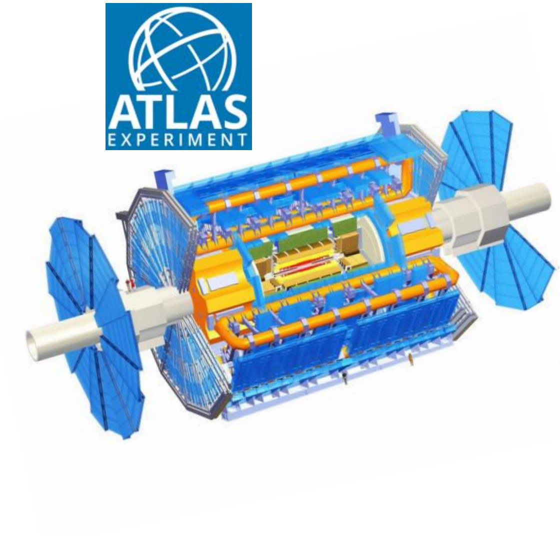
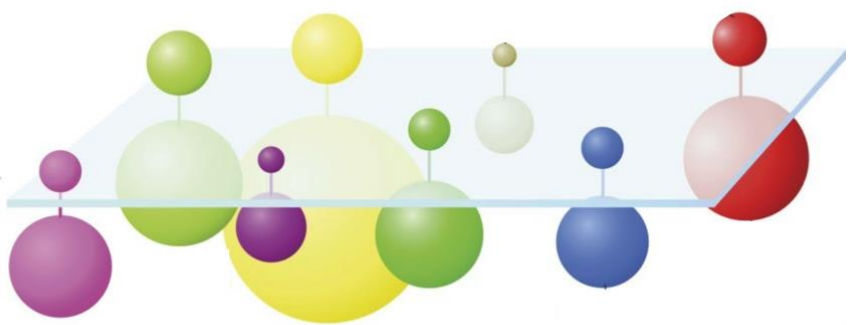
21st Dec 2018

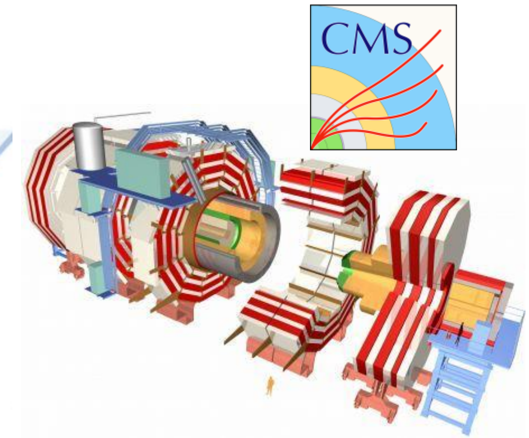
The 4th China LHC Physics Workshop (CLHCP 2018)

Wuhan, Central China Normal University

Searches for SUSY at LHC, Run-II







PEKING UNIVERSITY

Antonis Agapitos

Outline

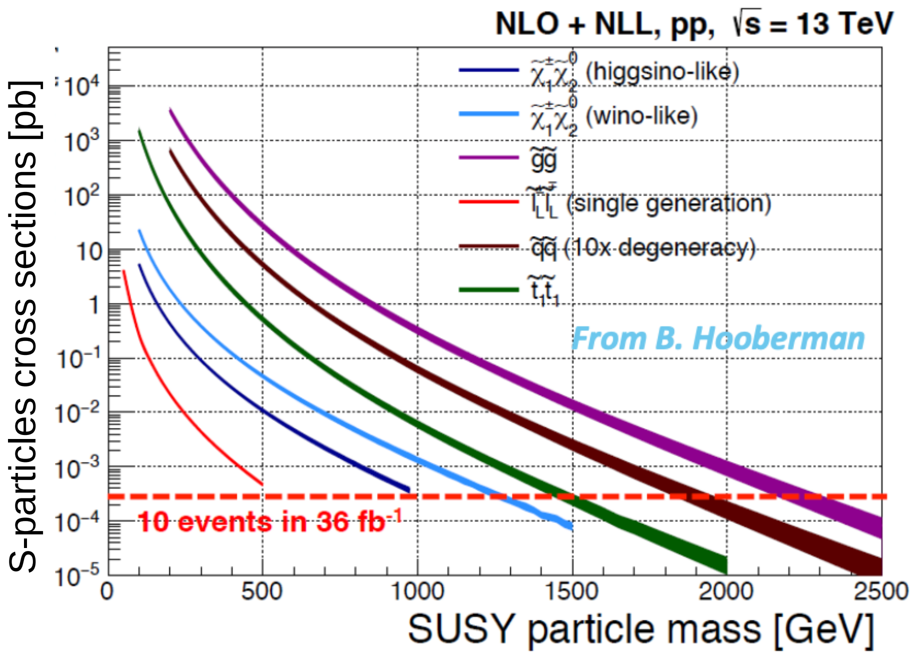
- Disclaimer: It is impossible to cover all Run-2 results in ~20 min
- Focus only on highlight results of the last ~1-2 years from ATLAS & CMS (Personal biases are unavoidable at this mission)

Talk's structure:

1. STRONGLY produced SUSY:
   - Gluino direct production
   - Stop (& squark) direct production

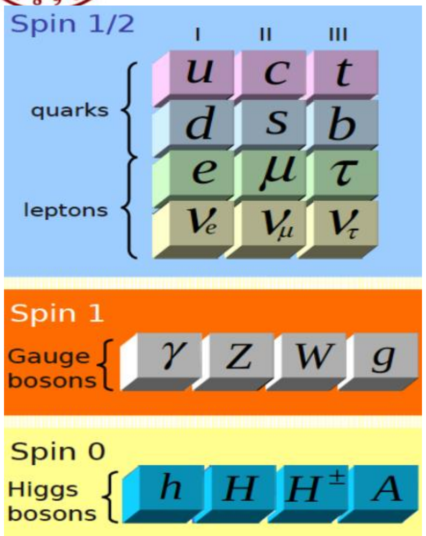
2. ELECTROWEAK production:
   - Chargino-Neutralino production
   - Higgsinos / sleptons

3. REST SUSY:
   - RPV
   - GMSB



→ Focus: Signal signatures features, event selection, exclusion limits
→ Skip: physics objects, prediction methods, simulations, systematics treatment
→ Spoiler: No statistically significant excess of events; no evidence of SUSY (yet)

Why SUSY? A bit of motivation…

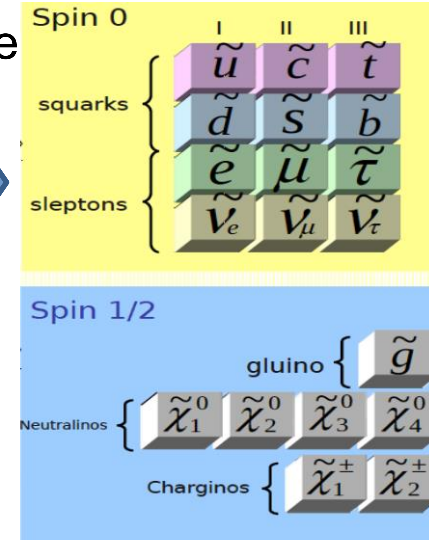


SUSY proposed as a "New Principle" of Nature

Spin-based symmetry [Δspin = ½]
linking fermions(matter) to bosons(forces)

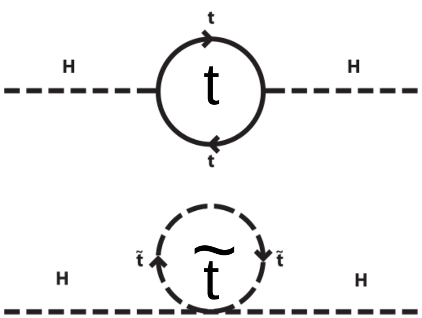
It is a whole framework, not a model (MSSM)
Same couplings as in SM but unknown flavor mixing, masses, couplings & BRs…

$M_{\text{SM-particle}}$ < or << $M_{\text{SUSY-Sparticle}}$



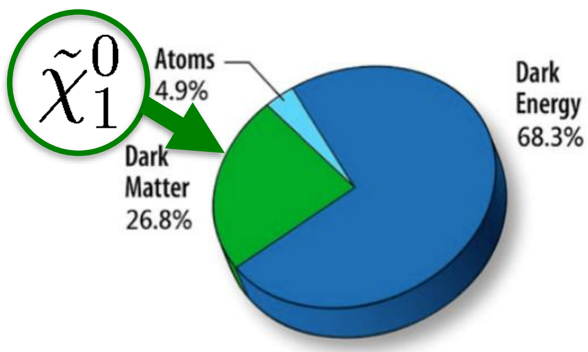
SUSY proposes solutions to three SM shortcomings:

◆ Hierarchy Problem



Sparticle loops cancel out corrections (if Λ_{cut}~< 1 TeV)

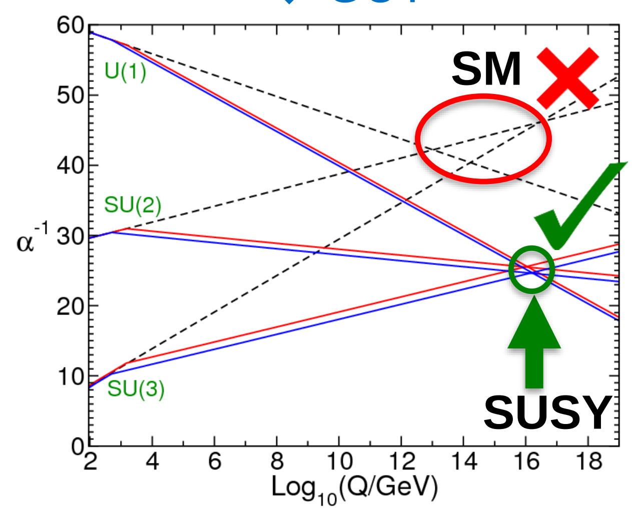
◆ Dark Matter



$P_R=(-1)^{2S+3(B+L)}$

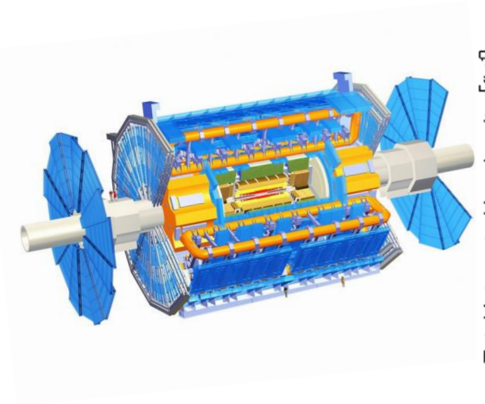
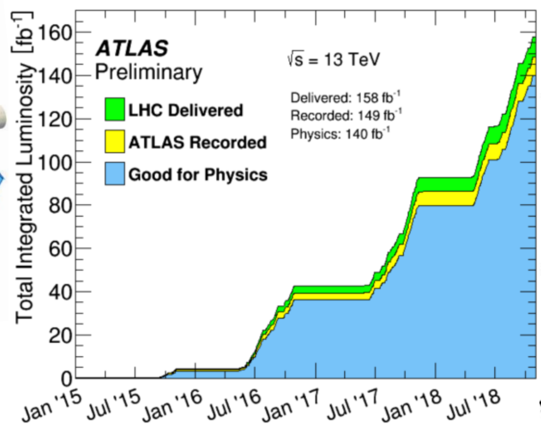
If "R-parity" conserved
LSP → DM candidate

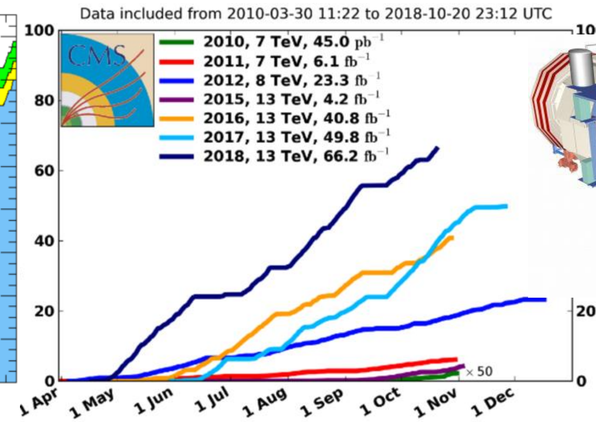
◆ GUT

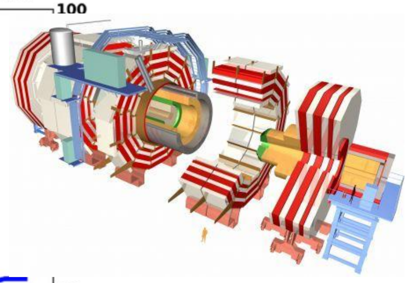


a^{-i} converges @~10^{16} GeV

Run-2: 2015-2018, Int.Lumi: 2x140 fb^{-1}

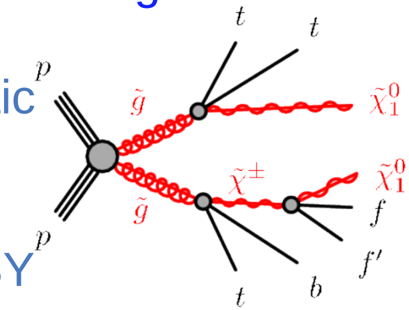


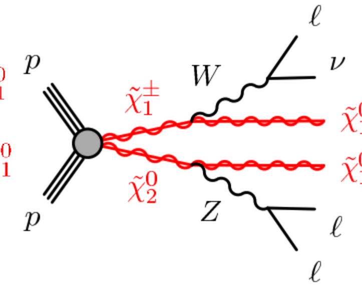


- ATLAS & CMS have recorded ~150 fb^{-1} of data (each) during Run-2
- ~140 fb^{-1}/experiment certified as “good” for physics.
- Only a few have been analyzed for the moment (~26%, 36 fb^{-1}, basically 2016 data)
  → Moriond 2019, on March, will probably hosts (some) full Run-2 results
- This talk includes mainly results with these ~26% (36 fb^{-1}) of Run-2 data.
  → not the best moment for Run-2 (strong) conclusions on SUSY…

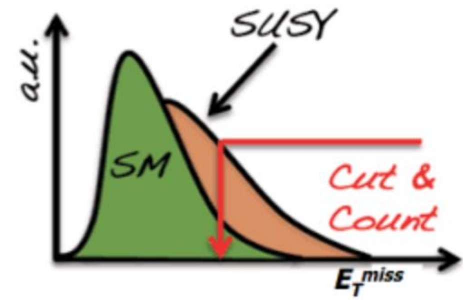
How to…

Look for an excess of events at the tails of discriminating variables.





1. Exploitation of signal Final State (SF) kinematic features to distinguish from the background:
   → jets, t, b, MET, l, …
   → 2 LSPs main common feature of RPC SUSY leading to significant MET
   → Use sophisticated variables, and/or MVA techniques, hybrid physics objects for this

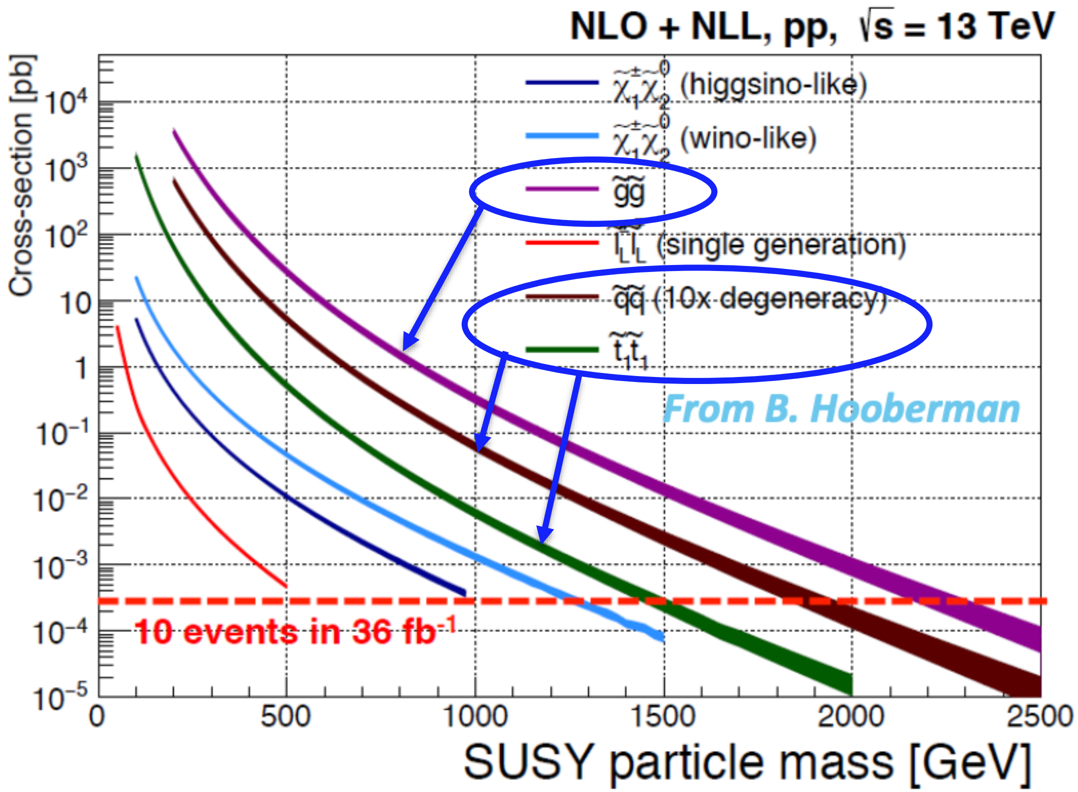


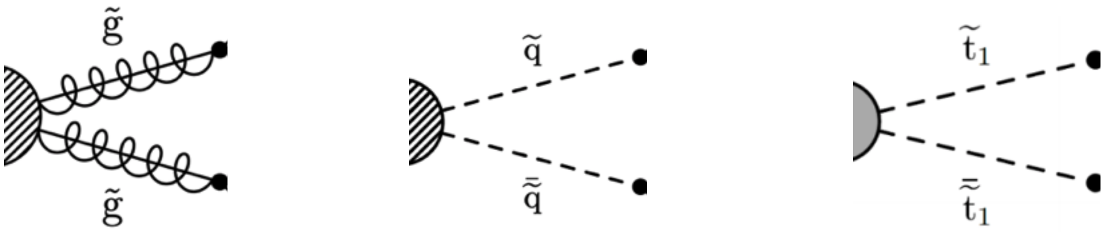
2. Implement cut & count selection (or MVA) to suppress SM background → Divide in many bins (observables) to enhance sensitivity

3. Perform Data-Driven (MC-based) SM background prediction.

4. Derive statistical inferences (exclusion limits) on sparticles masses involved in each studied process. (Using "Simplified Models" for this)

1) “Strong” SUSY production

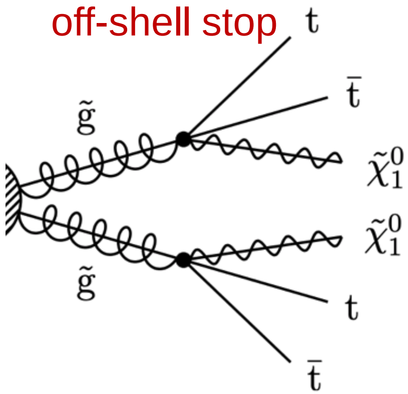




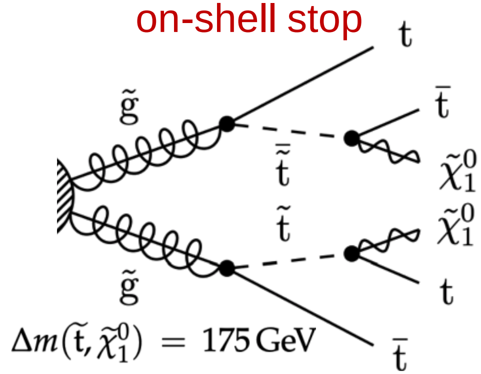
Direct production of gluino-pair (map)

Decay with stop (stop-induced):

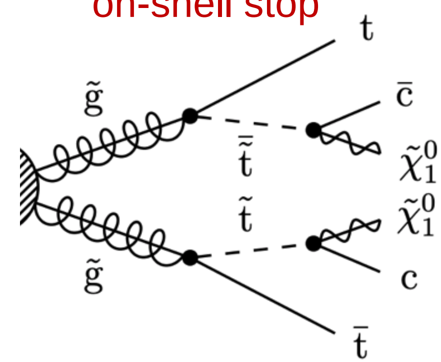
off-shell stop



on-shell stop

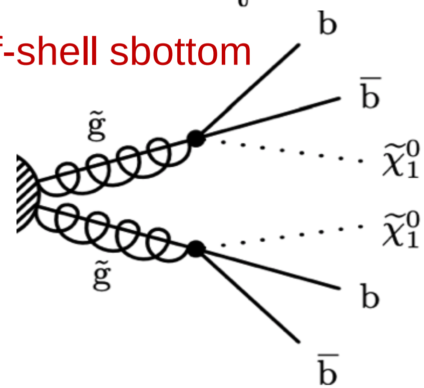


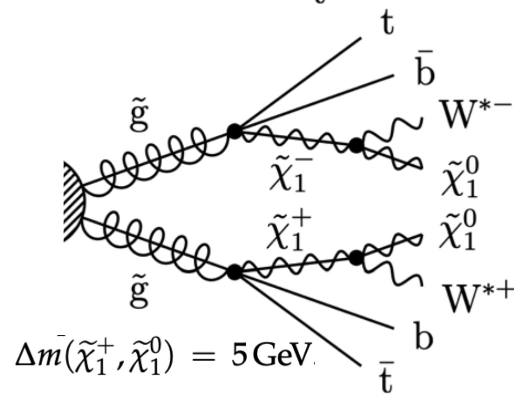
on-shell stop



Decays with sbottoms or with charginos

off-shell sbottom





Mixtures of decays also considered:

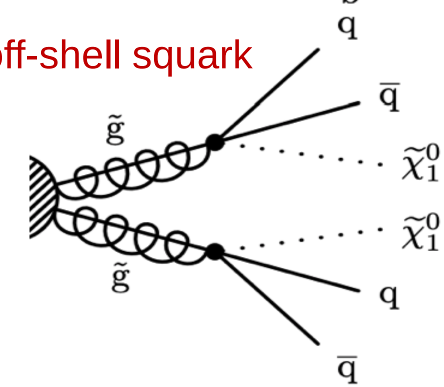
$\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_1^0$ (25%)

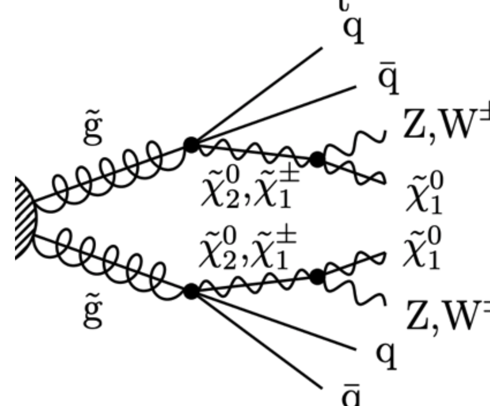
$\tilde{g} \rightarrow \bar{t}b\tilde{\chi}_1^+$ +cc (50%)

$\tilde{g} \rightarrow b\bar{b}\tilde{\chi}_1^0$ (25%)

Decays with non-3rd generation squark

off-shell squark

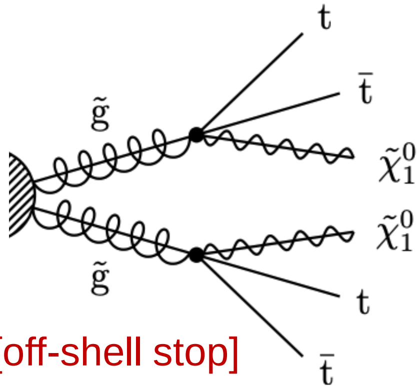




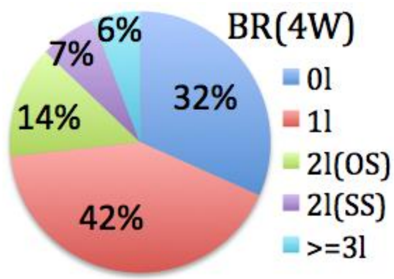
$\tilde{\chi}_2^0$, $\tilde{\chi}_1^+$, or $\tilde{\chi}_1^-$ is 1/3 for each on- or off-shell Z ($W^{\pm}$) boson

Main features: → 2 LSPs, many jets, many t/b-quarks, t→Wb so many W-bosons in FS

Search for gluino-pair (with stops*)

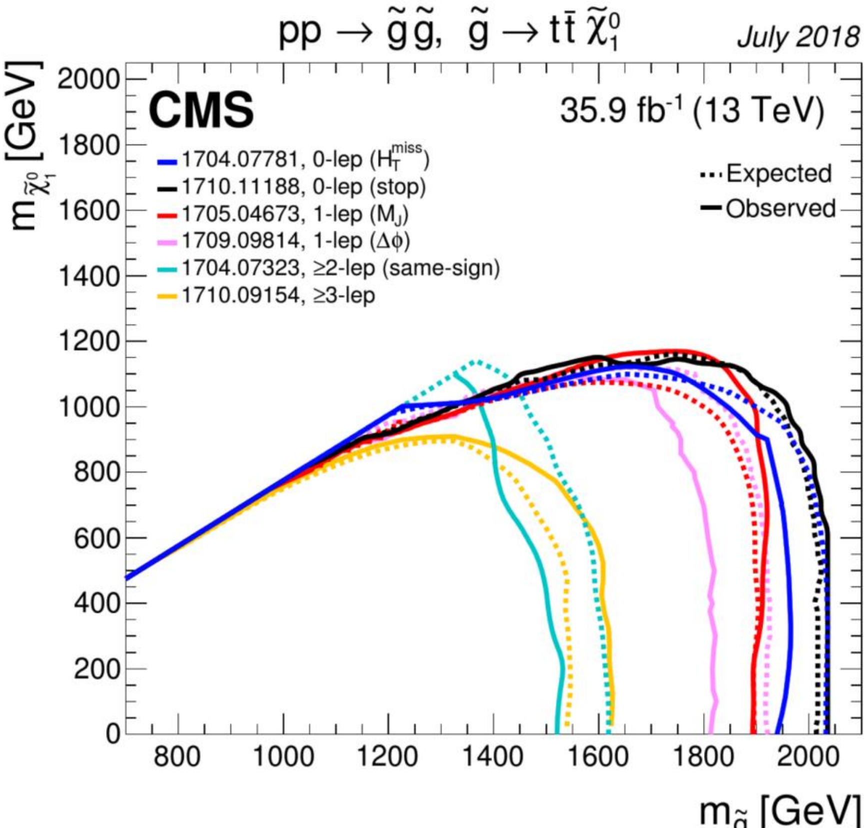


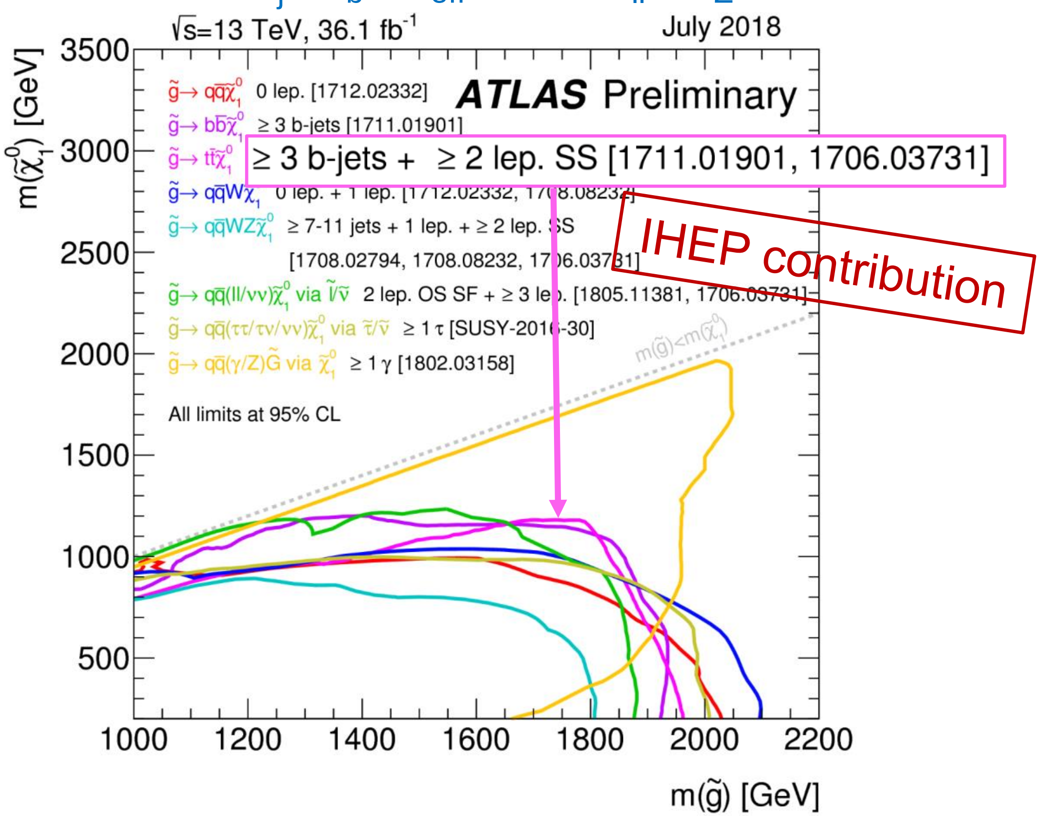
[off-shell stop]



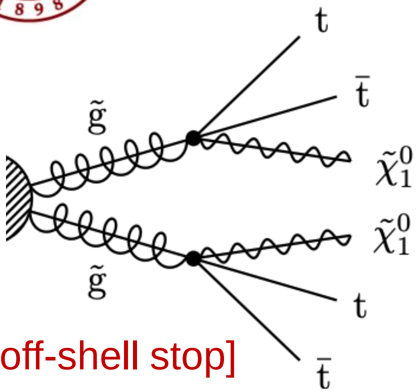
Atlas limits: Using all Final States (FS) in combination.
Very generic searches to probe multiple FSs

- 1711.01901: 0l & >=1l, MET, N_j, N_b>=3, M_{eff}, $M_{T(l,MET)}$, $M_T^{min}{}_{(b,MET)}$, M_J^{Σ}
- 1706.03731: 2l(SS) or >=3l, MET, N_j, N_b, M_{eff}, veto M_{ll}~M_Z →19 bins





