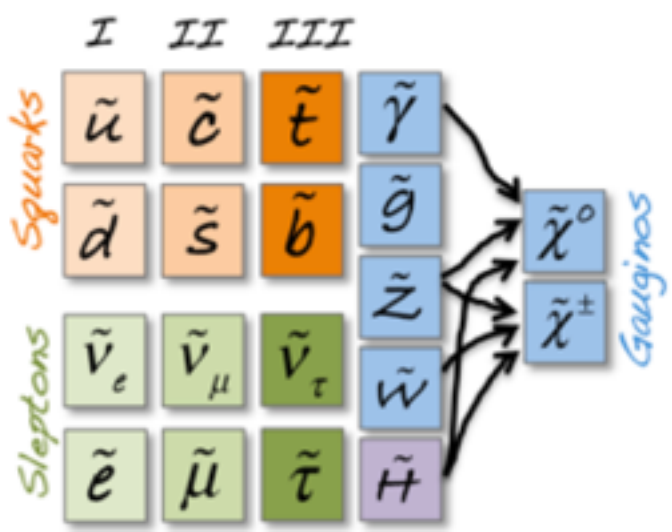
Searches for Supersymmetric particles in ATLAS

Supersymmetric



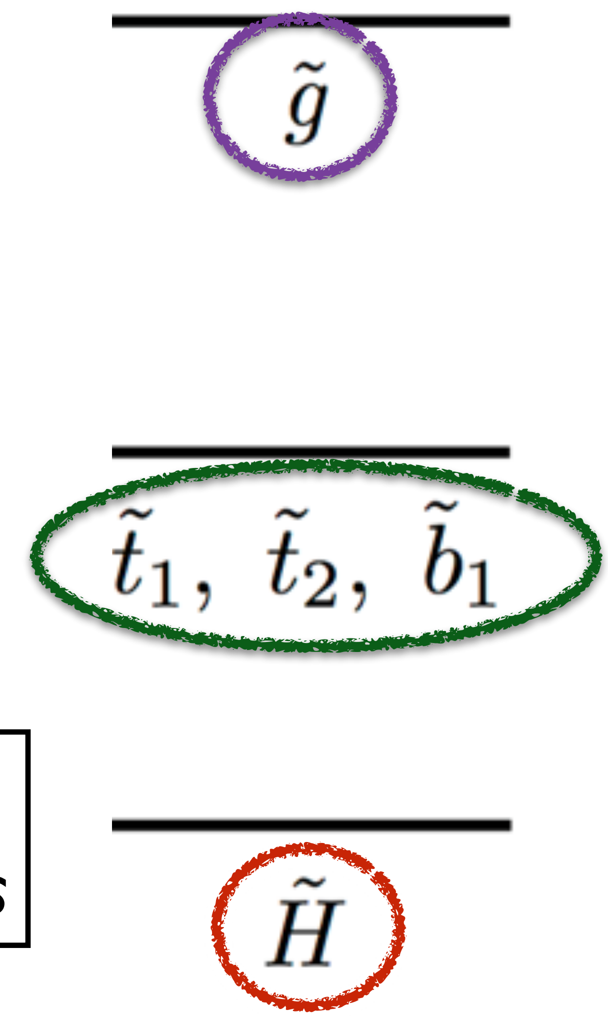
52nd Rescontres de Moriond
on QCD and High Energy Interactions

Simone Amoroso

on behalf of
the ATLAS Collaboration

SUSY searches in ATLAS

- *Squarks* and *gluinos* production through strong interaction are prime candidates for discovery due to the high production cross sections
- In natural scenarios *3rd generation* sparticles should have lower masses, but also have lower cross-sections
- *Charginos and Neutralinos* as well as *sneutrinos and staus* have both low mass and are produced through weak interactions, challenging searches



In conventional realisation of SUSY, a special role is played by the higgsinos, stops and gluinos, as they couple strongest to the Higgs

- R-parity conserving (*RPC*) signatures
  - Sparticles are produced in pairs, with each decay ending with an LSP, mostly the lightest neutralino or the gravitino

→ E_T^{miss} +X

- R-parity violating (*RPV*) signatures
  - Resonances in multi-jets/leptons, can produce *single sparticles* and the *LSP decays*
  - If the couplings are small signature of *displaced decays* of the LSP

SUSY SEARCHES IN ATLAS

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In conventi...
higgsinos, *s*...

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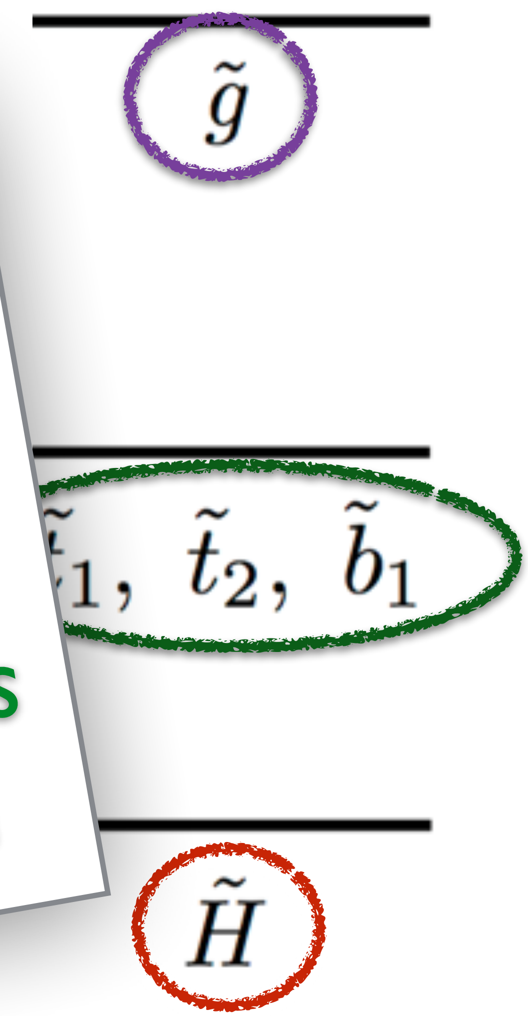
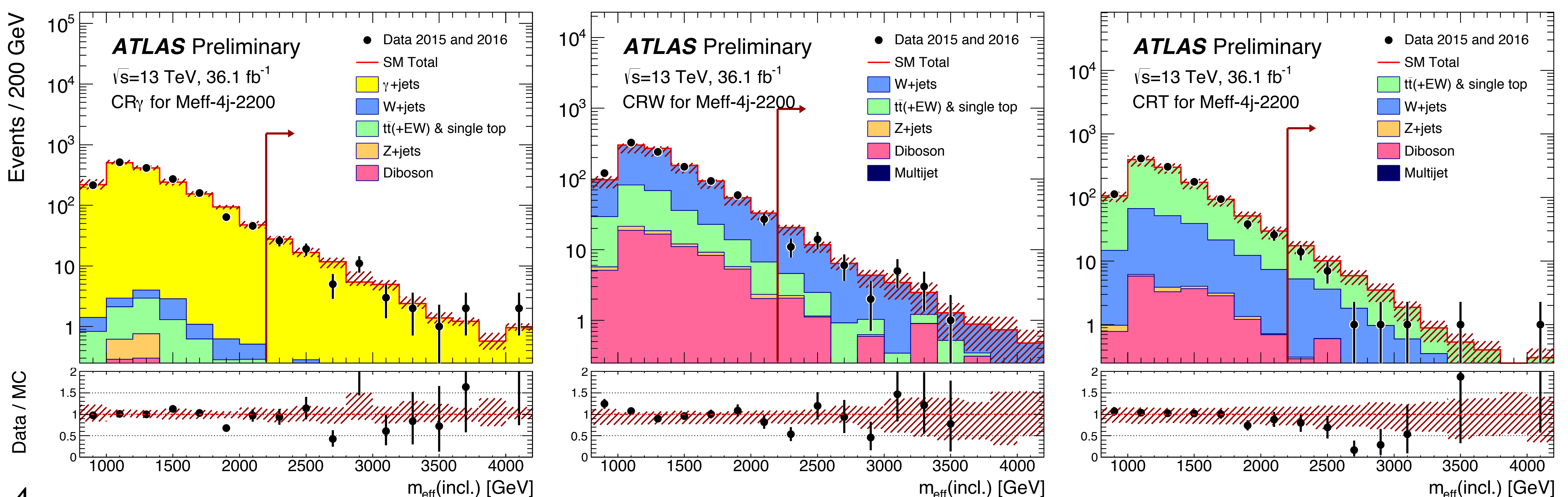
Supersymmetry comes with a complex and rich phenomenology

Targeted by Inclusive searches for more generic signatures and dedicated analysis to adequately cover the full spectrum



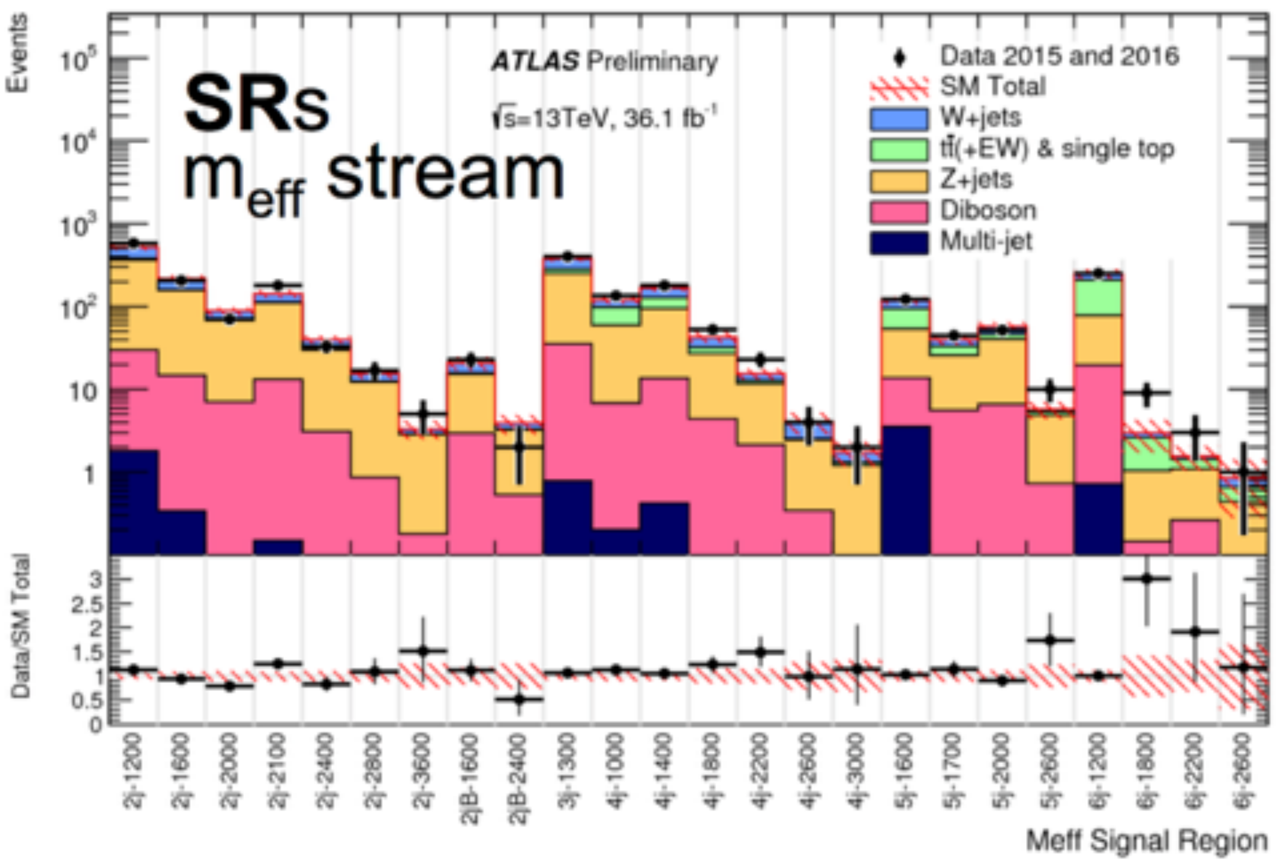
0L+2-6 jets+MET

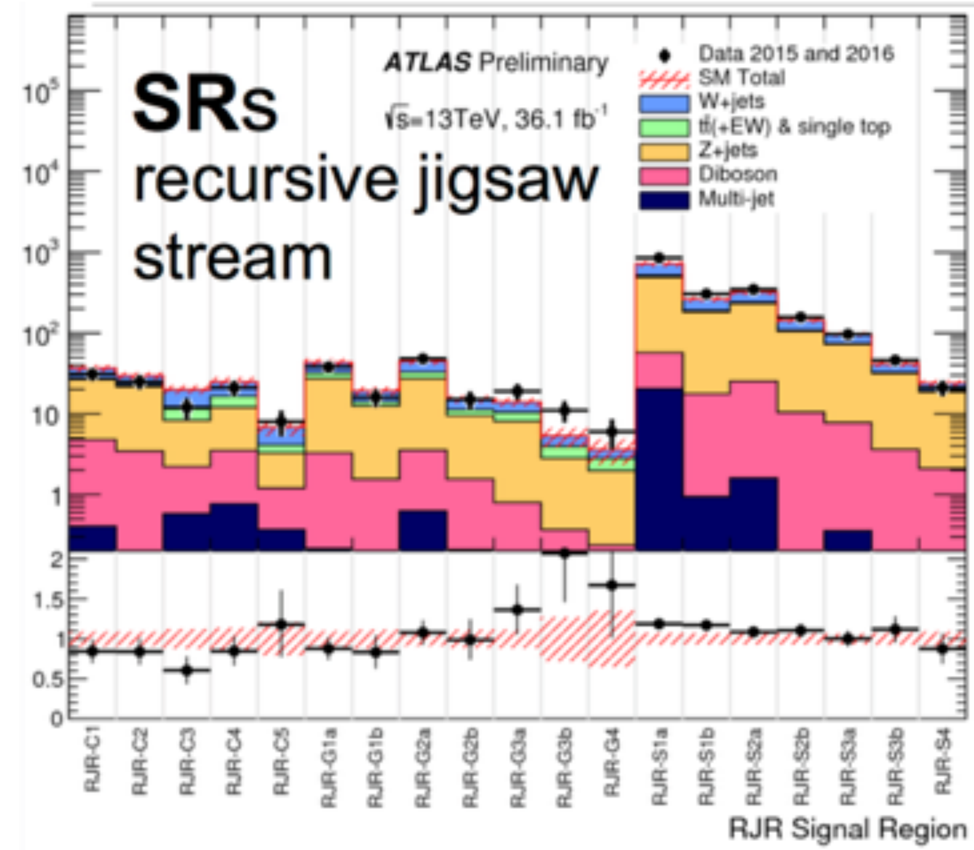
- Search for direct or 1-step decays of squarks and gluinos
- Traditional ***effective mass*** analysis
  - $m_{eff}=H_T^{jets}+E_T^{miss}$ used as discriminant
  - Two new regions require a large-R jet compatible with W/Z-boson mass
- ***Recursive Jigsaw*** analysis
  - Assume a specific decay topology to reconstruct particles four-momenta
  - Effective for the compressed spectra
- Backgrounds normalised in control regions, extrapolated to the signal regions
  - 1 lepton CR are used for **W+jets** and **ttbar**, *b*-tag/veto to separate the two
  - Z(to neutrinos)+jets is extrapolated using a **gamma+jets** CR

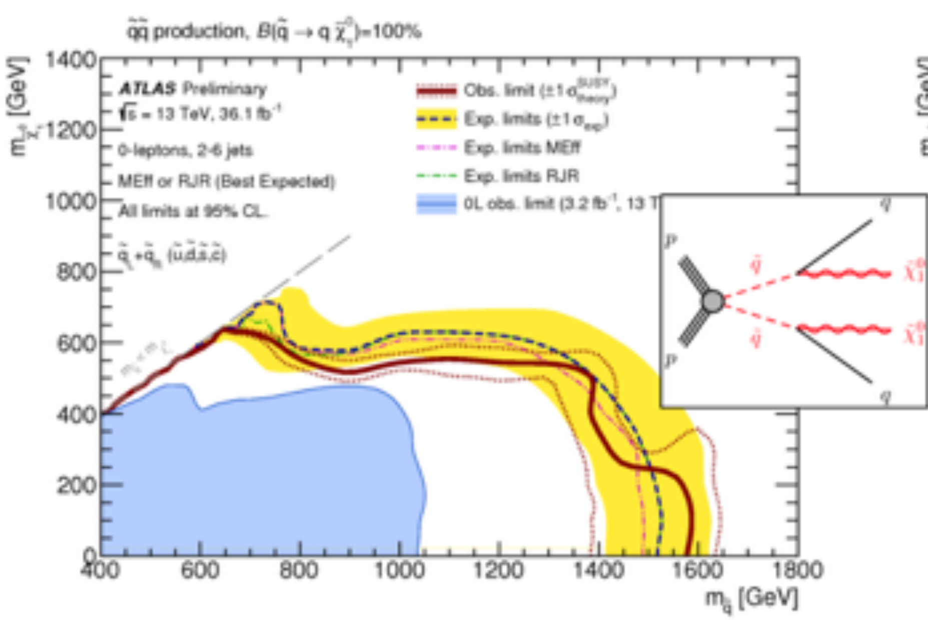


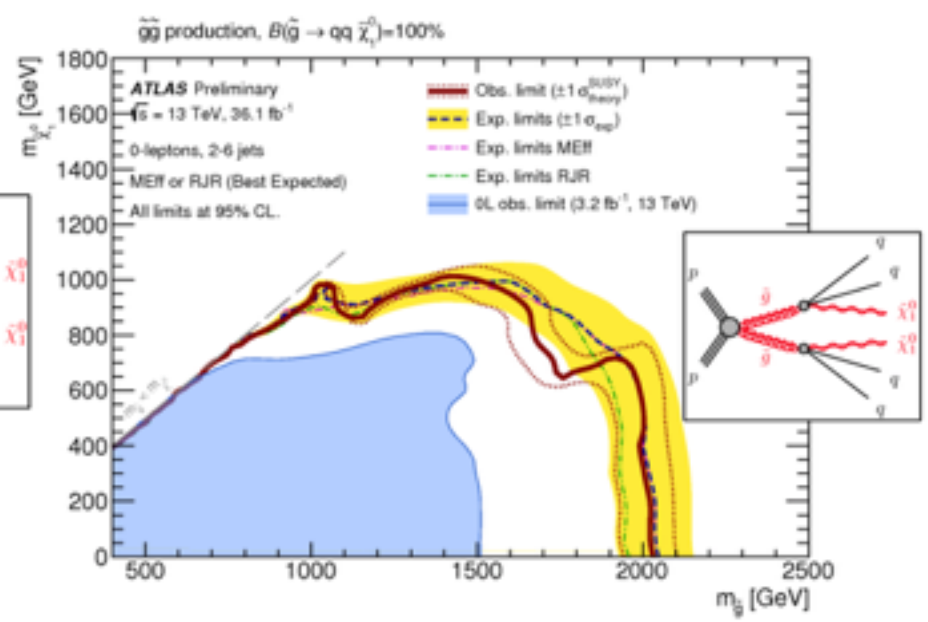
0L+2-6 jets+MET

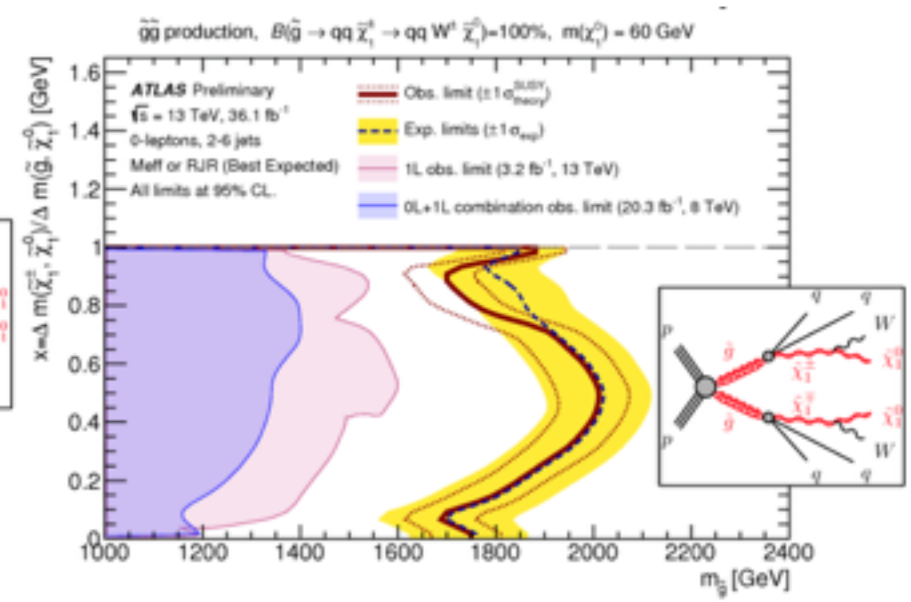
No significant excess is observed in the 43 signal regions



