TOP + SUSY

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On behalf of **CMS** and **ATLAS Collaborations**

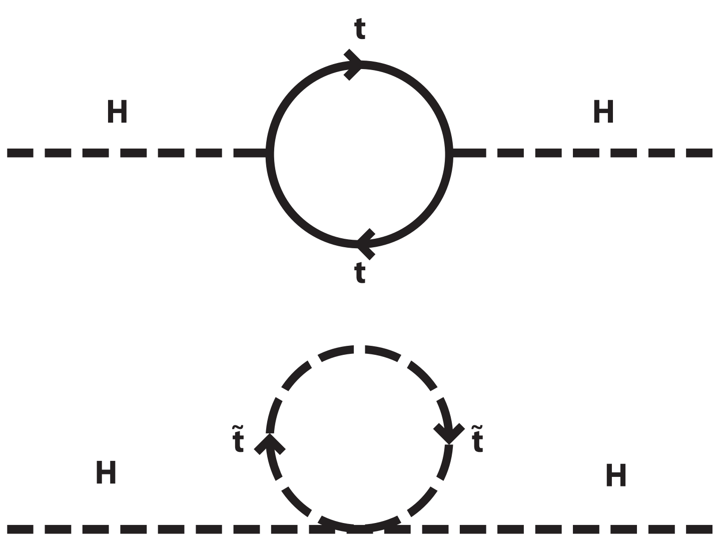
Sep 19, 2018

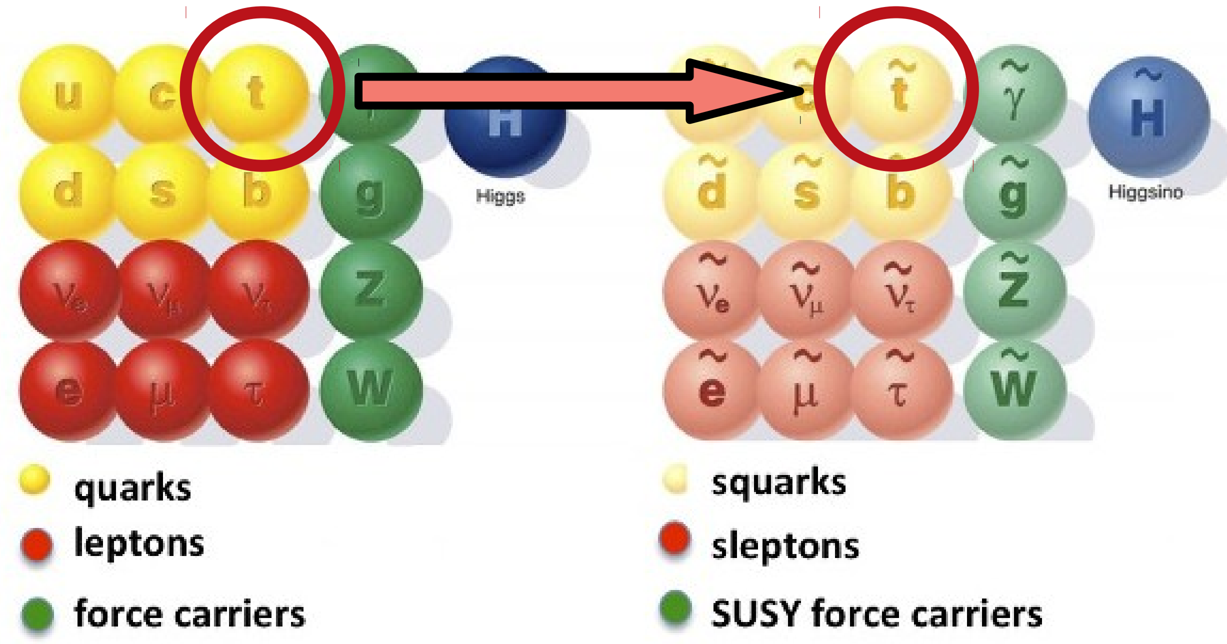
TOP 2018, **Bad Neuenahr.**

Why SUSY and top quarks?

Supersymmetry introduces a symmetry between bosons and fermions. Several new particles may be there.

The SM fine tuning on higgs mass is solved: contributions from top and stop can cancel out.

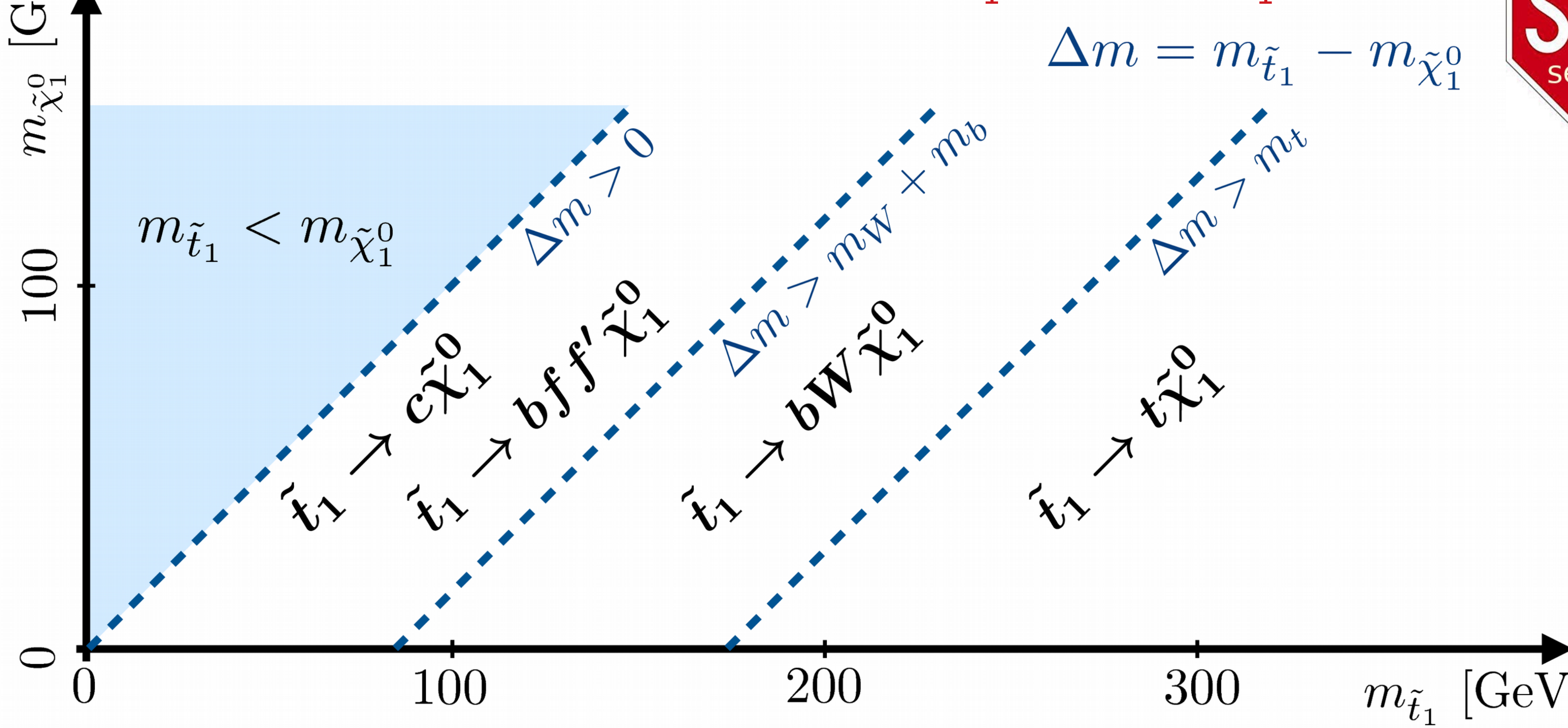




- Natural SUSY ↔ ~low levels of fine tuning: $m(\tilde{t}_1) < 1\text{-}2$ TeV.
- Top squark (stop quark) is often the less massive squark: may be produced in pp collisions.

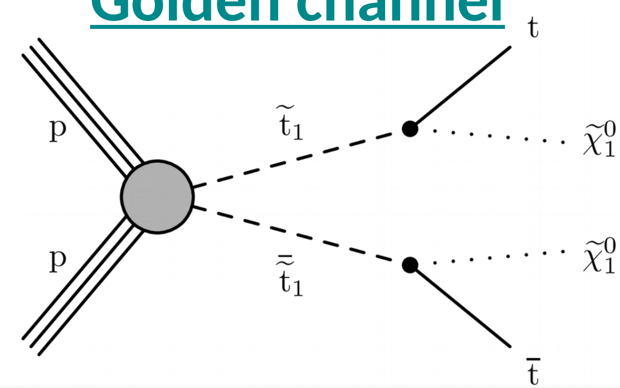
Stop quark: summary

Searches parametrized by m($\tilde{t}_1$) and m($\tilde{\chi}_1^0$).



Special case: m(stop) ~ m(top quark): very difficult search (overwhelming tt background). New results from CMS.

