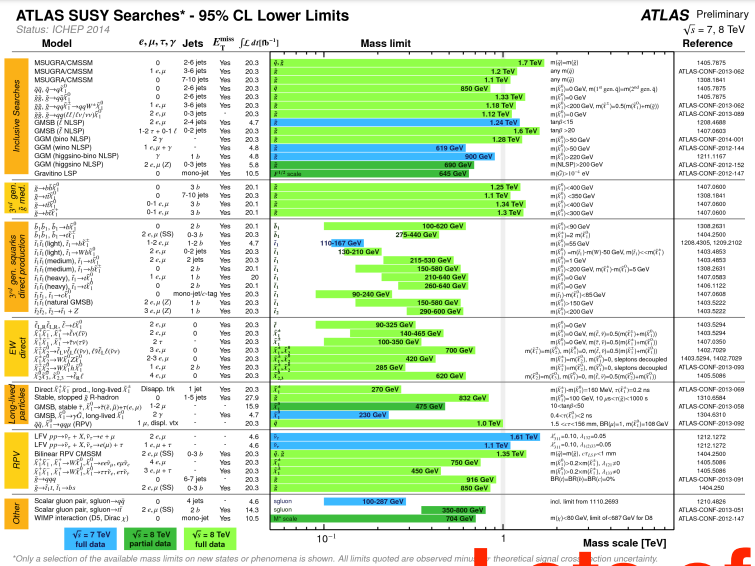
# Fun with Excesses

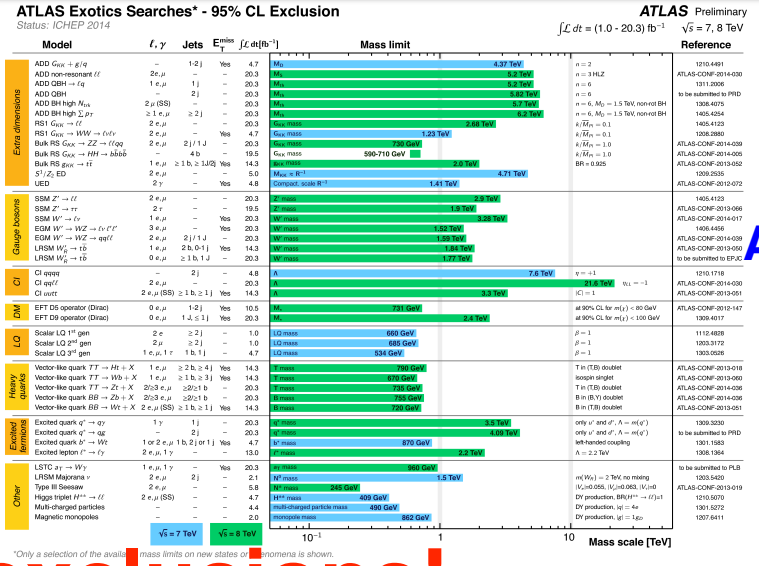
Ben Hooberman

# Exclusions

ATLAS SUSY

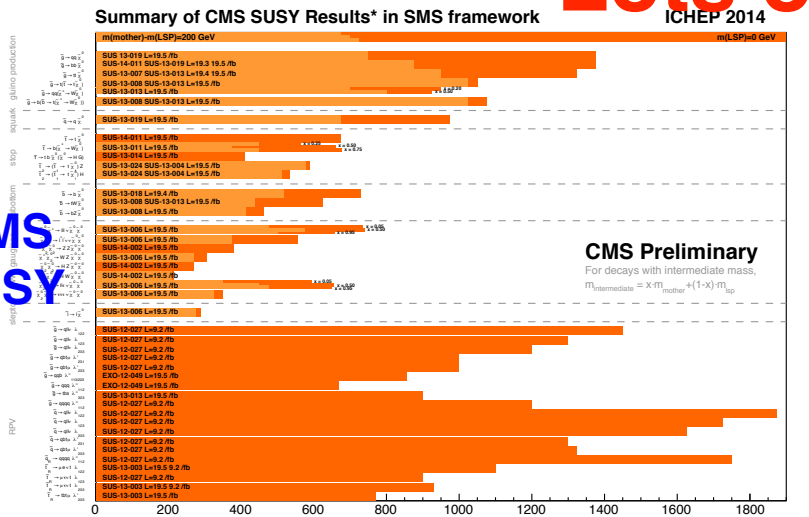



ATLAS EXO

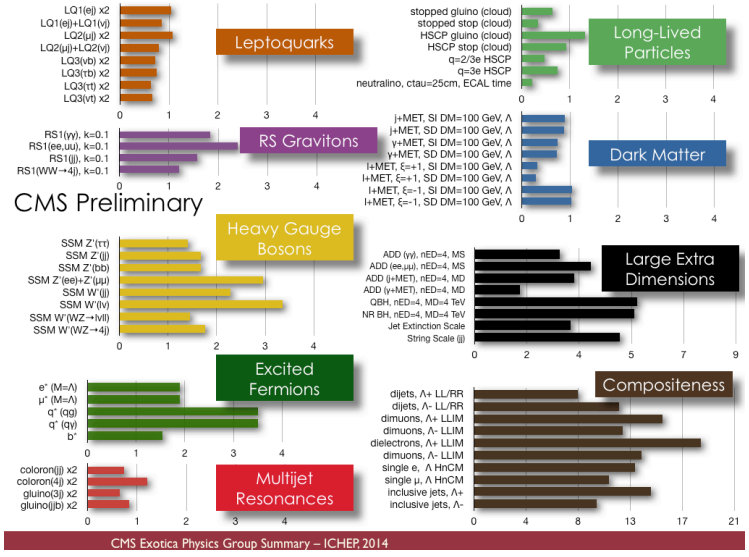



• Lots of exclusions!

CMS SUSY



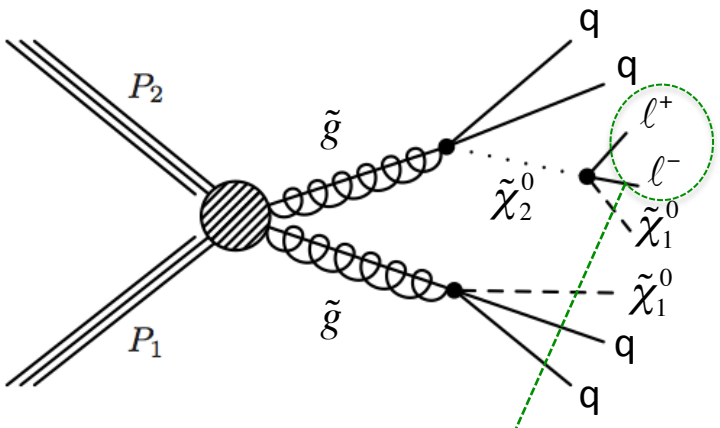

CMS EXO



# Excesses

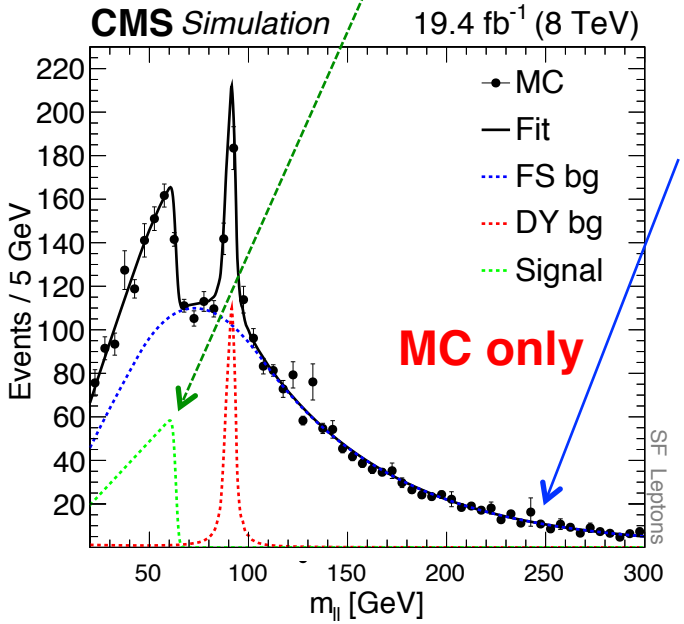
- …but very few excesses
- Expect several 3σ fluctuations, but almost none observed
- Will show personal selection of >2σ excesses
- Goals:
  - Make sure they're checked in run 2 (and by other experiment)
  - Identify cross-checks: kinematic distributions, background estimates, etc
  - Identify possible signal models ⟶ check other final states

# Dilepton Mass "Edge" Search



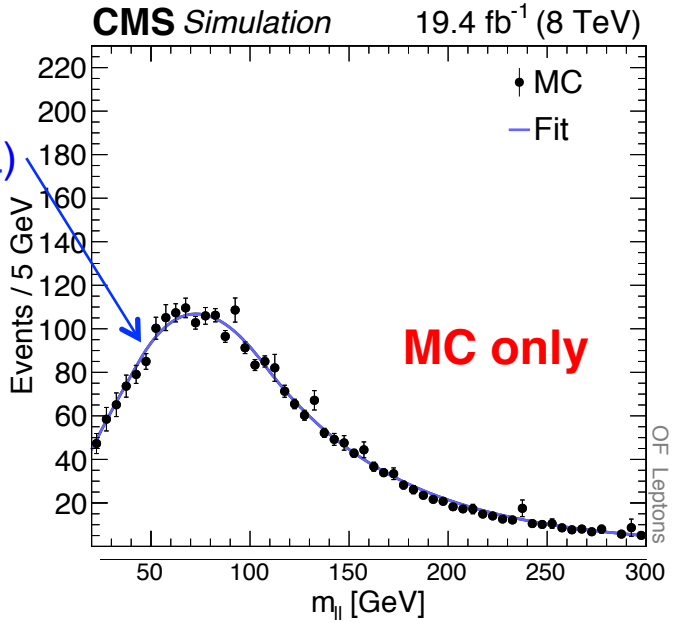

- Search for decay $\tilde{\chi}_2^0 \rightarrow \ell^+\ell^-\tilde{\chi}_1^0$
- $M_{\ell\ell}$ (sensitive variable) uses only clean, well-measured leptons
- Striking feature + simple background estimation (using eμ events)

**ee+μμ: search region**




ttbar
N(ee+μμ)=N(eμ)

**eμ: for bkg modeling**



# CMS Edge Results

2 e/μ leptons with $p_T > 20$ GeV and $|\eta| < 1.4$
($n_{jets} \geq 2$ AND $E_T^{miss} > 150$ GeV) OR
($n_{jets} \geq 3$ AND $E_T^{miss} > 100$ GeV)

