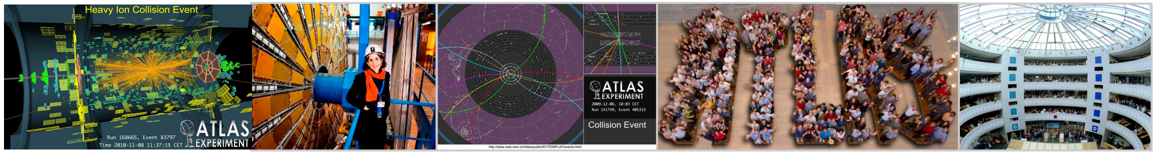

Searches for new resonances with the ATLAS detector

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University of Massachusetts—Amherst

On behalf of the ATLAS Collaboration

PANIC '14, Hamburg

BSM physics @ the LHC

- Searches for Beyond Standard Model physics is a primary goal of the LHC program at CERN
- Such new physics could manifest in many ways; one of the most obvious is in the form of new resonance(s)
- ATLAS strategy: Model-independent searches, in the absence of a discovery, set limits on benchmark/generic models, and/or physically interesting ones

Randall-Sundrum

Extra Dimensions

Arkani-Dimopoulos-Dvali

Z'

W'

Gauge Bosons

Excited Fermions

q*

LSTC

MWT

Techni color

Dark Matter

C. Clement's talk

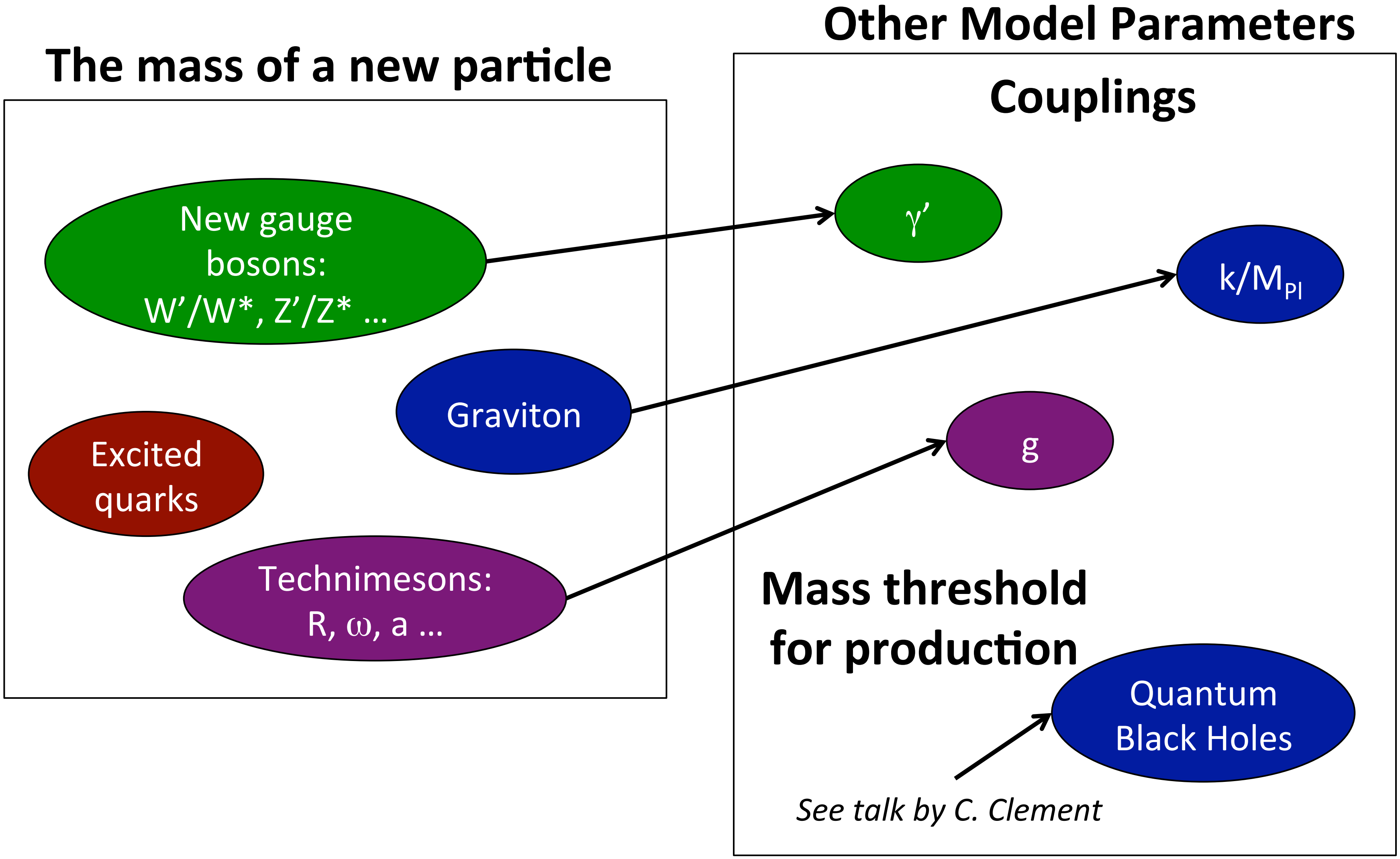
New quarks

D. Calvet's talk

4th gen

VLQ

What do we set limits on?



The mass of a new particle

New gauge bosons: W’/W*, Z’/Z* …

Graviton

Excited quarks

Technimesons: R, ω, a …

Other Model Parameters

Couplings

γ'

k/M_{Pl}

g

Mass threshold for production

Quantum Black Holes

See talk by C. Clement

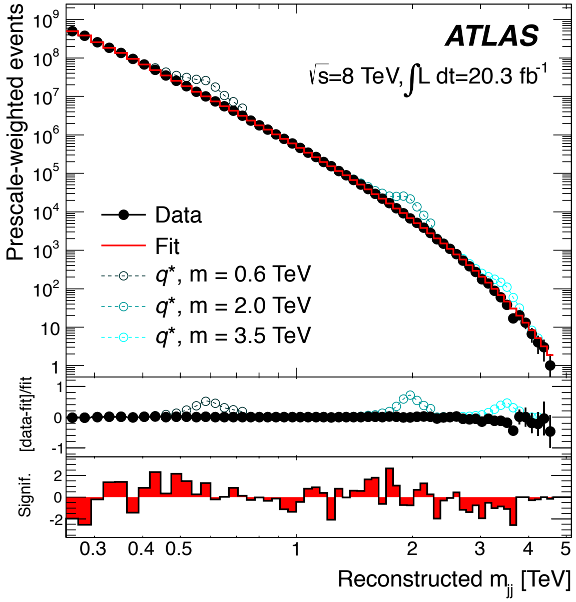
Dijet resonances

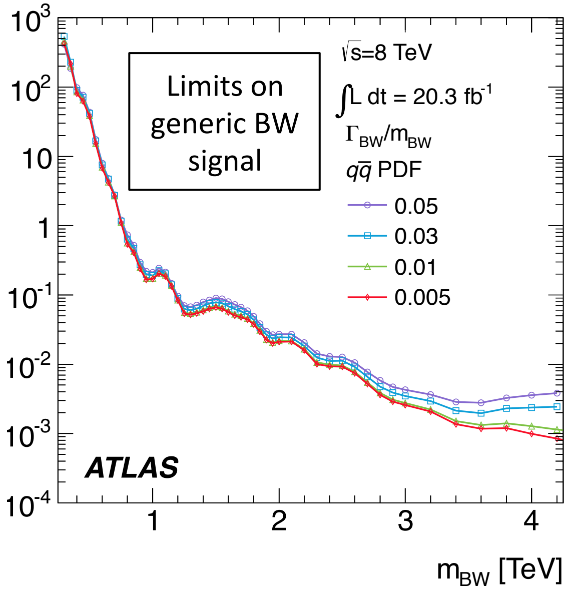
arXiv:1407.1376

Criteria:
≥ 2 anti-k_t 6, p_T > 50 GeV jets
Poorly-measured high p_T jets rejected
$\|y\|$ < 2.8, m_{jj} > 250 GeV

BG from data fit:
$f(x) = a(1-x)^b x^{(c+d\ln x)}$
χ^2 = 79 for 56 DOF

Systematics:
BG fit func. choice, qual.
Jet Energy Scale
Luminosity, beam energy
Theoretical uncert.





