Top squarks searches & connection to precision top physics

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Top Quark Physics at the Precision Frontier

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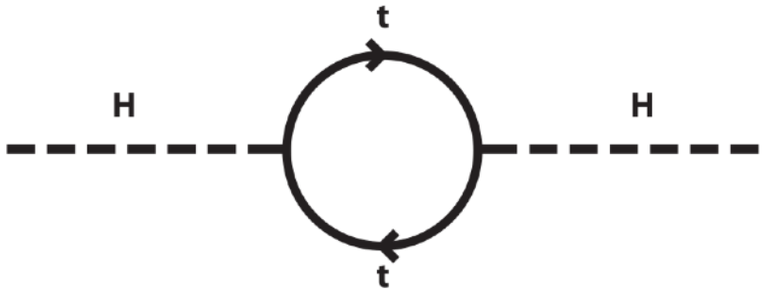
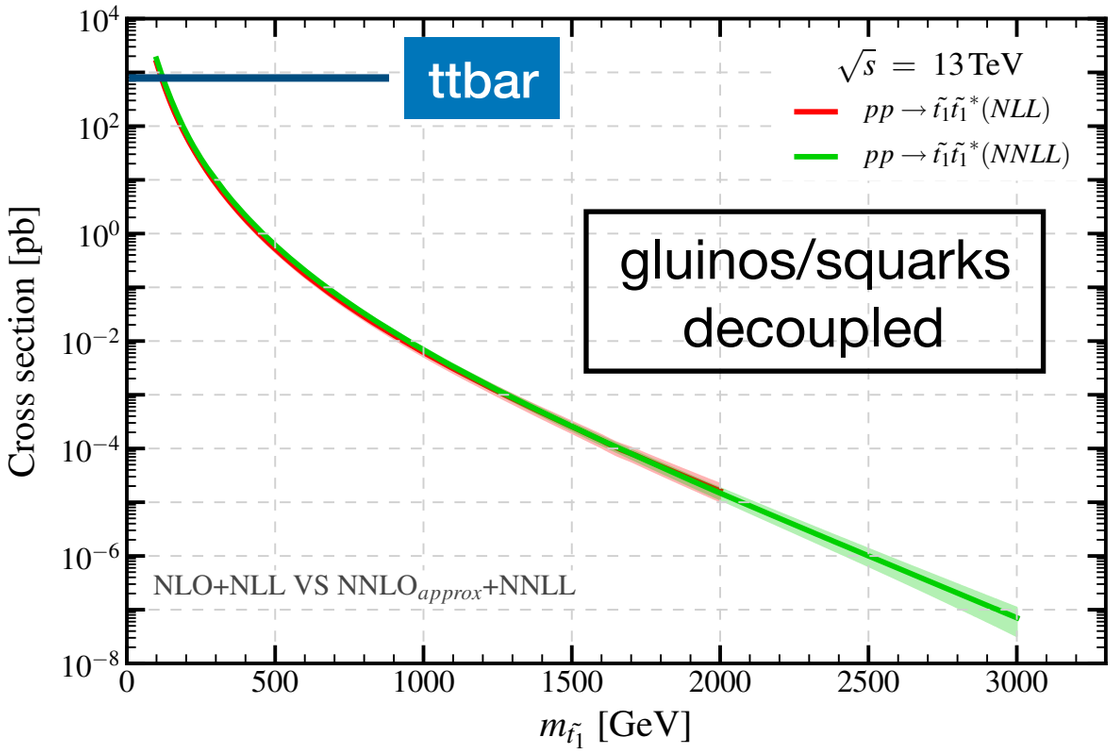
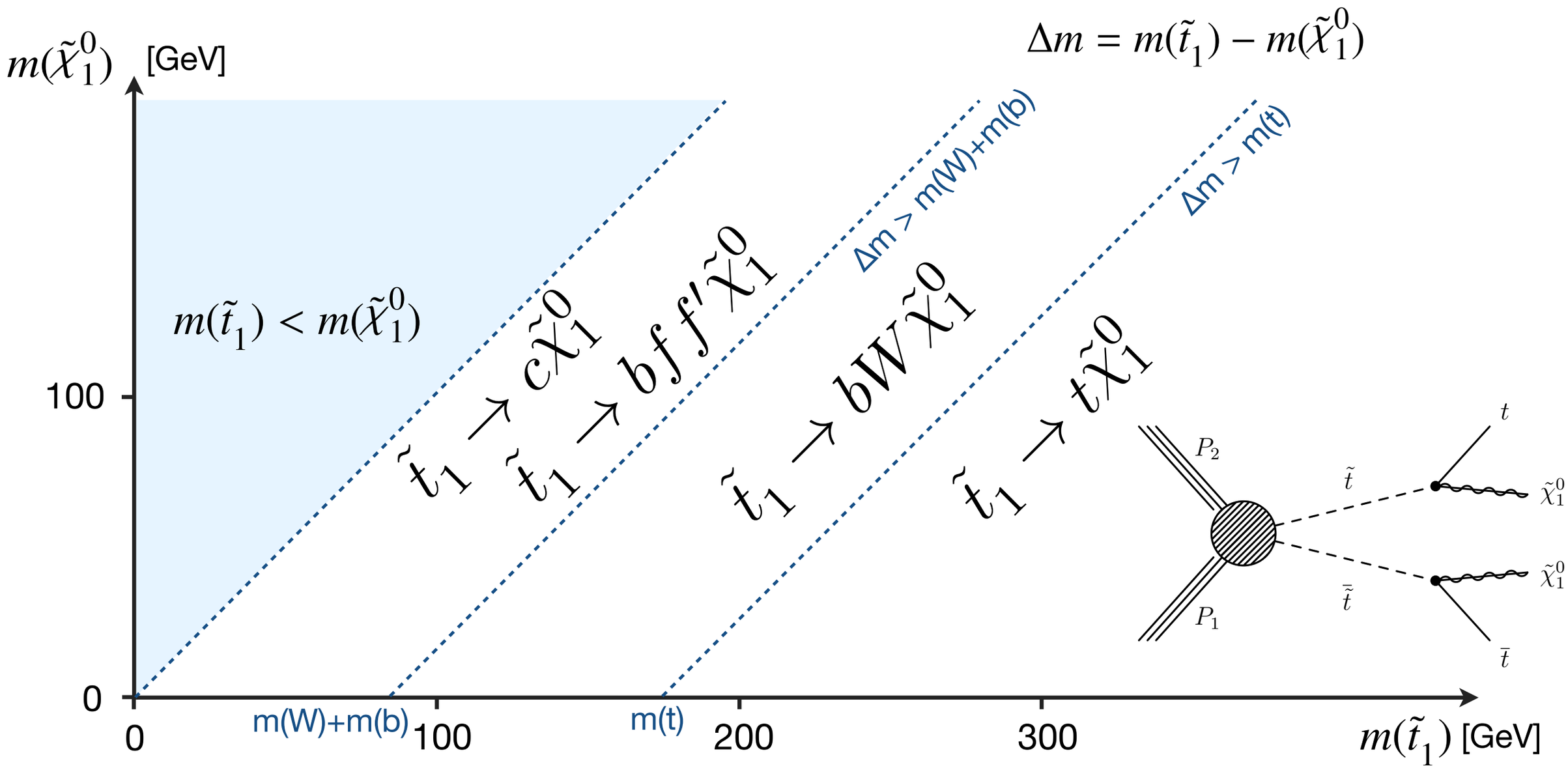
Top squarks

