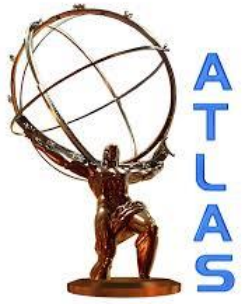
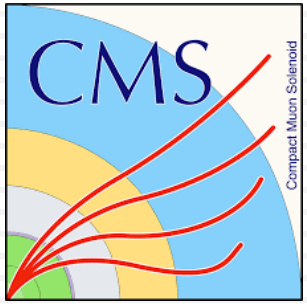
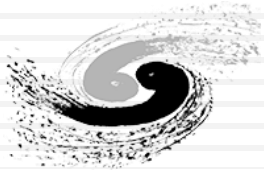
SUSY Searches in ATLAS and CMS



Jin Wang (IHEP, CAS)

On behalf of CMS and ATLAS Collaborations





Institute of High Energy Physics
Chinese Academy of Sciences

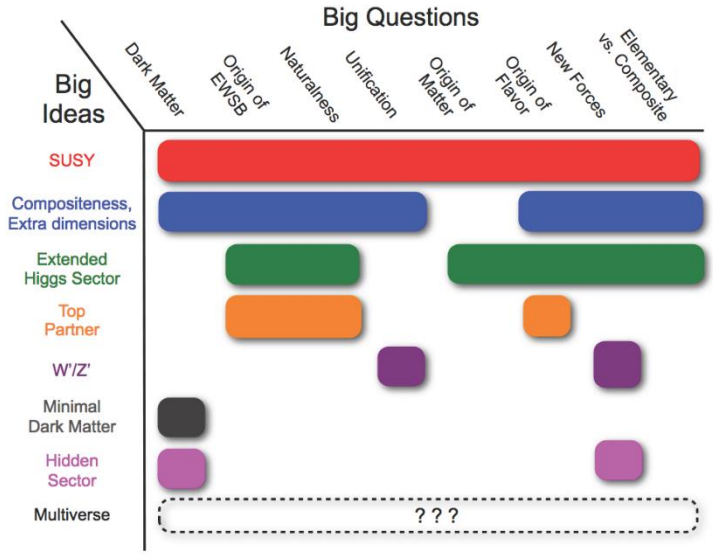
Sunday, November 8, 2020

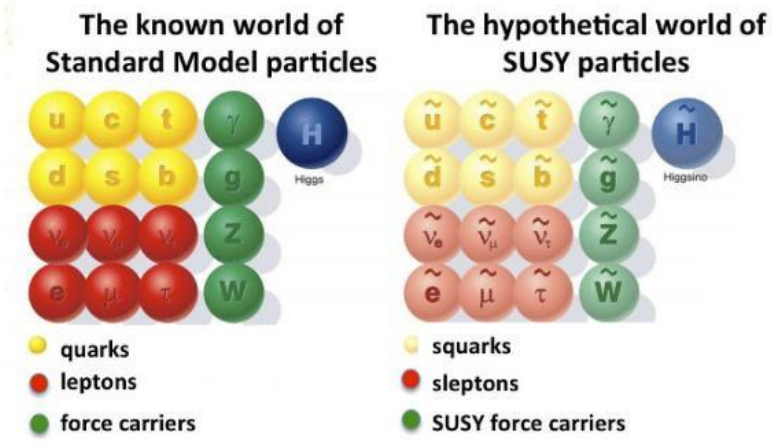
The 6th China LHC Physics Workshop

Why Supersymmetry?

- Standard Model (SM) has many unsolved questions
  - Higgs mass fine tunning and naturalness
  - Dark Matter
  - SM forces unification
  - …..
- Supersymmetry is one of the most promising beyond SM (BSM) theories that answer these questions
  - symmetry that can rotate boson into fermions and viceversa
  - have partners for all SM particles, spin different by 1/2

arXiv:1311.0299

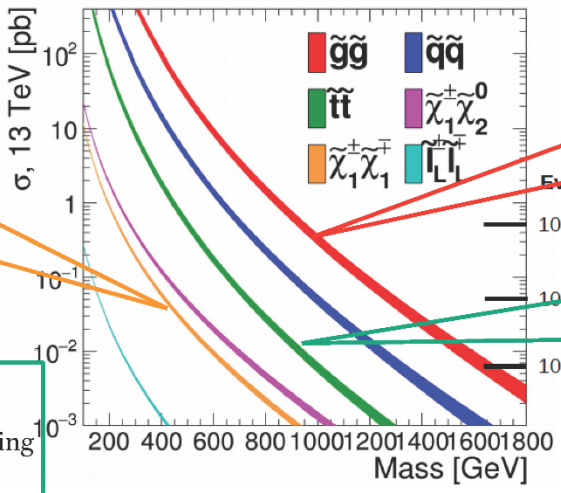




SUSY production in LHC

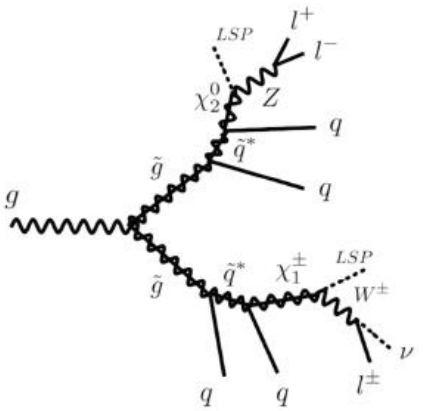
Electroweak Production
Small production cross section
Often targeting small mass splitting

Long-lived analysis
Displaced jets/ℓ and disappearing tracks, delayed γ



Strong Production
High production xsec
Mostly inclusive searches

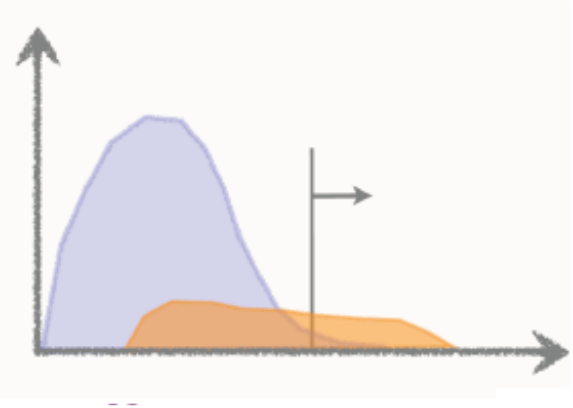
3rd gen. production
More targeted analyses
Can be lighter than other squarks



- SUSY production in pp collisions can be very complex
  - with multiple SM objects and massive undetectable particles on both legs (large missing transverse energy E_T^{miss})
  - if R-parity is conserved sparticles are produced in pairs and decay into the lightest SUSY particle (LSP)
  - concentrate on Simplified Models of SUSY (SMS)
    - with direct light squark production and the only open decay mode if light squarks are NLSP

SUSY search challenges

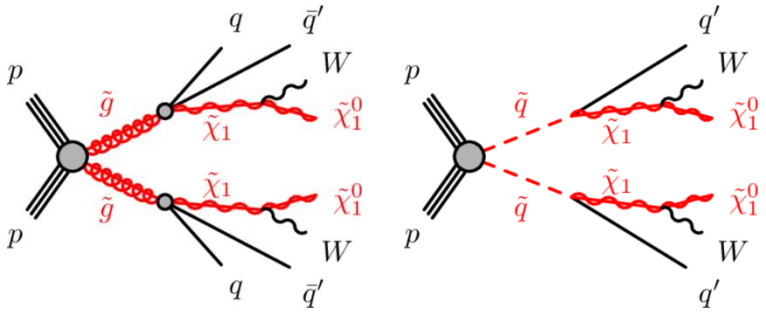
- SUSY searches are very challenging
  - Large final state multiplicity
  - Distribute more in object kinematic tails
  - Large uncertainties on background estimation
  - Easily affected by detector performance



- Typical analysis strategies
  - Categorization with final state multiplicities
  - Explore different signature kinematics and using multivariate techniques
    - E_T^{miss}, H_T, $mass_T$ etc
  - Rely on data to estimate backgrounds
    - Control regions, data side-bands, validation regions etc.
  - Careful detector calibration and offline filters to exclude noisy events

