Searches for Dark Matter with the ATLAS Detector using Resonances with Jets

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Why Dark Matter?

Cluster Collisions

Gravitational Lensing

Galactic Rotation Curves

- Ordinary Matter: 5%
- Dark Matter: 26%
- Dark Energy: 69%

CMB Measurements
Why Dark Matter?

Cluster Collisions

Dark Matter 26%
Ordinary Matter 5%

... and many more astrophysics measurements suggest that Dark Matter exists.

But can we detect it in a laboratory?
Searching for Dark Matter

To detect Dark Matter, it must interact with Standard Model* somehow.

Indirect Detection

Direct Detection

Production at Colliders

* aka laboratory equipment
Searching for Dark Matter

To detect Dark Matter, it must interact with Standard Model* somehow.

Indirect Detection  Direct Detection  Production at Colliders

DM  SM  DM  DM

SM  DM

ATLAS Searches

* aka laboratory equipment
EFT Dark Matter Model

New particle (Dark Matter) with a parametrizable interaction to the Standard Model.
EFT Dark Matter Model

New particle (Dark Matter) interacts with the Standard Model.

- Works great for heavy Dark Matter, but...
  - not ideal for light Dark Matter
  - hides richer phenomenology
Simplified Dark Matter Model

- Model recommended by the LHC Dark Matter Forum
  - An (axial) mediator (mass $m_R$) couples to Dark Matter (mass $m_{DM}$)
  - Independent couplings to quarks ($g_{SM}$, flavor independent) and DM ($g_{DM}$)
- Common model used by all searches and all LHC experiments!

Why Jets in DM Signal?

Dark Matter particles are not seen by the detector.

**MET+X Searches**
- Produce DM with an ISR object
- Search for momentum imbalance in transverse plane (MeT) from DM

**Dijet Searches**
- Decay Z' back into quarks and look for a bump in $m_{jj}$ spectrum
- A signal does not mean DM, but lack of signal will constrain the simplified DM model
Inclusive and exclusive signal regions in MeT

- 6 bins in range 250 GeV to 700 GeV
- \(Z \rightarrow \nu \nu + \text{jets}\) background determined from \(W \rightarrow \mu \nu + \text{jets}\) events
  - Similar data-driven technique for other boson backgrounds
  - Simultaneous fit done in CRs+SR
- Jet smearing for multi-jet background
- Other backgrounds determined using MC
MET+Jet Results

- No signal seen → limits
- Also limits on extra dimension and SUSY models
- Single bin Signal Region (and control regions)
- Z/W background k-factors estimated via simultaneous fits to Z/W control regions
  - Same k-factor for $Z \rightarrow \nu\nu + \gamma$ as for $Z \rightarrow \ell\ell + \gamma$
- Data-driven estimation of photon fakes
  - Miss-ID'ed electrons from $e^+\gamma$ sample scaled by measured miss-ID rate
  - ABCD method for miss-ID'ed jets
MET+Photon Results

- No signal seen → limits
- Also limits on extra dimension and effective \( \gamma \gamma \chi \chi \) coupling
• Add Z' + Higgs coupling to simplified model

• Searches for a ~125 GeV bump in $m_{jj}/m_J$ distributions, divided by $N_{bjets}$

• Background estimated by simultaneous fitting control regions
  • $m_{jj}/m_J$ sidebands constrain $Z\rightarrow\nu\nu+jets$
  • one-muon CR to constrain $W+jets$ and $ttbar$
  • two-lepton CR to constrain $Z+jets$
Add $Z'$ + Higgs coupling to simplified model

Searches for a ~125 GeV bump in $m_{jj}/m_J$ distributions, divided by $N_{bjets}$

Background estimated by simultaneous fitting control regions

$m_{jj}/m_J$ sidebands constrain $Z \rightarrow \nu \nu + jets$

one-muon CR to constrain $W+jets$ and $t\bar{t}$

two-lepton CR to constrain $Z+jets$

No jet with $\Delta \phi_{j,MeT} < 0.35$

1 jet > 45 GeV

One fat jet, with 0,1,2 btags
MET+H(→bb) Results

- No signal seen → limits
MET+H(→bb) Results

- No signal seen → limits
MET+H(→bb) Results

- No signal seen → limits
Dijet

\[ y^* = \frac{|y_1 - y_2|}{2} < 0.6 \]

- Search for bump on smooth \( m_{jj} \) spectrum
- QCD background modeled with a falling function
  \[ p_0 (1 - x)^{p_1} x^{p_2}, \quad x = \frac{m_{jj}}{\sqrt{s}} \]
- A non-resonant version also available
Dijet Results

- No signal seen → limits
- Also set limits on excited quarks, QBH, W' and Gaussian signals
Summary

DM Simplified Model Exclusions

Axial-vector mediator, Dirac DM
\[ g_q = 0.25, \ g_{\text{DM}} = 1 \]

\[ \Omega_c \ h^2 < 0.12 \]

\[ 2 \times \text{DM Mass} = \text{Mediator Mass} \]

\[ E_T^{\text{miss}} + \gamma \ 13 \text{ TeV} \]
\[ \text{arXiv:1604.01306} \]

\[ E_T^{\text{miss}} + \text{jet} \ 13 \text{ TeV} \]
\[ \text{arXiv:1604.07773} \]
DEVELOPING NEW SEARCHES

AXAL VECTOR MEDIATOR, DIRAC DM

$g_q = 0.25$, $g_{DM} = 1$

$\Omega_c h^2 < 0.12$

$2 \times$ DM Mass = Mediator Mass

$\Omega_c h^2 = 0.12$

DM Mass [TeV]

Mediator Mass [TeV]
Conclusion

- Rich program of Dark Matter searches in ATLAS
  - Shown: MET+jet, MET+photon, MET+higgs, dijet
  - Not shown: MET+V, MET+heavy flavour, MET+(h→γγ), MET+h(→ZZ)
- Now unified with a standard simplified model
  - Can cover almost entire mediator/DM mass plane
- Almost excluded $g_{SM}=0.25$, $g_{DM}=1$
  - Light DM $\sim<200$ GeV mostly excluded
  - Heavy mediators $>1$ TeV excluded
- Smaller couplings still open
Other MET+Jet Limits
Other MET+Photon Limits

**ATLAS**
- EW EFT model
- $\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$
- 95% CL lower limit on $m_\chi$ [GeV]
- Observed limit
- Expected limit
- Expected ± 1σ
- Expected ± 2σ
- Truncated limits

**ATLAS**
- ADD model
- $\sqrt{s} = 13$ TeV, 3.2 fb$^{-1}$
- 95% CL lower limit on $M_D$ [TeV]
- Observed limit
- Expected ± 1σ
- Expected ± 2σ
- 8 TeV ATLAS observed limit
- Number of extra dimensions
Other Dijet Limits

\[ \sigma \times A [\text{pb}] \]

ATLAS
\[ \sqrt{s}=13 \text{ TeV} \]
3.6 fb\(^{-1}\)
|y\(^*\)| < 0.6

- QBH (BM)
- QBH (QBH)
- QBH (RS)

- Z' (0.30)

- q'
- W'

- Observed 95% CL upper limit
- Expected 95% CL upper limit
68% and 95% bands
Image Credits

Universe Composition: https://darkmatterdarkenergy.com/2015/03/07/planck-mission-full-results-confirm-canonical-cosmology-model/