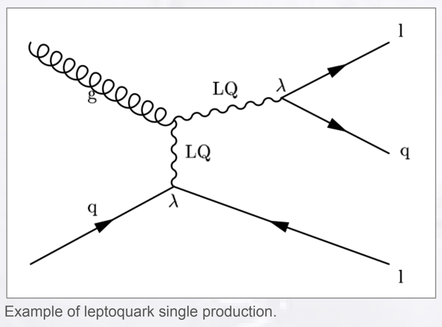
PLHC Conference – Perugia 2011

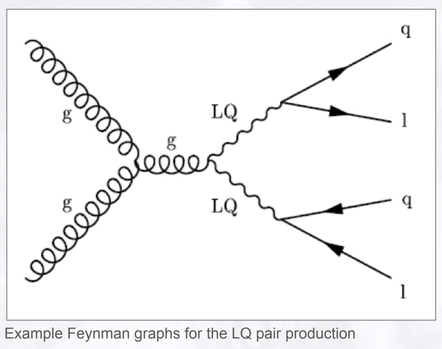
Search for first and second generation leptoquarks at the ATLAS Experiment

Leptoquark Models

- Standard Model: No explanation for the striking **symmetry** between quarks (q) and leptons (l)
- Possible explanation: **Leptoquarks (LQ)** are hypothetical particles that
  - carry both lepton and baryon QN
  - **couple to both quarks and leptons**
  - carry color charge
  - are predicted by models with quark and lepton sub-structur, **GUT-models** and models of extended technicolor
- **Pair-Production** reaction occurs mostly via QCD processes which involve only the strong coupling constant
- **Model-Parameters** (pair-production):
  - Leptoquark mass M_{LQ}
  - β is branching fraction for a LQ decay into a charged lepton and a quark

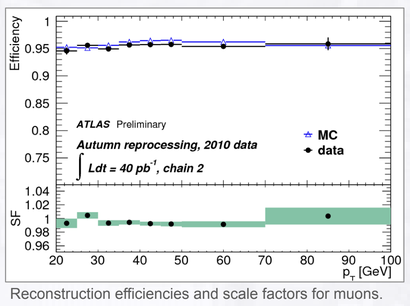


Example of leptoquark single production.

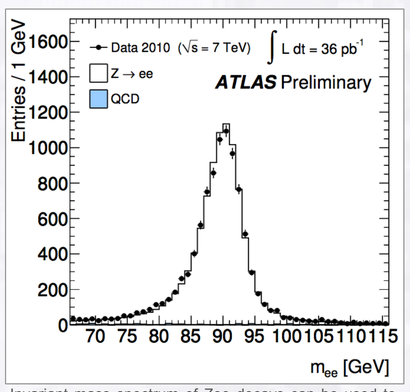


Example Feynman graphs for the LQ pair production

Performance of the ATLAS Detector



Reconstruction efficiencies and scale factors for muons.

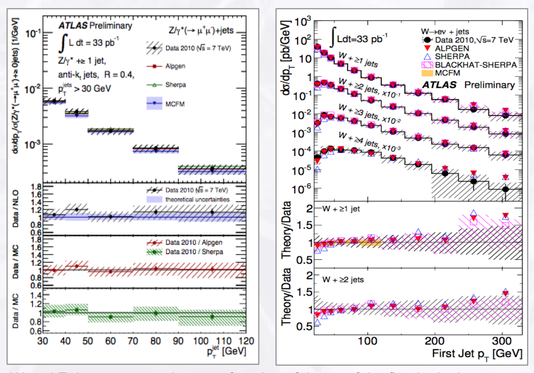


Invariant mass spectrum of Zee decays can be used to constrain energy scale/resolution for electron candidates

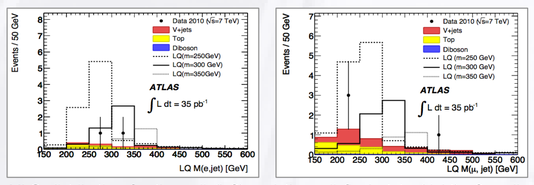
- Expected LQ-pair signature in the detector are two high energetic jets (jj) and two opposite sign, high energetic leptons (ll, lν) of the same generation
  - Need to understand detector performance for electrons, muons, jets and missing transverse energy
  - Extensive use of data-driven performance determination methods (e.g. Z-boson decay)
- The following uncertainties have been determined for this analysis
  - ≈5% on jet energy scale uncertainty
  - ≈1% on muon reco. efficiency uncertainty
  - ≈0.5% muon momentum scale
  - ≈3-5% electron identification efficiency (η-dependent)
  - ≈3% electron energy scale and resolution

