Summary of SUSY searches

5th ComHEP: Colombian Meeting in High Energy Physics

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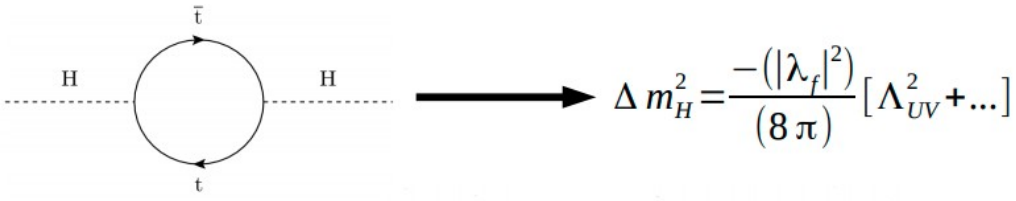
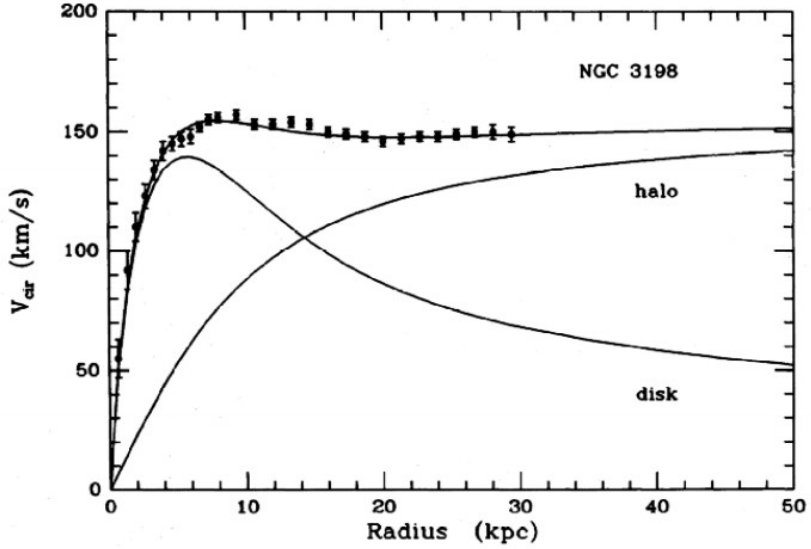
EXCELENCIA MARÍA DE MAEZTU

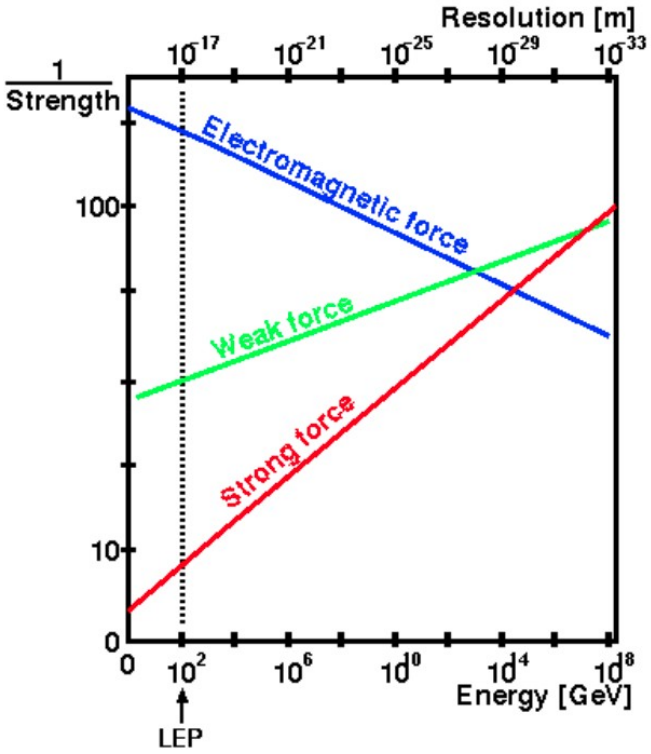
The Standard Model: not quite everything

- The Standard Model of Particles even if extremely successful cannot explain everything
  - **The hierarchy problem** → stability of the Higgs mass under quantum corrections
  - **The problem of dark matter** → gravitational effects observed but not a "candidate"
  - **Impossibility to achieve Grand Unification** → not converging couplings at Λ_{GUT}



$$\Delta m_H^2 = \frac{-(|\lambda_f|^2)}{(8\pi)}[\Lambda_{UV}^2 + \ldots]$$





Supersymmetry: elegant and gorgeous

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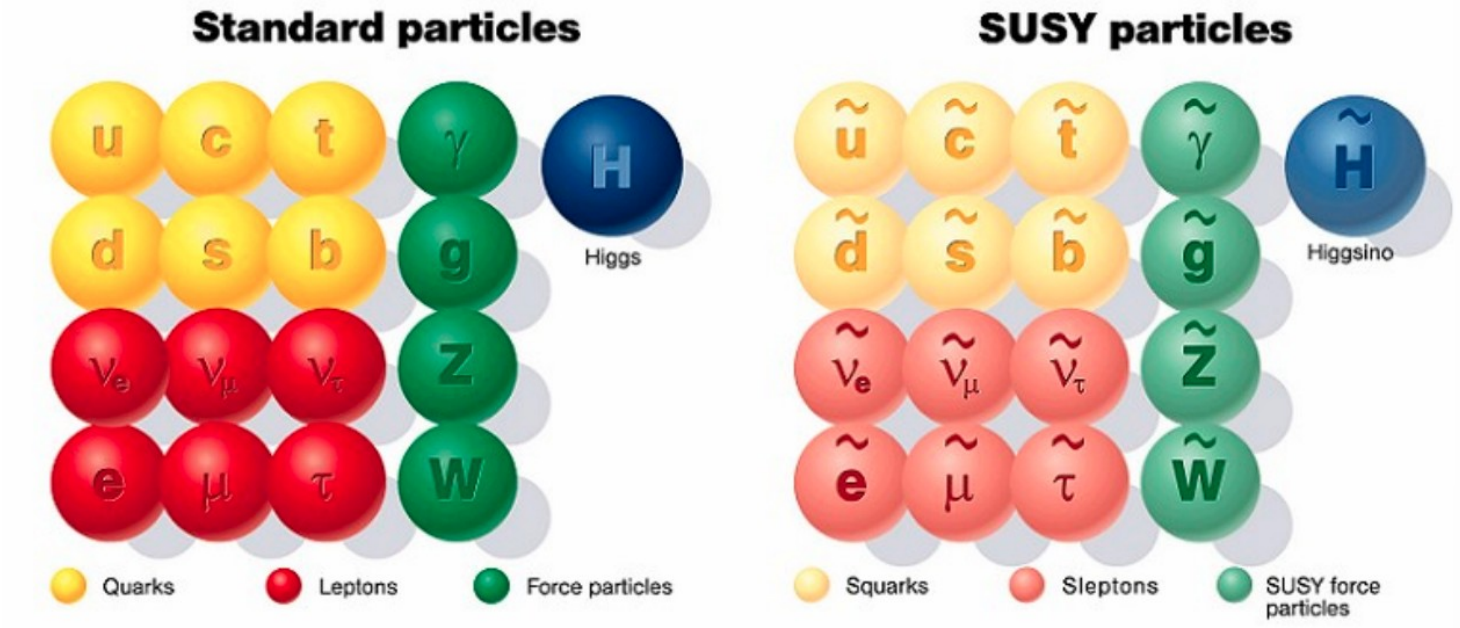
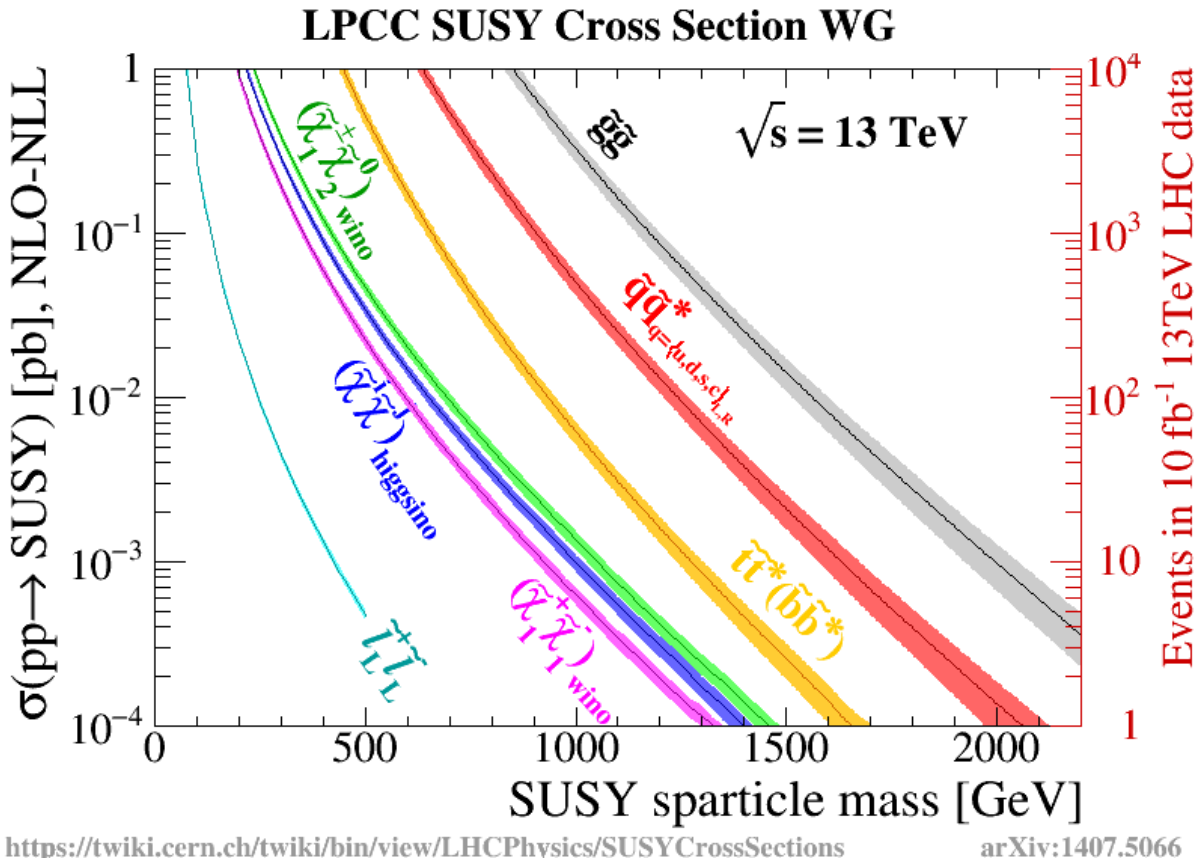
- Supersymmetry imposes a new fundamental symmetry between fermions and bosons
- The new super-partners give answers to the aforementioned problems
  - Δm_H **compensated by boson loops** → if gluino, stop, higgsino masses in the TeV scale
  - **Provides DM candidates** → combinations of electroweak and Higgs SUSY partners
  - **Leads to unification** → running couplings coincident at Λ_{GUT}



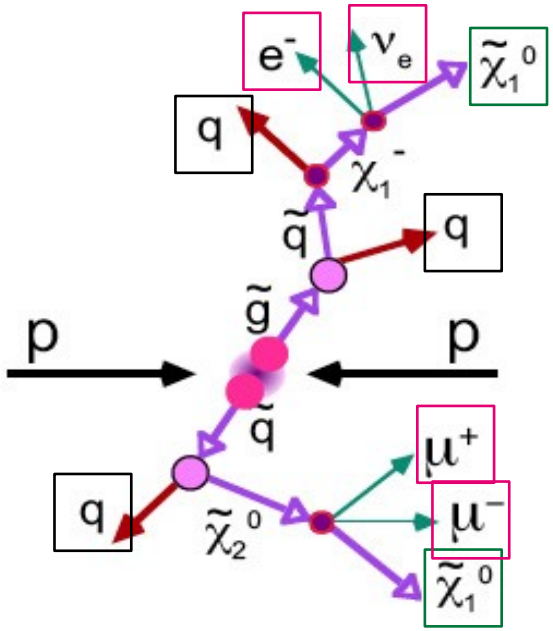
The LHC as a SUSY factory

- If SUSY is a reallity thousands of SUSY particles would have been produced at the LHC
- Large search programs put in place by the LHC experiments in the last years
  - Looking mainly for prompt Strong, Third Generation and EWK SUSY production



How does a classic SUSY topology look like?

