SEARCHES FOR NON-SUSY EXOTICS IN ATLAS

CHRISTOPHER MARINO

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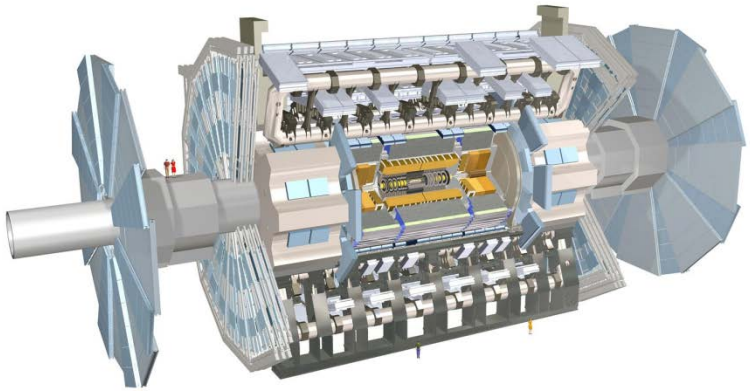
University of Victoria

MOTIVATION

- **Standard Model (SM) has generally given excellent agreement with experimental observation**
- **Discovery of Higgs boson provides an important missing piece**
- **Questions remain…**
  - Dark matter, naturalness, unification with gravity…

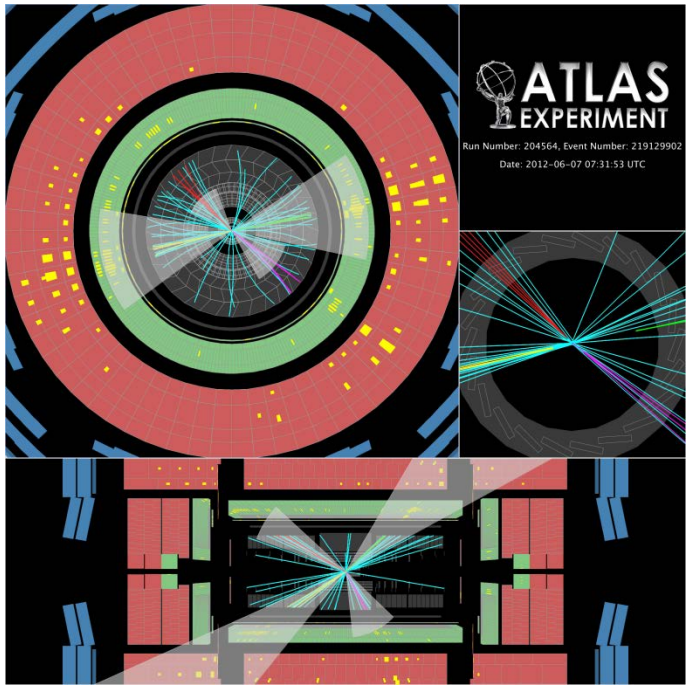
- **SUSY is one route to answering many questions**
- **But we can look for much with ATLAS data that is not SUSY…**



OVERVIEW OF EXOTIC RESULTS

- **New Heavy Bosons**
  - Z', W', **G***
- **Searches at High Energy Scales**
  - **Contact Interactions**
  - Black Holes
  - Excited electrons
  - **Dijet resonances**
- **Unique Signatures**
  - Long-lived particles

NEW!

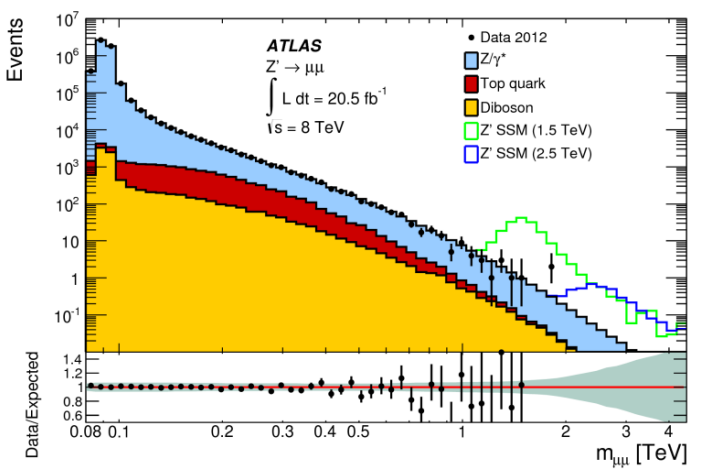


- ***Some recent*** **searches for non-SUSY new physics**
  - No significance evidence for new physics
  - 2012 data using ~20 fb-1
  - Limits set on a wide set of predictions for Exotics extensions

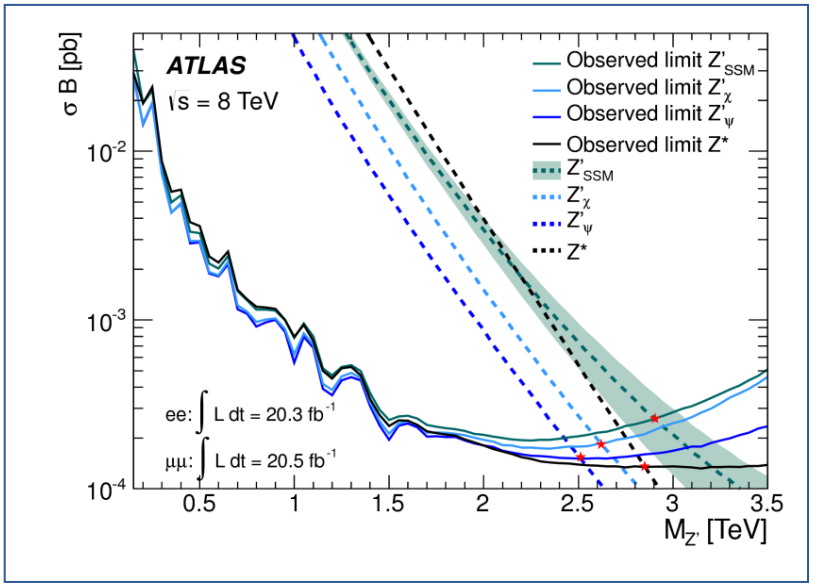
SEARCHES FOR NEW HEAVY BOSONS

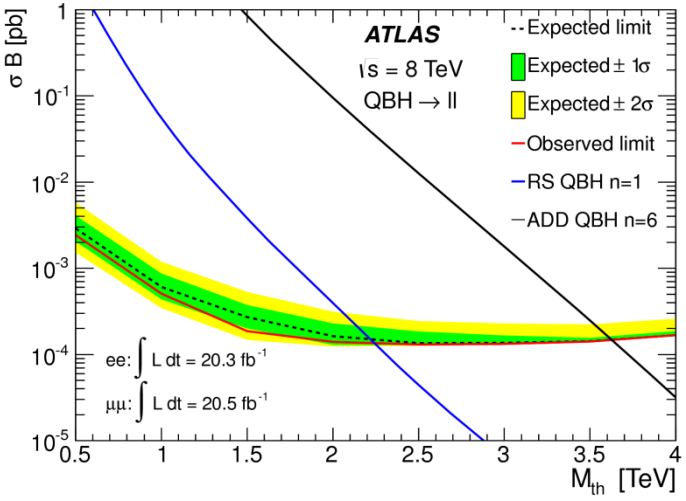
- **Searches for new strong dynamics or for extra dimensions**
- **Provide non-SUSY explanation for electroweak symmetry breaking**
- **Signature based searches provide more model independence, but various benchmark models used**

