Dark Matter Searches at CMS at $\sqrt{s} = 13$ TeV

University of BRISTOL

Eshwen Bhal

Supervisor: Bjoern Penning

Dark matter searches will be conducted with the CMS experiment at the LHC using Run-2 data at a centre-of-mass energy of 13 TeV. Supersymmetry is currently the most popular theory that accommodates dark matter candidates, and will be the main focus of this PhD. The majority of the work conducted will be analysis-based and may include interdisciplinary aspects such as astrophysical dark matter searches. Projected results from this undertaking would involve setting world-leading limits on the masses of dark matter and its mediator in different models, and possibly discovering other properties like its production frequency at the LHC.

Introduction

The Universe is filled with a non-baryonic form of matter labelled "dark" matter. This substance does not interact with any of the four fundamental forces, apart from gravity. Whilst evidence and observations have been astrophysical in nature (Figs. 1 and 2), understanding the properties of dark matter shifts the responsibility to particle physics.

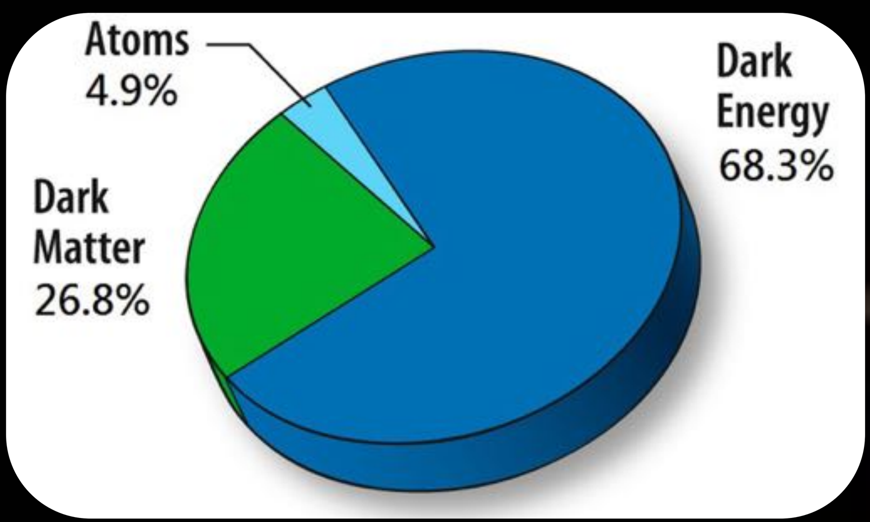

Fig. 1: The components that make up the total energy density of the Universe. These values are taken from the Planck satellite.

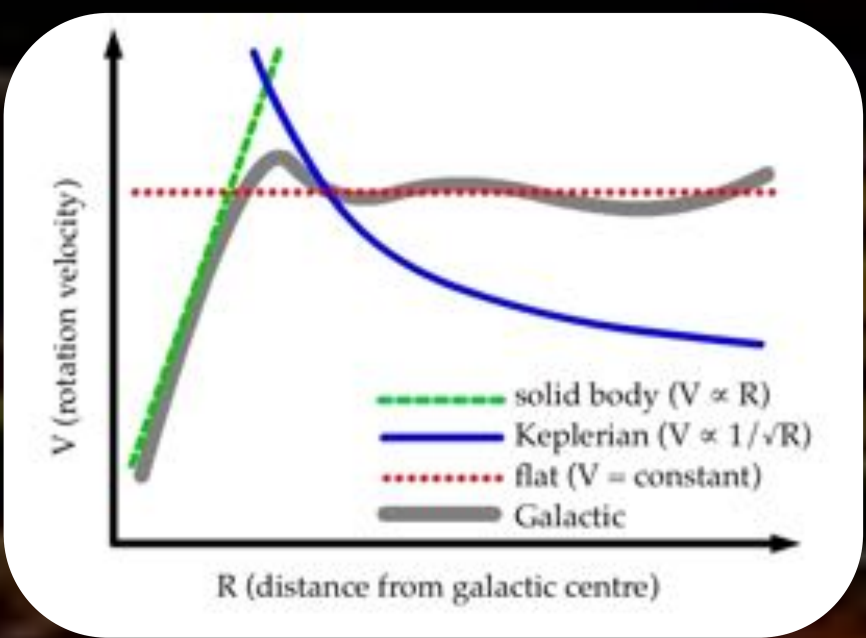

Fig. 2: An observed galactic rotation curve (grey) with standard kinematic curves. A source of invisible matter must dominate to explain the roughly flat rotation curves seen in astronomy.

