Search for dark matter with the ATLAS detector at the LHC

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on behalf of the ATLAS collaboration

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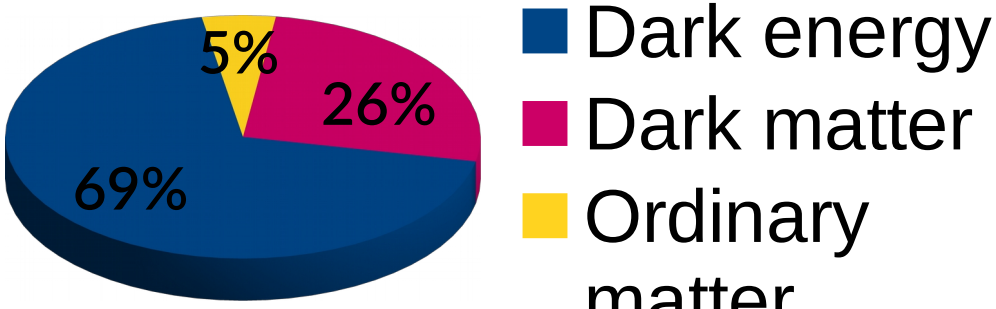
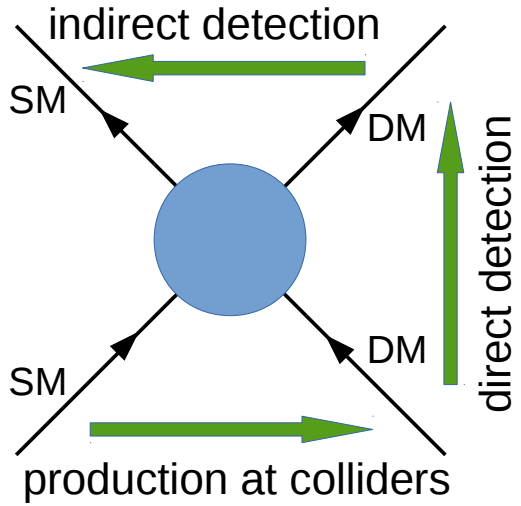
Introduction



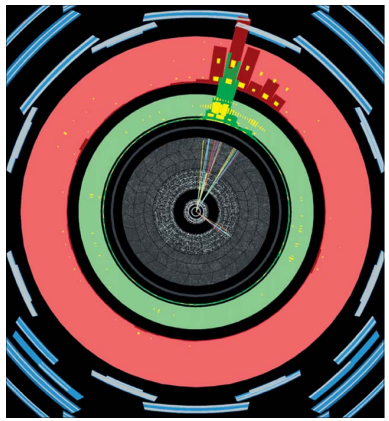


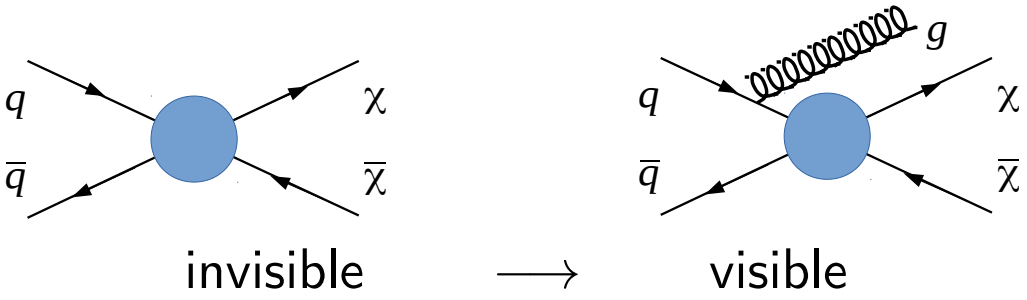
Dark matter (DM) searches:

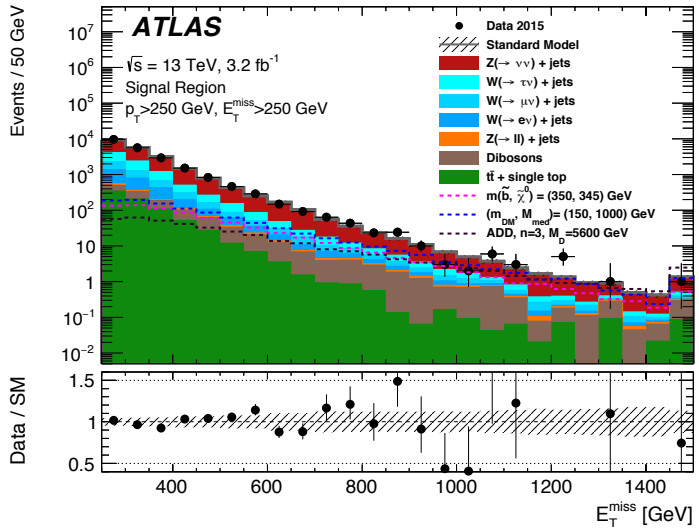
- direct detection (scattering of DM on atomic nuclei in the detector)
- indirect detection (annihilation/decay of DM into the Standard model (SM) particles)
- production and detection **at particle accelerators** (annihilation of SM into DM particles)

Introduction

- DM can not be directly observed in ATLAS (does not interact with the detector)
- production of DM pairs can be identified via presence of an imbalance in transverse momenta ("missing energy") in the plane transverse to the beam line $E_T^{\text{miss}} = |-\sum \vec{E_T}^{\text{visible}}|$
- Hermetic calorimetric coverage of the ATLAS detector provides a good measurement of E_T^{miss}.
  - Consider signatures with radiation of extra particles

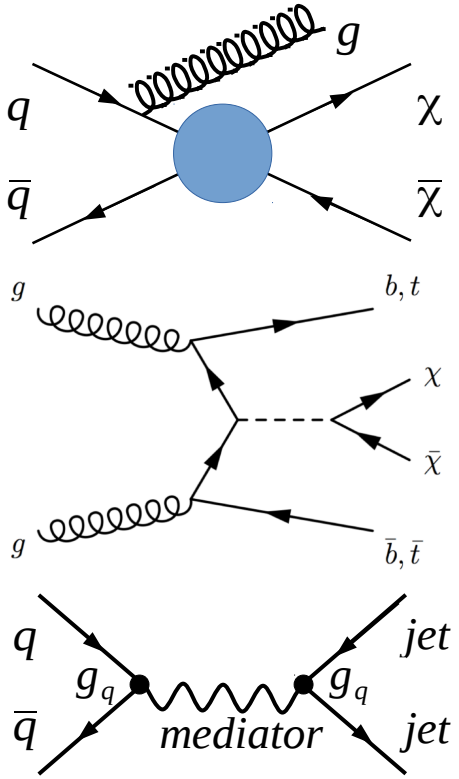






Introduction

- Mono-X (DM recoiling against X)
  Generic experimental signature:
  $pp \to E_T^{\text{miss}} + X$, where X =jet, γ, W/Z ($\to$ lep/jets), t/b or H
- Associate Production
- Search for mediators (dijet resonance)



