Search for top squark production in fully-hadronic final states in proton-proton collisions at 13 TeV

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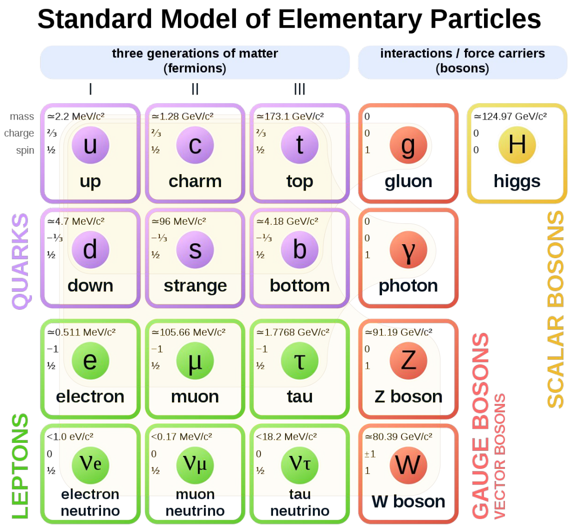
DPF21
July 12-14 2021

Supersymmetry: Top squark

- Supersymmetry posits a partner to every known Standard Model particle:
  - A fermion for every boson
  - A boson for every fermion
- Dark matter candidate
- Could help explain shortcomings of the SM like the fine-tuning problem
  - Third-generation squarks would have large couplings to the Higgs boson, therefore producing some of the largest corrections
- The top squark should be the lightest and easiest to produce

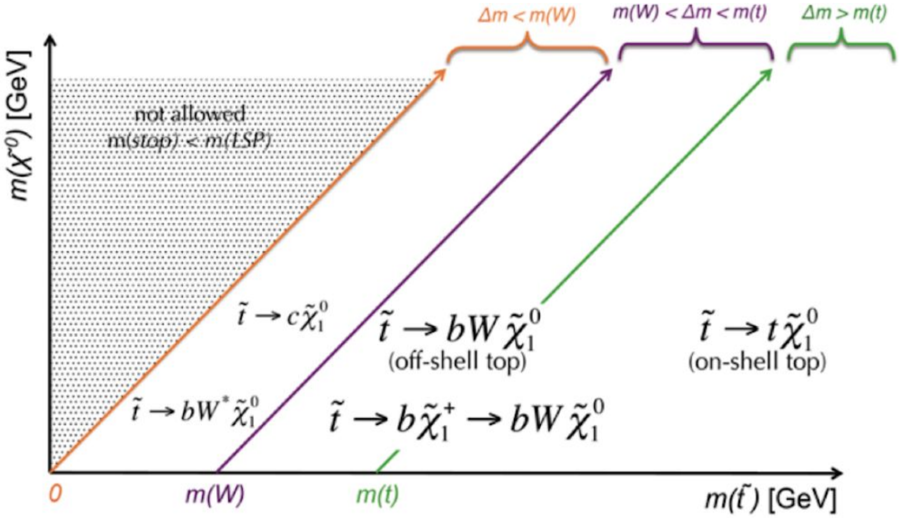


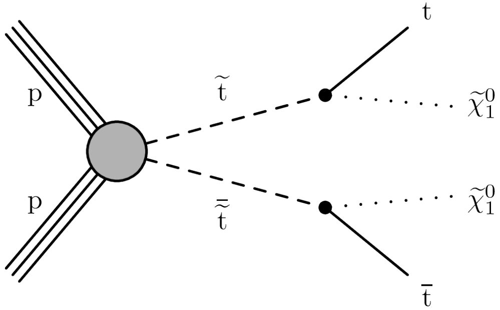
Search Regions and Signal Models

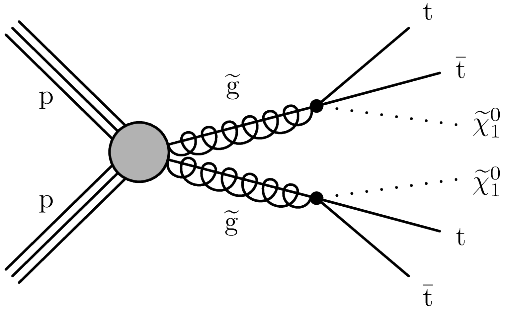
- Comprehensive search of nine signal models
    - Direct stop production and gluino-mediated production
    - Compressed (low Δm) and uncompressed (high Δm) regions

$$\text{stop production} : \Delta m = m_{\tilde{t}} - m_{\tilde{\chi}_1^0}$$

$$\text{gluino production} : \Delta m = m_{\tilde{g}} - m_{\tilde{\chi}_1^0}$$







The decay modes that make up the six direct stop production models we analyze.
The three gluino-mediated production models we analyze also follow these decays through either an on-shell or off-shell top squark.

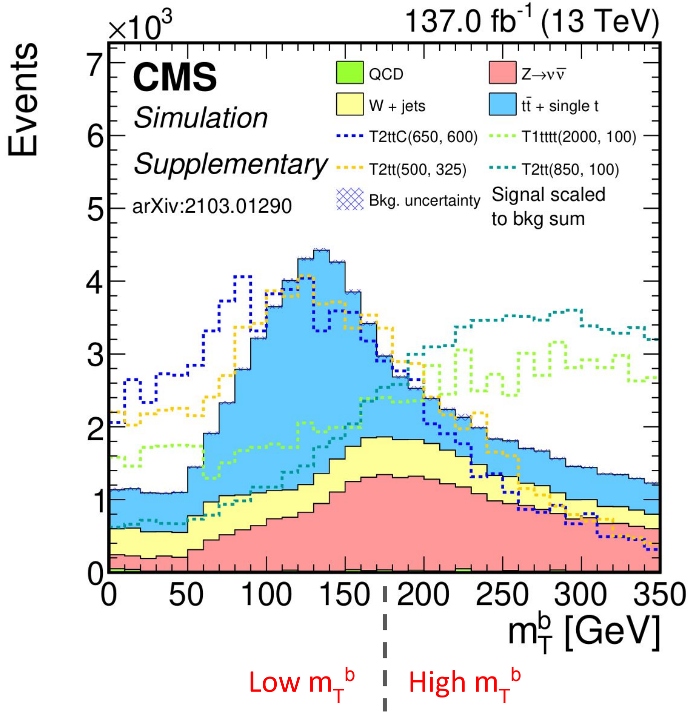
Search Strategy

183 search bins split across low and high Δm regions

Low Δm

Targeting:
Compressed and low-Δm direct stop production models

Use soft b tagger to tag quarks that do not pass jet p_T threshold



High Δm

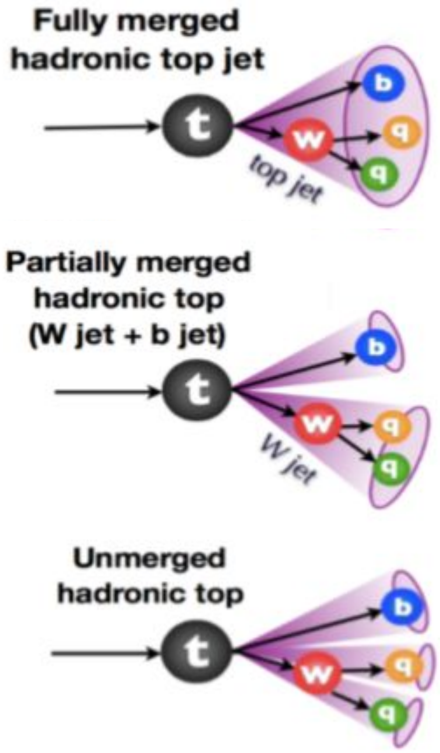
Targeting:
high-Δm direct stop production models and gluino-mediated models

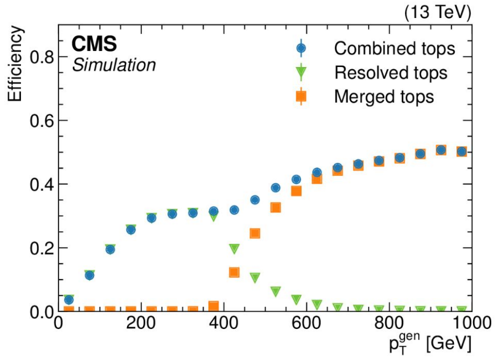
Use deep neural network to tag top quarks and W bosons

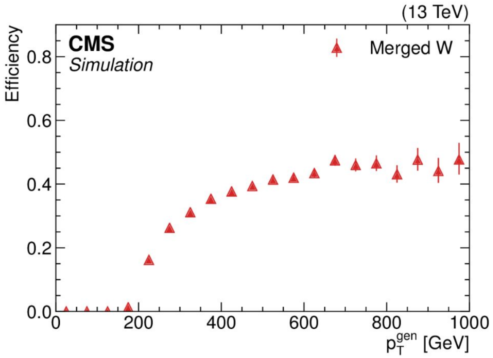
$$M_T(b_{1,2}, \not{E}_T) \equiv \begin{cases} m_T(b, \not{E}_T) & N_b = 1, \\ \mathrm{Min}[m_T(b_1, \not{E}_T), m_T(b_2, \not{E}_T)], & N_b \geq 2, \end{cases}$$

Top/W Tagging

- Building on strategy of previous stop searches using combination of merged top/W with resolved top tagger to cover full range of top p_T
- Merged top/W:
  - Uses deep neural network to discriminate Top/W from background
- Resolved top:
  - Uses neural network to improve discrimination over boosted decision tree based taggers employed in previous searches
  - Candidates that overlap with tagged merged top/W removed







Standard Model Backgrounds

Lost Lepton

- Events that have a lepton but pass the lepton veto due to the lepton failing kinematic cuts or falling outside of detector acceptance.