HIGH-MASS DILEPTON RESONANCES



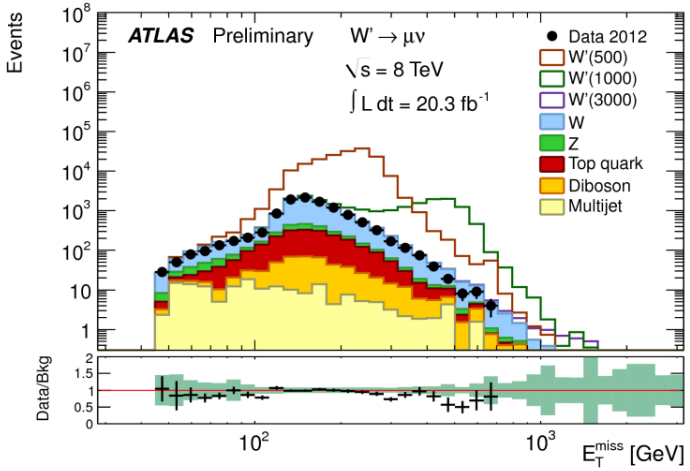
- **Invariant mass isolated muon or electron pairs**
- **Dominant background is Z/γ* → ll**
- **Data-driven estimation of di-jet and W+jet backgrounds**
- **Limits set of various models with no excess above SM background:**
  - SSM Z', E6 Z' , Z*
  - Minimal models, Walking Technicolor
  - RS-Graviton, Quantum Black Holes

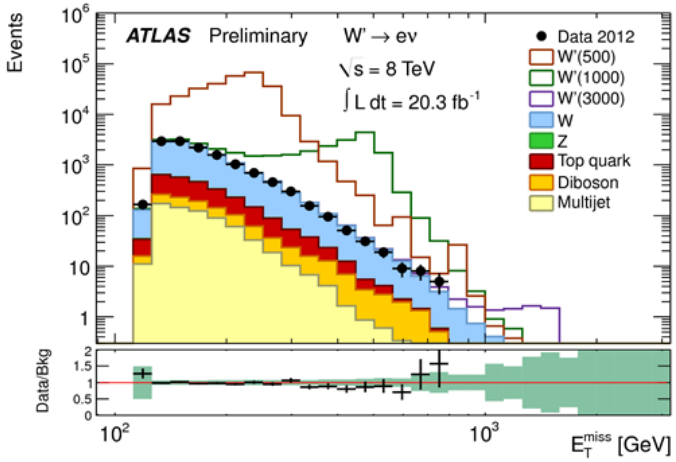




arXiv:1405.4123

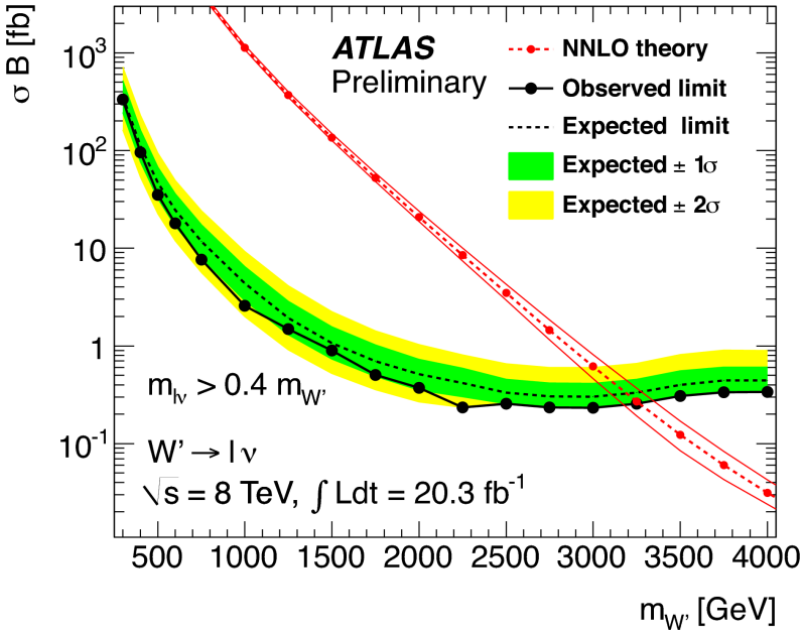
LEPTON + E_T^{MISS} HIGH-MASS STATES





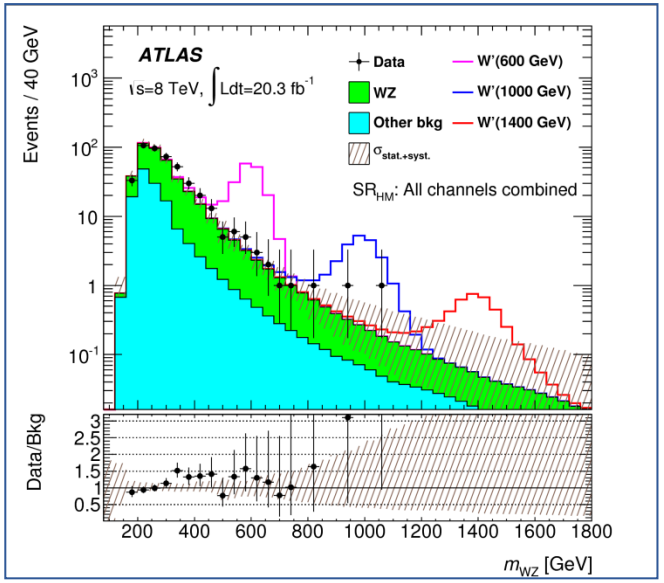
[ATLAS-CONF-2014-017]

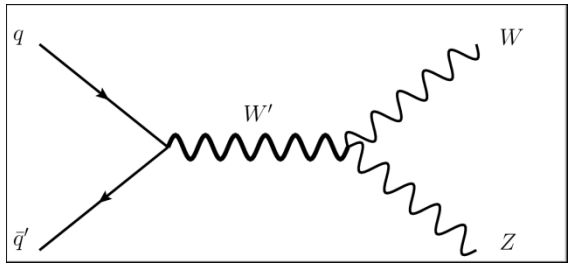
- **W' / W* → lυ**
- **Isolated high-P_T lepton + missing transverse energy are selected**
- **W is main background**
- **Combined limit (~3.2 TeV) from muon and electron channels**
  - Also dark matter interpretation