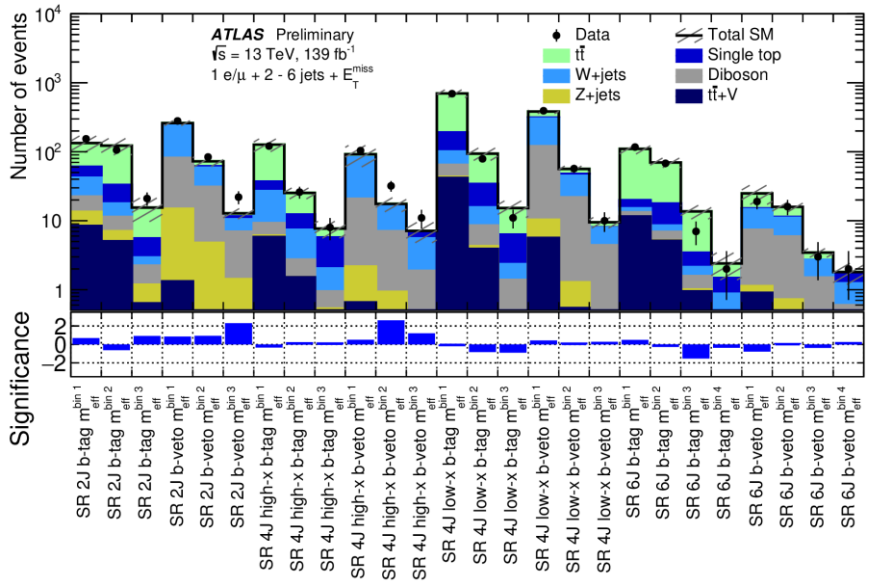
Gluinos and squark production

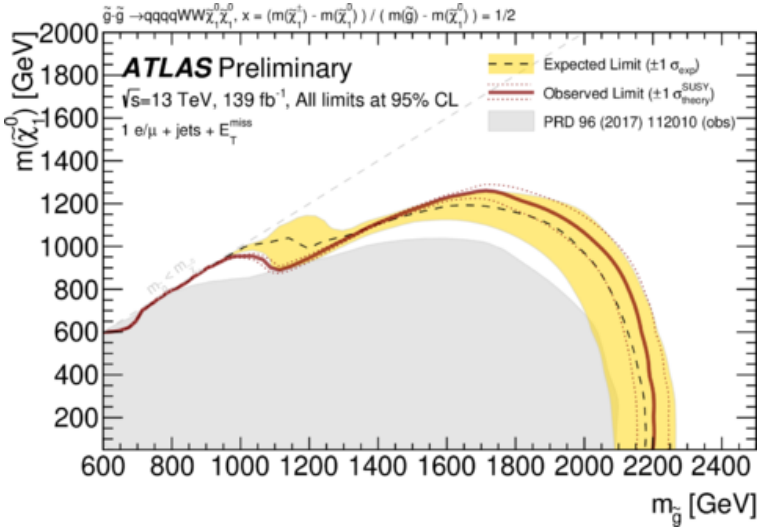
- Gluinos, 1rst/2nd generation squarks pair production
  - large E_T^{miss}, 0-3 leptons, multiple jets and photons



- One lepton search: ATLAS-CONF-2020-047
  - target different gluino, chargino and LSP masses and bkg composition

Leading contribution from IHEP

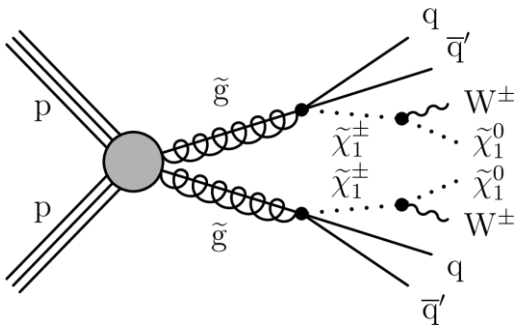




limits of $\tilde{g}$ ($\tilde{q}$) masses up to 2.2 TeV (1.37 TeV)

Gluinios with long lived particles

- Long lived charginos from gluinio decay
  - assuming Δm(chargino, neutralino)~O(100)MeV
  - chargino is long lived (cτ of ~10s cm), and decays into a soft pion and neutralino
  - use disappearing tracks inside the tracker volume to reduce backgrounds



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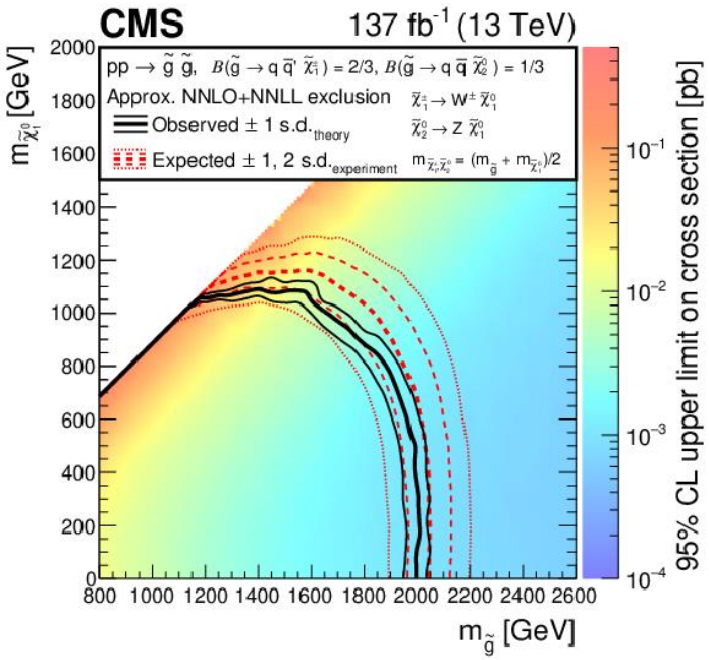
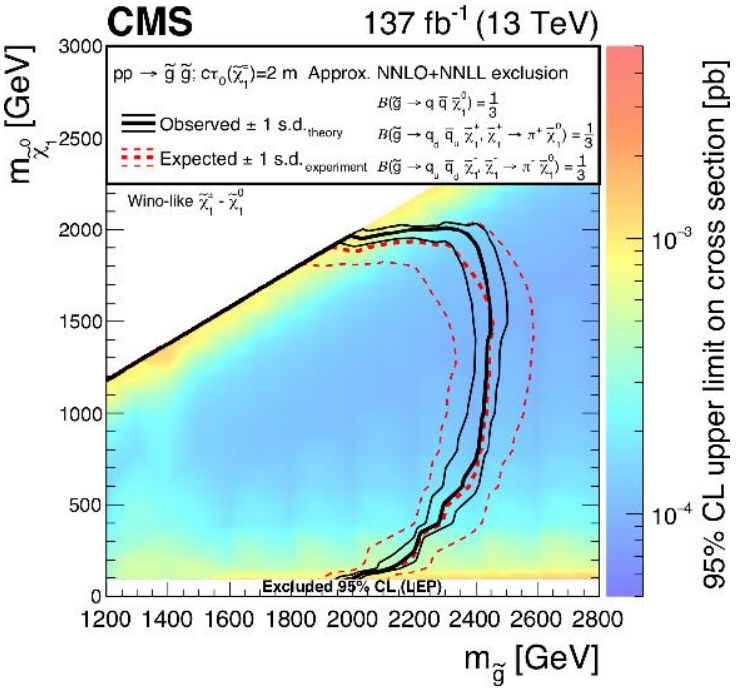
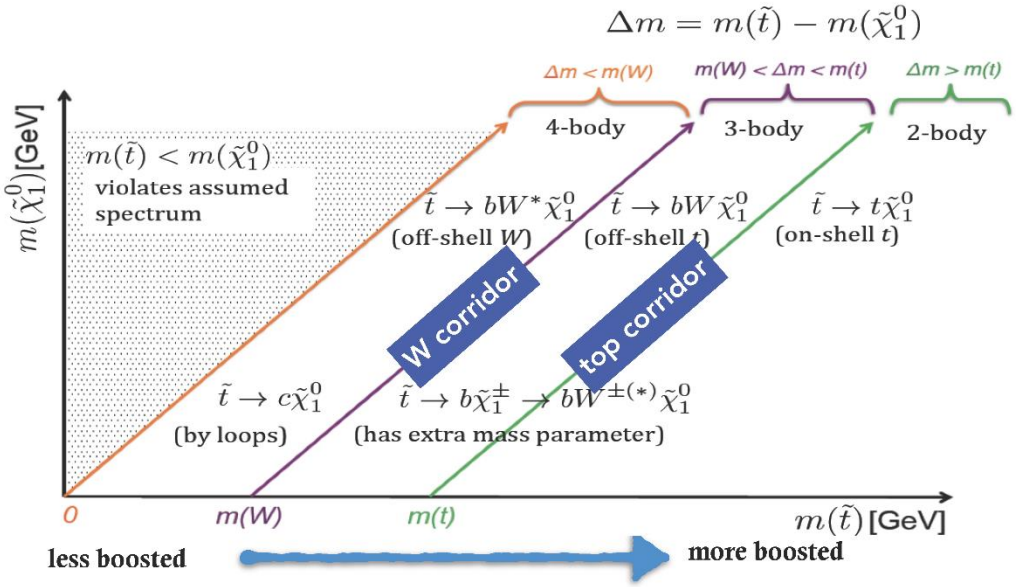


