Searches for Squarks and Gluinos at the LHC

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on behalf of the CMS & ATLAS Collaborations

DIS 2019

Torino - April 10th 2019

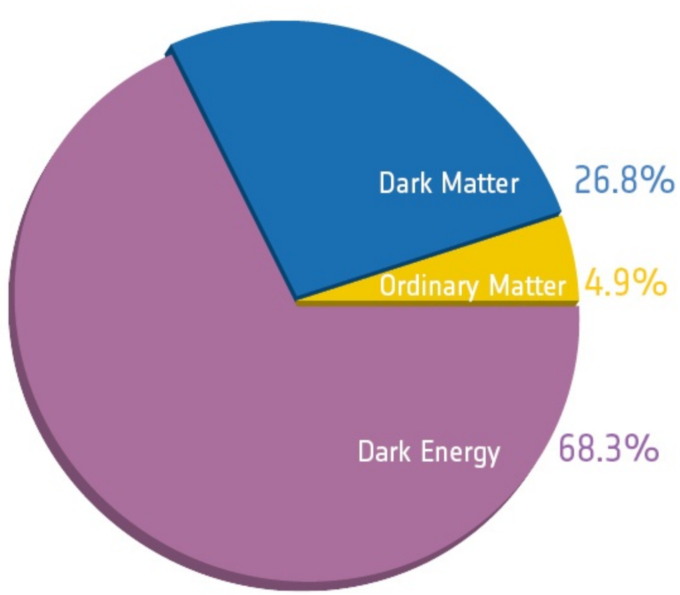
Supersymmetry (SUSY)

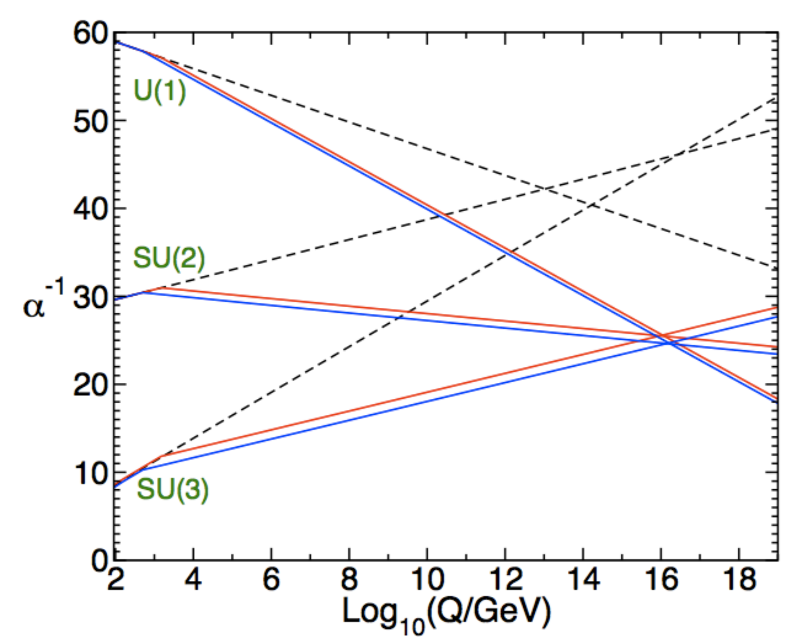
Super-symmetry provides elegant solutions to theoretical and experimental open questions of the Standard Model

- stabilises higgs mass at the EWK scale

$$\Delta m_H^2|_{\mathrm{tot}} \simeq \frac{\lambda_f^2}{4\pi^2}(m_S^2 - m_f^2)\ln\frac{\Lambda}{m_S}$$

- provides a Dark Matter candidate





- provides unification of gauge couplings

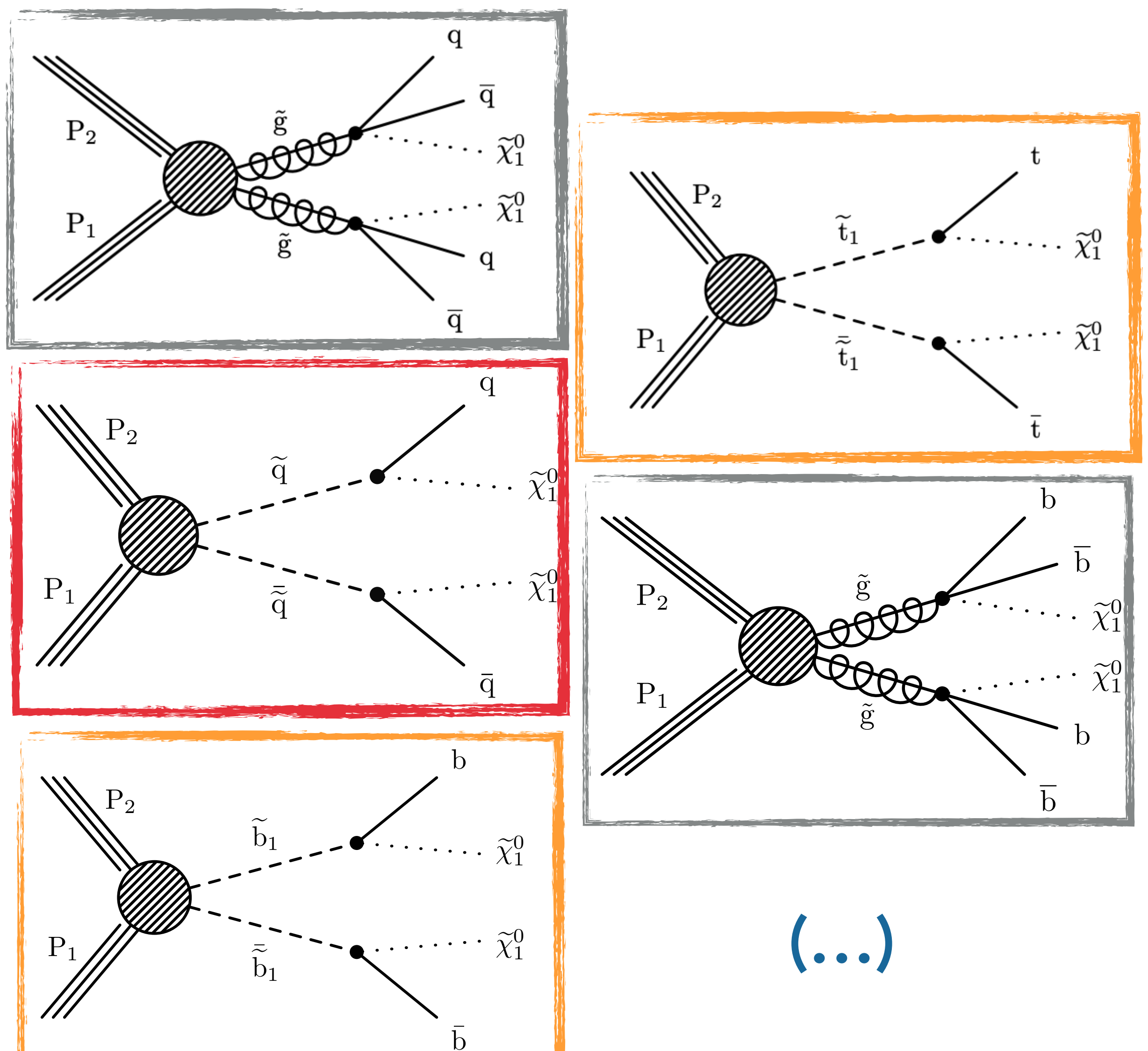
Strong SUSY at the LHC

Squarks and gluinos produced via **strong-interaction**

=> largest cross-sections => highest mass reach

If R-parity is conserved (RPC) and lightest SUSY particle (LSP) is neutral

=> get large **missing transverse momentum (MET)** and large event activity, with hard jets and/or leptons



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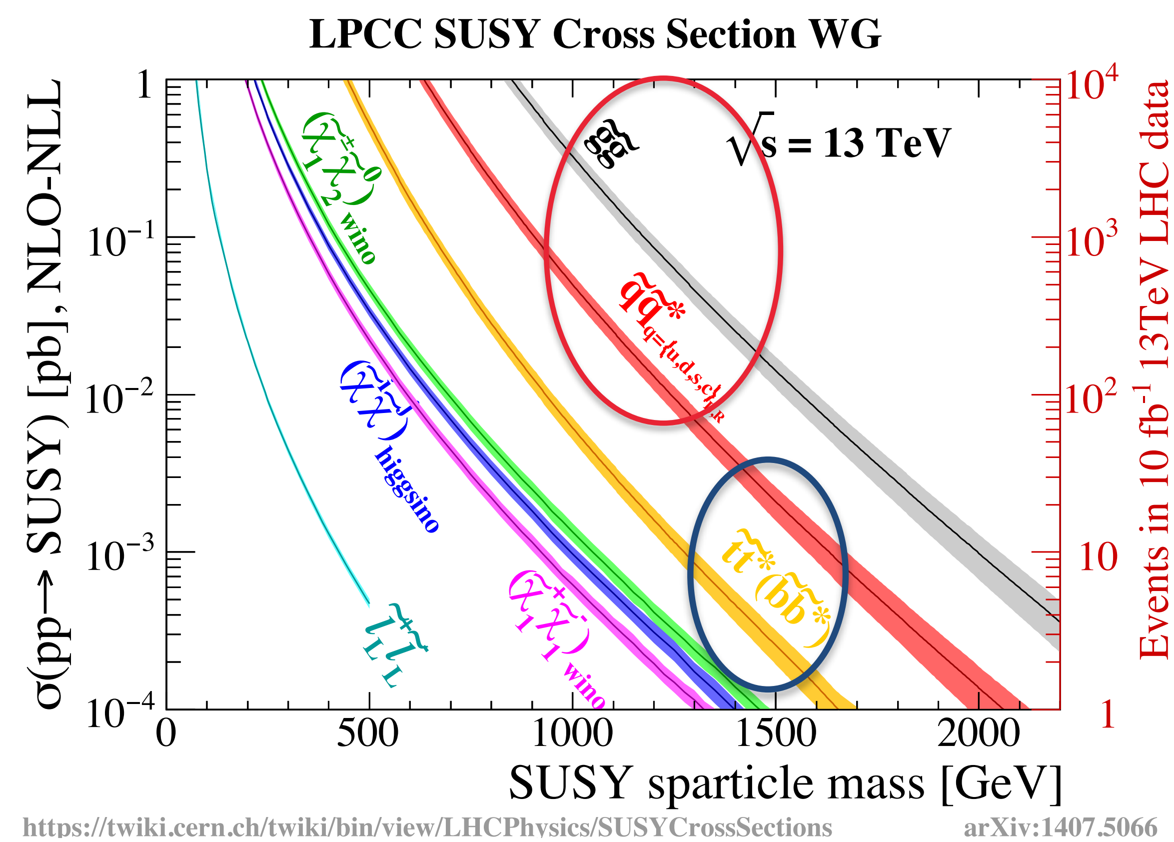
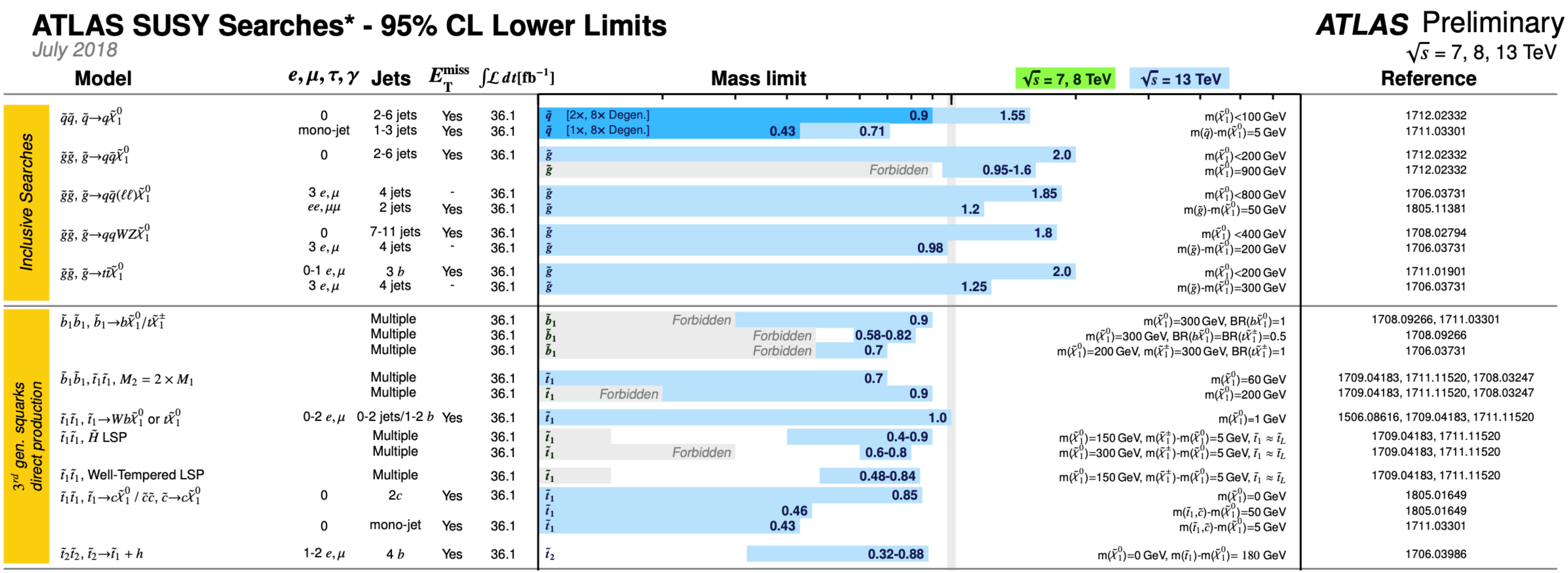


STRONG SUSY AFTER 36 fb^{-1} @ 13 TEV

Situation after 36 fb^{-1}

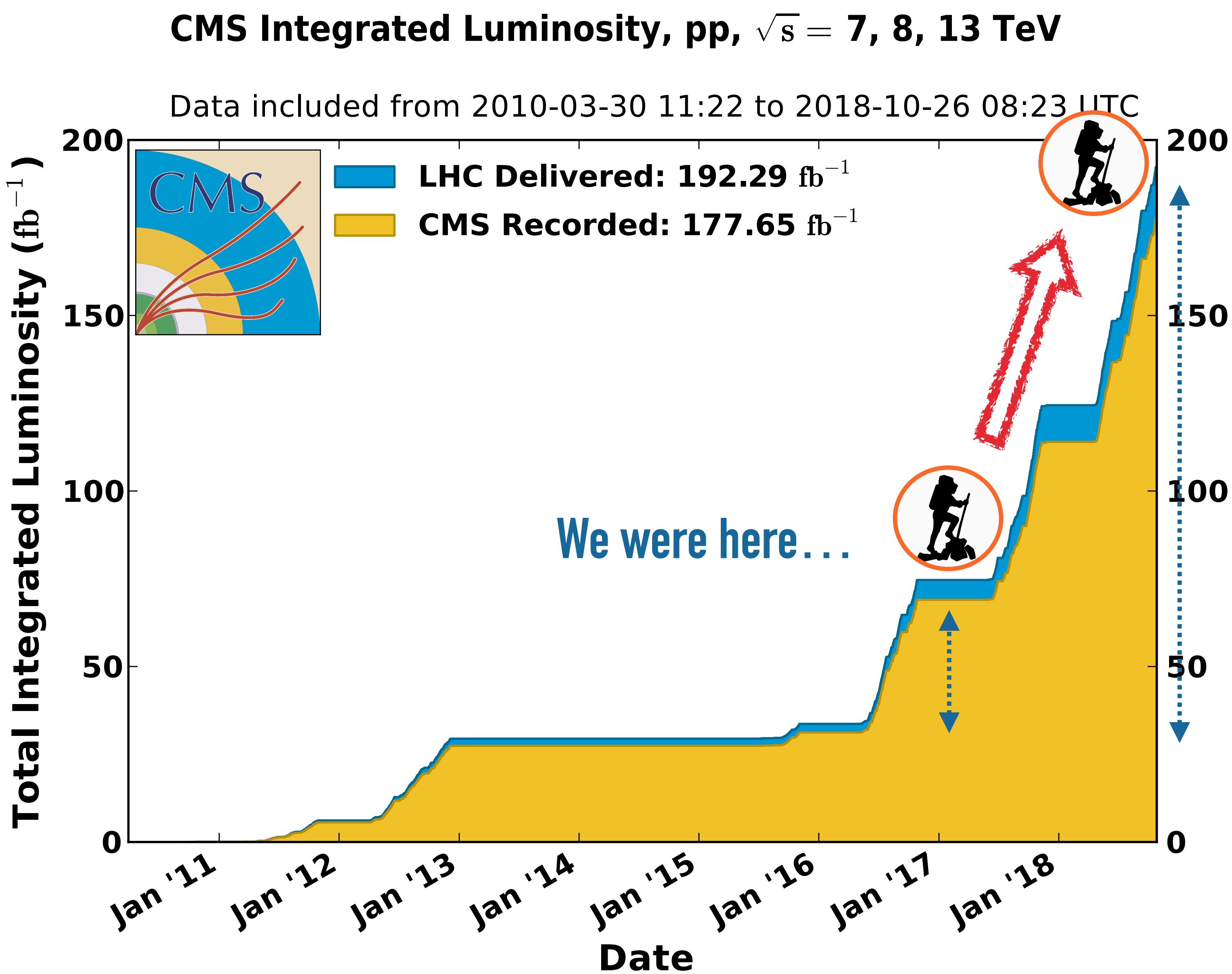
- extremely rich and varied set of SUSY searches from CMS & ATLAS (inclusive & targeted)
- but no sign of SUSY so far !



