The University Of Sheffield.

Searches for - non-SUSY - new physics at ATLAS

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(On behalf of the ATLAS collaboration)

23rd Rencontres de Blois

Introduction

- Within the SM itself and based on calculations on SM:
  - Naturalness problem: Mass of yet-to-be-discovered Higgs boson

    Higgs? SUSY?
  - CP violation in SM not enough: Why more matter than antimatter?

    Does CKM triangle close? New flavor?
- Completely absent from SM:
  - No unification of the 3 forces

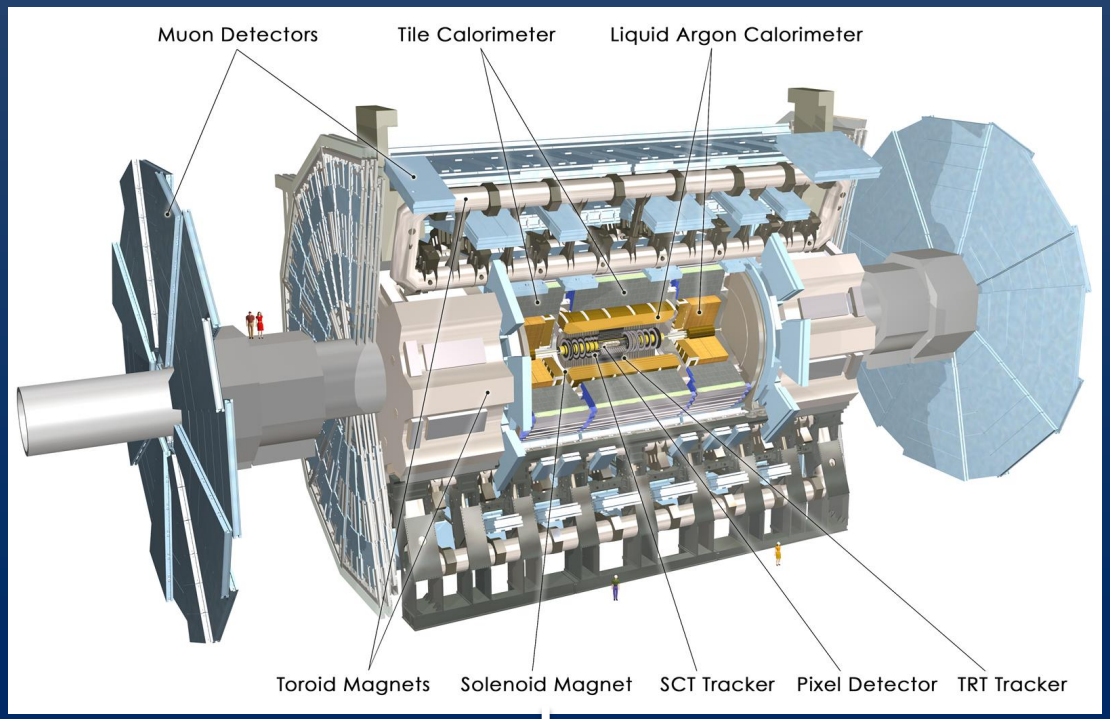
    Technicolor? E6?
  - Also where is gravity?

    Extra dimensions?
  - Why three families?

    4th generation?
  - Arbitrary "input" parameters. Why is $m_d > m_u$? Why $m_e < m_n - m_p$?

[See talk on Monday by Rohini Godbole – "Review of SUSY and Extra Dimensions"]

Outline

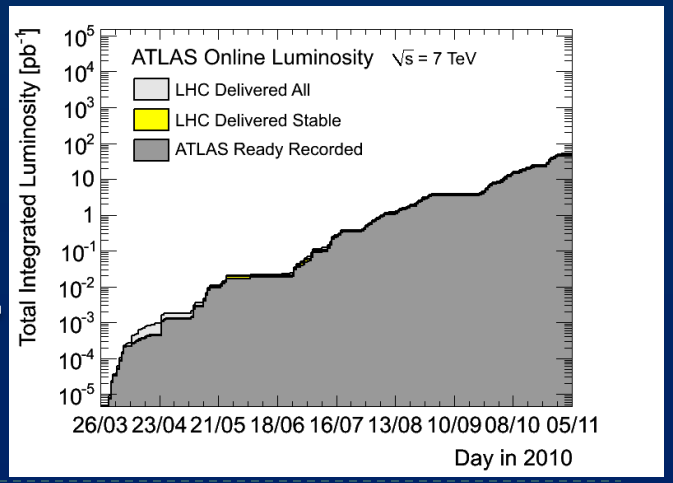


- Di-jet resonance
- ttbar resonance
- Leptoquarks
- Fourth generation quarks
- New Heavy bosons
- Contact interaction
- Randall-Sundrum Graviton

Results

ATLAS detector

~45 pb^{-1}

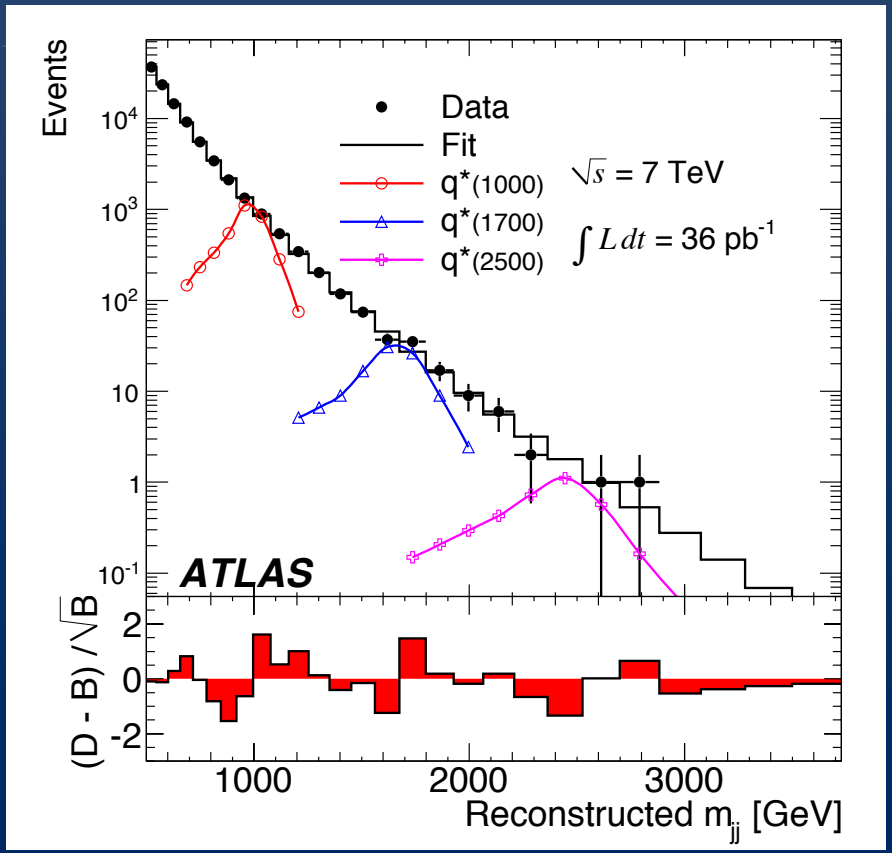


New physics in di-jet events

arxiv:1103.3864
J. Phys. 13 (2011) 053044

- These '2 → 2' scattering processes are well described within SM
  - sensitive to new phenomena
- Observables :
  - Di-jet invariant mass
  - Di-jet angular distributions of energetic jets relative to the beam axis
- Events with two highest p_T jets recoiling back to back with rapidities, y_1 and y_2

$$y^* = \frac{1}{2}\ln\left(\frac{1+|\cos\vartheta^*|}{1-|\cos\vartheta^*|}\right) = \frac{1}{2}(y_1 - y_2)$$



