# ATLAS RESULTS ON SUSY SEARCHES

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on behalf of the ATLAS Collaboration

# EXECUTIVE SUMMARY

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We haven’t found it.

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We haven't found it.

Let me elaborate on that...

# OUTLINE

- General remarks
- simplified model limits
- pMSSM limits
- long lived searches, RPV
- run2 and beyond

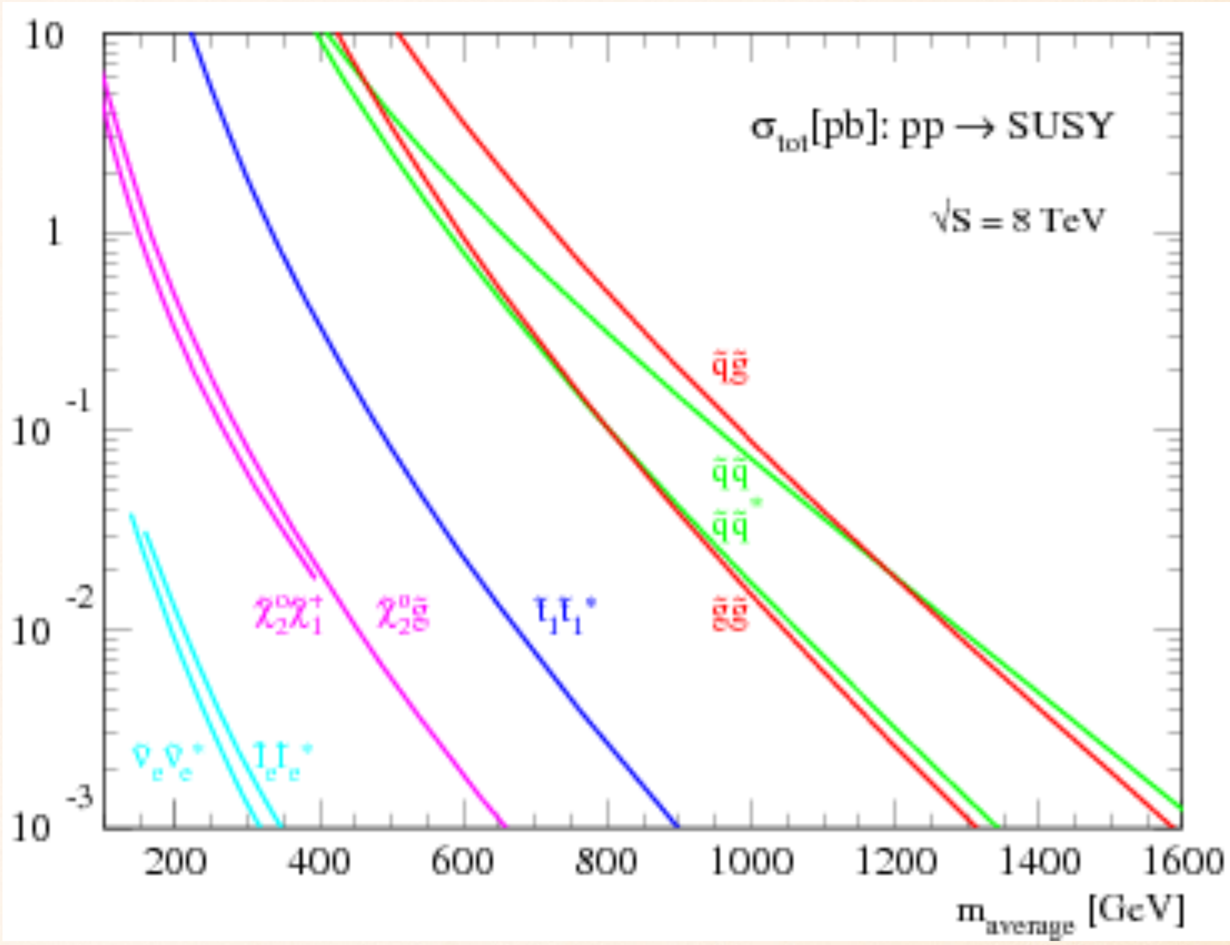
# OVERVIEW

Searches for R-parity conserving SUSY, based on $E_T^{MISS}$ final states

- squark and gluinos
- direct stop and sbottom
- direct electroweak production

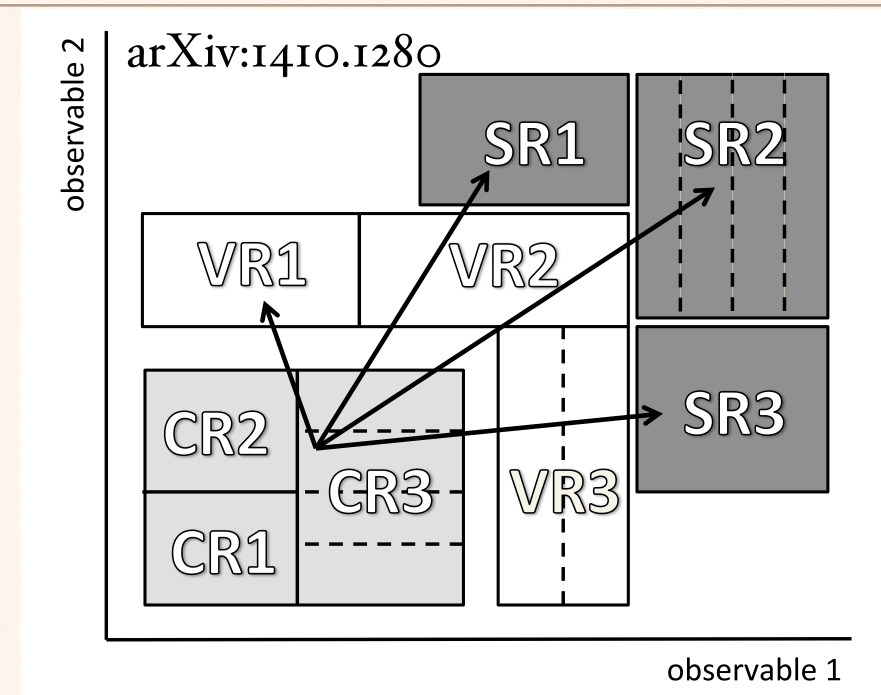
RPV searches, based on high multiplicities (jets or leptons) or resonances (jet-jet, jet-lepton, di-lepton)

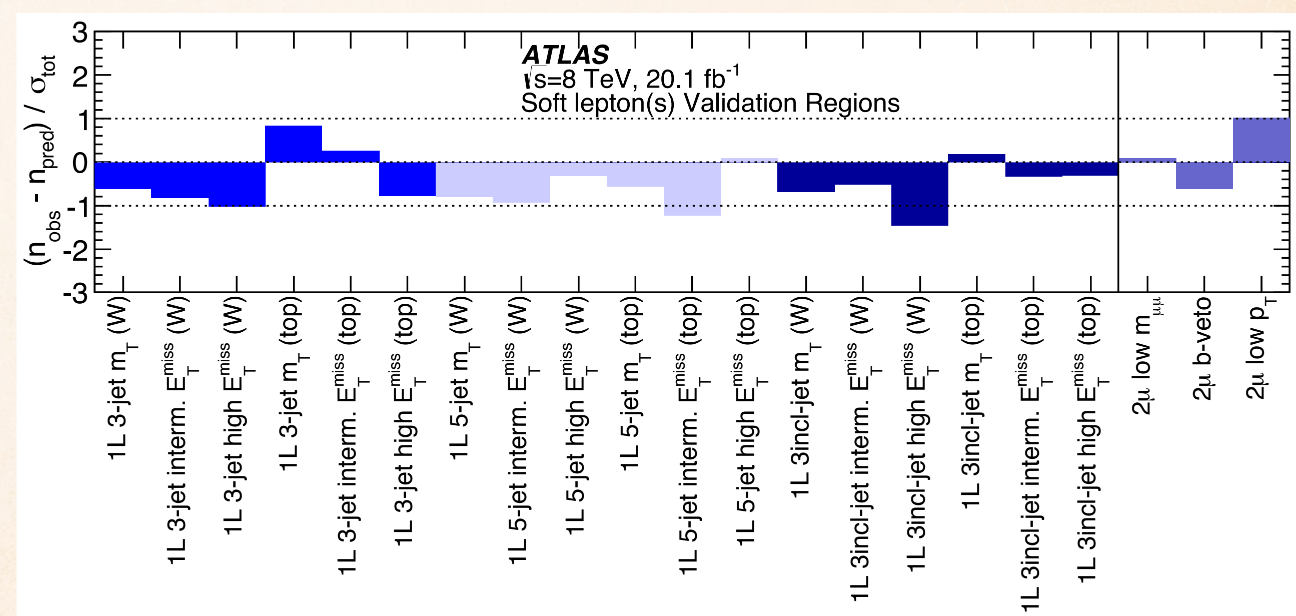
Long lived particle searches (could be RPC or RPV), requiring specialised techniques (re-tracking, time-of-flight, dEdx, etc.)



# A TYPICAL ATLAS SUSY SEARCH

- **Signal selection** (*signal region SR*) targeting a specific SUSY production/decay mode
- **Background estimate:**
  - Irreducible backgrounds estimated *using control region (CR)* data as a constraint and MC to extrapolate from CR to SR in a likelihood fit
  - Reducible background (fake/non isolated leptons, $E_T^{Miss}$ from jet mismeasurement) from data.
  - Use only well modelled variable in CR => SR extrapolations ! *Validation regions (VR)* used to check the assumptions in the background estimate and the CR => SR variable modelling.




example: validation region results of the soft lepton selection of arXiv:1501.03555

# INTERPRETATION OF RESULTS

- Search optimized on **simplified models** (single production and decay mode) but interpreted for **more general cases**: simplified models with 2 decay modes as a function of the BR, MSSM 2D slices, constrained models (mSUGRA, NUHM, GMSB, ...), **19-D scan of pMSSM (NEW!)**

- A major effort has been done to assess how general our limits really are. I will discuss this in detail. Is SUSY hiding in

  - Compressed mass spectra ?

  - RPV decays in fully hadronic final states ?

  - Multiple and/or long decay chains the analysis is not optimised for ?

- We also encourage reinterpretation of our results, providing model independent limits on $N_{BSM}$ for each SR, and additional information on HEPdata (cutflows, efficiency and acceptance maps for benchmark signal grids, 1D distributions)

Links to paper, figures, auxiliary material and HEP data can all be found from the public ATLAS SUSY page :
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

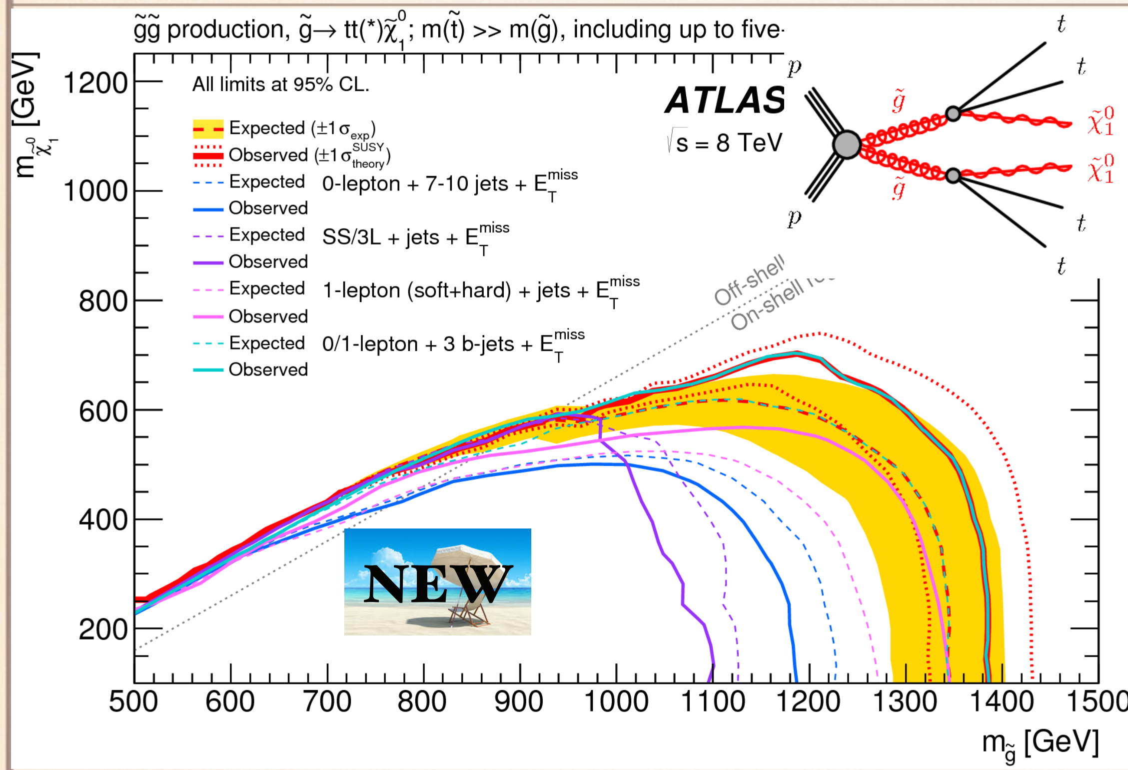
# OUTLINE

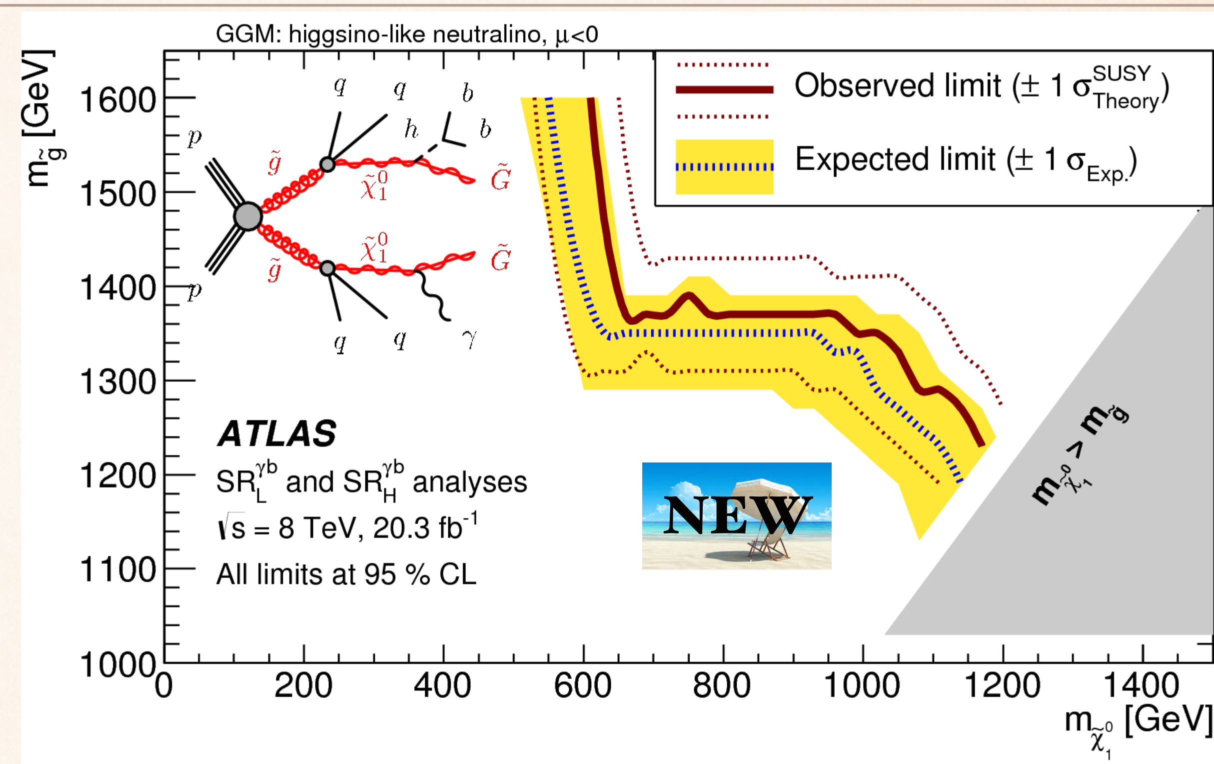
- General remarks
- **simplified model limits**
- pMSSM limits
- long lived searches, RPV
- run2 and beyond

= results released this summer

# GLUINOS - DIFFICULT TO HIDE

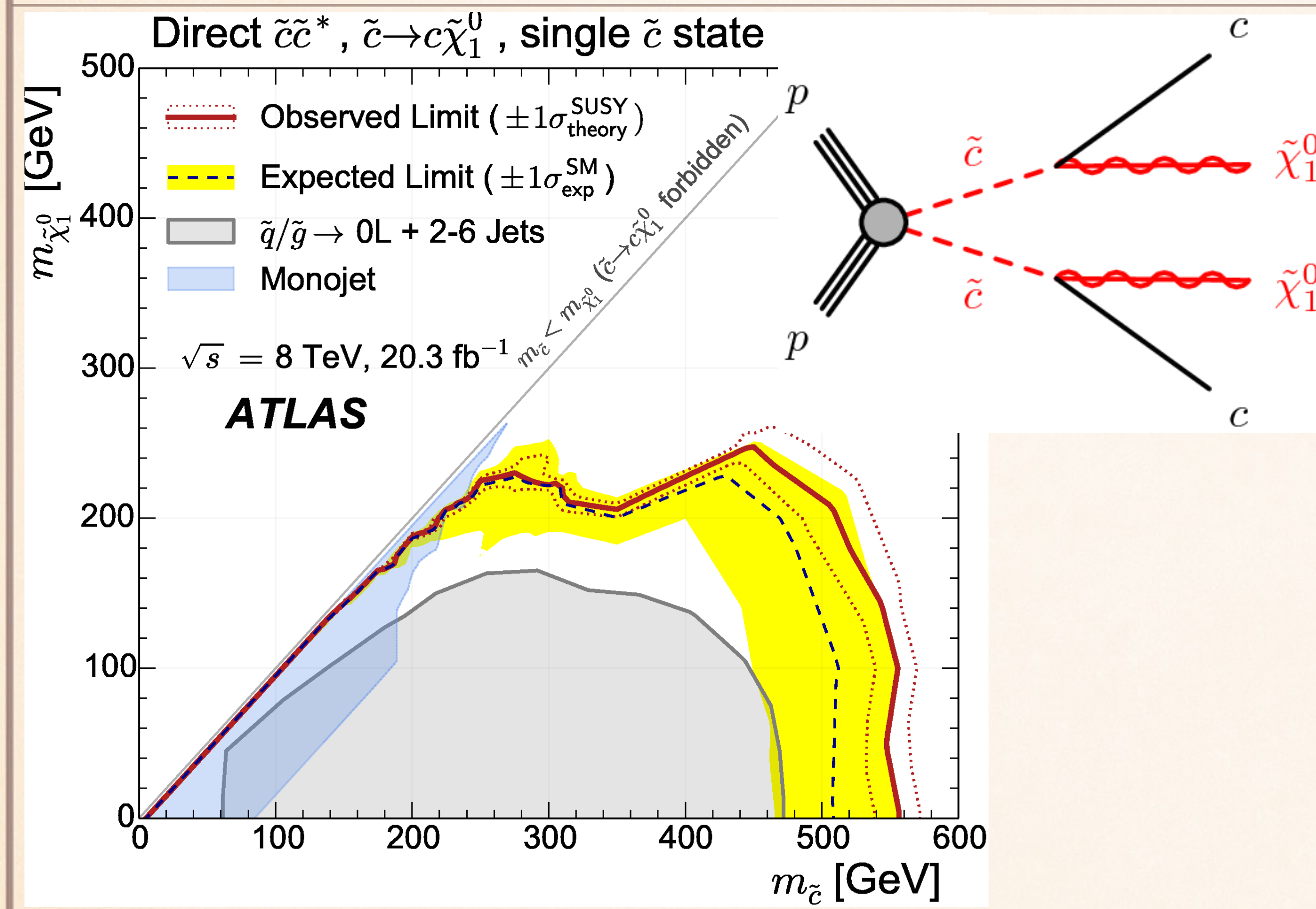
**More details in the parallel session talks of A. Kastanas and Y. Minami**




- A summary of the ATLAS limits to squarks and gluino is presented in arXiv:1507.05525, not including the photon channels which are in arXiv:1507.05493
- For light LSP (small $m_g$-$m_{LSP}$) gluino limits between 1150 and 1340 GeV (around 600 GeV).
- Limits on fully hadronic RPV decays (arXiv:1502.05686) still between 600 and 950 GeV.
- It's hard to hide a gluino ! (colour octet, high cross section)

# SQUARKS - NOT SO DIFFICULT




| flavour | light N1 | small ΔM |
|---|---|---|
| sup | 470 GeV | 240 GeV |
| scharm | 540 GeV | 240 GeV |
| sbottom | 620 GeV | 240 GeV |
| stop | 700 GeV | 240 GeV |

**Limits on single squark, qN1 decay.**

- Limits for 8-fold mass degeneracy, light stable LSP, and simple decay are 600-900 GeV.
- Relax these conditions, and limits get a lot weaker - a 200 GeV squark might be allowed !
- A squark mass-degenerate with the LSP is excluded up to about 240 (430) GeV for 1 (8-fold) mass degeneracy, with little dependence on flavour and decay mode, by the mono jet search

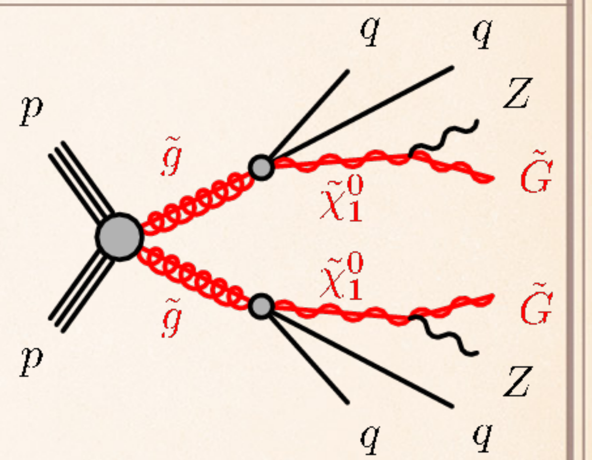
# SOME REFERENCES

**inclusive squark/gluinos ATLAS papers**

| channel | journal | arXiv |
|---|---|---|
| 0L+(2-6)jets+MET | JHEP 1409, 176 | 1405.7875 |
| 0L+(7-10)jets+MET | JHEP 1310, 130 | 1308.1841 |
| (0-1)L+3b-jets+MET | JHEP 1410, 024 | 1407.0600 |
| SS/3L+jets+MET | JHEP 1406, 035 | 1404.2500 |
| 2L+jets+MET | EPJC 75,318 | 1503.03290 |
| 1L+jets+MET | JHEP 1504, 116 | 1501.03555 |
| taus+jets+MET | JHEP 1409, 103 | 1407.0603 |
| NEW photons+jets+MET | submitted to PRD | 1507.05493 |
| NEW **summary paper** | submitted to JHEP | 1507.05525 |

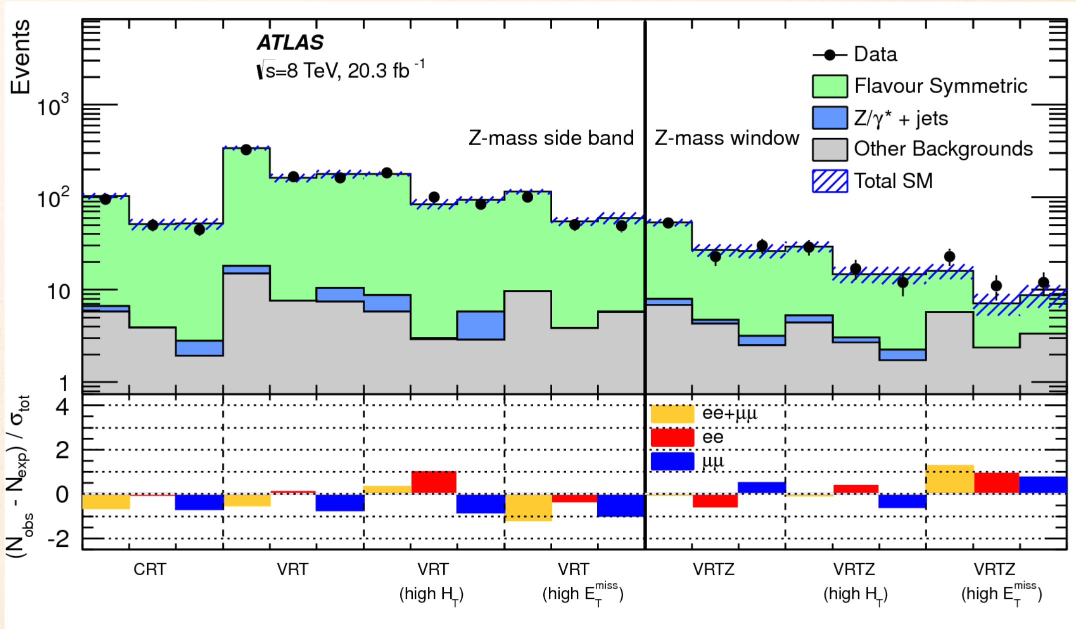
# MANY LIMITS - AND ONE HINT ?

arXiv:1503.03290




- Search for a Z boson (ee or μμ), jets ($H_T$ > 600 GeV), $E_T^{Miss}$ > 225 GeV
- Main backgrounds flavour symmetric, estimated from eμ data
- A combined (ee+μμ) excess of 3.0 sigma over SM observed. At least 14 phone papers on this on the archive.
- Looking forward to run2 results, but don't be too excited ! We have 180 SR in run1 (0.5 three-σ excesses expected, one is observed), no excess in CMS Z+MET (cuts are different though) and in 0-lepton channel (need some model tuning).

| Channel | SR-Z same-flavour combined |
|---|---|
| Observed events | 29 |
| Expected background events | $10.6 \pm 3.2$ |
| Flavour-symmetric backgrounds | $6.0 \pm 2.6$ |
| $Z/\gamma^* +$ jets (jet-smearing) | $0.07 \pm 0.05$ |
| Rare top | $0.35 \pm 0.12$ |
| $WZ/ZZ$ diboson | $2.9 \pm 1.0$ |
| Fake leptons | $1.3^{+1.7}_{-1.3}$ |



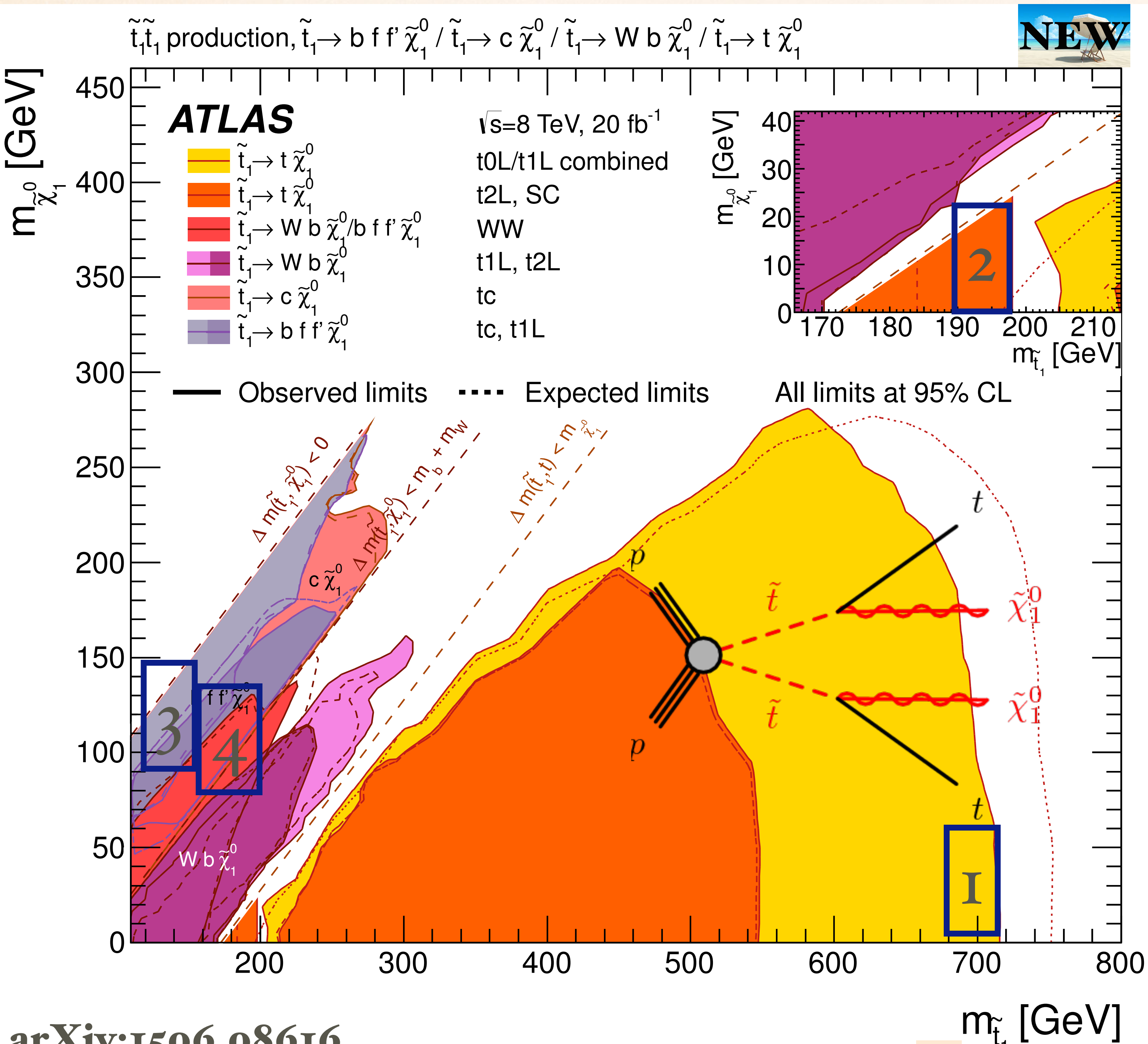
# THIRD GENERATION SEARCHES

- A light stop (and sbottom) are well motivated by naturalness. Thus, ATLAS has a program of dedicated searches for these.

