor transmission through the XTAX after T4, even though the model's predictions were rather unchanged with respect to the Q-split optics. This was the first sign of a discrepancy with the MADX model. Understanding the behaviour of the beam optics in the TT20 lines is of the highest priority when considering a redesign of the optics in the dedicated ECN3 beam delivery scenario.

During a campaign of dedicated kick response measurements a clear inconsistency with the MADX optics model of TT20 was observed, reducing the likelihood that the initial conditions are the problem. A few possible sources of the discrepancy were identified from beam-based data and the MADX model. The quadrupole string 2105, which comprises 7 quadrupoles (4 defocusing and 3 focusing) was the first suspect, which was carefully checked by in-situ measurements during ITS2 in 2022 and no anomalies were found, either on the power converter or magnets.

The present working hypothesis is that the inaccuracy on the QNL and/or QTL transfer functions (current to optical strength) is the main contributor to the observed discrepancy. The TT20 lines rely heavily on these type of quadrupoles. This was pointed out by numerical minimisation of the error between beam-based measurements and MADX model [35, 36]. Such a hypothesis was also corroborated by discovering that the wrong transfer function is used for the QNL family in the SPS control system (LSA) (already corrected during 2022 run, but not yet tested operationally) and that the source for the transfer function used for the QTL family is unknown. These magnets were designed and manufactured in the 1970's and the quality of the available documentation is lacking. In order to tackle this issue in the primary lines, but also elsewhere in the NA, a magnetic measurement campaign has been scoped into NA-CONS Phase 1 with priority on measuring the QNL and QTL transfer functions. This campaign will take place in the magnetic measurements lab in Prevessin and includes the measurement of the transfer functions and the dynamic behaviour due to eddy current effects on spare magnets without vacuum chambers.

In 2023, additional beam time has been requested during the recommissioning period and dedicated MDs to help further understand the problem. The hypothesis of inaccurate transfer functions will be tested empirically by scaling the QTL and QNL quadrupoles. Additional data with different quadrupole settings will also be collected, iteratively measuring the transfer matrix parameters to reduce the search space for the solution. Such studies are paramount for the deployment of any new optics in TT20.

3.2.2 T4 target bypass

The front-end of the T4 production target is composed of multiple 2 mm thick Be plates of different lengths (between 40 - 500 mm) arranged one on top of another with a separation of 40 mm. This geometry provides the opportunity to bump the beam vertically between the target plates. It is important to differentiate this approach at bypassing the T4 target to others proposed in the past, e.g. by blowing up the vertical beam size, because in this case there will be no interaction and attenuation of the beam with the target and no beam delivered in parallel to H6/H8 beamline users [37, 38].

With the installation of one additional vertical dipole magnet between MBN.241107 and MTN.241128 in TT24, a closed solution for a trajectory bump can be found in combination with two other bumpers (MDLV.240209 and MDXV.043048), already existing in the beamline for trajectory correction. A prototype system with a non-laminated magnet and spare power converter has been installed during the YETS22/23. This prototype system will allow tests with beam and the proof-of-principle during MDs in 2023 [39]. If the HI upgrade of ECN3 is approved, the prototype system would need to be replaced by a magnet with a laminated yoke and a new power converter to allow pulsed operation.

As a back-up solution for the magnetic bypass option, actuating the T4 target's head between cycles is being investigated. An evaluation of the engineering limits of the existing T4 target movement system is underway, including feasibility studies for a rapid movement (10 mm/s) and stress tests with $\mathcal{O}$(10M) cycles. An early prototype successfully demonstrated the validity of this proposal, triggering further studies and tests. This may prove useful for physics (optimising the use of different target lengths) in the future even if not adopted for the T4 bypass. The TF recommends that these studies are continued until the T4 trajectory bump bypass solution is validated.

3.2.3 Magnets and power converters

The requirements on magnets, power converters and related systems for a potential HI upgrade of ECN3 are summarised, taking only the dedicated beam delivery scenario into account and requirements in addition to those which are already included in NA-CONS baseline. The NA-CONS baseline foresees the systematic replacement of all power converters in BA2 and BA80 powering magnets in TT20, TDC2, TCC2, TT81, TT82 and TT83 in Phase 1 until the end of LS3. Phase 2, covering the period between LS3 and the end of LS4, includes the replacement of the remaining power converters in BA81 and BA82 (powering magnet circuits in EHN1, TDC8, TT85, TDC85 TCC8, ECN3, TT84 and EHN2). For more details see [40], [41]. A series of hardware modifications are required for a HI upgrade of ECN3:

- A new vertical bumper magnet in TT24 between MBN.241107 and MTN.241128. This magnet has to feature an integrated field of $B \cdot dl = 0.17$ Tm, a laminated yoke to allow pulsed operation and an aperture of 200 mm to cope with the large horizontal excursion of the beam in the wobbling station (see Section 3.2.2).
- A vertical magnet at the end of the P4 line after QNL.043050 to dump unwanted residual beam bypassing T4 during normal SFTPRO operation on an absorber and so

protect the beam lines downstream of P4 from accidental irradiation (see Section 2.2.1 and 3.3.5). This magnet has to feature an integrated field of $B \cdot dl = 0.47$ Tm (equivalent to a deflection of 350 μrad for a 400 GeV proton beam) and a laminated yoke to allow pulsed operation.

- Two additional POLARIS power converters [42] to power the aforementioned magnets to been installed in BA80.
- DC cables and interlock (WIC) cables between the magnets and BA80.

The proposed new dedicated beam delivery scenarios are featuring two new dedicated ECN3 cycles to be combined into different supercycle options: (i) a short, dedicated ECN3 cycle (1.2 s flat top over 7.2 cycle length) compatible with BDF/SHiP; and (ii) a long, dedicated ECN3 cycle (4.8 s flat top over 14.4 cycle length) compatible with HIKE/SHADOWS. Both cycles will be tolerable for future powering solutions as foreseen in the NA-CONS baseline [42]. Although all new power converters can also handle the long SFTPRO cycles (9.6 s flat top over 26.4 cycle length) in terms of RMS-current, an upgrading of the EN/EL infrastructure in addition to the NA-CONS baseline will be required in case these cycles are foreseen to be used in the secondary beam lines of the NA as they generate additional demands on the powering infrastructure. A more detailed study about the motivation, timeline and costs for this upgrade needs to be launched.

ECN3 supercycle options which deploy up to four sequential short, dedicated ECN3 cycles could cause additional stress on some components of the new power converters. Due to the increased number of cycles per minute (up to 6.6 cycles/minute) with respect to the supercycles defined in the NA-CONS baseline (4 cycles/minute), a more intensive preventive maintenance program might be required for exchanging critical components more frequently. This would mainly concern power converters in the primary beamlines and the dedicated beamlines to ECN3.

Another request emerging from the proposed dedicated beam delivery scenarios, is the possibility to operate some beamlines in PPM mode. PPM operation becomes necessary to switch the optics between dedicated ECN3 cycles and standard STFPRO cycles for EHN1 and EHN2 within a SPS supercycle. This request concerns primarily the TT20 beamlines between LSS2 up to T4, but also beam lines downstream of T4 up to TCC8 (P4, P4:P6 and P42), which must be compatible with PPM operation to allow optimisation and transmission of SFTPRO beams to ECN3 in the future. This requires that all concerned beam lines are equipped with laminated magnets and new POLARIS and BOREAL power converters. For TT20, this is presently already the case apart from one exception: QSLD.2201 features a solid magnet yoke and hence cannot be cycled. However, optics solutions have been found to circumvent this problem.

Magnets around the targets of T2, T4 and T6 can also not be pulsed because of their solid iron yokes. Of particular interest for this study are the five MTN magnets around T4: a replacement of their solid yokes will be a time and cost intensive exercise probably impossible to accommodate in the timeline until LS3. The bypass of the T4 target using a magnetic bump solves this problem and the MTN magnets in T4 can continue to be operated in DC with some minor drawbacks (see Section 2.2.1).

Present limitations for PPM operation in the P4, P4:P6 and P42 beamlines are the actual power converters, the control system (CESAR), nine corrector magnets of type MDX and one quadrupole in P4 (QSL.043033). The solid MDX magnets could be replaced by laminated counterparts in LS3 (a design exists already from the East Area Consolidation project). For the non-laminated QSL in P4 a suitable optics solution has been found. The obsolete control system will be completely re-engineered until LS3, a work which is already foreseen in the NA-CONS baseline. The new LSA-based control system will be fully compatible with PPM operation. However, a full PPM operation of these beamlines can only expected after LS4 when the power converter consolidation will be completed, since part of the power converters for P4:P6 and P42 are located in BA81 and BA82. Also a re-scoping of the BA82 consolidation to LS3, as discussed on several occasions in the context of upgrading the TCC8/ECN3 infrastructure for future HI experiments [15], will not change the situation drastically. Post-LS4 PPM compatibility scenarios are shown in Figure 4.