Model	Obs. Limit [TeV]
q*→qg	4.09
s8→gg	2.72
W'→qq̄'	2.45
Leptophobic W*→qq̄'	1.75
Leptophilic W*→qq̄'	1.66
QBH→q or g only	5.82
BlackMax BH	5.75

Acceptances range from 25-63%

Resonances are narrow: resolution 8% @ 200 GeV, <4% above 2 TeV

Dilepton resonances

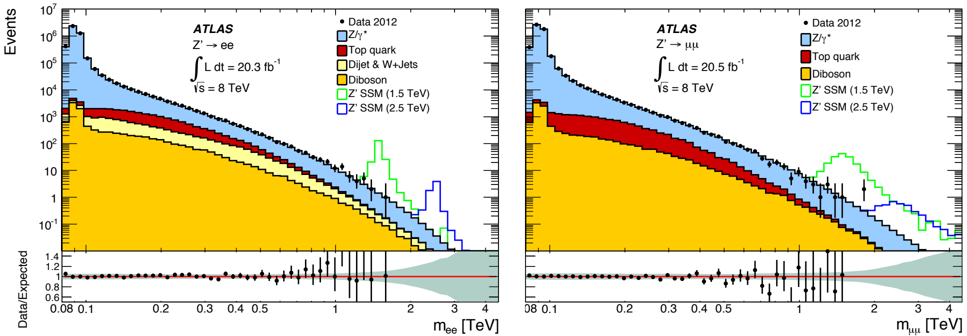
arXiv:1405.4123

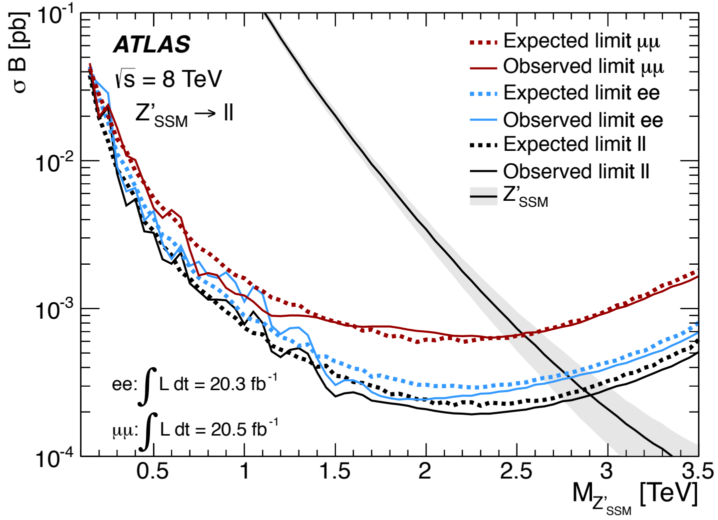
Criteria:
$\geq 2\ p_T > 25$ GeV e or μ
Reject poorly-measured E (electrons) or p (muons)

Backgrounds:
Irreducible, dominant: DY
Multi-jet (el channel only), Diboson, ttbar

Systematics:
Theoretical uncert.
Beam energy uncert.
Resolution (muons)
Multi-jet BG (electrons)

Model	Obs. Limit [TeV]
Z' SSM	2.90
Z' E6 χ	2.62
Z' E6 ψ	2.51
Z*	2.85
Z' (B-L)	2.75
Z' 3R	2.72
RS G*, k/Mpl = 0.1	2.68
RS QBH	2.24
ADD QBH	3.65
MWT R1, g=2	1.99





ℓ + MET resonances

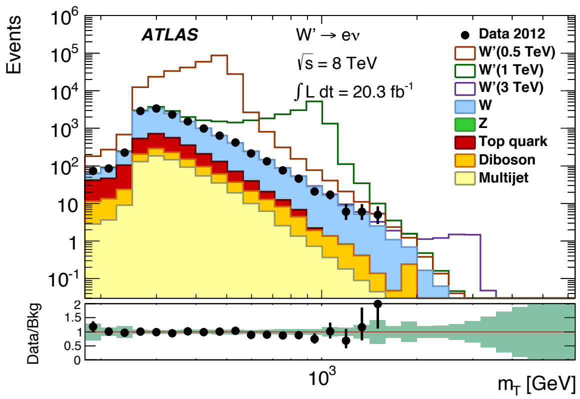
arXiv:1407.7494

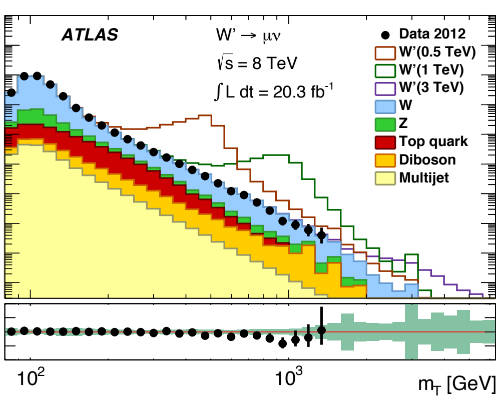
Criteria:
el isolated with p_T > 125 GeV, $\|\eta\|$ < 2.5
In el channel, if other good el with p_T > 20 GeV, reject
μ p_T > 45 GeV, $\|\eta\|$ < 2.0 les 1.0 <$\|\eta\|$< 1.3
In el channel, MET > 125 GeV, in μ channel, MET > 45 GeV

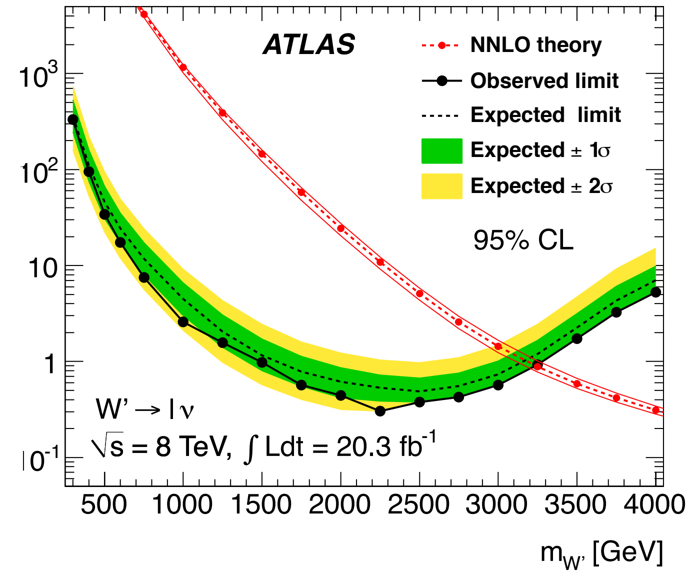
Systematics:
Uncert. on BG cross sections
Muon momentum resolution
Monte-Carlo statistics
Reconstruction and trigger efficiency

Backgrounds:
SM W is dominant
Also contributions from: SM Z→$\ell\ell$, W/Z decays to τ, $t\bar{t}$ and single top, multi-jet