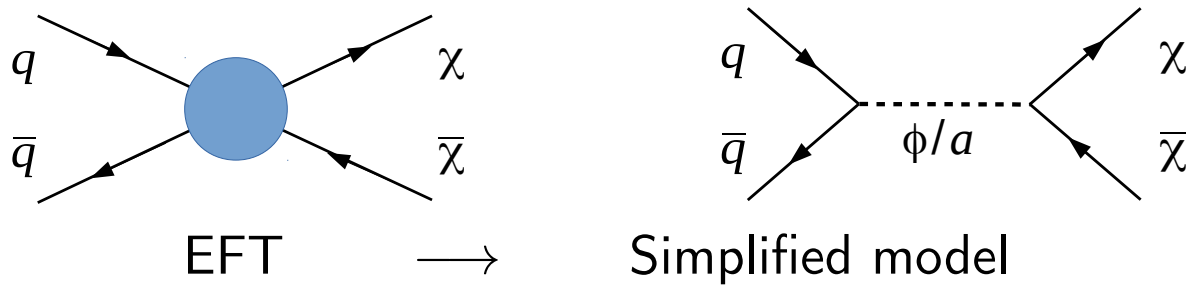
Many DM searches in ATLAS, this talk does not aim to cover them all.

Approaches

Complete models (e.g. SUSY):
+ Give more specific predictions
– Less general approach
– Large number of free parameters

Effective field theories (EFTs): arXiv:1008.1783
Extensively used in Run-I
DM and SM particle interaction is described by the effective operators. Parameters: m_χ and M^*.
+ More generic
– Valid only for low momentum transfer $Q^2_{\rm tr} << M^2_{\rm med} = M^* g_\chi g_q$.

Simplified models: arxiv:1506.03116
Commonly used in Run-II. DM and SM particles interact via a mediator.
+ Cover features of a class of models and stay valid at high energies.
+ Described by a small number of free parameters (e.g. $M_{\rm med}, m_\chi, g_{\rm SM}, g_{\rm DM}$)



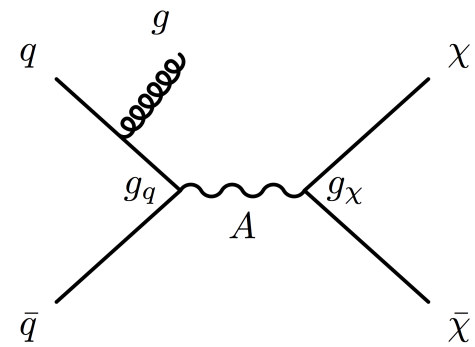
LHC DM forum report: arxiv:1507.00966

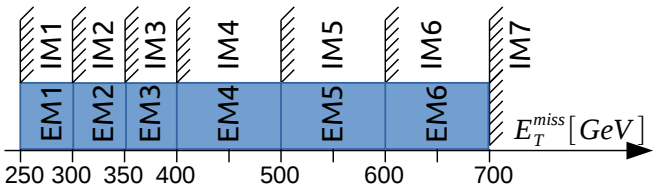
Results presentation: arxiv:1603.04156

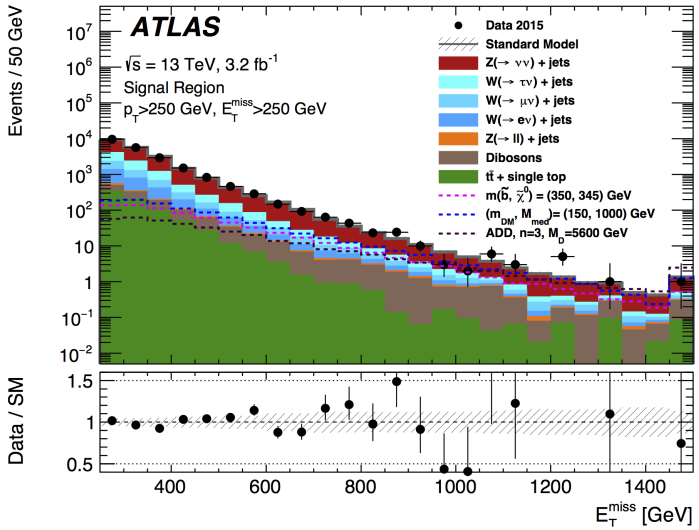
Mono-jet search

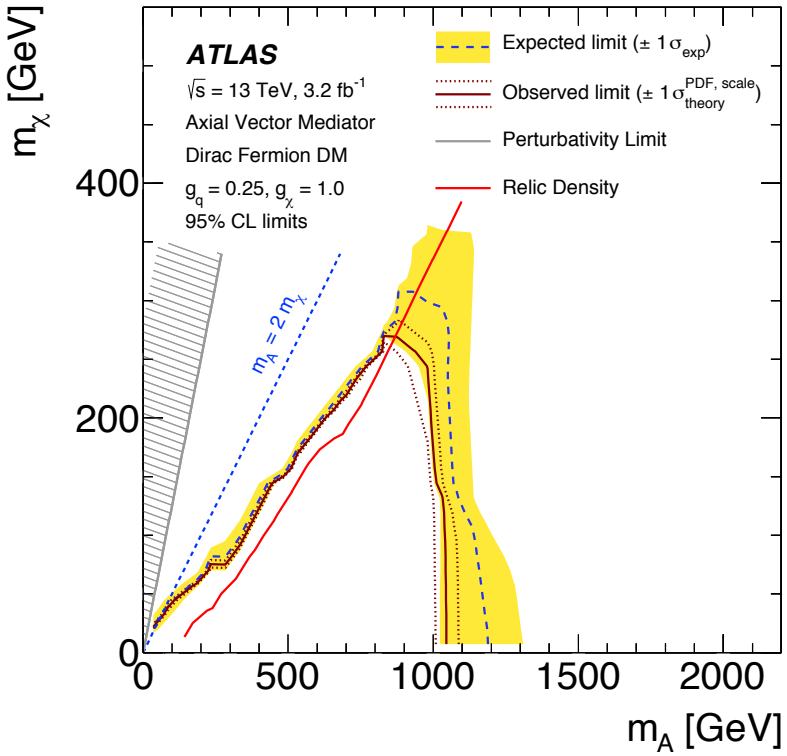
Phys. Rev. D 94, 032005

- Requires large E_T^{miss} and at least 1 high p_T jet
- signal regions (SR) inclusive and exclusive in E_T^{miss}
- dominant backgrounds: $Z(\nu\bar{\nu})$+jets, $W(l\bar{\nu})$+jets
- results interpreted with an axial vector mediator model; Dirac fermion DM
- parameters: m_χ, m_A, coupling g_χ and flavor-universal coupling to quarks g_q.