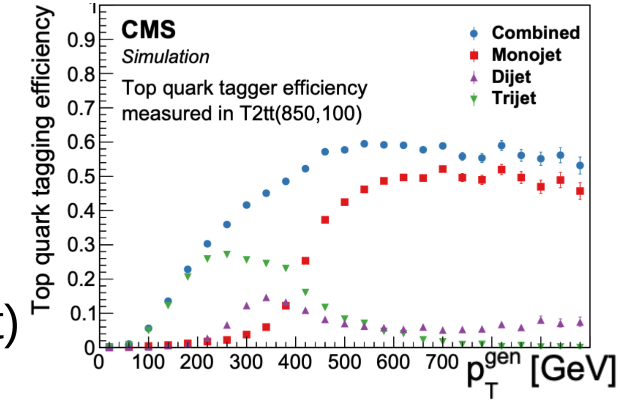
Search for gluino-pair with top-tagging

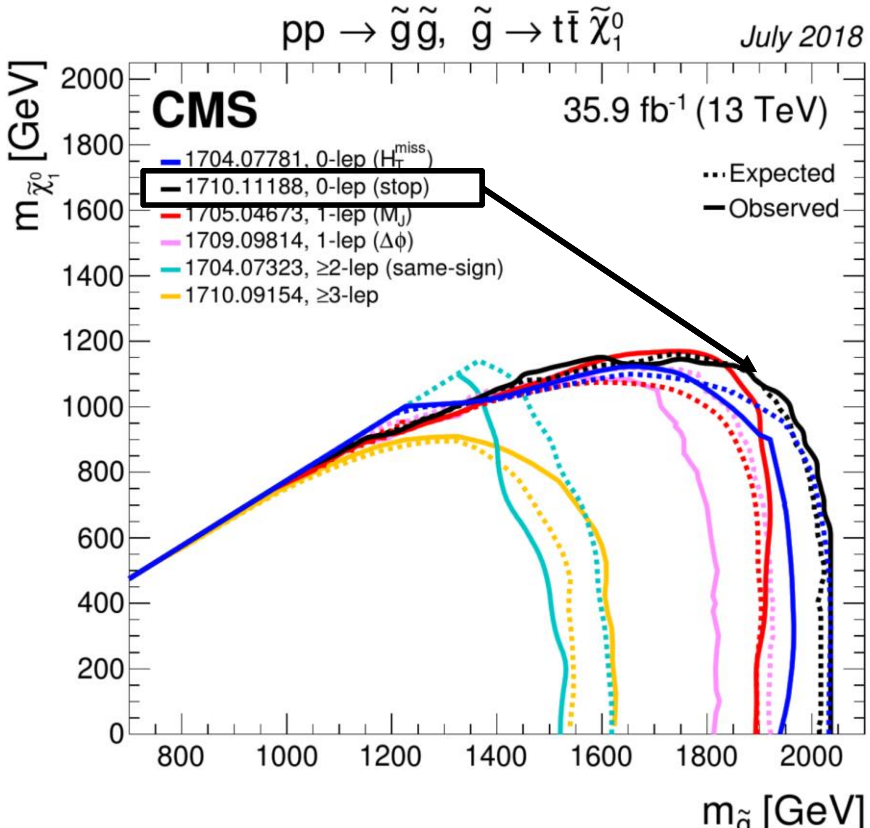


[off-shell stop]

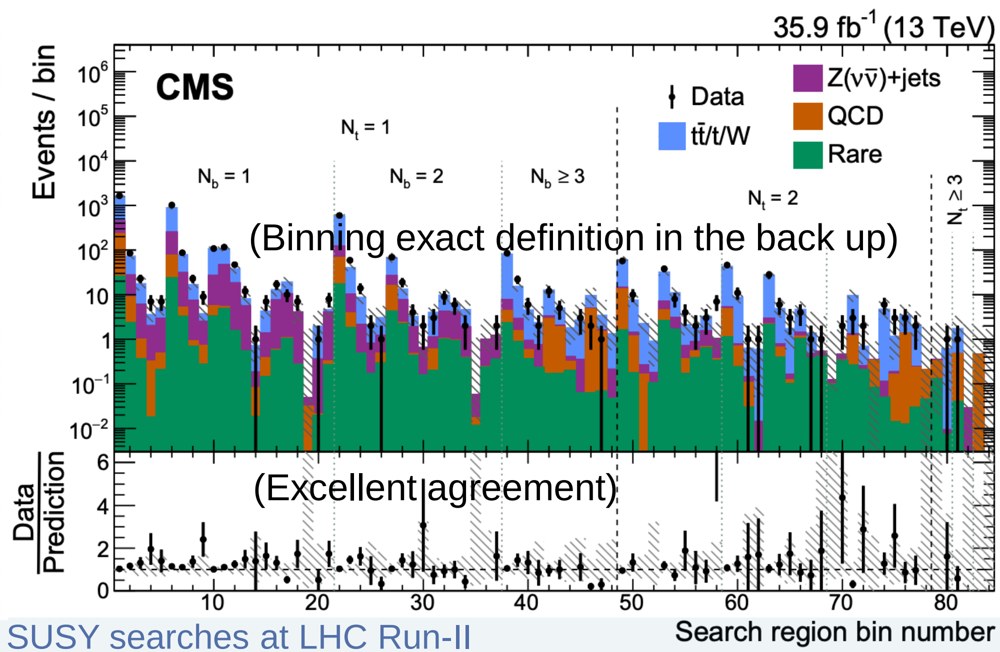
Full-hadronic, 4t → 4Wb in FS
→ top-tagging algo:

- 3-prong ak8-jet, or
- 2-prong ak8-jet + ak4, or
- 3 resolved ak4-jets (with a b-jet)

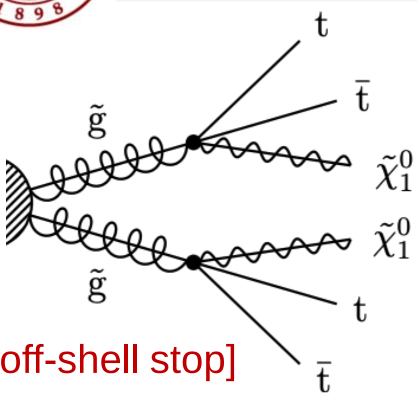




- $N_{j\text{-}ak4} >= 4$, $N_b >= 1$, $N_t >= 1$
- MET> 250 GeV, H_T> 300 GeV, M_{T2}> 200 GeV
- SR Binning: N_b, N_t, MET, H_T(or M_{T2})→84 bins



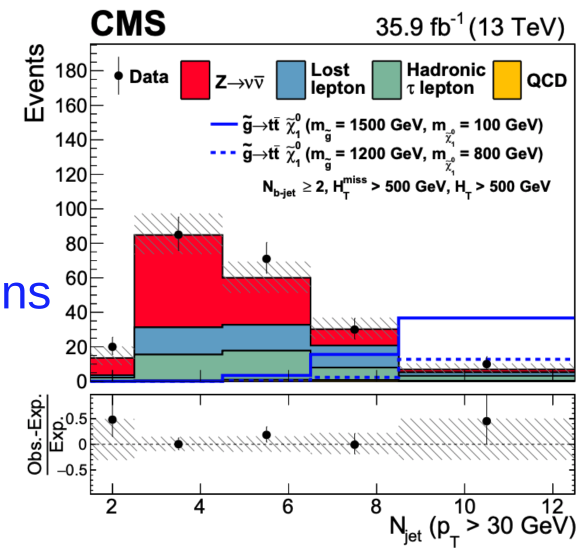
Search for gluino-pair with H_T^{miss}

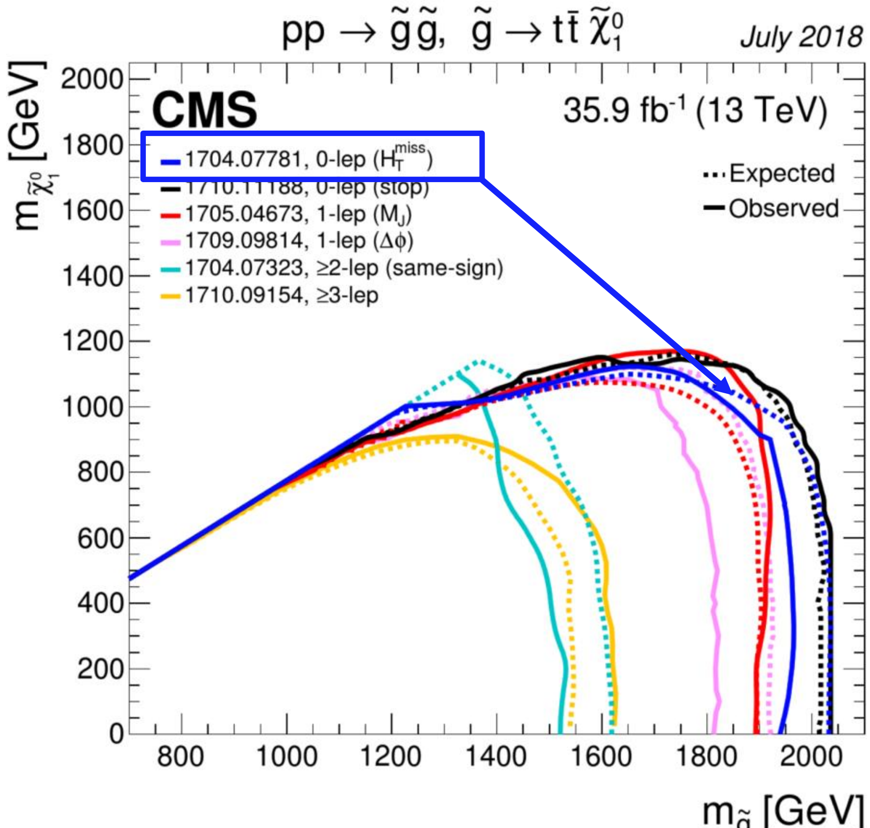


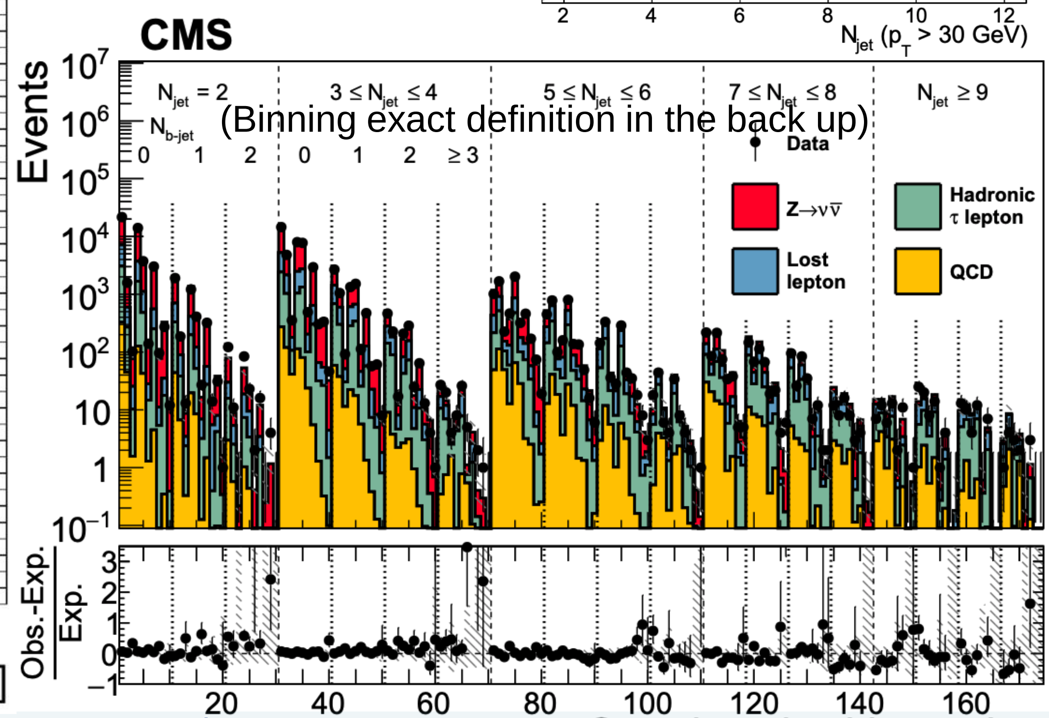
[off-shell stop]

Full-hadronic search

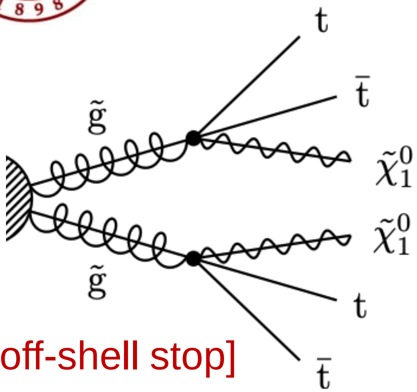
- $N_{j\text{-}ak4}$ >= 2, N_b >= 0,
- MET > 300 GeV, H_T > 300 GeV,
- $\Delta\Phi(MET, j_{1,2[3,4]})$>0.5[>0.3]
- Binning: N_j, N_b, MET, H_T→174 bins



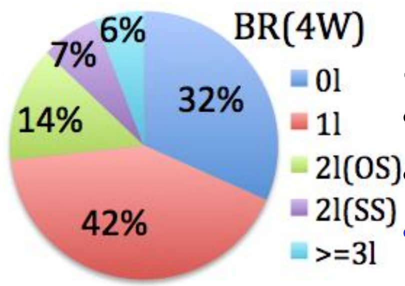




Search for gluino-pair in 1Lep with ΔΦ

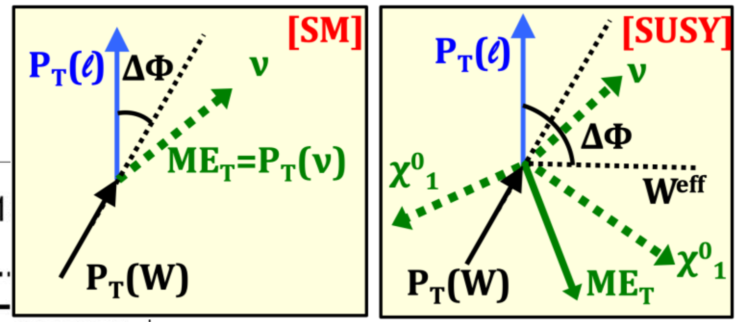


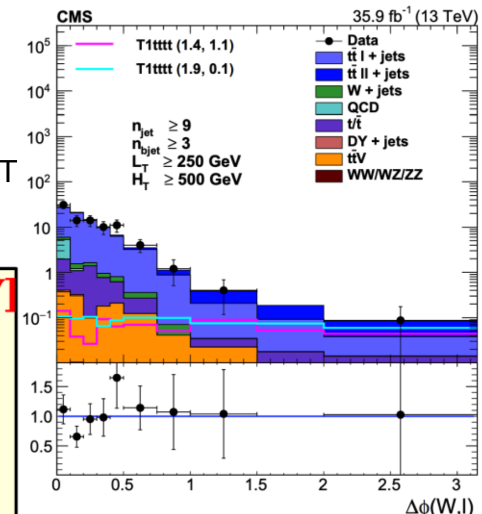
[off-shell stop]

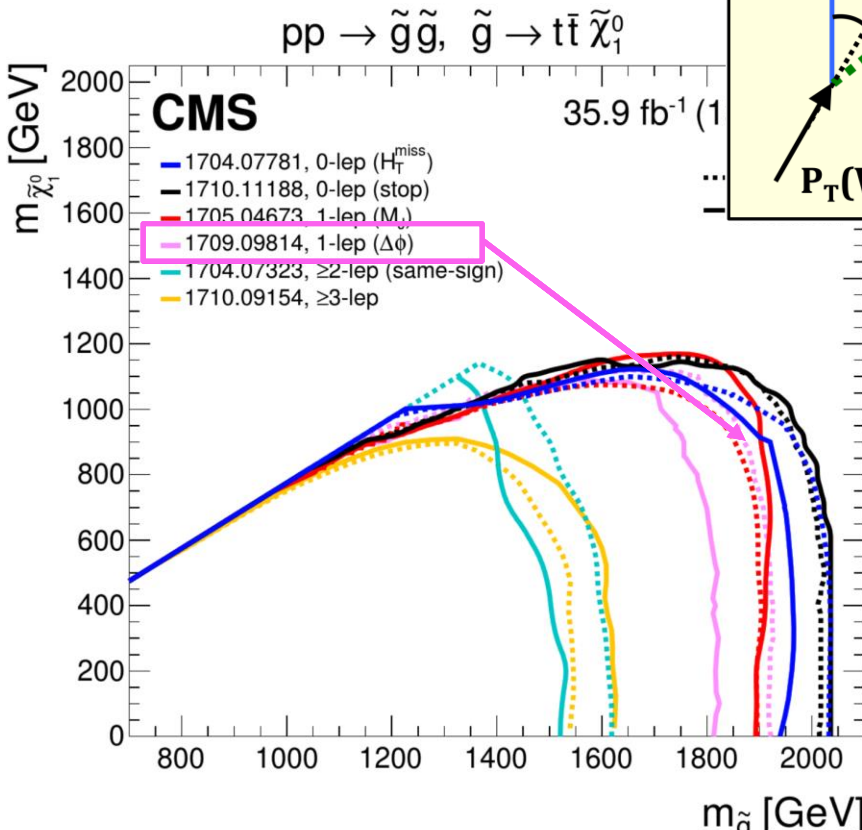


1-lep. search.

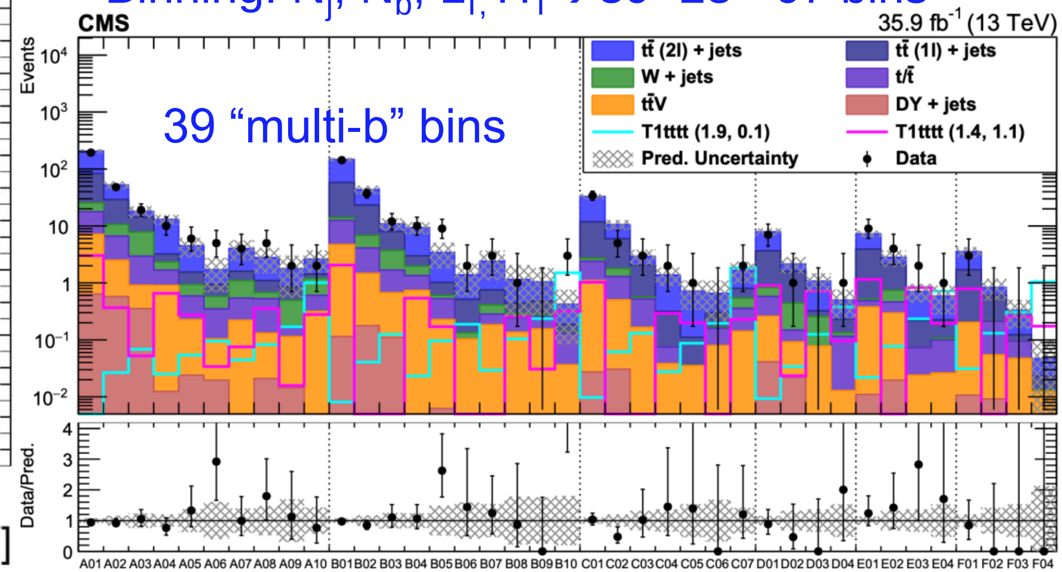
- $N_j >= 5$, $N_b >= 0$,
- Large: L_T=MET+PT_l, H_T
- Large: $\Delta\Phi(W_{l\nu}, l)$ →







- Binning: N_j, N_b, L_T, H_T → 39+28= 67 bins



Gluino-pair search in 0l & 1l

New @ 80 fb^{-1}

ATLAS-CONF-2018-041 Gluino-pair direct prod., variable BRs.

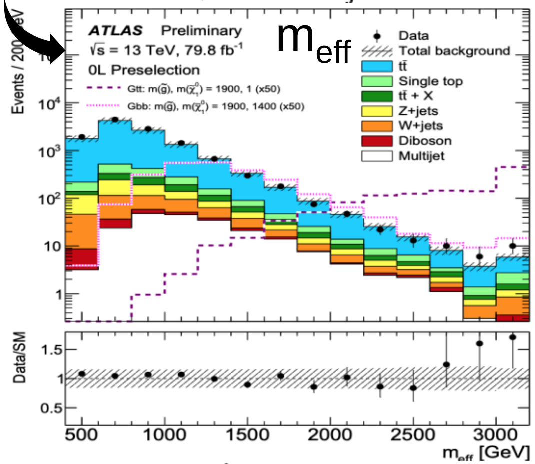
→Selection cuts & binning: N_l=0&1, $N_j \geq 4$, $N_b \geq 3$, MET, and:

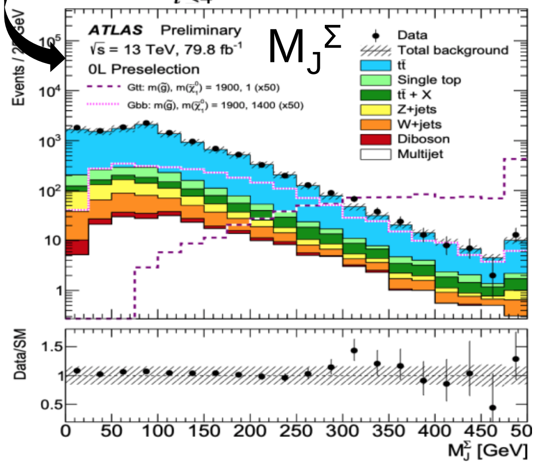
Chargino-mediated decay at one leg $\Delta M(\chi^{\pm}_1,\chi^0_1)$=2 GeV
→ soft undetected fermions

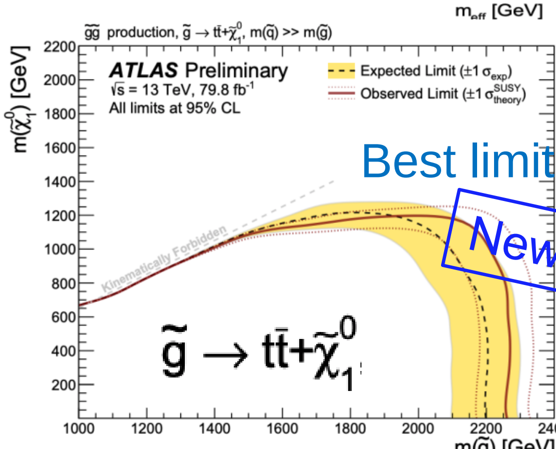
$$m_T = \sqrt{2 p_T^{\ell} E_T^{\rm miss}\{1-\cos[\Delta\phi(\vec{p}_T^{\rm miss}, \vec{p}_T^{\ell})]\}} \qquad \Delta\phi^{4j}_{\rm min} = \min_{i\leq 4}\left(|\phi_{{\rm jet}_i} - \phi_{\vec{p}_T^{\rm miss}}|\right)$$

$$m_{T,\rm min}^{b\text{-jets}} = \min_{i\leq 3}\left(\sqrt{2 p_T^{b\text{-jet}_i} E_T^{\rm miss}\{1-\cos[\Delta\phi(\vec{p}_T^{\rm miss}, \vec{p}_T^{b\text{-jet}_i})]\}}\right)$$

$$m_{\rm eff} = \sum_i p_T^{{\rm jet}_i} + \sum_j p_T^{\ell_j} + E_T^{\rm miss} \qquad M_J^{\Sigma} = \sum_{i<4} m_{J,i}$$