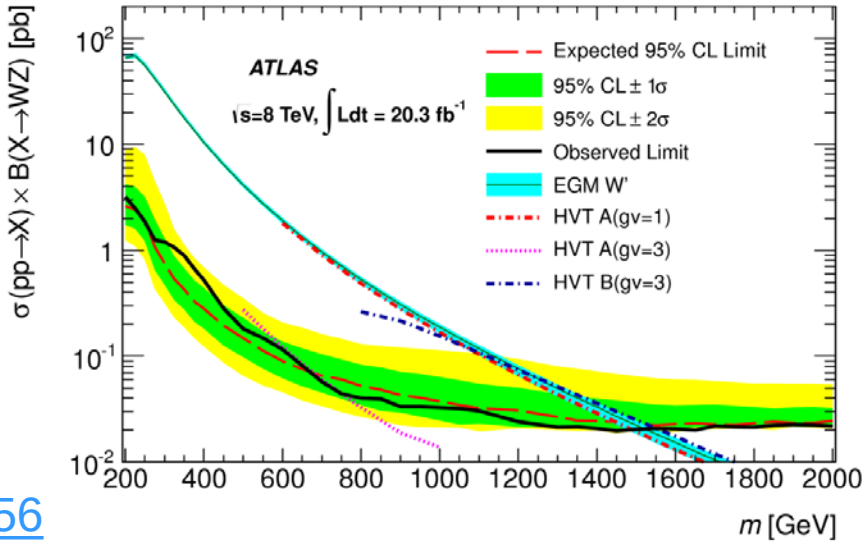


WZ RESONANCES TO LEPTONS

- **W'→ WZ →3l+υ**
- **Exactly 3 charged leptons are selected**
  - eυee, μυee, eυμμ, μυμμ
- **Dominant background is SM WZ production, consistent with data**
- **95% C.L. limits are set combining 4 decay channels**
  - Extended gauge model W'
  - Heavy Vector Triplet

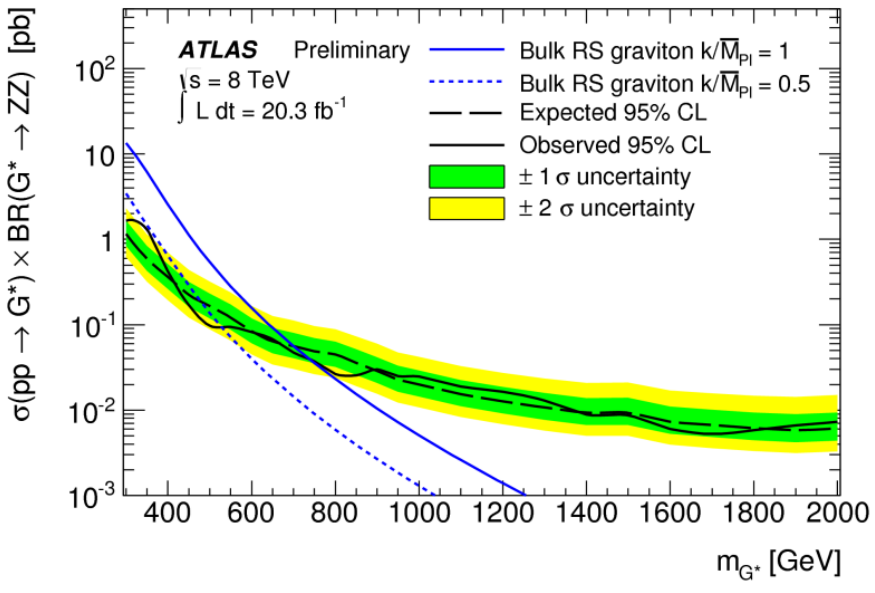


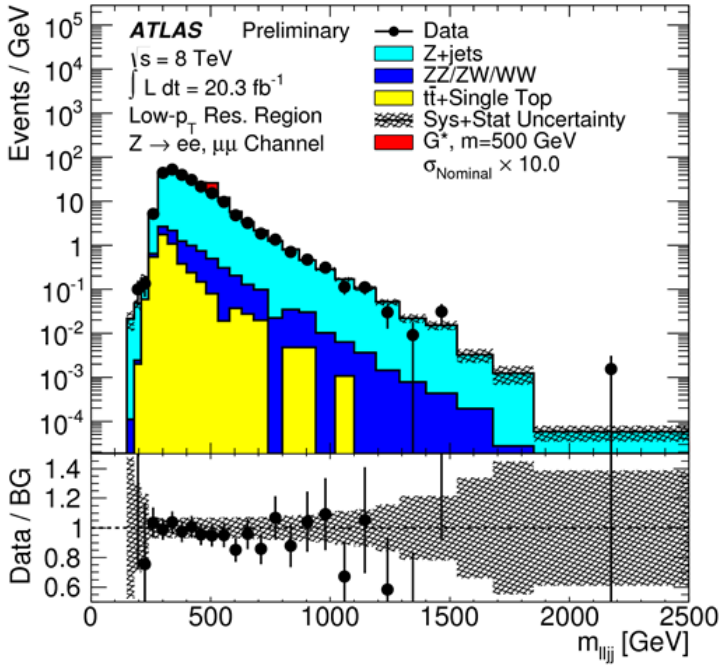




arXiv:1406.4456

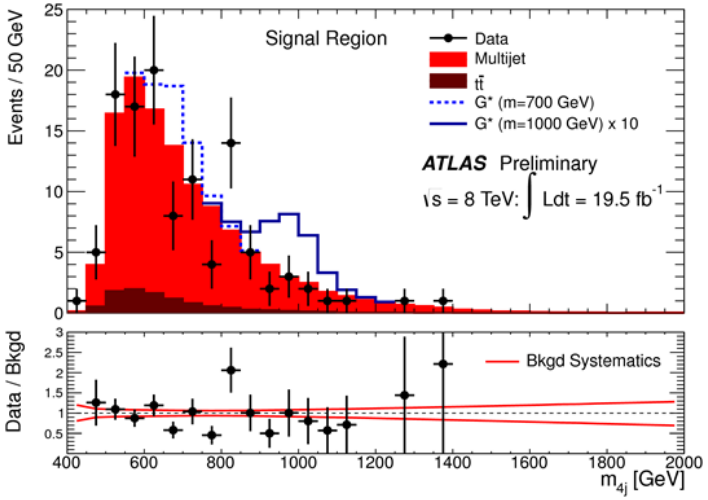
RESONANT DIBOSON PRODUCTION TO LEPTONS AND QUARKS

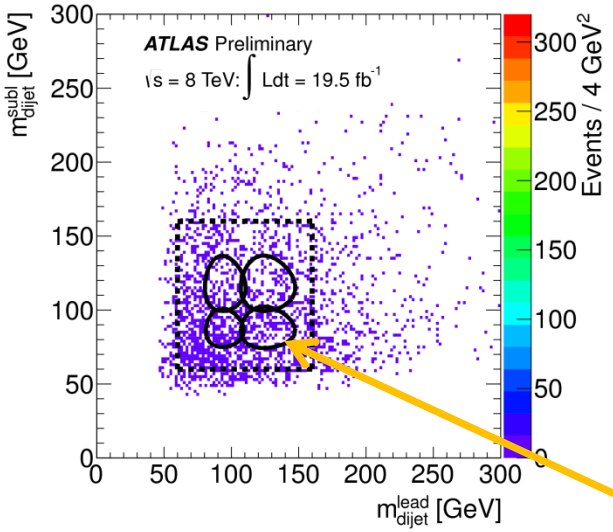




- **ZZ or ZW → llqq**
- **Mass of dijet, dilepton system reconstructed in 3 regions**
  - High and low P_T regions where jets are resolved and merged-jet regions
- **Z+jet dominant background is corrected with data from sidebands**
- **Upper limits set on σ x BR of Kaluza–Klein gravitons predicted by Randall–Sundrum and EGM W'**