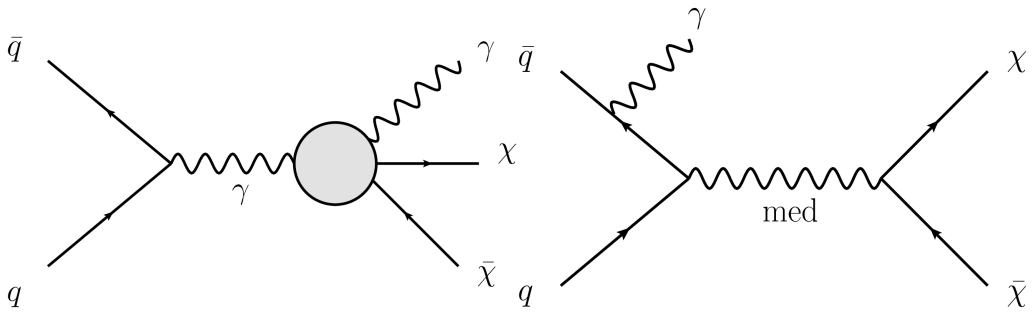


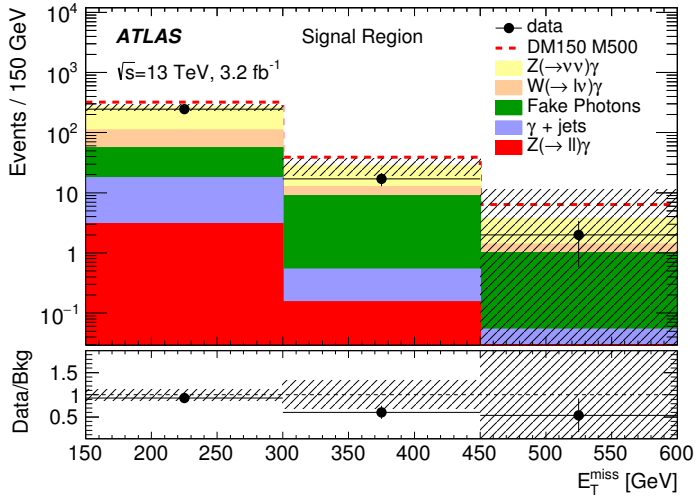


Mono-photon search

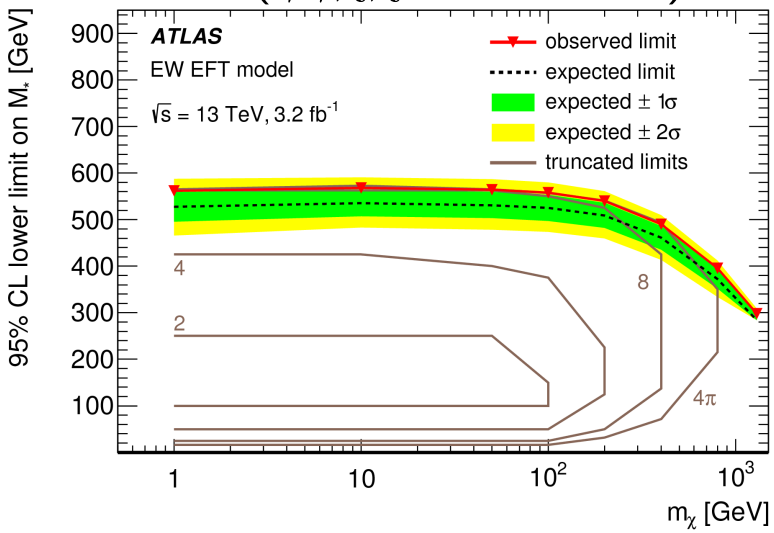
JHEP06 (2016) 059

- Large E_T^{miss} and high-p_T photon, minimal extra jet activity, no lepton
- Dominant background $Z(\to \nu\bar{\nu}) + \gamma$, where γ due to initial-state radiation
- strength of the EFT interaction is controlled by M_*, for simplified models limits are set on the signal strength μ

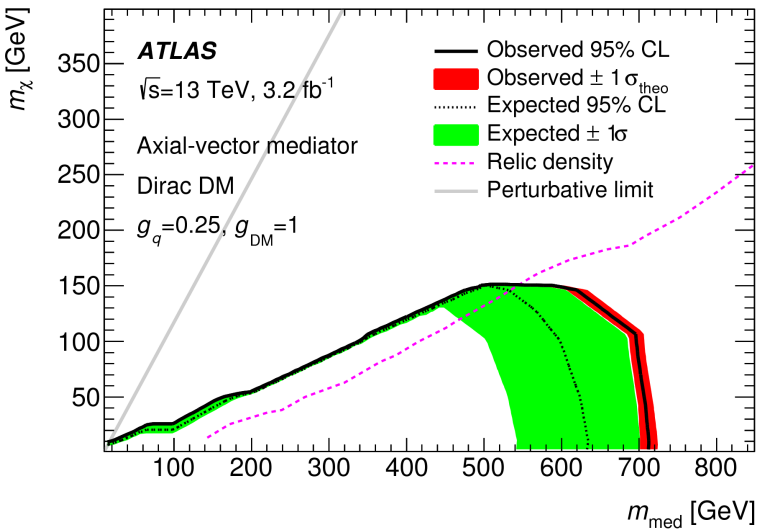




EFT ($\gamma\gamma\chi\chi$ interaction)



