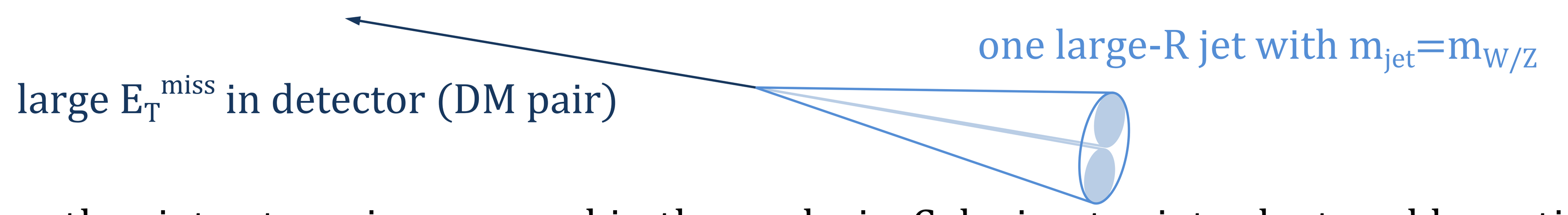
Search for Dark Matter Produced in Association with a Hadronically Decaying Vector Boson at $\sqrt{s}$ =13 TeV with the ATLAS Detector

Introduction

Dark Matter (DM) is the dominant component of matter in the universe, but its particle nature remains a mystery. At particle colliders, the DM particles are not directly detectable, but their presence can be inferred from the recoil against a visible particle. The search for DM pair produced in association with a hadronically decaying W or Z boson, a.k.a. V+E_T^{miss} (missing transverse momentum) final-state, is performed using 3.2 fb^{-1} of LHC data collected by the ATLAS detector. The data are consistent with the Standard Model predictions and are interpreted in terms of both an effective field theory and a simplified model containing DM. Limits on DM production improve on earlier ATLAS results.

Jet Categories

This analysis focuses on $W/Z \rightarrow qq$ events with large E_T^{miss}. In this case, the vector boson is highly recoiled and both quarks from the decay will be naturally close to each other. In order to capture the hadronic products of the vector boson, the trimmed anti-k_t algorithm clustered calorimeter jets with radius parameter R=1.0 (large-R jets) are used. Events are required to have at least one large-R jet.



Two other jet categories are used in the analysis. Calorimeter jets clustered by anti-k_t algorithm with R=0.4 (narrow jets) are used in background suppression and jets reconstructed from inner-detector tracks and clustered by anti-k_t algorithm with R=0.2 (track jets) are used for b-tagging.