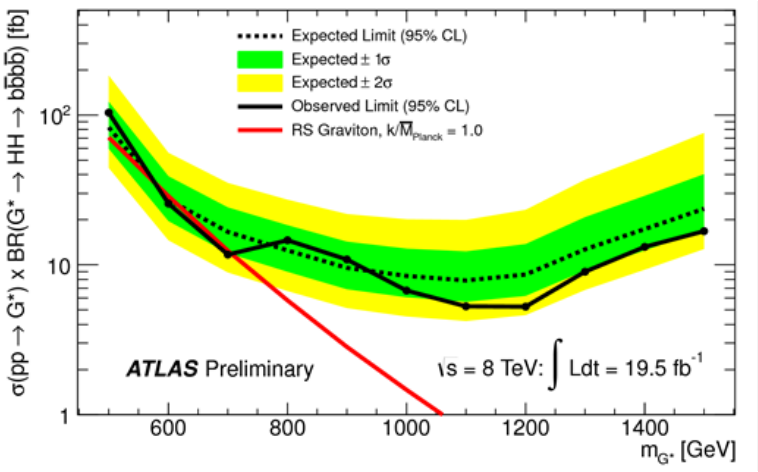
RESONANT HIGGS-PAIR PRODUCTION → 4B





ATLAS-CONF-2014-005

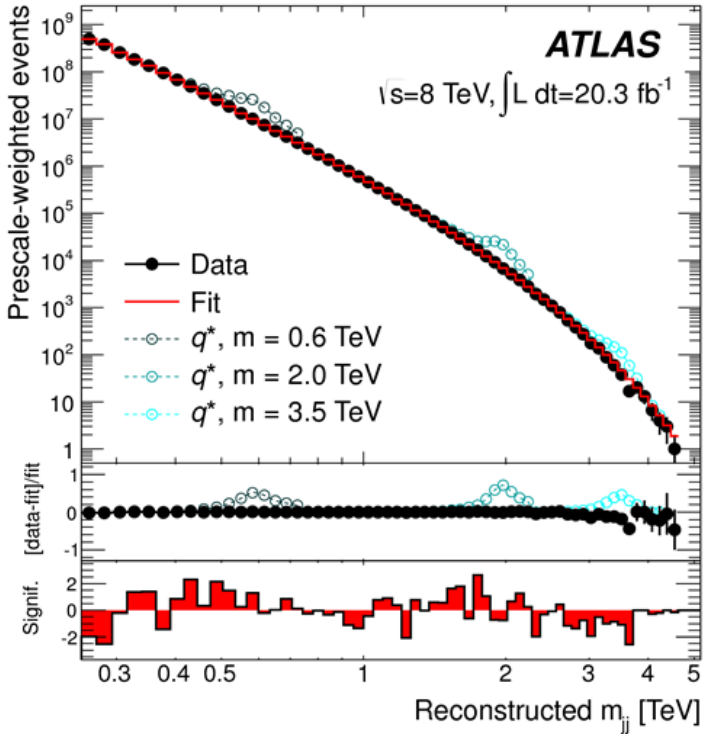
- **Search for Kaluza-Klein excitation of RS graviton**
  - G* → HH → 4b (~3% BR)
- **Invariant mass of 4 b-jets with P_T > 40 GeV**
- **Two pair of b-tagged jets with dijet invariant mass ~ M_H**
- **No excess observed**
  - Observed upper limits on σxBR ranges from 100 fb at 500 GeV to 7 fb at 1 TeV
  - Limits on KK G* in warped (RS) ED 590 to 710 GeV

