Searches for Beyond SM physics at the LHC

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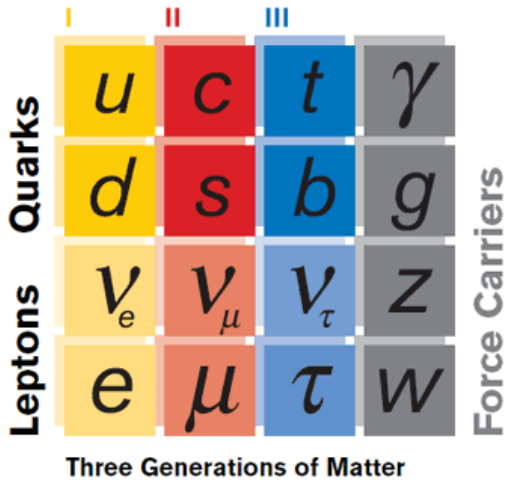
For the ATLAS, CMS and LHCb collaborations

Institute of Physics, 8th April 2013

Searching for new physics

Standard Model: remarkably successful description of known phenomena, **but** requires new physics at the TeV scale.



Extra Dimensions

- Large, warped, or universal extra dimensions
- Might provide:
  - Dark Matter candidate
  - Solution to Hierarchy problem
  - Unification of forces
- Searches for new heavy particles, black holes..

Strong EW symmetry breaking

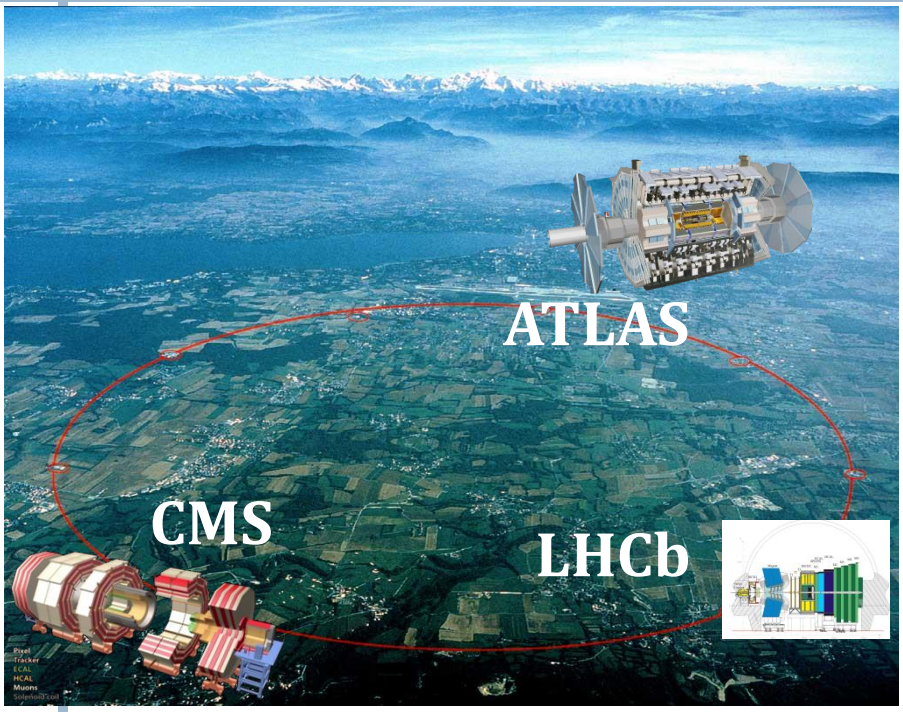
- Modern variants of Technicolor
- Might provide:
  - Dark Matter
  - Hierarchy problem
- Possibly search for composite Higgs, new heavy vector bosons (Z', W'...), 4th generation of quarks

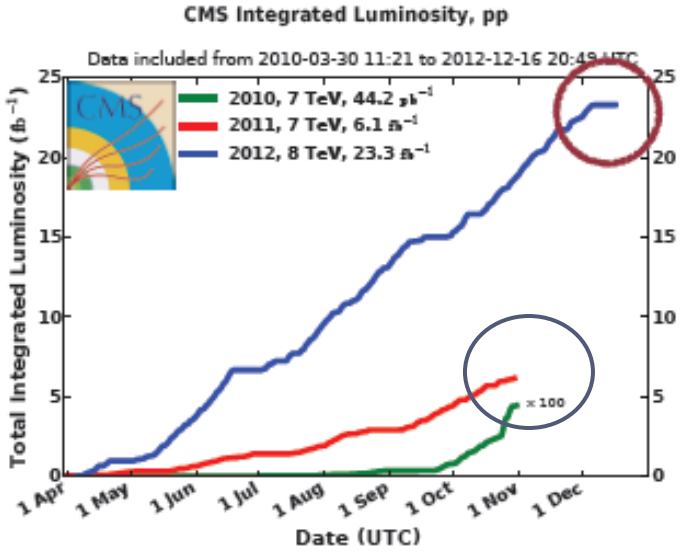
Supersymmetry

- Introduce heavy superpartners, scalar particles, light neutral Higgs
- More than100 parameters even in MSSM

The LHC

LHC Run I just concluded. Exceptional machine performance, high efficiency of experiments in collecting data (>90%)

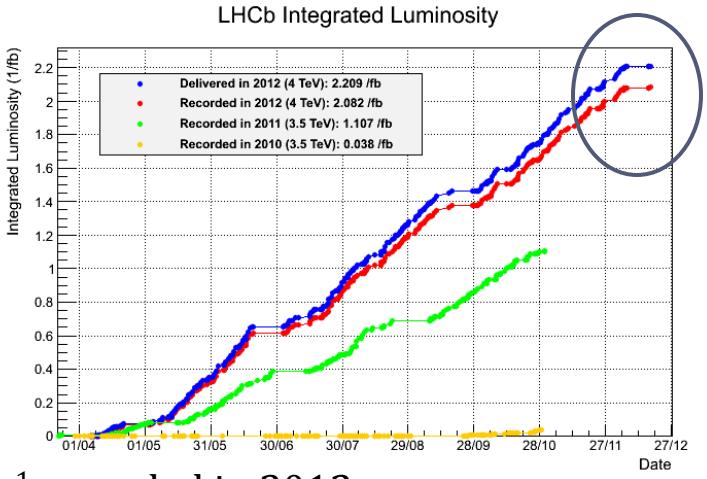


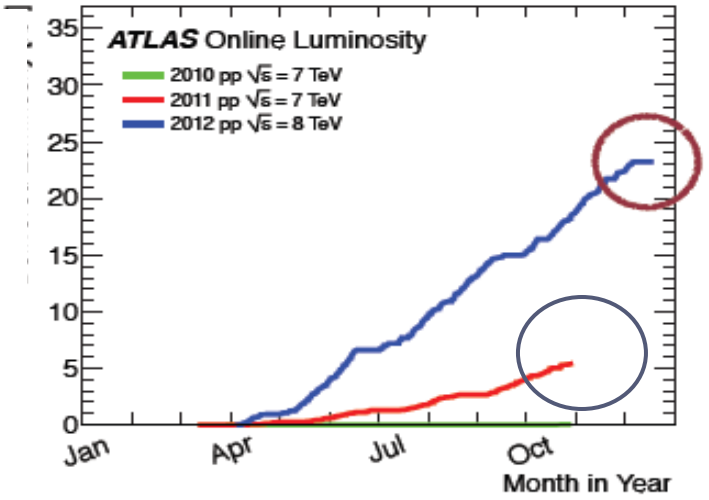


~ 5 fb-1 @ 7 TeV

~ 21 fb-1 @ 8 TeV

recorded (per exp.)





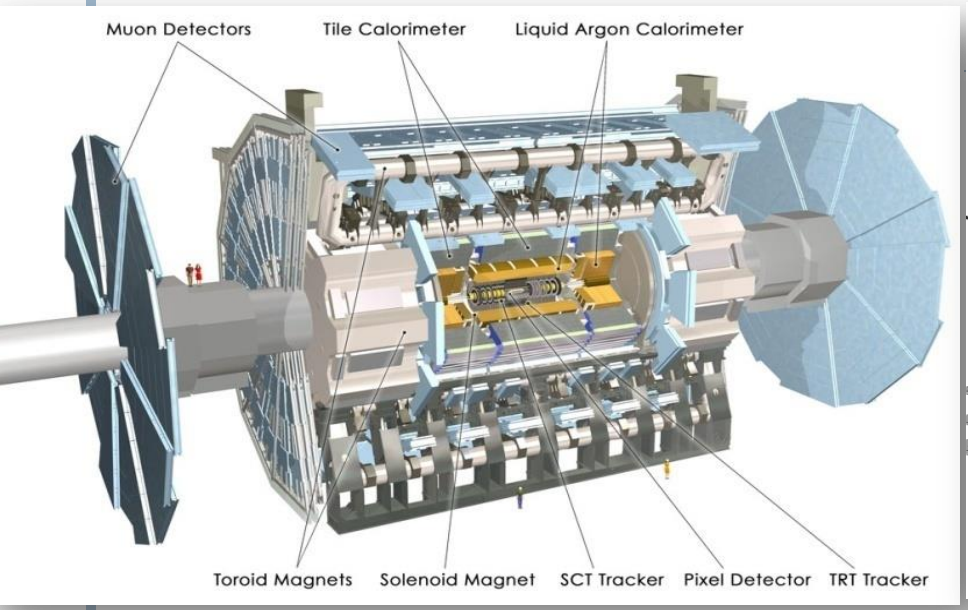
2.1 fb^{-1} recorded in 2012,
1.1 fb^{-1} in 2010/2011

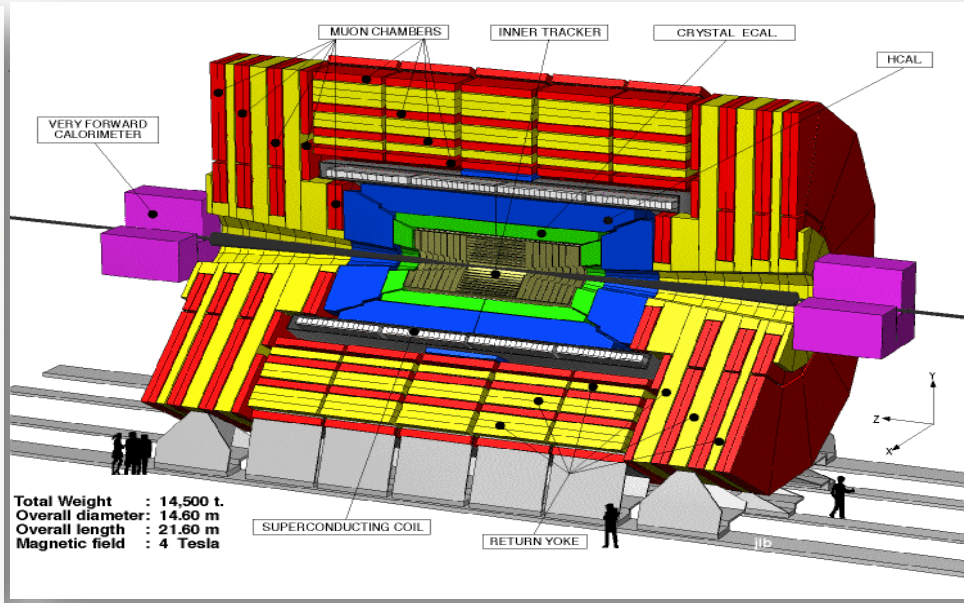
25*44 m
7000 tons

ATLAS

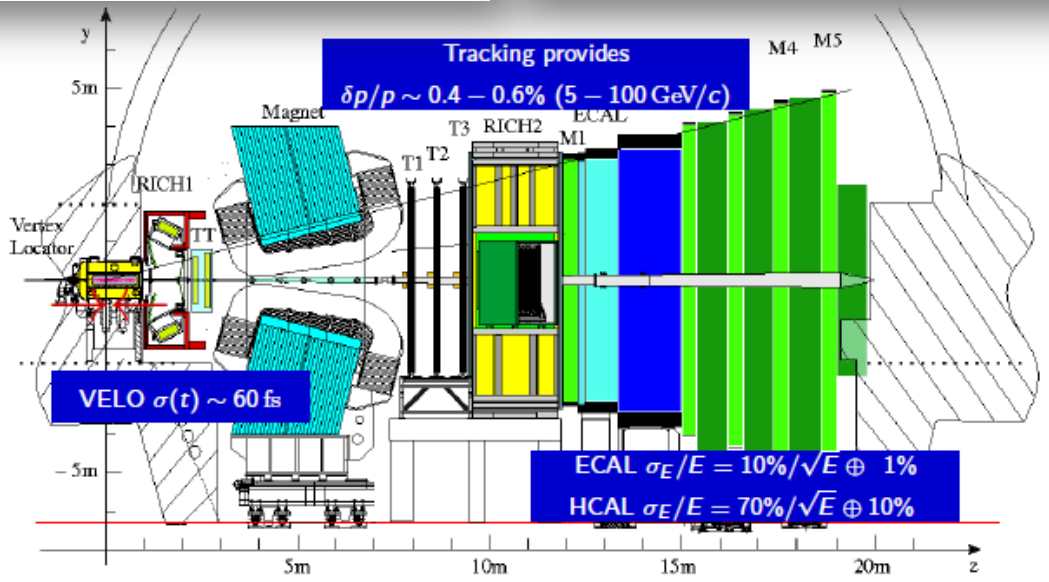
CMS

15*21 m
14500 tons





LHCb



Outline

- Not comprehensive (but quite dense!) overview of latest results of searches for new physics from ATLAS, CMS and LHCb
  - Indirect and direct searches, from 'simple' to more complex topologies, searching for the unexpected

In this talk:

Heavy Resonances
- dileptons
- diphotons
- dijets

.. or W', Z' and heavy neutrinos in
- lepton+MET
- dibosons

Extra dimensions
- dileptons
- diphotons
- jet +MET (also for Dark Matter)

4th generation
- chiral or vector-like

Supersymmetry
- 3rd generation, weak production, indirect constraints

Long-lived particles

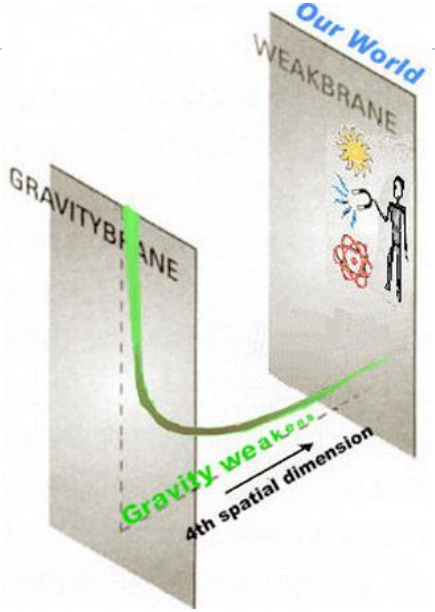
Most of the results shown in this talk use the full 2012 data-set (8 TeV)

Resonances: Extra Dimensions, new gauge bosons and more

Large Extra Dimensions

$$\phi(x) = \phi(x + k2\pi R)$$
$$(k = 0, 1, 2, ...)$$
$$p = k/R$$

Randall-Sundrum

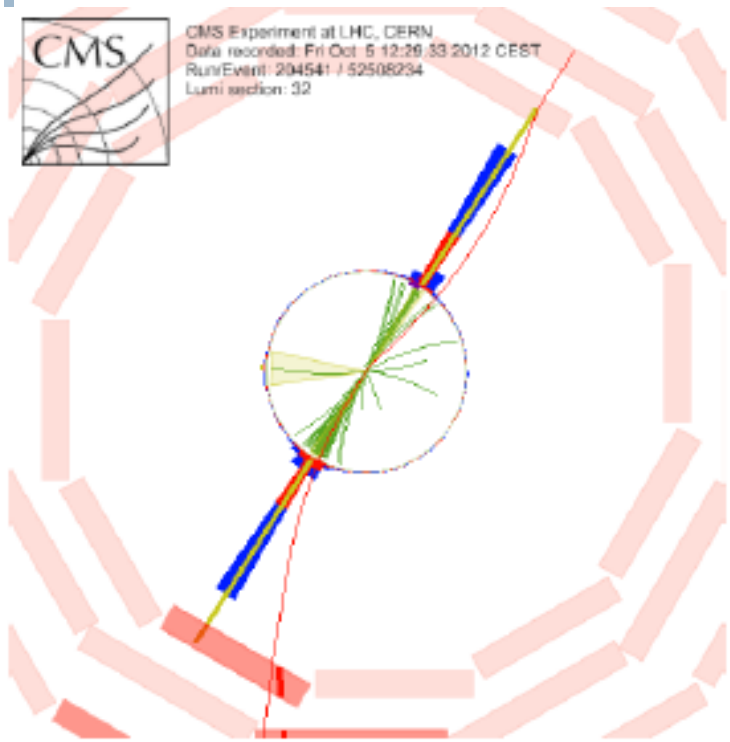


Z' and W' bosons

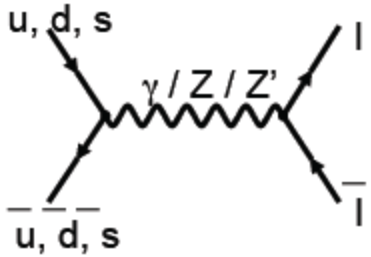
Naturally arise from many SM extensions (GUTS - E6,SO(10),..., extra dimensions etc..)

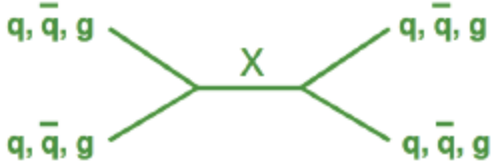
Search for high mass resonances

- *Di-lepton resonances* have a strong track record for discovery → J/ψ, ϒ, Z
  - Enlarge the possible final states: looking in ***dijet, dileptons, dibosons and more***!
- Construct pair invariant mass and look for excesses in the high mass spectrum



Di-jet event,
Mjj =5.15 TeV





Advantages

→ Sensitive to many BSM scenarios:

- ZSSM in Sequential SM (with same Z-coupling as in SM)
- Z' models from E6 and SO(10) GUT groups
- The Kaluza-Klein (KK) model in Extra Dimension
- Little, Littlest Higgs model …

→ relatively clean with good S/B (SM-tails)

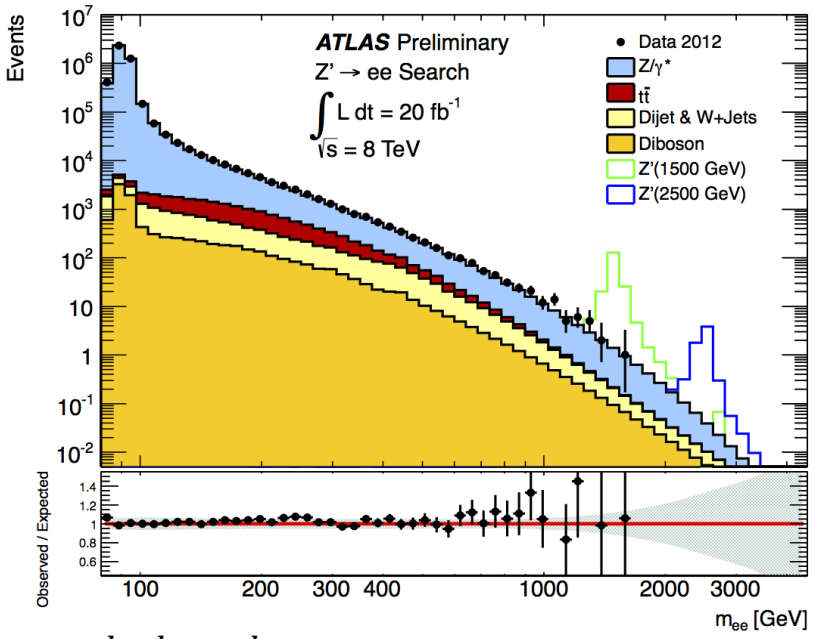
→ Experimental challenges

- detector resolution can be a key player
- extra care for *E* and *p* recontruction > 1 TeV

Di-lepton final states: resonance searches

Searches in di-electron and di-muon final states carried using the full data-set:

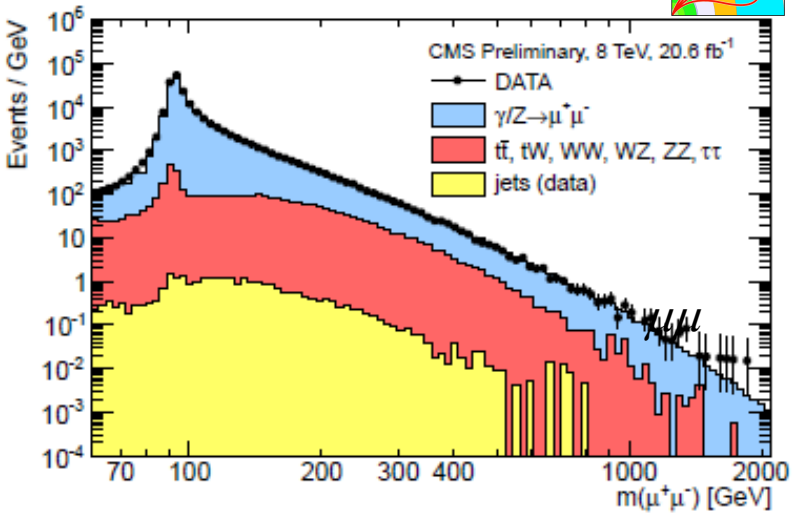
- Extra Dimension (Randall-Sundrum) and Z' models foresee narrow resonances

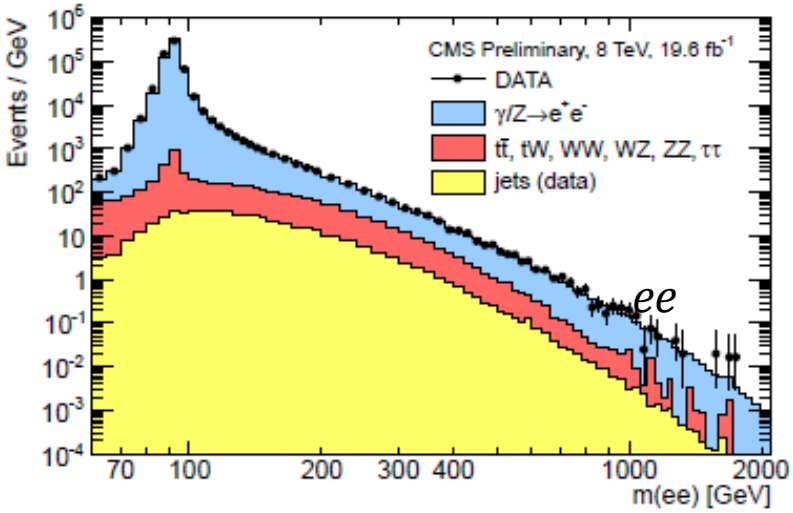


ee only shown here

ATLAS-CONF-2013-017

PAS EXO12061

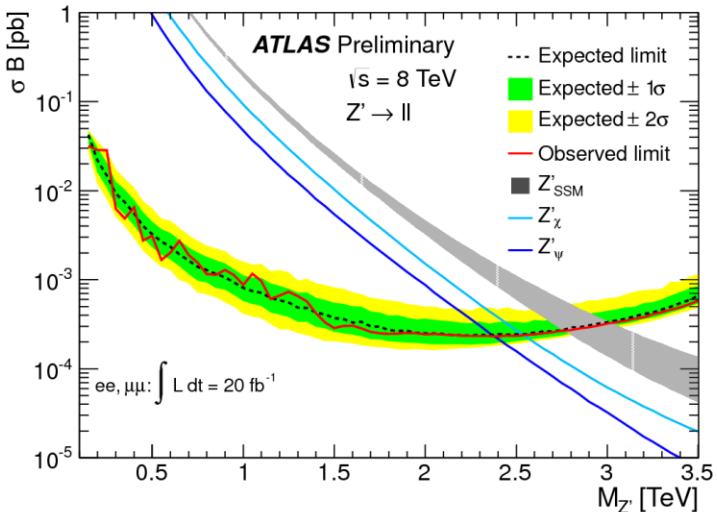


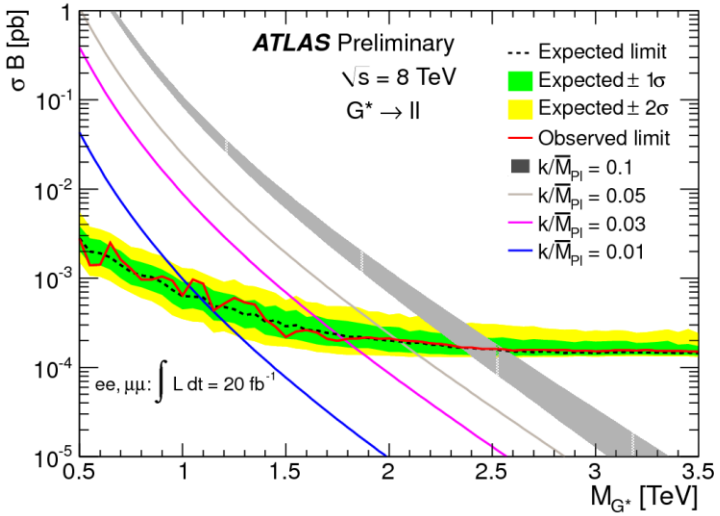


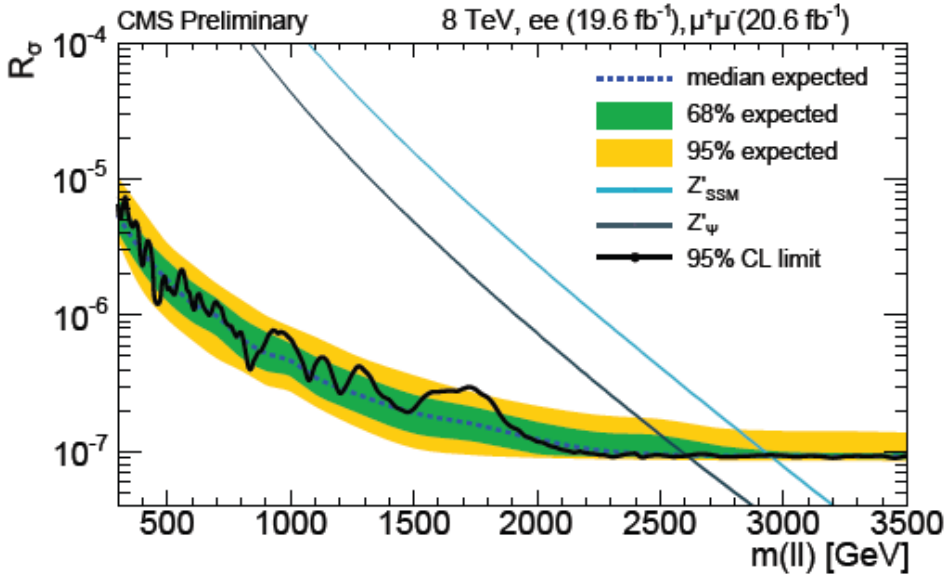
Di-lepton searches: results

Constrain Z' and RS graviton (G*) production in e^+e^- and $\mu^+\mu^-$ invariant mass distributions

$$R_\sigma = \frac{\sigma(pp \to Z' + X \to \ell\ell + X)}{\sigma(pp \to Z + X \to \ell\ell + X)}$$







Exclusion limits on Sequential SM Z', E6-motivated Z' and spin-2 RS graviton.

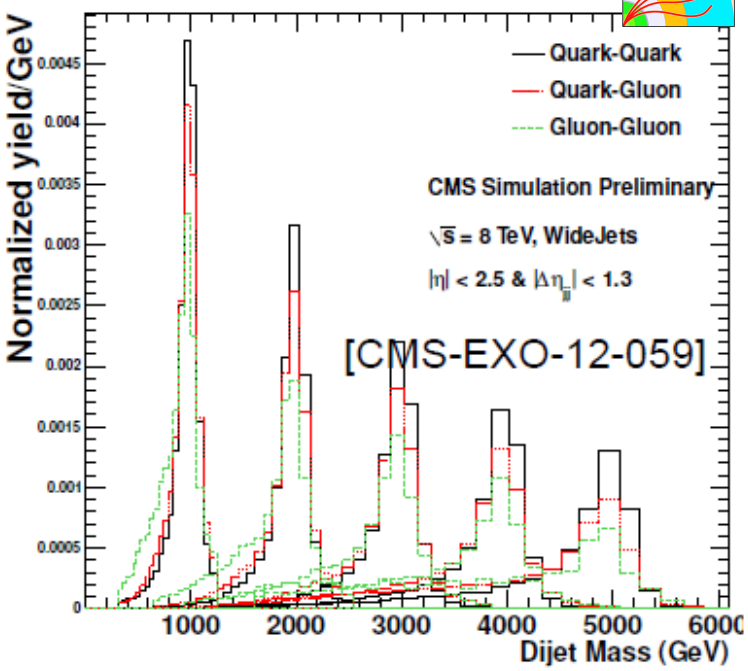
CMS (in back-up): also dedicated search for non resonant dilepton production (ADD models)

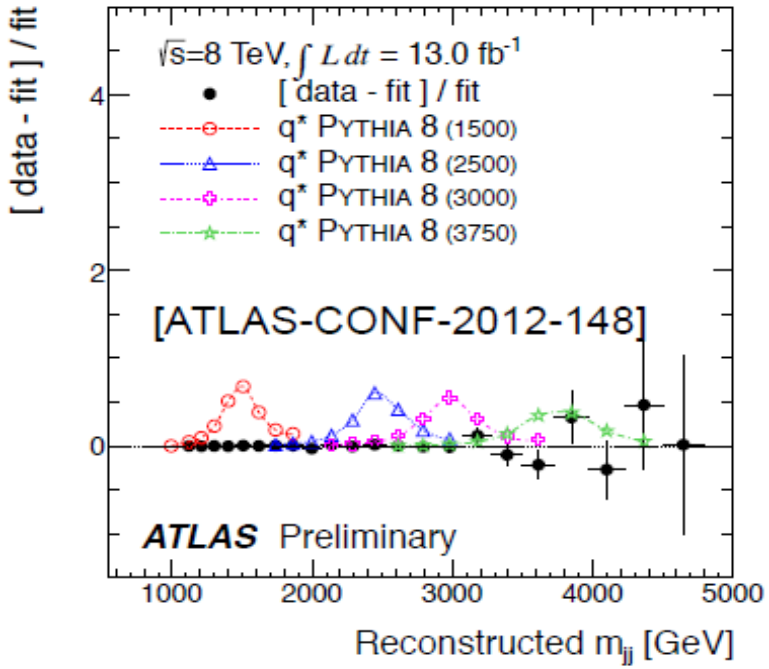
CMS-PAS-EXO-12-027
CMS-PAS-EXO-12-031

Dijet resonance searches

Generic search for new physics in the dijet spectrum → Sensitive to excited quarks, contact interactions, axigluons, W', Z', …

- look for **central** resonances (ATLAS: $|\Delta y|<1.2$; CMS: $|\Delta\eta|<1.3$)
  - CMS also separates by state (qq, qg, gg)