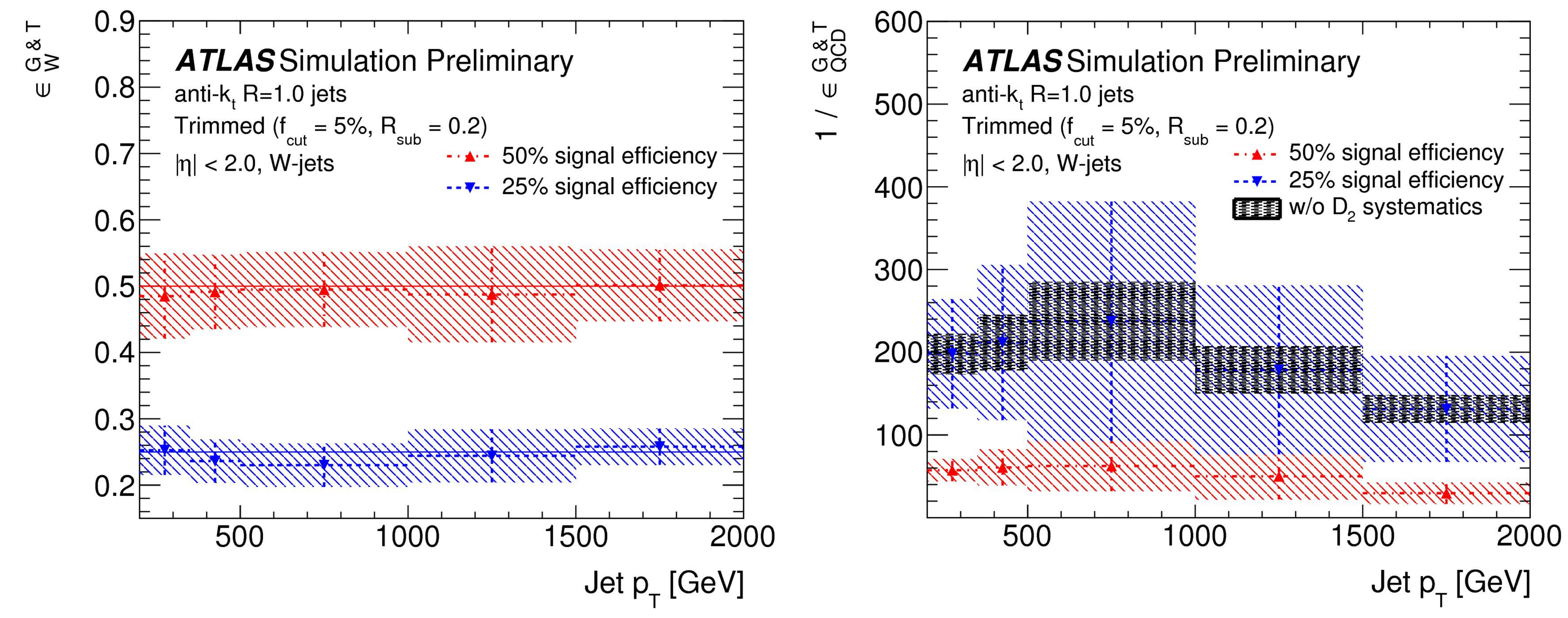
Boson Tagging

To better separate the signal and $Z \rightarrow \nu\nu$ background, the internal structure of the leading large-R jet is required to be consistent with a W or Z boson decay. This can be verified in terms of two quantities: invariant mass m_{jet} and D_2, which identifies jets with two distinct concentrations of energy.

D_2: a variation on the ratio of energy correlations which optimises the separation between one-prong and two-prong decays, in analytical terms

Vector boson tagger[1]

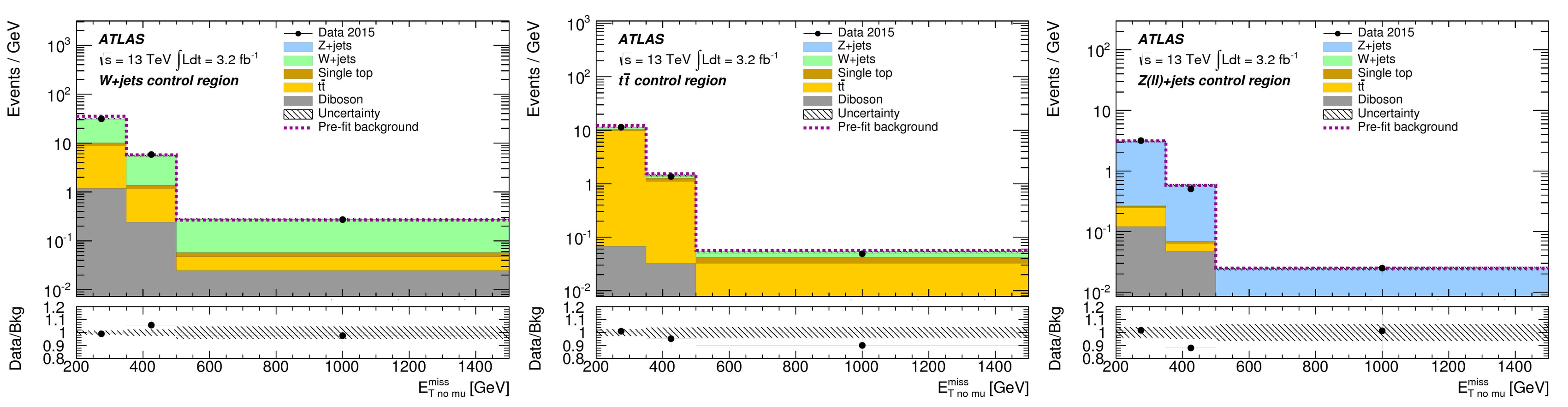
- Use m_{jet} and D_2 as input variable
- Derived with fixed signal efficiency: 50% for medium working point and 25% for tight working point
- Medium working point used in the analysis



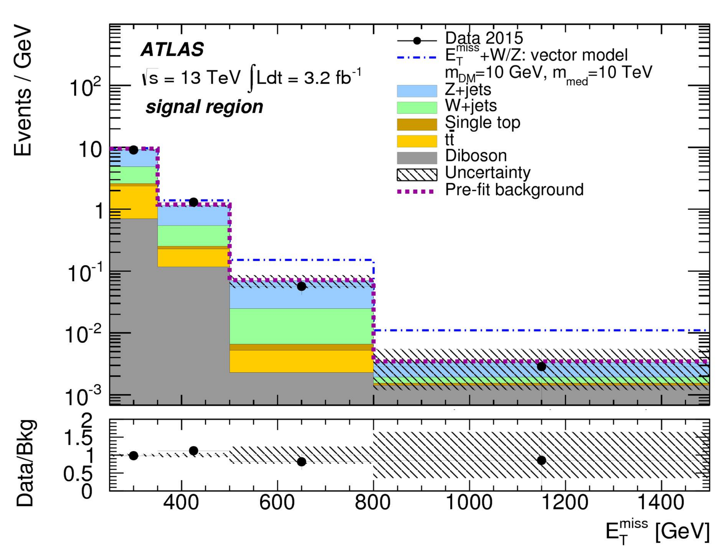
signal efficiency (left) and background rejection (right) versus jet p_T for W boson tagger

Post-fit Results

The distributions of E_T^{miss} (or $E_T^{miss,no\mu}$ for CRs) after the profile-likelihood fit[2] under the background-only hypothesis are shown below. The floating background-normalization parameters are consistent with unity within one standard deviation. No significant deviation from Standard Model predictions is observed.