Model	Obs. Limit [TeV]
W' SSM	3.24
W*	3.21







Wγ resonances

arXiv:1407.8150

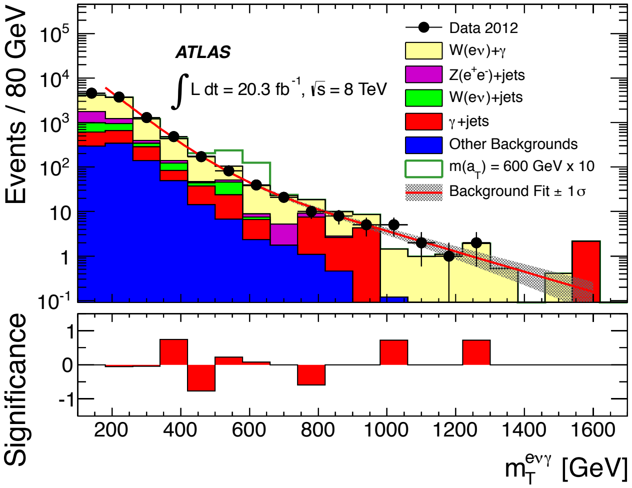
$\ell\nu\gamma$ criteria:
ℓ p_T > 25 GeV
γ E_T > 40 GeV
MET > 35 GeV
$m_{T(\ell,\ MET)}$ > 40 GeV
if ℓ=e, $m_{e\gamma}$ not in 15 GeV of m_Z

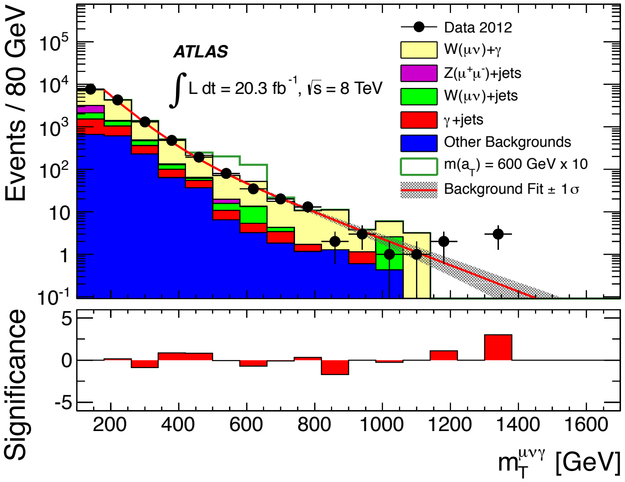
ΔR(ℓ,γ) > 0.7,
ℓ & γ isolated

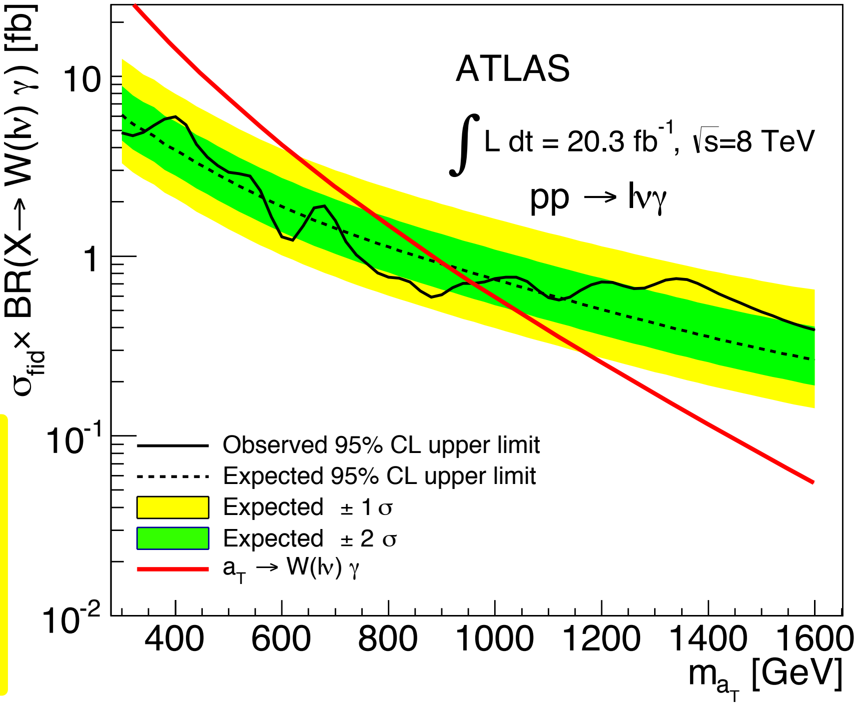
Backgrounds:
Dominant is SM Vγ
Vγ, diboson, top BG from MC
W/Z+jets data-driven estimate

Systematics:
γ reco and ID
MET calib.
Luminosity

Model	Obs. Limit [GeV]
LSTC $a_T \rightarrow W\gamma$	275-960





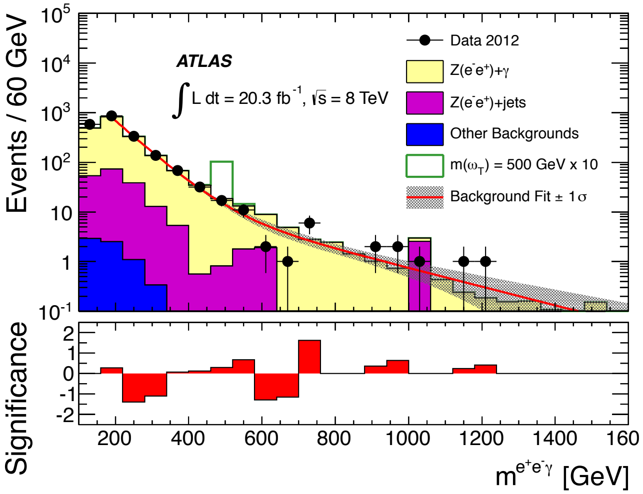


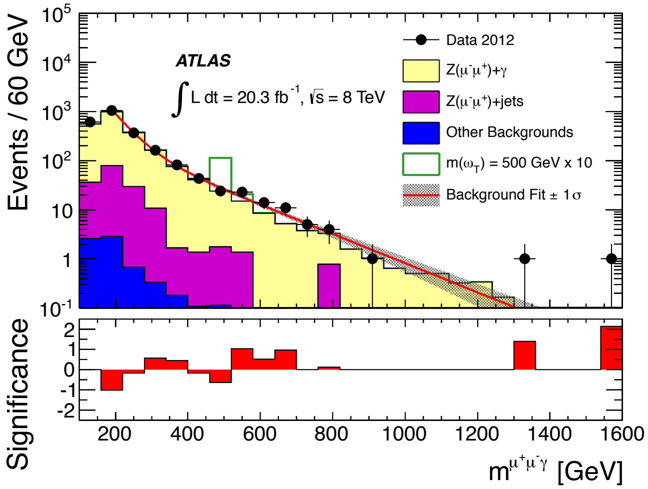
Zγ resonances

arXiv:1407.8150

$\ell\ell\gamma$ criteria:
ℓ opp. charge, same flavor
65 < $m_{\ell\ell}$ < 115 GeV
γ E_T > 40 GeV
if ℓ=μ, ≥1 μ has track in MS and ID