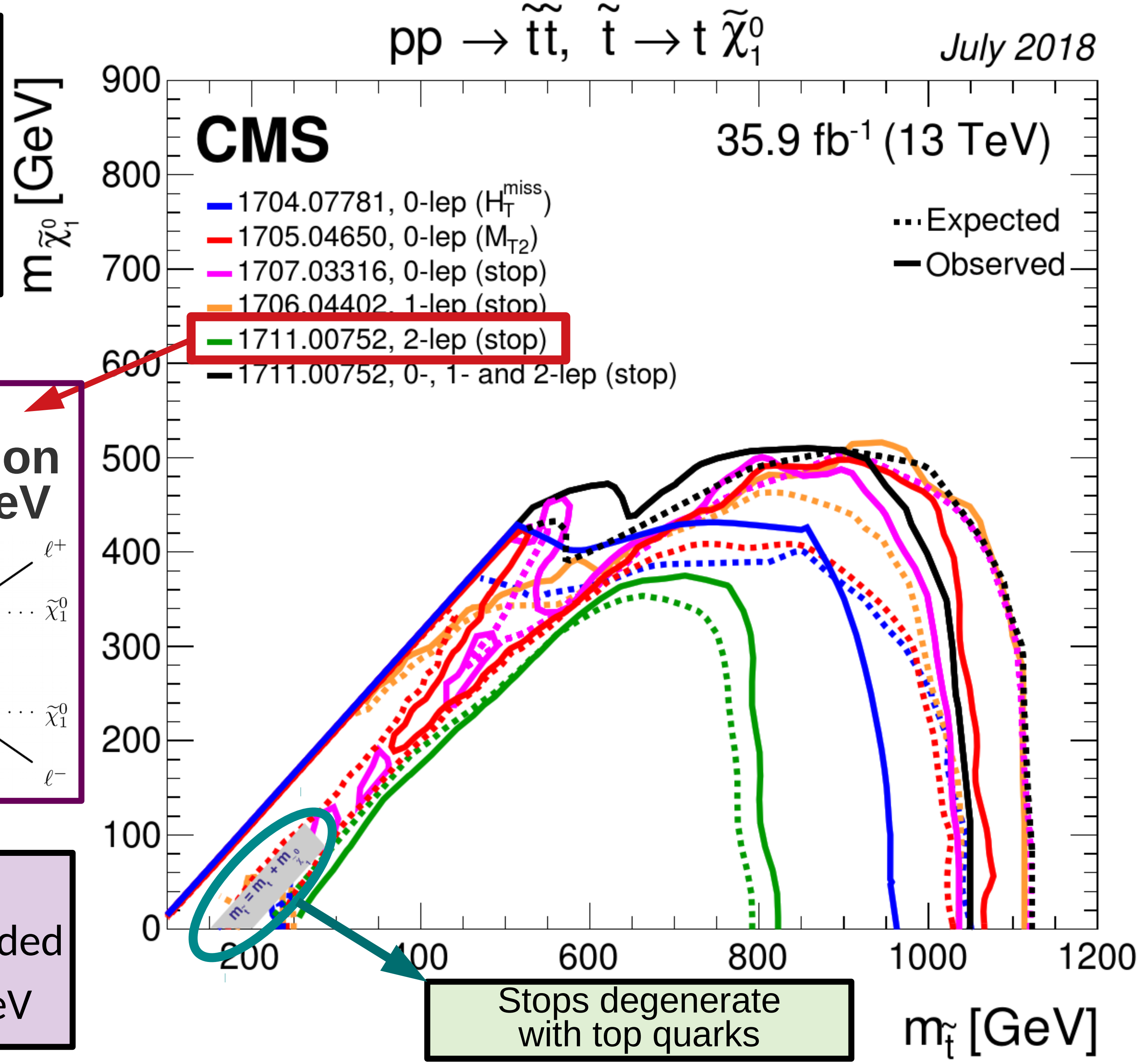
Golden channel



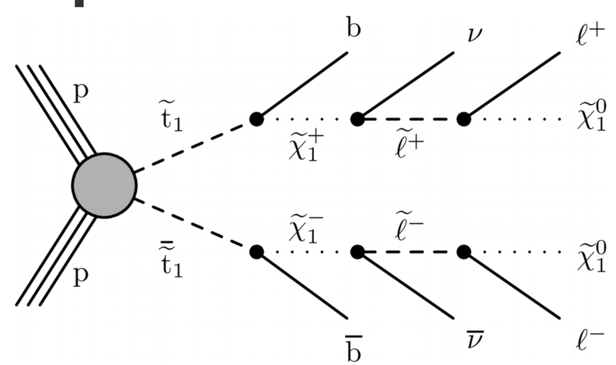
Other stop decays: chargino-mediated, stau-mediated.

Overview of stop pair production (CMS)

Stop production exclusion limits up to $m(\tilde{t}_1) \sim 1.1$ TeV



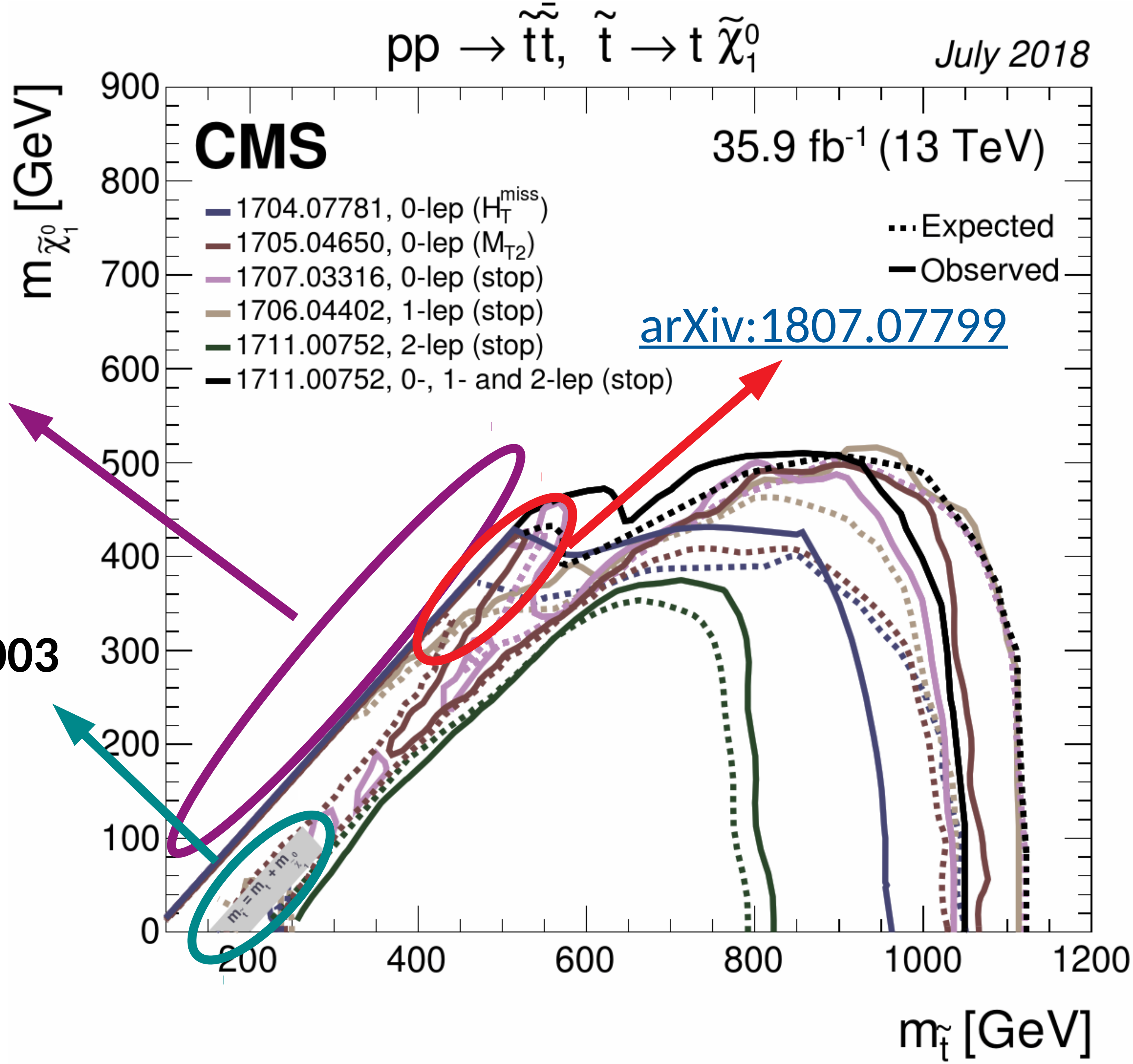
Also stop to sleptons: exclusion up to 1.2 – 1.3 TeV



Compressed stop, $\Delta m(\tilde{t}_1,\tilde{X}_1^0) = m_W$ excluded up to $m(\tilde{t}_1) \sim 550$ GeV

Stops degenerate with top quarks

Recent CMS results



arXiv:1805.05784

arXiv:1807.07799

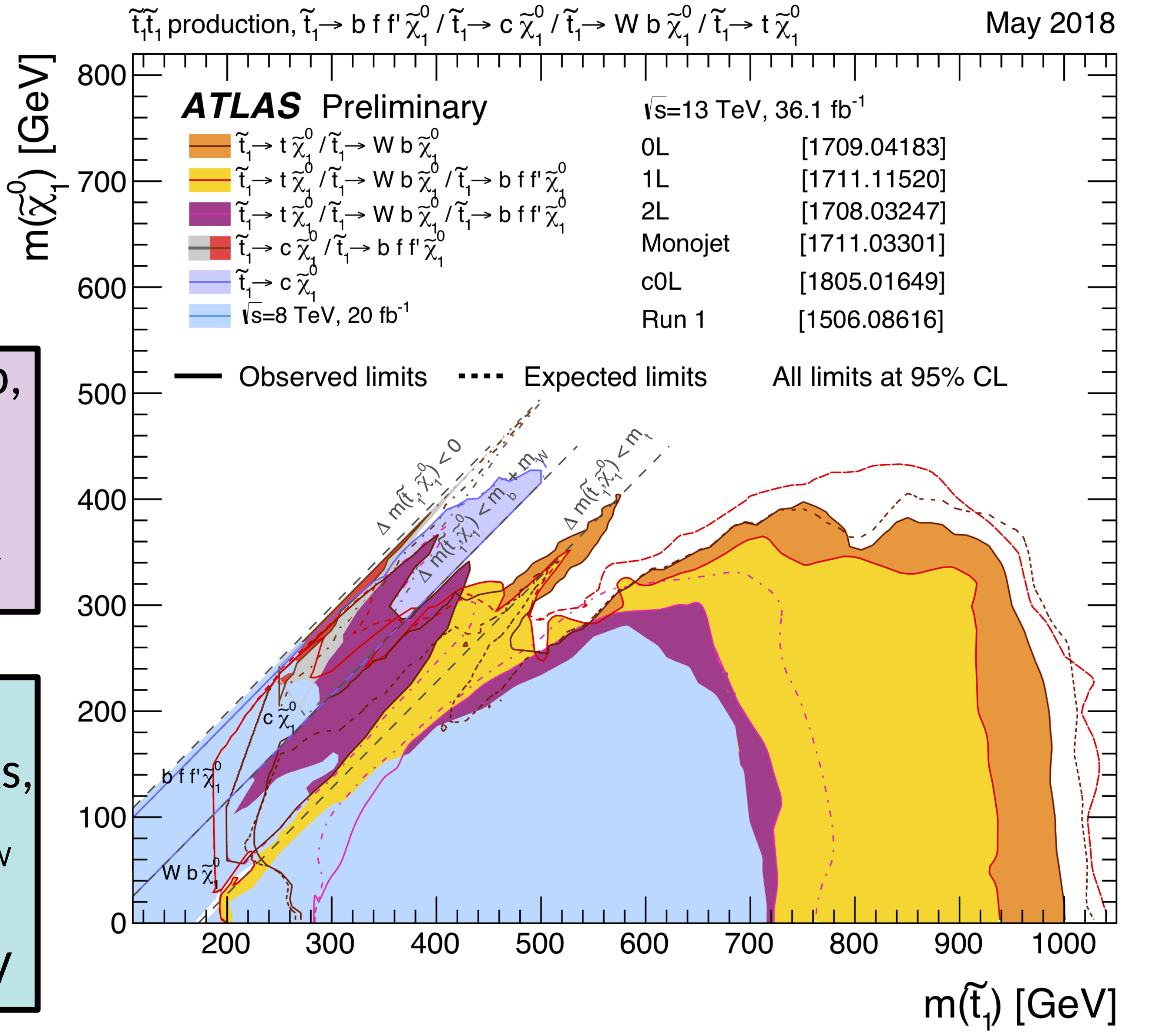
CMS-PAS-SUS-18-003

Overview of stop pair production (ATLAS)