- Classic searches at the LHC are looking for pair production of SUSY particles
- Long decay chains are expected including a large variety of Standard Model particles
  - Because of the branching fractions this translates into large number of jets
- If R-parity is conserved the lightest neutralino (LSP) is stable and escapes detection
  - Leaving a large amount of Missing Transverse Momentum in the event



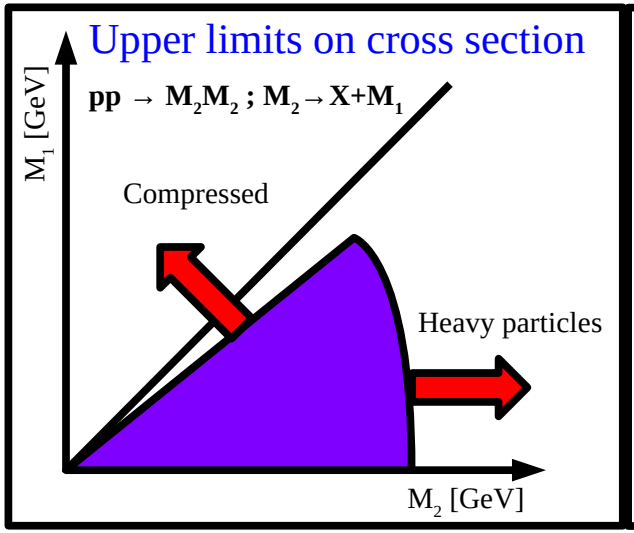
Large number of jets

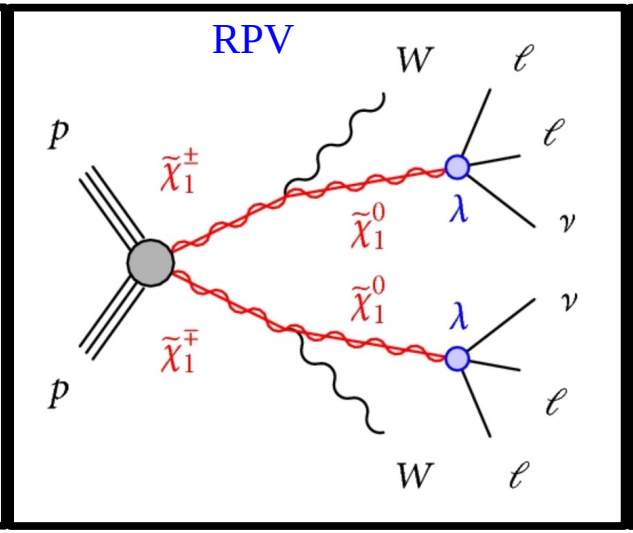
Large transverse missing momentum

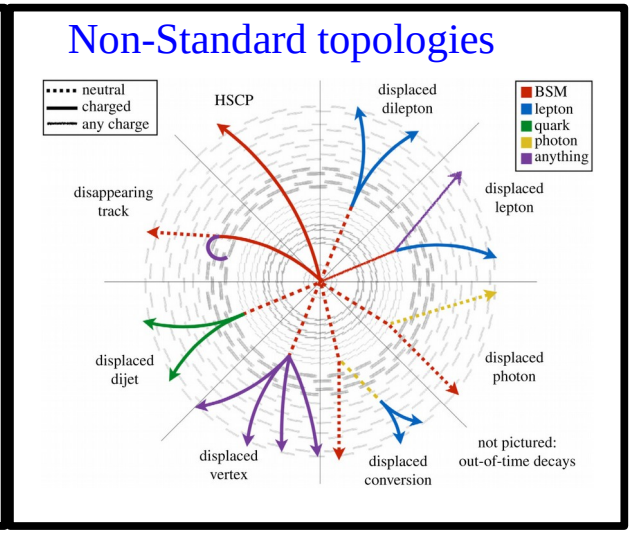
Potentially large multiplicity of other SM particles

Where is SUSY? Hiding from us?

- Are SUSY particles too heavy for 13 TeV? Cross sections very small at the LHC?
- Has SUSY a very compressed spectra giving place to soft-like signatures?
- Is R-parity not conserved? No or low missing-transverse momentum-like signatures?
- Is SUSY produced in non-conventional topologies: Long-lived particles, stealth SUSY?







Disclaimer

- Literally hundreds of very interesting SUSY results produced by the experiments
- Impossible to cover all of them in this talk
- Focus on some recent highlights using the full luminosity of Run 2 (in most of the cases)
  - Also with some personal bias :-)
- Have a look at the experiments result pages in you are interested in any specific analysis

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

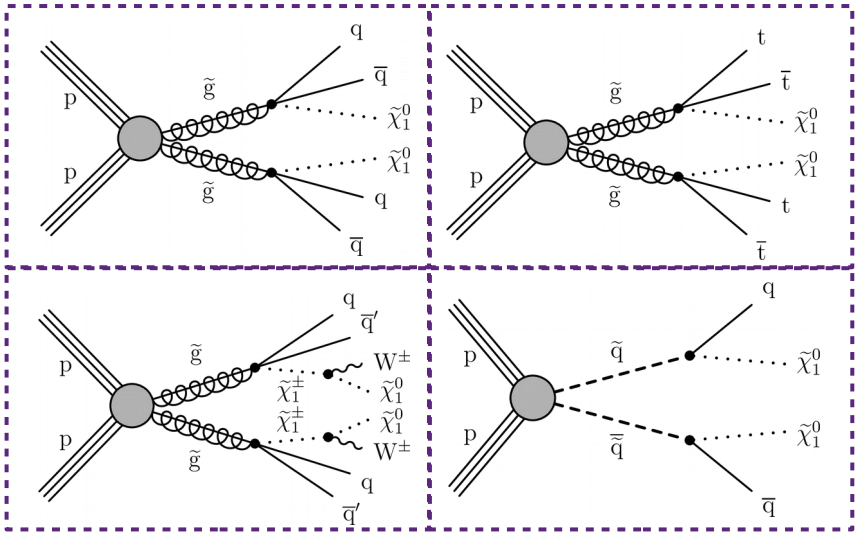
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

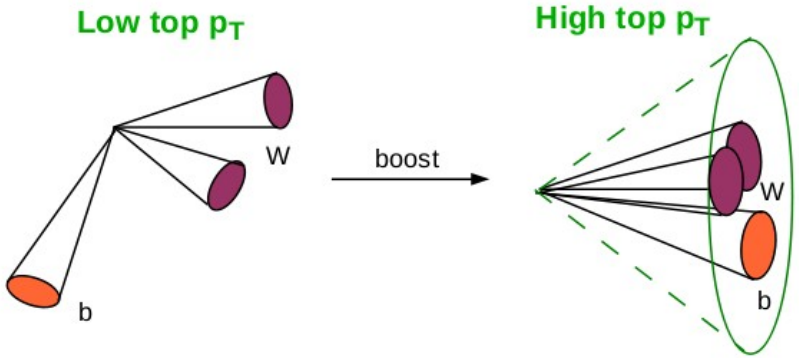
https://lhcbproject.web.cern.ch/Publications/LHCbProjectPublic/Summary_QEE.html

+ have a look at HEP data: a lot of analysis information. ATLAS even starting to publish full statistical likelihoods (search for it in their page), other experiments will follow.

Strongly produced SUSY

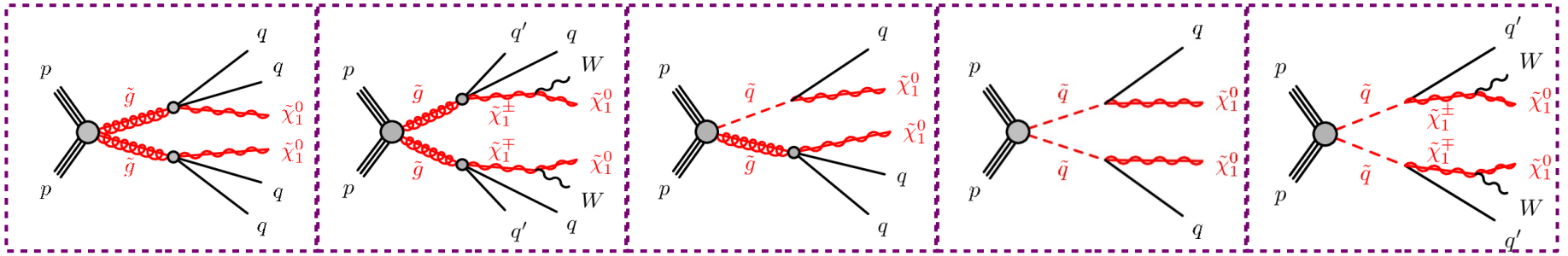
- Gluino and light squark pair-production yielding topologies with a high multiplicity of jets
  - Decay chains may involve several light-quarks, b-quarks or top-quarks
  - Chains with NLSP neutralinos/charginos migh produce additional Z or Ws
- All-hadronic analysis are dominating most of this phase space using jets-sensitive quantities
- Single-lepton searches still have good sensitivity for signatures with W bosons
- Battlehorse: higher sparticle masses produce boosted objects → jet substructure, fat jets, etc





