Searches for gluinos and squarks

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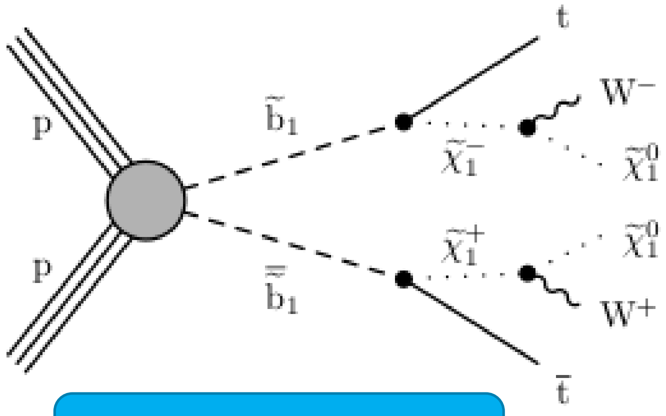
Outline of the talk

- Introduction
- 2015-2018 based
  - search with two same-sign leptons or at least three leptons and jets based on ATLAS-CONF-2019-015 (139 fb^{-1}) [details in Bertrand Martin’s talk]
  - and CMS-SUS-19-008 (137 fb^{-1})
  - inclusive search CMS-SUS-19-005 (137 fb^{-1}) [reinterpretation in Joe Pastika’s talk]
  - and search for long lived charginos based on the same paper above
- Conclusions

Introduction

Need for new physics and SUSY

- Although the huge success of the Standard Model, it is known that the SM cannot be the final theory because of several reasons
- SUSY must be a broken symmetry (if any) and there are many ways to break it
- In this talk simplified model (SMS) based interpretations of strong production SUSY searches are used.
- SMSs are effective models and phenomenology is less important.



Example SMS

Main observables

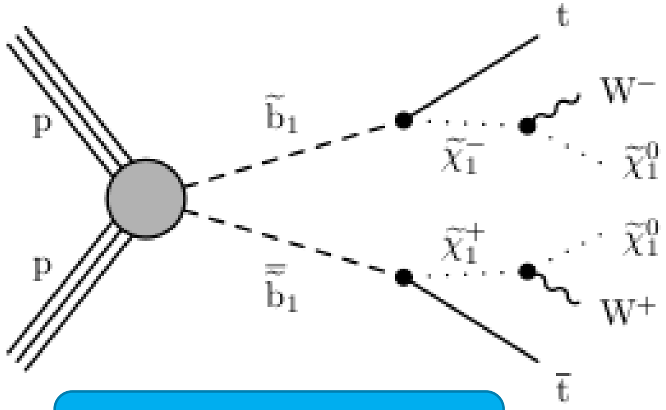
- MET = $| -\sum_{all} \vec{p}_T |$
- $H_T = \sum_{jets} |\vec{p}_T|$
- MHT = $| -\sum_{\text{jets}} \vec{p}_T |$
- $m_{eff} = \text{MHT} + \text{H}_\text{T}$
- $M_{T2} = \min_{MET(\text{X}1)+MET(X2)=MET} [\max(M_T^{(1)}, M_T^{(2)})]$
  - where $M_T^{(i)}$ are the transverse masses of the pseudo-jets. Pseudo-jets are obtained by jet pairing with the largest dijet invariant mass and iteratively cluster all selected jets until two stable jets are left
  - The minimization is performed over all trial momenta satisfying the MET constraint, where MET(X1) and MET(X2) are the vectors decomposed to the pseudo-jets.

Final states

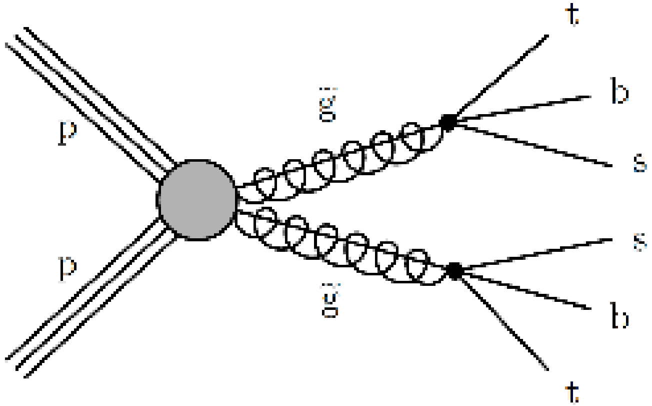
with two same-sign leptons or at least three leptons, jets and MET

Basic information

- Based on ATLAS-CONF-2019-015 and CMS-SUS-19-008
- Basic information
  - center-of-mass energy: 13 TeV with
  - total integrated luminosity: 139 (137) fb^{-1}
  - years corresponding to: 2015-2018
- Signature:
  - either two isolated ele/muon with the same electric charge, or at least three isolated ele/muon (inclusive NLO cross-section is of the order of 1 pb => suppressed by more than three orders of magnitude with respect to the production of opposite-sign lepton pairs)
  - Jets and MET



Example RPC SMS



Example RPV SMS

Interpretation using R-parity conserving (RPC) and violating (RPV) SUSY SMSs

Signal regions

- Simple kinematic variables such as
  - the number of leptons and their relative electric charges,
  - the number of jets,
  - the number of b-tagged jets,
  - the effective mass and
  - the invariant mass of same-sign electron

  are used to categorize events in the ATLAS while in CMS the following extra variables
  - MET,
  - H_T,
  - minimum M_T
  - and lepton p_T

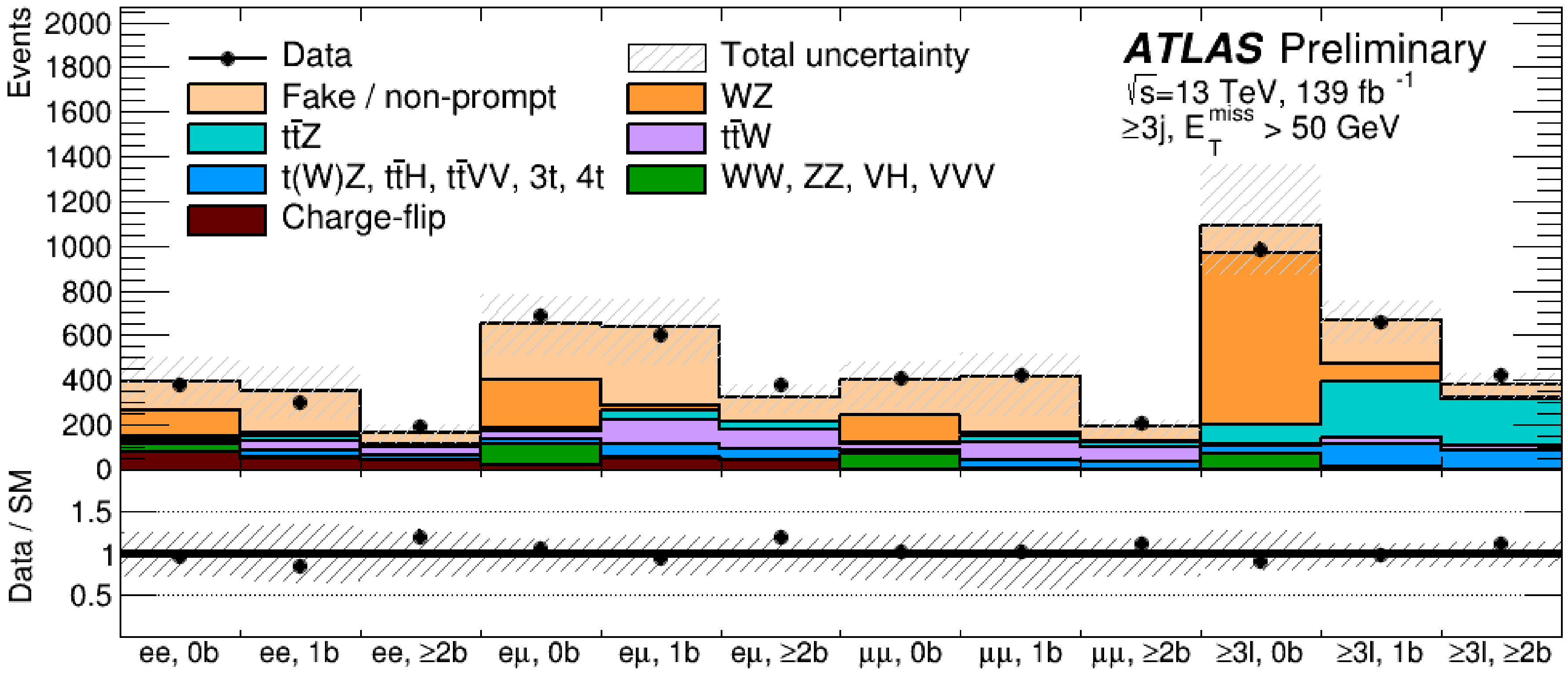
  are used, too. CMS further categorizes by the p_T of the leptons: HH (high high), HL, LL

Background composition

- Main sources are
  - Events with two or more prompt leptons, including a genuine SS pair
    - Processes like WZ, SS W pair, or ttbar + X contribute to this category
    - Estimated using simulated samples, with correction factors applied to take into account the small data/MC differences
  - Events with at least one nonprompt or fake lepton
    - Processes like ttbar+jets and W+jets contribute to this category
    - Estimated from data
  - Events with a pair of opposite sign leptons, one of them mistakenly reconstructed with the wrong charge.
    - ‘charge-flipped’ electrons contribute about the level of 10%. This is the situation when the charge of a prompt electron is mismeasured.