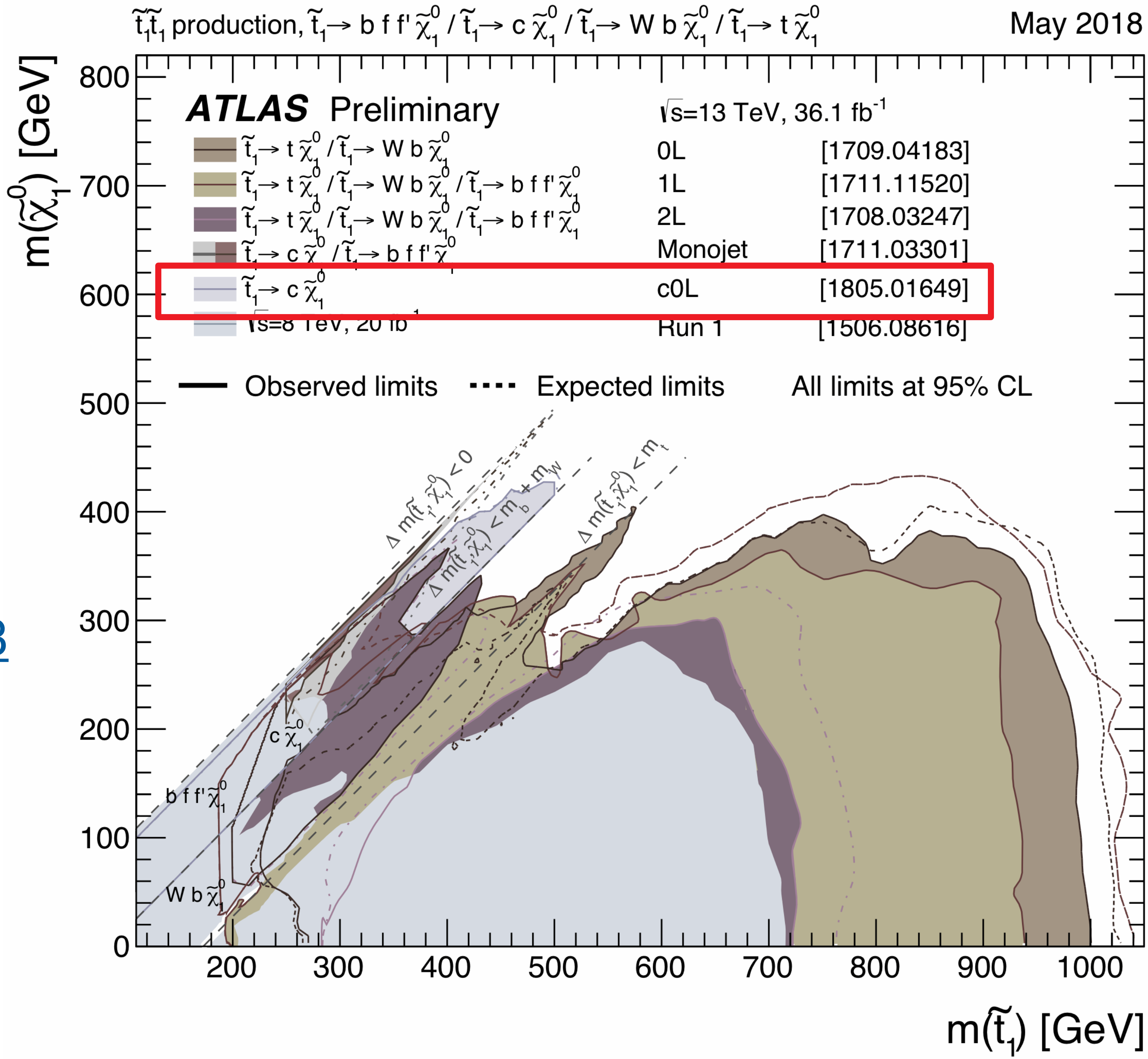
Stop production exclusion limits up to $m(\tilde{t}_1) \sim 1$ TeV

Compressed stop, $\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) = m_W$ excluded up to $m(\tilde{t}_1) \sim 420$ GeV

4 body decay / decay to c quarks, $\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) < m_W$ excluded up to $m(\tilde{t}_1) \sim 500$ GeV



Recent ATLAS results



Also from ATLAS:

Phys. Rev. D 98, 032008 (2018)

arXiv:1803.10178

stop to stau

Stop quark degenerate with top quark

$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) = m_t$ → Stops and ttbar produced with very similar kinematics.

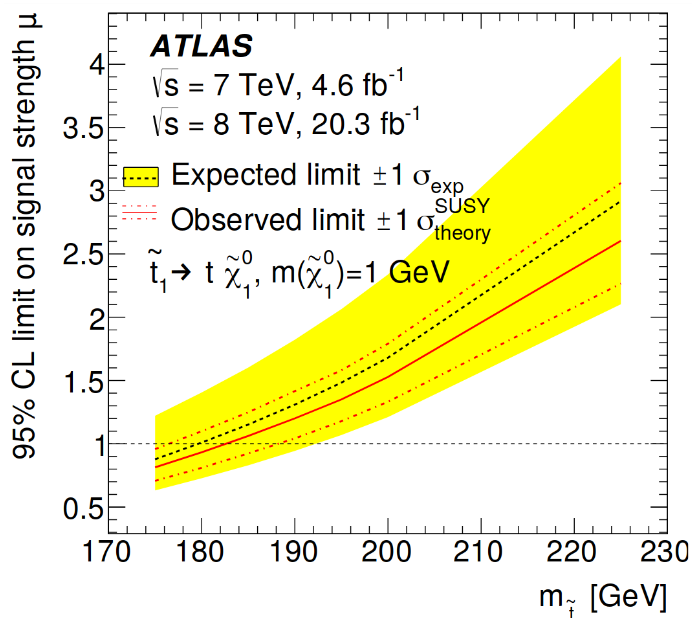
Overwhelming SM background:

$\sigma[13TeV](pp \rightarrow t\bar{t}) = 832$ pb

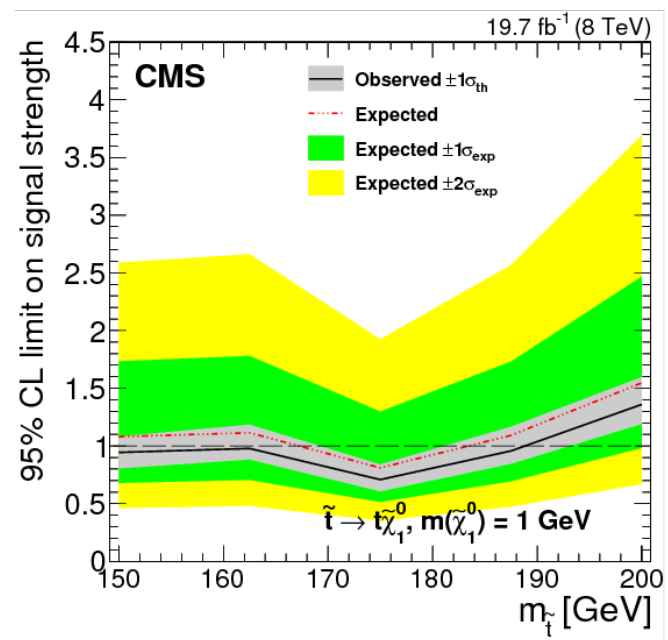
$\sigma[13TeV](pp \rightarrow \tilde{t}_1\tilde{t}_1, m(\tilde{t}_1) = 175$ GeV$) = 121$ pb

→ **Sensitivity reached through tt cross section precision prediction.**

Full-degenerate model, $m(\tilde{t}_1) = 175$ GeV, $m(\tilde{\chi}_1^0) = 1$ GeV, already excluded at 8 TeV by ATLAS and CMS.



Eur. Phys. J. C74 (2014) 3109



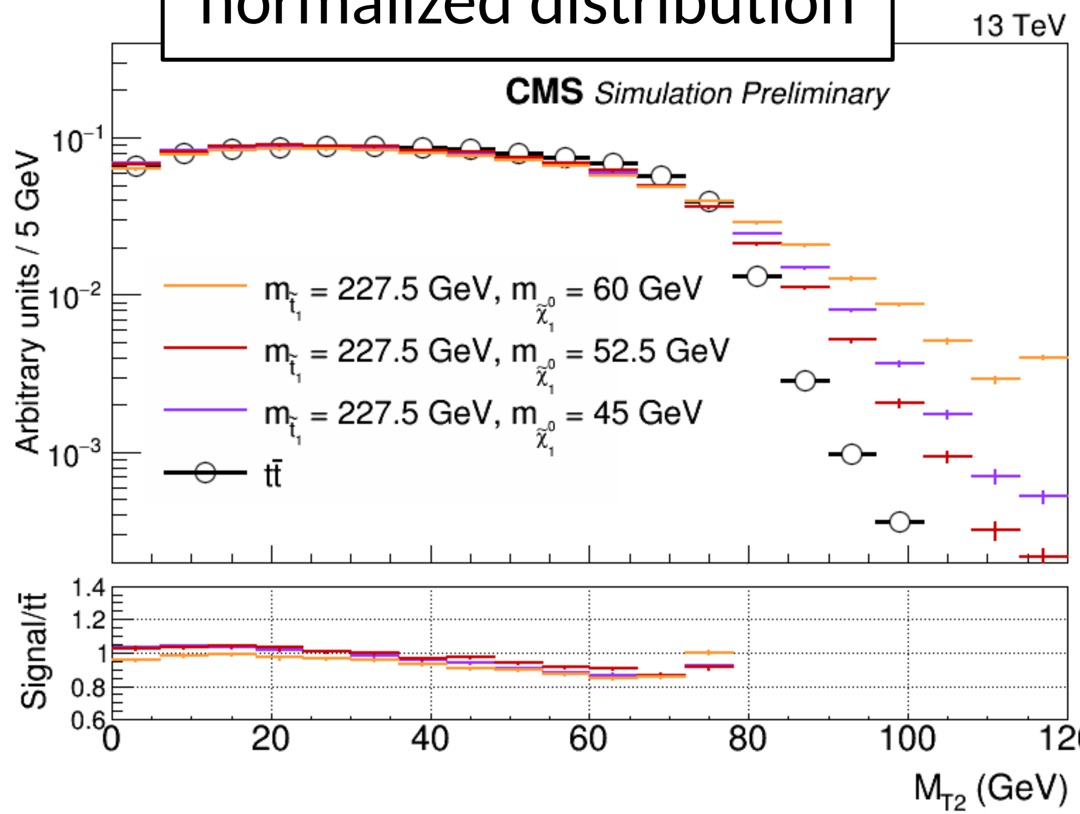
JHEP 08 (2016) 029

Stop quark degenerate with top quark (CMS)

CMS-PAS-SUS-18-003

Search with opposite-charged eμ pair and jets.
13 TeV, 35.9 fb[-1].

