Search for Exotics (and Higgs) Physics beyond the Standard Model with the ATLAS Detector

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Plan of this talk

- LHC and ATLAS detector.
- Signature based search strategy.
- Dileptons/Multi-leptons signature
- Lepton(s) + jet(s) signature
- Dijets/Multi-jets signature
- Top quarks signature
- Vector bosons signature
- Other signatures
- Conclusions.

Other topics

- BSM Higgs:
 - "Beyond the Standard Model Higgs Physics Using the ATLAS Detector" (Guillermo Hamity).
- Dark Matter:
 - "Searches for Dark Matter with the ATLAS Detector" (Ketevi Assamagan).
- Supersymmetry (SUSY):
 - "SUSY Searches in the ATLAS Detector" (Lawrence Lee JR).

LHC

- Large Hadron Collider (LHC)
 - Collide two protons (pp-collision).
 - Center of mass energy:
 - Run1: 2011, 7 TeV, ~5 fb⁻¹; 2012, 8 TeV, ~20 fb⁻¹
 - Run2 (2015 ~): 13 TeV or 14 TeV



- Only recent results with 8TeV data are presented in this talk.
- Selection is based on my preference.

ATLAS Detector

- From inside to outside
 - Inner tracker: reconstruct charged tracks.
 - Calorimeter: detect particle energies.
 - Electromagnetic calorimeter: electros and photons
 - Hadronic calorimeter: charged and neutral hadrons.
 - Muon detector: detect muons.



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Need for BSM physics

- There are many problems with the Standard Model (SM).
 - Hierarchy Problem
 - Neutrino mass term
 - Dark matter
 - Gravity
 - •
- Possible solution is a Beyond the Standard Model (BSM) physics?
 - Supersymmetry?
 - Extra dimensions?
 - Higher symmetry/Unified model?
 - Seesaw mechanism?
 - ...

Signature based search (1)

- To search for a new physics, experimentalists look for particles in final states produced by the new physics.
- An example: Zee-Babu model
 - Physics point of view:
 - A model to generate small neutrino mass with a two loop diagram.
 - Introduce two new scalar particles: h⁺, k⁺⁺
 - Lepton flavor violation is also introduced.
 - Experimental point of view:
 - Look for the new particles.
 - How they are produced in pp-collisions?
 - How they decay?



Signature based search (2)

- Production q γ^*, Z^* q γ^*, Z^* q γ^*, Z^* k^* h^- q γ^*, Z^* k^* h^- q γ^*, Z^* h^* $h^ h^ h^ h^ h^-$
 - The new particle k is either pair produced or produced along with h.
- Decay
 - $k^{++} \rightarrow e^+e^+, e^+\mu^+, \mu^+\mu^+, etc.$
- Look for same-sign lepton pair(s) in final states.

Signature vs Physics models

- Many new physics models can be searched by same signature.
 - (Example) Same-sign diletpon signature:
 - SUSY, Universal Extra Dimensions, Left-right symmetric models, neutrino mass models, Doubly charged Higgs, Vector-like quarks.
 Many extensions of the SM have been
- A new model can be probed by many signatures.
 - (Example) Type III seesaw model:
 - 2 leptons + 2 jets
 - 3 leptons
 - 4 leptons

jets + MET developed over the past decades: 1 lepton + MET Supersymmetry Same-sign di-lepton Extra-Dimensions Dilepton resonance Diphoton resonance Technicolor(s) Diphoton + MET Little Higgs Multileptons Lepton-jet resonance No Higgs Lepton-photon resonance GUT Gamma-jet resonance Diboson resonance Hidden Valley Z+MET Leptoquarks W/Z+Gamma resonance Top-antitop resonance Compositeness Slow-moving particles 4th generation (t', b') Long-lived particles LRSM, heavy neutrino Top-antitop production Lepton-Jets etc... Microscopic blackholes Dijet resonance etc... (for illustration only)