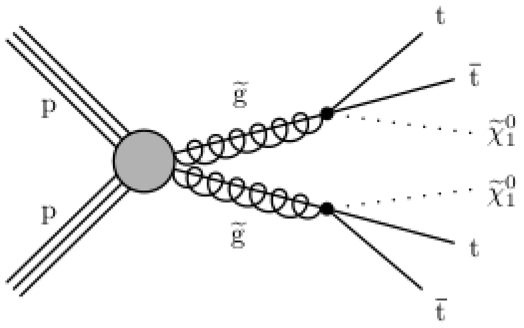
Signal regions and background

- The x axis shows the different SRs, the box below is the ration of events from data and MC simulation, the hashed bands are the total uncertainties

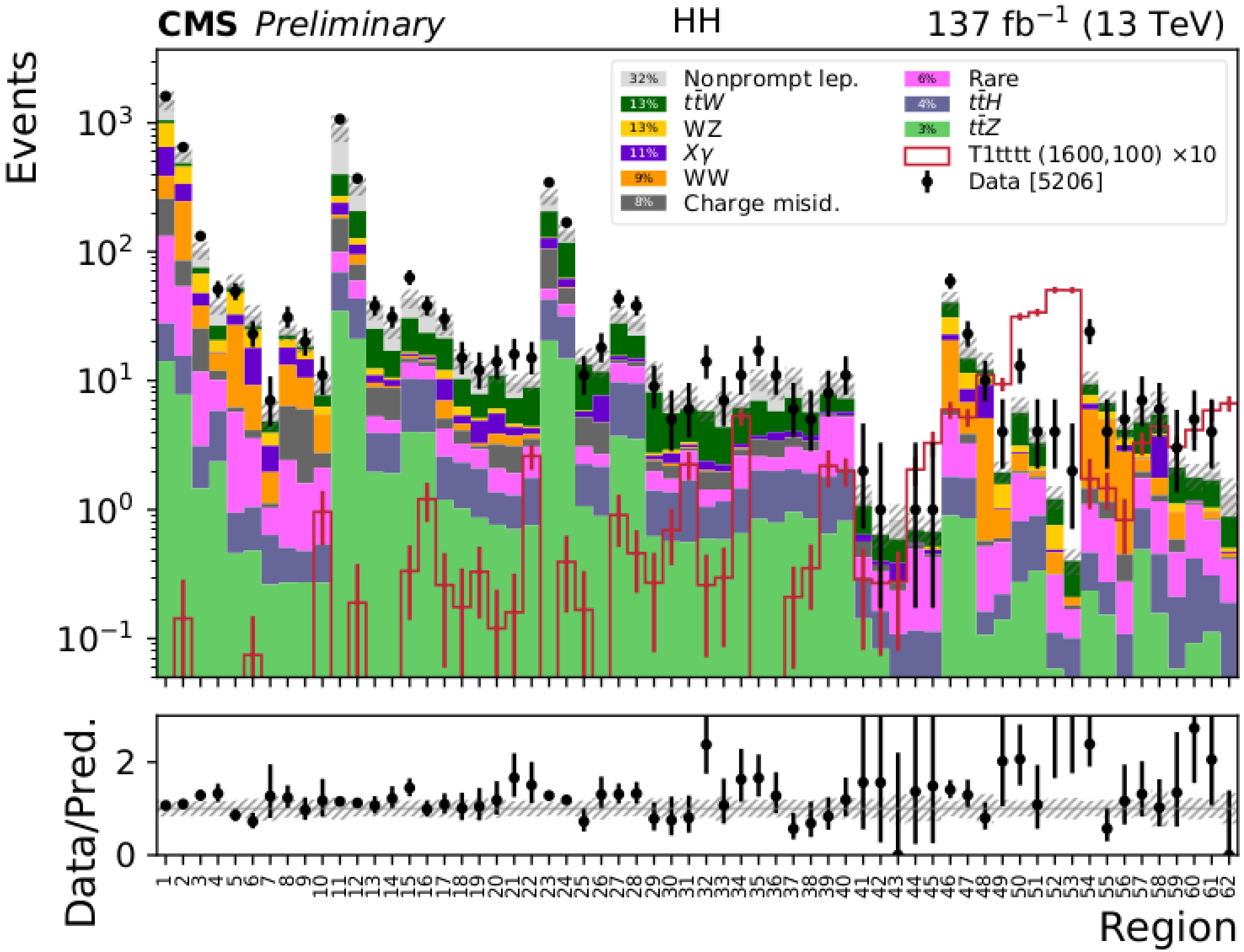


Signal regions and background

- The numbers on the x axis denote certain signal regions.
- In this plot the T1tttt signal is shown with a red curve

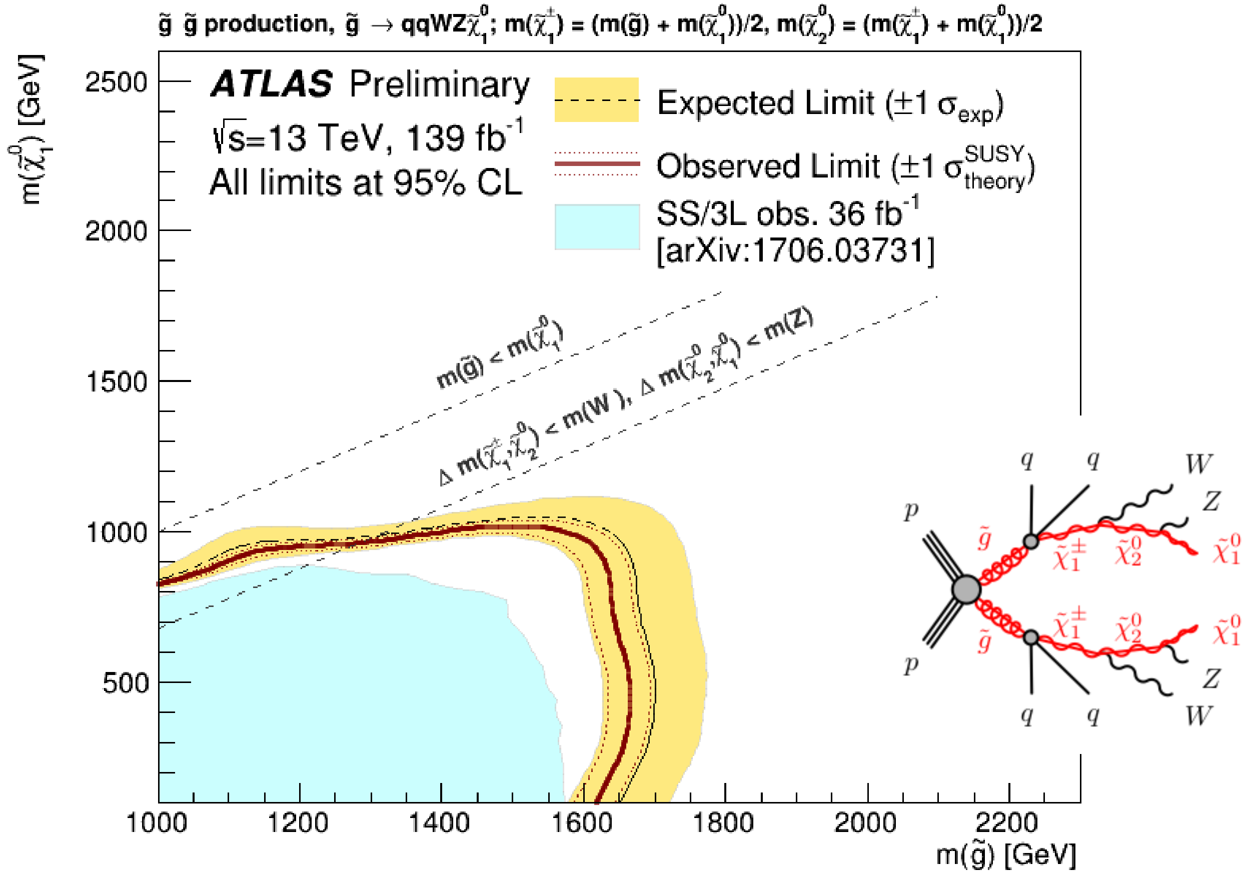


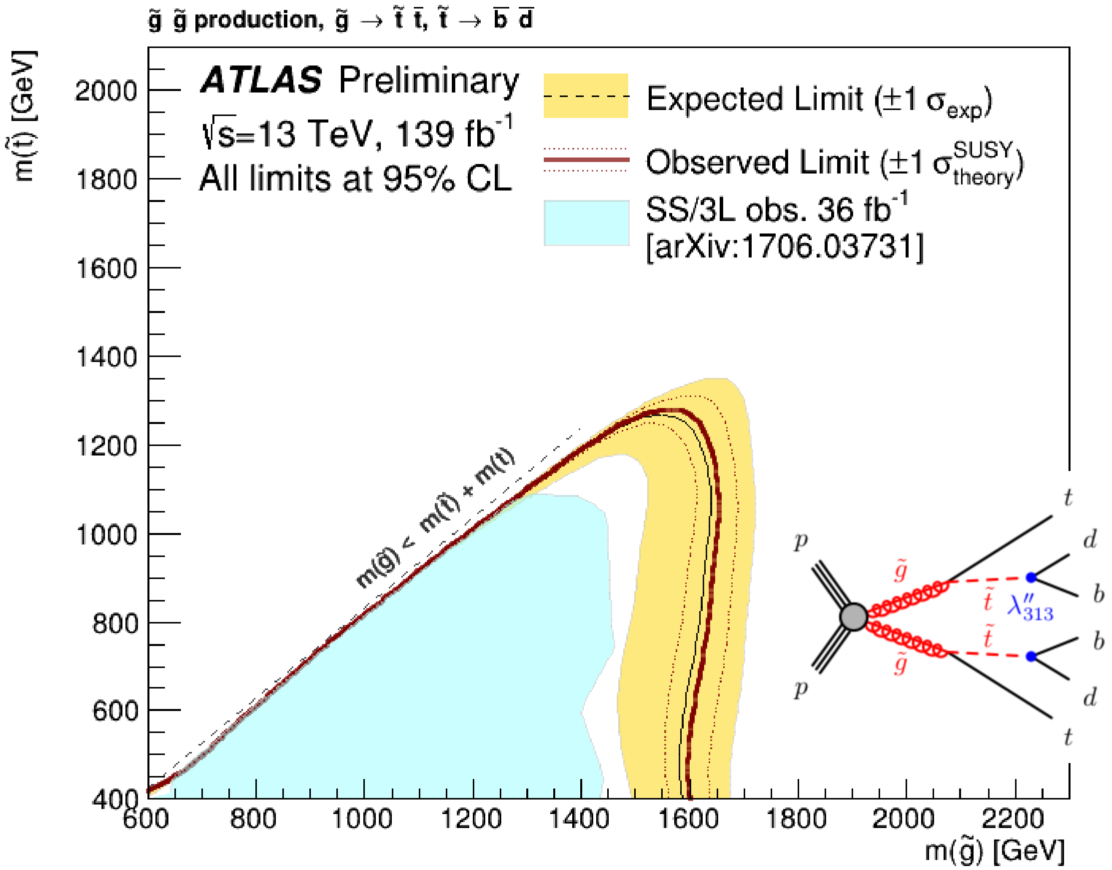
T1tttt



Exclusion limits

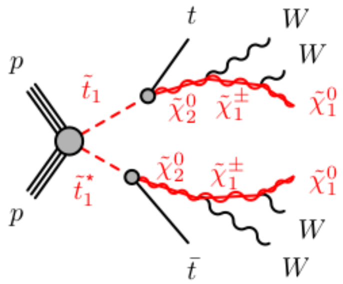
- 95% confidence level exclusion limits on the production of pairs of gluinos

