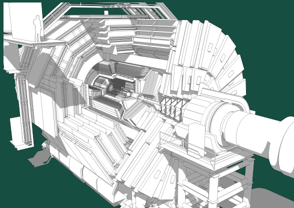
Simplest Fermion Vector-Like Portal Dark Matter model:

Search in the compressed mass region at the CMS experiment

Camilo Salazar

camilo.salazar@cern.ch

May 22, 2019



1. Introduction

2. Motivation

3. Model

4. Collider searches for DM

5. Samples Generation

6. Samples Selection

7. Samples Selection

8. Samples Selection

9. Remarks

10. Backup

UNIVERSIDAD
DE ANTIOQUIA

Introduction

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

Dark Matter (DM) constitutes one of the main unsolved problems in fundamental physics. Ever since it was proposed to explain the rotation curves of galaxies, some other astronomical observations left little doubt of its existence.

Whatever DM is, the Standard Model (SM) is not able to produce a candidate that have, at the present time in the universe, stability and also interact very little or not at all with known matter, proven properties of DM.

UNIVERSIDAD DE ANTIOQUIA

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

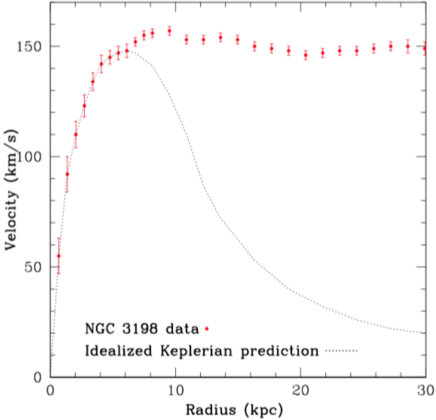


Figure 1: Measured rotational velocities of HI regions in NGC 3198 compared to an idealized Keplerian behavior [Astron. and Astrophys. 223, 47-60]

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

UNIVERSIDAD DE ANTIOQUIA

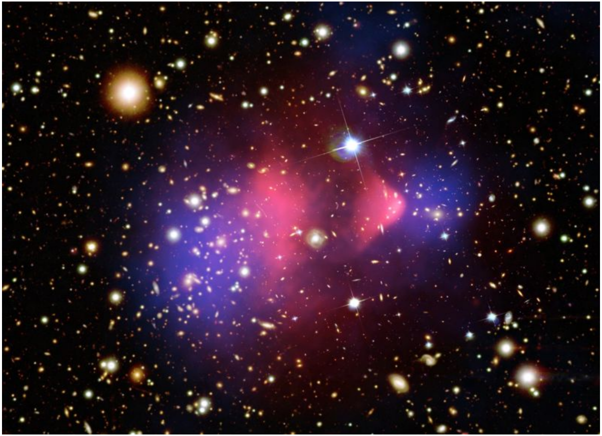


Figure 2: The Bullet cluster, the result of a subcluster (the "bullet") colliding with the larger galaxy cluster 1E 0657-56 [arXiv:1711.02117]

Motivation

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

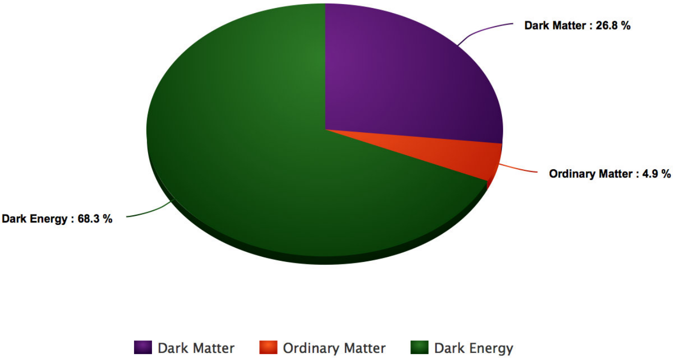


Figure 3: Simplified plot showing the estimate abundances

Detection Channels

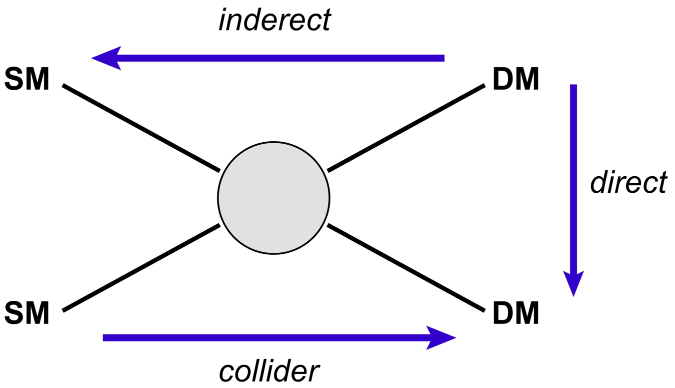


Figure 4: Schematic showing the possible dark matter detection channels.