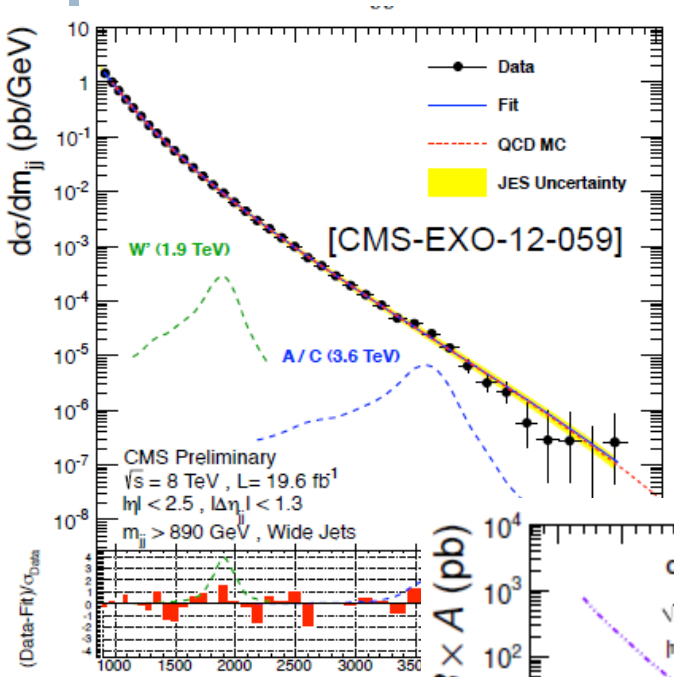


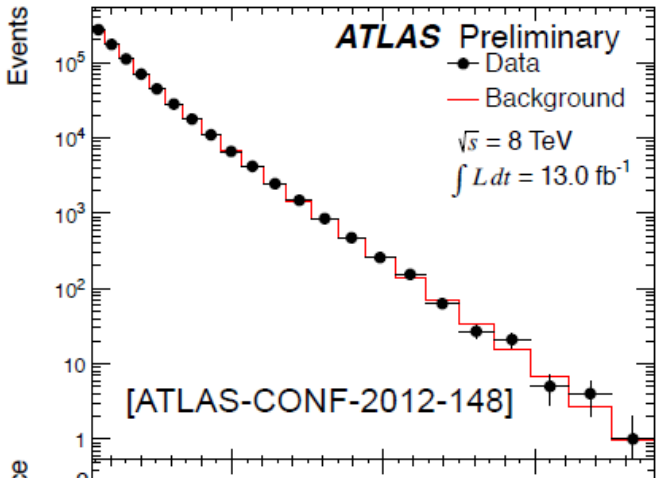


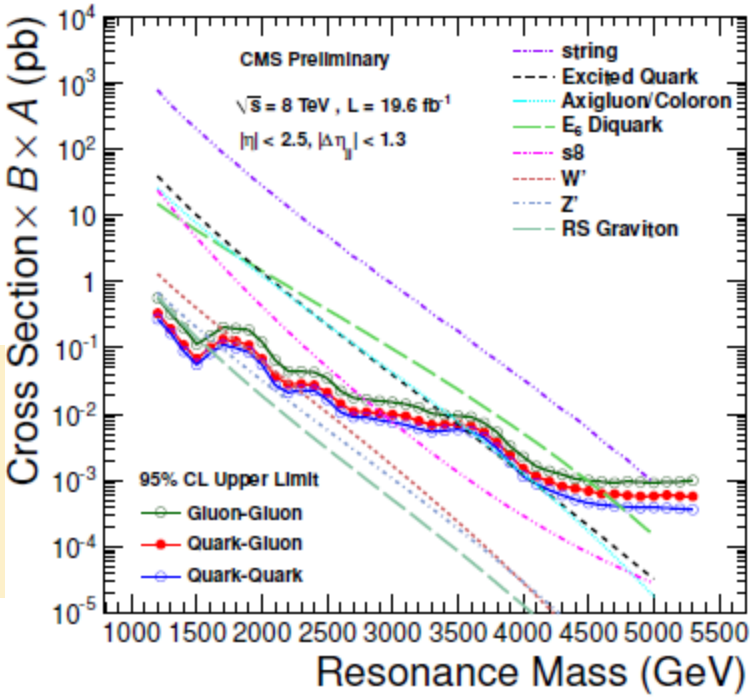
Observed and fitted dijet mass distributions →
Search for bump over continuous background fit

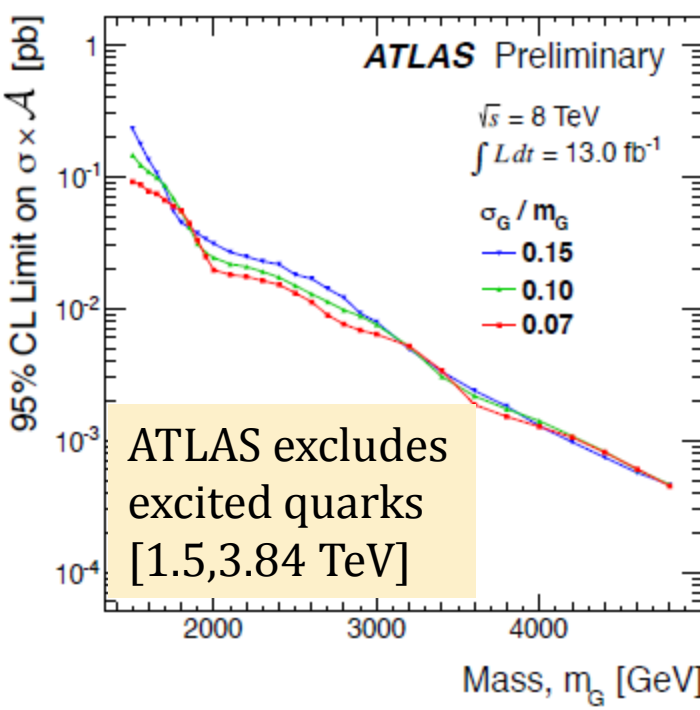
$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}; \quad x \equiv m_{jj}/\sqrt{s}$$

Dijet resonance searches: results







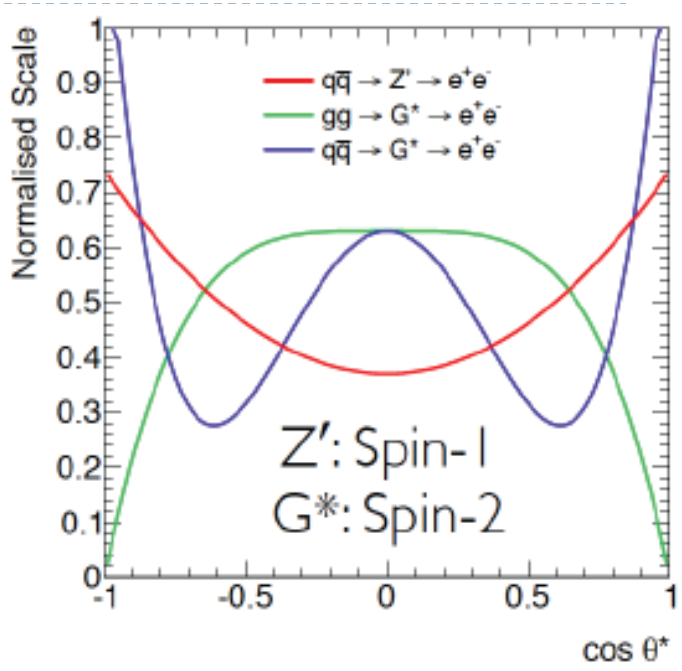


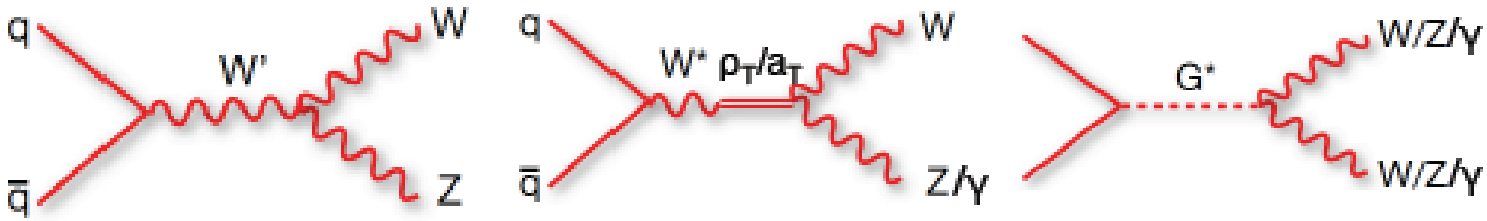
CMS excludes f.i. SSM Z' [1.2,1.68 TeV] and many more new particles

ATLAS excludes excited quarks [1.5,3.84 TeV]

Resonant diboson production

- Several SM extensions predict the existence of heavy resonances decaying in WW, **WZ** or **ZZ**
  - W' in Extended Gauge Model (charged, spin 1, fermionic couplings like W, triple gauge W'WZ)
  - Technimesons
    - ρT (spin 1) or aT (spin 0) in WZ or Wγ
  - RS graviton (spin2, neutral, decaying in WW, ZZ or γγ)

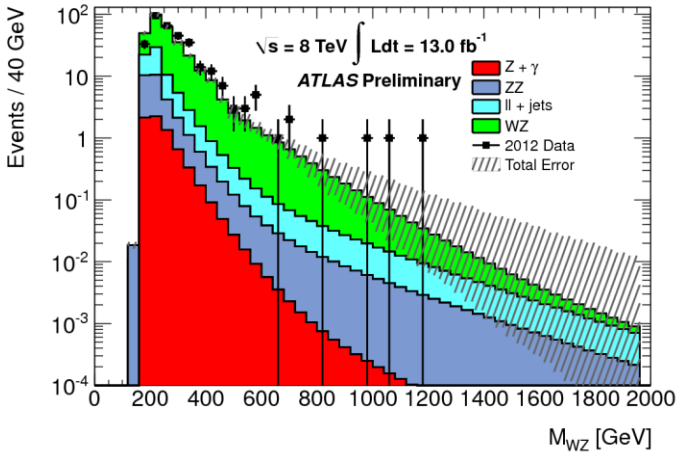


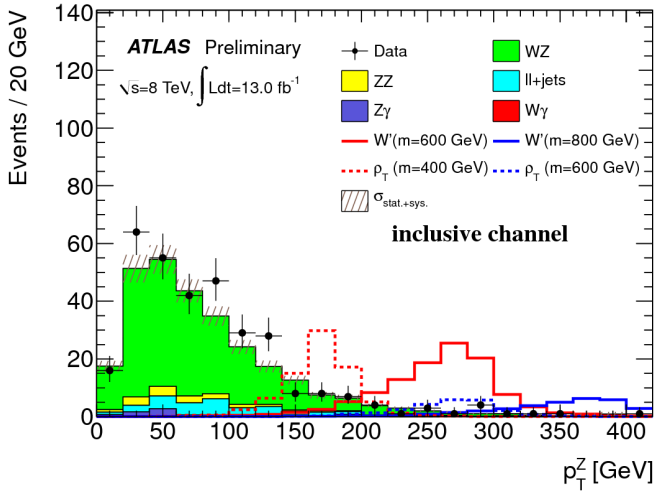


Resonant WZ production

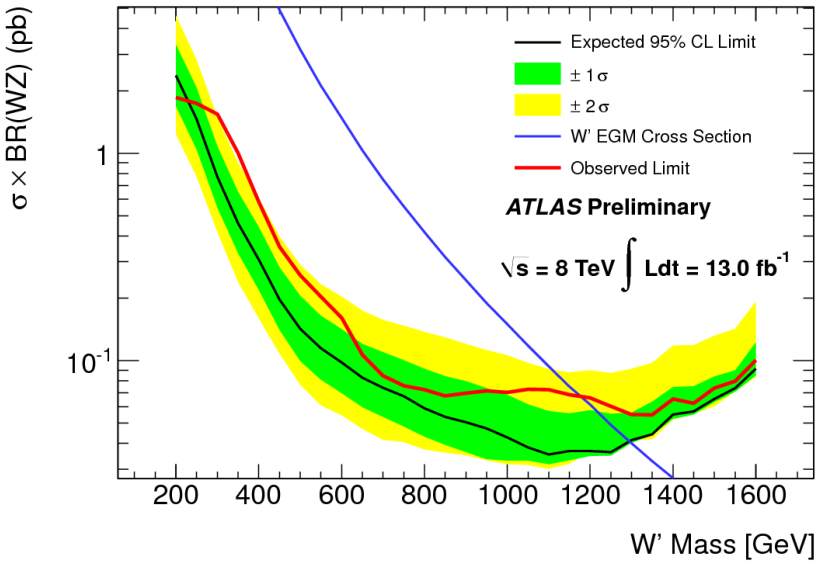
ATLAS-CONF-2013-015

- WZ→ lllv: trilepton + Missing Transverse Momentum (E_T^{Miss})
  - Resonant diboson production (ZZ,WZ,Zγ,Wγ) taken from MC simulation
  - Reducible background from misidentified leptons (Z+jets, ttbar, Wt) from data





Example of interpretation: W' in Extended Gauge Models



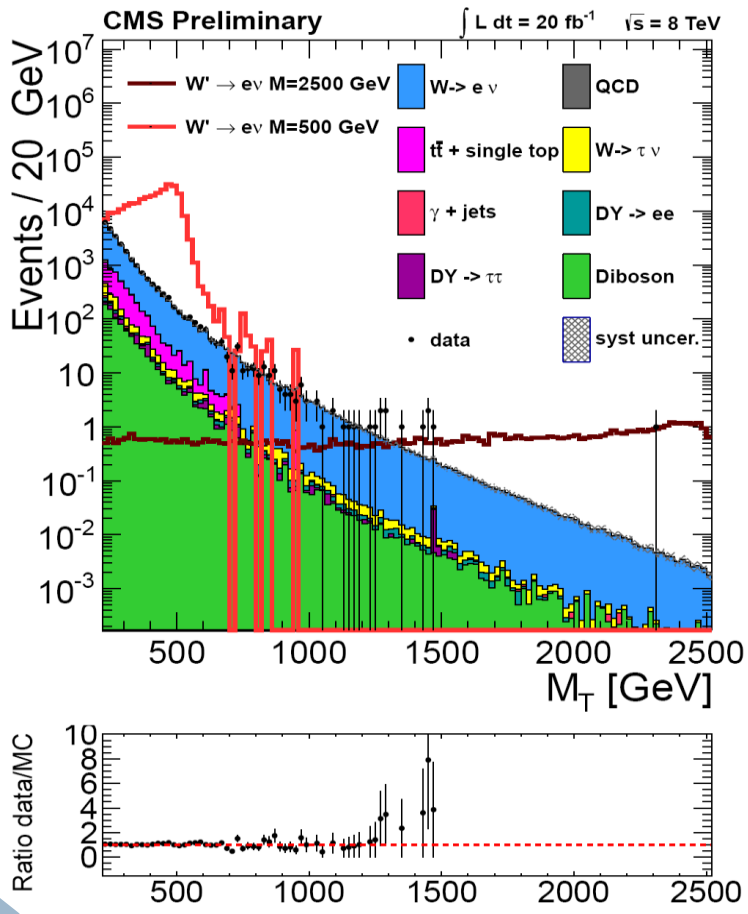
In back-up: Search for resonant ZZ→ llqq (l=e, μ) (7. 2 fb-1): exclude G* mass above 860 GeV

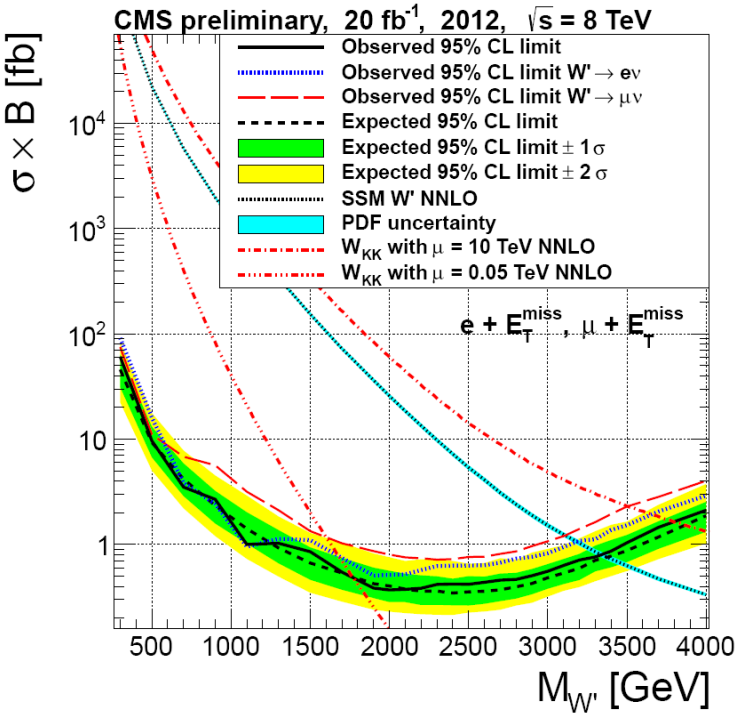
ATLAS-CONF-2012-150

W' in lepton+E_T^{Miss}

PAS EXO12060

- Search for new physics in final states with an electron or a muon and a low mass neutrino
  - Sensitive to SM-like W', split universal Extra Dimensions and Kaluza-Klein W^2_{KK} states, compositness and contact interactions





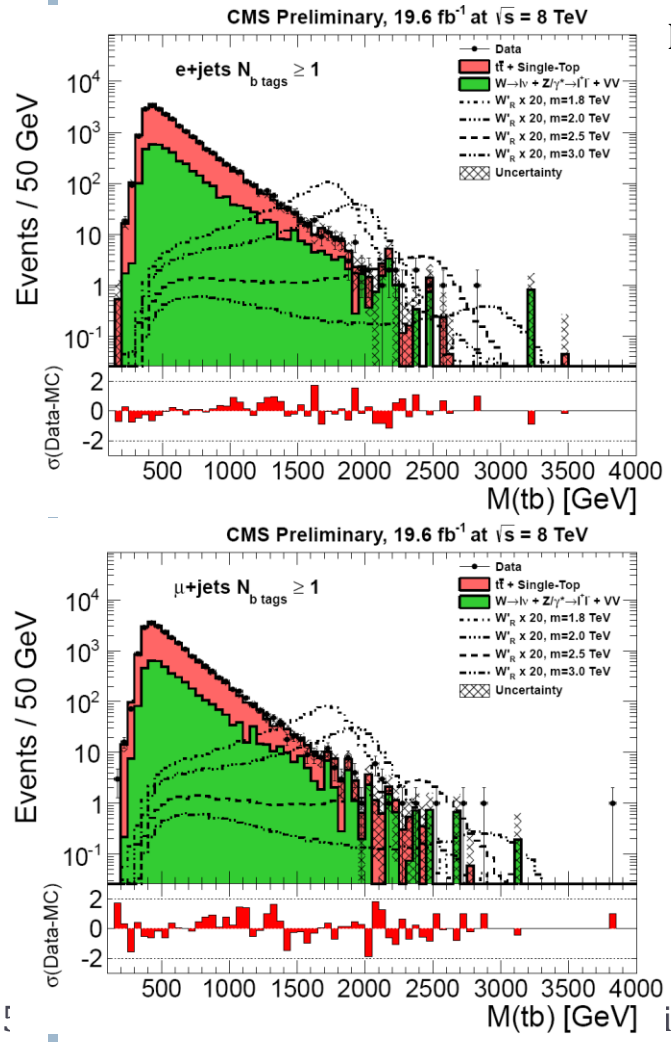
Mass exclusion limits at 95% CL for a SM-like W′ boson. Limit depends on SM interference

SSM Model	mass limit (TeV)
no interference	3.35
constructive interference	3.60
destructive interference	3.10

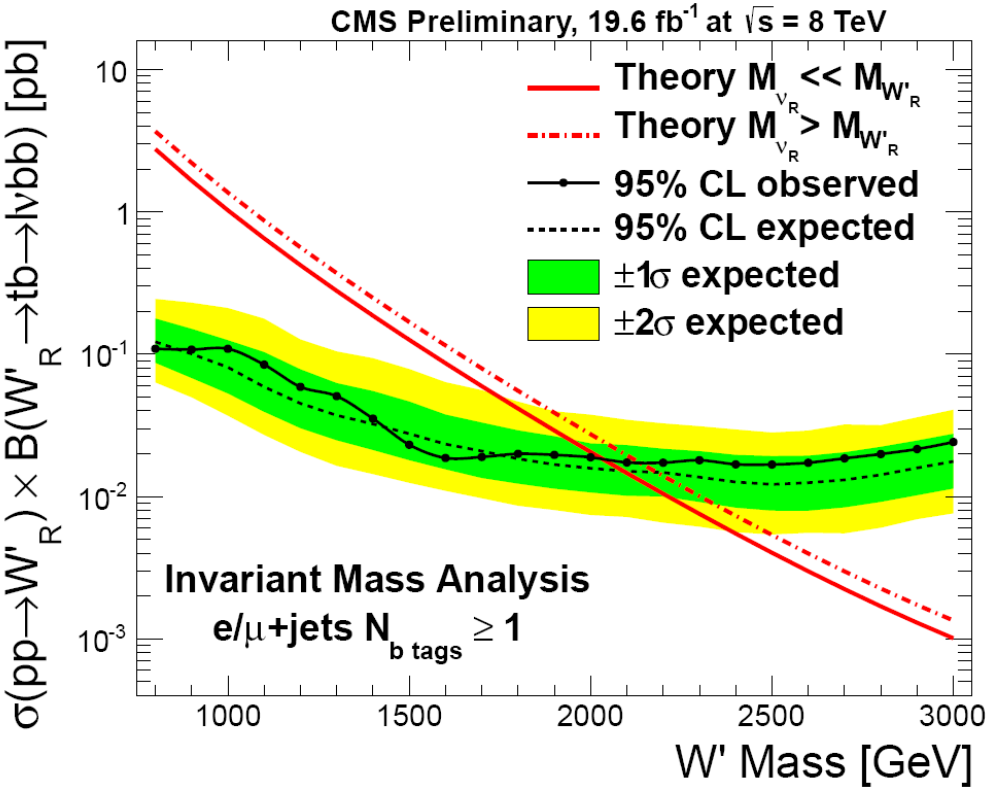
Search for W' in t+b final states

B2G-12-010

- W' decaying in top+b quarks predicted by Extra Dimensions, little Higgs and Technicolor models
- Final states events with one lepton (e or μ) + (b)-jets +E_T^{Miss}

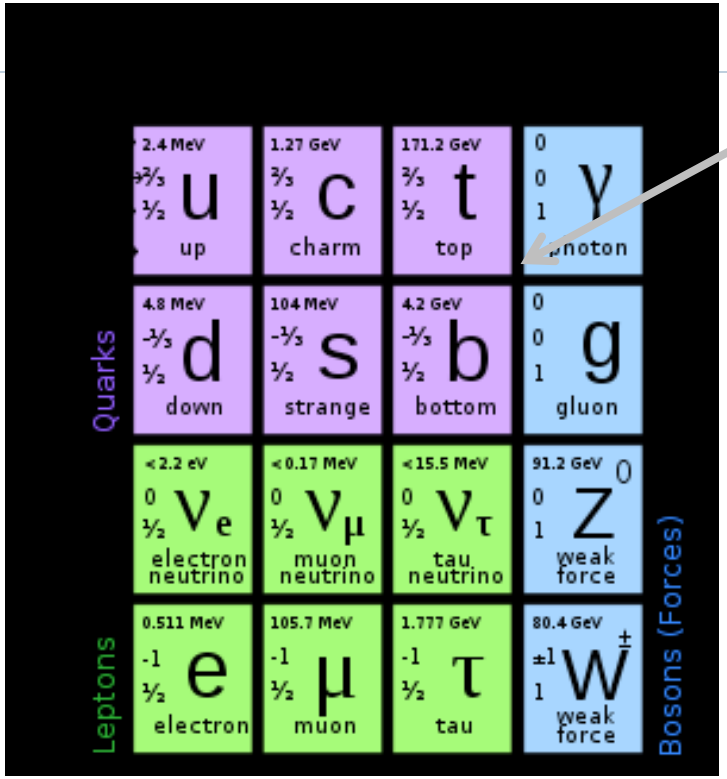


Main SM background: top and single top



Limits also apply to W_L boson if no SM-interferences are taken into account.

4th generation, vector-like quarks



Why nothing here?

4th generation / heavy quarks

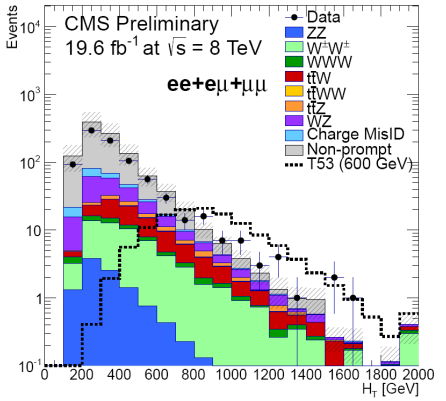
Searches for heavy quarks carried out by CMS and ATLAS

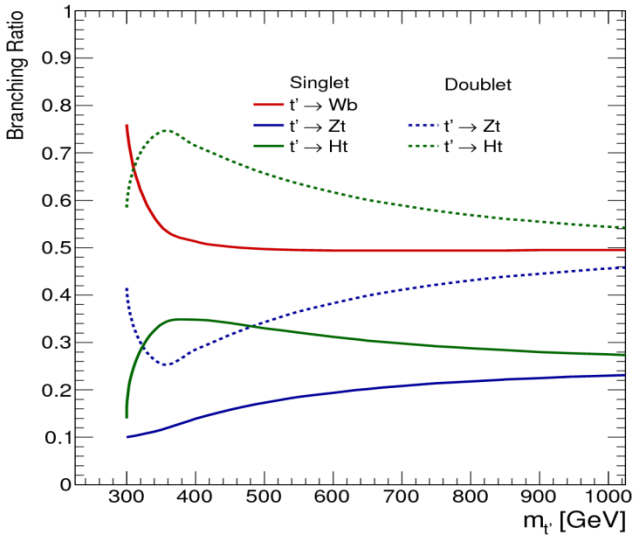
- denoted as *T* and *B*, and/or *t'* and *b'* ; or *Q* (*Q'*) for either flavor
- Top partners with *Q*= 5/3 (*CMS-B2G-12-012, in back-up)* →

and excited top (t*) also searched for (CMS)

- Complex final states:
  - $T \to Wb$, $B \to Wt$ or $T \to Zt$, $T \to$ Higgs+t, $B \to Zb$
- Usually assume 100% BR for one decay modes
  - ATLAS uses also different hypothesis for *T* decay BR in *Wb/Ht/Zt*
  - as computed with theory-based calculations (PROTOS)

T (5/3) → t+W





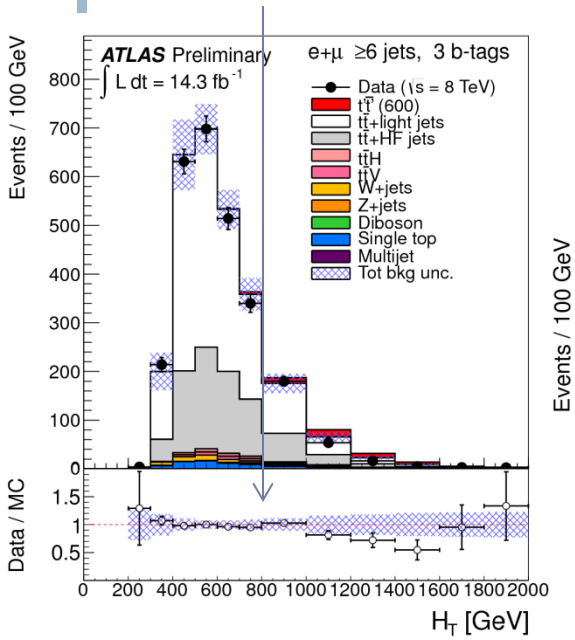
- In general both single and pair productions considered
- Mechanism and cross section depend on *Q* nature
  - Chiral or vector-like

Search for vector-like *T*

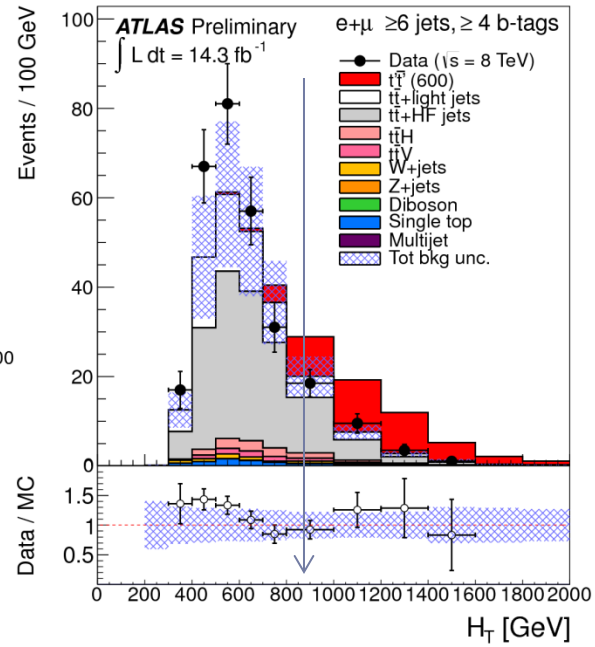
- *T*→*Wb*, *Zt*, *Higgs*+*t* decays considered

ATLAS-CONF-2013-018

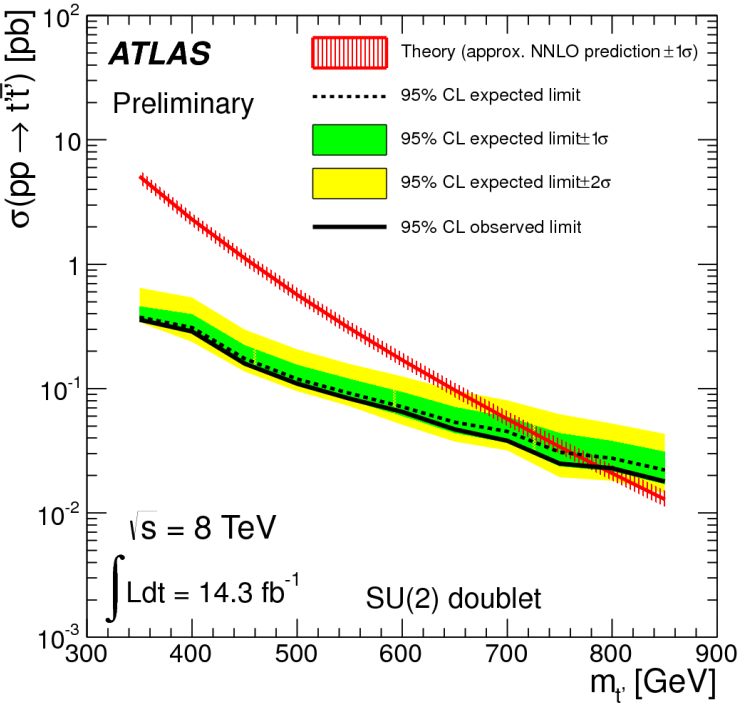
- Use 1 lepton (e,μ) + ≥6 jets + E_T^{Miss} plus transverse mass M_T
  - Major SM background: ttbar+jets
  - bin in number of b-tags, from 2 to 4 b-jets



Regions with
$H_T=\Sigma\ p_T$ (jets) < 700 GeV
used as Control Regions



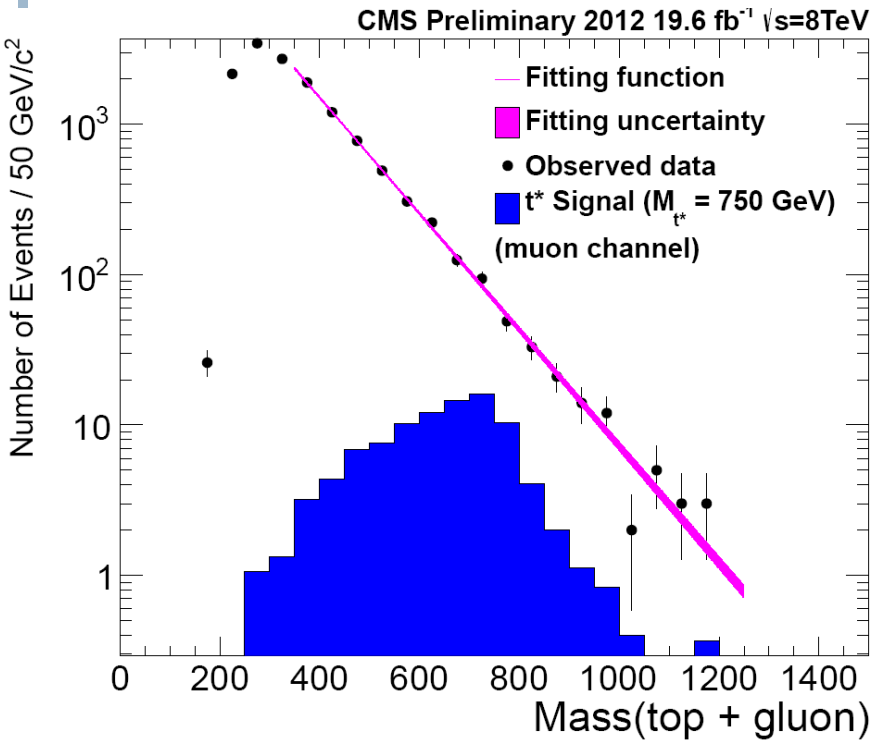
Limits on weak-isospin double and singlet models:
→ Exclude *T* < 790 (640) GeV for a doublet (singlet) model