For strong RPC SUSY, similar maximal reach on sparticle masses between CMS & ATLAS:

- gluino ~ 2 TeV
- stop ~ 1 TeV
- light squarks ~1.55 TeV

THE PATH TOWARDS THE SUMMIT…



Now getting to the (local) summit !

up to x 4 statistics => ~x 2 signal significance

In this talk: **personal selection** of first **full Run-2** (~140 fb^{-1}) and **partial Run-2** results

Overview of Recent Results

Very latest results on gluino and squark production

CMS

MT2 + jets	**137 fb^{-1}**	**SUS-19-005**
SS leptons + jets / 3 leptons	**137 fb^{-1}**	**SUS-19-008**
GGM combination	36 fb^{-1}	SUS-18-005
Diphoton + MET	36 fb^{-1}	SUS-17-011
Delayed jets + MET	**137 fb^{-1}**	**EXO-19-001**

ATLAS

b-jets + H + MET	**139 fb^{-1}**	**CONF-2019-011**
DV + displaced muon	136 fb^{-1}	CONF-2019-006
Pixel ionisation, calorimeter and muon timing	32 fb^{-1}	arXiv:1902.01636
ttbar spin correlations	**36 fb^{-1}**	**arXiv:1903.07570**

⇨ Check out all CMS & ATLAS SUSY public results

MT2 ANALYSIS STRATEGY

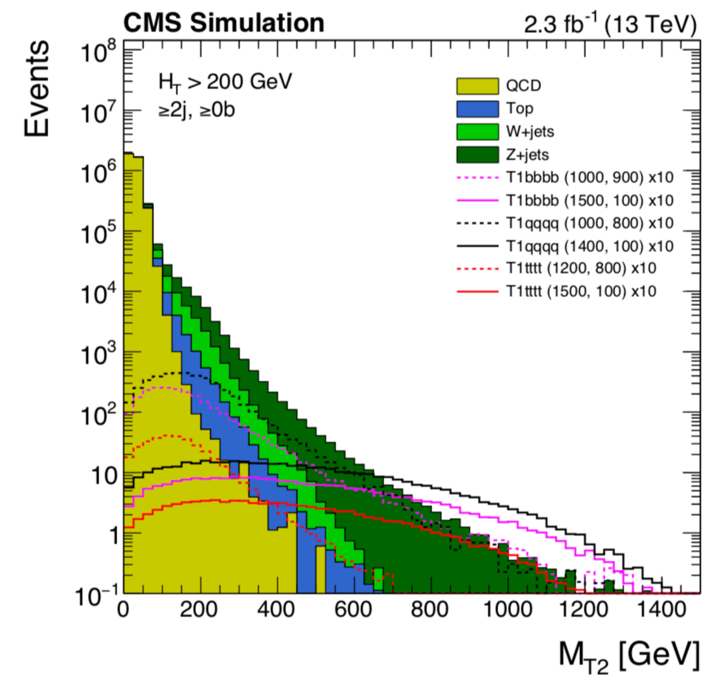
SUS-19-005

Inclusive search in final states with **0-lepton + MET + jets**

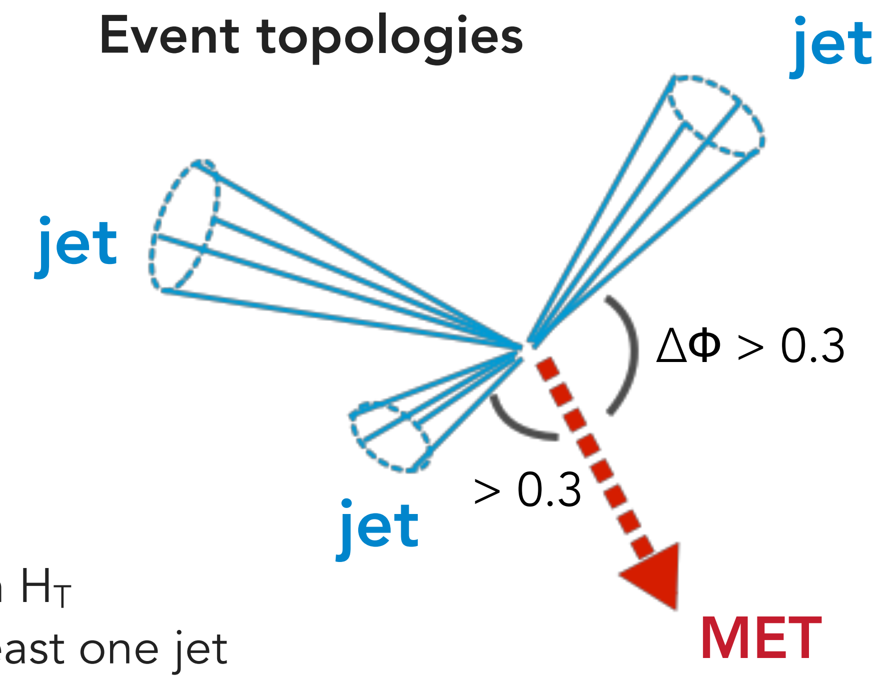
Targets gluinos and squarks pair production, including 3rd generation

Search variable **MT2**

- generalisation of transverse mass M_T to case of two decay chains with an invisible particle each
- MET-like, enhanced S/B discrimination in the tails



Event topologies



High H_T
At least one jet

μ/e veto
isolated track veto

trigger on MET, H_T, or H_T+MET

Phase space binned in "topological regions"
= **(H_T, N_j, N_{bj})** bins

each topological region further binned in MT2

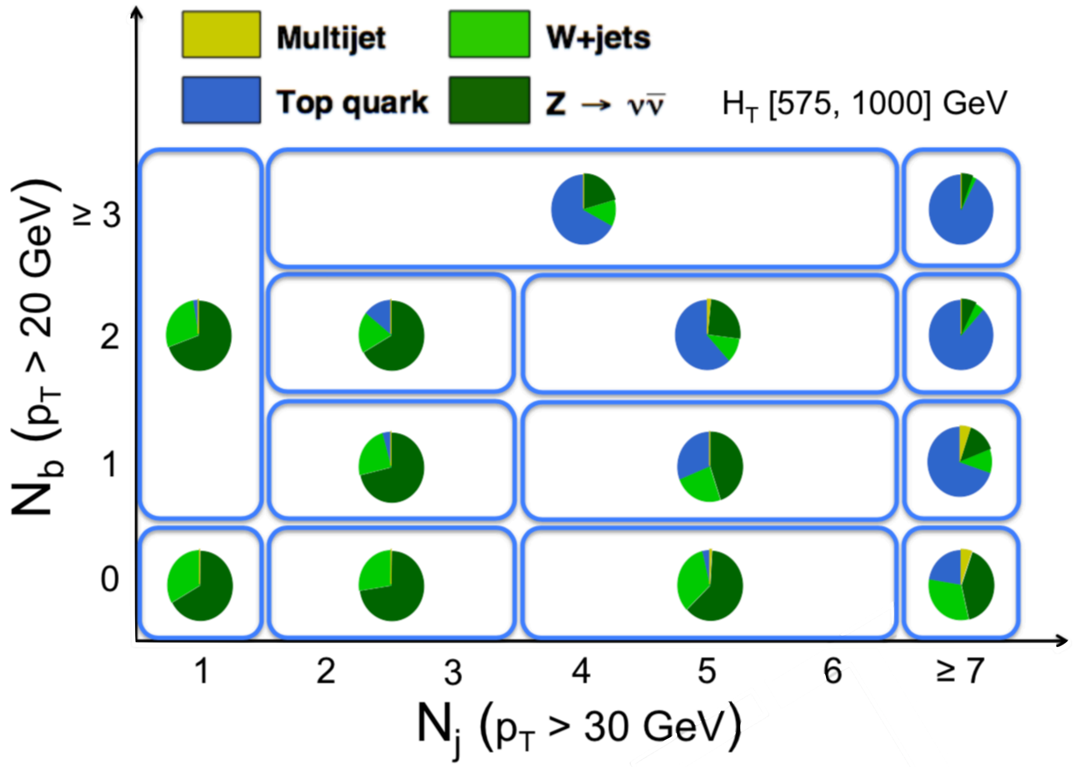
O(300) search regions!

⇨ predicted background fitted to the data in all topological regions simultaneously to extract the signal

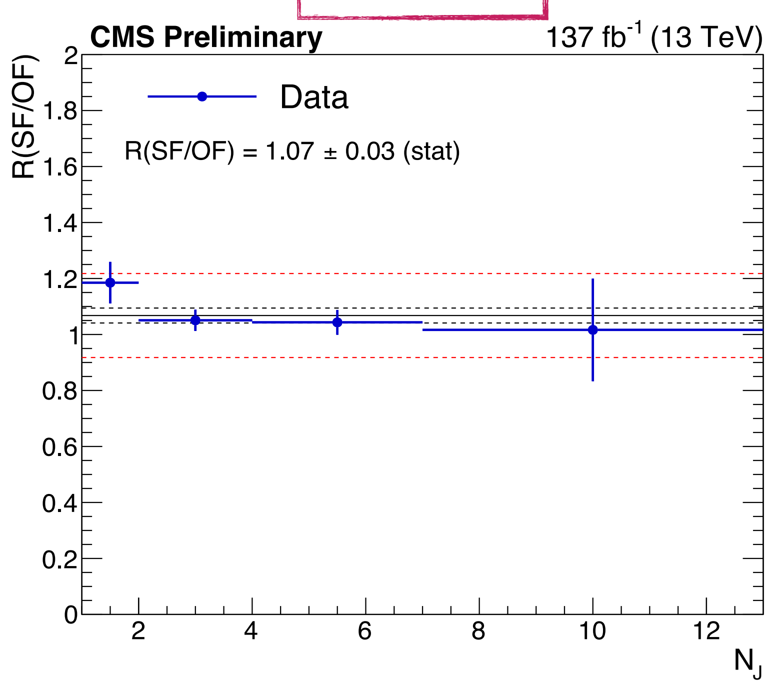
MT2 ANALYSIS BACKGROUNDS

Main backgrounds:

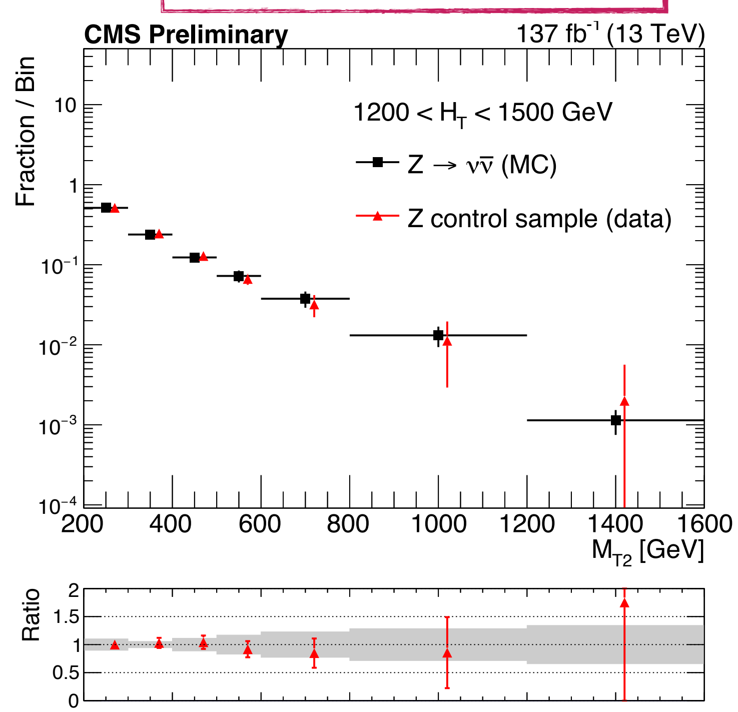
- **Z(vv)+jets** and **lost lepton** (W+jets & top)
- transfer factors from 2-lepton and 1-lepton CRs to SR, in each (H_T, N_j, N_{bj}) bin
- shape of MT2 taken from data in the CR until stats are too low, then MC is used to distribute events



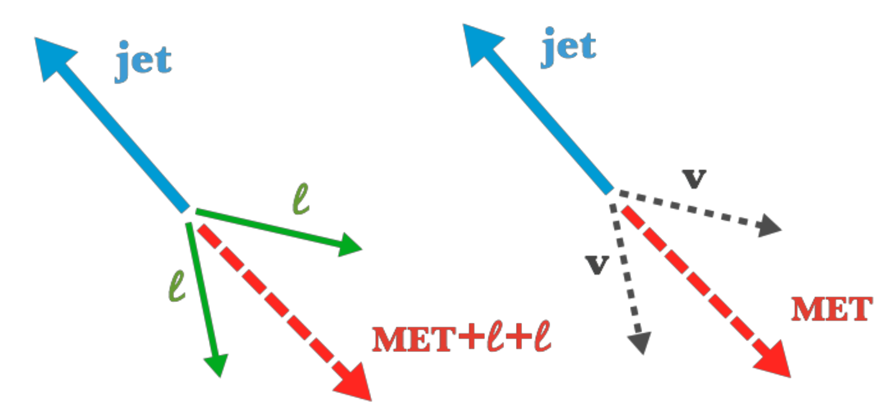
R(SF/OF)



MT2 shape for Z(vv)



- For Z(vv)+jets, use Z(ll)+jets with leptons added vectorially to MET

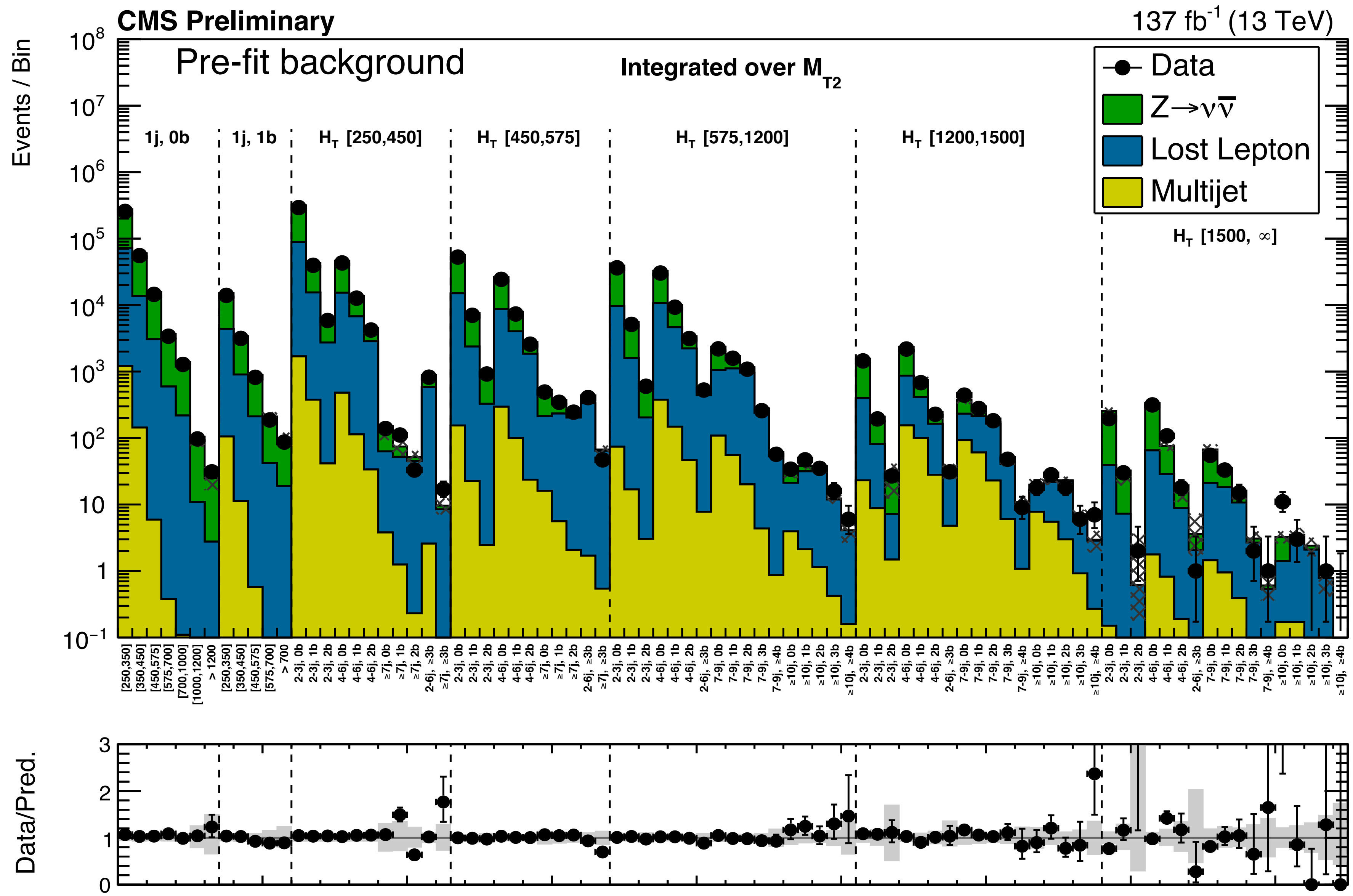


- top contamination in Z(ll) CR estimated via ABCD method

RESULTS

SUS-19-005

Background estimation compared to data observed in signal regions, integrated in MT2 in all (H_T, N_j, N_{bj}) bins