ΔR(ℓ,γ) > 0.7,
ℓ & γ isolated

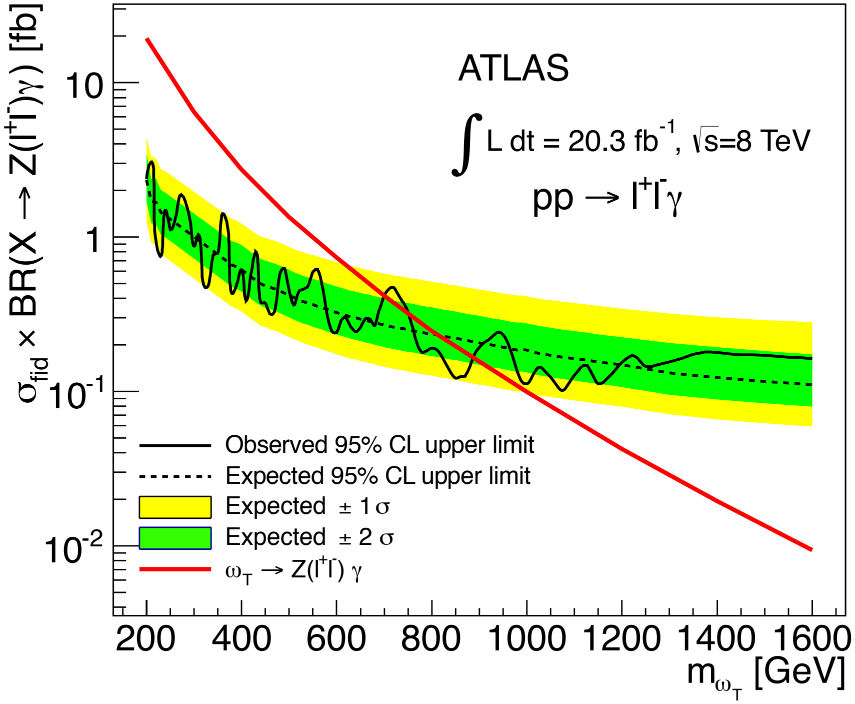




Systematics:
γ reco and ID
MET calib.
Luminosity

Backgrounds:
Dominant is SM Vγ
Vγ, diboson, top BG from MC
W/Z+jets data-driven estimate

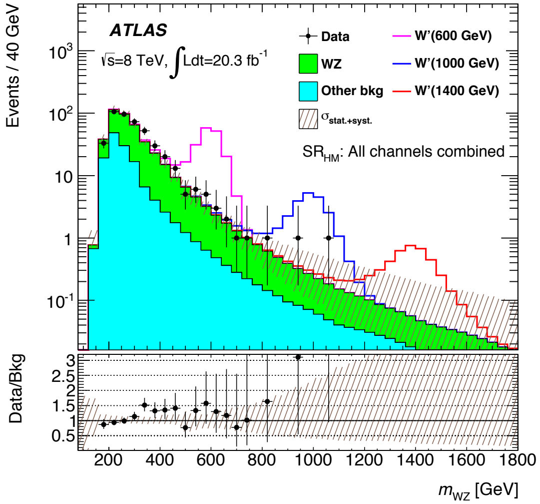
Model	**Obs. Limit [GeV]**
LSTC $\omega_T \to Z\gamma$	200-700, 750-890
LSTC $\phi \to Z\gamma$	200-1180



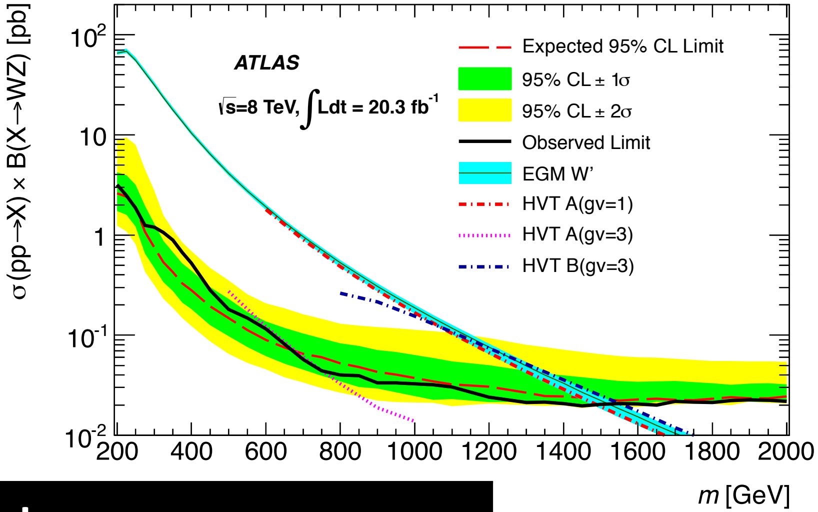
WZ resonances

arXiv:1406.4456

Signal criteria:
3 ℓ with $p_T > 25$ GeV
MET > 25 GeV
Reject if 4th ℓ with $p_T > 20$ GeV
ℓ iso, except from same-flavor ℓ (collimated high p_T Z decays)
2 ℓ opp. sign, same flavor, have $m_{\ell\ell}$ within 20 GeV of m_Z
$\Delta y(W,Z) < 1.5$
High-mass ($m_{\ell\nu\ell\ell} > 250$ GeV) and low-mass search regions
HM: $\Delta\phi_{(\ell,MET)} < 1.5$, LM: $\Delta\phi_{(\ell,MET)} > 1.5$



Model	Obs. Limit
W' EGM	1.49 TeV



Also limits on Heavy Vector Triplets model, constrains couplings directly

Backgrounds:
Dominant is SM WZ
BG with ≥3 real prompt ℓ, or γ faking ℓ, from MC
BG with jets faking leptons estimated from data

Systematics:
Theory (dominant)
High mass extrapolation

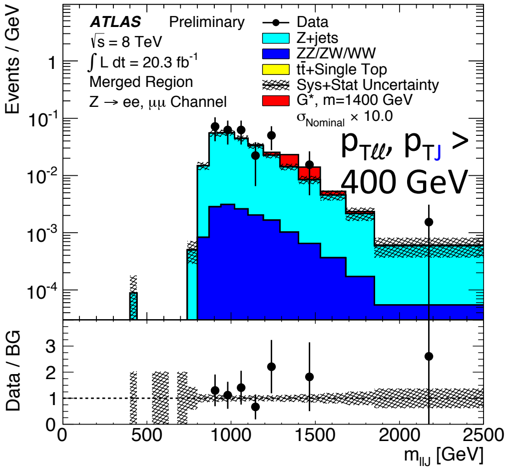
ZZ and ZW resonances

ATLAS-CONF-2014-039

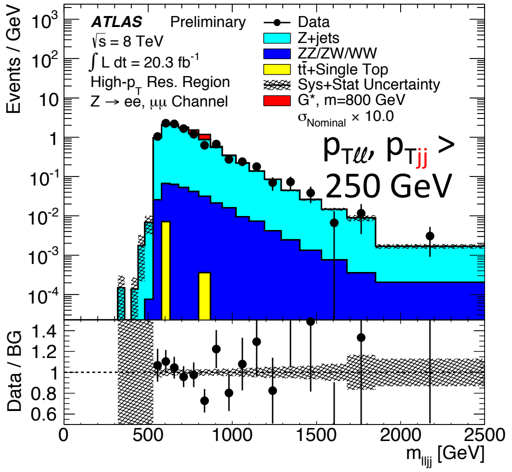
Signal criteria:
Exactly 2 ℓ, 2 resolved jets (j) or one unresolved (J)
ℓ pT > 25 GeV
ℓ iso, except from same-flavor ℓ (collimated high p_T Z decays)
j reconstructed with anti-k_t 4, j p_T > 30 GeV, |η| < 2.1
J reconstructed with Cambridge-Aachen R=1.2, J p_T > 100 GeV, |η| < 1.2
66 < $m_{\ell\ell}$ < 116 GeV 70 < $m_{jj/J}$ < 110 GeV

Systematics:
Data-driven corrections to BG
ISR/FSR modeling

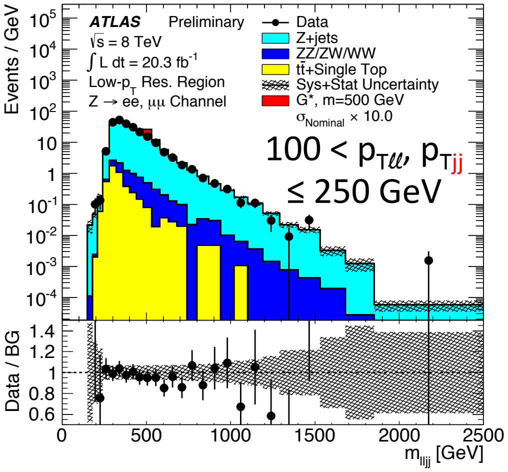
Backgrounds:
SM Z + jets (dominant), tt, non-res. diboson