Z Invisible

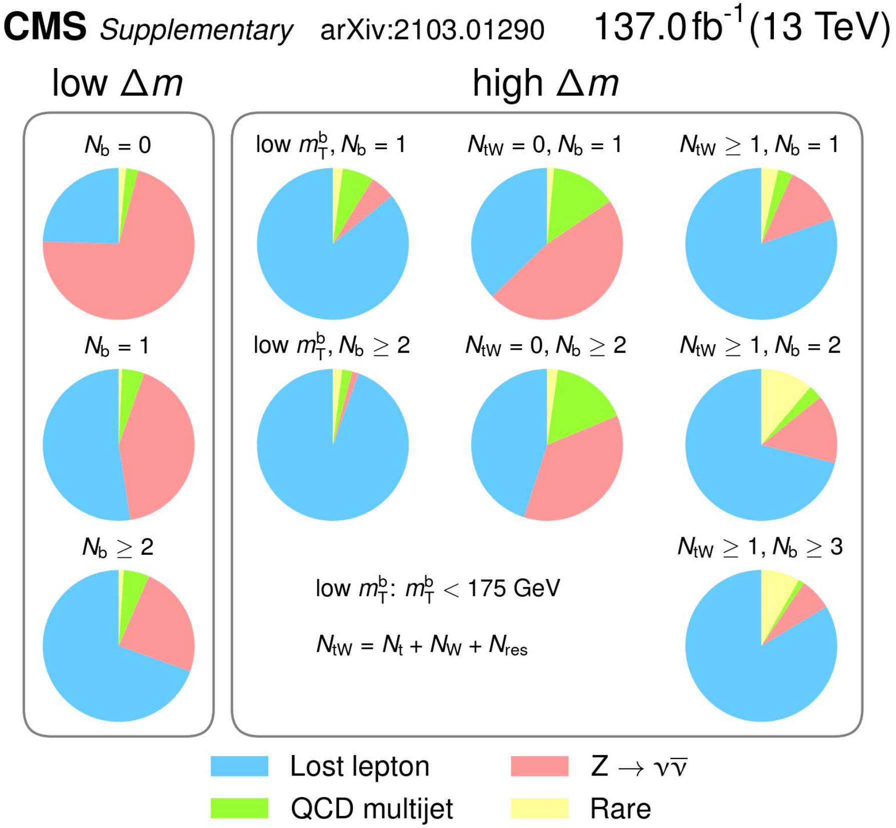
- Events that have a Z boson that decays to neutrinos, resulting in missing transverse energy.

QCD

- Events in which fake missing transverse energy is present due to jet energy mismeasurement.

ttZ and Rare

- Remaining processes that pass our selection.

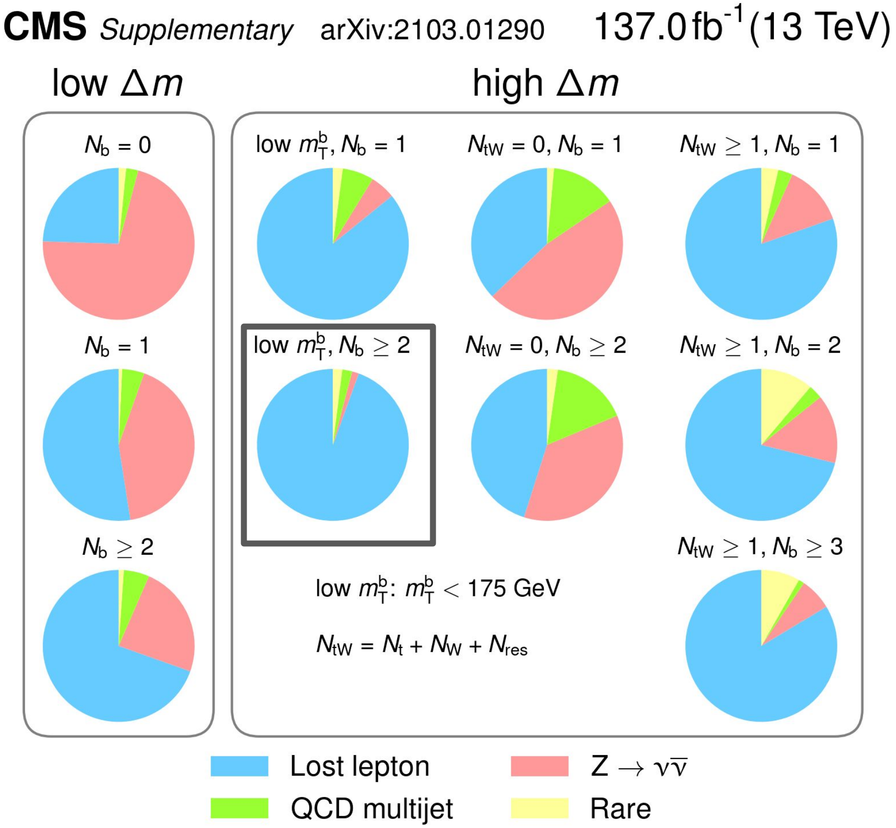


Relative composition of each background using final background predictions

Lost Lepton

Lost Lepton

- Events that have a lepton but pass the lepton veto due to the lepton failing kinematic cuts or falling outside of detector acceptance.
- Consists of tt, W+jets, single top, tW, ttX, diboson, and triboson
    - X = W, Z, H, or γ



Background composition from data-driven background predictions

Lost Lepton Background Estimation

Lost Lepton

- Events that have a lepton but pass the lepton veto due to the lepton failing kinematic cuts or falling outside of detector acceptance.
- Consists of tt, W+jets, single top, tW, ttX and multiboson
  - X = W, Z, H, or γ
- Estimate using transfer-factor method
  - Single-lepton control region
  - Top/W multiplicity extrapolation
- Rare samples (multiboson, ttZ, ttH, ttG) include additional charged gen lepton requirements to avoid overlap

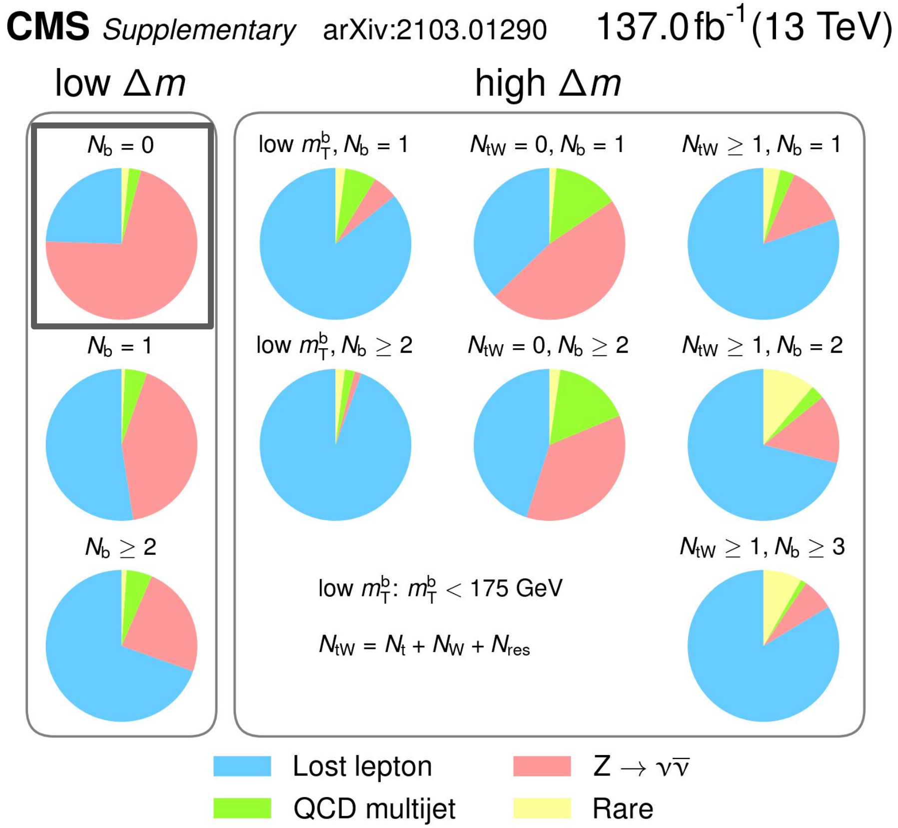
$$N_{\text{pred}}^{\text{LL}} = N_{\text{data,loose bin}}^{\text{1 lep}} \cdot TF$$

$$TF = TF_{\text{CR}\rightarrow\text{SR}} \cdot TF_{\text{SR-extrap}} = \frac{N_{\text{MC,loose bin}}^{\text{0 lep}}}{N_{\text{MC,loose bin}}^{\text{1 lep}}} \cdot \frac{N_{\text{MC,search bin}}^{\text{0 lep}}}{N_{\text{MC,loose bin}}^{\text{0 lep}}}$$

Z Invisible

Z Invisible

- Events that have a Z boson that decays to neutrinos, resulting in missing transverse energy.

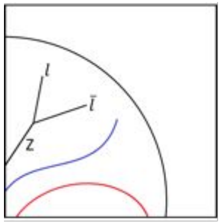


Background composition from data-driven background predictions

Z Invisible Background Estimation

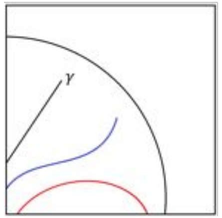
$$N^{\mathrm{SR}}_{Z\rightarrow\nu\nu} = \boxed{R_Z}\,\boxed{S_\gamma}\,N^{\nu\nu}_{\mathrm{MC}}$$

Normalization **Shape**



Z to ℓℓ + jets: R_Z (Z normalization factor)

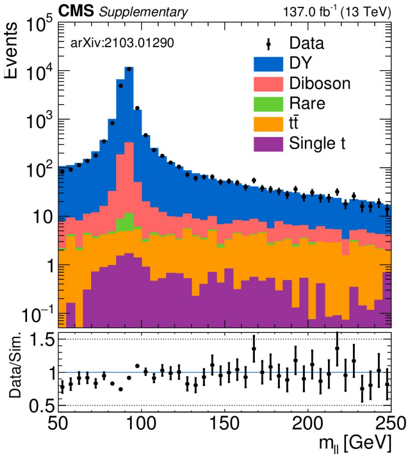
- Dielectron and dimuon selections
- Use to get normalization

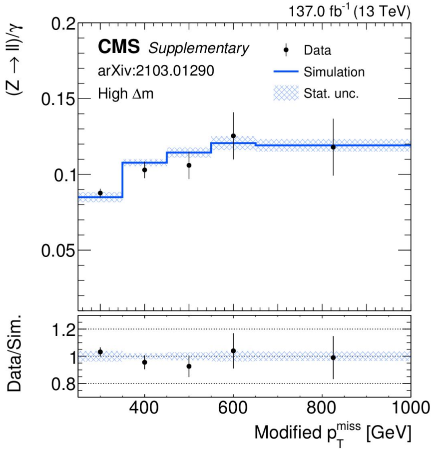


Photon + jets: S_γ (MET shape weight)

- Single photon selection
- Binned in all search bin variables except top/W multiplicity

◦ Reconstructed Z or photon 4-vector is added to p_T^{miss} to mimic Z(νν).

