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The SHiP experiment

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Summary. — SHiP is a fixed-target experiment whose Technical Proposal has been recently submitted to the CERN SPS committee. A 400 GeV proton beam, extracted from the SPS, would be dumped on a heavy target, integrating 2×10^{20} pot in 5 years of data taking. The physics aim of the experiment is twofold: to probe different models with exotic long-lived particles (heavy neutral leptons and dark photons for instance) and to improve the knowledge about tau neutrino (the less known Standard Model particle) physics. In this contribution, a brief description of the SHiP experiment and its physics discovery potential are reported.

1. – Introduction

The Standard Model (SM) provides a consistent description of the fundamental constituents of the Nature and of their interactions. Its predictions have been tested by a large number of experiments that culminated with the discovery of the Higgs boson [1, 2]. No direct or indirect evidence for new physics has been found so far, even if the Standard Model is not the ultimate theory, since it does not explain a certain number of observed phenomena: neutrino masses and oscillations, Baryon Asymmetry of the Universe (BAU) and Dark Matter (DM). New Physics can be investigated with accelerators either increasing collision energies ("energy frontier") or statistics ("intensity frontier"), aiming at the discovery of new particles with heavy masses or with small couplings to ordinary SM particles, respectively. Extensions of the Standard Model in the low-mass region foresee the existence of particles as singlets with respect to the SM gauge group. These particles couple to different singlet composite operators (so-called Portals) of the SM.

SHiP (Search for Hidden Particles [3, 4]) is a beam dump experiment recently proposed at the CERN SPS committee. Exploiting a 400 GeV/c proton beam extracted from the Super-Proto-Synchrotron (SPS), it is designed to explore the so-called "hidden

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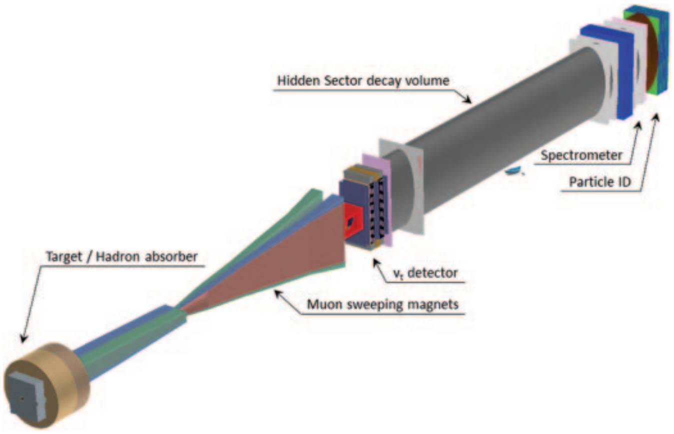


Fig. 1. – Layout of the SHiP facility. See text for the description.

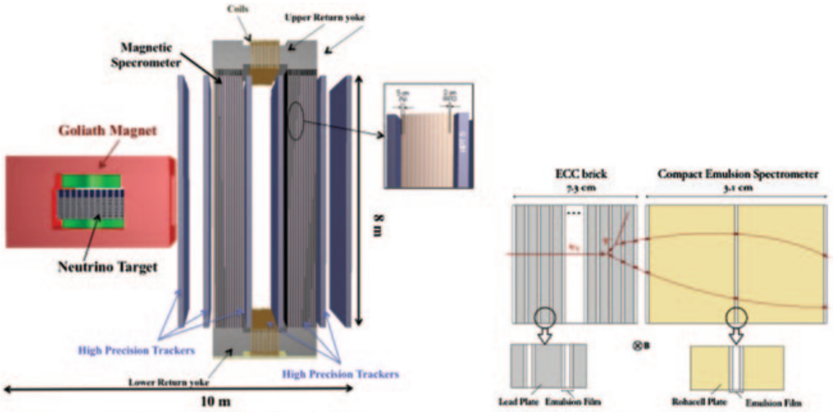
sector", looking for particles foreseen in new theories beyond the Standard Model, such as dark photons, scalar singlets, heavy neutral leptons and axions. With the proton energy enhancing the production of charmed mesons, and in particular D_s mesons, a high flux of ν_τ and anti-ν_τ is expected. The facility, if endowed with a neutrino detector, could be therefore used to study the physics of ν_τ, the less known SM particle (so far only a few have been observed by the Donut [5] and the OPERA [6] experiments) and of charm production by ν_e and ν_μ interactions with the target.