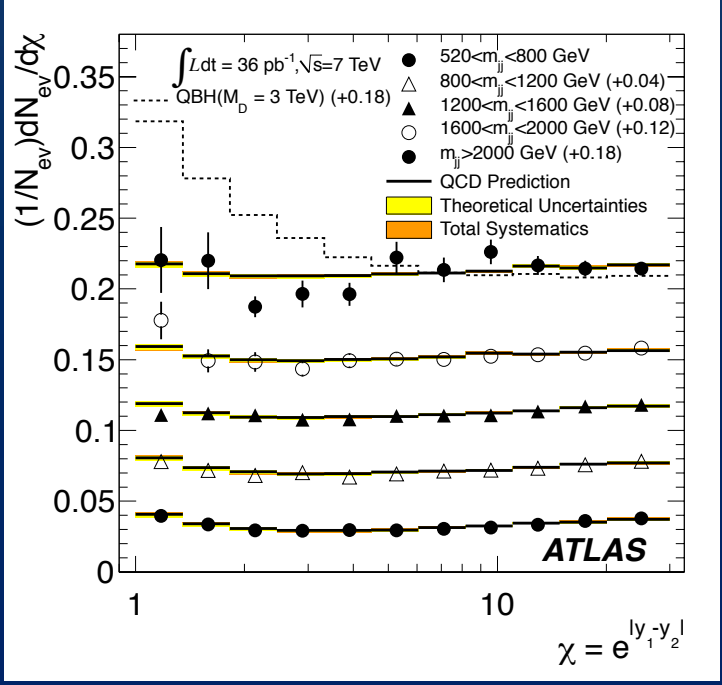
No evidence for a bump using :
χ^2 test ⟹ p-value 0.88
BumpHunter (Phys. Rev. D79: 011101)
Set exclusion limits

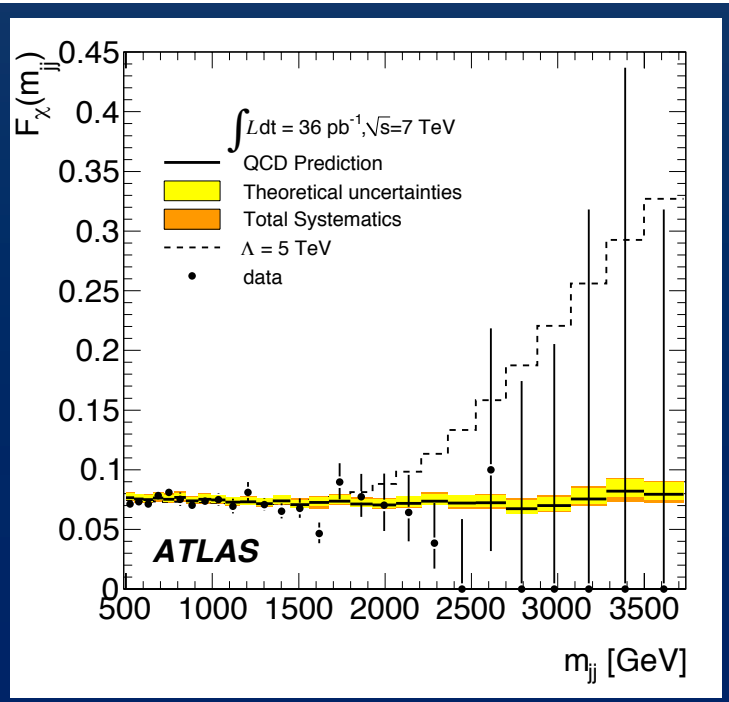
Di-jet angular distribution

- $\chi \equiv \exp(|y_1-y_2|)$ distribution is relatively flat for QCD
- Average of y_1 & y_2, $|y_B| < 1.10$ and $|y^*|<1.70 \Longrightarrow \chi \sim 30$

- Fraction of di-jets produced centrally versus total number of di-jets :

$$F_\chi\left(\left[m_{jj}^{\min} + m_{jj}^{\max}\right]/2\right) \equiv \frac{N_{events}\left(|y^*| < 0.6, m_{jj}^{\min}, m_{jj}^{\max}\right)}{N_{events}\left(|y^*| < 1.7, m_{jj}^{\min}, m_{jj}^{\max}\right)}$$

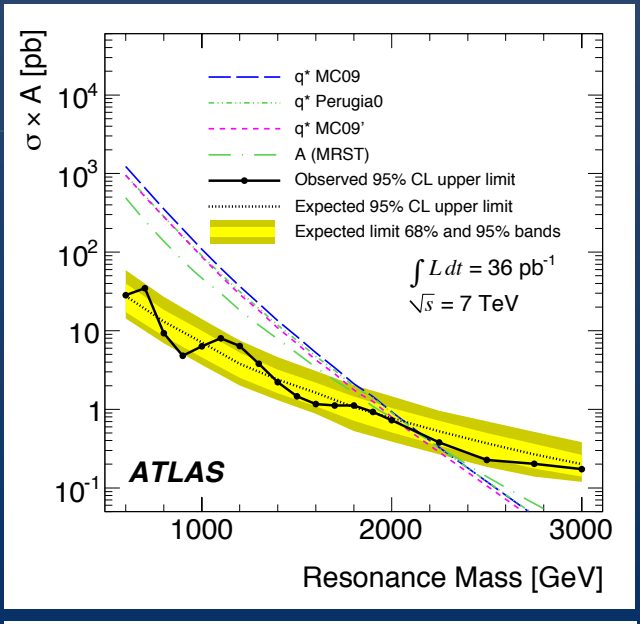


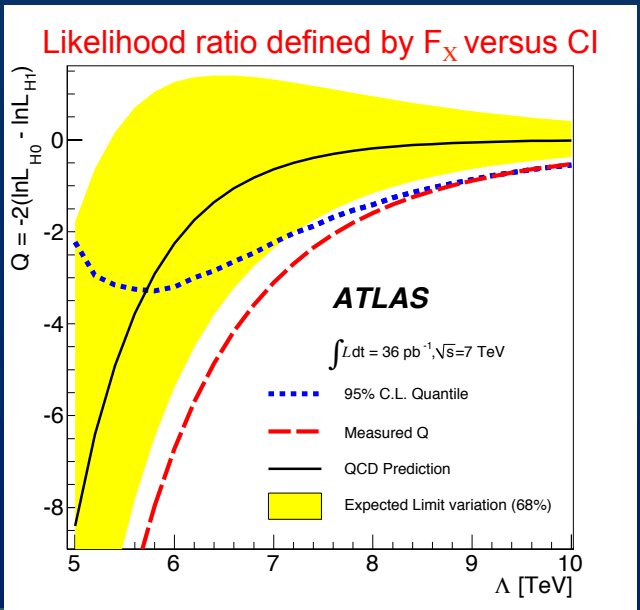


Di-jet Results

95% C.L. Limits (TeV)

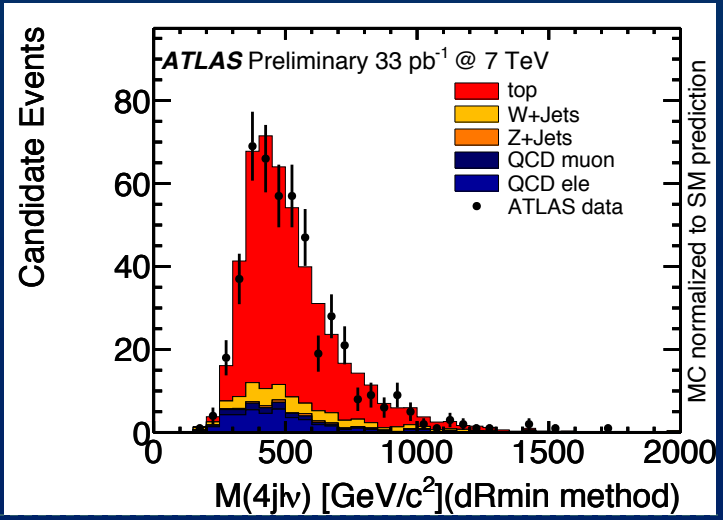
Observable	Expected	Observed
Exited quark q*		
m_{jj}	2.07	2.15
$F_X(m_{jj})$	2.12	2.64
Randall-Meade quantum black hole for n=6		
m_{jj}	3.64	3.67
$F_X(m_{jj})$	3.49	3.78
Axigluon		
m_{jj}	2.01	2.10
Contact interaction Λ		
$F_X(m_{jj})$	5.72	9.51

