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SEARCHES FOR STRONGLY INTERACTING SUSY PARTICLES

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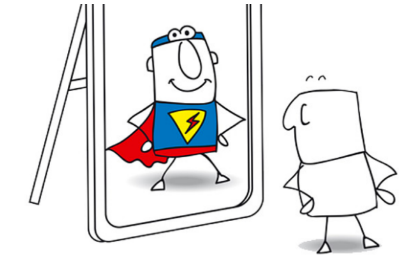
ATLAS EXPERIMENT

CMS

CERN

QUARK - LEPTON TAIPEI, TAIWAN, 16-20 SEP 2019

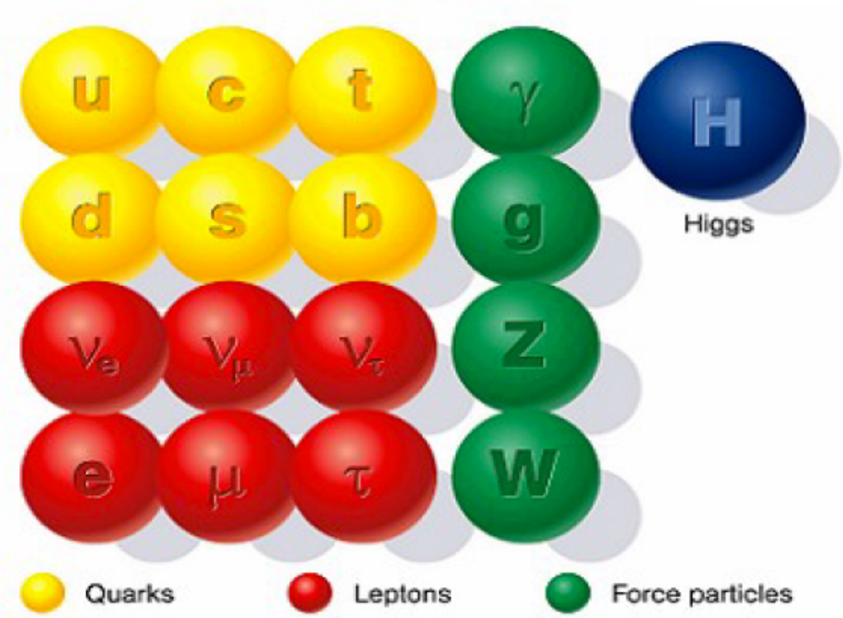
SUPERSYMMETRY



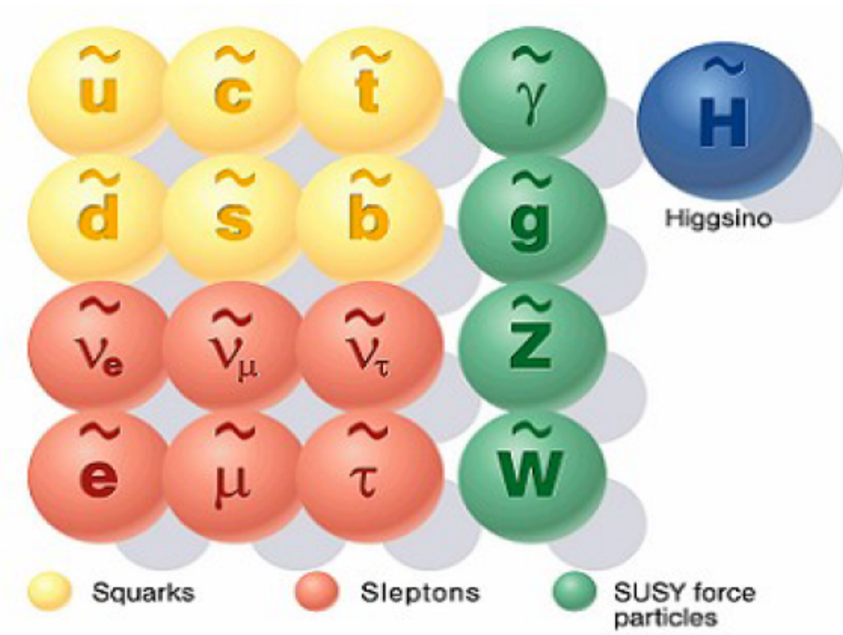
- **Standard Model (SM)** is a very successful theory and has been found to be in agreement with experimental measurements, but it does not explain problems such as:
  - hierarchy problem,
  - Dark Matter (DM),...

- **Supersymmetry (SUSY)** can solve these problems by introducing a super partner (SUSY particle) for each SM particle:

SM particles



SUSY particles



$R = (-1)^{3(B-L)+2s}$

$$R = \begin{cases} +1 \text{ for SM particles} \\ -1 \text{ for SUSY particles} \end{cases}$$

$\widetilde{H}_u^0\ \widetilde{H}_d^0\ \widetilde{W}^0\ \widetilde{B}^0 \xrightarrow{\text{mixing}} \widetilde{\chi}_1^0\ \widetilde{\chi}_2^0\ \widetilde{\chi}_3^0\ \widetilde{\chi}_4^0$ neutralinos

$\widetilde{H}_u^+\ \widetilde{H}_d^-\ \widetilde{W}^+\ \widetilde{W}^- \xrightarrow{\text{mixing}} \widetilde{\chi}_1^\pm\ \widetilde{\chi}_2^\pm$ charginos

R-parity conservation
- SUSY particles pair-produced
- Lightest SUSY particle (LSP) is stable
- DM candidate

R-parity violation
- LSP not necessarily neutral and stable

SUPERSYMMETRY @ LARGE HADRON COLLIDER

SUSY particles can be produced by several mechanisms @ the LHC

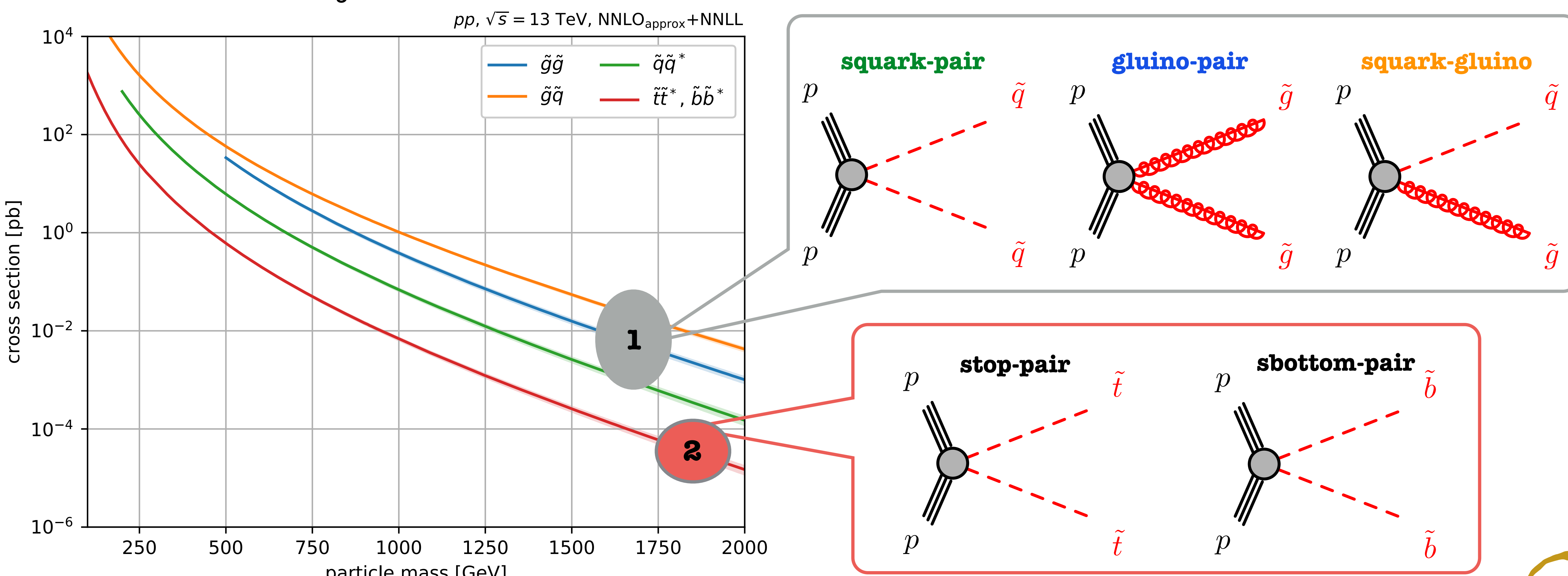
In this talk, the main focus will be on:

1) Strong production of squarks (1st and 2nd generations) and gluinos

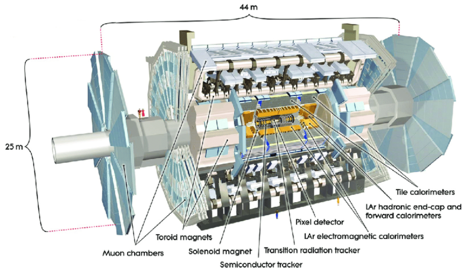
- High cross-section
- Sensitivity up to high SUSY particle masses
- Jet-rich final states

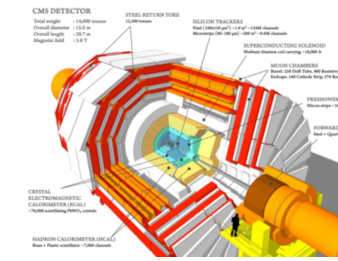
2) 3rd generation of squarks (stop and sbottom)

- Lower cross-sections than for the 1st and 2nd generations of squarks and gluinos
- Light 3rd generation squarks preferred by naturalness arguments
- Final states with b-jets



RUN 2 DATASET

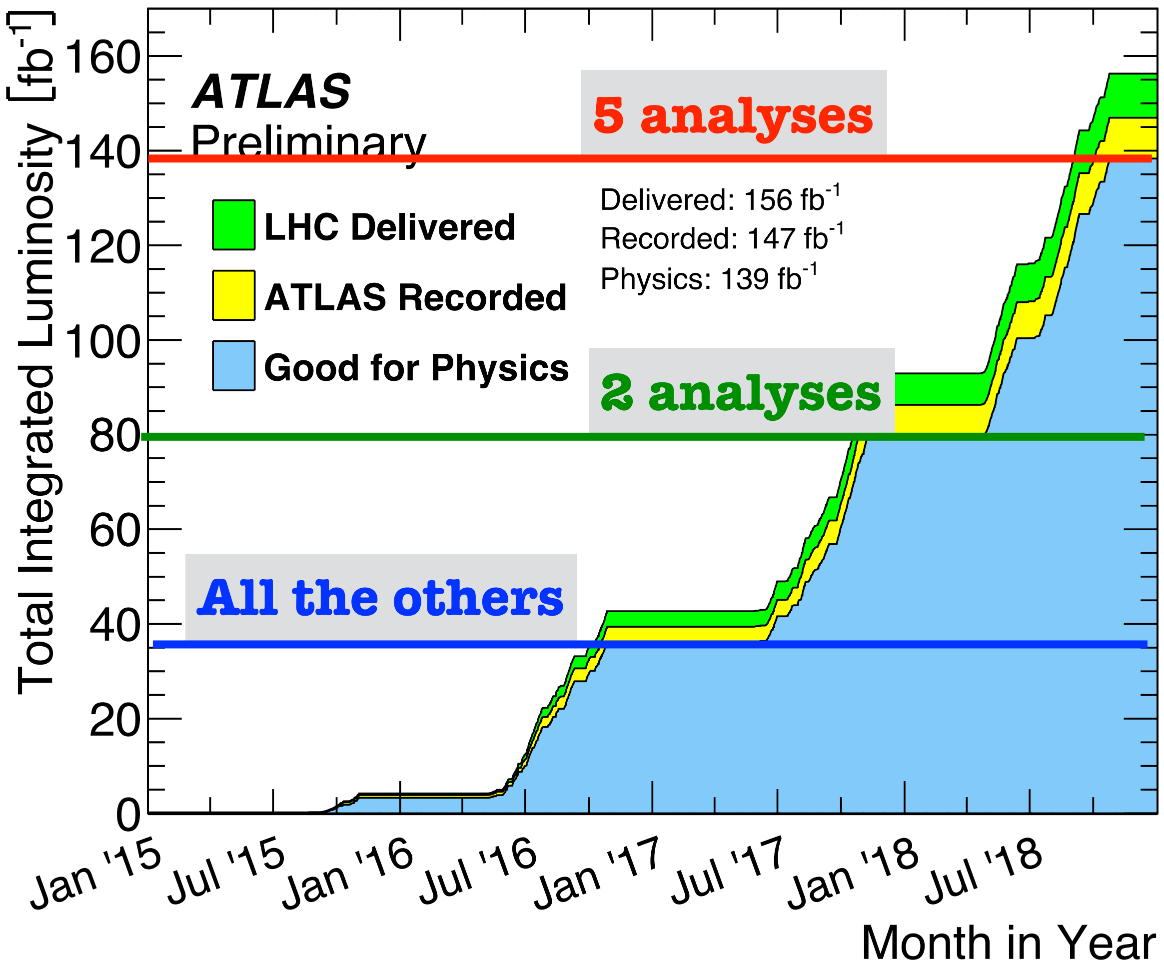




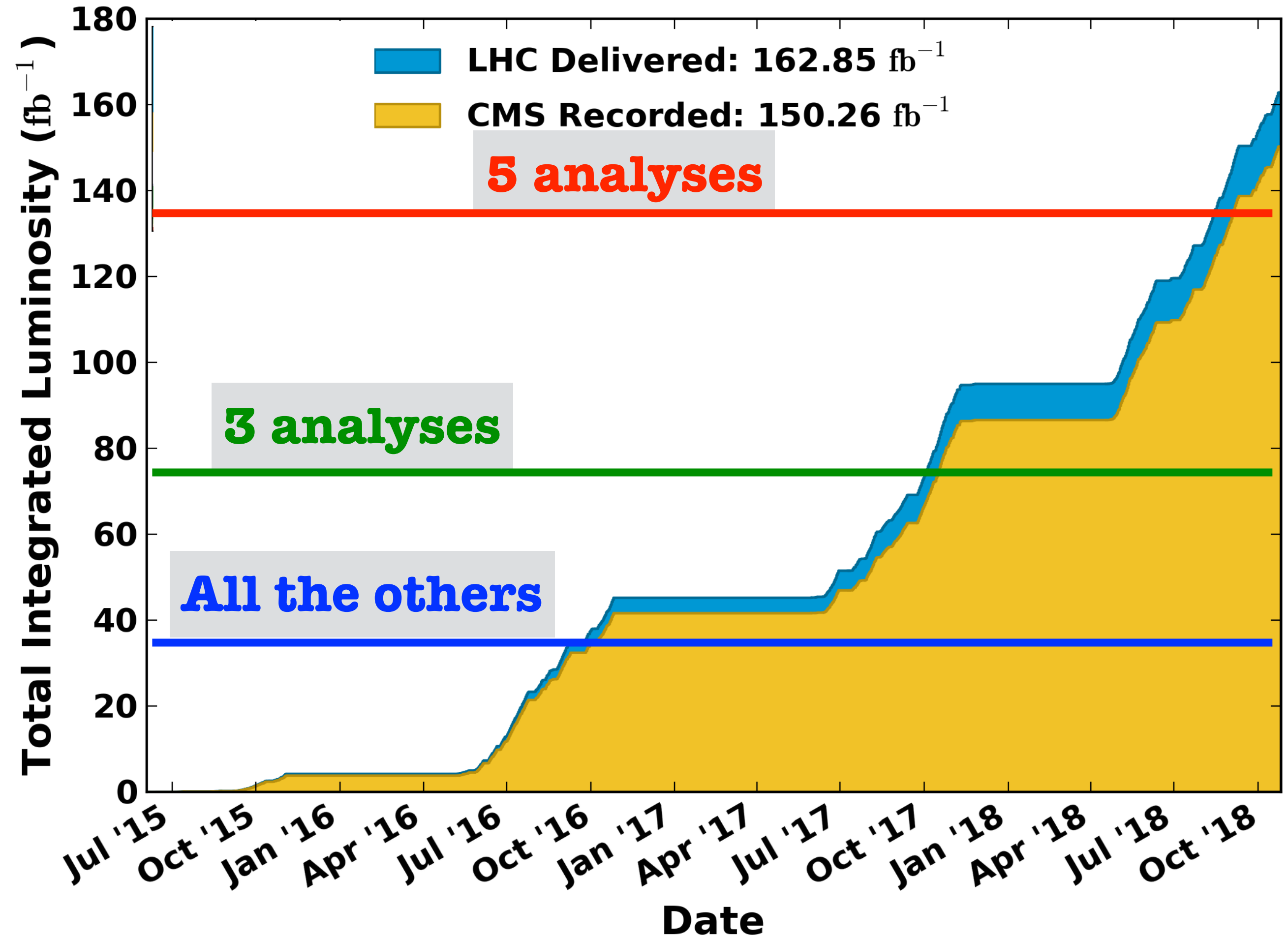
- Fantastic performance of the **LHC**, **ATLAS** and **CMS** during the Run 2 data taking

Proton-proton collision data @ 13 TeV,
good for physics, recorded by:

139 fb^{-1}



137 fb^{-1}



- In this talk, only **results** obtained analyzing the **full Run 2 dataset**

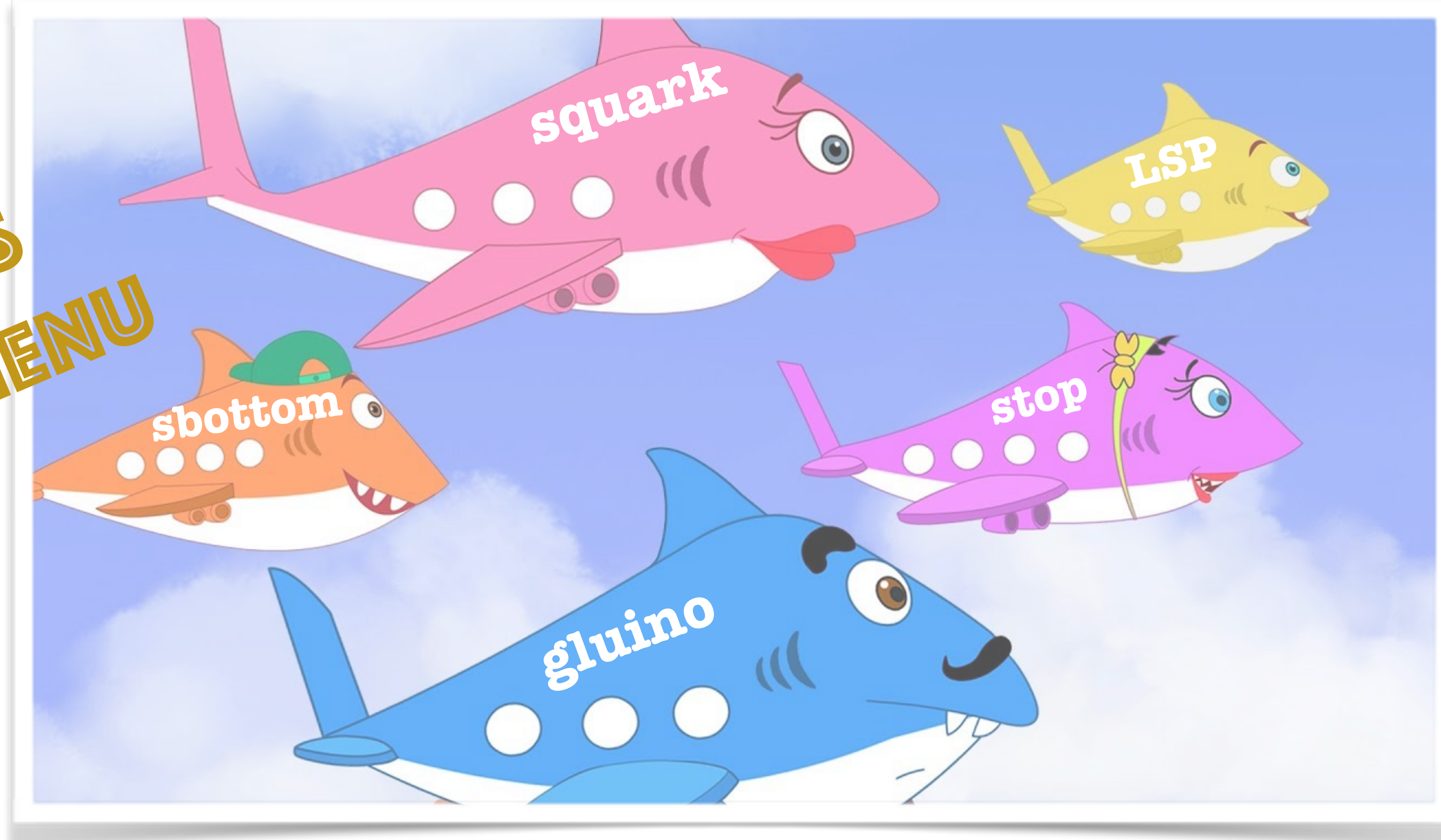
- **All the other SUSY results** are available:

ATLAS SUSY public results page: here && **CMS** SUSY public results page: here

Overview of recent SUSY searches*

* Only searches for squarks and gluinos

Today's menu



Full Run 2 dataset

ATLAS EXPERIMENT

Channel	Link
0L 2-6 jets	CONF-2019-040
≥ 2L SS	CONF-2019-015
Stop Z	CONF-2019-016
Stop 1L	CONF-2019-017
Sbottom	arXiv:1908.03122

CMS

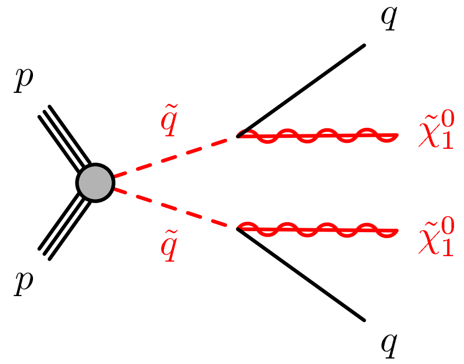
Channel	Link
0L with MT2	SUS-19-005
0L with MHT	SUS-19-006
1L with M_J	SUS-19-007
≥ 2L SS	SUS-19-008
Stop 1L	SUS-19-009

SEARCHES FOR SUPERSYMMETRIC PARTICLES

- Both experiments employ similar analysis strategy

Study a specific decay chain using **simplified model**:

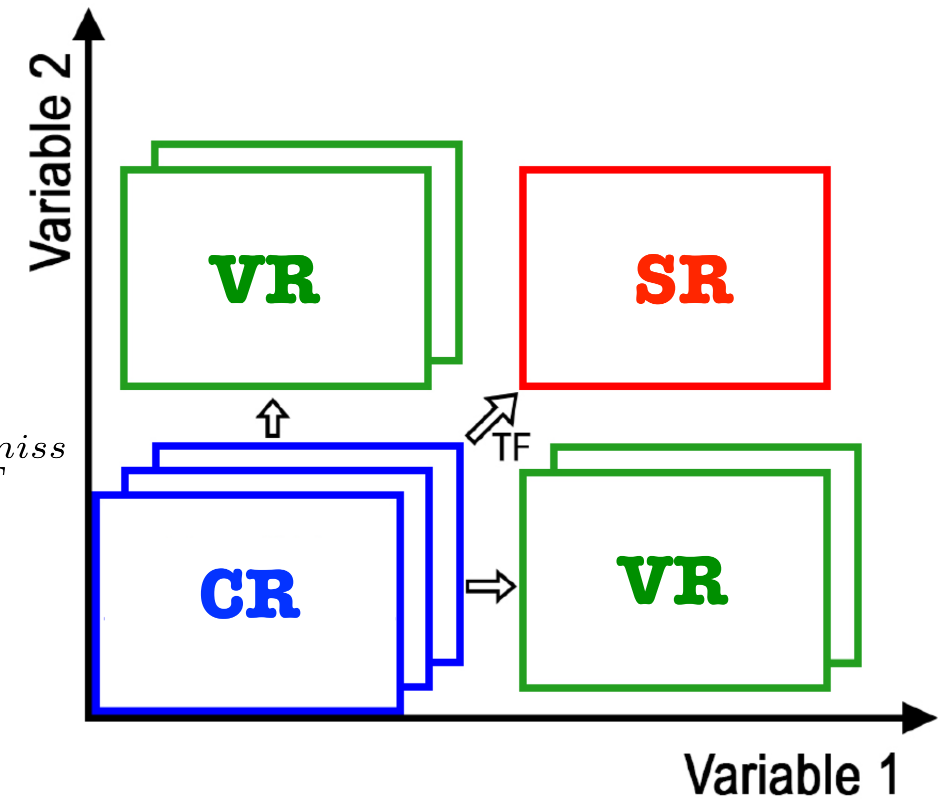
- Simple approach for SUSY searches with small number of particles
- Assumed branching ratio usually 100%
- Decays described by masses and cross-sections



- **Signal region (SR)** designed based on requirements on signal/background discriminating variables to target specific decay chains

Background estimation:

- MC normalized data in process-enhanced **control regions (CRs)** for dominant backgrounds
- Data-driven estimates for fake/non-prompt leptons, fake E_T^{miss}
- MC simulated data for additional backgrounds



- **Validation regions (VRs)** used to check the assumptions in the background estimate and the CR → SR extrapolation

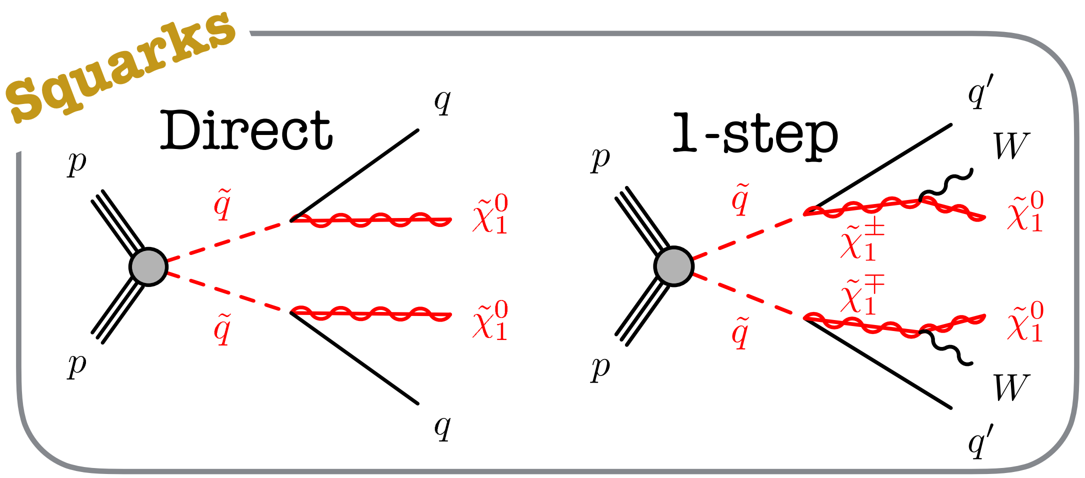
Unblinded SR, and:

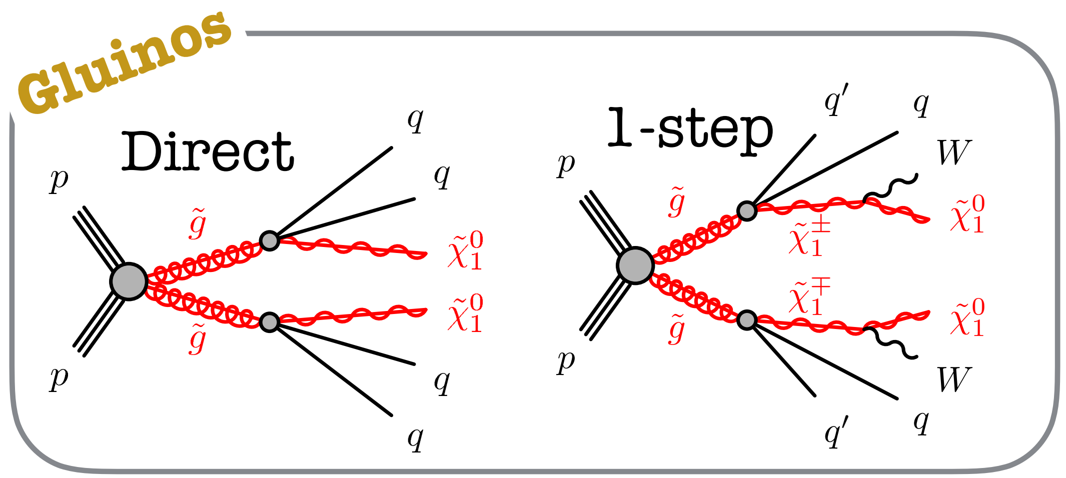
- celebrate in the case of excess
- if there is no the excess, set model limits and keep the dream alive!

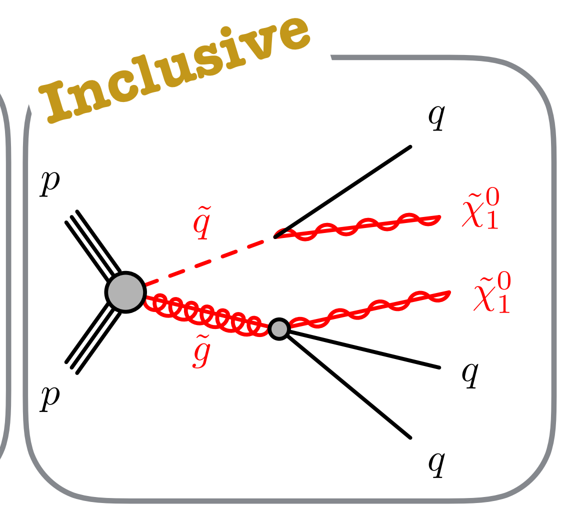
INCLUSIVE HADRONIC SEARCHES

CONF-2019-040

- Searches for squarks (1^{st} and 2^{nd} generations) and gluinos with jets
- Wide range of signal models:





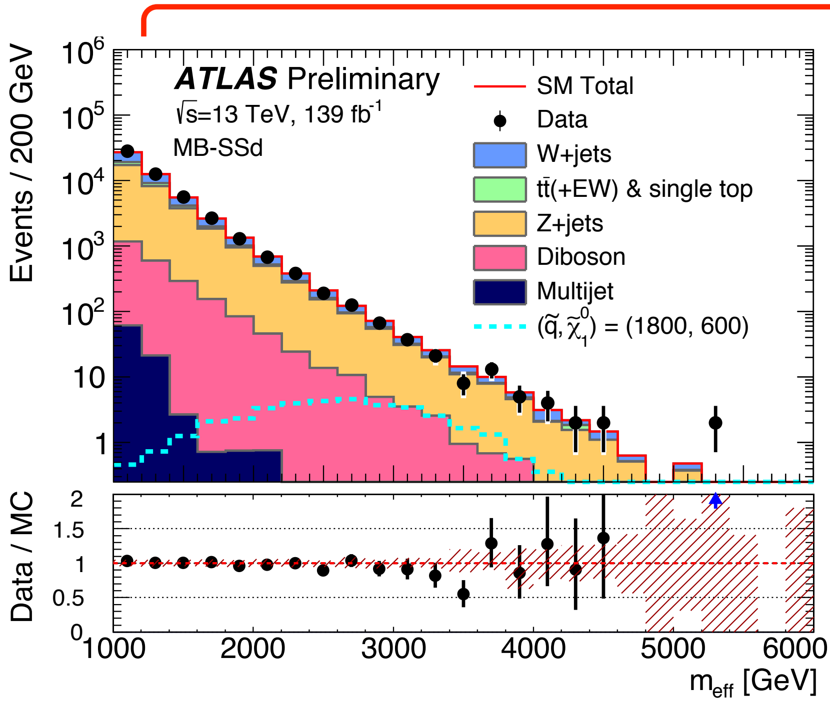


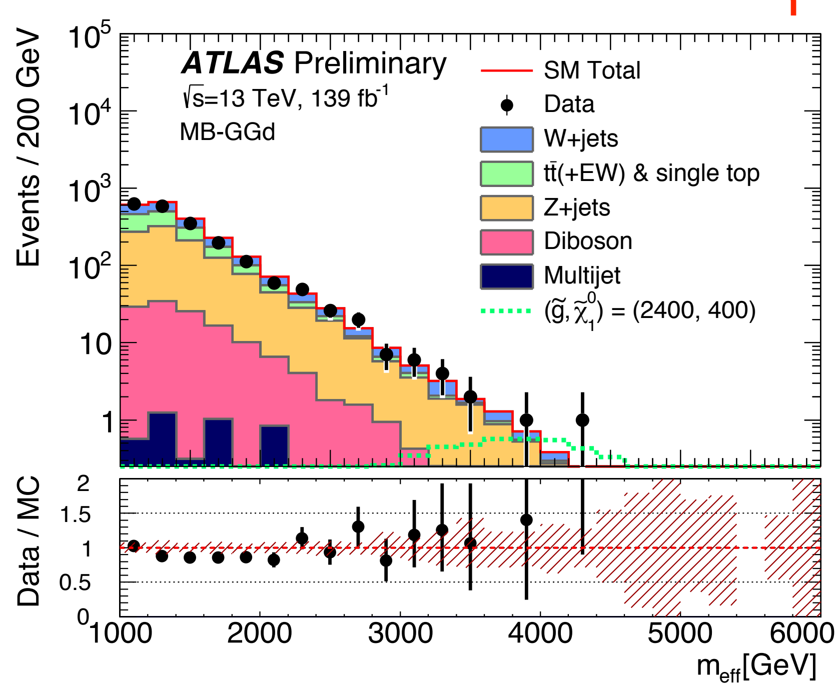
- **Final state** contains 0L, high jet multiplicity and large E_T^{miss}

