Other BSM (non-SUSY) searches in ATLAS

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ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 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 $\ell\ell/\gamma\gamma$	2γ or $2e,\mu$	–	–	4.7	M_S 4.18 TeV	$n = 3$ HLZ NLO	1211.1150
	ADD QBH $\rightarrow \ell q$	$1\,e,\mu$	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD BH high N_{trk}	$2\,\mu$ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq 1\,e,\mu$	≥ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	ATLAS-CONF-2014-016
	RS1 $G_{KK} \rightarrow \ell\ell$	$2\,e,\mu$	–	–	20.3	G_{KK} mass 2.47 TeV	$k/\overline{M}_{Pl} = 0.1$	ATLAS-CONF-2013-017
	RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell\ell qq/\ell\ell\ell\ell$	2 or 4 e,μ	2 j or –	–	1.0	G_{KK} mass 845 GeV	$k/\overline{M}_{Pl} = 0.1$	1203.0718
	RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell\nu$	$2\,e,\mu$	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	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 $g_{KK} \rightarrow t\bar{t}$	$1\,e,\mu$	≥ 1 b, $\geq$ 1J/2j	Yes	14.3	g_{KK} mass 0.5-2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	$2\,e,\mu$	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	$2\,\gamma$	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2\,e,\mu$	–	–	20.3	Z' mass 2.86 TeV		ATLAS-CONF-2013-017
	SSM $Z' \rightarrow \tau\tau$	$2\,\tau$	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \rightarrow \ell\nu$	$1\,e,\mu$	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\,\ell'\ell'$	$3\,e,\mu$	–	Yes	20.3	W' mass 1.52 TeV		ATLAS-CONF-2014-015
	LRSM $W'_R \rightarrow t\bar{b}$	$1\,e,\mu$	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	$2\,e,\mu$	–	–	5.0	Λ 13.9 TeV	$\eta_{LL} = -1$	1211.1150
	CI $uutt$	$2\,e,\mu$ (SS)	≥ 1 b, ≥ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C\rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator	–	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator	–	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	$2\,\mu$	≥ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	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
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$	$1\,e,\mu$	≥ 2 b, ≥ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	$1\,e,\mu$	≥ 1 b, ≥ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $BB \rightarrow Zb + X$	$2\,e,\mu$	≥ 2 b	–	14.3	B mass 725 GeV	B in (B,Y) doublet	ATLAS-CONF-2013-056
	Vector-like quark $BB \rightarrow Wt + X$	$2\,e,\mu$ (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 $q^* \rightarrow q\gamma$	$1\,\gamma$	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	–	13.0	q^* mass 3.84 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2012-148
	Excited quark $b^* \rightarrow Wt$	1 or $2\,e,\mu$	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	$2\,e,\mu,1\,\gamma$	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LRSM Majorana ν	$2\,e,\mu$	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	$2\,e,\mu$	–	–	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 $H^{\pm\pm} \rightarrow \ell\ell$	$2\,e,\mu$ (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

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

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

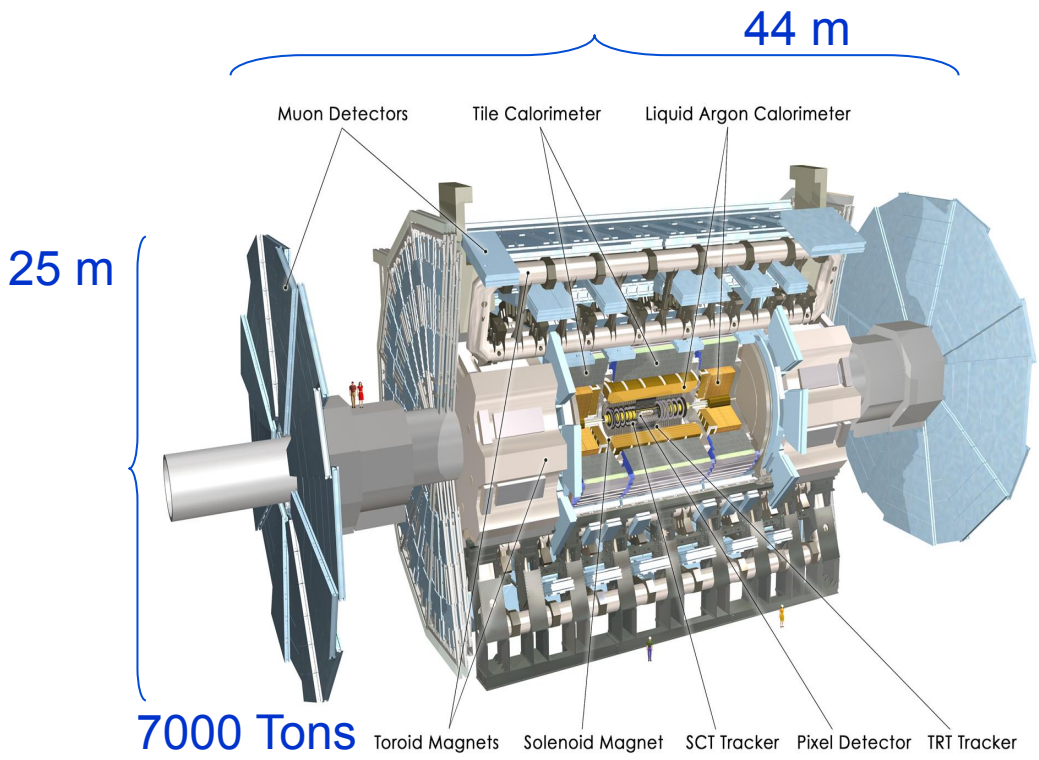
*Only a selection of the available mass limits on new states or phenomena is shown.

Results with complete 8 TeV dataset

- New spin 1 resonances
- Extra dimensions
  - Randall-Sundrum (RS)
  - Arkani-Hamed, Dimopoulos, Divali (ADD)
  - classical and quantum black holes
- Dark matter
- New phenomenon in events with three charged leptons

ATLAS Detector

- A general purpose detector
- Trackers
  - Pixel
  - Silicon microstrip tracker (SCT)
  - Transition radiation tracker (TRT)
- Solenoid
  - 2T magnetic field
- Calorimeter
  - Electromagnetic (EM)
    - Liquid Argon (LAr)
  - Hadronic (HAD)
    - scintillating tiles in central barrel, LAr in end caps (EC)
- Muon Spectrometer
  - excellent momentum resolution
  - independent momentum measurement at high p_T
- Three large superconducting toroids
  - one barrel and two ECs
  - eight-fold azimuthal symmetry around calorimeter
  - 1.2T magnetic field



$\eta \equiv -\ln\tan(\theta/2)$; polar angle θ is the angle from the beam axis

Detector component	η coverage	
	Measurement	Trigger
Tracking	± 2.5	
EM calorimetry	± 3.2	± 2.5
Hadronic calorimetry (jets)		
barrel and end-cap	± 3.2	± 3.2
forward	$3.1 < \lvert\eta\rvert < 4.9$	$3.1 < \lvert\eta\rvert < 4.9$
Muon spectrometer	± 2.7	± 2.4

The ATLAS Collaboration, G. Aad et al., The ATLAS Experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003.

Heavy Resonances

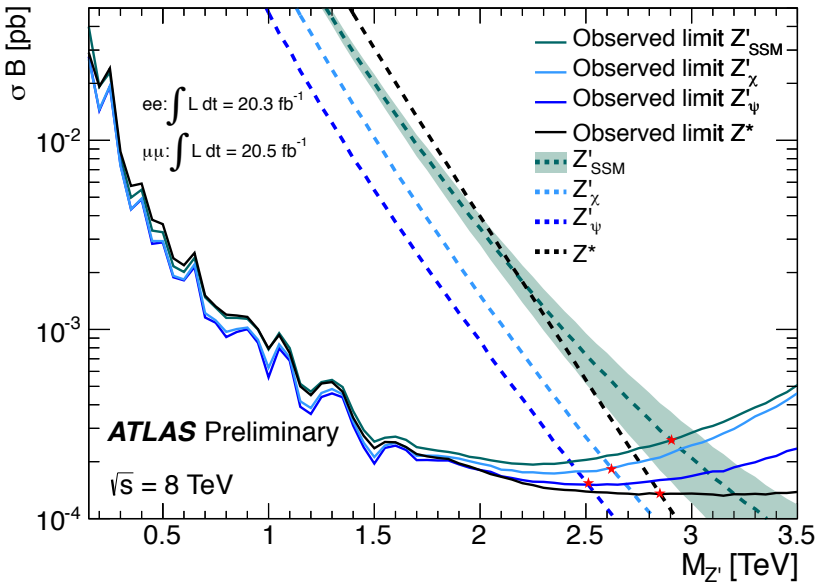
- Predicted by various extensions of Standard Model (SM)
  - Sequential Standard Model (SSM)
    - same coupling of Z'_{SSM} (W'_{SSM}) to fermions as Z_{SM}(W_{SM})
  - GUT-inspired theories
    - Z'_{ψ} and Z'_{χ} lightest mass resonances predicted by E_6 based theories
  - Weak-doublet spin-1 bosons
    - anomalously interacting Z* and W* bosons
  - Diboson resonance predicted by Extended Gauge Model (EGM)
  - Excited quarks (q*) predicted by composite models