M_{T2} gen level,
normalized distribution



Strategy

- Sensitivity to (near-)degenerate stop signal through precise $t\bar{t}$ cross section estimate.
- Increase the sensitivity to higher stop masses and larger $\Delta m(\tilde{t}_1,\tilde{\chi}_1^0)$ differences using $M_{T2}(e,\mu)$.

$$M_{T2}^2 = \min_{p_{T1}^{miss}+p_{T2}^{miss}=E_{\mathrm{T}}^{\mathrm{miss}}} \left(\max \left[m_T^2(p_T^{\ell 1}, E_{\mathrm{T}}^{\mathrm{miss}}), m_T^2(p_T^{\ell 2}, E_{\mathrm{T}}^{\mathrm{miss}}) \right] \right)$$

Degenerate stop – Background estimate

CMS-PAS-SUS-18-003

Precise estimate of $t\bar{t}$ from MC, Powheg + Pythia8 sample. Contributes to ~94% of SM background.

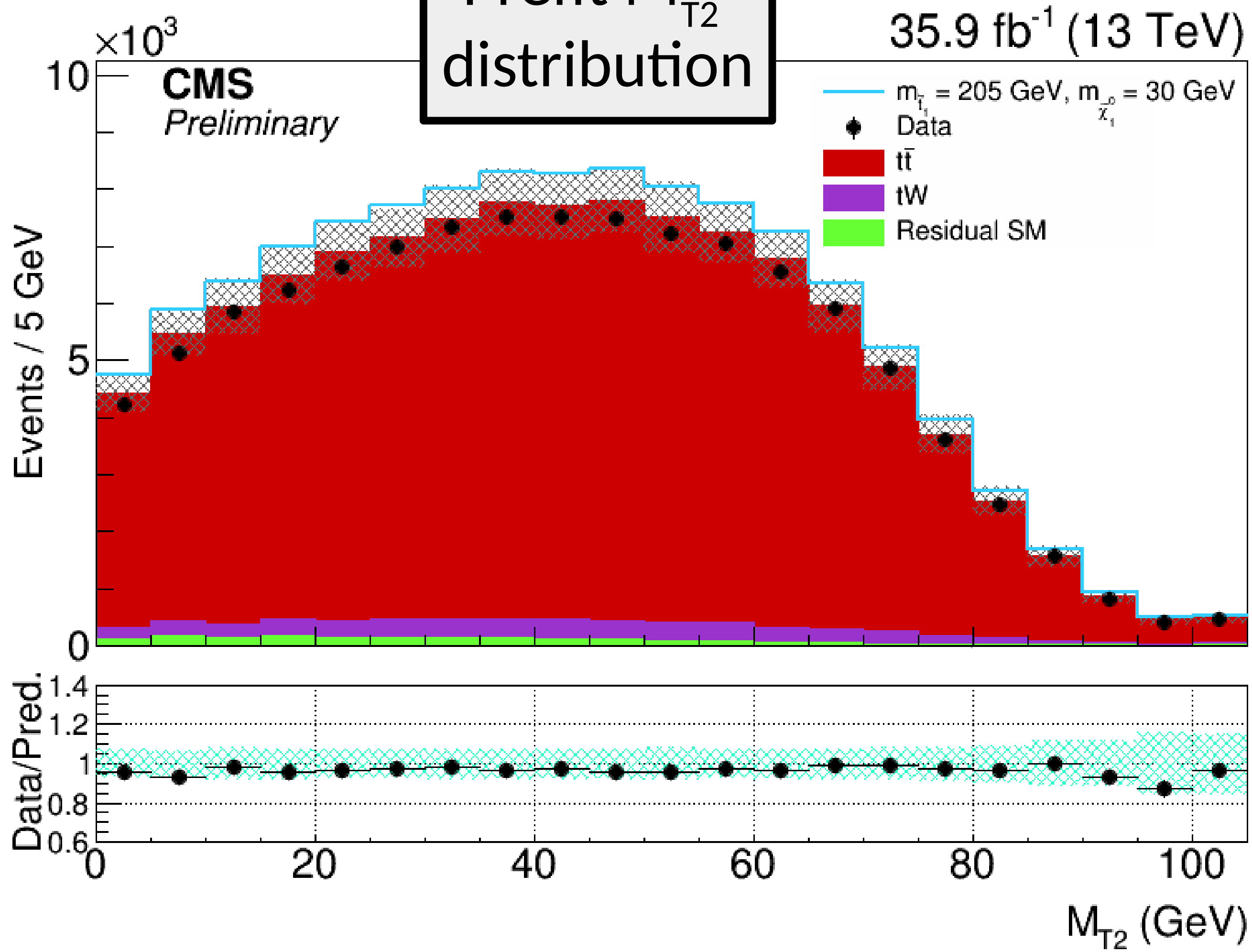
Other backgrounds: **tW** (~4%) and **residual SM** (2%: WW, WZ, ZZ, DY, ttW, ttZ, nonprompt leptons).

$t\bar{t}$ normalized to NNLO + NNLL cross section, 831.76 pb.

arXiv:1112.5675

No significant excess observed over the SM prediction.

Prefit M_{T2} distribution



Degenerate stop – Uncertainties

CMS-PAS-SUS-18-003

Most important experimental uncertainties: Lepton efficiencies, jet energy scale, b-tagging efficiencies.

See TOP-PAS-17-001 and talk from Matteo Defranchis

Several modeling uncertainties on $t\bar{t}$ acceptance for each bin in the M_{T2} distribution.

Source	Range (%)
ME/PS matching (h_{damp})	0.3 – 2
Initial state radiation	0.5 – 1
Final state radiation	0.6 – 1.2
Color reconnection	≈ 1.5
ME scales	0.3 – 1
PDF	≈ 0.6
Top mass (acceptance)	≈ 1
Top p_T reweighting	0.1 – 0.5
Underlying event	≈ 0.8

Total experimental uncertainties: 2–4 %.

Dominant uncertainty:
6% $t\bar{t}$ normalization uncertainty from **PDF + scale + top mass**.

Degenerate stop – Results

CMS-PAS-SUS-18-003

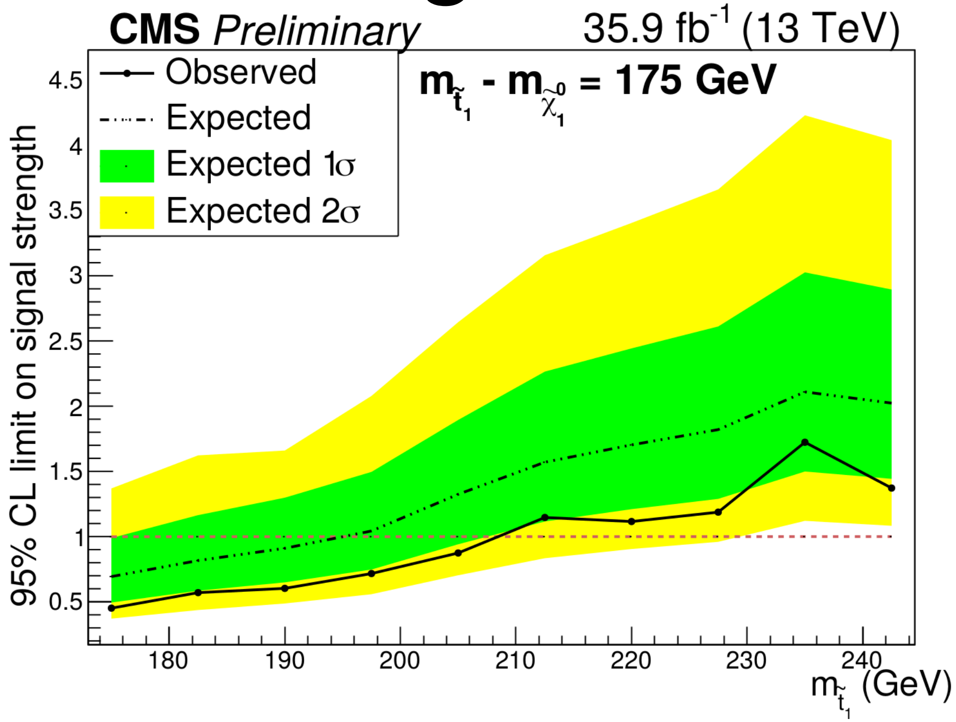
Process	with $M_{T2} > 0$ GeV	with $M_{T2} > 90$ GeV
$t\bar{t}$	$102\,400 \pm 7400$	1680 ± 260
tW	4700 ± 1400	92 ± 32
Nonprompt leptons	1330 ± 400	30 ± 11
DY + $t\bar{t}$V+ Dibosons	570 ± 100	19 ± 6
Total Background	$109\,000 \pm 7600$	1821 ± 260
Signal: $m_{\tilde{t}_1} = 175.0$ GeV, $m_{\tilde{\chi}^0_1} = 1.0$ GeV	$16\,400 \pm 2500$	276 ± 53
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}^0_1} = 22.5$ GeV	8070 ± 1240	232 ± 41
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}^0_1} = 30.0$ GeV	7830 ± 1200	157 ± 27
Signal: $m_{\tilde{t}_1} = 205.0$ GeV, $m_{\tilde{\chi}^0_1} = 37.5$ GeV	6140 ± 650	262 ± 45
Signal: $m_{\tilde{t}_1} = 242.5$ GeV, $m_{\tilde{\chi}^0_1} = 67.5$ GeV	3550 ± 540	106 ± 19
Data	105 893	1694

<u>Sensitivity mostly from:</u>

$m(\tilde{t}_1) = 175$ GeV, $m(\tilde{\chi}_1^0) = 1$ GeV → Signal cross section.

$m(\tilde{t}_1) = 242.5$ GeV, $m(\tilde{\chi}_1^0) = 67.5$ GeV → High M_{T2} score.