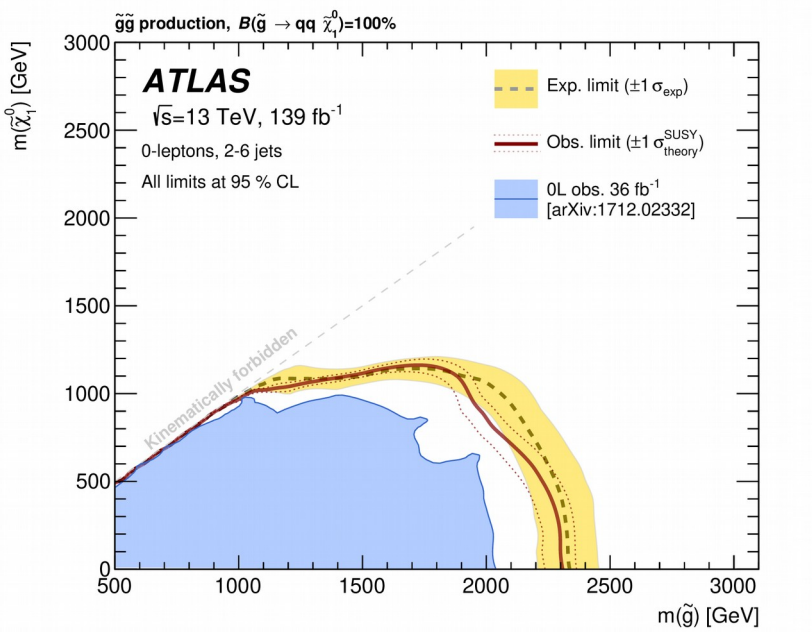
Inclusive gluino-light squark search

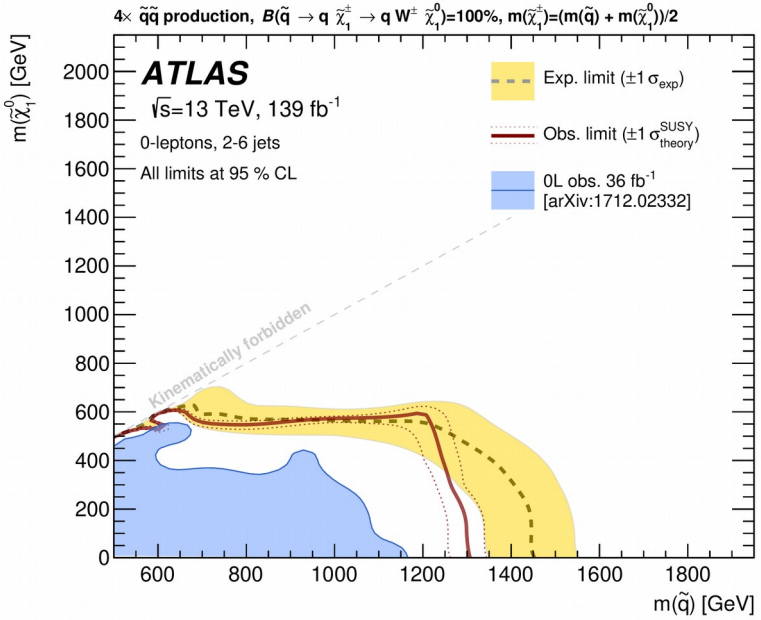
- Search looking for several topologies involving gluino and squark production



- Rejecting b-tagged jets in order to remove ttbar background

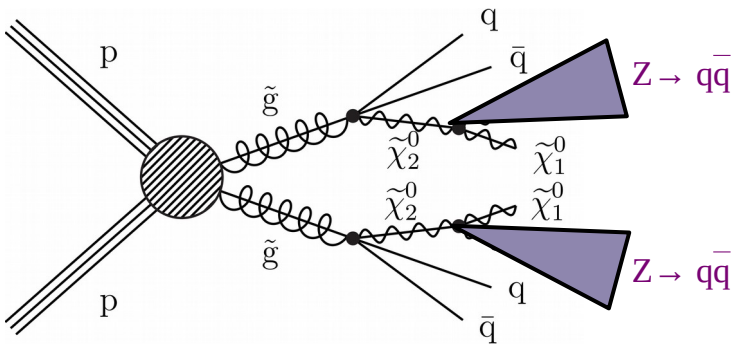
arXiv:2010.14293





Gluino production with boosted Z

- Exploring topologies with large jet multiplicity and a boosted Z decaying into jets
- The two Z bosons produce two AK8 jets (R_{jet}=0.8) → using soft-drop jet mass



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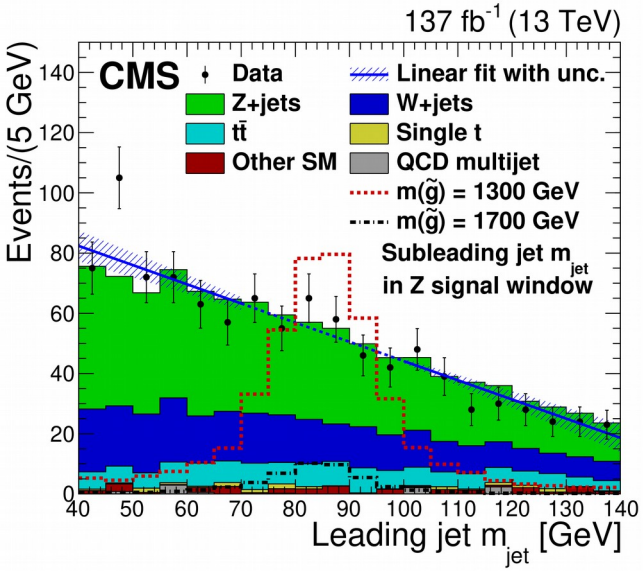
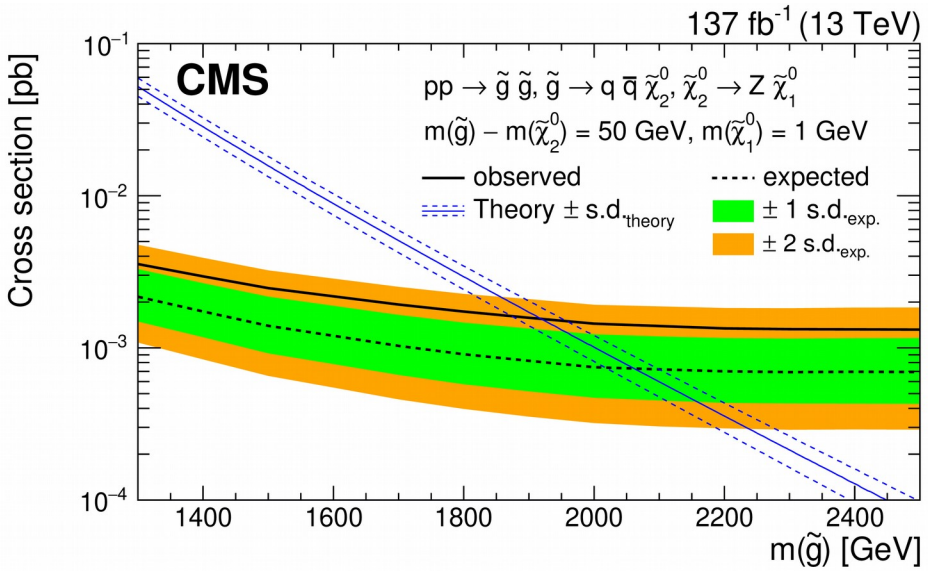
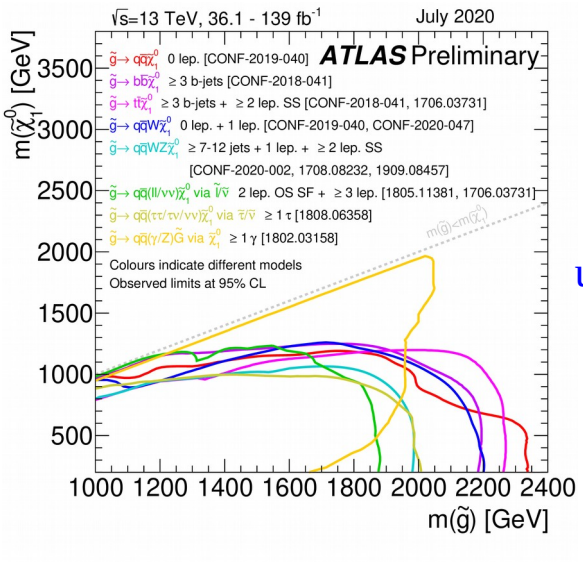
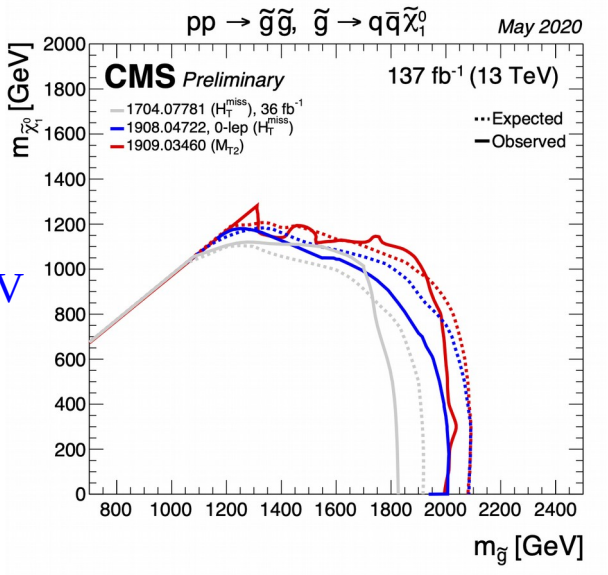