- Superpartner of the top quark
  - **Spin 0**
  - Mass?
  - Top squarks can have large mixing because of large top Yukawa
- Naturalness arguments favor at least one top squark to be light enough to produce at the LHC
- **Cross section depends strongly on mass**
  - at the top mass, factor of ~5 smaller than $t\bar{t}$





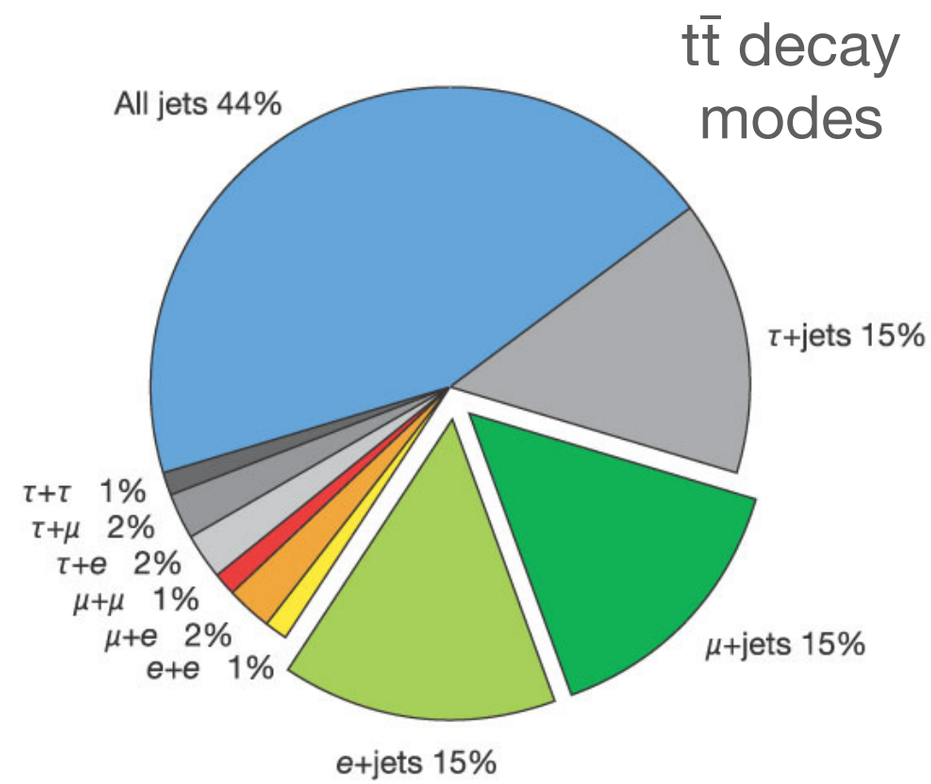
Top squark decays



- Different analysis techniques depending on Δm

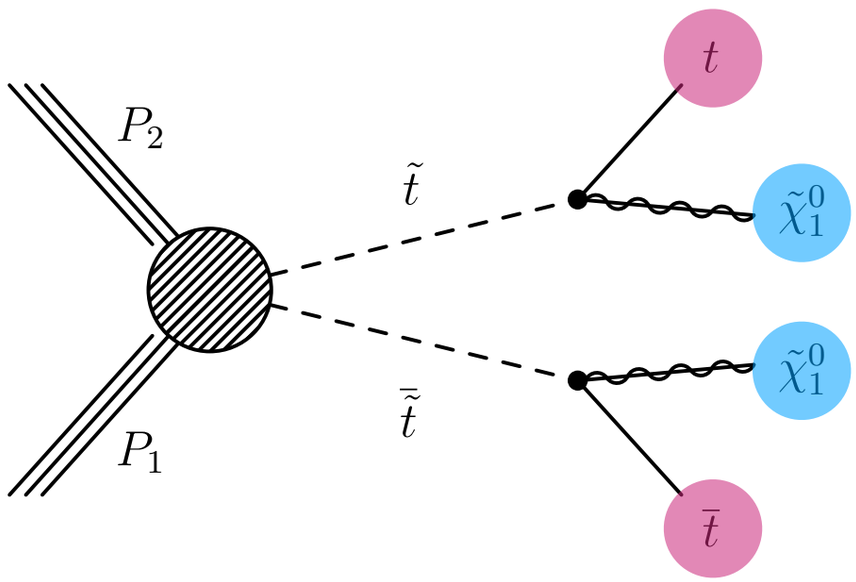
Top squark searches

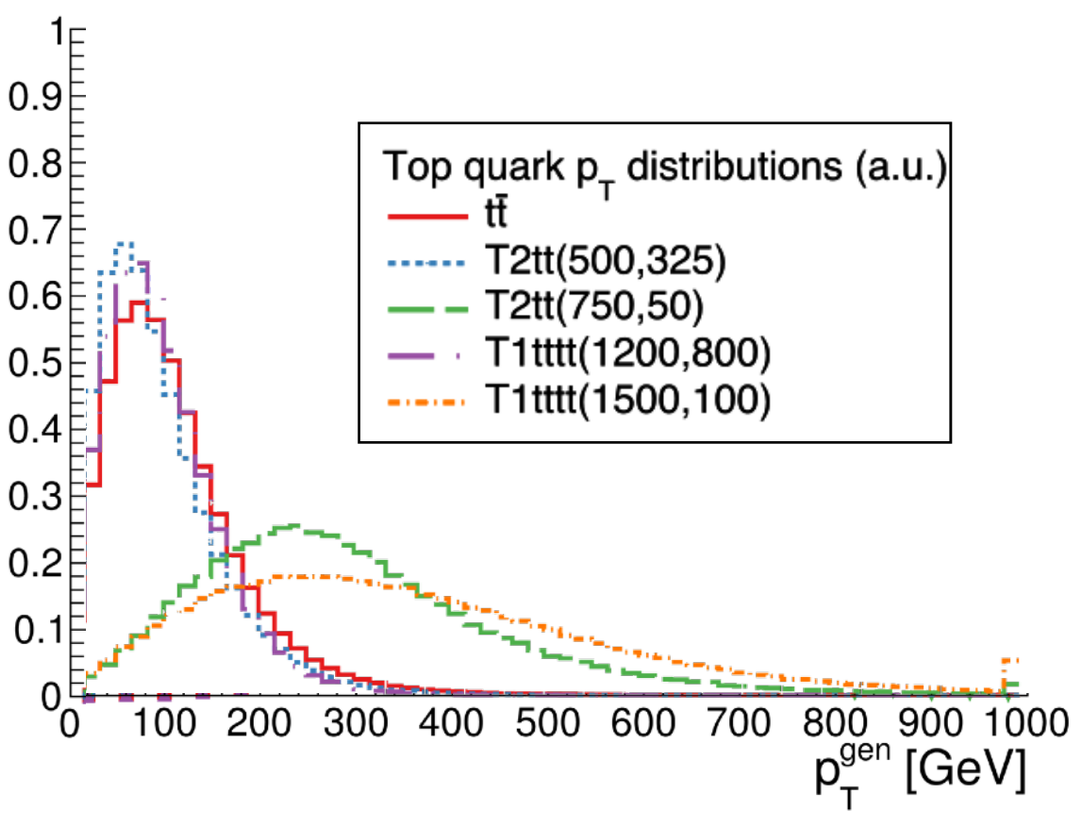
- "General purpose" searches split by lepton categories
- **0 lepton**
  - Largest branching fraction
  - Main background from lost lepton ($t\bar{t}$ and W+jets)
  - Also $Z \rightarrow \nu\nu$, $t\bar{t}Z$, QCD multijet
- **1 lepton (usually e/μ)**
  - Background from lost lepton from dilepton $t\bar{t}$, no QCD multijet
- **2 lepton**
  - Smallest branching fraction, cleaner environment
  - Hard to compete with 0/1-lepton for most of phase space