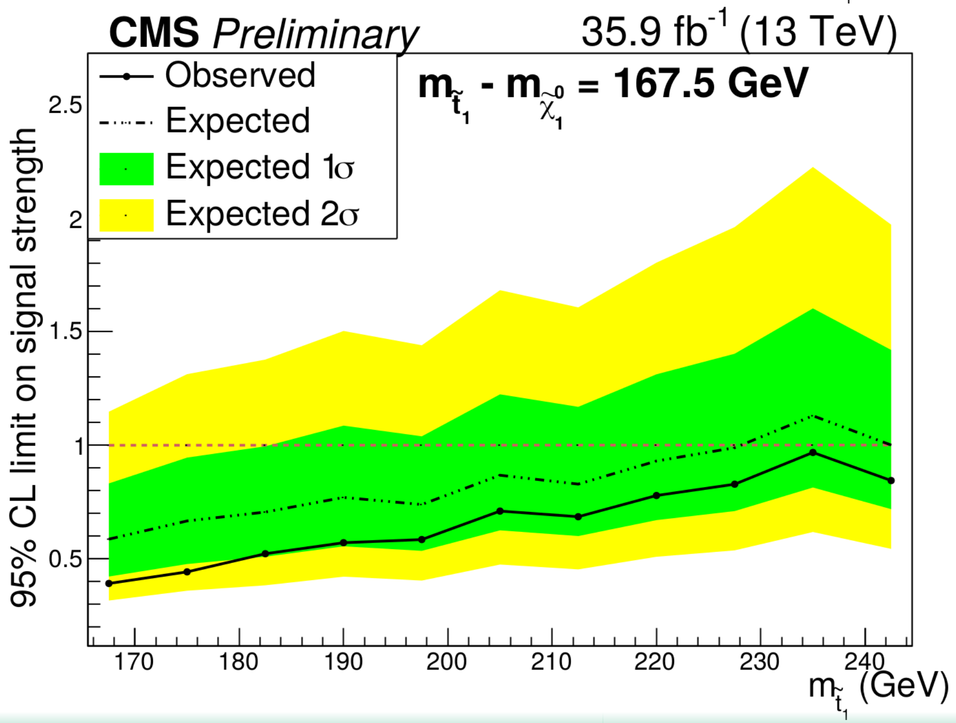
Degenerate stop – Exclusion limits

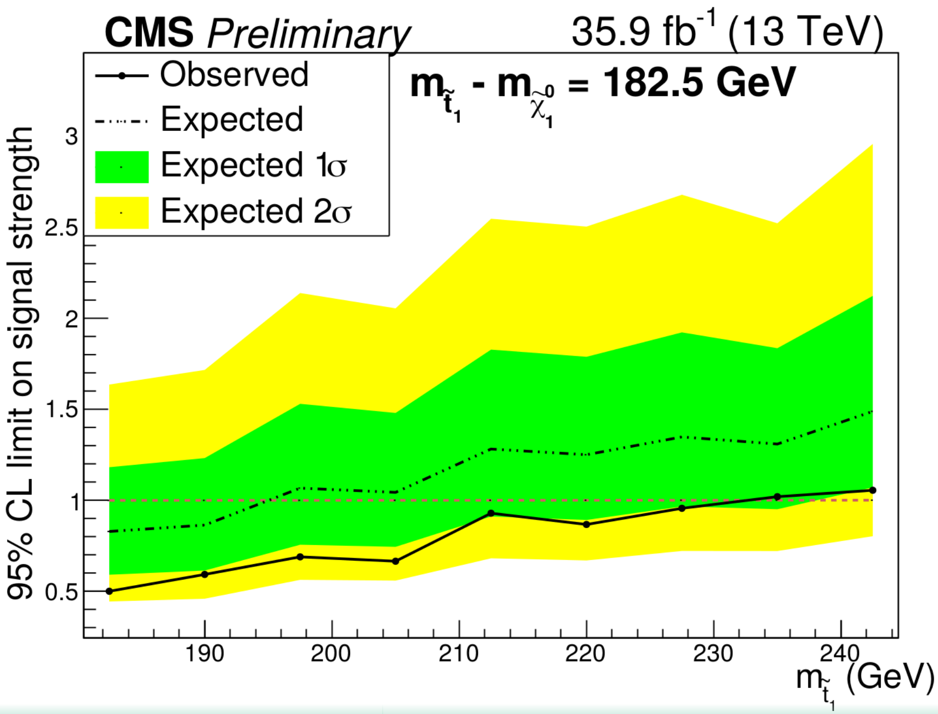


CMS-PAS-SUS-18-003

Exclusion limits up to a stop mass of 205 GeV for the degenerate stop with $\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) = m_t$.

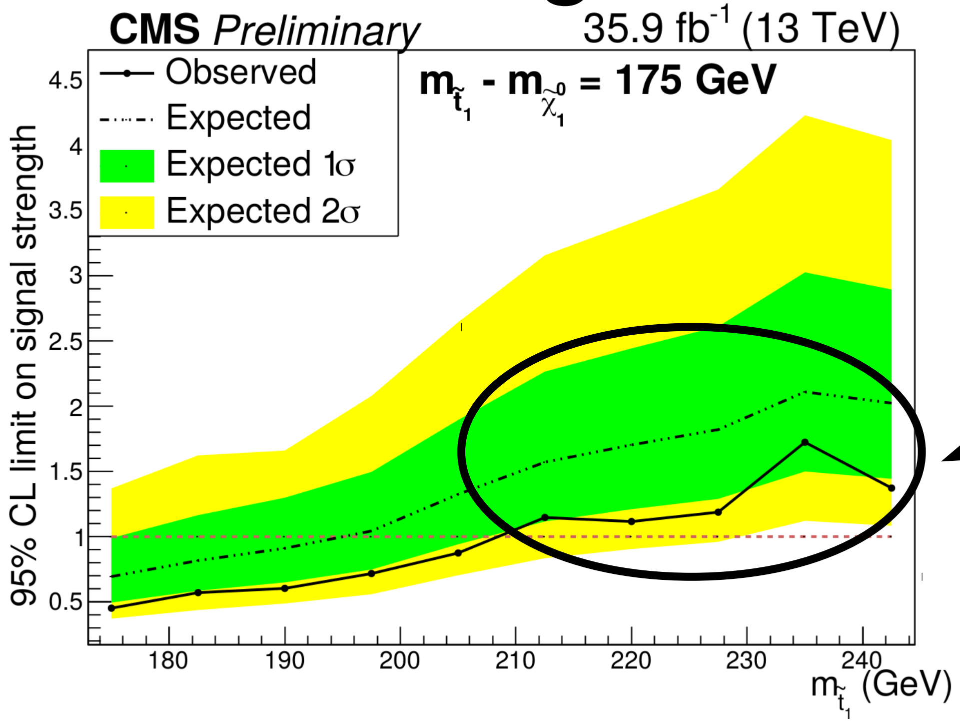
Exclusion limits up to a stop mass of **235** (**245**) GeV for $\Delta m(\tilde{t}_1,\tilde{\chi}_1^0) = m_t + (-)\ 7.5$ GeV.





Degenerate stop – Prospects

CMS-PAS-SUS-18-003



Limited sensitivity in this region.

Some space for improvements:
→ Lepton and b-tagging efficiencies.
→ Jet energy scale / MET resolution.
→ tt modeling.

Analysis will benefit from full Run 2 dataset.

Compressed stop (CMS)

Search with two opposite-charged leptons.

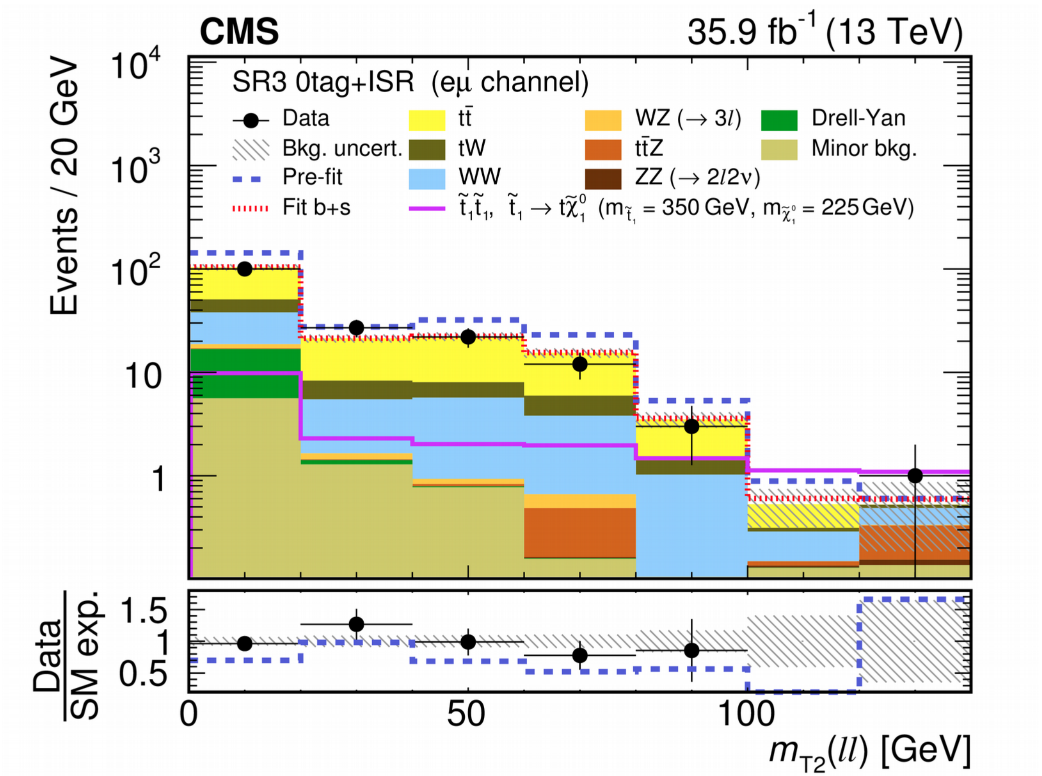
arXiv:1807.07799
Submitted to JHEP.

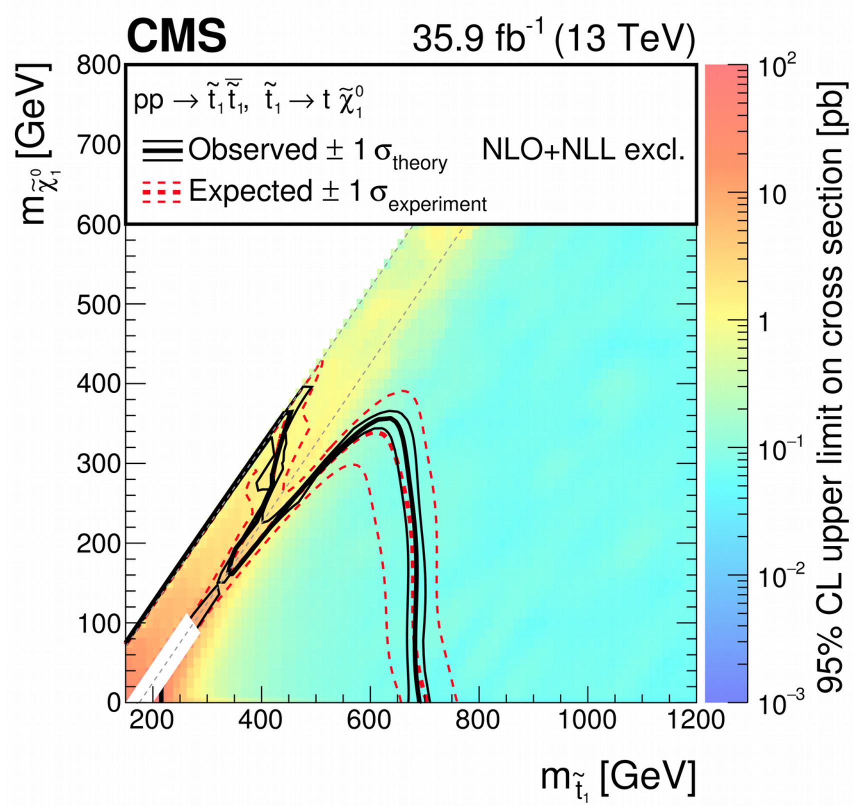
Target stop production model:

$$m_W < m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \lesssim m_t$$

Off shell top quarks → softer b-jets.