Signal and Backgrounds

- Analysis is performed separately in the lljj final state and in the lνjj final state where the electron and muon decay channel are considered
- **Dominating background** processes are
  - Z+jets and tt^{-} for the lljj case
  - W +jets and tt^{-} for the lνjj case
  - The production cross-sections of vector-boson in association with jets have been measured in independent analyses. A very good agreement between theoretical predictions and measurement was found.
- **The signal regions** in the four final states are defined using a random grid search optimization method
  - S_T: scalar p_T sum of selected objects
  - M_T: transv. mass (E_T^{Miss} and lepton)
  - M_{LQ}: invariant mass of jet and lepton
- The final signal selection cuts and the expected signal and background events are shown on the right side



W and Z+jets cross section as a function of the p_T of the first jet in the event.



MLQ distribution for the eνjj (left) and the μνjj final state (right) after all selections. The expected LQ signals for various masses are also shown.

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

Optimized signal selection cuts.

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
QCD	$0.02 \pm^{0.03}_{0.02}$	0.06 ± 0.01	$0.00 \pm^{0.01}_{0.00}$	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	—

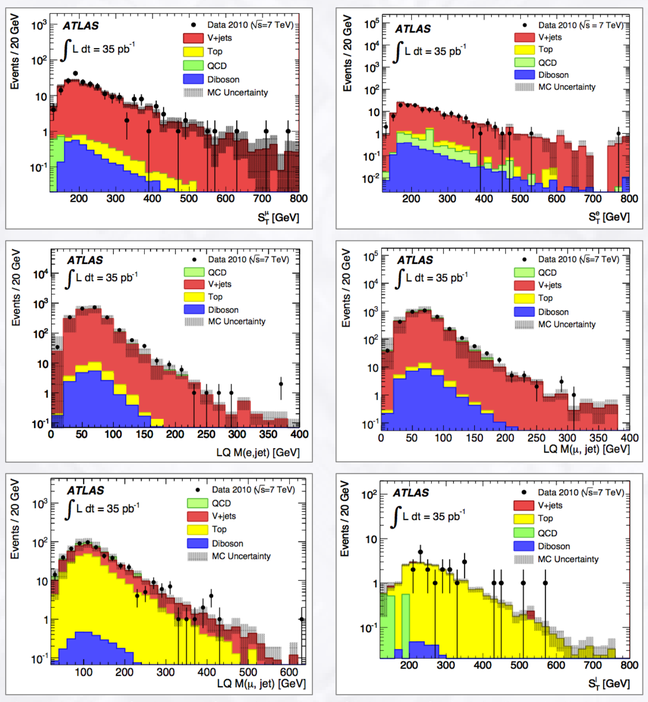
Expected and observed number of events after all selection cuts.

Control Regions

- Z+jets background yield in the signal region arises in the tails of distributions.
  - Use data-assisted method

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

  - Result agrees with purely Monte Carlo-based estimates within 10%
- Top-Pair background estimated from Monte Carlo predictions
- Control samples are used to validate the background determination based on MC:
  - **Z+2 jet events**: two jets, two lepton with $81 \le M_{ll} \le 101$GeV
  - **W+2/3 jet events:** two or three jets, a charged lepton and E_T^{Miss} such that $40\text{GeV} \le M_T \le 150$ GeV
  - **Top-pair events:** at least two jets and both an electron and a muon selected
- **Good agreement** between data and MC predictions



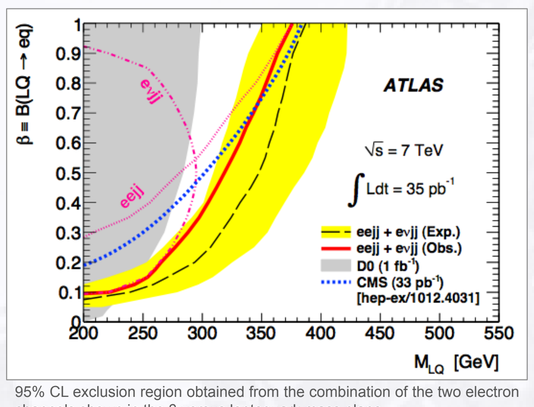
Kin. distributions for the μμjj final states (top, left), the eejj final state (top, right), the eνjj (middle, left) and μνjj (middle, right) in the Z control region. Lower plots show tt control region.