$t\bar{t}$ is almost always main background

$\tilde{t}$ vs t

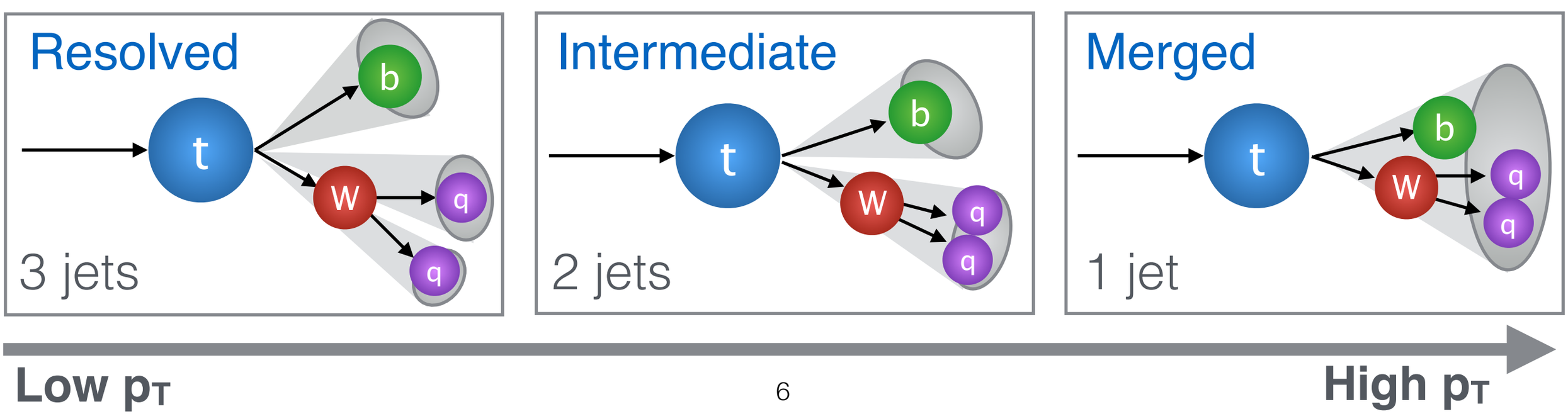




- Key handle: **Missing transverse momentum** (p_T^{miss}) from undetected neutralinos
- Depending on top squark mass, the top quarks can have **large p_T**
- Can attempt to reconstruct (transverse) top squark mass, e.g. M_{T2} variable etc

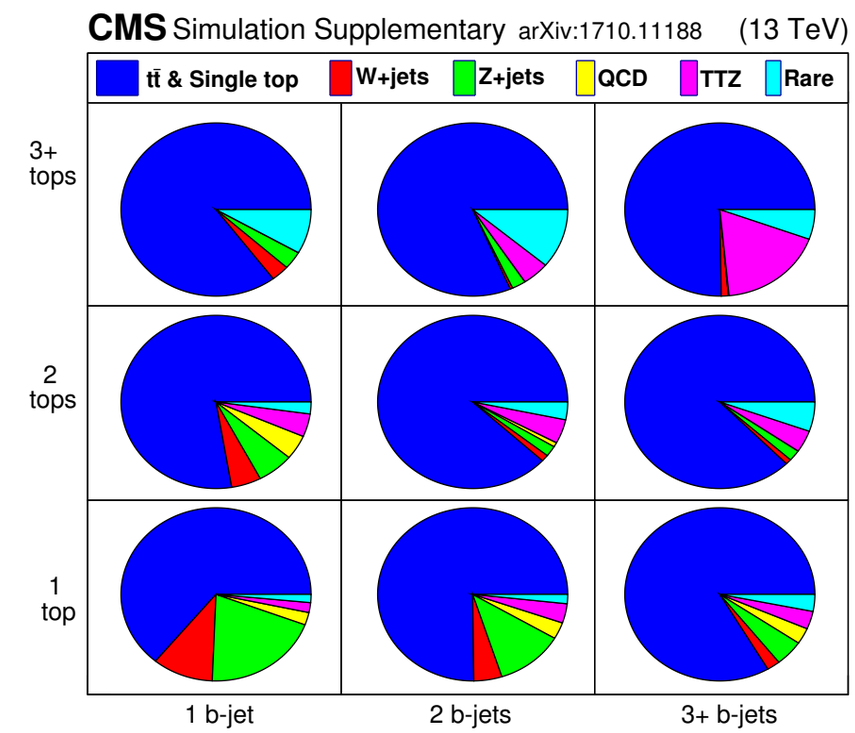
Top squark search in all-hadronic channel (CMS)

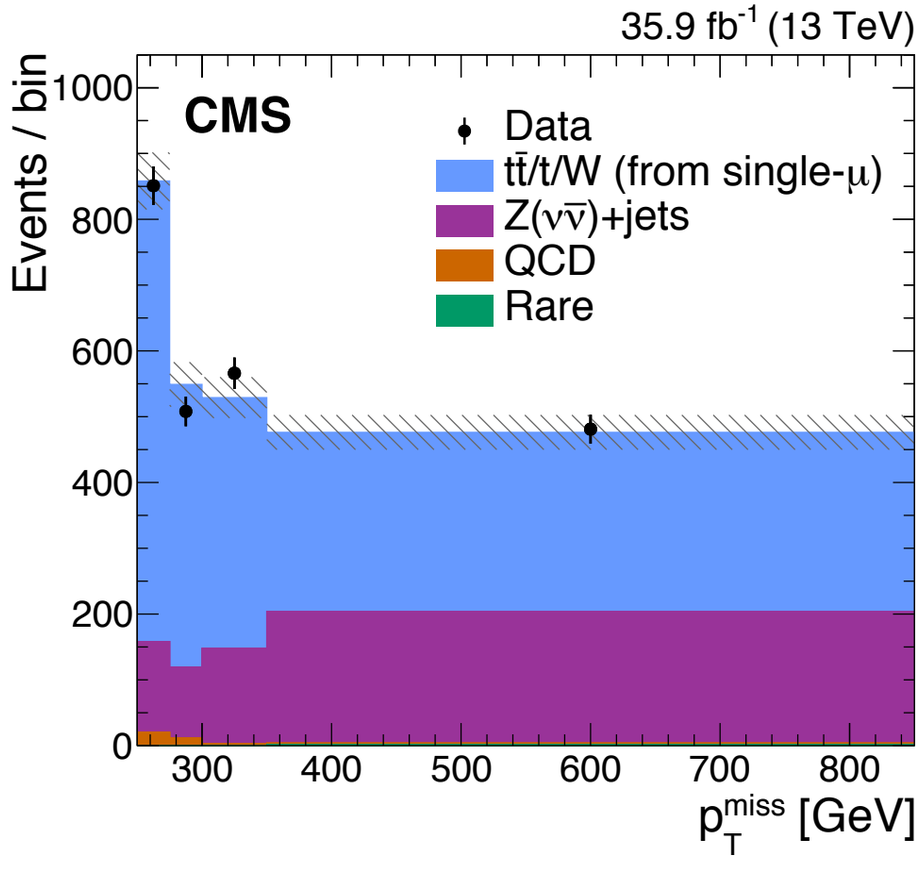
- Targets direct and gluino-mediated top squark production
- Suppress non-ttbar background by using **top quark tagging**
  - Custom 3-step algorithm
  - Maximize efficiency across top p_T spectrum
- Construct 84 signal regions based on N_b, N_t, p_T^{miss}, M_{T2}, H_T



