Search for Dark Matter in the Upgraded High Luminosity LHC at CERN
Master thesis project proposed by
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Astrophysical measurements indicate the presence of large amounts of invisible matter in the Universe. It is usually refered to as "Dark Matter" because it is invisible in the electromagnetic spectrum, but can be inferred by its gravitional influence on visible bodies.

Recent measurements from the Planck satellite show that Dark Matter constitutes approximately 27% of the mass of the Universe. The question "what is Dark Matter?" has become one of the most prominent physics puzzles in a long time.

The microscopic world is described by particle physics theory which encompasses quarks, leptons, neutrinos and so called vector bosons that mediate the interaction between particles. Despite the success of particle physics theory with the recent discovery of the Higgs boson, several theoretical arguments indicate that today's theory is incomplete, as an example it does not contain nor predict any particle that could explain dark matter.

Independently from the dark matter question, current particle physics theory cannot explain why the mass of the Higgs boson is relatively small. If new particles with masses below 1000 times the mass of a proton are introduced , the problem with the mass of the Higgs boson could be solved. These new particles could as well make up the dark matter.

The ATLAS experiment at the Large Hadron Collider at CERN has been designed to search for the Higgs boson and new particles up to masses with several thousand times that of a proton. It is possible that dark matter particles could be produced in the LHC proton-proton collisions and are in fact actively being searched for in the data collected in 2011 and 2012.

An upgrade version of the LHC accelerator is planned for 2021. In its upgraded form the LHC will provide much larger number of proton-proton collisions per second and will allow for significantly enhanced sensitivity to dark matter. Nevertheless the exact expected sensitivity to dark matter production at the upgraded LHC has not been precisely estimated yet.

The very large number of simultaneous collisions will lead to degraded detector performance, for example in terms of energy resolution. This degradation of the performance will impact observables that are critical for detection a dark matter signal over other proton-proton collision backgrounds.

The goal of the present project is to study, using detector simulation, the effect of large number of simultaneous collisions on the performance of the detector, and how it affects observables critical to dark matter detection with the ATLAS experiment. The final result of this work could be a comparison between the expected signal over background ratio in various scenarios of detector performance and number of collisions per unit of time.

In a particle collider experiment like ATLAS the data consists of proton-proton collisions and for each collision a large number of observables. In this study there are two types of collisions:

"Signal" corresponds to a set of simulated collisions containing proton-proton → dark matter particles. In this project two different theories of dark matter will be investigated.

"Background" corresponds to a set of collisions containing only common physics processes that are well understood from earlier studies.

In this project simulated "signal" and "background" datasets are to be used. The signal datasets are being simulated and will be ready by end of november. The simulated background dataset is ready to be used. A dataset is a set of collisions and for each collision a large number of observables are saved and can be studied. The datasets are available in so-called ROOT format. ROOT is a C++ based data analysis framework developed by CERN and Fermilab.

The following project steps are envisioned:

1) Implement a C++ programme that loops over the collisions inside the signal and background datasets.

2) For each collision retrieve the relevant observables (variables used to extract the signal over the background) and apply "smearing functions" to emulate the effect of the high luminosity on the observables.

3) For both signal and background datasets, compare observables before and after smearing. What observables are the least/most affected?

4) Implement selection criteria that selects the signal collisions efficiently while reduces significantly the background. In a first step the selection criteria should be taken from existing studies.

5) Selection criteria can be evaluated and compared with each other using a figure of merit *Z*, that measures the sensitivity of the experiment to the dark matter signal. Calculate Z for the given selection criteria before and after smearing.

6) What is the effect of the high luminosity (smearing) on the value of Z?

7) Investigate other selection criteria and observables, to mitigate the effect of high luminosity. Use Z to rank different criteria after smearing.

8) Conclude on the effect of the high luminosiy on the sensitivity for dark matter and possible ways to mitigate its effects using alternative observables and selection criteria.