Searches for new physics at ATLAS

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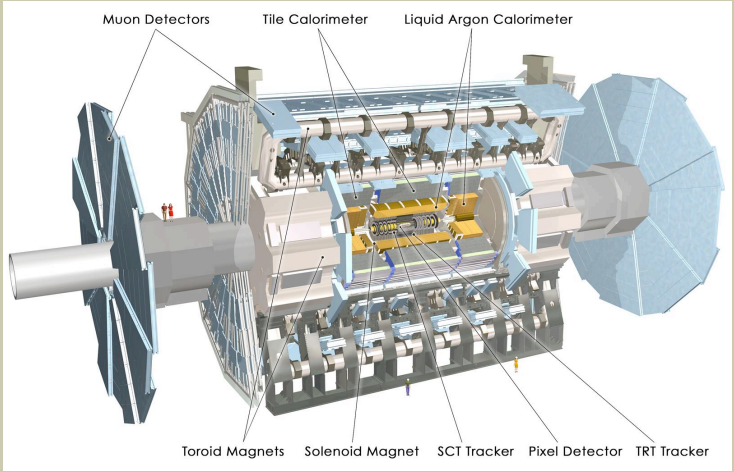
20/06/2011

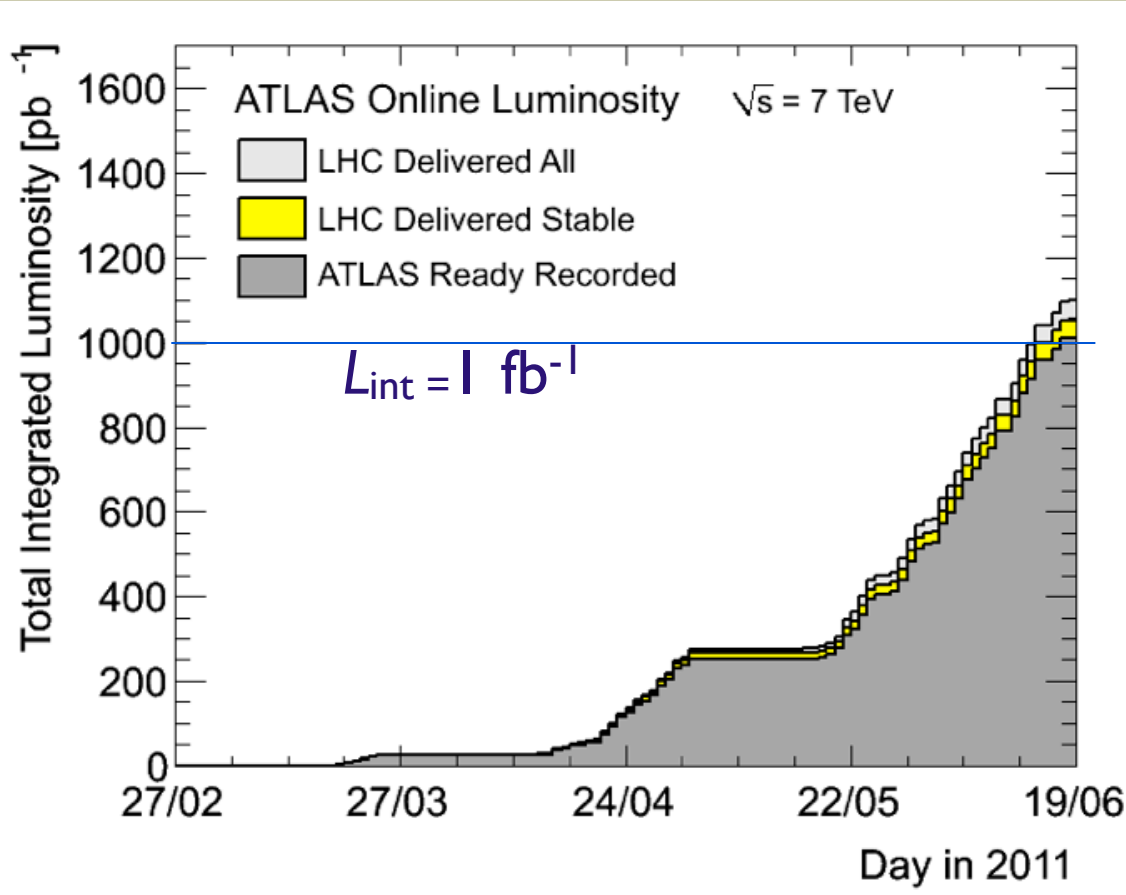
On behalf of the ATLAS collaboration

Outline



- Limits from resonances
  - dijets
  - dileptons : Z' & Contact IA
  - dileptons : W' bosons
  - diphotons : Gravitons
  - ttbar
- New particle searches
  - 4th generation quarks
  - Lepto-quarks
- Susy Searches

LHC has been giving us data at ever increasing pace. $L_{int} = 1\ fb^{-1}$ reached as of 17th June 2011.



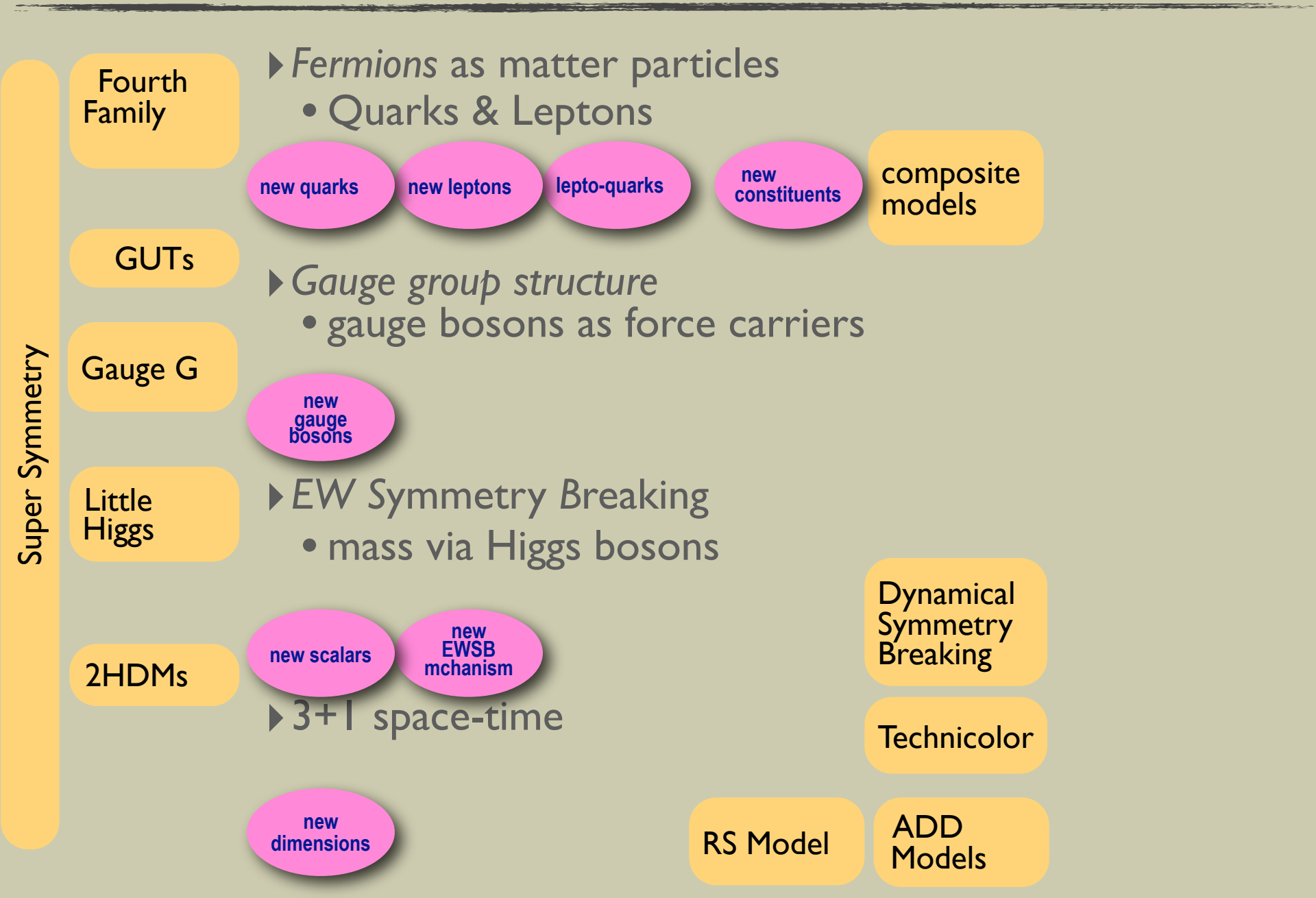
introduction: SM

- *Fermions* as matter particles
  - Quarks & Leptons
- *Gauge group structure*
  - gauge bosons as force carriers
- *EW Symmetry Breaking*
  - mass via Higgs bosons
- 3+1 space-time

SM is like your old car: you like it but you also know it has problems...

- *SM can not be the final theory:*
  - Hierarchy problem: $\delta H \sim M_H$
  - EW and Strong forces not unified
  - Arbitrary fermion masses & mixings
  - Arbitrary number of families
  - Unknown source of baryogenesis

introduction: SM to BSM

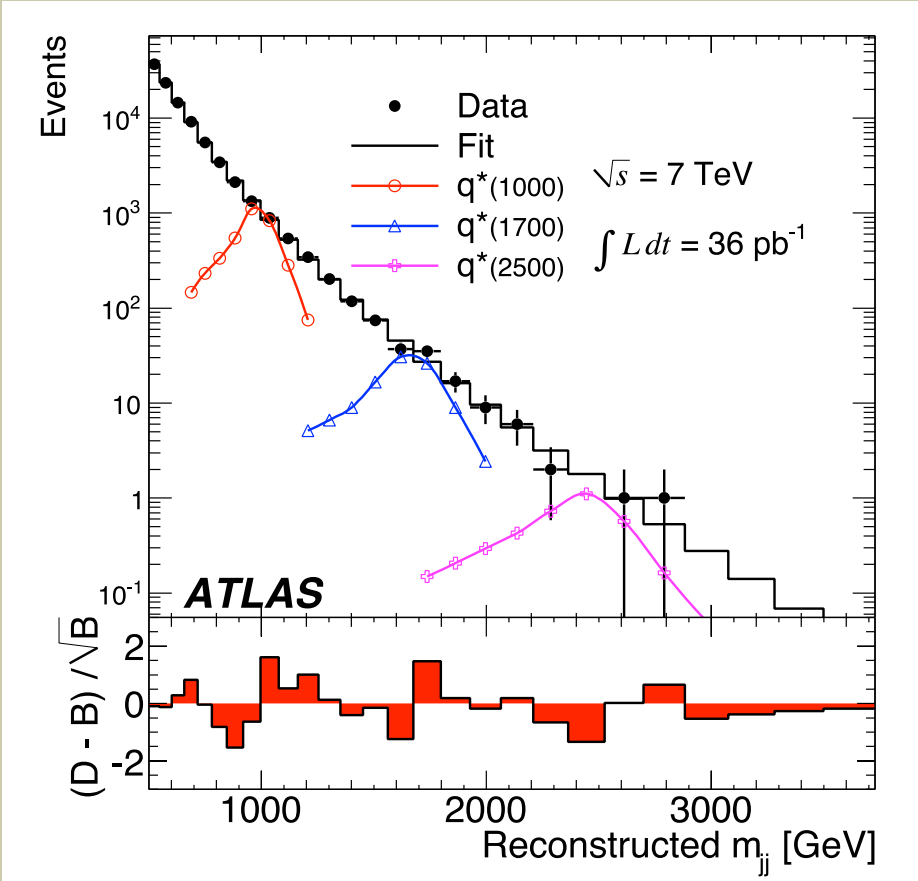


di-jet Resonances

arxiv:1103.3864

- 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

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



- No evidence for a bump in m_{jj}
  - X^2 test, p-value 0.88
  - Set exclusion limits

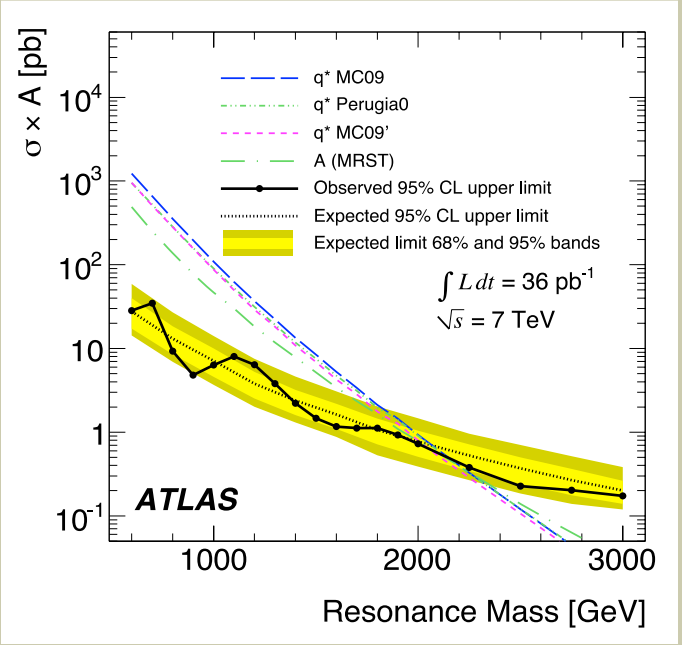
di-jet Limits

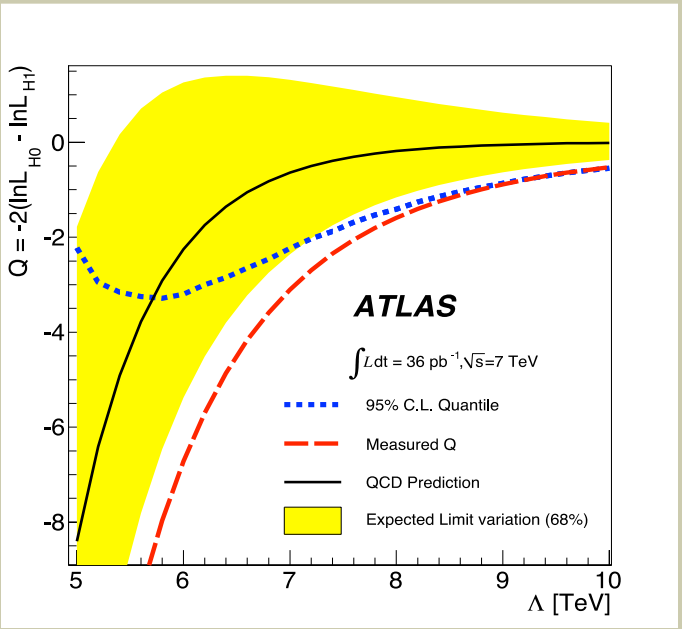
95% C.L. Limits (TeV)

