Search for 1st and 2nd generation leptoquarks in ATLAS

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on behalf of the ATLAS collaboration

http://arxiv.org/abs/1104.4481

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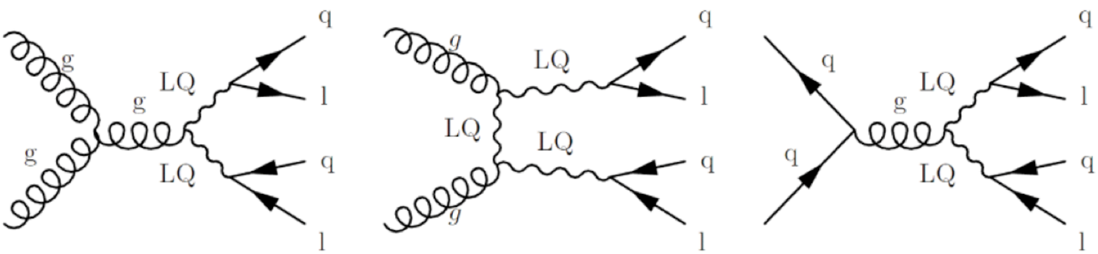
Why leptoquarks?

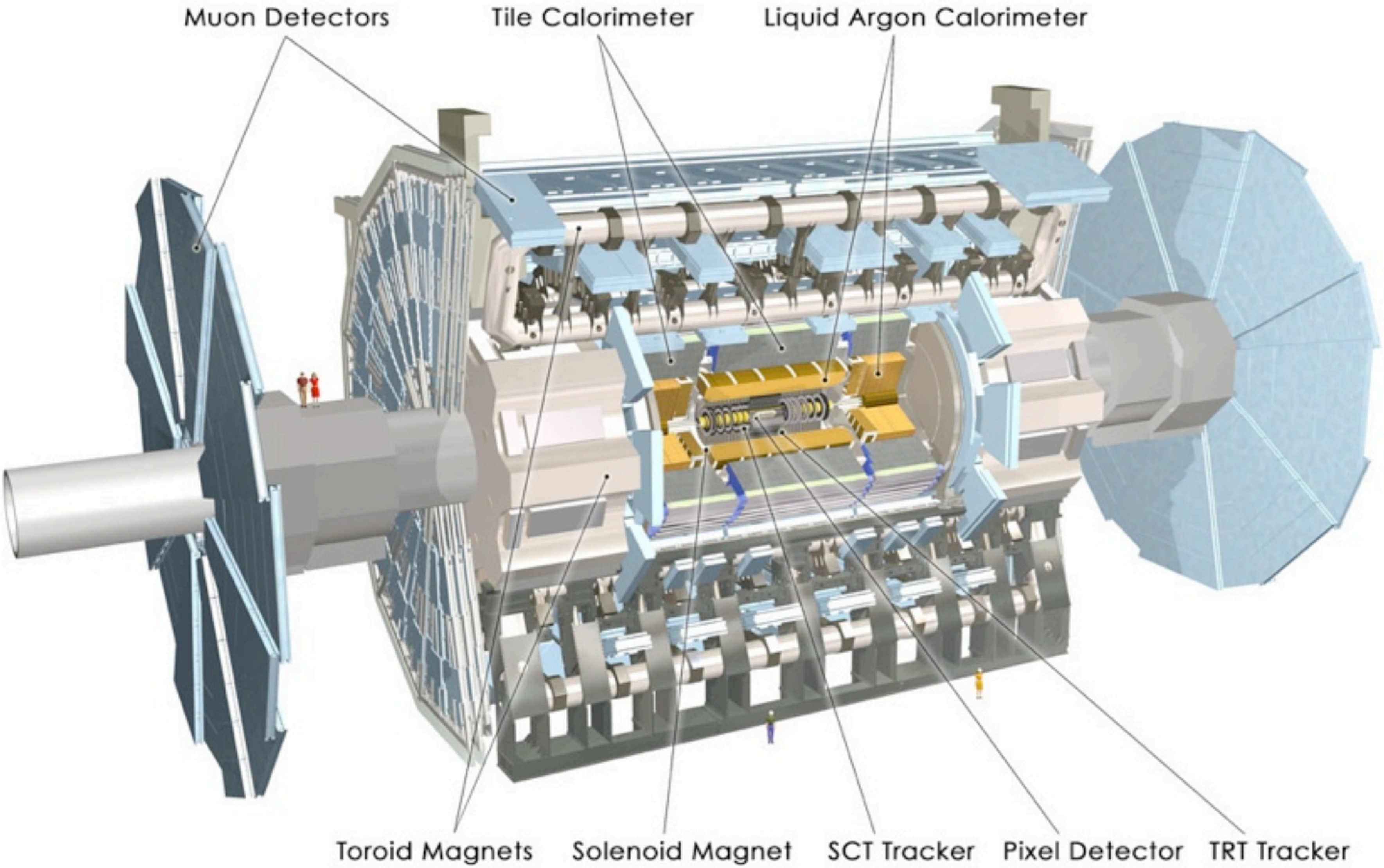


- Coupling only within a generation assumed
- Pair production xsection ~1 pb at LQ mass = 300 GeV
- β = branching fraction to lq (vs νq)

- Inspired by symmetry between lepton and quark generations
- Predicted by many GUT models
- Carry color charge, baryon and lepton quantum numbers
- Fractional electric charge

4 analyses: lljj, lνjj (l = e,μ)
Pair production of scalar LQs

ATLAS detector



Object selection

Electrons

Good EM shower

Track pointing to EM Cluster

$E_T > 20$ GeV, |eta| < 2.47 (excluding crack)

Loose isolation cuts

Jets

Anti-Kt with R parameter = 0.4

$P_T > 20$ GeV, |eta| < 2.8

dR(lepton,jet) > 0.5

Jet quality cuts

Other

Reweight #vertex distribution in MC to match data

Require good quality primary vertex

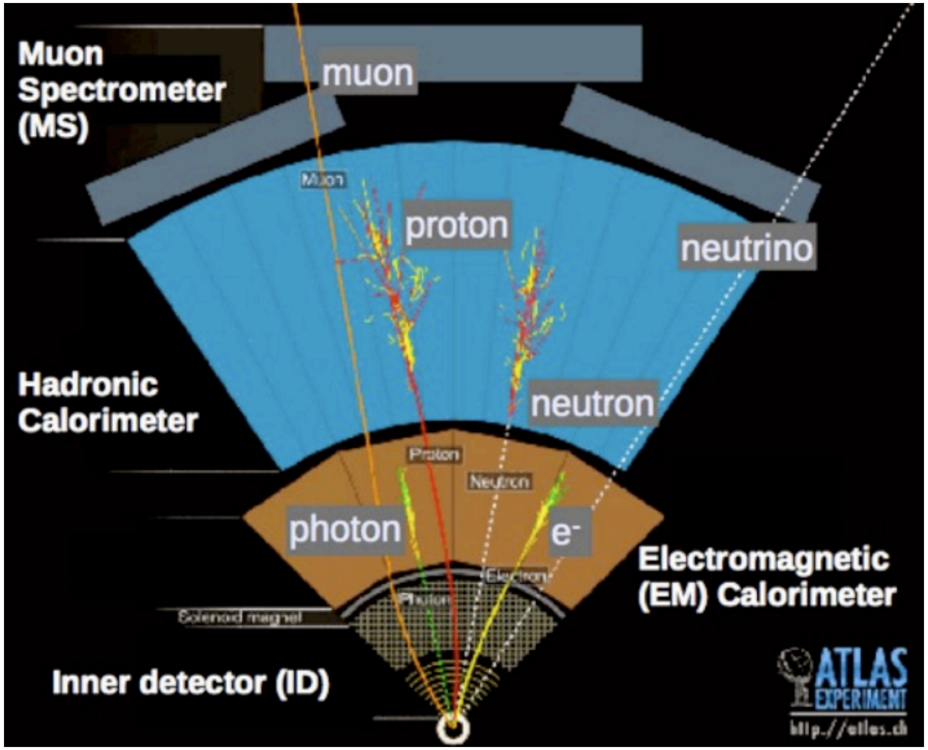
MET corrected for muons

Muons

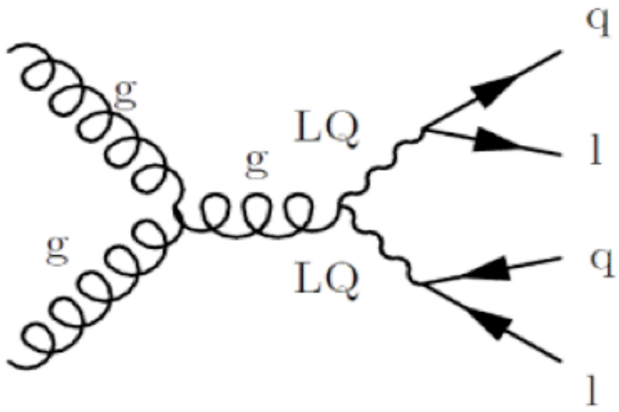
Matched tracks in the inner detector and muon spectrometer with matching p

