Searches for strong production of SUSY particles with the ATLAS detector

John Anders
On behalf of the ATLAS collaboration
32nd Rencontres de Blois

UNIVERSITÄT BERN

ATLAS EXPERIMENT

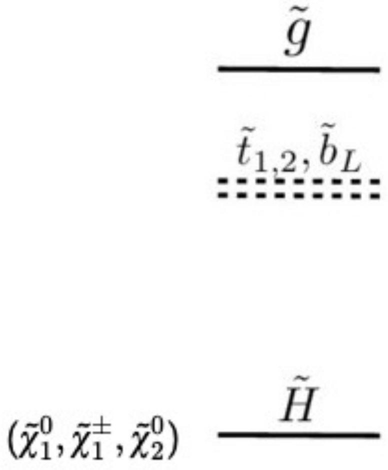
Strong SUSY

- SUSY theories introduce an additional (spin) symmetry to the SM
  - Very rich phenomenology due to introduction of SUSY partner particles
  - Provides a solution to the hierarchy problem
  - Can lead to gauge unification

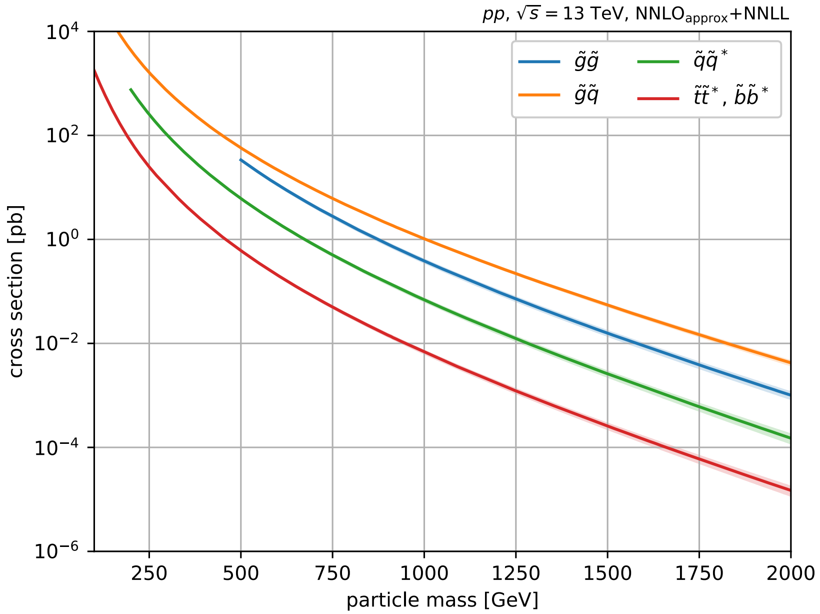
- Searches focusing on gluino & squark production
  - Many particles in the final states (jets, leptons, photons)

- Dedicated 3G SUSY searches (top- and bottom-squarks)
  - Unique phenomenology & final states with heavy fermions

- LHC can probe the ~TeV regime for strong production
  - Preferred from naturalness considerations

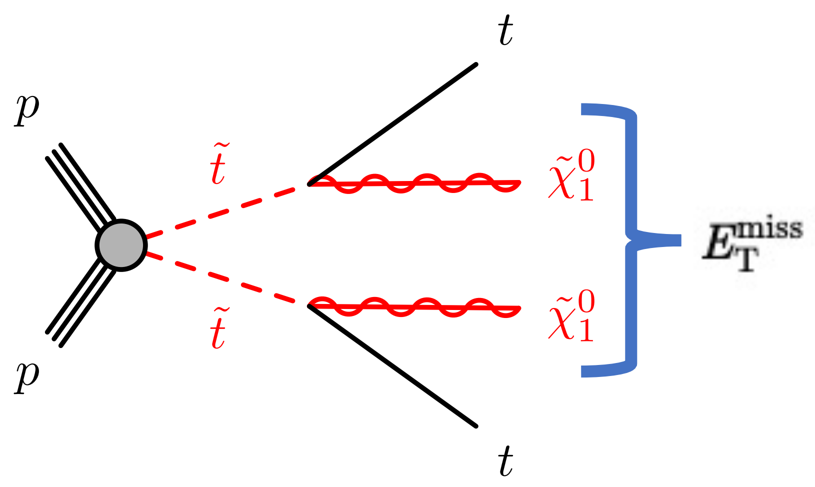


Natural SUSY mass spectra



RPC vs RPV

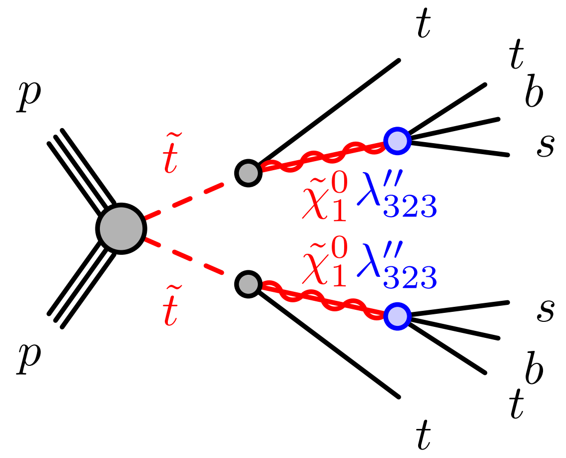
- R-Parity Conservation (RPC):
  - Prevents Proton decay
  - Conserves Baryon & Lepton number
  - Lightest SUSY particle (LSP) is stable and non-interacting (DM candidate)
  - Final states containing large Missing Transverse momentum



- R-Parity Violation (RPV):
  - Most general super-potential contains B- & L-number violating terms (non-zero lambda terms)

$$W_{R_p} = \mu_i H_u L_i + \frac{1}{2}\lambda_{ijk} L_i L_j E_k^c + \lambda'_{ijk} L_i Q_j D_k^c + \frac{1}{2}\lambda''_{ijk} U_i^c D_j^c D_k^c$$

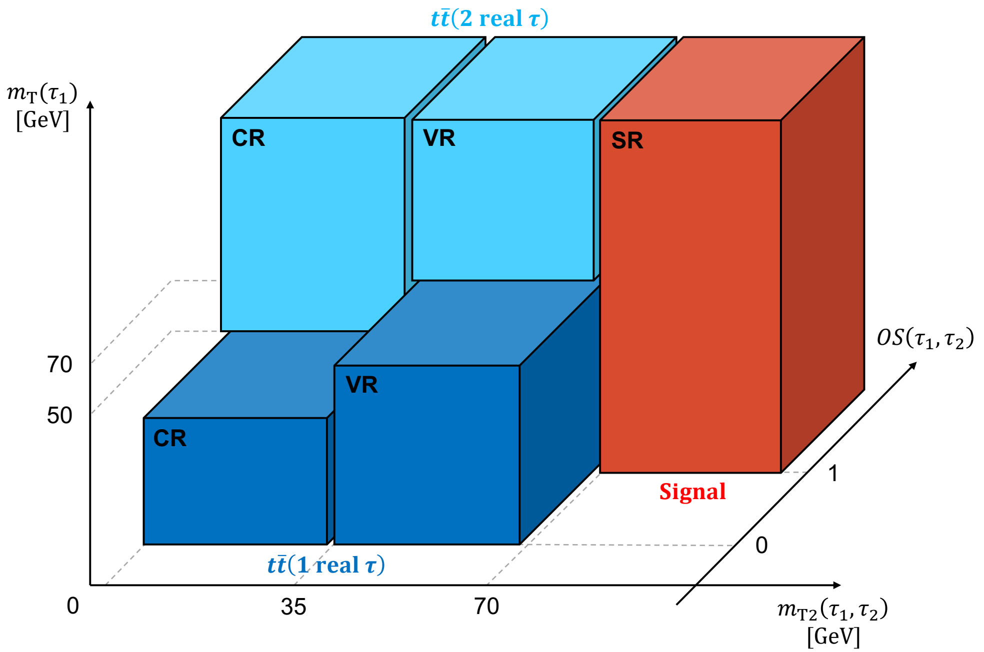
  - Other conditions (not just R-parity) can prevent proton decay
  - More weakly constrained than RPC scenarios
  - Very rich phenomenology, final states with many particles (and small missing transverse momentum)
  - Covering prompt RPV decays



ATLAS SUSY Search Strategy

- Will cover 7 analysis (targeting RPC and RPV scenarios), all following a similar general strategy

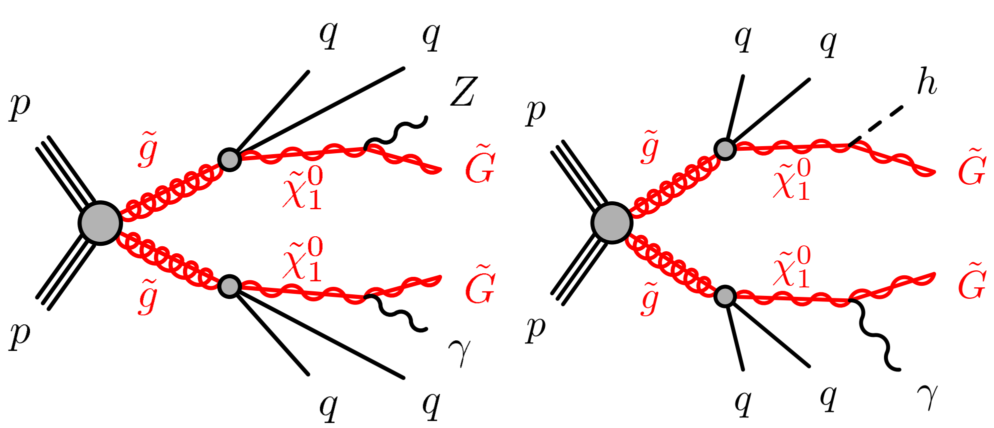
  - Signal Regions (SRs) are defined based upon kinematic differences between SUSY signal and SM background
    - Can be a region with multiple bins, or just a single-bin region
  - SM backgrounds are estimated in Control regions (CRs)
    - Semi-data driven method with normalisation in an orthogonal kinematic region
  - If possible, fully data-driven background methods are used
    - Often used to estimate backgrounds arising from detector mismeasurement
  - Background estimate validated in Validation regions (VRs)
    - Again, orthogonal to the CR & SR

