Search for 2nd generation Leptoquarks with ATLAS at the LHC

ATLAS D-Workshop
DESY Zeuthen
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Overview

- Leptoquarks
- signal and standard model background
- selection variables
- triggering
- exclusion limits
- conclusions and outlook

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Leptoquarks

- What are Leptoquarks ?
  - Leptoquarks (LQ) are hypothetical particles, which carry both lepton- and baryon-numbers. LQ interactions conserve the lepton- and baryon-numbers separately.
  - LQ have not been observed yet, but many extensions of the Standard Model predict them:
    - superstring-inspired E_6 models
    - Grand Unifying Theories (GUTs)
    - technicolor models
    - etc.

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LQ properties

- Neither flavor changing neutral current excesses nor lepton number violation excesses have been observed
  → 1st Assumption: LQ couple only to one generation of quarks and to one generation of leptons of the standard model

- 2nd assumption: LQ interactions are chiral; otherwise LQ would mediate rare decays.

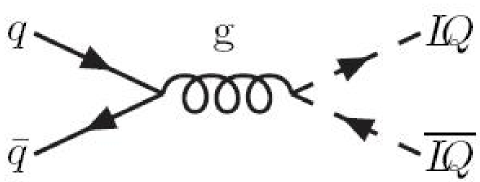
- With the assumptions above there are 14 kinds (mBRW model) of LQ, that differ by:
  - spin (scalar or vector)
  - fermion number F = 3 B + L
  - isospin
  - chirality of the coupling

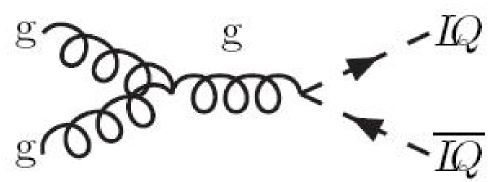
- LQ carry non-integer charges (± 5/3e, ± 4/3e, ± 2/3e, ± 1/3e)

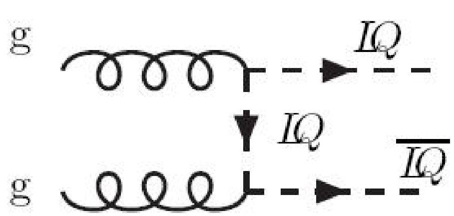
- LQ $\rightarrow \ell^{\pm}$ q or LQ $\rightarrow \nu$ q

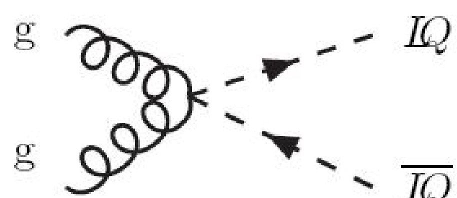
How are LQ produced ?

- only pair production of scalar LQ considered here → single production depends on the unknown Yukawa coupling









- all shown processes do not depend on the (unknown) q-ℓ-LQ coupling
  → cross-section only depends on mass of LQ and QCD
- 2^{nd} Generation:
  LQ → q + μ (or q + ν_{μ})
- excluded mass limit for 2^{nd} generation LQ:
  ~ 250 GeV (β=1)
  β = BR(LQ_2 → q + μ)

Signal and Standard Model background

- signal ($\beta=1$):

m(LQ) in GeV	σ(NLO) (in pb)
300	10.10000
400	2.24000
600	0.22500
800	0.03780
1000	0.00836
1200	0.00221
1400	0.000655
1600	0.000210
1800	0.0000714

- background:

process	σ x BR (in pb)
$Z/\gamma^*(\mu\mu)$+jets $p_T^{jet}>20$GeV	313
$t\bar{t}$ ($\mu\nu j$ $\mu\nu j$)	9.5
ZZ ($\mu\mu$ jj)	1.2
ZW ($\mu\mu$ jj)	1.2
WW ($\mu\nu$ $\mu\nu$)	1.1

expected $\int L\, dt$ of the LHC:

1st month at 14 TeV: 5 pb^{-1}

1 year at design *L*: 10 fb^{-1}

→ expected number of events:

Z/γ^*+jets: 1.6k LQ_{400}:11.2 LQ_{1200}:0.01

Z/γ^*+jets: 3.1M LQ_{400}:22.4k LQ_{1200}:22.1

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Selection variables

2 μ (opposite charge) and 2 jets

p_T^{μ} > 60 GeV (both muons)

E_T^{jet} > 25 GeV (both jets)

μ isolation: in cone (ΔR = 0.4) around muon less than 60 GeV E_T

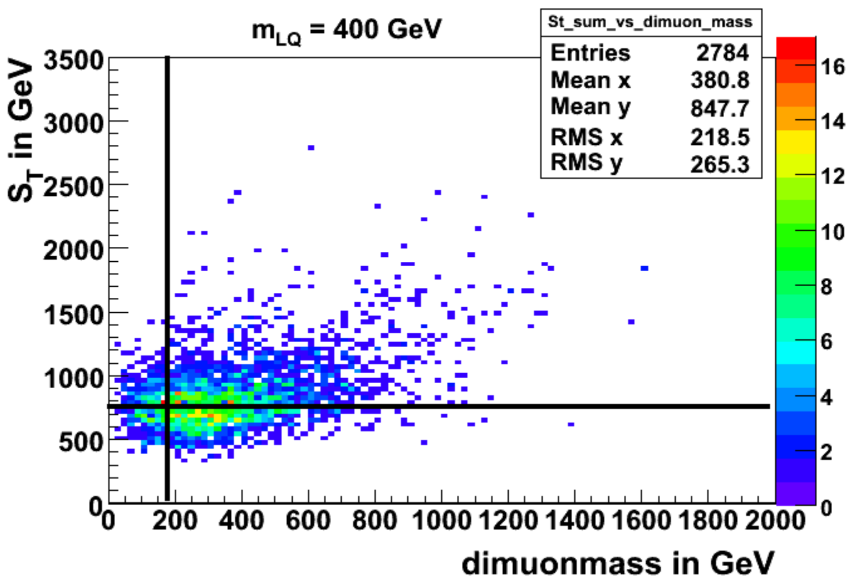
S_T > 750 GeV (for m_{LQ} = 400 GeV)

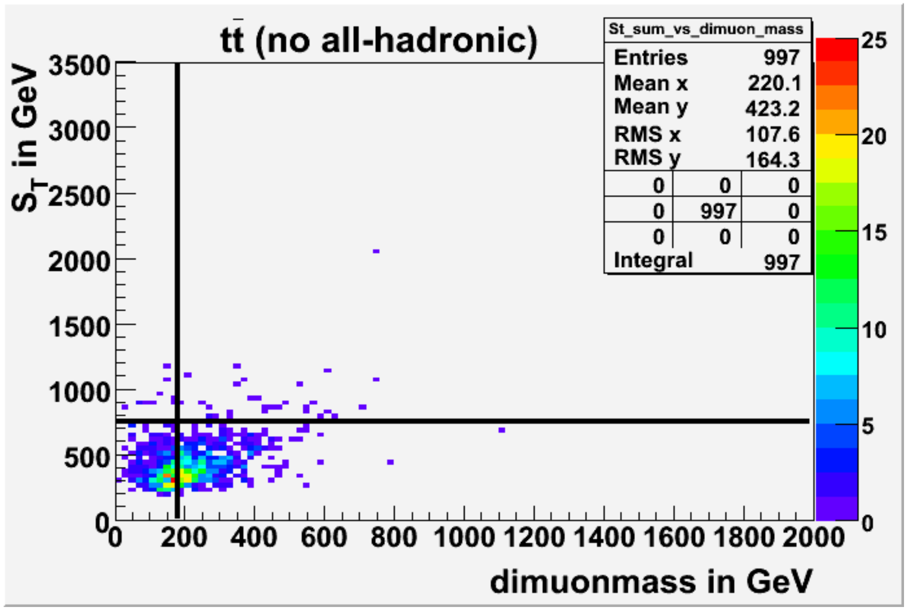
dimuonmass > 180 GeV

LQ m = 400 GeV (sample 6679):

