No stone left unturned?

Searches for Physics Beyond the Standard Model at the ATLAS experiment

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Big open questions



LHC + ATLAS: searching for surprises

- In this talk: Searches for (non-SUSY) New Physics
- Simple final states to more complex

W. Fedorko, CAP, Laurentian University June 2014

Dilepton Resonance Search

- Di-electrons channel
 - Leading E_T > 40 GeV, Sub-leading E_T > 30 GeV, both isolated
- Di-muon channel
 - p_T > 25 GeV, isolated
 - High p_T quality cuts
 - Opposite sign



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Run Number: 209353 Event Number: 46681378 Date: 2012-08-27, 22:08:31 CET TITITI

EXPERIMENT

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EtCut > 1.0 GeV

Cells: Tiles, EN

EtCut > 0.5 GeV PtCut > 0.4 GeV Muon: blue Cells: Tiles, EMC

Dilepton Resonance Search: interpretation



Model	Expected Limit [TeV]	Observed Limit [TeV]
Z′ _{SSM}	2.87	2.90
Z′ _x	2.60	2.62
Ζ' _ψ	2.46	2.51
Ζ*	2.82	2.85

Also interpretations in QBH, MWT

Di-lepton Contact interaction search

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Jncorrected

-0.2

-0.4

-0.6

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Data 2012

Background

— Λ⁻_{LL} = 14 TeV

----· Λ⁺_{LL} = 14 TeV

— A_{IB} = 14 TeV

----· Λ⁺_{LB} = 14 TeV

2

m_{ee} [TeV]

0.2 0.3 0.4

ee: L dt = 20.3 fb

s = 8 TeV

- Re-interpretation in terms of 'Fermi' interaction
- Opposite sign requirement for e⁺e⁻ \bullet
- $\cos\theta$ * utilized to improve sensitivity \bullet

Data 2012

Top guarks

- A_1 = 14 TeV

- A⁺₁₁ = 14 TeV

M_s = 4.0 TeV (GRW)

m_{uu} [TeV]

Diboson

Photon-Induced

Ζ/γ*

Events 10⁷

10⁵

10⁴

10³

102

10

10

1.2

0.8 0.6

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0.1

Data / Bkg . 1

ATLAS Preliminary

 $\mu\mu$: L dt = 20.5 fb⁻¹

vs = 8 TeV

0.3 0.4

0.2

0 1





Search in lepton and E_T^{miss} final state

- Electrons:
 - $E_{T}, E_{T}^{miss} > 125 \text{ GeV}, \text{ isolated}$
- Muons:
 - E_T, E_T^{miss}> 45 GeV, isolated
- Optimized m_T cut (250-900 GeV)





Search in to lepton and E_t^{miss} : interpretation

Mono-W interpretation:





• Observed Mass Limits:

- $m_{W'} > 3.19 \text{ TeV}$
- m_{w*} > 3.08 TeV

Search for new phenomena in lepton+jet final state 0000000

- Anti- k_T R=0.6 jet E_T > 125 GeV
- Isolated, central photon, separated from the jet $E_T > 125$ GeV
- Pseudorapidity separation < 1.6





QBH Limit: М_{тн} > 4.6 TeV

q* Limit m_{g*} > 3.5 TeV

arXiv:1404.0051

$Z(\rightarrow |+|^{-})+E_{T}^{miss}$ search

- e^+e^- or $\mu^+\mu^-$ pair in Z window, leptons isolated
- Topological cuts on E_T^{miss} and p_T^{II}







Interpretations for DM-nucleon scattering, scalar particle mediator model and $ZZ\chi\chi$

Fiducial cross-section limits [fb]:

E _t ^{miss} threshold [GeV]	150	250	350	450
Expected limit	3.0	0.73	0.36	0.27
Observed limit	2.7	0.57	0.27	0.26

$W/Z \rightarrow qq' + E_T^{miss} search$

- One 'Cambridge-Aachen' large radius (1.2) jet
 - p_T > 120 GeV, m_i 50-120 GeV, |η|<1.2, sub-jets balanced
- Veto on additional narrow jets and leptons
- Signal regions $E_T^{miss} > 350, 500 \text{ GeV}$



Interpretations for DM-nucleon scattering; Higgs as a mediator limit at $m_H = 125 \text{ GeV}$: $\sigma < 1.3 \text{ pb}$ Fiducial limits published W. Fedorko, CAP, Laurentian University June 2014



PRL 112, 091804 (2014)