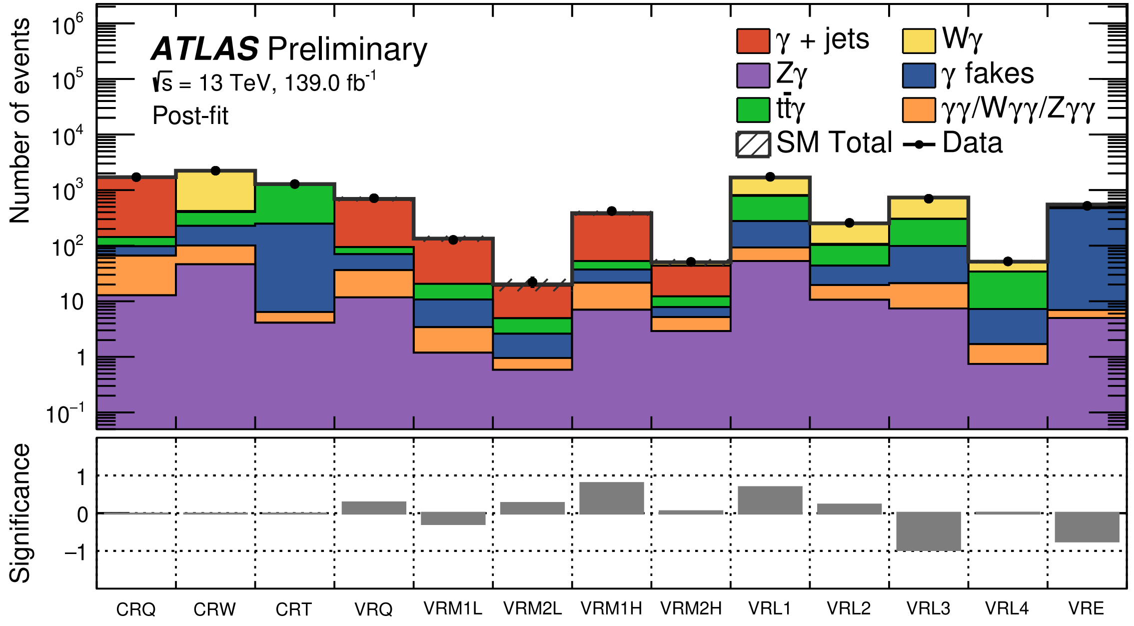


- Results are interpreted in a model-independent manner and also in the context of simplified SUSY models
  - A likelihood fit is performed with the CRs & SR

ATLAS-CONF-2021-028

- RPC Scenarios with General Gauge Mediation (GGM)
  - Pair production of gluinos
  - Leading to Gravitino LSP
  - NLSP is either Higgsino or Bino
- Three SRs defined using final states with a high p_T photon
  - Many jets, large H_T and large E_T^{miss}
  - Optimised to target different regions of phase space
- Follow up to the 36fb^{-1} analysis (2.36σ local excess)
- CRs defined for the 3 main backgrounds
  - γ+Jets: $\Delta\phi(j, E_T^{miss}) < 0.4$ (inverted SR selection)
  - Wγ, estimated in ≥ 1L, 0 b-jet region
  - ttγ, estimated in ≥1L, ≥1 b-jet region
- Data driven method for electrons & jets "faking" photons
  - Electron misidentification rate measured using the ratio between Zee to Zeγ events
  - ABCD method, defined with isolation criteria, used to estimate events with jets reconstructed as photons

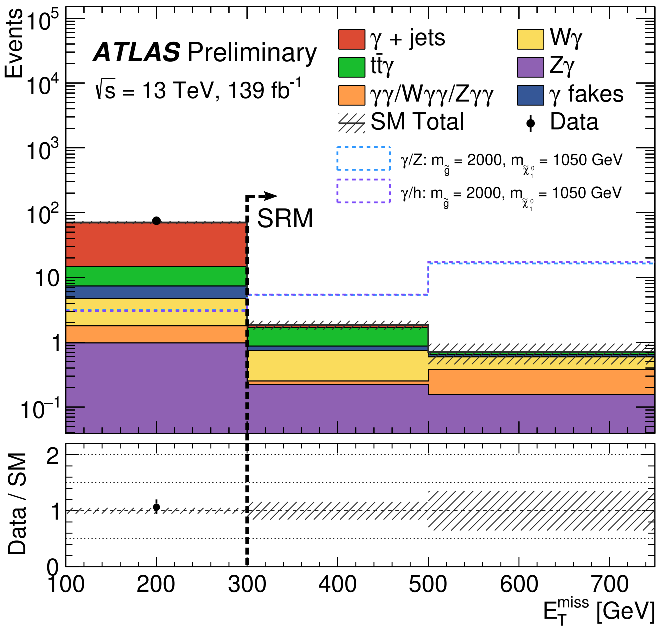


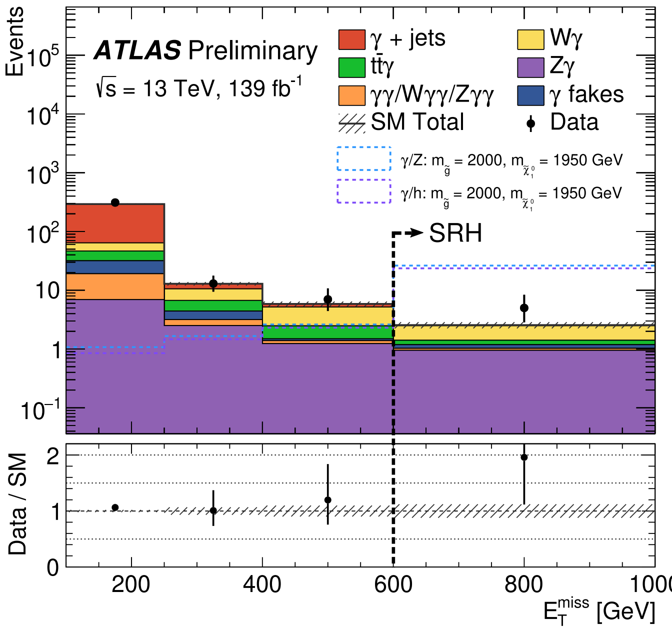


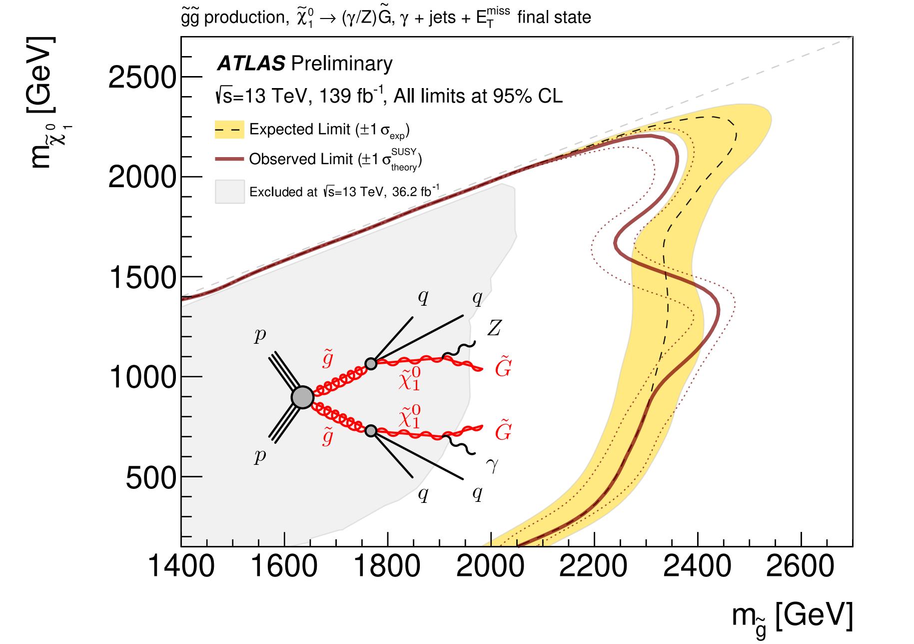
Photons + Jets + E_T^{miss} (RPC)

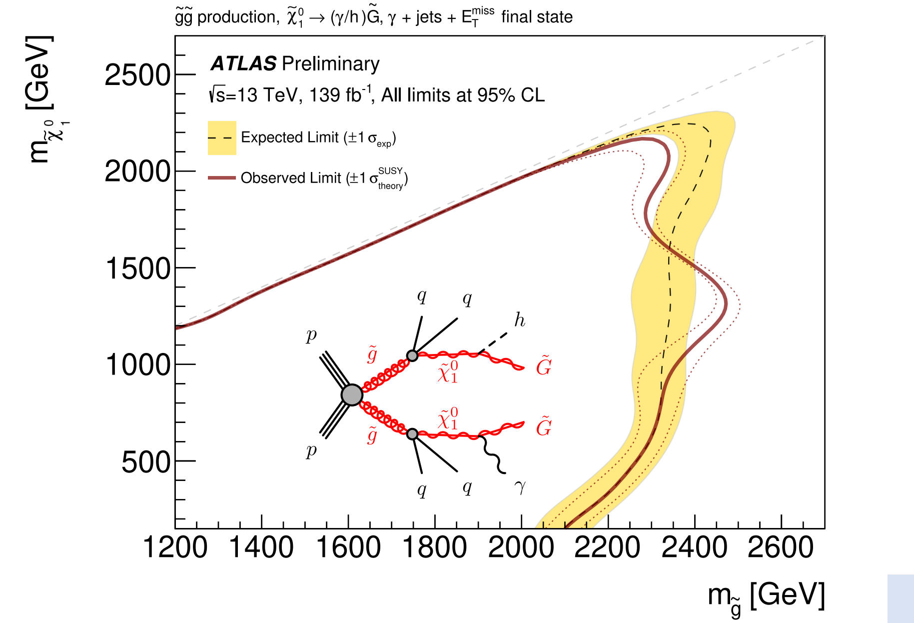
ATLAS-CONF-2021-028

- No significant excesses above the SM
  - Previous (36 fb^{-1}) excess no longer present
- 95% CL Limits set in gluino-neutralino mass plane
  - Using the SR with best expected sensitivity



