Search for Supersymmetry and Exotic processes with the ATLAS detector

Beware of the sleeping beauty!

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Kruger LHC Workshop 2012

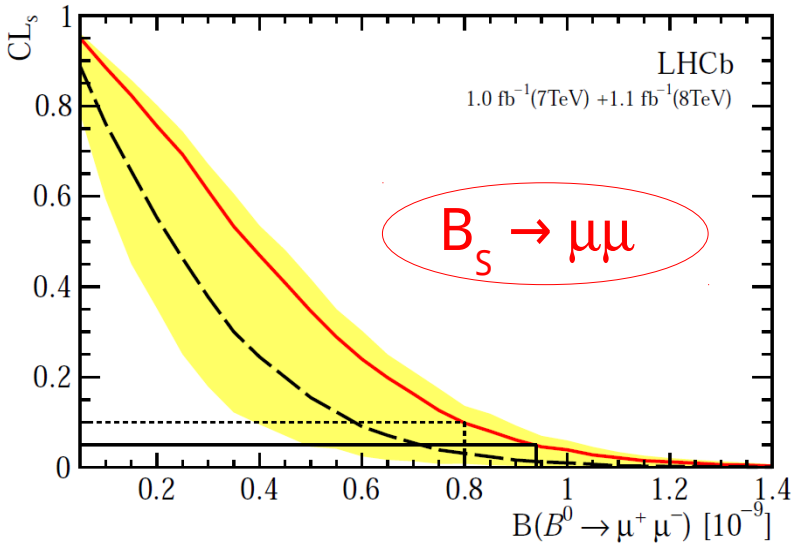
[†]on behalf of the ATLAS collaboration

Storyline

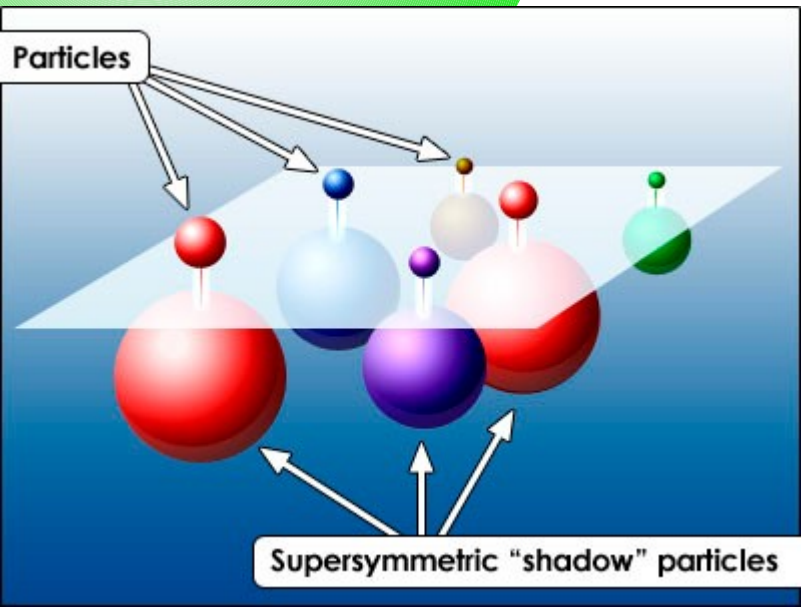
- Introduction to Beyond the Standard Model Searches
- Supersymmetry in ATLAS
- Exotic phenomena in ATLAS
- Summary

Go beyond the known world

- The standard model is to this day the best description of matter and forces
- However, it is not a complete theory and many models ~~were~~ are developed by theorists to overcome these lacking ingredients, such as dark matter candidates
- The SM continues to guide us in this journey



SUPERsymmetry



- Heavier superpartners with spin-½ compared to the SM
- MSSM: 105 parameters to be determined!

- Introducing R-parity (aka matter parity)
  - SM particles (+1), SUSY particles (-1)
  - Phenomenology centered around the Lightest Supersymmetric Particle (LSP)
  - Can be violated

Quest for supersymmetry in ATLAS

- Looking for various scenarios of Supersymmetry
  - Strong production
  - Weak production
  - Long-lived particles
  - R-parity violating models (with LSP decays)

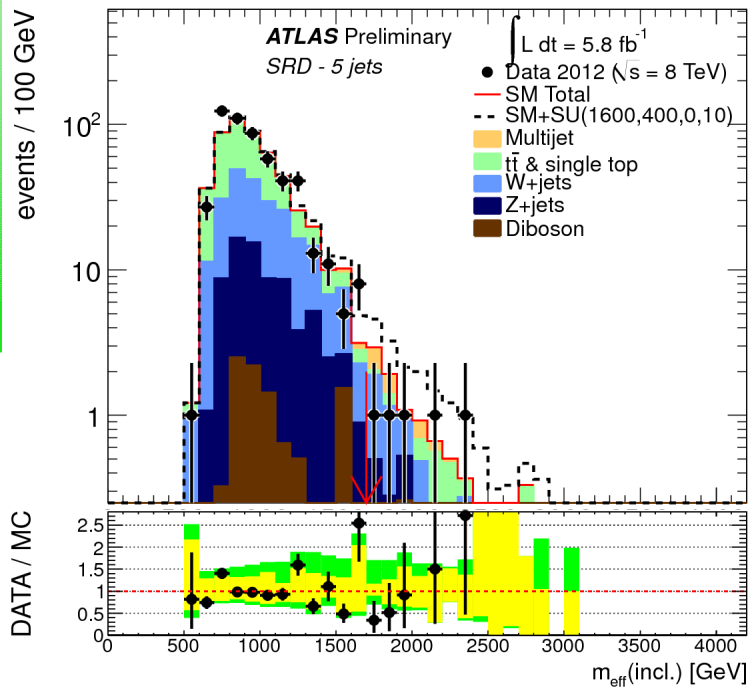
Several searches updated with 8 TeV data

- Setting constraints on various flavours of MSSM
  - cMSSM/mSUGRA
  - pMSSM
  - GMSB
  - AMSB

Search for coloured sparticles

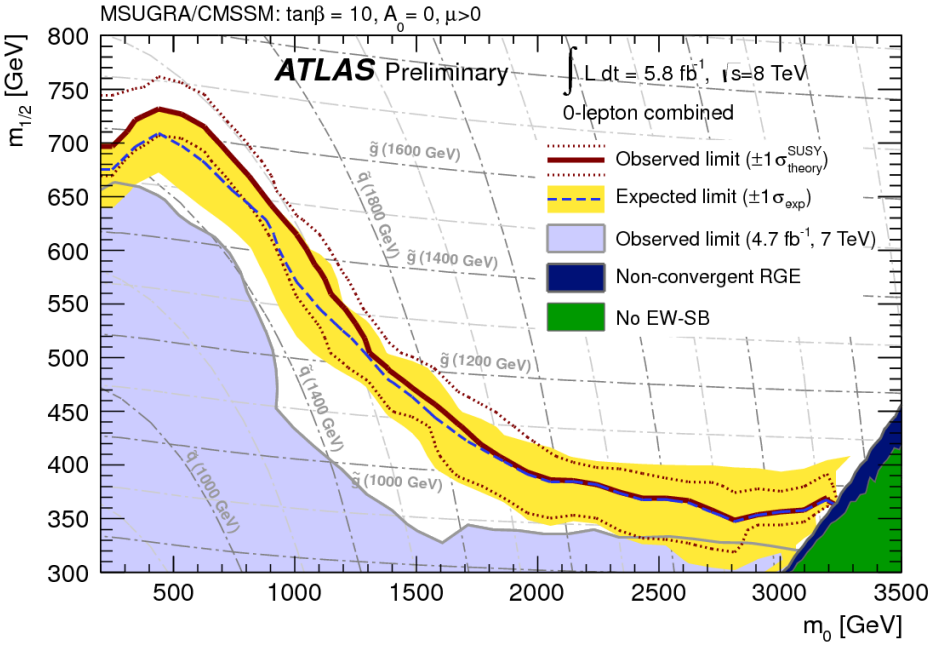
8 TeV

ATLAS-CONF-2012-109



- Searching for $\tilde{q} \to q\chi_1^0, \tilde{g} \to q\bar{q}\chi_1^0$
  - Events without leptons and ≥ 2-6 jets + $\not{E}_T$
- Backgrounds: W(lν)+jets, Z(νν̄)+jets, tt̄+jets, multijets
- 12 signal regions covering 5 different jet multiplicities

- Setting further limits on mSUGRA
  - $m_{\tilde{q},\tilde{g}} > 1500$ GeV
- Simplified model with $\chi_1^0 = 0$
  - $m_{\tilde{g}} > 1100$ GeV
  - $m_{\tilde{q}} > 730$ GeV

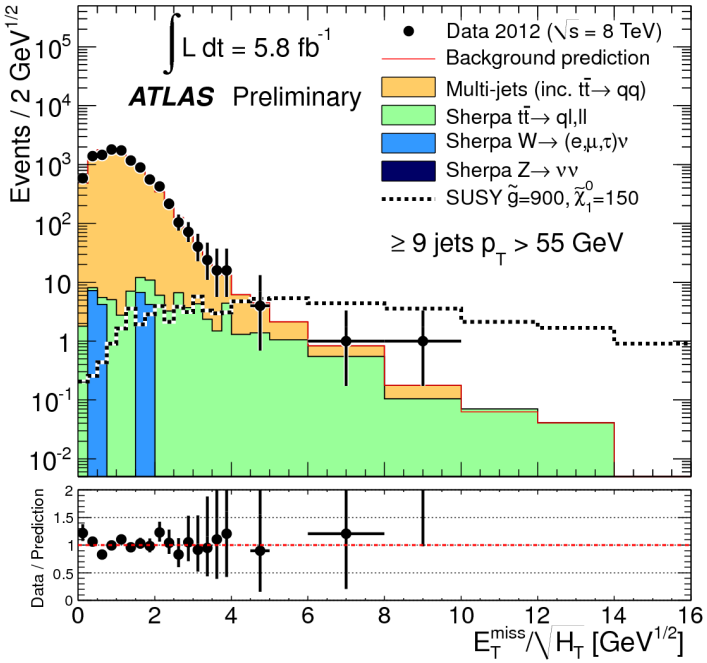


Search for coloured sparticles

8 TeV

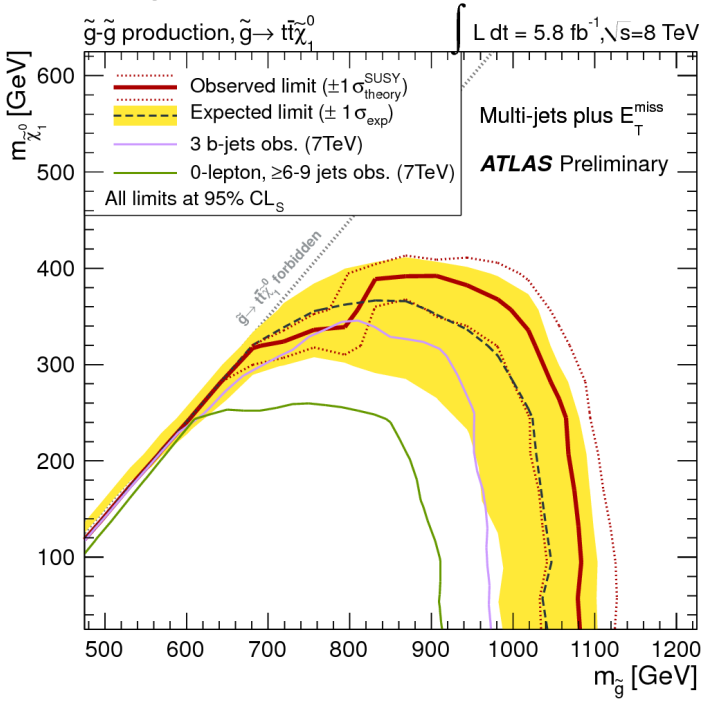
ATLAS-CONF-2012-103

- Search for hadronic events with high jets multiplicities
  - Models with $m_{\tilde{q}} > m_{\tilde{g}}$
- Select events with $E_T^{miss}/\sqrt{H_T} > 4$ GeV in 6 signal regions based on jet multiplicity (from >=6 to >= 9 jets) and jet p_T
- Background: QCD multijets, leptonic $t\bar{t}$ and W/Z+jets



Exclusion:

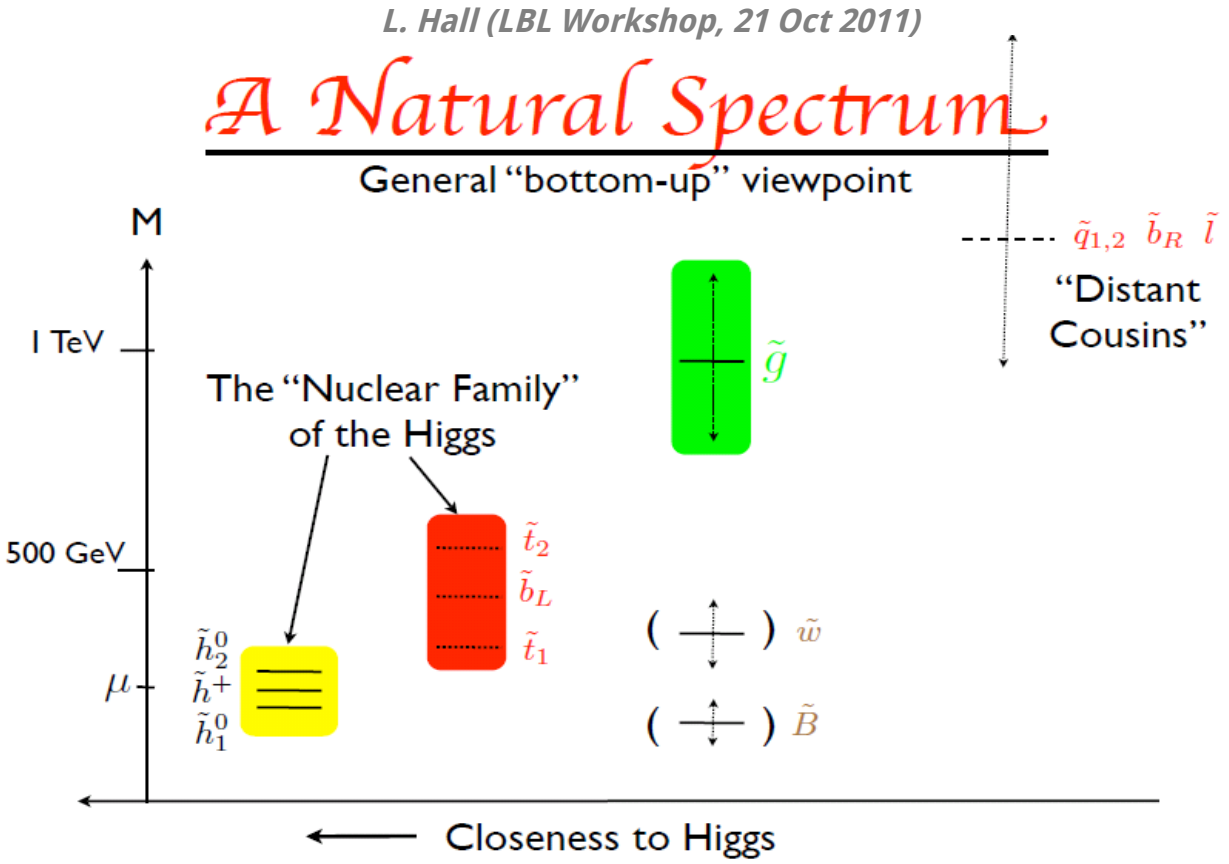
- $m_{\tilde{g}}$ > 1.0 TeV for $m_{\chi_1^0}$ > 300 GeV



