TARGET SYSTEMS DESIGN FOR A HIGH INTENSITY FACILITY IN THE CERN'S ECN3 AREA

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Abstract

A new high-intensity fixed-target facility could be accommodated at CERN by fully exploiting the Super Proton Synchrotron. Multiple physics experiment proposals such as BDF/SHiP, HIKE and SHADOWS are being considered. Amongst the different possibilities to locate such experiments and their respective target complex at CERN, the ECN3 hall in the North Area has been selected for further study. This contribution will detail the status of the design and physics optimisation of the target systems proposed for a high intensity upgrade in ECN3. Radiation protection considerations, remote handling strategy, services supply, installation, operation, maintenance, and decommissioning aspects are herein discussed.

INTRODUCTION

Following the interest to further exploit CERN's Super Proton Synchrotron (SPS) for fixed target experiments, multiple proposals for high intensity experimental physics have been made to use the slow extraction 400 GeV/c proton beam at the North Area (NA) from Run 4 onwards (2029). The Beam Dump Facility (BDF) [1] coupled with the Search for the Hidden Particle Experiment (SHiP) [2], and the High-Intensity Kaon Experiments (HIKE) [3] jointly with the Search for Hidden And Dark Objects With the SPS (SHADOWS) [4] are the candidates that stood out from the Physics Beyond Collider (PBC) Study Group proposals [5, 6]. Despite their common interest in high intensity beams, and regardless of the physics case at stake, both BDF/SHiP and HIKE/SHADOWS will require distinct beam line arrangements, target systems, detector setups, and consequently specific infrastructure and service requirements, radiation protection considerations, and handling and operational design strategies for their target systems. In case an experiment is approved, this paper describes the new target systems and infrastructure modifications.

High Intensity Scenarios

The high intensity requirements demanded by the experiments differ mostly in SPS extraction spill length and repetition rate as well as integrated and pulsed intensity (Table 1). Yet, the experiment proposals will operate above today's NA beam parameters, both in terms of intensity per spill as well as total intensity on target (hence average beam power) [7]. These conditions have been the basis for the conceptual design of the new target systems and have also been taken in parallel as main input for a Task Force mandated to assess the technical feasibility to increase the intensity to the location of the new experiment, as reported in Refs.[8, 9].

Table 1: High Intensity Requirements [7]

Experiment	**Pulse | Cycle length [s]**	**POT/pulse [p^+/pulse]**	**POT/year [p^+/y]**
BDF/SHiP	1.2 | 7.2	4.0×10^{13}	4.0×10^{19}
HIKE	4.8 | 14.4	$1.2–4.0 \times 10^{13}$	$0.7–2.4 \times 10^{19}$
SHADOWS	4.8 | 14.4	2.0×10^{13}	1.2×10^{19}

TCC8 and ECN3 Areas

The chosen experiment will make use of a slow extracted beam to the North Area at 400 GeV/c, which will be transported 838 m via the T21-T22-T24 beamline in TCC2 - TT83 - TT85 - TDC85 transfer tunnels to the TCC8 and ECN3 tunnel and cavern halls, where the target systems and experiments will be placed (Fig. 1).

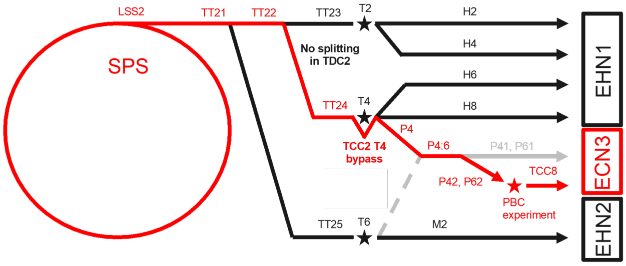

Figure 1: North Area beam lines. Dedicated beam delivery to the new experiment in ECN3 highlighted in red [8].

The area presents no horizontal slope and is entirely located 9 m below the natural ground level. The 170 m long and 10 m wide TCC8 target hall was built for free-standing target systems in direct connection with ECN3 [10], and is equipped with a 30 ton travelling crane with 4.5 m free space below the hook. The ECN3 cavern, downstream TCC8, is about 100 m in length, 16 m wide, and has a usable height of 8 m along its length. The later is defined by the existing 45 tonne travelling crane, which overlaps the one of the preceding tunnel allowing transport between the areas. A $4 \times 8\,\mathrm{m}^2$ wide access shaft for materials presently serves the two underground areas and is located just at the junction between them. Currently, the upstream part of TCC8 is allocated to the T10 target station and its mobile dump collimator XTAX (Target Attenuator eXperimental), which are

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used by the NA62 experiment, which extends downstream to the end of ECN3 [11]. Between the T10 target and XTAX location, the area is highly activated and an over-pressurised confinement volume is in place. In case of approval, the entire tunnel and cavern will have to be dismantled during CERN's Long Shutdown 3 (LS3, 2026-2028) to make space for the new physics endeavour. The underground setting of the caverns, the area availability (post LS3) and size, and the fact that the tunnel infrastructure is already loosely activated have been key factors to select TCC8 and ECN3 as the ideal venue for a high intensity experiment within CERN's SPS complex [12]. Moreover, a substantial cost reduction will be obtained by reusing an existing location, even with the additional shaft of $8 \times 8\,\mathrm{m}^2$ section that is proposed for SHIP at the downstream end of the ECN3 cavern to accommodate the transport needs for the experiment installation, while freeing TCC8's crane for the Target Complex installation. Minor civil engineering works are also expected in the floor of both caverns and for both experimental proposals.