In SR the E_T^{miss} distribution for a simplified model DM signal, with m_χ=10 GeV and m_{med}=10 TeV and scaled by a factor of 10^4 , is also plotted.



Process	Events
Z+jets	544 ± 33
W+jets	275 ± 24
$t\bar{t}$ and single-top	211 ± 19
Diboson	89 ± 12
Total Background	1120 ± 47
Data	1121

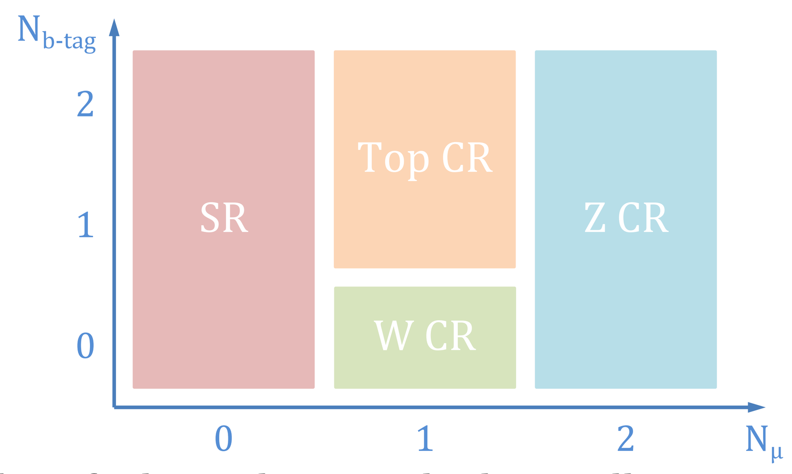
Predicted and observed number of events in SR after the profile-likelihood fit under the background-only hypothesis.

Major sources of systematic uncertainty include the modelling of large-R jet observables, the energy scale of the narrow jets, theoretical uncertainties of background modelling, parton distribution functions and lepton reconstruction and identification efficiencies.

Background Estimation

Signal region (SR)

- E_T^{miss} > 250 GeV
- No reconstructed lepton
- At least one large-R jet
- QCD suppression cuts



Dominant backgrounds

- $Z \rightarrow \nu\nu$ production in association with jets
- Leptonic decaying W/Z + jets, lepton not identified or τ decaying hadronically
- Top-quark pair production

The kinematic distributions of the three largest backgrounds are estimated using simulated event samples but the normalization is determined using control regions (CRs) where the DM signal is expected to be negligible

Control regions

- Z CR: two μ with invariant mass 66 < $m_{\mu\mu}$ < 116 GeV, selecting $Z \rightarrow \mu\mu$ events which are kinematically similar to $Z \rightarrow \nu\nu$ process
- W CR: one μ with zero b-tagged track jet not associated with the large-R jet
- Top CR: one μ with at least one b-tagged track jet not associated with the large-R jet

Each CR requires at least one large-R jet, while the E_T^{miss} cut is loosened to 200 GeV in order to increase the statistics.