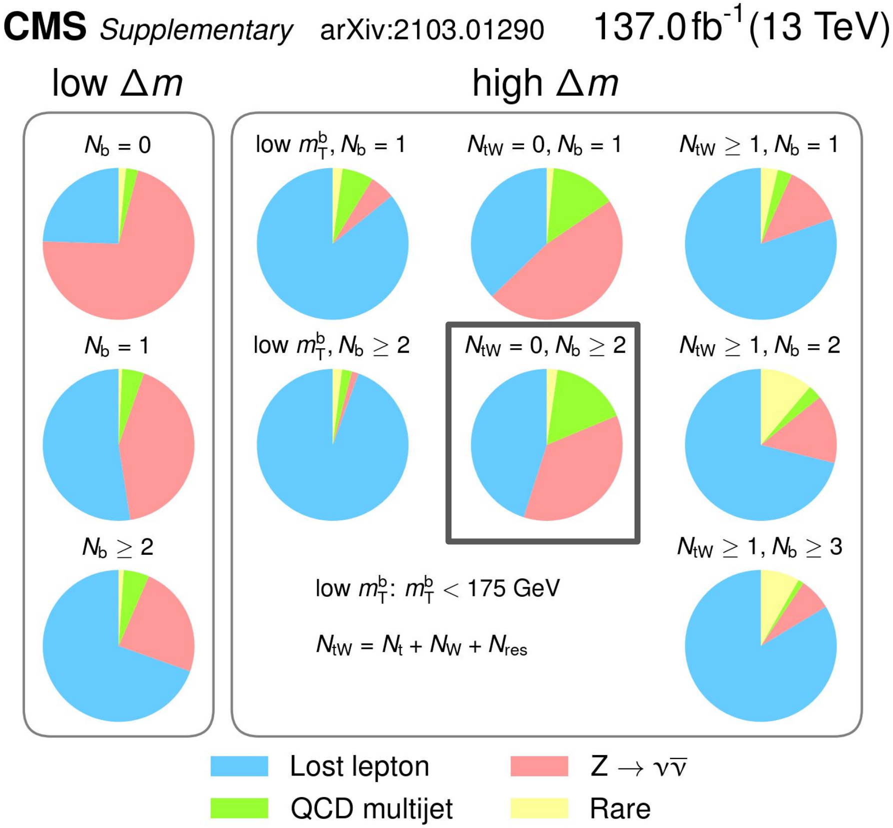




QCD

QCD

- Events in which fake missing transverse energy is present due to jet energy mismeasurement.
- Control region for transfer factor method is defined to have a leading jet aligned with MET
- Uses a similar transfer factor method as discussed in prior slides

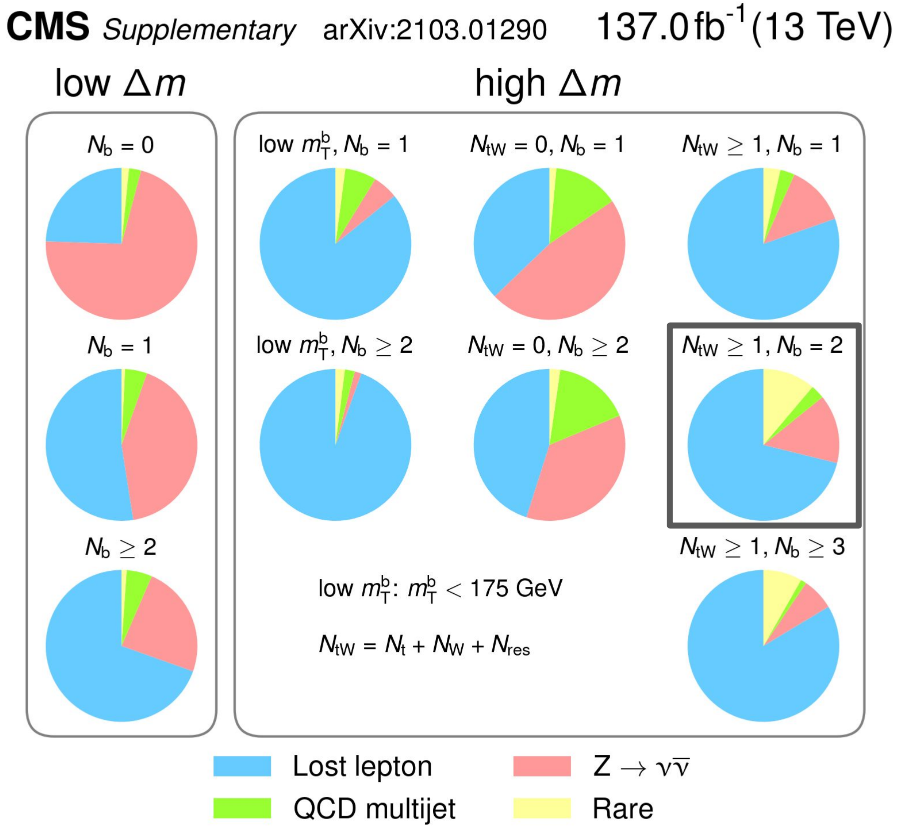


Background composition from data-driven background predictions

TTZ and Rare

ttZ and Rare

- Remaining processes that pass our selection.
- While they have different kinematics, ttZ is irreducible when Z→νν and top quarks decay hadronically
- Rare background includes diboson, triboson, Higgs, and other rare processes

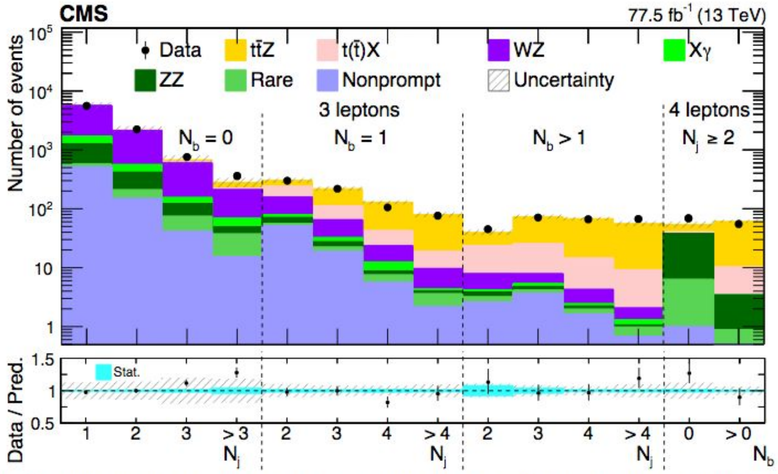


Background composition from data-driven background predictions

TTZ and Rare Background Estimation

ttZ and Rare

- Remaining processes that pass our selection.
- While they have different kinematics, ttZ is irreducible when Z→νν and top quarks decay hadronically
    - Use CMS measurement in 3- and 4-leptons to get TTZ normalization scale factor: **1.21 +/- 0.10**
    - Scale factor multiplied by TTZ cross section to normalize TTZ MC
- Rare background includes diboson, triboson, Higgs, and other rare processes
    - Normalized with theory cross sections



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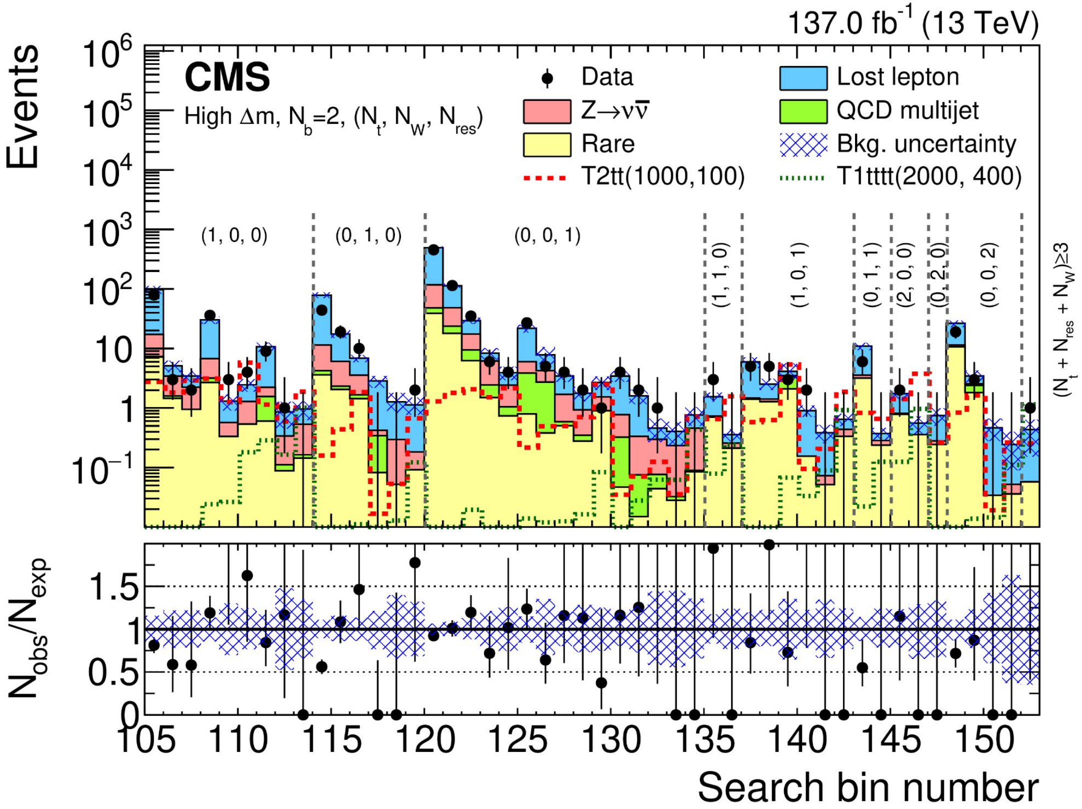
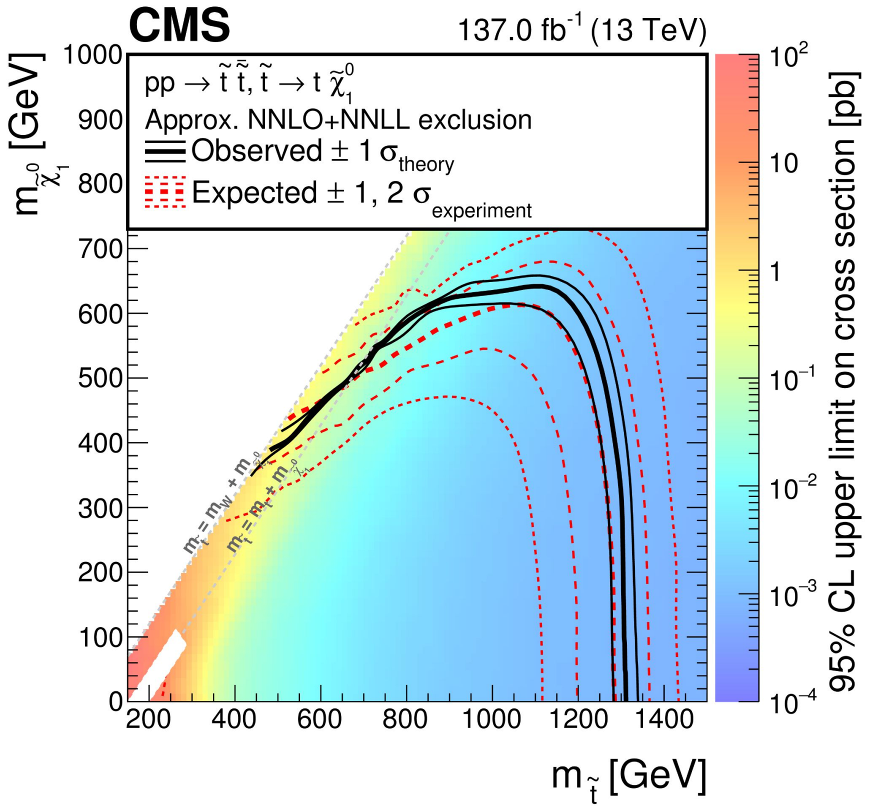
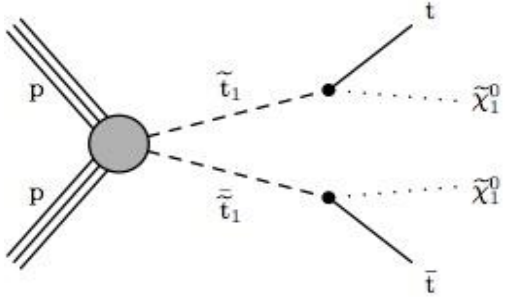
Data vs Prediction HM $N_b = 2, \geq 3$