Model

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

The VLF model introduce a vector-like charged fermion also $SU(2)_L$ singlet, and a scalar particle. The free Lagrangian reads

$$\mathcal{L} = \mathcal{L}_{SM} + m_F \bar{F} F + (Y_\ell S \bar{F} \ell_R + \text{h.c.}) + V(S, H) \;;$$

m_F is the singlet fermion mass parameter, ℓ_R are the SM right-handed lepton fields, Y_ℓ are the Yukawa couplings. The contribution to the scalar potential is given by

$$V(S, H) = \frac{m_S^2}{2} S^2 + \frac{\lambda_S}{4} S^4 + \lambda_{SH} S^2 |H|^2 \;,$$

with scalar mass parameter m_S and quartic couplings λ_S and λ_{SH}.

Kinetic Lagrangian

The kinetic terms for thevector-like charged fermion reads as follows

$$\mathcal{L}\ \bar{F}(D_\mu\gamma^\mu)F, \tag{1}$$

consequently the simplest production and decay process at the LHC is pair-production of vector-like fermions, followed by their subsequent decay to a lepton and the DM scalar.

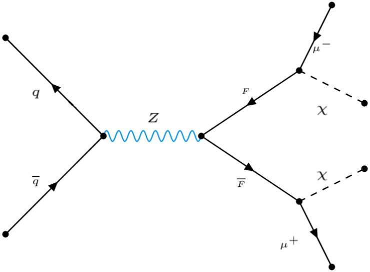


Figure 5: Pair-production of vector-like fermions ($pp \to F^- F^+$), in a Drell-Yan process, followed by their decay into a lepton and the DM particle ($F^- \to \ell^- S + \text{ h.c.},\ \ell = \mathrm{e}, \mu, \tau$)

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

UNIVERSIDAD DE ANTIOQUIA

We focus on scenarios where the vector-like portal for DM annihilation is dominant and, therefore, we set initially.

$$\lambda_{SH} = 0;$$

also we assume that the DM candidate does not couples to the electron.

$$Y_e = 0;$$

the remaining parameters, Y_μ,Y_τ , m_S and m_F are allowed to vary freely.
Also we are searching into the compress mass regime

$$\Delta m = m_F - m_S \lesssim 50 \text{ GeV}$$

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

UNIVERSIDAD DE ANTIOQUIA

Signals

1. Cascades of heavier particles to the DM candidate and SM.
2. DM production in association with other SM particles,

One-muon + jet channel

The process chows in Figure 5, leads to the signature opposite sign leptons plus missing energy however,

- for small $\Delta m(F - S)$ the probability that one or both leptons are not detected in the collider increases.
- $pp \to F^+ F^- j$ provides a jet which can be used as a trigger.

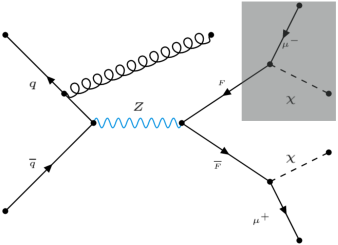


Figure 6: Pair-production of vector-like fermions, followed by their decay into a lepton and the DM particle, one missing lepton and a ISR jet

Parameter Region

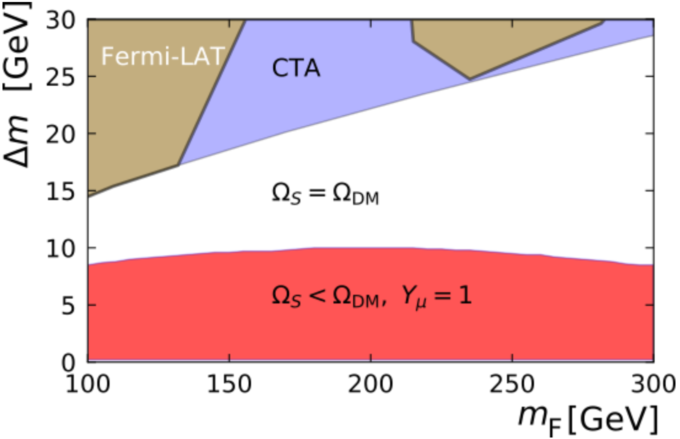


Figure 7: m_F vs Δm. The brown upper region is excluded by Fermi-LAT H.E.E.S, while the combined upper region with light and dark magenta are the prospects for Cherenkov Telescope Array. The Red area is the area where the relic density is not satisfy by the model

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

The backgrounds for this process are single top, WZ, and w+jets. This last one being the most important.

