Search for Pair Production of 1st Generation Scalar Leptoquarks Using Events Containing 2 Electrons and 2 Jets Produced in pp Collisions at $\sqrt{s}$=7 TeV

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Overview

The analysis is performed by the group of the University of Maryland and is described in CMS PAS EXO-10-005. This talk is based on the slides of Paolo Rumerio

- Intro to Leptoquarks (LQ's)
- 1st generation LQ: analysis strategy for the eejj channel
- Data and MC samples
  - int. lum. = 1.1 pb^{-1}
- Data - MC comparison
  - After electron and jet pre-selection
- Optimization and final selection
- Estimates of the backgrounds
  - Z+jets and ttbar (dominant); and QCD multi-jets (small)
- Systematic uncertainties
- Upper limit and M_{LQ} exclusion

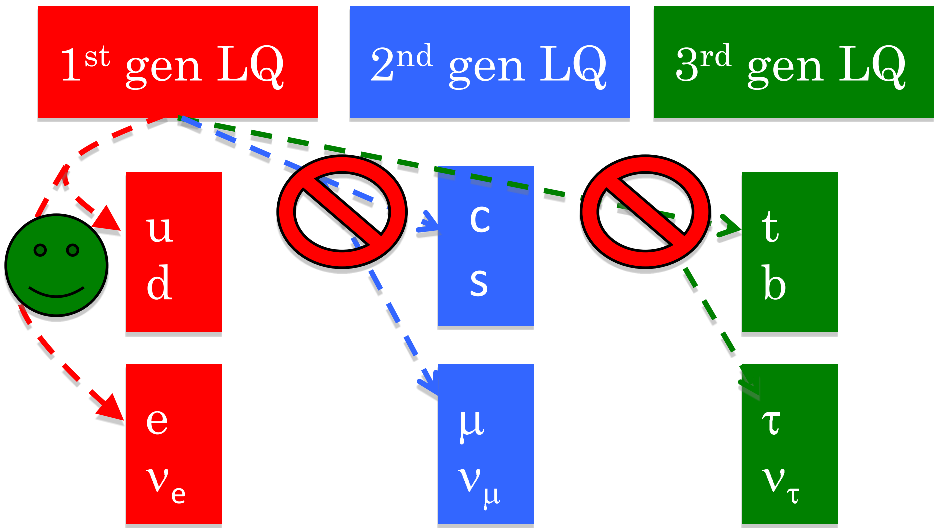
Introduction on Leptoquarks

- Leptoquarks (LQ) are conjectured exotic particles that carry both color and lepton quantum number, fractional charge, and primarily decay in leptons and quarks (GUT, Technicolor, Composite models, …) [**D. E. Acosta and S. K. Blessing, Leptoquark searches at HERA and the Tevatron, Ann. Rev. Nucl. Part. Sci. 49 (1999) 389434. doi:10.1146/annurev.nucl.49.1.389]**

- Experimental limits on lepton number violation, flavour-changing neutral currents, and proton decay favor three generations of LQs (for LQ masses directly accessible at the current colliders) [**S. Davidson, D. C. Bailey, and B. A. Campbell, Model independent constraints on leptoquarks from rare processes, Z. Phys. C61 (1994) 613644, arXiv:hep-ph/9309310. doi:10.1007/BF01552629]**

Introduction on Leptoquarks (2)

- In the scenario considered here, a LQ couples to a lepton from the same Standard Model generation. Inter-generational mixing is forbidden.
- Pair production of LQs via *gg* fusion dominates at LHC, single production becomes comparable only at M = ~ 1 TeV [**Kramer, M. and 479 Plehn, T. and Spira, M. and Zerwas, P. M., Pair production of scalar leptoquarks at the CERN LHC, Phys. Rev. D 71 (Mar, 2005) 057503. doi:10.1103/PhysRevD.71.057503],**
[A. Belyaev, C. Leroy, R. Mehdiyev, and A. Pukhov, Leptoquark single and pair production at LHC with CalcHEP/CompHEP in the complete model, JHEP 09 (2005) 005, arXiv:hep-ph/0502067]

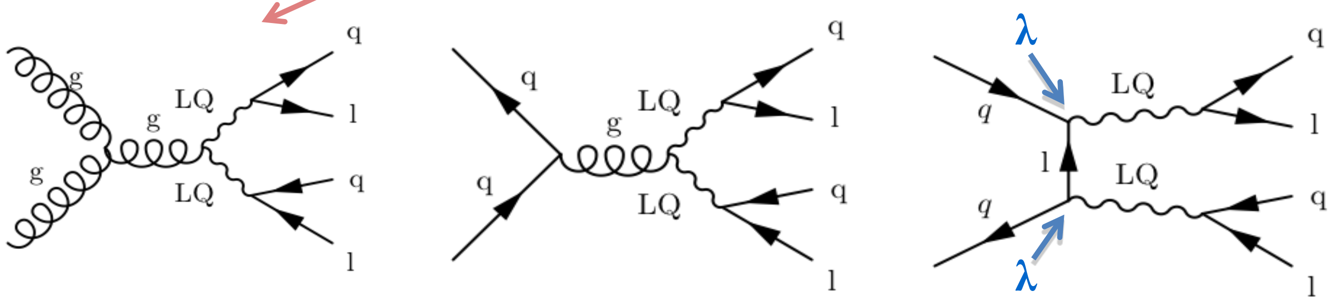


M_{LQ}	LQ mass
λ	l-q-LQ coupling
β	BR(LQ→$l^{+/-}$ + q)
LQs can be scalar* or vector	

(*) In this study

LQ production at hadron colliders

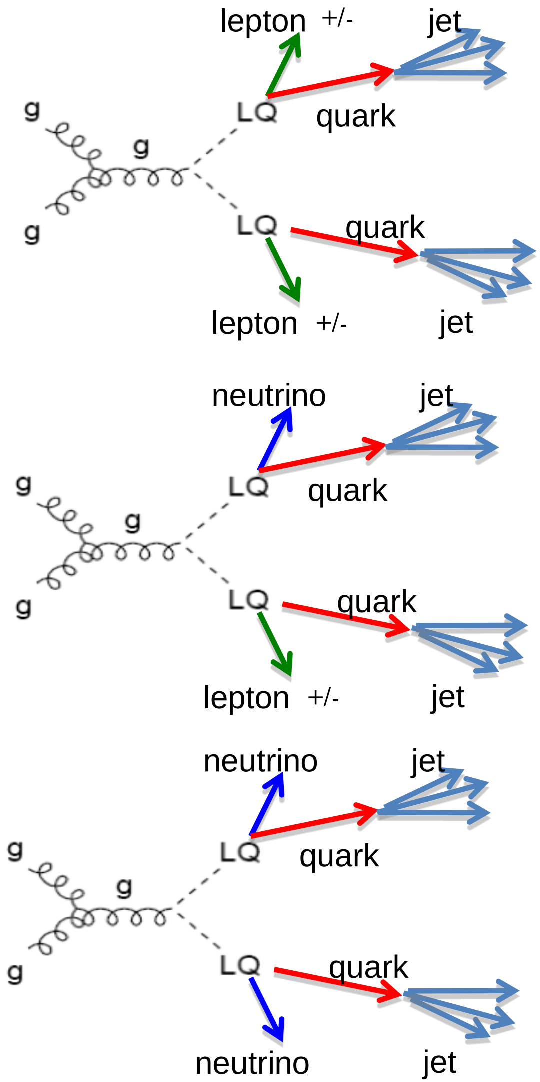
- Pair production of LQs via *gg* fusion
  - pair production almost independent from LQ-l-q coupling (λ)



