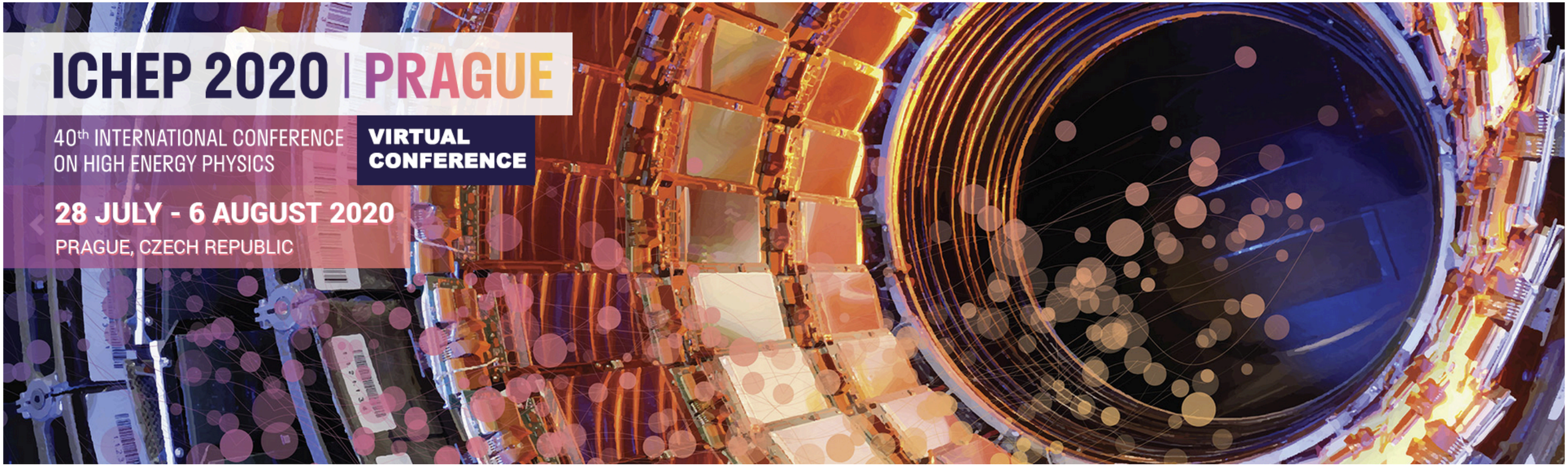


Supersymmetry: experimental overview

Cristina Botta, University of Zurich

On behalf of the ATLAS and CMS Collaborations

ATLAS EXPERIMENT

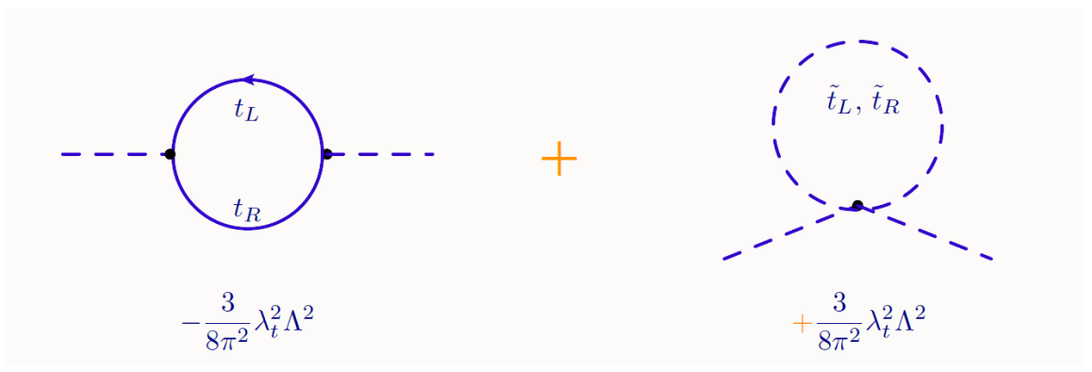
UNIVERSITAS TURICENSIS MDCCC XXXIII

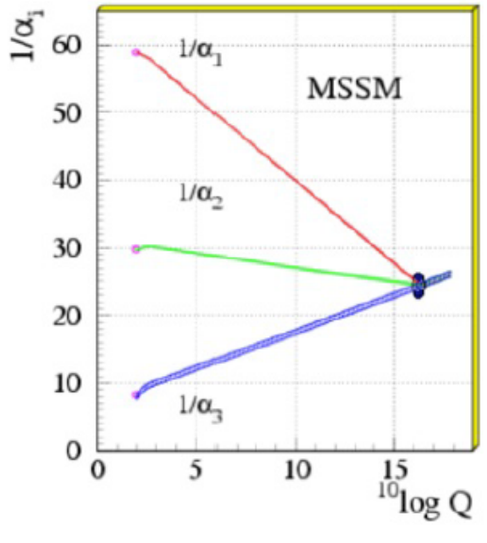
CMS

Supersymmetry and its needs

- **Still the most attractive theory model that could potentially solve the shortcomings of the Standard Model**

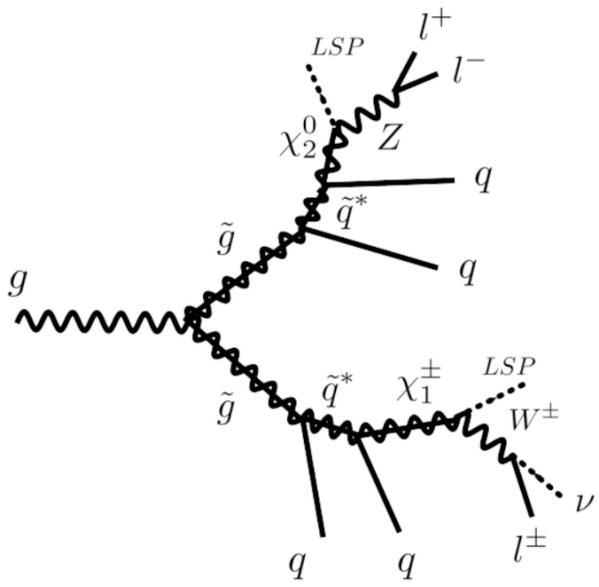
  - **very compelling theory:** symmetry that can rotate boson into fermions and viceversa
    - needs **partners for all SM particles**, spin different by 1/2, charged under SM charges
  - can provide a **Dark Matter candidate**
    - **if R-parity is conserved:** stable LSP
      - neutral candidate of the extended EWK sector perfect WIMP: **lightest neutralino**
  - can solve **the Hierarchy problem**, and make the theory natural
    - if the most important states to solve the problem are at the weak scale: **Higgsinos <~300 GeV, top squarks <~1TeV, gluinos <~2 TeV**
  - can predict the **SM forces unification** at the high scale, just below the Planck scale



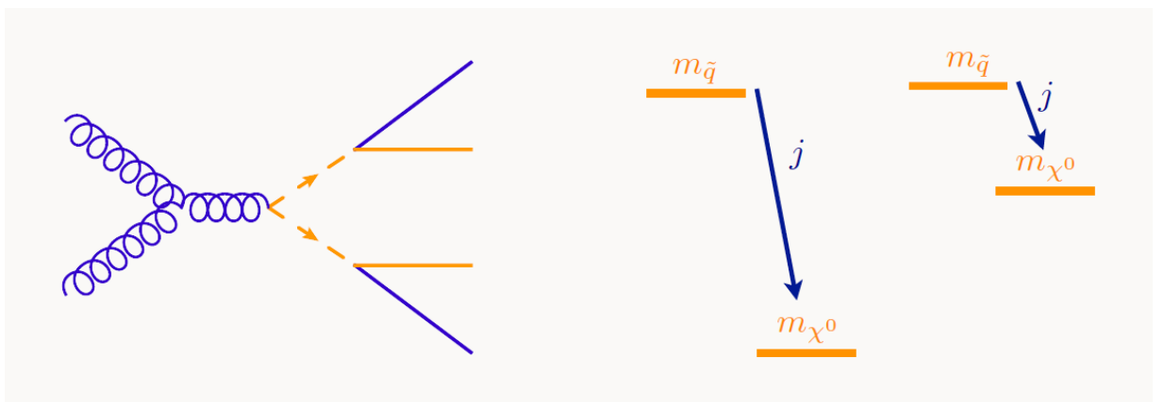


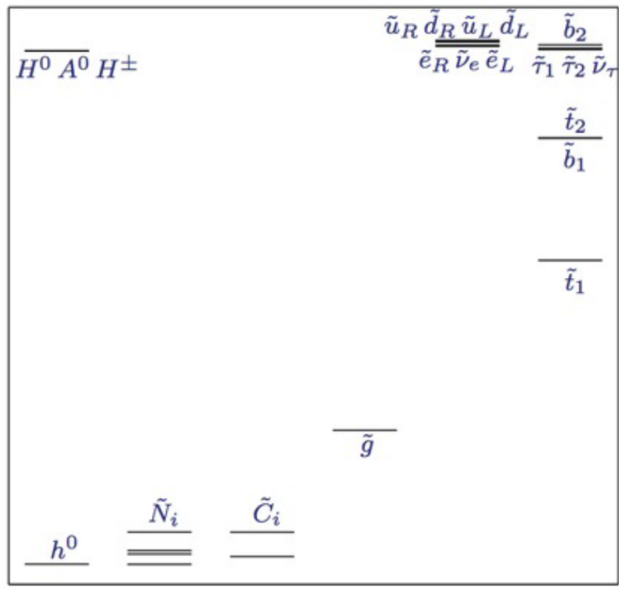
Searching SUSY at LHC

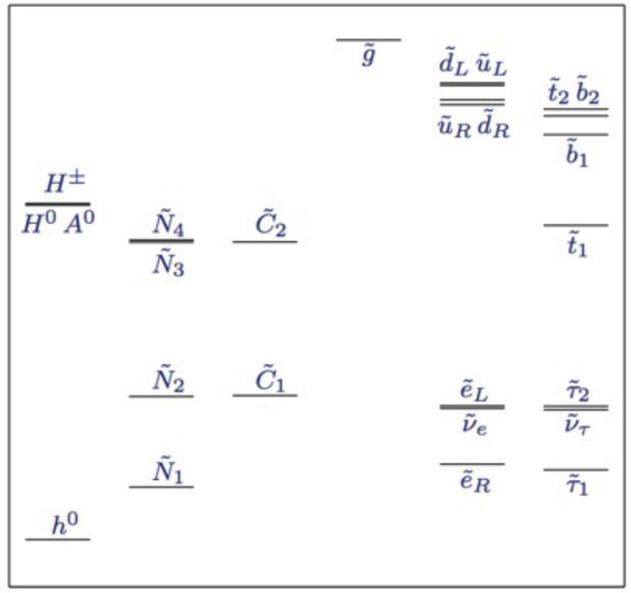
- **Standard searches in pp collisions: final states with large missing transverse energy (E_T^{miss})**
  - if R-parity is conserved sparticles are **produced in pairs and decay into the LSP**
  - final states with multiple SM objects and **massive undetectable particles on both legs**



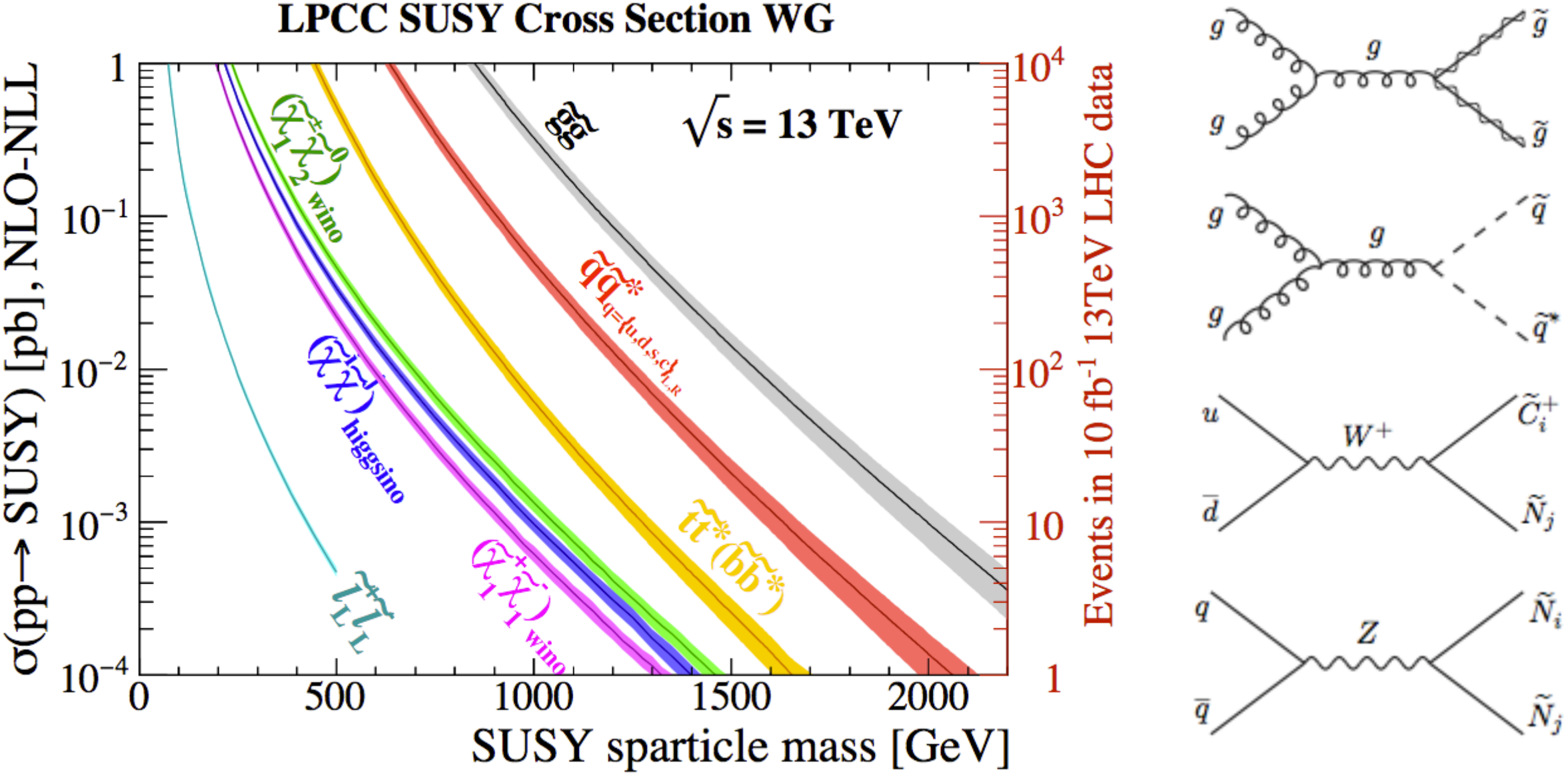
- **So many possible mass spectra to test: since LHC RunII Simplified Model approach**
  - **to design searches focus on a few new particles at the time**
    - ex. concentrate on direct light squark production and **the only open decay mode if light squarks are NLSP** (all other particles not in the reach)







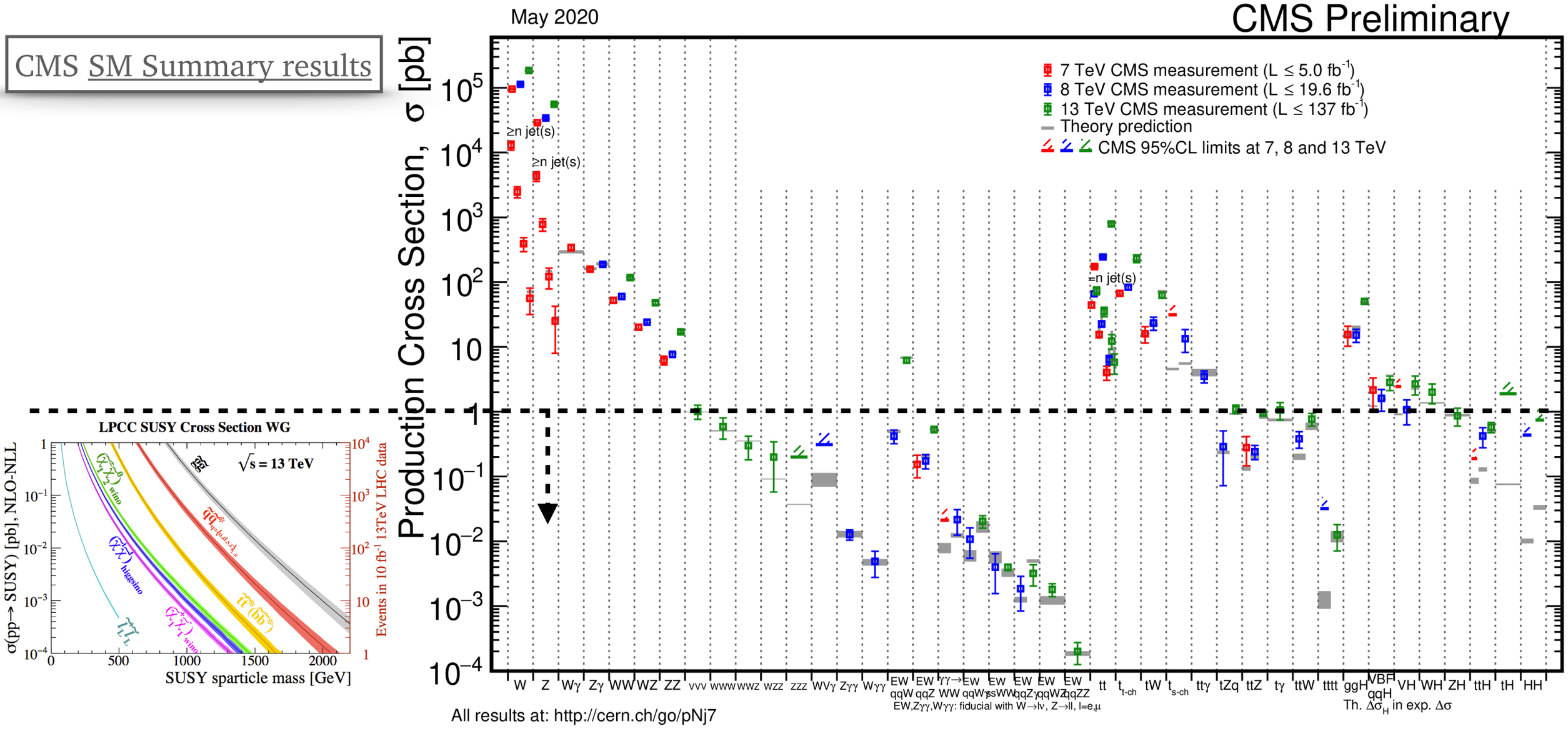
SUSY production at 13 TeV



- Cross section falls as a rock with the sparticle mass
- Strong sector: largest cross sections, gluon induced
- EWK sector: much lower cross sections, quark induced

