Search for Pair Production of Scalar Leptoquarks

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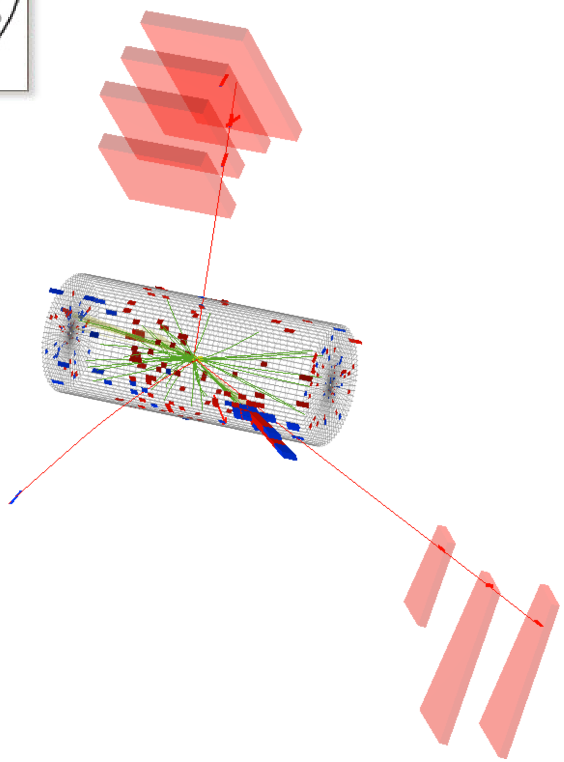
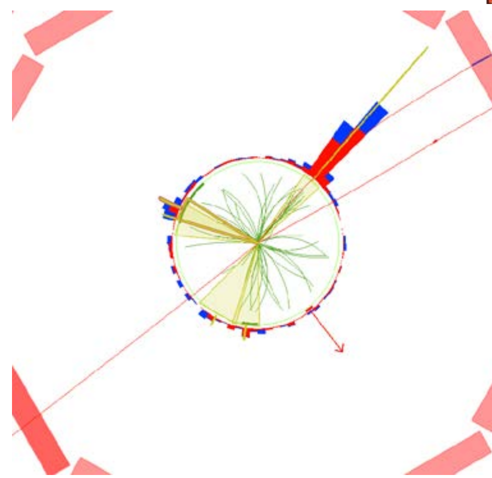




Meeting of the Division of Particles and Fields of the APS, August 9th, 2011

Overview

- Physics of Leptoquarks
- Leptoquark Production at the LHC
- Searches for Pair Production of Scalar Leptoquarks with the CMS detector:
  - eejj and μμjj searches
  - eνjj and eejj combined search
- Conclusions

Physics of Leptoquarks

- Leptoquarks (LQ) are predicted by many extensions of the Standard Model: GUTs, Technicolor, Composite models.
- Hypothetical particles that carry both baryon and lepton numbers, thus couple to a lepton-quark pair. They carry fractional electric charge, color triplet, can be scalar* of vector particles.
- Experimental limits on lepton number violation, FCNC, and proton decay favor three generations of LQs with no inter-generational mixing.

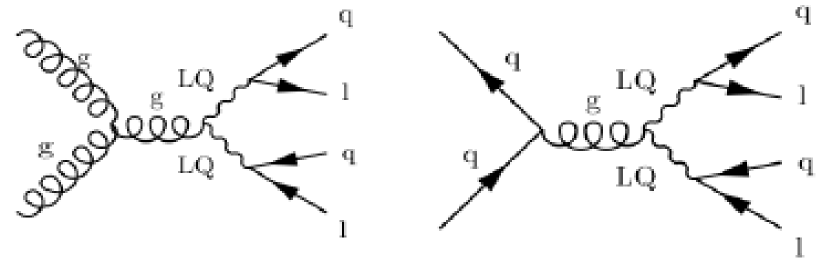
- Production and decay are characterized by:
  - LQ mass
  - Branching ration to lq (β)
  - LQ-l-q coupling (λ)

Model parameters	
M_{LQ}	LQ mass
β	BR(LQ→$l^{+/-}$ + q)
$\lambda_{l\text{-}q\text{-}LQ}$	l-q-LQ coupling

* only scalar LQ production considered here

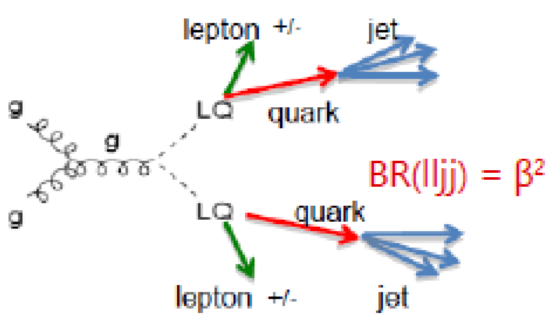
LQ Production at the LHC

- At hadron colliders, LQs are mainly pair-produced via gg fusion and qq annihiliation

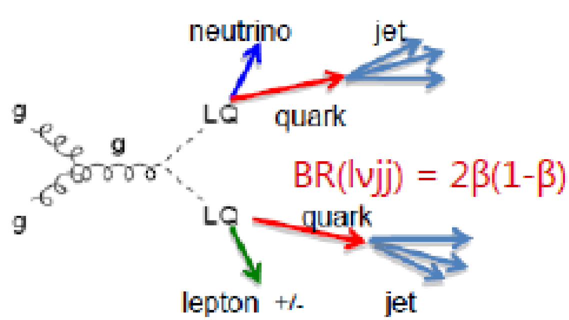


- These dominant production mechanism are not very sensitive to λ, and single LQ production becomes significant above the LQ mass range probed with 2010 data (shown here).

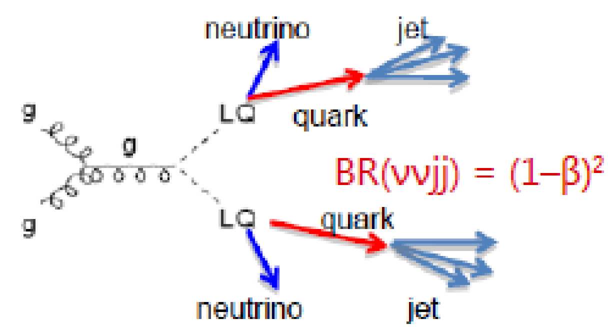
- Final state signatures (3 LQ generations: e, μ, τ)



Dilepton+jets



Lepton+jets+MET



MET+jets

Searches for Pair Production of Scalar LQs with the CMS Detector

- At CMS, searches for 1st generation (eejj and eνjj) and 2nd generation ($\mu\mu$jj) were performed and published on ~34 pb^{-1} of data from the 2010 LHC run
- Analysis strategy (heavy object, excess in S_T, M(ll) and M_T(ln) spectra):
  - Single lepton Triggers (efficient and robust)
  - Event Signature Preselection:
    - High momentum final state objects (two or more isolate leptons, two or more jets, or one isolated lepton, two or more jets and larger transverse missing energy, MET).
    - Lower threshold on M(ll), M_T (lν) and S_T

      $S_T = p_T(l_1) + p_T(l_2 \text{ or MET}) + p_T(jet_1) + p_T(jet_2)$
  - Backgrounds Estimate:
    - Major sources: Z,W +jets and t anti-t production (shapes from MC, normalization from data). Negligible multijet determined from data
  - Final Selection:
    - Optimization on M(ll), M_T(lν) and S_T
  - No evidence of LQ, upper limit on cross-sections, lower limit on M_{LQ}

eejj: Preselection

Preselection:

Single or Double EM trigger (100%)

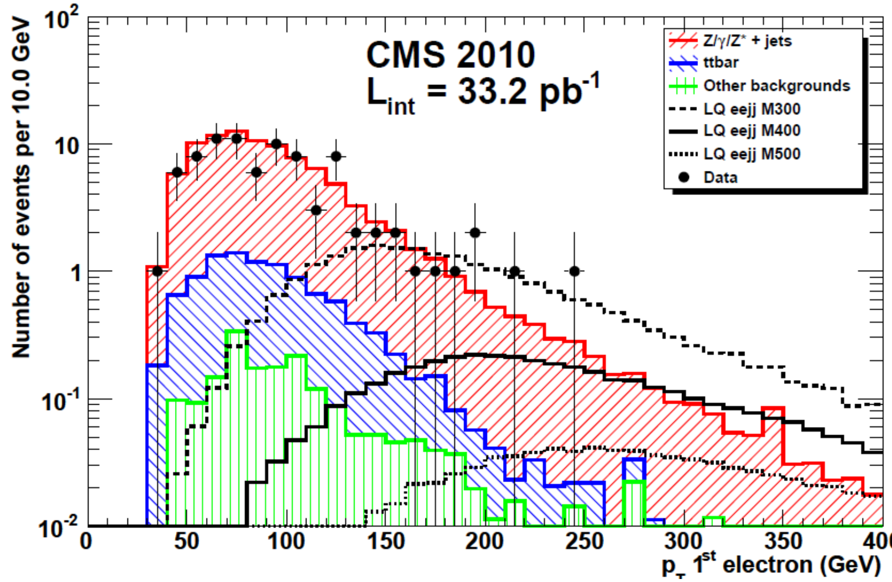
$\geq$ 2 isolated electrons p_T>30 GeV, $|\eta|$<2.5

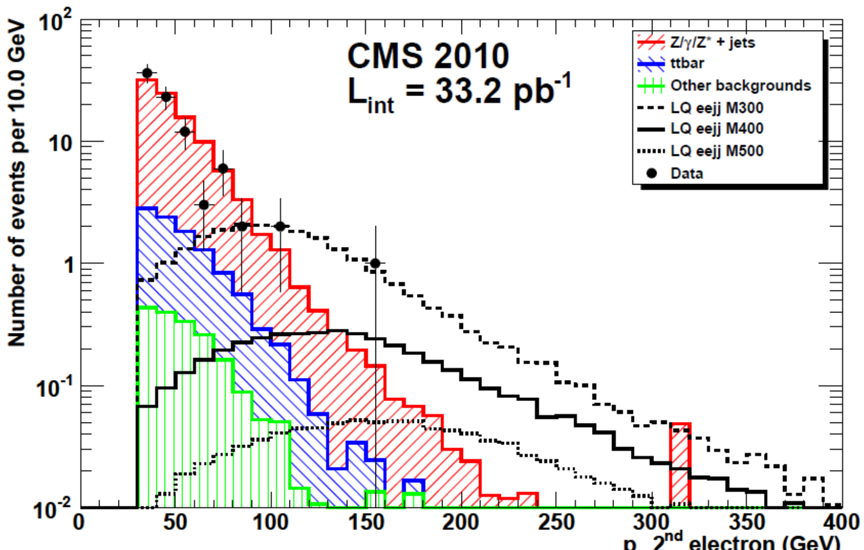
$\geq$ 2 jets p_T>30 GeV, $|\eta|$<3.0

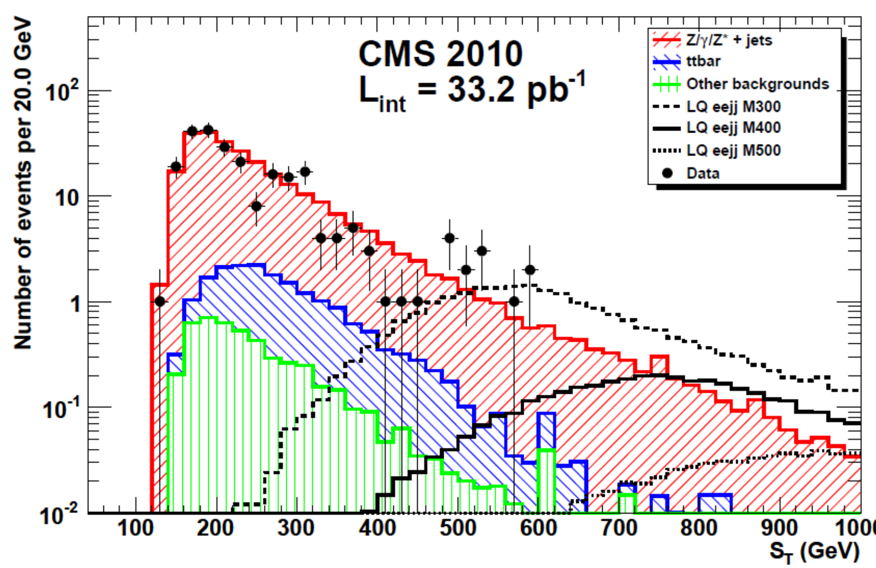
$\Delta R(e,j)$>0.7

M(ee)>50 GeV

$S_T = p_T(e_1) + p_T(e_2) + p_T(j_1) + p_T(j_2)$>250 GeV







μμjj: Preselection

Preselection:

Single Muon trigger (99%)

≥ 2 isolated muons p_T>30 GeV, |η|<2.4

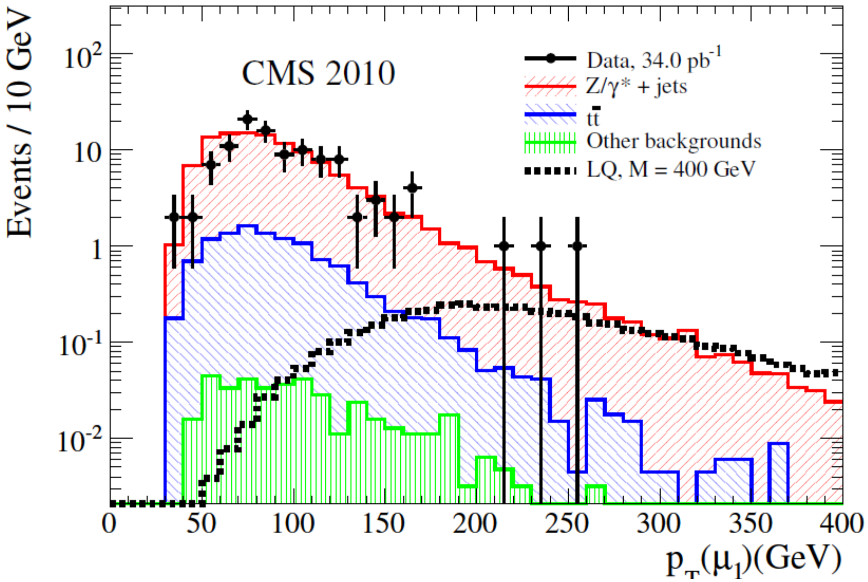
(≥ 1 with |η|<2.1)