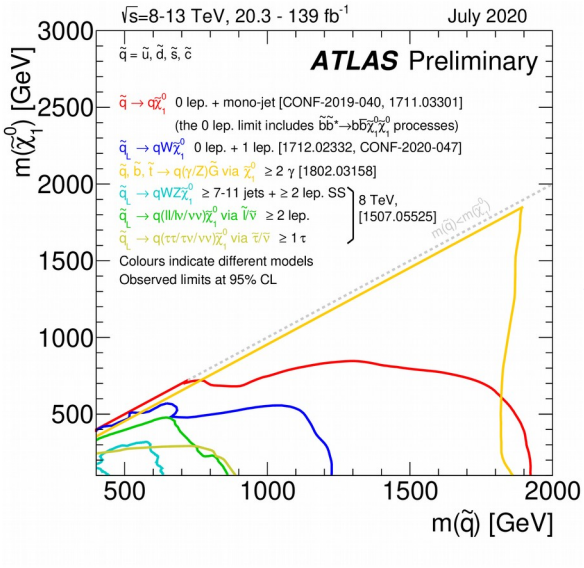


Strongly produced SUSY: (brief) summary

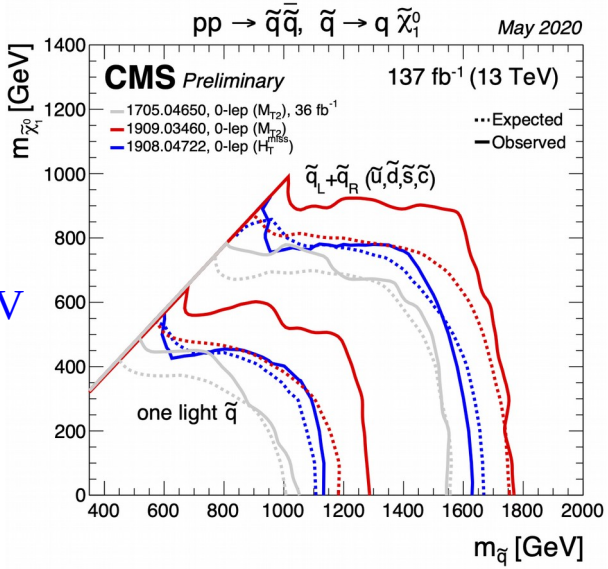


Gluino mass limits
up to 2100-2300 GeV



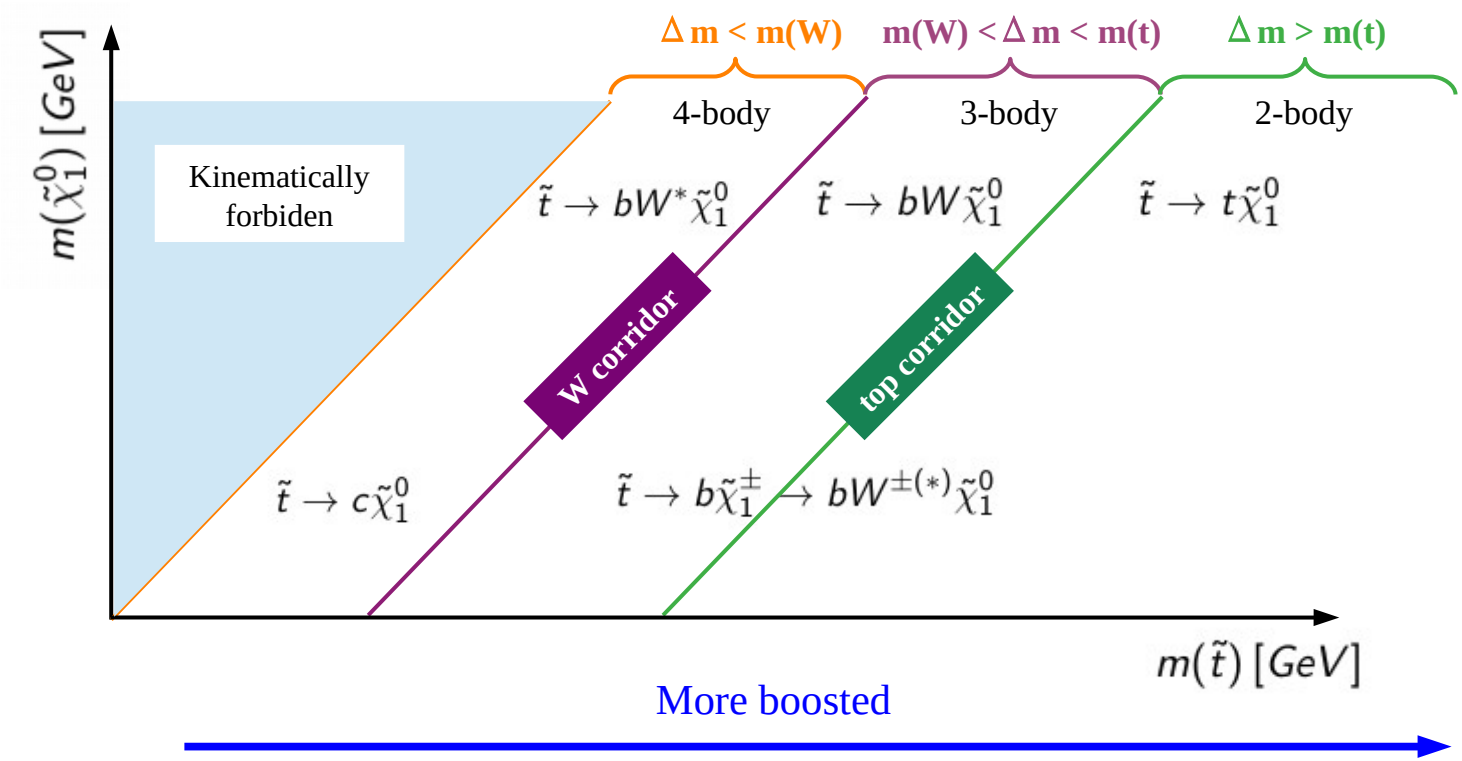


squark mass limits
up to 1800-2000 GeV



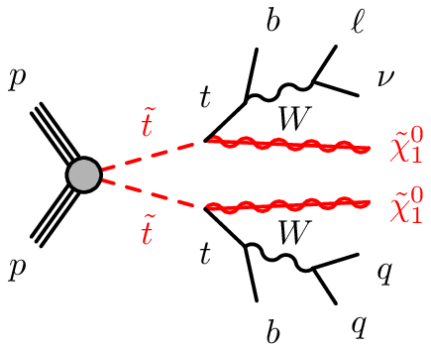
Third generation searches: stop

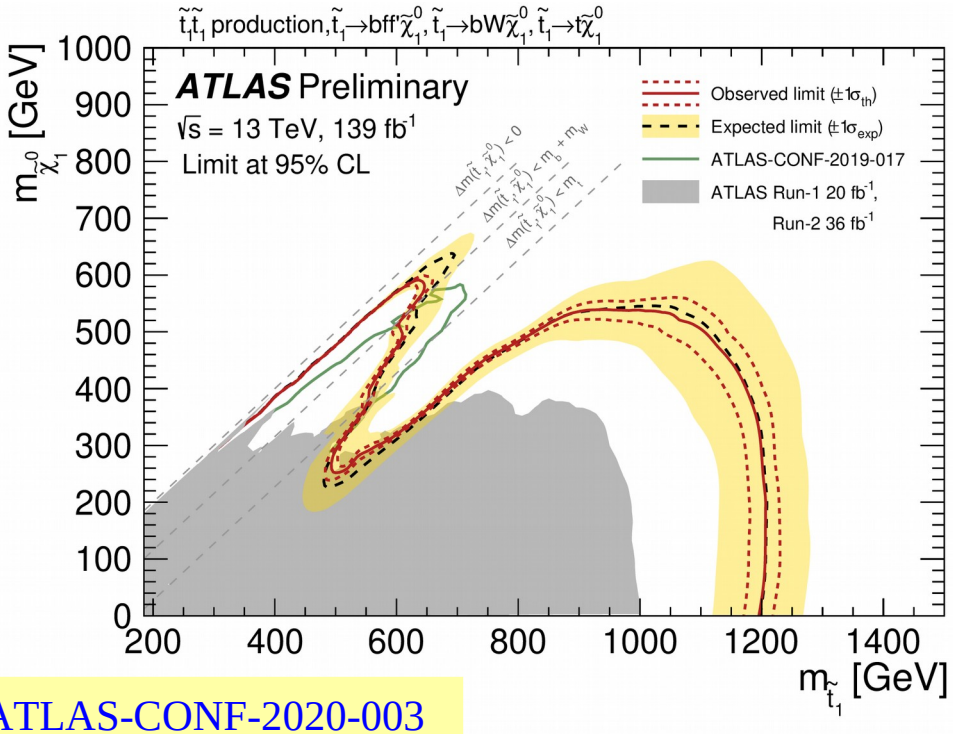
- The stop landscape comprises a rich variety of topologies according to the mass splitting
- Several final state are exploited: all hadronic, single lepton and di-lepton final sates
- Battlehorse 1: expanding to higher masses → boosted jets, top taggers, and other techniques
- Battlehorse 2: Filling the corridors → compressed spectra, low transverse missing momentum



Example: single lepton stop searches

- Use of b-taggers to identify events susceptible of having top quarks
- Discriminating variables: transverse invariant mass, topness, etc
- Categories targeting heavy stops producing boosted top quarks
- Also categories with sensitivity to corridor regions (less missing transverse momentum)





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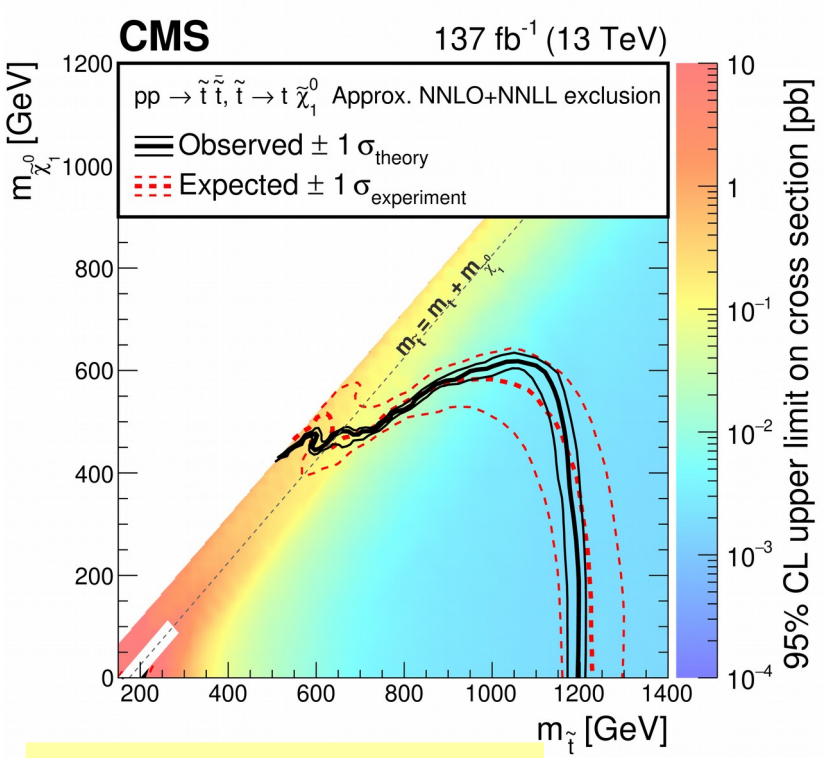

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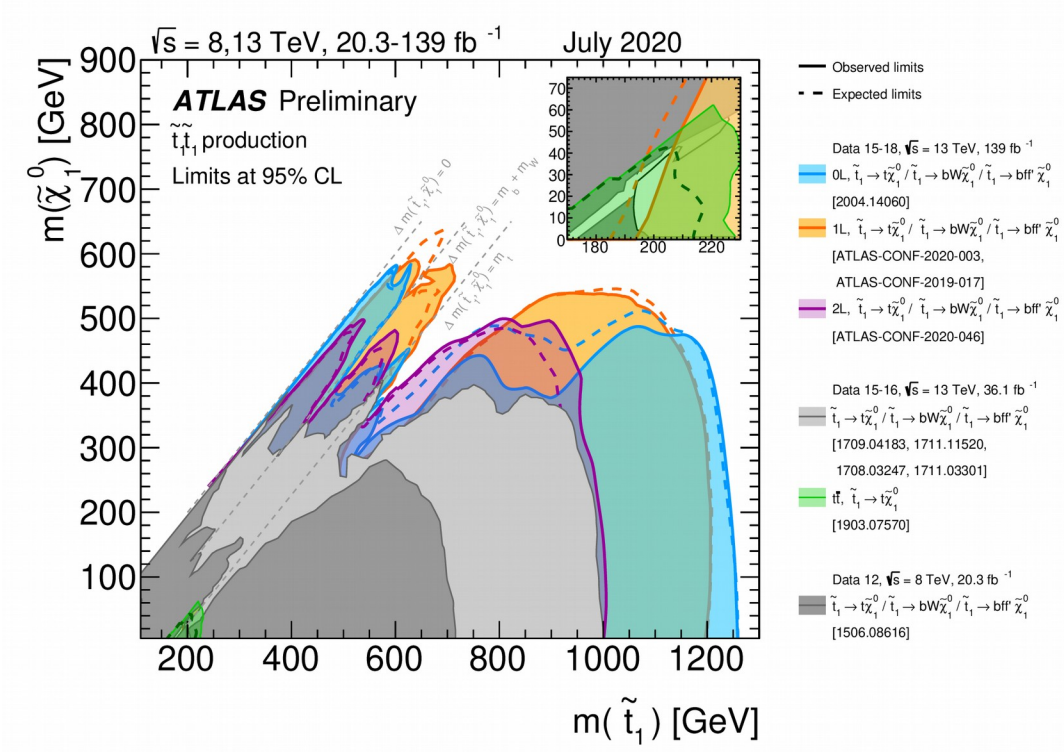
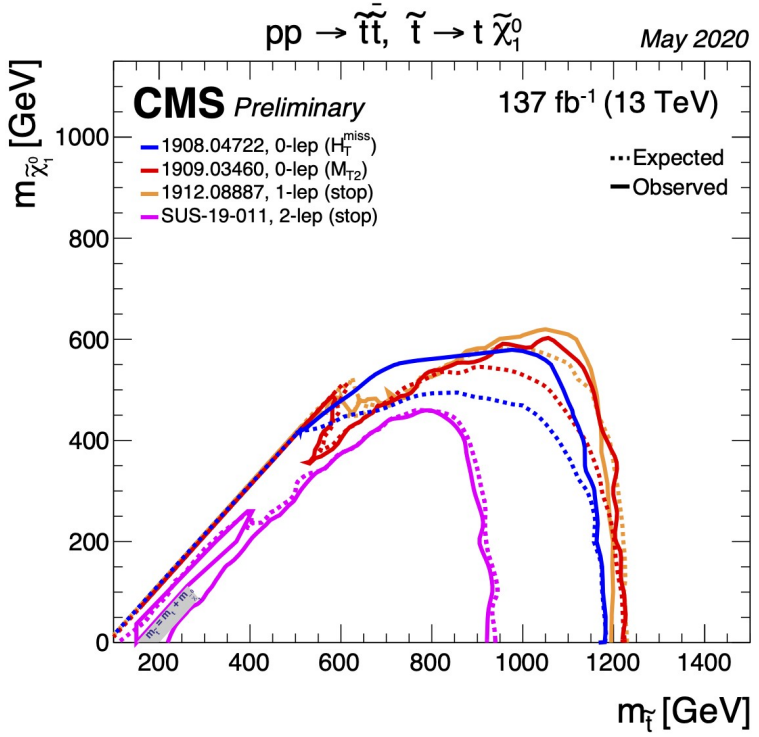
Stop searches: (brief) summary