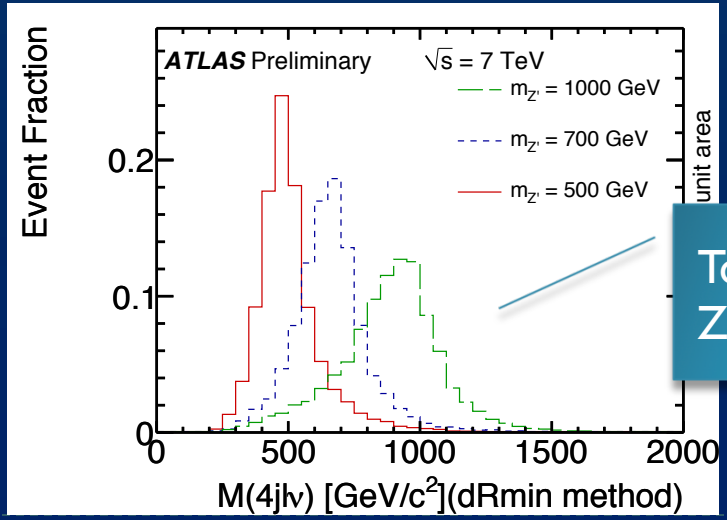




ttbar Resonances

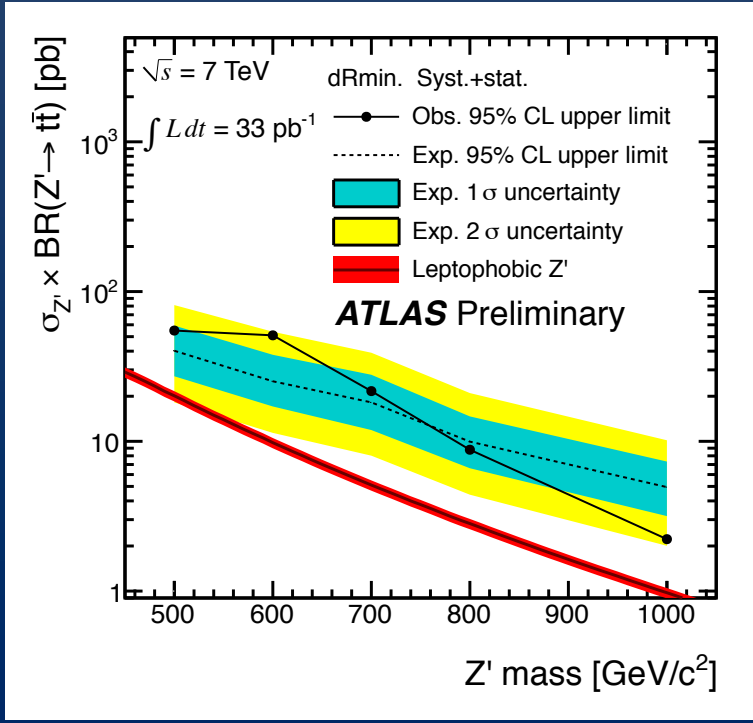
- Signature : (At least one W reconstructed leptonically):
  - High p_T isolated lepton (e,μ), at least four jets and large missing energy
- Observable :
  - Invariant mass of ttbar computed from the reconstructed objects in the final state
    - Objects are not assigned to either of the t (i.e. no t reconstruction)
- Two methods to reconstruct ttbar: 4 hardest jets - four highest p_T jets and dRmin method - as "4 hardest jet", removes jet if $\Delta R(j,\ell) > 2.5\text{-}0.015\times m_j$

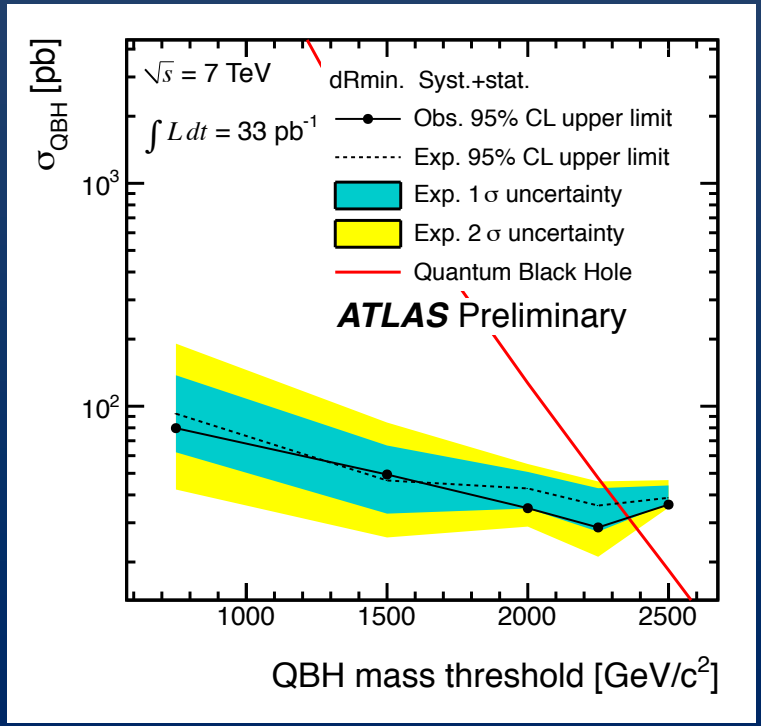




Topcolor Z' model

Limits on ttbar Resonances





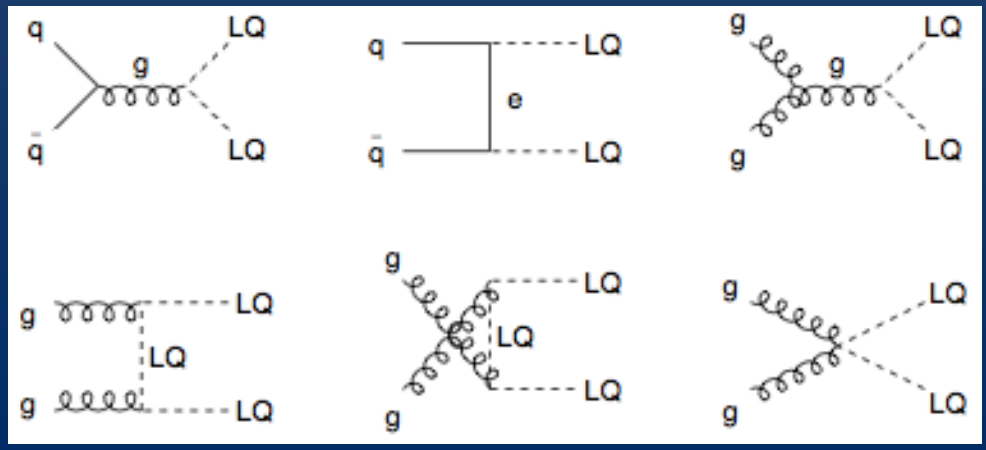
- The observed cross section limits on σ×Br(Z' → ttbar) ranges from 55 pb at M = 500 GeV to 2.2 pb at M=1000 GeV
- Exclude M_{QBH} < 2400 GeV @ 95% C.L.

Leptoquarks searches

arxiv:1104.4481
accepted by PRD

- Leptoquarks – particles that carry both lepton and baryon quantum numbers
- Many models predict leptoquarks
  - Quark and lepton sub-structure
  - Theories seek GUT
  - Extended technicolor
- LQ search - LQ pair production e/μ for 1st/2nd LQ generation through ℓℓjj and ℓνjj

Leptoquark production from qqbar annihilation or gluon fusion (hep-ph/9808413v1)



$$\sigma\left(pp \to lljj\right) \equiv \sigma_{LQ} \times \beta^2$$

$$\sigma\left(pp \to l\nu jj\right) \equiv \sigma_{LQ} \times 2\beta(1-\beta)$$

$$\beta \equiv Br(LQ \to l + X)$$

Leptoquarks searches

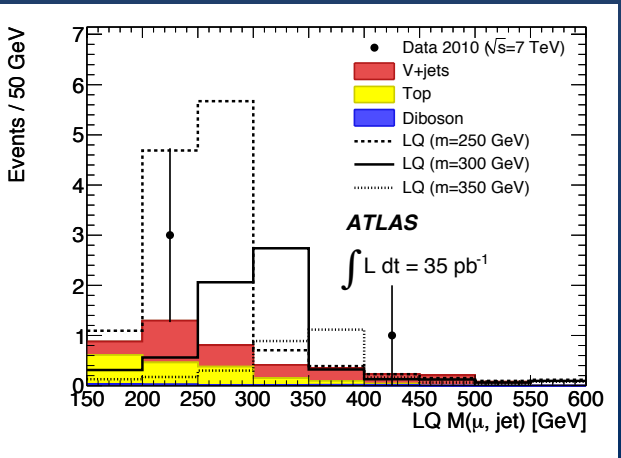
- Observables:
  - For ℓℓjj : Transverse energy in the event