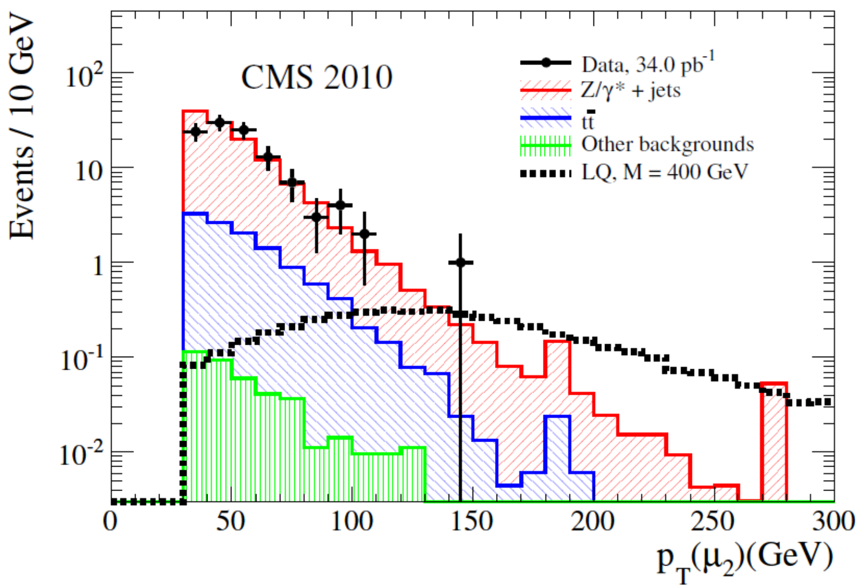
≥ 2 jets p_T>30 GeV, |η|<3.0

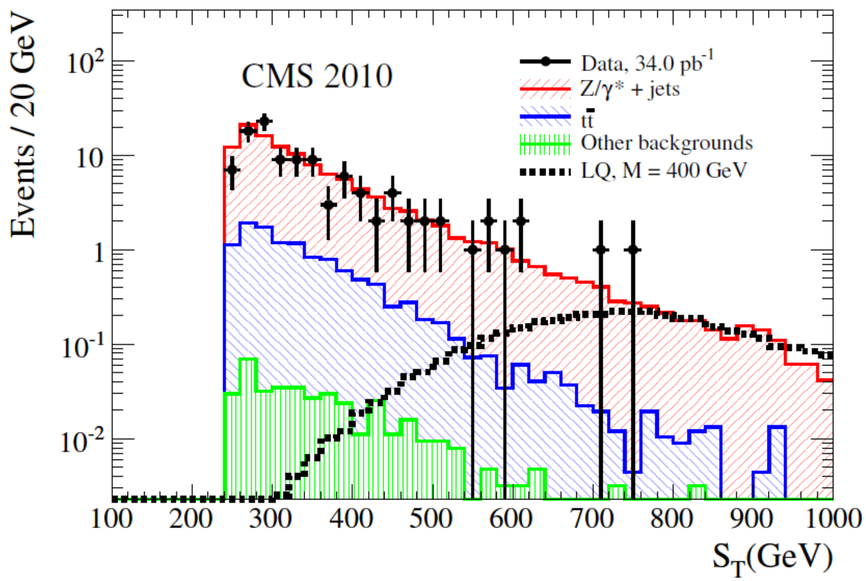
ΔR(μ,μ)>0.3

M(μμ)>50 GeV

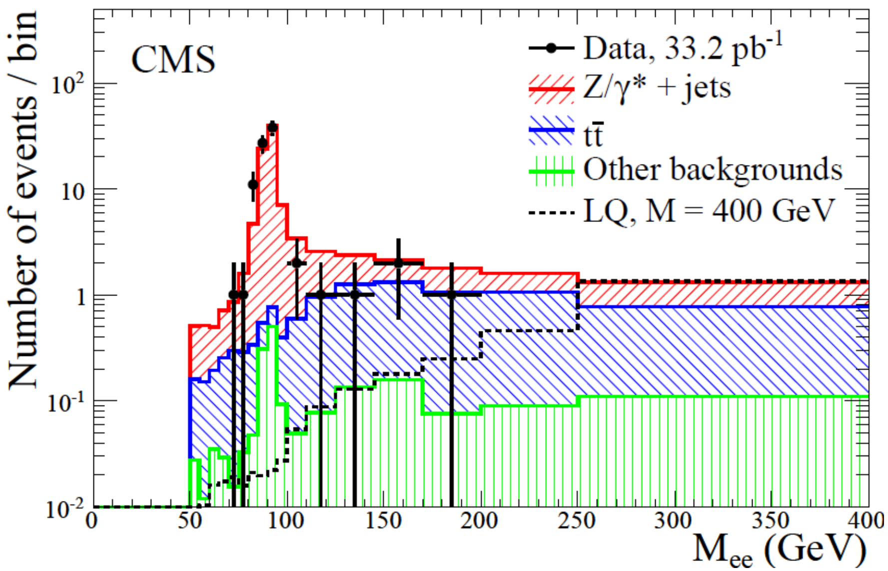
$S_T = p_T(\mu_1) + p_T(\mu_2) + p_T(j_1) + p_T(j_2)$>250 GeV

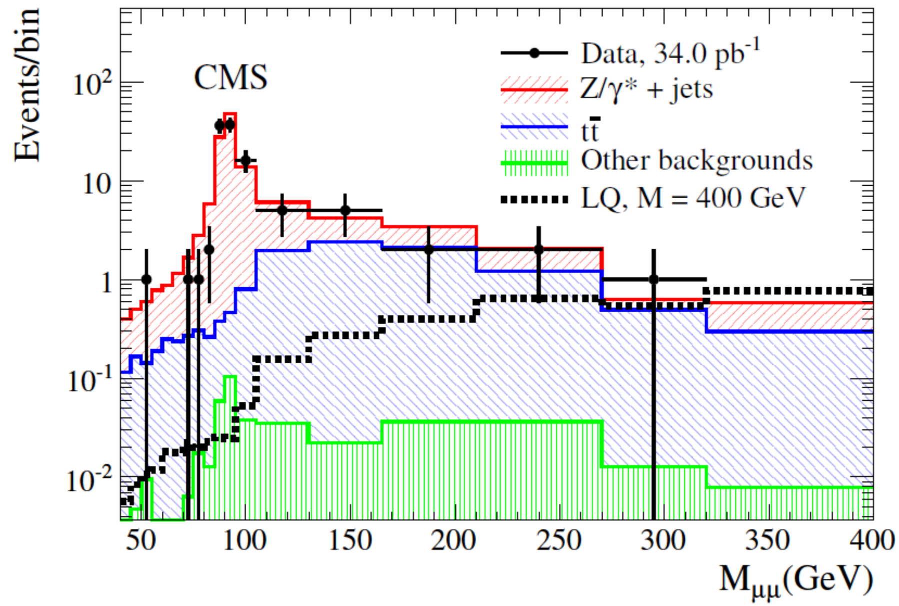






Background Estimates (eejj and μμjj)