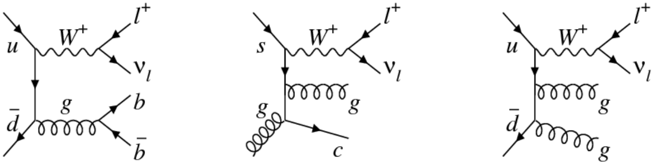


Figure 8: Some W+jets diagrams

Samples Generation

The Monte Carlo(MC) collision samples for the signal and the BackGrounds (BG) were generated using a combination of MadGraph (version 2.5.5) for the event generation, Pythia (version 8.233) for the hadronization and Delphes (version 3.4.1) for the detector effect emulation.

	W+Jets	**WZ**	**SingleTop**
σ (Pb)	3377.37	22.82	288.17
$\sigma \times \mathcal{L}$	337737000	2282000	28817000
MC	50214	173715	319006
Weight	6725.95	14.65	90.33

Table 1: Weights for the MC samples, based on the expected events.

Background Tunig

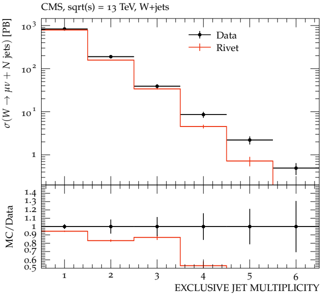
To generate the background we use the tunes extract for the data from CMS at the reference [CMS-PAS-GEN-17-001]

PYTHIA parameter	**Value**
PDF Set	NNPDF3.1
$\alpha_S(MZ)$	0.118
SPACESHOWER:RAPIDITYORDER	on
MULTIPARTONINTERACTIONS:ECMREF [GeV]	7000
α_S^{ISR}	0.118/NLO
α_S^{FSR}	0.118/NLO
α_S^{MPI}	0.118/NLO
α_S^{ME}	0.118/NLO
MULTIPARTONINTERACTIONS:PT0REF [GeV]	1.41
MULTIPARTONINTERACTIONS:ECMPOW	0.03344
MULTIPARTONINTERACTIONS:CORERADIUS	0.7634
MULTIPARTONINTERACTIONS:COREFRACTION	0.63
COLORRECONNECTION:RANGE	5.176
χ^2/dof	1.04

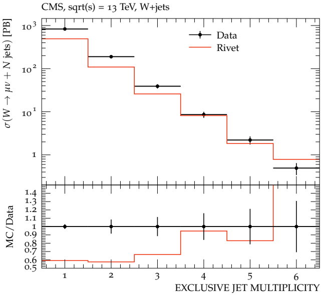
Table 2: Pythia 8 parameter values

Background Tuning

After the tunig we use Rivet[] over the analysis [PhysRevD.96.072005] to compare



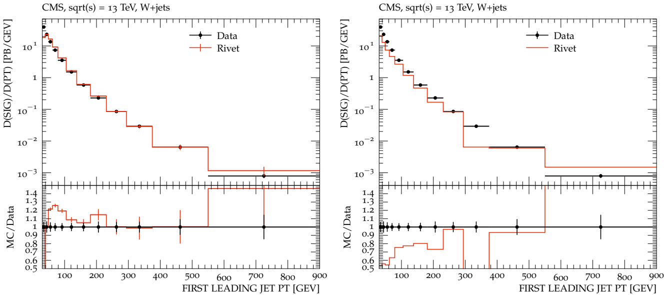
(a)



(b)

Figure 9: Differential cross section measurement for the exclusive jet multiplicities with tune (a) and with out tune (b)

