Hunting for Physics Beyond the Standard Model by ATLAS and CMS

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On behalf of ATLAS and CMS

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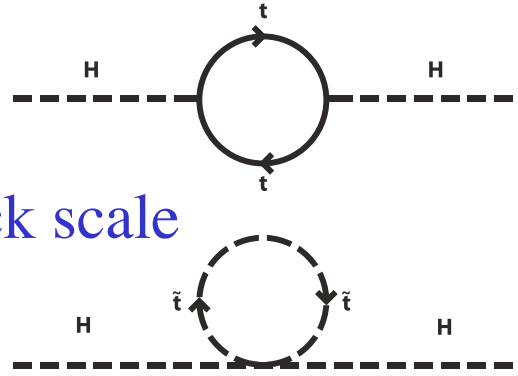
Outline

- Desperately seeking SUSY
- Hunting in the exotic land
- Summary

Desperately Seeking SUSY

1985 Movie
-- SUSY searches predate this
-- may have better luck this time…

SUSY



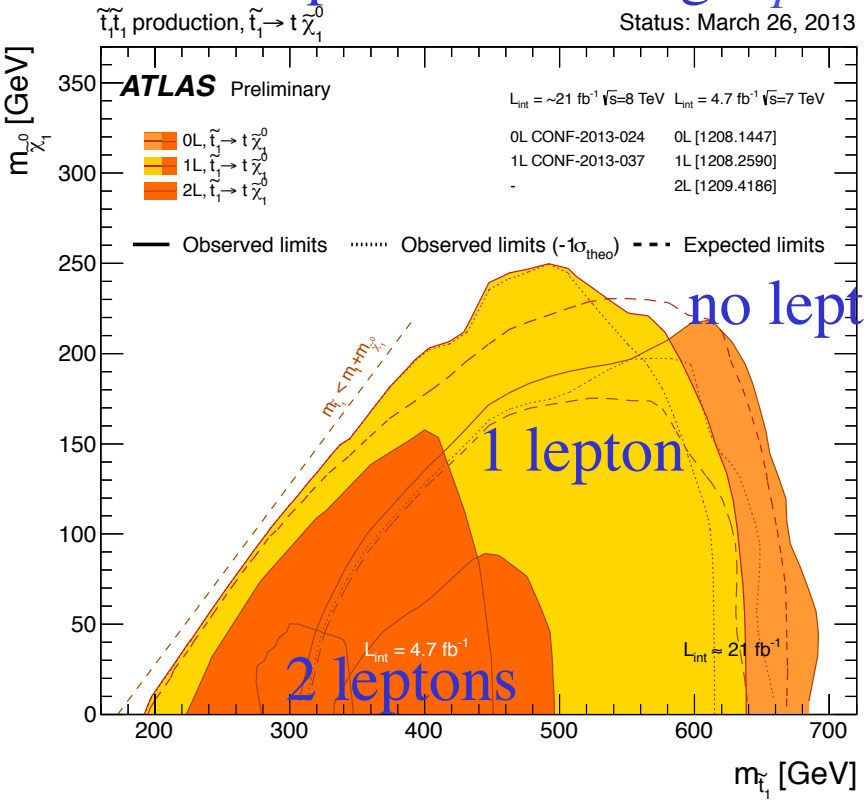
- Main motivation for SUSY:
  - cancel quadratic divergent in Higgs mass
  - bonus: provide dark matter candidate
  - bonus: convergent of gauge couplings at Planck scale
- Experimental search strategy:
  - assume R-parity is conserved
    - ⇨ lightest supersymmetric particle (LSP) is stable
    - ⇨ large missing transverse energy (E_T)
  - will also present searches with R-parity violation
- caveat: SUSY has many free parameters
  - ⇨ conversion of result into exclusion limits require assumptions:
    - decay chains
    - masses and branching fractions

Search for Stop-Pair Production

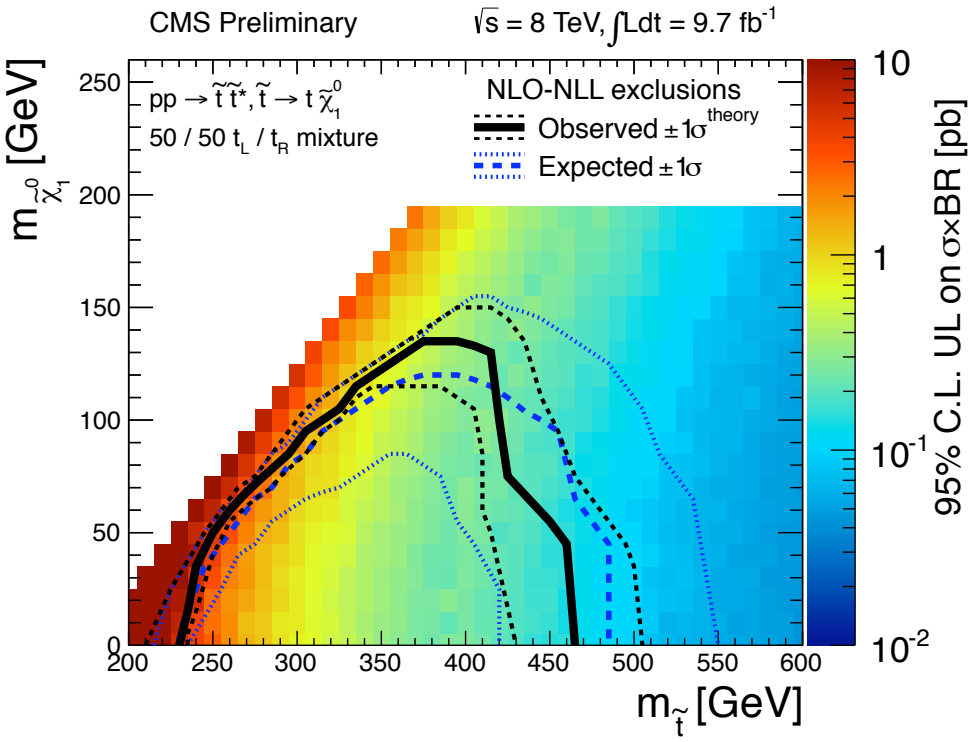
$$pp \rightarrow \tilde{t}_1 \tilde{t}_1$$

$$\tilde{t}_1 \rightarrow t \tilde{\chi}_1^0$$

≤ 2 leptons + missing E_T



1 lepton + ≥ 4 jets (≥ 1 b-jet) + missing E_T



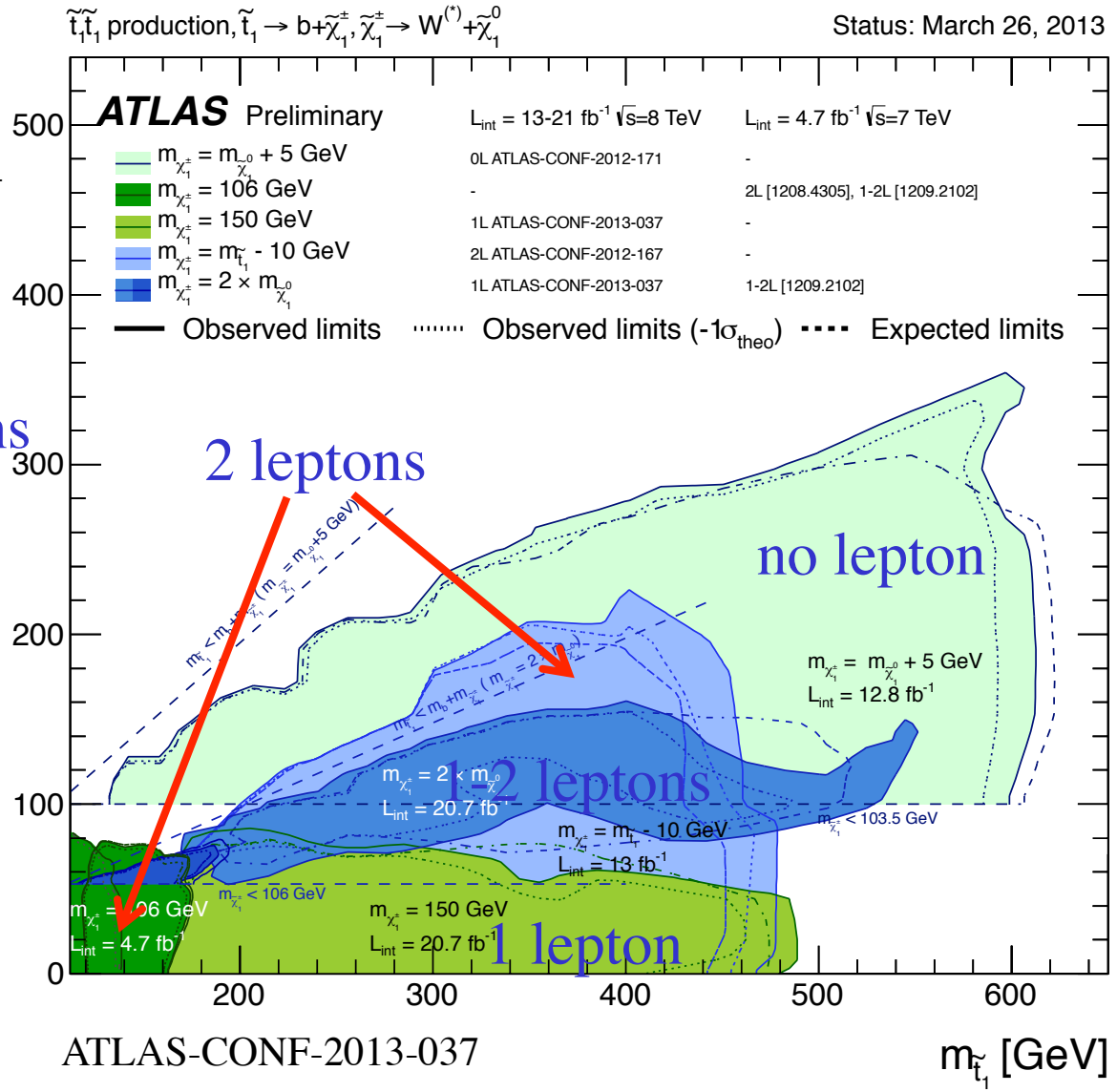
Search for Stop-Pair Production

- Search for medium heavy stop:

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

$$\tilde{\chi}_1^{\pm} \rightarrow W^{(*)} + \tilde{\chi}_1^0$$

- Lepton multiplicity depends on assumptions
  - may be too soft to reconstruct
- Exclude stop up to 410 GeV for massless LSP and 150 GeV chargino @95%CL

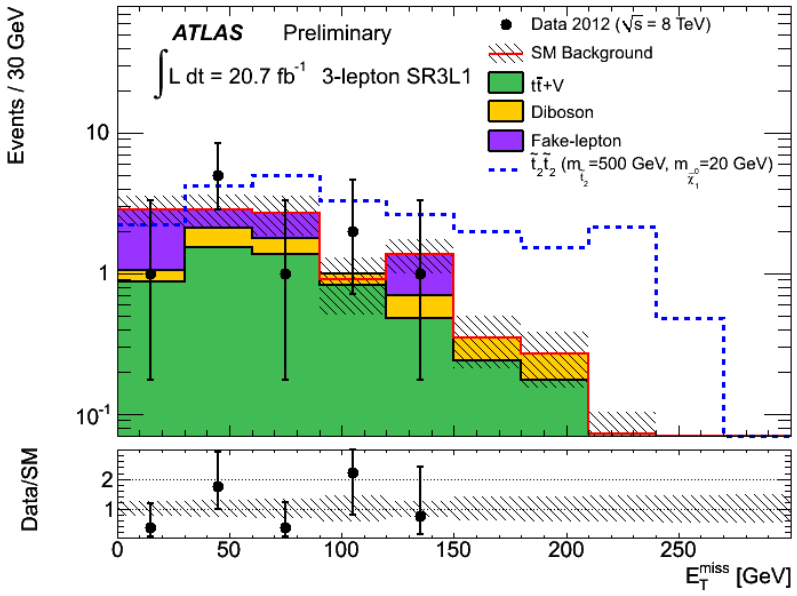


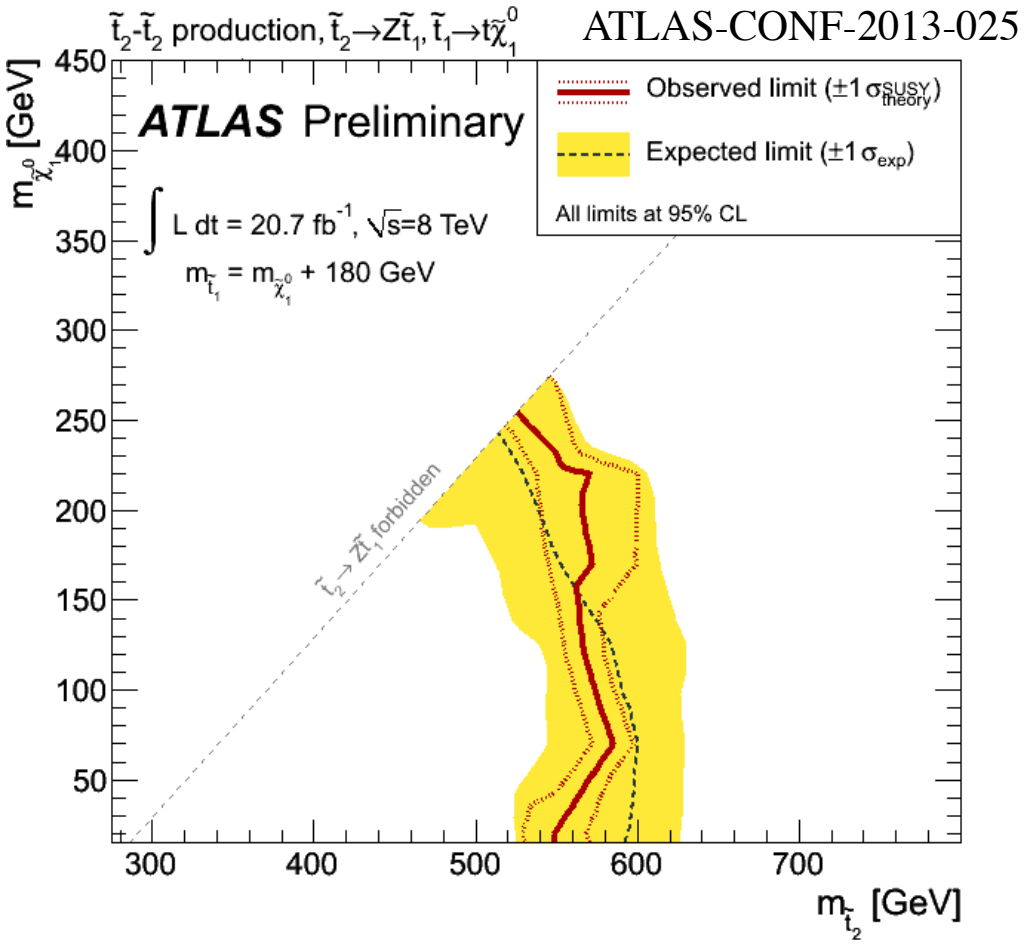
ATLAS-CONF-2013-037

Search for Stop-Pair Production

$$\tilde{t}_2\tilde{t}_2 \rightarrow Z\tilde{t}_1 Z\tilde{t}_1 \rightarrow Zt\tilde{\chi}_1^0 Zt\tilde{\chi}_1^0$$