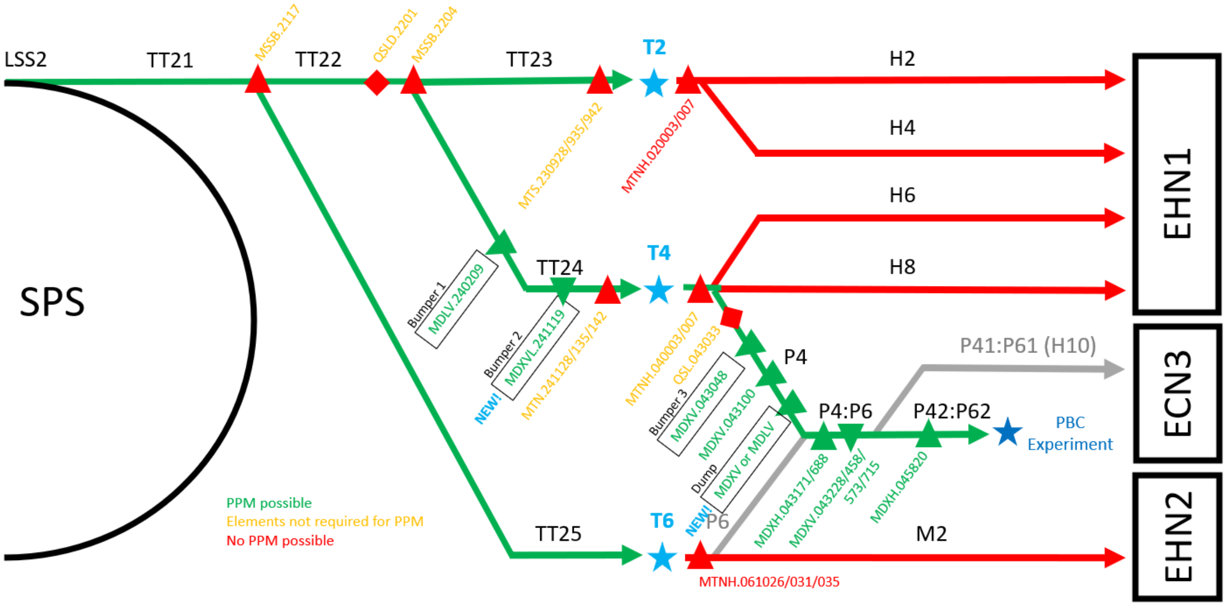


Figure 4: PPM compatibility of TT20 and NA beam lines after LS4

3.2.4 Beam instrumentation

The beam instrumentation requirements for the future operation of the NA primary lines have been specified [43, 44] with R&D currently underway [45, 46]. In view of better understanding the primary beam transmission from SPS to ECN3, the NA-CONS project scope and schedule were reviewed and updated by the TF, with an emphasis on installing beam instrumentation in TCC2 and P42 during the YETS22/23. In order to urgently improve understanding and demonstrate loss-free transport with MD studies in 2023, a series of consolidation and upgrade requests were rapidly advanced.

During the YETS22/23 additional beam profile monitors (BSGs, 4 in total) foreseen in NA-CONS Phase 1 will be installed in P42 [47] to perform optics and dispersion measurements. In parallel, a new beam loss monitoring (BLM) system will be installed [48], comprising 13 monitors chosen at critical locations including the EHN1 ramp and ECN3 bridge, to measure and permit optimisation of the prompt beam loss not presently possible. The installation is compatible with a future, complete installation should the HI facility be approved, totalling 40 monitors. During the YETS23/24, additional BLMs will be installed in TDC2 and TCC2 upstream of the targets as part of NA-CONS Phase 1. After commissioning in 2023, a passive optical fibre dosimeter covered by NA-CONS Phase 1 will be installed at selected locations to catch any beam loss hotspots missed by the BLM system.

It is also proposed to widen the scope of NA-CONS Phase 1 to include the consolidation of the TBIs around the TCC2 targets following the 2022 vacuum incident [49]. As part of the consolidation it is recommended to upgrade the instrumentation to include BSGs.

The measurement of the intensity of the slow extracted beam is part of the NA-CONS baseline to provide an accurate measurement ($\sim$ %) that was available in the past [50]. Studies in recent years have repeatedly shown large systematic errors on the secondary emission monitors (BSIs) giving large uncertainties on the POT measured of up to $\sim 40\%$, and hence making transmission estimations in the primary transfer lines unreliable [51, 52]. The installation of consolidated BSI devices is included as baseline in NA-CONS Phase 1.

Fast spill monitoring to quantify the quality of the spill is also included as baseline in NA-CONS Phase 1 along with longitudinal BLMs to measure extraction and splitting efficiency.

3.2.5 P42 transmission measurement

An intensive effort was launched by the TF to understand the absolute calibration of the BSIs in the NA primary lines with activation foils [53]. Two successful activation foil irradiations were carried out on the BSI in front of the T10 target in TCC8 in 2022, confirming the BSI calibration factor for this location to be accurate to within 2%. Due to the Secondary Emission Yield (SEY) dependence of the foils with irradiation dose and vacuum environment [51], simultaneous irradiation measurements for all targets (T2/T4/T6/T10) are planned in order to calibrate all BSIs and provide a relative transmission measurement from T4 to T10. The study reported in [51, 52] indicates that the BSI on T4 measures systematically 20% lower than expected. This R&D effort must continue with a strategy that can be automated or carried out in the future without personnel access to remove and transport the foils for analysis. The feasibility to install a fast BCT in TT20 to complement and eventually replace the activation foil measurements, as is done regularly in the East Area [54], is being investigated.

During these investigations the Gafchromic films showed evidence of a large halo containing several % of the beam that could be causing the elevated radiation levels along P42 at the EHN1 ramp and ECN3 bridge. Even though radiation levels measured at the EHN1 ramp were reduced when the beam position monitors (BSPs) were retracted from impinging the beam, halo was still observed on the Gafchromic film. The source of the halo is still under investigation with detailed simulations being carried out with FLUKA and BDSIM.

The hotspot in TT83 at the junction where the P6 beamline merges with P42 is a clear candidate that is affecting the transmission and possibly contributing to the radiation levels at the EHN1 ramp. For this reason the currently unused magnets that merge the P6 beamline onto P42 will be removed and the P42 vacuum chamber aperture enlarged during the YETS22/23 [55].

3.2.6 Vacuum

The consolidation of the TT20 vacuum system is included in the baseline of NA-CONS Phase 1 and is not expected to limit performance. The P42 beamline has an uninterrupted vacuum sector that spans from the T4 XTAX to the T10 target. Historically, the vacuum in P42 was achieved by means of turbomolecular pumps, however, these were moved to K12 and replaced by rotary pumps during the transition to NA62 for financial reasons. The resulting pressure is now limited to 10^{-3} mbar and deemed adequate for proton transport today, but contributing to distributed beam losses as vacuum levels are degrading due to ageing problems.

The new proposal of installing BSGs in the YETS22/23 calls again for a secondary vacuum installation to achieve at least $\sim 10^{-4} - 10^{-5}$ mbar for the monitors exploiting secondary emission. As an alternative to putting the full beamline under secondary vacuum, a cost-optimised solution was agreed within the tight installation deadline for the YETS22/23 [47]. Vacuum windows creating sectors around each BSG will provide the required vacuum conditions whilst keeping the rest of the line in primary vacuum. The installation of vacuum windows is not desirable in P42 and windows will not be installed around the BSG located at sensitive locations upstream of the EHN1 ramp to minimise any increase in radiation levels. Studies are underway with FLUKA and BDSIM in the TF to compute the effect of vacuum pressure on radiation levels, for which preliminary results confirm already the estimated requirements mentioned above.

It is foreseen to rescope NA-CONS Phase 1 to achieve a vacuum level in P42 of 10^{-4} mbar without windows. The strategy to be adopted will be chosen in light of the experience with the P42 BSG vacuum upgrade. If a further improvement is required to achieve $< 10^{-5}$ mbar the cost will be significantly higher, dominated by the installation of ion pumps and retrofitting of the vacuum line, which will also require an extensive cabling campaign.

The consolidation of pumping units is already planned as part of NA-CONS Phase I. It will comprise the replacement of all rotary vane pumps and their local control crates, the upgrade of the main gate valve (V2) connecting the pump to the vacuum system, the exchange of active Pirani gauges to a more robust rad-hard technology and the consolidation of the corresponding cabling and electrical sockets. The same applies to the hardware itself where all bellows, windows and chambers exhibiting any signs of damage or deterioration in TCC2 are planned to be replaced. As an example, the consolidation of T6 VXSS chamber is already planned for YETS22/23.

3.2.7 Survey and alignment

The alignment and smoothing of the NA primary lines is foreseen as part of the NA-CONS project. In particular, there are two items that need surveyed and smoothed as priority in the context of the HI upgrade (i) the connection of TT20 through the T4-XTAX system to P4/P42 and (ii) the survey and smoothing of P42.

The work in TCC2 can only take place during a long shutdown as the radiation levels forbid any long intervention. The NA-CONS project will allow the survey team to install a permanent network in TCC2 to ease the measurement in the area. In this context it will be possible to know the position of the equipment in the junction from TT20 to P4/P42. Once the position is known, realignment is possible if the dose is limited and alignment systems are available (should also be tackled by NA-CONS). The P42 transfer line will be surveyed and smoothed already in YETS22/23 as measurements after LS2 showed large deviations, especially in roll angle. This activity is limited by the activation of certain collimators in the TT83 tunnel.

NA-CONS for survey will also cover a part on the instrumentation and measurement methods. As example the new design of the VXSS vacuum chamber will allow a remote measurement of the equipment while it was uncertain how to measure the old one. The target station consolidation should also allow an easier measurement of the equipment. On a global point of view, the tools used for measurement and jigs must be updated to meet new standards for survey measurement. Additionally, it is important to define all equipment that must be measured accurately and assess if the actual design allows for a precise measurement.

One last consideration concerns the theoretical trajectory. The legacy strategy in the NA was to align the magnets with relation to the local gravity considering the theoretical trajectory from BEATCH. The migration to MADX is underway to remove this legacy roll correction. To proceed, a new trajectory must be calculated, and new tools have to be developed to measure accurately the new roll values.

3.3 Beam intercepting devices

A series of primary beam intercepting devices are key for the safe operation of the NA and in particular, for the intensity increase discussed in this document. The majority of these devices are already being considered in Phase 1 of NA-CONS, in order to solve a series of operational issues encountered during recent years and to increase reliability.

