Recasting ATLAS-EXOT-2016-25

Search for Dark Matter Associated with a Higgs Boson Decaying to bbbar at sqrt(s) = 13 TeV with ATLAS

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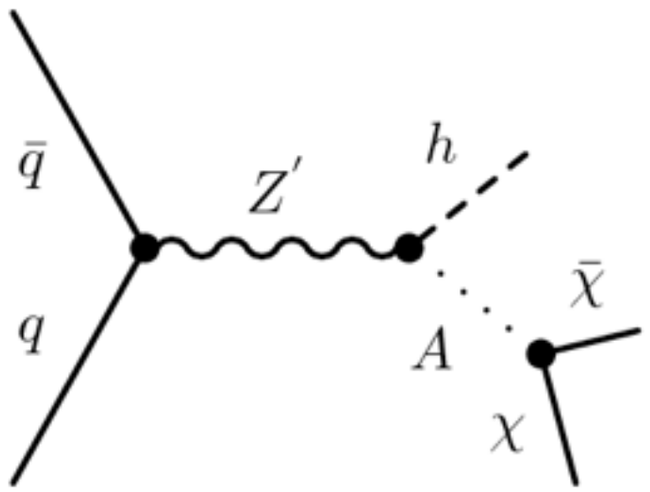
Introduction

- ATLAS-EXOT-2016-25
  - arXiv:1707.01302
  - Submitted to Phys. Rev. Letter

- 2 Higgs Doublet Model with an additional U(1) gauge symmetry yielding an additional massive Z'
  - 5 Higgs bosons : SM h, H, A, H±
  - Z' couples to h and A, where A decays to DM
  - Concentrate on largest BR h->bbbar channel

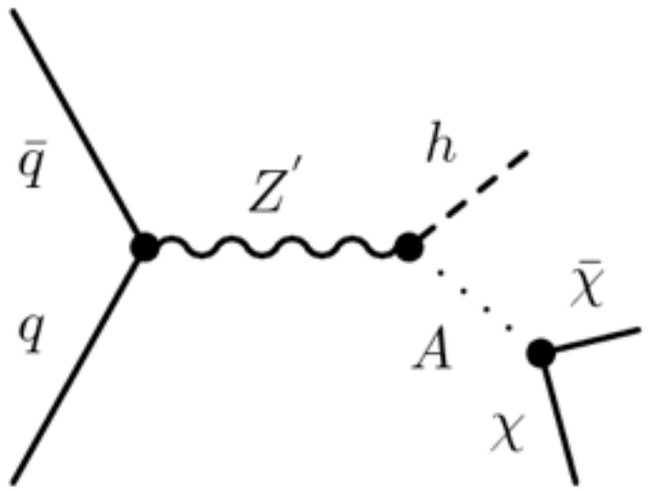


- Cross-section table, UFO model, MadGraph cards were provided from ATLAS

Monte Carlo Generation

- UFO model, MadGraph cards were provided from ATLAS

- Several parameters were decided as below
  - m(chi) = 100 GeV
  - tan(beta) = 1
  - g(Z') = 0.8
  - m(H) = m(H+) = m(H-) = 300 GeV

