The 4th China LHC Physics Workshop CLHCP 2018

Search for Exotics Physics at ATLAS and CMS







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CLHEP 2018 @ CCNU, Liang Li

Outline

- Motivation
- Resonances Search
- Dark Matter Search
- Long-lived Particles
 Search
- Summary



Why Exotics?

Status: July 2018

Model

ADD QBH

ADD $G_{KK} + g/q$

ADD BH high 5 pt

ADD BH multijet

ADD non-resonant yy

Finding new physics

- No one knows for sure where ٠ is the new physics
 - Leave nothing untouched
 - Go "exotic"! •
- How "exotic" can one go?
 - New interactions and products: resonances
 - **Broad kinematic reach** ٠
 - Low to high masses
 - 28 GeV resonances not covered here, sorry!
 - New signatures: long-lived • particles, emerging jet
 - Dark matter •
- Model independent if possible

Not possible to cover all searches Only focus on recent results

Personal taste

 10^{-1}

Extra d	RS1 $G_{KK} \rightarrow \gamma\gamma$ Bulk RS $G_{KK} \rightarrow WW/ZZ$ Bulk RS $g_{KK} \rightarrow tt$ 2UED / RPP	2γ - multi-channel $1 e, \mu \ge 1 b, \ge$ $1 e, \mu \ge 2 b, \ge$	– 1J/2jYes ≥3jYes	36.7 36.1 36.1 36.1	G _{FK} mass 4.1 TeV G _{KK} mass 2.3 TeV Box moss 3.8 TeV KK mass 1.8 TeV	$\begin{split} & k/\overline{M}_{Pl} = 0.1 \\ & k/\overline{M}_{Pl} = 1.0 \\ & \Gamma/m = 15\% \\ & \text{Tier} (1,1), \mathcal{B}(A^{(1,1)} \rightarrow tt) = 1 \end{split}$	1707.04147 CEPIN-EP-2018-179 1804.10823 1803.09678
Gauge bosons	$\begin{array}{l} \text{SSM } Z' \rightarrow \ell\ell \\ \text{SSM } Z' \rightarrow \tau\tau \\ \text{Leptophobic } Z' \rightarrow bb \\ \text{Leptophobic } Z' \rightarrow tr \\ \text{SSM } W' \rightarrow \ellr \\ \text{SSM } W' \rightarrow \taur \\ \text{HVT } V' \rightarrow WV \rightarrow qqq \ \text{model B} \\ \text{HVT } V' \rightarrow WV + TW \\ \text{HVT } V' \rightarrow WH / ZH \ \text{model B} \\ \text{LSM } W_K^{e} \rightarrow tb \end{array}$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	- 1J/2j Yes Yes Yes	36.1 36.1 36.1 79.8 36.1 79.8 36.1 36.1 36.1	Z' mass 4.5 TeV Z' mass 2.42 TeV Z' mass 2.1 TeV Z' mass 3.0 TeV Z' mass 3.0 TeV W' mass 5.6 TeV W' mass 3.7 TeV V' mass 4.5 TeV V' mass 3.2 TeV V' mass 3.2 STeV V' mass 3.2 ST EV	$\Gamma/m = 156$ $g_V = 3$ $g_V = 3$	1707.02424 1709.07242 1805.09299 1804.10823 ATLAS-CCNF-2018-01 1801.08992 ATLAS-CCNF-2018-01 1712.06518 CEPN-EP-2018-142
CI	Cl qqqq Cl f£qq Cl tttt	- 2 j 2 e,μ - ≥1 e,μ ≥1 b, ≥	– – ≥1jYes	37.0 36.1 36.1	Λ Λ Λ 2.57 TeV	21.8 TeV η ⁻ _{LL} 40.0 TeV η _{LL} C ₄₊ = 4π	1703.09217 1707.02424 CEPN-EP-2018-174
МQ	Axial-vector mediator (Dirac DM) Colored scalar mediator (Dirac DM VVXX EFT (Dirac DM)	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	ij Yes jYes jYes	36.1 36.1 3.2	mead 1.55 TeV model 1.67 TeV M. 700 GeV	$\begin{array}{l} g_{\eta}{=}0.25, \ g_{\chi}{=}1.0, \ m(\chi) = 1 \ {\rm GeV} \\ g_{-}1.0, \ m(\chi) = 1 \ {\rm GeV} \\ m(\chi) < 150 \ {\rm GeV} \end{array}$	1711.03301 1711.03301 1608.02372