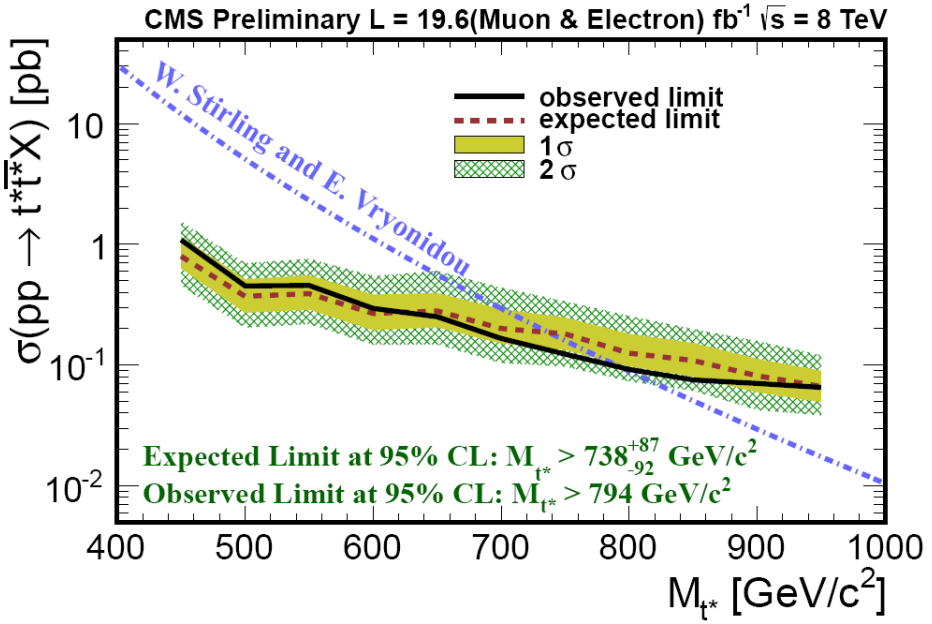


Search for excited top quarks

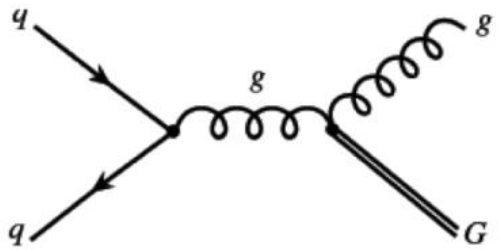
CMS-B2G-12-014

- Consider t* decaying in t+gluons:
  - Right-handed t* quarks expected to be the lightest spin-3/2 Regge excitation predicted in string realizations of the RS model
    - pair-production cross section ~ few pb at 500 GeV
  - 1 lepton (e,μ) + >= 6 jets



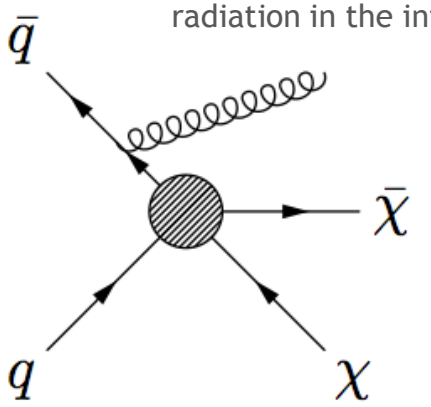


1 object and nothing else: Monojets



$qq \rightarrow gG$, $qg \rightarrow qG$, gg$\rightarrow gG$, G = Graviton

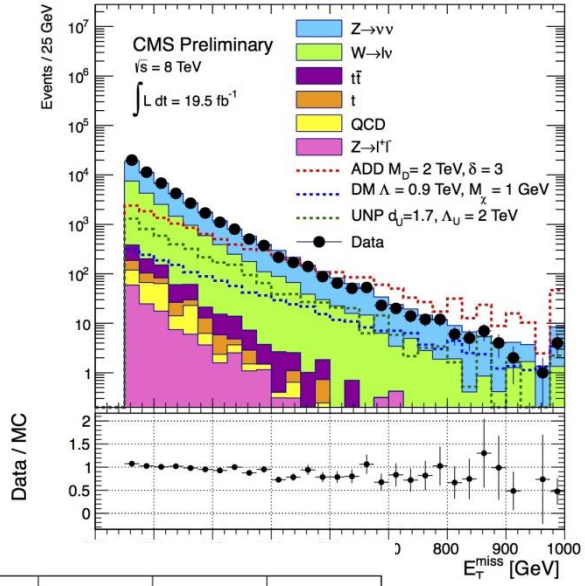
Energetic gluon/photon radiation in the initial sate

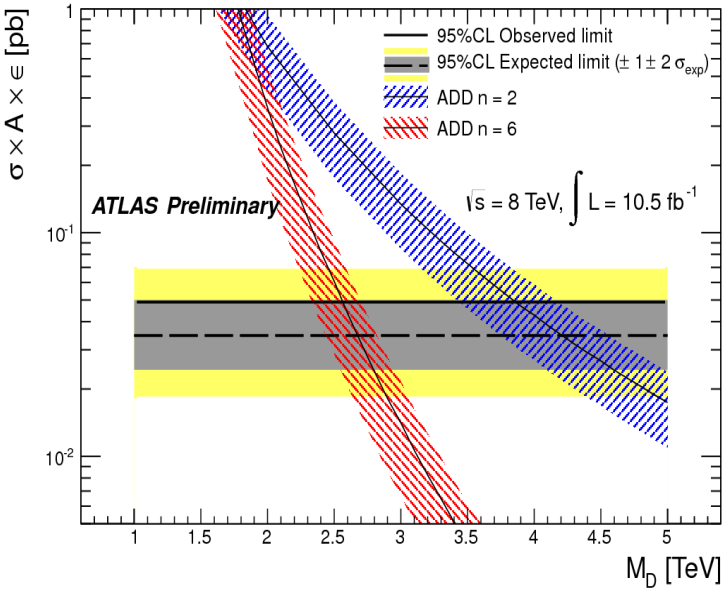


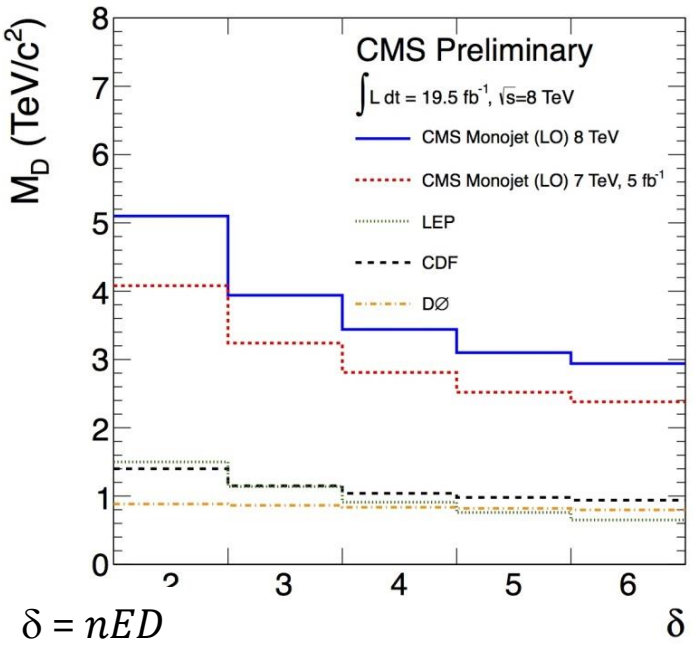
= WIMP

Monojets

- Monojet is a simple and striking signal
  - High-pT jet with no object to balance pT
  - Main background is Z → ν ν + jet(s)
- Limits on graviton in Large Extra Dimension (ED):
  - Set on Modified Planck scale (MD) for N extra dimensions
- Constraints on Dark Matter (more in back-up)
- **ATLAS** result obtained with 10.8 fb^{-1} (ATLAS-CONF-2012-147)
- **CMS** result obtained with 20.6 fb^{-1} (CMS-PAS-EXO-12-048)







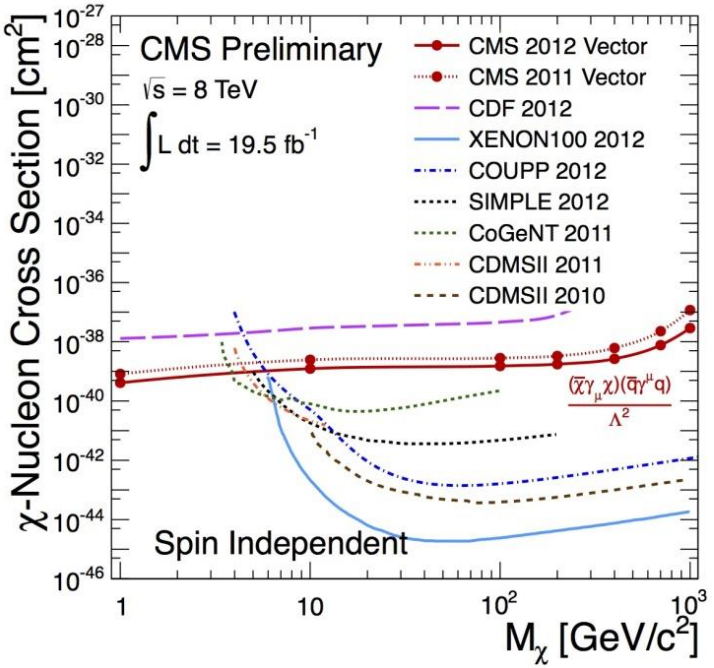
Monojets results as constraints on DM

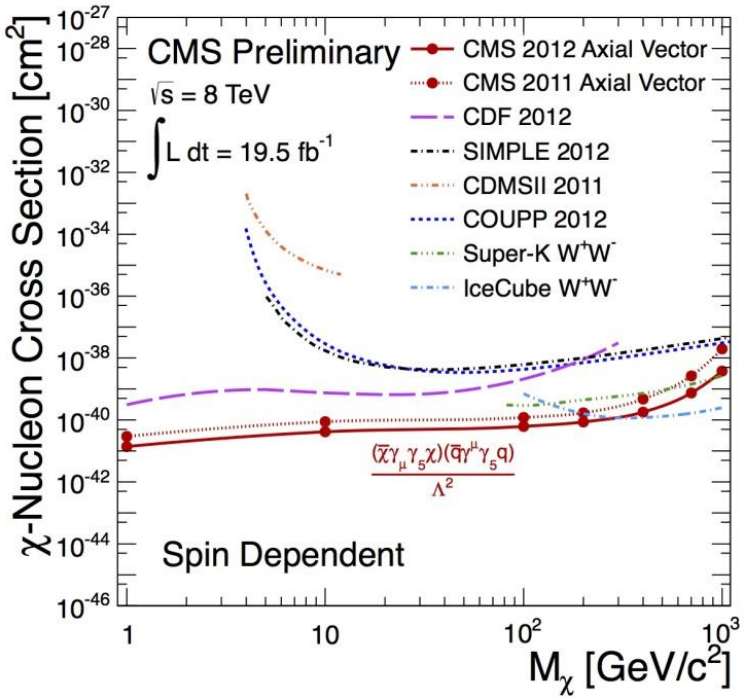
Limit on WIMP pair production cross-section can be transformed into limit on effective WIMP-hadronic contact interaction:

Vector (SI): $(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)\cdot\Lambda^{-2}$

Axial-v. (SD): $(\bar{\chi}\gamma_\mu\gamma^5\chi)(\bar{q}\gamma^\mu\gamma^5 q)\cdot\Lambda^{-2}$

WIMP-nucleon scattering xsect $\sigma \propto \frac{1}{\Lambda^4}$





Searches for Supersymmetry

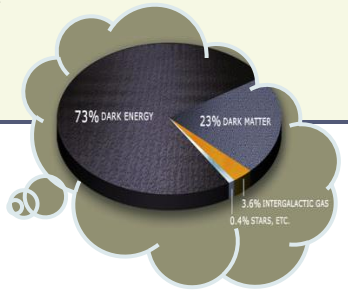
→ superpartner for every SM particle, spin differs by one half

Many good reasons to consider SUSY:

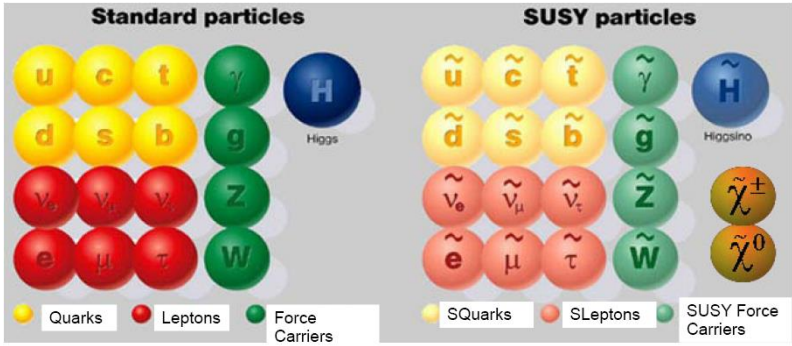
- Fermion and Boson loops protect the Higgs mass at large energies (reduces "fine tuning")
  - Higgs 'candidate' → lightest neutral CP-even SUSY Higgs "h"

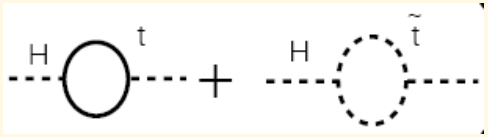
- unification of 3 coupling constants at high energy in one point (GUT scale at 10^{16} GeV?)

- offers (with R-parity conservation) weakly interacting massive particles for Dark Matter with a mass of O(100) GeV



R-parity = $(-1)^{3(B-L)+2s}$
-1 for sparticles
1 for particles





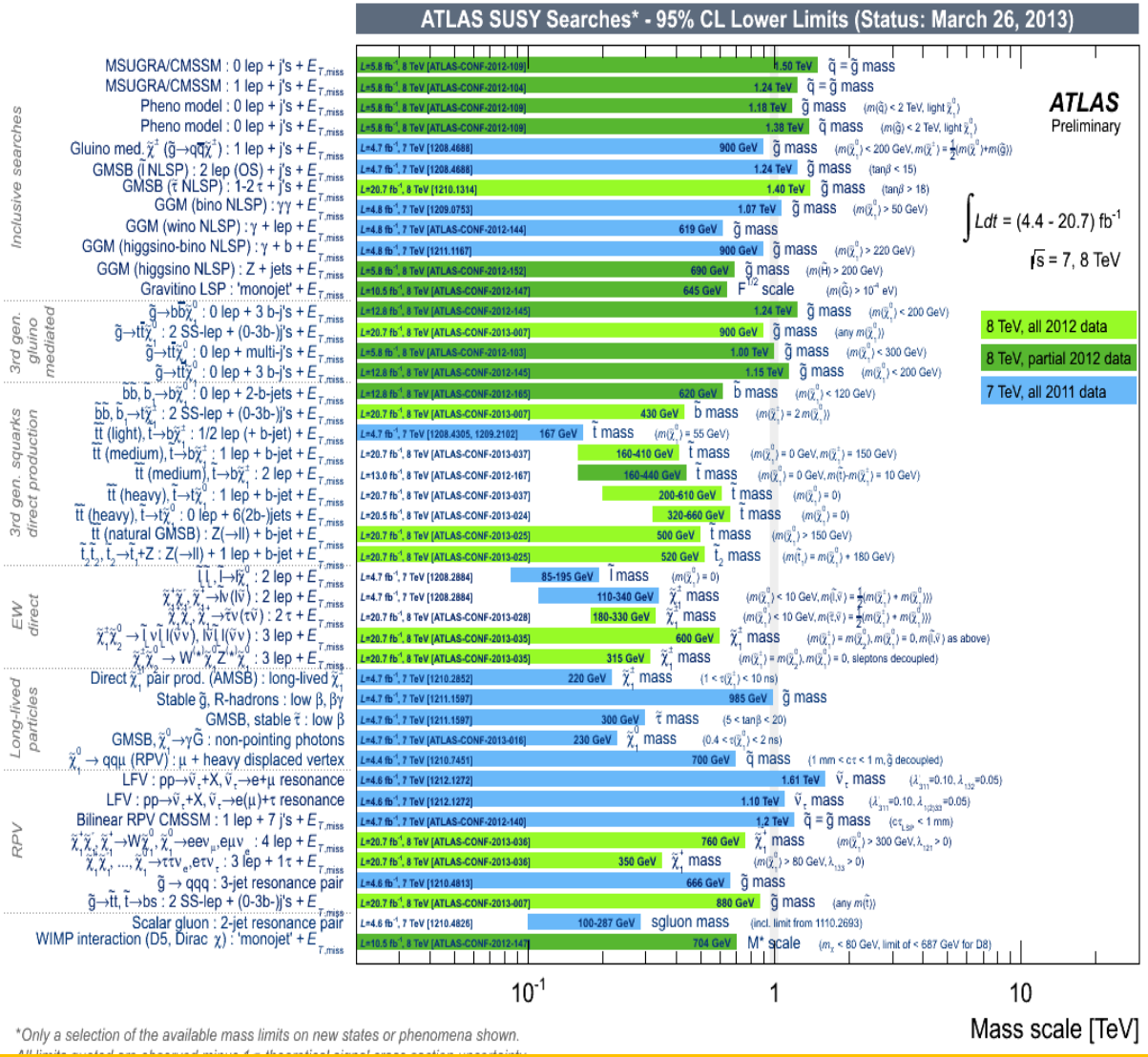
Light stops and gauginos/higgsinos to cancel divergences in higgs mass

Searches for SUSY @ ATLAS and CMS

A broad search programme:

- Effort to probe maximum area of SUSY parameter space possible
- Several full dataset results public for Winter:
  - 8 for ATLAS
  - 4 for CMS

More in preparation for LHCP



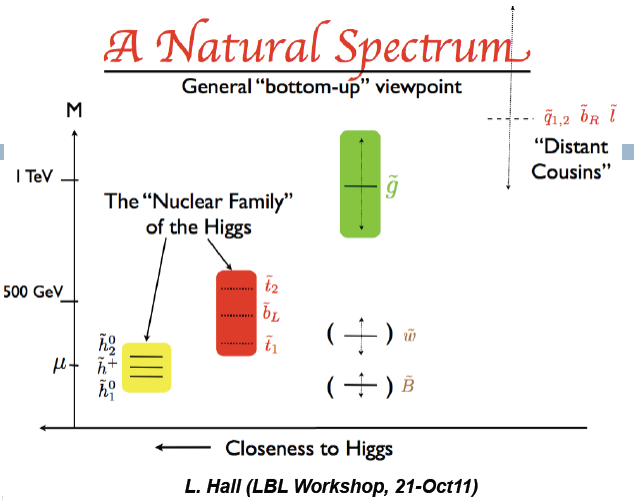
Wide range of signatures covered → Here will focus on 'natural' SUSY *(others in back-up)*

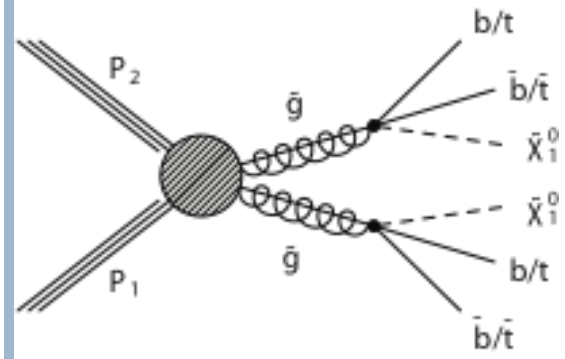
"Natural" SUSY

Lightest squarks are stop/sbottom, gluinos possibly not too heavy, gauginos accessible

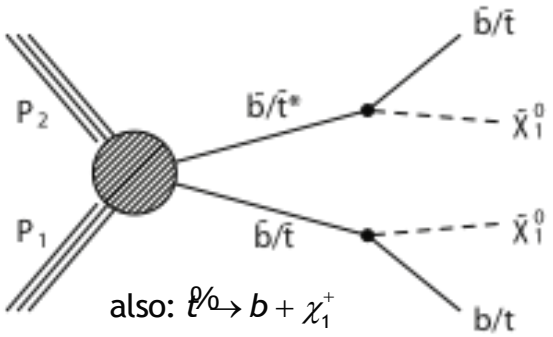
Low cross-sections and large SM backgrounds require dedicated searches

Strong & strategic approach by ATLAS and CMS



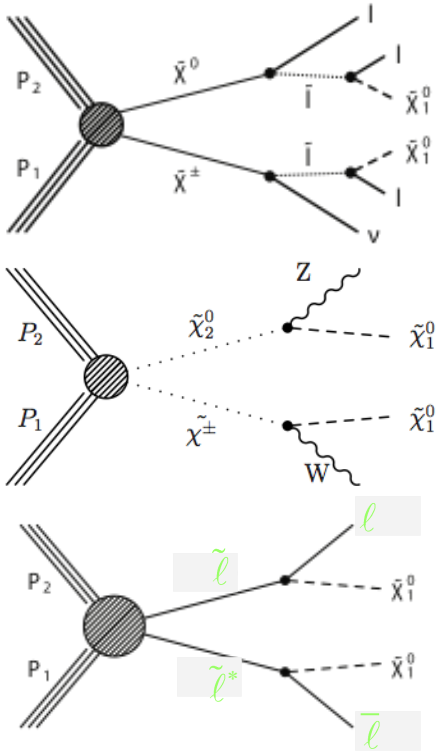


Gluino-mediated $\tilde{b}/\tilde{t}$ production



Direct $\tilde{b}/\tilde{t}$ pair production

Associated gaugino production

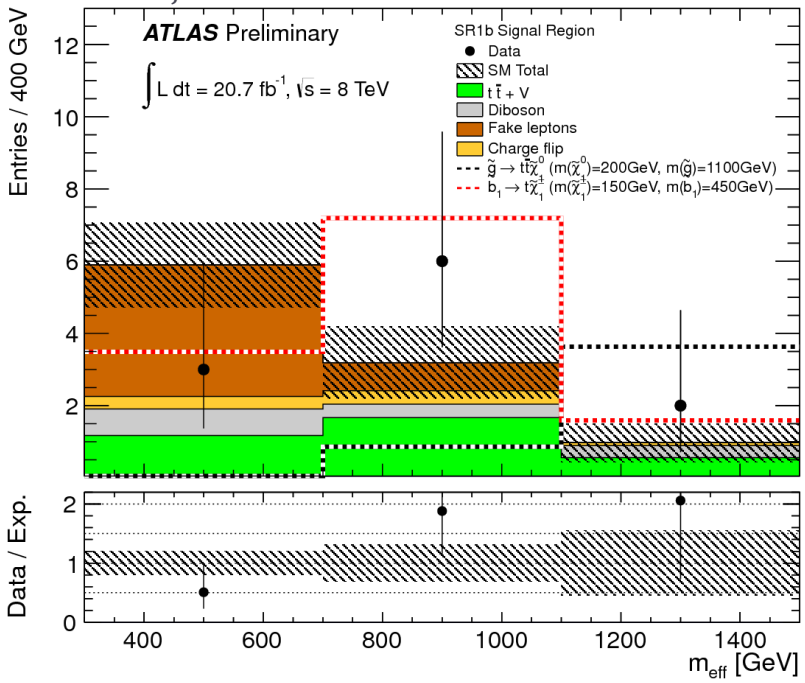


Direct slepton-pair production

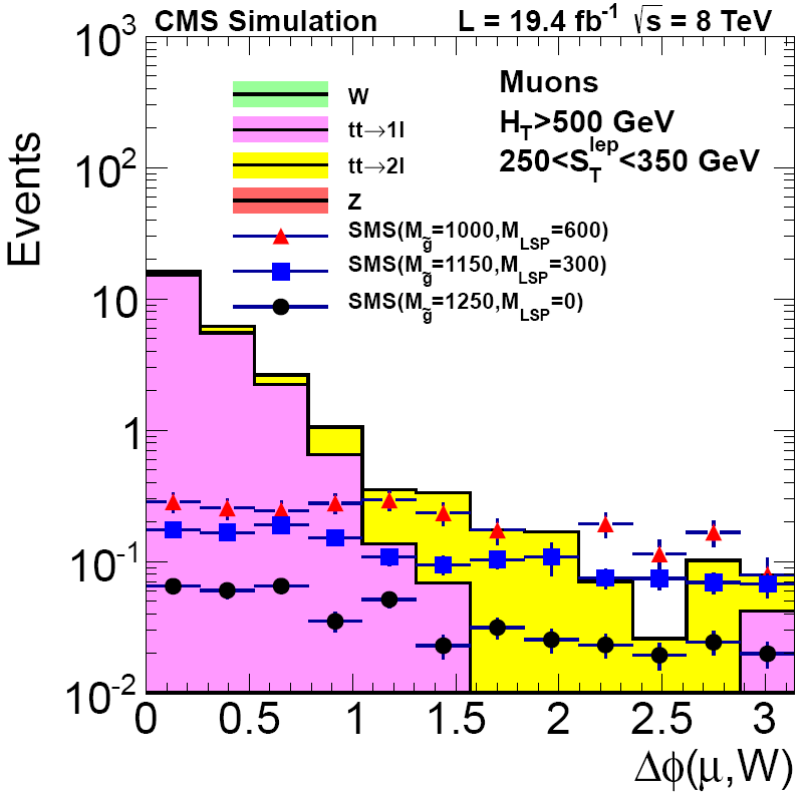
Stop via gluino pair production (I)

- Final state contains up to 4 bjets, up to 12 jets and 4 leptons (possibly same sign):
  - Many different analyses developed to target this final state. Here the ones using full 8 TeV dataset:
    - **ATLAS:** 2 same sign leptons + (b)-jets and large E_T^{Miss} (20.7 fb^{-1}, ATLAS-CONF-2013-007):
      - Very versatile analysis, mostly data-driven bkg estimate, 3 Signal Regions defined on N bjets, E_T^{Miss} and M effective
    - **CMS:** 1-lepton + >= 6 jets (2 or 3 bjets) (19.8 fb^{-1}, CMS-PAS-SUS-13-007):
      - Two complementary approaches:
        - 'Lepton Spectrum' → large E_T^{Miss} and H_T
        - 'Delta Phi' → $\Delta\phi$(W,l) and total transverse energy ($S_T$lep)

SR: $N_b \geq 1$, $N_{jet} \geq 3$, $E_T^{Miss} > 150$ GeV

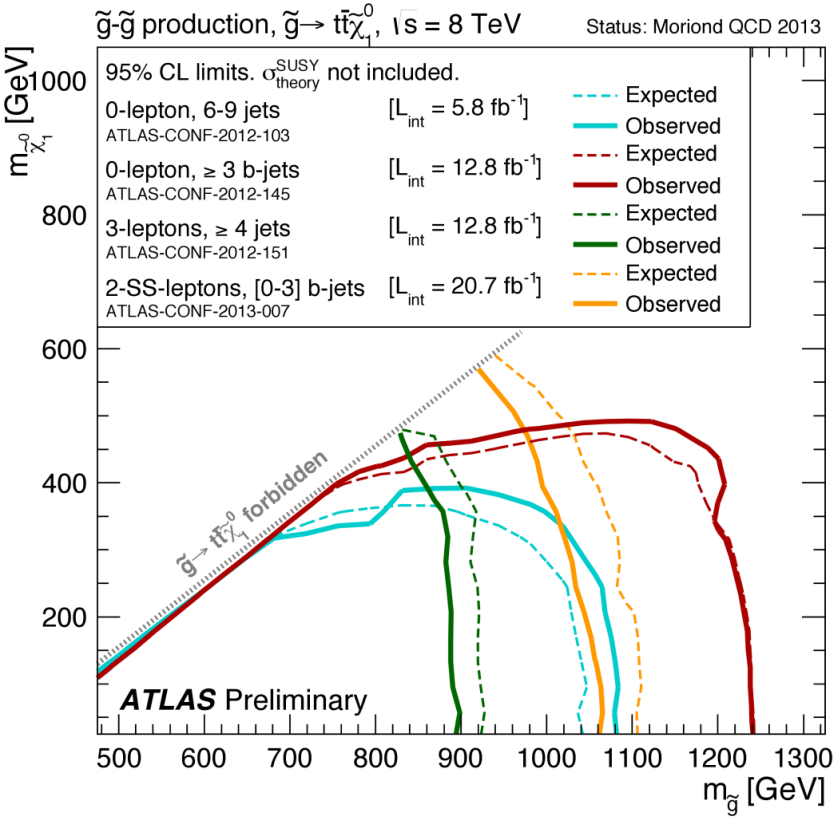


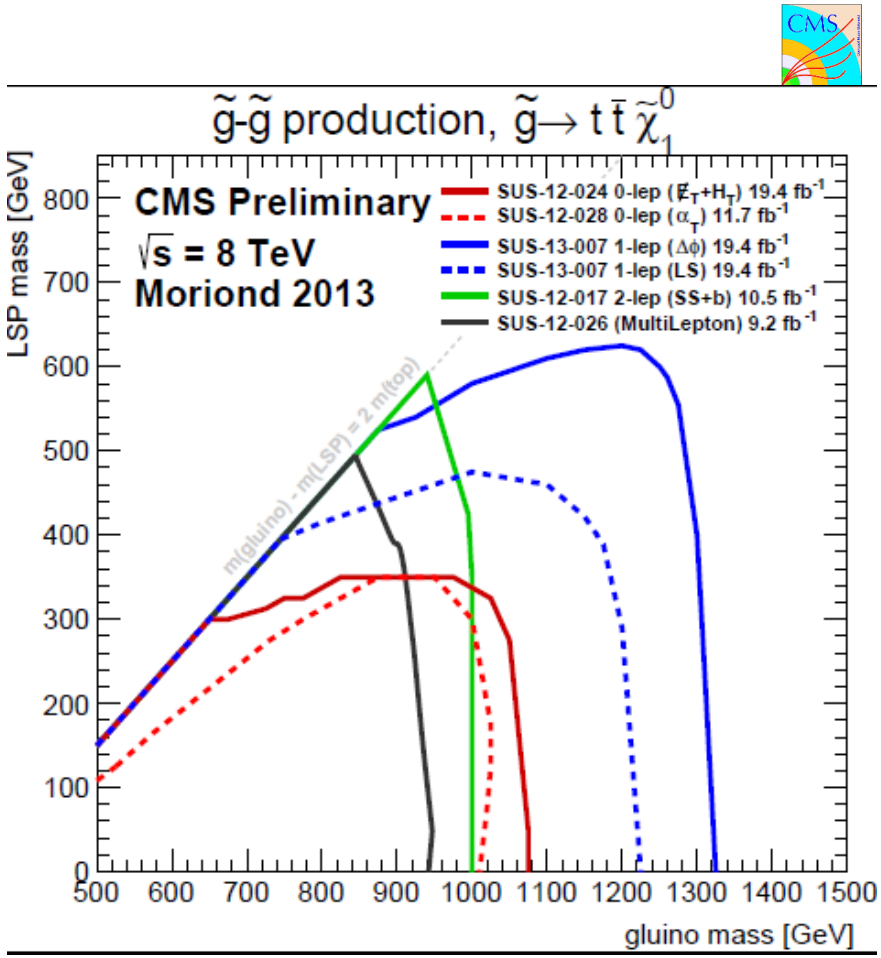
SR: $N_b \geq 3$, $N_{jet} \geq 6$



Stop via gluino pair production (II)

- Final state contains up to 4 bjets, up to 12 jets and 4 leptons (possibly same sign):
  - Many different analyses developed to target this final state. Here also:
    - **ATLAS:** Multijet, 3 bjets (0-lepton); 3-lepton; Same Sign leptons;
    - **CMS:** MET+HT, Alpha_T (0-lepton); Dphi, Lepton Spectrum (1-lepton); Multilepton; SS leptons;





Direct stop pair production

- Decay of stop depends on SUSY mass spectrum

$\tilde{t}\,\bar{\tilde{t}}$ production where $\tilde{t} \rightarrow t\,\tilde{\chi}_1^0$ → **heavy**

or: stop in b + $\chi^{\pm}_1$ → **medium/heavy**

Signature:

0-lepton + ≥ 6 jets (≥ 2 b-tagged jets) + E_t^{Miss}
ATLAS-CONF-2013-024

1-lepton + ≥ 4 jets (1-2 b-tagged jets) + E_T^{miss}
ATLAS-CONF-2013-037

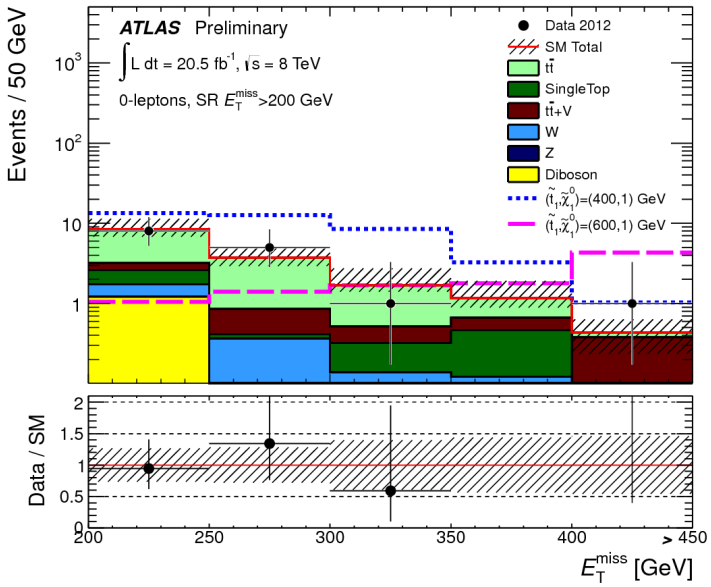
Backgrounds

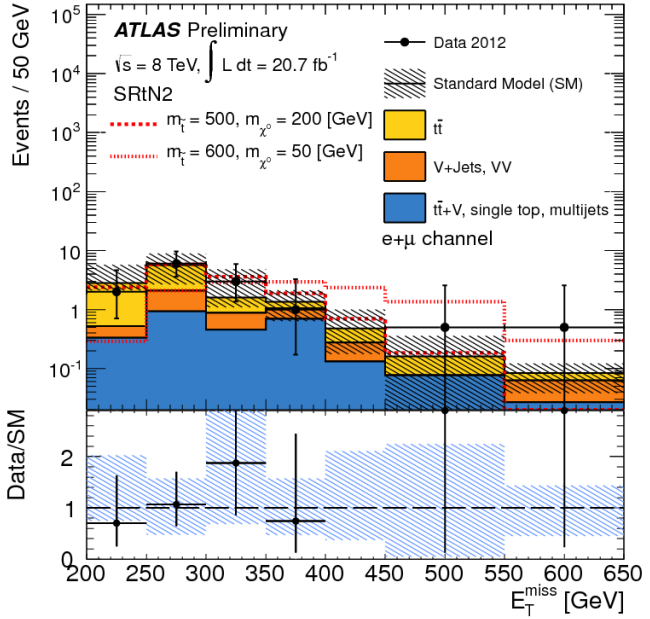
Semi-leptonic ttbar,
Z → νν +jets (0-lepton)
W→τν+jets (1-lepton)

