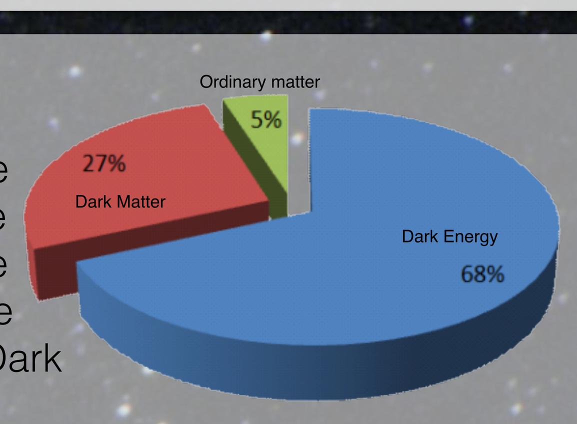
Dark Matter searches with the CMS experiment

Florencia Canelli, Annapaola de Cosa, Giorgia Rauco, Alberto Zucchetta
Open Day of the Department of Physics | University of Zurich, 21-22 November 2019

What is the Universe made of?

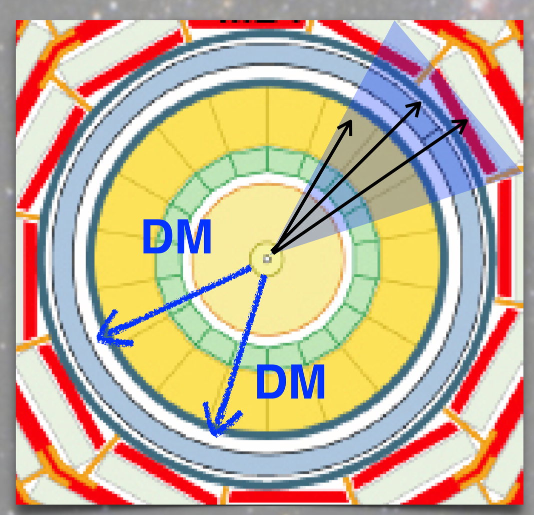
The compelling evidence for Dark Matter (DM) is strongly supported by a variety of astronomical and cosmological observations. It accounts for about 27% of the Universe energy content, more than five times the ordinary matter. Despite the immense experimental effort carried out to shed light on the nature of Dark Matter, we haven't observed it yet. The Dark Matter problem remains one of the most exciting open mysteries of modern physics. If Dark Matter interacts with ordinary matter, we may be able to produce it at the Large Hadron Collider (LHC) and observe it. The CMS UZH group has led some of the most interesting searches for Dark Matter at the LHC, with the latest studies being the search for **DM produced in association with Top Quarks**, and the investigation of new scenarios involving models predicting Dark Matter being made of a multitude of particles, interacting through a dark strong force and manifesting as **Semivisible Jets**.



DM + Top Quarks

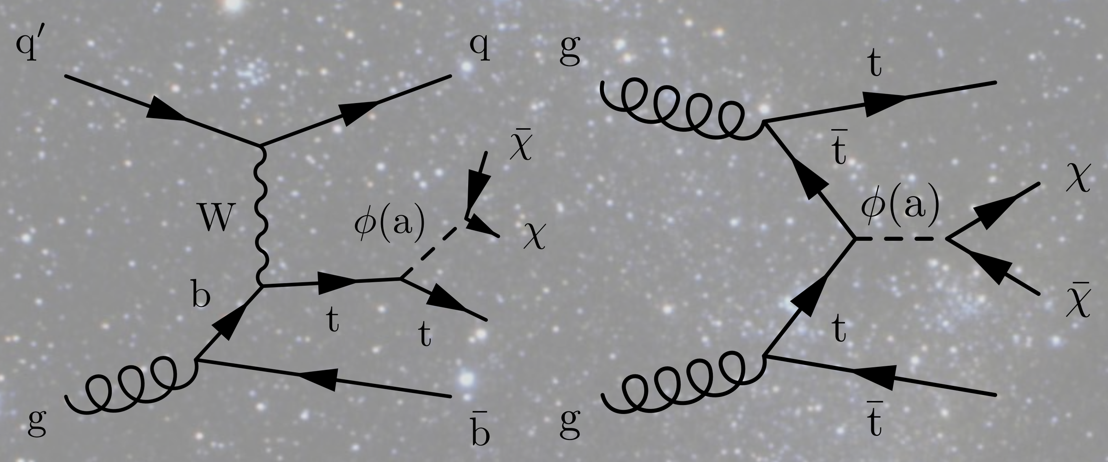
JHEP 03 (2019) 141

Weakly Interactive Massive particles, **WIMPs**, are among the most popular DM candidates. If WIMPs interact with SM particles through a massive mediator, we may be able to produce them at the LHC. Being stable particles, WIMPs would escape undetected, remaining invisible. If the SM-DM mediator is a spin-0 particle, it is expected to couple predominantly to heavy quarks (top and bottom).