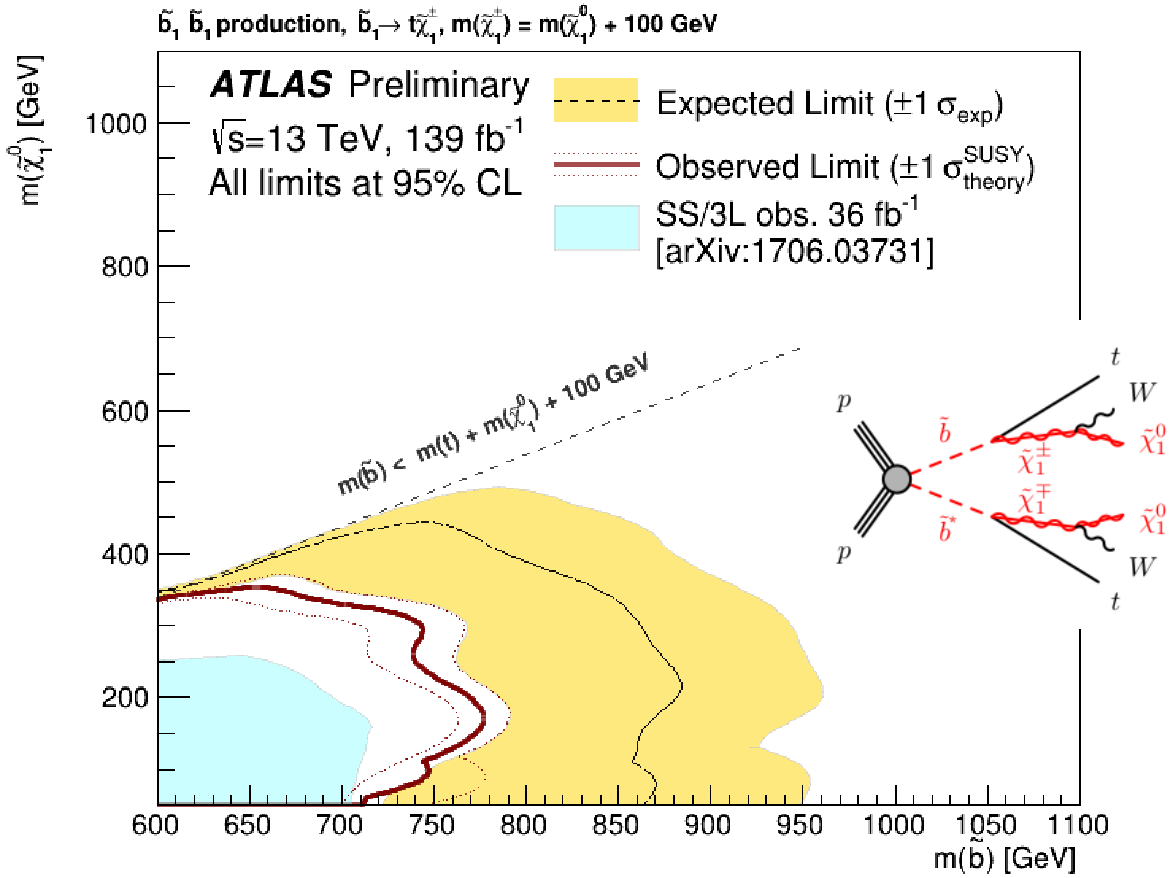


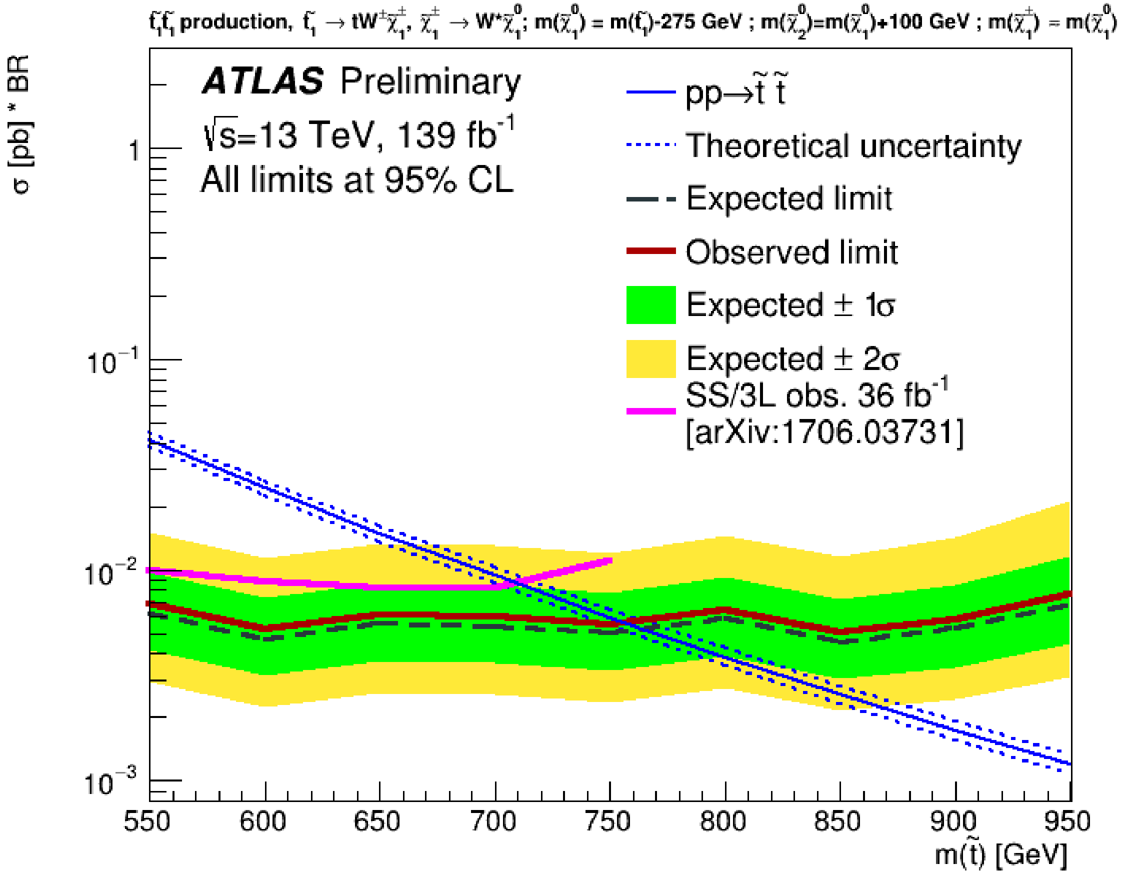


Exclusion limits

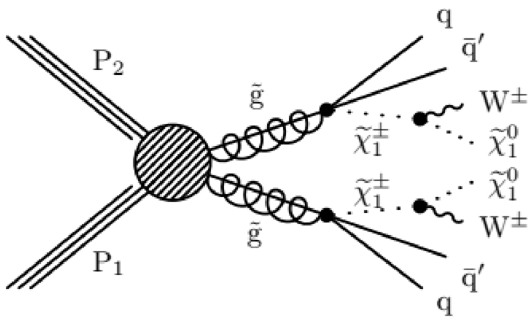
➢ Exclusion limits on the production of third-generation squarks