BDF/SHIP

Target Systems Design

At the core of the facility, BDF/SHiP would have a high-density target to fully absorb the primary beam (approximately 350 kW beam power) and maximise the production of charmed mesons and other processes that are potential sources of feebly interacting particles. While the high density of the target also contributes to suppress backgrounds, the remaining flux of background particles must be reduced by a hadron absorber and a magnetic muon shield immediately downstream of the target. Moreover, the high integrated intensity imposes strict radiation protection considerations.

The water-cooled target will sit inside a He-filled vessel to detect any possible leaks. The implementation of the target vessel provides a straightforward, fully remote means for handling the target and connecting the services upon installation and removal. Equipped with an isostatic positioning system and survey markers, the target vessel will be pre-aligned before installation. The first layer of shielding (mostly to block the shower of secondary particles) consists of 400 cm of cast iron around the target vessel. Cast-embedded stainless steel pipes for the water cooling will be used to extract up to 12 kW of thermal power deposited in the shielding. The target assembly and this proximity shielding will be confined in a low vacuum (1×10^{-3} mbar) tank of approximately $6.2 \times 1.7 \times 2.6\,\mathrm{m}^3$ in order to reduce air activation and reduce radiation-accelerated corrosion due to ozone production and various other nitric acid compounds. A second assembly of cast iron and concrete blocks encapsulates the vacuum tank. The latter may be completed - in specific areas - with an outer layer of marble to reduce residual dose to workers during maintenance interventions. The routing of the connections to services (vacuum, water, helium and electrical) is made upstream, where the beam instruments, beam window and a collimator are located.

Downstream the target vessel, a 5 m long section of magnetised US1010 steel [13] with a 1.6 T field will be integrated to deflect high energy muons and stop low energy ones as well as most electromagnetic radiation and hadrons coming from the target (Fig. 2).

Civil engineering works will have to be done below the target assembly to embed extra shielding.

The main BDF target shielding assembly will have a volume of about 12 m long, 4.6 m high and 5.6 m width. In total, $180\,\mathrm{m}^3$ of cast iron and about $360\,\mathrm{m}^3$ of concrete and marble will be used in the target complex. The shielding design is based on CERN standard cast iron and concrete blocks, however a particular effort is being made towards reusing already activated blocks from different spent facilities at CERN (CNGS target area, TT7 PS neutrino beam dump) in view of meeting CERN's sustainability goals [14].

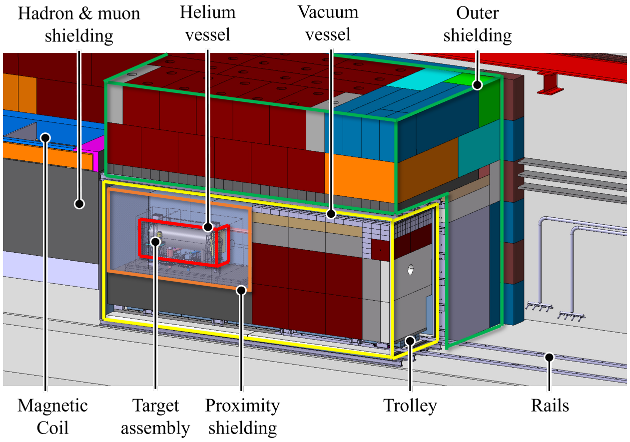

Figure 2: BDF conceptual Target System in TCC8/ECN3. Upstream shielding, collimator, and beam instrumentation are not represented.

Handling Aspects

The current design foresees the extraction of the target from its confinement from the upstream side, where there is more space available despite the need to dismantle part of the beam line to access it (as opposed to a lateral access). The target and proximity shielding will be mounted on a motor-free trolley that can be pulled and pushed. The trolley slides on rails with chain-action rollers to avoid any grease usage. The target and proximity shielding utilities must be disconnected at the door of the vacuum confinement since no intermediate connections are foreseen inside the tank.

The steps to access the target, whether for maintenance or replacement, have been optimised to reduce the amount of work required near the target. Firstly, the upstream section of the beam pipe is disconnected. The upstream concrete shielding and mask-collimator are then removed, followed by the beam instrumentation. Secondly, dedicated tooling is installed (optimised for hands-on intervention), and services associated with the target and proximity shielding are disconnected. The vacuum vessel can then be vented and opened. Thirdly, the target trolley is pulled out of the outer shielding assembly. At this stage, the proximity shielding is removed. Lastly, maintenance or removal of the target He vessel is carried out. From the proximity shielding removal onward, only fully remote activities are required. The reverse procedure is applied for re-installation.