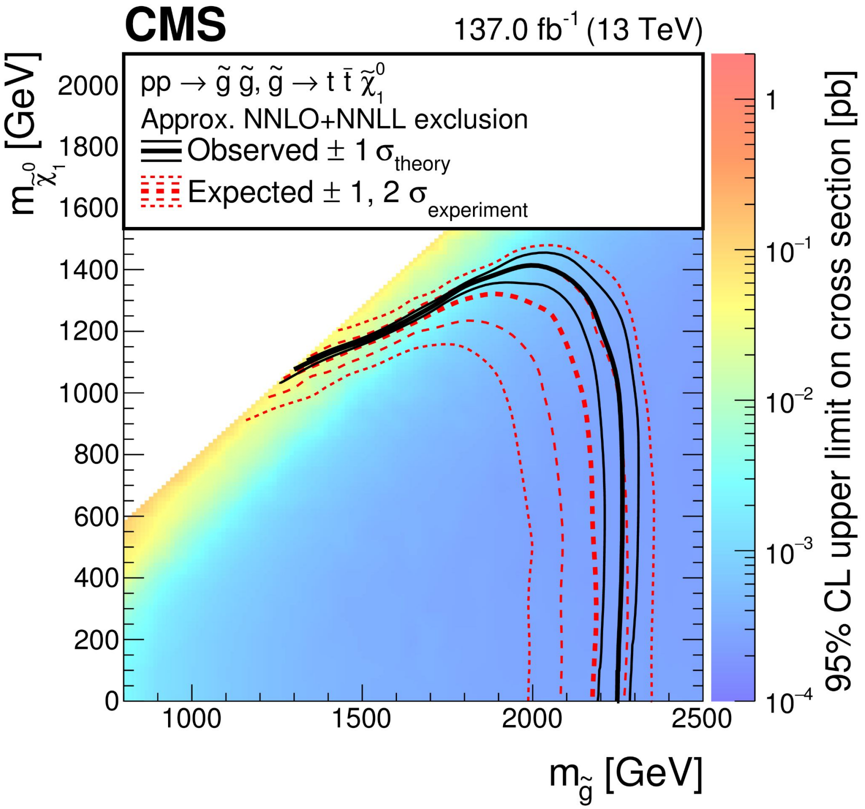
Expected/Observed Limit for T2tt

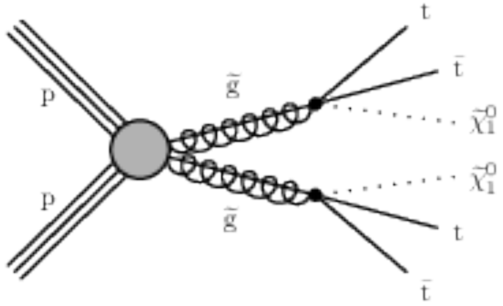




- Direct production model
- Maximum likelihood fit used to calculate limits
- Limit reaches 1.3 TeV on stop mass with small neutralino mass

Expected/Observed Limit for T1tttt

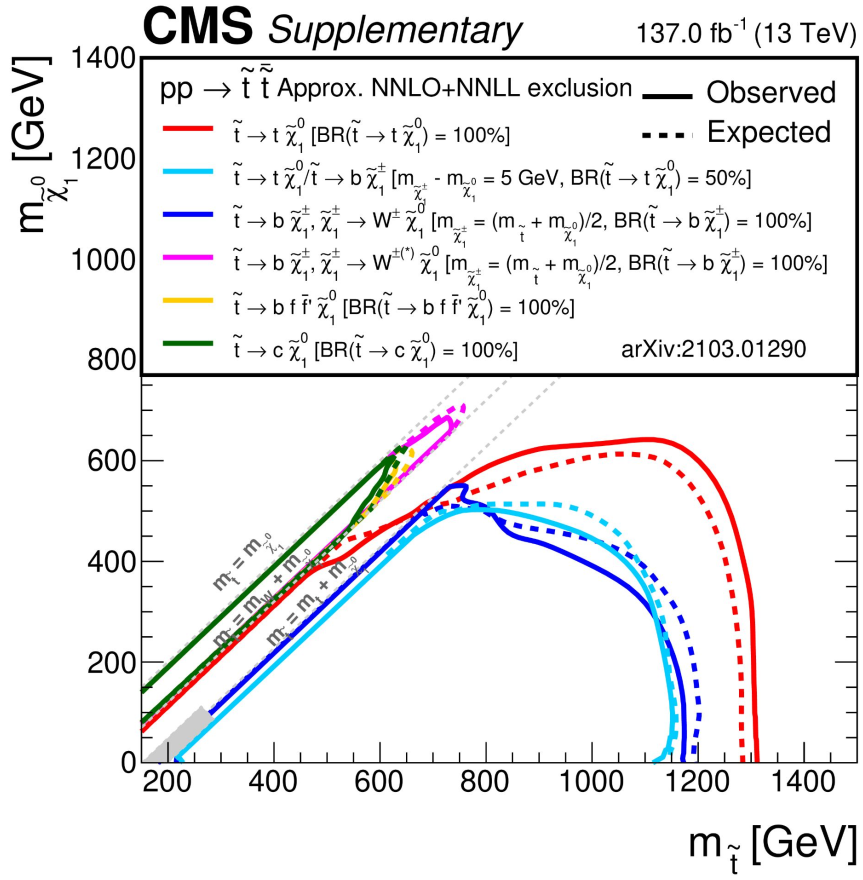




- Gluino-mediated model
- Limit reaches 2.19 TeV on gluino mass with small neutralino mass

Summary

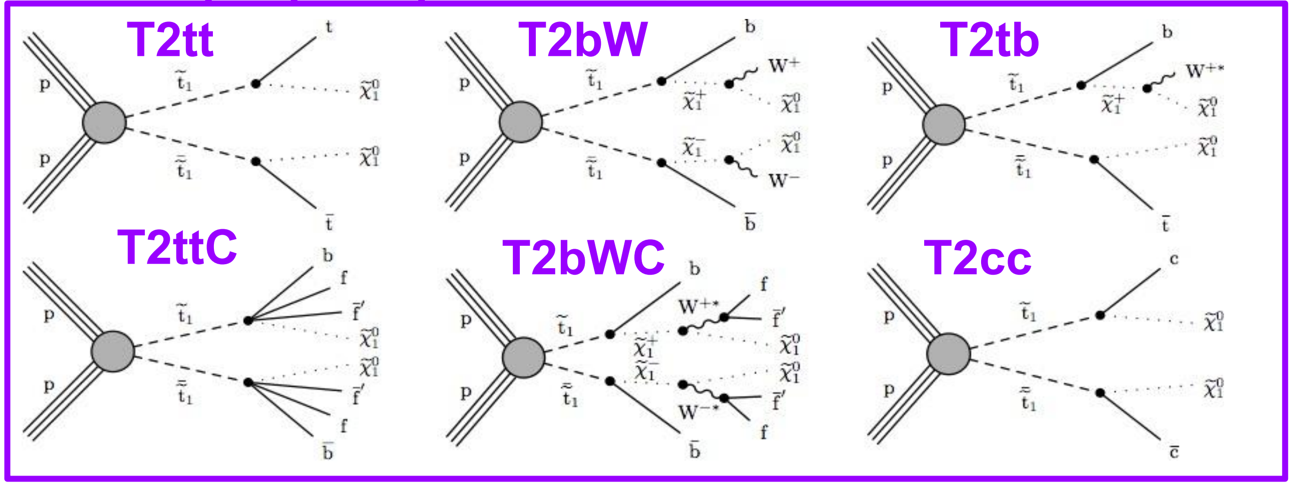
- Searched for direct and gluino-mediated top squark production with Run 2 data (137 fb^{-1})
- The search is based on events with at least two jets and large MET, featuring a top/W tagger as well as a soft-b tagger
- No statistically significant excess of events is observed relative to the SM predictions
  - Stop mass excluded below 1150 to 1310 GeV at minimal neutralino mass, depending on the decay mode
  - Stop mass for compressed models excluded below 630 to 740 GeV, depending on decay mode
  - Gluino mass excluded below 2150 to 2260 GeV, depending on the signal model
- Accepted for publication in Physical Review D



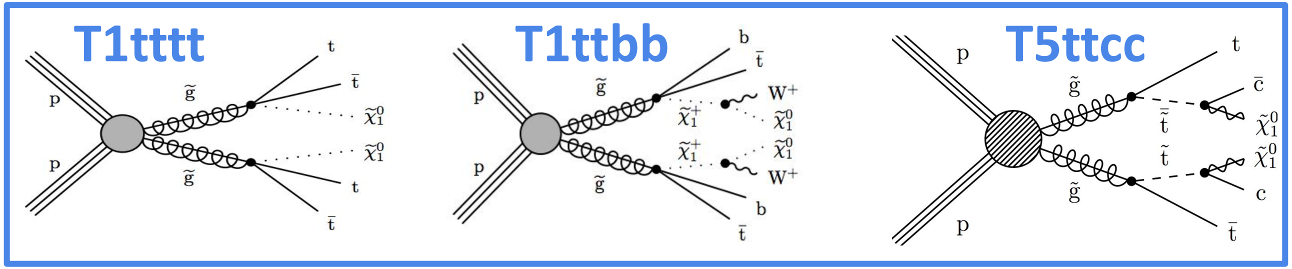
Backup

Simplified SUSY Models

Direct top squark production



Gluino mediated top squark production



Final states contain

- Neutralinos (seen as MET)
- Quarks (tops, bottoms, charms, and others)
- W bosons

