THE SPS BEAM DUMP FACILITY

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Abstract

The proposed SPS beam dump facility (BDF) is a fixed-target facility foreseen to be situated at the North Area of the SPS. Beam dump in this context implies a target aimed at absorbing the majority of incident protons and containing most of the cascade generated by the primary beam interaction. The aim is a general purpose fixed target facility, which in the initial phase is aimed at the Search for Hidden Particles (SHiP) experiment.

Feasibility studies are ongoing at CERN to address the key challenges of the facility. These challenges include: slow resonant extraction from the SPS; a target that has the two-fold objective of producing charged mesons as well as stopping the primary proton beam; and radiation protection considerations related to primary proton beam with a power of around 355 kW. The aim of the project is to complete the key technical feasibility studies in time for the European Strategy for Particle Physics (ESPP) update foreseen in 2020. This is in conjunction with the recommendation by the CERN Research Board to the SHiP experiment to prepare a comprehensive design study as input to the ESPP.

INTRODUCTION

The physics motivations for exploring the so-called Hidden Sector are well established. One potential avenue is to search for MeV to GeV hidden particles in fixed target experiments. To this end, the SPS beam dump facility (BDF) has been proposed as a fixed-target facility foreseen to be situated at the North Area of the SPS. Beam dump in this context implies a target which aims to absorb as many of incident protons as possible and contain most of the cascade generated by primary beam interactions.

Exploitation of the facility in the first instance is foreseen to be by the SHiP experiment [1]. SHiP is being designed to explore Hidden Sector models with vector, scalar, neutrino, axion-like SM portals (and others) in the MeV-GeV range [2]. Other possibilities that might be explored to fully exploit the large potential of the new facility include experiments equipped with fine-grained calorimeters or massive liquid argon TPC to search for non-standard ratios of neutrino neutral-current and charged-current interactions. Other possibilities are experiments to search for particles with fractional charges, detectors to measure the $\nu_\tau \to \nu_X$ oscillations, experiments to search for the lepton flavour violating decay $\tau \to 3\mu$ and other rare or forbidden τ decays, and experiments to search for rare muon interactions or decays.

OVERVIEW OF FACILITY

The idea is to site the BDF near the existing facilities at the North Area of the SPS. Slow extraction of 400 GeV/c protons from the SPS is foreseen using existing slow extraction hardware situated at point 2. The extracted beam is to be transferred along the existing transfer line to the North Area (TT20) up to a switch in an existing cavern (TDC2). This switch sends the beam into a short ~350 m long new beam line. This line defines the beam geometry up to the target, and has to be equipped with a system to provide adequate spatial dilution of the beam on the target together with instrumentation and steering elements. Ongoing studies are based on the assumption that the target and experimental facility will be located upstream of the existing North Area experimental hall (EHN1) - see Fig. 1.

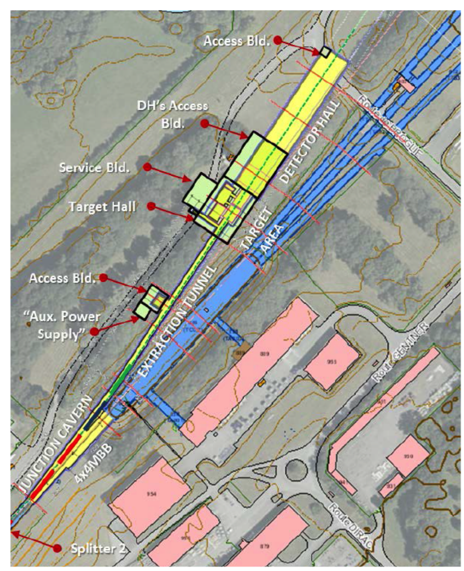

Figure 1: Overview of proposed BDF layout upstream of the North Area of the SPS. In blue and pink are existing facilities.

The target is designed to contain most of the cascade generated by the primary beam interaction. It is embedded in a massive iron shielding absorbing the remaining primary protons and produced hadrons emerging from the target. The hadron absorber is followed by an active muon shield and an experimental hall, which houses the SHiP detector.

As SHiP requires pushing the primary proton beam to a power of around 355 kW, radiation protection considerations strongly determine the design of the facility. In particular

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high prompt and residual dose rates call for considerable shielding and remote interventions in the target area. The risk and environmental impact from releases of radioactivity by air and water as well as the soil activation will also heavily influence the design. Studies include expected prompt and residual dose rates in the various accessible areas of SHiP as well as the levels of stray radiation in the surrounding areas.