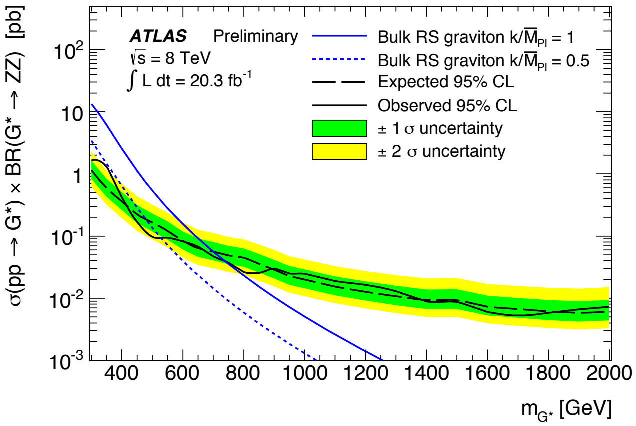
$p_{T\ell\ell}$, p_{TJ} > 400 GeV



$p_{T\ell\ell}$, p_{Tjj} > 250 GeV



100 < $p_{T\ell\ell}$, p_{Tjj} ≤ 250 GeV



Model	Obs. Limit
W' EGM	1.59 TeV
Bulk RS G*, k/Mpl = 1.0	740 GeV

4 b jets resonances

ATLAS-CONF-2014-005

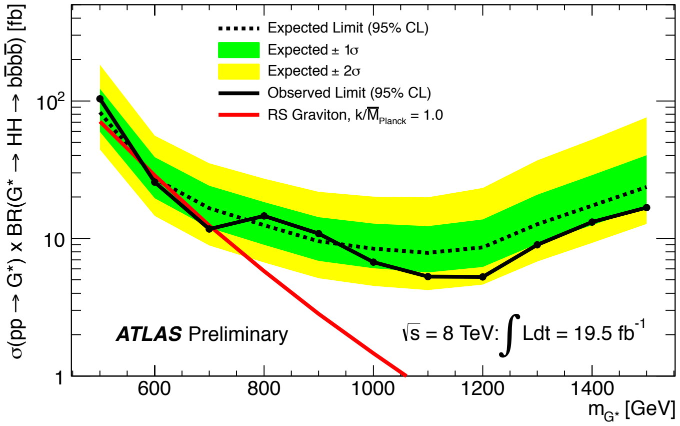
Signal criteria:
≥4 anti-k_t 4 j, b-tagged, $p_T > 40$ GeV, $\lvert\eta\rvert < 2.5$
Reject events with high p_T j coming from non-collision BG
Form 2 dijet pairs using j a, b: $\Delta R_{ab} < 1.5$, $p_{Tab} > 200$ GeV
j with $p_T > 30$ GeV, and not in dijets but in $\Delta R < 1.5$: Reject event if likely from tt
Require 4j mass consistent with HH hypothesis

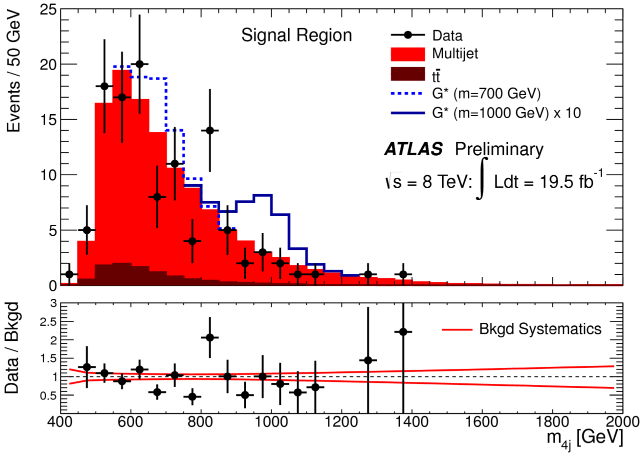
b-tagging:
Multivariate requirements combined in NN
Trk impact params, displaced vtx, c/b hadron decays
Working point used 70% efficient

Systematics:
BG shape, yield
Jet calibration
b-tagging

Backgrounds:
~90% from multi-jets (data-driven)
10% tt (shape MC, yield dd), <1% Z+ jets (MC)

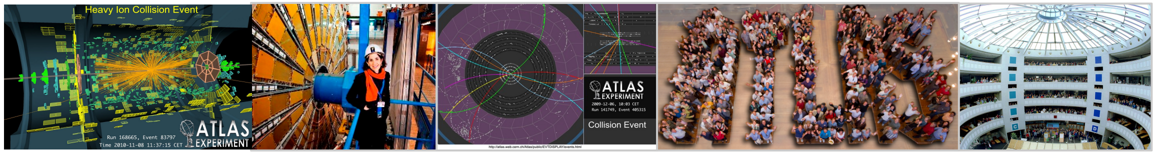
Model	Obs. Limit
Bulk RS G*	590-710 GeV





Summary

- No evidence for new resonances found, but limits have been set on many models
  - In many cases, general limits assuming no specific model have also been set (useful for further interpretation)
- Sensitivity to new resonances dramatically increases with center of mass energy of collisions
  - Preparations for Run II are underway
  - In some cases possible to surpass Run I sensitivity with just a few fb^{-1} @ 13 TeV


Heavy Ion Collision Event
Run 168665, Event 83797
Time 2010-11-08 11:37:15 CET
ATLAS EXPERIMENT
ATLAS EXPERIMENT
Collision Event

BACKUP


ATLAS Collaboration

Model parameters

- **ADD**: One or more ED. KK excitations of Graviton and quantum black holes (QBH) predicted. New resonance is lightest Graviton mode (G*). QBH not resonances, but for some models can be treated as such, so some limits on mass threshold for QBH production (M_{th}). (*For dedicated BH/QBH searches see talk by C. Clement*).
- **RS 1**: Two 4D branes in a 5D bulk, with ED in bulk compactified. SM particles confined to one brane. Limits set on G* mass vs coupling k/Mpl.
- **Bulk RS**: As RS 1, but SM particles can propagate into the bulk.
- **W’, Z’**: Benchmarks SSM and EGM. Sequential Standard Model high-mass gauge bosons have same couplings as SM W/Z. Extended Gauge Model has modified coupling to WZ. Limits set on masses of new bosons.
- **W*, Z***: Chiral gauge bosons with masses near weak scale. Limits set on their masses.
- **q***: Excited states of a composite quark. Limits set on excited quark mass.
- **Technicolor**: (Low Scale Technicolor, Minimal Walking Technicolor) New force analogous to strong force. Models include Higgs boson consistent with LHC discovery. Limits set on masses of new technimesons, couplings.