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

m_{jj} : reconstructed invariant mass

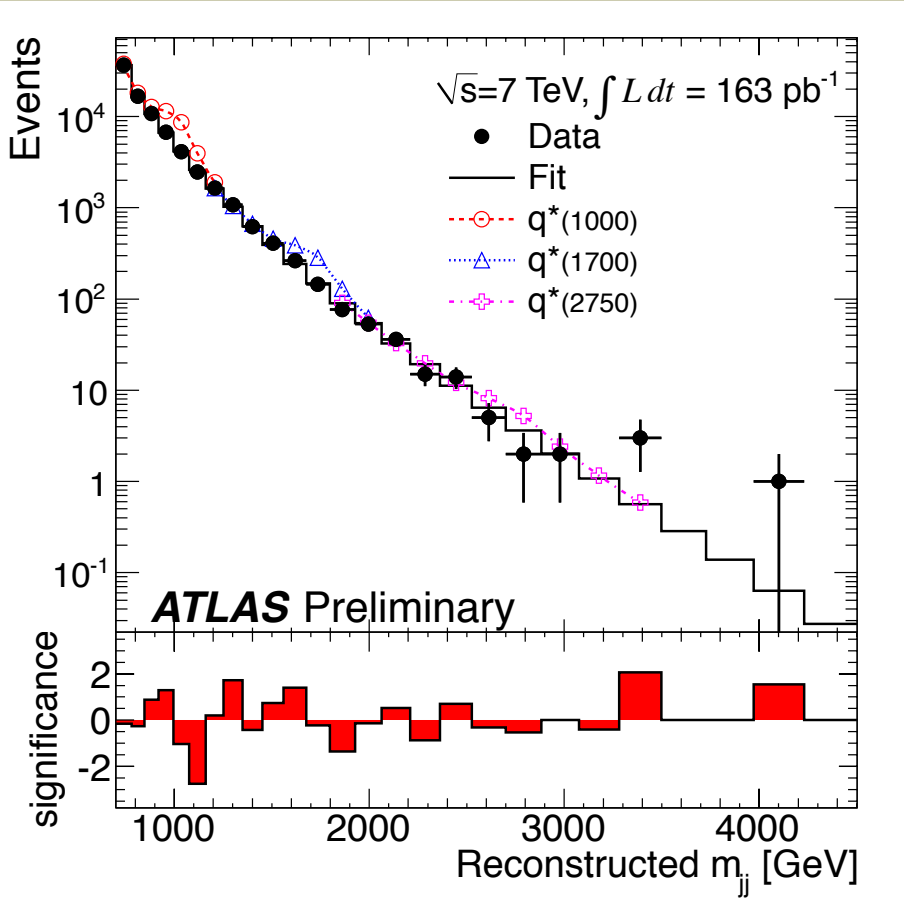
F_X : scale at which new physics appears

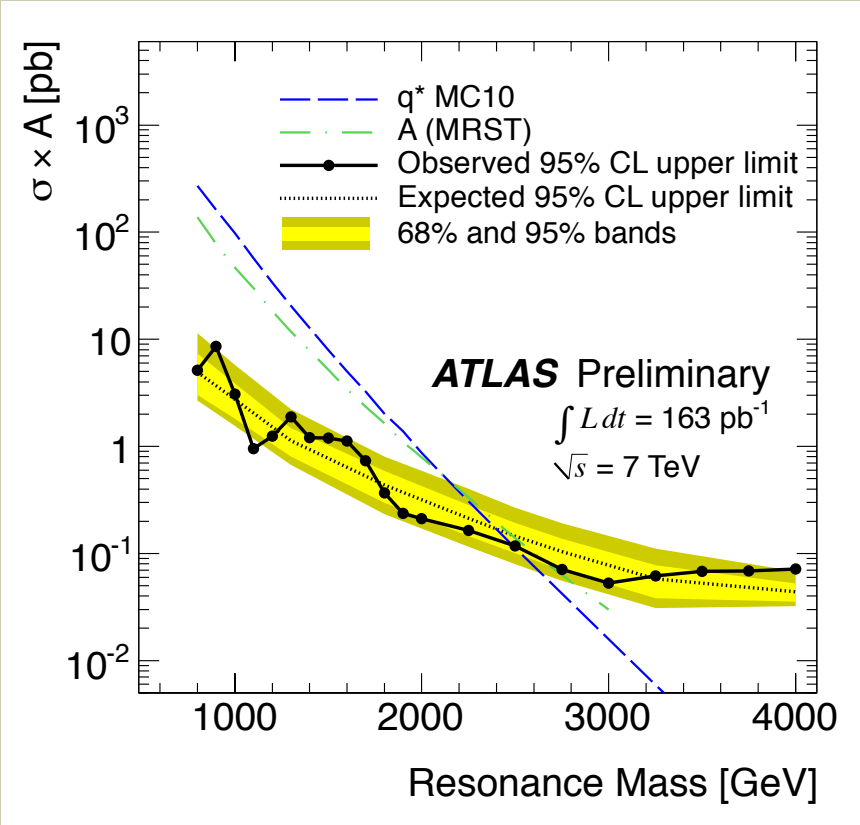




di-jet 2011 updates

ATLAS-CONF-2011-081





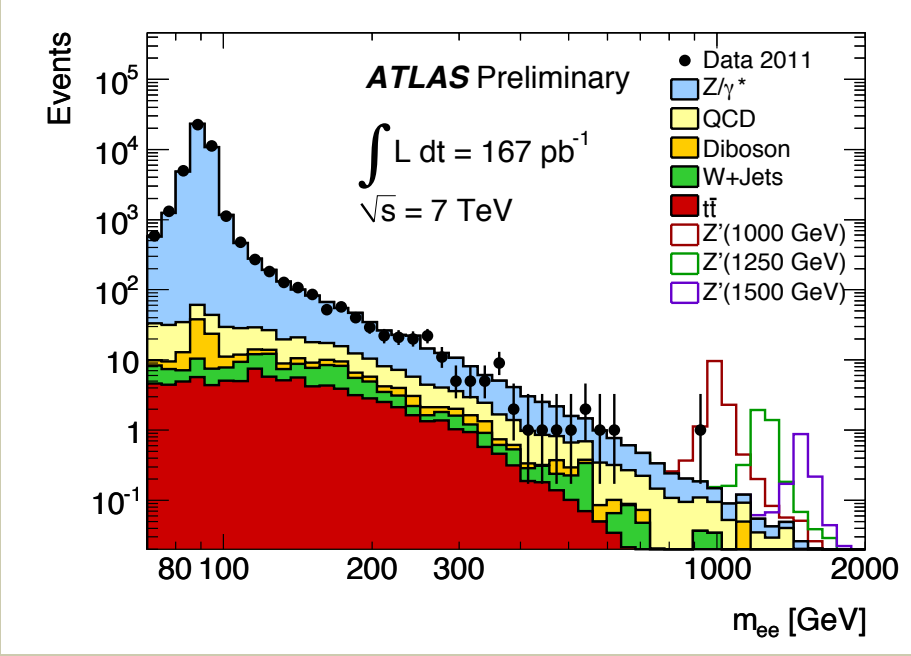
95% C.L. Limits (TeV)

Observable	Observed
Exited quark q*	
m_{jj}	2.49
Axigluon	
m_{jj}	2.67

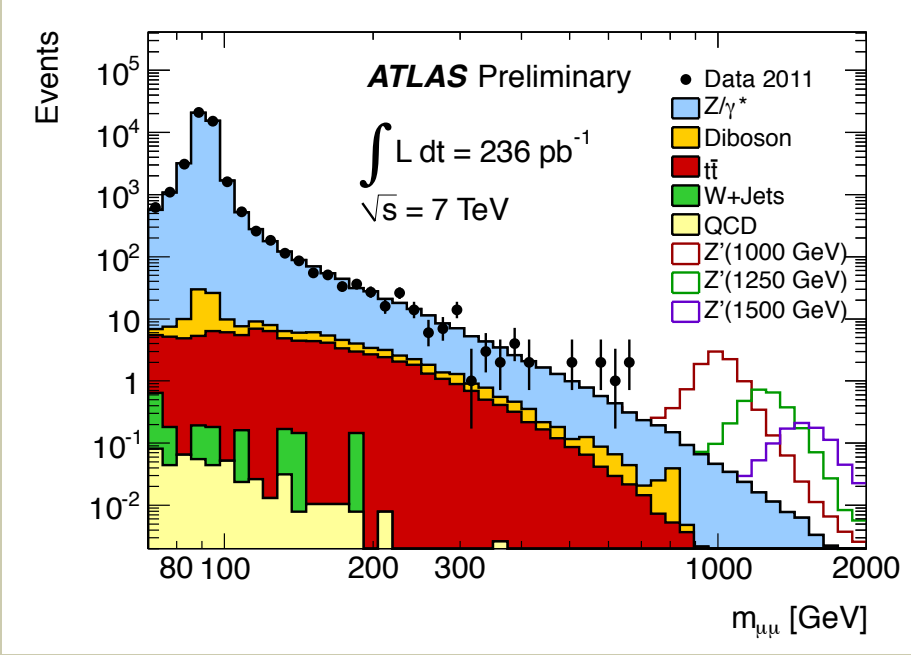
di-lepton Resonances

ATLAS-CONF-2011-083

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



electrons

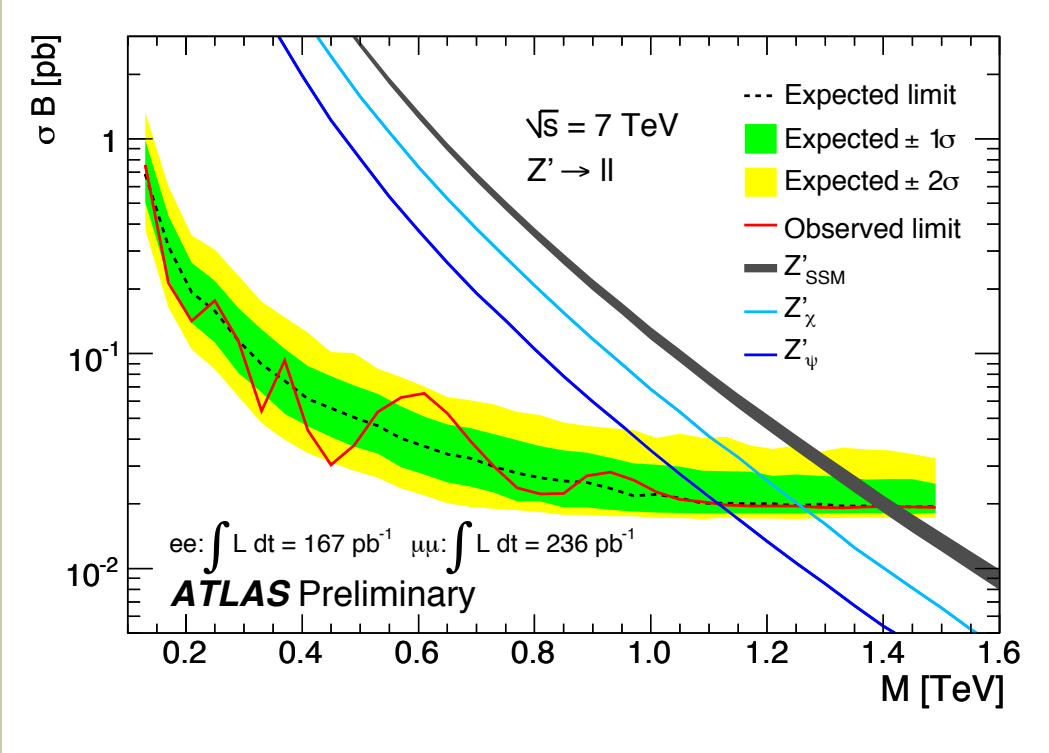


muons

di-lepton Limits

- Previous lower Limits [TeV] *assuming SM couplings*

	W'	Z'
CDF	1.12	1.071
D0	1.0	1.023



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

$M_{Z'}$ (SSM) > 1.407 TeV

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

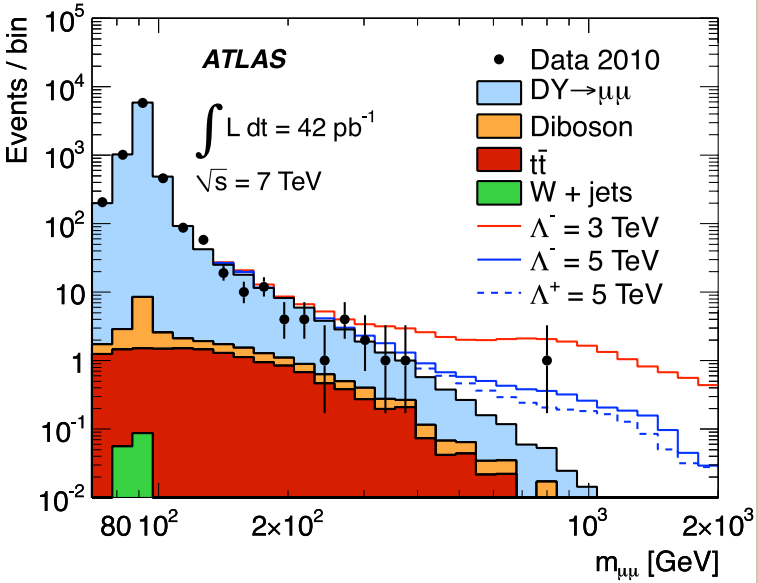
E6	Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
Mass limit (TeV)	1.116	1.142	1.150	1.203	1.230	1.259

