PROCEEDINGS OF SCIENCE

# Neutrino physics with the SHiP experiment at CERN

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**On behalf of the SHiP Collaboration**

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 400 GeV proton beam extracted from the SPS will be dumped on a heavy target with the aim of integrating $2 \times 10^{20}$ pot in 5 years. A dedicated detector will allow the study of neutrino cross-sections and angular distributions. $\nu_\tau$ deep inelastic scattering cross sections will be measured with a statistics 1000 times larger than currently available, with the extraction of the F4 and F5 structure functions, never measured so far and allow for new tests of lepton non-universality with sensitivity to BSM physics.

*The 39th International Conference on High Energy Physics (ICHEP2018)*
*4-11 July, 2018*
*Seoul, Korea*

*Speaker.





PoS(ICHEP2018)335

## 1. Introduction

The SHiP (Search for Hidden Particles) [1, 2] is a new intensity-frontier fixed target experiment designed to explore the unexplored parameter space of superweak coupling down to $10^{-10}$ by searching for hidden particles. The hidden particles have been predicted in a large number of recently elaborated models of hidden sectors beyond the Standard Model. These particles are very weakly interacting long-lived neutral particles whose mass ranges are from sub-GeV up to $O(10)$ GeV. Using 400 GeV CERN SPS proton beam, the SHiP plans to produce the hidden particles from decays of charm and beauty mesons, and also study the unknown physical properties of tau neutrinos and anti-tau neutrinos.

## 2. Physics motivation

Recently, a various kind of hidden sector theories [2] has tried to explain the mysteries beyond the Standard Model, such as the Baryon asymmetry of the Universe (BAU), Dark matter (DM), and neutrino mass. Many hidden sector models often include the hidden particles with low mass around GeV scale. Typical aspects of the these particles have superweak couplings and thus have long lifetimes. Since no new physics was discovered at LHC yet, it is possible that we have not observed these particles due to their extremely feeble interactions, rather than due to their heavy masses. Therefore we need to pursue the intensitiy frontier, along with the energy frontier.

There are several potals towards the hidden sector, such as Neutrino, Scalar, Vector and Axion portals. In case of Neutrino portal, the $\nu$MSM (Neutrino Minimal Standard Model) which is the extension of the Standard Model by adding right-handed neutrinos with masses below the electroweak scale was proposed. These neutrinos are called Heavy Neutral Leptons (HNLs). Amomg 3 HNLs, the lightest HNL could be the DM particle and the other two HNLs which have masses in the GeV range can explain BAU and neutrino mass [2].

## 3. Experimental setup and method

### 3.1 Hidden particle detection

The hidden particle detector is designed to search in particular for very weakly interacting long-lived particles. It consists of Vacuum vessel which is a long (∼50 m) evacuated decay volume, Calorimeters and Muon detectors with a magnet at the far end [1], as shown in Figure 1. This allows full reconstruction and particle identication of hidden particle decays. For HNL detection, the main experimental signature involves two charged decay tracks ($HNL \to \pi\mu$).

The target is TZM(Titanium-Zirconium doped Molybdenum alloy) followed by layers of pure Tungsten. Behind the target, Hadron absorber and Active muon shield are located in order to reject 2ry hadrons and muon tracks. The hidden particles would be produced in a proton beam dump at high intensity 400 GeV from decay of charm or beauty particles.

With an integrated total of $2 \times 10^{20}$ pot (protons on target) in 5 years run, the SHiP experiment can achieve sensitivity for HNL up to 3 orders of magnitute better than previous searches [3], accessing a significant fraction of the unexplored parameter space mostly consistent with the cosmological allowed region.



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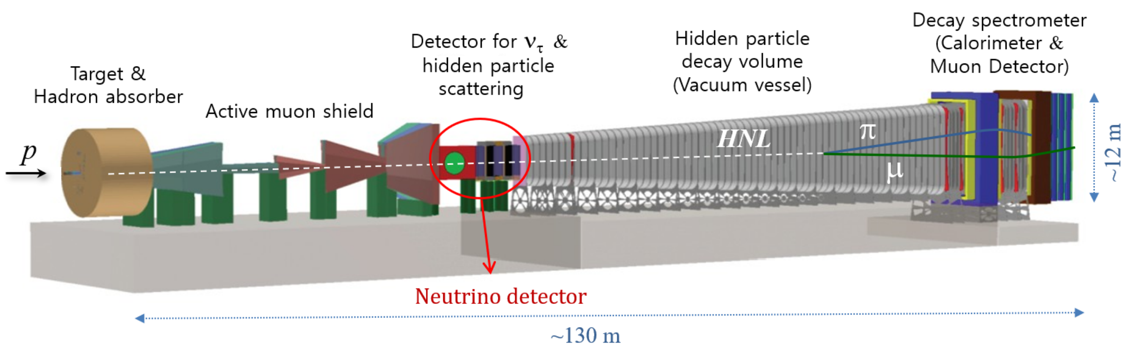


**Figure 1:** The SHiP detector

### 3.2 $\nu_\tau$ detection

The $\nu_\tau$ is the least known particle in the Standard Model. The neutrino detector is placed in front of the Vacuum vessel which is a hidden particle decay volume as shown in Figure 1. We use the OPERA-like ECC (Emulsion Cloud Chamber) as both target and detector for $\nu_\tau$ detection. The ECC target has a sandwich structure of emulsion films and lead plates. It can play roles in 3D image detector, tracker and calorimeter. The ECC has micrometric accuracy for $\tau$ lepton identification ($c\tau \sim 87\mu$m) and has been proven a suitable $\nu_\tau$ detector. Target tracker attached behind the ECC can provide information on the precise positions and angles of outgoing tracks. The ECC, Target tracker and CES (Compact Emulsion Spectrometer) will be surrounded by a magnetic field as shown in Figure 2.