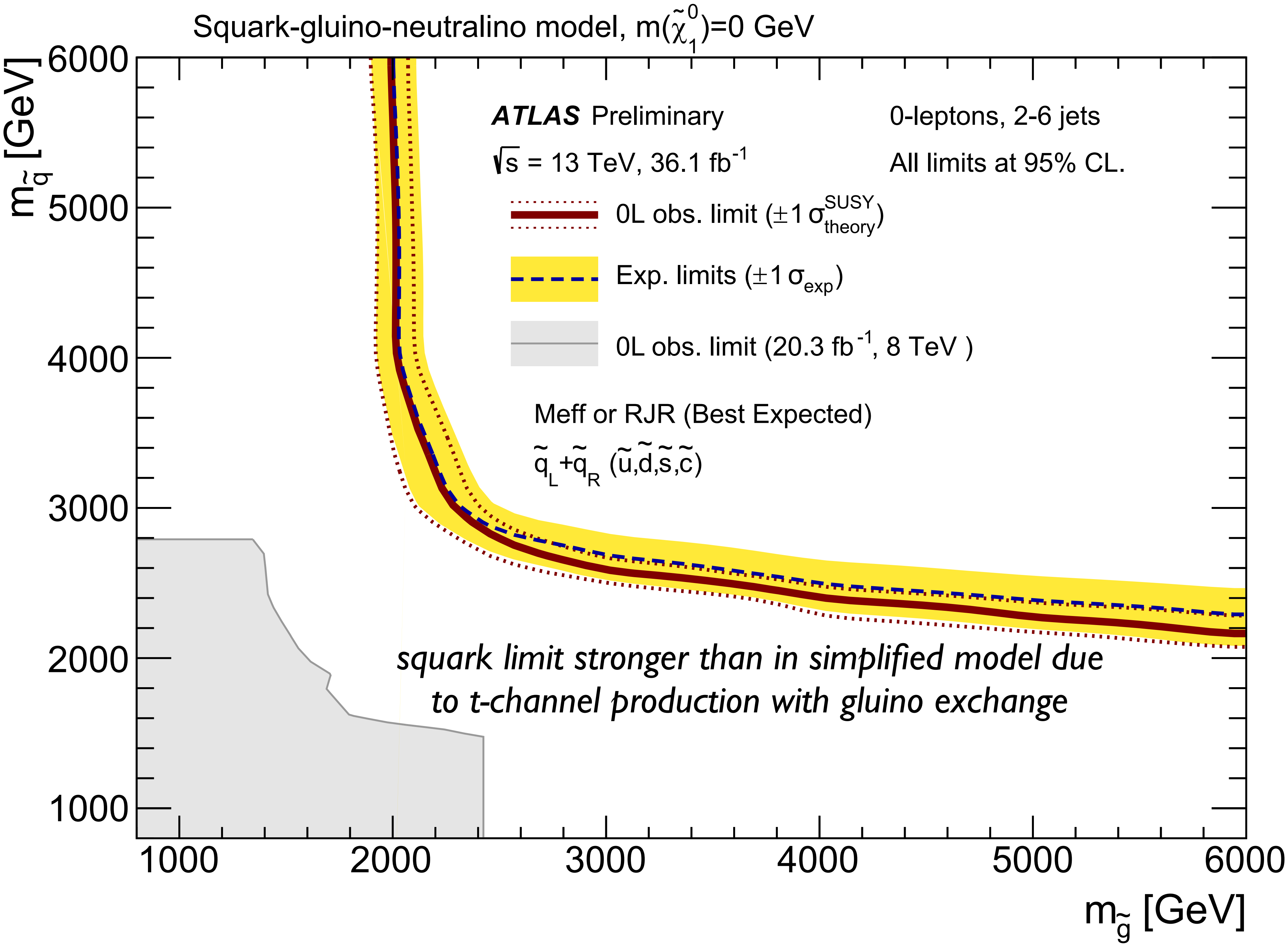






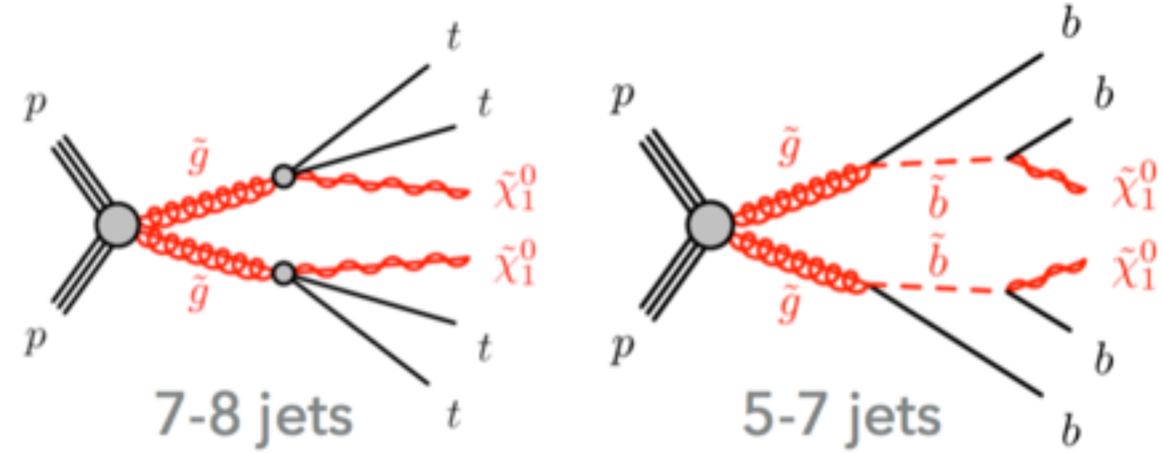


0L+2-6 jets+MET

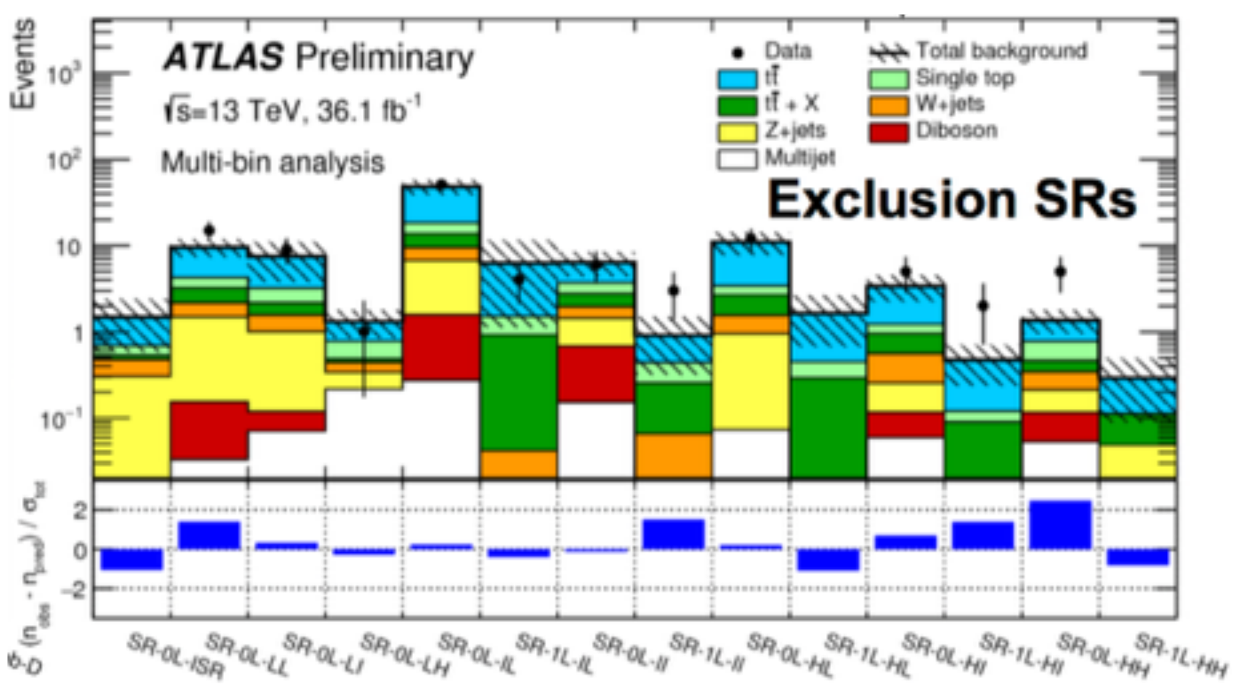


Squarks up to 1.6 TeV and gluinos up to 2 TeV are excluded

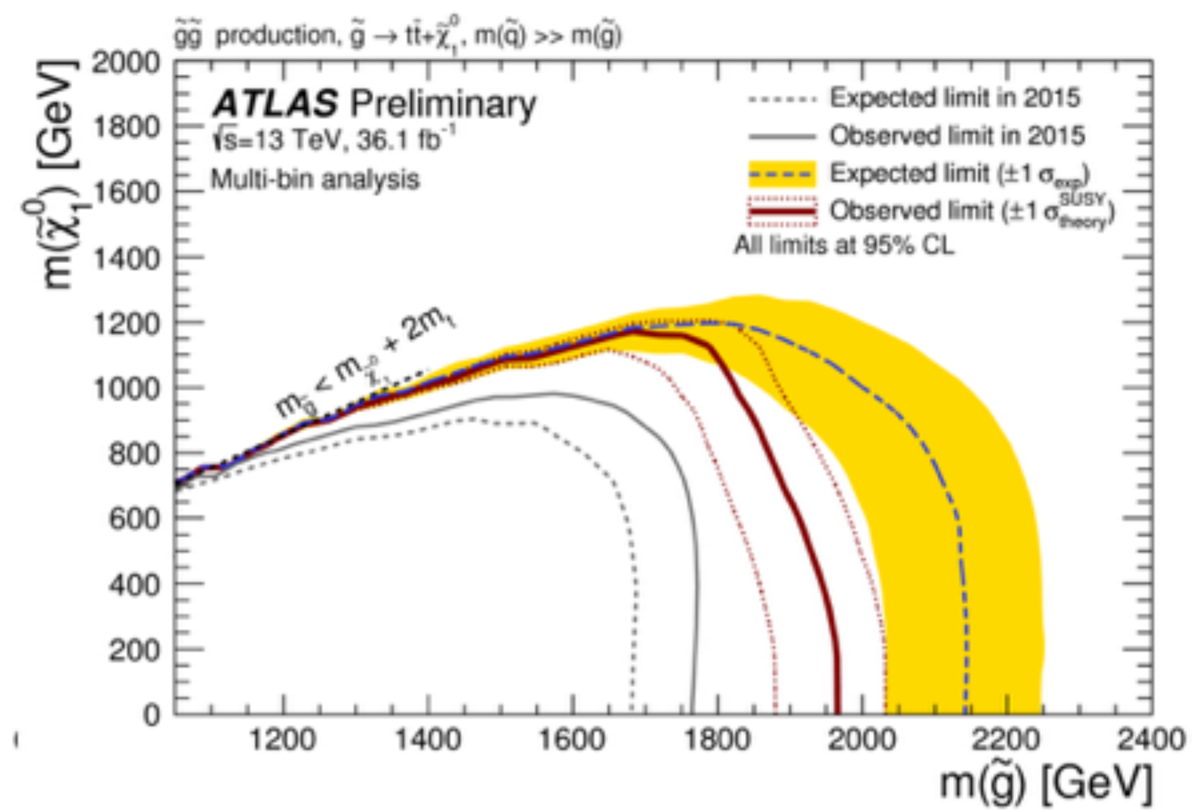
0/1L+>3b-jets+MET



- Search for gluino mediated stop and sbottom production
  - Search defines 10 SR optimised for discovery with varying requirements on the jet and *b*-jet multiplicity, m_{eff}, m_T, E_T^{miss} and the sum of jet masses in the event



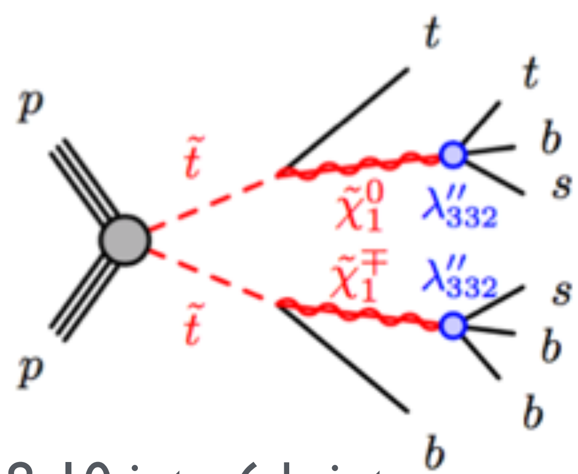
- Backgrounds estimated with a simultaneous fit to orthogonal CRs
  - top is the dominant background, normalised in a 1-lepton CR



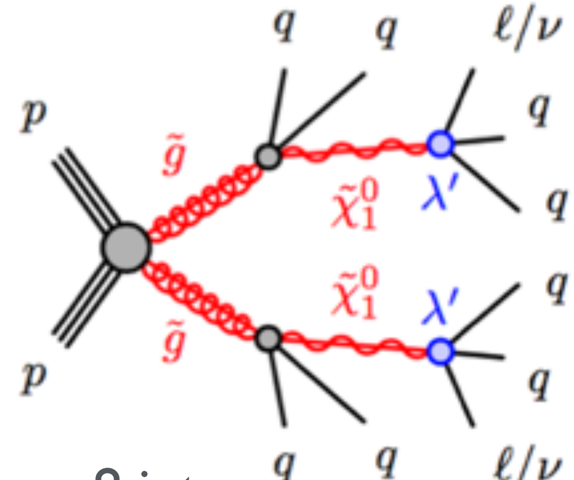
- No significant excess is observed
- Binned orthogonal signal regions are combined for the exclusion
  - selections on N_{jets} and m_{eff} to cover different mass spectra

RPV 1L 8-12 jets

- Search targeting final states with one lepton, high jet (8 to 12) and *b*-jets (up to 4) multiplicities, with no requirement on E_T^{miss}
  - Interpreted in different RPV models with ***many top-quarks*** in the final state



8-10 jets, 6 b-jets



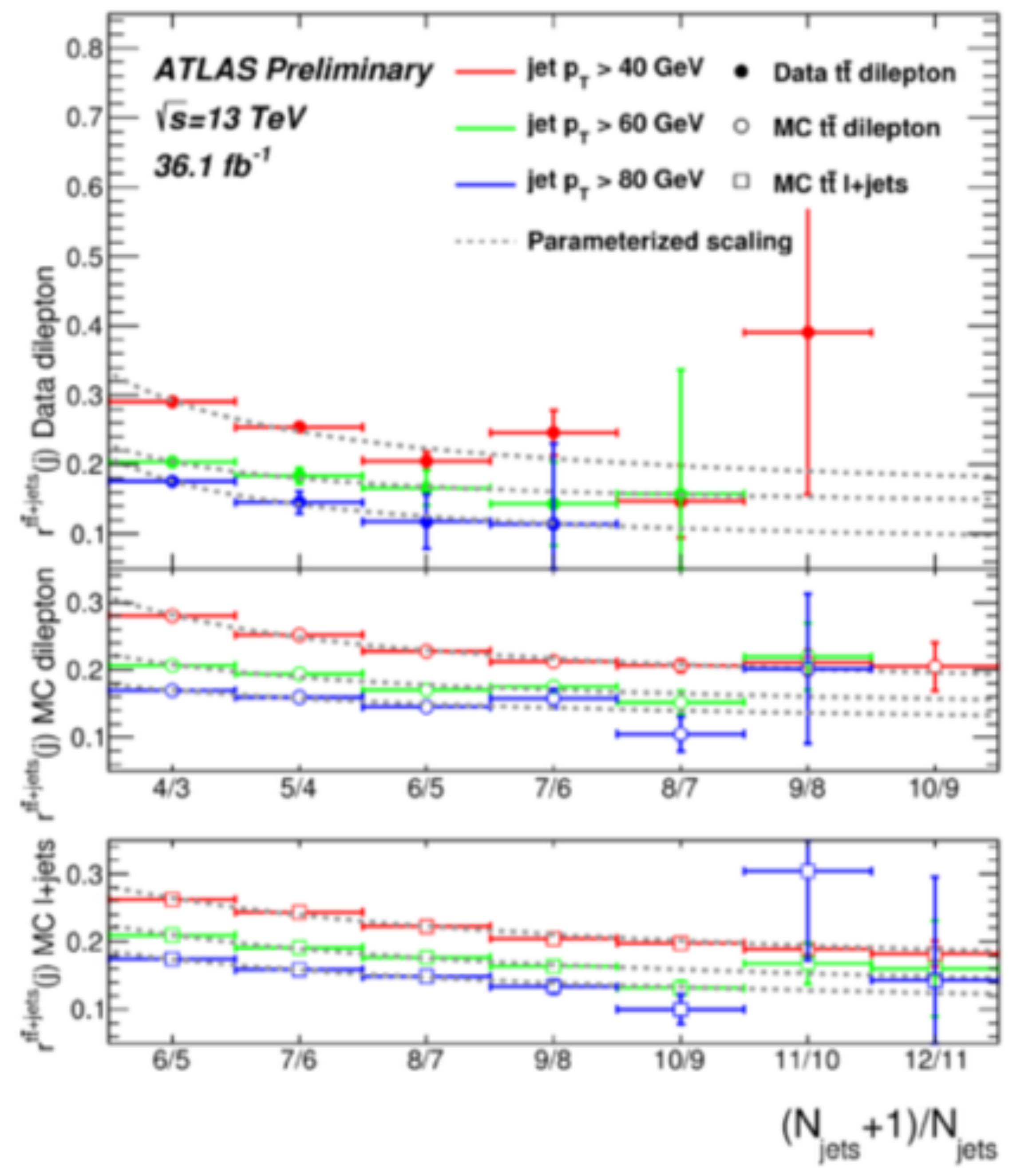
8 jets

- Dominant background is from W+jets and top-quark pair production
  - Estimated fully data-driven by deriving a ***scaling behaviour*** at lower jet multiplicities (5 to 7)