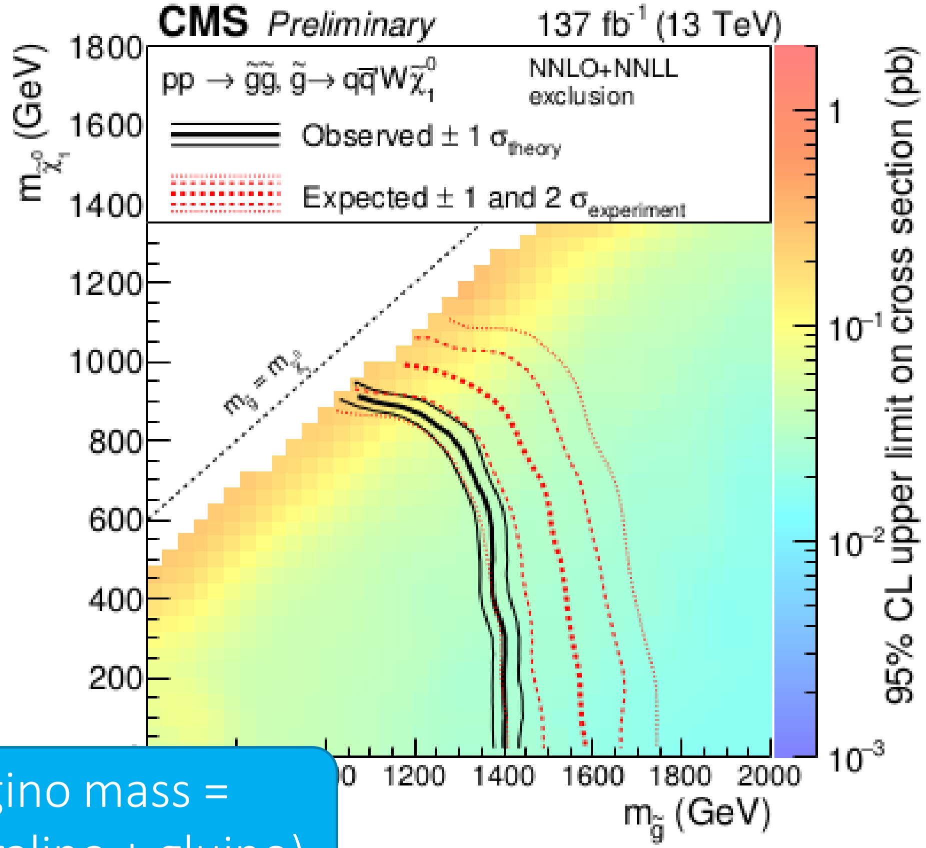


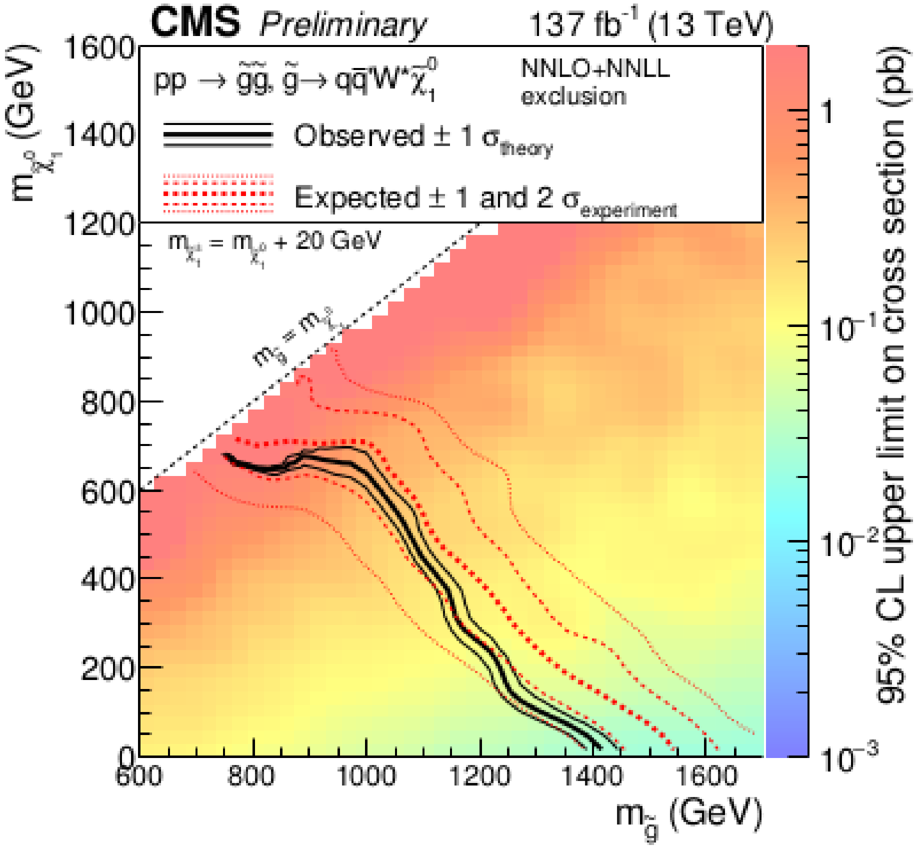
Exclusion limits



- Exclusion regions at 95% CL for the
- This model is studied with two different assumptions for the chargino mass (left and right plot)

Chargino mass = neutralino + 20 GeV

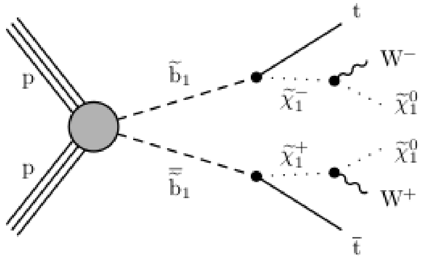


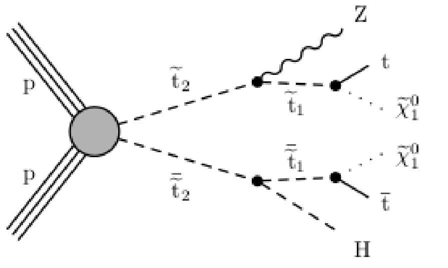


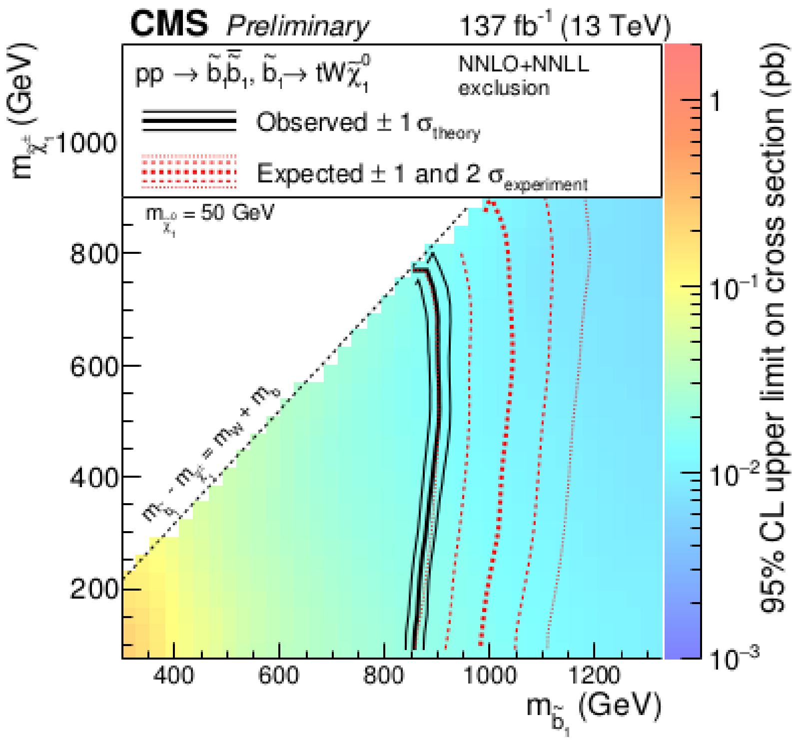
Chargino mass = 0.5(neutralino + gluino)

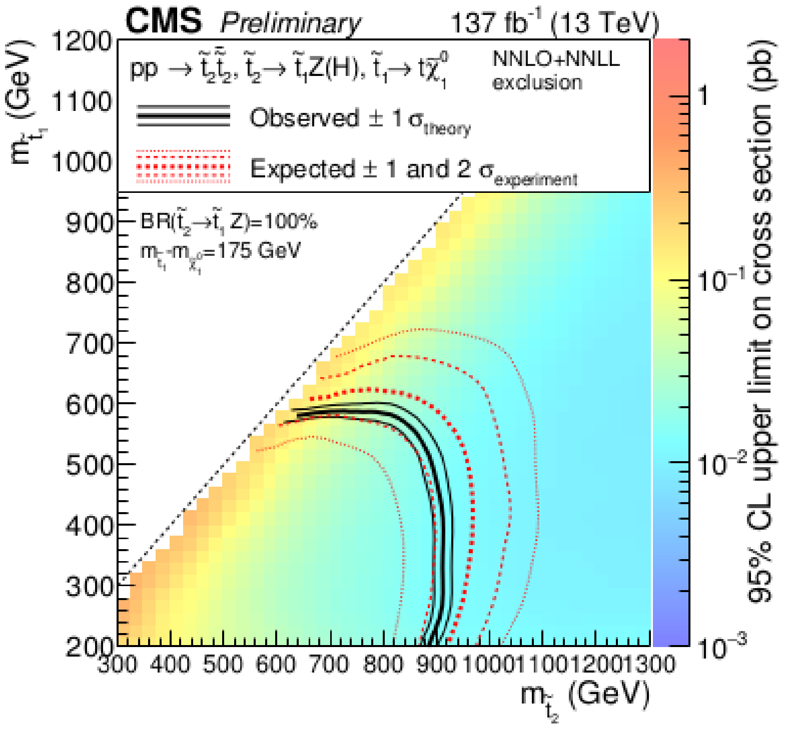
Exclusion limits

- Exclusion limits on the production of third-generation squarks
- Left plot is for the bottom squark and the right is for the top squark with the SMSs shown above the plots