0-lepton: Loose, medium, tight signal regions using E_T^{miss}

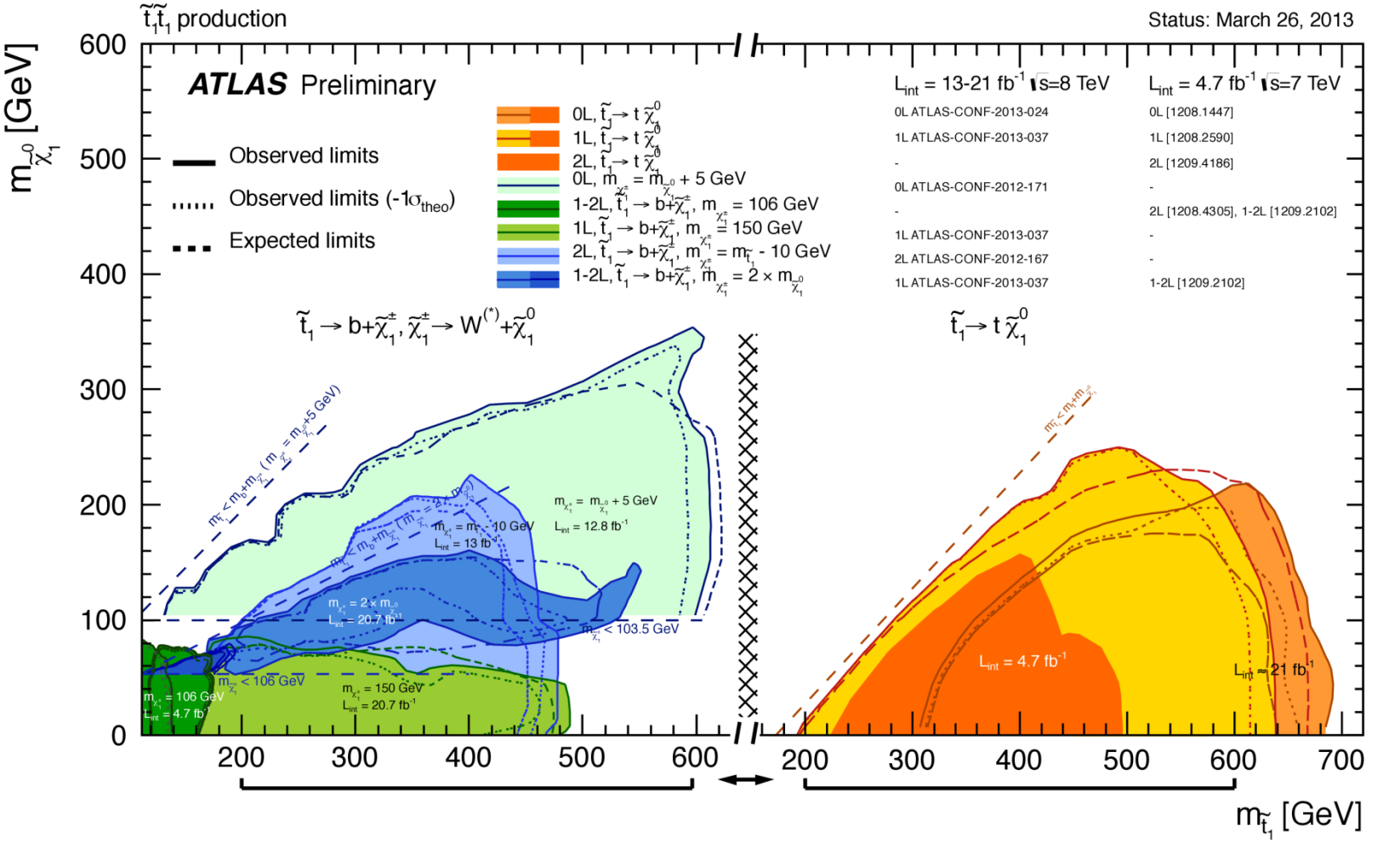
1-lepton: Loose, medium, tight signal regions using various complex observables and (mT, E_t^{miss}) cut- and count and shape fit

CMS Results (1-lepton): CMS-PAS-SUS-12-023





ATLAS Direct stop search summary



Note that these plots overlay contours belonging to different stop decay channels, different sparticle mass hierarchies, and simplified decay scenarios.

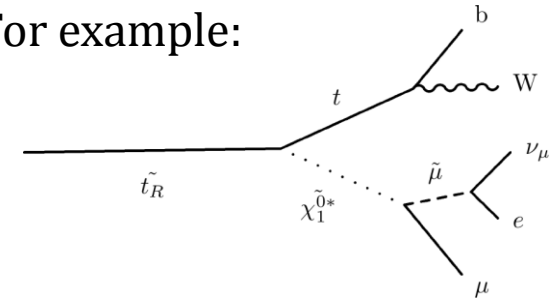
In back-up: search for t2 → t1 +Z and t1 in Gauge Mediated scenarios: ATLAS-CONF-2013-025

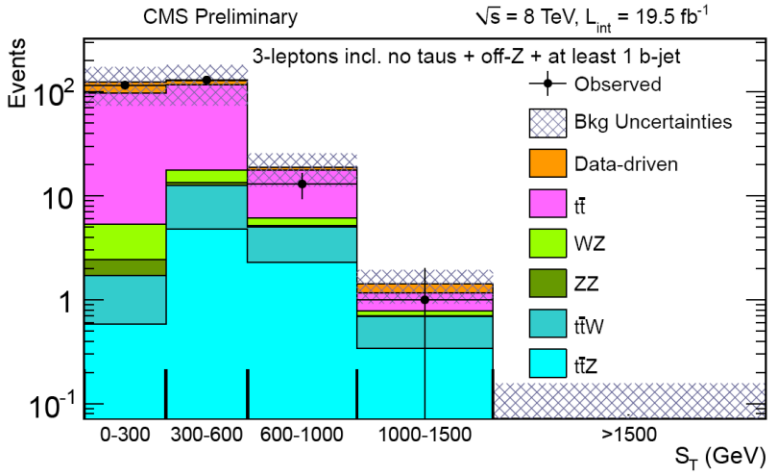
Direct stop in RPV scenarios

PAS SUS-13-003

$$\tilde{t} \to t\tilde{\chi}^0 \Rightarrow \tilde{\chi}^0 \to 2l + \nu \text{ or}$$
$$\tilde{\chi}^0 \to l/\nu + q\bar{q} \quad \textbf{RPV model}$$

For example:

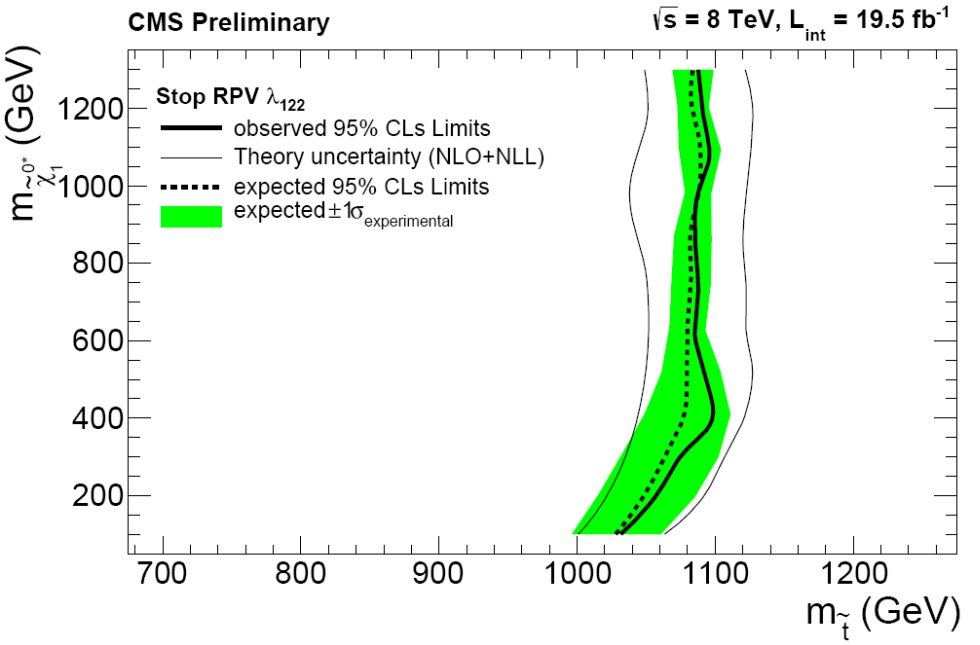




Signature:
3-leptons or more + 0 or ≥1 b-jets + E_t^{Miss}

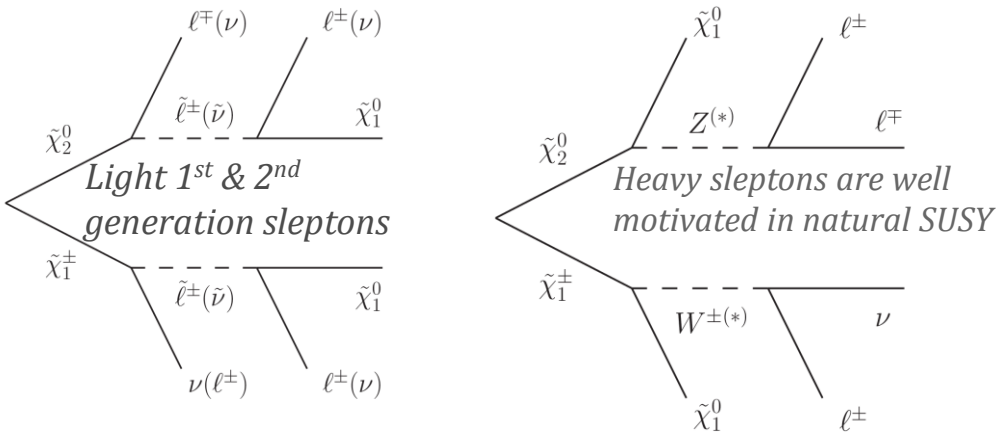
Discriminant variables:
ST (scalar sum of $E_T$miss, H_T, L_T), mll (Z-veto if OS-SF leptons)

Backgrounds
WW, WZ, tt+V, misidentified leptons

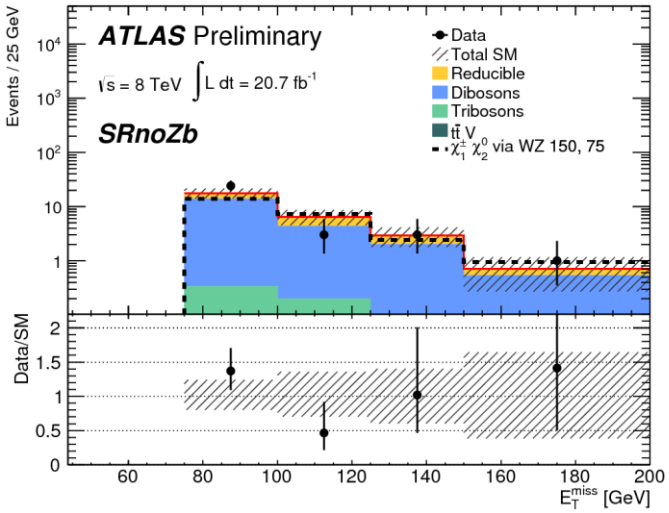


Chargino-neutralino pair production

ATLAS-CONF-2013-035



Intermediate Z-depleted signal region



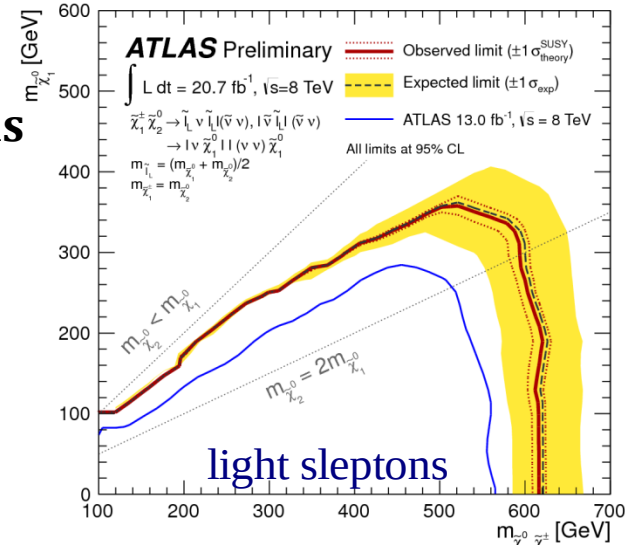
Signature: 3 leptons (e, μ), SFOS pair + E_T^{miss}

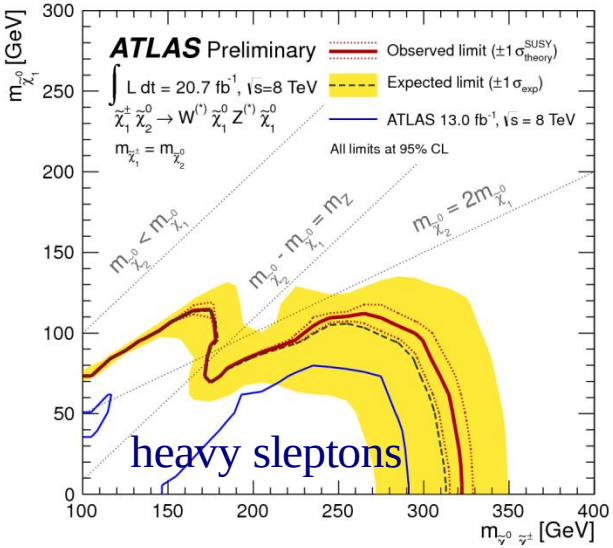
Loose, medium, tight signal regions that are Z-rich / Z depleted

Backgrounds

Irreducible
WZ, ZZ, VVV, ttbar+V

Reducible
Ttbar, Z+jets

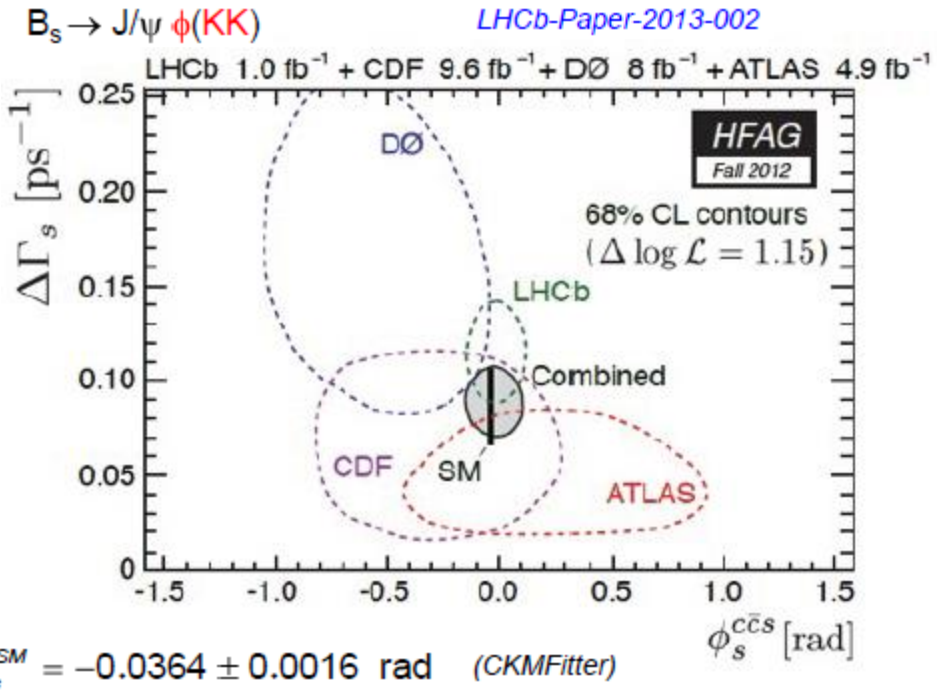


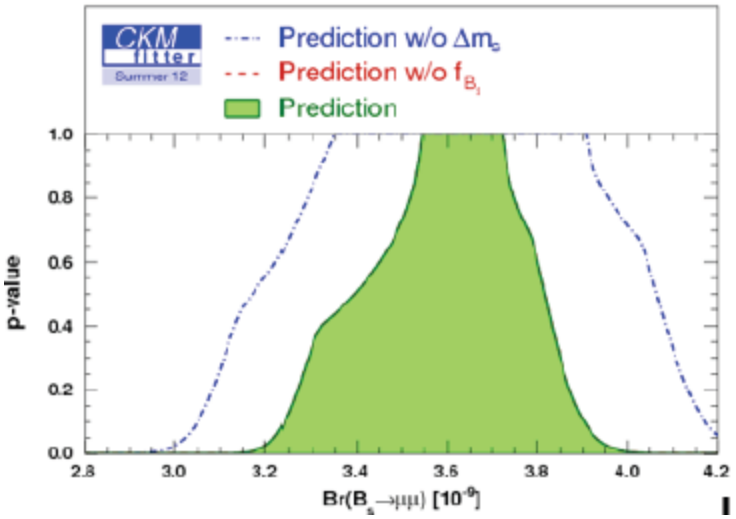


Improved limits in challenging WZ region*

CMS (9.2 fb-1, PAS-SUS-12-022) and other ATLAS results in back-up

Indirect constraints on SUSY and other BSM models

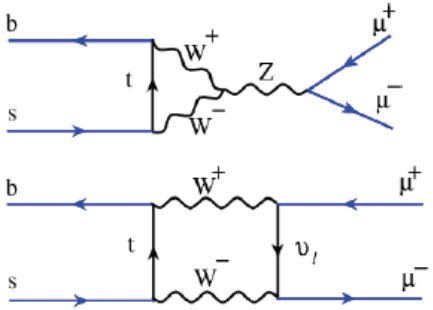


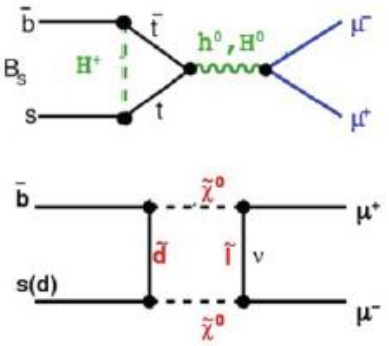


$B_s \rightarrow \mu\mu$

First evidence of the decay Bs→μμ
Phys.Rev.Lett 110, 021801 (2013)

- Constrain MSSM with large tan β
- Enhancement from many BSM models
- In SM:



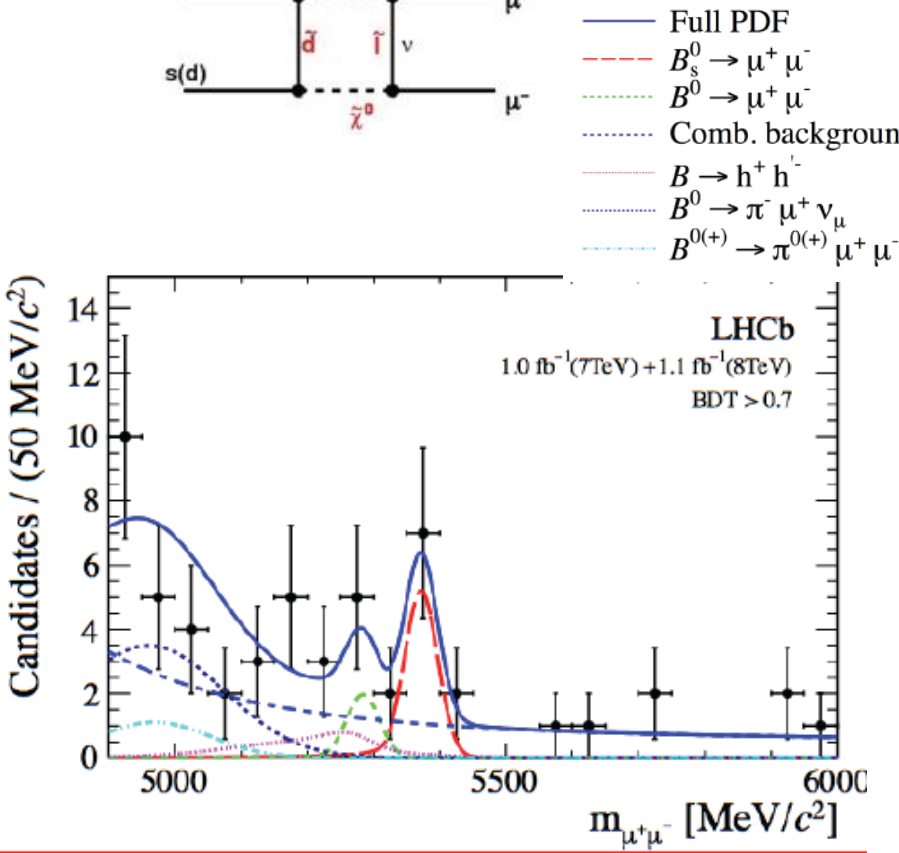


$BR(B_s \rightarrow \mu^+\mu^-) = (3.23 \pm 0.27) \times 10^{-9}$

Maximize sensitivity by classifying events according to two variables:

- $m_{\mu\mu}$
- Boosted Decision Tree (BDT) combining geometrical and kinematic information

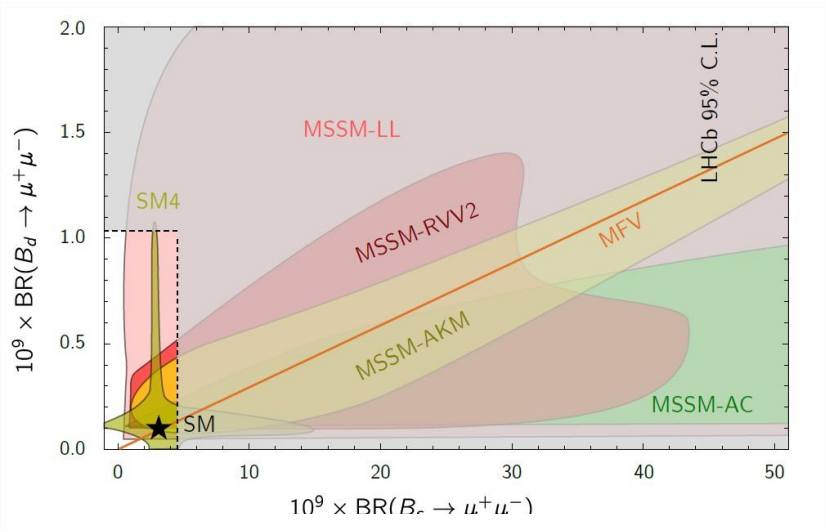
Data driven calibration of BDT for signal from Bd,s→h+h'-events

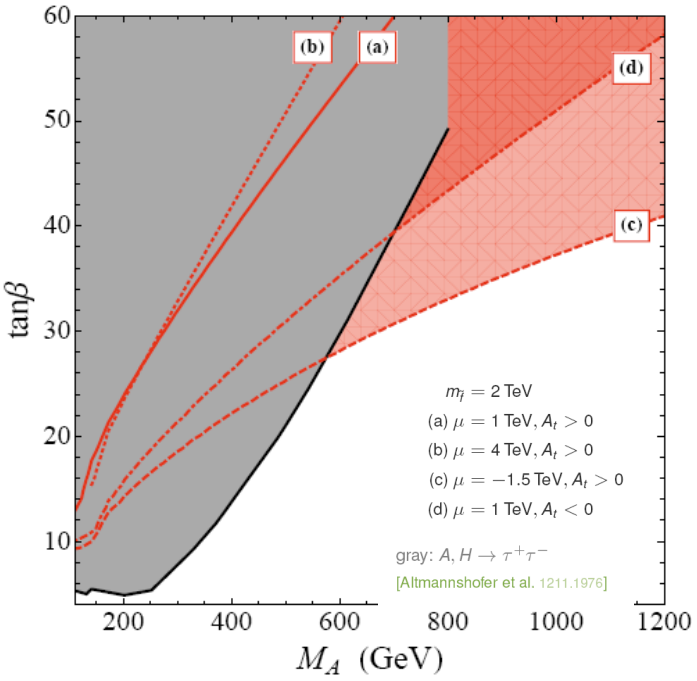


$BR(B_s^0 \rightarrow \mu^+\mu^-) = (3.2^{+1.5}_{-1.2}(\text{stat.}) \pm 0.2(\text{syst.})) \times 10^{-9}$

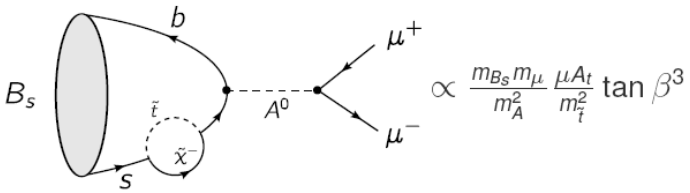
Probability of background-only fluctuations: $5\times10^{-4} \Leftrightarrow 3.5\ \sigma$ **(first evidence!)**

LHCb $B_s \rightarrow \mu\mu$ and SUSY





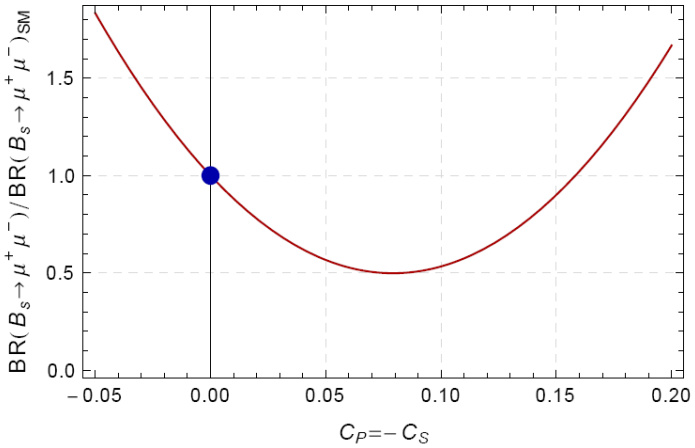
What can this tell us about SUSY?



Large tan β with light pseudoscalar Higgs disfavoured

'Natural' (small fine tuning) MSSM scenarios barely affected

- SUSY-BR(Bs→μμ) is ~ to SM-BR
- in some scenarios can even be suppressed!

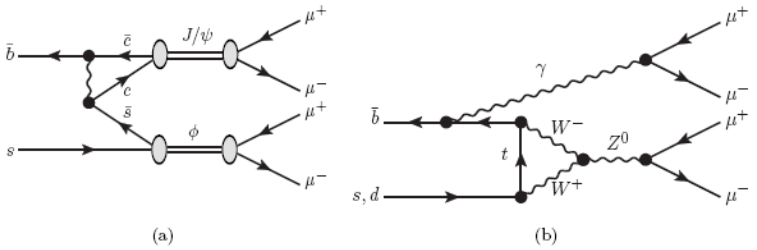


(Straub, Moriond QCD)

Direct searches for BMS @ LHCb

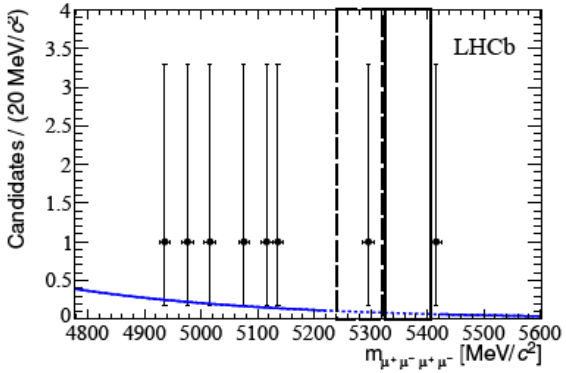
- **Search for $B_s \rightarrow \mu\mu\ \mu\mu$:** Strongly suppressed in SM, BR can be enhanced in SUSY models (direct production of new scalar S, and pseudoscalar P, both decaying in μμ) LHCB-PAPER-2012-049

SM-like



SUSY-like

Non-resonant candidates



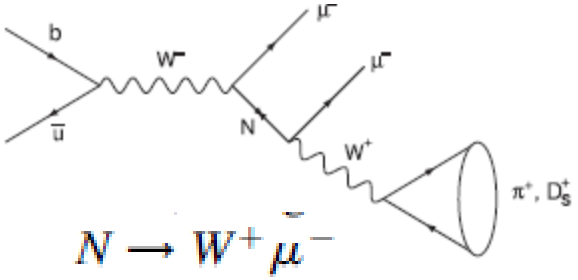
Limits (SM BR < 10^{-10})

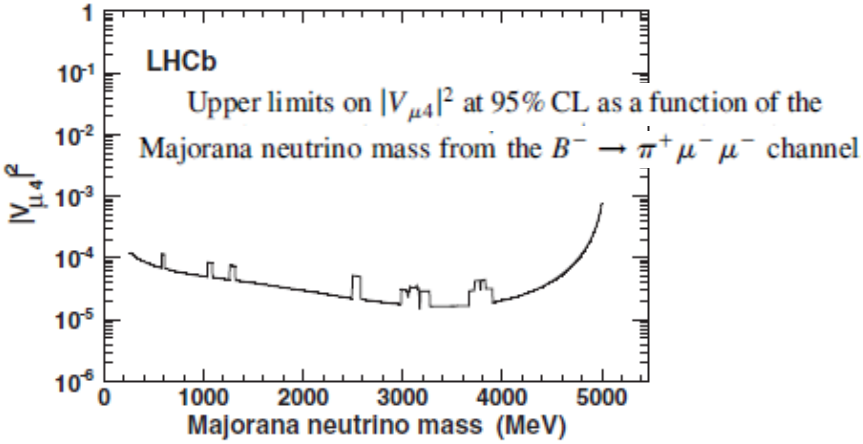
$$\mathcal{B}(B_s^0 \to SP) < 1.6\ (1.2) \times 10^{-8}$$

$$\mathcal{B}(B^0 \to SP) < 6.3\ (5.1) \times 10^{-9}$$

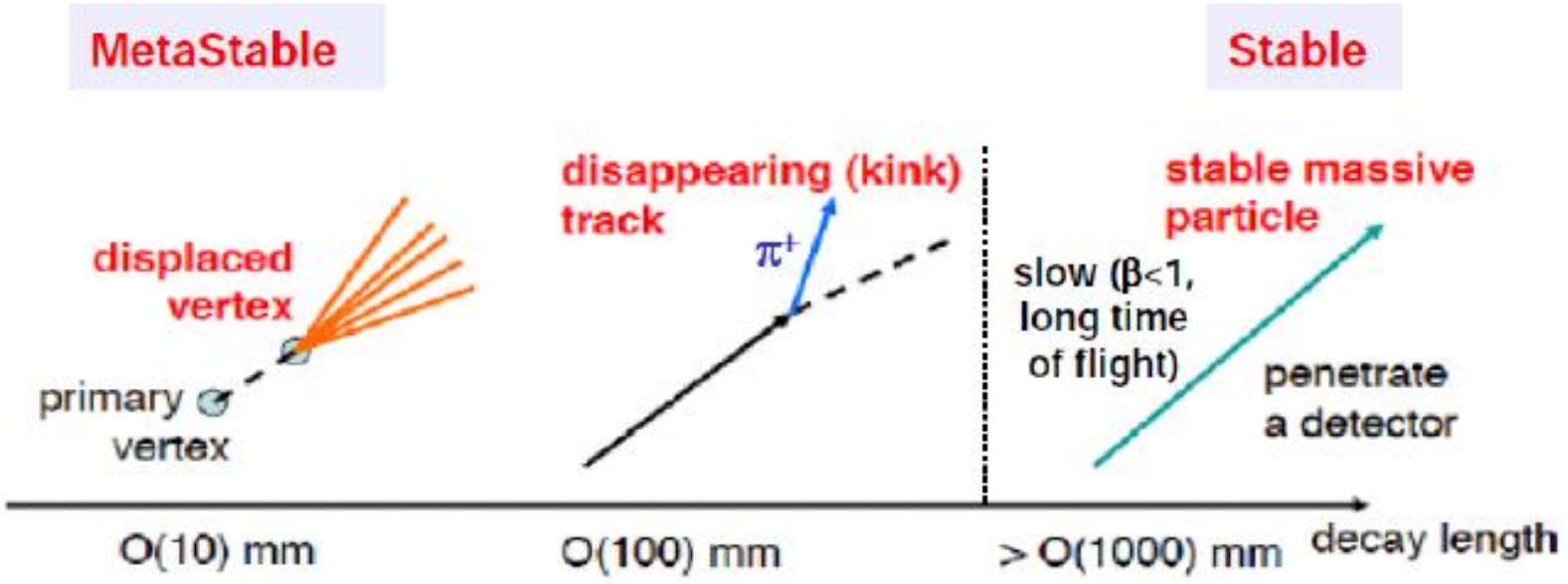
- **Search for Majorana neutrinos (N)**

Phys. Rev. D 85 (2012) 112004



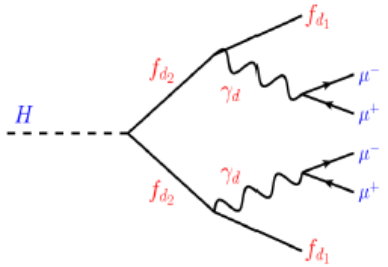


Long-lived particles



Long-Lived particles

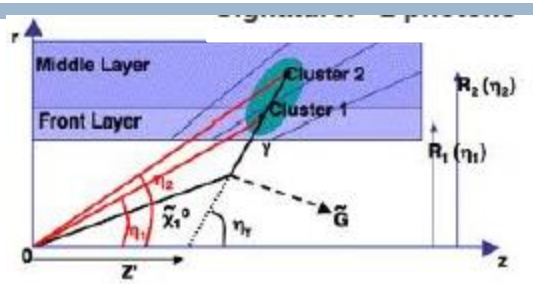
- Several new physics models could give raise to new, massive particles with long-lifetime.
  - If ΔM(chargino-neutralino) ≈ 100 MeV (eg. in **AMSB**):
    - Long-lived charginos → disappearing tracks (ATLAS: JHEP01(2013)131)
  - If very heavy squarks mediate gluinos decay (strong virtuality):
    - Long-lived gluinos → R-hadrons (eg. **Split SUSY**)
  - In **Gauge Mediated SUSY Breaking (GMSB)** couplings might be weak → long-lived sleptons or photons depending on NLSP (gravitino LSP)
  - In **R-Parity Violating SUSY**, LSP might decay:
    - Displaced vertex (ATLAS: PLB 719 (2013) 280)
  - **Hidden sectors** (ATLAS: arXiv:1210.0435, CMS: arXiv:1211.2472):
    - Higgs decay to hidden sector neutral particles:
      - displaced vertex
    - Higgs decay to hidden sector fermions:
      - Collimated pairs of leptons (lepton-jets)