Search tools: ATLAS and CMS

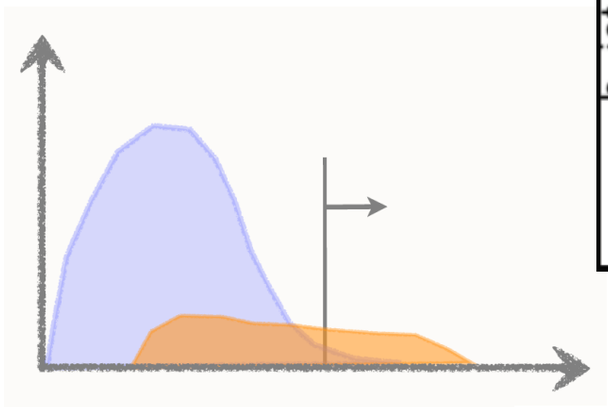
CMS SM Summary results

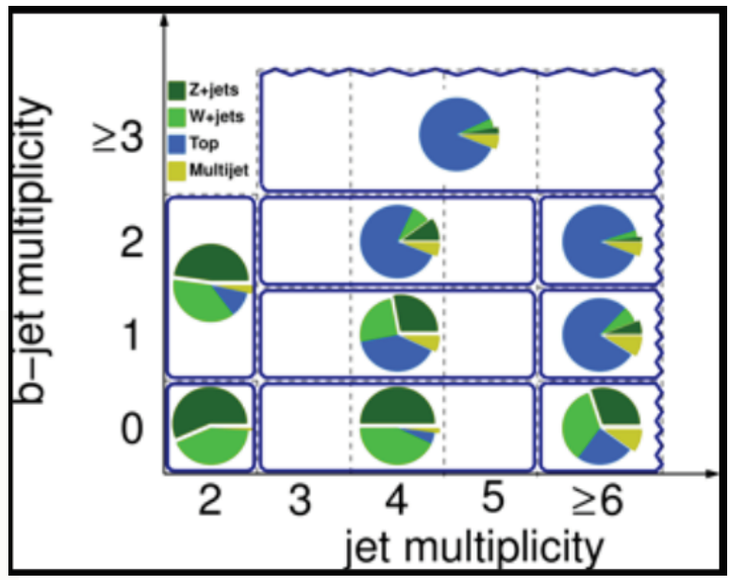


- **We have learnt how to calibrate well our detectors:**
  - agreement between measurements and predictions for **many SM processes**
- **Demonstrate sensitivity to rare SM processes with same NP cross section**
  - advanced bkg reduction techniques
  - large dataset: LHC RunII 2015-18 **~140 fb-1 @ 13 TeV**

Search strategies at ATLAS and CMS

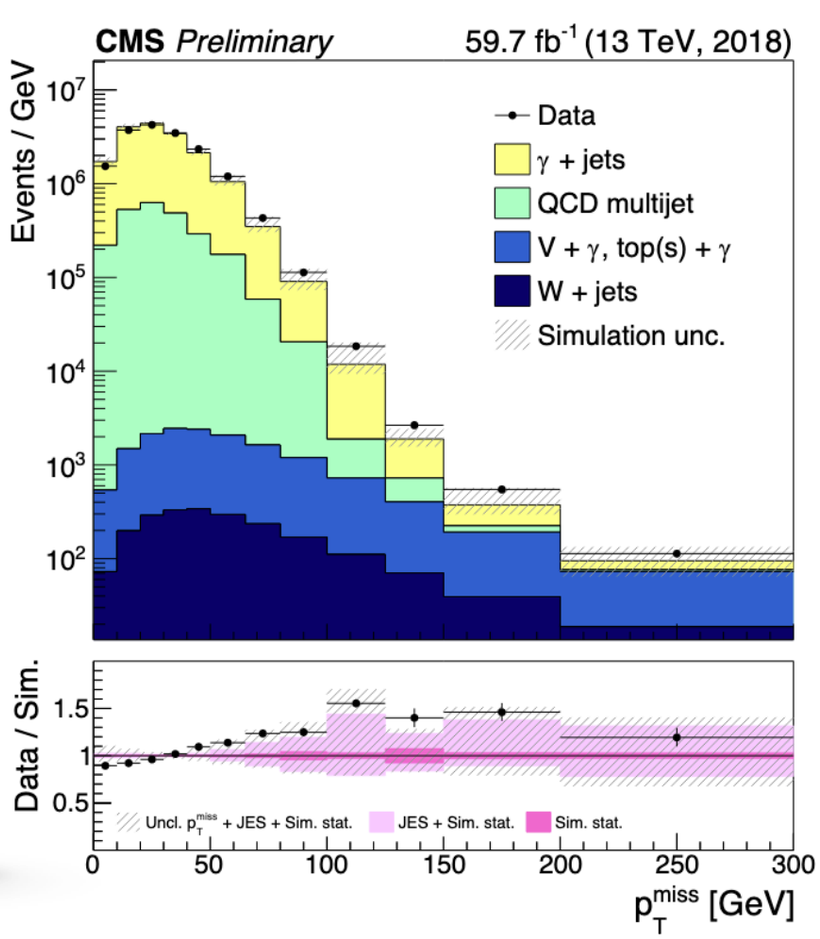
- **Standard discovery strategy:**
  - demand multiple **energetic objects: jets, b-jets, leptons**
  - determine suitable kinematic variables (E_T^{miss}, M_T, M_{T2}, H_T...) and count events in the **tails**
  - in SM bkg any kinematic variable with dimension of mass **falls more rapidly**





- **Experimental challenges**
  - hard to understand tails due to **detector effects and bkg modelling in extreme regions of the phase-space**
  - regions where the predictions from MC are subject to sizeable uncertainties

- **Rely as much as possible on data**
  - define **"control-regions (CR)"** kinematically closed to the **"signal-regions (SR)"** enriched in a specific background to normalise the predictions



CMS **NEW** DP-2020/031

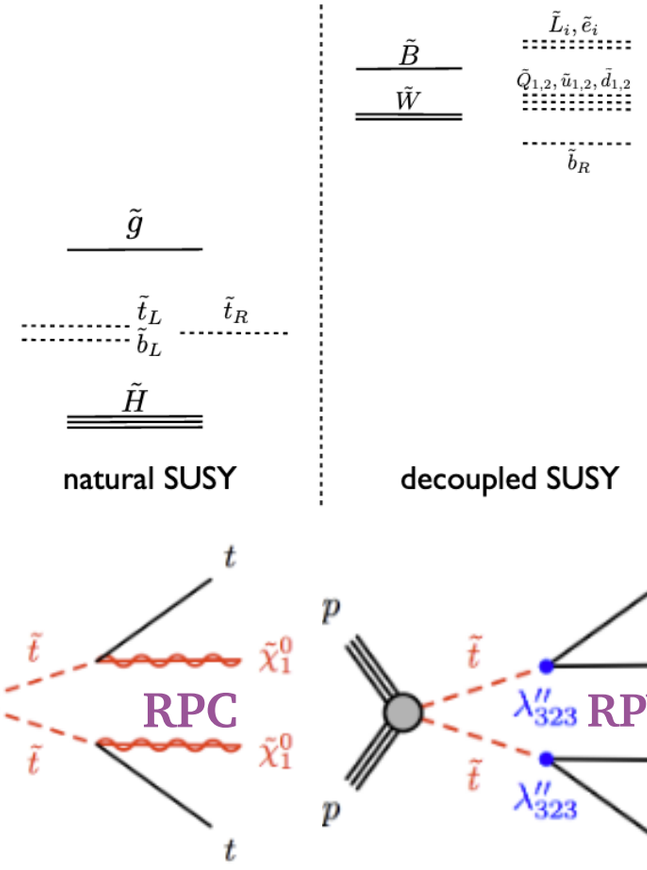
SUSY searches at LHC in 2020

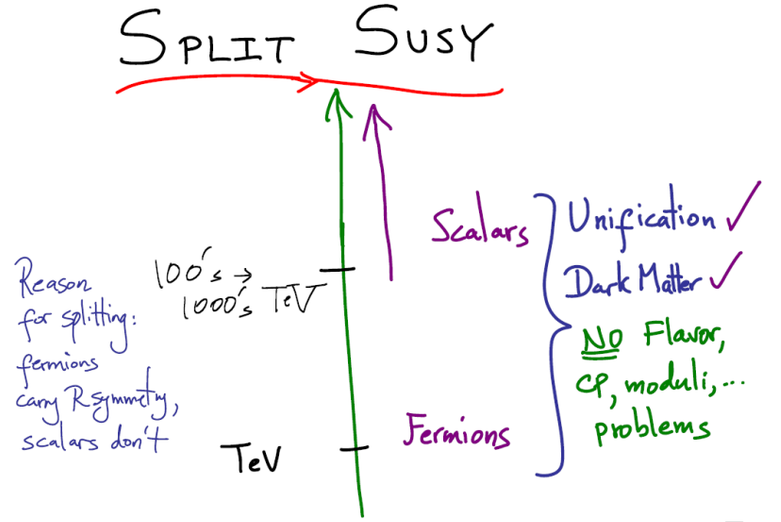
- **Update standard searches to full dataset: SUSY RunII legacy results**
  - **exclude most of the region of the parameter space** where SUSY can give us naturalness **and** DM **and** unification

- **Before relaxing assumptions: designed new analysis strategies to target remaining corners**
  - **compressed mass spectra:**
    - **moderate E_T^{miss}, soft/displaced objects**
    - small acceptance due to challenges in triggering and reconstruction, S/B: **sparticles can still be "lighter"**

- **Giving up on DM: R-Parity violating SUSY (RPV)**
  - **LSP not stable: no E_T^{miss},** multiple (resonant) SM objects
  - LSP decays can be suppressed by small RPV couplings **(λ',λ"): displaced signatures**

- **Giving up on Naturalness: mini-split SUSY**
  - theory built in the past years: **sfermions up to ~100 TeV, keep -inos near(ish) the weak scale**
  - **displaced decays** in searches for accessible -inos that decay through heavy sfermions





From Arkani-Hamed's talk

A non-comprehensive selection of results

- **Provide an overview of current status focusing on few particular examples either from ATLAS or CMS**
  - detailed presentations on all the most recent ATLAS and CMS analyses can be found in the **parallel talks of the previous days:**

Squarks and Gluinos at ATLAS by Aaron Paul O'Neill

Top squarks at CMS by Soham Bhattacharya

Top and bottom squarks at ATLAS by Thomas James Stevenson

Leptonic final states at CMS by Ashraf Mohamed

EWK production at ATLAS by Sarah Alderweireldt

Digging deeper into SUSY parameter space at CMS by Sezen Sekmen

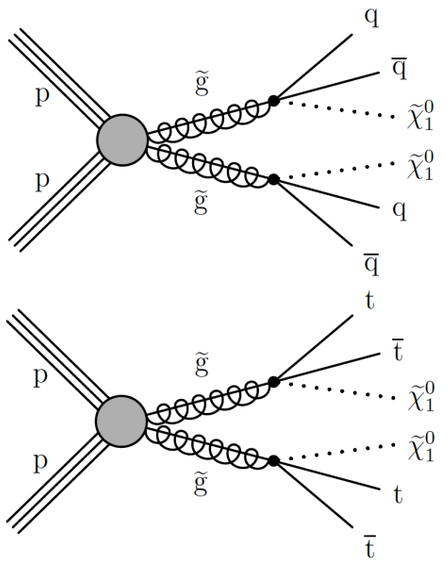
Beyond the cut-and-count in ATLAS analyses by Frederik Ruehr

Identification of soft objects at ATLAS by Shion Chen

RPV SUSY in ATLAS by Johannes Josef Junggeburth

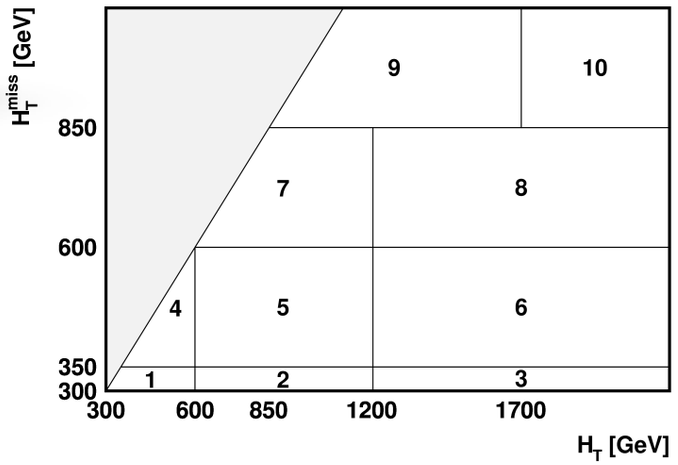
SUSY with long-lived particles in ATLAS by Tova Ray Holmes

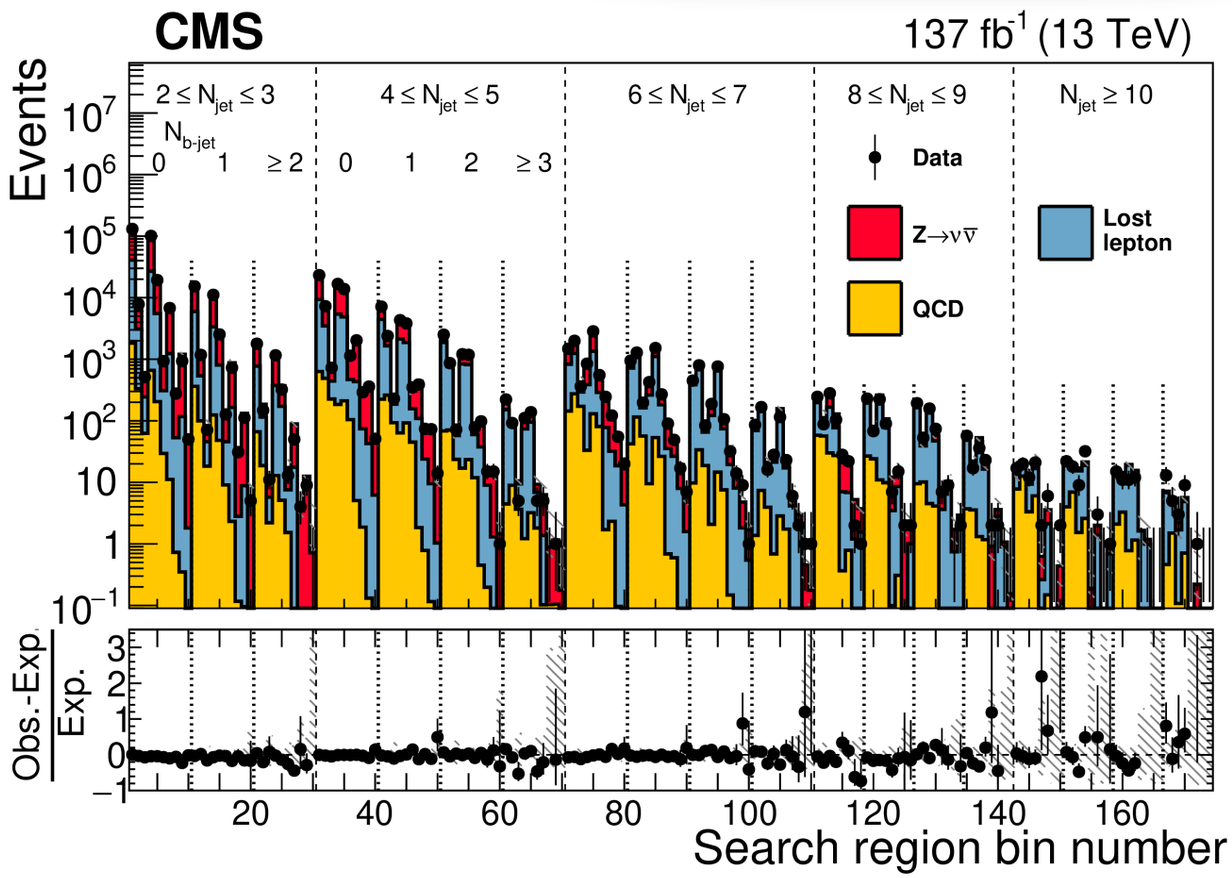
Gluinos: a full hadronic search

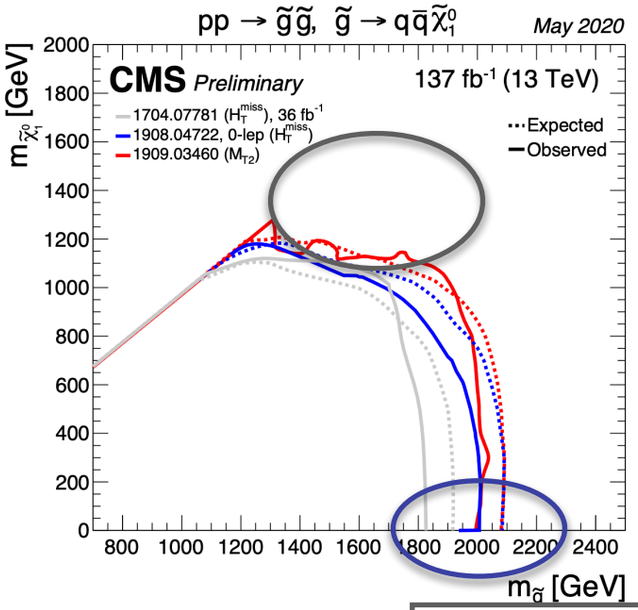


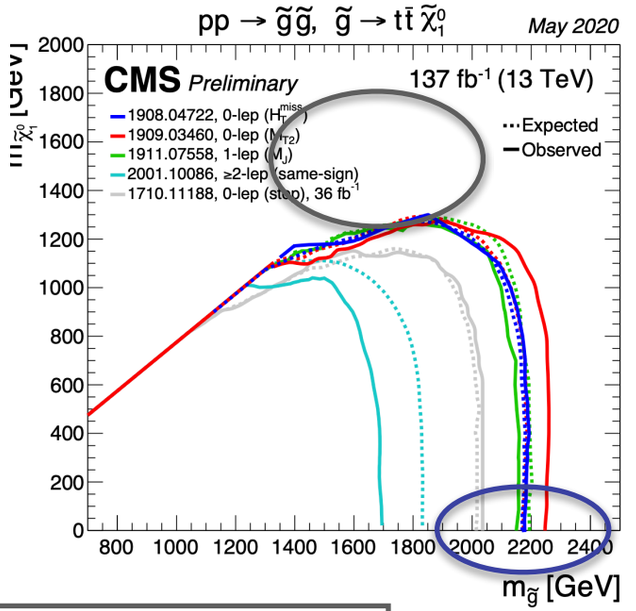
- **Typical simplified model: gluinos NLSP, decay through virtual squarks (NNLSP), if top squarks more naturalness-friendly**
  - inclusive full hadronic searches: **multiple jets and large E_T^{miss}**
  - many SRs to target different sparticle mass spectra, and bkg composition: **N_{jets}, $N_{b\text{-}jets}$, E_T^{miss}, H_T, H_T^{miss}, M_{T2}**