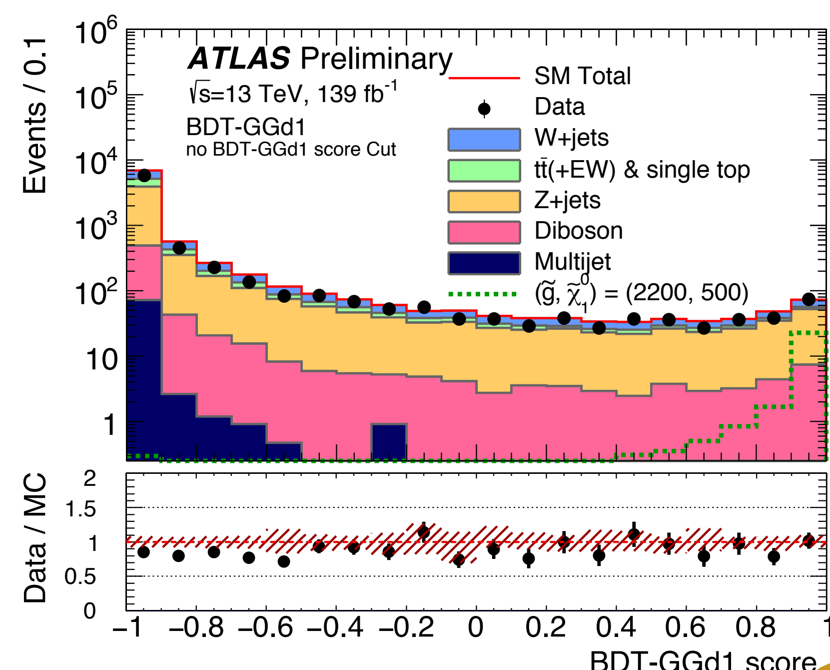
Two sets of **SRs** are defined using different jet multiplicities, E_T^{miss}, $\Delta\phi(j_i, p_T^{miss})_{min}$, m_{eff}

+

either specific range of kinematic variables or values of the BDT output variable





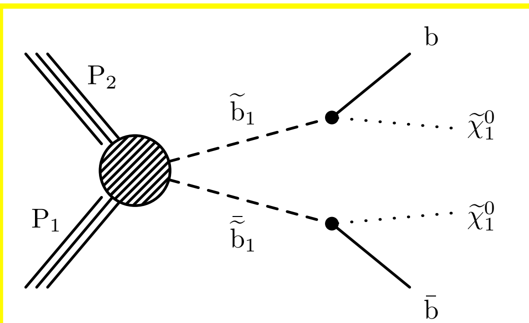


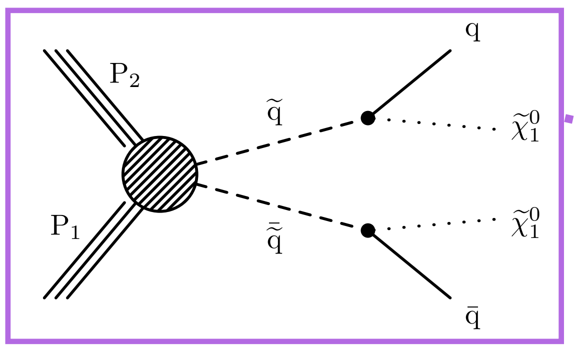
SUS-19-005

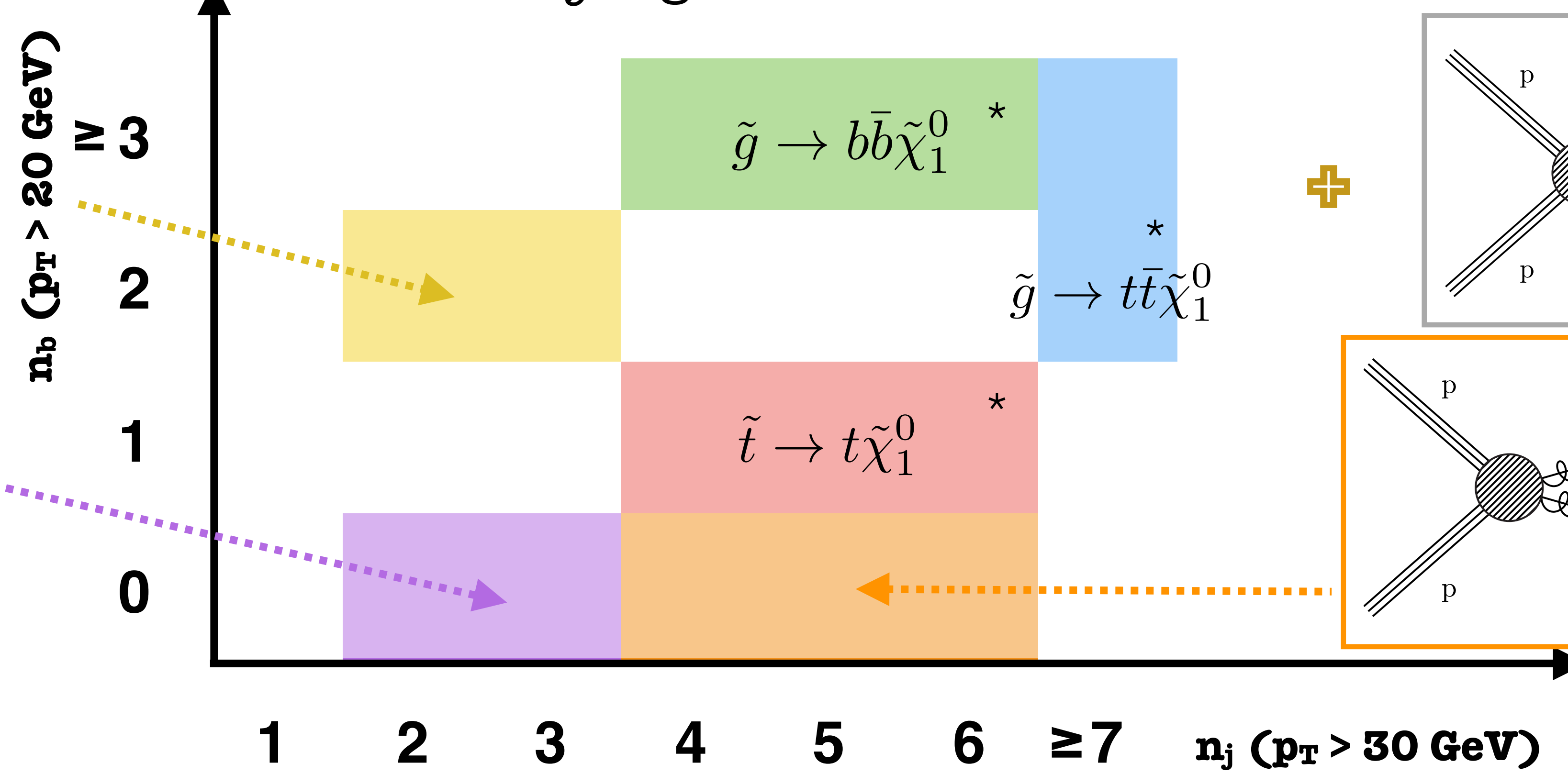
SUS-19-006

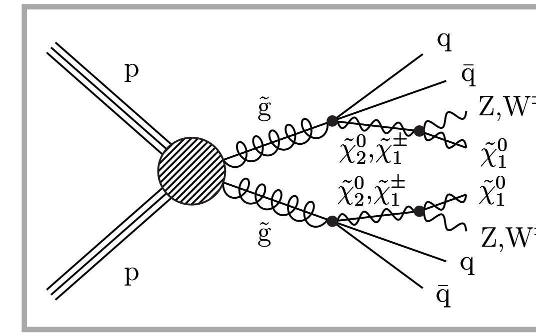
- Searches for squarks (1st, 2nd and 3rd generations) and gluinos with jets

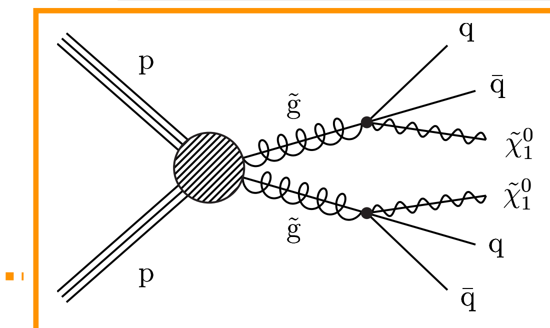
Many signal models:











*backup slides

- **Final state** contains 0L, high jet multiplicity and large E_T^{miss}

Two sets of **SRs** are defined using various discriminating variables such as:

n_j, n_b, $H_T = \sum_{jets} |\vec{p}_T|$

+

transverse momentum imbalance inferred through **M_{T2}**

$$M_{T2} = \min_{\vec{p}_T^{\,missX(1)} + \vec{p}_T^{\,missX(2)} = \vec{p}_T^{\,miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)}\right)\right]$$

or

variable **MHT**

$$MHT = |-\sum_{jets} \vec{p}_T|$$

INCLUSIVE HADRONIC SEARCHES

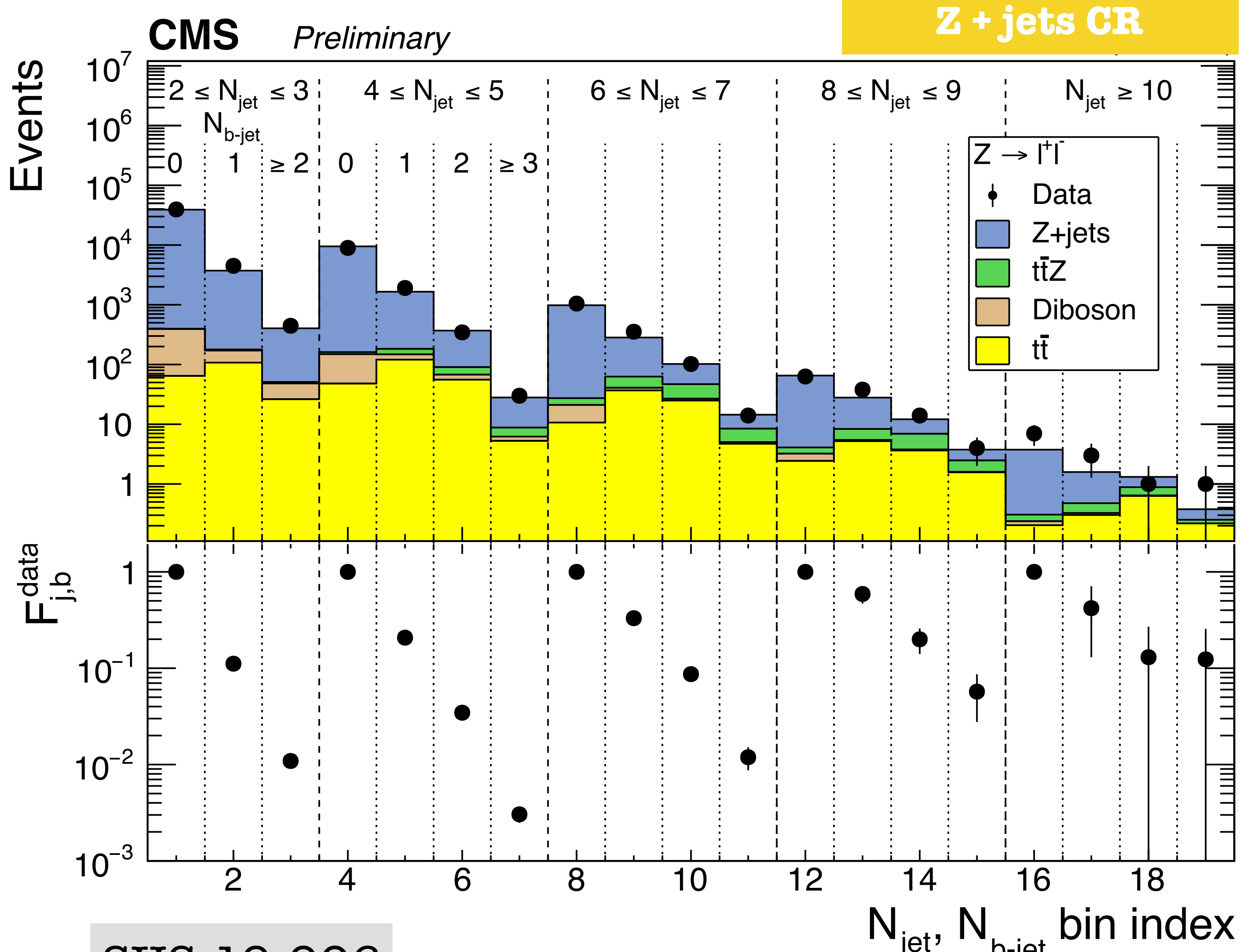
Dominant backgrounds estimated in **CRs** defined for each **SR**:

- **$t\bar{t}$**
- **W+jets**

} CRs with an isolated lepton

- **Z+jets** → CR with an isolated photon or 2 leptons

Z + jets CR



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$t\bar{t}$ CR

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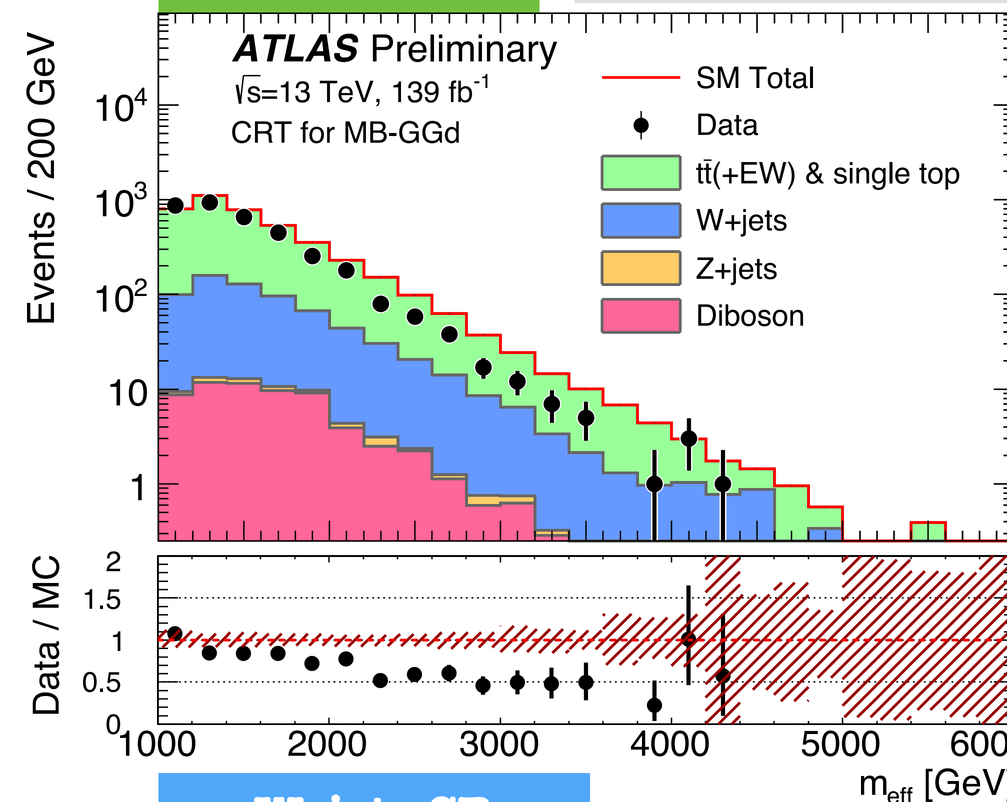
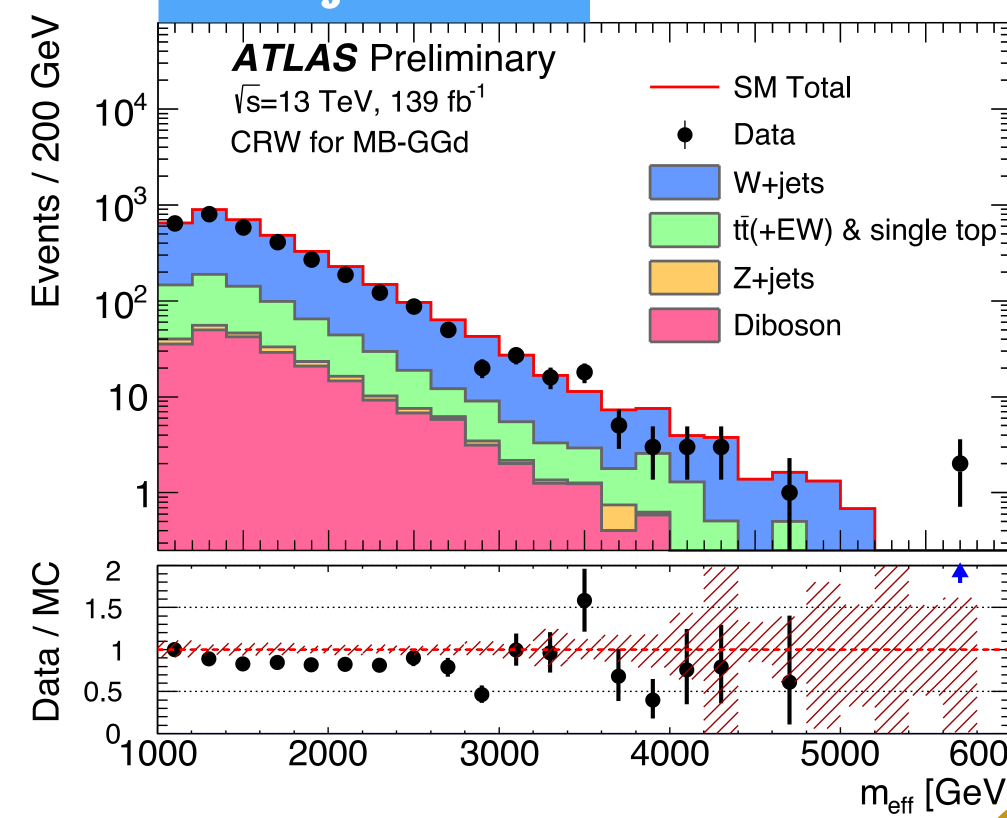


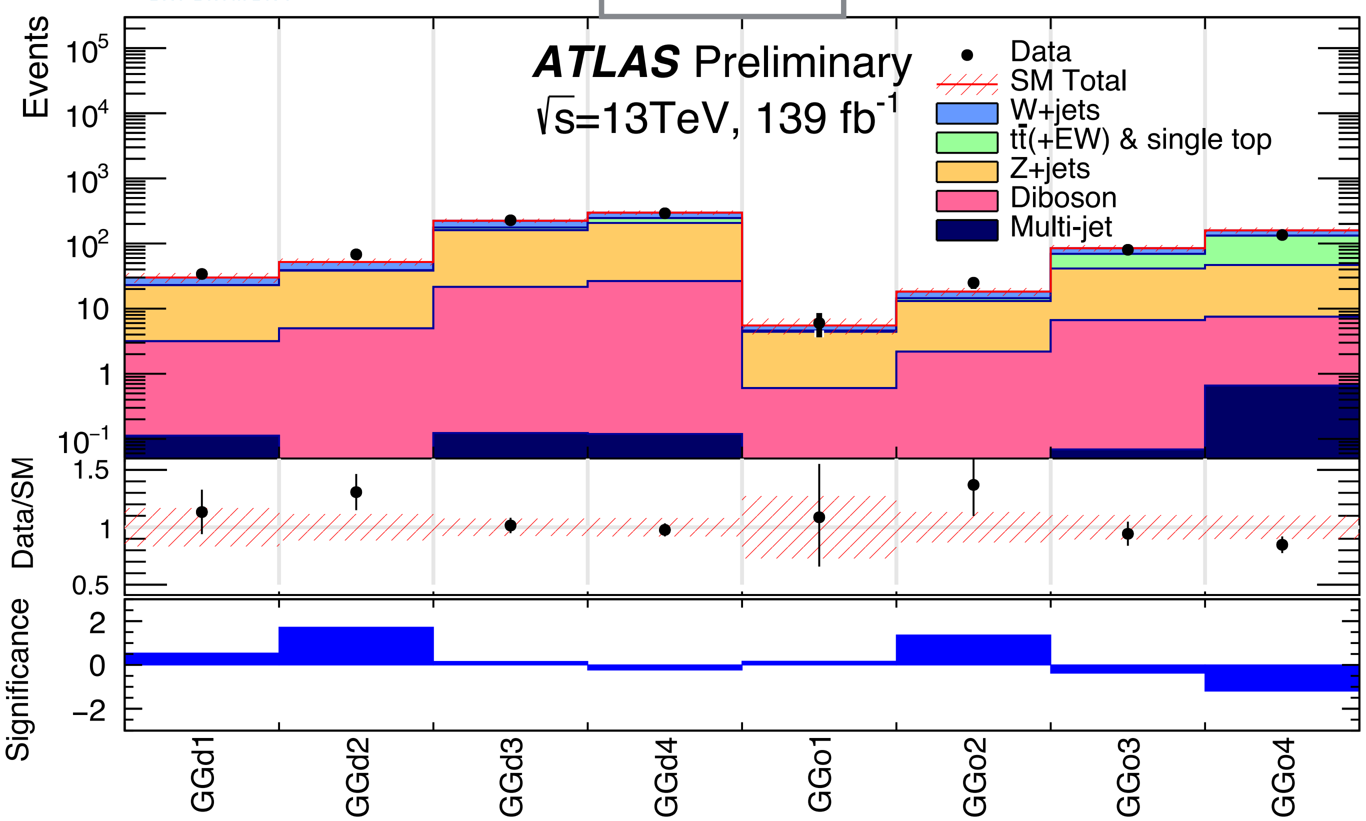
W+jets CR



INCLUSIVE HADRONIC SEARCHES

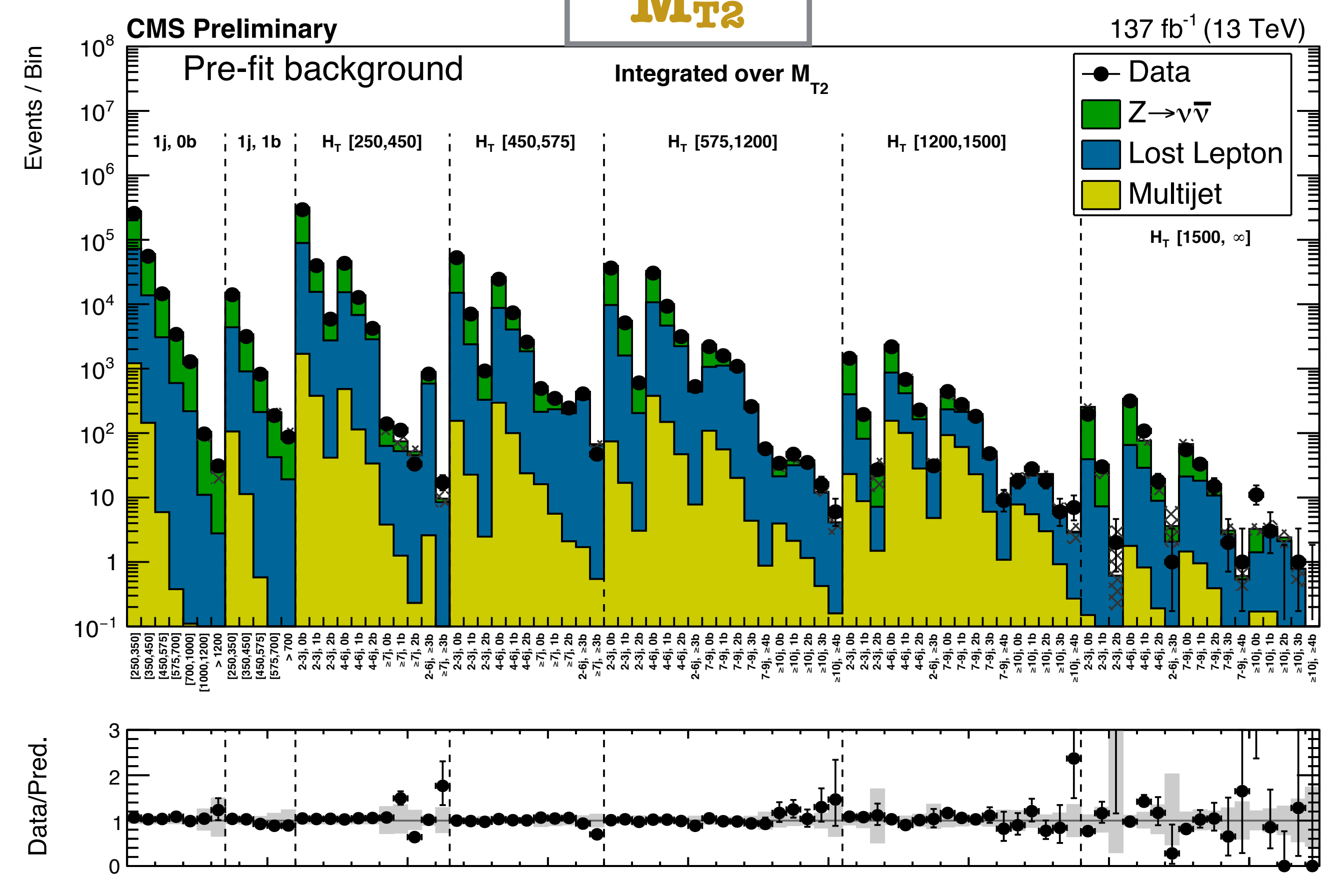
Both experiments found **good agreement** between data and the SM expectation in all the **SRs**