Detector and Particle identification

e/γ

EM cluster with assoc. ID track (e, conv. γ)

Conv. vtx. resolve between e and conv. γ

Trk-clus match, trk qual, shower shape in calo to reject hadronic BG

e →use *medium* level working point

γ →use *tight* level working point

el (γ) in |η|< 2.47 (2.37), less 1.37<|η|<1.52

μ

Usually trk in ID and MS

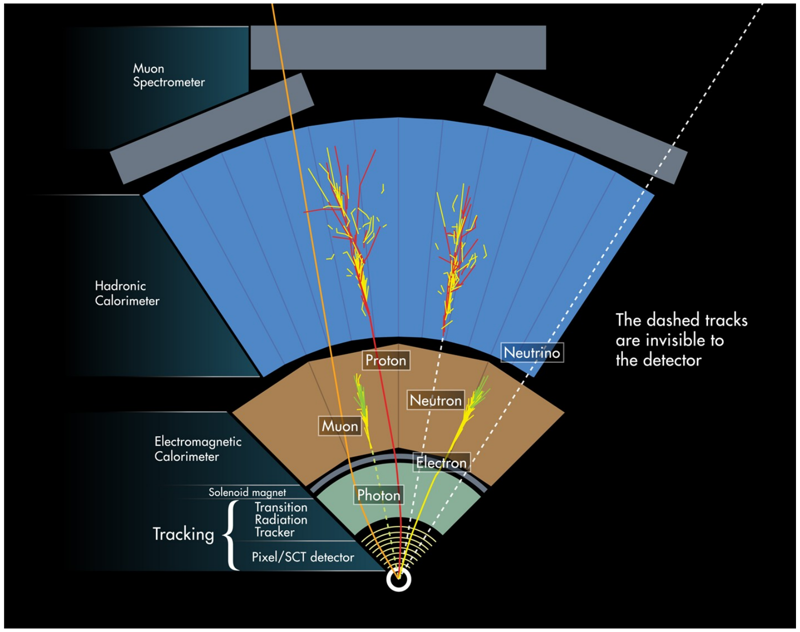
Can use just ID trk+ calo, or just MS trk

Use stringent req. on MS hits, MS/ID trk match

MET

From sum of E_T of all clusters in calo (|η| < 4.9) and μ

Correct for clus. assoc. w/reco obj.



j

Seeded by clusters in hadronic calo

Reconstruct with anti-k_t algorithm in |η| < 2.8, with cone size 0.6 or 0.4

For j with |η| < 2.5 use vertexing to reject pileup

Matrix method for fake BG estimation

Method used in several searches

- Jets can fake muons or electrons or photons (more common)
- Estimate BG from data-driven method:
  - Have a nominal selection (as for the signal candidates)
  - Have a loosened selection (background-enriched sample)
  - Relate number of events that pass/fail each selection to the number of events with no fakes and the number of events with fakes
  - Use also probabilities that a real e/μ/γ passes each selection (r) and the probability a jet fakes e/μ/γ

Matrix method for fake BG estimation (2)

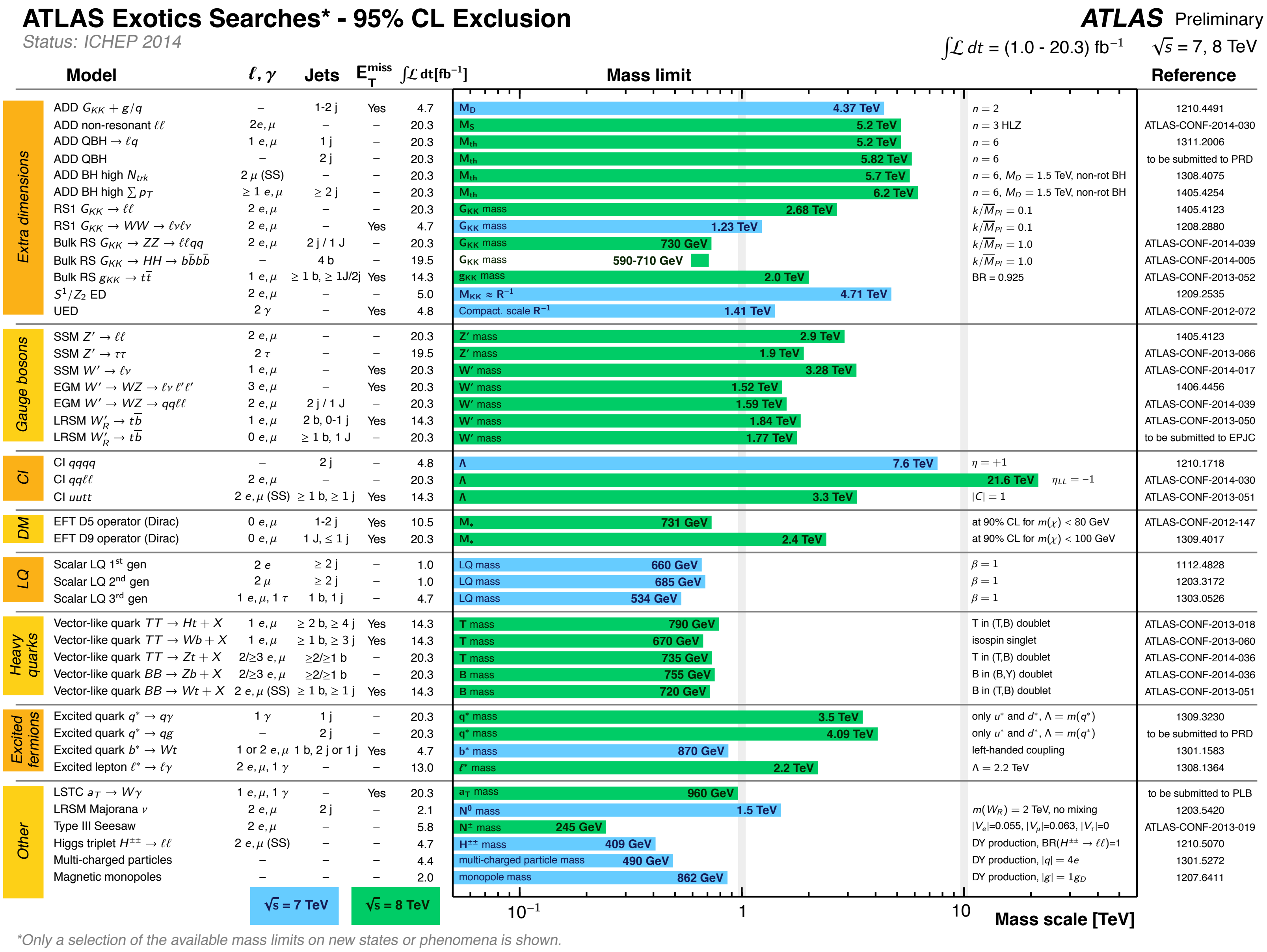
Method used in several searches

- Can form matrix relating number of events where objects pass nominal (T) selection vs loosened (L) selection, and number of events with real prompt particles (R) vs fakes (F):

$$\begin{pmatrix} N_{TT} \\ N_{TL} \\ N_{LT} \\ N_{LL} \end{pmatrix} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1(1-r_2) & r_1(1-f_2) & f_1(1-r_2) & f_1(1-f_2) \\ (1-r_1)r_2 & (1-r_1)f_2 & (1-f_1)r_2 & (1-f_1)f_2 \\ (1-r_1)(1-r_2) & (1-r_1)(1-f_2) & (1-f_1)(1-r_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{RR} \\ N_{RF} \\ N_{FR} \\ N_{FF} \end{pmatrix}$$

Specific equation taken from arXiv: 1405.4123

Overview of all ATLAS Exotics results



ATLAS Exotics Searches* - 95% CL Exclusion

Status: ICHEP 2014

ATLAS Preliminary

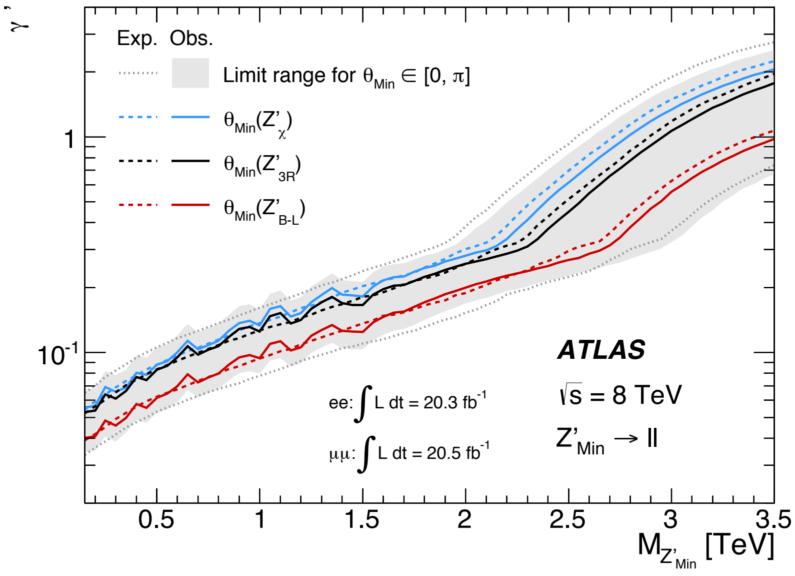
$\int\mathcal{L}\,dt$ = (1.0 - 20.3) fb^{-1} $\sqrt{s}$ = 7, 8 TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt[\text{fb}^{-1}]$	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 $\ell\ell$	$2e, \mu$	–	–	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, $\lvert g \rvert = 1g_D$	1207.6411