- Stop masses are excluded up to 1200 GeV mainly by all-hadronic and single lepton searches
- Corridors excluded up to stop masses of 600 GeV (all-hadronic, single lepton, and dedicated)
- Dedicated analysis also excluding the low mass corridors (the “ttbar-like stop” analyses)





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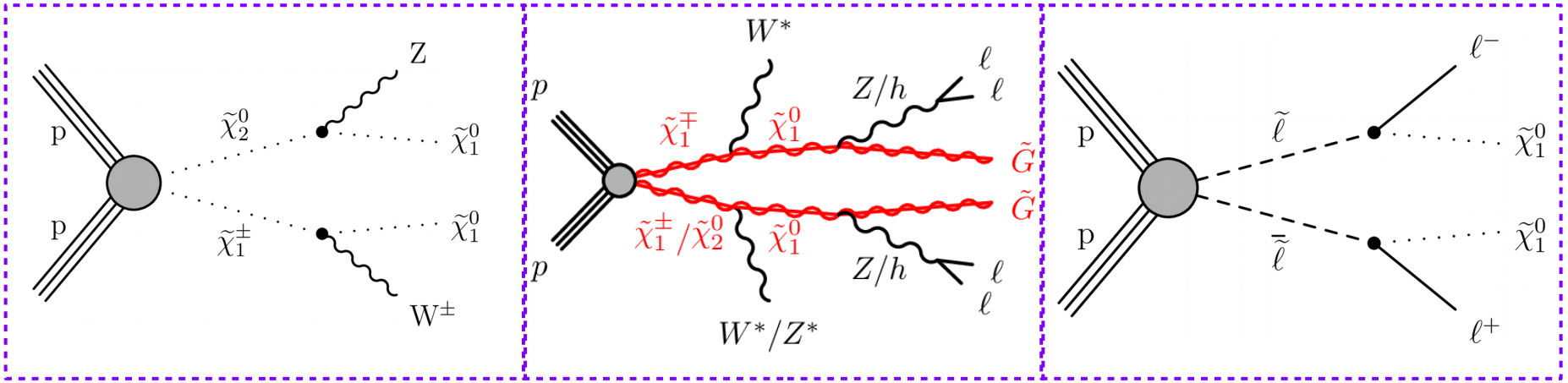
EWK searches

- Production of charginos, neutralinos and sleptons decaying into the lightest neutralino
- But also Gauge Mediated Symmetry Breaking (GMSB) models with LSP the Gravitino



- Decay chains involve a number of W/Z/H bosons with large transverse missing momentum
- Interesting final states: 2 opposite-sign, 2 same-sign leptons or multileptons
- Battlehorse 1: Exploring the high mass regions → boosted objects → boosted Z or W
- Battelhorse 2: Compressed spectra where mass splitting of neutralinos is small.

2 opposite-sign, same flavor EWK searches

- Looking for 2 opposite-sign, same-flavor leptons compatible with the Z boson
  - Jets are requested to be compatible with the Z/W bosons (or b-jets compatible with the H)
  - Categories requesting for fat jets ($\Delta R_{jet} = 0.8$) to catch very boosted bosons
- Looking also for 2 non-resonant opposite sign same flavor leptons with no jets (sleptons)

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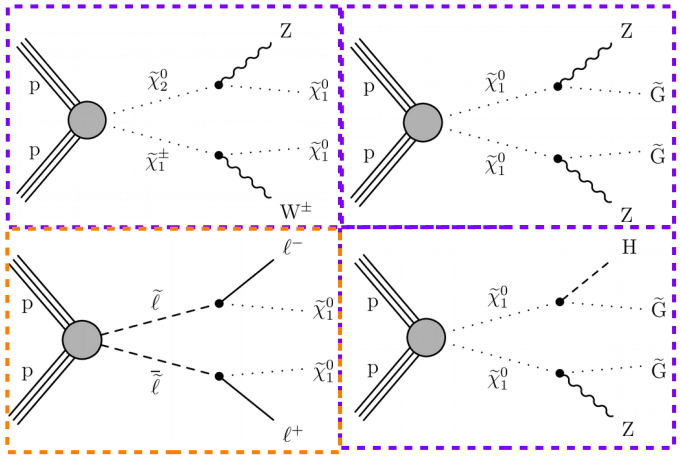
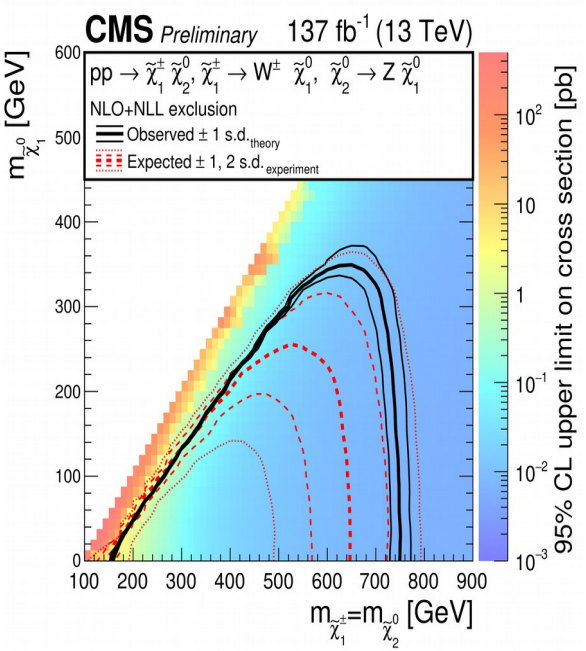
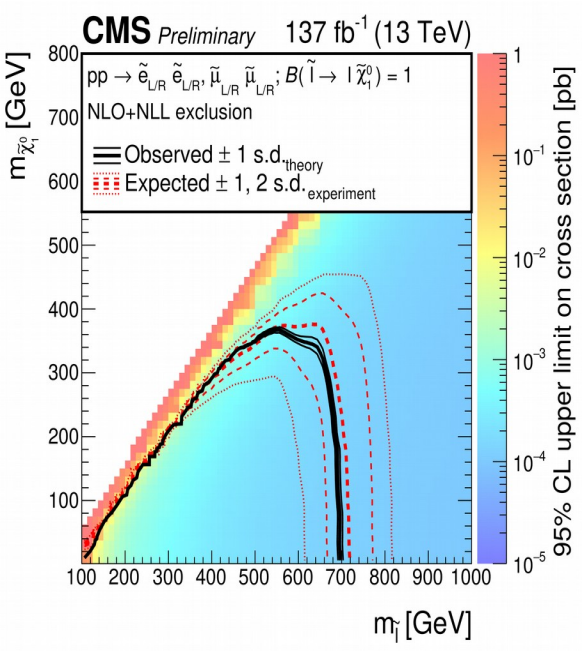
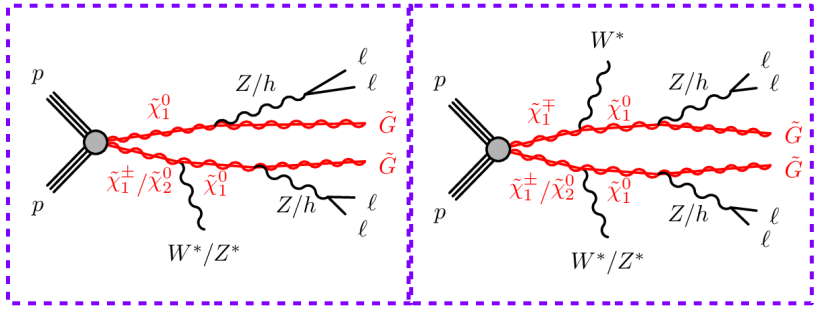






EWK searches with 4 leptons

- GMSB model with long decay chains with large multiplicity of bosons (W, Z or H)
- Low-background search → Di-boson, tri-boson, ttZ and other multi-boson signatures



