Search for dark matter with a top quark pair in the dilepton final state at $\sqrt{s} = 13$TeV with the CMS experiment

Cédric Prieels
Instituto de Física de Cantabria
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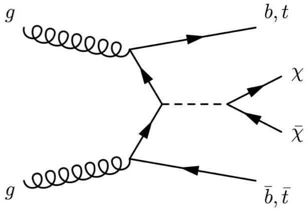
The data analysed throughout this work has been collected in 2016 by the CMS detector of the LHC at a center of mass energy of $\sqrt{s} = 13$ TeV (35.9 fb^{-1}).

We are searching for a particular dark matter candidate produced in association with a $t\bar{t}$ pair **decaying leptonically**:

- Spin 1/2 DM χ (1 GeV)
- Spin 0 scalar (S)/pseudoscalar (PS) mediator ϕ
- Mediator mass $\in [10, 500]$ GeV

$\rightarrow$ Interesting because of its clean signatures, and the low number of significative backgrounds (but low BR).



All the results have been published (EXO-17-014) as the result of the collaboration between three groups (IFCA, DESY, North Western).

The dileptonic final state consists of two leptons coming from the decay of the W (themselves originating from the decay of the two tops), two b-jets and some **missing transerve energy** E_T^{miss}.

We only consider events having **two and only two tight leptons** ($p_T > 25$ and 20 GeV) of opposite charge. Moreover, we require :

- At least two jets
- At least one b-tagged jet
- $m_{ll} > 20$ GeV
- $|m_{ll} - m_Z| > 15$ GeV (ee and $\mu\mu$)
- $E_T^{\text{miss}} > 50$ GeV

Our dominant background is the SM $t\bar{t}$ production, taken directly from MC and checked in a control region.

Two backgrounds are then calculated using **datadriven methods**: the non-prompt leptons (thight-to-loose method), and the DY+jets (Rin-out method, from a data control region in the Z peak window).

All the other minor backgrounds are taken directly from MC.

Process	Events
$t\bar{t}$	$\sim 92\%$
tW	$\sim 4\%$
Non-prompt	$\sim 2\%$
Z+jets	$\sim 1\%$
$t\bar{t}V$	$< 1\%$

All the discrimination is based on the separating power of **four variables**, used as input to a **neural network**.

- E_T^{miss}
- $\Delta\Phi(ll, E_T^{\text{miss}})$
- m_{T2}^{ll}
- dark p_T

The dark p_T is a variable developped in order to try and estimate the value of the p_T of the mediator of the DM interaction.

Basically, the momenta of the tops can be computed from the kinematics of their measured decay products. By computing the kinematics of the SM $t\bar{t}$ process, we can get a set of 6 non-linear equations relating six unknowns.

$$\{p_T^l, p_T^{\bar{l}}, p_T^b, p_T^{\bar{b}}, E_{T,x}^{\text{miss}}, E_{T,y}^{\text{miss}}\}$$

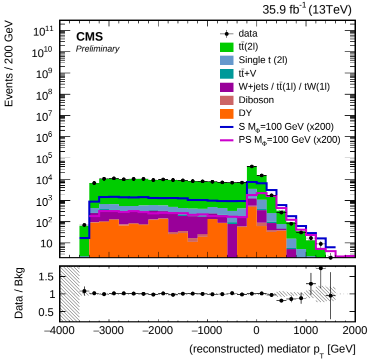
By resolving these equations, we get to a fourth order equation in one of the components of the three-momentum, giving us up to 4 real roots.

However, the dark matter hipothesis modifies the constraints of the previous system (the p_T of both the x and y contributions of the DM).

$\rightarrow$ Intuitively, one can expect not to find any solutions to the top reconstruction when these quantities get higher values.