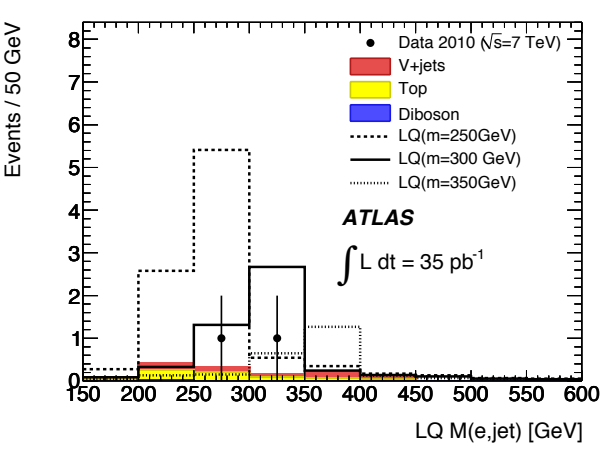
  or for ℓνjj : Transverse mass

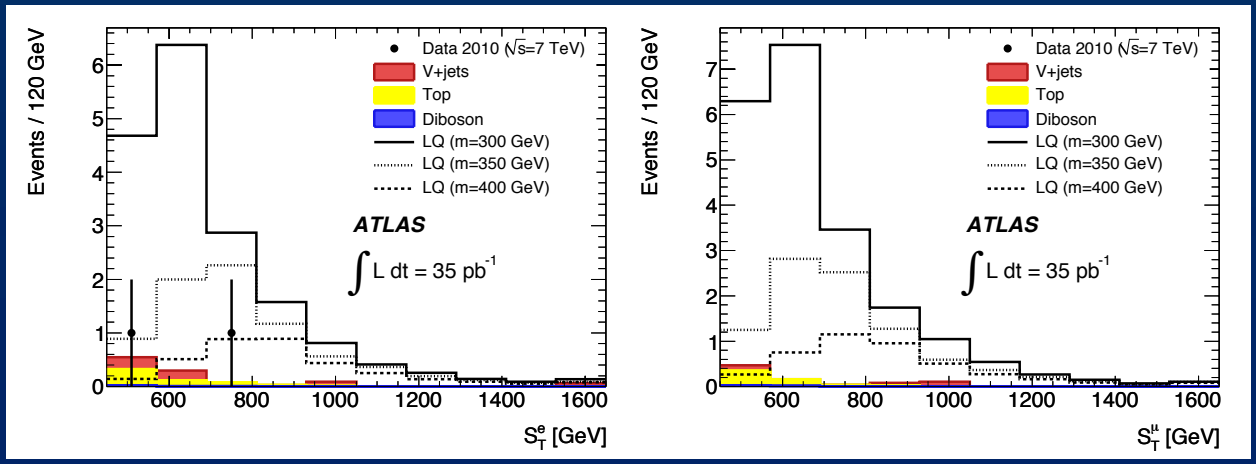
$$S_T^l = p_T^{l_1} + p_T^{l_2} + p_T^{j_1} + p_T^{j_2}$$

$$M_{LQ}^T = \sqrt{2 p_T^j E_T^{miss} (1 - \cos\phi^j)}$$

- Backgrounds :
  - ℓℓljj : Z+jet and ttbar and ℓνjj : W+jets and ttbar

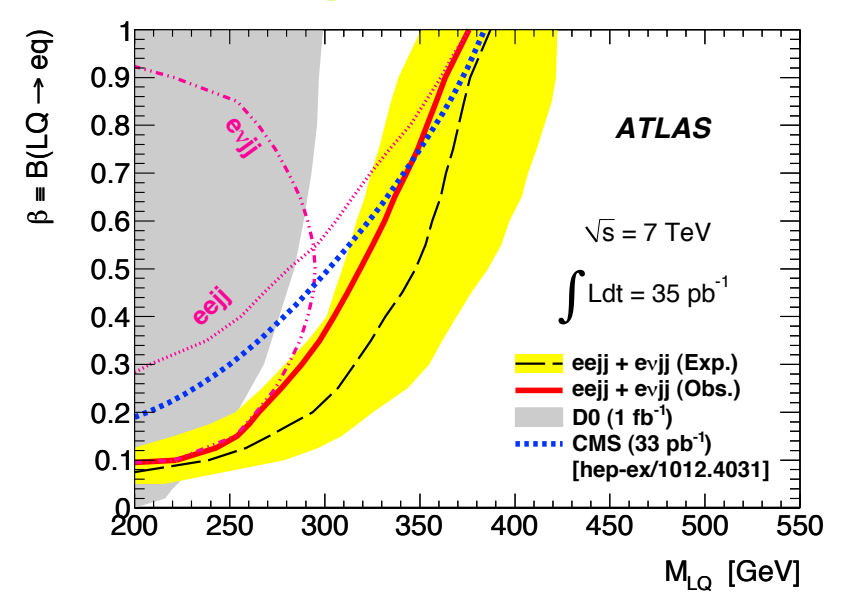




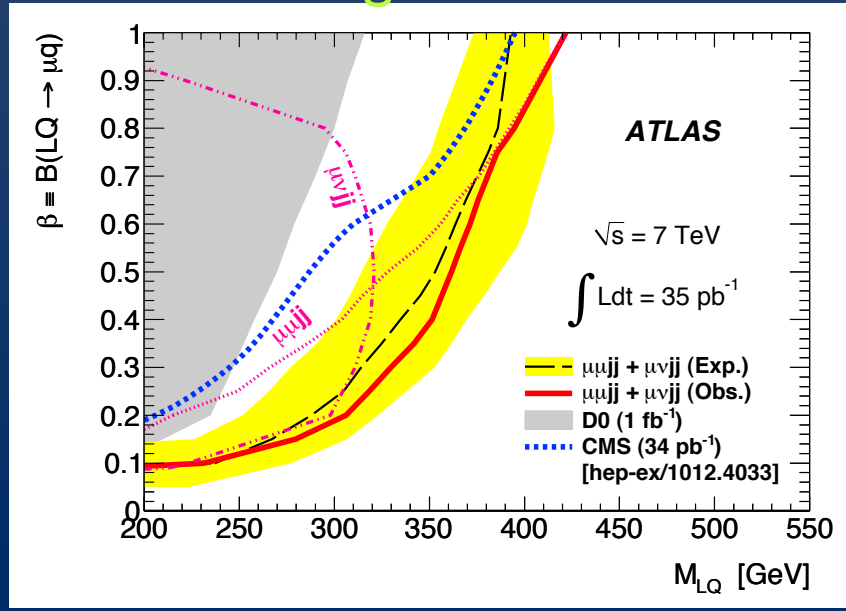


Limits on Leptoquarks

1st generation



2nd generation



95% C.L. Lower limit on LQ (Modified frequentist method)

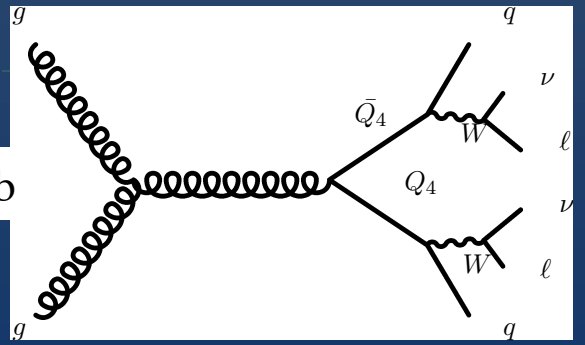
Type (β)	Expected limit (GeV)	Observed limit (GeV)
1st generation (1.0)	387	376
1st generation (0.5)	348	319
2nd generation (1.0)	393	422
2nd generation (0.5)	353	362