=> No significant excess over the SM predictions

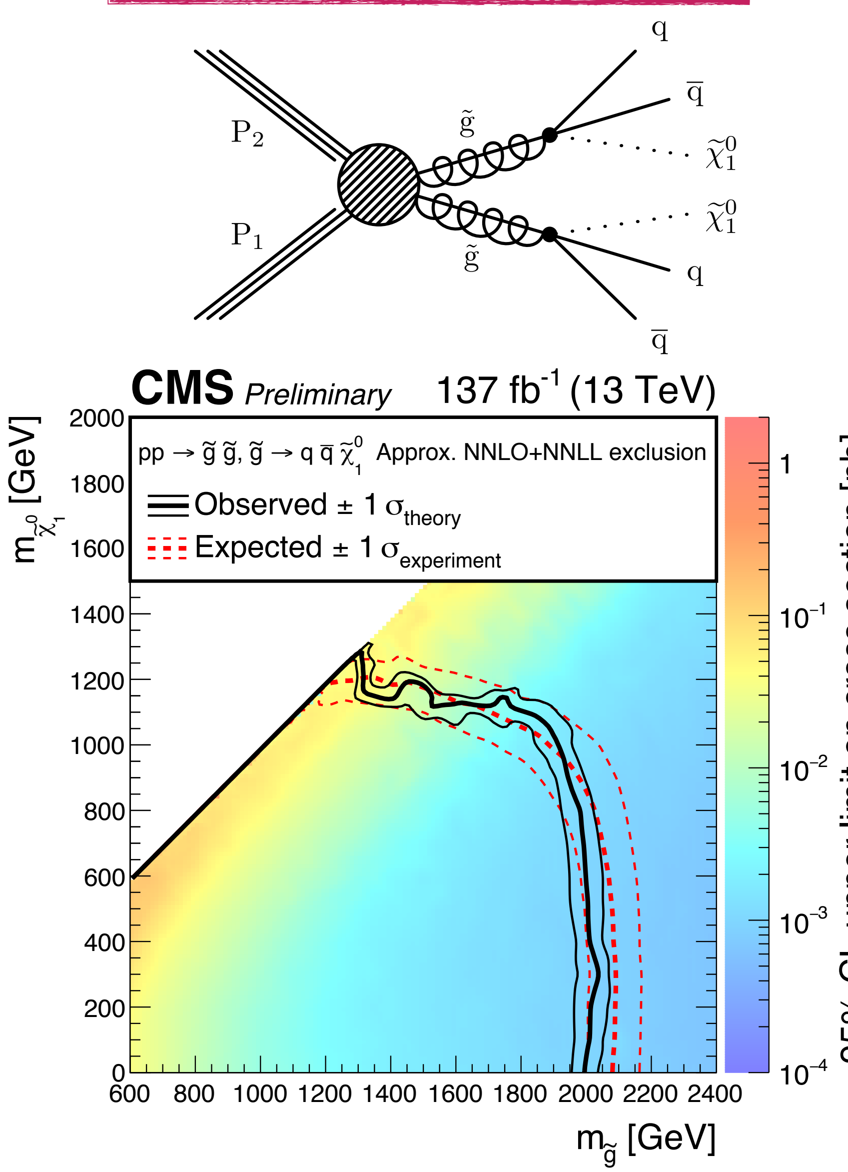
RESULTS GLUINOS

SUS-19-005

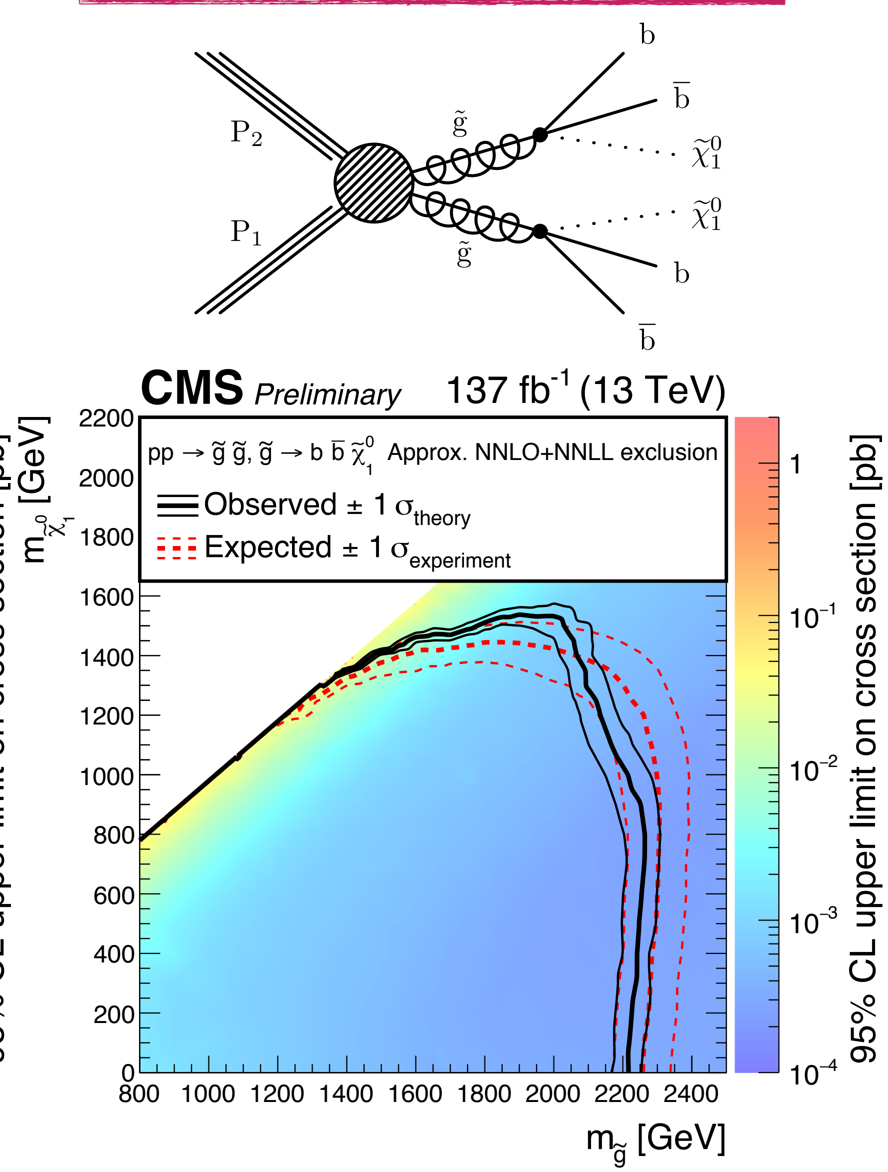
No significant excess over the SM predictions

=> exclusion limits on simplified models, **gluino pair production**

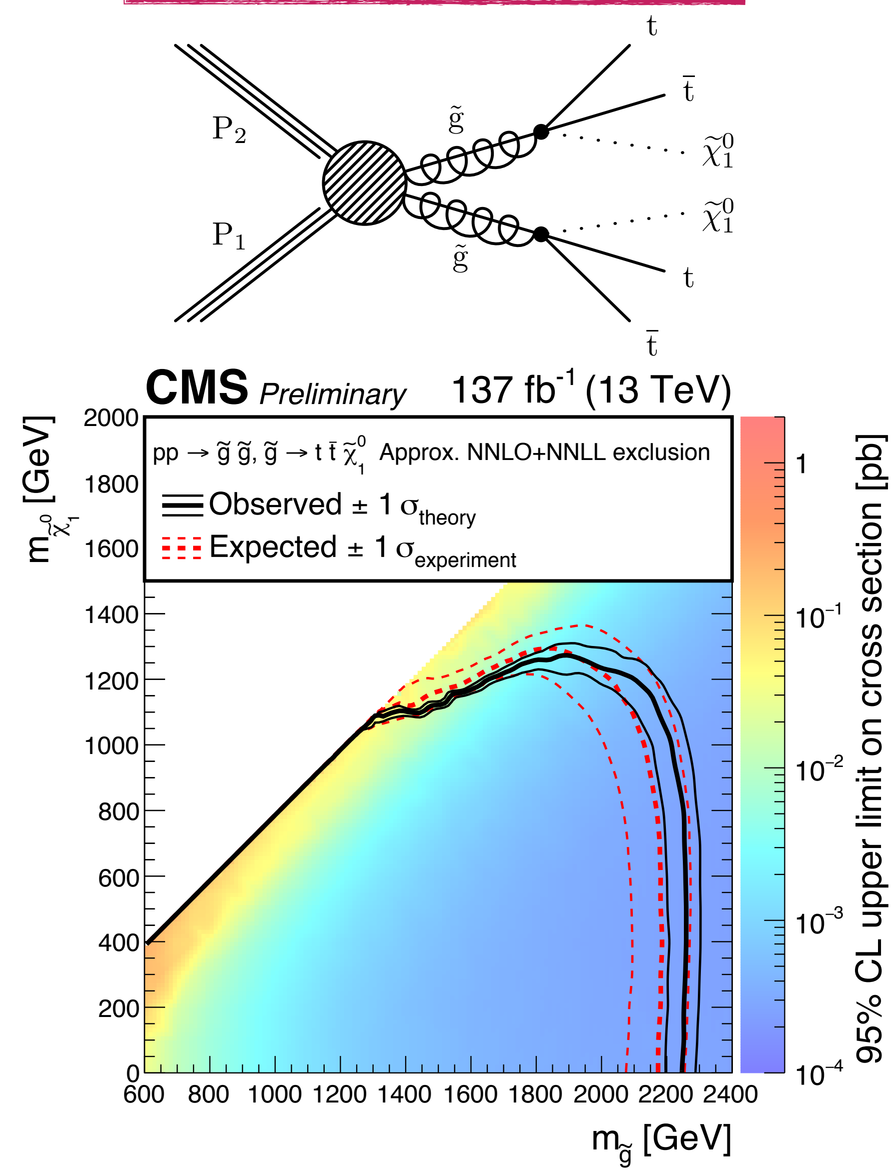
Gluino to light quarks + LSP



Gluino to bottom quarks + LSP



Gluino to top quarks + LSP



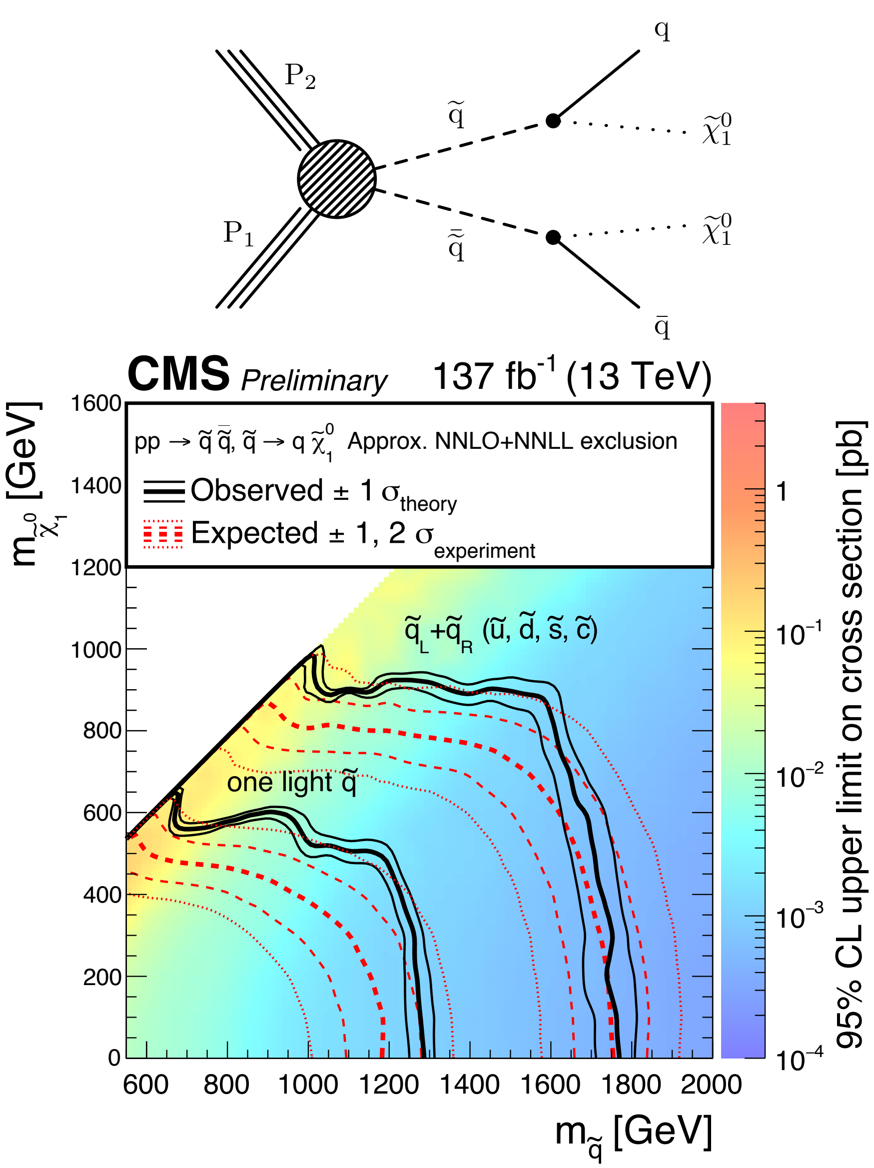
Maximal excluded gluino masses ~ **2.3 TeV**

Results Squarks

No significant excess over the SM predictions

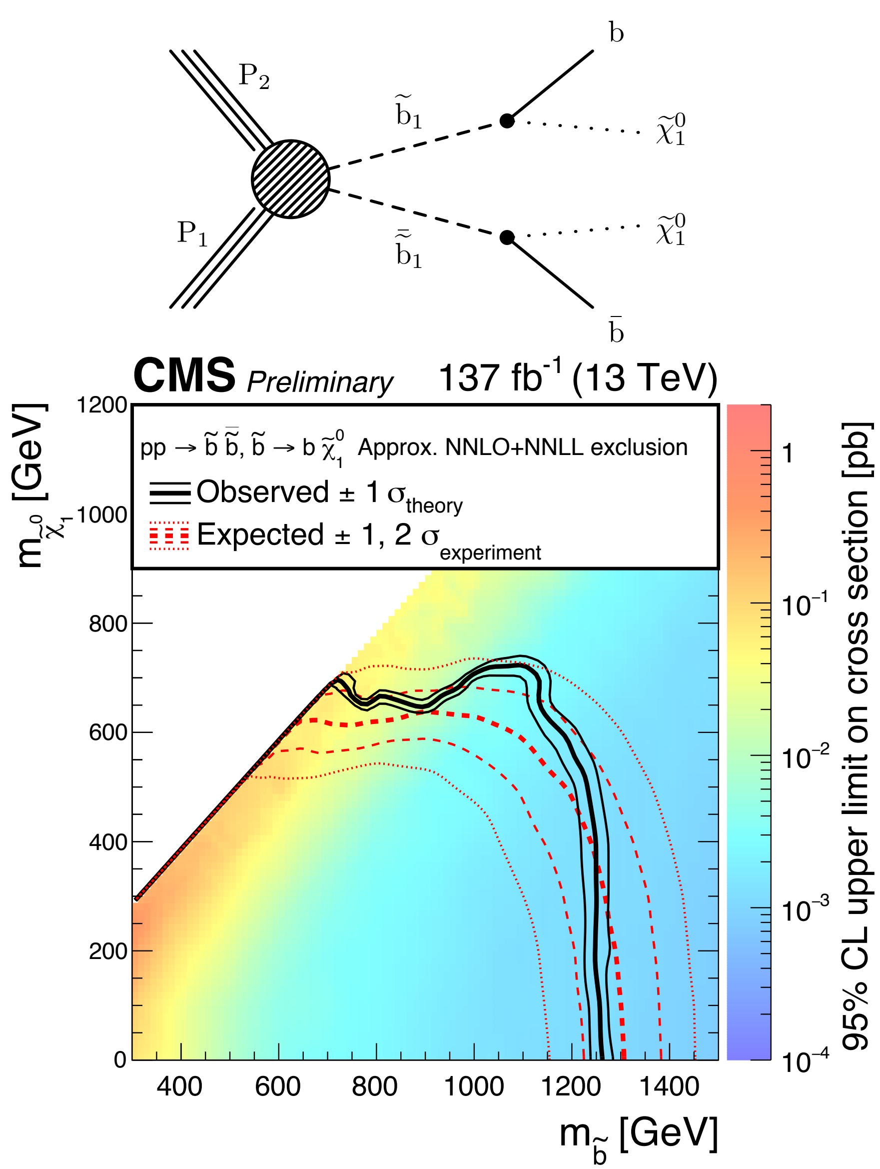
=> exclusion limits on simplified models, **squark pair production**