## Counting experiment

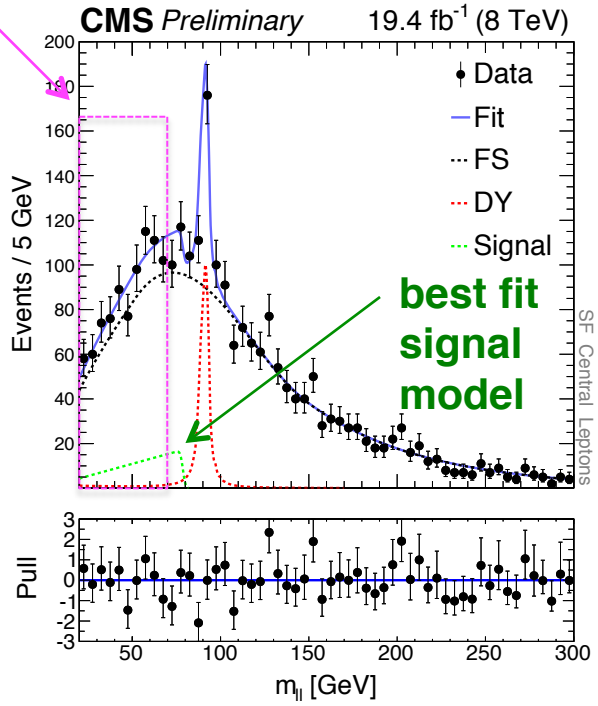
$20 < M_{\ell\ell} < 70$ GeV:

| | Central |
|---|---|
| Observed [SF] | 860 |
| Flav. Sym. [OF] | $722 \pm 27 \pm 29$ |
| Drell–Yan | $8.2 \pm 2.6$ |
| Total estimates | $730 \pm 40$ |
| Observed – Estimated | $130^{+48}_{-49}$ |
| Significance [$\sigma$] | 2.6 |

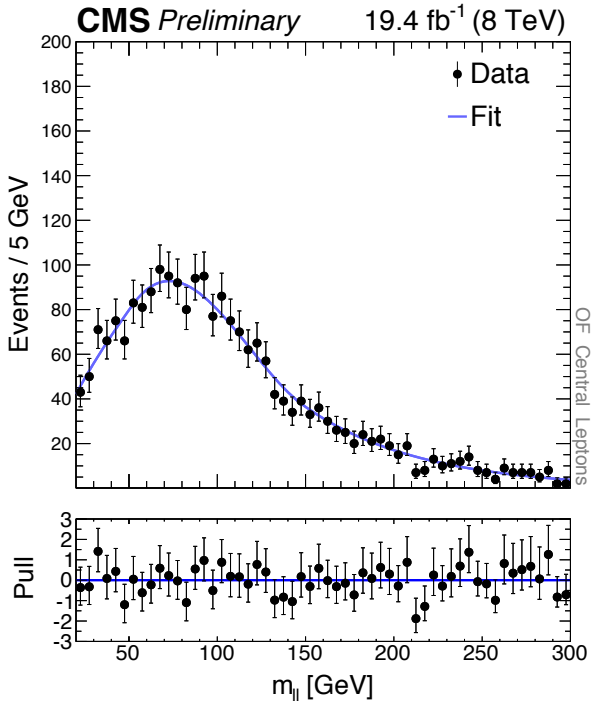
## Fit $M_{\ell\ell}$ distribution:

| | Central |
|---|---|
| Drell–Yan | $158 \pm 23$ |
| Flav. Sym. [OF] | $2270 \pm 44$ |
| $R_{SF/OF}$ | 1.03 |
| Signal events | $126 \pm 41$ |
| $m_{\ell\ell}^{edge}$ [GeV] | 78.7 ± 1.4 |

ee+μμ search region




eμ control region




- **2.6σ excess** in counting experiment
- **$M_{edge}$ = 79 GeV** from fit (also ~3σ excess)

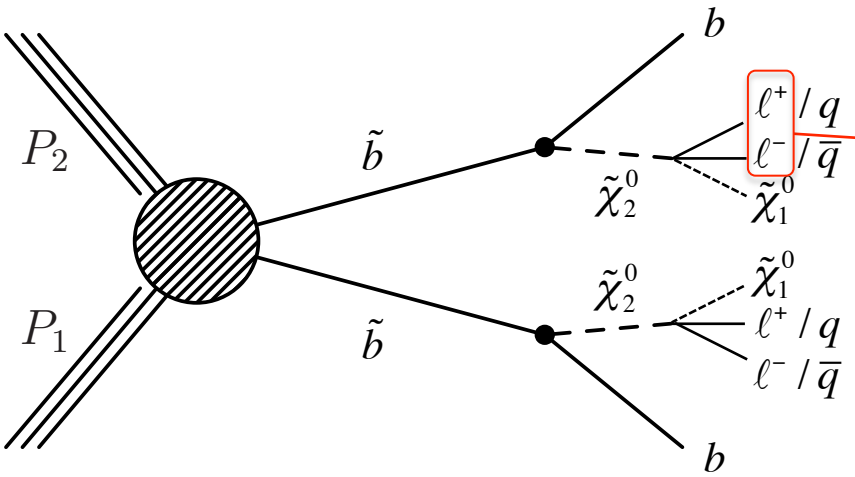
**CMS-PAS-SUS-12-019**

# Possible Explanations

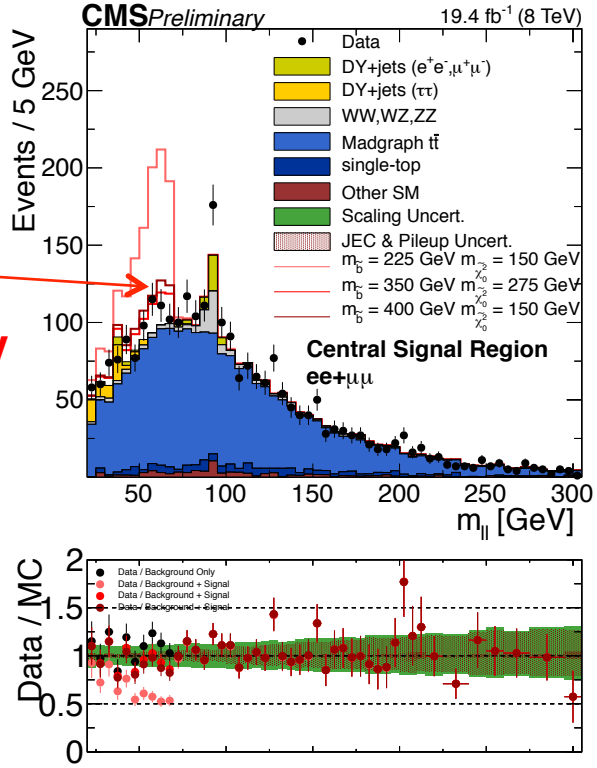
- Problems with 2ℓ triggers for ttbar estimation
  - e.g. broken eμ trigger would produce ee+μμ "excess"
  - Cross-checked with 1ℓ and $E_T^{miss}$ triggers ⟶ consistent results
- Underestimation of Z+jets (off-shell Z, mismeasured leptons)
  - Would need to be underestimated by ×15 to explain results
  - Check in 2ℓ+1 jet events ⟶ no excess at low $M_{\ell\ell}$
  - $n_{b\text{-jets}} = 0$ bin shows no excess (excess mostly in 1b and 2b bins)
- Underestimation of fake lepton backgrounds
  - Could populate ee more than eμ, μμ ⟶ but ee and μμ results consistent
  - Data-driven fake background estimation confirms this bkg is negligible
  - Tighten the lepton $d_0$ and isolation cuts ⟶ no significant changes
- It is difficult to come up with systematic effects that explain this ⟶ fluctuation or signal?

# Constructing a (Simplified) Model

- Need $\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$ decay to explain edge
- Need strong production (squarks/gluinos) to explain jets
- Excess events don't have very large $n_{jets}$ ⟶ squark-pairs
- Excess events have b-jets ⟶ choose sbottom-pairs
- $M_{edge} \sim m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$ ⟶ fix at 70 GeV



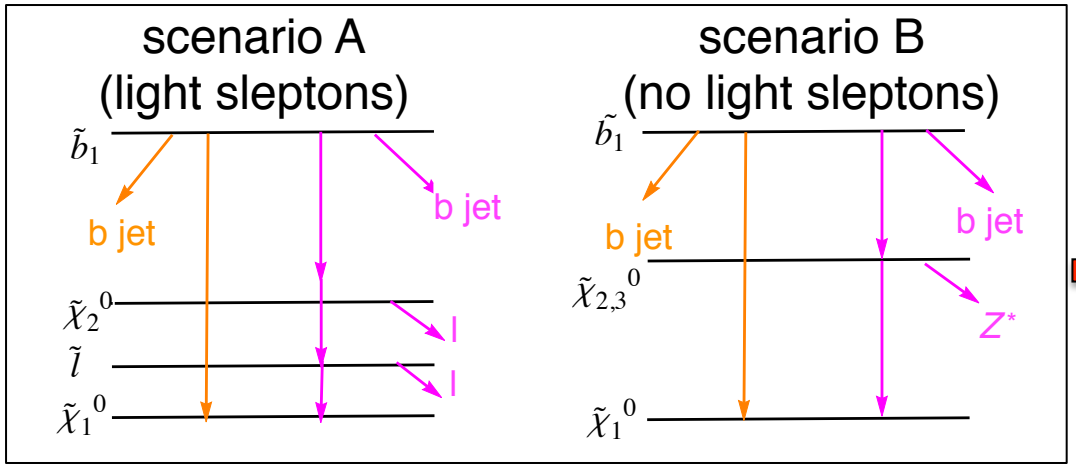

**~350-400 GeV sbottoms?**



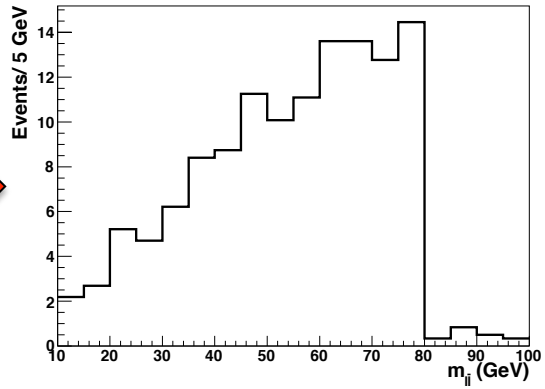

- … but no confirmation from 4ℓ or all-hadronic searches

# Constructing a (Full) Model

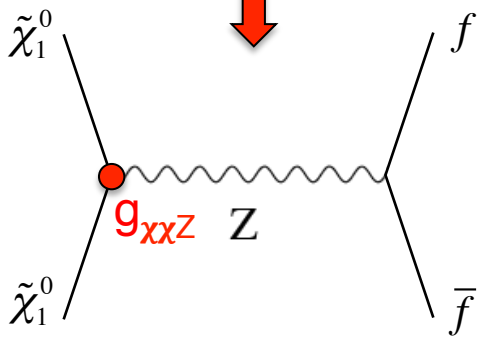
- Construct 2 models with 390 GeV sbottom-pairs, choose SUSY parameters to fit CMS edge while evading other LHC constraints



