The SHiP (Search for Hidden Particles) proposal

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SHiP is a new general purpose fixed target facility [1] at the CERN SPS. The 400 GeV proton beam from the SPS will be dumped on a heavy target, integrating 2×10^{20} POT (Protons On Target) in 5 years. The detector will probe models with light long-lived exotic particles and masses below $\mathcal{O}(10)$ GeV/c^2. The sensitivity to Heavy Neutrinos will allow probing the mass range between the kaon and the charm meson mass. Another, emulsion based, detector will measure the ν_τ deep inelastic scattering cross sections. Recoiling electrons will allow the direct detection of light dark matter.

1 The objective of SHiP

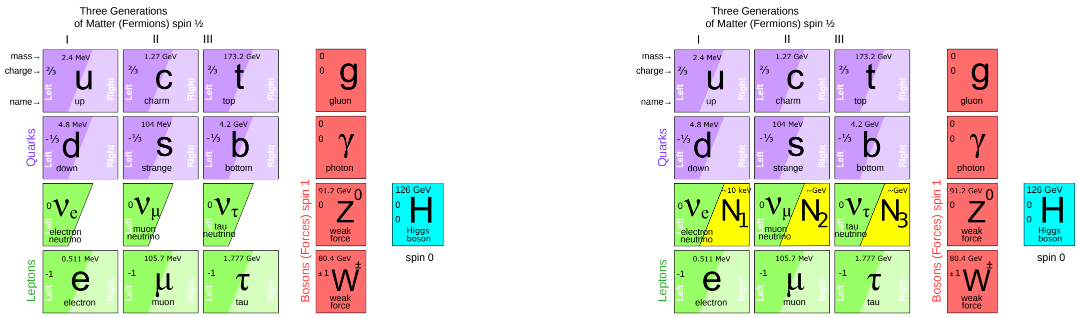
Despite intensive searches at the LHC and elsewhere, no significant deviations from the Standard Model of particle physics have been found. However, a number of experimental facts cannot be explained by the Standard Model, such as: neutrino masses and oscillations, dark matter, inflation and the baryonic asymmetry of the universe (BAU). Many theoretical models explain these facts by introducing very weakly interacting new particles with masses up to a few GeV/c^2. SHiP will try to find experimental support for some of these models.

2 Extensions of the Standard Model

It is possible that the particles responsible for the BSM problems have not been observed due to their extremely feeble interactions, rather than their heavy masses. Even in the scenarios in which BSM physics is related to high-mass scales, many models contain degrees of freedom with suppressed couplings that stay relevant at much lower energies.

2.1 Portals

It could be that some of the new particles do not interact directly with the SM sector. These "hidden sectors" may nevertheless be accessible thourgh sufficiently light particles ("mediators"), which are coupled to SM particles via renormalizable interactions with small dimensionless coupling constants ("portals"). There are 3 types of portal, depending on the mass dimension of the SM singlet operator: vector (dark photons), scalar (hidden scalars) and neutrino (HNLs). The production branching ratios of hidden sector particles are $\mathcal{O}(10^{-10})$, with c$\tau \sim \mathcal{O}$(km) and they would travel unperturbed through matter.

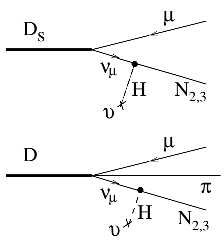


(a) The Standard Model (b) νMSM

Figure 1: Adding three right handed Majorana HNLs to the Standard Model

2.2 The ν Minimal Standard Model (νMSM)

Many current observations can be explained by a minimal extension of the Standard Model: the addition of three right-handed heavy neutral leptons (HNLs) (see Figure 2.2, [2]). A light $\mathcal{O}(1\,keV)$ N_1 serves as dark matter candidate, mass-degenerate $\mathcal{O}(100\ \mathrm{MeV/c^2}$ – few $\mathrm{GeV/c^2})$ $\mathrm{N}_{2,3}$ give mass to the active neutrinos via the see-saw mechanism, and $N_{2,3}$ account for leptogenesis and hence explain baryogenesis by increased CP violation. In the νMSM, HNL production takes place in semi-leptonic decays from charm ($M_{HNL} < 2\ \mathrm{GeV/c^2}$) and beauty ($M_{HNL} < 5\ \mathrm{GeV/c^2}$), see Figure 2(a). Some examples of HNL decays into SM particles are shown in Figure 2(c) and branching ratios in Figure 2(b)(see [3]).

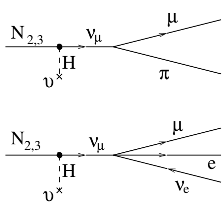


(a) HNL production

$$\mathrm{Br}(D \to\ HNL\ X \sim 10^{-8} - 10^{-12})$$
$$\mathrm{Br}(B \to\ HNL\ X \sim 10^{-12} - 10^{-16})$$

$$\mathrm{Br}(HNL \to \mu(e)\pi) \sim 0.1 - 50\%$$
$$\mathrm{Br}(HNL \to \mu(e)\rho) \sim 0.5 - 20\%$$
$$\mathrm{Br}(HNL \to \mu(e)\nu_e) \sim 1 - 10\%$$

(b) HNL production/decay BRs



(c) HNL decays

Figure 2: HNL production from charm/beauty (a) and HNL decays (c)