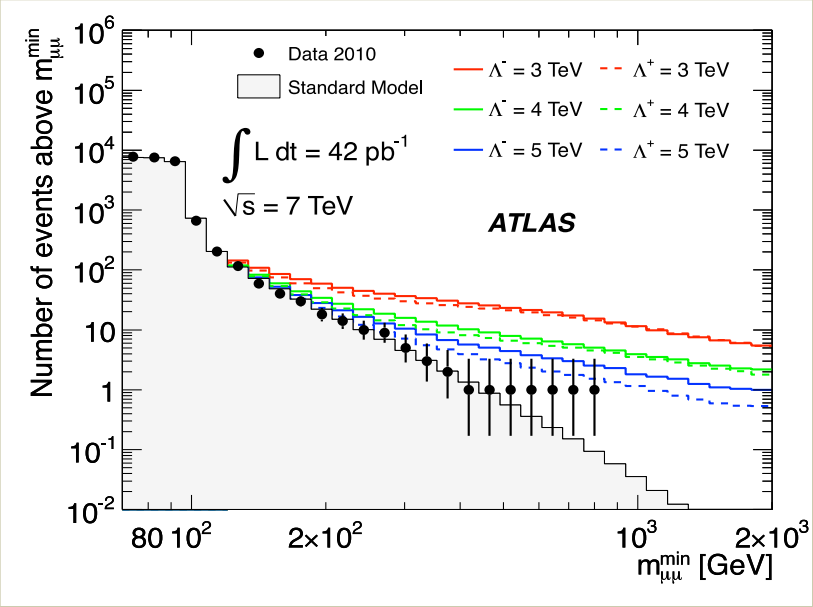
di-leptons on contact Interactions

arxiv:1104.4398

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

g : coupling constant
Λ: energy scale below which fermion constituents are bound
$g/\Lambda^2=1$ and η_{LL}, η_{LR}, $\eta_{RR}=1$





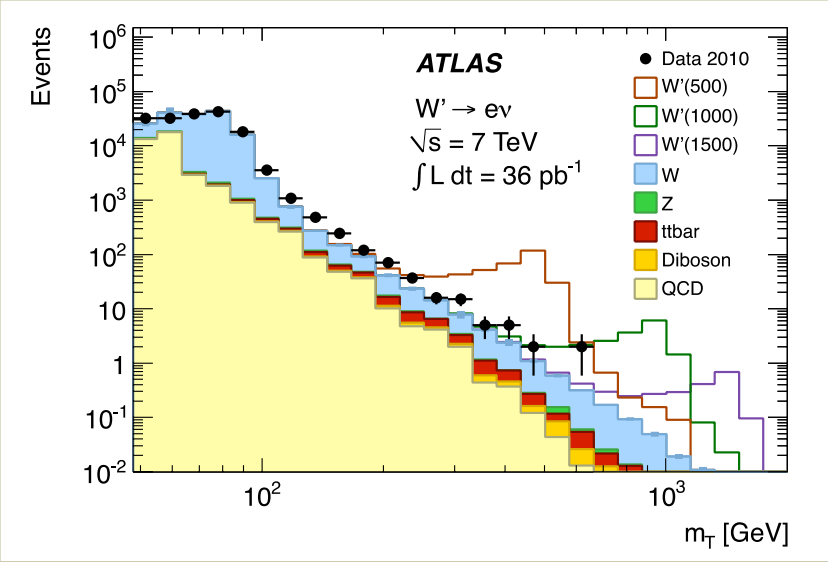
- Use the same event selection as in heavy resonance searches
  - Signal broad deviation from SM not a peak

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

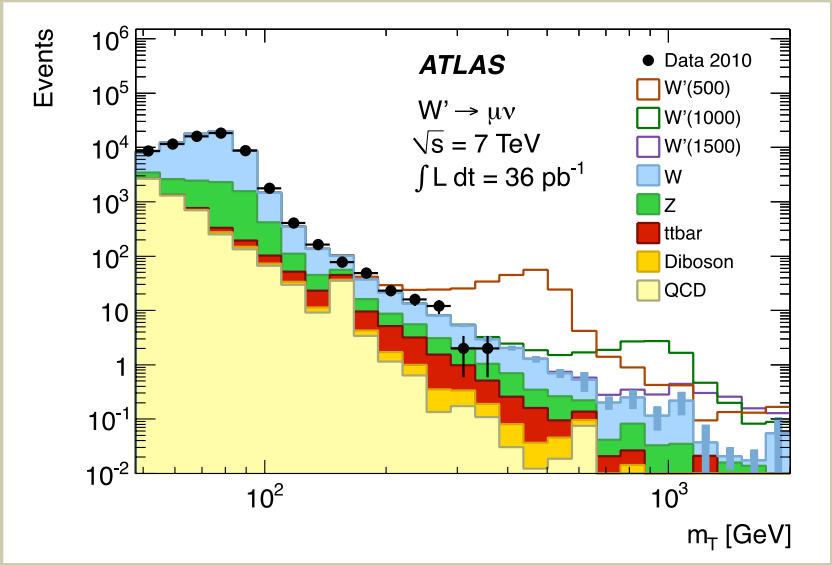
di-leptons on W' and W*

arxiv:1103.1391

- 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 → l ν (irreducible) Drell-Yan, ttbar, di-boson QCD multi-jet, Cosmic rays (from data)
- Signal W' (PYTHIA), W* (CompHep using CTEQ6L1)



electron channel



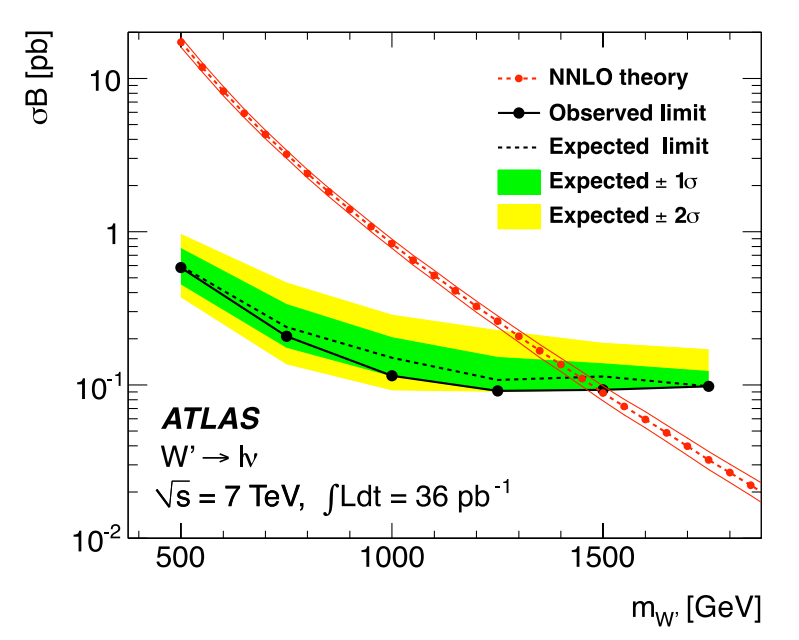
muon channel

W' and W* Limits

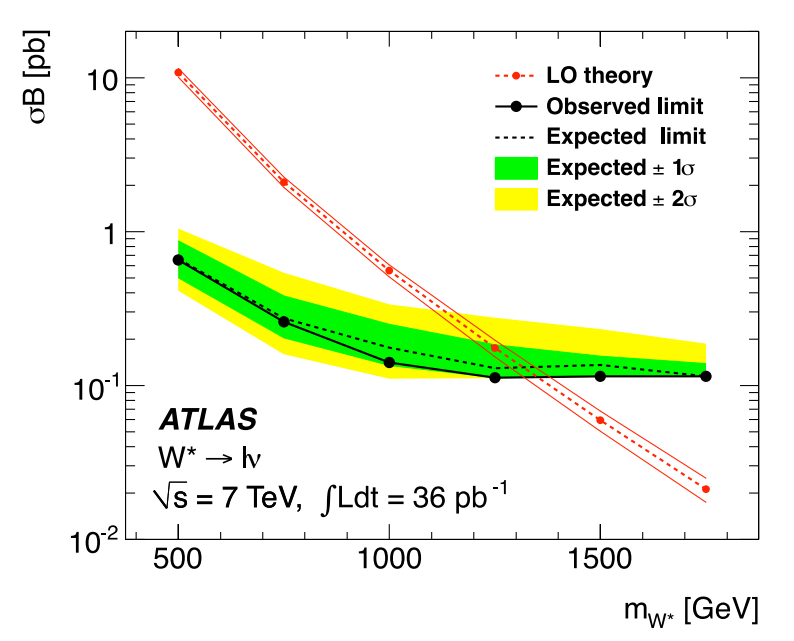
recall other limits

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

e/μ combined result for W'