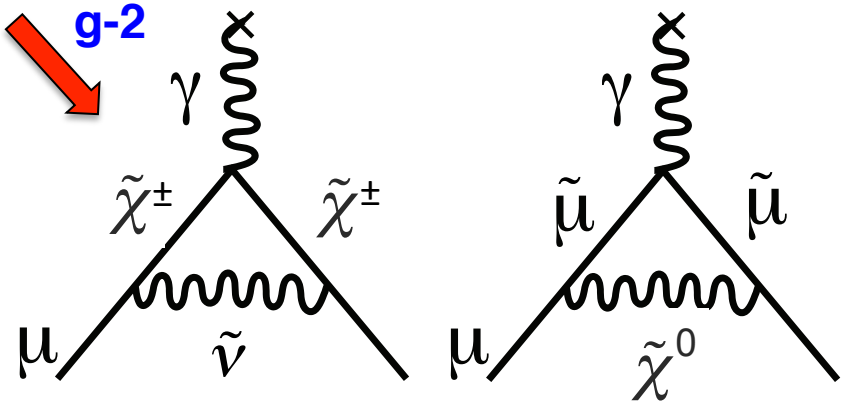

**dilepton mass edge**




**DM relic density**




**g-2**




Wagner and Huang, Phys. Rev. D91 (2015) 015014

# ATLAS 3ℓ Results

- Observe excesses in SR0τa ($\ell^+\ell^-\ell$, $\ell^+\ell^-\ell'$)
  - 3ℓ (no τ) with 1 SFOS pair, categorize events with $M_{SFOS}$, $M_T$, $E_T^{miss}$
  - Excesses have moderate $E_T^{miss}$, $M_T$ values

$M_{SFOS}$ 12-40 GeV
$M_T < 80$ GeV
$E_T^{miss}$ 50-90 GeV
**2.2σ**

| Sample | SR0τa-bin01 | SR0τa-bin02 | SR0τa-bin03 | SR0τa-bin04 | SR0τa-bin05 | SR0τa-bin06 |
|---|---|---|---|---|---|---|
| $WZ$ | $13.2^{+3.4}_{-3.2}$ | $3.0 \pm 1.4$ | $7.8 \pm 1.6$ | $4.5^{+1.1}_{-1.0}$ | $6.3 \pm 1.6$ | $3.7 \pm 1.6$ |
| $ZZ$ | $1.4^{+0.6}_{-0.5}$ | $0.12 \pm 0.06$ | $0.40 \pm 0.14$ | $0.20 \pm 0.18$ | $1.5 \pm 0.5$ | $0.25^{+0.14}_{-0.11}$ |
| $t\bar{t}V + tZ$ | $0.14 \pm 0.05$ | $0.07 \pm 0.04$ | $0.04^{+0.05}_{-0.04}$ | $0.14 \pm 0.13$ | $0.11 \pm 0.08$ | $0.047^{+0.022}_{-0.021}$ |
| $VVV$ | $0.33 \pm 0.33$ | $0.10 \pm 0.10$ | $0.19 \pm 0.19$ | $0.6 \pm 0.6$ | $0.26^{+0.27}_{-0.26}$ | $0.24 \pm 0.24$ |
| Higgs | $0.66 \pm 0.26$ | $0.15 \pm 0.08$ | $0.64 \pm 0.22$ | $0.46^{+0.18}_{-0.17}$ | $0.36^{+0.14}_{-0.15}$ | $0.33^{+0.13}_{-0.12}$ |
| Reducible | $6.7 \pm 2.4$ | $0.8 \pm 0.4$ | $1.6^{+0.7}_{-0.6}$ | $2.7 \pm 1.0$ | $4.3^{+1.6}_{-1.4}$ | $2.0 \pm 0.8$ |
| Total SM | $23 \pm 4$ | $4.2 \pm 1.5$ | $10.6 \pm 1.8$ | $8.5^{+1.7}_{-1.6}$ | $12.9^{+2.4}_{-2.3}$ | $6.6^{+1.9}_{-1.8}$ |
| Data | 36 | 5 | 9 | 9 | 11 | 13 |
| $p_0$ ($\sigma$) | 0.02 (2.16) | 0.35 (0.38) | 0.50 | 0.40 (0.26) | 0.50 | 0.03 (1.91) |
| $N^{95}_{exp}$ | $14.1^{+5.6}_{-3.6}$ | $6.2^{+2.5}_{-1.7}$ | $8.4^{+3.1}_{-2.3}$ | $7.7^{+3.1}_{-2.1}$ | $9.0^{+3.6}_{-2.5}$ | $8.0^{+3.2}_{-1.9}$ |
| $N^{95}_{obs}$ | 26.8 | 6.9 | 7.3 | 8.4 | 7.9 | 14.4 |
| Sample | SR0τa-bin07 | SR0τa-bin08 | SR0τa-bin09 | SR0τa-bin10 | SR0τa-bin11 | SR0τa-bin12 |
| $WZ$ | $7.6 \pm 1.3$ | $0.30^{+0.25}_{-0.24}$ | $16.2^{+3.2}_{-3.1}$ | $13.1^{+2.5}_{-2.6}$ | $19 \pm 4$ | $3.7 \pm 1.2$ |
| $ZZ$ | $0.55^{+0.16}_{-0.14}$ | $0.012^{+0.008}_{-0.007}$ | $1.43^{+0.32}_{-0.28}$ | $0.60^{+0.12}_{-0.13}$ | $0.7 \pm 1.2$ | $0.14 \pm 0.09$ |
| $t\bar{t}V + tZ$ | $0.04^{+0.15}_{-0.04}$ | $0.12^{+0.13}_{-0.12}$ | $0.16^{+0.09}_{-0.12}$ | $0.12 \pm 0.10$ | $0.41^{+0.24}_{-0.22}$ | $0.12 \pm 0.11$ |
| $VVV$ | $0.9 \pm 0.9$ | $0.13^{+0.14}_{-0.13}$ | $0.23^{+0.24}_{-0.23}$ | $0.4 \pm 0.4$ | $0.6 \pm 0.6$ | $0.6 \pm 0.6$ |
| Higgs | $0.98^{+0.29}_{-0.30}$ | $0.13 \pm 0.06$ | $0.32 \pm 0.11$ | $0.22^{+0.10}_{-0.11}$ | $0.28 \pm 0.12$ | $0.12 \pm 0.06$ |
| Reducible | $4.0^{+1.5}_{-1.4}$ | $0.40^{+0.27}_{-0.26}$ | $4.1^{+1.3}_{-1.2}$ | $1.9^{+0.9}_{-0.8}$ | $5.7^{+2.1}_{-1.9}$ | $0.9^{+0.5}_{-0.4}$ |
| Total SM | $14.1 \pm 2.2$ | $1.1 \pm 0.4$ | $22.4^{+3.6}_{-3.4}$ | $16.4 \pm 2.8$ | $27 \pm 5$ | $5.5^{+1.5}_{-1.4}$ |
| Data | 15 | 1 | 28 | 24 | 29 | 8 |
| $p_0$ ($\sigma$) | 0.37 (0.33) | 0.50 | 0.13 (1.12) | 0.07 (1.50) | 0.39 (0.28) | 0.21 (0.82) |
| $N^{95}_{exp}$ | $9.6^{+3.9}_{-2.5}$ | $3.7^{+1.5}_{-0.9}$ | $12.7^{+4.9}_{-3.5}$ | $11.3^{+4.5}_{-3.1}$ | $13.8^{+5.4}_{-3.7}$ | $6.9^{+2.9}_{-1.7}$ |
| $N^{95}_{obs}$ | 10.8 | 3.7 | 18.0 | 18.3 | 15.3 | 9.2 |

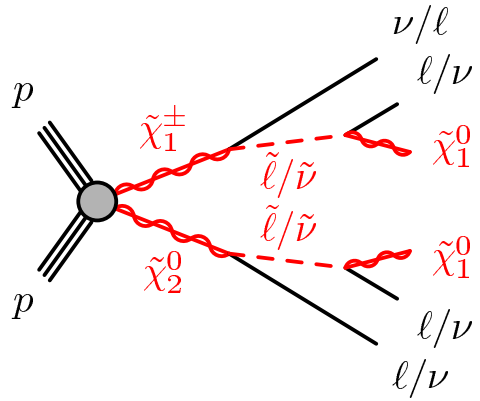
$M_{SFOS}$ 40-60 GeV
$M_T < 80$ GeV
$E_T^{miss} > 75$ GeV
**1.9σ**

$M_{SFOS}$ 60-81 GeV
$M_T > 80$ GeV
$E_T^{miss}$ 50-75 GeV
**1.5σ**

**ATLAS, Phys. Rev. D. 90, 052001 (2014)**

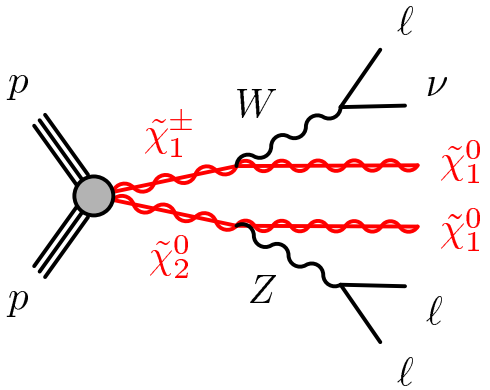
# ATLAS 3ℓ Interpretations

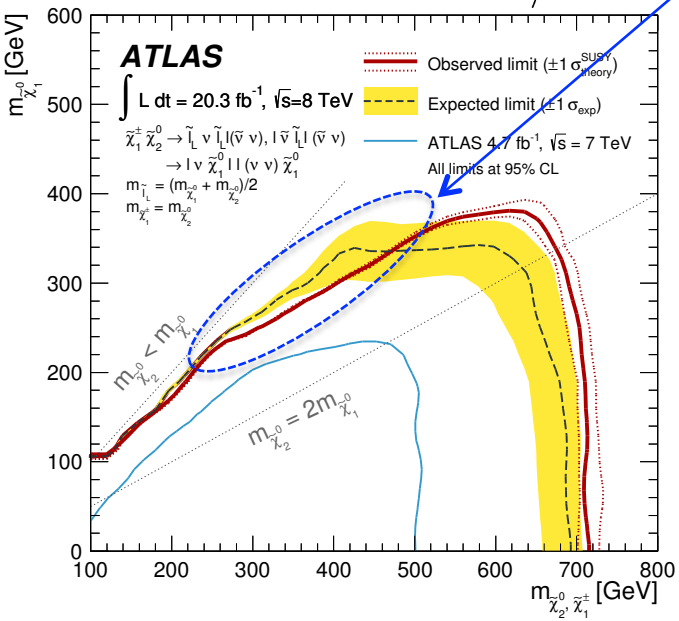
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production
**with** light sleptons