Light flavour squarks



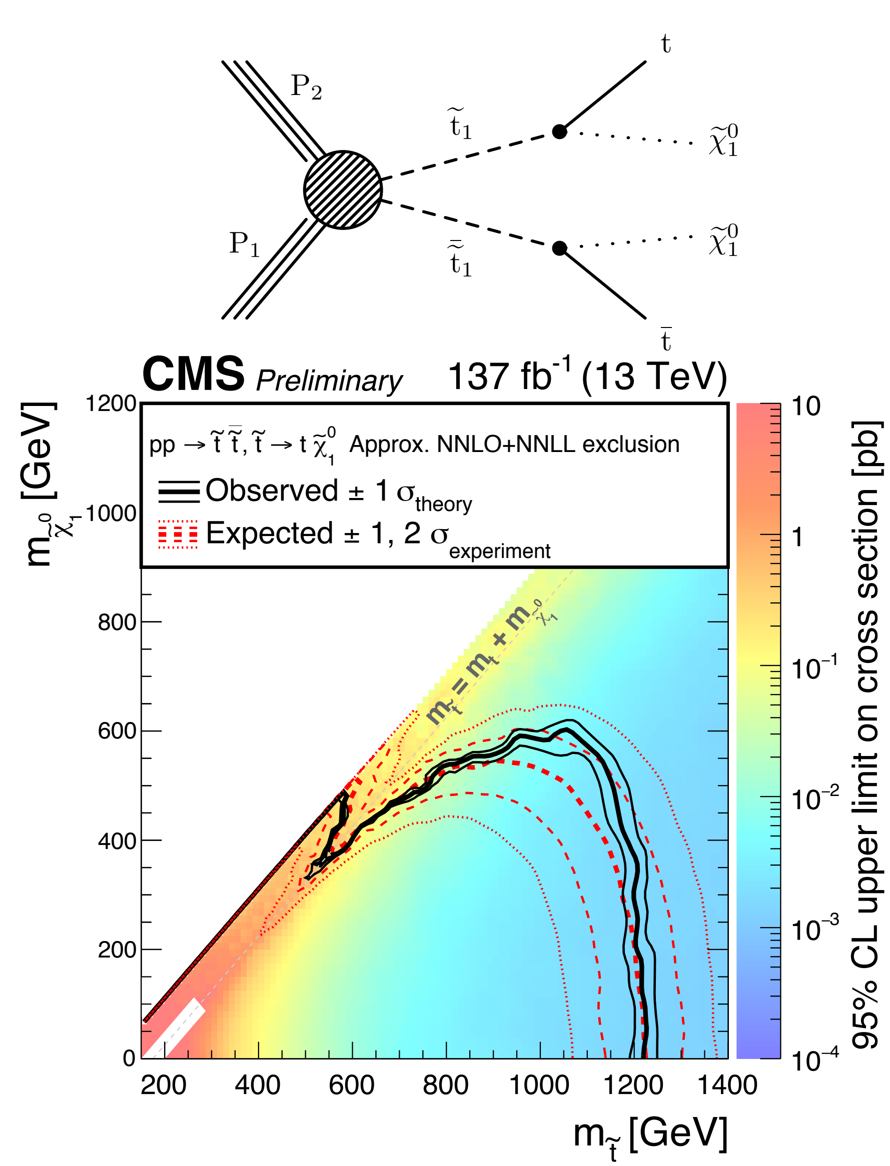
assuming 8-fold, max. limit on light flavour squark ~**1.8 TeV**

Bottom squarks



max. limit on sbottom ~ **1.3 TeV**

Top squarks



max. limit on stop ~ **1.2 TeV**

MT2 + Disappearing Track

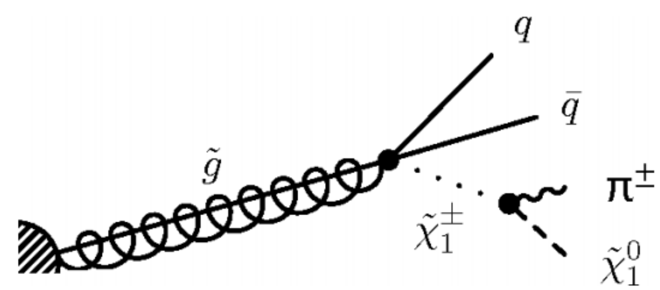
SUS-19-005

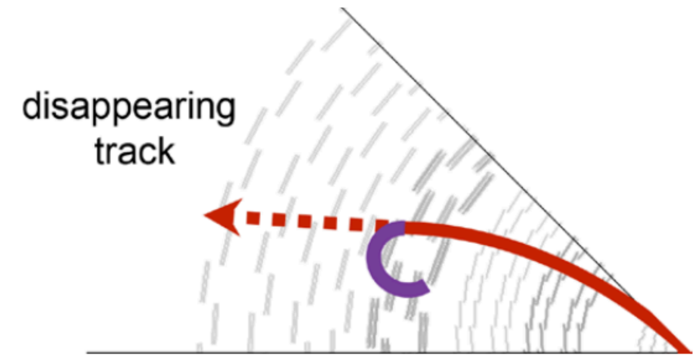
Targets:

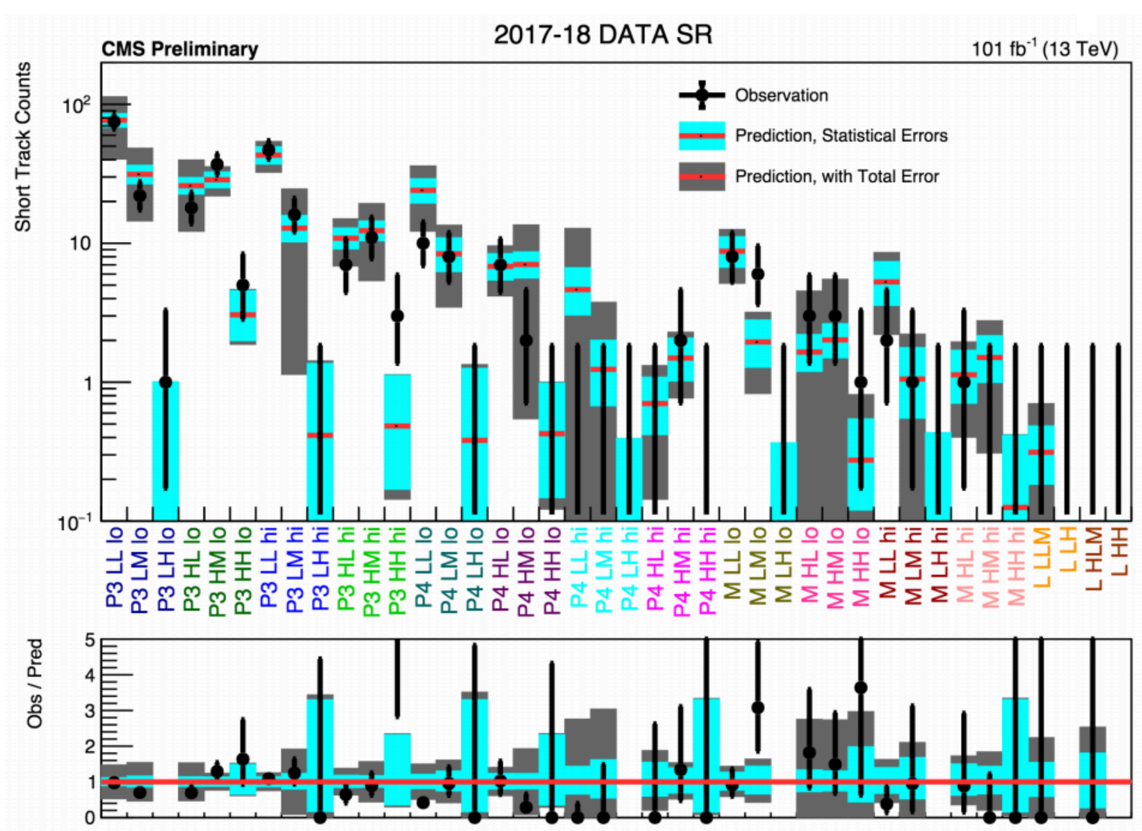
- strong susy with **long-lived charginos**
- chargino decays to pion and neutralino with $\Delta m(\tilde{\chi}^{\pm}_1, \tilde{\chi}^0_1) \sim 100$ MeV

Signature:

- pion too soft to be detected
- **disappearing track + jets + MET**







Analysis strategy:

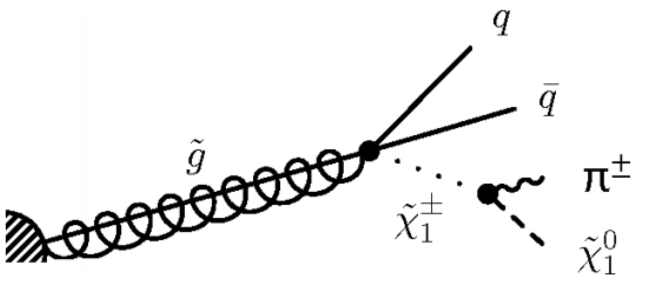
- bins in $\mathbf{N_j}$, $\mathbf{H_T}$, dis. **track length** and $\mathbf{p_T}$
- background: **fake tracks** and poorly reconstructed tracks from pions/leptons
- fake rate estimated from data in **low MT2 sideband** and validated at intermediate MT2

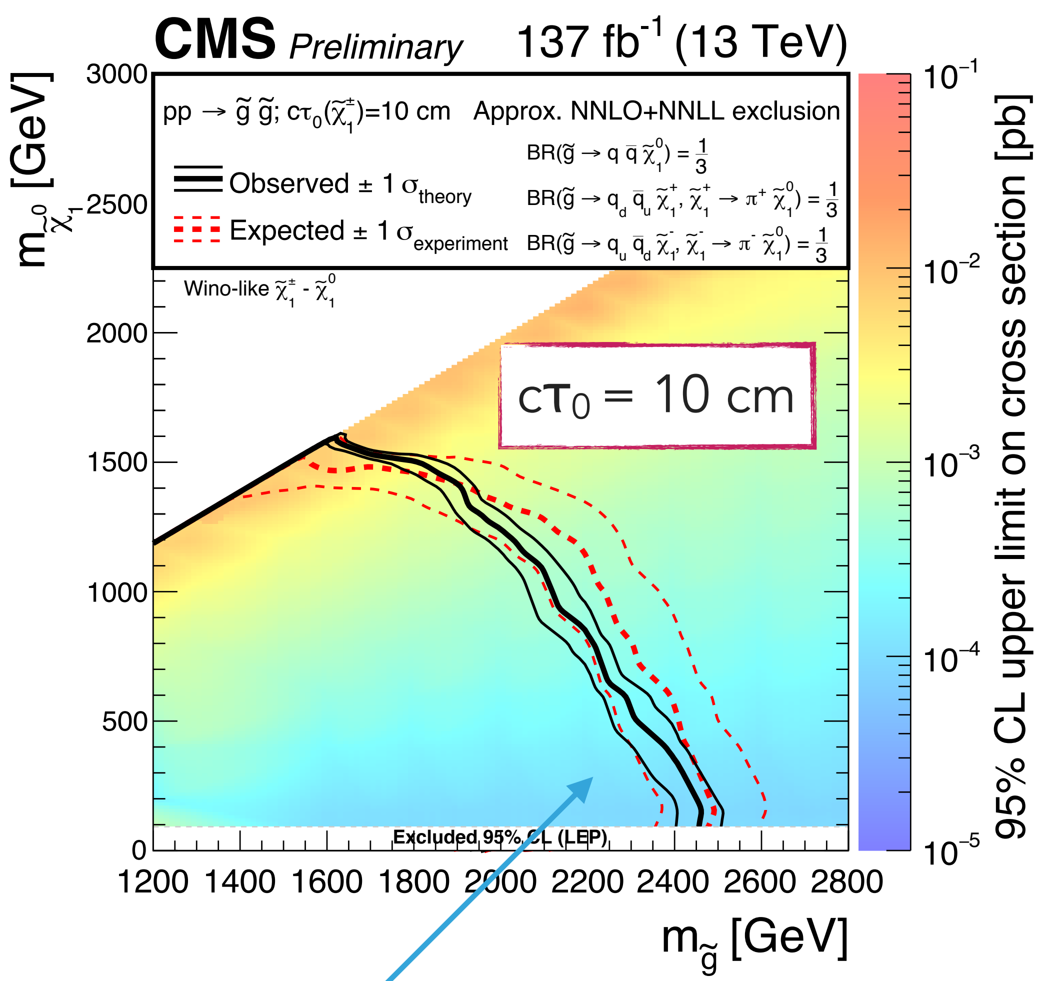
No significant excesses over predictions

MT2 + DISAPPEARING TRACK

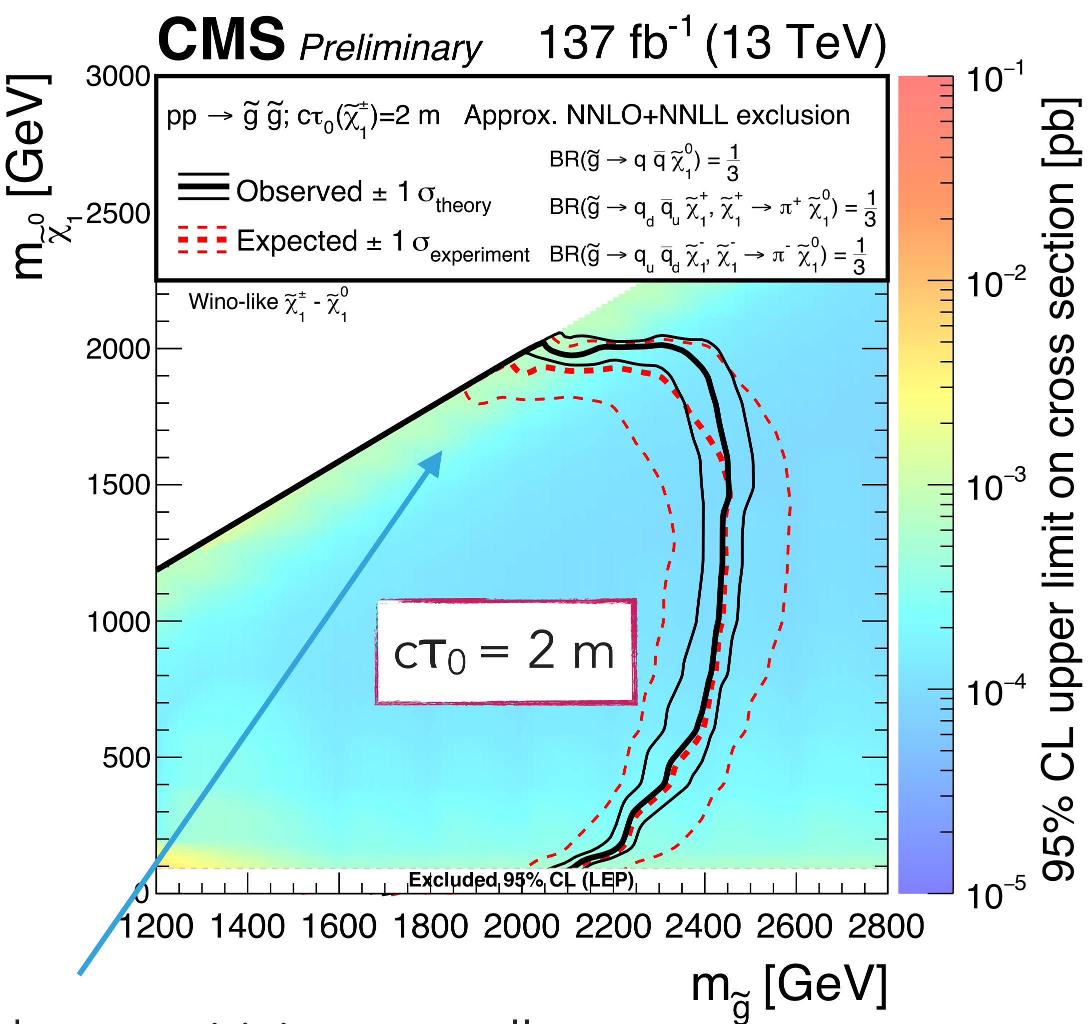
SUS-19-005

Can probe gluino up to 2460 GeV, neutralino up to 2000 GeV





higher sensitivity to large $\Delta m(\tilde{g},\tilde{\chi}^0_1)$ for short tracks



higher sensitivity to small $\Delta m(\tilde{g},\tilde{\chi}^0_1)$ for long tracks