Experimental setup:

CERN's Large Hadron Collider (LHC) has allowed us to probe high energies and create exotic particles that existed when the Universe was hot; the temperature was high enough to produce these particles – including dark matter – in abundance. Once it cooled, these particles were no longer spontaneously created: a thermal freeze out occurred. [1] The Compact Muon Solenoid (CMS) experiment at the LHC aims to detect the signatures of dark matter production from various theories, such as Supersymmetry. With a projected 150 fb^{-1} of data from Run-2 at a centre-of-mass energy of 13 TeV (tera-electron volts), we may learn much more about dark matter.

Theory

Supersymmetry (SUSY) is the leading candidate for physics beyond the Standard Model of Particle Physics. [2] It introduced a spin symmetry that predicts a fermionic superpartner for each boson, and vice versa. If the lightest supersymmetric particle (LSP) is stable and electrically neutral, it would provide a promising dark matter candidate.

Fig. 3: A Feynman diagram depicting dark matter (DM) pair production from Standard Model (SM) particles. Within the circle are the subprocesses that produce dark matter.

The conservation of *R*-parity [2] means that the decay cascades of SUSY particles produced in a collider ends with the LSP, and Standard Model particles with each decay. These are normally energetic hadrons, which then create showers of new hadrons from pair production that are detected as "jets". Due to dark matter LSPs being undetectable, the reconstructed event from the detector would contain "missing" transverse energy (MET) which would be required to satisfy energy and momentum conservation. The predominant sources of MET in collider events are from neutrinos, misreconstructed particles, and possibly new particles.

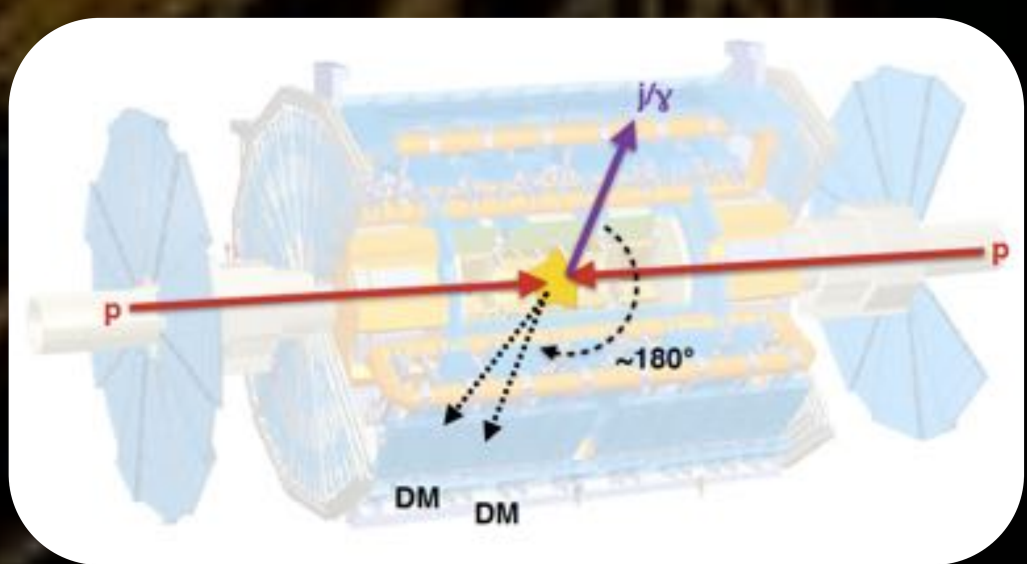

Fig. 4: An example of a *pp* collision at an accelerator producing dark matter (reconstructed as MET) and recoiling SM particles.

So the characteristics of SUSY in a collider would be high MET from the LSPs, and several hadronic jets. This is something CMS is looking for.

