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SHiP: a new facility with a dedicated detector for studying tau-neutrino properties and nucleon structure functions

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SHiP: a new facility with a dedicated detector for studying tau-neutrino properties and nucleon structure functions

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Abstract. SHiP is a new general purpose fixed target facility, whose Technical Proposal has been recently reviewed by the CERN SPS Committee, who recommended that the experiment proceeds further to a Comprehensive Design phase. 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 2×10^{20} pot in 5 years. A dedicated detector downstream of the target will allow to probe a variety of models with light long-lived exotic particles and masses below a few GeV/c^2. Another dedicated detector will allow the study of neutrino cross-sections and angular distributions, which was the focus of the poster. ν_τ deep inelastic scattering cross sections will be measured with a statistics 1000 times larger than currently available, with the extraction of the F_4 and F_5 structure functions, never measured so far and allow for new tests of lepton non-universality with sensitivity to BSM physics. Moreover, ν_τ's will be distinguished from $\bar{\nu}_\tau$'s, thus providing the first observation of the $\bar{\nu}_\tau$. With ν_μ scattering it will be possible to reduce by about 50% the current uncertainty on the strange content of the nucleon in the range of the x variable between 0.05 and 0.3, complementary to LHC measurements. The detector will be based on several techniques developed for the OPERA experiment at LNGS.

Introduction

The standard model of particle physics (SM) has proven to be extremely successful. However, phenomena like dark matter, baryon asymmetry or neutrino masses can only be explained with physics beyond the SM. Searches for new particles can be done in several ways. While current accelerator-based experiments are exploring the energy frontier, SHiP (Search for Hidden particles) [1] uses a complementary approach and is designed to test a variety of models [2] at the intensity frontier. This direct search for weakly interacting particles in the mass range of a few GeV is accomplished by a new fixed target facility proposed in the North Area at CERN.

400 GeV protons from the SPS are injected into a new beam line aimed at a high density target of ten interaction lengths, composed of Tungsten and Molybdenum. During a run time of five years, an integrated number of 2×10^{20} protons on target is foreseen. The target is then followed by a hadron stopper and a magnetic muon sweeper, reducing the muon flux from approx. 10^{10} to 10^5 muons per spill. Further downstream the experimental setup then follows a neutrino detector and finally the hidden particle decay volume and detector. An illustration of the experimental setup is depicted in Figure 1.

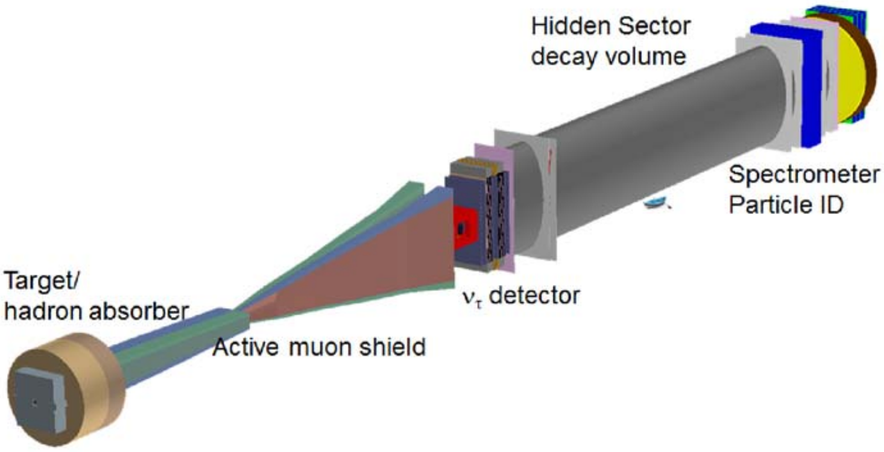

Figure 1. The SHiP facility. 400 GeV protons are shot at the target, followed by a hadron stopper and a magnetic muon sweeper. After that, the neutrino detector and the decay volume for hidden particles and detector for their daughters follow.

Tau-neutrino physics

Besides possible unknown weakly interacting particles, a huge amount of neutrinos of all flavors will be produced in the target. For example, τ-neutrinos are produced in the decay of D_S mesons, where the expected number $N_{\nu_\tau+\bar{\nu}_\tau}$ to be produced is given by:

$$N_{\nu_\tau+\bar{\nu}_\tau} = 4N_p\frac{\sigma_{c\bar{c}}}{\sigma_{pN}}f_{D_s}Br(D_s \to \tau) = 2.85\times10^{-5}N_p = 5.7\times10^{15},$$

with $N_p = 2\times10^{20}$ the number of interacting protons, $\sigma_{c\bar{c}}$ the cross-section of the associated charm production and σ_{pN} the hadronic cross-section per nucleon in the target, f_{D_s} the fraction of D_S mesons produced and $Br(D_s \to \tau)$ the branching ratio for the decay of these into a τ.