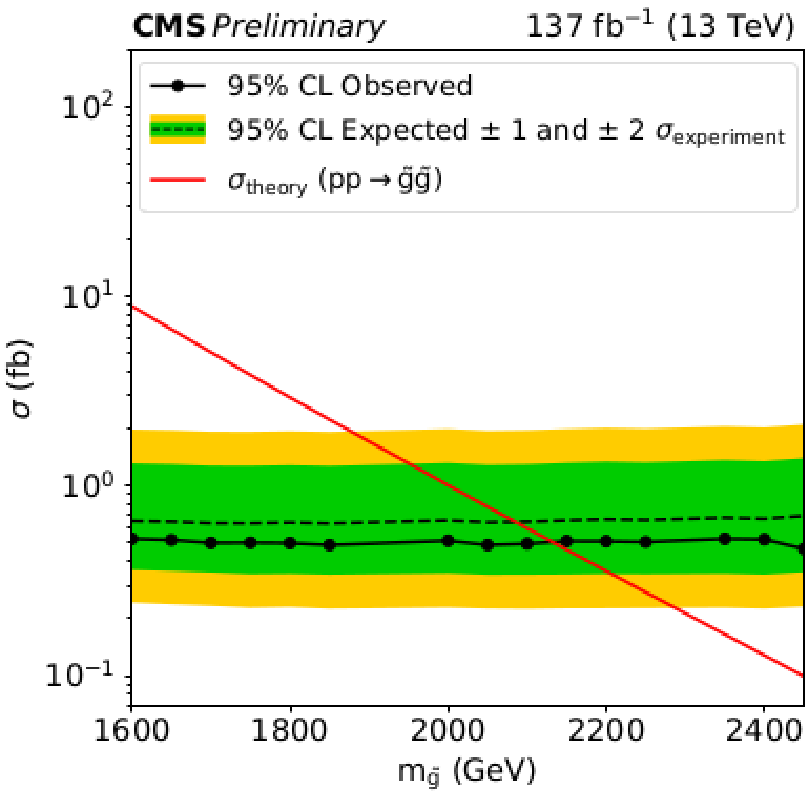


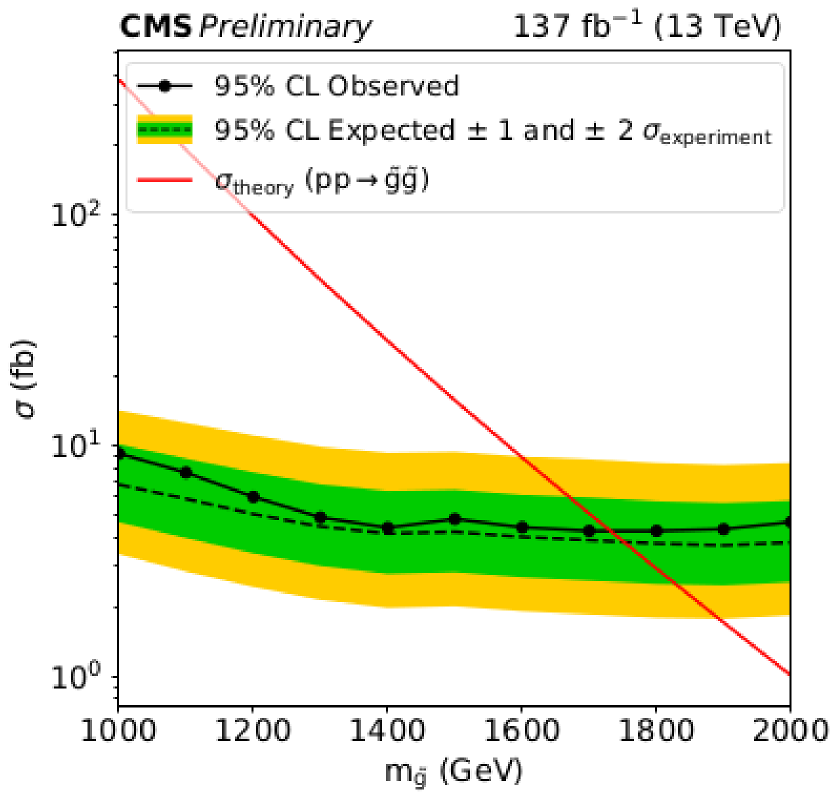




Exclusion limits

- Limits on RPV gluino pair production with each gluino decaying into four quarks and one lepton (T1qqqqL, left)
- and each gluino decaying into a top, bottom, and strange quark (T1tbs, right)





Exclusions summary

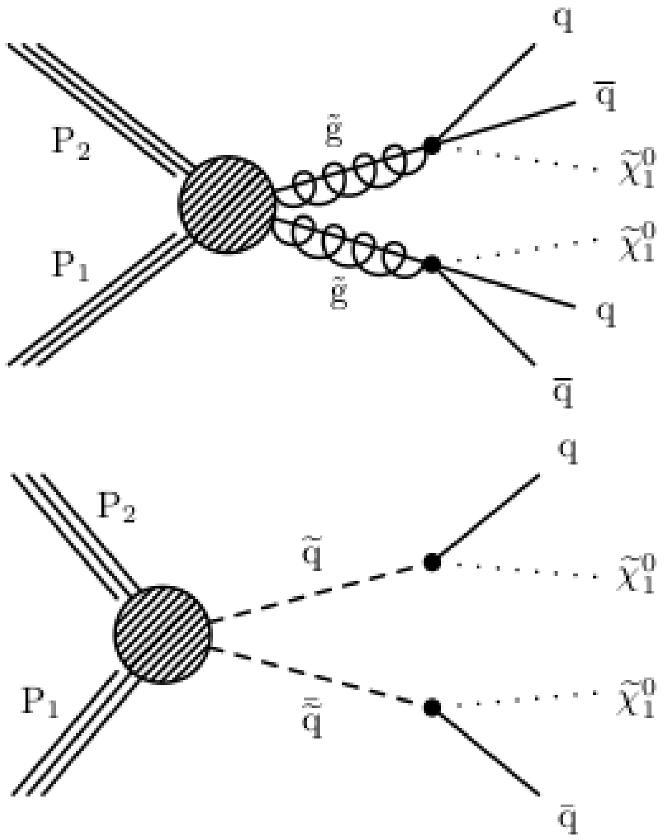
- SUSY searches with final states with two same-sign leptons or at least three leptons and jets
  - with the total integrated luminosity: 139 (137) fb^{-1}
  - center-of-mass energy: 13 TeV
  - corresponding to years 2015-2018
  - gave the following 95% exclusion limits:
    - From ATLAS 1.6 TeV for gluino masses and 750 GeV bottom and top squark masses.
    - From CMS the observed lower mass limits are as high as 2.1 TeV for gluinos, and 900 GeV for top and bottom squarks.

Final states

with jets and significant transverse momentum imbalance (and disappearing tracks)

Basic information

- Based CMS-SUS-19-005
- Basic information
  - center-of-mass energy: 13 TeV
  - total integrated luminosity: 137 fb^{-1}
  - years corresponding to: 2015-2018
- Signature:
  - at least one jet
  - MET
- Interpretation using simplified models of R-parity conserving SUSY

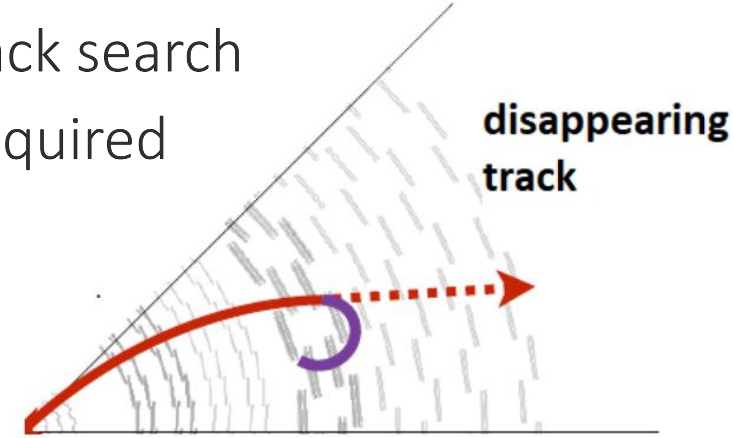


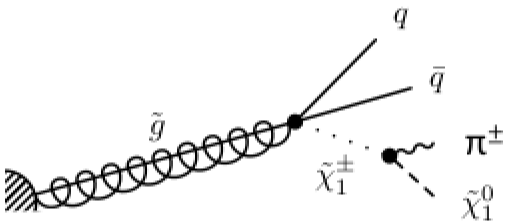
Signal regions

- Simple kinematic variables such as
  - the the number of jets,
  - the number of b-tagged jets,
  - the H_T and
  - the M_{T2} (>400 GeV cut for high H_T region)

  are used to categorize events.

- Additionally for the disappearing track search
  - a short (disappearing) track is required



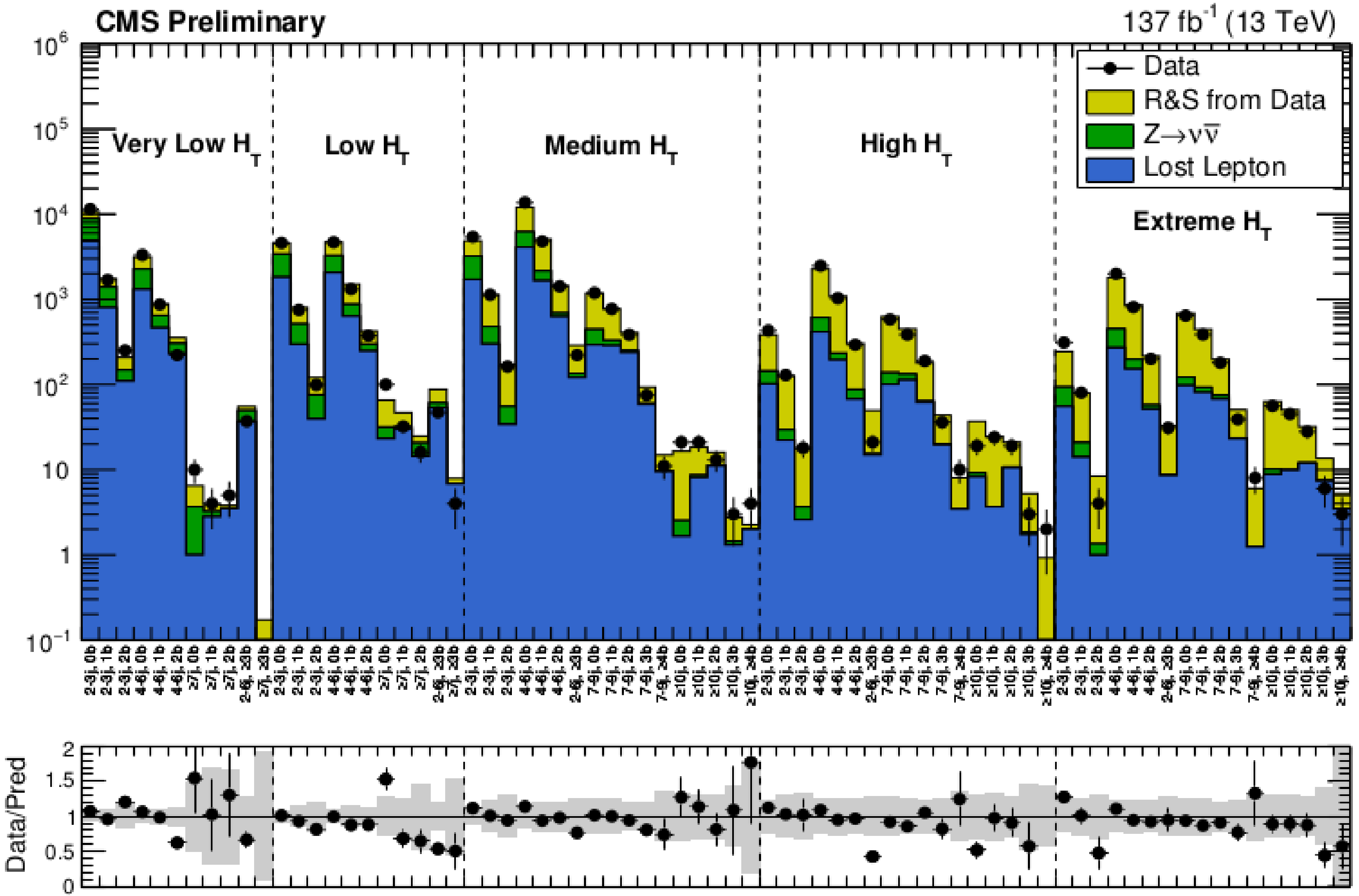


Backgrounds for the inclusive search

- The backgrounds in jets-plus-MET final states typically arise from three categories of SM processes:
  - Lost lepton (mostly from W+jets and tt+jets events)
  - irreducible, i.e., Z+jets events
  - instrumental background, i.e., mostly multijet events with no genuine MET
- Background is estimated from data
- The rebalance and smear (R&S) method is used to estimate multijet backgrounds, that consists of two steps.
  - In the first step, multijet events are rebalanced by adjusting the transverse momenta of the jets such that the resulting MET is approximately null.
  - In the smearing step, the p_T of the jets in each rebalanced seed event are smeared according to the jet response function, in order to emulate the instrumental effects