Lepton + jet search for quantum black holes



- p_{T lepton}, p_{T jet}> 130, leptons isolated
- Topological cuts: $|\Delta \phi_{l,j}| > \pi/2$, $|<\eta_{l,j}>|<1.25$, $|\Delta \eta|<1.5$
- m_{min} cut as a function of M_{TH}

Observed limits: n=6: M_{TH} > 5.3 TeV n=2: M_{TH} > 4.7 TeV

Lepton+jets search for microscopic black holes



95% CL Upper Limi

Observed (n=6)
Expected (n=6)

ATLAS

L dt = 20.3 fb⁻¹, (s = 8 TeV

- $\Sigma p_T > 2 \text{ TeV}$
- 3 objects with $p_T > 100$ GeV, one- an isolated lepton



- Observed Limits (non-rotating, $M_D = 1.5 \text{ TeV}$, n = 6) $M_{TH} > 6.2 \text{ TeV}$
- Limits published on variety of microscopic black hole scenarios and string balls.

PRD 88, 072001 (2013) Same-sign dimuon + tracks search for microscopic black holes

- Leading muon p_T > 100 GeV isolated
- Subleading $p_T > 15 \text{ GeV}$
- Leading and sub-leading p_T muons same-sign, separated $\Delta R > 0.2$ 0
- 40 tracks with $p_T > 10 \text{ GeV}$ •



- Observed limit on σ_{vis} < 0.16 fb •
- Observed limit on M_{TH} (non-rotating $M_D = 1.5$ TeV, n=6) $M_{TH} > 5.7$ TeV 0
- Variety of microscopic black hole scenarios and string balls constrained 0

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Ivl'I' WZ resonant production search

- Exactly 3 isolated (calo+track) electrons and muons p_T > 25 GeV
 - Isolation criteria exclude same flavor lepton
 - Two must be same flavor, opposite sign with $m_{\rm II}$ within 20 GeV of the Z
 - $e-\mu$ separation $\Delta R > 0.1$
- $E_T^{miss} > 25 \text{ GeV}$
- p_{zv} from m_W constraint
- Δy(W,Z) < 1.5
- For searches for $m_{W'} > 250 \text{ GeV SR1}$: $\Delta \Phi(I, E_T^{miss}) < 1.5; m_{W'} < 250 \text{ GeV SR2}$: $\Delta \Phi(I, E_T^{miss}) > 1.5;$



Observed limits: EGM W': m_{W'} > 1.52 TeV HVT W': m_{W'} > 0.76 – 1.56 TeV

Fiducial cross section limits published

Resonant HH production search decay to 4 b quarks 20000 **11111**



- 4 b-tagged jets $p_T > 20$ GeV
- 2 'dijets' ΔR_{ii} < 1.5, p_{T, ii} > 200 GeV
- tt veto, t hypothesis formed using extra jets •
- Elliptical cut in m_{ii}^{lead}-m_{ii}^{sublead} plane



ATLAS-CONF-2014-005



Di-tau resonance search (all hadronic channel)

- τ candidates: jets with 1 or 3 tracks, p_T > 50 GeV
- 2τ opposite sign, back-to-back candidates, leading $p_T > 150$ GeV
 - BDT ID
- m_{T,}^{tot} threshold dependent on signal hypothesis (400-850 GeV)





SSM Z' limit m_{Z'} > 1. 90 TeV

Di-top resonance search (l+jets channel)

- Exactly one mini-isolated e or μ , $p_T > 25$ GeV
- $E_T^{miss} > 30 \text{ GeV}$ (e-channel); $E_T^{miss} > 20$ $E_T^{miss} + m_{T,l met} > 60 \text{ GeV}$, p_{zv} from W constraint
- Boosted sample:
 - One narrow (R=0.4) $p_T > 25$ GeV, b-tagged
 - One large radius (R=1.0) 'trimmed' jet $p_T > 300$ GeV, $m_i > 100$ GeV, splitting scale 40 GeV
- Resolved sample (fails boosted sample first)
 - 4 narrow jets or 3 narrow jets with one m_i > 60 GeV, one b-taged
 - X² selects best assignment of jets to partons





Limits: m_{gKK} > 2.0 TeV m_{z'} > 1.8 TeV

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ATLAS-CONF-2013-052



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Heavy vector-like quark searches ATLAS-CONF-2013-056 ATLAS-CONF-2013-056 ATLAS-CONF-2013-056