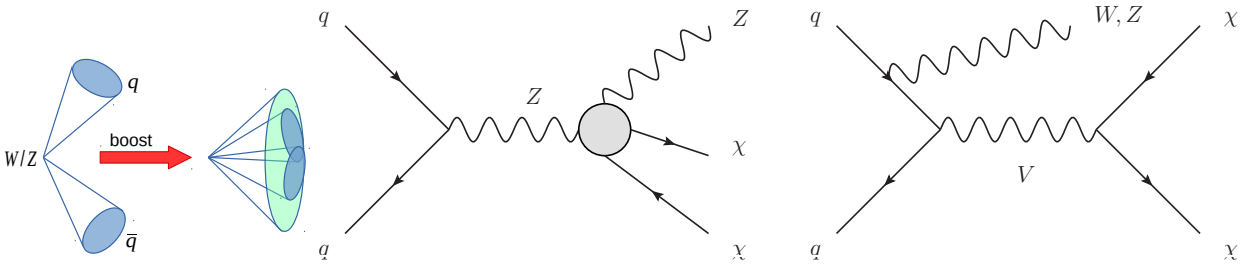
simplified model with axial-vector mediator

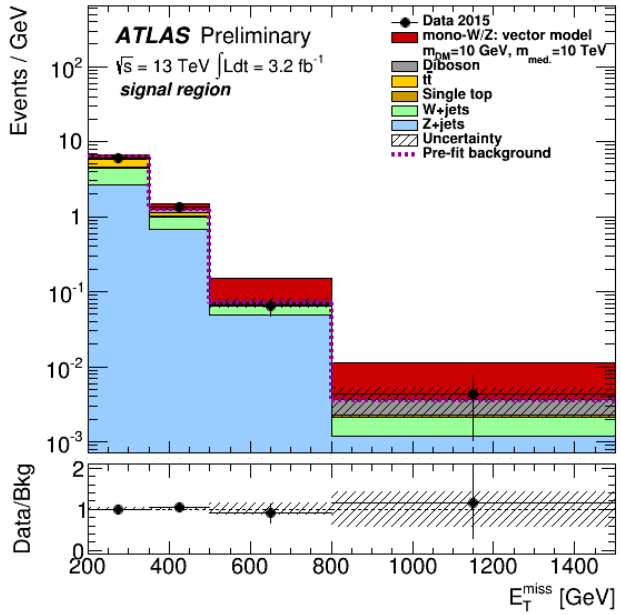


Mono-V(hadronic) search

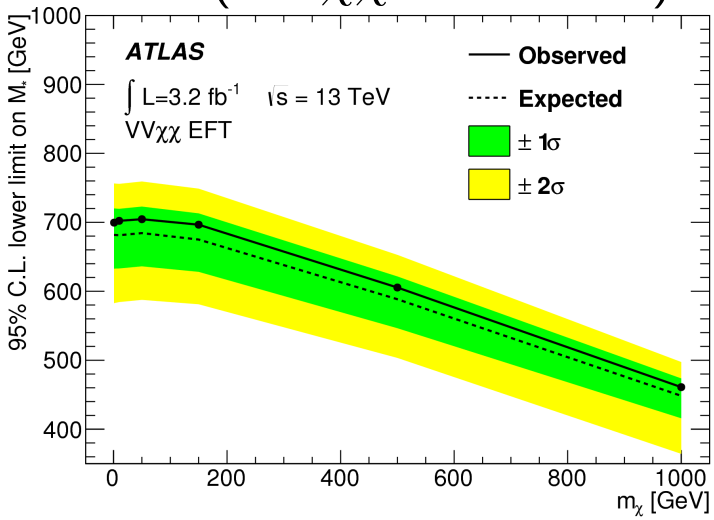
JHEP 01 (2016) 172

- W/Z hadronic decays (BR larger)
- dominant backgrounds: $Z \to \nu\nu$, W/Z+jets (unidentified leptons)
- utilize small- and large-radius jets

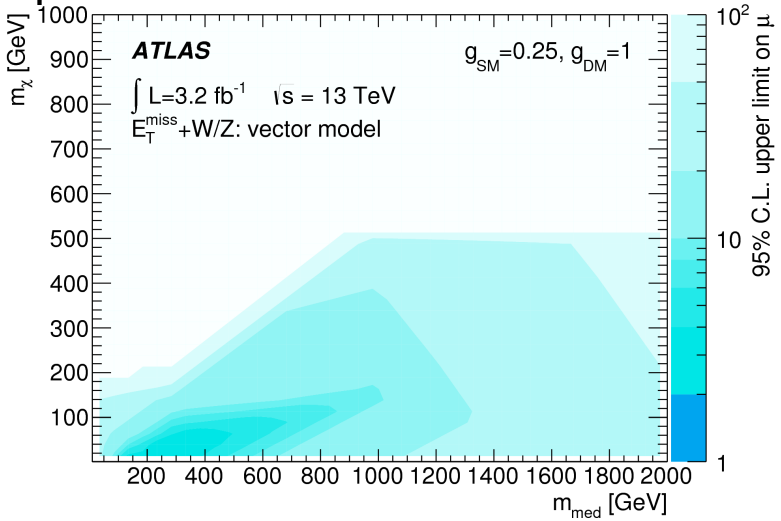




EFT ($VV\chi\chi$ interaction)