Simulated with FastSim

Search Strategy

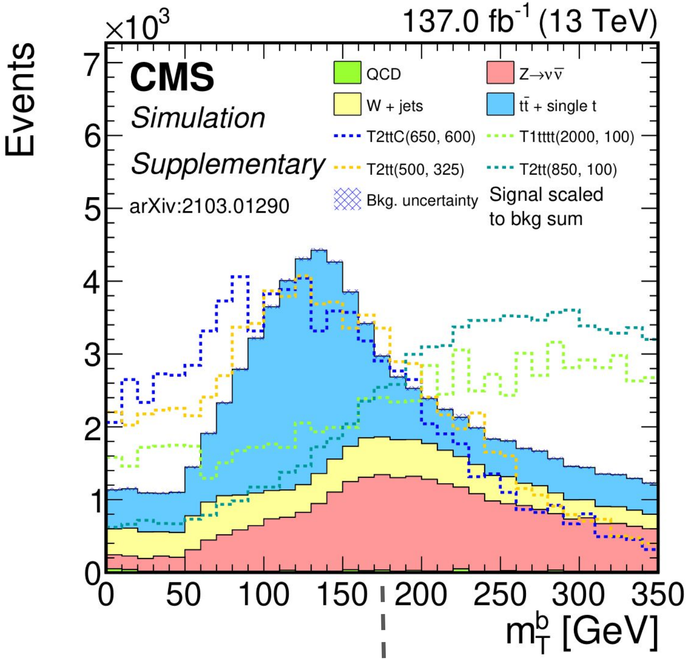
Categorize low Δm and high Δm by m_T^b values

$$M_T(b_{1,2}, \not{E}_T) \equiv \begin{cases} m_T(b, \not{E}_T) & N_b = 1, \\ \mathrm{Min}[m_T(b_1, \not{E}_T), m_T(b_2, \not{E}_T)], & N_b \geq 2, \end{cases}$$

Low Δm

Targeting T2ttC, T2bWC, T2cc and low-Δm T2tt, T2bW, T2tb

$m_T^b < 175$ GeV
Veto Top and W
ISR/soft-b tagging
$N_j \geq 2$
$\Delta\phi(j_1, p_T^{miss}) > 0.5$
$\Delta\phi(j_{2,3}, p_T^{miss}) > 0.15$
$MET/\sqrt{H_T} > 10$



Low m_T^b = top BG enhanced

High m_T^b = top BG depleted

High Δm

Targeting high-Δm T2tt, T2bW, T2tb and gluino-mediated models

$m_T^b > 175$ GeV (*)
Top/W tagging

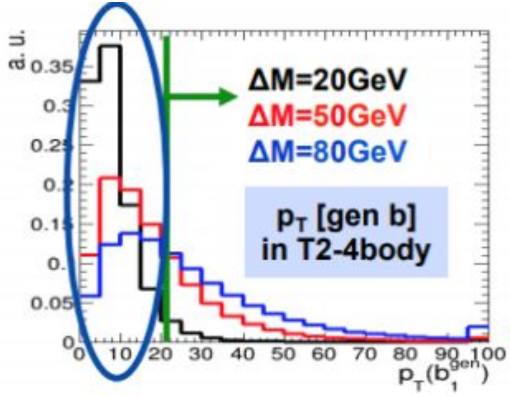
$N_j \geq 5$; $N_b \geq 1$
$\Delta\phi(j_{1,2,3,4}, p_T^{miss}) > 0.5$

* A small subset of the high Δm bins require $m_T^b < 175$ GeV, but also require $N_{res} \geq 1$ and $N_j \geq 7$

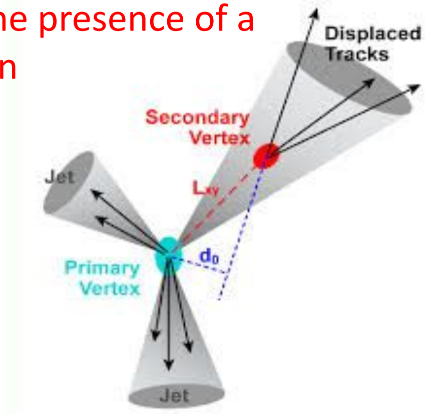
Soft b Tagging

Many SUSY models (e.g. T2ttC, T2bWC) predict soft b quarks, often failing jet p_T threshold for tagging (20 GeV)

- Increase signal acceptance by requiring the presence of a secondary vertex (sv) with below selection



Improvement →



~50% signal efficiency ~5% BKG
Eff: truth-matched IVF to B/D in ttbar
On top of IVF efficiency
BKG: non truth-matched IVF from ttbar/V+Jets

IVF selection

→ |IP2D|<3, SIP3D > 4
→ cos (SV-PV,p) > 0.98
→ N_{trks} > 2
→ ΔR (jet, IVF) >0.4 [orthogonal to any jet]
→ p_T (IVF) < 20 GeV

Inclusive Vertex Finder (IVF) algorithm used

Based on the soft b tagging in SUS-16-049

soft b scale factors measured with data in a soft-muon control region

Soft b SFs:

- 2016: 1.08 ± 0.03
- 2017: 1.05 ± 0.06
- 2018: 1.19 ± 0.06

Background: Transfer-Factor Method

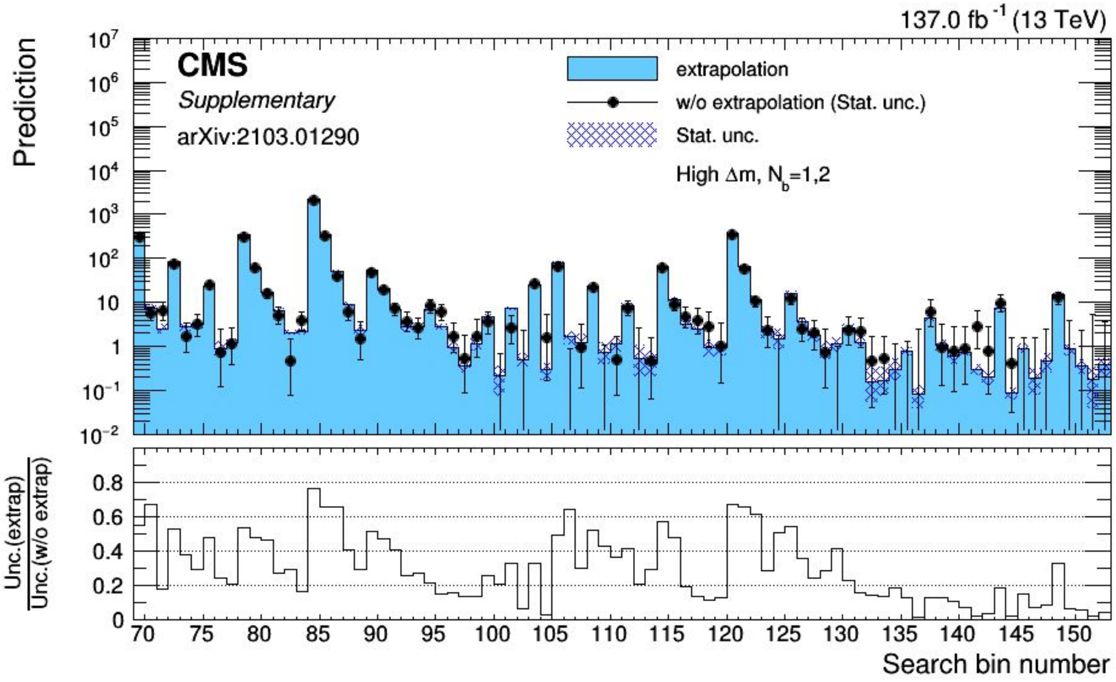
- Control region (CR):
  - Enriched background
  - Depleted signal
- Calculate data in the control region multiplied by Transfer factor (TF).
- Transfer factor: Ratio of MC in the search region over the control region.
- Extrapolation: The CR is not binned in top and W multiplicities, so the high Δm region has an extrapolation factor for these variables.

$$N_{\text{pred}} = N_{\text{data}}^{\text{CR}} \cdot TF$$

$$TF \equiv TF_{\text{CR}\to\text{SR}} \cdot TF_{\text{SR-extrap}}$$

$$= \frac{\text{MC}_{\text{SR}}}{\text{MC}_{\text{CR}}} \cdot \frac{\text{MC}_{\text{SR}}(\text{specific top/W multiplicity})}{\text{MC}_{\text{SR}}}$$

Lost Lepton High Δm Prediction



- TF "extrapolation" method reduces uncertainty
- Trust tagger SFs, measured from data, to get tag multiplicity right
- Much better CR data stats
- Prediction without extrapolation (black dots) only includes statistical uncertainty -- much worse even without systematics

Z Invisible: Normalization (Rz)

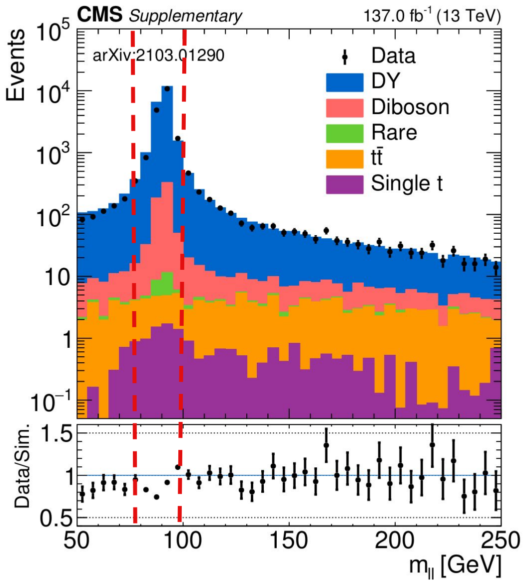
- The normalization R_Z is calculated in the Z to ℓℓ control region.
  - R_Z is calculated for Z to ee and Z to μμ separately, and then averaged
  - Also define R_T as the ratio for non-Z backgrounds.