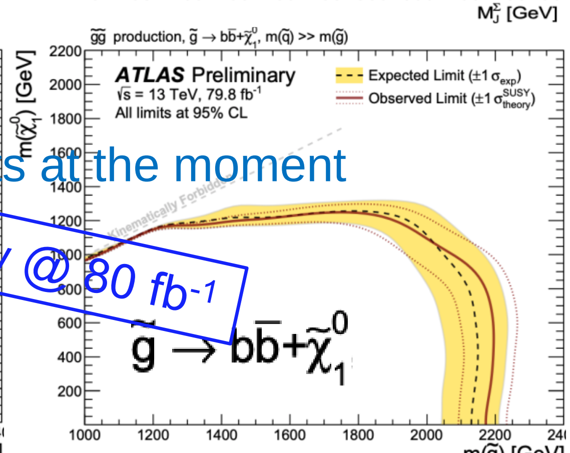


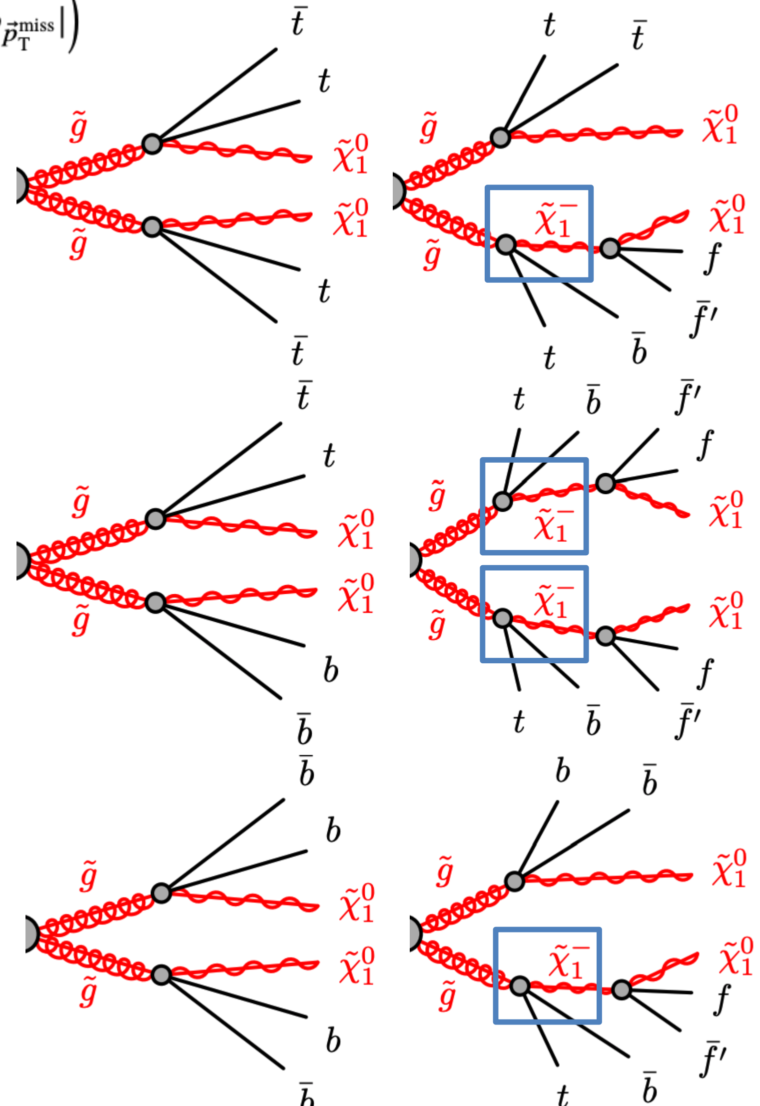




Best limits at the moment

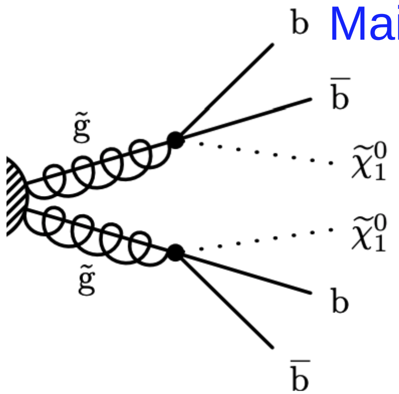
New @ 80 fb^{-1}

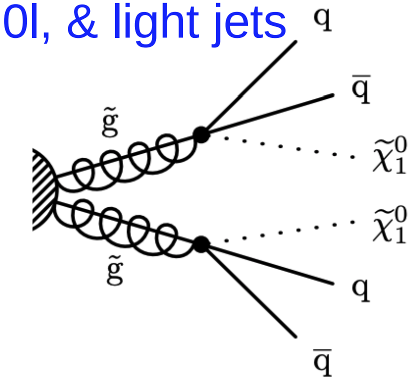


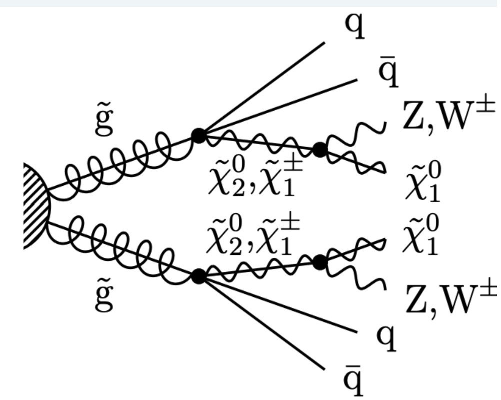


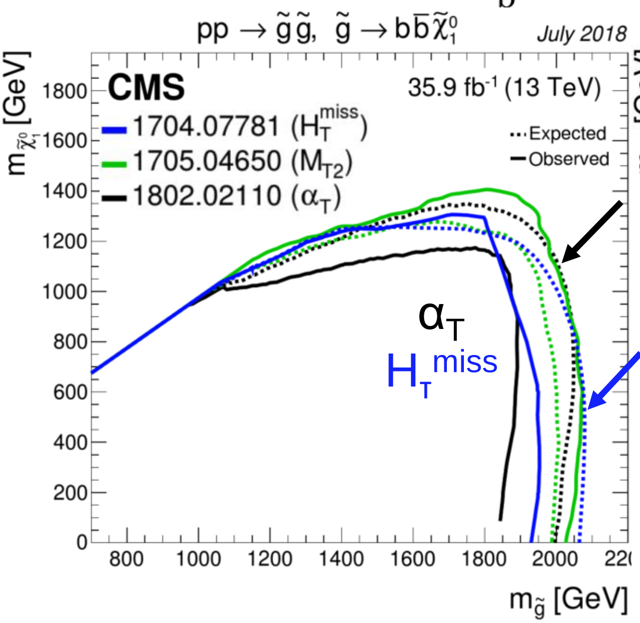
Search for gluinos in other signatures

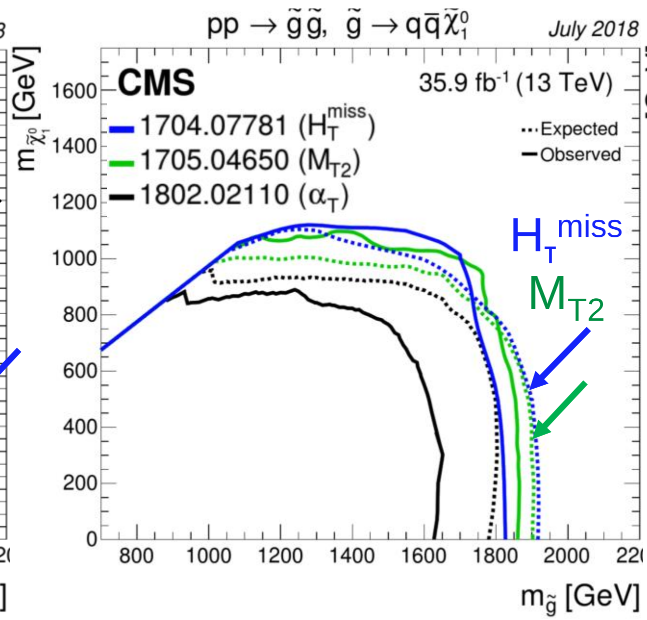
Main feature:0l, & light jets

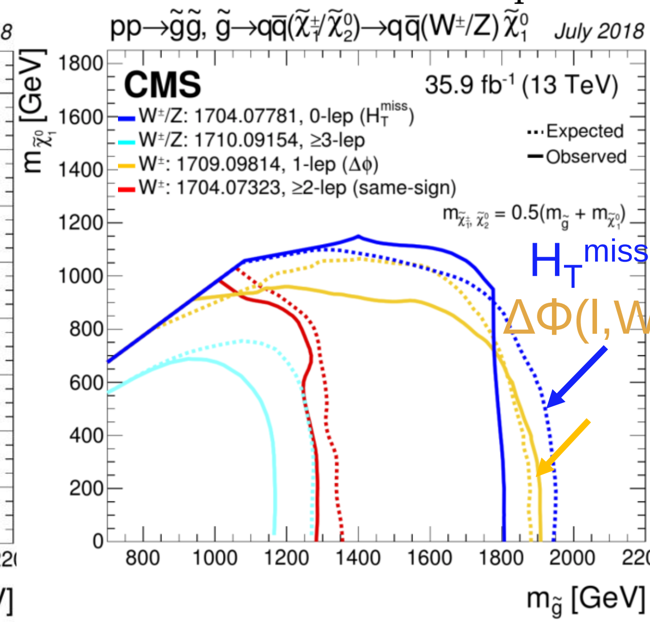








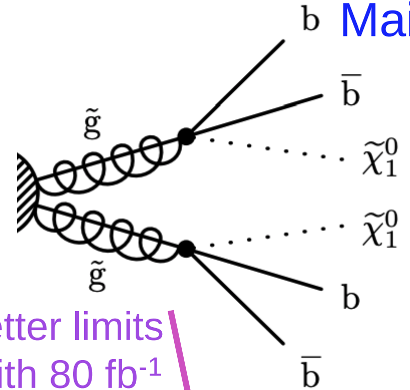


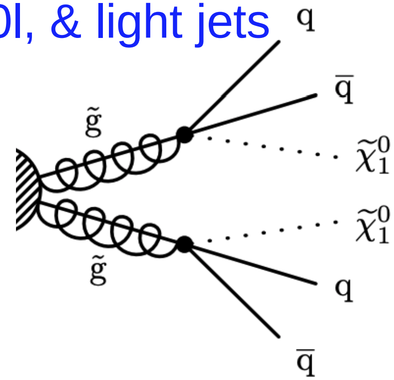


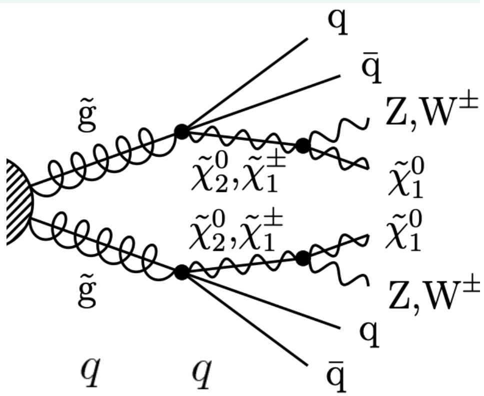
- 1705.04650: M_{T2}: all-hadronic. Cluster jets in 2 hemispheres → form 2 pseudo-jets → form: $M_{T2} = \min_{\vec{p}_T^{\text{miss}X(1)} + \vec{p}_T^{\text{miss}X(2)} = \vec{p}_T^{\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$ binning: $N_{j\text{-ak4}}$, N_b, H_T, M_{T2}
- 1802.02110: α_T ($=E_T^{j2}/M_{T(j1,j2)}$), Full-had. Cuts/bins N_j, N_b, MET, H_T, $\Delta\varphi^*_{min}(H_t^{vec}$,MET)

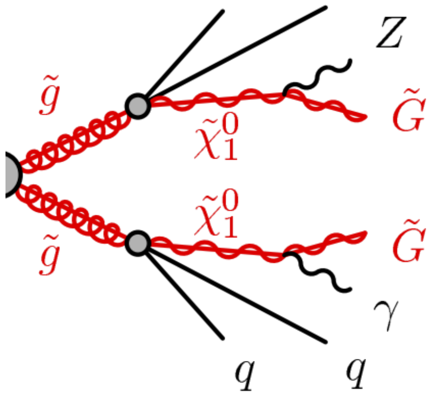
Search for gluinos in other signatures

Main feature:0l, & light jets

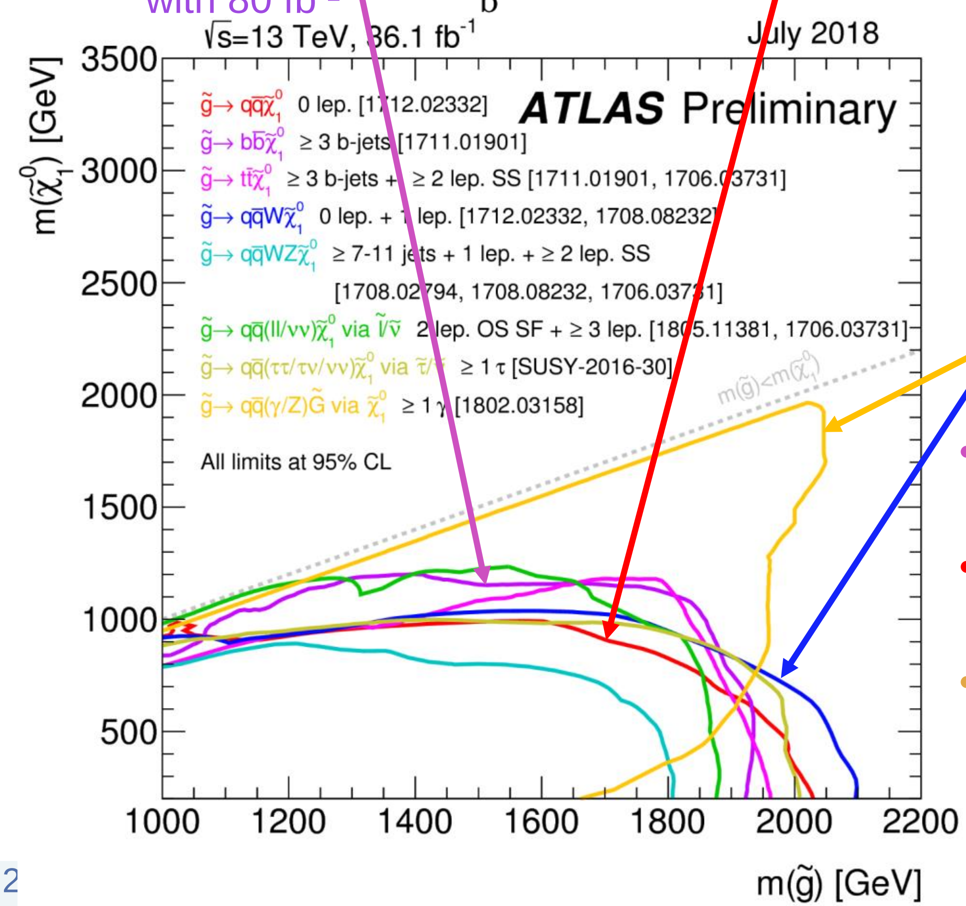








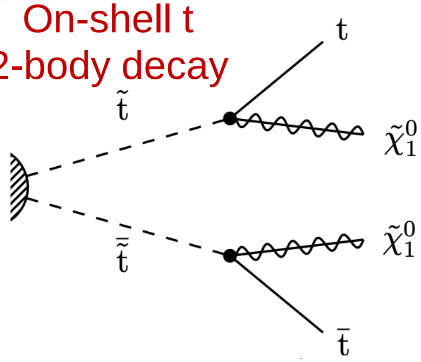
Better limits with 80 fb^{-1}



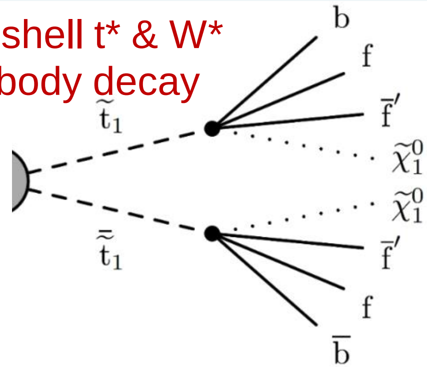
- 1711.01901→ Purple limits: 0-lep, MET, N_j, $N_b \geq 3$, M_{eff}, $M_T^{min}{}_{(b,MET)}$
- 1712.02332→ red & blue limits (0-lep) RJR (Recursive Jigsaw Reco) technique
- 1802.03158→ yellow limits, GMSB model 1 or 2 γ, MET, Jets, 0lep, and more. (With a "modest" excess of events)

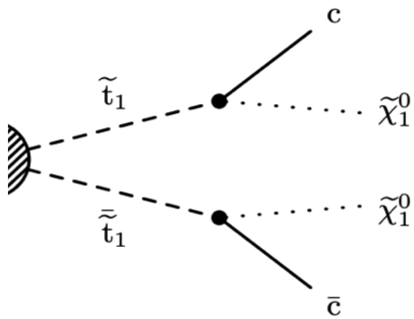
Search for direct stop-pair (map)

On-shell t
2-body decay

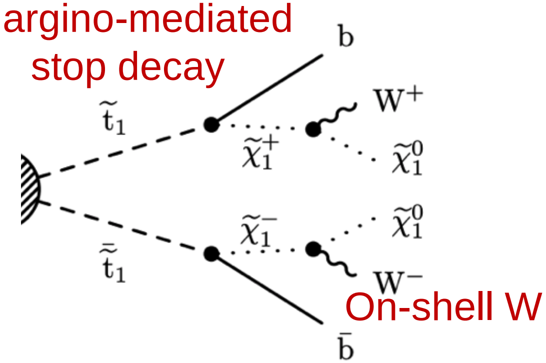


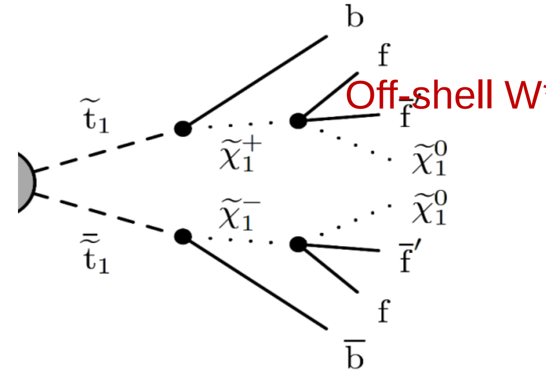
Off-shell t* & W*
4-body decay



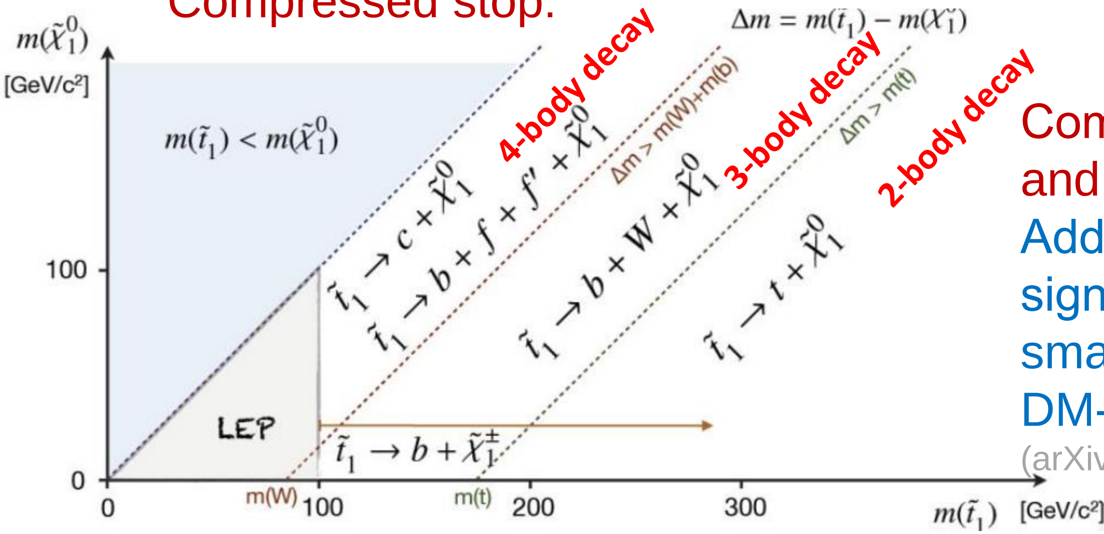


Chargino-mediated
stop decay





Compressed stop:



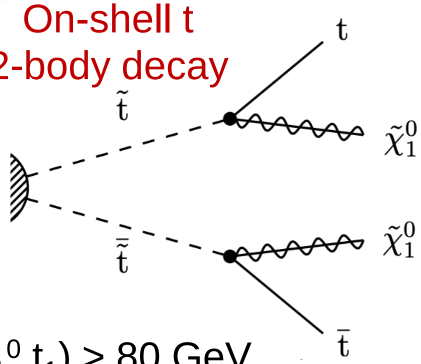
Compressed FS leads to "soft" objects and perhaps low/no MET.

Additional motivation for "compressed signal" comes from DM coannihilation: small: $\Delta M(t_1,\chi_1^0)$ → leads to the observed DM-relic density.

(arXiv:1212.6847v2, arXiv:1111.4467v1)

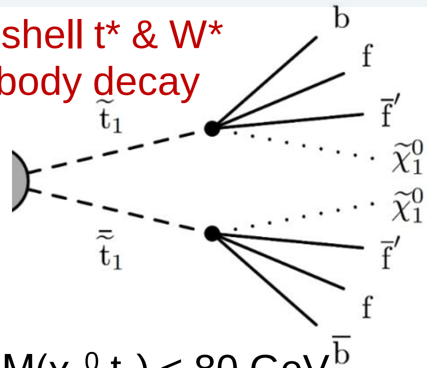
Limits for direct stop-pair production

On-shell t
2-body decay



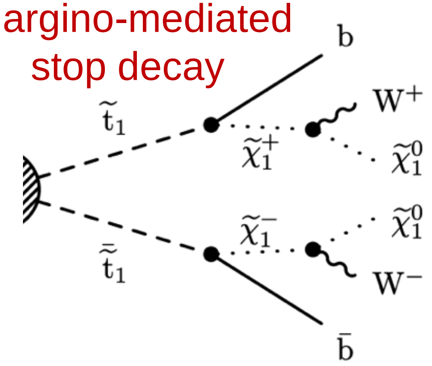
$\Delta M(\chi_1^0, t_1) > 80$ GeV

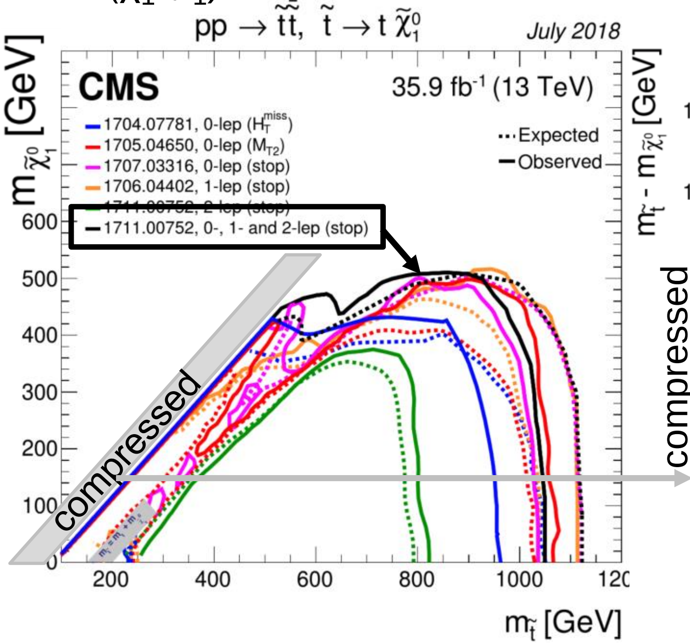
Off-shell t* & W*
4-body decay

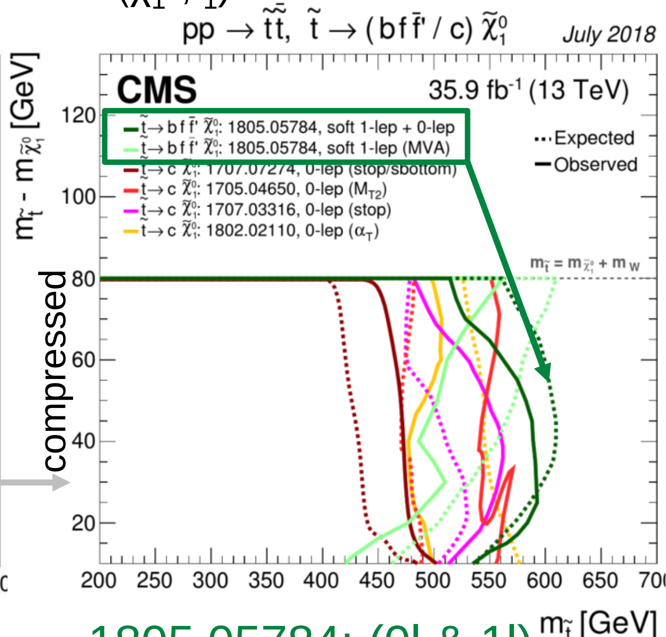


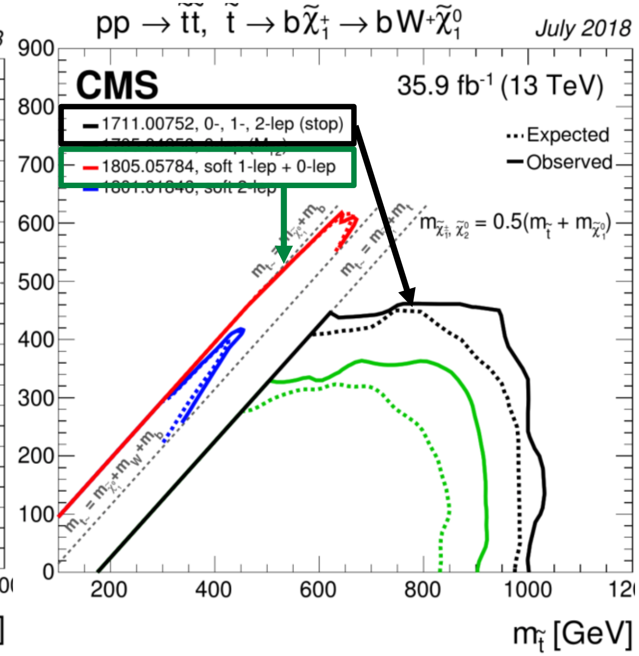
$10 < \Delta M(\chi_1^0, t_1) < 80$ GeV

Chargino-mediated
stop decay









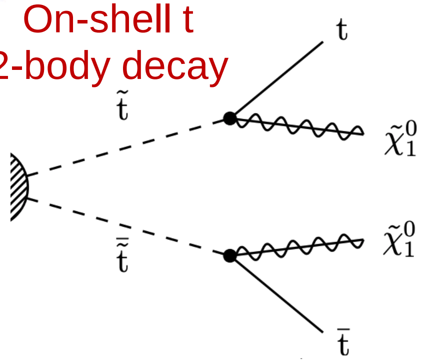
Top-tagging (0l)
in combination with
1l+2l searches

1805.05784: (0l & 1l)
$N_{hard\text{-}j}$<=2, ISR, MET, H_T
PT_l<30 GeV (soft)
$M_{T(l,MET)}$ and more…→44 bins

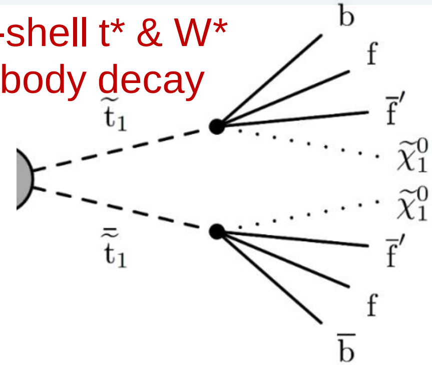
The two searches
on the left provide the
best limits here as well

Limits for direct stop-pair production

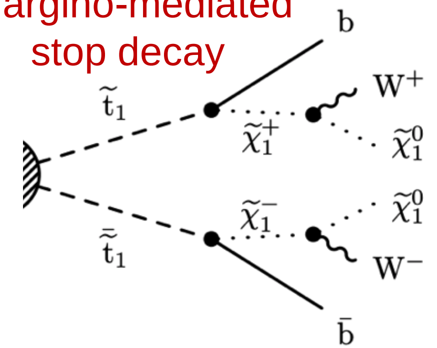
On-shell t 2-body decay

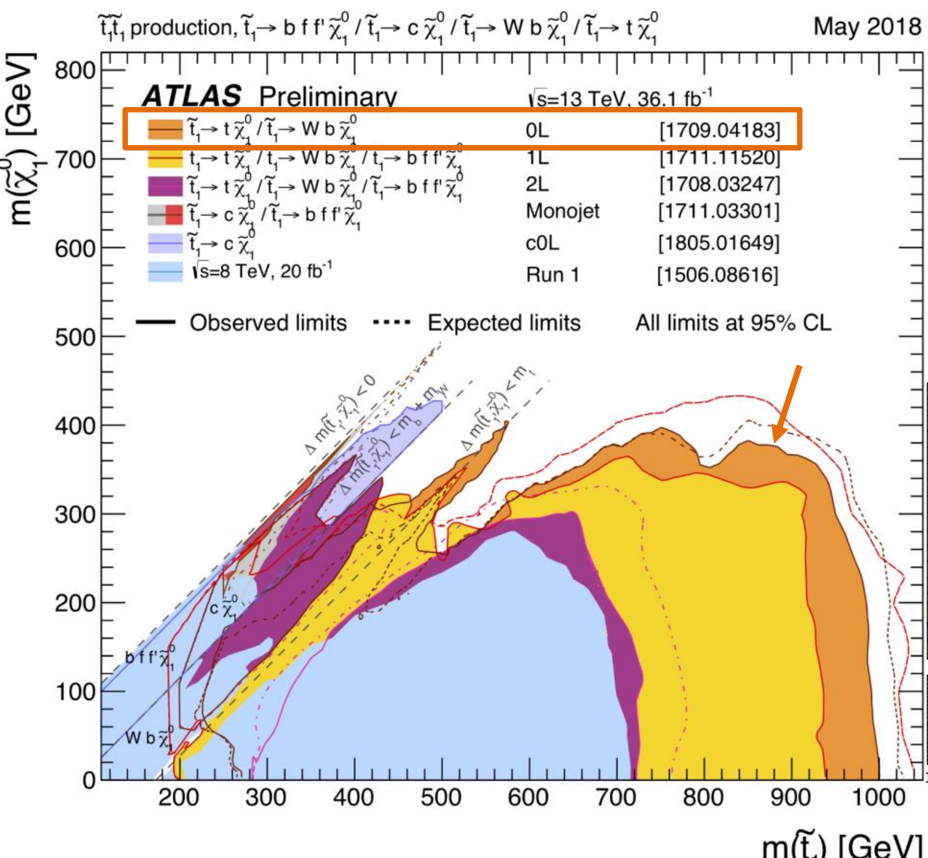


Off-shell t* & W* 4-body decay



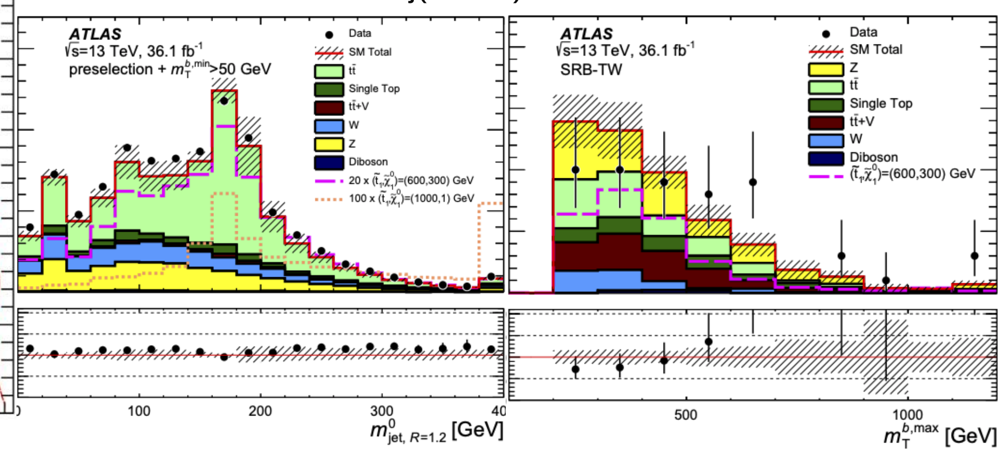
Chargino-mediated stop decay





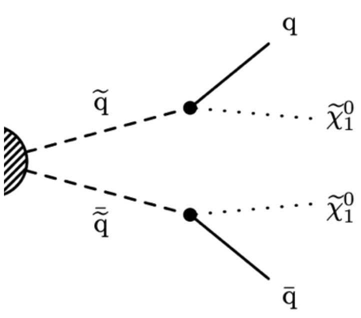
Similar coverage from ATLAS: 1709.04183,
Generic: different SRs → probe diff. signals (0l), $N_j \geq 4$, $N_b \geq 1$, MET>250 GeV, top-mass reco techniques.
$\Delta\varphi(j_{1,2}$,MET)>0.4, … and more…→ 14 bins

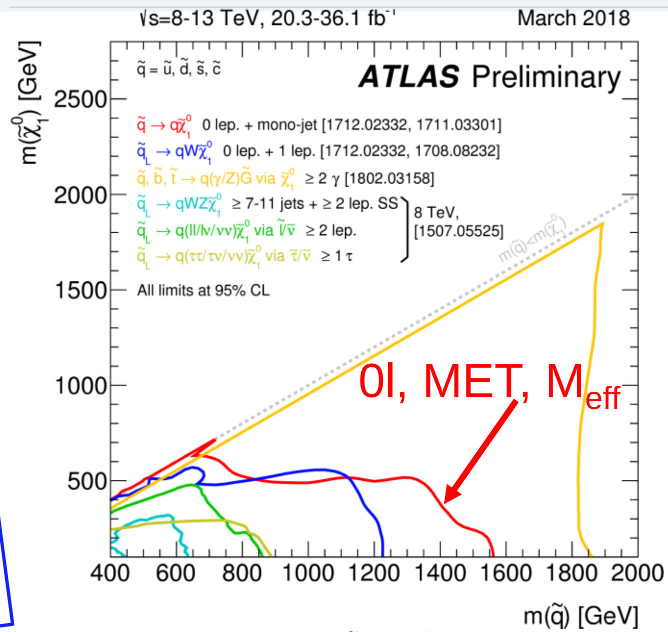
At preselection: $M_{j(R=1.2)}$ At a SR: $M_T^{b,max}$