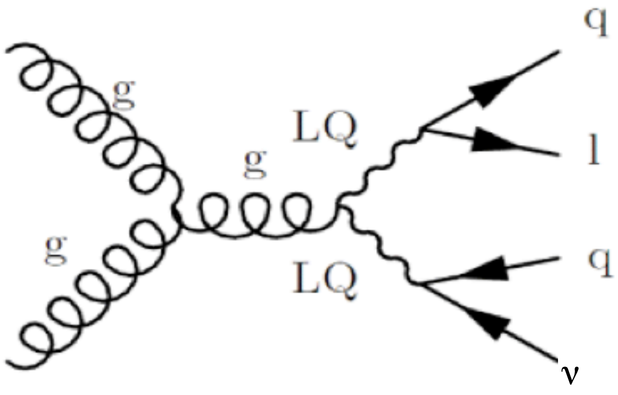
$P_T > 20$ GeV, |eta| < 2.4

Loose isolation cuts



LQ phenomenology





- Signature: 2 or more energetic jets (> 30 GeV) and ...
- Dilepton: 2 opposite-sign, same-flavor leptons > 30 GeV or
- Single lepton: 1 lepton > 30 GeV, MET > 25 GeV, M_T(l,MET) > 40 GeV

LQ backgrounds

Background	Relative size	Estimation strategy
Top quark pairs	Large	Model with MC, cross-check in control regions
Drell-Yan/Z +jets	Large for dileptons, small for single leptons	Normalize to Z+2jet window, MC to extrapolate to signal region. Check check control regions
W+jets	Large for single leptons. Small for dileptons	Monte Carlo, check in control regions
Single top	Small	Monte Carlo
Diboson	Small	Monte Carlo
Fake leptons	Small	Various data-driven methods

Fakes leptons for single lepton analyses

Single electrons

- Estimated by fitting the M_T distributions to the total simulated background and a QCD enriched sample
- A matrix method is used to remove the shape of the residual real electron contamination
- MET/jet dphi cut removes QCD background

Single muons

D: MET>25 and |d0|<0.1 mm
A: MET<25 GeV and |d0|<0.1 mm
B: MET<25 GeV and |d0|>0.1 mm
C: MET>25 GeV and |d0|>0.1 mm

$$N_{QCD} = \frac{N_A N_C}{N_B}$$

- Small signal and other background contamination removed with MC

Dileptons

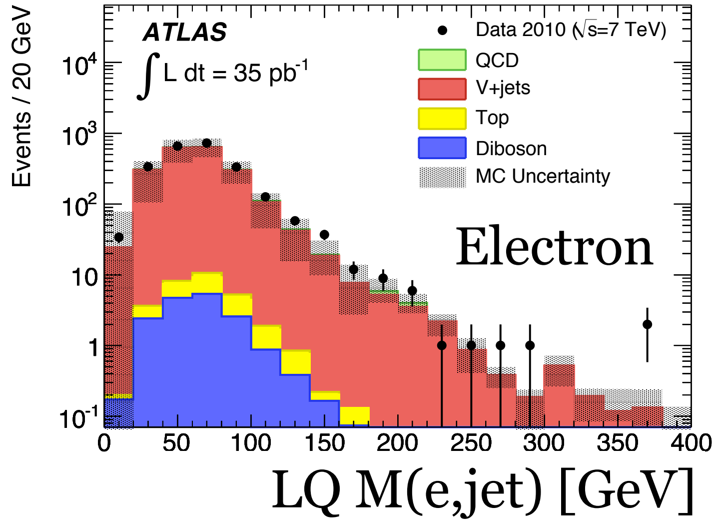
- Fit isolation distributions to templates
- Signal from MC, background from QCD-enriched sample

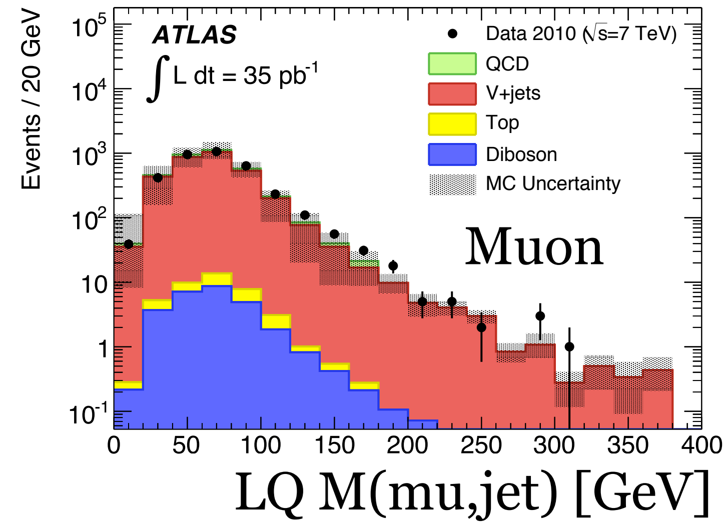
Control region strategy

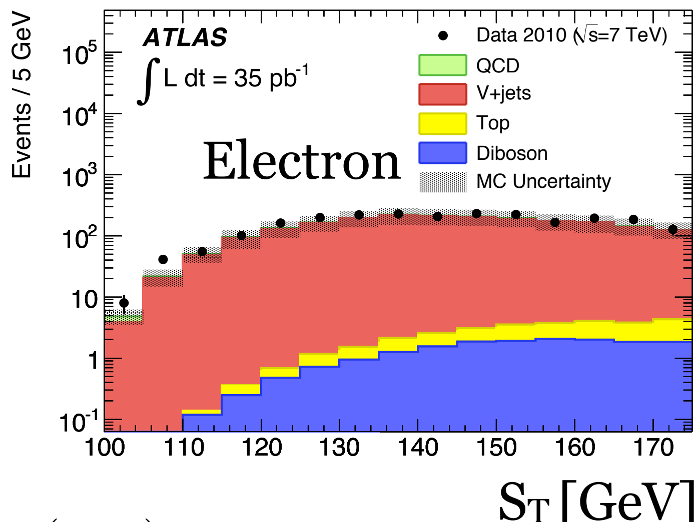
- Before looking at signal region, define control regions that have minimal signal contamination and enhance the important backgrounds
  - Of particular importance - ttbar and V+jets