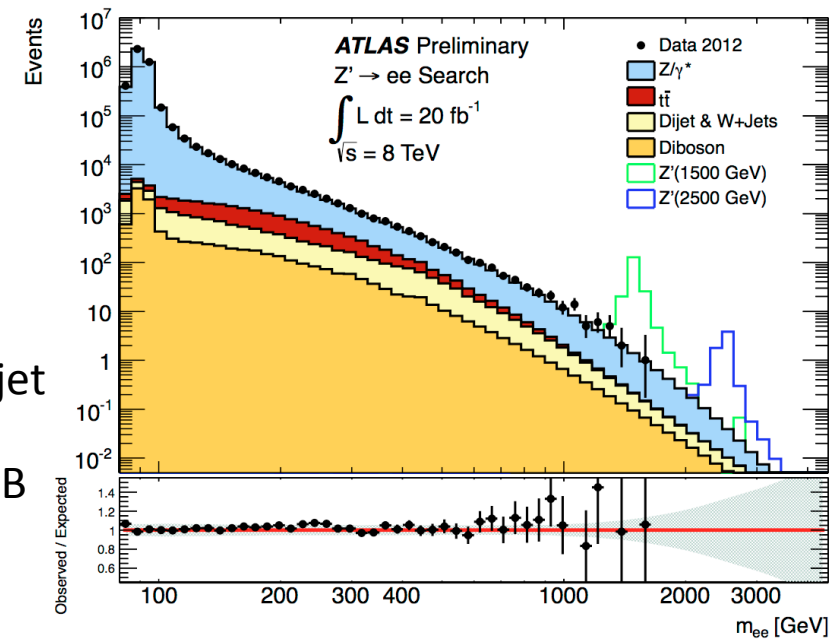
Z'/Z*-> ee , μμ

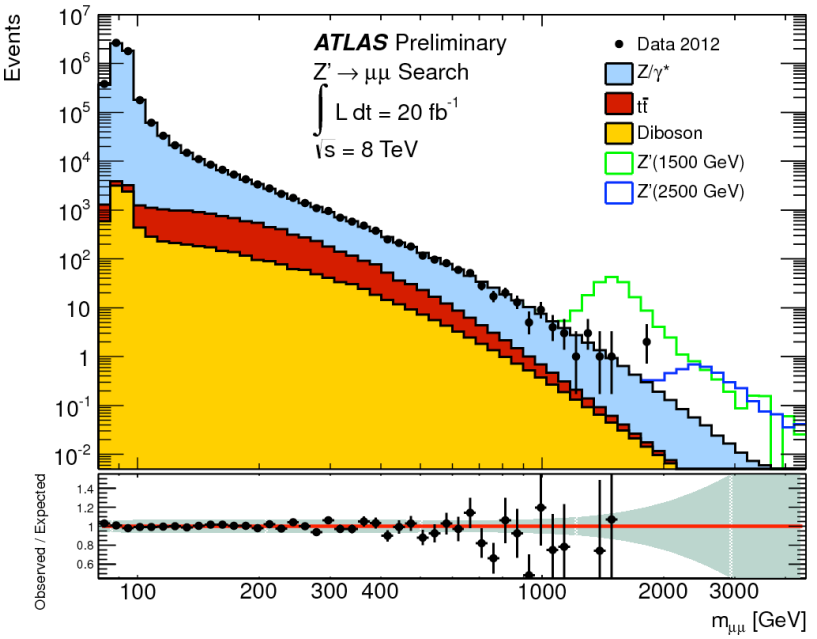
ATLAS-CONF-2013-017

- Two isolated electrons/muons
  - clean signature with low background
- Electroweak backgrounds estimated from MC
  - Drell-Yan, diboson, ttbar, tW
- Data driven multijet and W+jets backgrounds
- Sum of MC scaled to data after subtracting multijet and W+jet
- 95% confidence level combined upper limit on σB

Model	Width [%]	Observed Mass Limit [TeV]	Expected Mass Limit [TeV]
Z'_{SSM}	3.0	2.90	2.87
Z'_{χ}	1.2	2.62	2.60
Z'_{ψ}	0.5	2.51	2.46
Z^*	3.4	2.85	2.82







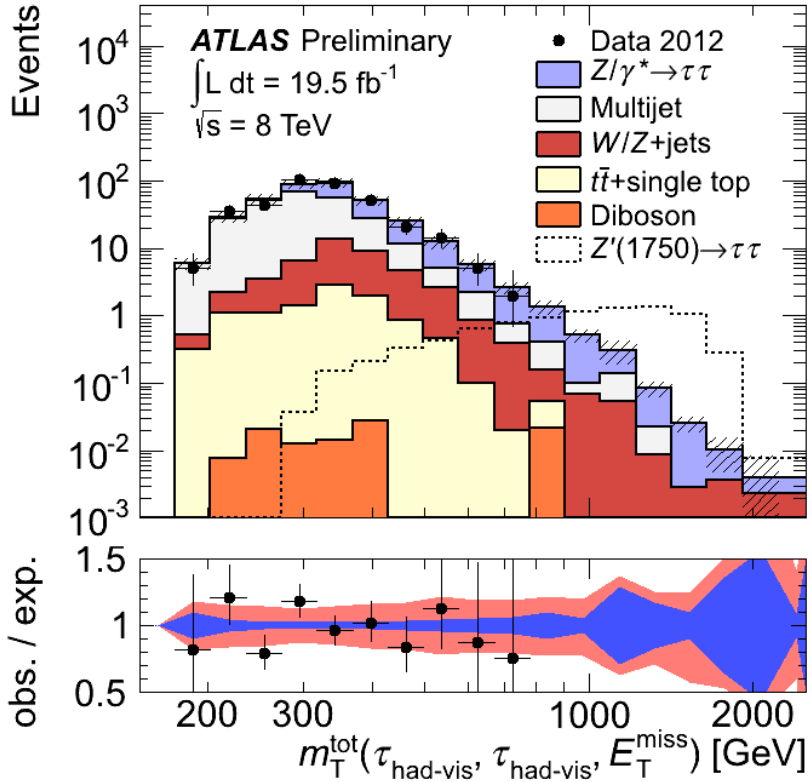
Z`-> τ τ

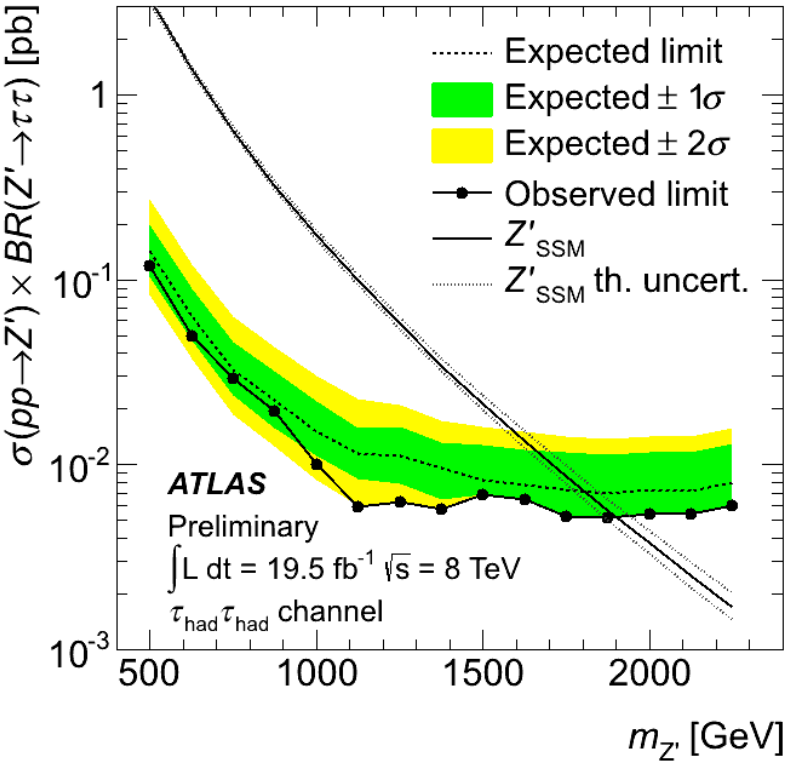
ATLAS-CONF-2013-066

- Analysis complements the search in dielectron and dimuon channels
- Both tau leptons assumed to decay hadronically
  - Both 1 and 3-prong decays included
  - Multivariate algorithms (BDT) used for tau identification (60% efficiency)
- Drell Yan (Z->ττ/γ*) dominant background at high mass: estimated from MC

	$Z/\gamma^* \to \tau\tau$	Multijet	W/Z+jets	Top	Diboson	SM total	Data	$Z'_{SSM}(1750)$
$m_T^{tot} > 850$ GeV	1.0 ± 0.2	0.2 ± 0.1	0.2 ± 0.1			1.4 ± 0.3	0	5.6 ± 1.0