3.3.1 External TT20 transfer line beam dump, TED

The consolidation of the external Transfer line Dump (TED) is considered as baseline in Phase 1 of NA-CONS. The 24 ton device is a movable assembly that enters the beamline when required to prevent beam transport to the downstream part of TT20. The thermo-mechanical performance of the existing device has been studied in detail [56] and a functional specification for its consolidation completed [57], with operation of the HI upgrade in mind. The design was revised to include a simplified and improved core, shielding and translation systems. The new TT20 TED design will be modular in nature, in order to be adaptable - with minor modifications - to the consolidation of the LHC transfer line TEDs (spares) in TI2 and TI8, currently pending approval by the ACC-CONS project. Future exploitation of the TT20 TED foresees a maximum annual load of $\sim 1 \times 10^{17}$ protons [57]. In order to increase the operational reliability and reduce the weight of the assembly, a shielding design improvement is being discussed [58].

Interestingly, the new TT20 TED design will be compatible with increased intensity per cycle ($> 4 \times 10^{13}$ ppp) with an appropriate duty cycle for future slow extraction development of a hybrid mode of operation to increase the proton throughput to the NA. Cooling of the assembly will be optimised with sustainability in mind. Apart from optimising the core, the shielding and translation system will be optimised based on best practices and adaptation to the foreseen dumped intensities.

The translation system of the Transfer line Beam Stopper (TBSE) is also included in NA-CONS Phase 1, while the absorbing core requires no other modifications.

3.3.2 Splitter collimator, TCSC

The TCSC collimators protecting the MSSB splitters are capable of splitting SFTPRO beams of up to 4.2×10^{13} ppp [59]. However, the excessive induced radioactivity from the splitting process poses serious problems for operation at high intensity. The TCSC collimators are radiologically the most problematic beam elements in TDC2. In view of the downtime incurred during 2022 when the TCSC's water-cooling circuit sprung a leak, it is recommended by the TF to consolidate these devices in NA-CONS Phase 1 by employing basic ALARA design principles to reduce dose to personnel and avoid longer cool-down times before interventions in TDC2. These design improvements include a low-Z tank with improved handling, new support tables (to allow more accurate alignment while allowing easier remote exchange of the assembly) and an improved water cooling design with quick connections to permit the possibility of installing marble shielding [60, 61]. Some of these improvements are a direct result of the successful implementation of the LIU SPS internal beam dump [62]. These upgrades will reduce the dose to personnel intervening in the area. However, these improvements will not necessarily improve the efficiency and source of the beam loss, estimated using simulations and measurements at $\sim 3\%$ per splitter [30, 52].

Although an upgrade of the splitting efficiency is not mandatory when considering a dedicated beam delivery scenario to the HI facility in ECN3, it is strongly recommended to further improve the radiological situation in TDC2 and reliability in Run4. Crystal technology based on multiple crystals stacked in an array and aligned in volume-reflection (identical to the SPS extraction specification [63]) offer a factor ~ 5 reduction in the beam lost in the splitting process [30]. A single optimised crystal would offer an improvement consistent with its single-pass channelling efficiency and up to a loss reduction factor of ~ 2. As emphasised above, the in-house development of crystals via the DECRYCE project [31] will play an important role in the realisation of advanced crystal technology for applications at CERN.

3.3.3 T4 target and XTAX

Thermomechanical studies of the T4 target were performed to understand that the Be plates, and specifically their points of support, would be very close to failure during steady-state operation close to 2×10^{13} ppp in the shared beam delivery scenario. For sustained operation at such intensities an upgrade of the T4 target system would be recommended and the Be plates likely replaced with graphite [64], but is not required for the dedicated beam delivery scenario.

Several consolidations in the target systems in TCC2 (including T4) are requested to be implemented in NA-CONS Phase 1, in order to guarantee an isostatic positioning of the TBIU/D and the target box.

There are 14 XTAX devices installed in the NA complex downstream the 4 production targets that are suffering from repeated reliability issues linked to their support tables reaching their end of life, e.g. mechanical problems, controls issues and water leaks causing NA downtime. Presently, the supporting table of 7 devices (including one spare) are included in NA-CONS Phase 1 to address the reliability issues. The XTAX T6 on P62 can be postponed to NA-CONS Phase 2 because the line is presently not in use. The XTAX on T10 could also be removed from NA-CONS pending a decision on the physics programme to be conducted in ECN3.

Different options are being considered to take advantage of the work needed to consolidate the XTAX support tables. The cheapest option, including a basic consolidation of the support tables only with reuse of the absorber blocks, still requires an ALARA study to evaluate its feasibility in LS3. If necessary, and driven by ALARA, new blocks based on the same design are also being considered. A final option including an upgrade of the T4 XTAX with a new design including the active cooling of the absorber blocks for higher intensity beams could also be considered.

In the event of an accidental failure scenario, more than a single-shot of the dedicated beam at 4×10^{13} ppp would melt the copper in the second block of XTAX if impacting directly [65, 66]. In fact, even shared beam at 2×10^{13} ppp would damage the blocks. It is therefore of vital importance that the XTAX aperture is protected against shaving or full beam impact at HI. The consequences of such an event need to be assessed and studied in detail, although a single high intensity shot is not expected to halt operation. The safety and machine protection considerations also need detailed study but the risk should be significantly reduced with a Beam Interlock System (BIS) input from the XTAX position, monitoring the TT20 dipole magnet currents and interlocking on a suitably positioned BLM.

The TF recommends that the joint (SY-STI/BE-EA) XTAX WG [67] investigates the various options and agrees on future strategy with representatives from safety and machine protection in 2023, and aiming at a conceptual design review before the end of the year.

3.3.4 T4 TBI vacuum windows

No limitation exists for the vacuum windows between the T4 Target and the XTAX, including the TBIU and TBID beam windows [68].

3.3.5 P42 Beam Dump for Commissioning

Under the constraints of the existing wobbling system around the T4 target, the fraction of the beam that does not interact with the target on the operational SFTPRO cycle will still enter P42, as it does today for NA62 in ECN3. The first fixed collimator XTCX.X0430042 that could intercept this beam with a suitable wobbling setup is uncooled and cannot be used as a temporary absorber. In addition, the integration constraints to access it for upgrade are challenging. It is therefore proposed to dump the beam, if needed, on a new dedicated absorber installed in the upstream part of P42.

A suitable location has been identified where the vertical aperture is being increased with the removal of the P6 magnets during the YETS22/23. The dump system would be relatively simple and only require a laminated vertical dipole magnet deflecting the beam down onto the new absorber [33]. The latter would thus be an internal dump under vacuum, with an aperture large enough to allow the beams to TCC8/ECN3 to pass through. An effort will be made to either re-use an available spare (for instance from TIDVG4 [69]) or profit from a simpler design to match the requirements.

Once the work in TCC8/ECN3 is completed, the beam on SFTPRO cycles could in principle be transported to the production target in TCC8 and exploited for physics in ECN3. However, the operation and optimisation of the two different cycles will be challenging before LS4 and before the power converters in BA81 have been consolidated to pulse in PPM mode. If the protons on the SFTPRO cycle either (i) cause transmission losses in P42 or (ii) pose problems for the experimental user in ECN3, they could be dumped on the new absorber.

3.4 Radiation protection constraints

NA-CONS Phase 1 covers only RP costs related to the TT20, TDC2 and TCC2 areas. The costs for the SPS-LSS2 areas will depend on the need of studies and future work foreseen for this area. As a conclusion of the RP studies carried out to date, and the various mitigation measures identified, an high intensity TCC2-TCC8 beam transfer is expected to be compliant with CERN's RP code.

3.4.1 LSS2 to TCC2

The slow extraction system in LSS2 induces dose rates that strongly limit the accessibility of the SPS. Radiation levels reach easily more than 10 mSv/h at a distance of 40 cm after a cooldown period of 1 day. It is a similar story in TDC2 where the splitting process generates dose rates after 1 day of cooling that can easily reach more than 50 mSv/h at a distance of 40 cm. As discussed above, it is of paramount importance to reduce the beam losses (per proton delivered to the NA) including a re-design, where possible, of the beamline equipment using less activation-prone materials and appropriate shielding [70]. All three target-XTAX setups in TCC2 are also subject to high activation, which is caused by the secondary particle cascade that is induced by the proton beam impact on the target. Although all three target-XTAX configurations are highly activated, it shall be mentioned that the T6 target shows the highest activation level due to the highest annual proton flux impacting its target. Dose rates of 45 mSv/h can be found at a distance of 40 cm from the T6-XTAX after cooldown periods of $\sim$ 50 days. In order to improve the radiological situation around the targets and the XTAXs, a redesign of the area should be considered or the intensity on the targets in TCC2 not further increased. The implementation and use of ALARA techniques is strongly encouraged for interventions in all critical radiation areas in LSS2, TDC2 and TCC2.

3.4.2 TCC2 to TCC8

Two critical locations above the P42 beamline were identified, where already the present-day TCC2 to TCC8 beam transfer with a total of 1.89×10^{18} POT/yr provokes elevated prompt radiation levels close to or even exceeding the classification limit of the given area.

One is at the ramp on the Salève side of EHN1 where only $\sim$1.2 m of soil is present between the TT85 tunnel and the ramp providing limited shielding. Several extensive measurement campaigns were performed to precisely map the prompt dose rates present on the ramp and its surroundings during beam operation [71]. It revealed that already with the current NA62 beam operation the given area classification limit for a Non-Designated Area

(2.5 μSv/h) was exceeded. The measurements in combination with various FLUKA MC simulations allowed to better understand the observed radiation fields hinting to beam losses of the order of 10^{-4} occurring in the beamline elements below the ramp and its direct vicinity [18, 71, 72].