→ *See V. Consorti talk on squarks/gluinos Searches*

3rd generation squarks

- Direct measures of naturalness in SUSY
  - If low fine-tuning, expect $m_{\tilde{t}} \sim m_t$



ATLAS-CONF-2012-165

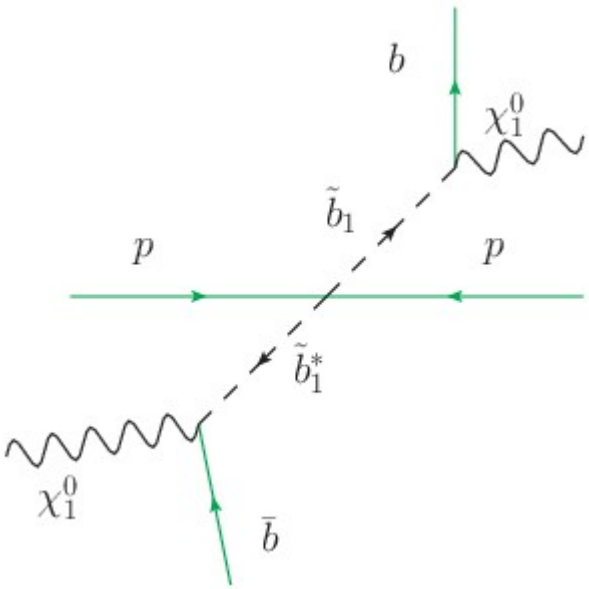
Direct Sbottom

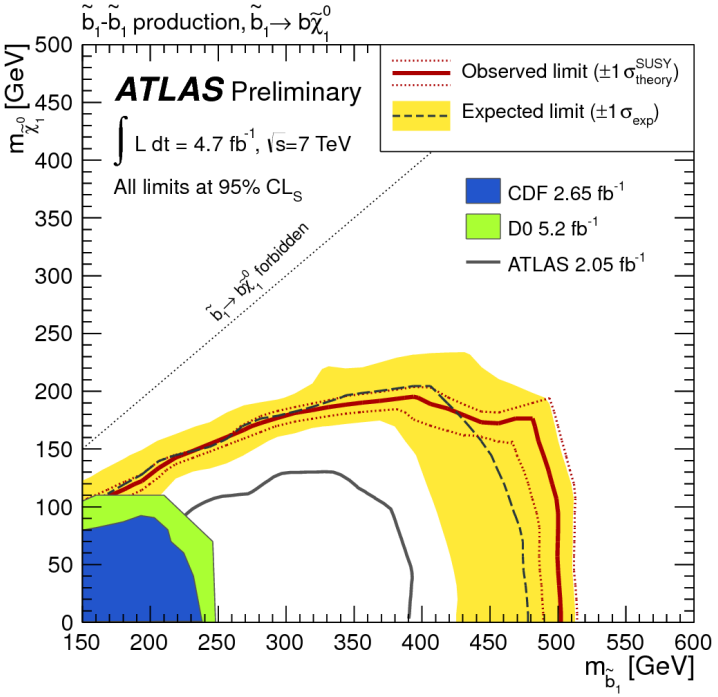
ATLAS-CONF-2012-106

- Signature: exactly 2 b-jets and missing E_T
- Using m_{CT} for background discrimination

$$m_{CT} = \sqrt{\left(E_T(b_1) + E_T(b_2)\right)^2 - \left(p_T(b_1) - p_T(b_2)\right)^2}$$

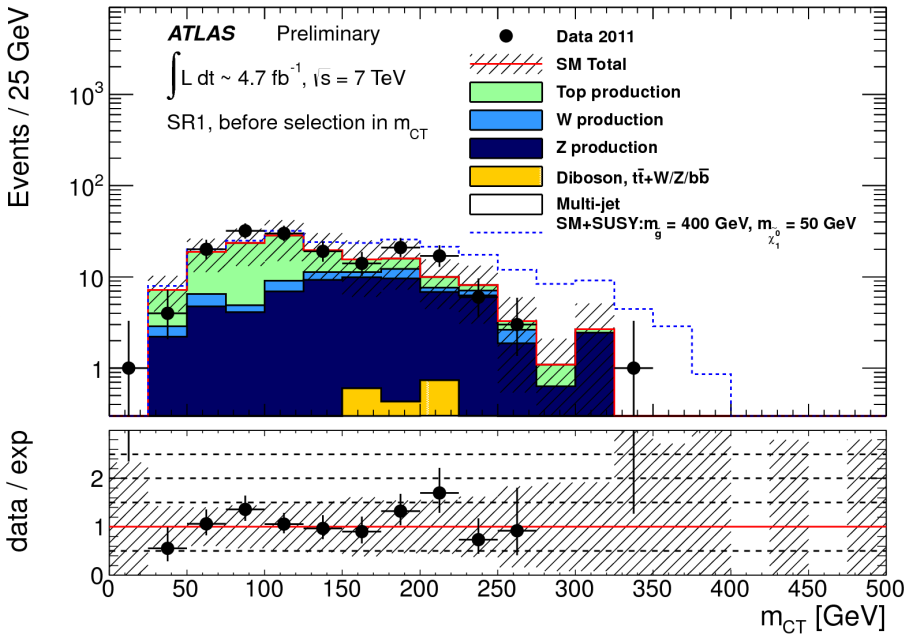
- Backgrounds: $t\bar{t}$, W+HF, Z+HF





Exclusions:

- $m_{\tilde{b}}$ = 490 GeV for $m_{\chi_1^0}$ = 0
- $m_{\chi_1^0}$ < 180 GeV for $m_{\tilde{b}}$ = 400 GeV



ATLAS-CONF-2012-166
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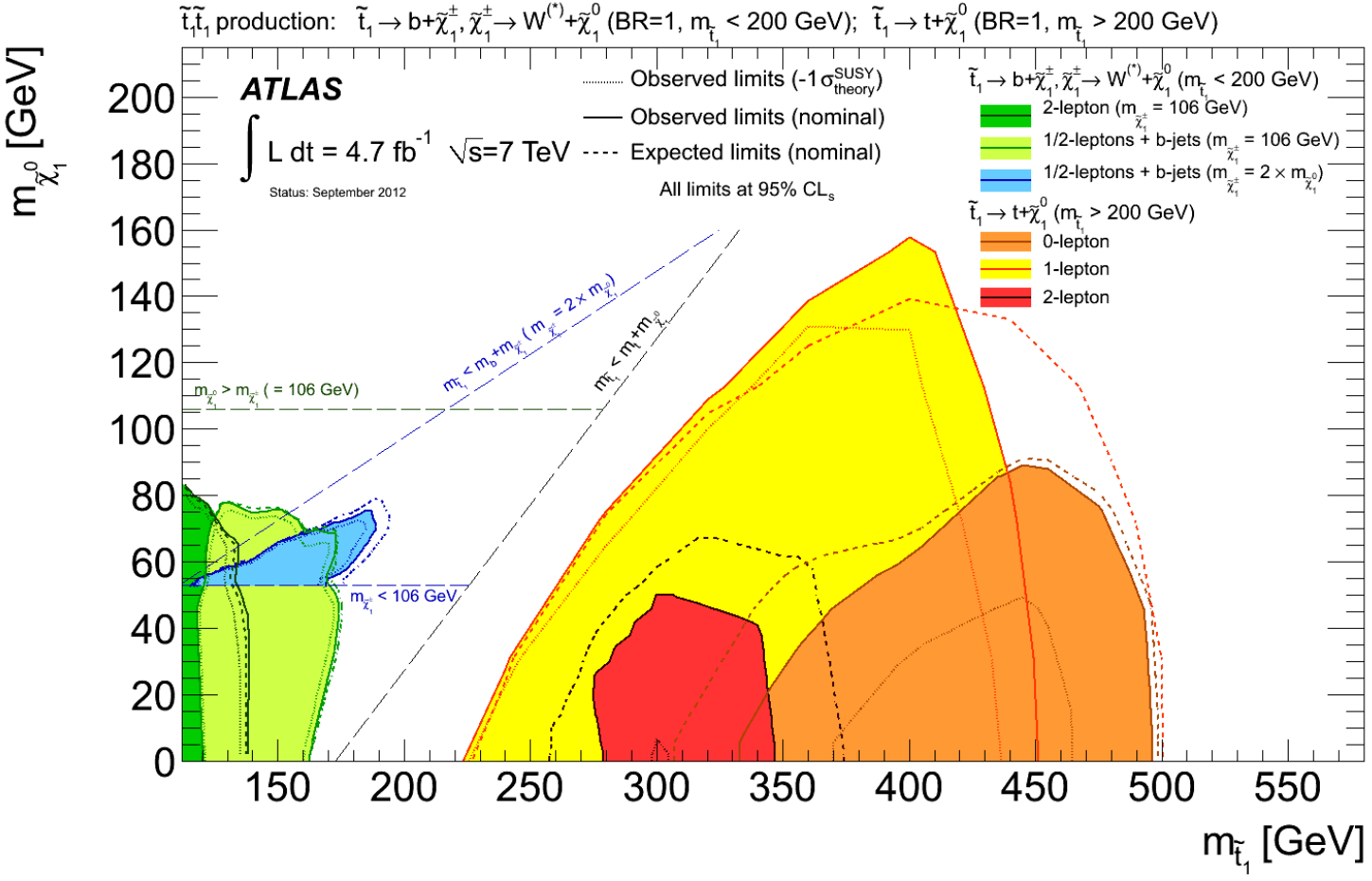
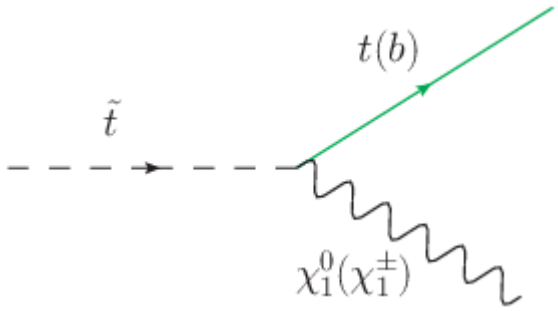
Direct Stop

Summary of 5 stop searches in 7 TeV data (5 fb^{-1})