$$r_j = \boxed{c_0} + \boxed{c_1/(j + c_2)}$$

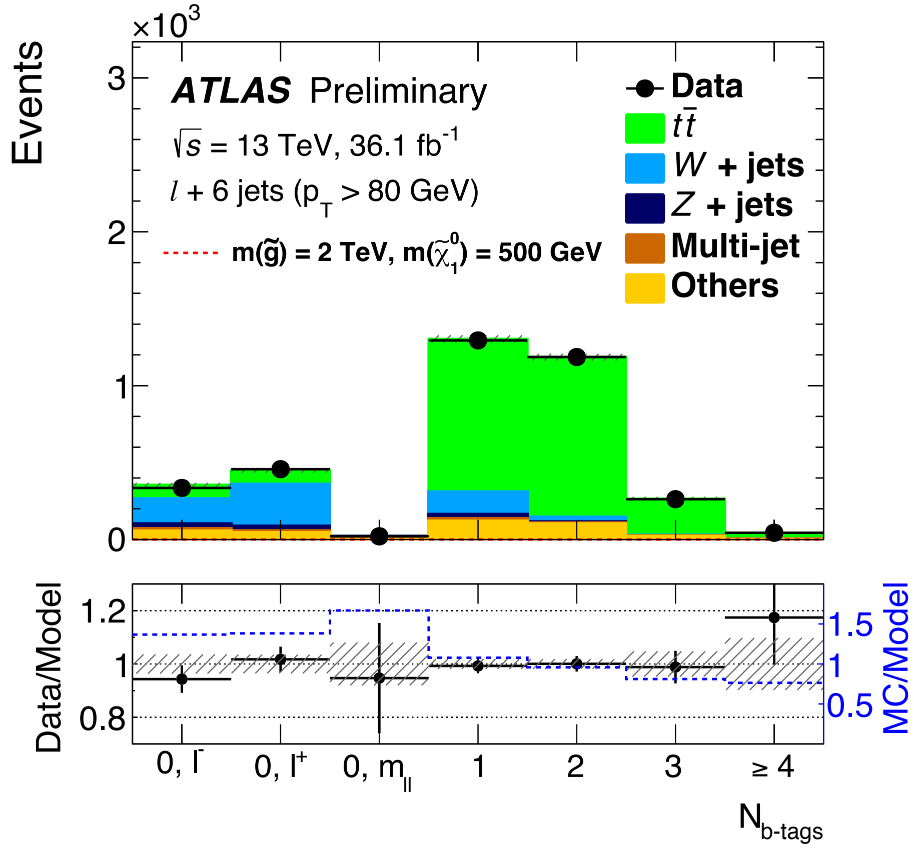
N_{jets+1}/N_{jets} *staircase* *Poisson*

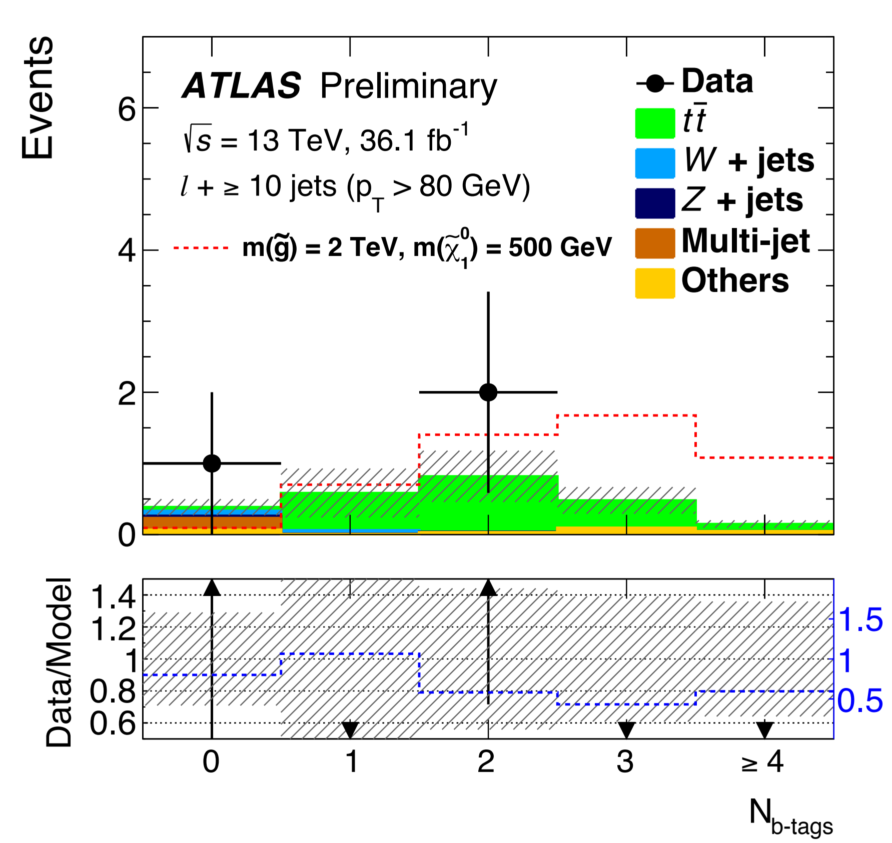
  - The *b*-jet multiplicity template for the top background is extracted from the 5-jet bin and evolved to the higher multiplicities by parametrising the *b*-jet emission probability



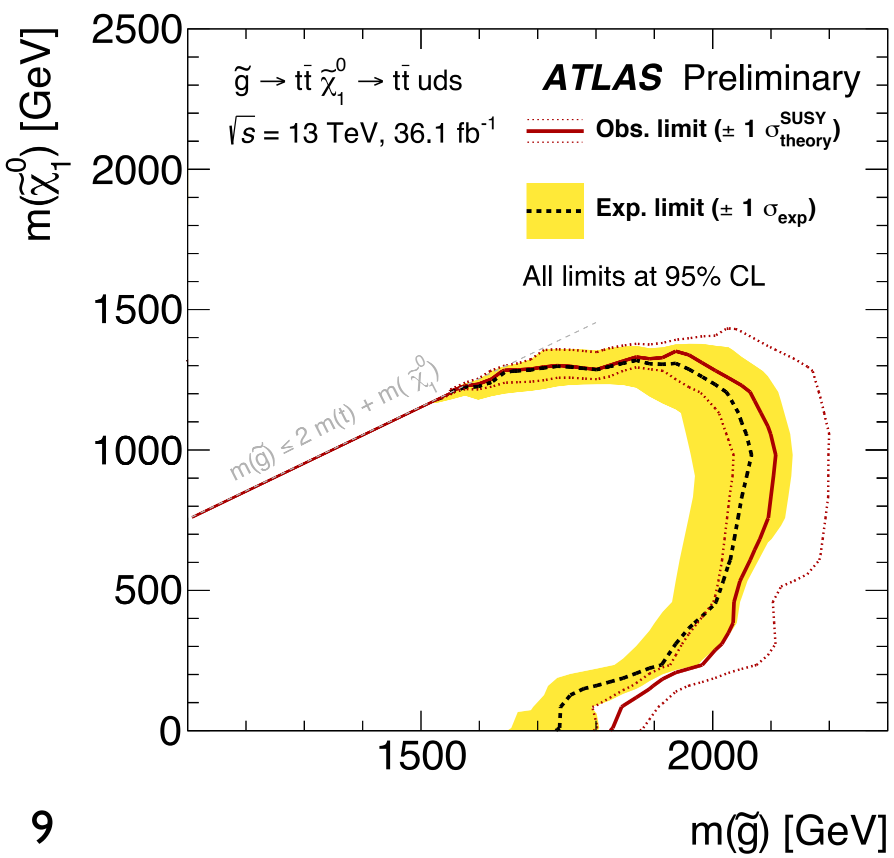
RPV 1L+8-12 JETS

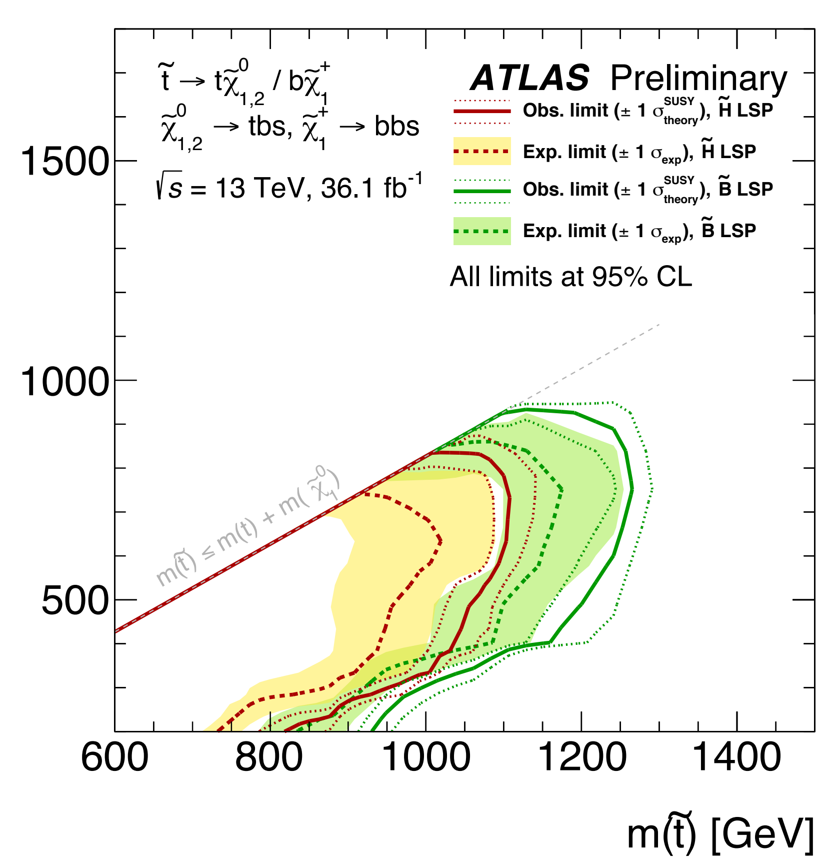
- Analysis performed independently for three selections with jets with p_T>40, 60, 80 GeV
- Results are in agreement with the model prediction in all of the regions





- Limits are set on the four simplified models considered
- *Bonus*: Sensitive also to SM 4-top production, an upper limit of 6.5 the SM cross section is obtained

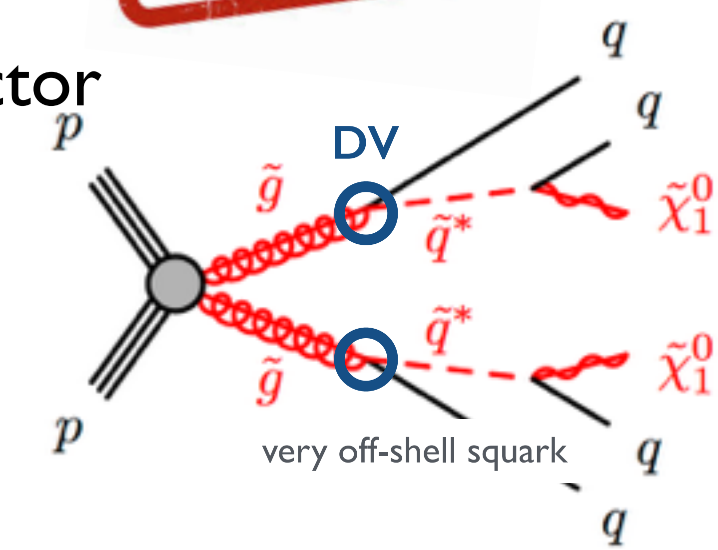




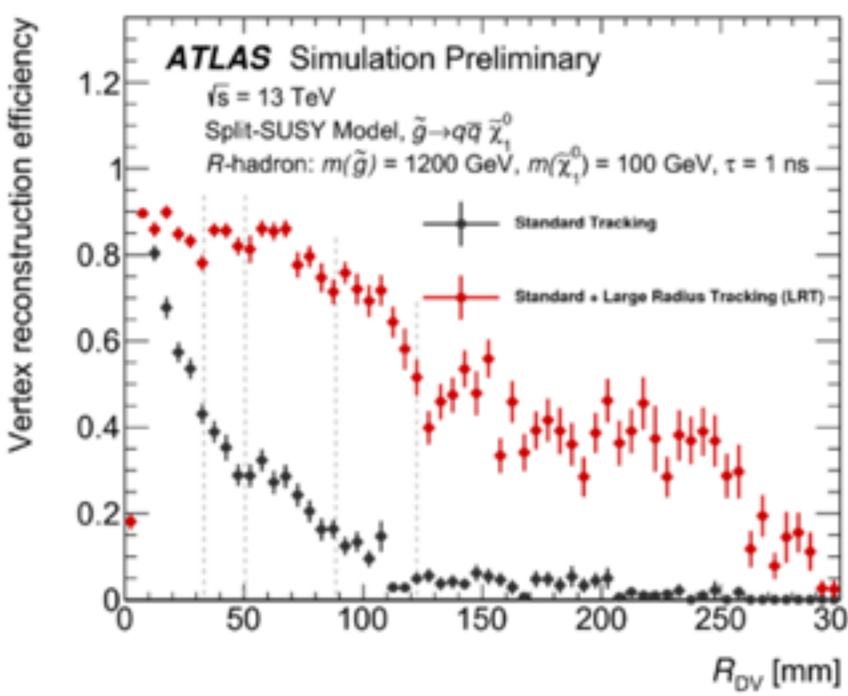
gluinos hard to hide, even with RPV decays

DISPLACED VERTICES (+MET)

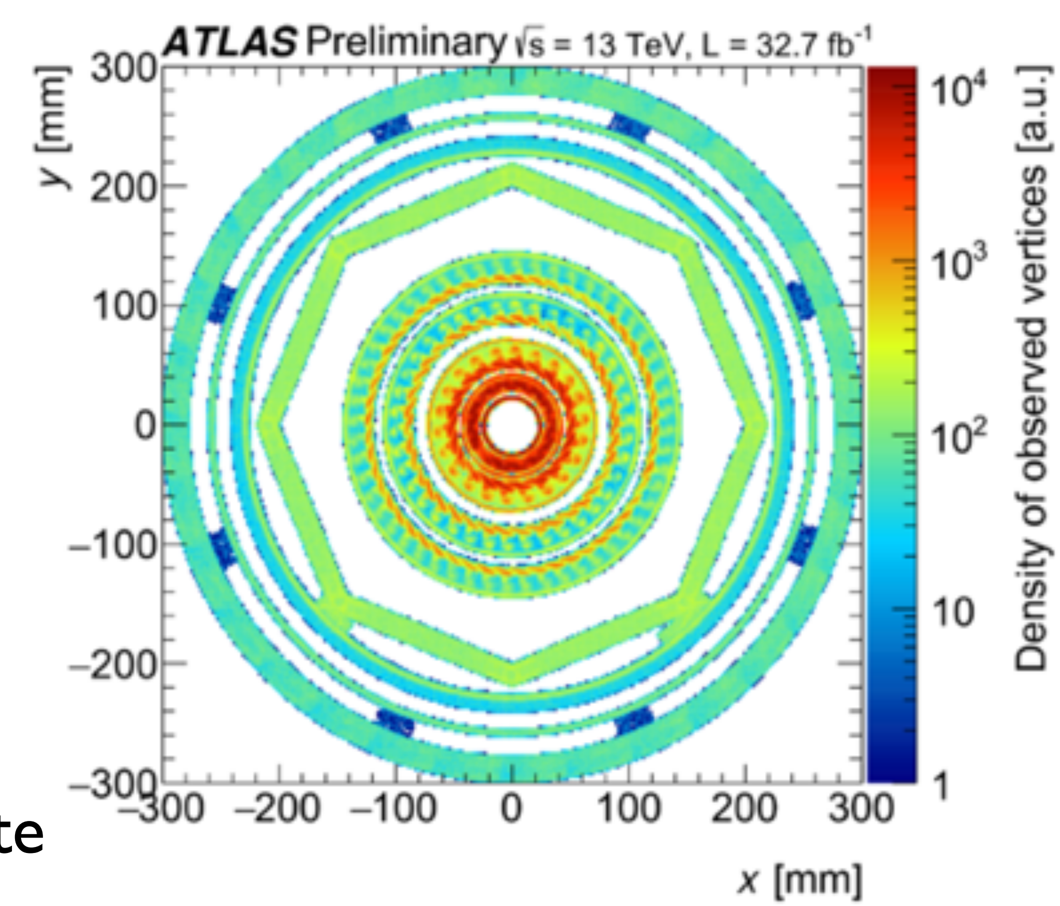
UPDATED



- Search for displaced vertices decaying into the Inner Detector
  - Predicted in models of R-parity violation or split-SUSY
  - Benchmark signal: gluino hadronizing into an R-hadron



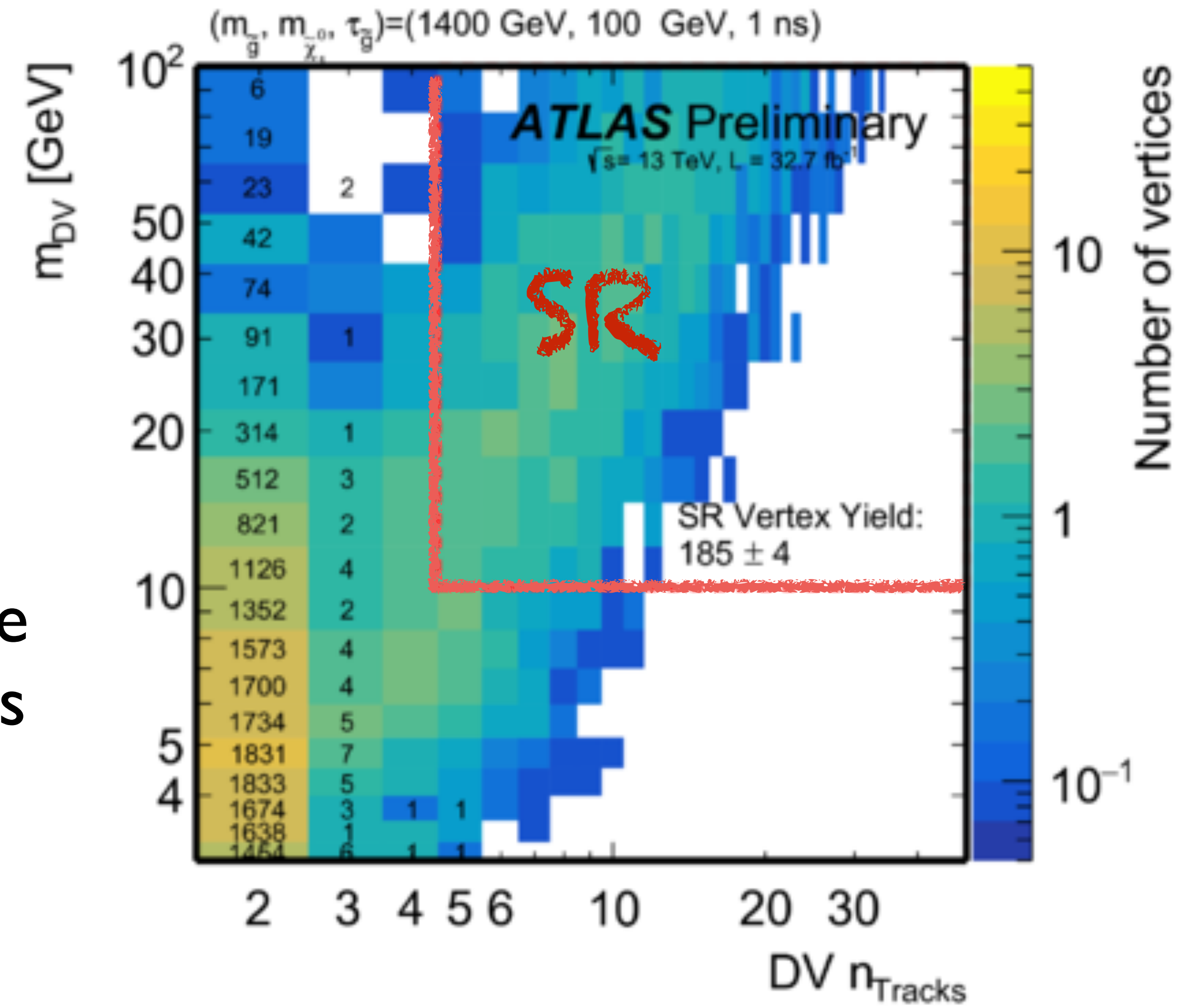
- Rerun the standard track and vertex reconstruction with looser requirements to improve signal efficiency at large radii
- Backgrounds are instrumental and estimated from data