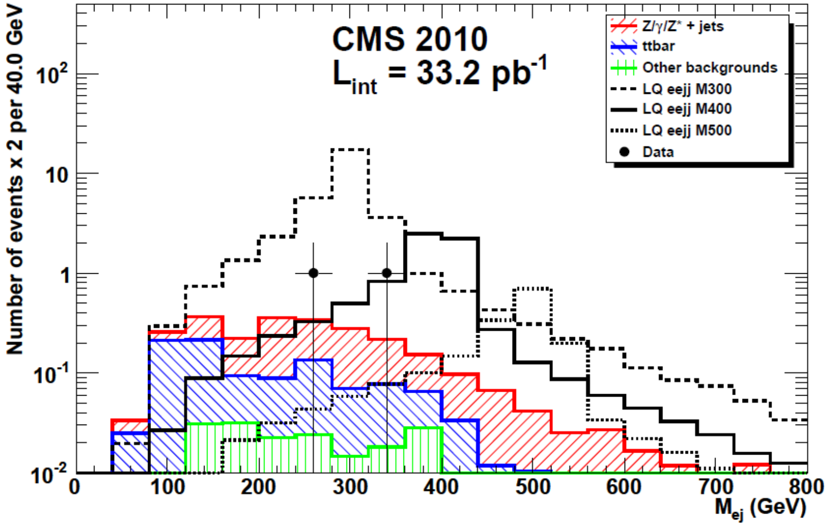


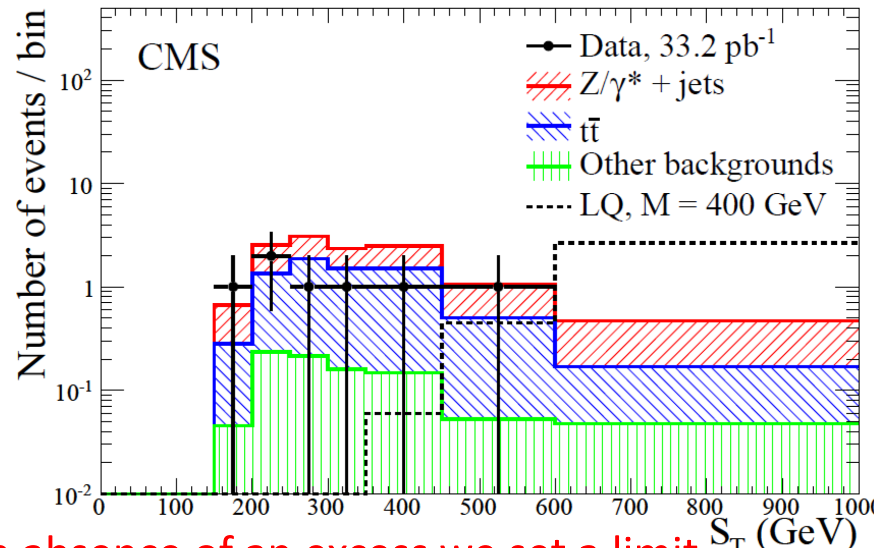


- Z+jets determined from MC, but rescaled by data/MC at the Z peak at preselection (1.20±0.14 for eejj, 1.28±0.14 for μμjj). Normalization uncertainty from (statistically dominated) uncertainty on the ratio, shape uncertainty from comparing MC with different renormalization and factorization scales and matching thresholds.
- t anti-t normalization and uncertainty based on a CMS cross-section measurement
- VV+jets determined from MC (neglible)
- QCD Multijet determined from data control samples (negligible).

eejj: Final Selection

- M(ee)>125 GeV to reduce Z+jets, S_T optimized for different M_{LQ} (see Table)



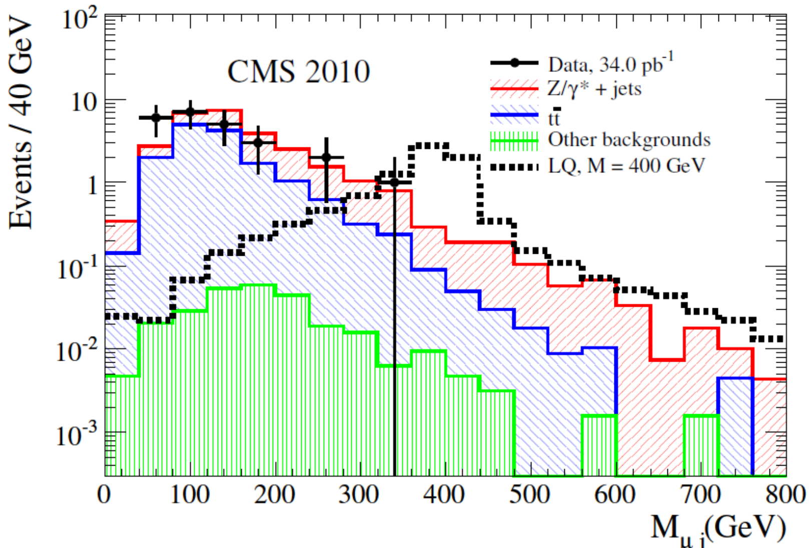


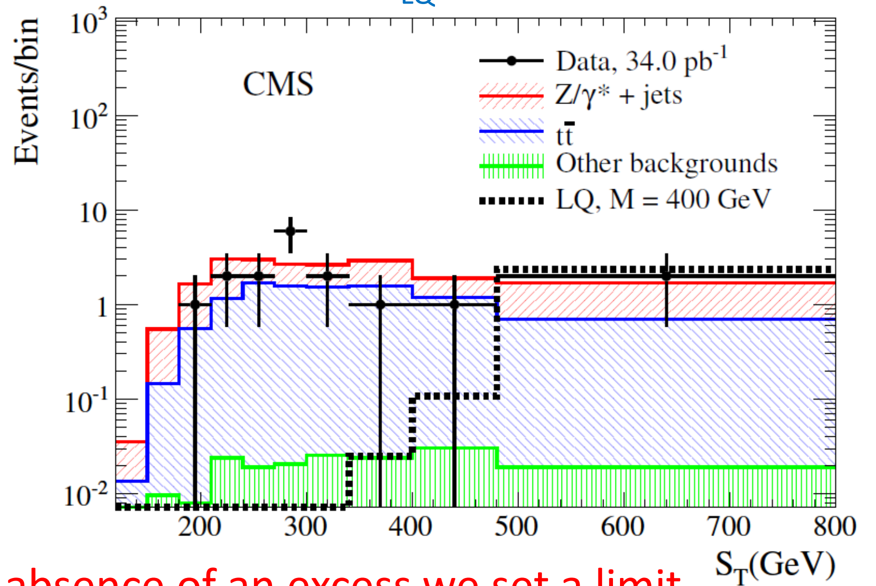
- Good Data/SM Background Agreement. In absence of an excess we set a limit

M_{LQ} (S_T Cut) [GeV]	Signal samples (MC) Selected Events	Acceptance × Efficiency	Standard model background samples (MC) Selected events in $t\bar{t}$ + jets	Z/γ^* + jets	Others	All	Events in data	Obs./Exp. 95% C.L. u.l. on σ [pb]
200 (S_T > 340)	117.5 ± 0.8	0.297 ± 0.002	2.6 ± 0.1	2.0 ± 0.2	0.27 ± 0.05	4.9 ± 0.2	2	0.441/0.720
250 (S_T > 400)	43.8 ± 0.2	0.380 ± 0.002	1.3 ± 0.1	1.3 ± 0.1	0.14 ± 0.02	2.7 ± 0.1	1	0.309/0.454
280 (S_T > 450)	24.4 ± 0.1	0.403 ± 0.002	0.69 ± 0.05	0.87 ± 0.07	0.10 ± 0.02	1.7 ± 0.1	1	0.305/0.373
300 (S_T > 470)	17.3 ± 0.09	0.430 ± 0.002	0.52 ± 0.05	0.75 ± 0.07	0.10 ± 0.02	1.4 ± 0.1	1	0.292/0.332
320 (S_T > 490)	12.3 ± 0.06	0.451 ± 0.002	0.43 ± 0.04	0.65 ± 0.07	0.08 ± 0.02	1.2 ± 0.1	1	0.283/0.305
340 (S_T > 510)	8.88 ± 0.04	0.469 ± 0.002	0.32 ± 0.04	0.56 ± 0.06	0.08 ± 0.02	0.96 ± 0.08	1	0.278/0.279
370 (S_T > 540)	5.55 ± 0.02	0.496 ± 0.002	0.26 ± 0.03	0.47 ± 0.06	0.07 ± 0.02	0.80 ± 0.07	1	0.267/0.254
400 (S_T > 560)	3.55 ± 0.02	0.522 ± 0.002	0.20 ± 0.03	0.41 ± 0.05	0.06 ± 0.02	0.67 ± 0.07	1	0.257/0.234
450 (S_T > 620)	1.70 ± 0.01	0.539 ± 0.002	0.12 ± 0.02	0.28 ± 0.05	0.02 ± 0.01	0.42 ± 0.06	0	0.174/0.210
500 (S_T > 660)	0.868 ± 0.003	0.565 ± 0.002	0.08 ± 0.02	0.23 ± 0.05	0.02 ± 0.01	0.33 ± 0.05	0	0.166/0.194