- Single LQ production becomes comparable only at $M_{LQ} \approx$ 1 TeV for $\lambda \approx \lambda_{EM}$ (well above the current reach of CMS) [4]
- Results from HERA restrict λ to be small ($< \lambda_{EM} \approx 0.3$) for M_{LQ}<300 GeV/c^2 [5, 6]
- This analysis is sensitive to a large range of couplings for which the LQ decays promptly and with small width
  - $\Gamma_{LQ}/M_{LQ} = \lambda^2/16\pi \approx 0.2\%$ for $\lambda \approx \lambda_{EM}$, measurement dominated by calorimeter resolution

Signature of LQ decays

- β is an unknown parameter
  - BR(LQ $\rightarrow l^{+/-} + q$) = β
  - BR(LQ $\rightarrow \nu + q$) = 1-β
- 3 different signatures
  - **lljj**: 2 charged leptons + 2 jets
  - **lνjj**: 1 charged lepton + 2 jets + MET
  - **ννjj**: 2 jets + MET
- 3 LQ generations
  - 1st gen: electrons (e)
  - 2nd gen: muons (μ)
  - 3rd gen: taus (τ)



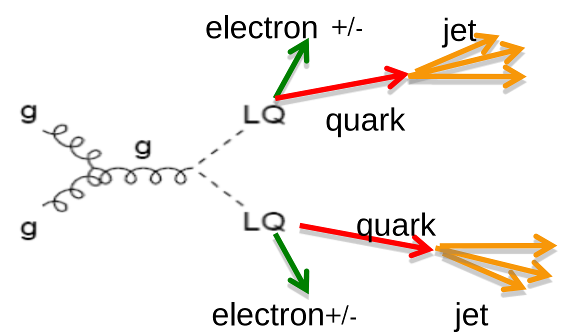
lljj β^2

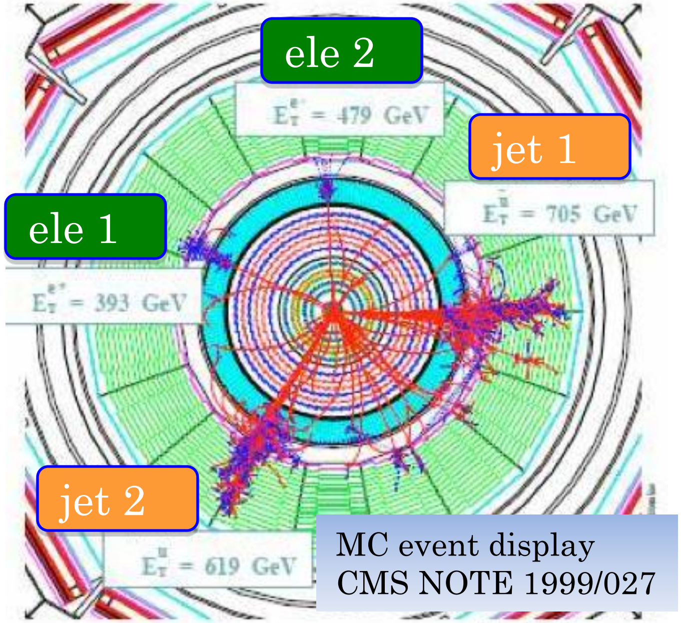
lνjj $2(1-\beta)\beta$

ννjj $(1-\beta)^2$

1^{st} Gen. LQ - Analysis strategy

- Search for 1st generation scalar LQ in the *eejj* channel
- Robust and efficient e.m. trigger
- HEEP (High Energy Electrons and Photons) electron selection
- Optimization of kinematic selection to minimize upper limit on LQ cross section
  - 2 isolated high-Pt electrons, 2 high-Pt jets
  - A cut on Mee to remove Z+jet bkg
  - $S_T = p_T(e1) + p_T(e2) + p_T(j1) + p_T(j2) > f(M_{LQ})$
- Background estimation:
  - The data-driven techniques developed for 100 pb^{-1} [8] cannot yet be applied with the current luminosity
  - MC is used for main backgrounds (Z+jets and ttbar)
    - A combined data-driven and MC strategy is used to assess the uncertainty
  - The small QCD background is determined from data





Data Sample

- Primary and secondary datasets containing HLT_Photon20
  - HLT trigger almost 100% efficient for LQ signal events

- Total integrated luminosity 1.1 pb^{-1} (+-11%) of certified data
- Applied basic event selection:
  - Skim: at least 1 supercluster with Pt>10 GeV/c
  - Firing of BPTX coincidence
  - >25% of high purity tracks, if there are more than 10 tracks
  - At least 1 primary vertex (ndof≥5) with |z|<15 cm
- ➢ ECAL and HCAL cleaning of beam-induced noise

Cut	Events in Data
No Cut	22164492
Skim	18263968
Beams Crossing (BPTX trigger)	17890974
No Beam-Induced Bkg in Pixels	17890496
Good Primary Vertex	17696848

MC signal samples

- LQ samples produced with
  - Pythia 6.422 and PDF CTEQ6L1
  - CMSSW 3_5_6
  - LQ parameters: small resonance width, β=1
- Sample production:
  - FullSim spring 2010 production for M_{LQ} = 300 GeV/c^2
  - FullSim private production for M_{LQ} = 100, 200 GeV/c^2

LQ mass (GeV)	N. Events Generated	Equivalent Luminosity (pb^{-1})	σ_{NLO} (pb) $\mu = M_{LQ}$	$\mu = M_{LQ}/2$	$\mu = 2M_{LQ}$	δ_σ (pb) due to PDF unc.
100	50k	1.12×10^2	386	444 (+15%)	333 (-14%)	13.4 (±3.5%)
200	50k	4.20×10^3	11.9	13.5 (+13%)	10.2 (-14%)	0.97 (±8.2%)
300	50k	4.13×10^4	1.21	1.37 (+13%)	1.04 (-14%)	0.16 (±13%)