Non pointing photons

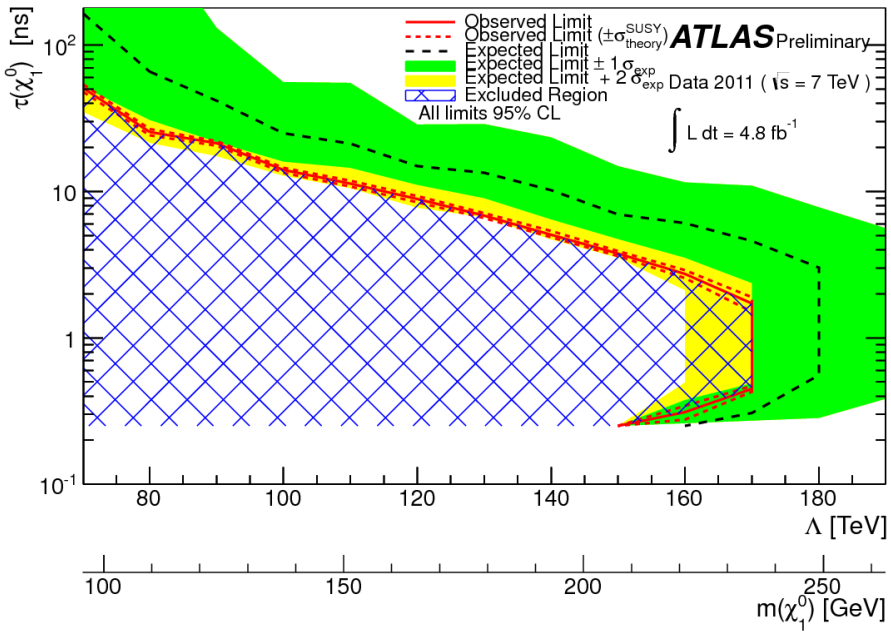
- In GMSB, the gravitino is the LSP
- Phenomenology driven by nature of NLSP:
  - If $\chi_1^0 \rightarrow \gamma + G$, neutralino can be long-lived
  - Signature: 2 photons + high ETMiss
- Use γ flight direction and time of flight (TOF) from Calorimeter

Photons do not point back to the primary vertex

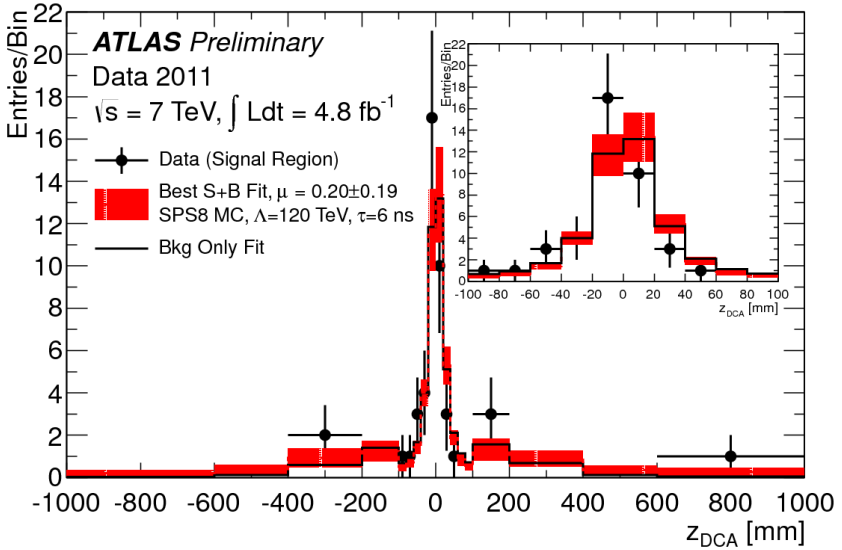


zDCA: difference between the z-coordinate of the γ extrapolated back to its distance-of-closest-approach (DCA) to the beamline (ie. x = y = 0) and zPV, the z-coordinate of the PV

ATLAS-CONF-2013-1226



ATLAS: for Λ=120 TeV, $\tau < 8.7$ ns are excluded at 95% CLs, the expected limit would exclude $\tau < 14.6$ ns.



PAS EXO-11-035

CMS: $m(\chi^0_1) > 220$ GeV (for $c\tau < 500$ mm), on the proper decay length of the lightest neutralino, $c\tau > 6000$ mm (for $m(\chi^0_1) < 150$ GeV) excuded at the 95% CL

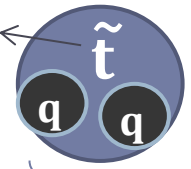
Search for Stable Massive Particles

- Also referred to as Heavy stable charged particles (HSCPs)
- Within SUSY: **R-hadrons** →
  - Stable → cτ ≥ size of detector
  - Produced with β<1

EXO-12-026

Colored sparticles can hadronise into long-lived bound hadronic states

Heavy parton carrying most of the momentum



Light quark system (LQS)

Tracker only

- Sensitive to any promptly produced HSCP
- Uses dE/dx in tracker to separate signal from background

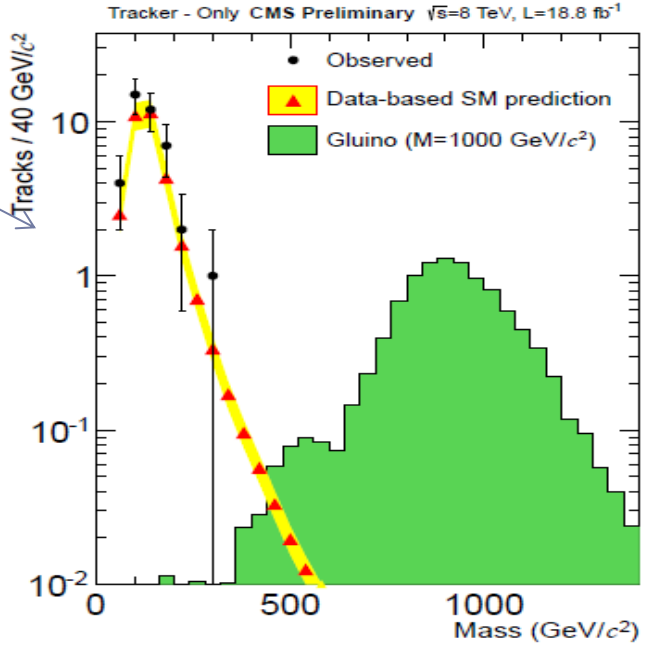
Muon Only

- Sensitive to any HSCP crossing muon detector
- Uses TOF to separate signal from BKG

$$\beta^{-1} = 1 + (c\,\delta_t)/L$$

Tracker+TOF

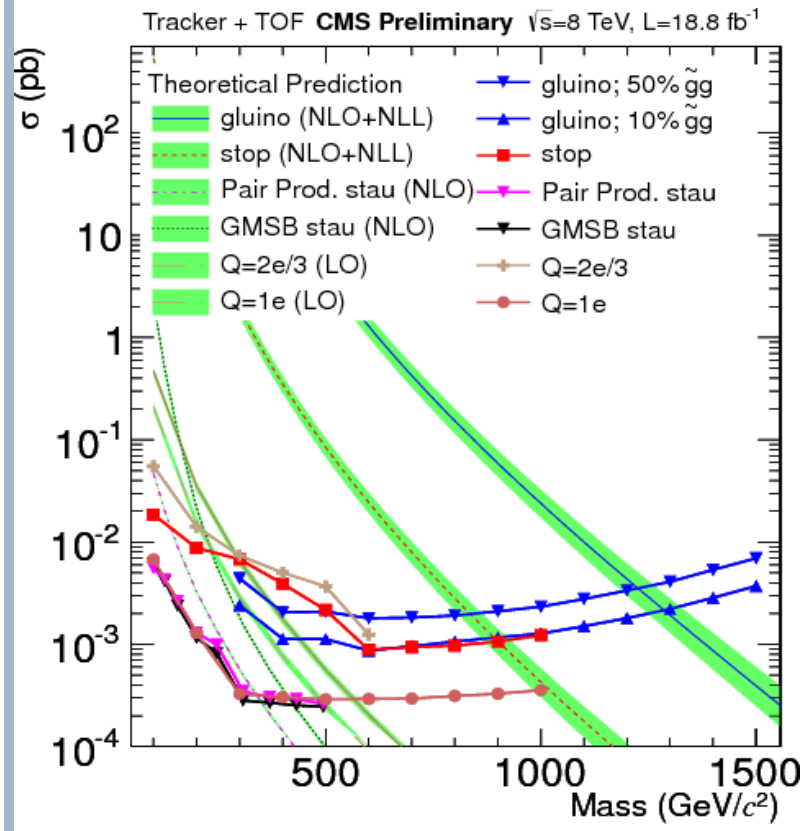
- uses both



@ATLAS: R hadrons and stable sleptons http://arxiv.org/abs/1211.1597 *(7 TeV)*

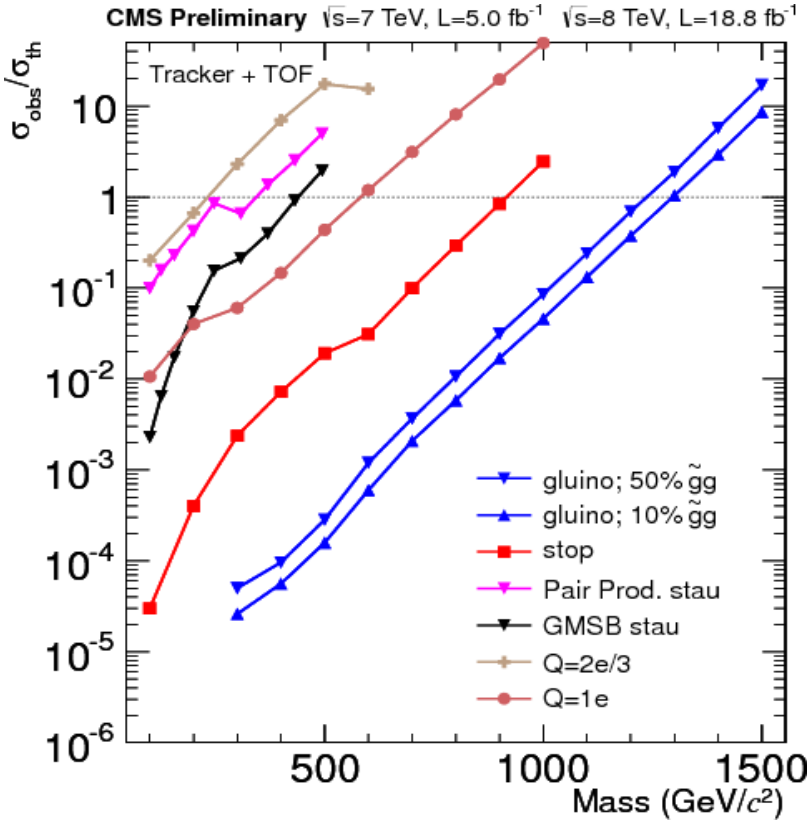
SMP: CMS Results

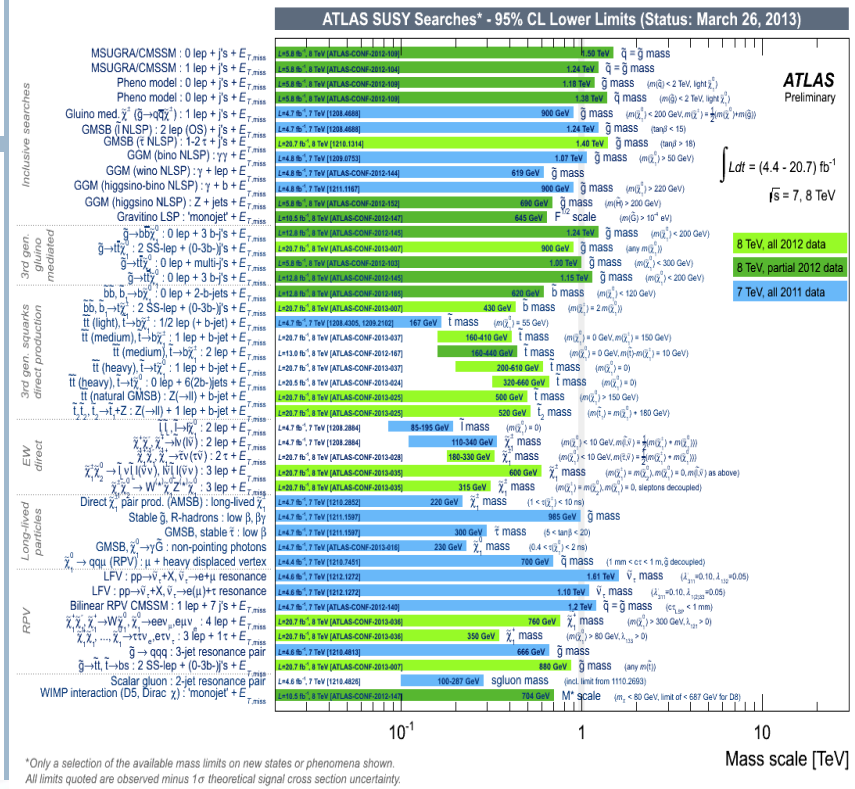
- Consider (and combine) 7 and 8 TeV results

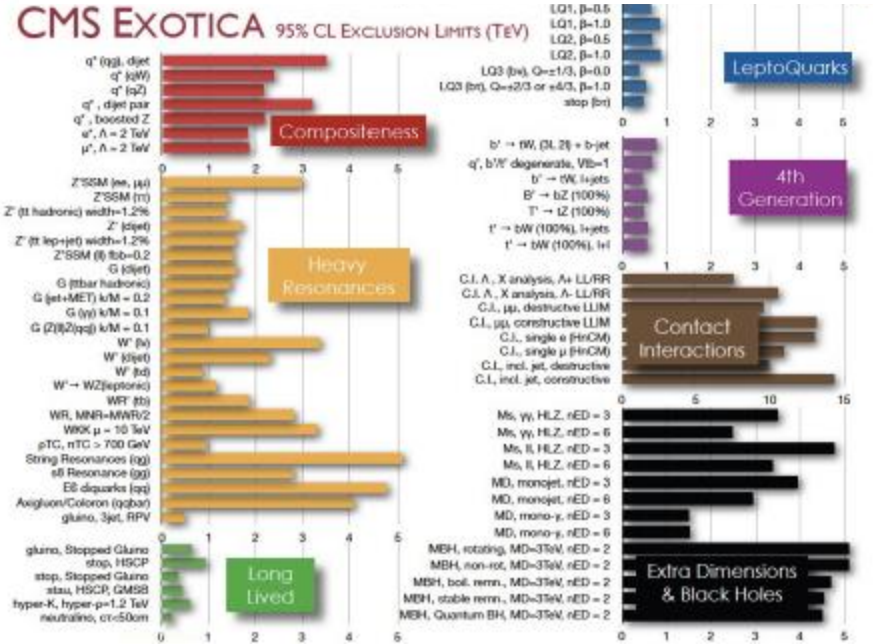


Cross section upper limits at 95% C.L. on various signal models for the **tracker+TOF** analysis (at **8TeV**)

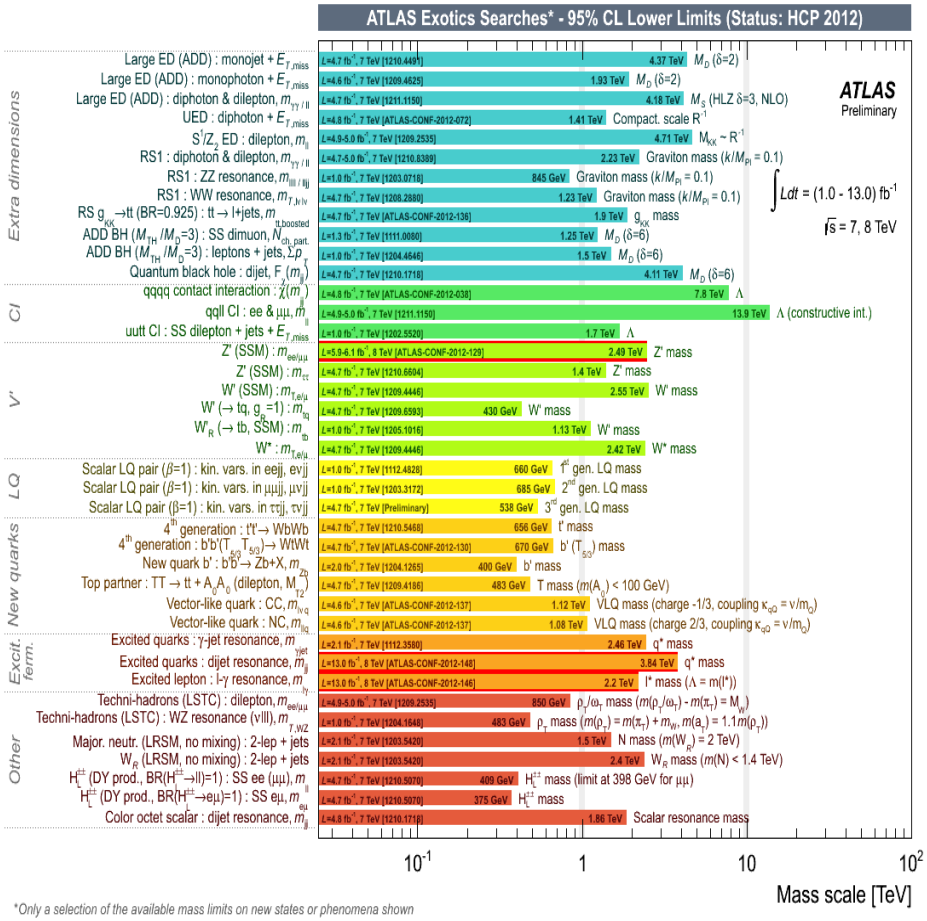
Ratio of the Cross-section upper limits at 95% C.L. to theoretical cross-section prediction for various signal models: **tracker+TOF** analysis for 2011 data (at 7TeV) and 2012 data (at 8TeV) **combined**







Each bar is one or more searches



Summary and conclusions

- Impressive program of searches!
  - several beyond SM models explored at the LHC as well as signature based searches carried out
    - Looking for the unknown, pretty much everywhere!
  - Strenuous work of analyses teams in all experiments to analyze all data in very short time (< 3 months from end of pp Run I)
    - UK contributions across many areas of research
- Much more expected in the next few months and years, with the Run II at LHC
- To know more:

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G
http://lhcb.web.cern.ch/lhcb/lhcb_page/physics_results/recent_lhcb_results/Default.html

Back up

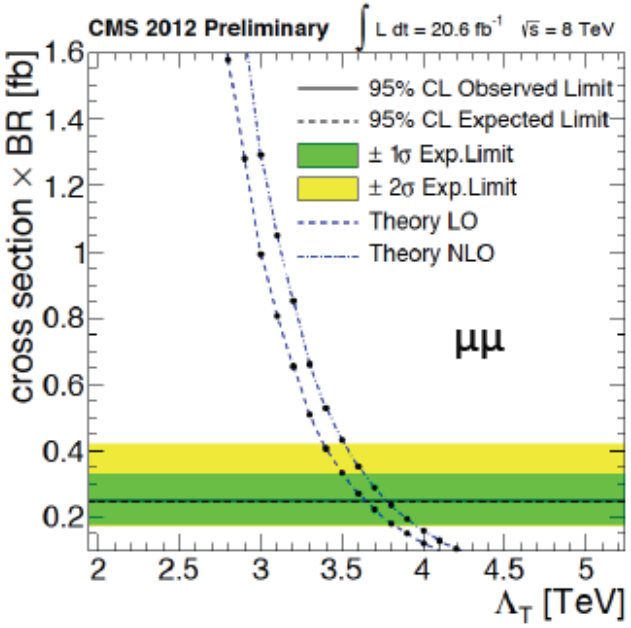
Di-lepton: non resonant searches

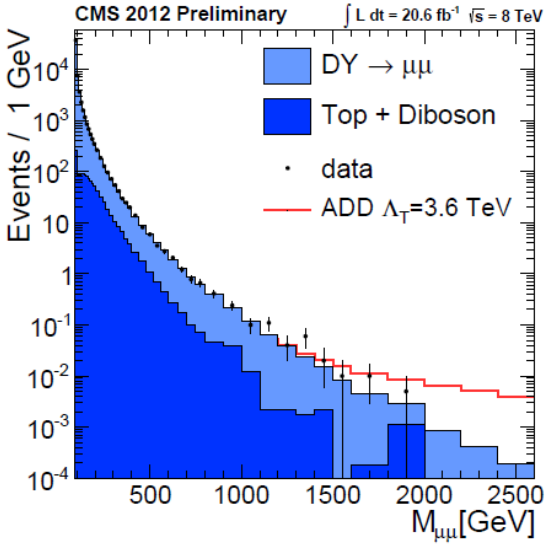
Dedicated searches for non-resonant signals in dielectron and **dimuon** final states

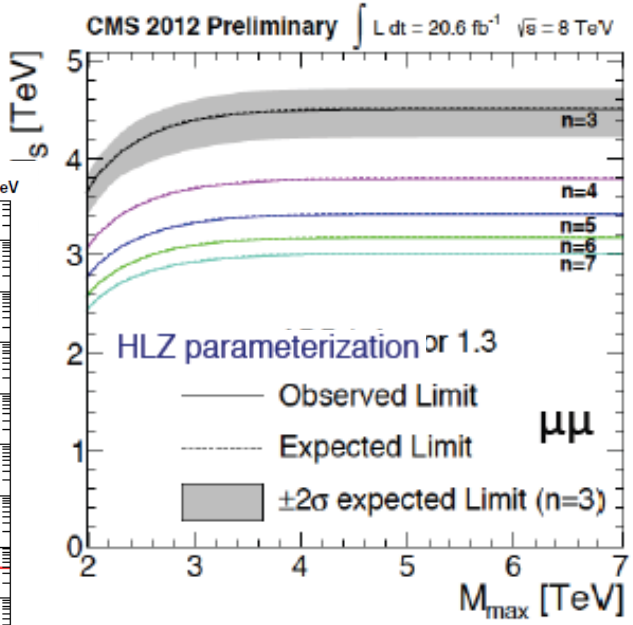
CMS-PAS-EXO-12-027
CMS-PAS-EXO-12-031

- Enrichment due to virtual Graviton (ADD model)
- Two possible parameterizations of LO x-section:
  - **GRW:** single parameter Λ_T
  - **HLZ:** n and $Ms(\Lambda) \simeq M\mathrm{Pl}(4+n)$, n=N extra dimensions

GRW parameterization

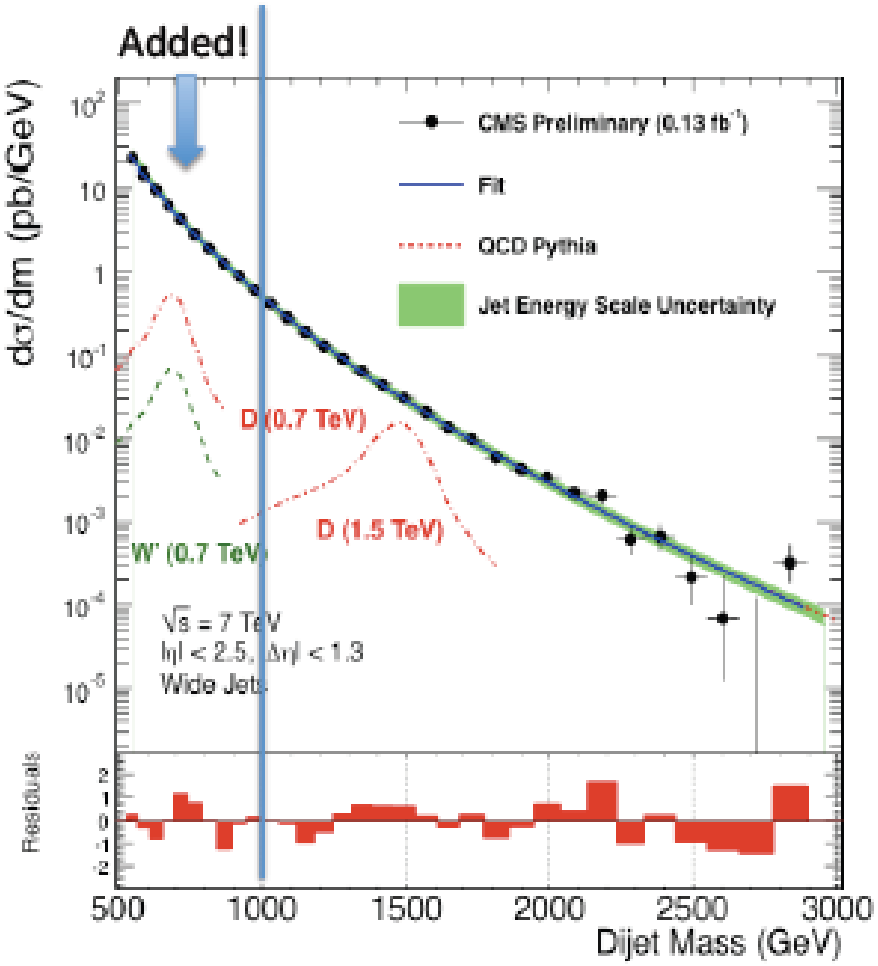






Channel	M_s [TeV] n=2	n=3	n=4	n=5	n=6	n=7
μμ	3.69	4.49	3.77	3.41	3.17	3.00
ee	3.99	4.77	4.01	3.63	3.37	3.19
combined	4.35	4.94	4.15	3.75	3.49	3.30

Dijet Resonance Search below 1 TeV



Data Scouting: ~1kHz

- Novel trigger and data acquisition strategy applied to physics analysis
- Trigger: $H_T > 250$ GeV
  - Reduced event content:
    - HLT calorimeter jets only
    - no raw data
    - no offline reconstruction
  - Bandwidth (rate x size) under control

Data Parking: 300-600 Hz

- looser and new triggers
  - increased range for many analyses
- For the shutdown

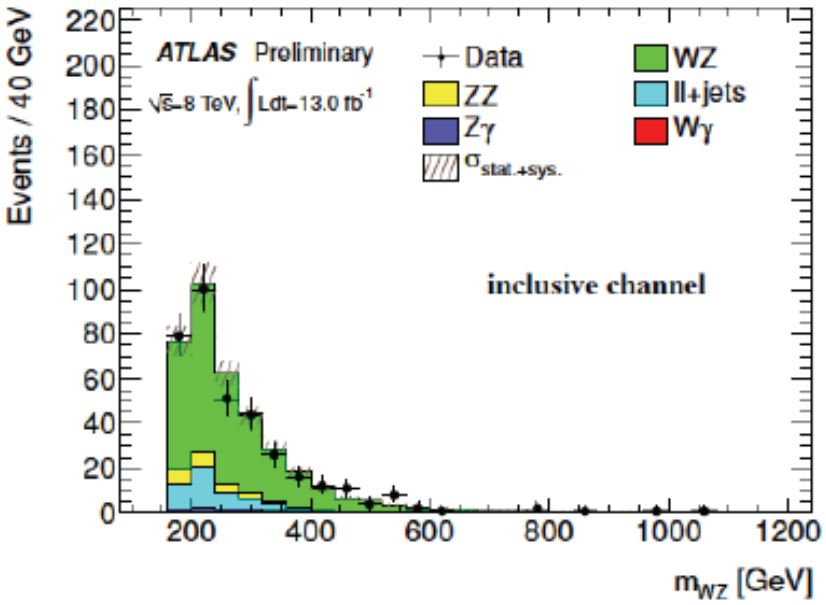
Resonant WZ production

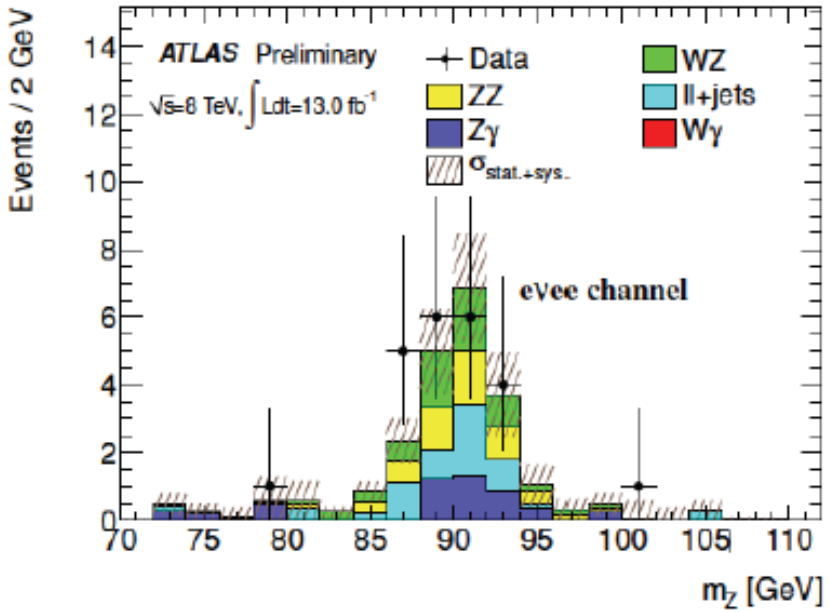
- WZ→ lllν: trilepton + Missing Transverse Momentum (E_T^{Miss})
  - Resonant diboson production (ZZ,WZ,Zγ,Wγ) taken from MC simulation
  - Reducible background from misidentified leptons (Z+jets, ttbar, Wt) estimated from data
  - Two control regions used to check predictions:
    - **WZ and Z+jets regions**