Dileptons/Multi-leptons

- Dileptons
 - Opposite-sign same flavor
 - High mass resonance search (arXiv:1405.4123, PRD90,052005(2014))
 - Heavy gauge boson Z', Excited boson Z*, Spin-2 graviton, Quantum Black Holes, Technicolor
 - Non-resonant dileptons (arXiv:1407.2410, EPJC)
 - Contact Interaction (Ilqq), Large Extra Dimensions
 - Opposite-sign mixed flavor
 - Lepton Flavor Violation: $Z \rightarrow e \mu$ (arXiv:1408.5774, PRD90,072010(2014))
 - Same-sign dileptons (arXiv:1412.0237, JHEP)
 - SUSY, Extra dimension, Neutrino mass models, Doublycharged Higgs
- 3 or more leptons (arXiv:1411.2921)
 - SUSY, Neutrino mass models, Doubly-charged Higgs

Dileptons/Multi-leptons (2)

- Diphoton resonance (arXiv:1210.8389, NJP15,242(2013))
 - KK Graviton (Extra dimensions)

Dilepton resonance (arXiv:1405.4123, PRD90,052005(2014))

- Z' and $Z^* \rightarrow I^+I^-$
- Two isolated opposite-charge same-flavor leptons.
- Electron: leding E_T >40GeV, subleading E_T >30GeV
- Muon p_T >25GeV



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Dilepton Resonane (2)



LFV Z \rightarrow e μ (arXiv:1408.5774, PRD90,072010(2014))

• Lepton Flavor Violation (LFV) decay $Z \rightarrow e\mu$.



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Same-sign dilepton (arXiv:1412.0237, JHEP)

- Two isolated same-sign leptons:
 - Electron leading pT>12GeV, others pT>6GeV
 - Muon leading pT>18GeV, others pT>12GeV
- Z-veto



Same-sign dilepton (2)





Observed

516

438

3 or more charged leptons (arXiv:1411.2921)

Event selection

- 3 or more isolated leptons
- Leading lepton: electron or muon with p_T >26GeV
- Second lepton: electron or muon with $p_T > 15 \text{GeV}$
- Third lepton: electron or muon with $p_T > 15 GeV$ or tau with $p_T > 20 GeV$
- This is a generic search and include multiple Signal Regions depending on
 - On-Z, Off-Z
 - MET = missing transverse energy
 - $H_T = \text{scalar sum of } p_T$
 - m_{eff} = scalar sum of missing E_T , jet H_T and lepton p_T

3 or more leptons (2)

Cross section limits in various signal regions:



3 or more leptons (3)

Doubly-charged Higgs in tau decay mode:



Mass limit : $H_L^{++} > 400 \text{ GeV}$

Lepton + X

- Lepton + X general search (ATLAS-CONF-2014-006)
 - Events with isolated electrons, photons, muons, jets.
- Lepton + MET (neutrino) (arXiv:1407.7494, JHEP09(2014)037)
 - Heavy gauge boson W', Exited boson W*.
- Lepton + jet
 - Scalar Leptoquarks:
 - 1st generation (arXiv:1112.4828, PLB709(2012)158-176)
 - 2nd generation (arXiv:1203.3172, EPJ C72(2012)2151)
 - 3rd generation (arXiv:1303.0526, JHEP06(2013)033)
 - Microscopic Black Holes (arXiv:1405.4254, JHEP08(2014)103)
 - Quantum Black Holes (arXiv:1311.2006, PRL112,091804(2014))
 - Excited Leptons (arXiv:1308.1364, NJP15(2013)093011)

L + Missing energy (arXiv:1407.7494, JHEP09(2014)037)



- One isolated electron with E_T>125GeV + MET>125GeV
- Or one muon with $p_T > 45 \text{GeV} + \text{MET} > 45 \text{GeV}$
- No additional lepton with p_T >20GeV



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Dijets/Multi jets

- Dijet resonance (arXiv:1407.1376, PRD)
 - Excited quarks, Color octet scalars, Heavy and excited W bosons, Quantum black holes,
- Multi jets
 - Resonant Higgs Pair Production (ATLAS-CONF-2014-005)
 - $X \rightarrow HH \rightarrow bbbb$
 - Two Higgs doublet models, KK graviton
- Photon + jet (arXiv:1309.3230, PLB728,562(2013))
 - Quantum Black Holes, Excited quarks
- Dark matter search:
 - "Searches for Dark Matter with the ATLAS Detector" (Ketevi Assamagan).