	$\mu\mu jj$		$\mu\nu jj$		
Event Source	Control Region $Z+\geq 2$ jets	$t\bar{t}$	Control Region $W+2$ 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	$6.0 \pm^{11.0}_{6.0}$	$0.0 \pm^{0.1}_{0.0}$	300 ± 100	130 ± 50	54 ± 32
Total Bkg	200 ± 25	25 ± 4	3600 ± 1100	1100 ± 330	570 ± 120
Data	216	22	3588	1120	547

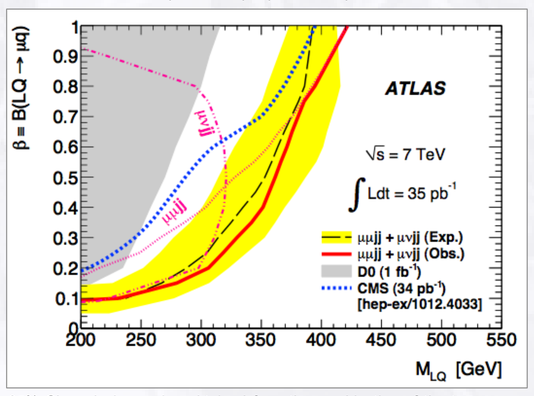
	$eejj$		$e\nu jj$		
Event Source	Control Region $Z+\geq 2$ jets	$t\bar{t}$	Control Region $W+2$ jets	$W+\geq 3$ jet	$t\bar{t}$
V+jets	150 ± 23	0.3 ± 0.1	2100 ± 700	580 ± 190	180 ± 60
Top	2.0 ± 0.3	24 ± 4	21 ± 4	44 ± 9	210 ± 40
Diboson	2.0 ± 0.3	0.8 ± 0.1	17 ± 4	8.3 ± 1.9	2.1 ± 0.5
QCD	$4.0 \pm^{14.0}_{4.0}$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

The predicted and observed yields in the control samples for the muon final states. Top refers to both single top and top-pair events. Both stat. and syst. uncertainties are included.

Exclusion Limits



95% CL exclusion region obtained from the combination of the two electron channels shown in the β versus leptoquark mass plane



95% CL exclusion region obtained from the combination of the two muon channels shown in the β versus leptoquark mass plane

- The number of observed events in the
  - eejj-channel (1st generation, β=1.0)
  - eνjj-channel (1st generation, β=0.5)
  - μμjj-channel (2nd generation, β=1.0)
  - μνjj-channel (2nd generation, β=0.5)

  agree with SM expectation within the statistical and systematic uncertainties
- **95% CL upper limits** on LQ pair–production cross sections are determined using a modified **frequentist approach**
  - Systematic uncertainties incorporated via nuisance parameters
  - Improve limits by kin. shapes rather than only the number of events
- Results for the **1st and 2nd generation** leptoquarks are shown on the right side

Conclusion and References

- The data in the high signal-to-background signal region are in good agreement with the Standard Model expectations.
- 95% CL upper bounds on the production cross section are determined
- Translated into lower bounds for first (second) generation LQ masses of **M_{LQ}>376 (422) GeV** and **M_{LQ} >319(362) GeV** for β=1.0 and β=0.5
- References and further reading

- The ATLAS Collaboration, Search for pair production of first or second generation leptoquarks in proton-proton collisions at √s=7 TeV using the ATLAS detector at the LHC. Apr 2011, arXiv:1104.4481 [hep -ex]
- The ATLAS Collaboration, Measurement of the production cross section for W-bosons in association with jets in pp collisions using 33 pb-1 of data at √s = 7 TeV with the ATLAS detector, ATLAS-CONF-2011-060
- The ATLAS Collaboration, Measurement of the production cross section for Z/γ* in association with jets in pp collisions at √s = 7 TeV with the ATLAS Detector, ATLAS-CONF-2011-042

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ATLAS EXPERIMENT