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

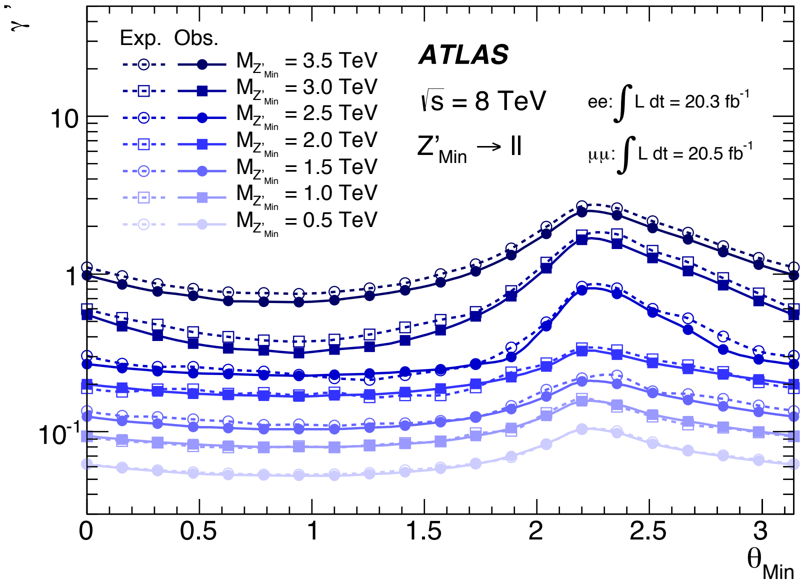
Dilepton resonances

arXiv:1405.4123



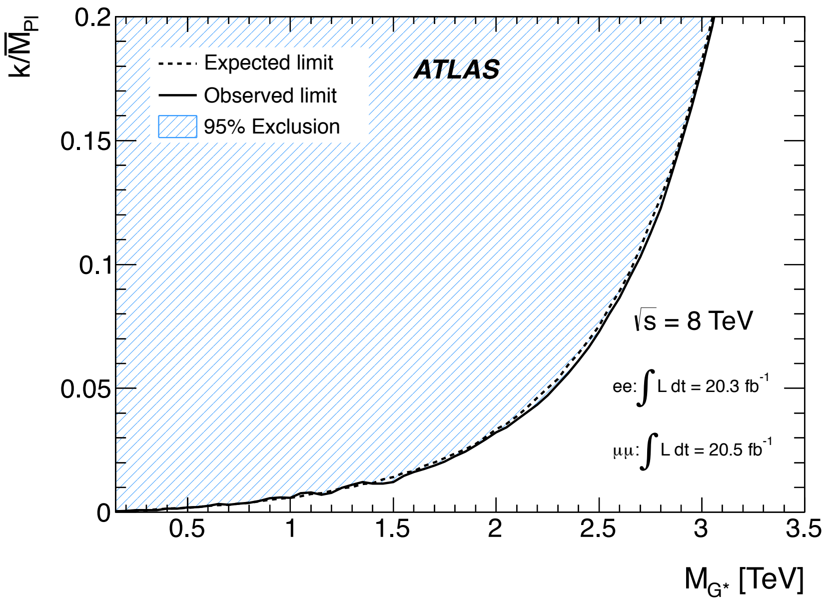
Limits set on Z' mass vs coupling g' in the Minimal Models framework. Here the model is completely characterized by 3 parameters: 2 coupling constants, g_Y and g_{B-L}, and $M_{Z'}$. The coupling constants can be written in terms of γ' and θ_{Min}.

Limits can also be set on γ' and θ_{Min} for fixed values of $M_{Z'}$.