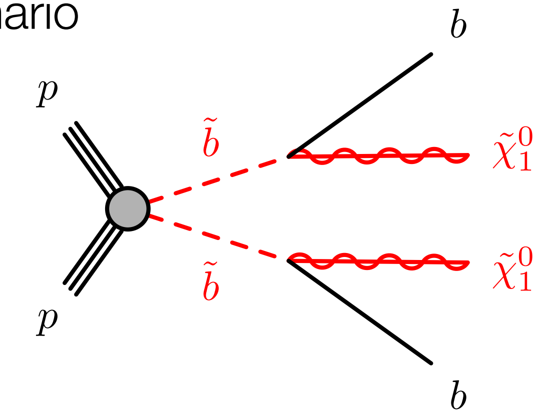


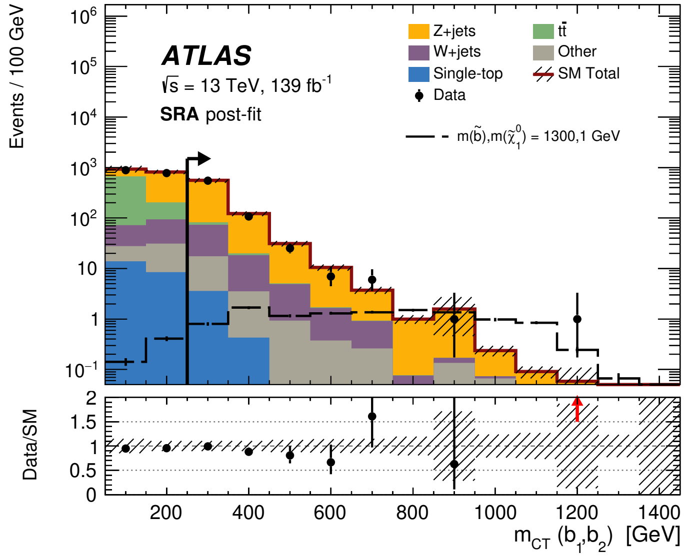


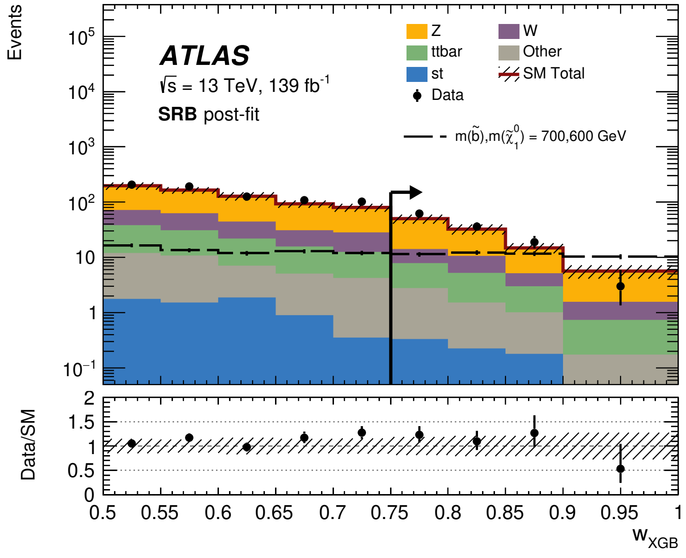


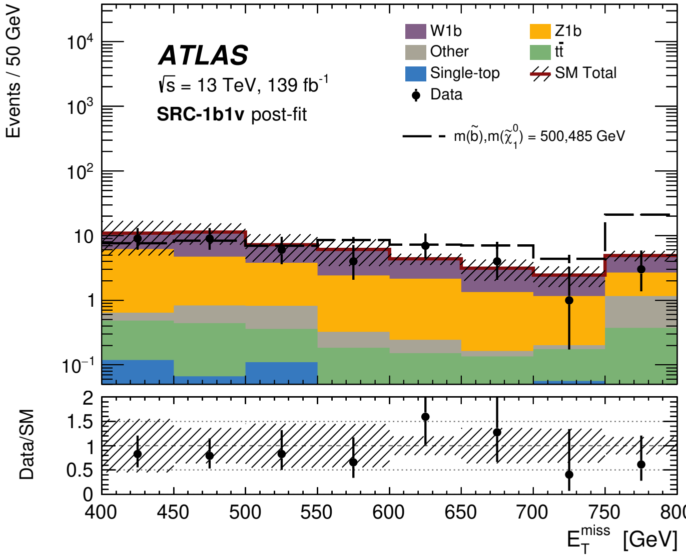
[JHEP 05 (2021) 93]

- Search for sbottom pair production in final states with 0L, b-jets and high E_T^{miss}
  - 3 sets of SRs defined, each targeting a different sbottom-neutralino mass splitting scenario
  - SRA - large mass splitting, using m_{CT}
  - SRB - intermediate splitting, using a BDT
  - SRC - very compressed scenario using an ISR selection
    - Uses specifically developed soft-b-tagging algorithm to ID secondary vertices
  - Main background in all regions is Z+Jets, estimated in dedicated 2L regions
    - Additional CRs defined to estimate top and W+jets in SRC region (1L selection)





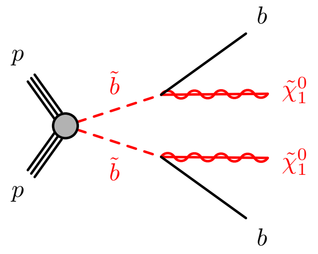


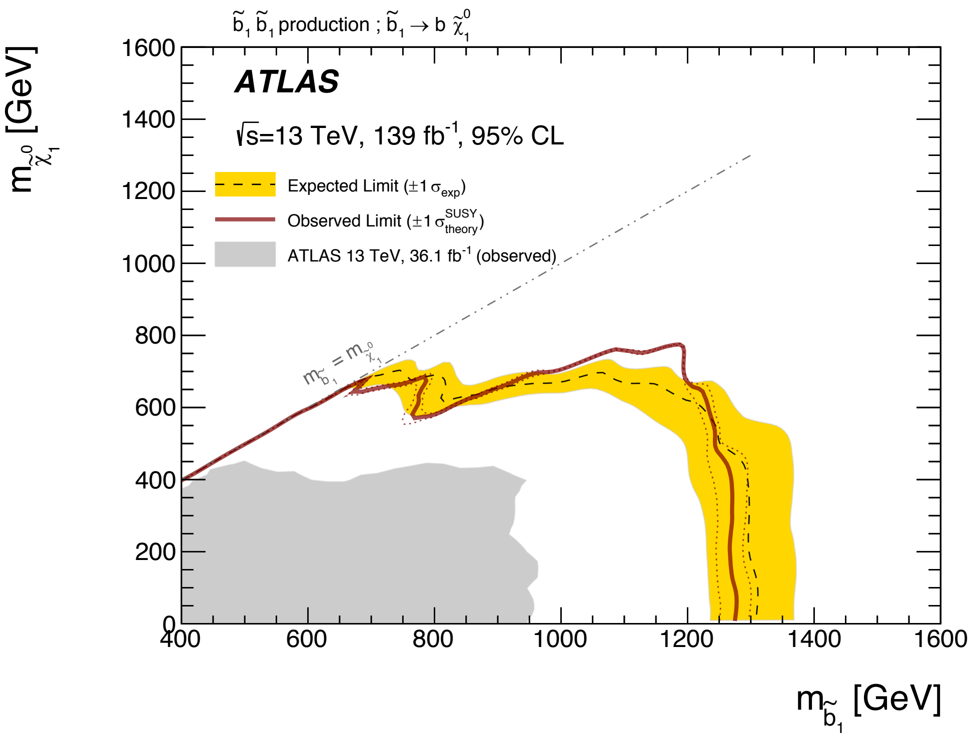


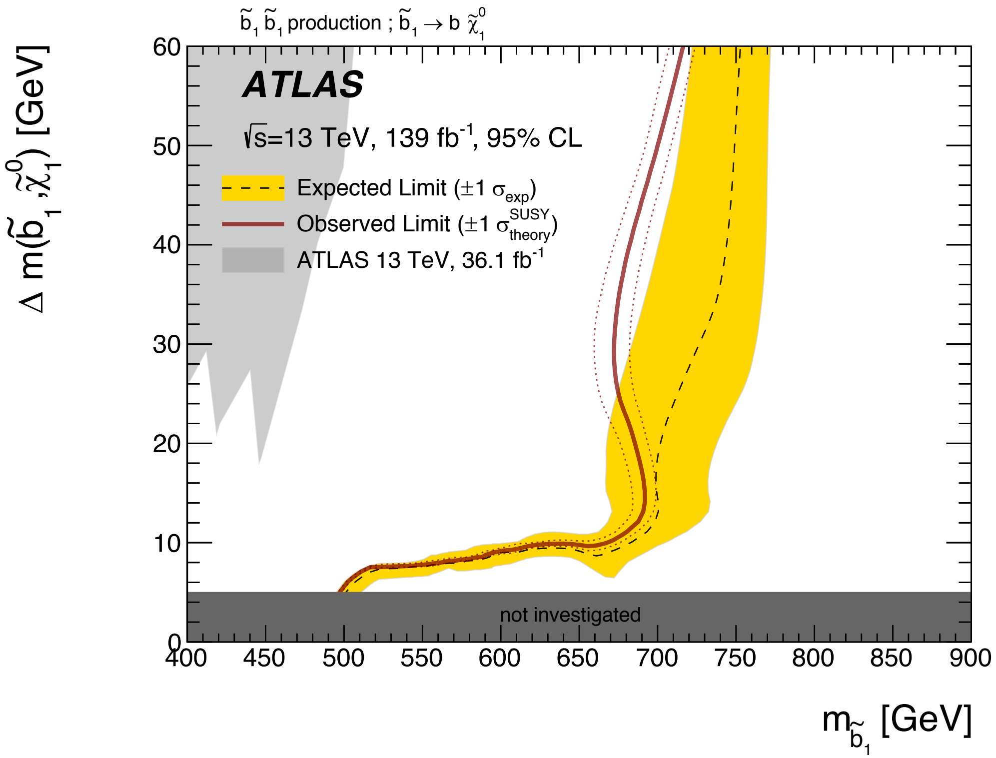
b-jets & E_T^{miss} (RPC)