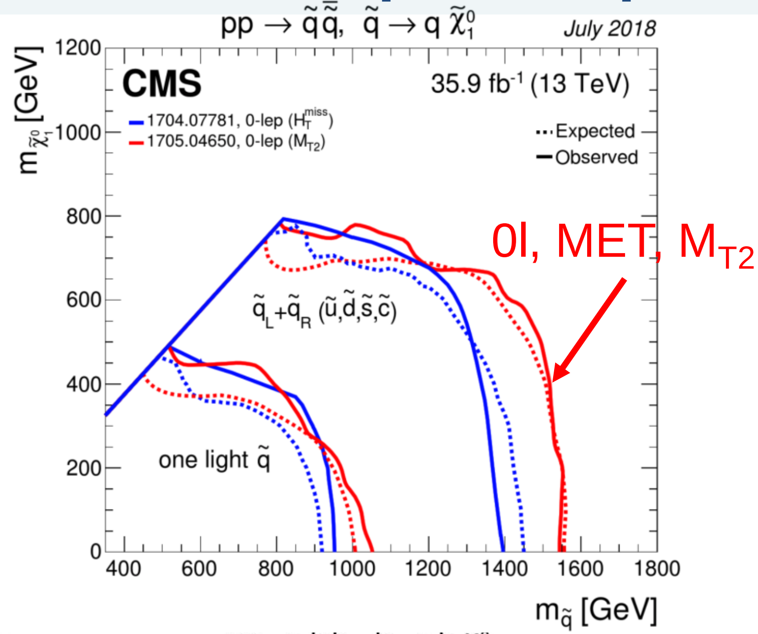


1709.04183

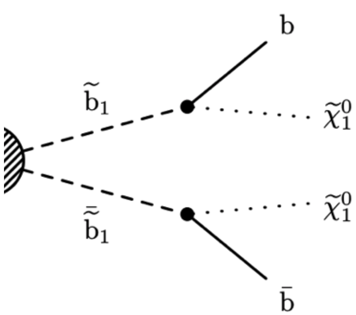
Search for direct sbottom & squark-pair

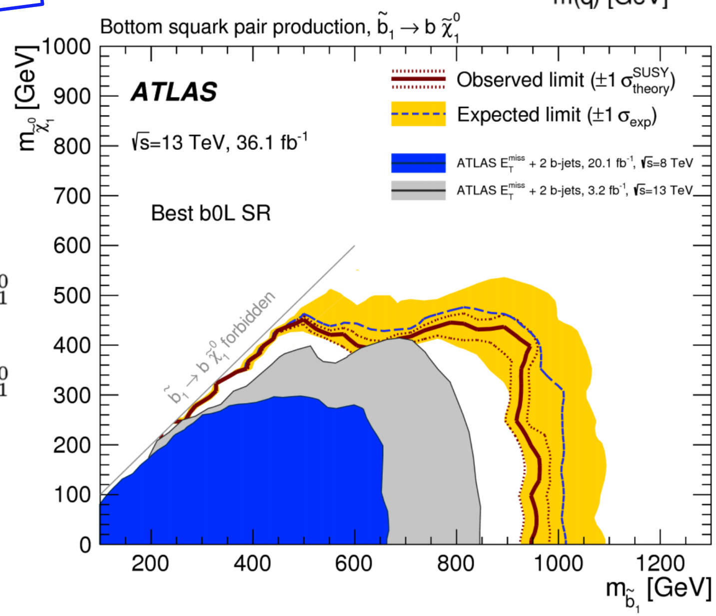


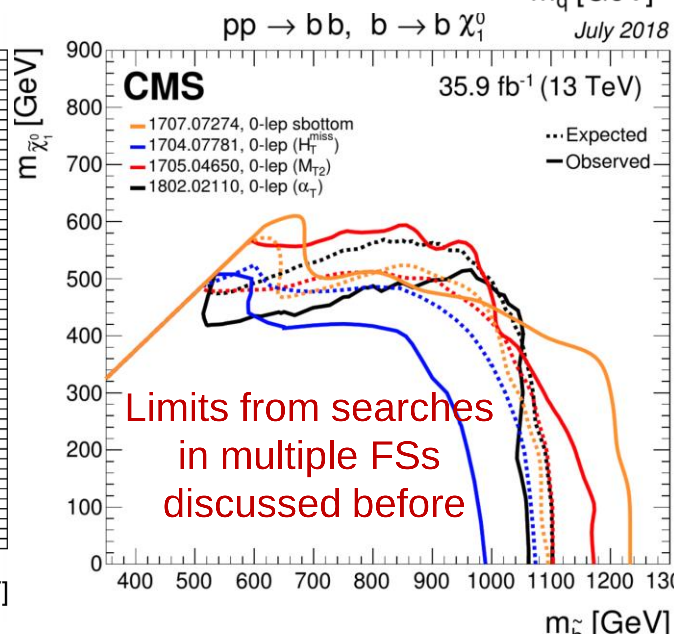




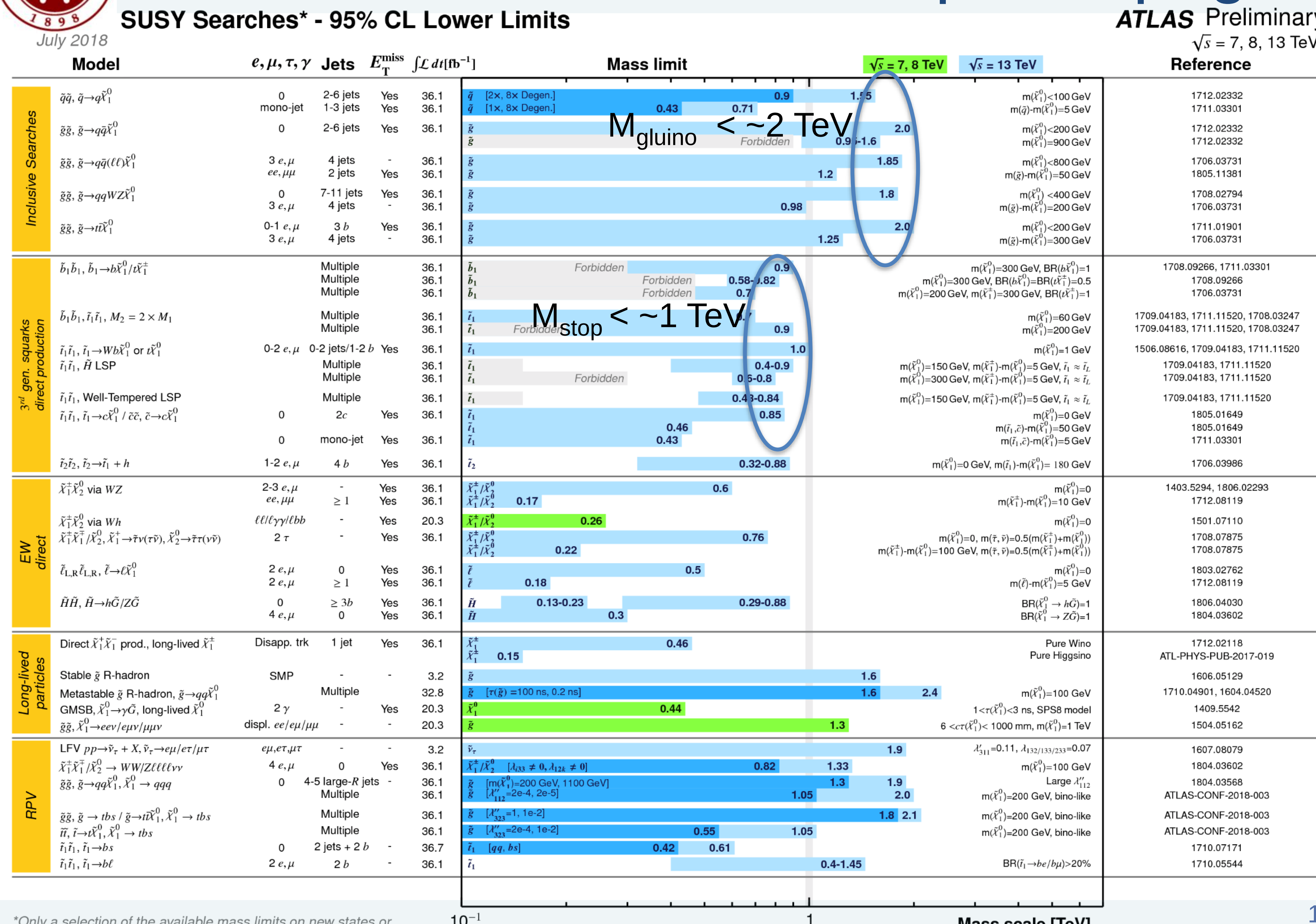
0-lep, low N_j
large MET & M_{T2}



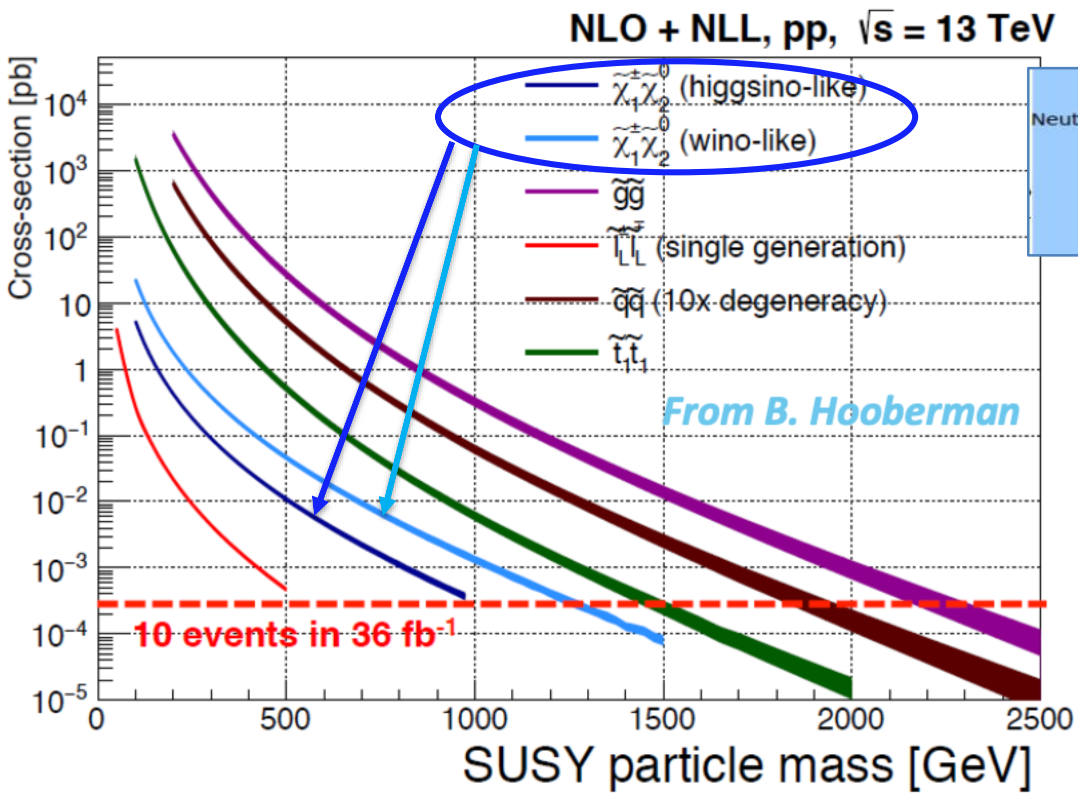


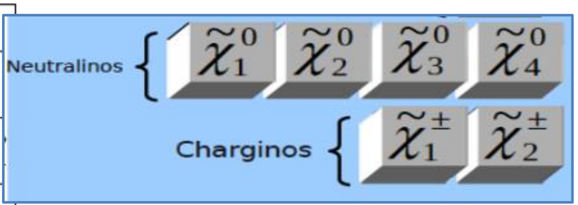


Much more results on the public pages

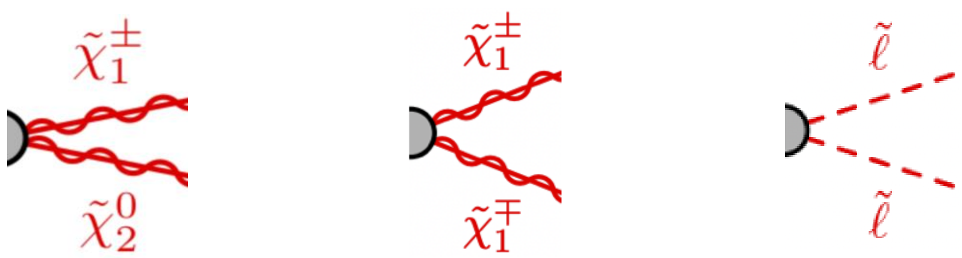


2) "EWK" SUSY Production



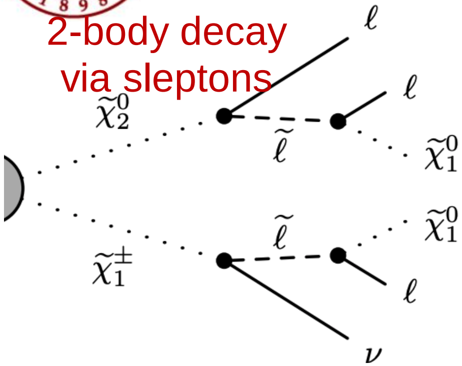


If colored sparticles are much heavier than EWK partners,
→ EWK production will be the dominant

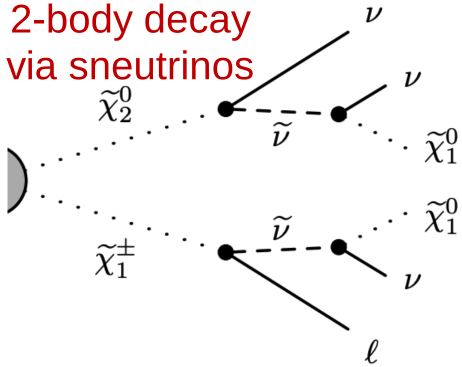


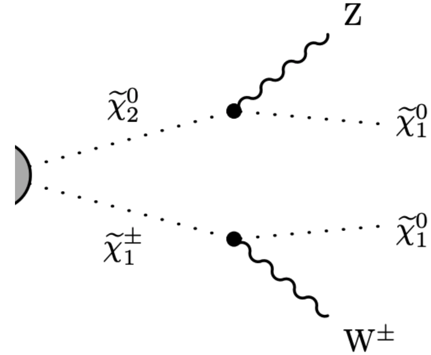
Direct $\chi_1^\pm,\chi_2^0,\chi_1^0$ production signatures

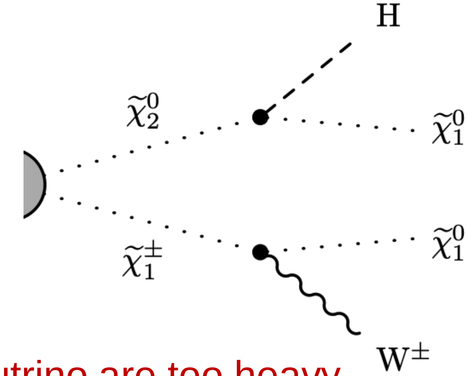
2-body decay via sleptons



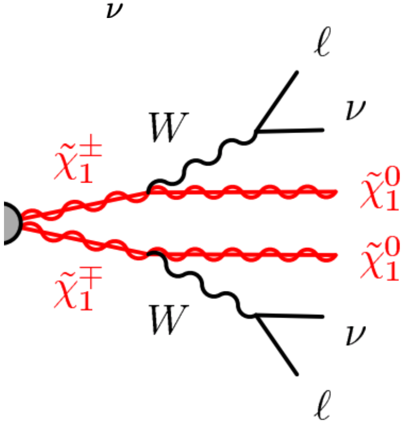
2-body decay via sneutrinos







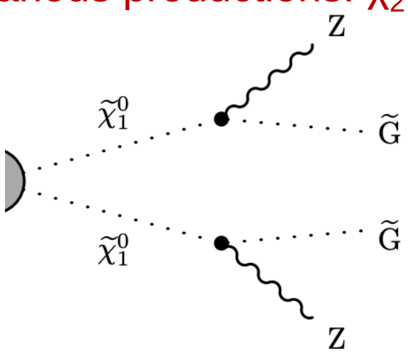
If slepton/snueutrino are too heavy
→WEK-inos to bosons→ 3-lep 3%

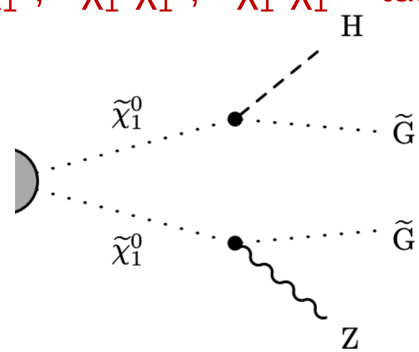


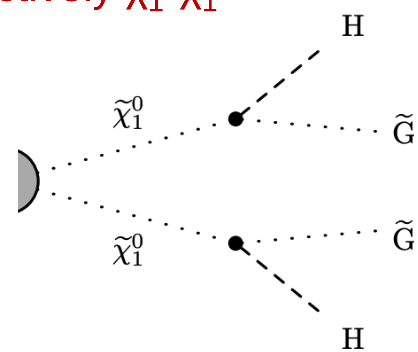
We assume $\chi_2^0\ \chi_1^\pm$ mass degenerate

Leptons, neutrinos & bosons in FS (apart from LSPs)

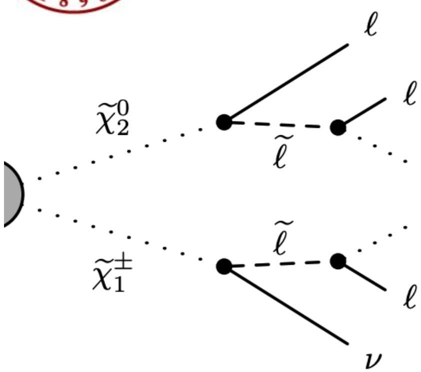
Vanishingly small x-sect. Higgsinos: $\chi_2^0\ \chi_1^\pm\ \chi_1^0$ in GMSB model & effectively M_G~0
The various productions: $\chi_2^0\chi_1^\pm$, $\chi_2^0\chi_1^0$, $\chi_1^\pm\chi_1^\pm$, $\chi_1^0\chi_1^\pm$ turns to effectively $\chi_1^0\chi_1^0$







Search for χ_2^0, $\chi_1^\pm$ production CMS



Various scenarios for the decay mediator:

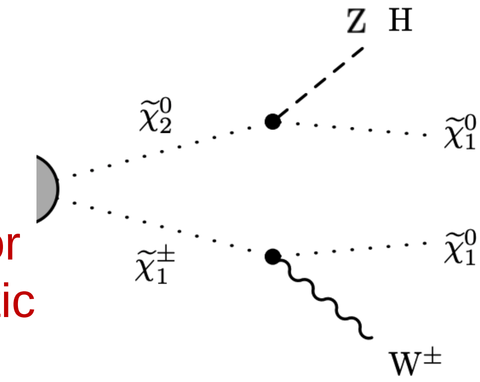
- 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to \tilde{\tau}\nu\tilde{l}l$, x_l=0.5)
- 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to \tilde{\tau}\nu\tilde{l}l$, x_l=0.05)
- 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to \tilde{\tau}\nu\tilde{l}l$, x_l=0.95)

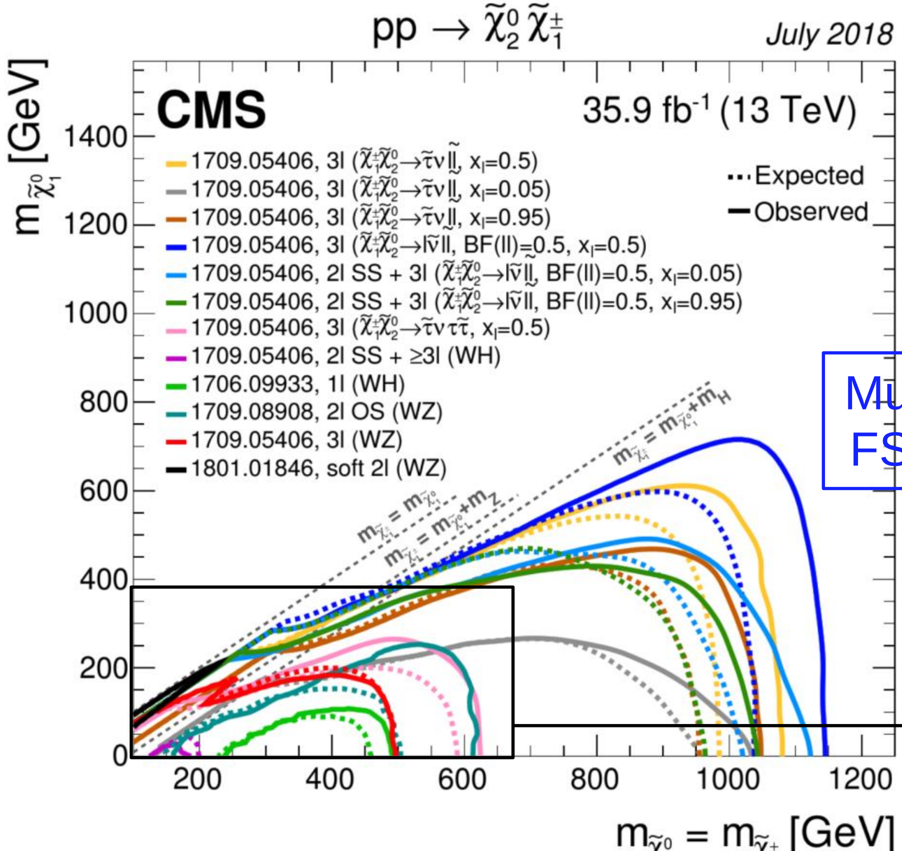
} (l_R)τ-enriched

- 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to l\tilde{\nu}ll$, BF(ll)=0.5, x_l=0.5)
- 2l SS + 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to l\tilde{\nu}\tilde{l}l$, BF(ll)=0.5, x_l=0.05)
- 2l SS + 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to l\tilde{\nu}ll$, BF(ll)=0.5, x_l=0.95)

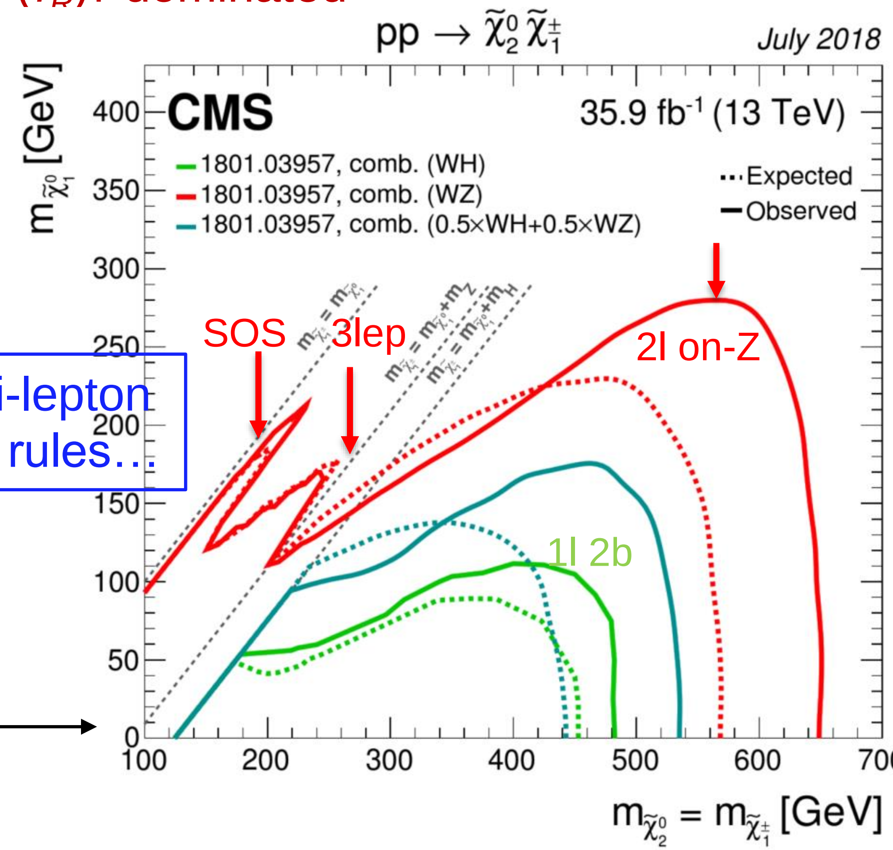
} ($\nu_L l_L$)flavor democratic

- 3l ($\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to \tilde{\tau}\nu\tau\tilde{\tau}$, x_l=0.5) → (τ_R)τ-dominated



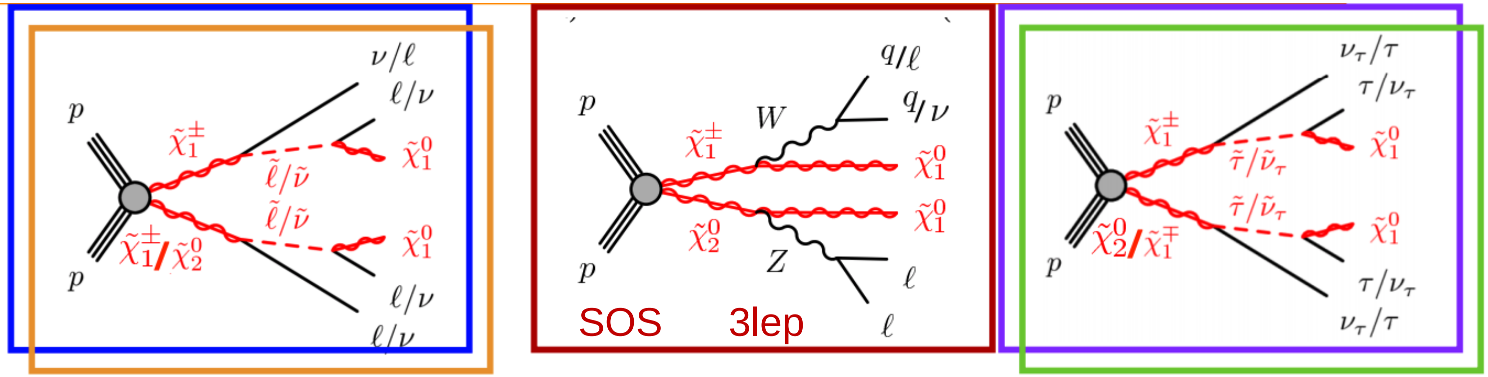


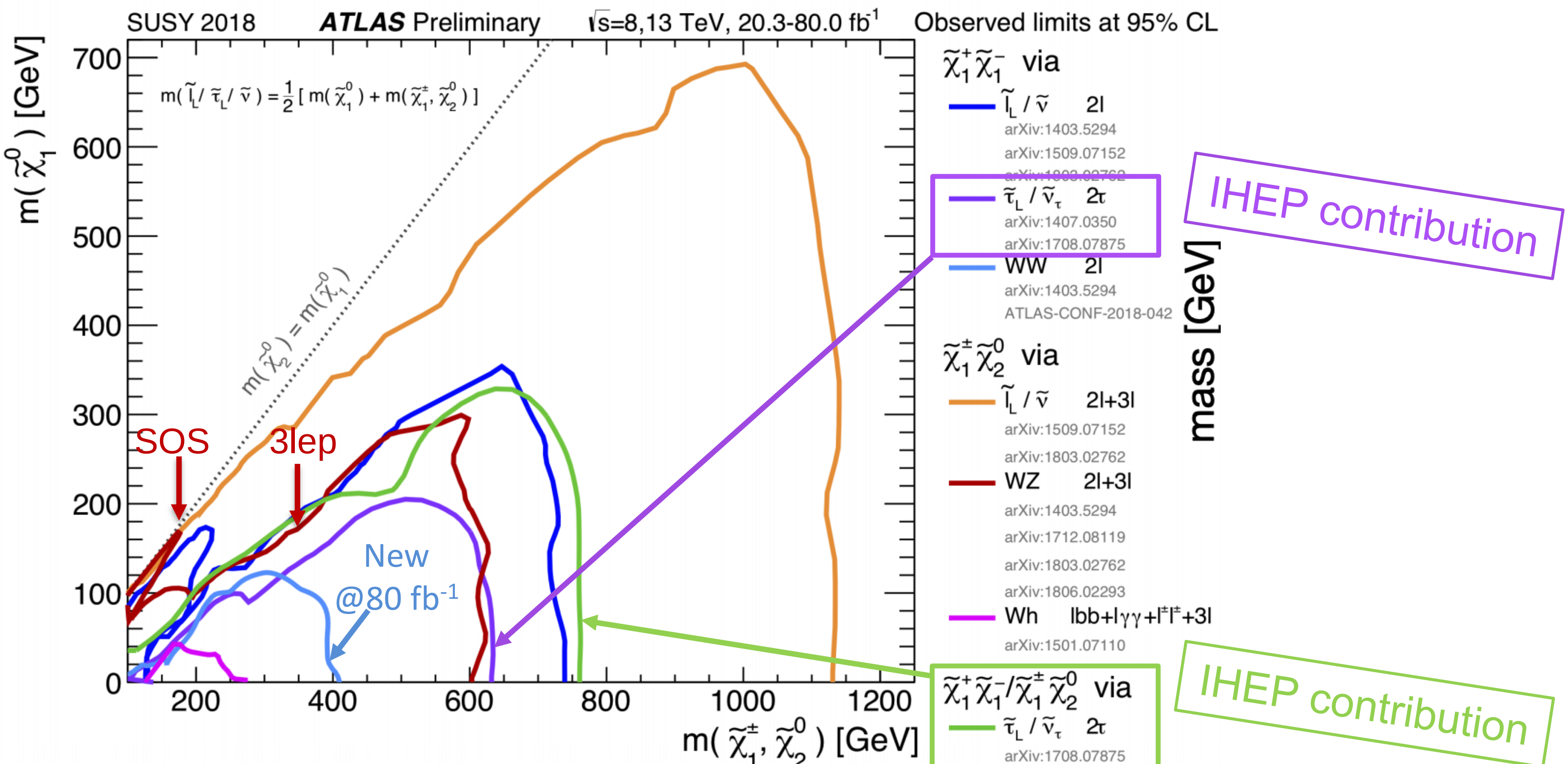
Multi-lepton FSs rules…



Search for $\chi_2^0, \chi_1^\pm$ production ATLAS

Boxes colors in accordance with limits

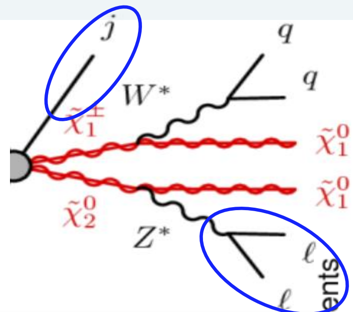




Compressed W-inos (SOS)

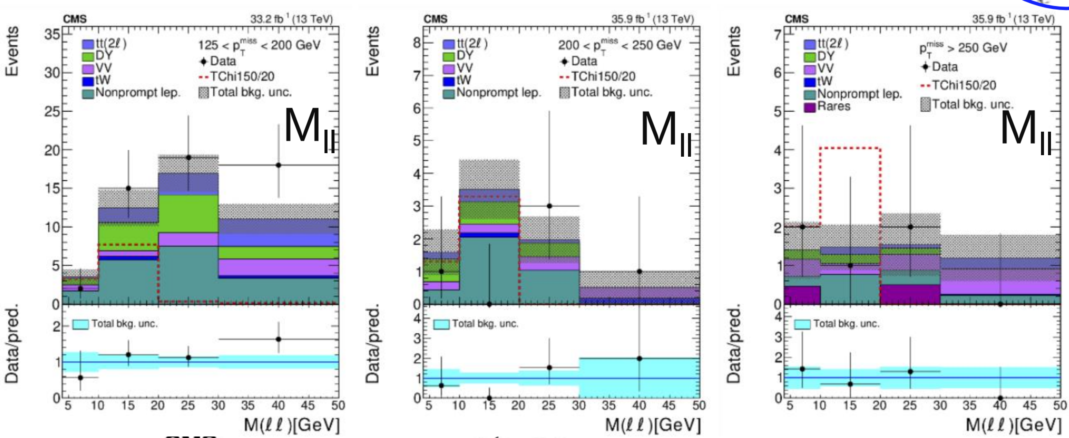
CMS: 1801.01846

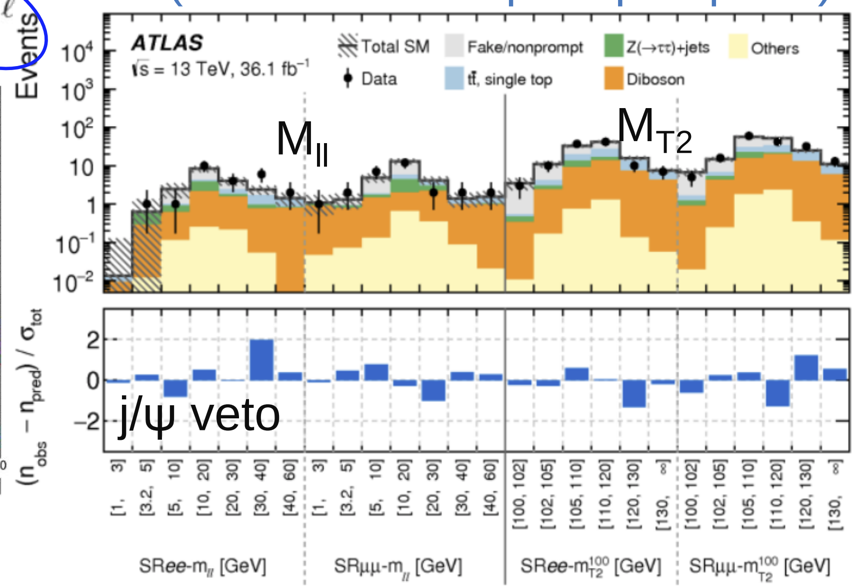
- 2-soft OS lep , MET , ISR jet
- Search bins: using M_{ll}, MET (Sensitive to stop-pair prod.)