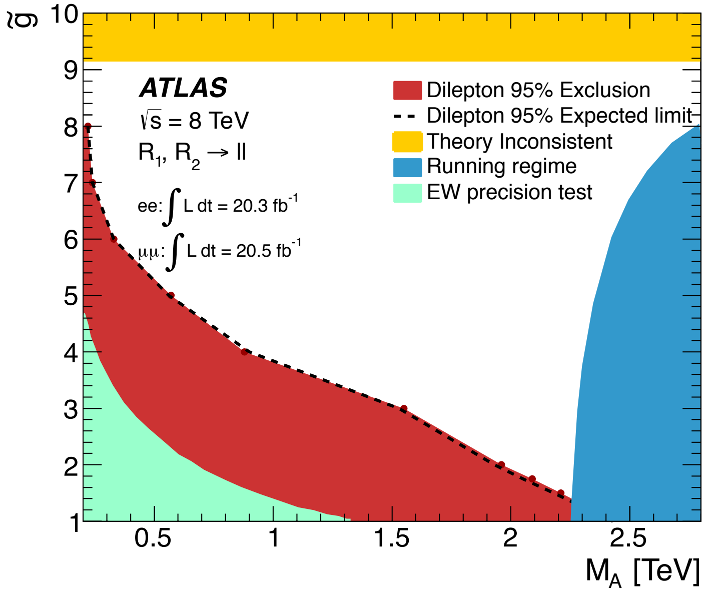
Dilepton resonances

arXiv:1405.4123



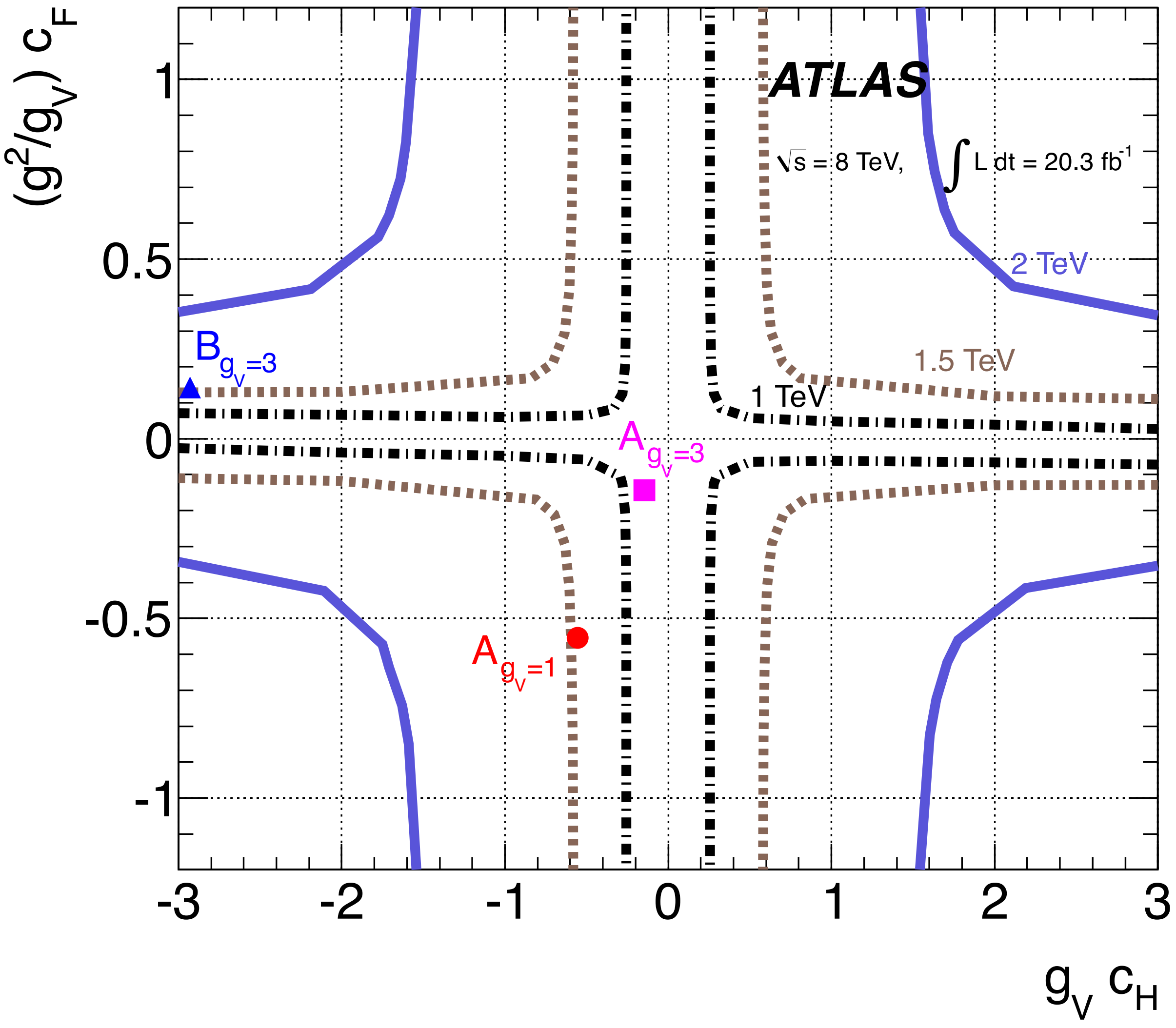
Limits set on G* mass in the RS1 model as a function of the coupling to SM particles, k/M_{Pl}.

Limits set on the bare-axial mass vs the coupling of the new spin-1 resonance to SM fermions, in the Minimal Walking Technicolor model.



WZ resonances

arXiv:1406.4456



Observed 95% exclusion contours in the HVT parameter space $\{(g^2/g_V)c_F, g_Vc_H\}$ for resonances of mass 1 TeV, 1.5 TeV and 2 TeV. Also shown are the benchmark model parameters A(gV=1), A(gV=3) and B(gV=3). The observed limits for the benchmark HVT resonances are 1.49, 0.76 and 1.56 TeV, respectively.

4 b jets resonances

ATLAS-CONF-2014-005

Check consistency with ttbar hypothesis

- m_W formed extra jet + jet in the dijet with lowest probability of being a b jet
- m_t taken from invariant mass of extra jet + dijet
- $\sigma_{m_W} = 0.1m_W$, $\sigma_{m_t} = 0.1m_t$, $M_W = 80.4$ GeV, $M_t = 172.5$ GeV
- Define variable X_{tt}:

$$X_{tt} = \sqrt{\left(\frac{m_W - M_W}{\sigma_{m_W}}\right)^2 + \left(\frac{m_t - M_t}{\sigma_{m_t}}\right)^2}$$

- If either dijet for the event has $X_{tt} < 3.2$ for any combination, the event is rejected

4 b jets resonances

ATLAS-CONF-2014-005

Check consistency with HH hypothesis

- “Signal Region” defined by making elliptical cut in plane of leading dijet invariant mass, m_{JJ}, and sub-leading dijet invariant mass, m_{jj}
- $\sigma_{m_{JJ}} = 0.1 m_{JJ}$, $\sigma_{m_{jj}} = 0.1 m_{jj}$, $M_{JJ} = 124.0$ GeV, $M_{jj} = 115.0$ GeV
- Define variable X_{HH}:

$$X_{HH} = \sqrt{\left(\frac{m_{JJ} - M_{JJ}}{\sigma_{m_{JJ}}}\right)^2 + \left(\frac{m_{jj} - M_{jj}}{\sigma_{m_{jj}}}\right)^2}$$

- $X_{HH} < 1.6$ defines the signal region

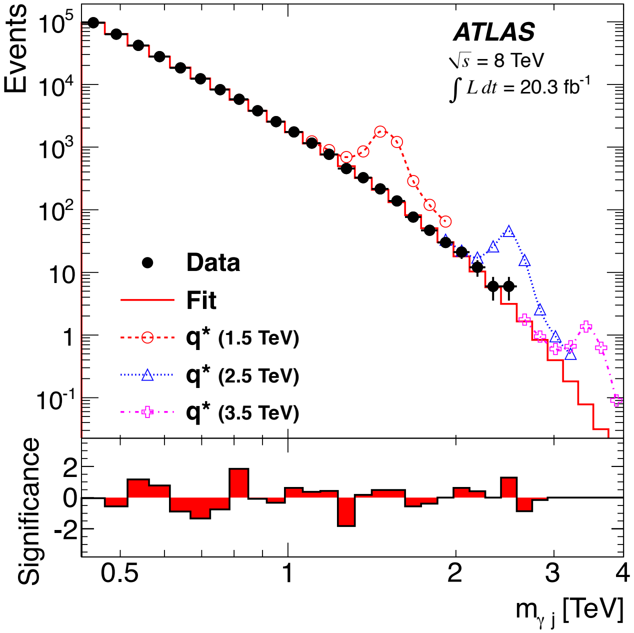
γ + jet resonances

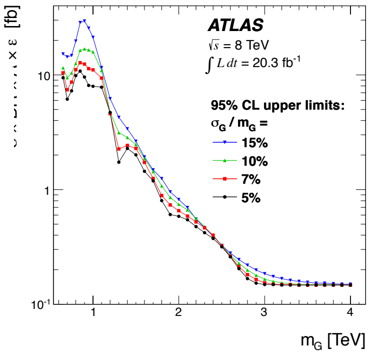
arXiv:1309.3230

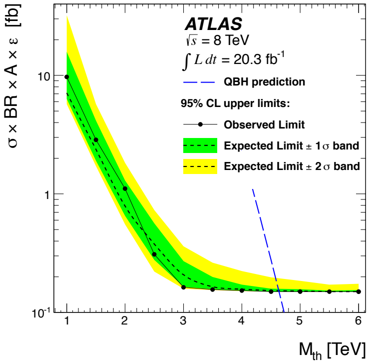
Signal criteria:
AntiKT6 j p_T > 125 GeV in $\|\eta\|$< 2.8
γ iso., p_T > 125 GeV in $\|\eta\|$ < 1.37
Exactly 1 j such that $\Delta R(\gamma, j) < 0.1$
$\|\Delta\eta_{\gamma j}\| < 1.6$

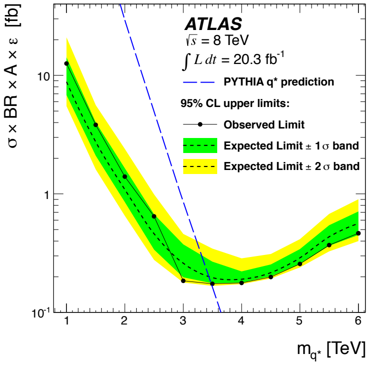
Data-driven BG:
Estimate from fit to $m_{\gamma j}$, validate with MC and data control regs.
$f(x) = a(1-x)^b x^{-(c+d\ln x)}$

Systematics:
Luminosity
γ trigger, ID, iso. eff.
γ, j E scales









Model	**Obs. Limit**
Gaus. res. 5% width, m=1 TeV m=4 TeV	σ*Br*A*ε < 8 fb 0.1 fb
QBH n=6	M_{th} < 4.6 TeV
q*	m_{q*} < 3.5 TeV