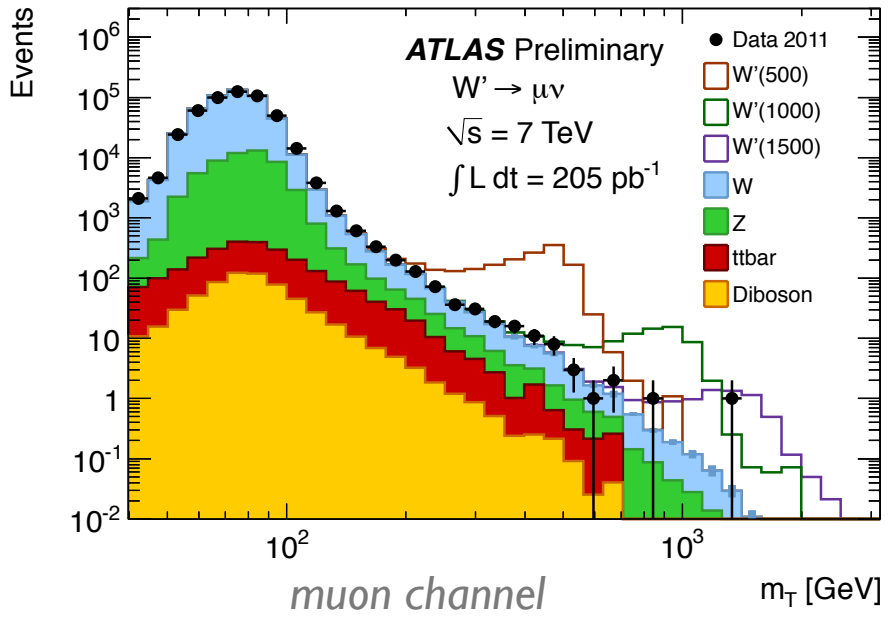
e/μ combined result for W*



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

$m_{W'} > 1490$ GeV and $m_{W^*} > 1350$ GeV

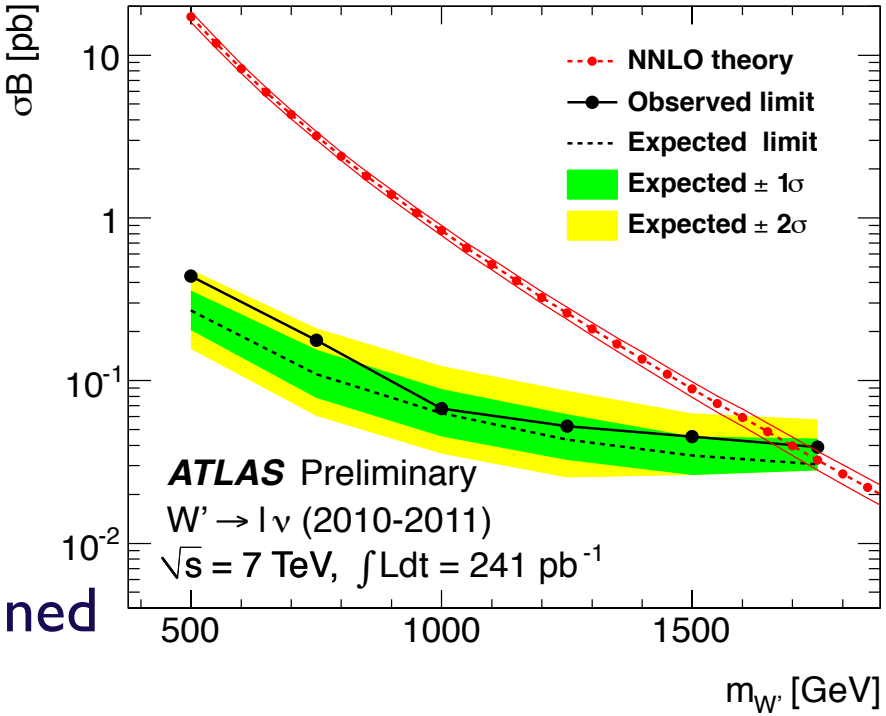
W' and W* 2011 updates



muon channel

ATLAS-CONF-2011-082

early 2011 data
L_{int}=205 pb^{-1}

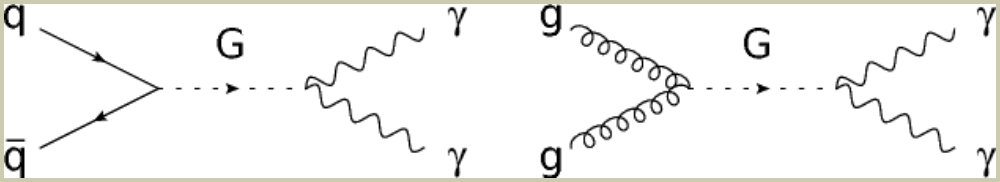


2010 & early 2011 combined
95% CL below 1.70 TeV

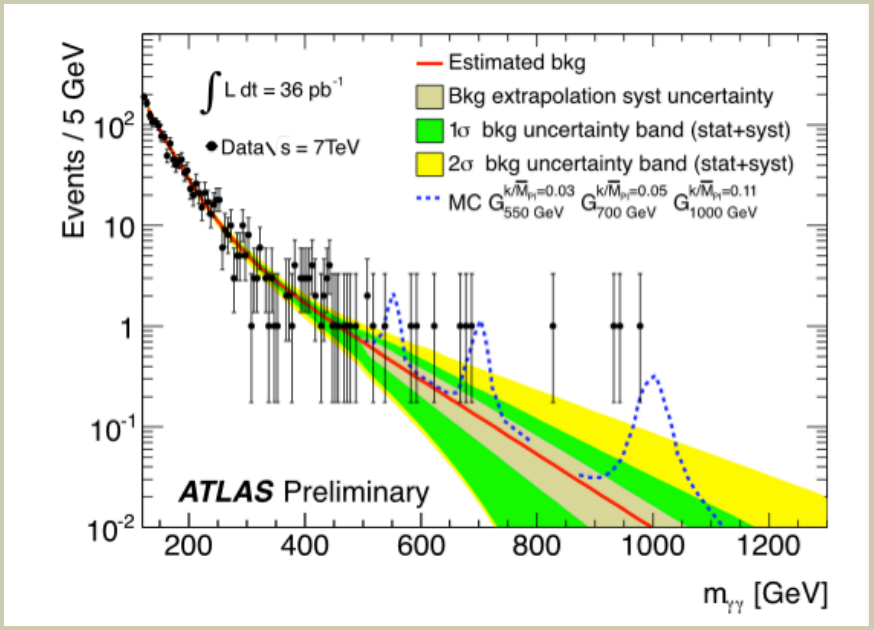
di-photons on RS Gravitons

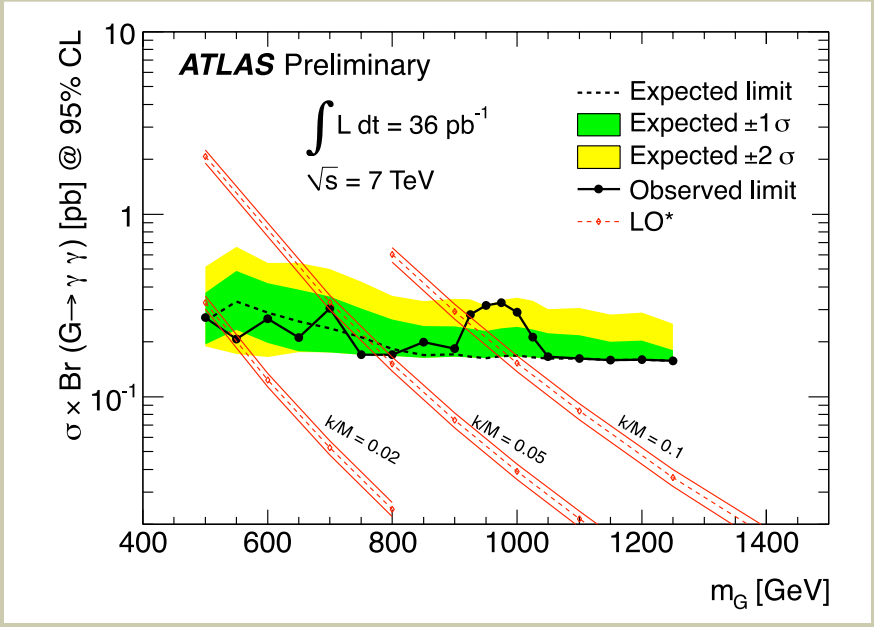
ATLAS-CONF-2011-044

- RS introduces an extra spatial dimension (ED) to resolve hierarchy problem



  - TeV scales ⇒Plank scale $\Lambda_\pi = 1/\sqrt{8}\times M_{Pl}\exp(k\,\pi\,r_c)$ (k=curvature, r_c : ED radius)





Massive graviton excitations Kaluza-Klein (KK) tower

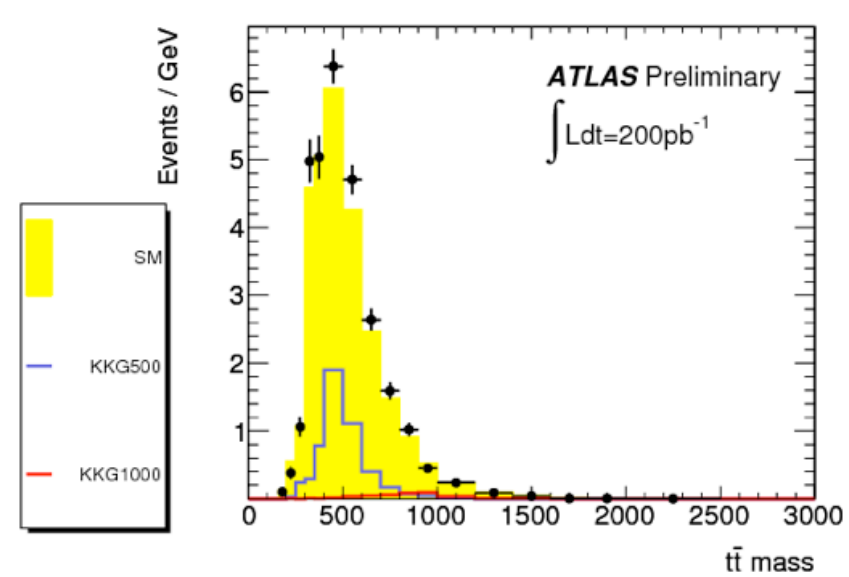
m_G > 545 (920) GeV for k/M_{Pl} = 0.02 (0.1) @ 95 C.L.

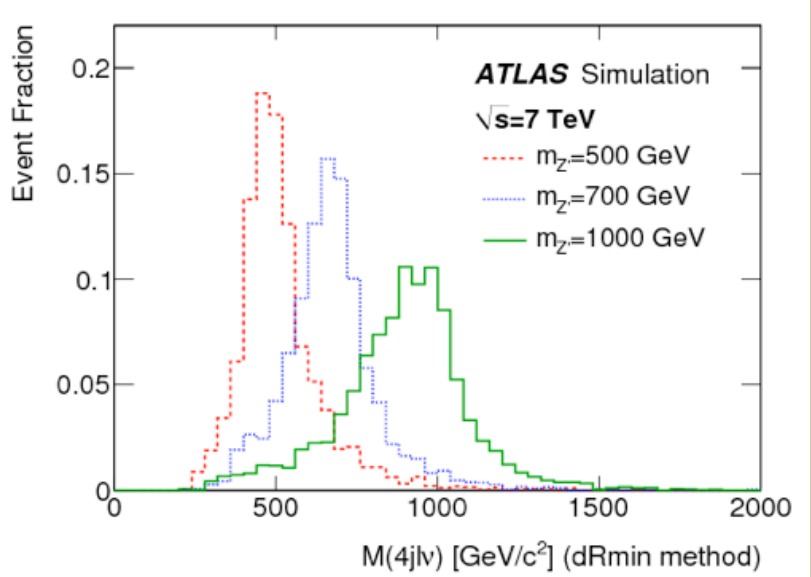
(m_G limits for coupling 0.01 and 0.1 by D0: 560 and 1050 GeV CDF : 459 and 963 GeV)

ttbar Resonances

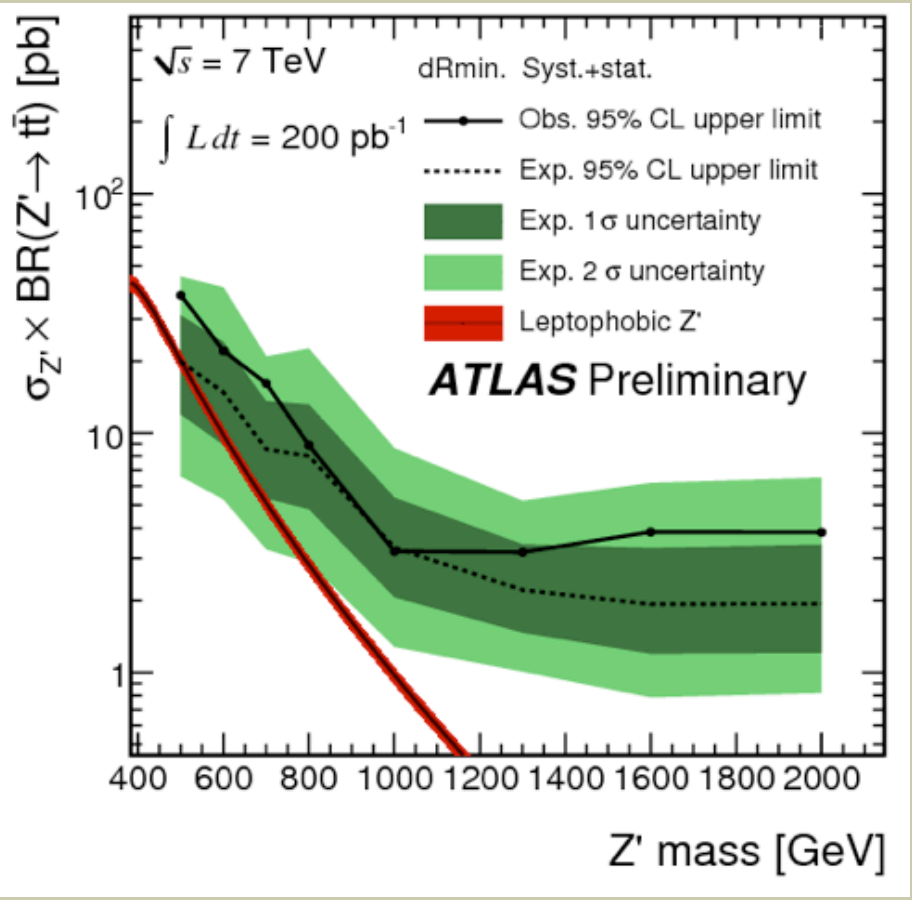
ATLAS-CONF-2011-087

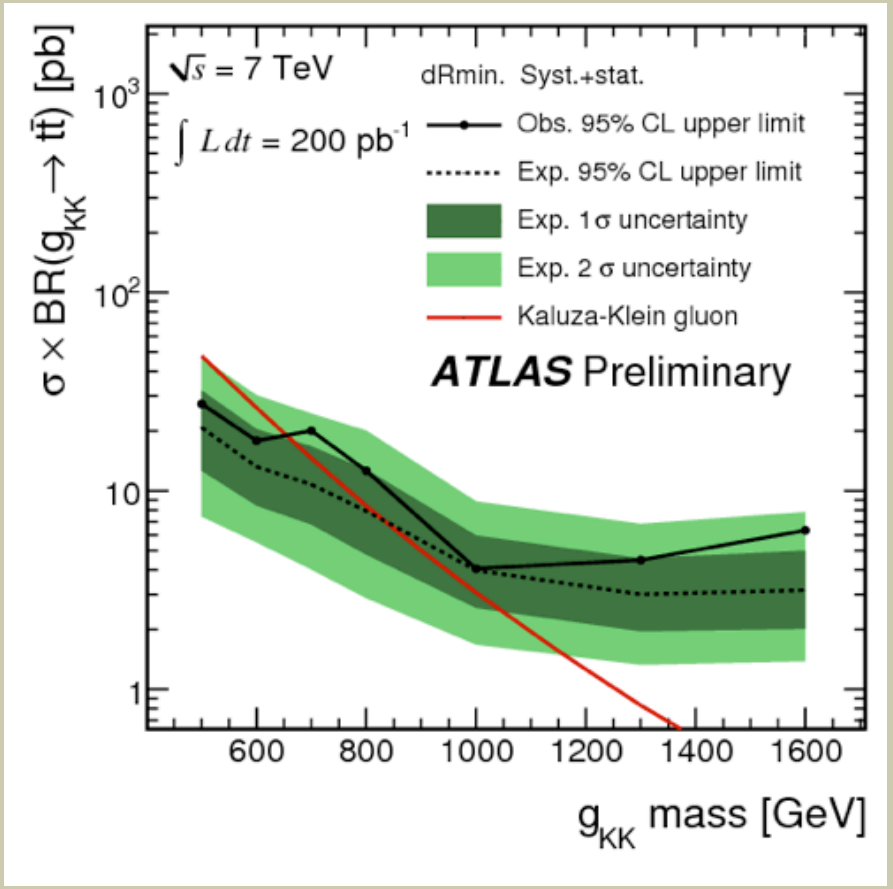
- Signature : (At least one W reconstructed leptonically):
  - High pT isolated lepton (e,μ), jets and large missing energy
- Observable :
  - Invariant mass of ttbar computed from the reconstructed objects in the final state
    - Objects are not assigned to either of the t (i.e. no t reconstruction)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





ttbar Limits





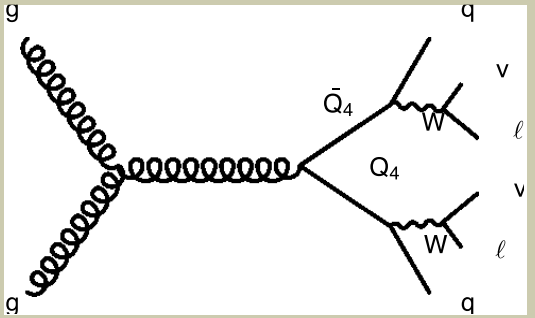
- The observed cross section limits on σ×Br(Z' → ttbar) ranges from 38 pb at M = 500 GeV to 2.2 pb at M=1300 GeV for leptophobic Z'
- Exclude $M_{gKK} < 650$ GeV @ 95% C.L.