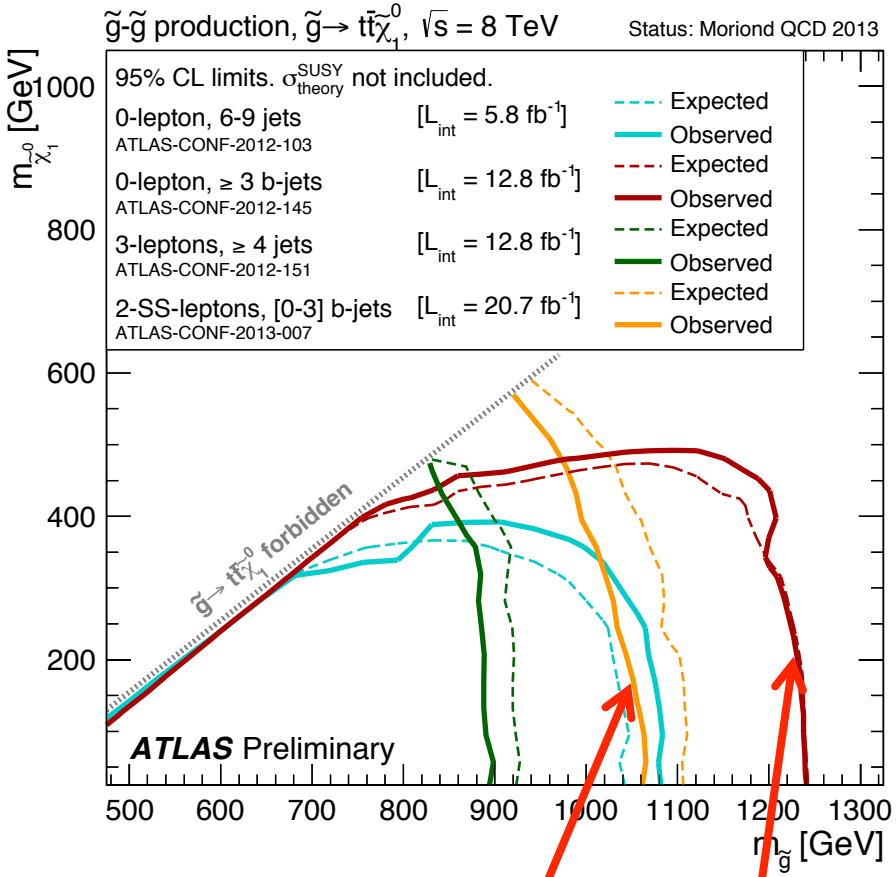
- Search for Z + b-jets + missing E_T
- Can also interpret result in gauge-mediated supersymmetry breaking (GMSB) scenarios

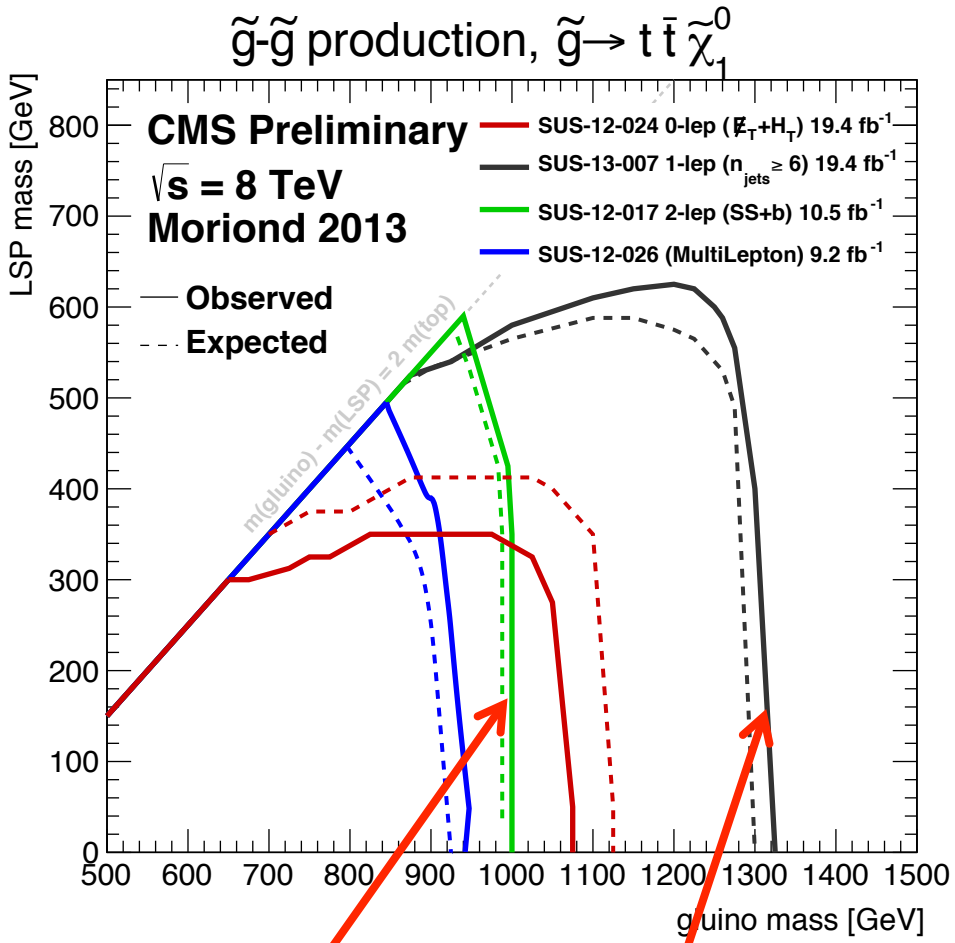




ATLAS-CONF-2013-025

Search for Gluino-Pair Production





2 SS-leptons + ≤ 3 b-jets

0 lepton + ≥ 3 b-jets
12.8 fb^{-1}

2 SS-leptons + b-jets

1 lepton + ≥ 6 jets
19.4 fb^{-1}

Search for Gluino-Pair Production

$pp \to \tilde{g}\tilde{g}$

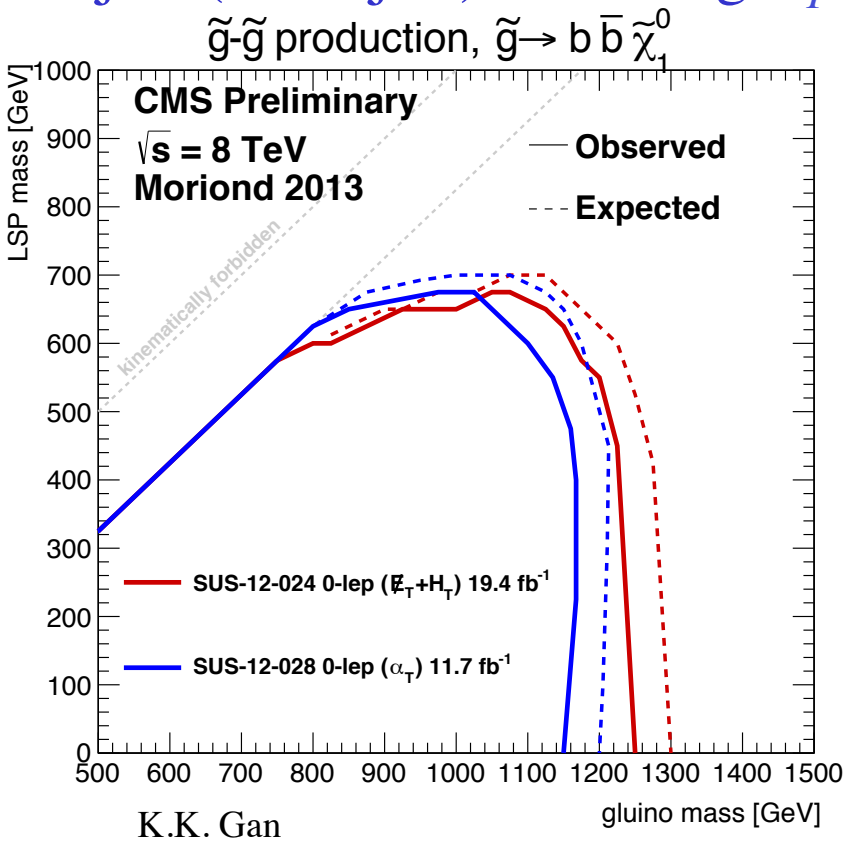
$\tilde{g} \to b\bar{b}\,\tilde{\chi}_1^0$