Cross sections and uncertainties from [3]

MC background samples (Spring 2010 production)

- MC samples for estimating background contribution:
  - ttbar + jets events, MADGRAPH, inclusive production, inclusive top decays, $\sigma_{NNLO,\ Approx}$;
  - Z/γ + jets events (<= 5 jets), ALPGEN, in bins of Pt from 0 to 1600 GeV/c, Z decaying into leptons (e, μ, τ), σ_{NNLO};
  - W + jets events (<= 5 jets), generated using ALPGEN, in bins of Pt from 0 to 1600 GeV/c, W decaying into leptons (e, μ, τ), σ_{NNLO};
  - VV events (VV = WW, WZ or ZZ), generated with PYTHIA, inclusive W and Z decays, σ_{NLO};
  - Single top events, MADGRAPH, inclusive production of s, t and tW channels, inclusive top decays, σ_{NLO}.

Main Bkgs (ttbar + jets, Z/γ + jets)

"Other Bkgs" in next slides & plots (W + jets, VV, single top)

Electrons, Jets and Event pre-selection

- Electrons: standard reconstruction with ID and isolation optimized for high Pt (HEEP)
  - Not in the ECAL barrel-endcap gap ($|\eta| < 1.442$ or $1.560 < |\eta| < 2.5$)
- Jets: CaloJets, anti-kt algorithm with cone radius $\Delta R = 0.5$
  - Relative (L2) and absolute (L3) jet corrections
  - Residual jet energy correction applied to jets in data [10]
  - Recommended "loose Jet ID" to remove anomalous noise in calorimeters
  - Given a selected electron, the closest jet within ΔR=0.3 is removed
- Pre-selection:

  Use relatively low Pt cuts to allow enough data to compare data and MC
  - 2 electrons: Pt > 25 GeV/c and $|\eta|<2.5$
  - 2 jets: Pt > 20 GeV/c and $|\eta|<3.0$
  - Min ΔR between any of the 2 selected electrons and any of the 2 selected jets > 0.7

Z+jets MC normalization

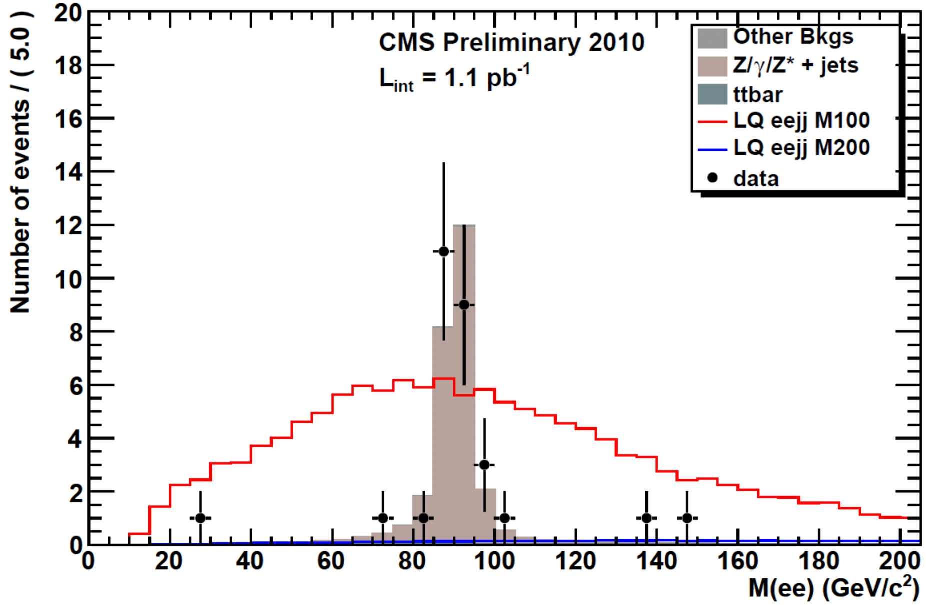
After pre-selection:

- The shape of data and MC distributions agree (see next slides)
- The number of events in data is ~1.5 σ larger than in MC

2 eles Pt>25 GeV/c, |η|<2.5
2 jets Pt>20 GeV/c , |η|<3
DR(e,j) > 0.7

hence:

- We rescale up the MC by the ratio DATA/MC(at the Z) = 24/16 ≈ 1.5, obtained after pre-selection and requiring events at Z peak ($80<M_{ee}<100$ GeV/c^2)
- We quote a systematic uncertainty on the rescaling of the Z+jets MC derived from the stastistical error on the DATA: 1/sqrt(24) = 20%



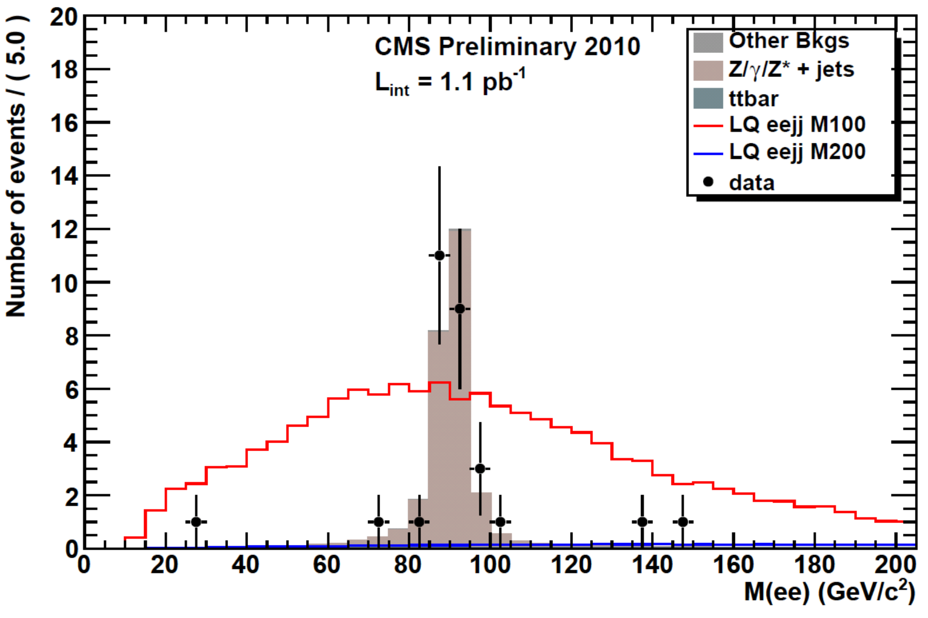
Events in MC Signal	Selection Efficiency	Events in MC samples $t\bar{t}$ + jets	Z/γ + jets	Other Bkgs	All Bkgs	Events in Data
7.19±0.03	0.55±0.00	0.76±0.01	27.0±0.2	0.35±0.01	28.1±0.2	29