Fourth generation quarks

ATLAS-CONF-2011-022

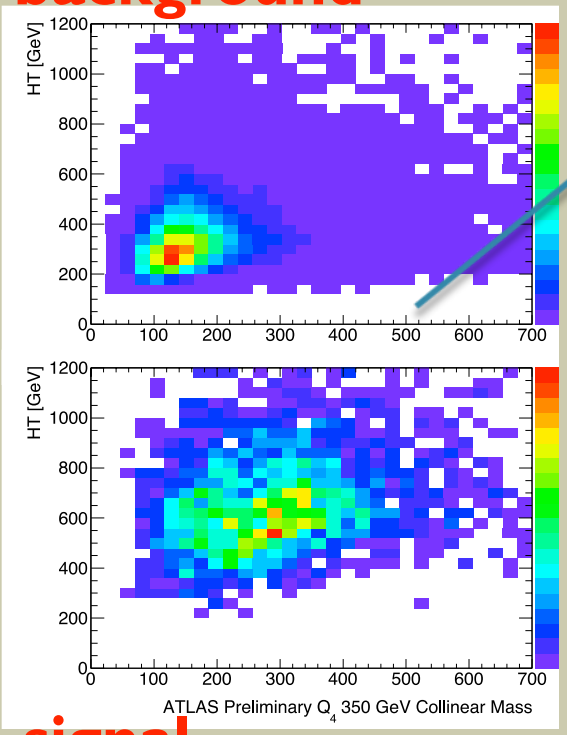
- Fourth generation is not excluded with the EW fit
- Pair production of Q_4
  - Ws decay leptonically
- Discriminating variables : H_T and $M_{collinear}$
- Main background : ttbar

$$Q_4\bar{Q}_4 \rightarrow W^+qW^-q$$



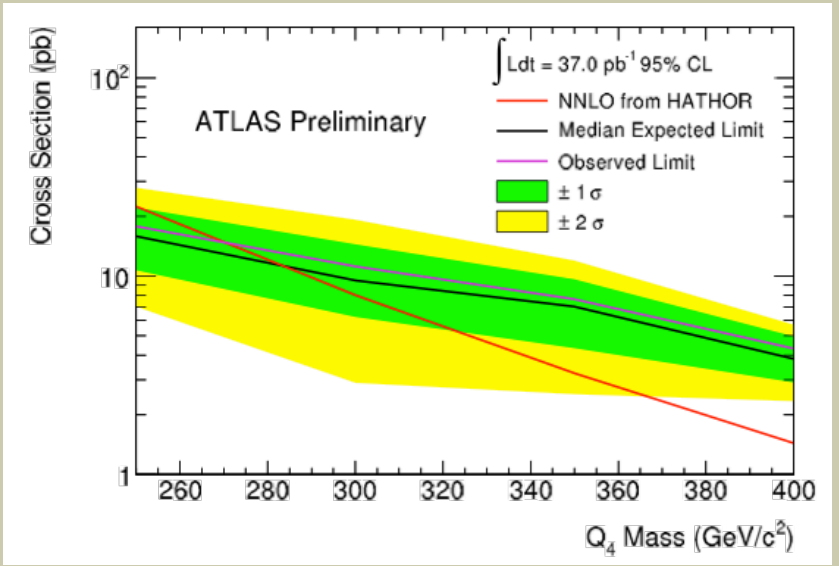
$$H_T = E_T^{l^+} + E_T^{l^-} + E_T^{q_1} + E_T^{q_2} + E_T^{miss}$$

background



signal

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



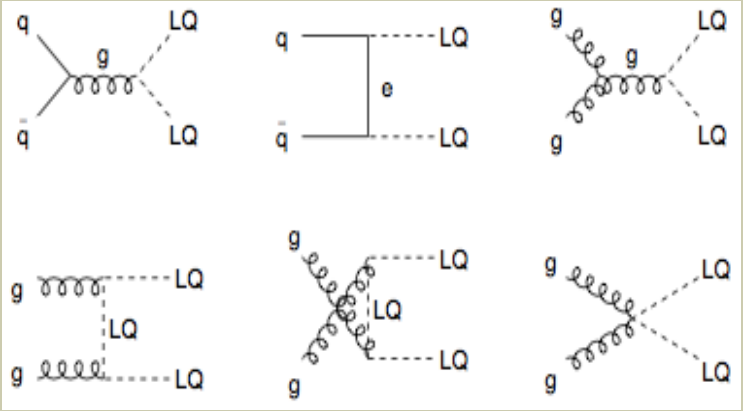
$m_{Q4} > 270$ GeV/c^2 @ 95% C.L.

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

Leptoquark Searches

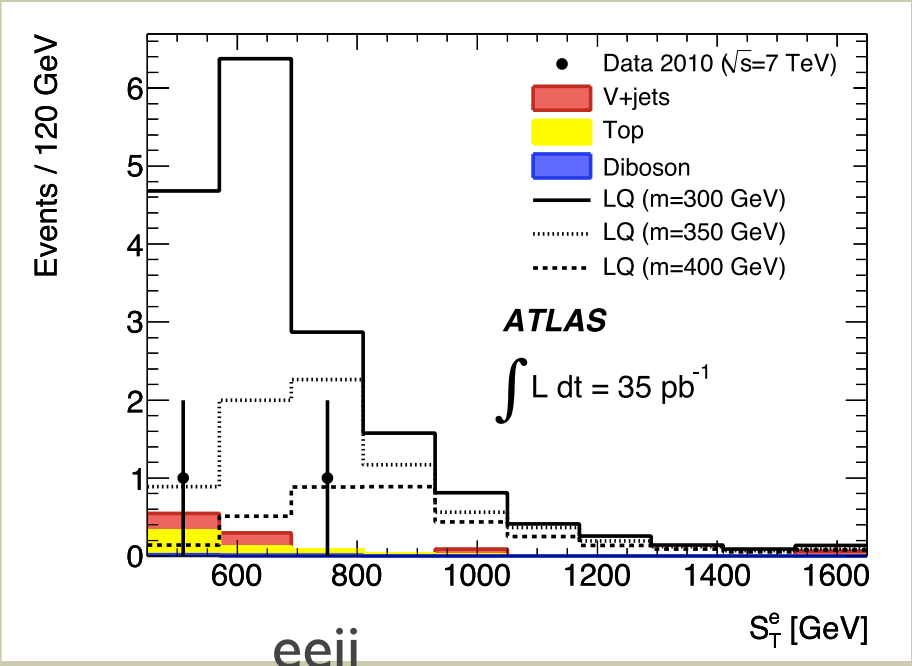
arxiv:1104.4481

- Observables:
  - Leptoquark invariant mass or transverse mass depending on the lepton charge.
- Backgrounds :
  - lljj : Z+jet and ttbar and lvjj : W+jets and ttbar
- Rejection:
  - measured transverse energy:

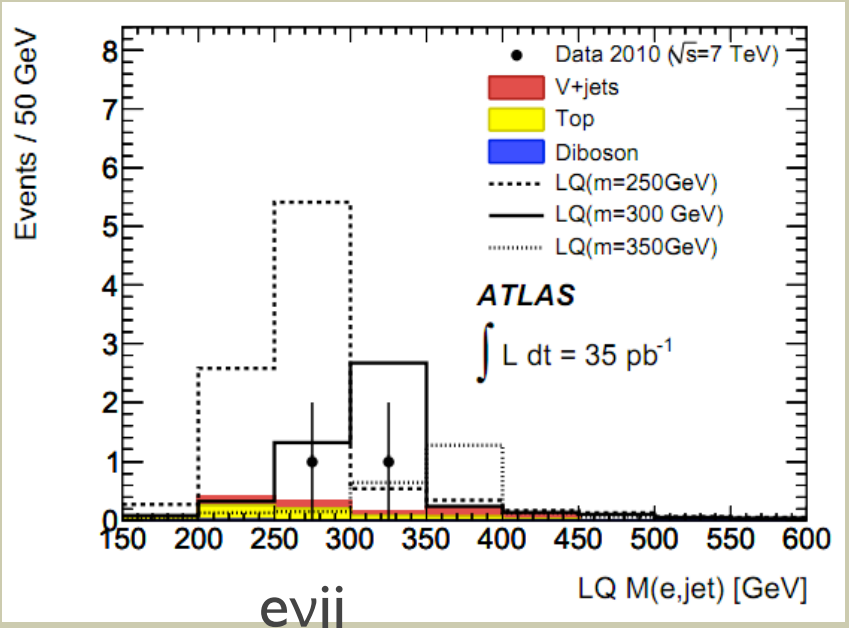


$$S_{\mathrm{T}}^{\ell} = p_{\mathrm{T}}^{\ell_1} + p_{\mathrm{T}}^{\ell_2} + p_{\mathrm{T}}^{\mathrm{j}_1} + p_{\mathrm{T}}^{\mathrm{j}_2}$$

$$S_{\mathrm{T}}^{\nu} = p_{\mathrm{T}}^{\ell_1} + E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{\mathrm{j}_1} + p_{\mathrm{T}}^{\mathrm{j}_2}$$



