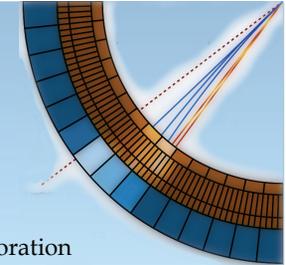


Search for dark matter in events with a Z boson and missing transverse momentum at ATLAS [1]

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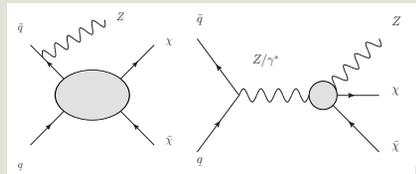
Dark matter at the LHC

- Additional gravitationally-interacting matter exists in the universe: dark matter (DM)
 - High energy colliders (such as the LHC) offer a promising way to identify DM
- Assume DM appears in the detector as missing transverse momentum (E_T^{miss}), balanced against some Standard Model (SM) object (jet, γ , W or Z)

$pp \rightarrow \chi\bar{\chi}Z(\rightarrow \ell^+\ell^-)$, where $\ell = e, \mu$, offers a clean signal

- Search for contact interaction operators:
 - D1 (scalar), D5 (vector), D9 (tensor) [2]
 - dimension-5 $\chi\chi ZZ$ [3]
 - dimension-7 $\chi\chi ZZ\gamma^*$
- Also include simplified model (with accessible mediating particle)

The mono-Z channel



Analysis details

- Combination of single lepton (high p_T) and dilepton (low p_T) triggers
- Reconstruct Z boson from e^+e^- or $\mu^+\mu^-$ pair ($p_T > 20$ GeV)
- $m_{\ell\ell} \in [76 \text{ GeV}, 106 \text{ GeV}]$
- Veto events with a third lepton ($p_T > 7$ GeV) or a jet ($p_T > 25$ GeV)
- Signal features back-to-back and balanced Z and E_T^{miss} , so require
 - $\Delta\phi(E_T^{\text{miss}}, p_T^{\ell\ell}) > 2.5$
 - $|p_T^{\ell\ell} - E_T^{\text{miss}}|/p_T^{\ell\ell} < 0.5$
- Final signal regions: $E_T^{\text{miss}} > 150, 250, 350, 450$ GeV

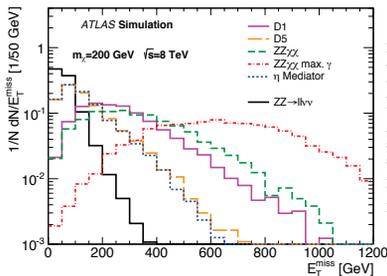


Fig. 2: Shape of the E_T^{miss} distribution of a subset of DM models, and simulated samples of ZZ background. From [1].

Process	E_T^{miss} threshold [GeV]			
	150	250	350	450
ZZ	41 ± 15	6.4 ± 2.4	1.3 ± 0.5	0.3 ± 0.1
WZ	8.0 ± 3.1	0.8 ± 0.4	0.2 ± 0.1	0.1 ± 0.1
WW, tt, Z → τ ⁺ τ ⁻	1.9 ± 1.4	0 ^{+0.7} _{-0.0}	0 ^{+0.7} _{-0.0}	0 ^{+0.7} _{-0.0}
Z+jets	0.1 ± 0.1	-	-	-
W+jets	0.5 ± 0.3	-	-	-
Total	52 ± 18	7.2 ± 2.8	1.4 ± 0.9	0.4 ^{+0.7} _{-0.4}
Data	45	3	0	0

Table 1: Observed yields and expected SM backgrounds in each signal region.