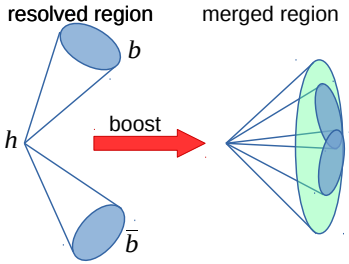
simplified model with vector mediator

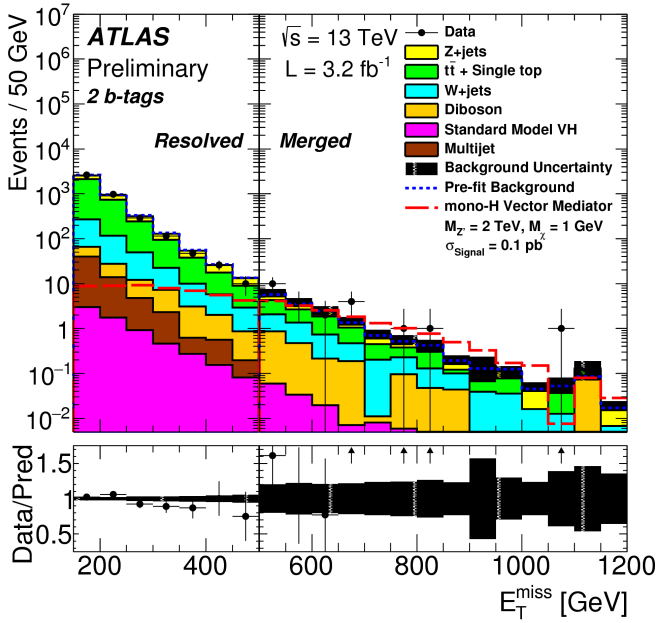


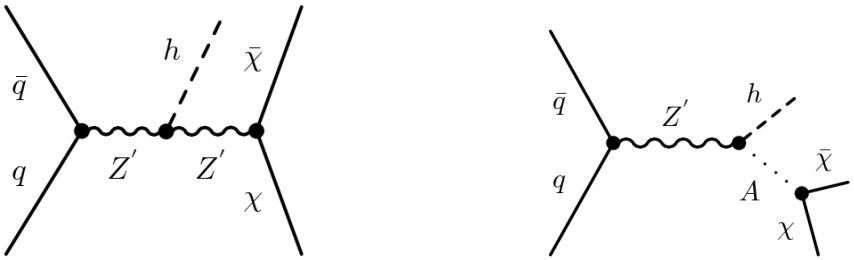
Mono-Higgs search

ATLAS-CONF-2016-019

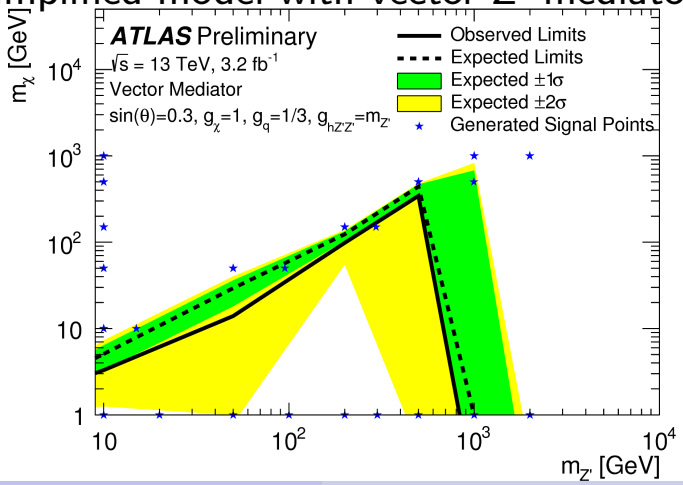
- $E_T^{\text{miss}} + h,\ h \to b\bar{b}$
- small- and large-R jets exploited depending on E_T^{miss}
  - shape-fit of the invariant dijet mass or mass of large-R jet
  - dominant backgrounds: SM $W/Z+$ jets, $t\bar{t}$



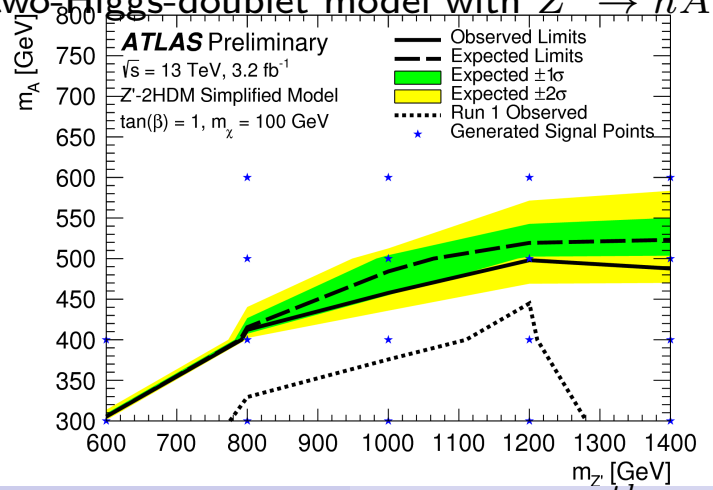




simplified model with vector Z' mediator



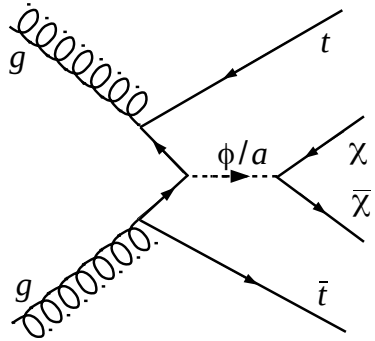
two-Higgs-doublet model with $Z' \to hA$



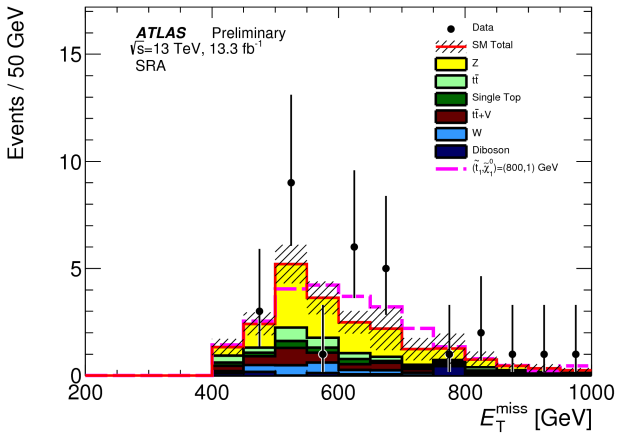
DM+$t\bar{t}$

Interaction between quark and scalar Dirac DM: $\frac{m_q}{M_*^3}\bar{q}q\bar{\chi}\chi \Rightarrow$ coupling to the heavy quarks is stronger $\Rightarrow$ larger sensitivity

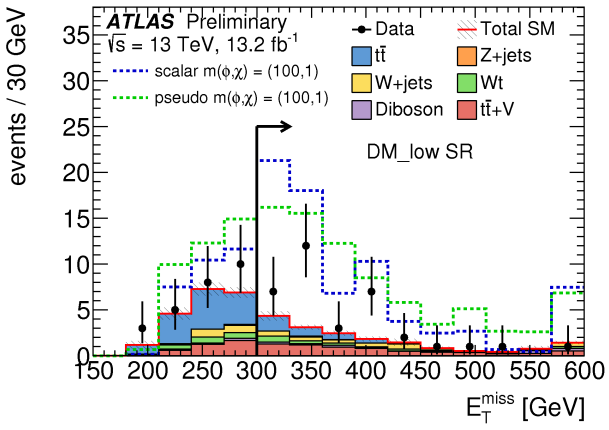
- Interpretation of SUSY search to the simplified model with Dirac fermion DM and scalar/pseudo-scalar mediator
- Three searches: hadronic, semi-leptonic and di-leptonic decays of the top quarks:



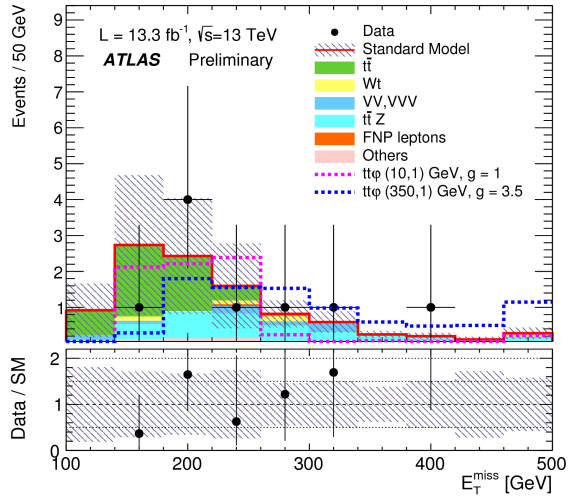
0 lep: ATLAS-CONF-2016-077



1 lep: ATLAS-CONF-2016-050



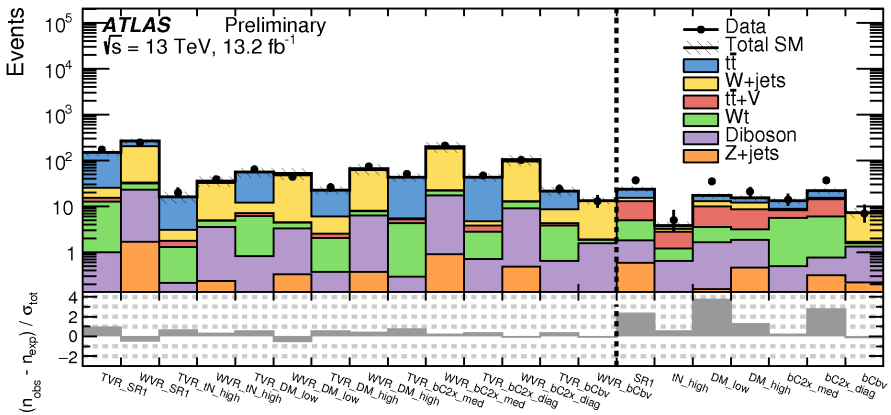
2 lep: ATLAS-CONF-2016-076

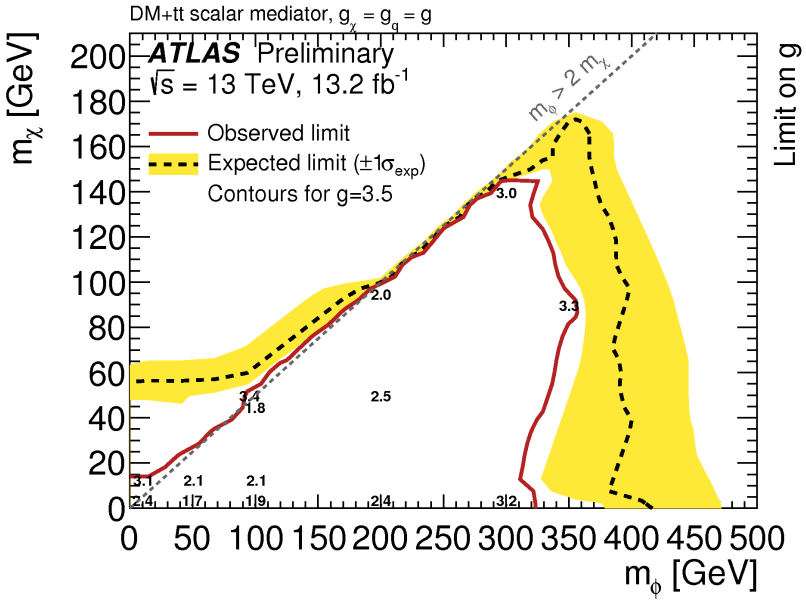


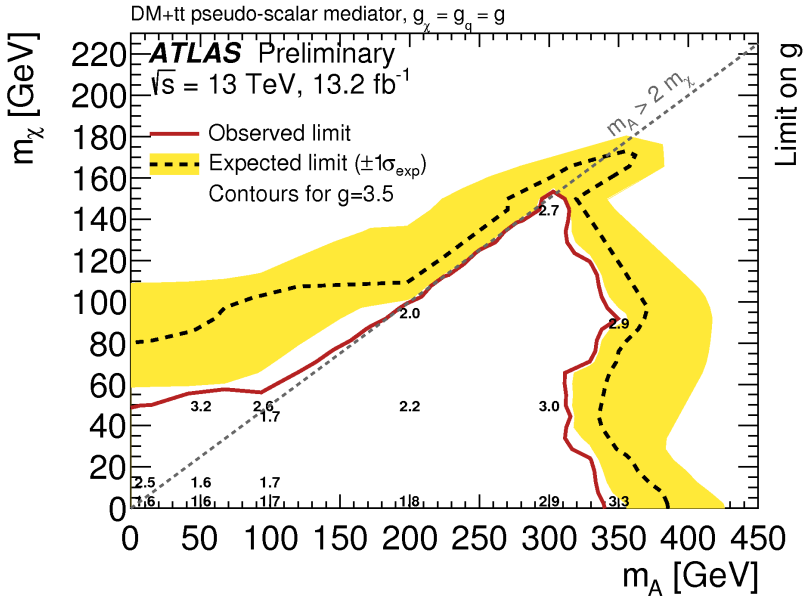
DM+$t\bar{t}$, 1L

ATLAS-CONF-2016-050

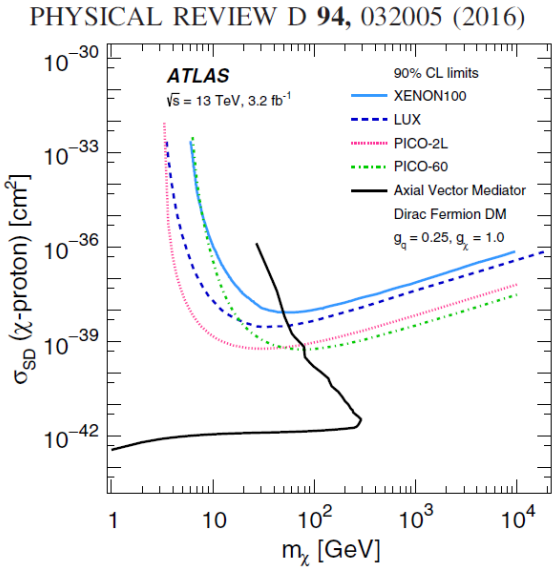
- $pp \to t\bar{t}\chi\bar{\chi}$, $t\bar{t} \to bW(q\bar{q})bW(l\bar{\nu})$
- Excess of 3.3 σ observed in DM_low
- Mild deviation of 2.6 σ is found in bC2x_diag
- Dominant backgrounds: $t\bar{t}$, single top Wt, $t\bar{t} + Z(\to \nu\bar{\nu})$, and W+jets
  - Main discriminating variables: E_T^{miss}, m_T, $amT2$, topness