The most stringent results to date

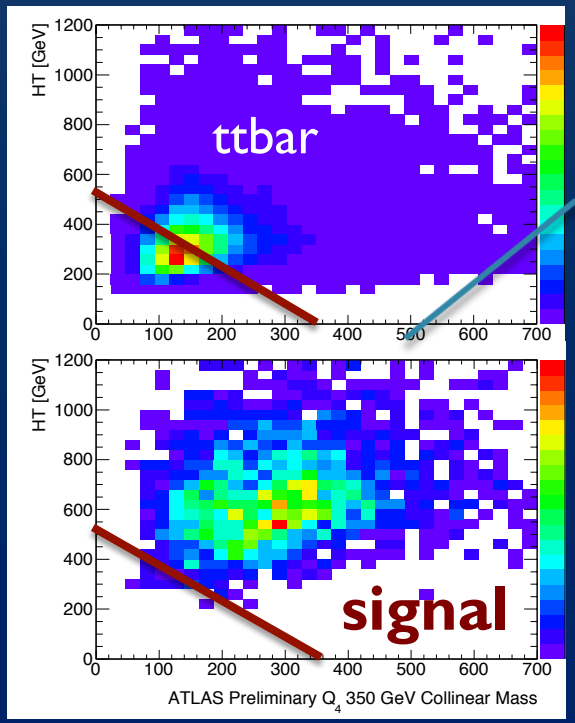
ATLAS-CONF-2011-022

Fourth generation quarks

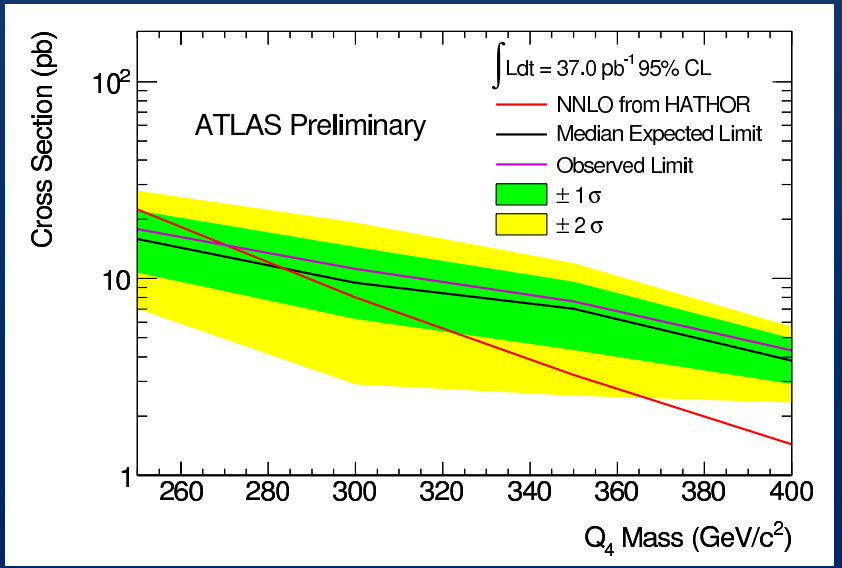
- Fourth generation is not excluded with the EW fit
- Pair production of Q_4
  - Ws decay leptonically $Q_4\bar{Q}_4 \rightarrow W^+qW^-q$ q=u,d,c,s or b
- Discriminating variables : H_T and M_{Q4} (assignments of particles that makes Q_4 mass difference minimum)



$$H_T = E_T^{l^+} + E_T^{l^-} + E_T^{q_1} + E_T^{q_2} + E_T^{miss}$$



$H_T > X\text{-}Y\times M_{coll.}$ remove significant background while sacrificing a small fraction of events



$m_{Q4} > 270$ GeV/c^2 @ 95% C.L.

(95% C.L limits by CDF $m_{d4} > 372$ GeV and $m_{u4} > 356$ GeV)

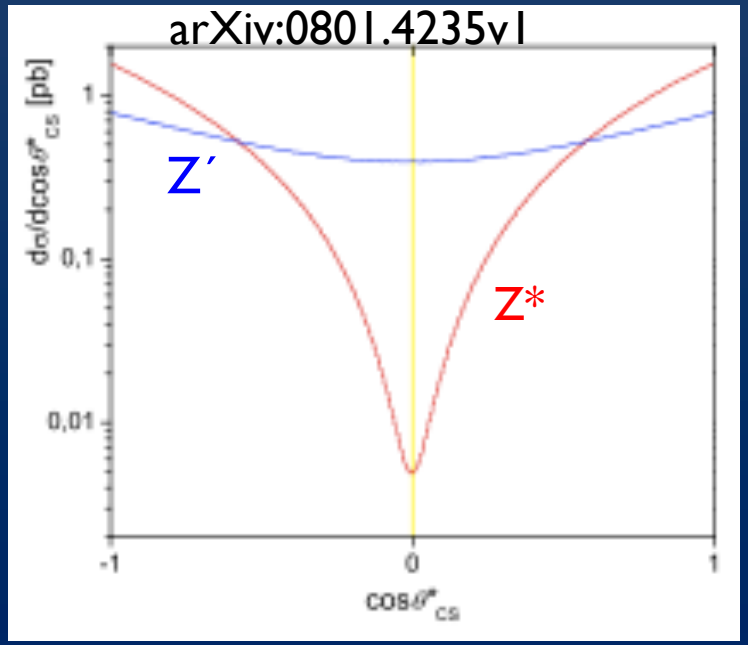
Introduction for new heavy bosons

- Many models predict additional new heavy gauge bosons beyond SM ($W'^{(*)}$,$Z'^{(*)}$)
- Sequential Standard Model (SSM)
  - Same coupling to fermions as SM
    - Width increases linearly with W'/Z' mass
- GUT E6 inspired Z'
  - Different model leads to specific Z' states :

$$Z'_{\psi}, Z'_{N}, Z'_{\eta}, Z'_{I}, Z'_{S}, Z'_{\chi}$$

- New Chiral boson spin 1 bosons - W*, Z*
  - Excited bosons
  - Different couplings to fermions (magnetic moment type)
- Previous lower Limits [TeV]

	W'	Z'
CDF	1.12	1.071
D0	1.0	1.023
CMS	1.58	1.14

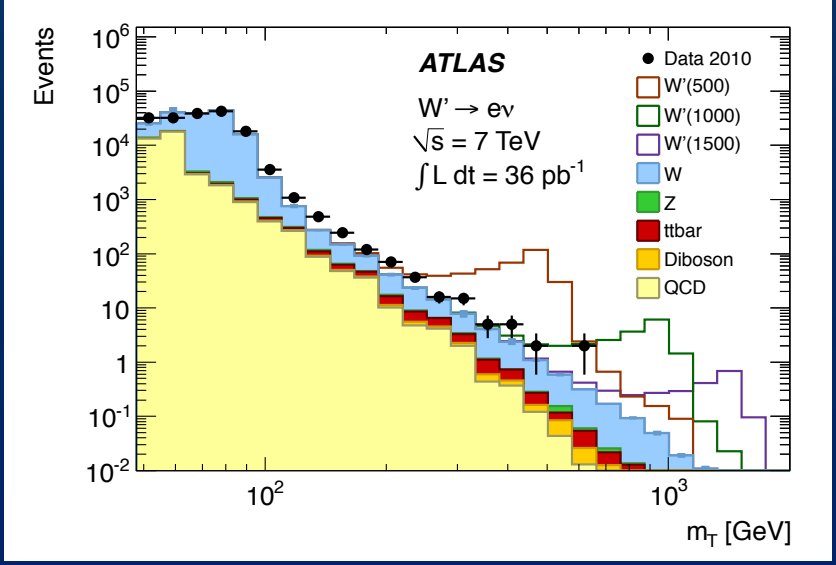


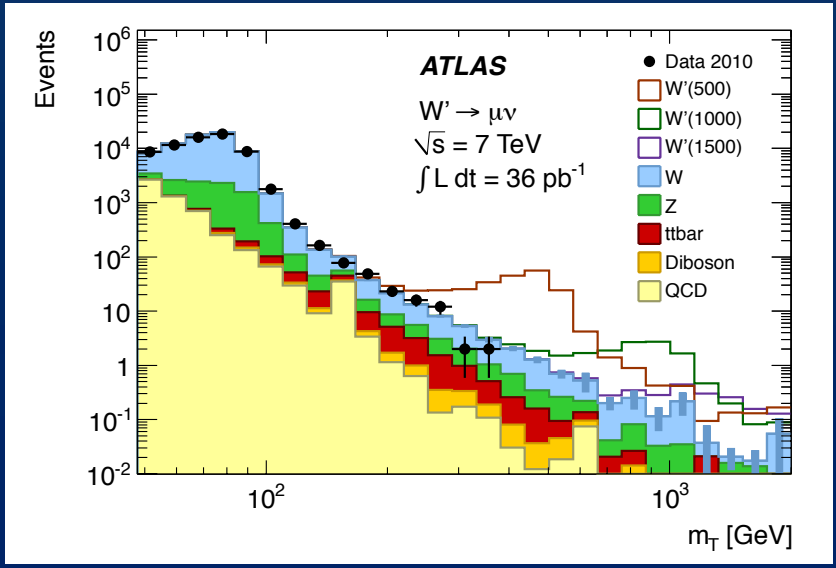
(Differential cross section for Z' and Z* at 800GeV < $M_{\ell\ell}$ < 1200 GeV)