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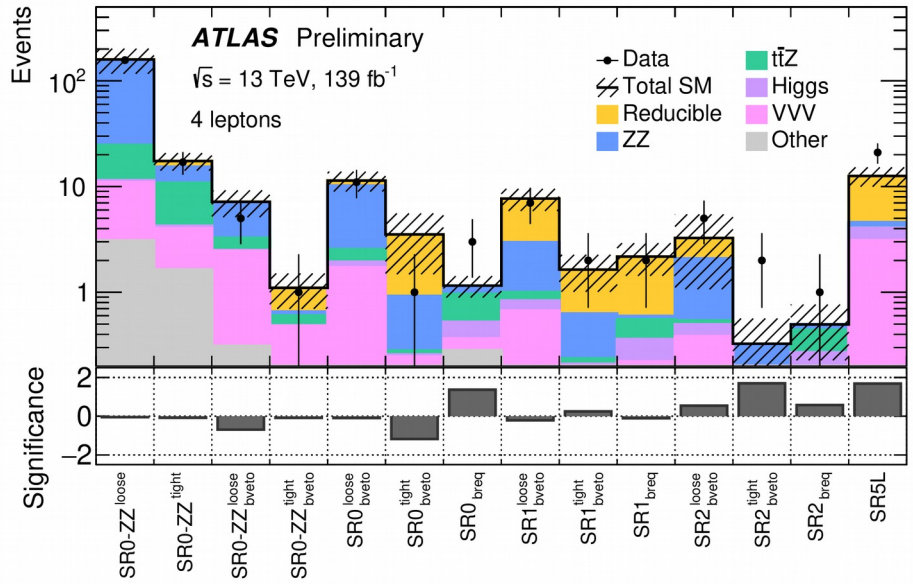
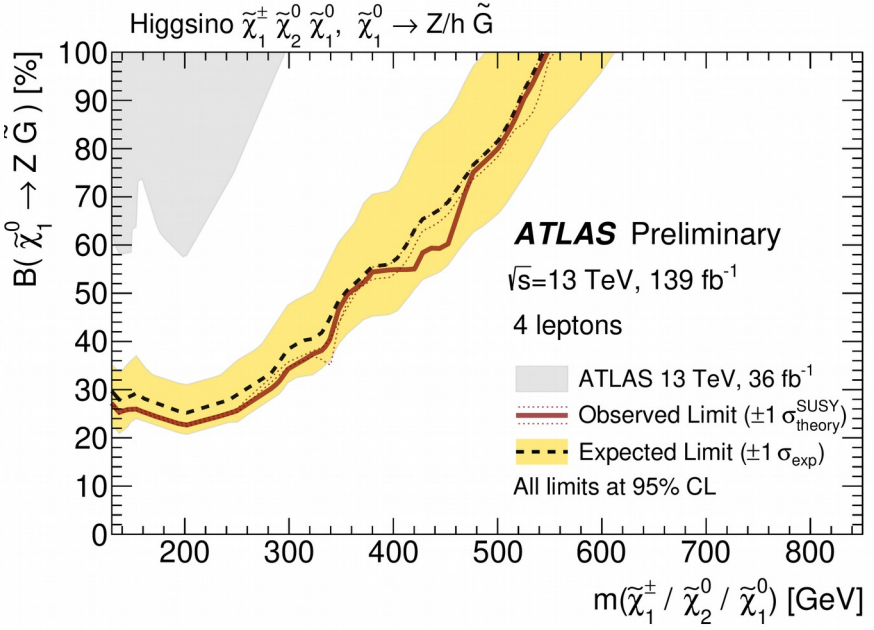
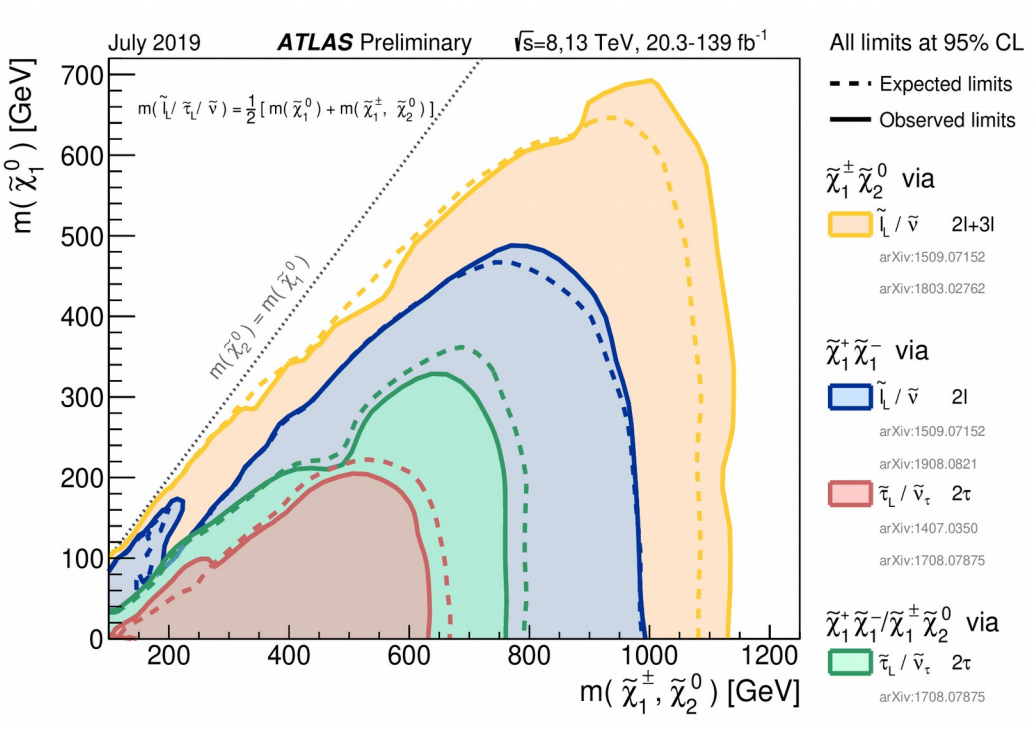


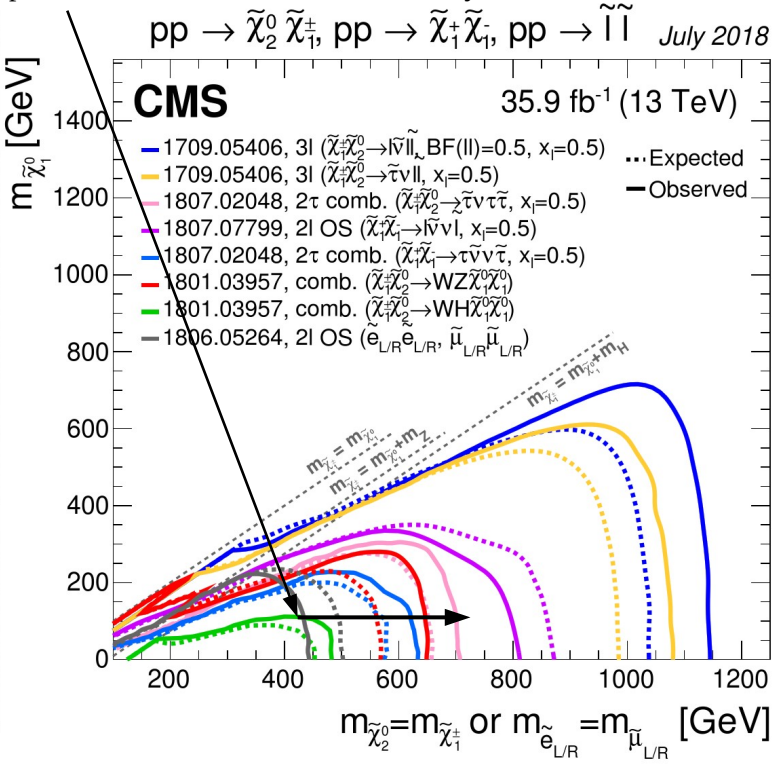


EWK searches: (brief) summary

- Upper limits on charginos/neutralinos crossing the 1 TeV barrier
- Stronger limits coming from slepton mediated decays in long decay chains
- Weaker limits coming from boson mediated decays (or even weaker for direct sleptons)
- More analysis with the full Run2 luminosity to come on this front

Slepton limits pushed to 700 GeV with full luminosity





R-parity violating SUSY searches

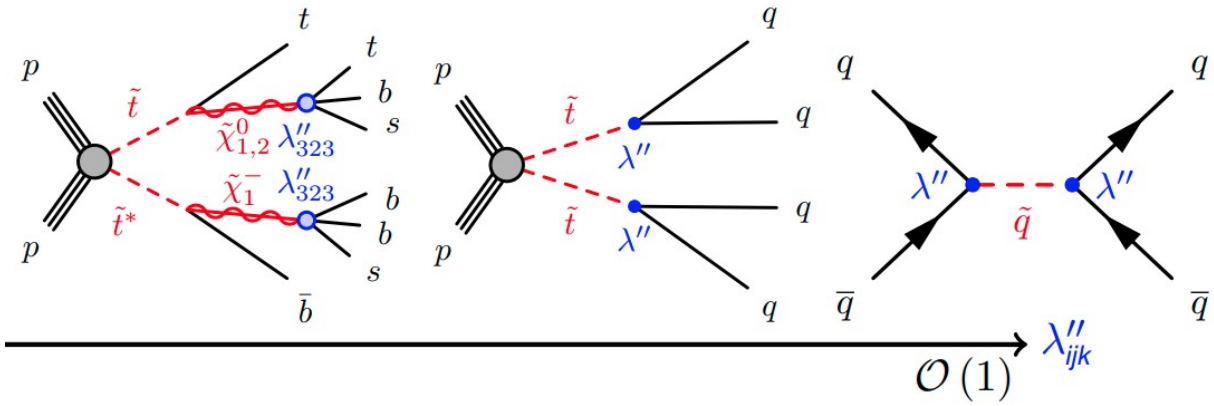
- The most general superpotential of the MSSM contains terms explicitly violating R- parity

$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Violates Leptonic Number Violates Barionic Number

- In R-parity violating models SUSY particles decay fully to Standard Model particles
  - Three body decays of produced neutralinos in the decay chain
  - Decay of the primary SUSY particle
  - Single SUSY production mediated by SUSY particle

No transverse missing momentum in the event (except for neutrinos)



R-Parity violating searches: 4 leptons

- The EWK search with 4 leptons can also target RPV models with tri-lepton vertices
- Discriminating variable is $m_{eff} = p_{Tmiss} + \Sigma p_{Tleptons} + \Sigma p_{Tjets}$

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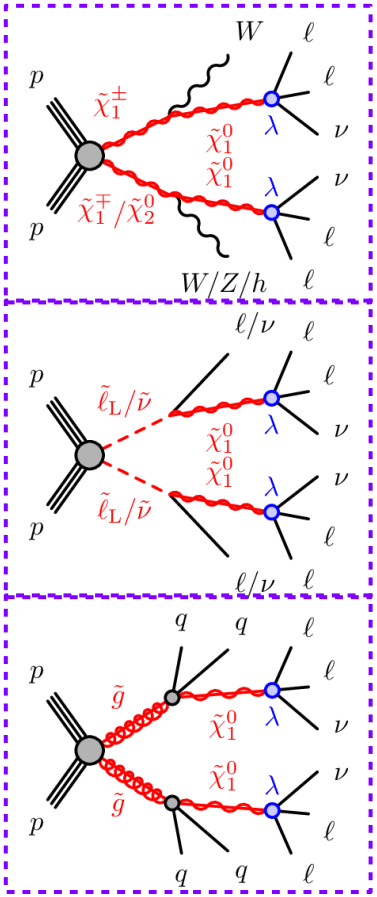