CMS: JHEP10(2019)244



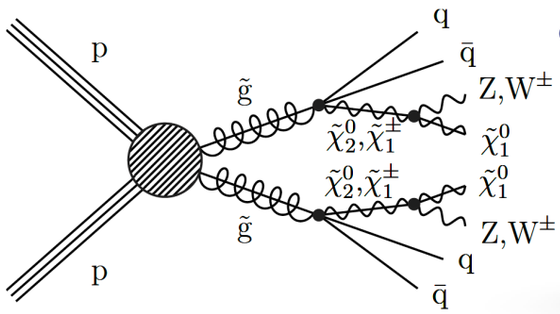






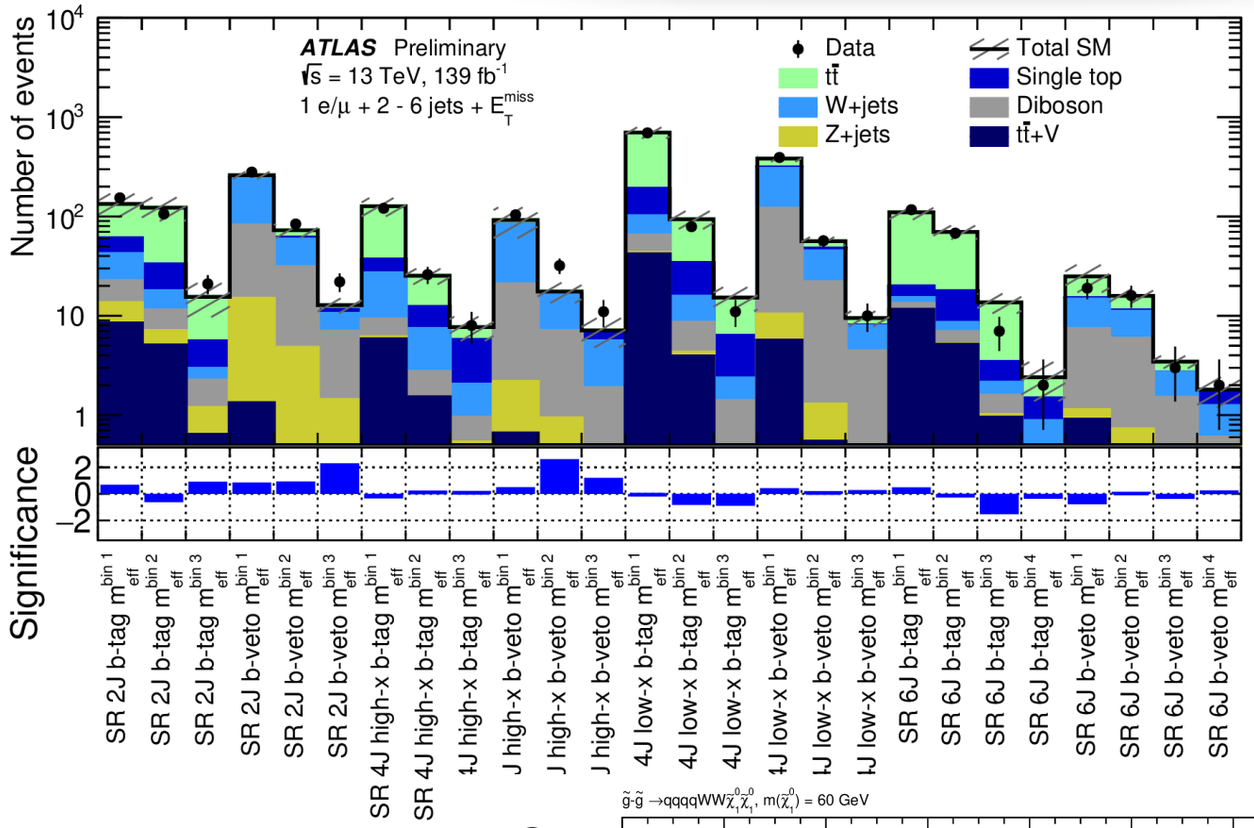
CMS SUSY Summary results

Gluinos: when charginos are available

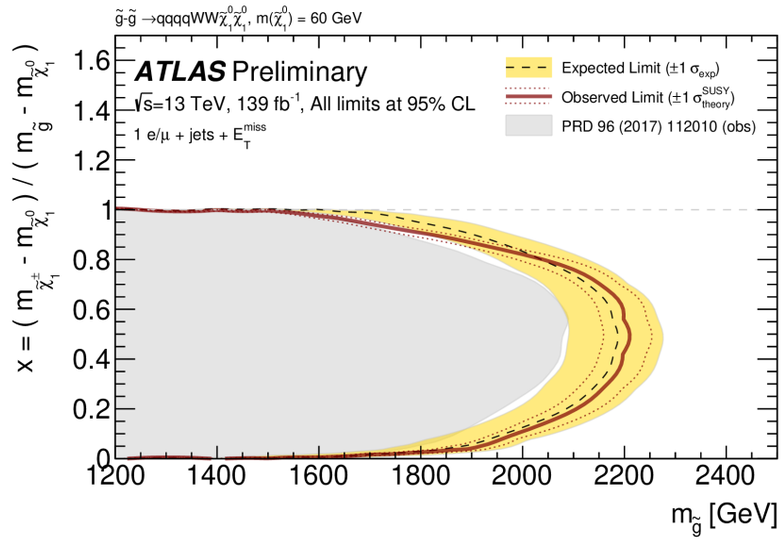


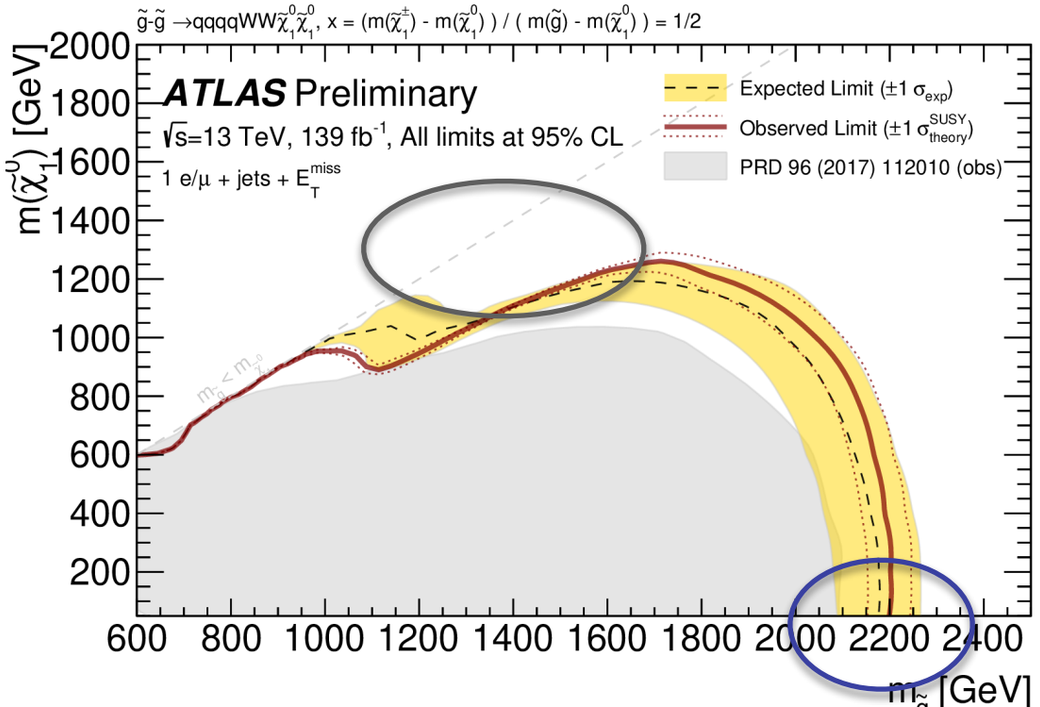
- **Model "next door" gluinos NNLSP, Wino NLSP or Higgsinos LSP**
  - single lepton searches exploiting one W→ℓυ, or tagging Z→qq/ℓℓ

NEW ATLAS CONF-2020-047



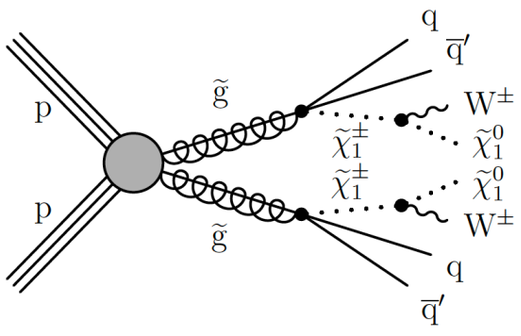
- **Several signal regions with one lepton (e,μ), jets, and E_T^{miss}**
  - target different **gluino, chargino and LSP masses** and bkg composition
  - binned with: **$M_T(\ell, E_T^{miss})$, N_{bjets}, m_{eff} (scalar sum:E_T^{miss},ℓ,jets p_T)**
- ℓp_T down to 6/7 GeV to target Δm(chargino-LSP) of few tens of GeV (Higgsino LSP)



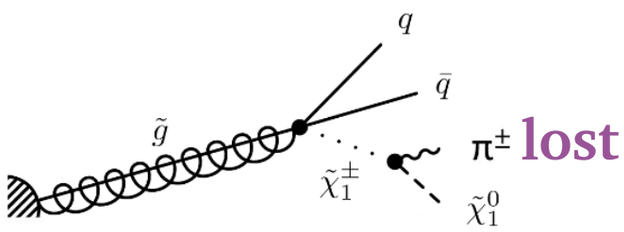


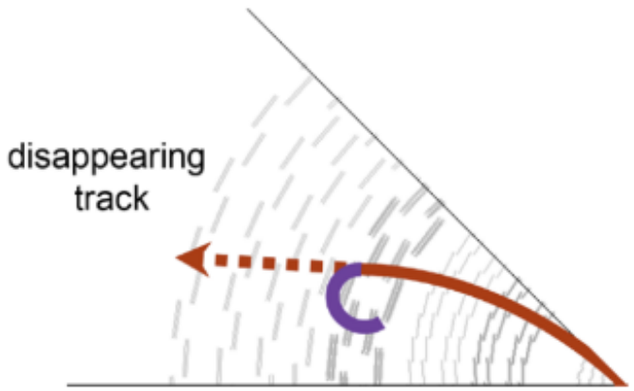
Gluinos: compressed regions?

- **Gluinos excluded up to 2 TeV for massless LSP, expected limits weaken down to 1.2 TeV in compressed region**
  - smaller **Δm($\tilde{g}$-LSP)**, signal is more SM bkg like

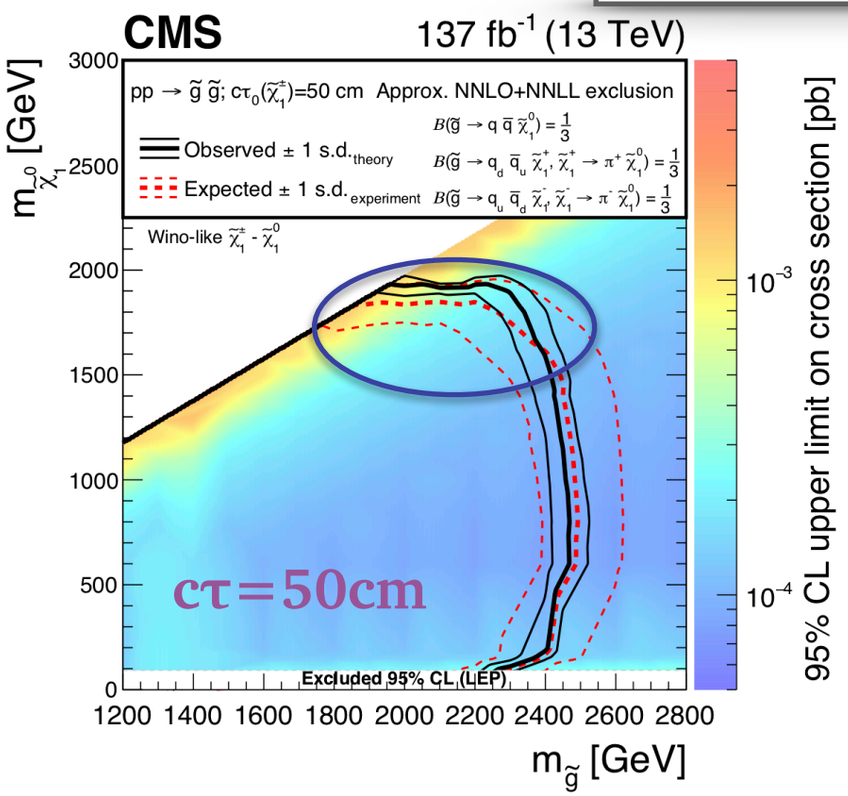


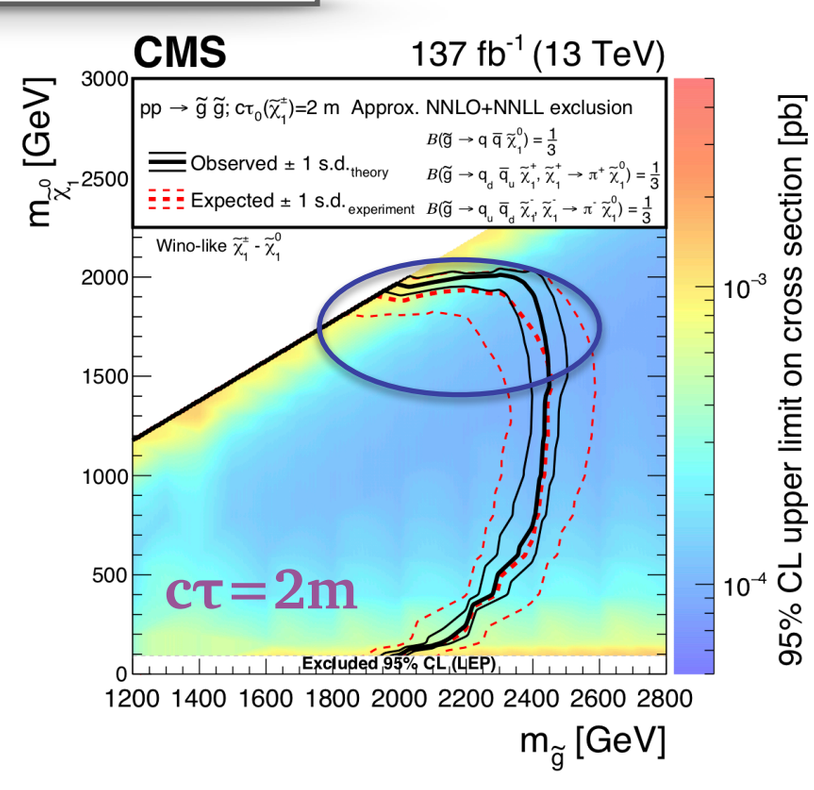
- **In peculiar topologies this region is accessible:**
  - assuming **Wino LSP Δm(chargino, neutralino)~O(100)MeV**
  - **chargino is long lived (cτ of ~10s cm),** and decays into a soft pion and neutralino
  - identification of **disappearing tracks** inside the tracker volume (<1m) reduce bkg as much as 10000x





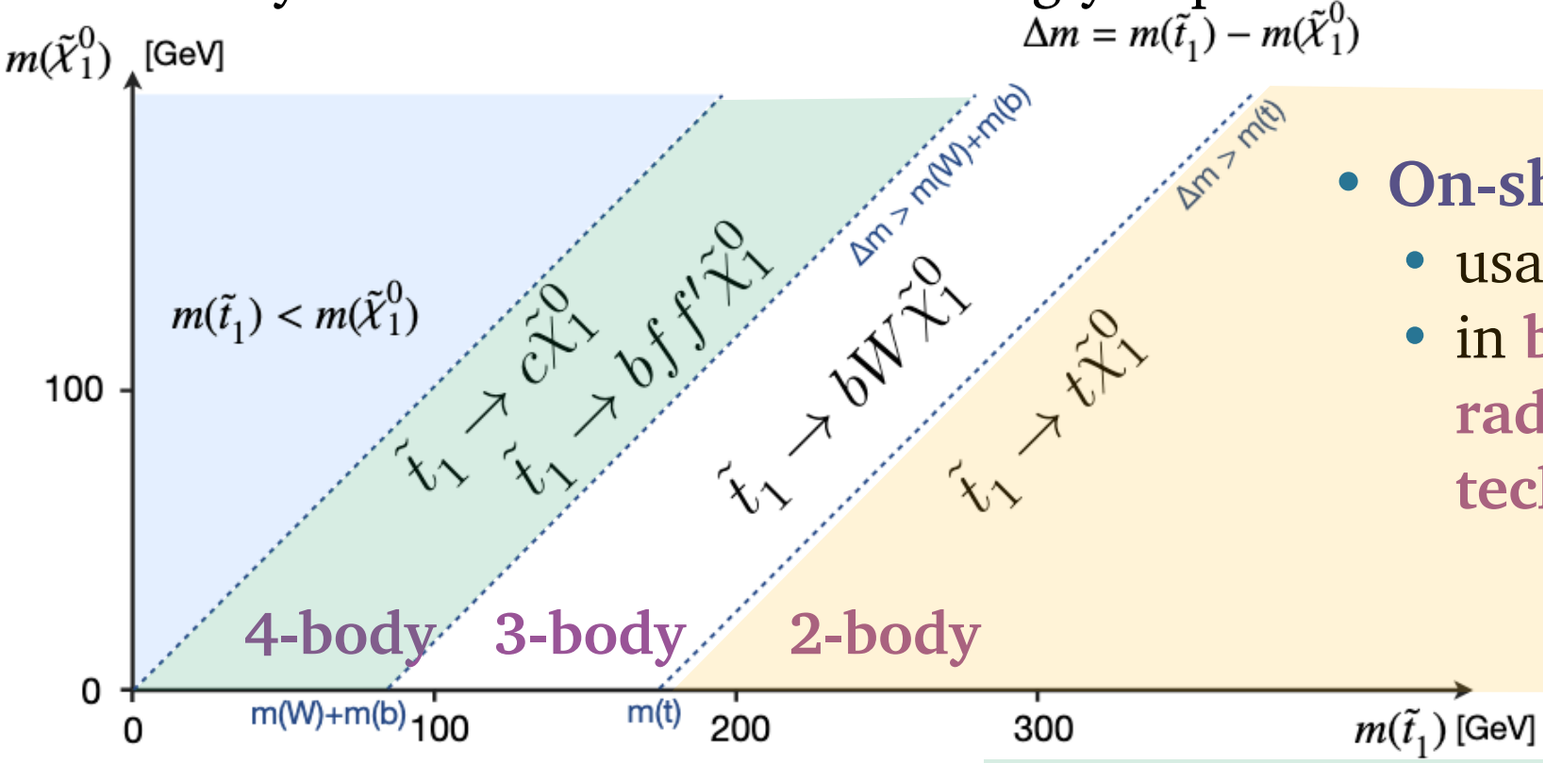
CMS Eur.Phys.J.C80(2020)3



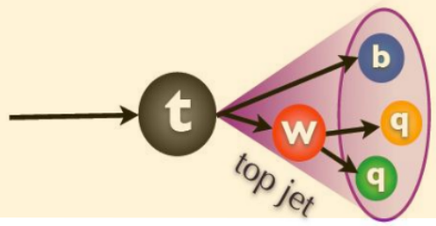


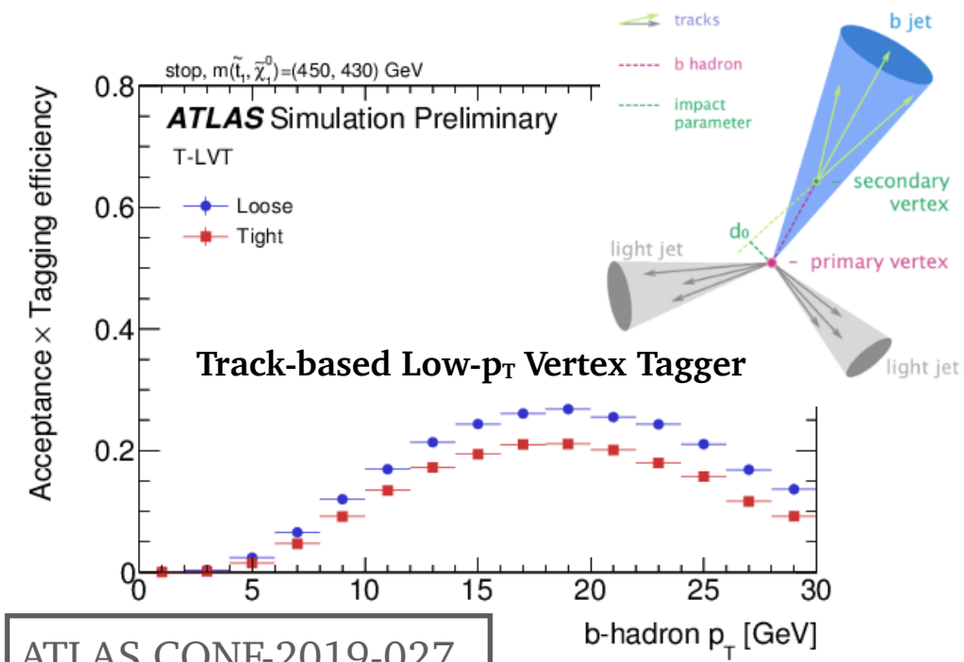
Top squarks: can they still be light?