ΓO	Scalar LQ 1 st gen Scalar LQ 2 nd gen Scalar LQ 3 rd gen	$\begin{array}{ccc} 2 \ e & \geq 2 \\ 2 \ \mu & \geq 2 \\ 1 \ e, \mu & \geq 1 \ b, \end{array}$	j – j – ≥3jYes	3.2 3.2 20.3	LO mass 1.1 TeV LO mass 1.05 TeV LQ mass 640 GeV	$\beta = 1$ $\beta = 1$ $\beta = 0$	1605.06035 1605.06035 1508.04735
Heavy quarks	$ \begin{array}{l} VLQ \ TT \rightarrow Ht/Zt/Wb + X \\ VLQ \ BB \rightarrow Wt/Zb + X \\ VLQ \ T_{5/3} T_{5/3} T_{5/3} \rightarrow Wt + X \\ VLQ \ Y \rightarrow Wb + X \\ VLQ \ B \rightarrow Hb + X \\ VLQ \ QQ \rightarrow WqWq \end{array} $	$\begin{array}{ll} \mbox{multi-channel} \\ \mbox{multi-channel} \\ 2(SS)/\geq 3 \ e,\mu \ge 1 \ b, \ge \\ 1 \ e,\mu \ge 1 \ b, \ge \\ 0 \ e,\mu, 2 \ \gamma \ge 1 \ b, \ge \\ 1 \ e,\mu \ge 4 \end{array}$	≥1j Yes ≥1j Yes ≥1j Yes j Yes	36.1 36.1 3.2 79.8 20.3	T mass 1.37 TeV B mass 1.34 TeV T top mass 1.34 TeV Y mass 1.44 TeV B mass 1.21 TeV O mass 690 GeV	$\begin{split} & \text{SU(2) doublet} \\ & \text{SU(2) doublet} \\ & \mathcal{B}(T_{5;3} \rightarrow Wt) = 1, \ \text{c}(T_{5;3} Wt) = 1 \\ & \mathcal{B}(Y \rightarrow Wb) - 1, \ \text{c}(YWb) - 1/\sqrt{2} \\ & \epsilon_B = 0.5 \end{split}$	ATLAS-CONF-2018-XX ATLAS-CONF-2018-XX CERN-EP-2018-171 ATLAS-CONF-2016-07 ATLAS-CONF-2018-XX 1509.04261
Excited fermions	Excited quark $q^* \rightarrow qg$ Excited quark $q^* \rightarrow q\gamma$ Excited quark $b^* \rightarrow bg$ Excited lepton ℓ^* Excited lepton ν^*	$\begin{array}{cccc} - & 2j \\ 1\gamma & 1j \\ - & 1b, 1 \\ 3e, \mu & - \\ 3e, \mu, \tau & - \end{array}$	- - 1 j - -	37.0 36.7 36.1 20.3 20.3	41" mass 6.0 TeV 42" mass 5.3 TeV 5" mass 2.6 TeV 2" mass 3.0 TeV 2" mass 1.6 TeV	only u^* and d^* , $\Lambda = m(q^*)$ only u^* and d^* , $\Lambda = m(q^*)$ $\Lambda = 3.0 \text{ TeV}$ $\Lambda = 1.6 \text{ TeV}$	1703.09127 1709.10440 1805.09299 1411.2921 1411.2921
Other	Type III Seesaw LRSM Majorana ν Higgs triplet $H^{\pm\pm} \rightarrow \ell \ell$ 22 Higgs triplet $H^{\pm\pm} \rightarrow \ell \tau$ Monotop (non-res prod) Multi-charged particles Magnetic monopoles	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	j Yes - - Yes -	79.8 20.3 36.1 20.3 20.3 20.3 20.3 7.0	N° mass 560 GeV N° mass 2.0 TeV N° mass 870 GeV H ^{at} mass 400 GeV H ^{at} mass 657 GeV H ^{at} mass 67 GeV multi-thrappe partice mass 755 GeV morpode mass 1.34 TeV	$\begin{split} m(\mathcal{W}_{ik}) &= 2.4 \text{ TeV, no mixing} \\ \text{DY production, PI}(H_{\ell^+}^{**} \to \ell \tau) &= 1 \\ \text{a}_{\text{non-rss}} &= 0.2 \\ \text{DY production, } q &= 5e \\ \text{DY production, } q &= 5e \\ \text{DY production, } q &= 1p_0, \text{ spin } 1/2 \end{split}$	ATLAS-CONF-2018-020 1506.06020 1710.09748 1411.2921 1410.5404 1504.04188 1509.08059

Limit

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

36.7

37.0

3.6

 ℓ, γ Jets † $\mathsf{E}_{\tau}^{\text{miss}} \int \mathcal{L} dt [fb^{-1}]$

2 j

≥ 3 j

0 e. µ 1 – 4 j Yes 36.1

2 y

 $\geq 1 \ e, \mu$ ≥ 2 j -3.2

√s = 8 TeV

+Small-radius (large-radius) jets are denoted by the letter j (J).