MET, b-tag multiplicity, selection of ISR Jet. Further binning in M_{T2}.





Limits extend up to 420 and 360 GeV for the stop and neutralino masses.

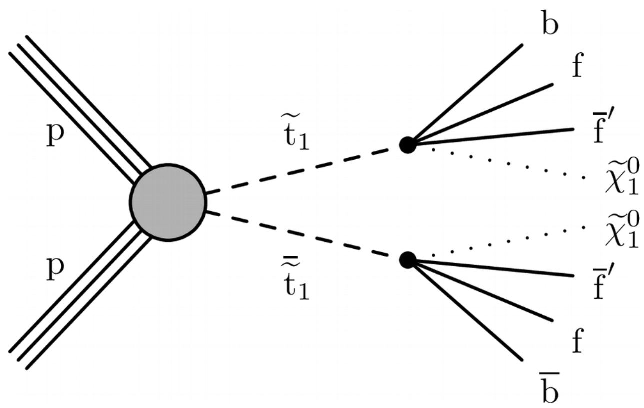
Stop production via 4-body decay (CMS)

Search with one lepton and large MET.

arXiv:1805.05784

Submitted to JHEP.

$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} < m_W$$



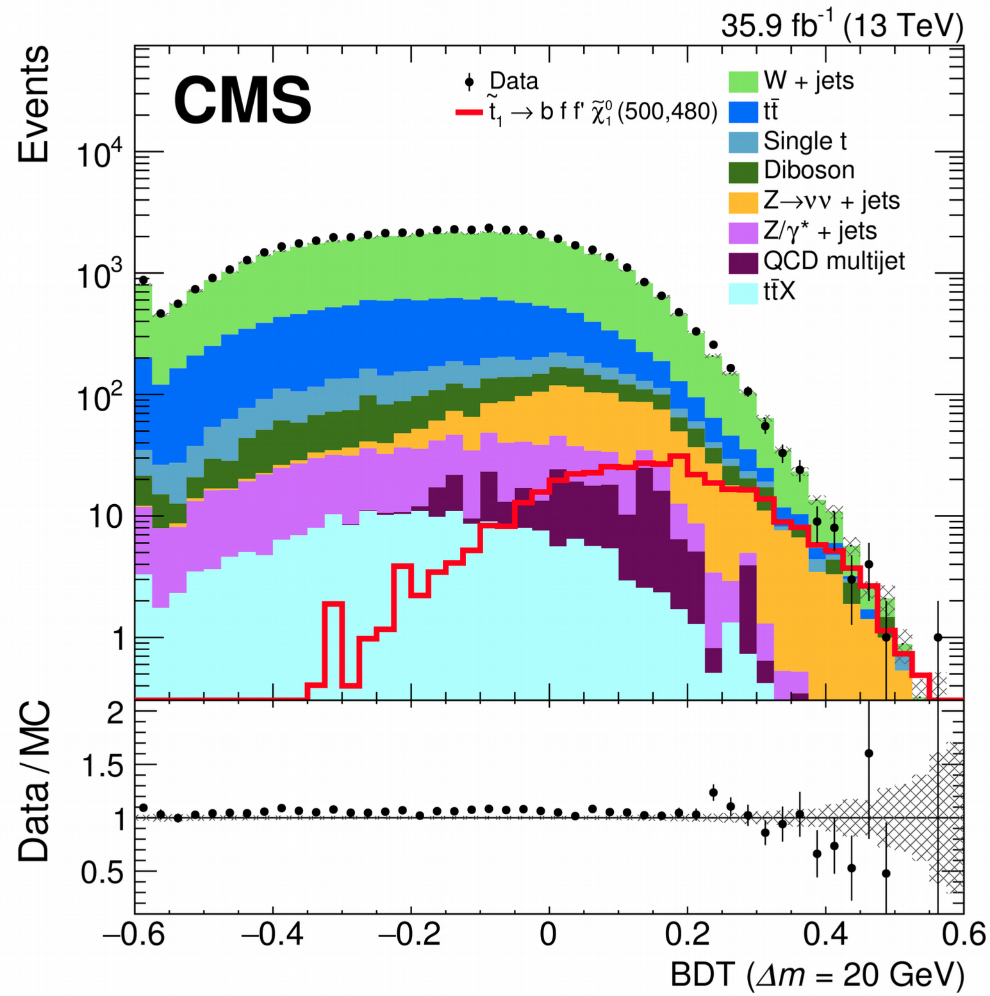
Requirement: ISR Jet, p_T > 100 GeV

Lepton p_T > 3.5 (5) GeV for muons (electrons).

Two different approaches:

- MVA analysis (lepton, leading jet, MET, H_T, nJet, nBtag).
- Cut and count (C&C) approach. Best discriminating variables: lepton p_T, m_T.

SM normalization from control region at low MVA score (MVA) or high lepton p_T (C&C).



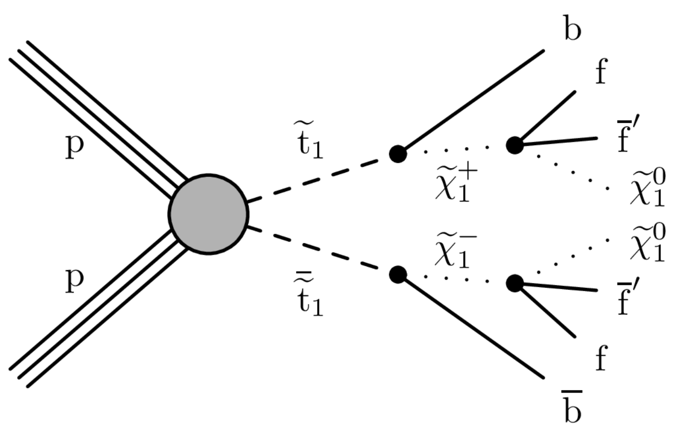
Stop production via 4-body decay (CMS)

MVA training depending on $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$, from 10 to 80 GeV.

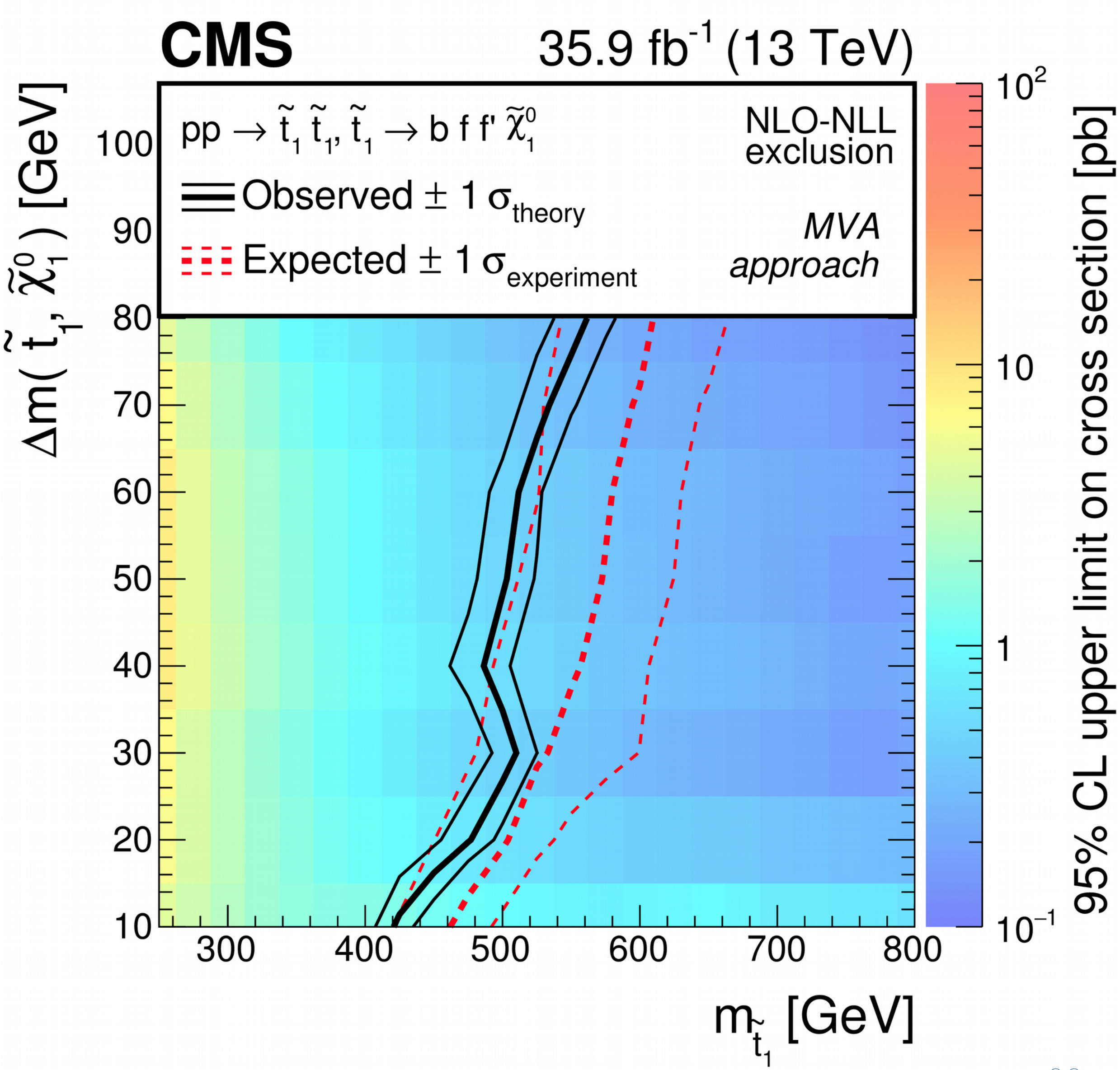
arXiv:1805.05784

Submitted to JHEP.

Also interpretation for chargino- mediated decays:



Also, results from ATLAS: JHEP 01 (2018) 126



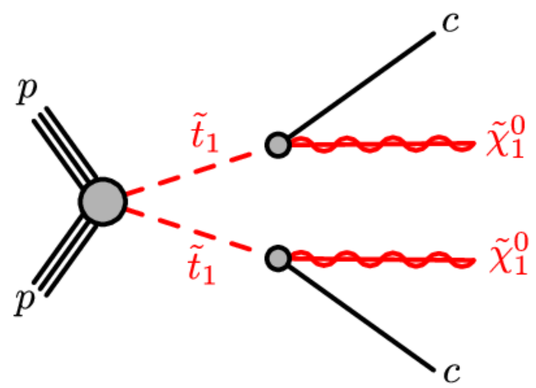
Limits set from 420 to 560 GeV for the stop mass, depending on $\Delta m(\tilde{t}_1, \tilde{\chi}_1^0)$.