Dijet resonance (arXiv:1407.1376, PRD)

- Two well measured jets with $p_T > 50 \text{GeV}$ • $m_{ii} > 250 \text{GeV}$
- Prescale-weighted events 10⁹ ATLAS 10 √s=8 TeV, **∫**L dt=20.3 fb⁻¹ 10^{7} 10⁶ 10⁵ 10⁴ Data 10^{3} ---⊚--- *q**, m = 0.6 TeV 10² ------ *q**, m = 2.0 TeV ----- *q**, m = 3.5 TeV [data-fit]/fit Signif. 0.3 0.4 0.5 2 3 1 Reconstructed m_{ii} [TeV]



Dijet resonance (2)



Top quark final states

- ttbar resonance (ATLAS-CONF-2013-052)
 - Leptophobic topcolor Z', Kaluza-Klein gluons
- Same-sign top etc. (ATLAS-CONF-2013-051)
 - 4th generation down-type chiral quarks (b'), Vector Like Quarks, Composite top partners (T_{5/3}), Same-sign top pairs, Contact interactions.
- Vector Like Quarks (VLQ)
 - Little Higgs, Composite Higgs.
 - $VLQ \rightarrow H + t$ (ATLAS-CONF-2013-018)
 - VLQ \rightarrow W + b (ATLAS-CONF-2013-060)
 - VLQ \rightarrow Z + t/b (arXiv:1409.5500, JHEP)
- $W' \rightarrow t b$:
 - I + jets final states (arXiv:1410.4103, PLB)
 - qqbb final states (arXiv:1408.0889, EPJC)

ttbar resonance (ATLAS-CONF-2013-052)

- ttbar \rightarrow b I + bbar I
- Isolated lepton ($p_T > 25 \text{GeV}$) + well defined b-jet
- e+jets: MET>30GeV, m_T >30GeV
- μ +jets: MET>20GeV, MET+m_T>60GeV
- Angular distance between I and j < 1.5



σ_z. × BR(Z'→ tī) [pb] 10 Exp. 95% CL upper limit $L dt = 14.3 \text{ fb}^{-1}$ Exp. 1 o uncertainty Exp. 2 o uncertainty ---- Leptophobic Z' (LO x 1.3) ATLAS Preliminary 10 10

 $\sqrt{s} = 8 \text{ TeV}$

Topcolor Z' mass < 1.9 TeV

Obs. 95% CL upper limit

$VLQ \rightarrow Zt/b$ (arXiv:1409.5500, JHEP)



- Isolated electrons and muons
- Well defined b-jet
- Z candidate: opposite-charge, same –flavor leptons with |m(ll) – m(Z)| < 10GeV



Event selection					
Z boson candidate preselection					
≥ 2 central jets					
$p_{\rm T}(Z) \ge 150 {\rm ~GeV}$					
Dilepton	channel	Trilepton channel			
=2 le	eptons	≥ 3 leptons			
$\geq 2 b$ -tag	gged jets	≥ 1 b-tagged jet			
Pair production	Single production	Pair production	Single production		
$H_{\rm T}({\rm jets}) \ge 600 {\rm ~GeV}$	≥ 1 fwd. jet	-	≥ 1 fwd. jet		
Final discriminant					
m(.	Zb)	$H_{ m T}({ m jets+leptons})$			



$VLQ \rightarrow Zt/b$ (2)

Pair production mass limits:

	Single	t mass limit	[GeV]	Doublet mass limit [GeV]			
Hypothesis	Dilepton	Trilepton	Comb.	Dilepton	Trilepton	Comb.	
$B\bar{B}$	690 (665)	610 (610)	685(670)	765 (750)	540(530)	755(755)	
$T\bar{T}$	620(585)	620 (620)	655 (625)	705 (665)	700(700)	735 (720)	