Background prediction

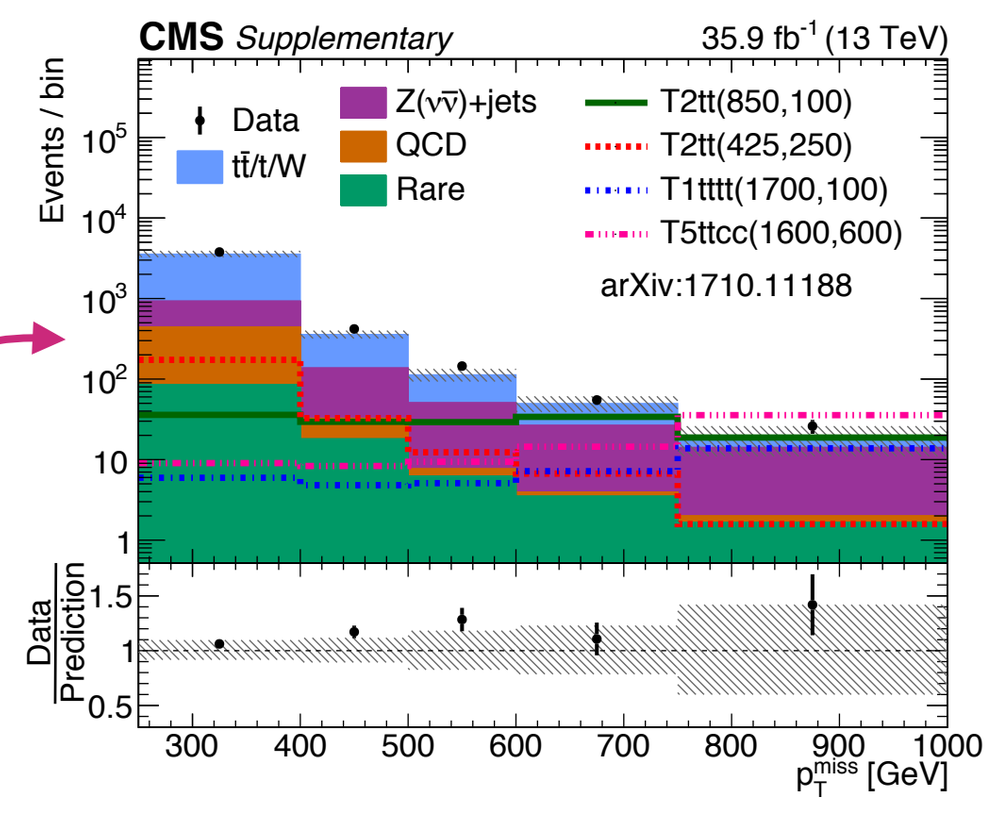
- $t\bar{t}$ is main background in all categories
  - lost lepton
  - hadronic tau
- Estimated using 1-lepton control region and MC transfer factors
- Prediction and observation agree