$t\bar{t}$ (no all-hadronic 5200)

$$S_T = \Sigma E_T$$





31.4% of LQ events left

34 $t\bar{t}$ events left

Selection variables II

S_T cut increases linearly with increasing m_{LQ} :

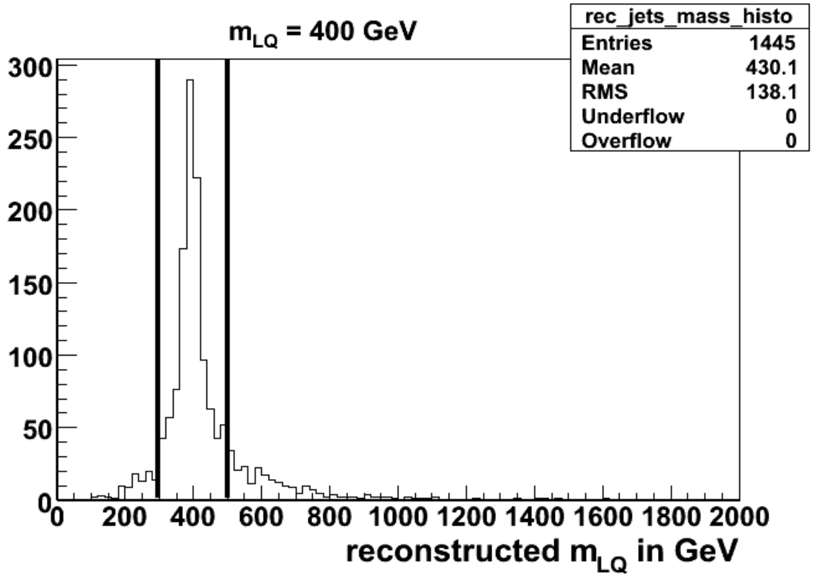
m_{LQ} = 300 GeV S_T > 650 GeV
m_{LQ} = 400 GeV S_T > 750 GeV
m_{LQ} = 600 GeV S_T > 950 GeV
m_{LQ} = 800 GeV S_T > 1150 GeV
m_{LQ} = 1200 GeV S_T > 1550 GeV

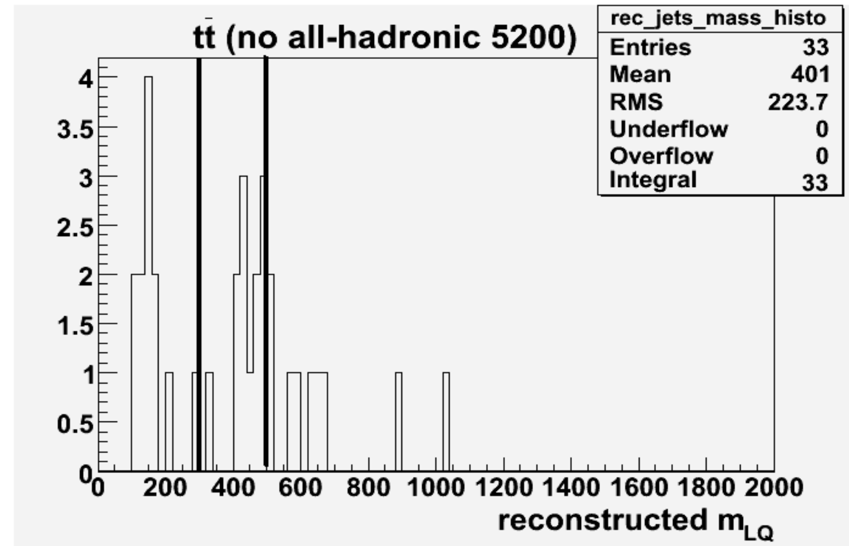
additional cut: reconstructed LQ mass has to be