Single production cross section limits:



$W' \rightarrow tb (L+jets)$ (arXiv:1410.4103, PLB)

- Isolated leptons with $p_T > 30 \text{GeV}$
- Well measured jets with p_T >25GeV



- $W' \rightarrow t \text{ bbar} \rightarrow W(Iv)b \text{ bbar}$
- 1 lepton + 2 b-jets (+ jet)
- MET>35GeV
- m_T(W)+MET>70GeV



W_L' > 1.70 TeV

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Vector boson final states

More details on Blue analysis

- Diboson resonances (V = Z or W)
 - GUT, Little Higgs, Technicolor, Composite Higgs, Extra dimensions.
 - WZ \rightarrow IvII (full leptonic) (arXiv:1406.4456, PLB737,223(2014))
 - $ZZ/ZW \rightarrow IIjj$ (arXiv:1409.6190, EPJC)
 - Wγ and Zγ (arXiv:1407.8150, PLB738,428(2014))
 - WH/ZH \rightarrow Wjj/Zjj (ATLAS-CONF-2013-074)
- Heavy lepton search
 - Heavy neutrino \rightarrow Wv (ATLAS-CONF-2012-139)
 - Left-right symmetric model
 - Heavy lepton \rightarrow Z/ (ATLAS-CONF-2013-019)
 - Type III seesaw model

WZ \rightarrow IVII (full leptonic) (arXiv:1406.4456, PLB737,223(2014))

- Exactly 3 isolated leptons with pT>25GeV
- MET>25GeV
- Z candidate: opposite-charge same-flavor leptons with |m(II) – m(Z)| < 20GeV



$ZZ/ZW \rightarrow IIqq$ (arXiv:1409.6190, EPJC)

- Exactly two isolated oppsite-charge, same-flavor leptons with 66GeV < |m(II) - m(Z)| < 116GeV
- qq side: two well measured jets or one large-R jet. Mass agrees with Z or W.



- Extended Gauge Model
 W' → WZ
- KK Graviton $G^* \rightarrow ZZ$



Other Signatures

- Exotic charges
 - Highly ionizing particles (arXiv:1207.6411, PRL109(2012)261803)
 - Magnetic monopoles
- Long Lived Particles (LLP)
 - LLP decays away from the pp interaction point.
 - Look for displaced decay point (vertex).
 - Special trigger is required.
 - Displaced lepton-jets (LJ):
 - $H \rightarrow dark photon (arXiv:1409.0746, JHEP)$
 - Displaced jets:
 - Heavy scalar → Hidden Valley LLP pair (ATLAS-CONF-2014-041)
- BSM Higgs specific searches:
 - "Beyond the Standard Model Higgs Physics Using the ATLAS Detector" (Guillermo Hamity).

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$LLP \rightarrow lepton-jets$ (arXiv:1409.0746, JHEP)

- pp \rightarrow 2(4) dark photons \rightarrow 2(4) lepton-jets (LJ)
- Dark photons decay in the calorimeter.



- LJ signature:
 - μμ: two muons in the muon detector and no near-by jets.
 - ee: one jet in the calorimeter.
 - No matching tracks in the inner tracker.
 - Type0 (muons), Type1 (muons and jets), Type2 (jets)
- Two LJs with back-to-back (large angular separation)

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LLP \rightarrow lepton-jets (2)



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Conclusions

- Signature based search was done to look for physics Beyond the Standard Model (BSM).
- Recent results with 2012, 8TeV data are presented.
- No significant deviation from the Standard Model.
- Limits are set for new physics models/particles.
- Please see other talks for BSM Higgs, Dark Matter and SUSY.