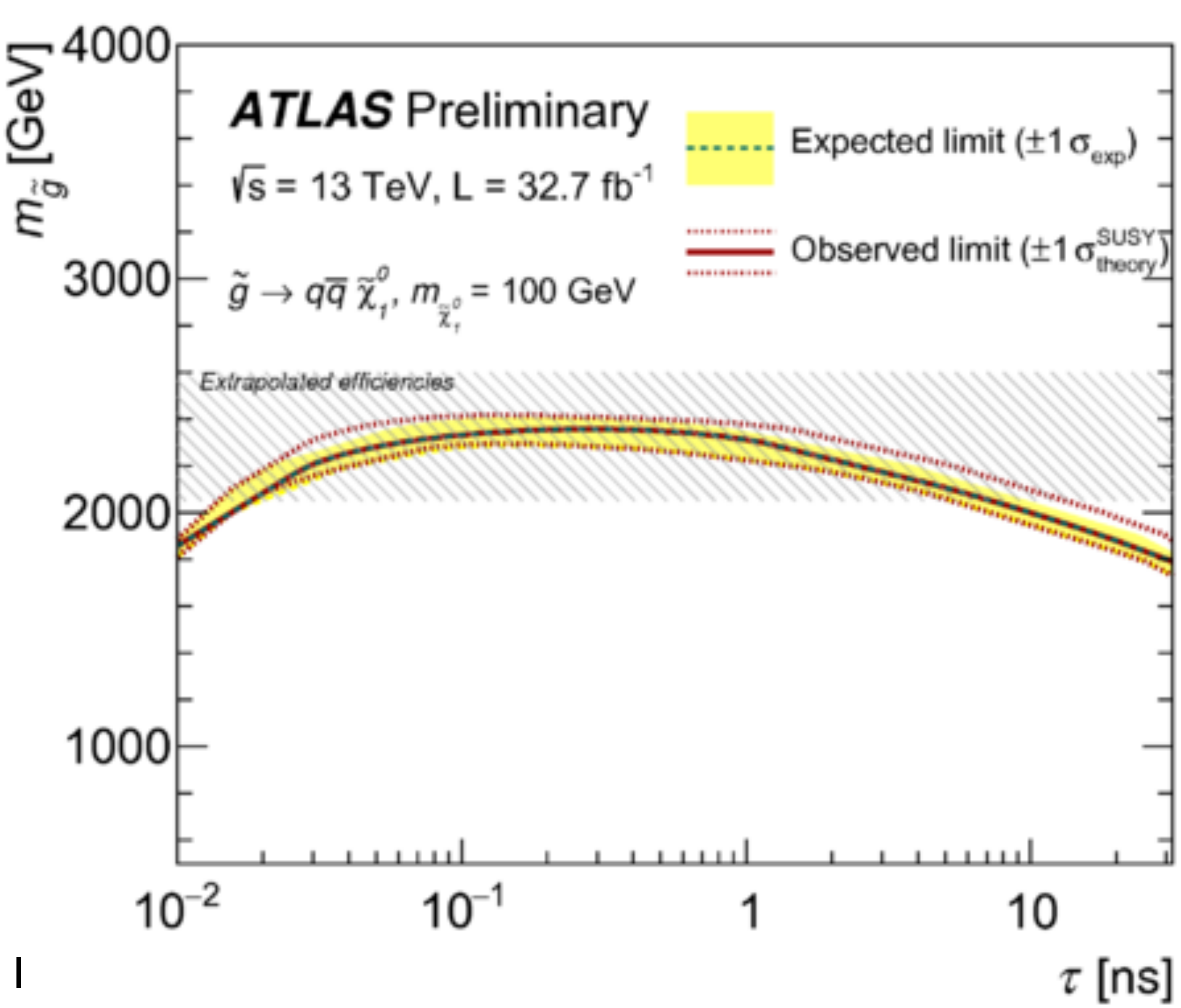


- High track multiplicity hadronic interactions
  - DV in regions with high material density vetoed
  - The remaining contribution extrapolated from low-mass vertexes
- Merged DV extrapolated from low-n_{trk} region
- Random large-angle track crossing are estimated by adding random tracks to an N-1 track template

DISPLACED VERTICES (+MET)

- The signal region requires a displaced vertex with a mass greater than 10 GeV and high track multiplicity (>5 tracks)
- Bkg estimate is validated in a number of signal depleted regions
- No event is observed in the SR, compatible with the bkg. expectation of 0.2±0.2 events

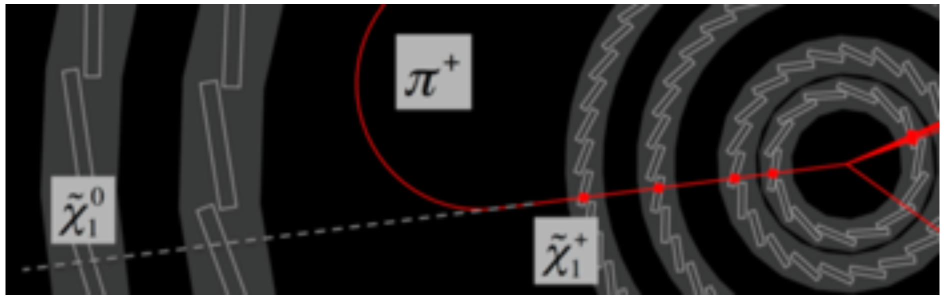




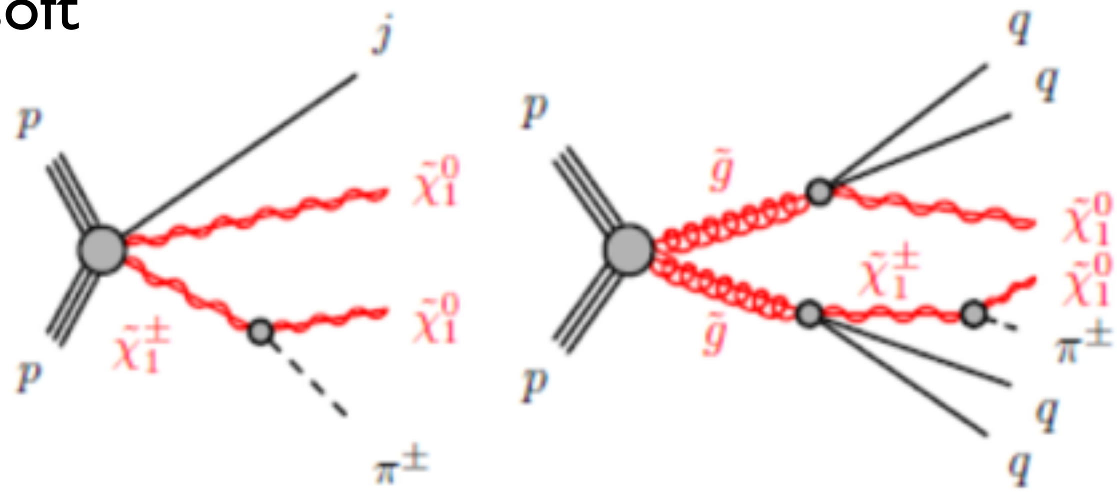
- Limits are set as on gluino R-hadrons as a function of masses and lifetime
- For a lifetime of 1ns gluino masses up to 2.2 TeV are excluded

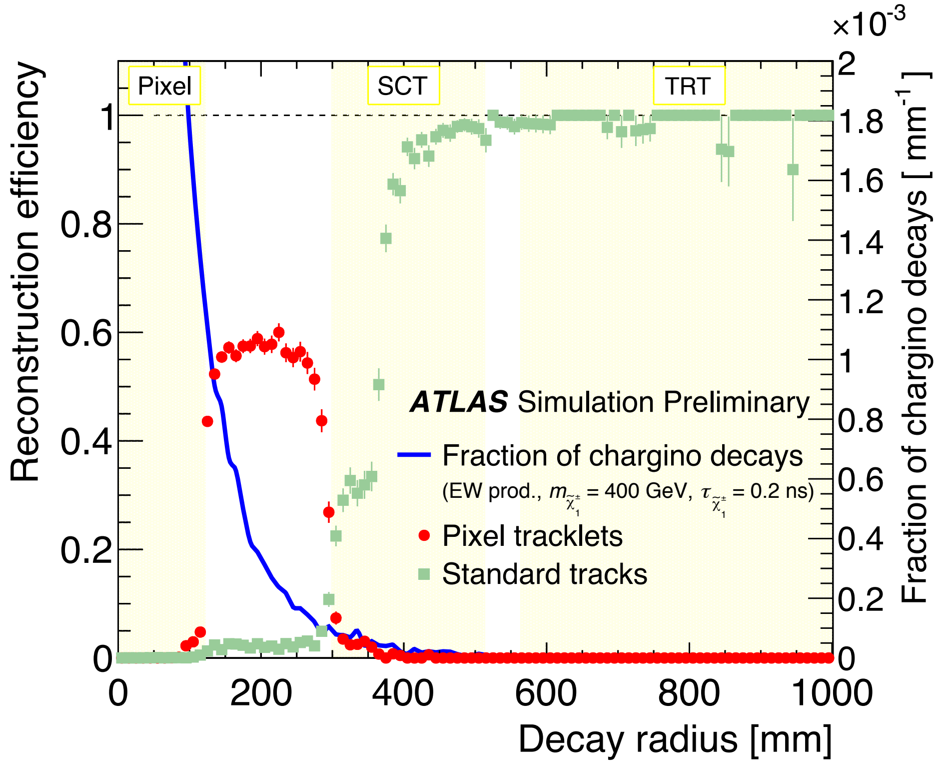
Limits on displaced decays are tighter than for prompt!

DISAPPEARING TRACKS

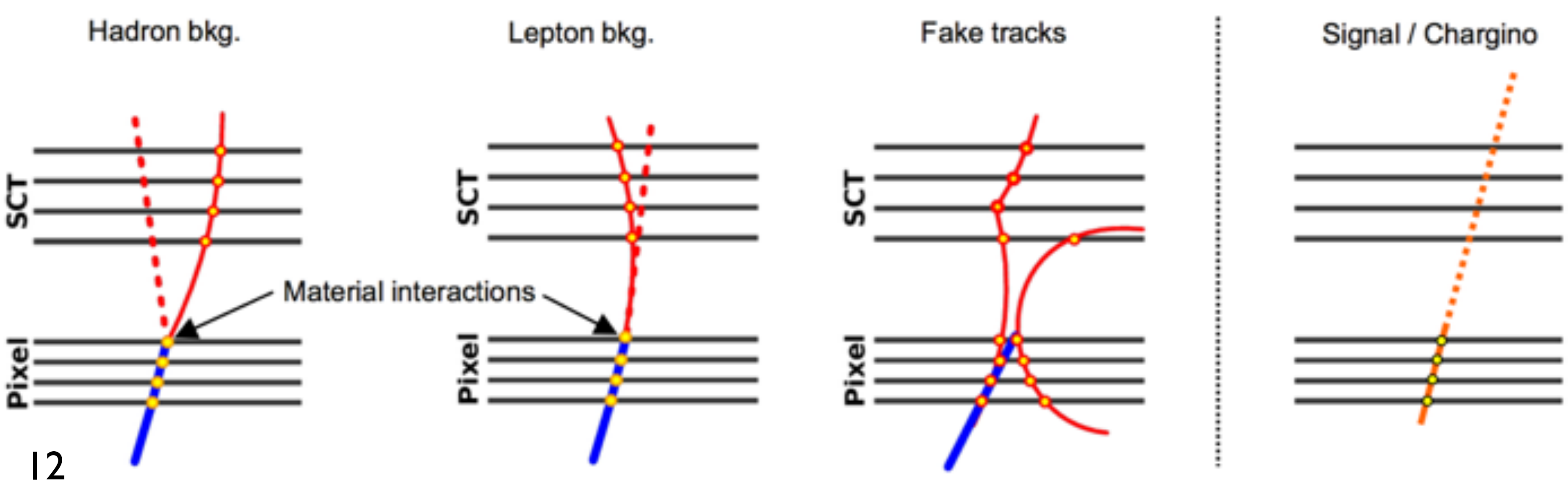


- Search for a disappearing track in the inner detector:
  - Chargino and neutralino nearly degenerate, the soft pions in the decay are not reconstructed
  - For Wino LSP generic prediction of ~160 MeV splittings, or lifetimes of **~0.2ns -> 6cm**



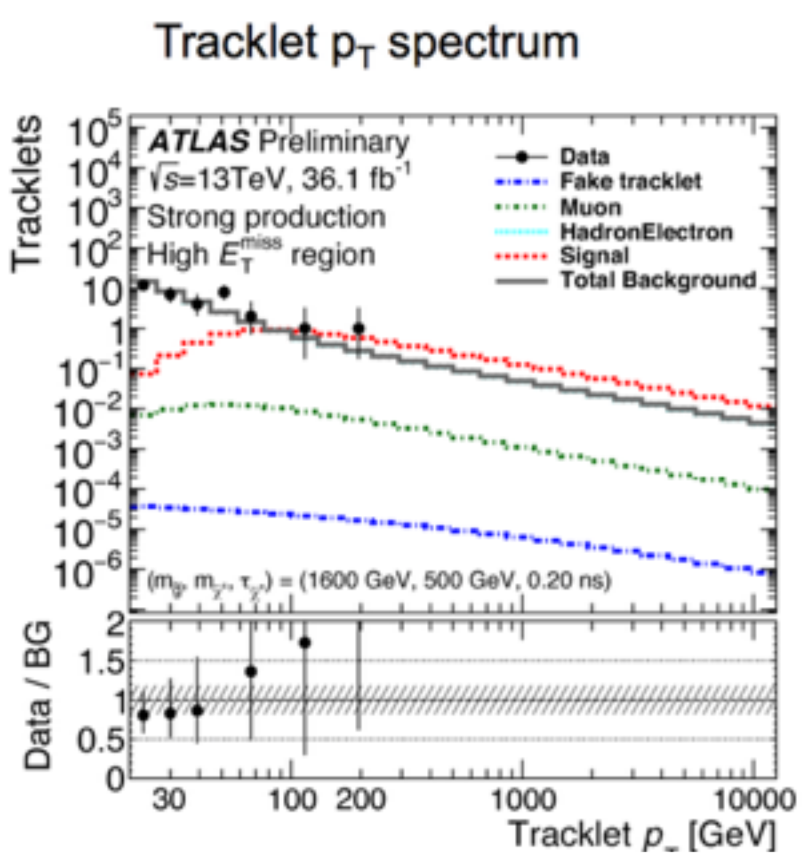


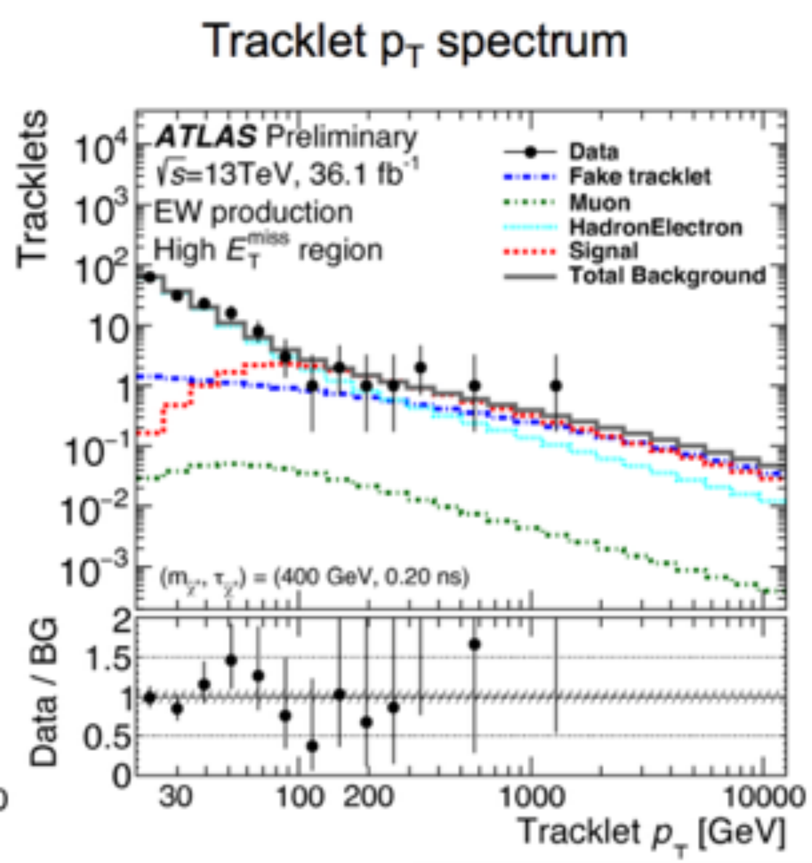
- Two selections are defined for weak (direct) and strong (gluino) production
- Makes use of ***pixel-only tracks***, 10x increase in acceptance over standard tracks for low lifetimes
- Backgrounds estimated by a ***simultaneous fit to the tracklet p_T*** distribution