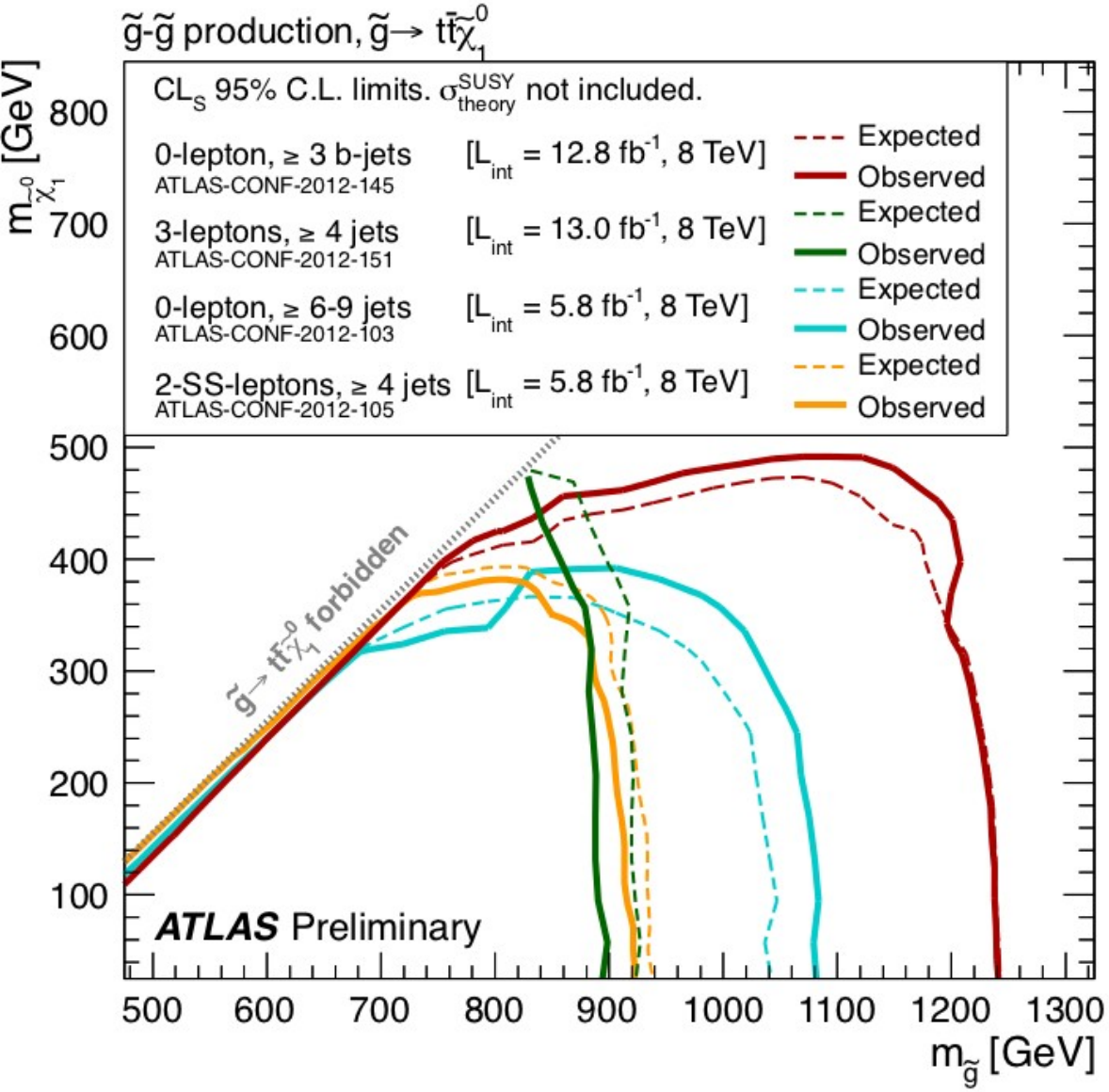


arXiv:1208.4305
arXiv:1209.2102
arXiv:1208.1447
arXiv:1208.2590
arXiv:1209.4186

Gluino-mediated Stop Production

8 TeV

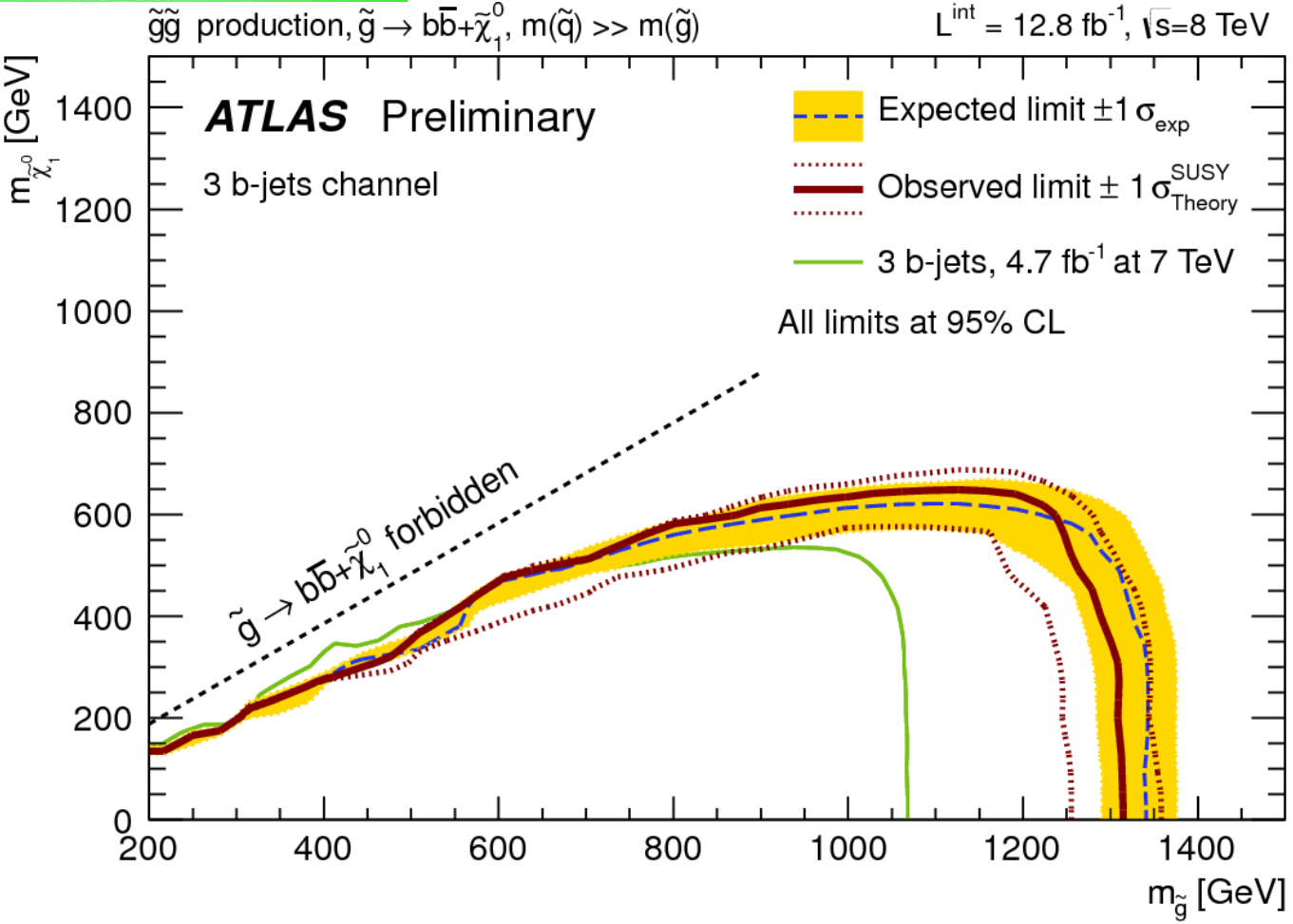
ATLAS-CONF-2012-103/105/145/151



Gluino-mediated Sbottom Production

8 TeV

ATLAS-CONF-2012-145



Improved reach compared to 7 TeV data

Exclusions:

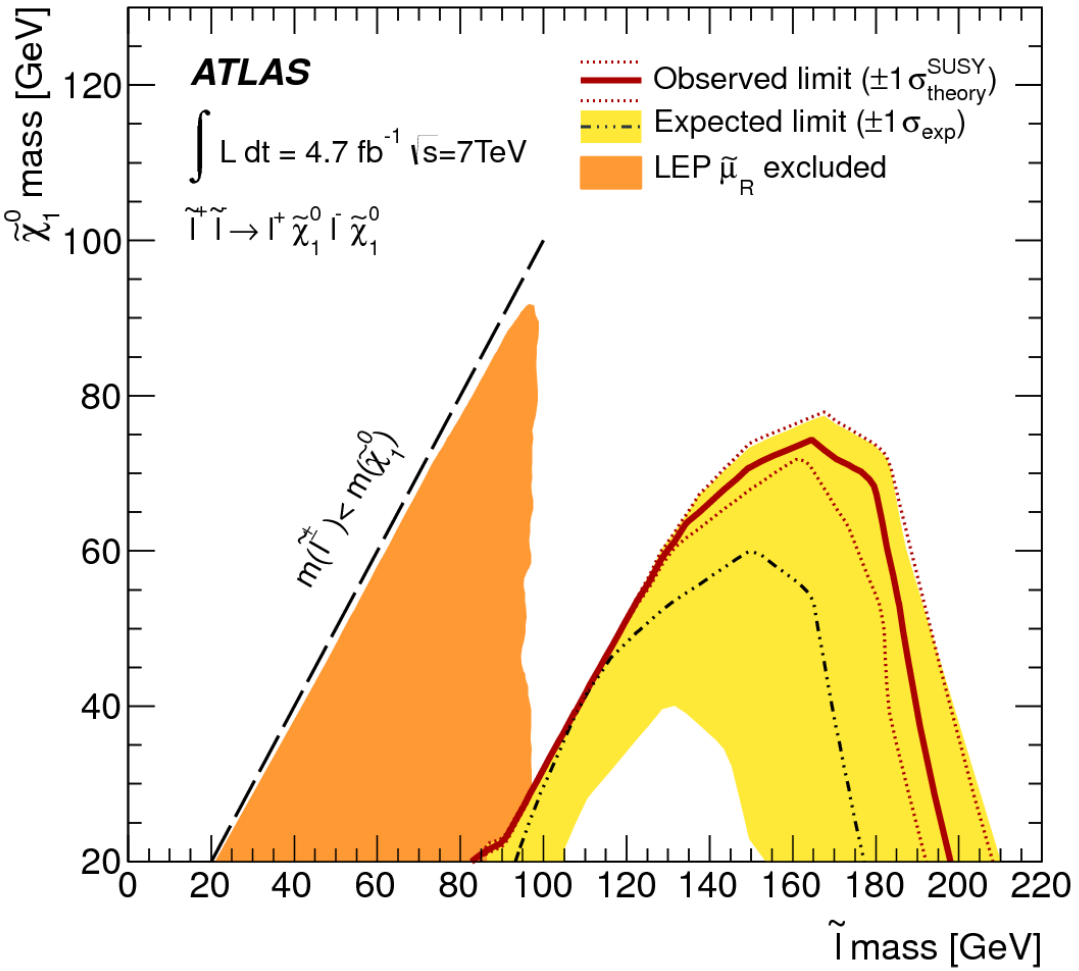
- $m_{\tilde{g}} < 1240$ GeV for $m_{\chi_1^0} < 200$ GeV
- $m_{\chi_1^0} < 570$ GeV for $m_{\tilde{g}} = 1100$ GeV

Direct Sleptons production

arXiv:1208.2884

$$\tilde{\ell}^{\pm} \rightarrow \ell^{\pm} \tilde{\chi}_1^0$$

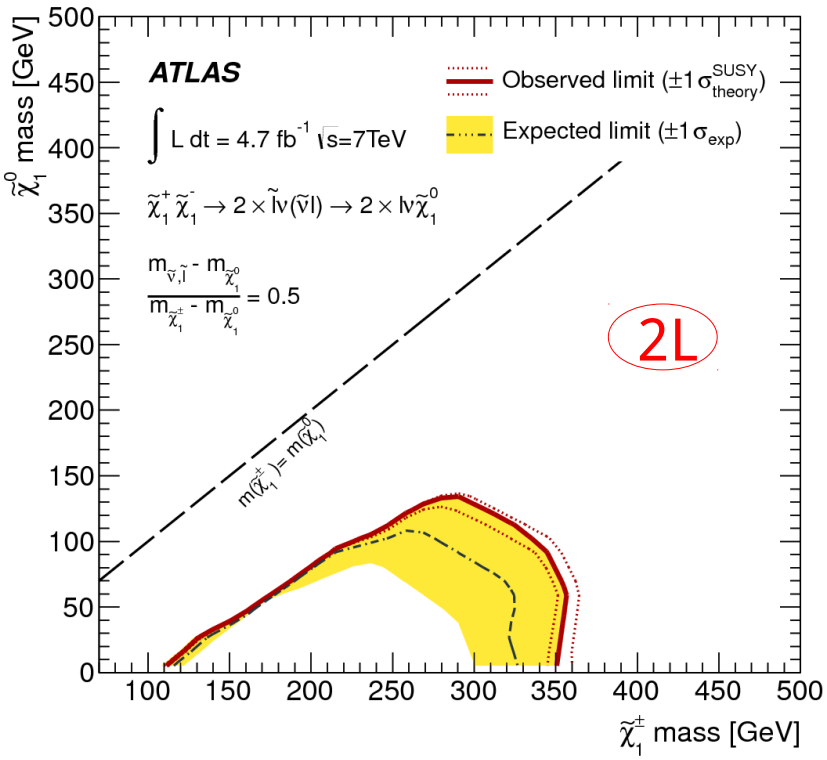
Significant improvement on LEP reach!

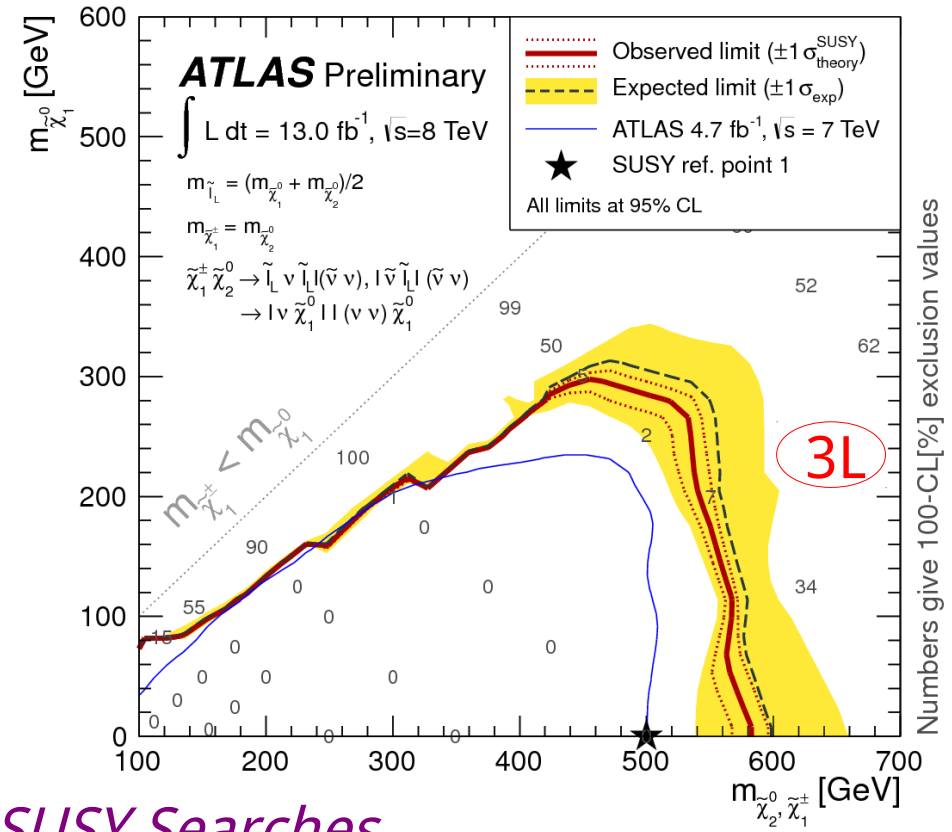


Direct Gauginos Production

- Decays through intermediate particles (W/Z or sleptons)
- Leptonic signatures (2/3 leptons) and missing E_T
- Backgrounds: top, W/Z+jets, WW/ZZ, non-isolated leptons

ATLAS-CONF-2012-154
arXiv:1208.2884



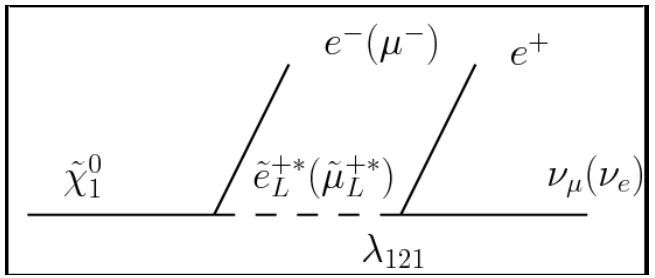


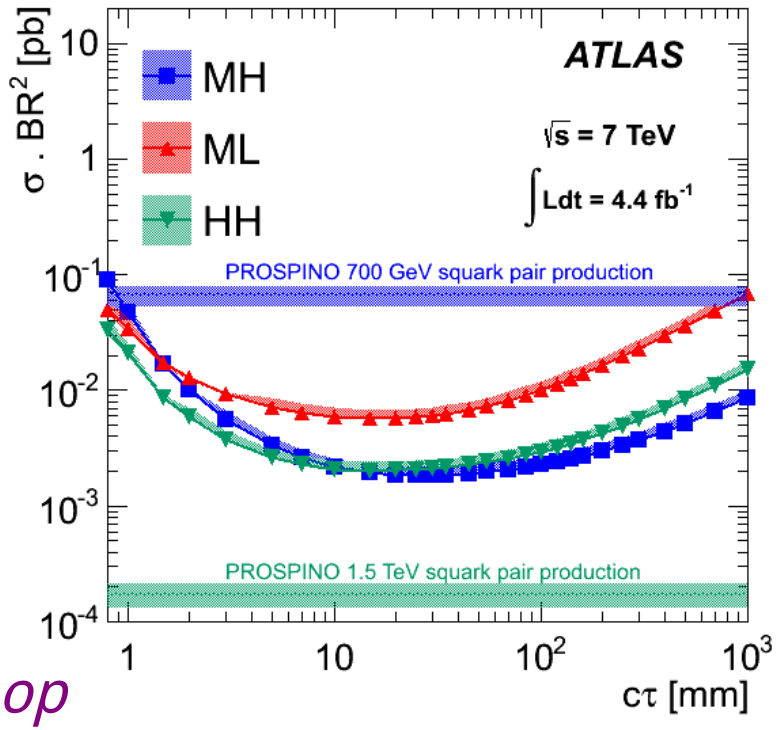
→ *See M. Hodgkinson talk on Natural SUSY Searches*

RPV and LLP searches

ATLAS-CONF-2012-153
arXiv:1210.7451

- Models with R-parity violating terms
  - Large lepton multiplicities from LSP decay
  - Full hadronic 3-jet resonance from gluino decay
- Stable Massive Particles
  - Long-lived ($\beta < 1$)
  - Muon-like particle
  - Requires different trigger and timing paradigm for detection





