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

Eshwen Bhal

Supervisor: Henning Flächer

University of BRISTOL

Dark matter, whilst abundant in the universe, is difficult to probe at particle accelerators. This search will utilise the CMS general purpose detector with the goal of identifying dark matter as part of a "semi-visible jet". With a jet + missing transverse momentum ($p_{\mathrm{T}}^{\mathrm{miss}}$) final state, many techniques are being investigated to construct an optimal signal region and reduce the dominant QCD background. Although this analysis is currently incomplete, we expect to develop a well-defined search for benchmark models of this type that can aid future searches.

Introduction

The observable universe contains a major component not explained by the Standard Model. Making up around one quarter of the total energy density, astrophysical evidence suggests there exists a massive neutral constituent – labelled "dark matter" – that exhibits a significant gravitational influence on cosmological structures.

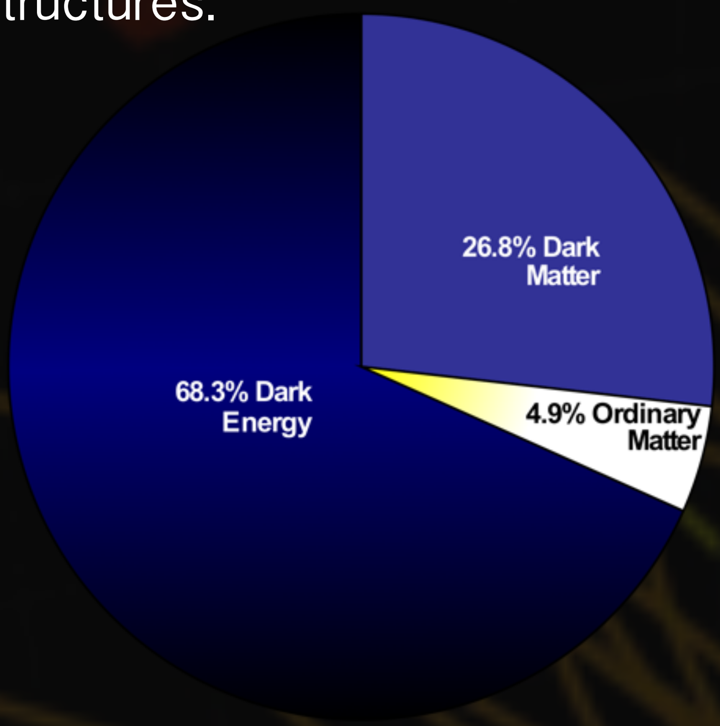

Fig. 1: Energy distribution in the universe according to the Planck satellite measurements in 2013. Values taken from Ref. [1].

The elusiveness of dark matter has led to a plethora of theories proposing its nature. This collider search aims to search for it as an invisible component within a hadronic jet, colloquially known as a *semi-visible* jet [2]. Though still in its early stages, this novel search will explore unique final states arising from a recent theory of dark matter, and probe search regions typically avoided by LHC analyses. We aim to use the full 2016-17 dataset collected by the CMS experiment for our analysis.

Theory

The model describing semi-visible jets [2] posits a hidden sector comprising a dark QCD-esque force. Dark quarks are created from the decay or exchange of the mediator that acts as a portal from the visible to the dark sector. These can then hadronise below a dark confinement scale Λ_d. Some species of dark hadron remain stable, whilst others can decay back into visible states (set in simulation with the variable r_{inv}). The final state jet will contain a mix of dark and Standard Model hadrons.