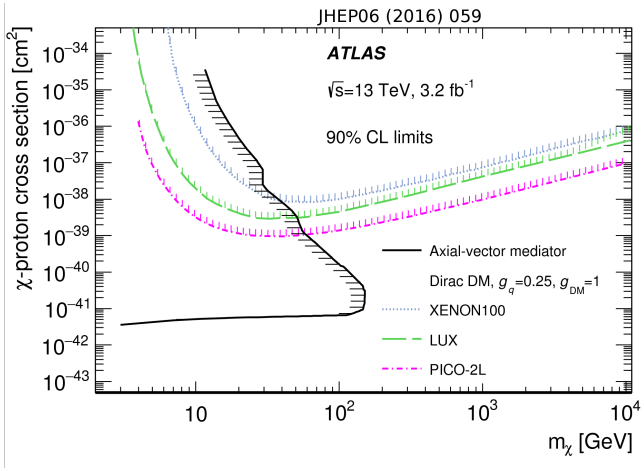


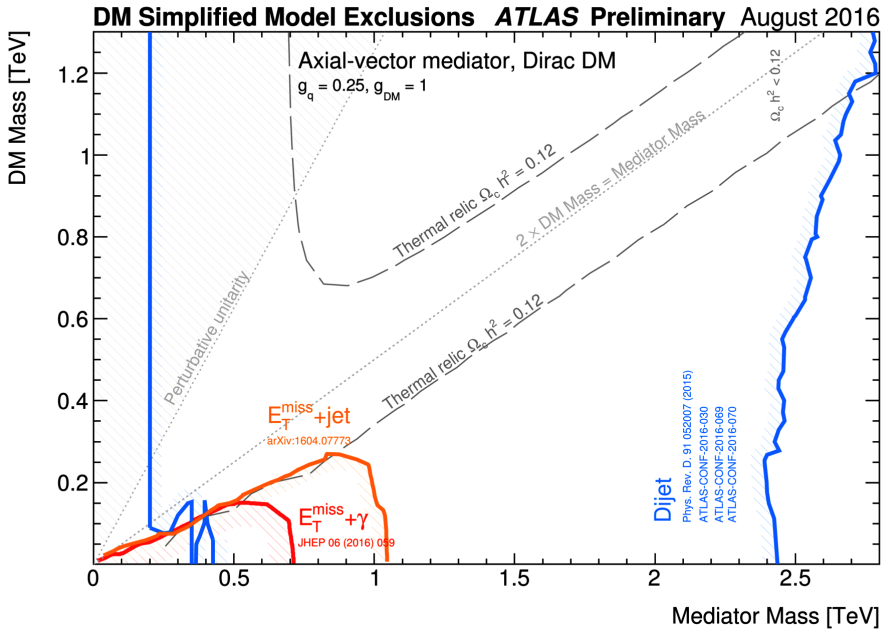


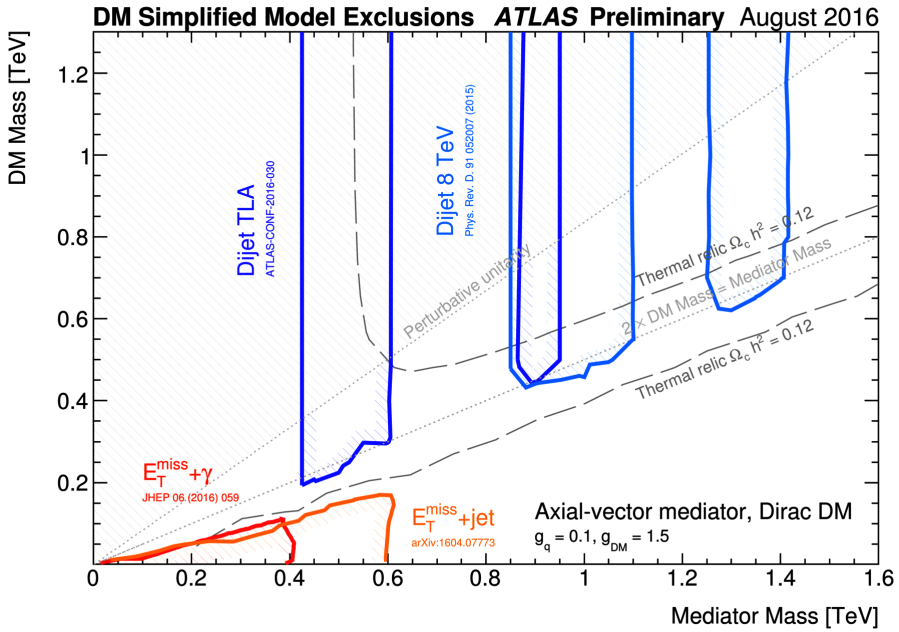


Comparison to direct searches and summary









Conclusion

- The LHC is sensitive to DM production in association with additional particles.
- Many DM searches are carried out in ATLAS (under assumption of SUSY, EFT, simplified models, etc.).
- Observed data are consistent with SM predictions $\Rightarrow$ limits are set.
- Results of the ATLAS searches complement the direct searches constraints.

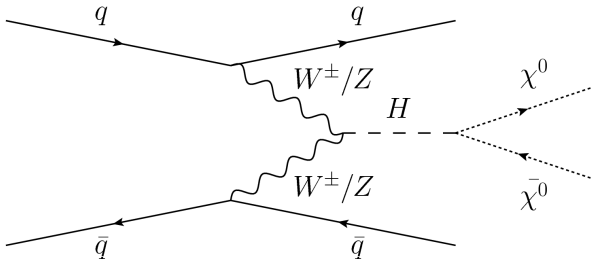
Thank you!