Behind the magnetic sweeper, these neutrinos will be detected by a dedicated neutrino detector, shown in the left panel of Figure 2, which is based on the OPERA concept [3].

This detector will consist of a magnetized target based on the emulsion cloud chamber (ECC) technique. Neutrinos will interact in lead plates interleaved with nuclear emulsion for the detection of charged particles. Additionally, each ECC unit is followed by a compact emulsion spectrometer (CES), made of emulsion films interleaved with a low density material such as rohacell, to measure charge and momentum of charged particles emerging from neutrino interactions in the magnetic target and thus allowing for a separation between neutrinos and antineutrinos. The design of the ECC and CES bricks is shown in the right panel of Figure 2. The target will fit 1155 bricks, which have to be completely exchanged every six months of running for scanning. Assuming a 9.6 tons neutrino target and taking into account the geometrical acceptance, the number of neutrino interactions can then be estimated using the standard model cross-section which is shown in Table 1.

This large number of neutrino interactions allows for several interesting studies. The τ-neutrino is the least known particle in the standard model, so far only a few candidates have been experimentally observed by DONUT and OPERA. SHiP will bring great improvement to the determination of the ν_τ charged current cross-section, including the possibility of the determination of the F_4 and F_5 structure functions. The ability to separate ν_τ from $\bar{\nu}_\tau$ interactions allows to experimentally observe the anti-tau-neutrino for the first time ever.

In about 5 % of the neutrino and anti-neutrino interactions, charmed hadrons are produced—a process which is extremely sensitive to the strange quark content of the nucleon. These

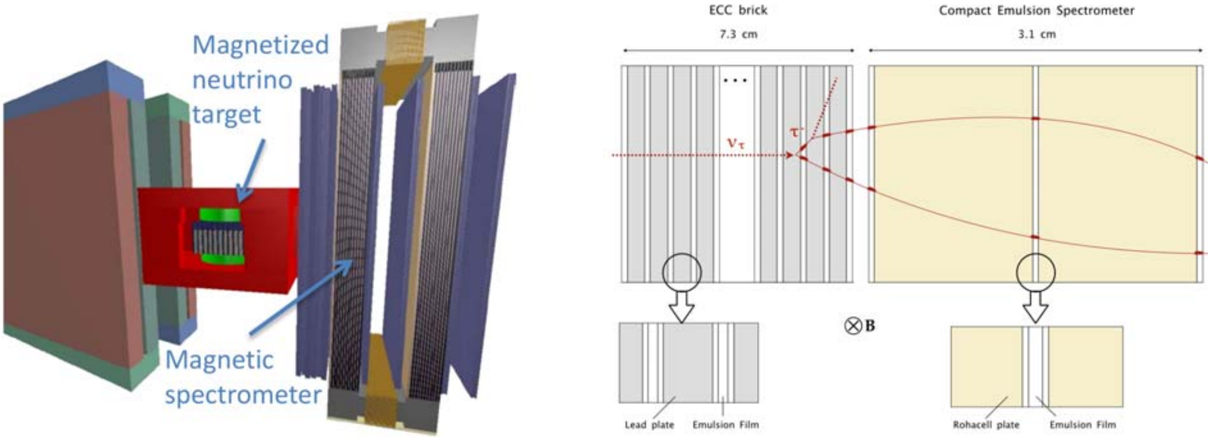

Figure 2. *Left:* Scheme of the ν_τ-detector. Neutrinos are detected by a hybrid detector consisting of a magnetized neutrino target followed by an electromagnetic spectrometer. *Right:* Design of the ECC bricks and CES.

Table 1. Expected number of neutrino interactions in the neutrino target.

	$< E >$ (GeV)	Number of interactions
ν_μ	30	2.3×10^6
ν_e	46	3.4×10^5
ν_τ	58	7.1×10^3
$\bar{\nu}_\mu$	27	9.5×10^5
$\bar{\nu}_e$	46	1.4×10^5
$\bar{\nu}_\tau$	58	3.6×10^3

charmed hadrons can be identified topologically in the nuclear emulsions by detecting their decay vertex. SHiP will integrate about 10^5 charm events, exceeding current statistics by an order of magnitude and will thus be able to significantly improve knowledge of the strange quark content of the nucleon.

Outlook

The SHiP experiment has recently been proposed to be built at CERN. A Comprehensive Design Report of the SHiP facility is expected to be ready in 2018. The construction and installation are foreseen to last until the third long shutdown of the LHC, which will allow to start data taking in 2026. The facility will have a dedicated neutrino detector, able to significantly improve measurements of the tau-neutrino cross-sections and allowing, for the first time ever, an experimental observation of the $\bar{\nu}_\tau$.

References

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