± 75 GeV around real m_{LQ} for LQ_{300}
± 100 GeV around real m_{LQ} for LQ_{400}
± 150 GeV around real m_{LQ} for LQ_{600}
± 200 GeV around real m_{LQ} for LQ_{800}
± 300 GeV around real m_{LQ} for LQ_{1200}

because detector resolution gets worse for higher momenta

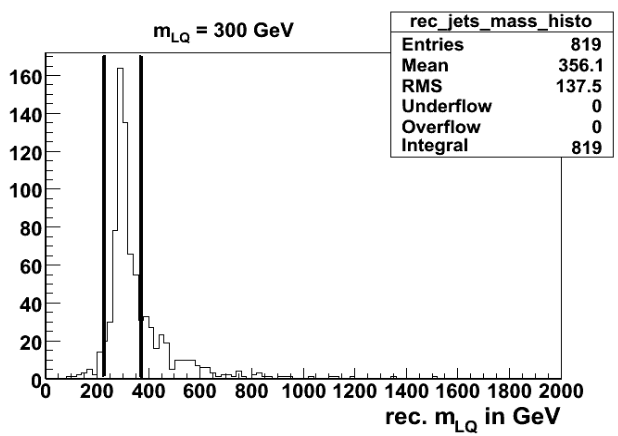
Selection variables III

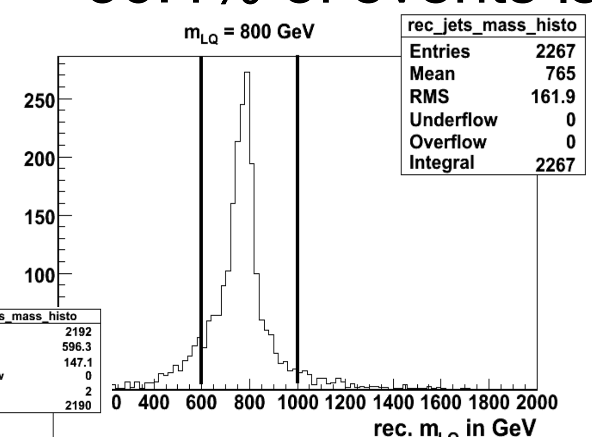


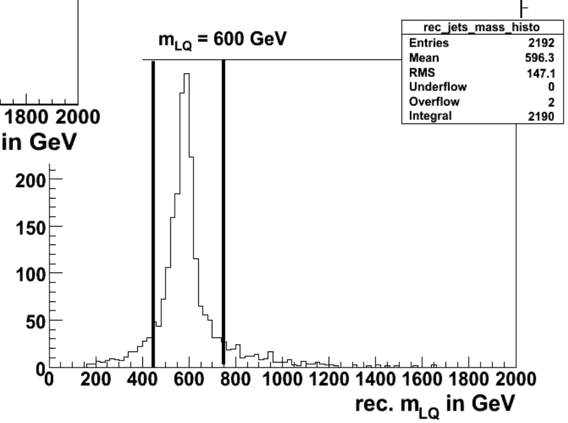


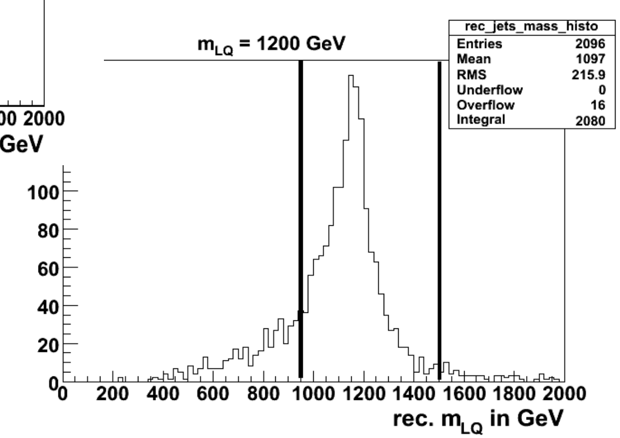
77.2% of LQ left in mass range

36.4% of events left in mass range



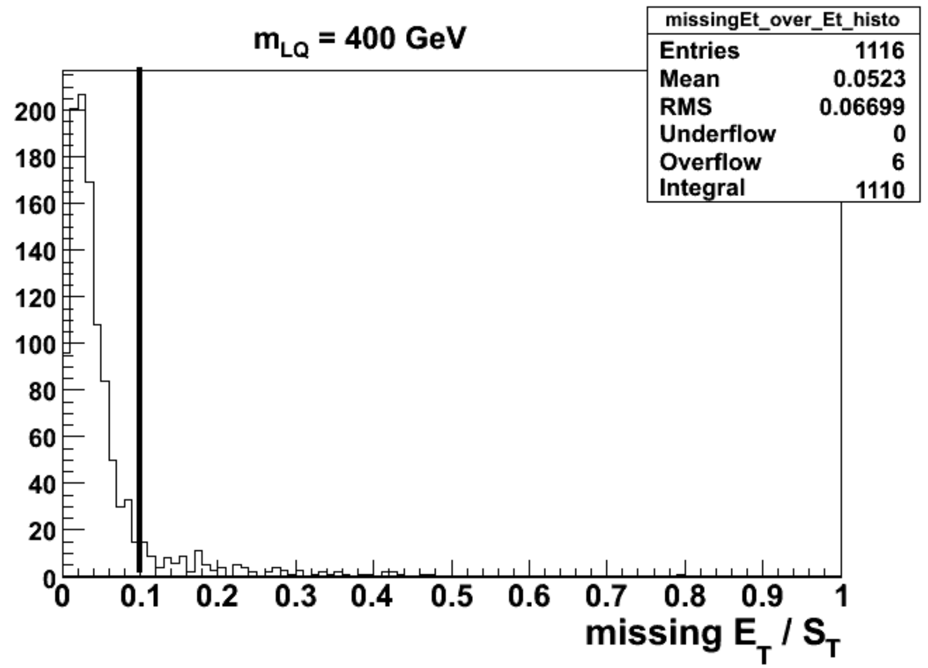