95% observed (expected) credibility limit on σB: 1.9(1.8) TeV



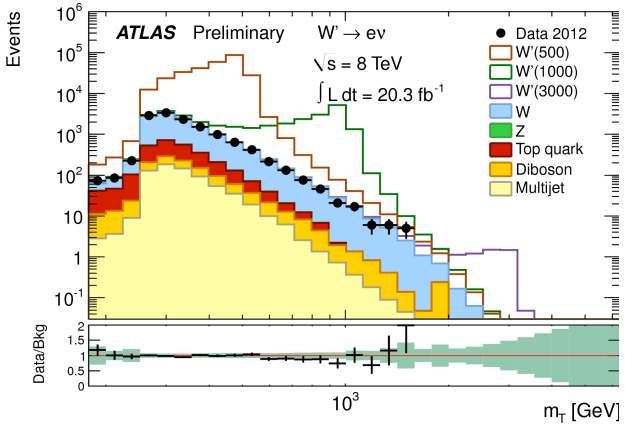


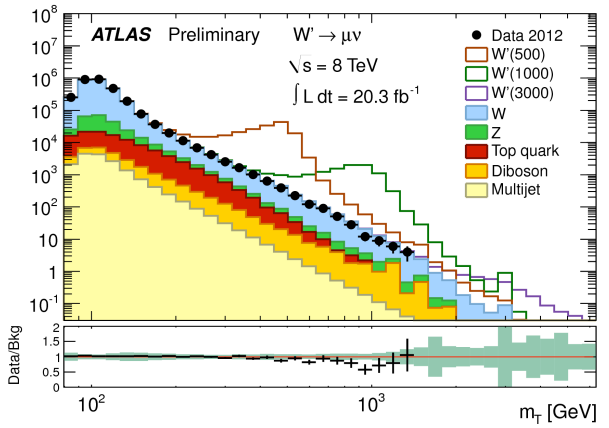
ATLAS-CONF-2014-017

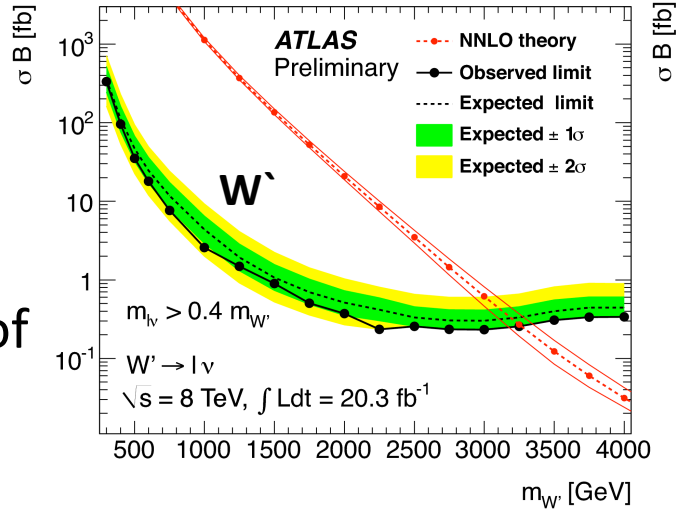
W'(W*)-> e/μ ν

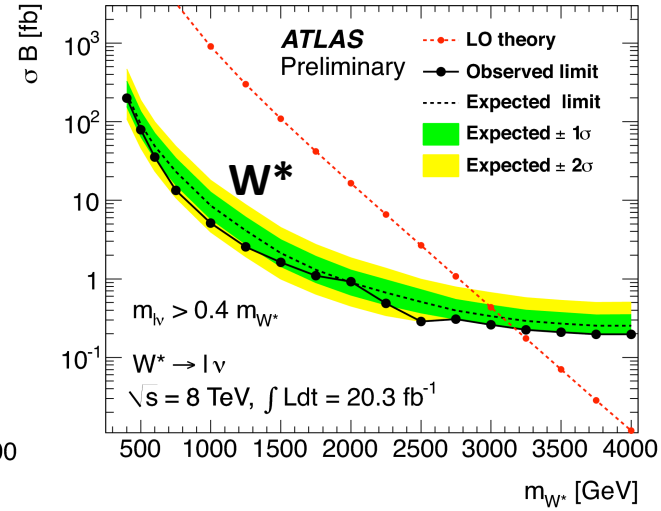
$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}} E_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \varphi_{\ell\nu})}$$

- Isolated lepton and missing transverse energy (MET)
- Electron channel
  - p_T^e and MET > 125 GeV
- Muon channel
  - p_T^μ and MET > 45 GeV
- EW background estimated from MC
- Data driven estimate of multijet background









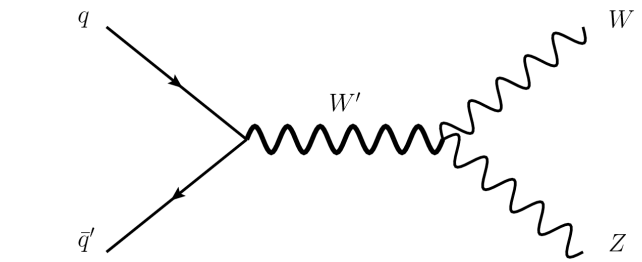
95% credibility level upper limit on σB in fiducial region $m_{l\nu} > 0.4\, m_{W'/W^*}$

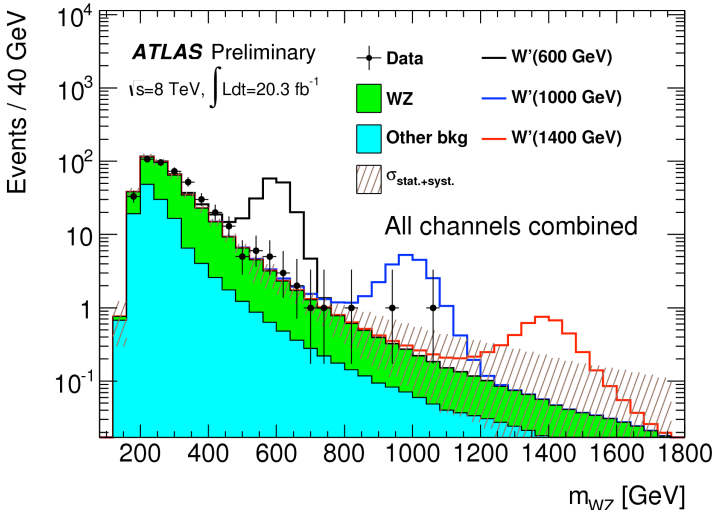
	$m_{W'}$ [TeV]		m_{W^*} [TeV]	
decay	Exp.	Obs.	Exp.	Obs.
$e\nu$	3.15	3.15	3.04	3.04
$\mu\nu$	2.98	2.98	2.80	2.80
both	3.19	3.27	3.08	3.17

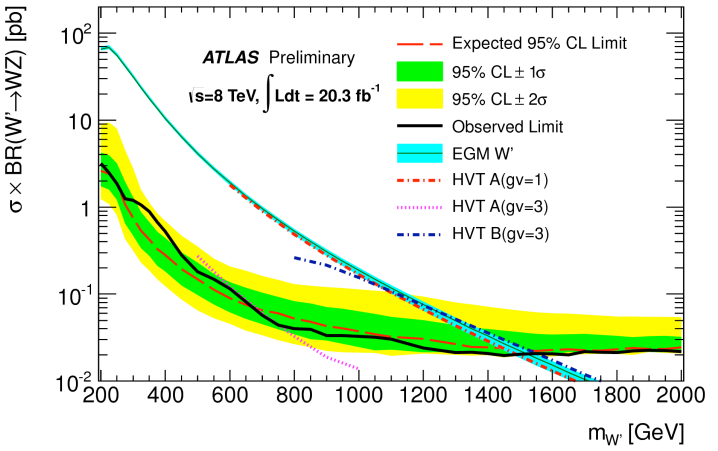
W'-> WZ -> 3l+υ

ATLAS-CONF-2014-015

- Extended Gauge Model W'
  - same coupling to fermion as SM W
  - suppressed coupling to WZ by $(m_W/m_{W'})^2$
- Exactly three leptons
- Two signal regions defined to improve sensitivity
  - $m_{W'} > 250$ GeV, $\Delta\phi$(lepton,MET) < 1.5
  - $m_{W'} < 250$ GeV, $\Delta\phi$(lepton,MET) > 1.5







	Excluded EGM W' mass (TeV)				
	evee	*μvee*	*evμμ*	*μvμμ*	combined
Expected	1.21	1.16	1.17	1.16	1.49
Observed	1.20	1.19	1.06	1.17	1.52

q*-> qγ

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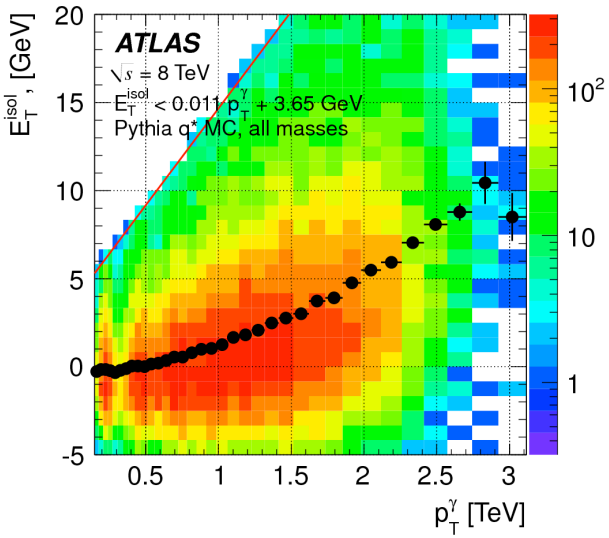
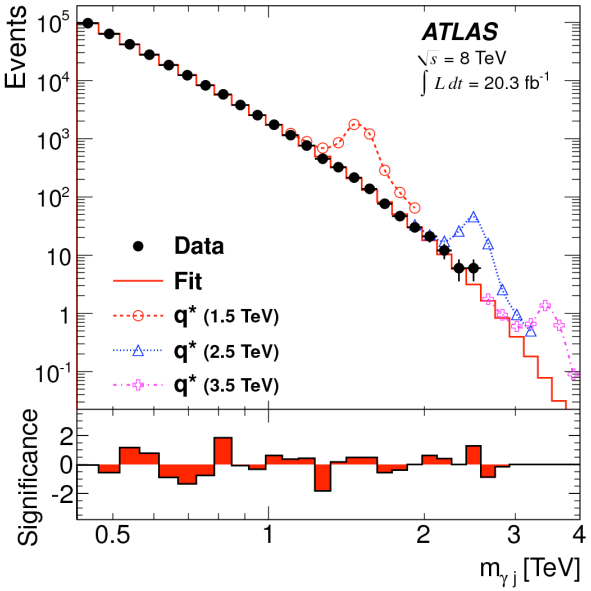
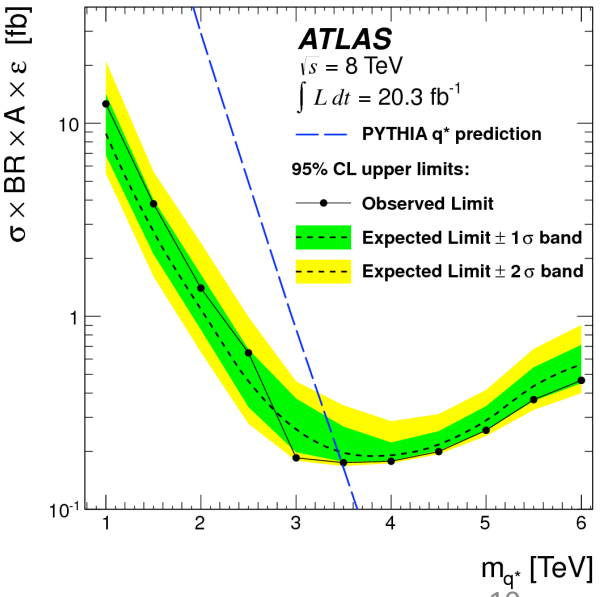
- Searching for excited quark with mass m_{q^*}
- p_T > 125 GeV for photon and jet
- p_T dependent isolation criteria to preserve efficiency
  - $E_t^{isol} < 0.011 p_T^{\gamma} + 3.65$ GeV
- $m_{\gamma j}$ spectrum fitted dijet function

$$f(x \equiv m_{\gamma j}/\sqrt{s}) = p_1(1-x)^{p_2} x^{-(p_3 + p_4 \ln x)}$$

excited quark masses below 3.5 TeV excluded at 95% credibility level







Extra dimensions (ED)