Several mitigation measures were proposed of which several were already, or are currently, being implemented. The most favourable measures are naturally those that resolve the problem at the source, i.e. reducing the beam loss, further leading to less activation of the beamline and higher beam transmission to the experiments, as explained in Section 3.2.5. Additional mitigation measures were implemented, including the improvement of shielding in the trench next to the EHN1 ramp and fencing off the most critical area next to the ramp [73]. Further shielding improvements were studied that would further reduce radiation levels by more than an order of magnitude [74].

Civil engineering requirements and corresponding floor shielding needs in TCC8/ECN3 are driven by the surrounding soil activation and were optimised based on a dedicated FLUKA study. It is important to note that this is based on a conservative assumption and can possibly be further relaxed by a hydrogeological study to be carried out similar to the past TDC2/TCC2 study. The TF recommends this study to be launched as soon as possible.

3.4.3 Accidental beam loss scenarios

Further FLUKA studies were performed to investigate accidental beam loss scenarios along the shallow transfer tunnels (TT83 and TT85) housing the P4/P42 beamline [72, 74]. The loss of an entire NA62 spill at nominal intensity would create a maximum dose of ~ 300 μSv/spill at the EHN1 ramp, which is acceptable (below the limit of 1 mSv) if there are no visitors in the area and provided the beam is interlocked after 1 spill. Presently, an RP monitoring system is already installed with an interlock capability.

When scaling to the higher intensities as given in Table 1 the limit would be exceeded and the following two mitigation measures should be implemented: (i) halt the extraction and dump internally in the SPS using an interlock input to the BIS from the BLM system and selected power converters, and (ii) increase the effectiveness of the shielding at the ramp [74]. In the latter case, replacing the concrete shielding by iron yields a factor 50 reduction in the prompt dose, which would be sufficient to stay well below the 1 mSv limit in the case of accidental beam loss.

The situation at the ECN3 bridge is similar with ~ 50 μSv/spill reached with the uncontrolled beam loss of the nominal NA62 intensity [74]. Shielding studies at the bridge show that a reduction of more than an order of magnitude in the prompt dose rates can be achieved with moderate improvements [74] and civil engineering studies for such a shielding improvement have been launched. A dedicated measurement campaign will be performed during commissioning, whilst shielding options are studied in parallel and a software interlock is implemented as soon as possible.

3.5 Machine protection

The machine protection architecture foreseen as part of the NA-CONS project is compatible with a dedicated ECN3 beam delivery scenario [75, 76, 77, 78, 79]. The Beam Interlock

System is modular and distributed across the North Area primary and secondary beamlines. It can be easily adapted to the needs of future beam transfer and target systems. A detailed study on the required machine protection inputs is needed for the HI facility in ECN3 in 2023. The technical specifications are presently being written and new interlocking requirements are now being worked out. The protection of the primary beamlines would exploit signals provided by several pieces of equipment. These include power converters' current monitoring, warm magnet protection systems, BLM systems, vacuum valves, beam intercepting devices, transfer line elements and the access system. The Beam Interlock System will only allow slowly extracting the beam from the SPS ring if safe conditions are met. The system has a reaction time ($\sim$ few turns), well below the spill length to avoid accidental damage to equipment. The deployment of the new BIS is foreseen as baseline in NA-CONS Phase 1 and during LS3, however, there will be a transition period where modern interlocks will coexist with old and software interlocks because the consolidation of power converters in BA81 and BA82 currently is not planned to happen until LS4.

The BIS will have to decode which cycle-type is being played. As the XTAX will not be able to take a high intensity beam impact, new conditions will have to be checked to prevent slow extracting a high-intensity beam if the T4 XTAX are not in the out-of-beam position.

The BIS of SPS-LSS2 will also be implicated in the scope of the HI upgrade. Specifically for P42, the BIS system will replace the machine protection functionality of the so-called P0-survey system, which monitors actively the currents of the beamline magnets, but which has slow reaction times of minutes. Equally important, the system will replace the WOBSU interlock, which dumps the beam in case of a failure of the wobbling magnets upstream and downstream of the T2 and T4 targets. The old system is slow and not able to protect the target station from all wobbling magnet failures.

3.6 Dedicated ECN3 user and destination in the North Area

In comparison to the non-PPM SFTPRO NA operation today, the introduction of a dedicated NA user in ECN3 will bring with it the concept of ECN3 user (USER) and ECN3 destination (DEST), not only for the relevant magnets and power converters (see Section 3.2.3), but also for the machine protection system and other systems that need to understand the cycle-type (dedicated ECN3 or SFTPRO) being played, including the NA users and experiments themselves. The distribution of timing signals to the NA is part of the NA-CONS project but the individual NA user requirements will need to be followed-up carefully to ensure that post-LS3 operation is compatible with a dedicated cycle and NA user in ECN3.

3.7 TDC2/TCC2 considerations

The NA target stations in TCC2 represent a vital transition point for all NA experiments and therefore a future HI facility in ECN3. The recent problems experienced during the recommissioning after LS2 highlighted the impact of the degrading reliability of ageing equipment on operation. With a longer-term outlook and to guide consolidation plans, the NA Commissioning WG tackled and analysed the multifaceted issues encountered after LS2, including hardware failures, scheduling, procedures and the definition of equipment responsibility to ensure that commissioning after LS3 runs smoothly. It is important that the outcome and recommendations made by the NA Commissioning WG and the technical analysis of recent equipment failures [80, 81, 82, 83] coordinated by the NA-CONS project are heeded to guide the consolidation strategy of the zone and to reduce the risk of downtime during future operation. The deployment of such recommendations is already underway with critical actions performed during interventions, technical stops and YETSs.

Although a dedicated beam delivery mode to ECN3 relaxes the need for significant upgrades in TDC2 and TCC2 during LS3, some targeted but significant consolidation is still required in the zone. In particular, the following items have been identified as the minimum work needed during LS3 to improve the future reliability of the NA in Run4 in light of the lessons learnt recently:

- Partial redesign or replacement of critical beamline equipment, such as the VXSS vacuum chambers, the TCSC and to some extent, the TBIU;
- Replacement and rerouting of DC and signal cables;
- Replacement and rerouting of water cooling hoses and connections;
- Establish an alignment network for measurements in TCC2, and connecting up and downstream beamlines;
- Prioritised consolidation of items in the TDC2 splitting system;
- Prioritised consolidation of items in the TCC2 target system.

4 TCC8 and ECN3 infrastructure and service needs

The NA-CONS project is separated in two phases (i) Phase 1: 2019-2028 (up to end LS3), prioritising the primary beam areas TT20, TDC2, TCC2 and the initial section of the NA Transfer Tunnels and (ii) Phase 2: 2029-2034 (up to end LS4), completing the consolidation of the secondary beam areas. The main challenge for optimising the cost and resources of the ECN3 HI upgrade plans together with NA-CONS has been to find a technical solution and timeline compatible with the planned consolidation of the service buildings BA81 and BA82 in Phase 2, including the power converters they house, and TCC8/ECN3.

4.1 ECN3 experimental user requirements

In collaboration with the NA-CONS project, the experimental user requirements, including target system, for the exploitation of TCC8 and ECN3 as a HI facility were collected to allow preliminary cost and resource estimates for future infrastructure and service needs [15]. The studies carried out in the scope of the Comprehensive Design Study for the SPS Beam Dump Facility [10] were used to give preliminary cost estimates where more detailed information is not yet available. If the facility is pursued for installation in the future, the process will include a two-year TDR phase with detailed functional and technical specifications, which will be formalised along with the relevant Engineering Change Requests.

Nevertheless, a number of NA-CONS Technical Coordination Committee meetings and discussions were performed over the past months in order to: (i) ensure the technical feasibility; (ii) allow for a related resource estimate; (iii) agree on possible/conflicting timelines and (iv) identify additional optimisation options. In addition to the beamline related items mentioned before, the main items concerned are:

- BA82 and alternative options;
- TCC8 target system and shielding requirements;
- Experimental magnet and powering requirements;
- Electrical, cooling and ventilation infrastructure needs;
- Decomissioning and related radioactive waste handling;
- Transport and handling needs.

4.2 TCC8 target system and shielding requirements

The instantaneous and integrated beam intensity requested by both the BDF/SHiP and HIKE/SHADOWS experimental proposals require a major upgrade of the target systems presently installed in TCC8. Both proposals require a multi-hundred kW average beam power impacting the production target.

Given the specific physics requirements and the average beam power, a major modification of the target systems is expected for both initiatives. Following years of experience at CERN of FT operation, and the best practices in the international community, as well as requirements to comply with the Tripartite Authority, the target systems of a new facility will have more stringent design requirements (see also [13]). The target complex resulting from the SPS Beam Dump Facility Comprehensive Design Study [10] was indeed compliant with these requirements. The proposed implementation of these facilities in the TCC8/ECN3 complex is still compatible, provided that an ad-hoc design is implemented; studies executed during 2021-2022 proved that a high-power target station could achieve compliance with these criteria, provided that an appropriate shielding configuration is implemented.

A target complex based on an hermetic bunker [84] and a high-Z production target [85, 86] (currently Ta or Nb-cladded TZM/pure W hybrid) is foreseen for the BDF/SHiP initiative, in a somewhat similar fashion as neutron spallation sources operating at ISIS (UK) [87], at LANSCE (US) [88] and proposed STS at ORNL (US) [89]. In order to cope with the 350 kW average beam power, a bunker configuration with cooled stainless steel shielding, passive cast iron blocks, as well as concrete and marble shielding is foreseen (for a total volume of around 150 m^3). Remote manipulation and handling techniques are foreseen for the handling of the very radioactive production target, profiting from existing experience at CERN as well as worldwide. The production target and the first layer of water cooled shielding are inserted in a vacuum (or inert gas) vessel in order to reduce radiation-accelerated corrosion close to the production target.

For the HIKE proposal a target complex based on the experience of CNGS is proposed, with a production target based on radiation-cooled graphite or He-gas cooled beryllium.