JHEP 05 (2021) 93

- Results consistent with the SM expectation
  - SRA – multi-bin fit in both m_{CT} and m_{eff}
  - SRB – shape fit in BDT discriminant
  - SRC – multi-bin fit in the number of soft-b-vertices





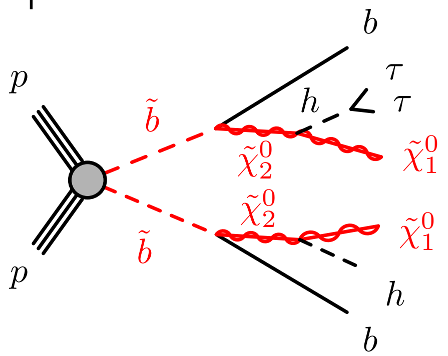


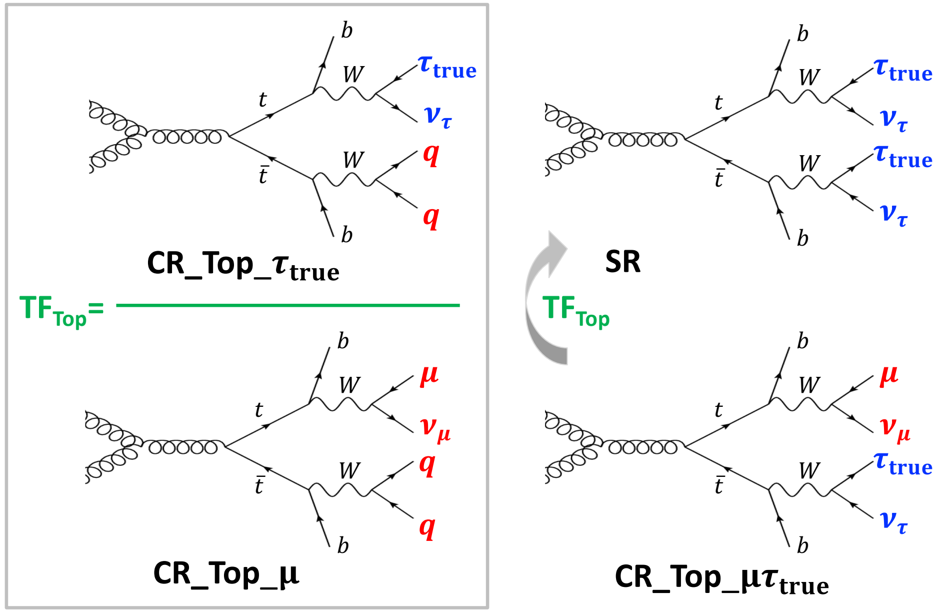
Significantly gain in sensitivity in the compressed region, driven by soft-b-tagging

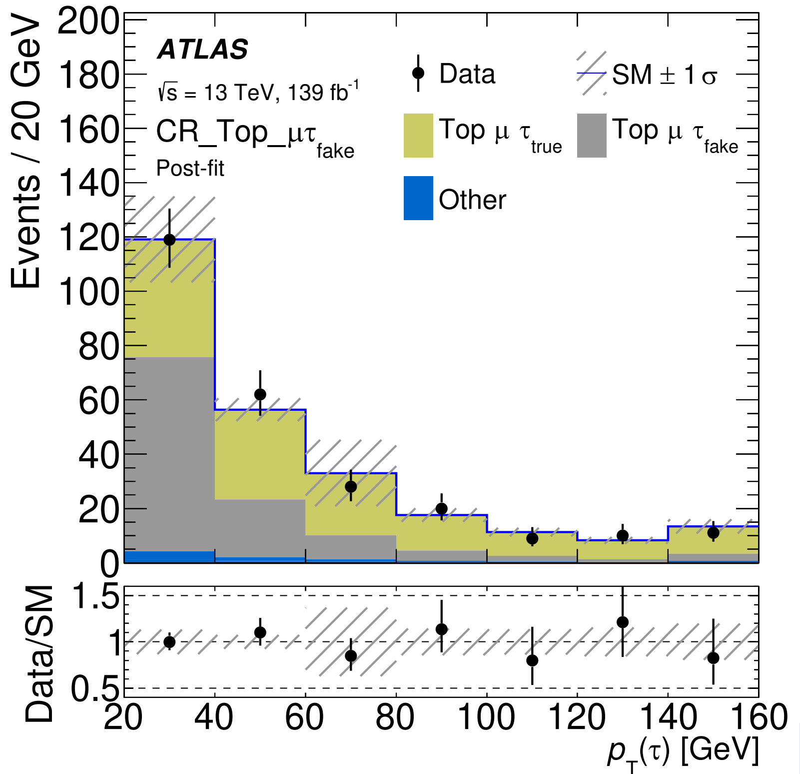
Sbottom with Taus, b-jets and E_T^{miss} (RPC)

PRD 104, 032014 (2021)

- Sbottom search in final states with hadronically decaying taus, b-jets and high E_T^{miss}
  - Two-step SUSY decay, with Wino-like NLSP decaying to Bino-like LSP (and Higgs)
  - SR defined requiring at least two hadronic-taus and at least two b-jets
    - Key discriminating variable: $\Theta_{min}(\tau, b)$ (minimum 3D angle between tau, and b-jet)
  - Main background arising from top-processes and Z+jets
  - Significant effort estimating the background arising from leptons mis-identified as taus
    - Uses ratio of tau to muon events with hadronic top-decays