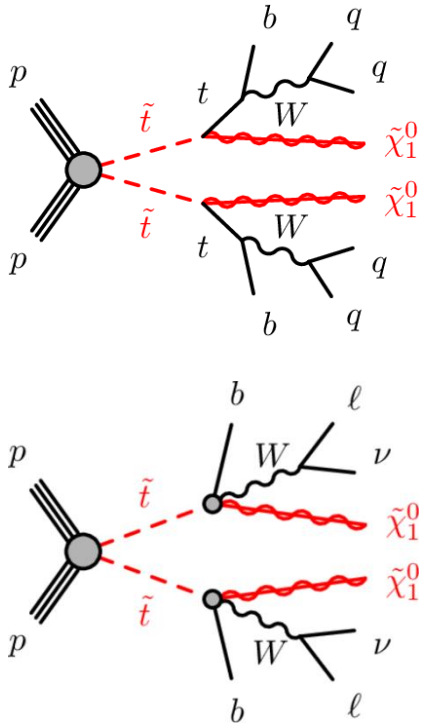
Improve limits in compressed regions



Stop searches

- Different stop decay modes with different mass splitting

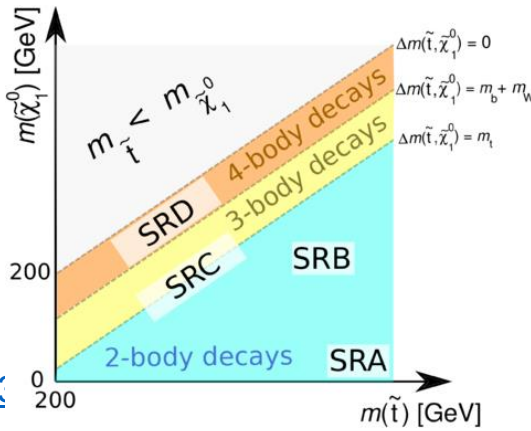


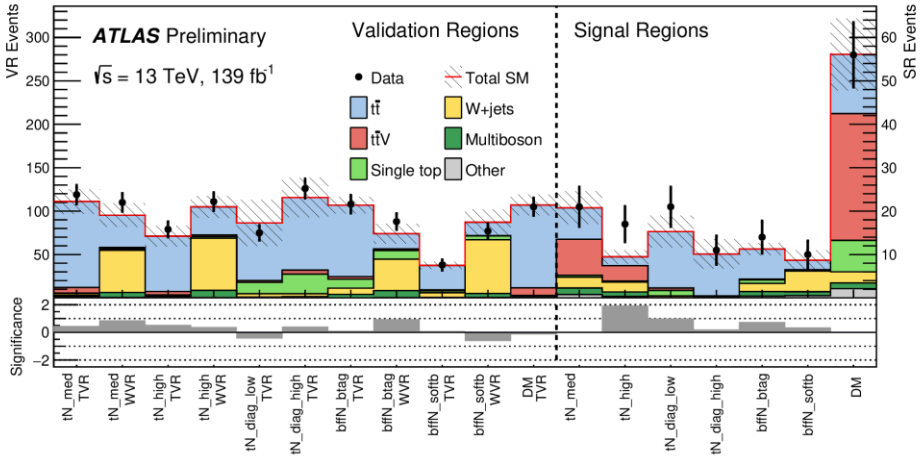


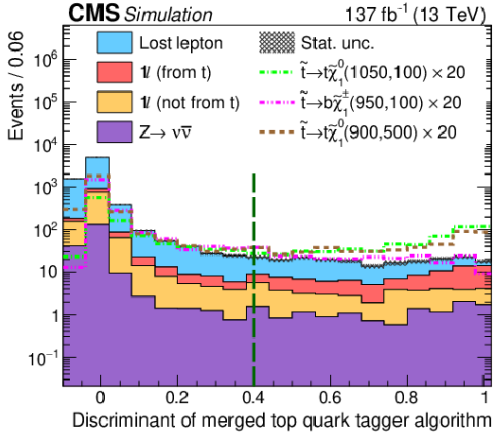
- Large splitting: 2-body decay with on-shell tops
  - Top tagger, large radius jets in boosted regions with merged decay products
- Compressed region: 4-body decay to soft objects
  - Soft b-tagging, soft leptons, high p_T initial state radiation (ISR) jet

Stop searches

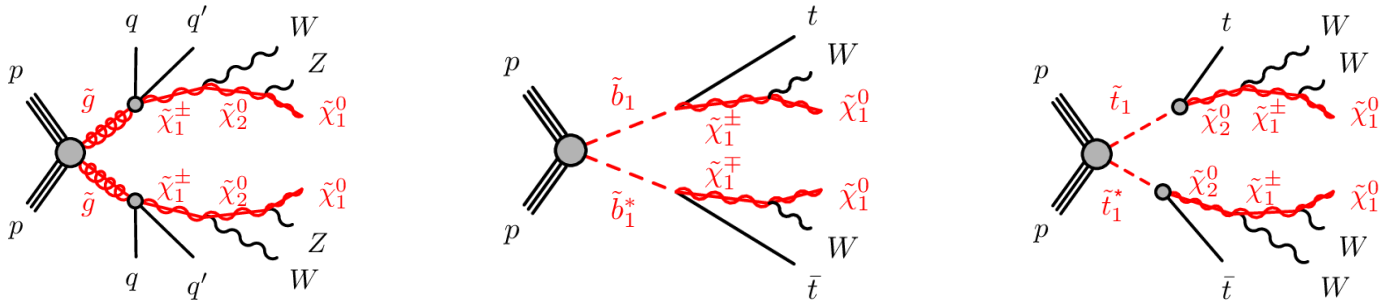
- Full hadronic search: Eur. Phys. J. C 80 (2020) 737
  - veto e/μ, E_T^{miss} >250 GeV
  - SRA-C: Njets≥4 GeV, Nbjets≥2, N hadronic top/W
  - SRC-D: use a high-pT jet from ISR
  - SRD: track-jets with pT>5 GeV
- Single lepton search: ATLAS-CONF-2020-003, JHEP 05 (2020) 03
  - one e/μ, large E_T^{miss}
  - compressed region: ISR jet, soft b-tagging and soft leptons
  - on-shell top region: hadronic top tagging, 'topness' variable





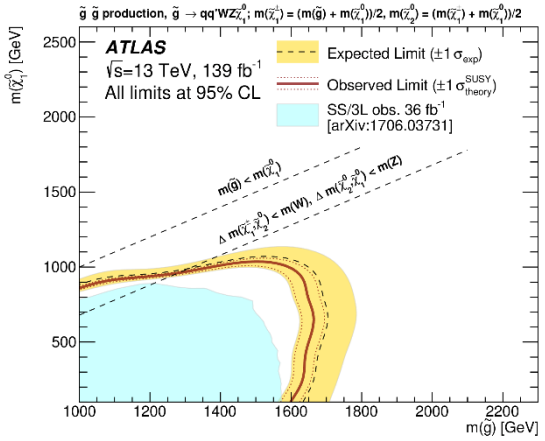


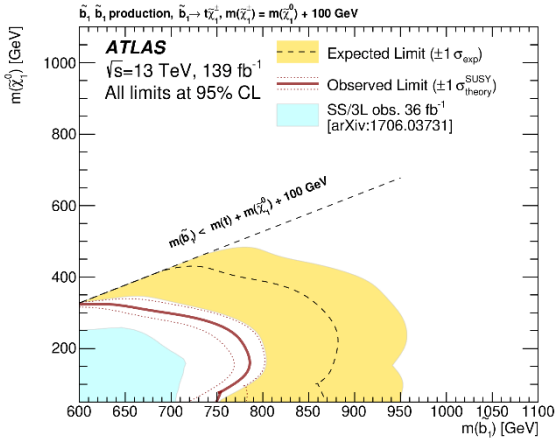
Stop searches

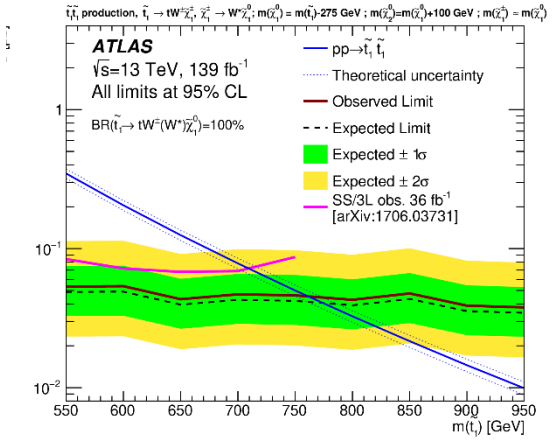


- Gluinos and sqark searches in final states with same-sign leptons and jets: JHEP 06 (2020) 46
  - Final states with jets and either two isolated leptons (electrons or muons) with the same electric charge, or at least three isolated leptons
  - Testing simplified supersymmetric models featuring both R-parity conservation and R-parity violation