→ See H. Hayward talk on RPV/LLP in this workshop

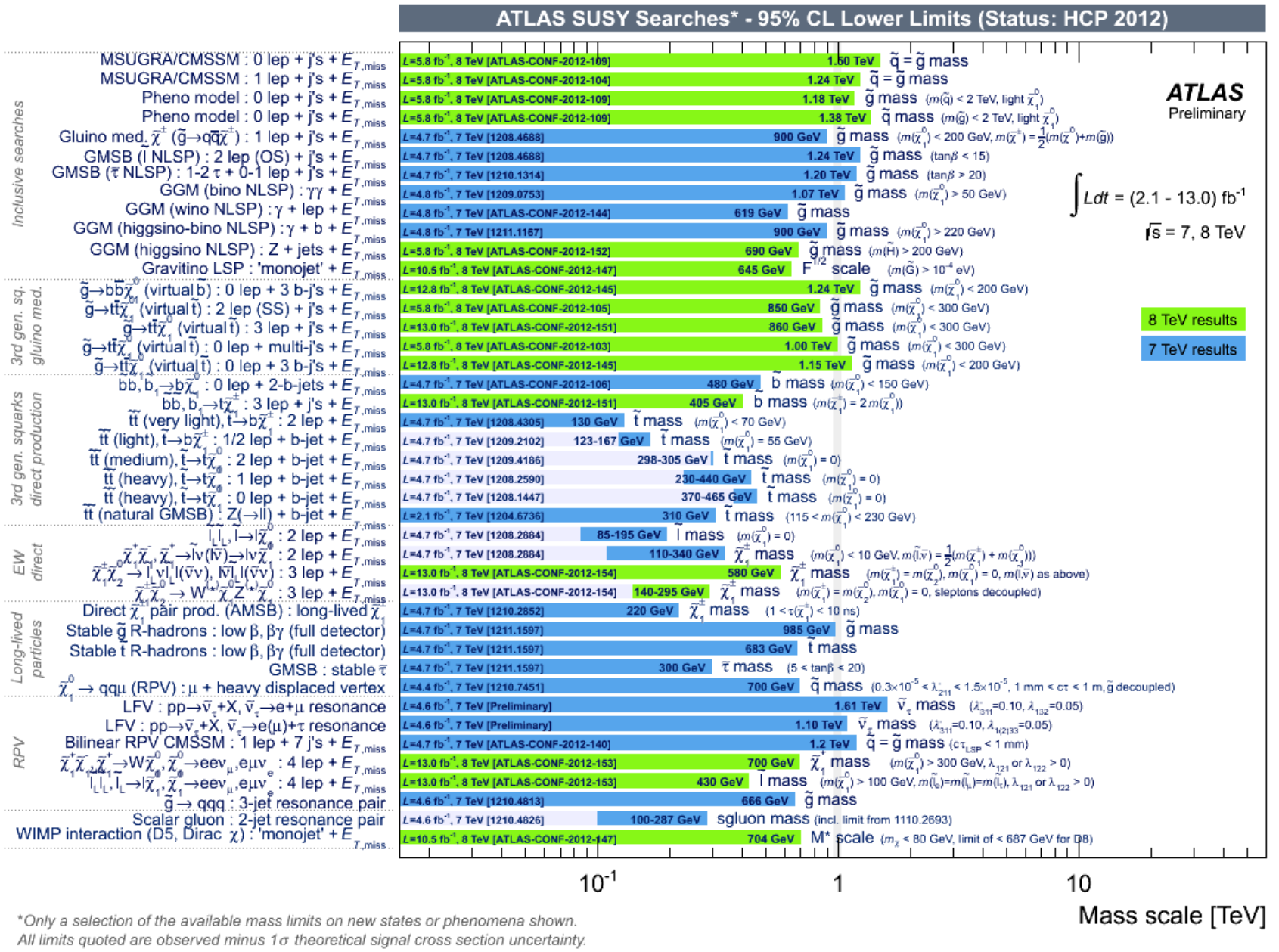
SUSY in ATLAS in 2012

Inclusive searches

Natural SUSY

Long-Lived Particles

R-Parity Violating Models

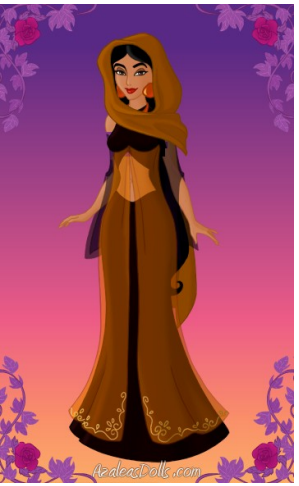


*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

BSM outside SUSY: Exotics

- Many other BSM models studied in ATLAS
  - Heavy Gauge Bosons (Z', W')
  - Excited fermions (f*->fγ)
  - Extra-Dimensions (ADD, UED, RS)
  - Exotic Higgs models ($H^{\pm\pm}$)
  - New quarks (4th generation, vector-like)
  - and much more!

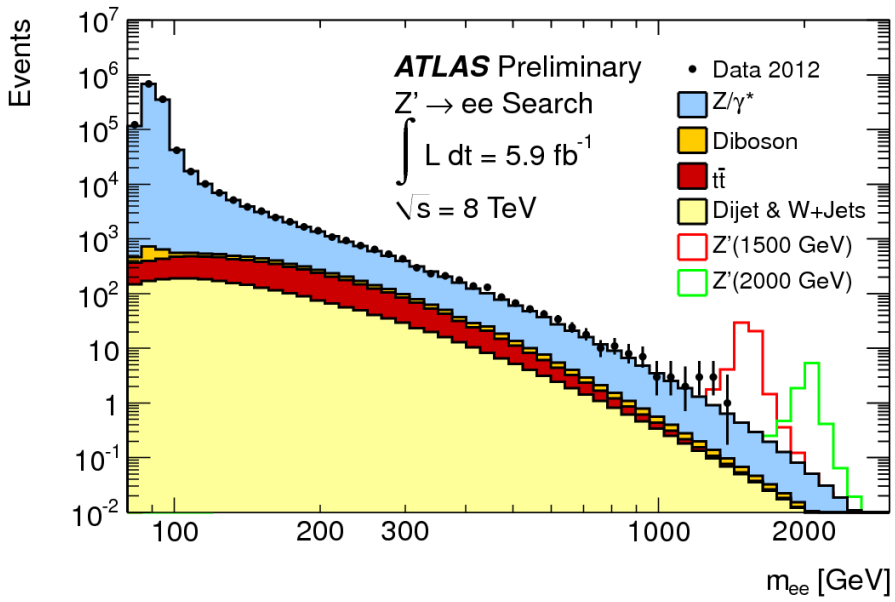
Updated with 8 TeV data



Heavy resonances: dilepton

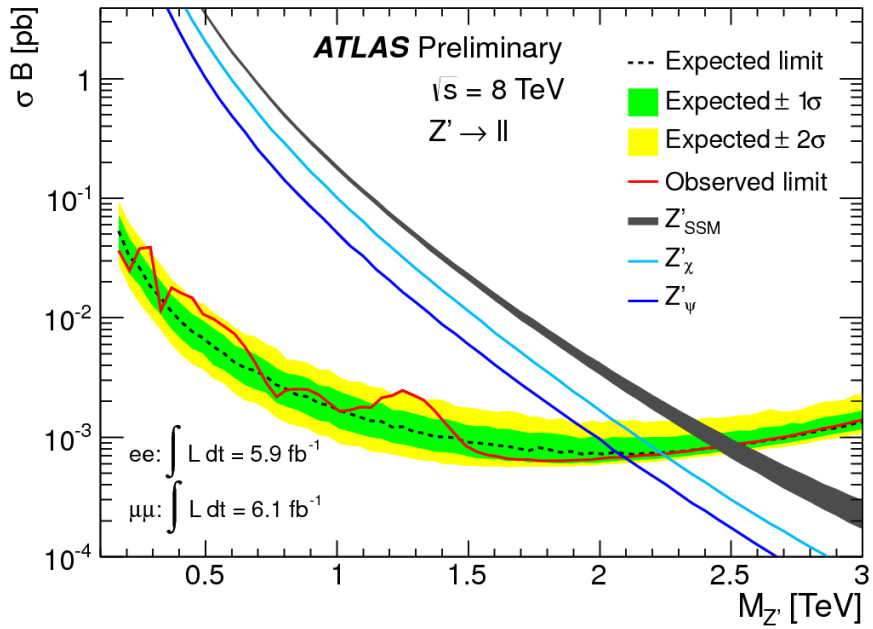
8 TeV

ATLAS-CONF-2012-159



- Heavy gauge bosons search (Z')
- Search in ee, μμ channels
- No significant excess over background observed

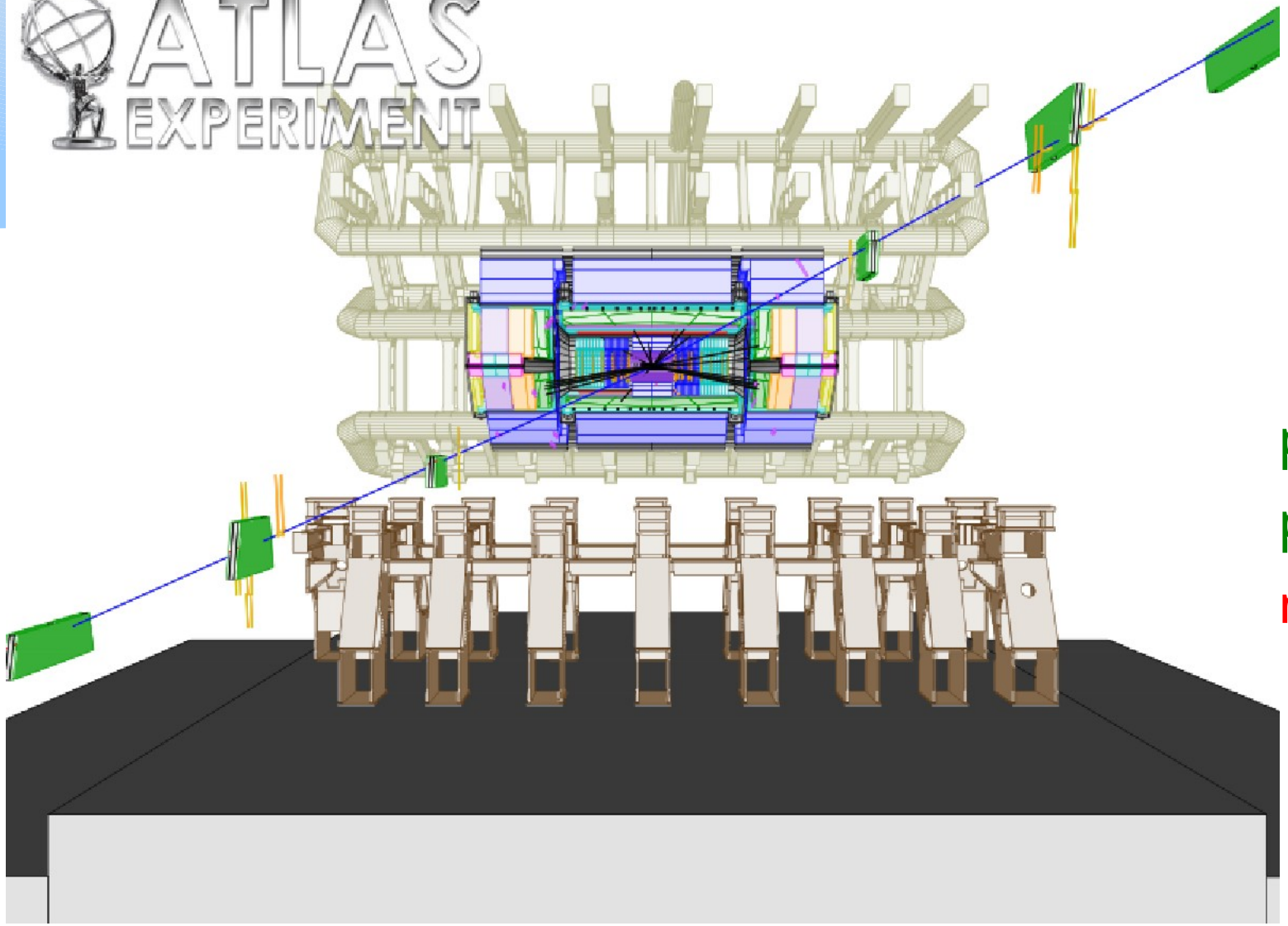
- Exclusion limits in various E6 Z' models
- Z' with m < 2 TeV excluded in all cases
- m < 2.49 TeV excluded in SSM Z' models



Highest m_{inv} μμ event in ATLAS

8 TeV

ATLAS-CONF-2012-159



$p_T^{\mu 1}$ = 289 GeV (top)

$p_T^{\mu 2}$ = 274 GeV (bottom)

$m_{\mu\mu}$ = 1258 GeV

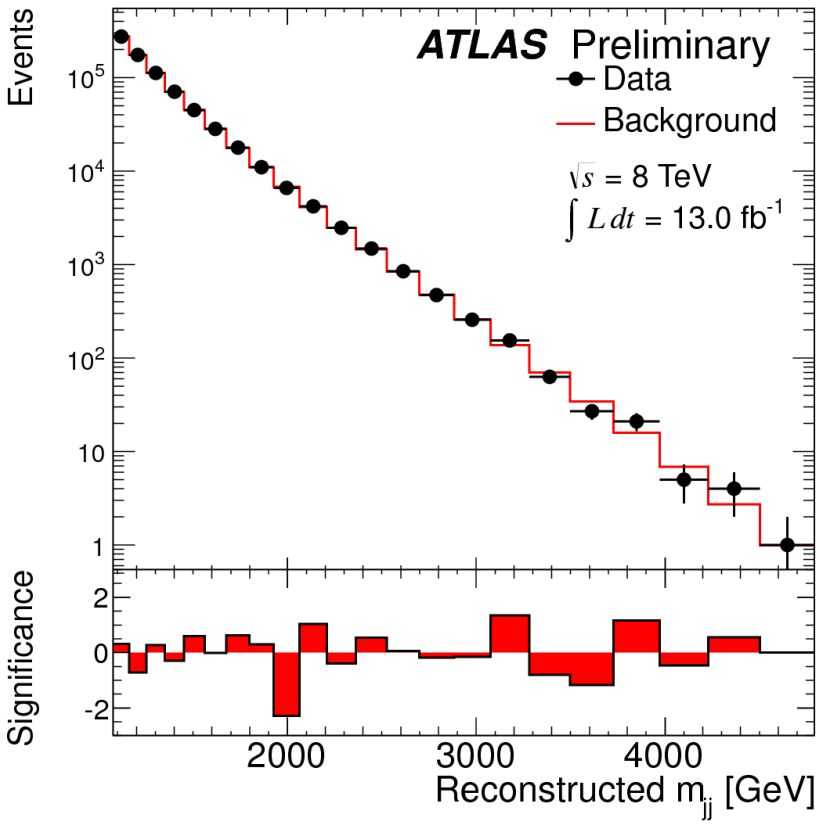
Heavy resonances: dijets

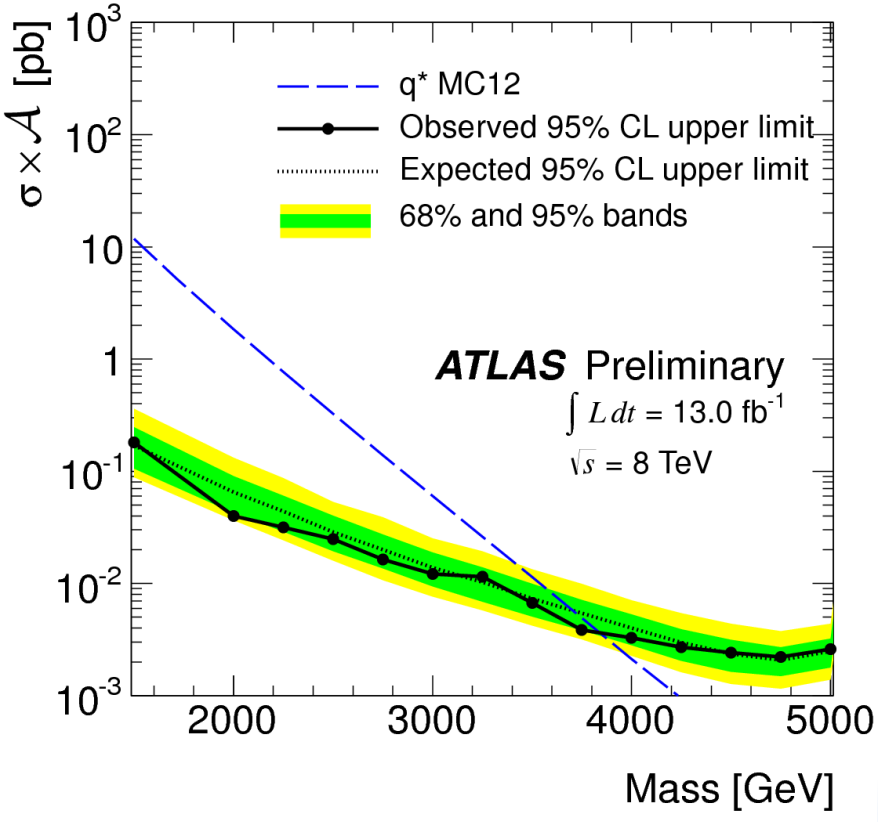
8 TeV

- Test for quark compositeness
- Search for excited quarks: q* → qg
- Low mass limit for q* = 3.84 TeV