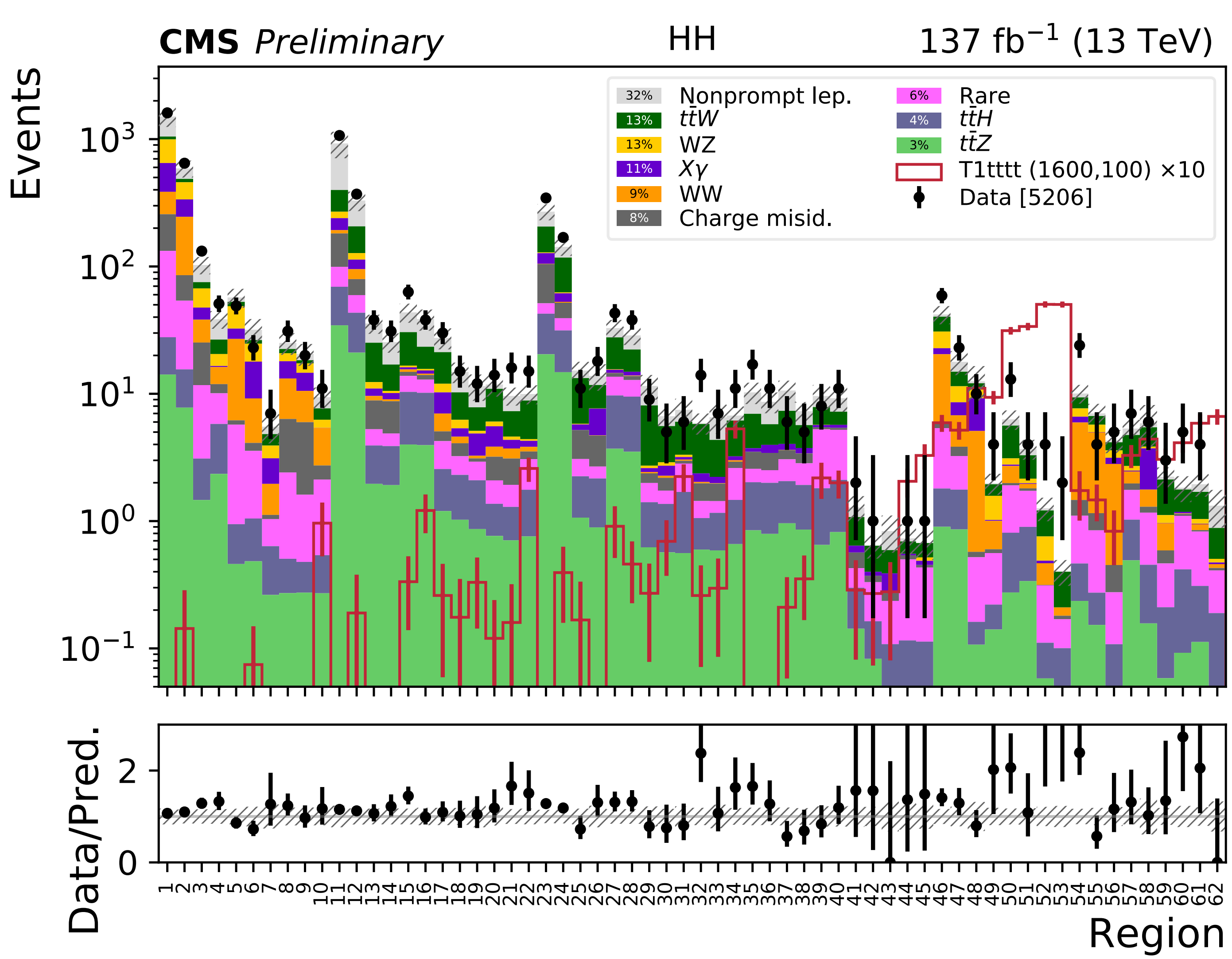
2L SS + MULTILEPTON

Signature: **two SS or three or more light leptons** (electrons and muons) and at **>= 3 jets**

very rare signature in SM => low-background search

Targets:

- RPC strong production **with W/Z in the decay**
- low lepton p_T & MET categories suitable to probe **RPV** scenarios



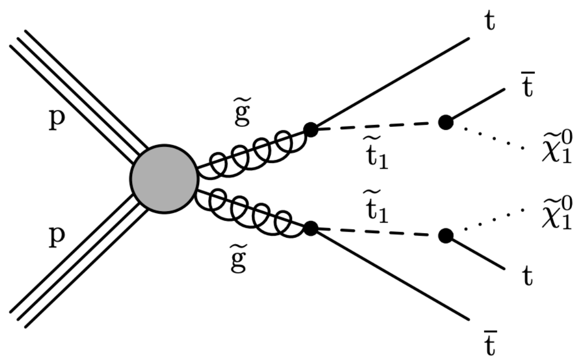
Categorisation based on **N-lep**, **lep p_T**, **N_j**, **N_{bj}**, **MET**, **H_T**

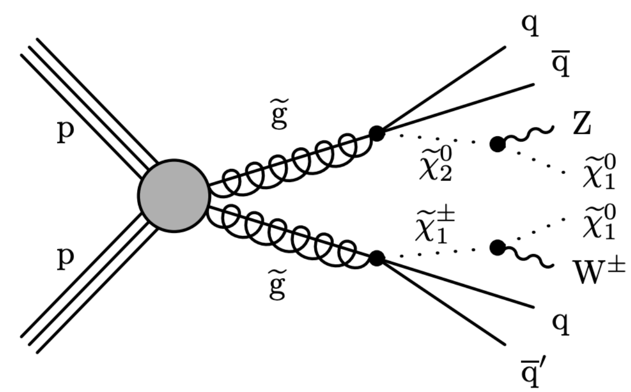
Backgrounds:

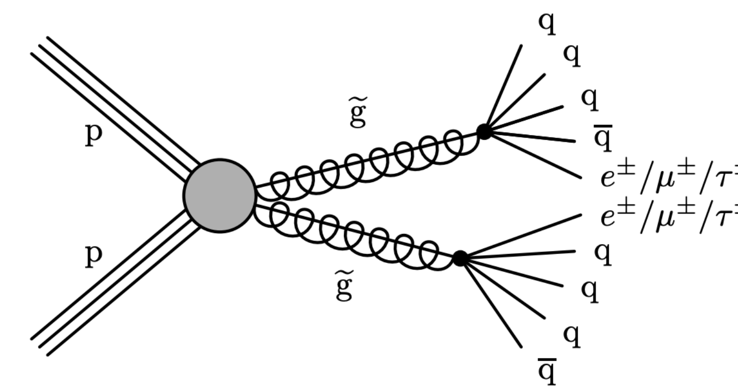
- rare SM processes leading to 2L-SS estimated via data/MC ratios
- fake leptons (data-driven) with "tight-to-loose" ratio method

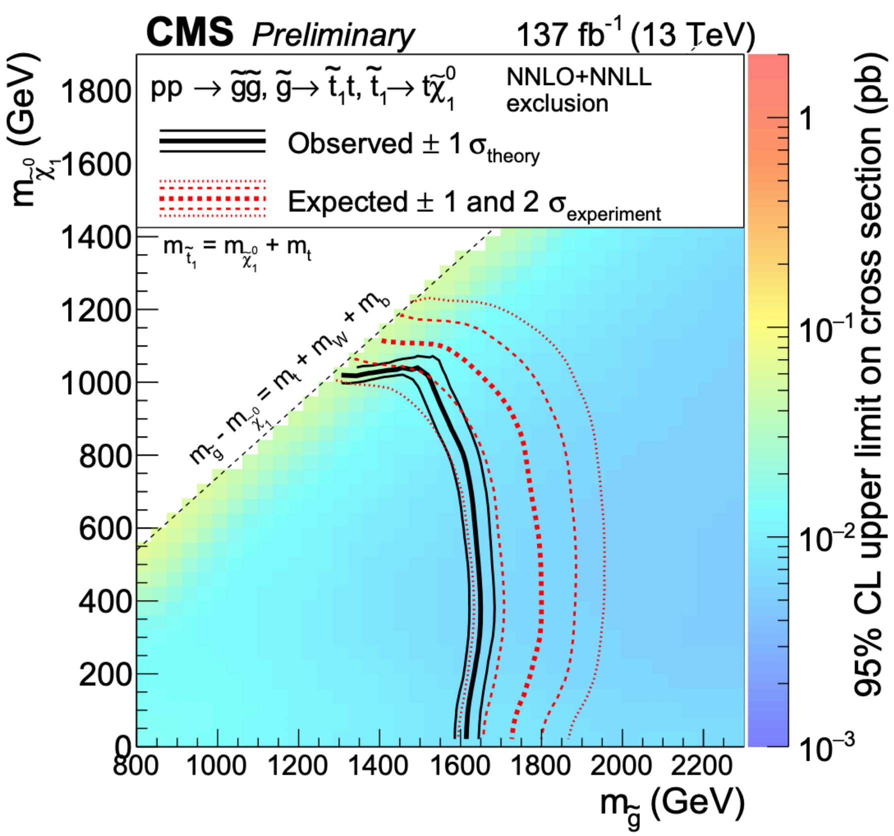
Largest deviation from SM predictions 2.6 σ, but adjacent bin in H_T shows -1.6σ

2L SS + MULTILEPTON

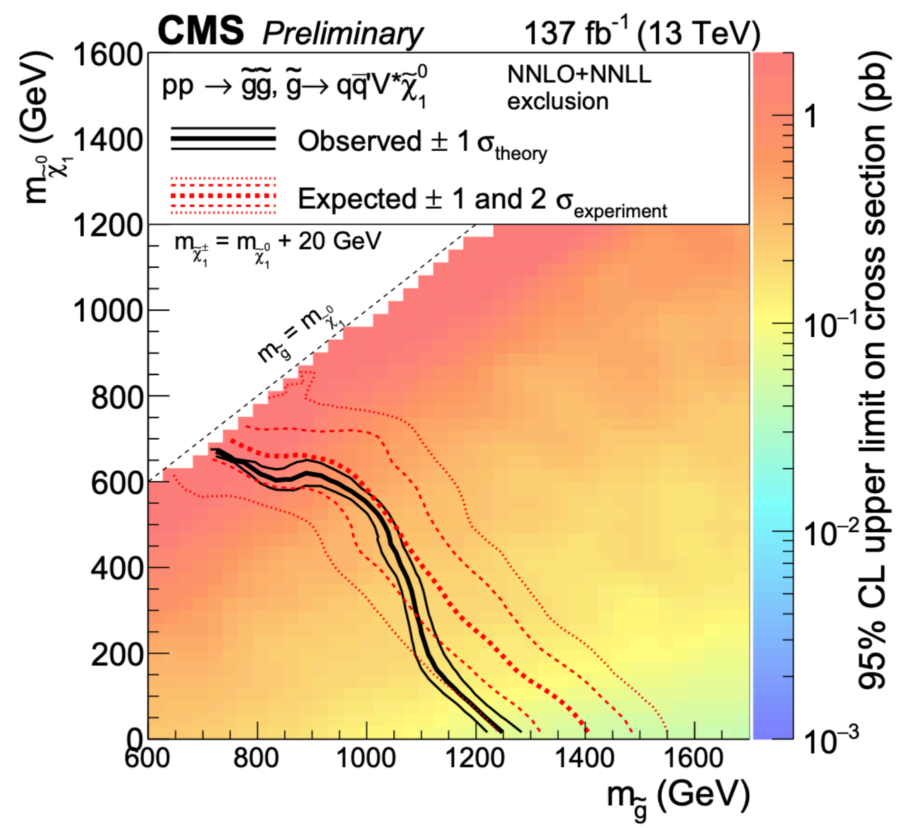




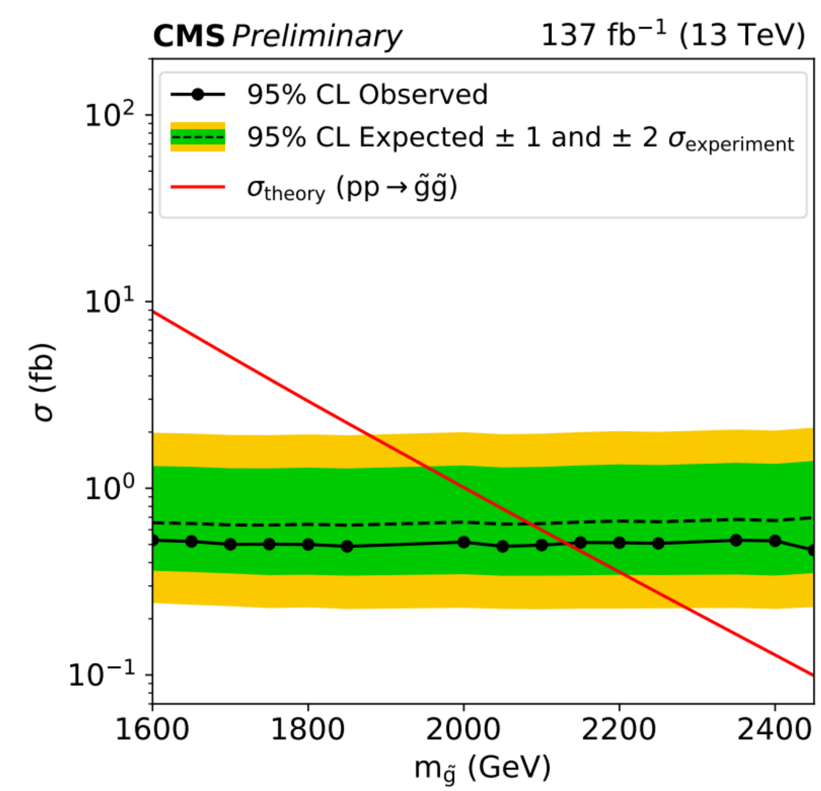




on-shell 3rd gen. squarks
$\Delta m(\tilde{t},\tilde{\chi}^0_1)=m_t$



$\Delta m(\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_1) = 20$ GeV



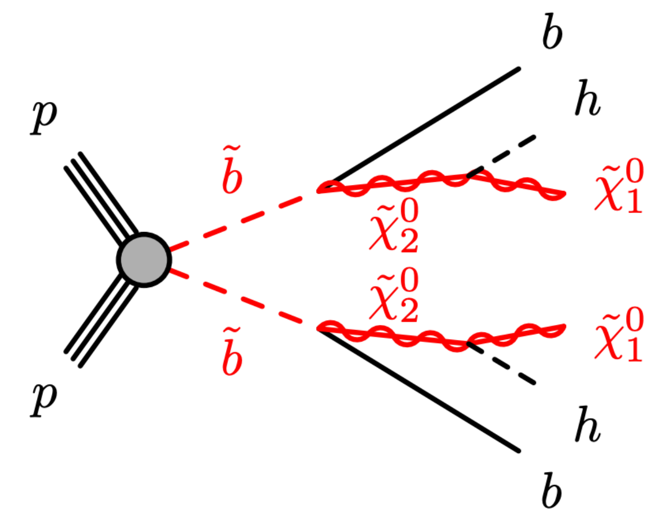
RPV w/ non-zero coupling in the baryonic sector

MET + B-JETS + H(BB)