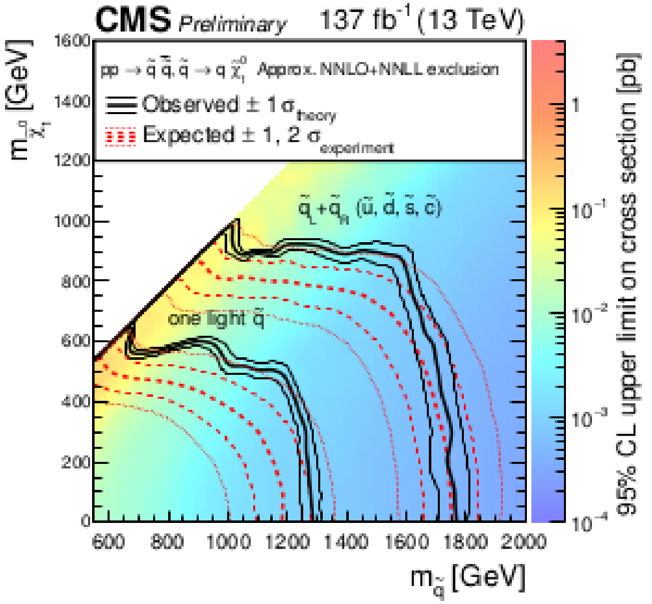
Signal and background regions

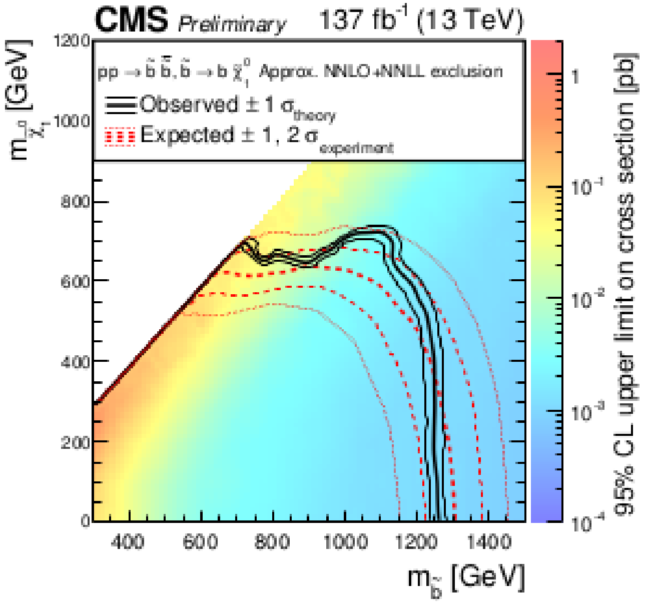
- Validation of the R&S multijet background prediction, in control regions in data with $\Delta\phi_{min} < 0.3$
- Bins on the x-axis are the (HT, #jet, #b-jet) topological regions.
- The gray band represents the total uncertainty on the prediction.

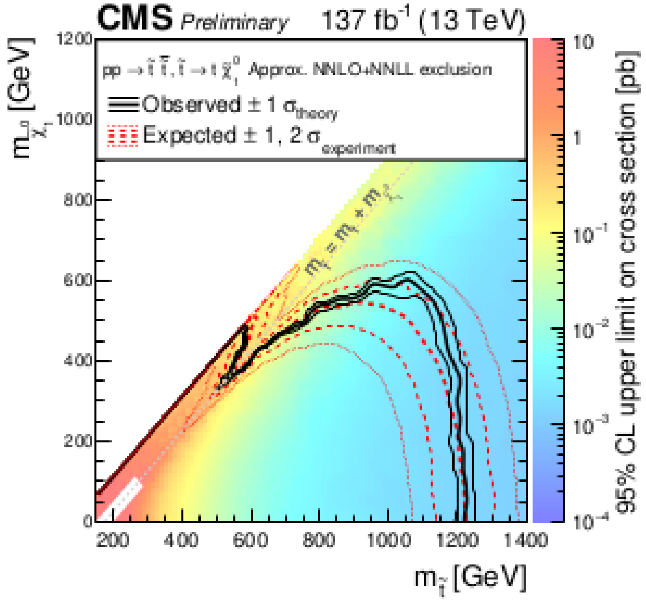


Exclusion limits for the inclusive search

- 95% confidence level exclusion limits on the light-flavor squark pair production (above left),
- bottom squark pair production (above right),
- and top squark pair production (below)
- White diagonal band corresponds to the region where selection is a strong function of the mass difference which leads to high uncertainties in the cross section limit due to MC granularity

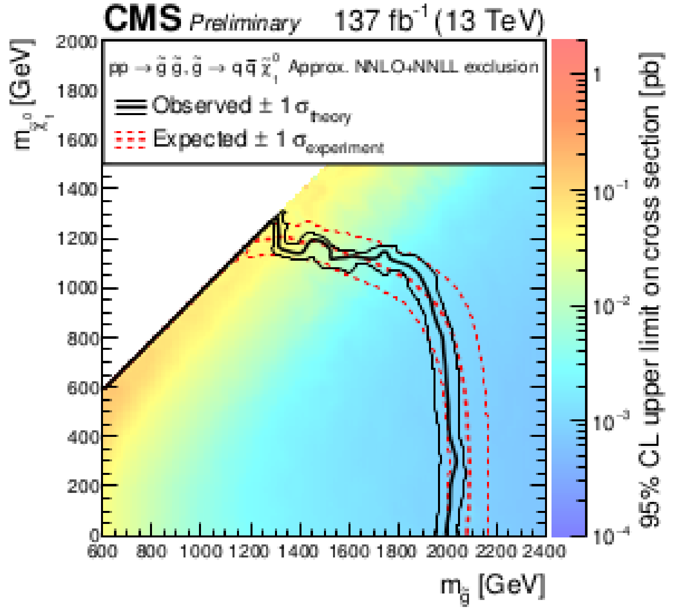


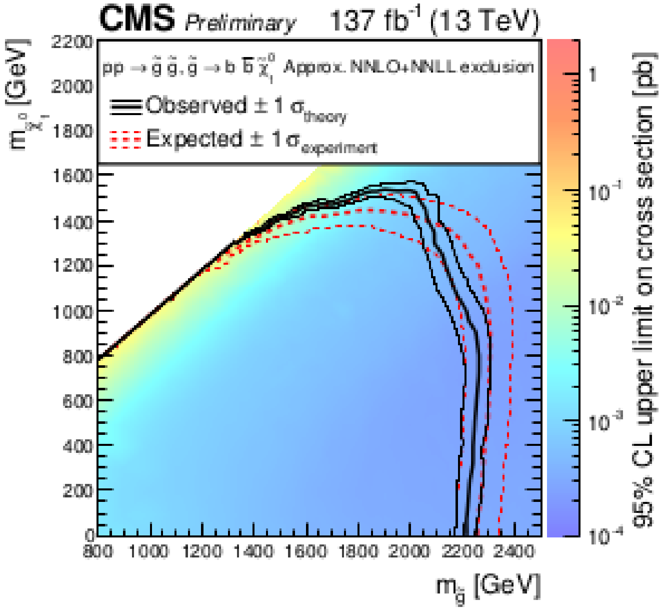


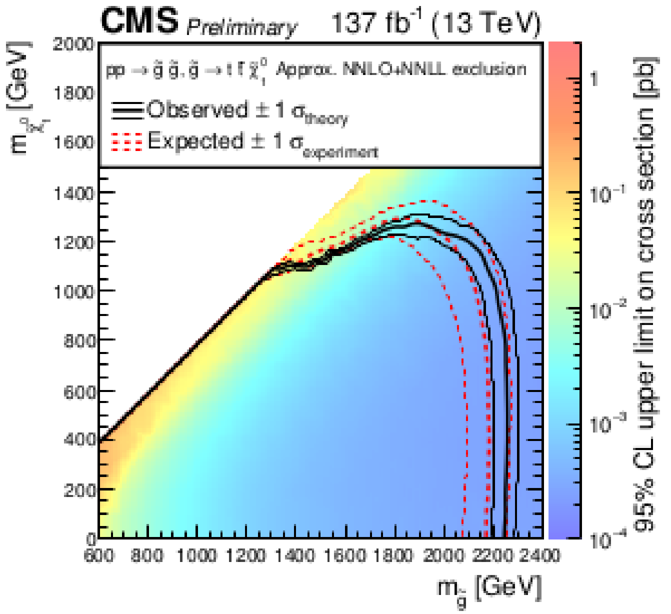


Exclusion limits for the inclusive search

- 95% confidence level exclusion limits on the production of pairs of gluino-mediated light-flavor (u,d,s,c) squark production (above left),
- gluino-mediated bottom squark production (above right),
- and gluino-mediated top squark production (below).







Background for disappearing tracks search

- The background from SM processes consists of events containing disappearing tracks from three main sources:
  - fake tracks,
  - charged pions (undergoing a significant interaction in the tracking detector or poorly reconstructed),
  - leptons (undergoing a significant interaction in the tracking detector or poorly reconstructed).