Stop to c quark (ATLAS)

Search with c-tagged jets at 13 TeV.

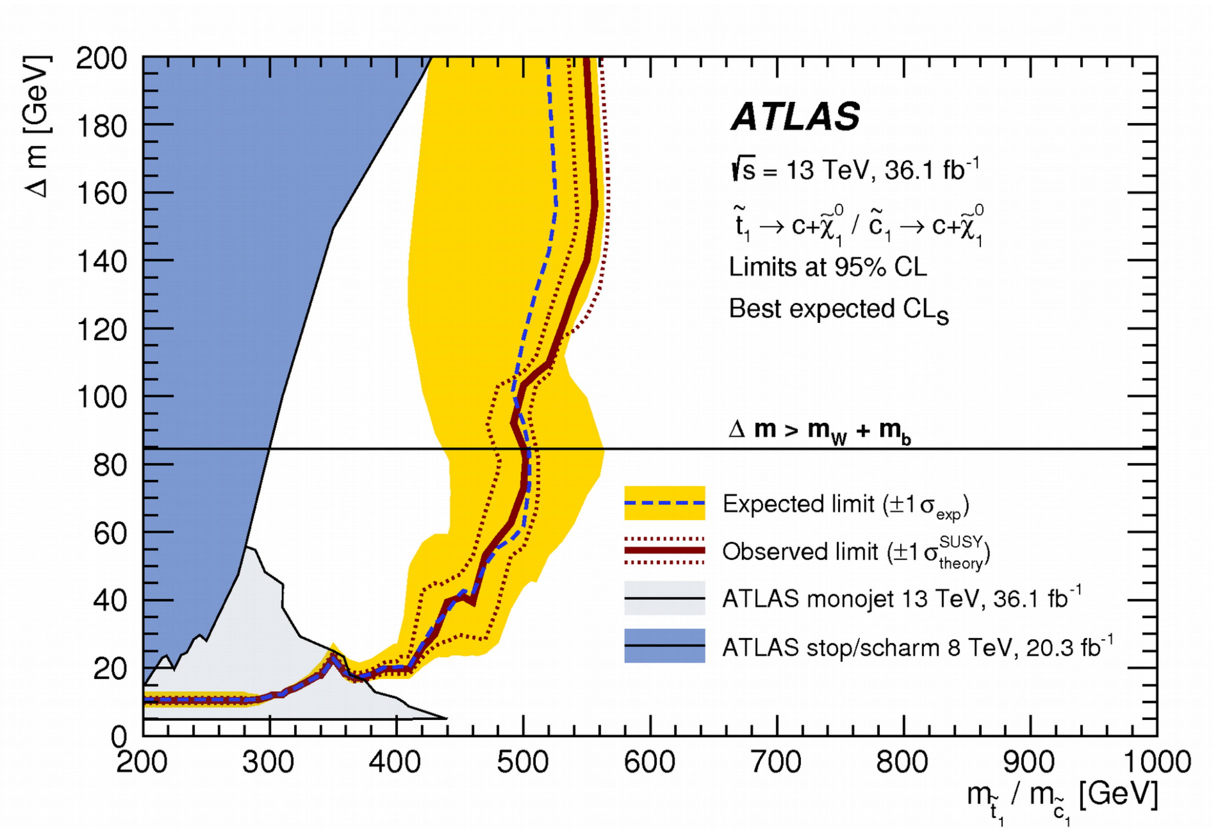
arXiv:1805.01649

JHEP 09 (2018) 050

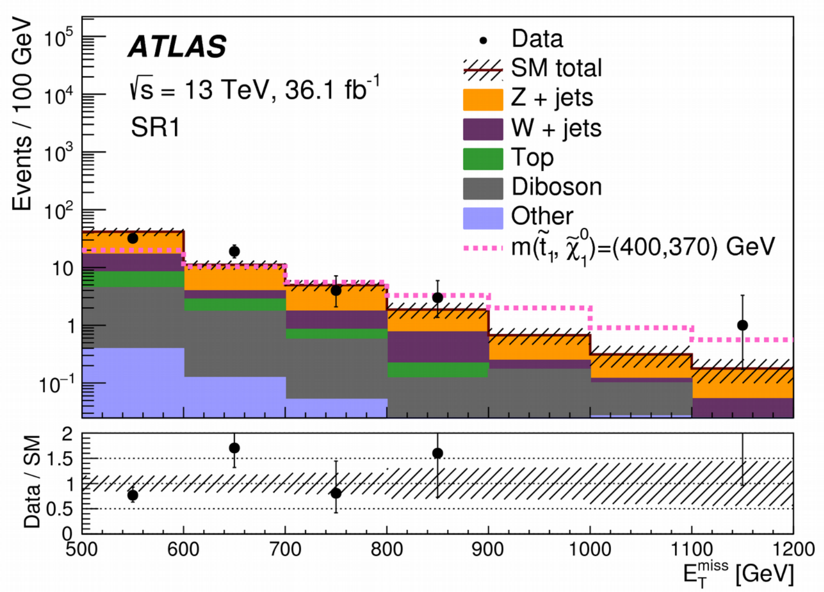


Events with 2 c-tagged jets and large MET. Non c-tagged, high-p_T ISR jet required.

Signal regions in categories of jet multiplicity, jet p_T, m_T^c.



Main backgrounds: W, Z, $t\bar{t}$. Estimated from data CR.



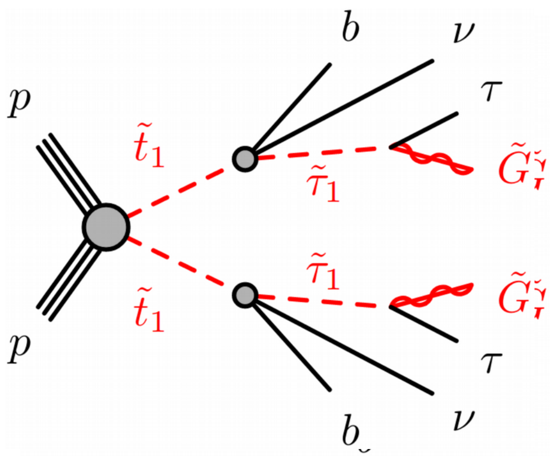
Main uncertainties: c-tag efficiency, jet energy scale.

Stop to tau leptons (ATLAS)

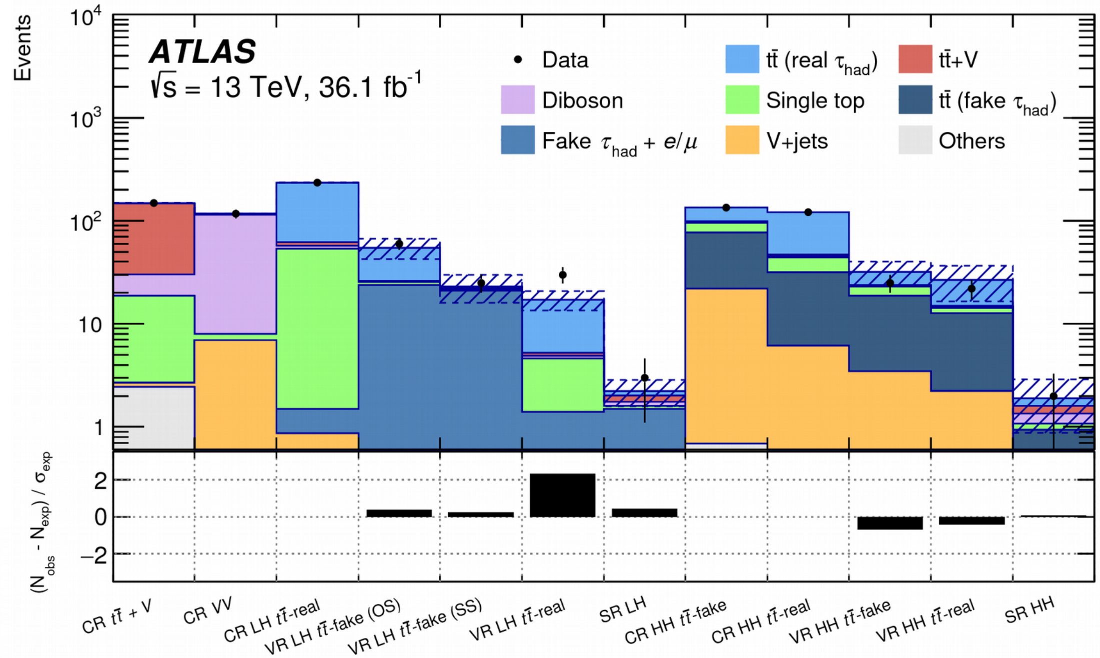
Stau-mediated decay.

Events with two taus.

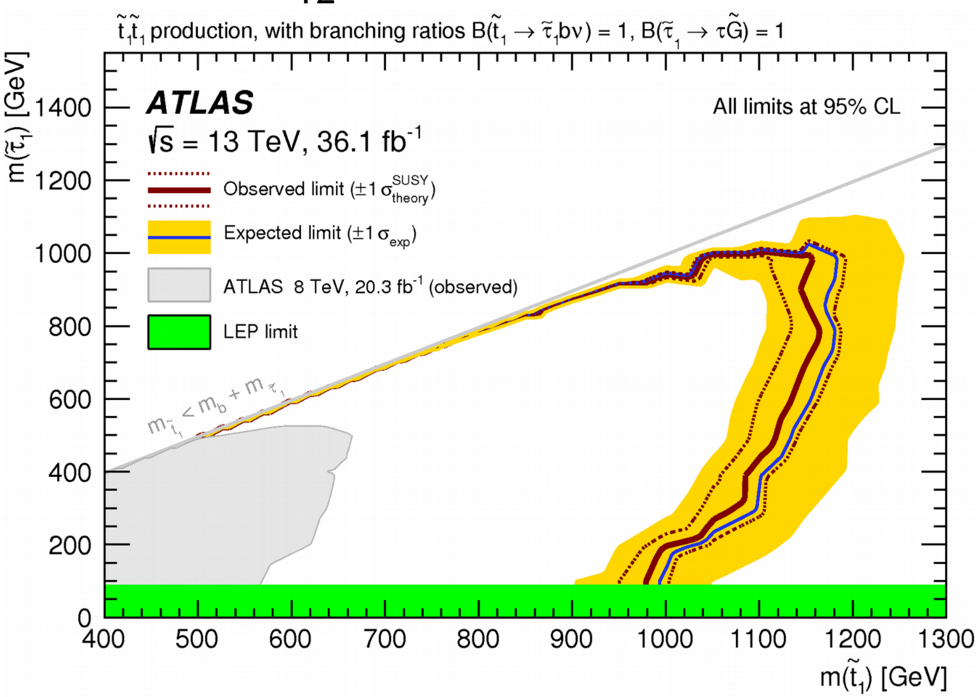
arXiv:1803.10178
Phys. Rev. D 98, 032008 (2018)



2 channels:
$\tau_h\tau_l$, $\tau_h\tau_h$.