We can estimate the p_T of the DM by:

- Defining the **cost function** as the distance between the polynomium and the x-axis
- Minimizing it with a gradient descent method on both $\{E_{T,x}^{\text{miss}}, E_{T,y}^{\text{miss}}\}$



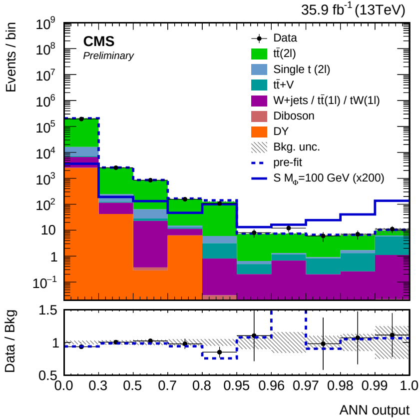
The four previous variables are used as input to a neural network (ANN) that will now be detailed.

The neural network used is made out of **two hidden layers** of 3 and 6 neurons respectively, and makes use of the **tanh activation function**.

A **different ANN** is trained for each mediator model and for each mediator mass, due to the different kinematics associated.

The training is only performed against the $t\bar{t}$ process.

Scalar 100 GeV mediator (x200)



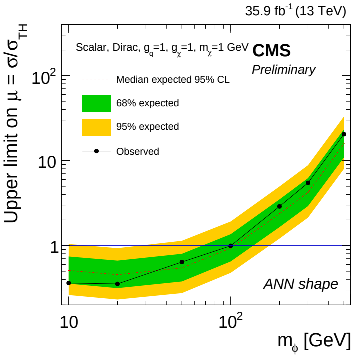
The systematic calculation implies **studying the effect of a change on the signal or background yields** under modification of some parameter.

The impact of different systematics **(normalization, shape)** has been taken into account to compute the limits.

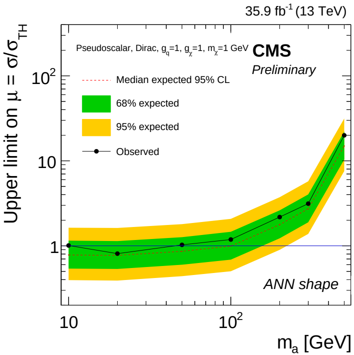
Systematic	Normalization	Shape?
Lumi	2.5 %	No
PU	3 %	No
Non-prompt	30 %	No
Drell-Yan	30 %	No
Other MC	50 %	No
MC stat	1-5 %	Yes
B-tagging	1 %	Yes
ID-iso	4 %	Yes
Trigger	2 %	Yes
JES	1-10 %	Yes
QCD	4-10 %	Yes
PDF	2-3 %	Yes
Top p_T	1 %	Yes

Both the expected and observed upper limits on the signal strength are then computed.

Scalar mediator



Pseudoscalar mediator



With this analysis, we manage to exclude the scalar mediators up to a mass of 105 GeV (observed: 101 GeV), and the pseudoscalar mediators up to a mass of 100 GeV (observed: 46 GeV).

The combination of the dileptonic channel with other final states (semihadronic, hadronic) has already been performed, and is documented in EXO-16-049.

Now that we have access to the 2017 data and MC, we plan on repeating the analysis while making improvements/exploring some leads :

- Using a Deep Neural Network instead of the ANN (gain in sensitivity?)
- Improve the calculation of the dark p_T variable (analytic calculation?)
- Study of boosted and/or long lived tops
- Smaller improvements regarding the calculation of the systematics, the optimisation of the leptons ID, the triggers and the b-tagging.

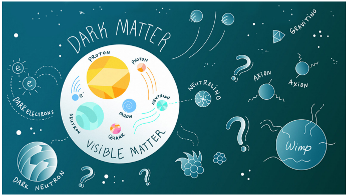
Thank you
for your attention!

Any questions?

Since the discovery of the Higgs boson in 2012, all the predictions made by the Standard Model have been succesfully discovered. Particle physicsts are therefore now searching for eventual extensions to this theoretical model.

We know from astronomical observations that the baryonic matter can only account for 4% of the total mass of the Universe.

Different theories (such as the existence of DM) have been developped in order to explain these observations.



The E_T^{miss}, corresponds to the imbalance of vector momentum in the plane perpendicular to the beam direction.