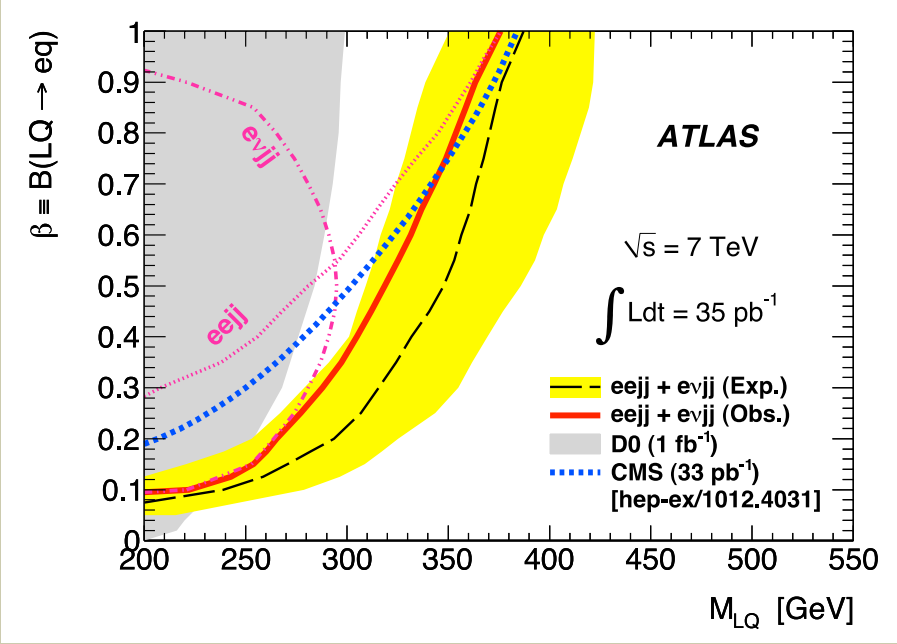
eejj



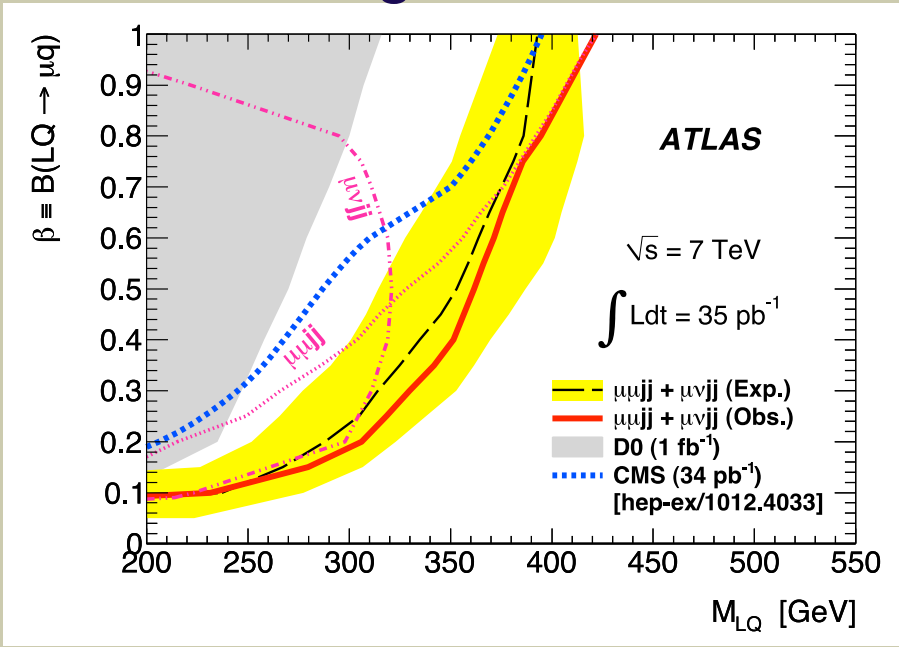
evjj

Leptoquark Limits

1st generation



2nd generation



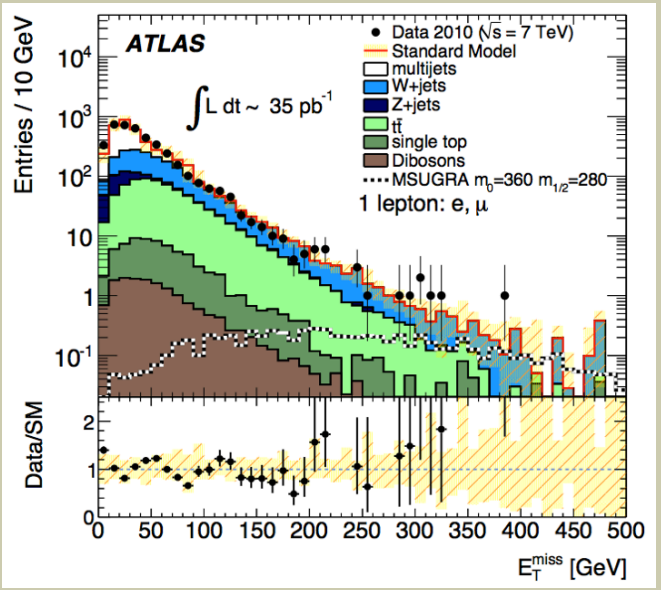
95% C.L. Lower limit on LQ

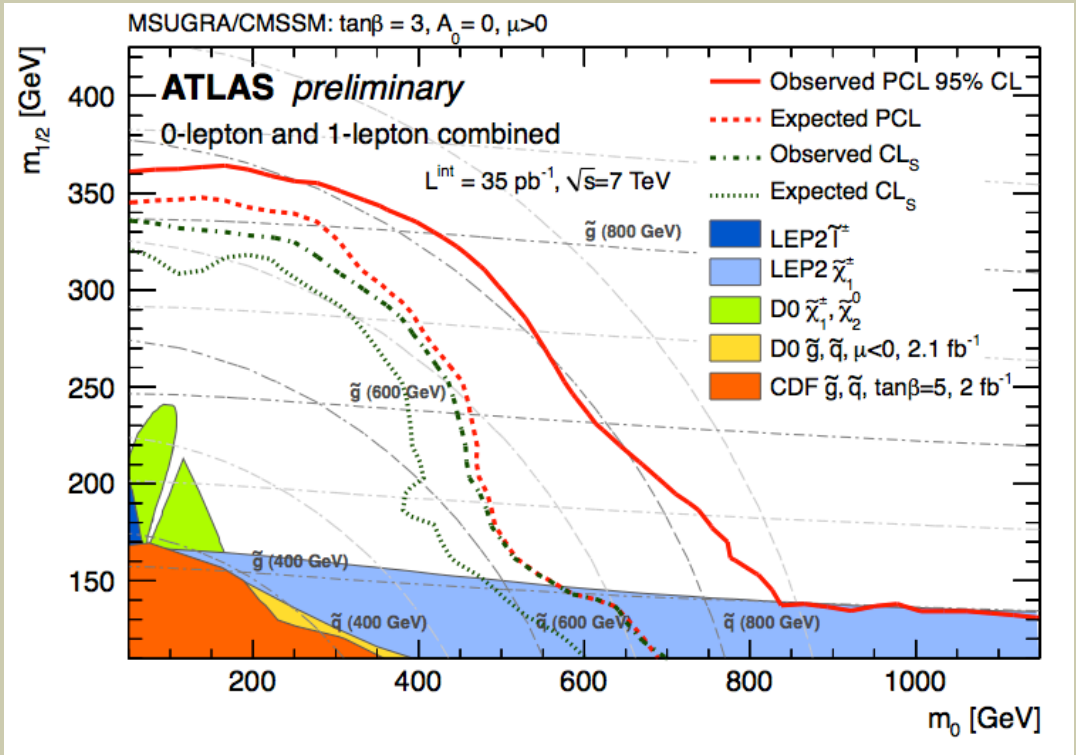
Type (β)	Expected limit (GeV)	Observed limit (GeV)
1st generation (1.0)	387	376
1st generation (0.5)	348	319
2nd generation (1.0)	393	422
2nd generation (0.5)	353	362

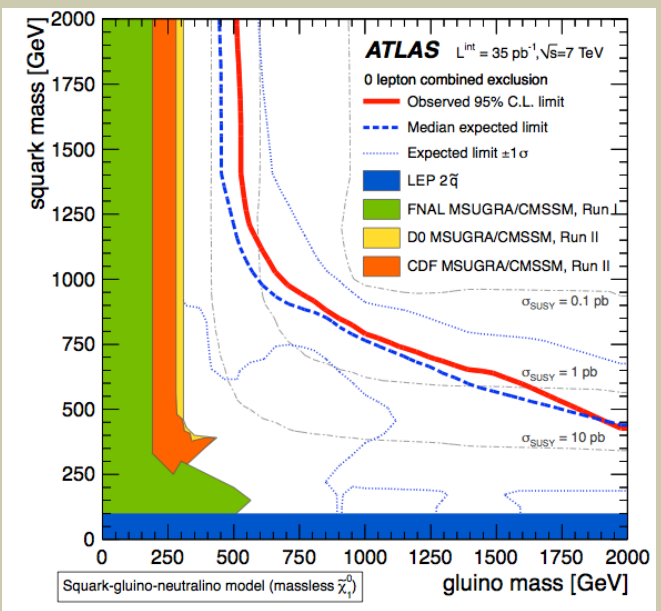
Susy Searches -1

ATLAS-CONF-2011-064

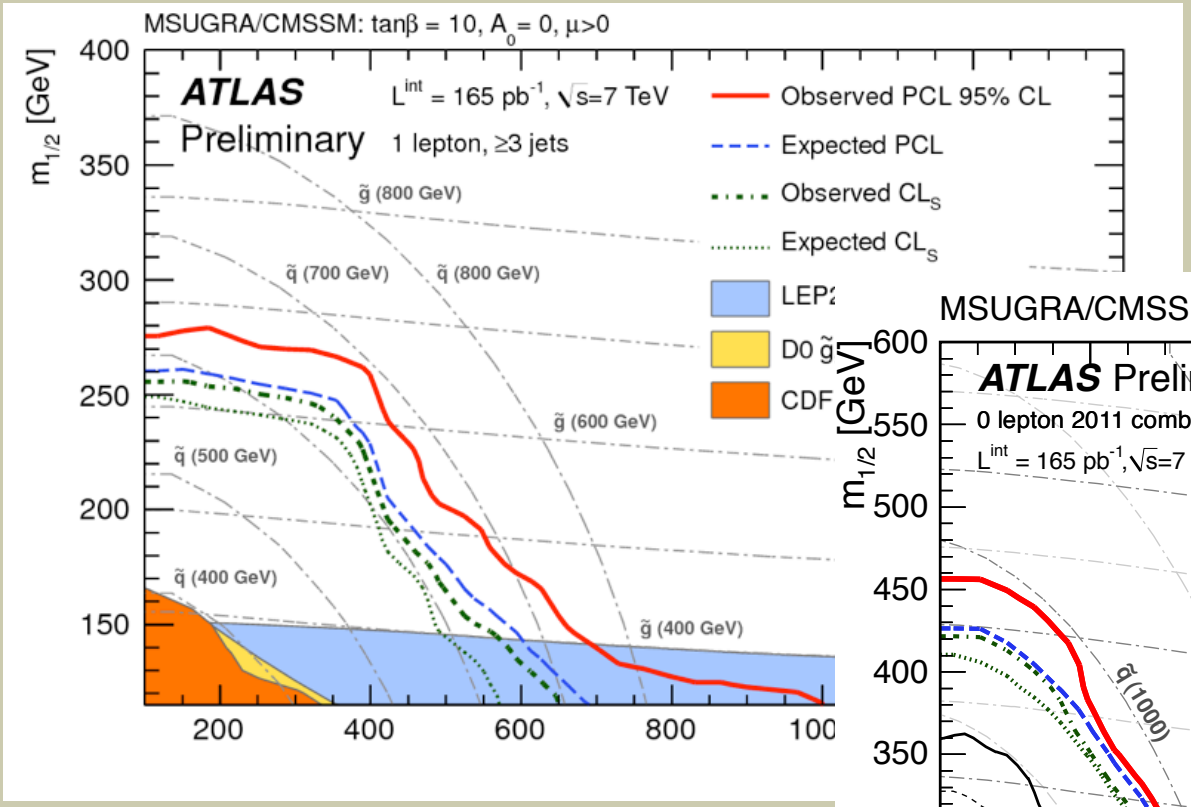
- Squarks & Gluinos w/ final state: jets+met+ 0,1 leptons
  - 1 lepton details in arXiv:1102.2357
  - 0 lepton details in arXiv:1102.5290
- no deviation from SM
  - squarks and gluinos of equal mass are excluded below 815 GeV at 95% CL

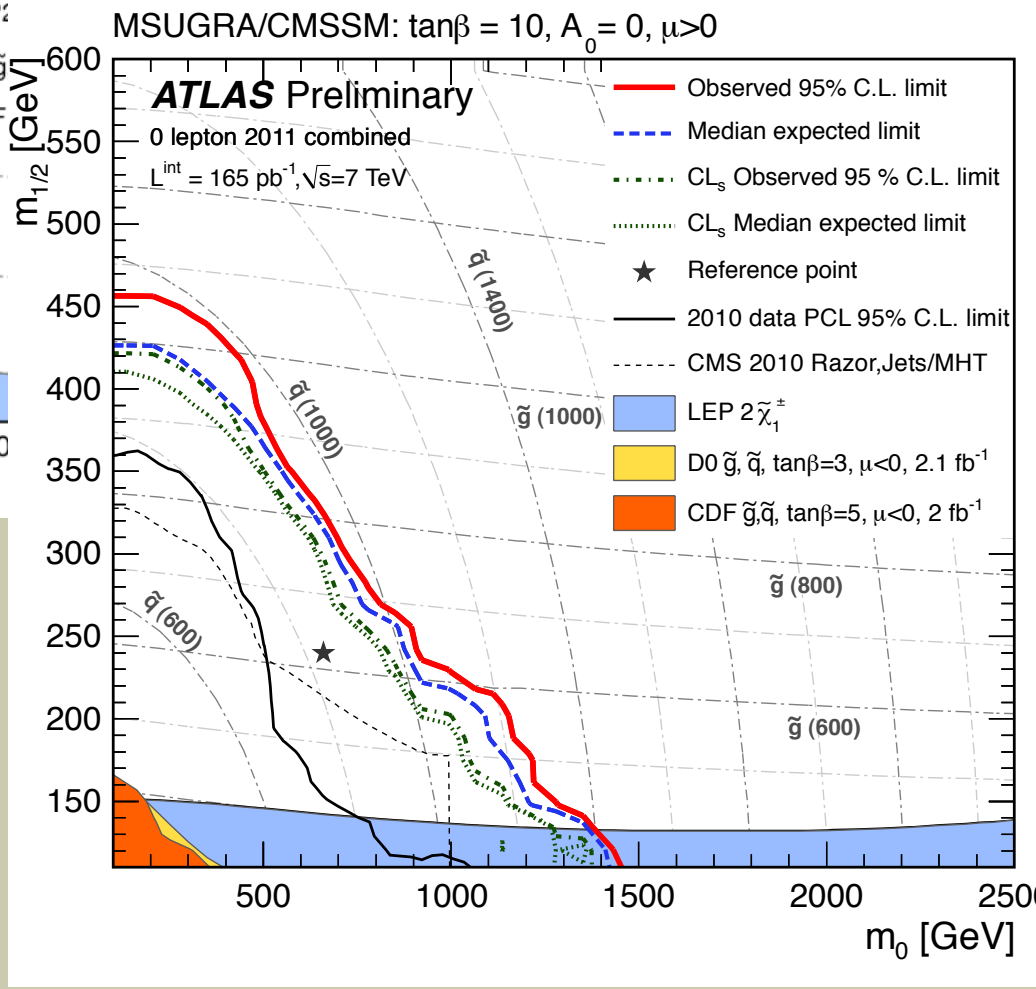






Squarks & Gluonos 2011 updates





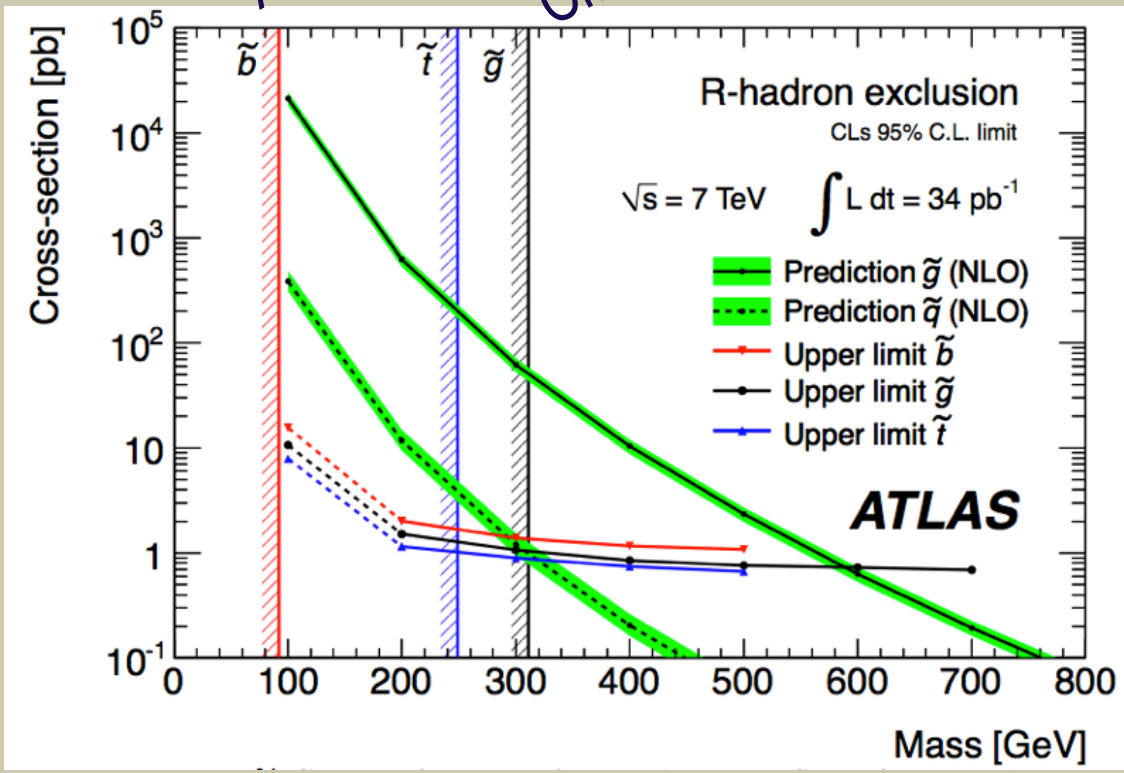
- Much better limits with L_{int}=165pb^{-1}
- Still no sign of susy..