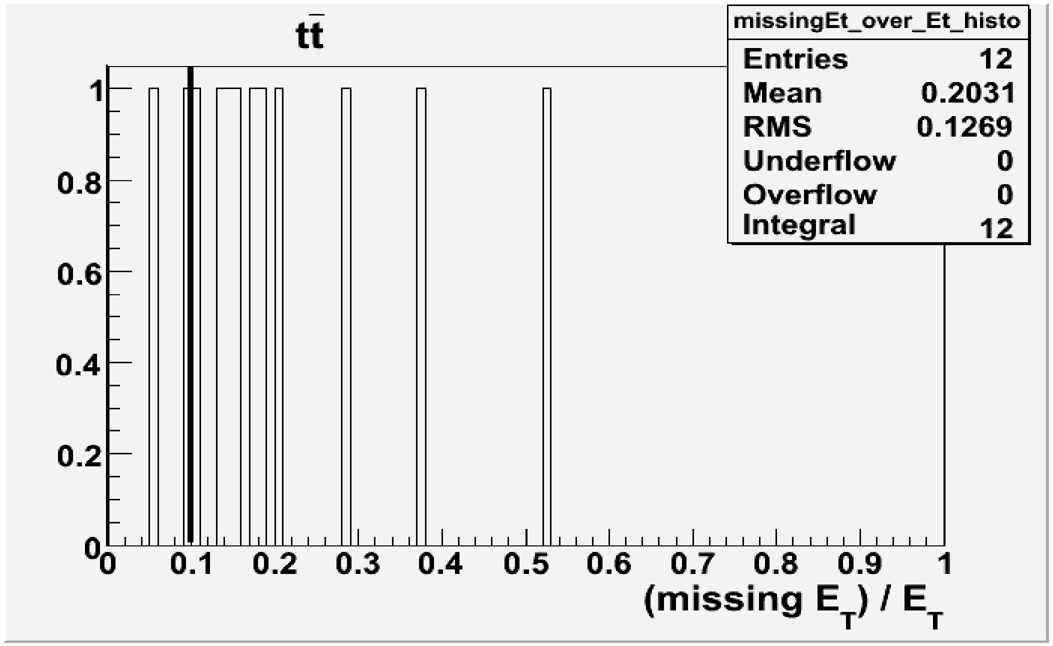




missing E_T

additional cut: (missing E_T) / S_T < 0.1, mainly to suppress $t\bar{t}$ background





89.0% of LQ events left survive cut

16.7% of $t\bar{t}$ events left survive cut

cuts	LQ (v12) m=400GeV σ=2.24 pb	tt (5200,no all-hadronic) σ=461 pb	5115 DY m_{ll}>150GeV σ ≈ 7.7 pb	5151 Z(μμ) σ= 1662 pb	5985 WW σ=1.1pb	5987 WZ σ=7.8pb
without cuts	4607 LQ pairs	603300 (12706 fully muonic)	19750	99150	34000	37900
+ 2 OS muons	76.32%	8.38%	44.57%	45.71%	2.97%	8.09%
+ 2 jets	76.25%	8.31%	37.80%	34.79%	2.54%	7.72%
Distance(μ_1,μ_2) ΔR > 0.2	76.04%	7.50%	37.78%	34.79%	2.53%	7.68%
+ p_T^μ > 25 GeV	73.04%	1.47%	36.44%	27.67%	0.88%	4.36%
+ E_T^{jet} > 25 GeV	72.22%	1.41%	9.41%	3.09%	0.18%	2.72%
+ μ/jet exclusion ΔR = 0.4	66.23%	1.24%	9.20%	3.08%	0.17%	2.70%
+ dimuonmass > 125 GeV	60.97%	0.39%	9.02%	0.06%	0.10%	0.17%
+ p_T^μ > 60 GeV	56.37%	0.14%	6.14%	0.03%	0.05%	0.09%
+ S_T > 300 GeV	56.37%	0.12%	3.21%	0.01%	0.02%	0.05%
+ dimuonmass > 180 GeV	51.31%	0.09%	2.74%	0.01%	0.02%	0.04%
+ S_T > 750 GeV	31.37%	0.00547%	0.16203%	0.00%	0.00%	0.005%
+ m_{LQ} ±100 GeV	24.24%	0.00199%	0.08101%	0.00%	0.00%	0.003%
+ ME_T/S_T < 0.1	21.55%	0.00050%	0.07595%	0.00%	0.00%	0.000%