BDT



CONF-2019-040

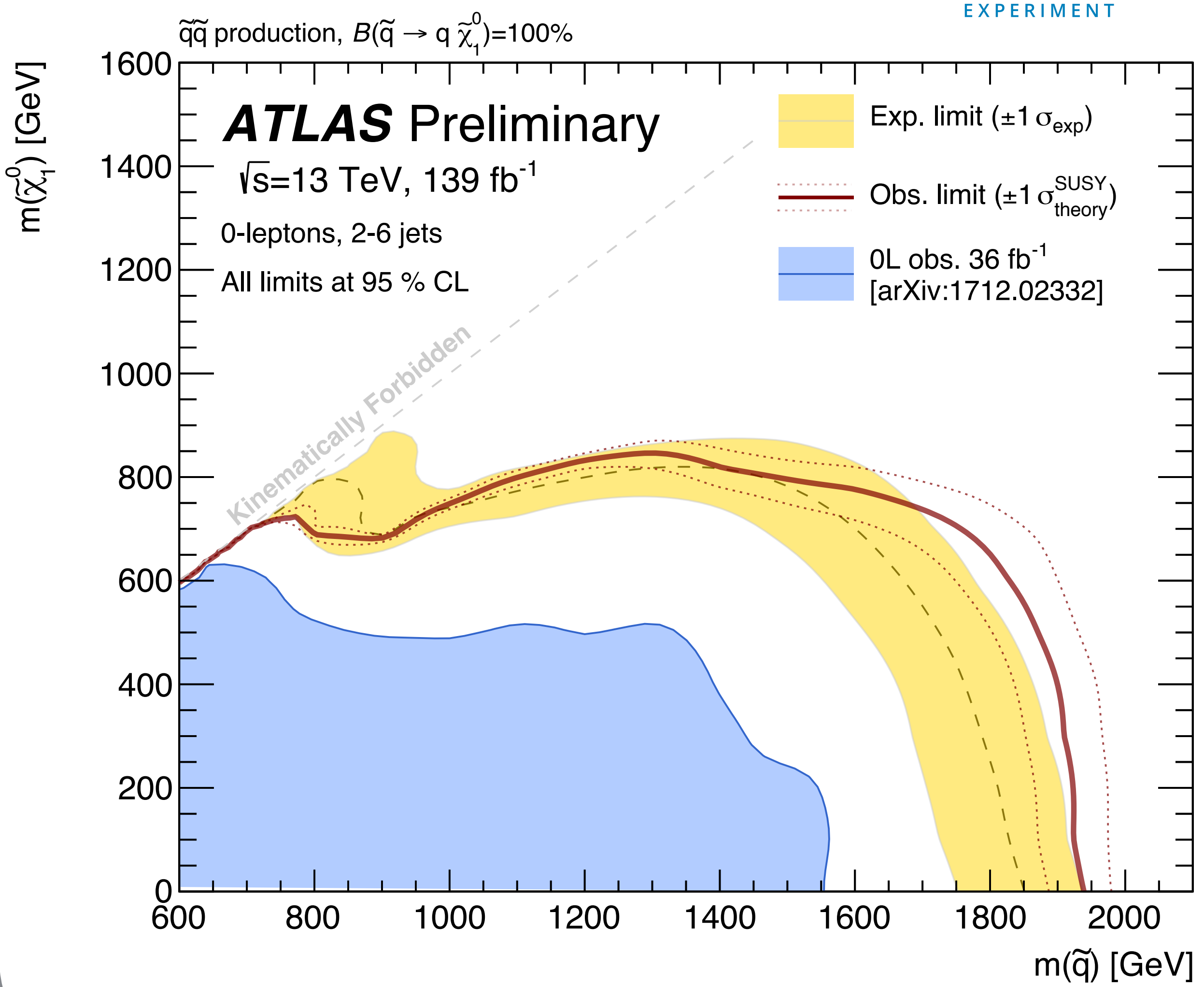
M_{T2}



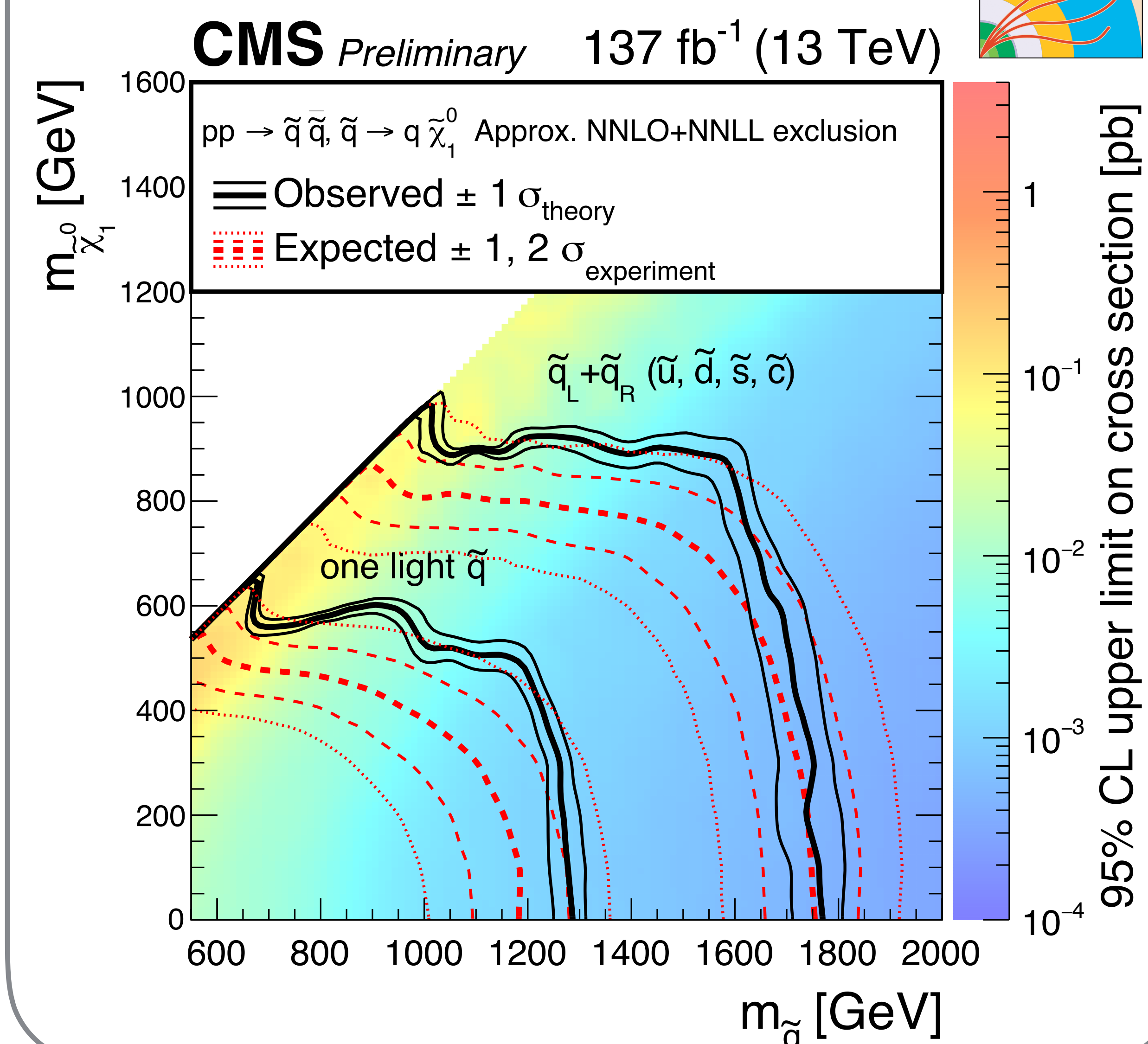
SUS-19-005

SQUARK-PAIR PRODUCTION

CONF-2019-040



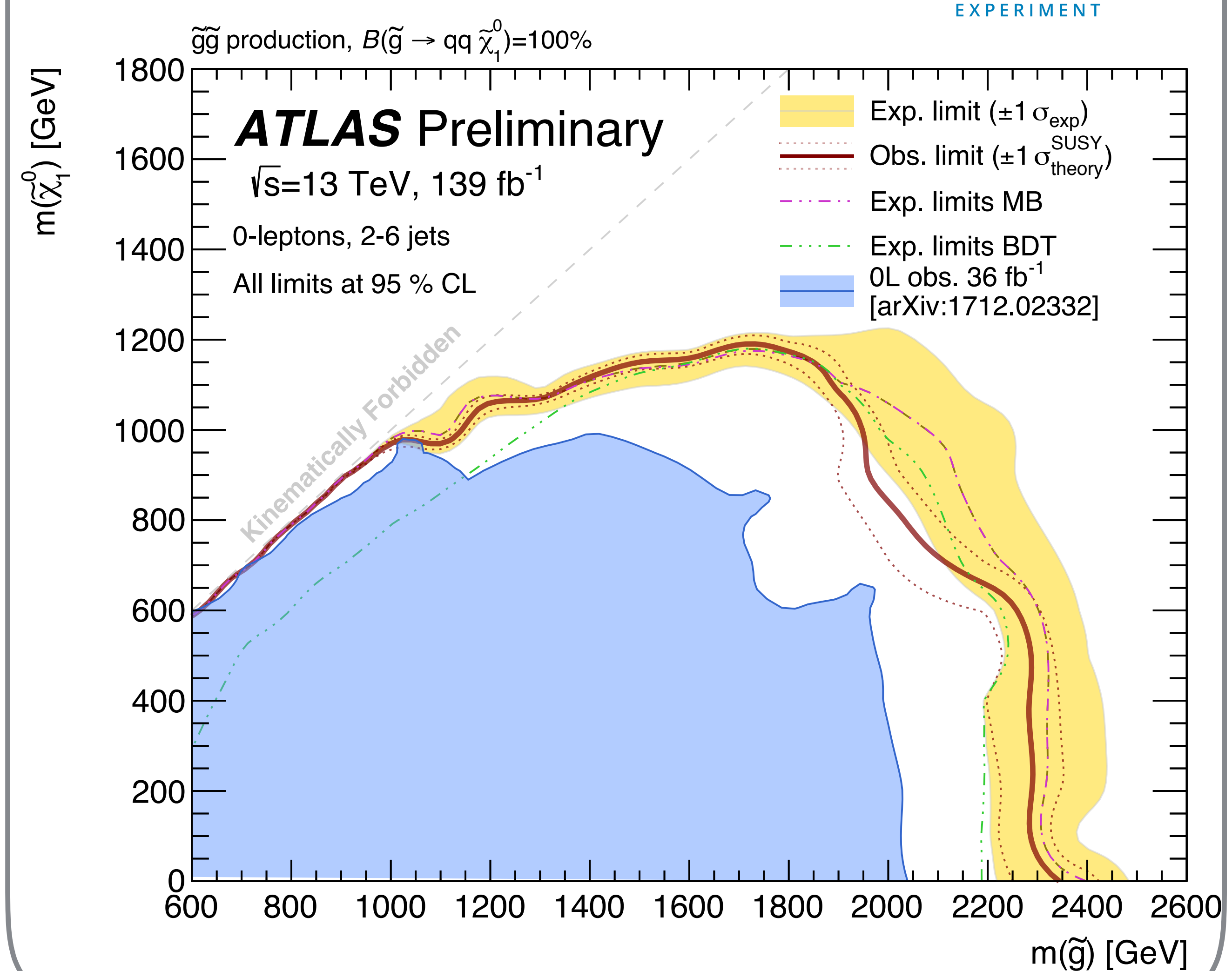
SUS-19-005



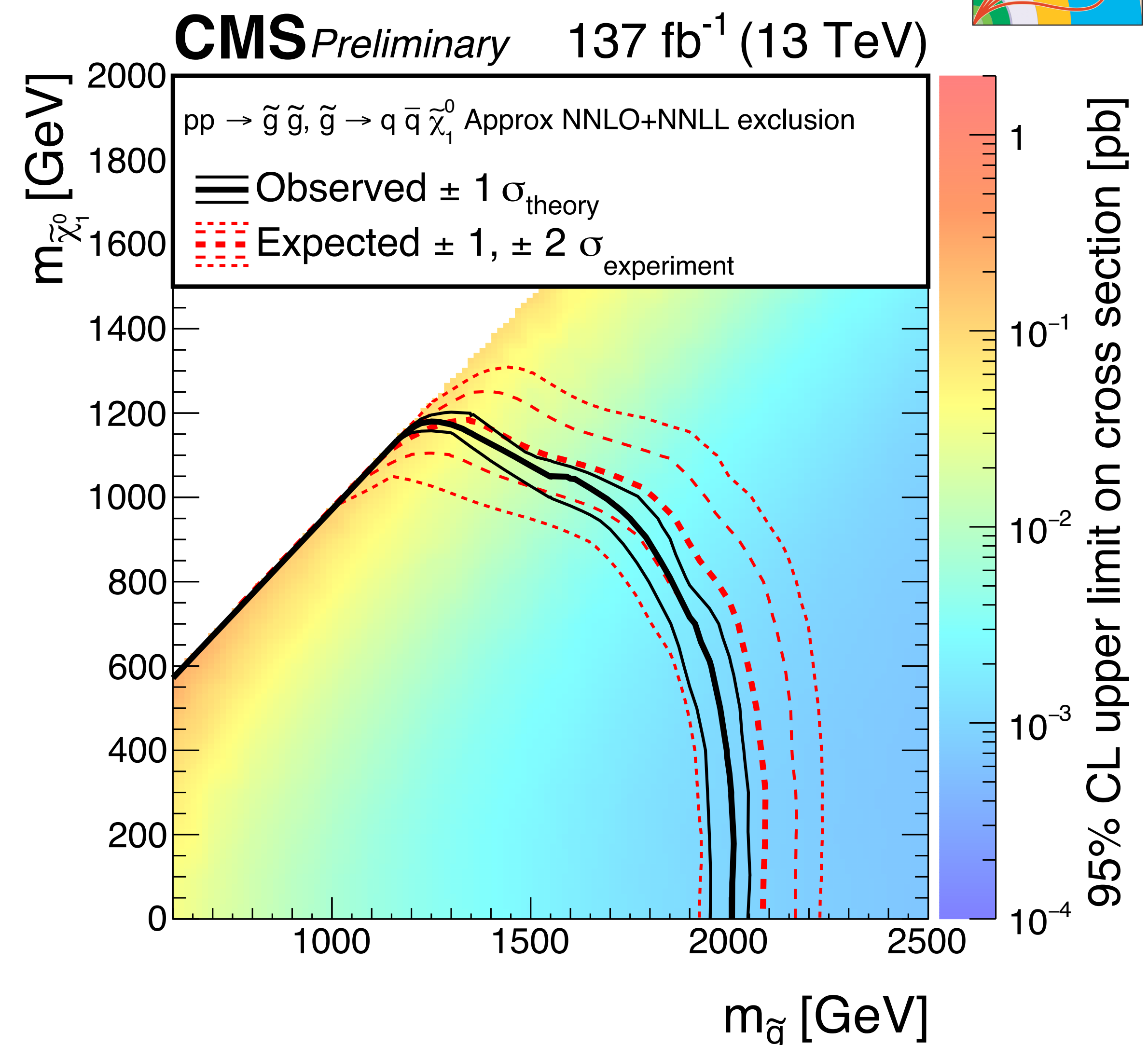
Squark masses up to **1.94 TeV** (ATLAS) and **1.77 TeV** (CMS) excluded for low LSP masses

GLUINO-PAIR PRODUCTION

CONF-2019-040



SUS-19-006



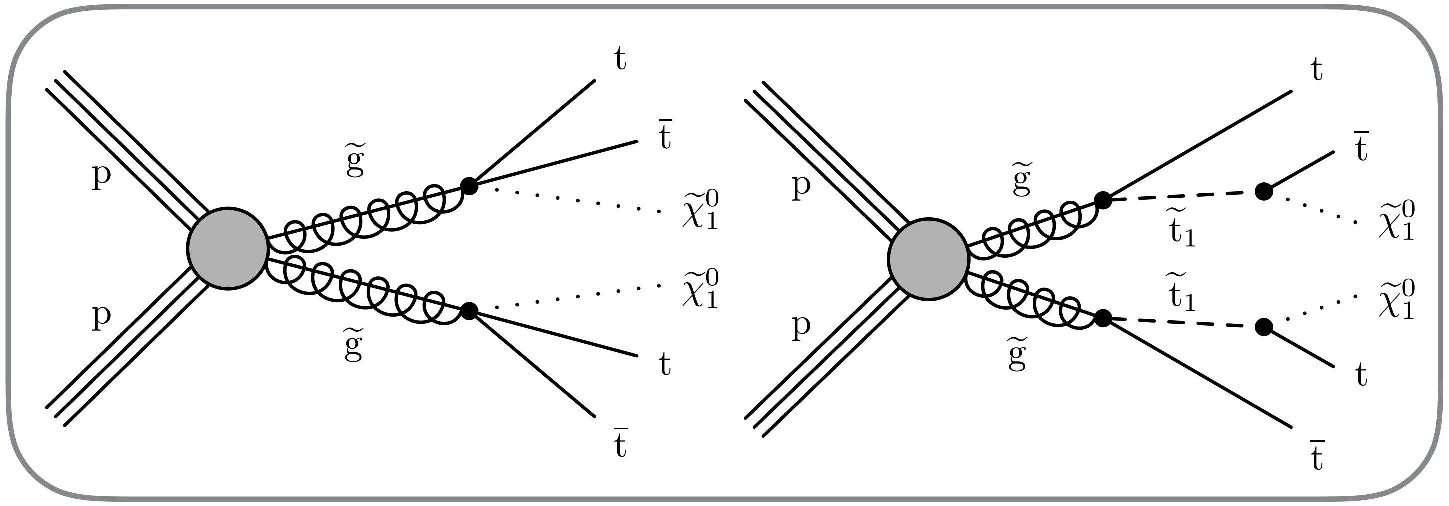
Mass limits have reached ~ **2.3 TeV** (ATLAS) and ~ **2 TeV** (CMS) for low LSP masses

+ the interpretations of the other signal models:
1-step squark-pair/gluino-pair decays, inclusive … see backup slides

SEARCHES FOR GLUINOS WITH A LEPTON

- Searches for gluinos in events with exactly one lepton and jets

SUS-19-007



Final state contains:

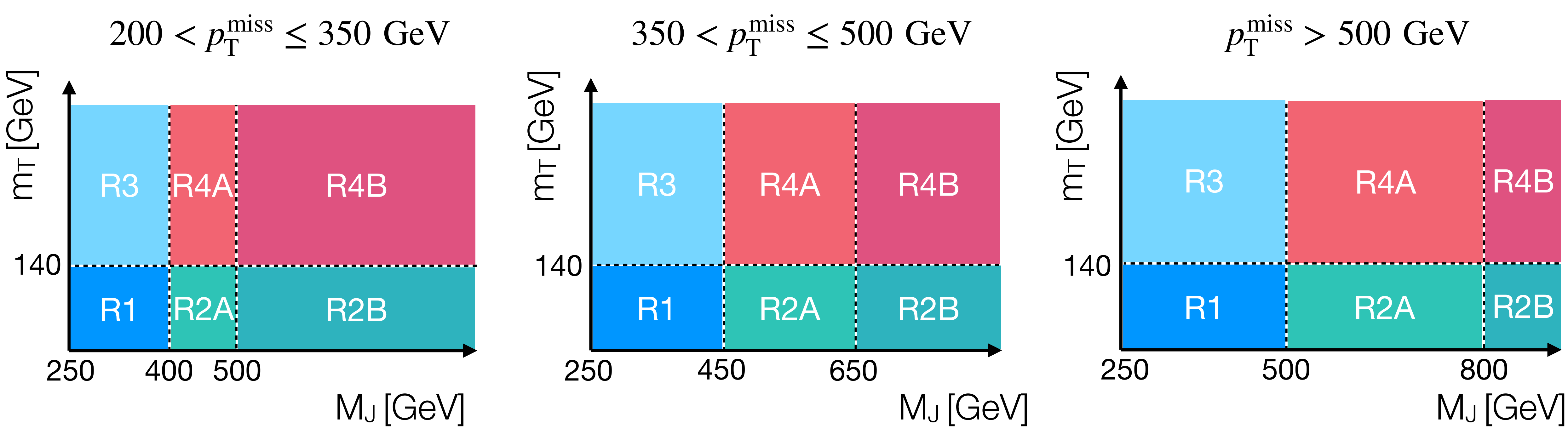
- 1 lepton,
- jets including at least one b-jet, and
- large E_T^{miss}

SRs are defined using kinematic variables such as:

$$m_T = \sqrt{2p_T^l p_T^{miss}[1 - cos(\Delta\phi_{l,p_T^{miss}})]} \text{ and } M_J = \sum_{J_i = large-R jets} m(J_i)$$

+

additional bins in p_T^{miss}, n_j and n_b to improve sensitivity

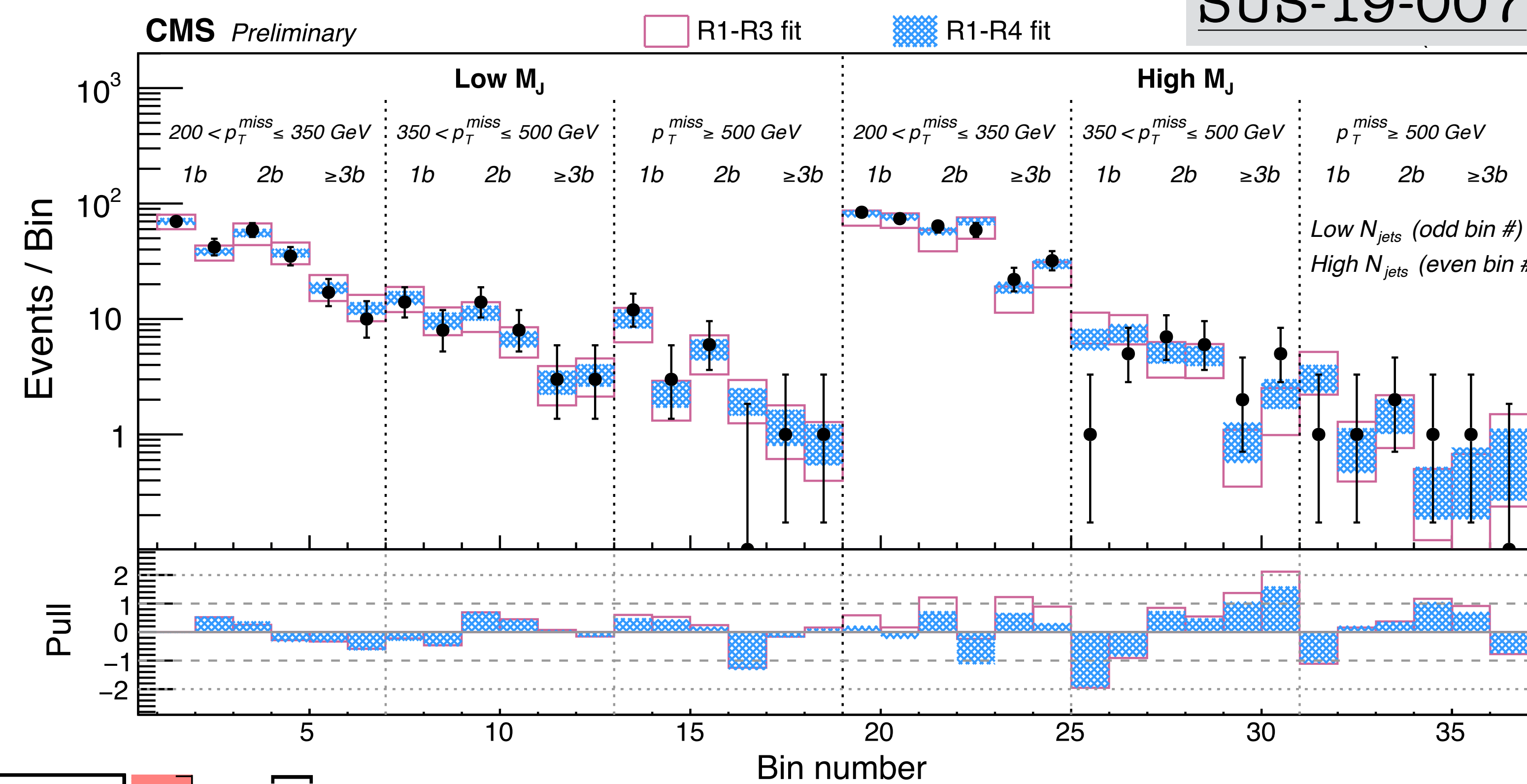


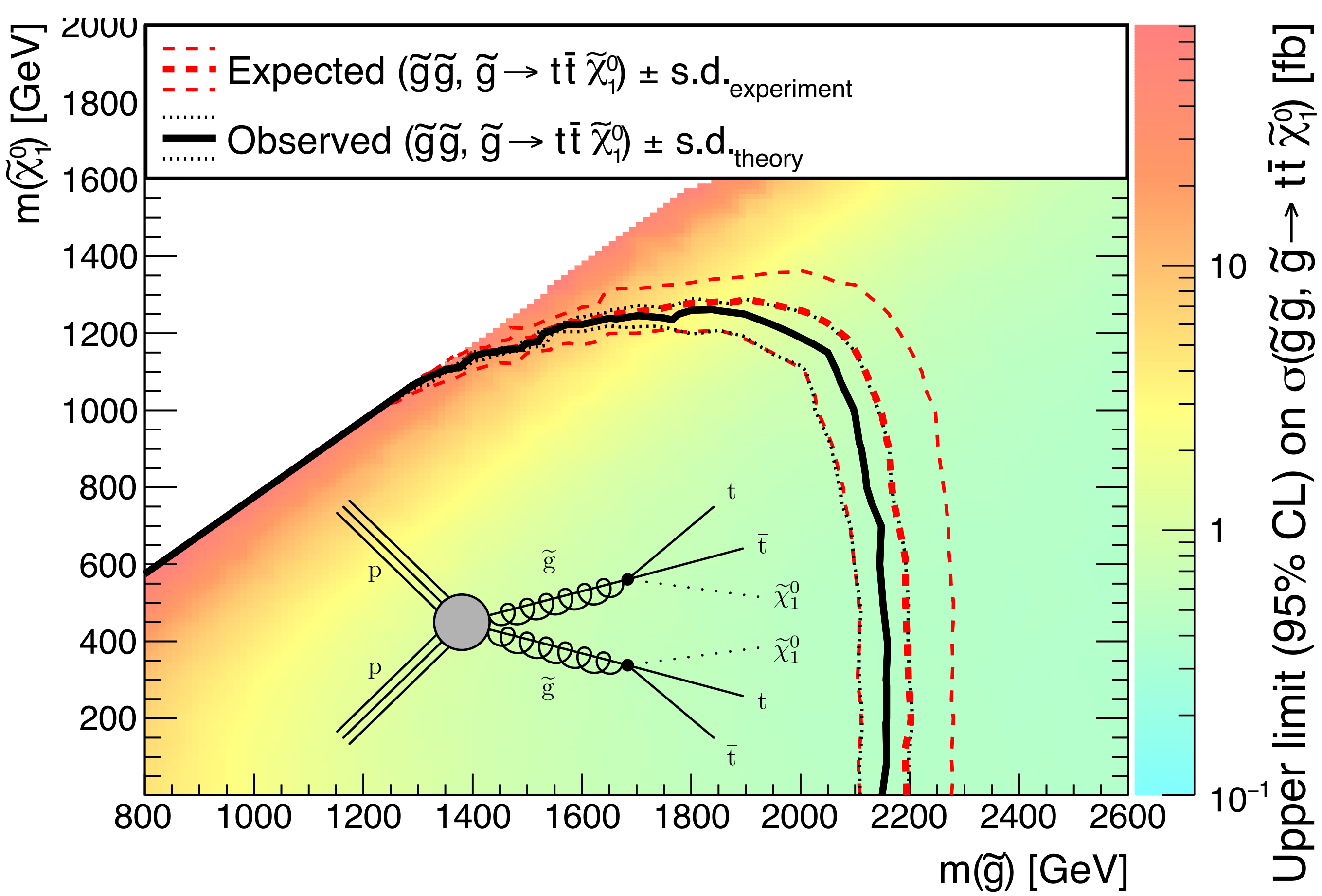
SEARCHES FOR GLUINOS WITH A LEPTON

SUS-19-007

Dominant background arrives from:

- leptonic decays of $t\bar{t}$
- estimated with ABCD in M_J and m_T plane
- extra bins in p_T^{miss}, n_j and n_b used





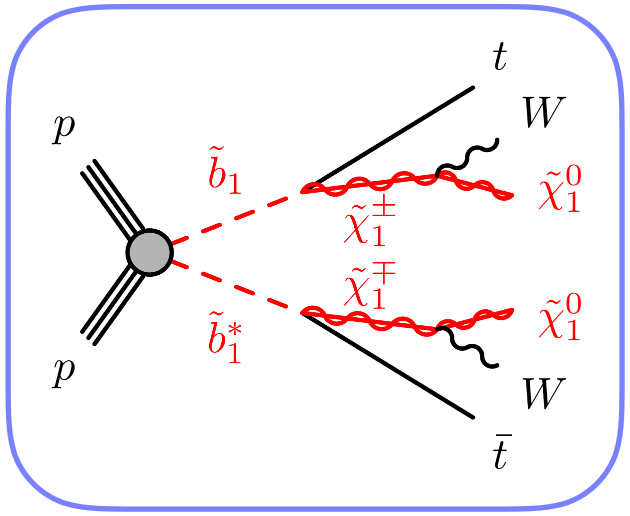
- **No significant excess** in data over the expected background contributions from the SM is observed

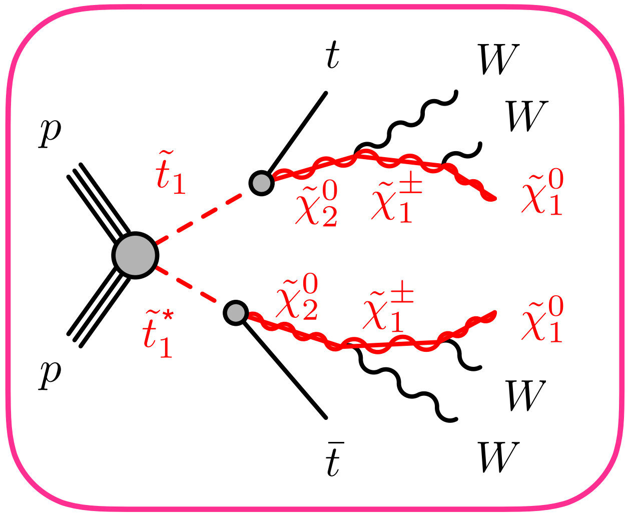
- Gluino masses up to **2.15 TeV** are excluded for low LSP masses

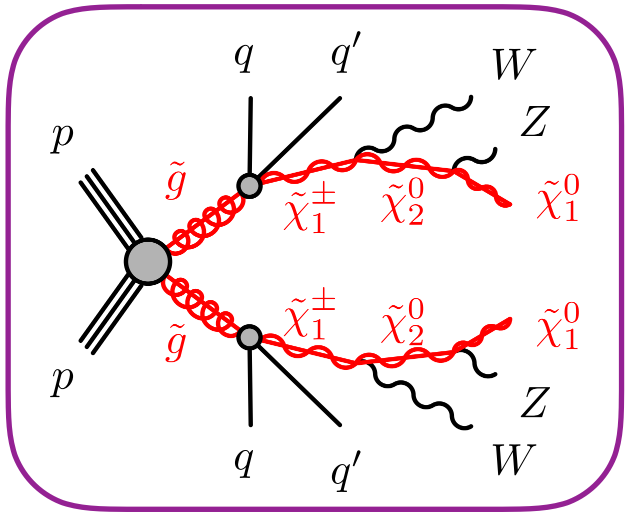
SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

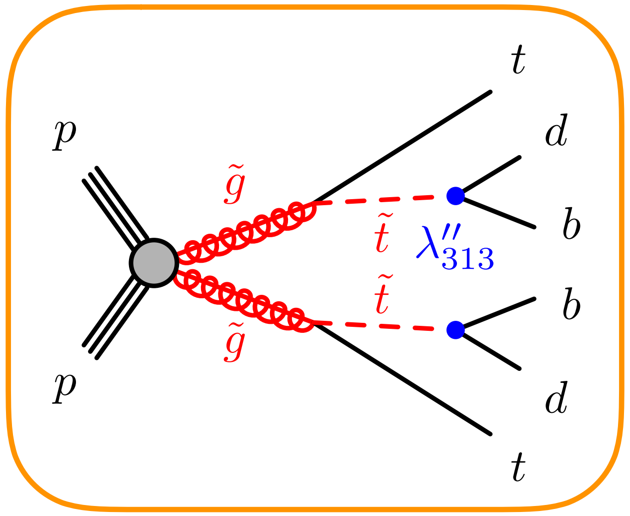
ATLAS EXPERIMENT

- Searches for squarks and gluinos in events with jets and either 2 same sign leptons or at least 3 leptons — CONF-2019-015
- Wide range of signal models (including R-parity violating scenarios):









- **Final state** contains 2 same sign leptons (or at least 3), jets and large E_T^{miss} (not for R-parity violating scenarios)

Five **SRs** are defined using various discriminating variables such as:

n_l, n_b, n_j, E_T^{miss}, m_{eff}, m_{eff}/E_T^{miss}

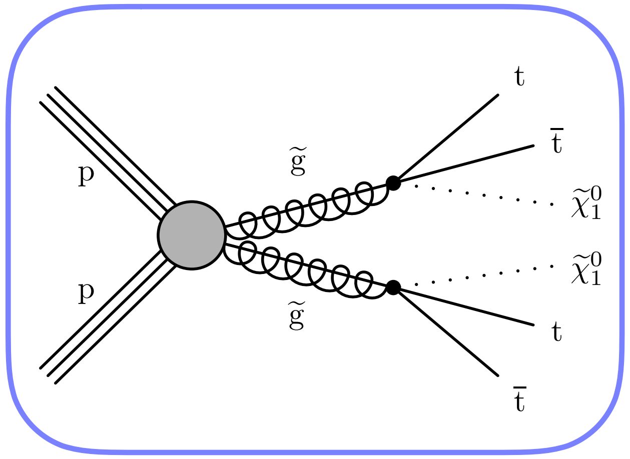
SR	n_ℓ	n_b	n_j	E_T^{miss} [GeV]	m_{eff} [GeV]	E_T^{miss}/m_{eff}
Rpv2L	$\geq 2\ (\ell^\pm\ell^\pm)$	≥ 0	$\geq 6\ (p_T > 40\,\text{GeV})$	–	> 2600	–
Rpc2L0b	$\geq 2\ (\ell^\pm\ell^\pm)$	$= 0$	$\geq 6\ (p_T > 40\,\text{GeV})$	> 200	> 1000	> 0.2
Rpc2L1b	$\geq 2\ (\ell^\pm\ell^\pm)$	≥ 1	$\geq 6\ (p_T > 40\,\text{GeV})$	–	–	> 0.25
Rpc2L2b	$\geq 2\ (\ell^\pm\ell^\pm)$	≥ 2	$\geq 6\ (p_T > 25\,\text{GeV})$	> 300	> 1400	> 0.14
Rpc3LSS1b	$\geq 3\ (\ell^\pm\ell^\pm\ell^\pm)$	≥ 1	no cut but veto $81\,\text{GeV} < m_{e^\pm e^\pm} < 101\,\text{GeV}$			> 0.14

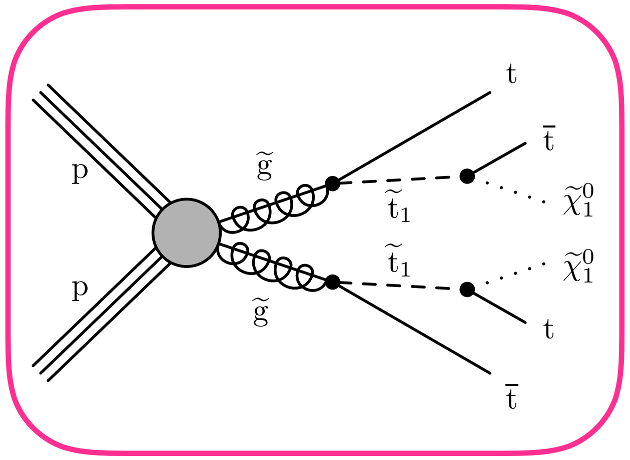
SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

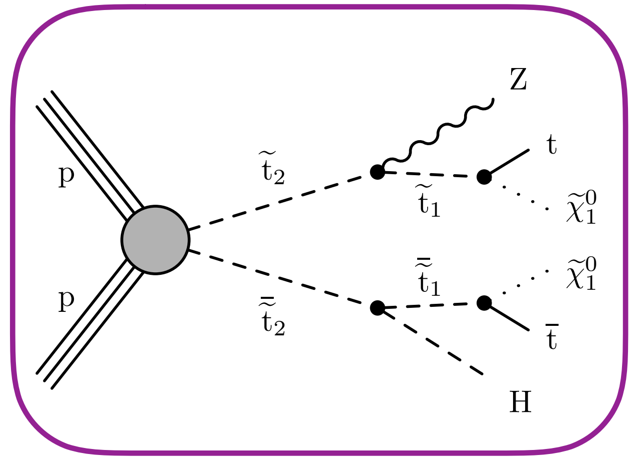
- Searches for squarks and gluinos in events with jets and either 2 same sign leptons or at least 3 leptons

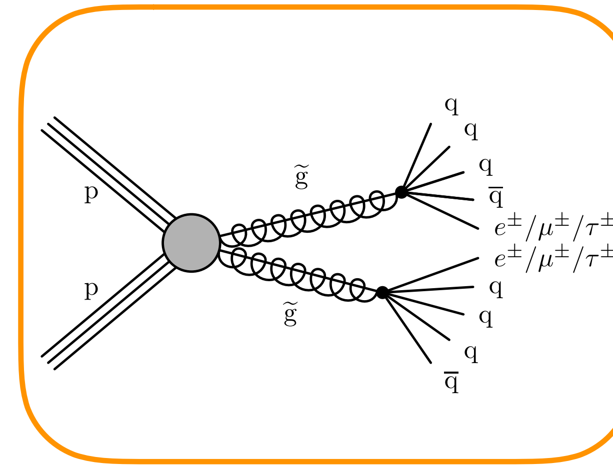
SUS-19-008

- Various signal models (including R-parity violating scenarios):









✚ many others. See backup slides!

- **Final state** contains 2 same sign leptons (or at least 3), jets and large E_T^{miss} (not for R-parity violating scenarios)

Five sets of **SRs** are defined using different discriminating variables such as:
n_l, $p_T(l)$, n_j, n_b, E_T^{miss} and H_T

1. SSHH (high-high) - exactly 2L with $p_T > 25$ GeV
2. SSHL (high-low) - exactly 2L, one with $p_T > 25$ GeV and one with $p_T < 25$ GeV
3. SSLL (low-low) - exactly 2L with $p_T < 25$ GeV
4. LM (low E_T^{miss}) - exactly 2L with $p_T > 25$ GeV and $E_T^{miss} < 50$ GeV
5. ML (multi-leptons) - ≥3L, at least one with $p_T > 25$ GeV

sensitive to particular topologies

SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

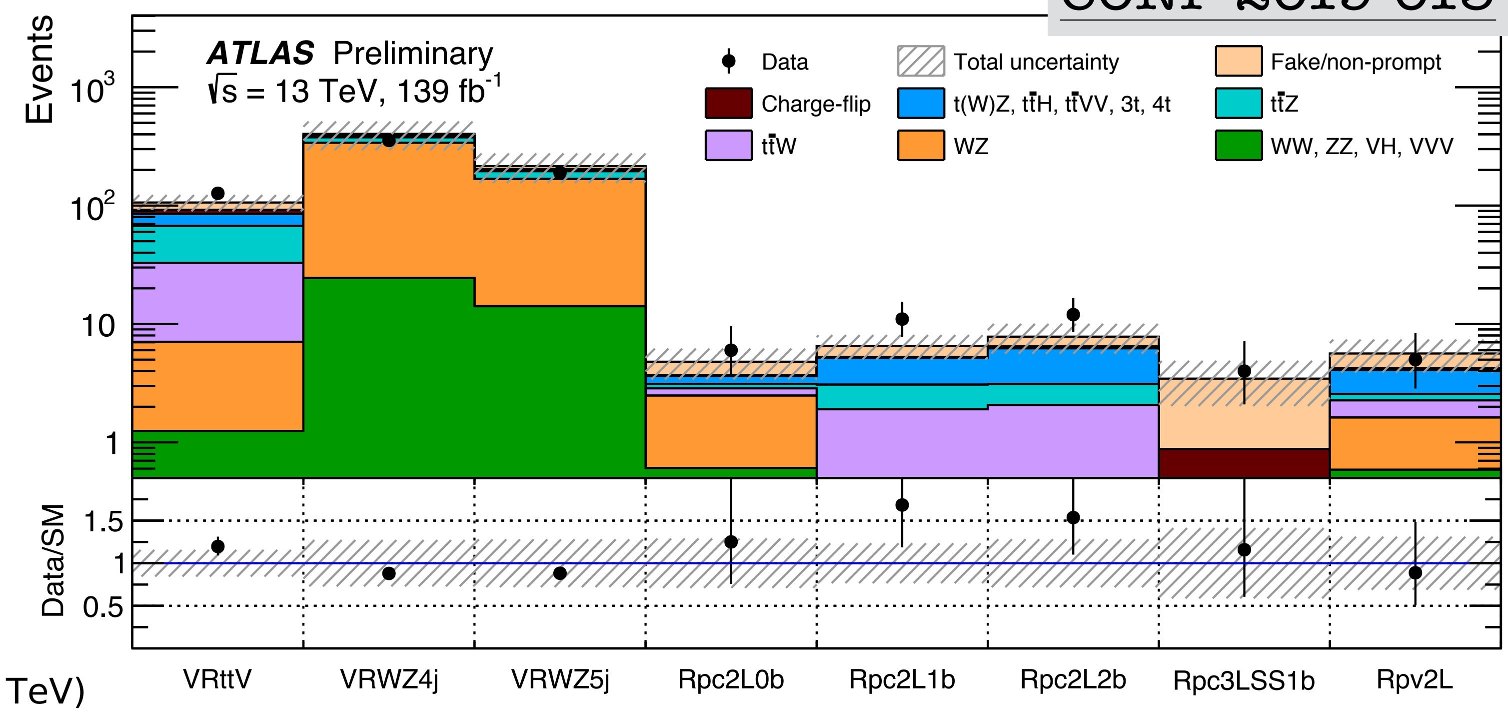
Dominant backgrounds:

- prompt $\ell^{\pm}\ell^{\pm}$ from WZ+jets, WW, ZZ, $t\bar{t}$+W/Z/h, X+γ

Additional backgrounds:

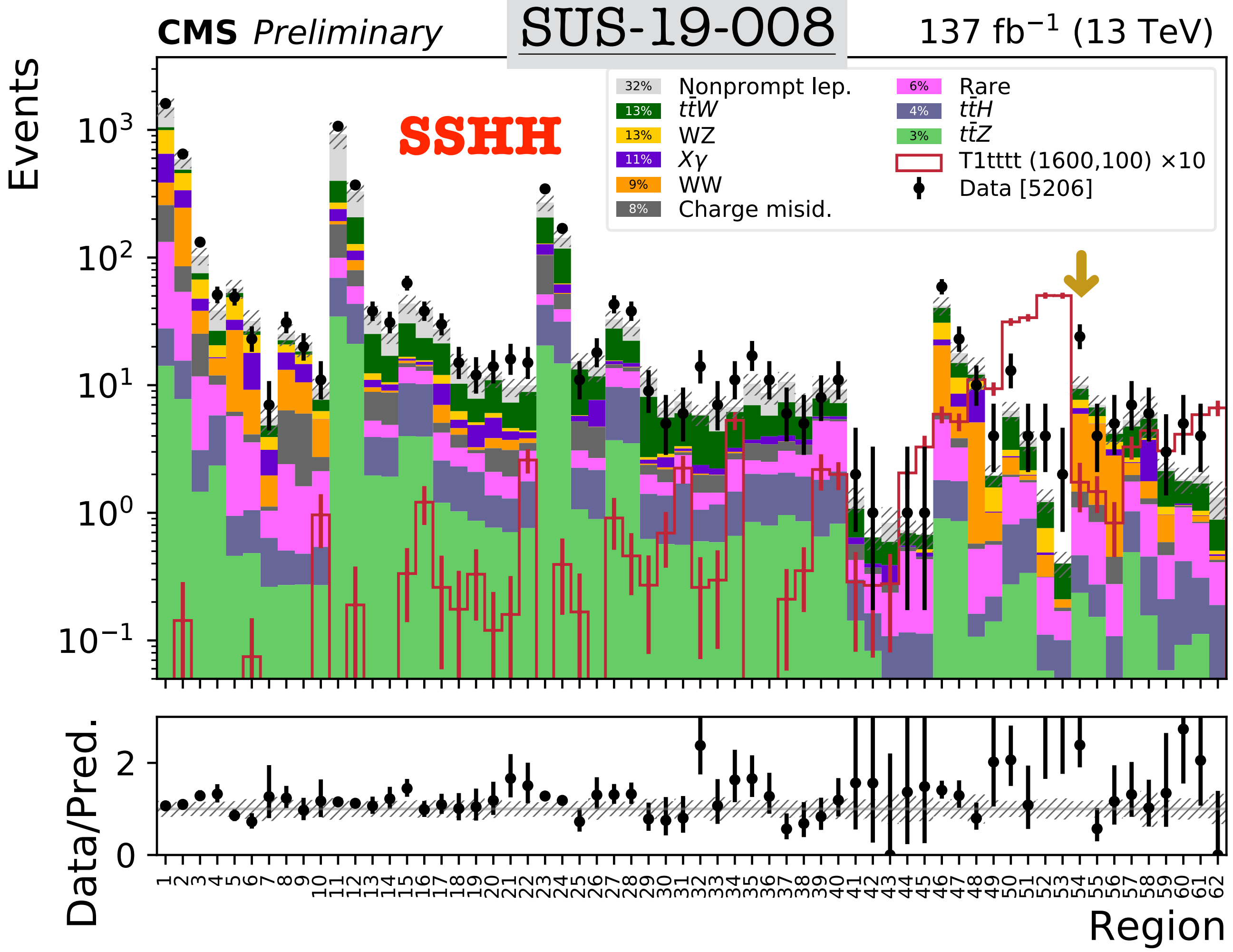
- Charge-flip electrons
- Fake/non-prompt leptons

CONF-2019-015



VRs SRs

SUS-19-008

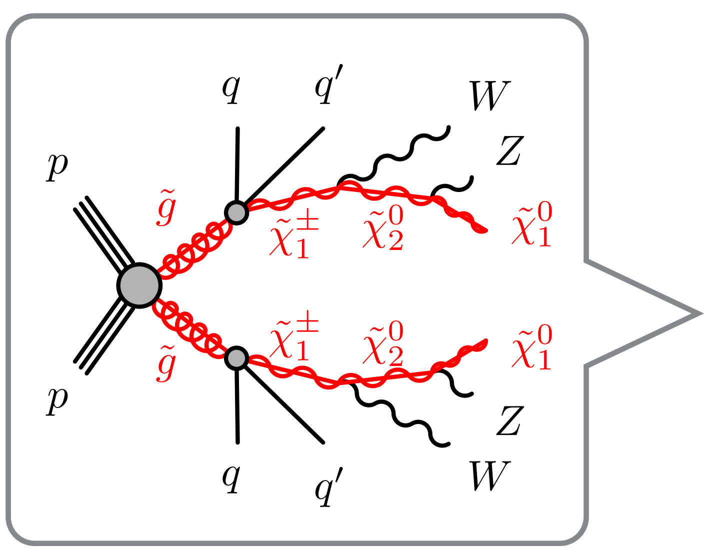


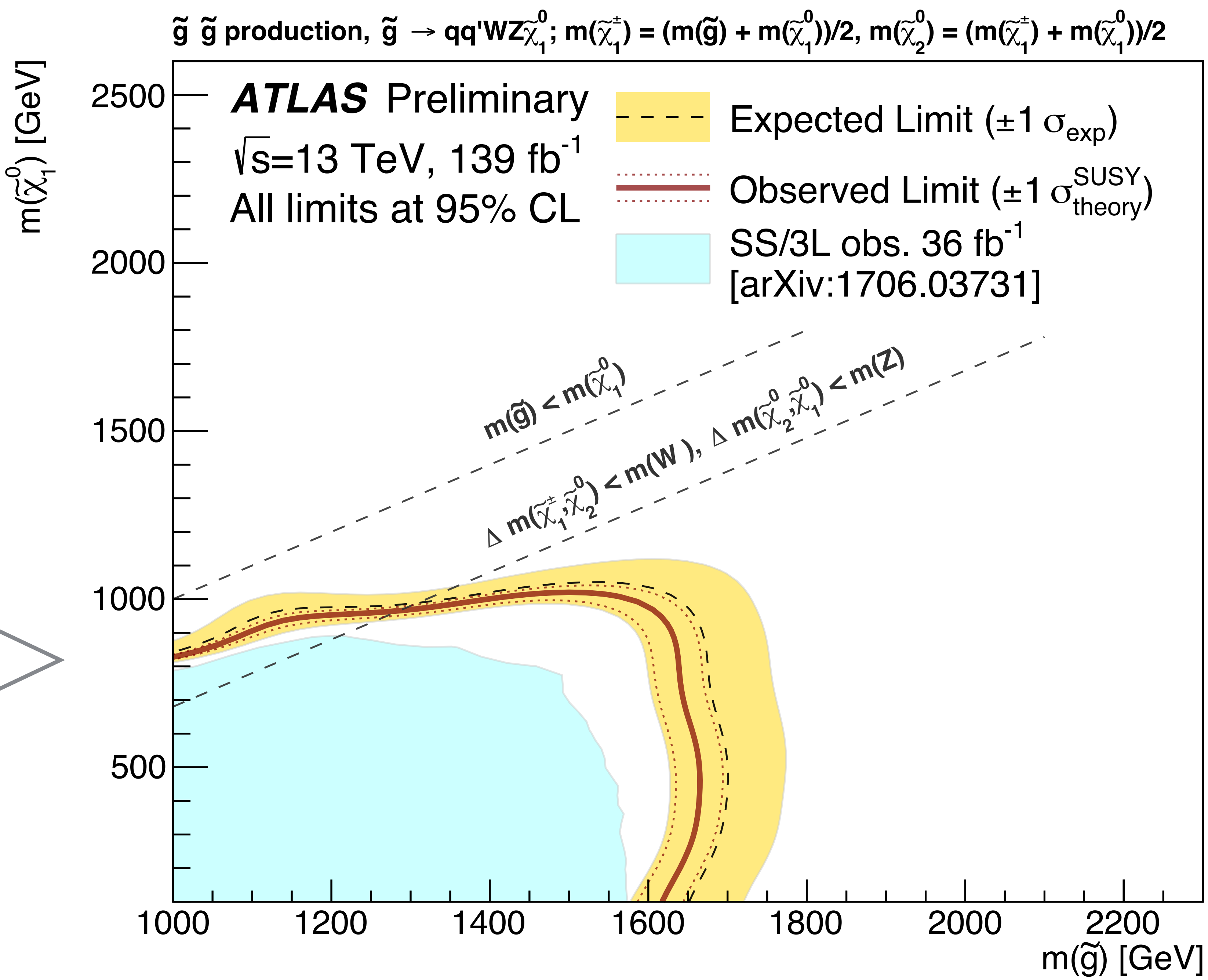
- The properties of the events are consistent with expectations from the SM backgrounds and **no significant** excess is observed in the **SRs**
- Largest excess of **2.6** (CMS)

SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

CONF-2019-015

GLUINO-PAIR PRODUCTION





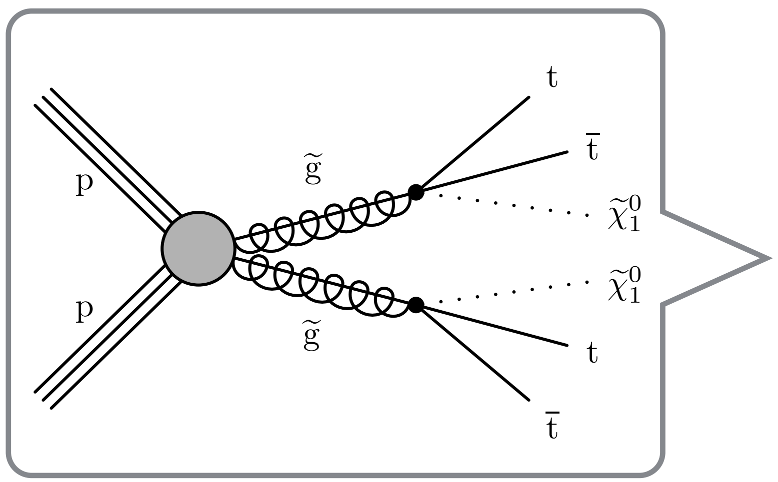
Mass limits have reached ~ 1.6 TeV for low LSP masses

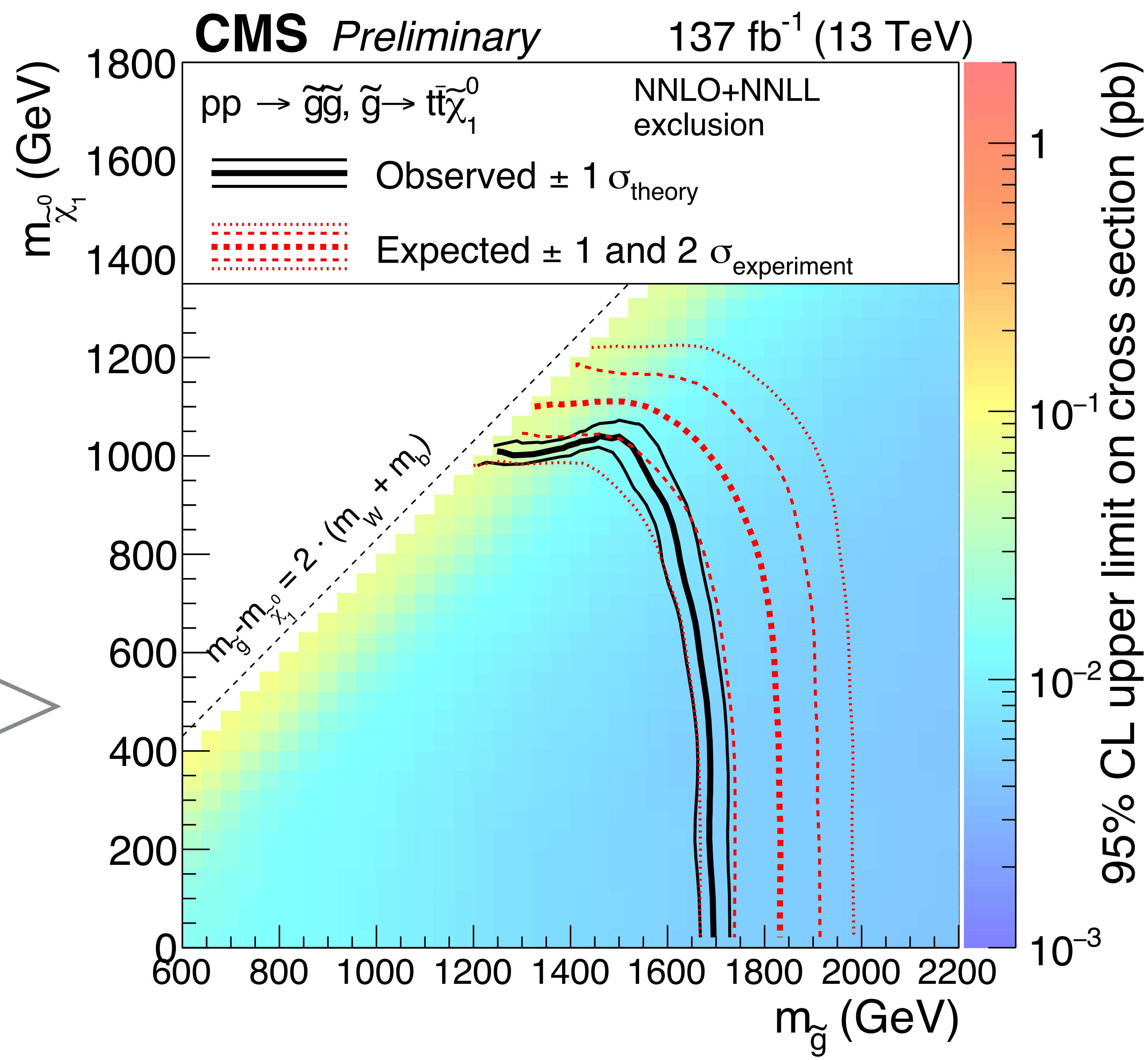
+ the interpretations of the other signal models in backup

SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

SUS-19-008

GLUINO-PAIR PRODUCTION

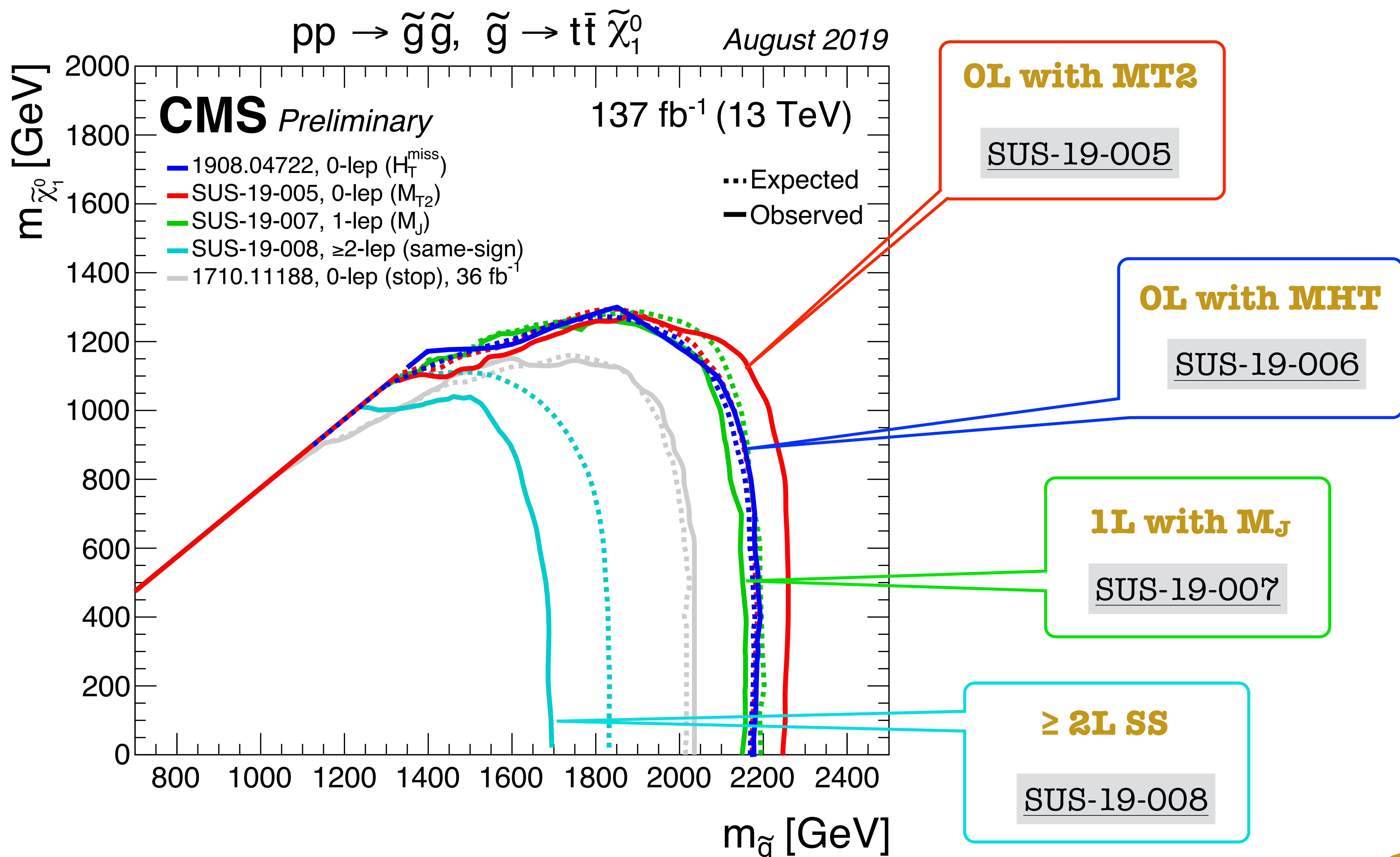




Mass limits have reached ~ 1.7 TeV for low LSP masses

+ the interpretations of the other signal models in backup

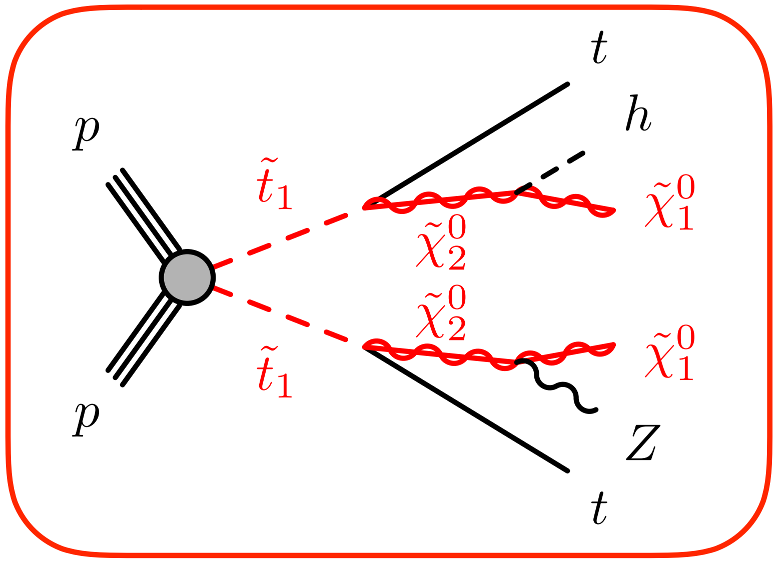
SEARCHES FOR GLUINOS

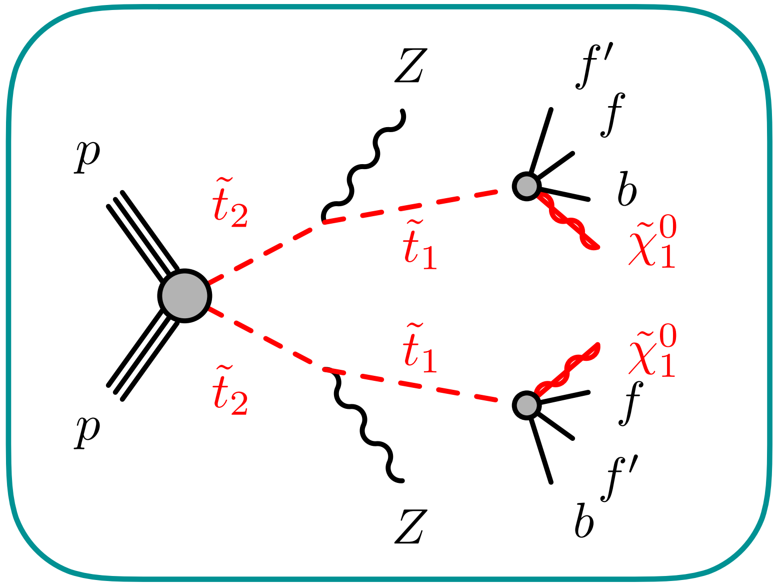


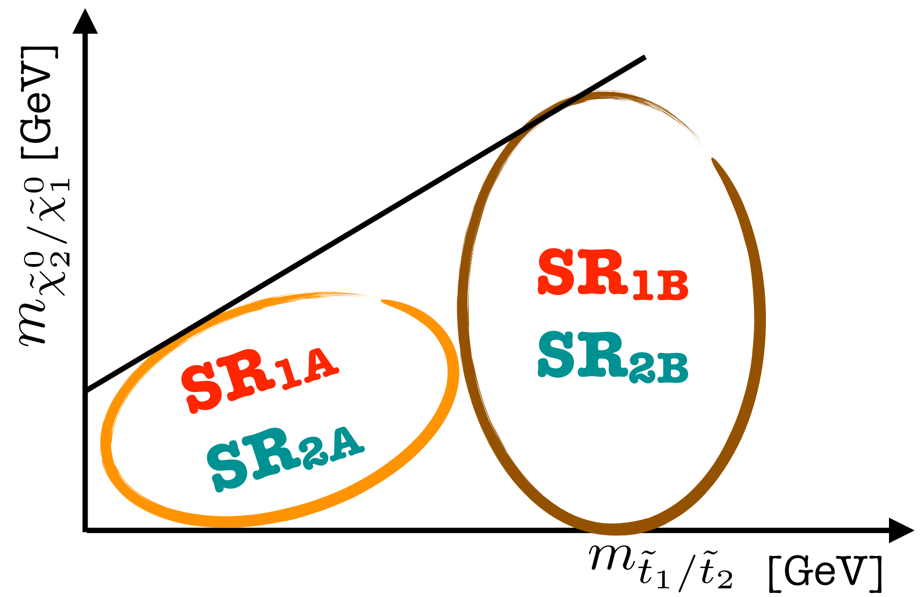
SEARCH FOR TOP SQUARKS WITH Z BOSONS

CONF-2019-016

- Search for top squark pair production in events with at least one Z boson



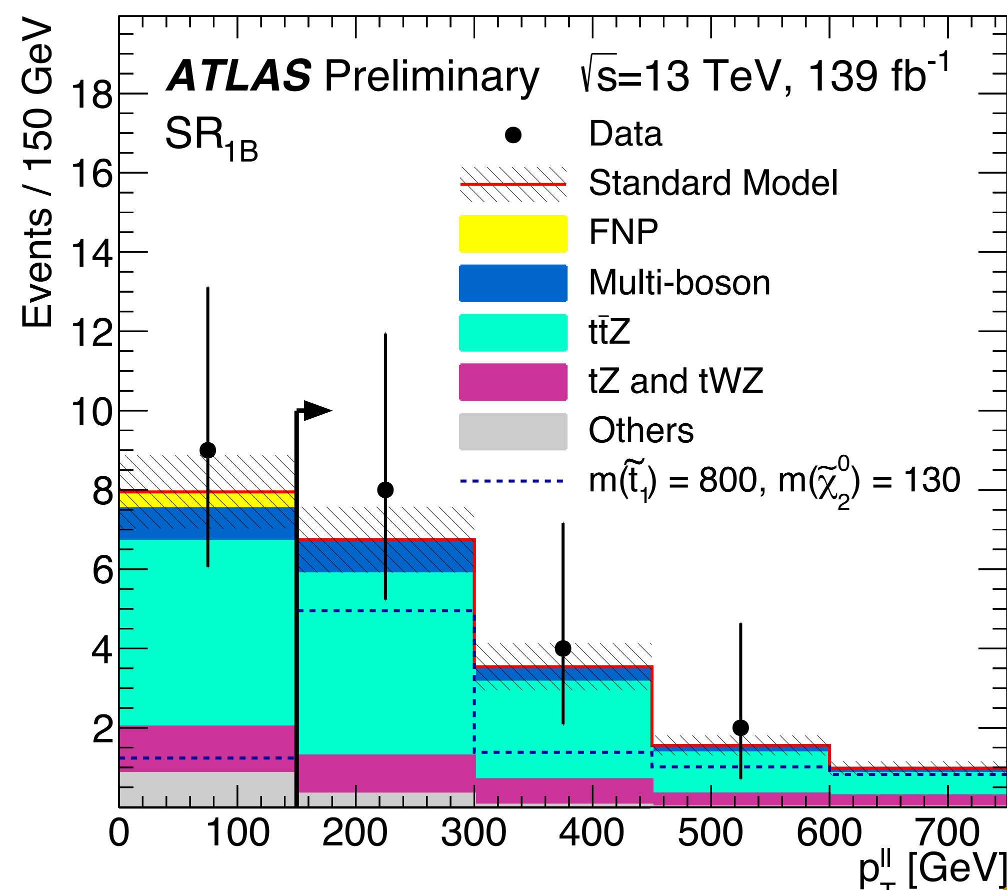




- **Final state** contains at least 3L (2L OS from Z decay and an additional lepton(s) from top decay), jets and large E_T^{miss}

- Two sets of **SRs** are defined using lepton kinematics, (b-)jet kinematics, E_T^{miss} and m_T:

1. **SRA**$_{1(2)}$ for small $\tilde{\chi}_2^0(\tilde{t}_2^0) - \tilde{\chi}_1^0$ mass splittings
2. **SRB**$_{1(2)}$ for large $\tilde{\chi}_2^0(\tilde{t}_2^0) - \tilde{\chi}_1^0$ mass splittings

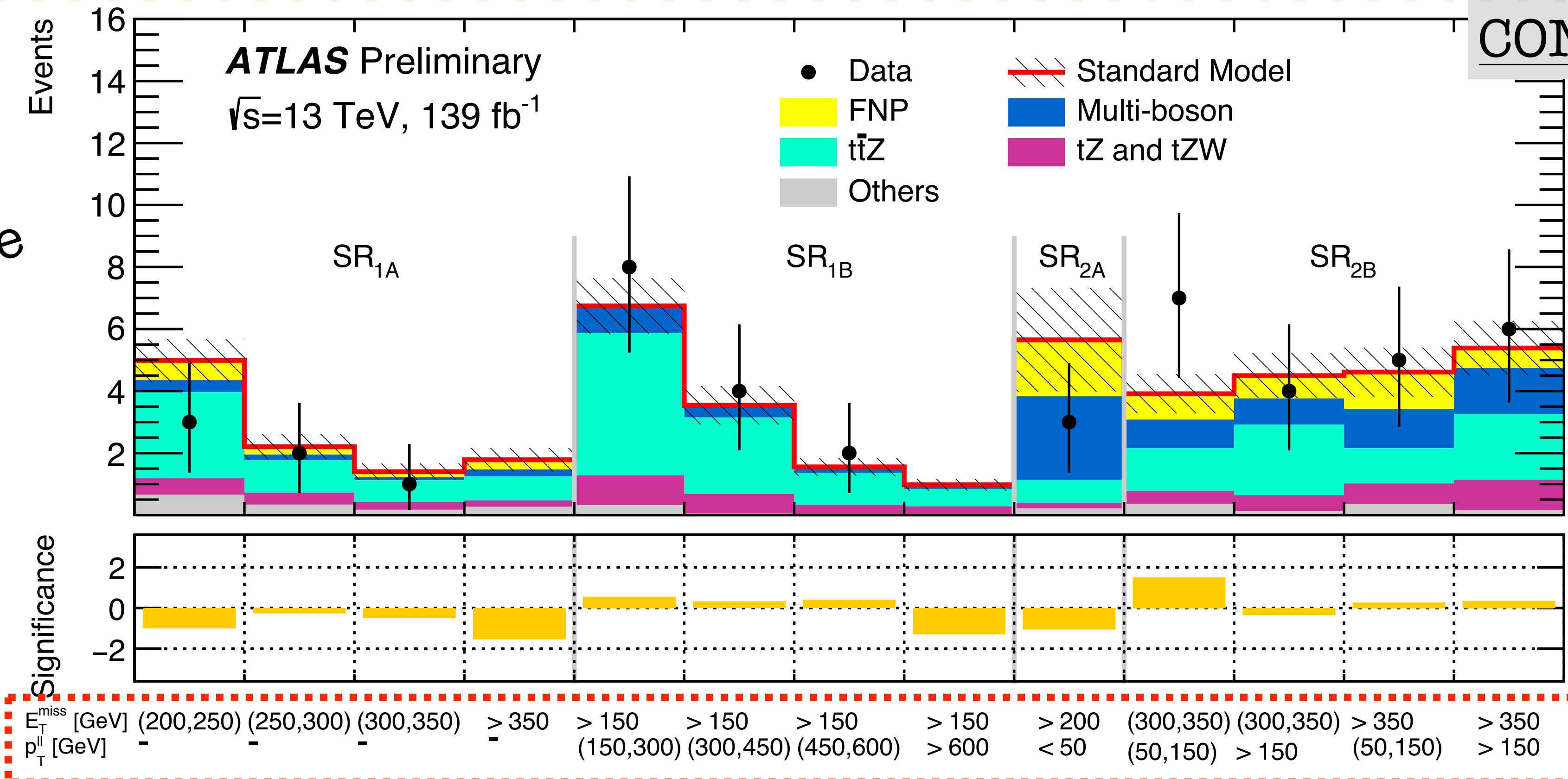


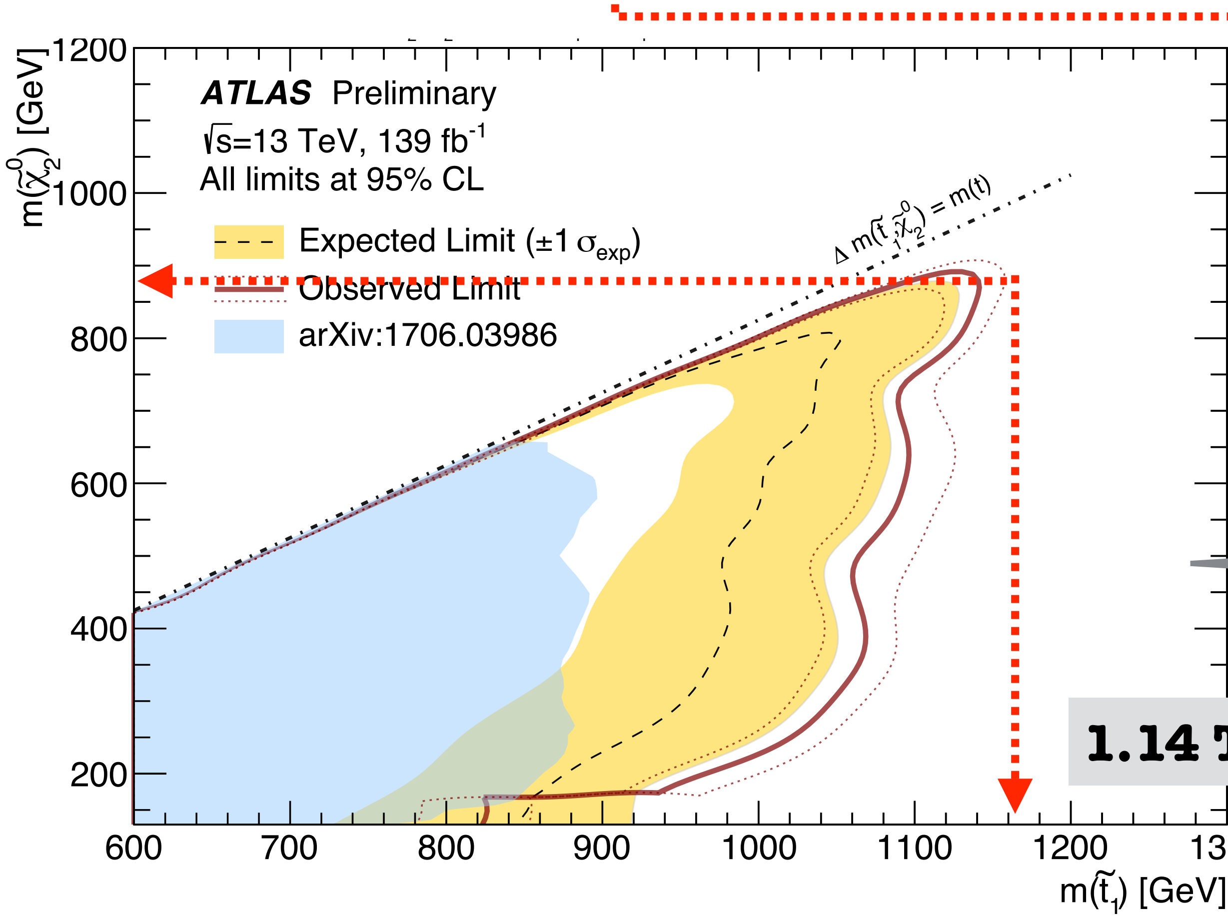
- **Dominant backgrounds** are **$t\bar{t}Z$** and **multi-boson** production (estimated in the dedicated **CRs**) with additional contributions from fake and non-prompt leptons (**FNP**)

SEARCH FOR TOP SQUARKS WITH Z BOSONS

CONF-2019-016

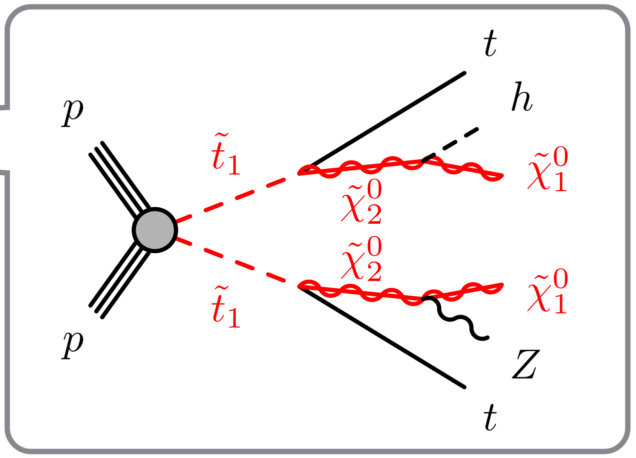
Good agreement between data and the SM prediction is observed





1.14 TeV

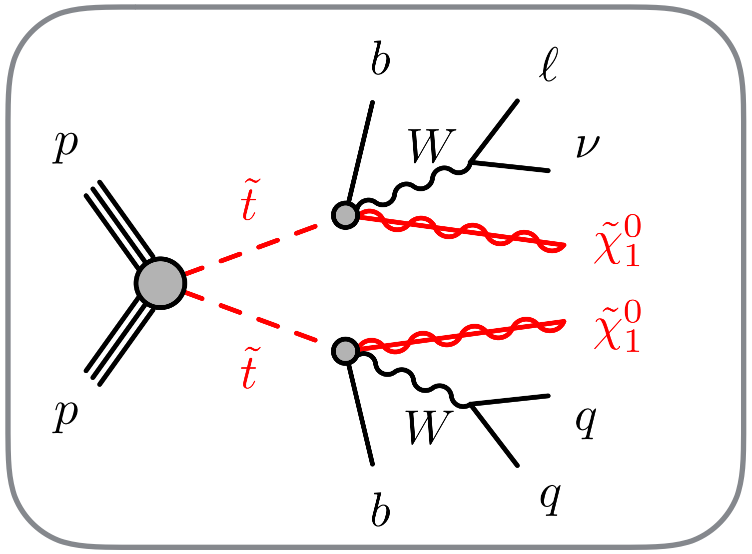
Limits are set on masses of top squark and LSP using **the relaxed versions of the SRs** that are defined based on bins in E_T^{miss} and $p_T(ll)$