Most discriminant variables:
MET, M_{T2}.



Main uncertainties:

- $\tau_h\tau_l$: fake lepton estimate.
- $\tau_h\tau_h$: Jet and tau related unc.

Exclusion limits up to a stop mass of 1.16 TeV.

Conclusions

General searches with 2016 dataset from CMS and ATLAS:

- No SUSY stops with mass below ~ 1 TeV.

New searches: looking into the corners or other decay modes.

- Is stop degenerate with top quark?
- Compressed 3-body or 4-body decays?
- Decays into charm quarks?
- Decays through staus or charginos?

Still, top quark very present in SUSY searches, both related to it's SUSY partner of as SM background.

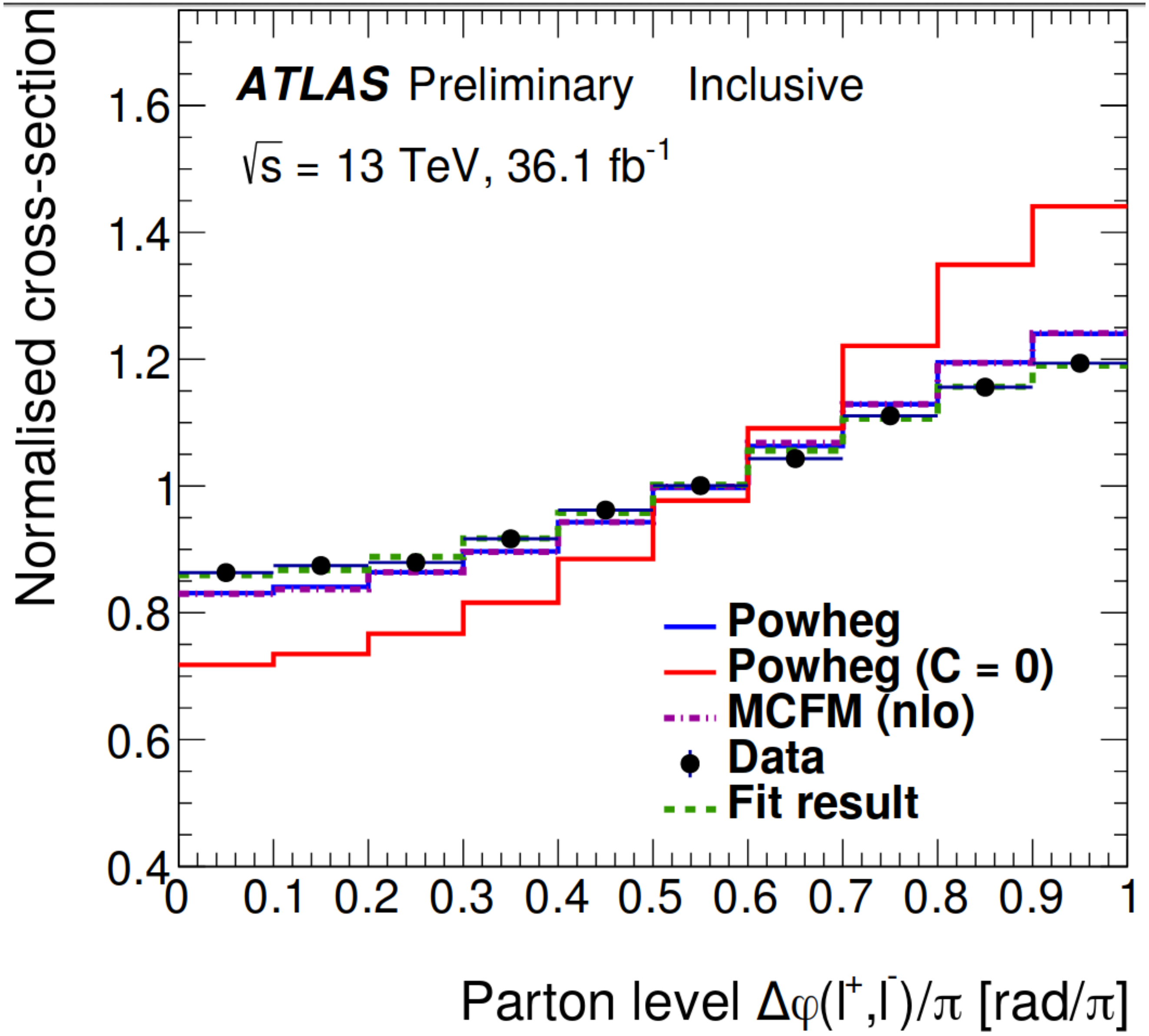
Prospects: new searches and updated/upgraded searches with ~4-5 times the luminosity (~36 fb-1 → ~150 fb-1).

Thank you for your attention!!

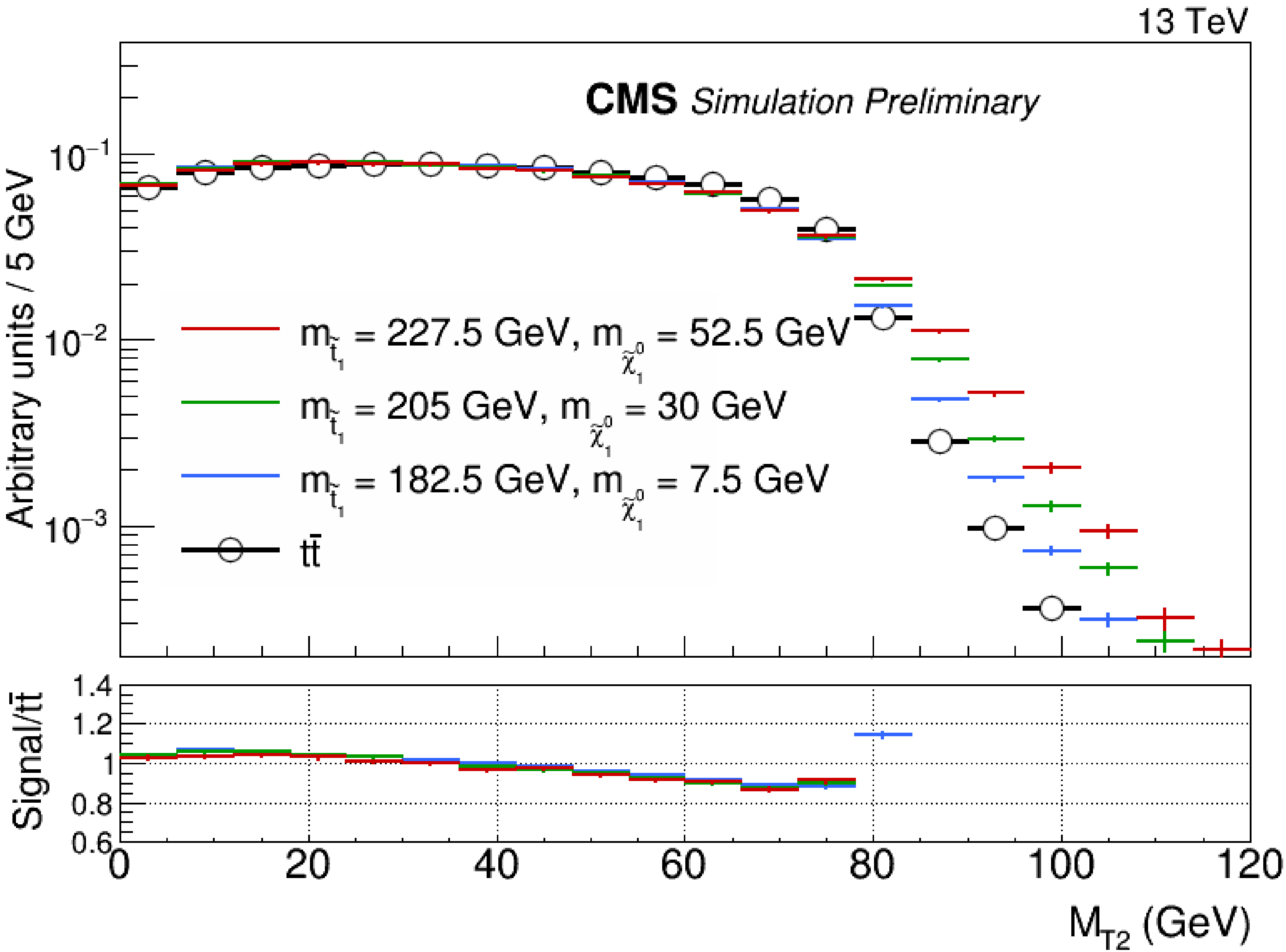
BACK UP SLIDES

Top-antitop spin correlations (ATLAS)

ATLAS-CONF-2018-027



M_{T2} for near-degenerate stop pairs



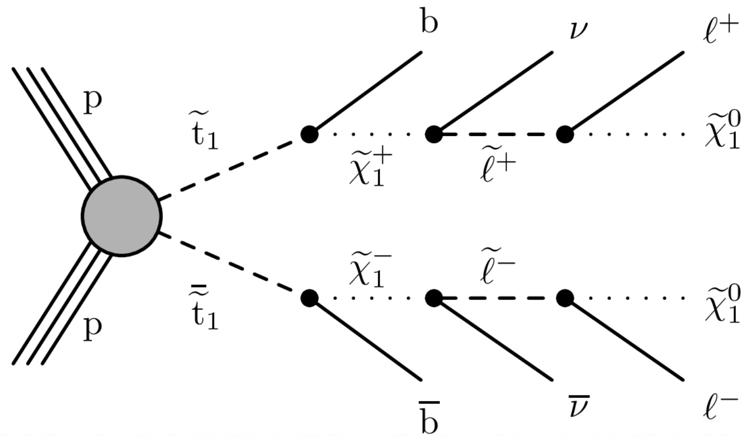
Stop to c quark (ATLAS)

Search with c-tagged jets at 13 TeV, 36.1 fb^{-1}.

arXiv:1805.01649

	SR1	SR2	SR3	SR4	SR5
Trigger	E_T^{miss} triggers				
Leptons	$0\ e$ AND $0\ \mu$				
E_T^{miss} [GeV]	> 500				
$\Delta\phi_{min}(\text{jet}, \boldsymbol{E}_T^{miss})$ [rad]	> 0.4				
$N_{c-\text{jets}}$	≥ 1				
N_{jets}	≥ 2	≥ 3	≥ 3	≥ 3	≥ 3
Leading jet c-tag veto	yes	yes	yes	yes	no
$p_T^{j_1}$ [GeV]	> 250	> 250	> 250	> 250	> 300
$p_T^{j_2}$ [GeV]	–	–	> 100	> 140	> 200
$p_T^{j_3}$ [GeV]	–	–	> 80	> 120	> 150
$p_T^{c_1}$ [GeV]	< 100	> 60	> 80	> 100	> 150
m_T^c [GeV]	$\in (120, 250)$	$\in (120, 250)$	$\in (175, 400)$	> 200	> 400

Stop to sleptons (CMS)



Phys. Rev. D 97, 032009 (2018)