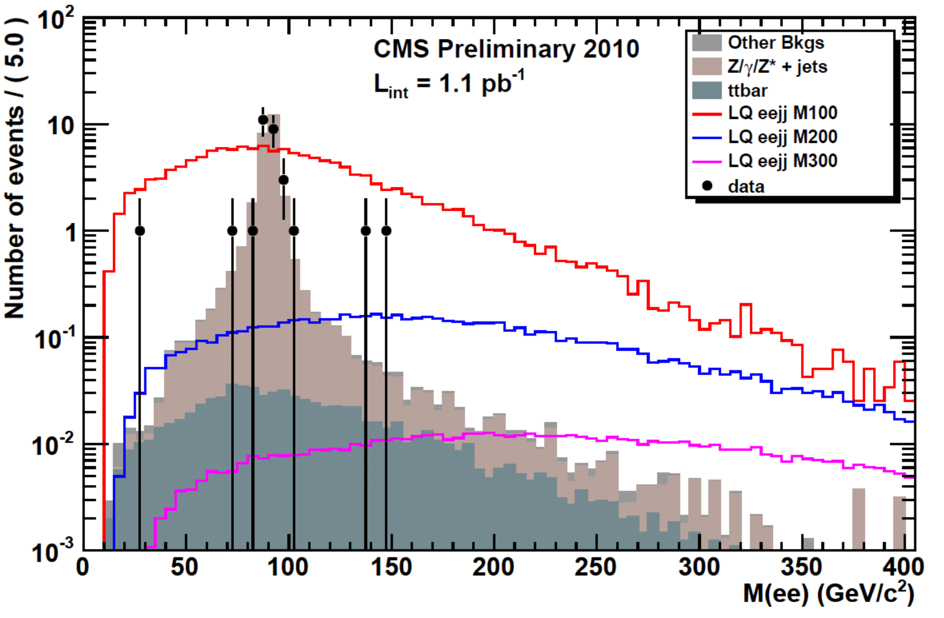
After Z+jets MC rescaling

→ All plots and tables in the following slides have the Z+Jets rescaling applied.

Mee after Pre-selection

- Linear and log scale

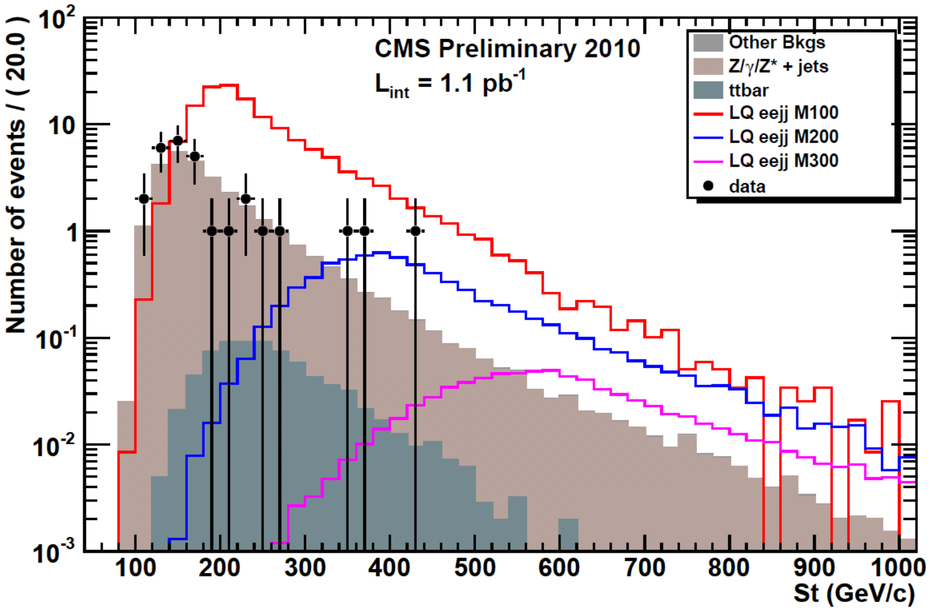


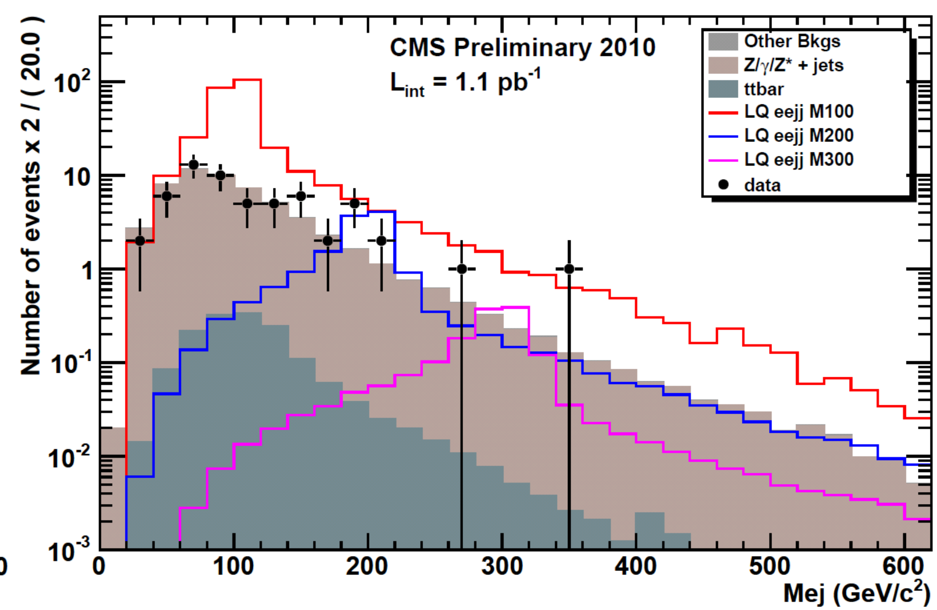


2 eles Pt>25 GeV/c, |η|<2.5
2 jets Pt>20 GeV/c , |η|<3
ΔR(e,j) > 0.7

S_T and Mej after pre-selection

- Left plot: S_T (scalar sum of the Pt of the 4 objects)
- Right plot: electron-jet invariant mass
  - There are 2 ways to combine 2 electrons and 2 jets to make 2 candidate LQ's; the pair of Mej values with minimum difference is used