ATLAS-CONF-2012-148

PLB 708 (2012) 37-54
arXiv:1108.6311

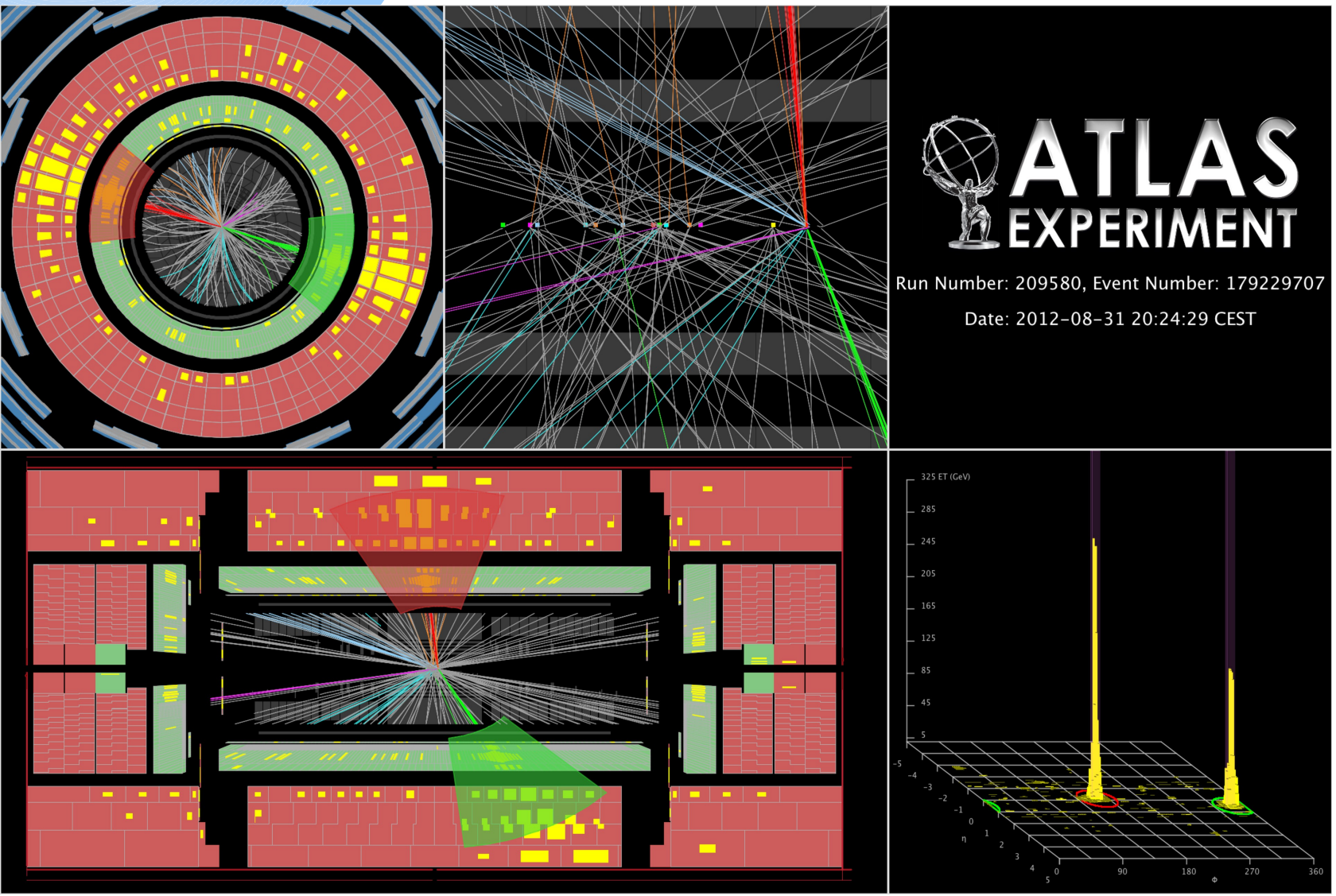




Highest m_{inv} dijet event in ATLAS

8 TeV

ATLAS-CONF-2012-148



P_T^{j1} = 2.29 TeV

P_T^{j2} = 2.19 TeV

m_{jj} = 4.69 TeV

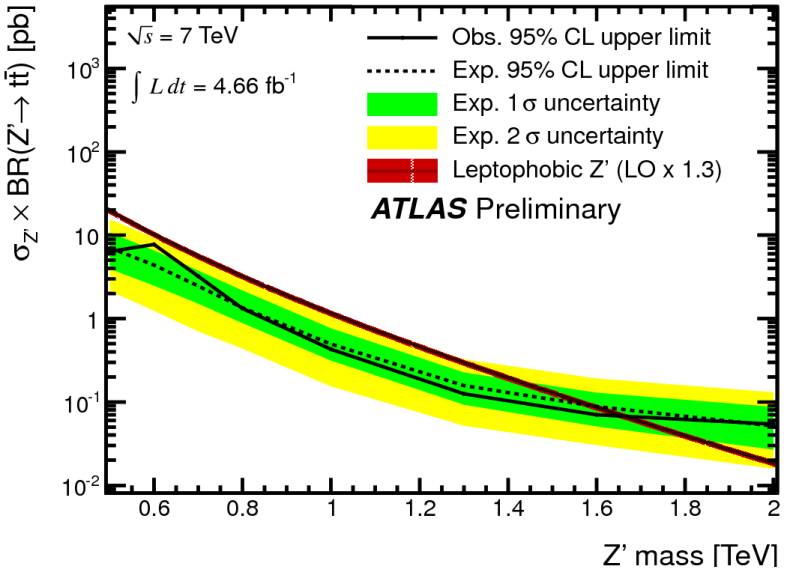
ΣE_T = 4.85 TeV

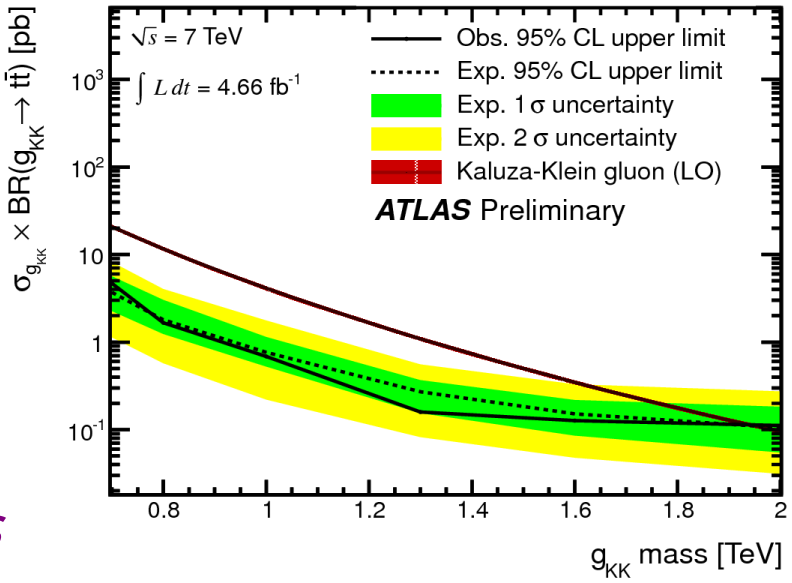
$\not{E}_T$ = 47 GeV

Heavy resonances: $t\bar{t}$

ATLAS-CONF-2012-136
arXiv:1211.2202

- Lepton+jets: $t\bar{t} \rightarrow W(l\nu)bW(qq)b$ shown here, also searched in fully hadronic top decays
- Combining resolved and boosted jet reconstruction techniques
- Setting Limits on Z' and Kaluza-Klein gluons
  - Z' mass > 1.7 TeV
  - g_{KK} mass > 1.9 TeV



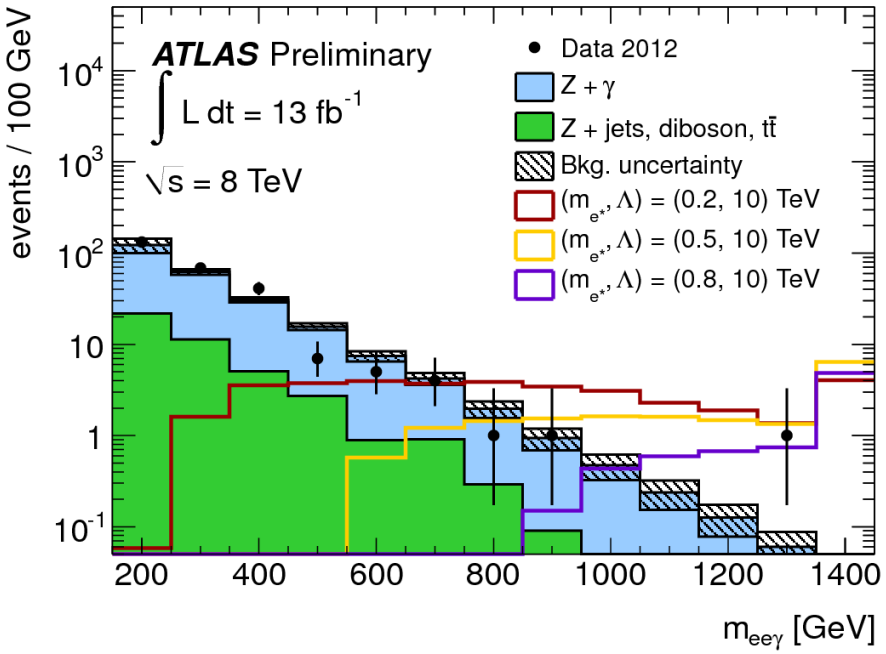


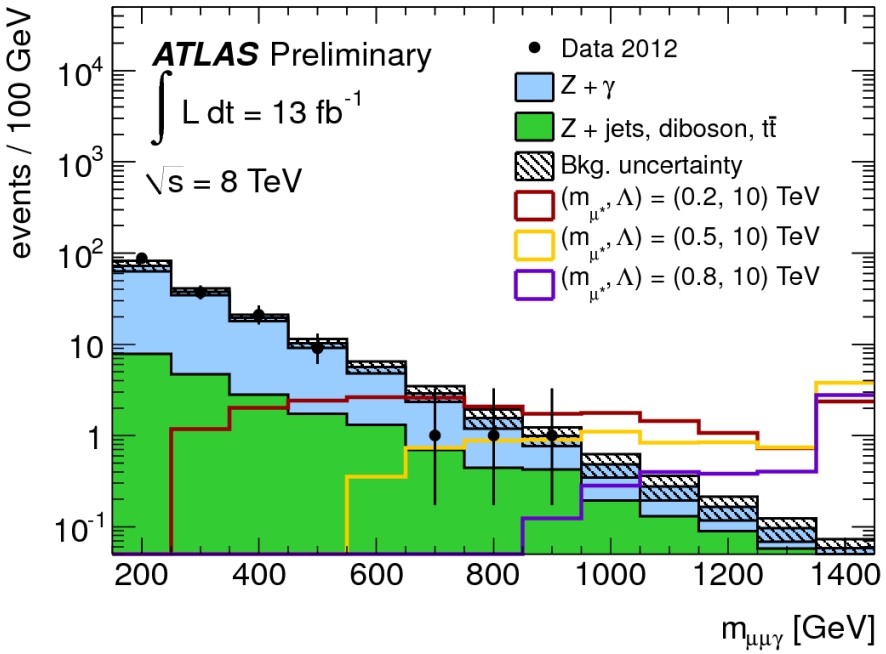
→ See S. Viel talk on Heavy Resonance Searches

Excited leptons

8 TeV

ATLAS-CONF-2012-146





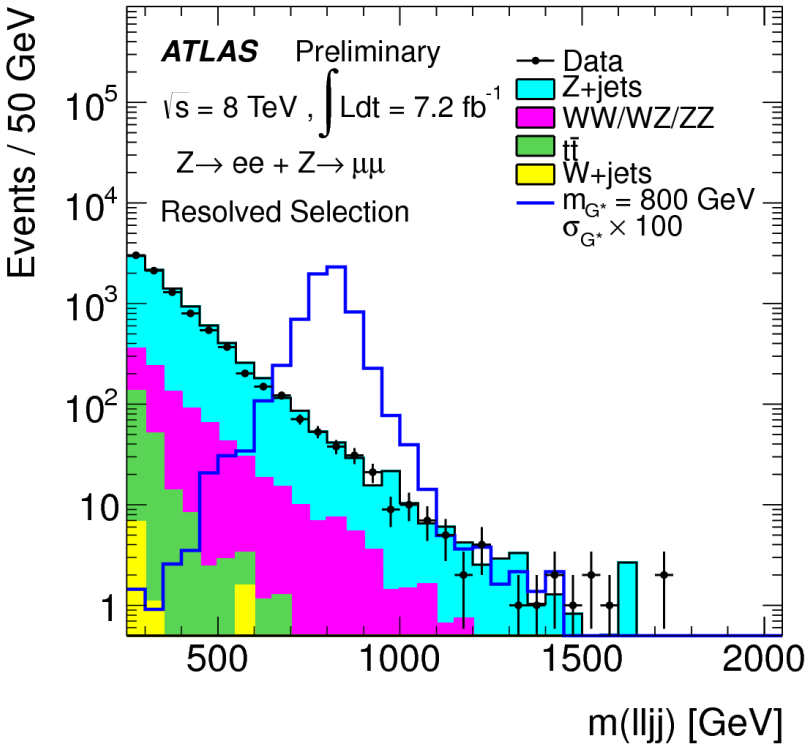
- Probing lepton compositeness with scale Λ: l*->lγ
- Search in ee, μμ channels
- Look for excess in $m_{ll\gamma}$ → sensitive to all l* width
- For $\Lambda = m_{l^*}, m_{l^*} < 2.2$ TeV are excluded