- A solution to hierarchy problem: M_{Pl} (10^{19} GeV) > M_{EW} (10^{2} GeV)
- More than 3+1 dimensions
- Gravity originated on Planck brane can propagate in bulk
- SM fields confined to 3+1 dimensions
- Randall-Sundrum (RS) and Arkani-Hamed, Dimopoulos, Divali (ADD)
- Spin 2 resonance, G*
  - Dilepton (ee,μμ)
  - DiHiggs (4b)
- Quantum black holes (QBH)
  - Dilepton (ee,μμ)
  - Lepton (e,μ)+jet
  - Photon+jet
- Classical black holes (CBH)
  - Multi-object (e,μ + jets)
  - Like sign dimuon

G*-> ee, μμ

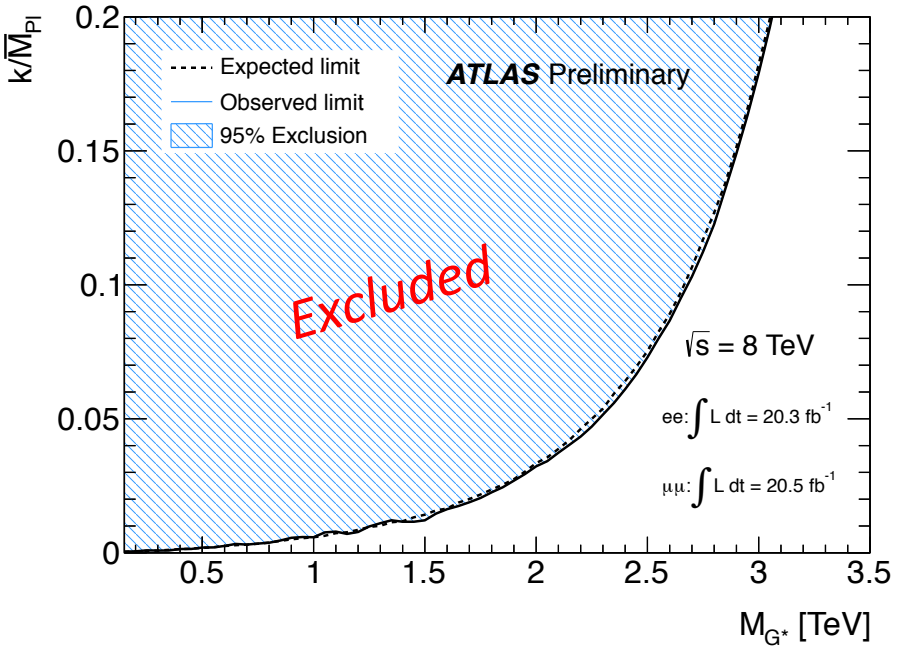
ATLAS-CONF-2013-017

- Lightest excitation of Graviton, G*
- Narrow resonances in dilepton and diphoton
- Branching ratio to 2 leptons small but large signal to background ratio

κ: scale that defines warp factor of extra dimensions

$$\overline{M}_{\mathrm{Pl}} = M_{\mathrm{Pl}}/\sqrt{8\pi}$$

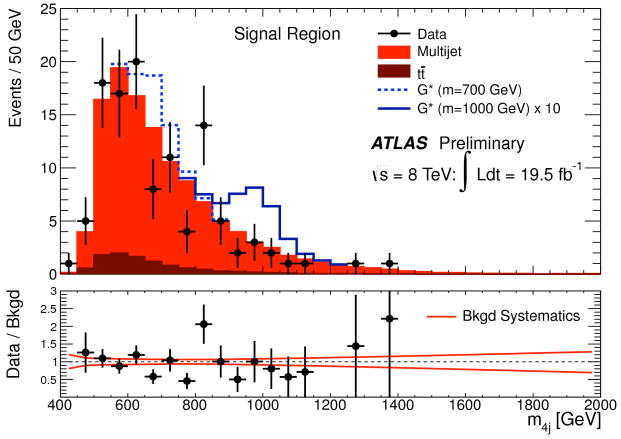
$k/\overline{M}_{\mathrm{Pl}}$	0.01	0.03	0.05	0.1	0.2
Observed limit on M_{G^*} [TeV]	1.25	1.96	2.28	2.68	3.05
Expected limit on M_{G^*} [TeV]	1.28	1.95	2.25	2.67	3.05

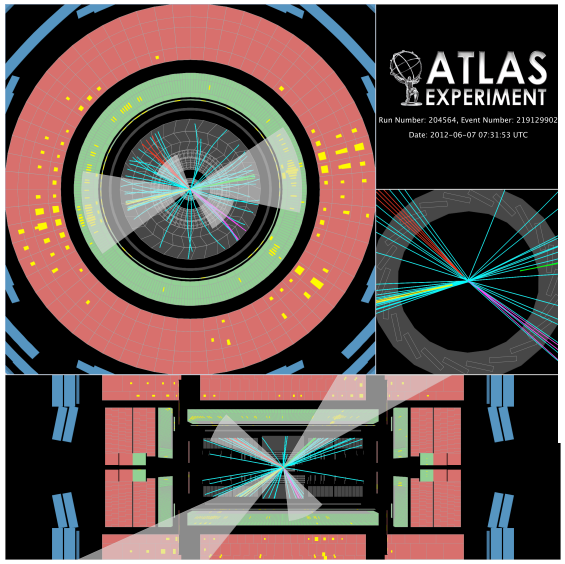


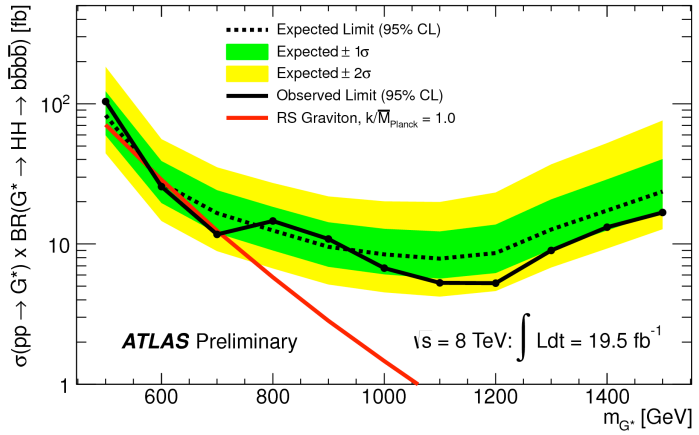
ATLAS-CONF-2014-005

G*->HH->4b

- Bulk RS model
- Decay to heavy objects preferred
- Branching fraction of G* to HH is 7%
- Width of G* resonance smaller than resolution of m_{4j} (~15%)
- At least 4 b-tagged jets with $p_T > 40$ GeV





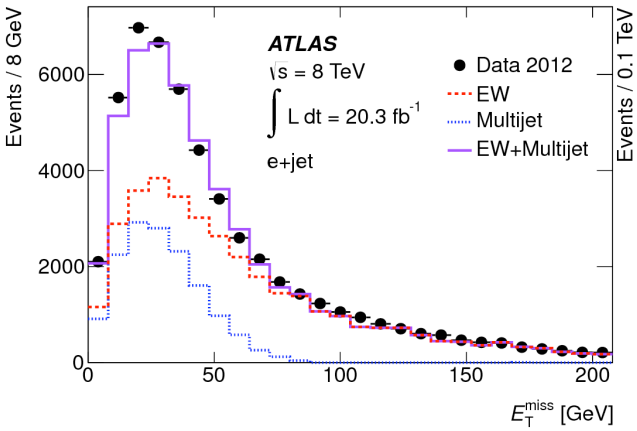


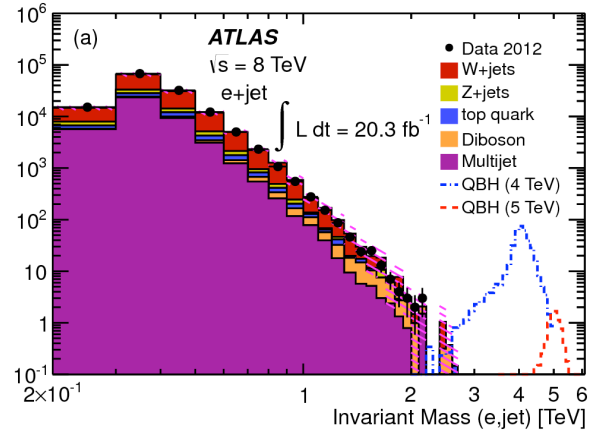
$$k/\bar{M}_{\mathrm{Pl}} = 1.0$$

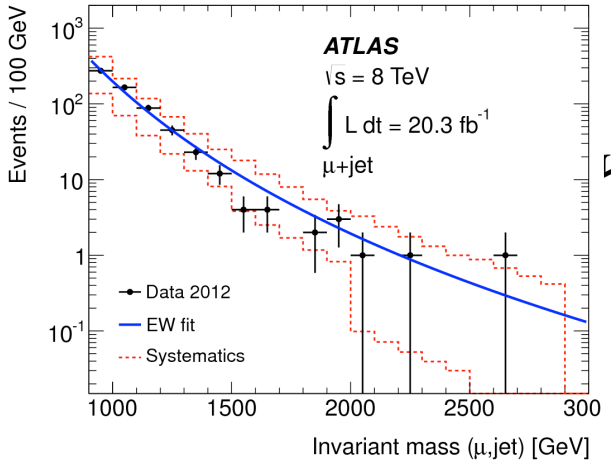
ADD ED: QBH-> e/μ + jet

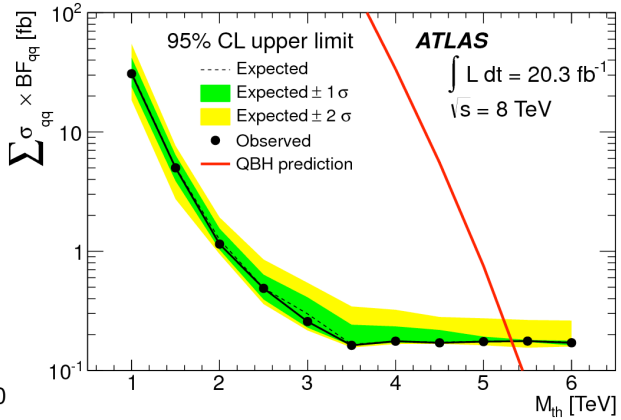
Phys. Rev. Lett 112, 091804 (2014)