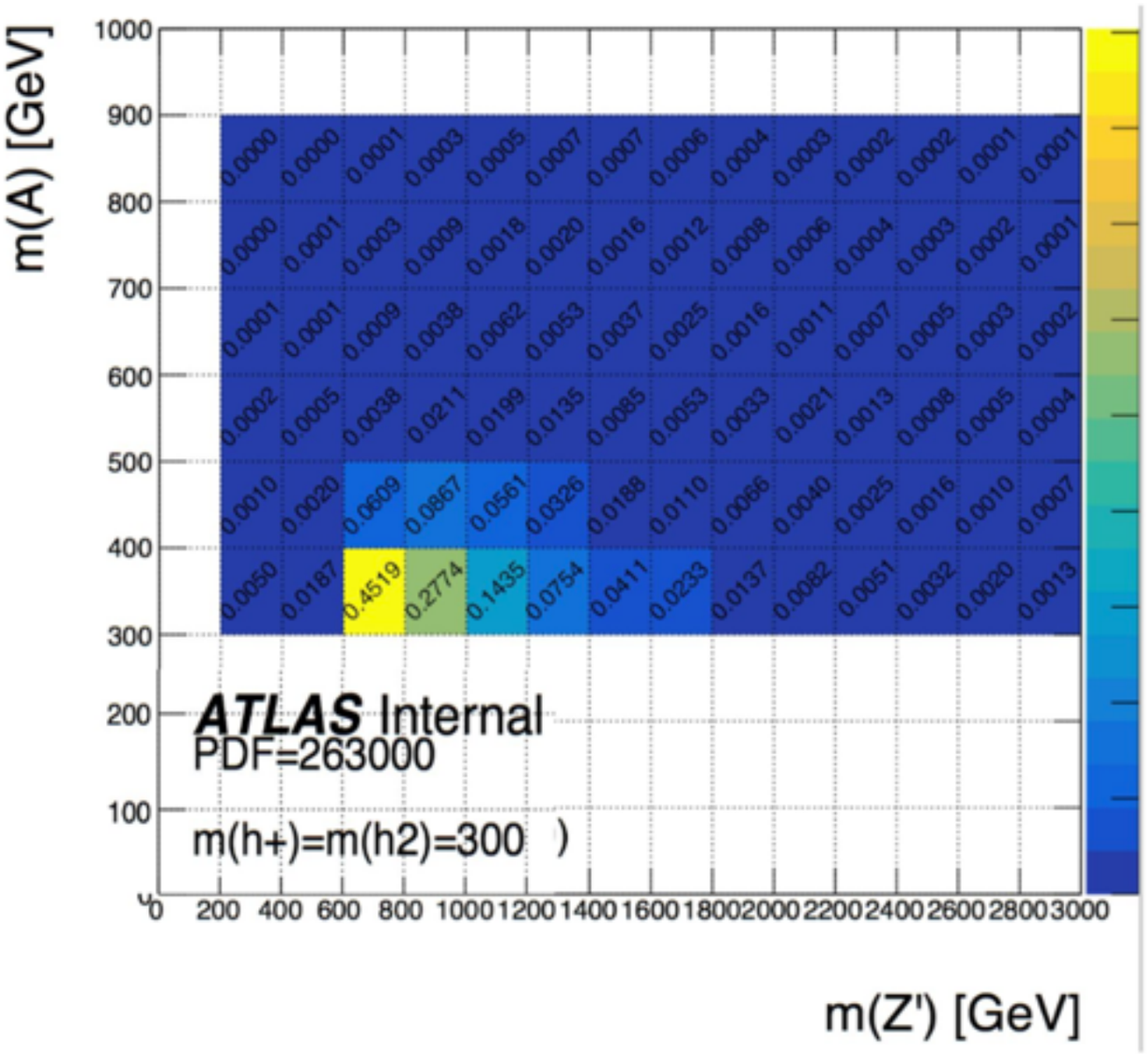


- A->2DM was specified, but h->bbbar was not specified

- m(Z', A) = (600, 300), (1400, 600), (2600, 300) GeV
- Corrected the decay widths of Z' and A due to different masses
- 100K events for each signal samples

Monte Carlo Generation

- Cross-section table was provided from ATLAS



Cross-section Comparison

(Z', A)	MG5	ATLAS
600, 300	0.4522000	0.4519300
1400, 600	0.0037490	0.0037460
2600, 300	0.0020430	0.0020345

[pb]

Looks very good!

Object Selection

- Leptons
  - Loosely defined electrons and muons with Pt > 7 GeV
  - Used for vetoing events

- Small jets
  - anti-kt algorithm with dR = 0.4 cone used for reconstruction
  - Central jets : |eta| < 2.5, Pt > 20 GeV
  - Forward jets : |eta| > 2.5, Pt > 30 GeV
  - no electron candidates within jet more than than dR = 0.2

- Large jets
  - anti-kt algorithm with dR = 1.0 cone used for reconstruction
  - |eta| < 2.0, Pt > 200 GeV

Signal Region

- Resolved region
  - Use small jets reconstructed with dR 0.4 cone
  - Relatively small MET region (MET < 500 GeV)

- Merged region
  - Use large jets reconstructed with dR 1.0 cone
  - Large MET region (MET > 500 GeV)

Selections (resolved)	(a)	(b)	(c)
$E_{\mathrm{T}}^{\mathrm{miss}} < 500$ GeV	0.997	0.606	0.022
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	0.890	0.604	0.022
$p_{\mathrm{T}}^{\mathrm{miss,trk}} > 30$ GeV (not for 2 b-tags)	0.711	0.546	0.020
$\min\left[\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,j}\right)\right] > \pi/9$	0.685	0.497	0.017
$\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss,trk}}\right) < \pi/2$	0.671	0.480	0.016
$N_j \geq 2$	0.658	0.460	0.014
$p_{\mathrm{T},h}^{\text{leading } j} \geq 45$ GeV	0.655	0.459	0.014
$H_{\mathrm{T}} > 120$ GeV or 150 GeV	0.651	0.459	0.014
$\Delta\phi\left(\vec{p}_h^{\,j_1}, \vec{p}_h^{\,j_2}\right) < 7\pi/9$	0.633	0.441	0.012
$\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T},h}\right) > 2\pi/3$	0.620	0.439	0.012
τ veto	0.603	0.424	0.012
$\Delta R\left(\vec{p}_h^{\,j_1}, \vec{p}_h^{\,j_2}\right) < 1.8$	0.506	0.385	<0.01
b-jet Veto	0.503	0.383	<0.01
H_{T}-Ratio Cut (0.63)	0.499	0.382	<0.01
$50 < m_{h,\mathrm{reco}}/\mathrm{GeV} < 280$	0.481	0.378	<0.01
$N(b\text{-tags}) = 2$	0.246	0.177	<0.01
$N(b\text{-tags}) = 1$	0.197	0.164	<0.01