Even though the facility would operate at a lower average power than BDF/SHiP (roughly 100 kW), the physics requirements resulting from the kaon beam would require a significant shielding improvement with respect to the current NA62 target systems, with a resulting total volume comparable to (or higher than) BDF/SHiP. A new target-XTAX system would also be required, with a major upgrade of the XTAX blocks cooling and maintenance capabilities, and a change of material configuration for the new absorber. Full remote handling of the various components is also a pre-requisite to be compatible with ALARA requirements.

In order to increase sustainability for the project and reduce cost for raw materials, recovery of passive cast iron blocks is being investigated from existing CERN facilities, in synergy with other proposed initiatives, such as the ISOLDE beam dump replacement project. It is foreseen to recover at least 100 - 120 m^3 of passive cast iron blocks from facilities like the CNGS hadron absorber as well as from the old PS neutrino facility in TT7. An initial investigation of this possibility has been sponsored in the framework of PBC.

4.3 Civil engineering

A preliminary civil engineering study [90] has been carried out on the required modifications to the existing infrastructure for the implementation of an HI facility housing the different PBC experiment requests: BDF/SHiP, HIKE and SHADOWS. It is important to note that the corresponding requirements might be relaxed following the hydrogeological study (as performed for ECN4) proposed by the RP team.

The installation of the new target complex with the associated shielding requires minimal civil engineering works in the TCC8 area. The existing floor will be lowered locally and a dedicated confined area will be created with fire resistant walls, separating the target area from the ECN3 hall and the rest of the TCC8. In the BDF/SHiP design the size of the pit under the target station will be approximately 4 m long, 4 m wide and 1 m deep to embed part of the shielding and some of the services. For HIKE, the required excavation for the target area is 25 m long, 2.5 m wide with the depth varying between 0.4 and 0.8 m. Due to the size of the required modification, the slab will be excavated to the full depth and a new reinforced foundation slab will be built to maintain the structural stability of the tunnel. As an alternative option, if the beamline is lifted up by 0.4 m, the excavation works could be reduced to two small square pits of $2.5 \times 5 \times 0.4$ m for the target station and XTAX, thus avoiding the need of a new reinforced slab. For the installation of SHADOWS next to HIKE a 12 m long, 2.5 m wide and 1 m deep trench will be constructed with a new reinforced slab under the detector. In the case that excavation is only required under the iron yoke of the dipole magnet the excavation will be reduced to $2.8 \times 3 \times 1$ m. On the surface a new service building will be constructed with an area of approximately 500 m^2 to house all the dedicated services needed for the target complex in both cases of BDF/SHiP and HIKE/SHADOWS. The local electrical installation would require the construction of a concrete platform to support the transformers measuring about $12{\times}8$ m for HIKE/SHADOWS or $12{\times}4$ m for BDF/SHiP.

In the ECN3 cavern local excavation works will be also required to house the SHiP spectrometer magnet. The floor under the magnet will be lowered by 1 m over a 5 m long and 7 m wide area. Given the small size of the existing shaft to ECN3 in building 911, a new equipment shaft is proposed to be built at the end of the cavern for civil engineering works and to allow the installation and access to the experimental area, for which part of the building 918 will be demolished and the existing services will be rerouted. On the top of the shaft a new access building will be constructed and equipped only with a crane for transport purposes. During LS5, in the proposed third implementation phase of HIKE called KLEVER, a new 155 m long new extension tunnel with an access shaft would need to be built in the existing ECN3 cavern to house the 100 m longer beamline and beam dump.

Due to the impact of the civil engineering activities in the implementation of the HI facility, a decision deadline has been requested not to arrive later than Q4 2023 for an execution in Q4 2025.

4.4 General infrastructure and services

A brief summary of the most relevant points for the upgrade of TCC8/ECN3 are included below for completeness, which are presently being followed-up together with the NA-CONS project to provide a coherent cost estimate for the HI upgrade for the NA.

4.4.1 Access and safety

No major changes are foreseen in the NA-CONS project baseline for TT20 and TCC2. Access separation of TCC8 will be needed to allow for work on the target and experiment installation during Run4 whilst beam operation continues to the rest of the NA. Access control would be needed if a new shaft is installed on the downstream end of ECN3. Potentially new fire doors will have to be installed with an impact on the compartmentalisation and on the fire detection scheme. A FIRIA analysis of the new target complex and compartmentalisation study should be organised. New buildings and shafts will have as well to be equipped with fire detection. The recently renovated EHN2-BA82 centrale can be scaled to protect a larger perimeter. The access control system will have to be implemented according to the new premises and related restrictions (target building, target area, shafts, new service building for PC and cooling station). The safety aspects in TCC8 and ECN3 will need a detailed and experiment-specific study.

4.4.2 Cooling and ventilation

The cooling and ventilation for the target complex in TCC8 and ECN3 is out of the scope of the NA-CONS project but linked intrinsically to the planned consolidation of the service building BA82, in addition to TCC8 and ECN3. The extra capacity required for the experiment(s) should be borne by the upgrade of the facility. A potential sixth cooling cell is included in the study phase of the civil engineering for the fifth cell already planned in Phase 1, if it is required in the future for the ECN3 upgrade. As suggested in Section 4.4.6, the option of having a new service building hosting the power converters for the experimental magnets would require the dedicated cooling and ventilation equipment, including pumps, control racks and heat exchangers for the demineralised water. It is required by the EN-CV group to receive the go ahead no later than 2023 to study the technical modifications to be brought to the BA82 and the new installation to be organised. The most critical aspect is the need of more detailed user requirements from the experiments to progress on the studies.

4.4.3 Electrical distribution

The electrical distribution for the target complex in TCC8 and ECN3 is out of the scope of the NA-CONS project but linked intrinsically to the planned consolidation of the service building BA82, in addition to TCC8 and ECN3. The extra scope required for the experiment(s) should be borne by the upgrade of the facility. In case a new service building is decided to host the power converters for the experimental magnets together with a dedicated cooling station, the corresponding local electrical infrastructure will have to be deployed. A decision deadline is set to Q4 2023 for work execution during LS3.

4.4.4 Transport and handling

An important logistical support will be required all along the process of equipment decommissioning in the area (TCC8, ECN3) with a particular care for materials like target, XTAX and highly activated equipment. Waste disposal will have to be organised accordingly. In the same way, transport and handling support will be needed for the installation of the target complex and the experiment(s). An upgrade of the crane in TCC8 will be required to improve its movement system and remote handling capability, along with three new overhead cranes: in ECN3 for the new shaft, in the new service building and in the extension tunnel (KLEVER experiment). A personnel lift for the new shaft may also be required.

4.4.5 Magnets and power converters

The main difference between the experimental requests relate to the secondary beam line downstream of the primary target. For the BDF/SHiP experiment there will be no secondary beamline downstream of the target and the present K12 beamline will be removed along with the existing power converters. For HIKE/SHADOWS experiments the K12 beamline will remain and be rebuilt, with the required magnets depending on the phase of the experimental proposal [15]. Additional power converters are needed for experimental magnets in TCC8 and ECN3. The requirements on these converters are experiment specific:

- BDF/SHiP requires additional power converters for the hadron absorber (1), the SND muon system (6) and the decay spectrometer (1). Power converters will also be needed for the sweeping dipole magnets required to dilute the beam on the BDF target.

- SHADOWS requires additional power converters for the spectrometer (1), the Magnetized Iron Blocks (MIBs) (3) and the NaNU magnet (1). In case the existing MNP33 magnet will be replaced by a new normal-conducting or superconducting spectrometer, one extra converter will be required for HIKE.

4.4.6 Consolidation of BA82

Historically, the magnets in EHN2 and ECN3 are powered from BA82. The consolidation of BA82 is foreseen only in Phase 2 of NA-CONS during LS4, however the experiments will be ready for data taking already in Run4. The anticipation of the BA82 consolidation from NA-CONS Phase 2 to Phase 1 seems extremely challenging for some service groups because the BA82 consolidation needs to be completed within LS3, otherwise the operation of EHN2 in Run4 would be jeopardised, because also parts of the K12 and M2 beam lines are powered from BA82.

Instead, the installation of the additional required converters could be foreseen in the new service building planned for ancillary equipment for the target systems in TCC8. Possible advantages of this approach would be the decoupling of the powering system for the experiments from BA82 and hence the installation work can be performed after LS3 without impacting the operation of K12, M2 and EHN2. The BA82 consolidation can be done in NA-CONS Phase 2 as planned meaning no re-scoping, no anticipation of budget, and a better distribution of work load on a longer time scale. Shorter DC cable lengths between power converters and experimental magnets would lead to further savings.

4.4.7 Other services

The impact on other services such as cryogenics, gas distribution and IT infrastructure will need iterating with the specific experiment(s).

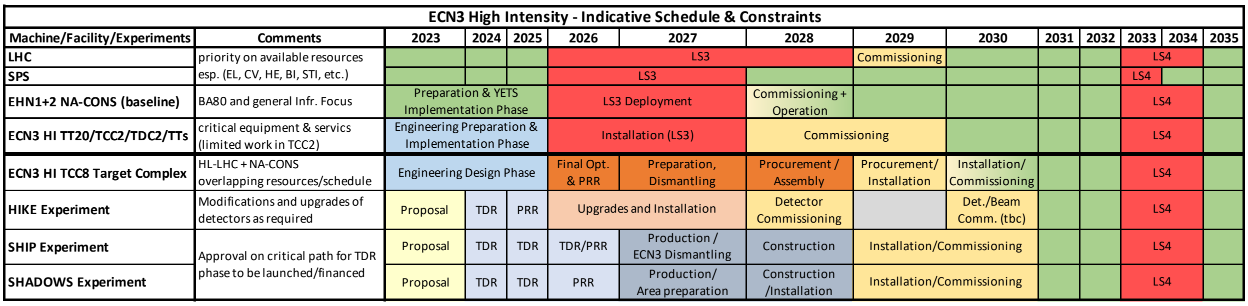
4.4.8 Integration, dismantling and installation

The integration, dismantling, installation and decommissioning cost are experiment specific and not covered in the baseline of NA-CONS.