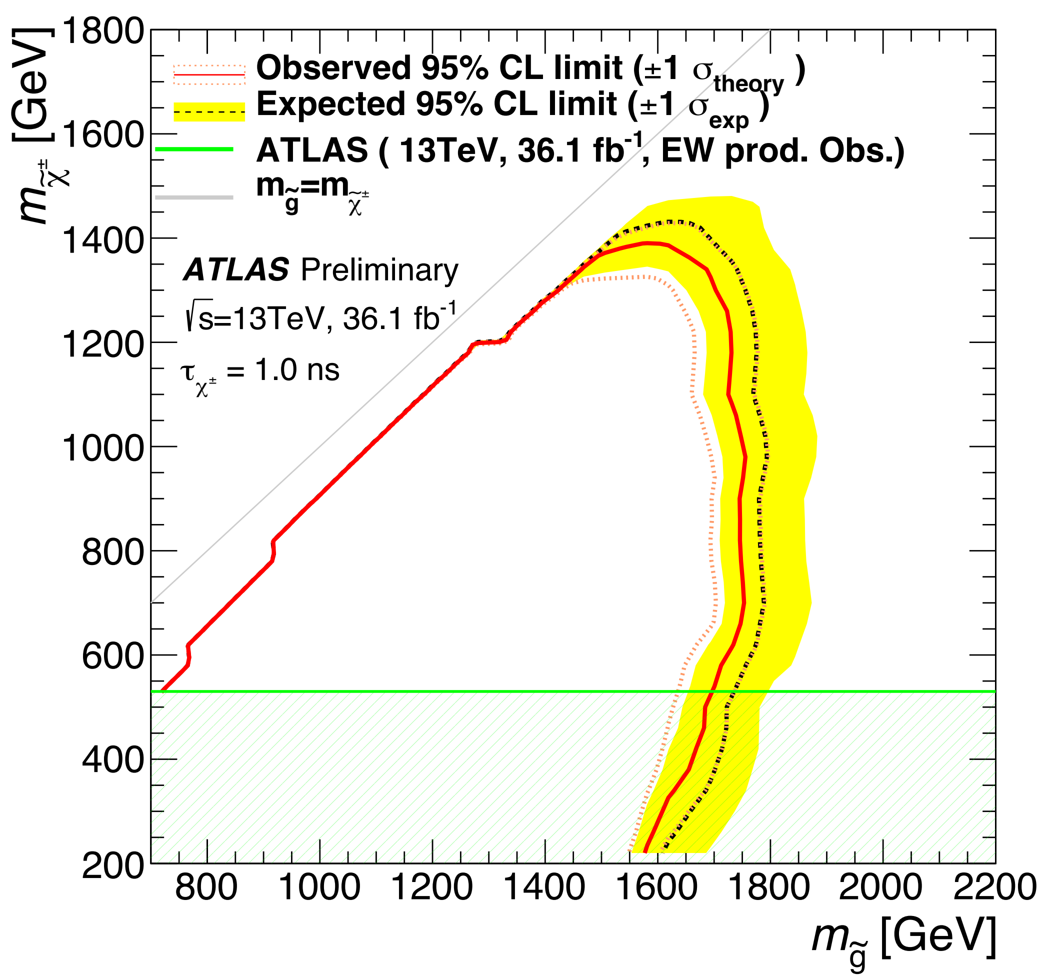
- p_T templates are built for each background category
- typically using CR with standard tracks smeared for a tracklet resolution function

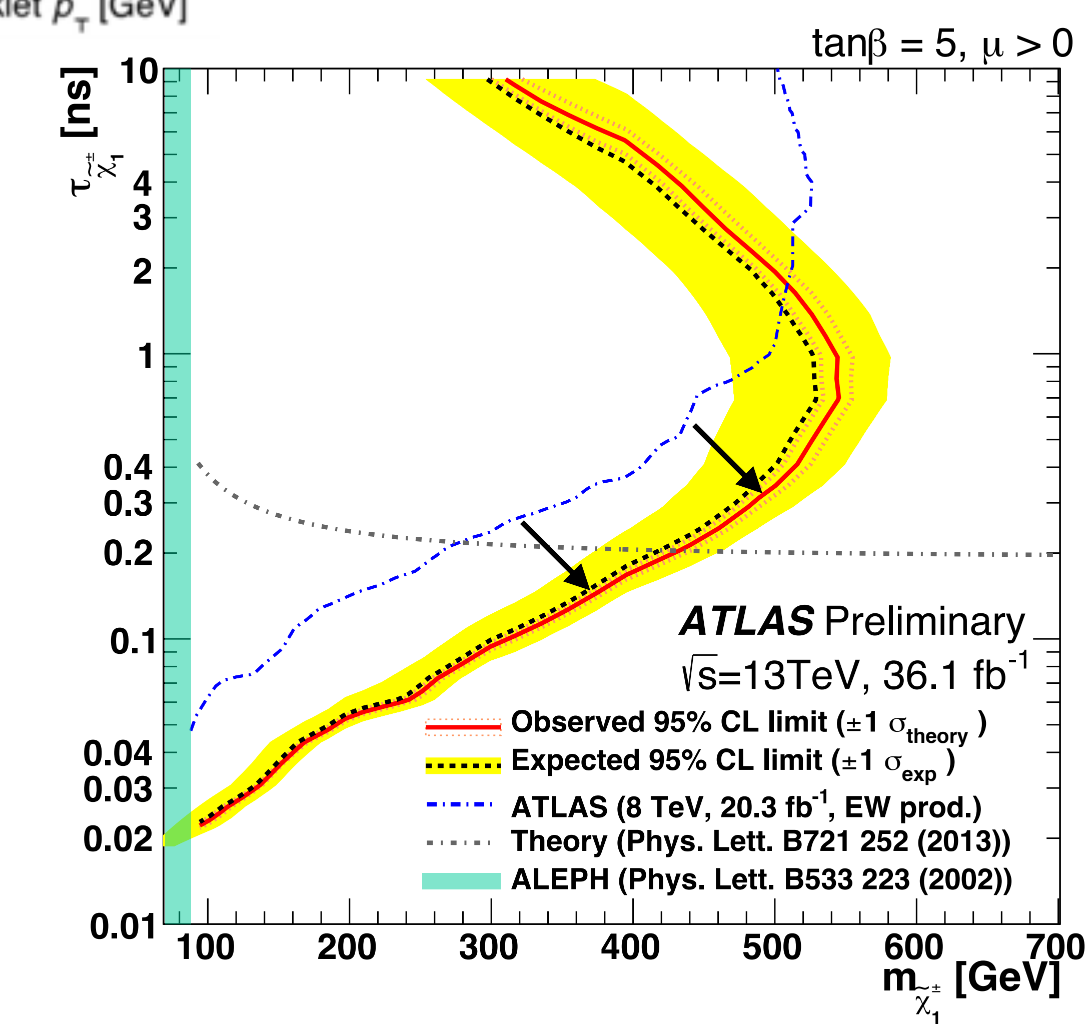
DISAPPEARING TRACKS





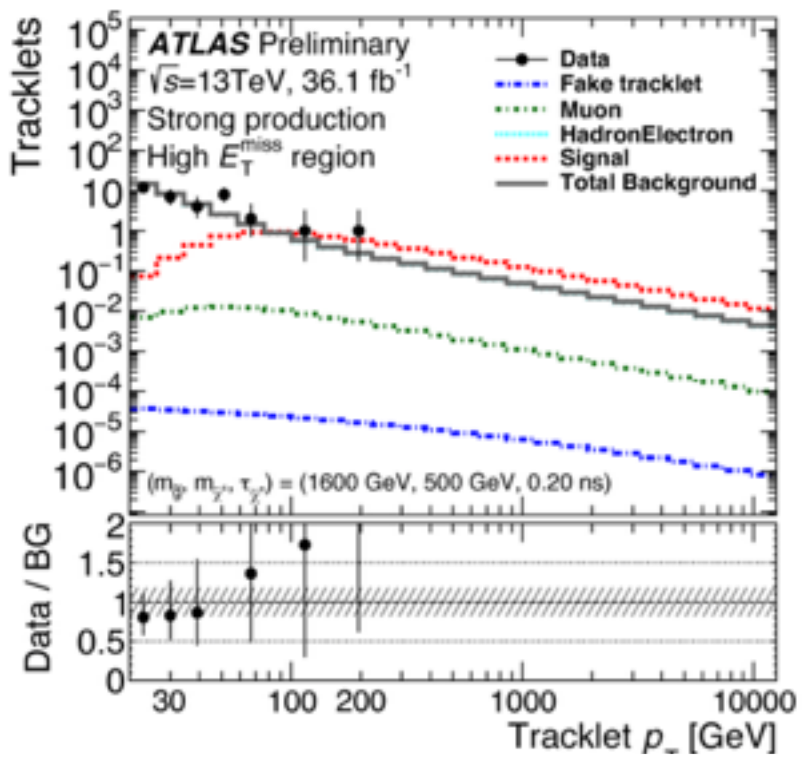
- No significant excess is observed
- For ewk production limits are significantly improved at low lifetimes
- For strong production reaching 1.4 (1.1) TeV in chargino mass for lifetimes of 1.0 (0.2) ns



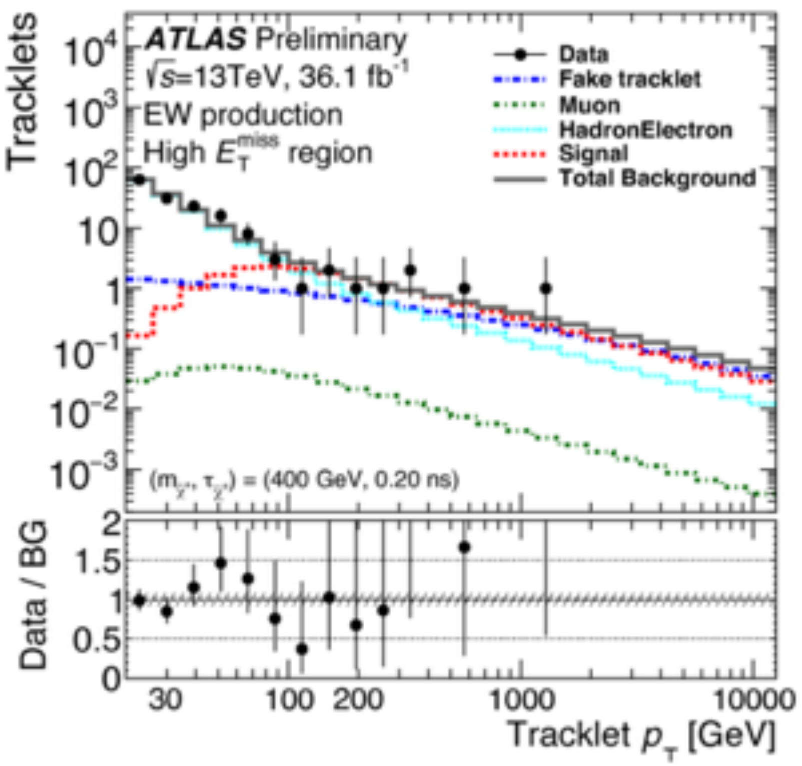


DISAPPEARING TRACKS

Tracklet p_T spectrum



Tracklet p_T spectrum



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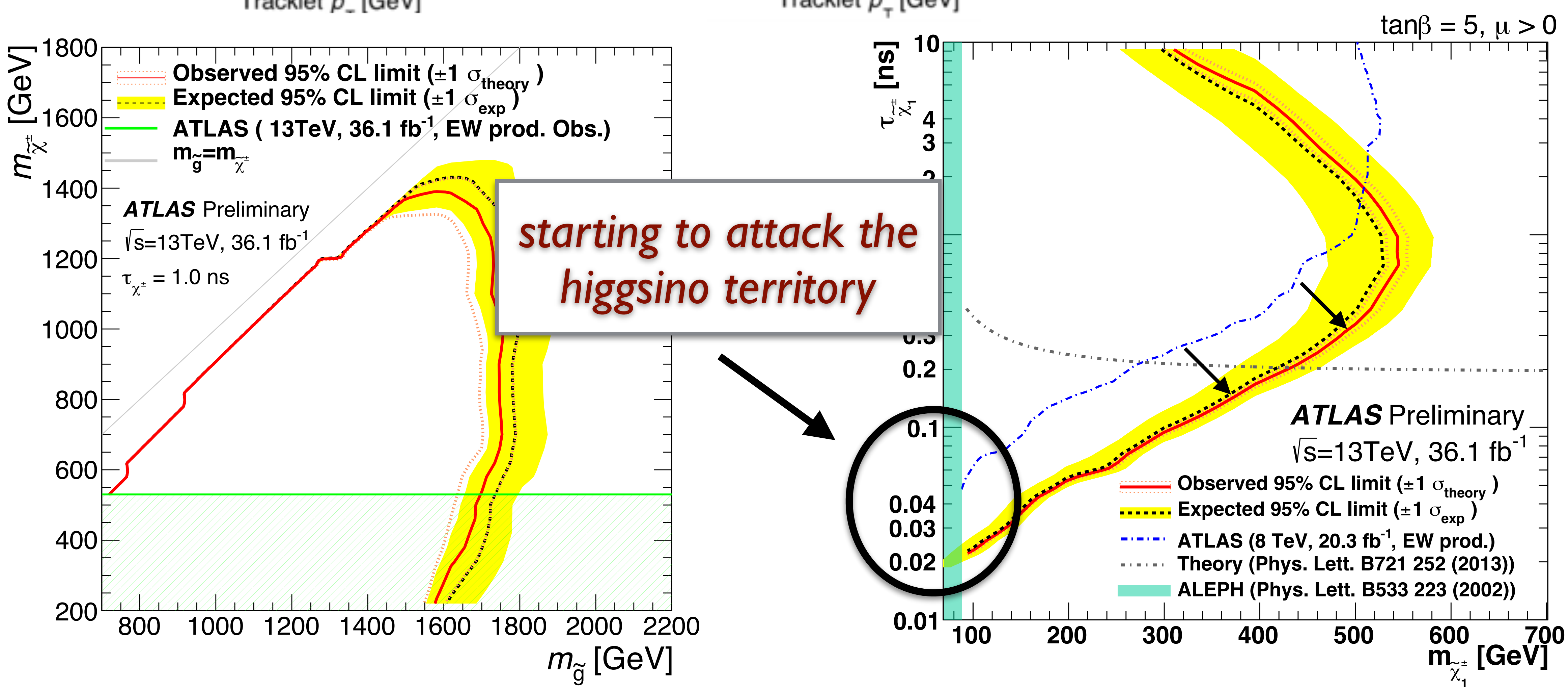
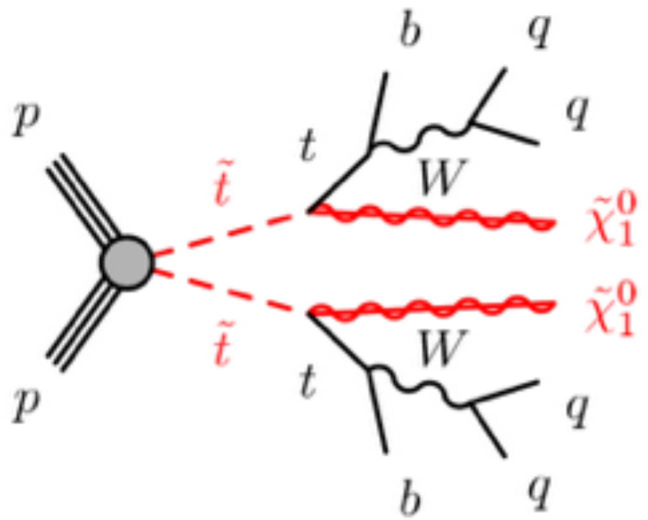
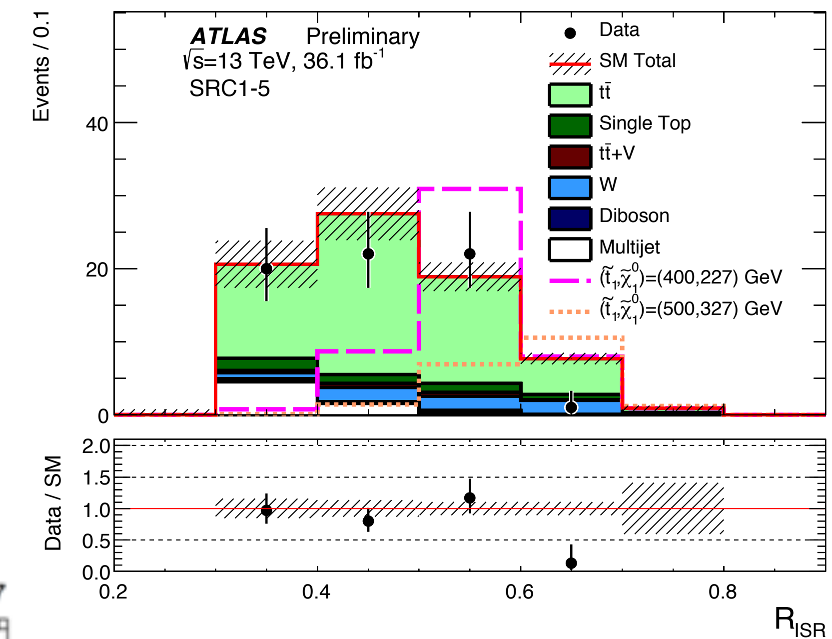


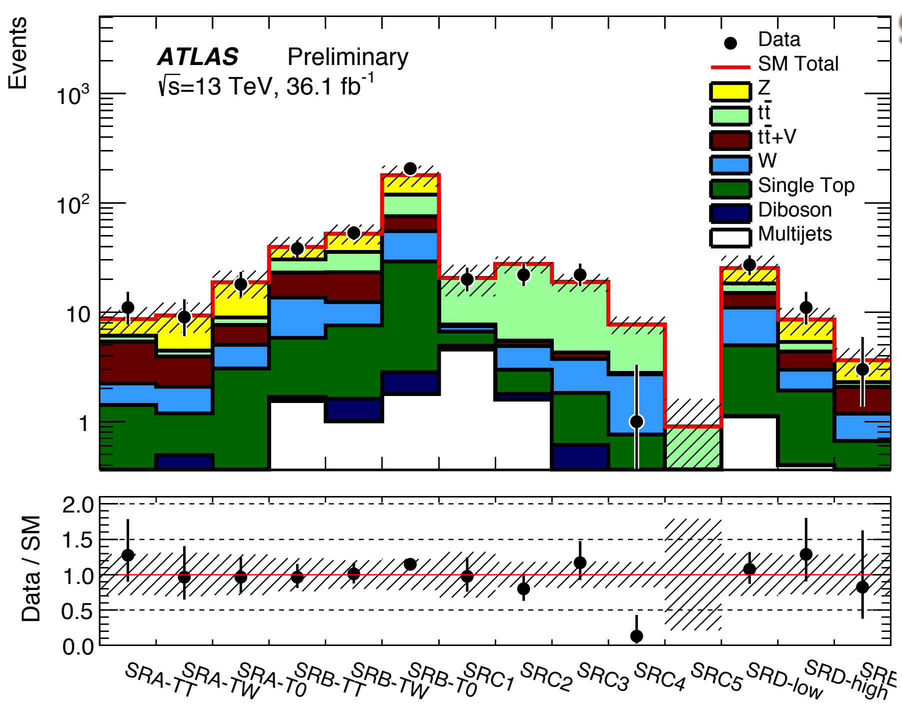
ALL-HADRONIC STOP

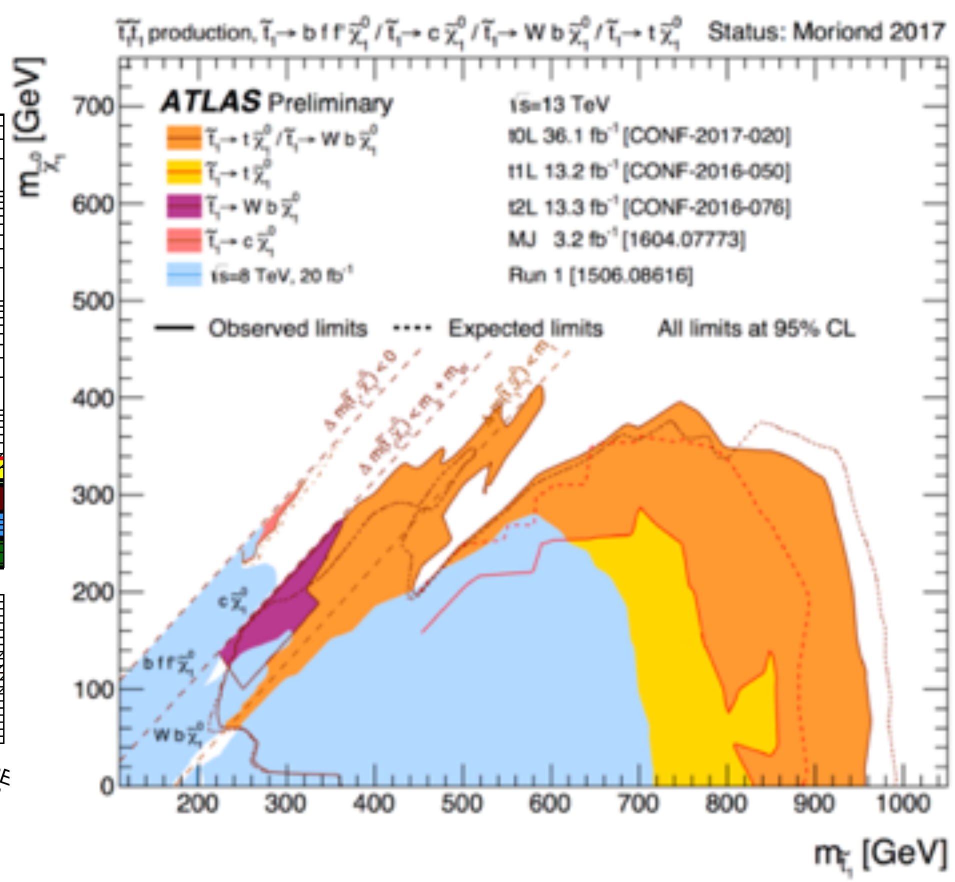


- Two inclusive SRs targeting small/large mass splittings
  - For large mass splittings three categories are defined based on the number of top/W-tagged large-R jets
  - For small mass splittings RJR variables are used in an ISR-like selection