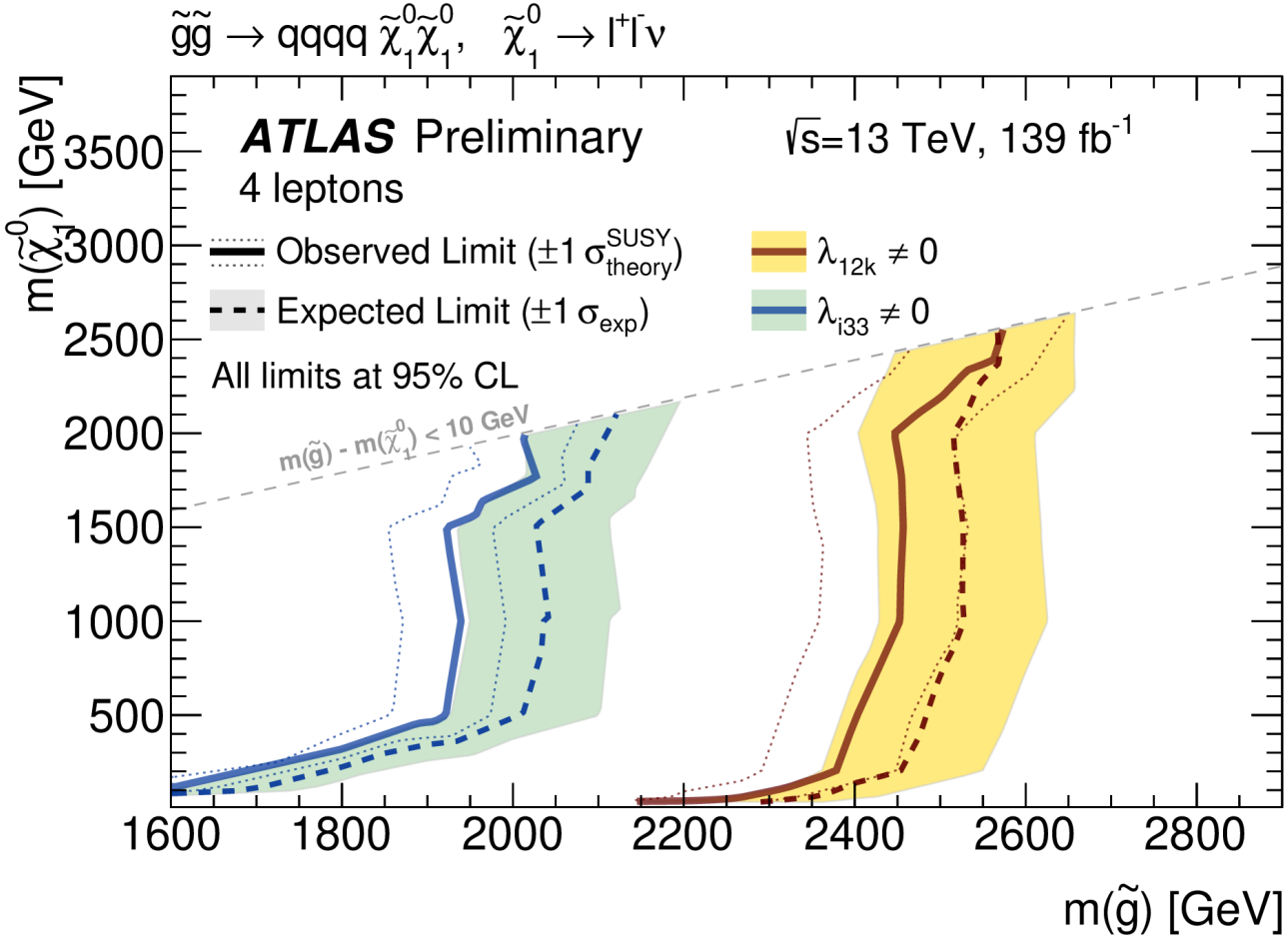

R-Parity violating searches: Same Sign leptons

- Direct production of gluinos with 2 same sign leptons leptons in the final state
- Large presence of light quark jets in the event or top-like signatures with b-jets

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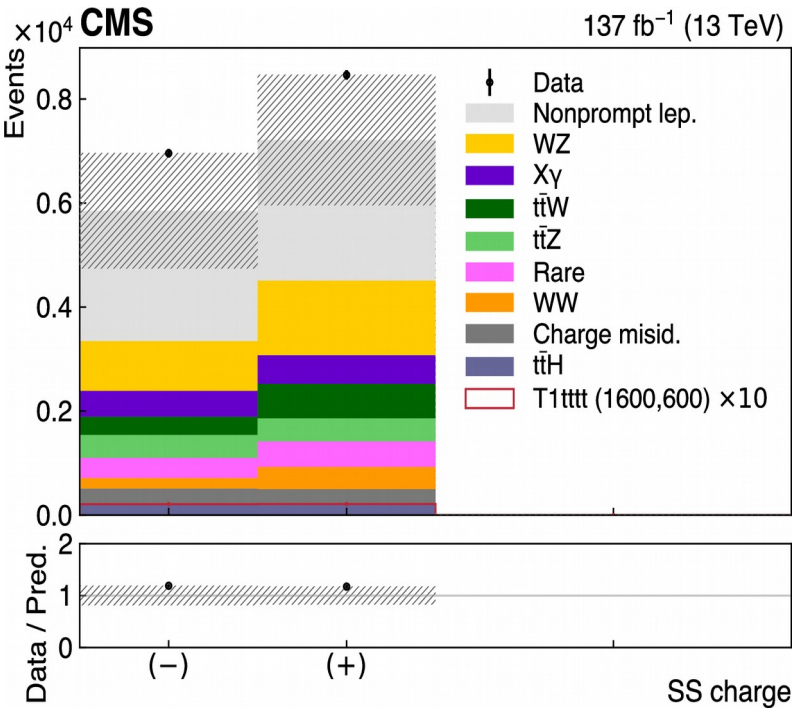
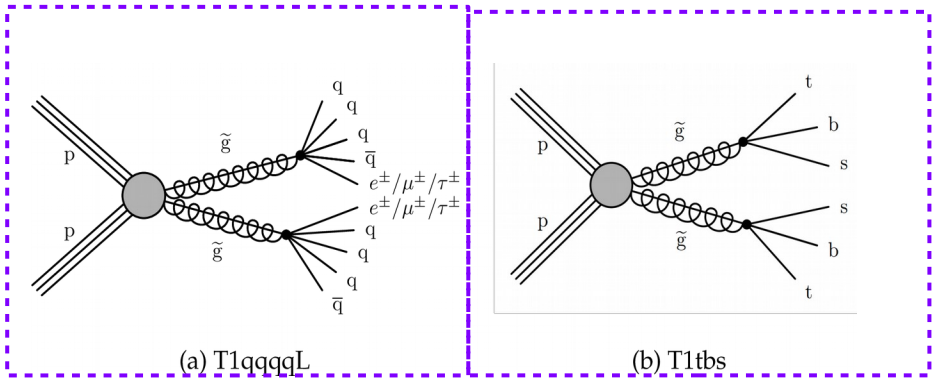
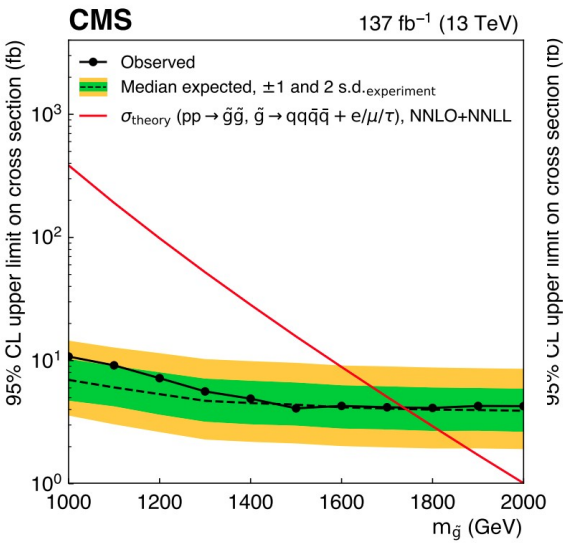
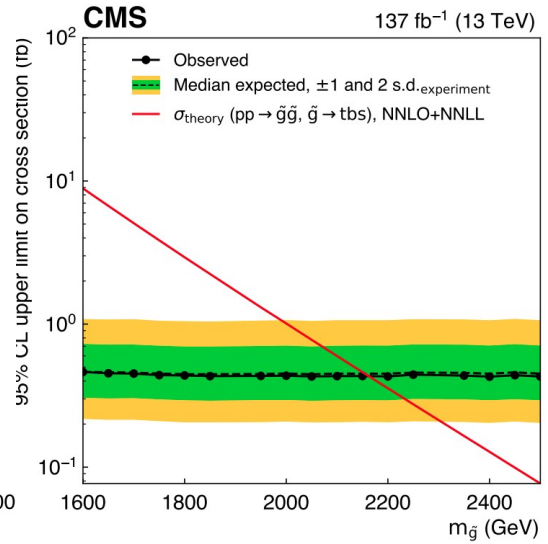


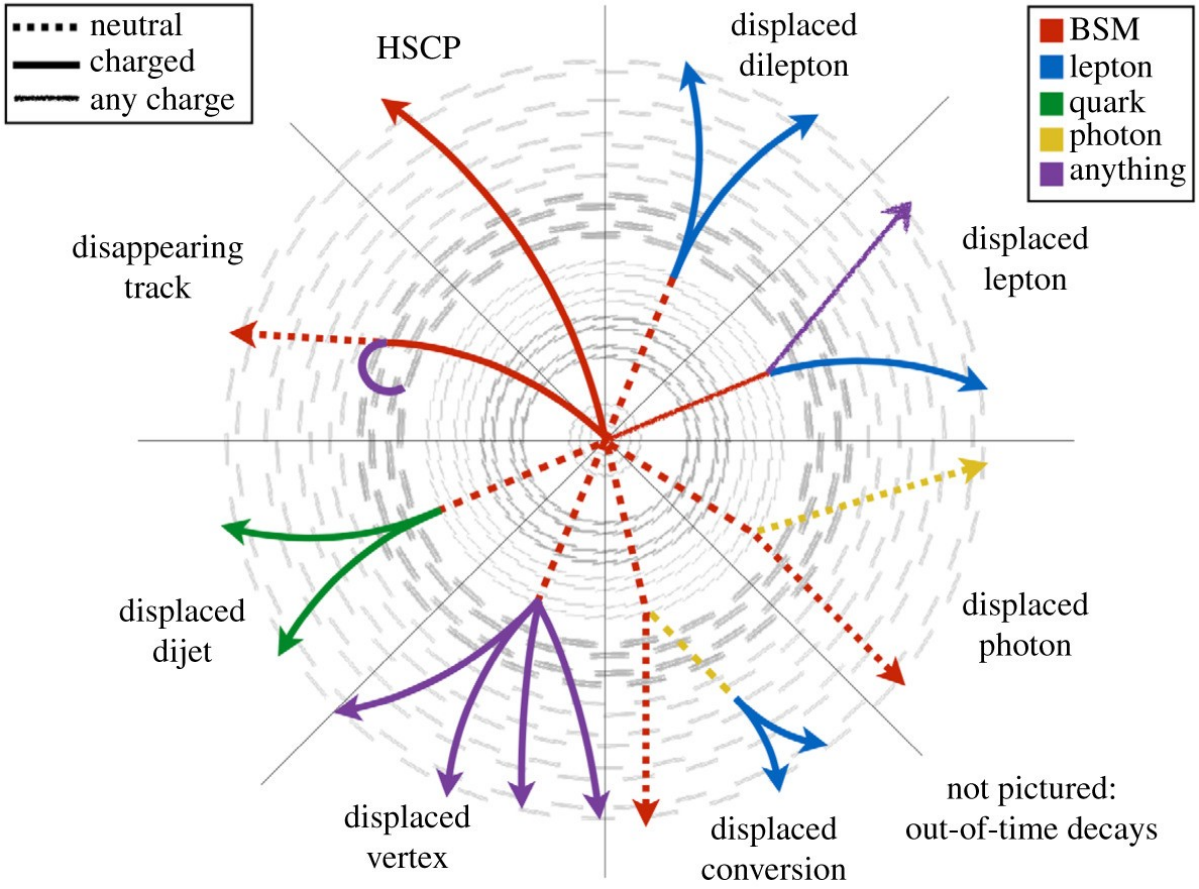






SUSY with non-prompt signatures

- SUSY (as many other BSM) could be realized in final states with non-conventional signatures
- Technically-complicated searches challenging reconstruction and analysis methods

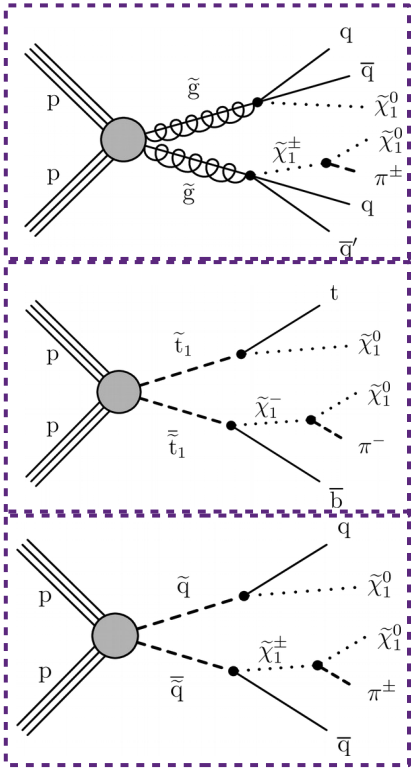


Long lifetimes

- Small couplings
- Very compressed spectra
- Heavy (off-shell) mediators

Long-lived charginos: disappearing tracks

- Compressed spectrum of charginos and neutralinos yield LL charginos decaying in the tracker
  - For a ΔM of about 100 MeV → chargino decay length of about 10 cm
- The SM daughter is too soft to be reconstructed so the chargino track disappears
- Searching for hadronic activity using the M_{T2} variable + a disappeared track