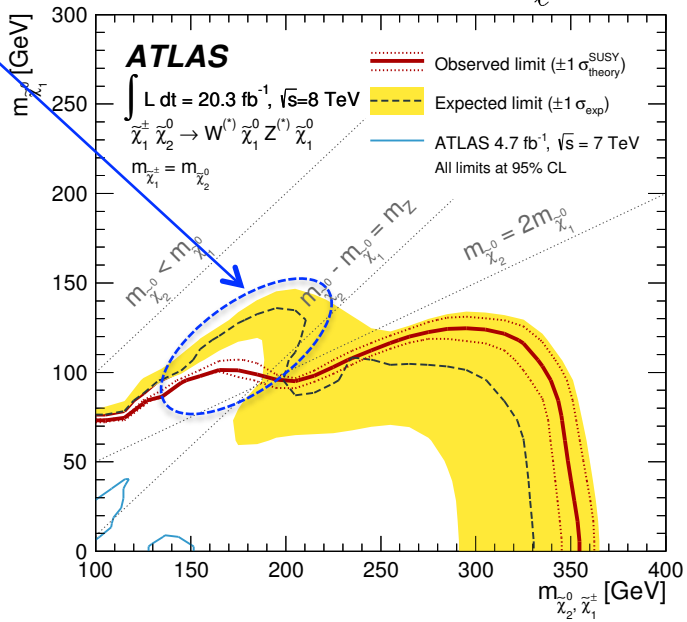



**most sensitive search region:**
SR0τa-bin01
$N_{data} = 36$
$N_{bkg} = 23 \pm 4$
**2.2σ**

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production
**without** light sleptons



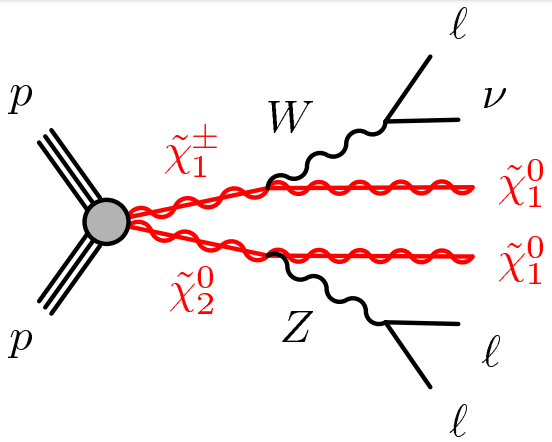



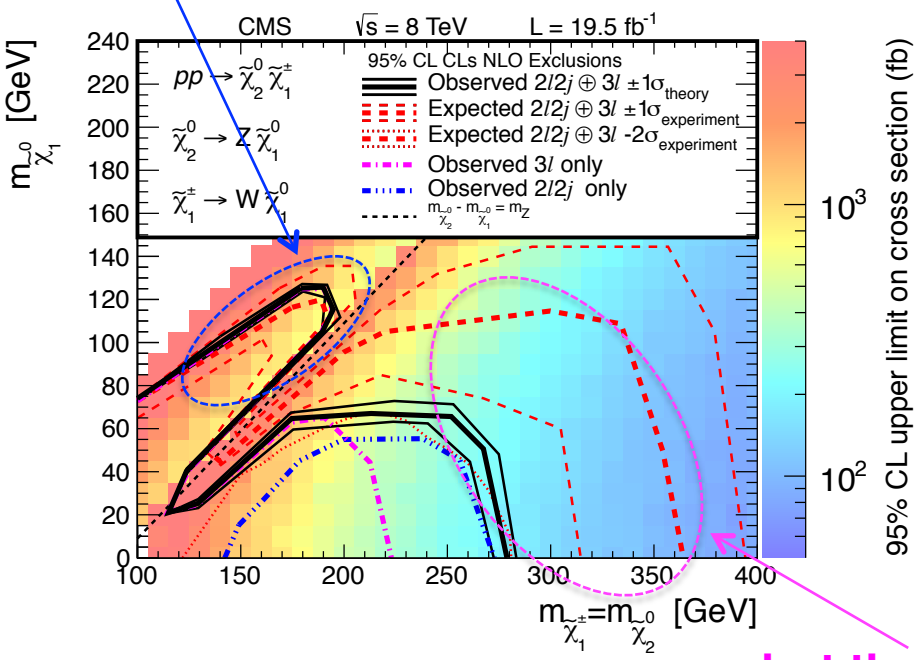

ATLAS, Phys. Rev. D. 90, 052001 (2014)

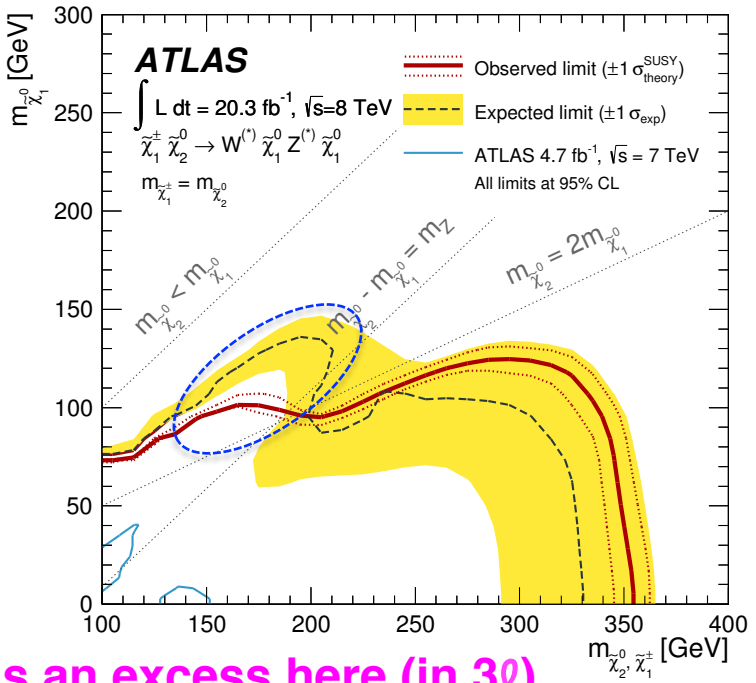
# CMS 3ℓ Cross-check

- CMS search for $\chi^+\chi^0 \rightarrow WZ + E_T^{miss}$
  - Search in WZ→3ℓ and WZ→(jj)(ℓℓ) channels