μμjj: Final Selection

- M(μμ)>115 GeV to reduce Z+jets, S_T optimized for different M_{LQ} (see Table)



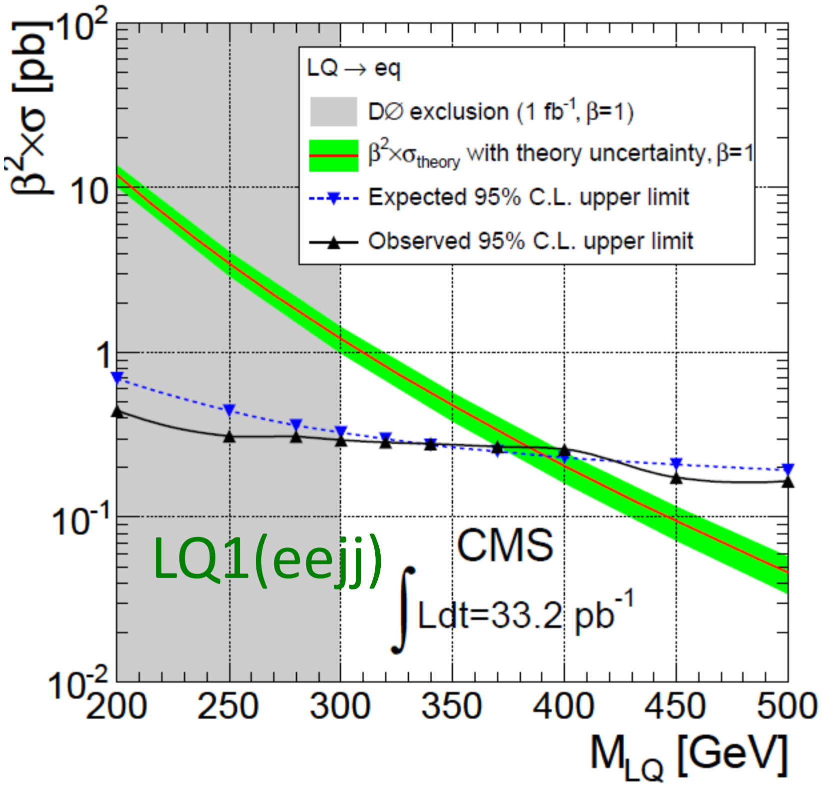


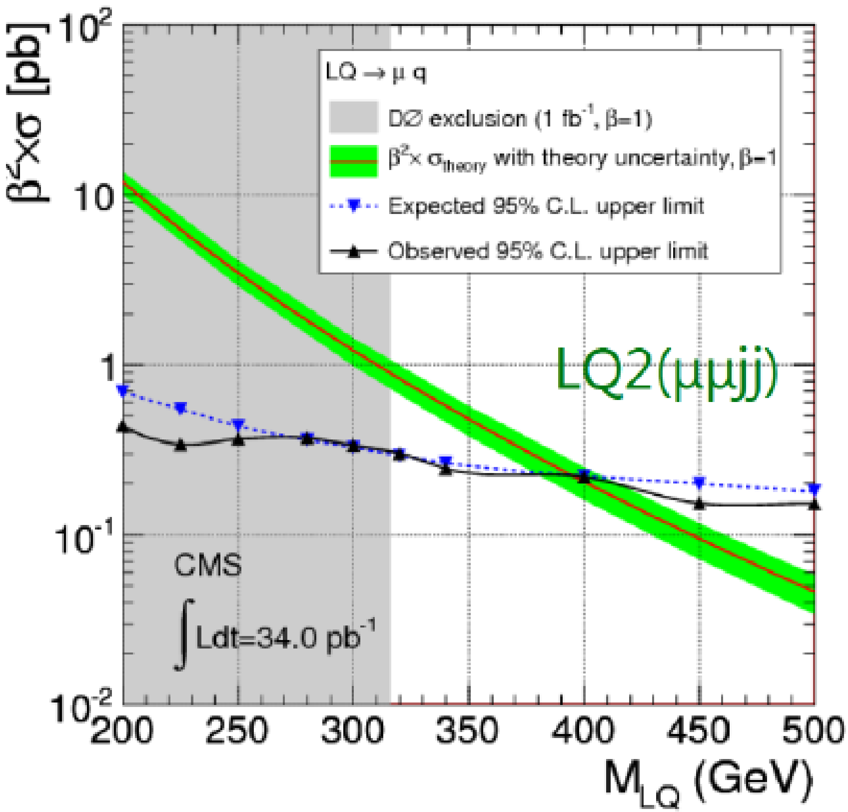
- Good Data/SM Background Agreement. In absence of an excess we set a limit

	Signal samples (MC)		Standard model background samples (MC)				Events	Obs./Exp.
M_{LQ} (S_T Cut)	Selected	Acceptance ×	Selected events in				in	95% C.L.
[GeV]	Events	Efficiency	$t\bar{t}$ + jets	Z/γ^* + jets	Others	All	data	u.l. on σ [pb]
200 ($S_T > 310$)	160 ± 20	0.388 ± 0.003	4.6 ± 0.1	4.08 ± 0.07	0.1 ± 0.01	8.8 ± 0.2	5	0.438/0.695
225 ($S_T > 350$)	89 ± 9	0.421 ± 0.003	3.1 ± 0.1	2.99 ± 0.05	0.07 ± 0.01	6.2 ± 0.1	3	0.339/0.547
250 ($S_T > 400$)	51 ± 5	0.437 ± 0.003	1.88 ± 0.09	1.92 ± 0.04	0.051 ± 0.009	3.9 ± 0.1	3	0.366/0.436
280 ($S_T > 440$)	28 ± 3	0.467 ± 0.003	1.15 ± 0.07	1.53 ± 0.03	0.038 ± 0.008	2.72 ± 0.08	3	0.371/0.361
300 ($S_T > 440$)	21 ± 2	0.518 ± 0.004	1.15 ± 0.07	1.53 ± 0.03	0.038 ± 0.008	2.72 ± 0.08	3	0.335/0.326
320 ($S_T > 490$)	14 ± 1	0.509 ± 0.004	0.64 ± 0.05	1.12 ± 0.02	0.019 ± 0.005	1.78 ± 0.06	2	0.300/0.292
340 ($S_T > 530$)	9 ± 1	0.508 ± 0.003	0.4 ± 0.04	0.79 ± 0.01	0.01 ± 0.004	1.20 ± 0.04	1	0.245/0.264
400 ($S_T > 560$)	4.0 ± 0.4	0.578 ± 0.004	0.31 ± 0.04	0.67 ± 0.01	0.01 ± 0.004	0.99 ± 0.04	1	0.219/0.222
450 ($S_T > 620$)	1.9 ± 0.2	0.600 ± 0.004	0.19 ± 0.03	0.49 ± 0.01	0.006 ± 0.003	0.69 ± 0.03	0	0.153/0.199
500 ($S_T > 700$)	0.9 ± 0.1	0.602 ± 0.004	0.09 ± 0.02	0.277 ± 0.006	0.003 ± 0.002	0.37 ± 0.02	0	0.152/0.180