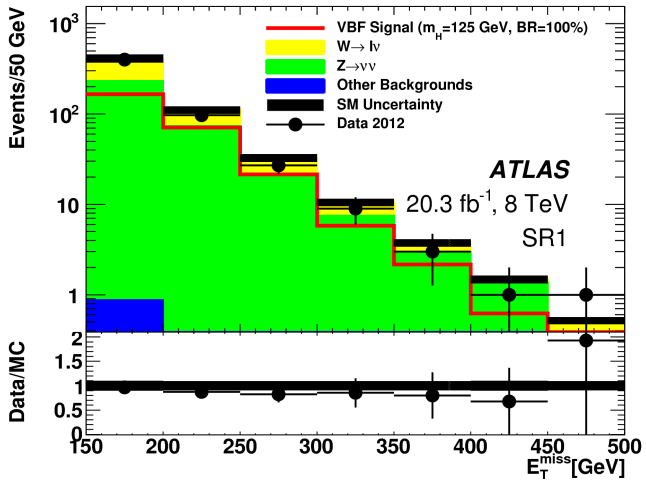
backups

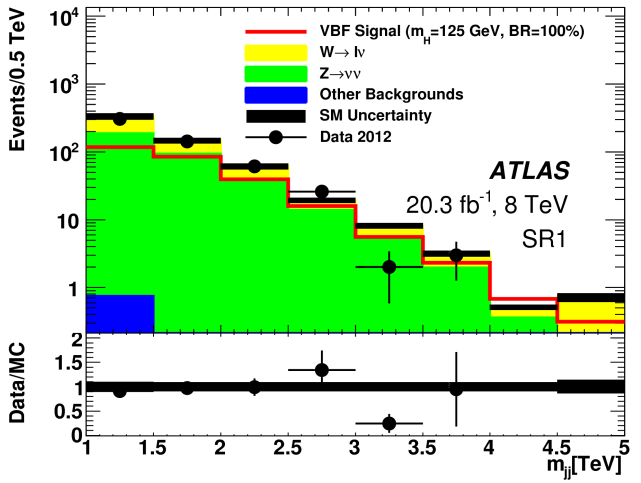
Higgs→invisible

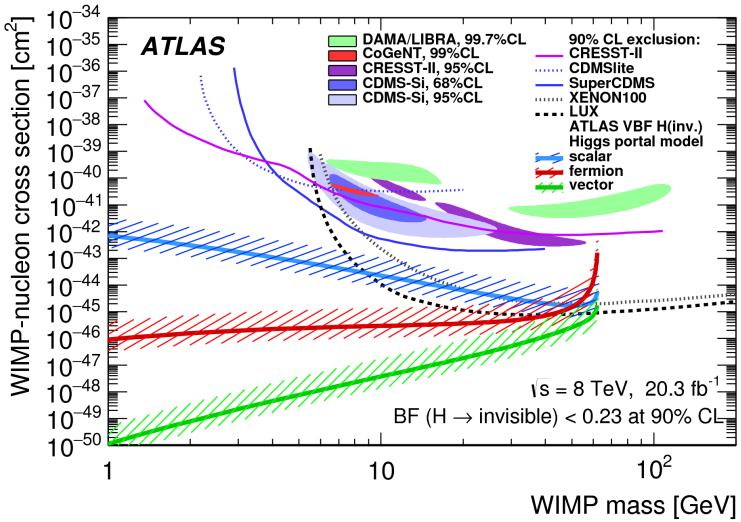
arXiv:1508.07869

- invisible decays of a Higgs boson produced via the vector-boson fusion (VBF) process.
- signature: 2 jets and large E_T^{miss}
- measure BR(Higgs $\rightarrow$ invisible) if kinematically allowed ($m_\chi < m_H/2$)
- results are interpreted in the Higgs-portal DM model; upper bounds on the DM-nucleon scattering cross section
- in particular sensitive to low m_χ









other DM searches at ATLAS

DM+$Z(\rightarrow l\bar{l})$ (at $\sqrt{s} = 8$ TeV)	arxiv:1404.0051v3
DM+$H(\rightarrow \gamma\gamma)$	ATLAS-CONF-2016-087
DM+$H(\rightarrow ZZ^* \rightarrow l^+l^-l'^+l'^-)$	ATLAS-CONF-2015-059
DM+$b\bar{b}$	ATLAS-CONF-2016-086

DM+$t\bar{t}$, 1L, SRs

ATLAS-CONF-2016-050

Variable	SR1	tN_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_{\mathrm{T}}>$ [GeV]	(80 50 40 40)	(120 80 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 260	> 450
$E_{T,\perp}^{\mathrm{miss}}$ [GeV]	–	> 180
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 22
m_{T} [GeV]	> 170	> 210
am_{T2} [GeV]	> 175	> 175
topness	> 6.5	–
m_{top}^{χ} [GeV]	< 270	–
$\Delta R(b,\ell)$	< 3.0	< 2.4
Leading large-R jet p_{T} [GeV]	–	> 290
Leading large-R jet mass [GeV]	–	> 70
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, 2^{\mathrm{nd}}\text{large-R jet})$	–	> 0.6

Variable	DM_low	DM_high
Number of (jets, b-tags)	$(\geq 4, \geq 1)$	$(\geq 4, \geq 1)$
Jet $p_{\mathrm{T}}>$ [GeV]	(60 60 40 25)	(50 50 50 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300	> 330
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 9.5
m_{T} [GeV]	> 120	> 220
am_{T2} [GeV]	> 140	> 170
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet}_i))$ $(i \in \{1-4\})$	> 1.4	> 0.8
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	> 0.8	–

Variable	bC2x_diag	bC2x_med	bCbv
Number of (jets, b-tags)	$(\geq 4, \geq 2)$	$(\geq 4, \geq 2)$	$(\geq 2, = 0)$
Jet $p_{\mathrm{T}}>$ [GeV]	(70 60 55 25)	(170 110 25 25)	(120 80)
b-tagged jet $p_{\mathrm{T}}>$ [GeV]	(25 25)	(105 100)	–
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 230	> 210	> 360
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14	> 7	> 16
m_{T} [GeV]	> 170	> 140	> 200
am_{T2} [GeV]	> 170	> 210	–
$\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert (i=1)$	> 1.2	> 1.0	> 2.0
$\lvert\Delta\phi(\mathrm{jet}_i, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})\rvert (i=2)$	> 0.8	> 0.8	> 0.8
Leading large-R jet mass [GeV]	–	–	$[70, 100]$
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	–	–	> 1.2