- N >= 1 extra dim.
- Plank scale M_D ~ 1 TeV
- Fractionally charged QBHs
- Violation of lepton and baryon number conservation
- M_{th} ~ M_D









- $p_T^{e,\mu,j}$ > 130 GeV
- Δη(e/μ,jet) < 1.5

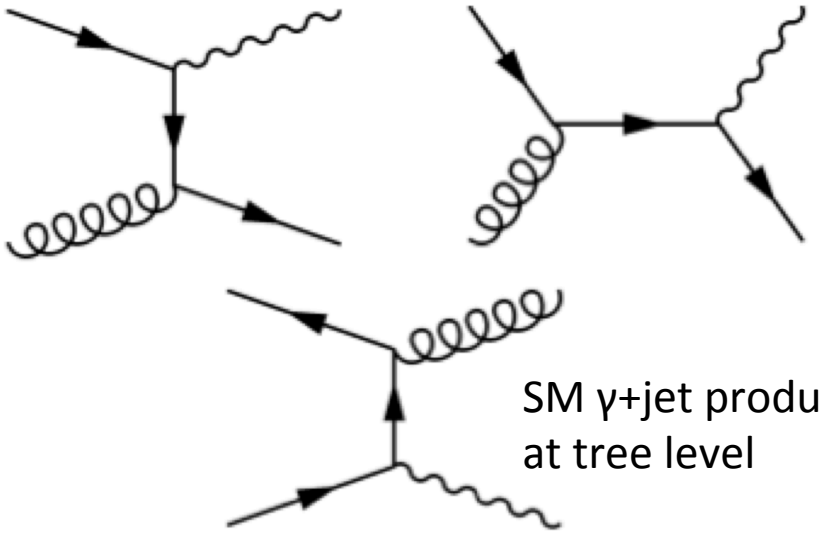
First limits on QBH decaying to lepton+jet
M_{Th} < 5.3 TeV excluded

- Backgrounds normalized to data in low invariant-mass control region and extrapolated through fits to high invariant-mass region

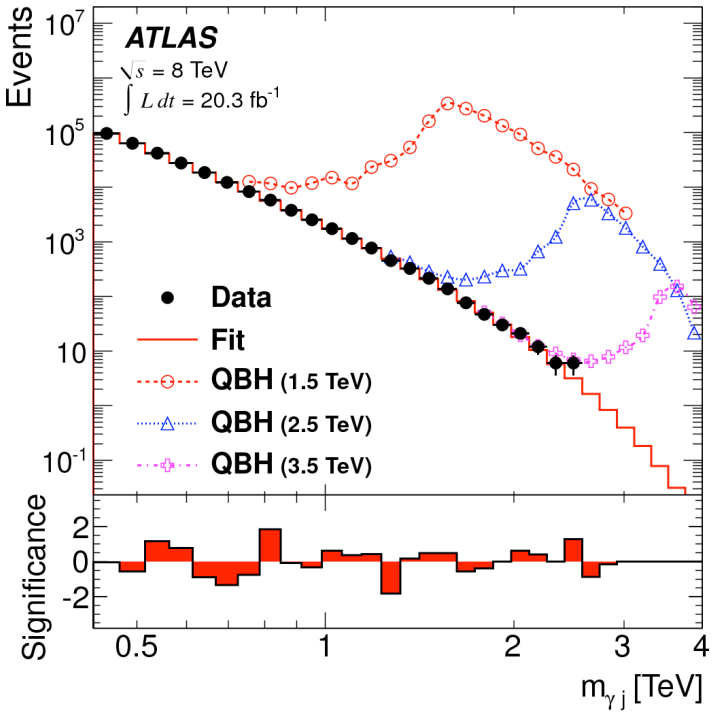
ADD ED:QBH-> γ + jet

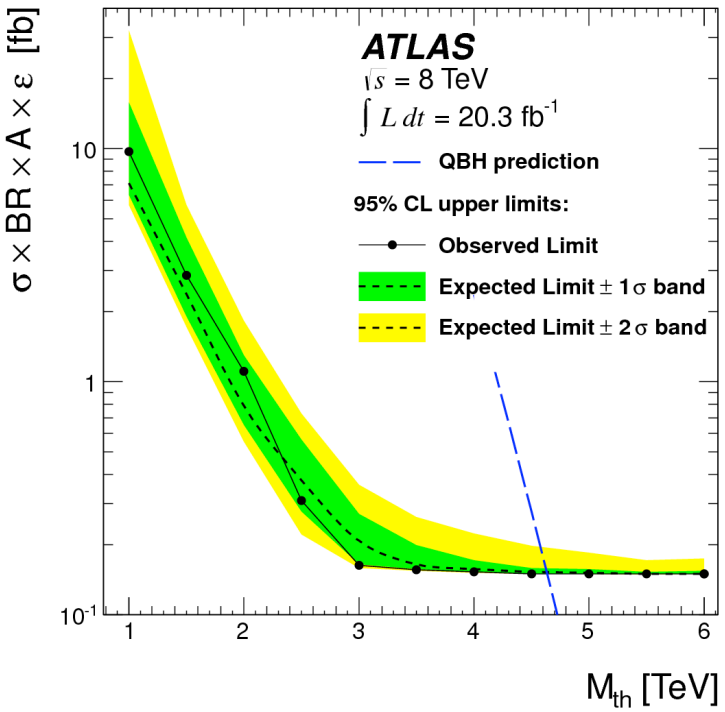
Phys. Lett. B 728C (2014) 562-578

- Another interpretation of q*->qγ search
- Model paramaeters assumed to be the same as for lepton +jet search
- First limits on QBH decaying to γ+jet



SM γ+jet production at tree level





QBH masses below 4.6 TeV excluded

QBH-> ee,μμ

- Another interpretation of dilepton resonance search
- Electrically neutral QBH produced via quark antiquark or gg fusion
- QBH can decay to two leptons
- No violation of lepton and baryon number conservation

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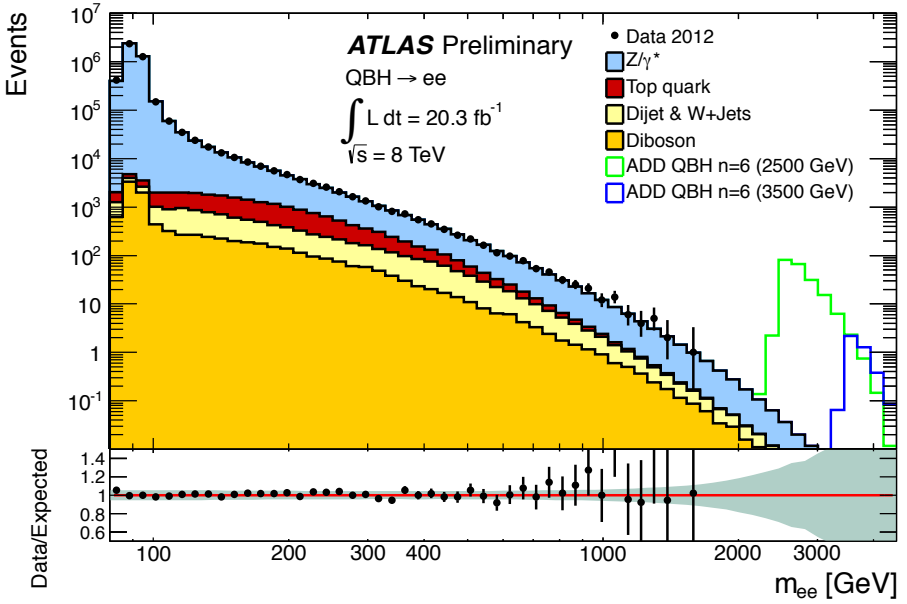
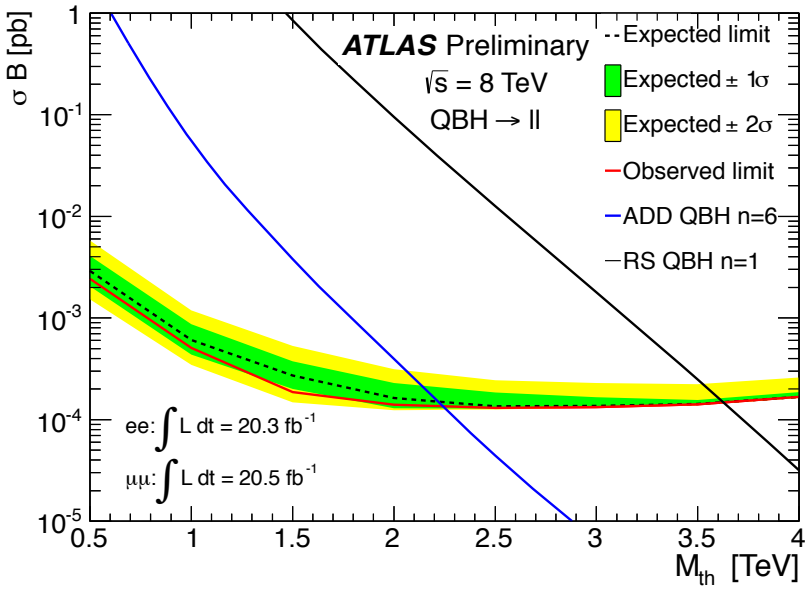
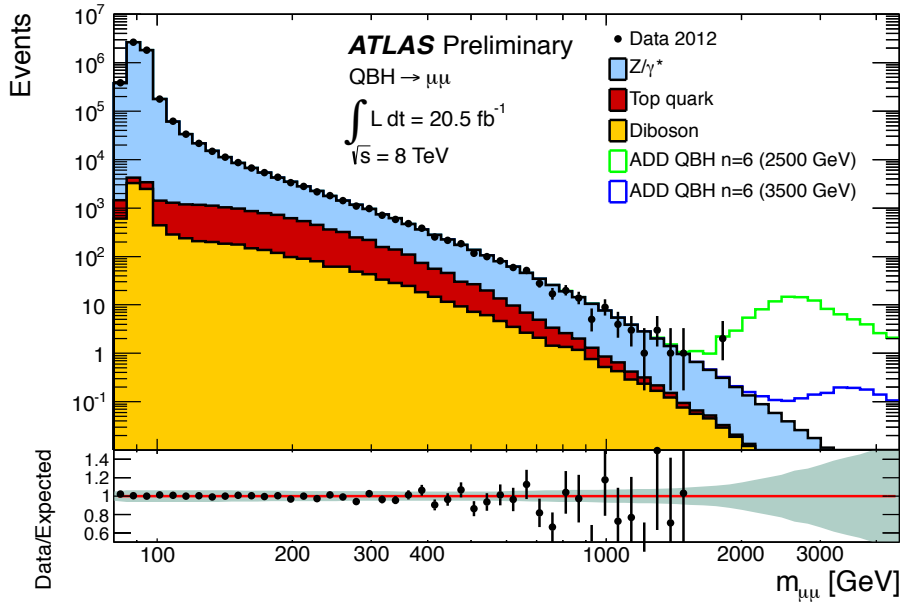
+ prelim. updates