**no excess here**



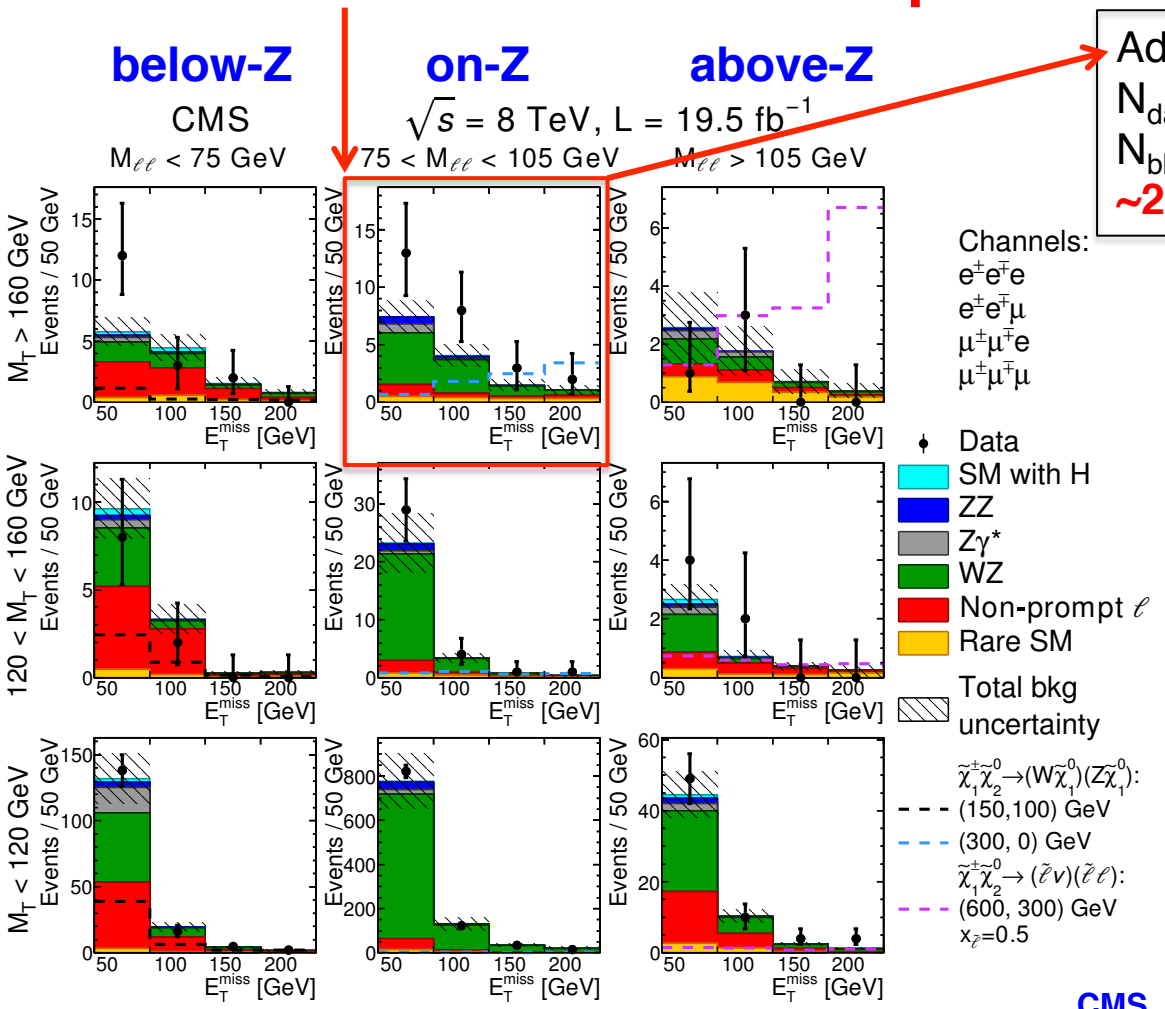




**… but there is an excess here (in 3ℓ)**

CMS, EPJC 74 (2014) 3036

# CMS 3ℓ Results

- Excess due to **3ℓ events with SFOS on-Z pair and large $M_T$**




Add up $E_T^{miss}$ bins:
$N_{data}$ = 26
$N_{bkg}$ = 14 ± 3
**~2σ**

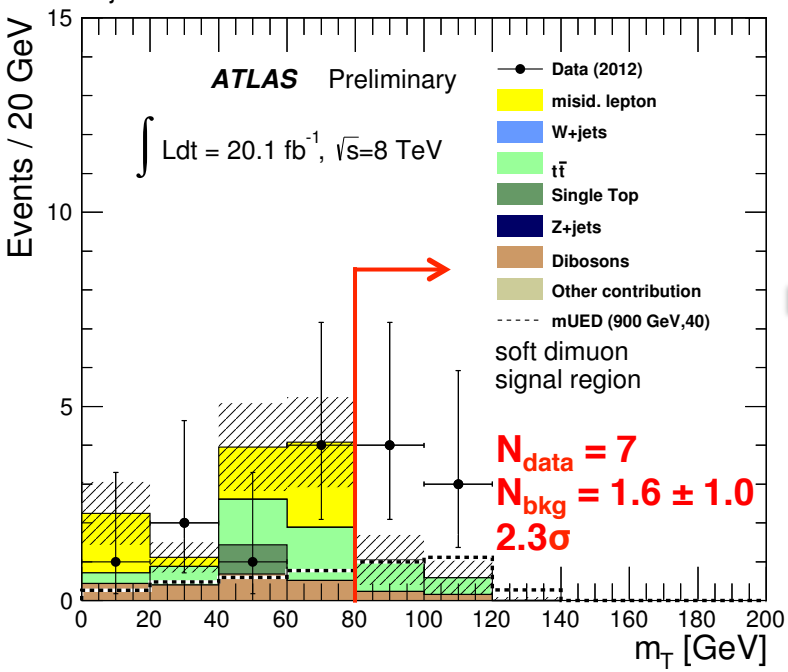
CMS, EPJC 74 (2014) 3036

- Key experimental challenge: modeling $M_T$ tails

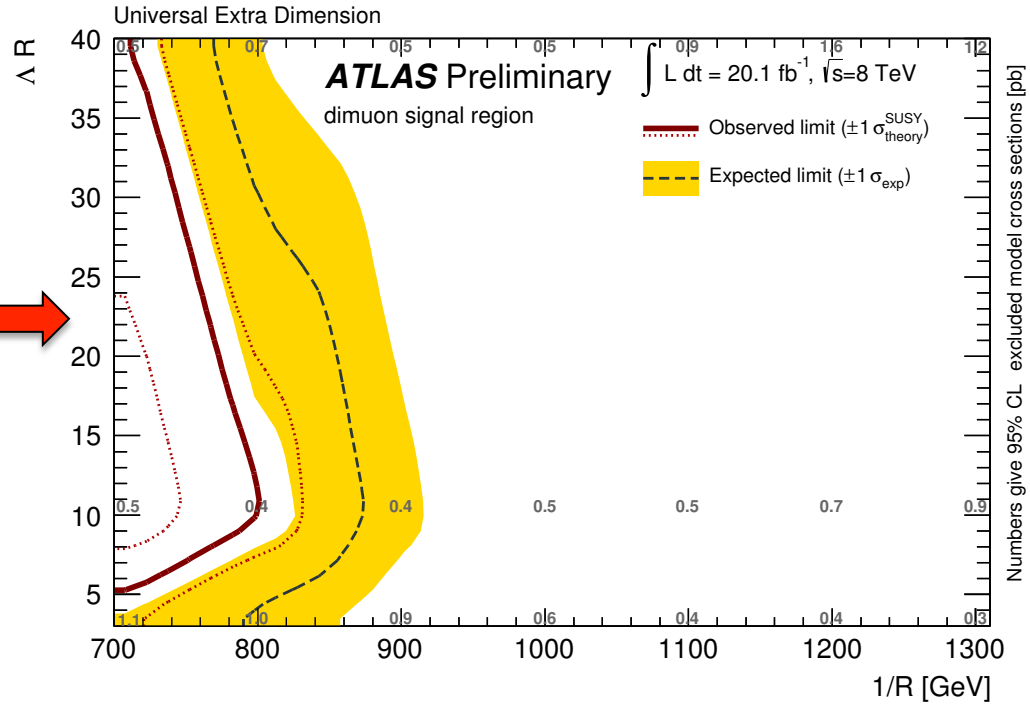
# ATLAS Soft 2μ Excess

- Excess events with 2 soft muons, jets, and $E_T^{miss}$
  - N.B. excess gone in paper arXiv:1501.03555 [hep-ex]

2 muons, $p_T$ 6-25 GeV, off-Z
$n_{jets} \geq 2$, $E_T^{miss} > 170$ GeV, $M_T > 80$ GeV




Minimal (SM + 1 extra dimension) UED
R = compactification scale
Λ = cutoff

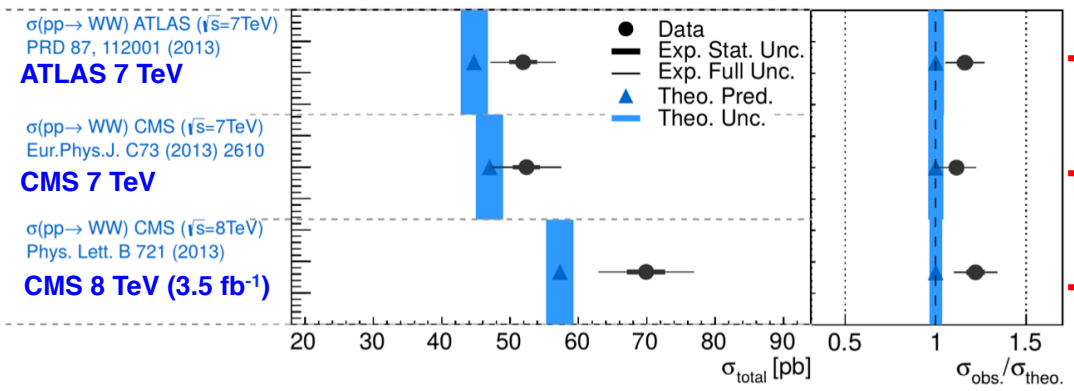


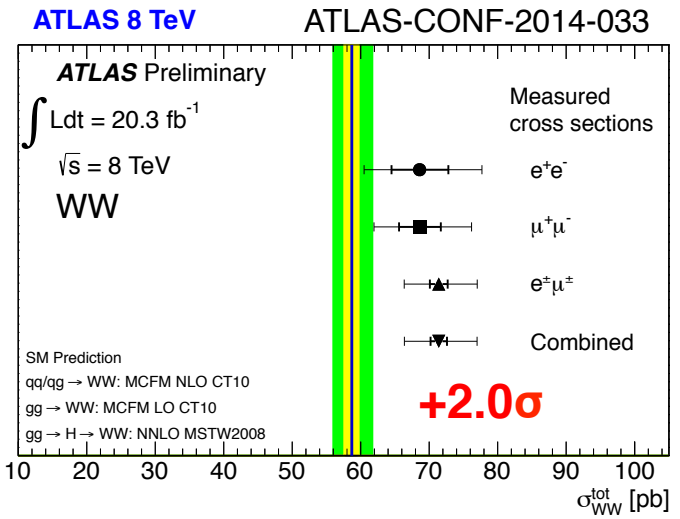

ATLAS-CONF-2013-062

# WW Excess

- Measured σ(pp⟶$W^+W^-$) exceeds theory prediction for both CMS and ATLAS, at 7 TeV and 8 TeV
  - W, Z, WZ, ZZ rates ~agree with theory
  - Explanation from higher order corrections (to jet veto acceptance) [1-4]?

Standard Model prediction: $58.7^{+1.0}_{-1.1}$ (PDF) $^{+3.1}_{-2.7}$ (total) pb



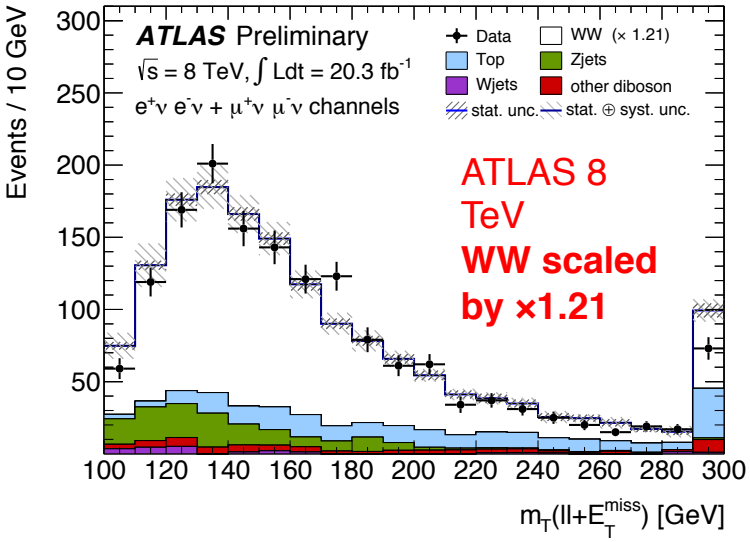



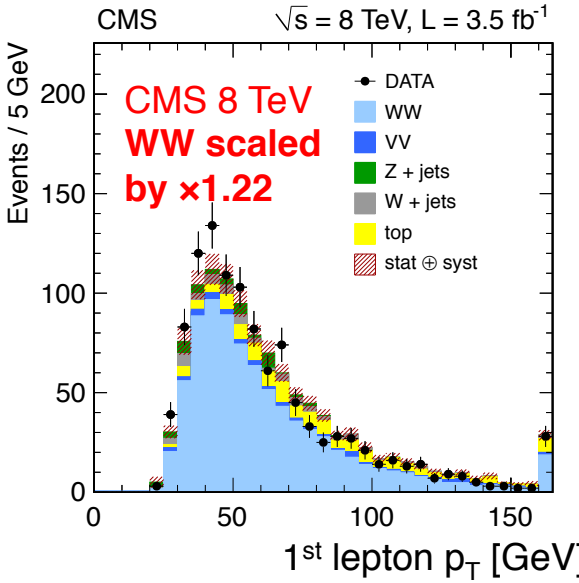


[1] Baglio et al, "Massive gauge boson pair production at the LHC: a next-to-leading order story"
[2] Dawson et al, "Threshold Resummed and Approximate NNLO results for $W^+W^-$ Pair Production at the LHC"
[3] Jaiswal and Okui, "An Explanation of the WW Excess at the LHC by Jet-Veto Resummation"
[4] Monni and Zanderighi, "On the excess in the inclusive $W^+W^-$⟶$\ell^+\ell^-\nu\nu$ cross section"

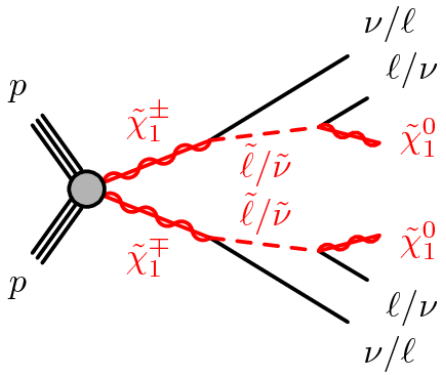
# WW Excess

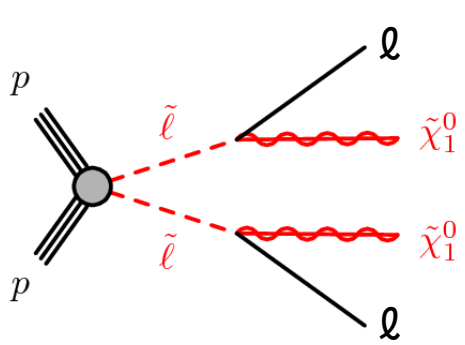
- The shapes agree, but the rates are high by ~20%:

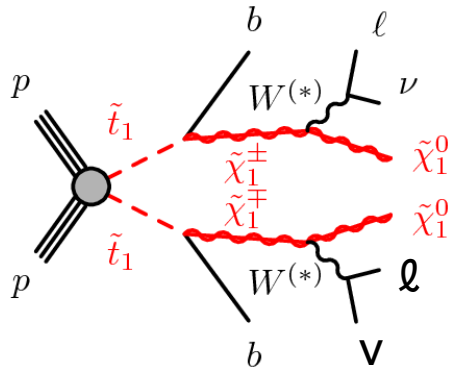



- Possible SUSY explanations [1-4] ⟶ light charginos, sleptons or stops?