Leading contribution from IHEP



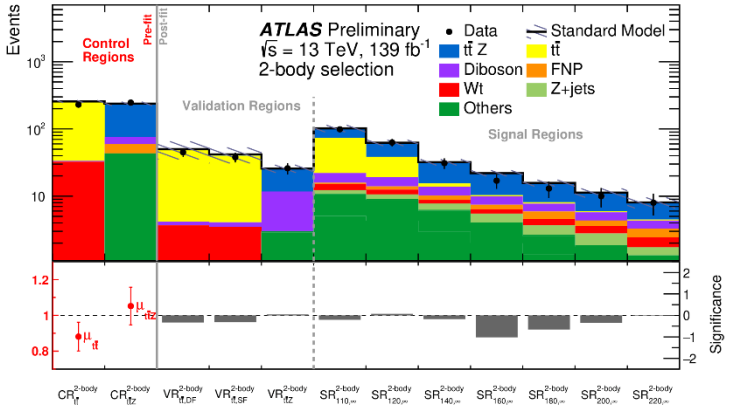


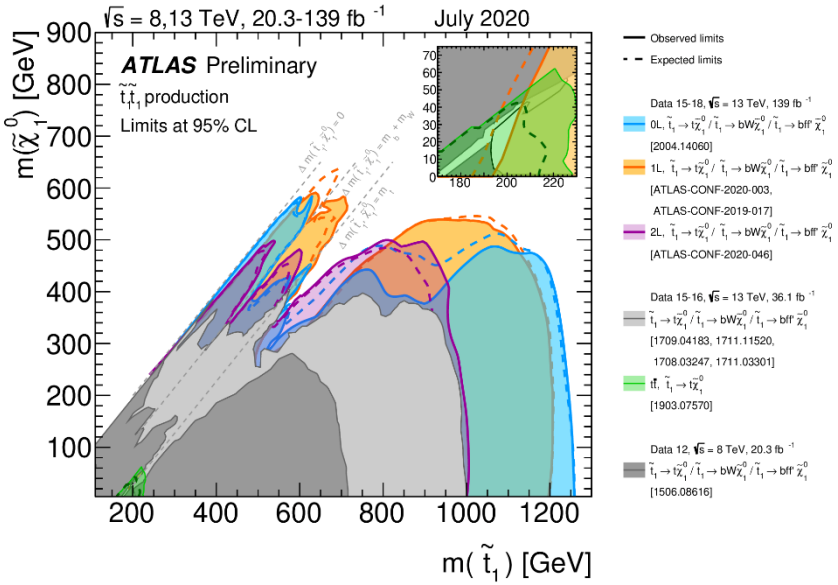


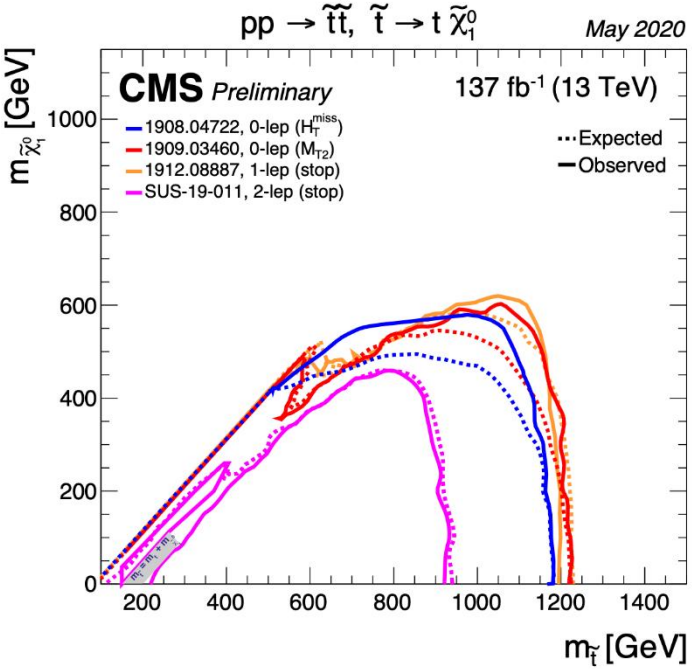
Stop searches

- Dilepton search
  - two OS e/μ, large E_T^{miss}
  - SR for compressed region
    - ISR jet and soft leptons
  - SR with on-shell tops
    - lepton-based top transverse mass

ATLAS-CONF-2020-046

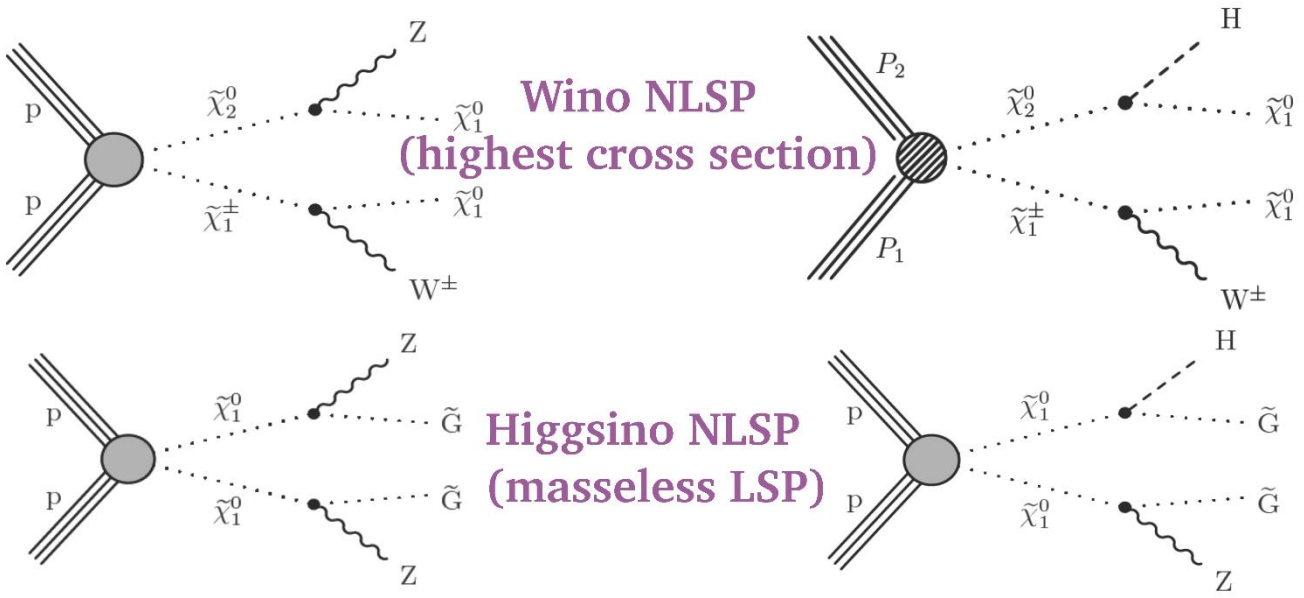






Electroweakinos searches

- Electroweakinos in compress spectra are highly motivated by theory
  - bino-wino cohannihilation: LSP reproduce the correct DM abundance
  - Naturalness: naturally compressed Higgsino can still be light
- Much smaller cross section and soft objects
- Searches rely on multi-lepton final states with clean signatures



Electroweakinos searches

- Tag one leptonically decaying Z with high pT leptons, with two additional jets and E_T^{miss}
  - Leptonic decay Z + E_T^{miss} + hadronic decay of another vector boson
  - W+Higgs(bb), Z+Higgs(bb),

