Dark Matter searches at ATLAS
IX International Conference on Interconnections between Particle Physics and Cosmology
Dark Matter

• ample evidence for existence of dark matter

• stable, neutral and weakly interacting massive particle (WIMP) might be best candidate
  → need to go beyond Standard Model

• no unambiguous direct evidence so far

• complement direct detection limits at the LHC
ATLAS searches

- **general mono-X+ E_T^{miss} strategy**
  - invisible DM particles escape detection
    - tag events using recoil object(s) X (Standard Model particle from ISR)
  - measure E_T^{miss}
    → infer DM candidate
  - variety of X’s under investigation
ATLAS searches

- **general mono-X + $E_T^{\text{miss}}$ strategy**
  - effective field theory (EFT)
  - approximation of contact $qq\chi\chi$ interaction through heavy mediator
  - agnostic search, suited for comparison to other searches
  - poor approximation when interaction’s momentum transfer larger than intermediate state’s mass
  - results parameterised by DM scale ($M_\chi$) and interaction strength ($M^*$)

- different recoil objects probe different operators

<table>
<thead>
<tr>
<th>Name</th>
<th>Operator</th>
<th>Type of interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1</td>
<td>$\frac{m_q^2}{M_*^2}\bar{\chi}q\hat{q}q$</td>
<td>Scalar, WIMP-quark</td>
</tr>
<tr>
<td>D5</td>
<td>$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu q\gamma^\mu q$</td>
<td>Vector</td>
</tr>
<tr>
<td>D8</td>
<td>$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5 q\gamma_\mu\gamma^5 q$</td>
<td>Axial-vector</td>
</tr>
<tr>
<td>D9</td>
<td>$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu} q\sigma_{\mu\nu} q$</td>
<td>Tensor</td>
</tr>
<tr>
<td>D11</td>
<td>$\frac{\alpha_s}{(4\pi M_*^2)^3}\bar{\chi}q G_{\mu\nu} \bar{G}_{\mu\nu}$</td>
<td>Scalar, WIMP-gluon</td>
</tr>
<tr>
<td>C1</td>
<td>$\frac{m_q^2}{M_*^2}\bar{\chi}q\hat{q}q$</td>
<td>Scalar, WIMP-quark</td>
</tr>
<tr>
<td>C5</td>
<td>$\frac{\alpha_s}{4M_*^2}\bar{\chi}\gamma^\mu q G_{\mu\nu} \bar{G}_{\mu\nu}$</td>
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</tr>
</tbody>
</table>
ATLAS searches

- **mono-jet + \text{E}_T^{\text{miss}}** \textcolor{red}{(arXiv:1502.01518, submitted to EPJC)}
  - event selection
    - central leading jet with \( p_T > 120 \) GeV and \( p_T > 0.5 \cdot \text{E}_T^{\text{miss}} \)
    - 9 signal regions with \( \text{E}_T^{\text{miss}} \) thresholds from 150 to 700 GeV
    - jet and \( \text{E}_T^{\text{miss}} \) back to back / recoiling
      \( \Delta \phi(\text{sel. jets, E}_T^{\text{miss}}) > 1.0 \)
    - lepton and isolated track veto
  - main background
    - \( Z(\nu\nu) + \) jets, constrained using
      \( W(l\nu) \) and \( Z(l\ell) \) control regions
    - \( W(l\nu) + \) jets, mostly when \( l=\tau \)
ATLAS searches

- **mono-jet + $E_T^{\text{miss}}$** (arXiv:1502.01518, submitted to EPJC)
  - all measurements are consistent with SM
  - limits for six EFT operators (D1, D5, D8, D9, D11, C5)
  - most sensitive signal region is used in each case
  - truncation procedure applied to ensure EFT validity (simplest: only use events where $Q_{\text{tr}} < M_{\text{med}}$)
  - complementarity of direct/indirect detection and colliders → each experiment has its strength
ATLAS searches

- **mono-jet + \( E_T \text{miss} \)** (arXiv:1502.01518, submitted to EPJC) (ATL-PHYS-PUB-2014-007)
  - simplified model results also available
    - more model parameters
    - complete description for physics at the LHC

- improved sensitivity expected with first months of LHC run 2
- stronger focus on simplified models in run 2
ATLAS searches

  - event selection
    - high-energy photon
    - large $E_T^{\text{miss}}$
  - no leptons, at most one jet
  - main background
    - $Z(\nu\nu) + \gamma$
    - $W\gamma$ / $Z\gamma$ with lost leptons
    - $W$ / $Z$ with leptons / jets misidentified as $\gamma$
    - estimated via dedicated control regions
ATLAS searches