- To find R_Z:
  - Split dilepton mass distribution into two regions
    - On Z mass integral: ($81 < m_{\ell\ell} < 101$ GeV)
    - Off Z mass integral: ($50 < m_{\ell\ell} < 81$ GeV) and ($m_{\ell\ell} > 101$ GeV)
  - Invert matrix to solve for R_Z and R_T

$$\begin{bmatrix} N^{\mathrm{Data}}_{\mathrm{on-Z}} \\ N^{\mathrm{Data}}_{\mathrm{off-Z}} \end{bmatrix} = \begin{bmatrix} N^{Z\to LL}_{\mathrm{on-Z}} & N^{\mathrm{Other}}_{\mathrm{on-Z}} \\ N^{Z\to LL}_{\mathrm{off-Z}} & N^{\mathrm{Other}}_{\mathrm{off-Z}} \end{bmatrix} \begin{bmatrix} R_Z \\ R_T \end{bmatrix}$$

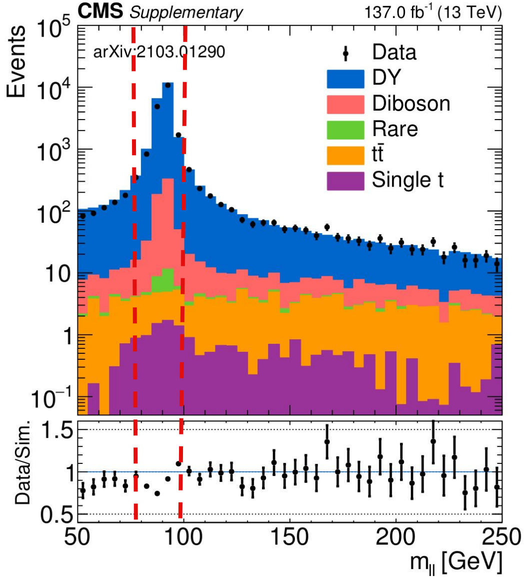
From simulation

Z to ee

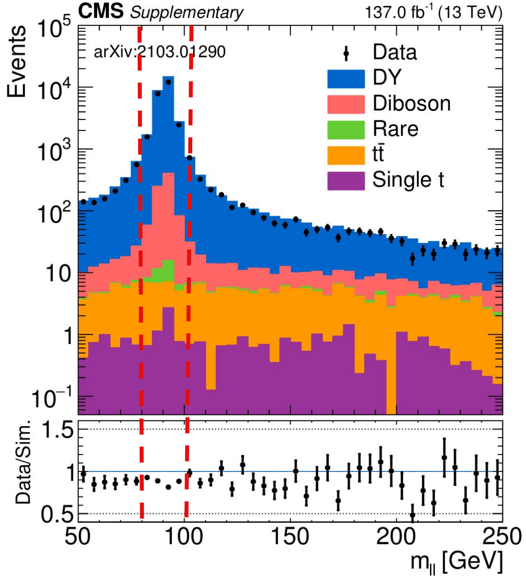


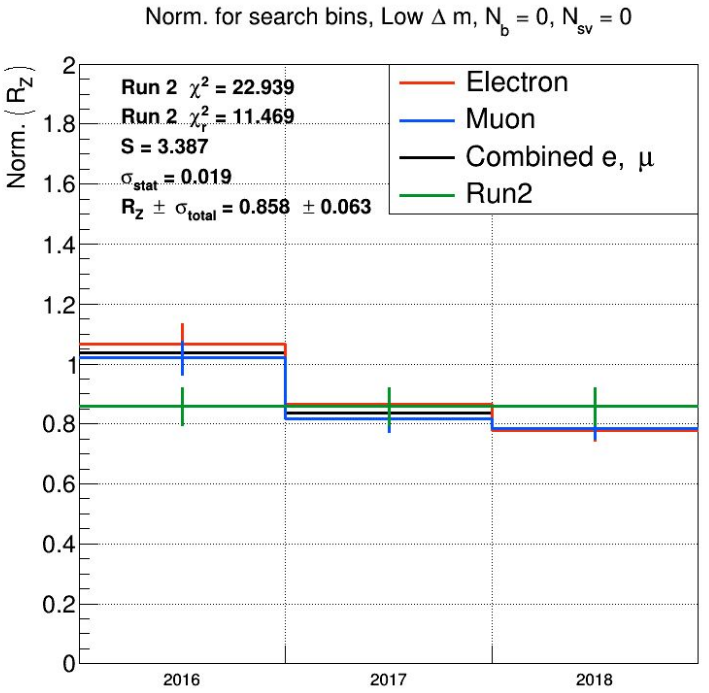
Z Invisible: Normalization (Rz)

Z to ee



Z to μμ





Rz = 0.858 ± 0.063 for low Δm, N_b = 0 and N_{sv} = 0.

Derive systematic uncertainty associated with variation of Rz vs. data-taking years.

Z Invisible: Shape (Sγ)

- The shape factor S_γ is calculated in the photon control region.
  - Normalize MC to data in photon control region (in bins of N_b/N_j).
  - CR (control region) bins are defined using the presence of the photon plus intrinsic MET
    - For the high Δm CR bins have no top/W selection, but use all other search variables
  - Obtain shape factor by Data/MC comparison in each CR bin.
  - Shape factor is fit using nuisance parameters with Higgs Combined.

$$S_\gamma^{\mathrm{low}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, N_{\mathrm{SV}}, p_{\mathrm{T}}^{\mathrm{ISR}}, p_{\mathrm{T}}^{\mathrm{b}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right) = \frac{N^{\mathrm{data}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, N_{\mathrm{SV}}, p_{\mathrm{T}}^{\mathrm{ISR}}, p_{\mathrm{T}}^{\mathrm{b}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right)}{Q \cdot N^{\mathrm{MC}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, N_{\mathrm{SV}}, p_{\mathrm{T}}^{\mathrm{ISR}}, p_{\mathrm{T}}^{\mathrm{b}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right)}$$

$$S_\gamma^{\mathrm{high}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, m_{\mathrm{T}}^{\mathrm{b}}, H_{\mathrm{T}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right) = \frac{N^{\mathrm{data}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, m_{\mathrm{T}}^{\mathrm{b}}, H_{\mathrm{T}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right)}{Q \cdot N^{\mathrm{MC}}\left(N_{\mathrm{j}}, N_{\mathrm{b}}, m_{\mathrm{T}}^{\mathrm{b}}, H_{\mathrm{T}}, p_{\mathrm{T}}^{\mathrm{miss}(\gamma)}\right)}$$

Shape factors

$$Q\left(N_{\mathrm{b}}, N_{\mathrm{j}}\right) = \frac{N^{\mathrm{data}}\left(N_{\mathrm{b}}, N_{\mathrm{j}}\right)}{N^{\mathrm{MC}}\left(N_{\mathrm{b}}, N_{\mathrm{j}}\right)}$$

Data/MC normalization

Z Invisible: Z vs. Photon Systematic

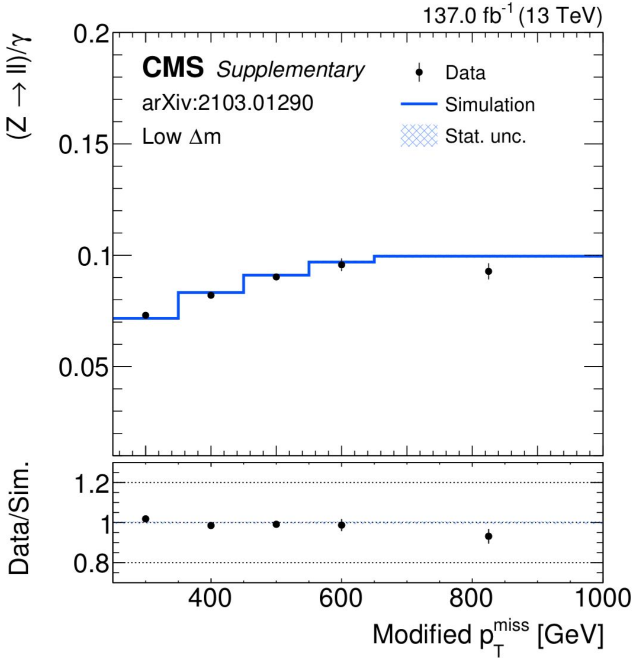
Since photon data and MC are used to predict Z to neutrinos, it is important to confirm that photon and Z data and MC are similar. In each CR, MC is normalized to data. Note that the photon CR has better statistics than the Z CR.

Upper panels: (Z->ll)/γ data (**black**) and MC (**blue**) ratios.

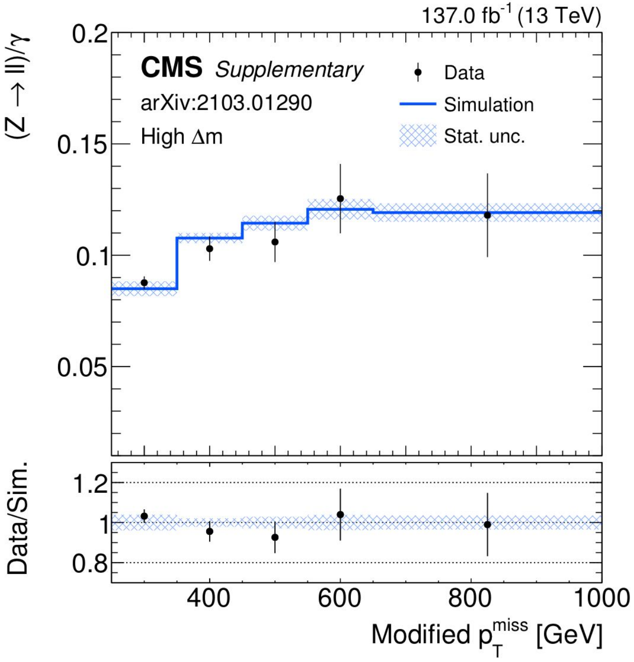
Lower panels: (Z->ll)/γ data/MC "double ratio."

Assign small differences seen in the (Z->ll)/γ double ratio as a systematic uncertainty.

Low Δm selection



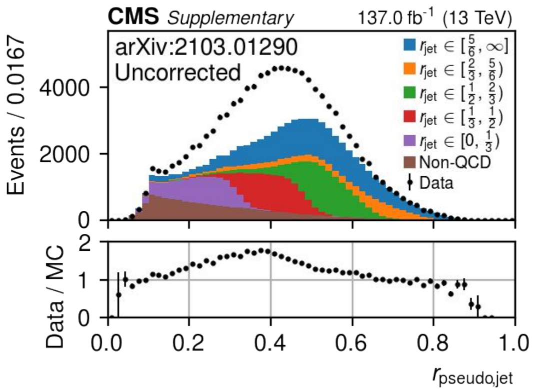
High Δm selection

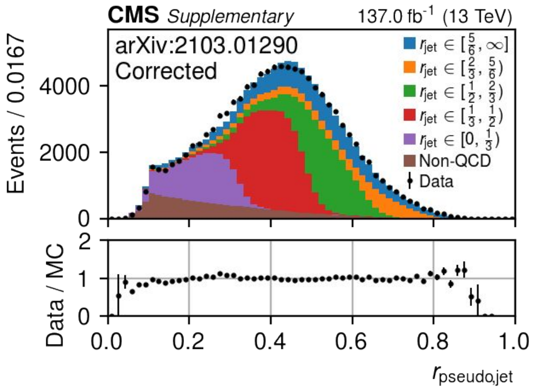


QCD Background Estimation

QCD

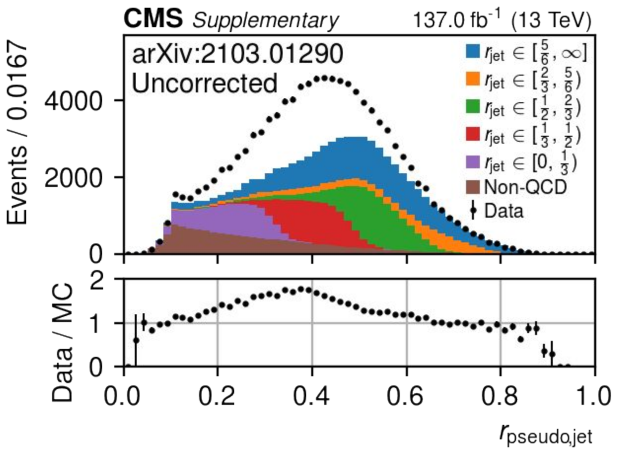
- Events in which fake missing transverse energy is present due to jet energy mismeasurement.
- Control region for transfer factor method is defined to have a leading jet aligned with MET
- Smear QCD MC to improve stats
  - Smear two leading gen jets
  - Small window around jet response
- Apply jet response correction
  - MC is known to underestimate the width of the jet-energy response function
  - Further exacerbated by smearing