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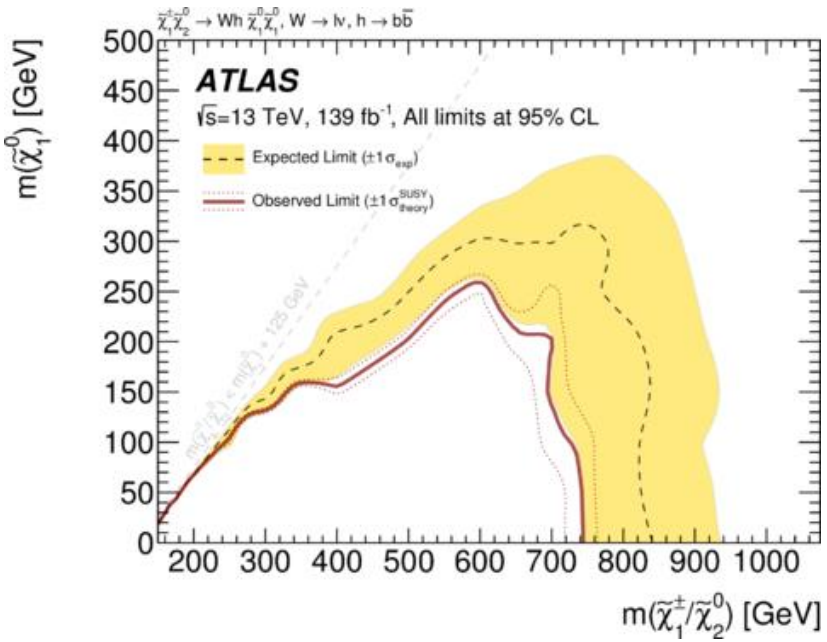
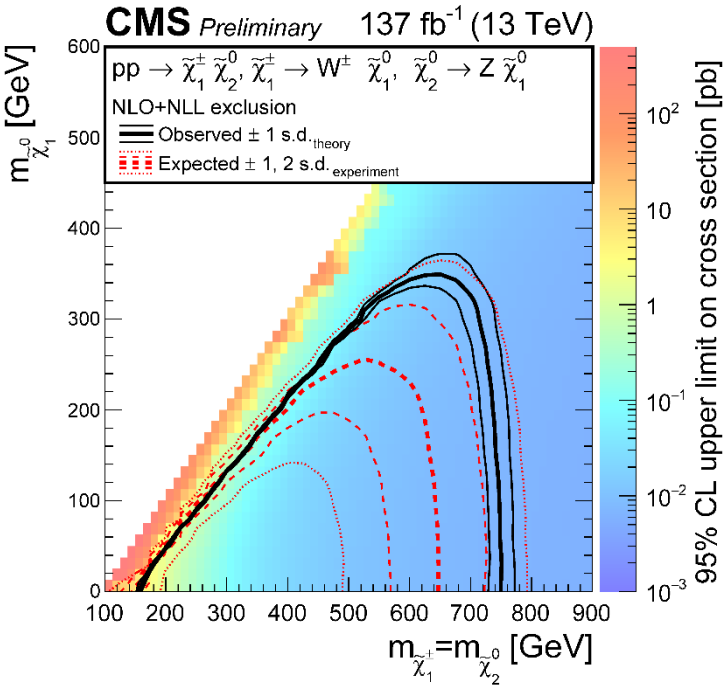


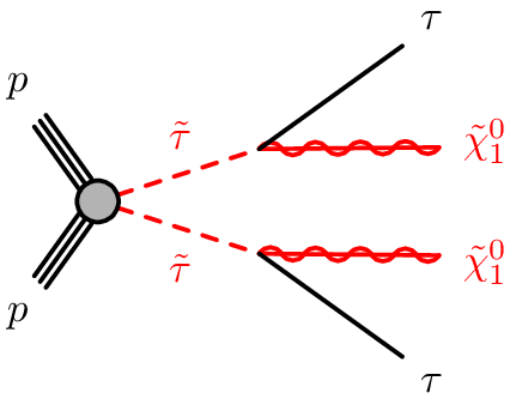
CMS-PAS-SUS-20-001



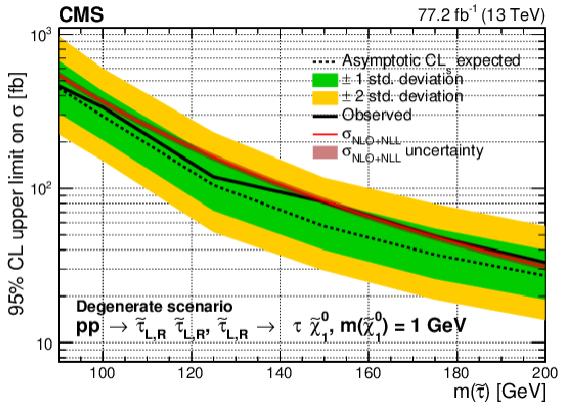
Leading contribution from IHEP

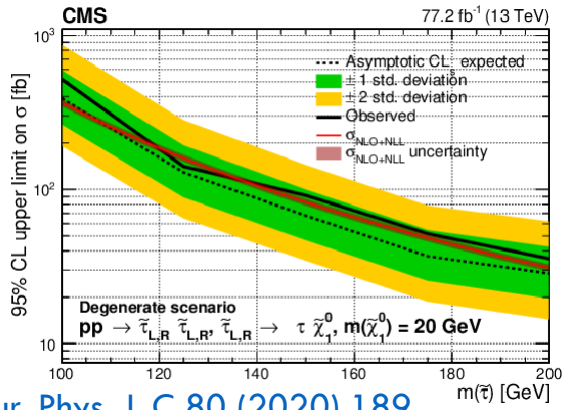
Electroweakinos searches

- Search for direct stau production in events with two hadronic tau leptons
  - a dark-matter relic density in stau coannihlation consistent with cosmological observations
  - highlight of ATLAS SUSY searches, led by IHEP and Nanjing University
- Final states with hadronic taus
  - large background from jets→tau misidentification
  - exploit cross objects triggers like E_T^{miss}+tau, tau+ℓ to lower thresholds and increase as much as possible signal acceptance



Phys. Rev. D 101 (2020) 032009





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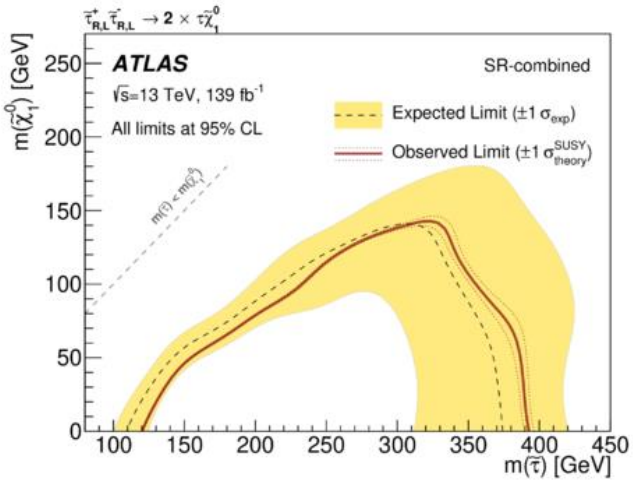
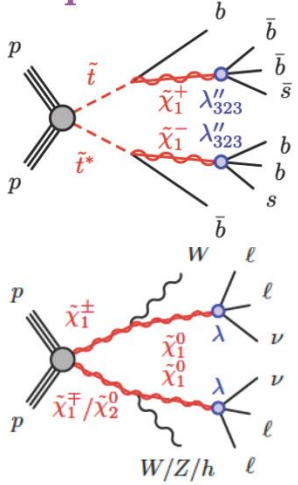
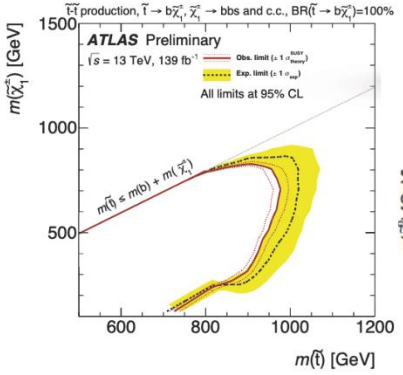


SUSY searches with reduced assumptions

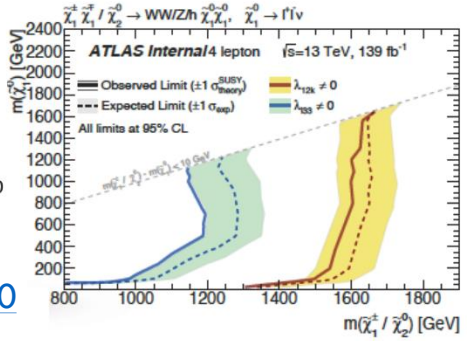
- **Prompt searches for RPV:** R-parity violating SUSY
  - **full hadronic: much harder,** but high multiplicity and resonant structure can offer handles
  - **leptonic: better sensitivity,** cleaner final states arXiv:2010.01015