2. – Experiment description

The SHiP facility is composed of the target region, the neutrino detector and the hidden sector detector. A sketch of the layout is shown in fig. 1. More details can be found in [3].

2˙1. *Target section.* – In the SHiP beam dump facility, a 400 GeV/c proton beam is extracted from SPS in spills of 1 s and directed into a water-cooled target, made by four interaction lengths of titanium-zirconium–doped molybdenum (TZM) alloy (58 cm) followed by six interaction lengths of pure tungsten (58 cm). To maximize the production of heavy mesons and minimize the production of neutrinos and muons, the target is designed to contain the proton shower. The peak (average) beam power during the spill (SPS cycle) amounts to 2.56 MW (350 kW). The target is followed by a hadron absorber and by a muon sweeping magnet to reduce the muon flux on the neutrino detector in a region as large as 5 m wide horizontally. The slow extraction (1 s) of the beam from the SPS is motivated by minimizing the combinatorial background from the residual muons that reach the experimental area. The physics reach of the experiment, described in details in [4], has been studied assuming a total number of 2×10^{20} proton-on-target (pot), reachable in five years of operation.

2˙2. *Neutrino detector.* – The neutrino detector, shown in fig. 2(a), is located downstream of the muon sweeping magnet and it is a modular target, whose basic unit is made of an Emulsion Cloud Chamber (ECC) brick and of a Compact Emulsion Spectrometer (CES), as shown in fig. 2(b). The brick is made, like in OPERA, by 56 lead



(a) *Layout of the neutrino detector.*

(b) ***Schematic representation of the neutrino detector unitary cell.***

Fig. 2. – Layout of the SHiP neutrino detector (a) and of its basic cell (b).

sheets, 1 mm thick, alternated to 57 nuclear emulsion layers. The lead is the target for neutrino interactions, while the emulsions are used as tracking devices with micro-metric precision, allowing to identify and reconstruct τ lepton decays, as done in OPERA [6]. More technical details about ECC bricks can be found in [7].

The measurement of the charge of the particles produced in τ decays is performed, for muons and hadrons, by a CES located downstream of the brick. It is made of a sandwich of light material plates (Rohacell) and emulsion films for a total length of 3.1 cm. In a magnetic field of 1 T, it is designed to reconstruct the particle momentum with a resolution better than 20% below 12 GeV.

The target consists of more than one thousand units, for a total mass of about 9.6 t. It is complemented by planes of electronic detectors to provide the time-stamp of the event and to link the muon tracks in the target with the magnetic spectrometer. Different options are open for the electronic tracker: scintillating fibres, MicroMegas and r-wells. A precision of 100 μm is required.

Finally a muon spectrometer with an iron dipolar magnet is used to maximize muon identification probability and measuring the momentum also for large angle tracks. The main background for the detection of ν_τ Charged Current (CC) interactions is indeed given by charmed hadrons production in ν_μ CC events, when the muon produced in the CC interaction is not detected.

2˙3. *Hidden sector detector*. – The Hidden Sector detector is designed to look for evidence of new particles decaying in a single large volume. A layout of the detector, located downstream of the neutrino one, is shown in fig. 3. The guiding lines for its design are the identification of the particles in the final state of the decays and the background suppression to less than 1 event over the full data-taking period.

The decay volume is defined by a vacuum vessel with an elliptical cross-section of 5 m width by 10 m height. The length of the tube is 62 m, consisting of 50 m of fiducial decay volume and a 12 m long magnetic spectrometer instrumented with straw tubes. In order to reduce the background due to neutrino interactions, a vacuum level of 10^{-6} bar is needed. The vessel itself will be instrumented with a background tagger, the external

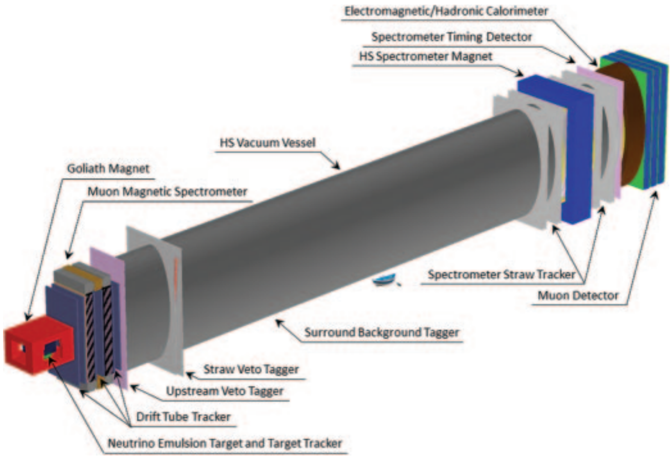


Fig. 3. – Layout of the SHiP detectors. The Hidden sector detector is visible downstream of the neutrino detector.

surface of the tube being instrumented with 30 cm thick liquid scintillator units. An upstream veto tagger, made by wall of plastic scintillator bars, will be used to identify events with kaon production in neutrino interactions happening in the last layers of the neutrino detector muon spectrometer. Background originating in the entrance window of the vacuum vessel is tagged by a straw veto tagger, located in vacuum 5 m downstream.