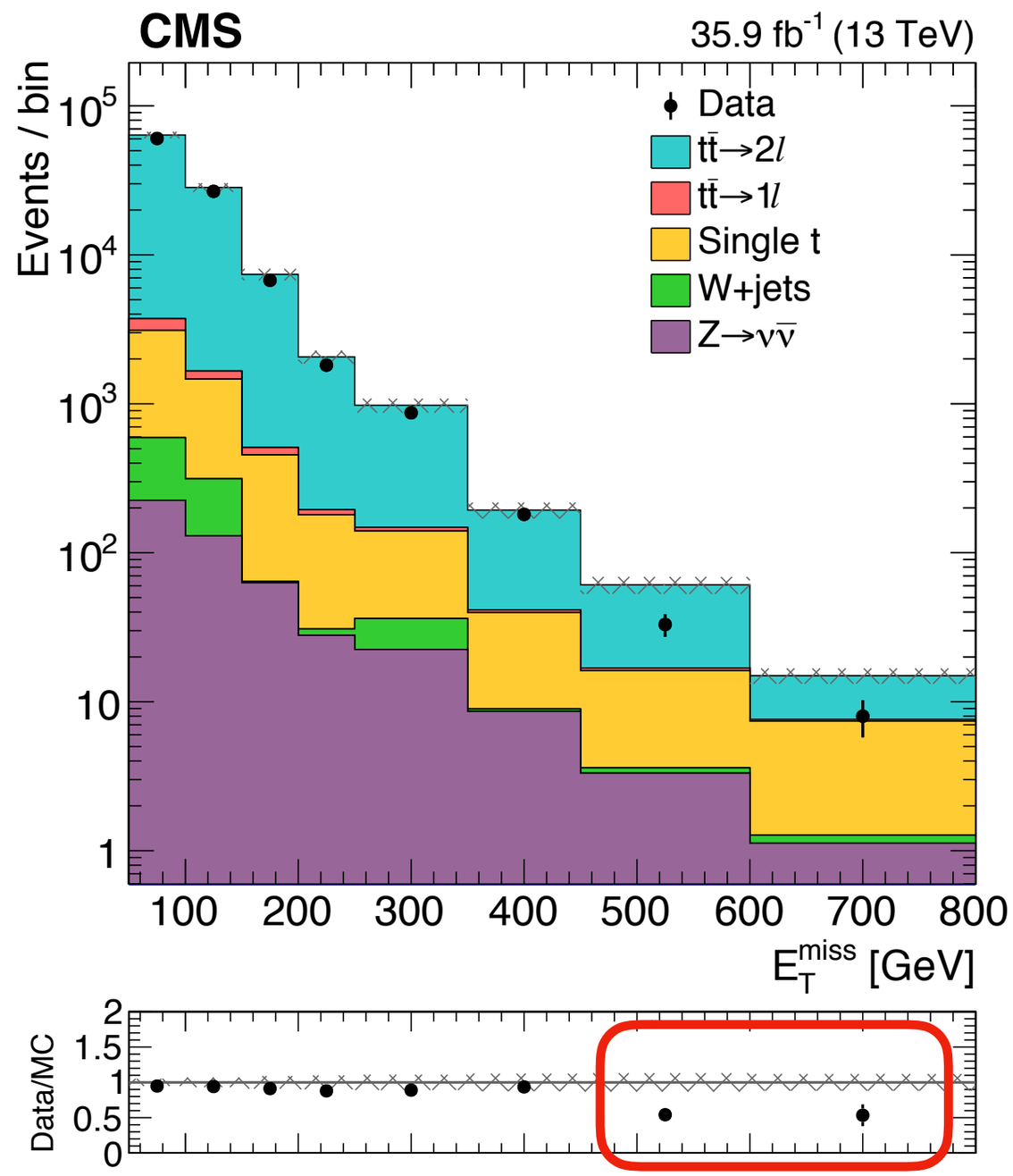
Validation in sideband region

Prediction for signal selection

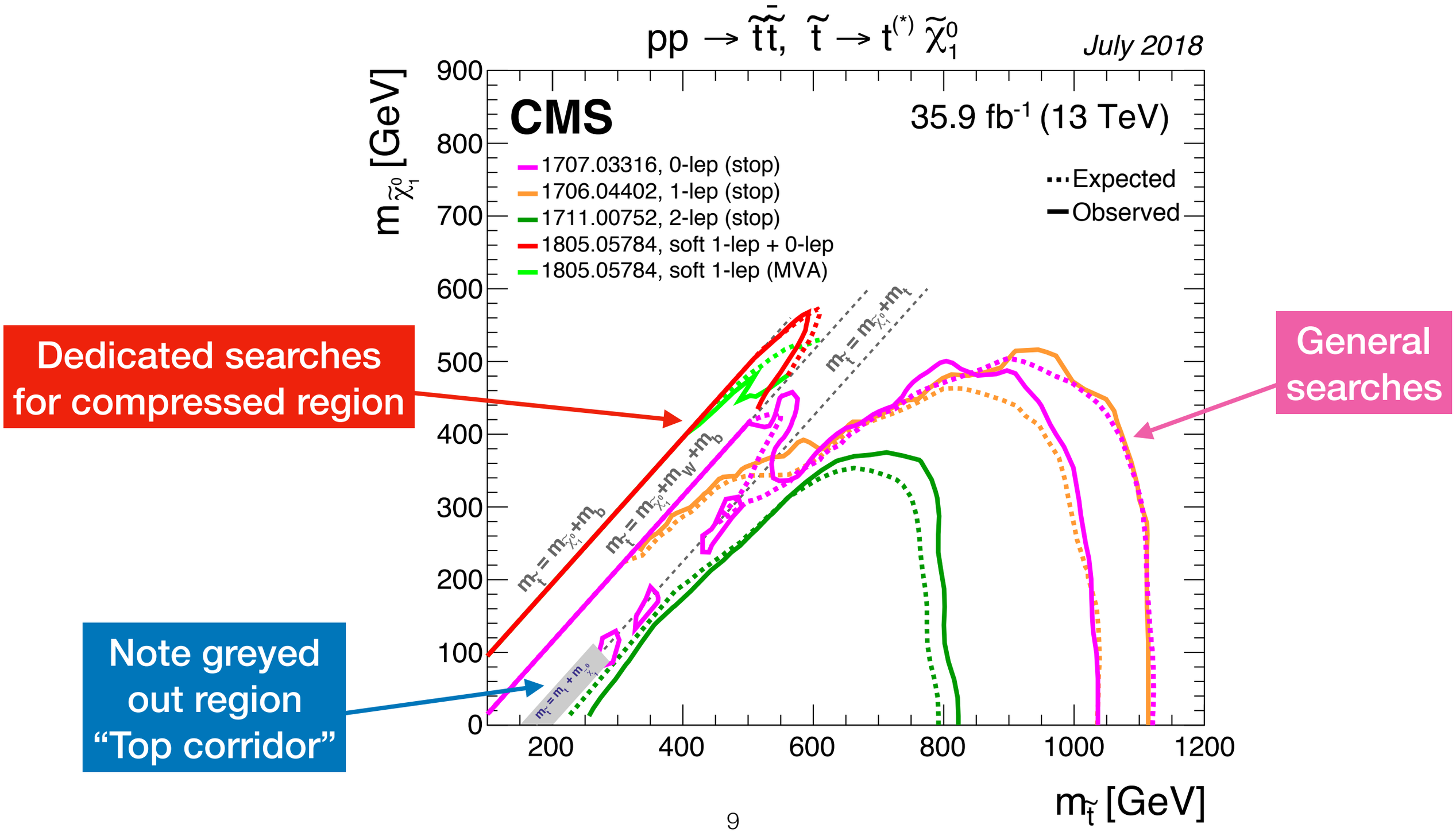


1-lepton example

- Main background is **lost leptons from dilepton $t\bar{t}$**
- Predicted from an eμ control sample, using bin-by-bin **transfer factors (from MC)**
- Control region bins are aggregated in p_T^{miss} to reduce statistical uncertainties
- **p_T^{miss} distribution in control region** used as correction factor with half the difference as systematic uncertainty (25% at high MET)



Status last Summer



ISR modeling for compressed spectra

- **For compressed signal models, analyses rely on initial state radiation** to boost the top squarks and create larger p_T^{miss} or higher p_T's to pass the event selection
- ISR modeling important signal systematic (up to 15%), and is **validated using $t\bar{t}$ control sample**

CMS example

- Madgraph (LO) + Pythia8 with MLM matching used
- In 2016, reweighting needed to make N_j^{ISR} spectrum agree (factor 0.92–0.51 for 1–6 extra jets), taking half the difference from 1 as uncertainty
- For 2017, newer tune was used in MC, and reweighting is no longer needed

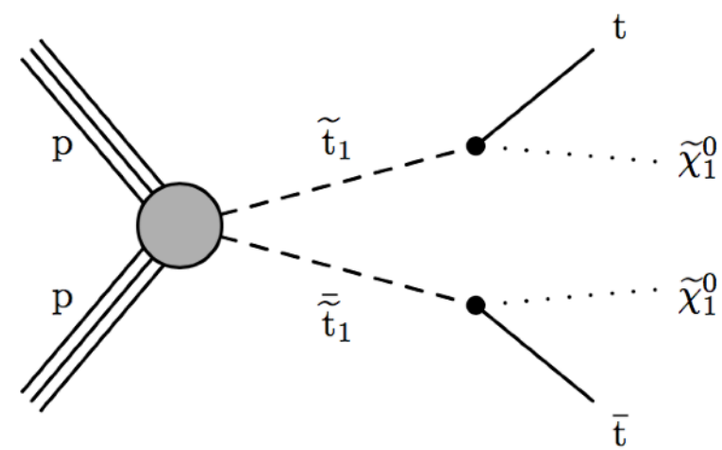
Direct impact from precision top measurements