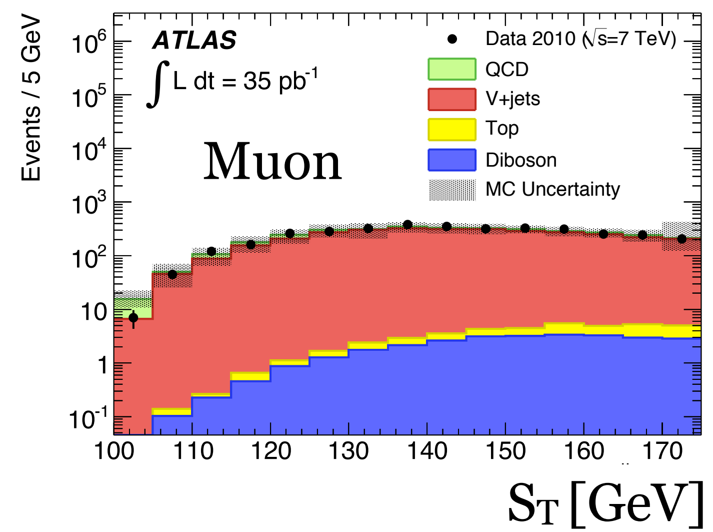
W+2jets exclusive

- njets == 2
- 40 GeV < M_T < 150 GeV
- L_T > 60 GeV
- S_T < 175 GeV









$$L_T = p_T(l) + \not{E}_T$$
$$H_T = p_T(jet_1) + p_T(jet_2)$$
$$S_T = L_T + H_T$$

LQ mass = Average invariant mass among all pairings giving smallest mass difference

Single lepton ttbar control region

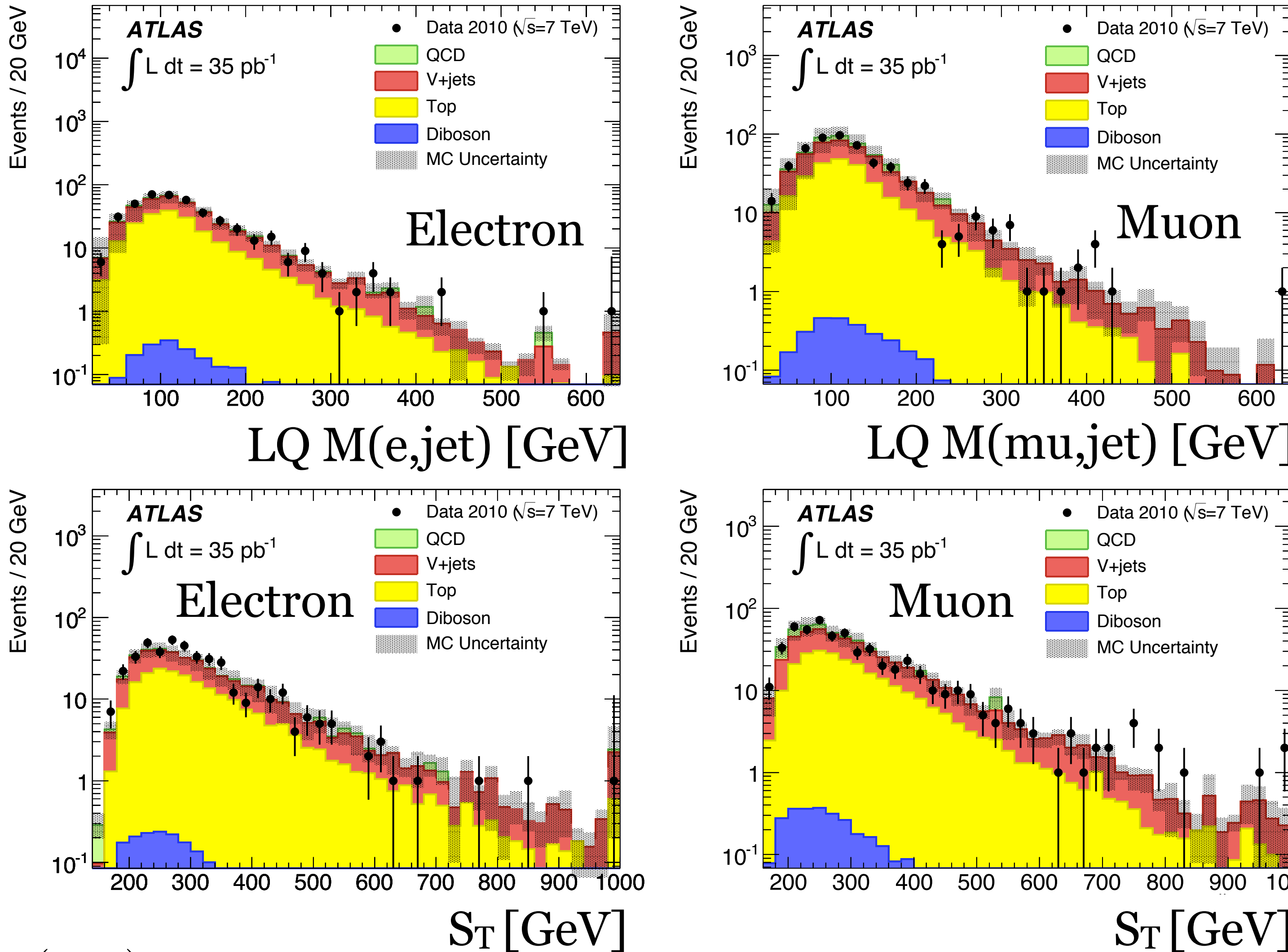
ttbar

njets >=4

40 GeV < M_T < 150 GeV

L_T > 60 GeV

Jet 1, 2, 3 > 50,40,30 (GeV)



$$L_T = p_T(l) + \not{E}_T$$

$$H_T = p_T(jet_1) + p_T(jet_2)$$

$$S_T = L_T + H_T$$

LQ mass = Average invariant mass among all pairings giving smallest mass difference