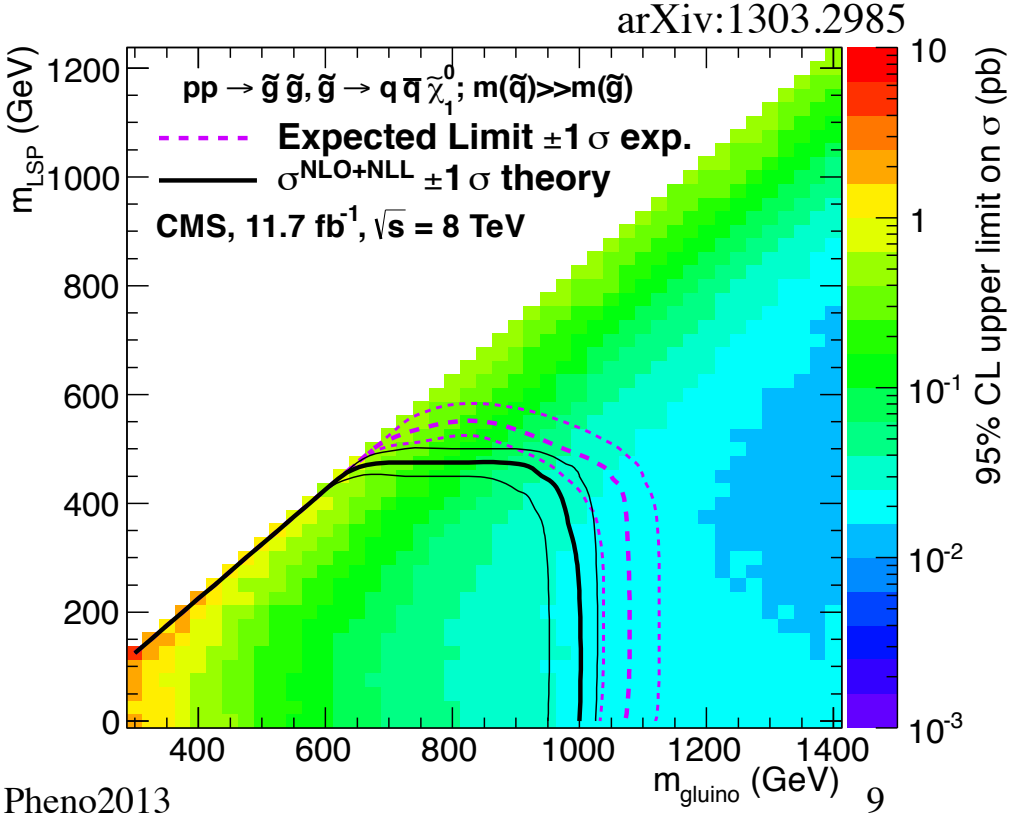
≥ 3 jets (≥ 1 b jets) + missing E_T

$pp \to \tilde{g}\tilde{g}$

$\tilde{g} \to q\bar{q}\,\tilde{\chi}_1^0$

≥ 4 jets + missing E_T





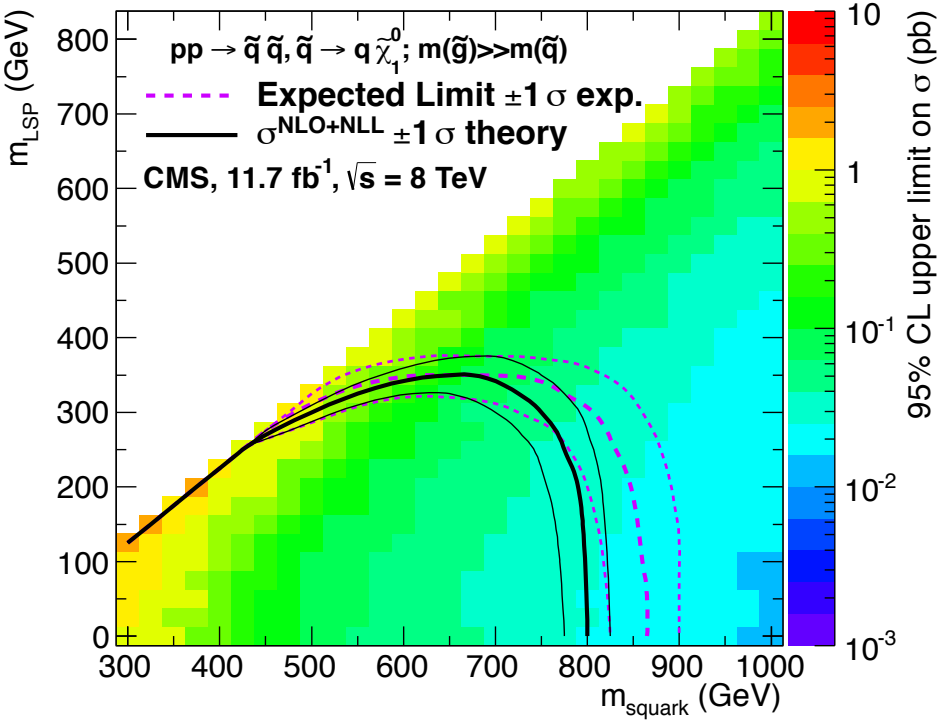
Search for Squark-Pair Production

arXiv:1303.2985

$pp \to \tilde{q}\tilde{q}$

$\tilde{q} \to q q \tilde{\chi}_1^0$

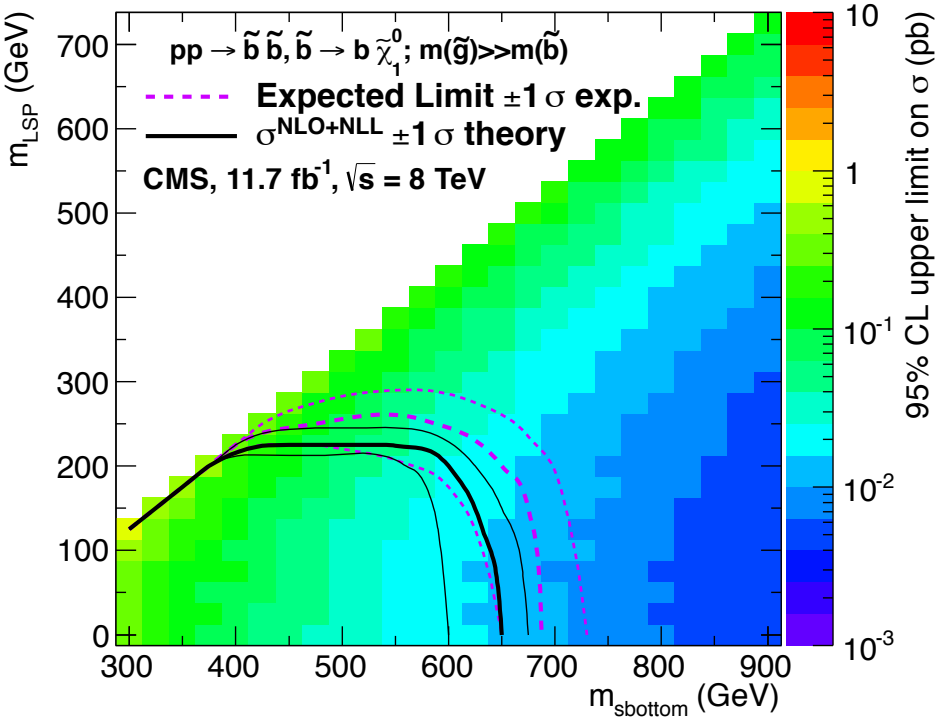
2-3 jets + missing E_T



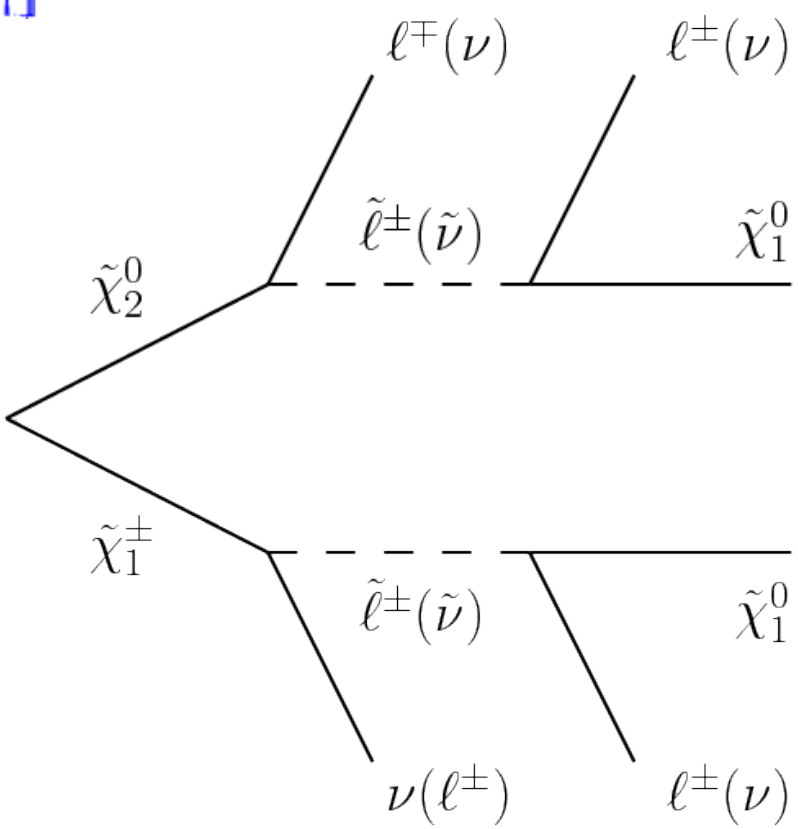
$pp \to \tilde{b}\tilde{b}$

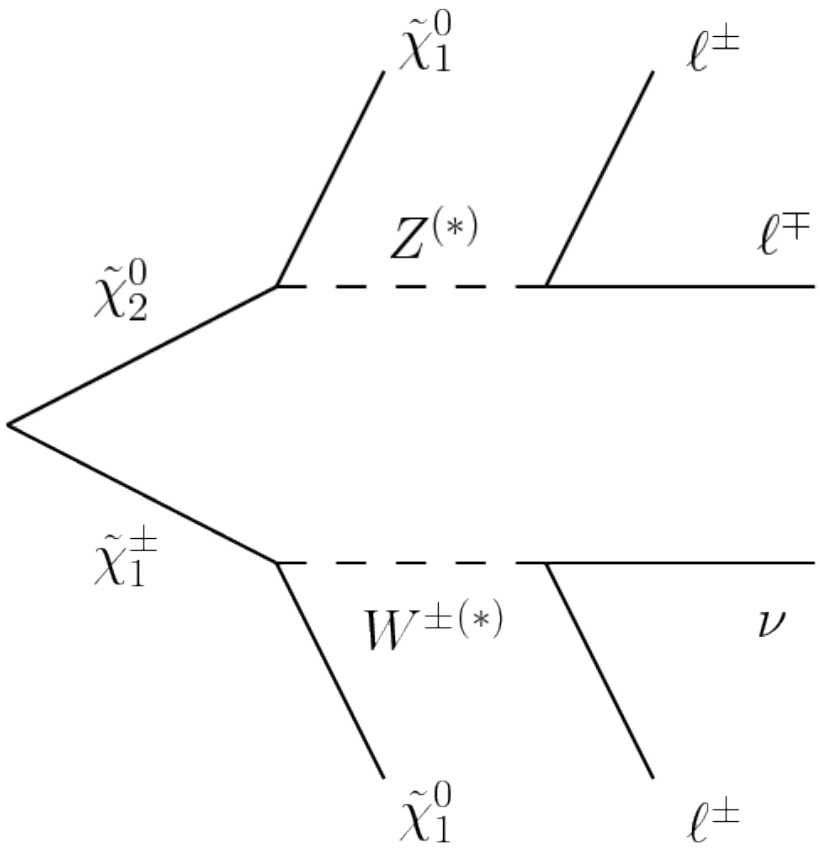
$\tilde{b} \to b \tilde{\chi}_1^0$

2-3 jets + 1-2 *b* jets + missing E_T



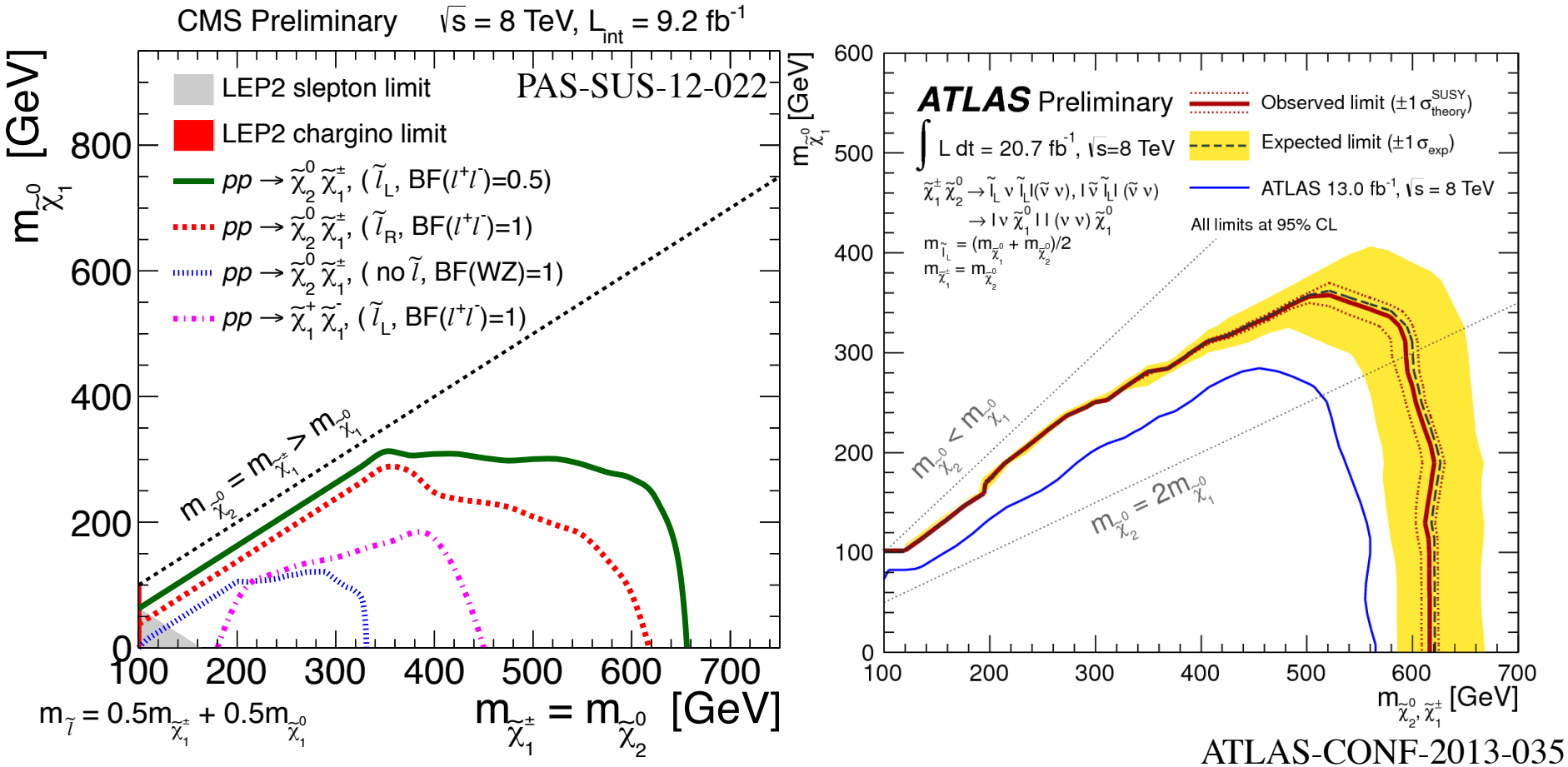
Search for Charginos & Neutralinos





- signature: 3 leptons + missing E_T

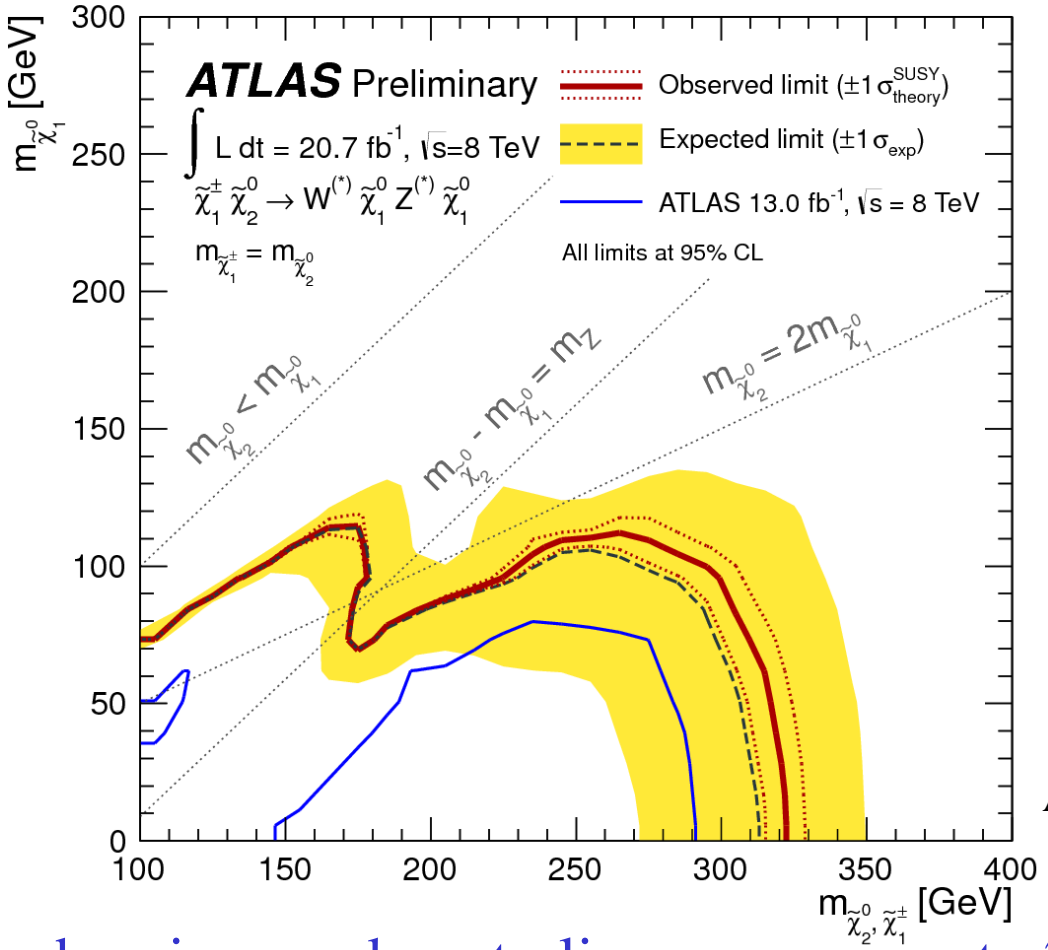
Search for Charginos & Neutralinos



ATLAS-CONF-2013-035

- exclude charginos and neutralinos masses up to 650 GeV if decay via sleptons to massless lightest neutralino

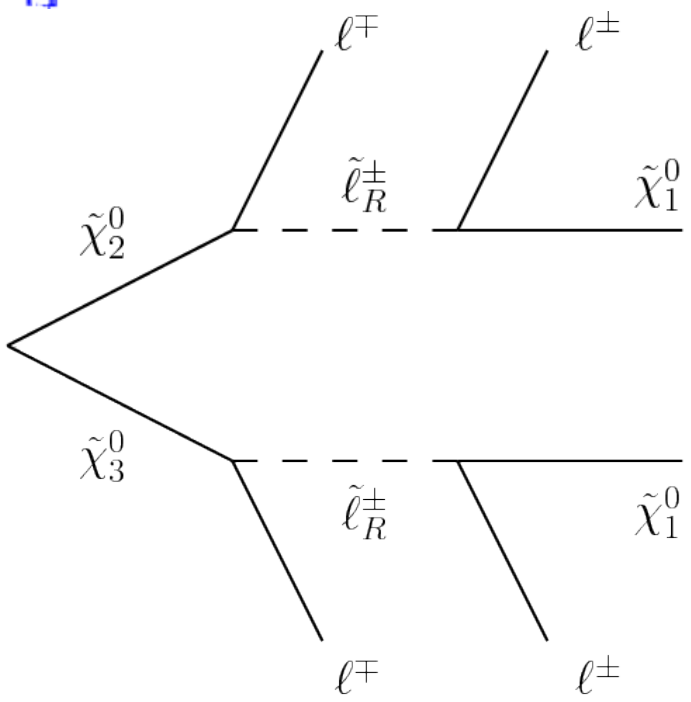
Search for Charginos & Neutralinos

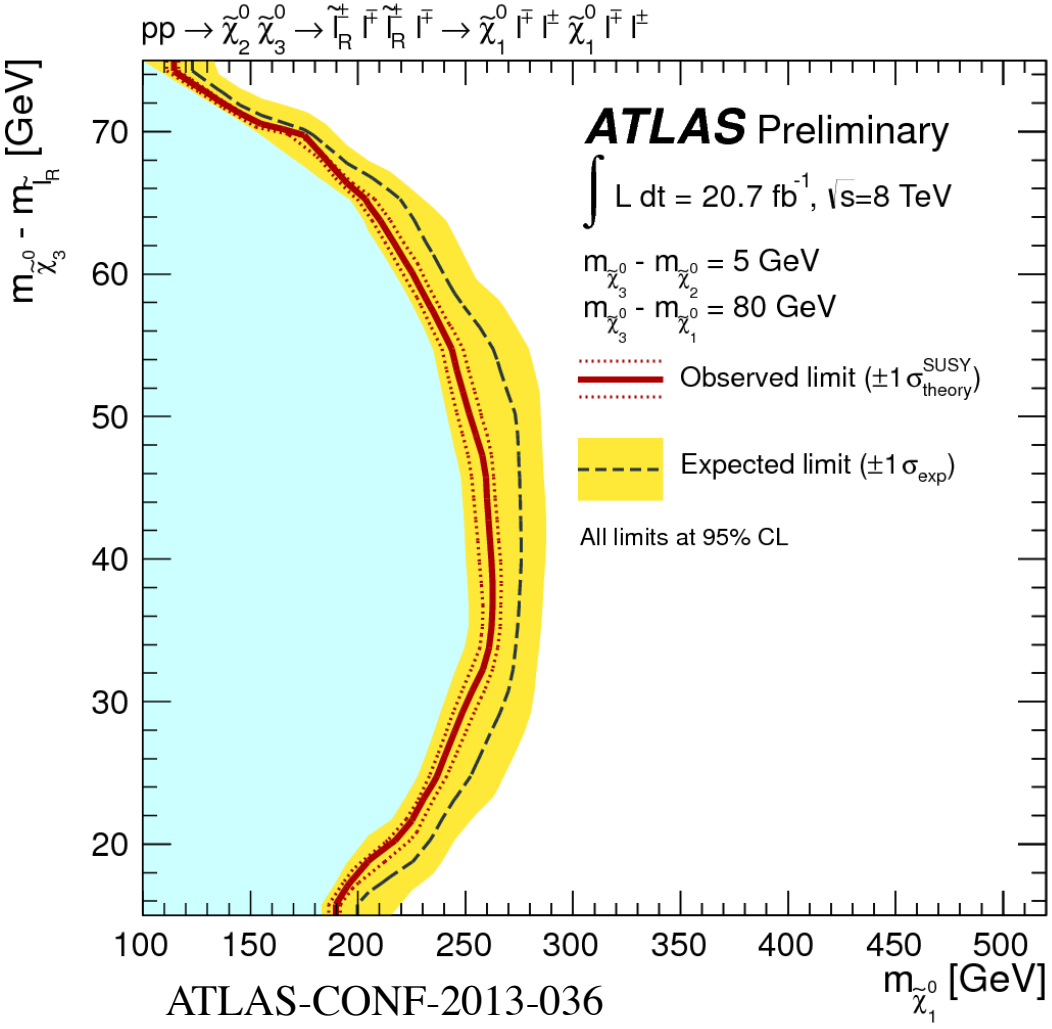


ATLAS-CONF-2013-035

- exclude charginos and neutralinos masses up to 315 GeV if decay via W^*/Z^* to massless lightest neutralino