- Main backgrounds from Z+jets, ttbar, tt+V
  - Z+jets extrapolated from a Z->ll control region
  - A 1-lepton CR is used for ttbar
  - The ttZ contribution is extrapolated from tt+gamma CR





- No excess is observed
- Limits are set on the top squark as function of the neutralino mass

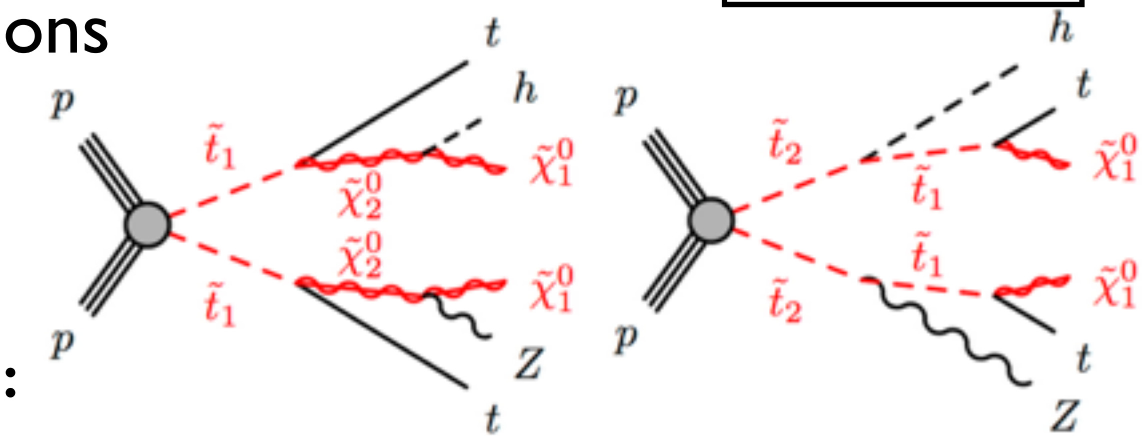
Bounds on the stop mass reaching almost 1 TeV

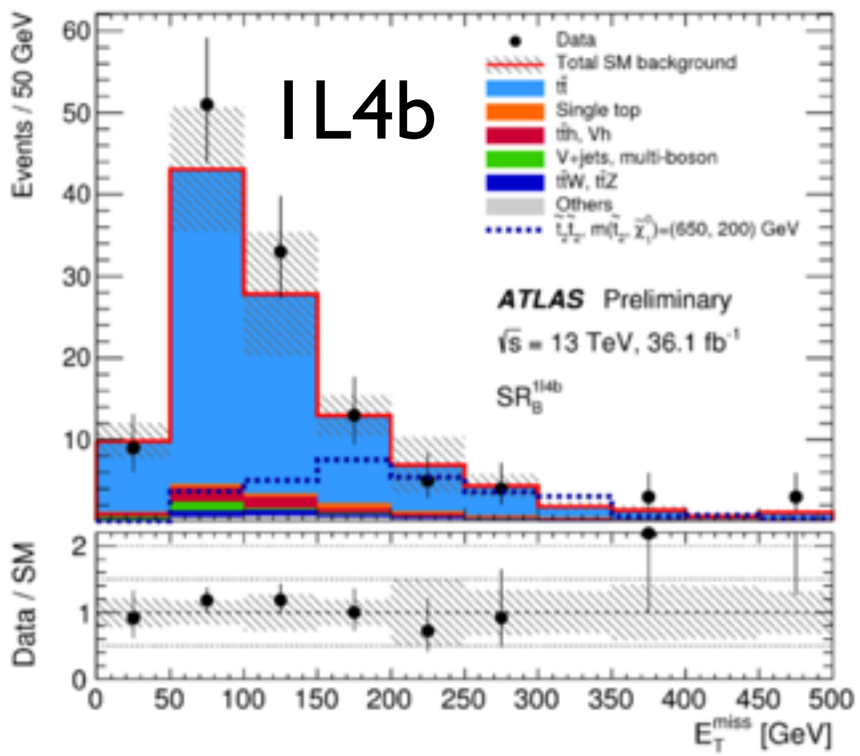
Stop to Z/Higgs

$$\tilde{t}_1 \rightarrow t + \tilde{\chi}_2^0$$
$$\tilde{\chi}_2^0 \rightarrow Z/h + \tilde{\chi}_1^0$$

$$\tilde{t}_2 \rightarrow Z/h + \tilde{t}_1$$
$$\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0$$

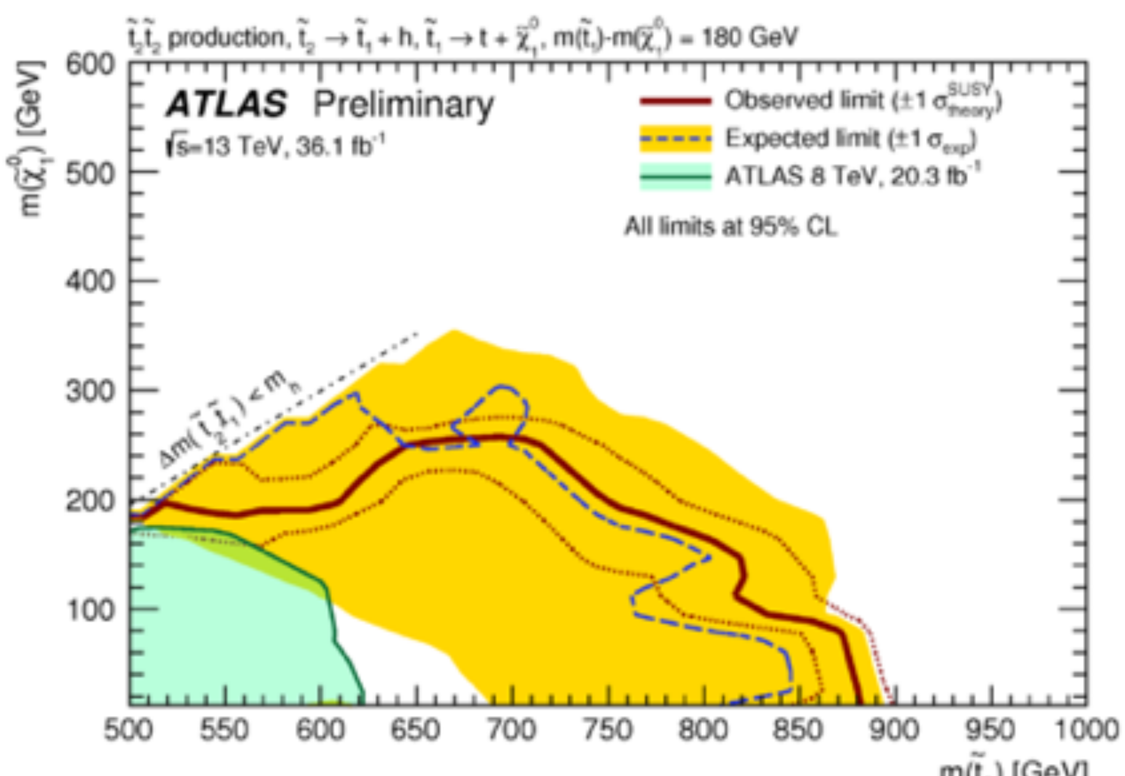
- Search for stop in decays with Z- or Higgs-bosons
  - Bosons produced ether in the decays of the stop1 or of the neutralinos

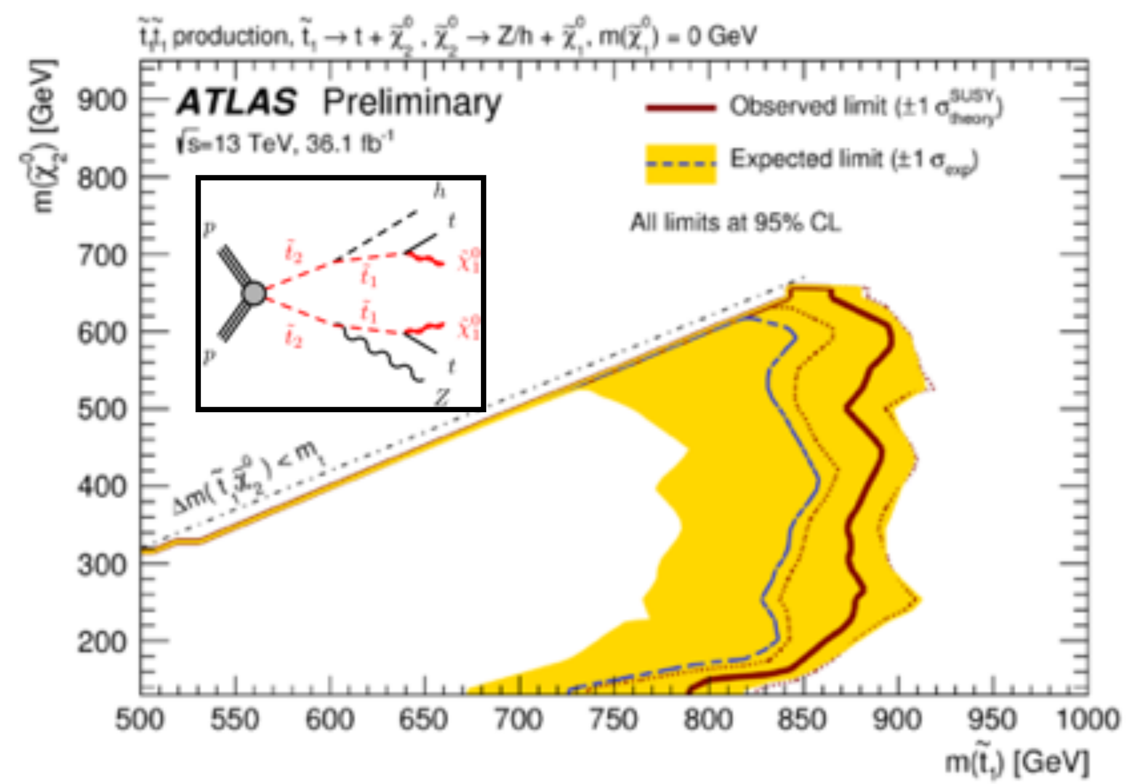




- **Z-bosons channel:**
  - Requires three leptons (one Z candidate) and one *b*-jet
  - Dominated by ttZ and diboson background
- **Higgs-bosons channel:**
  - Requires one/two leptons and four *b*-tags (one H candidate)
  - Dominated by ttbar background

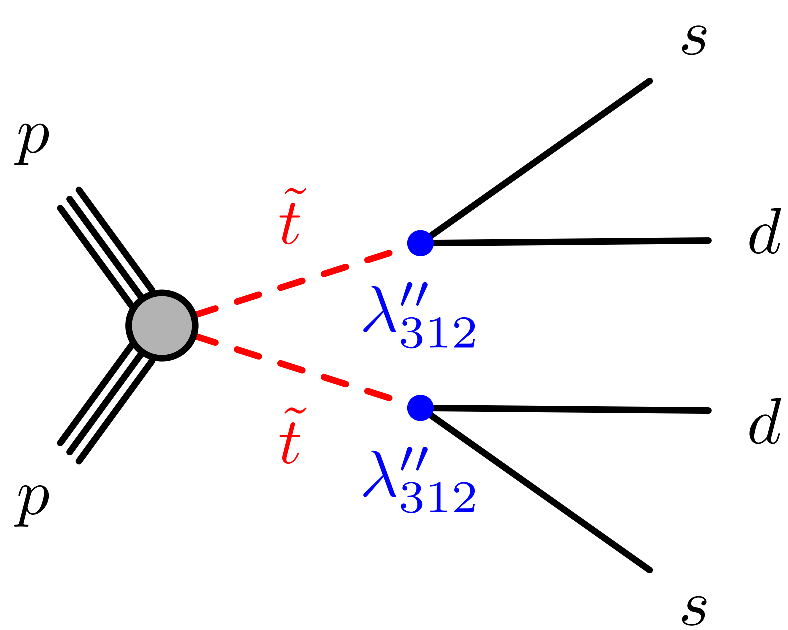
- Stop1/stop2 masses up to 800 GeV are excluded





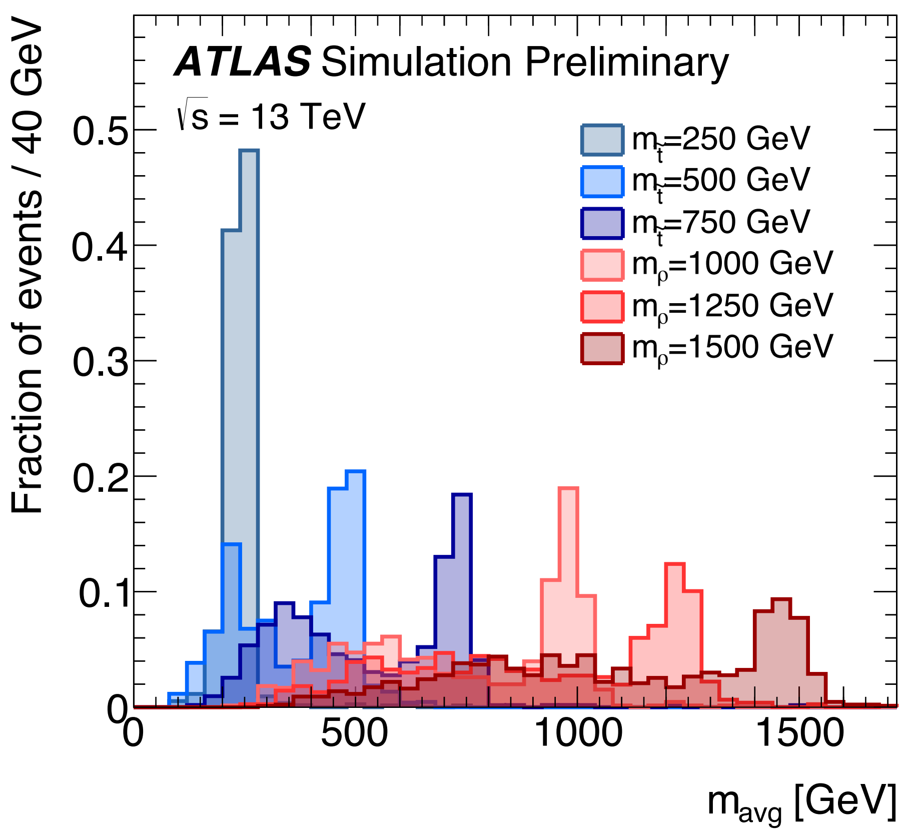
Stop in RPV

UPDATED



- Search targeting the pair production of new resonances, each decaying into two jets
  - SUSY scenarios with ***top squark*** LSP, and decays through R-parity violating couplings into ***d,s*** or ***b,s*** quarks

- Two resonance candidates are built pairing the four leading jets according to their angular separation
  - An ***inclusive selection*** and a ***two-tag selection*** requiring a *b*-tagged jet per candidate resonance are defined:
  - As final discriminant the average mass of the two candidates is used:

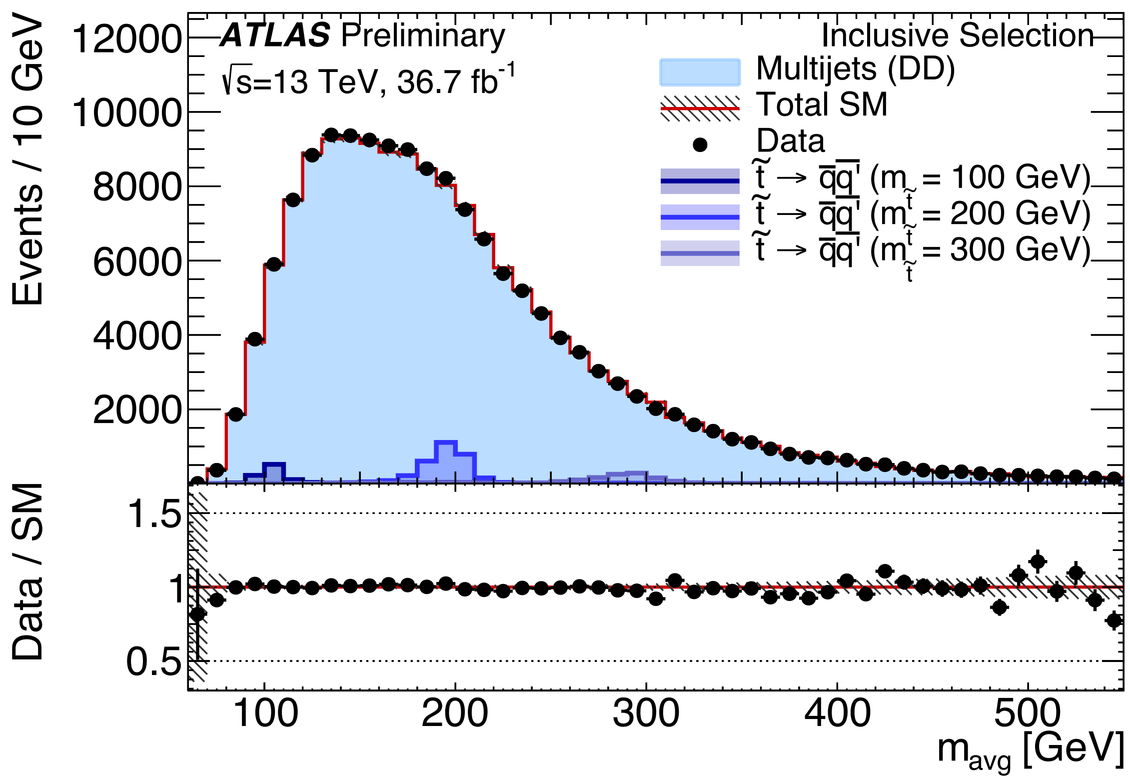


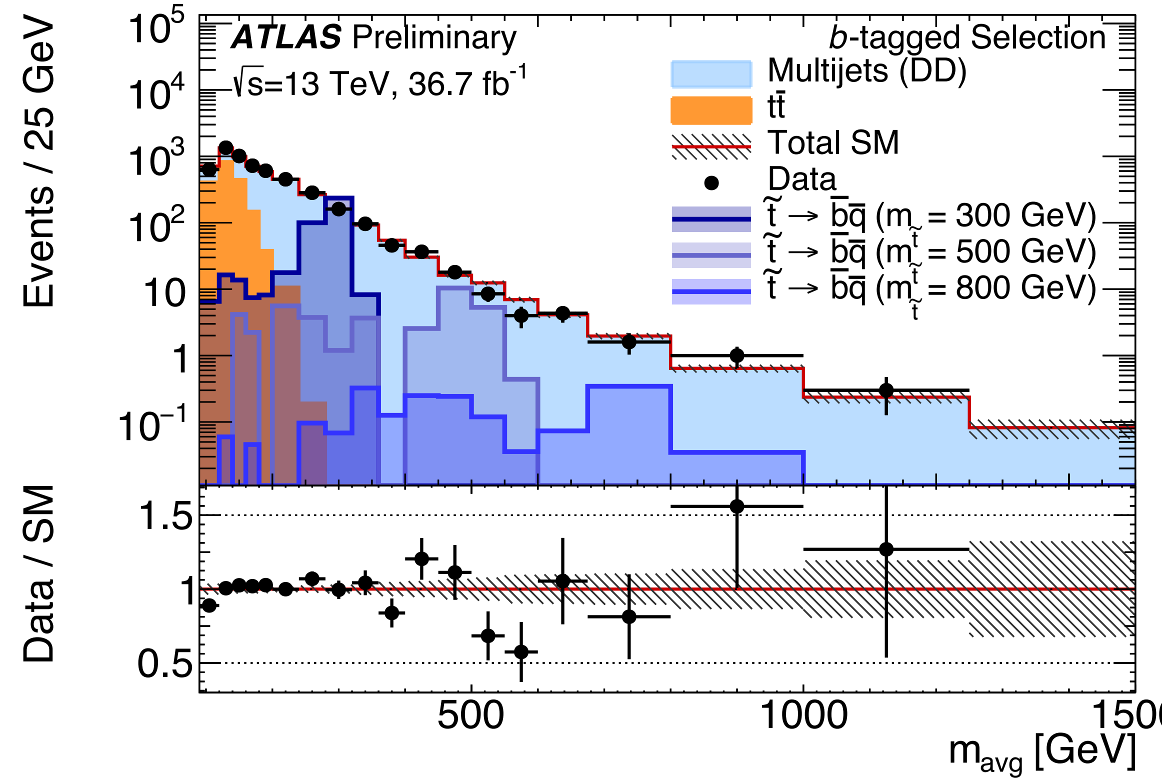
$$m_{\rm avg} = \frac{1}{2}(m_1 + m_2)$$

- The background from multijet production is estimated from data with an ***ABCD*** method
  - ABCD in the two-tag selection performed in a *b*-tag veto region and ***extrapolated*** to the two-tag plane
  - Background from top production taken from MC

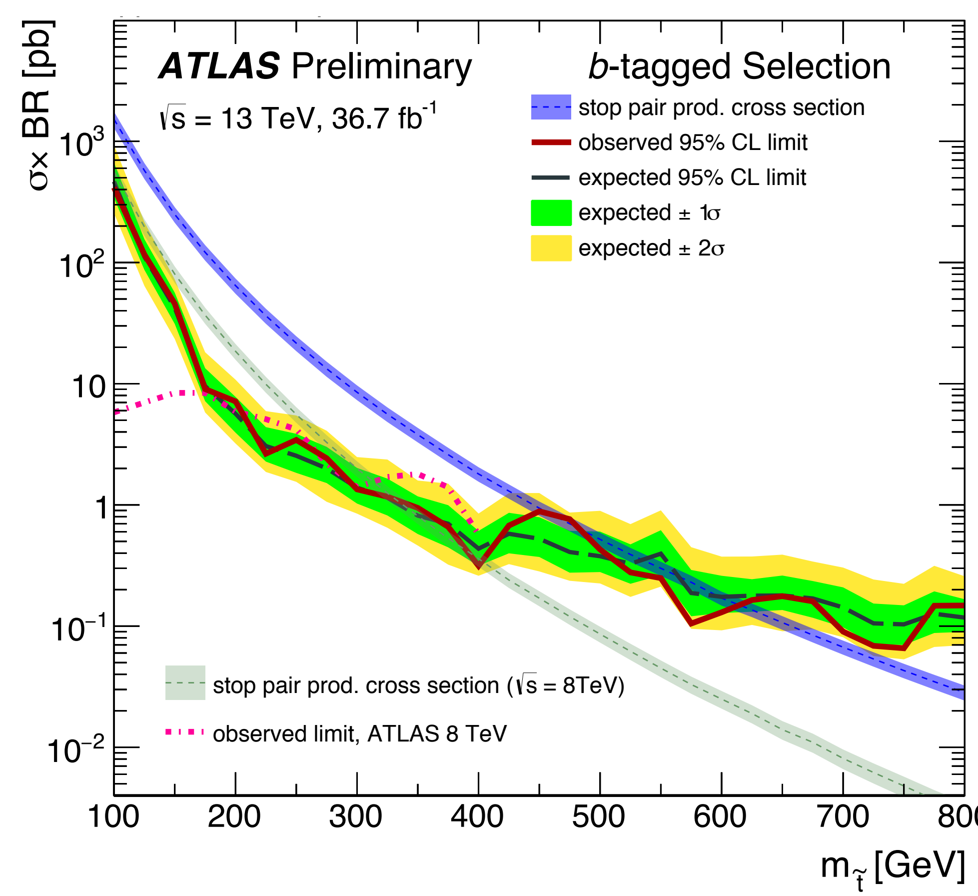
Stop in RPV

- No excess is observed in data over the predicted background

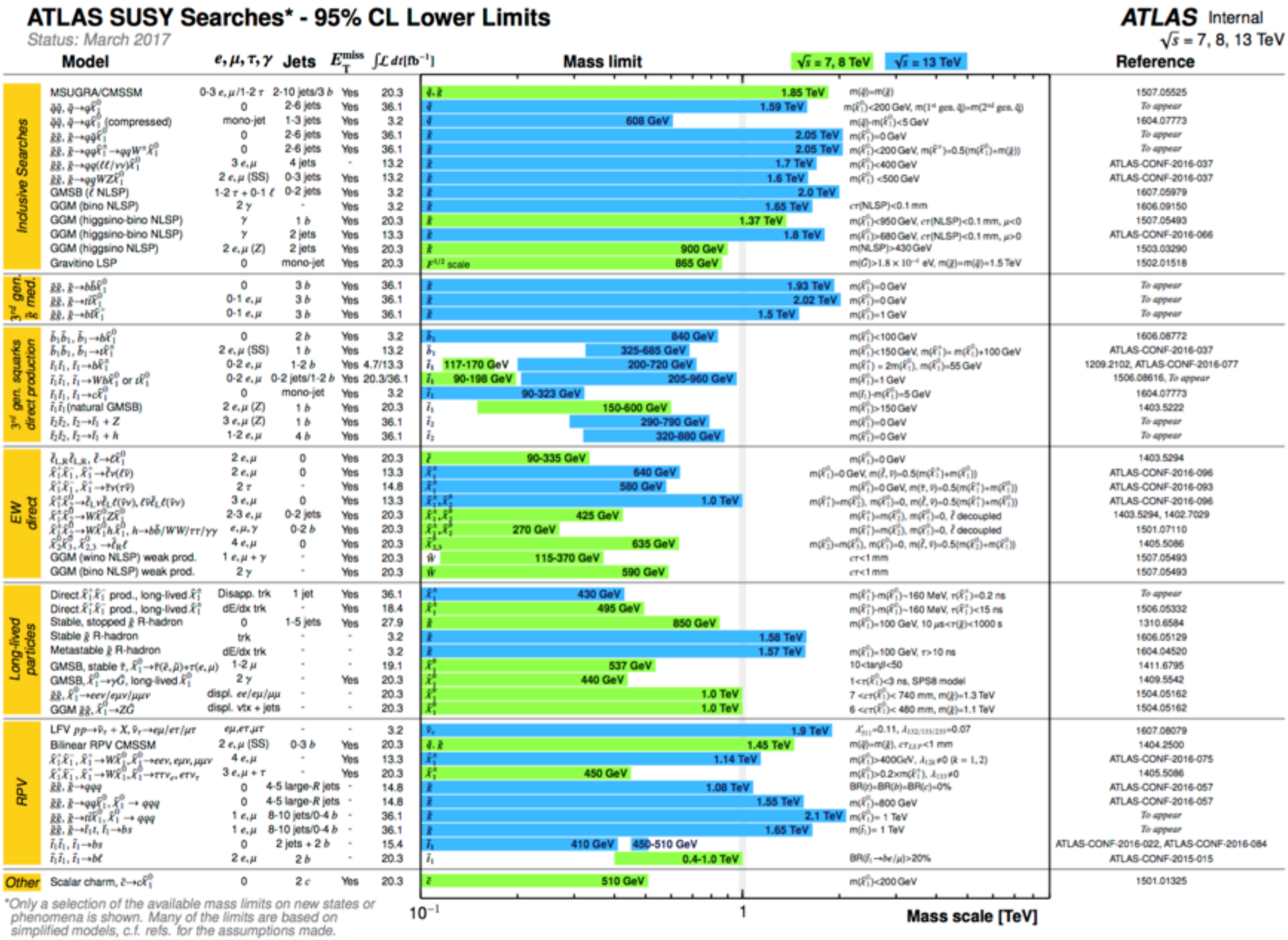


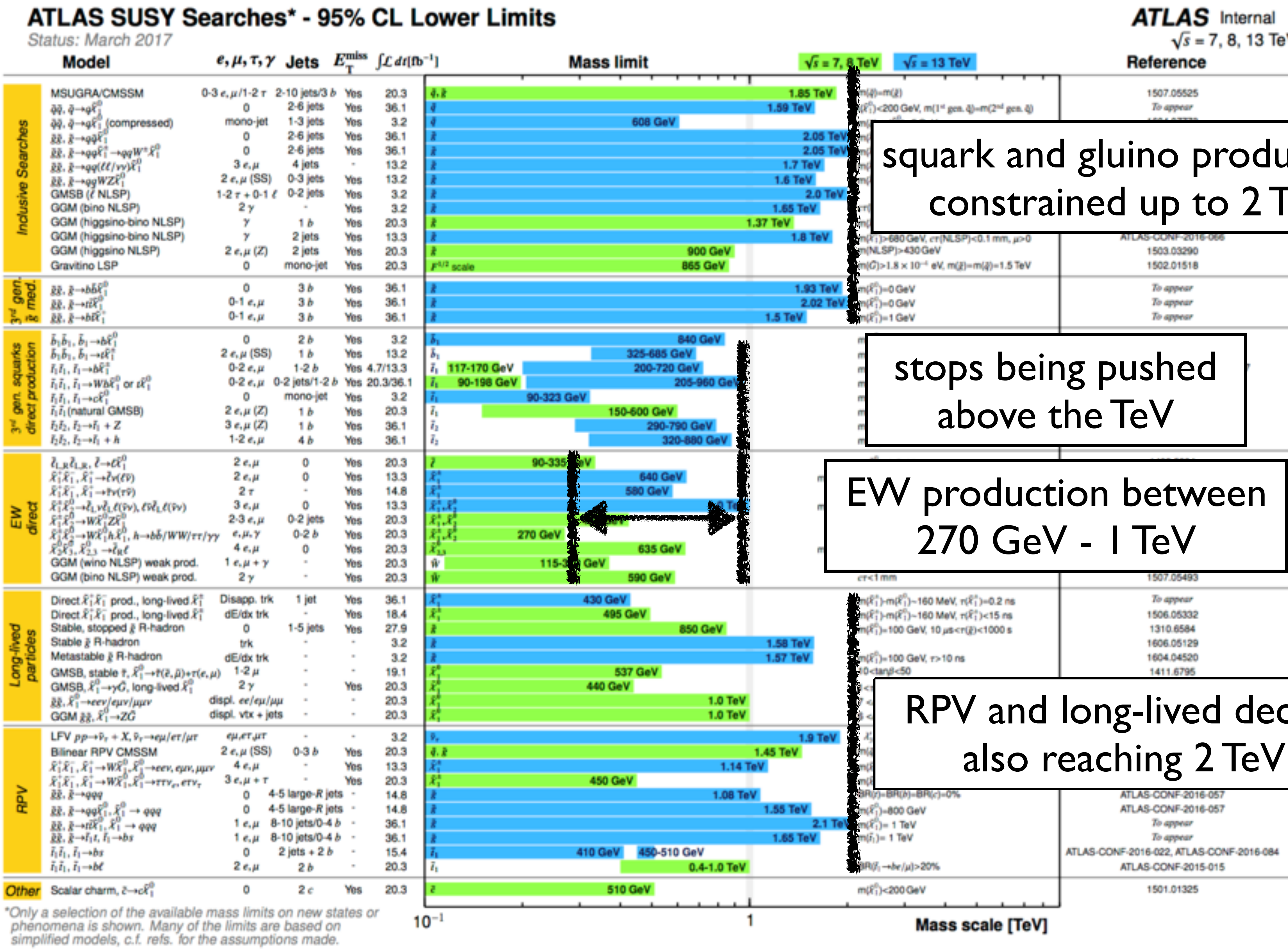


- Top squarks are excluded for masses between 100 and 410 GeV if they decay into two quarks
- For decays into *bs* the exclusion goes between 100 and 610 GeV



Natural SUSY under stress also with baryonic RPV


ATLAS SUSY Searches* - 95% CL Lower Limits
Status: March 2017
ATLAS Internal
$\sqrt{s}$ = 7, 8, 13 TeV
Model
e, μ, τ, γ
Jets
E_T^{miss}
$\int \mathcal{L} dt [fb^{-1}]$
Mass limit
$\sqrt{s}$ = 7, 8 TeV
$\sqrt{s}$ = 13 TeV
Reference
Inclusive Searches
MSUGRA/CMSSM | 1.85 TeV | 1507.05525
1.59 TeV | To appear
608 GeV | 1604.07773
2.05 TeV | To appear
2.05 TeV | To appear
1.7 TeV | ATLAS-CONF-2016-037
1.6 TeV | ATLAS-CONF-2016-037
GMSB ($\tilde{\ell}$ NLSP) | 2.0 TeV | 1607.05979
GGM (bino NLSP) | 1.65 TeV | 1606.09150
GGM (higgsino-bino NLSP) | 1.37 TeV | 1507.05493
GGM (higgsino-bino NLSP) | 1.8 TeV | ATLAS-CONF-2016-066
GGM (higgsino NLSP) | 900 GeV | 1503.03290
Gravitino LSP | 865 GeV | 1502.01518
3rd gen. $\tilde{g}$ med.
1.93 TeV | To appear
2.02 TeV | To appear
1.5 TeV | To appear
3rd gen. squarks direct production
840 GeV | 1606.08772
325-685 GeV | ATLAS-CONF-2016-037
117-170 GeV | 200-720 GeV | 1209.2102, ATLAS-CONF-2016-077
90-198 GeV | 205-950 GeV | 1506.08616, To appear
90-323 GeV | 1604.07773
$\tilde{t}_1\tilde{t}_1$ (natural GMSB) | 150-600 GeV | 1403.5222
290-790 GeV | To appear
320-880 GeV | To appear
EW direct
90-335 GeV | 1403.5294
640 GeV | ATLAS-CONF-2016-096
580 GeV | ATLAS-CONF-2016-093
1.0 TeV | ATLAS-CONF-2016-096
425 GeV | 1403.5294, 1402.7029
270 GeV | 1501.07110
635 GeV | 1405.5086
GGM (wino NLSP) weak prod. | 115-370 GeV | 1507.05493
GGM (bino NLSP) weak prod. | 590 GeV | 1507.05493
Long-lived particles
Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$ | 430 GeV | To appear
Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$ | 495 GeV | 1506.05332
Stable, stopped $\tilde{g}$ R-hadron | 850 GeV | 1310.6584
Stable $\tilde{g}$ R-hadron | 1.58 TeV | 1606.05129
Metastable $\tilde{g}$ R-hadron | 1.57 TeV | 1604.04520
GMSB, stable $\tilde{\tau}$ | 537 GeV | 1411.6795
GMSB, long-lived $\tilde{\chi}_1^0$ | 440 GeV | 1409.5542
1.0 TeV | 1504.05162
GGM | 1.0 TeV | 1504.05162
RPV
LFV | 1.9 TeV | 1607.08079
Bilinear RPV CMSSM | 1.45 TeV | 1404.2500
1.14 TeV | ATLAS-CONF-2016-075
450 GeV | 1405.5086
1.08 TeV | ATLAS-CONF-2016-057
1.55 TeV | ATLAS-CONF-2016-057
2.1 TeV | To appear
1.65 TeV | To appear
410 GeV | 450-510 GeV | ATLAS-CONF-2016-022, ATLAS-CONF-2016-084
0.4-1.0 TeV | ATLAS-CONF-2015-015
Other
Scalar charm, $\tilde{c} \to c\tilde{\chi}_1^0$ | 510 GeV | 1501.01325
10^{-1}
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.



squark and gluino production constrained up to 2 TeV

stops being pushed above the TeV

EW production between 270 GeV - 1 TeV

RPV and long-lived decays also reaching 2 TeV

Summary

- Presented eight ***new results*** using the full 13 TeV dataset collected so far
  - Large increase in sensitivity from the Run 1 results
  - But no significant deviation observed yet
- Natural SUSY paradigm more and more under stress
- Exploitation of the 13 TeV dataset has just started, can still hope for surprises