Z+jets control region

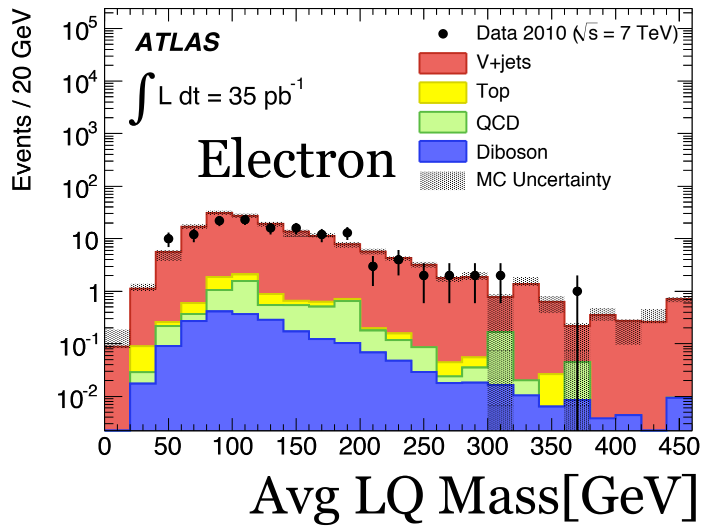
Z+2jets

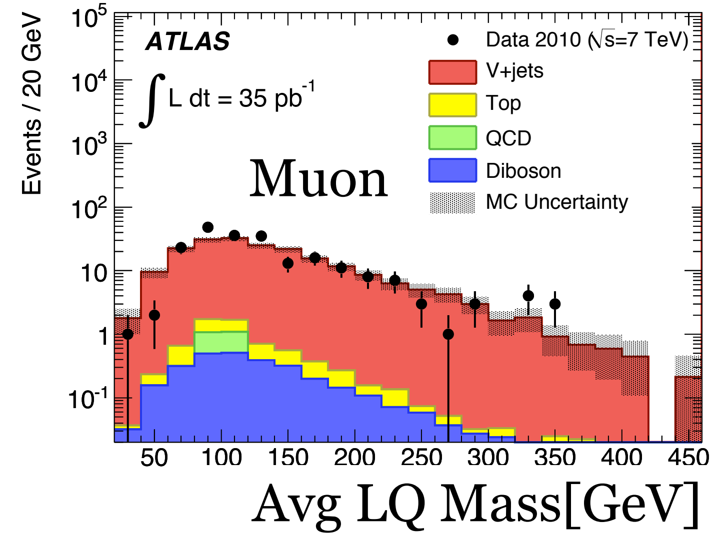
njets >= 2

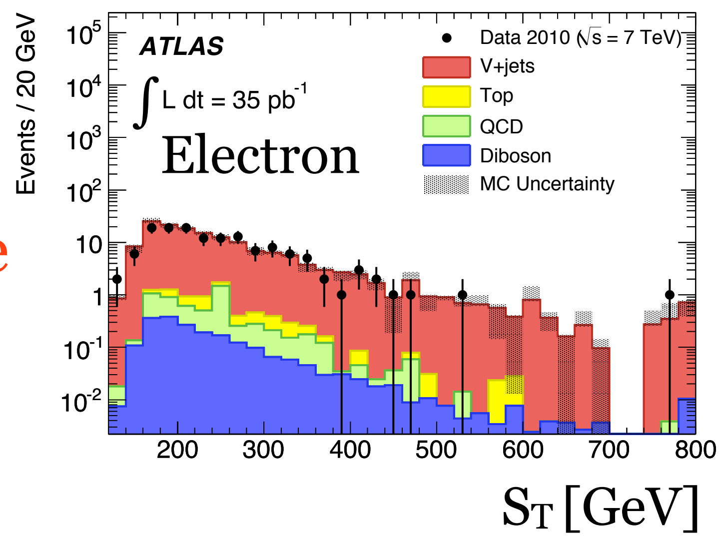
2 opposite sign same flavor leptons

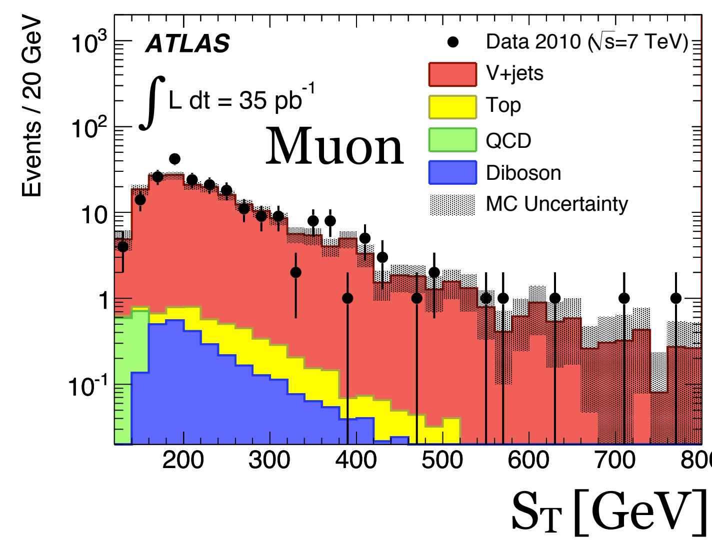
81 GeV < M_{ll} < 101 GeV

Average LQ mass = Average invariant mass among all pairing giving smallest mass difference







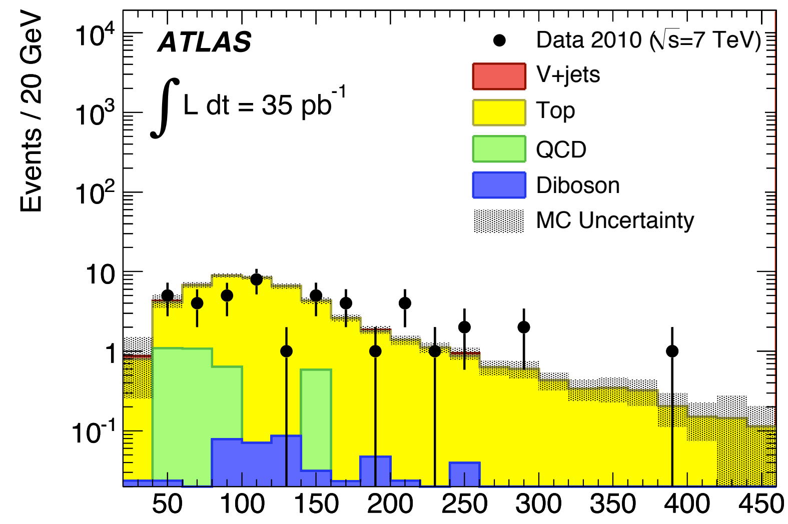


$$S_T^{\ell} = p_T^{\ell_1} + p_T^{\ell_2} + p_T^{j_1} + p_T^{j_2}$$

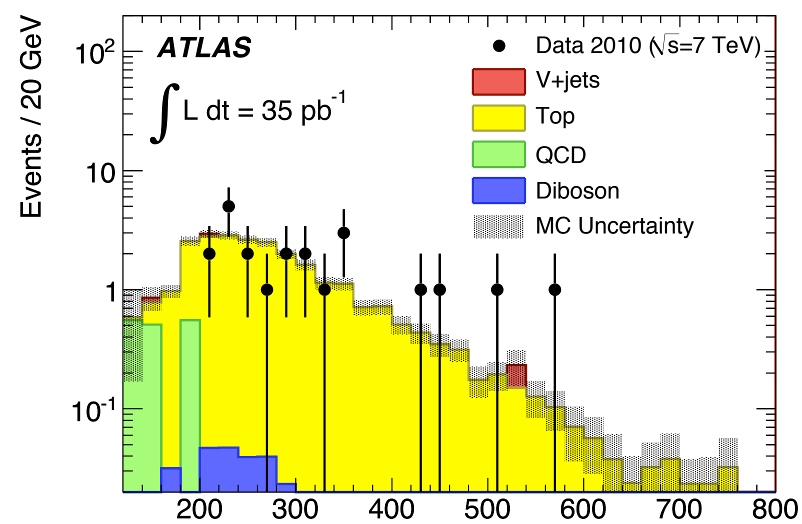
Dilepton ttbar control region

TTbar
njets >=2
2 opposite sign, opposite flavor leptons

- Good agreement in all control regions within uncertainties
    - Fakes and background estimation under control



Avg LQ Mass[GeV]



S_T [GeV]

Control region yields

	$eejj$		$e\nu jj$		
Event	Control Region		Control Region		
Source	$Z+\geq 2$ jets	$t\bar{t}$	$W+2$ jets	$W+\geq 3$ jet	$t\bar{t}$
V+jets	150 ± 23	0.3 ± 0.1	2100 ± 700	580 ± 190	180 ± 60
Top	2.0 ± 0.3	24 ± 4	21 ± 4	44 ± 9	210 ± 40
Diboson	2.0 ± 0.3	0.8 ± 0.1	17 ± 4	8.3 ± 1.9	2.1 ± 0.5
QCD	$4.0\ ^{+\ 14.0}_{-\ 4.0}$	$0.0\ ^{+\ 0.1}_{-\ 0.0}$	64 ± 14	68 ± 15	29 ± 7
Total Bkg	158 ± 25	25 ± 4	2200 ± 700	700 ± 200	420 ± 80
Data	140	22	2344	722	425

	$\mu\mu jj$		$\mu\nu jj$		
Event	Control Region		Control Region		
Source	$Z+\geq 2$ jets	$t\bar{t}$	$W+2$ jets	$W+\geq 3$ jet	$t\bar{t}$
V+jets	190 ± 24	0.3 ± 0.1	3300 ± 1100	900 ± 300	250 ± 80
Top	2.7 ± 0.5	24 ± 4	14 ± 3	53 ± 1	260 ± 50
Diboson	0.2 ± 0.1	0.8 ± 0.1	28 ± 6	14 ± 3	3.0 ± 0.7
QCD	$6.0\ ^{+\ 11.0}_{-\ 6.0}$	$0.0\ ^{+\ 0.1}_{-\ 0.0}$	300 ± 100	130 ± 50	54 ± 32
Total Bkg	200 ± 25	25 ± 4	3600 ± 1100	1100 ± 330	570 ± 120
Data	216	22	3588	1120	547

Z+jets background (dilepton signal region)

Data-assisted method: Scale the number of expected events in signal region in MC using the number of Z events in data

$$N_D^{\mathrm{sig}} = \frac{N_D^{\mathrm{Z}}}{N_{MC}^{\mathrm{Z}}} N_{MC}^{\mathrm{sig}}$$

Do for different dilepton mass windows, different generators, and with and without njet cuts