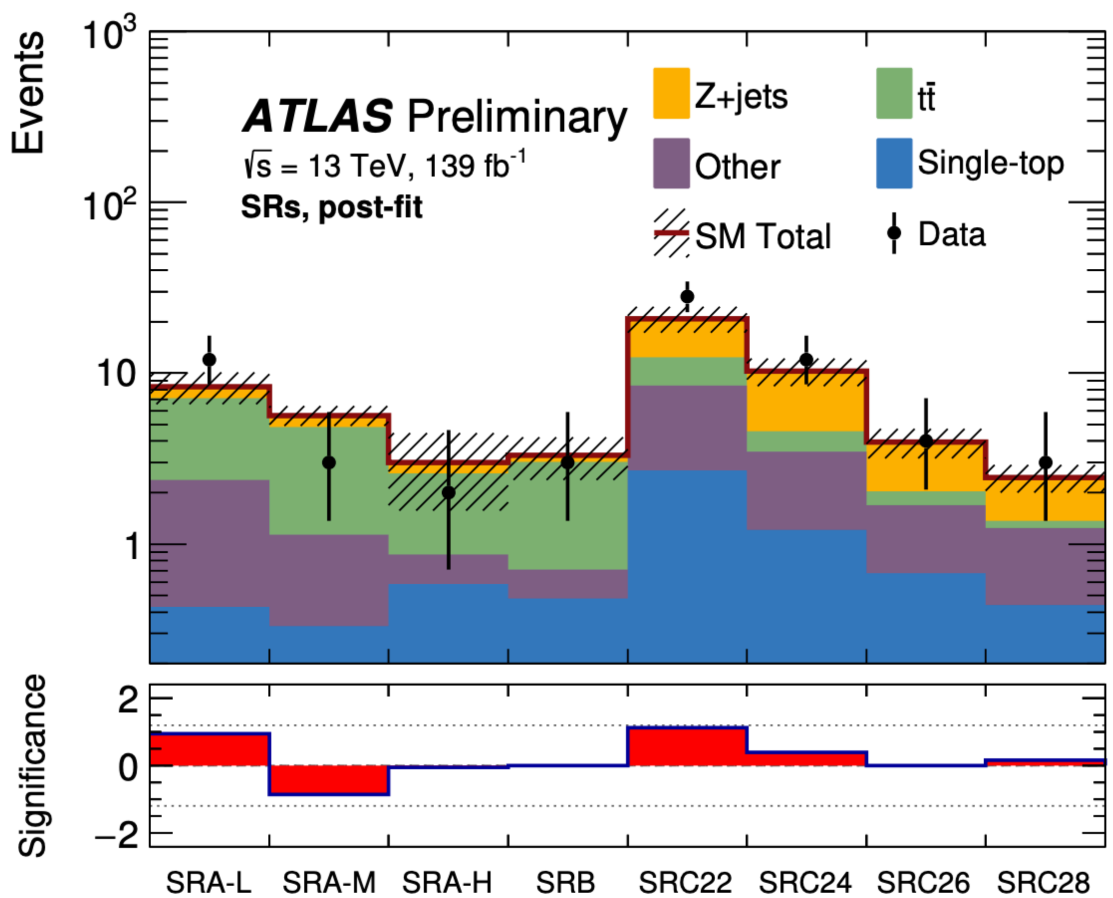
ATLAS-CONF-2019-011

Targets **sbottom** pair production with **Higgs** in the decay chain:

- fixed $\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, sufficient to produce on-shell *h*
- fixed LSP mass, $m(\tilde{\chi}^0_1)$=60 GeV, motivated by relic density



Signature: **up to 6 jets, multiple b-tags, MET, 0-leptons**



Signal regions **target three topologies:**

- SRA moderate-high $\Delta m(\tilde{b},\tilde{\chi}^0_2)$
- SRB small $\Delta m(\tilde{b},\tilde{\chi}^0_2)$, fixed $\Delta m(\tilde{b},\tilde{\chi}^0_2)$
- SRC small $\Delta m(\tilde{b},\tilde{\chi}^0_2)$, fixed $\tilde{\chi}^0_1$

Dominant backgrounds:

- top in SRA and SRB
- Z+jets in SRC

Bkg estimation via **simultaneous fit** in 1-lep, 2-lep control regions

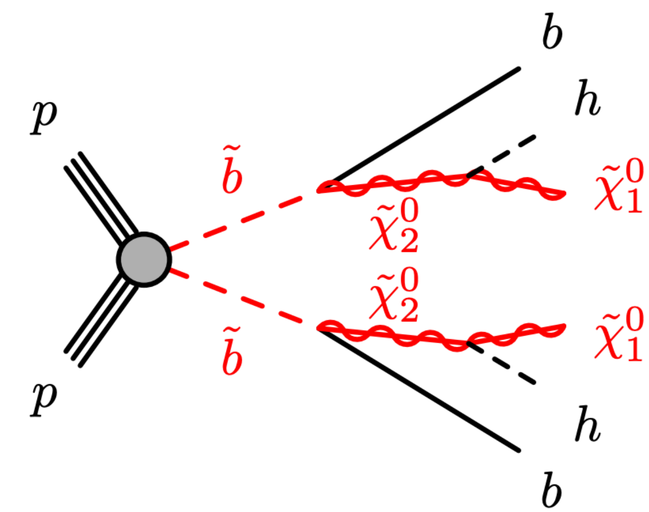
No significant deviation over the SM predictions

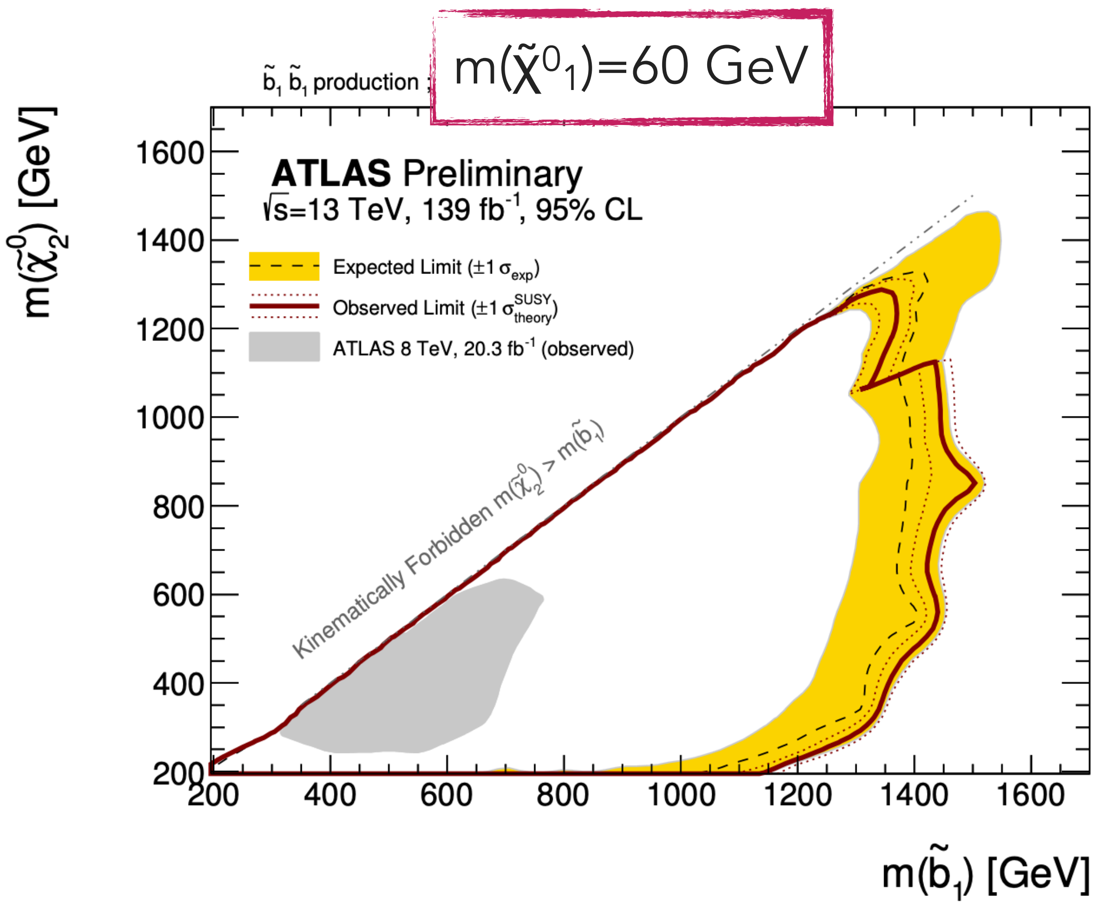
MET + B-JETS + H(BB)

ATLAS-CONF-2019-011

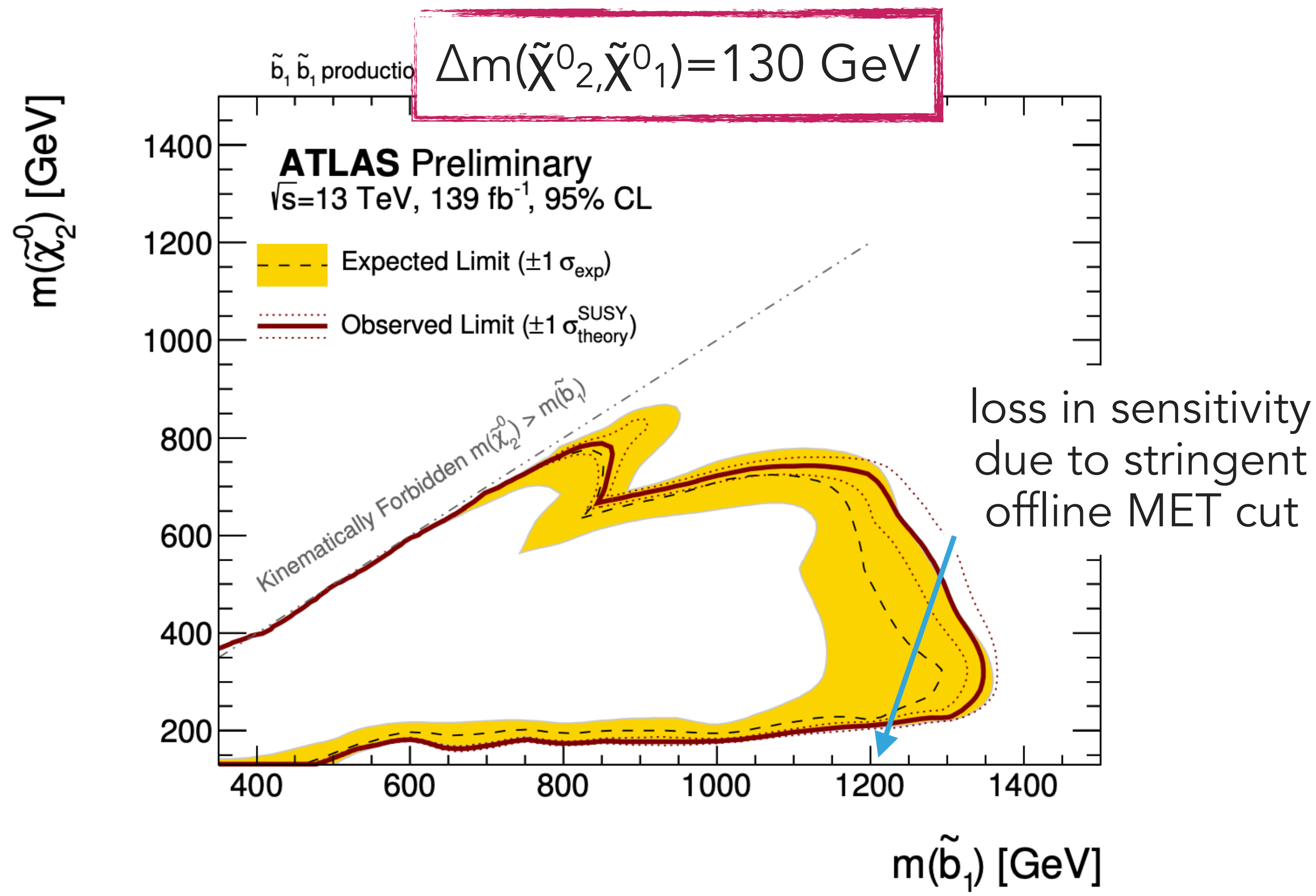
Significant improvement wrt Run-1 search

Complementarity to other sbottom searches





maximal excluded sbottom mass ~ 1.5 TeV



maximal excluded sbottom mass ~ 1.35 TeV

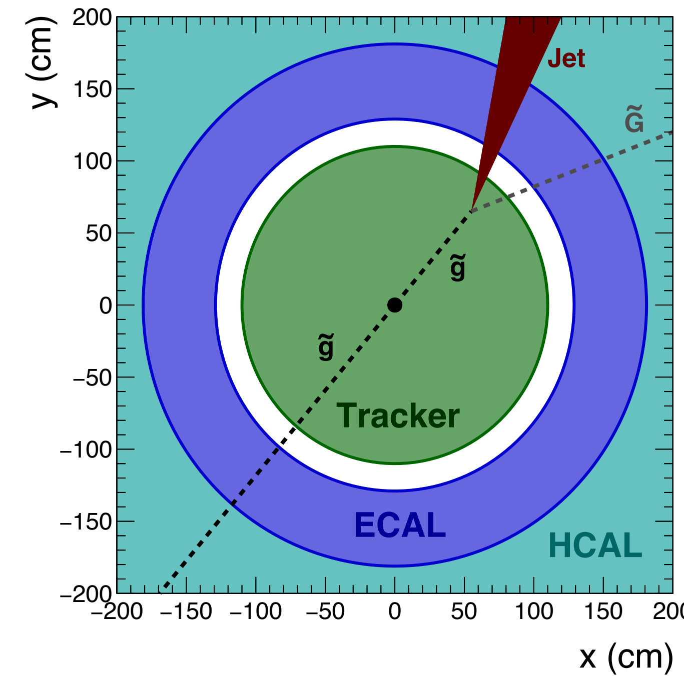
Delayed Jets + MET

SUS-19-001

Signature is **delayed jets + large MET**, using ECAL timing

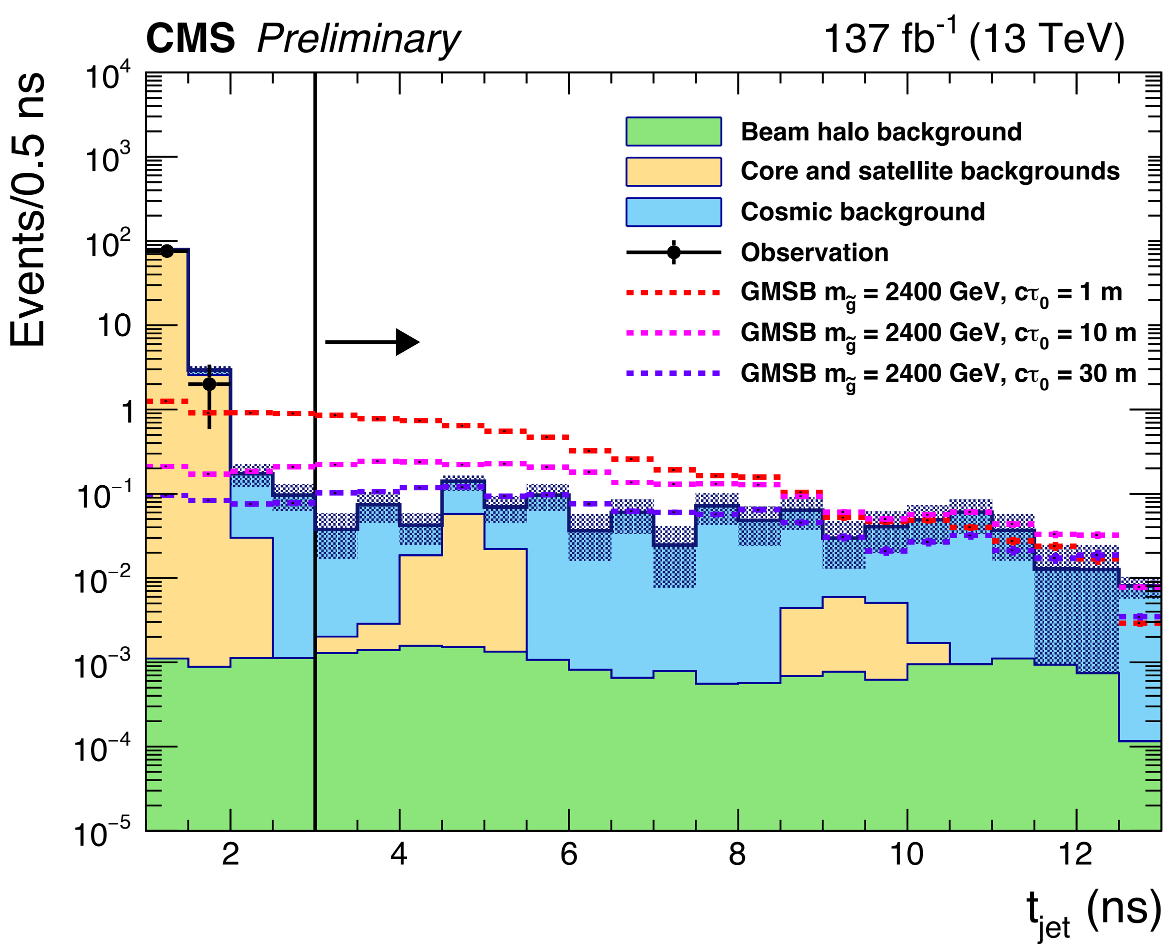
Targets **long-lived neutral hadronic** particles decaying to **jets + invisible**

Benchmark model: (one) long-lived gluino ($\tilde{g} \Rightarrow \tilde{G}g$) in GMSB



Event selection:

- MET>300 GeV, barrel jets, pt>30 GeV, t_{jet}>3ns, t_{jet}<20ns
- **Jet cleaning** aims to kill various sources of instrumental background:
  - ECAL noise, beam halo, cosmics, oot pile-up, satellite bunches