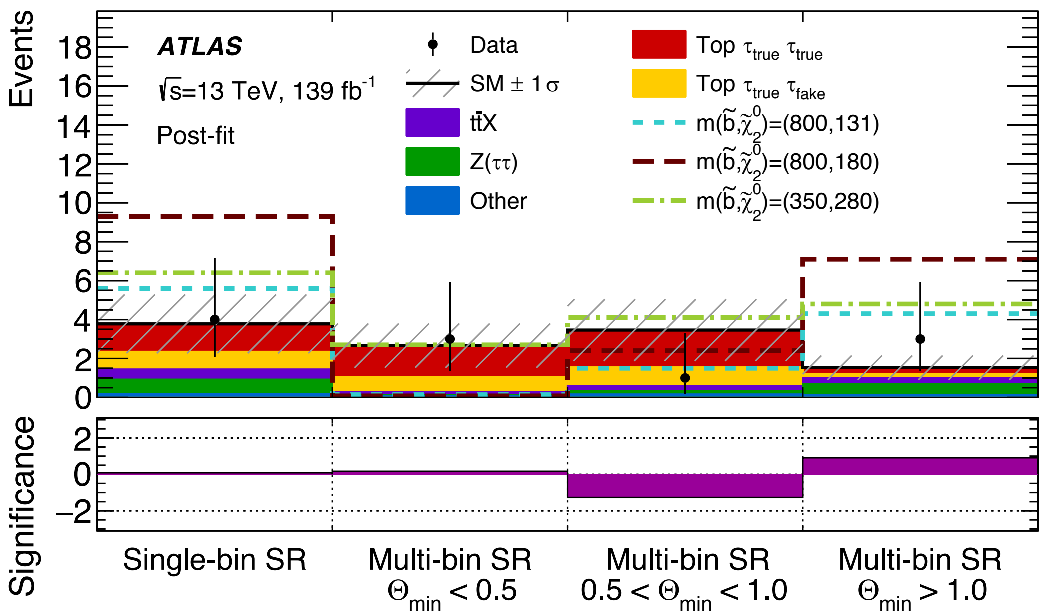


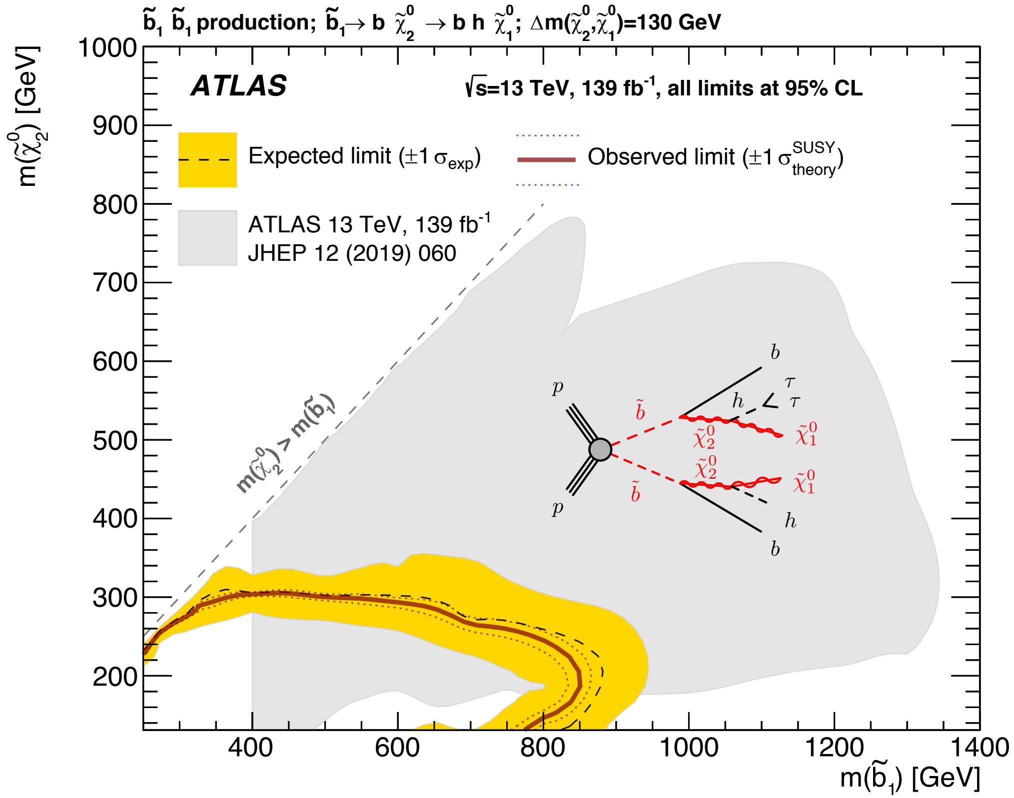


Sbottom with Taus, b-jets and E_T^{miss} (RPC)

PRD 104, 032014 (2021)

- Fit performed in Θ_{min} (τ ,b)
  - Peaks at low values expected for top-backgrounds, larger values for sbottom signals



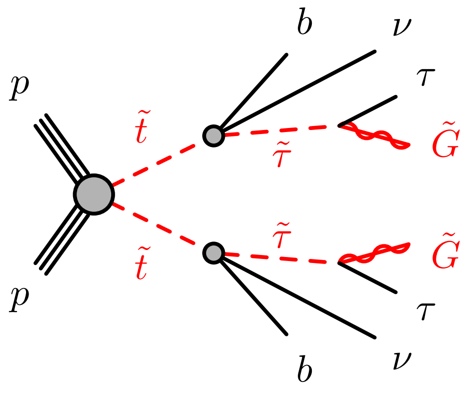


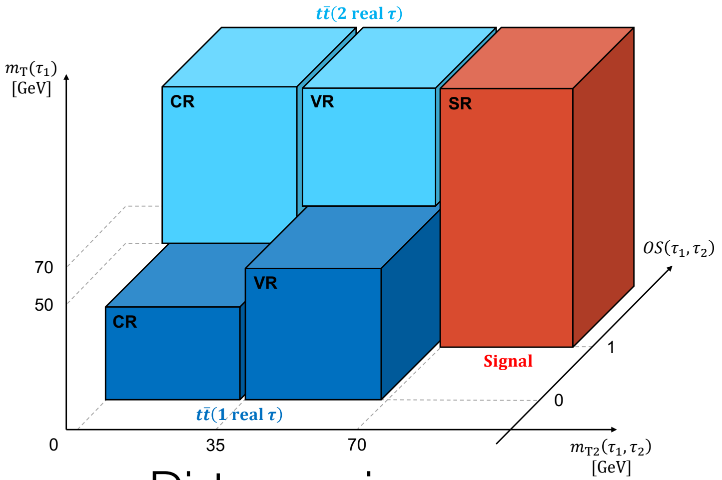
- Limits placed in a previously uncovered region of the phase space, benefitting from targeting a different final state with respect to the previous analysis

Stop to stau with tau leptons b-jets and E_T^{miss} (RPC)

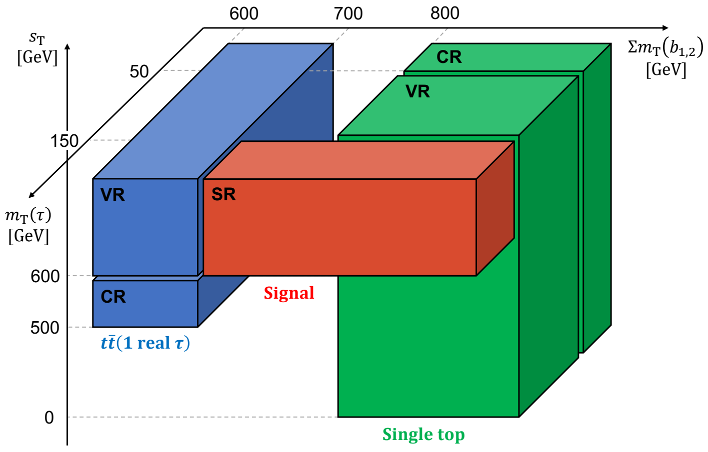
2108.07665

- Stop search in scenarios with an intermediate stau decay
  - GMSB scenario with Gravitino LSP
- Final states with hadronically decaying taus (1 or 2), 0L, E_T^{miss} and b-jets
- Two SRs defined, both targeting large mass splitting between stop-stau
  - Di-tau SR using $m_{T2}(\tau_1, \tau_2)$ as key discriminating variable
  - Single-tau SR uses scalar sum of $p_T(\tau)$ and $p_T(j_1)$, $p_T(j_2)$
- Main backgrounds arise from top-production (top-pair and single-top)