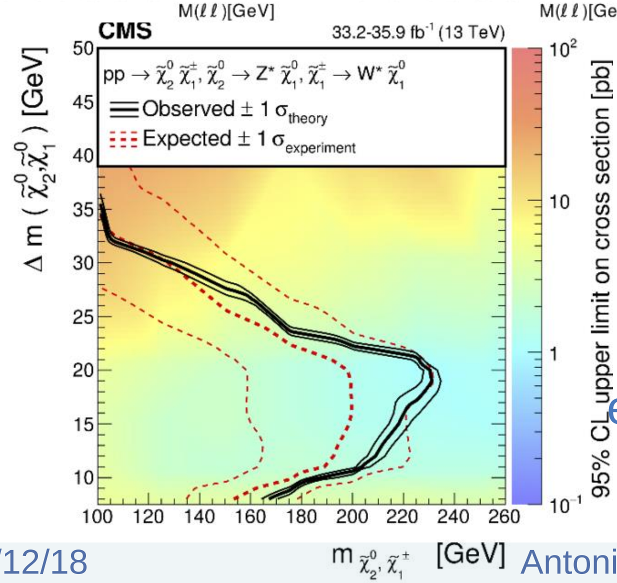


ATLAS: 1712.08119

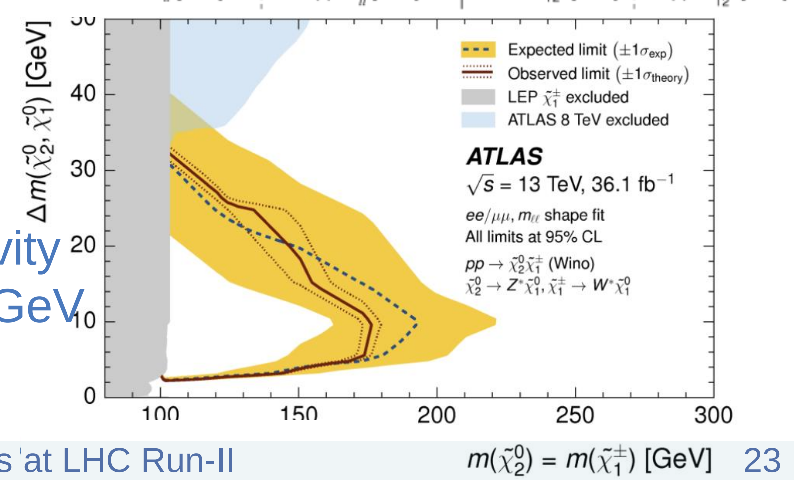
- 2-soft OS lep , MET , ISR jet
- Search bins: using M_{ll}, M_{T2} (Sensitive to slepton-pair prod.)





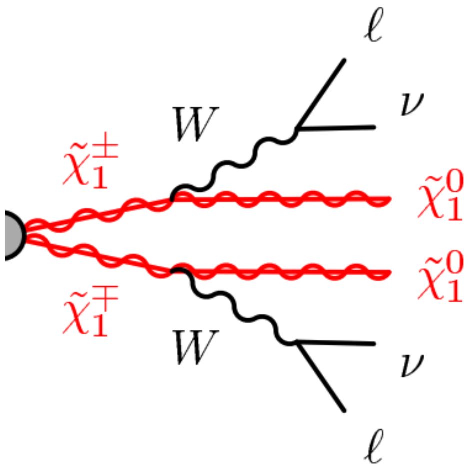


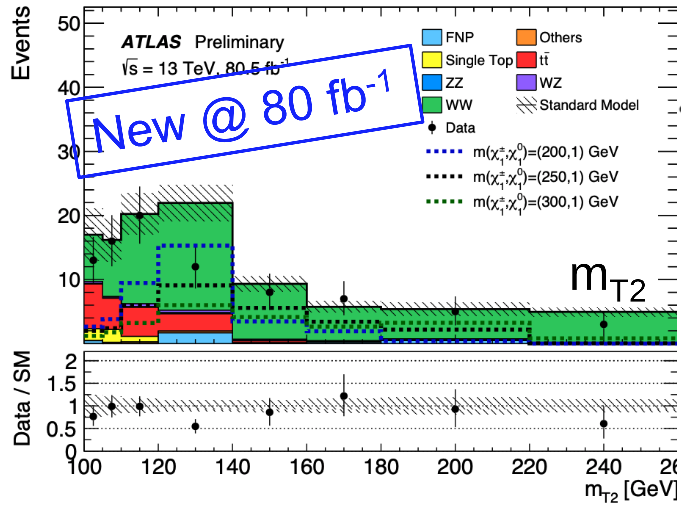
Very similar sensitivity excl. up to M_{t1}~220 GeV for ΔM~20 GeV

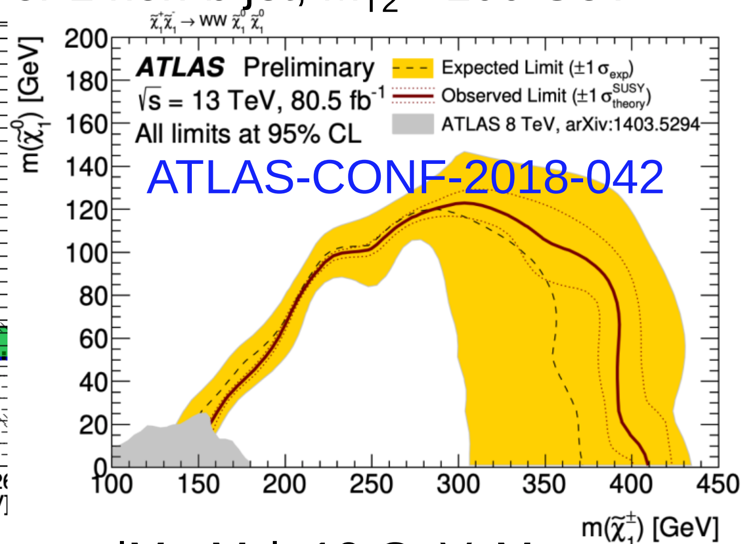


$\chi_1^{\pm},\chi_1^{\pm}$ pair production (ATLAS)

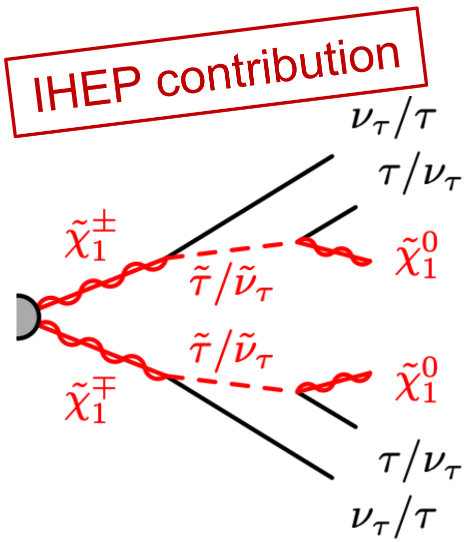
- Charginos: $\chi^{\pm}_1,\chi^{\pm}_1 \rightarrow$ 2 OS-lep. MET>110 GeV, 0 or 1 non-b jet, M_{T2} >100 GeV

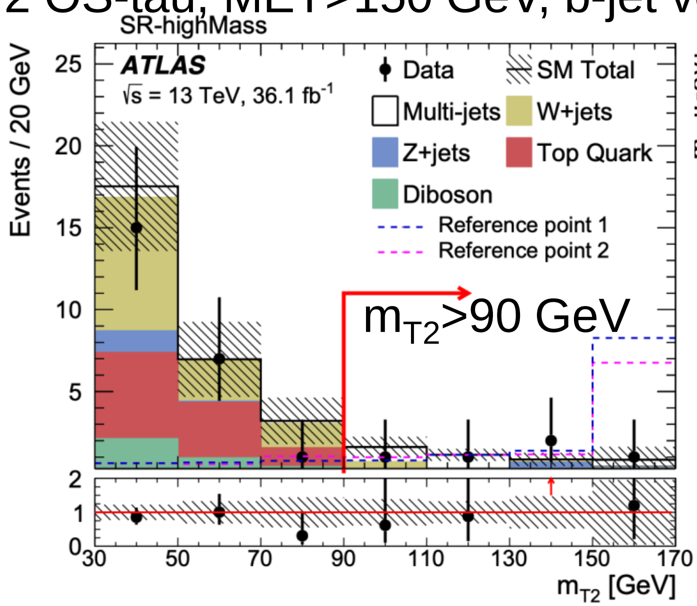


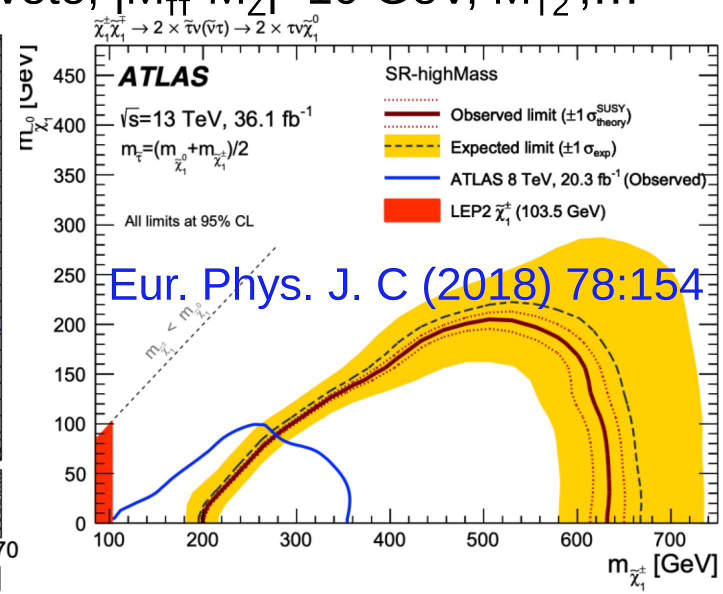




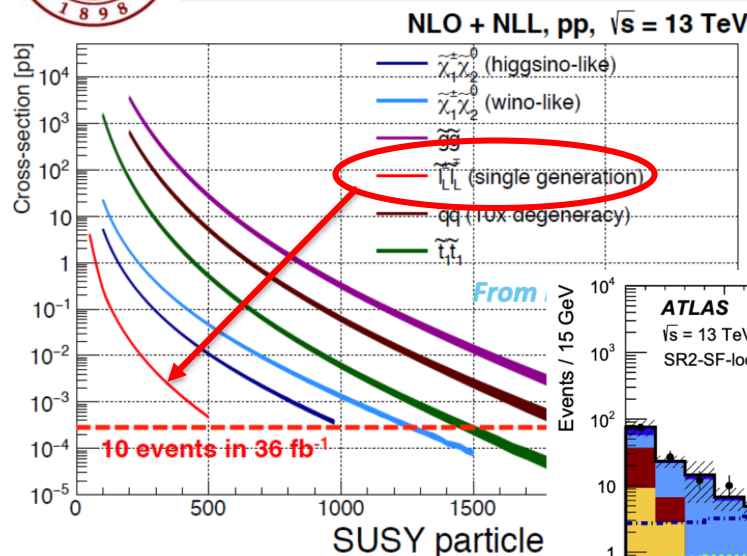
- Stau/snueutrino: 2 OS-tau, MET>150 GeV, b-jet veto, $|M_{TT}-M_Z|$<10 GeV, M_{T2} ,…



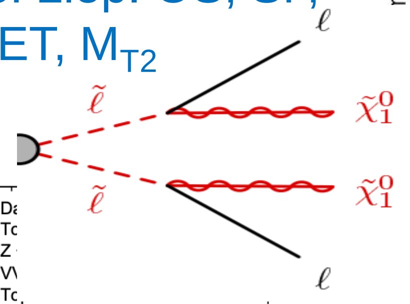


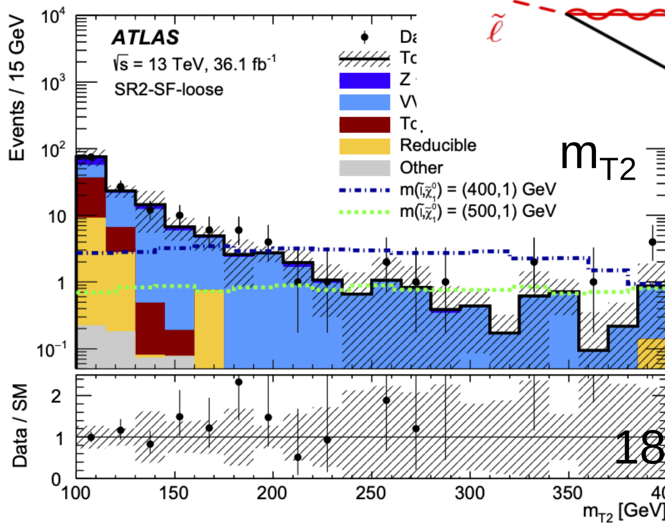


More searches… sleptons, GMSB…



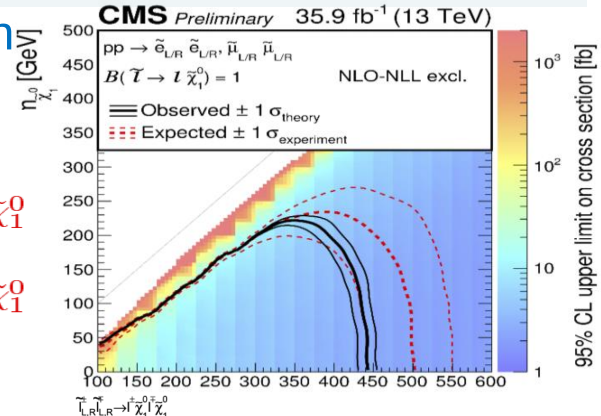
Very small x-sec, but clean signature: 2lep. OS, SF, 0-jets, MET, M_{T2}

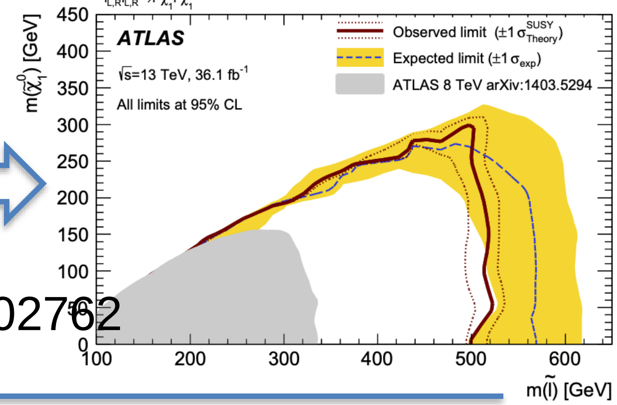




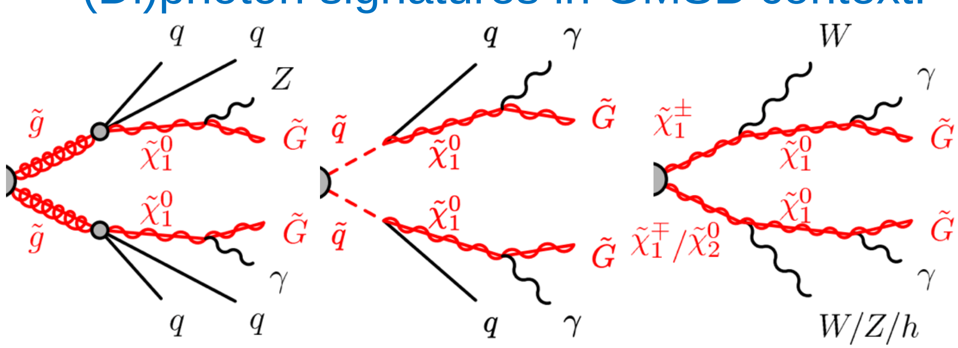
m_{T2}

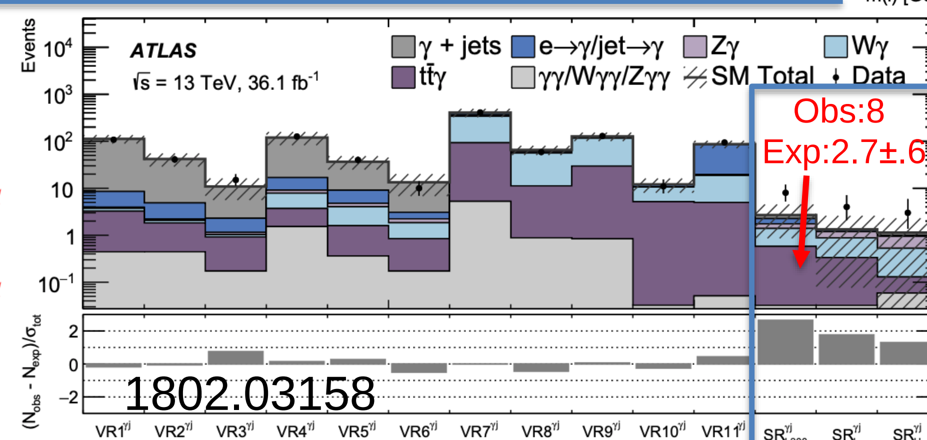
1803.02762





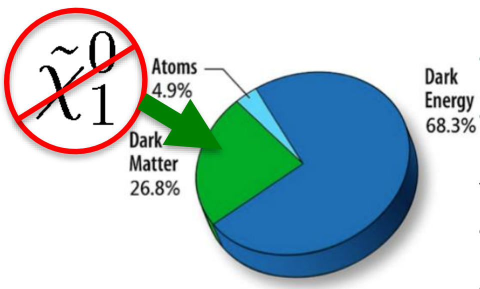
- (Di)photon signatures in GMSB context:





1802.03158

RPV SUSY searches (Huge chapter)



R-parity : $P_R=(-1)^{2S+3(B+L)}$ not conserved→

- LSP unstable → SUSY decays to SM finally →No DM candidate
- No MET from LSPs at SFs→ SM-like signatures (ie: multi-jet)

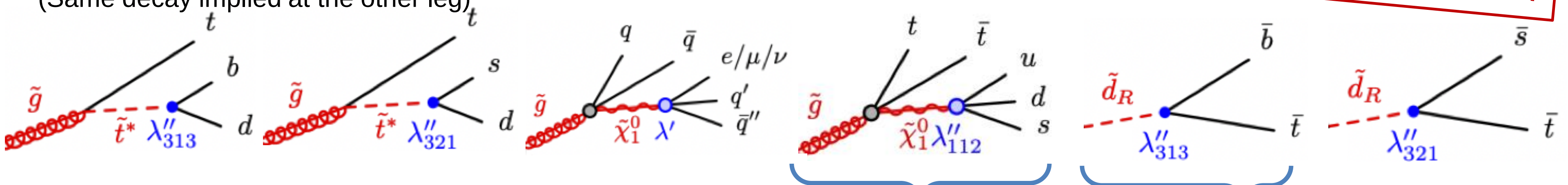
Searches Machinery:

- Boosted/merged jets with substructure (N-subjetinness)
- Resonances at jet masses
- Extra discrimination with std "tools": H_T, S_T N_j, N_b,…

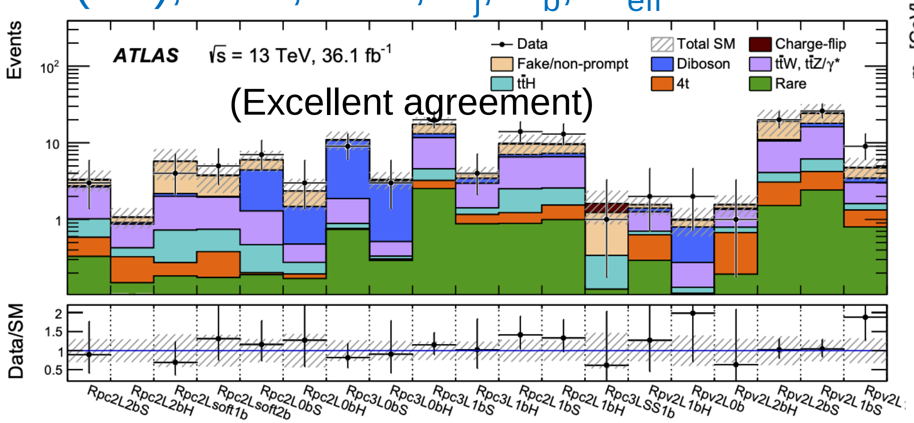
- ATLAS: 1706.03731. Generic search probing these in FS:

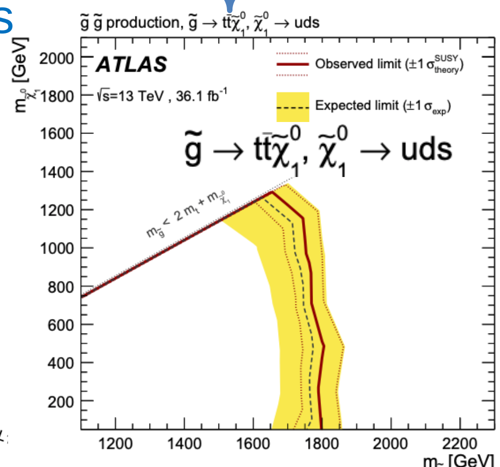
IHEP contribution

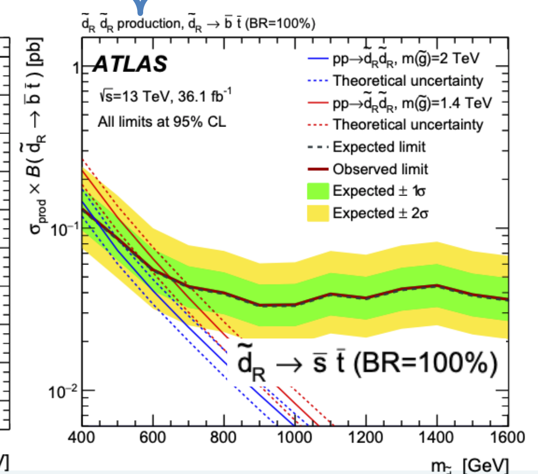
(Same decay implied at the other leg)



2l(SS), >=3l, MET, N_j, N_b, M_{eff}…→19 bins

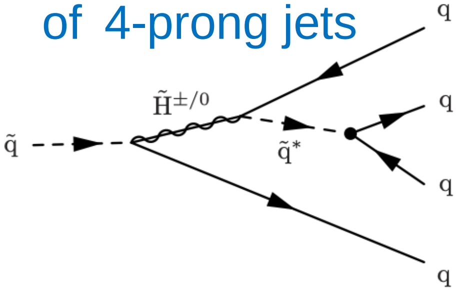


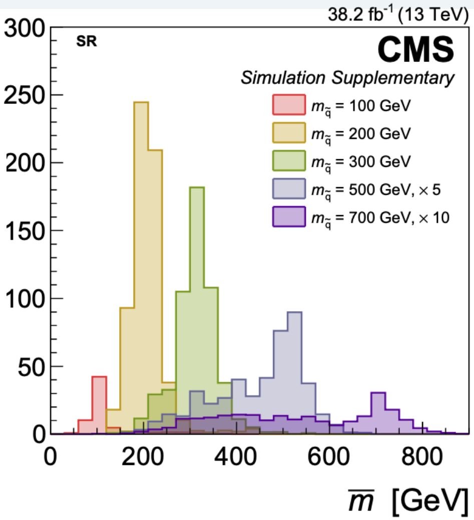




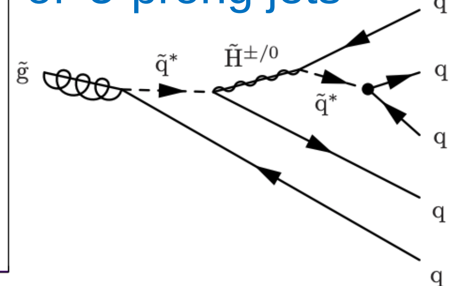
RPV SUSY, with "bump" of massive jets

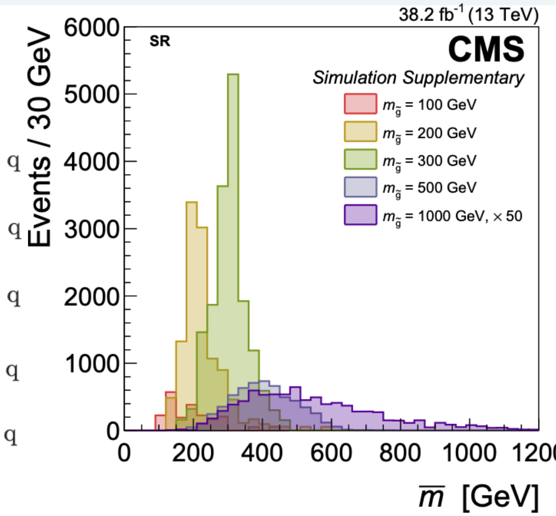
Squarks as pair of 4-prong jets





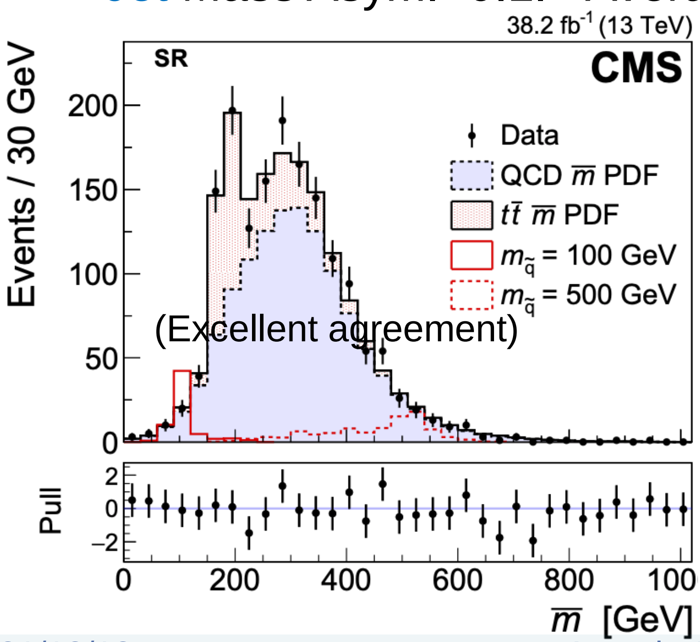
Gluinos as pair of 5-prong jets

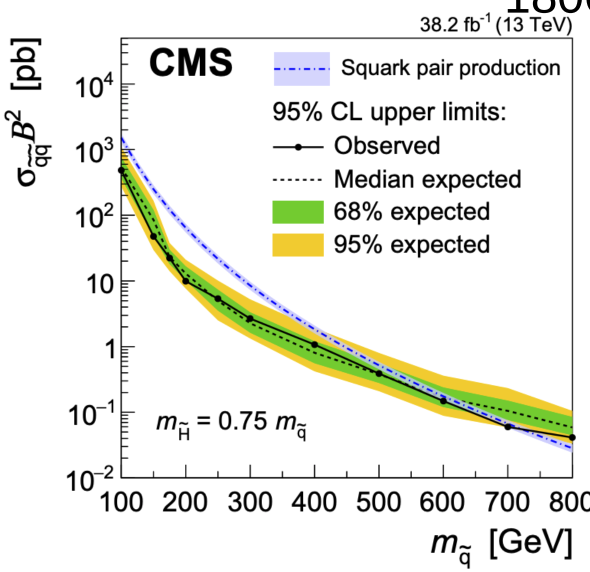


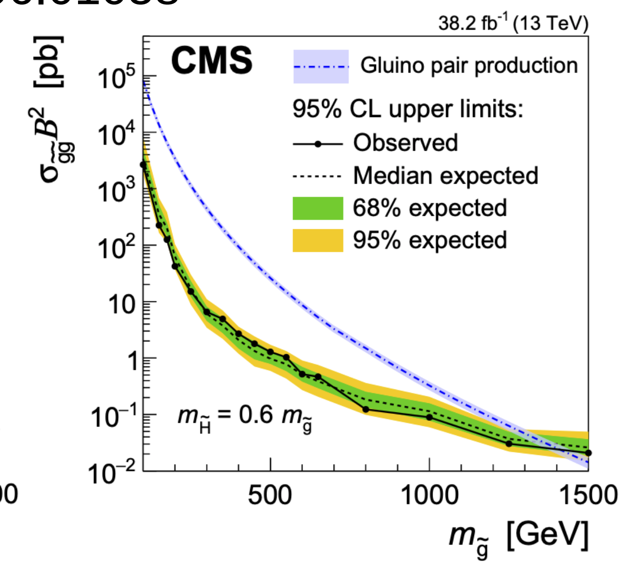


- High H_T, P_{Tj}. Use τ42, τ43, τ21 cuts. $\tau_N \equiv \frac{1}{d_0}\sum_i p_{T,i}\min\{\Delta R_{1,i}, \ldots, \Delta R_{N,i}\}$ $d_0 \equiv \sum_i p_{T,i} R$
- Jet Mass Asym.<0.1. Average Mass of 2 "fat" massive jets is the key observable:

1806.01058







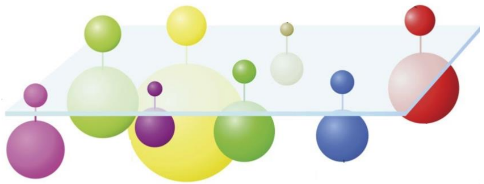
Summary & conclusion

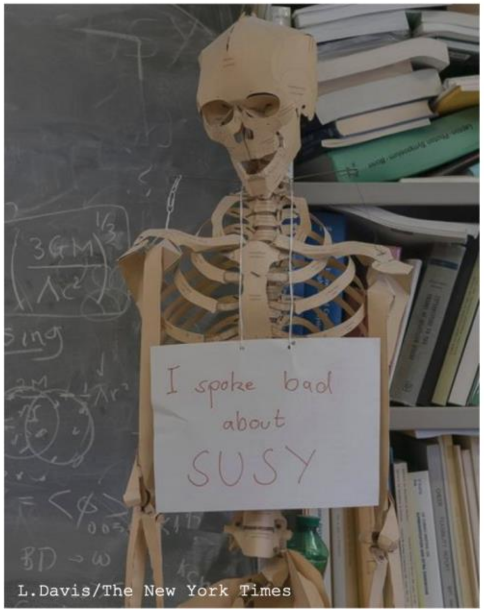
- There are really many more (uncovered here) results.
- ATLAS & CMS are searching for SUSY in every possible combination
- We haven’t found evidence of SUSY (yet)