- **Assume stop NLSP: direct top squark pair production**
  - decay modes and kinematic strongly depends on **Δm(t̃-LSP)**



- **On-shell tops: Δm>m_t**
  - usage of hadronic **top taggers**
  - in **boosted regime** exploit **large radius jets and jet substructure techniques**



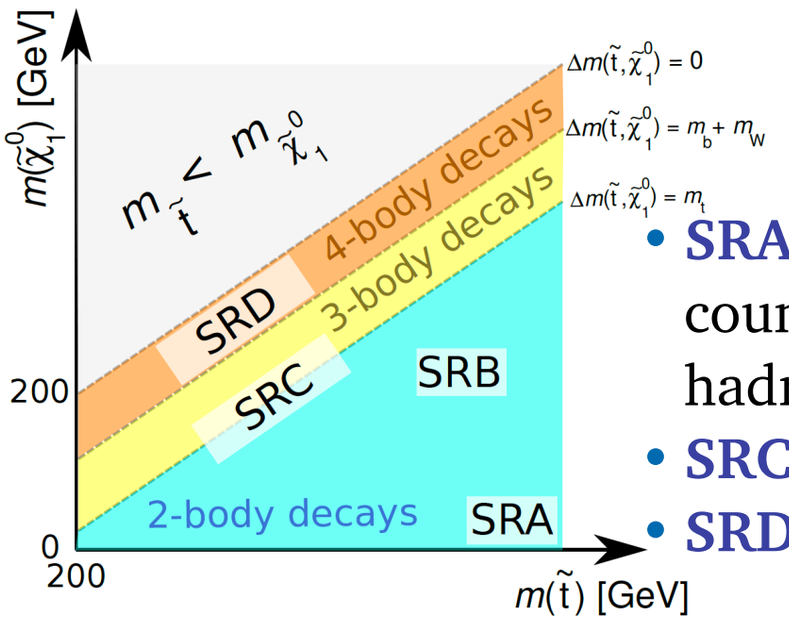


ATLAS CONF-2019-027

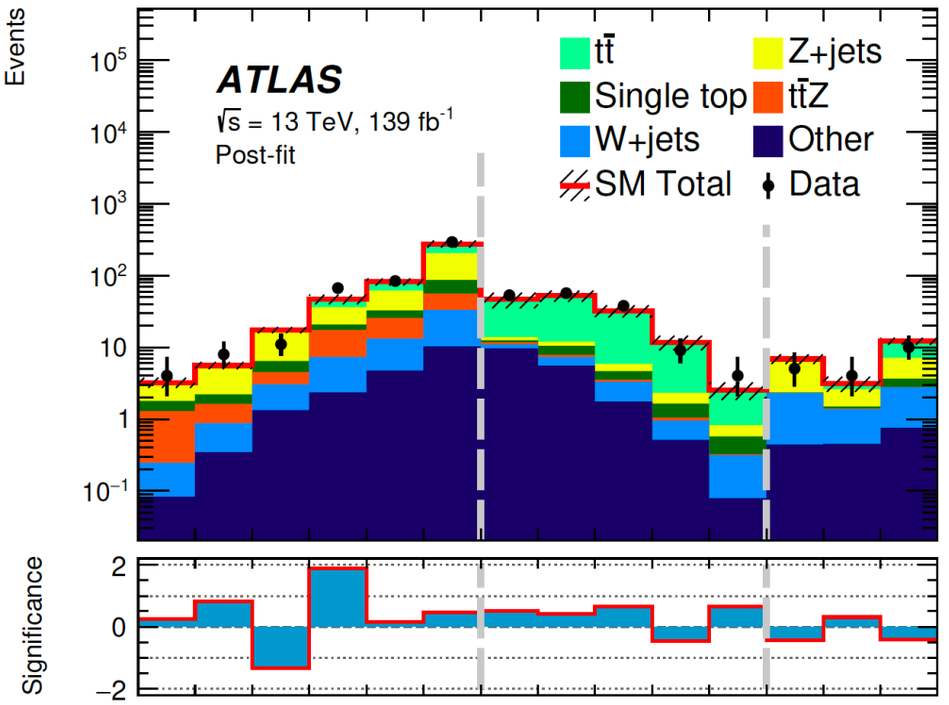
- **Compressed region (Δm<m_W): off-shell t and W**
  - challenging: very soft decay products
  - **LSP reproduce the correct DM abundance** (cohannihilation stops and LSP)
  - **high-p_T ISR jet** to boost sparticle pair and reduce overwhelming bkg with:
    - **soft b-tagging with track-jets/ secondary vertices (5 GeV)**
    - **soft leptons (down to 3.5/4 GeV)**

Top squarks: 0 leptons search

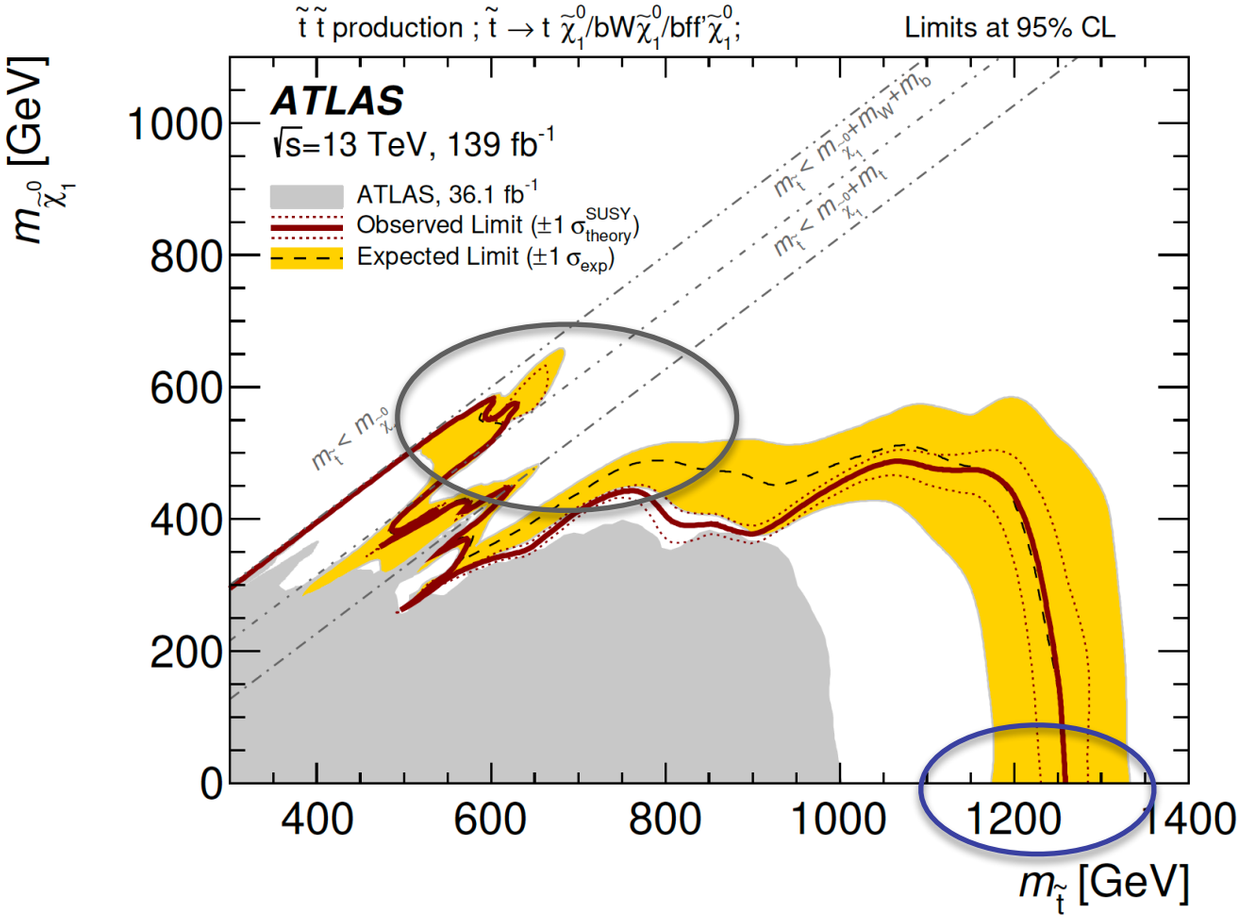
- **Full hadronic search: veto e/μ, E_T^{miss}>250 GeV**

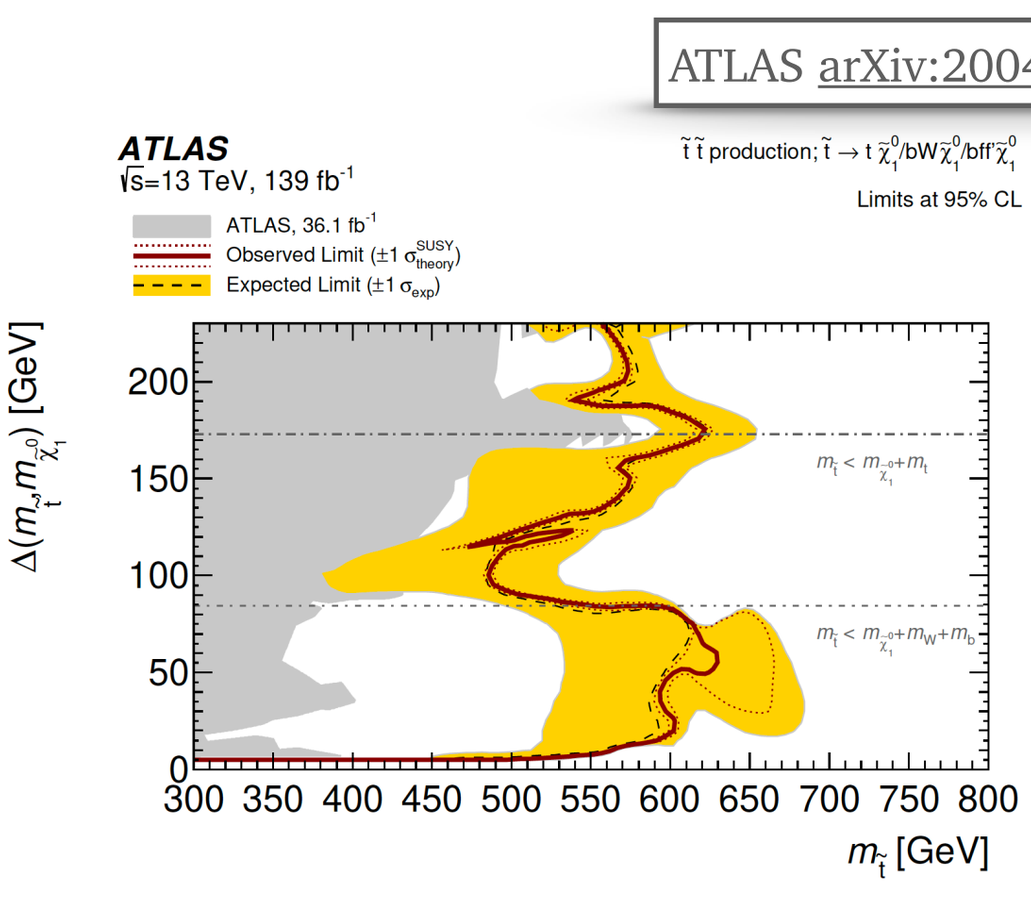


- **SRA-C:** $N_{jets} \geq 4$ GeV, $N_{bjets} \geq 2$, count numbers of reconstructed hadronic top/hadronic W
- **SRC-D:** use a high-p_T jet from ISR
- **SRD:** track-jets with p_T>5 GeV



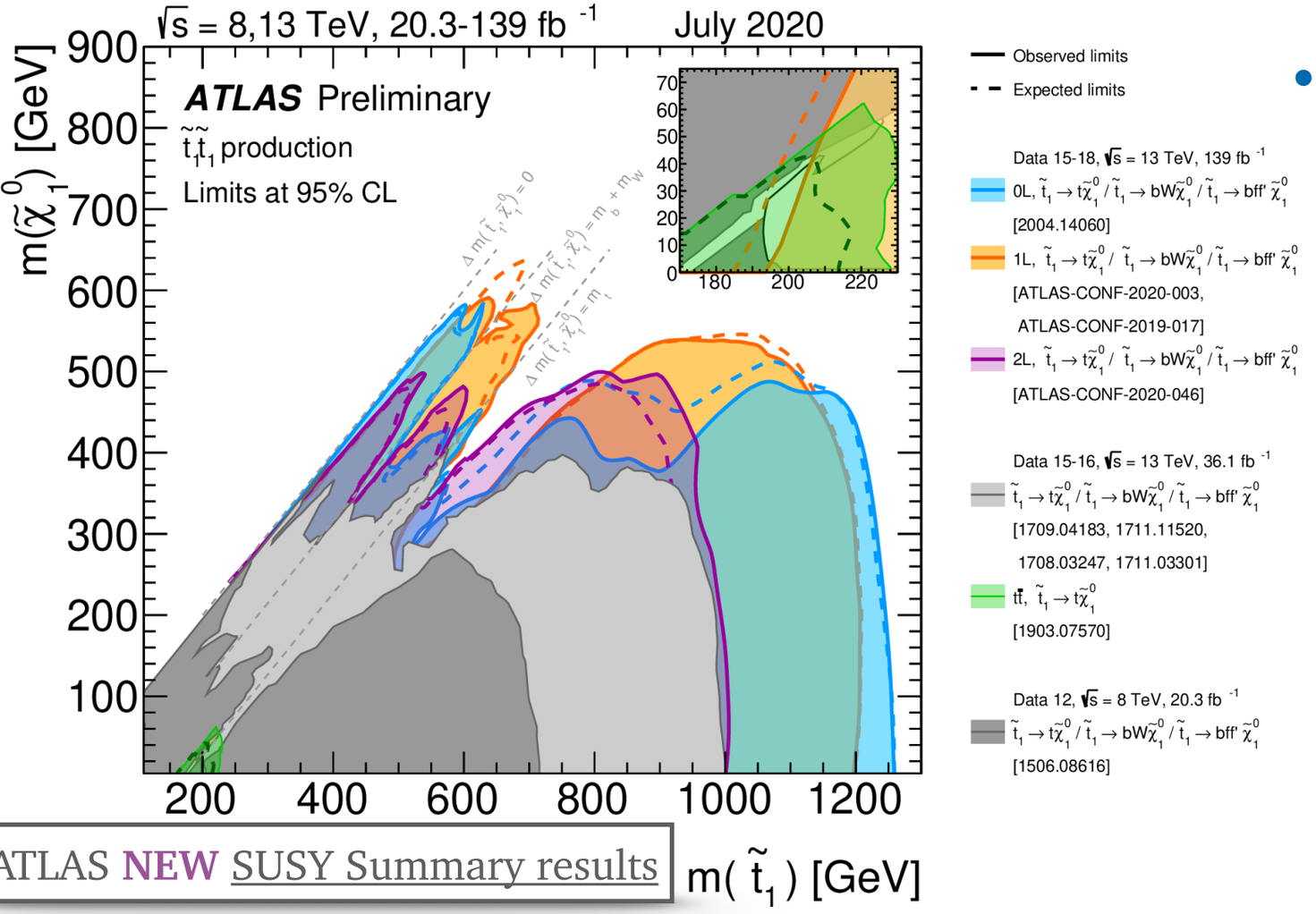
ATLAS arXiv:2004.14060





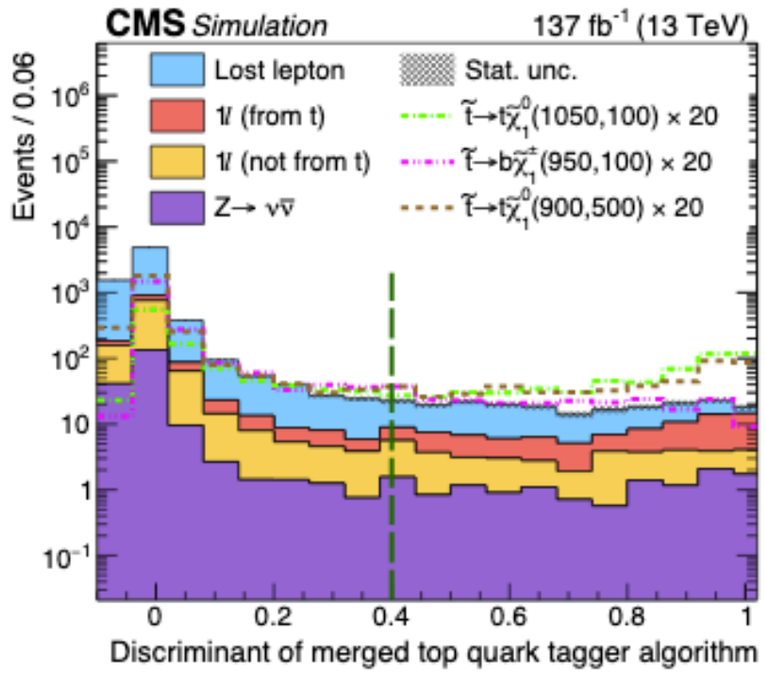
Top squarks: 1 or 2 leptons searches

- **Single lepton search: one e/μ, E_T^{miss}>250 GeV** ATLAS CONF-2020-003
  - SR for compressed region: **ISR jet, soft b-tagging and soft leptons**: e(μ)[4.5(4)-25] GeV
  - SR with on-shell tops: use **hadronic top tagging, and 'topness' variable** to estimate compatibility with di-lepton ttbar with lost lepton (main bkg)
- **Dilepton search: two OS e/μ, E_T^{miss}>250 GeV** ATLAS **NEW** CONF-2020-046
  - SR for compressed region: **ISR jet and soft leptons:** e [4.5-25] GeV, μ [4-25] GeV
  - SR with on-shell tops: use of **lepton-based stransverse mass m_T^{ll}**