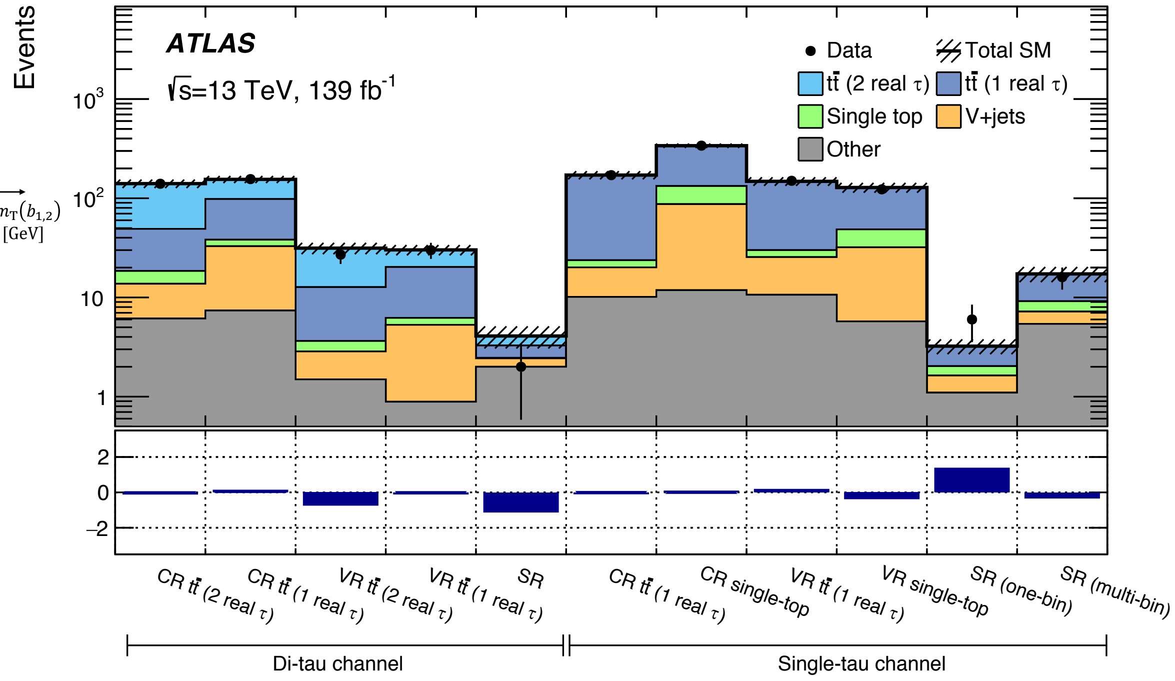




Di-tau regions



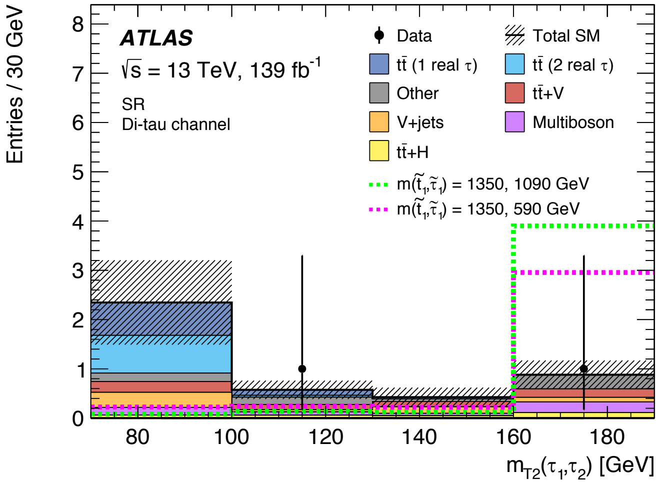
Single-tau regions

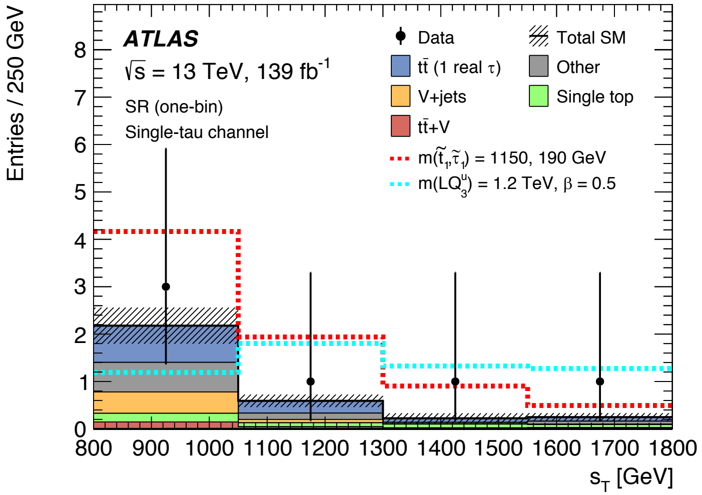


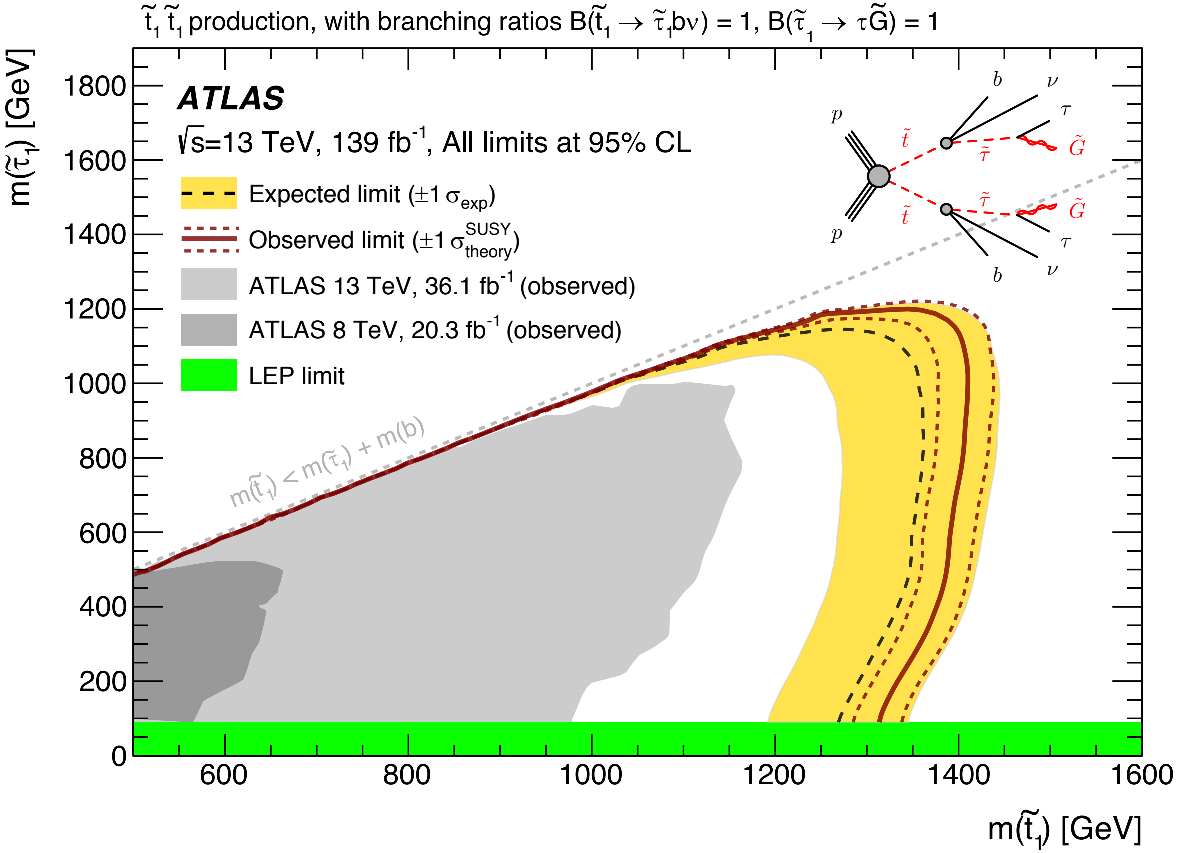
Stop to stau with tau leptons b-jets and E_T^{miss} (RPC)

SUSY-2019-18

- Observed events in good agreement with the post-fit background prediction





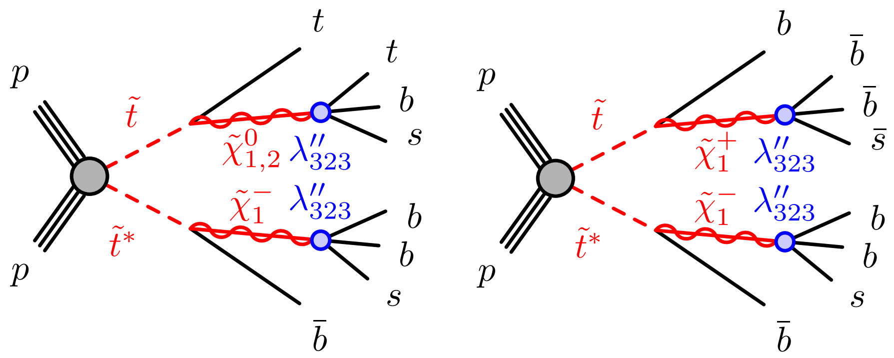


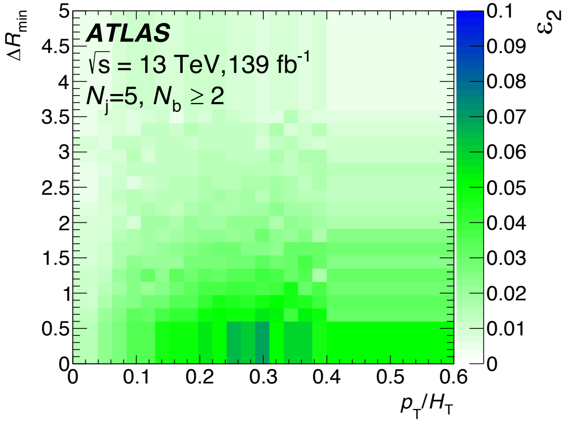
Significant gain in analysis reach compared to previous result

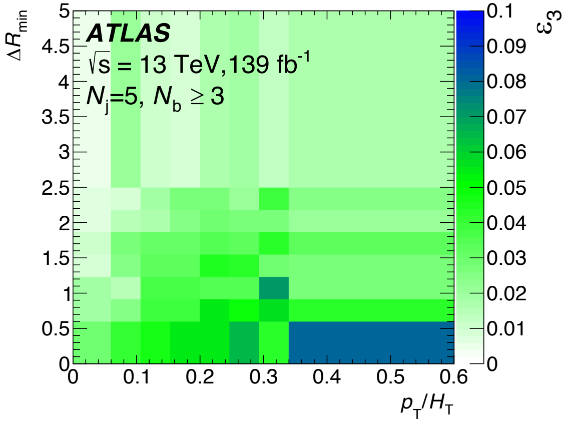
Stop search with many b-jets (RPV)

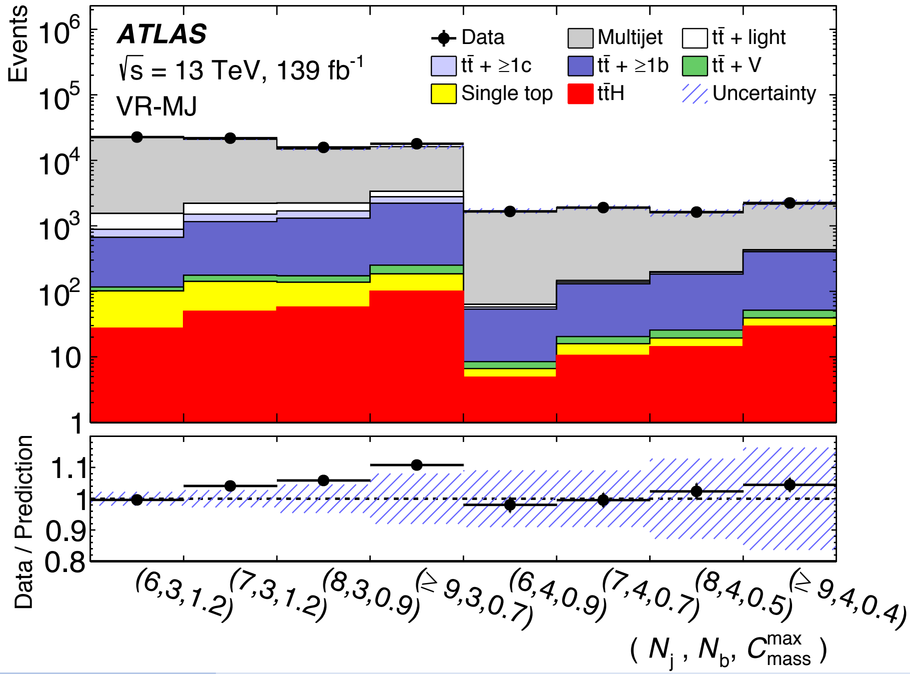
EPJC 81 (2021) 11

- RPV Stop search with non-zero λ''_{323}
  - Baryon number violating decay
  - Leading to a final state with many b-jets
- SRs defined with at least 6 jets, 4 of which are b-jets, and 0L
  - SRs are split into different n_{jet} & $n_{b\text{-}jet}$ multiplicities
- Multi-jet production is the main background, and is estimated in a fully data-driven manner using a two-step method
  - Extrapolate the number of b-jets from a 5-jet (≥ 2 b-jet) region, to higher b-jet multiplicities using a parameterised probability that an additional b-jet is present in the event
  - Probability of additional b-jets is then extended to higher multiplicities