Surviving cross-sections

process	σ * Br(pb)	∫ L dt (pb^{-1}) of available sample	surviving σ * Br (pb) after cuts for m_{LQ} = 300GeV	surviving σ * Br (pb) after cuts for m_{LQ} = 400GeV	surviving σ * Br (pb) after cuts for m_{LQ}=600GeV	surviving σ * Br (pb) after cuts for m_{LQ}=800GeV	
ZZ→μμjj(v10)	1.2	23,000	0	0	0	0	
WW 5985	24.5	1,338	$< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$	$< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$	$< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$	$< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$ $< 2.2\ 10^{-3}$	
ZW 5987	7.8	4,859	$6.2\ 10^{-4}$ $6.2\ 10^{-4}$ $< 6.2\ 10^{-4}$	$4.1\ 10^{-4}$ $2.1\ 10^{-4}$ $< 6.2\ 10^{-4}$	$2.1\ 10^{-4}$ $< 6.2\ 10^{-4}$ $< 6.2\ 10^{-4}$	$4.1\ 10^{-4}$ $2.1\ 10^{-4}$ $2.1\ 10^{-4}$	
DY m_{ll} > 150 GeV 5115	~ 7.7	2,565	0.026 0.010 0.009	$1.3\ 10^{-2}$ $6.2\ 10^{-3}$ $5.8\ 10^{-3}$	$5.1\ 10^{-3}$ $2.0\ 10^{-3}$ $2.0\ 10^{-3}$	$3.1\ 10^{-3}$ $1.2\ 10^{-3}$ $< 1.2\ 10^{-3}$	
$t\bar{t}$ 5200	461	1,294	$5.2\ 10^{-2}$ $8.5\ 10^{-3}$ $3.1\ 10^{-3}$	$3.0\ 10^{-2}$ $8.5\ 10^{-3}$ $1.5\ 10^{-3}$	$7.7\ 10^{-3}$ $4.6\ 10^{-3}$ $2.3\ 10^{-3}$	$2.3\ 10^{-3}$ $2.3\ 10^{-3}$ $7.7\ 10^{-4}$	
Leptoquark 300 GeV 400 GeV 600 GeV 800 GeV	10.1 2.24 0.225 0.0378	463 2057 20,009 116,323	1.77 1.22 1.11	0.70 0.54 0.48	0.110 0.089 0.078	0.019 0.016 0.014	+ S_T-cut + mass-cut + mE_T/S_T-cut

Triggering

Trigger efficiency of selected m_{LQ} = 400 GeV pair events (after S_T-cut):

L1_Mu40: 96.66%

L2_Mu6: 99.22%
EF_Mu6: 99.15%

L2_Mu6I: 99.36%
EF_Mu6I: 99.22%

L2_Mu20i: 97.44% (no isolation/starts with L1_Mu20)
EF_Mu20i: 97.23% (no isolation)