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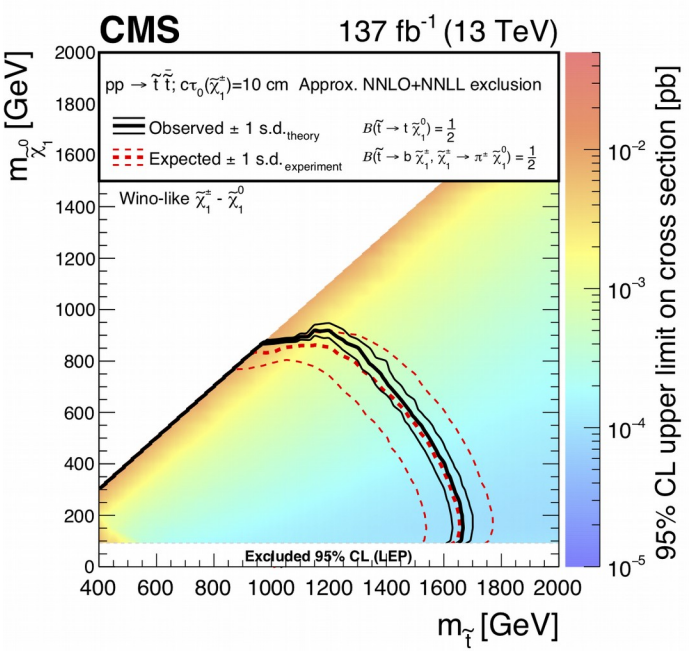
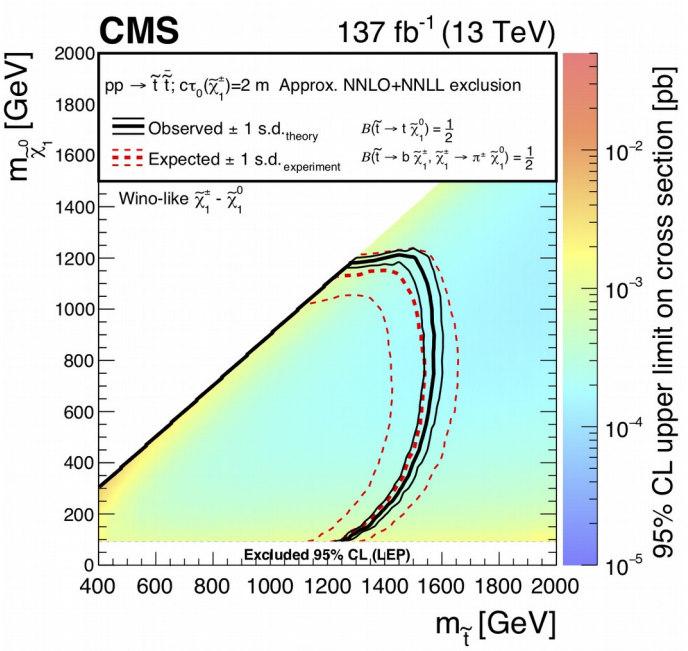
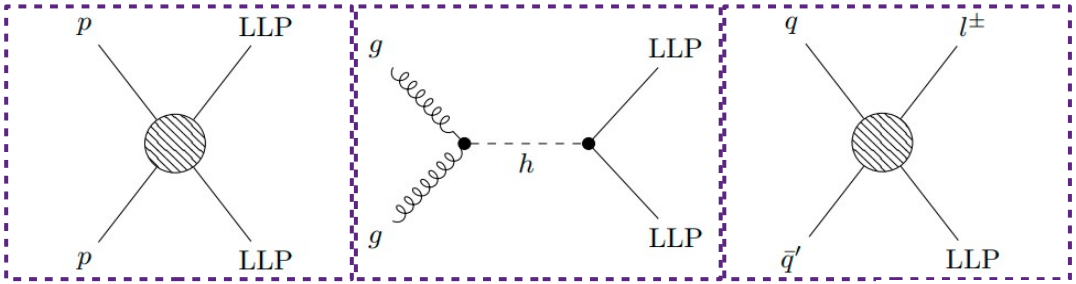


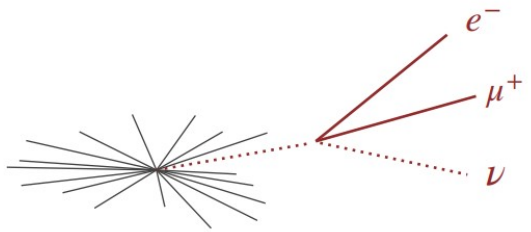


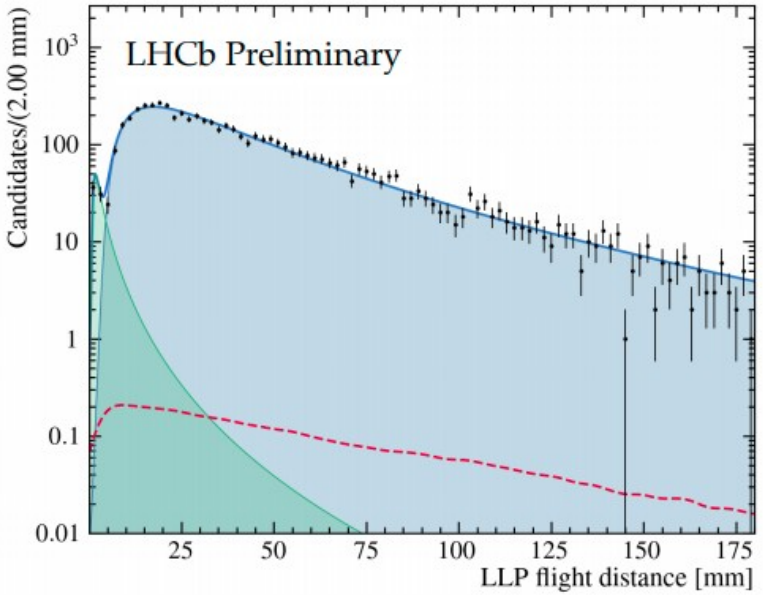
Long-lived neutralino with RPV decay

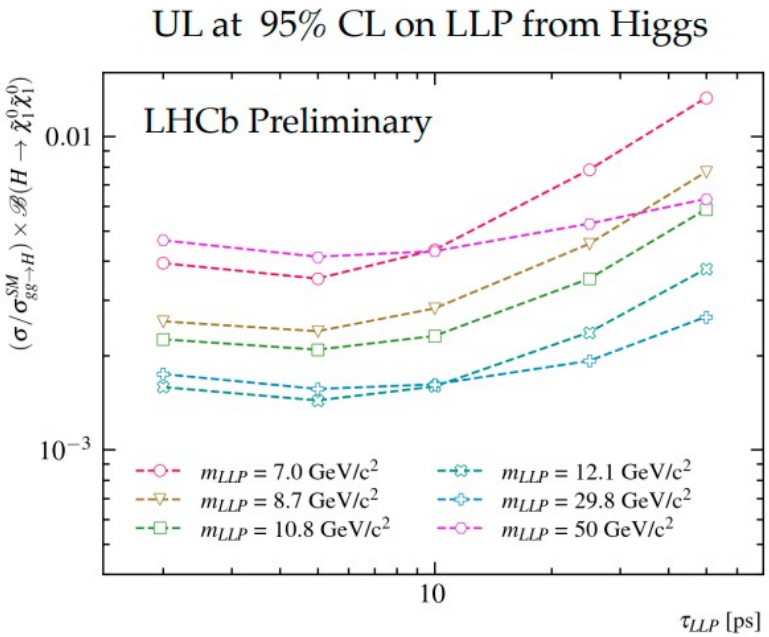
- Long-lived neutralinos decaying in RPV vertex into electron + muon + neutrino
- Simultaneous fit to the corrected mass and the flight distance

LHCb-PAPER-2020-027
(in preparation)



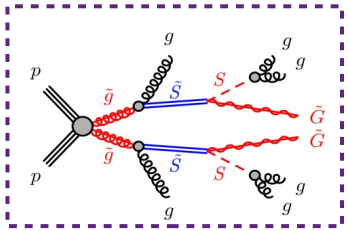






SUSY with displaced jets and leptons

- Class of R-parity conserving SUSY with a hidden sector superfield S and superpartner $\tilde{\tilde{S}}$
- If the mass splitting between the two is small the lifetime of the S superfield is large



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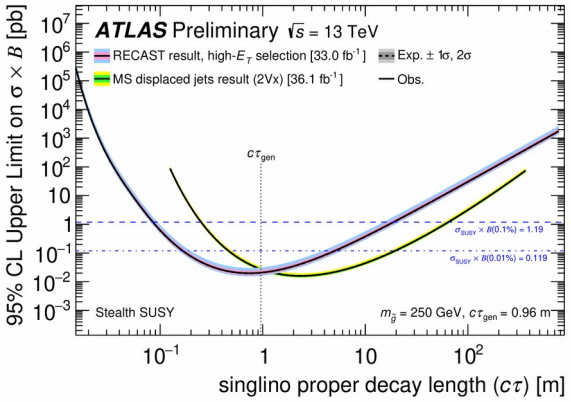
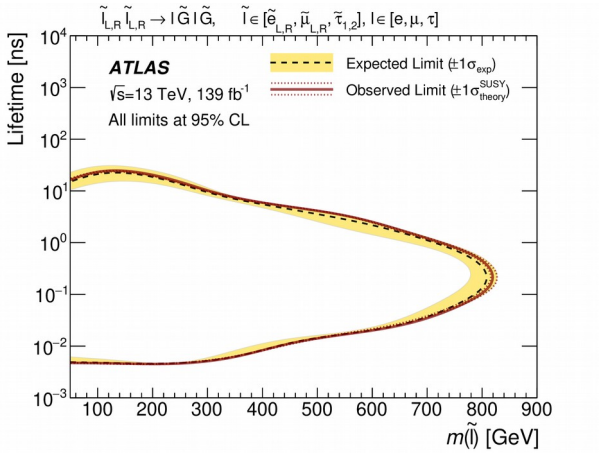
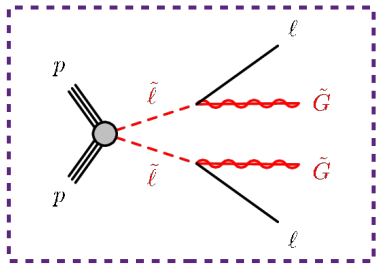


- Slepton production in GMSB model → coupling to gravity small → long slepton lifetime





arXiv:2011.07812

Summary & outlook

- Supersymmetry is still a very appealing theory providing answers to many SM problems
- Extensive SUSY search programs are put in place by the experiments at the LHC
- Classic signatures being expanded to increase the mass reach and address compress spectra
- R-Parity Violating models and/or models with non-conventional signatures being explored
- Still many results to come with the full Run 2 luminosity

Stay tuned!!!