3 Experimental requirements and detector design

Because the hidden particles are expected to be predominantly accessible through the decays of heavy hadrons, the facility is designed to maximise their production and detector acceptance. With 2×10^{20} POT, the charm production at the SPS exceeds any existing facility. The hidden particles having a significant p_T, the detector should be placed close to the target (see Figure 3). A critical component of SHiP is the muon shield, which deflects the high flux of muon background away from the detector. The detector is designed to reject the background

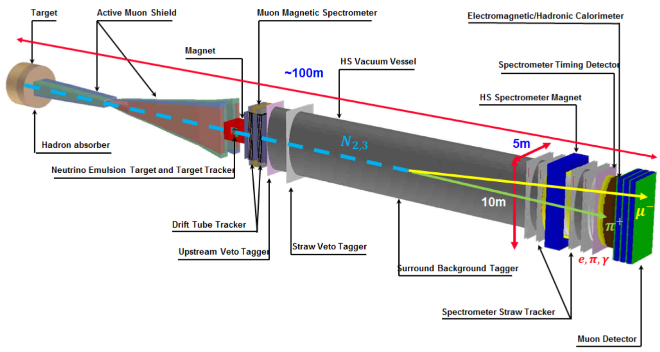
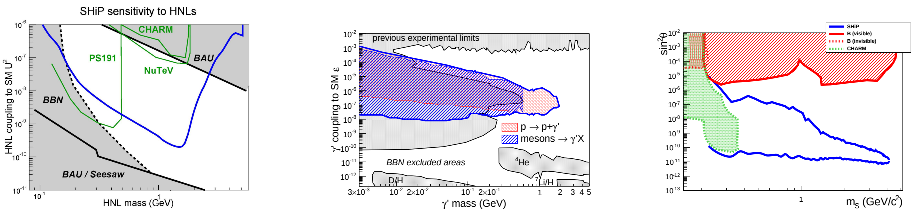


Figure 3: The SHiP detector



(a) HNL

(b) Dark photon

(c) Hidden scalars

Figure 4: SHiP sensitivities (blue) compared to theoretical and experimental limits

down to below 0.1 events in the sample of 2×10^{20} POT.

A large magnetic spectrometer is located downstream of a 50 m-long and 5×10 m-wide decay volume. To suppress the background from neutrino interactions, the decay volume is maintained under vacuum. The spectrometer is designed to accurately reconstruct the decay vertex, mass and impact parameter of the decaying particle at the target. Calorimeters followed by muon chambers identify electrons, photons, muons and charged hadrons. A high-resolution timing detector measures the coincidence of the decay products to reject combinatorial backgrounds.

The decay volume is surrounded by background taggers to detect neutrino and muon inelastic scattering in the surrounding structures, which may produce long-lived SM V^0 particles such as K_L, etc. The experimental facility also hosts a compact emulsion spectrometer based on the Opera [4] concept, upstream of the hidden-particle decay volume.

4 Sensitivities

The sensitivities of SHiP to HNL, dark photon and hidden scalars are shown in Figure 4. From these figures it can be seen that SHiP probes a unique range of couplings and masses.

5 Neutrino physics and light dark matter detection

Over 5 years of running $5.7 \times 10^{15} \nu_\tau$ and $\bar{\nu_\tau}$ candidates via $pN \to XD_s(\to \tau\nu_\tau)$ are expected. With these fluxes we expect $\sim 10^4(10^3)\nu_\tau(\bar{\nu_\tau})$, $\sim 10^5\nu_e(\bar{\nu}_e)$ and $\sim 10^6\nu_\mu(\bar{\nu_\mu})$ interactions. This will enable the first direct observation of $\bar{\nu_\tau}$, the first independent measurement of σ_{ν_τ} and $\sigma_{\bar{\nu_\tau}}$ cross-sections.

The emulsion spectrometer can be transformed into a light dark matter emulsion calorimeter to detect electron recoils. For this, the emulsion is interleaved with heavy absorber strips. By reconstructing the electron direction and energy one can distinguish LDM- from ν-scattering.

6 Status of the project

The SPSC has positively reviewed the Technical Proposal [1] and the CERN Research Board has recommended SHiP to proceed with a Comprehensive Design Study. A report will be given to the Physics Beyond Colliders working group so that it can provide input to the next European Strategy Group.

During the Comprehensive Design phase the layout of the experimental facility and the geometry of the detectors will be further optimized. This involves a detailed study of the muon-shield magnets and the decay volume. A measurement of the μ-flux coming from a replica SHiP target is planned at the SPS in 2018 [5]. It also comprises revisiting the neutrino background in the fiducial volume, together with the background detectors, to decide on the required type of technology for evacuating the decay volume.

The SHiP collaboration currently consists of over 250 members from 49 institutes in 17 countries. The SHiP physics case was demonstrated to be very strong by a collaboration of more than 80 theorists in the SHiP Physics Proposal [6].

7 Conclusions

The intensity frontier greatly complements the search for new physics at the LHC. Major improvements and new results are expected during the next decade in neutrino and flavour physics, proton-decay experiments and measurements of the electric dipole moments. CERN will be well-positioned to make a unique contribution to exploration of the hidden-particle sector with the SHiP experiment at the SPS.

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