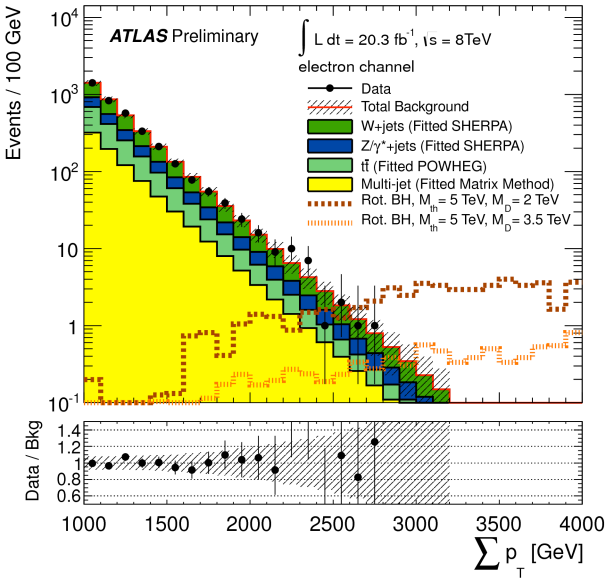
ADD ED: Classical Black Holes-> e/μ + jets

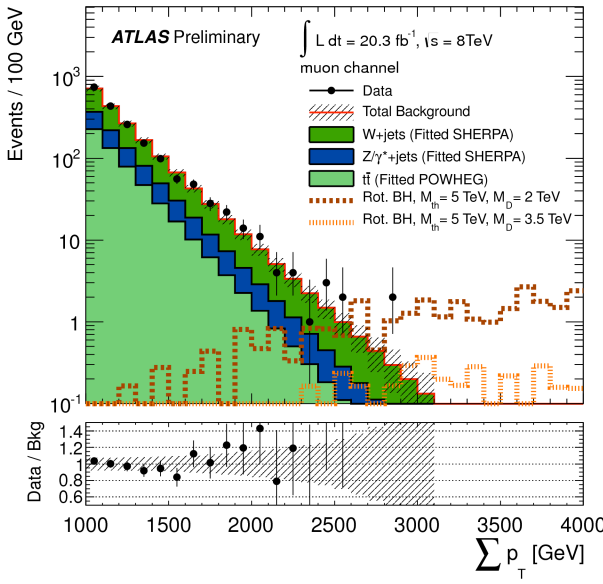
ATLAS-CONF-2014-016

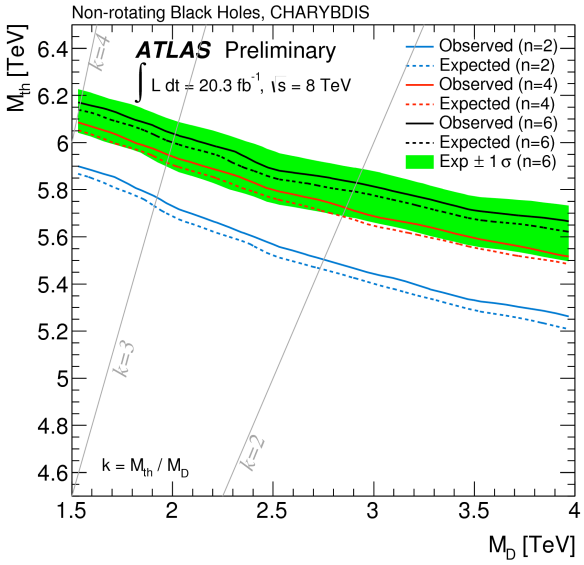
Quantity	Region	
	Sideband	Signal
$\sum p_T$	1000–2000 GeV	> 2000 GeV
object multiplicity	at least 3 objects above 100 GeV	
leading lepton	at least 1 lepton with p_T > 100 GeV	

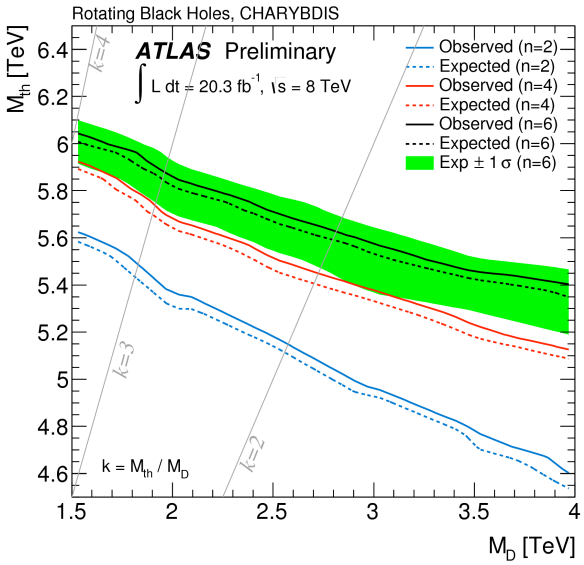
$$\sum p_T = \sum_{i=\text{objects}} p_{T,i} \quad \text{if} \quad p_{T,i} > 60\ \text{GeV}$$

$$\mathcal{F} = (1-x)^{p_0}\, x^{p_1}\, x^{p_2 \log(x)}$$









95% CL lower limit

Angular Mom.	Excluded M_{th} value [TeV] for:	
	M_D = 1.5 TeV	M_D = 4 TeV
Non-rotating	6.2	5.7
Rotating	6.0	5.4

ADD ED: Classical Black Holes-> μμ (same sign)

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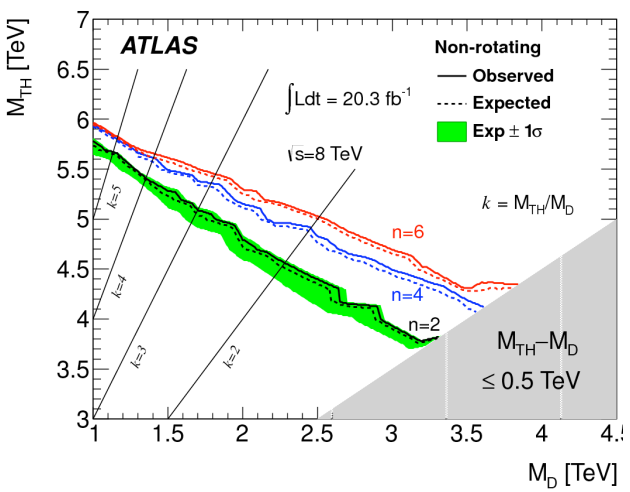
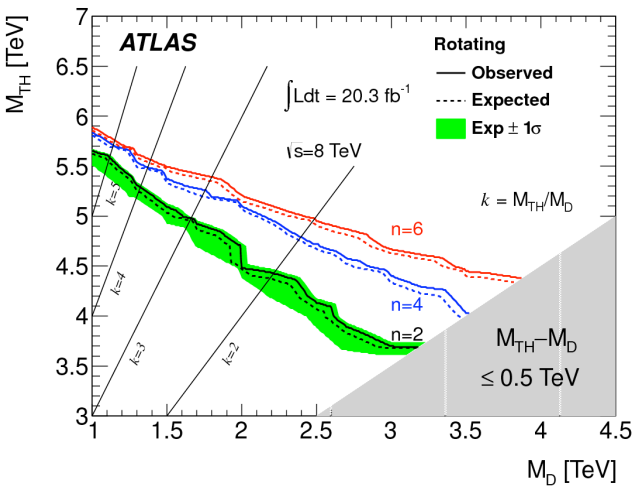
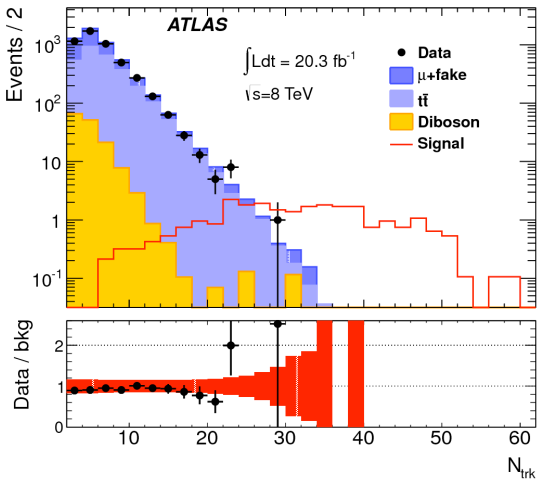
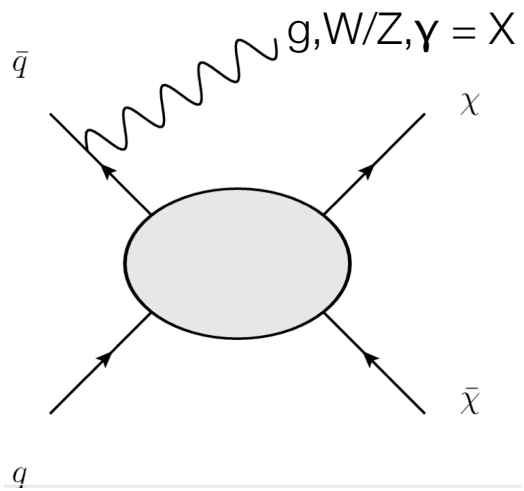
- Fundamental Planck scale M_D ~ 1 TeV
- Like sign dimuon final state from decay of black holes
- Low standard model background
- Signal region characterized by high track multiplicity