Estimated with data-driven ABCD method [6], with E_T^{miss} and $\eta^{\ell\ell}$ as uncorrelated variables

- Validated with second method: fitting $\Delta\phi(E_T^{\text{miss}}, p_T^{\ell\ell})$ and E_T^{miss} distributions at low values, extrapolating to signal region; difference taken as systematic uncertainty of method

Estimated in control region (rich in jets-reconstructed-as-electrons), and normalised to the signal regions with factor obtained in low- E_T^{miss} region

Backgrounds

Estimated from Monte Carlo (POWHEG BOX 1.0 [4], ZZ normalised to include gg initial state, PYTHIA8 [5] used for hadronization)

Estimated from data in $e\mu$ channel, scaled to $ee, \mu\mu$ channels

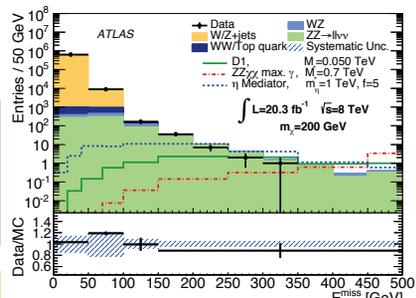
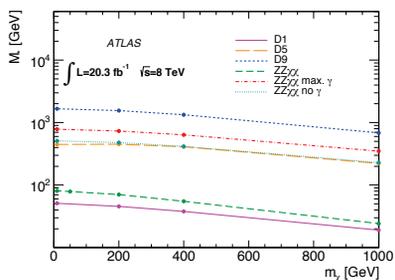


Fig. 3: E_T^{miss} distributions after all event selections other than the E_T^{miss} selection for the signals, expected background and observed data. From [1].

EFT results



	E_T^{miss} threshold [GeV]			
	150	250	350	450
Expected Limits [fb]	3.0	0.73	0.36	0.27
Observed Limits [fb]	2.7	0.57	0.27	0.26

Table 2: The observed and expected upper limits on the fiducial cross section at 95% C.L. for each signal region.

Fig. 4: Observed 95% C.L. lower limits on the mass scale of included effective field theory operators. The values below the corresponding line are excluded. From [1].

Comparison with direct detection

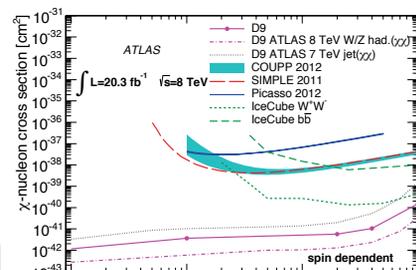


Fig. 5: Observed 95% C.L. upper limits on the χ -nucleon scattering cross section, for spin-dependent (top) and spin-independent (bottom) operators. Other search limits are shown only for comparison, as they are obtained assuming the interactions are mediated by operators different from those used for the ATLAS limits. From [1].

t-channel simplified scalar mediator model

- Simplified models: allow the mediating particle to be accessible at LHC energies
 - m_{η} : additional degree of freedom

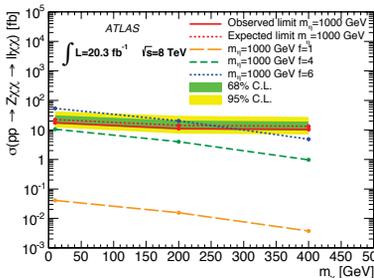
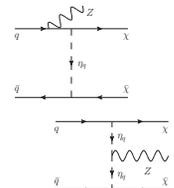


Fig. 6: Observed 95% C.L. upper limits on the cross section of the scalar-mediator theory. Production cross sections predicted from theory are shown for $m_{\eta} = 1000$ GeV and for different values of the coupling strength, f . Taken from [1].

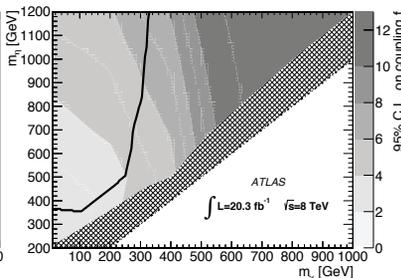


Fig. 7: Observed 95% C.L. upper limits on the coupling strength, f , of the scalar-mediator theory. The upper left-hand region is excluded by relic abundance calculations.

[1] ATLAS Collaboration, Search for dark matter in events with a Z boson and missing transverse momentum in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, submitted to Phys. Rev. D, arXiv:1404.0503, CERN-PH-EP-2014-237.
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