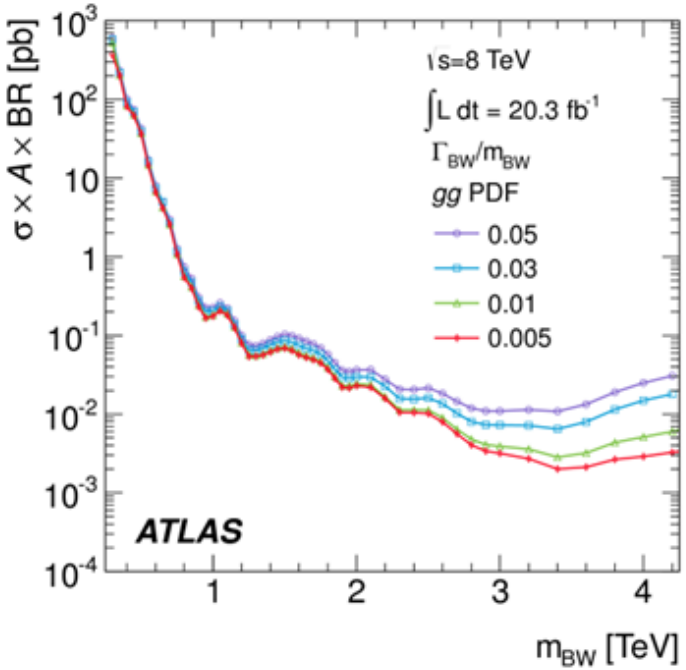


Signal, ZZ and ZH Regions

SEARCHES AT HIGH ENERGY SCALES

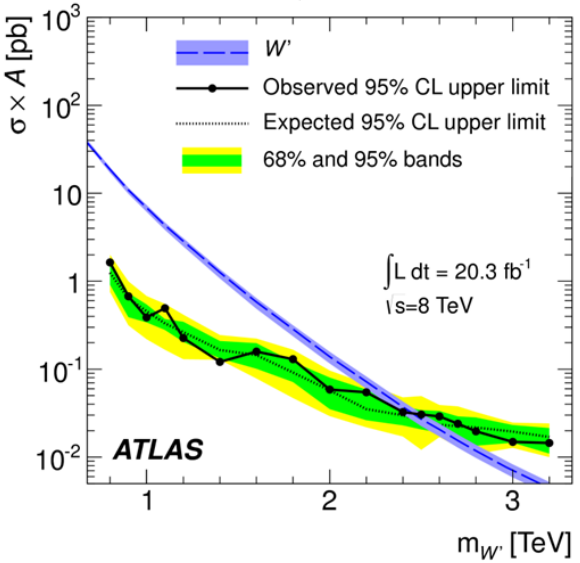
DIJET MASS RESONANCES



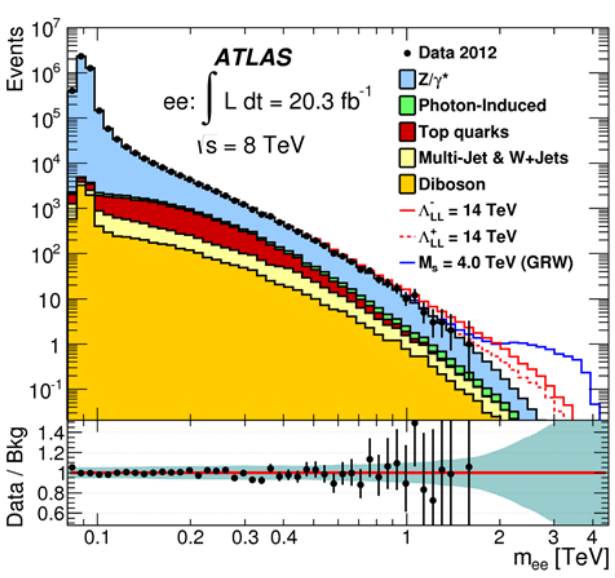


arXiv:1407.1376

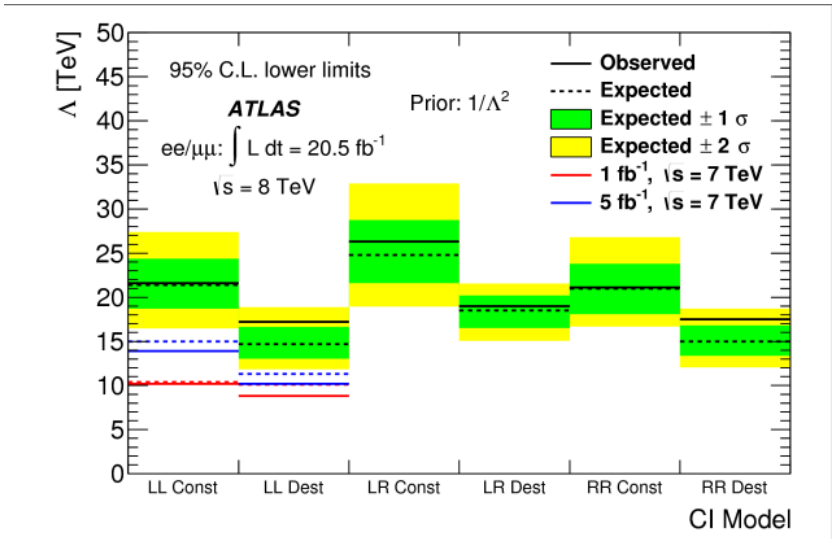
- **Dijet masses up to about 4.5 TeV are probed (down to 250 GeV using prescaled/delayed stream triggers)**
- **No resonance-like features are observed in the dijet mass spectrum**
- **Limits on σ × A for a simple Gaussian resonance or a Breit-Wigner narrow resonance decaying to dijets**
- **Specific models: excited quarks, color-octet scalars, W', W*, BH, and ED**

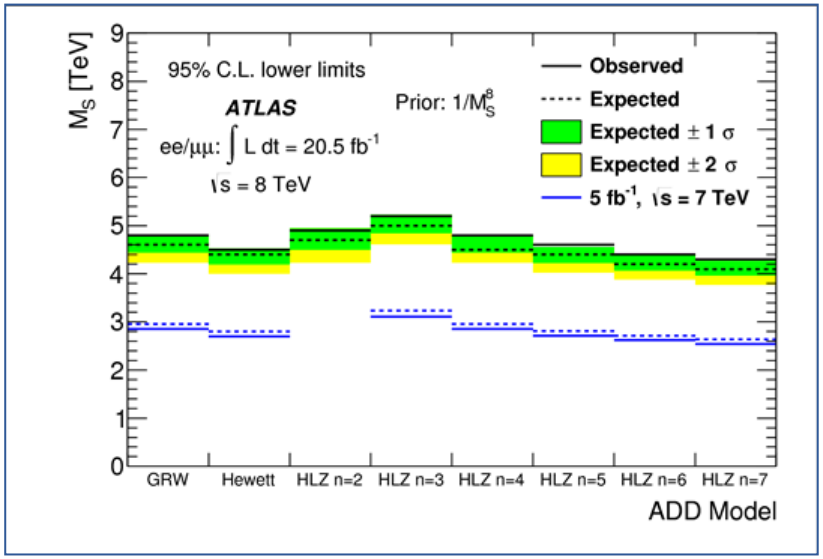


SEARCH FOR CONTACT INTERACTIONS AND LARGE EXTRA DIMENSIONS



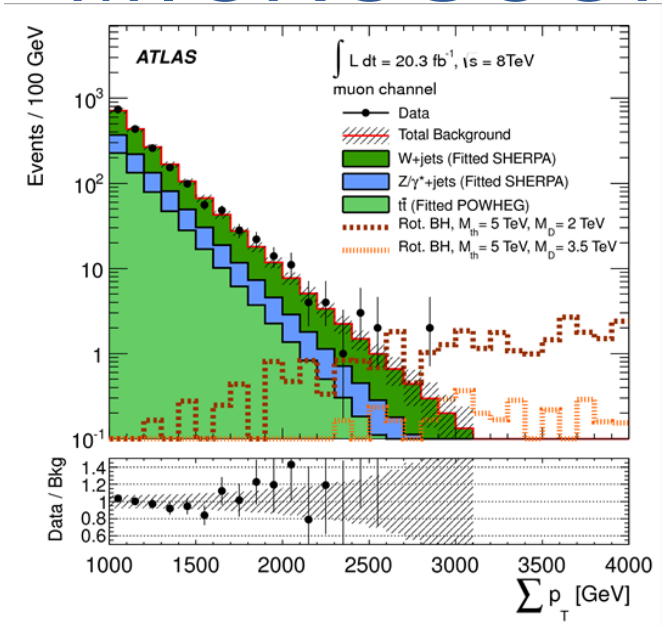
- **Complementary search to dilepton resonance search (non-resonant)**
- **Contact interactions (CI) and Arkani-Hamed, Dimopoulos and Dvali model (ADD) with large extra dimensions**
- **Limits are set on**
  - CI scale, Λ, 15.4 - 26.3 TeV
  - ED string scale, M_S, 4.1 - 6.1 TeV