Random Grid Search (RGS) optimization

- Optimize cuts to give highest signal significance
- Random Grid Search
  - Grid is set of signal events
  - Significance is the Poisson probability that the background fluctuates to signal + background
- No shapes taken into account for optimization
  - But shapes used for limit setting (binned CLs method)

Results of RGS optimization

$eejj$ and $\mu\mu jj$	$e\nu jj$	$\mu\nu jj$
$M_{ll} > 120$ GeV	$M_{\mathrm{T}} > 200$ GeV	$M_{\mathrm{T}} > 160$ GeV
$\overline{M_{\mathrm{LQ}}} > 150$ GeV	$M_{\mathrm{LQ}} > 180$ GeV	$M_{\mathrm{LQ}} > 150$ GeV
$p_{\mathrm{T}}^{\mathrm{all}} > 30$ GeV	$M_{\mathrm{LQ}}^{\mathrm{T}} > 180$ GeV	$M_{\mathrm{LQ}}^{\mathrm{T}} > 150$ GeV
$S_{\mathrm{T}}^{\ell} > 450$ GeV	$S_{\mathrm{T}}^{\nu} > 410$ GeV	$S_{\mathrm{T}}^{\nu} > 400$ GeV

Systematics

* = Dielectron
** = Dimuon

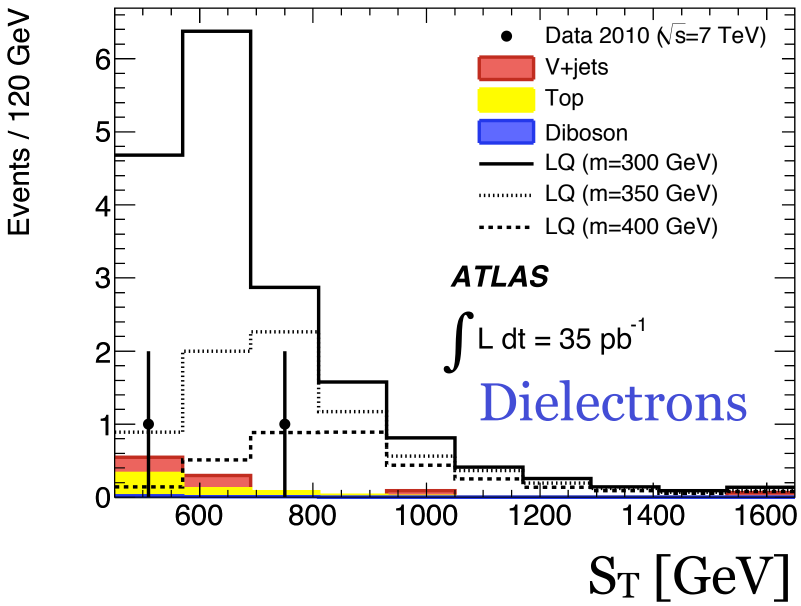
Channel	V+jets $lljj$	V+jets $l\nu jj$	Top $lljj$	Top $l\nu jj$	Diboson $lljj$	Diboson $l\nu jj$	LQ (300 GeV) $lljj$	LQ (300 GeV) $l\nu jj$
Production Cross Section	—	4	13	13	5	5	18	18
Modeling	34*, 45**	40	35	35	—	—	—	—
Electron Energy Scale & Resolution*	+13, -0.2	5	10	2	7	1	8	1
Muon Momentum Scale & Resolution**	20	5	7	2	8	1	6.7	1
Jet Energy Scale	6	+22, -13	+9, -18	32	+16, -6	+17, -24	2	3
Jet Energy Resolution	16	10	0.3	26	4	14	0.3	3
Luminosity	0.3	11	11	11	11	11	11	11
Pile up	< 0.1	5	< 0.1	4	< 0.1	6	< 0.1	2
Total Systematics	39* 52**	+49, -45	47* (+49 -44)**	57	(+22, -16)	+26,- 31	22	22

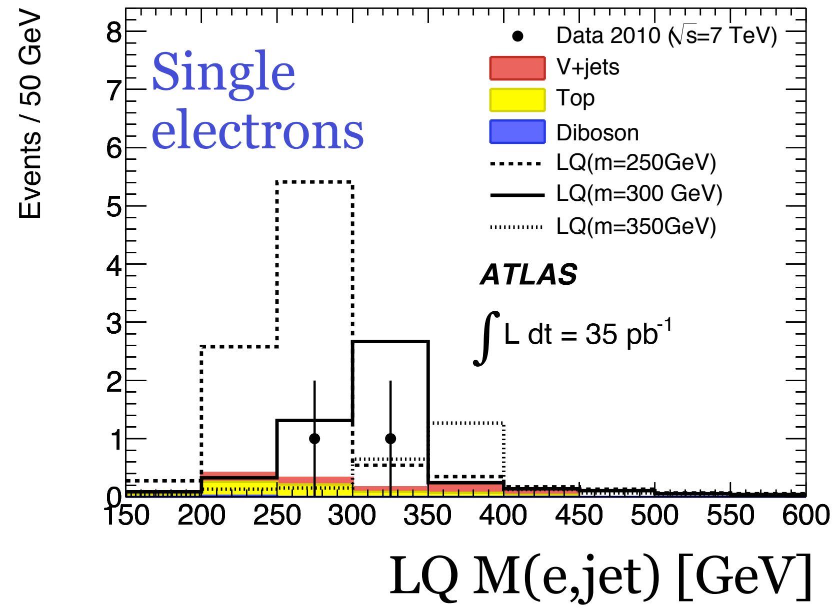
- Large systematics - but analyses still statistically limited
  - Dominated by modeling uncertainties on backgrounds and jet energy resolution and scale