- Main differences with inclusive squark searches : b-tagging, dedicated top candidate reconstruction (for some channels), softer cuts on jets and ETMiss (we assume a single mass eigenstate produced in s-channel while inclusive searches are optimised for 8-fold mass degeneracy)

| | | |
|---|---|---|
| scharm | PRL 114, 161801 | arXiv:1501.01325 |
| sbottom | JHEP 1310, 189 | arXiv:1308.2631 |
| stop 0L | JHEP 1409, 015 | arXiv:1406.1122 |
| stop 1L | JHEP 1411, 118 | arXiv:1407.0583 |
| stop 2L | JHEP 1406, 124 | arXiv:1403.4853 |
| stop to charm | PRD 90, 052008 | arXiv:1407.0608 |
| NEW stop stau | | coming soon |
| stop2/gmsb (Z+jets+MET) | EPJC 74, 2883 | arXiv:1403.5222 |
| NEW **summary paper** | **submitted to EPJC** | **arXiv:1506.08616** |

# STOP, DIRECT DECAY TO LSP

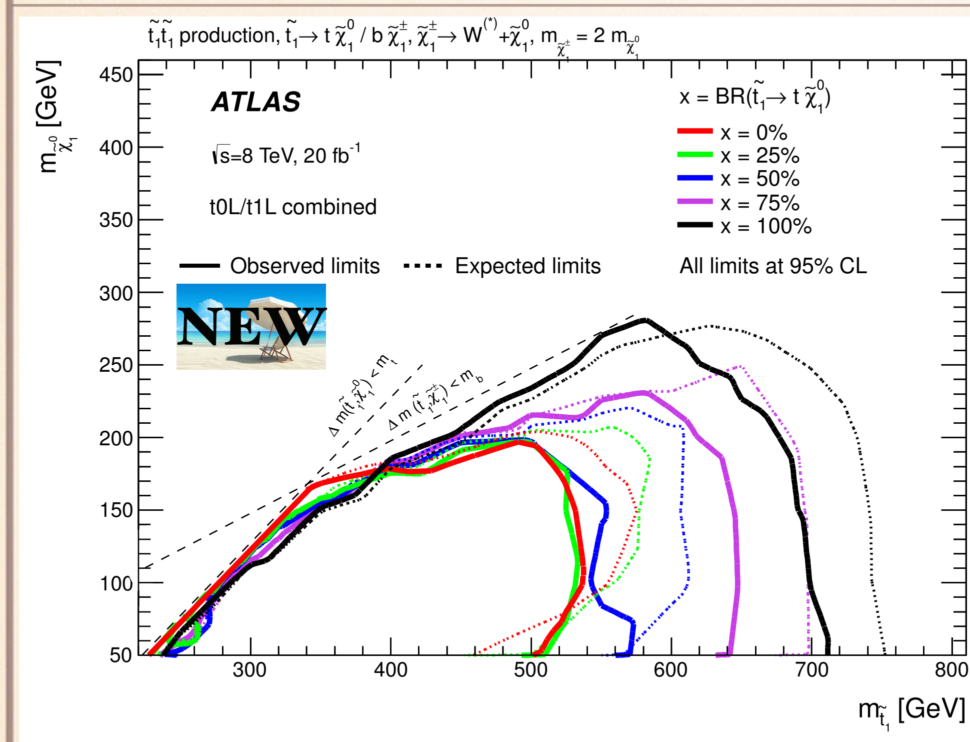


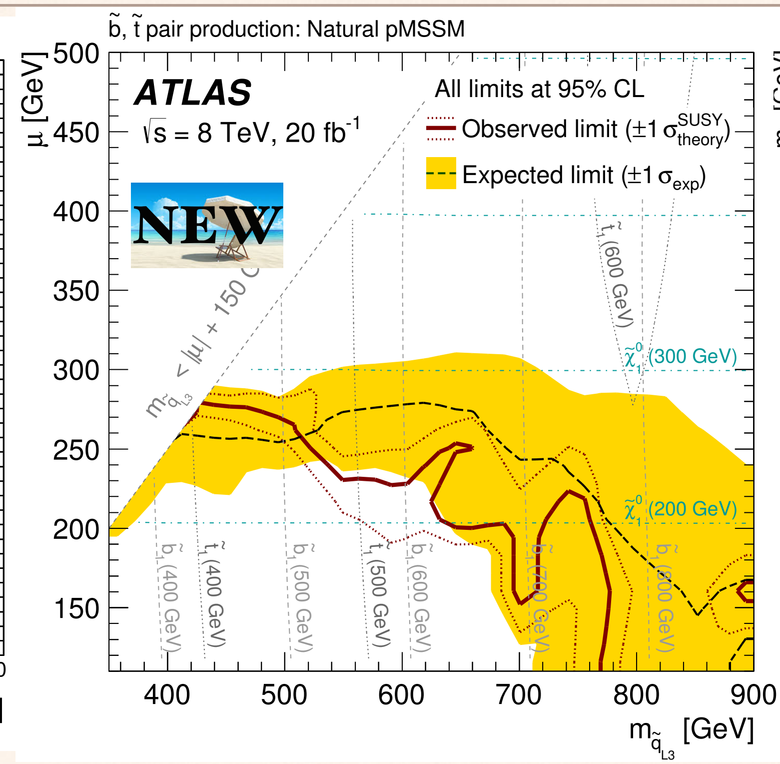

arXiv:1506.08616

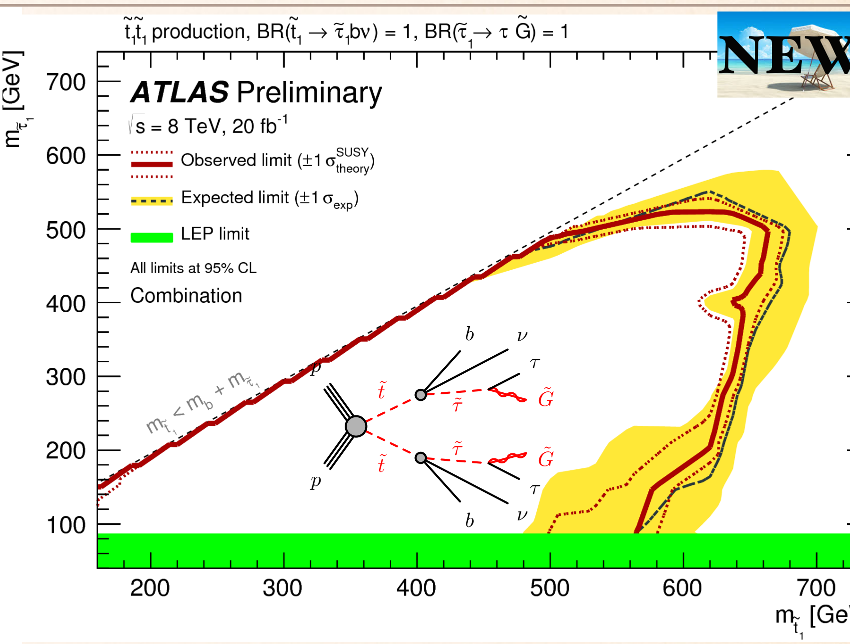
1. Combination of 0+1L channels, improves heavy stop sensitivity by 50 GeV
2. ttbar spin correlation and cross section reinterpretation
3. soft lepton, charm tagging, monojet, covering the 4-body and charm LSP decays
4. "WW-like stop" 2L+MET analysis covering gap between 3-body and 4-body

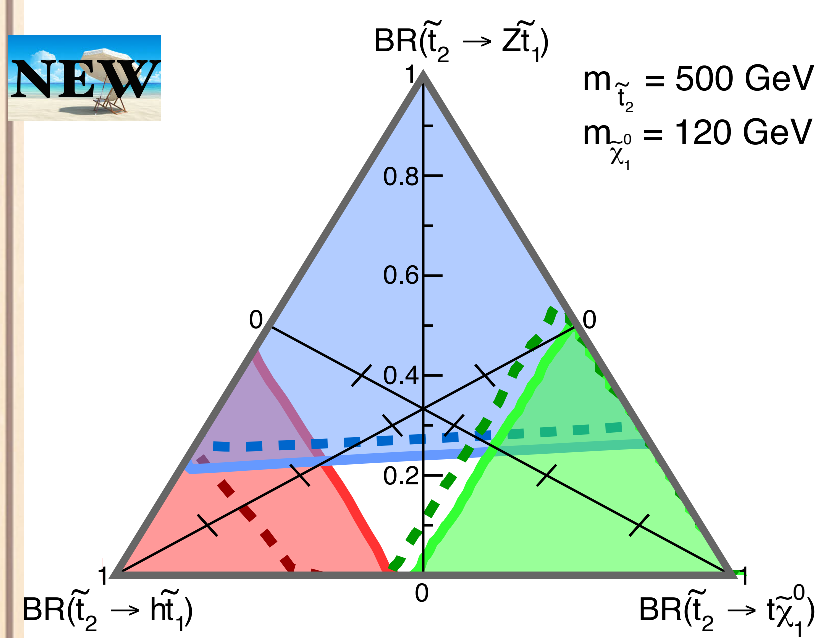
Even in this simple scenario, stop mass down to 200 GeV are possible for compressed mass spectra

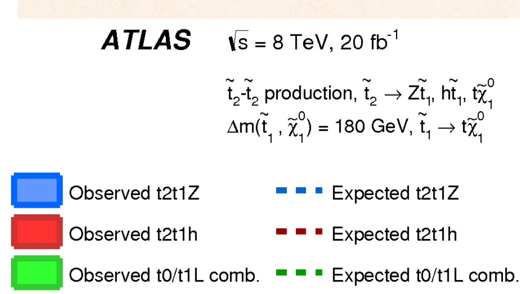
# STOP - MORE POSSIBILITIES



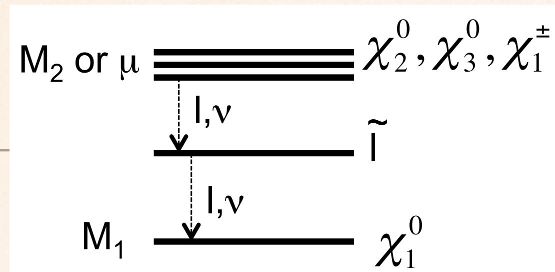



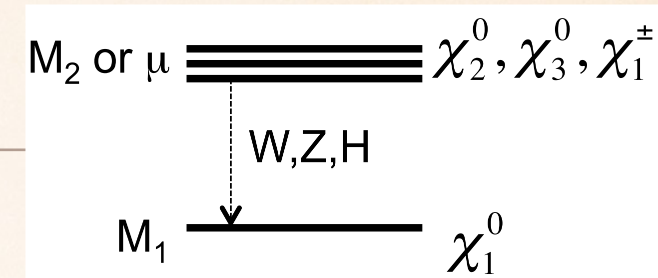



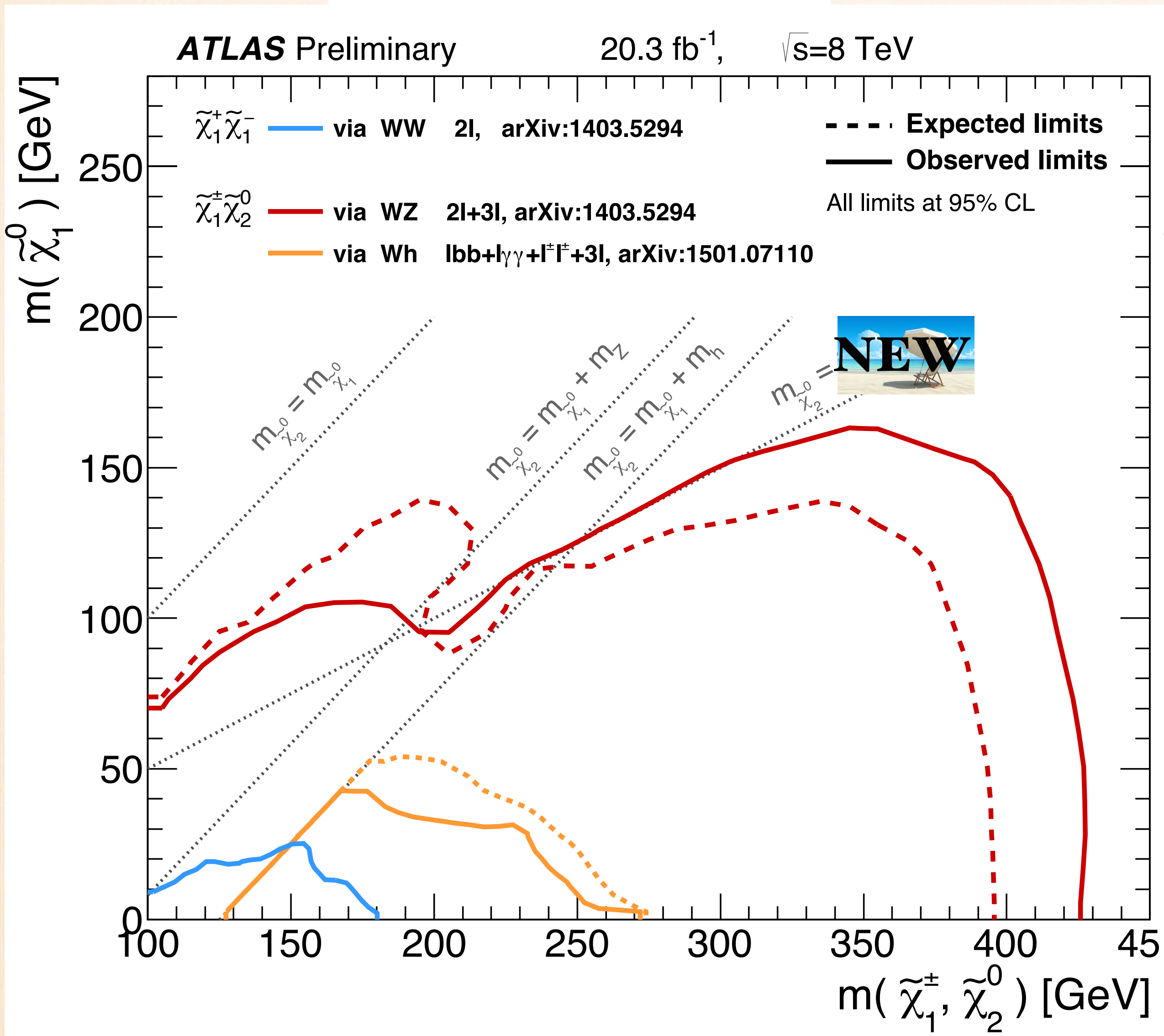



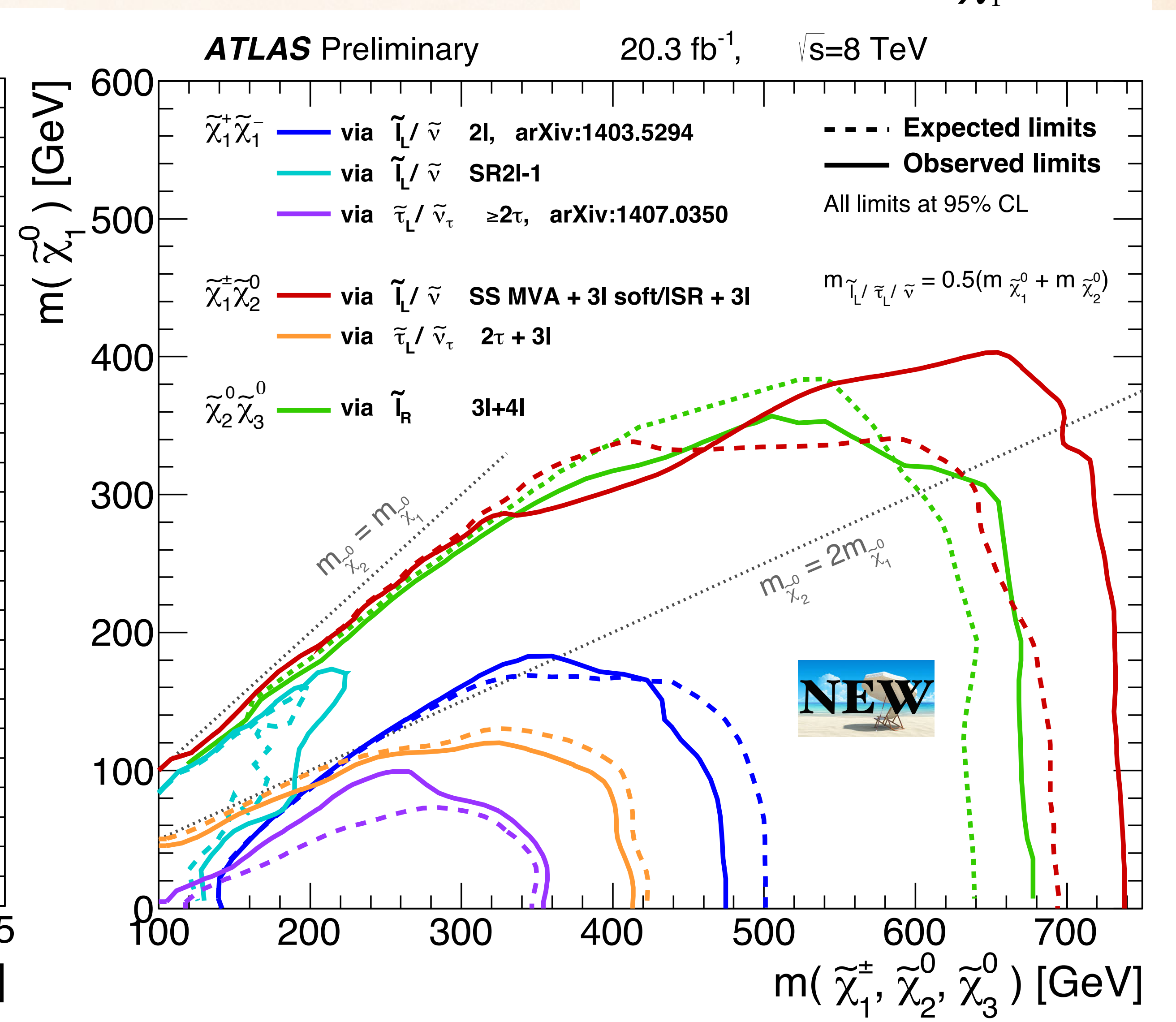

- Non-100% branching ratios, pMSSM slices (more examples: paper and parallel session talk of **P. Butti**)
- No great loss of sensitivity even if most analyses not optimised on these scenarios.
- Dedicated search for stop decaying through stau to τν b G

# DIRECT ELECTROWEAK PRODUCTION



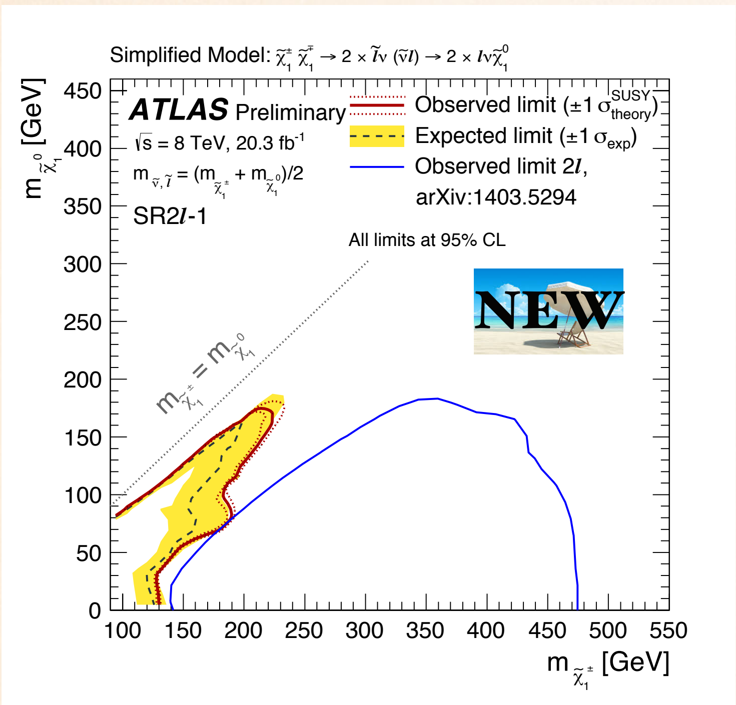



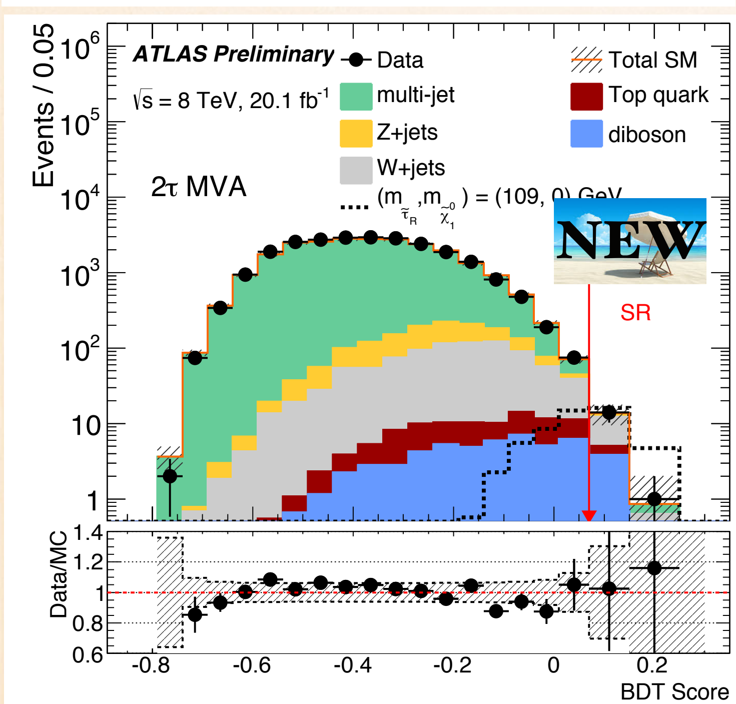



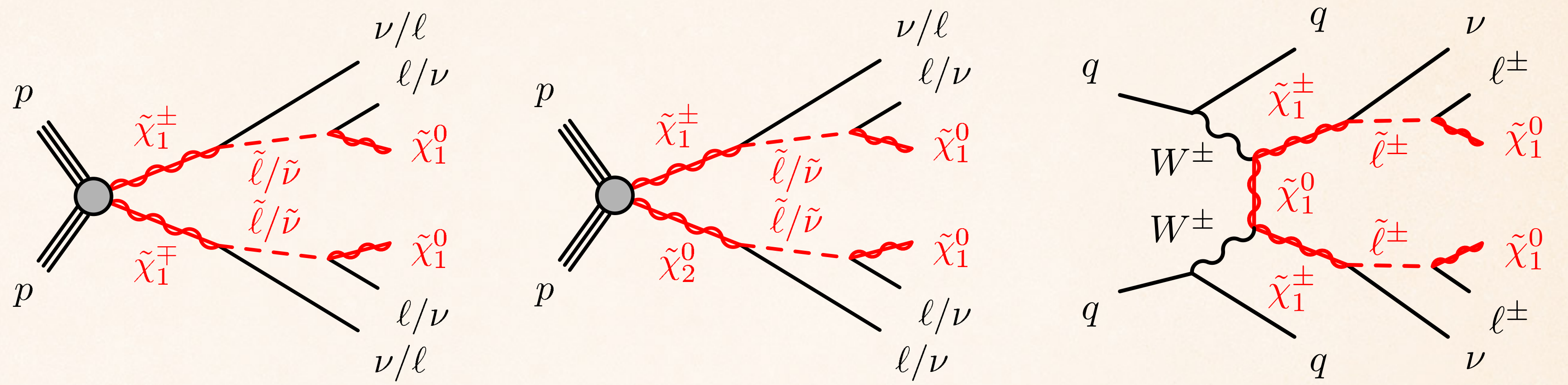

- <u>No limit</u> if only EWKinos with $0.2 < \Delta M < 30$ GeV without intermediate sleptons ($\mu \ll M_1, M_2$).

# ELECTROWEAK PRODUCTION SUMMARY PAPER

## See the talk of Christophe Bock for all details

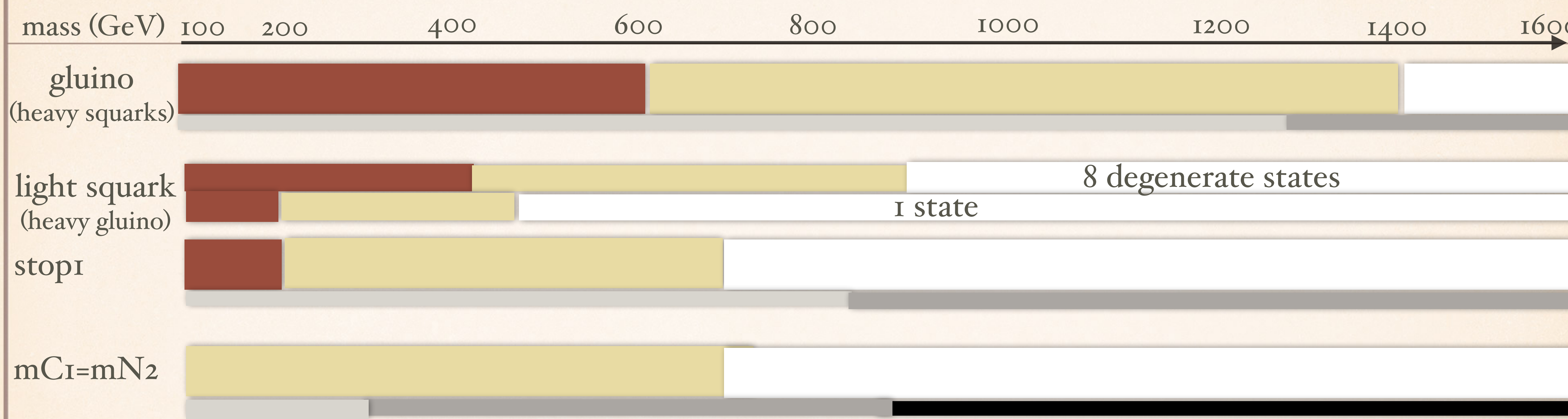


- A new search with 2 hadronic taus and a MVA discriminant, targeting direct stau production
- New searches with 2 OS, 2 SS, or 3 soft leptons, targeting C1C1 or C1N2 with compressed spectra.
- A new search with 2 SS leptons, two VBF jets, and $E_T^{Miss}$, targeting C1C1 with compressed spectra.
- statistical combinations of different analyses
- New interpretations (dependence on intermediate slepton mass, pMSSM, GMSB, and NUHM limits)

# SO HOW WELL IS SUSY ?




difficult to evade limits — limits dependent on assumptions — no constraint

Fine tuning $\Delta \equiv \frac{2\delta m_H^2}{m_h^2}$.

- < 10
- 10-100
- > 100

Fine tuning bars based on formulas from arXiv:1110.6926 with m(t1)=m(t2), xt=0, tan $\beta$ large, $\Lambda = 10^3$ TeV. Use with care - other calculations proposed, possible dependence on the fundamental parameters of SUSY breaking.

Much more constrained than before LHC run1, but plenty of room for light (low FT) SUSY
Beside, the above is valid for simplified models in the standard scenario. **But**

- Are simplified model limits realistic ? What if competing decays, complex spectra
- Beyond the standard scenario: RPV, long lived particles, beyond MSSM

=> **next slides**

# OUTLINE

- General remarks
- simplified model limits
- **pMSSM limits**
- long lived searches, RPV
- run2 and beyond

# PMSSM SUMMARY PAPER

## (COMING SOON)

Interpreted in the general [19-parameter] pMSSM
- “phenomenological” MSSM
- R-parity conserving
- Neutralino LSP

Random sampling of the parameters (with sparticle masses up to **4 TeV)**

**500 million** models sampled

Apply prior experimental constraints:

**EW** precision measurements

Mass bounds e.g. from **LEP, Tevatron**

**ΩLSP < ΩPlanck**

Consider carefully the remainder

**310,327** : models before Run-1

**30 billion** : signal events generated

**44,559** : models required detector simulation

**600 million :** signal events thru GEANT

Present exclusion (fraction of models) in 2D or 1D projections.

Interpret with care, some dependence on constraints and scan range

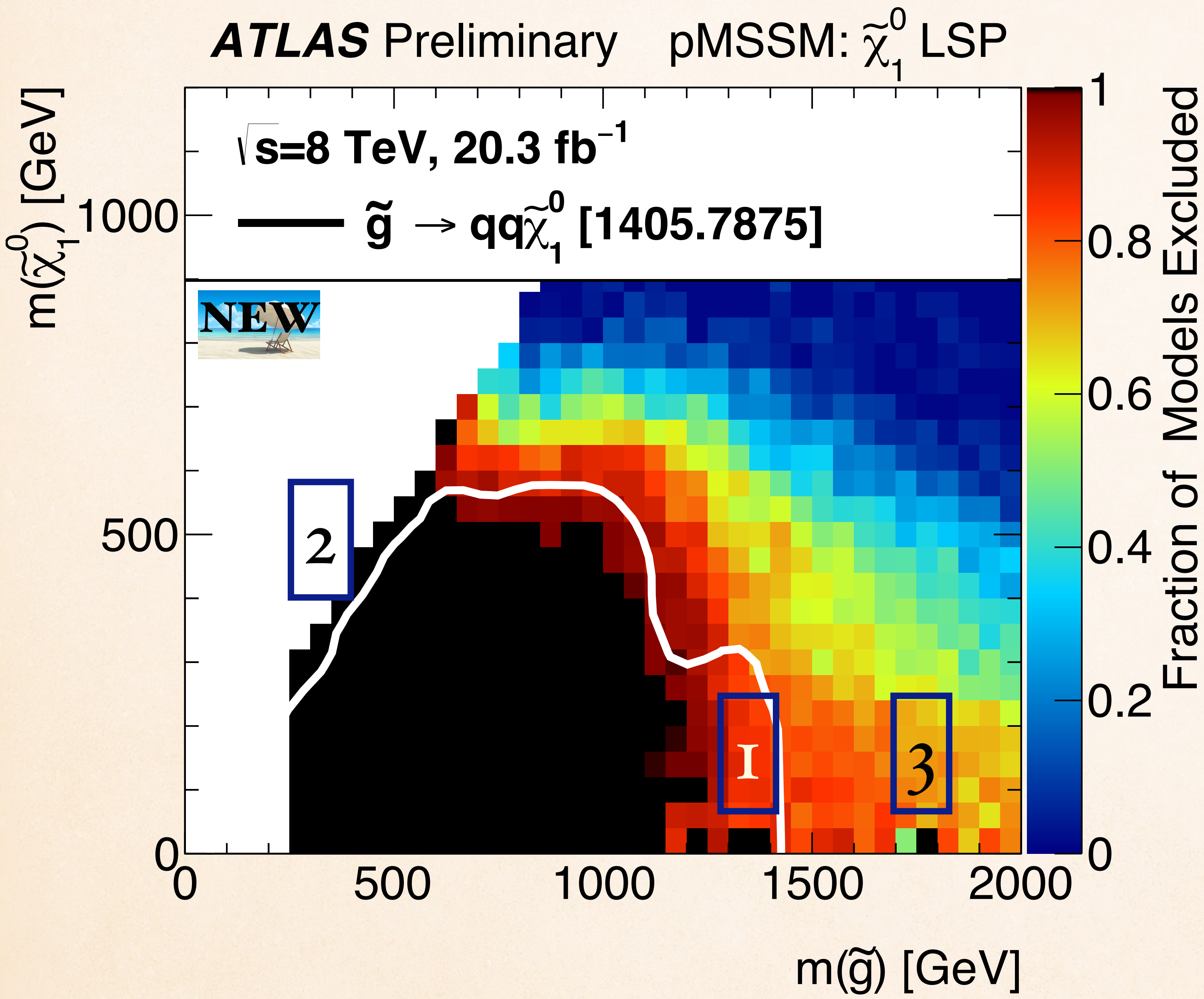
Following the approach of “SUSY without prejudice”, arXiv:0812.0980

| | |
|---|---|
| Inclusive | 0-lepton + 2–6 jets + $E_T^{miss}$ |
| | 0-lepton + 7–10 jets + $E_T^{miss}$ |
| | 1-lepton + jets + $E_T^{miss}$ |
| | $\tau(\tau/\ell)$ + jets + $E_T^{miss}$ |
| | SS/3-leptons + jets + $E_T^{miss}$ |
| | 0/1-lepton + 3$b$-jets + $E_T^{miss}$ |
| | Monojet |
| 3rd generation | 0-lepton stop |
| | 1-lepton stop |
| | 2-leptons stop |
| | Monojet stop |
| | Stop with Z boson |
| | 2$b$-jets + $E_T^{miss}$ |
| | $tb+E_T^{miss}$, stop |
| Electroweak | $\ell h$ |
| | 2-leptons |
| | 2-$\tau$ |
| | 3-leptons |
| | 4-leptons |
| | Disappearing Track |
| Other | Long-lived particles |
| | $H/A \to \tau^+\tau^-$ |

**Only a preview/overview given here, more detailed results in the parallel session talk of C. Wanatotaroj**

**Evaluate limits from 22 separate run1 search papers**

# STRONG PRODUCTION



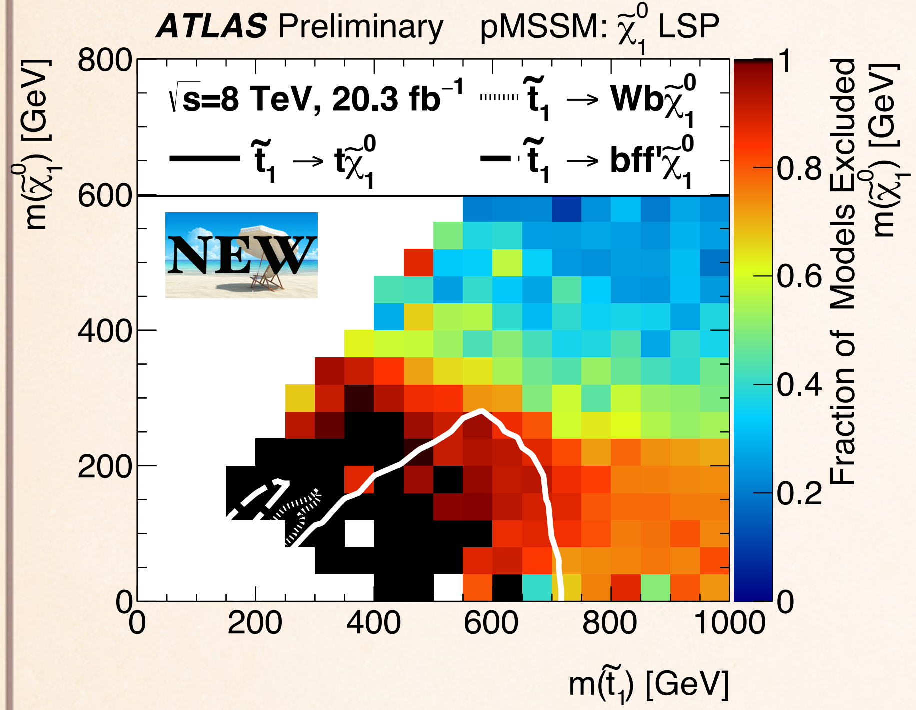

- The fraction of models excluded is drawn as a function of pair of parameters

1. Limits from a simplified model drawn for comparison. pMSSM limits are not radically different !

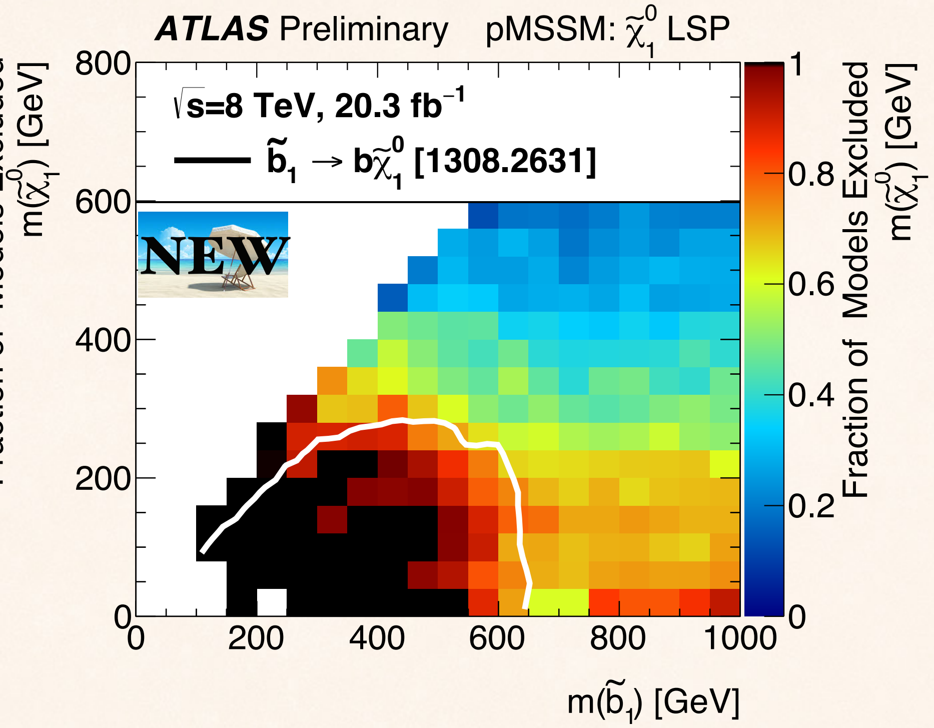
2. All models with compressed gluino-neutralino spectra are excluded up to about 600 GeV by monojet analysis