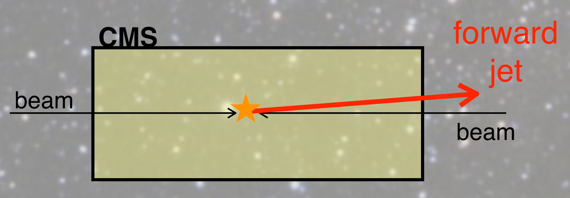
New results are now derived from the combination of multiple selection categories that are defined to target either the **single top quark or the top quark pair** signature.

The final states rely on the measurement of the missing transverse energy (**MET**) in the event resulting from the lack of balanced energy in the detector since the DM passes through it without interacting.



Strategy

- Depending on the number of leptons, events are classified in **two channels**: **semileptonic and hadronic**.
- Dominant background are from top quark pair and V+Jets processes.
- WIMP particles recoil against SM particles, so events with large opening angle between MET and jets are selected (minΔϕ(jet$_{1,2}$, MET)>1.0)
- Events are then classified according to the number of reconstructed b-jets.
  - Additional separation according to the number of jets lying in the forward region of the detector to enhance t-channel production

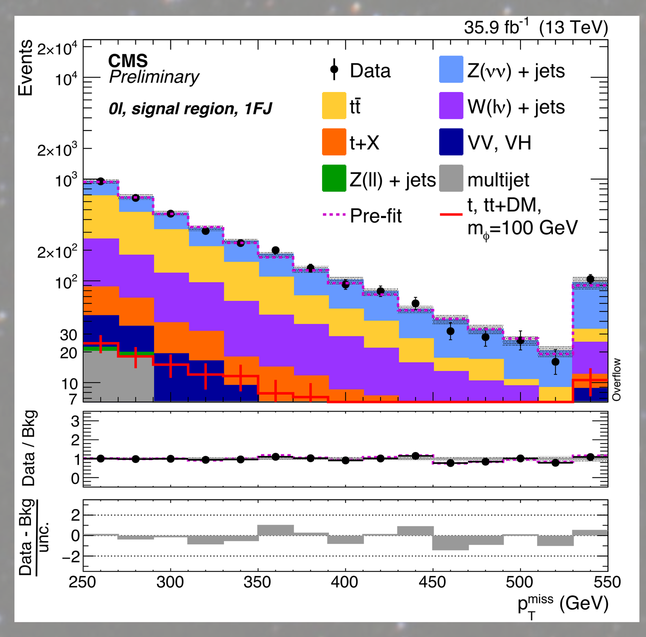


	Single-lepton SRs			All-hadronic SRs		
	1ℓ, 1 b-tag, 0 FJ	1ℓ, 1 b-tag, 1FJ	1ℓ, 2 b-tag	0ℓ, 1 b-tag, 0 FJ	0ℓ,1 b-tag, 1 FJ	0ℓ, 2 b-tag
Forward jets	=0	≥1	—	= 0	≥1	—
n_b	=1	=1	≥2	= 1	=1	≥2
n_{lep}	=1	=1	=1	= 0	=0	=0
$p_T(j_1)/H_T$		—			—	<0.5
n_{jet}		≥2			≥3	
p_T^{miss}		>160 GeV			>250 GeV	
m_T		>160 GeV			—	
m_{T2}^W		>200 GeV			—	
$\min\Delta\phi(j_{1,2}, \vec{p}_T^{miss})$		>1.2 rad.			>1.0 rad.	
m_T^b		>180 GeV			>180 GeV	

- 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 MET distribution in data.

Results

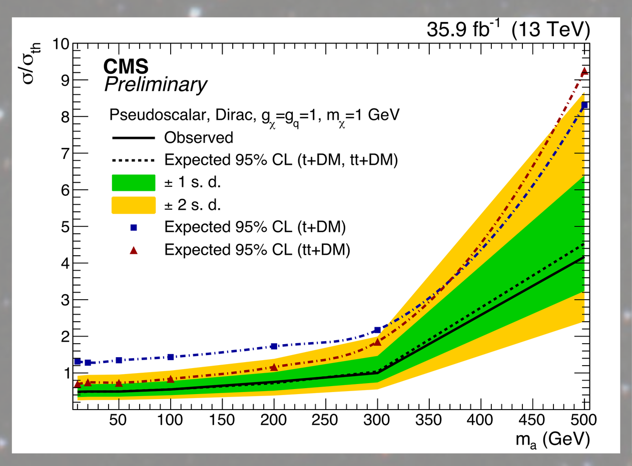
A DM signal would appear as an **excess of events** in the MET spectrum over the SM background.