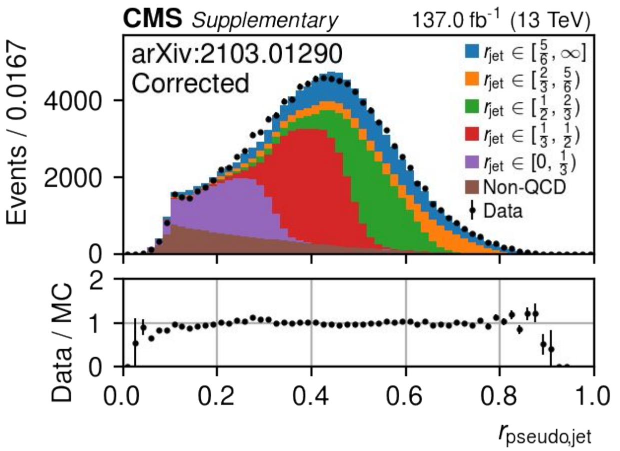


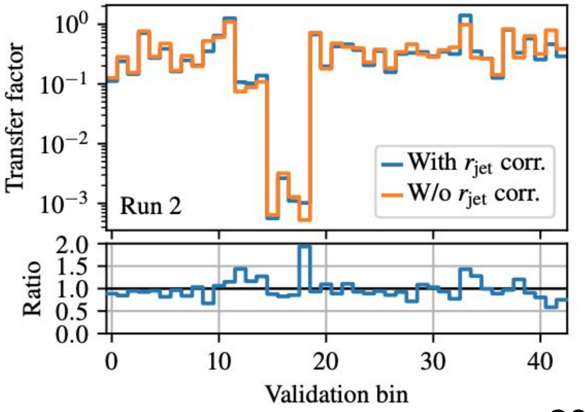


QCD Jet-Response Correction

- After smearing, correct jet response in smeared QCD MC
- In the QCD CR:
  - Choose the jet in each event most closely aligned to the MET
  - Bin MC in p_T(reco)/p_T(gen) to make five templates w/ bin edges: [0, ⅓, ½, ⅔, ⅚, ∞]
  - Fit to data as a function of p_T(reco)/[p_T(reco) + MET], a proxy for the jet response
- Apply resulting scale factors to smeared QCD MC in both SR and CR
- Effects on transfer factor are not huge -- mostly cancels in ratio







Signal Distributions and Systematics

- Systematics include (typical values):
  - MC statistics (up to 100%)
  - Integrated luminosity (1.8%)
  - JEC (up to 26%)
  - MET resolution (up to 12%)
  - MET trigger efficiency (<1%)
  - Pileup weight (up to 15%)
  - Lepton veto efficiency (up to 10%)
  - b tagging efficiency (up to 14%)
  - Soft b tagging efficiency (up to 5%)
  - Merged top & W tagging efficiency (up to 17%)
  - Resolved top tagging efficiency (up to 20%)
  - Renormalization and factorization scale uncertainties (up to 7%)
  - ISR signal uncertainty (up to 37%)
  - Fastsim MET uncertainty (up to 40%)

Baseline Selection

General Idea

- Search trigger: HLT_PFMETx_PFMHTx(_HT60)
- Two or more jets
- Large MET
- Large H_T
- Veto charged leptons
- HEM veto for 2018
- Top/W tagging
- b-tagging (jet p_T>20 GeV)
- Soft b-tagging
- Applying PUWeights, BtagWeights, ISRWeights (2016 ttbar), PreFireWeights (2016/2017) and top p_T reweighting (ttbar) for all backgrounds

Baseline selection	
Jets	$N_j \geq 2$: $R = 0.4$, $p_T > 30\,\text{GeV}$, $\lvert\eta\rvert < 2.4$
H_T	$H_T > 300\,\text{GeV}$
p_T^{miss}	$p_T^{miss} > 250\,\text{GeV}$ $\Delta\phi\left(\vec{p}_T^{miss}, j_1\right) > 0.5$ $\Delta\phi\left(\vec{p}_T^{miss}, j_2\right) > 0.15$ $\Delta\phi\left(\vec{p}_T^{miss}, j_3\right) > 0.15$ (when applicable)
Veto electron	$p_T > 5\,\text{GeV}$, $\lvert\eta\rvert < 2.5$, $p_T^{sum} < 0.1\,p_T$
Veto muon	$p_T > 5\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $p_T^{sum} < 0.2\,p_T$
Veto τ_h	$p_T > 20\,\text{GeV}$, $\lvert\eta\rvert < 2.4$, $m_T < 100\,\text{GeV}$
Veto track	PF charged candidates, $\lvert\eta\rvert < 2.5$, $m_T < 100\,\text{GeV}$ $p_T > 5\,\text{GeV}$, $p_T^{sum} < 0.2\,p_T$ for electron and muon tracks $p_T > 10\,\text{GeV}$, $p_T^{sum} < 0.1\,p_T$ for charged hadron tracks

Baseline Selection

- Trigger: HLT_PFMETx_PFMHTx(_HT60)
- Lepton Selection
  - Veto ID electron: $p_T > 5$ GeV, $|\eta| < 2.5$, miniISO < 0.1
  - Loose muon: $p_T > 5$ GeV, $|\eta| < 2.4$, miniISO < 0.2
  - Isotrack: cut-based charged PF candidates
  - Tau: $p_T > 20$ GeV, $|\eta| < 2.4$, medium ID
- N_j ($p_T > 30$ GeV) ≥ 2, $|\eta| < 2.4$
- $\Delta\varphi(j_1,MET) > 0.5$, $\Delta\varphi(j_{23},MET) > 0.15$
- MET > 250 GeV
- $H_T > 300$ GeV
- HEM Veto: $\eta[-3.2, -1.2]$, $\varphi[-1.77, -0.67]$, $p_T > 30$ GeV
- Bjets: deepCSV medium working point, $p_T > 20$ GeV
- Top/W: deepAK8 (0.5%(1%) mistag WP for t(W) from JMAR)
  - Softdrop mass requirements: $65 < M_{SD}(W) < 105$ GeV, $M_{SD}(top) > 105$ GeV
- Deep resolved top (2% mistag WP)
- Applying PUWeights, BtagWeights, ISRWeights (2016 ttbar), PreFireWeights (2016/2017) and top p_T reweighting (ttbar) for all backgrounds

General idea

- at least 2 jets
- large MET
- 0 charged leptons
- top/W/b tagging

Baseline Selection

Baseline selection	
Jets	$N_j \geq 2$: $R = 0.4$, $p_T > 30\,\text{GeV}$, $\|\eta\| < 2.4$
H_T	$H_T > 300\,\text{GeV}$
p_T^{miss}	$p_T^{miss} > 250\,\text{GeV}$ $\Delta\phi(\vec{p}_T^{miss}, j_1) > 0.5$ $\Delta\phi(\vec{p}_T^{miss}, j_2) > 0.15$ $\Delta\phi(\vec{p}_T^{miss}, j_3) > 0.15$ (when applicable)
Veto electron	$p_T > 5\,\text{GeV}$, $\|\eta\| < 2.5$, $p_T^{sum} < 0.1\,p_T$
Veto muon	$p_T > 5\,\text{GeV}$, $\|\eta\| < 2.4$, $p_T^{sum} < 0.2\,p_T$
Veto τ_h	$p_T > 20\,\text{GeV}$, $\|\eta\| < 2.4$, $m_T < 100\,\text{GeV}$
Veto track	PF charged candidates, $\|\eta\| < 2.5$, $m_T < 100\,\text{GeV}$ $p_T > 5\,\text{GeV}$, $p_T^{sum} < 0.2\,p_T$ for electron and muon tracks $p_T > 10\,\text{GeV}$, $p_T^{sum} < 0.1\,p_T$ for charged hadron tracks
Low Δm baseline selection	
N_t, N_W, N_{res}	$N_t = N_W = N_{res} = 0$
m_T^b	$m_T^b < 175\,\text{GeV}$ (for events with $N_b \geq 1$)
ISR jet	$N_j(\text{ISR}) = 1$: $R = 0.8$, $p_T^{ISR} > 200\,\text{GeV}$, $\|\eta\| < 2.4$ $\Delta\phi(\vec{p}_T^{miss}, j_{ISR}) > 2$
p_T^{miss}	$p_T^{miss} / \sqrt{H_T} > 10\,\sqrt{\text{GeV}}$
High Δm baseline selection	
Jets	$N_j \geq 5$: $R = 0.4$, $p_T > 30\,\text{GeV}$, $\|\eta\| < 2.4$
b-tagging	$N_b \geq 1$
p_T^{miss}	$\Delta\phi(\vec{p}_T^{miss}, j_{1,2,3,4}) > 0.5$

High Δm Search Bins

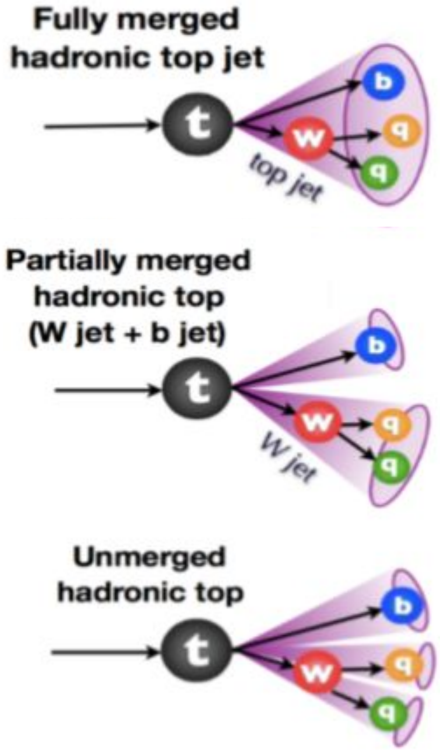
Search bins: 130 high Δm bins

- Low m_T^b search bins with at least one resolved top are for signals with medium Δm
- High m_T^b search bins are binned in N_b, N_t, N_W, and N_{res} to target models with varying numbers of b, tops and W bosons
- Search bins are further binned in MET (and HT) for broad range of potential SUSY mass spectra