3. For $m_{LSP} < 250$ GeV, visible effect from disappearing track analysis killing wino LSP models.

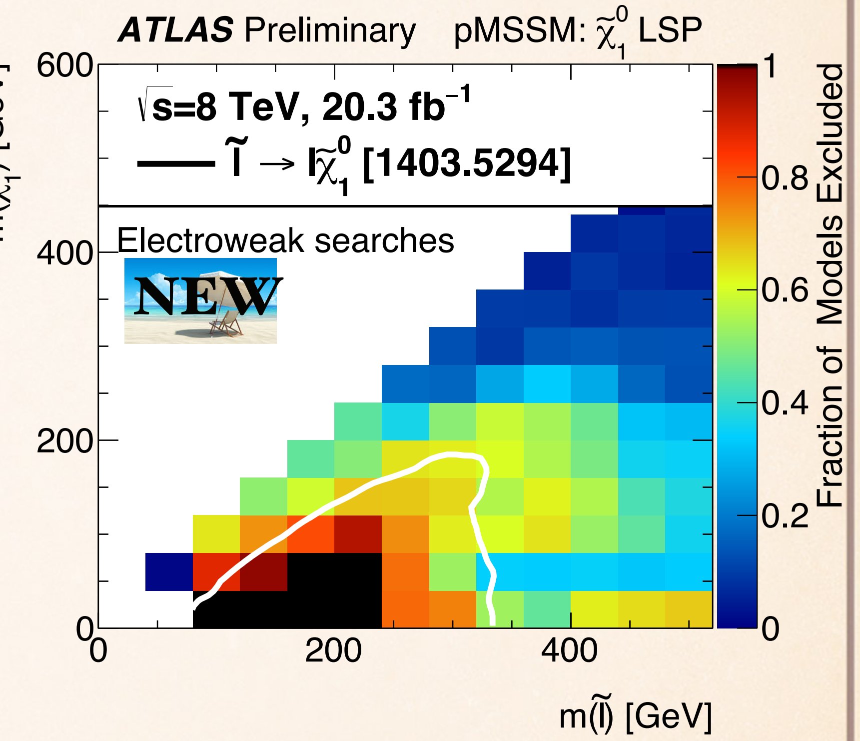
# OTHER EXAMPLES




Stop

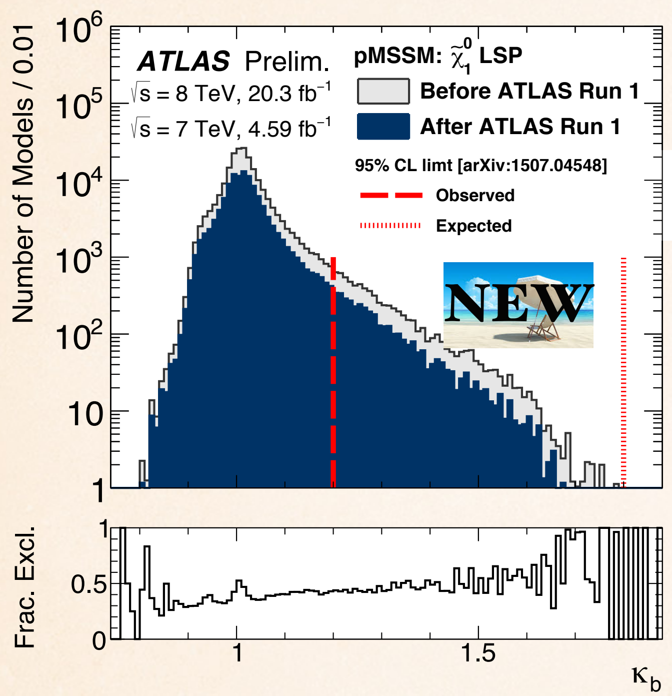


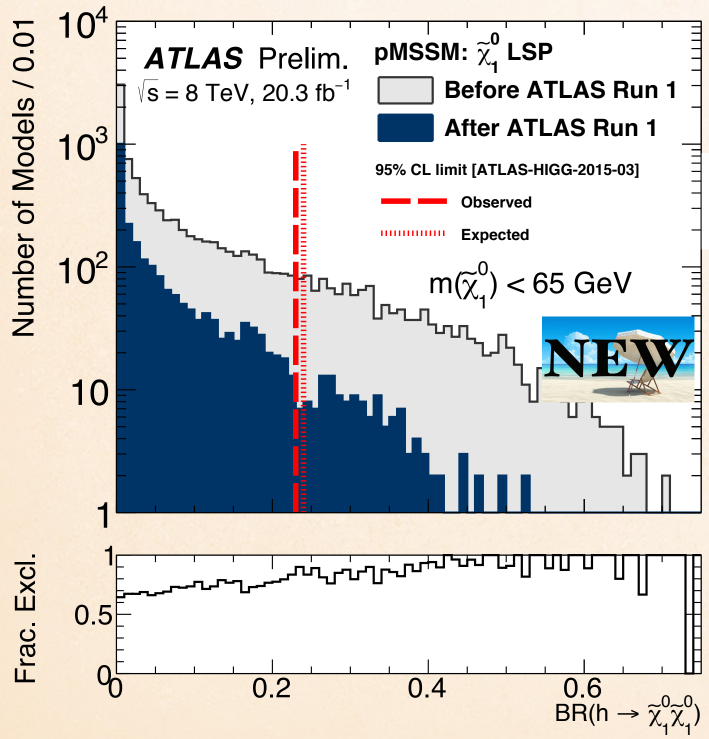

Sbottom

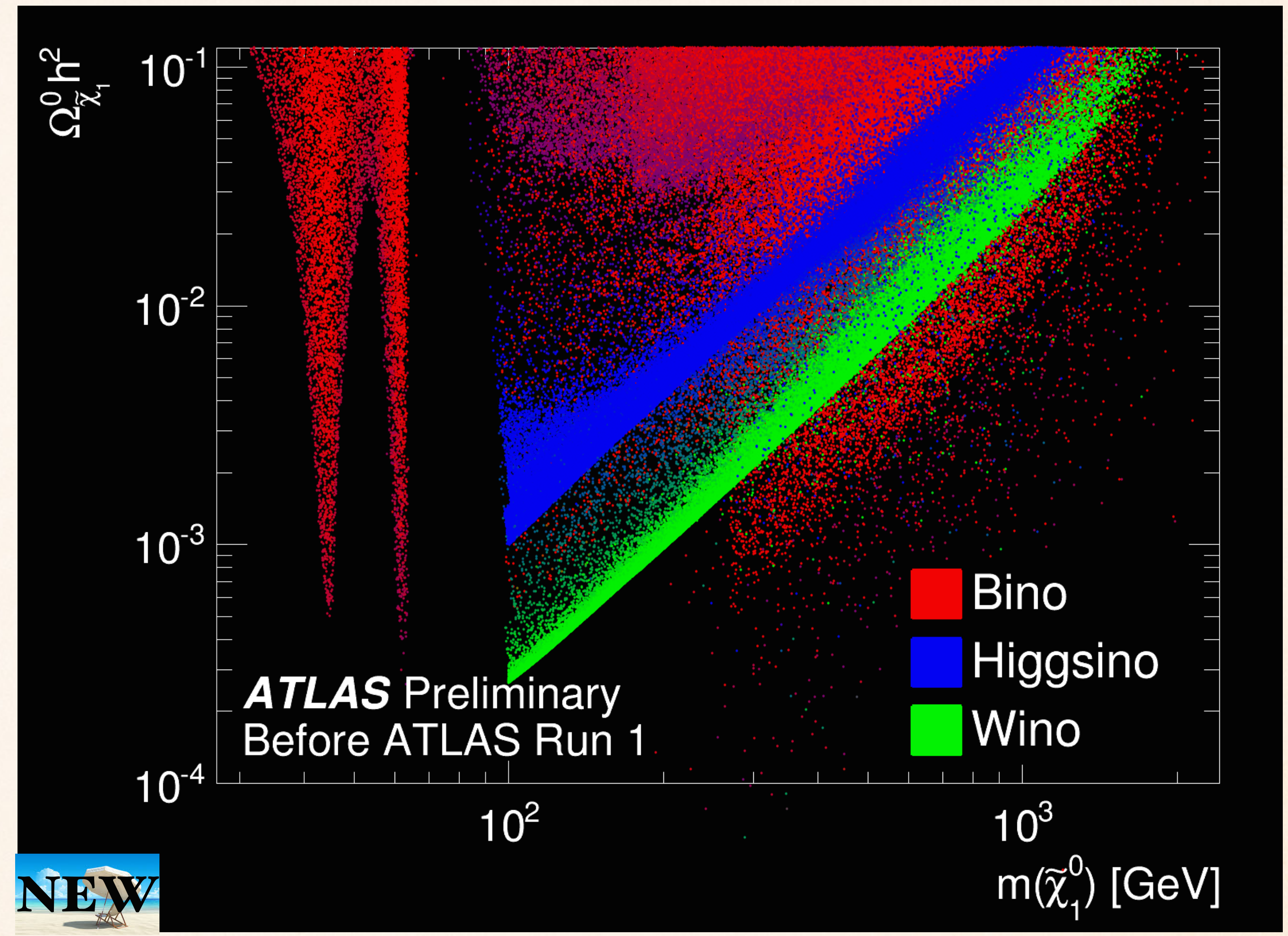



Slepton

# HIGGS AND DARK MATTER




- The distribution of Hbb coupling and H to invisible BR is compared to the measurements
- Relic density vs neutralino mass shown before and after run1 atlas constraints (animation)

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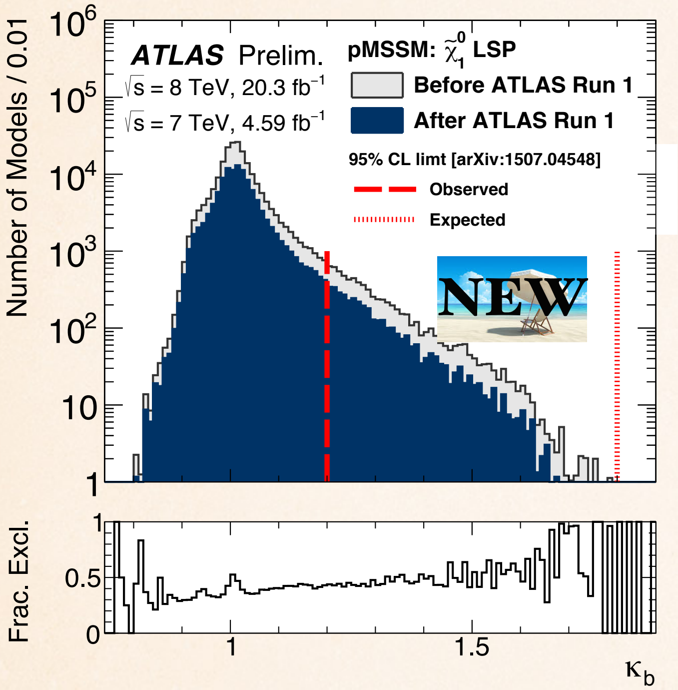


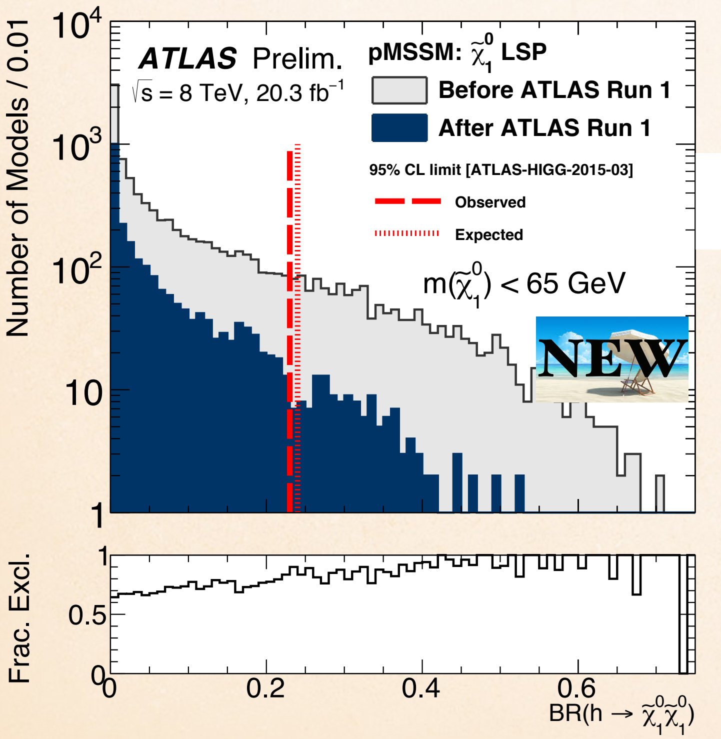


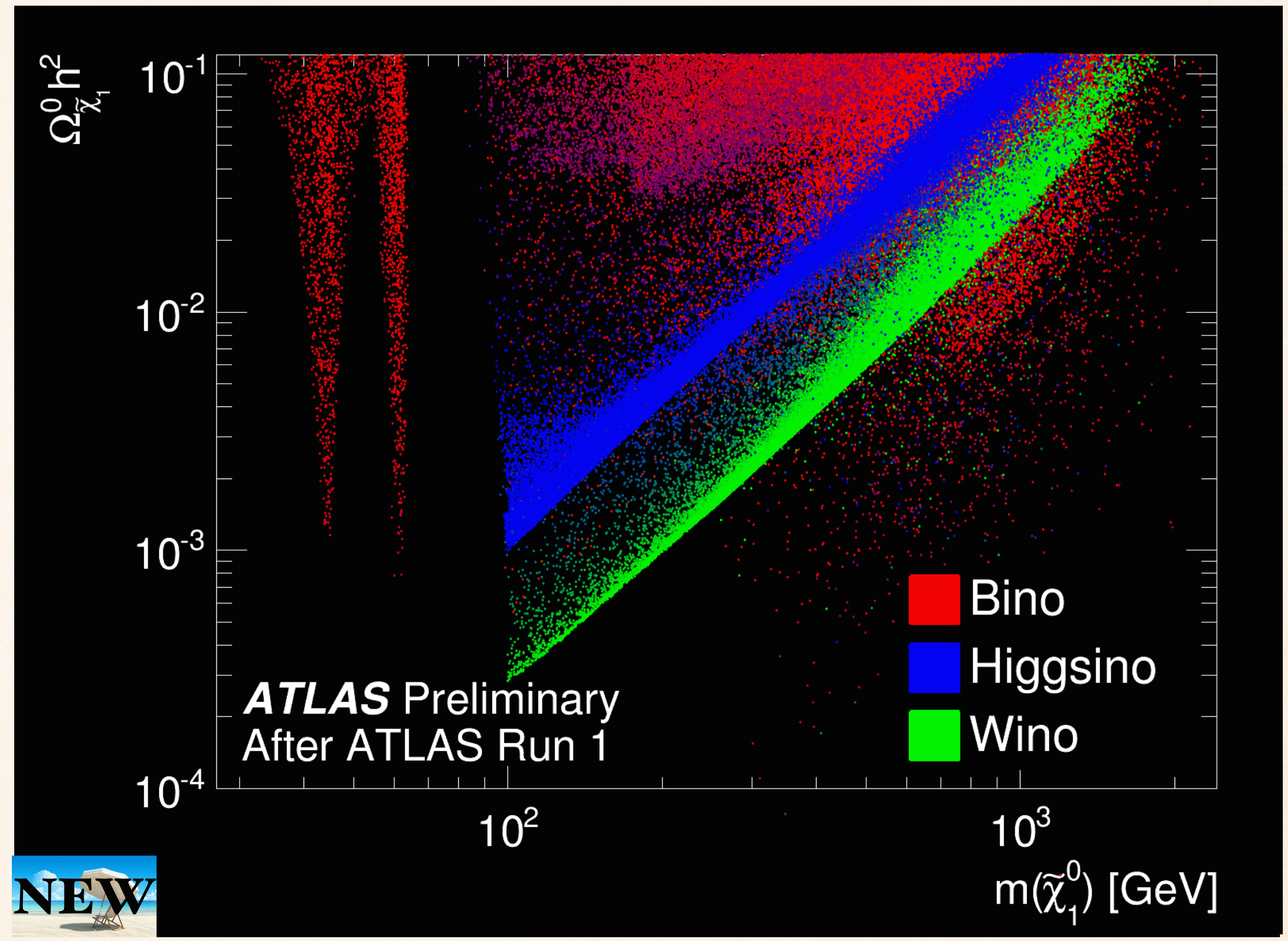


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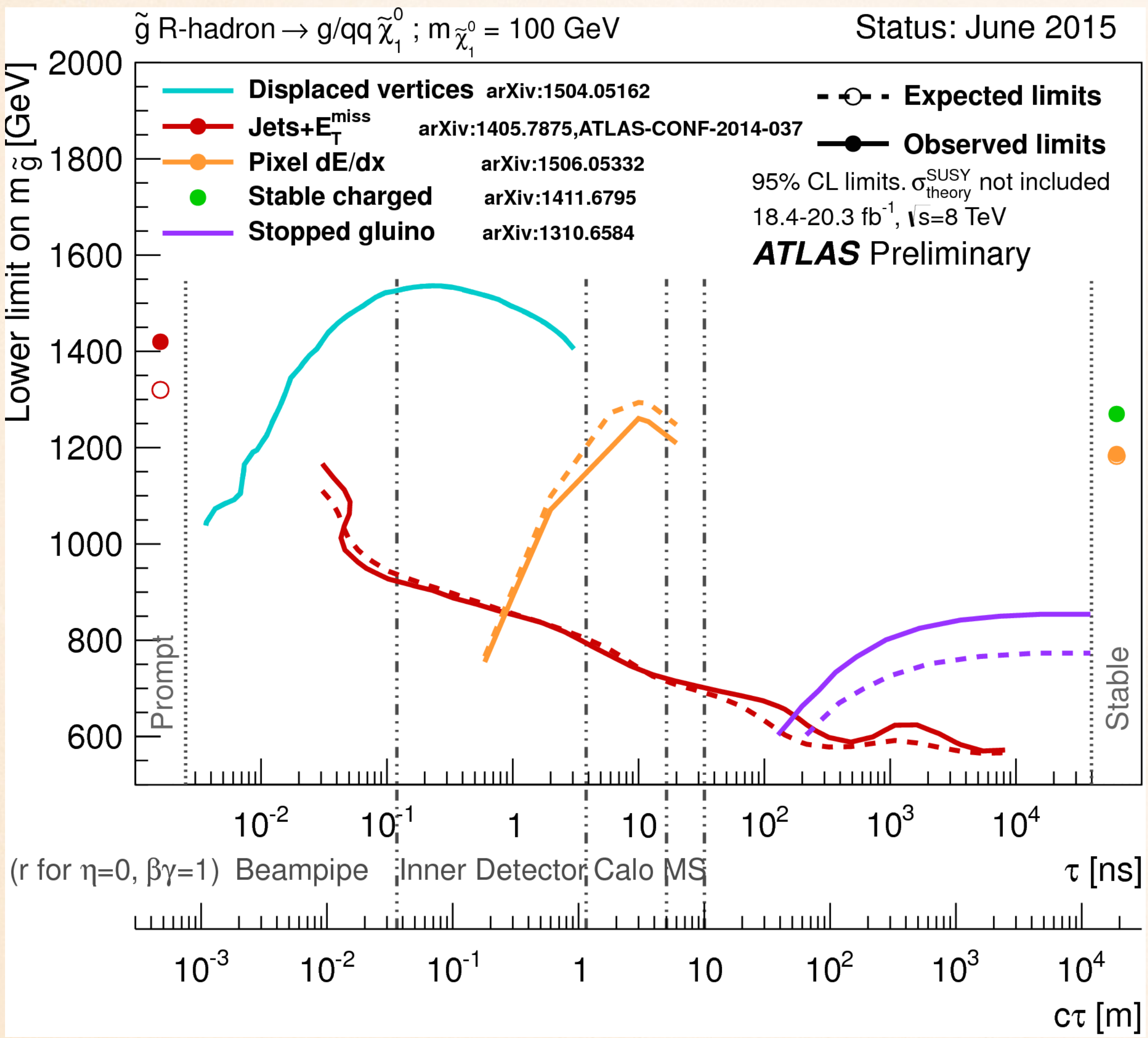
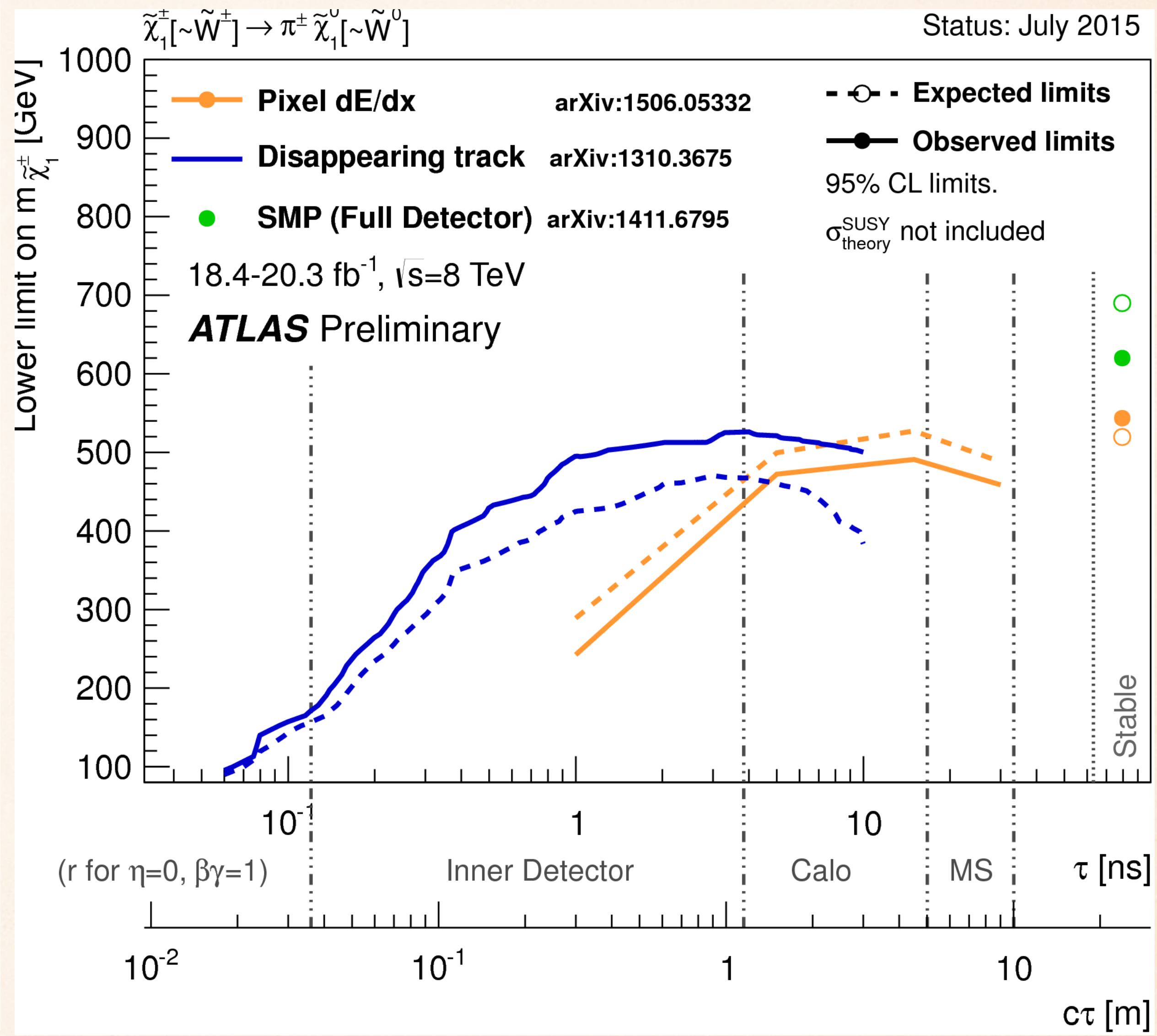
# LONG LIVED (S)PARTICLES




**Prompt decay**, **displaced vertices**, **dEdx**/**TOF** searches provide robust limits on strongly interacting particles over the full lifetime range.

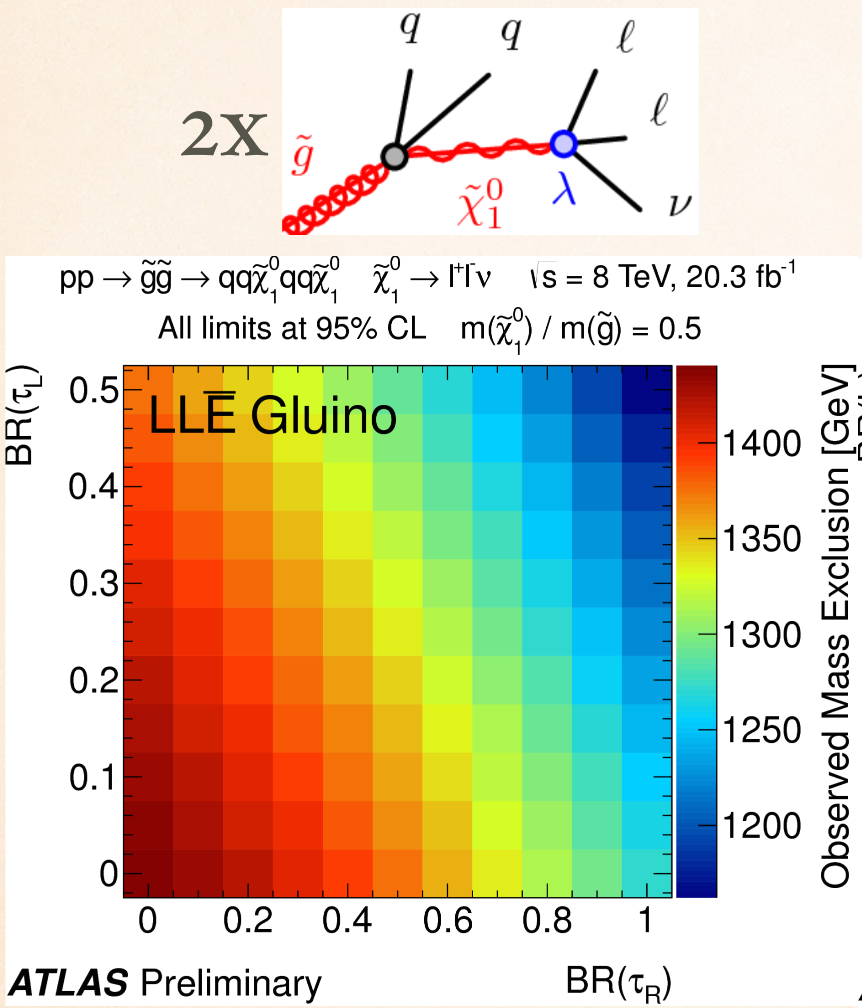
Non pointing photons (1409.5542) not included in the plots

# R-PARITY VIOLATION

A systematic study of the sensitivity to RPV SUSY with LLE and LQD couplings

ATLAS-CONF-2015-018

2X

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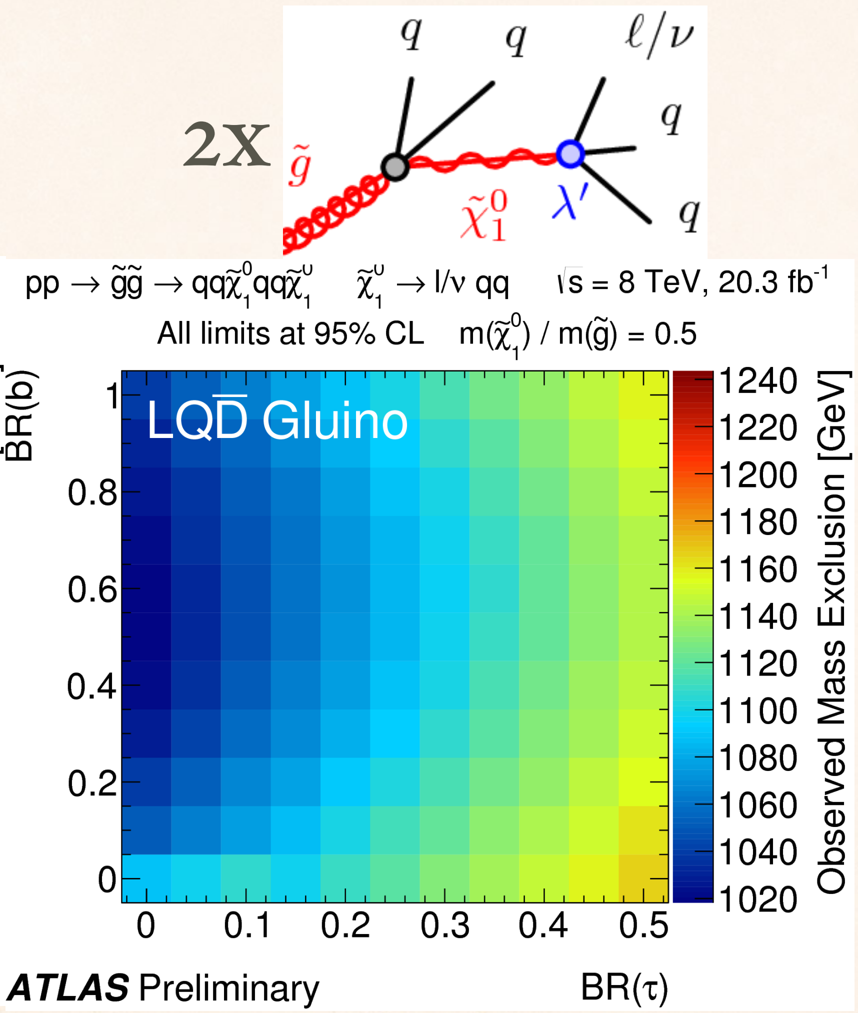


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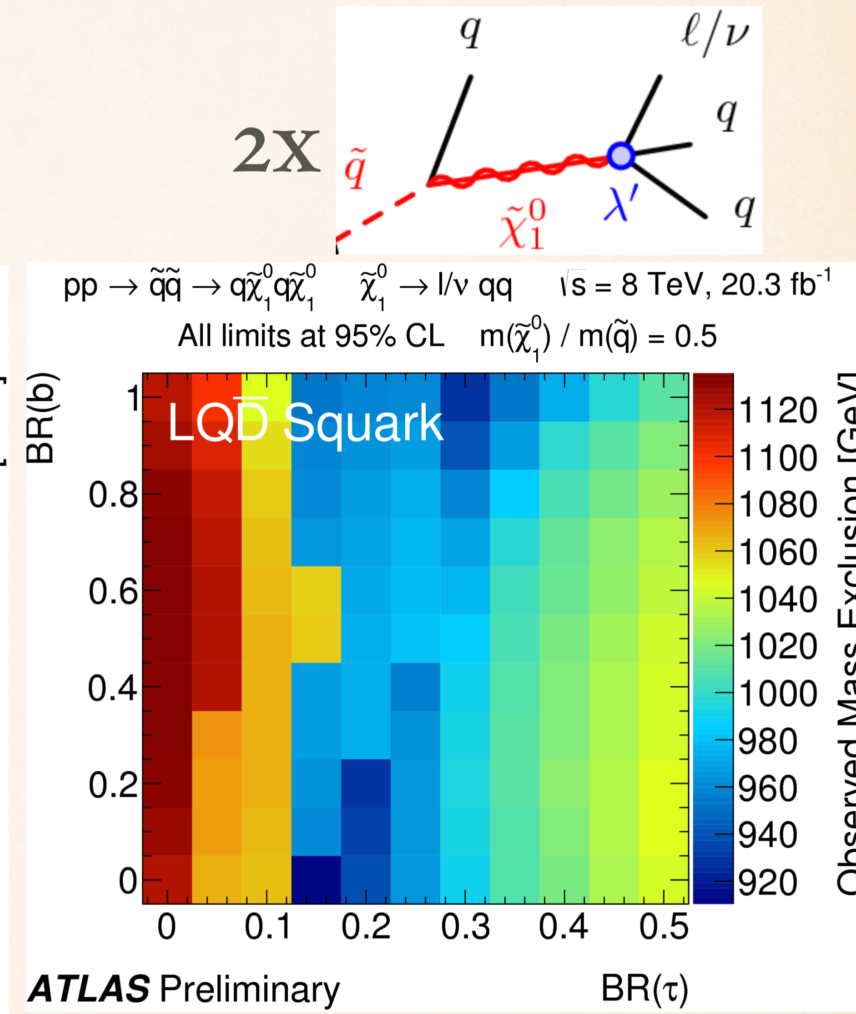
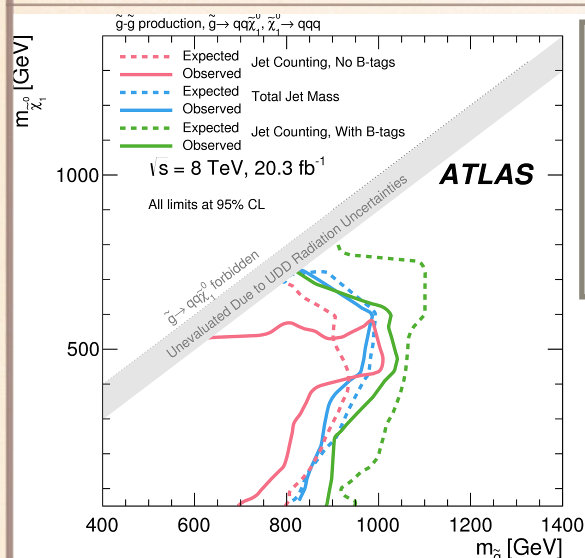
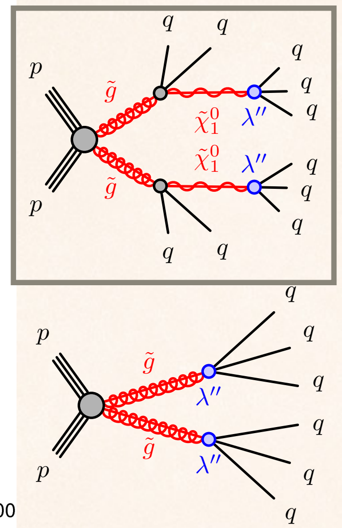
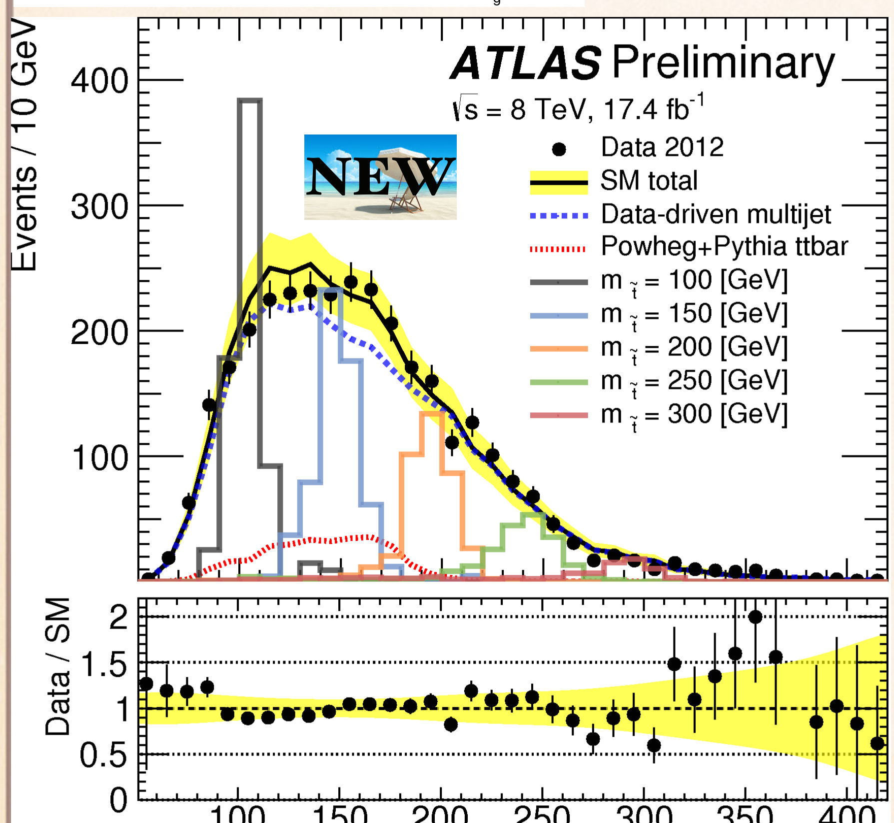



- best limits from RPC SS/3L and RPV 4L searches, 1050-1400 GeV depending on BR and neutralino mass
- best limits from RPC 0L and 1L searches, 900-1200 GeV depending on BR and neutralino mass
- best limits from RPC 0L and 1L searches, up to 1200 GeV, but **no limit** if neutralino is light. Will need a targeted search.

# R-PARITY VIOLATION, UDD




ATLAS-CONF-2015-026

- gluino UDD decays - limits between 600 and 950 GeV from dedicated multi-jet analyses (1502.05686). Even better limits if non-prompt decay, from displaced vertices
- stop decay to bs. **100** to 310 GeV limit using b-tagging and large-R jet mass
- Both analysis data-driven, using innovative large-R jet techniques to separate the signal from the QCD background
- Not enough sensitivity for squark UDD decays in light jets only (low energy constraints?)

RPV is not that stealthy, but requires a dedicated effort for fully hadronic states. Some blind spots remain for squarks. Trigger on multijet states not trivial as luminosity increases!

