Project 3 in Research-based Particle Physics, FYS5555

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**Project description:** *«Searching for Dark Matter by using mono-Z process leading to the final state l+l- and missing transverse energy MET»*

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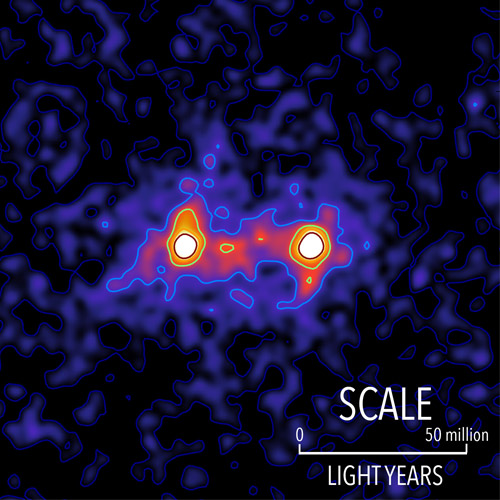


Figure 1: Image shows Dark matter filaments (red) that purportedly bridge the space between galaxies (white).[1][2]

**Abstract:**

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***INTRODUCTION:***

The field of Dark matter is attracting a lot of attention recently. As the Large Hadron Collider is close to reaching many of its goals, many particle physicists are trying to go further by looking at physics beyond the Standard Model theory. And the nature of Dark matter is still a mystery. We believe that the composition of the Universe is 75 percent Dark energy, 20 percent Dark matter and 5 percent normal matter. The advent of modern science has made it possible for us to obtain a lot of knowledge about the 5 percent fraction. However, we are still far behind in understanding the other 95 percent. This project will try to shed some more light on the mystery of Dark matter.

There is little direct evidence of Dark matter. But plenty of indirect. Because of this, we also have several candidates that could be Dark matter. The many candidates suggest that there are equally many ways of finding Dark matter since the candidates cover a wide span of scientific fields. This project will focus on the process , meaning mono-Z to dilepton and missing transverse energy MET. On beforehand we were given a shellcode that was meant to be adjusted to our project description. Analysis cuts are implemented and the results are presented as plots that are discussed in later sections.

The layout of the text is as following. We begin with a short theory section meant to provide a background for understanding the later results and discussion, then continue with an experimental procedure, before we go on to the results and discussion. This is the most important part of the text. Code can be found in the necessary formats on:

<https://github.com/FurkanYekmal/FYS5555---Researchbased-Particle-Physics>

in addition to the one found in the appendix.

***THEORY:***

In this section a closer look at the most important theory will be done. The text will only focus on the aspects that are relevant for understanding the results and following discussion seen in the next section. For a more thorough look at Particle Physics, books like Mark Thomsons, *Modern Particle Physics*, are recommended.[3]

**Lepton:**

A lepton is an elementary particle of half-integer spin (spin 1/2) that does not undergo strong interactions. It follows, just like the fellow lepton quark, Fermi-Dirac statistics and can have either charge -1, 0, +1. Each lepton has its own anti-particle. The electron has the positron, the muon has the anti-muon, and the neutrinos have the anti-neutrions etc. We divide the leptons into three generations. A table follows below.

Table 1: Table shows the classification of the leptons. It classifies them according to generation, type, mass and charge.[3]

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Generation | Particle | Symbol | Charge | Mass/GeV |
| First | Electron | e^- | -1 | 0,0005 |
| First | Neutrino | (v\_e) | 0 | <10^-9 |
| Second | Muon | µ^- | -1 | 0,106 |
| Second | Neutrino | (v\_µ) | 0 | <10^-9 |
| Third | Tau | ^- | -1 | 1,78 |
| Third | Neutrino | (v\_) | 0 | <10^-9 |

The electron, muon and tau undergo both electromagnetic and weak interactions, while the neutrinos only undergo weak interactions.[3]

**Dark matter:**

We know that the matter that is visible in current telescopes only represents a fraction of total amount of matter in the Universe.[4] A large amount of the total matter seems like it does not emit light. This is called Dark matter. Basically, Dark matter is a hypothetical invisible mass that is seen as being responsible for adding gravity to galaxies and other structures.[5] Dark matter should not be confused with Dark Energy. The only things they have in common is that both are components that do not emit or absorb light.[6] Dark matter is built up almost like ordinary matter and clusters to form galaxies.

In early 20th century it was found that that the dispersion velocity of galaxies was much higher than what could be attributed to luminous matter. Soon it was found that most of the matter in the Universe was Dark matter.[4] Following this discovery, Dark matter was separated into two classes: cold and hot. Hot moves with relativistic velocity (meaning speed of light), while cold does it with non-relativistic. The last class is considered to be the most likely candidate for Dark matter.