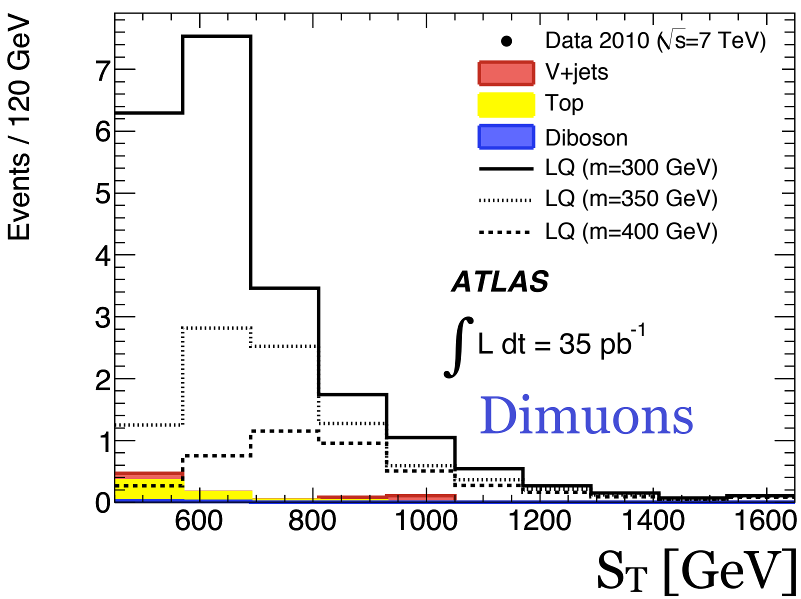
Expected and observed events

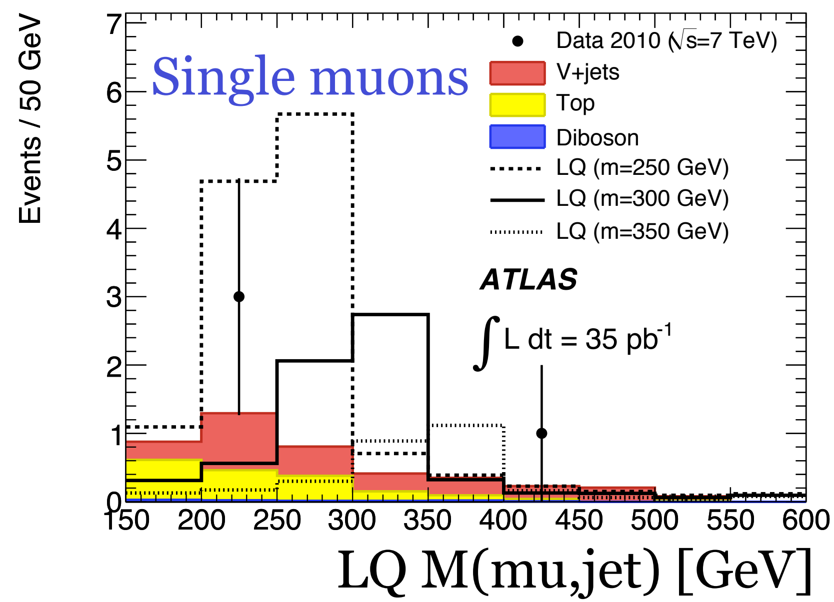
Source	$eejj$	$e\nu jj$	$\mu\mu jj$	$\mu\nu jj$
V+jets	0.50 ± 0.28	0.65 ± 0.38	0.28 ± 0.22	2.6 ± 1.4
Top	0.51 ± 0.23	0.67 ± 0.39	0.52 ± 0.23	1.6 ± 0.9
Diboson	0.03 ± 0.01	0.10 ± 0.03	0.04 ± 0.01	0.10 ± 0.03
Other Bkg.	$0.02\ ^{+0.03}_{-0.02}$	0.06 ± 0.01	$0.00\ ^{+0.01}_{-0.00}$	0.0 ± 0.0
Total Bkg	1.1 ± 0.4	1.4 ± 0.5	0.8 ± 0.3	4.4 ± 1.9
Data	2	2	0	4
LQ(250 GeV)	38 ± 8	9.6 ± 2.1	45 ± 10	13 ± 3
LQ(300 GeV)	17 ± 4	5.1 ± 1.1	21 ± 5	6.4 ± 1.4
LQ(350 GeV)	7.7 ± 1.7	2.6 ± 0.6	9.4 ± 2.1	3.0 ± 0.7
LQ(400 GeV)	3.5 ± 0.8	—	4.4 ± 1.0	—