2 eles Pt>25 GeV/c, |η|<2.5
2 jets Pt>20 GeV/c , |η|<3
ΔR(e,j) > 0.7

Selection optimization

- The final selection is based on 7 variables
- Min Pt and max η of electrons and jets optimized by maximizing S/√(S+B)
- M_{ee} and S_T (the most signal-background discriminating variables) are optimized as a function of M_{LQ} for the 1 pb^{-1} luminosity scenario
  - by minimizing upper limit to LQ cross section in absence of observed signal, set with a Bayesian method [8]

Final, optimized selection

M_{LQ}	$p_{T,electrons}^{min}$	$p_{T,jets}^{min}$	$\eta_{electrons}^{max}$	η_{jets}^{max}	M_{ee}	$\mathrm{Min}\Delta R(e,\mathrm{jets})$
All	>30 GeV/c	>30 GeV/c	<2.5	<3.0	>100 GeV/c^2	>0.7
100 GeV/c^2	S_T >140 GeV/c					
200 GeV/c^2	S_T >280 GeV/c					
300 GeV/c^2	S_T >380 GeV/c					

Expectations and plots for final selection

- After the final selection optimized shown in the previous slide:

M_{LQ} (GeV/c^2)	Events in MC Signal	Selection Efficiency	Events in MC samples $t\bar{t}$ + jets	Z/γ + jets	Other Bkgds	All Bkgs	Events in Data
100	50.2±0.6	0.12±0.00	0.303±0.006	0.63±0.03	0.044±0.004	0.97±0.03	2
200	5.17±0.03	0.39±0.00	0.163±0.005	0.23±0.01	0.019±0.003	0.42±0.01	0
300	0.688±0.003	0.52±0.00	0.054±0.003	0.099±0.006	0.007±0.001	0.160±0.007	0

  - The small QCD multi-jets background is discussed later

QCD multi-jets background

- Small background that can be estimated from data:
  - by fake rate method applied to events with 2 isolated (super)clusters and 2 jets (ccjj sample)

$$N_{eejj}^{QCD} = \sum_{ccjj \text{ events in data}} P(e|c_1) \times P(e|c_2)$$

- Fake rate, P(e|c), determined on a dijet-like sample:
  - At least one isolated (HoE<0.05) supercluster Pt>10 GeV/c (ECAL-spike cleaned)
    → NEW: added EcalIso request to the definition of supercluster
  - At least one jet Pt>10 GeV/c and Δϕ(jet,supercluster) > 3.0
  - If more than 1 supercluster, inv. mass of any pair not within 60-120 GeV/c^2
  - Reconstructed PF MET < 10 GeV

Contamination of W→υe & Z →ee reduced to 2%, while γ+jets is 10% (from MC study)

- Fake rate is compatible with constant:

EB

$$P(e|c)_{barrel} = (7.1 \pm 0.3) \times 10^{-3}$$

EE

$$P(e|c)_{endcap} = (4.4 \pm 0.1) \times 10^{-2}$$

QCD multi-jets background

- Contamination-corrected (from MC) fake rates for W/Z and γ+jets :

$$P(e|c)_{barrel} = (6.1 \pm 0.3) \times 10^{-3} \qquad P(e|c)_{endcap} = (4.0 \pm 0.1) \times 10^{-2}$$

- Estimate of N_{eejj}(QCD) obtained using the corrected fake rates:

M_{LQ} (GeV/c^2)	N^{data}_{ccjj}	N^{QCD}_{eejj}	
100	243	0.079 ± 0.007	← 8% of ALLBKG
200	47	0.013 ± 0.002	← 3%
300	13	0.003 ± 0.001	← 2%

This is the range where we set the M_{LQ} lower limit.

- Closure test using 1.1 pb^{-1} of DATA
  - predict number of ecj events by applying the fake rate to ccj :
    - Predicted = 66.7 +- 1.6 (was 74.9 +- 1.7 with uncorrected fake rates)
    - actual = 38.3 (was 51 without contamination correction)
  - |predicted - true| / true = 0.74 +- 0.32
  - Systematic error from ccj → ecj closure test: 75% (To be doubled for ccjj → eejj)
  - St shape compatible
  - Highest **$S_T = P_T(c1)+P_T(c2)+P_T(j)$** in DATA of about 260 GeV

Systematic uncertainties

Systematic Uncertainty	Magnitude	Effect on Signal Efficiency	Effect on $N_{t\bar{t}}$	Effect on $N_{Z/\gamma+\text{jet}}$	Effect on N_{AllBkg}
Jet Energy Scale	±10%	±3%	±12%	±19%	±16%
Electron Energy Scale	±1(3)%	±1%	±4%	±16%	±10%
Integrated Luminosity	±11%	-	±11%	±11%	±11%
MC Statistics	See slide 17	±1%	±3%	±5%	±3%
Electron Reco/ID/Iso	†	±20%	±20%	±20%	±20%
MC normalization to data	†	-	-	±20%	±11%
ISR/FSR	†	±5%	±30%	±40%	±33%
PDF	†	±0.5%	±7%	±5%	±5.5%
Fact/Ren scale	†	-	-	±2%	±1%
QCD estimate	150%	-	-	-	±5%
Total		±21%	±40.5%	±56.5%	±46.5%

This table refers to M_{LQ} = 200 GeV/c^2

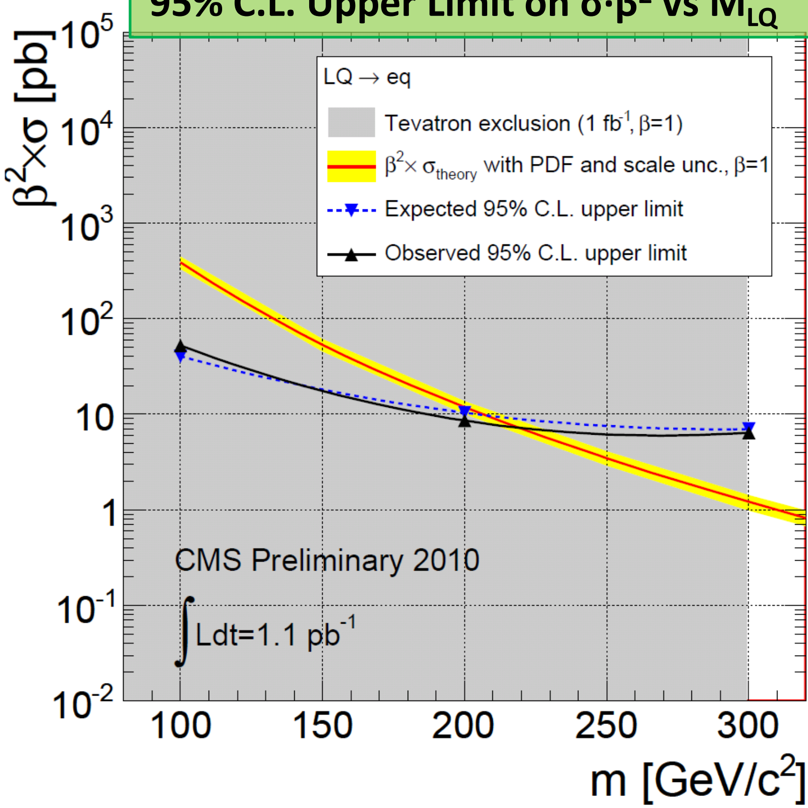
The effect on AllBkg takes into account relative Z+jets and ttbar contributions and their correlation in each specific case