- New results with x4 higher stat (140 fb^{-1}) will come soon
- If full Run-2 results provide no evidence… perhaps we’ll be allowed to “speak bad” about Natural SUSY… →

- Four SUSY talks at our workshop:

14:00	**Beyond Standard Model** (until 16:00) (Science Hall 101)
14:00	SUSY Search activities at IHEP - Da Xu (IHEP, Beijing)
14:15	Inclusive and Electroweakino SUSY search with leptons - Yang LIU (IHEP)
14:30	Electroweakino SUSY search with Wh - Huajie Cheng (高能所)
14:45	Search for direct stau production with the ATLAS detector - ChenZheng Zhu (S)



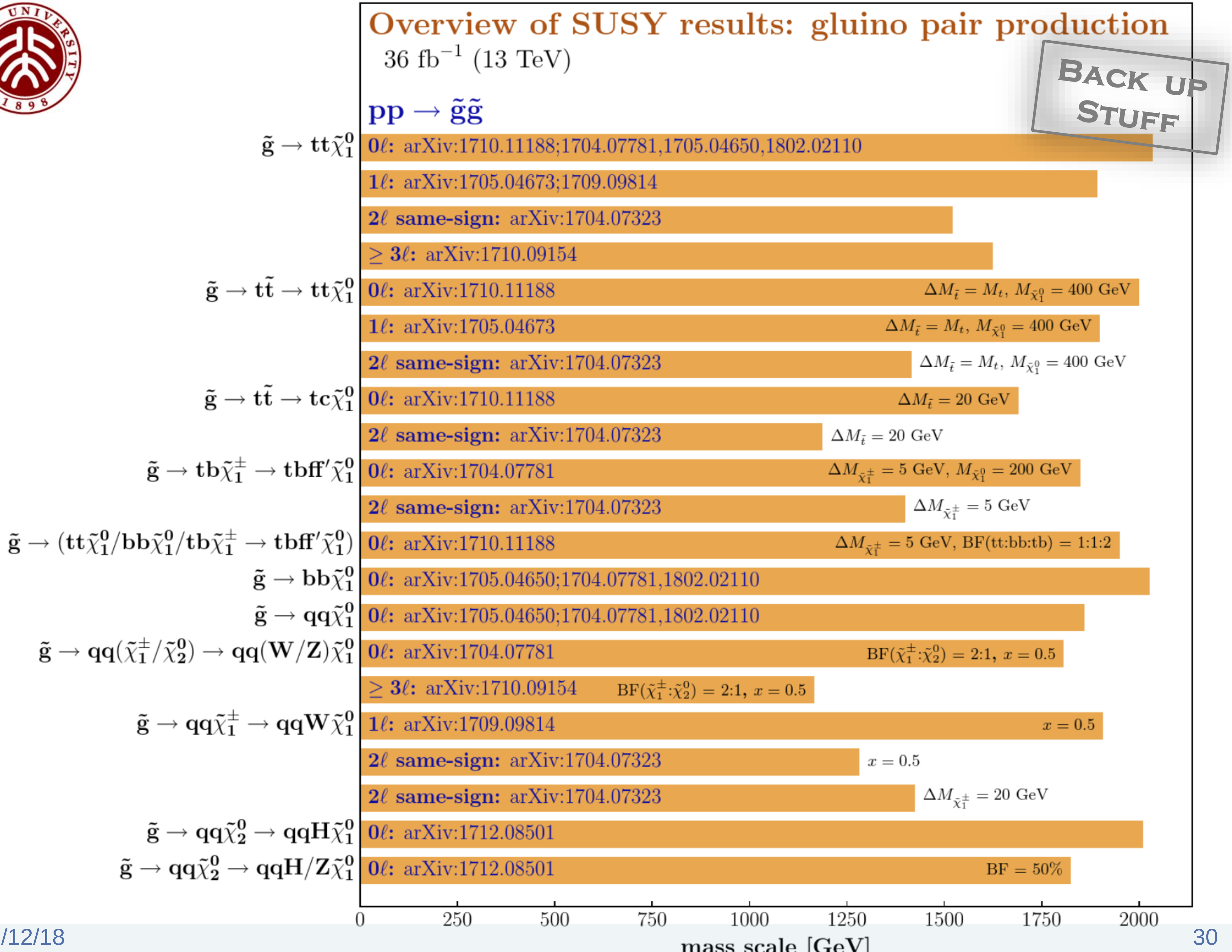


More SUSY results and details on experiments’ public pages:

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

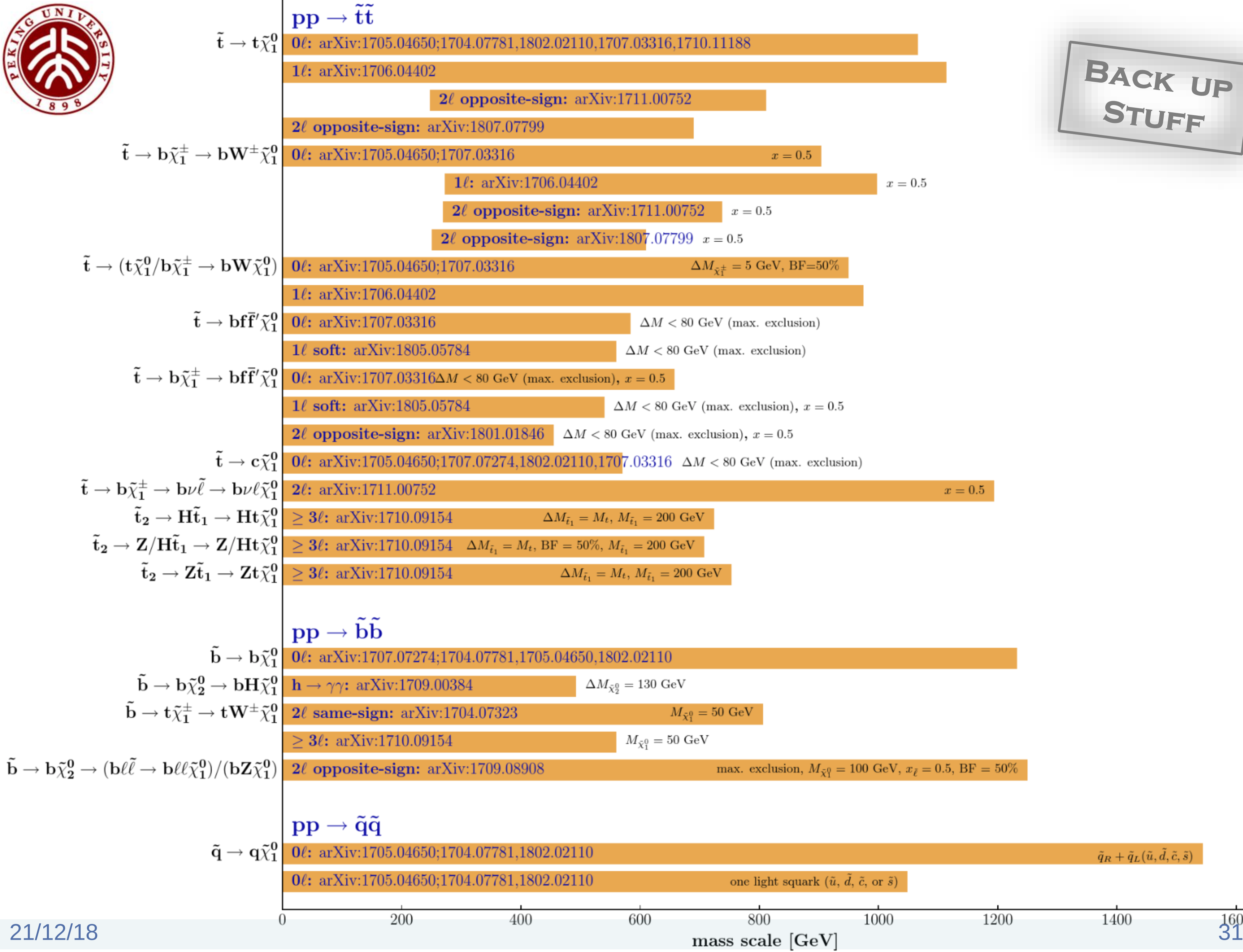
→ https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

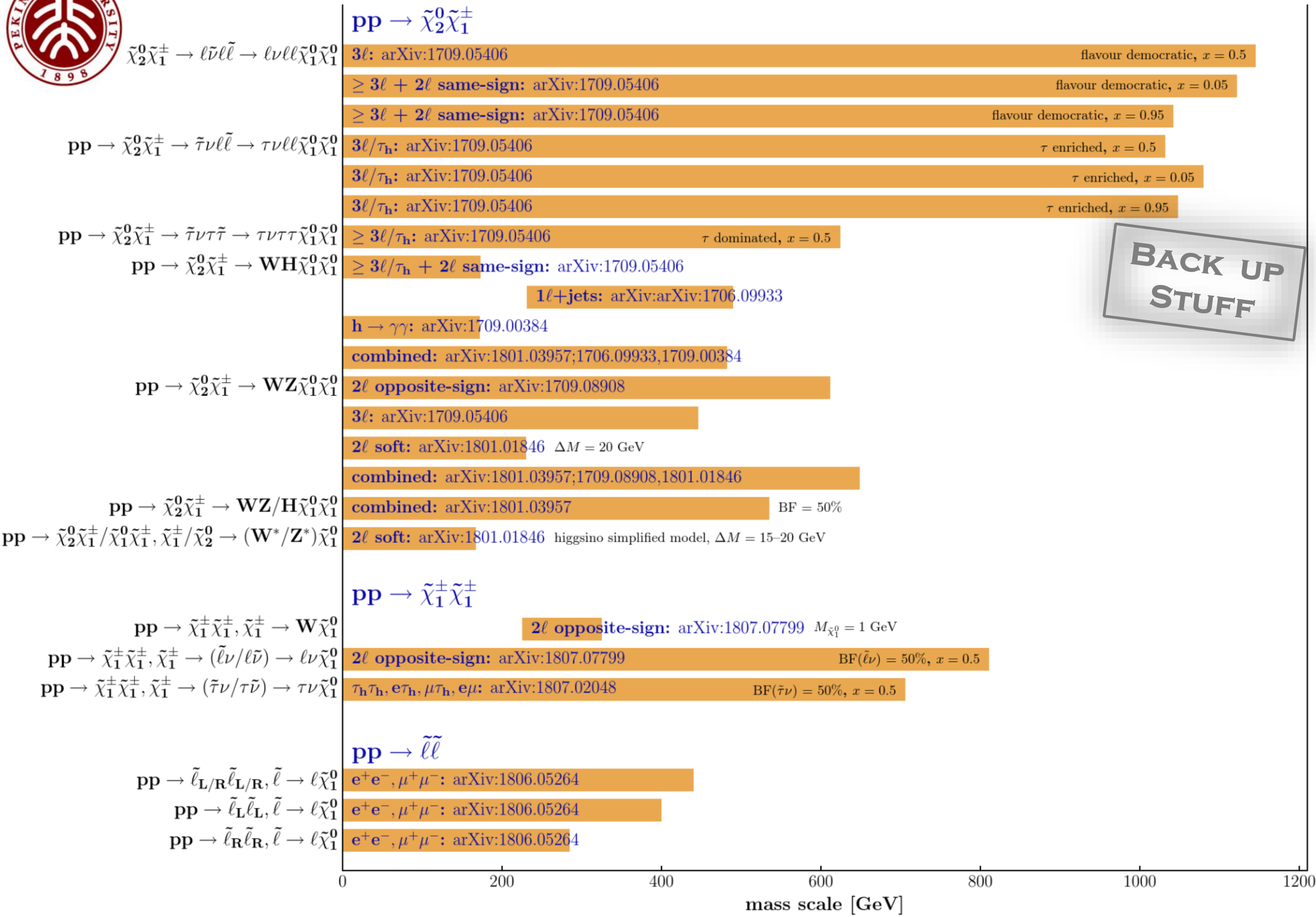
Back up Stuff

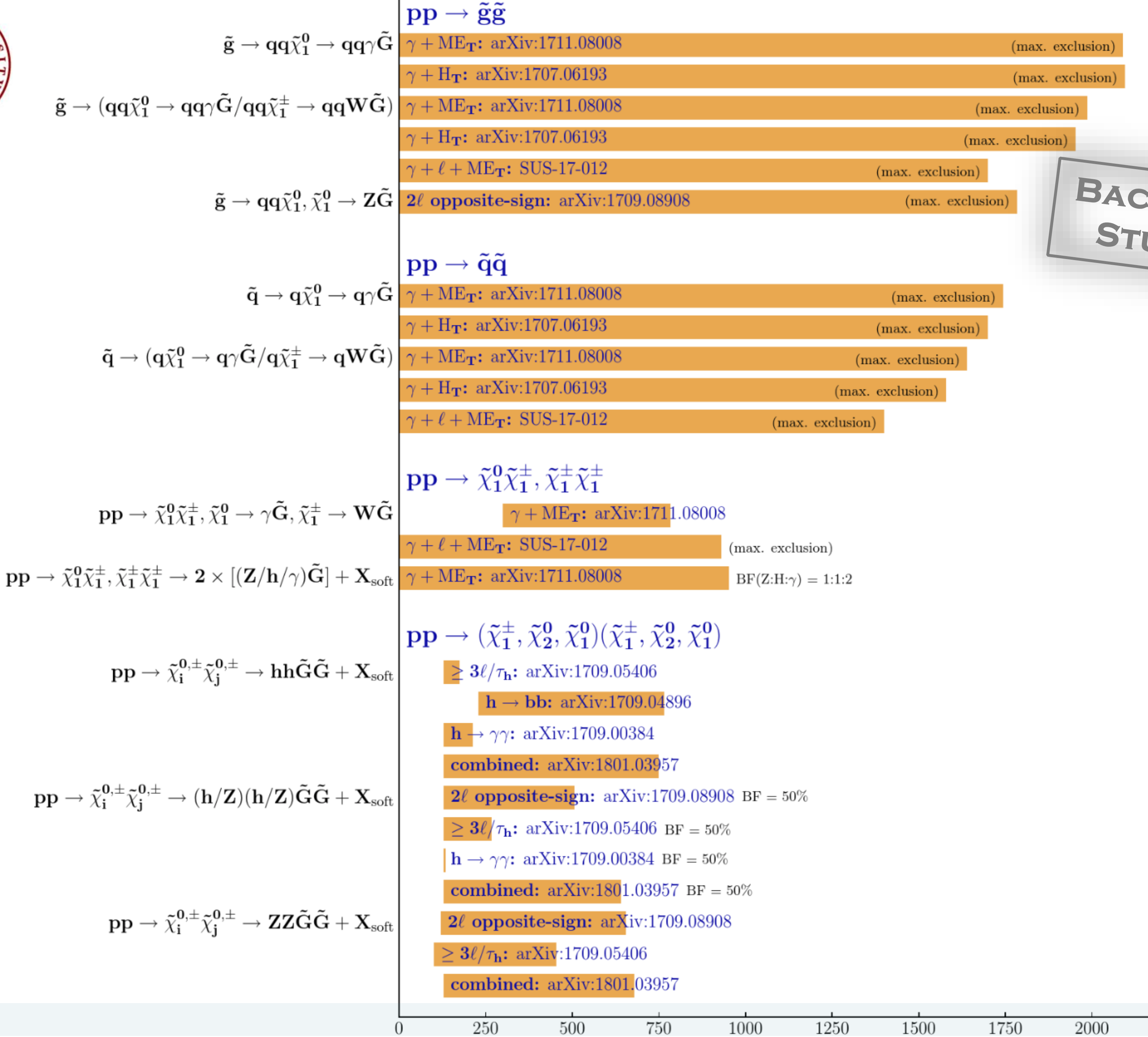


Overview of SUSY results: gluino pair production
36 fb^{-1} (13 TeV)
BACK UP STUFF
$pp \rightarrow \tilde{g}\tilde{g}$
$\tilde{g} \rightarrow tt\tilde{\chi}_1^0$
0ℓ: arXiv:1710.11188;1704.07781,1705.04650,1802.02110
1ℓ: arXiv:1705.04673;1709.09814
2ℓ same-sign: arXiv:1704.07323
$\geq 3\ell$: arXiv:1710.09154
$\tilde{g} \rightarrow t\tilde{t} \rightarrow tt\tilde{\chi}_1^0$
0ℓ: arXiv:1710.11188
$\Delta M_{\tilde{t}} = M_t$, $M_{\tilde{\chi}_1^0} = 400$ GeV
1ℓ: arXiv:1705.04673
$\Delta M_{\tilde{t}} = M_t$, $M_{\tilde{\chi}_1^0} = 400$ GeV
2ℓ same-sign: arXiv:1704.07323
$\Delta M_{\tilde{t}} = M_t$, $M_{\tilde{\chi}_1^0} = 400$ GeV
$\tilde{g} \rightarrow t\tilde{t} \rightarrow tc\tilde{\chi}_1^0$
0ℓ: arXiv:1710.11188
$\Delta M_{\tilde{t}} = 20$ GeV
2ℓ same-sign: arXiv:1704.07323
$\Delta M_{\tilde{t}} = 20$ GeV
$\tilde{g} \rightarrow tb\tilde{\chi}_1^\pm \rightarrow tbff'\tilde{\chi}_1^0$
0ℓ: arXiv:1704.07781
$\Delta M_{\tilde{\chi}_1^\pm} = 5$ GeV, $M_{\tilde{\chi}_1^0} = 200$ GeV
2ℓ same-sign: arXiv:1704.07323
$\Delta M_{\tilde{\chi}_1^\pm} = 5$ GeV
$\tilde{g} \rightarrow (tt\tilde{\chi}_1^0/bb\tilde{\chi}_1^0/tb\tilde{\chi}_1^\pm \rightarrow tbff'\tilde{\chi}_1^0)$
0ℓ: arXiv:1710.11188
$\Delta M_{\tilde{\chi}_1^\pm} = 5$ GeV, BF(tt:bb:tb) = 1:1:2
$\tilde{g} \rightarrow bb\tilde{\chi}_1^0$
0ℓ: arXiv:1705.04650;1704.07781,1802.02110
$\tilde{g} \rightarrow qq\tilde{\chi}_1^0$
0ℓ: arXiv:1705.04650;1704.07781,1802.02110
$\tilde{g} \rightarrow qq(\tilde{\chi}_1^\pm/\tilde{\chi}_2^0) \rightarrow qq(W/Z)\tilde{\chi}_1^0$
0ℓ: arXiv:1704.07781
BF($\tilde{\chi}_1^\pm$:$\tilde{\chi}_2^0$) = 2:1, $x = 0.5$
$\geq 3\ell$: arXiv:1710.09154
BF($\tilde{\chi}_1^\pm$:$\tilde{\chi}_2^0$) = 2:1, $x = 0.5$
$\tilde{g} \rightarrow qq\tilde{\chi}_1^\pm \rightarrow qqW\tilde{\chi}_1^0$
1ℓ: arXiv:1709.09814
$x = 0.5$
2ℓ same-sign: arXiv:1704.07323
$x = 0.5$
2ℓ same-sign: arXiv:1704.07323
$\Delta M_{\tilde{\chi}_1^\pm} = 20$ GeV
$\tilde{g} \rightarrow qq\tilde{\chi}_2^0 \rightarrow qqH\tilde{\chi}_1^0$
0ℓ: arXiv:1712.08501
$\tilde{g} \rightarrow qq\tilde{\chi}_2^0 \rightarrow qqH/Z\tilde{\chi}_1^0$
0ℓ: arXiv:1712.08501
BF = 50%
0
250
500
750
1000
1250
1500
1750
2000
mass scale [GeV]

BACK UP STUFF




$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1$
$\tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to \ell\tilde{\nu}\ell\tilde{\ell} \to \ell\nu\ell\ell\tilde{\chi}^0_1\tilde{\chi}^0_1$
3ℓ: arXiv:1709.05406 flavour democratic, $x = 0.5$
$\geq 3\ell + 2\ell$ same-sign: arXiv:1709.05406 flavour democratic, $x = 0.05$
$\geq 3\ell + 2\ell$ same-sign: arXiv:1709.05406 flavour democratic, $x = 0.95$
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to \tilde{\tau}\nu\ell\tilde{\ell} \to \tau\nu\ell\ell\tilde{\chi}^0_1\tilde{\chi}^0_1$
$3\ell/\tau_h$: arXiv:1709.05406 τ enriched, $x = 0.5$
$3\ell/\tau_h$: arXiv:1709.05406 τ enriched, $x = 0.05$
$3\ell/\tau_h$: arXiv:1709.05406 τ enriched, $x = 0.95$
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to \tilde{\tau}\nu\tau\tilde{\tau} \to \tau\nu\tau\tau\tilde{\chi}^0_1\tilde{\chi}^0_1$
$\geq 3\ell/\tau_h$: arXiv:1709.05406 τ dominated, $x = 0.5$
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to WH\tilde{\chi}^0_1\tilde{\chi}^0_1$
$\geq 3\ell/\tau_h + 2\ell$ same-sign: arXiv:1709.05406
1ℓ+jets: arXiv:arXiv:1706.09933
$h \to \gamma\gamma$: arXiv:1709.00384
combined: arXiv:1801.03957;1706.09933,1709.00384
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to WZ\tilde{\chi}^0_1\tilde{\chi}^0_1$
2ℓ opposite-sign: arXiv:1709.08908
3ℓ: arXiv:1709.05406
2ℓ soft: arXiv:1801.01846 $\Delta M = 20$ GeV
combined: arXiv:1801.03957;1709.08908,1801.01846
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1 \to WZ/H\tilde{\chi}^0_1\tilde{\chi}^0_1$
combined: arXiv:1801.03957 BF = 50%
$pp \to \tilde{\chi}^0_2\tilde{\chi}^\pm_1/\tilde{\chi}^0_1\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1/\tilde{\chi}^0_2 \to (W^*/Z^*)\tilde{\chi}^0_1$
2ℓ soft: arXiv:1801.01846 higgsino simplified model, $\Delta M = 15$–20 GeV
$pp \to \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1$
$pp \to \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1 \to W\tilde{\chi}^0_1$
2ℓ opposite-sign: arXiv:1807.07799 $M_{\tilde{\chi}^0_1} = 1$ GeV
$pp \to \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1 \to (\tilde{\ell}\nu/\ell\tilde{\nu}) \to \ell\nu\tilde{\chi}^0_1$
2ℓ opposite-sign: arXiv:1807.07799 BF$(\tilde{\ell}\nu) = 50\%$, $x = 0.5$
$pp \to \tilde{\chi}^\pm_1\tilde{\chi}^\pm_1, \tilde{\chi}^\pm_1 \to (\tilde{\tau}\nu/\tau\tilde{\nu}) \to \tau\nu\tilde{\chi}^0_1$
$\tau_h\tau_h, e\tau_h, \mu\tau_h, e\mu$: arXiv:1807.02048 BF$(\tilde{\tau}\nu) = 50\%$, $x = 0.5$
$pp \to \tilde{\ell}\tilde{\ell}$
$pp \to \tilde{\ell}_{L/R}\tilde{\ell}_{L/R}, \tilde{\ell} \to \ell\tilde{\chi}^0_1$
$e^+e^-, \mu^+\mu^-$: arXiv:1806.05264
$pp \to \tilde{\ell}_L\tilde{\ell}_L, \tilde{\ell} \to \ell\tilde{\chi}^0_1$
$e^+e^-, \mu^+\mu^-$: arXiv:1806.05264
$pp \to \tilde{\ell}_R\tilde{\ell}_R, \tilde{\ell} \to \ell\tilde{\chi}^0_1$
$e^+e^-, \mu^+\mu^-$: arXiv:1806.05264
0
200
400
600
800
1000
1200
mass scale [GeV]
BACK UP STUFF



BACK UP STUFF

1706.03731

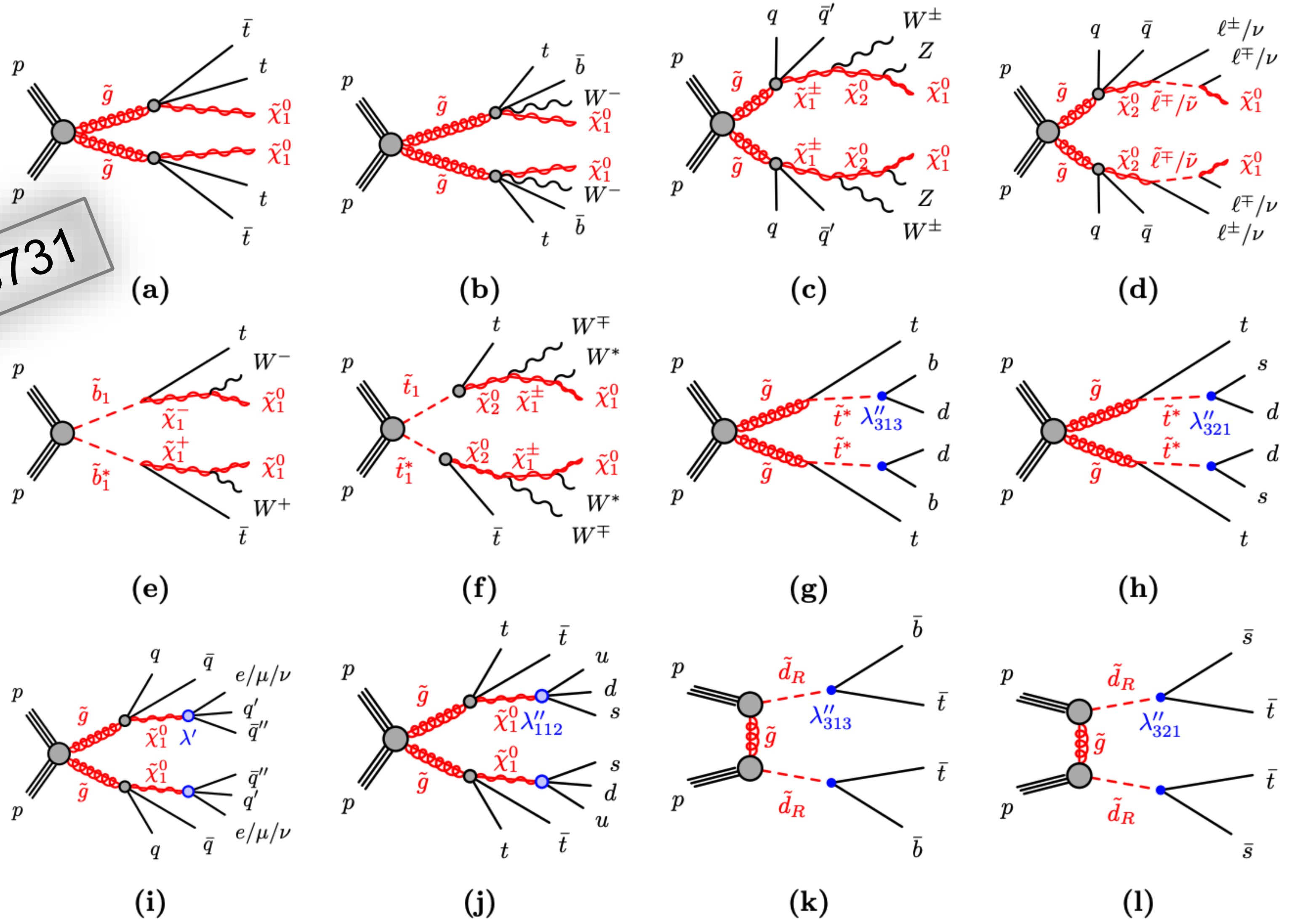
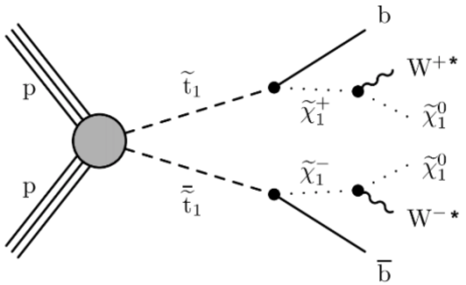


Figure 1. RPC SUSY processes featuring gluino ((a), (b), (c), (d)) or third-generation squark ((e), (f)) pair production studied in this analysis. RPV SUSY models considered are gluino pair production ((g), (h), (i), (j)) and t-channel production of down squark-rights ((k), (l)) which decay via baryon- or lepton-number violating couplings λ'' and λ' respectively. In the diagrams, $q \equiv u, d, c, s$ and $\ell \equiv e, \mu, \tau$. In figure 1d, $\tilde{\ell} \equiv \tilde{e}, \tilde{\mu}, \tilde{\tau}$ and $\tilde{\nu} \equiv \tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$. In figure 1f, the W^* labels indicate largely off-shell W bosons — the mass difference between $\tilde{\chi}_1^\pm$ and $\tilde{\chi}_1^0$ is around 1 GeV.



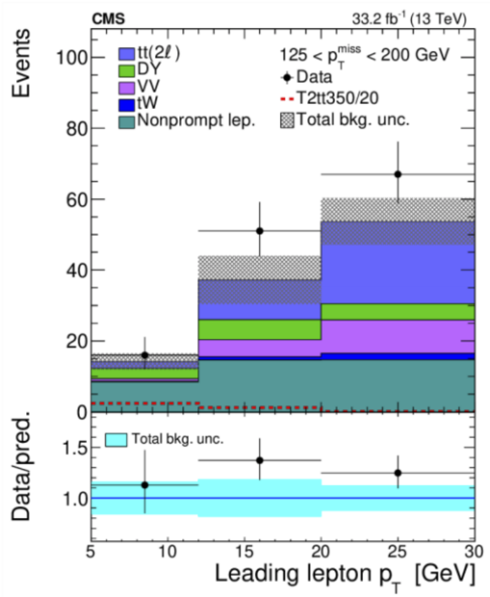
Compressed stops

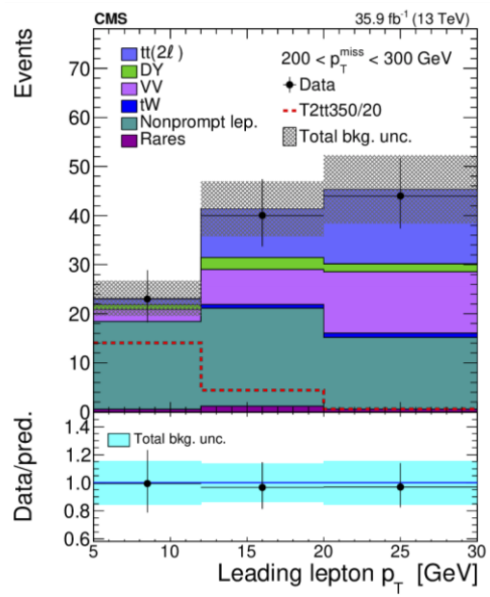
Compressed scenario with small $\Delta m\ (\tilde{t}, LSP)$ proceeds through an off-shell W, resulting in low-p_T decay products.

