11 The SHIP Experiment

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Two of the main reasons not to consider the Standard Model (SM) a complete theory of fundamental interactions are the existence of dark matter and the baryon-antibaryon asymmetry in the universe. However, the only direct evidence of physics beyond the SM is the violation of lepton flavour in the neutrino sector observed in neutrino oscillations [1]. Intriguingly, models with right-handed majorana neutrinos or heavy neutral leptons (HNLs) can give a simultaneous explanation to neutrino masses and mixings, baryon-antibaryon asymmetry and dark matter. The most promising of these models is the ν Minimal Standard Model (νMSM). In this model the lightest of these neutrinos (N_1), has a mass in the keV region and it is sufficiently stable to play the role of dark matter. The other two neutrinos ($N_{2,3}$) are almost degenerate in mass, have a mass in the GeV region and are responsible for neutrino oscillations and baryon-antibaryon asymmetry in the universe.

The search for these particles is experimentally very challenging since they couple very weakly to SM particles and have a long lifetime. Searches for these particles have been performed in the past but present constraints are mostly outside the cosmologically interesting region where baryogenesis, dark matter and neutrino oscillations can be simultaneously explained. Fig. 11.1 shows constraints on the $N_{2,3}$ mass and the mixing of HNLs with the muon neutrinos U_μ^2.

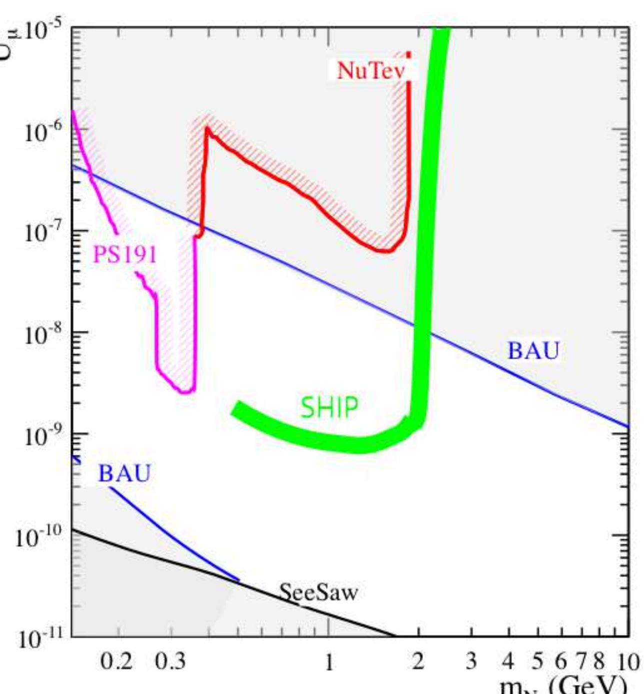

FIG. 11.1 – Experimental and theoretical constraints on the νMSM as a function of the mass of $N_{2,3}$ and their mixing with ν_μ. The SHIP sensitivity is indicated.

HNLs can be produced in (semi)-leptonic decays of mesons, by mixing with active SM neutrinos. Recently, a new fixed target experiment (SHIP) was proposed at SPS of CERN to search for HNLs. The SHIP experiment will probe the high intensity frontier, i.e. extensions of the SM with weakly coupled long lived particles, and is complementary to the high energy frontier explored by large general purpose detectors. The Expression Of Interest of the SHIP experiment [2] was submitted to the SPS committee (SPSC) in October 2013. The SPSC recognized the scientific value of the proposal and encouraged the preparation of a Technical Proposal for the experiment. A preliminary design of the SHIP experiment is shown in Fig. 11.2.

The 400 GeV proton beam of the SPS will be dumped into a heavy target. A hadron absorber will be placed behind the target to stop secondary pions and kaons before they decay (semi)leptonically, so that only muons survive after the absorber. In order to reduce the muon flux to an acceptable level, a 50 m muon shield consisting of heavy material (either Tungsten or Uranium) is proposed. Following the muon shield there is a 2×50 m long, 5 m diameter vacuum tank. This tank is used as a fiducial decay volume, i.e. only decays within this volume will be considered for the analysis. The pressure inside the vacuum tank is about 10^{-2}mbar, which reduces the background due to neutrino interactions with the air in the decay volume to a negligible level. The detector itself consists of two identical elements placed inside the vacuum tank. They are composed of a veto system, four tracking stations, a dipole magnet, a calorimeter and a muon detector (see Fig. 11.2). N. Serra performed the necessary MC studies of the experimental sensitivity and was strongly involved in the optimization of the detector concept. The expected sensitivity to HNLs for muonic decays is shown in Fig. 11.1. The SHIP experiment will offer the possibility to search for HNLs in the cosmologically most interesting region, improving by several orders of magnitude present sensitivities. In addition to models with HNLs,