- Jet/electron energy scales: re-ran analysis with modified scales
- Electron Reco/ID/Iso: determined using W→υe [11] with 100 nb-1 of data
- MC renormalization is described in previous Z+jets slide
- Initial/Final State Radiation: LQ, Z+jets and ttbar FastSim samples generated with Pythia using modified ISR/FSR parameters as prescribed in [12]
- PDF and renormalization/factorization effect on cross sections:
  - provided by M. Kraemer for LQ at 7 TeV [3]; from CMS twiki [9] for bkgs
- PDF effect on signal and bkg efficiencies: determined using re-weighting technique

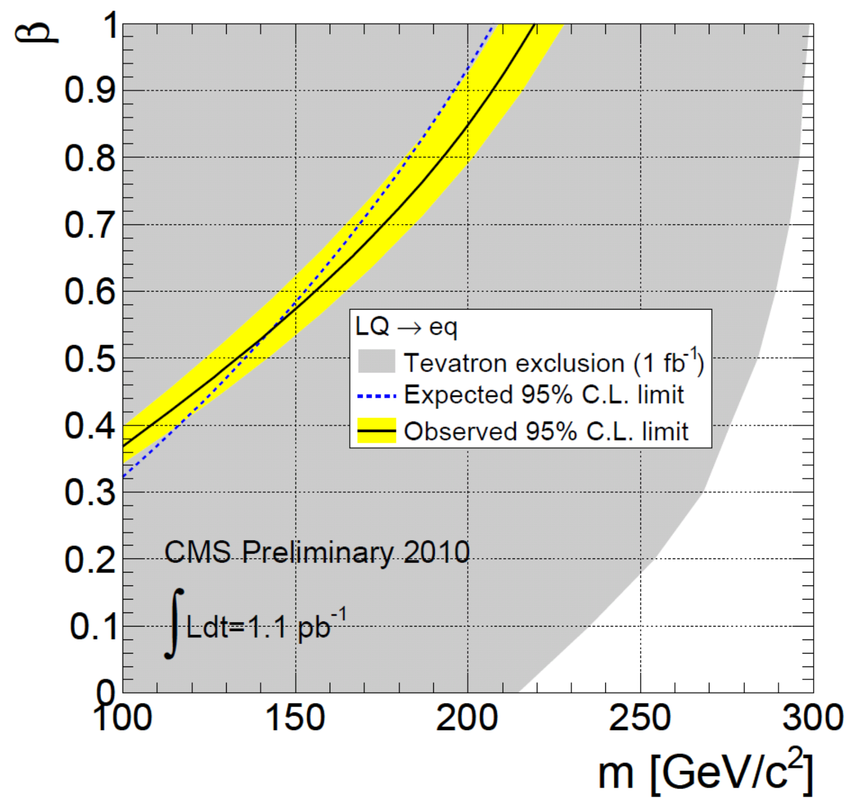
Upper limit and M_{LQ} exclusion

- Observation from data are consistent with SM bkg expectations
  - an upper limit on the LQ cross section is set using a Bayesian approach [8]
    - Systematic uncertainties are included in the upper limit calculation
- A lower limit on the LQ mass is set to 220 GeV/c^2 for β=1
  - The Tevatron limit is 299 GeV/c^2 [7]

95% C.L. Upper Limit on $\sigma \cdot \beta^2$ vs M_{LQ}



Min. β for 95% C.L. LQ Exclusion vs M_{LQ}



References

[1] : D. E. Acosta and S. K. Blessing, Leptoquark searches at HERA and the Tevatron, Ann. Rev. Nucl. Part. Sci. 49 (1999) 389434. doi:10.1146/annurev.nucl.49.1.389.

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[3] : Kramer, M. and 479 Plehn, T. and Spira, M. and Zerwas, P. M., Pair production of scalar leptoquarks at the CERN LHC, Phys. Rev. D 71 (Mar, 2005) 057503. doi:10.1103/PhysRevD.71.057503;

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[4] : A. Belyaev, C. Leroy, R. Mehdiyev, and A. Pukhov, Leptoquark single and pair production at LHC with CalcHEP/CompHEP in the complete model, JHEP 09 (2005) 005, arXiv:hep-ph/0502067.