Upper limits on BR x Cross-Section (eejj and μμjj)

In absence of an excess of data above predictions, we use a Bayesian method to set an upper limit on the production cross-section times the branching ratio for a pair of LQs





Limits on the mass of a scalar LQ1(LQ2): 384 GeV (394 GeV) for β=1

Phys. Rev. Lett. 106, 201802 (2011), Phys. Rev. Lett. 106, 201803 (2011)

eνjj: Preselection

Preselection:

Single EM trigger

1 isolated electrons p_T>35 GeV, |η|<2.2

≥ 2 jets p_T>30 GeV, |η|<3.0

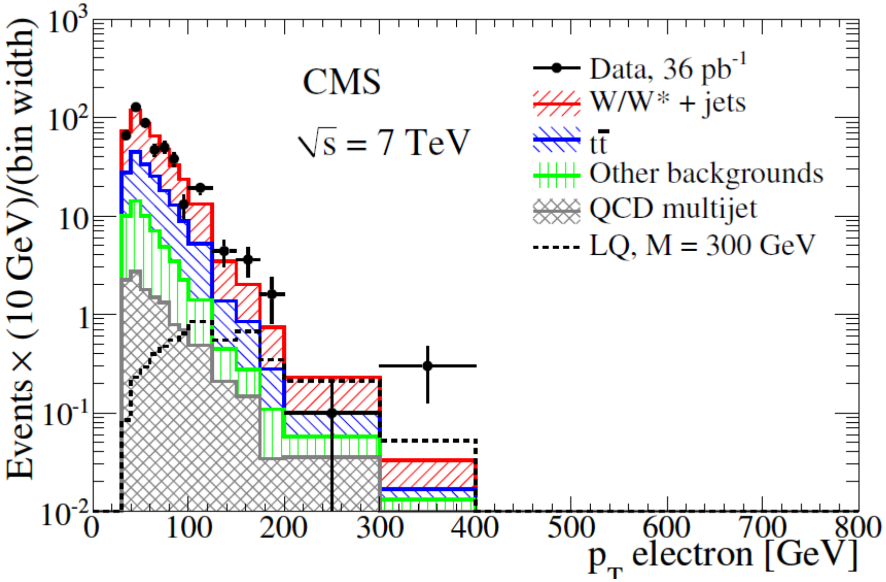
MET > 45 GeV

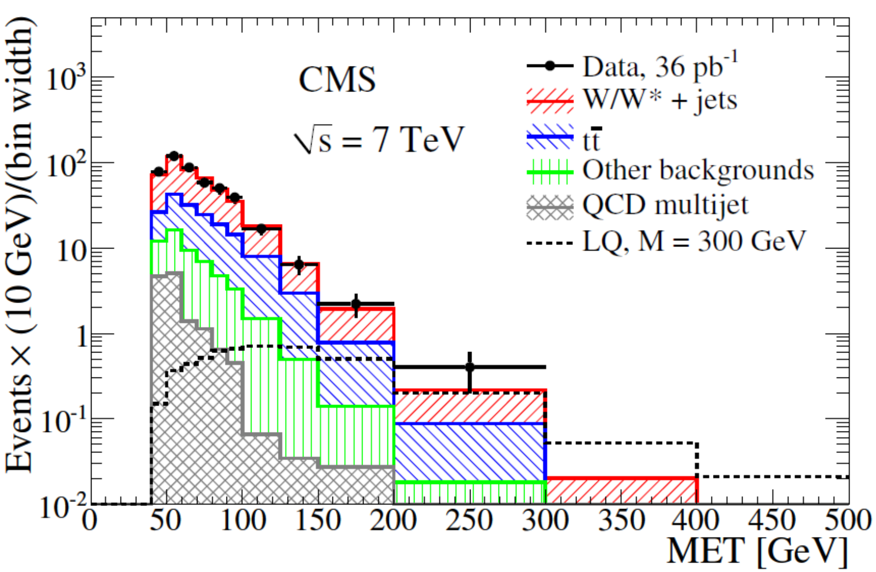
ΔR(e,j)>0.7

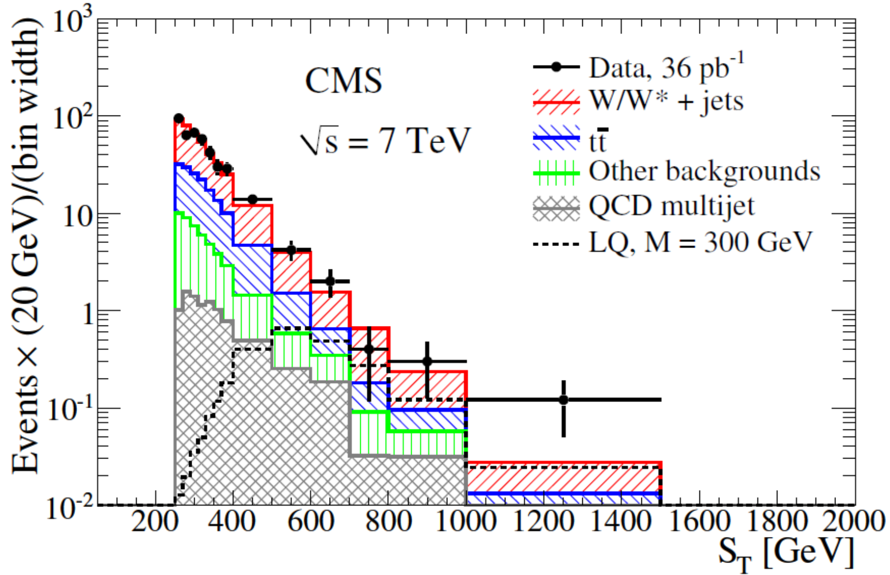
Muon veto

|ΔΦ(MET,e)| > 0.8 and |ΔΦ(MET,j1)| > 0.5

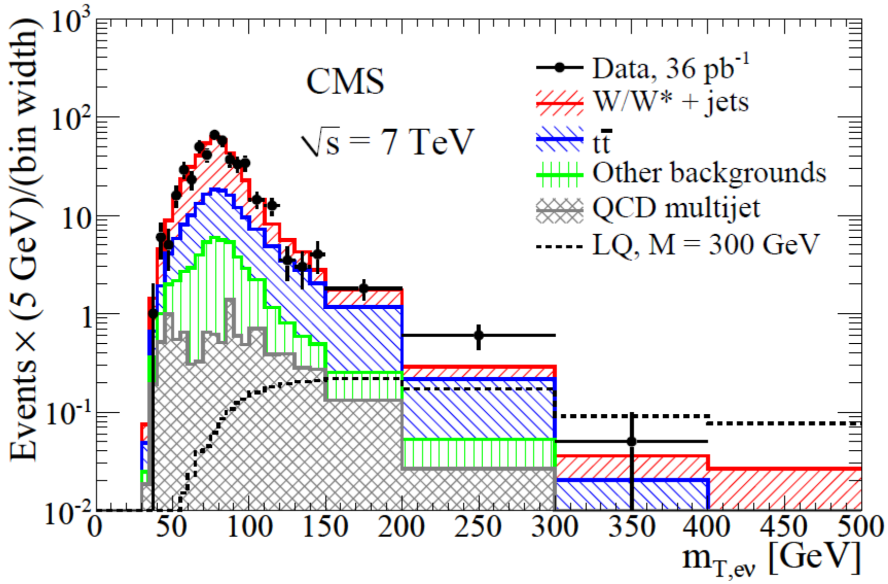
$S_T = p_T(e) + p_T(MET) + p_T(j_1) + p_T(j_2)$>250 GeV