Susy Searches -2

arXiv:1103.1984

- Stable hadronising Squarks and Gluinos (R-hadrons)
  - slowly moving stable particles with final state:
  - High pT track associated with energy depositions in the calorimeter.
  - ATLAS also sought for neutral R-hadrons
  - no excess observed
    - 95%CL limits set

Aleph CDF CMS



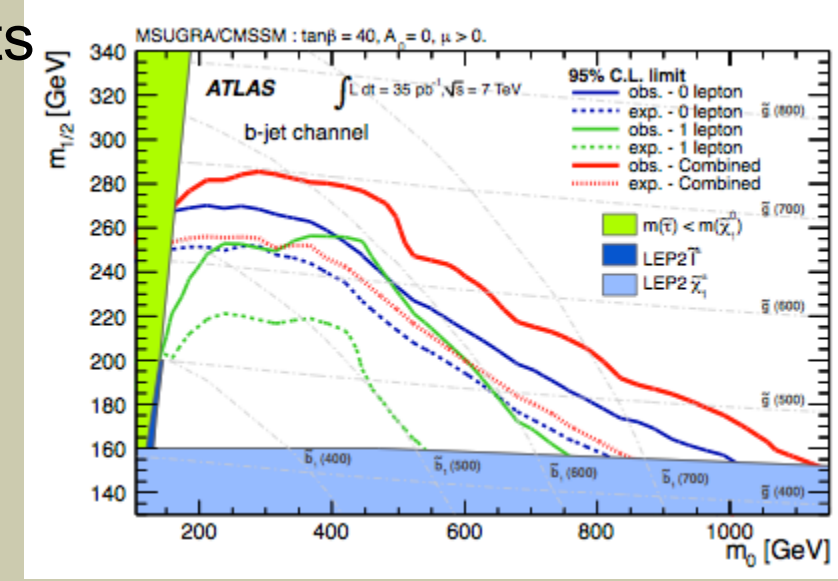
sbottom	stop	gluino
294	309	586

masses in GeV

Susy Searches -3

- Gluinos w/ final states : MET+ b-jets
  - no excess, Limit set @ 95%CL
  - m_{gluino}>590GeV for $m_{sbottom}$<500GeV

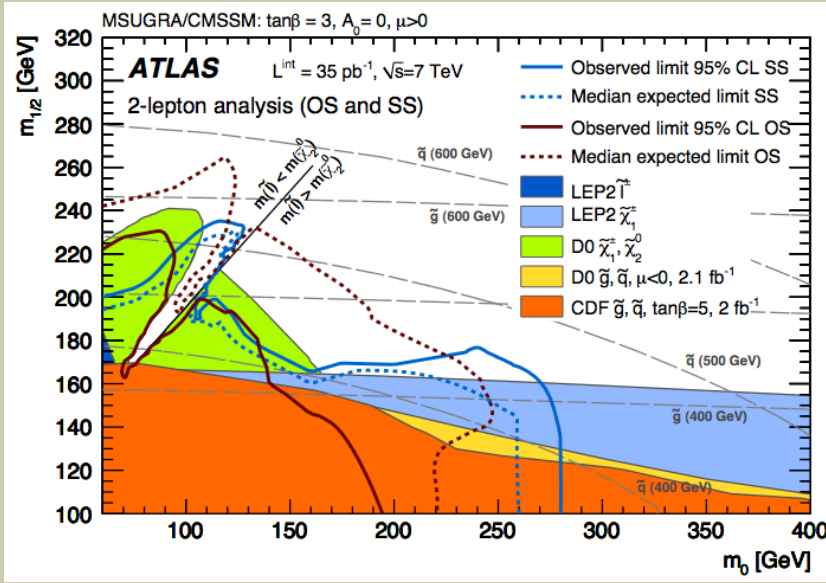
  arXiv:1103.4344



- Neutralinos & squarks w/ final states: MET+ll
  - opposite vs same&opposite signs
  - no excess, Limit set @ 95%CL
  - m_{squark} > [450 .. 690] GeV depending on specific susy model

  arXiv:1103.6208

  arXiv:1103.6214



Conclusions

- Very successful LHC run at 7 TeV so far.
  - ~50 pb^{-1} data is collected in 2010
- Many BSM scenarios studied with 2010 and early 2011 data.
  - No deviations from the SM found; yet.
- TeV scale limits were set :
  - some world's best limits
- 2011 data taking is going very well :
  - Lumi record set …
  - 2011 target reached → more than 1fb^{-1} already collected.
- Keep watching us for new results!

Backup slides

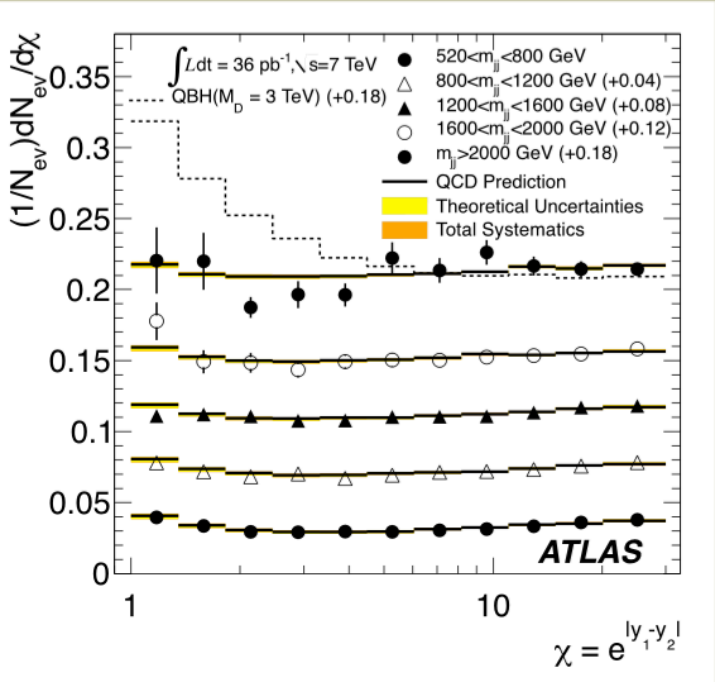
di-jet angular distribution

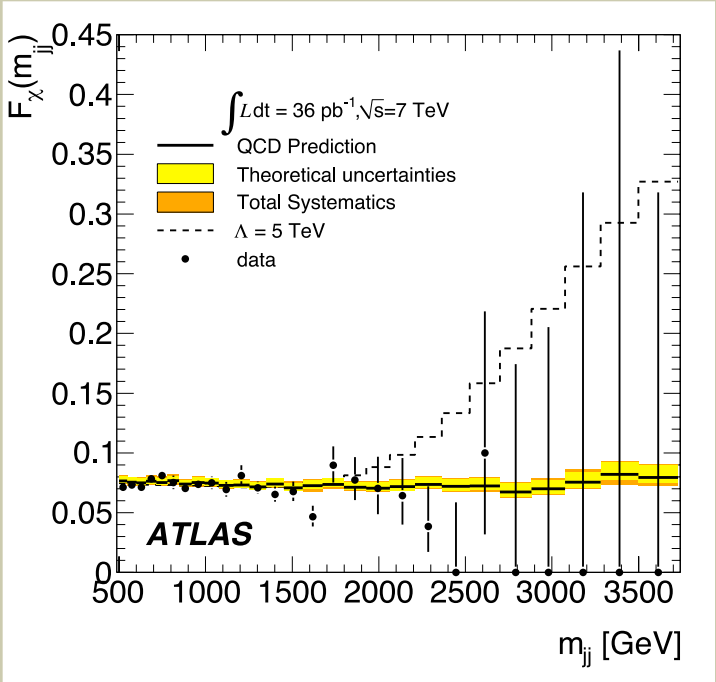
- χ distribution is relatively flat for QCD

$$\chi \equiv \exp\left(\left|y_1 - y_2\right|\right)$$

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

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





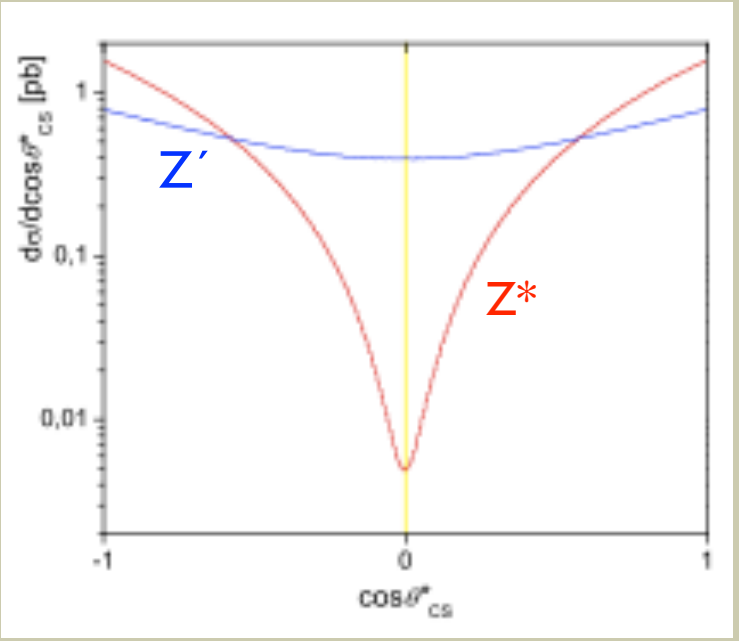
About new heavy bosons

- 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)

arXiv:0801.4235v1



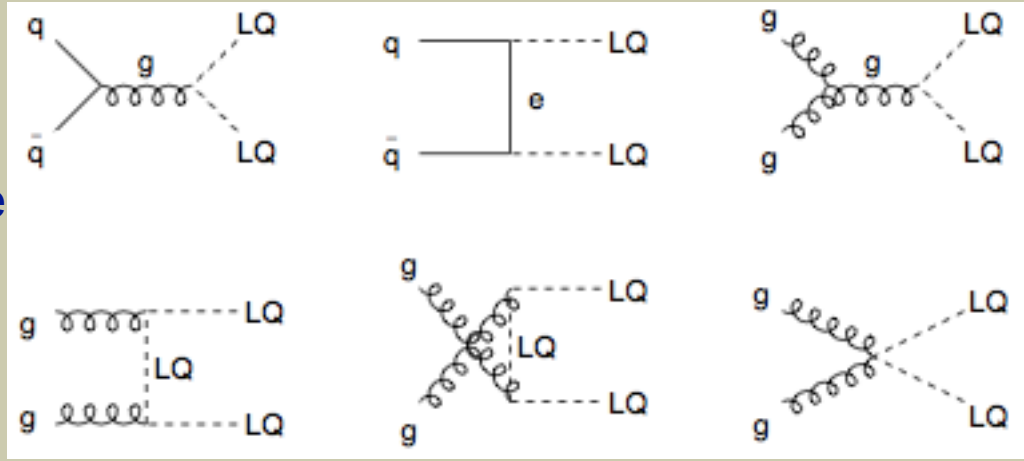
Differential cross section for Z' and Z* at 800GeV < M_{ll} < 1200 GeV

Leptoquarks searches

arxiv:1104.4481

- Leptoquarks – particles that carry both lepton and baryon quantum numbers

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



- Many models predicts leptoquarks
  - Quark and lepton sub-structure
  - Theories seek GUT
  - Extended technicolor

- LO search - LQ pair production e/μ for 1st/2nd LQ generation through lljj and lνjj

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

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

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

Susy Searches

- Give up the (so far) observed "spin" asymmetry between matter and force carriers: partners for all SM particles
  - solves Fine Tuning, DM.. problems
- SUSY not observed: sparticles heavy: broken symmetry
- Rich phenomenology (even with R_{parity}):
  - large # of parameters: >100 in MSSM case[R]
  - many SB options: MSSM, mSUGRA, GMSB, AMSB..
- Common properties:
  - cascade decays of sparticles to high p_T objects ,
  - stable LSP escapes undetected: large E_T^{miss} .