5 Timeline, summary and next steps

5.1 Preliminary timeline

A preliminary implementation timeline for the ECN3 HI facility is shown in Fig. 5, along with the assumed schedule and constraints for the LHC, SPS and NA.



ECN3 High Intensity - Indicative Schedule & Constraints

Machine/Facility/Experiments	Comments	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
LHC	priority on available resources esp. (EL, CV, HE, BI, STI, etc.)				LS3			Commissioning				LS4		
SPS					LS3							LS4		
EHN1+2 NA-CONS (baseline)	BA80 and general Infr. Focus	Preparation & YETS Implementation Phase			LS3 Deployment		Commissioning + Operation					LS4		
ECN3 HI TT20/TCC2/TDC2/TTs	critical equipment & servics (limited work in TCC2)	Engineering Preparation & Implementation Phase			Installation (LS3)		Commissioning					LS4		
ECN3 HI TCC8 Target Complex	HL-LHC + NA-CONS overlapping resources/schedule	Engineering Design Phase			Final Opt. & PRR	Preparation, Dismantling	Procurement / Assembly	Procurement/ Installation	Installation/ Commissioning			LS4		
HIKE Experiment	Modifications and upgrades of detectors as required	Proposal	TDR	PRR	Upgrades and Installation		Detector Commissioning		Det./Beam Comm. (tbc)			LS4		
SHIP Experiment	Approval on critical path for TDR phase to be launched/financed	Proposal	TDR	TDR	TDR/PRR	Production / ECN3 Dismantling	Construction	Installation/Commissioning				LS4		
SHADOWS Experiment		Proposal	TDR	TDR	PRR	Production/ Area preparation	Construction /Installation	Installation/Commissioning				LS4		

Figure 5: Preliminary implementation schedule of the ECN3 High Intensity facility.

The proposed schedule assumes a timely decision on the go-ahead for the HI facility as part of the MTP exercise in 2023, following a positive experiment-agnostic recommendation from the SPSC on a High Intensity Physics Programme in ECN3, to allow beam delivery studies to advance. The approval early in 2023 would be an important step in tackling the outstanding issues on beam delivery topics as an engineering design phase is launched immediately ahead of LS3. In parallel, and before the end of 2023, the SPSC should recommend the specific experiment(s) to exploit the HI facility, followed by a final Research Board decision before the end of 2023. The TDR/PRR phases of the intensity upgrade would start immediately in 2024 for the beam delivery, target complex and experiment implementation of the specific facility, which is a tight but feasible timeline on the critical path.

5.1.1 Implications for LS3

The availability of resources for equipment/service groups will be critical given other CERN priorities already foreseen in LS3 for HL-LHC, the ATLAS/CMS Phase-II upgrades, and NA-CONS Phase 1. For this reason the TCC8/ECN3 implementation schedule is foreseen to run into Run4, with a decoupling of ECN3 from the rest of the NA to allow parallel operation of EHN1/EHN2 immediately after LS3.

5.2 Summary and next steps

A high intensity upgrade of the North Area appears feasible and could be implemented on a timeline consistent with NA-CONS Phase 1 during LS3, for exploitation by new physics experiments housed in TCC8/ECN3 during Run4. A dedicated beam delivery scenario is recommended to avoid not only the inevitable and resource-intensive work that would be necessary to upgrade TCC2 during LS3, but also ensure operation for both EHN1 and EHN2 for the present Run4 operation window. Instead, targeted consolidation of the primary beam areas upstream of TCC8 could be carried out in line with NA-CONS Phase 1, with the upgrade work of TCC8/ECN3 decoupled to the years after LS3.

If the upgrade is pursued, the highest priority task to follow-up in 2023 is to demonstrate transport without beam loss from TCC2 to TCC8 by exploiting the early installation of beam instrumentation, the prototype T4 target bypass and various beamline modifications and improvements made during the YETS22/23. The advancement of magnetic measurements is an important step, combined with optics measurements, to understand the TT20 optics discrepancy. Equally important and requiring management approval, immediately launching an engineering design phase is essential to allow for the required continuation of studies relating to beam delivery and implementation of NA-CONS Phase 1 in LS3. Many key equipment and service groups will need additional support to address further design and schedule optimisations to be developed in parallel to experiment-specific decisions to be made towards the end of 2023. In particular, these would focus on high-priority consolidation items (to solve operational and reliability issues) in TDC2 and TCC2, as well as a detailed study of the XTAX machine protection and safety options. It is important to point out that these efforts will significantly improve the present day operation and radiological situation in the North Area, beneficial not only for a future ECN3 HI facility, but equally for all other NA FT experiments and users.

The TF suggests the following wider recommendations to prepare the CERN accelerator complex to deliver a HI upgrade to the NA:

- Understand and optimise SFTPRO transmission throughout the complex before LS3;
- Probe the SFTPRO intensity limits through the CERN accelerator complex;

- Understand how to safely and reliably slow-extract intensities $> 4.2 \times 10^{13}$ ppp from the SPS;
- Approval and support for in-house crystal development at CERN;
- Survey of post-LS3 NA users to understand rate limitations and plan mitigations through optimised beam delivery (spill length/quality) and/or improved detector and readout technology.

References

[1] European Strategy For Particle Physics Preparatory Group, “Physics briefing book,” 2019. [Online]. Available: https://arxiv.org/abs/1910.11775

[2] “Physics Beyond Colliders Study Group,” https://pbc.web.cern.ch/.

[3] C. Vallee, “Introduction and scope,” 7-9 Nov 2022, presented at the Physics Beyond Colliders Annual Workshop 2022. [Online]. Available: https://indico.cern.ch/event/1137276

[4] D. Banerjee *et al.*, “The North Experimental Area at the CERN Super Proton Synchrotron,” CERN, Tech. Rep. CERN-ACC-NOTE-2021-0015, 2021. [Online]. Available: https://cds.cern.ch/record/2774716

[5] L. Gatignon *et al.*, “Some recollections concerning the P42 beam line,” CERN, Tech. Rep. SPSX-L-RPT-0001-1.1, 2022. [Online]. Available: https://edms.cern.ch/document/2756790

[6] O. Aberle *et al.*, “Study of alternative locations for the SPS Beam Dump Facility,” Tech. Rep. CERN-PBC-Notes-2022-002, 2022. [Online]. Available: https://cds.cern.ch/record/2802705

[7] G. Arduini, “Physics Beyond Colliders Post-LS3 Experimental Options in ECN3,” 8 Apr 2022. [Online]. Available: https://indico.cern.ch/event/1144133

[8] J. Bernhard (BE-EA, CBWG), and M. Brugger (BE-EA, ECN3 TF, CBWG), M.A. Fraser (SY-ABT, ECN3 TF, BDF WG), and R. Jacobsson (EP-LBD, BDF WG), Y. Kadi (NA-CONS), “Memo: Support for Engineering Studies as input to the ECN3 Beam Delivery Task Force by the PBC ECN3 Beam Delivery Task Force (ECN3 TF) chairs, the PBC Beam Dump Facility (BDF) / PBC Conventional Beam (CB) WG convenors, and the NA-CONS project leader,” CERN, Geneva, Tech. Rep. EDMS #2758293, 2022. [Online]. Available: https://edms.cern.ch/document/2758293

[9] O. Aberle *et al.*, “BDF/SHiP at the ECN3 High-Intensity Beam Facility Letter of Intent,” CERN, Geneva, Tech. Rep. CERN-SPSC-2022-032, SPSC-I-258, 2022. [Online]. Available: https://cds.cern.ch/record/2839677

[10] C. Ahdida *et al.*, *SPS Beam Dump Facility - Comprehensive Design Study*, ser. CERN Yellow Reports: Monographs. Geneva: CERN, 2020. [Online]. Available: https://cds.cern.ch/record/2703984

[11] E. Cortina Gil *et al.*, “HIKE, High Intensity Kaon Experiments at the CERN SPS: Letter of Intent. HIKE, High Intensity Kaon Experiments at the CERN SPS,” CERN, Geneva, Tech. Rep. CERN-SPSC-2022-031, SPSC-I-257, 2022, address all correspondence to hike-eb@cern.ch. [Online]. Available: https://cds.cern.ch/record/2839661

[12] M. Alviggi *et al.*, "SHADOWS Letter of Intent," CERN, Geneva, Tech. Rep. CERN-SPSC-2022-030, SPSC-I-256, 2022. [Online]. Available: https://cds.cern.ch/record/2839484

[13] C. Ahdida and M. Calviani, "Considerations on Target Systems for ECN3: design & requirements," Tech. Rep. EDMS #2798727, 17 Nov 2022, presented at the Joint BDF-CB WG meeting #4. [Online]. Available: https://edms.cern.ch/document/2798727/1.1

[14] M. Brugger and M. Fraser, "ECN3 intensity scenarios post-LS3," CERN, Geneva, Tech. Rep. EDMS #2797516, 2021. [Online]. Available: https://edms.cern.ch/document/2797516

[15] A. Charalambous, F. Gautheron, and Y. Kadi, "User Requirements for a High Intensity Beam Facility at TCC8/ECN3," CERN, Geneva, Tech. Rep. EDMS #2791543, SPSX-X-SPC-0001, 2021. [Online]. Available: https://edms.cern.ch/document/2791543

[16] H. Bartosik *et al.*, "SPS Operation and Future Proton Sharing Scenarios for the SHiP experiment at the BDF facility," CERN, Tech. Rep., 2018. [Online]. Available: https://cds.cern.ch/record/2650722