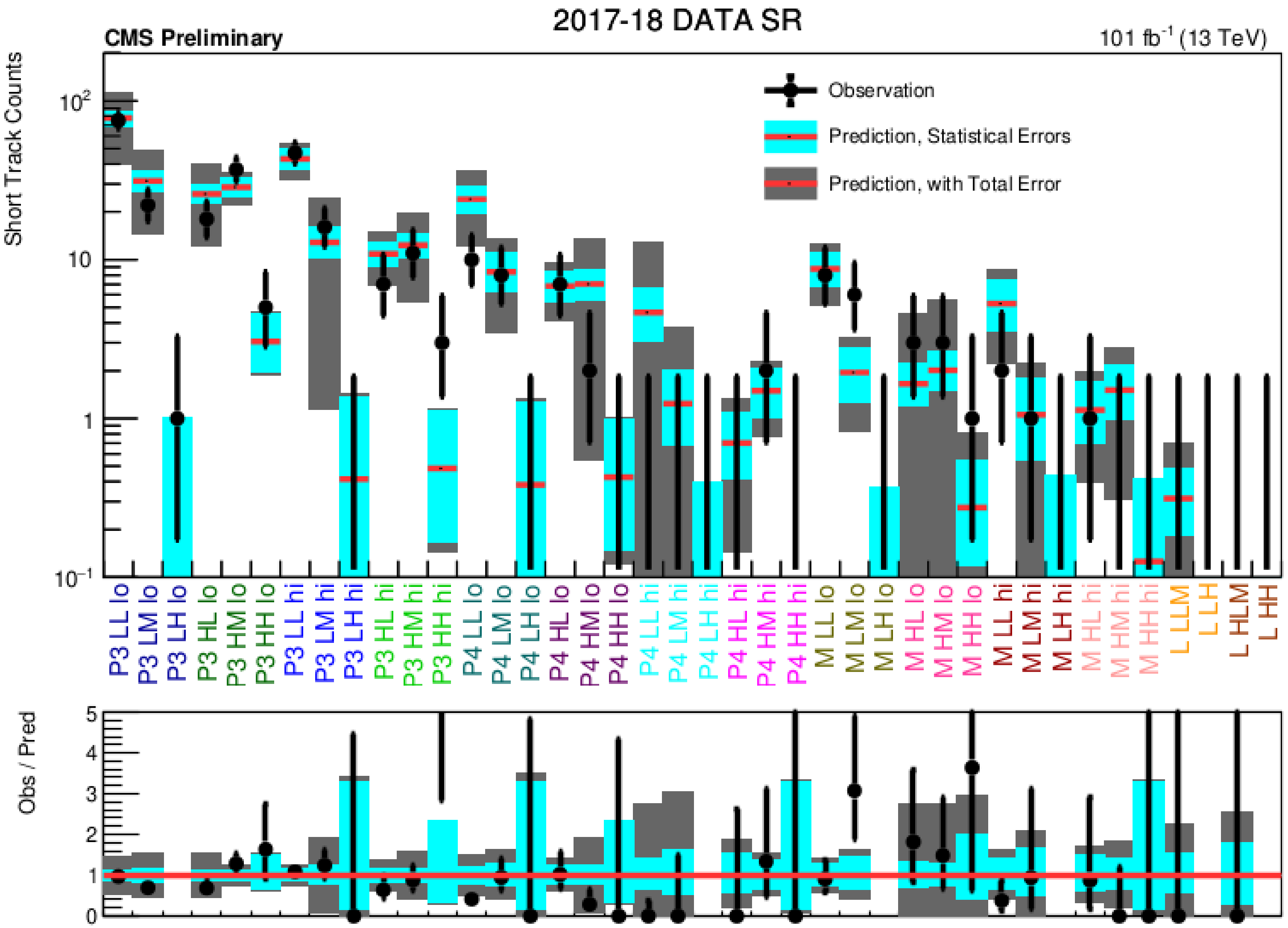
- The background is estimated from data: $N_{ST}^{est} = \frac{N_{ST}^{obs}}{N_{STC}^{obs}} N_{STC}^{obs}$

  where ST is for short tracks (i.e. disappearing one), STC is for short track candidates

- The background prediction is validated in data in an intermediate M_{T2} validation region ($100 < M_{T2} < 200$ GeV), orthogonal to the high M_{T2} signal region

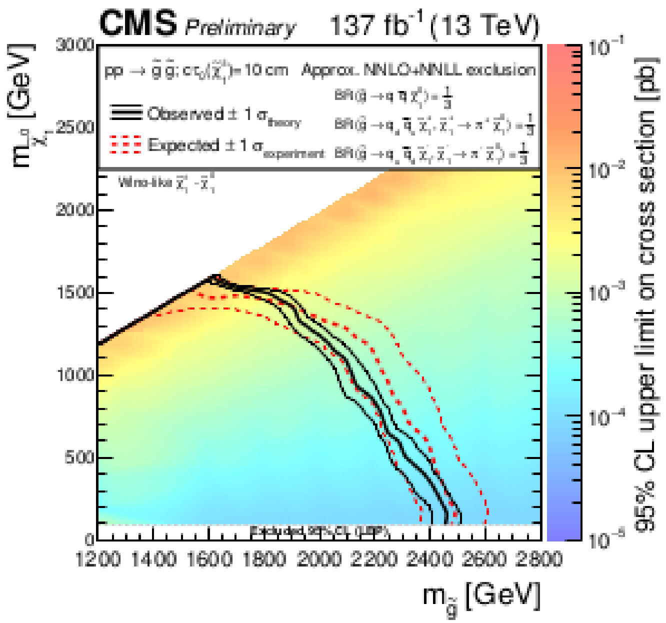
Signal and background regions

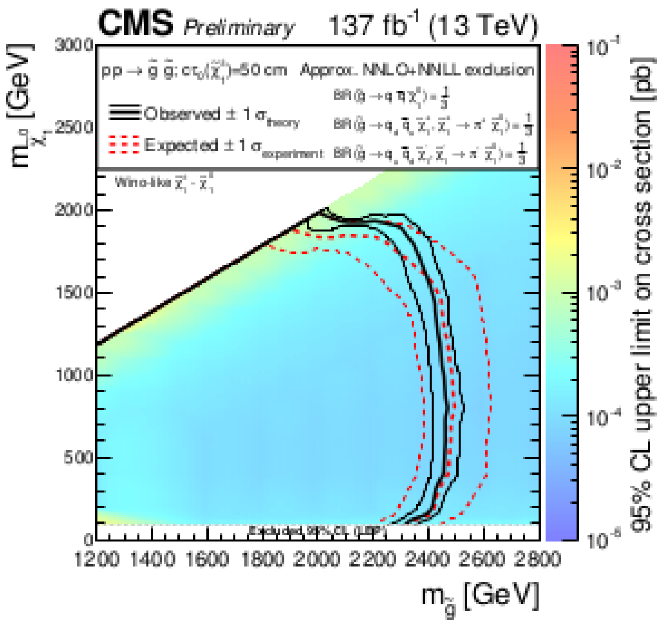
- Comparison of estimated background and observed data events in 2017-2018 data (NB: new pixel in 2017)
- The black points are the actual observed data counts.
- The cyan band represents the statistical uncertainty on the prediction.
- The gray band represents the total uncertainty.

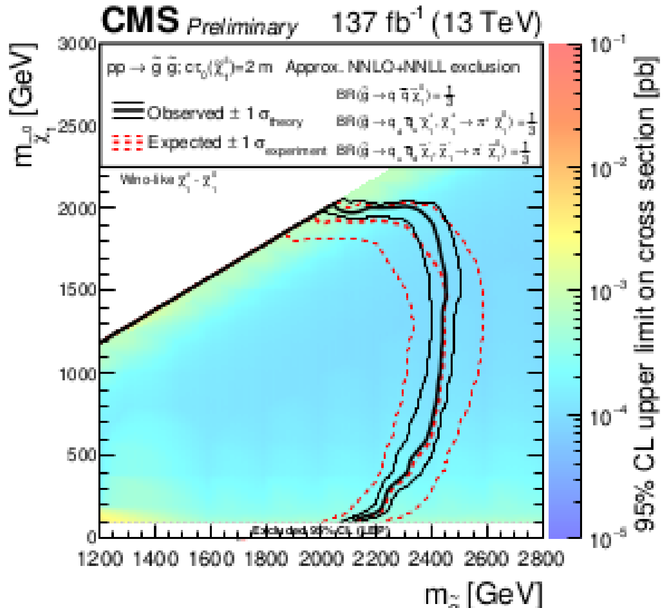


Exclusion limits in the disappearing track search

- Exclusion limits at 95% CL for gluino-mediated light-flavor (u,d,s,c) squark production with cτ = 10 cm (above left),
- 50 cm (above right),
- and 200 cm (below).
- Exclusion limits tend to be strongest in longer cτ models when the neutralino mass is near the mass of the gluino,
- and shorter cτ when large mass splitting generates a large boost.