At the energy of the SPS, the fully leptonic decays of the $D_s$ mesons are the principal source of $\nu_\tau$. The number of the observed $\nu_\tau$ so far is 19 events, where 9 events from DONuT and 10 events from OPERA experiment. But $\bar{\nu}_\tau$ has not yet been detected. The charge determination of decay products of $\tau$ lepton is essential to separate $\nu_\tau$ and $\bar{\nu}_\tau$. The charge can be measured by curvature of the $\tau$ decay track such as $\mu$ under magnetic field using the CES and the Muon filter (Figure 2). We use RPC as Muon filter.

With a 10 tonne ECC target, about 6200 $\nu_\tau$ and 4700 $\bar{\nu}_\tau$ signal events are expected to be observed with an integrated $2 \times 10^{20}$ pot in 5 years. 1200, 4000, and 1000 $\nu_\tau$ (1000, 3000, and 700 $\bar{\nu}_\tau$) events are expected for the decay channels of $\tau \to \mu, \tau \to h$, and $\tau \to 3h$, respectively. The $\tau \to e$ decay channel is currently not considered for the discrimination of $\nu_\tau$ and $\bar{\nu}_\tau$. Since the cross section of $\nu_\tau$ is slightly larger than that of $\bar{\nu}_\tau$ theoretically, the expected numbers are different accordingly. In this experiment, $\bar{\nu}_\tau$ can be directly observed for the first time.

The cross section and magnetic moments of $\nu_\tau$ and $\bar{\nu}_\tau$ will be measured. And the proton structure functions F4 and F5, which can be derived only from $\nu_\tau$ and $\bar{\nu}_\tau$ cross section measurements, will be extracted. As charmed hadron decays are also a source of $\nu_e$ and $\nu_\mu$, the SHiP will be able to study neutrino-induced charm production from all flavours with a dataset which is more than one order of magnitude larger than those collected by previous experiments.

In addition, this neutrino detector can be used for search for light DM through the scattering off the atomic electrons of its lead-emulsion target. At beam dump facility, DM in the GeV and sub-GeV mass range can be copiously produced via dark photon decay and would be relativistic.

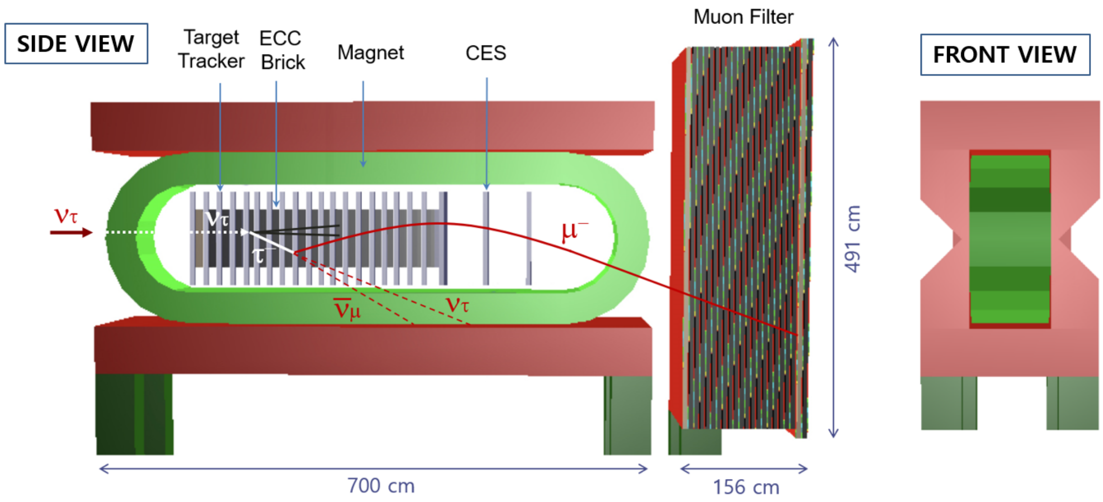


**Figure 2:** Neutrino detector and $\nu_\tau$ scattering

## 4. Summary

The SHiP is a newly proposed multi-purpose beam dump experiment at the CERN SPS, whose challanging goals are the direct search for hidden non-Standard Model particles and the study of the unknown properties of $\nu_\tau$ and $\bar{\nu}_\tau$.

The CERN SPSC has positively reviewed the SHiP Technical and Physics proposals [1, 2], and the CERN Research Board has recommended the SHiP Collaboration to proceed with a Comprehensive Design Study. This status report will given to the Physics Beyond Colliders working group so that it can provide input to the next update of the European Strategy for Particle Physics in 2019. The SHiP aims to start data taking in 2026, as soon as the SPS resumes operation after long shutdown LS3. It will be a great opportunity to open new physics by pursuing intensity frontier.

## 5. Acknowledgements

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT) (No. 2018R1A2B2007757).

## References

[1] The SHiP Collaboration, *A facility to Search for Hidden Particles (SHiP) at the CERN SPS*, April 2015 [arXiv:1504.04956]; The SHiP Collaboration, *The experimental facility for the Search for Hidden Particles at the CERN SPS*, submitted to JINST (2018) [arXiv:1810.06880].

[2] S. Alekhin et. al, *A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case*, Rep. Prog. Phys. **79** (2016) 124201 [arXiv:1504.04855].

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