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

√s = 13 TeV

ATLAS Preliminary

 $\sqrt{s} = 8, 13 \text{ TeV}$

1711.03301

1707.04147

1703.09217

1606.02265

1512.02586 1707.04147

Reference

 $\int \mathcal{L} dt = (3.2 - 79.8) \text{ fb}^{-1}$

n = 2

n = 6

10

Mass scale [TeV]

n = 3 HLZ NLO

9,55 TeV n = 6, Mp = 3 TeV, rot BH

n = 6, M_D = 3 TeV, rot BH

7.7 TeV

8.6 TeV

8.2 TeV

8.9 TeV

Resonances: Dijet Scan



Large kinematic range scan

- Limits on the universal coupling g'_q between a leptophobic Z' boson and quarks for various assumed Z' width
- More beyond simple dijets: b-jets, top quark jets...

Resonances: Double b-jets



Select events with dedicated double-b tagger and constrain main QCD backgrounds with control region using "pass-fail ratio"

- Soft-drop jet mass M_{SD} peaks at φ(bb)/A(bb) for signals (AK8/CK15)
- Background only fits show good agreement with data, with clear W and Z contributions
- No significant excess for signal masses between 50-350 GeV
- Exclusion limits: $\sigma X \phi(bb)/A(bb) \sim 79(86)pb$, coupling $g_{ab}/g_{aA} \sim 3.9$ (2.5)

Resonances: Double b-jets (Boosted)



Select large-R jet for hadronically decaying resonance

- Data-driven estimation via fitting large-R jet mass distribution m_J in SR, validated by data in CR_{QCD}
- Boosted tt events constrained by MC template fitted to CR_{tt} data
- Combined SM fit of V + jets, H + jets process and search for extra exotic signals in m_J distribution with the range of 70 and 230 GeV

Resonances: Top Quark Jets



Select same-sign leptons with b-jet to look for vector-like quark, four-top-quark, and same-sign top-quark pair production

- Fake lepton background estimated by matrix method, mis-charge ID estimated by Z->ee enriched data sample
- Use validation region (VR) to verify background modelling in SR

Resonances: Top Quark Jets



Observed(expected) limit on BSM EFT (tttt) cross section: 21fb (15fb)

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arXiv:1811.02305

Long-lived particle signatures in a detector

J. Antonelli



Long-lived particle signatures in a detector

J. Antonelli



ATLAS Long-lived Particle Searches* - 95% CL Exclusion

ATLAS Preliminary

Status: July 2018



Displaced objects: vertices, leptons, jets... **Disappearing tracks, (Heavy/Multi-) Charged Particles...**

Long-lived Particles: Displaced Jets



- Displaced vertex associated with dijet, build discriminant from vertex track multiplicity, vertex L_{xy} significance and Cluster RMS
- Limits obtained for pair-produced LLPs, gluino and squark masses

Long-lived Particles: Displaced Jets



Event signature: Z_d decaying within the TileCal and no charged tracks point to the primary vertex

- Define calorimeter-ratio jet (CRjet) with log₁₀(E_{Tile}/E_{LAr})>1.2
- Data-driven method to estimate background using W+jets sample

Long-lived Particles: Multi-charged Particles



The significance variable of S(dE/dx) is a powerful discriminator

- Use 2D S(TRT dE/dx) S(MDT dE/dx) to define signal and control region, background estimation using ABCD method and sideband
- No observed events (<1 background expected)
- Multi-charged particles mass lower limit: 980–1220 GeV

Dark Matter Searches



χ(m_{DM}) ✓ (Mono-)X + MET

- X=jet, photon, W, Z, H, t...
- jet: most general and powerful
- photon: less powerful
- W/Z hadronic: large background
- W/Z leptonic: clean signature, small signal
- Higgs: Higgs portal
- Top: Yukawa-like coupling, more complex signature

✓ Di-X Resonance

- X=jet, photon, W, Z, H, t...
- Resonance scan
- ✓ Searches comparison
 - Collider vs. direct/indirect searches



Dark Matter Searches

ATLAS-CONF-2018-051



- Use MET distribution to extract signal
 - Different shape, although overwhelming background
- ✓ Background modelling important

Dark Matter Searches: Vector or Axial Vector Mediator

ATLAS-CONF-2018-051



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Dark Matter Searches: Scalar or Pseudo-Scalar ATLAS-CONF-2018-051



Dark Matter Searches Comparison: Spin Dependent

Dark Matter Searches Comparison: Spin Dependent



Dark Matter Searches Comparison: Spin Dependent



Dark Matter Searches Comparison: Spin Independent

Dark Matter Searches Comparison: Spin Independent



Dark Matter Searches Comparison: Spin Independent



Summary

Extensive exotics searches done at LHC

- Most searches analyzed 36fb⁻¹ data
 - Resonances scan
 - New signatures
 - Long-lived particles
 - Dark matter
- 150fb⁻¹ already collected
- No new (exotic) physics found so far
- Continue the effort to search for all possible final states and signatures
 - Many more interesting ideas to test and search
 - No one knows when or where the new physics will appear