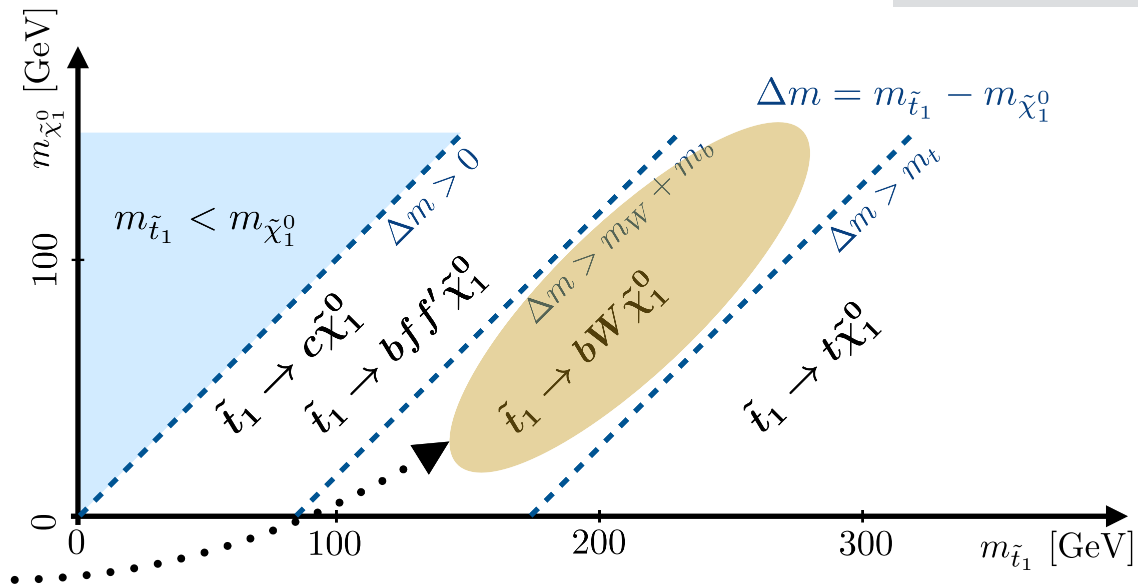


SEARCH FOR TOP SQUARKS IN THE 3-BODY DECAY MODE

CONF-2019-017

- Search for top squark pair production with exactly one lepton





Final state contains 1L, high jet multiplicity and large E_T^{miss}

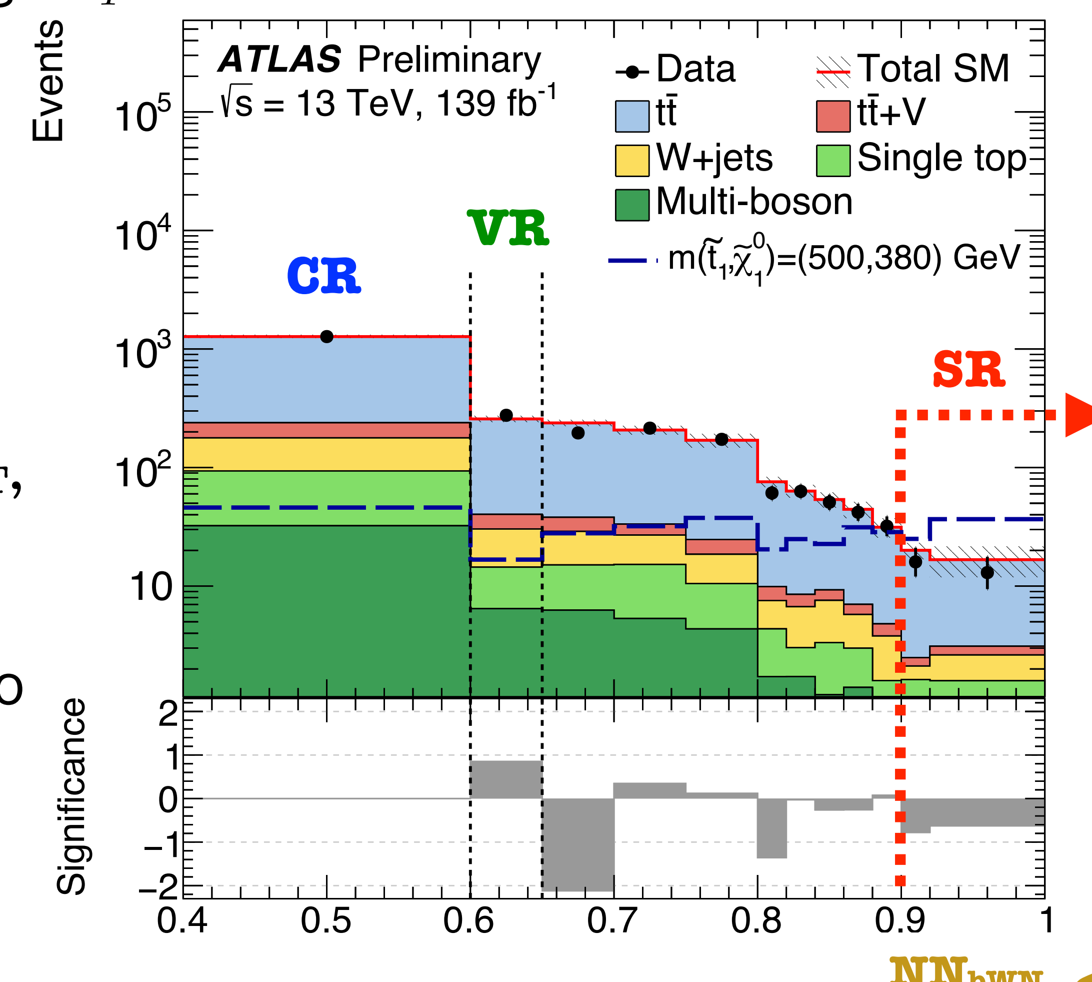
Dominant background is the $t\bar{t}$ process

Machine learning approach was developed to separate the signal from $t\bar{t}$

SR is designed using n_l, n_j, n_b, E_T^{miss}, $|\Delta\phi(j_{1,2}, \vec{p}_T^{\,miss})|$, m_T, and **the output discriminator: NN_{bWN}**

The background is estimated in the **CR**, orthogonal to the SR due to the selection on **NN_{bWN}**

The background modelling is validated in the **VR**

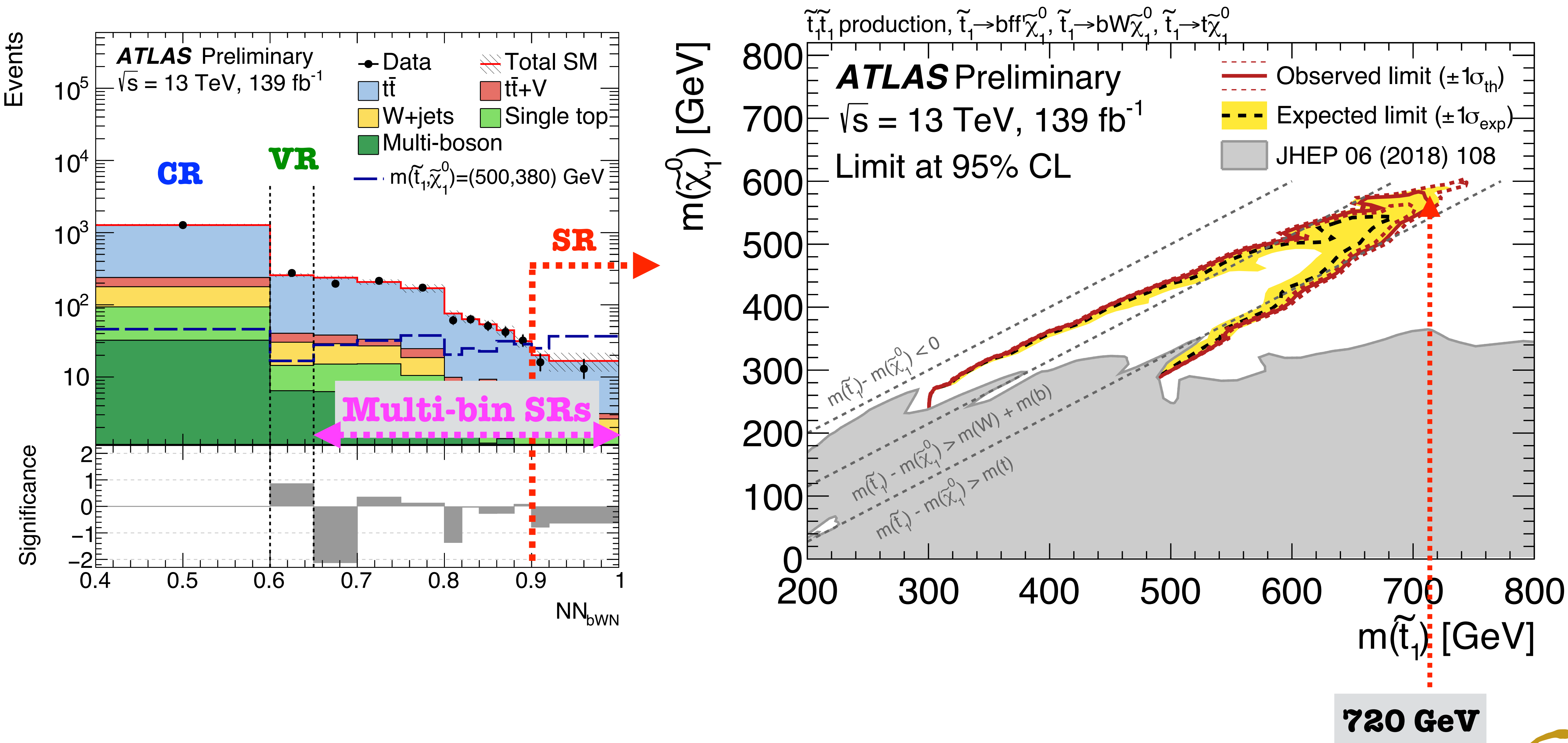


SEARCH FOR TOP SQUARKS IN THE 3-BODY DECAY MODE

CONF-2019-017

- **No excess** over the SM prediction is observed
- Limits are set on masses of top squark and LSP using the **multi-bin SRs** ➜ 10 bins:

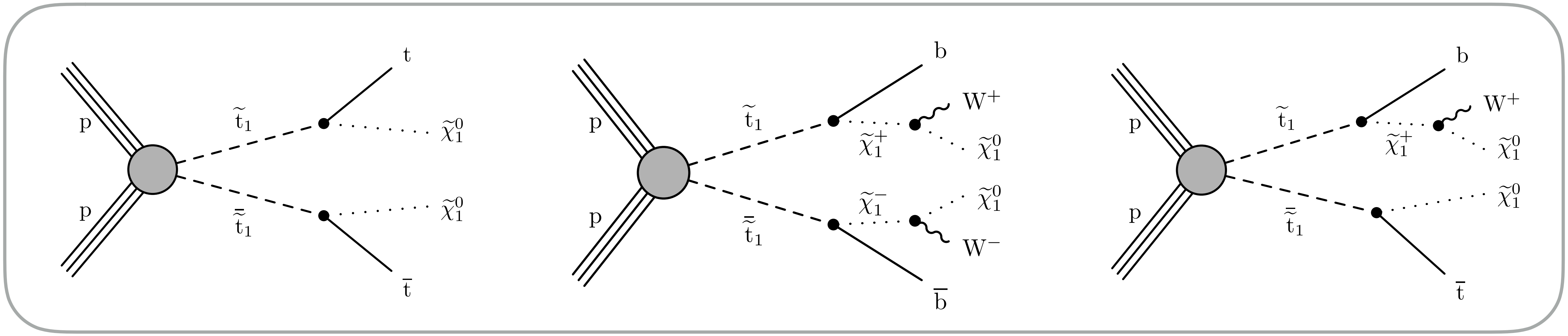
$$\mathrm{NN_{bWN}} \in [0.65^*, 0.7^*, 0.75^*, 0.8, 0.82, 0.84, 0.86, 0.88, 0.9, 0.92, 1]$$



SEARCH FOR TOP SQUARKS WITH A LEPTON

SUS-19-009

- Search for top squarks with a single lepton



Final state contains 1L, high jet multiplicity and large E_T^{miss}

SRs are designed using n_j, n_b, E_T^{miss}, M_{bl} (b-jet, l)

+

either resolved or boosted hadronic top tagger

Dominant backgrounds estimated in CRs:

$t\bar{t}$, single top and **W+jets** (lost lepton)

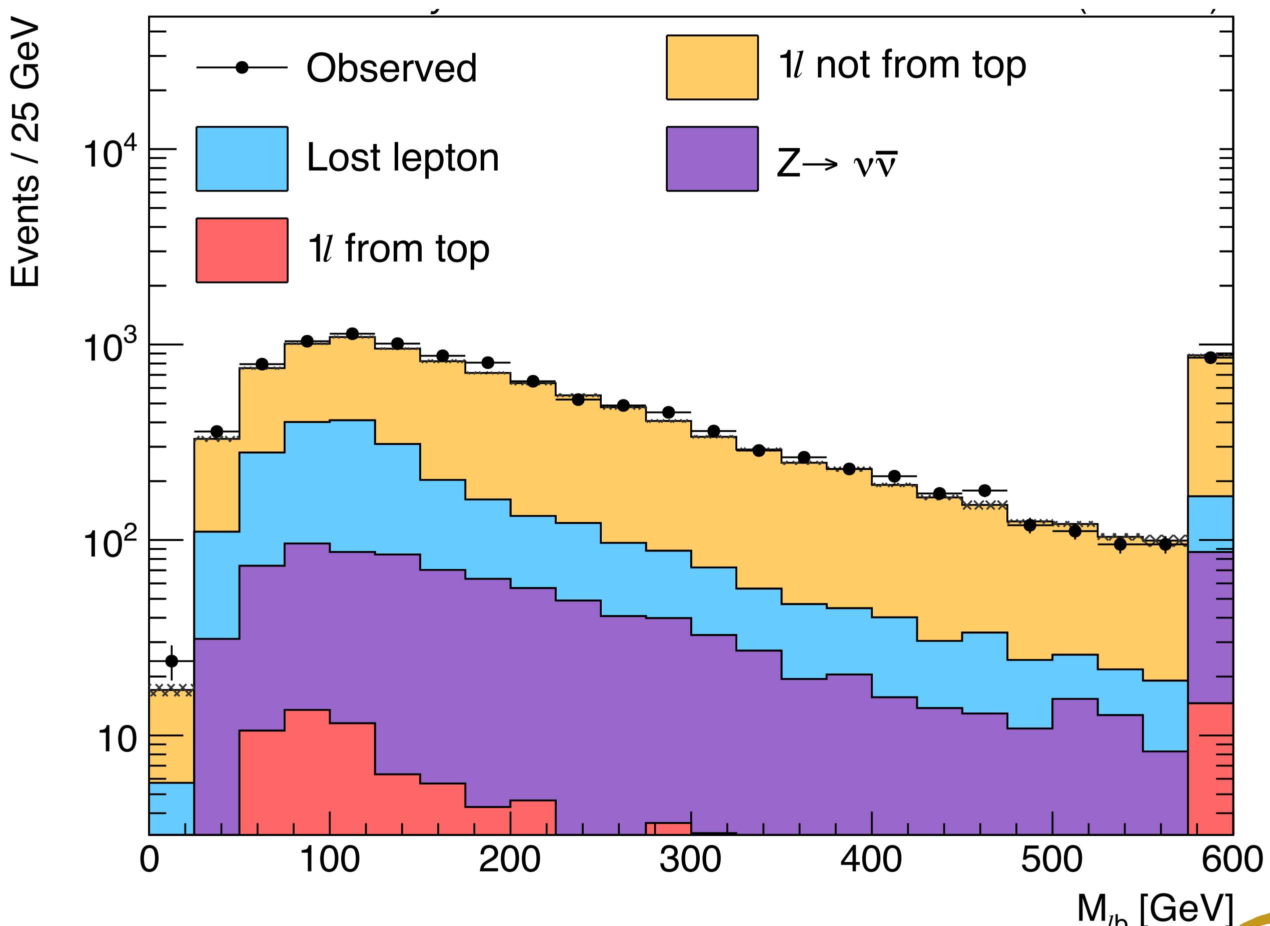
➟ CRs with two leptons

W+jets (1 lepton)

➟ CR without b-jets or with soft b-jets

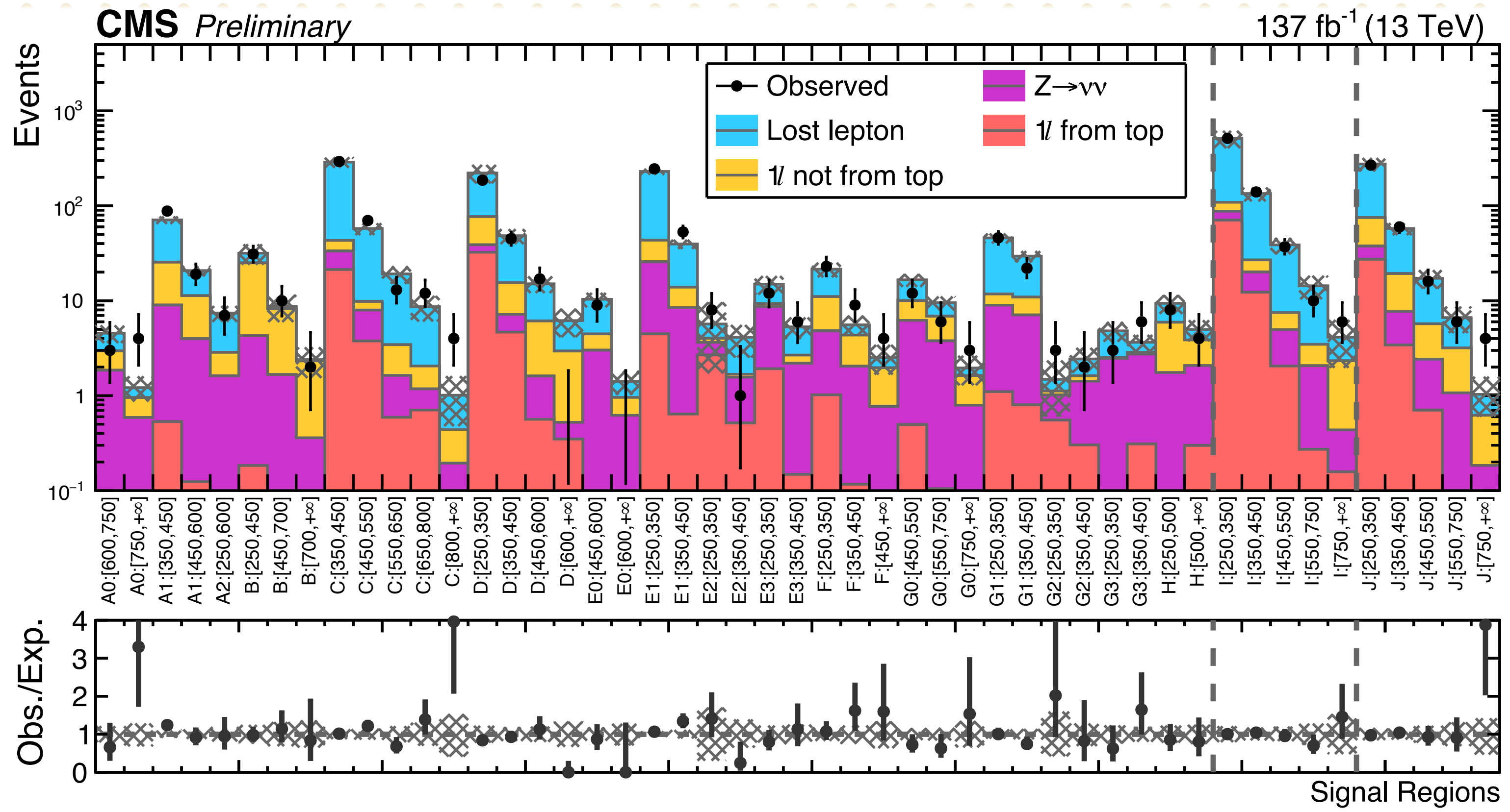
$t\bar{t}$ (1 lepton) & **$Z \rightarrow \nu\bar{\nu}$**

➟ estimated from MC simulated data



SEARCH FOR TOP SQUARKS WITH A LEPTON

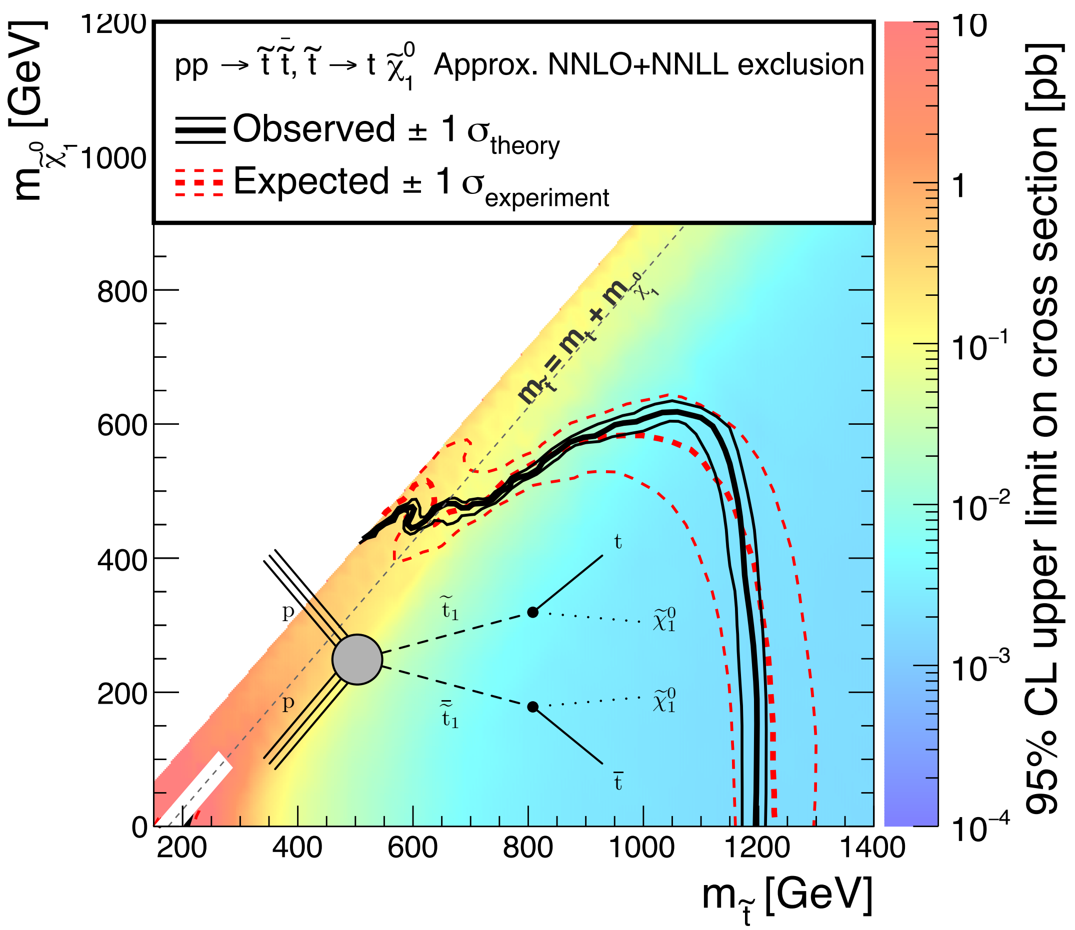
SUS-19-009



	N_J	t_{mod}	$M_{\ell b}$ [GeV]
A	2–3	> 10	≤ 175
B	2–3	> 10	> 175
C	≥ 4	≤ 0	≤ 175
D	≥ 4	≤ 0	> 175
E	≥ 4	0–10	≤ 175
F	≥ 4	0–10	> 175
G	≥ 4	> 10	≤ 175
H	≥ 4	> 10	> 175

X0: Inclusive
X1: Untagged
X2: Boosted top
X3: Resolved top

I: $N_J \geq 5$, $N_{b,med} \geq 1$
J: $N_J \geq 3$, $N_{b,soft} \geq 1$

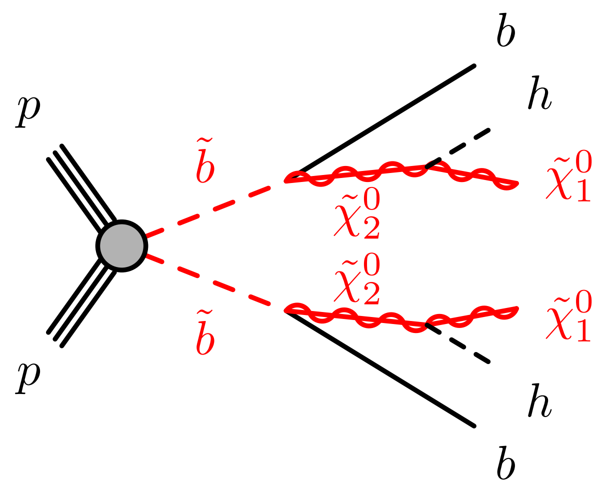


- The observed data are **consistent** with expectations from the SM processes
- Top squark masses up to **1.2 TeV** are excluded for low LSP masses

SEARCH FOR BOTTOM SQUARKS WITH DECAYS TO HIGGS

- Search for bottom squark pair production with Higgs bosons

arXiv:1908.03122



- **Final state** contains 0L, high jet multiplicity with many of these jets originating from b-quarks and large E_T^{miss}
- Two mass hierarchy scenarios are considered:

1) $m(\tilde{\chi}_1^0)$ = 60 GeV
2) $\Delta m(\tilde{\chi}_2^0, \tilde{\chi}_1^0)$ = 130 GeV

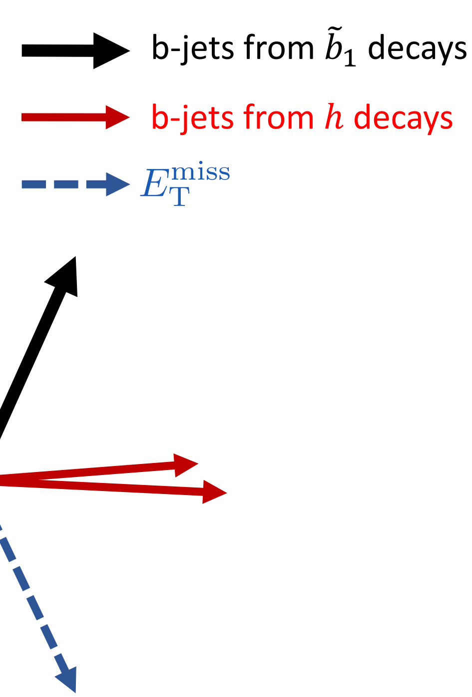
Three sets of non-orthogonal **SRs** are defined to target different mass hierarchies using various discriminating variables: n_j, n_b, $\Delta\phi(j_{1-4}, p_T^{miss})$, $\Delta\phi(j_1, p_T^{miss})$

+

either Higgs bosons reconstruct algorithms m_{eff} or the Object-based E_T^{miss} significance

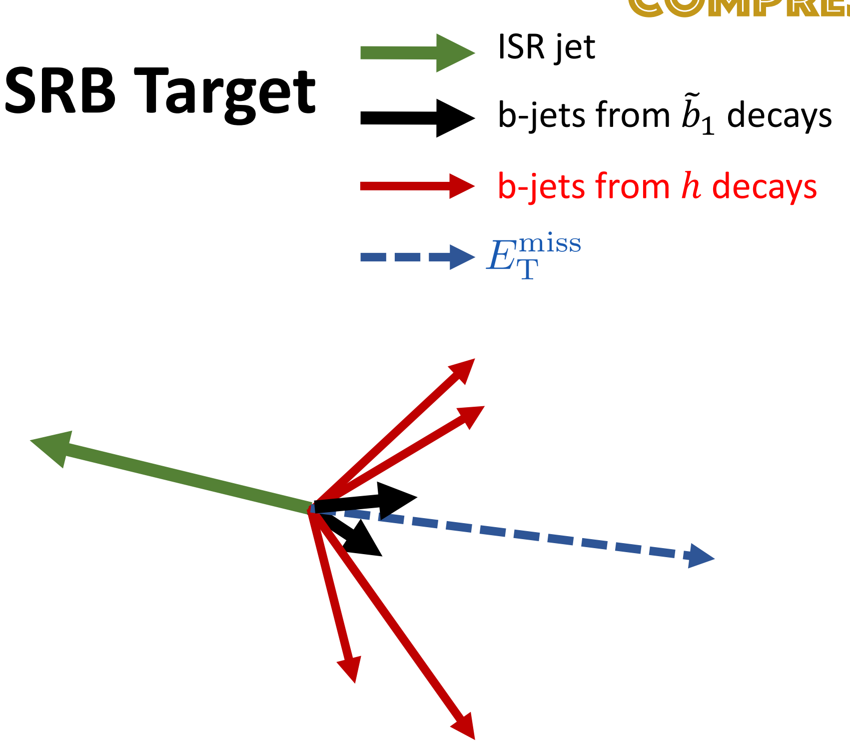
BULK

SRA Target

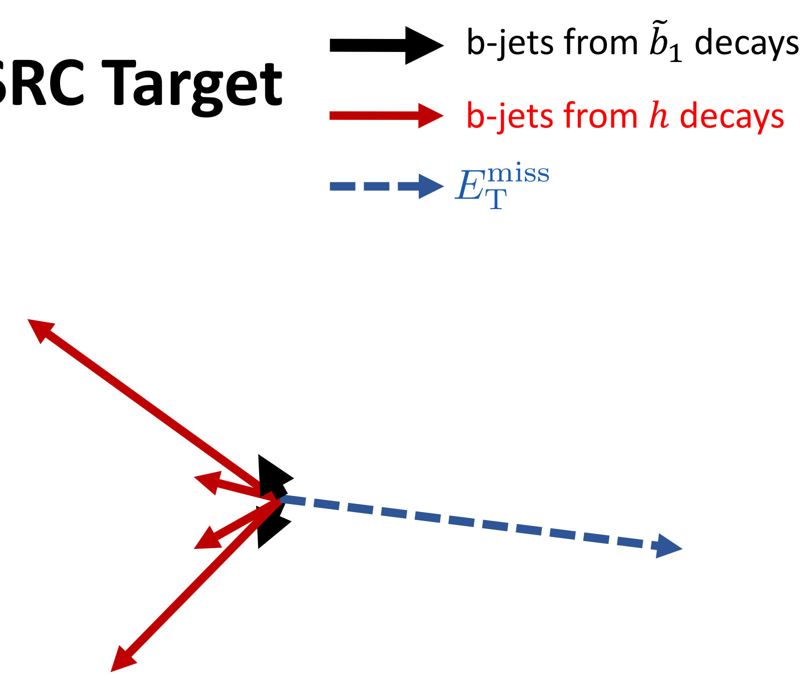


COMPRESSED

SRB Target



SRC Target



SEARCH FOR BOTTOM SQUARKS WITH DECAYS TO HIGGS

arXiv:1908.03122

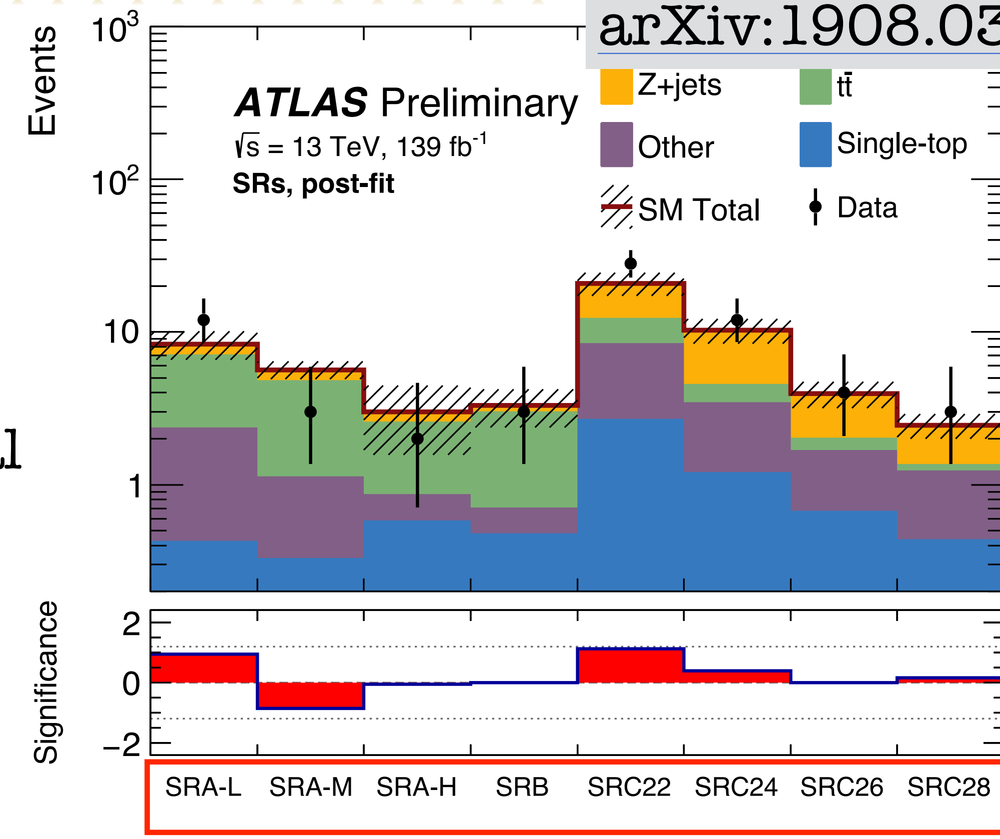
Dominant backgrounds estimated in the **CRs**:

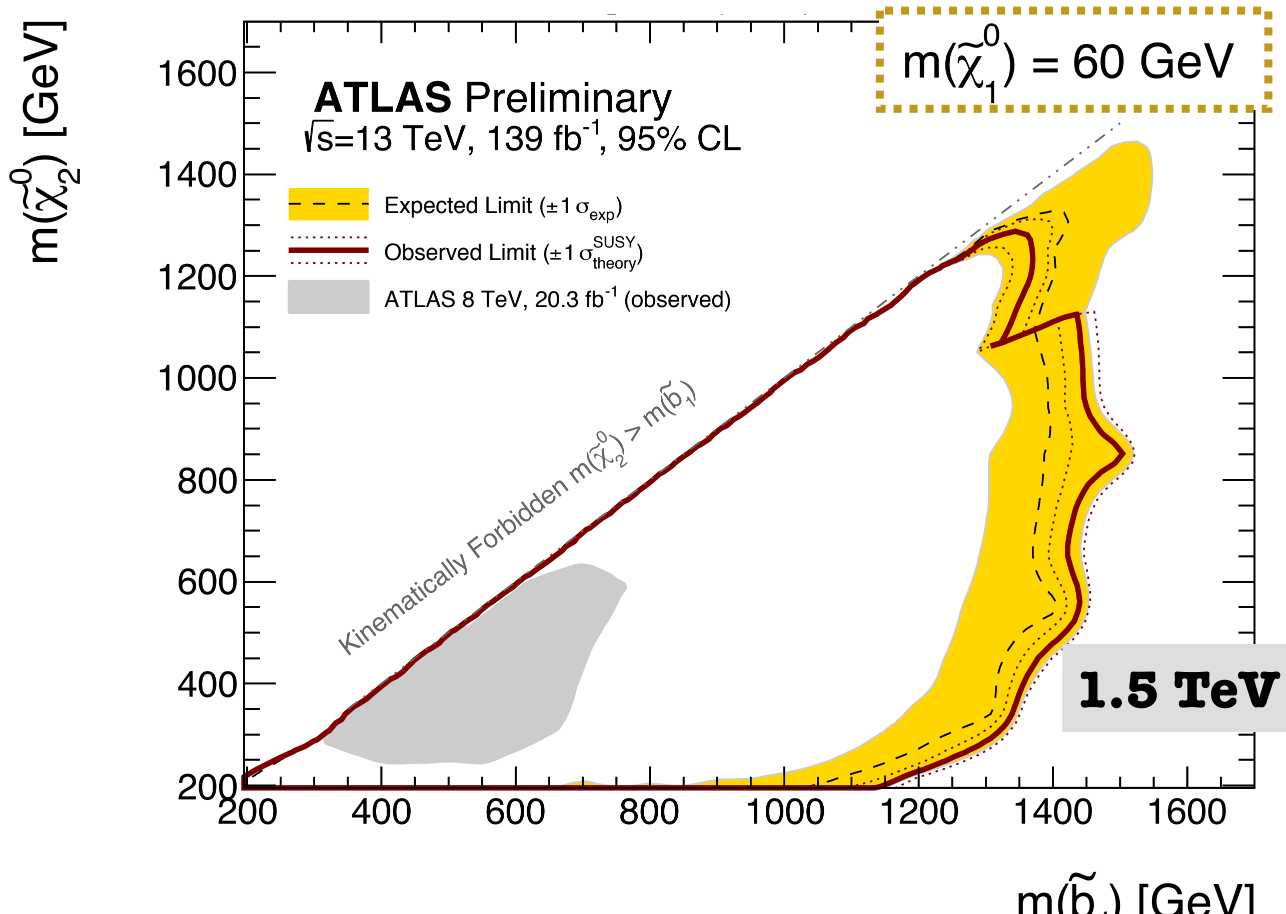
- $t\bar{t}$ (SRA and SRB)
- $Z \rightarrow \nu\bar{\nu}$ and top-related processes (SRC)

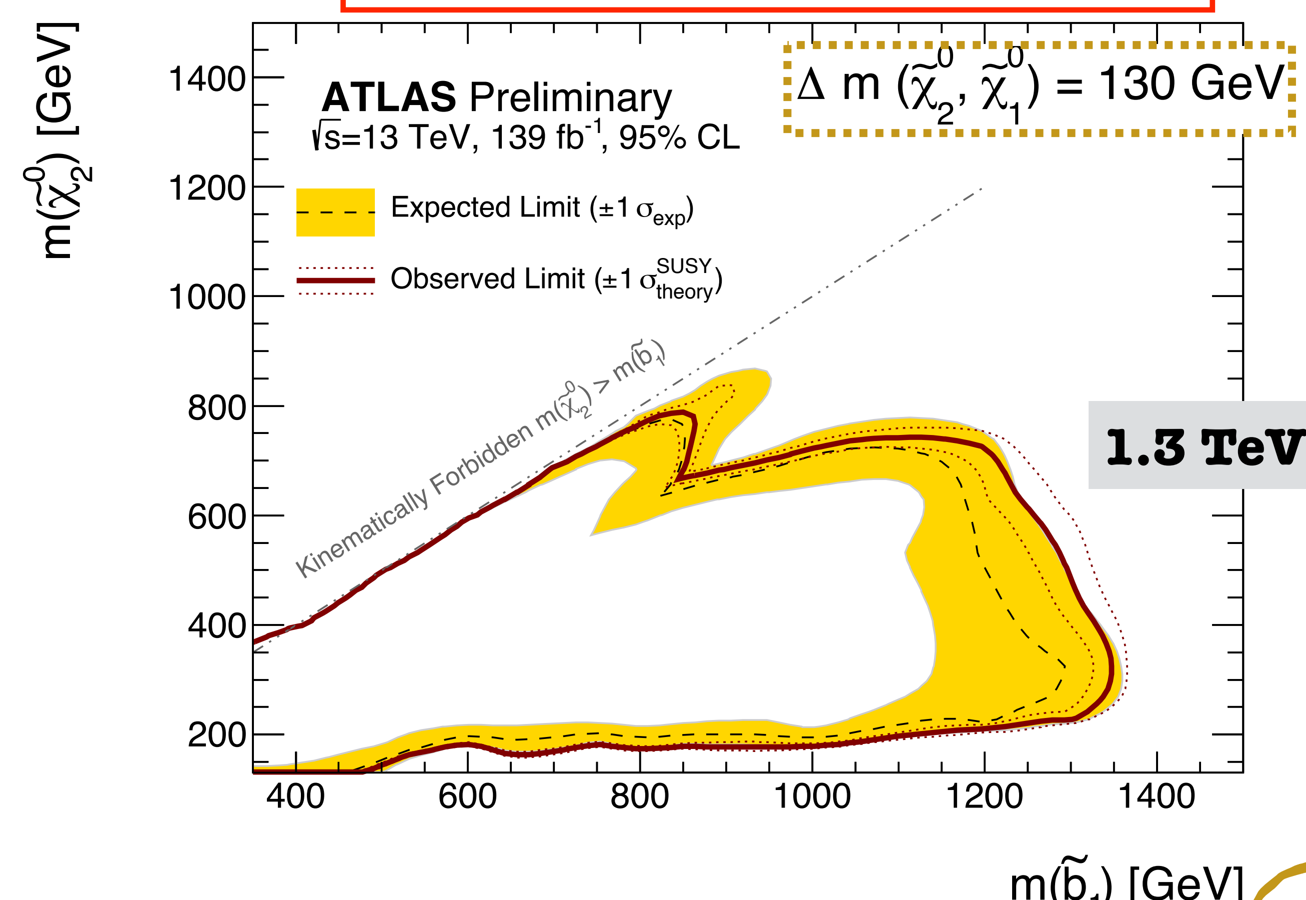
Other: $t\bar{t}$ +W/Z, $t\bar{t}$+h, diboson, W+jets

The background modelling is validated in orthogonal **VRs** defined with 0L and different b-jet selections

No significant excess is observed beyond the SM expectation in the **SRs**



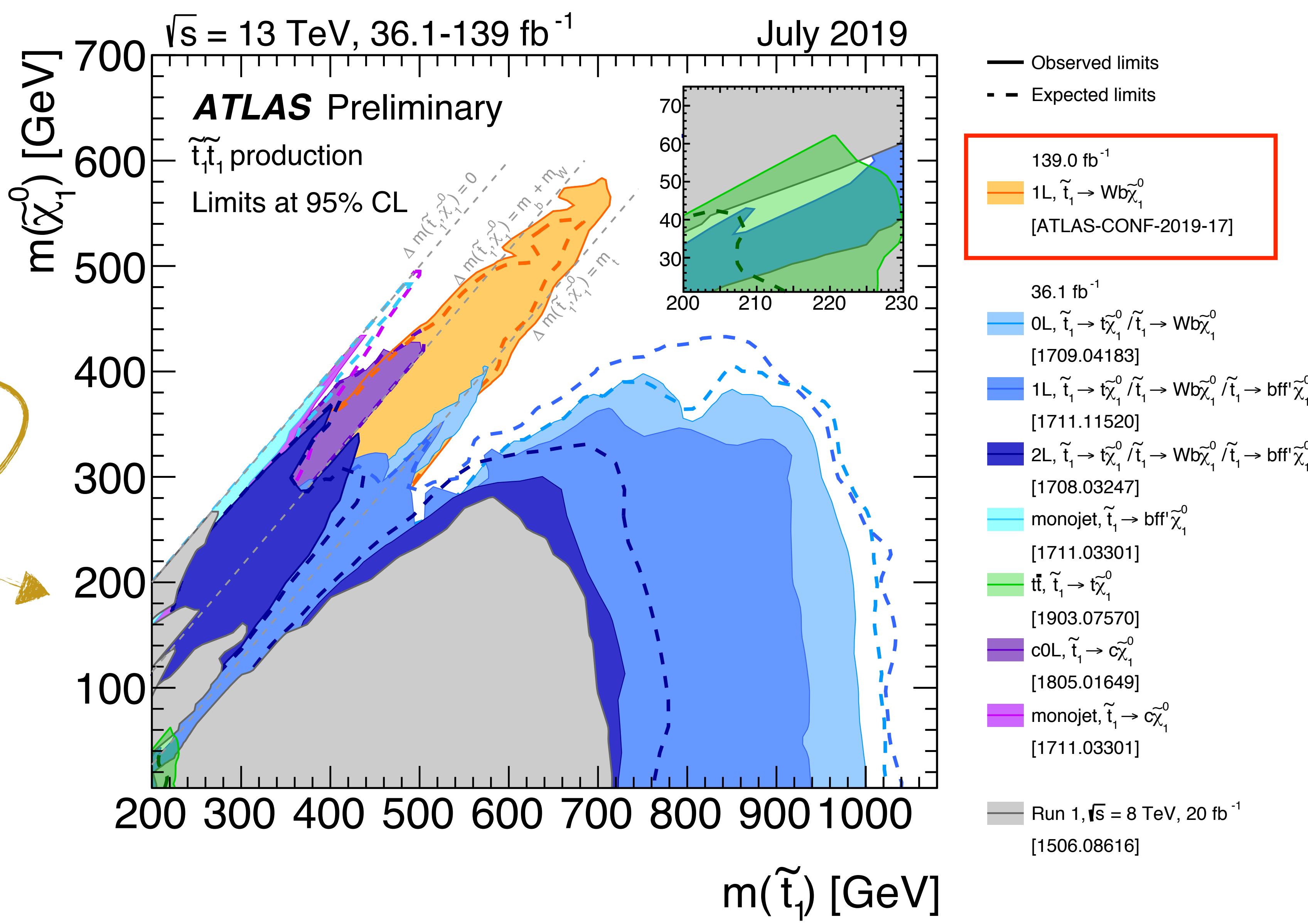




SEARCHES FOR TOP AND BOTTOM SQUARKS

$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \to b\tilde{\chi}^0_1/t\tilde{\chi}^\pm_1$		Multiple		36.1	$\tilde{b}_1$	Forbidden 0.9	$m(\tilde{\chi}^0_1)$=300 GeV, $BR(b\tilde{\chi}^0_1)$=1	1708.09266, 1711.03301
		Multiple		36.1	$\tilde{b}_1$	Forbidden 0.58-0.82	$m(\tilde{\chi}^0_1)$=300 GeV, $BR(b\tilde{\chi}^0_1)=BR(t\tilde{\chi}^\pm_1)$=0.5	1708.09266
		Multiple		139	$\tilde{b}_1$	Forbidden 0.74	$m(\tilde{\chi}^0_1)$=200 GeV, $m(\tilde{\chi}^\pm_1)$=300 GeV, $BR(t\tilde{\chi}^\pm_1)$=1	ATLAS-CONF-2019-015
$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1 \to b\tilde{\chi}^0_2 \to bh\tilde{\chi}^0_1$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$	Forbidden 0.23-1.35	$\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=100 GeV	SUSY-2018-31
					$\tilde{b}_1$	0.23-0.48	$\Delta m(\tilde{\chi}^0_2,\tilde{\chi}^0_1)$=130 GeV, $m(\tilde{\chi}^0_1)$=0 GeV	SUSY-2018-31
$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	E_T^{miss}	36.1	$\tilde{t}_1$	1.0	$m(\tilde{\chi}^0_1)$=1 GeV	1506.08616, 1709.04183, 1711.11520
$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to Wb\tilde{\chi}^0_1$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$	0.44-0.59	$m(\tilde{\chi}^0_1)$=400 GeV	ATLAS-CONF-2019-017
$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to \tilde{\tau}_1 b\nu$, $\tilde{\tau}_1 \to \tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	E_T^{miss}	36.1	$\tilde{t}_1$	1.16	$m(\tilde{\tau}_1)$=800 GeV	1803.10178
$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1 \to c\tilde{\chi}^0_1$ / $\tilde{c}\tilde{c}$, $\tilde{c} \to c\tilde{\chi}^0_1$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$	0.85	$m(\tilde{\chi}^0_1)$=0 GeV	1805.01649
					$\tilde{t}_1$	0.46	$m(\tilde{t}_1,\tilde{c})-m(\tilde{\chi}^0_1)$=50 GeV	1805.01649
	0 e,μ	mono-jet	E_T^{miss}	36.1	$\tilde{t}_1$	0.43	$m(\tilde{t}_1,\tilde{c})-m(\tilde{\chi}^0_1)$=5 GeV	1711.03301

$\tilde{t}_1\tilde{t}_1$ production



$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2 \to \tilde{t}_1 + h$	1-2 e,μ	4 b	E_T^{miss}	36.1	$\tilde{t}_2$	0.32-0.88	$m(\tilde{\chi}^0_1)$=0 GeV, $m(\tilde{t}_1)-m(\tilde{\chi}^0_1)$= 180 GeV	1706.03986
$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2 \to \tilde{t}_1 + Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$	Forbidden 0.86	$m(\tilde{\chi}^0_1)$=360 GeV, $m(\tilde{t}_1)-m(\tilde{\chi}^0_1)$= 40 GeV	ATLAS-CONF-2019-016

SUMMARY

- The latest results of SUSY searches at the **ATLAS** and **CMS** experiments with the **full Run 2 dataset** have been presented
- Unfortunately, no SUSY particles have been found

- **Many other searches** are currently **in progress**, some of which hopefully give us **hints** for SUSY
- Stay tuned for more SUSY results!

THANK YOU FOR YOUR ATTENTION!

BACKUP

INCLUSIVE HADRONIC SEARCHES

	MB-SSd	MB-GGd	MB-C
N_j	≥ 2	≥ 4	≥ 2
$p_T(j_1)$ [GeV]	> 200	> 200	> 600
$p_T(j_{i=2,\ldots,N_{j_{min}}})$ [GeV]	> 100	> 100	> 50
$\lvert\eta(j_{i=1,\ldots,N_{j_{min}}})\rvert$	< 2.0	< 2.0	< 2.8
$\Delta\phi(j_{1,2,(3)}, \boldsymbol{p}_T^{miss})_{min}$	> 0.8	> 0.4	> 0.4
$\Delta\phi(j_{i>3}, \boldsymbol{p}_T^{miss})_{min}$	> 0.4	> 0.2	> 0.2
Aplanarity	-	> 0.04	-
$E_T^{miss}/\sqrt{H_T}$ [GeV$^{1/2}$]	> 10	> 10	> 10
m_{eff} [GeV]	> 1000	> 1000	> 1600

	BDT-GGd1	BDT-GGd2	BDT-GGd3	BDT-GGd4
N_j	≥ 4			
$\Delta\phi(j_{1,2,(3)}, \boldsymbol{p}_T^{miss})_{min}$	≥ 0.4			
$\Delta\phi(j_{i>3}, \boldsymbol{p}_T^{miss})_{min}$	≥ 0.4			
$E_T^{miss}/m_{eff}(Nj)$	≥ 0.2			
m_{eff} [GeV]	≥ 1400		≥ 800	
BDT score	≥ 0.97	≥ 0.94	≥ 0.94	≥ 0.87
$\Delta m(\tilde{g}, \tilde{\chi}_1^0)$ [GeV]	1600 – 1900	1000 – 1400	600 – 1000	200 – 600

	BDT-GGo1	BDT-GGo2	BDT-GGo3	BDT-GGo4
N_j	≥ 6		≥ 5	
$\Delta\phi(j_{1,2,(3)}, \boldsymbol{p}_T^{miss})_{min}$	≥ 0.4			≥ 0.2
$\Delta\phi(j_{i>3}, \boldsymbol{p}_T^{miss})_{min}$	≥ 0.4			≥ 0.2
$E_T^{miss}/m_{eff}(Nj)$	≥ 0.2			
m_{eff} [GeV]	≥ 1400		≥ 800	
BDT score	≥ 0.96	≥ 0.87	≥ 0.92	≥ 0.84
$\Delta m(\tilde{g}, \tilde{\chi}_1^0)$ [GeV]	1400 – 2000	1200 – 1400	600 – 1000	200 – 400

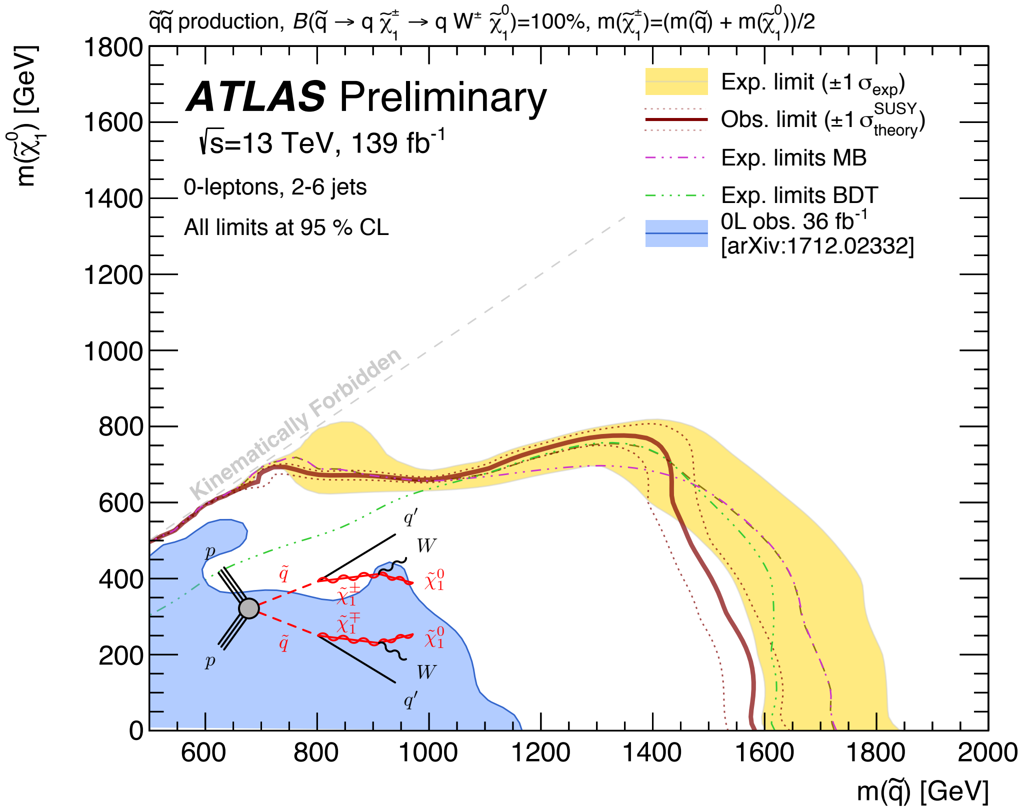
INCLUSIVE HADRONIC SEARCHES

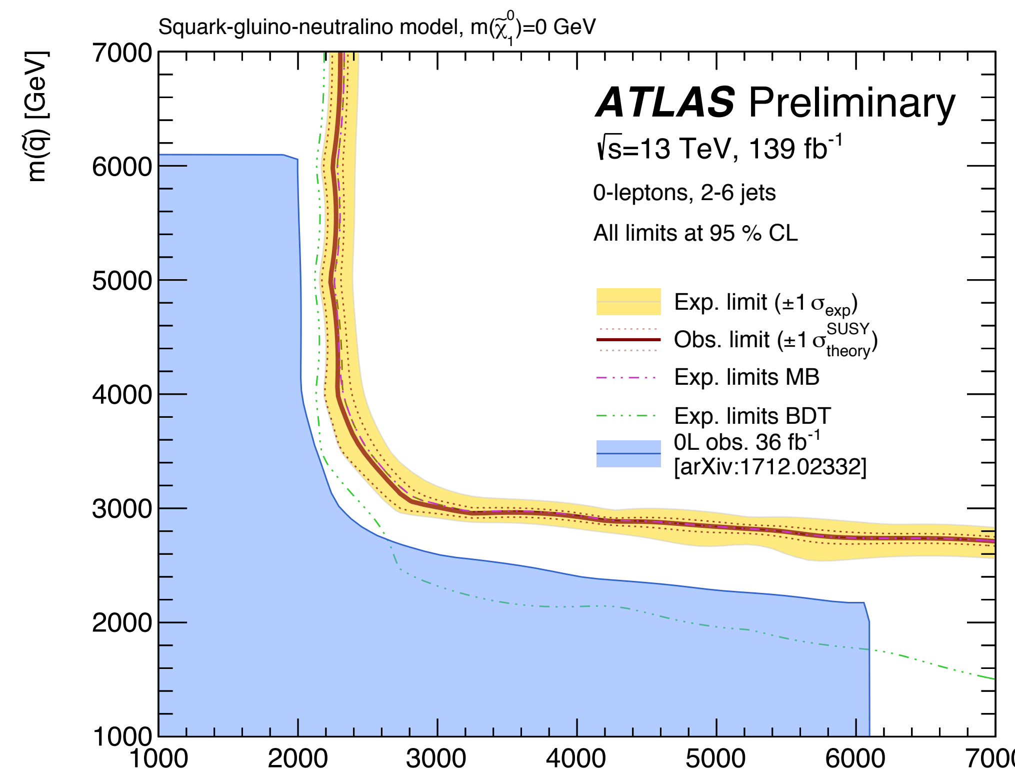
BDT regions				
Signal Region	**GGd1**	**GGd2**	**GGd3**	**GGd4**
Fitted background events				
Diboson	3.0 ± 0.9	4.9 ± 1.4	21 ± 5	26 ± 7
Z/γ^*+jets	20 ± 4	33 ± 5	139 ± 14	180 ± 18
W+jets	7.0 ± 2.6	13.2 ± 3.5	48 ± 8	52 ± 9
$t\bar{t}$(+EW) + single top	$0.1^{+0.3}_{-0.1}$	$0.6^{+0.8}_{-0.6}$	16 ± 5	39 ± 11
Multi-jet	$0.1^{+0.1}_{-0.1}$	$0.1^{+0.1}_{-0.1}$	$0.1^{+0.1}_{-0.1}$	$0.1^{+0.1}_{-0.1}$
Total bkg (pre-fit)	29	56	253	348
Total bkg	30 ± 5	52 ± 6	223 ± 17	298 ± 23
Observed	34	68	227	291
$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	0.13	0.25	0.33	0.36
S^{95}_{obs}	19	34	46	50
S^{95}_{exp}	16^{+6}_{-5}	22^{+8}_{-5}	43^{+17}_{-12}	54^{+20}_{-15}
p_0 (Z)	0.30 (0.52)	0.05 (1.60)	0.44 (0.15)	0.50 (0.00)

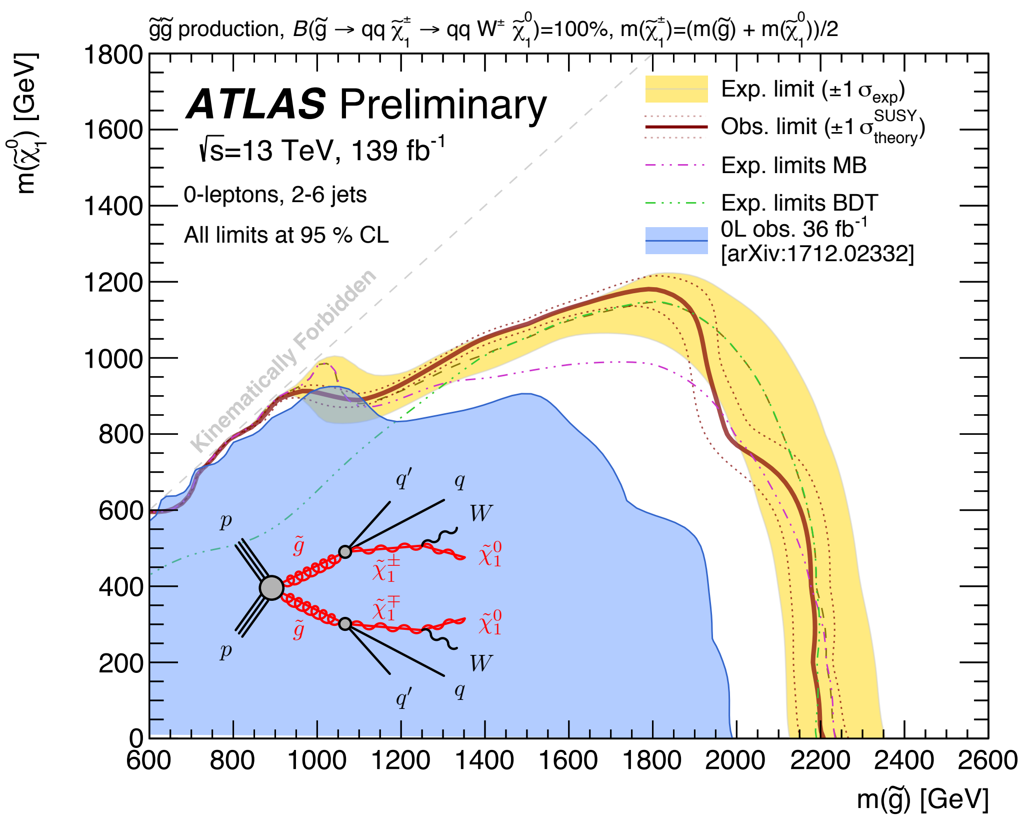
Signal Region	**GGo1**	**GGo2**	**GGo3**	**GGo4**
Fitted background events				
Diboson	0.6 ± 0.2	2.2 ± 0.6	6.6 ± 2.2	6.8 ± 2.1
Z/γ^*+jets	3.8 ± 1.3	10.9 ± 1.9	35 ± 6	39 ± 7
W+jets	0.9 ± 0.5	3.8 ± 1.3	16 ± 4	27 ± 6
$t\bar{t}$(+EW) + single top	0.2 ± 0.2	1.3 ± 0.8	28 ± 6	85 ± 14
Multi-jet	–	–	$0.1^{+0.1}_{-0.1}$	$0.5^{+0.5}_{-0.5}$
Total bkg (pre-fit)	7	25	111	178
Total bkg	5.5 ± 1.5	18.3 ± 2.4	85 ± 9	159 ± 16
Observed	6	25	80	135
$\langle\epsilon\sigma\rangle^{95}_{obs}$ [fb]	0.05	0.12	0.16	0.18
S^{95}_{obs}	7	17	22	25
S^{95}_{exp}	$6.6^{+2.5}_{-1.8}$	11^{+5}_{-2}	25^{+10}_{-7}	37^{+14}_{-10}
p_0 (Z)	0.41 (0.22)	0.10 (1.28)	0.50 (0.00)	0.50 (0.00)

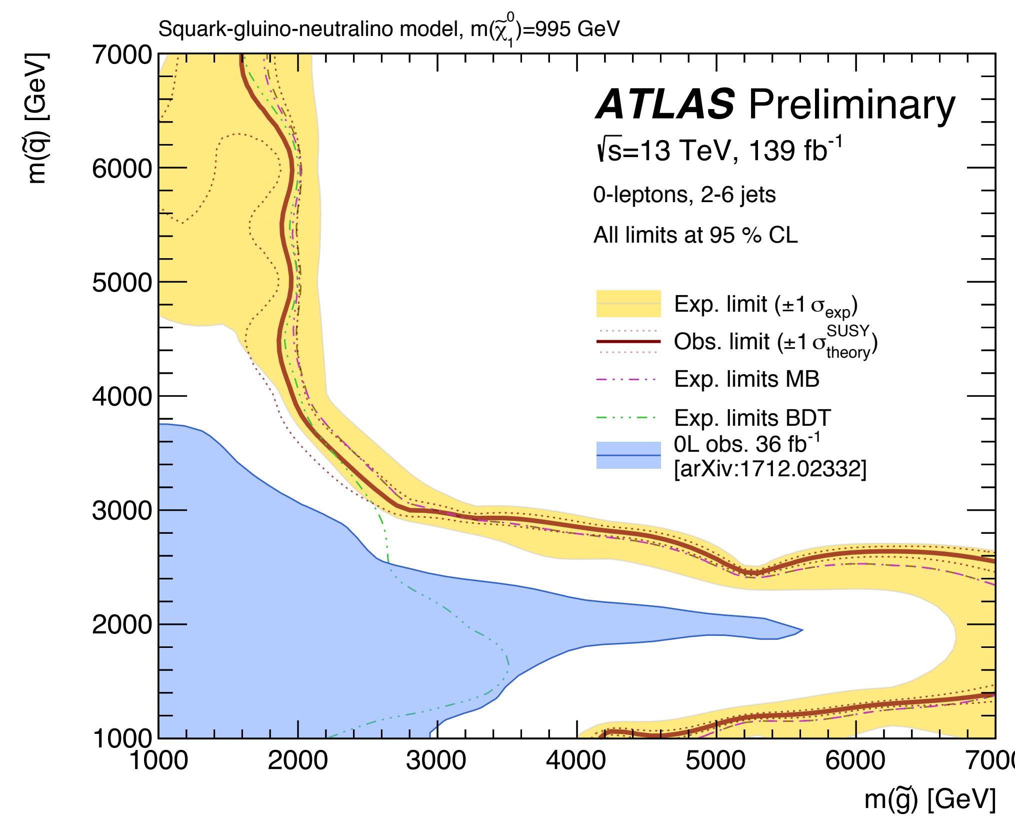
INCLUSIVE HADRONIC SEARCHES

Inclusive







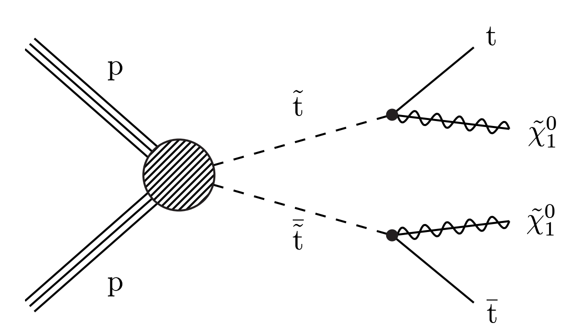


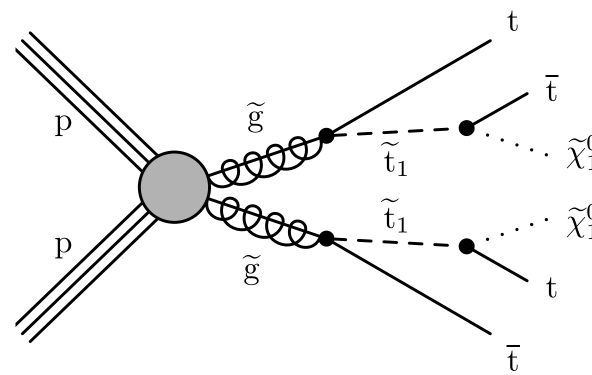
INCLUSIVE HADRONIC SEARCHES

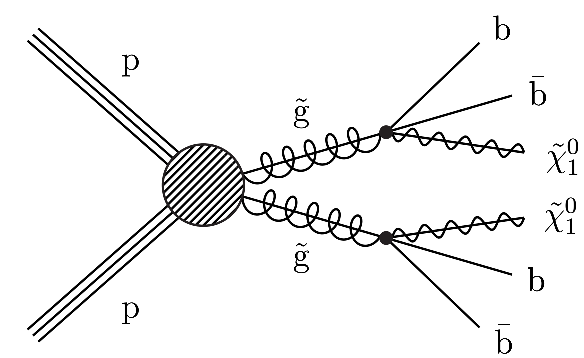
H_T range [GeV]	Jet multiplicities	M_{T2} binning [GeV]
[250, 450)	2 – 3j, 0b	[200, 300, 400, ∞)
	2 – 3j, 1b	[200, 300, 400, ∞)
	2 – 3j, 2b	[200, 300, 400, ∞)
	4 – 6j, 0b	[200, 300, 400, ∞)
	4 – 6j, 1b	[200, 300, 400, ∞)
	4 – 6j, 2b	[200, 300, 400, ∞)
	≥ 7j, 0b	[200, 300, 500, ∞)
	≥ 7j, 1b	[200, 300, ∞)
	≥ 7j, 2b	[200, 300, ∞)
	2 – 6j, ≥ 3b	[200, 300, 400, ∞)
	≥ 7j, ≥ 3b	[200, 300, ∞)
[450, 575)	2 – 3j, 0b	[200, 300, 400, 500, ∞)
	2 – 3j, 1b	[200, 300, 400, 500, ∞)
	2 – 3j, 2b	[200, 300, 400, 500, ∞)
	4 – 6j, 0b	[200, 300, 400, 500, ∞)
	4 – 6j, 1b	[200, 300, 400, 500, ∞)
	4 – 6j, 2b	[200, 300, 400, 500, ∞)
	≥ 7j, 0b	[200, 300, 400, ∞)
	≥ 7j, 1b	[200, 300, 400, ∞)
	≥ 7j, 2b	[200, 300, 400, ∞)
	2 – 6j, ≥ 3b	[200, 300, 400, 500, ∞)
	≥ 7j, ≥ 3b	[200, 300, 400, ∞)
[575, 1200)	2 – 3j, 0b	[200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, ∞)
	2 – 3j, 1b	[200, 300, 400, 600, 800, 1000, ∞)
	2 – 3j, 2b	[200, 300, 400, 600, 800, ∞)
	4 – 6j, 0b	[200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, ∞)
	4 – 6j, 1b	[200, 300, 400, 600, 800, 1000, ∞)
	4 – 6j, 2b	[200, 300, 400, 600, 800, ∞)
	2 – 6j, ≥ 3b	[200, 300, 400, 600, 800, ∞)
	7 – 9j, 0b	[200, 300, 400, 600, 800, ∞)
	7 – 9j, 1b	[200, 300, 400, 600, 800, ∞)
	7 – 9j, 2b	[200, 300, 400, 600, 800, ∞)
	7 – 9j, 3b	[200, 300, 400, 600, ∞)
	7 – 9j, ≥ 4b	[200, 300, 400, ∞)
	≥ 10j, 0b	[200, 300, 500, ∞)
	≥ 10j, 1b	[200, 300, 500, ∞)
	≥ 10j, 2b	[200, 300, 500, ∞)
	≥ 10j, 3b	[200, 300, ∞)
	≥ 10j, ≥ 4b	[200, ∞)