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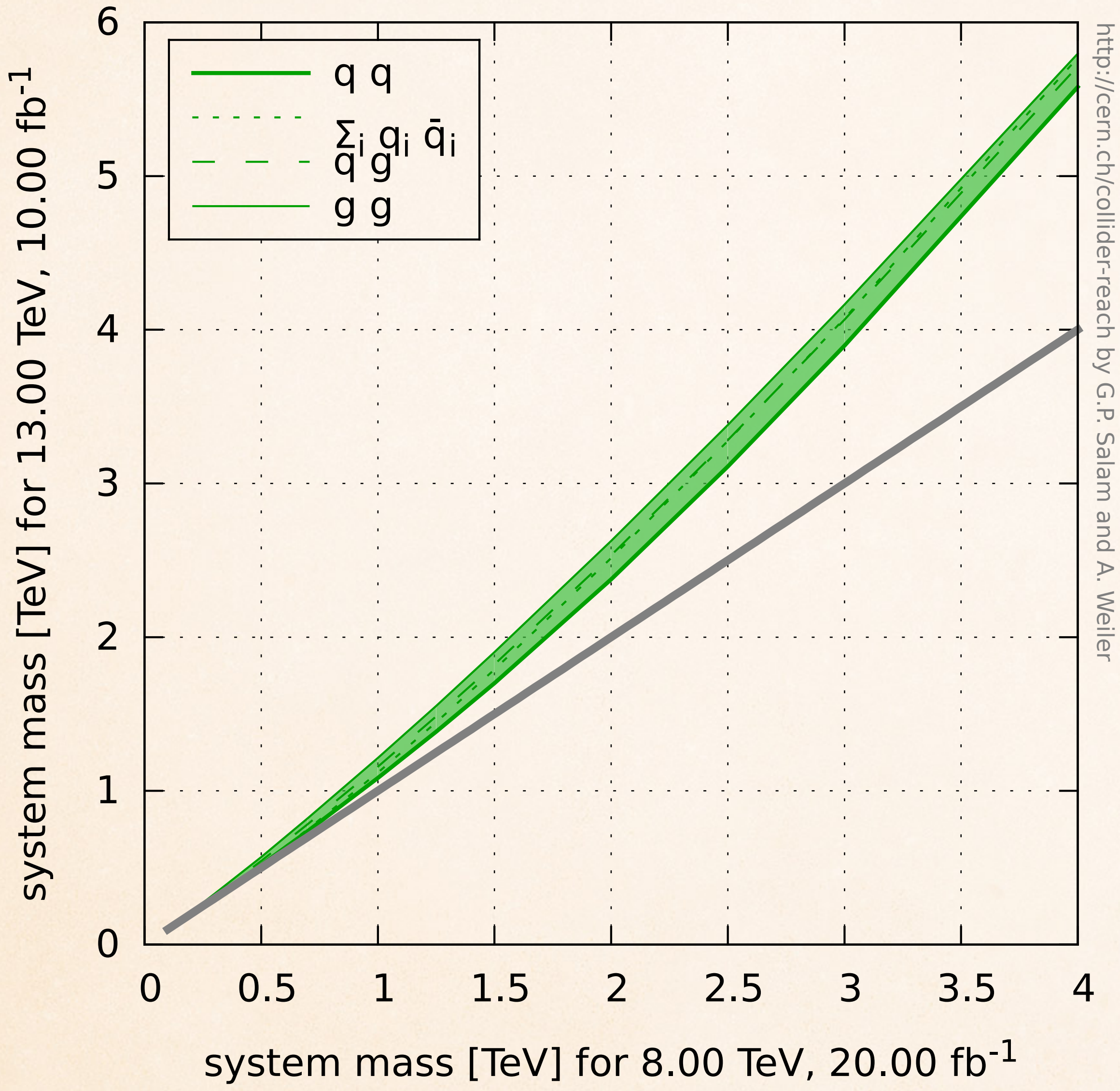
- **run2 and beyond**

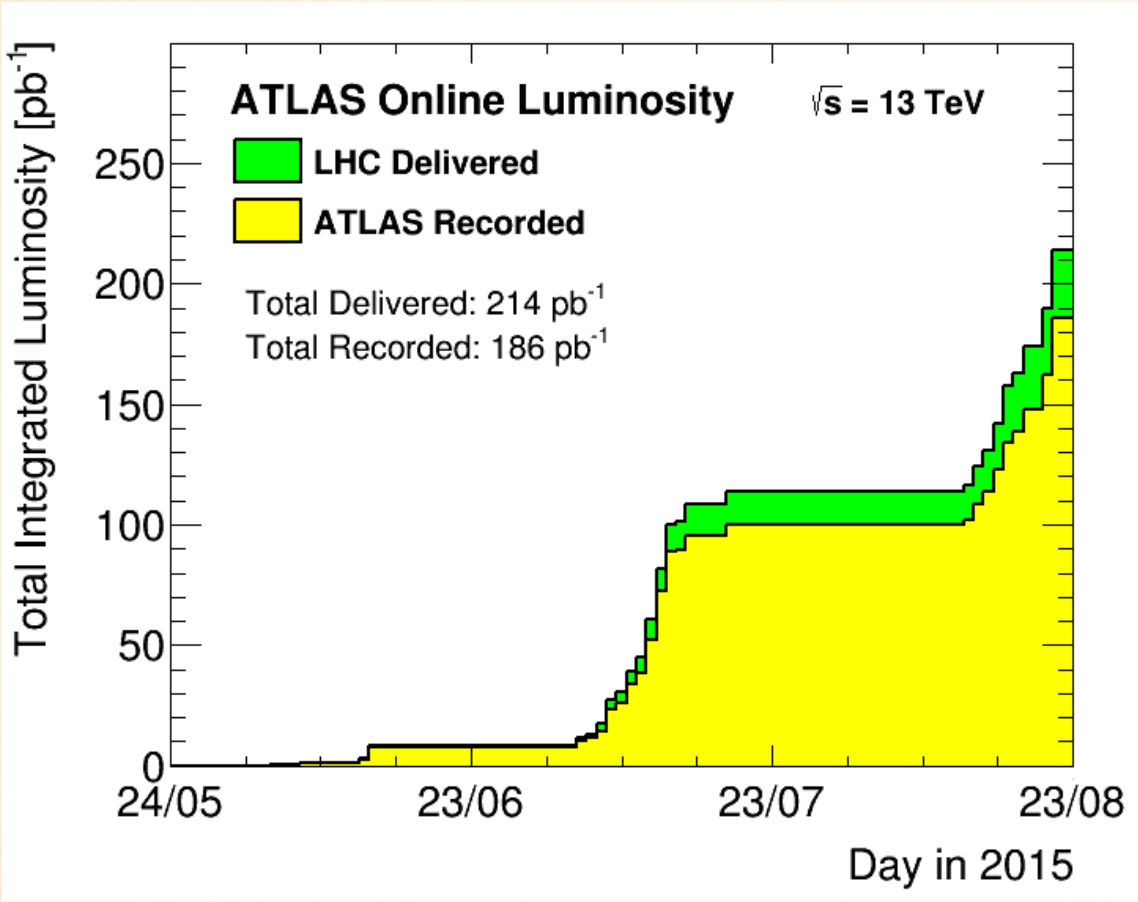
# 13 TEV COLLISIONS

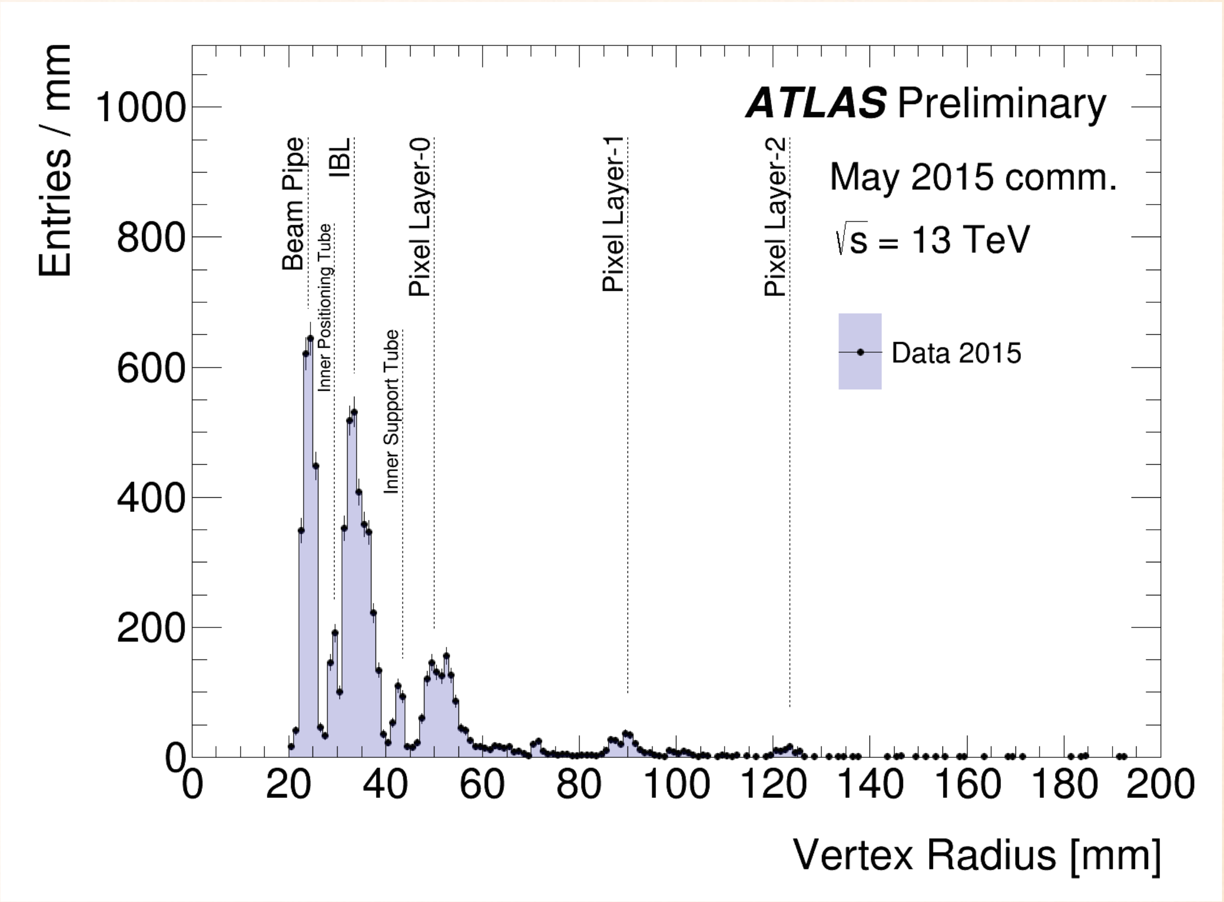



**Salam, Weiler** **http://cern.ch/collider-reach**

- Greatest gain from the collision energy for heavy particles
- Early searches focus on high mass (i.e. strong production, high S/B).
- Electroweak production, difficult low-mass blind spots will require more luminosity

# EARLY DATA

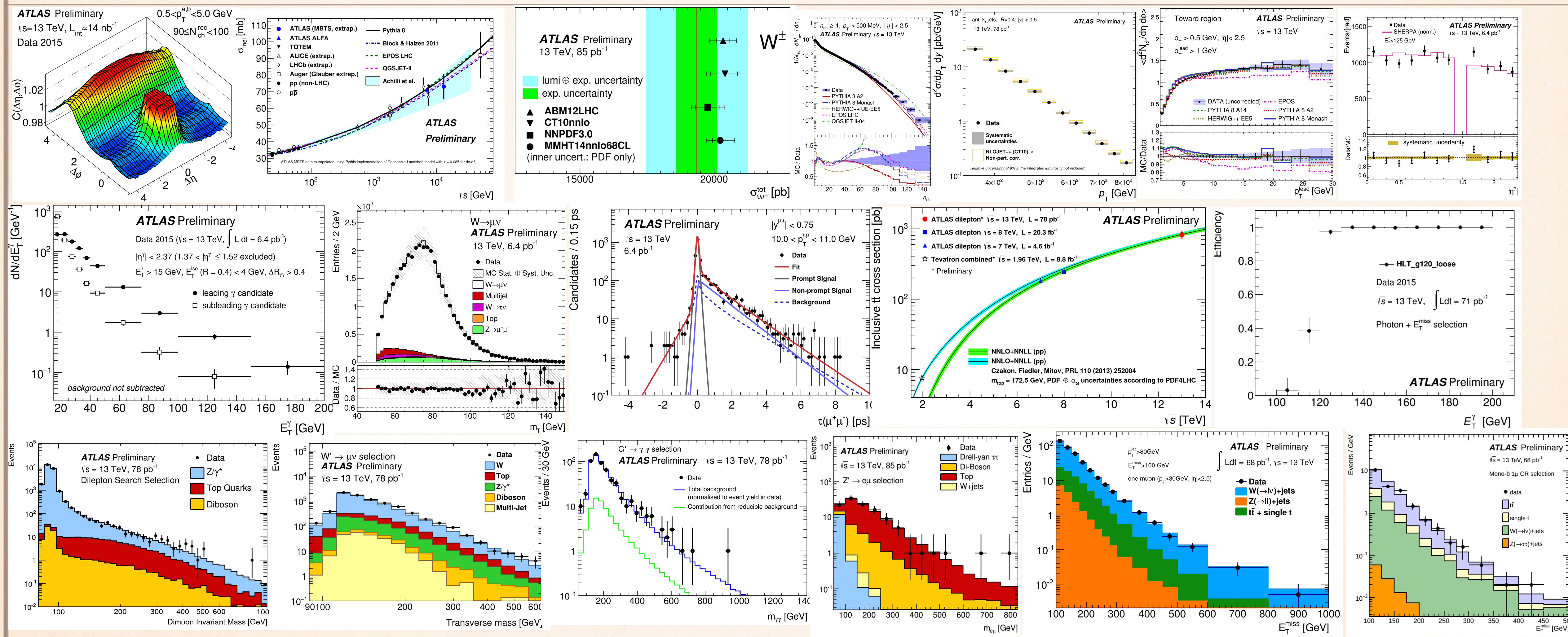



- 0.18 fb$^{-1}$ recorded
- A few fb$^{-1}$ expected in September and October (with large uncertainties)
- 100 fb$^{-1}$ expected by the end of run2

- Radius of hadronic interactions, the new pixel layer (IBL) is visible

# RUN2 ANALYSIS RESULTS

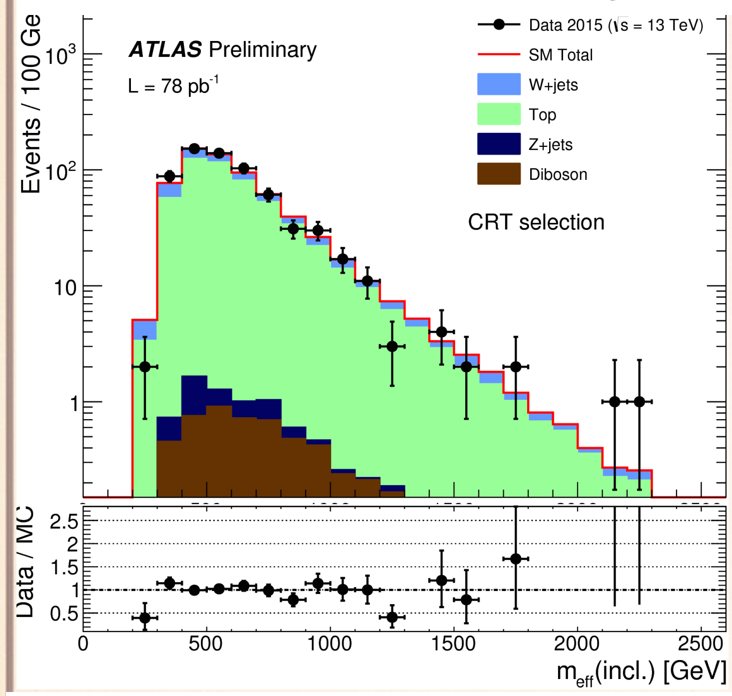



- Plenty of detector performance and physics results (including charge particle multiplicity, jet, W , Z, and top cross sections) see

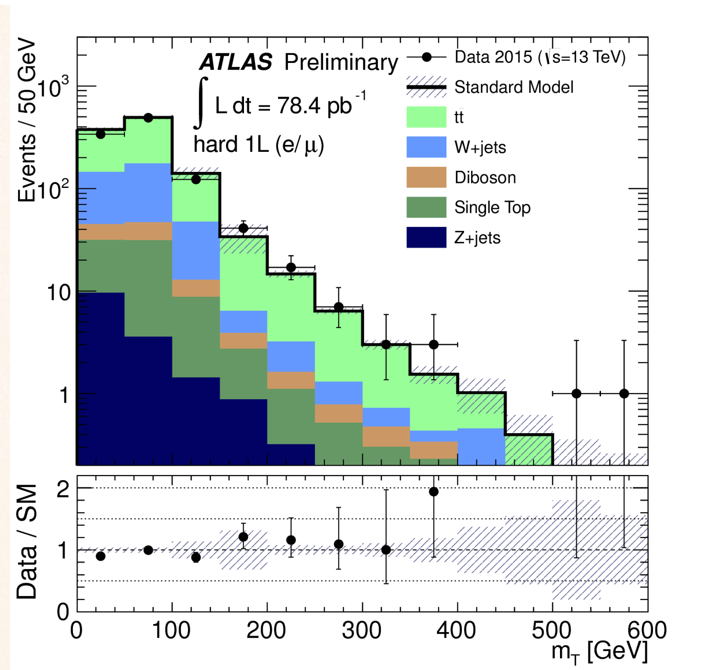
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Summer2015-13TeV

# RUN2 SUSY BACKGROUND STUDIES

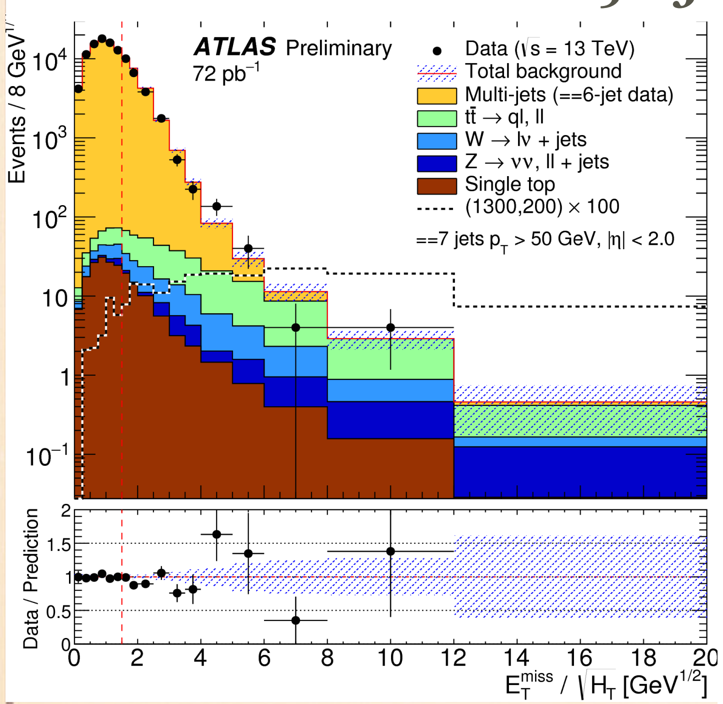
**ATLAS-PHYS-PUB-2015-028**



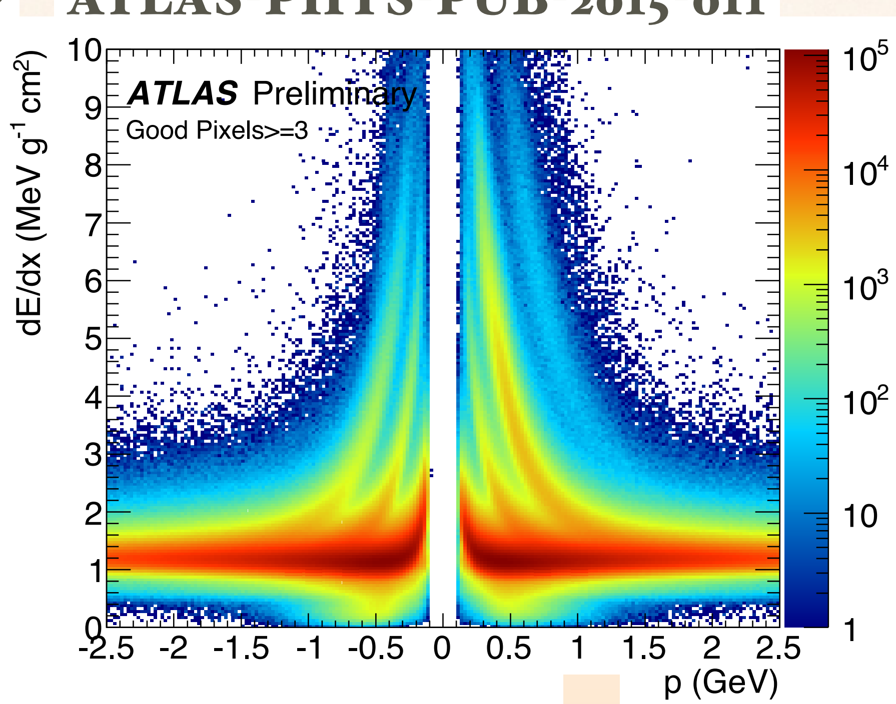

**ATLAS-PHYS-PUB-2015-029**




**ATLAS-PHYS-PUB-2015-030**




**ATLAS-PHYS-PUB-2015-011**




- Backgrounds appear to be well modeled
- More details in parallel session talks

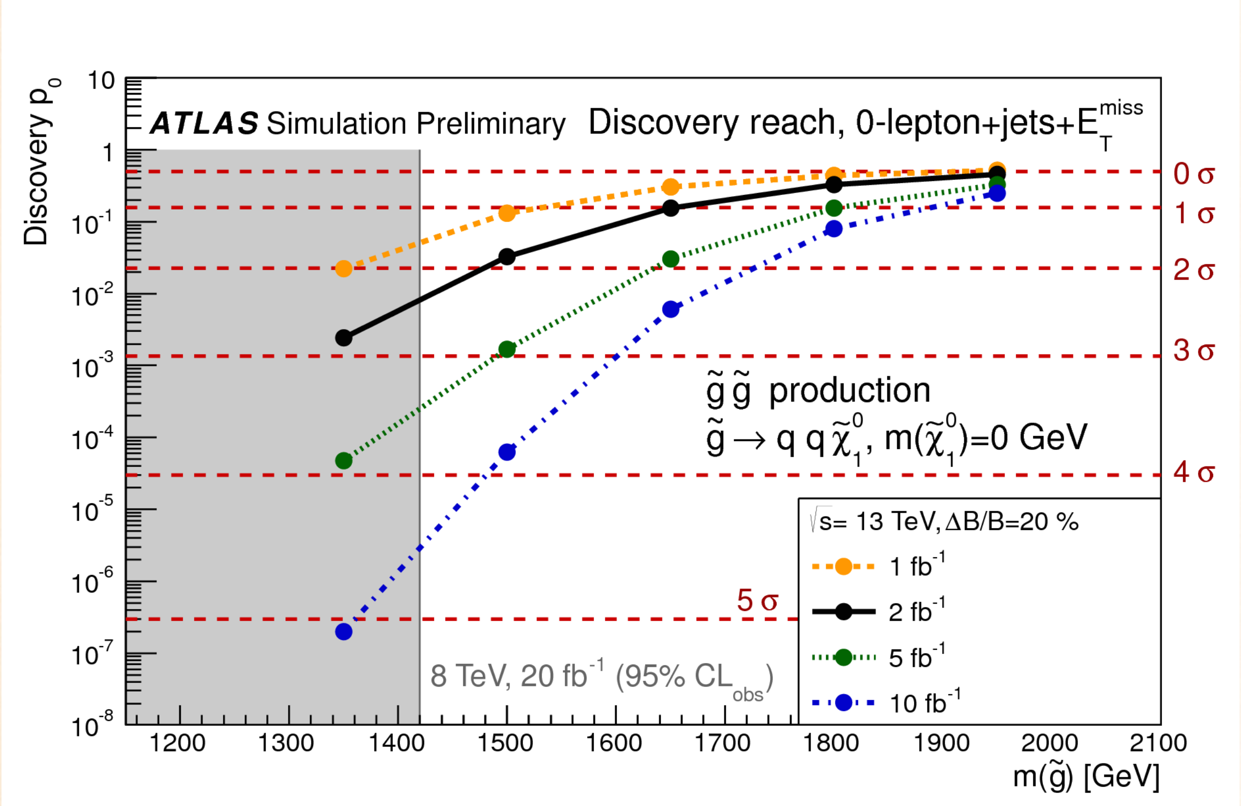
*top left:* Zero lepton search, top CR

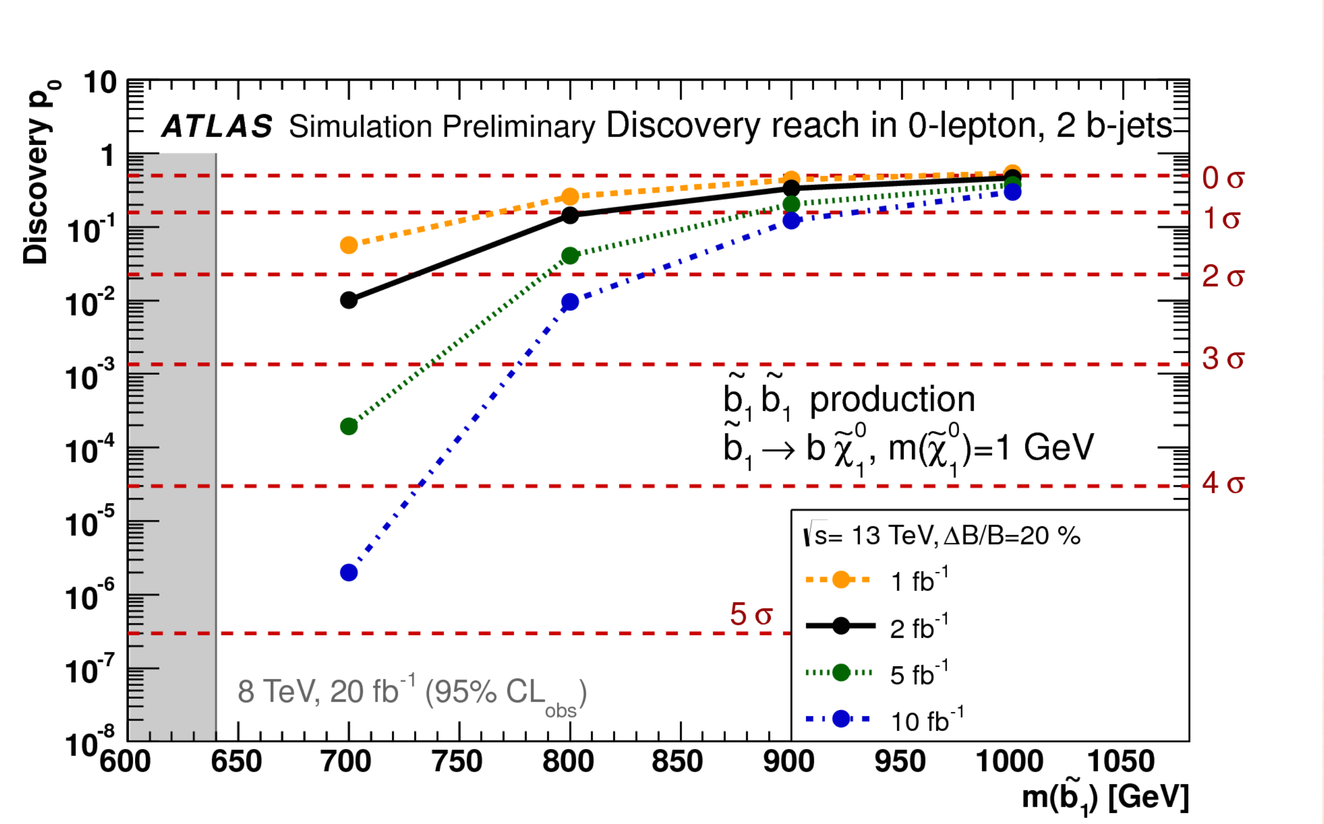
*bottom left:* Multijet search, 7-jet data vs data driven QCD estimate

*top right:* One lepton search, data vs background (normalised in CRs)

*bottom right:* pixel dEdx

# RUN2 PROSPECTS




- Possibility of a 3σ excess for gluino or sbottom signals not excluded by run1 searches with a few $fb^{-1}$

# CONCLUSIONS

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We haven't found it.

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We haven't found it. **Yet**

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Stay tuned !

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We haven't found it. **Yet**

Stay tuned !

And check out the ATLAS SUSY parallel session talks:

P.F. Butti, direct pair production of third generation squarks (today)
A. Kastanas, searches with photons and taus (today)
G. Cottin, long lived sparticles (today)
K. Bredlinger, squark and gluinos with two leptons (tomorrow)
Y. Minami, inclusive searches for squark and gluinos (thursday)
C. Wanotayaroj, pMSSM interpretations (thursday)
C. Bock, electroweak production (thursday)
E.T. Pastor, RPV with lepton number violation (friday)
B.D. Jackson, RPV with baryon number violation (friday)

# BACKUP

# SUSY FINE TUNING FORMULAS

- The derivation of upper bounds on the different SUSY particles from naturalness was first discussed in a paper of Barbieri and Giudice in 1987 (Nucl. Phys. B306, 63)

- After the 2011 LHC results pushed limits on squark and gluinos around 1 TeV, lots of discussion on naturalness-based susy spectra. In slide X I used the formulas in Papucci, Rudermann and Weiler, arXiv:1110.6926v1

$$\mu \lesssim 200\,\mathrm{GeV}\left(\frac{m_h}{120\,\mathrm{GeV}}\right)\left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

Tree-level Higgs mass relation to Higgsinos. Very simple, just solve for delta.

$$\delta m_{H_u}^2|_{stop} = -\frac{3}{8\pi^2}y_t^2\left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2\right)\log\left(\frac{\Lambda}{\mathrm{TeV}}\right)$$

$$\sqrt{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \lesssim 600\,\mathrm{GeV}\frac{\sin\beta}{(1+x_t^2)^{1/2}}\left(\frac{\log(\Lambda/\,\mathrm{TeV})}{3}\right)^{-1/2}\left(\frac{m_h}{120\,\mathrm{GeV}}\right)\left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

One loop Higgs mass relation to stops. The **minimum** fine tuning for a given lightest stop mass occurs for sinb =1, no mixing, and mt1 = mt2. I put these conditions and solved for delta.

$$\delta m_{H_u}^2|_{gluino} = -\frac{2}{\pi^2}y_t^2\left(\frac{\alpha_s}{\pi}\right)|M_3|^2\log^2\left(\frac{\Lambda}{\mathrm{TeV}}\right)$$

$$M_3 \lesssim 900\,\mathrm{GeV}\sin\beta\left(\frac{\log(\Lambda/\,\mathrm{TeV})}{3}\right)^{-1}\left(\frac{m_h}{120\,\mathrm{GeV}}\right)\left(\frac{\Delta^{-1}}{20\%}\right)^{-1/2}$$

Two loop contribution from gluinos. The **minimum** fine tuning for a given gluino mass occurs for sinb =1. I put these conditions and solved for delta.

# SYSTEMATIC UNCERTAINTIES

| | Source | Relative systematic uncertainty (%) | | | |
|---|---|---|---|---|---|
| | | **Binned soft single-lepton** | | | **Soft dimuon** |
| | | **3-jet** | **5-jet** | **3-jet inclusive** | **2-jet** |
| | Total systematic uncertainty | 20 | 24 | 17 | 43 |
| | Lepton identification | – | – | 5 | – |
| 1 | JER | 6 | – | – | – |
| | JES (flavour composition) | – | – | – | 5 |
| 2 | Fake leptons | 10 | 6 | 5 | 40 |
| | $t\bar{t}$ MC generator | 11 | 9 | 7 | 8 |
| 3 | $t\bar{t}$ parton shower | – | 19 | – | – |
| | $t\bar{t}$ scales, ISR and FSR | – | – | 9 | 5 |
| 4 | $t\bar{t}$ normalisation | – | 7 | – | – |
| 5 | MC statistics | 8 | – | 6 | 7 |

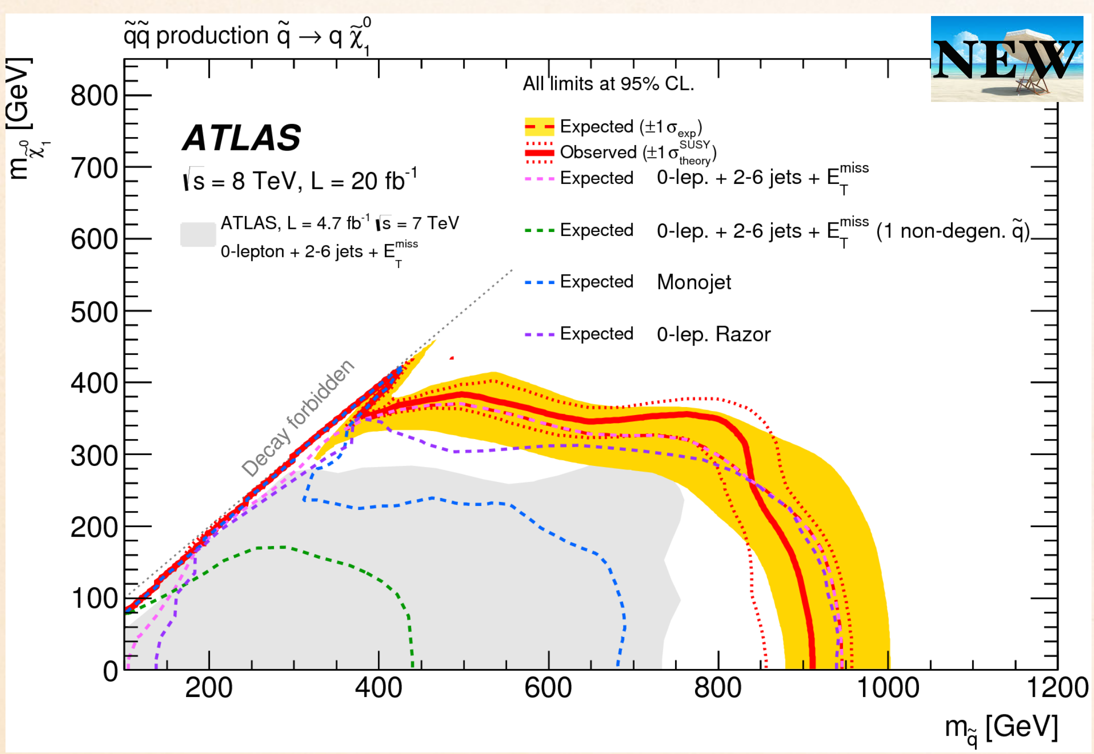
Only leading systematics shown (analysis specific), but the structure is typical

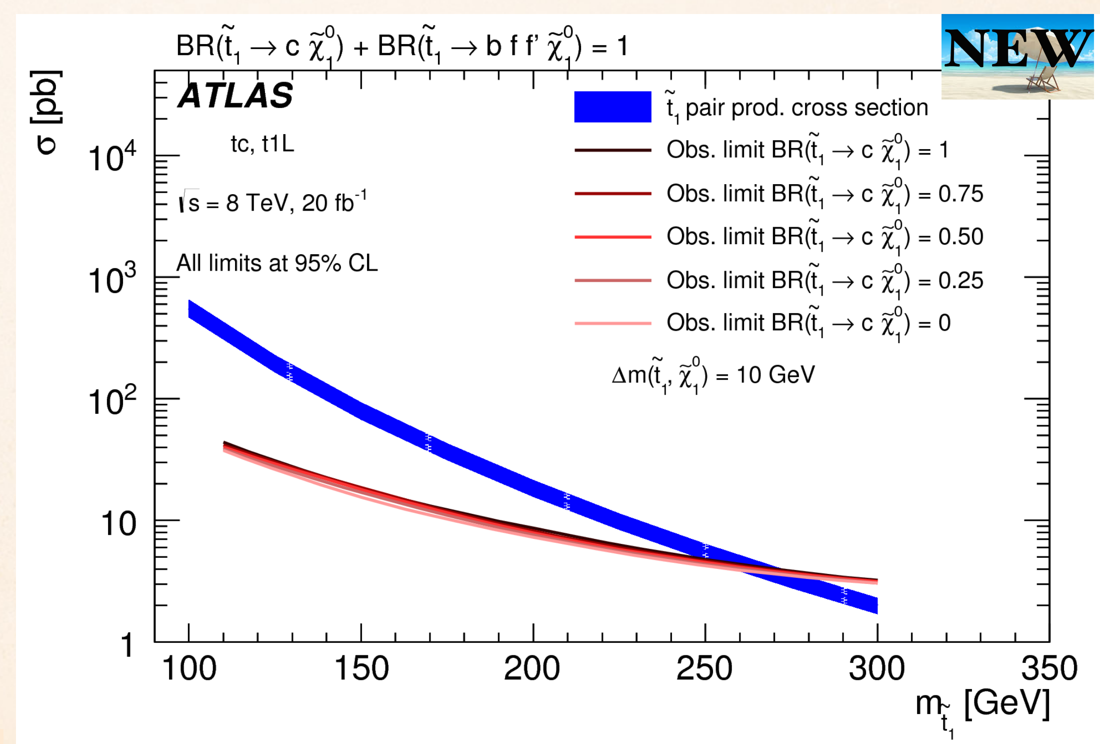
1. Detector response systematics
2. Analysis specific systematics (closure test, statistics of control samples, dependency on true fake composition) on the data driven background estimate
3. Theoretical uncertainties
4. Normalization of background (from CR statistics)
5. MC statistics

Many systematics cancel or are reduced in the CR => SR extrapolation. Validation regions and multiple check in data to show that the data are well modeled within systematics - in particular, the variable used in the extrapolation.