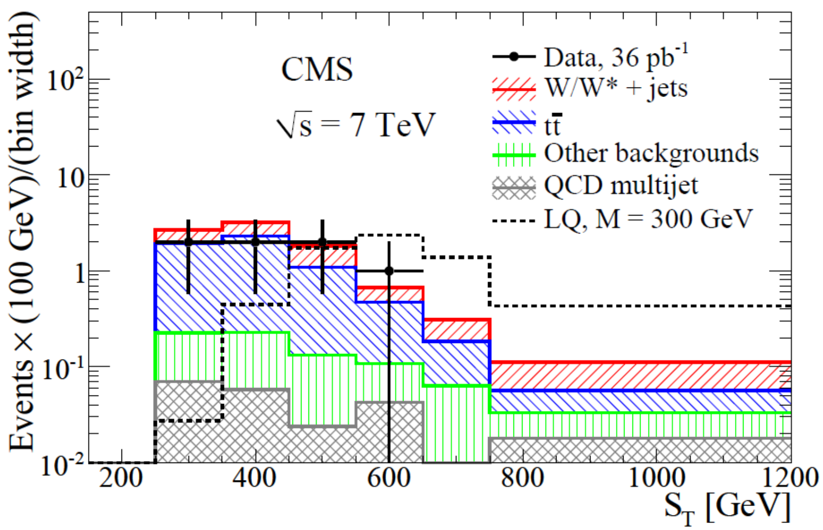
Background Estimates (eνjj)

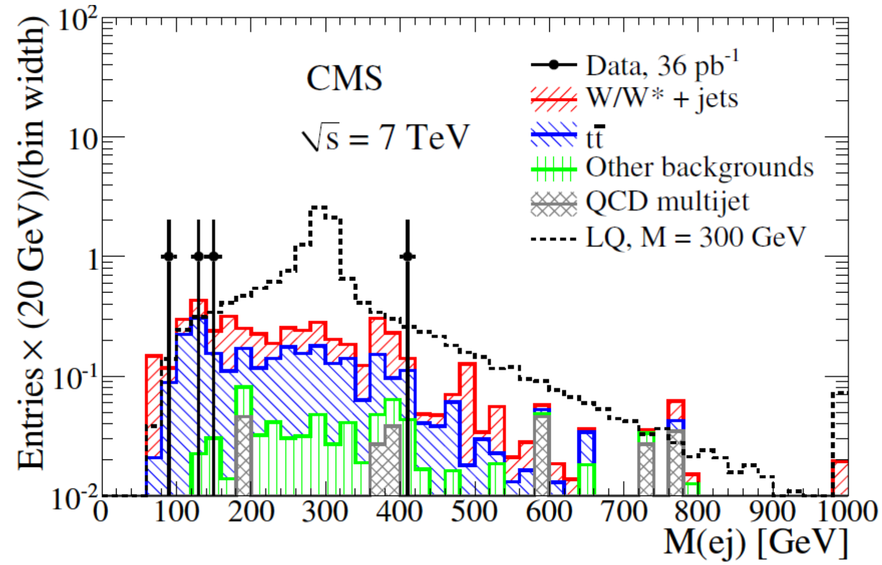


- W+jets determined from MC, but rescaled by data/MC in 50 < M_T(eν) < 110 GeV
  Normalization uncertainty from (statistically dominated) uncertainty on the ratio, shape uncertainty from comparing MC with different renormalization and factorization scales and matching thresholds.
- t anti-t uncertainty based on a CMS cross-section measurement
  No rescaling needed. Shape uncertainty determined from MC
- QCD Multijet determined from data control sample.
- Other sources of background negligible

eνjj: Final Selection

- $M_T(e\nu)$>125 GeV, min(p_T(e),MET) > 85 GeV , S_T optimized for different M_{LQ} (see Table)