Proposed method

I am working with CMS in inclusive searches for physics beyond the Standard Model (SUSY being one aspect). These, in principle, require three sets of data: the data from *pp* collisions at the LHC; the expected signal from particle decays due to new physics; and estimates of the background events from Standard Model processes (to distinguish the signal from the background).

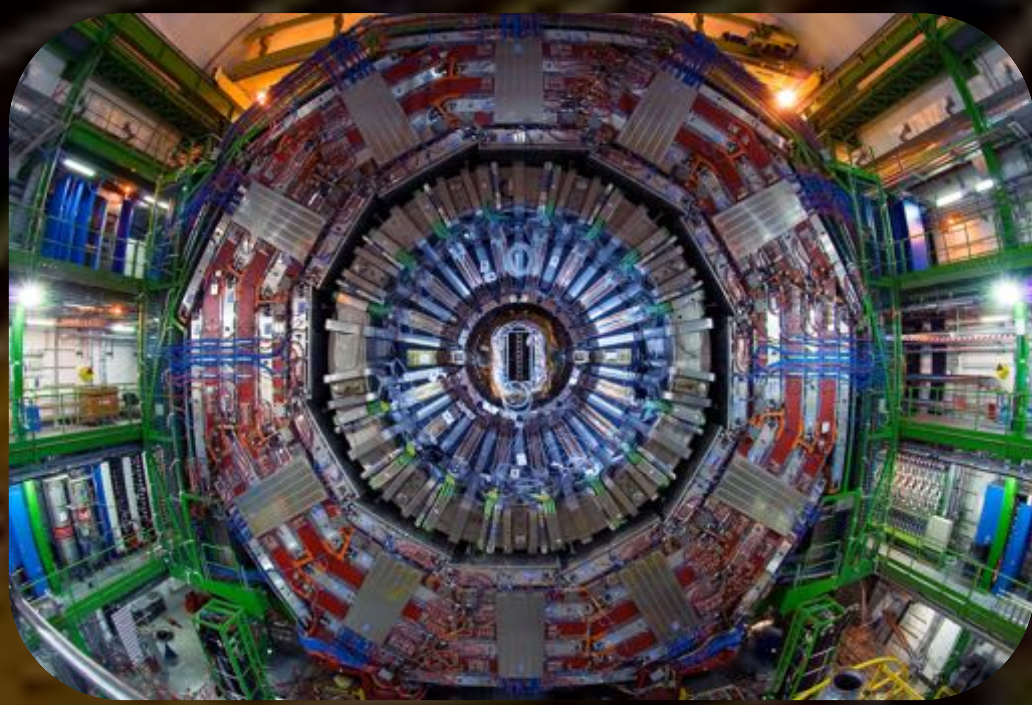

Fig. 5: The CMS detector at the LHC.

Much of the work will be analysis, either sifting through the LHC data or generating the simulated signal/background. By the end of this PhD, the entire Run-2 dataset will be available, providing an enormous number of collider events.

Other sources of knowledge could also be used. Astrophysical observations have shown several independent channels that prove its existence [3], and there are more experiments to explore them further. These can be combined with our efforts to give us much greater scope in the hunt for dark matter.