# HIDING SUSY - COMPRESSED ?

- Sensitivity degrades when ΔM(X,LSP) is small. For ΔM => 0, the monojet (ISR) + $E_T^{MISS}$ (the XX system) provides sensitivity, with little dependence on the X decay mode
- No sensitivity to EWK production yet but powerful limits for single squark (240 GeV), squark octet (430 GeV) and gluinos (roughly 600 GeV)
- Irreducible and large Z(νν)+jet background - sensitivity is systematic limited (3-4% error on background in SR in run1!). At 13 TeV sensitivity improves (signal x-sec increases more), but it's difficult to make projections - it will depend on the precision we achieve on the background.

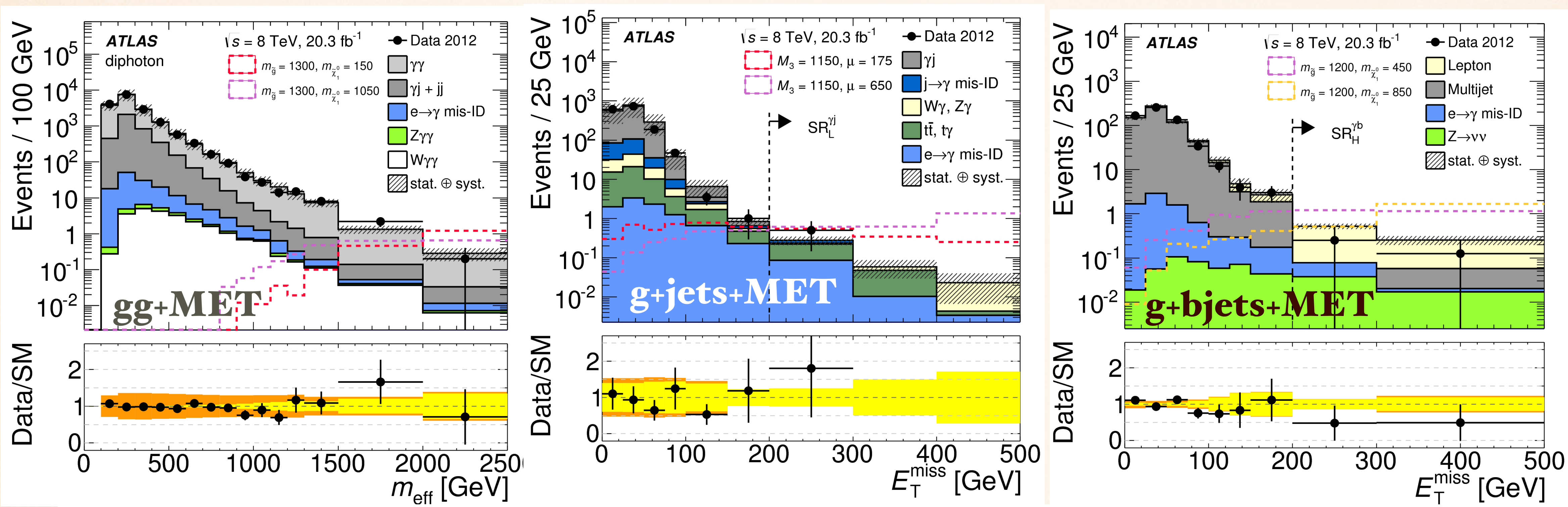


# PHOTON+X PAPER

(arXiv:1507.05493)

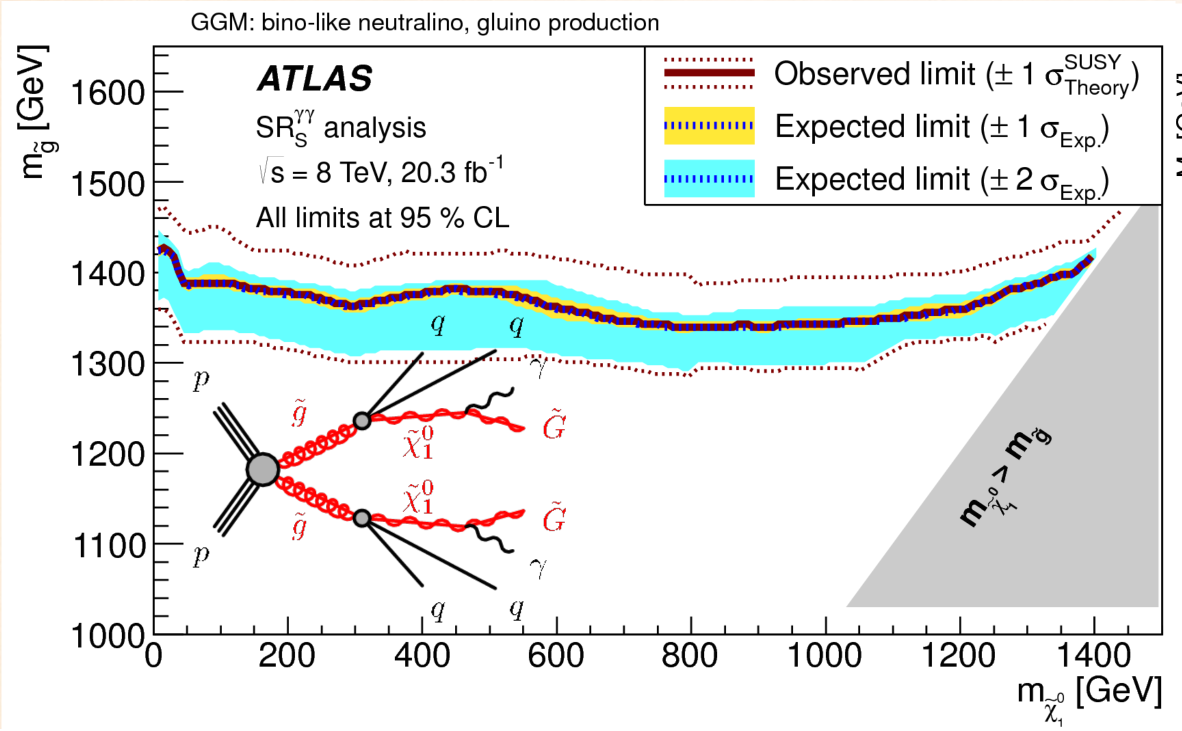
- Four channels : γγ+MET, γ+jets+MET, γ+b-jets+MET, γ+lepton+MET

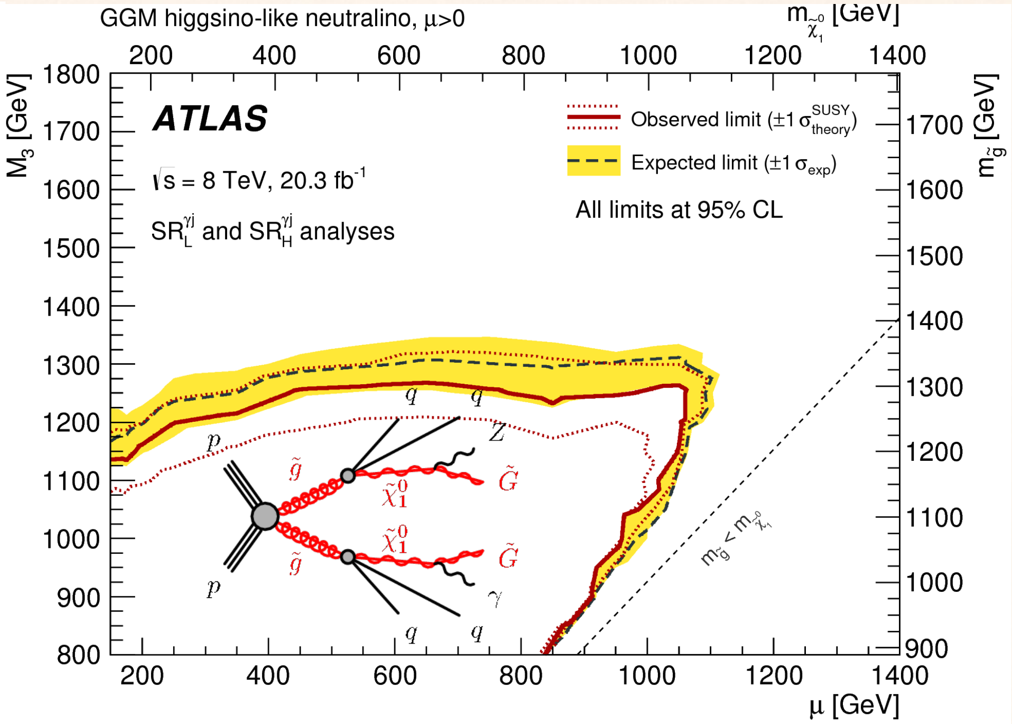


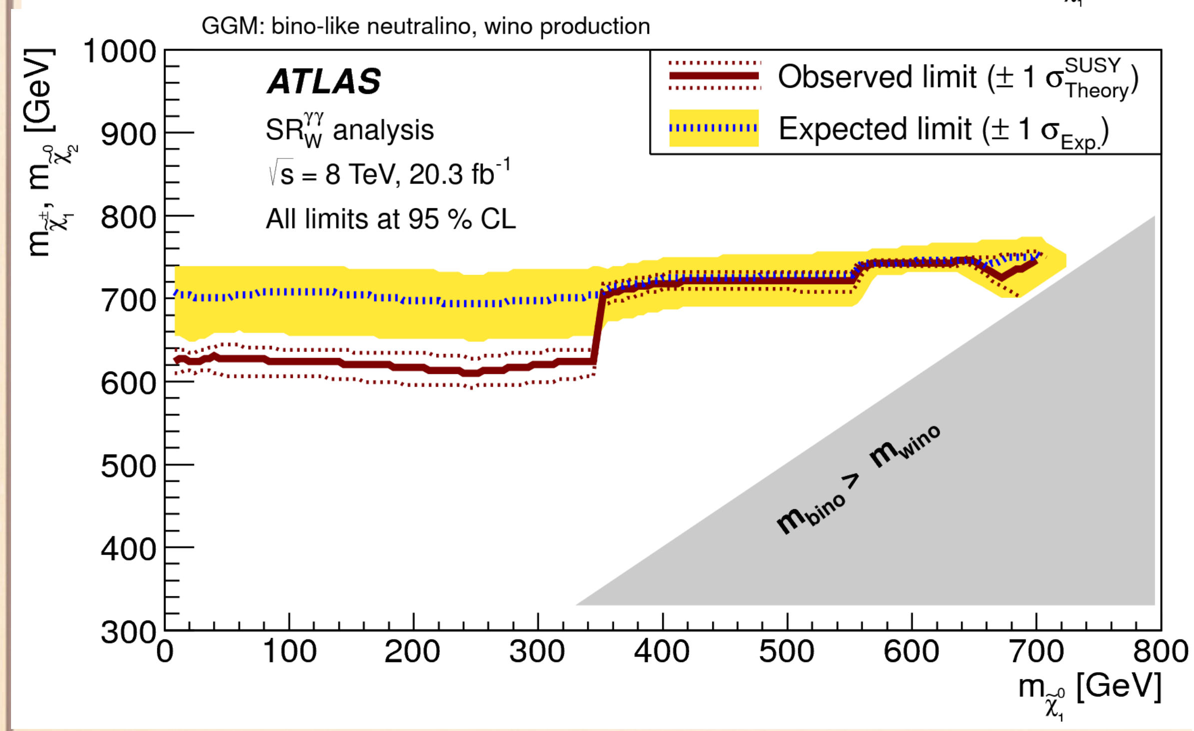

| GGM Model | Experimental Signature | Produced State(s) | Compositio n of NLSP | Free Parameters |
|---|---|---|---|---|
| Gluino-bino | diphoton | gluino | bino | $M_{\tilde{g}}, M_{\tilde{\chi}_1^0}$ |
| Wino-bino | diphoton | wino | bino | $M_{\tilde{W}}, M_{\tilde{\chi}_1^0}$ |
| Higgsino-bino ($\mu < 0$) | photon+b | gluino, higgsino | higgsino/ bino | $M_{\tilde{g}}, f_{-}(M_1, \mu)$ |
| Higgsino-bino ($\mu > 0$) | photon+j | gluino, higgsino | higgsino/ bino | $M_{\tilde{g}}, f_{+}(M_1, \mu)$ |
| Wino NLSP | photon+$\ell$ | wino | wino | $M_{\tilde{W}}$ |

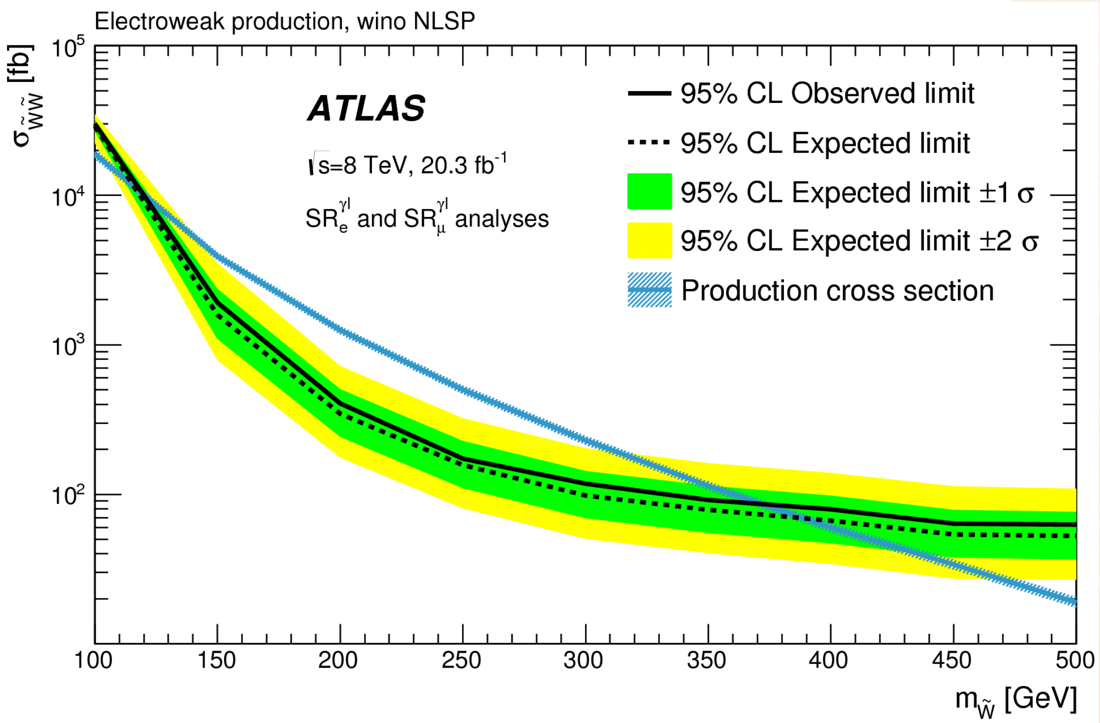
# PHOTON+X PAPER

(arXiv:1507.05493)

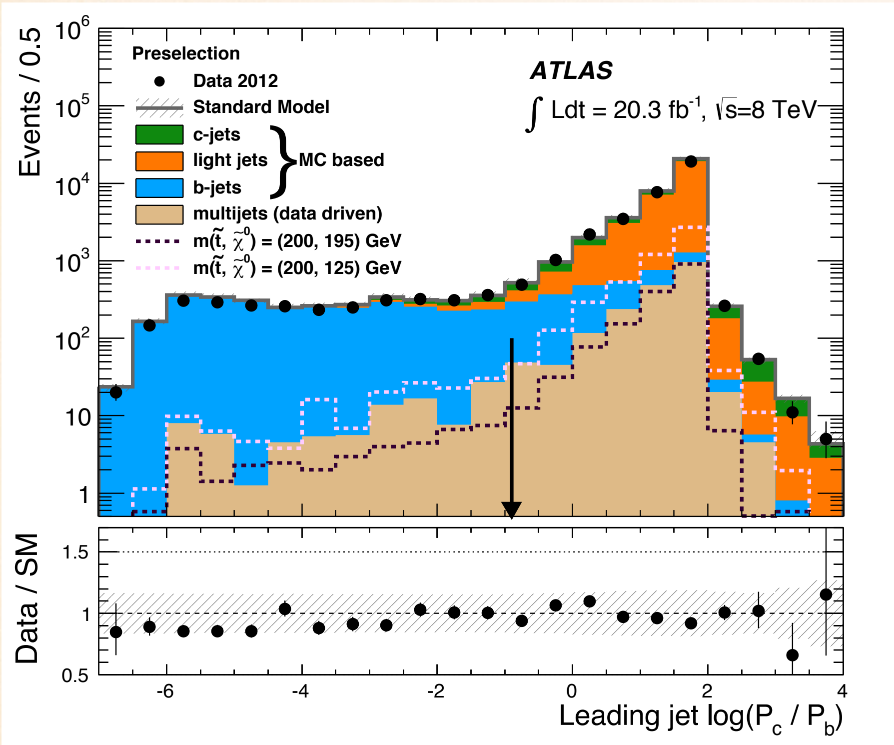


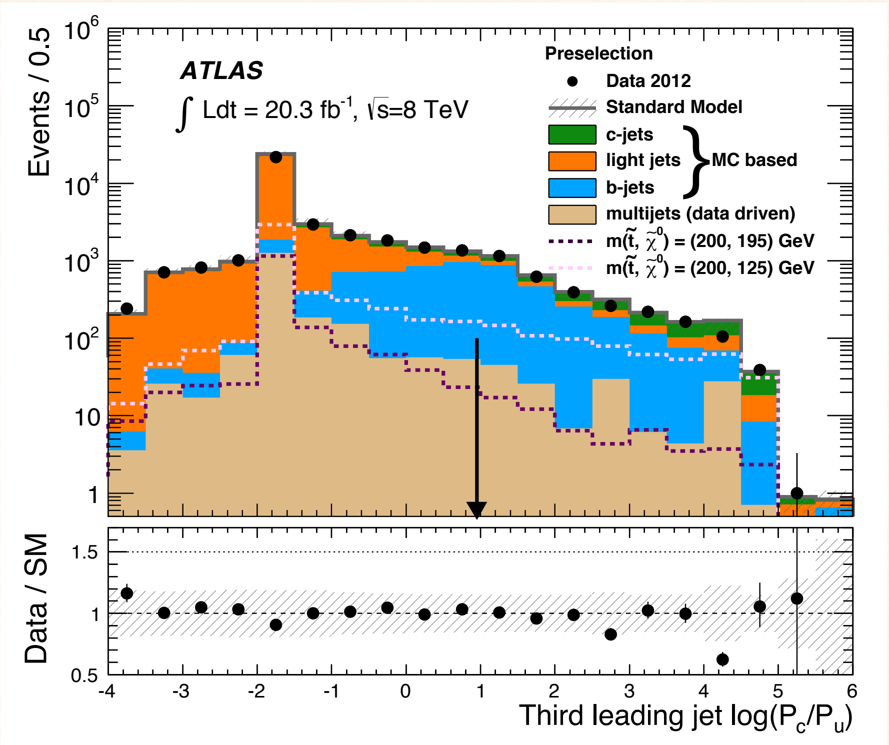



# CHARM TAGGING



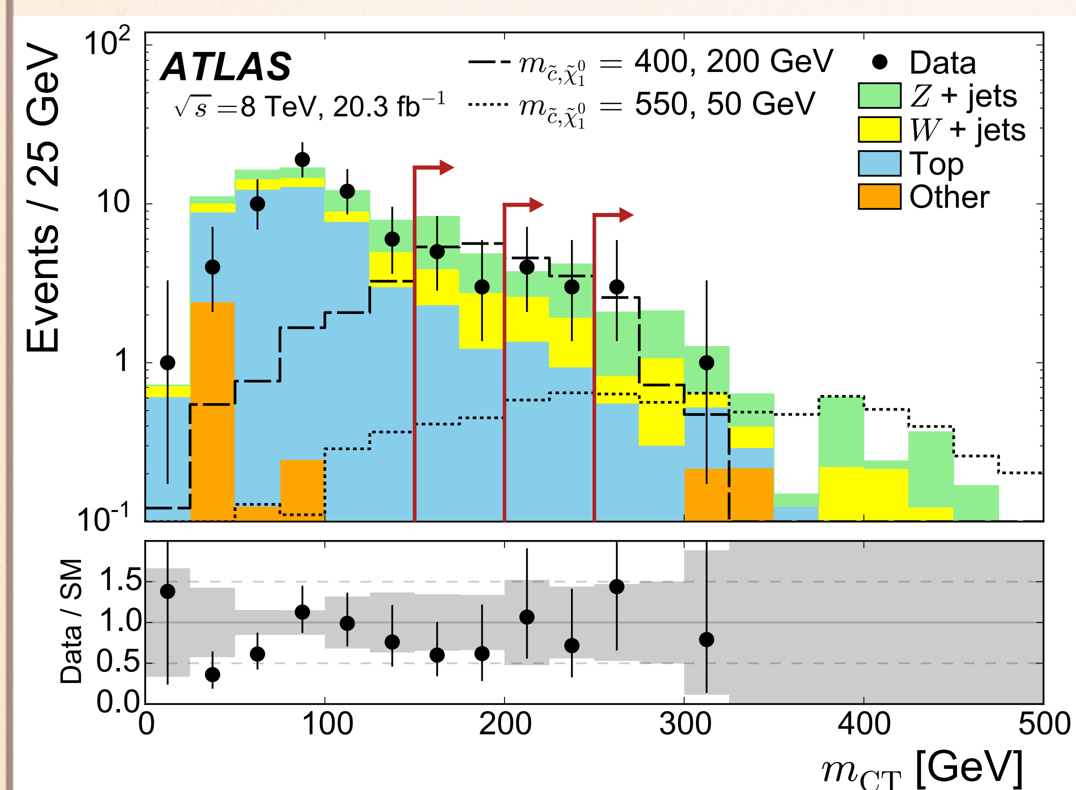

Two multivariate discriminants, trained to reject b-jets and light-jets, respectively.
Working point used in SUSY papers : 19% charm efficiency, 13% b-jet efficiency, 0.5% light jet efficiency

# STOP TO CHARM AND SCHARM

| Preselection | | |
|---|---|---|
| Primary vertex | | |
| $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV | | |
| At least one jet with $p_{\mathrm{T}} > 150$ GeV and $\|\eta\| < 2.8$ | | |
| Jet quality requirements | | |
| Lepton vetoes | | |
| At least four jets with $p_{\mathrm{T}} > 30$ GeV and $\|\eta\| < 2.5$ | | |
| $\Delta\phi(\text{jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$ | | |
| All four jets must pass loose tag requirements ($b$-jet vetoes) | | |
| At least one medium charm tag in the three subleading jets | | |
| Signal region | C1 | C2 |
| Minimum leading jet $p_{\mathrm{T}}$ (GeV) | 290 | 290 |
| Minimum $E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV) | 250 | 350 |

| **Signal Region** | C1 | C2 |
|---|---|---|
| Observed events (20.3 fb$^{-1}$) | 208 | 71 |
| SM prediction | $210 \pm 21$ | $75 \pm 11$ |
| $W(\to e\nu)$ | $11 \pm 2$ | $3.0 \pm 0.7$ |
| $W(\to \mu\nu)$ | $8 \pm 2$ | $3.0 \pm 0.7$ |
| $W(\to \tau\nu)$ | $42 \pm 9$ | $14 \pm 3$ |
| $Z/\gamma^* (\to e^+e^-)$ | – | – |
| $Z/\gamma^* (\to \mu^+\mu^-)$ | $0.07 \pm 0.01$ | $0.04 \pm 0.01$ |
| $Z/\gamma^* (\to \tau^+\tau^-)$ | $0.7 \pm 0.1$ | $0.15 \pm 0.03$ |
| $Z(\to \nu\bar{\nu})$ | $62 \pm 9$ | $27 \pm 3$ |
| $t\bar{t}$, single top, $t\bar{t}$+V | $63 \pm 13$ | $18 \pm 4$ |
| Dibosons | $21 \pm 13$ | $10 \pm 9$ |
| Higgs | $0.16 \pm 0.03$ | $0.07 \pm 0.01$ |
| Multijets | $2 \pm 2$ | $0.1 \pm 0.1$ |

**stop to charm search [arXiv:1407.0608]**




| $m_{\mathrm{CT}}$ (GeV) | >150 | >200 | >250 |
|---|---|---|---|
| Top | $7.4 \pm 2.7$ (7.1) | $3.9 \pm 1.6$ (3.7) | $1.6 \pm 0.7$ (1.5) |
| $Z$+jets | $14 \pm 3$ (13) | $7.7 \pm 1.7$ (7.0) | $4.3 \pm 1.2$ (3.9) |
| $W$+jets | $7.2 \pm 4.5$ (7.4) | $4.1 \pm 2.6$ (4.2) | $1.9 \pm 1.2$ (1.9) |
| Multijets | $0.3 \pm 0.3$ | $0.2 \pm 0.2$ | $0.05 \pm 0.05$ |
| Others | $0.5 \pm 0.3$ | $0.4 \pm 0.3$ | $0.4 \pm 0.3$ |
| **Total** | **$30 \pm 6$** | **$16 \pm 3$** | **$8.2 \pm 1.9$** |
| **Data** | **19** | **11** | **4** |

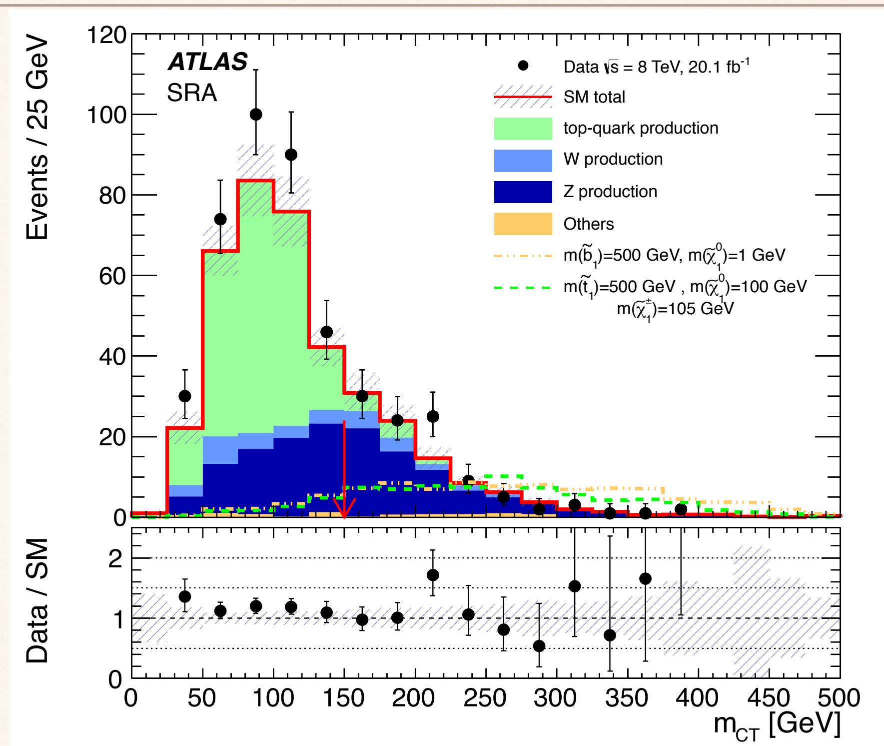
**scharm search [arXiv:1501.01325]**

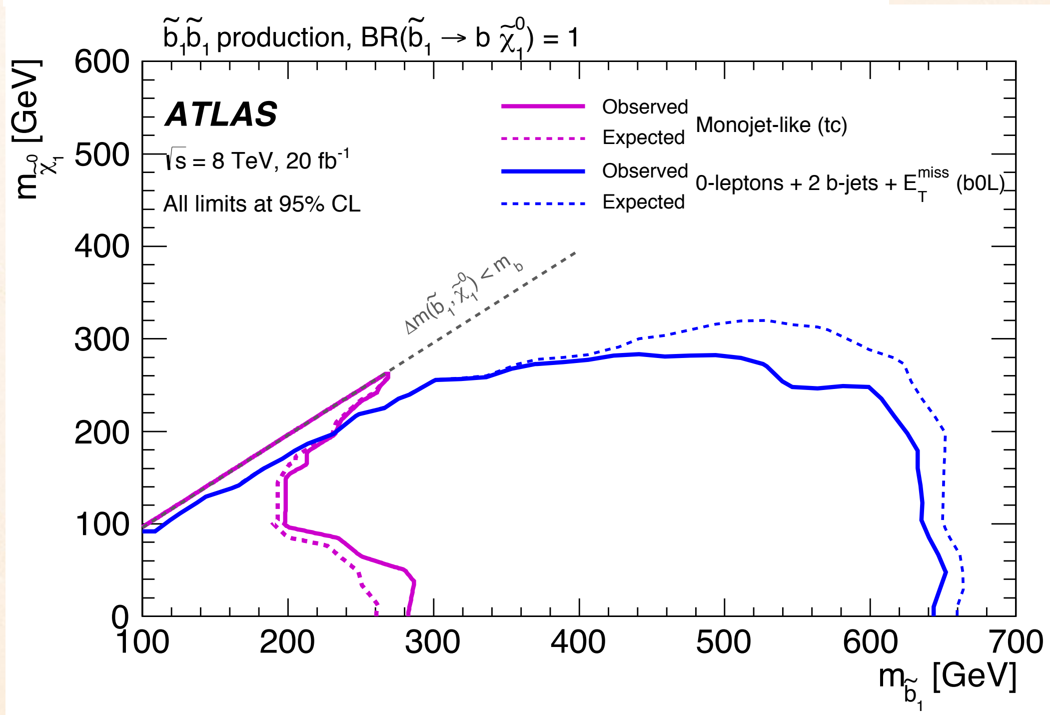
Two leading jets c-tagged, pt>130, 100 GeV , mcc > 200 GeV, MET > 150 GeV, $M_{CT}$(cc,MET) > 150,200,250 GeV

top, Z+jets, W+jets normalized to CR. Multijet from jet smearing data driven technique.

