Optimization of the Selection of Hidden Particles in the SHiP Experiment

Search for Hidden Particles

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Objective of the Thesis

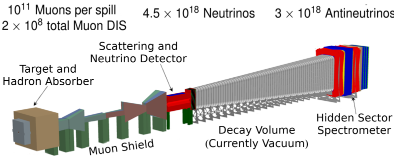
The goal of this project is to maximize the selection efficiency of Heavy Neutral Leptons, Dark Photons and Sgoldstinos using machine learning algorithms

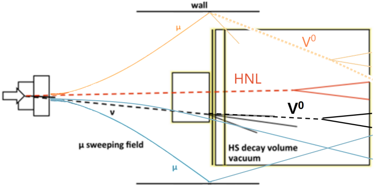
SHiP is a discovery experiment designed to find particles whose production is heavily suppressed ($O(10^{-10})$).

Therefore, the background must be totally under control to ensure a zero background environment.

To this end I am simulating the following background processes :

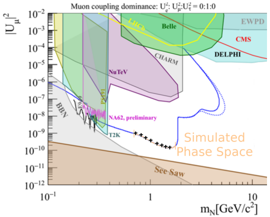
- Neutrino Deep Inelastic Scattering - 10^6 events of ν_e, ν_μ, $\overline{\nu}_e$ and $\overline{\nu}_\mu$ each, generated with GENIE between the SND muon detector and the second target tracker at the HS, with Geant4 used to describe the spectrometer
- Muon Deep Inelastic Scattering - 3×10^6 events were simulated using Pythia8 in similar conditions to the neutrinos
- Muon Combinatorial from $\approx 2 \times 10^9$ muons surviving the absorber





Heavy Neutral Leptons / Dark Photons

All the Hidden Sector Particles were generated using Pythia8, and then propagated through the apparatus with Geant4.



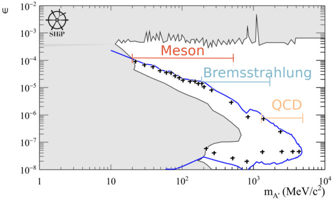
Heavy Neutral Leptons

Production Modes :

- D decay
  2×10^{18} mesons
- B decay
  2×10^{14} mesons

Decay Modes :

- $N \rightarrow \ell^{\pm}\ \pi^{\mp}$
- $N \rightarrow \ell^{\pm}\ \rho^{\mp}$
- $N \rightarrow \rho^{0}\ \nu_{\ell}$



Dark Photons

Production Modes :
(Photon Mixing)

- Meson Decay
- Proton Bremmstrahlung
- QCD Fusion

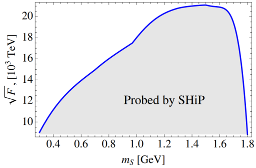
Decay Modes :

- $A' \rightarrow \ell^{+}\ \ell^{-}$
- $A' \rightarrow q\ \overline{q}$

To properly optimize the separation of the decay products of the HS particles from the background, **5000 events** were generated for each specified point in the phase space.

Sgoldstinos

At SHiP there is a chance to probe the **breaking scale** $\sqrt{F}$ of a possible supersymmetric sector up to 10^3 TeV. This can be accomplished through the detection of the SM decays of **Sgoldstino** particles, either scalar or pseudoscalar, whose couplings are proportional to F^{-1}.



$$\mathrm{Br}(B \to X_s S) =$$

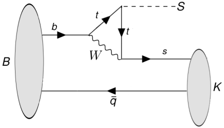
$$= 0.3 \times \left(\frac{m_t}{m_W}\right)^4 \times \left(1 - \frac{m_S^2}{m_b^2}\right)^2 \times (A_Q v + F\theta)^2 \times \left(\frac{100\ \mathrm{TeV}}{\sqrt{F}}\right)^4$$

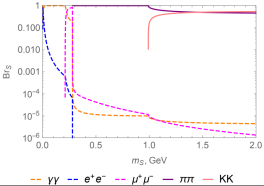
$$\Gamma(S \to X^0 \bar{X}^0) \approx \frac{4\alpha_s^2(M_3)}{\beta^2(\alpha_s(M_3))} \frac{\pi m_S^3 M_3^2}{4F^2} \sqrt{1 - \frac{4m_X^2}{m_S^2}}$$

$$\Gamma(S \to \pi^+\pi^-) = 2\Gamma(S \to \pi^0\pi^0)$$

$$\Gamma(S \to K^+K^-) = \Gamma(S \to K^0\bar{K}^0)$$

- As of now there is **no Sgoldstino implemented** in the SHiP software.
- I am **implementing a scalar Sgoldstino** in Pythia8 of up to 2 GeV, produced through B decays.
- For $m_S > 2$ GeV the phenomenology becomes more complex, and is not particularly useful at SHiP.
- As such **S decays** primarily to $X\overline{X}$, with $X = \pi$ or K.





Plan of Action

I am doing a standard kinematic analysis to distinguish signal from background. However, Neural Networks will also be utilized in order to perform a multivariate analysis with the goal of improving the selection efficiency of hidden particles. This should be more impactful in the study of decays with missing energy. Among the variables of interest the **transverse momentum**, the **impact parameter** and the **opening angle** are of special interest.

Detector optimization

Currently the **Decay Volume** is set at a pressure of at least 10^{-2} **bar** to minimize neutrino interactions.
Maintaining the efficiency of selection of HS particles while simultaneously keeping the purity level of the sample in an **air filled vessel** would be extremely beneficial.

$\Downarrow$

The decays of the HS particles are also compared against the neutrino DIS background in an **air filled** Decay Volume.
Neural Networks might be pivotal in preserving the 0 background environment.

Pinpointing HS Particles

SHiP is not just a Hidden Sector discovery experiment.
We want to **discover specific particles**, and **reconstruct** their **invariant masses** as accurately as possible. Then, **Neural Networks** might be able to **distinguish** effectively different **HS particles** with similar decay modes, and consequently enhance the precision of the measurements.