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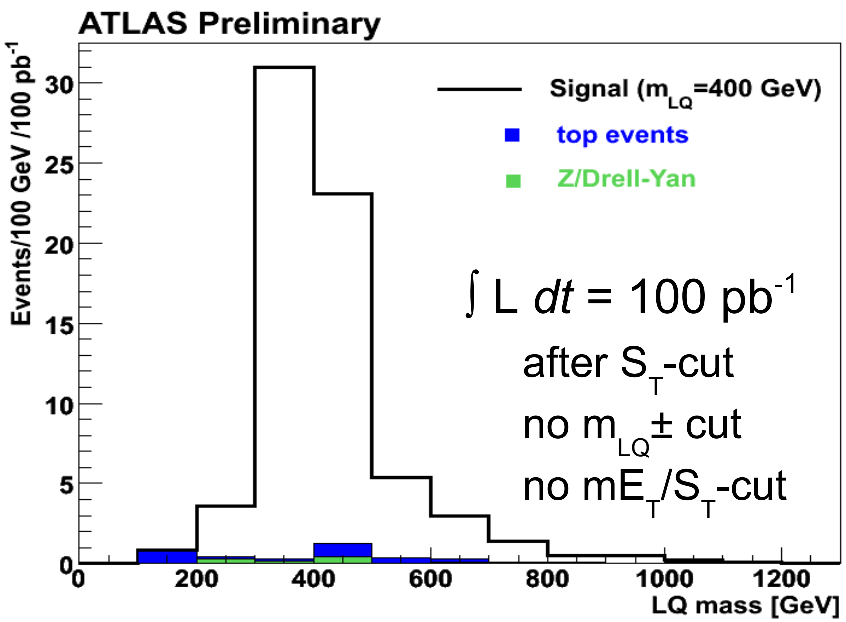
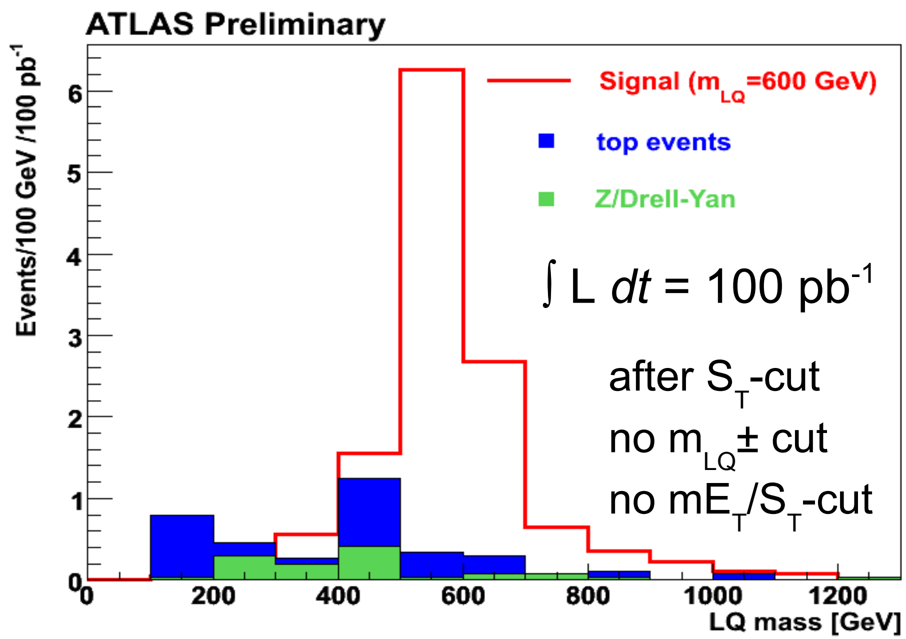
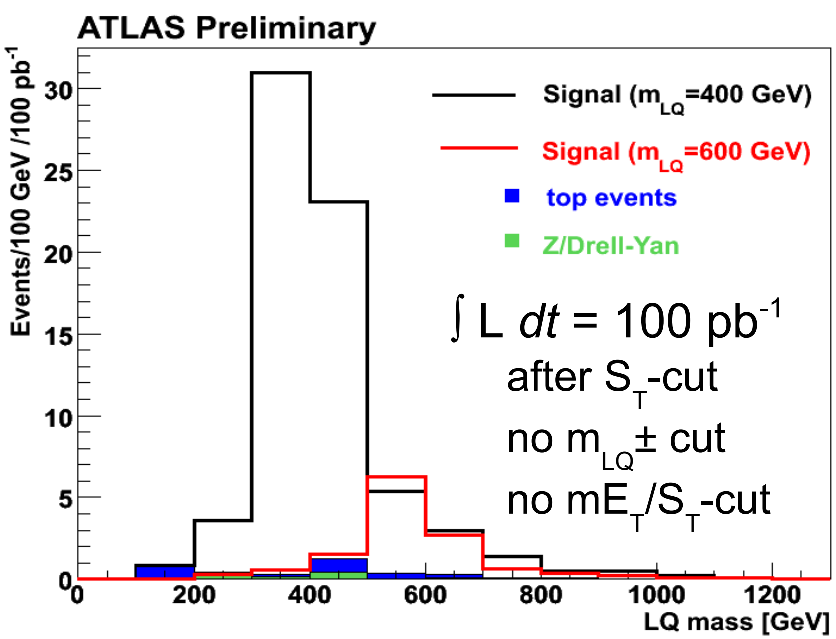
Exclusion limits







after all cuts (incl. m_{LQ}±-cut and mE_T/S_T-cut)

ATLAS Preliminary

Leptoquark mass	Expected Luminosity for exclusion with 95% C.L.
300 GeV	2.8 pb^{-1}
400 GeV	6.6 pb^{-1}
600 GeV	40 pb^{-1}
800 GeV	220 pb^{-1}

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Conclusions

- backgrounds suppressed quite well
- high trigger efficiency
- Leptoquarks up to around m_{LQ} = 600 GeV can be discovered or excluded already in the early phase of the LHC

Outlook

- study of pile-up samples
- contributing to dilepton-jets CSC note
- analysis with advanced statistical tool TMVA ?

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