ATLAS **NEW** SUSY Summary results

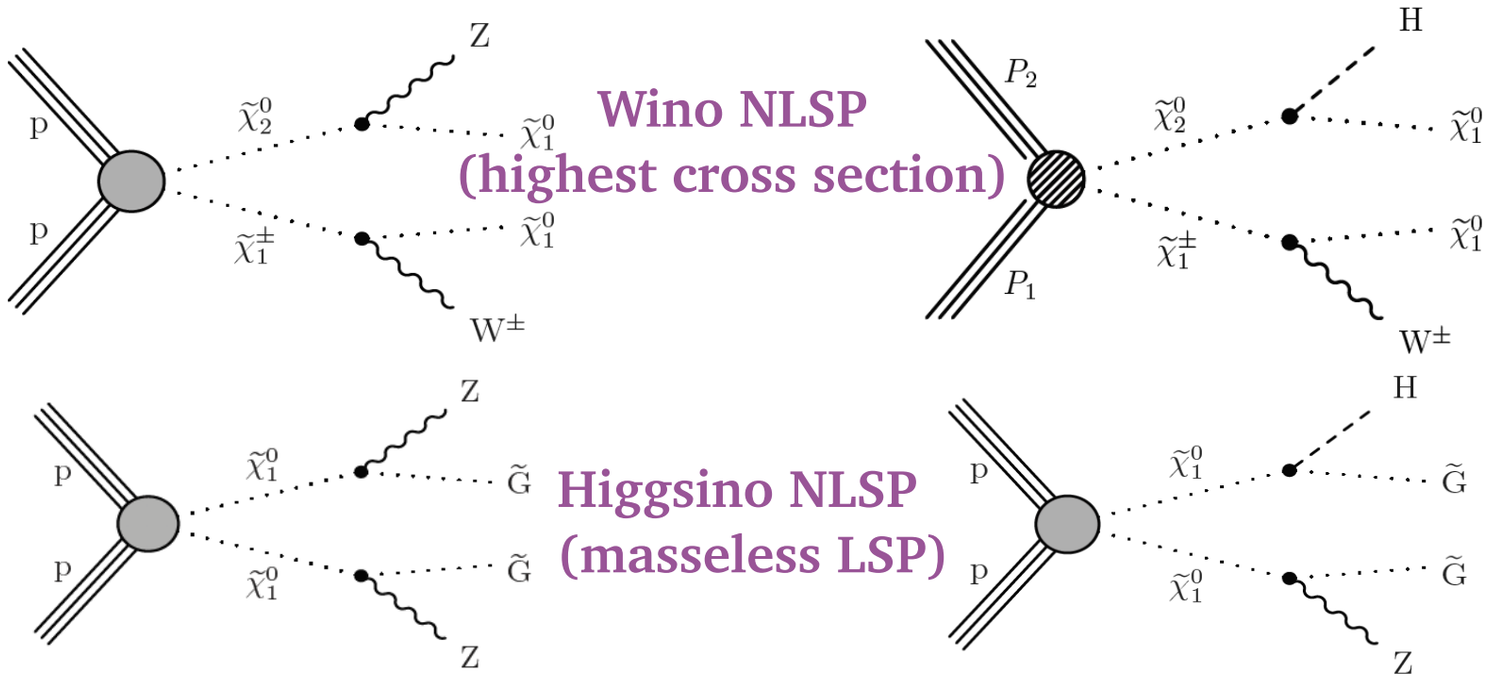
- **DNN hadronic top taggers used in CMS for the on-shell top regions**

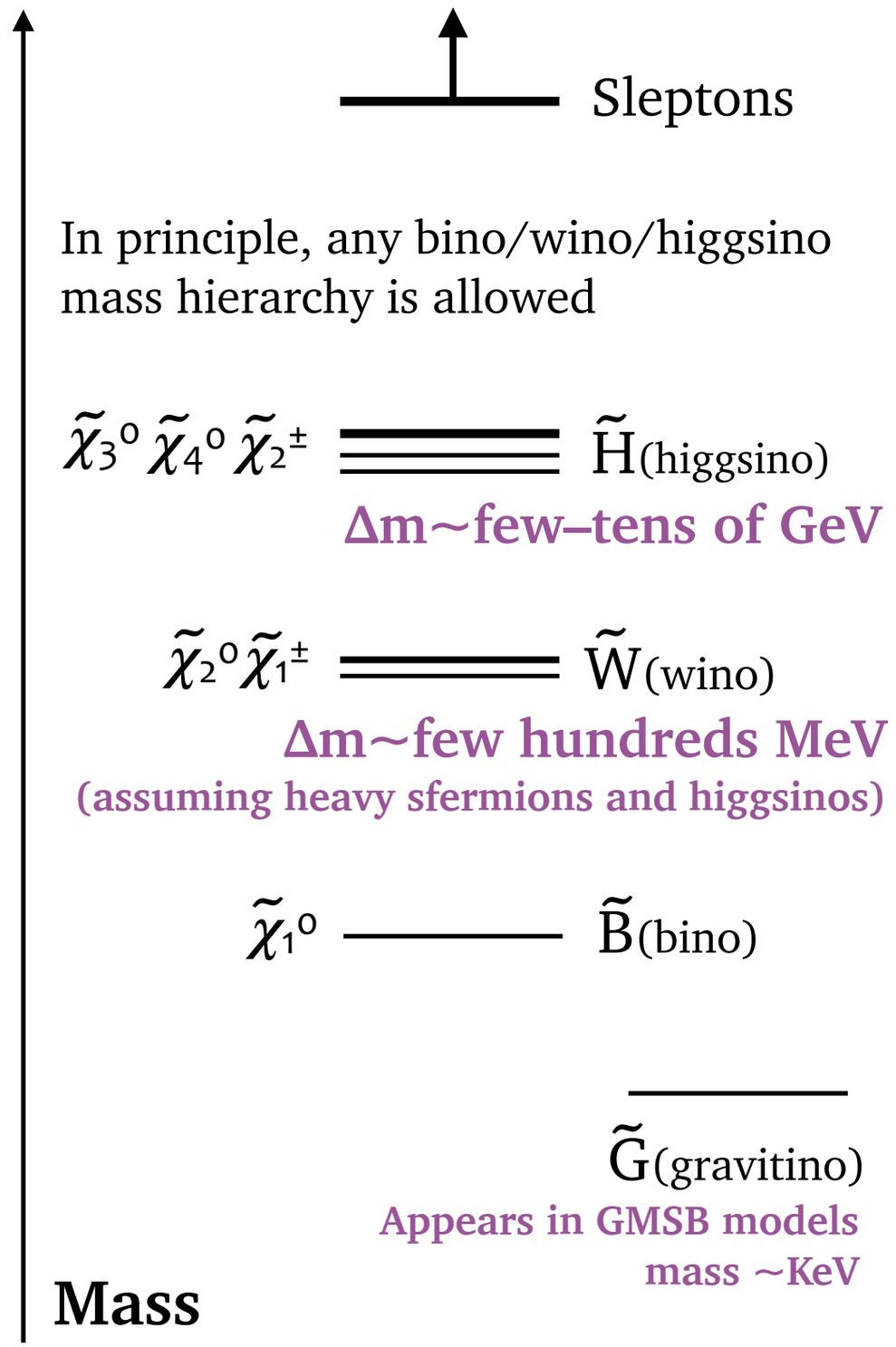


CMS JHEP 05(2020)032

Electroweakinos: dealing with leptons

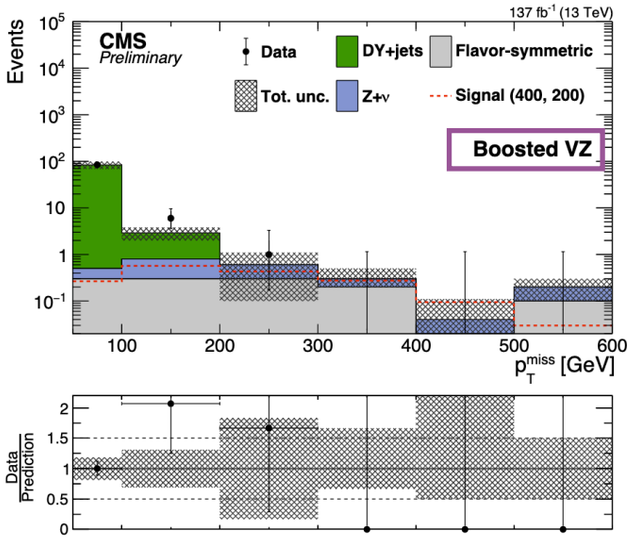
- **EWK sector: much lower cross sections**
  - sensitivity to **lower sparticle masses**
  - final states too much SM like if dealing with W,Z,H hadronic decays, **searches rely on leptonic final states**
- **2 e/μ OSSF, 3 or more e/μ/τ_h**
  - **high or low p_T leptons** used to access different values of Δm(NLSP-LSP)
  - additional tagging of **H→γγ, H→bb**

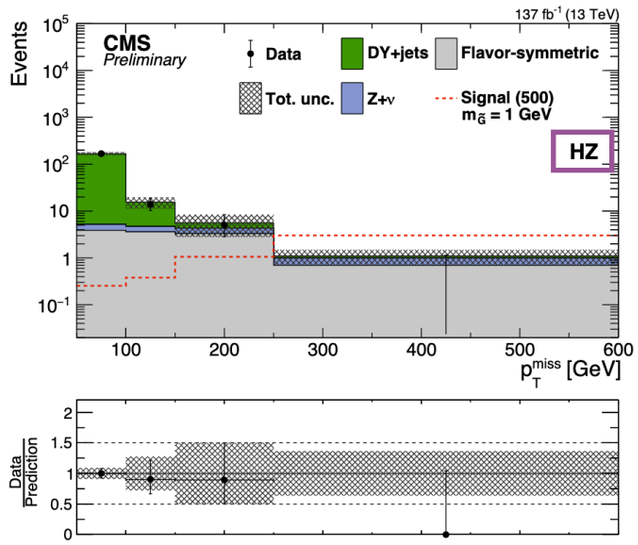




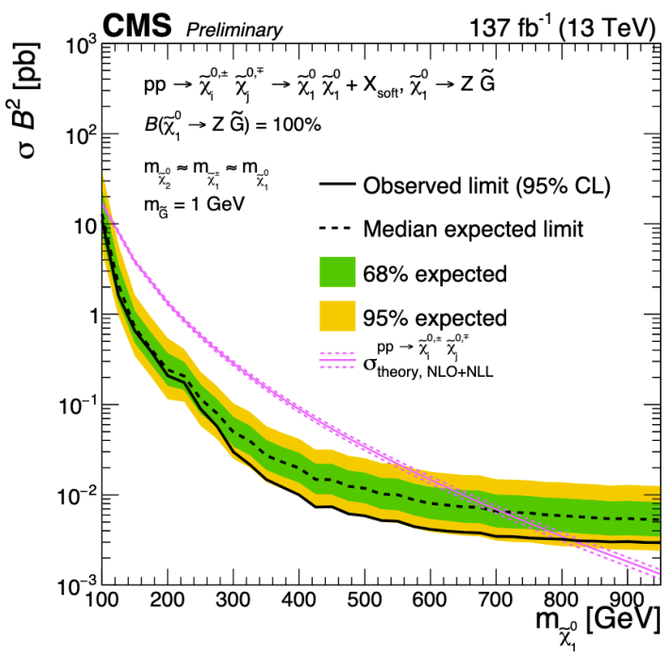
Electroweakinos: 2 e/μ OSSF on-Z

- **Tag one leptonically decaying Z with high p_T leptons (25,20 GeV), dilepton trigger, two additional jets and moderate E_T^{miss}**
  - E_T^{miss} SR for Z+hadronically decaying V(Z/W) in **resolved** or **boosted** regime, Z+H(bb)

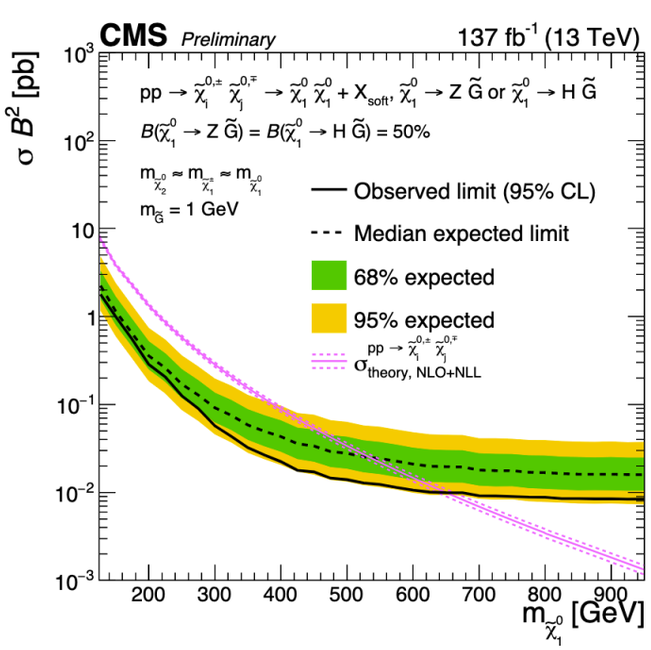




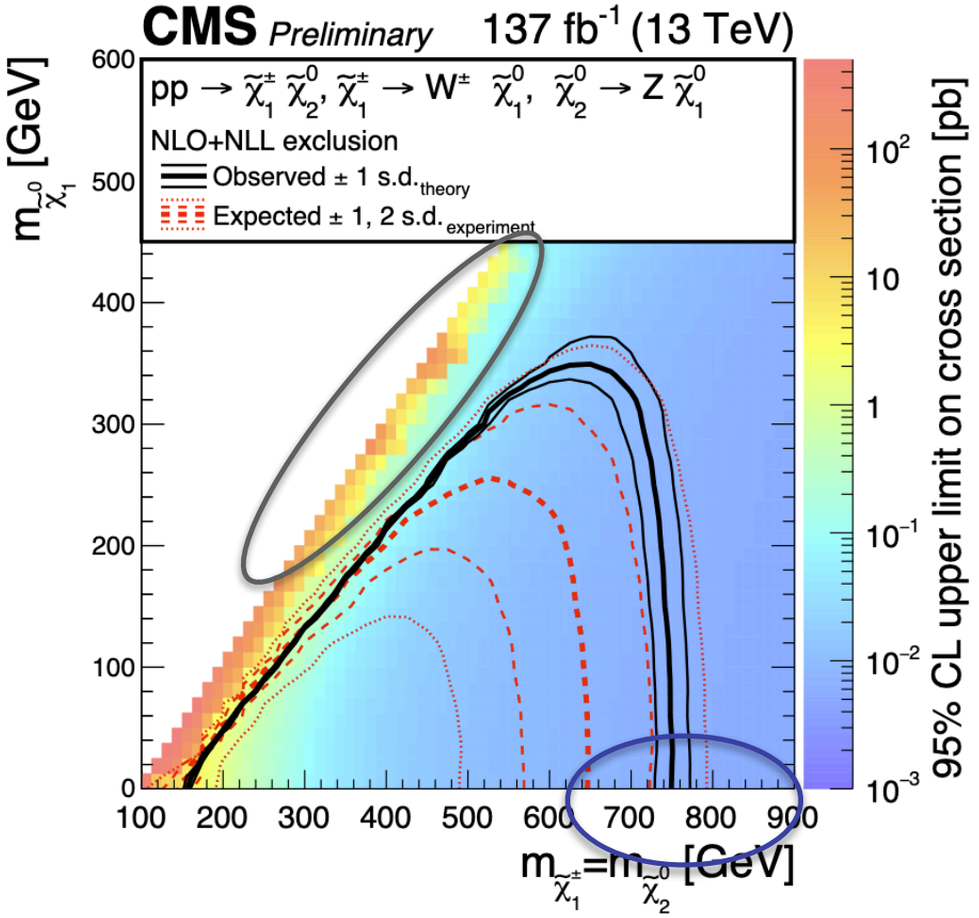
CMS **NEW** SUS-20-001



ZZ, Gravitino LSP



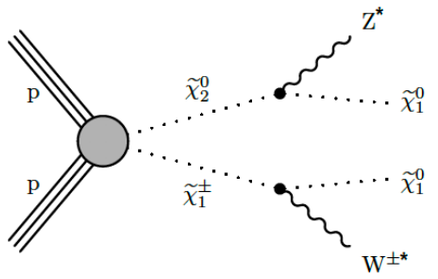
ZH, Gravitino LSP

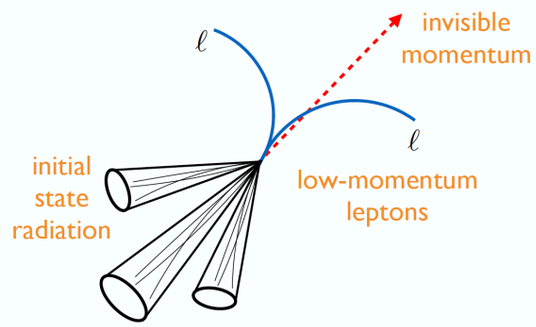


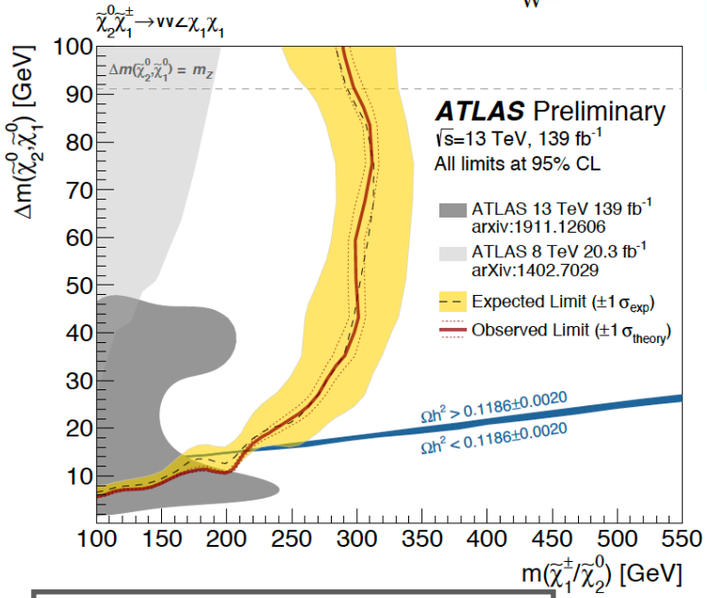
WZ, Wino NLSP, Bino LSP

Electroweakinos: compressed spectra

- **2 OSSF or 3 soft e/μ + ISR, SR bins: $m_{ll}^{(min)}$ down to 1 GeV, proxy of the Δm**