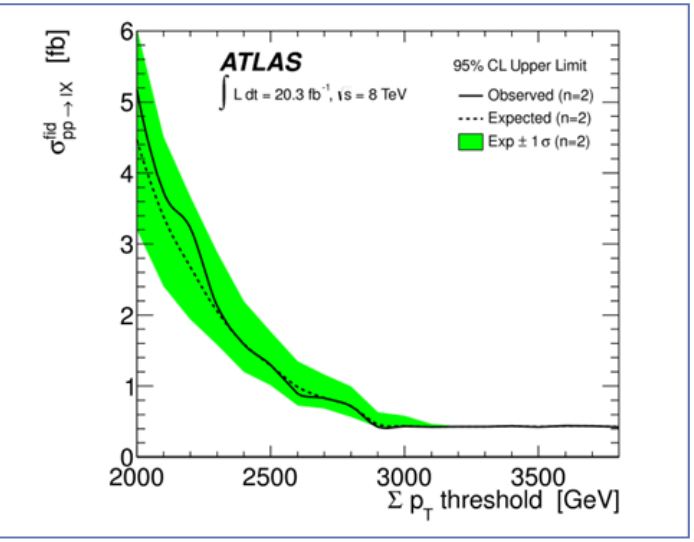


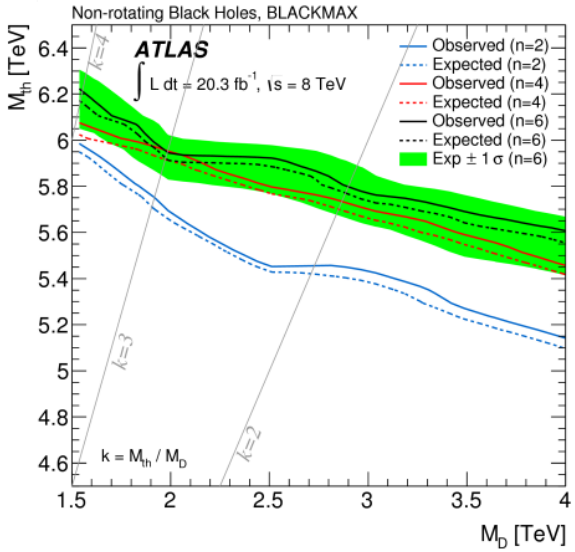
arXiv:1407.2410

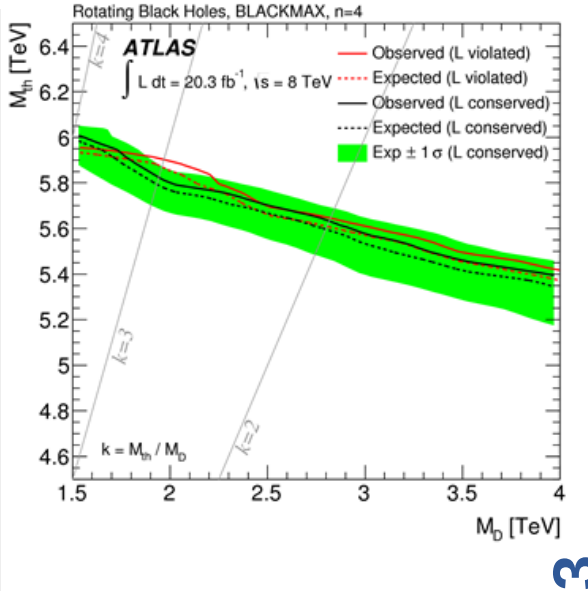
MICROSCOPIC BLACK HOLES



- **Search for high-P_T leptons + jets**
  - At least one isolated muon or electron
  - At least two additional leptons or jets
- **ADD 2, 4, and 6 ED models:**
  - Scale in extra dim.: M_D
  - Production threshold: M_{th}

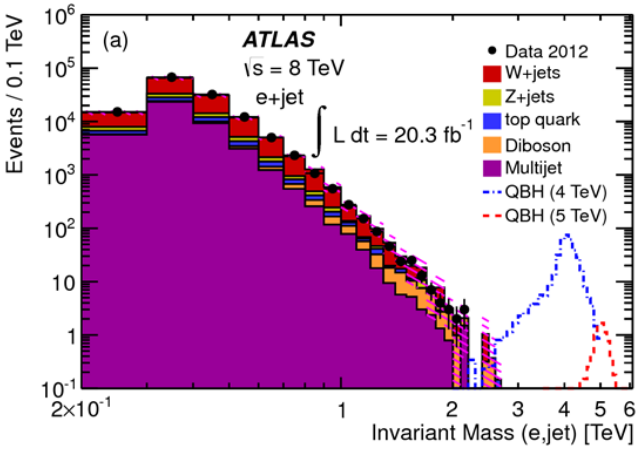


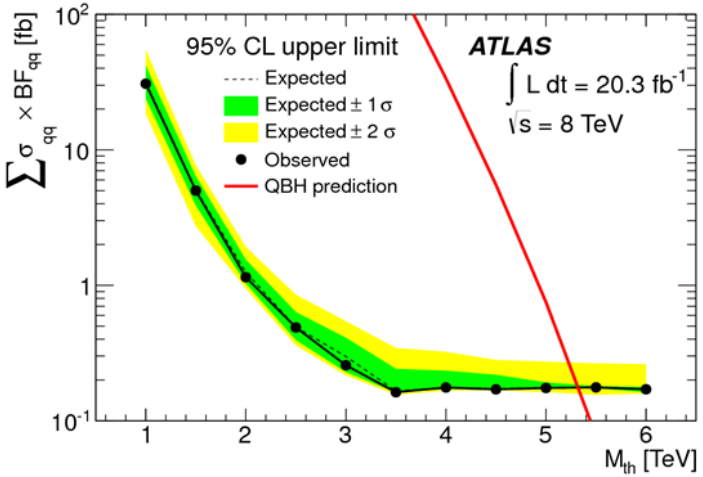




arXiv:1405.4254

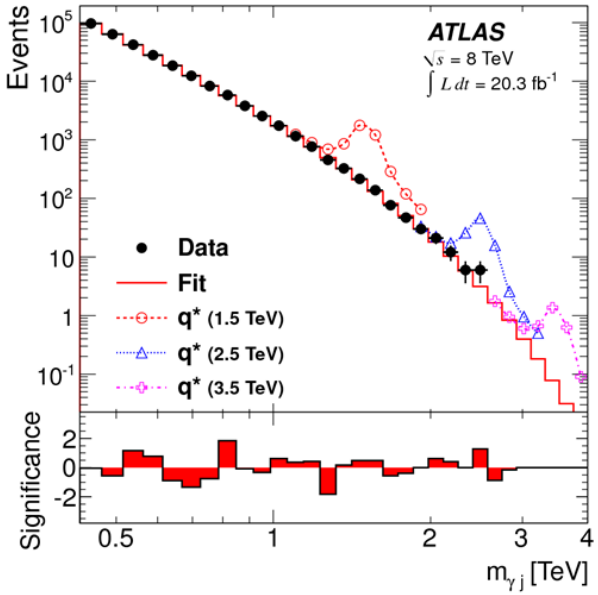
QUANTUM BLACK-HOLE PRODUCTION

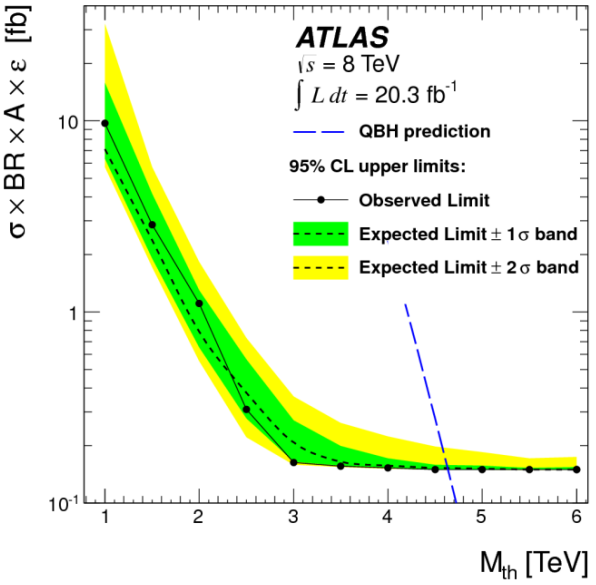




arXiv:1311.2006

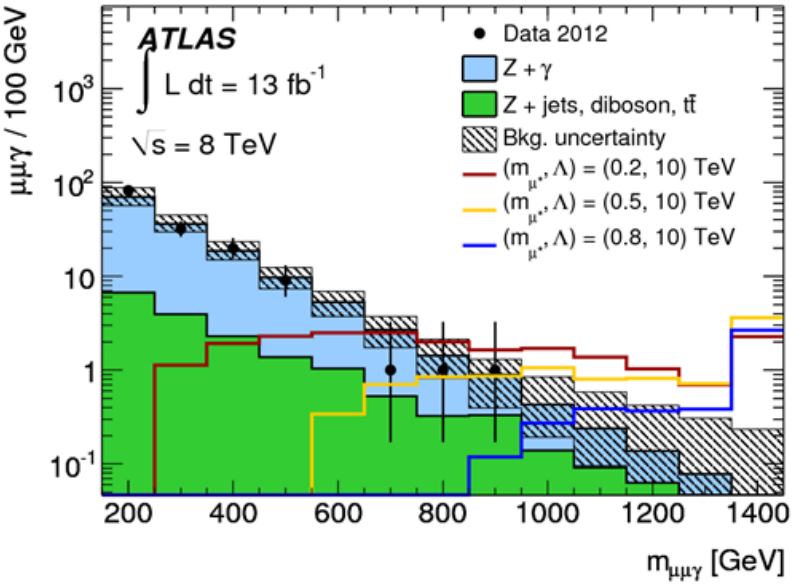
- **Lepton+jet and Photon+jet final states**
- **Invariant mass of trigger object (γ, e, μ) and high P_T jet**
- **Limits of 5.3 and 4.6 TeV respectively**
- **Photon+jet also limits excited quarks**