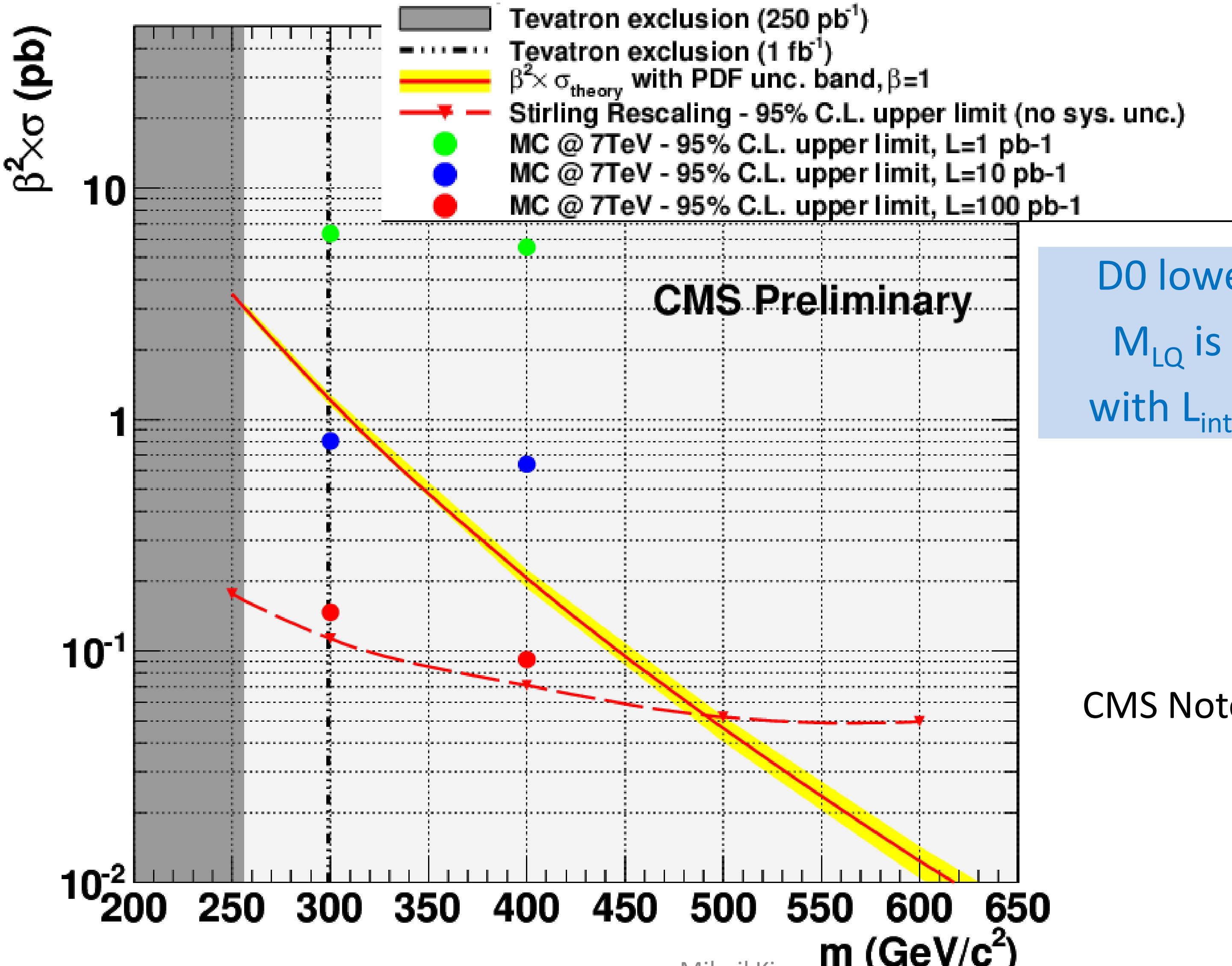
[5] : H1 Collaboration, A. Aktas et al., Search for leptoquark bosons in e p collisions at HERA, Phys. Lett. B629 (2005) 919, arXiv:hep-ex/0506044. doi:10.1016/j.physletb.2005.09.048.

[6] : Ilias Panagoulias, Search for Leptoquarks and Contact Interactions at HERA, 18th International Workshop on Deep Inelastic Scattering and Related Subjects (DIS 2010), April 19-23, 2010, Florence, Italy

[7] : D0 Collaboration, "Search for pair production of first-generation Leptoquarks in ppbar collisions at sqrt(s)=1.96 TeV", Phys.Lett.B681:224-232,2009

[8] : CMS PAS EXO-08-010, "Search for Pair Production of First Generation Scalar Leptoquarks at the CMS Experiment"

Expected Upper Limits for M_{LQ}=300-400 GeV/c^2 with Int. Lum.=1, 10, 100 pb^{-1}



D0 lower limit on M_{LQ} is 299 GeV with L_{int}=1 fb^{-1} [7]

CMS Note 2010/008

Conclusions

- A search for pair production of 1st generation scalar LQ's was performed with 1.1 pb^{-1} of integrated luminosity
- After a pre-selection, data and MC kinematics distributions are in good agreement and the Z+jets MC is normalized to data at the Z peak
- After applying a tighter selection, optimized for exclusion of the LQ hypothesis, the observed number of events agree with SM expectation
- The main systematic uncertainties have been estimated
- A Bayesian approach that includes treatment of the systematic uncertainties as nuisance parameters is used to set limits on the LQ cross section
- By comparing such upper limits to a theoretical calculation of the LQ cross section, the existence of LQ's with mass below 220 GeV/c^2 are excluded for β=1
  - this result does not yet extend the region of LQ masses excluded by the Tevatron

Analyses in progress

- A similar search for pair production of 2nd generation scalar LQ's is in the process of approval
- Searches for leptoquarks in the channels with a lepton, neutrino and two jets are underway, results are expected later this year or early next year.
- In the same Exotica subgroup searches for Right-handed W and heavy neutrino of the Left-right symmetric model are underway by the INR (Moscow) – Minnesota group. This analysis deals with the same final state llqq. The interesting mass in this analysis is in higher masses (about 800 GeV), for this reason it requires the integral luminocity of at least 50/pb. The first results are expected early next year.

Backup

Z+Jets MC Cross section

- The Alpgen Z+jet datasets come in 21 bins of Pt and Njets
- For each bin, the cross section used in LQ1 analysis is

$$\sigma = \sigma_Z^{LO} * \varepsilon_{filter} * F$$

- Values of $\boldsymbol{\sigma_{tot}^{LO}}$ and ε_{filter} are reported at https://twiki.cern.ch/twiki/bin/view/CMS/ProductionReProcessingSpring10#ALPGEN
- F is a common factor applied for all bins such that

$$\Sigma_{all\ bins} (\sigma_Z^{LO} * \text{filter efficiency} * F) = \sigma_Z^{NNLO}$$

where σ_Z^{NNLO} is taken from the *StandardModelCrossSections* Twiki [9]
- We received feedback from Fabian Stoeckli (convener of generator group), who confirmed that this is the suggested procedure for the normalization of the Z+jet Alpgen sample
- We are using the value of σ_Z^{NNLO} relative to M_{ll} > 50 GeV cut, available at [9]
- We verified that the Z+jet Alpgen sample is generated with M_{ll}>40 GeV cut → we asked the generator group to provide the σ_Z^{NNLO} for this cut as well

