Dark Matter searches with the CMS experiment

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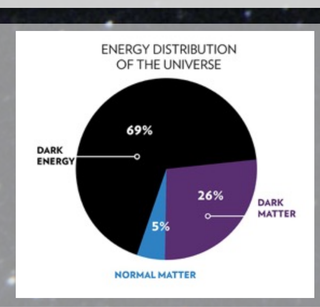
What is the Universe made of?

Cosmology studies and astrological measurements determined that the visible component of the universe accounts for just the 5% of the total universe mass, being the rest composed by dark energy (69%) and Dark Matter (DM, 26%).
The nature of DM, despite the many studies carried out in the last decades and the constraints that have been set on its properties, **still remains unknown**. At particle colliders (LHC), the DM can be produced in proton-proton collisions if it interacts through electroweak forces.
The CMS UZH group focuses on the **search for DM when produced in association with a top quark**, or investigates new scenarios where the DM is produced through strong interactions and can be discovered in **semi-visible jets**.

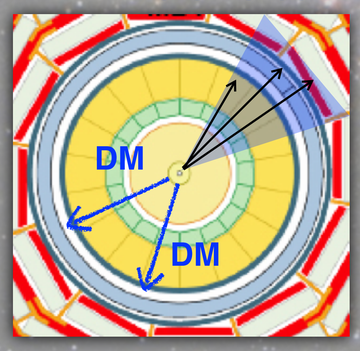


TYPE TO ENTER A CAPTION

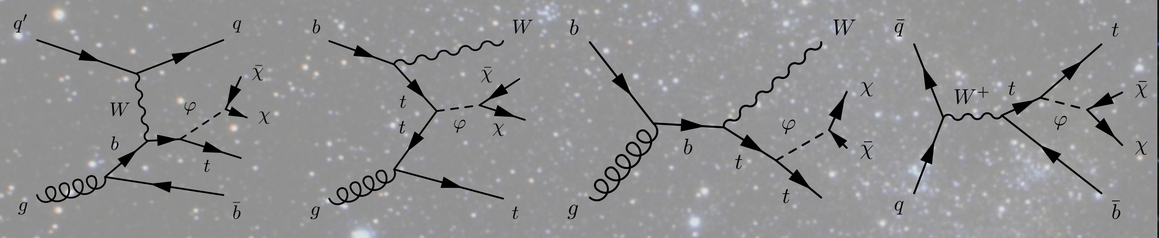
DM + single top

CMS-EXO-18-010

Dark Matter can be produced at LHC through a massive particle, the mediator, that couples with SM particles and decays into a pair of DM candidates, which escape undetected. If the mediator is a spin-0 particle, it is expected to couple predominantly to heavy quarks (top and bottom). So far, previous searches at the LHC considered only the production in association with two top or bottom quarks.



However, an unexplored channel, consisting in DM production in association with a single top quark, is found to **improve significantly the sensitivity** of these searches and it is here **studied for the first time**.
The signature of this study relies on the **lack of energy in the detector** in the transverse plane (p_T^{miss}), since the event has to be balanced but being the DM invisible (i.e. doesn't leave any track in the detector).



Strategy (selection & backgrounds)

Depending on the number of leptons, events are divided in **two channels**:

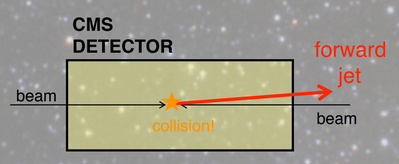
semileptonic channel

- SM backgrounds: tt and W + jets processes
- ≥ 1 identified b jet, at least 2 jets with p_T > 30 GeV and p_T^{miss} > 160 GeV
- the transverse mass m_T, the mass between the lepton and the p_T^{miss} should not be compatible with W boson from top quark decay
- $\min\Delta\phi(jet_{1,2}, p_T^{miss})$ > 1.2, because the jet system and the DM should be back-to-back to converse the energy balance

hadronic channel

- Dominant backgrounds are tt and and Z → neutrinos processes
- ≥ 1 identified b jet, at least 3 jets with p_T > 30 GeV and p_T^{miss} > 250 GeV
- $\min\Delta\phi(jet_{1,2}, p_T^{miss})$ > 1.0 to reject QCD multijet production with misreconstructed jets
- M_T^b and the ratio between the leading jet p_T and the total hadronic activity in the event (p_T/H_T) to reject tt

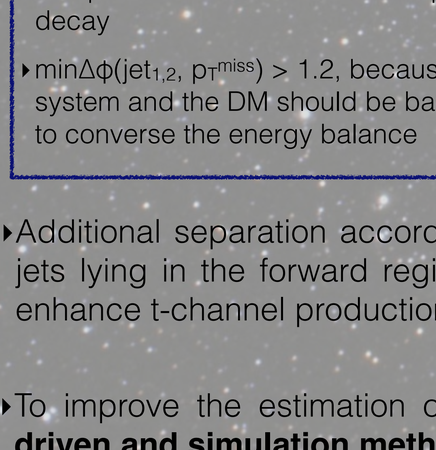
- Additional separation according to the number of jets lying in the forward region of the detector to enhance t-channel production



- To improve the estimation of the main backgrounds, a **mixture of data-driven and simulation methods** are used and enriched background control regions are built, deriving scale factors to match the p_T^{miss} distribution in data.