Stop NLSP, chargino LSP
search based on final states with large b-jets multiplicity



Wino NLSP, Bino LSP
search based on final states with four or more leptons (e, μ,τ)

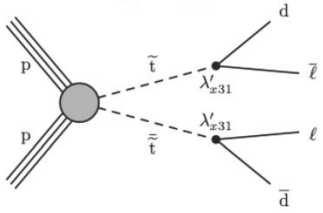


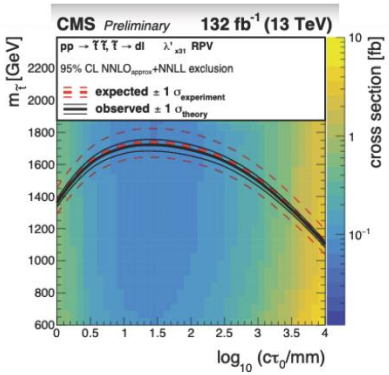
ATLAS-CONF-2020-040

- **Displaced objects searches for RPV and mini-Split SUSY: displaced jets**

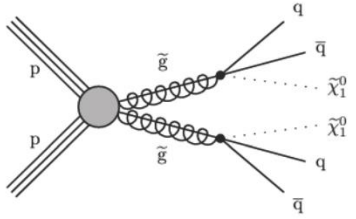
CMS-PAS-EXO-19-021

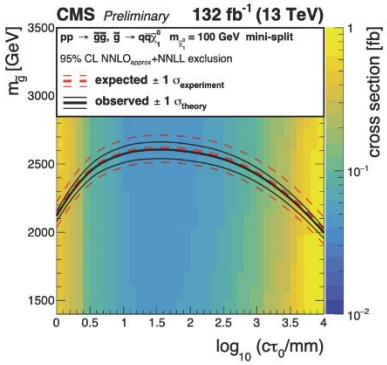
RPV top squarks





gluinos decay through heavy squarks





Summary and prospects

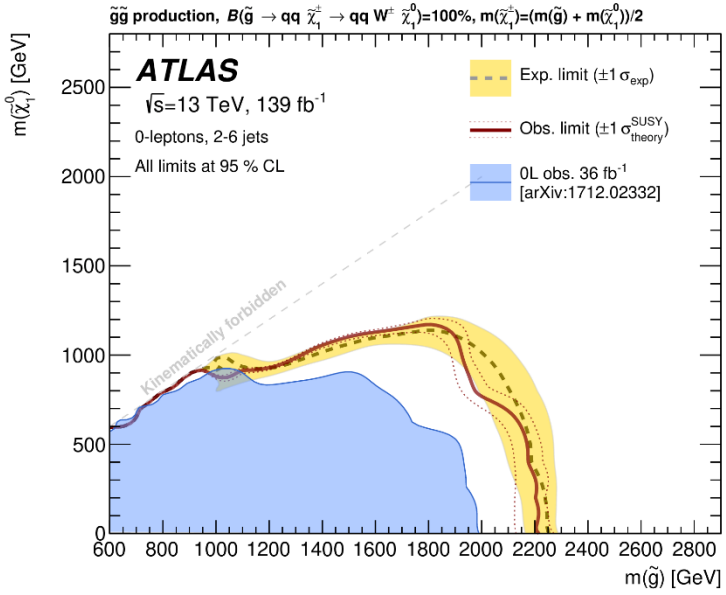
- ATLAS and CMS SUSY searches are completing with full Run2 data
  - Strengthen limits on SUSY particle mass and different models
    - gluinos excluded up to 2.4 TeV, stop excluded up to ~1.2 TeV, charginos excluded up to ~700 GeV
  - Analyses are reaching difficult corners
    - compressed gluinos and top squarks, light Higgsinos, direct stau production etc.
  - Explored more targeted triggers and more sophisticated and refined tools/techniques
  - Results are now also published with likelihood for reinterpretation
    - ATL-PHYS-PUB-2019-029, arXiv:1809.05548 (CMS)
  - More recent SUSY searches with reduced of the assumptions
    - R-parity violating SUSY
    - Mini-split SUSY: give up on naturalness

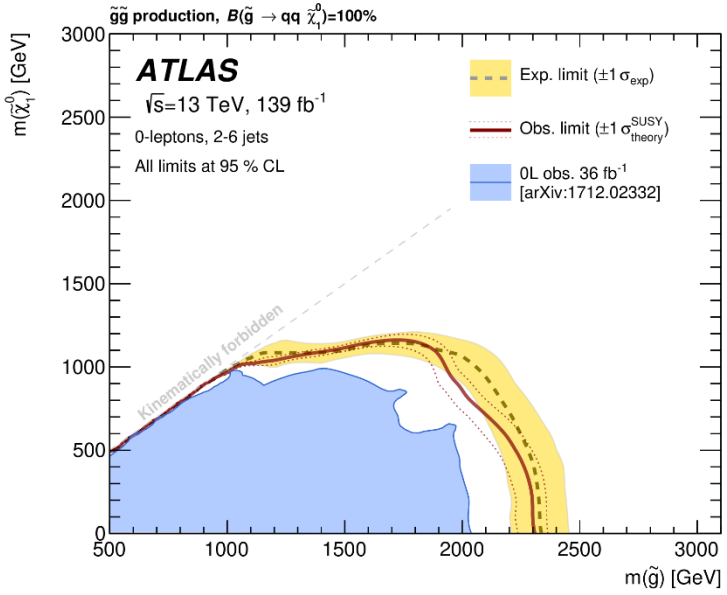
- Exciting results await with updated detectors and larger statistic data in the future!

Backups

0 lepton squarks and gluinos searches

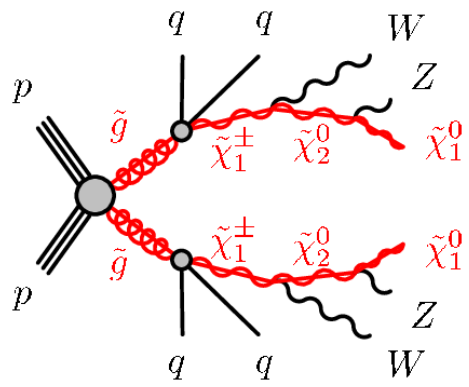
- An exclusion limit at the 95% confidence level on the mass of the gluino is set at 2.30 TeV for a simplified model containing only a gluino and the lightest neutralino, assuming the latter is massless.
  - arXiv:2010.14293