[17] D. Forkel-Wirth, "Zonage radiologique au CERN," Tech. Rep. EDMS #810149, 2007. [Online]. Available: https://edms.cern.ch/document/810149

[18] J. Bernhard *et al.*, "Recent Studies on Radiation at the ramp to EHN1 from the P42 beam," CERN, Geneva, Tech. Rep. SPSX-S-SSR-0001, EDMS #2816855, 2022. [Online]. Available: https://edms.cern.ch/document/2816855

[19] "SAFETY CODE F Rev. Radiation Protection," Tech. Rep. EDMS #335729, 2006. [Online]. Available: https://edms.cern.ch/document/335729/

[20] K. Li, "SFTPRO, SFTION, HiRadMat and AWAKE Beam Production and Delivery," 5 - 8 Dec 2022, presented at the Joint Accelerator Performance Workshop. [Online]. Available: https://indico.cern.ch/event/1194548

[21] M. Vadai, "Barrier Bucket Studies for the PS-SPS Transfer of SFTPRO: Status and Plans," 10 Oct 2022, presented at the 9th meeting of the PBC Accelerator Complex Capabilities Working Group. [Online]. Available: https://indico.cern.ch/event/1212850/contributions/5101516/attachments/2539171/4370769/2022-11-01-PS-SPS-barrier-bucket-synchronisation.pdf

[22] M. Vadai *et al.*, "Beam loss and transmission along the chain," 5 - 8 Dec 2022, presented at the Joint Accelerator Performance Workshop. [Online]. Available: https://indico.cern.ch/event/1194548/contributions/5093944/attachments/2562459/4417094/2022-12-07-beam-loss-in-the-complex-barrier-bucket-vadai.pdf

[23] T. Prebibaj, G. Arduini, H. Bartosik, and M. A. Fraser, "SPS Operation and Future Proton Sharing Scenarios for the ECN3 facility," CERN, Geneva, Tech. Rep. CERN-PBC-Notes-2023-001, 2023. [Online]. Available: https://cds.cern.ch/record/2848908

[24] M. Pari *et al.*, "Characterization of the slow extraction frequency response," *Phys. Rev. Accel. Beams*, vol. 24, p. 083501, Aug 2021. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.24.083501

[25] M. Fraser *et al.*, "SPS Slow Extraction Losses and Activation: Challenges and Possibilities for Improvement," in *Proc. IPAC'17.* JACoW Publishing, Geneva, Switzerland, 2017, paper MOPIK045, pp. 611–614. [Online]. Available: https://jacow.org/ipac2017/papers/MOPIK045.pdf

[26] M. Fraser *et al.*, "SPS Slow Extraction Losses and Activation: Update on Recent Improvements," in *Proc. IPAC'19.* JACoW Publishing, Geneva, Switzerland, 2019, paper WEPMP031, pp. 2391–2394. [Online]. Available: http://accelconf.web.cern.ch/ipac2019/papers/WEPMP031.pdf

[27] B. Balhan *et al.*, "Improvements to the SPS Slow Extraction for High Intensity Operation," CERN, Tech. Rep. CERN-ACC-NOTE-2019-0010, 2019. [Online]. Available: https://cds.cern.ch/record/2668989

[28] F.M. Velotti *et al.*, "Septum shadowing by means of a bent crystal to reduce slow extraction beam loss," *Phys. Rev. Accel. Beams*, vol. 22, p. 093502, Sep 2019. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.22.093502

[29] M. Fraser *et al.*, "Demonstration of slow extraction loss reduction with the application of octupoles at the CERN Super Proton Synchrotron," *Phys. Rev. Accel. Beams*, vol. 22, p. 123501, Dec 2019. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.22.123501

[30] P. Arrutia Sota and M. Fraser, *Optimisation of Slow Extraction and Beam Delivery from Synchrotrons.* CERN master thesis, 2020. [Online]. Available: https://cds.cern.ch/record/2749240

[31] L. Esposito and M. Calviani, "DEvelopment of CRYstals for Collimation and Beam Extraction project management plan (DECRYCE Project)," CERN, Geneva, Tech. Rep. EDMS #2809729, 2023. [Online]. Available: https://edms.cern.ch/document/2809729

[32] F. Velotti *et al.*, "Beam size specification for TT20," CERN, Geneva, Tech. Rep. EDMS #2787943, 2022. [Online]. Available: https://edms.cern.ch/document/2761319/1

[33] R. Ramjiawan, "MD results and P42 SFTPRO beam dump options (for ECN3 in dedicated mode)," 24 Nov 2022, presented at the ECN3 TF Meeting #14. [Online]. Available: https://indico.cern.ch/event/1223801

[34] G. Arduini and M. Gyr, "*Legacy optics repository*," 2007. [Online]. Available: http://project-ps-optics.web.cern.ch/project-PS-optics/cps/TransLines/TT20/2011/strength/

[35] F.M. Velotti, "TT20 optics measurements," 18 May 2022, presented at SPS MPC #20 - NA spill quality, part I. [Online]. Available: https://indico.cern.ch/event/1159207

[36] F. Velotti, “TT20 optics measurements - update,” 13 Oct 2022, presented at ECN3 Task Force Meeting #11. [Online]. Available: https://indico.cern.ch/event/1206726/

[37] L. Gatignon, J. Bernhard *et al.*, “The report of the Conventional Beams Working Group to the Physics Beyond Collider Study and to the European Strategy for Particle Physics,” CERN, Tech. Rep., 2022. [Online]. Available: https://cds.cern.ch/record/2650989/

[38] D. Banerjee *et al.*, “Target Bypass Beam Optics for Future High Intensity Fixed Target Experiments in the CERN North Area,” in *Proc. IPAC’21*. JACoW Publishing, Geneva, Switzerland, 2021, paper WEPAB185, pp. 3046–3048. [Online]. Available: https://jacow.org/ipac2021/papers/WEPAB185.pdf

[39] T. Zickler *et al.*, “Bumper Magnet Installation and Vacuum Layout Modifications in TT24,” CERN, Geneva, Tech. Rep. SPS-MC-EC-0001, EDMS #2797504, 2022. [Online]. Available: https://edms.cern.ch/document/2797504

[40] T. Zickler *et al.*, “Operation Scenarios in TT20 and NA Secondary Beam Lines in the Context of NA-CONS,” CERN, Geneva, Tech. Rep. EDMS #2746889, 2023. [Online]. Available: https://edms.cern.ch/document/2746889

[41] G. Le Godec and I. Josifovic, “Power Converters Consolidation for North Area and TT20 Transfer Line,” CERN, Geneva, Tech. Rep. SPSX-R-WD-0002, EDMS #2488121, 2022. [Online]. Available: https://edms.cern.ch/document/2488121

[42] I. Josifovic and Y. Gaillard, “POLARIS Converter Family for TT20 and North Area Consolidation,” CERN, Geneva, Tech. Rep. SPSX-R-ES-0001, EDMS #2801702, 2022. [Online]. Available: https://edms.cern.ch/document/2801702

[43] M. Fraser and F. Velotti, “Upgraded Beam Instrumentation for Slow Extraction at SPS,” CERN, Geneva, Tech. Rep. EDMS #2113420, 2019. [Online]. Available: https://edms.cern.ch/document/2113420

[44] I. Ortega Ruiz *et al.*, “Final report of the EABI Working Group - Executive summary version,” CERN, Geneva, Tech. Rep. EDMS #2222321, 2019. [Online]. Available: https://edms.cern.ch/document/2222321

[45] B. Salvachua, “Optical BLM system: Project Status and update on SPS LSS2,” 2021, presented at the SLAWG Meeting #68, Geneva, Switzerland.

[46] F. Roncarolo *et al.*, “Fast Spill Monitor Studies for the SPS Fixed Target Beams,” presented at IBIC’22, Kraków, Poland, Sep. 2022, paper WE3C3, unpublished.

[47] M. Fraser *et al.*, “Installation of additional Beam Profile Monitors in the North Area P42 Primary Line,” CERN, Geneva, Tech. Rep. SPSX-B-EC-0002, EDMS #2777725, 2022. [Online]. Available: https://edms.cern.ch/document/2777725

[48] M. Fraser *et al.*, “Installation of Beam Loss Monitors in the North Area P42 Primary Line,” CERN, Geneva, Tech. Rep. SPSX-B-EC-0003, EDMS #2777729, 2022. [Online]. Available: https://edms.cern.ch/document/2777729

[49] J. Grenard *et al.*, "Consolidation of North Area Target Stations T2, T4, T6, T10," CERN, Geneva, Tech. Rep. SPSX-T-WD-0004 EDMS #2800862, 2022. [Online]. Available: https://edms.cern.ch/document/2800862

[50] K. Bernier *et al.*, *Calibration of secondary emission monitors of absolute proton beam intensity in the CERN SPS North Area*, ser. CERN Yellow Reports: Monographs. Geneva: CERN, 1997. [Online]. Available: https://cds.cern.ch/record/339460

[51] M. Fraser *et al.*, "Slow Extraction Efficiency Measurements at the CERN SPS," in *Proc. IPAC'18*. JACoW Publishing, Geneva, Switzerland, 2018, paper TUPAF054, pp. 834–837. [Online]. Available: http://accelconf.web.cern.ch/ipac2018/papers/TUPAF054.pdf

[52] Y. Dutheil, "Splitter MD analysis," 8 Sept 2021. [Online]. Available: https://indico.cern.ch/event/1072891/

[53] M. Van Dijk, "Calibration of the T10 Target," 19 Jan 2023, presented at the ECN3 Task Force Meeting #16, Geneva, Switzerland. [Online]. Available: https://indico.cern.ch/event/1240306/