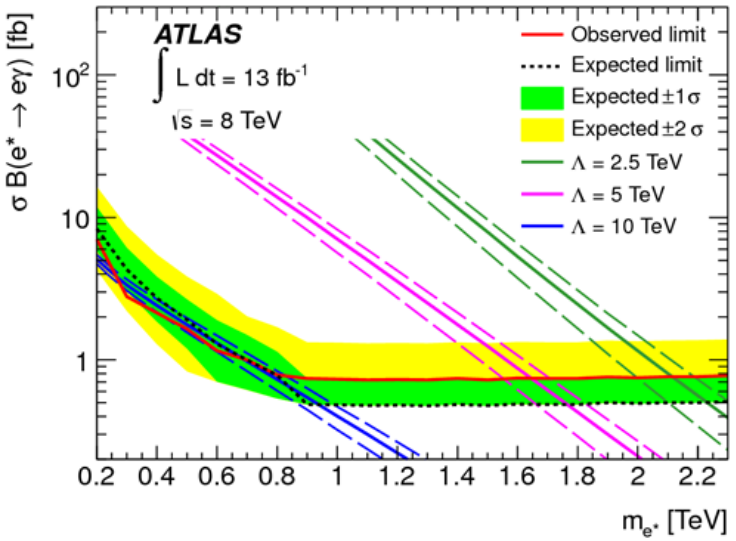


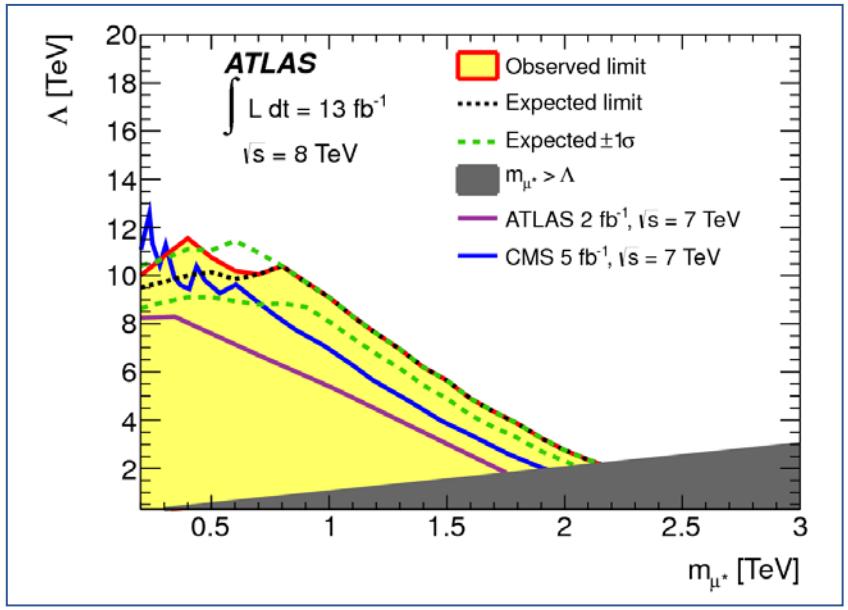


Phys. Lett. B 728C (2014) 562-578

EXCITED LEPTONS





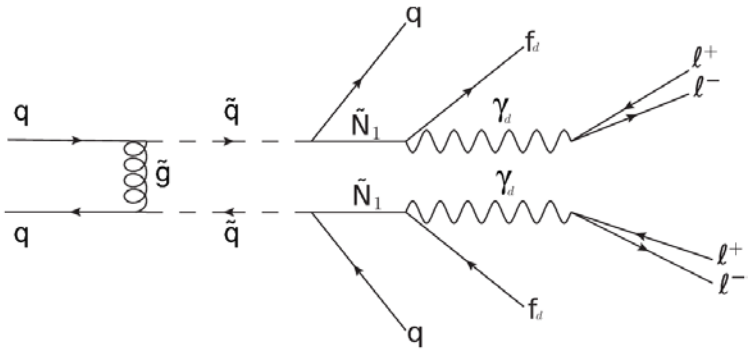


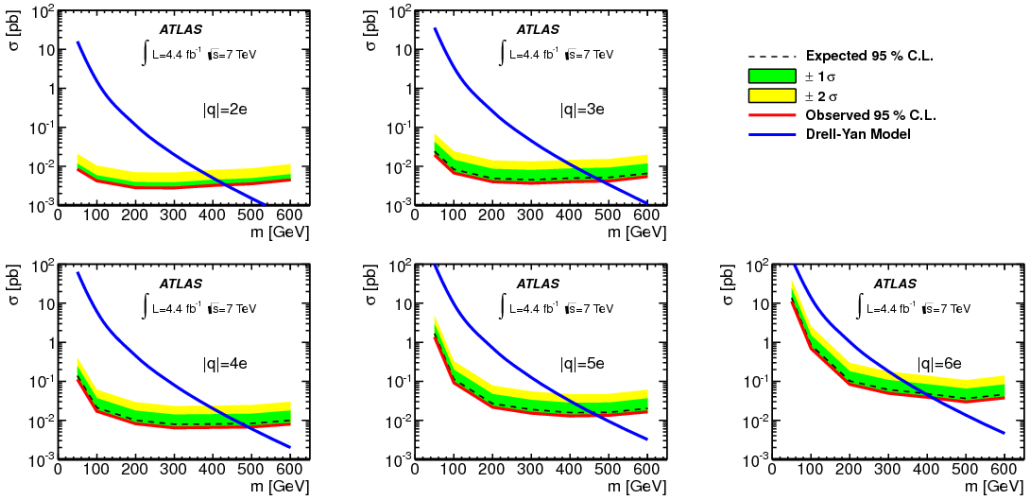
- **Excited leptons:**
- **ll* → llγ**
- **Strong or weak production**
- **Model-independent searches**

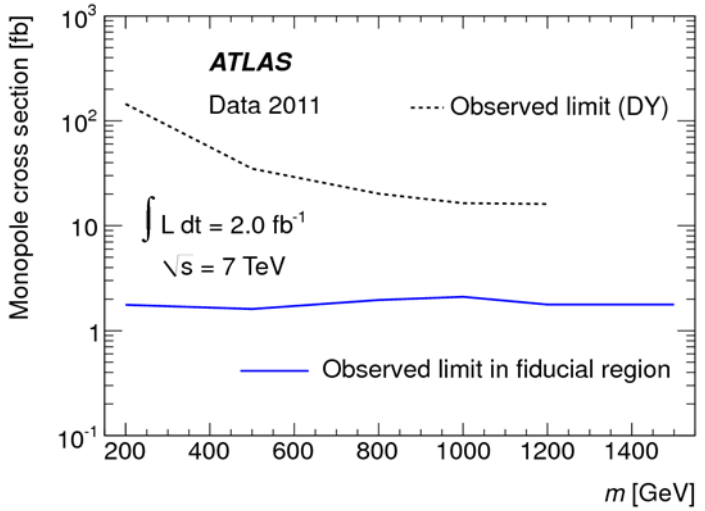
NJP 15 (2013) 093011

UNIQUE SIGNATURES

- **Long-lived Particles utilize special signatures that may require custom triggers or reliance on associated production**
- **Examples:**
  - Lepton Jets
  - Multi-charge particles
  - Monopoles
- **One brand new result with 20 fb^-1**
- **More updates coming very soon!**