ATLAS Exotics Searches* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS	Preliminarv
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 $\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1} \quad \sqrt{s} = 7, 8 \text{ TeV}$

	Model	<i>ℓ</i> ,γ	Jets	$\mathbf{E}_{\mathrm{T}}^{\mathrm{miss}}$	∫£ dt[ft	- ⁻] Mass limit		Reference
Extra dimensions	$\begin{array}{l} \text{ADD } G_{KK} + g/q \\ \text{ADD non-resonant } \ell\ell \\ \text{ADD OBH} \to \ell q \\ \text{ADD OBH} \to \ell q \\ \text{ADD OBH } \text{high } \mathcal{V}_{trk} \\ \text{ADD BH high } \mathcal{V}_{trk} \\ \text{Bulk RS } \mathcal{G}_{KK} \rightarrow \mathcal{H} \\ \text{ADD } \mathcal{V}_{trk} \\ \text{ADD BH high } \mathcal{V}_{trk} \\ \mathcal$	$\begin{array}{c} - \\ 2e, \mu \\ 1 e, \mu \\ - \\ 2 \mu (SS) \\ \ge 1 e, \mu \\ 2 e, \mu \\ 2 e, \mu \\ 2 e, \mu \\ - \\ 1 e, \mu \\ 2 e, \mu \\ 2 \gamma \end{array}$	$\begin{array}{c} 1-2j\\ -\\ 1j\\ 2j\\ -\\ \geq 2j\\ -\\ 2j/1J\\ 4b\\ \geq 1b, \geq 1J\\ -\\ -\\ -\\ -\\ -\end{array}$	Yes Yes Yes Yes	4.7 20.3 20.3 20.3 20.3 20.3 20.3 20.3 4.7 20.3 19.5 14.3 5.0 4.8	$\begin{tabular}{ c c c c c } \hline M_D & & & & & & & & & & & & & & & & & & &$	$\begin{split} n &= 2 \\ n &= 3 \text{ HLZ} \\ n &= 6 \\ n &= 6 \\ n &= 6, \ M_D &= 1.5 \text{ TeV, non-rot BH} \\ n &= 6, \ M_D &= 1.5 \text{ TeV, non-rot BH} \\ k/\overline{M}_{Pl} &= 0.1 \\ k/\overline{M}_{Pl} &= 0.1 \\ k/\overline{M}_{Pl} &= 1.0 \\ BR &= 0.925 \end{split}$	1210.4491 ATLAS-CONF-2014-030 1311.2006 to be submitted to PRD 1308.4075 1405.4254 1405.4254 1405.4123 1208.2880 ATLAS-CONF-2014-039 ATLAS-CONF-2014-035 1209.2535 ATLAS-CONF-2012-072
Gauge bosons	$\begin{array}{l} \mathrm{SSM}\; Z' \to \ell\ell \\ \mathrm{SSM}\; Z' \to \tau\tau \\ \mathrm{SSM}\; W' \to \ell\nu \\ \mathrm{EGM}\; W' \to WZ \to \ell\nu\; \ell'\ell' \\ \mathrm{EGM}\; W' \to WZ \to qq\ell\ell \\ \mathrm{LRSM}\; W'_R \to t\bar{b} \\ \mathrm{LRSM}\; W'_R \to t\bar{b} \end{array}$	2 e,μ 2 τ 1 e,μ 3 e,μ 2 e,μ 1 e,μ 0 e,μ	_ _ 2 j / 1 J 2 b, 0-1 j ≥ 1 b, 1 J	- Yes Yes - Yes	20.3 19.5 20.3 20.3 20.3 14.3 20.3	Z' mass 2.9 TeV Z' mass 1.9 TeV W' mass 3.28 TeV W' mass 1.52 TeV W' mass 1.59 TeV W' mass 1.84 TeV W' mass 1.77 TeV		1405.4123 ATLAS-CONF-2013-066 ATLAS-CONF-2014-017 1406.4456 ATLAS-CONF-2014-039 ATLAS-CONF-2013-050 to be submitted to EPJC
CI	Cl qqqq Cl qqℓℓ Cl uutt	_ 2 e, μ 2 e, μ (SS)	2 j _ ≥ 1 b, ≥ 1	– – j Yes	4.8 20.3 14.3	Λ 7.6 TeV Λ Λ 3.3 TeV	$\eta = +1$ 21.6 TeV $\eta_{LL} = -1$ C = 1	1210.1718 ATLAS-CONF-2014-030 ATLAS-CONF-2013-051