Background Tuning

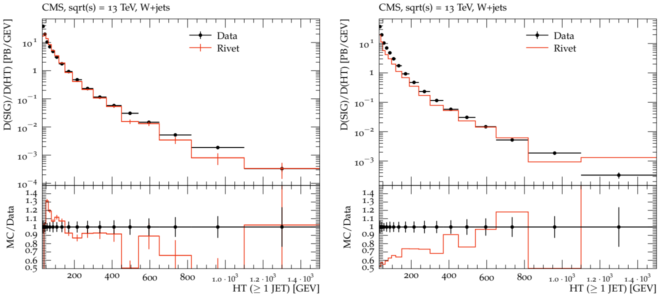


(a) (b)

Figure 10: Differential cross section measurement for the exclusive jet multiplicities with tune (a) and with out tune (b)

Background Tuning

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

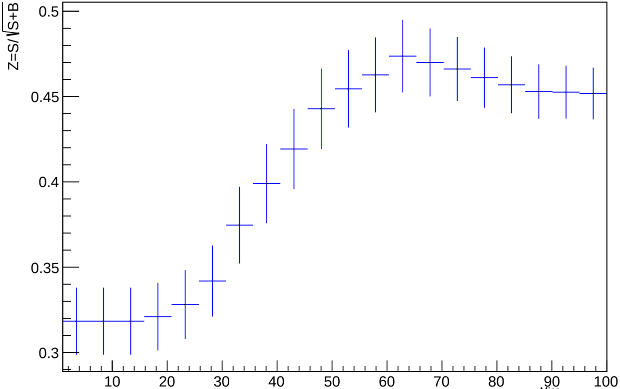


(a) (b)

Figure 11: Differential cross section measurement for the jets HT for at least 1 jet with tune (a) and with out tune (b)

Selection

The values for the cuts were defined through an optimization process based on the $\frac{S}{\sqrt{S+B}}$, we normalize all MC to 100 fb^{-1} luminosity and the signal mass point $m_F = 140$GeV vs $\Delta m = 20$GeV



UNIVERSIDAD DE ANTIOQUIA

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

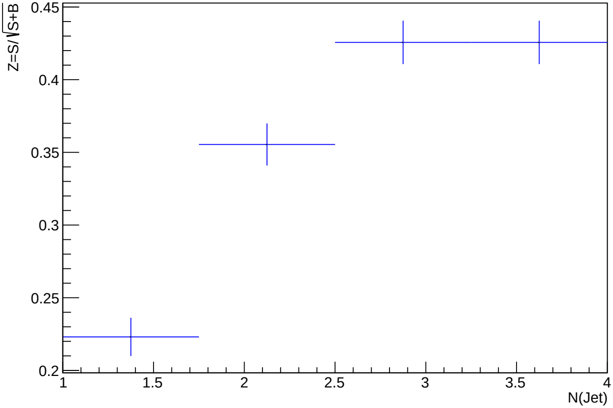


Figure 13: Significance of the cut (type less- than) for the number of Jets

Selection

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

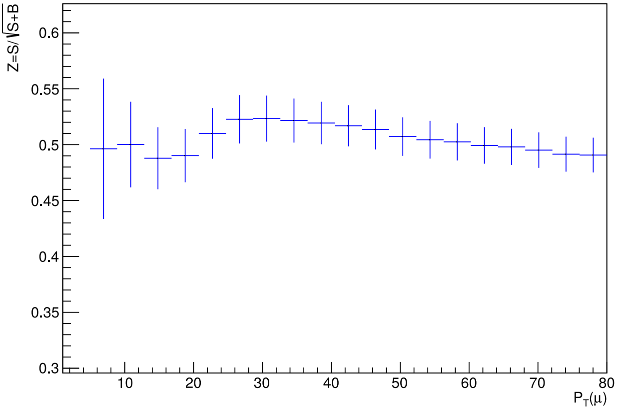


Figure 14: Significance of the cut (type less- than) for the $p_T(\mu)$

UNIVERSIDAD DE ANTIOQUIA

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

Cut	**Selection**
Trigger	MonoJet
$N(\mu)$	1
$p_T(\mu)$	<30 GeV
$N(Jet)$	<3
m_T(p_T(\mu),MET)	<60