→ See J. Almond talk on New Particle Searches

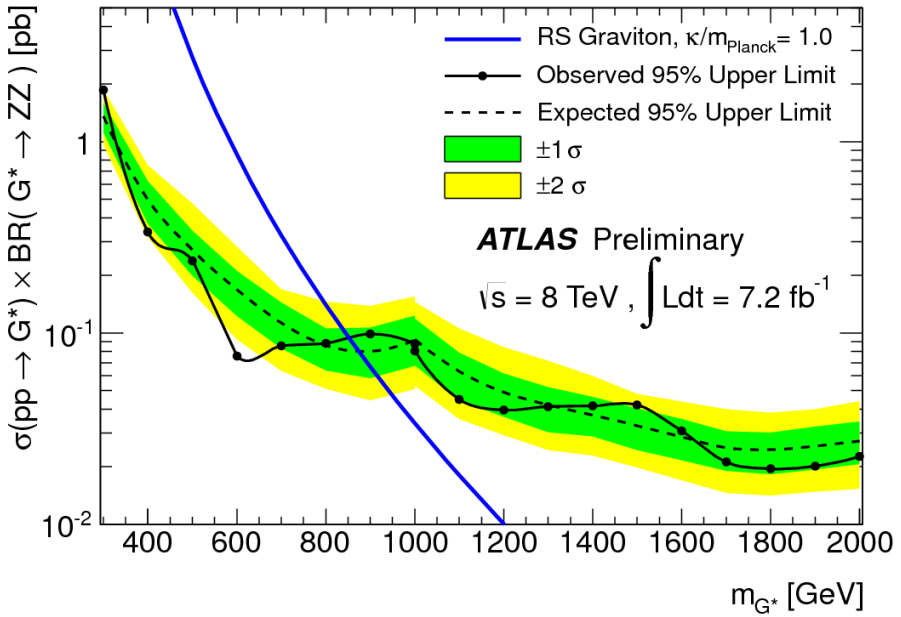
ZZ resonance

8 TeV

ATLAS-CONF-2012-150



- ZZ → llqq (better rejection of QCD multijets background than qqqq)
- High mass, 2 jets → 1 massive jet (Boosted Z)
- No resonant feature observed



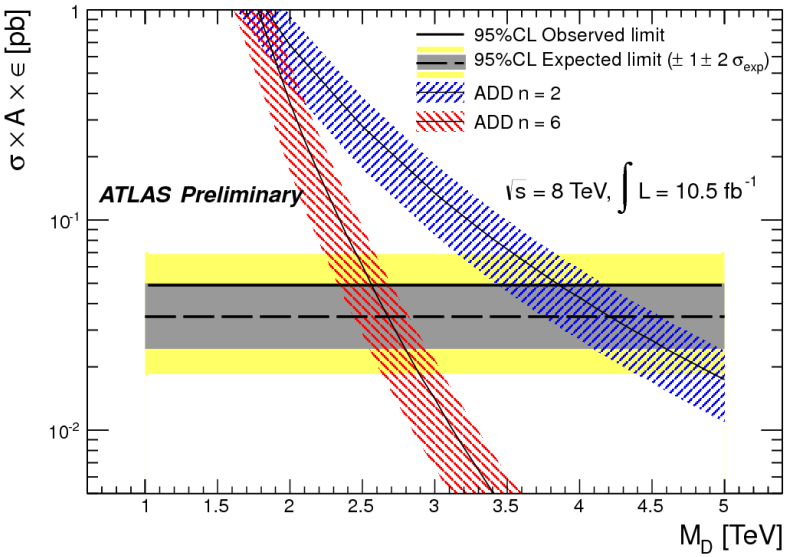
- Setting Limits on a spin-2 Bulk RS G*
- Lower mass limit of 850 GeV for coupling parameter $\kappa/\bar{m}_{P1}$ = 1.0

Monojet + $\not{E}_T$

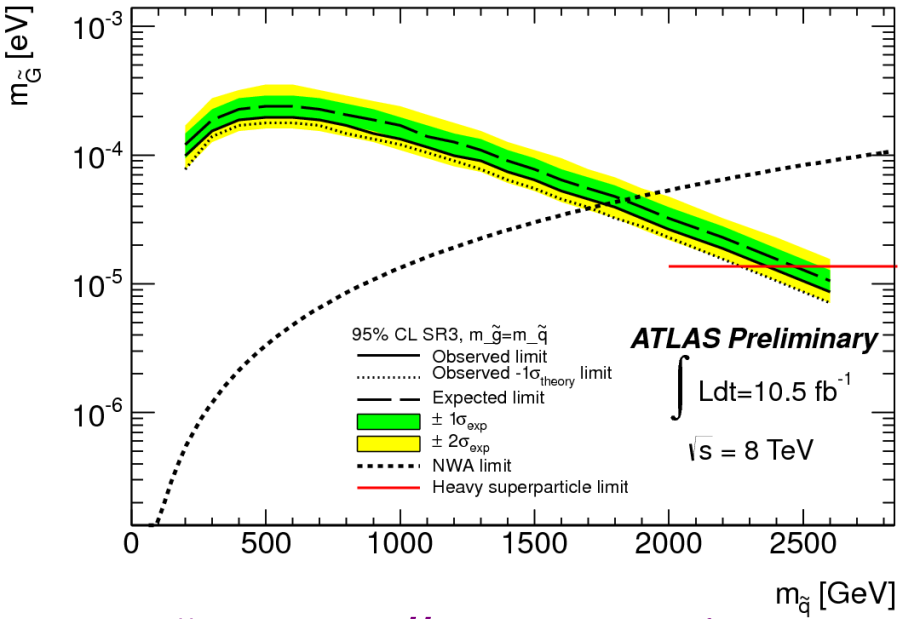
8 TeV

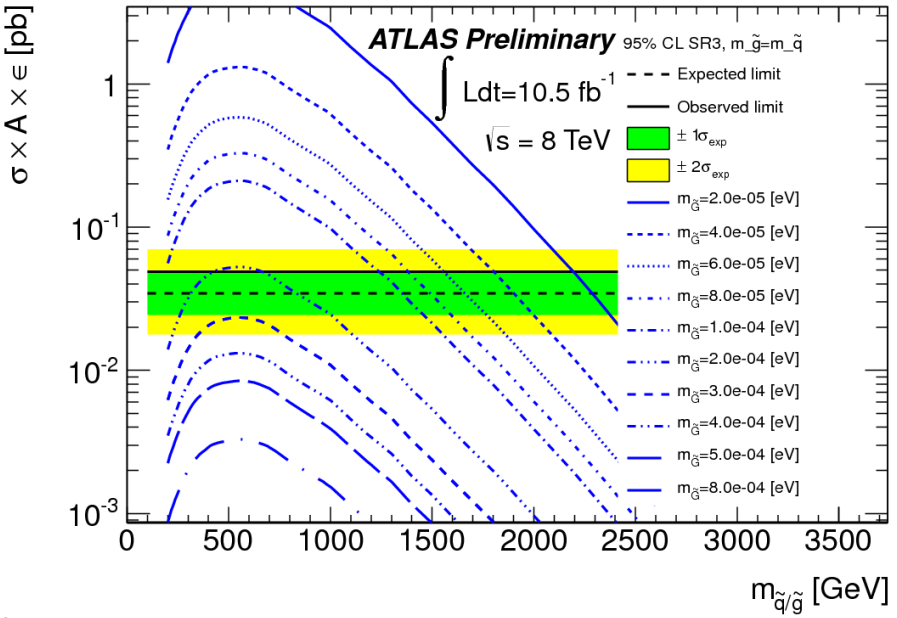
ATLAS-CONF-2012-147

arXiv:1210.4491



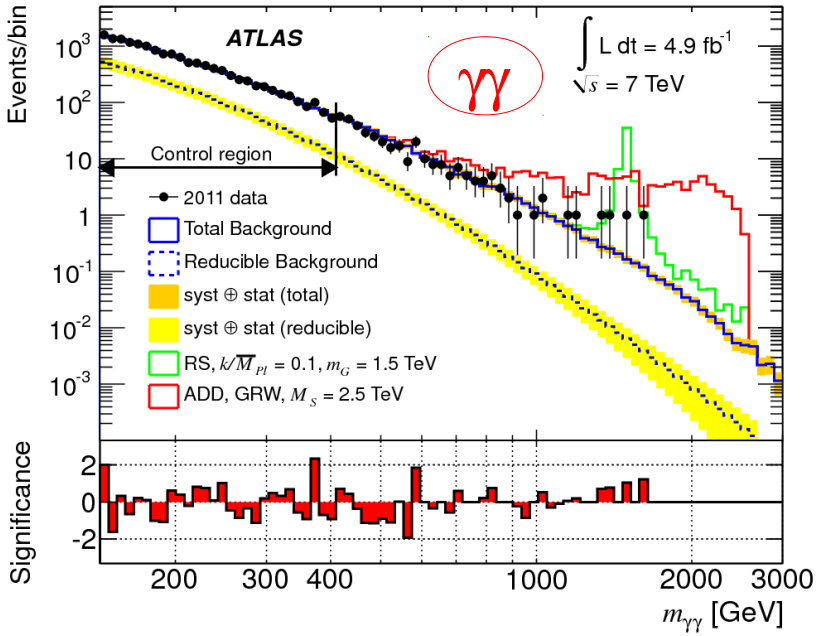
- Probing for ADD extra-dimension graviton and WIMPs (also GMSB SUSY)
- M_D > 2.5 TeV for various n values (ADD)
- For $m_{\tilde{q}} = m_{\tilde{g}}$, best bounds on $m_{\tilde{G}}$ to date

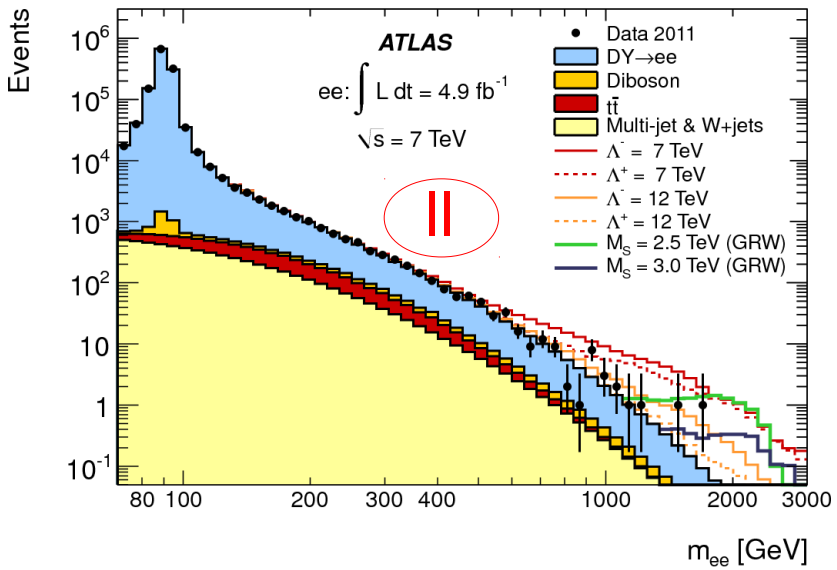




→ *See R. Pöttgen talk on Monojet/Monophoton*

Extra dimensions in γγ, ll





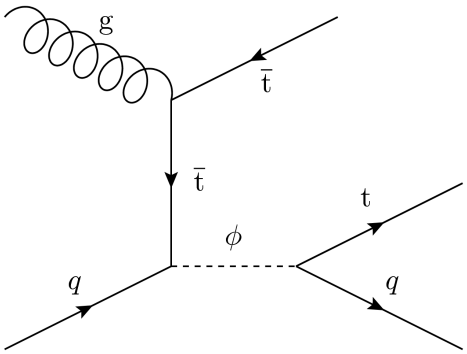
arXiv:1211.1150
arXiv:1210.8389

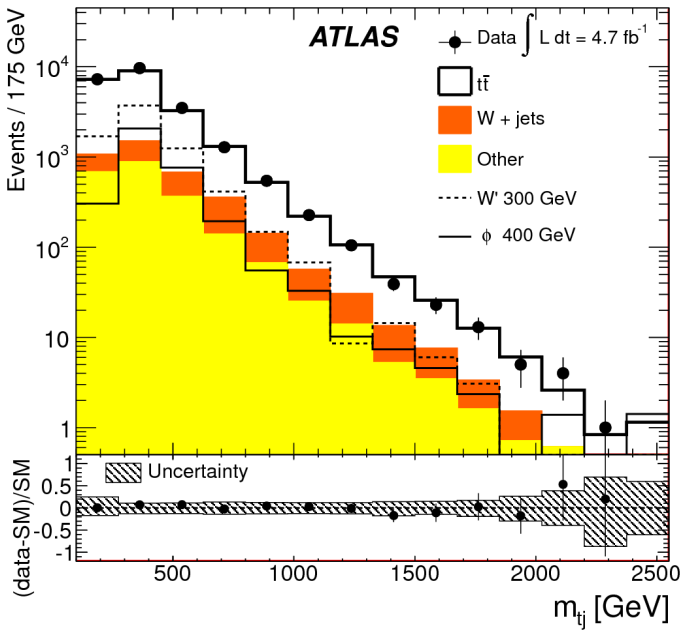
- 2 isolated photons and non-resonant dilepton search combined results
- ADD limits: 2.8-4.2 TeV < M_S
- M_G (RS) > 1.03 (2.23) TeV for $\kappa/\bar{m}_{P1}$ = 0.01 (0.1)

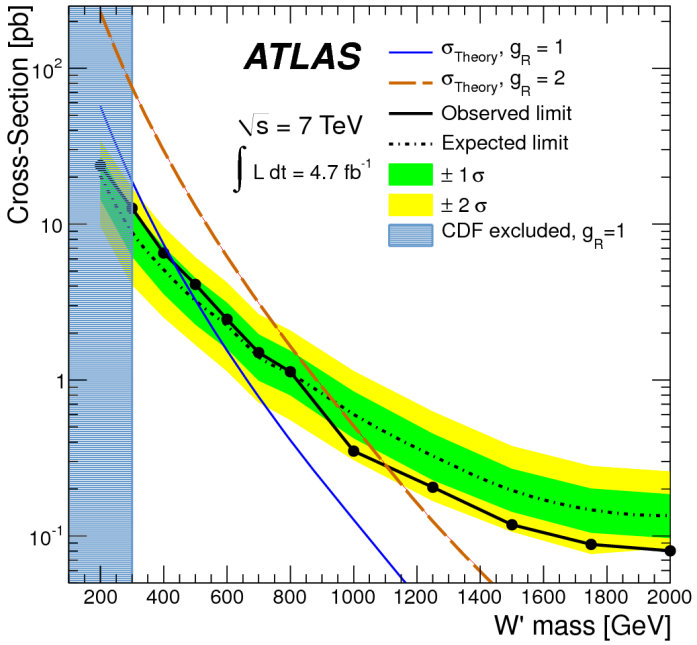
Top + jet resonance in $t\bar{t}$ + jets