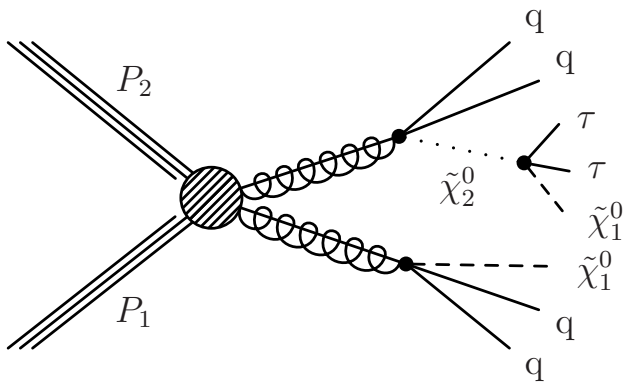
Search for Neutralino with Four Leptons

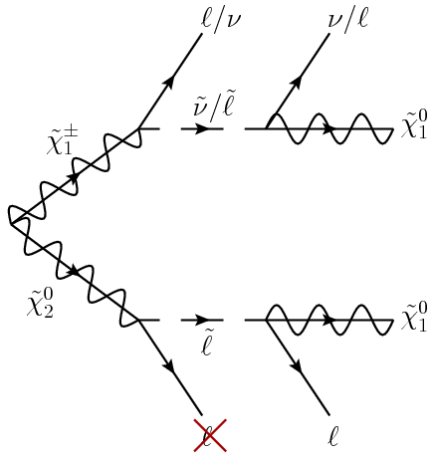


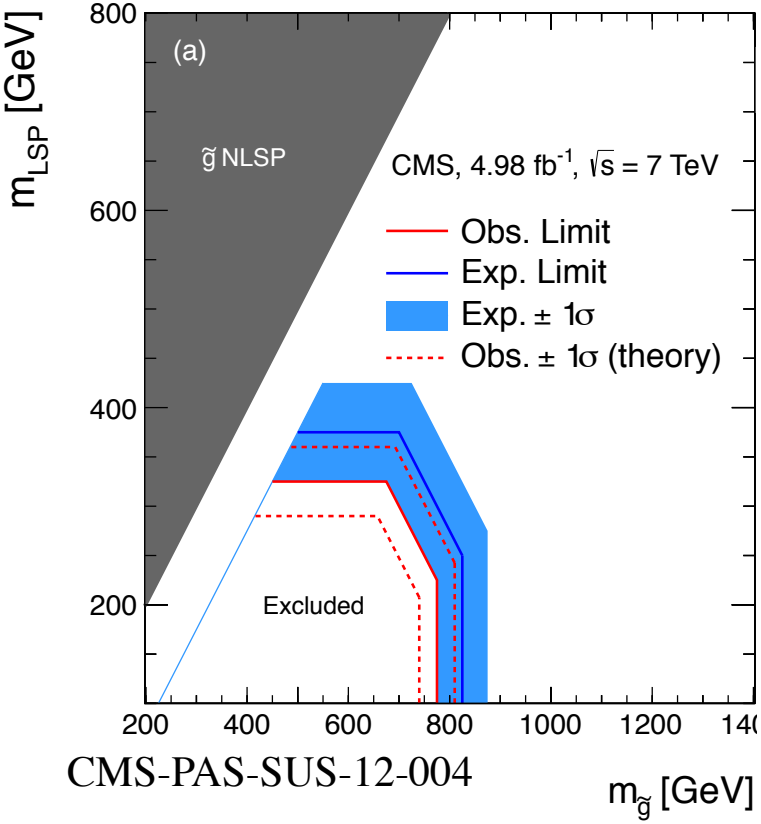


ATLAS-CONF-2013-036

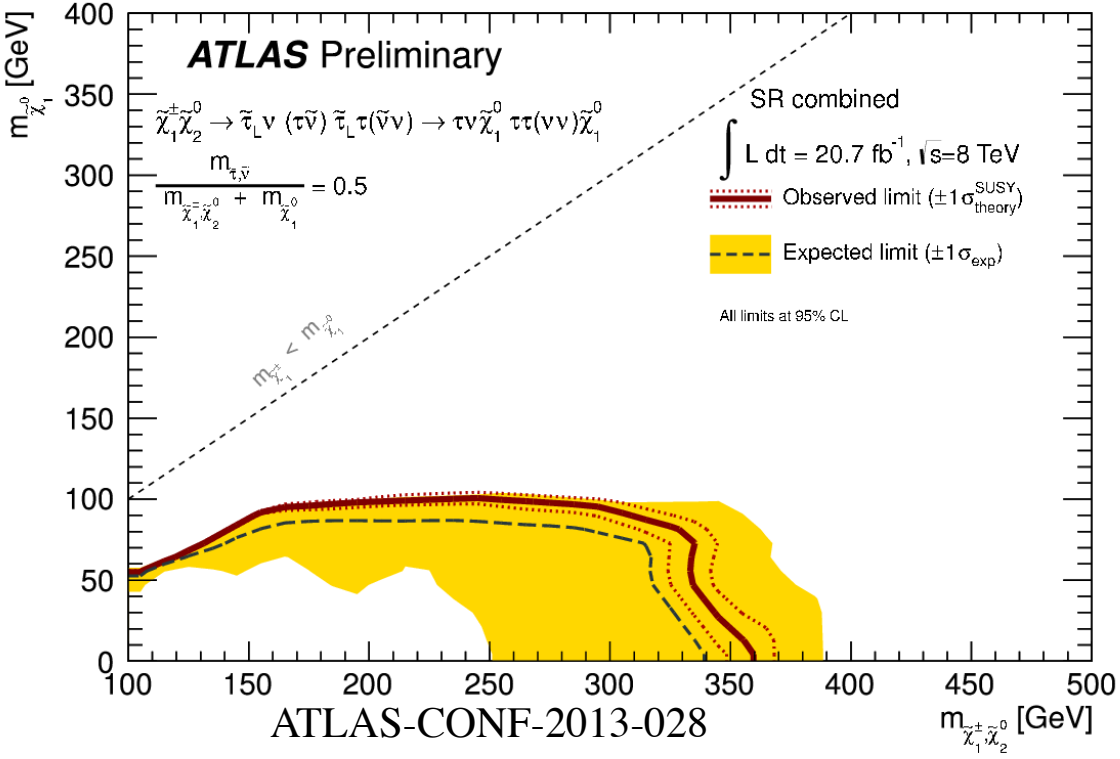
Search with τ Leptons







CMS-PAS-SUS-12-004



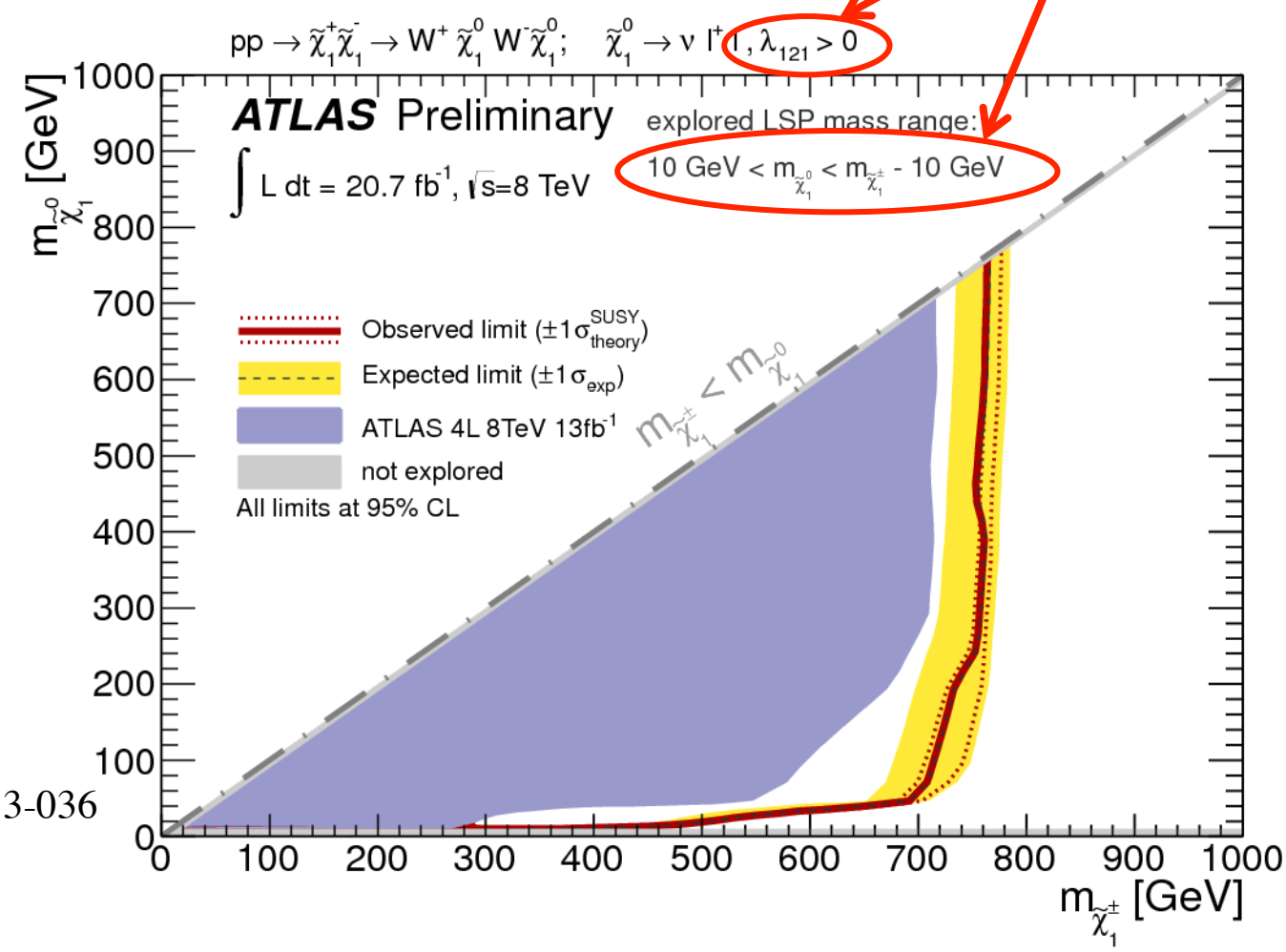
ATLAS-CONF-2013-028

Search for R-Parity Violating SUSY

$$pp \rightarrow \tilde{\chi}_1^+ \tilde{\chi}_1^- \rightarrow W^+ \tilde{\chi}_1^0 W^- \tilde{\chi}_1^0$$

$$\tilde{\chi}_1^0 \rightarrow \ell^+ \ell^- \nu$$

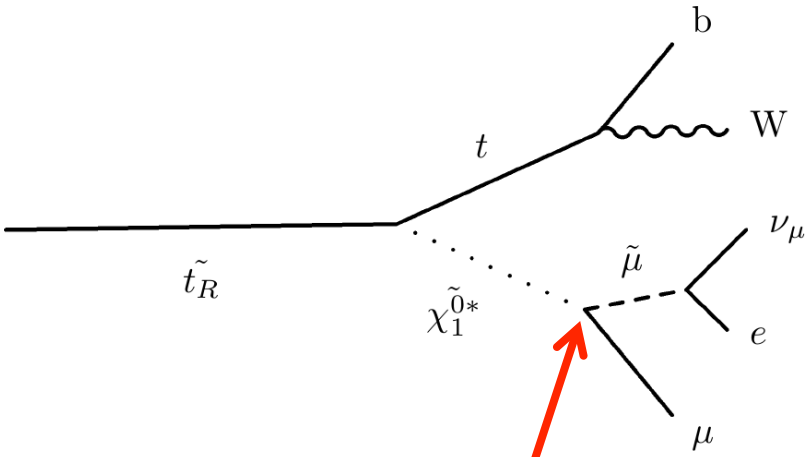
Many other searches with different assumptions