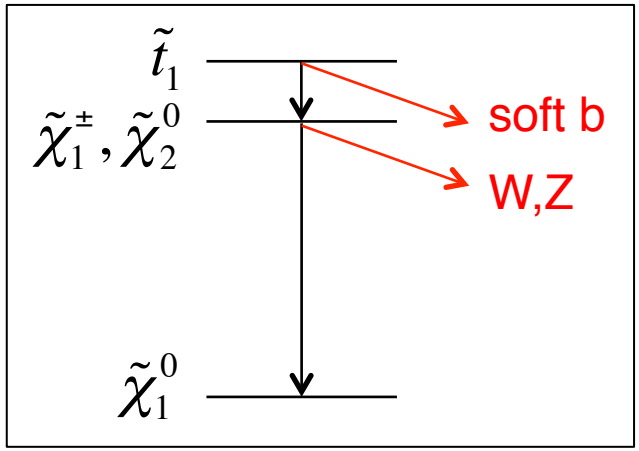



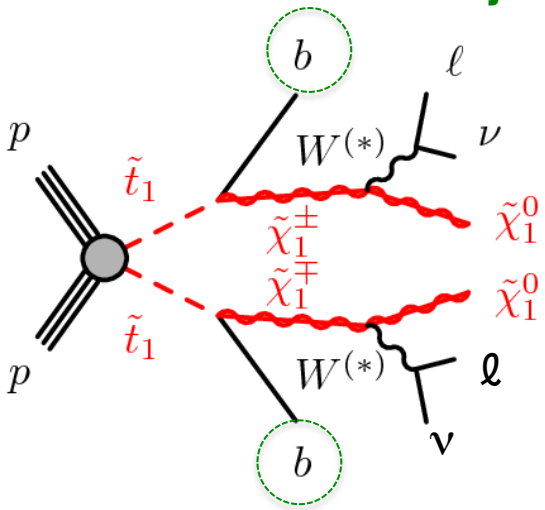


[1] Curtin, Jaiswal, Meade, "Charginos Hiding in Plain Sight
[2] Curtin et. al, "Casting Light on BSM Physics with SM Standard Candles"
[3] Rolbiecki and Sakurai, "Light stops emerging in WW cross section measurements?"
[4] Kim et. al, "'Stop' that ambulance! New physics at the LHC?"

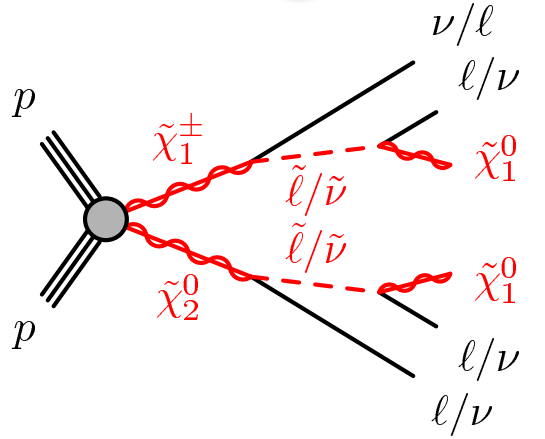
# Light Stops?




soft b-jets (missed)




**$\ell^+\ell^-$+$E_T^{miss}$ → WW and SUSY soft 2μ excesses?**



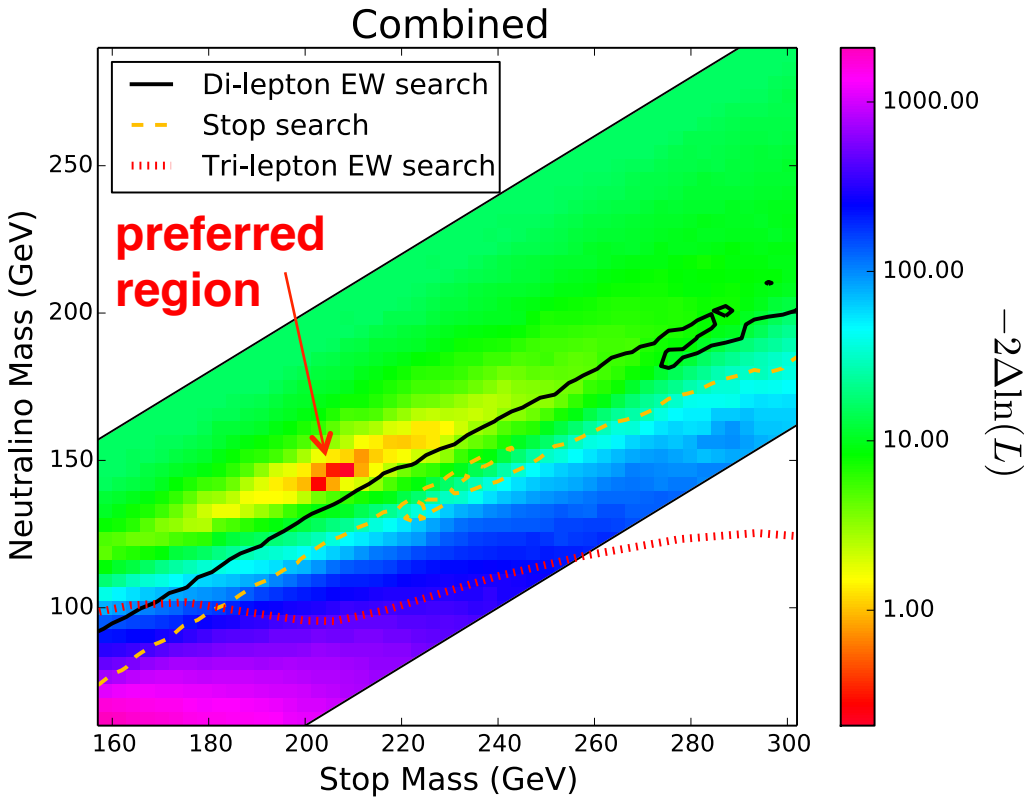

**3$\ell$+$E_T^{miss}$ → SUSY 3$\ell$ excess?**

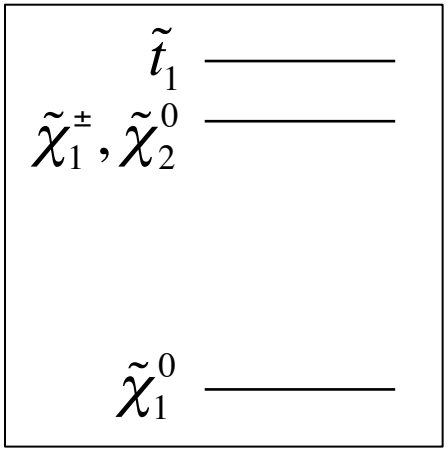
- Possible explanation for WW, SUSY 3$\ell$ and soft 2$\ell$ excesses?

**Kim et. al, "'Stop' that ambulance! New physics at the LHC?"**

# Extracting SUSY Particle Masses

- Perform likelihood analysis of several CMS/ATLAS searches ⟶ extract most likely SUSY particle masses



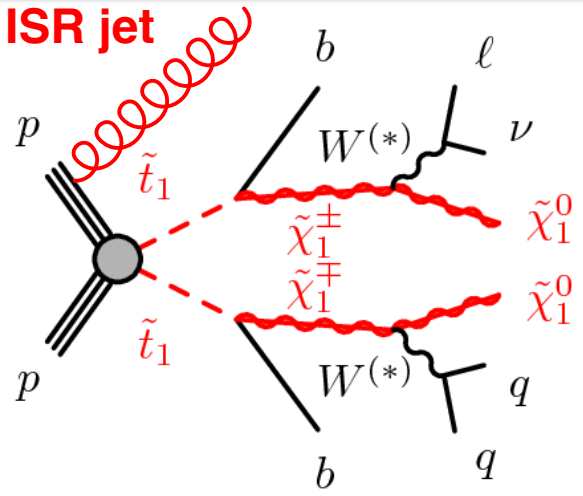

$$m_{\tilde{t}_1} = 202^{+35}_{-25}\ \text{GeV},$$

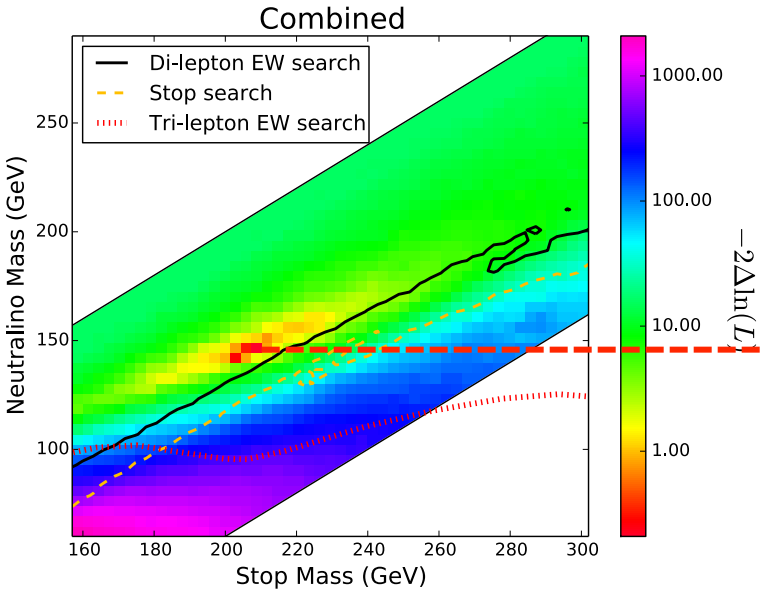
$$m_{\tilde{\chi}_1^0} = 140^{+25}_{-15}\ \text{GeV}$$