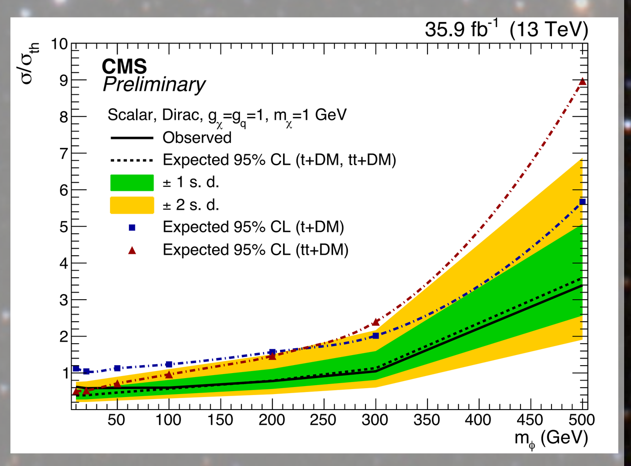


A combined signal+background fit is performed on the **MET distributions** in the different channels. Systematics due to resolution and efficiency of the detector, theory assumptions, reconstructions of the objects, are also taken into account.

No deviation between data and the predictions is observed, and upper limits on the DM production rate are set.

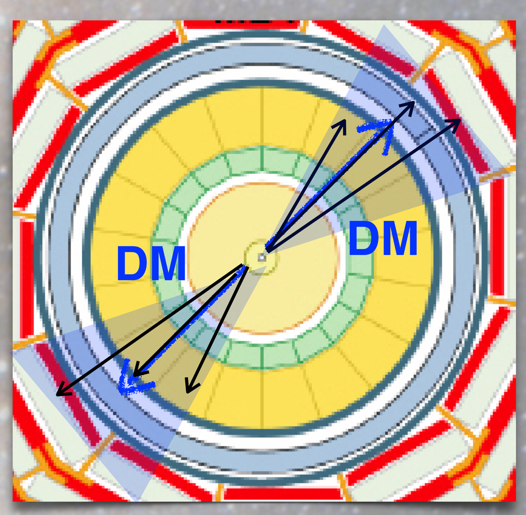
Mediator masses **below 290 and 300 GeV** for the scalar and pseudoscalar hypotheses are excluded.



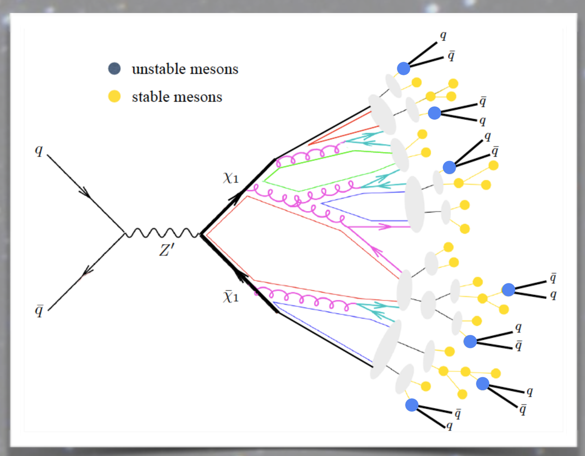


DM in Semivisible Jets

CMS WORK IN PROGRESS



Relaxing the hypothesis of DM being made of WIMP opens up interesting scenarios. A promising idea is that there is a DM sector that can made of a multitude of particles interacting with SM particles through a **dark weak force** and a heavy mediator, and interacting among themselves through a **dark strong force**.



In this scenario DM would manifest in LHC particle collisions with collimated sprays of SM particles mixed to dark particles, which are invisible to the detector. This peculiar signature takes the name of ***Semivisible (SV) Jets***.