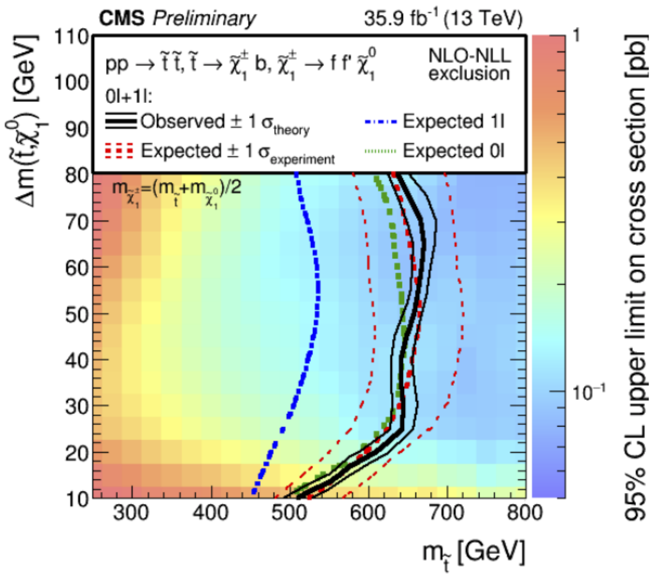
Rely on large ISR boost for sizeable E_T^{miss}

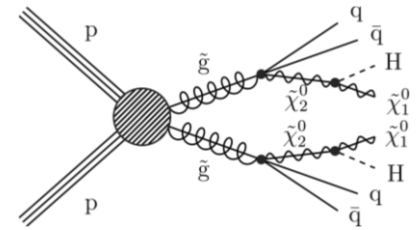
Searches with 1l and 2l,

- Backgrounds from MC normalized to data in control regions.





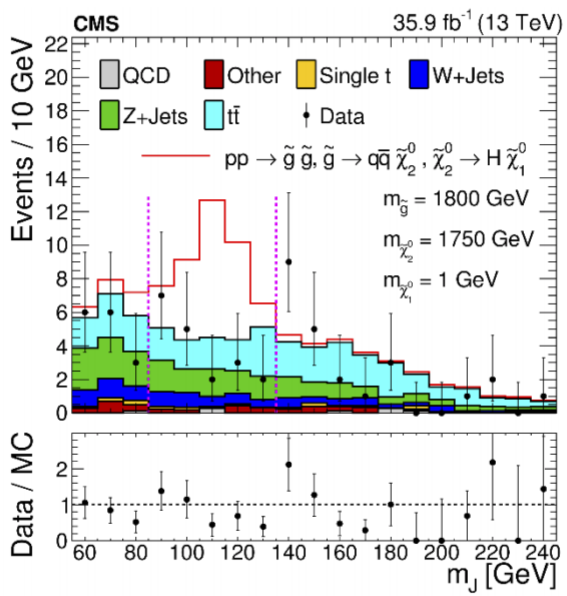


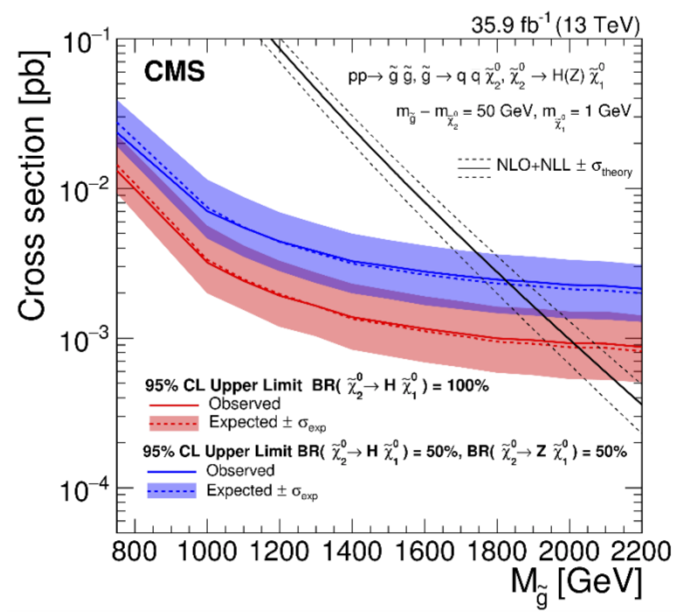


Boosted Higgs search

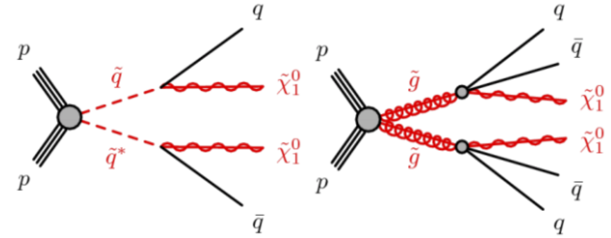
High p_T $H \rightarrow b\bar{b}$ decay with small opening angle. Use large angle jets to capture full Higgs decay. Identify Higgs tags by presence of two displaced sub-jets. **Jet mass shows clear peaking** structure

Select **events with 1 or 2 Higgs tags** and large missing energy. Backgrounds predicted from **mass and bb-tag sidebands** in data.

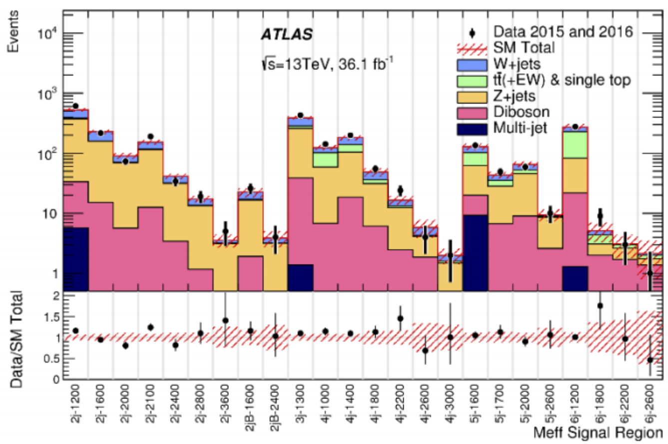


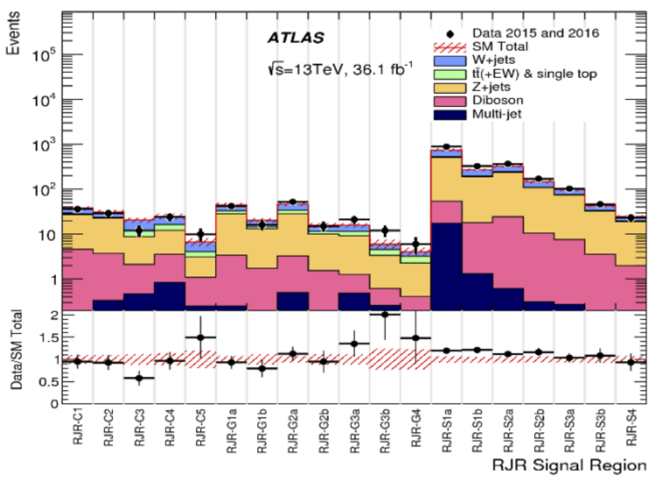


arXiv:1712.08501



0L search for squarks and gluinos



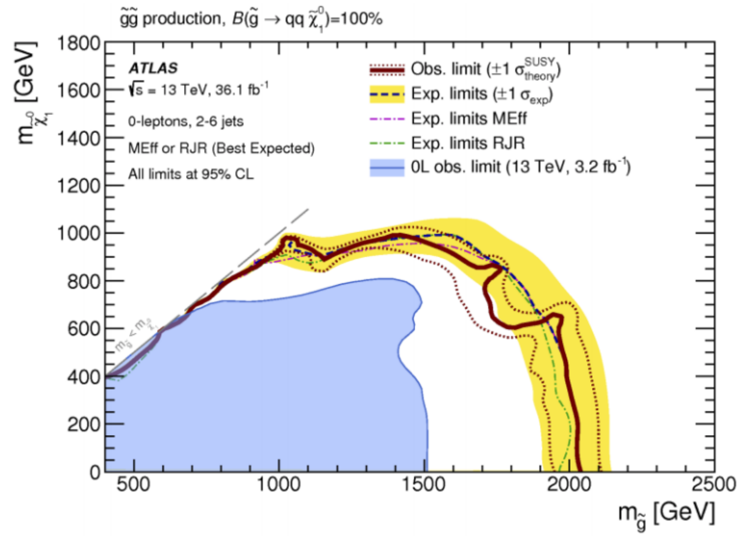


Events with 0-leptons and 2-6 jets. Signal regions defined using:

- $m_{eff} = \sum_{jet} p_T^{jet} + E_T^{miss}$ or the **Recursive Jigsaw Reconstruction** (RJR)

Using the **best** SR of the two approaches.

Masses of up to 2 TeV (gluinos) and 1.5 TeV (squarks) are probed.



ATLAS GMSB search: 1/2γ, 0l, Nj>=5

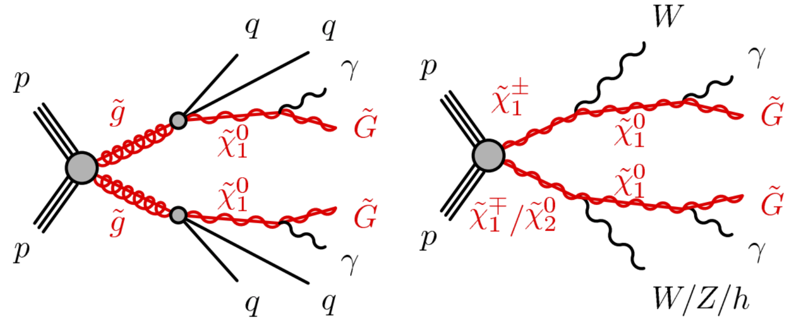


Figure 1: Typical production and decay processes for the (left) gluino-production and (right) electroweak-production instances of the GGM model for which the NLSP is a binolike neutralino. These models are referred to in the text as the gluino–bino and wino–bino models, respectively.

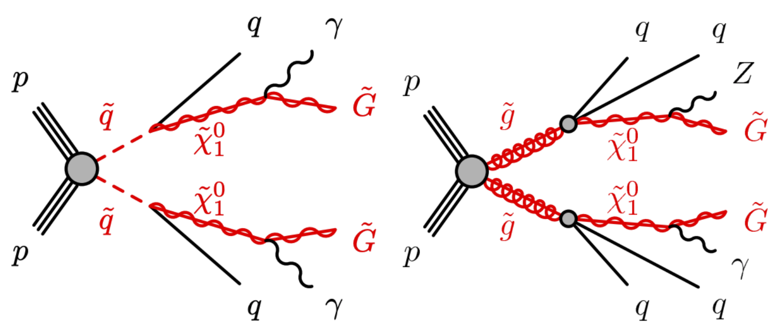
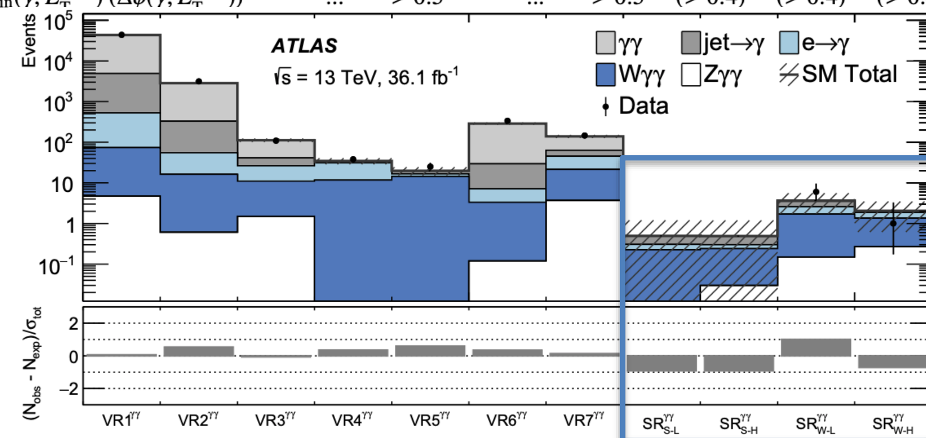
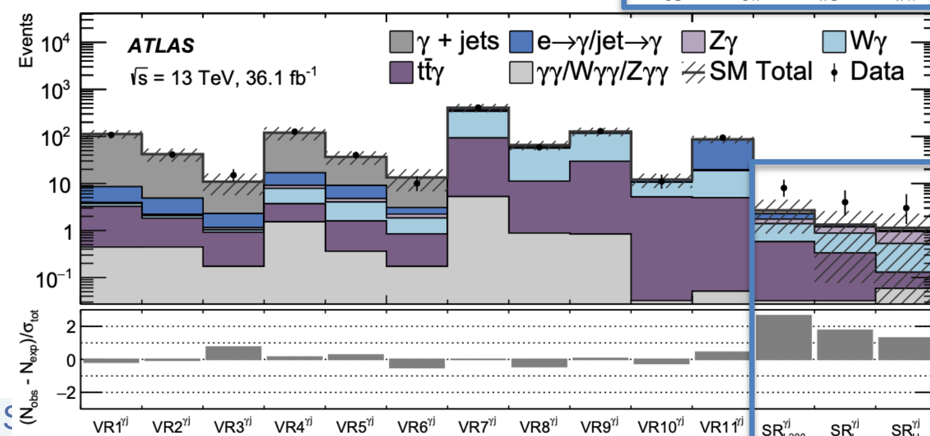


Figure 2: Typical production and decay processes for (left) the squark-production instance of the GGM model for which the NLSP is a binolike neutralino, and (right) the gluino-production instance of the GGM model for which the NLSP is a higgsino–bino neutralino admixture. These models are referred to in the text as the squark–bino and higgsino–bino models, respectively.

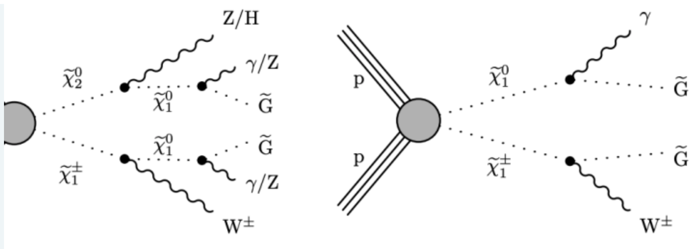
Table 1: The requirements defining the seven SRs for the diphoton and photon+jets searches. All symbols are defined in the text. An ellipsis is entered when no such requirement is made in the given signal region.

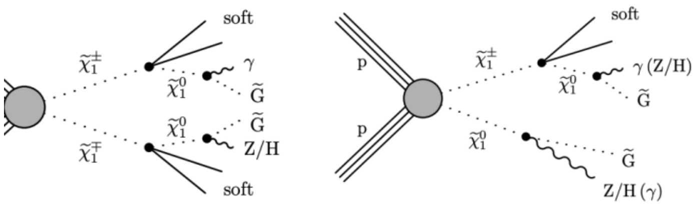
Signal region	$SR^{\gamma\gamma}_{S-L}$	$SR^{\gamma\gamma}_{S-H}$	$SR^{\gamma\gamma}_{W-L}$	$SR^{\gamma\gamma}_{W-H}$	$SR^{\gamma j}_{L}$	$SR^{\gamma j}_{L200}$	$SR^{\gamma j}_{H}$
Number of photons	≥ 2	≥ 2	≥ 2	≥ 2	≥ 1	≥ 1	≥ 1
E_T^γ [GeV]	> 75	> 75	> 75	> 75	> 145	> 145	> 400
Number of jets	...	...	...	...	≥ 5	≥ 5	≥ 3
Number of leptons	...	...	...	...	0	0	0
E_T^{miss} [GeV]	> 150	> 250	> 150	> 250	> 300	> 200	> 400
H_T [GeV]	> 2750	> 2000	> 1500	> 1000	...	...	...
m_{eff} [GeV]	...	...	...	...	> 2000	> 2000	> 2400
R_T^4	...	...	...	...	< 0.90	< 0.90	...
$\Delta\phi_{min}(\text{jet}, E_T^{miss})$	> 0.5	> 0.5	> 0.5	> 0.5	> 0.4	> 0.4	> 0.4
$\Delta\phi_{min}(\gamma, E_T^{miss})$ ($\Delta\phi(\gamma, E_T^{miss})$)	...	> 0.5	...	> 0.5	(> 0.4)	(> 0.4)	(> 0.4)





CMS 1711.08008, GMSB, >=1γ

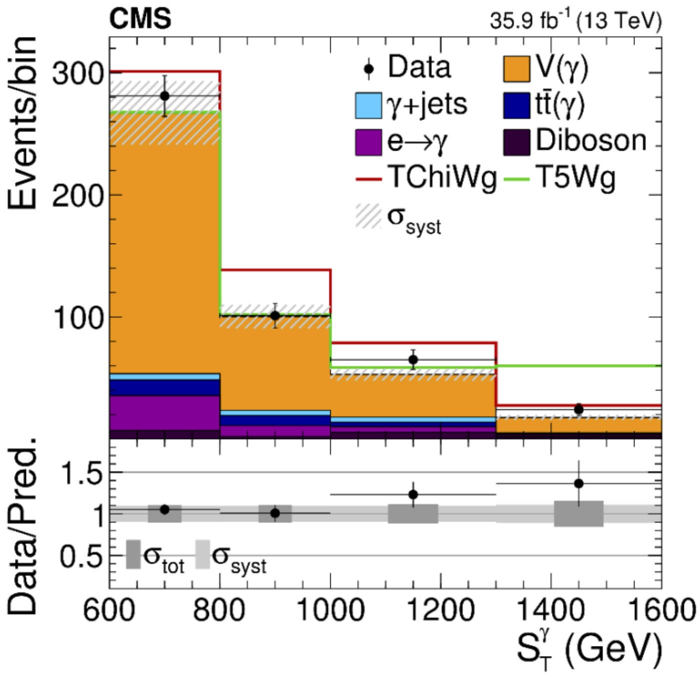


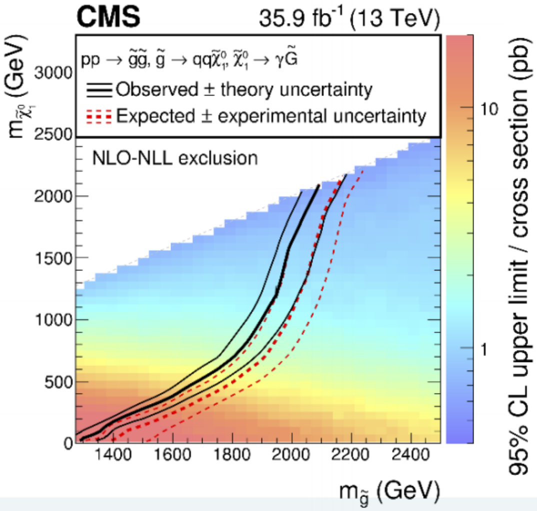


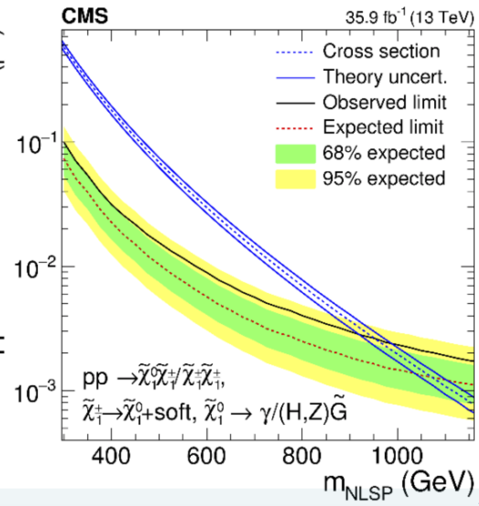
At least one photon and large E_T^{miss}

Signal regions defined in bins of $S_T^{\gamma} = E_T^{miss} + \sum_{\gamma_i} p_T(\gamma_i)$

Gaugino masses up to 950 GeV and gluino masses up to 2100 GeV are probed.

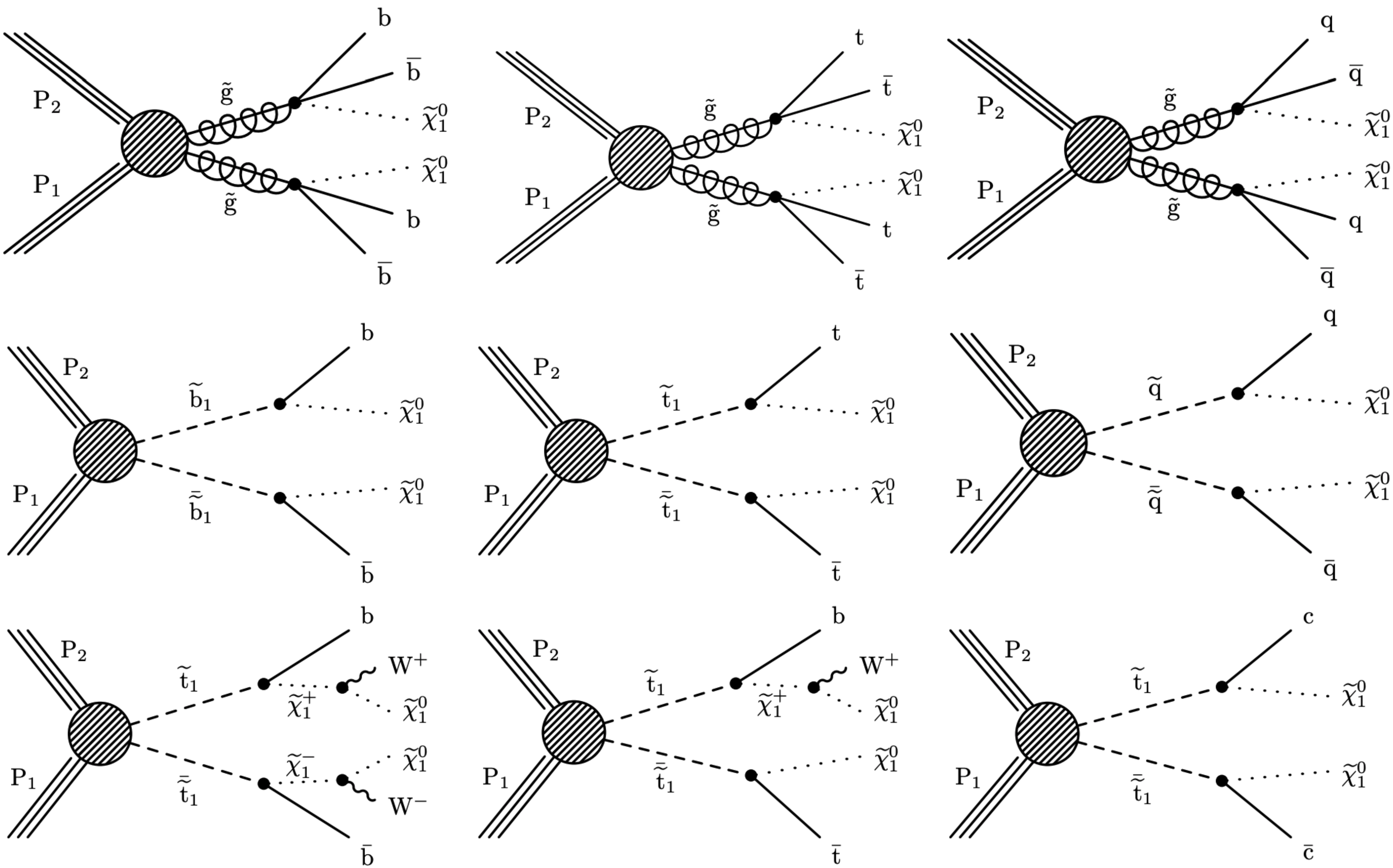






This analysis sets the most stringent limits for the studied models.

More Signatures from M_{T2} 1705.04650



Simplified Models of SUSY Signals

- We can categorise SUSY signals in terms of **production** and **decay** modes:

SUSY Production:

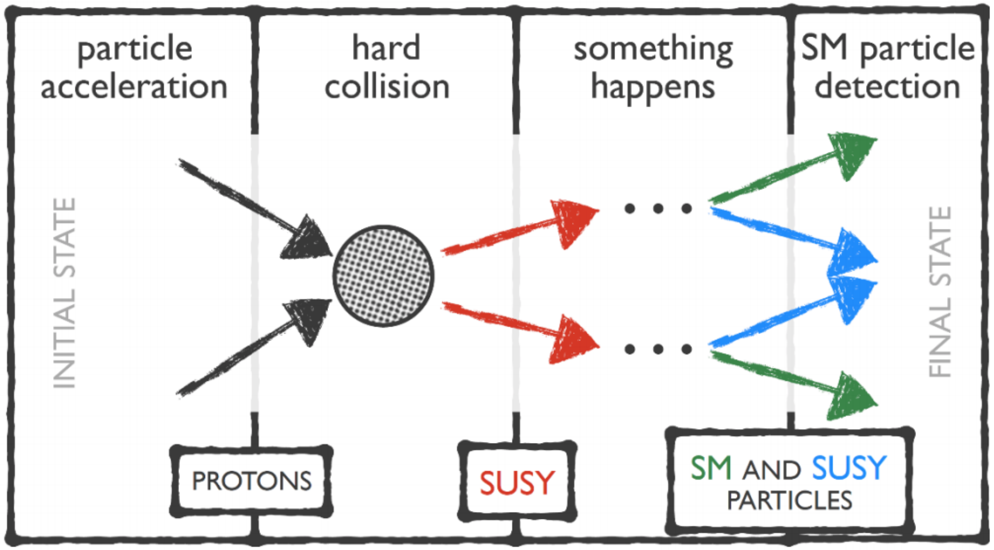
- Typically pair-produced (MSSM; assuming R-parity conservation)
- Production modes → choice guided by cross-sections

SUSY Decay:

- Decay into SUSY and SM particles → final states
- **Mass splitting Δm** (final - initial SUSY particles) dictates possible decay modes and kinematics

Production modes:

- Strong: squarks, gluinos
- **EWK**: charginos, neutralinos, sleptons

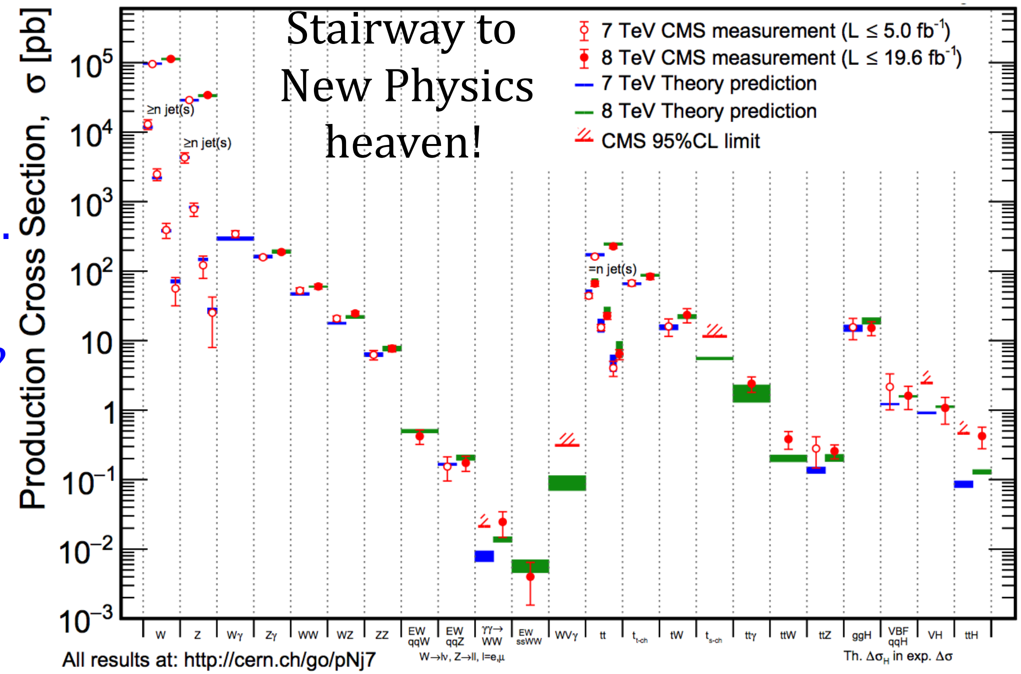


Final states:

- Hadronic (0ℓ) = **jets**
- Single-**leptonic** (1ℓ)
- Multi-**leptonic** (2ℓ+)
- **MET** in the form of LSPs (neutralinos) and neutrinos

SM: Successes & Shortcomings

- ◆ SM: Very successful theory:
  - Precisely pred.: $\sigma \sim [10^{11} - 10^{-3}]$ pb
  - Successful pred. of Higgs BRs.
  - No evidence for deviation from SM.
- ◆ But SM seams not a "final theory":
  - "Hierarchy/Naturalness" problem?
  - GUT Unification?
  - Gravity QFT ?
- ◆ Dark Matter & Dark Energy ?