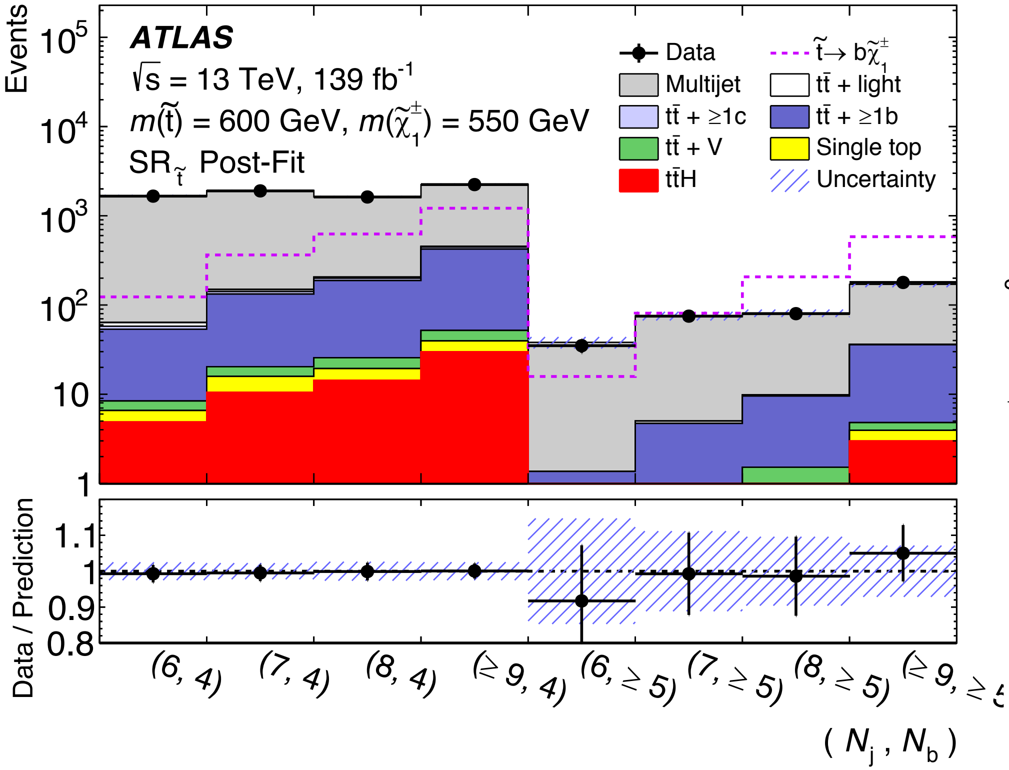


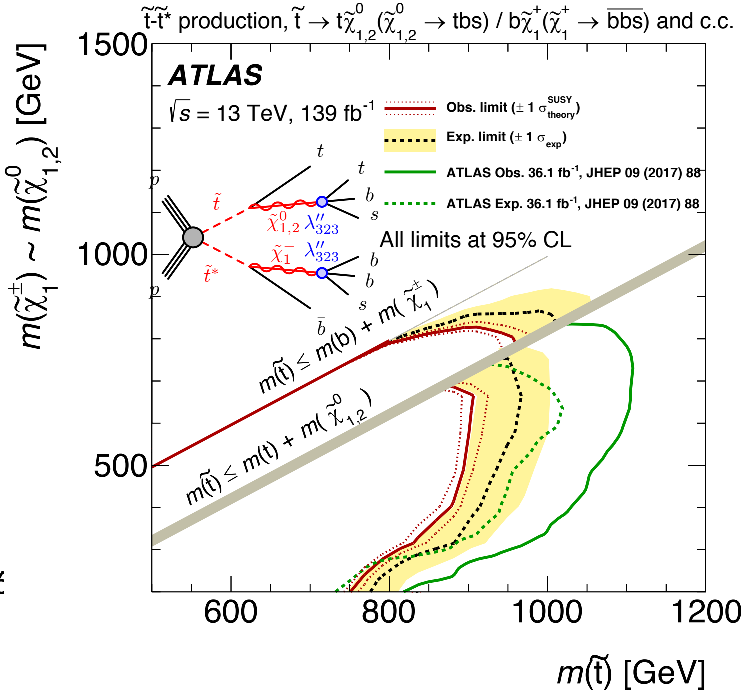


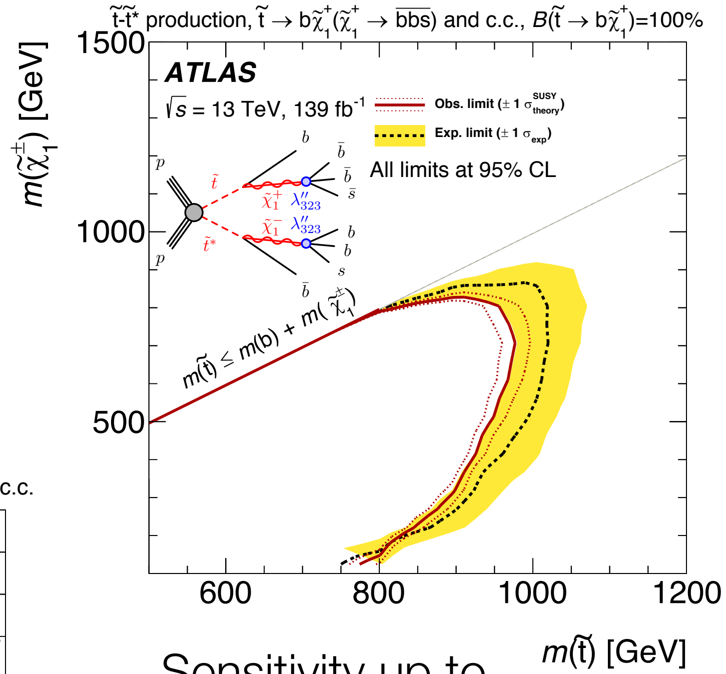
Stop search with many b-jets (RPV)

EPJC 81 (2021) 11

- Good agreement with the post-fit background expectation
- Statistical combination of each n_{jet}, $n_{b\text{-}jet}$ bin is performed to enhance signal sensitivity





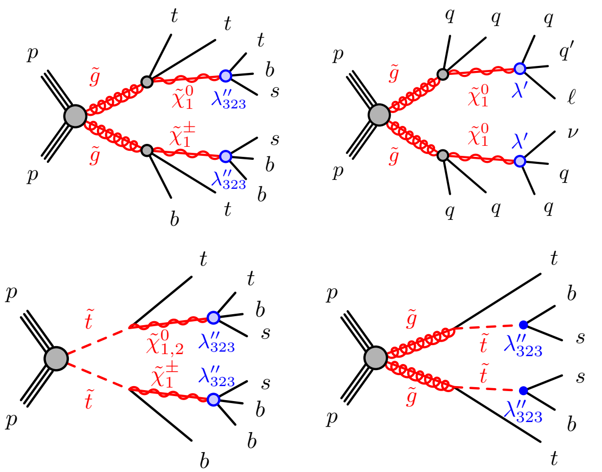


Sensitivity up to m_{stop} = 1TeV in scenarios with the largest b-jet multiplicities

RPV Search with 1L and many jets (RPV)

2106.09609

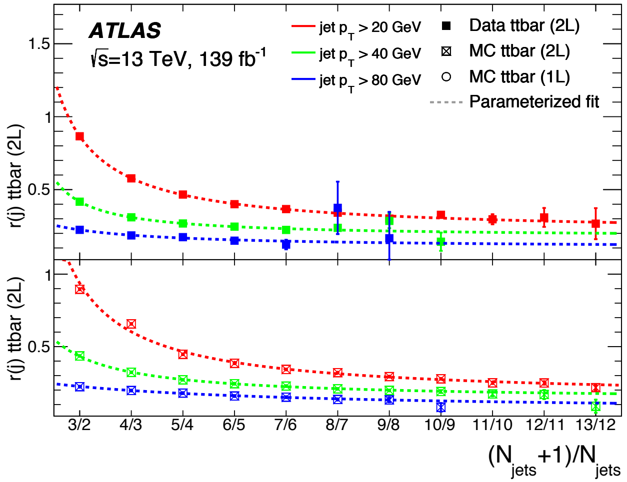
- Very powerful search in final states with at least 1L and many jets
  - Sensitive to gluino and stop pair production in a variety of RPV scenarios
  - Various intermediate decays are considered
- Two sets of SRs with either 1L or 2L (same-charge)
  - ‘Jet counting analysis’ using SRs with high jet and b-jet multiplicities and requirements on the jet p_T thresholds

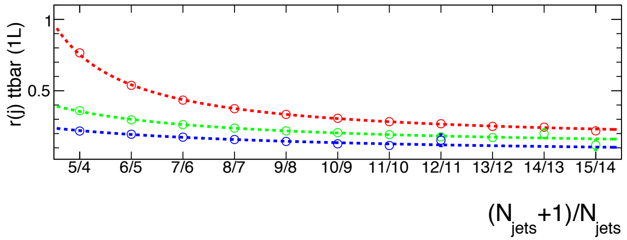


- Main backgrounds for each region are estimated using a fully data-driven method
  - Functional form used to describe the evolution of background events (per process) with respect to jet-multiplicity

$$r^X(j) = N^X(j+1)/N^X(j)$$

  - $r^X(j)$ is constant at high jet-multiplicities and “staircase scaling” is used to estimate $N^X(j+1)$
  - b-jet multiplicity extrapolation from low b-jet multiplicity regions, to higher b-jet multiplicities