W' and W* searches

arxiv:1103.1391
Accepted by PLB

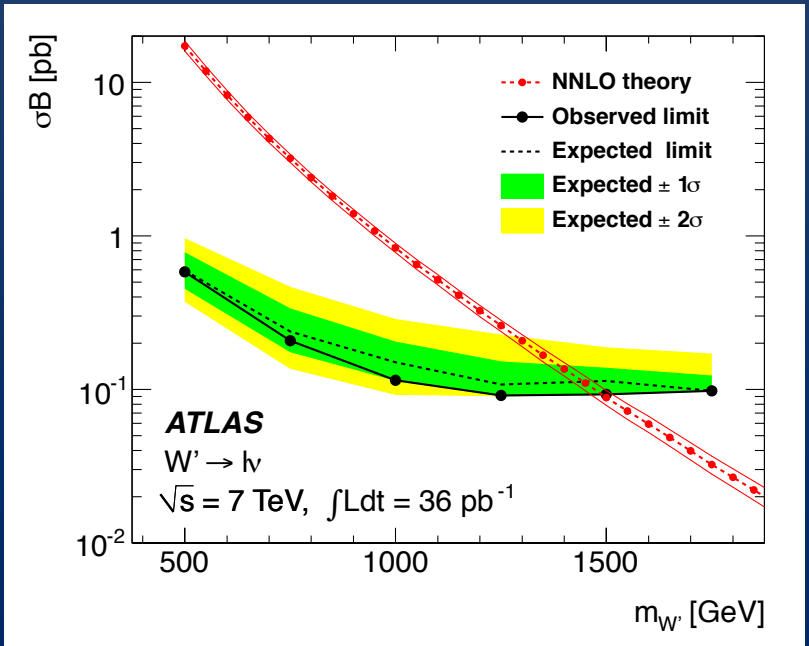
- Signature :
  - High p_T isolated lepton (e,μ) and large missing energy
- Observable :
  - Transverse mass $m_T = \sqrt{2 p_T E_T^{miss} (1 - \cos\varphi_{lv})}$
- Backgrounds
  - $W \rightarrow \ell\nu$ (irreducible) Drell-Yan, ttbar, di-boson QCD multi-jet, Cosmic rays (from data)
- Signal W' (PYTHIA), W* (CompHep using CTEQ6L1)



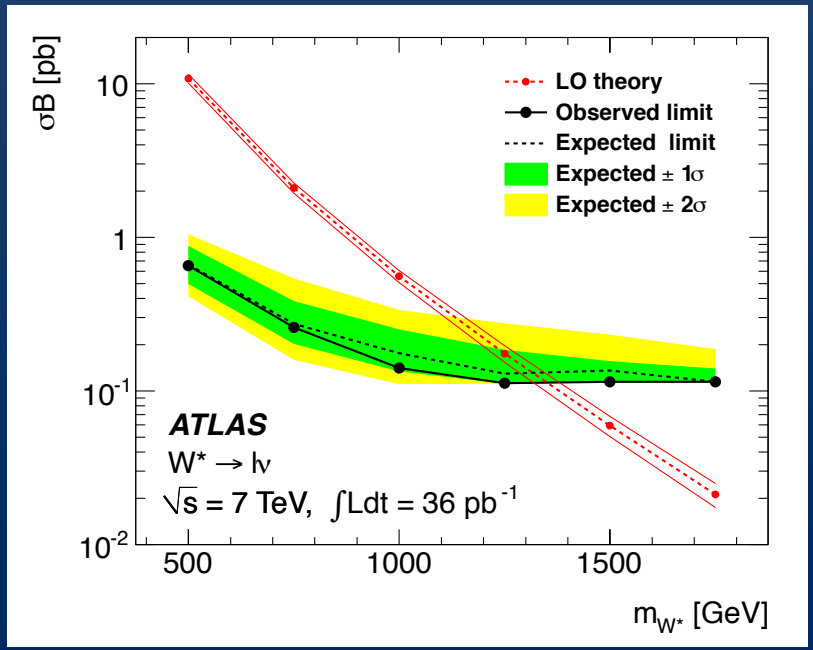


Results on W' and W*

e/μ combined result for W'



e/μ combined result for W*



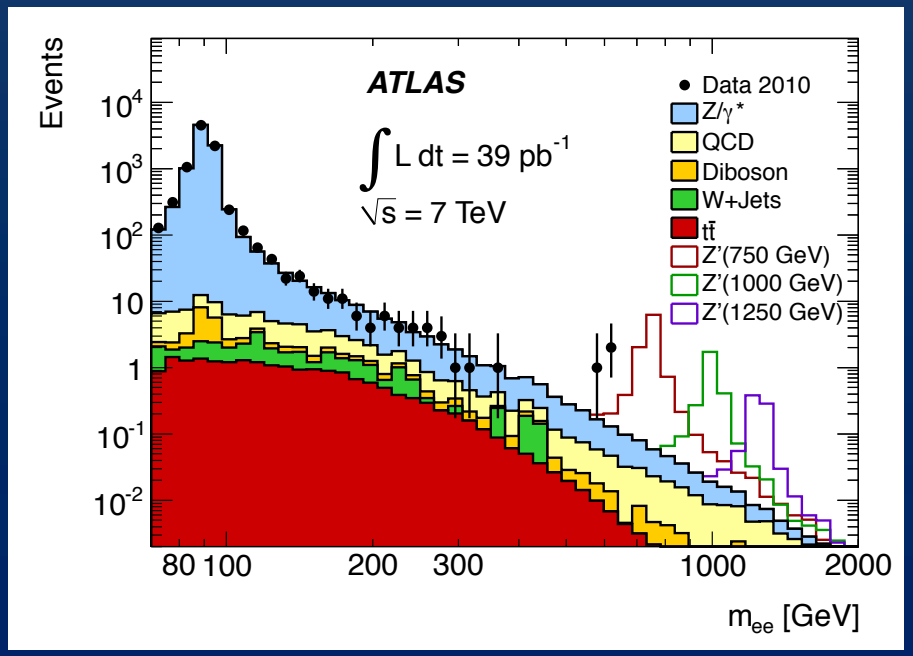
- No evidence for an excess found
- Lower limits on W' and W* are set at 95% C.L.

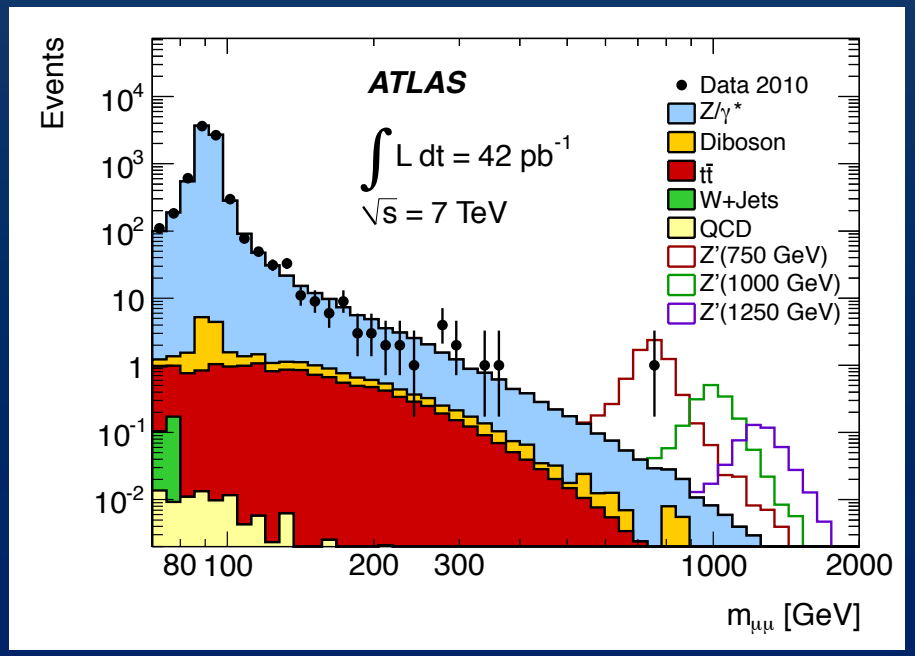
  $m_{W'}$ > 1490 GeV and m_{W^*} >1350 GeV (the most stringent to date)