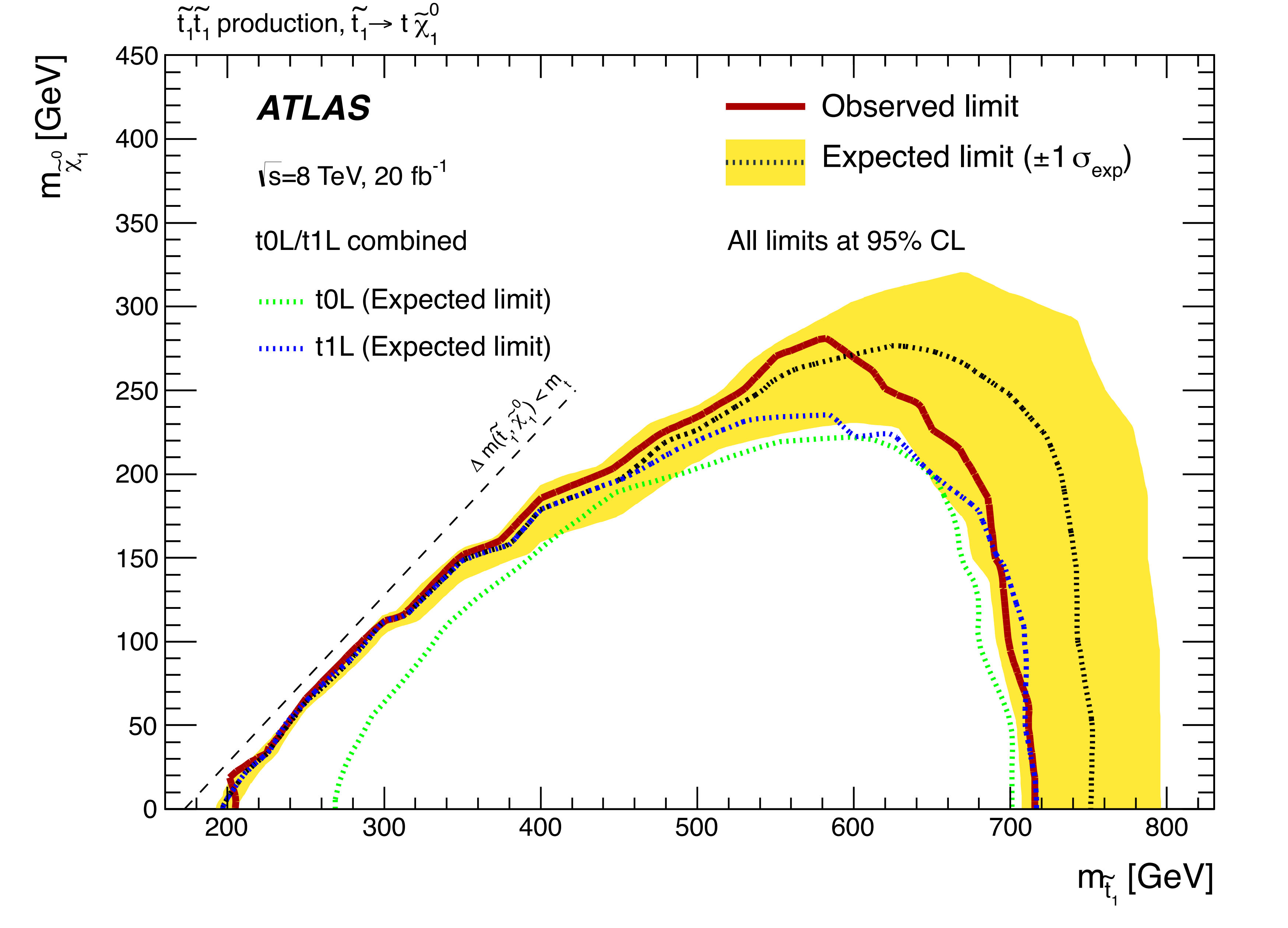
# SBOTTOM SEARCH

| Description | Signal Regions | |
|---|---|---|
| | SRA | SRB |
| Event cleaning | Common to all SR | |
| Lepton veto | No $e/\mu$ after overlap removal with $p_{\mathrm{T}} > 7(6)$ GeV for $e(\mu)$ | |
| $E_{\mathrm{T}}^{\mathrm{miss}}$ | $> 150$ GeV | $> 250$ GeV |
| Leading jet $p_{\mathrm{T}}(j_1)$ | $> 130$ GeV | $> 150$ GeV |
| Second jet $p_{\mathrm{T}}(j_2)$ | $> 50$ GeV, | $> 30$ GeV |
| Third jet $p_{\mathrm{T}}(j_3)$ | veto if $> 50$ GeV | $> 30$ GeV |
| $\Delta\phi(\boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}}, j_1)$ | - | $> 2.5$ |
| $b$-tagging | leading 2 jets ($p_{\mathrm{T}} > 50$ GeV, $\lvert\eta\rvert < 2.5$) | 2nd- and 3rd-leading jets ($p_{\mathrm{T}} > 30$ GeV, $\lvert\eta\rvert < 2.5$) |
| | $n_{b\text{-jets}} = 2$ | |
| $\Delta\phi_{\mathrm{min}}$ | $> 0.4$ | $> 0.4$ |
| $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(k)$ | $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(2) > 0.25$ | $E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}(3) > 0.25$ |
| $m_{\mathrm{CT}}$ | $> 150, 200, 250, 300, 350$ GeV | - |
| $H_{\mathrm{T},3}$ | - | $< 50$ GeV |
| $m_{bb}$ | $> 200$ GeV | - |



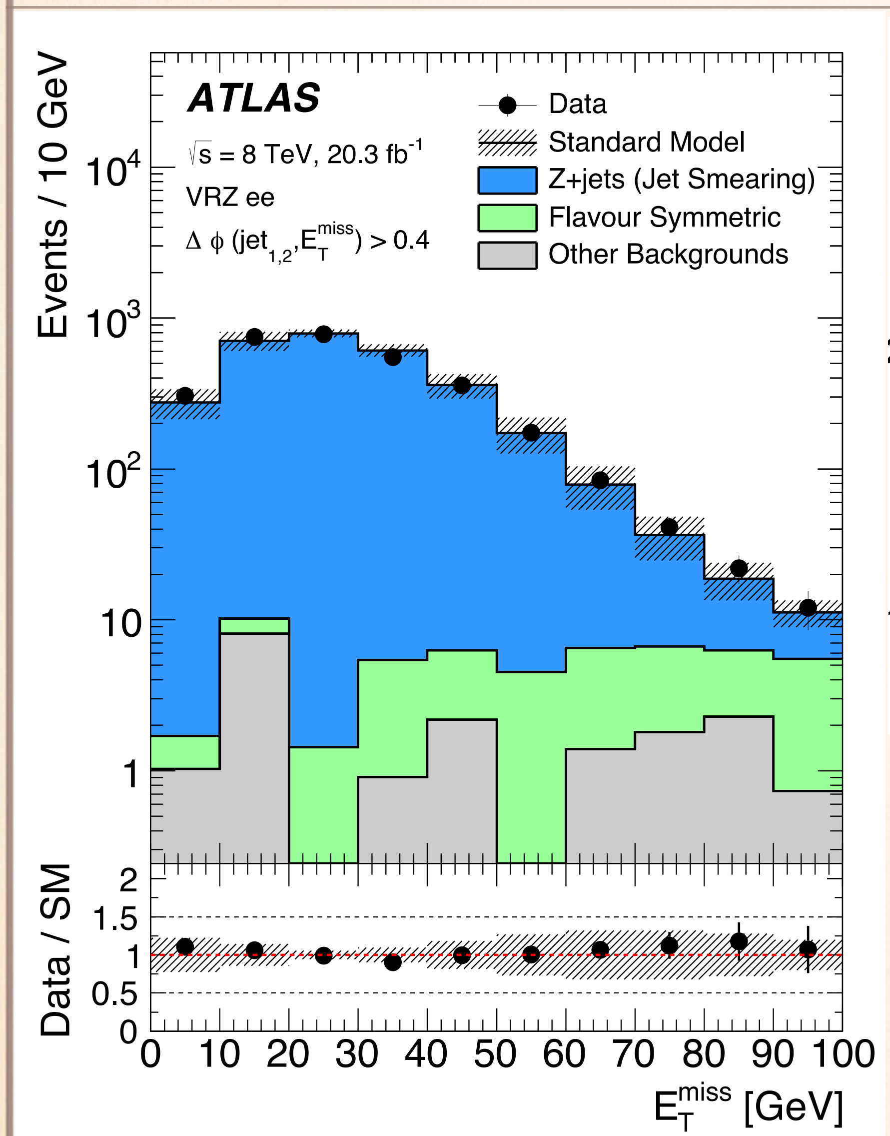



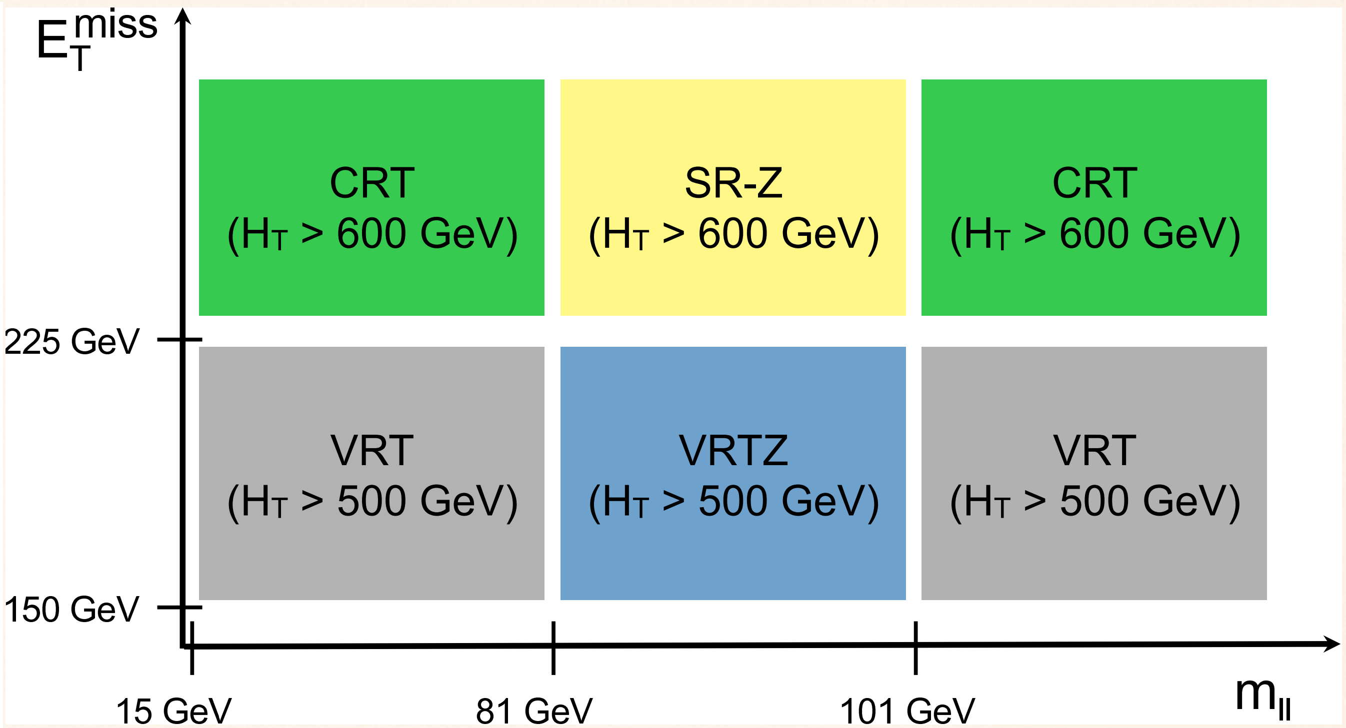
# STOP 0+1L COMBINATION

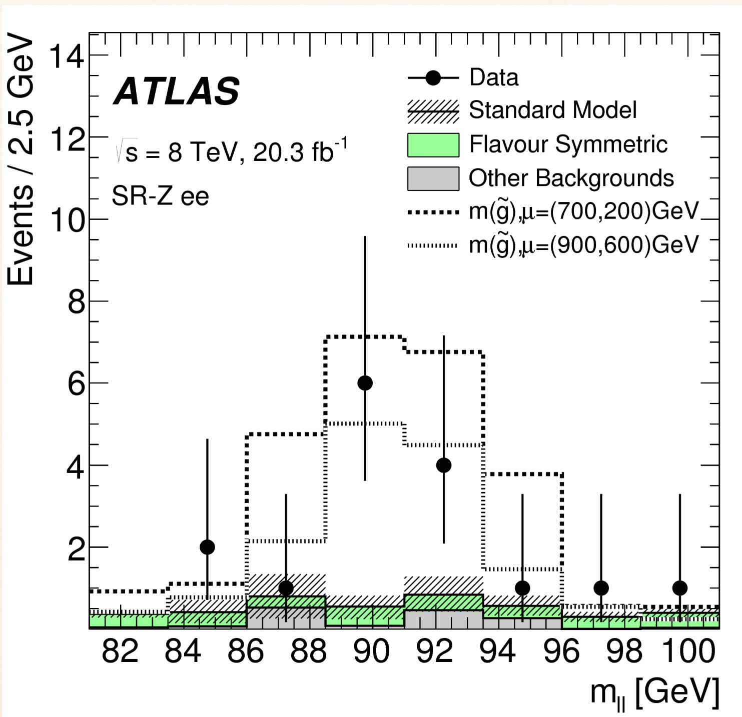


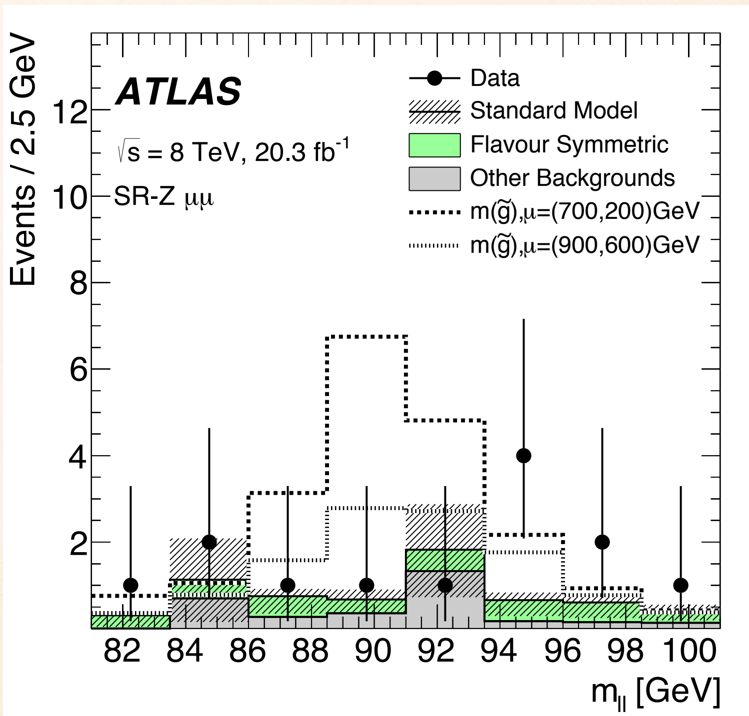

- Statistical combination of zero lepton and one lepton selection. Improves limit by about 50 GeV at high stop or LSP mass.

# Z+MET SEARCH



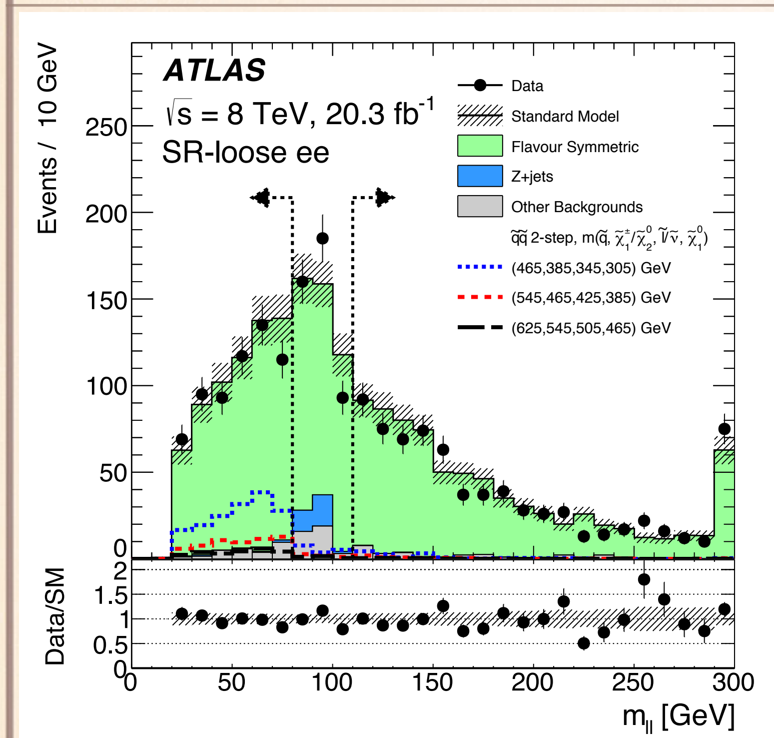



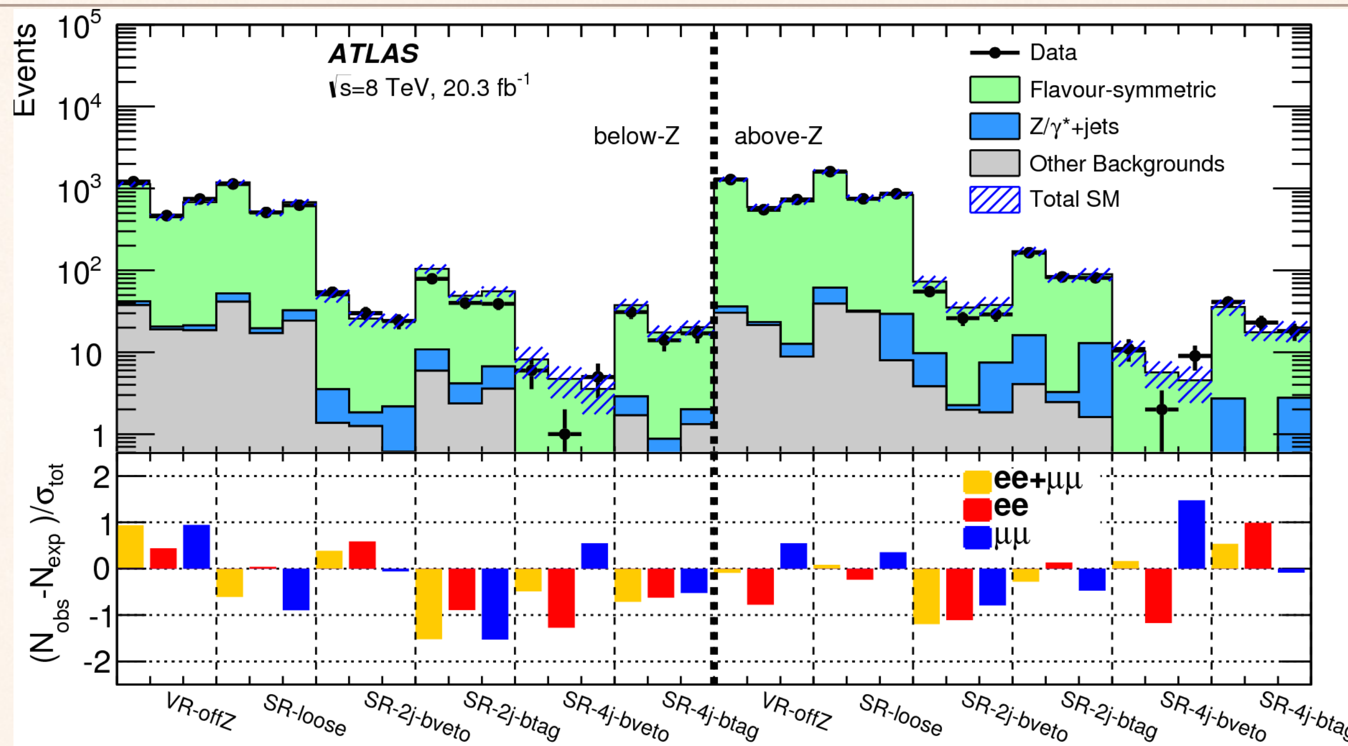



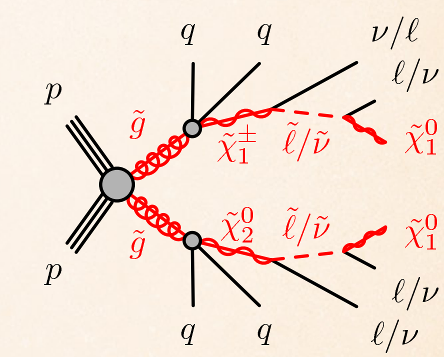




Z+jets background from Z seed selection plus jet smearing. Negligible in SR because of delta phi and MET cuts

# EDGE ANALYSIS



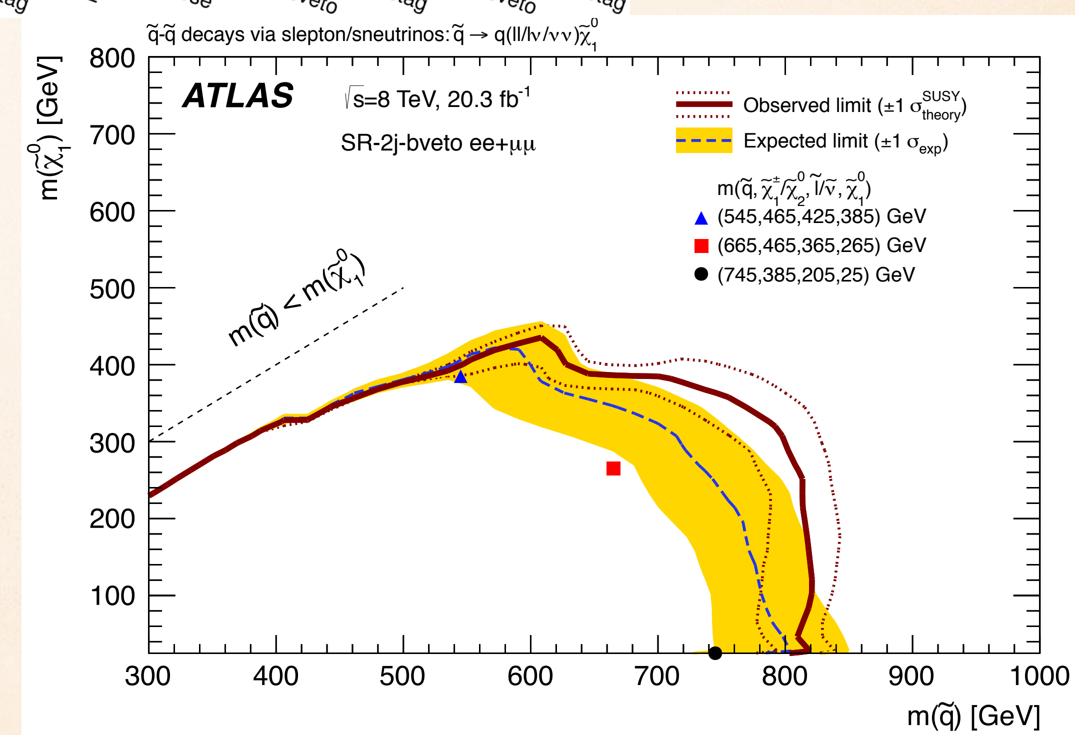



SR: loose (targeting the signal hint in CMS data), 2jet with bveto/tag (squark production), 4 jet with bveto/btag (gluino production)

2 SF leptons with invariant mass less than X, with X optimized for each signal benchmark (best expected sensitivity)

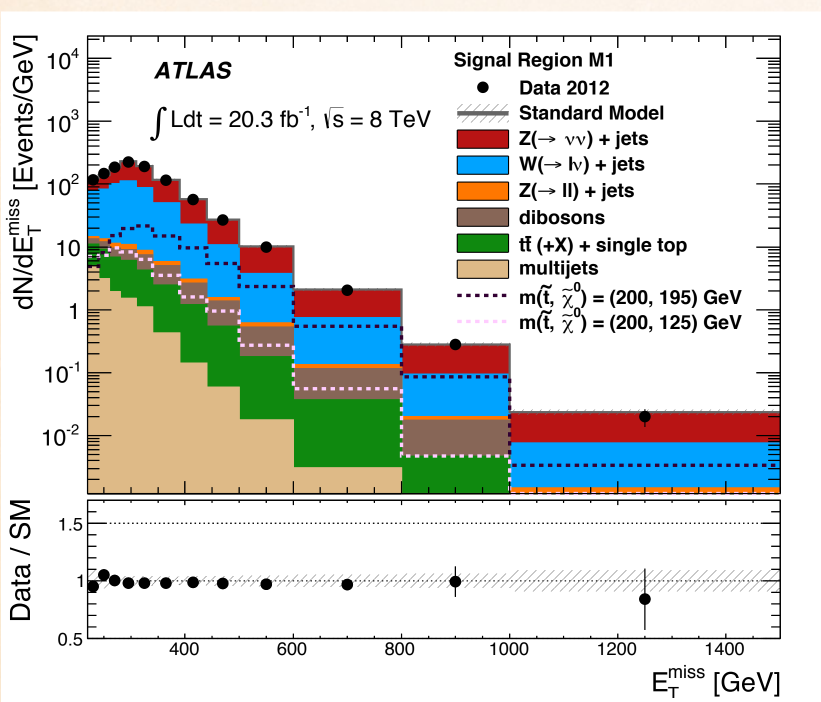
DY normalized to Z peak, flavour symmetric backgrounds from emu

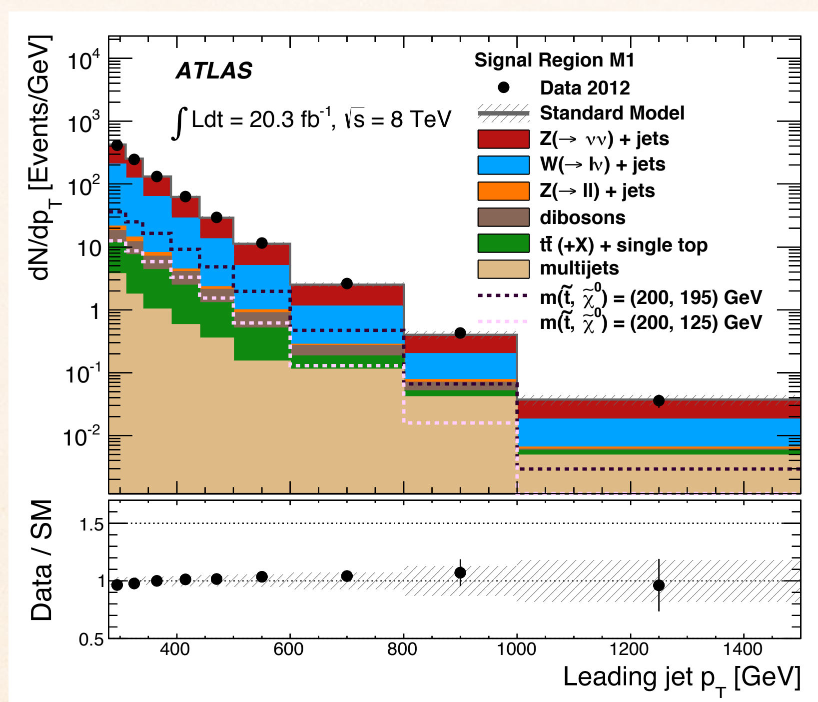


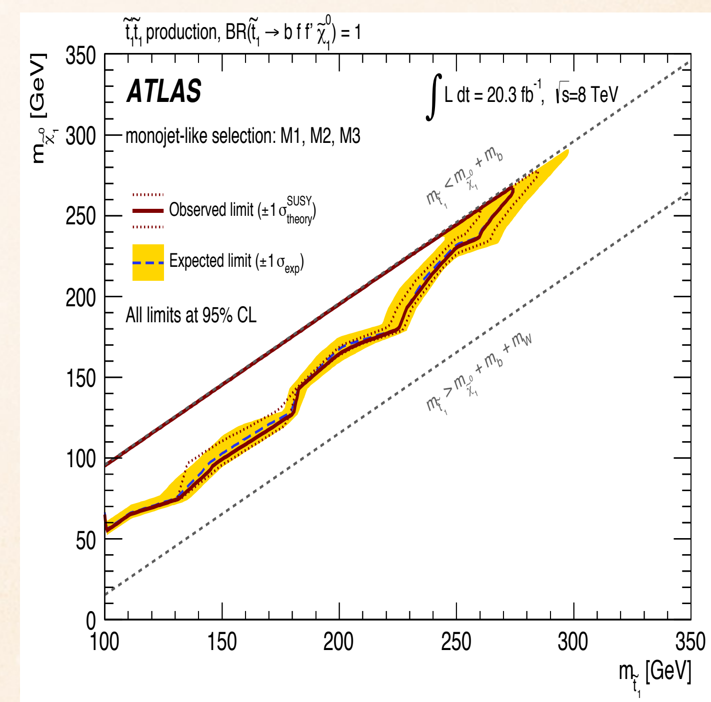
# MONOJET SEARCH

| Preselection | | | |
|---|---|---|---|
| Primary vertex | | | |
| $E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV | | | |
| At least one jet with $p_{\mathrm{T}} > 150$ GeV and $\lvert\eta\rvert < 2.8$ | | | |
| Jet quality requirements | | | |
| Lepton vetoes | | | |
| Monojet-like selection | | | |
| At most three jets with $p_{\mathrm{T}} > 30$ GeV and $\lvert\eta\rvert < 2.8$ | | | |
| $\Delta\phi(\mathrm{jet}, \mathbf{p}_{\mathrm{T}}^{\mathrm{miss}}) > 0.4$ | | | |
| Signal region | M1 | M2 | M3 |
| Minimum leading jet $p_{\mathrm{T}}$ (GeV) | 280 | 340 | 450 |
| Minimum $E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV) | 220 | 340 | 450 |

| **Signal Region** | M1 | M2 | M3 |
|---|---|---|---|
| Observed events (20.3 fb$^{-1}$) | 33054 | 8606 | 1776 |
| SM prediction | $33450 \pm 960$ | $8620 \pm 270$ | $1770 \pm 81$ |
| $W(\to e\nu)$ | $3300 \pm 140$ | $700 \pm 43$ | $130 \pm 12$ |
| $W(\to \mu\nu)$ | $3000 \pm 100$ | $700 \pm 29$ | $133 \pm 8$ |
| $W(\to \tau\nu)$ | $7800 \pm 290$ | $1690 \pm 74$ | $320 \pm 24$ |
| $Z/\gamma^* (\to e^+e^-)$ | – | – | – |
| $Z/\gamma^* (\to \mu^+\mu^-)$ | $170 \pm 27$ | $53 \pm 9$ | $13 \pm 3$ |
| $Z/\gamma^* (\to \tau^+\tau^-)$ | $95 \pm 6$ | $17 \pm 1$ | $1.8 \pm 0.3$ |
| $Z(\to \nu\bar{\nu})$ | $17400 \pm 720$ | $5100 \pm 240$ | $1090 \pm 72$ |
| $t\bar{t}$, single top, $t\bar{t}$+V | $780 \pm 73$ | $150 \pm 19$ | $27 \pm 4$ |
| Dibosons | $650 \pm 99$ | $220 \pm 40$ | $60 \pm 14$ |
| Higgs | – | – | – |
| Multijets | $300 \pm 300$ | $30 \pm 30$ | $4 \pm 4$ |

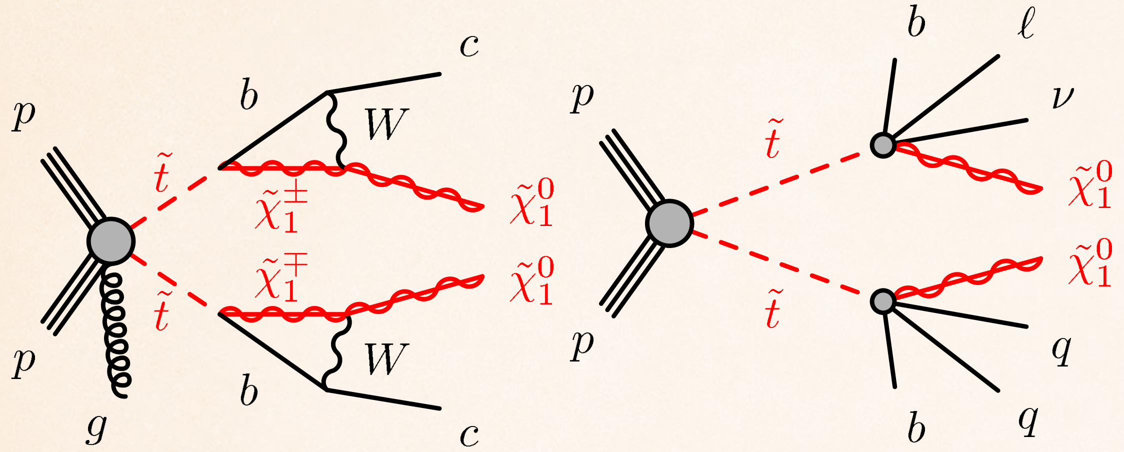


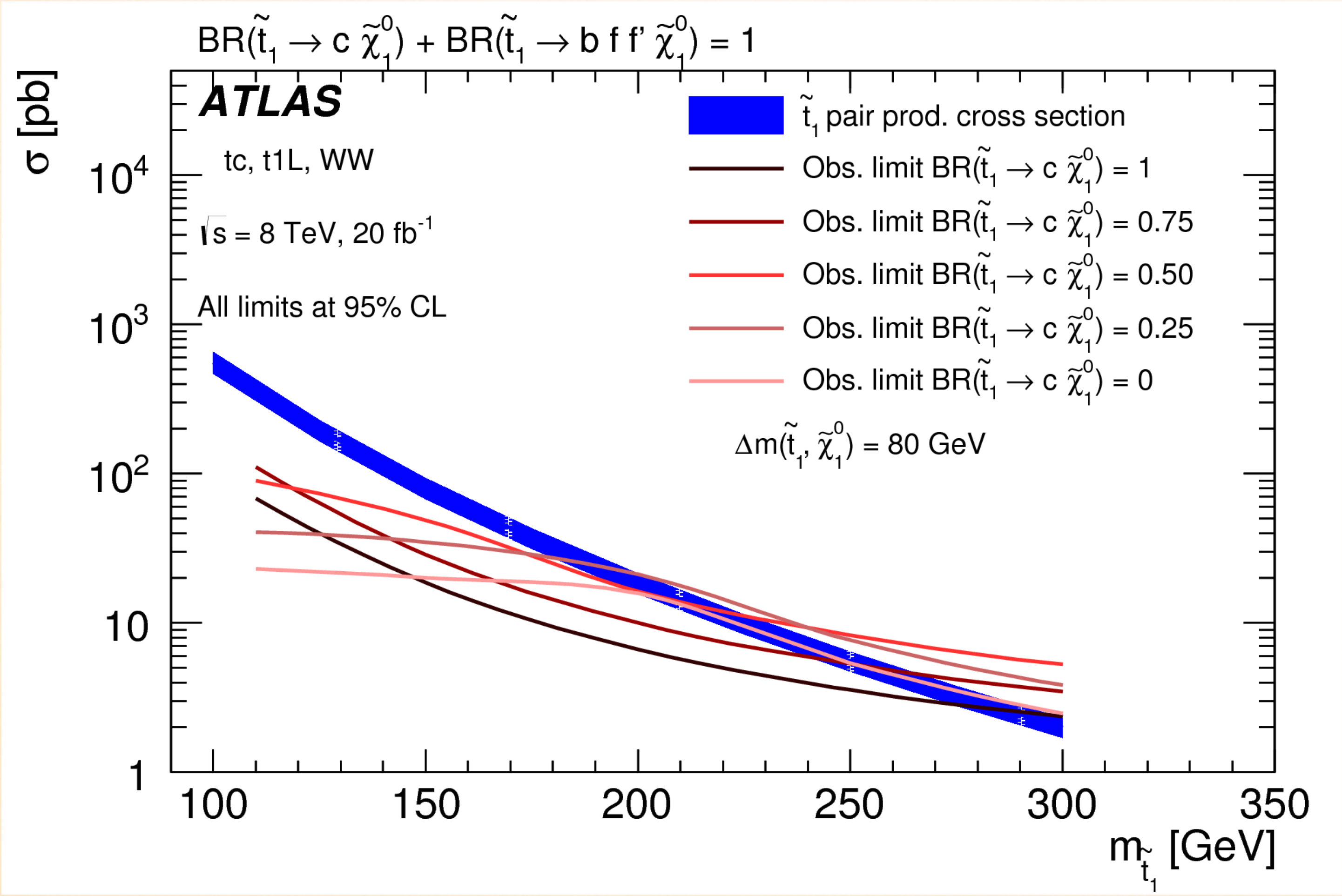




Main backgrounds W+jets, Z+jets, estimated from 1/2 lepton CRs with otherwise the same selections as the SR

# STOP COMPRESSED



# WW-LIKE STOP SEARCH

| SR | WW-SR1 | WW-SR2 | WW-SR3 | WW-SR4 | WW-SR5 | WW-SR6 | WW-SR7 |
|---|---|---|---|---|---|---|---|
| $p_T(\ell_1)$ | > 25 GeV | | | | | | |
| $p_T(\ell_2)$ | > 20 GeV | | | | | | |
| $R_1$ | > 0.3 + $m_{\text{eff}}$ (TeV) | | | | | | |
| $m_{T2}$ | > 20 GeV | | | | | | |
| $\Delta X$ | < 0.02 | | | | | | |
| $R_2$ | > 0.5 | | | | | | |
| $\lvert\cos\theta_b\rvert$ | < 0.8 | < 0.8 | < 0.8 | - | - | < 0.8 | - |
| $m_{T2}$ | < 45 GeV | > 25, < 55 GeV | - | > 70 GeV | > 90 GeV | > 25, < 70 GeV | > 80 GeV |