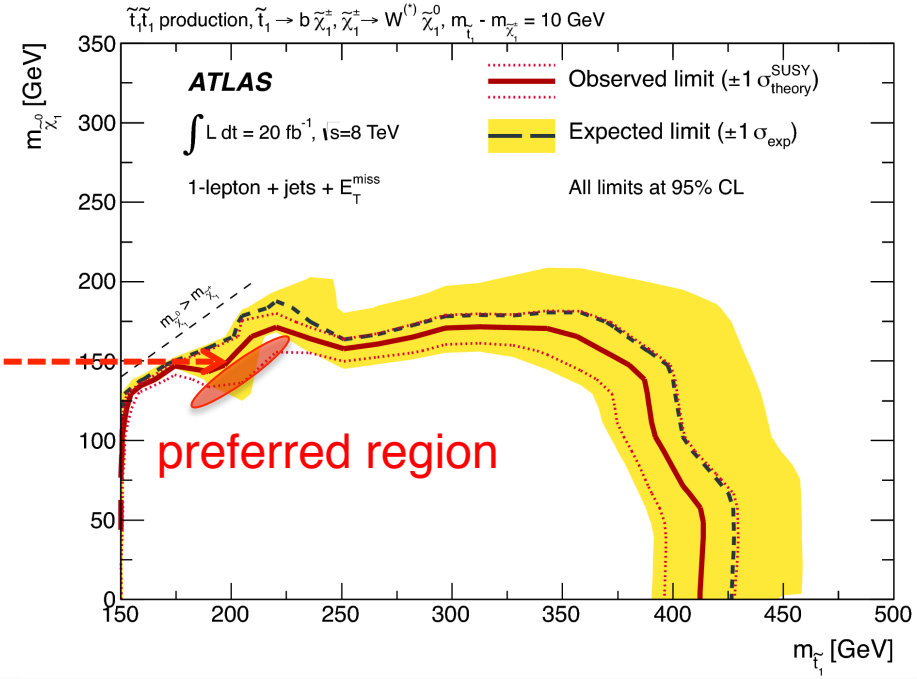
$$m_{\tilde{\chi}_1^{\pm}} = m_{\tilde{\chi}_2^0} = m_{\tilde{t}} - 7\ \text{GeV}$$

# ATLAS Stop 1ℓ Search

- ATLAS 1ℓ stop search probes this model using ISR jet selection
- Preferred region is excluded, but at edge of sensitivity



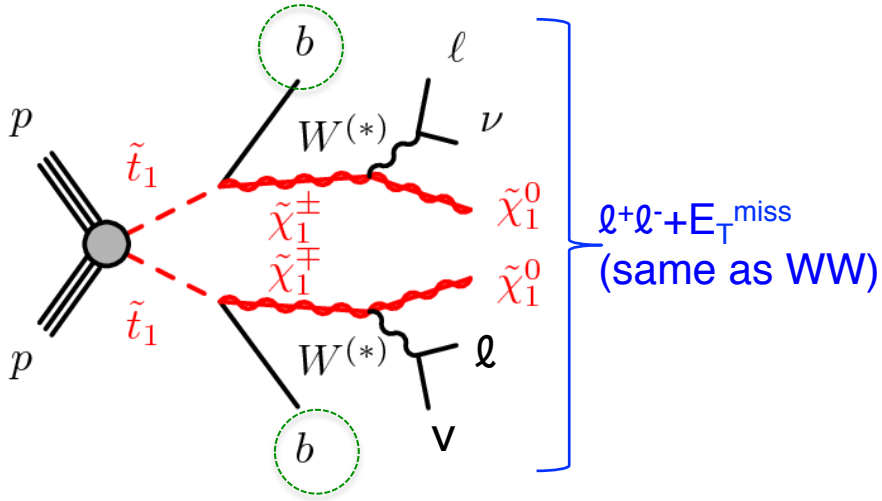



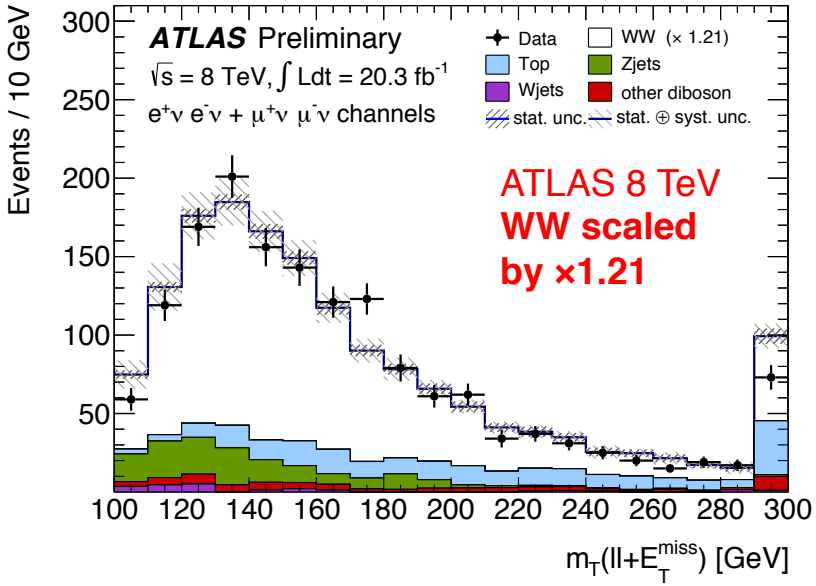




**ATLAS, JHEP 11 (2014) 118**

# 2ℓ + soft-b Analysis

- Test for stops in WW cross section measurement
- Difference between signal (stops) vs. bkg (WW) is presence of **soft b-jets**
- **Add requirement of ≥1 soft b-jet to WW-like selection**
- Need soft ($p_T \gtrsim 10$ GeV) b-tagging ⟶ track-jets



# Summary of Excesses

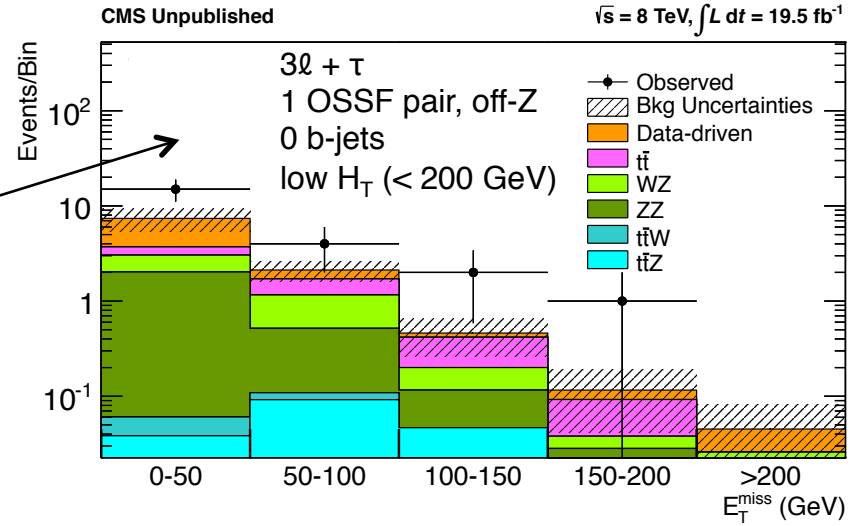
## March 2015

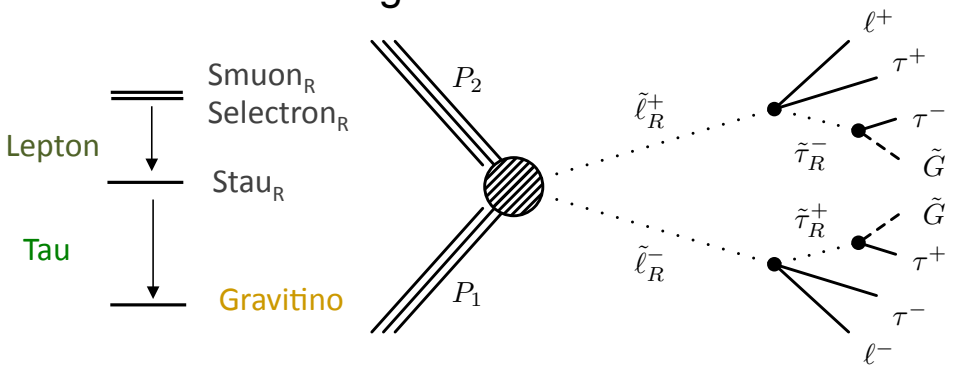
| Search | Dataset | Max Significance | Reference |
|---|---|---|---|
| Dilepton mass edge | CMS 8 TeV | **2.6σ** | CMS-PAS-SUS-12-019 |
| WW cross section | CMS 7 TeV | **1.0σ** | EPJC 73 2610 (2013) |
| WW cross section | CMS 8 TeV | **1.7σ** | PLB 721 (2013) |
| $3\ell+E_T^{miss}$ electroweak SUSY | CMS 8 TeV | **~2σ** | EPJC 74 (2014) 3036 |
| $4\ell+E_T^{miss}$ electroweak SUSY (see backup) | CMS 8 TeV | **~3σ** | PRD 90, 032006 (2014) |
| Higgs→μ$\tau$ (lepton flavor violation) | CMS 8 TeV | **2.5σ** | CMS-PAS-HIG-14-005 |
| 1st gen. leptoquarks (eejj / evjj channels) | CMS 8 TeV | **2.6σ / 2.4σ** | CMS-PAS-EXO-12-041 |
| ttH with same-sign muons | CMS 8 TeV | $\mu_{ttH} = 8.5^{+3.5}_{-2.7}$ | arXiv:1408.1682v1 [hep-ex] |
| Dijet resonance search | CMS 8 TeV | **~2σ** | arXiv:1501.04198 [hep-ex] |
| Heavy right-handed neutrinos | CMS 8 TeV | **2.8σ** | EPJC 74 (2014) 3149 |
| $3\ell+E_T^{miss}$ electroweak SUSY | ATLAS 8 TeV | **2.2σ** | PRD 90, 052001 (2014) |
| Soft $2\ell+E_T^{miss}$ strong SUSY | ATLAS 8 TeV | **2.3σ** | ATLAS-CONF-2013-062 |
| WW cross section | ATLAS 7 TeV | **1.4σ** | PRD 87, 112001 (2013) |
| WW cross section | ATLAS 8 TeV | **2.0σ** | ATLAS-CONF-2014-033 |
| Z+jets+$E_T^{miss}$ | ATLAS 8 TeV | **3.0σ** | arXiv:1503.03290 [hep-ex] |
| Monojet search | ATLAS 8 TeV | **1.7σ** | arXiv:1502.01518 [hep-x] |
| H→h(bb)h(γγ) | ATLAS 8 TeV | **2.4σ** | arXiv:1406.5053 [hep-ex] |