$E_T^{miss} < 25$ GeV, $m_T^W < 25$ GeV

m_T= *Transverse Mass*

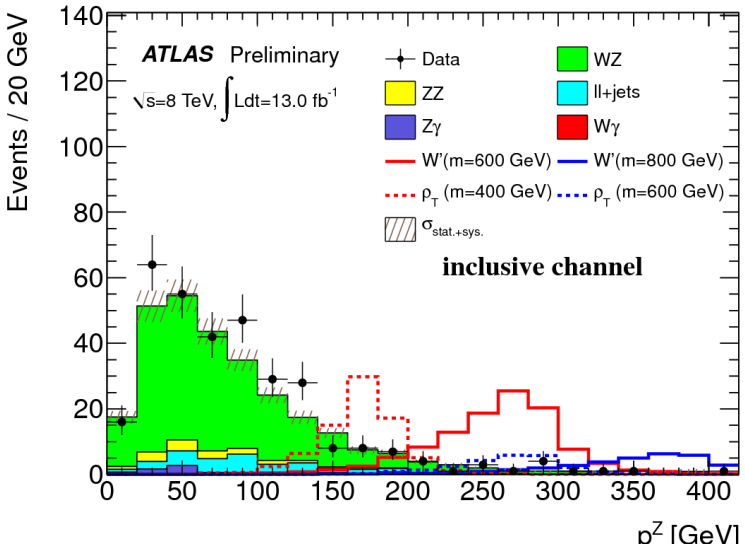
$\Delta y(W,Z) > 1.8$ and $\Delta\phi(W,Z) < 2.6$

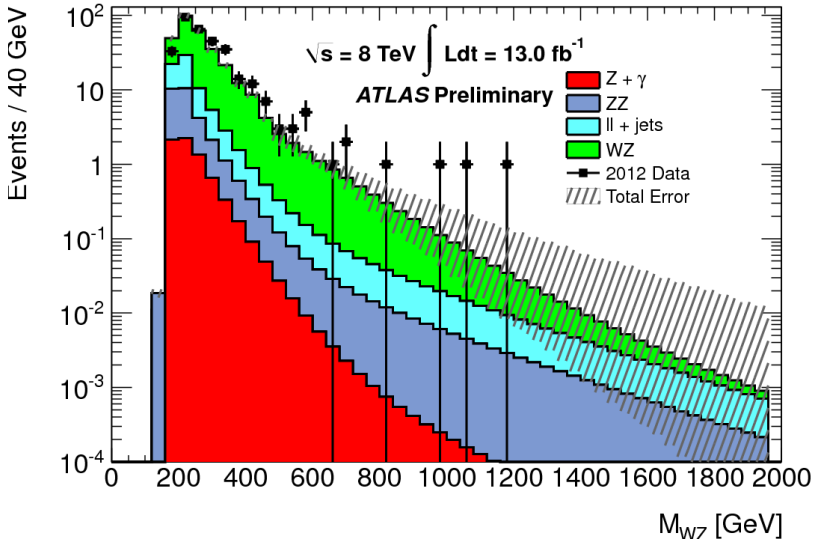




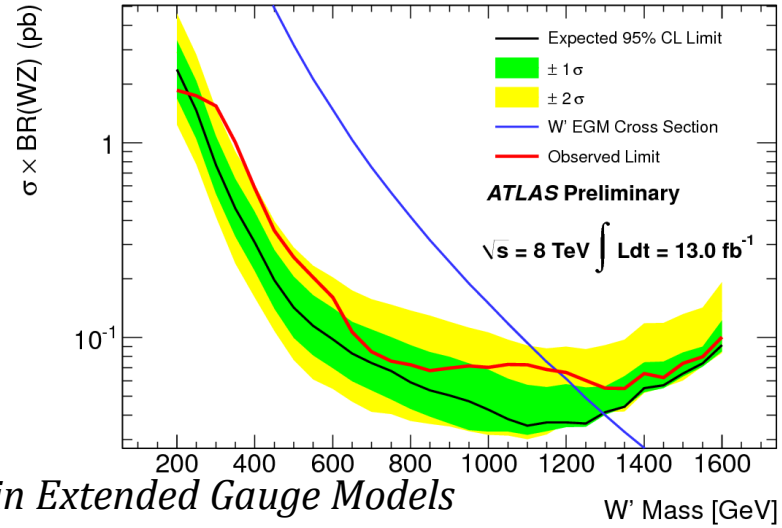
Resonant WZ production: results

- No excess observed:

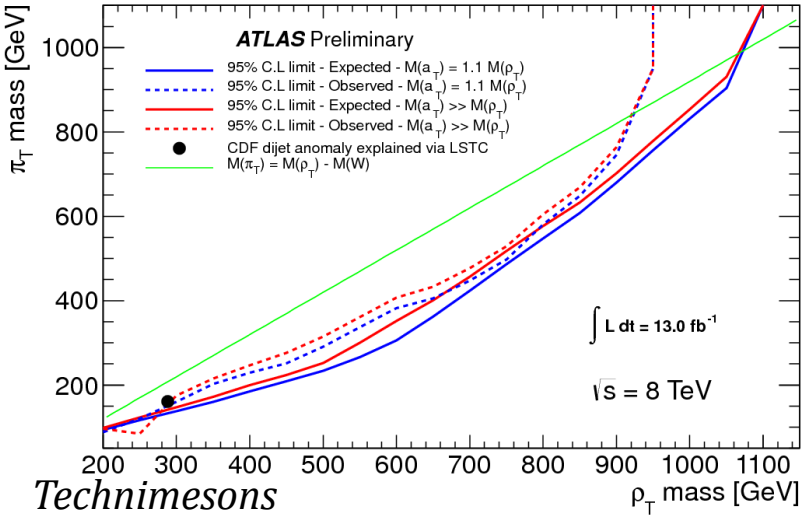




Exclusion limits



W' in Extended Gauge Models

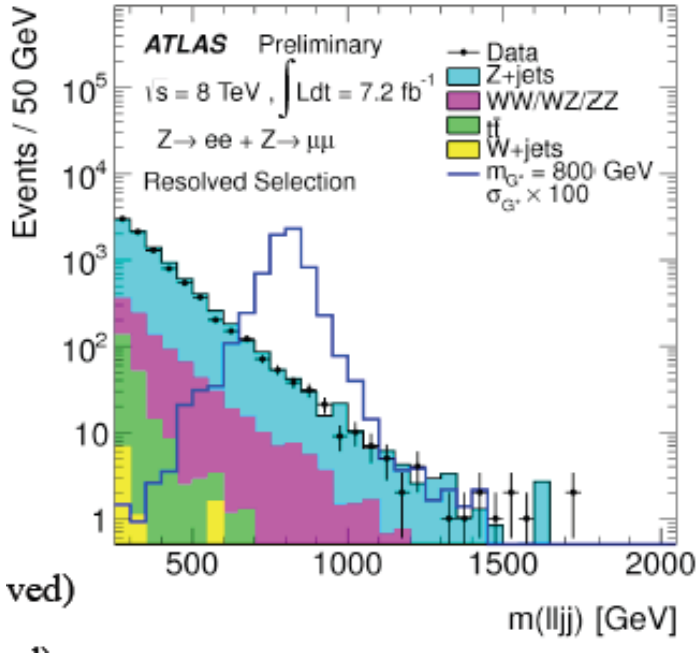


Technimesons

Resonant ZZ production

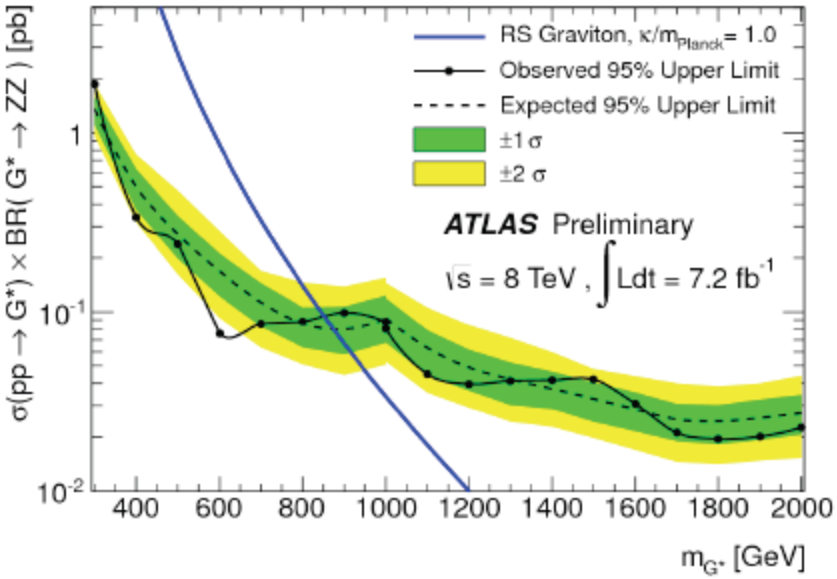
ATLAS-CONF-2012-150

- Search for resonant ZZ→ llqq (l=e, μ)



Two signal regions to treat jet-jet overlap

- *Resolved*: $p_T(ll)$>50GeV
  - Two leading jets: $\Delta\phi_{jj}$<1.6, 65 < m_{jj} < 115 GeV
- *Merged*: $p_T(ll)$ > 200GeV
  - Leading jet: $p_T(j)$>200GeV, m_j > 40 GeV



Use **Bump Hunter** algorithm to test for the presence of a signal.
Fit mlljj distribution with smooth background hypothesis:

$$f(m;p_{0,1,2,3}) = p_0 \frac{(1-x)^{p_1}}{x^{p_2+p_3\ln(x)}} \qquad x = \begin{cases} m_{lljj}/\sqrt{s} \text{ (resolved)} \\ m_{llj}/\sqrt{s} \text{ (merged)} \end{cases}$$

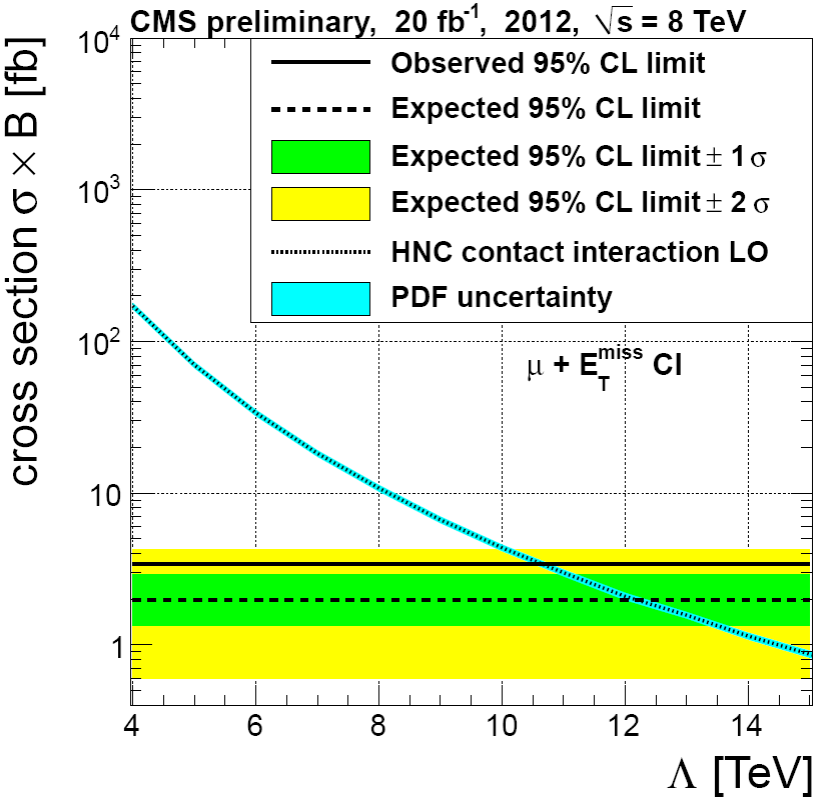
Upper limit on σ(pp->G*)× BR(G*-> ZZ)

Lower limit m_{G^*}: 850 GeV @ 95% C.L.

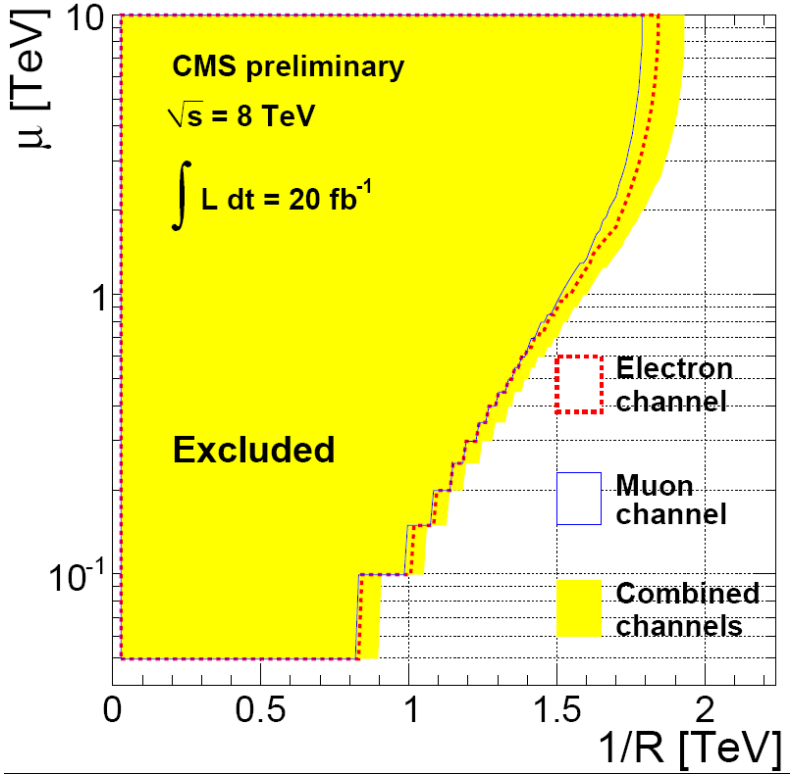
W' in lepton+E_T^{Miss}

- Search for new physics in final states with an electron or a muon and a low mass neutrino
- Additional interpretations:

Limits for contact interactions (HNC model) in the μ+MET channel.
Excludes Λ < 10.9 TeV (13 TeV in electron channel)



95% CL limits on the split-UED parameters μ and 1/R derived from the W' mass limits taking into account the corresponding width of the W^2_KK.



Search for W' in t+b final states:

left-handed and right-handed couplings dependence

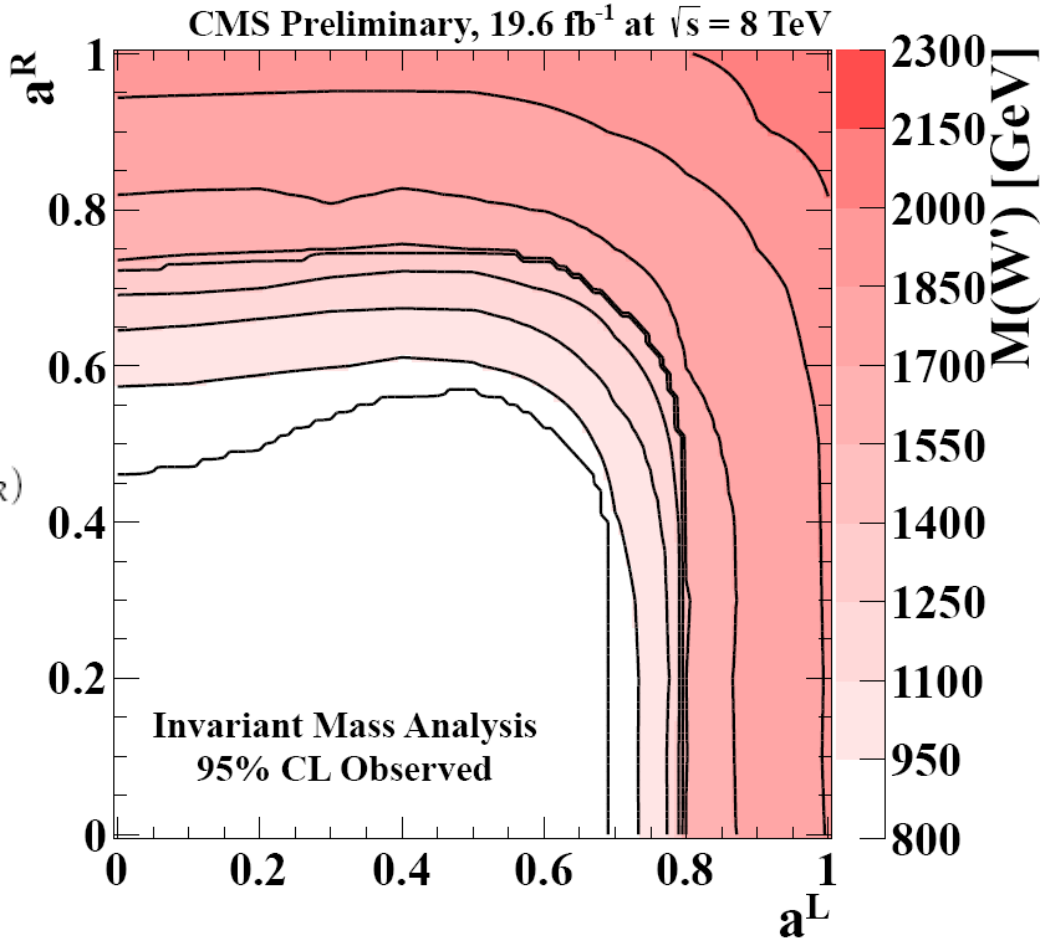
Cross section for single top production via W' boson for any set of couplings

$$(a^L, a^R)$$

$$\begin{aligned}\sigma &= \sigma_{SM} + a^L_{ud}a^L_{tb}\left(\sigma_L - \sigma_R - \sigma_{SM}\right) \\ &+ \left(\left(a^L_{ud}a^L_{tb}\right)^2 + \left(a^R_{ud}a^R_{tb}\right)^2\right)\sigma_R \\ &+ \frac{1}{2}\left(\left(a^L_{ud}a^R_{tb}\right)^2 + \left(a^R_{ud}a^L_{tb}\right)^2\right)\left(\sigma_{LR} - \sigma_L - \sigma_R\right)\end{aligned}$$

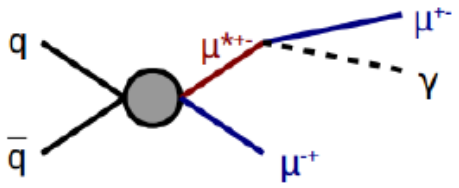
Assume equal production and decay couplings a_{ud} and a_{tb}

Contour plots of M(W') in the (aL, aR) plane(95% CL limits)

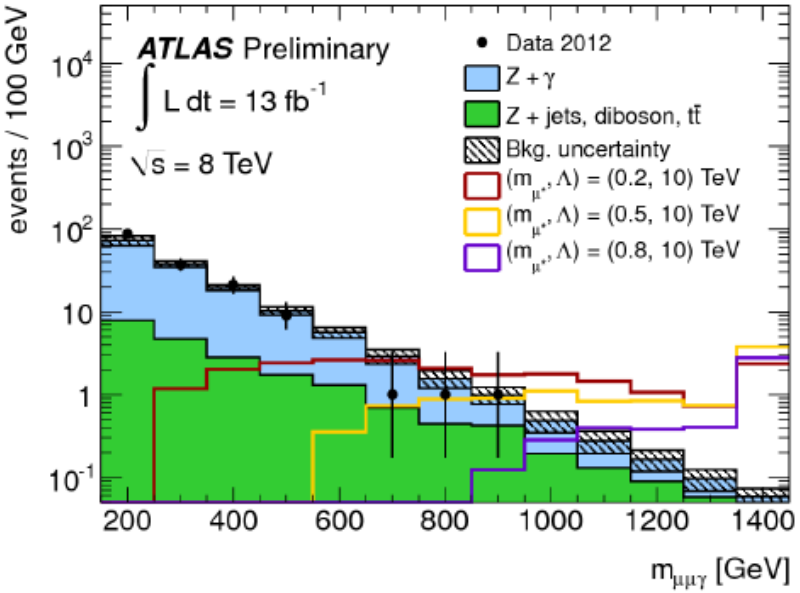


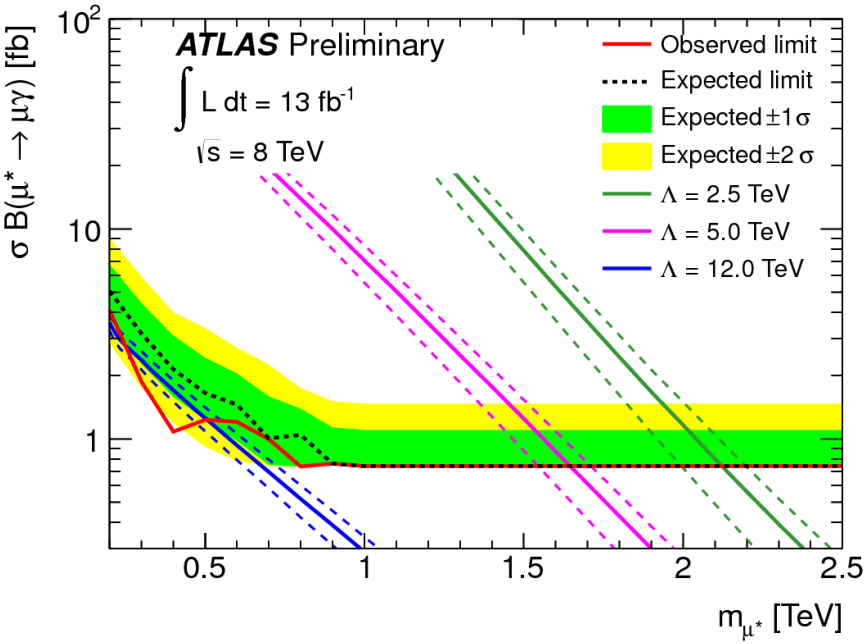
Excited leptons

- l* in llγ, selection similar to Z' analysis with an additional photon



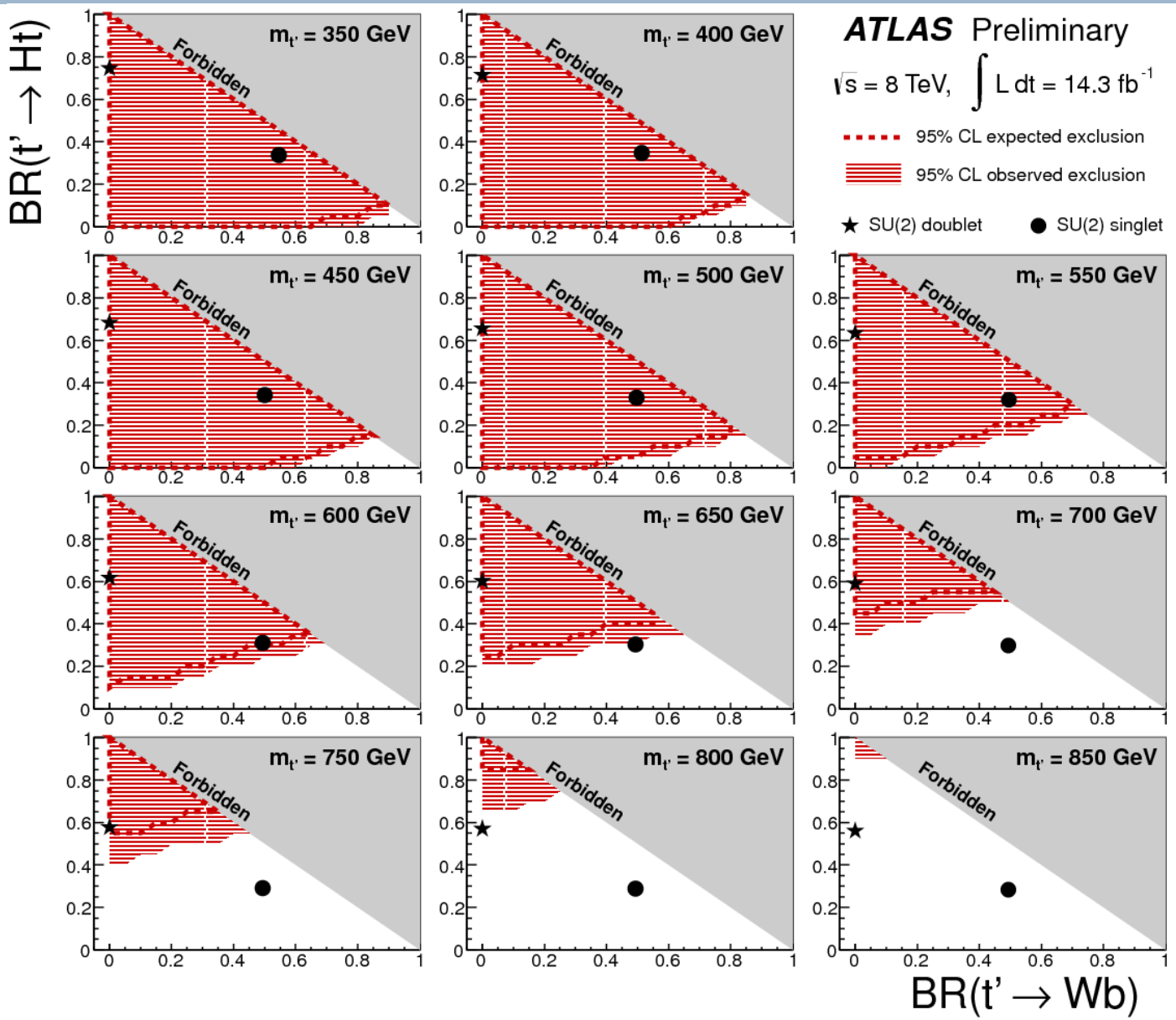
- Use total llγ mass as discriminant:
  - Electron channel plot similar





Λ = 2.5 TeV	e*	μ*
expected limit (TeV)	2.28	2.13
observed limit (TeV)	2.17	2.13

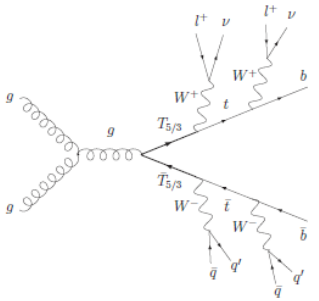
Search for vector-like T

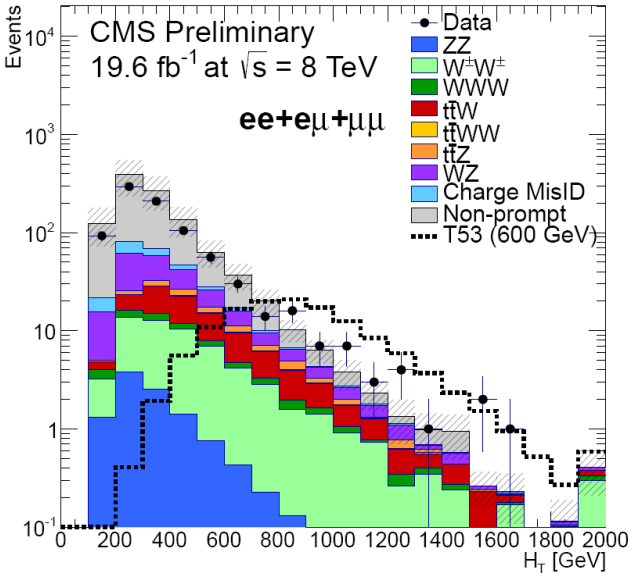


Search for top partners with charge 5e

CMS-B2G-12-012

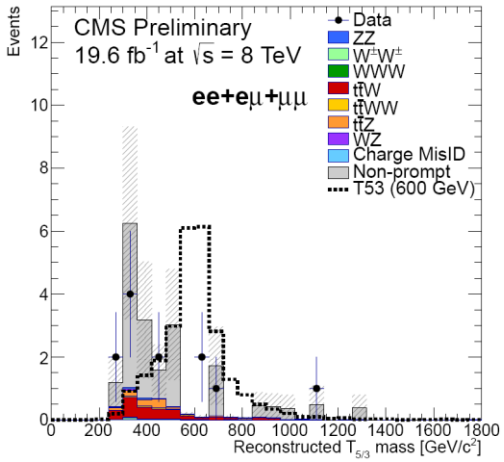
- Search for pair production of charge 5/3 *T*, $T \rightarrow Wt$ BR=100%
  - Final state signature: same-sign (SS) leptons outside Z mass window + H_T>900 GeV
  - Require ≥5 "constituents" in addition to two SS leptons
    - Constituent: lepton, jet, V-tagged jet (2-jets), or top-tagged jet (3-jets)



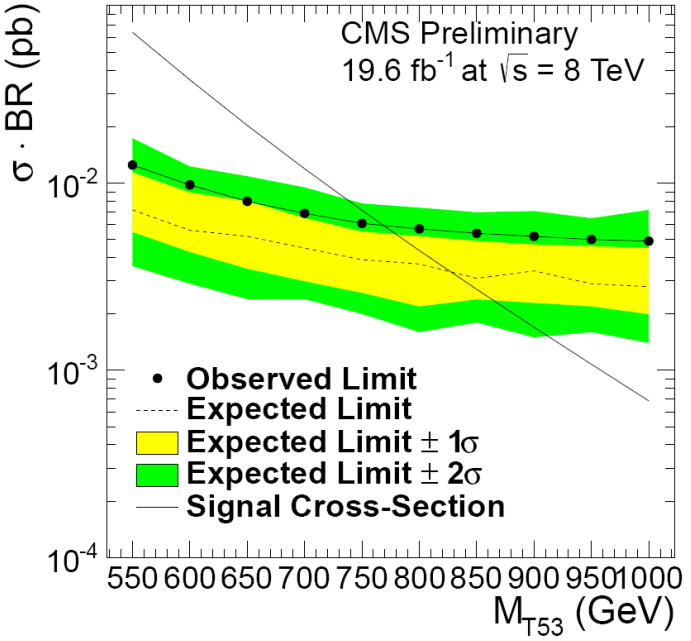


Reconstruction of the *T* 5/3 mass can be used to distinguish it from other exotic particles

- **"top-tagging"** algorithm based on identifying jet substructure (t→jjj merged in one jet)
- similarly for **V-tagged jets** = W boson decay products merged in one jet



Exclude 5/3 Top Partners with masses up to 770 GeV (830 GeV expected)



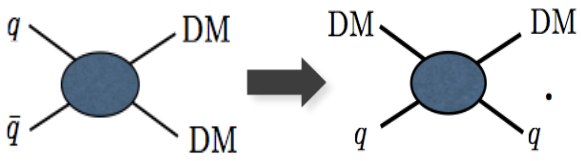
Monojets results as constraints on D

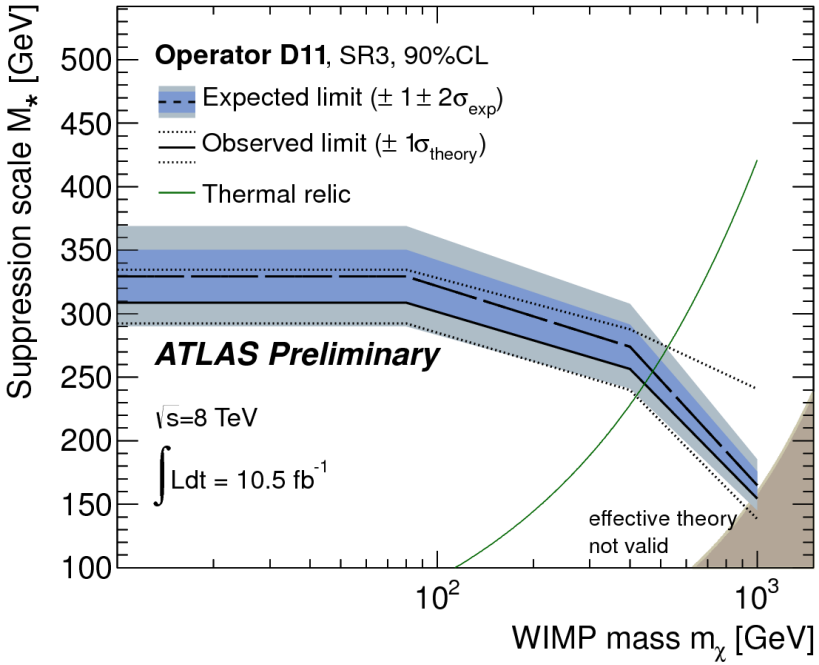
Limit on WIMP pair production cross-section can be transformed into limit on effective WIMP-hadronic contact interaction:

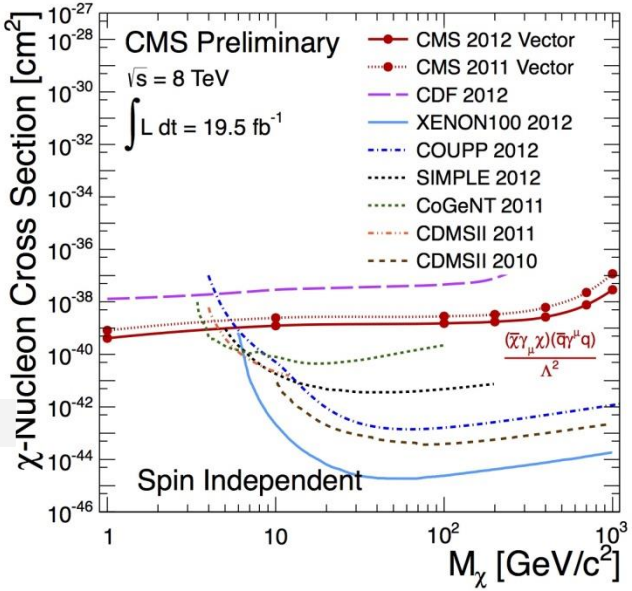
Vector (SI): $(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)\cdot\Lambda^{-2}$