Dark matter (DM)

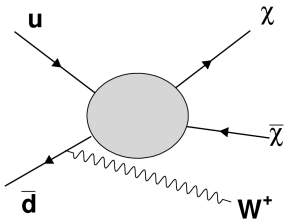


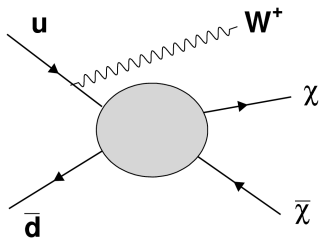
- Production of dark matter particles recoiling against X (X=g,W/Z,γ)
- Hadronic decays mono W/Z
- Leptonic decays of mono W/Z

Name	Operator	Coefficient
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
D2	$\bar{\chi}\gamma^5\chi\bar{q}q$	im_q/M_*^3
D3	$\bar{\chi}\chi\bar{q}\gamma^5 q$	im_q/M_*^3
D4	$\bar{\chi}\gamma^5\chi\bar{q}\gamma^5 q$	m_q/M_*^3
D5	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D6	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu q$	$1/M_*^2$
D7	$\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D8	$\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$	$1/M_*^2$
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D10	$\bar{\chi}\sigma_{\mu\nu}\gamma^5\chi\bar{q}\sigma_{\alpha\beta}q$	i/M_*^2
D11	$\bar{\chi}\chi G_{\mu\nu}G^{\mu\nu}$	$\alpha_s/4M_*^3$
D12	$\bar{\chi}\gamma^5\chi G_{\mu\nu}G^{\mu\nu}$	$i\alpha_s/4M_*^3$
D13	$\bar{\chi}\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$i\alpha_s/4M_*^3$
D14	$\bar{\chi}\gamma^5\chi G_{\mu\nu}\tilde{G}^{\mu\nu}$	$\alpha_s/4M_*^3$

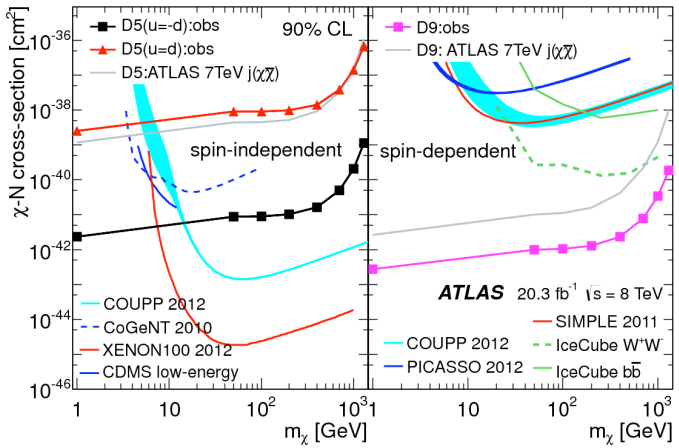
Phys. Rev. Lett 112, 041802 (2014)

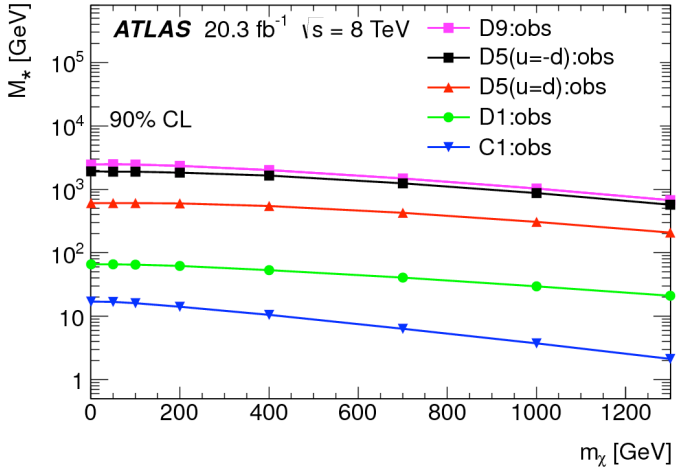
DM: Hadronic decays of W/Z

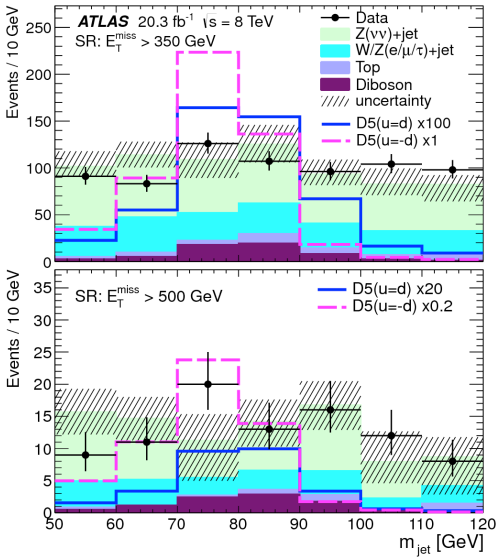




- Interference between radiation from u and d quarks
- C(u)=-C(d)=> constructive interference=>mono-W could be the most sensitive channel
- Large radius jets: R=1.2 to capture both quarks from W and Z decay: Jet p_T > 250 GeV
- Two signal regions with large MET: 350 and 500 GeV





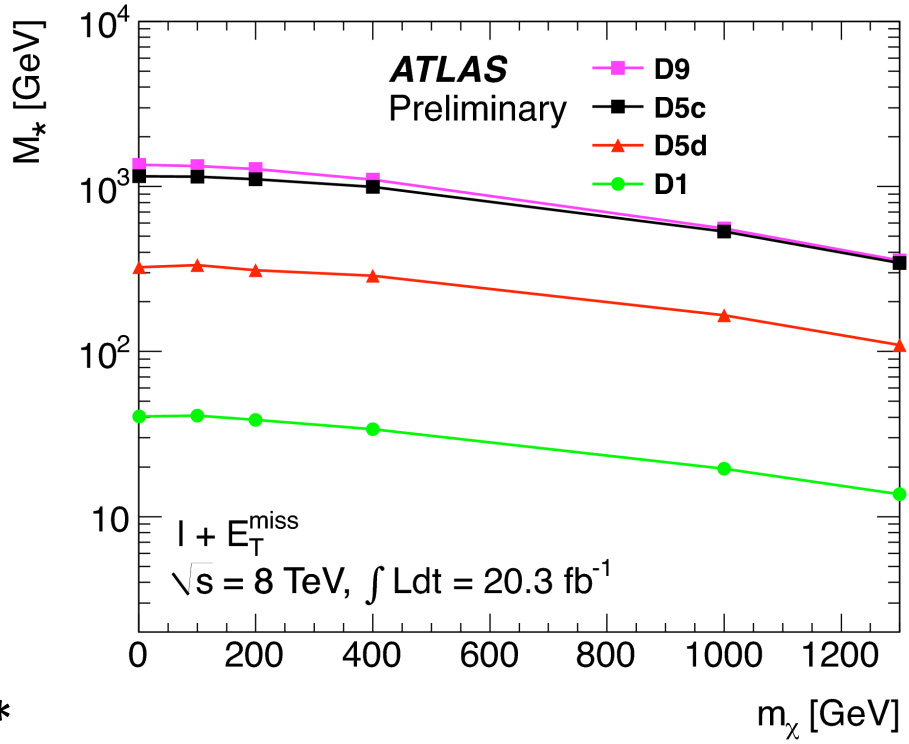


- 90% CL limit on M_* for various operators coupling the Weakly Interacting Massive Particles (WIMPs) to SM particles
- Strongest limits on M_* for the case of constructive interference
- Spin independent case: 3 orders of magnitude better than monojet at 7 TeV

DM: Leptonic decays of W

ATLAS-CONF-2014-017

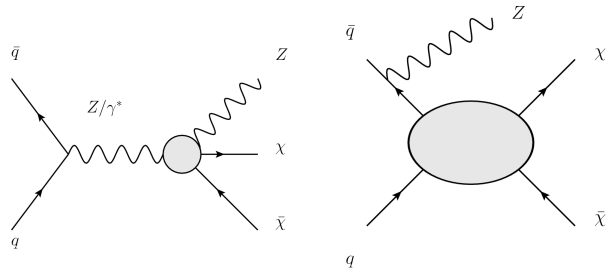
- Another interpretation of lepton+MET resonance search
- First direct ATLAS search for dark matter particles in this channel
- 95% CL lower limits on M_*