ATLAS-CONF-2017-017	Search for long-lived charginos based on a disappearing-track signature in pp collisions at sqrt(s)=13TeV with the ATLAS detector
ATLAS-CONF-2017-022	Search for squarks and gluinos in final states with jets and missing transverse momentum using 36 fb−1 of sqrt(s)=13 TeV pp collision data with the ATLAS detector
ATLAS-CONF-2017-021	Search for production of supersymmetric particles in final states with missing transverse momentum and multiple b-jets at sqrt(s)=13 TeV proton-proton collisions with the ATLAS detector
ATLAS-CONF-2017-020	Search for a Scalar Partner of the Top Quark in the Jets+ETmiss Final State at sqrt(s)=13 TeV with the ATLAS detector
ATLAS-CONF-2017-019	Search for direct top squark pair production in events with a Higgs or Z boson, and missing transverse momentum in sqrt(s)=13 TeV pp collisions with the ATLAS detector
ATLAS-CONF-2017-013	Search for new phenomena in a lepton plus high jet multiplicity final state with the ATLAS experiment using sqrt(s)=13 TeV proton-proton collision data
ATLAS-CONF-2017-025	A search for pair-produced resonances in four-jet final states at sqrt(s)=13 TeV with the ATLAS detector
ATLAS-CONF-2017-026	Search for long-lived, massive particles in events with displaced vertices and missing transverse momentum in 13 TeV pp collisions with the ATLAS detector

BACKUP

Discriminating variables

- Plethora of observables used by SUSY searches to maximally exploit event information:

complexity

Reconstructed object multiplicities, momenta, energies, e.g. $\mathbf{N_{jet/b\text{-}tag/\ell/\gamma}}$, $\mathbf{p_T}$, $\mathbf{E_{T,miss}}$, …

Scale variables, e.g. $\mathbf{m_{eff}} = \Sigma p_T + E_{T,miss}$,

Angular variables, e.g. **min** $\mathbf{\Delta\Phi}$(jet, $E_{T,miss}$), …

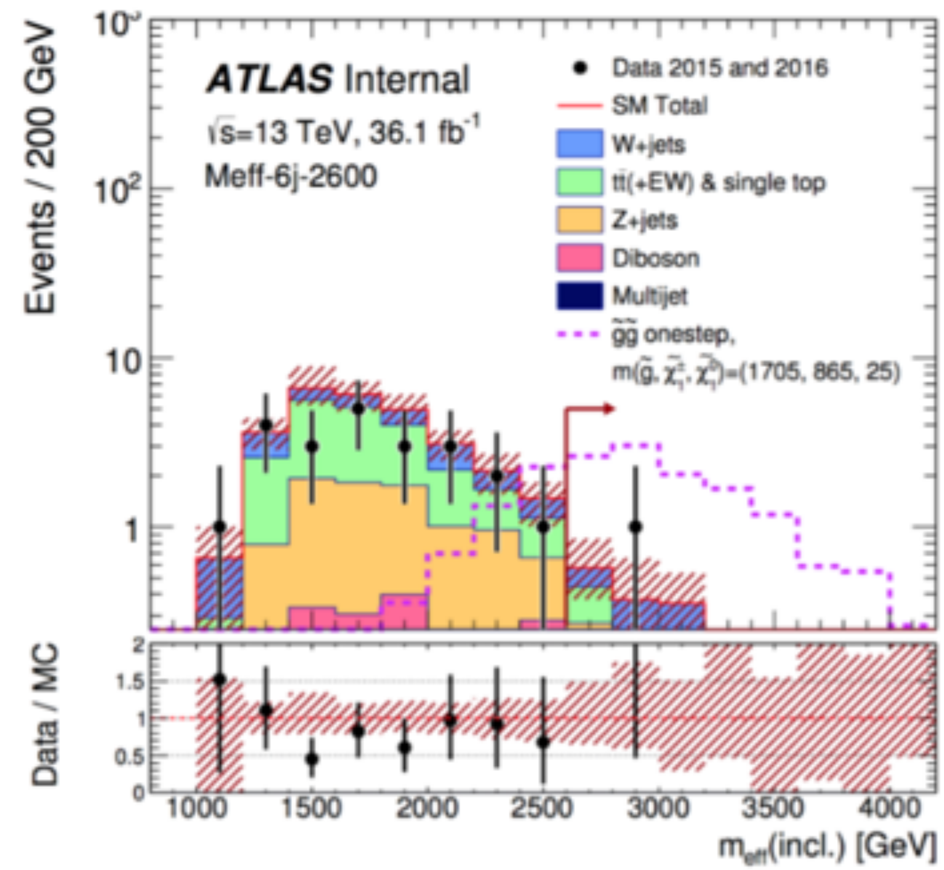
Mass variables, e.g. $\mathbf{m_{\ell\ell}}$, $\mathbf{m_T}^{\mathbf{b/\ell/j}}$, $\mathbf{\Sigma m_{fat\text{-}jet}}$, …

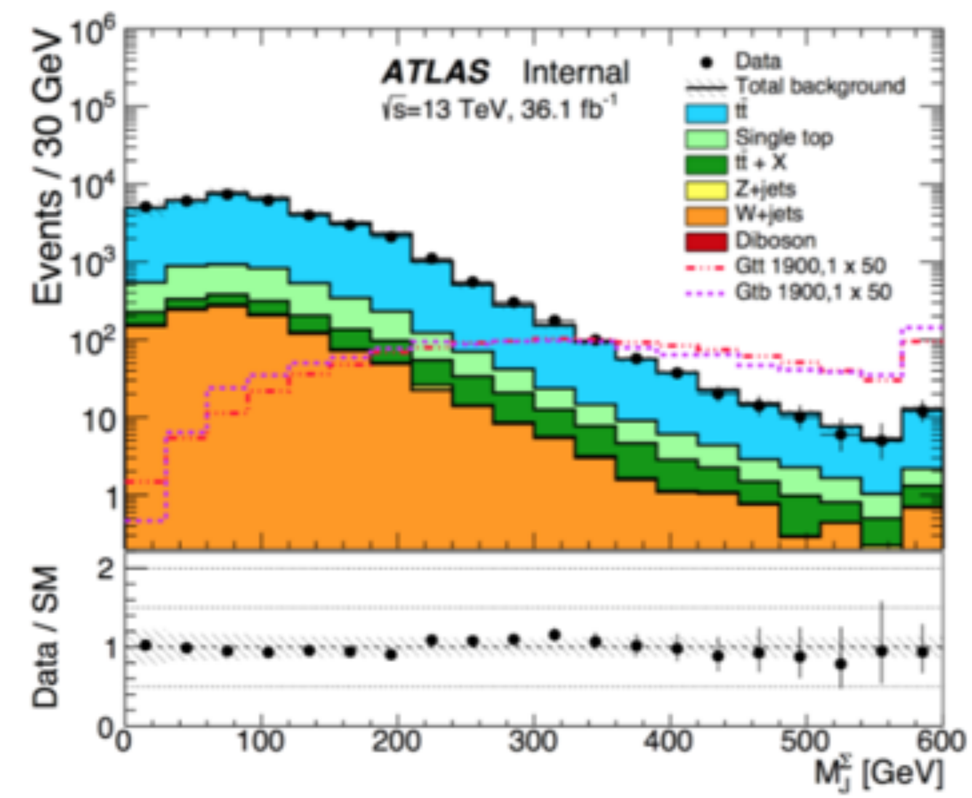
Event shape variables, e.g. **Aplanarity**, …

Hypothesis-based event variables e.g. $\mathbf{m_{T2}}$, …

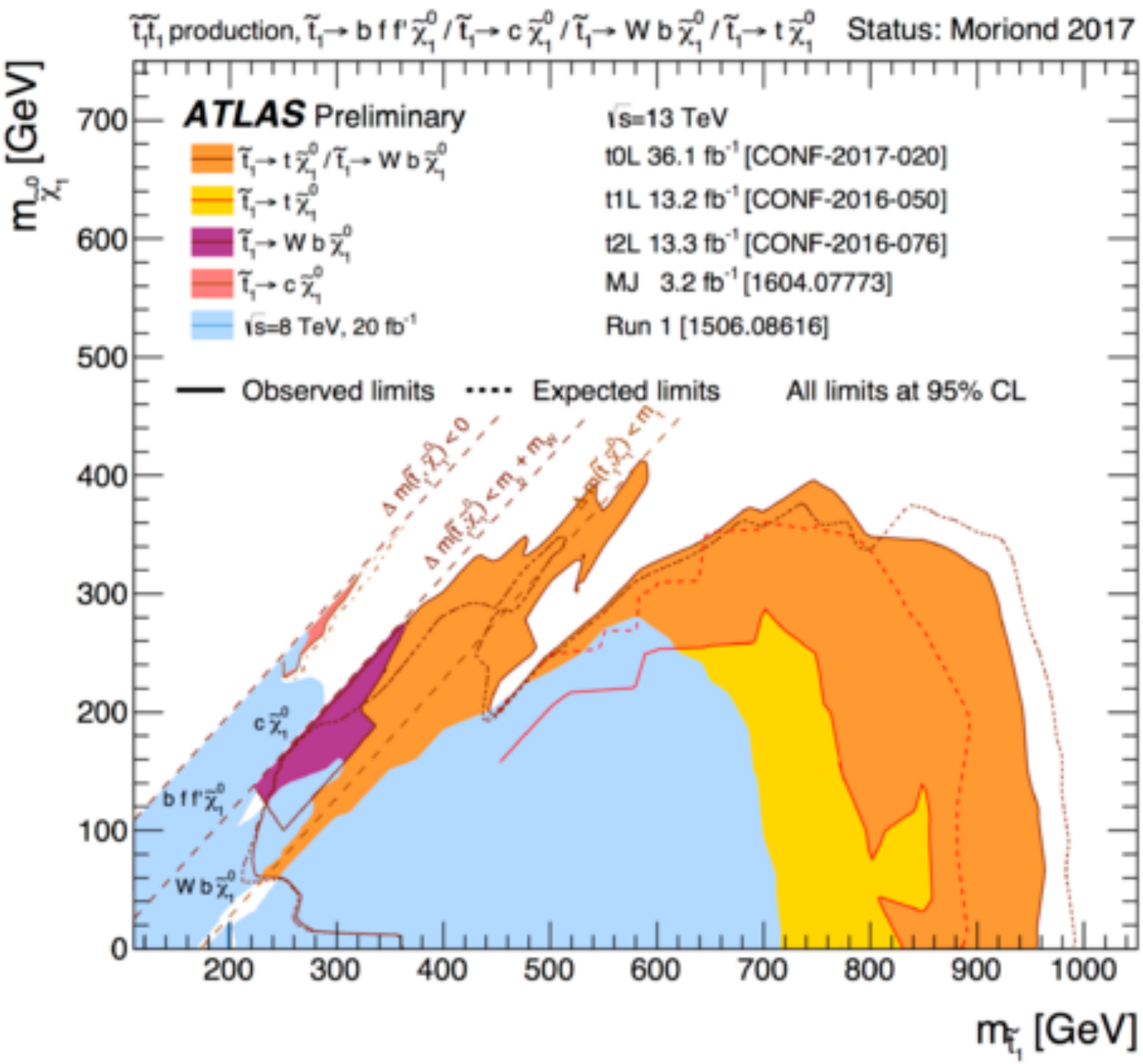
⋮

More complex methods, e.g. new **recursive jigsaw reconstruction** [arxiv:1607.08307], …



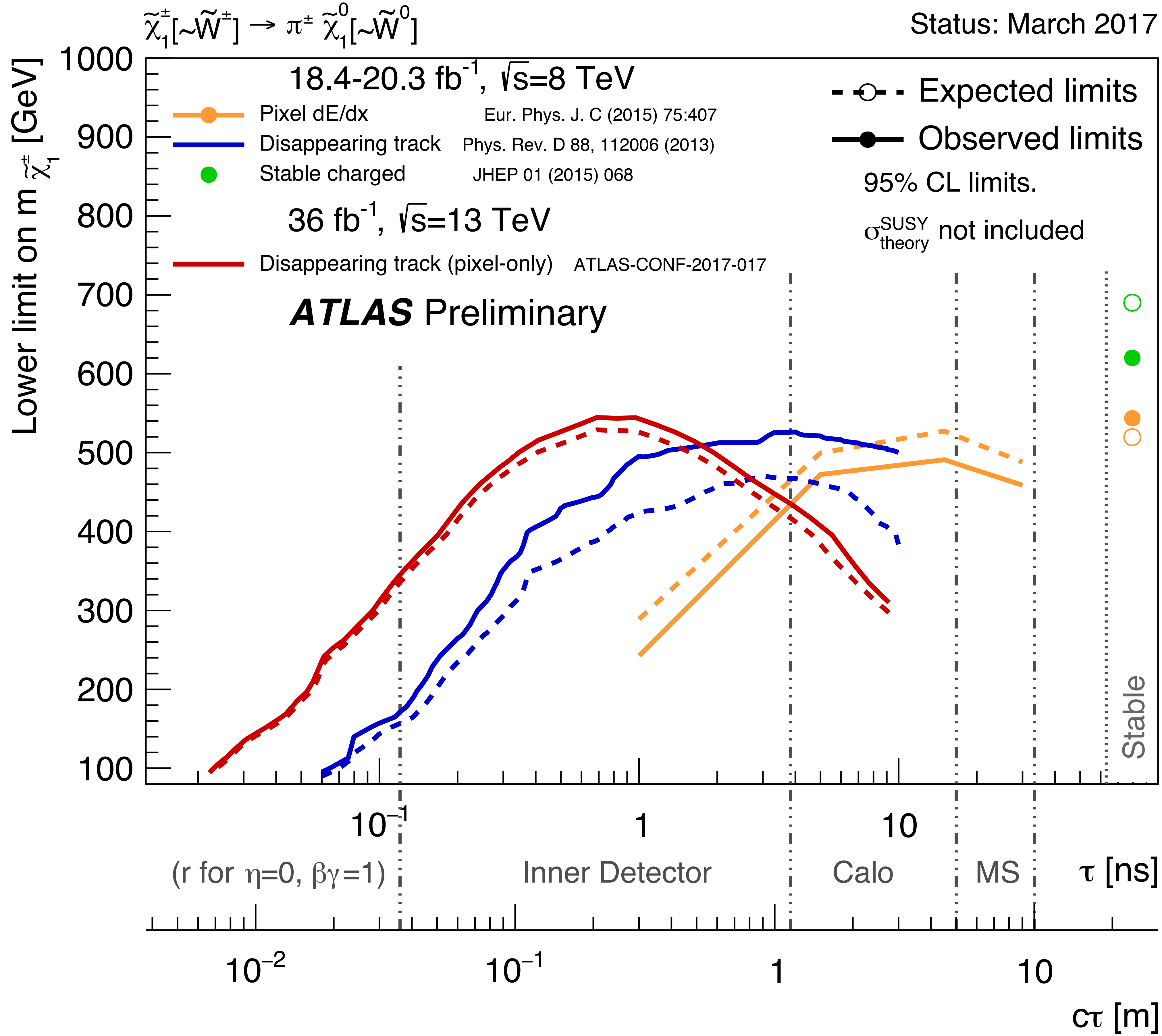


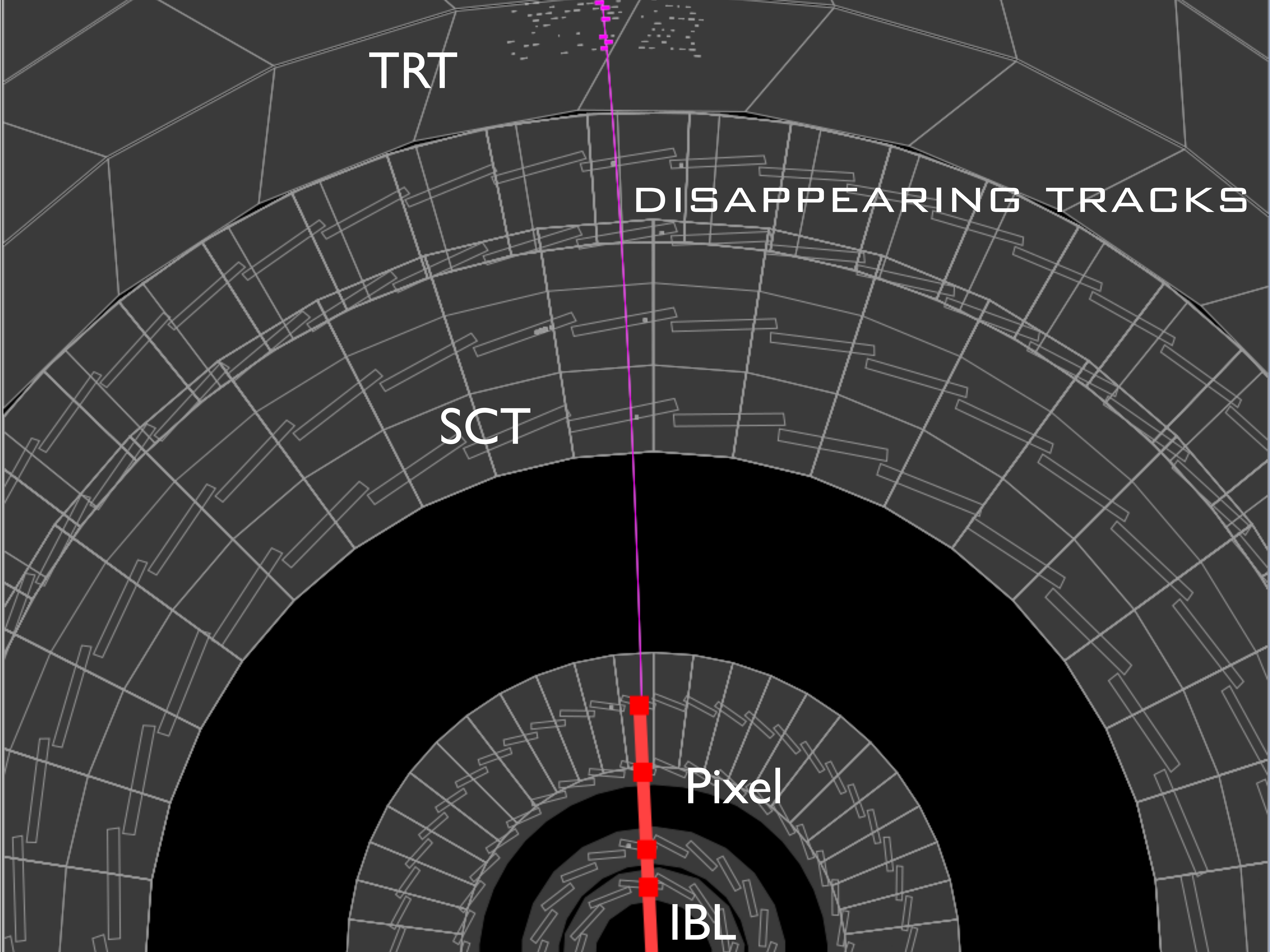
Stop limits



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \to c \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to t \tilde{\chi}_1^0$
Status: Moriond 2017
ATLAS Preliminary
$\sqrt{s}$=13 TeV
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$
t0L 36.1 fb^{-1} [CONF-2017-020]
$\tilde{t}_1 \to t \tilde{\chi}_1^0$
t1L 13.2 fb^{-1} [CONF-2016-050]
$\tilde{t}_1 \to W b \tilde{\chi}_1^0$
t2L 13.3 fb^{-1} [CONF-2016-076]
$\tilde{t}_1 \to c \tilde{\chi}_1^0$
MJ 3.2 fb^{-1} [1604.07773]
$\sqrt{s}$=8 TeV, 20 fb^{-1}
Run 1 [1506.08616]
Observed limits
Expected limits
All limits at 95% CL
$c \tilde{\chi}_1^0$
$b f f' \tilde{\chi}_1^0$
$W b \tilde{\chi}_1^0$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]

Long-lived charginos




TRT
DISAPPEARING TRACKS
SCT
Pixel
IBL

Backup