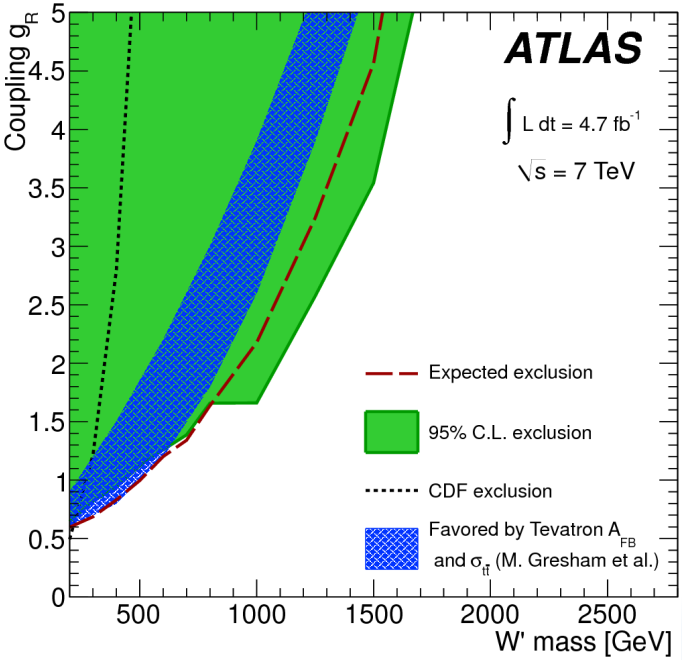
- 1 hadronic, 1 leptonic W decay
- Tevatron measured 3.4σ deviation in $t\bar{t}$ A_{FB}
- No deviation observed by ATLAS
- m < 430 GeV excluded for both ϕ, W' (for g_R=1)

arXiv:1209.6593



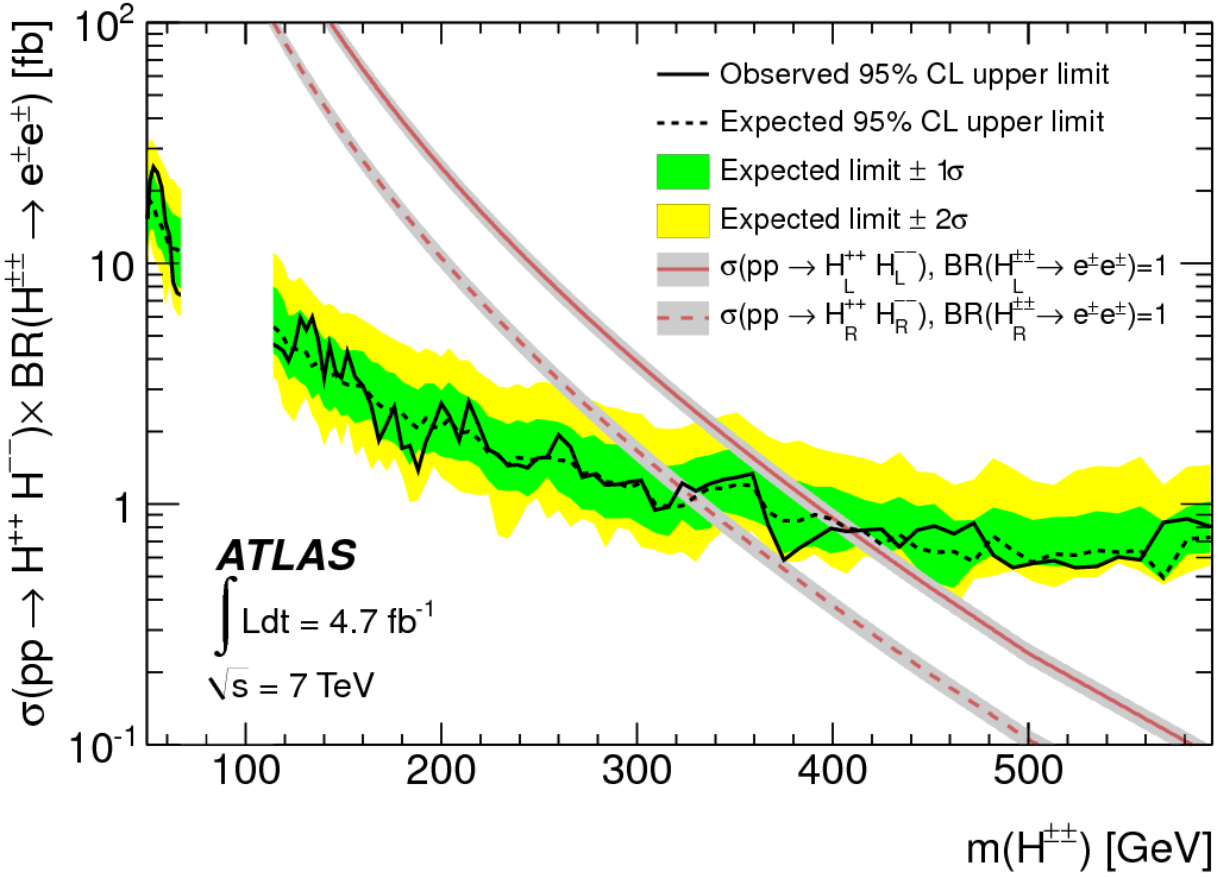


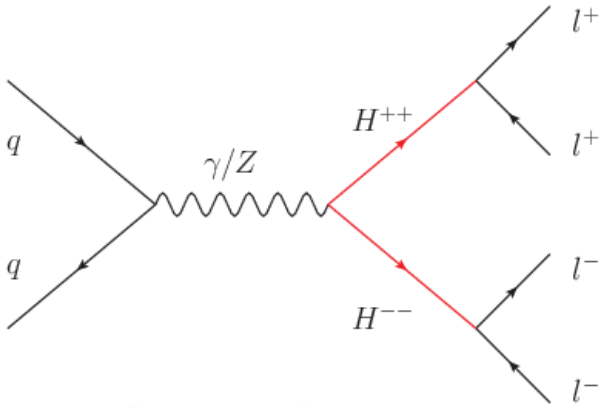




Doubly charged Higgs

arXiv:1210.5070





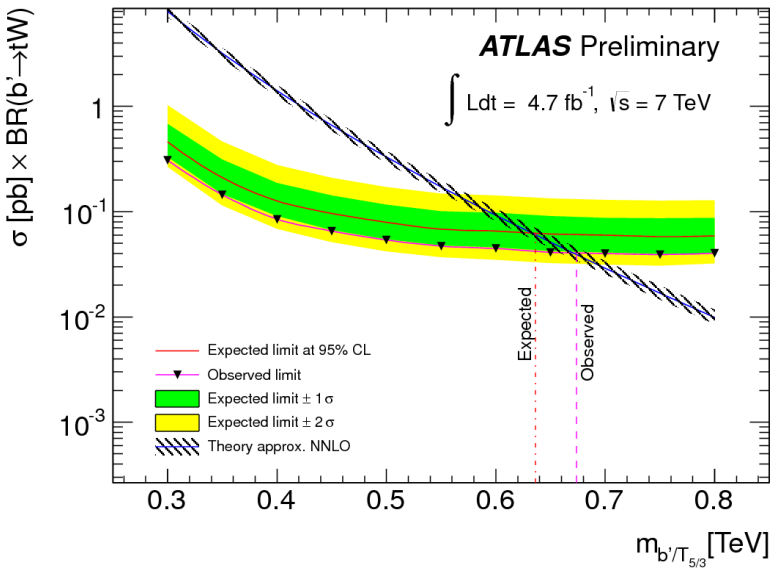
- Model with Higgs triplet
- $H^{\pm\pm} \rightarrow l^{\pm\pm}l'^{\pm\pm}$ (ee,eμ,μμ)
- Prompt ($t\bar{t}$+W/Z, W/Z) and non-prompt (HF, conversions) backgrounds
- $m_{H^{\pm\pm}}$ limits depend on decay channel

ee	μμ	eμ
409 GeV	398 GeV	375 GeV

→ See A. Ferrari talk on BSM Higgs Searches

ATLAS-CONF-2012-130

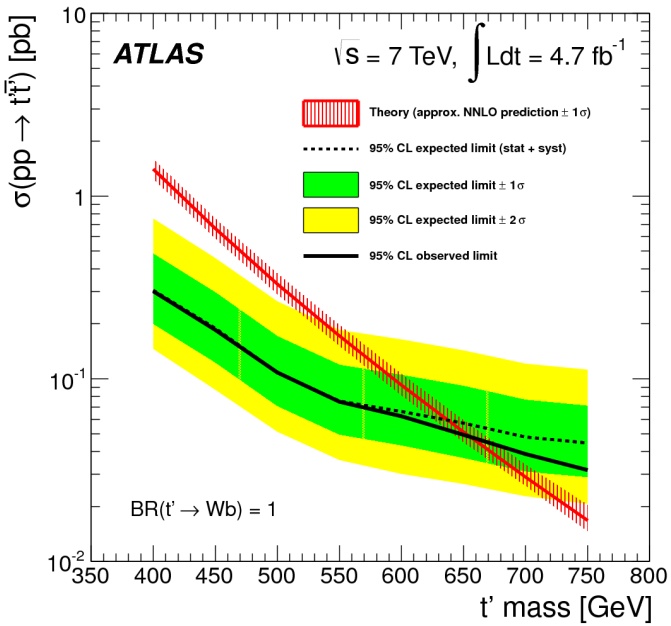
Heavy quark searches



- Same-sign dilepton, 2 jets (1 b-jet)
- Probing for pair production of b', $T_{5/3}$ ($l^+l^+\nu\nu b\bar{b}q\bar{q}qq$)
- 4 events observed, 5.6 events expected
- $m_{b',T5/3} > 0.67$ TeV

arXiv:1210.5468

- Search for t' in channel $t'\bar{t}' \rightarrow WbWb$
- Lepton+ jets final state
- $m_{t'} > 656$ GeV for BR(t' → Wb)=1



Exotics in ATLAS in 2012

Extra Dimensions

Contact Interactions

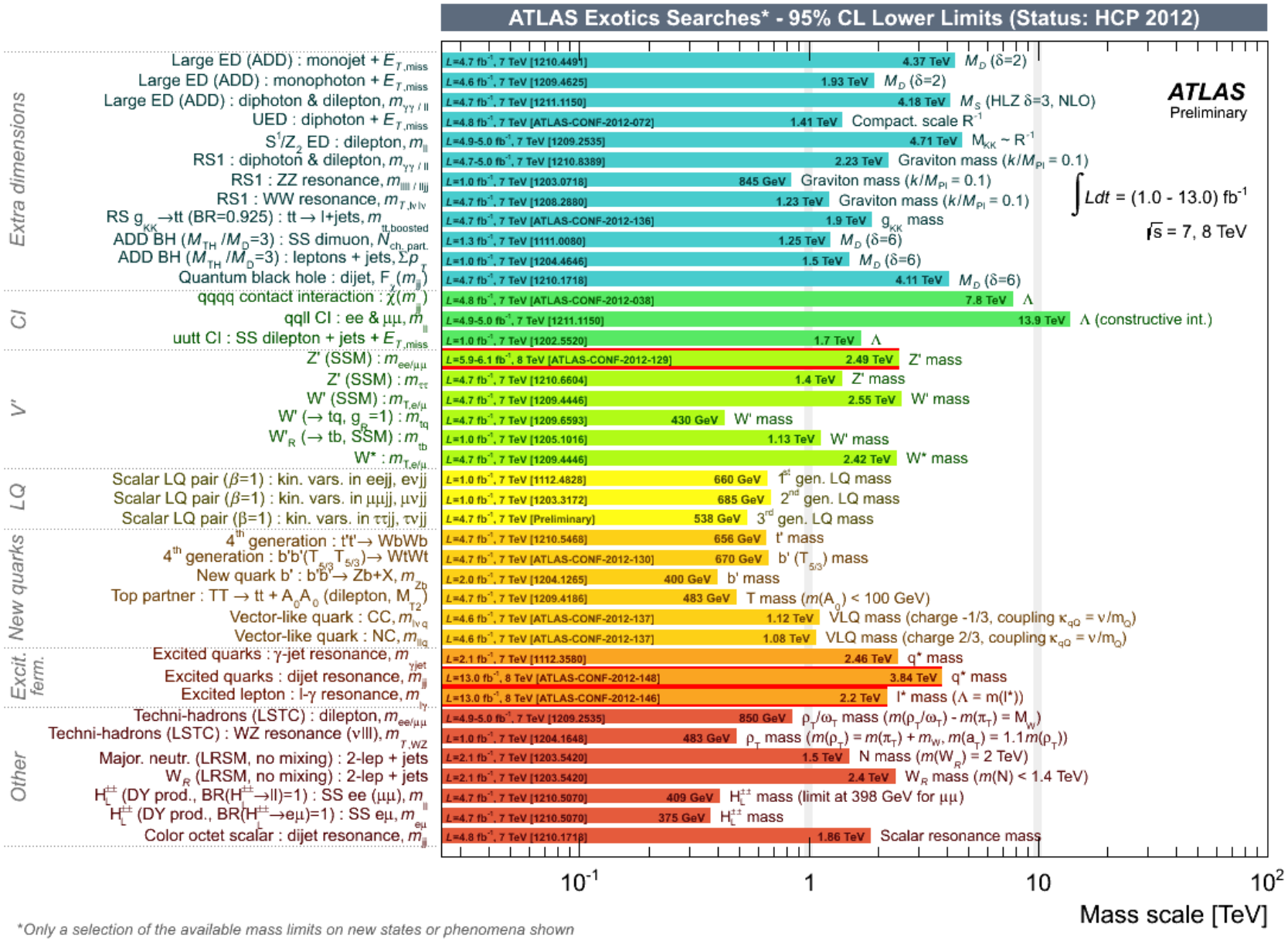
Heavy Gauge Bosons

Leptoquarks

New quarks

Excited Fermions

Other



*Only a selection of the available mass limits on new states or phenomena shown

Summary

- ATLAS is actively searching for BSM signatures
- Supersymmetry searches
  - 23 (10) Public CONF notes with 7 (8) TeV
  - 49 Papers with 2010-2011 7 TeV data
  - http://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- Exotic searches
  - 48 (6) Public CONF notes with 7 (8) TeV
  - 52 Papers with 2010-2011 7 TeV data
  - http://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Conclusion

- Huge progress achieved in 7+8 TeV ATLAS data
  - 1st and 2nd generation squarks and gluino masses above 1 TeV
  - Natural SUSY more and more appealing (searches for light sbottom, stop and gauginos)
- Great variety of exotic models probed in ATLAS
  - Pushing limits further on exotic particle masses, cross-sections, and couplings
- No deviation from the SM found until now, but searching in many places
- Just imagine what 14 TeV will bring… Stay tuned!