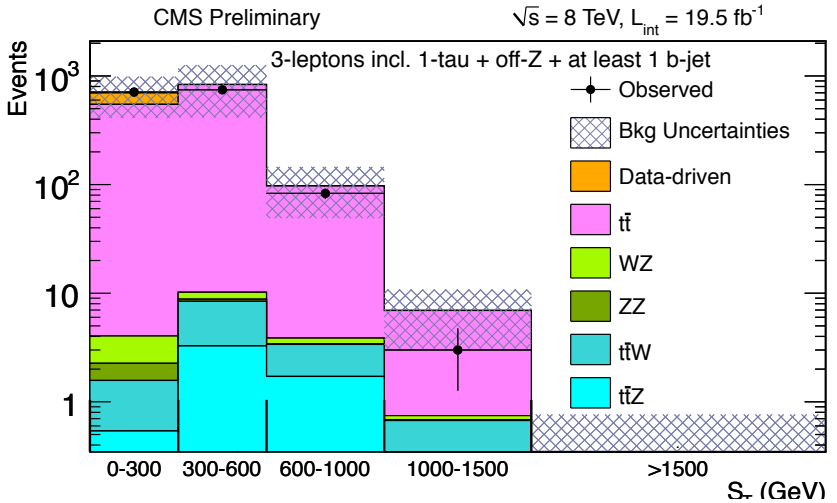


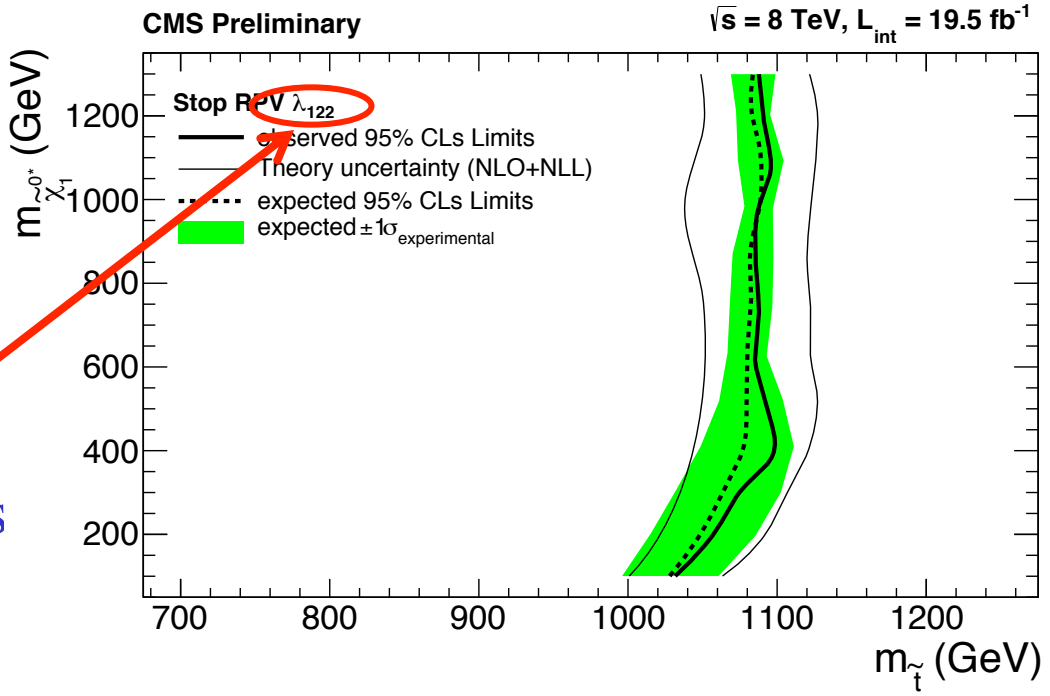
ATLAS-CONF-2013-036

Search for R-Parity Violating SUSY

- Search for ≥ 3 leptons (≥ 0 τ) + ≥ 1 *b*-jets



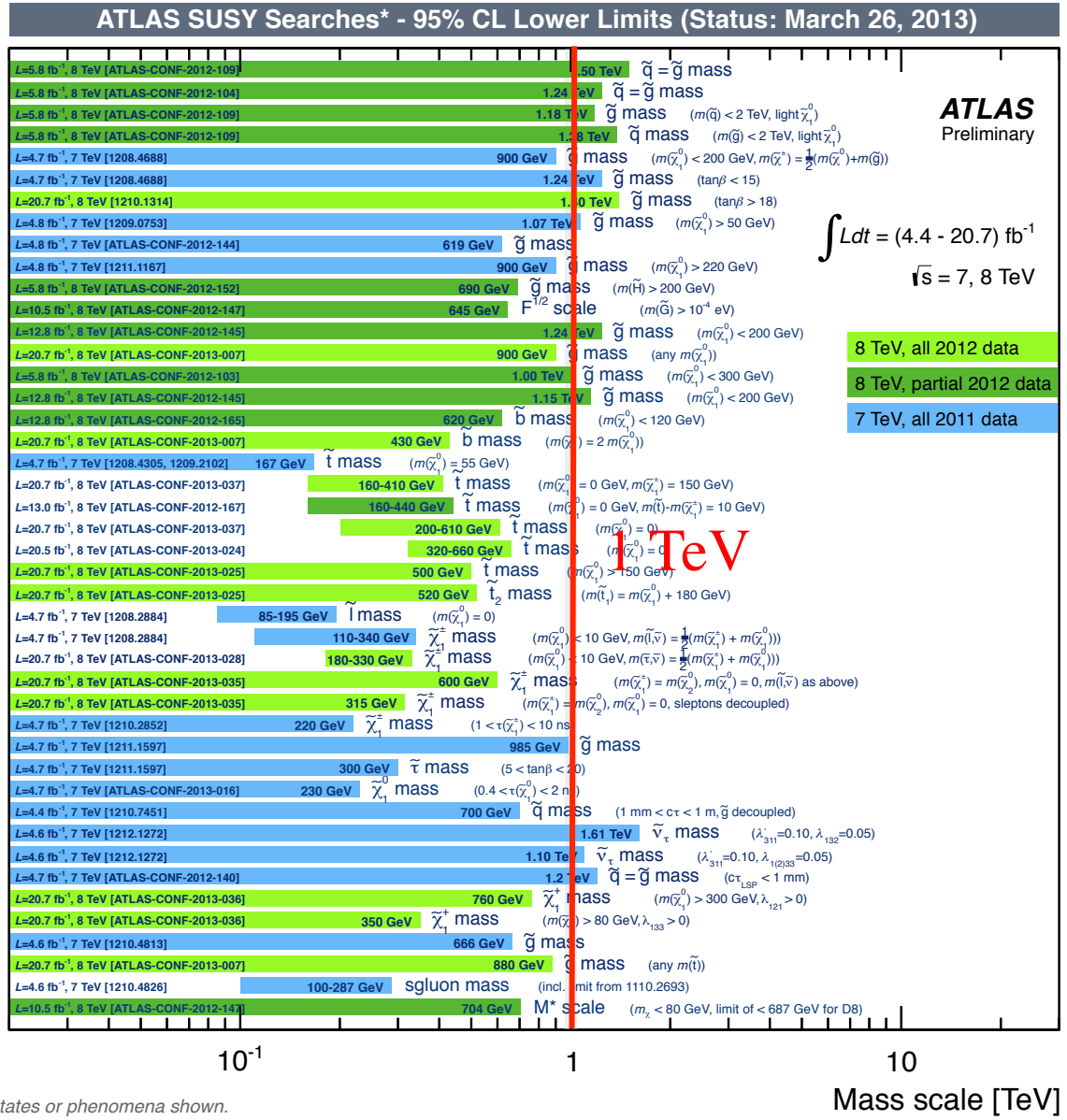




Many other searches with different assumptions

K.K. Gan

Summary of ATLAS SUSY Searches



Inclusive

Gluinos

Squarks

1 TeV

Neutralinos

Long lived

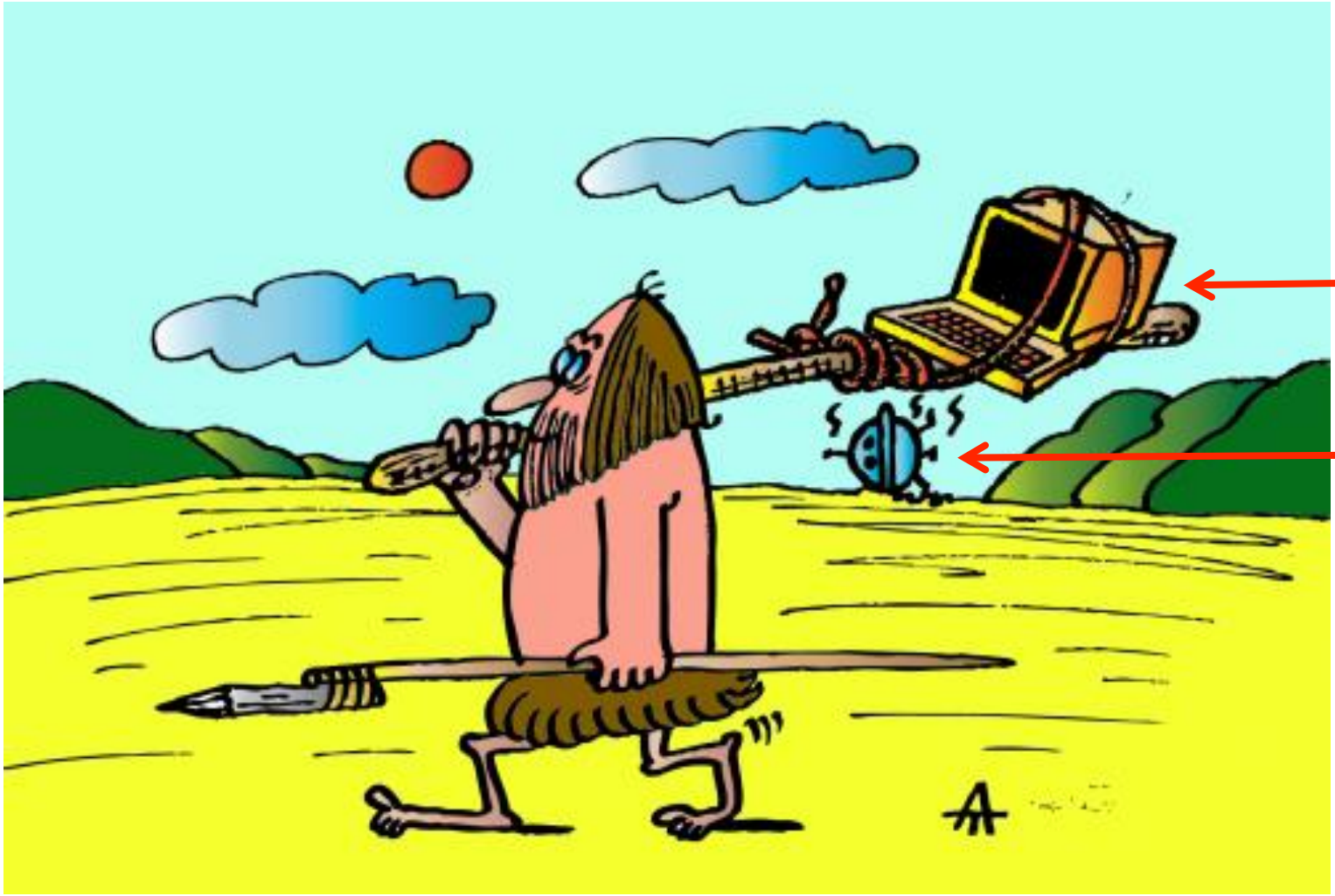
RPV

*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.

Summary of SUSY Searches

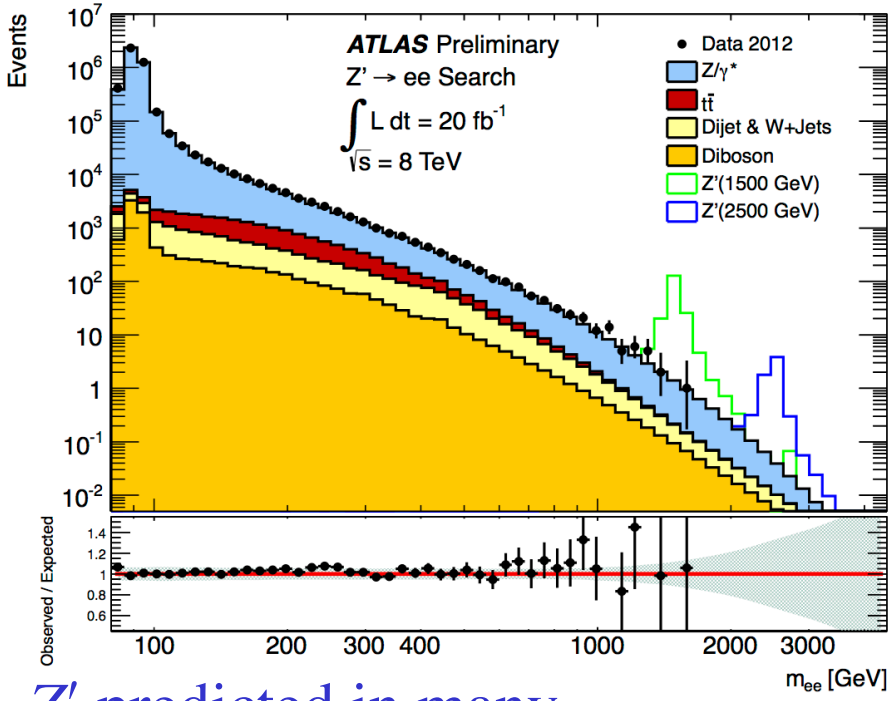
- No sign of SUSY yet but…
  - SUSY has many free parameters…
  - ⇨ difficult to totally exclude SUSY
  - ⇨ provide job security…
  - ⇨ experimenters (and theorists) love SUSY

Hunting in the Exotic Land

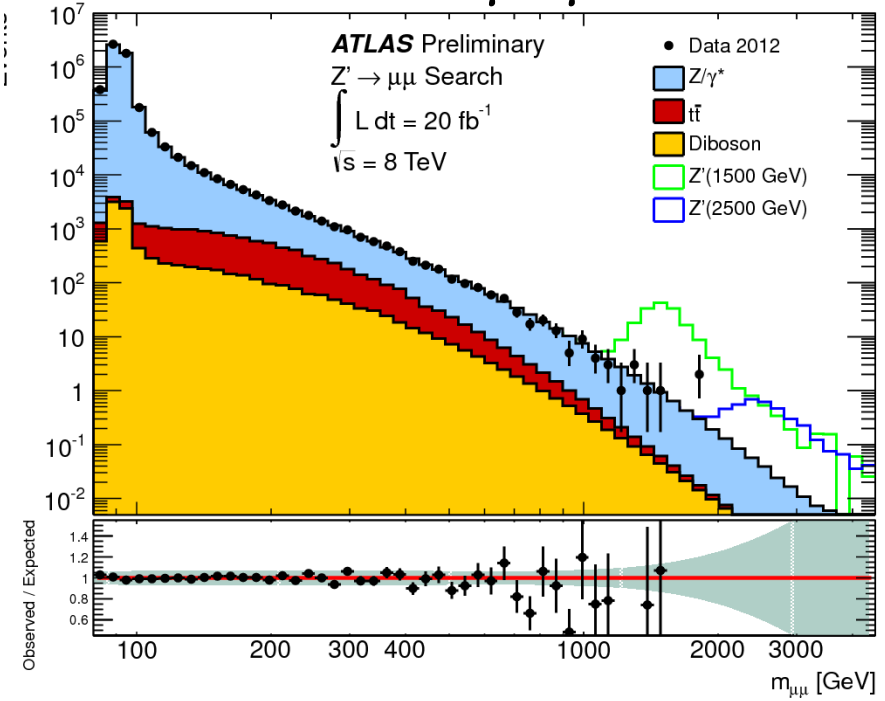


Search for Dilepton Resonances

$Z' \rightarrow e^+e^-$



$Z' \rightarrow \mu^+\mu^-$

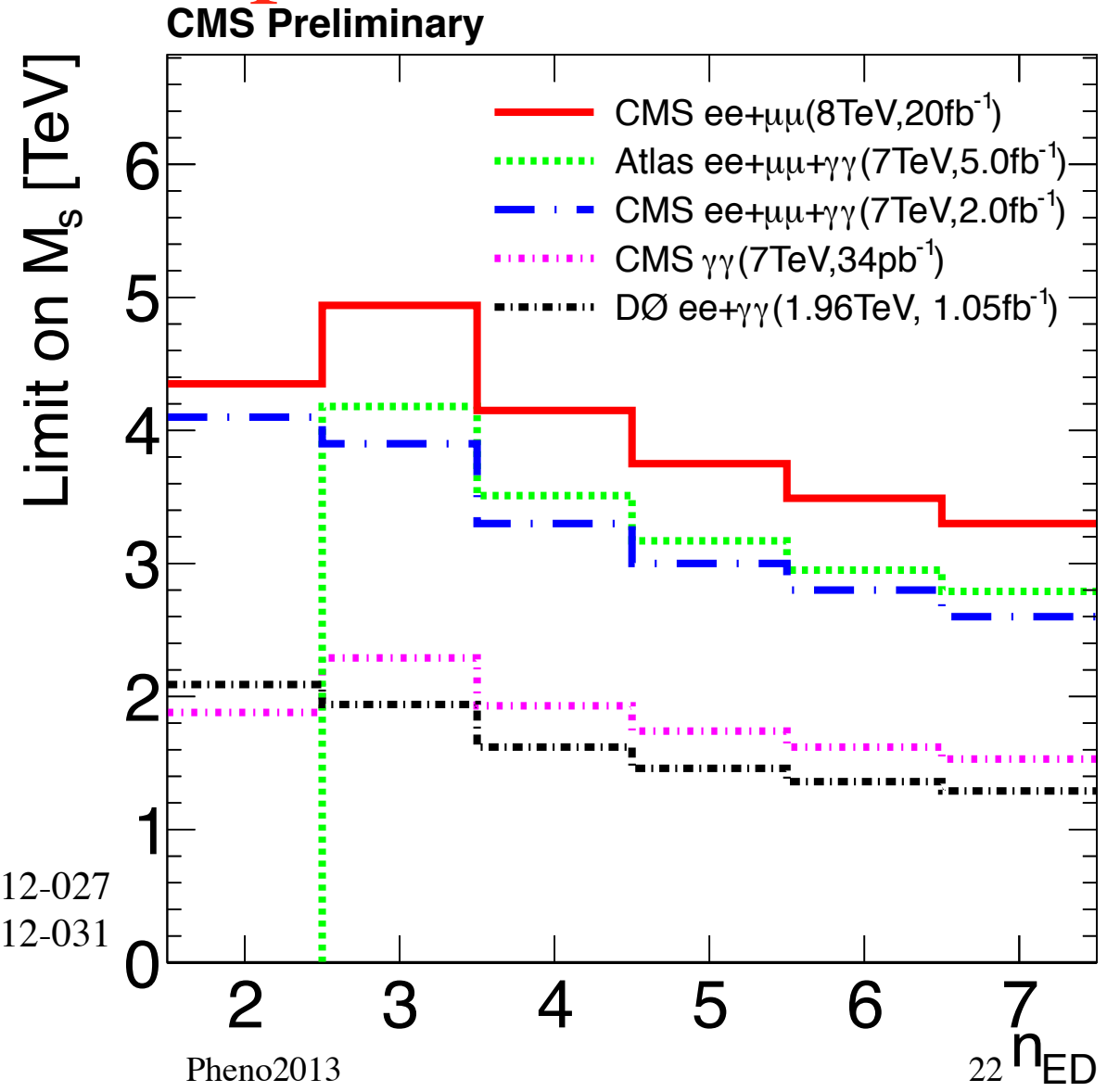


- Z' predicted in many beyond SM theories:
  - sequential SM
  - extra dimensions
  - grand unification models

M(TeV)@95%CL	e^+e^-	$\mu^+\mu^-$	l^+l^-
Sequential SM	2.79	2.48	2.86
E6 (6 models)			2.38-2.54
Graviton (G^*)	2.40	2.10	2.47

Search for Dilepton Resonances

- ADD solution to hierarchy problem:
  - SM particles in 4D
  - gravity in $4+n_{ED}$ dimensions
  - KK graviton could enhance dilepton x-section