Outside of the vacuum vessel, a timing detector with a 100 ps time resolution will be used to reduce random association of two muons. Two technologies are under consideration: plastic scintillator bars or multi-gap resistive plate chambers. The electromagnetic calorimeter, followed by the hadronic calorimeter, made both by a Shashlik structure of interlaced lead and plastic scintillator planes, will be used for particle identification purposes. Finally a muon detector composed by four stations of extruded plastic scintillator strips readout by wavelength-shifting fibres, separated by three iron muon filters, will be used to identify muons.

3. – Physics reach

The physics case of SHiP has been extensively studied in [4], both for theories beyond the Standard Model and for neutrino physics.

As examples, in fig. 4 the sensitivity is shown for the Heavy Neutral Lepton (neutrino portal) and for the dark photon (vector portal). Heavy Neutral Leptons (HNL) are sterile and massive right-handed neutrinos, introduced to explain neutrino masses in the see-saw mechanism. In the νMSM model [8], three HNL are introduced with masses below m_W. They couple to standard neutrinos through the Higgs boson and in the SHiP facility are produced in semi-leptonic decays of mesons produced by proton interactions in the target. Dark photons are gauge bosons of a minimalistic New Physics model, with a broken $U(1)^{'}$ symmetry in the dark sector, that couple to the SM photon.

The SHiP facility is also a copious factory of charmed particles. With 2×10^{20} pot and a lead target mass of 9.6 t, the detection of about 1700 ν_τ and 900 anti-ν_τ is expected, mainly from D_s decays, allowing, for the first time, the detection of anti-ν_τ and the measurement of the CC cross sections. Such a large sample of events will bring

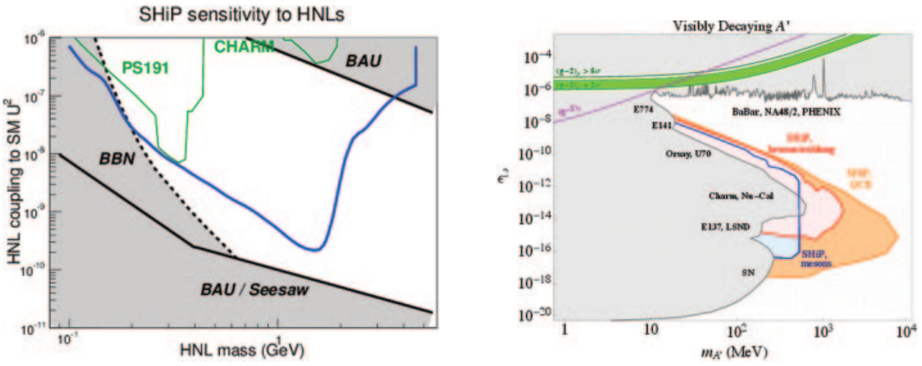


Fig. 4. – Left: SHiP discovery potential in the parameter space of the νMSM model in case of electron neutrino coupling dominance and inverse hierarchy of the three standard neutrino masses; limits from cosmology and Big Bang Nucleosynthesis are also drawn. Right: SHiP sensitivity to Dark Photons.

opportunities to measure the five Deep Inelastic Scattering (DIS) structure functions, $F_1(x)$.....$F_5(x)$. The additional structure functions $F_4(x)$ and $F_5(x)$ are unobservable for neutrinos of other flavours since, in the differential CC cross section, their effect is mitigated by a power of the charged leptonic partner mass.

It would be also possible to measure with unprecedented precision, using the ECC technique, the charmed particle production rate in ν_μ CC interaction. About 2×10^6 ν_μ CC interactions are indeed expected with about 10^5 charm candidates. Charm production in neutrino scattering is extremely sensible to the strange quark content of the nucleon, especially for anti-neutrinos. SHiP will improve significantly the uncertainty on the strange quark distribution in the nucleon for x values between 0.03 and 0.35.

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