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SHiP: a new facility with a dedicated detector to search for new long-lived neutral particles

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The Search for Hidden Particles experiment (SHiP) is a new general purpose fixed target facility, whose Technical Proposal has been recently reviewed by the CERN SPS Committee and by the CERN Research Board. The two boards recommended that the experiment proceeds further to a Comprehensive Design phase in the context of the new CERN Working group "Physics Beyond Colliders", aiming at presenting a CERN strategy for the European Strategy meeting of 2019. In its initial phase, the 400GeV proton beam extracted from the SPS will be dumped on a heavy target with the aim of integrating $2 \cdot 10^{20}$ pot in 5 years. A dedicated detector, based on a long vacuum tank followed by a spectrometer and particle identification detectors, will allow probing a variety of models with light long-lived exotic particles and masses below O(10) GeV /c^2. The main focus will be the physics of the so-called hidden portals, i.e. search for dark photons, light scalars, pseudo-scalars, and heavy neutrinos. The sensitivity to heavy neutrinos will allow for the first time to probe, the mass range between the kaon and the charm meson mass, a coupling range for which baryogenesis and active neutrino masses could also be explained. Another dedicated emulsion-based detector will allow detection of light dark matter from dark photon decay in an unexplored parameter range.

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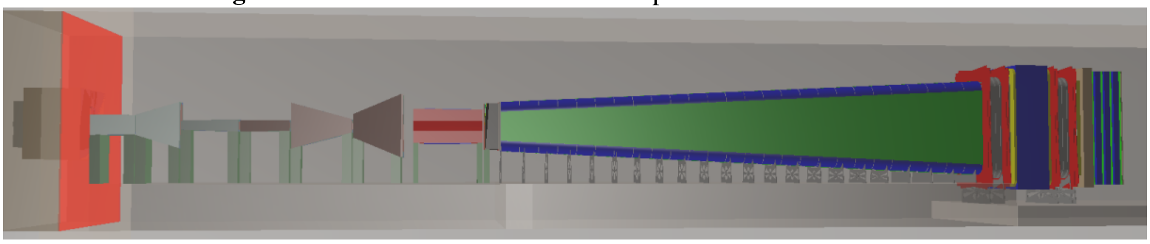
Despite the successful confirmation of the all standard model (SM) predictions with the Higgs boson discovery [1, 2], there are still unexplained phenomena which cannot be described by SM. Among those is the observation of a non-zero neutrino mass, not predicted by the SM [3], the baryon asymmetry in the universe [4], and the existing of dark matter and dark energy. Although there is clear cosmological evidence of the existence of new physics, we haven't observed traces of it either direct or indirect searches. There are two regions of parameter space where new particles can reside. One is in the region of high-energies and is mainly explored by experiments at the LHC. The other is in the region of high-intensities and can be probed by maximising interaction rates.

Figure 1: Geometric view of the SHiP experiment from simulations.



The recently proposed Search for Hidden Particles (SHiP) experiment is dedicated to searching for new physics in the largely unexplored domain of very weakly interacting particles with masses below $O(10)$ GeV/c^2 and decay lengths of tens of meters [5]. The geometric configuration of the experiment is shown in Figure 1. The SHiP experimental setup is a general purpose fixed target facility at the CERN Super Proton Synchrotron (SPS) accelerator [6]. As new physics particles are prevalently expected to be found in heavy hadrons decays by most theories, the experiment was designed to maximise their production, keeping the lowest possible background level. It can be achieved by delivering of $2 \cdot 10^{13}$ protons on target per second with a momentum of 400 GeV/c extracted from the SPS on a molybdenum-tungsten target. A heavy thick target helps to absorb all SM particles and boost charm and beauty hadron production. To absorb the remaining hadrons, the target will be followed by a 5 m thick iron shielding.

Along with a high production rate of heavy hadrons, a level of muons of $10^{11}/s$ is expected. These muons can provide a source of background, and hence their flux has to be reduced by several orders of magnitude over the shortest possible distance to achieve the largest possible acceptance for new physics particles. For these purposes, SHiP is using a magnetic deflecting system which consists of a set of different polarities magnets to sweep away produced in the target muons from the detector acceptance [7].

The experimental facility is also ideally suited for studying interactions of the least well known τ-neutrino. There will therefore be an emulsion target downstream of the muon shield with a maximum acceptable charged particle flux of $10^3/mm^2$ for an exposure based on the emulsion cloud concept developed in OPERA and a muon spectrometer.

The hidden sector detector starts with a 50 m long decay volume maintained at a pressure of $O(10^{-3})$ bar in order to suppress a background induced by the inelastic neutrino interaction in the fiducial volume. This background is especially dangerous as it can mimic a signal in the following tracking stations. Therefore, the spectrometer is designed in the way to be able to reconstruct with a high precision the decay vertex, the mass and the impact parameter with respect to the target. The decay volume is surrounded by scintillator detectors to keep under control any charged particles which enter or exit the fiducial volume. Particle identification is provided by a set of calorimeters and muon stations. A timing detector with a resolution less than 100 ps ensures a rejection of the combinatorial background by coincidence timing requirement.

In the simulation, fixed target collisions of protons are generated by PYTHIA8 [8], neutrino interactions by GENIE [9] and inelastic muon interactions by PYTHIA6 [10]. The heavy flavour production in cascade interactions is also taken into account [11]. The SHiP detector response is simulated in the GEANT4 [12] framework. All the simulation is performed within the Fair-Root [13] framework. Detailed simulation studies showed that we can expect zero background level, keeping a high signal efficiency.

SHiP will be able to probe a wide range of new physics theories such as heavy neutral leptons, dark photons, axion-like particles in unexplored parameter space. This is achieved by keeping combinatorial,deep-inelastic scattering, neutrino and cosmic backgrounds at the zero level. These together will make SHiP a world leading experimental facility to probe physics at the intensity frontier which is complementary to searches for new physics at the energy frontier.

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