DM	EFT D5 operator (Dirac) EFT D9 operator (Dirac)	0 e,μ 0 e,μ	1-2 j 1 J, ≤ 1 j	Yes Yes	10.5 20.3	M. 731 GeV M. 2.4 TeV	at 90% CL for $m(\chi) < 80$ GeV at 90% CL for $m(\chi) < 100$ GeV	ATLAS-CONF-2012-147 1309.4017
ГО	Scalar LQ 1 st gen Scalar LQ 2 nd gen Scalar LQ 3 rd gen	2 e 2 μ 1 e, μ, 1 τ	≥ 2 j ≥ 2 j 1 b, 1 j		1.0 1.0 4.7	LQ mass 660 GeV LQ mass 685 GeV LQ mass 534 GeV	$egin{array}{lll} eta=1\ eta=1\ eta=1\ eta=1\ eta=1\ eta=1 \end{array}$	1112.4828 1203.3172 1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$ Vector-like quark $TT \rightarrow Wb + X$ Vector-like quark $TT \rightarrow Zt + X$ Vector-like quark $BB \rightarrow Zb + X$ Vector-like quark $BB \rightarrow Wt + X$	$\begin{array}{c} 1 \ e, \mu \\ 1 \ e, \mu \\ 2 / \geq 3 \ e, \mu \\ 2 / \geq 3 \ e, \mu \\ 2 & e, \mu \\ 2 \ e, \mu \ (\text{SS}) \end{array}$	$ \begin{array}{l} \geq 2 \ b, \geq 4 \\ \geq 1 \ b, \geq 3 \\ \geq 2/{\geq}1 \ b \\ \geq 2/{\geq}1 \ b \\ \geq 2/{\geq}1 \ b \\ \geq 1 \ b, \geq 1 \end{array} $	j Yes j Yes – j Yes	14.3 14.3 20.3 20.3 14.3	T mass 790 GeV T mass 670 GeV T mass 735 GeV B mass 755 GeV B mass 720 GeV	T in (T,B) doublet isospin singlet T in (T,B) doublet B in (B,Y) doublet B in (T,B) doublet	ATLAS-CONF-2013-018 ATLAS-CONF-2013-060 ATLAS-CONF-2014-036 ATLAS-CONF-2014-036 ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \rightarrow q\gamma$ Excited quark $q^* \rightarrow qg$ Excited quark $b^* \rightarrow Wt$ Excited lepton $\ell^* \rightarrow \ell\gamma$	1 γ - 1 or 2 e, μ 2 e, μ, 1 γ	1 j 2 j 1 b, 2 j or 1 –	– – jYes –	20.3 20.3 4.7 13.0	q* mass 3.5 TeV q* mass 4.09 TeV b* mass 870 GeV f* mass 2.2 TeV	only u^* and d^* , $\Lambda = m(q^*)$ only u^* and d^* , $\Lambda = m(q^*)$ left-handed coupling $\Lambda = 2.2 \text{ TeV}$	1309.3230 to be submitted to PRD 1301.1583 1308.1364
Other	LSTC $a_T \rightarrow W\gamma$ LRSM Majorana ν Type III Seesaw Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$ Multi-charged particles Magnetic monopoles	$ \begin{array}{c} 1 \ e, \mu, 1 \ \gamma \\ 2 \ e, \mu \\ 2 \ e, \mu \\ 2 \ e, \mu \\ (SS) \\ - \\ - \\ \sqrt{s} = \end{array} $	- 2 j - - - - 7 TeV	Yes 	20.3 2.1 5.8 4.7 4.4 2.0 8 TeV	ar mass 960 GeV Nº mass 1.5 TeV N* mass 245 GeV H** mass 409 GeV multi-charged particle mass 490 GeV monopole mass 862 GeV 10 ⁻¹ 1	$m(W_R) = 2 \text{ TeV, no mixing}$ $ V_e =0.055, V_{\mu} =0.063, V_{\tau} =0$ DY production, BR($H^{\pm\pm} \rightarrow \ell \ell$)=1 DY production, $ q = 4e$ DY production, $ g = 1g_D$	to be submitted to PLB 1203.5420 ATLAS-CONF-2013-019 1210.5070 1301.5272 1207.6411
							iviass scale [IeV]	

*Only a selection of the available mass limits on new states or phenomena is shown.