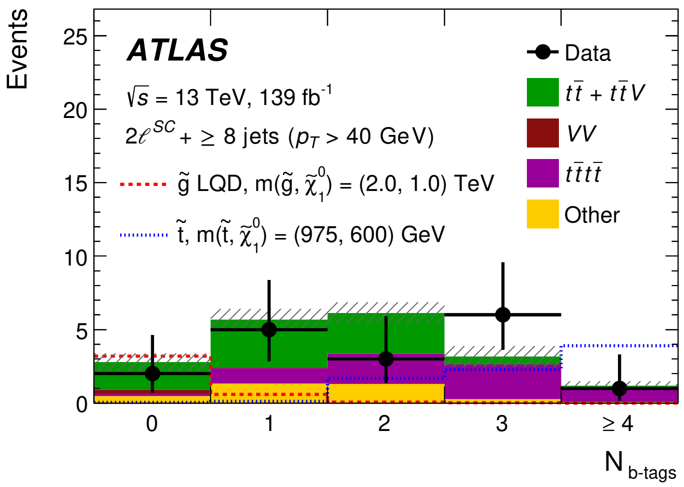


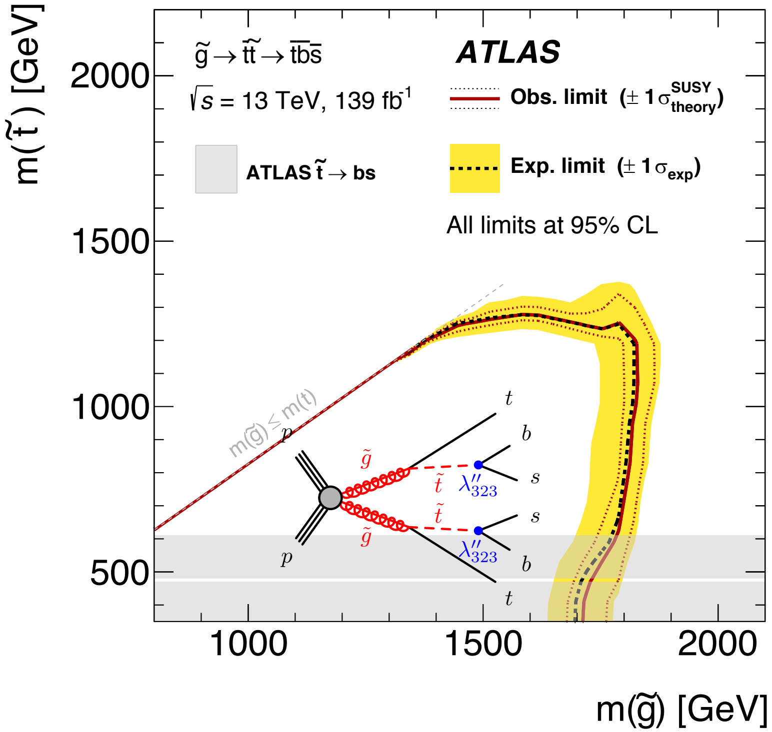


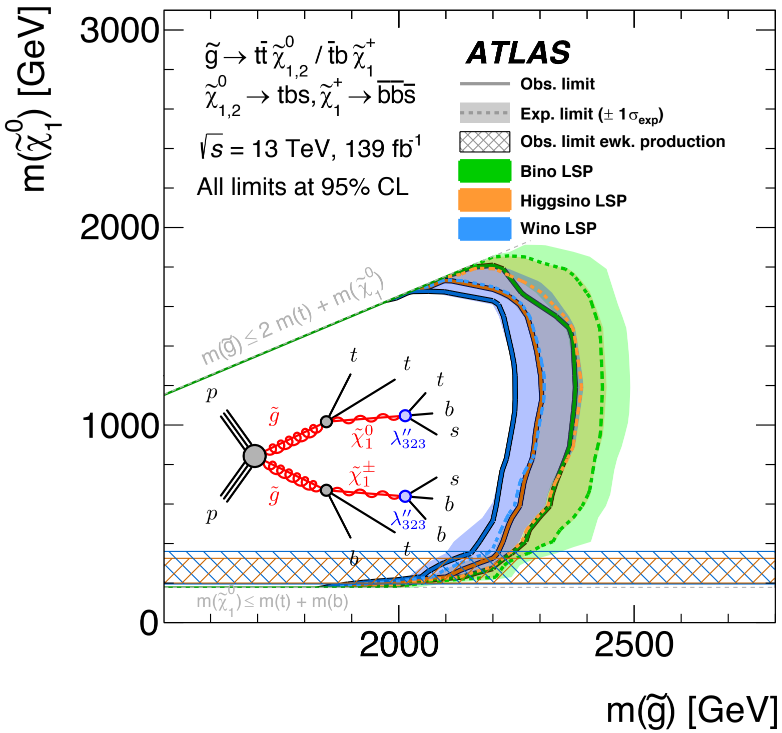
RPV Search with 1L and many jets (RPV)

2106.09609

- Data consistent with SM background predictions
- Significant gain in sensitivity compared to previous results
- Limits also placed using different assumptions on the neutralino composition



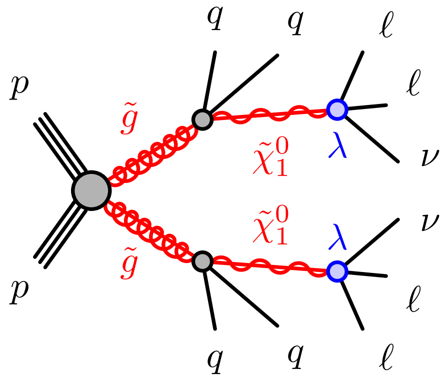


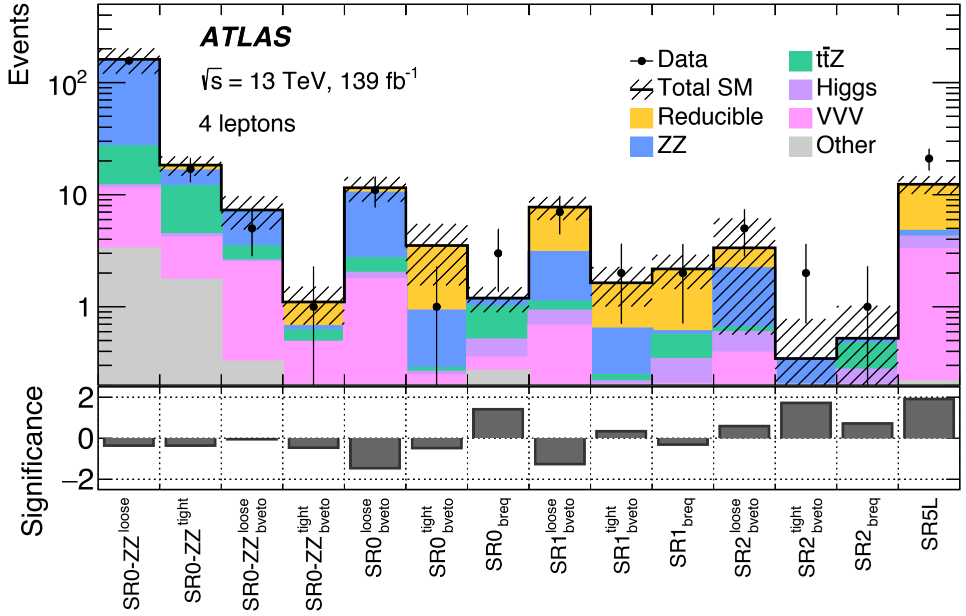


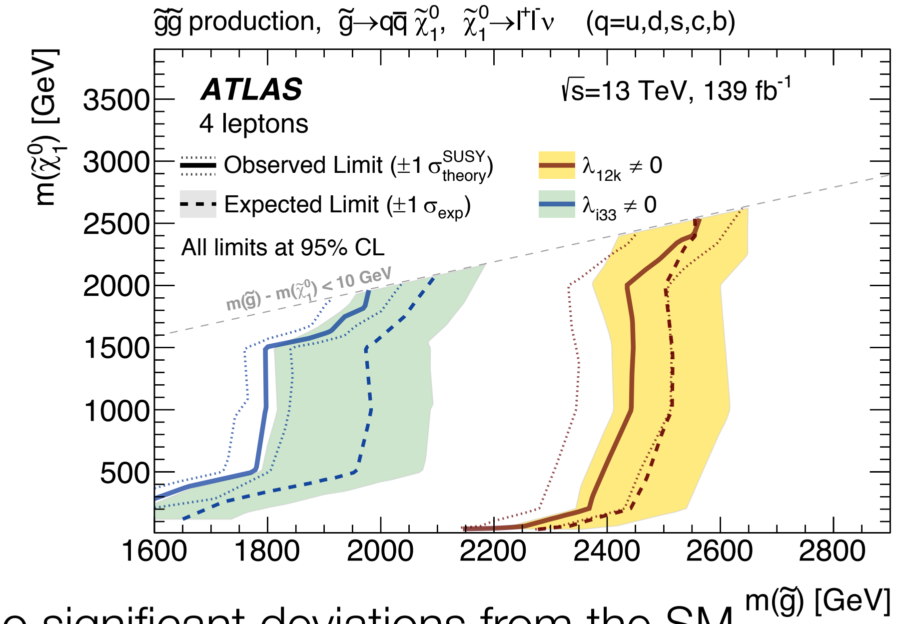
Final states with 4L (RPV)

JHEP 07 (2021) 167

- Search for SUSY in final states with at least 4L
  - Targets both strong & EWK, RPC and RPV scenarios
    - EWK interpretation discussed in A. Cervelli's talk
  - For strong-production, gluino pair-production with non-zero λ_{12k} or λ_{i33} is considered
  - Regions defined requiring at least 1 b-jet and high m_{eff}
- Main backgrounds arise from ZZ and ttZ







No significant deviations from the SM
95% CL limits placed in the two strong RPV scenarios considered

Conclusion

- Comprehensive ATLAS search program targeting strongly produced SUSY, in both RPC and RPV scenarios throughout Run 2
- Greatly enhanced sensitivity compared to early Run 2 results
  - Due to the increased data, but also more complex analysis methods
  - Data-driven estimates of key backgrounds
- Further searches are ongoing to fully exploit the Run 2 dataset
  In addition to the on-going work preparing for Run 3 and beyond!