- T->Wb search:
 - I+jets channel selection, 1 b-tag
 - Discrimination against tt:
 - H_{T} , I-v collimated, W_{had} -b and I-b separation
- T->Ht search
 - I+jets + H->bb selection
 - High jet multiplicity 2,3,4 b-tag SRs
- T(B)->Zt(b) search
 - Selection of high $p_T Z$ ->e⁺e⁻, $\mu^+\mu^-$
 - 2 b-tagged jets
 - High H_T of central jets







T(B)

T(B)

20000

5000000

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Γ(B),~~

Heavy vector-like quark searches



d2

Search for muonic lepton jets

- 3 μ 'MS only' trigger
- Muon Jets : clustering of MS tracks
- Exclusively two 2 opposite sign μ-MJs required

- Isolated, separated, with no ID activity



PLB 722, 305 (2013) PRL 109 (2012) 261803

Monopoles, multi-charged particles

• Discriminate using the TRT dE/dX, high threshold hits



General search

- Broad search
- Trigger and exclusive final state classification
- Regions of highest deviation from prediction identified in m_{inv} and m_{eff} spectra
- Trials factor accounted for using pseudo-experiments



No stone left unturned?

ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 2014

E_{τ}^{miss} $\int \mathcal{L} dt [fb^{-1}]$ Mass limit Model l, γ Jets Reference ADD $G_{KK} + g/q$ Yes 1-2 j 4.7 4.37 TeV 1210.4491 n = 2ADD non-resonant $\ell \ell / \gamma \gamma$ 2γ or 2e, μ 4.7 4.18 TeV n = 3 HLZ NLO 1211.1150 -ADD QBH $\rightarrow \ell a$ 1 j 1 e, µ _ 20.3 5.2 Te n = 61311.2006 ADD BH high N_{trk} 2 µ (SS) 20.3 n = 6, M_D = 1.5 TeV, non-rot BH _ 1308 4075 5 7 Tel ADD BH high $\sum p_T$ $\geq 1 e, \mu$ ≥ 2 j 20.3 n = 6, Mp = 1.5 TeV, non-rot BH ATLAS-CONF-2014-016 _ RS1 $G_{KK} \rightarrow \ell \ell$ 2 e. µ 20.3 2.47 TeV $k/\overline{M}_{Pl} = 0.1$ ATLAS-CONF-2013-017 RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell \ell q q / \ell \ell \ell \ell$ 2 or 4 e, µ 2 j or 845 GeV $k/\overline{M}_{Pl} = 0.1$ 1203.0718 1.0 G_{KK} mas RS1 $G_{KK} \rightarrow WW \rightarrow \ell \nu \ell \nu$ 1.23 TeV 2 e, µ Yes 4.7 G_{KK} mas $k/\overline{M}_{Pl} = 0.1$ 1208.2880 Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ 590-710 GeV $k/\overline{M}_{Pl} = 1.0$ ATLAS-CONF-2014-005 4 b 19.5 G_{KK} mass Bulk RS $g_{KK} \rightarrow t\bar{t}$ 1 e, µ $\geq 1 \text{ b}, \geq 1 \text{J/2j}$ Yes 14.3 grr mass BR = 0.925ATLAS-CONF-2013-052 0.5-2.0 TeV $S^1/Z_2 ED$ 2 e, µ 1209.2535 5.0 M_{KK} ≈ R⁻ 4.71 TeV UED 2γ Yes 4.8 1.41 TeV ATLAS-CONF-2012-072 Compact, scale R SSM $Z' \rightarrow \ell \ell$ 2 e, µ 20.3 ATLAS-CONF-2013-017 _ _ 2.86 TeV SSM $Z' \rightarrow \tau \tau$ 2τ 19.5 1.9 TeV ATLAS-CONF-2013-066 uge SSM $W' \rightarrow \ell v$ 1 e, µ Yes 20.3 ATLAS-CONF-2014-017 Ga EGM $W' \rightarrow WZ \rightarrow \ell \nu \, \ell' \ell'$ 3 e, µ Yes 20.3 ATLAS-CONF-2014-015 .52 TeV 1 e, µ LRSM $W'_{D} \rightarrow t\overline{b}$ 2 b, 0-1 j ATLAS-CONF-2013-050 Yes 14.3 84 TeV CI qqqq 2 j 4.8 $\eta = +1$ 7.6 TeV 1210 1718 _ _ 5 CI ggll 2 e, µ 5.0 **13.9 TeV** $\eta_{LL} = -1$ 1211.1150 CI uutt $2 e, \mu$ (SS) $\geq 1 b, \geq 1 j$ Yes 14.3 3.3 TeV |C| = 