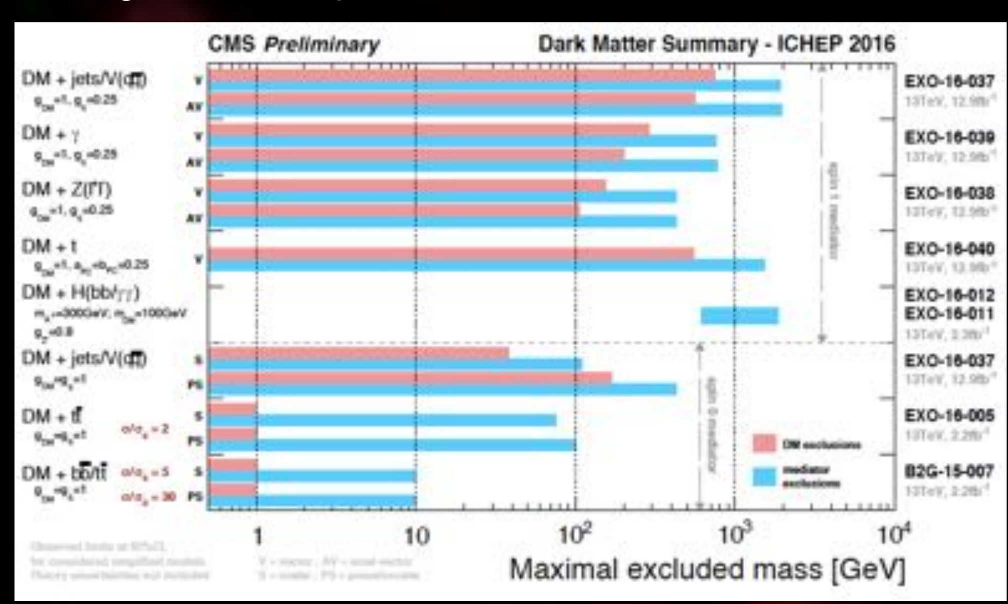

Fig. 6: Limit plots of the dark matter mass and that of its mediator from several analyses. [4] Masses below these values are excluded. Specific models and decay channels were used, and these are currently the world-leading mass measurements.

Projected results

There are many aspects in which our understanding of dark matter can be improved. Over the course of this PhD, my intention is to be able to constrain some of its characteristics. With the full Run-2 dataset, it will be possible to set the world's best limits on the masses of dark matter particles in different theory frameworks and from different decay modes. These could be pushed higher than those set by Figs. 6 and 7 by orders of magnitude. I may also be able to determine how often it is produced at the LHC, the favoured decay modes that produce it, and devising methods to accurately detect these modes. Any progress in these areas will aid in future endeavours to further understand dark matter.

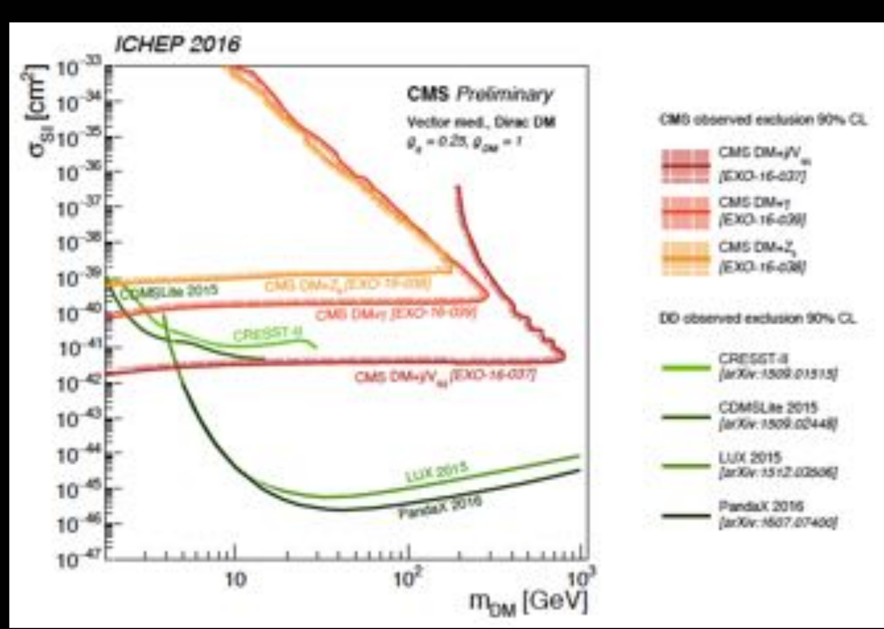

Fig. 7: Limit plots of the spin-independent production cross section (effectively the likelihood to produce the particle) as a function of dark matter mass from several experiments. [4]

[1] Michael E. Peskin. "Dark matter and particle physics", in: *J. Phys. Soc. Jap.* 76 (2007).
[2] Stephen P. Martin, "A Supersymmetry Primer", in: *Adv. Ser. Direct. High Energy Phys. 18* (1998).
[3] Hitoshi Murayama. "Physics Beyond the Standard Model and Dark Matter", arXiv: 0704.2276 [hep-ph] (2007).
[4] CMS Collaboration, "Dark Matter Summary Plots from CMS for ICHEP 2016".

CMS CERN