Backup slides

Direct Stop

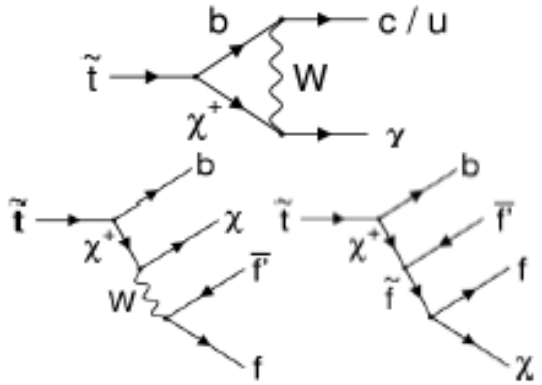
M.-H. Genest

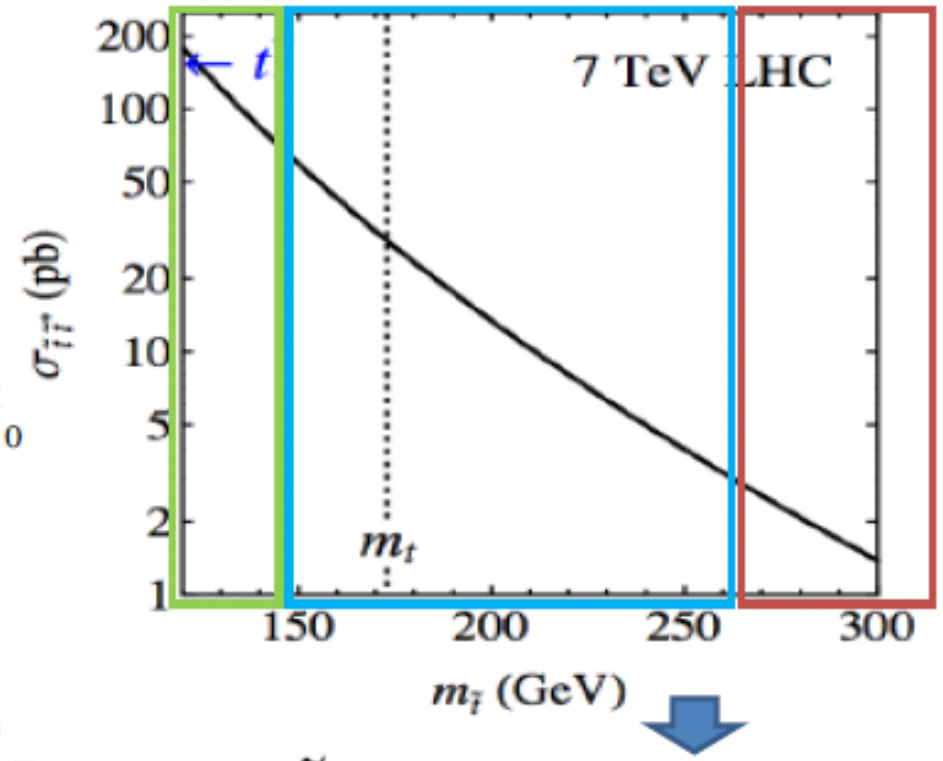
Several decay modes are possible, depending on the couplings and the SUSY particle mass hierachy

High cross sections, very similar to SM background

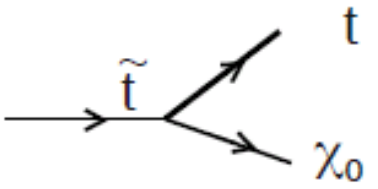
$$\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm} \to bW^{\pm}\tilde{\chi}_0$$

$$\tilde{t}_1 \to c\,\tilde{\chi}_0$$





Low cross section (2 pb or less), high mass:
Mostly stop → top +LSP



$b + \tilde{\chi}^{\pm}$ and, where kinematically allowed, $t + \tilde{\chi}^{0}$
Need powerful discriminating variables to reject top BG

Mass ranges , ΔM (stop – neutralino), ΔM (stop-chargino), ΔM(chargino-neutralino) all play a crucial role in the search optimization

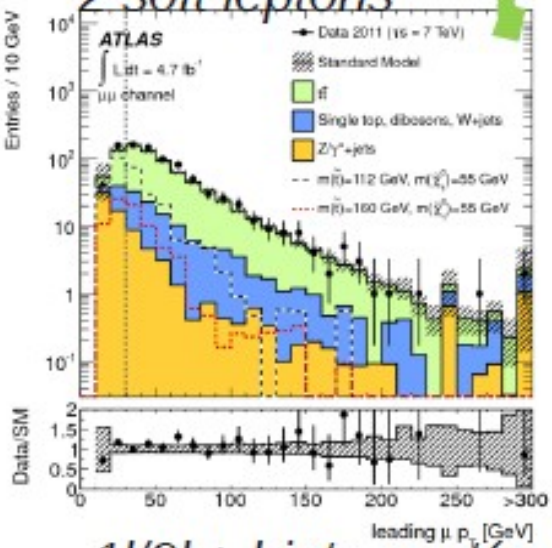
Direct Stop

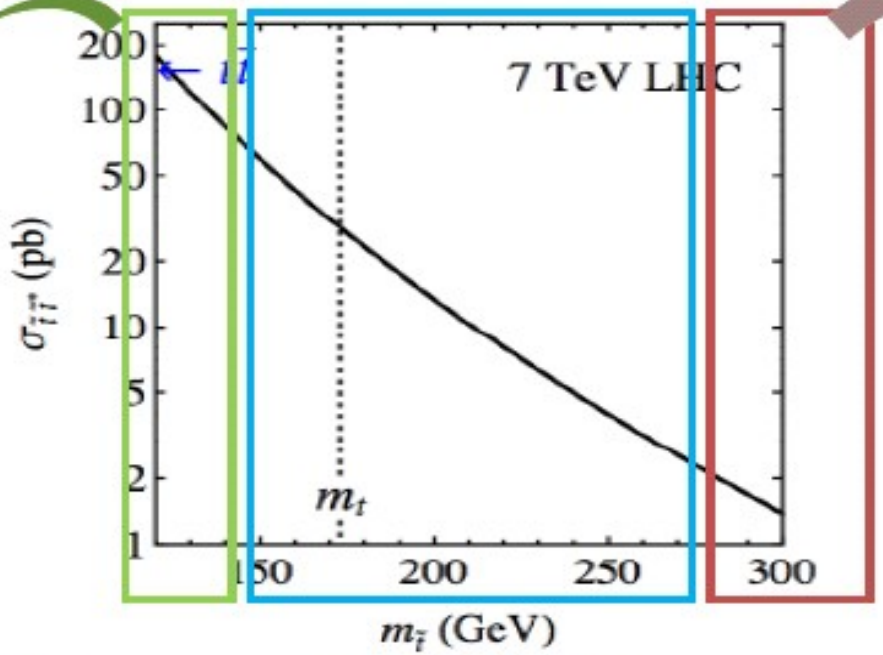
M.-H. Genest

- Five searches with 5 fb^{-1} (+ 1 in natural GMSB with 2 fb^{-1}) @ 7 TeV

$\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow bW^{\pm}\tilde{\chi}_0$

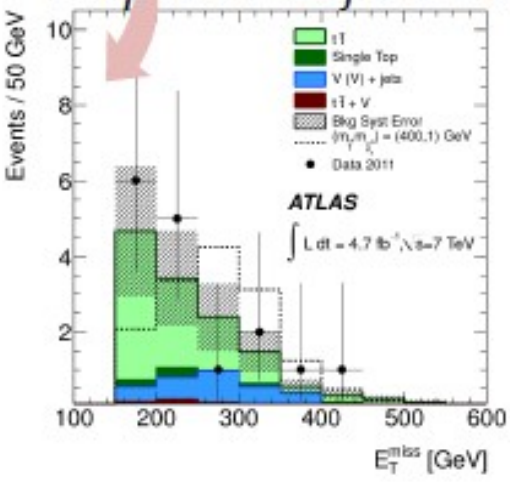
2 soft leptons



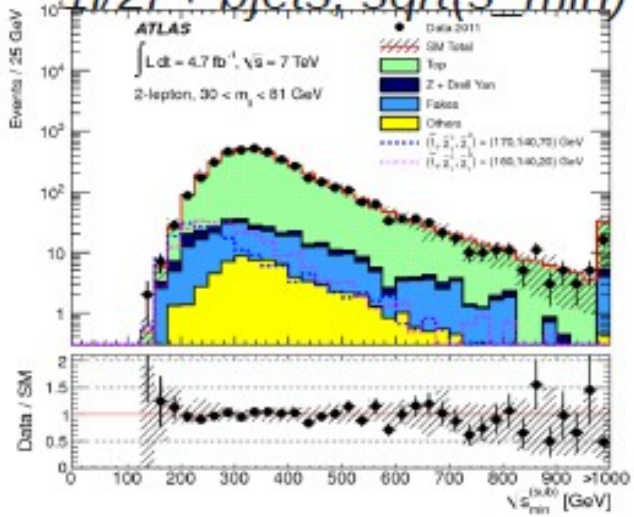


$t + \tilde{\chi}^0$

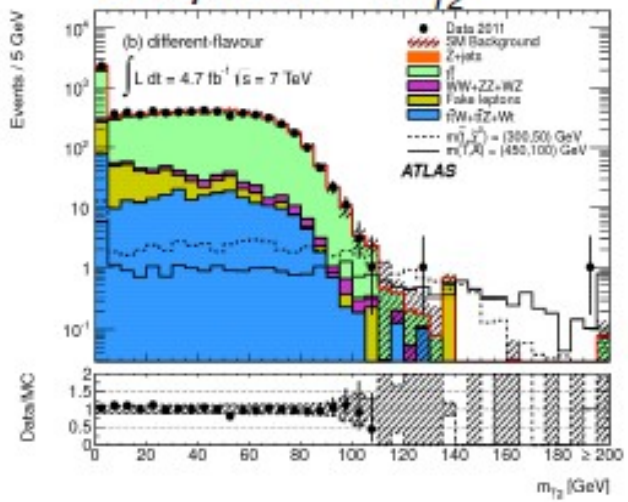
0 leptons + bjets + MET



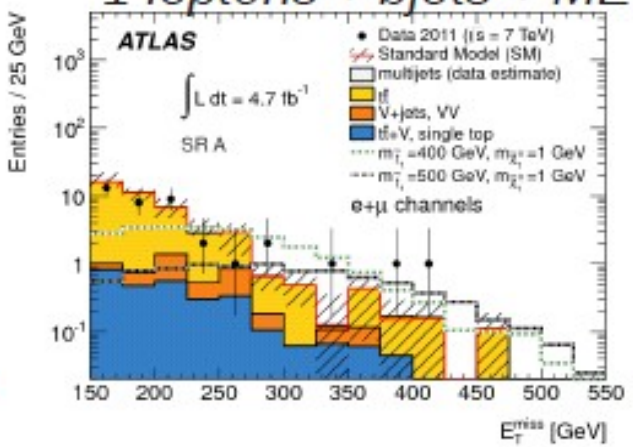
1l/2l + bjets, sqrt(s_min)



2 leptons + m_{T2}



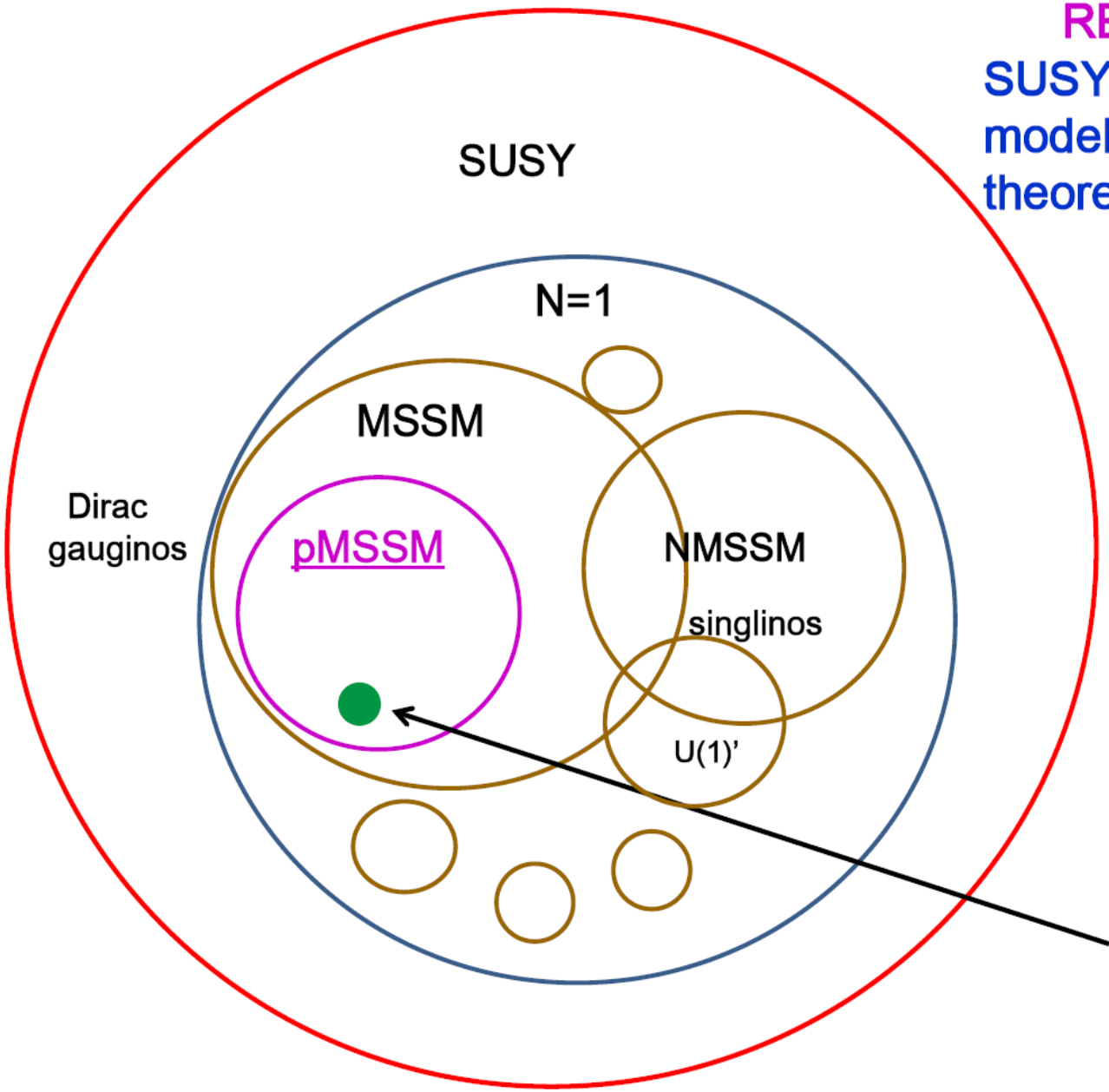
1 leptons + bjets + MET



pMSSM

T. Rizzo
BNL
13 Sep. 2012

REMINDER:
SUSY is *not* a single model but a very large theoretical framework



pMSSM

arXiv:1206.5800

- Phenomenological MSSM
  - 19 parameters (less constrained than cMSSM)
  - Neutralino or Gravitino LSP
- Motivated by recent Higgs mass measurement
  - Assuming $m_H = 125 \pm 2$ GeV
- Low fine-tuning
- Parameter space not excluded by current LHC results