Selections (merged)	(a)	(b)	(c)
$E_{\mathrm{T}}^{\mathrm{miss}} > 500$ GeV	<0.01	0.394	0.977
$p_{\mathrm{T}}^{\mathrm{miss,trk}} > 30$ GeV (not for 2 b-tags)	<0.01	0.375	0.934
$\min\left[\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,j}\right)\right] > \pi/9$	<0.01	0.358	0.834
$\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss,trk}}\right) < \pi/2$	<0.01	0.356	0.822
$N_J \geq 1$	<0.01	0.353	0.818
τ Veto	<0.01	0.343	0.798
b-jet Veto	<0.01	0.326	0.782
H_{T}-Ratio Cut (0.57)	<0.01	0.325	0.782
$50 < m_{h,\mathrm{reco}}/\mathrm{GeV} < 270$	<0.01	0.282	0.705
$N(b\text{-tags}) = 2$	<0.01	0.136	0.150
$N(b\text{-tags}) = 1$	<0.01	0.147	0.442

- Cutflow table provided for both signal regions with 3 different mass points

Signal Region

Common

- No isolated electrons or muons (and veto taus)
- MET > 150 GeV
- dPhi(MET, jets), dPhi(MET, track MET) cuts
- #(b jets) = 1 OR 2

Resolved

- MET < 500 GeV
- higgs candidate (h cand.)
  - 2 b jets
  - 1 b jet + leading jet
- dPhi(h cand., MET) > 2pi/3
- HT > 120 or 150 GeV
- h cand. jets HT ratio > 0.63
- dR(h cand. jets) < 1.8

Merged

- MET > 500 GeV
- h cand.= leading large jet
- h cand. large jet HT ratio > 0.43

Resolved Region

	Z'600 A300		Z'1400 A600		Z'2600 A300	
	MA5	ATLAS	MA5	ATLAS	MA5	ATLAS
MET < 500	0.997	0.997	0.680	0.606	0.088	0.022
MET > 150	0.658	0.890	0.653	0.604	0.080	0.020
Pt trk miss > 30	0.643	0.711	0.648	0.546	0.079	0.017
dphi(MET,jet) > pi/9	0.622	0.685	0.592	0.497	0.071	0.016
dphi(MET,trk miss) < pi/2	0.621	0.671	0.591	0.480	0.071	0.014
# jet >= 2	0.517	0.658	0.495	0.460	0.043	0.014
Pt leading jet > 45	0.486	0.655	0.476	0.459	0.041	0.014
HT > 120 or 150	0.465	0.651	0.471	0.459	0.040	0.014
dphi(higgs jets) < 7pi/9	0.448	0.633	0.439	0.441	0.034	0.012
dphi(MET, higgs) > 2pi/3	0.442	0.620	0.435	0.439	0.033	0.012
tau veto	0.428	0.603	0.417	0.424	0.031	0.012
dR(higgs jets) < 1.8	0.361	0.506	0.361	0.385	0.022	0.010
b jet veto	0.353	0.503	0.356	0.383	0.022	0.010
HT ratio > 0.63	0.321	0.499	0.342	0.382	0.020	<0.01
50 < higgs mass < 280	0.284	0.481	0.325	0.378	0.019	<0.01
# bjet = 2	0.093	0.246	0.110	0.177	0.005	<0.01
# bjet = 1	0.096	0.197	0.106	0.164	0.005	<0.01

Merged Region

	Z'600 A300		Z'1400 A600		Z'2600 A300	
	MA5	ATLAS	MA5	ATLAS	MA5	ATLAS
MET > 500	0.003	<0.01	0.320	0.394	0.912	0.977
Pt trk miss > 30	0.003	<0.01	0.319	0.375	0.910	0.934
dPhi(MET,jet) > pi/9	0.002	<0.01	0.293	0.358	0.784	0.834
dPhi(MET,trk miss) < pi/2	0.002	<0.01	0.293	0.356	0.783	0.822
# fat jet > 0	0.002	<0.01	0.290	0.353	0.778	0.818
tau veto	0.002	<0.01	0.278	0.343	0.728	0.798
b jet veto	0.001	<0.01	0.260	0.326	0.701	0.782
HT ratio > 0.43	0.001	<0.01	0.259	0.325	0.700	0.782
50 < higgs mass < 270	0.001	<0.01	0.251	0.282	0.671	0.705