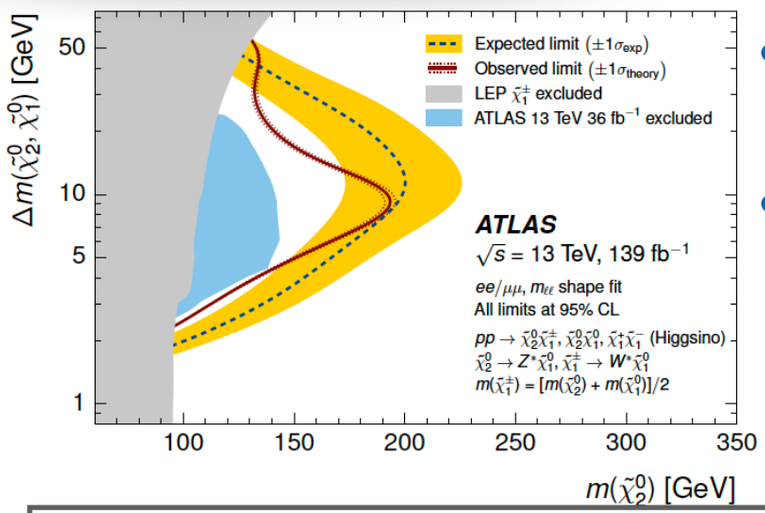






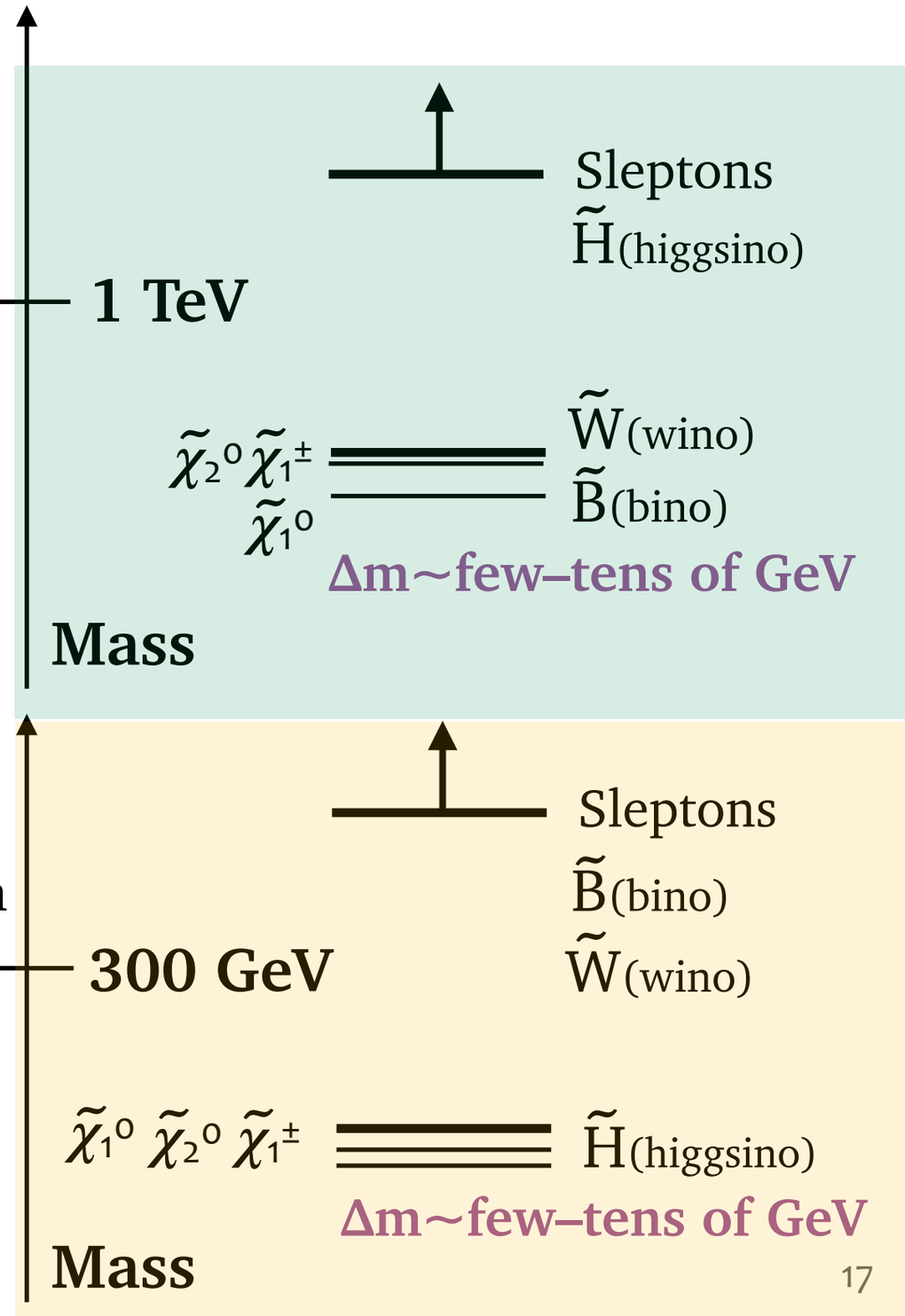
ATLAS CONF-2020-015

- Sensitivity to Δm of few GeV with **Wino cross section**
- **motivated by bino-wino cohannihilation:** LSP reproduce the correct DM abundance



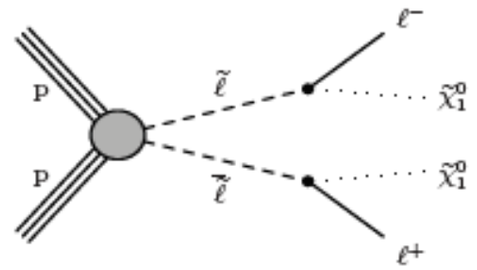
- Reached sensitivity also to **Higgsinos LSP** cross section
- **motivated by naturalness:** naturally compressed Higgsino **can still be light**

ATLAS Phys.Rev.D101,052005(2020)



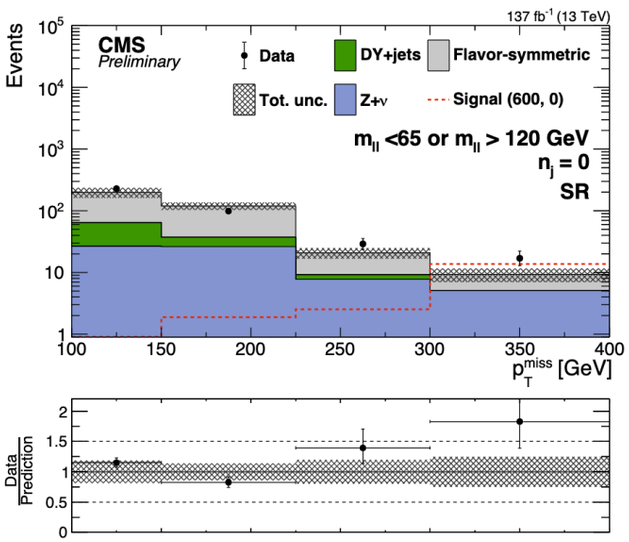
Sleptons, the rarest

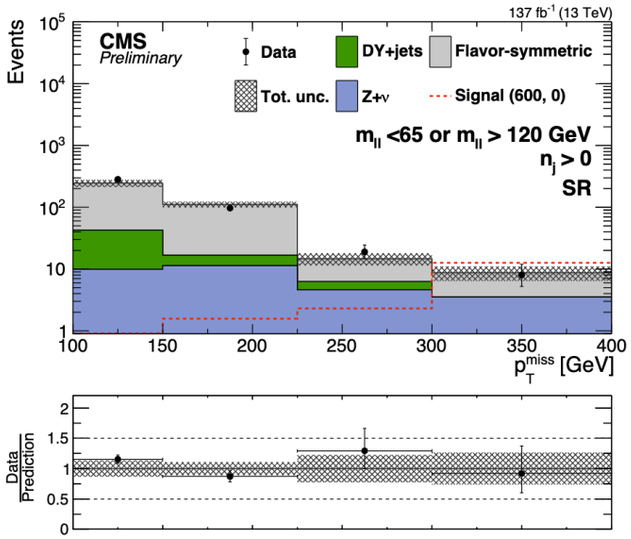
- **Direct slepton production: scalar partners of left- and right-handed e/μ**
  - mass degeneracy: $m(\tilde{e}_L)=m(\tilde{e}_R)=m(\tilde{\mu}_L)=m(\tilde{\mu}_R)$

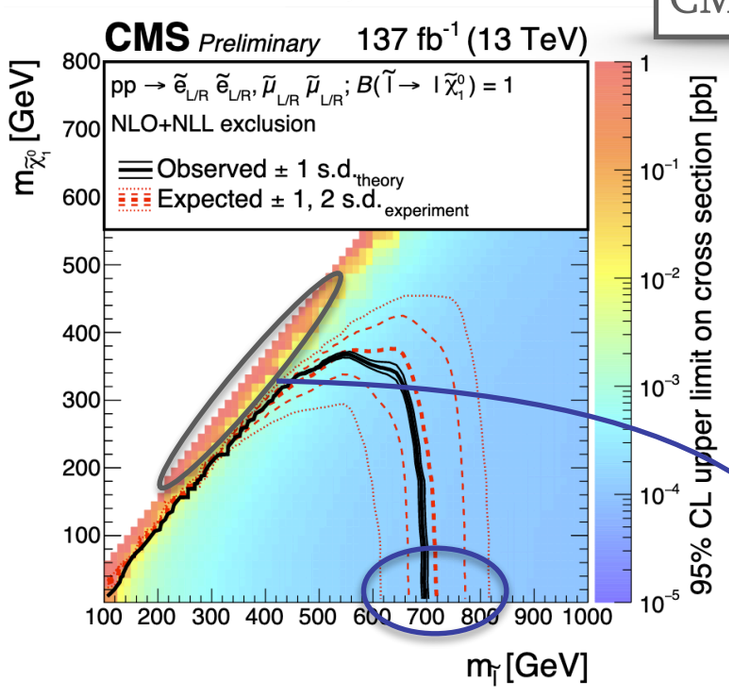


- **2 OSSF high p_T e/μ final state**
  - moderate E_T^{miss} and hadronic activity ($N_{jets}<2$ to allow ISR), Z-veto

CMS **NEW** SUS-20-001

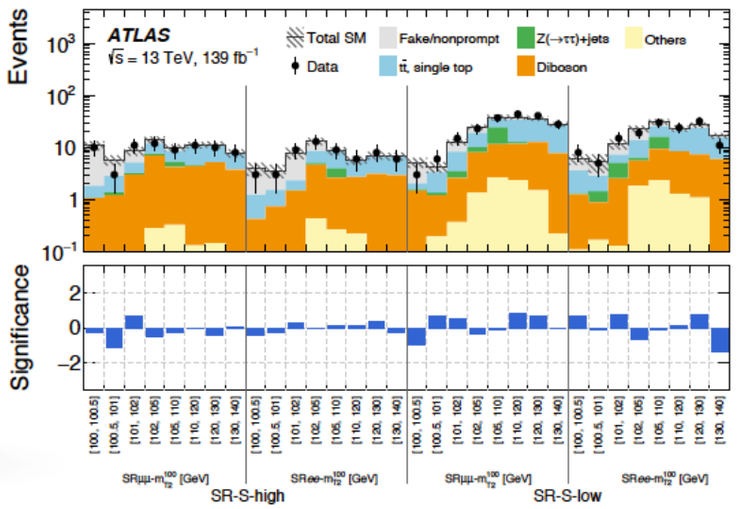


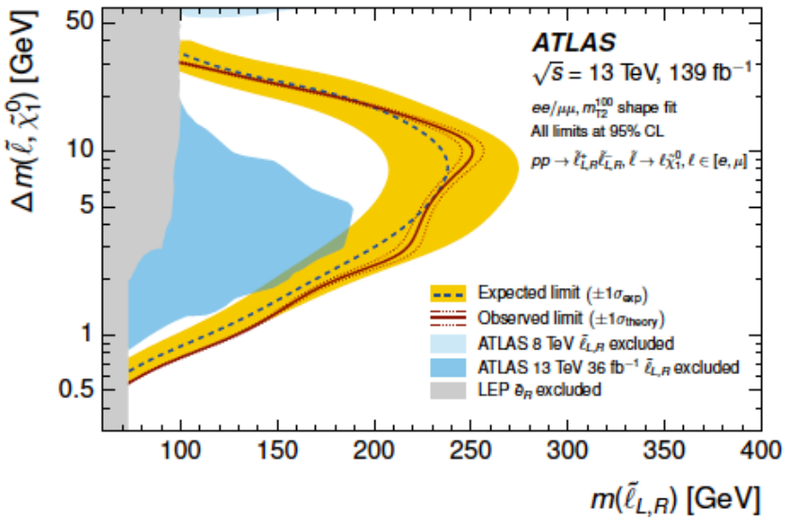




- **2 soft OSSF e/μ recoiling against ISR to target small Δm**
  - SR binned in M_{T2}^{ll}

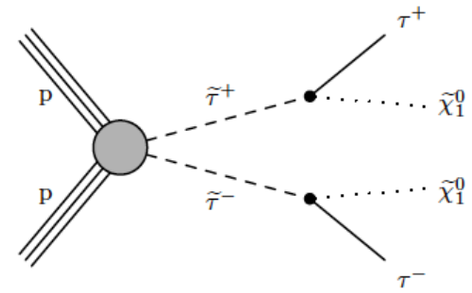
ATLAS Phys.Rev.D101,052005(2020)



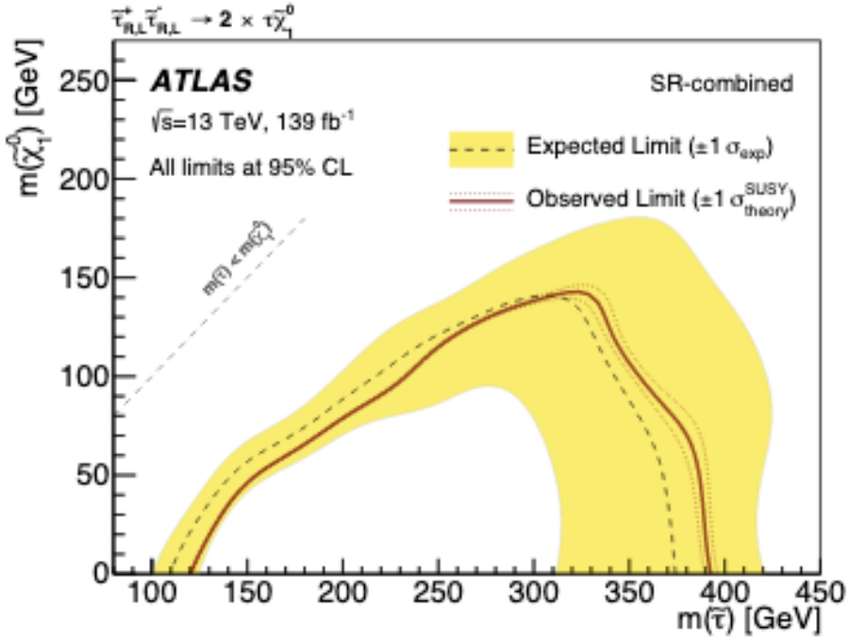


Sleptons, the rarest

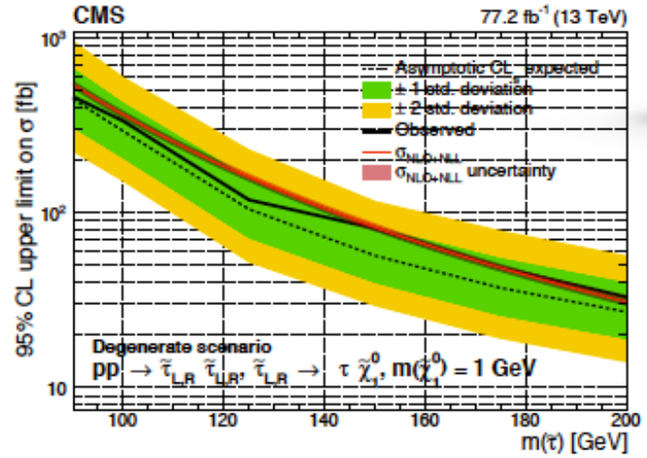
- **Direct slepton production: scalar partners of left- and right-handed τ**
  - mass degeneracy: $m(\tau_L)=m(\tau_R)$

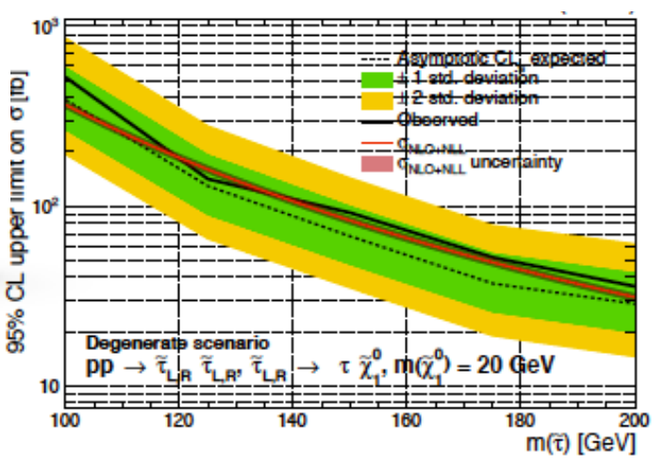


- **Final states with hadronic taus**
  - **lower signal acceptance:** tight τ_h ID and p_T, large background from **jets→τ_h misidentification**
  - exploit **cross objects triggers: $E_T^{miss}+\tau_h$, $\tau_h+\ell$** to lower thresholds and increase as much as possible signal acceptance



ATLAS Phys.Rev.D101,032009(2020)





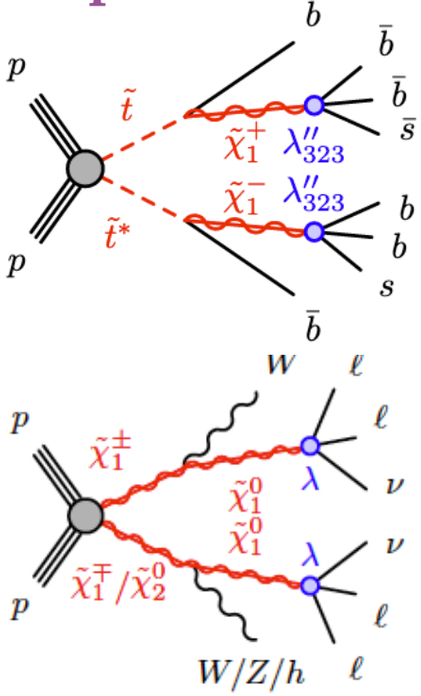
CMS Eur.Phys.J.C80(2020)189

- **Complementary results**
  - ATLAS extends the limit further in the bulk (more data analysed)
  - CMS sensitive to lower stau masses (combination of $\tau_h\tau_h$ and $\tau_h\ell$, and lower p_T thresholds)

- **Reached sensitivity to direct stau production.**

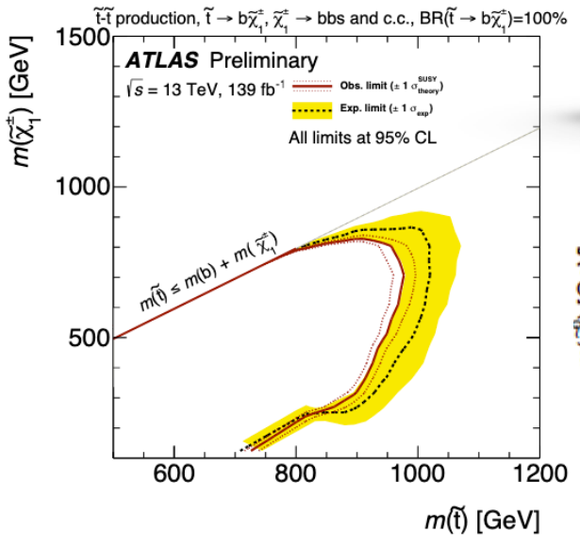
RPV and Split SUSY searches

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

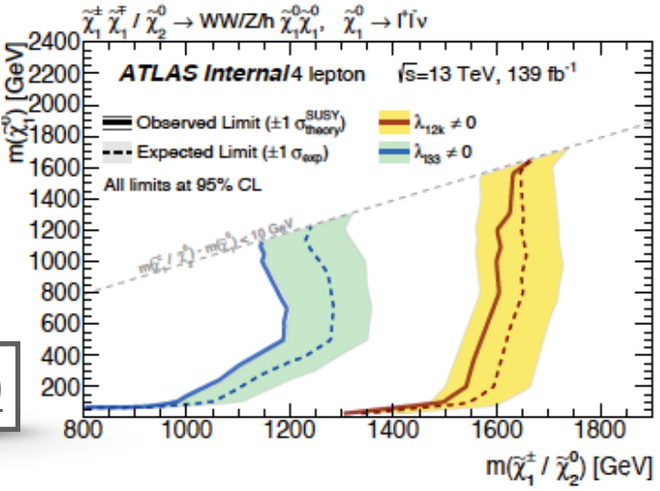


Stop NLSP, chargino LSP
search based on final states with large b-jets multiplicity