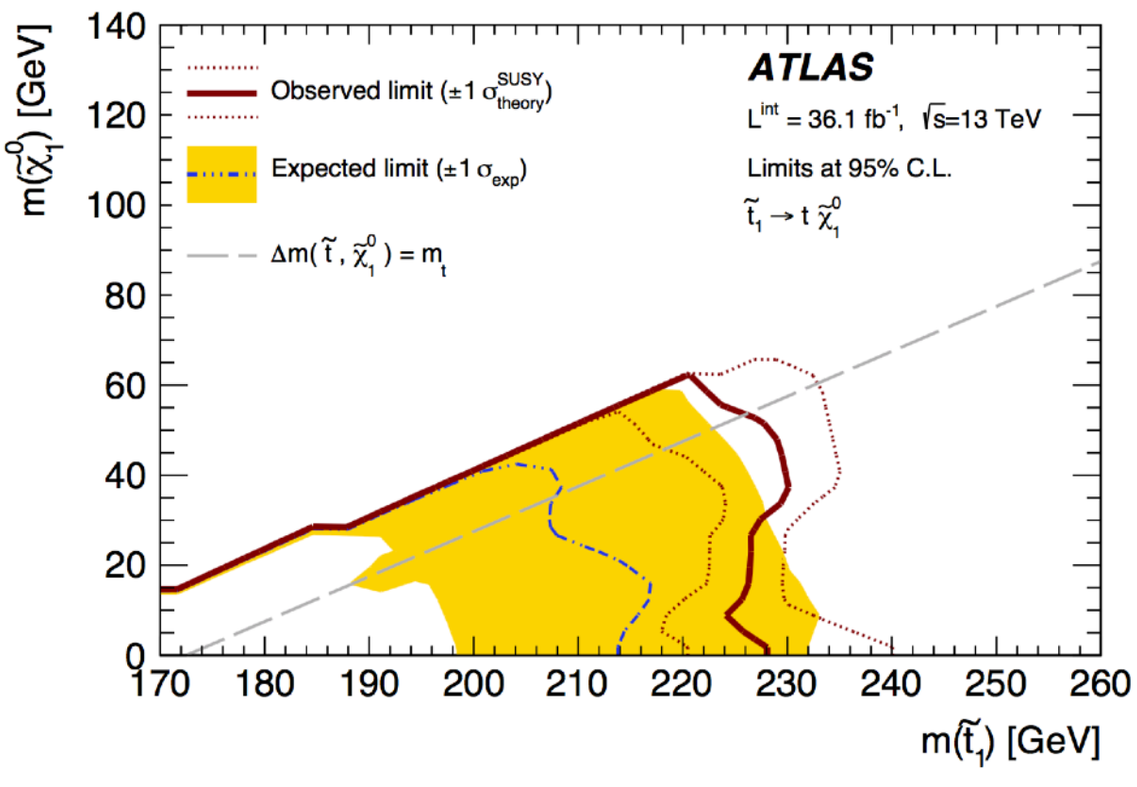
arXiv:1903.07570

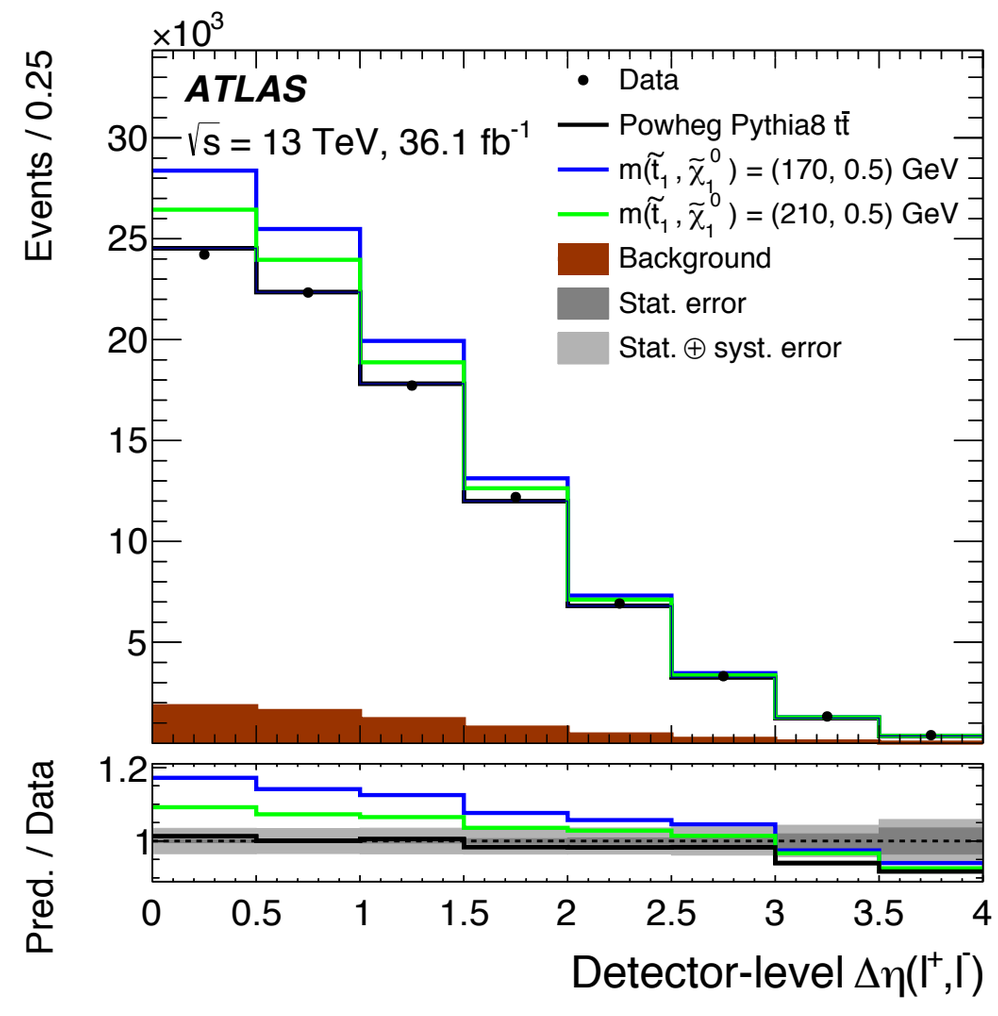
Top corridor

$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx 175\,\mathrm{GeV}$$

- Top quarks from squark decay produced ~at rest, looks very much like SM $t\bar{t}$
- Needs precision approach — use eμ final state
- ATLAS result using **$t\bar{t}$ spin correlations:**
  - double-differential distributions of **lepton $\Delta\phi$** (uncorrelated $t\bar{t}$ from top squarks) & **$\Delta\eta$** (scalar top squarks more central)