- Good Data/SM Background Agreement. In absence of an excess we set a limit

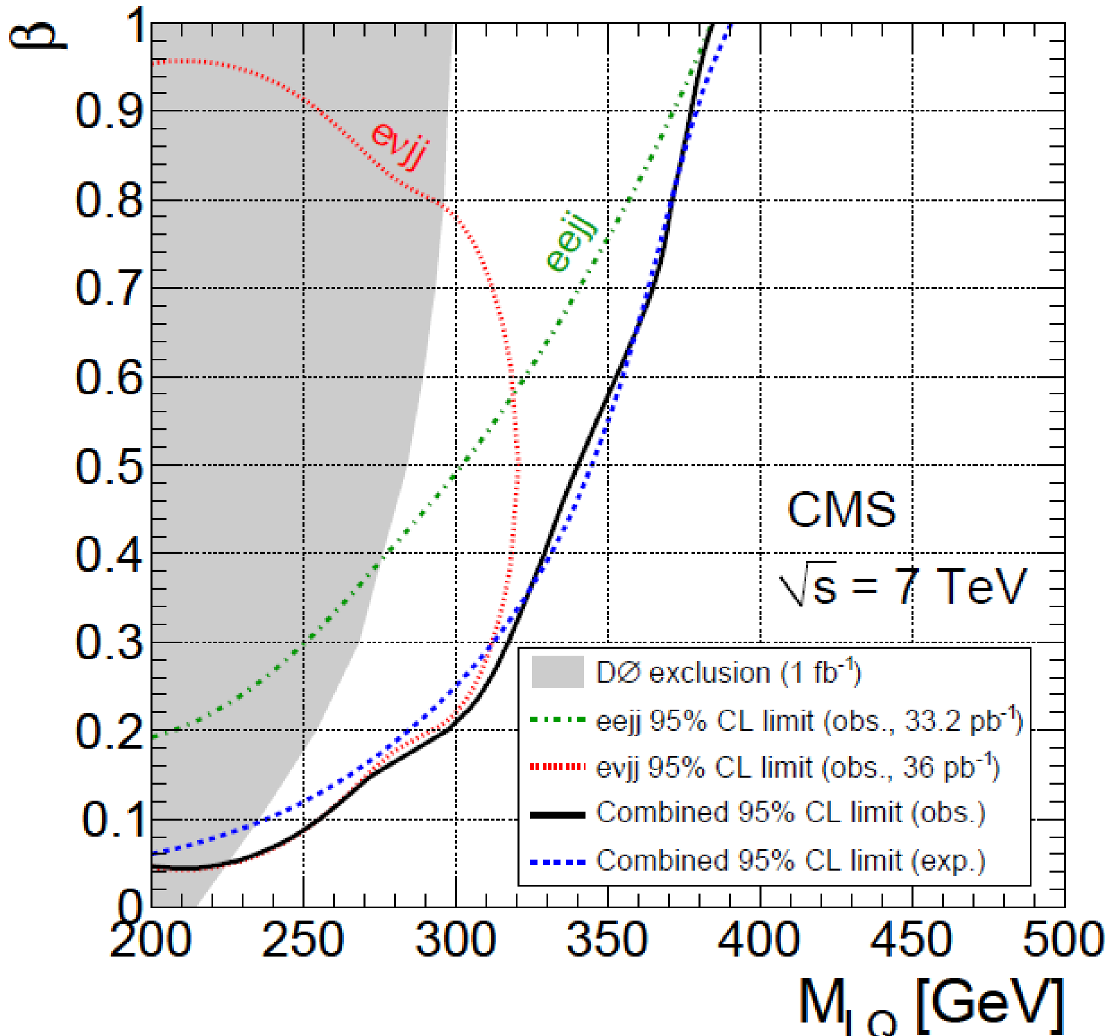
M_{LQ} (S_T cut) [GeV]	MC Signal Samples: Selected Events	MC Signal Samples: Acceptance × Efficiency	MC and QCD Background Samples, Selected Events in: $t\bar{t}$ + jets	W + jets	Other Bkgs	QCD	All Bkgs	Events in Data
200 ($S_T > 350$)	34.5±0.2	0.161	3.6±0.1	2.2±0.3	0.48±0.06	0.20±0.04	6.5±0.3	5
250 ($S_T > 410$)	15.9±0.1	0.255	2.24±0.09	1.7±0.3	0.35±0.05	0.18±0.05	4.4±0.3	3
280 ($S_T > 460$)	9.54±0.05	0.291	1.43±0.08	1.2±0.2	0.29±0.05	0.14±0.04	3.1±0.2	3
300 ($S_T > 490$)	6.89±0.03	0.317	1.09±0.07	1.0±0.2	0.27±0.05	0.14±0.04	2.5±0.2	2
320 ($S_T > 520$)	5.03±0.02	0.339	0.75±0.05	0.8±0.2	0.22±0.05	0.13±0.04	1.9±0.2	2
340 ($S_T > 540$)	3.73±0.02	0.364	0.65±0.05	0.7±0.2	0.20±0.05	0.12±0.04	1.6±0.2	2
370 ($S_T > 570$)	2.40±0.01	0.396	0.50±0.04	0.6±0.1	0.18±0.04	0.08±0.03	1.3±0.2	1
400 ($S_T > 600$)	1.57±0.01	0.426	0.34±0.04	0.5±0.1	0.17±0.04	0.08±0.03	1.1±0.1	1
450 ($S_T > 640$)	0.797±0.003	0.467	0.26±0.03	0.4±0.1	0.13±0.04	0.08±0.04	0.9±0.1	0
500 ($S_T > 670$)	0.417±0.001	0.500	0.18±0.03	0.4±0.1	0.12±0.04	0.08±0.04	0.8±0.1	0

Combined limits (eejj and eνjj)

The searches in the eνjj and eejj channels can be combined to extend the parameter space probed.

The limit on the mass of a scalar LQ1 for β=0.5
Is then set at 340 GeV

Submitted to Physics Letters B

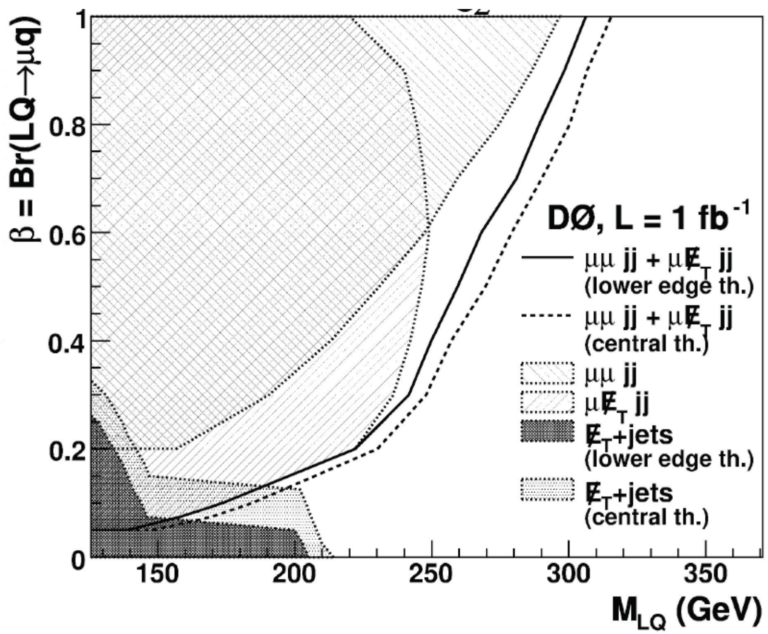


Conclusions

- Searches for pair production of 1^{st} and 2^{nd} generation scalar leptoquarks have been performed at CMS in the final states with:
  - ✓ two charged leptons, two jets
  - ✓ one charged lepton (electron), missing transverse energy, two jets
  - ✓ the 2010 full statistics
- In the absence of a signal we exclude:
  - ✓ 1^{st} generation LQ with masses below 384 GeV (β=1)
  - ✓ 2^{nd} generation LQ with masses below 394 GeV (β=1)
  - ✓ 1^{st} generation LQ with masses below 340 GeV (β=0.5)
- The β=1 results were the most stringent limits at the time of publication
- The β=0.5 and β=1 results have been combined and have been submitted for publication
- Analysis of the 2011 data is ongoing.

Backup

Other experiments LQ results

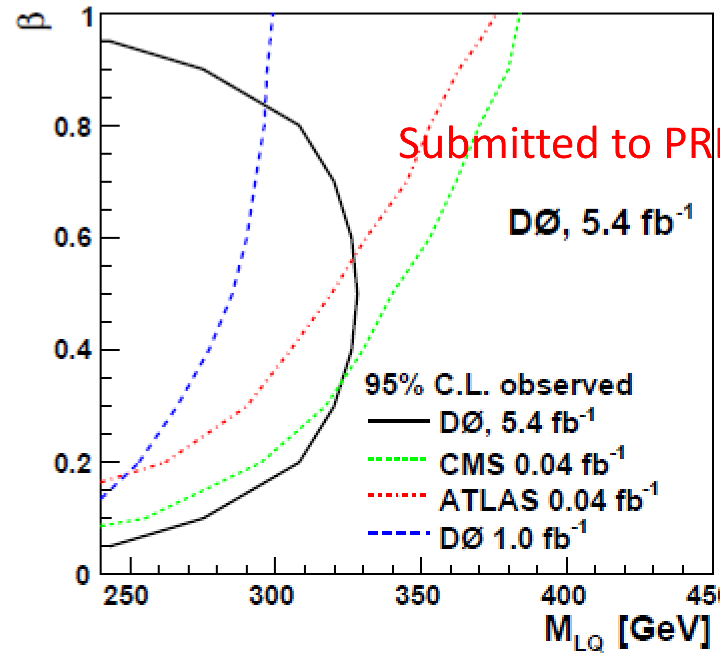


ATLAS (Submitted to PRD):

M_{LQ}<376(319) 1st gen

M_{LQ}<422(362) 2nd gen

Submitted to PRD-RC



H1 (Submitted to PLB):

M_{LQ}<800 1st gen with λ=0.3