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



ATLAS CONF-2020-016

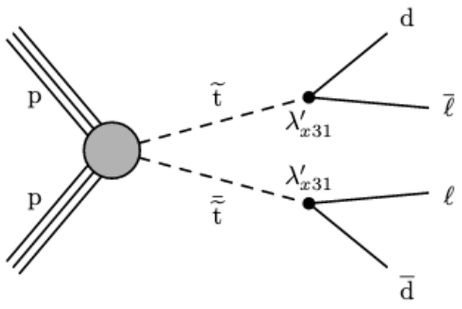


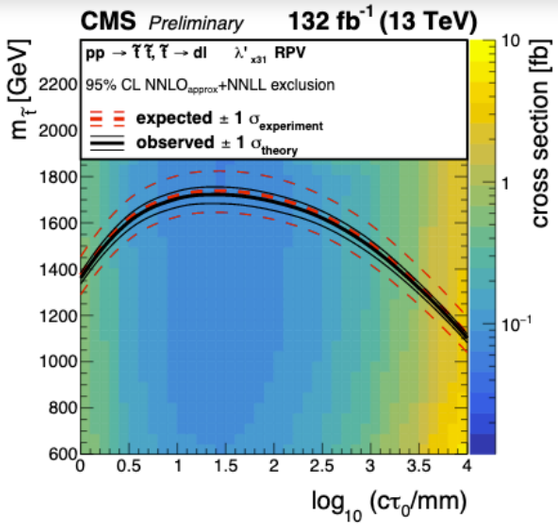
ATLAS **NEW** CONF-2020-040

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

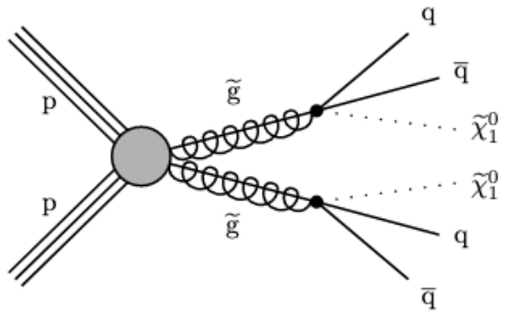
CMS EXO-19-021, See talk of Viviana Cavaliere on EXO searches

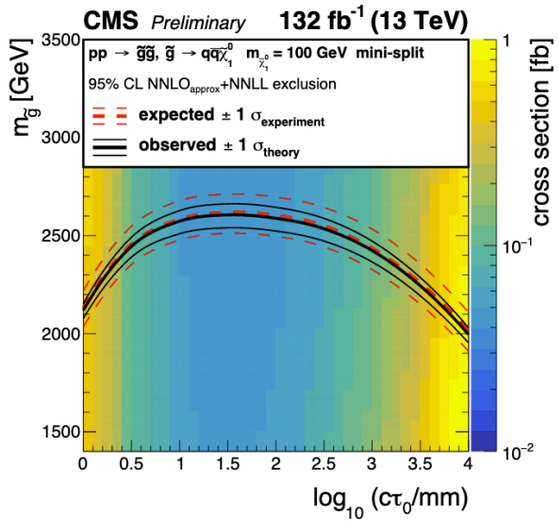
RPV top squarks





gluinos decay through heavy squarks





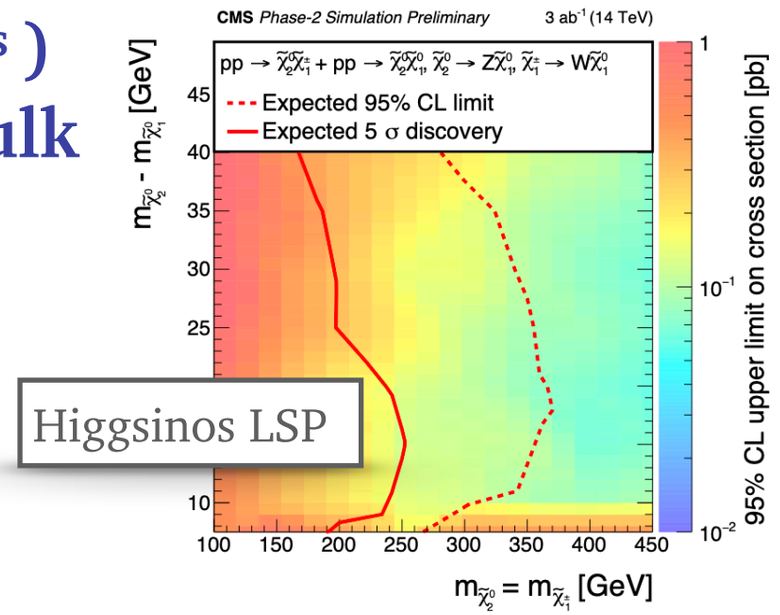
Summary and prospects

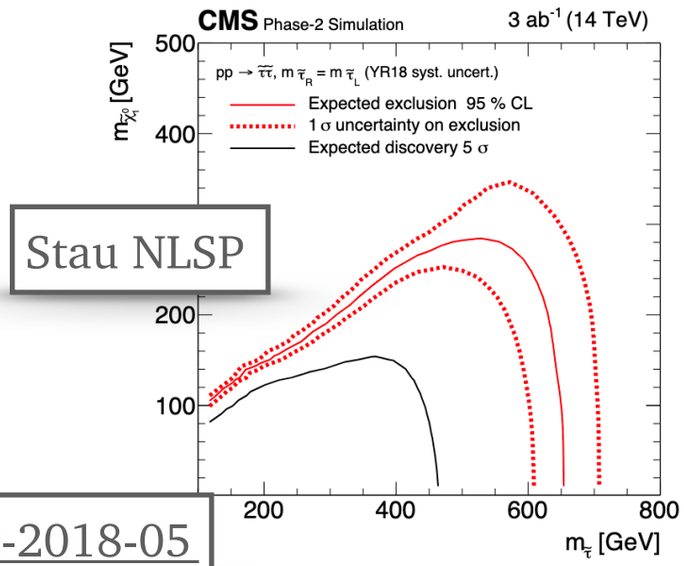
- **ATLAS and CMS are providing legacy RunII results (~140 fb^{-1})**
  - some new results presented during this conference, others will appear soon
  - **"reinterpretation friendly" results:**
    - **ATLAS** has started publishing **full likelihoods** [see here]
    - **CMS** has published **simplified likelihoods** for multi-bins analyses [see here]

- **Standard analyses (energetic jets/leptons and E_T^{miss}) have highly constrained RPC natural SUSY in the bulk**
  - NLSP gluinos excluded up to **~2 TeV**, NLSP top squarks up to **~1.2 TeV**, NLSP charginos (Wino) up to **~700 GeV**

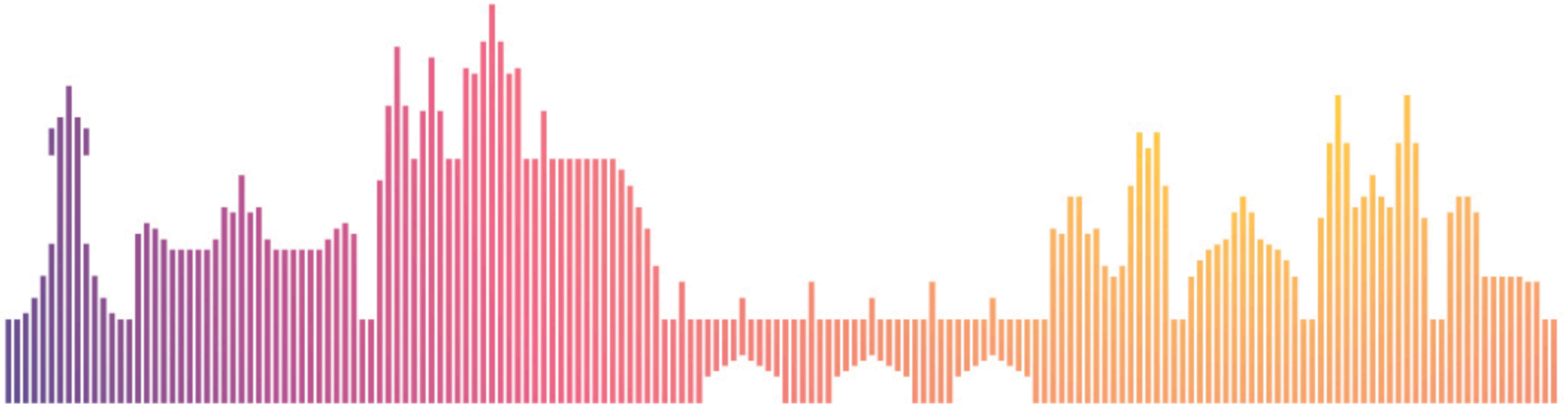
- **In the past years designed searches to cover the difficult corners where SUSY can still be "light"**
  - **sensitivity already reached** to compressed gluinos and top squarks, light Higgsinos, direct stau production…

- **Need high statistical power dataset to cover all the allowed parameter space:**
  - prepare **LHC RunIII** data-taking and detectors upgrade for **HL-LHC** to be able to perform same or extended searches in the future, **even at @200 PU**