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

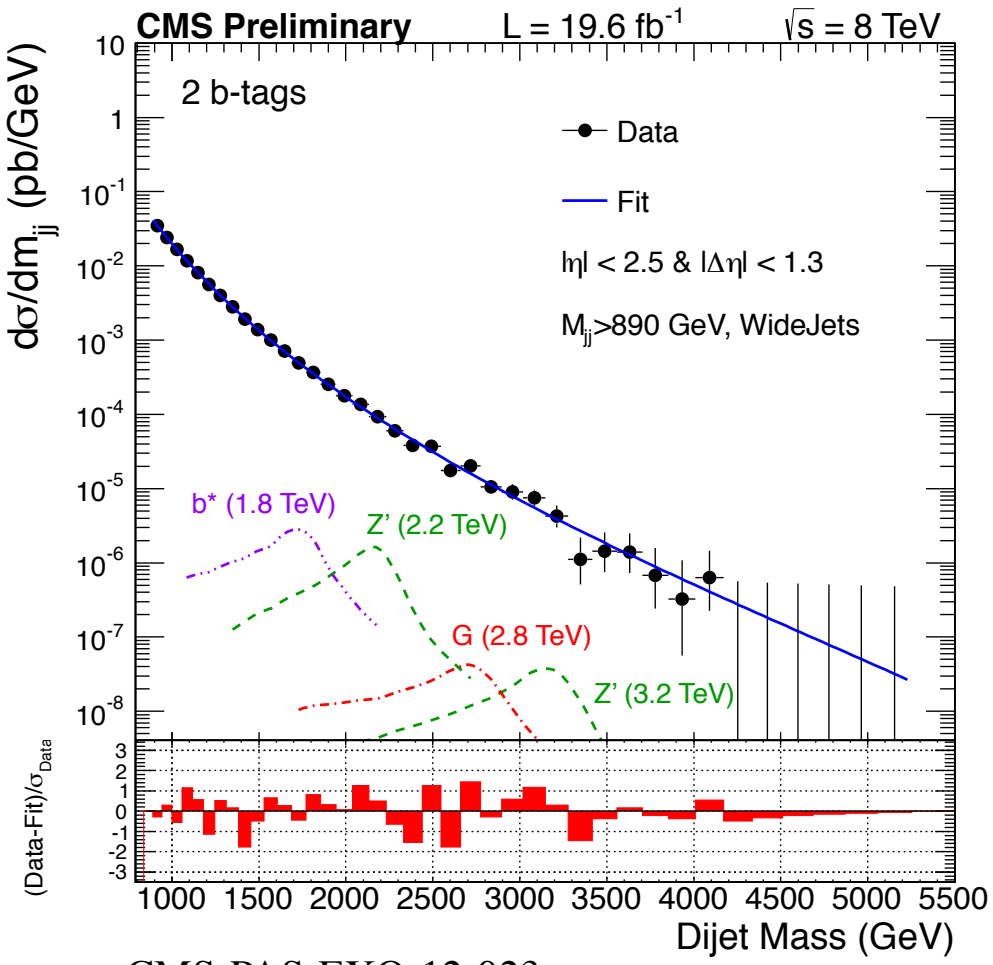
Search for Dijet Resonances

$Z' \to b\bar{b}$ or bg

- search for events with up to 2 b-jets

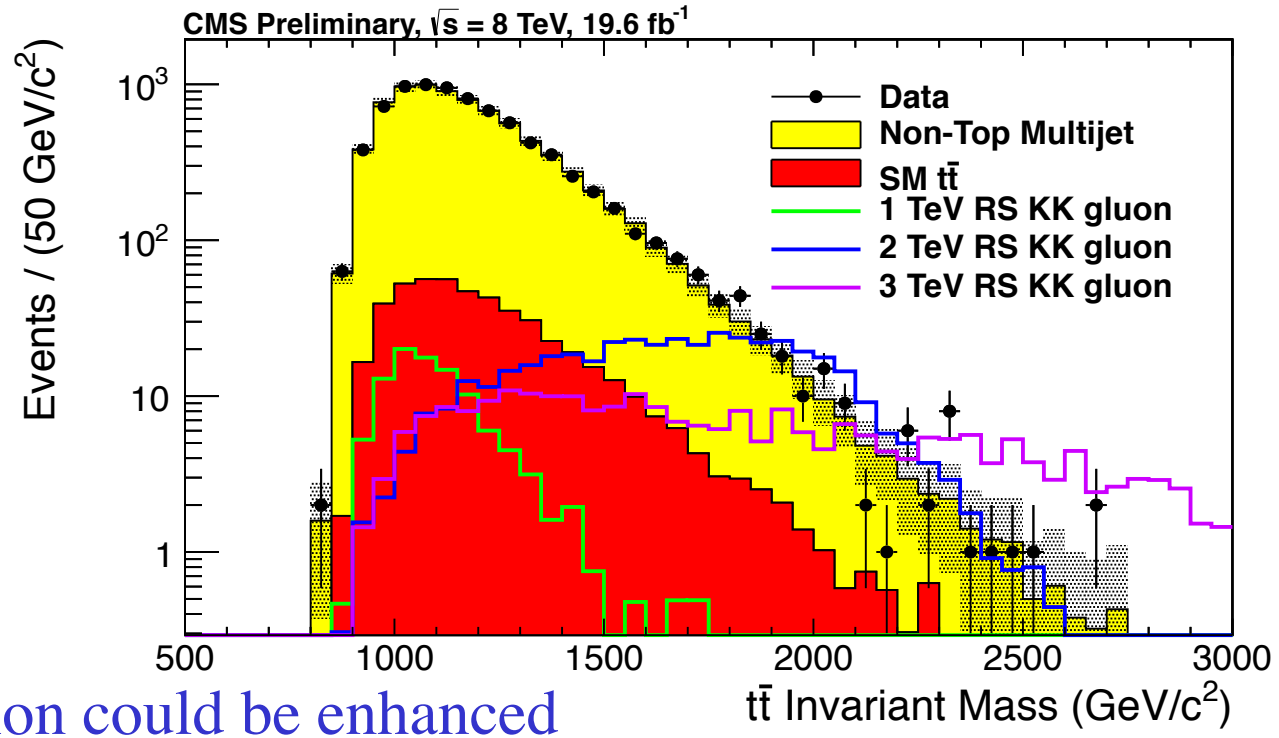
Excluded mass (TeV) @ 95% CL

Sequential SM	1.20-1.68
Graviton (G^*)	1.42-1.57
b^*	1.34-1.54



CMS-PAS-EXO-12-023

Search for Dijet Resonances



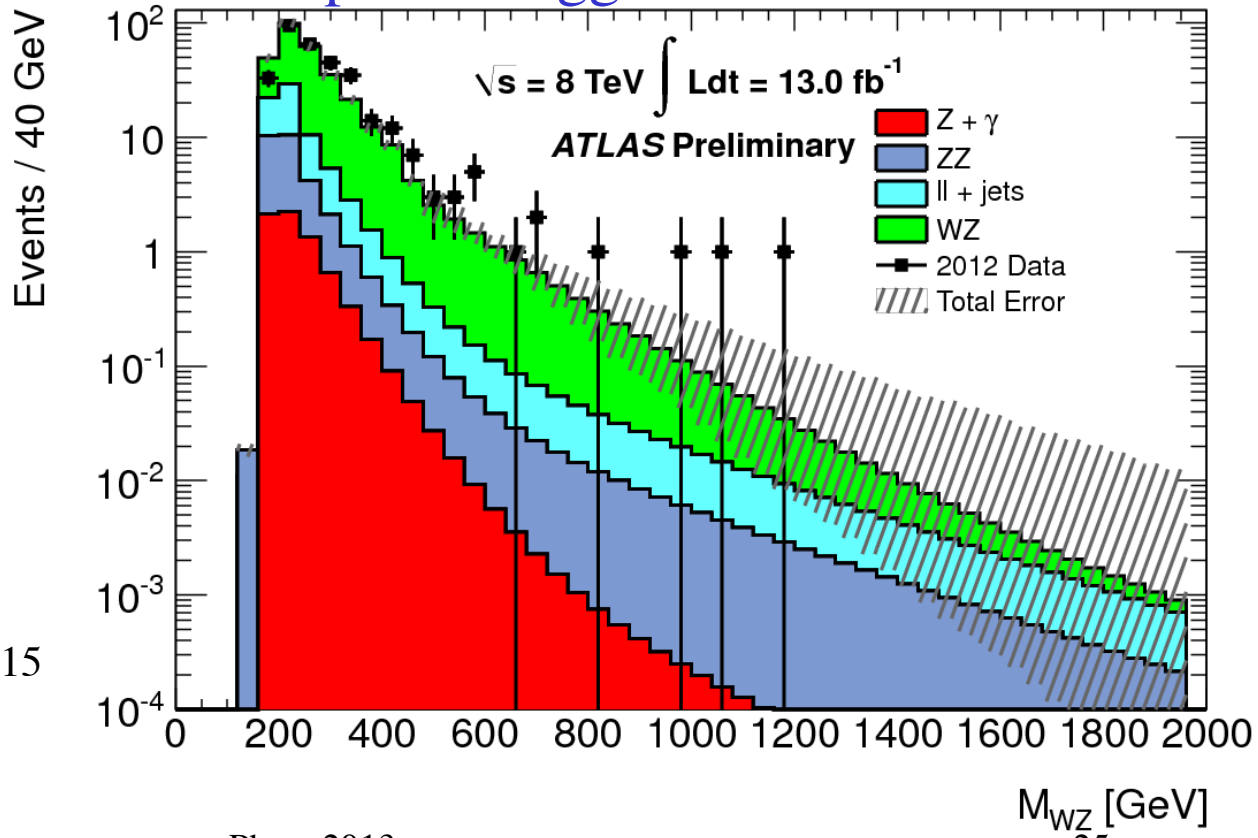
- Top-pair x-section could be enhanced due to RS KK gluon, Z'

CMS-PAS-B2G-12-005

- Reconstruct highly boosted tops with merged hadronic jets
- Exclude KK gluon < 1.8 TeV @ 95% CL
- Also set limits on x-sections due to Z' or non-resonant enhancement

Search for *WZ* Resonances

- *WZ* resonances predicted in many beyond SM theories:
  - technirho (ρ_T) in Technicolor models
  - new heavy gauge boson in composite Higgs models
- search for resonances in 3-lepton final state
- limits @95% CL:
  - M(W') > 1.18 TeV
  - M(ρ_T) > 0.92 TeV



ATLAS-CONF-2013-015

Search for Heavy Fermions

- Type III seesaw model: include a not so-heavy triplet (N^+, N^-, N^0) to generate a reciprocal seesaw mechanism

$$pp \to N^0 N^\pm$$

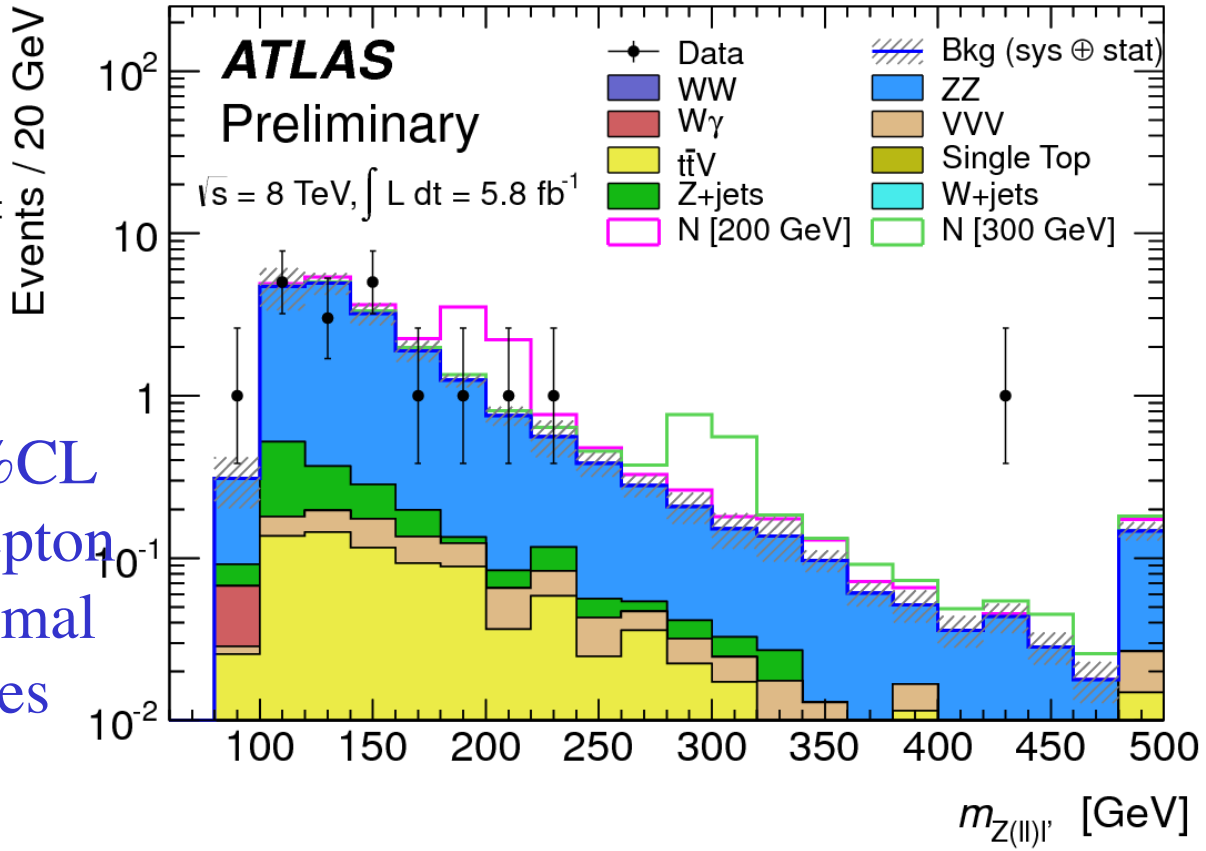
$$N^0 \to W^\pm \ell^\mp$$

$$N^\pm \to \ell^\pm Z \to \ell^\pm \ell'^\pm \ell'^\mp$$

⇨ search for Z + 2 leptons

⇨ $M > 245$ GeV @95%CL for nominal heavy lepton branching with maximal allowed mixing angles

ATLAS-CONF-2013-019



Search for Vector-Like Quarks

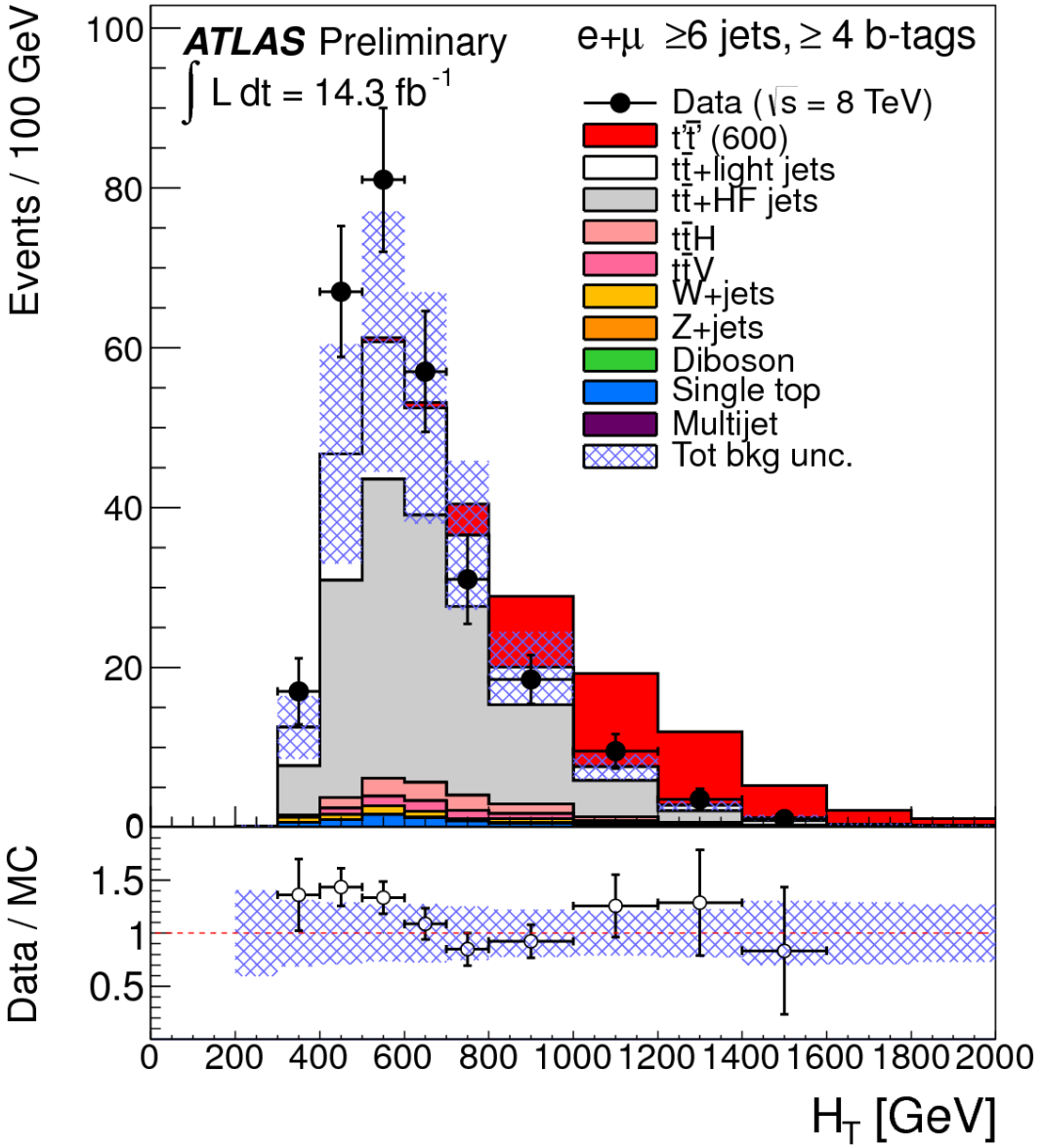
- Weak Isospin singlet:
  $t' \rightarrow Wb, Zt, Ht$
- Weak Isospin doublet:
  $t' \rightarrow Zt, Ht$
- Production/decay of interest:
  $t'\bar{t}' \rightarrow Ht\bar{H}\bar{t}, Zt\bar{H}\bar{t}, Wb\bar{H}\bar{t}$

  $H \rightarrow b\bar{b}$

  ⇨ search for lepton + ≥ 6 jets (≥ 2 b jets)

- Weak-isospin doublet:
  mass > 790 GeV @95%CL
- Weak-isospin singlet:
  mass > 640 GeV @95%CL