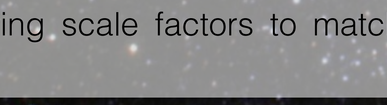
Results

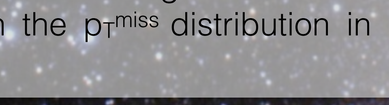
If DM would be present, an **excess of events** over the SM background expectation would be observed in the p_T^{miss} spectrum.



A combined signal+background fit is performed on the **p_T^{miss} distributions** in the different channels. Systematics due to resolution and efficiency of the detector, theory assumptions, reconstructions of the objects, are also taken into account.
No deviation between data and the predictions is observed, hence upper limits on the DM production rate are set.

Mediator masses below 290 and 300 GeV for the scalar and pseudoscalar hypotheses are excluded.



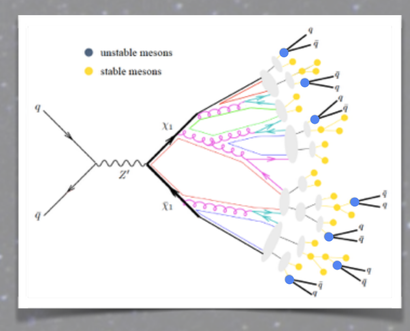


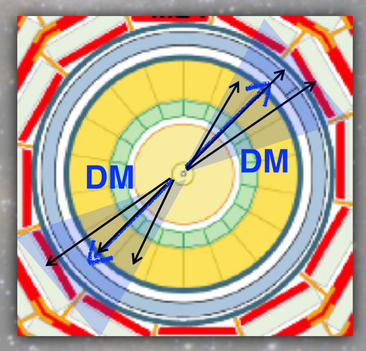
DM in semi-visible jets

CMS WORK IN PROGRESS

During the last decade theorists developed new more complex models, abandoning the WIMP assumption and proposing new models (Hidden Valley models) predicting the existence of a multitude of DM particles belonging to a *hidden sector* (Hidden Valley) interacting trough **new fundamental forces: weak and strong dark forces.**

Novel signatures can arise from this class of models: DM can manifest itself as collimated sprays of visible (SM) and invisible (dark) particles, referred to as ***semi-visible jets*** *(SVJ)*.

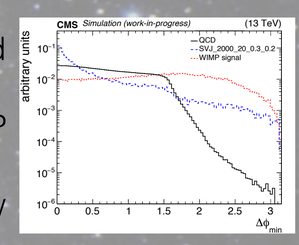


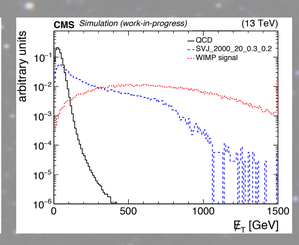


Only a fraction of SVJ momentum is visible to the detector (differently to SM jets). This implies:
- large **missing momentum (MET) in the event, aligned to the jets**
- overwhelming background coming from multijet processes

Strategy

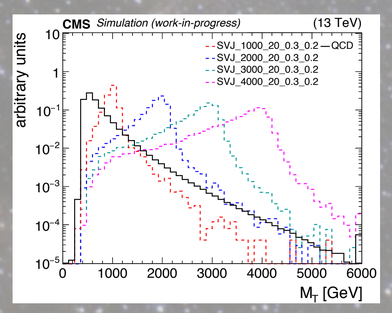
- SVJ signal lives at moderate MET and low Δφ(jet,MET)
  - as opposite to typical WIMP searches
- the main multijet background has low MET and low Δφ(jet,MET)





Requirement	Comment
≥ 2 AK8 jets, with p_T > 170 GeV	signal kinematics
lepton veto	suppress EWK backgrounds
$\Delta\phi_{min}(j_{1,2}, MET)$	
MET/M_T	reject QCD

A baseline selection is optimized to reject background-like events



To resolve the system, the baseline idea is:
i.identify the two semi-visible jets
ii.reconstruct their invariant transverse mass, computed considering the missing momentum too

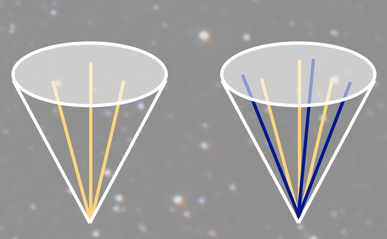
$$M_T^2 = M_{jj}^2 + 2(\sqrt{M_{jj}^2 + p_{T,jj}^2}\not{E}_T - \vec{p_{T,jj}} \cdot \vec{\not{E}_T})$$

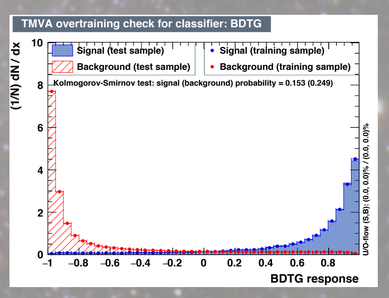
iii.fit the final spectrum and **look for a bump** over SM background

"regular" jet semi-visible jet

Semi-visible jet tagger

Semi-visible jets differ from "regular" jets, and to maximize the separation between background and signal **a dedicated jet identifier is built**





Several variables describing the shape and the properties of the jets are given as input to a a boosted decision tree (BDT)
- high discrimination between signal and background is reached
- powerful handle to reject the contamination from multijet processes and to increase the sensitivity of the analysis

Outlook and future prospects

Preliminary studies look promising, but there are still several aspects that need to be covered
- optimize the dedicated SVJ tagger
- finalize the background estimation strategy and implementation
- look at data collected by the CMS experiment in 2016 and 2017
- perform signal extraction and derive the results, interpreting them through a statistical analysis