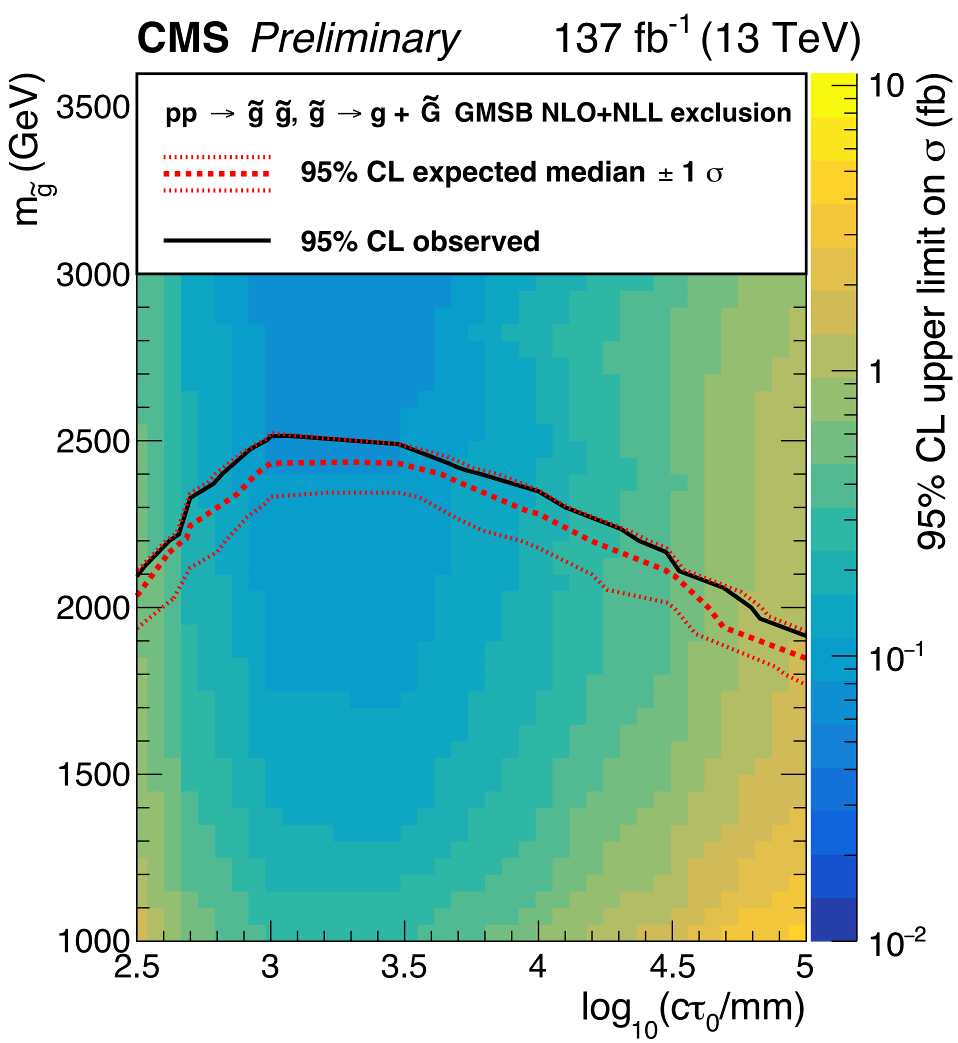
Residual backgrounds estimated from data control regions with inverted cuts, e.g. invert E^{CSC}_{ECAL}/E_{ECAL} < 0.8, E_{HCAL}/E_{total} > 0.2

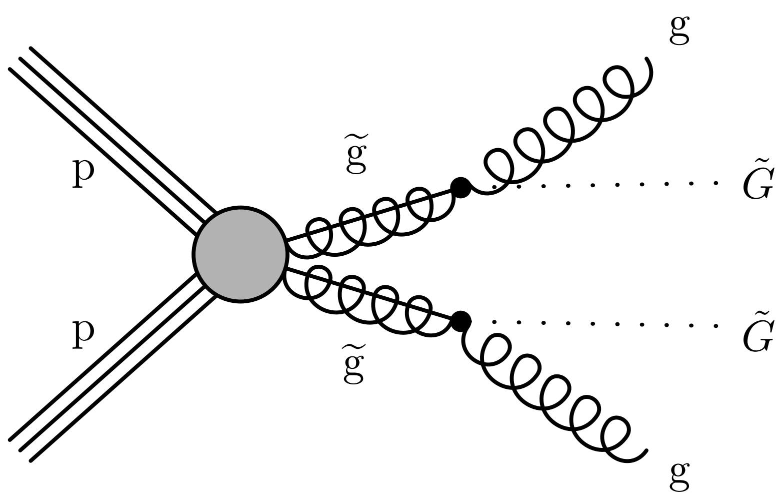
Background	Prediction
Beam halo	$0.02^{+0.06}_{-0.02}$ (stat) $^{+0.05}_{-0.01}$ (syst)
Core and satellite bunches	$0.11^{+0.09}_{-0.05}$ (stat) $^{+0.02}_{-0.02}$ (syst)
Cosmics	$1.0^{+1.8}_{-1.0}$ (stat) $^{+1.8}_{-1.0}$ (syst)

0 observed events consistent with prediction

Delayed Jets + MET

SUS-19-001

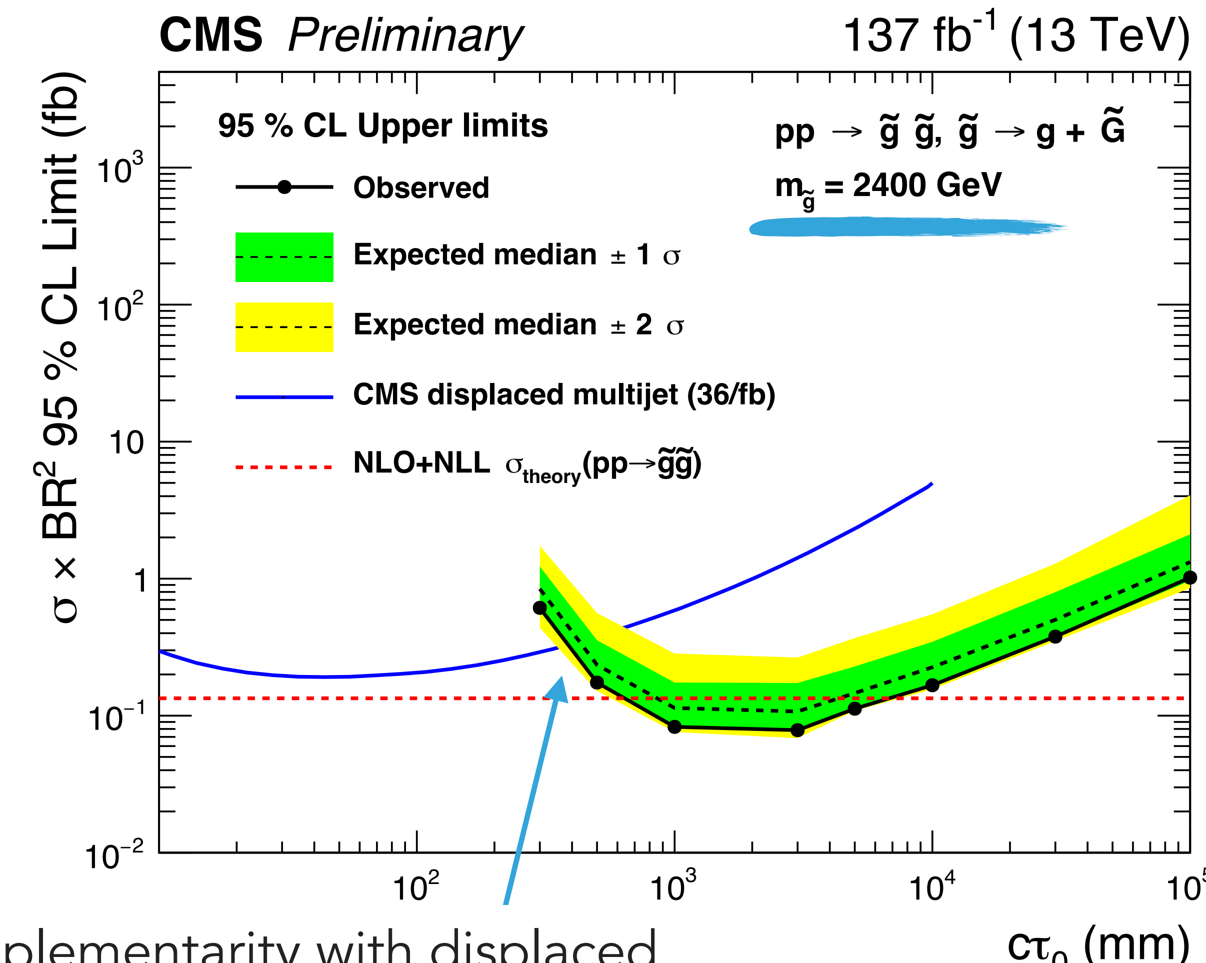




Gluino excluded up to

m = 2100, 2500 and 2150 GeV

for $c\tau_0$ = 0.3, 1.0, and 30 m

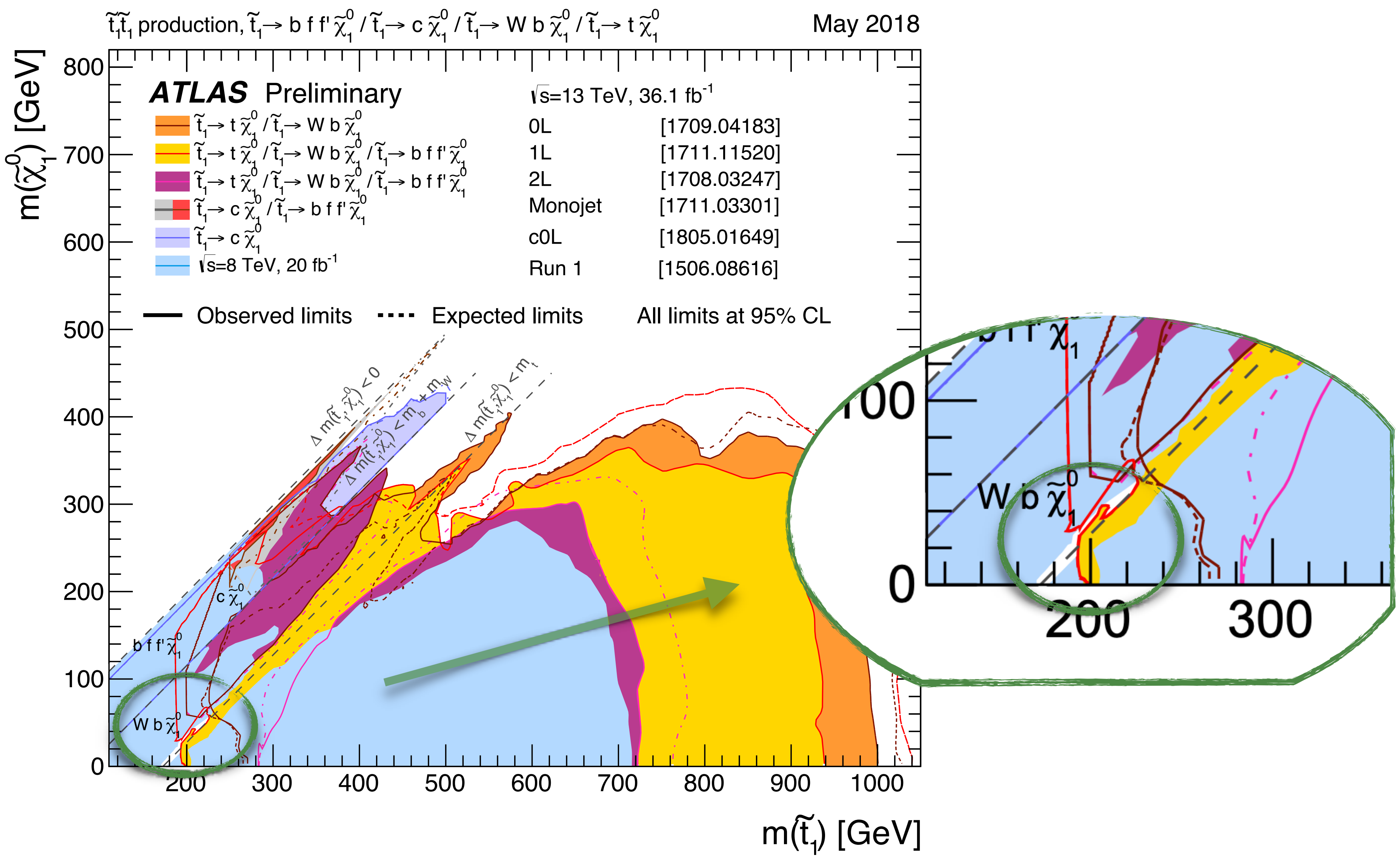


Complementarity with displaced jet search for $c\tau_0$ ~>1m

Top Corridor

Challenging region: **stop and top stop nearly degenerate in mass**

=> $\tilde{t}\tilde{t}$ production looks like ttbar production



=> Tackle with precise estimate of ttbar using clean channel (OS emu pair)

ATLAS arXiv:1903.07570   CMS arXiv:1901.01288

TOP CORRIDOR

arXiv:1903.07570

Signature:

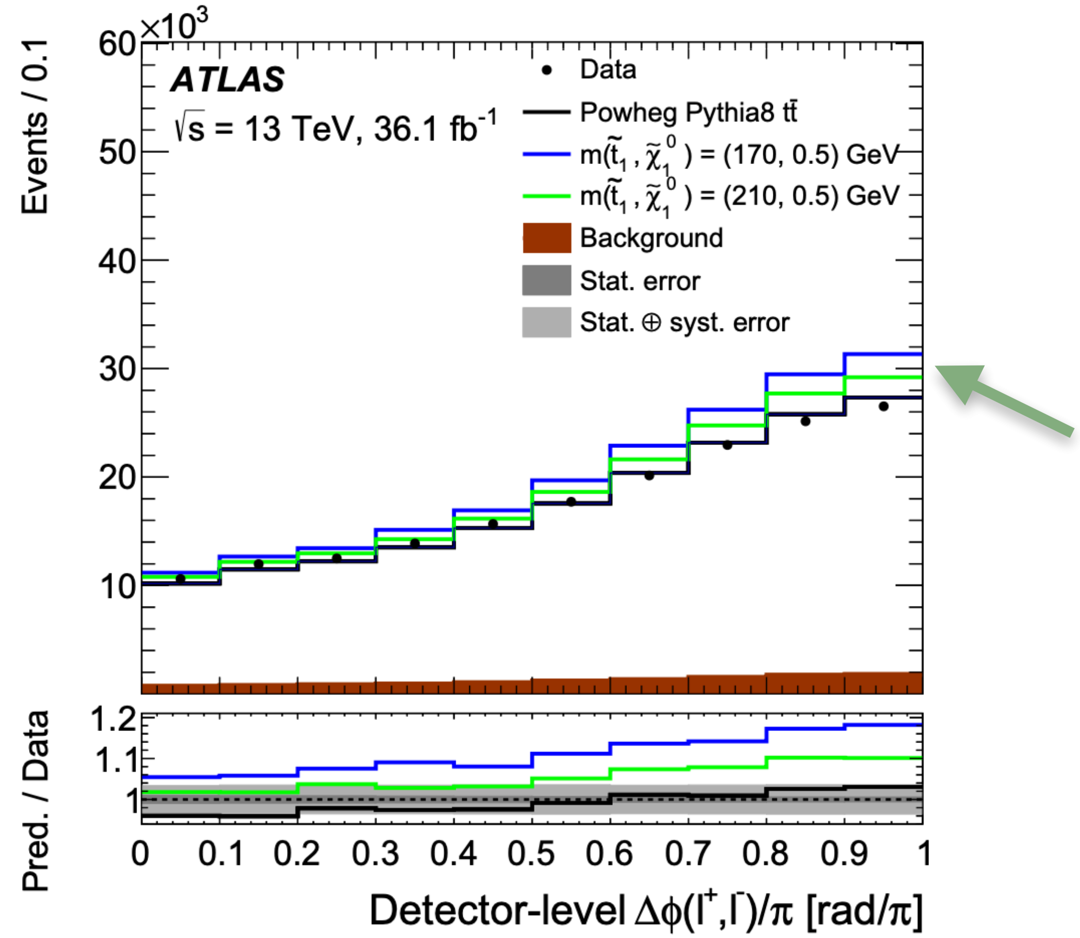
- stop pair production would produce **different spin correlation** compared to SM ttbar