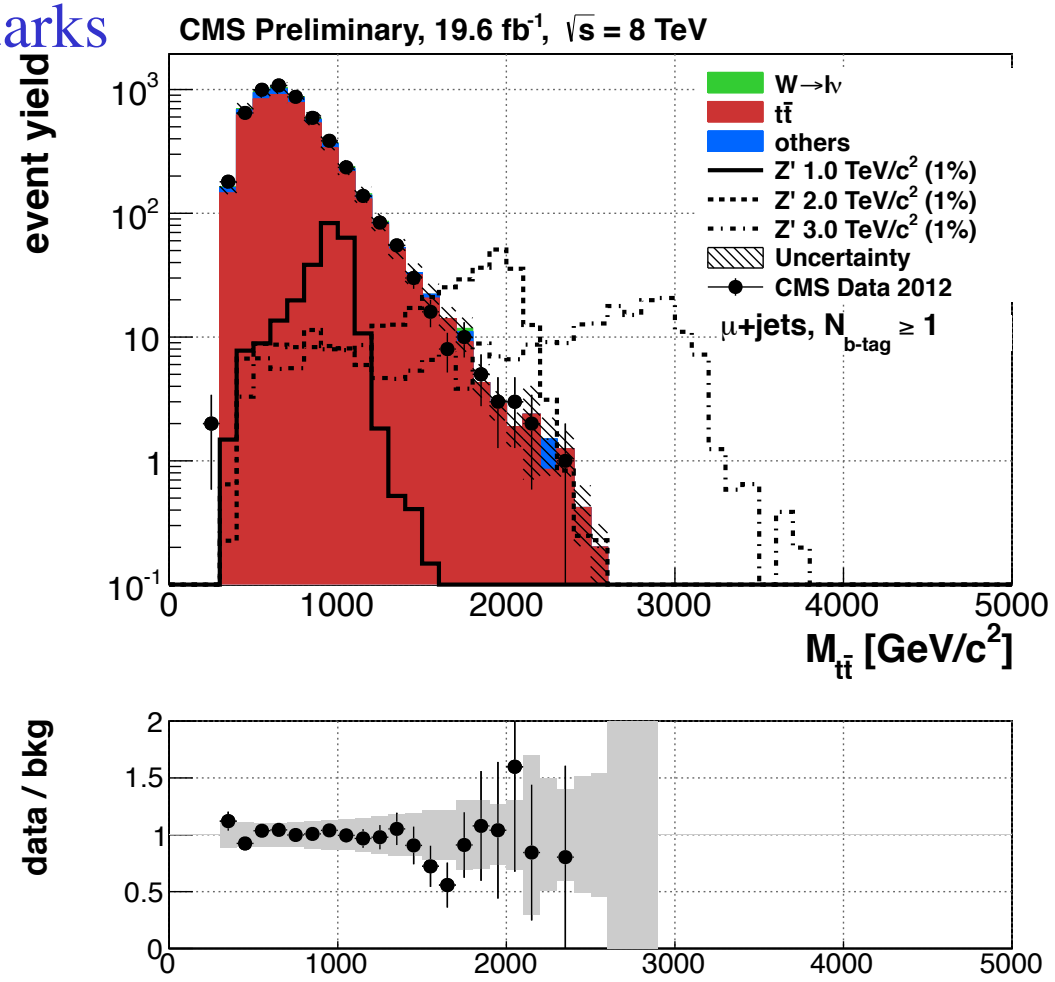
ATLAS-CONF-2013-018



Search for Top-Pair Resonace

- Many BSM theories predicts enhanced couplings to 3rd generation quarks
- Search for e/μ + ≥ 2 jets
- Some examples of 95% CL mass exclusion limits:
  - Topcolor Z'
    $\Gamma/M = 1.2\%$: M > 2.1 TeV
    $\Gamma/M = 10\%$: M > 2.7 TeV
  - KK excited gluon
    in RS model: M > 2.5 TeV
- Also set limits on x-sections times branching ratio of other models (not shown)

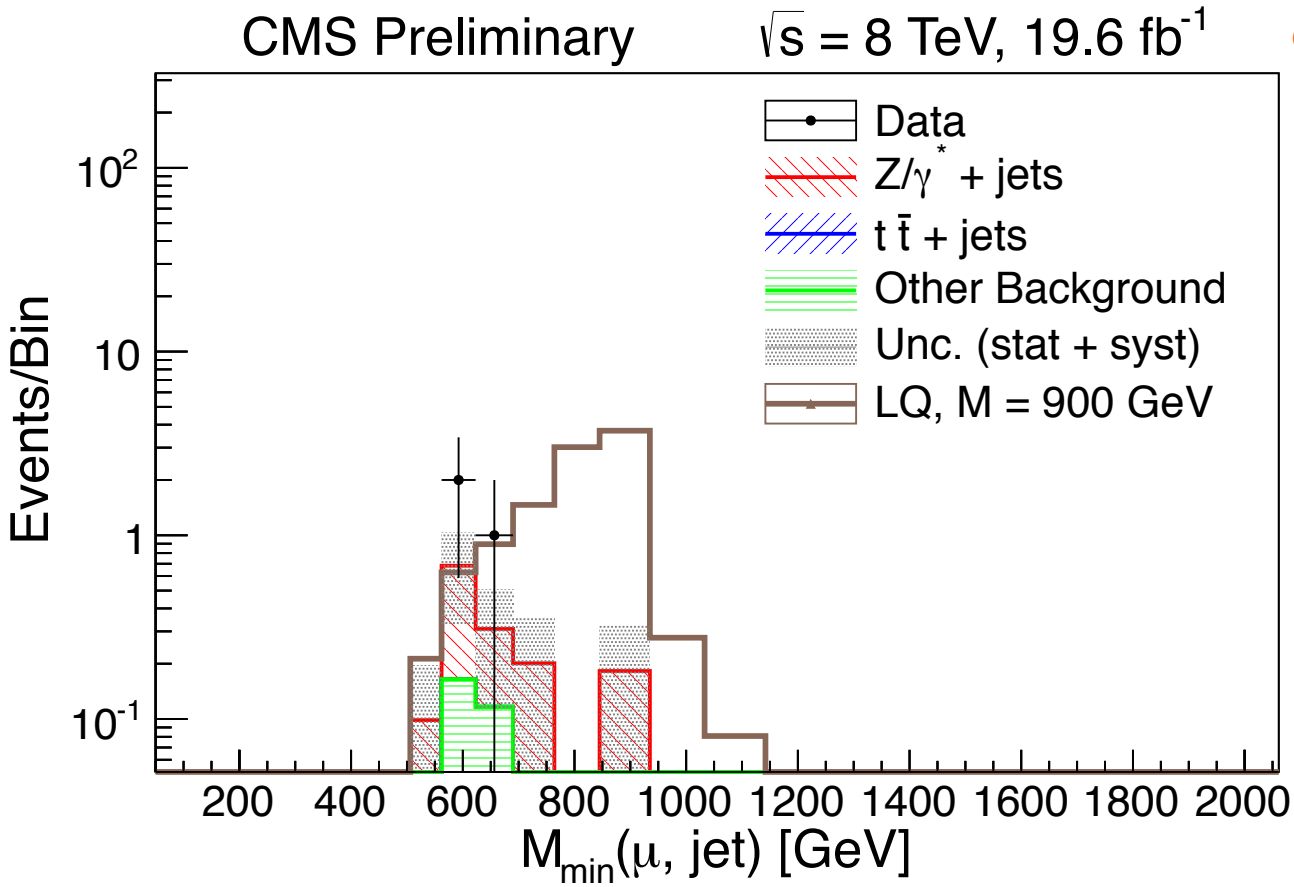
CMS-PAS-B2G-12-006



Search for 2nd Generation Lepto-Quark

- Lepto-quarks are predicted in grand unified theories, technicolor, and composite models

$$LQLQ \rightarrow \mu q \mu q \rightarrow 2\mu + 2\,jets$$

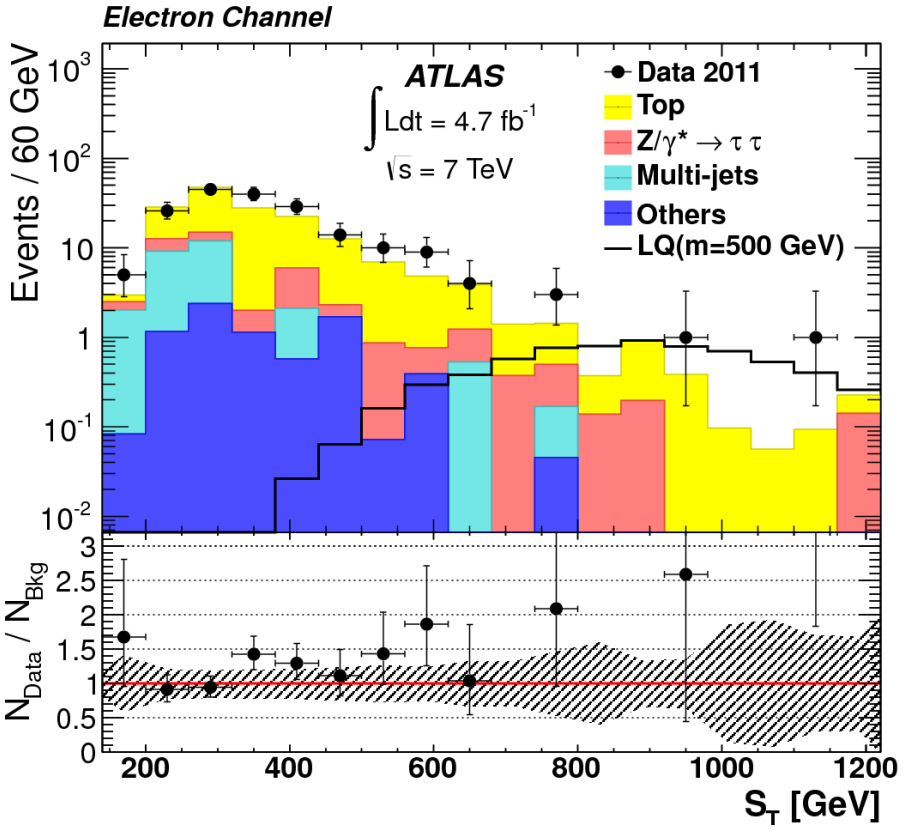


- M(LQ) > 1.07 TeV @95%CL

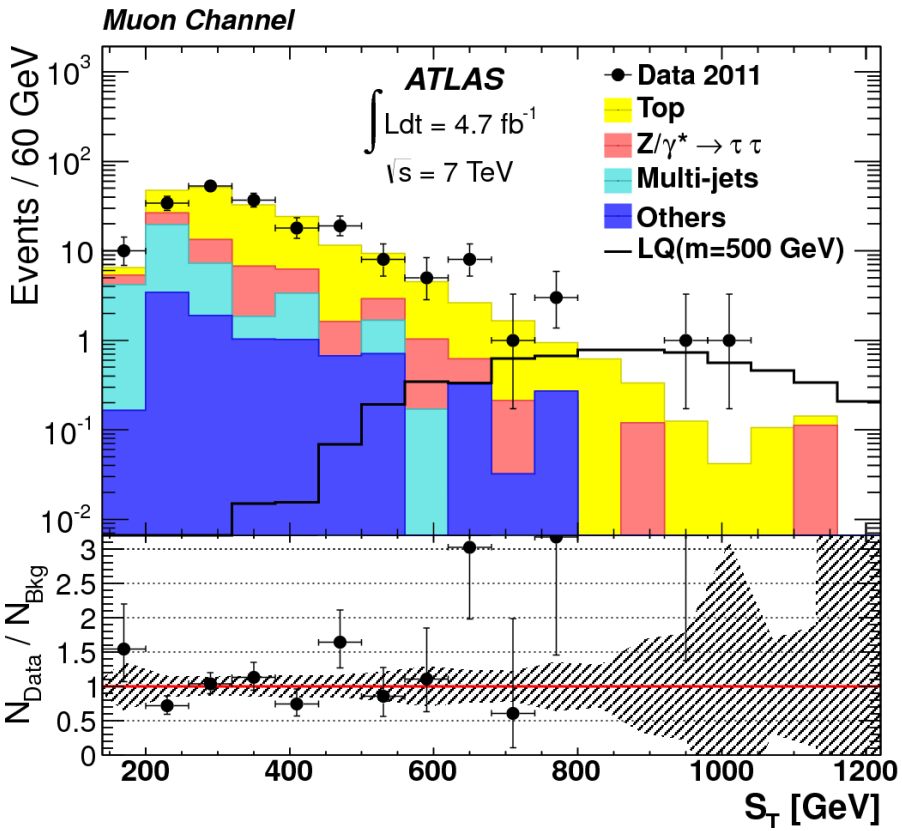
CMS-PAS-EXO-12-042

Search for 3rd Generation Lepto-Quark

$LQLQ \rightarrow \tau b \tau b \rightarrow e - hadron\ bb$



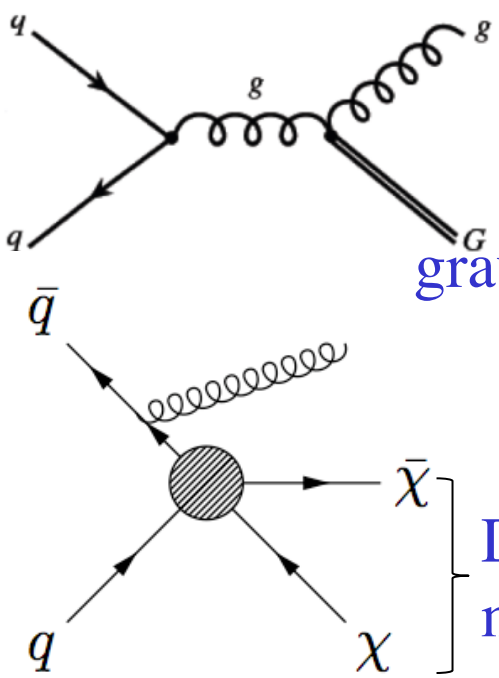
$LQLQ \rightarrow \tau b \tau b \rightarrow \mu - hadron\ bb$



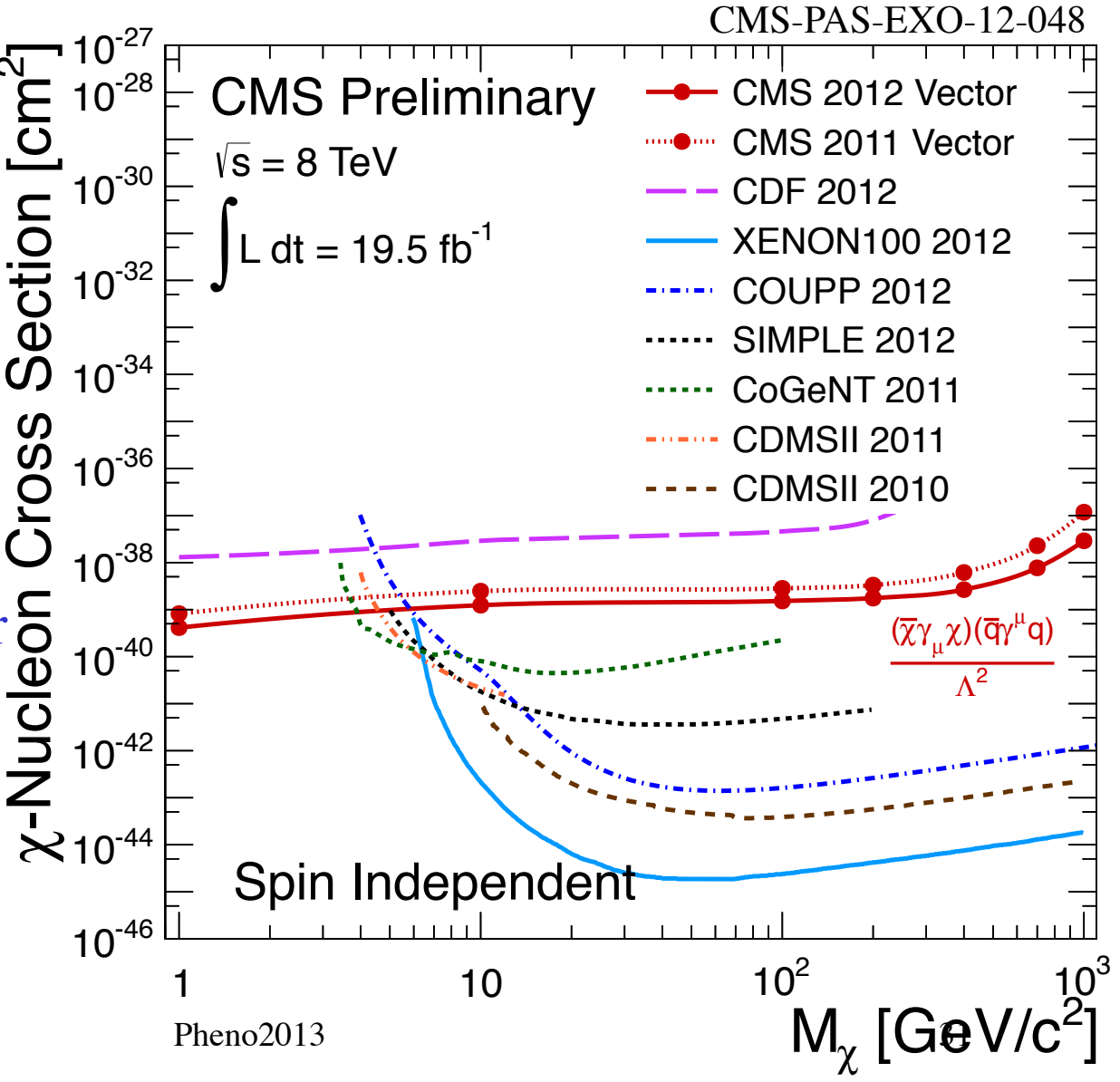
- Search for enhancement in scalar sum of transverse momentum (S_T)
- Mass > 534 GeV @95%CL