Variables used to set limits

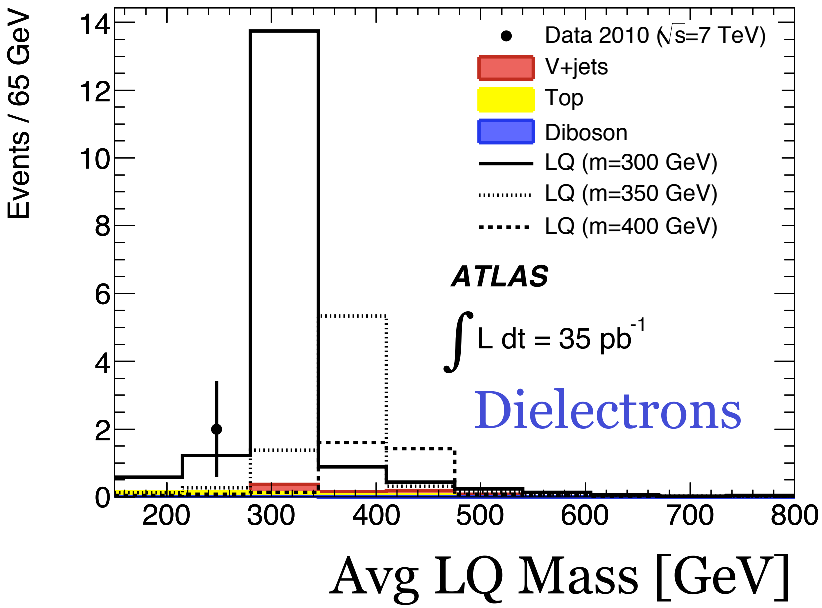


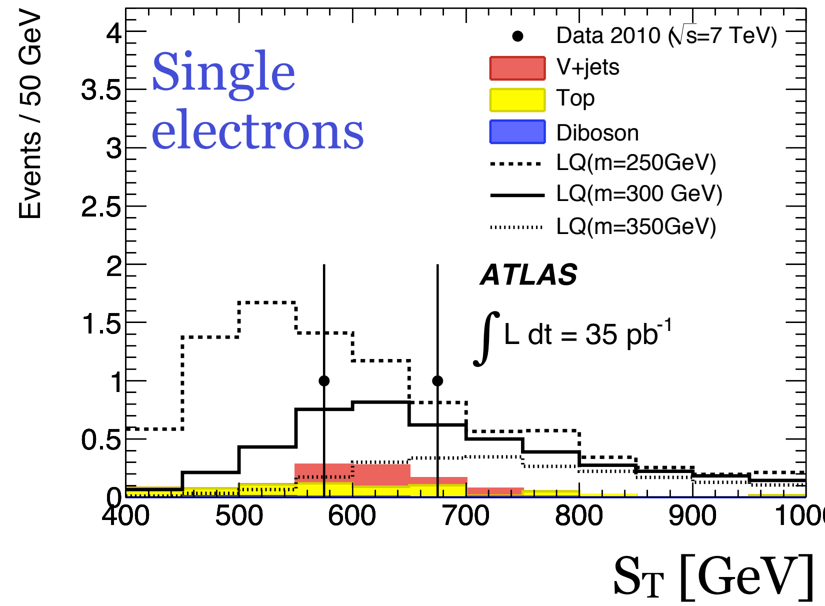


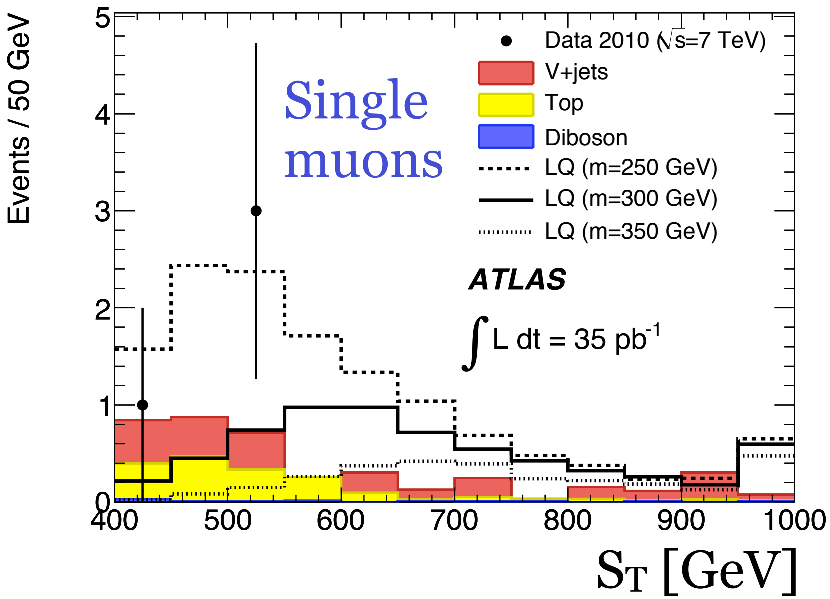




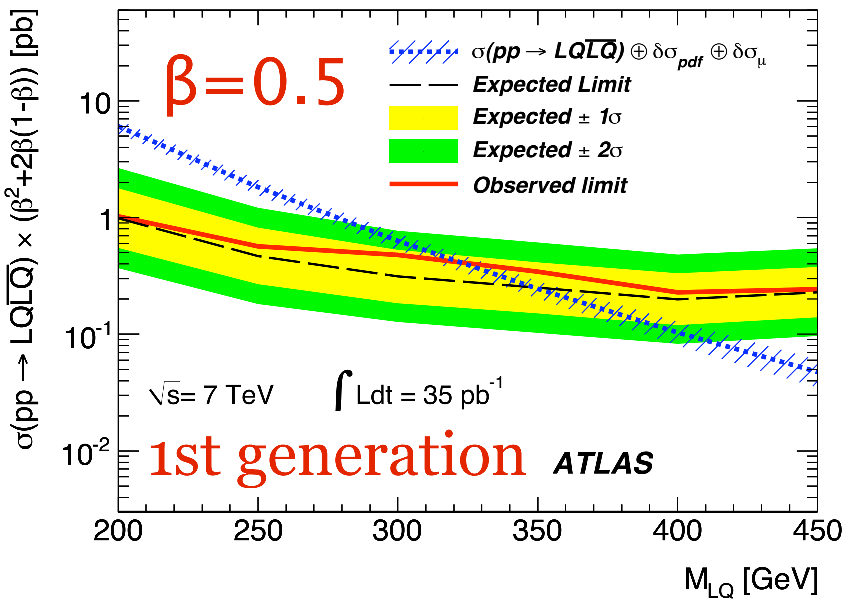
Kinematics of signal region data

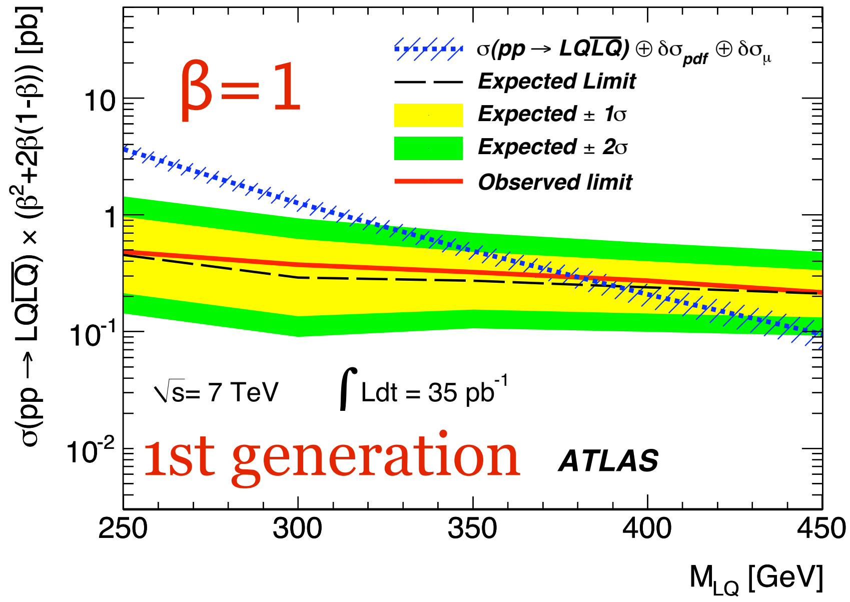






Limits


β=0.5
σ(pp → LQLQ) ⊕ δσ_pdf ⊕ δσ_μ
Expected Limit
Expected ± 1σ
Expected ± 2σ
Observed limit
√s= 7 TeV
∫Ldt = 35 pb^-1
1st generation
ATLAS
σ(pp → LQLQ) × (β^2+2β(1-β)) [pb]
M_LQ [GeV]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Expected Limit
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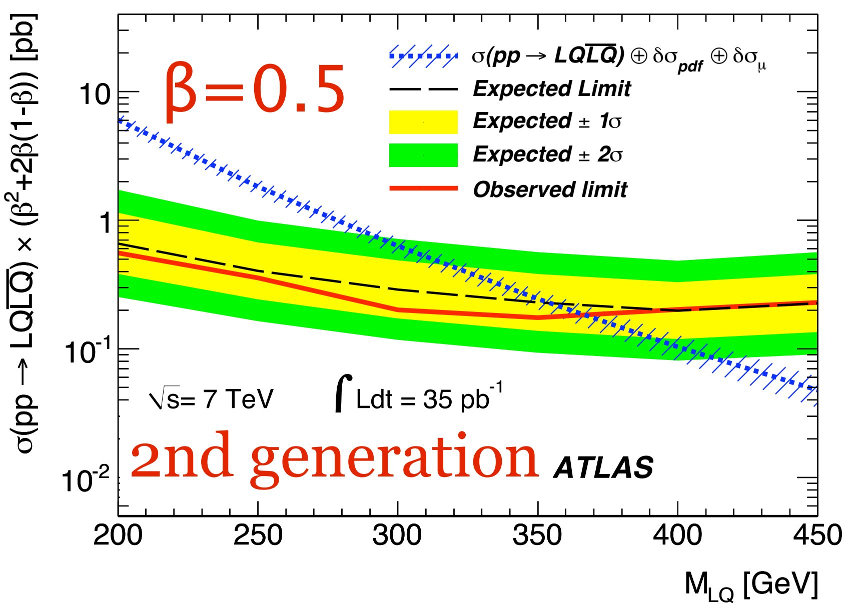
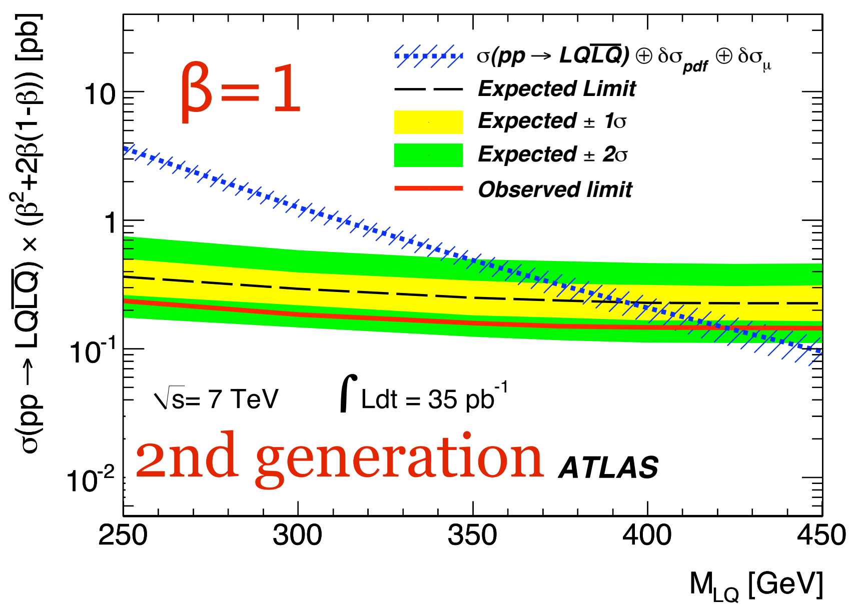
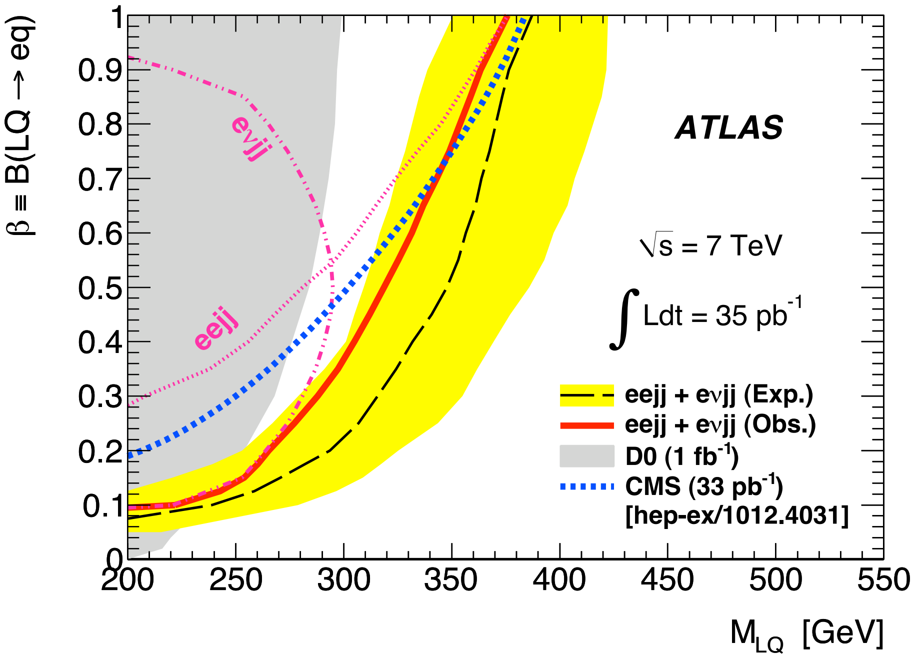
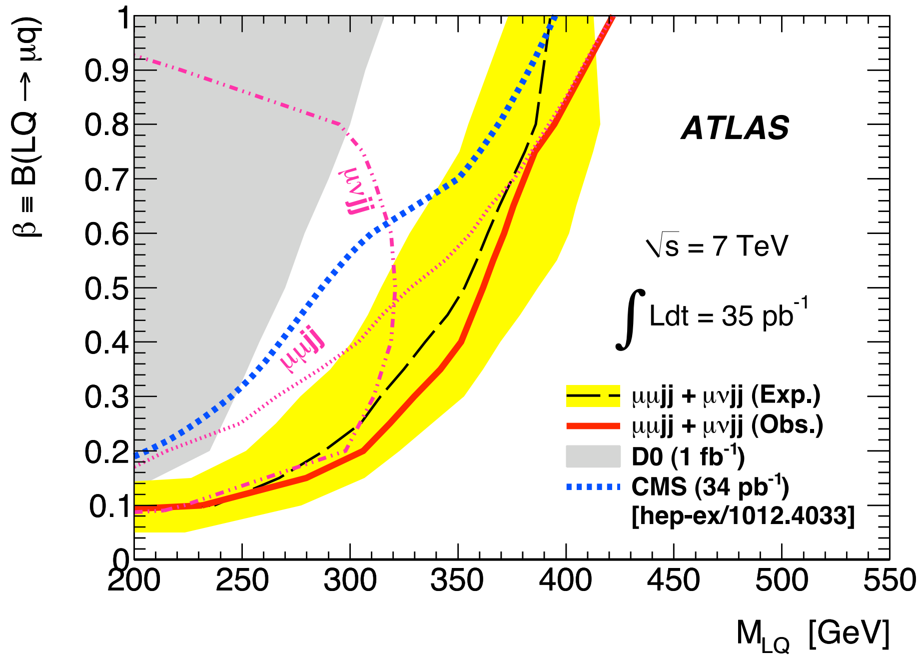