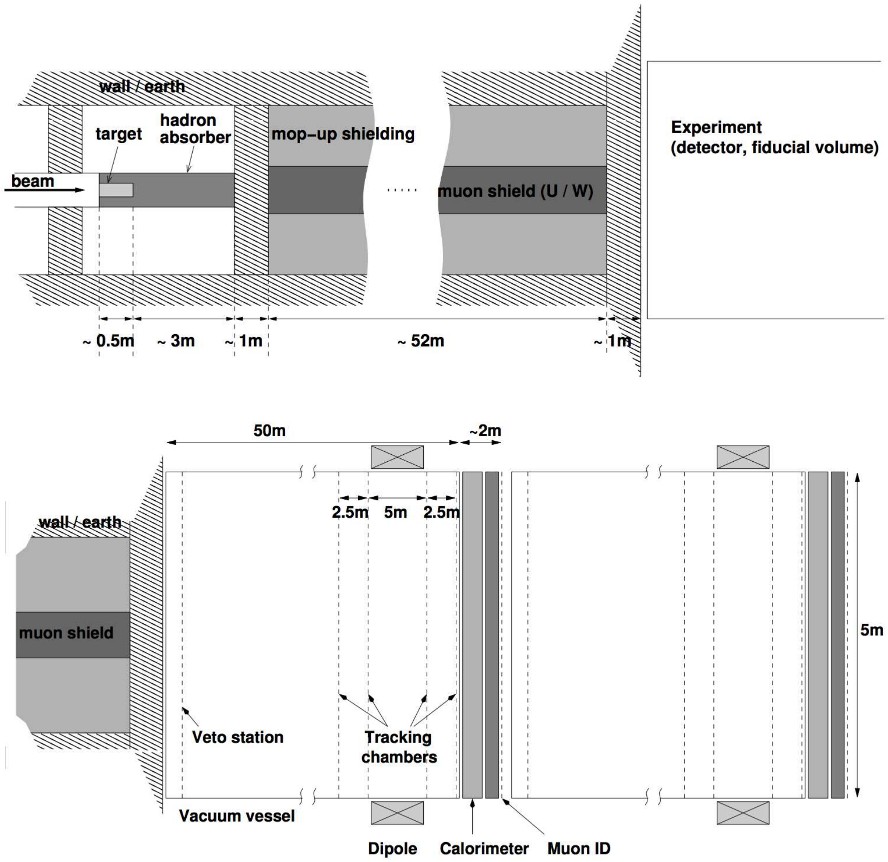

FIG. 11.2 – Schematic view of the target, hadron absorber and muon shield (top). Fiducial decay volume and the SHIP detector (bottom).

there are several other models that predict the existence of long lived hidden particles, the so called secluded sector [3]. The secluded sector interacts with the SM via portals, which are renormalizable interactions between the SM fields and hypothetical SM-singlets. Given the small couplings and the long lifetime of such particles, high statistics and large detectors are needed to discover these particles directly.

An incomplete list of models for which the SHIP experiment can probe a region of the parameter space challenging or not accessible by other experiments follows:

- Light sgoldstinos as SUSY partners of the goldstino, axion- and dilaton-like particles in SUSY extensions of the SM (see for instance [4])

- Light R-parity violating neutralinos in SUSY may be produced in decays such as $D \to \ell\chi$, and then decay into three-body final states, e.g. $\chi \to \ell^+\ell^-$.

- Light (axial) vectors in secluded Dark Matter models, as for instance massive paraphotons from a hidden sector [3]. They may be produced in heavy hadron decays like $\Sigma \to pV$ and decay into pairs of SM particles, e.g. $V \to \ell^+\ell^-$.

[1] Super-Kamiokande Collab., S. Fukuda *et al.*, Phys. Lett. B 539 (2002) 179.

[2] W. Bonivento *et al.*, arXiv:1310.1762, submitted to the SPSC.

[3] M. Pospelov, A. Ritz and M. B. Voloshin, Phys. Lett. B 662 (2008) 53.

[4] D. Gorbunov, Nucl. Phys. B 602 (2001) 213.