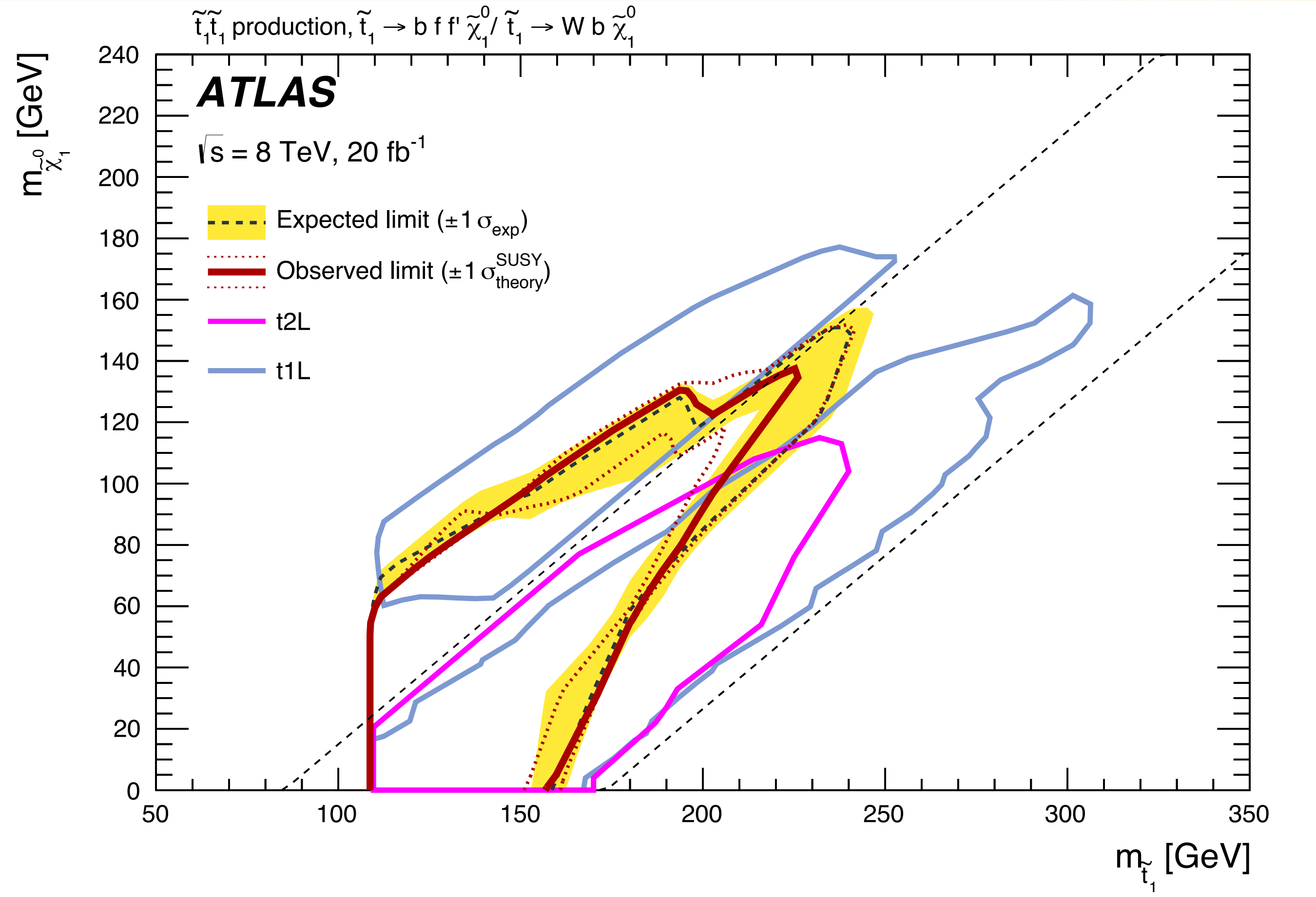
| **Signal channel** | Obs | Exp | $S^{95}_{\text{obs}}$ | $S^{95}_{\text{exp}}$ | $\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$[fb] |
|---|---|---|---|---|---|
| SR1 | 40 | 47 ± 14 | 22.6 | $25.2^{+9.4}_{-4.3}$ | 1.12 |
| SR2 | 71 | 80 ± 13 | 25.3 | $27.8^{+11.5}_{-4.1}$ | 1.24 |
| SR3 | 215 | 203 ± 27 | 48.4 | $46.6^{+4.9}_{-6.9}$ | 2.38 |
| SR4 | 88 | 81 ± 11 | 35.1 | $28.8^{+11.0}_{-5.4}$ | 1.73 |
| SR5 | 4 | 3.4 ± 0.9 | 6.2 | $5.7^{+2.1}_{-1.4}$ | 0.30 |
| SR6 | 160 | 154 ± 19 | 45.6 | $43.8^{+19.3}_{-14.4}$ | 2.25 |
| SR7 | 21 | 23 ± 4 | 12.4 | $13.4^{+4.8}_{-3.4}$ | 0.61 |

- 2 leptons, and mT2 > 20 GeV leaves ttbar, WW as major backgrounds
- R1=MET/$M_{\text{eff}}$ > 0.3+$M_{\text{eff}}$/TeV suppresses ttbar
- ΔX, R2, cos theta selections to discriminate signal and WW (different production mechanisms)

$$\Delta X = \frac{(p_z(\ell_1) + p_z(\ell_2))}{\sqrt{s}} \qquad R_2 = \frac{E_T^{\text{miss}}}{E_T^{\text{miss}} + p_T(\ell_1) + p_T(\ell_2)}$$

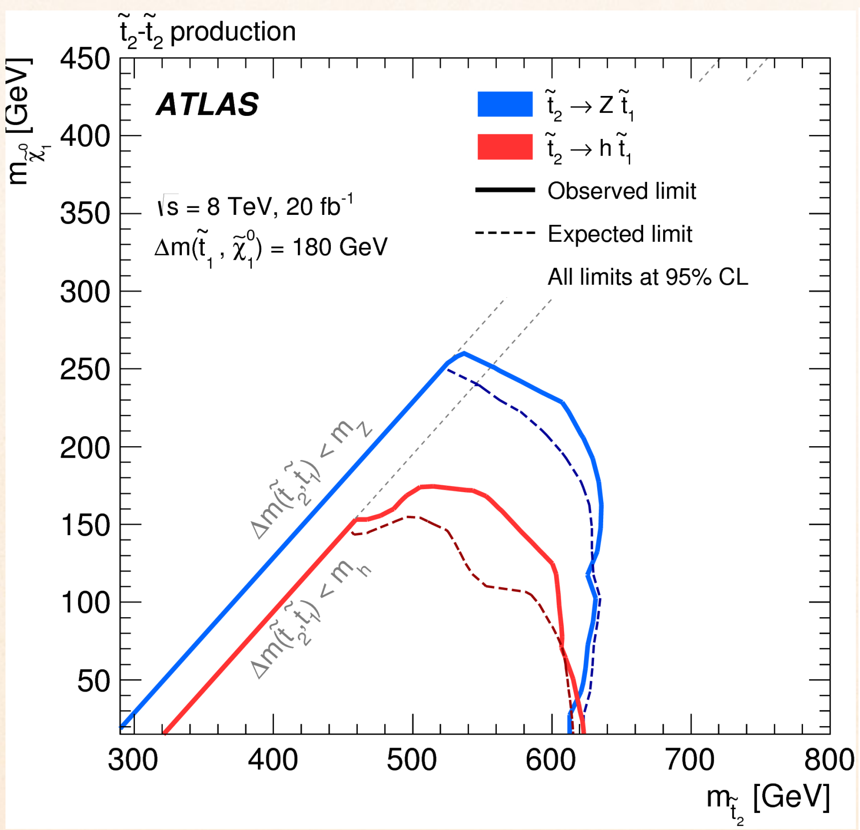
ttbar and WW normalized in control regions

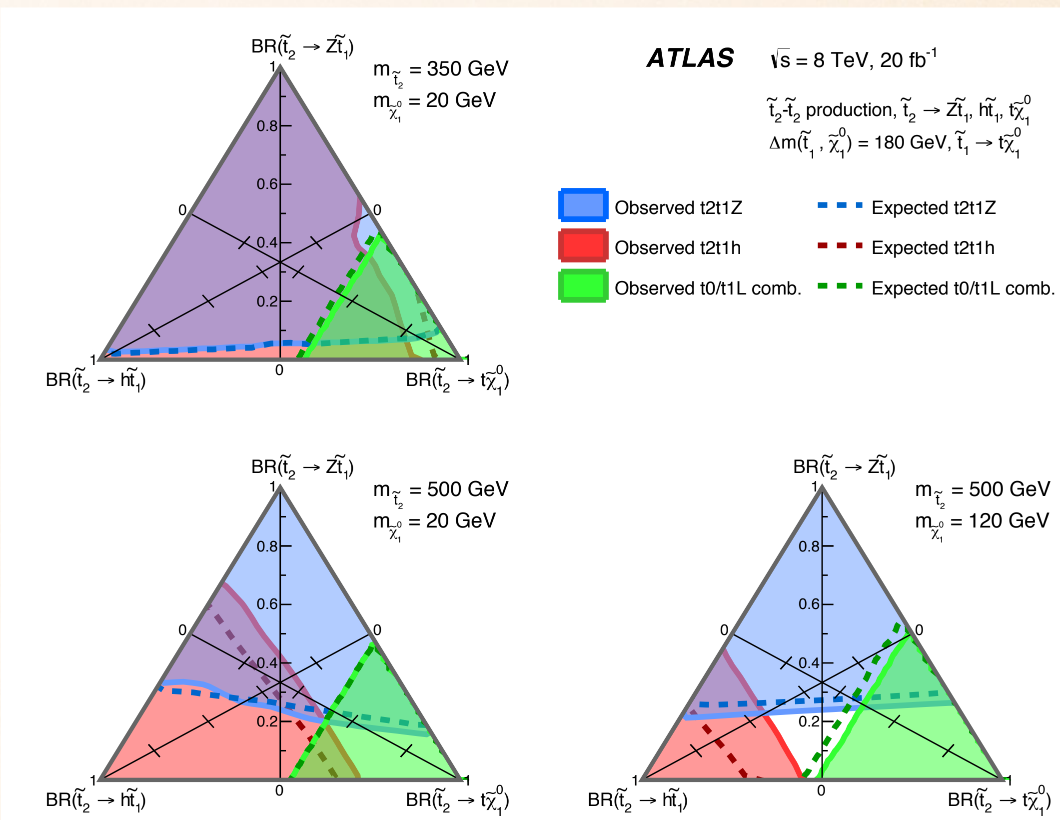
**No** requirement on the number of jets



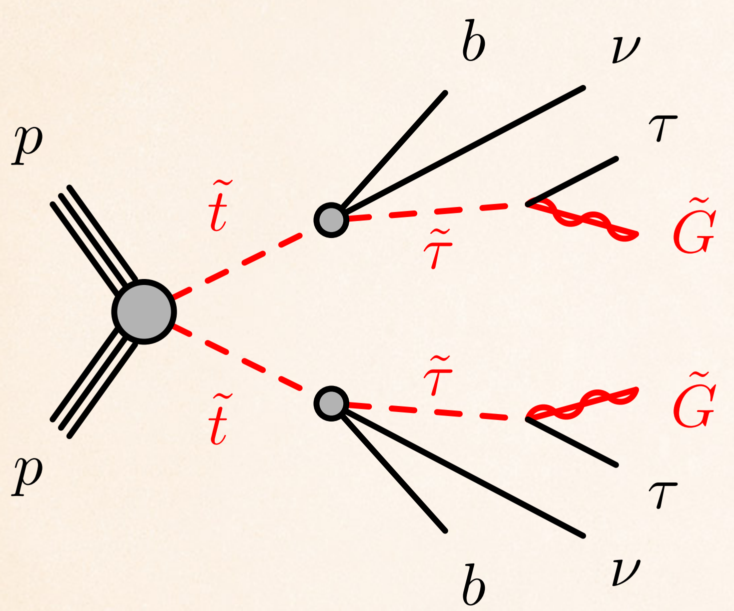
# STOP2 SEARCHES

- Z+bjets+MET search, from arXiv:1403.5222. Targeting decay to Z t1
- 1L+2b+4 jets+MET, fit in MT and HT bins to constrain background and uncertainties, and extract signal. Targeting decay to H(bb) t1
- Combination of stop1 searches in 0L and 1L channels, targeting the decay to top neutralino.



# STOP STAU SEARCH

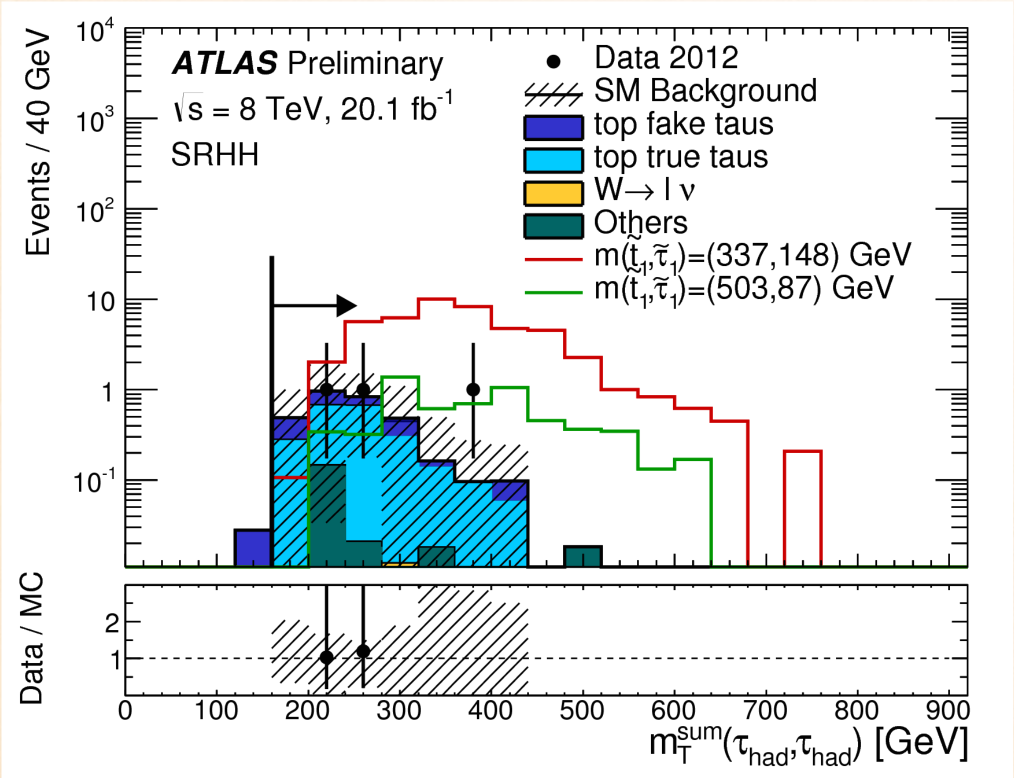


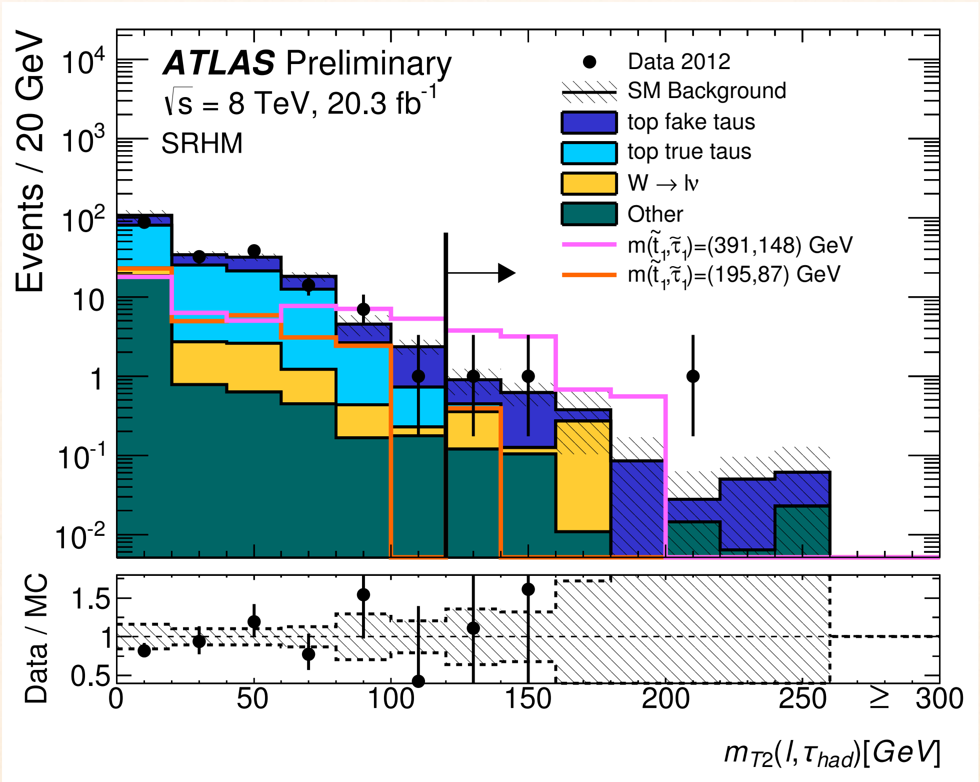

Three channel pursued

$\tau_{had}$ $\tau_{had}$ +b-jets +MET

$\tau_{had}$ + e/μ +b-jets+MET

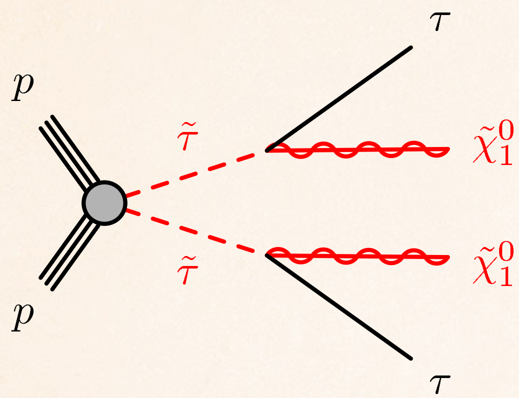
2x(e/μ)+MET



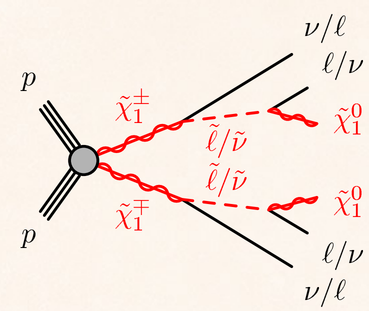



# EWK PAPER NEW ANALYSIS

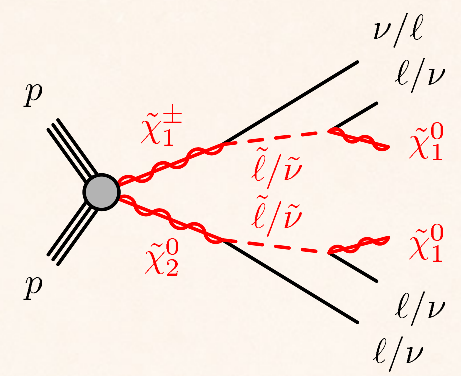
## 2 tau+MET MVA analysis



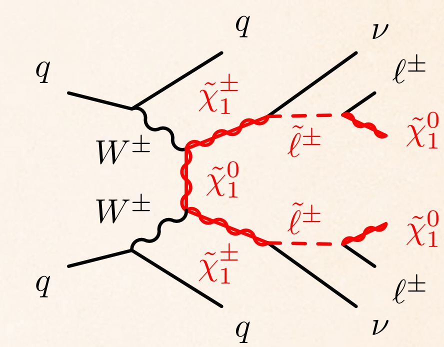

## 2LOS+ISRjet Razor analysis

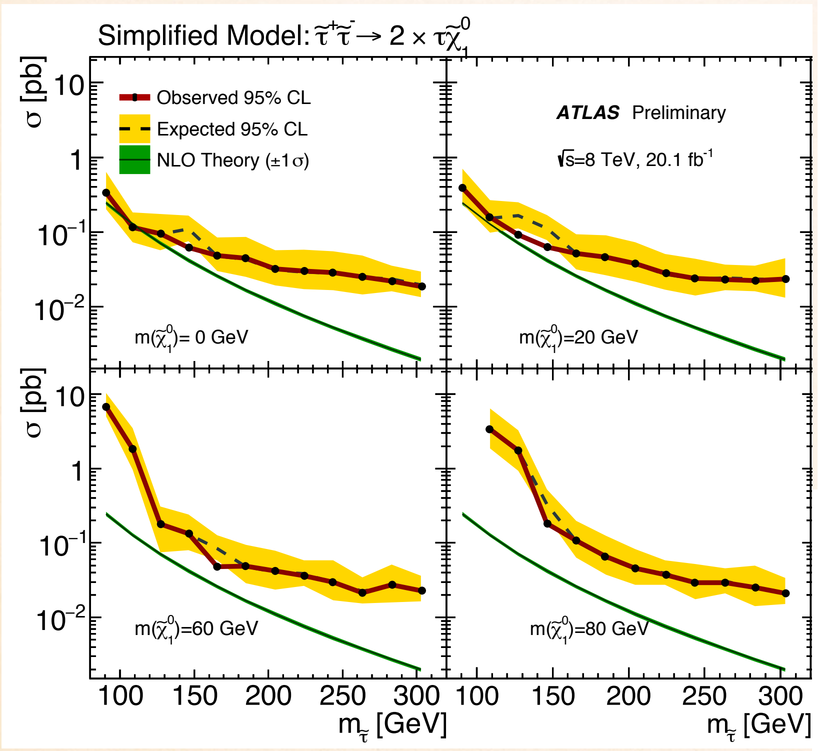


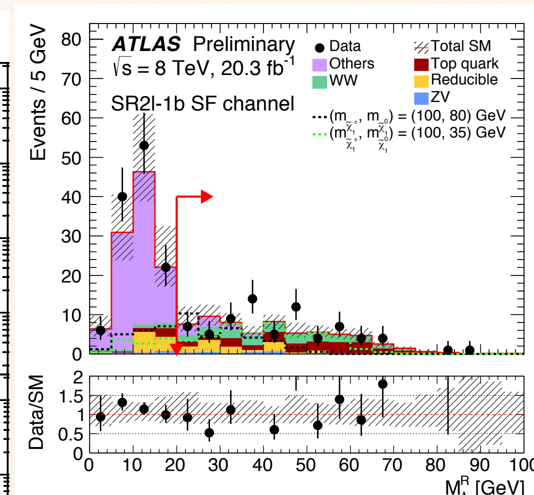

## 2LSS MVA and 3 soft lepton analyses

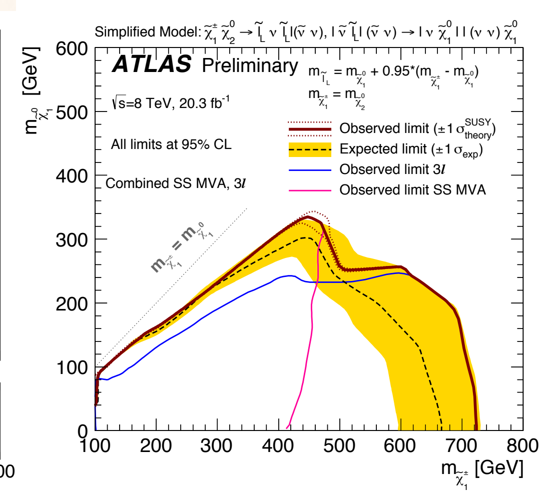


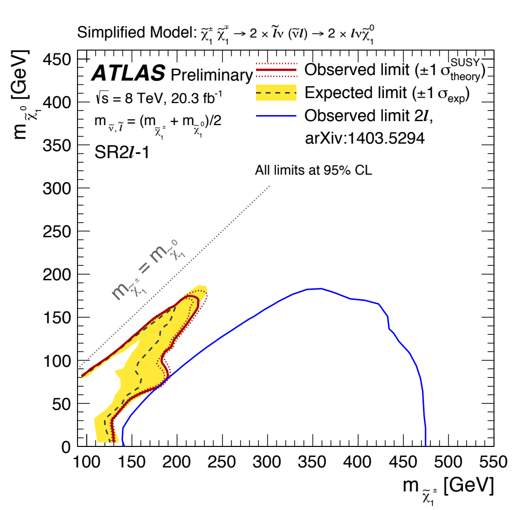

## 2 SS leptons + VBF jets analysis

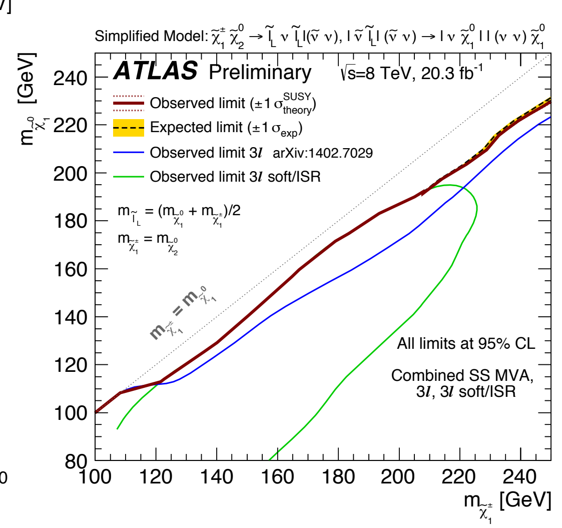


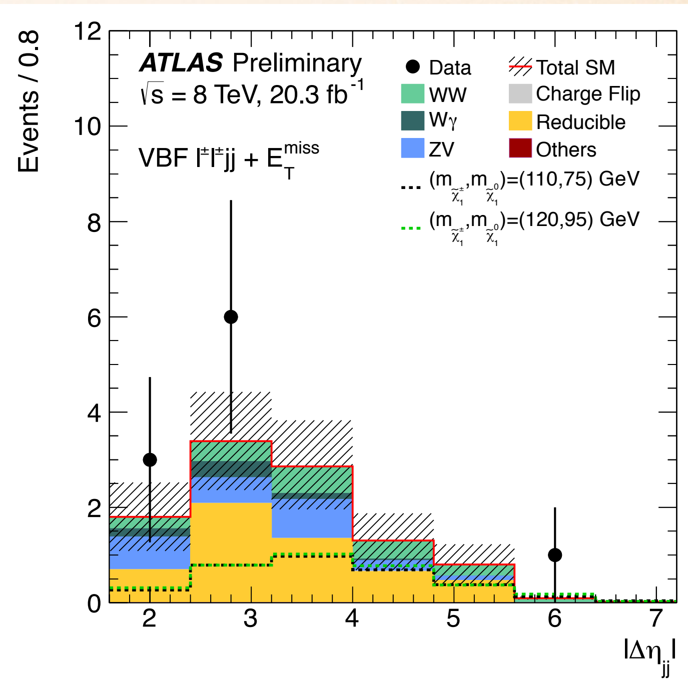



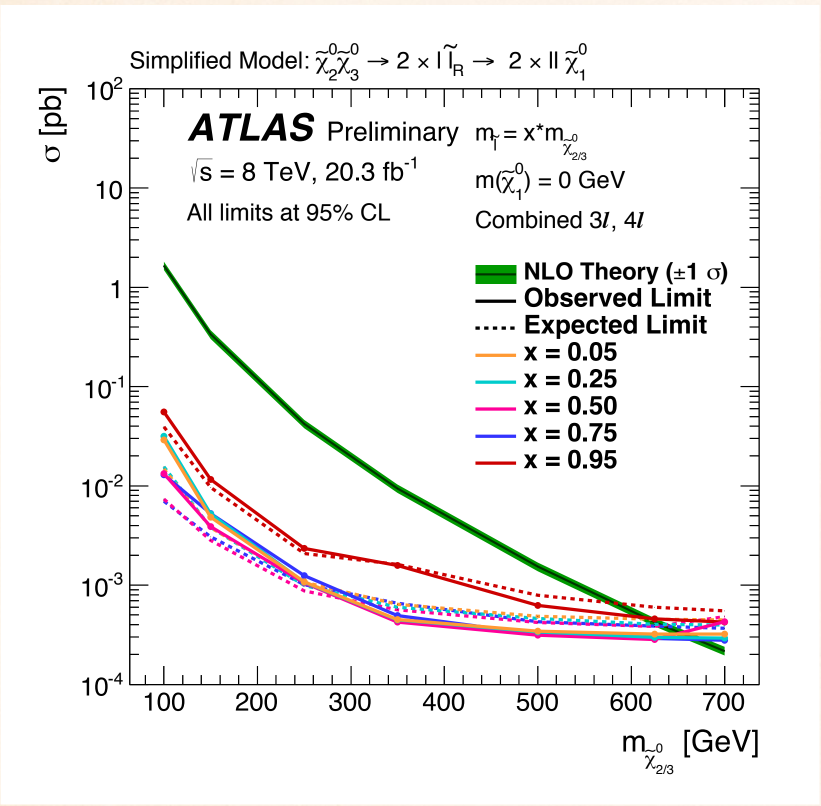



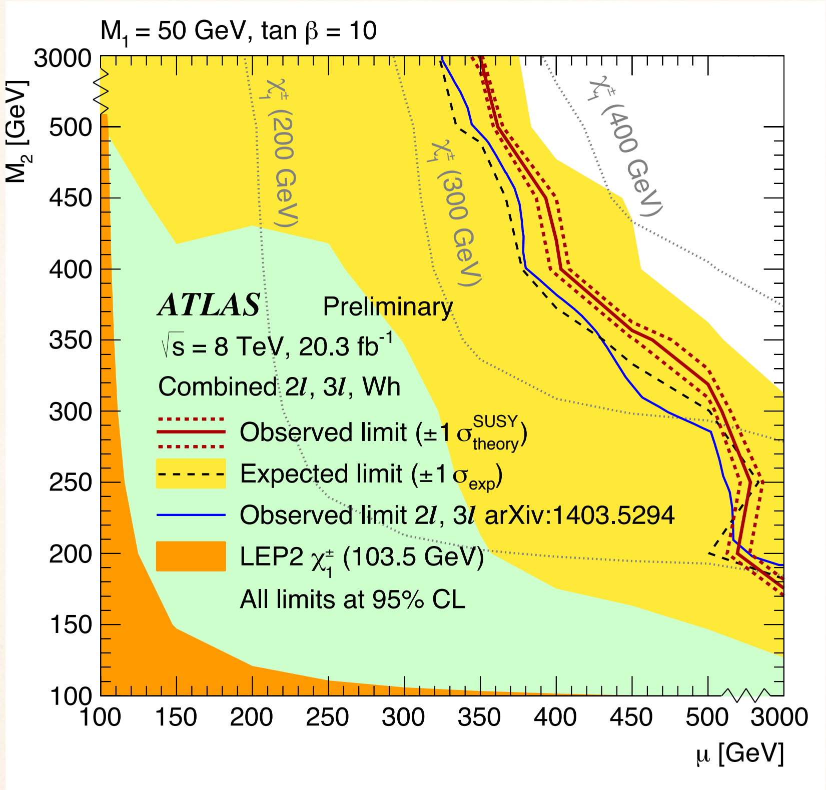



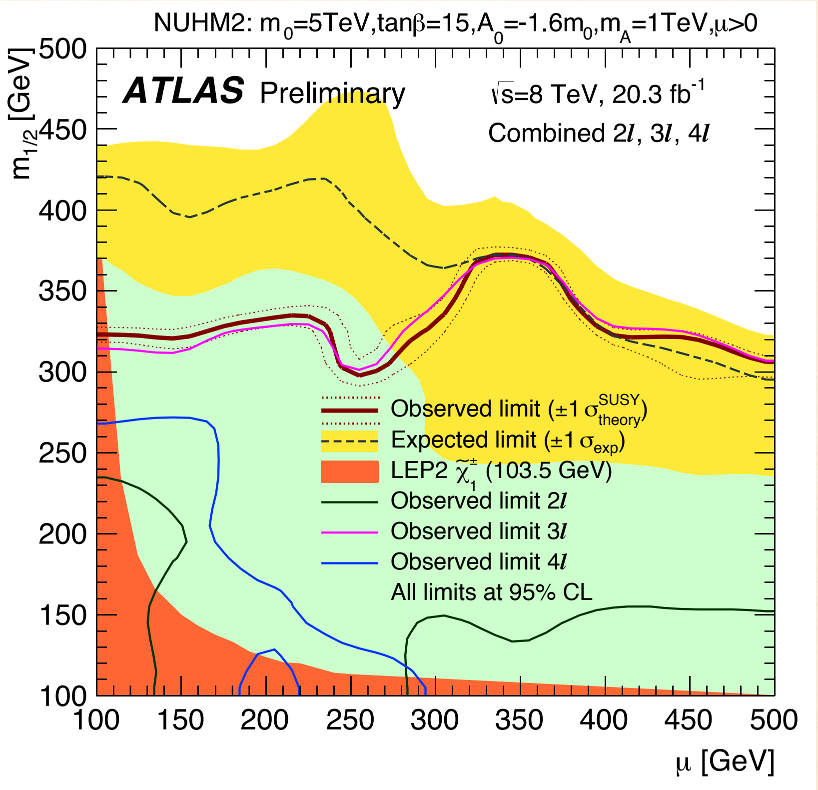
# EWK PAPER NEW INTERPRETATIONS




intermediate slepton mass scan

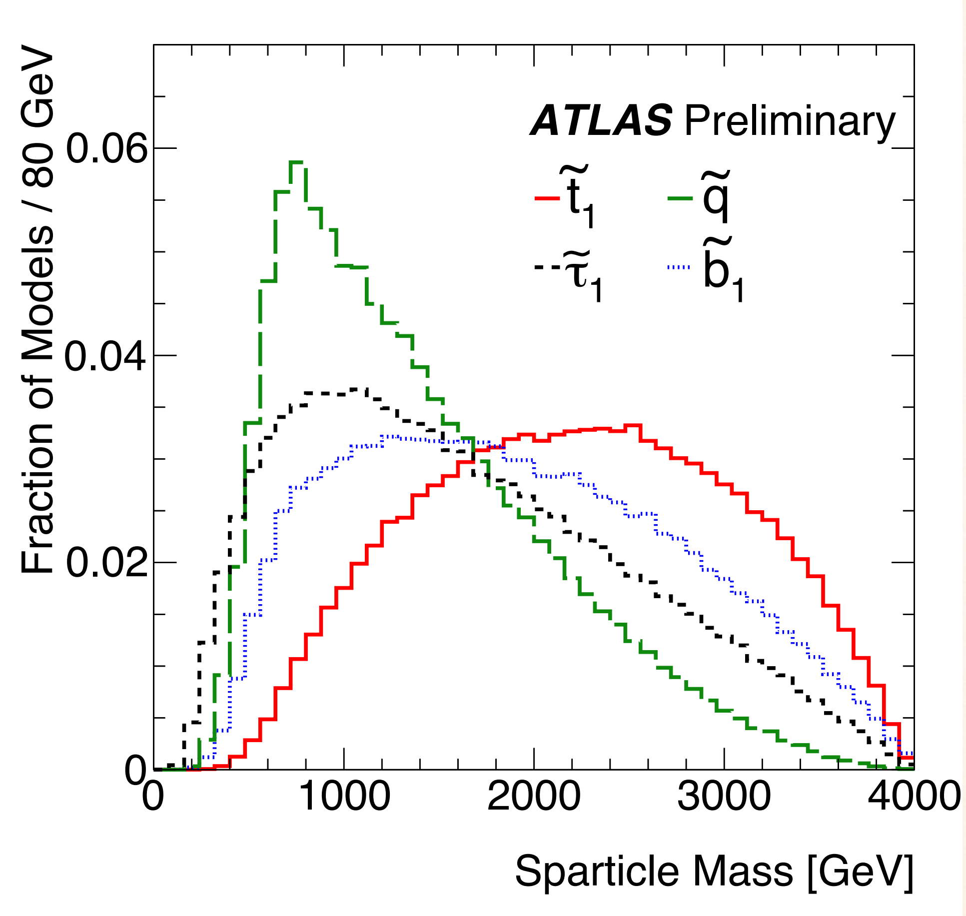



MSSM (with channels combination)




NUHM2 (with channels combination)