β=0.5
σ(pp → LQLQ) ⊕ δσ_pdf ⊕ δσ_μ
Expected Limit
Expected ± 1σ
Expected ± 2σ
Observed limit
√s= 7 TeV
∫Ldt = 35 pb^-1
2nd generation
ATLAS
σ(pp → LQLQ) × (β^2+2β(1-β)) [pb]
M_LQ [GeV]


β=1
σ(pp → LQLQ) ⊕ δσ_pdf ⊕ δσ_μ
Expected Limit
Expected ± 1σ
Expected ± 2σ
Observed limit
√s= 7 TeV
∫Ldt = 35 pb^-1
2nd generation
ATLAS
σ(pp → LQLQ) × (β^2+2β(1-β)) [pb]
M_LQ [GeV]

Combined limits



Extended the search beyond the Tevatron, and world's best limits for 2nd generation LQs



Conclusion

- World's best limits on pair production of scalar leptoquarks over much of the phase space
- Summer plans - add lots more LHC data!
  - Cut harder on kinematic distributions to study heavier LQ masses

Type (β)	Expected limit (GeV)	Observed limit (GeV)
1st generation (1.0)	387	376
1st generation (0.5)	348	319
2nd generation (1.0)	393	422
2nd generation (0.5)	353	362

Backup

dphi cut

$\Delta\phi$(jet,MET) >1.5×(1-MET/45),
where ϕ is in radians
and MET is in GeV

Preselection yield

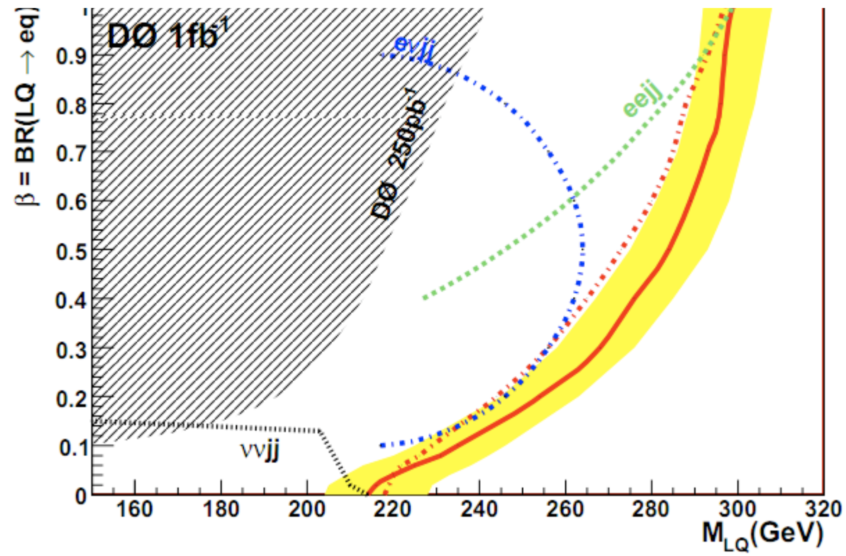
Channel	Predicted Yield	Observed Yield
$eejj$	610 ± 240	626
$e\nu jj$	6100^{+1000}_{-1100}	6088
$\mu\mu jj$	830^{+200}_{-150}	853
$\mu\nu jj$	9500 ± 2500	9248

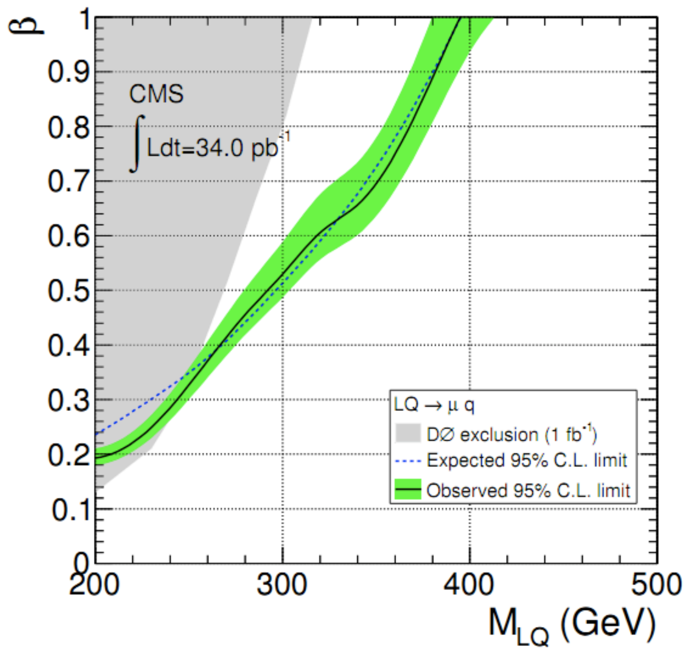
Current LQ limits

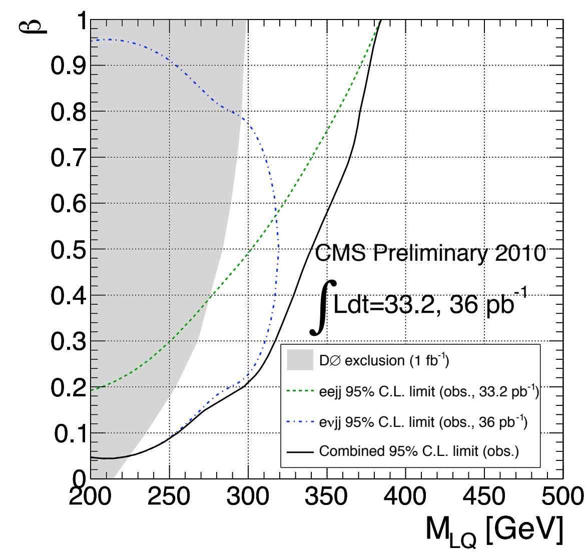
Tevatron limits from Dzero, β = 1, 95% CL limits:

1st generation: 299 GeV

2nd generation: 316 GeV







CMS sets stronger limits!