1ATLAS-CONF-2013-051 EFT D5 operator 1-2 j Yes 10.5 731 GeV at 90% CL for $m(\chi) < 80 \text{ GeV}$ ATLAS-CONF-2012-147 DM EFT D9 operator _ 1 J, ≤ 1 j Yes 20.3 2.4 TeV at 90% CL for $m(\chi) < 100 \text{ GeV}$ 1309.4017 Scalar LQ 1st gen 2 e ≥ 2 j 1.0 Q mass 660 GeV $\beta = 1$ 1112.4828 Q Scalar LQ 2nd gen 2μ ≥ 2 i $\beta = 1$ 1.0 LQ mass 685 GeV 1203.3172 Scalar LQ 3rd gen $1 \, e, \mu, 1 \, \tau$ 1 b, 1 j _ 4.7 LQ mass 534 GeV $\beta = 1$ 1303 0526 Vector-like quark $TT \rightarrow Ht + X$ $\geq 2 \text{ b}, \geq 4 \text{ j}$ Yes 14.3 T in (T,B) doublet ATLAS-CONF-2013-018 1 e. u Heavy Vector-like quark $TT \rightarrow Wb + X$ 1 e, µ ≥ 1 b, ≥ 3 j 14.3 isospin singlet ATLAS-CONF-2013-060 Yes 670 GeV Vector-like quark $BB \rightarrow Zb + X$ 2 e.u $\geq 2 b$ 14.3 725 GeV B in (B,Y) doublet ATLAS-CONF-2013-056 Vector-like quark $BB \rightarrow Wt + X$ 2 e, μ (SS) ≥ 1 b, ≥ 1 j Yes 14.3 B in (T,B) doublet ATLAS-CONF-2013-051 Excited quark $q^* \rightarrow q\gamma$ 1γ 1 i _ 20.3 3.5 TeV only u^* and d^* , $\Lambda = m(q^*)$ 1309.3230 Excited Excited quark $q^* \rightarrow qg$ 2 j _ 13.0 2 84 TeV only u^* and d^* , $\Lambda = m(q^*)$ ATLAS-CONF-2012-148 Excited quark $b^* \rightarrow Wt$ 1 or 2 e, µ 1 b, 2 j or 1 j Yes 4.7 870 GeV left-handed coupling 1301 1583 b* mass Excited lepton $\ell^* \rightarrow \ell \gamma$ 2 e, µ, 1 γ 13.0 $\Lambda = 2.2 \text{ TeV}$ 1308.1364 LRSM Maiorana v 2 e. µ 2 j _ 2.1 N⁰ mass 1.5 TeV $m(W_R) = 2$ TeV, no mixing 1203.5420 Type III Seesaw $|V_e|=0.055, |V_u|=0.063, |V_\tau|=0$ 2 e, µ 5.8 ATLAS-CONF-2013-019 245 GeV Other Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ 2 e, µ (SS) 4.7 DY production, BR($H^{\pm\pm} \rightarrow \ell \ell$)=1 1210.5070 H^{±±} mass 409 GeV Multi-charged particles 4.4 multi-charged particle mas 490 GeV DY production, |q| = 4e1301.5272 Magnetic monopoles 2.0 862 GeV DY production, $|g| = 1g_D$ 1207.6411 monopole mass . 1 √s = 7 TeV $\sqrt{s} = 8 \text{ TeV}$ 10^{-1} 1 10 Mass scale [TeV]

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

ATLAS Preliminary

 $\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1}$

 $\sqrt{s} = 7, 8 \text{ TeV}$



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Backup

DM limits nucleon scattering interpretation



arXiv:1404.0051

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DM limits from I+E_T^{miss} search



Z' sensitivity



Searches in the Higgs Sector: FCNC: t->q H

- tt search with one t decaying to qH and H -> γγ
- Two isolated photons
- tt selection (hadronic in 7 TeV data, leptonic and hadronic in 8 TeV data)



• Limits: B(t->qH)<0.79%, Yukawa coupling to c u < 0.17

ATLAS-CONF-2014-010

New physics interpretations of Constraints on: **Higgs properties**

- Use measured properties:
 - Production and decay rates: $h \rightarrow \gamma \gamma$, h->ZZ->4, h->WW->lvlv, h->bb, h->ττ
 - Mass: h->ZZ->4l, h->γγ

- Additional EW sinler
- 2HDM
- Simplified MSSM
- Higgs portal







arXiv:1405.4123

QBH and MWT limits in dilepton search