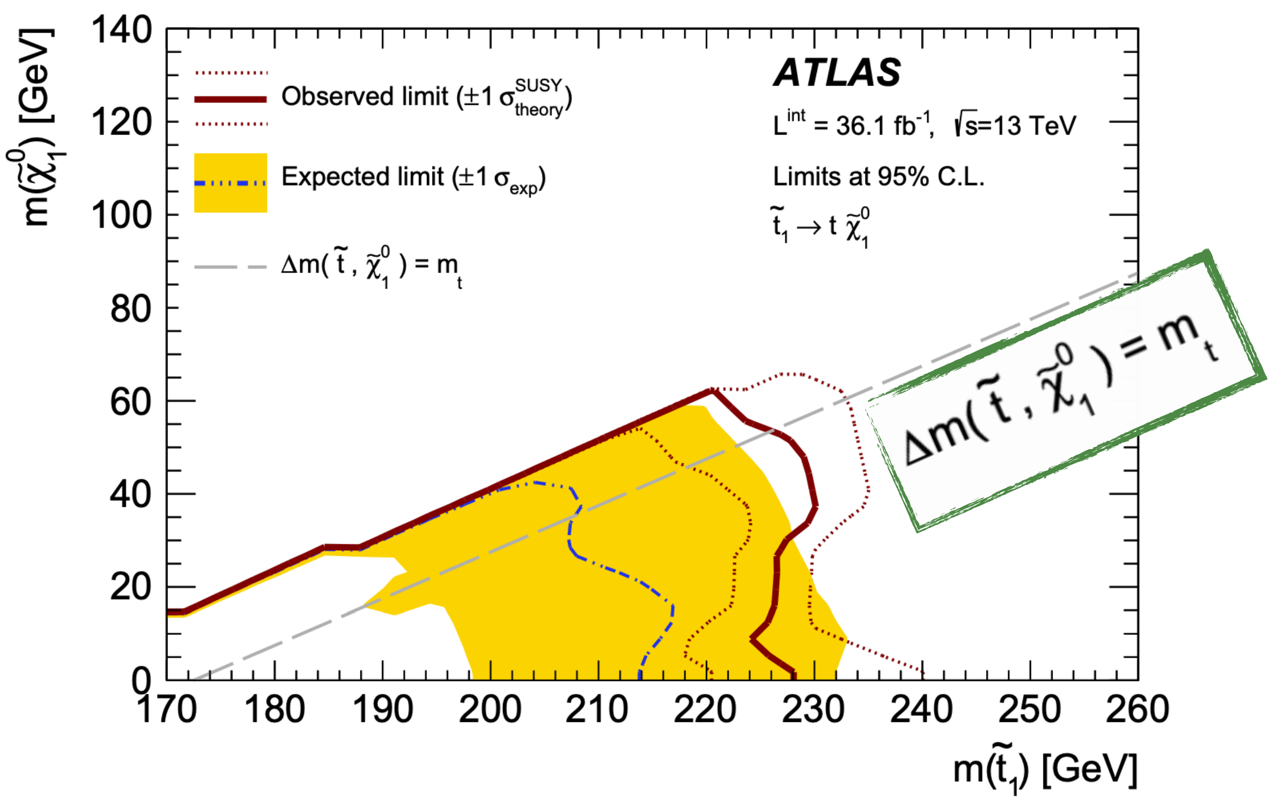
Observables:

- **Δϕ** and **Δη** of **OS emu pair** (leptons carry spin information of the parent top)

Strategy:

- Simultaneous fit of the SM Δϕ prediction (Powheg+Pythia) to observed data in three differential Δη regions





top corridor region largely excluded compared to generator prediction

Conclusions

An **extensive program of searches** for strongly produced SUSY particles

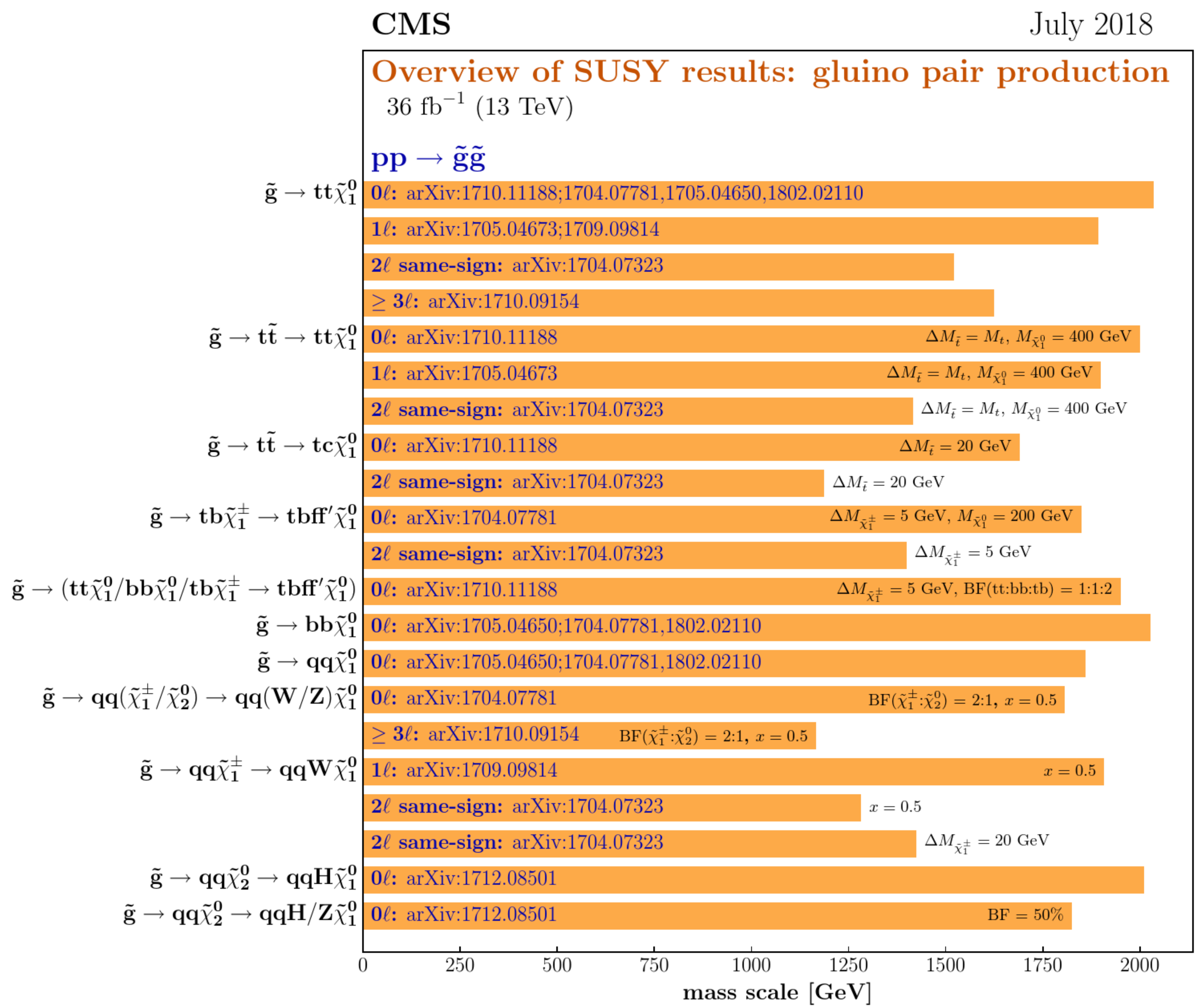
- complementarity of **inclusive** and **targeted** searches
- both standard and exotic / rare decay channels being explored

No significant excesses of events have been found so far

=> Many more results upcoming with full Run-2 dataset

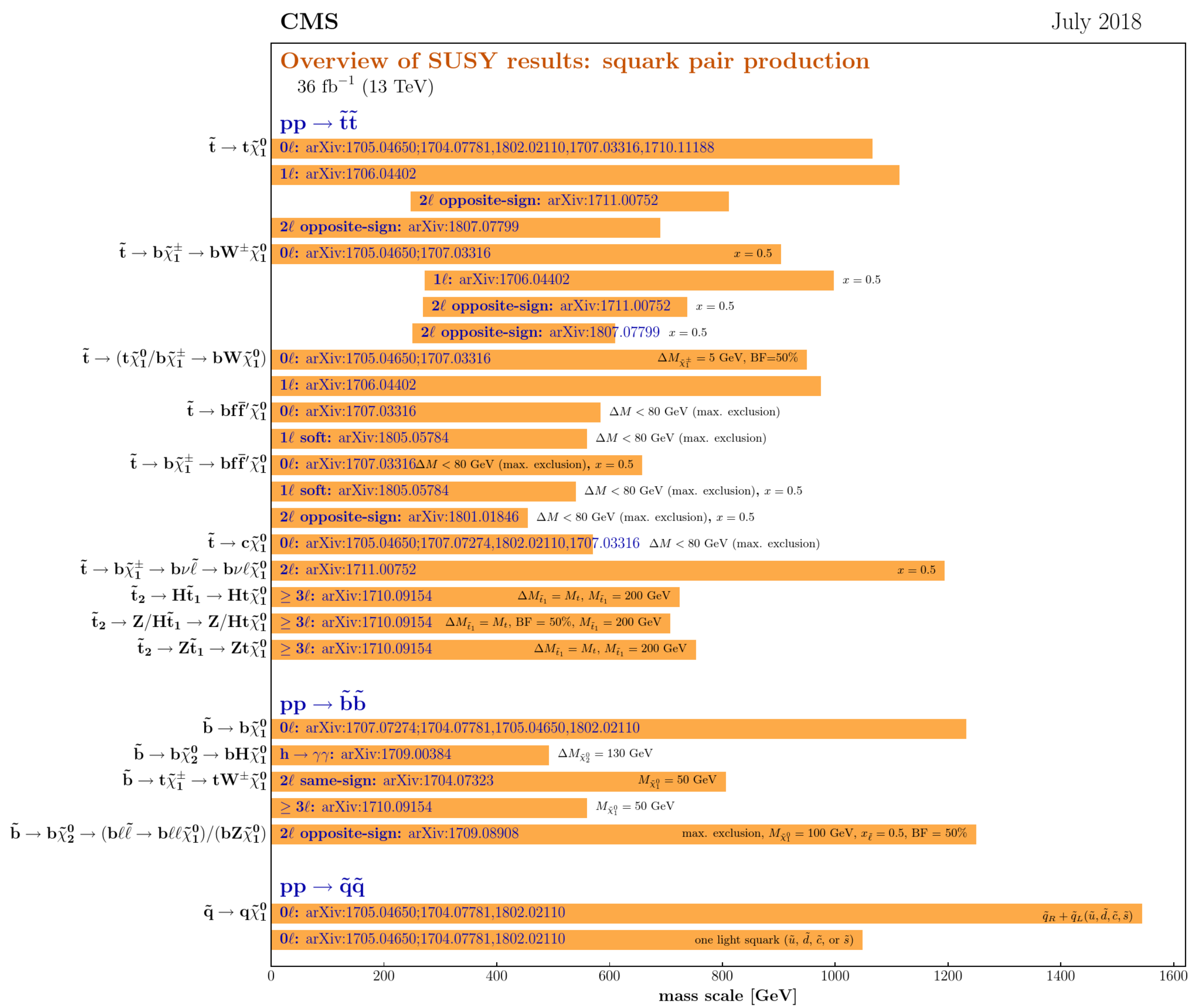
BACK-UP SLIDES

CMS LIMITS AFTER 36 FB^{-1} @ 13 TEV



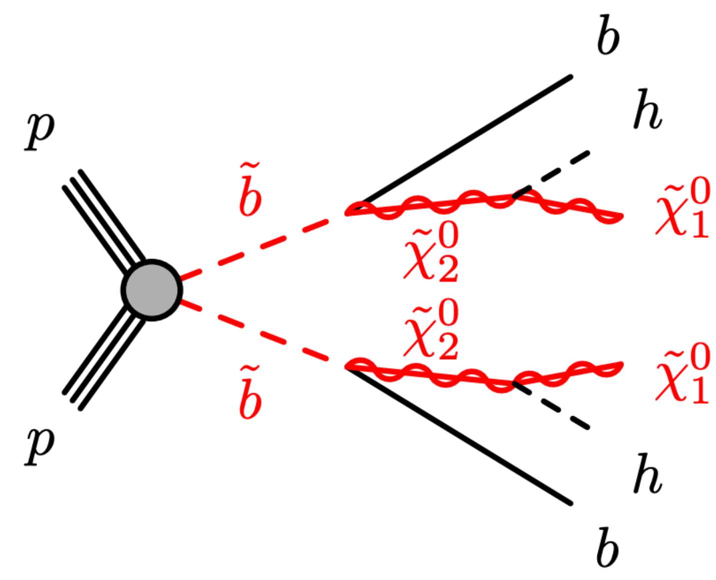
Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

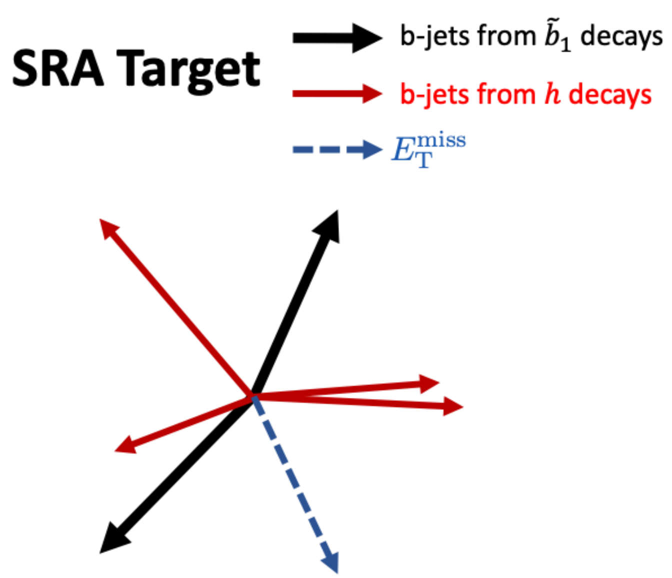
CMS Limits after 36 fb^{-1} @ 13 TeV



Selection of observed limits at 95% C.L. (theory uncertainties are not included). Probe **up to** the quoted mass limit for light LSPs unless stated otherwise. The quantities ΔM and x represent the absolute mass difference between the primary sparticle and the LSP, and the difference between the intermediate sparticle and the LSP relative to ΔM, respectively, unless indicated otherwise.

MET + B-JETS + H(BB)

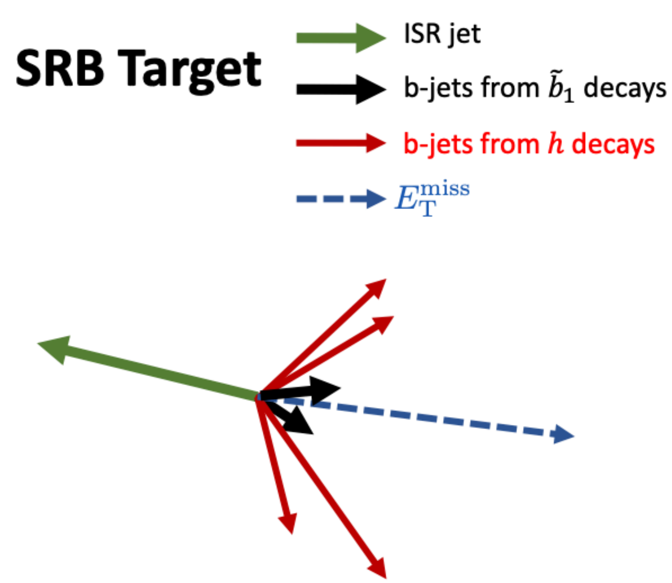




"bulk" region

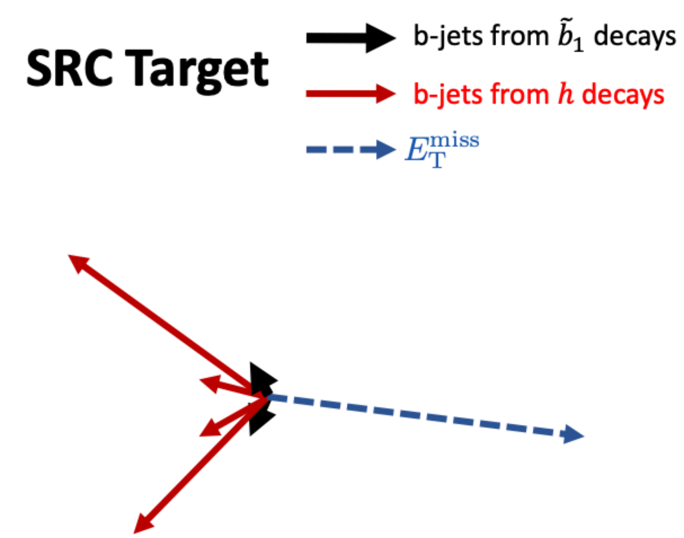
moderate-high $\Delta m(\tilde{b},\tilde{\chi}^0_2)$

all b-jets resolved



small $\Delta m(\tilde{b},\tilde{\chi}^0_2)$

ISR selection, low pT b-jets from $\tilde{b}$



$m(\tilde{\chi}^0_1)$ = 60 GeV (relic density)

small $\Delta m(\tilde{b},\tilde{\chi}^0_2)$

low pT b-jets