$m_{Higgs}^2 = m_{bare}^2 - [\pm\lambda\Lambda_{cut}^2 \pm ...] = 125^2\ GeV^2$

New Physics at: $\Lambda_{cut} \sim 10^2 - 10^{18}$ GeV

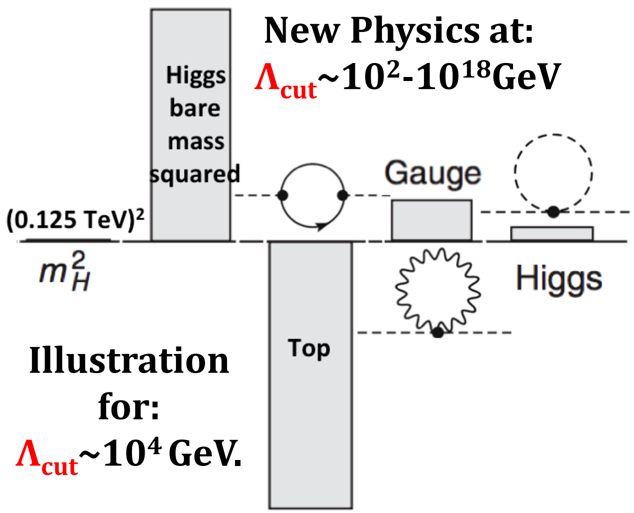
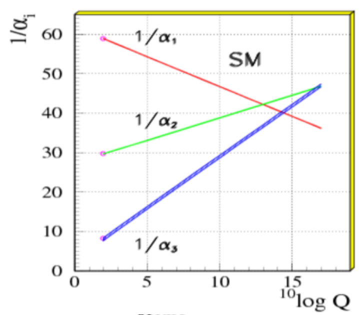
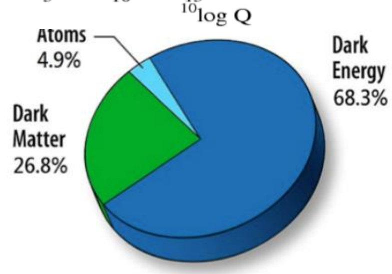
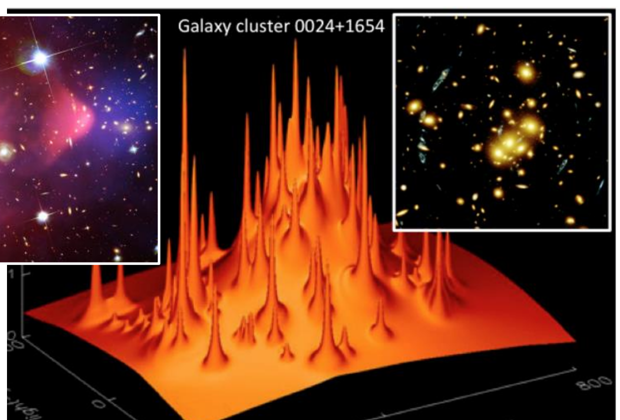


Illustration for: $\Lambda_{cut} \sim 10^4$ GeV.

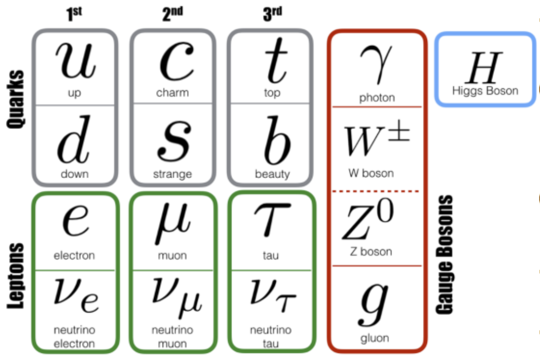


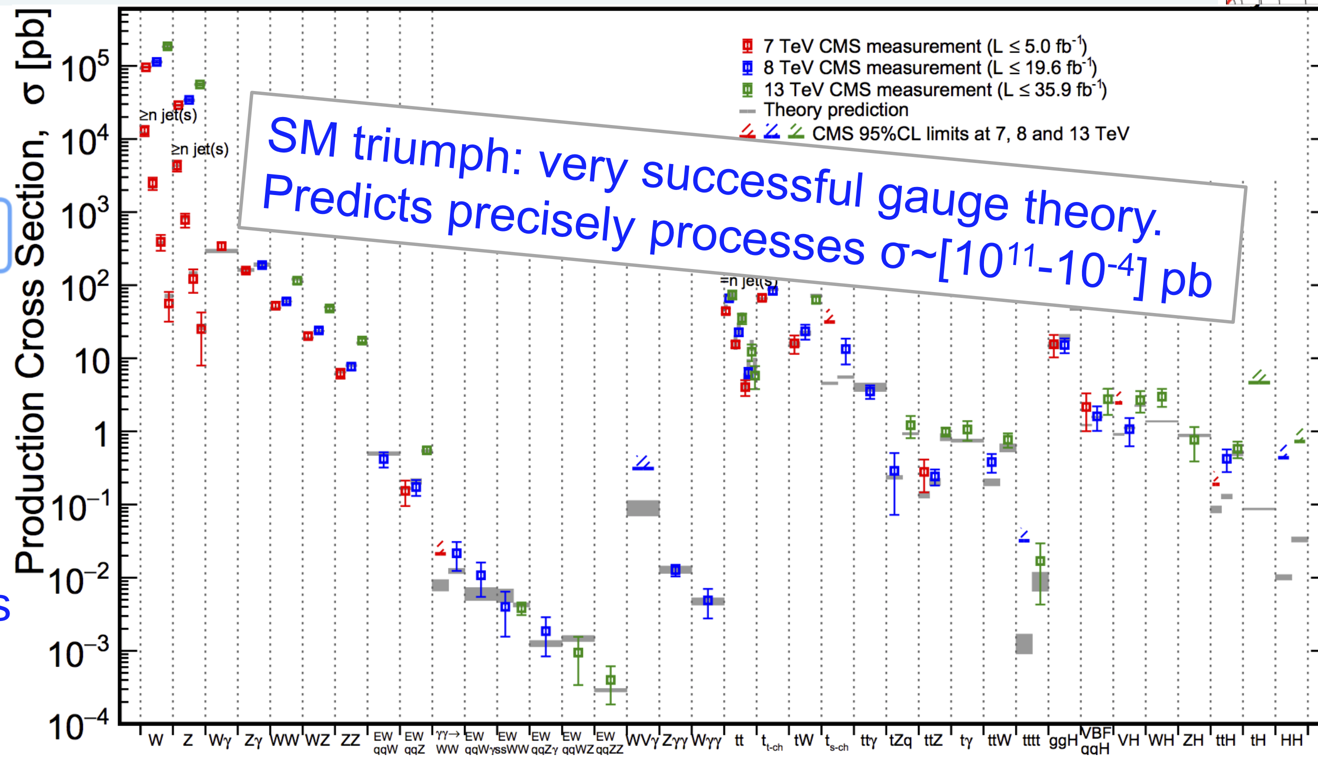




Gravitational Lensing over Galaxy Cluster

SM: successes & shortcomings



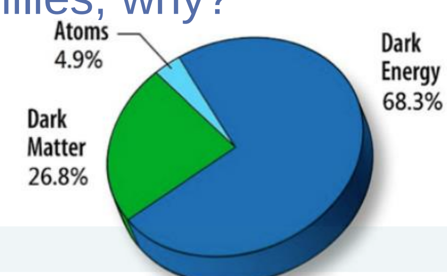


SM triumph: very successful gauge theory.
Predicts precisely processes $\sigma \sim [10^{11}\text{-}10^{-4}]$ pb

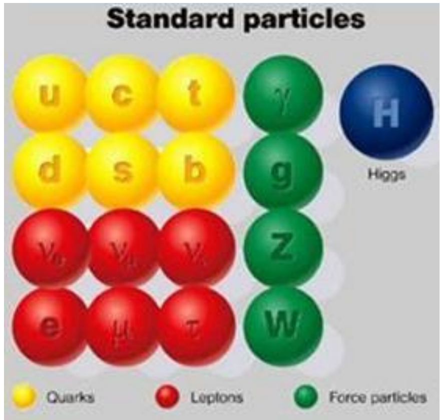
However SM looks like is not a complete theory:

- m_{Higgs}: renormalizable → $m_{Higgs}{}^2 = m_{bare}{}^2 - [\pm\lambda\Lambda_{cut}{}^2 \pm \dots] = 125^2\ \text{GeV}^2$
  Quantum corrections up to $\Lambda_{cut} \sim 10^2\text{-}10^{18}$ GeV
  $\Lambda_{cut} \sim 10^{18}$ GeV, Pl.-scale: $125^2 = 12345678901234567890123456789012345 - 12345678901234567890123456788996720$
  → "Hierarchy" or "Naturalness" Problem
- Unification GUT? Gravity QFT? 25 free param., 3 fermion families, why?
- Also shortcomings in Cosmology: Dark Matter, Dark Energy

→ SM looks "effective" rather than fundamental theory…



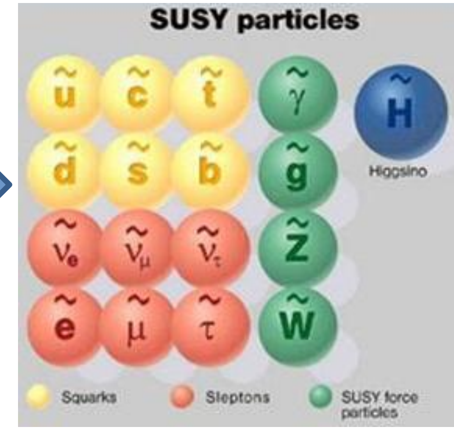
SUperSYmmetry: SUSY



New Principle of Nature
Δspin = ½

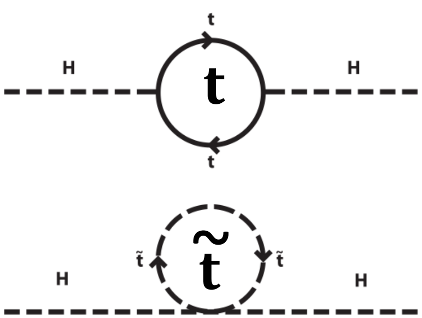
Spin Based Symmetry

Fermion ←→ Boson
$M_{SM\text{-}particle}$ < or << $M_{SUSY\text{-}Sparticle}$
Same couplings as in SM



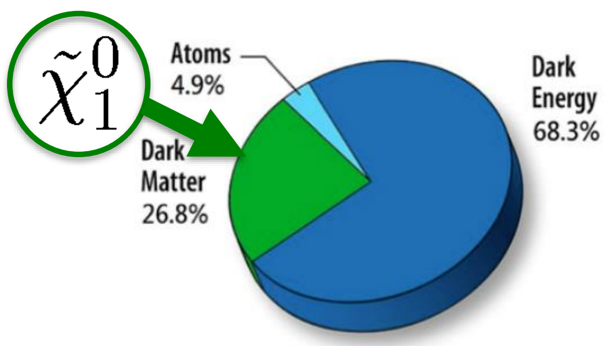
SUSY proposes solutions to SM problems:

◆ Hierarchy Problem



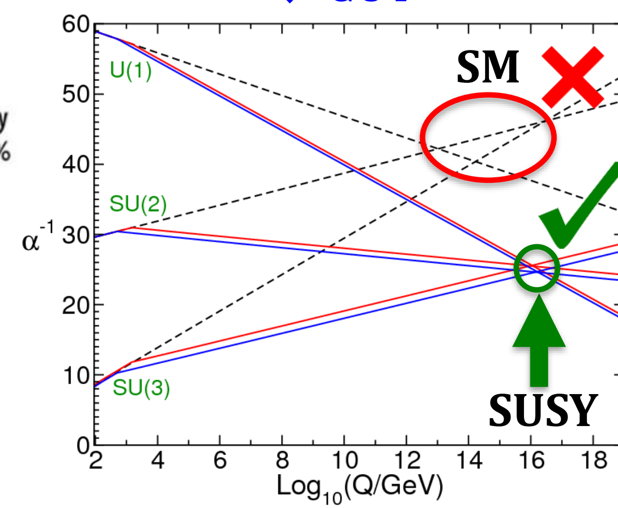
Sparticle loops cancel out corrections (if Λ_{cut}~< 1 TeV)

◆ Dark Matter



LSP → DM candidate
(if "R-parity" conserved)
$P_R=(-1)^{2s+3(B+L)}$

◆ GUT



a^{-i} converges @~10^{16} GeV

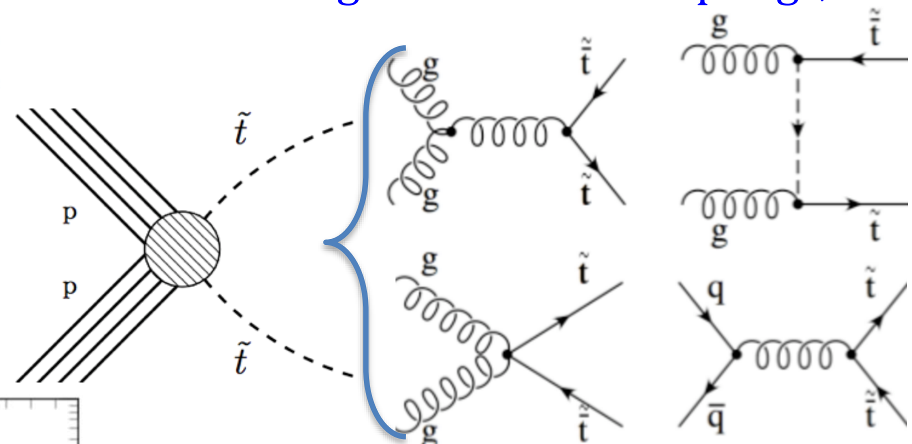
MSSM: couplings, production

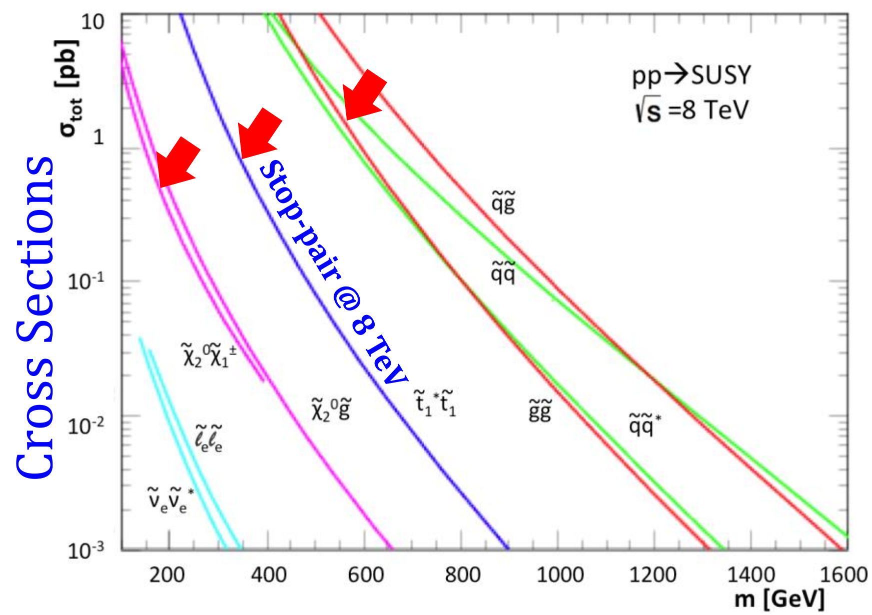
- MSSM: main framework (124 par.), cMSSM (5 par.) , pMSSM (19 par.).
- SUSY inherits SM couplings but:
  Flavor mixing → Mass eigenstates. Unknown mixing→ unknown couplings, BR...

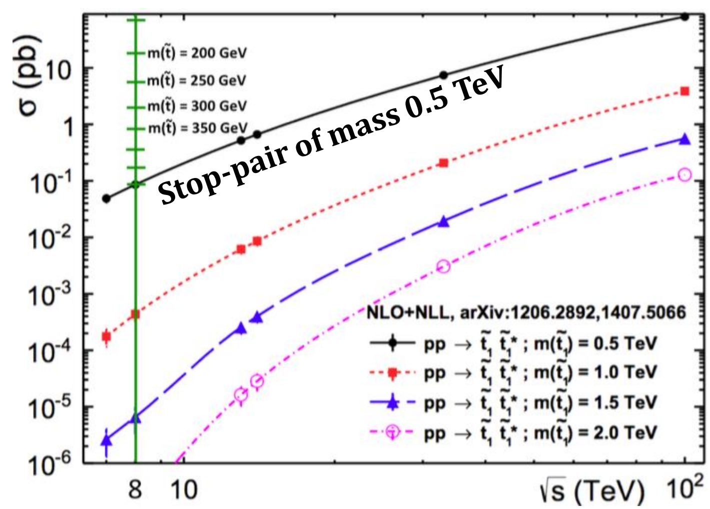
$$\tilde{B}, \tilde{W}^0, \tilde{h}^0, \tilde{H}^0 \;\Rightarrow\; \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$$

$$\tilde{W}^\pm \;\; \tilde{H}^\pm \;\Rightarrow\; \tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$$

- LHC can produce→
  & probe SUSY with x-sec:







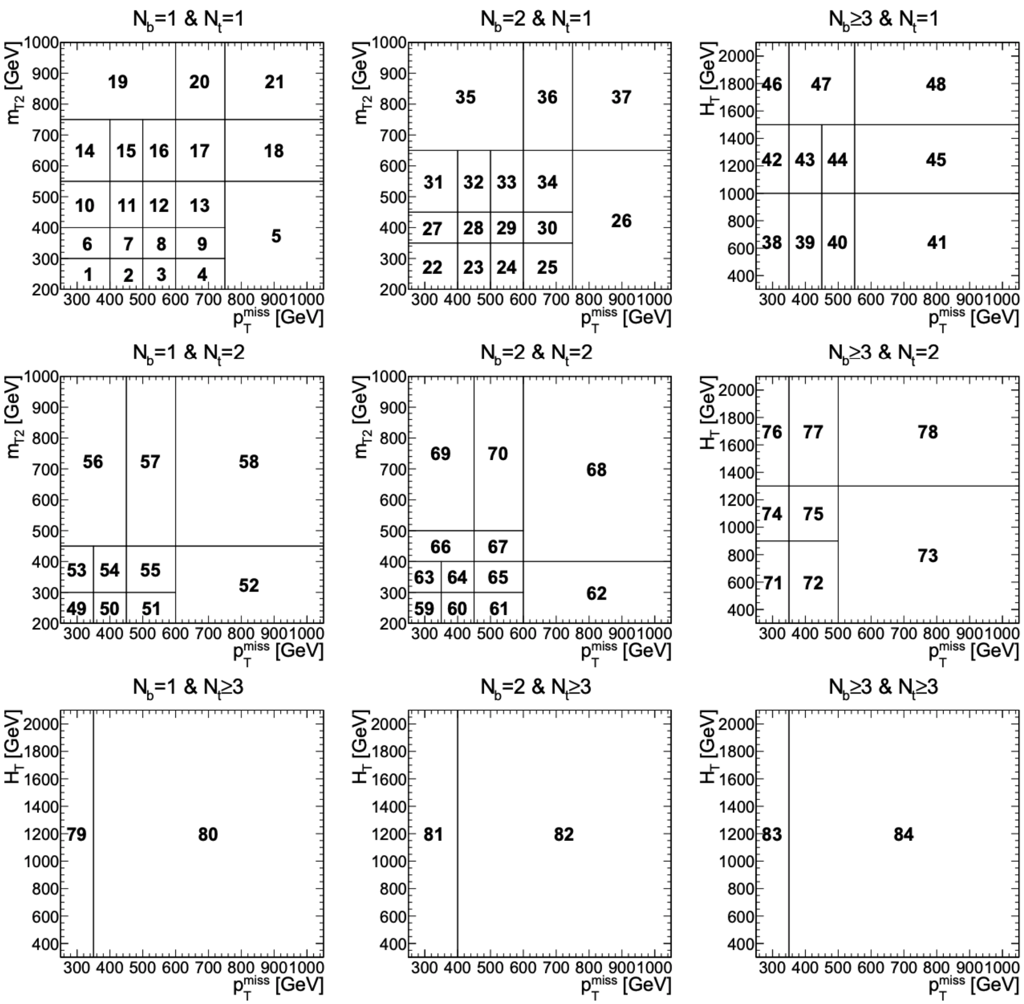
0954-3899

Reconstructing *R*-parity conserving supersymmetric events will be difficult at the large hadronic collider (LHC) because of the following factors which limit our knowledge of the event:

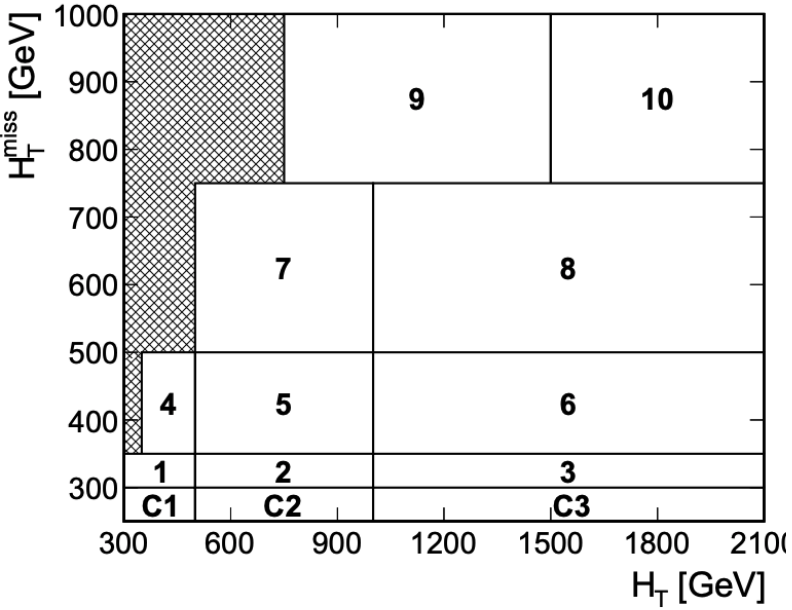
- two massive particles have escaped undetected;
- the masses of these particles are unknown;
- the masses of their ‘parent’ particles are unknown;
- the centre-of-mass energy of the collision is not known, and
- the boost along the beam axis of the collision centre-of-mass is not known either.

Full hadronic search SR-bins

1710.11188 top-tagging



1704.07781



- N_{jet}: 2, 3–4, 5–6, 7–8, $\geq$9;
- $N_{\text{b-jet}}$: 0, 1, 2, $\geq$3.

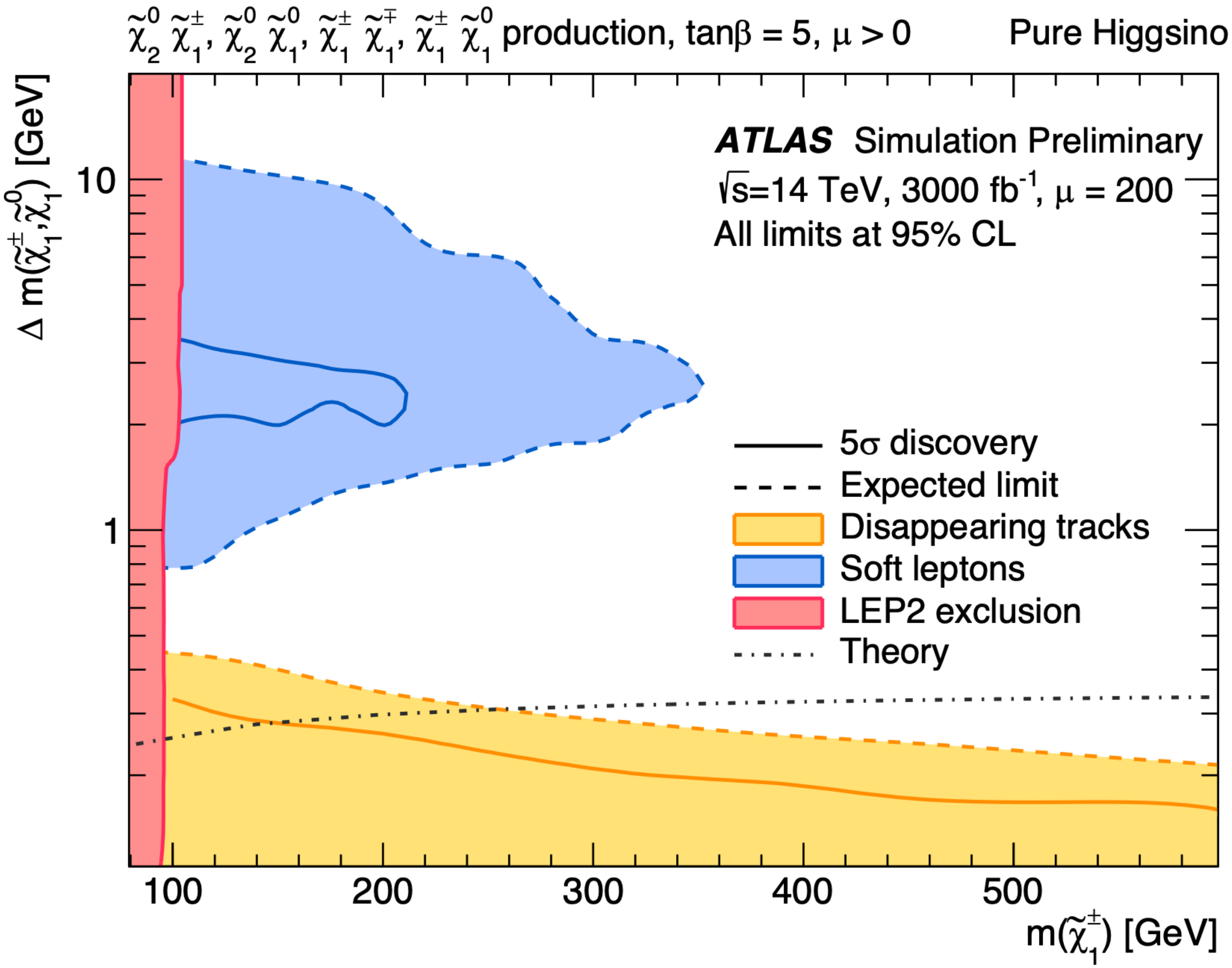
1-Lep ΔΦ search SR-bins

n_{jet}	n_{b}	L_{T} [GeV]	$\Delta\phi$ [rad]	H_{T} [GeV]	Bin name	Signal T1tttt ($m_{\tilde{g}}$, $m_{\tilde{\chi}^0}$) [TeV] (1.9, 0.1)	Signal T1tttt ($m_{\tilde{g}}$, $m_{\tilde{\chi}^0}$) [TeV] (1.4, 1.1)	Predicted background	Observed data
[6, 8]	=1	[250, 450]	1.0	[500, 1000]	A01	<0.01	3.02 ± 0.24	206 ± 15	194
				[1000, 1500]	A02	0.03 ± 0.01	0.37 ± 0.08	52.5 ± 8.2	48
				≥1500	A03	0.07 ± 0.01	0.05 ± 0.03	18.0 ± 4.2	19
		[450, 600]	0.75	[500, 1000]	A04	0.03 ± 0.01	0.66 ± 0.11	13.1 ± 2.7	10
				[1000, 1500]	A05	0.05 ± 0.01	0.27 ± 0.07	4.5 ± 1.7	6
				≥1500	A06	0.09 ± 0.01	0.03 ± 0.02	1.7 ± 1.0	5
		[600, 750]	0.5	[500, 1000]	A07	0.04 ± 0.01	0.08 ± 0.04	4.0 ± 1.6	4
				[1000, 1500]	A08	0.08 ± 0.01	0.35 ± 0.08	2.8 ± 1.3	5
				≥1500	A09	0.17 ± 0.02	0.02 ± 0.02	1.8 ± 1.2	2
		≥750	0.5	≥500	A10	1.01 ± 0.04	0.28 ± 0.07	2.6 ± 1.1	2
	=2	[250, 450]	1.0	[500, 1000]	B01	0.01 ± 0.01	2.06 ± 0.20	147 ± 11	143
				[1000, 1500]	B02	0.04 ± 0.01	<0.01	43.5 ± 7.5	37
				≥1500	B03	0.13 ± 0.01	<0.01	10.9 ± 2.8	12
		[450, 600]	0.75	[500, 1000]	B04	0.02 ± 0.01	0.54 ± 0.10	9.4 ± 2.2	10
				[1000, 1500]	B05	0.10 ± 0.01	0.17 ± 0.06	3.4 ± 1.7	9
				≥1500	B06	0.19 ± 0.02	<0.01	1.39 ± 0.82	2
		[600, 750]	0.5	[500, 1000]	B07	0.03 ± 0.01	<0.01	2.4 ± 1.3	3
				[1000, 1500]	B08	0.10 ± 0.01	0.26 ± 0.07	1.16 ± 0.90	1
				≥1500	B09	0.24 ± 0.02	0.03 ± 0.02	1.05 ± 0.78	0
		≥750	0.5	≥500	B10	1.50 ± 0.05	0.32 ± 0.08	0.42 ± 0.34	3
	≥3	[250, 450]	1.0	[500, 1000]	C01	0.01 ± 0.01	1.03 ± 0.14	32.9 ± 3.3	34
				[1000, 1500]	C02	0.06 ± 0.01	<0.01	10.6 ± 2.1	5
				≥1500	C03	0.13 ± 0.01	<0.01	2.93 ± 0.91	3
		[450, 600]	0.75	[500, 1000]	C04	0.03 ± 0.01	0.29 ± 0.07	1.38 ± 0.50	2
				[1000, 1500]	C05	0.09 ± 0.01	0.20 ± 0.06	0.72 ± 0.39	1
				≥1500	C06	0.20 ± 0.02	<0.01	0.66 ± 0.45	0
		≥600	0.5	≥500	C07	1.85 ± 0.05	0.23 ± 0.06	1.66 ± 0.69	2
≥9	=1	[250, 450]	1.0	[500, 1500]	D01	0.01 ± 0.01	0.90 ± 0.12	7.9 ± 1.1	7
				≥1500	D02	0.03 ± 0.01	0.02 ± 0.02	2.15 ± 0.67	1
		≥450	0.75	[500, 1500]	D03	0.13 ± 0.01	0.72 ± 0.11	1.08 ± 0.39	0
				≥1500	D04	0.38 ± 0.02	0.10 ± 0.04	0.50 ± 0.27	1
	=2	[250, 450]	1.0	[500, 1500]	E01	0.02 ± 0.01	1.15 ± 0.14	7.26 ± 0.97	9
				≥1500	E02	0.08 ± 0.01	<0.01	2.81 ± 0.89	4
		≥450	0.75	[500, 1500]	E03	0.23 ± 0.02	0.83 ± 0.12	0.71 ± 0.26	2
				≥1500	E04	0.72 ± 0.03	0.20 ± 0.05	0.59 ± 0.31	1
	≥3	[250, 450]	1.0	[500, 1500]	F01	0.03 ± 0.01	0.79 ± 0.11	3.55 ± 0.72	3
				≥1500	F02	0.13 ± 0.01	<0.01	0.83 ± 0.35	0
		≥450	0.75	[500, 1500]	F03	0.31 ± 0.02	0.26 ± 0.06	0.33 ± 0.17	0
				≥1500	F04	1.04 ± 0.04	0.17 ± 0.05	0.05 ± 0.05	0

1709.09814

Higgsinos expected sensitivity

DONE at DESY!



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