arXiv:1303.0526

Search for Monojet

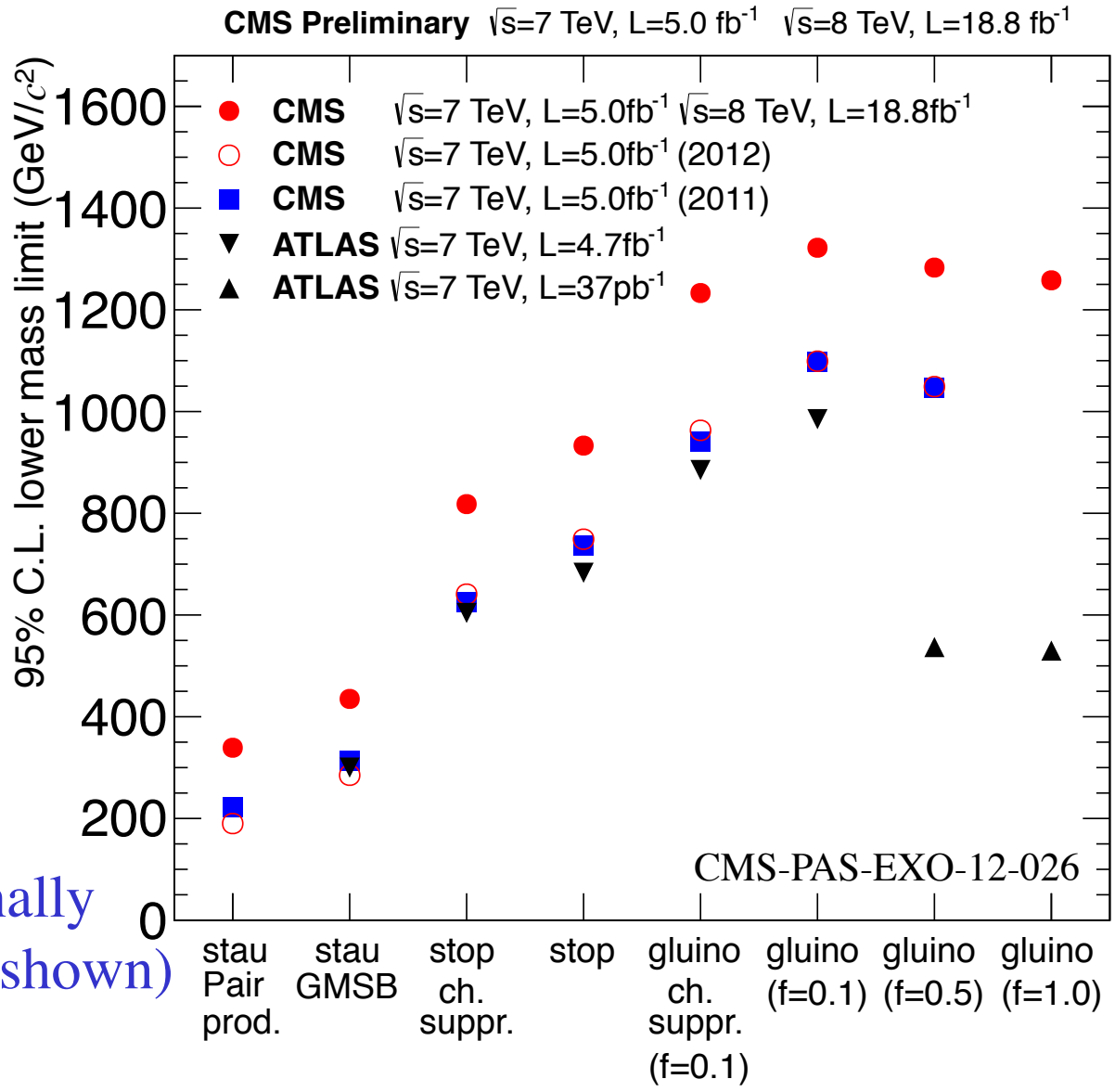


- Limits on extra dimensions, unparticle etc not shown



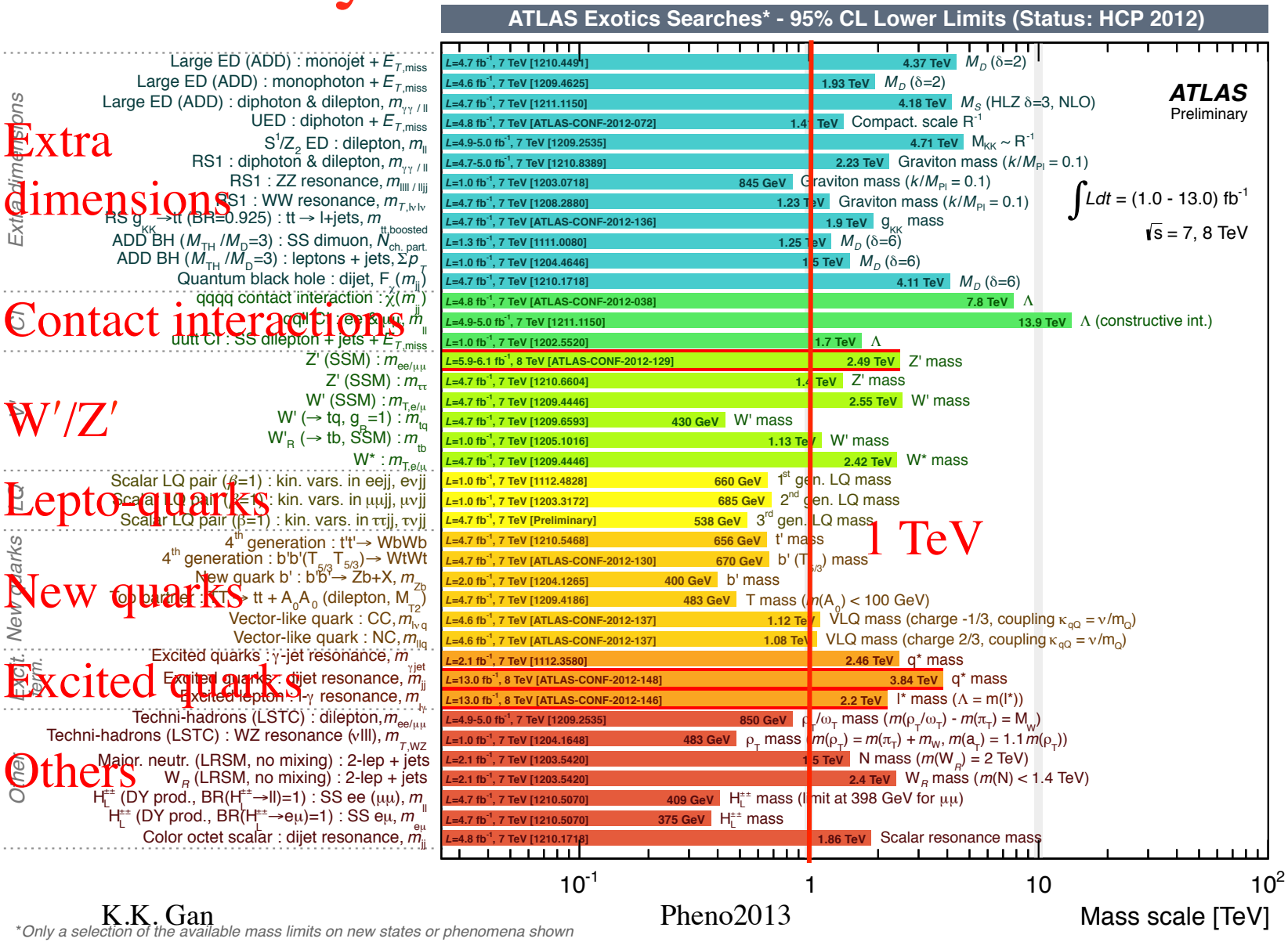
Search for Long-Lived Particles

- Many BSM have heavy, long-lived charged particles that are slow or have fractional or multiple charges ($\geq 2\,e$)
- Search for long lived charged particles with
  - high/low ionizing energy loss (dE/dx)
  - long time of flight
- Also limits on fractionally charged particles (not shown)



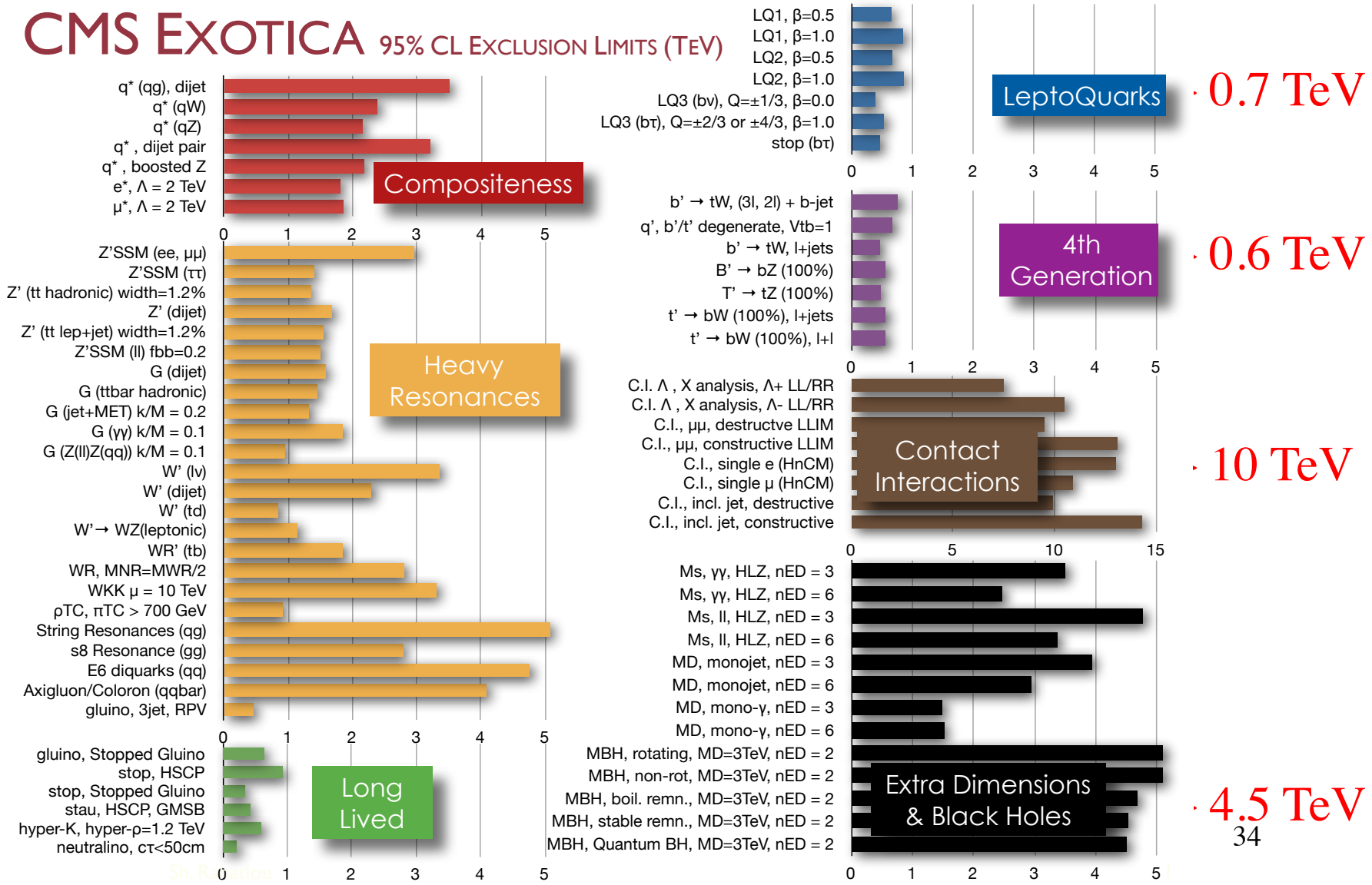
K.K. Gan

Summary of ATLAS Exotic Searches



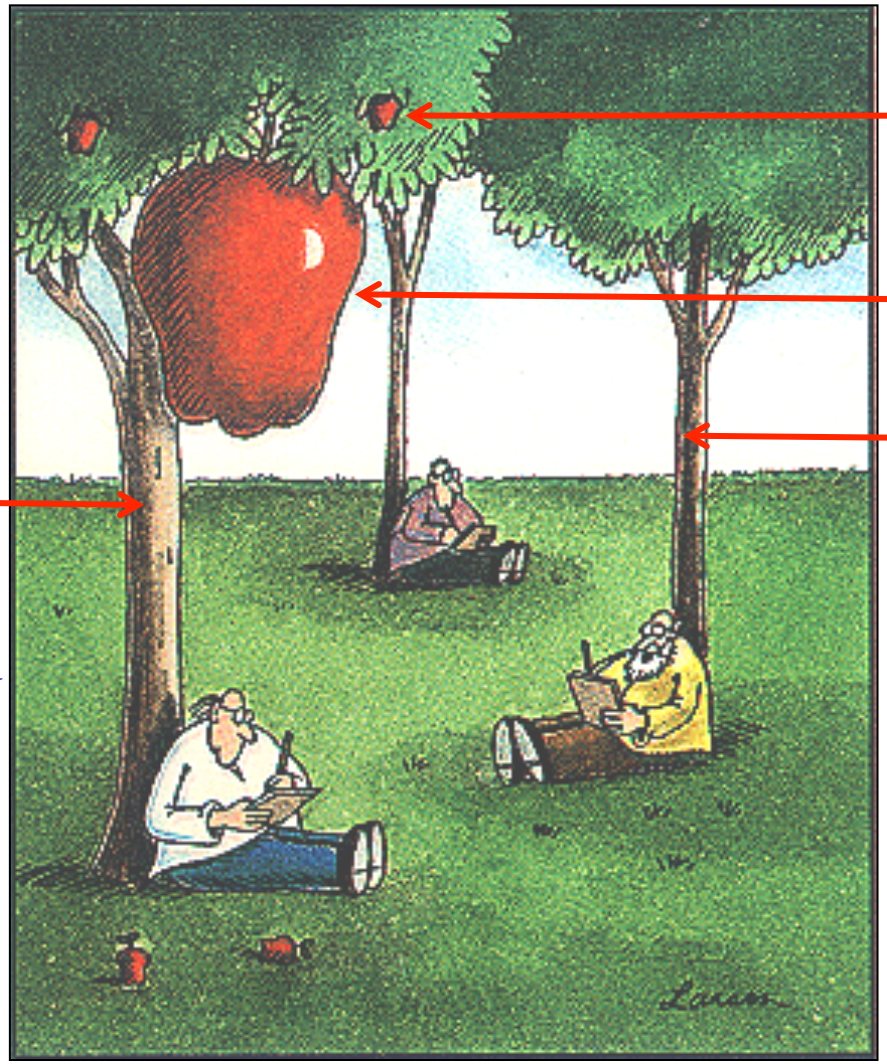
*Only a selection of the available mass limits on new states or phenomena shown

Summary of CMS Exotic Searches



Physicists busy searching for new particles with papers and pens…

Nothing new yet…



- Restart LHC in 2014 at ~13 TeV
  - expect 300 fb^{-1} by 2017