Di-lepton resonances

arxiv:1103.6218
accepted by PLB

- Signature: Opposite charge, same flavor di-lepton ($e^+e^-/\mu^+\mu^-$)
- Observable : invariant mass of di-lepton
- Backgrounds: Z/γ^* (Drell-Yan), QCD , ttbar, di-boson (WW/WZ and ZZ), W+jets
- Signals : Z' (PYTHIA), Z* (CompHEP using CTEQ6L1)





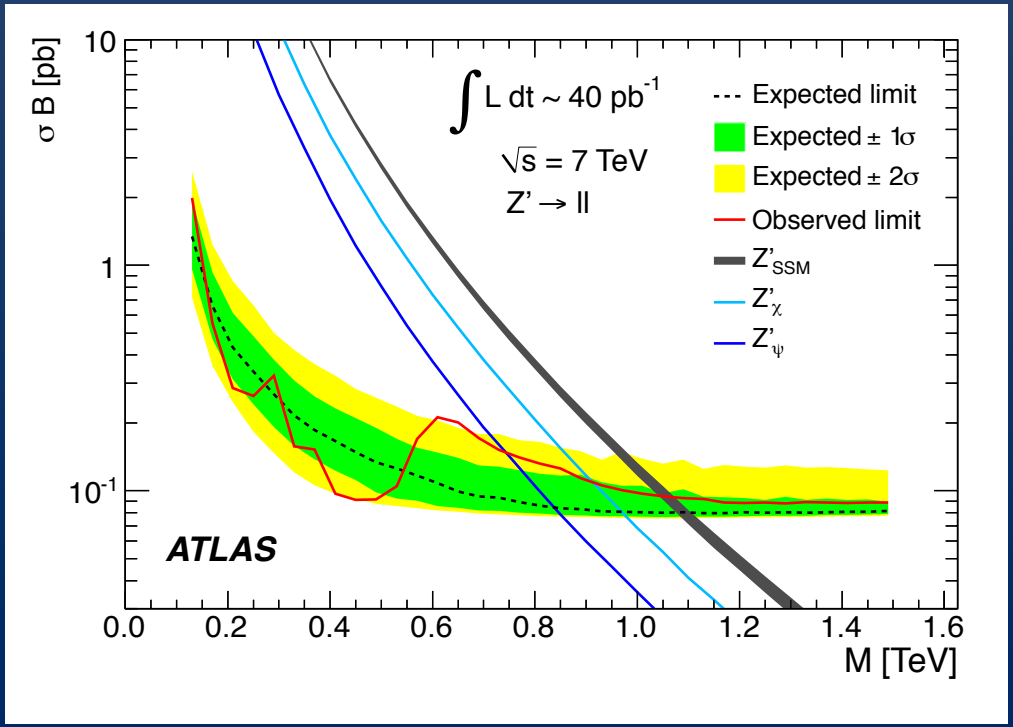
p-values for electron and muon are 5% and 22% - no statistically significant excess above the SM

Results on Z' and Z*

- No evidence for resonance found
- The $e^+e^-/\mu^+\mu^-$ combined mass limits @95 C.L.

$M_{Z'}$ (SSM) > 1.048 TeV

M_{Z^*} > 1.152 TeV (first limit on Z* mass)



E6	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit (TeV)	0.738	0.763	0.771	0.842	0.871	0.900

(Z'_S and Z'_I are the more stringent than previous results)

Contact Interactions in di-muon events

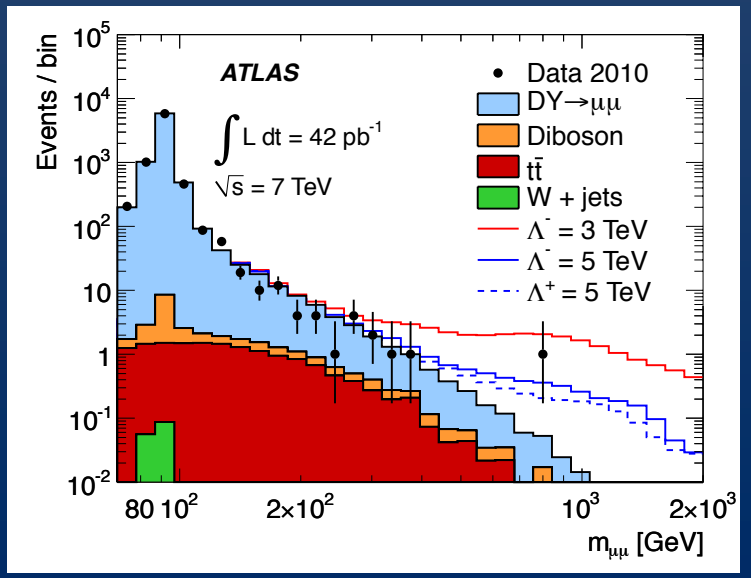
arxiv:1104.4398 submitted to PRD

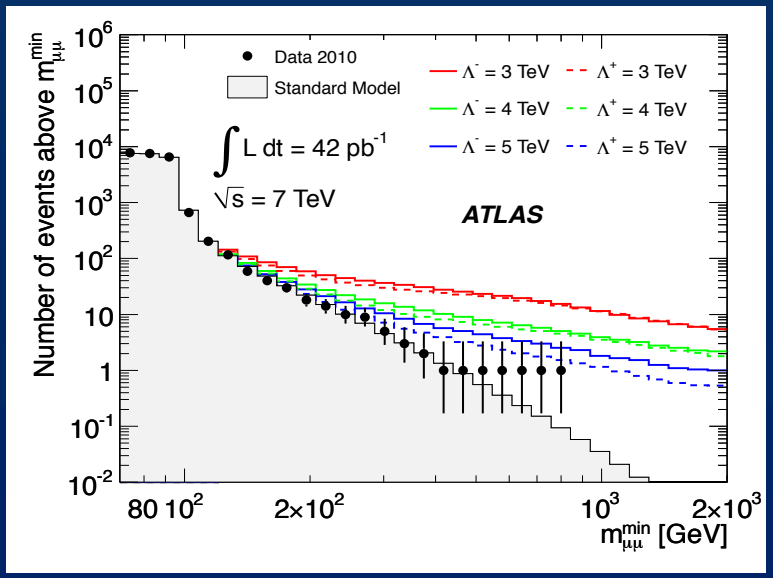
- CI model introduces hypothetical constituents of quarks and leptons that are bound together by a energy scale Λ

$$L = \frac{g}{2\Lambda^2}[\eta_{LL}\bar{\psi}_L\gamma_\mu\psi_L\bar{\psi}_L\gamma^\mu\psi_L + \eta_{RR}\bar{\psi}_R\gamma_\mu\psi_R\bar{\psi}_R\gamma^\mu\psi_R + 2\eta_{LR}\bar{\psi}_L\gamma_\mu\psi_L\bar{\psi}_R\gamma^\mu\psi_R]$$

$g^2/4\pi = 1$ and $\eta_{LL}, \eta_{LR}, \eta_{RR} = \pm 1$

- To estimate level of agreement data and MC
  - SM only pseudo experiments generated
  - Deviation from the SM quantified