  - all measurements are consistent with SM
  - truncation procedure applied to ensure EFT validity
  - limits for three EFT operators \((D5, D8, D9)\)
ATLAS searches

  - simplified model with $Z'$-like mediator
ATLAS searches

  - event selection
    - very central, large-radius jet with $p_T > 250$ GeV, $50$ GeV < $m_j$ < 120 GeV, momentum balance of subjets
    - two signal regions with $E_{T\text{miss}} > 350 / 500$ GeV
    - max. one narrow jet with $p_T > 40$ GeV
    - lepton and photon veto
  - main background
    - $Z(\nu\nu) +$ jets
    - $Z(ll) +$ jets and $W(l\nu) +$ jets, with lost lepton
ATLAS searches

  - all measurements are consistent with SM
  - limits for four EFT operators (C1, D1, D5, D9)
ATLAS searches

**mono-W/Z boson (leptonic)**  
- event selection W  
  - one high-$p_T$ lepton  
  - $E_T^{miss}$  
  - large $m_T$, incompatible with directly produced W  
- event selection Z  
  - two leptons with invariant mass consistent with Z  
  - large $E_T^{miss}$  
  - jet and third-lepton vetoes

(arXiv:1404.0051, PRD 90, 012004 (2014))
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ATLAS searches

  - main background
    - \( W: \ W(l\nu) \) tail, \( Z(ll) \) lost lepton, leptonic taus in \( W(\tau\nu), \ Z(\tau\tau), \) diboson
  - \( Z: \) diboson

\[ \int L \, dt = 20.3 \text{ fb}^{-1} \]

\[ L = 20.3 \text{ fb}^{-1} \]

\[ \ell s = 8 \text{ TeV} \]

\[ m_{\tau} = 200 \text{ GeV} \]

Data/MC

\[ E_{T}^{\text{miss}} \text{ [GeV]} \]

\[ 50 \text{ GeV} \]

\[ 0 \text{ to } 500 \text{ GeV} \]
ATLAS searches

- all measurements are consistent with SM
- limits for three EFT operators (D₁, D₅(c/d), D₉)
ATLAS searches

  - simplified model with “b-flavoured” DM proposed to explain gamma ray excess from galactic centre seen by Fermi-LAT and interpreted as DM annihilating to b quark pairs

- **event selection**
  - four signal regions with varying jet/b-jet multiplicity, 0/1 lepton, \( E_T^{\text{miss}} > 200 - 300 \) GeV, kinematic cuts to reduce SM top pairs

- **main background**
  - top-antitop-quark pairs estimated using dedicated control regions
  - single top production, W/Z + jets
ATLAS searches

  - all measurements are consistent with SM
  - limits for three EFT operators ($C_1$, $D_1$, $D_9$)
    - $D_1$ limits in top-quark SR better than in mono-jet, as scalar operators proportional to quark mass
  - simplified model excludes mediator masses between 300 and 500 GeV for WIMP mass around 35 GeV
ATLAS searches

- **Higgs (invisible)**
  - $V(jj/ll) + H^{inv}$
    - Higgs can decay into pair of DM particles if kin. allowed
    - selecting hadronic $W/Z + \text{large } E_T^{\text{miss}}$
    - six SRs in #jets (2/3) and #b-tags (0/1/2)
    - upper limit on BR $H^{inv}$ set at 78% for $V(jj)$ and 75% for $V(ll)$
  - **VBF H^{inv}**
    - more sensitive
    - selecting two separated jets + $E_T^{\text{miss}}$
    - upper limit on BR $H^{inv}$ set at 29%

(\text{arXiv:1504.04324}, \text{submitted to EPJC})
(\text{arXiv:1402.3244}, \text{submitted to PRL})
(\text{ATLAS-CONF-2015-004})
Conclusion

- broad variety of DM searches in ATLAS

- all data consistent with SM expectations
  ➔ limits on New Physics using both EFT approach and simplified models

- “Mono-X” searches set upper limits on effective scale of the DM-SM interaction as function of WIMP mass
  (for given operators limits range up to above 1 TeV for low WIMP mass)

- strong limits, compared to direct detection experiments, for low WIMP masses in the spin-independent case, and over the whole covered mass range for the spin-dependent case

- sensitivity increases significantly with 13 TeV