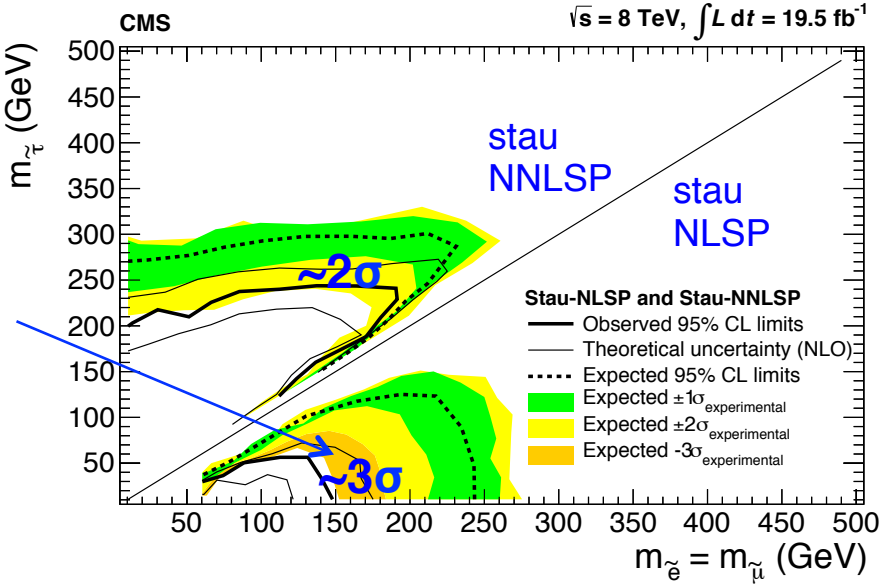
# Additional Material

# CMS 3ℓ + τ Excess

- SUSY multilepton (≥3ℓ) search
- Categorize events based on lepton number and flavor, # OSSF pairs, $M_{\ell\ell}$, $n_{b\text{-tags}}$, $E_T^{miss}$, and $H_T$
- 1 category has:
  - $N_{data}$ = 22 events
  - $N_{bkg}$ = 10 ± 2.4 events
  - ~3σ
- But: 64 total categories
  - Probability that ≥1 category has as large a fluctuation ~50%
  - Probability for all bins in ≥1 category to have as large a fluctuation ~5%



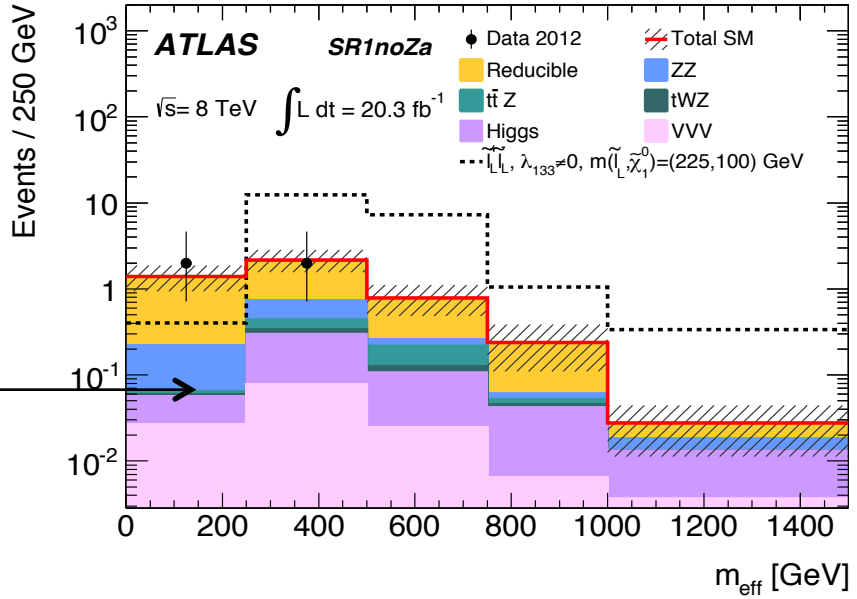



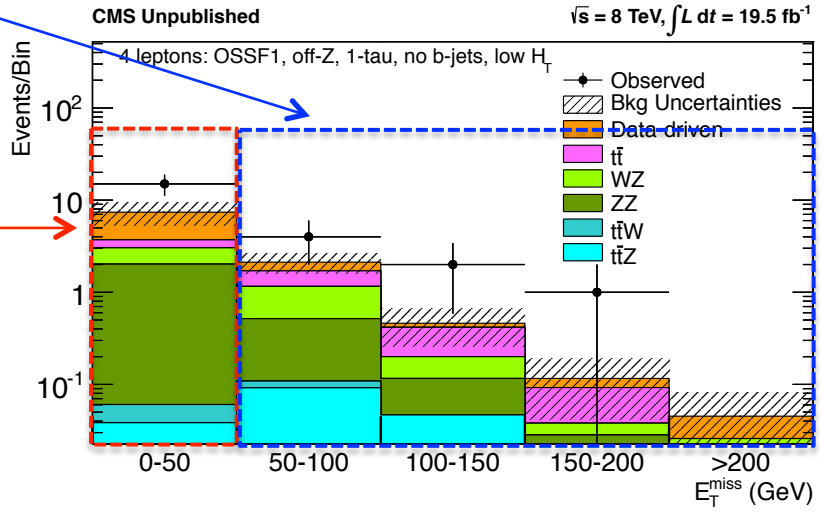
# ATLAS Cross-check

- ATLAS multilepton analysis probes similar regions but doesn't see any excesses

**SR1noZ:**
3ℓ + τ, Z-veto
$E_T^{miss} > 50$ GeV
**$N_{data} = 4$, $N_{bkg} = 4.6 \pm 1.3$**




**VR1noZ:**
3ℓ + τ, Z-veto
$E_T^{miss} < 50$ GeV, $m_{eff} < 400$ GeV
**$N_{data} = 7$, $N_{bkg} = 8.9 \pm 1.8$**




**ATLAS, Phys. Rev. D. 90, 052001 (2014)**

# ATLAS Soft 2ℓ Results

## ATLAS-CONF-2013-062

| | soft dimuon 2-jet |
|---|---|
| Observed events | 7 |
| Fitted background events | $1.6 \pm 1.0$ |
| Fitted $t\bar{t}$ events | $1.2 \pm 1.0$ |
| Fitted $W$+jets events | - |
| Fitted diboson events | $0.4 \pm 0.3$ |
| Fitted misidentified lepton events | $0.0^{+0.3}_{-0.0}$ |
| Fitted other background events | $0.01^{+0.06}_{-0.01}$ |
| MC expected SM events | $1.9 \pm 1.2$ |
| MC expected $t\bar{t}$ events | $1.5 \pm 1.2$ |
| MC expected $W$+jets events | - |
| MC expected diboson events | $0.4 \pm 0.3$ |
| data-driven misidentified lepton events | $0.0^{+0.3}_{-0.0}$ |
| MC expected other background events | $0.01^{+0.06}_{-0.01}$ |

| | soft single-lepton | | soft dimuon |
|---|---|---|---|
| | 3-jet | 5-jet | 2-jet |
| $N_\ell$ | 1 (electron or muon) | | 2 (muons) |
| $p_{\mathrm{T}}^{\ell}$(GeV) | [10,25] (electron) , [6,25] (muon) | | [6,25] |
| $p_{\mathrm{T}}^{\text{add. }\ell}$ (GeV) | < 7 (electron), < 6 (muon) | | |
| $m_{\mu\mu}$ (GeV) | – | – | >15 and $\lvert m_{\mu\mu} - m_Z \rvert > 10$ |
| $N_{\text{jet}}$ | [3,4] | $\geq 5$ | $\geq 2$ |
| $p_{\mathrm{T}}^{\text{leading jet}}$(GeV) | > 180 | | >70 |
| $p_{\mathrm{T}}^{\text{subleading jets}}$( GeV) | > 25 | | |
| $N_{b-\text{tag}}$ | – | – | 0 |
| $E_{\mathrm{T}}^{\text{miss}}$ (GeV) | >400 | >300 | >170 |
| $m_{\mathrm{T}}$ (GeV) | > 100 | | > 80 |
| $E_{\mathrm{T}}^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$ | > 0.3 | | – |
| $\Delta R_{\text{min}}(\text{jet}, \ell)$ | > 1.0 | – | > 1.0 |

## arXiv:1501.03555 [hep-ex]

| | Soft dimuon |
|---|---|
| Observed events | 6 |
| Fitted background events | $6.0 \pm 2.6$ |
| $t\bar{t}$ | $1.8 \pm 0.8$ |
| Other top quarks | $0.24 \pm 0.14$ |
| V+jets | $0.28 \pm 0.19$ |
| Diboson | $1.4 \pm 0.5$ |
| Fake leptons | $2.3^{+2.4}_{-2.3}$ |
| Expected background events before the fit | 6.8 |
| $t\bar{t}$ | 2.6 |
| Other top quarks | 0.24 |
| V+jets | 0.28 |
| Diboson | 1.4 |
| Fake leptons | 2.3 |

| | Single-bin (binned) soft single-lepton | | | Soft dimuon |
|---|---|---|---|---|
| | 3-jet | 5-jet | 3-jet inclusive | 2-jet |
| $N_\ell$ | 1 electron or muon | | | 2 muons |
| $p_{\mathrm{T}}^{\ell}$[GeV] | [7,25] for electron, [6,25] for muon | | | [6,25] |
| Lepton veto | No additional electron or muon with $p_{\mathrm{T}}$> 7 GeV or 6 GeV, respectively | | | |
| $m_{\mu\mu}$ [GeV] | – | – | – | [15,60] |
| $N_{\text{jet}}$ | [3,4] | $\geq 5$ | $\geq 3$ | $\geq 2$ |
| $p_{\mathrm{T}}^{\text{jet}}$[GeV] | > 180, 25, 25 | > 180, 25, 25, 25, 25 | > 130, 100, 25 | > 80, 25 |
| $N_{b-\text{tag}}$ | – | – | 0 | 0 |
| $E_{\mathrm{T}}^{\text{miss}}$ [GeV] | >400 | >300 | > 180 | |
| $m_{\mathrm{T}}$ [GeV] | > 100 | | >120 | > 40 |
| $E_{\mathrm{T}}^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$ | > 0.3 (0.1) | | > 0.1 | > 0.3 |
| $\Delta R_{\text{min}}(\text{jet}, \ell)$ | > 1.0 | – | – | > 1.0 (2nd muon) |
| Binned variable | ($E_{\mathrm{T}}^{\text{miss}}/m_{\text{eff}}^{\text{incl}}$ in 4 bins) | | | – |
| Bin width | (0.1, 4th is inclusive) | | | – |