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$W' \rightarrow tb (qqbb)$ (arXiv:1408.0886, EPJC)

• W' \rightarrow t bbar \rightarrow W(qq)b bbar



- One large-R jet with $p_T > 350 \text{GeV}$
- Large-R jet is widely distributed and include W(qq) and b.
- One b-jet with p_T>350GeV
- Angular distance between large-R jet and b-jet > 2.0



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Wy and Zy $_{(arXiv:1407.8150,\ PLB738,428(2014))}$

$W \rightarrow Iv, Z \rightarrow II mode$ Events / 80 GeV Events / 80 GeV Data 2012 Data 2012 10⁵ 10⁵ ATLAS W(ev)+y ATLAS W(μν)+γ Z(e⁺e⁻)+jets Z(µ+µ)+jets 10 L dt = 20.3 fb⁻¹, √s = 8 TeV L dt = 20.3 fb⁻¹, √s = 8 TeV 10⁴ W(ev)+jets W(uv)+jets 10³ +iets γ+jets 10³ Other Backgrounds Other Backgrounds 10² m(a_) = 600 GeV x 10 m(a_) = 600 GeV x 10 10² Background Fit ± 1 σ Background Fit ± 1 o 10 10 1 10 Significance Significance 200 400 600 800 1000 1200 1400 1600 200 400 600 800 1000 1200 1400 1600 m^{eνγ} [GeV] $m_{\tau}^{\mu\nu\gamma}$ [GeV] 10⁵ Events / 60 GeV Data 2012 Data 2012 104 ATLAS ATLAS Z(e⁻e⁺)+y Z(μ⁻μ⁺)+γ L dt = 20.3 fb⁻¹, **v**s = 8 TeV L dt = 20.3 fb⁻¹, **√**s = 8 TeV Z(e⁻e⁺)+jets Z(u⁻u⁺)+jets 10³ Other Backgrounds Other Backgrounds 10² m(ω_τ) = 500 GeV x 10 n(ω_τ) = 500 GeV x 10 Background Fit $\pm 1\sigma$ Background Fit ± 1 σ 10 1 eev 10 Significance 1600 200 400 600 800 1000 1200 1400 200 400 600 800 1000 1200 1400 m^{e⁺e⁻γ} [GeV] m^{μ+μ-γ} [GeV]

lvγ mode:

- Lepton p_T >25GeV
- Photon $E_{T}>45GeV$
- MET>35GeV Ily mode:
- 65 < |m(II) m(Z)|<115GeV
- Photon E_{τ} >40GeV

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Wy and Zy (2)





- Low Scale Technicolor model:
 - M(a_T) > 960 GeV
 - M(ω_T) > 890 GeV
- Singlet scalar resonance:
 - M(φ) > 1180 GeV

LLP pair (ATLAS-CONF-2014-041)

- Heavy scalar boson $(\Phi_{HS}) \rightarrow LLP(\pi_v)$ pair
- LLP candidate:
 - Narrow jet in hadronic calorimeter
 - Small energy deposit in EM calorimeter.
 - No matching track in the inner tracker.







Excluded proper decay length

MC sample	excluded range	excluded range		
$m_{\Phi}, m_{\pi v}$	$30\% \text{ BR } \Phi_{\text{HS}} \rightarrow \pi_{\text{v}} \pi_{\text{v}}$	10% BR $\Phi_{\rm HS} \rightarrow \pi_{\rm v} \pi_{\rm v}$		
[GeV]	[m]	[m]		
126, 10	0.10 - 4.38	0.13 - 2.30		
126, 25	0.27 - 10.01	0.37 - 5.12		
126, 40	0.54 - 12.11	0.86 - 5.62		

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