Fitting Strategy

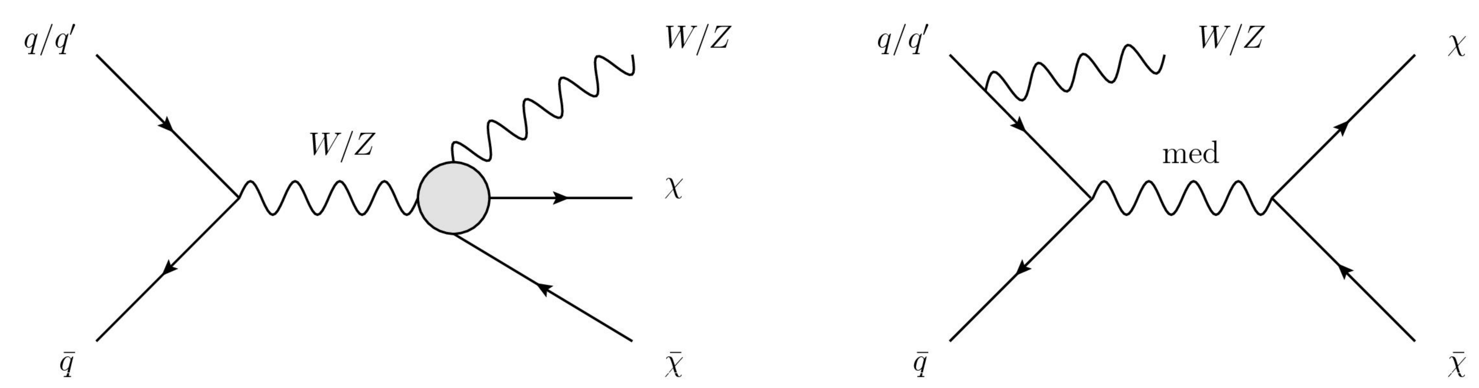
Fitting variables

- SR: E_T^{miss}, the negative vector sum p_T of reconstructed objects and soft terms
- CR: $E_T^{miss,no\mu}$, same as E_T^{miss} but excluding reconstructed μ

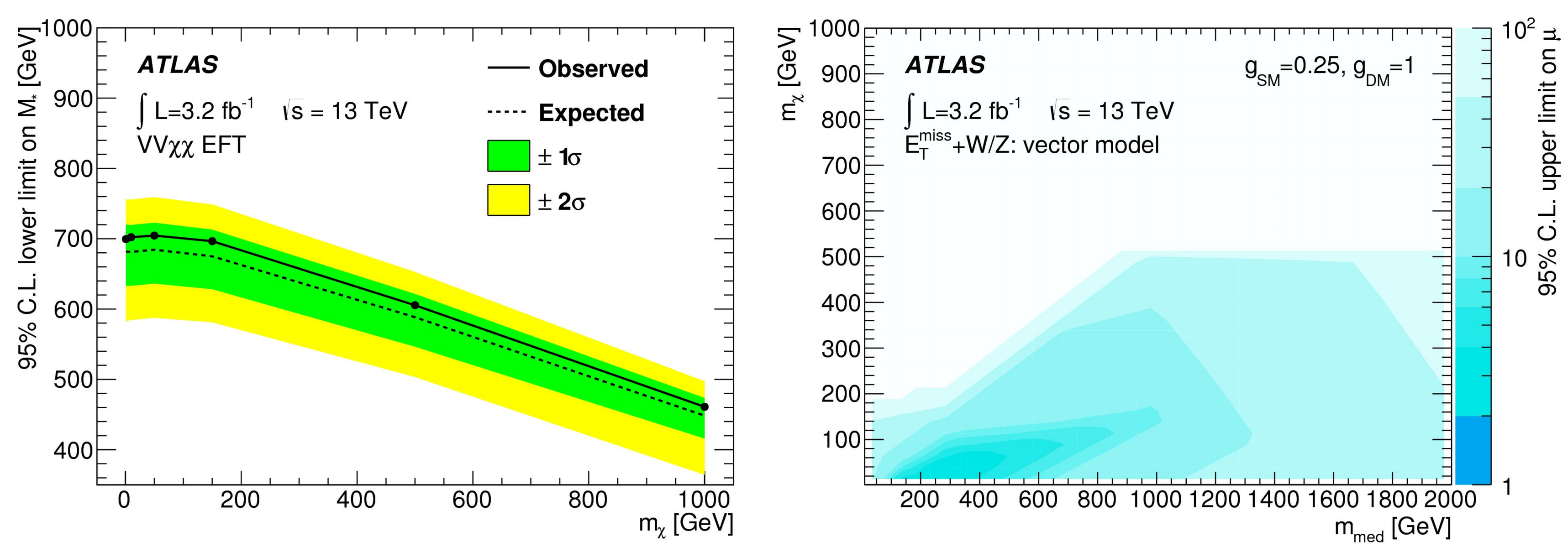
A profile-likelihood fit to the E_T^{miss} ($E_T^{miss,no\mu}$) distribution in the SR (CRs) is used to constrain the W boson, Z boson, and top backgrounds and extract the signal strength μ.

Limit Setting

Two theoretical models are used as benchmarks: a seven-dimensional $VV\chi\chi$ EFT model[3] (left) and a vector-mediated simplified model[4] (right). The signal samples are generated as a function of DM particle mass m_χ for the EFT model and in a grid of mediator mass m_{med} and m_χ for the simplified model.



Upper limits at 95% confidence level on μ are calculated using the CL_s method[5]. For the $VV\chi\chi$ EFT model, these limits are translated into constraints on the mass scale, M_*.



References

[1] ATL-PHYS-PUB-2015-033
[2] arXiv:1007.1727
[3] arXiv:1212.3352
[4] arXiv:1507.00966
[5] J. Phys. G 28 (2002) 2693–2704

More details about the search for dark matter produced in association with a hadronically decaying vector boson at $\sqrt{s}$ =13 TeV with the ATLAS detector can be found at Phys. Lett. B 763 (2016) 251

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