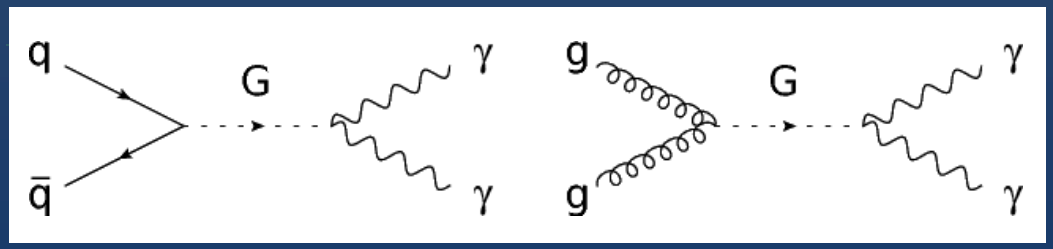


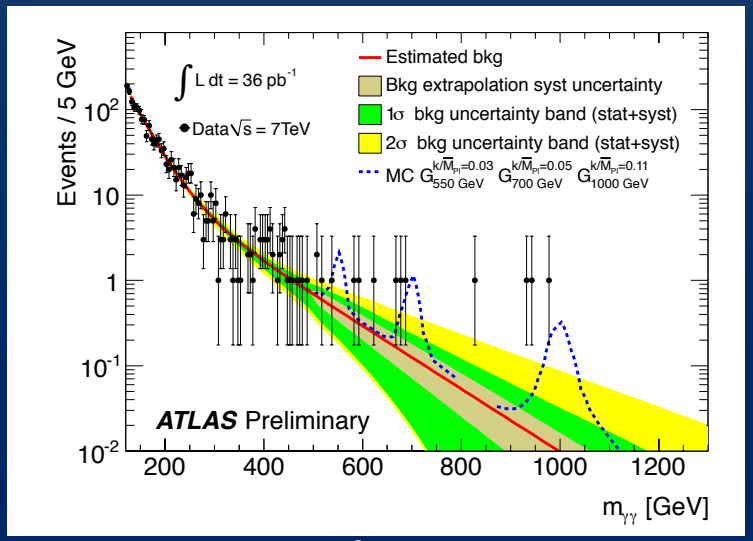
- Use the same event selection as in heavy resonance searches
  - Signal broad deviation from SM not a peak

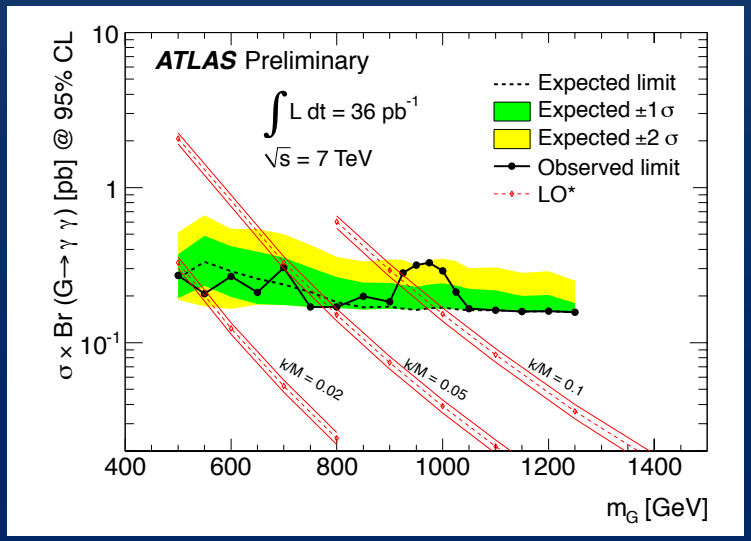
95% C.L. $\Lambda^- > 4.9$ TeV $\Lambda^+ > 4.5$ TeV

Randall-Sundrum Graviton in di-photon

- RS introduces an extra spatial dimension to resolve hierarchy problem :
  - The only propagator : Gravitons and Graviton excitation (Kaluza-Klein tower)
- Search for G $\longrightarrow\gamma\gamma$ (G could also decay to pairs of fermions or bosons)







- No evidence for narrow resonance (p-value, BumpHunter shows agreement between data and background only hypothesis)

  m_G > 545 (920) GeV for coupling k/M_{Pl} = 0.02 (0.1) @ 95 C.L.

  (m_G limits for coupling 0.01 and 0.1 by D0 : 560 and 1050 GeV CDF : 459 and 963 GeV)

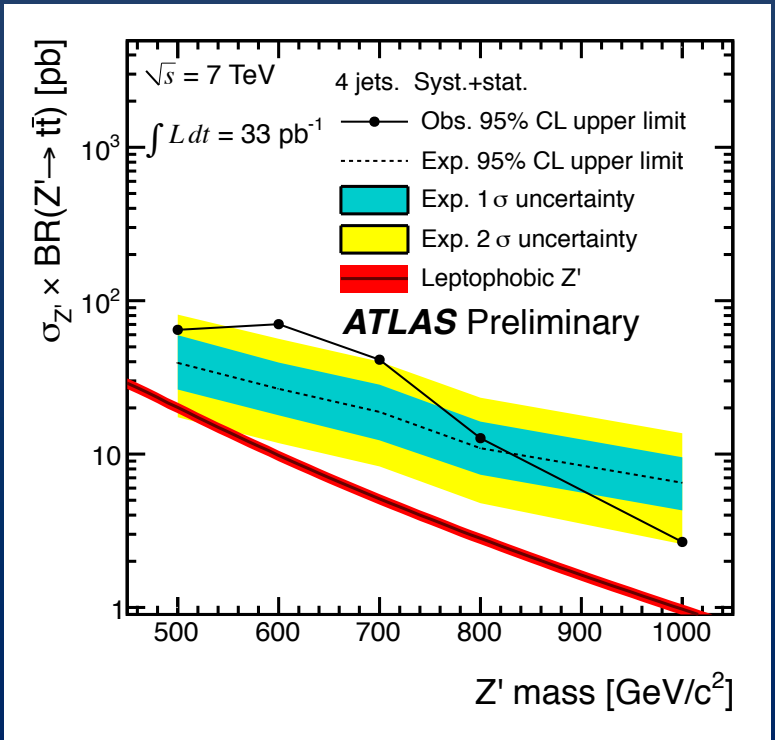
Conclusions

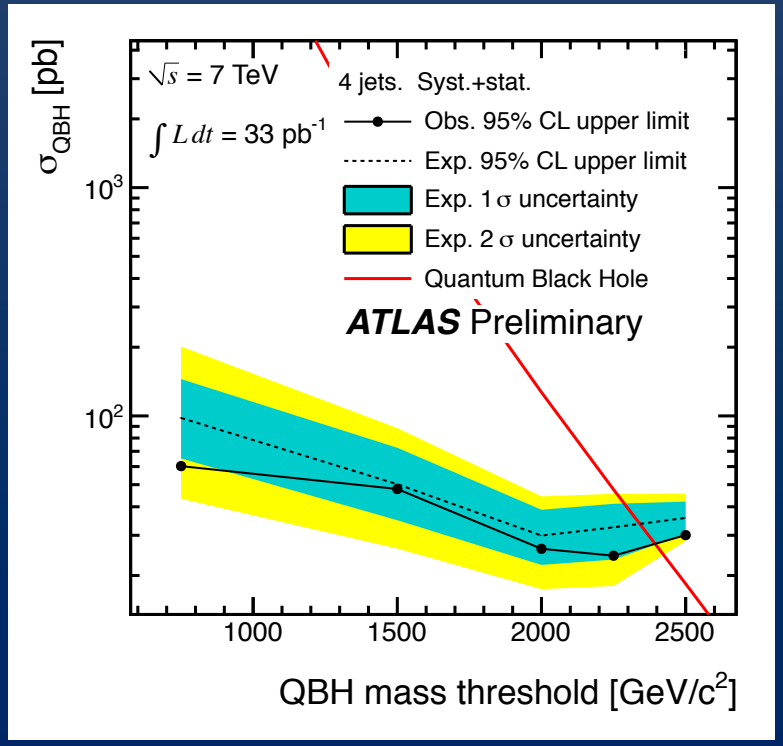
- With the very successful LHC run in 2010, 45 pb^{-1} data were collected at 7 TeV
- Many BSM scenarios studied
  - No deviations from the SM found so far
- We were able to set limits (some of the world's best limits) at TeV scale

2011 data taking is going very well and we are already exploring new regions ..

BACKUP

ttbar : Limits with “4-hardest jet”





Di-electron candidate (Z' search)

Highest invariant mass di-electron event with 617 GeV:

The highest momentum electron

p_T = 279 GeV
η = 1.22
ϕ = 1.74

The trailing electron
p_T = 276 GeV
η = 0.28
ϕ = -1.40