The key beam parameters foreseen are shown in Table 1.

Table 1: Key Beam Parameters Foreseen for SHiP

Momentum [GeV/c]	400
Beam Intensity per cycle [10^{13}]	4.2
Cycle length [s]	7.2
Spill duration [s]	1
Expected r.m.s. spot size (H/V) [mm]	6/6
Avg. beam power on target [kW]	400
Avg. beam power on target during spill [kW]	2900
Protons on target (POT)/year	4×10^{19}
Total POT in 5 year's data taking	2×10^{20}

Beam Extraction Slow extraction from SPS is accomplished with a set of suitably located extraction sextupoles used to create a stable area in horizontal phase space. This initial phase space area is larger than the area occupied by the beam. A dedicated servo-quadrupole consisting of 4 short quadrupoles moves the tune towards a third-order tune resonance shrinking the stable phase space area. Protons with coordinates outside the stable area move away from the beam core along the outward going separatrices, and eventually cross the wires of the ZS septum into its high field region. The ZS deflects the particles into the magnetic elements of the extraction channel consisting of thin MST and thick MSE septum magnets, which move the beam into TT20 proper. Slow extraction from the SPS in LSS2 is routinely used in the SPS operation for supplying beam to the North Area. Reducing the spill length to 1 s with $\approx 4.2\times10^{13}$ extracted protons risks being limited by the performance of the ZS electrostatic septa, which are liable to experience increased sparking, vacuum pressure rise, damage of the wires through beam heating and also secondary effects like high voltage feed-through damage. Studies are ongoing to better understand these effects, for example the scaling of the wire heating with the proposed extraction. Machine development tests have been performed at the end of the 2015 to probe experimentally these limits, with increasing intensity extracted over 1 s to the North Area on the SHIP cycle. Further machine development studies and simulations will be executed in 2017/2018 to validate the requested performances. The performance of the ZS with these very high extracted beam intensities in a short spill is likely to be a key factor in the overall SHiP performance.

The activation of the extraction region and of the aperture limits in the ZS will increase in proportion to the total number of protons extracted per year and equipment activation and degradation (e.g. of cables) can be expected. More detailed estimates can be made on the basis of the expected extraction duty cycle and yearly load, together with the data from past operation. Ways to reduce the beam losses are actively being investigated, for instance improved instrumentation in the extraction regions and possible use of crystal assisted extraction.

Transport along TT20 The target location allows the re-use of about 600 m of the present TT20 transfer line, which has sufficient aperture for the slow-extracted beam at 400 GeV/c. The powering scheme for the line remains basically unchanged up to the switch element, but re-matching of the final section of the line will be needed to allow the beam to pass with very low losses through the switch aperture – one potential issue to check is whether the line optics can be changed on a cycle-to-cycle basis within a super-cycle, at least for the quadrupole elements concerned.

Switching from TT20 One of the main challenges of the North Area location of the BDF is the 400 GeV/c switch out of TT20 to the new beam line, due to the high beam rigidity and absence of space in the present beam line. An interesting suggestion is to replace the three existing splitter magnets with by a laminated version with negative polarity switching. This would provide an elegant way of switching without sacrificing the full slow spill to one of the existing North Area beam lines. With a two-polarity splitter magnet, an extra beam line to the BDF is made possible while maintaining compatibility with nominal North Area operation.

New beam line to target A maximum deflection angle to exit the TDC2 tunnel is beneficial to reduce the longitudinal extent of the civil engineering works in the crucial junction region. Overall, an angle of at least 80-100 mrad is needed with respect to TT20. The use of large 6.2 m long 2 Tesla bending magnets (MBB) will be required. The configuration under consideration at present foresees the use of 1+16 MBB magnets grouped into a single dipole as early as possible and then four "standard' half-cells" of 4 dipoles each. The transverse optics is being studied but is not expected to pose problems – the main issue is the acceptance for the beam as a large blow-up of the transverse beam size is needed at the target.

Beam dilution on target The maximum beam energy density on the target is an issue for the target design. A dilution system (circular beam, 50 mm radius, 8 mm 1s) will be required in order to sweep the beam onto the target, in order to reduce the thermal stresses to a reasonable level. With a 1 s long extraction spill, a pair of orthogonal conventional magnets with a fast Lissajous powering function could be foreseen to maximize the length of the sweep on the target block. With a drift of at least 150 m available before the target and a sweep radius tentatively fixed at 30 mm, a maximum deflection of only 0.2 mrad per plane is needed. A full optimization of the sweep is ongoing taking into account the possible magnet and powering characteristics, as well as the limitations of the target in terms of protons per mm^2.