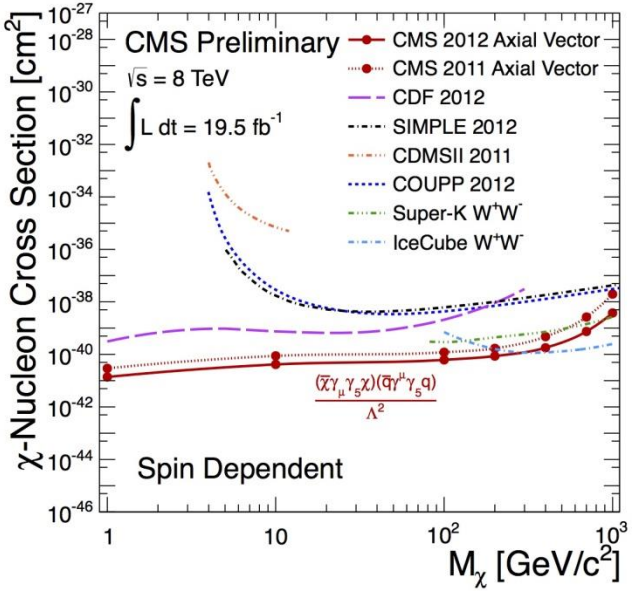
Axial-v. (SD): $(\bar{\chi}\gamma_\mu\gamma^5\chi)(\bar{q}\gamma^\mu\gamma^5 q)\cdot\Lambda^{-2}$

WIMP-nucleon scattering xsect $\sigma \propto \frac{1}{\Lambda^4}$





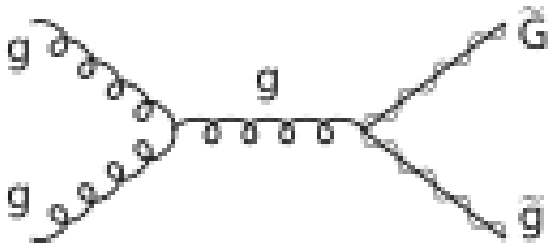




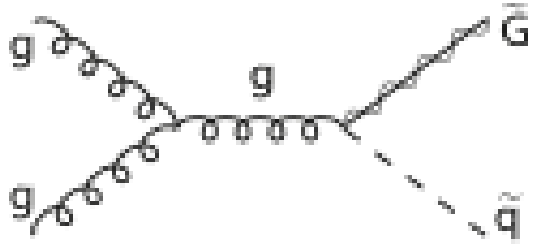
SUSY interpretation for Monojet results

- Search for gravitino production in association with squarks or gluinos
- Same signature as WIMP production, but not ISR search (similar to ADD)

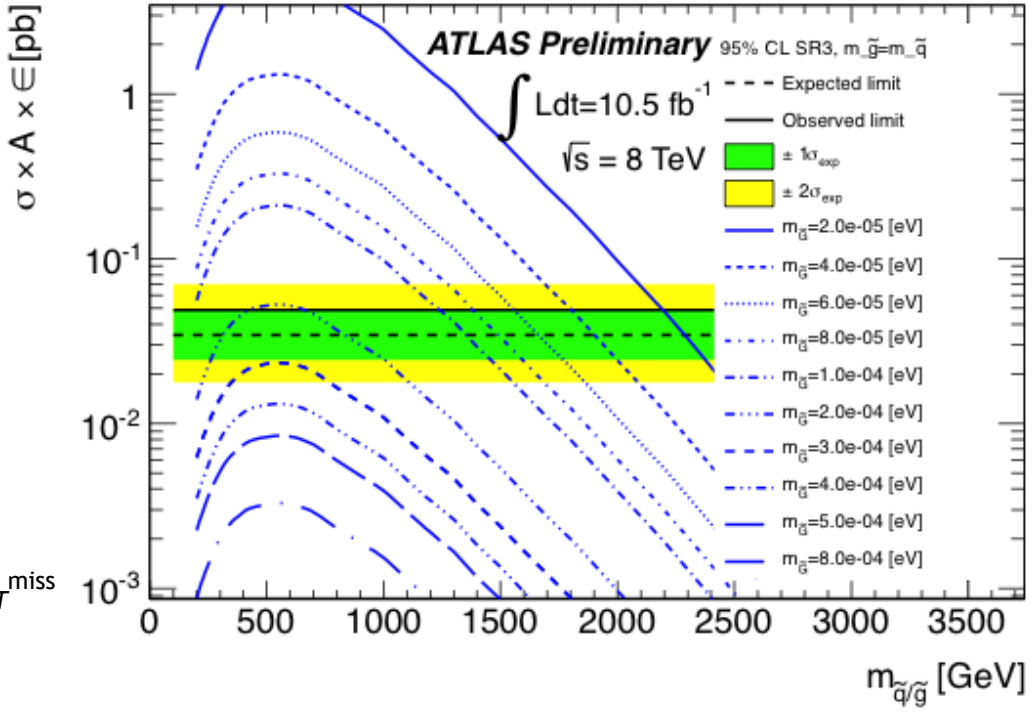
In GM SUSY, gravitino LSP with mass related to SUSY breaking scale
At LHC with low-scale SUSY breaking, direct $\tilde{G}+q$ or $\tilde{G}+\tilde{g}$ production can dominate. Cross-section ~ $1/m^2(\tilde{G})$



→ jet + E_T^{miss}



→ jet + E_T^{miss}

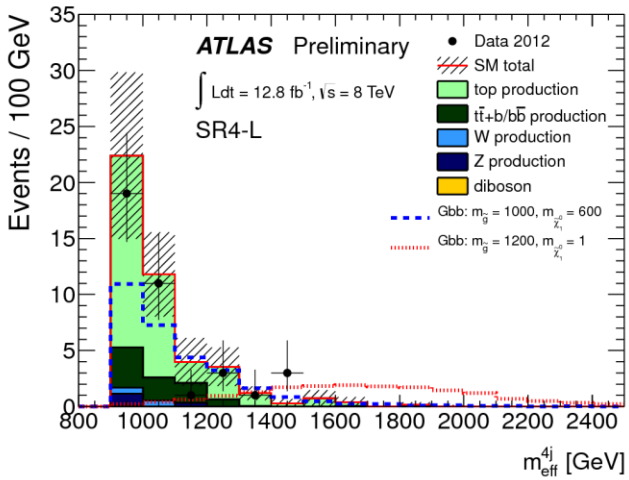


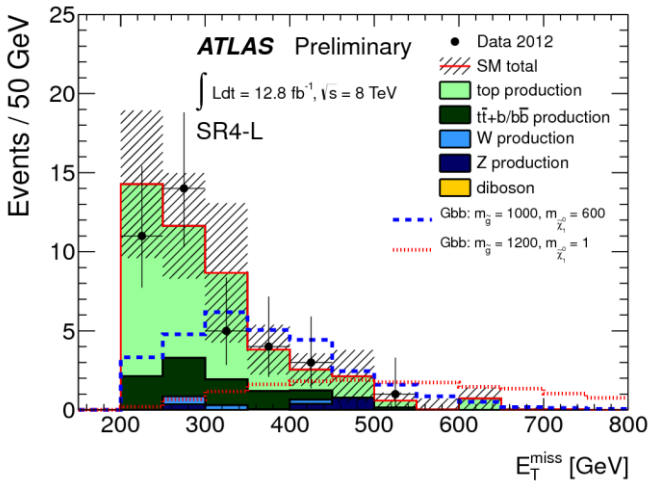
Lower limits on gravitino mass as function of squark/gluino masses

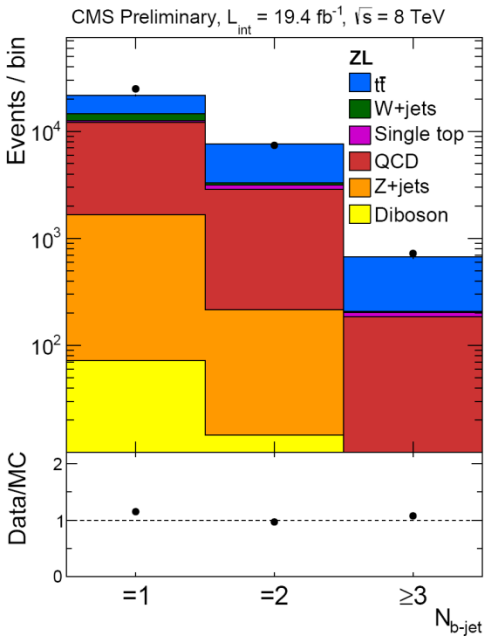
Improves existing limits by *O*(magnitude)

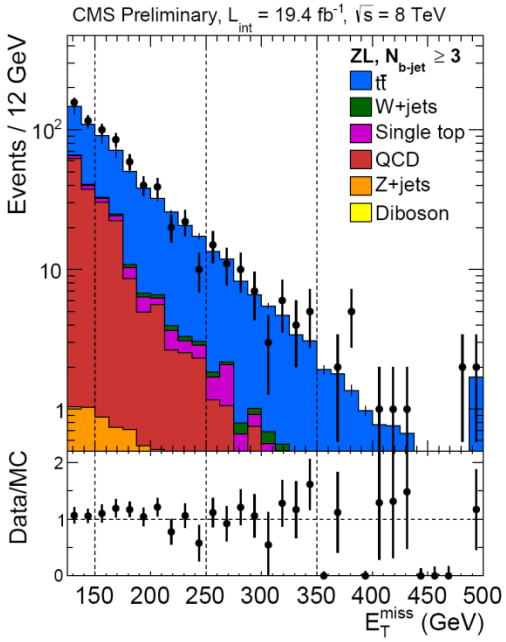
Sbottom via gluino pair production

- Final state contains up to 4 bjets and large E_T^{Miss}
  - Several different analyses developed to target this final state:
    - **ATLAS:** 0 leptons + 3 b-jets, large M effective = $E_T^{Miss} + H_T$ (12.8 fb^{-1}, ATLAS-CONF-2012-145)
    - **CMS:** 0 leptons+≥3 jets (≥1 b-jets) + large E_T^{Miss} (19.8 fb^{-1}, CMS-PAS-SUS-12-024)



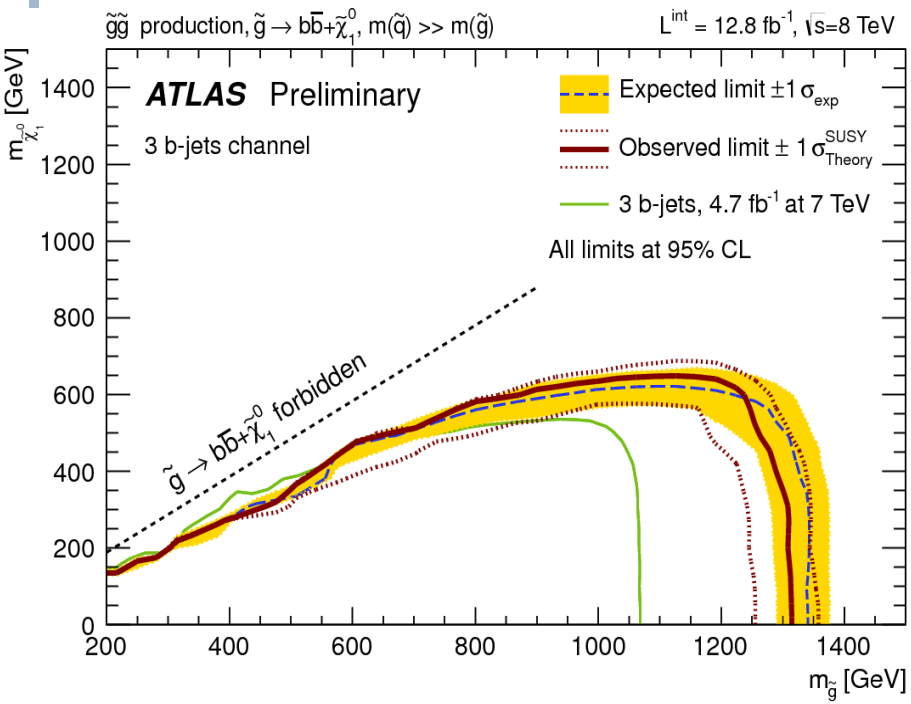


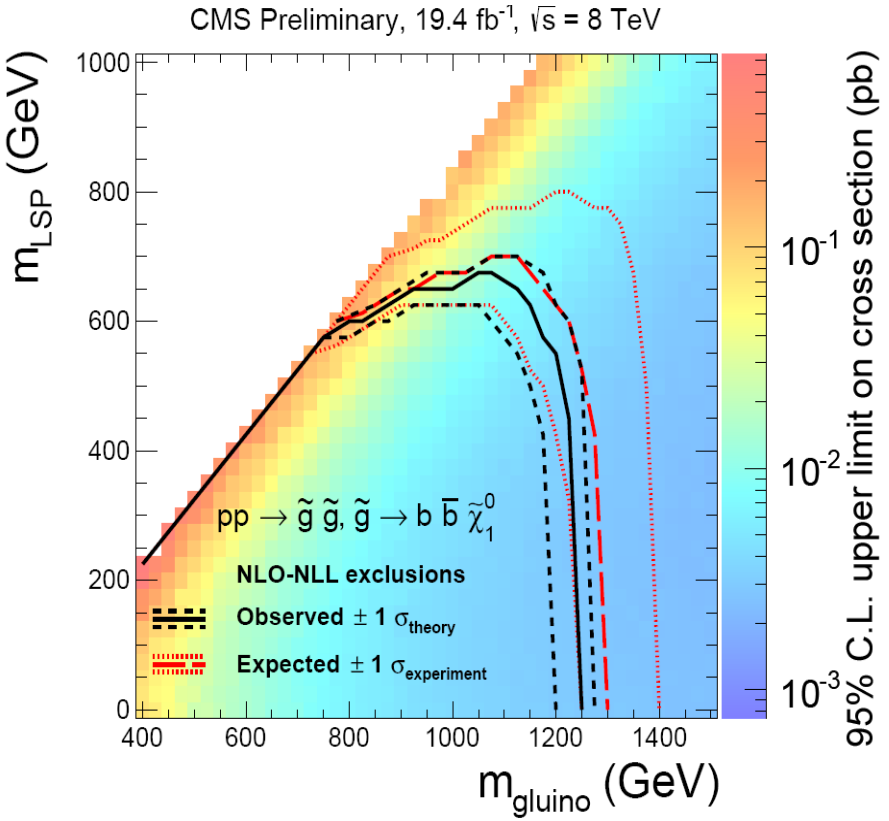




Sbottom via gluino pair production

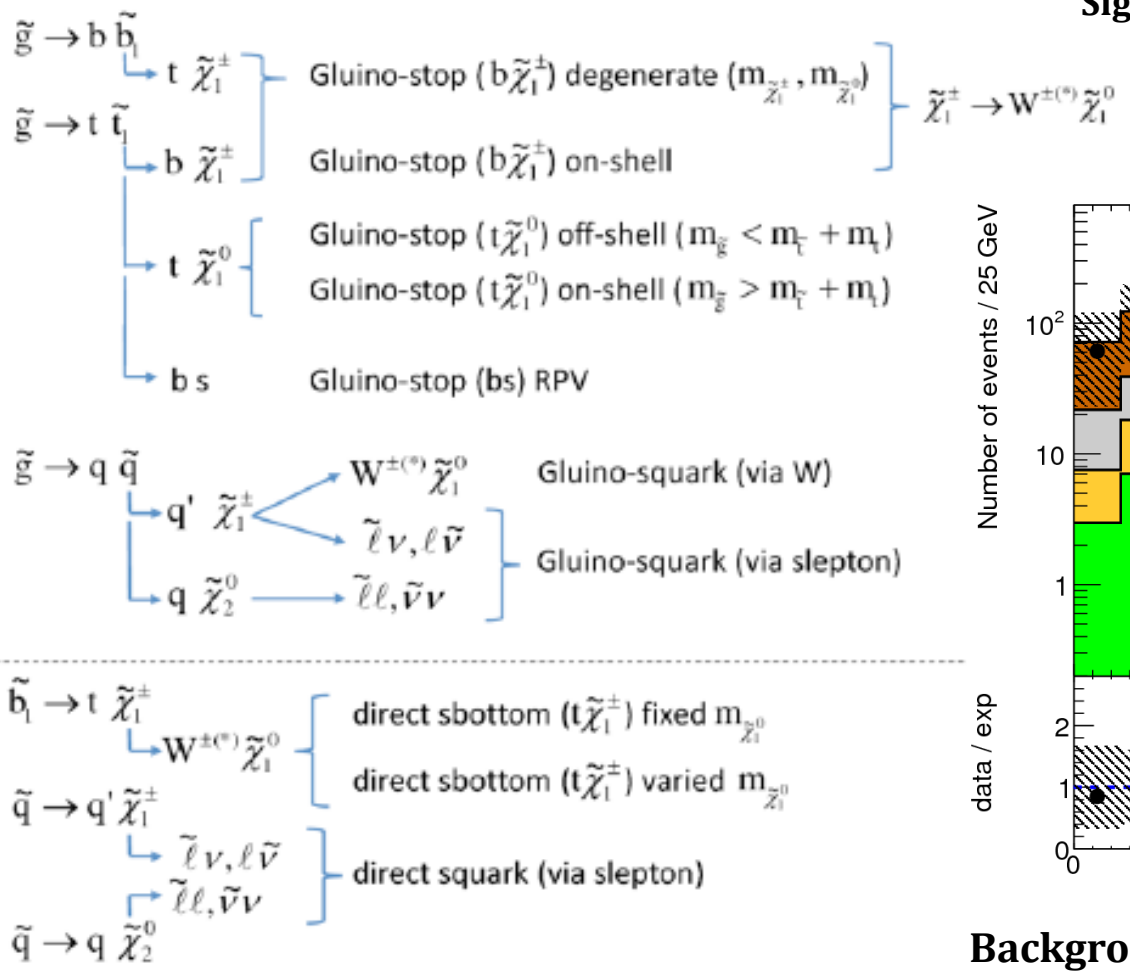
- Final state contains up to 4 bjets and large E_T^{Miss}
  - Several different analyses developed to target this final state:
    - **ATLAS:** 0 leptons + 3 b-jets, large M effective = $E_T^{Miss} + H_T$ (12.8 fb^{-1}, ATLAS-CONF-2012-145)
    - **CMS:** 0 leptons+≥3 jets (≥1 b-jets) + large E_T^{Miss} (19.8 fb^{-1}, CMS-PAS-SUS-12-024)



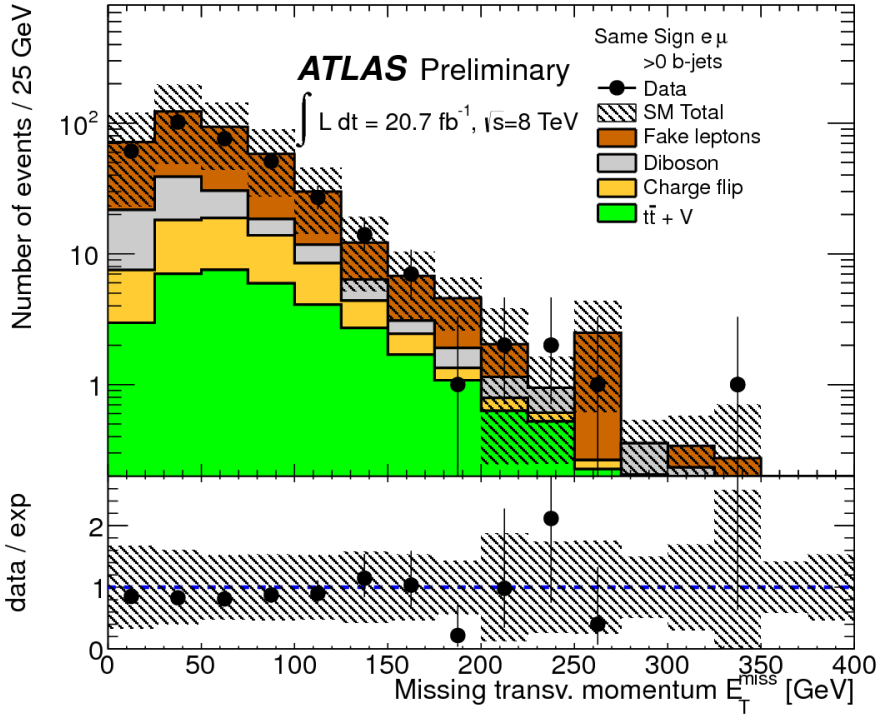


Strong production: Same Sign leptons

- Generic signature sensitive to new physics



Signature: $e^\pm e^\pm$, $\mu^\pm \mu^\pm$, $e^\pm \mu^\pm$
≥ 3, 4 jets (0, ≥ 1, 3 b-tagged jets)+ E_T^{miss}

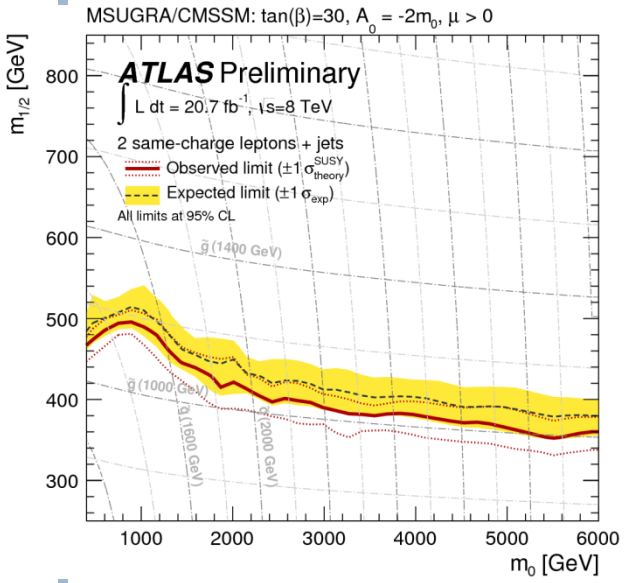


Backgrounds *(little reliance on MC)*
Irreducible ttbar+V, VV
Reducible Z+jets charge flip, ttbar, W+jets

ATLAS Same Sign leptons: additional interpretations

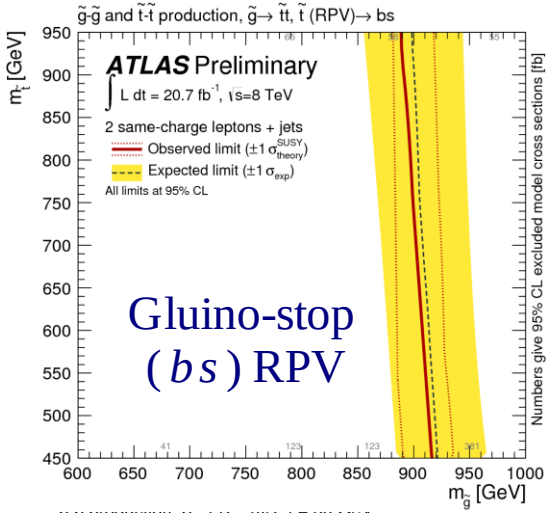
- Interpretation in MSUGRA/CMSSM and vast array of RPC/RPV simplified models

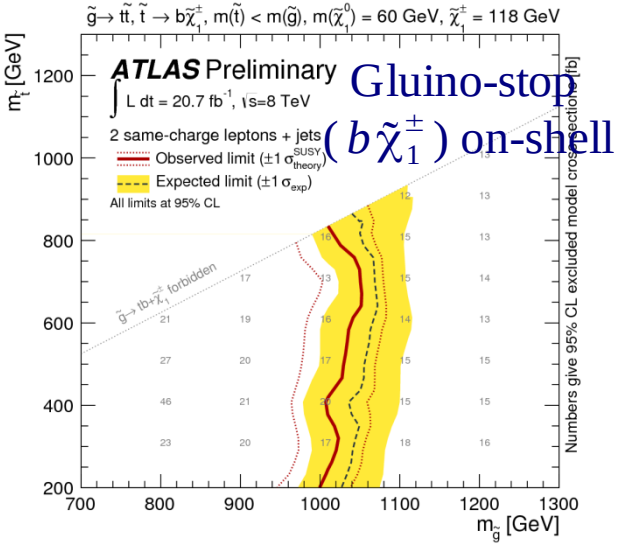
MSUGRA /CMSSM

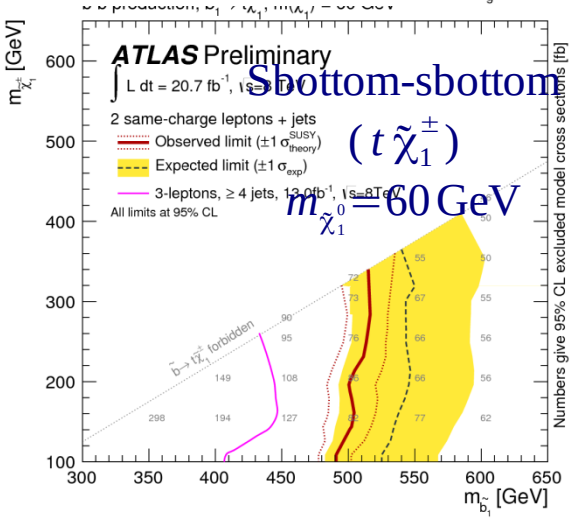


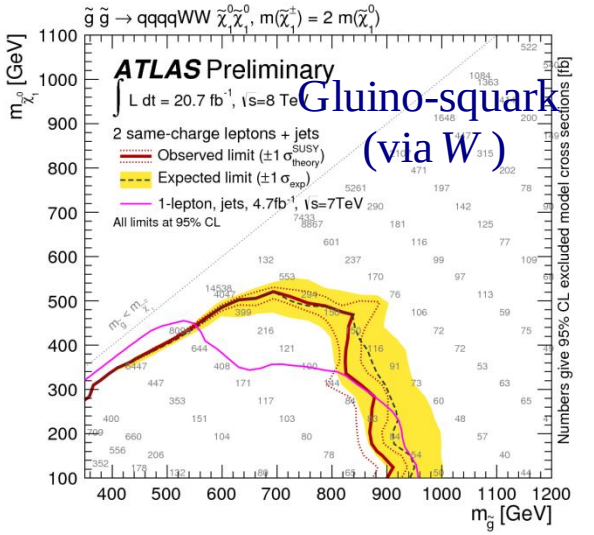
Can accommodate higgs mass ~126 GeV

ATLAS-CONF-2013-007









Direct stop production in Z+b-jets

ATLAS-CONF-2013-025

$\tilde{t}_2\tilde{t}_2$ production where $\tilde{t}_2 \to Z\tilde{t}_1$

First time directly addressed at the LHC!

probe parameter space with small $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$

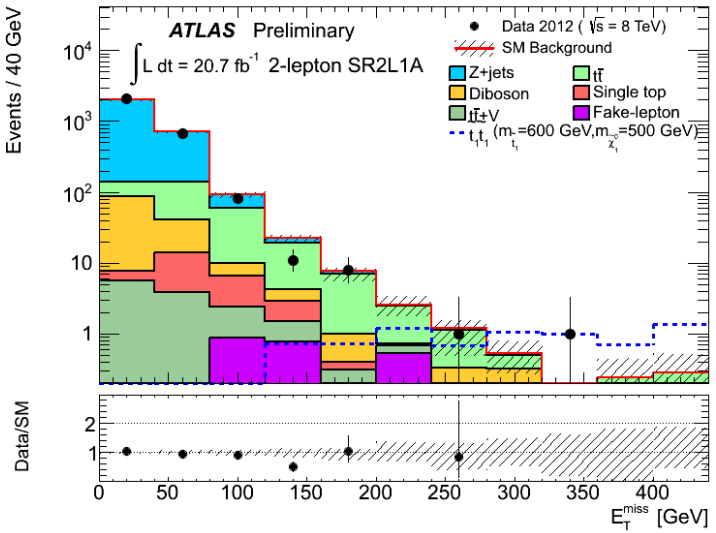
Natural gauge mediated SUSY breaking model

$\tilde{t}\tilde{t}$ dominant

Inspired by naturalness

cascade decay to $\tilde{\chi}_1^0 \to Z\tilde{G}$

Signature: 2-3 leptons, Z candidate,
3, 4 or ≥ 5 jets (≥ 1 b-tagged jets) + E_T^{miss}



Signal regions

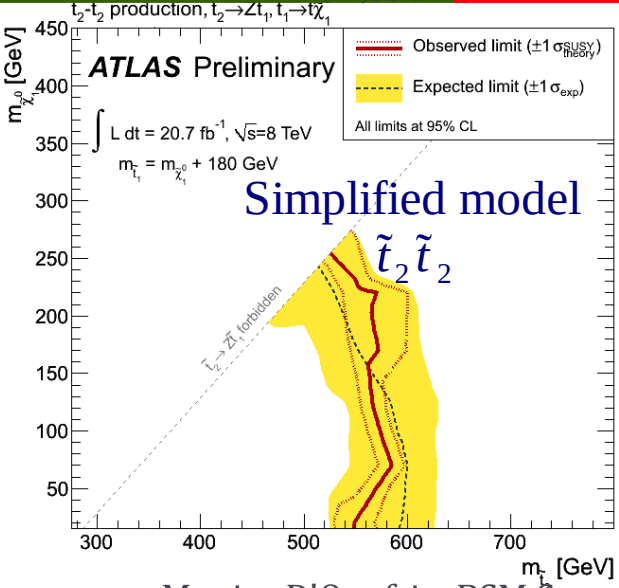
2L small & large $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$ | **3L** large $\Delta m(\tilde{t}_2, \tilde{t}_1)$, (non-)boosted Z

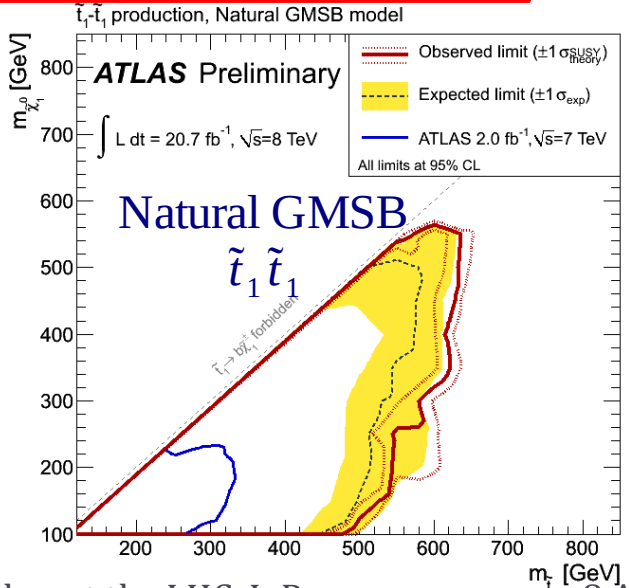
Backgrounds

Irreducible
VV, VVV, ttbar+V

Irreducible 2L, reducible 3L
Ttbar, Z+jets

Reducible
W+jets, multijets





Strong SUSY production: 1τ, 2τ

ATLAS-CONF-2013-026

- Gauge Mediated SUSY breaking models

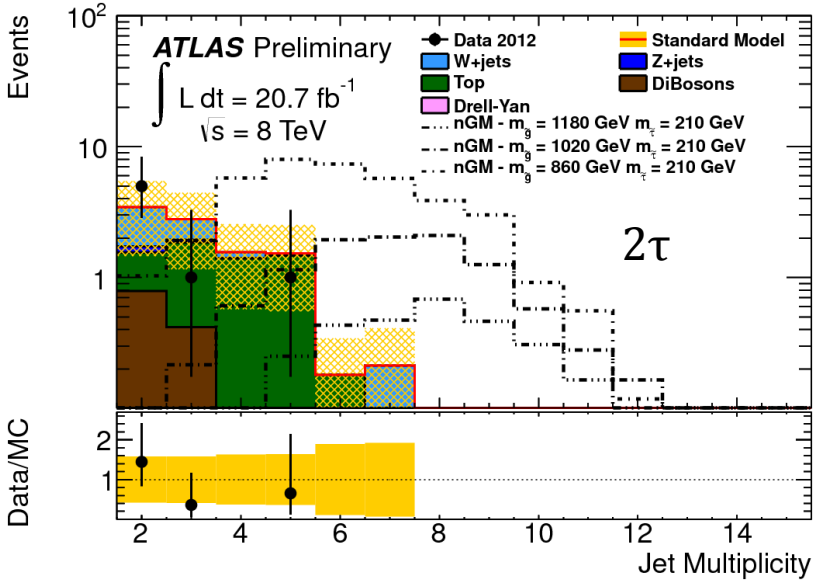
Stau is NLSP, prompt decay

where $\tilde{\chi}_1^0 \to \tau\,\tilde{\tau} \to \tau\,\tau\,\tilde{G}$ — 4 τ + jets from cascade decays

or $\tilde{\chi}_1^{\pm} \to \nu\,\tilde{\tau} \to \nu\,\tau\,\tilde{G}$ — 2 τ + jets from cascade decays