Issues (1)

- Trigger ?
  - MET trigger is applied but not specified in the paper

	MA5	ATLAS	MA5	ATLAS	MA5	ATLAS
MET < 500	0.997	0.997	0.680	0.606	0.088	0.022
MET > 150	0.658	0.890	0.653	0.604	0.080	0.020

- Electrons and Muons?
  - Cutflow does not show lepton veto but paper says they veto lepton events

- Solution!
  - Use # of events passing MET > 110 GeV AND no leptons as denominator

Issues (1)

Z'600 A'300

	BEFORE	AFTER	ATLAS
trigger & emu veto		1.000	
MET < 500	0.997	0.997	0.997
MET > 150	0.658	0.761	0.890
trk miss > 30	0.643	0.744	0.711
dphi(MET,jet) > pi/9	0.602	0.720	0.685
dphi(MET,trk miss) < pi/2	0.601	0.719	0.671
# jet >= 2	0.517	0.619	0.658
leading jet > 45	0.486	0.581	0.655
HT > 120 or 150	0.465	0.556	0.651
dphi(higgs jets) < 7pi/9	0.448	0.536	0.633
dphi(MET, higgs) > 2pi/3	0.442	0.529	0.620
tau veto	0.428	0.512	0.603
dR(higgs jets) < 1.8	0.361	0.432	0.506
bjet > 0	0.353	0.422	0.503
HT ratio > 0.63	0.321	0.384	0.499
50 < higgs mass < 280	0.284	0.340	0.481
b jet = 2	0.093	0.111	0.246
b jet = 1	0.096	0.115	0.197

Looks better!

Issues (2)

- b tagging for large jets?
  - 2 b jets inside the large jet is the significant signature for this analysis
  - They use b tagging on track jets which are matched to large jets since there is no b tagging for the large jet itself
  - Is it possible to use track jets information in MadAnalysis5?

Multivariate algorithms are used to identify jets containing b-hadrons (b-tagging), which are expected in $h \to b\bar{b}$ decays [67, 69]. These algorithms are applied directly to small-R jets, while for large-R jets they are applied to track-jets matched to large-R jets. Track-jets are reconstructed from ID tracks matched to the PV using the anti-k_t algorithm with $R = 0.2$, and must fulfill $p_{\mathrm{T}} > 10$ GeV and $|\eta| < 2.5$.

Issues (3)

- Horizontal divider?

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$N(b\text{-tags}) = 2$	0.246	0.177	<0.01
$N(b\text{-tags}) = 1$	0.197	0.164	<0.01

Issues (3)

- Horizontal divider?
  - Why is there a horizontal divider?
  - They only divide the signal regions depending on #(b jets) and MET
  - “If 50 < m(h reco) < 280 GeV” is an intermediate cut, why is the sum of “N(b-tags) = 2” and “N(b-tags) = 1” not 0.481?
  - Because they already vetoed b jets (requiring 1 or 2 b jets), the events passing “50 < m(h reco) < 280 GeV” should definitely contain 1 or 2 b jets

b-jet Veto	0.503	0.383	<0.01
H_T-Ratio Cut (0.63)	0.499	0.382	<0.01
$50 < m_{h,\text{reco}}/\text{GeV} < 280$	0.481	0.378	<0.01
$N(b\text{-tags}) = 2$	0.246	0.177	<0.01
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Issues (4)

- Lousy cutflow ?

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Issues (4)

- Lousy cutflow ?
  - #(jets) decided later
  - What if the event has no jets? How do they define the dphi(MET,jet)?
  - Do they keep the 0 jet event and veto it later?

$\min\left\lvert\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,j}\right)\right\rvert > \pi/9$	0.685	0.497	0.017
$\Delta\phi\left(\vec{E}_{\mathrm{T}}^{\mathrm{miss}}, \vec{p}_{\mathrm{T}}^{\,\mathrm{miss,trk}}\right) < \pi/2$	0.671	0.480	0.016
$N_j \geq 2$	0.658	0.460	0.014

- There are some cuts applied in the paper but not shown in the table
- Also there are some cuts in the table but not mentioned in the paper

Conclusion

- Recasting of ATLAS-EXOT-2016-25 has been done
- Looks very good in MC generation level
- We were able to implement most of the cuts in the signal region although some of them were ambiguous
- Some issues need to be discussed with the conveners of ATLAS
- Need to start writing validation note

Thank you