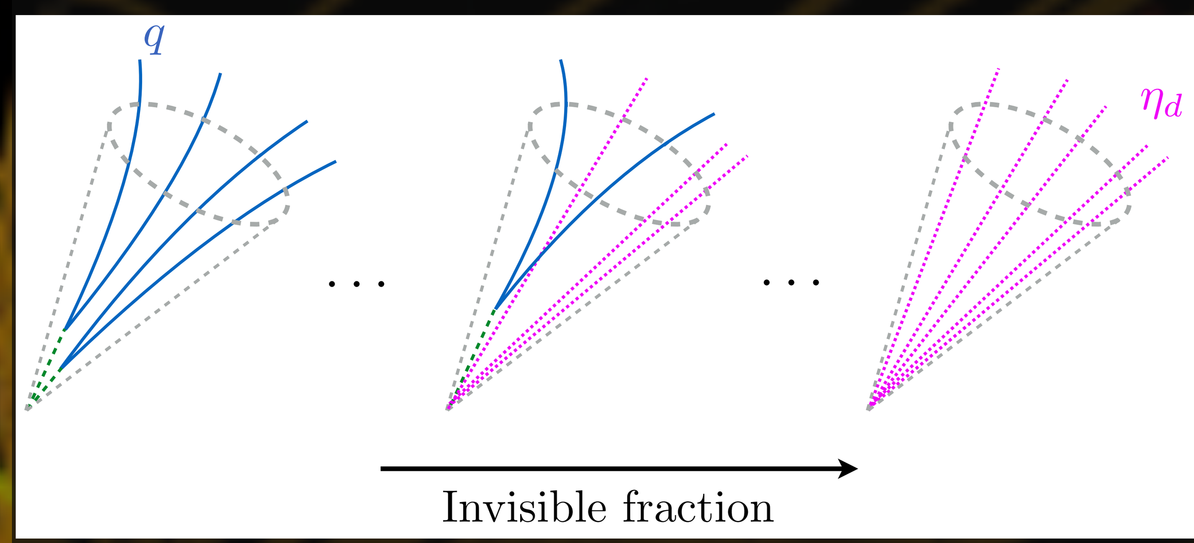

Fig. 2: Semi-visible jets containing varying fractions of stable dark particles (pink), and Standard Model quarks (blue) produced from unstable dark hadrons (green) [2].

Free parameters:

$m_{Z'/\Phi}$ — mediator mass (Z' for *s*-channel, Φ for *t*-channel)

Λ_d — dark confinement scale, related to running dark coupling α_d

m_d — dark quark mass

r_{inv} — fraction of invisible particles produced that remain stable

Analysis strategy

This analysis will search for jet + $p_{\mathrm{T}}^{\mathrm{miss}}$ final states, making QCD the dominant background process. This is difficult to reduce as signal objects can resemble mismeasured QCD jets. Several discriminating variables have been studied for optimisation including $E_{\mathrm{T}}^{\mathrm{miss}}$, M_{T}, and $\Delta\phi_{\mathrm{jj}}$. Multivariate analysis techniques such as boosted decision trees have also been considered. The remaining aspects of the analysis will be investigated in due course.

Our signal models are derived from Ref. [2] and are decomposed into the *s*-channel and *t*-channel UV completions (see Fig. 3). The predominant difference is the mediator interaction. As such, Monte Carlo events are generated separately for each channel. MadGraph5_aMC@NLO [3] computes the hard scattering process, while Pythia8 [4] and its Hidden Valley module are used to hadronise the Standard Model and dark particles.

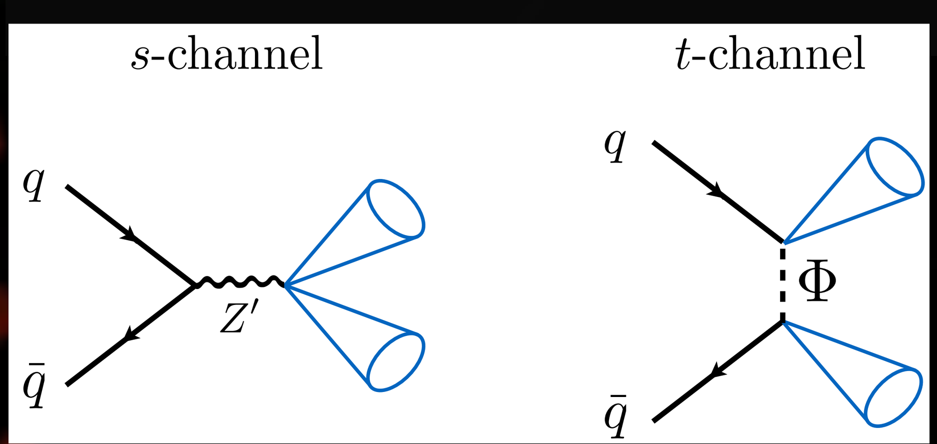

Fig. 3: The two UV completions of the model producing semi-visible jets [2]. These production modes have distinct features and may require different approaches in the analysis.