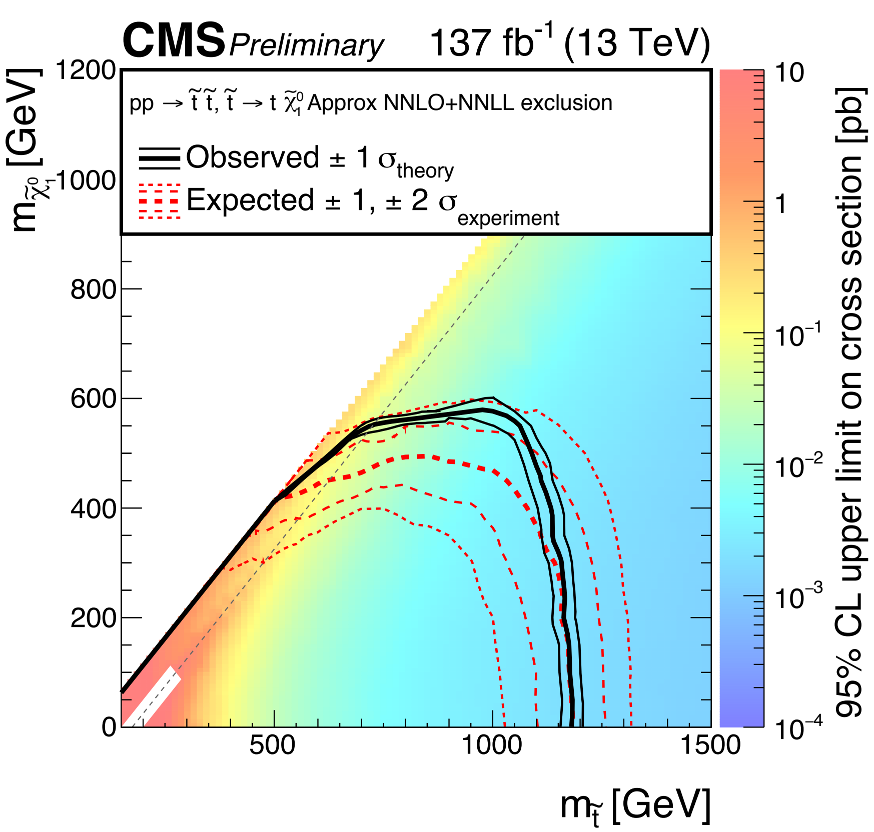
Source	Range [%]
Integrated luminosity	2.3–2.5
Limited size of MC samples	1–100
Renormalization and factorization scales	5
ISR modeling	0–30
b tagging efficiency, heavy flavors	0–40
b tagging efficiency, light flavors	0–20
Lepton efficiency	0–20
Jet energy scale	5
Fast simulation p_T^{miss} modeling	0–5

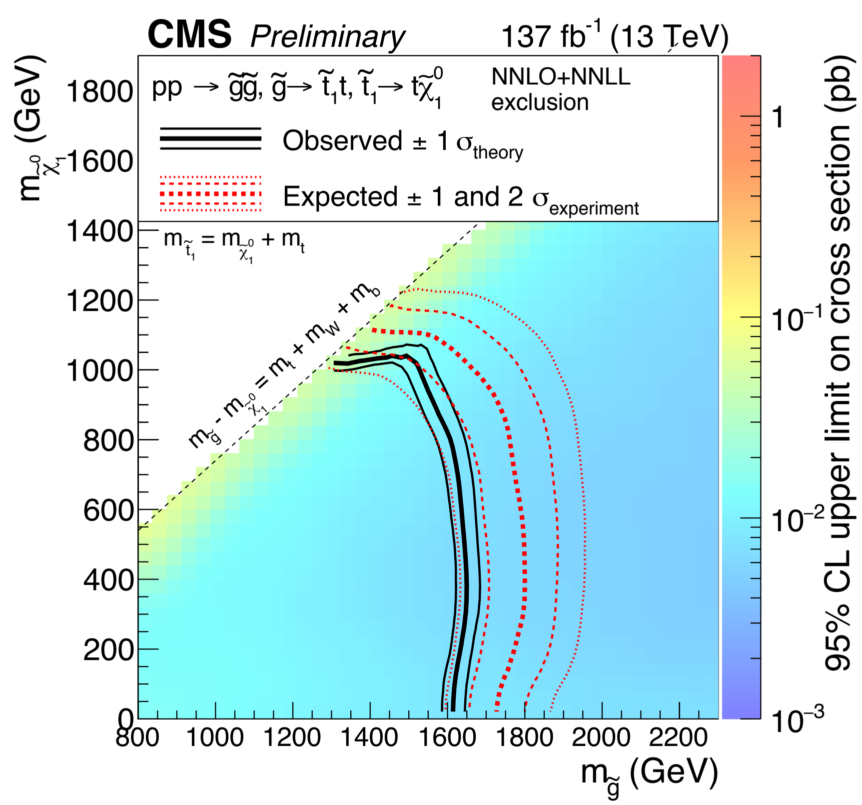
INCLUSIVE HADRONIC SEARCHES

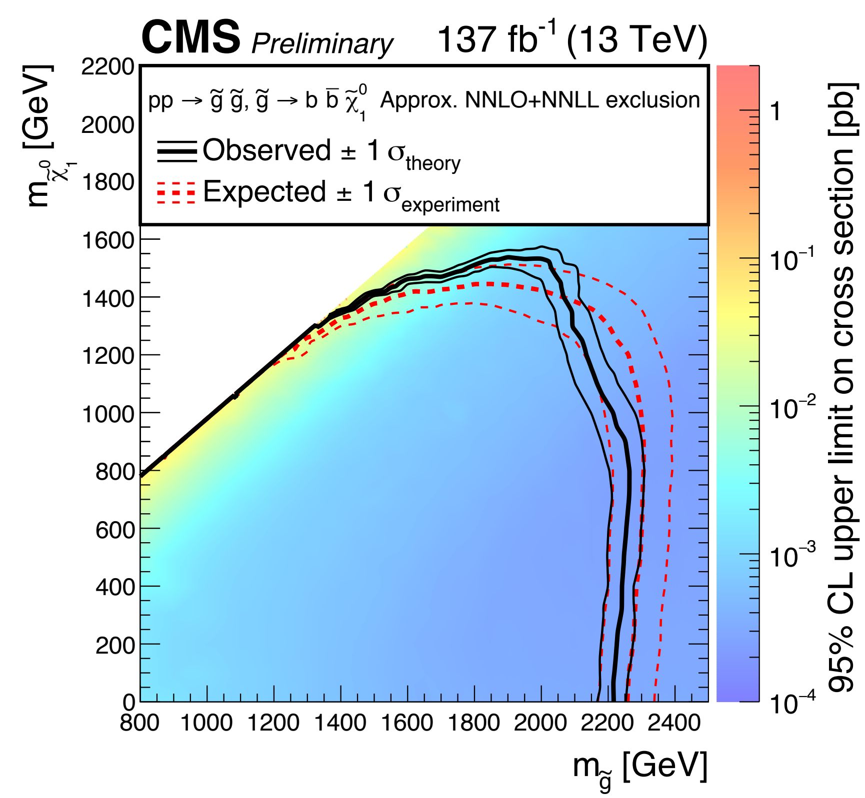




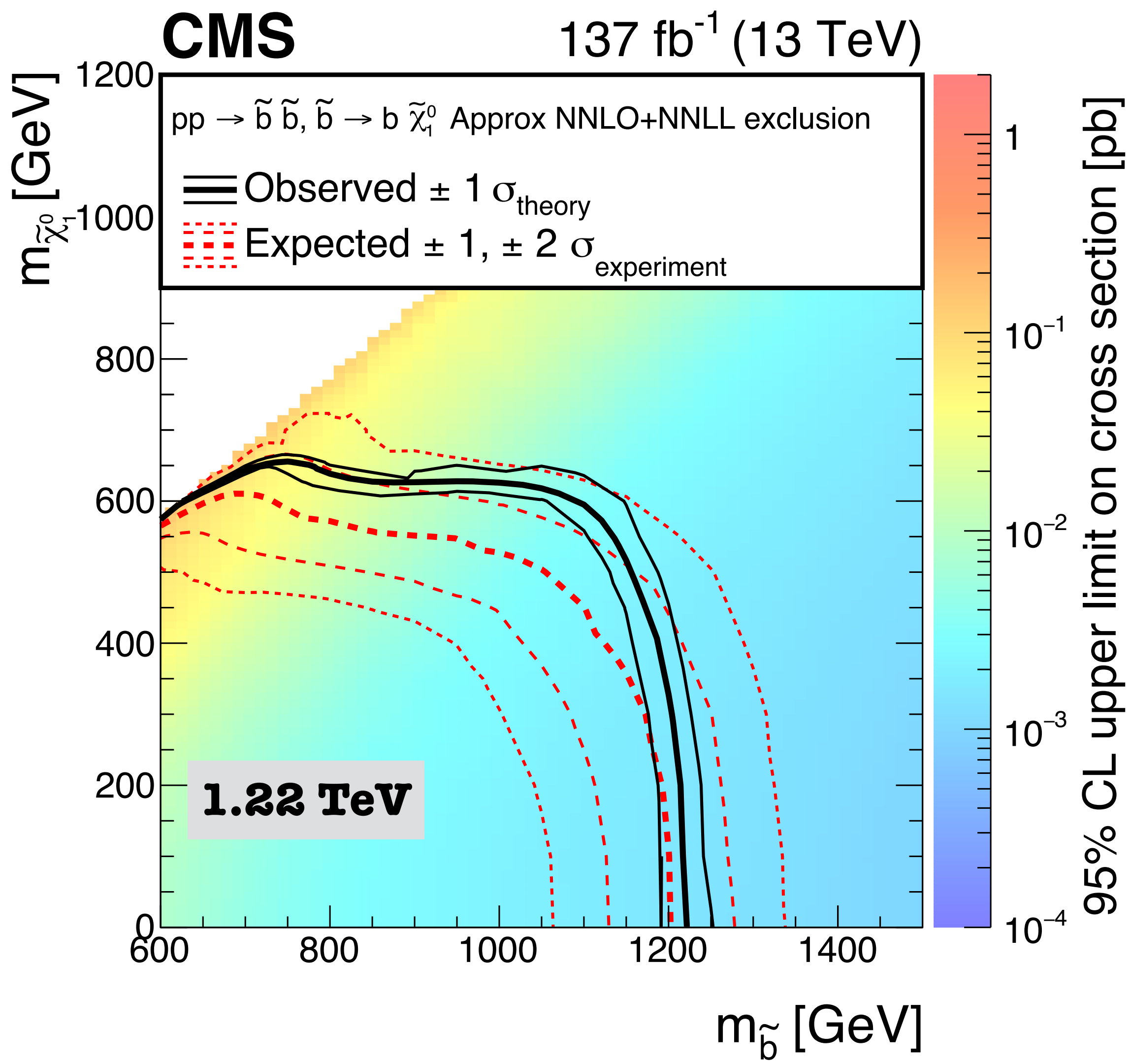


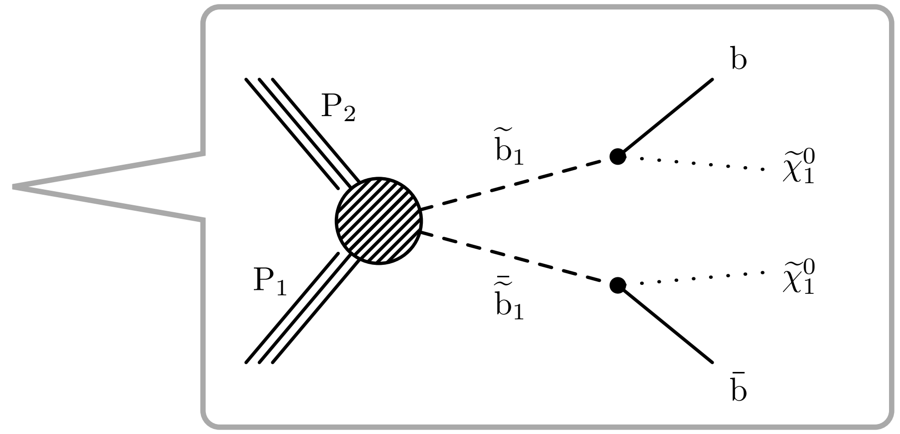


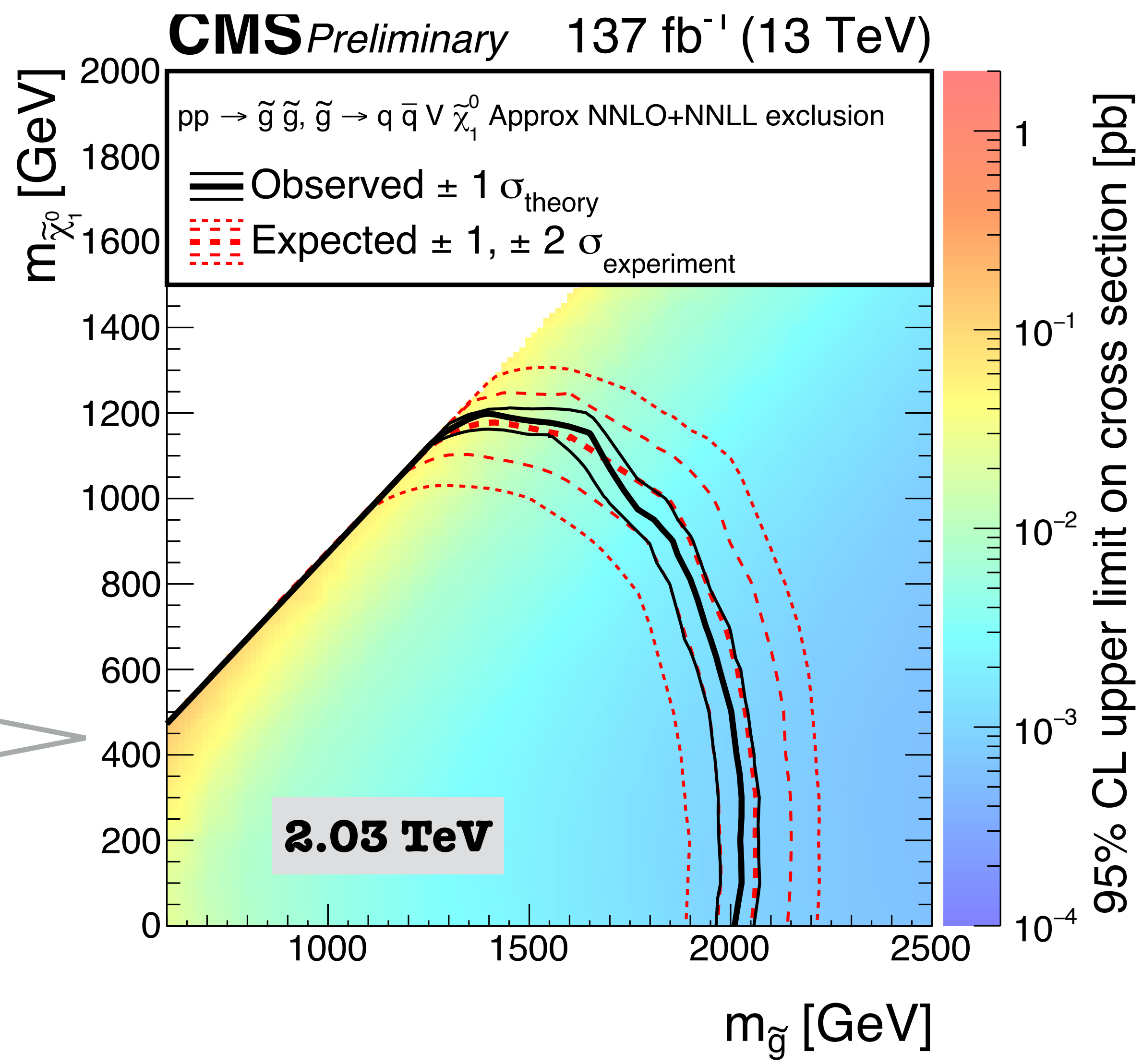


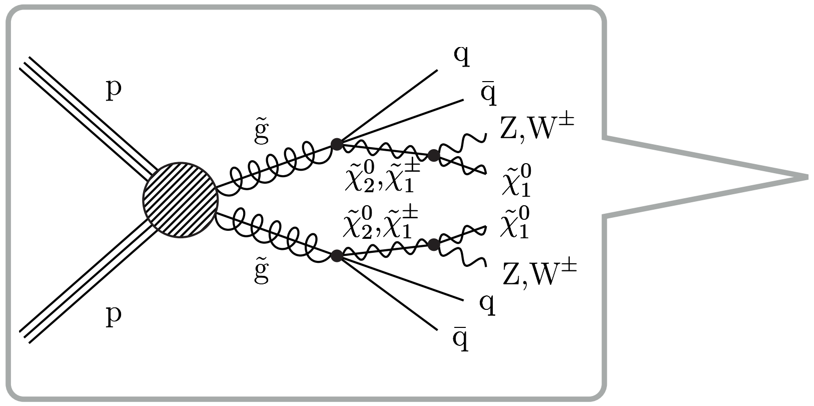


INCLUSIVE HADRONIC SEARCHES

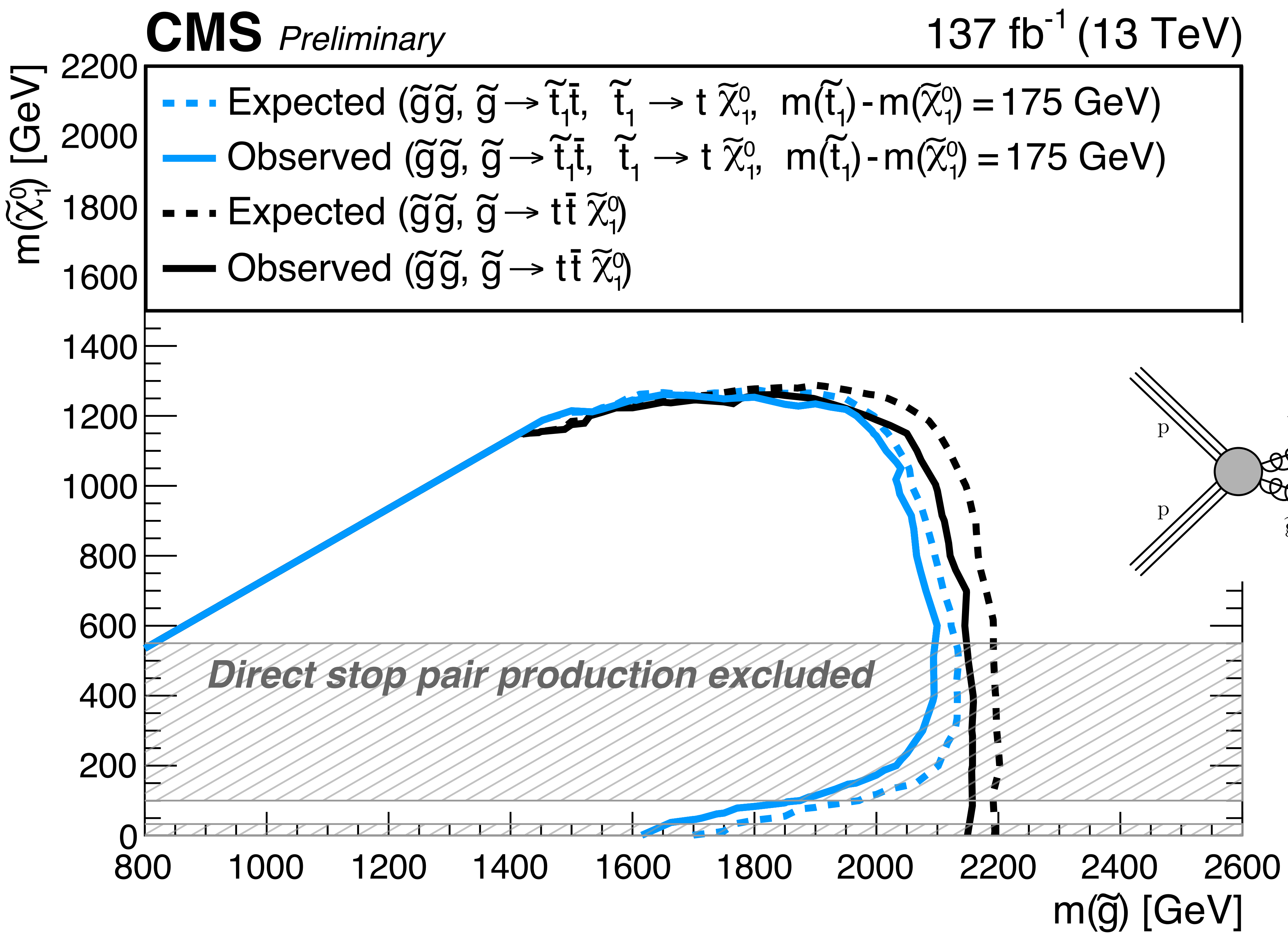


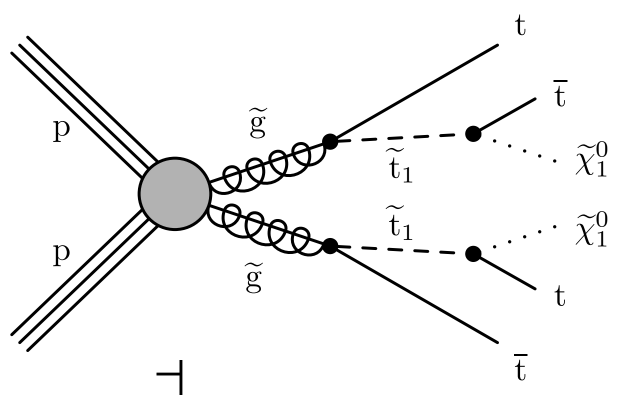




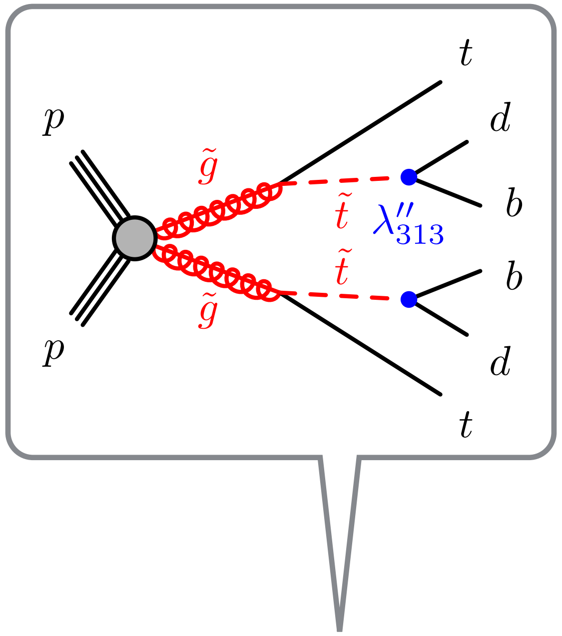


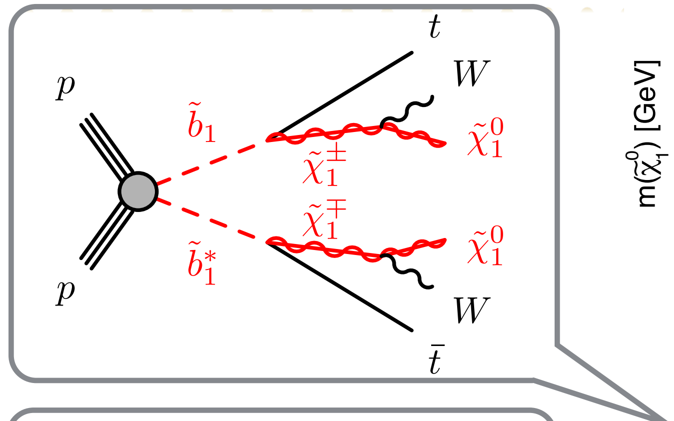
SEARCHES FOR GLUINOS WITH A LEPTON

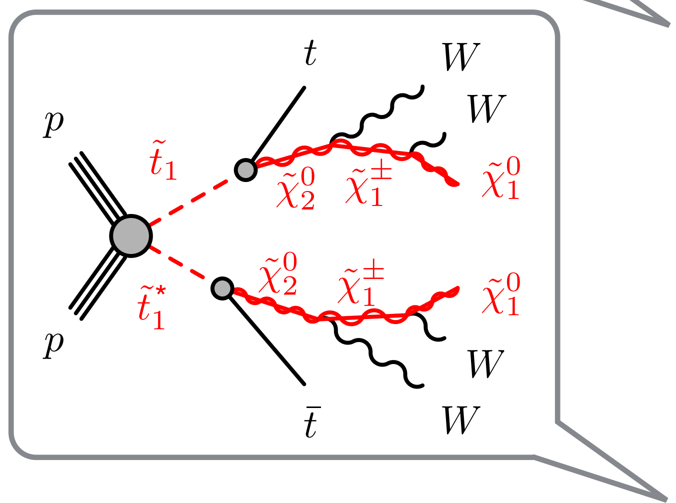


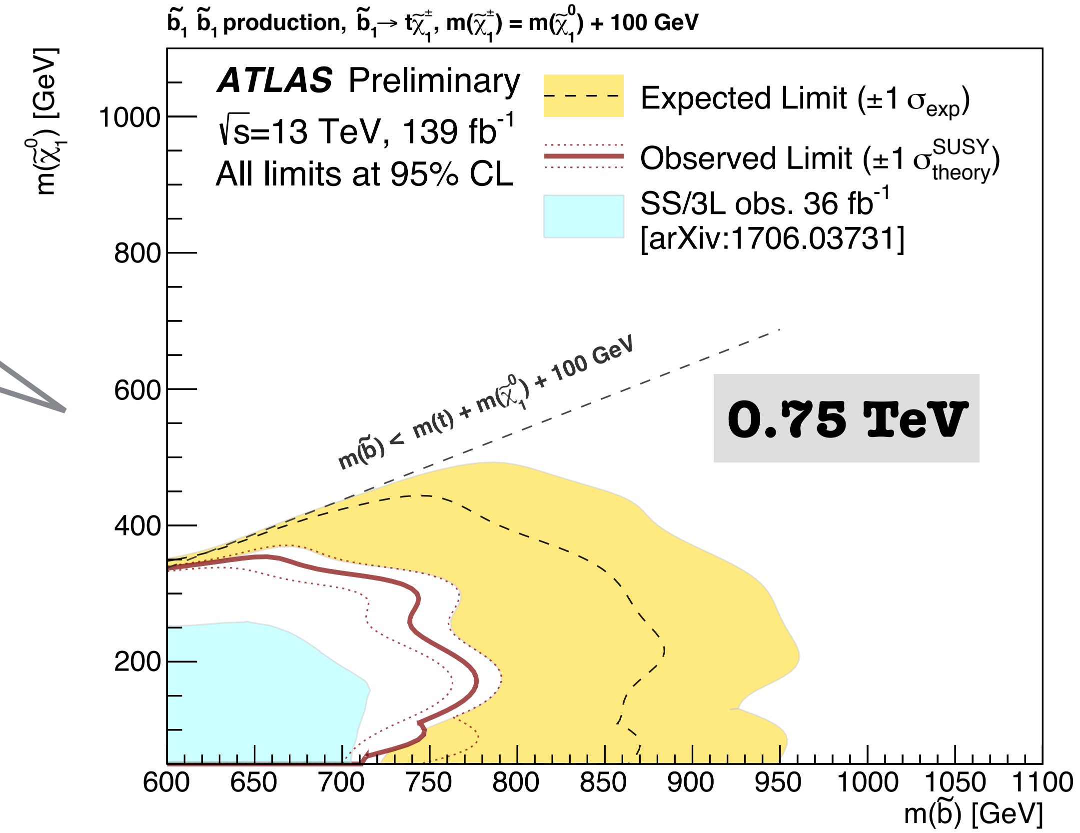


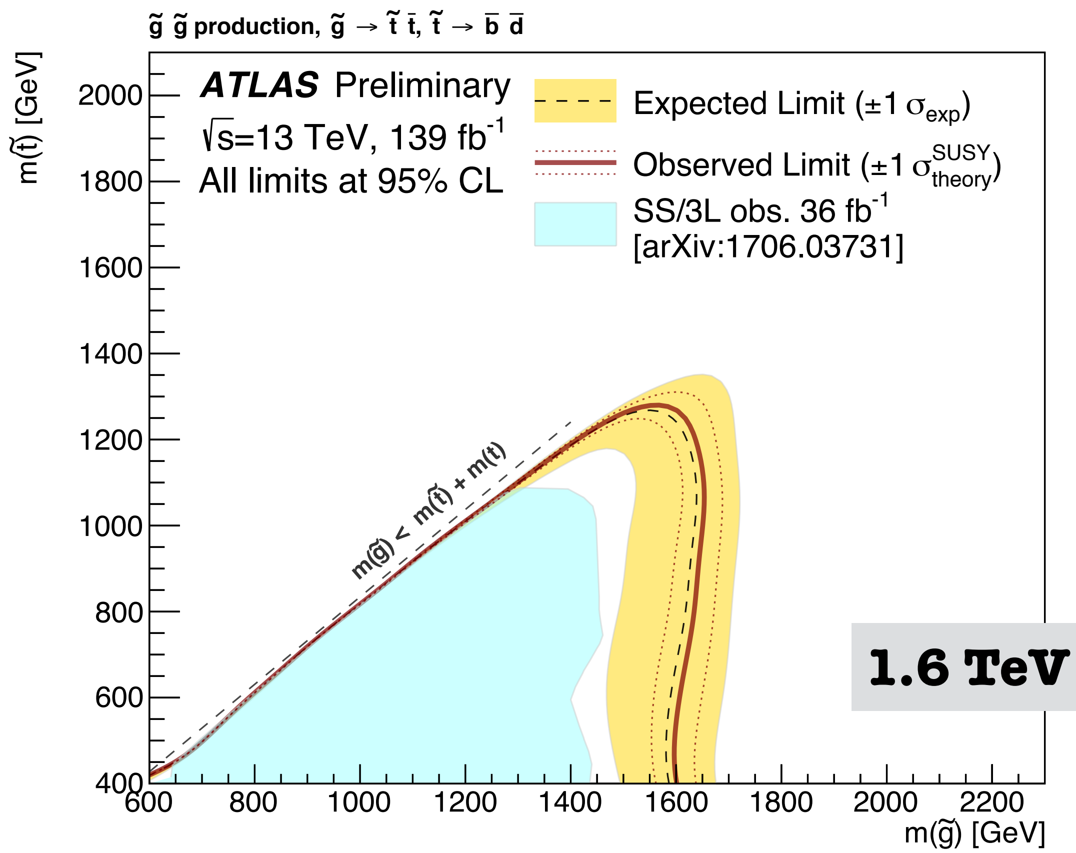
SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