has 5 parameters

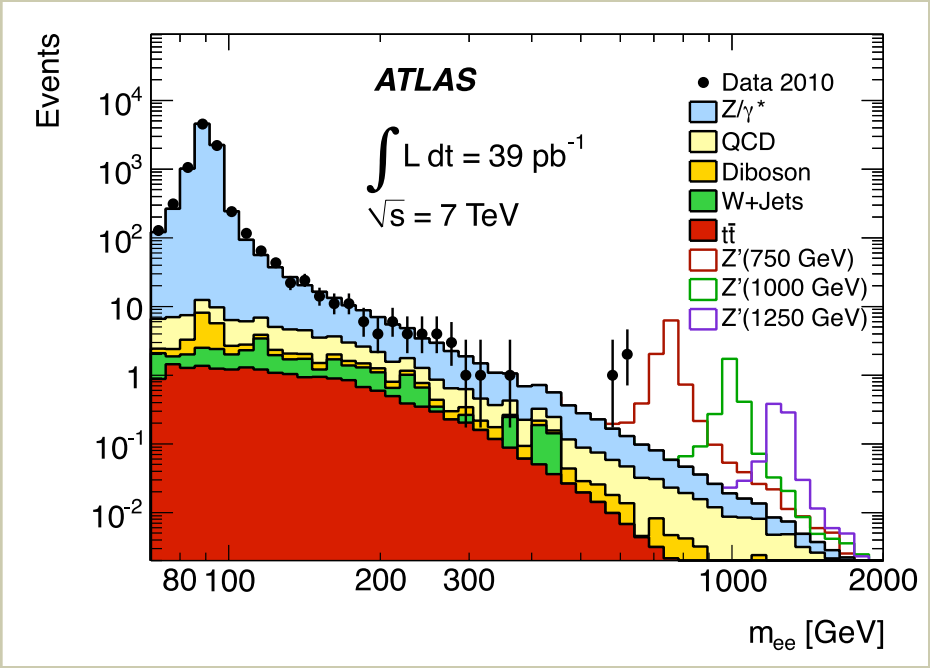
has 6 parameters

Look for: jets + E_T^{miss} and leptons +jets + E_T^{miss}

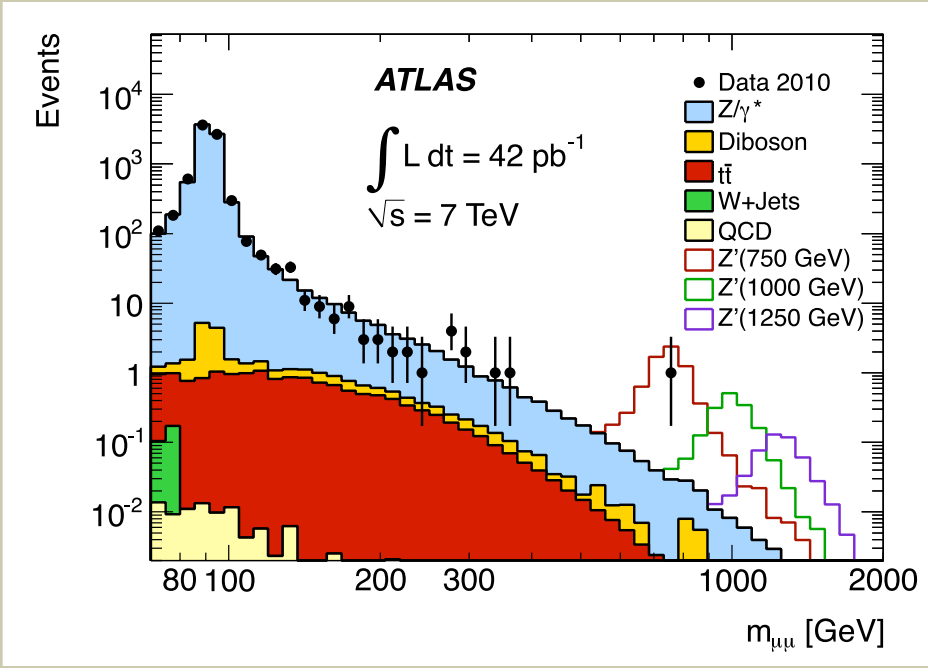
[R] #parameters=124 given in SN-ATLAS-2006-058

di-lepton Resonances w/ 2010 data arxiv:1103.6218

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



electrons

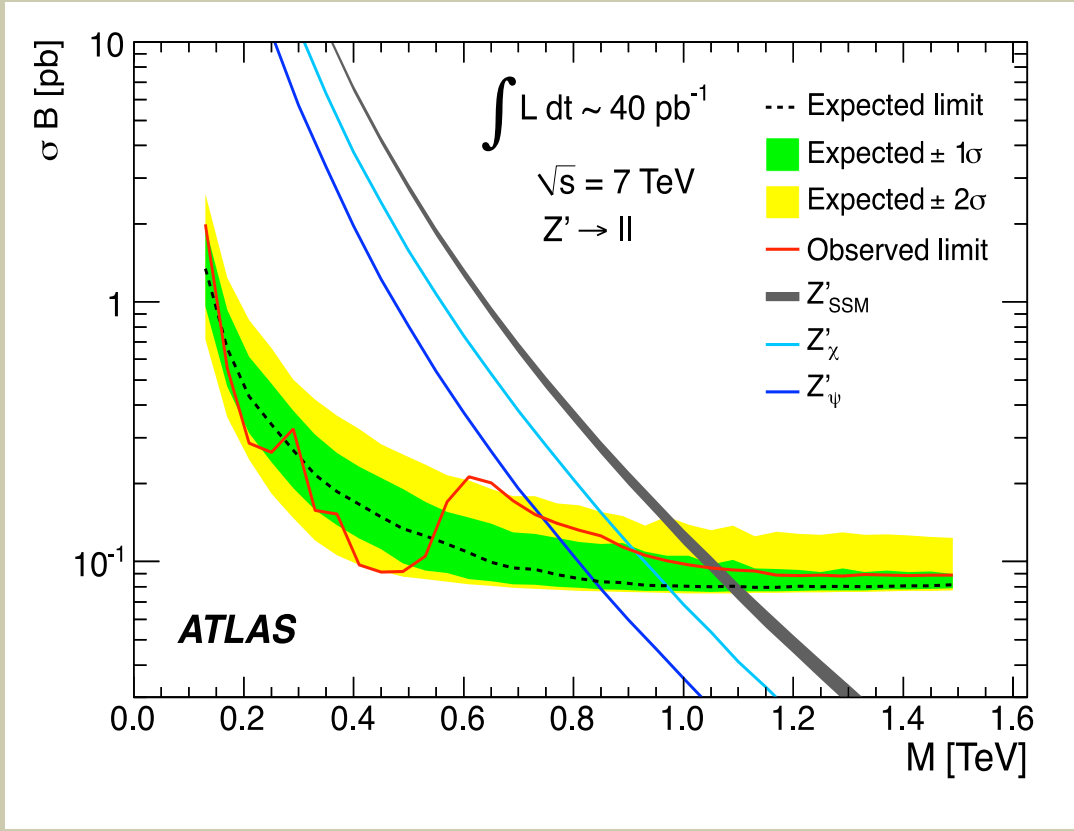


muons

di-lepton Limits w/ 2010 data

- Previous lower Limits [TeV] *assuming SM couplings*

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



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

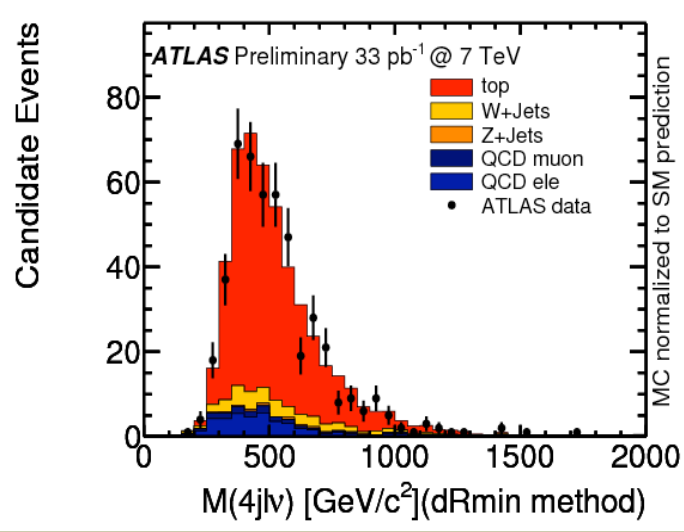
$M_{Z'}$ (SSM) > 1.048 TeV

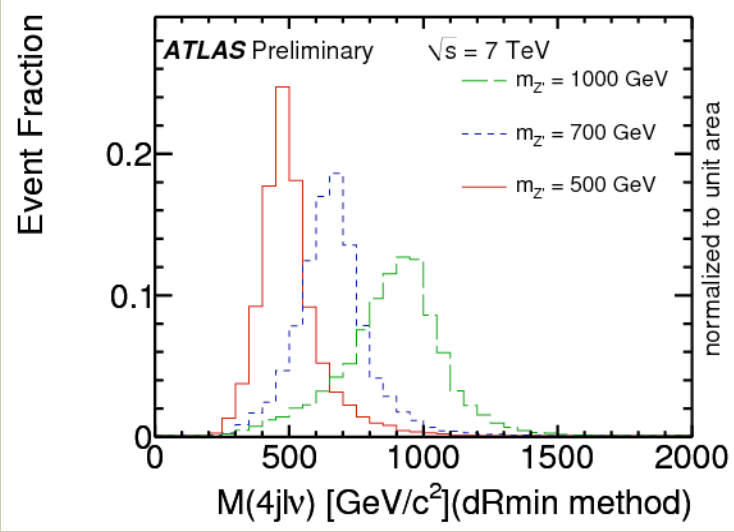
M_{Z^*} > 1.152 TeV (first limit on Z* mass)

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

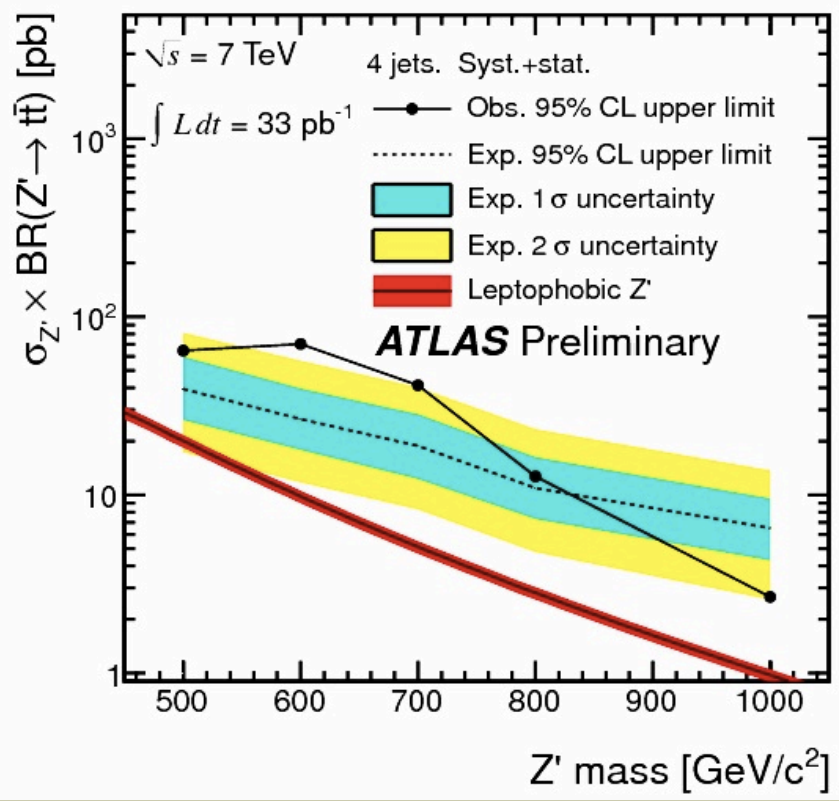
ttbar Resonances w/ 2010 data ATLAS-CONF-2011-070

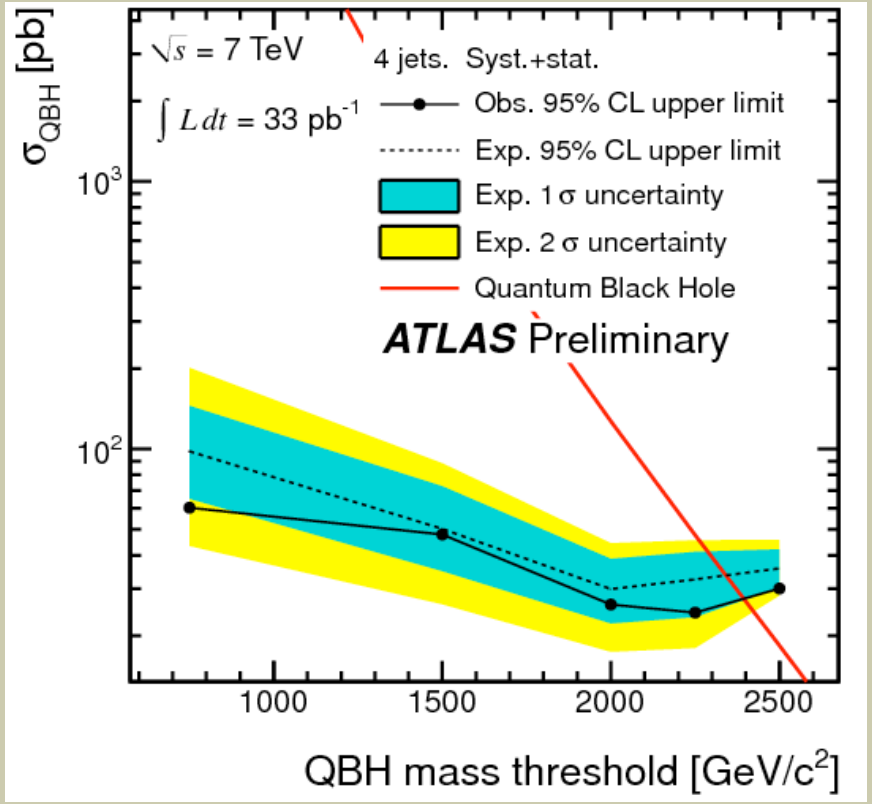
- Signature : (At least one W reconstructed leptonically):
  - High pT isolated lepton (e,μ), jets and large missing energy
- Observable :
  - Invariant mass of ttbar computed from the reconstructed objects in the final state
    - Objects are not assigned to either of the t (i.e. no t reconstruction)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





ttbar Limits w/ 2010 data





- 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.