Signature:
1 or 2 hadronic τ, ≥ 2 jets + E_T^{miss}

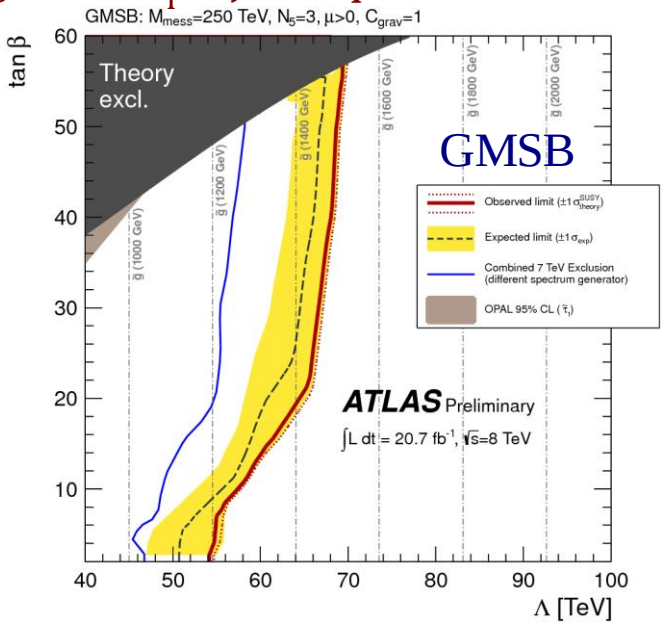
Signal regions: High mT, H_T, Njet requirements

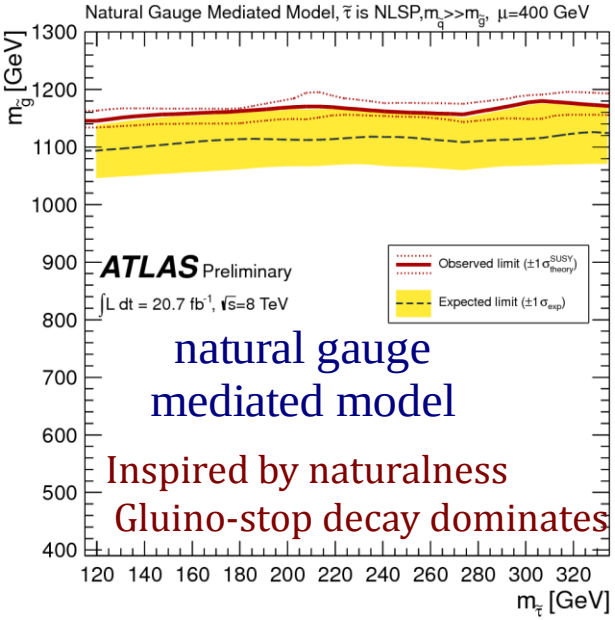


Backgrounds

Irreducible
Ttbar, W,Z+jets, VV, Drell-Yan

Reducible
Multijets



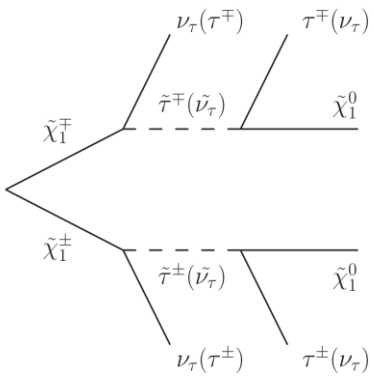


Weak SUSY production: 2τ

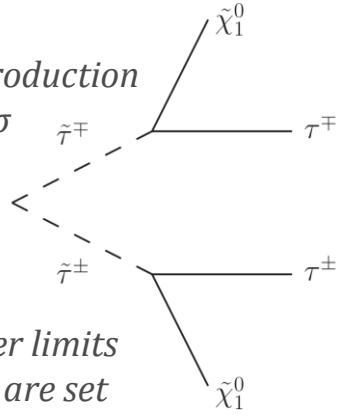
ATLAS-CONF-2013-028

- Light staus are well motivated in natural SUSY

First search for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}$ production with light staus from the LHC

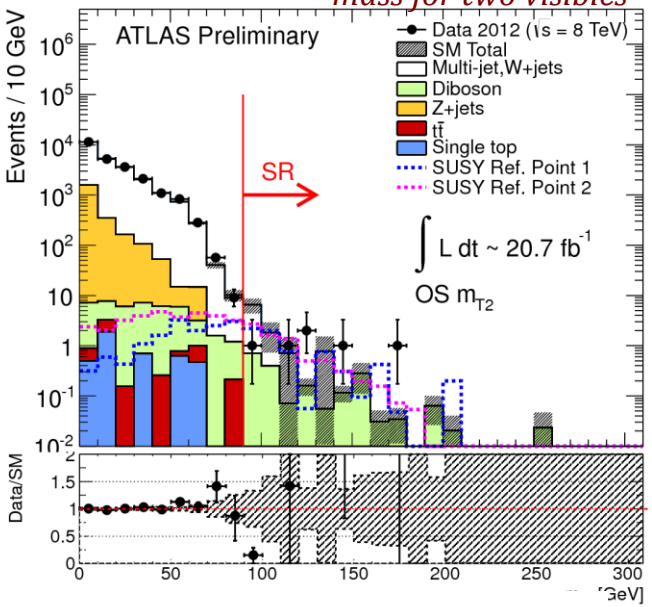


Direct stau production has very low σ



Upper limits on σ are set

m_{T2} generalised transverse mass for two visibles



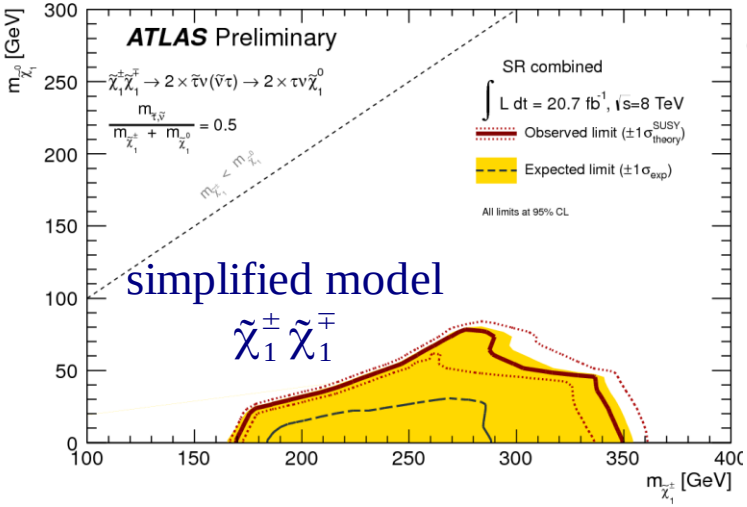
Signature: 2 OS hadronic τ + E_T^{miss}

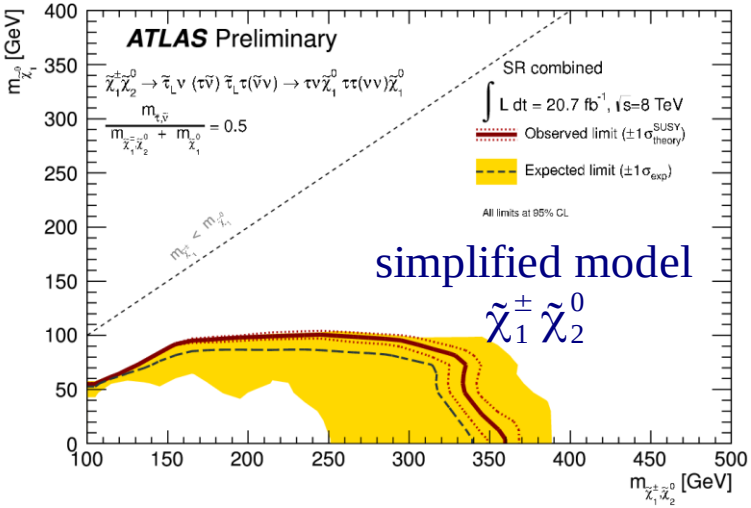
Signal regions: High E_T^{miss} and m_{T2} and (b) jet veto

Backgrounds

Reducible
W+jets, multijets

Irreducible
Z+jets, VV, ttbar, ttbar+V

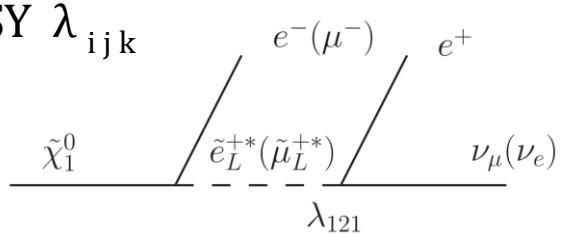




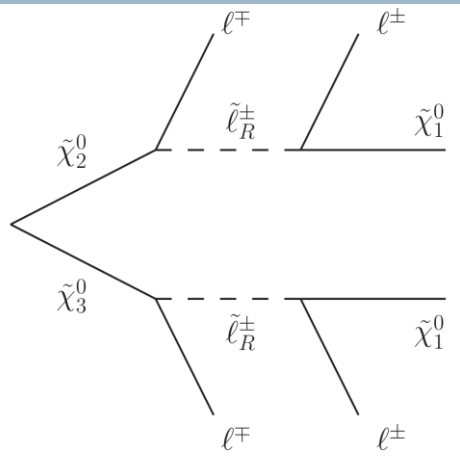
Multilepton SUSY: >= 4 lepton search

ATLAS-CONF-2013-036

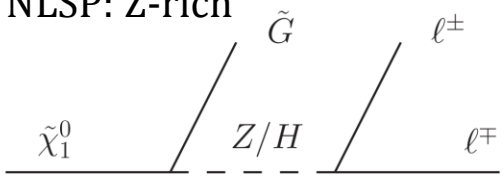
RPV SUSY λ_{ijk}



RPC $\tilde{\chi}_2^0\tilde{\chi}_3^0$ production



General gauge mediated SUSY breaking is neutralino NLSP: Z-rich



Versatile analysis!
Low backgrounds

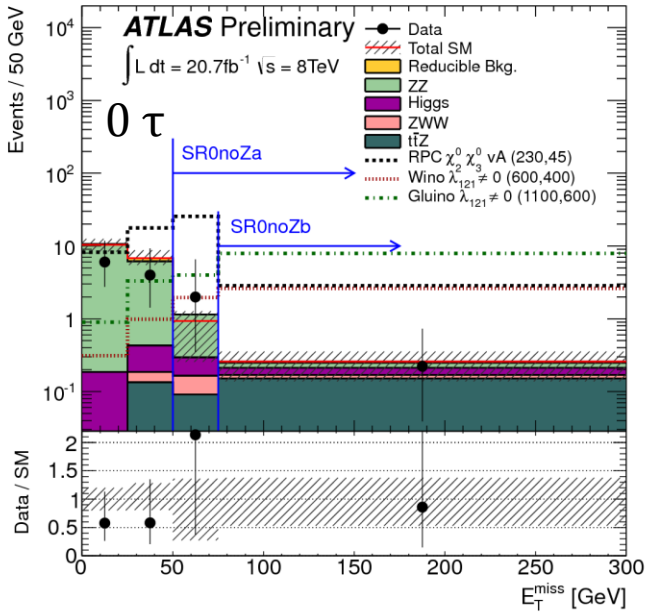
Signature: ≥ 4 leptons (0, 1 hadronic τ) + E_T^{miss}

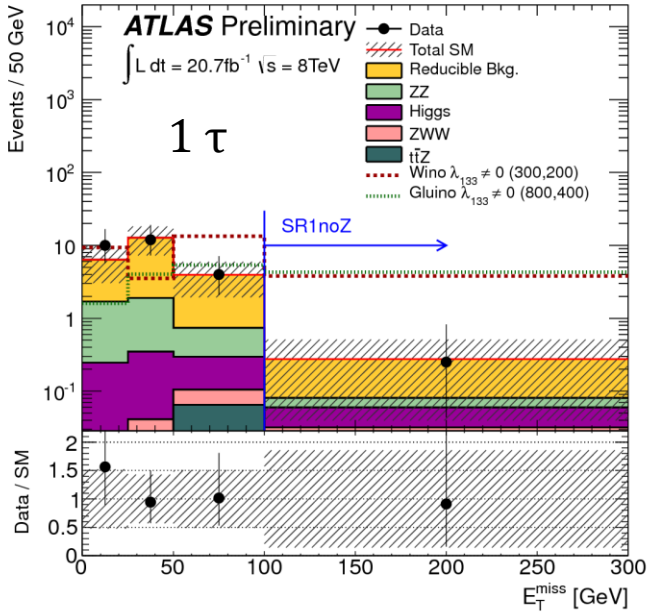
Signal regions
High E_t^{miss},
Z-rich / Z-depleted

Backgrounds

Irreducible
ZZ, ZWW,
ttbar+Z/WW, higgs

Reducible
Ttbar, Z+jets, WZ



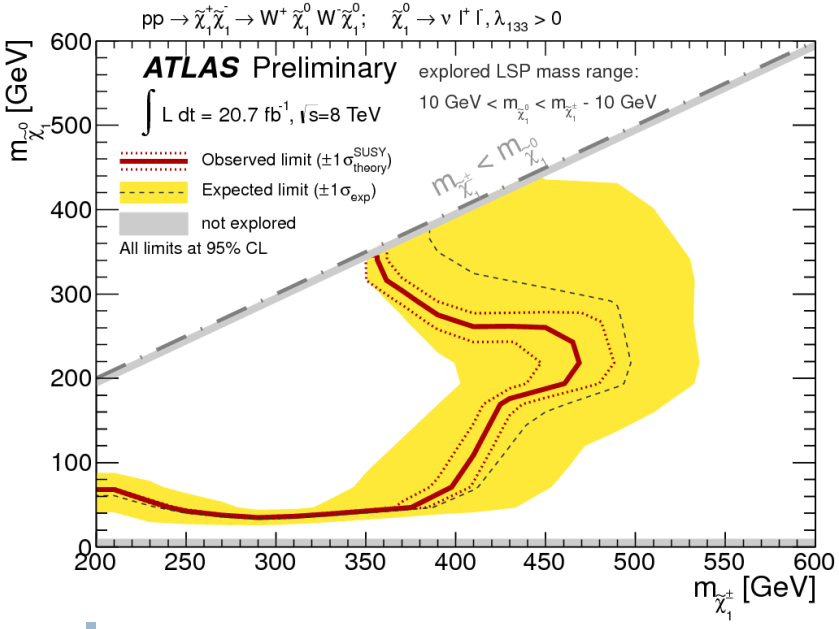


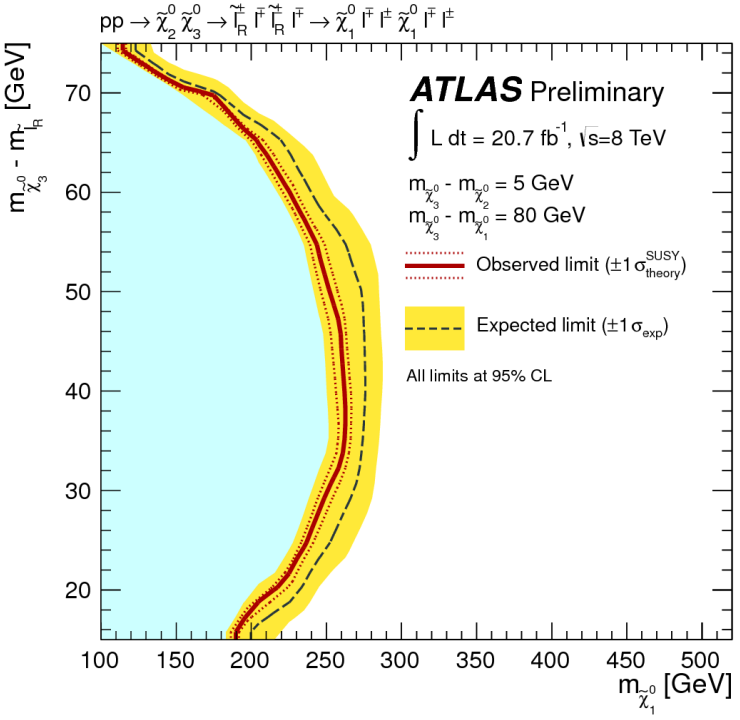
Multilepton SUSY: >= 4 lepton search

Wino NLSP

$\lambda_{133} > 0$

τ rich



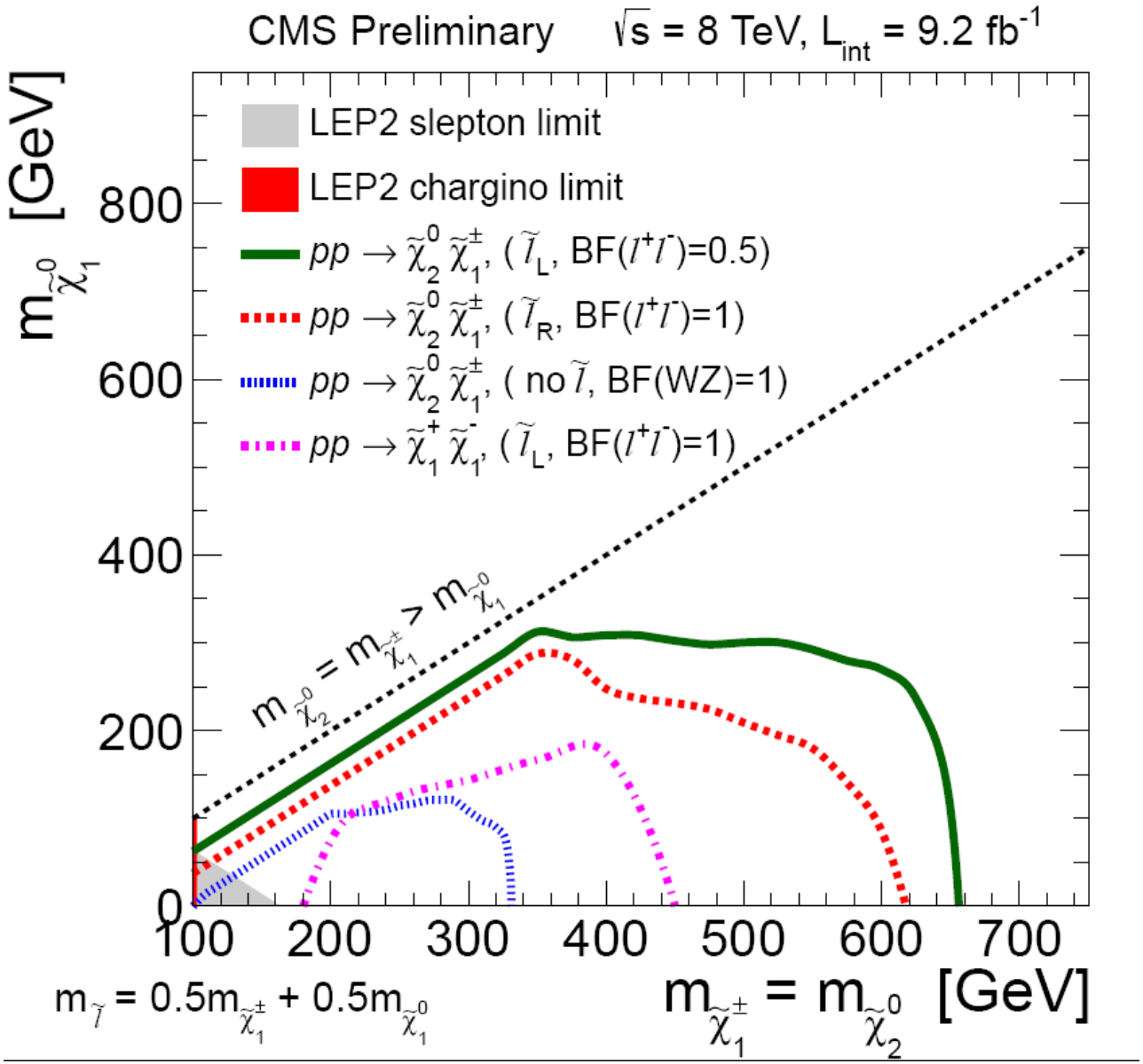


RPC

$\tilde{\chi}_2^0 \tilde{\chi}_3^0$

Some of the interpretation in RPC/RPV

CMS Chargino-neutralino summary



Direct stop pair production: 0 lepton

ATLAS-CONF-2013-024

- Decay of stop depends on SUSY mass spectrum

$\tilde{t}\,\bar{\tilde{t}}$ production where $\tilde{t} \rightarrow t\,\tilde{\chi}_1^0$ → **Target heavy stop**

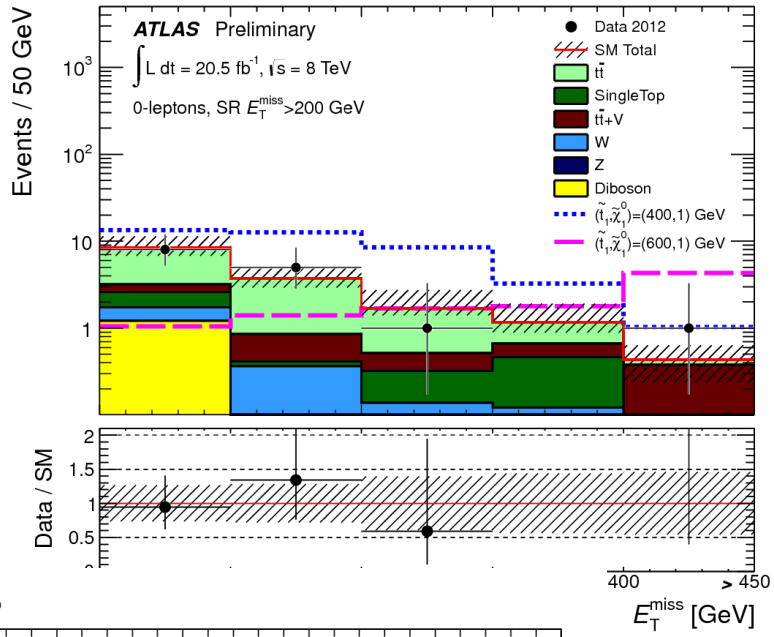
Search for fully hadronic decays of the top

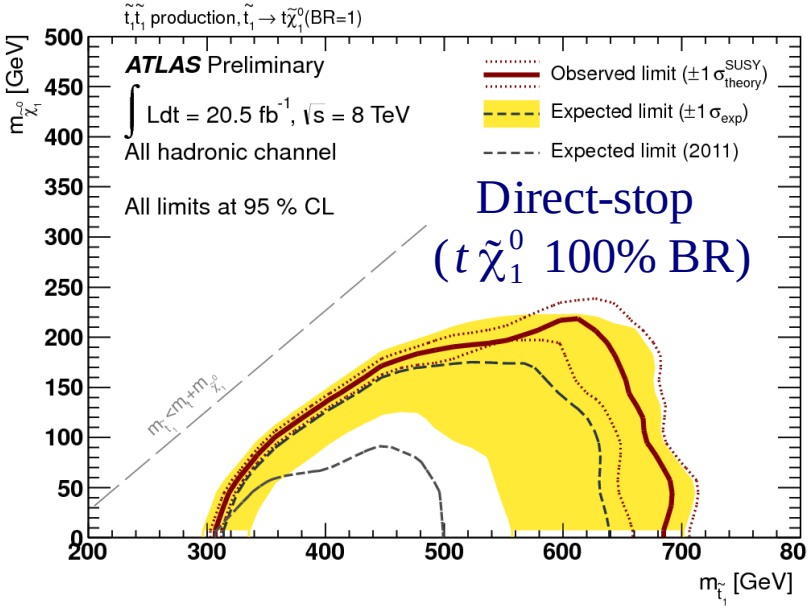
Signature: ≥ 6 jets (≥ 2 b-tagged jets) + E_T^{miss}

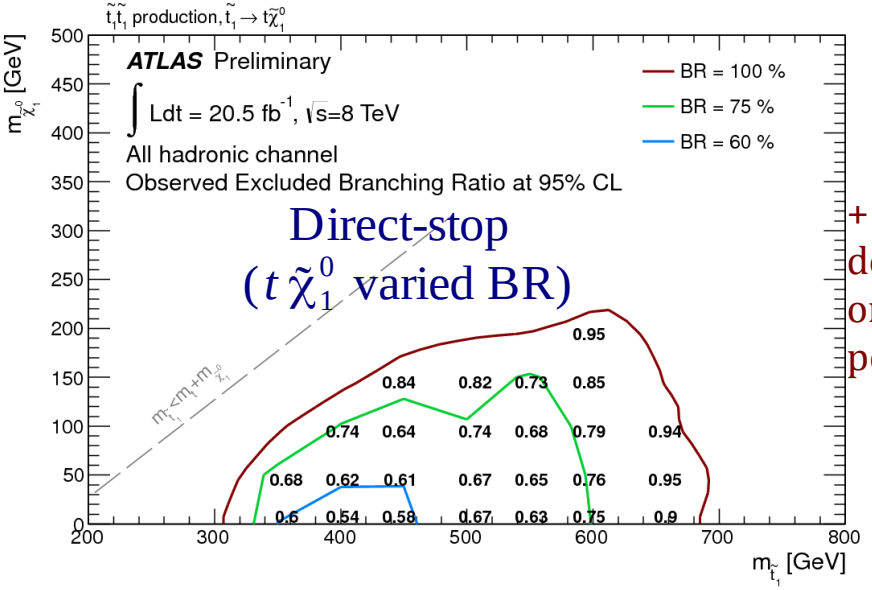
Backgrounds

Semi-leptonic ttbar, Z+jets, multijets

Loose, medium, tight signal regions using E_T^{miss}







+ little dependence on top polarisation

Direct stop production: 1 lepton

- Stop in top+neutralino

Signal regions

Loose: low Δ stop,top

medium high-mass $\tilde{\chi}_1^0$

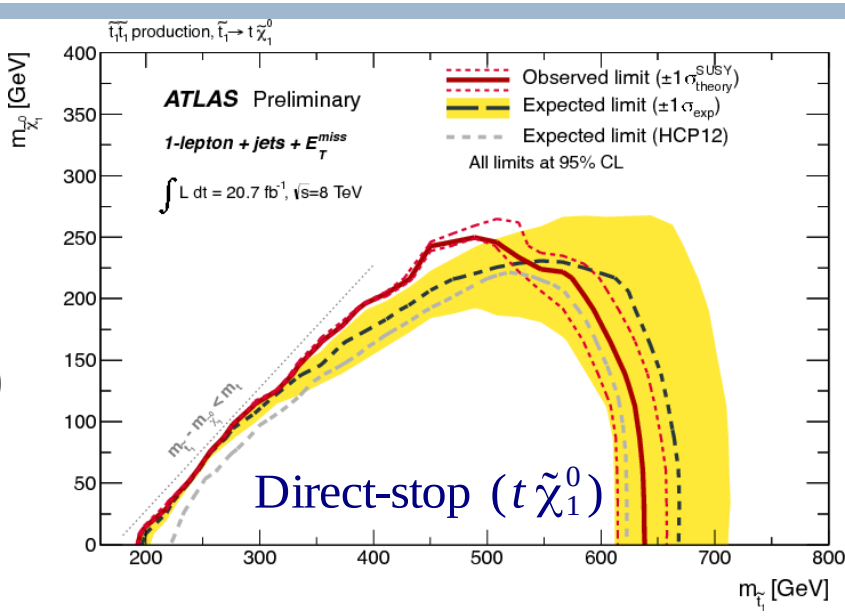
tight high-mass $\tilde{t}$

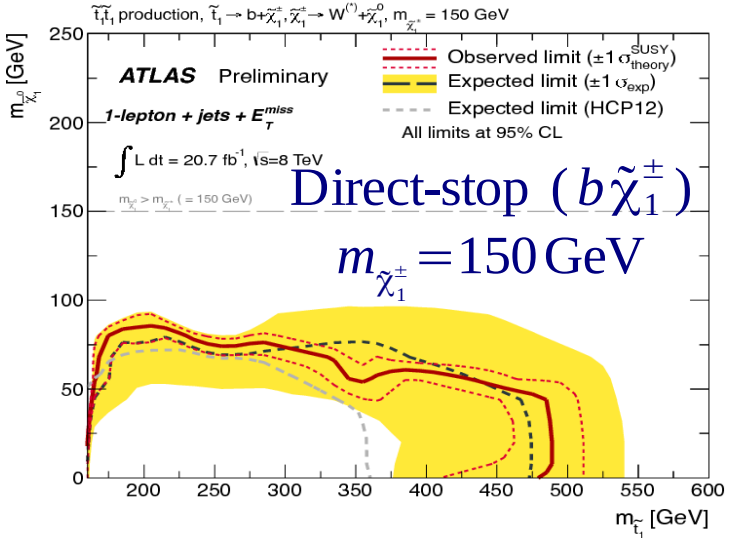
- Stop in b+chargino: $\tilde{t} \to b\tilde{\chi}_1^{\pm} \quad (\tilde{\chi}_1^{\pm} \to W^{(*)}\tilde{\chi}_1^0)$

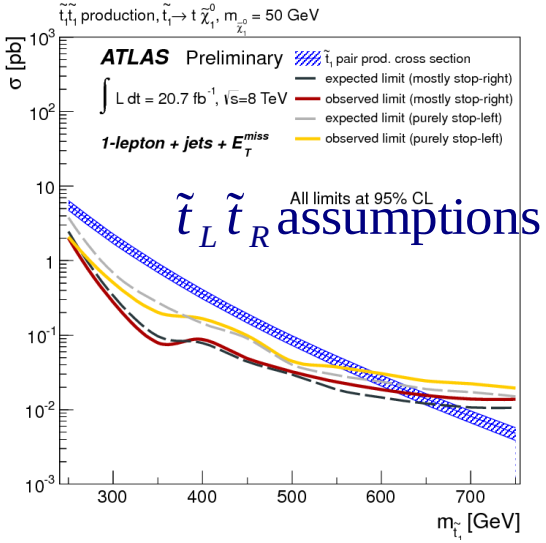
Signal regions

loose mid-mass $\tilde{t}, \tilde{\chi}_1^{\pm}$

medium, tight high-mass $\tilde{t}$, large $\Delta m(\tilde{t}, \tilde{\chi}_1^{\pm})$



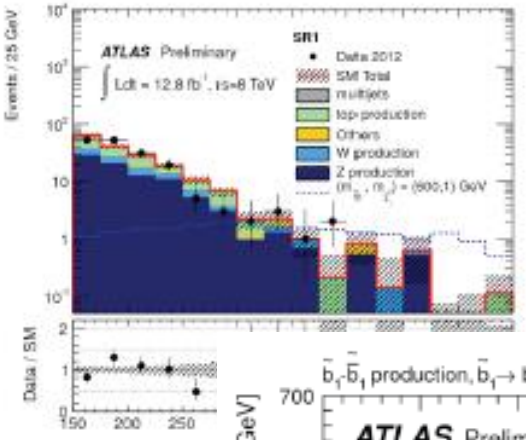




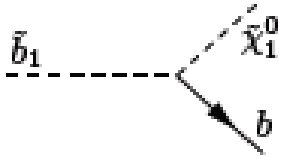
Some (~ 50-70 GeV) dependence on top polarisation

Direct sbottom pair production

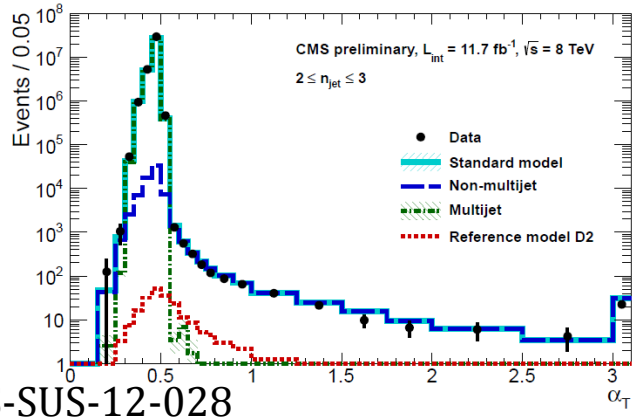
- Direct sbottom pair production with sbottom in b+neutralino
  → 0 lepton + 2 bjets + Missing ET



mCT



Alpha_T



ATLAS-CONF-2012-165

CMS-PAS-SUS-12-028