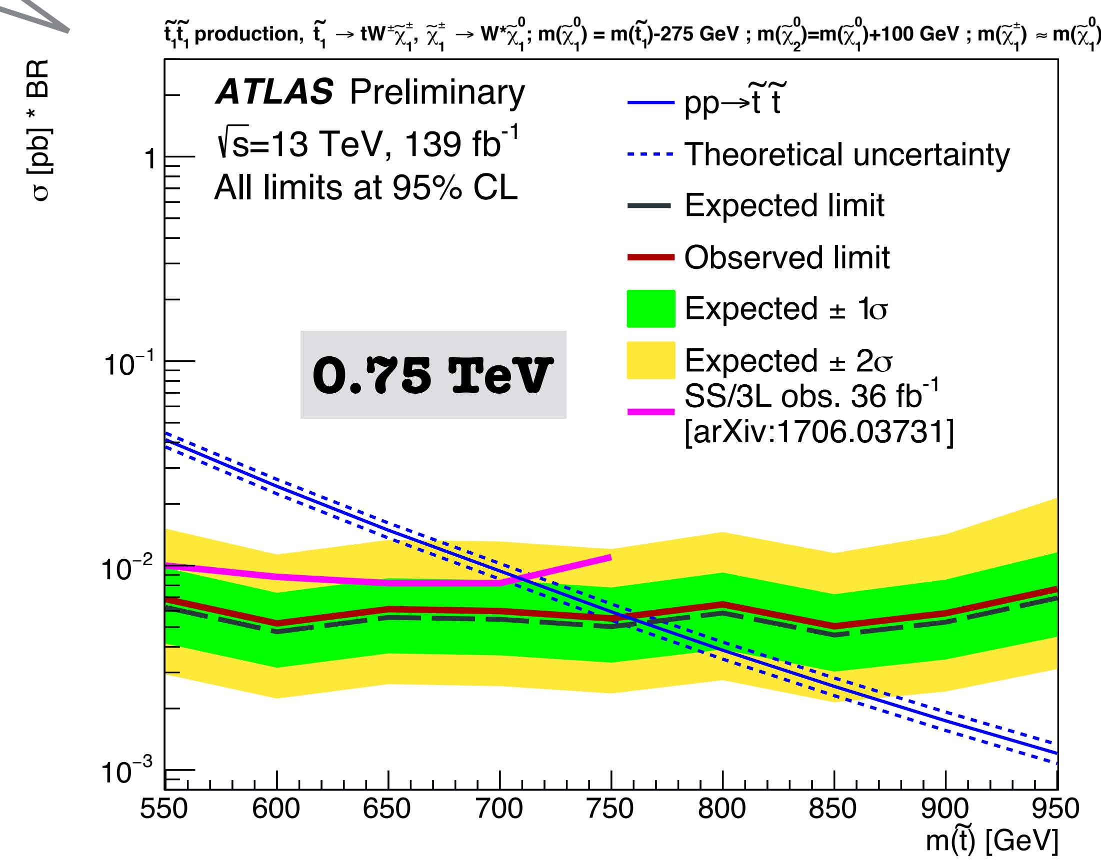




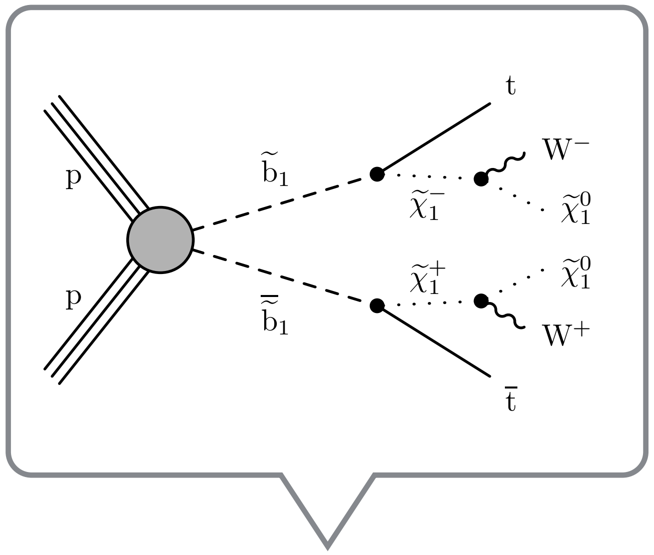


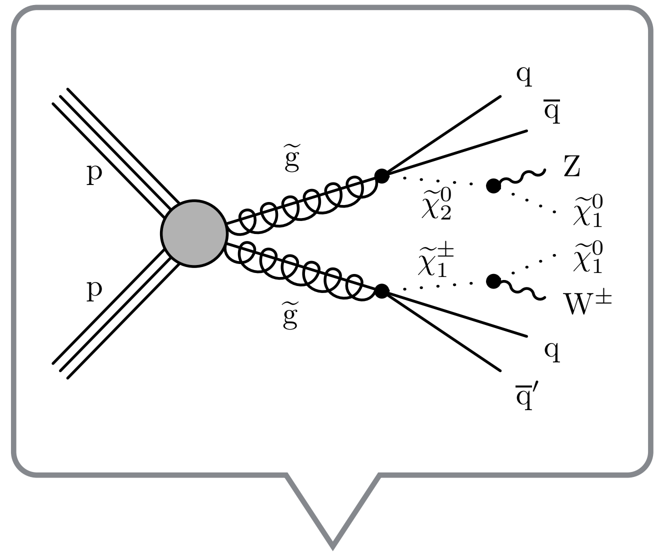


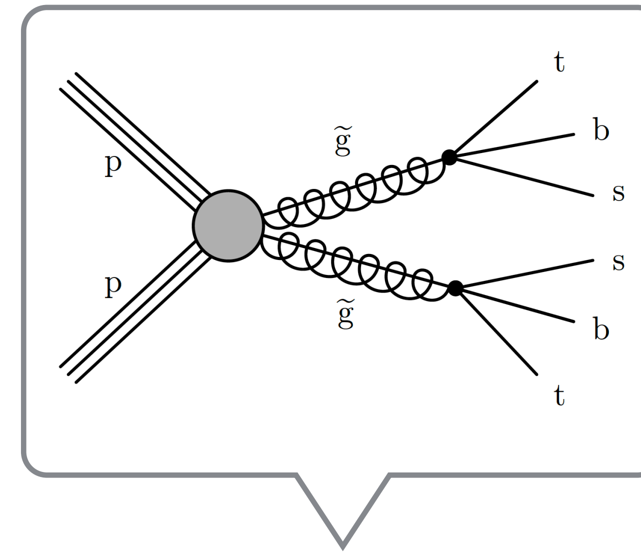


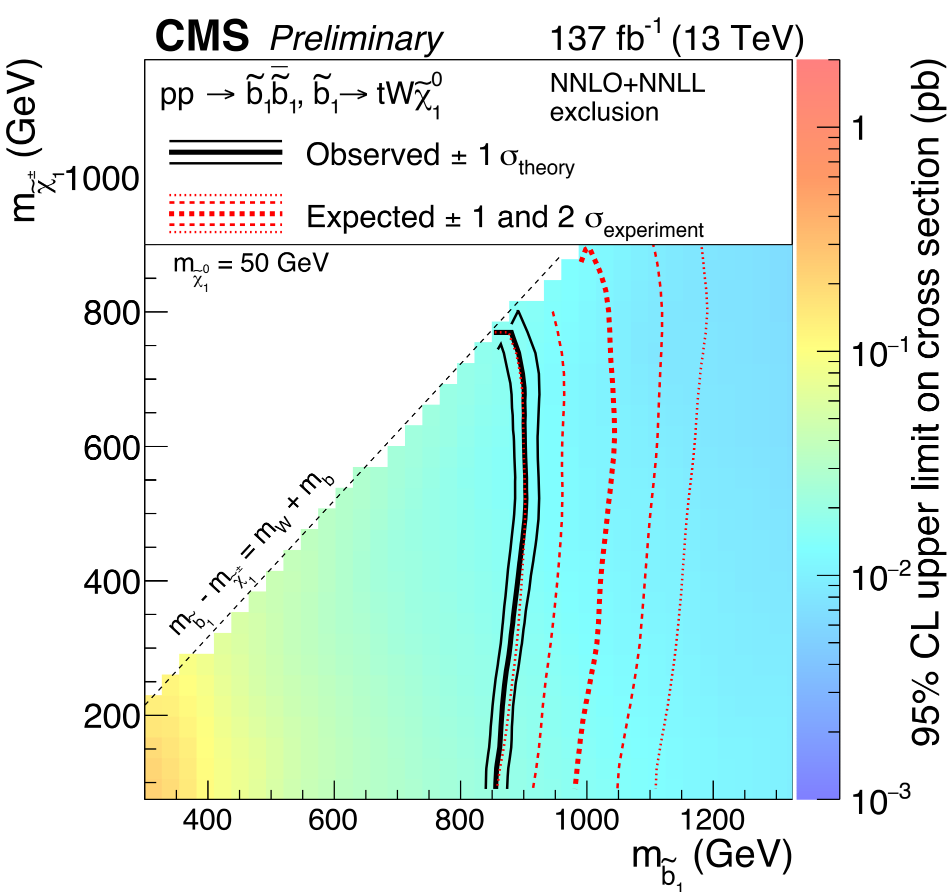


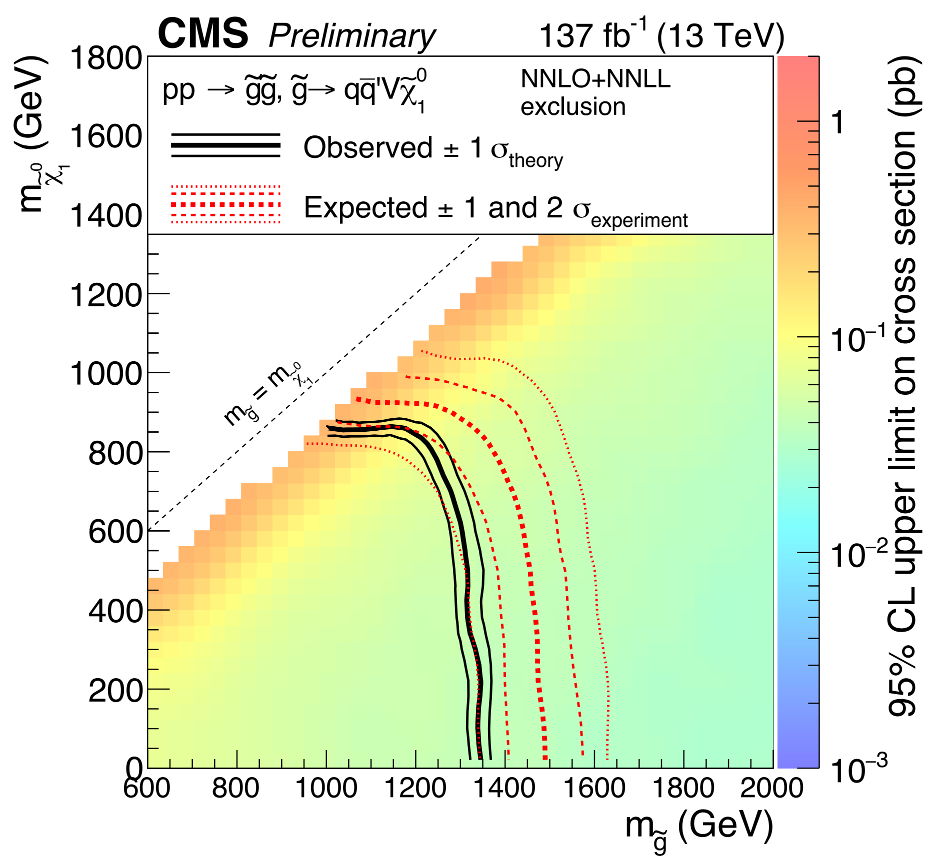
SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

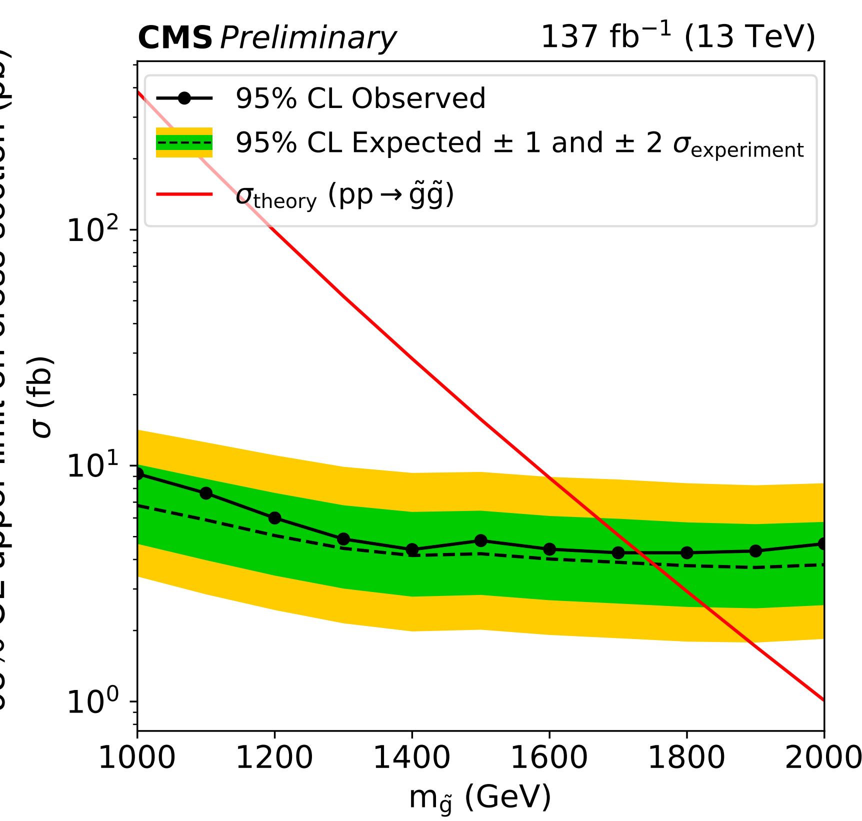




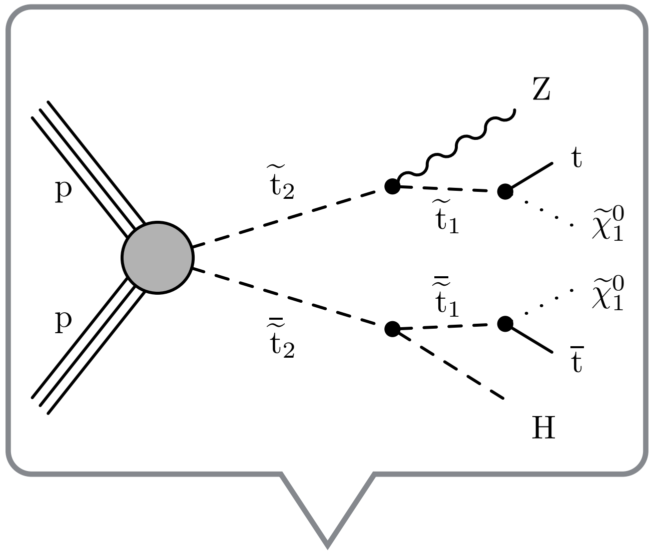


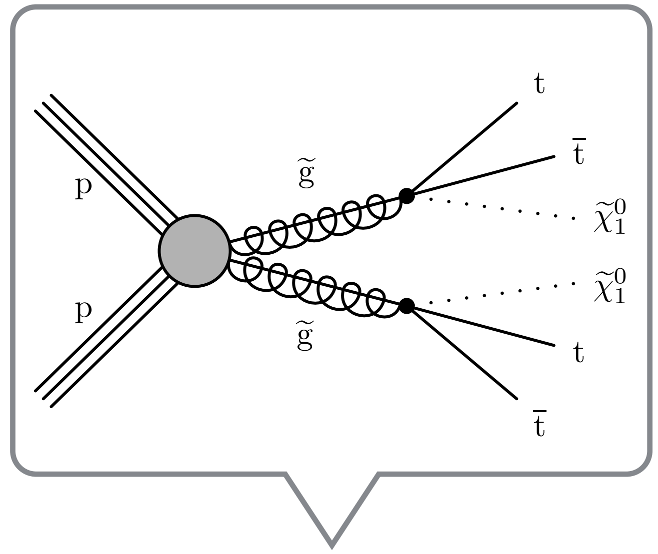


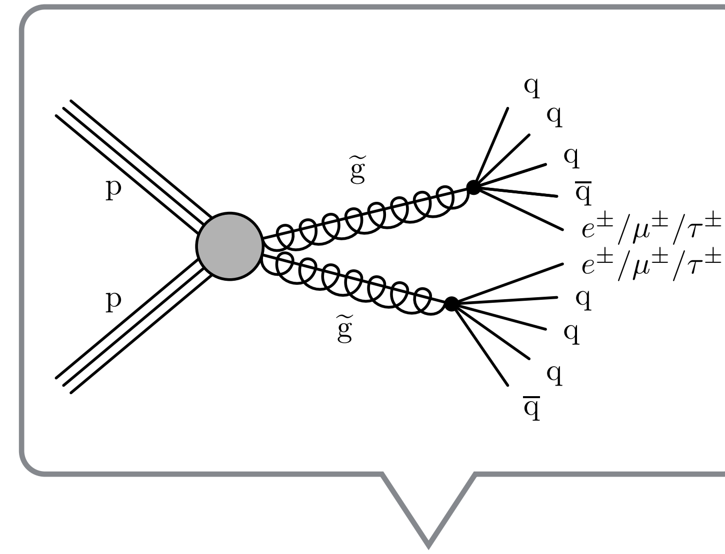


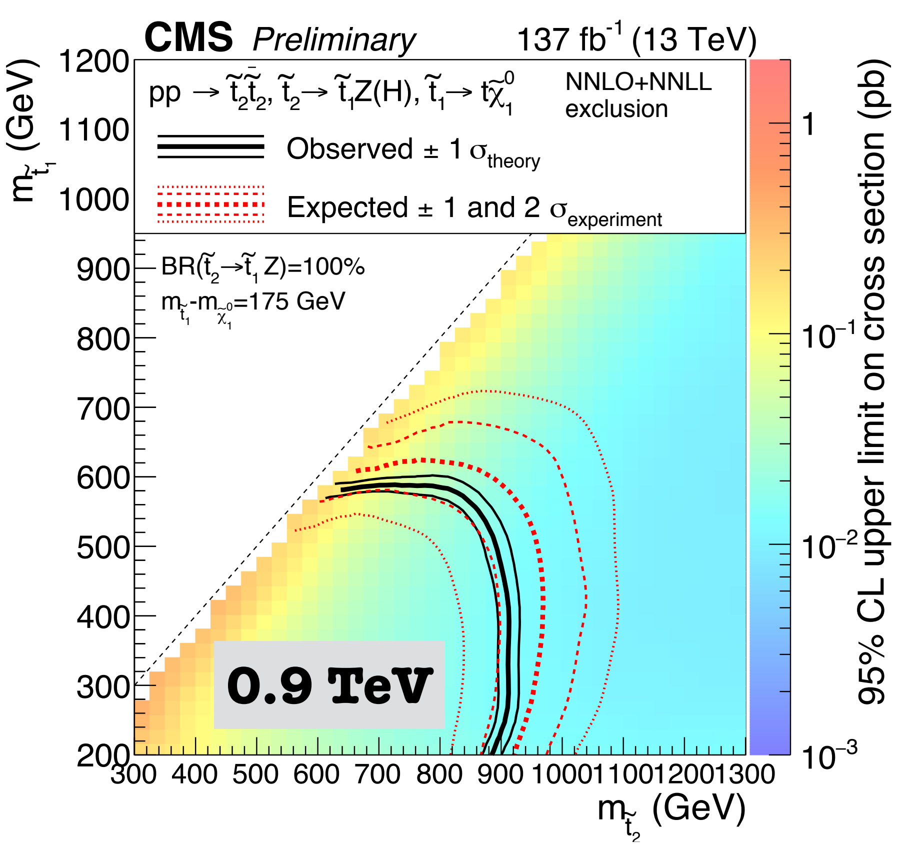


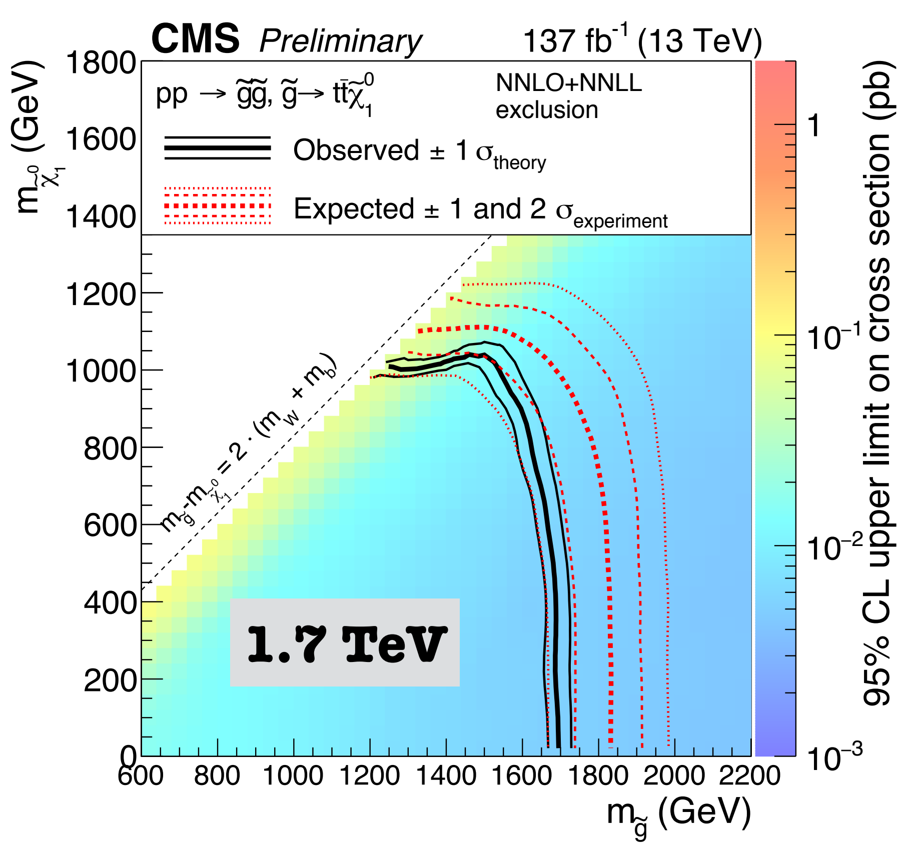
SEARCHES FOR SQUARKS AND GLUINOS WITH LEPTONS

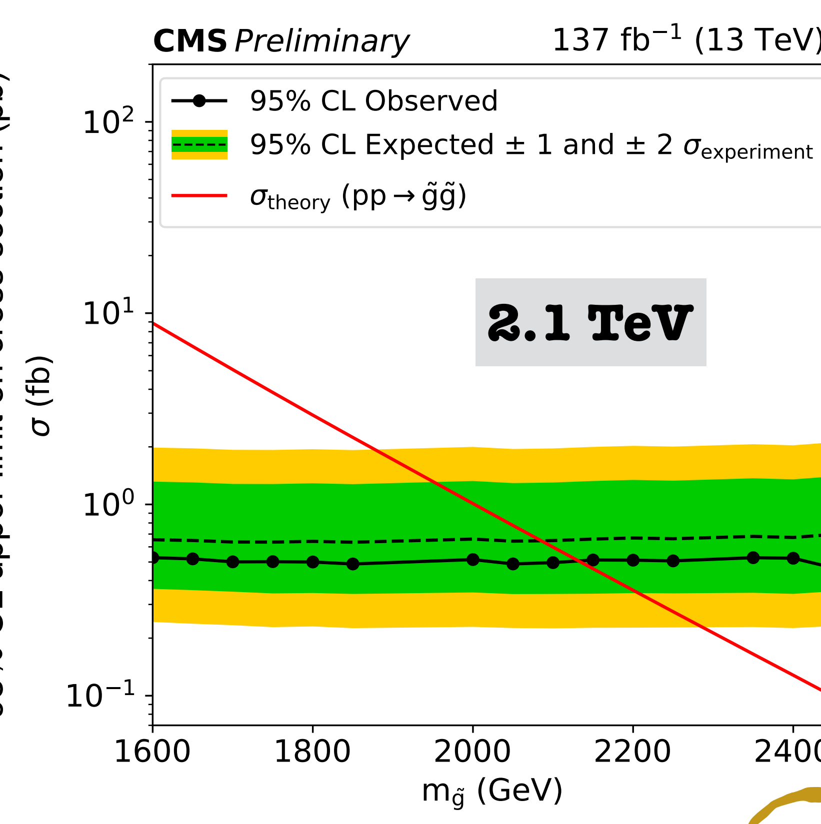












SEARCH FOR TOP SQUARKS WITH Z BOSONS

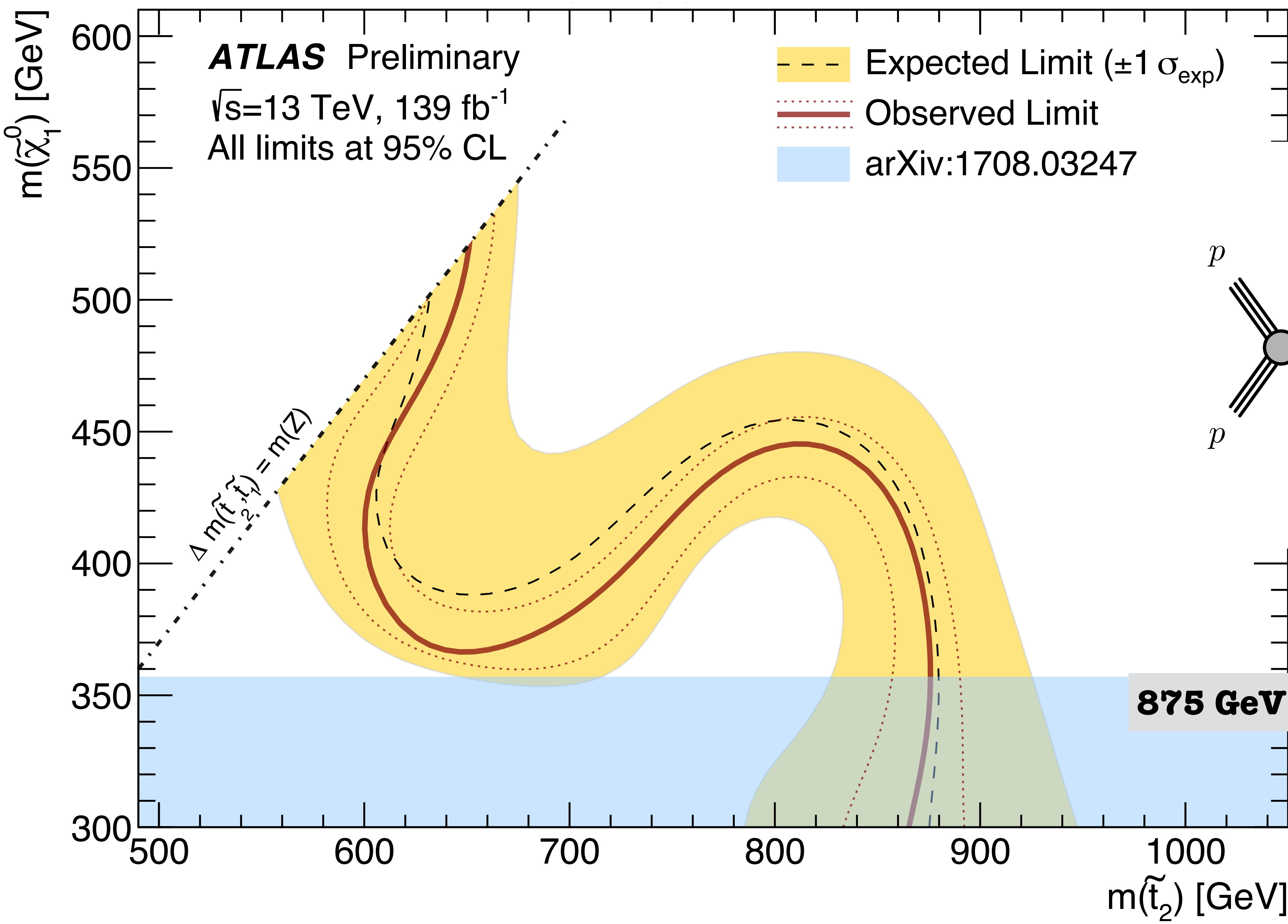
Requirement / Region	SR_{1A}	SR_{1B}	SR_{2A}	SR_{2B}
Third leading lepton p_T [GeV]	> 20	> 20	< 20	< 60
n_{jets} ($p_T > 30$ GeV)	≥ 4	≥ 5	≥ 3	≥ 3
$n_{b\text{-tagged jets}}$ ($p_T > 30$ GeV)	≥ 1	≥ 1	–	≥ 1
Leading jet p_T [GeV]	–	–	> 150	–
Leading b-tagged jet p_T [GeV]	–	> 100	–	–
E_T^{miss} [GeV]	> 250	> 150	> 200	> 350
$p_T^{\ell\ell}$ [GeV]	–	> 150	< 50	> 150
$m_{T2}^{3\ell}$ [GeV]	> 100	–	–	–

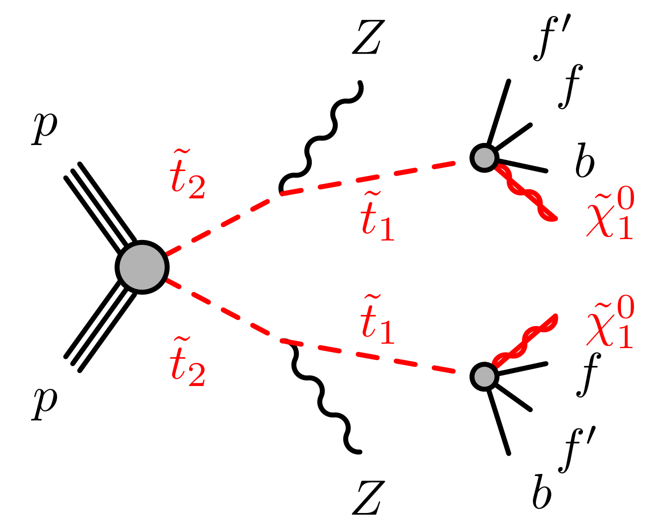
	SR_{1A}	SR_{1B}	SR_{2A}	SR_{2B}
Total systematic uncertainty (%)	13	13	29	15
Diboson theoretical uncertainties (%)	2	3	11	5
$t\bar{t}Z$ theoretical uncertainties (%)	3	6	4	5
Other theoretical uncertainties (%)	6	9	2	9
MC and FNP statistical uncertainties (%)	6	<1	14	7
Diboson fitted normalisation (%)	2	3	11	6
$t\bar{t}Z$ fitted normalisation (%)	5	9	2	7
Fake/non-prompt leptons efficiency (%)	4	<1	14	2
Jet energy resolution (%)	4	3	2	2
Jet energy scale (%)	1	4	<1	1
b-tagging (%)	3	5	1	5

	SR_{1A}	SR_{1B}	SR_{2A}	SR_{2B}
Observed events	3	14	3	6
Total (post-fit) SM events	5.4 ± 0.7	12.8 ± 1.6	5.7 ± 1.7	5.4 ± 0.8
Post-fit, multi-boson	0.50 ± 0.22	1.5 ± 0.5	2.7 ± 1.0	1.5 ± 0.6
Post-fit, $t\bar{t}Z$	2.5 ± 0.5	8.7 ± 1.6	0.73 ± 0.29	2.1 ± 0.5
Fake or non-prompt leptons	0.74 ± 0.24	0.04 ± 0.02	1.8 ± 1.1	0.65 ± 0.11
tZ, tWZ	0.9 ± 0.4	2.2 ± 1.2	0.19 ± 0.11	1.0 ± 0.5
Others	0.78 ± 0.17	0.37 ± 0.08	0.21 ± 0.06	0.16 ± 0.03
Pre-fit, multi-boson	0.59 ± 0.18	1.8 ± 0.5	3.2 ± 0.9	1.8 ± 0.4
Pre-fit, $t\bar{t}Z$	2.6 ± 0.4	8.9 ± 1.0	0.76 ± 0.27	2.2 ± 0.4
S_{obs}^{95}	4.6	10.9	4.9	7.0
S_{exp}^{95}	$6.1^{+2.5}_{-1.5}$	$9.4^{+3.3}_{-1.9}$	$6.2^{+2.5}_{-1.7}$	$6.5^{+2.5}_{-1.8}$
σ_{vis} [fb]	0.03	0.08	0.03	0.05
p_0	0.5	0.37	0.50	0.38

SEARCH FOR TOP SQUARKS WITH Z BOSONS

CONF-2019-016





SEARCH FOR TOP SQUARKS IN THE 3-BODY DECAY MODE

ATLAS EXPERIMENT

Input variable	Description
$E_{\mathrm{T}}^{\mathrm{miss}}$	Missing transverse energy
$\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	Azimuthal angle of the $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$
m_{T}	Transverse mass
$\Delta\phi(\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	Azimuthal angle between $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$ and lepton
m_{bl}	Invariant mass of leading b-tagged jet and lepton
$p_{\mathrm{T}}^{b_{jet}}$	Transverse momentum of the leading b-tagged jet
n_{jet}	Jet multiplicity
$n_{b-\mathrm{tag}}$	Number of b-tagged jets @ 77%
$p_{\mathrm{T}}(\ell)$	Transverse momentum of lepton
$\eta(\ell)$	Pseupdorapidity of lepton
$\phi(\ell)$	Azimuthal angle of lepton
$E(\ell)$	Energy of lepton

Architecture	Parameter set
Number of hidden layers	1
Neurons per hidden layer	128
Activation function	leaky relu ($\epsilon = 0.1$) [128]
Learning rate	10^{-3} [127]
Regularisation	$L2$ ($\lambda = 10^{-2}$) [123]
Weight initialisation	Glorot normal [129]
Batch size	32 [123]
Batch normalisation [130]	Yes

SEARCH FOR TOP SQUARKS WITH A LEPTON

Label	N_J	t_{mod}	$M_{\ell b}$ [GeV]	top tagging category	E_T^{miss} bins [GeV]
A0	2–3	≥ 10	< 175	–	[600, 750, $+\infty$]
A1				U	[350, 450, 600]
A2				M	[250, 600]
B			≥ 175	–	[250, 450, 700, $+\infty$]
C	≥ 4	< 0	< 175	–	[350, 450, 550, 650, 800, $+\infty$]
D			≥ 175	–	[250, 350, 450, 600, $+\infty$]
E0		0–10	< 175	–	[450, 600, $+\infty$]
E1				U	[250, 350, 450]
E2				M	[250, 350, 450]
E3				R	[250, 350, 450]
F			≥ 175	–	[250, 350, 450, $+\infty$]
G0		≥ 10	< 175	–	[450, 550, 750, $+\infty$]
G1				U	[250, 350, 450]
G2				M	[250, 350, 450]
G3				R	[250, 350, 450]
H			≥ 175	–	[250, 500, $+\infty$]

SEARCH FOR BOTTOM SQUARKS WITH DECAYS TO HIGGS

Variable	SRA	SRA-L	SRA-M	SRA-H
N_{leptons} (baseline)	$= 0$		$= 0$	
N_{jets}	≥ 6		≥ 6	
$N_{\text{b-jets}}$	≥ 4		≥ 4	
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 350		> 350	
$\min \Delta\phi(\text{jet}_{1-4}, \mathbf{p}_{\text{T}}^{\text{miss}})$ [rad]	> 0.4		> 0.4	
τ veto	Yes		Yes	
$p_{\text{T}}(b_1)$ [GeV]	> 200		> 200	
$\Delta R_{\text{max}}(b, b)$	¿ 2.5		¿ 2.5	
$\Delta R_{\text{max-min}}(b, b)$	¡ 2.5		¡ 2.5	
$m(h_{\text{cand}})$ [GeV]	> 80		> 80	
m_{eff} [TeV]	> 1.0	$\in [1.0, 1.5]$	$\in [1.5, 2.0]$	> 2.0

Variable	SRB
N_{leptons} (baseline)	$= 0$
N_{jets}	≥ 5
$N_{\text{b-jets}}$	≥ 4
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 350
$\min \Delta\phi(\text{jet}_{1-4}, \mathbf{p}_{\text{T}}^{\text{miss}})$ [rad]	> 0.4
τ veto	Yes
$m(h_{\text{cand1}}, h_{\text{cand2}})_{\text{avg}}$ [GeV]	$\in [75, 175]$
leading jet not b-tagged	Yes
$p_{\text{T}}(j_1)$ [GeV]	> 350
$\lvert\Delta\phi(j_1, E_{\text{T}}^{\text{miss}})\rvert$ [rad]	> 2.8
m_{eff} [TeV]	> 1

Variable	SRC	SRC22	SRC24	SRC26	SRC28
N_{leptons} (baseline)	$= 0$		$= 0$		
N_{jets}	≥ 4		≥ 4		
$N_{\text{b-jets}}$	≥ 3		≥ 3		
$E_{\text{T}}^{\text{miss}}$ [GeV]	> 250		> 250		
$\min \Delta\phi(\text{jet}_{1-4}, \mathbf{p}_{\text{T}}^{\text{miss}})$ [rad]	> 0.4		> 0.4		
$\mathcal{S}$	> 22	$\in [22, 24]$	$\in [24, 26]$	$\in [26, 28]$	> 28