Kinematics of signal models

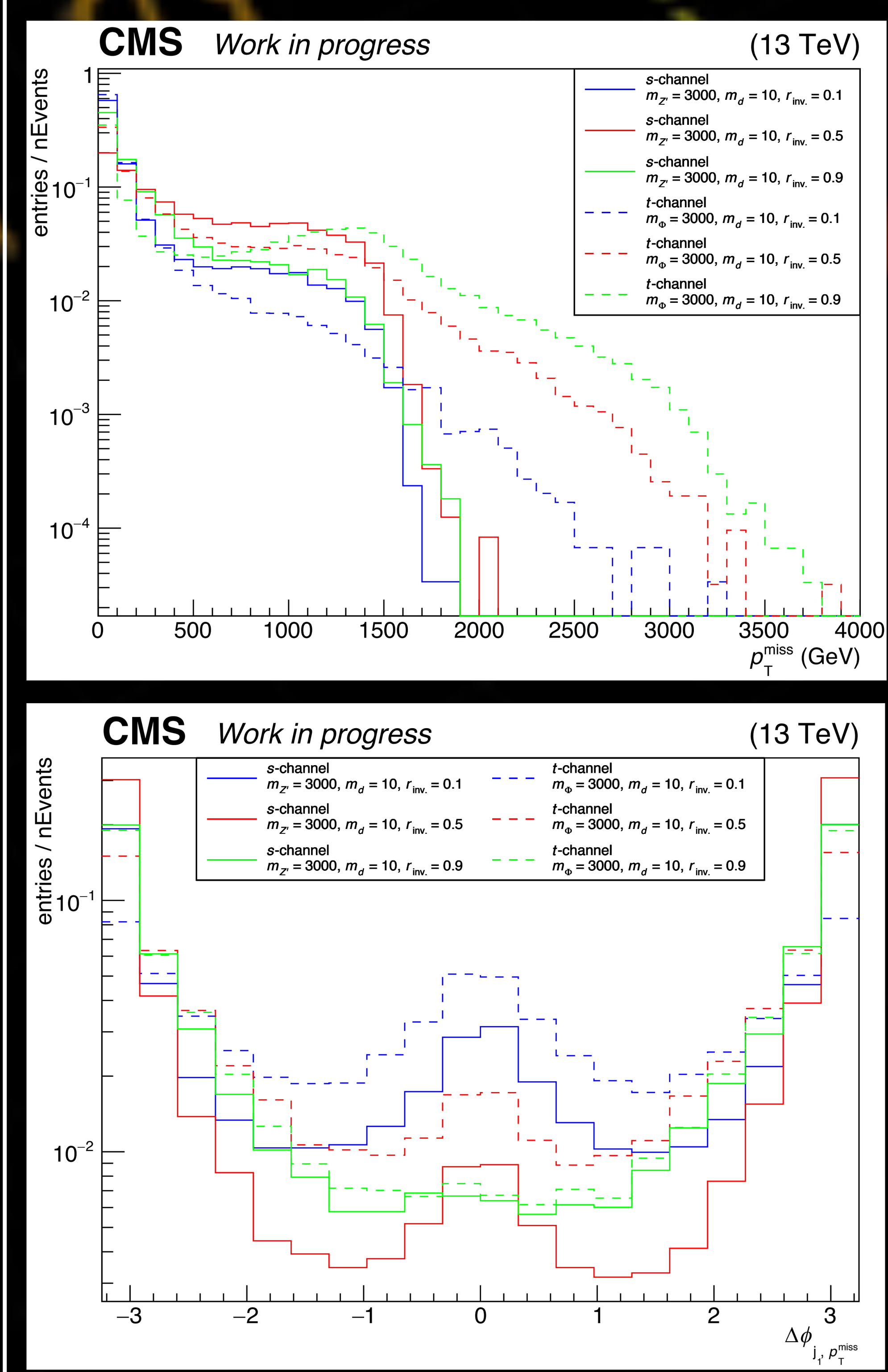

Fig. 4: The $p_{\mathrm{T}}^{\mathrm{miss}}$ spectra (top), and $\Delta\phi$ between the $p_{\mathrm{T}}^{\mathrm{miss}}$ and leading jet (bottom), in *s*-channel (solid line) and *t*-channel (dashed line) models. The r_{inv} parameter is varied to demonstrate its effect on the kinematics.

Anticipated results

Whilst it is difficult to predict the impact the analysis will have at this stage, the use of new dark matter models and untapped LHC search regions will lay a foundation for future exotic searches of this nature.

[1] The Planck Collaboration, "Planck 2013 results. XVI. Cosmological parameters". In: *A&A* 571 (2014).

[2] T. Cohen et al., "LHC Searches for Dark Sector Showers". In: *JHEP* 11 (2017), p. 196.

[3] J. Alwall et al., "The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations", arXiv:1405.0301 [hep-ph].

[4] T. Sjostrand et al., "An introduction to PYTHIA 8.2". In: Comput. Phys. Commun. 191 (2015), p. 159.