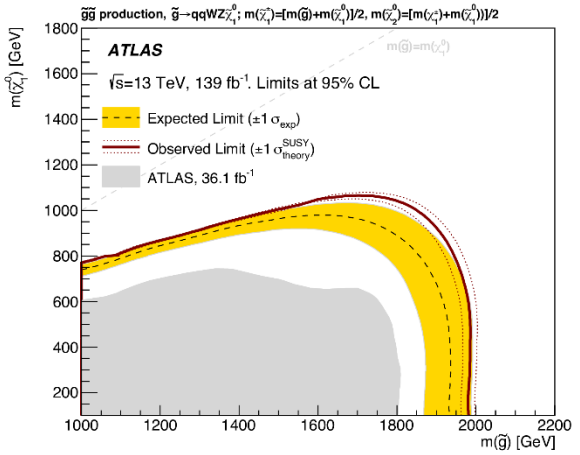


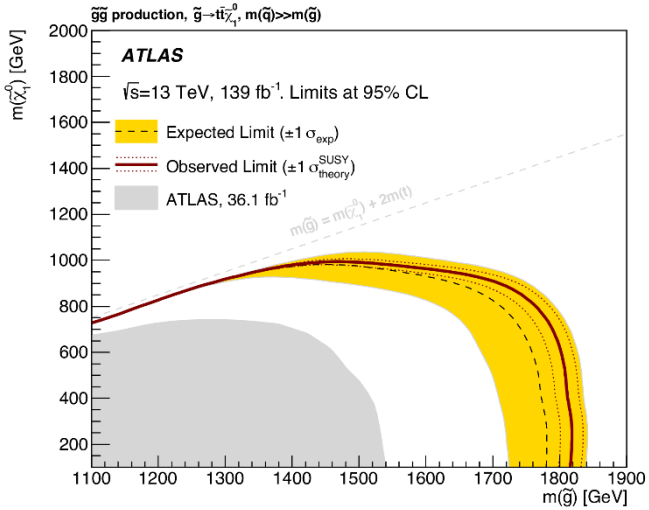


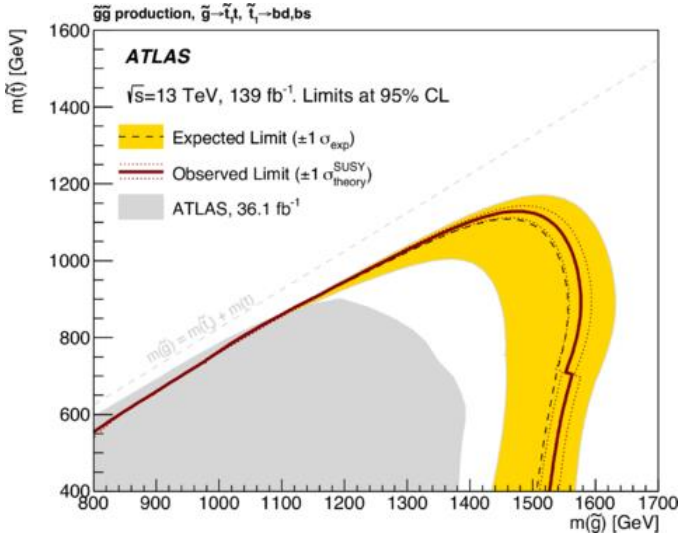
Gluino production with large jet multiplicities

- JHEP 10 (2020) 062: eight or more jets and moderate missing transverse momentum



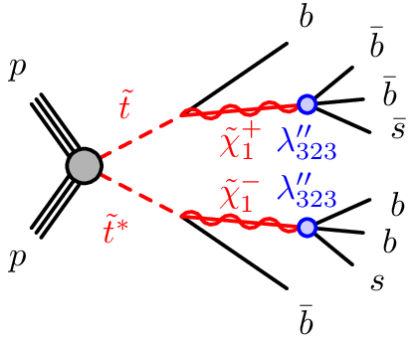


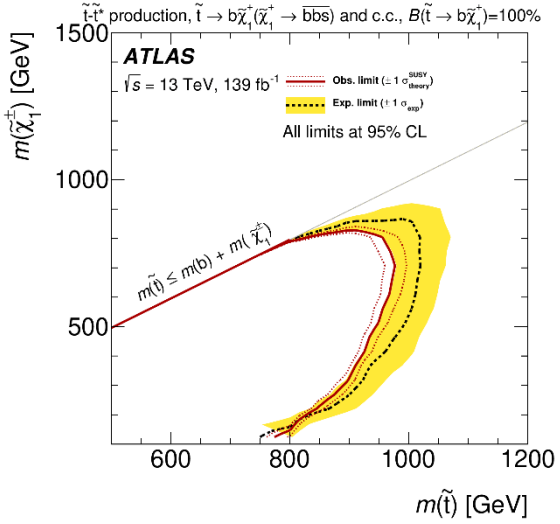


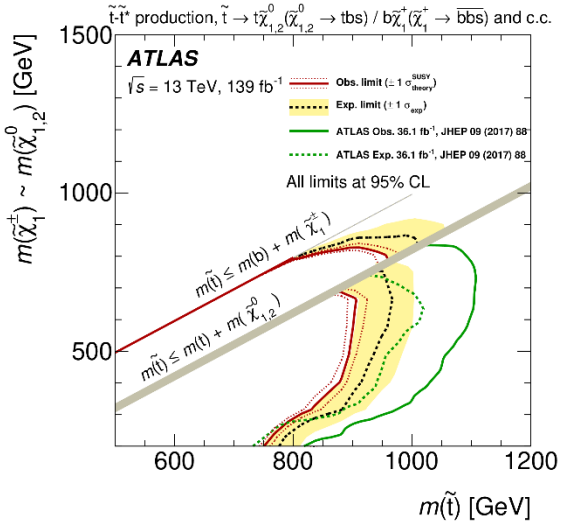


Stop production with large b-jet multiplicity

- arXiv:2010.01015: events characterised by high jet multiplicity, no leptons (electrons or muons), and four or more jets originating from the fragmentation of b-quarks (b-jets).

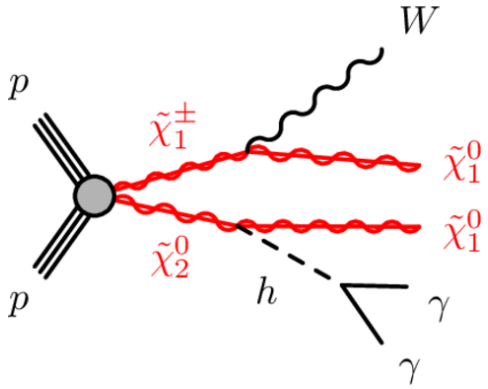


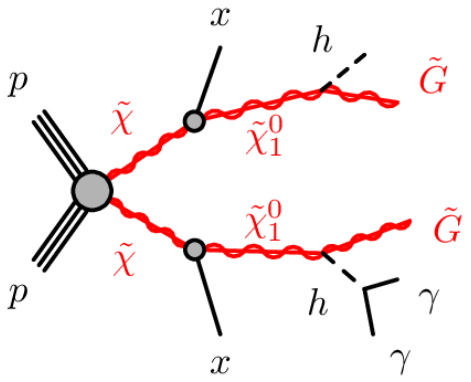


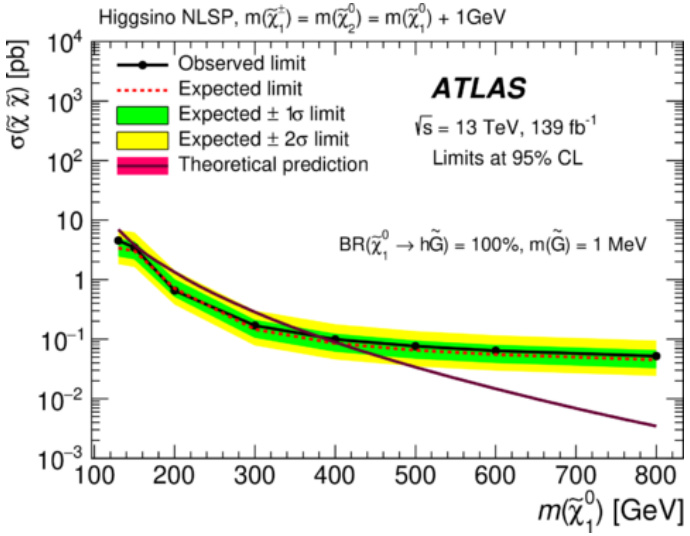


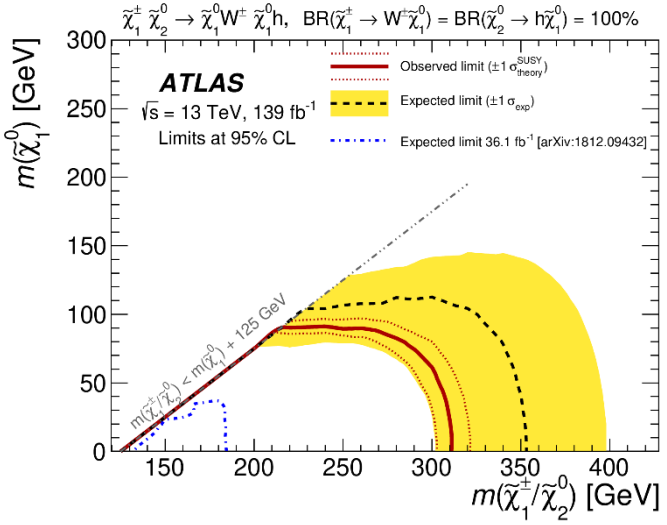
Chargino-neutralino with Higgs to 2 photons

- JHEP 10 (2020) 005 : chargino−neutralino pair decaying via the 125 GeV Higgs boson into photons