Exclusions summary

- SUSY searches with final states with jets and significant transverse momentum imbalance (and disappearing tracks)
  - with the total integrated luminosity: 137 fb^{-1}
  - center-of-mass energy: 13 TeV
  - corresponding to years 2015-2018
  - gave the following 95% exclusion limits:
    - 2250 GeV, 1770 GeV, 1260 GeV and 1225 GeV are obtained from the inclusive M_{T2} search for gluinos, light-flavor squarks, bottom squarks and top squarks, respectively.
    - The search for disappearing tracks extends the gluino mass limit to as much as 2460 GeV, and the neutralino mass limit to as much as 2000 GeV

Conclusions

Conclusions

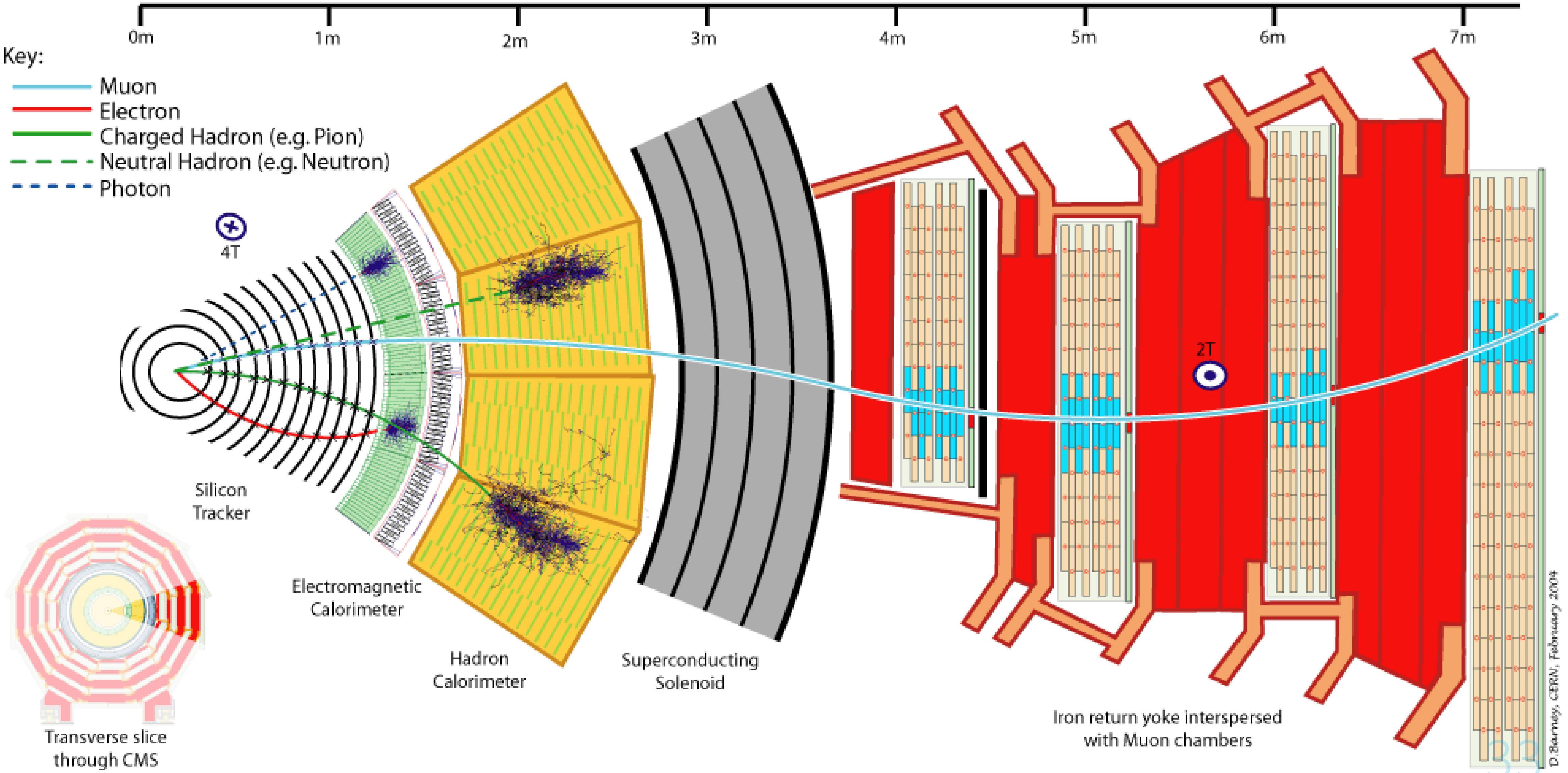
- Three searches
  - with the total integrated luminosity: 137 fb^{-1}
  - center-of-mass energy: 13 TeV
  - corresponding to years 2015-2018
  - were presented and gave the following best 95% exclusion limits for squarks and gluinos:
    - 2250 GeV, 1770 GeV, 1260 GeV and 1225 GeV are obtained from the inclusive M_{T2} search for gluinos, light-flavor squarks, bottom squarks and top squarks, respectively.
    - The search for disappearing tracks extends the gluino mass limit to as much as 2460 GeV, and the neutralino mass limit to as much as 2000 GeV

Backup

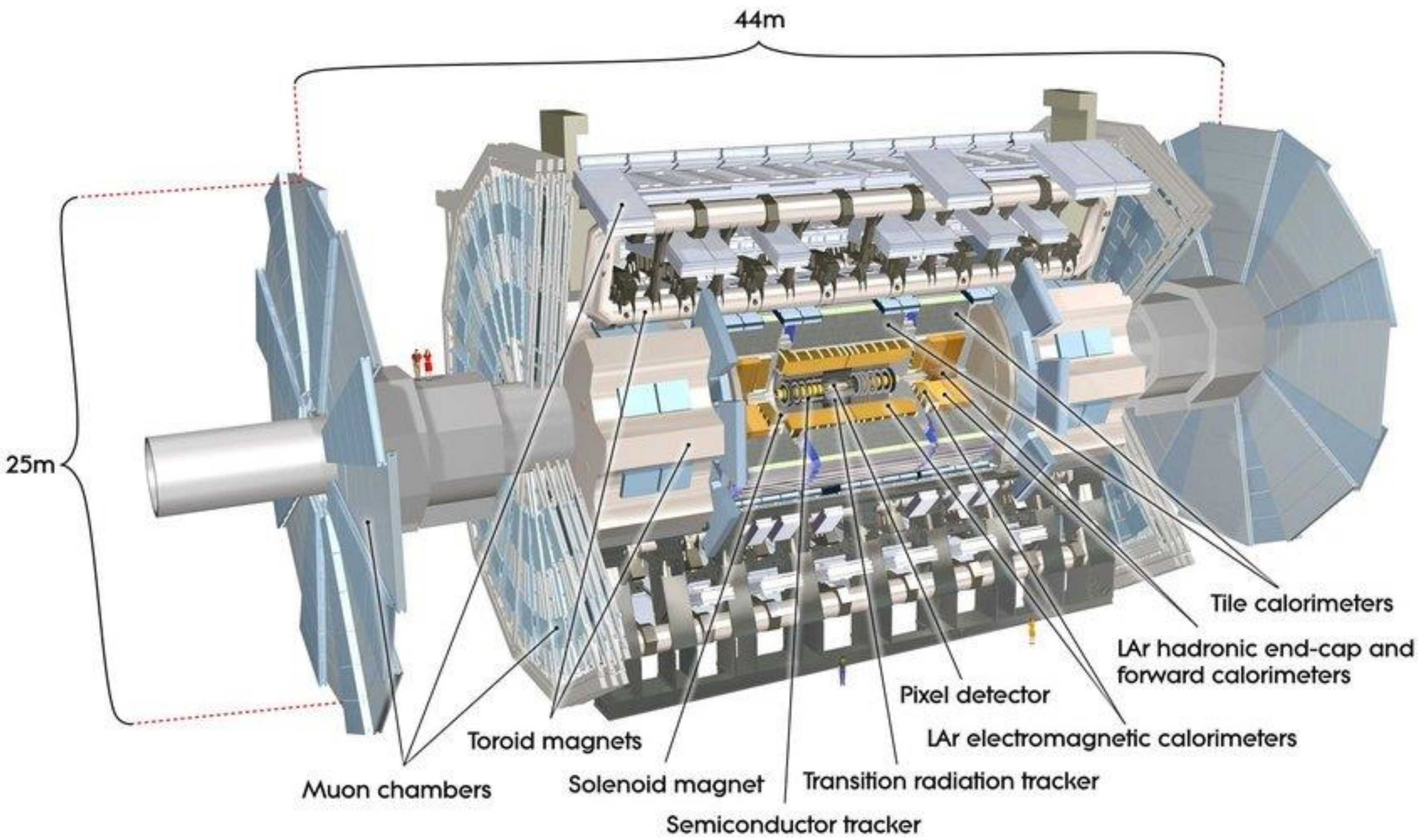
Need for new physics and SUSY

- Although the huge success of the Standard Model, it is known that the SM cannot be the final theory as
  - it does not give any candidate on Dark Matter
  - it does not give any reason why the mass of the Higgs is so low
  - does not provide a unification of the electroweak and strong forces
- Extending the SM with the superpartners of its particles seems to solve these problems theoretically. Superpartners of the SM fermions are bosons while the SM bosons become fermions
- SUSY must be a broken symmetry (if any) and there are many ways to break it
- In this talk simplified model (SMS) based interpretations of strong production SUSY searches are used.
- SMSs are effective models and phenomenology is less important.

CMS detector



ATLAS detector



Triggers for SS/3L

- Triggers used in ATLAS
  - for events with MET < 250 GeV, only lepton-based triggers with period-dependent lepton p_T thresholds are used
  - while for higher MET, MET based triggers are sufficient
- Triggers used in CMS
  - lepton-based triggers with period-dependent lepton p_T thresholds in all cases
  - and requirement of an additional condition on the presence of hadronic activity, HT>300 GeV for a subset of cases

Triggers for inclusive MT2 and disappearing tracks

- Triggers based on
  - HT
  - MET
  - MHT
  - Jet p_T

- In the search for disappearing tracks, events are selected requiring the presence of at least one disappearing track.

Trigger	2016: $p_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ and $H_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 300\,\mathrm{GeV}$ and $p_{\mathrm{T}}^{\mathrm{miss}} > 110\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 900\,\mathrm{GeV}$ or jet $p_{\mathrm{T}} > 450\,\mathrm{GeV}$ 2017 and 2018: $p_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ and $H_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 60\,\mathrm{GeV}$ and $p_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ and $H_{\mathrm{T}}^{\mathrm{miss}} > 120\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 500\,\mathrm{GeV}$ and $p_{\mathrm{T}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$ and $H_{\mathrm{T}}^{\mathrm{miss}} > 100\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 800\,\mathrm{GeV}$ and $p_{\mathrm{T}}^{\mathrm{miss}} > 75\,\mathrm{GeV}$ and $H_{\mathrm{T}}^{\mathrm{miss}} > 75\,\mathrm{GeV}$ or $H_{\mathrm{T}} > 1050\,\mathrm{GeV}$ or jet $p_{\mathrm{T}} > 500\,\mathrm{GeV}$

Exclusion limits

- Exclusion regions at 95% CL for the T1tttt model (left) and the T5tttt model (right)
- The solid, black curves represent the observed exclusion limits assuming the NNLO+NNLL cross section
- The dashed red curves show the expected limits