Target and Target Complex

Target design The BDF production target is one of the most challenging aspects of the proposed installation, due to the very high energy and power density that will be reached during operation. The target is effectively to be considered as a beam dump, as it will contain most of the cascade generated by the primary beam interaction. In terms of average beam power delivered on target during the spill, the installation will be in a similar operational regime as of the Spallation Neutron Source at ORNL (US) or to the Material Life Sciences spallation source at J-PARC (Japan), despite both of them operating with a liquid mercury target. Contrary to other spallation sources, where for most of the cases the beam is CW, the SPS operational parameters dictate an extremely high pulse intensity, followed by a cooling down of several seconds. In the SHiP case, the cycle-averaged beam power delivered on target is around 355 kW. However, when averaged over the pulse duration of 1 second, this power increases up to 2.56 MW.

For the SHiP target case, we have proposed a hybrid solution composed of (solid) molybdenum alloy and pure tungsten, for a total target length of 116 cm. The material selection is based on the requirement of having a high-Z material with a short interaction length, in order to increase as much as possible the reabsorption of pions and kaons produced in the spallation process that would otherwise generate a background for the experiment. The core plates are 30x30 cm^2 in transverse size, with a variable length according to the longitudinal direction. The first 58 cm – divided in 13 layers – are made out of TZM ((0.08%)titanium-(0.50%)zirconium-molybdenum alloy) for a total nuclear inelastic scattering length (λ) of 4λ, while the remaining 58 cm are composed by 4 blocks of pure tungsten (yielding 6λ), for a total of almost 10λ. TZM is chosen as it is stronger than pure molybdenum and possesses a higher recrystallization temperature and better creep resistance than pure molybdenum; it is especially suited for high-temperature applications, involving demanding mechanical loads. Pure W is on the contrary selected for the second half of the target due to its superior performances with irradiation as compared to alloys such as Inermet or Densimet. Due to the high energy deposition and due to the high temperature reached during steady state operation, the target will have to be actively cooled.

Target and target complex The BDF project requires the realization of a new multipurpose target complex on the Prevessin area, capable of exchanging target and shielding configuration in case of future experiments. Two target complex design are being considered and studied in detail (crane or trolley). The production target is located in a shielded bunker, 10 m long, 8.5 m wide at a depth of around 12 m from the surface. A He-vessel containing high purity He gas encloses the production target and shielding to avoid NOx formation and avoid high-mass activation products. The complex will include a massive US1010 magnetized shielding, which will deflect the muons produced in the target just after escaping it.

The envisaged shielding configuration is such as to avoid radiation activation of the fixed concrete civil engineering structures, which would allow for a much easier change of scope of the installation (i.e. for new experiments) as well as for the dismantling phase.

A pressure cascade between the various compartments, from -60 Pa (with respect to the outside environment) of the target hall to roughly -200 Pa for the most exposed zones shall be foreseen, at least during beam operation. A recirculation system for the most radioactive zones (areas contiguous to the helium-vessel) should be foreseen to allow for the decay of short-lived isotopes before release into the environment. The air-tightness of the various areas will be a central part of the target station design and will be interlocked with beam operation.

CONCLUSION

An in-depth study of the proposed BDF at CERN's SPS is underway. It is a challenging project. Beam related concerns include beam loss at extraction from SPS and the potential high cumulative radiation doses. The main technical challenges in the beam transfer domain are the design and construction of a new splitter/switch magnet, which is likely to require a longer lead-time than a 'normal' design of warm magnet, and the achievable performance of the ZS septum with the high extracted beam intensity, linked to the activation of the extraction region. The design of the dilution system will require some care in the magnet and powering choice, but the difficulty is reduced by the small kick strengths needed. Overall, and despite these interesting challenges, the beam transfer aspects appear feasible.

The target design must deal with high pulsed power and be designed for longevity and reliability. The target complex design must include consideration of handling and maintainability, and fully comply with the strictures of demanded by personnel and environmental protection considerations which have to take into account the close distance to the CERN site boundary. Serious in-depth studies are ongoing.

The project team aims to produce a conceptual design study by end 2018 to accompanied the SHiP proposal to be considered in the next update of the ESPP.

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