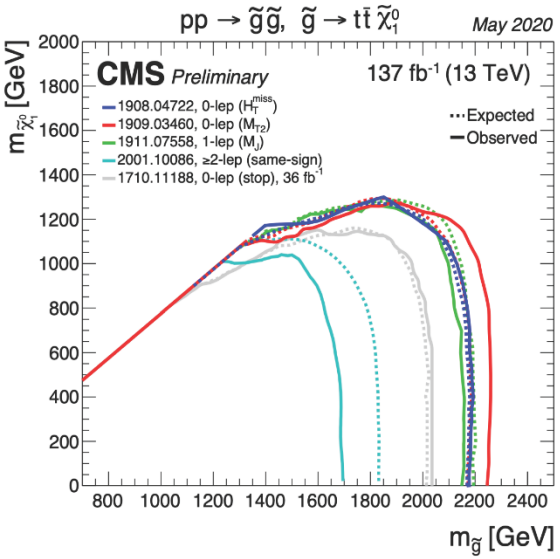


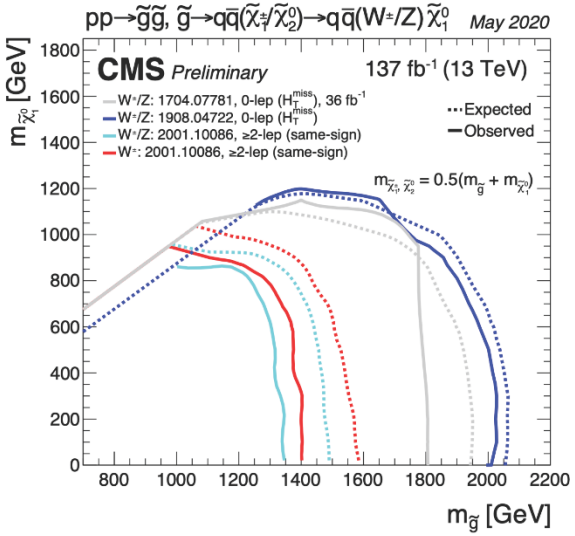


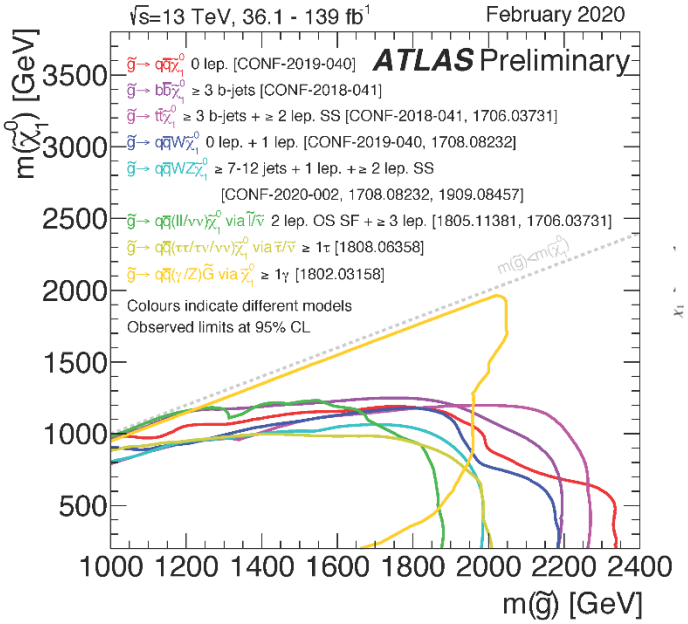




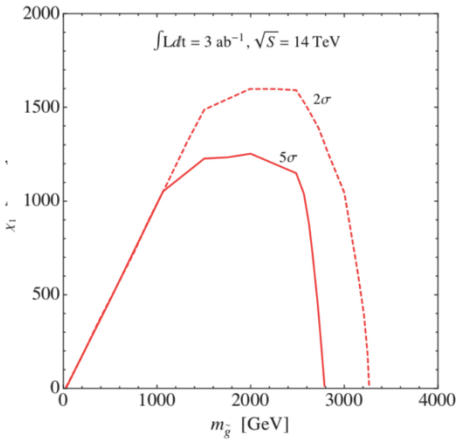
Overview of Gluino searches







More than 3 TeV @ HL-LHC!

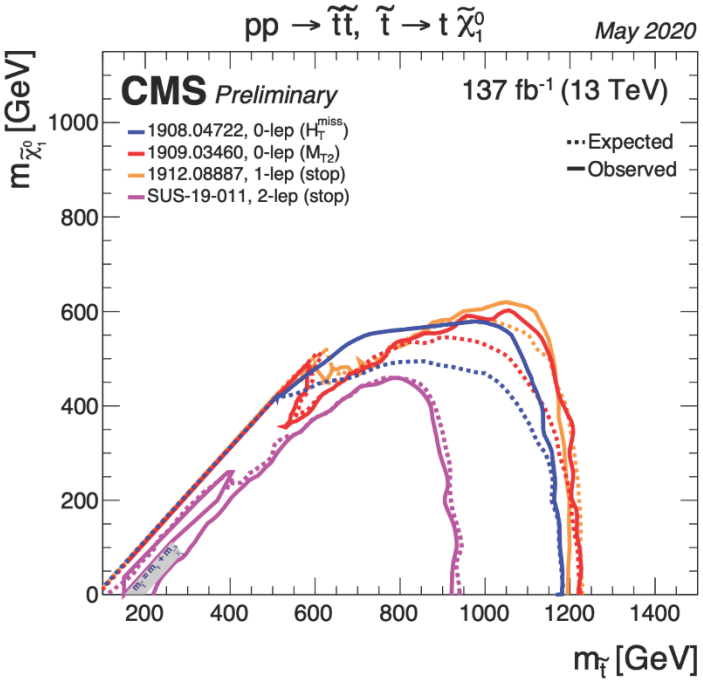


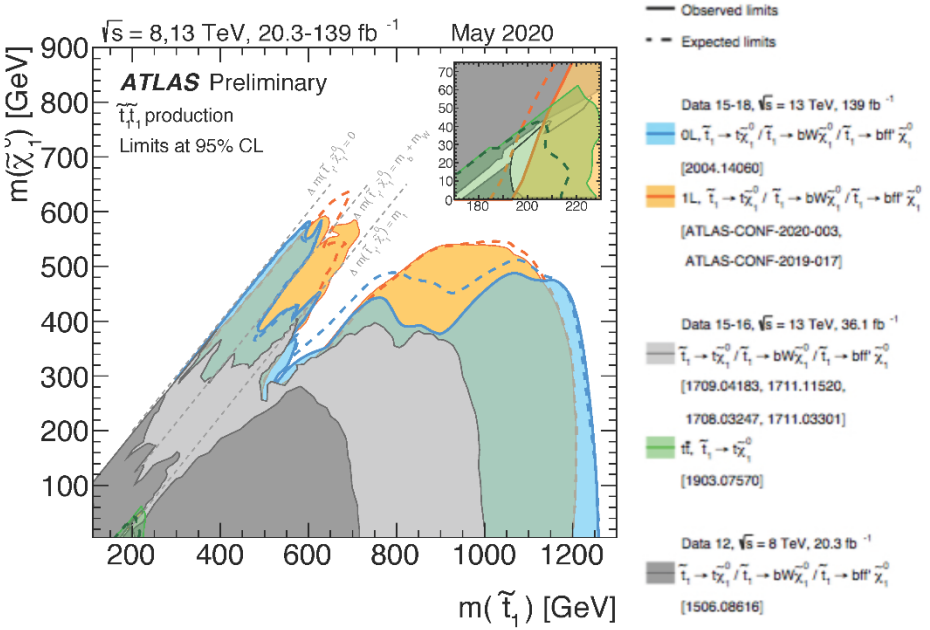
Exclude gluinos below 2.2 (1.6) in RPC (RPV) scenarios

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

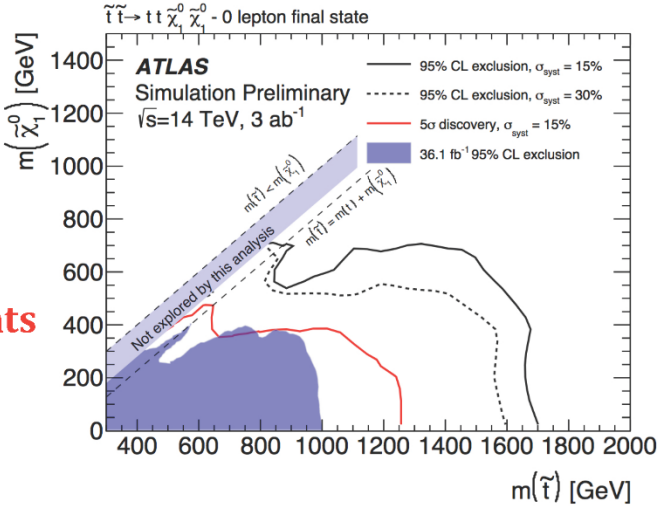
Weaker limits $\tilde{g} \to q\bar{q}V\tilde{\chi}_1^0$

Stop quarks overview





Stops lighter than 1.2 TeV are excluded
Weaker limits in compressed regions (<700 GeV)



Significant improvements expected at HL-LHE

Electroweak future prospects

HL-LHC will help to cover a lot of the phase space, but we still have some way to go!