CERN-LPCC-2018-05



Thank you for your attention

Cristina Botta, University of Zurich

On behalf of the ATLAS and CMS Collaborations

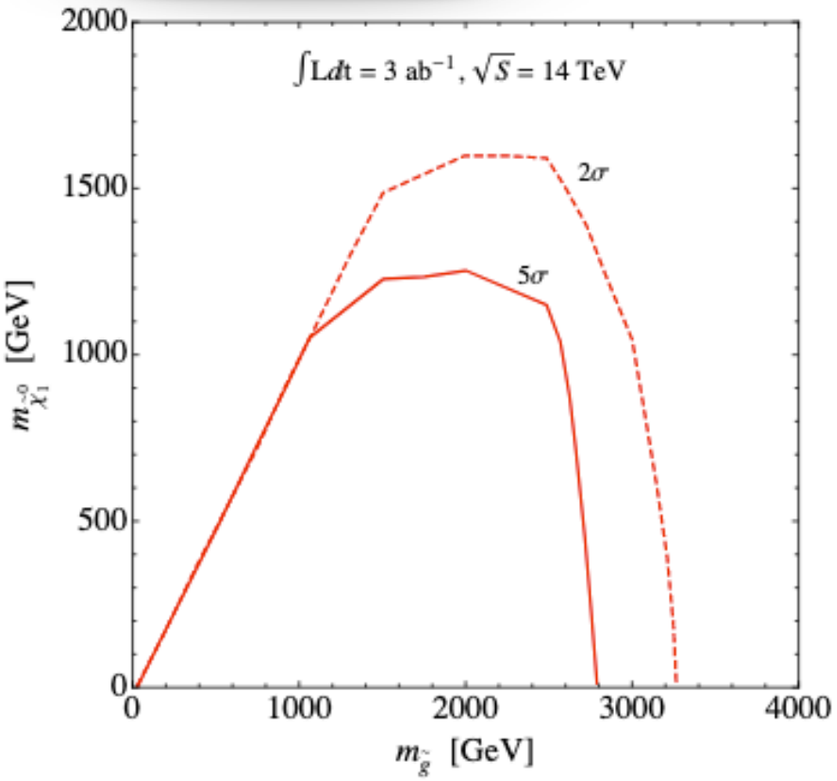
ATLAS SUSY Public Results

CMS SUSY Public Results

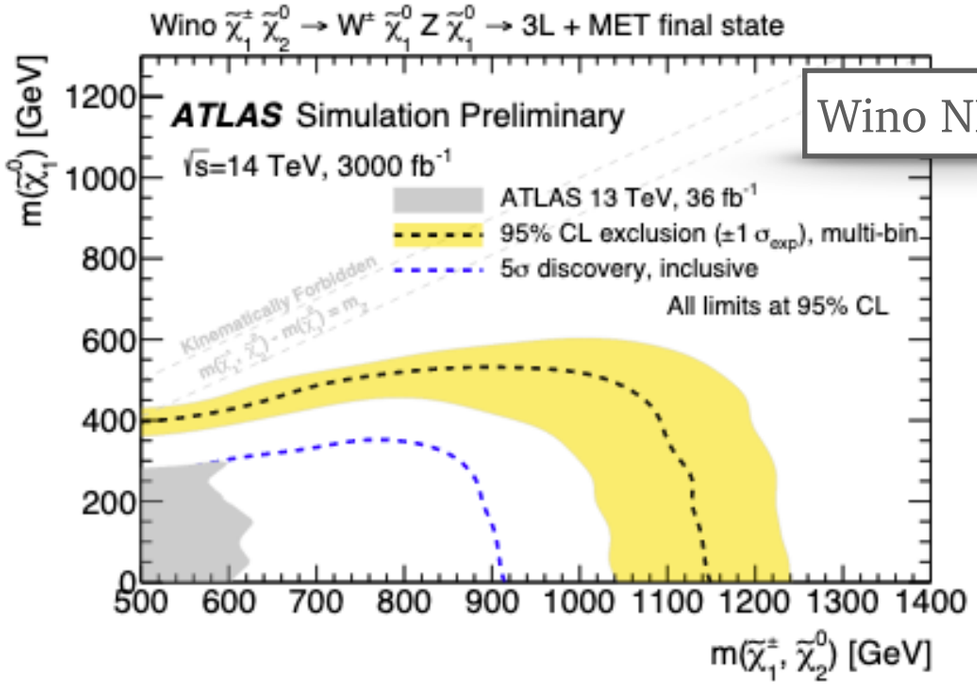
Backup

HL-LHC

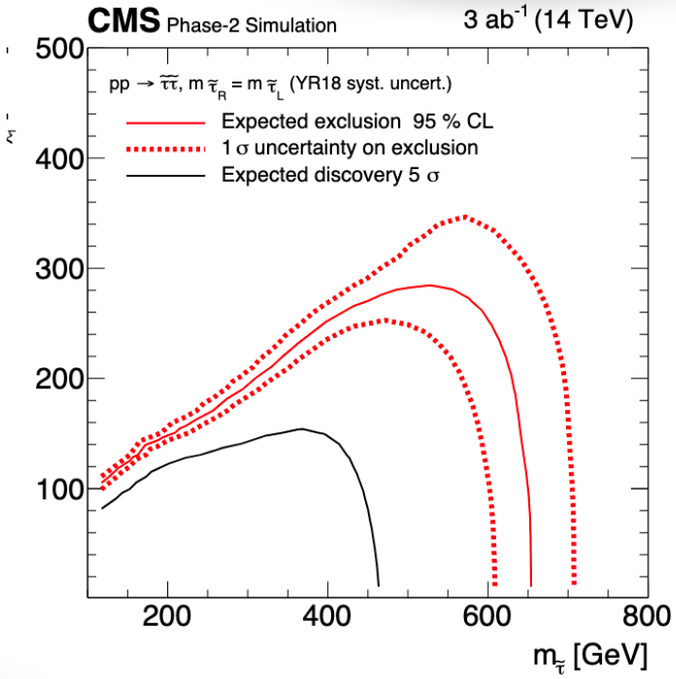
Gluinos NLSP



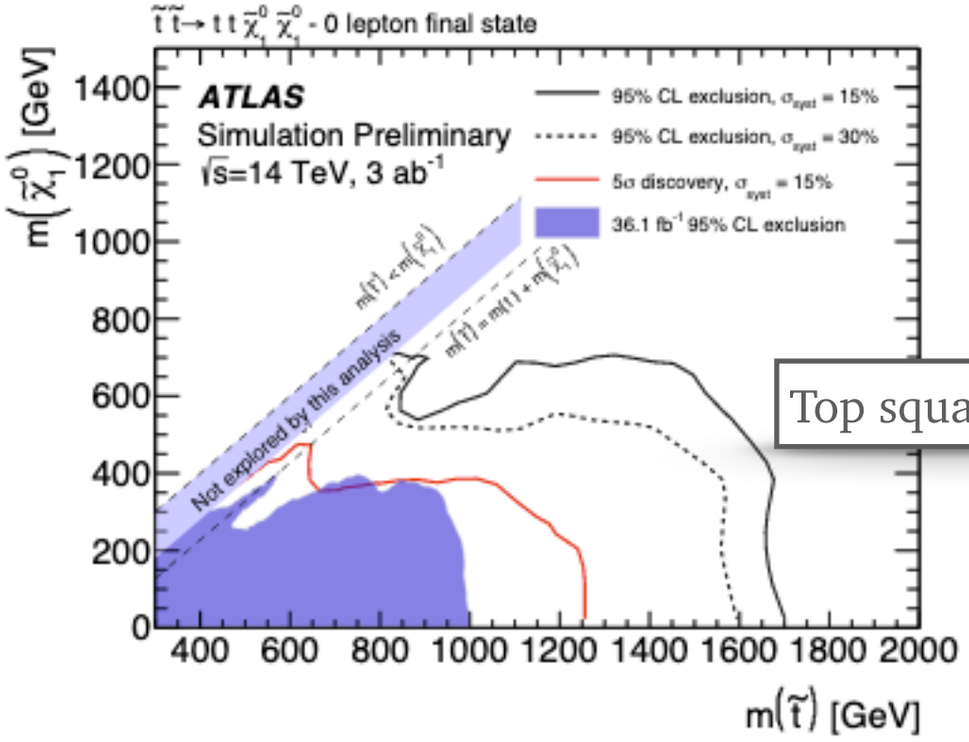
Wino NLSP



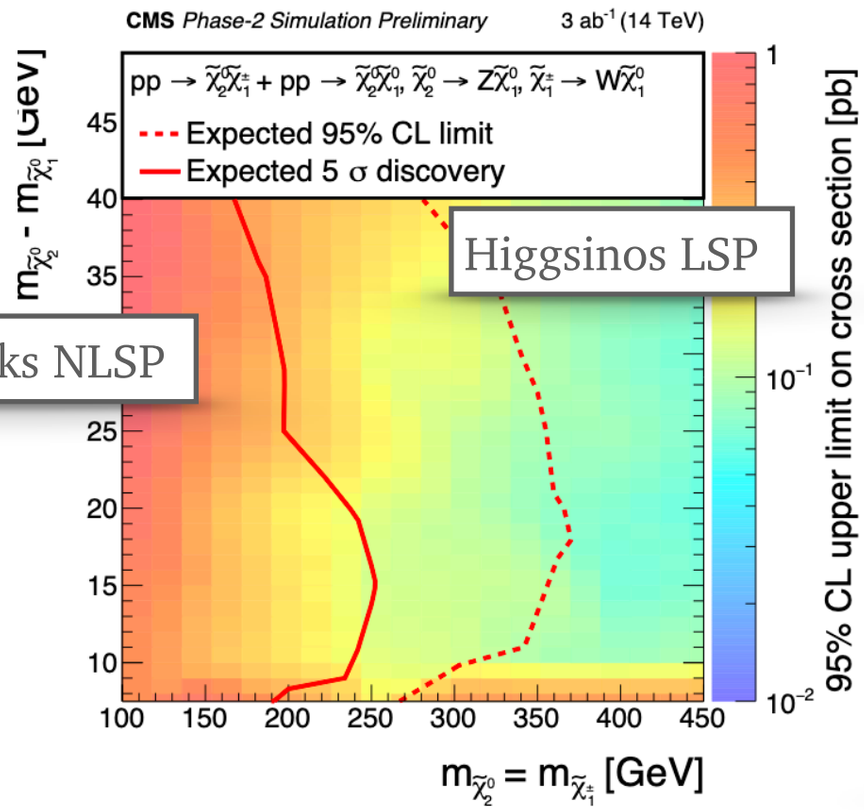
Stau NLSP



Top squarks NLSP



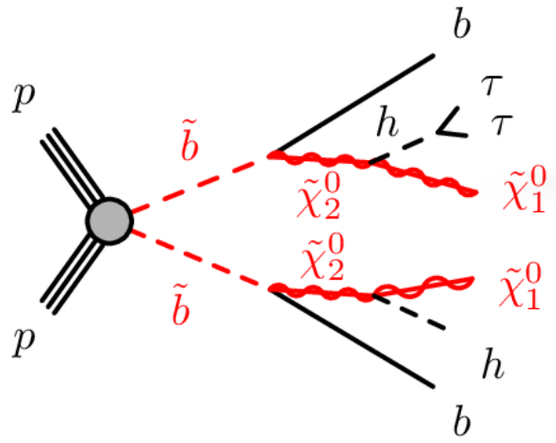
Higgsinos LSP



CERN-LPCC-2018-05

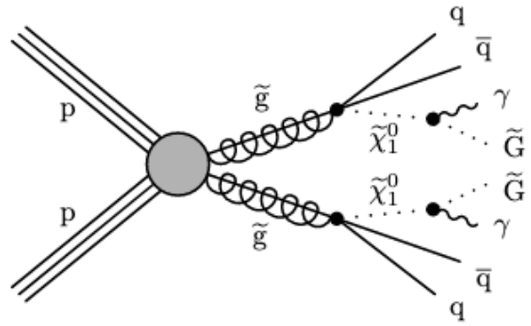
Dedicated searches

- **Target specific decay chain that could provide alternative signatures**



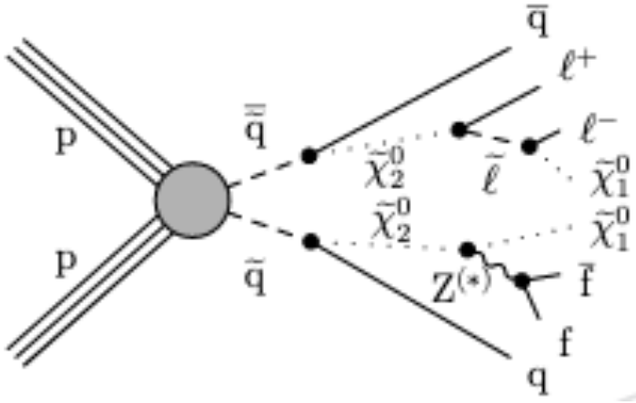
ATLAS **NEW** CONF-2020-031

H→ττ tag, plus b-jets



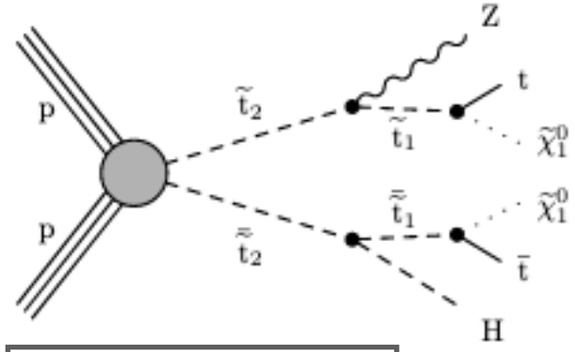
GGM models,
photons +E_T^{miss}

CMS JHEP 06 (2019) 143



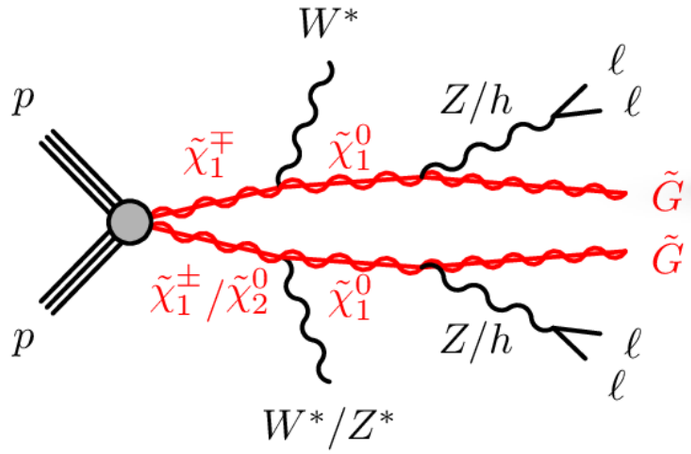
CMS **NEW** SUS-20-001

Fit for kinematic edge in m_{ll} shape



CMS SUS-19-008

tops + (ZZ/ZH/HH)
same-sign dilepton/trilepton

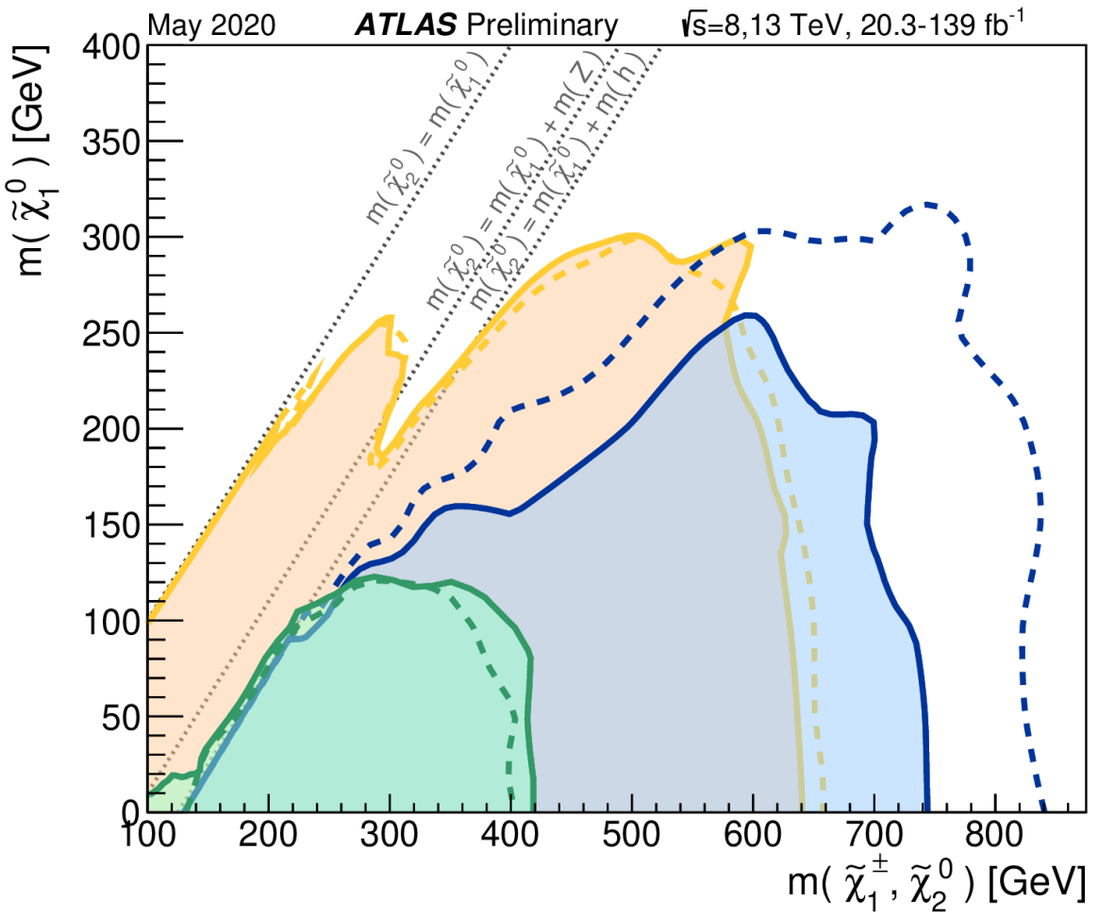


ATLAS **NEW** CONF-2020-040

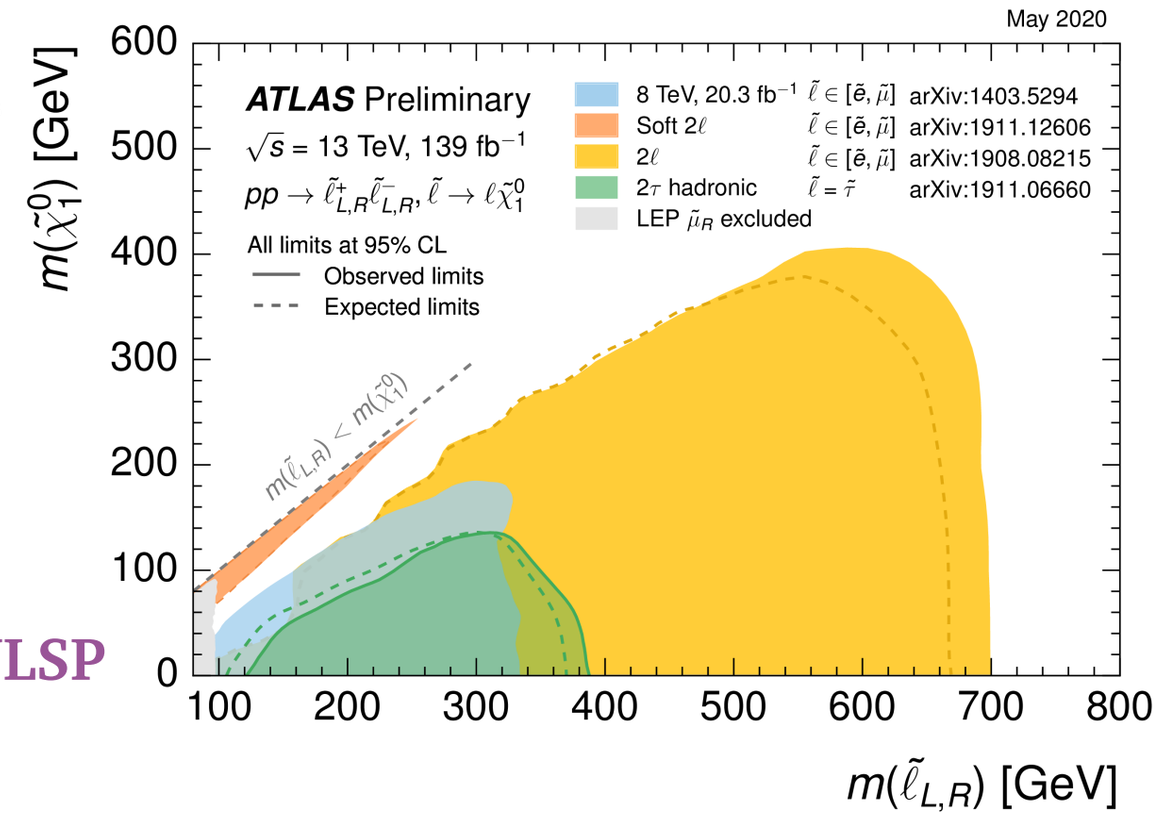
Higgsinos in GGM models
>4 leptons search

… and several others

Other summary plots



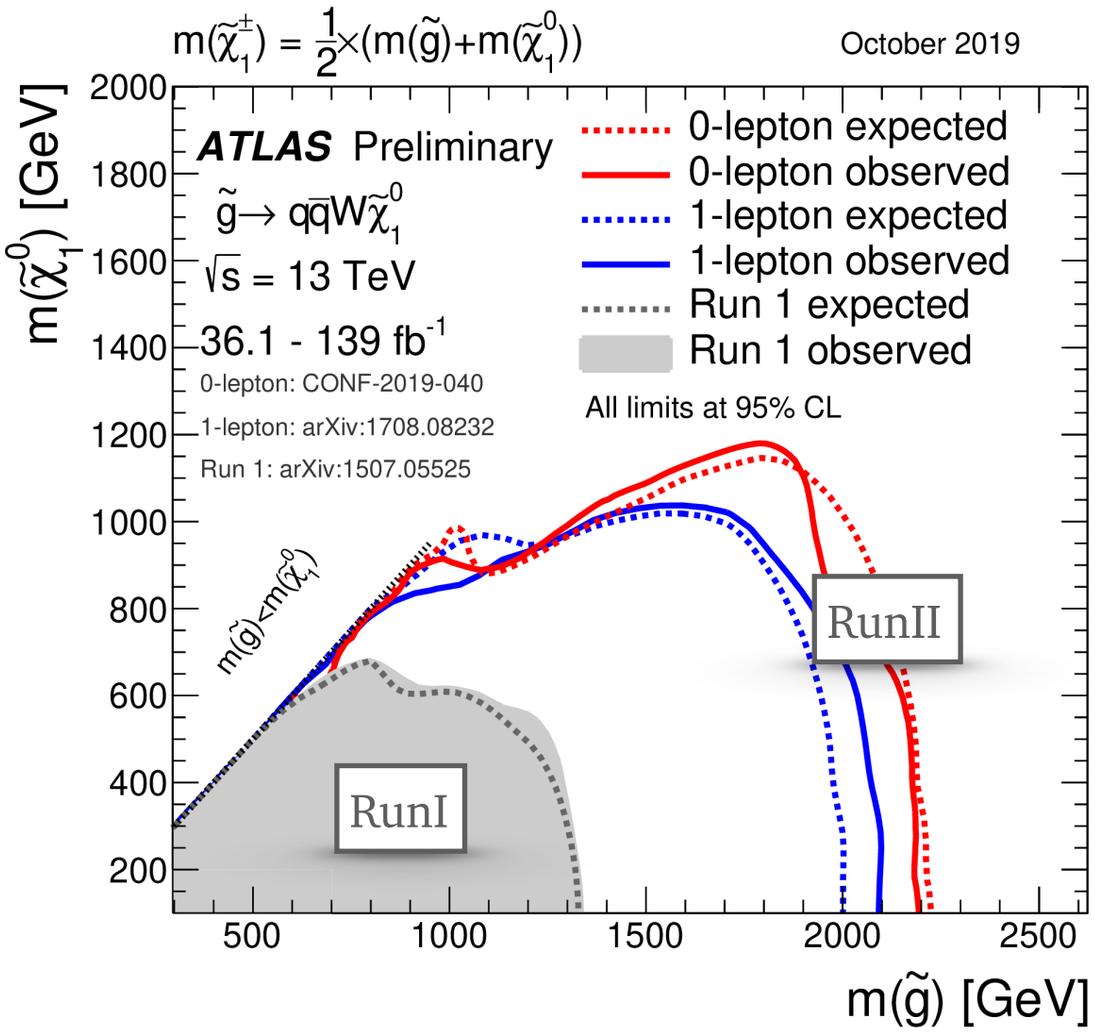
Wino NLSP



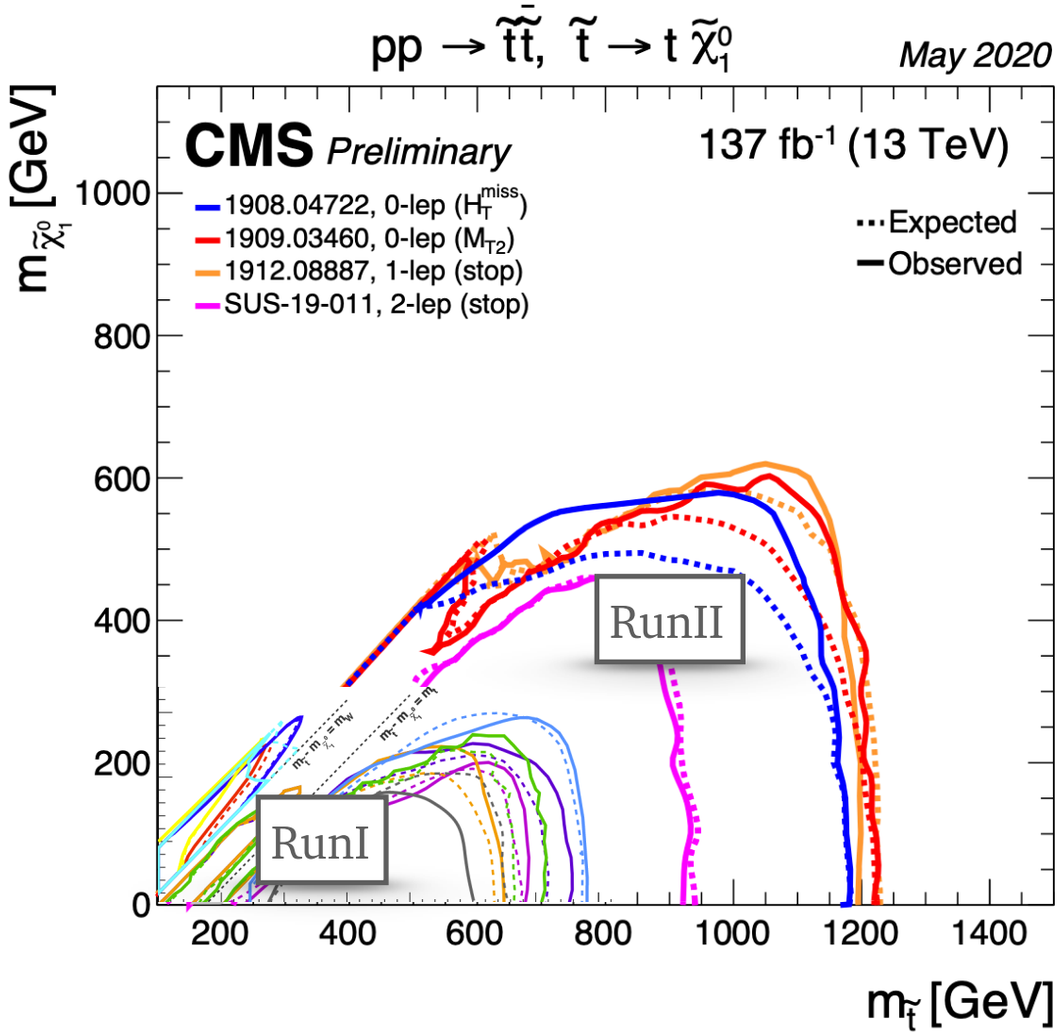
Light sleptons NLSP

ATLAS **NEW** SUSY Summary results

RunII vs RunI



ATLAS SUSY Summary results



CMS SUSY Summary results