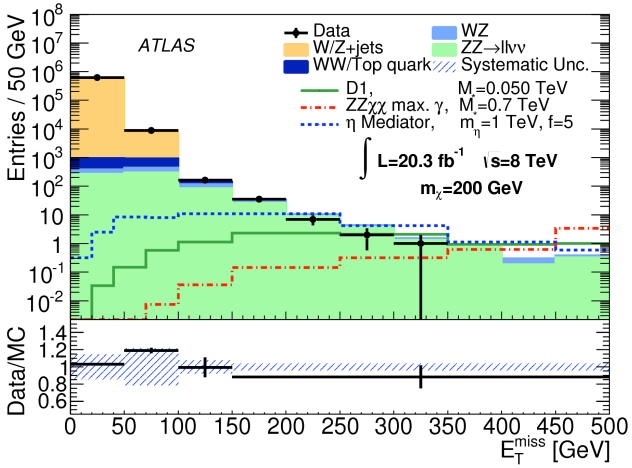


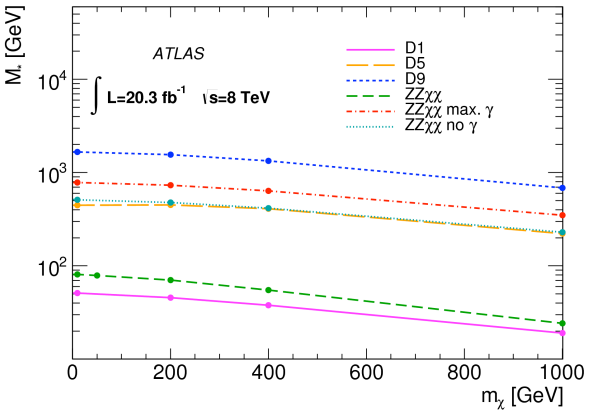
arXiv:1404.0051

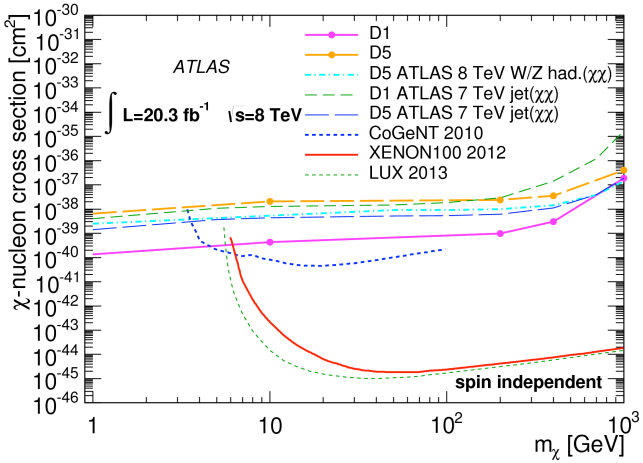
DM: Leptonic decays of Z

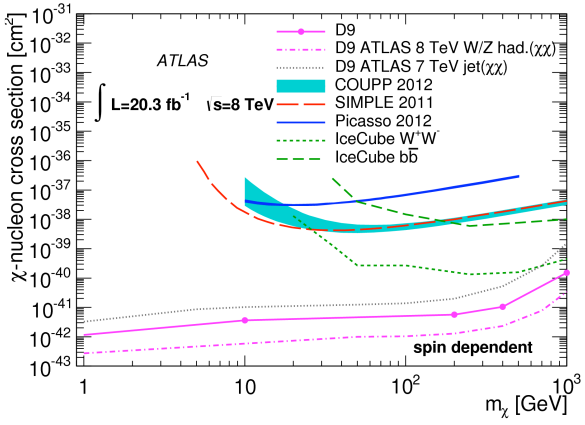
- Interaction between Z boson and WIMP investigated for the first time at the LHC
- Four signal regions using MET: 150, 250, 350 and 450 GeV
- 95% CL lower limits on M_* and upper limits on χ-nucleon scattering cross section
  - complement the limits in other channels











Multilepton search

ATLAS-CONF-2013-070

Lepton category

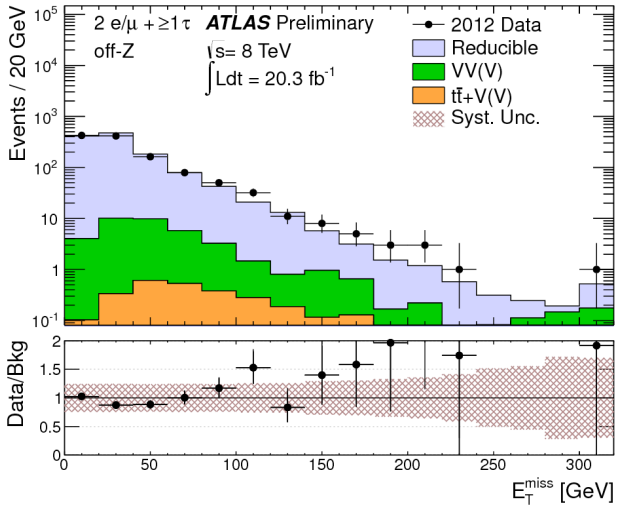
- On-Z 3e/μ
- On-Z 2 e/μ + τ_{had}
- Off-Z 3e/μ
- Off-Z 2 e/μ + τ_{had}

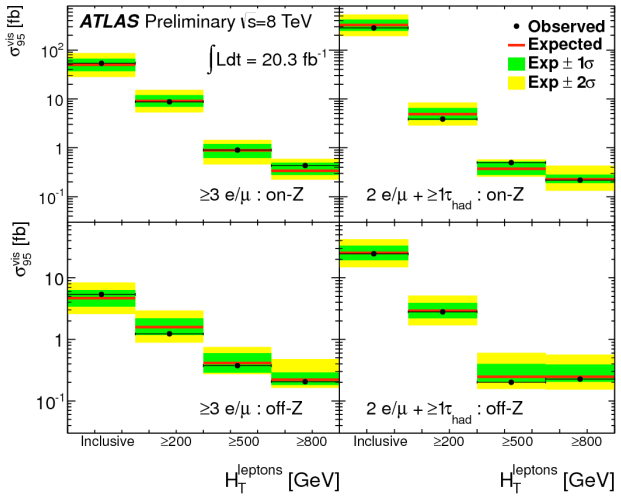
with on-Z : $|m_{\ell\ell} - m_Z| < 20$ GeV

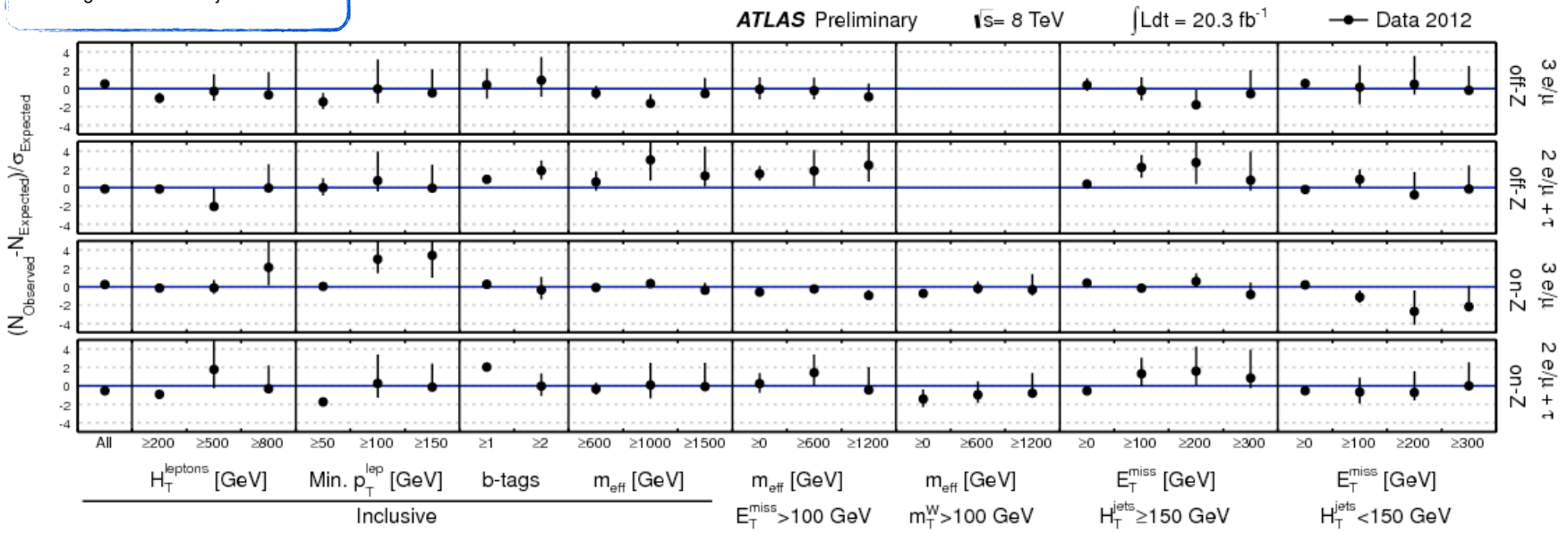
and off-Z : $|m_{\ell\ell} - m_Z| > 20$ GeV

Other variables

- $H_T^{leptons}$: Sum of 3 lepton p_T
- H_T^{jets}: Sum of all jet p_T
- E_T^{miss}: Missing transverse energy
- m_{eff}: $H_T^{leptons} + H_T^{jets} + E_T^{miss}$
- Min. $p_T(\ell)$: p_T of 3rd lepton
- b-tags: number of b-jets







Deviations of observed yields from expected yields, in units of the total uncertainty on the expected yield

Conclusions

- Searches for exotic phenomena carried out in a variety of channels at ATLAS
- No signs of heavy resonances, black holes or dark matter in 8 TeV dataset
- New limits have been set
- Looking forward to high energy and luminosity in 2015