[54] F. Ravotti *et al.*, "Calibration of the T08.XSEC devices by means of Al-foils activation and BCTF measurements," CERN, Geneva, Tech. Rep. EP-Tech-Note-2022-001, EDMS #2783968, 2022. [Online]. Available: https://edms.cern.ch/document/2783968

[55] J. Bernhard *et al.*, "P6 Beamline Magnets Removal in TT83 during YETS22-23," CERN, Geneva, Tech. Rep. SPSX-L-EC-0008, EDMS #2787943, 2022. [Online]. Available: https://edms.cern.ch/document/2787943

[56] A. Pilan Zanoni and A. Ciccotelli, "Description and thermo-mechanical performance of TT20 TED (Target Extraction Dump)," CERN, Geneva, Tech. Rep. SPS-TED-ER-0001, EDMS #1967622, 2018. [Online]. Available: https://edms.cern.ch/document/1967622

[57] M. Fraser, R. Ramjiawan, and F. Velotti, "Beam parameters for TT20 BIDs in the framework of NA-CONS and PBC ECN3 Beam Delivery Task Force," CERN, Geneva, Tech. Rep. SPSX-T-ES-0004, EDMS #2780156, 2018. [Online]. Available: https://edms.cern.ch/document/2780156

[58] H. Vincke, "Radiological design improvement study for the TED beam absorbers," Tech. Rep. EDMS #2816493, 2023. [Online]. Available: https://edms.cern.ch/document/2816493

[59] N. Solieri, "Summary of simulations and works during LS2 on TCSC collimator," CERN, Geneva, Tech. Rep. EDMS #2636426, 2019. [Online]. Available: https://edms.cern.ch/document/2636426

[60] M. Calviani, "Reports on SY-STI tasks for ECN3 TF," 29 Sept 2022, presented at the ECN3 Task Force Meeting #10, Geneva, Switzerland. [Online]. Available: https://indico.cern.ch/event/1202917/

[61] H. Vincke, "Radiological design improvements of the TCSC collimator," CERN, Geneva, Tech. Rep. EDMS #2790745, 2022. [Online]. Available: https://edms.cern.ch/document/2790745/

[62] S. Pianese *et al.*, "Design of the Future High Energy Beam Dump for the CERN SPS," in *Proc. 9th International Particle Accelerator Conference (IPAC'18), Vancouver, BC, Canada, April 29-May 4, 2018*, ser. International Particle Accelerator Conference, no. 9. Geneva, Switzerland: JACoW Publishing, June 2018, paper WEPMG004, pp. 2612–2615, https://doi.org/10.18429/JACoW-IPAC2018-WEPMG004. [Online]. Available: http://jacow.org/ipac2018/papers/wepmg004.pdf

[63] M. Fraser, B. Goddard, and F. Velotti, "Requirements of a Multi-Volume Reflection (MVR) crystal array located in LSS4 for the non-local shadowing of the ZS," CERN, Geneva, Tech. Rep. SPS-TECA-ES-0001, EDMS #2310234, 2021. [Online]. Available: https://edms.cern.ch/document/2310234

[64] C. Sharp and R. F. Ximenes, "FEM analysis of the T4 Target for the ECN3 high intensity scenarios," CERN, Geneva, Tech. Rep. EDMS #2812842, 2023. [Online]. Available: https://edms.cern.ch/document/2812842

[65] A. R. Francia and R. F. Ximenes, "FEM analysis of the T4 XTAX for the ECN3 high intensity scenarios," CERN, Geneva, Tech. Rep. EDMS #2812843, 2023. [Online]. Available: https://edms.cern.ch/document/2812843

[66] N. Solieri and A. Ciccotelli, "FEM Analysis of the Survival of the K12 TAX for Use in the Proposed KLEVER and NA62-4x Experiments," CERN, Geneva, Tech. Rep. SPSX-T-ER-0001, EDMS #2303290, 2023. [Online]. Available: https://edms.cern.ch/document/2303290

[67] M. Calviani and M. Brugger, "Memorandum - Proposal for a XTAX consolidation steering WG," CERN, Geneva, Tech. Rep. EDMS #2779687, 2022. [Online]. Available: https://edms.cern.ch/document/2779687

[68] A. R. Francia and R. F. Ximenes, "FEM analysis of the beam windows in T4 for the ECN3 high intensity scenarios," CERN, Geneva, Tech. Rep. EDMS #2812844, 2023. [Online]. Available: https://edms.cern.ch/document/2812844

[69] R. Ramjiawan, "Options for dumping the SFTPRO beam," Geneva, Switzerland, 9 Feb 2023, presented at the ECN3 TF Meeting #19. [Online]. Available: https://indico.cern.ch/event/1252011

[70] D. Björkman *et al.*, "Alternative Material Choices to Reduce Activation of Extraction Equipment," in *Proc. IPAC'19*. JACoW Publishing, Geneva, Switzerland, 2019, paper WEPMP024, pp. 2363–2366. [Online]. Available: http://accelconf.web.cern.ch/ipac2019/papers/WEPMP024.pdf

[71] C. Ahdida *et al.*, "Assessment of the radiation levels at the EHN1 ramp - Status report," CERN, Tech. Rep. EDMS #2770240, 2022. [Online]. Available: https://edms.cern.ch/document/2770240/

[72] C. Ahdida, E. Nowak, H. Vincke, and H. Vincke, "RP considerations for the beam transfer towards ECN3," Tech. Rep. EDMS #2746846, 2022. [Online]. Available: https://edms.cern.ch/document/2746846/

[73] M. Lazzaroni, "Renforcement blindage Rampe Salève et grillage," Tech. Rep. EDMS #2817819, 2022. [Online]. Available: https://edms.cern.ch/document/2817819/

[74] E. Nowak and C. Ahdida, "Shielding studies for the EHN1 ramp and bridge (P42)," CERN, Tech. Rep. EDMS #2815402, 2023. [Online]. Available: https://edms.cern.ch/document/2815402

[75] F. Gautheron *et al.*, "Strategy for the Consolidation and Upgrade of the North Experimental Area," CERN, Tech. Rep. EDMS #2144442, 2020. [Online]. Available: https://edms.cern.ch/document/2144442/1

[76] F. Gautheron *et al.*, "North Area Consolidation: Alternative Scenario," CERN, Tech. Rep. EDMS #2042932, 2020. [Online]. Available: https://edms.cern.ch/document/2042932

[77] J. Bernhard *et al.*, "Risk Analysis and User Requirements for BIS in the CERN North Area Beam Lines," CERN, Tech. Rep. EDMS #2435863, 2020. [Online]. Available: https://edms.cern.ch/document/2435863

[78] J. Uythoven and I. Ramirez, "BIS consolidation for the North Area and the related beam transfer lines," CERN, Tech. Rep. EDMS #2459282, 2022. [Online]. Available: https://edms.cern.ch/document/2459282

[79] A. Colinet and I. Ramirez, "Engineering Specification of the Beam Interlock System for SPS slow extraction and the North Area," CERN, Tech. Rep. EDMS #2810115, 2022. [Online]. Available: https://edms.cern.ch/document/2810115

[80] "Post Mortem of TCC2 - Part 1," 5 May 2022, NA-CONS TCC meeting, Geneva, Switzerland. [Online]. Available: https://indico.cern.ch/event/1155494/

[81] "Post Mortem of TCC2 - Part 2," 12 May 2022, NA-CONS TCC meeting, Geneva, Switzerland. [Online]. Available: https://indico.cern.ch/event/1155501/

[82] M. Calviani *et al.*, "Report from the Task Force TCSC water leak in TDC2," CERN, Geneva, Tech. Rep. EDMS #2810115, 6 May 2022. [Online]. Available: https://edms.cern.ch/document/2810115

[83] "Analysis of TBIU (T2) incident in TCC," 29 Sept 2022, NA-CONS TCC meeting, Geneva, Switzerland.

[84] K. Kershaw, J.-L. Grenard, M. Calviani *et al.*, "Design development for the beam dump facility target complex at cern," *Journal of Instrumentation*, vol. 13, no. 10, p. P10011, oct 2018. [Online]. Available: https://dx.doi.org/10.1088/1748-0221/13/10/P10011

[85] E. Lopez Sola, M. Calviani *et al.*, "Design of a high power production target for the beam dump facility at cern," *Phys. Rev. Accel. Beams*, vol. 22, p. 113001, Nov 2019. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.22.113001

[86] E. Lopez Sola, M. Calviani *et al.*, "Beam impact tests of a prototype target for the beam dump facility at CERN: Experimental setup and preliminary analysis of the online results," *Phys. Rev. Accel. Beams*, vol. 22, p. 123001, Dec 2019. [Online]. Available: https://link.aps.org/doi/10.1103/PhysRevAccelBeams.22.123001

[87] S. Gallimore and M. Fletcher, "Isis ts1 project summary," *Journal of Physics: Conference Series*, vol. 1021, no. 1, p. 012053, may 2018. [Online]. Available: https://dx.doi.org/10.1088/1742-6596/1021/1/012053

[88] L. Zavorka, M. J. Mocko, and P. E. Koehler, "Physics design of the next-generation spallation neutron target-moderator-reflector-shield assembly at lansce," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 901, pp. 189–197, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0168900218307393

[89] I. Remec, F. X. Gallmeier, and M. J. Rennich, "Neutronics analyses for the ornl's spallation neutron source second target station," *Journal of Physics: Conference Series*, vol. 1021, no. 1, p. 012084, may 2018. [Online]. Available: https://dx.doi.org/10.1088/1742-6596/1021/1/012084

[90] Synaxis AG, "CERN Prevessin Beam Dump Facility ECN3 & TCC8 - Report of Preliminary Study," Lausanne, Switzerland, Tech. Rep. EDMS #2815529, 2023. [Online]. Available: https://edms.cern.ch/document/2815529