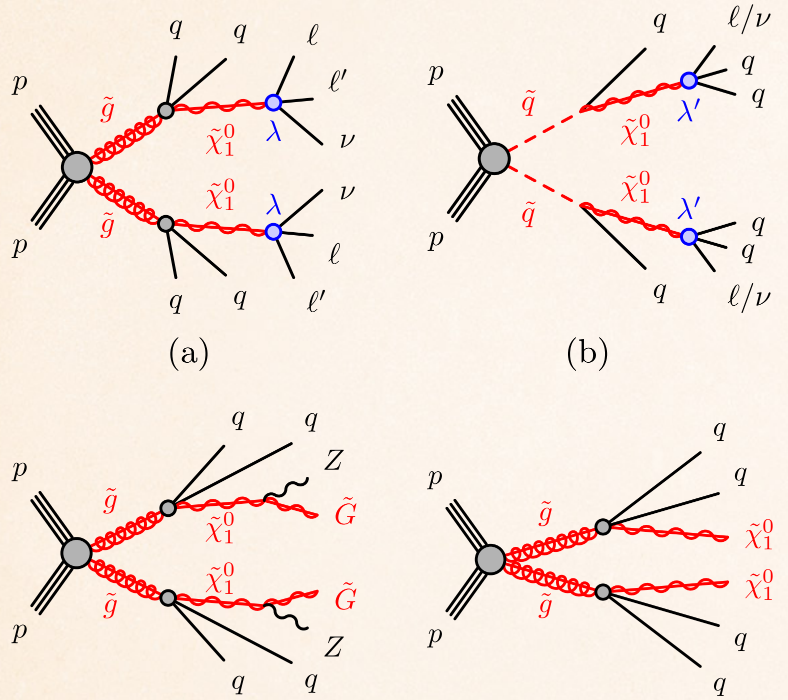
# PMSSM PAPER PARAMETER SCAN




| parameter | range [GeV] |
|---|---|
| slepton mass | 90-4000 |
| squark mass (1st/2nd gen.) | 200-4000 |
| squark mass (3rd gen.) | 100-4000 |
| M1,M2,mu | 0,70,80-4000 |
| gluino | 200-4000 |
| trilinear couplings | 0-4000 |
| $M_A$ | 100-4000 |
| tan beta | 1-60 |

- non-LHC constraints : delta rho, g-2, BR of b to sγ, Bs to μμ, B+ to τν, DM density, Z inv. width, chargino LEP limit
- Also ask for: light squarks above 200 GeV, Higgs mass between 124 and 126 GeV

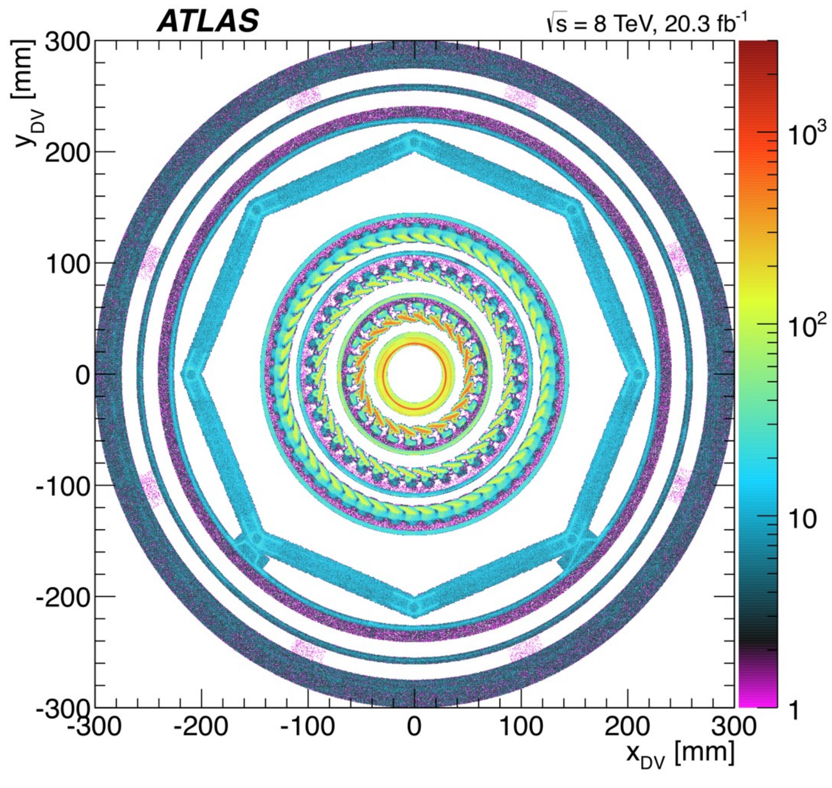
# DISPLACED VERTICES SEARCH



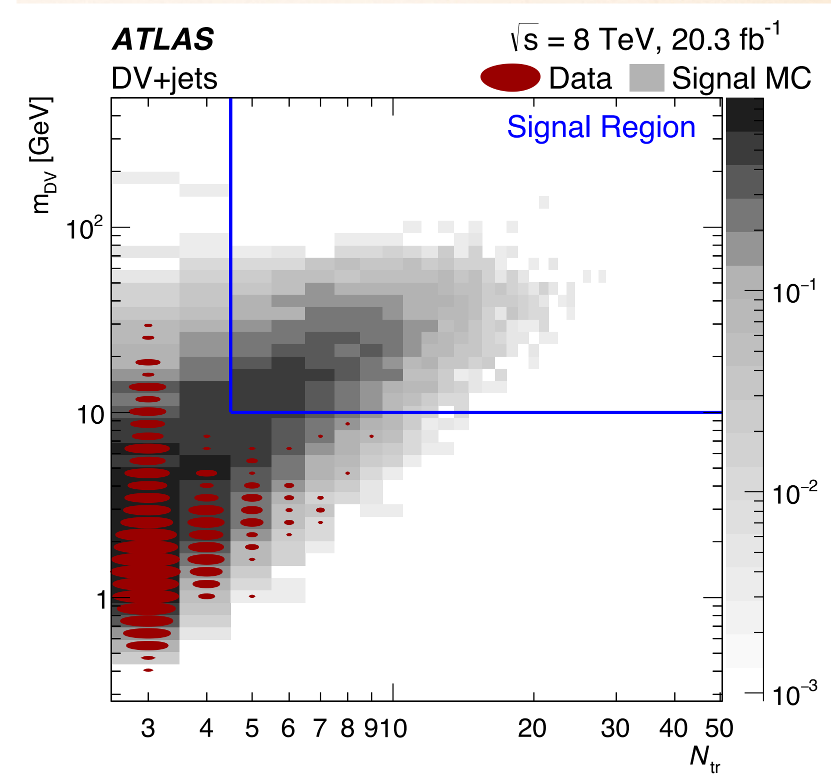

Targeting long lived gluino or neutralino - many interpretations!

| Channel | Upper-limit on visible cross-section [fb] |
|---|---|
| DV+jet | 0.14 |
| DV+$E_T^{miss}$ | 0.15 |
| DV+muon | 0.15 |
| DV+electron | 0.15 |
| $e^+e^-$ | 0.14 |
| $\mu^+\mu^-$ | 0.14 |
| $e^\pm\mu^\mp$ | 0.15 |

Either 5-track displaced vertex (DV) with jet, MET, electron or muon trigger, or a 2-lepton displaced vertex.



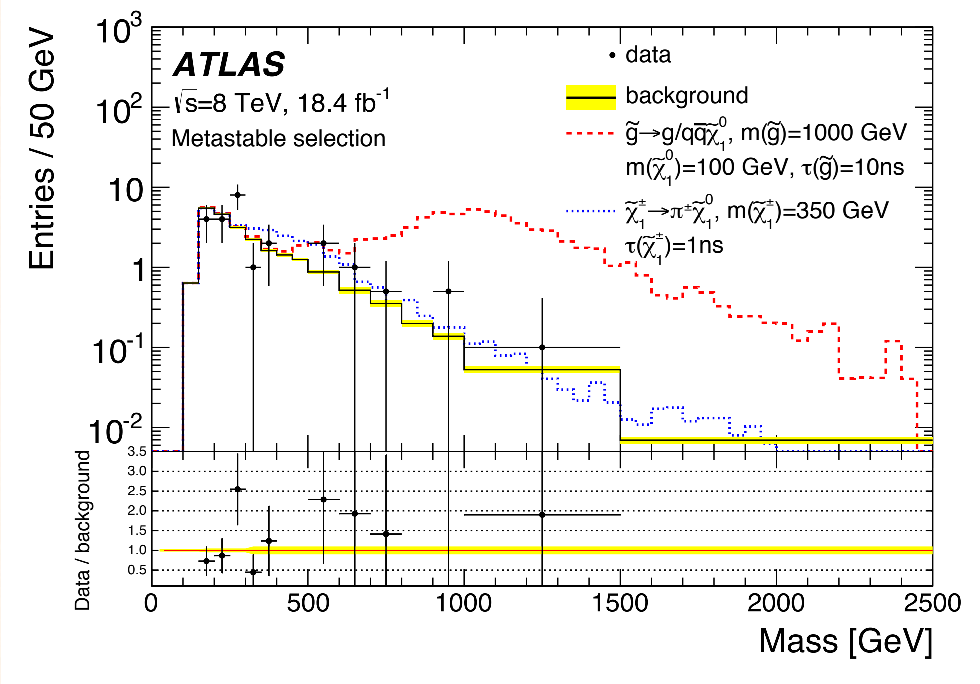

This is not simulation!
Position of reconstructed vertices, mapping the detector material. These regions are vetoed for the search.

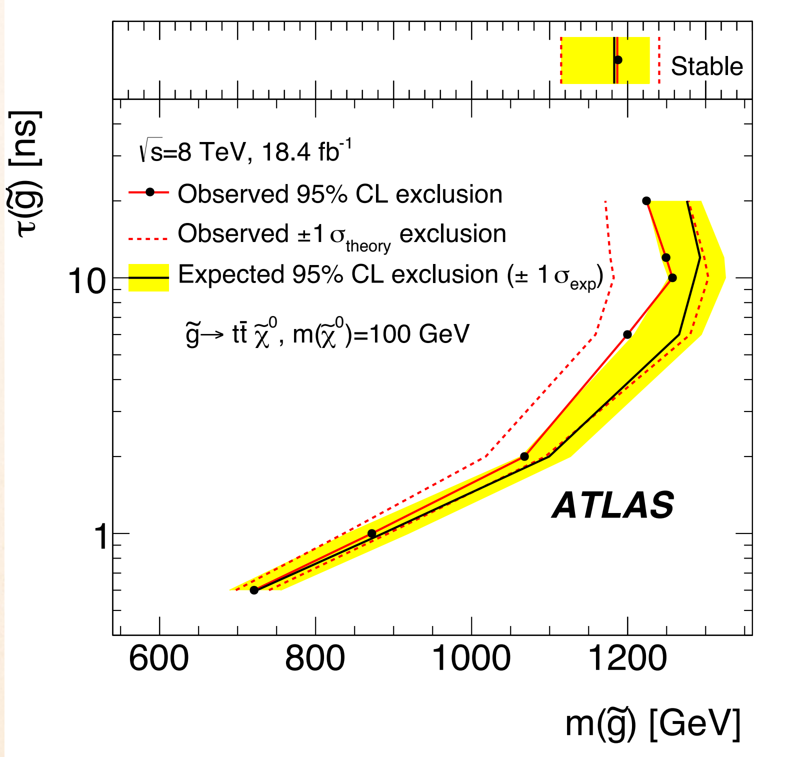



No event seen in the search region (5+ tracks, vertex mass > 10 GeV) for any channel.

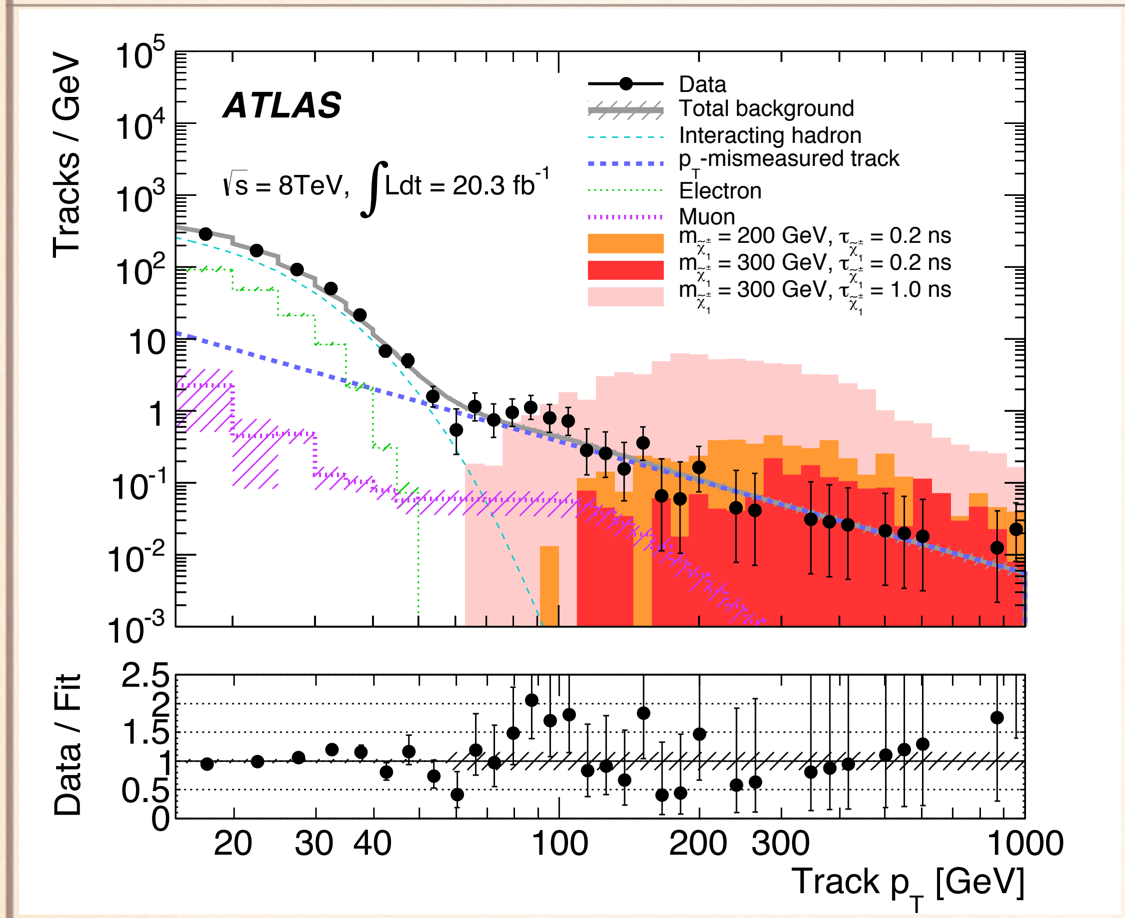
# PIXEL DEDX

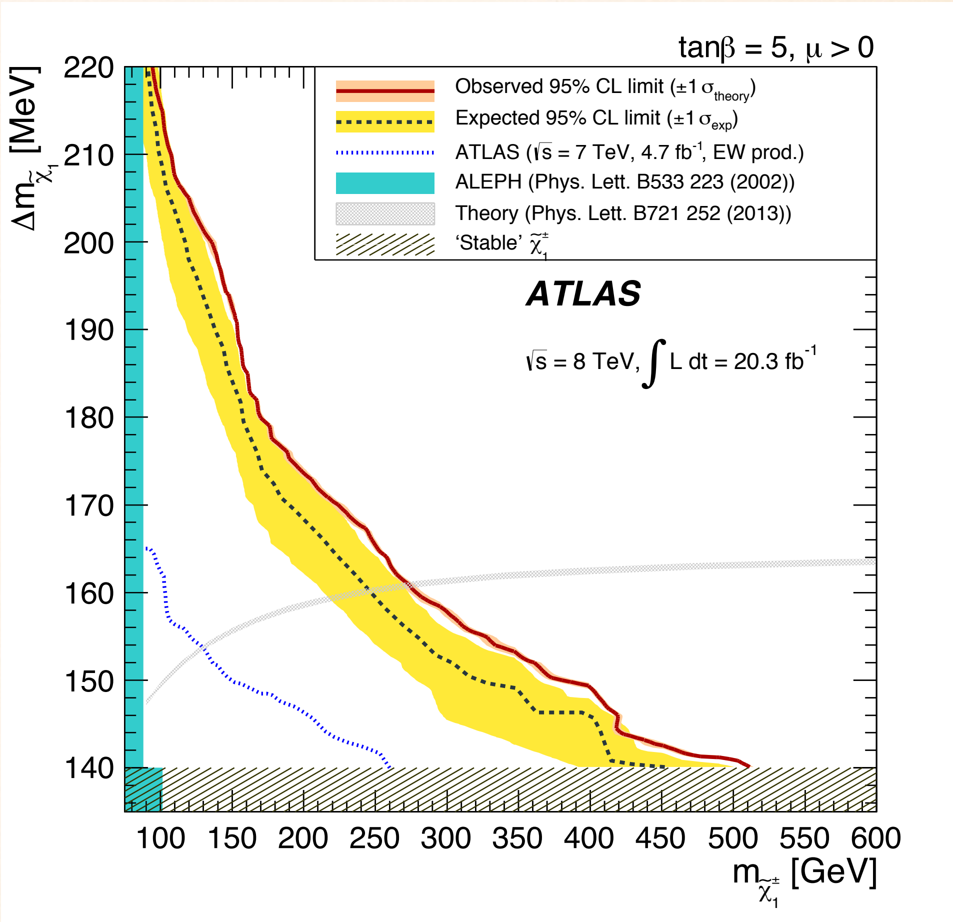
- MET > 100 GeV [trigger]
- One track with pT > 150 GeV, minimum 45 cm lenght, isolated, well measured.
- mT > 130 GeV [suppress W]
- Not an electron or (metastable selection only) a muon candidate
- Reconstruct βγ from dEdx, mass from βγ and momentum.
- Background entirely data driven



# DISAPPEARING TRACK SEARCH



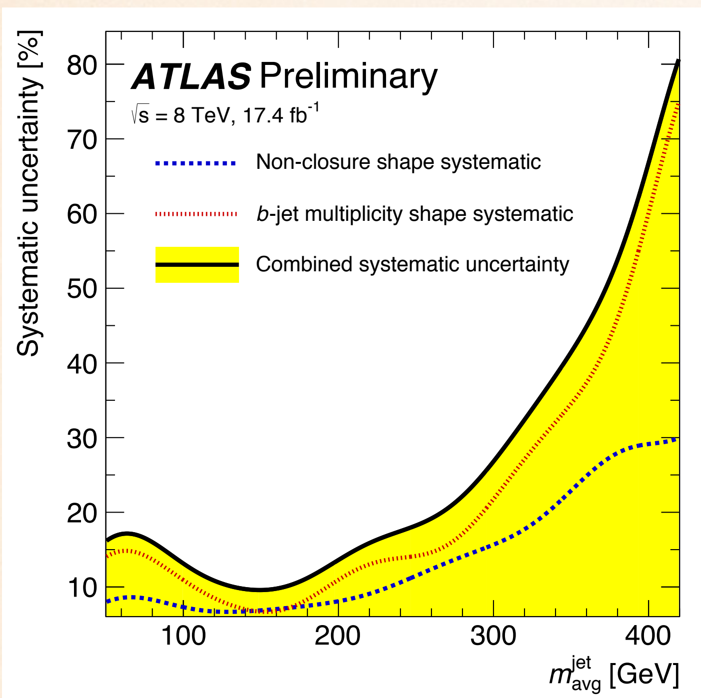



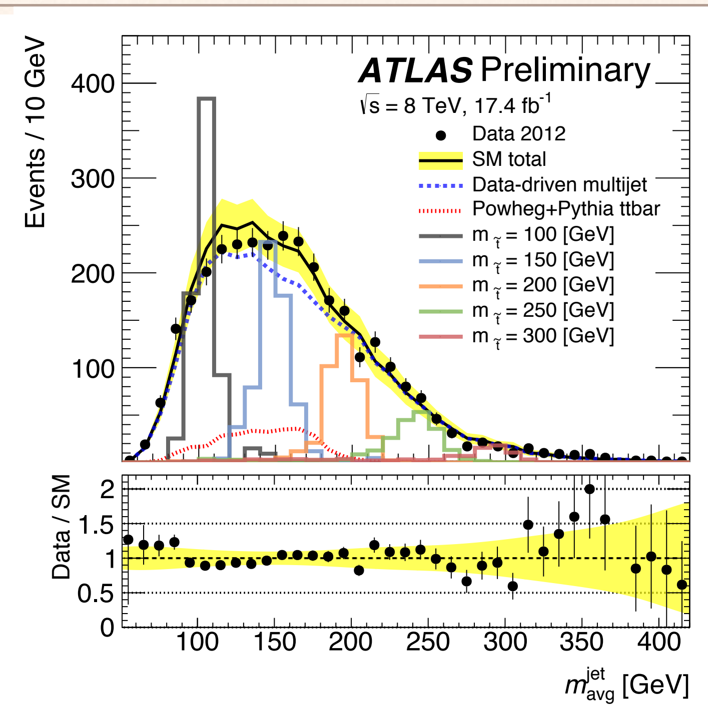

MET > 90, 1 jet with $p_T$ > 90, delta phi(jet,MET) > 1.5

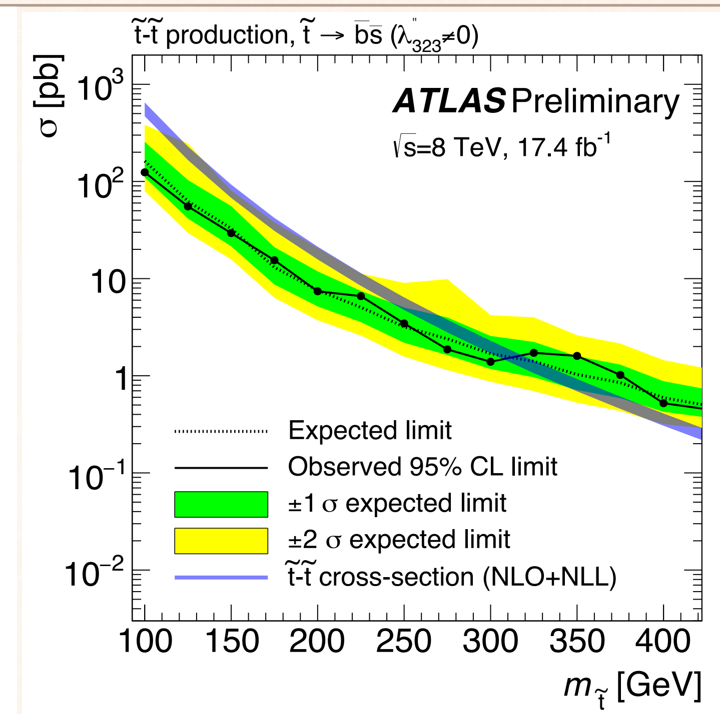
One well-reconstructed, isolated track with 3 pixel and 2 SCT hits, 0.1 < eta < 1.9, and less than 5 TRT hits ("disappearing")

# STOP 2X2 SEARCH

### ATLAS-CONF-2015-026



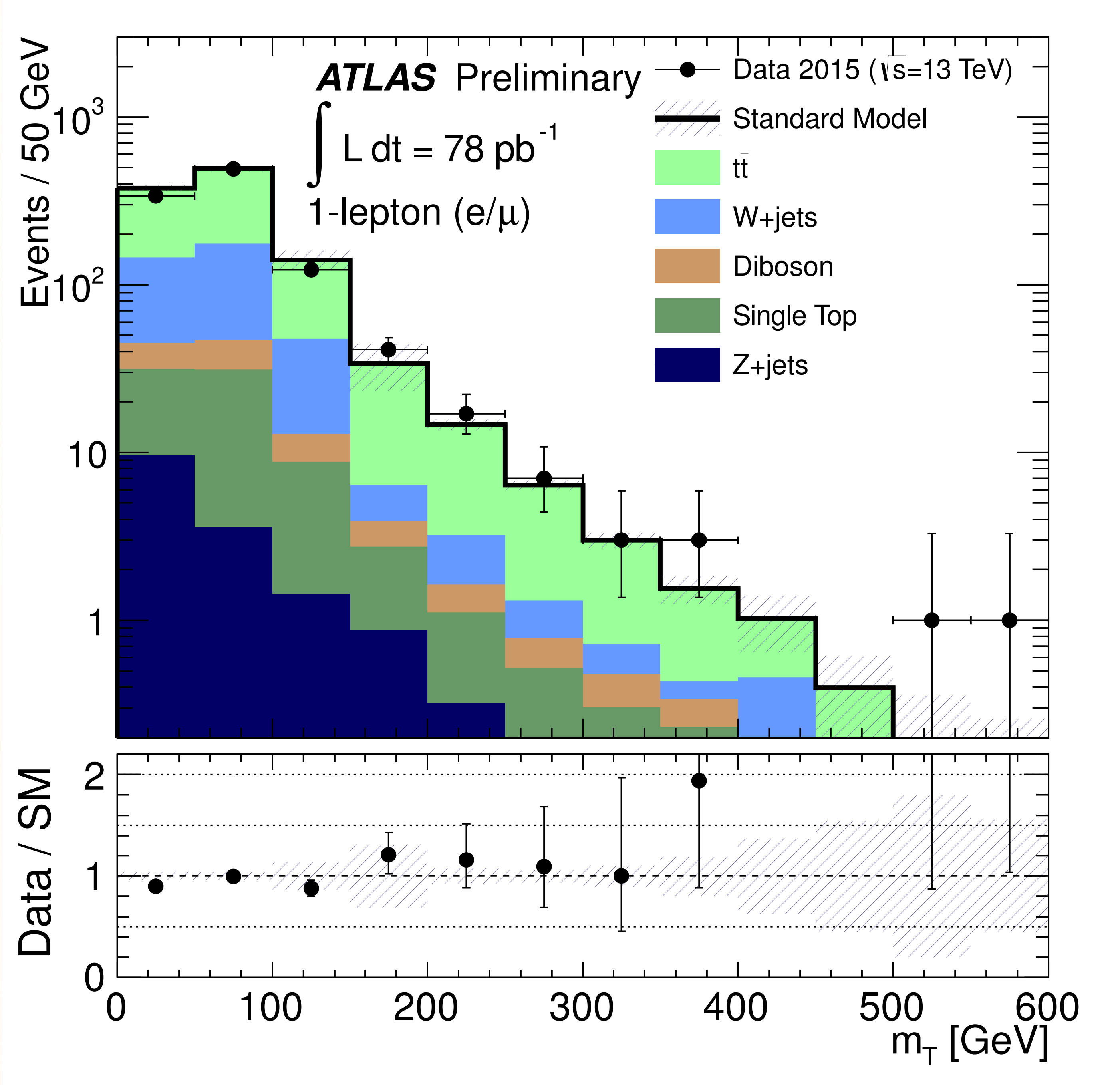




- Targeting low mass stop - boosted, a large jet containing the stop decay products.
- Signature : event $H_T > 600$ GeV, two R=1.5 jets with $p_T > 200$ GeV.
- Selections on the large-R jets center-of-mass production angle, the number of R=0.4 b-tagged jets, large-R jet mass asymmetry, the $p_T$ ratio between the two subjets in each large-R jets, define the SR as well as the CRs from which the multi-jet background is estimated (data-driven ABCD-like method)
- Final signature is a resonance in the average large-R mass spectrum

# RUN-2 SELECTIONS : 1-LEPTON

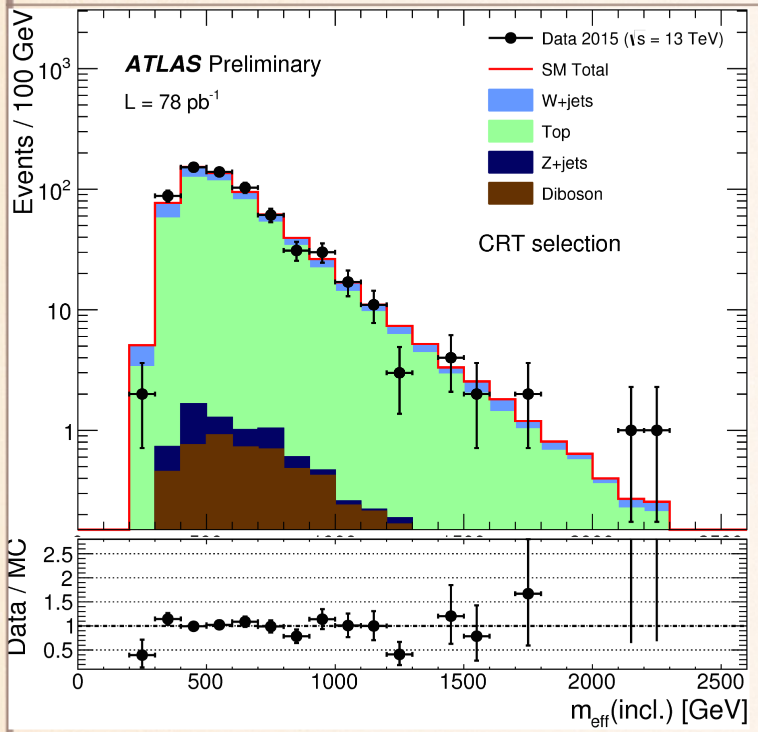
**ATLAS-PHYS-PUB-2015-029**



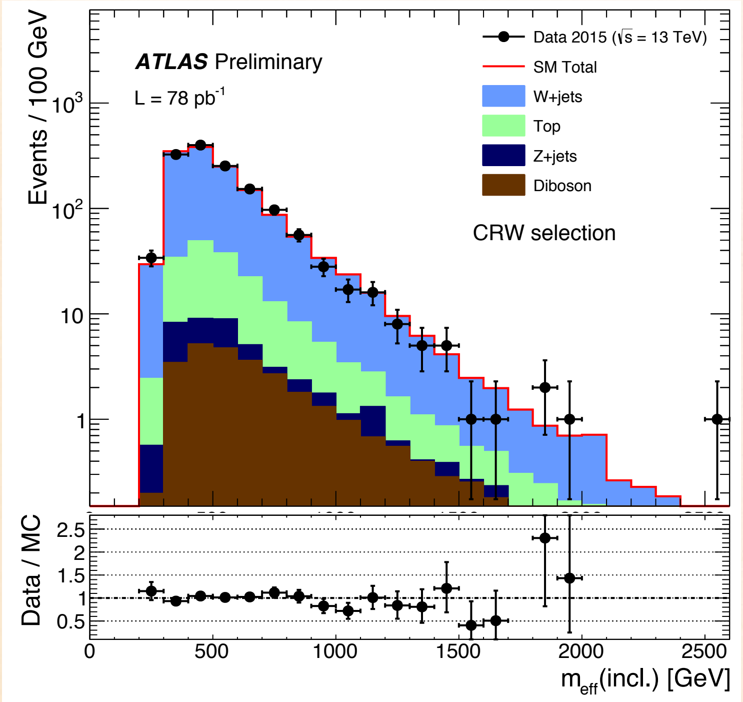

- One lepton with $p_T$>35 GeV, 4 jets with $p_T$ > 30 GeV, MET > 100 GeV
- 40 < $m_T$ < 100 with b-veto/tag normalizes the W+jets/ttbar.
- Powheg for top backgrounds, sherpa 2.1 for V+jets and di-bosons.

# RUN-2 SELECTIONS : 0-LEPTON 2 JETS

**ATLAS-PHYS-PUB-2015-028**




(Loose) CR effective mass distribution for the 0L analysis shown.



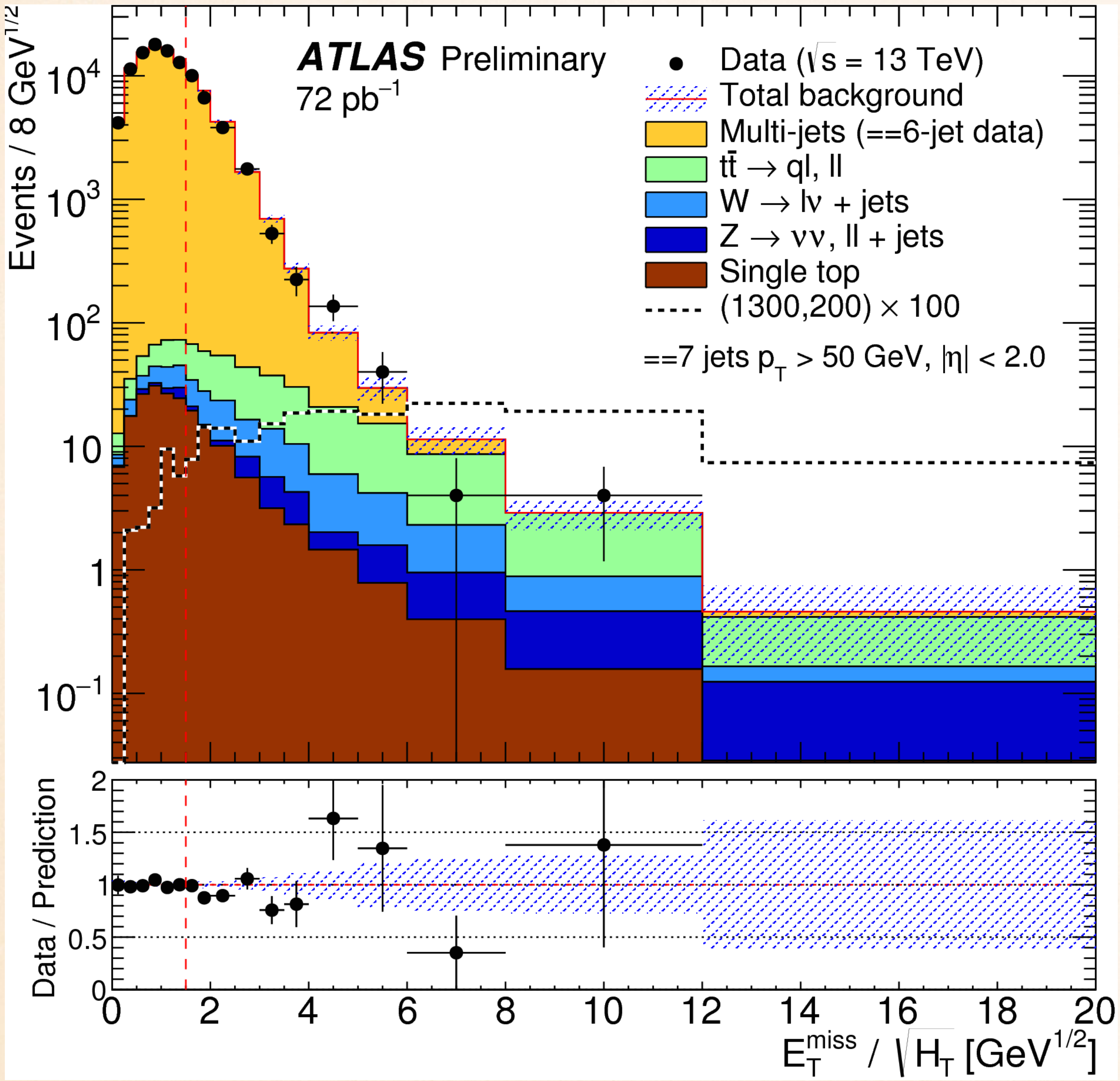

CRT/CRW : 1-lepton $p_T$>25 GeV, 30 < $m_T$ < 100 GeV, 2 jets with $p_T$ > 100,60 GeV, MET > 100 GeV, 1b-tag/veto

CRZ : 2 leptons in the Z peak, 2 jets with pT > 100,60 GeV, MET(inc. leptons) > 100 GeV

Powheg for top backgrounds, sherpa 2.1 for V+jets and di-bosons.

# RUN-2 SELECTIONS: 0L + 6-7 JETS

**ATLAS-PHYS-PUB-2015-030**




- 5j45 trigger - require 6 jets $p_T > 50$ GeV and $H_T > 600$ GeV
- Measure $H_T$/sqrt(MET) and use it as multi-jet template (after subtraction of top and EWK from MC)
- Normalize at low $H_T$/sqrt(MET) and compare to data in 7-jet selection