We have a parameter that describes the total density of the Universe, This parameter is again given by the following equation:

Where non-relativistic matter 0.3 and a cosmological constant 0.7. The contribution from luminous matter only contribute to 0.0051 of the total energy. This is equal to roughly 2 percent of the total matter contribution. At the same time, only 0.045 of the contribution comes from baryons (protons and neutrons).[3] The fact that luminous < matter in contribution means that that the Dark matter problematic is two-folded. Both baryonic and non-baryonic Dark matter must therefore exist.[4]

Continuing with the background for why Dark matter is so important, we have that as the Universe expanded, then it went from a state dominated by radiation to a state dominated by matter. With only an only-baryonic Universe it would be impossible for over-dense regions to collapse before recombination. This would furthermore lead to a too slow structure formation. This is not the case for non-baryonic Dark matter. Hot Dark matter with its top-down scheme for structure formation is less probable than the cold Dark matter scheme with a bottom-up scheme. Without going too much into this, it suggests that cold Dark matter is more probable as a candidate for Dark matter.

The cold Dark matter is supposed to have the following properties: collisionless, dissipationless, longliving and behaves as a perfect fluid. The most likely candidates are Weakly Interacting Massive Particles (WIMPS) and Massive Astrophysical Compact Halo Objects. WIMPS don’t interact with electromagnetic charges, but interacts with normal matter through weak force.[5] MACHOS are on the other hand ordinary objects that behave in extraordinarily manner. They are big star-like structures that glow too little.

As a final paragraph in this section, we will look at how broad the look for Dark matter is. In Hungary a team of researchers attempted to find dark photons, meaning photons that carry Dark matter.[8] The team suggests that there is a fifth force of nature with a new form of boson to mediate it. This again strongly implies that Dark matter might be as hypothetical as previously thought.

**Mono-Z process:**

The Z boson is responsible for mediating the weak force alongside the W boson. It is electrically neutral and has a mass of 90 GeV/c^2.[7] In this text we only consider the decay Z -> ll, so therefore the process is important for the project.

**Transverse energy momentum:**

is a variable in the codes used by CERN. We will focus on met\_et and neglect the met\_phi. met\_et is defined as “the transverse energy of the missing momentum vector”. With a Z boson energy given as 90 GeV/c^2 and a decay to dilepton we must in the simulation have a met\_et over 90 GeV/c^2 to find Dark matter. The two leptons (l+ and l-) will “neutralize” each others energy. That means that any energy above this is unexplainable and could be Dark Matter. It should be mentioned that it could also be explained by detector errors or other components being created in the decay process. This is an analysis cut, or prerequisite in layman terms.

**Comparable research done before:**

This section could be considered a form of Literature Review (as seen in larger form of texts like Master thesis). But some similar research has been done before and it is important to delineate the differences and why this is research is independent of those.

The ATLAS Collaboration have previously looked for Dark matter candidates with the ATLAS detector.[9] These Dark matter candidates were produced in association with a leptonically decaying Z boson in pp-collisions at sqrt(s) = 13 TeV, Very similar to this project. However, their results were slightly skewed compared to the results obtained in this text because in their project jets were included. In this project the focus will be on leptons alone. But the project from the ATLAS collaboration is highly recommended for further understanding and comparison.

Krauss et al investigated a mono-Z process where in that channel a single Z boson recoils against missing transverse momentum.[10] It is a search strategy meant to be complementary to monojet and monophoton searches. The process considered is the . It is a toy Dark matter model where the Z boson is emitted from either the initial state quarks or from the internal propagator. Their research is kind of similar to the one done here (but with a different process of course) with analysis cuts, and what they find is that here exists regions of parameter space where the signal is seen above background values. Meaning that there is a discovery potential, inferring that there could be a potential for Dark matter.

***EXPERIMENTAL PROCEDURE:***

The work in this project was based on a shell-code created by one of the supervisors. The main file that needed more work on was the MySelector.py file, In that particular file, there were several definitions that were necessary for the project description to be fulfilled. The Analysis cuts were also done in this file.

An analysis cut defines several variables that were predefined in the project description handed to the author. One of them was for example not to include jets despite similar research previously done on the matter, has done so. This was done due to the focus on the decay: Z -> ll. More examples can be found in the Code-section at the end of this text. The actual codes were implemented through Virtual Machine and access to CERN. This was done because of the availability of the programme Root at that server.

The analysis cuts can be seen in the table below. The table is called the selection criteria in the search.

Table 2: shows the selection criteria used for the search for dark matter

|  |  |
| --- | --- |
| Two leptons | Two opposite-sign leptons, leading (subleading) > 30 GeV |
| Third lepton veto | Veto events if any additional lepton with > 7 GeV |
|  | 76 GeV < < 106 Gev |
|  |  |
|  |  |
|  |  |
| Fractional difference |  |
| b-jets veto | N (b-jets) = 0 with b-jet |

The results from the coding were saved in histogram bins. The histograms were then plotted with MATLAB. And can be seen in the Results and Discussion section.

***RESULTS AND DISCUSSION:***

***CONCLUSION:***

***REFERENCES:***

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***APPENDIX: CODE:***

It should first be pointed out that all the files can be found on the Github website designed for sharing of codes.[11]