Z+Jets
ALPGEN – MADGRAPH comparison

- Number of events after full pre-selection
  - 2 electrons Pt>25 GeV/c $|\eta|<2.5$
  - 2 jets Pt>20 GeV/c $|\eta|<3.0$
  - Min ΔR(eles, jets) > 0.7

```
DATA            : 29 +/- 5.38
-----------------------------------
ZJetAlpgen : 18.2 +/- 0.1
ZJetMadgraph : 19.1 +/- 0.2
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ALLBKG (with Alpgen) : 19.3 +/- 0.1
ALLBKG (with Madgraph) : 20.2 +/- 0.2
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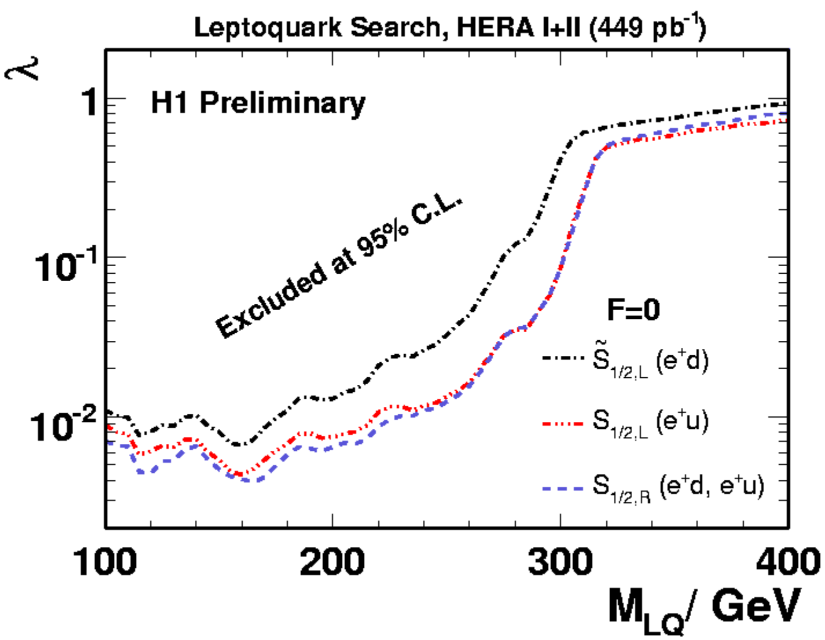
ALPGEN
data/MC at Z peak = 1.48 +- 0.31

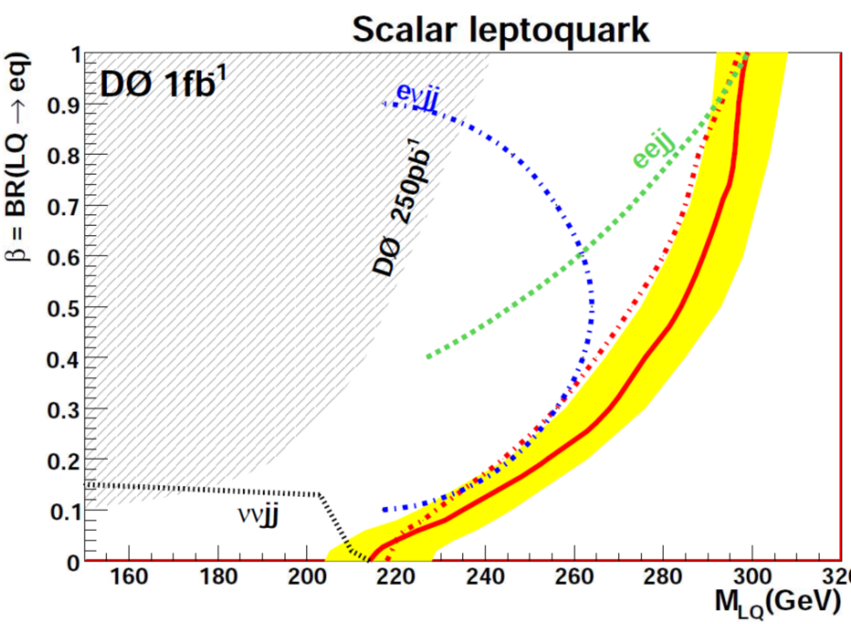
MADGRAPH
data/MC at Z peak = 1.40 +- 0.29

Leptoquarks
Tevatron and HERA Reach

Limits from HERA



Limits from D0



1st Gen. LQ in eejj - Trigger

- The presence of high energy electrons is exploited for the online selection of LQ pair events
- Trigger selection requires a single high E_T electromagnetic deposit without any isolation and track-matching (loose H/E and a shape requirements at L1 trigger)
  - Robust against initial detector mis-alignment and mis-calibration
- This selection is almost 100% efficient for electrons from LQ decays

M_{LQ} (GeV)	HLT_Photon15 _L1R	HLT_Photon25 _L1R
250	99.6%	99.3%
400	99.7%	99.6%

The HEEP Selection Cuts

HEEP Selection cuts v3.0

Official HEEP Selection v3.0 (Current Version)		
Variable	**Barrel**	**Endcap**
E_T	> 25 GeV	> 25 GeV
$\lvert\eta_{sc}\rvert$	< 1.442	$1.560 < \lvert\eta_{sc}\rvert < 2.5$
isEcalDriven	=1	=1
$\lvert\Delta\eta_{in}\rvert$	< 0.005	< 0.007
$\lvert\Delta\varphi_{in}\rvert$	< 0.09	< 0.09
H/E	<0.05	<0.05
$\sigma_{i\eta i\eta}$	n/a	<0.03
E^{2x5}/E^{5x5}	>0.94 OR $E^{1x5}/E^{5x5} > 0.83$	n/a
EM + Had Depth 1 Isolation	<2+0.03*Et	<2.5 for Et<50 else
		<2.5+0.03*(Et-50)
Had Depth 2 Isolation	n/a	<0.5
Track Isol: Trk Pt	<7.5	<15

Upper Limits: The Bayesian Approach

- 95% C.L. upper limit on the LQ pair production cross section *σ* is calculated using the Bayesian approach

$$\int_{-\infty}^{\sigma_{\rm up}(n)} p(\sigma|n, A, \mathcal{L}, b)\mathrm{d}\sigma = \frac{\int_{-\infty}^{\sigma_{\rm up}(n)} L'(n|\sigma, A, \mathcal{L}, b)\pi(\sigma)\mathrm{d}\sigma}{\int_{-\infty}^{+\infty} L'(n|\sigma, A, \mathcal{L}, b)\pi(\sigma)\mathrm{d}\sigma} = 0.95$$

$$L'(n|\sigma, A, \mathcal{L}, b) = \int_0^{+\infty}\int_0^{+\infty}\int_0^{+\infty} L(n|\sigma, A', \mathcal{L}', b')\underbrace{g(A')h(\mathcal{L}')f(b')}\mathrm{d}A'\mathrm{d}\mathcal{L}'\mathrm{d}b'$$

Flat prior

$$\pi(\sigma) = \begin{cases} 0 & \sigma < 0 \\ 1 & \sigma \geq 0 \end{cases}$$

$g(A'),\ h(\mathcal{L}'),\ f(b')$ Gaussian distributions describing uncertainties in *A*', $\mathcal{L}$, *b*'

Poisson distribution

$$L(n|\sigma, A', \mathcal{L}', b') = \frac{(\sigma A'\mathcal{L}' + b')^n}{n!}e^{-(\sigma A'\mathcal{L}' + b')}$$

- *n* = number of observed events
- *A* = acceptance×efficiency
- $\mathcal{L}$ = integrated luminosity
- *b* = expected number of background events