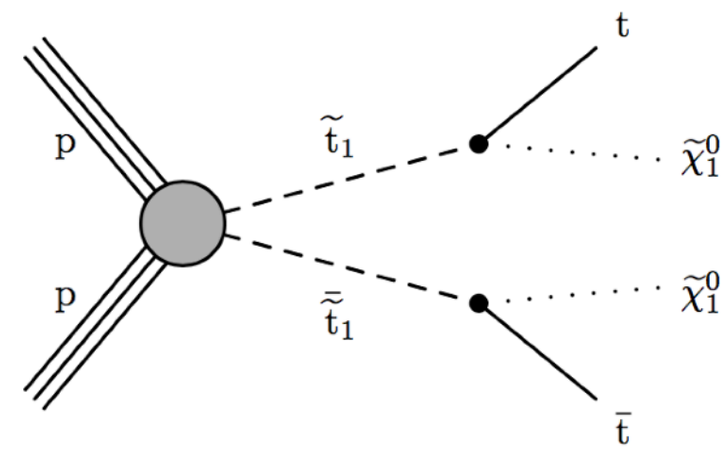


arXiv:1901.01288

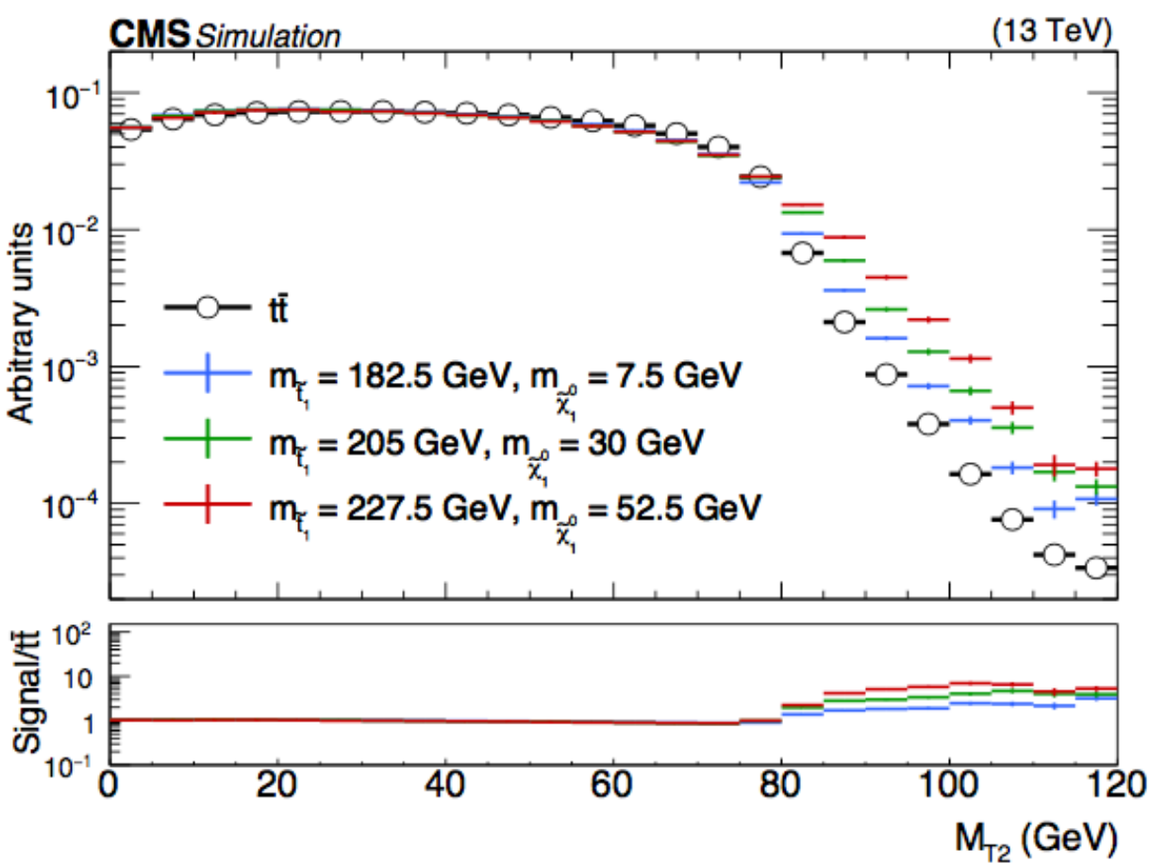
Top corridor

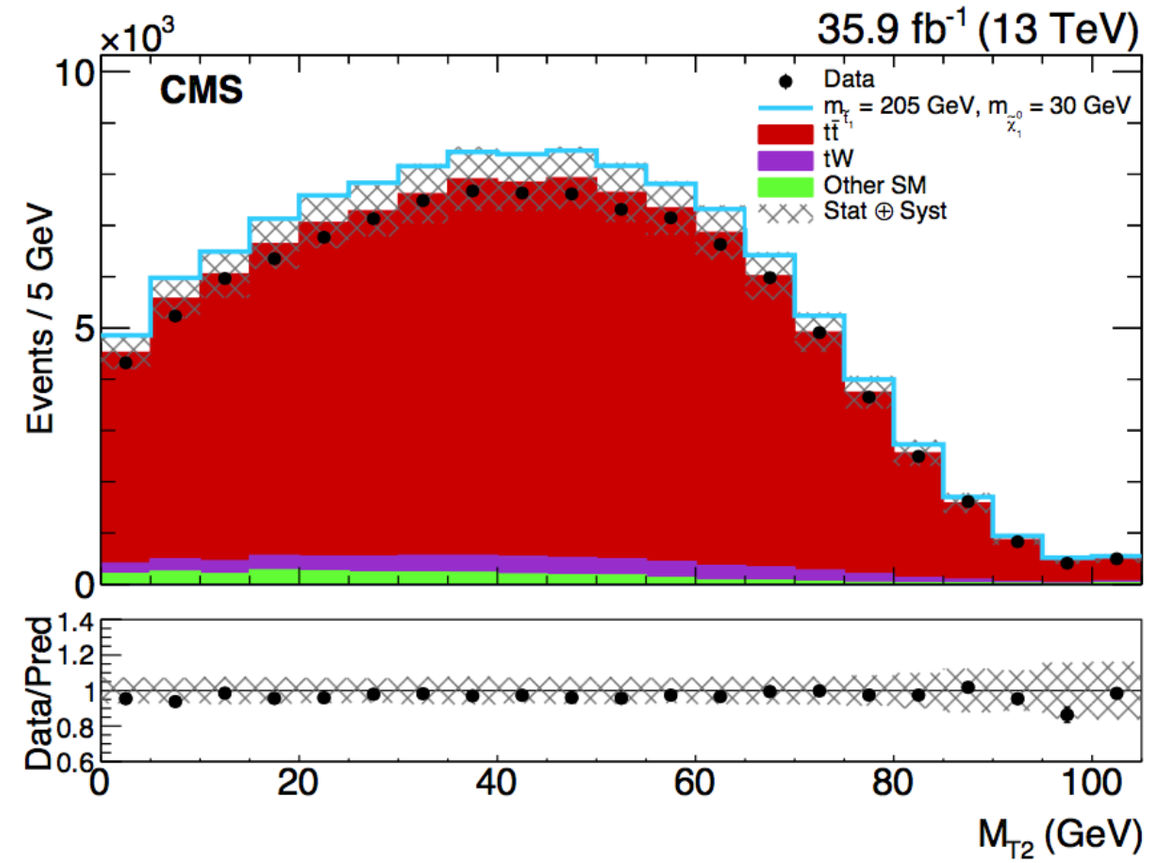
$$m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx 175\,\mathrm{GeV}$$

- Top quarks from squark decay produced ~at rest, looks very much like SM $t\bar{t}$
- Needs precision approach — use eμ final state
- CMS result using **precise estimate of $t\bar{t}$ (~6%)** and extra discrimination using M_{T2} variable



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





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Top corridor

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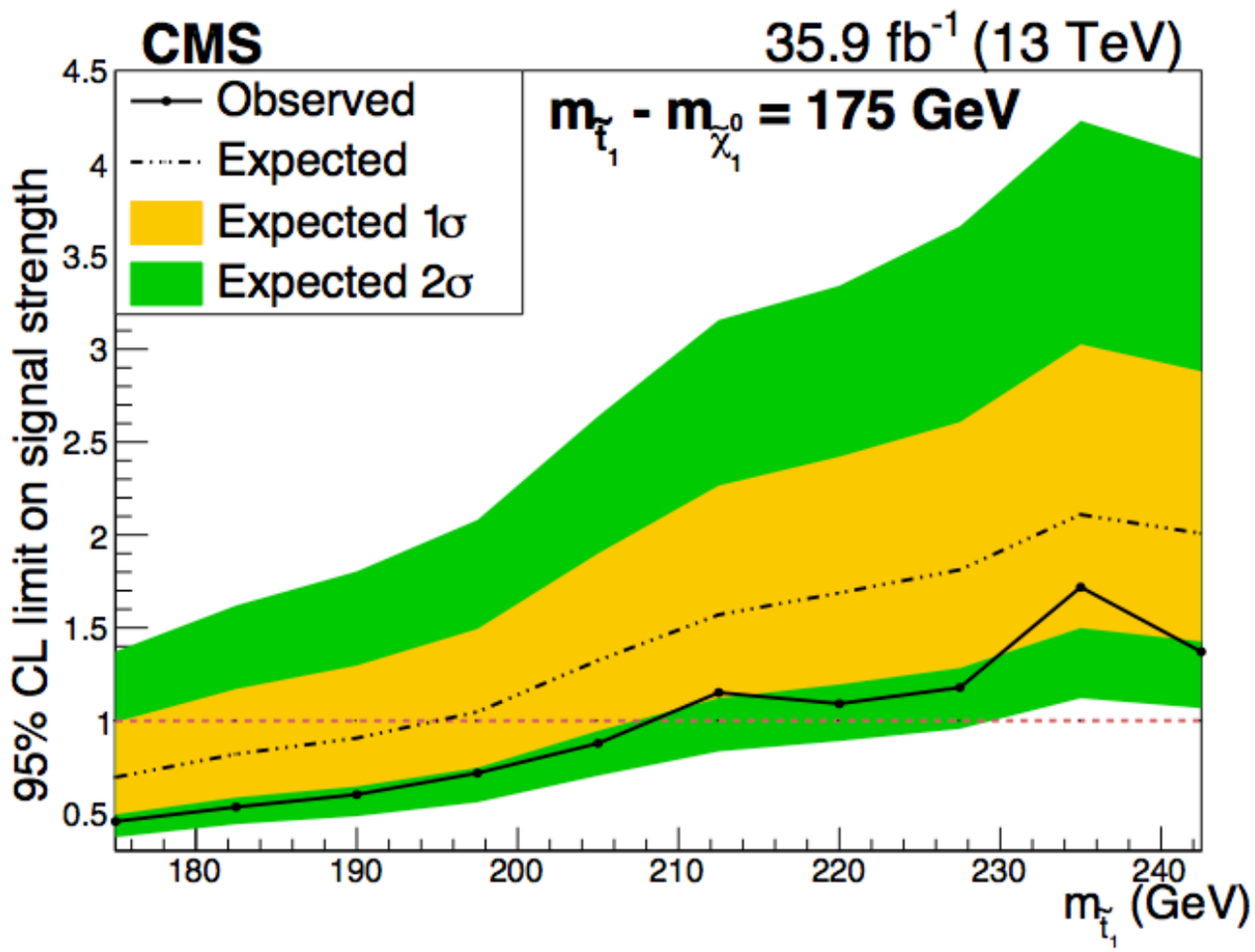