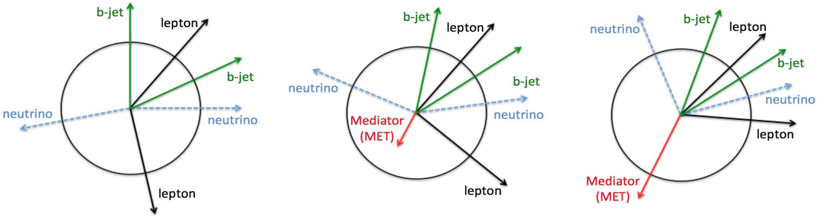
$$E_T^{\text{miss}} = -\sum_i \overrightarrow{p}_T(i)$$

We expect this variable to give some discrimination between the $t\bar{t}$ and our signal because we know that the eventual DM particles produced should escape the detector while being undetected.

The only way to detect the production of this kind of particle is therefore to look at the missing transverse energy.

This variable corresponds to the angle in the Φ plane, between the two leptons coming from the tops and the missing transverse energy.

$t\bar{t}$ background | $t\bar{t}$ + DM (low m_Φ) | $t\bar{t}$ + DM (high m_Φ)



We expect that the tops will be much closer to each other when the mass of the mediator produces raises, so this variable is expected to give some separation between the $t\bar{t}$ and the signal, at least for high mediator masses.

m_{T2}^{ll} has been introduced to measure the mass of a pair of particle produced in the particular case where both these particles decay into a final state including an undetected particle.

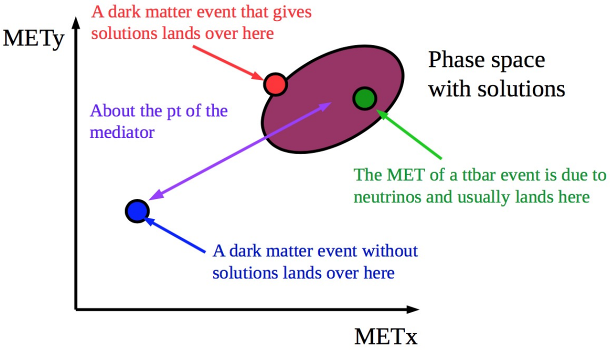
In this case we can only know the total amount of E_T^{miss} of the event considered and there is no way to know the exact contribution to this value given by each neutrino separately.

We then need to calculate the transverse mass for the two pairs of particles, for different repartitions of E_T^{miss}. The repartition giving rise to the smallest possible mass is kept as the value of m_{T2}^{ll}.

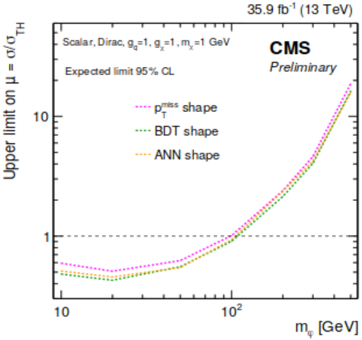
$$\begin{cases} \left(M_T^{(i)}\right)^2 = \left(m_{vis}^{(i)}\right)^2 + m_\chi^2 + 2 \cdot \left(E_T^{vis(i)} E_T^{\chi(i)} - p_T^{vis(i)} \cdot p_T^{\chi(i)}\right) \\ m_{T2}\left(m_\chi\right) = \min_{\sum_i p_T^{\chi(i)}} \left[\max\left(M_T^{(1)}, M_T^{(2)}\right)\right] \end{cases}$$

We expect this variable to give some discrimination between $t\bar{t}$ and our signal because we know that the transverse mass obtained this way for the W has to take values less or equal than the actual mass of the W. However, the presence of additional E_T^{miss} coming for the dark matter can break this condition.

A gradient descent method is performed to go back to the phase space with solution(s), and to estimate the value of the p_T of the DM mediator.



Three different groups have been working on this analysis, with different approaches E_T^{miss} shape, BDT and ANN).



The combination of the three possible final states (hadronic, semileptonic and dileptonic) has been performed (CADI line EXO-16-049).

The combined result has been approved in February 2018, and the CWR has now ended. The paper of the analysis is expected to be published soon.