Table 3: Cuts, monoJet triggers means MET>110 GeV, MHT>110 GeV

Results

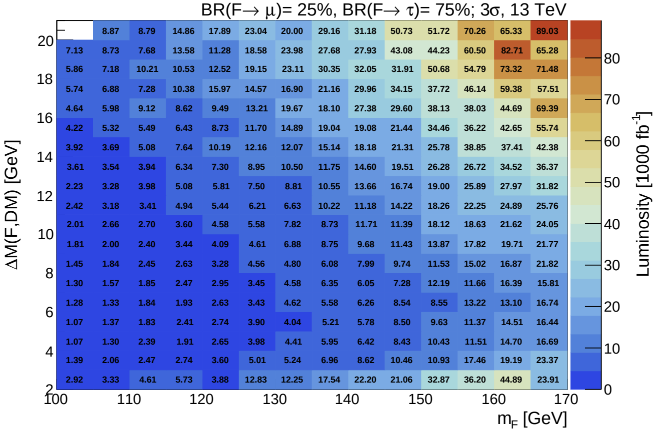


Figure 15: 3 σ reach for m_F vs Δm parameter space for various luminosity in 1000fb^{-1}.

Exclusion Potential

Introduction

Motivation

Model

Collider searches for DM

Samples Generation

Samples Selection

Samples Selection

Samples Selection

Remarks

Backup

UNIVERSIDAD DE ANTIOQUIA

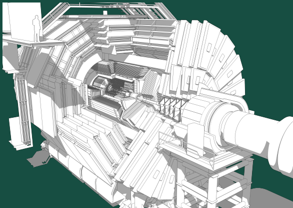
We want to exclude the region of parameters of the model, which is still unexplored Figure 7, the intersection between the regions in Figures 7 and 15 shows the exclusion potential for the study. The exclusion is carried out assuming that what is going to be observed is only the standard model

Remarks

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

1. Although the model have been analyzed. there is still the region of the parameter space ($\Delta m = m_F - m_S \lesssim 50$ GeV) with exclusion potential.
2. The full dark matter content may be explained either by freeze-out at higher redshifts, or by another dark matter content.
3. We can obtain exclusion sensitivity over a large region of parameter has not yet been covered by any other search.

Thank You.



C.Salazar

MC Validation

Introduction
Motivation
Model
Collider searches for DM
Samples Generation
Samples Selection
Samples Selection
Samples Selection
Remarks
Backup

To validate the W+Jets background we use the Table 1 from [CMS-PAS-SMP-16-005], where they have $\sqrt{s} = 13$ TeV proton-proton MC samples normalized to an integrated luminosity of 2.5 fb^{-1}

	$N_{Jets} = 1$	$N_{Jets} = 2$	$N_{Jets} = 3$	$N_{Jets} = 4$
CMS-PAS-SMP-16-005	1854568	384856	78271	14577
VLF-study	370200	345520	137282	62471
Diff	1484368	39336	-59011	-47894

Table 4: Number of events simulation as a function of the exclusive jet multiplicity. Events are required to have exactly one muon and one or more jets for the $W \to \mu\nu + jets$ production, muons are required to have $p_T > 25$ GeV and $|\eta| < 2.4$, and jets are required to have $p_T > 30$ GeV, and last $M_T > 50$ GeV

Currently looking into it.

Gamma-ray from the Galactic center measured Fermi-LAT Collaboration could be explained by these type of models.

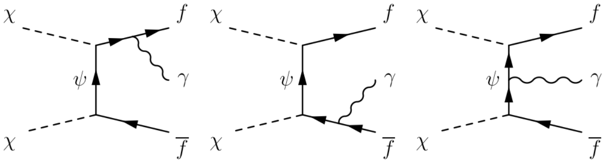


Figure 16: Internal Bremsstrahlung processes of (real) scalar DM. From [Phys Rev Lett. 2013 Aug 30;111(9):091301.]

Similar Searches

- Search for top squark pair production in pp collisions at $sqrt(s) = 13$ TeV using single lepton events (arXiv:1706.04402) 17
- Search for top squarks decaying via four-body or chargino-mediated modes in single-lepton final states in proton-proton collisions at $sqrt(s) = 13$ TeV (arXiv:1805.05784)

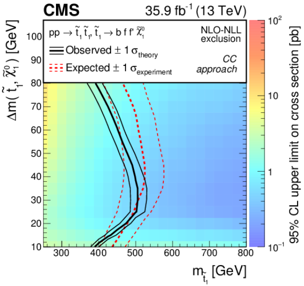


Figure 17: Exclusion limit at 95% for the four-body decay of the top squark as a function of $m(\tilde{t})$ and δm