Source	Range (%)
μ_F and μ_R scales	0.3–1.0
PDF	≈0.6
Initial-state radiation	0.5–1.0
Final-state radiation	0.6–1.2
ME/PS matching (h_{damp})	0.3–2.0
Underlying event	≈0.8
Colour reconnection	≈1.5
Top quark p_T reweighting	0.1–0.5
Top quark mass (acceptance)	≈1.0

Source	Range for $t\bar{t}$ and signal (%)
Muon efficiencies	≈1.4
Electron efficiencies	≈1.5
Trigger efficiency	≈0.6
Lepton energy scale	0.5–2.0
Jet energy scale	1.5–3.0
Jet energy resolution	0.3–3.5
btagging efficiency	1.2–2.0
Mistag efficiency	0.2–0.6
Unclustered energy	0.5–1.5
Pileup	0.5–3.5

Slightly worse sensitivity compared to spin correlation measurement

What about RPV?

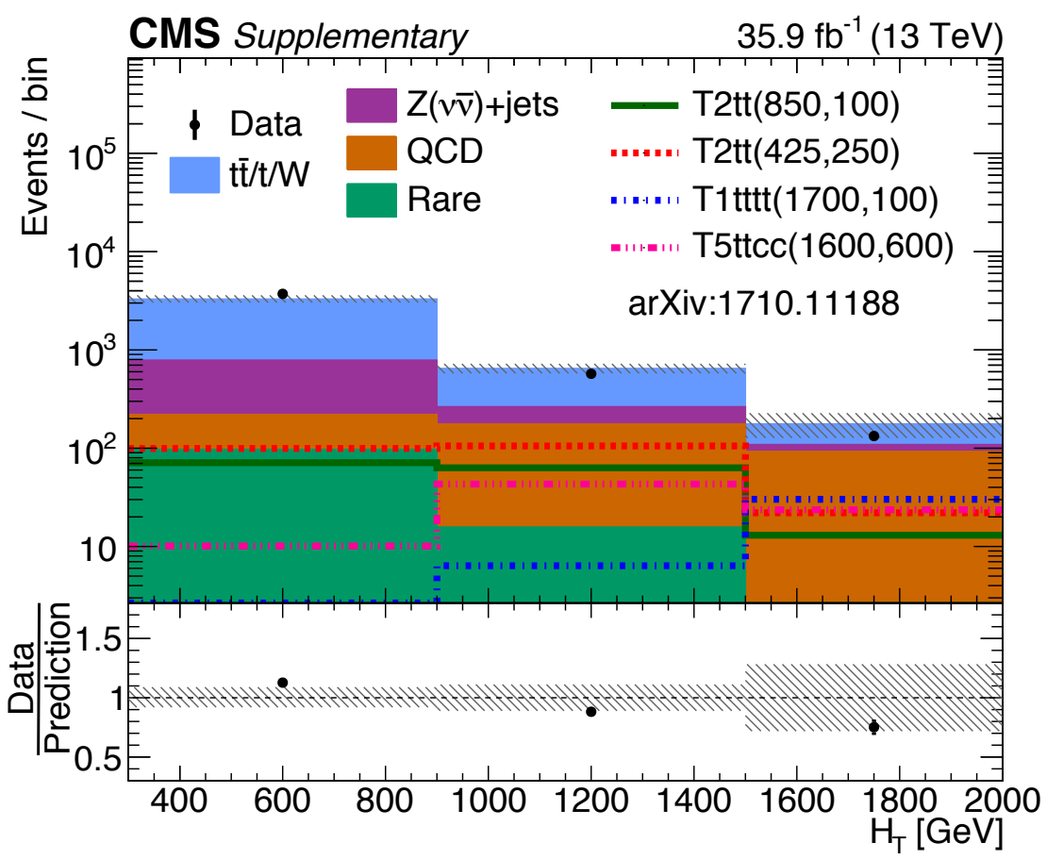
- Standard SUSY searches assume R-parity is conserved
  - Neutralino is stable → Missing transverse momentum
- With R-parity violation, other decay options become possible
  - Usually results in extra leptons or jets, instead of missing transverse momentum

Decay	Coupling	Topology
$\tilde{t} \to \ell j$	LQD	2l+2j, cf. leptoquarks
$\tilde{t} \to jj$	UDD	4j, paired dijets
$\tilde{t} \to t\tilde{\chi}^0$, $\tilde{\chi}^0 \to \ell jj$	LQD	ttbar + lepton(s) + jets
$\tilde{t} \to t\tilde{\chi}^0$, $\tilde{\chi}^0 \to jjj$	UDD	ttbar + 6 jets
$\tilde{t} \to b\tilde{\chi}^+$, $\tilde{\chi}^+ \to \ell\ell\ell$	LLE	6 leptons + 2 bjets
$\tilde{t} \to b\tilde{\chi}^+$, $\tilde{\chi}^+ \to jjj$	UDD	8 jets

$t\bar{t}$ often largest background
Cannot use p_T^{miss}, M_T, M_{T2} to suppress it

Impact from precision top quark measurements

- $t\bar{t}$ is main background for almost all top squark searches
- Differential $t\bar{t}$ cross section measurements very valuable! Especially as a function of variables often used in SUSY searches
  - Missing transverse momentum
  - M_{T2}
  - Number of jets
  - Transverse mass M_T(l,MET)
  - Hadronic activity, H_T
  - …



Word of caution

- Please keep in mind the possibility that there might be SUSY/other BSM in your $t\bar{t}$ signal selection!
- This is especially possible for tricky corners of parameter space, e.g. “stealthy stops”, or certain RPV scenarios, that have no extra p_T^{miss}
- Small top squark cross section means that this could be a small effect in your measurement
- Be careful when tuning SM $t\bar{t}$ MC, since that MC will also be used by new physics searches

Summary

- **$t\bar{t}$ is main background for most top squark searches**
- Often estimated using data control regions with MC transfer factors
- Transfer factor need to be modeled well
- In addition, correction factors are derived from Data/MC agreement in control regions
- **Better modeling of $t\bar{t}$ helps reduce systematic uncertainties**
  - Important for tricky corners of phase space
  - Will be more important for large data sets at HL-LHC
- **Keep up the good work! :-)**