Radiation Protection to Electronics

The BDF facility was optimised according to the ALARA approach taking into account prompt radiation, residual radiation, air and ground water activation as well as the environmental impact. The shielding assembly allows to reduce the above-ground prompt radiation to comply with the area classification limits. Its design takes into account the limitation of activation in the target and experimental areas guaranteeing access for interventions. Thanks to the iron shielding integration in the floor, the activation and contamination of ground water and soil is reduced. Air activation is minimised with the helium tank and the vacuum vessel. Furthermore, the air of the entire target bunker is confined with walls to keep a negative pressure with respect to the surrounding areas. Finally, the environmental impact from prompt radiation and releases of activated air is considered as optimised [15, 16].

HIKE AND SHADOWS

Target Systems Design

The HIKE experiment is proposed to be staged in different phases to explore kaon beams, as well as other physics cases with beam dump modes. SHADOWS would look at feebly-interacting particles with an off-axis setup running in parallel with HIKE in dump mode. Despite the lower requested number of protons on target, the multi-mode nature of the proposal brings a less compact beam line with several equipment in the secondary beam line requiring a significant amount of shielding.

The proposed target system consists of a primary target made of beryllium (or eventually carbon, to be defined). This is followed by a set of wobbling magnets downstream the target to momentum-select the secondary hadrons before passing via a collimator-absorber called TAX (Target Attenuator for eXperimental areas). The later will have a geometry with different aperture configurations and will also act as a beam dump depending on the operation setting. In-between, beam instrumentation and other intermediate collimators will be installed.

The TAX, the target assembly and the beam instrumentation will be mounted on vertical remotely controlled systems to allow choosing the operational configuration of the TAX, to properly align the equipment as well as to keep all the movement systems independent. All those elements must be enclosed by a shielding made out of blocks of cast iron, concrete and possibly marble. The shielding around the target will be water cooled. All the service connections will be routed to the lateral side of the beam line, allowing easy maintenance.

In the same way as for BDF, civil engineering works will have to be made on the floor of TCC8 to embed shielding.

The target shielding assembly extends over about 31 m, taking a section of 4.6 m high and 6 m width of the TCC8 tunnel (Fig. 3).

The shielding volume represents about 150 m^3 of cast iron and about 600 m^3 of concrete and marble. As in the case of BDF/SHiP, particular attention is put on the possibility of reusing already activated blocks from different spent CERN facilities to meet CERN's sustainability goals.

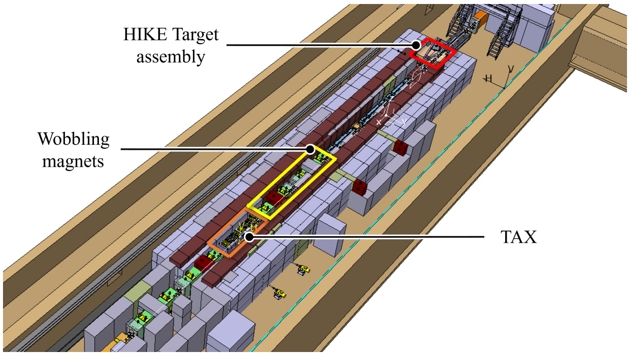

Figure 3: HIKE/SHADOWS conceptual Target System in TCC8/ECN3. Top shielding removed for illustration.

Handling Aspects

The different equipment and shielding assembly shall be designed in a way to be quickly and reliably exchanged. Therefore, the upper part of the shielding will be divided in multiple standard-size blocks in a way that they can be smoothly dismounted to allow access to the different confined equipment (target, collimator, magnets, TAX). The maintenance of the different equipment is foreseen with the help of the remotely controlled overhead travelling crane.

Radiation Protection to Electronics

For the HIKE/SHADOWS facility design, the same rational as for BDF has been applied, ensuring an optimised facility that is compliant with CERN's radiation protection code regarding dose to the personnel and members of the public. Even though the facility design of HIKE/SHADOWS is less compact than for BDF and has no helium/vacuum vessel, thus leading to higher air activation, the levels of the air activation and impact from its releases into the environment are still considered as optimised [17]. A particular challenge of this experimental setup will be limiting the radiation to electronics on the SHADOWS detectors and the radiation dose to the coils of the wobbling magnets [18, 19].

CONCLUSIONS

Two main experiment candidates are proposed for a future high intensity target facility at CERN in the SPS TCC8-ECN3 beam facility. The selected underground areas are compatible with both BDF/SHiP and HIKE/SHADOWS Target Systems implementation. Remote handling and radiation protection shielding optimisation are driving the designs. Further development of both concepts throughout 2023 is foreseen, in view of a management decision.

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