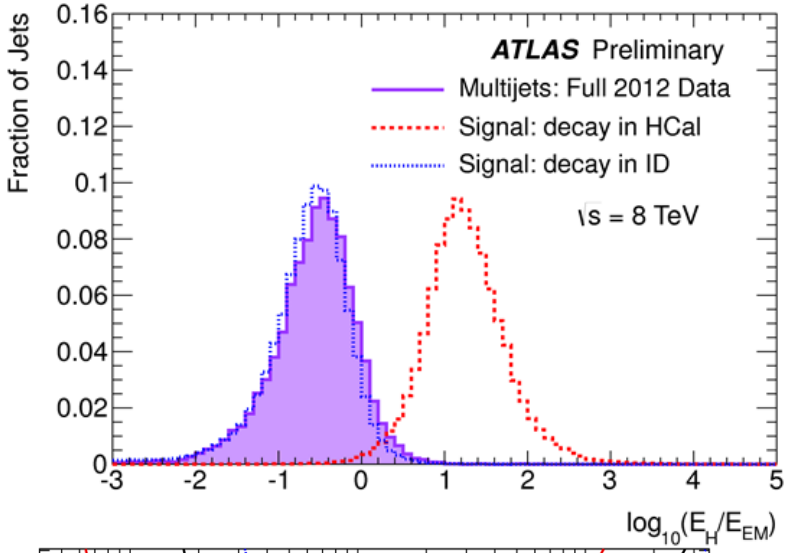


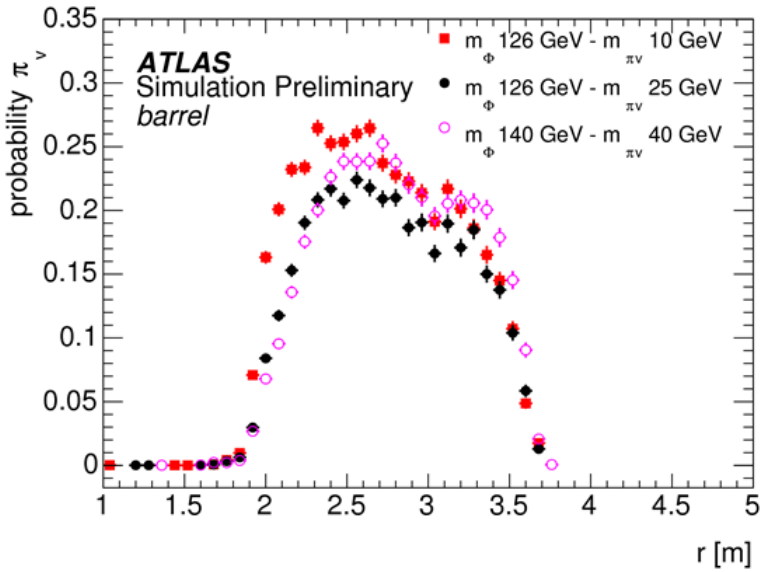


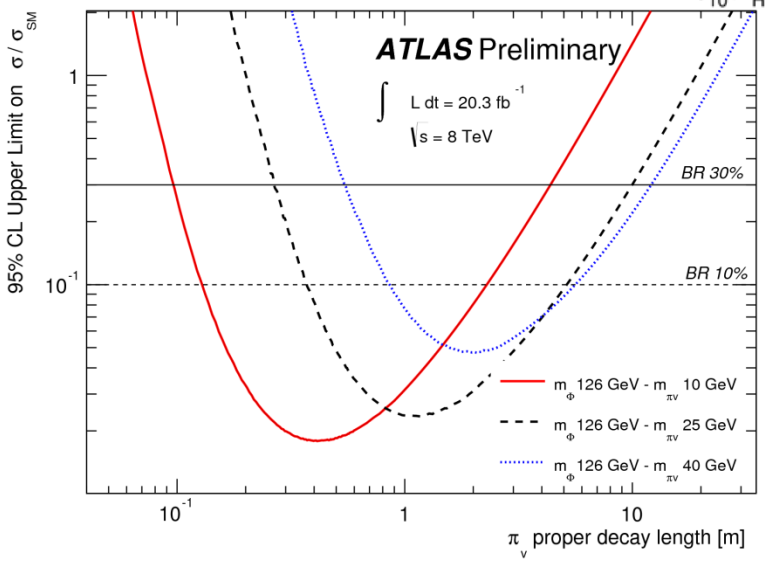


LIGHT HIGGS BOSON DECAYING TO LONG-LIVED WEAKLY-INTERACTING PARTICLES

- **Higgs boson decays to two long-lived neutral particles (π_v)**
  - Then $\pi_v \rightarrow$ bb, cc or $\tau\tau$
- **Events are selected using the specialized Cal-ratio trigger**
  - Jet with high Had/EM calorimeter energy ratio and E_T > 60 GeV
- **Jets must have**
  - $\log10(E_H/E_{EM}) > 1.2$
  - No good tracks in ID with P_T>1GeV
- **Main background SM QCD jets**







ATLAS-CONF-2014-041

CONCLUSIONS

- **Exotic searches provide an alternative to SUSY in answering remaining questions in particle physics**
- **Many searches for non-SUSY new physics performed with 2012 ATLAS data**
- **No evidence for new phenomena, but strong limits placed on many theoretical models of new physics in Run I**
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
- **Looking forward to Run II**
  - More energy, larger dataset
  - Tools developed and lessons learned from Run I
  - Improved triggering for unique signatures

ATLAS Exotics Searches* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS Preliminary

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

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 5.2 TeV	$n = 3$ HLZ	ATLAS-CONF-2014-030
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	20.3	M_{th} 5.82 TeV	$n = 6$	to be submitted to PRD
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1405.4254
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \rightarrow ZZ \rightarrow \ell\ell qq$	2 e, μ	2 j / 1 J	–	20.3	G_{KK} mass 730 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-039
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	14.3	g_{KK} mass 2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.9 TeV		1405.4123
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\,\ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		1406.4456
	EGM $W' \rightarrow WZ \rightarrow qq\ell\ell$	2 e, μ	2 j / 1 J	–	20.3	W' mass 1.59 TeV		ATLAS-CONF-2014-039
	LRSM $W'_R \rightarrow t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
	LRSM $W'_R \rightarrow t\bar{b}$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.77 TeV		to be submitted to EPJC
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	20.3	Λ 21.6 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2014-030
	CI $uutt$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C \rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator (Dirac)	0 e, μ	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator (Dirac)	0 e, μ	1 J, ≤ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $TT \rightarrow Zt + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	T mass 735 GeV	T in (T,B) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \rightarrow Zb + X$	2/$\geq$3 e, μ	$\geq$2/$\geq$1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	ATLAS-CONF-2014-036
	Vector-like quark $BB \rightarrow Wt + X$	2 e, μ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \rightarrow qg$	–	2 j	–	20.3	q^* mass 4.09 TeV	only u^* and d^*, $\Lambda = m(q^*)$	to be submitted to PRD
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		to be submitted to PLB
	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e \rvert$=0.055, $\lvert V_\mu \rvert$=0.063, $\lvert V_\tau \rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \rightarrow \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q \rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g \rvert = 1 g_D$	1207.6411

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

10^{-1} 1 10 **Mass scale [TeV]**

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