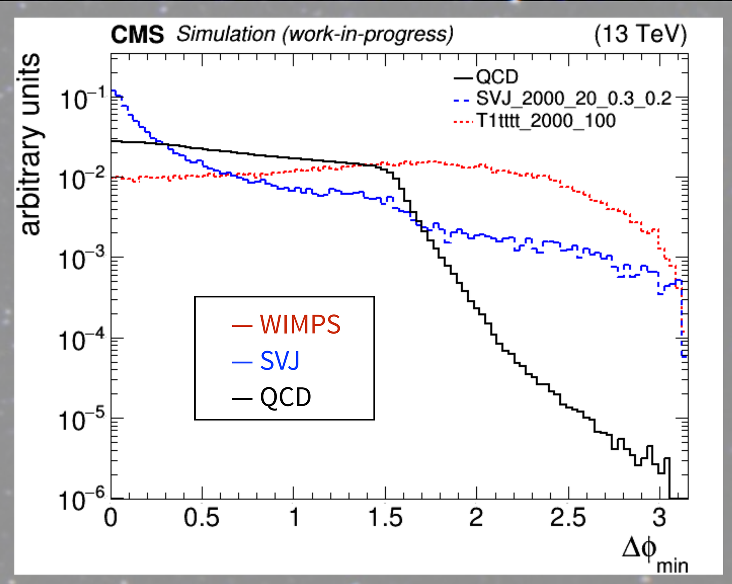
The invisible momentum carried by dark particles appears as an **imbalance in the collision event energy**, quantified by the **MET**

- **SV Jets** signature: **MET aligned to visible jets**
- **WIMP** signature: **MET recoiling against jets**

Strategy

- SVJ signal is characterised by MET aligned to the jets: low azimuthal opening angle, Δϕ(jet,MET)
  - as opposite to typical WIMP searches
- Dominant background (**SM multijet QCD** events) lays at low Δϕ(jet,MET) too

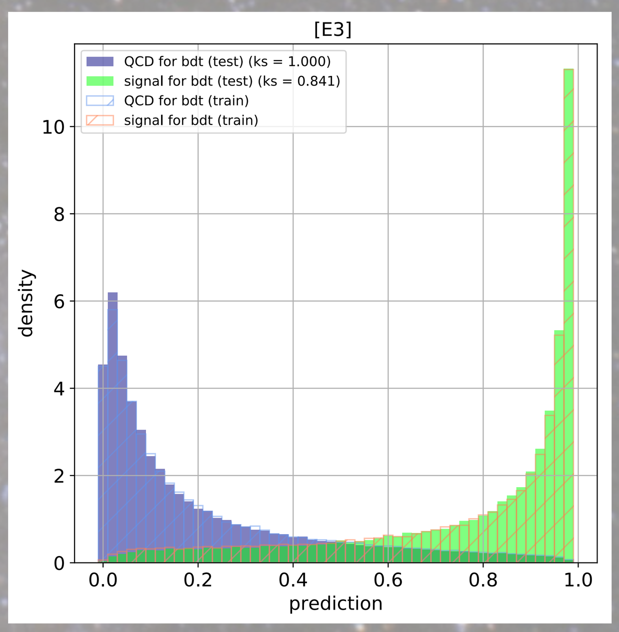
Requirement	Goal
≥ 2 AK8 jets, with p_T > 200 GeV	signal kinematics
lepton veto	suppress EWK backgrounds
$\Delta\phi_{min}(j_{1,2}$, MET) < 0.80	
MET/M_T < 0.25	reject QCD



Selection optimized to reject background data

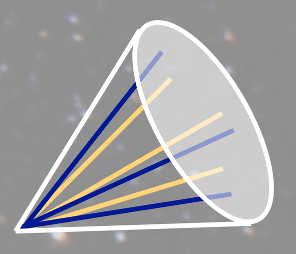
Semi-visible jet tagger

A **neural network** is trained to identify semi-visible jets, which differ from "regular" jets, enhancing the separation between background and signal jets with a **dedicated SV Jet. tagger**.



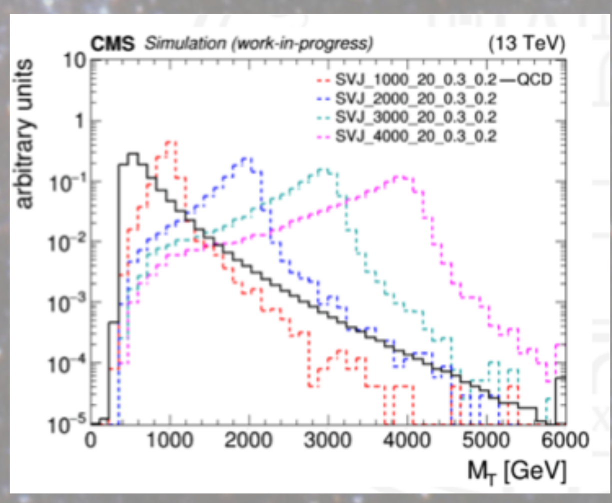
SM jet

Events are classified on the base the number of tagged jets.



SV jet

Results



A DM signal can appear as a bump on the MT spectrum which is reconstructed from the two leading jet momenta plus missing momentum:

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

Results compatible with background-only hypothesis. Mediator masses **below 3.9 TeV** are excluded for SV jet hypothesis of 30% invisible fraction and DM mass of 20 GeV.