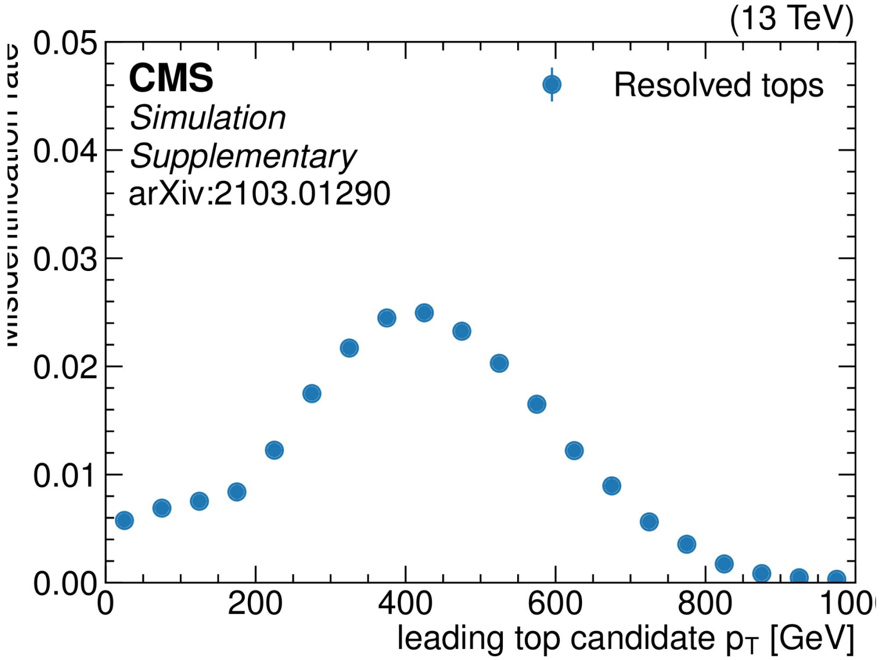
m_T^b [GeV]	N_j	N_b	N_t	N_W	N_{res}	H_T [GeV]	p_T^{miss} [GeV]	Bin number
<175	≥7	1	≥0	≥0	≥1	>300	[250, 300, 400, 500, ∞]	53–56
<175	≥7	≥2	≥0	≥0	≥1	>300	[250, 300, 400, 500, ∞]	57–60
>175	≥5	1	0	0	0	>1000	[250, 350, 450, 550, ∞]	61–64
>175	≥5	≥2	0	0	0	>1000	[250, 350, 450, 550, ∞]	65–68
>175	≥5	1	≥1	0	0	300–1000	[250, 550, 650, ∞]	69–71
>175	≥5	1	≥1	0	0	1000–1500	[250, 550, 650, ∞]	72–74
>175	≥5	1	≥1	0	0	>1500	[250, 550, 650, ∞]	75–77
>175	≥5	1	0	≥1	0	300–1300	[250, 350, 450, ∞]	78–80
>175	≥5	1	0	≥1	0	>1300	[250, 350, 450, ∞]	81–83
>175	≥5	1	0	0	≥1	300–1000	[250, 350, 450, 550, 650, ∞]	84–88
>175	≥5	1	0	0	≥1	1000–1500	[250, 350, 450, 550, 650, ∞]	89–93
>175	≥5	1	0	0	≥1	>1500	[250, 350, 450, 550, 650, ∞]	94–98
>175	≥5	1	≥1	≥1	0	>300	[250, 550, ∞]	99–100
>175	≥5	1	≥1	0	≥1	>300	[250, 550, ∞]	101–102
>175	≥5	1	0	≥1	≥1	>300	[250, 550, ∞]	103–104
>175	≥5	2	1	0	0	300–1000	[250, 550, 650, ∞]	105–107
>175	≥5	2	1	0	0	1000–1500	[250, 550, 650, ∞]	108–110
>175	≥5	2	1	0	0	>1500	[250, 550, 650, ∞]	111–113
>175	≥5	2	0	1	0	300–1300	[250, 350, 450, ∞]	114–116
>175	≥5	2	0	1	0	>1300	[250, 350, 450, ∞]	117–119
>175	≥5	2	0	0	1	300–1000	[250, 350, 450, 550, 650, ∞]	120–124
>175	≥5	2	0	0	1	1000–1500	[250, 350, 450, 550, 650, ∞]	125–129
>175	≥5	2	0	0	1	>1500	[250, 350, 450, 550, 650, ∞]	130–134
>175	≥5	2	1	1	0	>300	[250, 550, ∞]	135–136
>175	≥5	2	1	0	1	300–1300	[250, 350, 450, ∞]	137–139
>175	≥5	2	1	0	1	>1300	[250, 350, 450, ∞]	140–142
>175	≥5	2	0	1	1	>300	[250, 550, ∞]	143–144
>175	≥5	2	2	0	0	>300	[250, 450, ∞]	145–146
>175	≥5	2	0	2	0	>300	>250	147
>175	≥5	2	0	0	2	300–1300	[250, 450, ∞]	148–149
>175	≥5	2	0	0	2	>1300	[250, 450, ∞]	150–151
>175	≥5	2	$N_t + N_W + N_{res} \geq 3$			>300	>250	152
>175	≥5	≥3	1	0	0	300–1000	[250, 350, 550, ∞]	153–155
>175	≥5	≥3	1	0	0	1000–1500	[250, 350, 550, ∞]	156–158
>175	≥5	≥3	1	0	0	>1500	[250, 350, 550, ∞]	159–161
>175	≥5	≥3	0	1	0	>300	[250, 350, 550, ∞]	162–164
>175	≥5	≥3	0	0	1	300–1000	[250, 350, 550, ∞]	165–167
>175	≥5	≥3	0	0	1	1000–1500	[250, 350, 550, ∞]	168–170
>175	≥5	≥3	0	0	1	>1500	[250, 350, 550, ∞]	171–173
>175	≥5	≥3	1	1	0	>300	>250	174
>175	≥5	≥3	1	0	1	>300	[250, 350, ∞]	175–176
>175	≥5	≥3	0	1	1	>300	>250	177
>175	≥5	≥3	2	0	0	>300	>250	178
>175	≥5	≥3	0	2	0	>300	>250	179
>175	≥5	≥3	0	0	2	>300	[250, 350, ∞]	180–181
>175	≥5	≥3	$N_t + N_W + N_{res} \geq 3$			>300	>250	182

Top/W Tagging

- Top/W taggers are a defining feature of this analysis
- Continuing strategy of previous stop searches using combination of merged top/W with resolved top tagger to cover full range of top p_T
- Merged top/W: DeepAK8 @ 0.5%(1%) top(W) fake rate WP
  - Covers high-p_T top/W using AK8 jets
  - Uses deep NN to discriminate Top/W from background, large improvement over Nsubjettiness variables
- Resolved top: DeepResolved @ 2% fake rate WP
  - Covers low-p_T tops using combinations of AK4 jets
  - Uses NN to improve discrimination over BDT based taggers employed in previous searches [AN-2018/273]
  - DeepResolved candidates with AK4 jets overlapping with DeepAK8 tagger are discarded

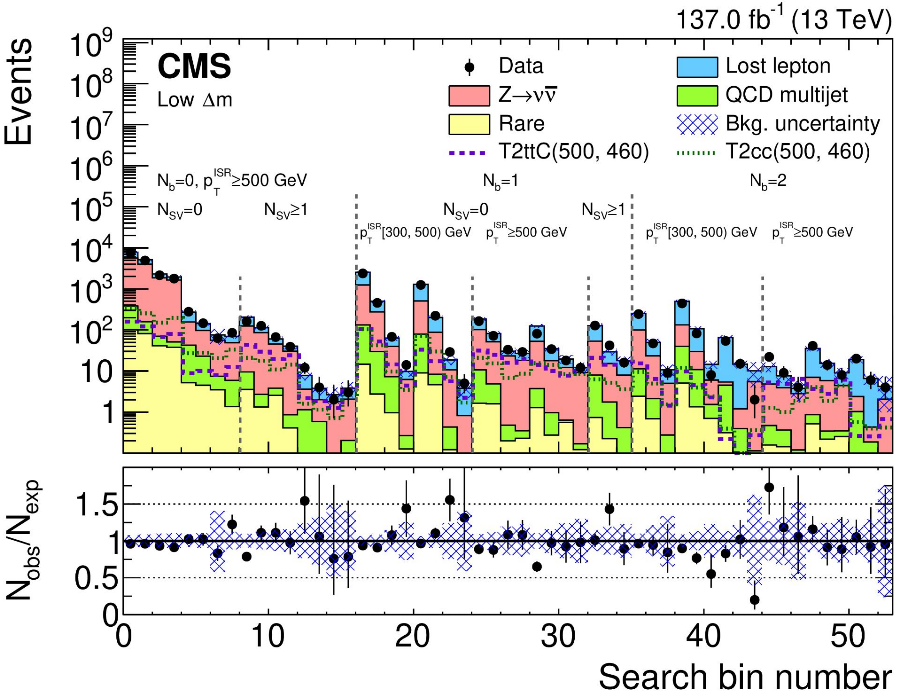


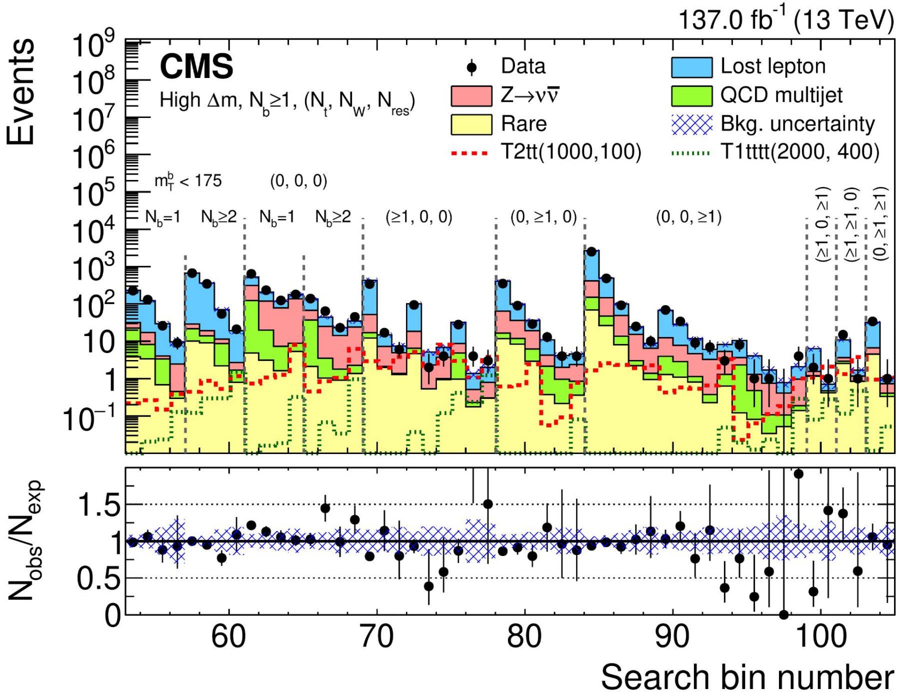
Top Tagging mistag rate



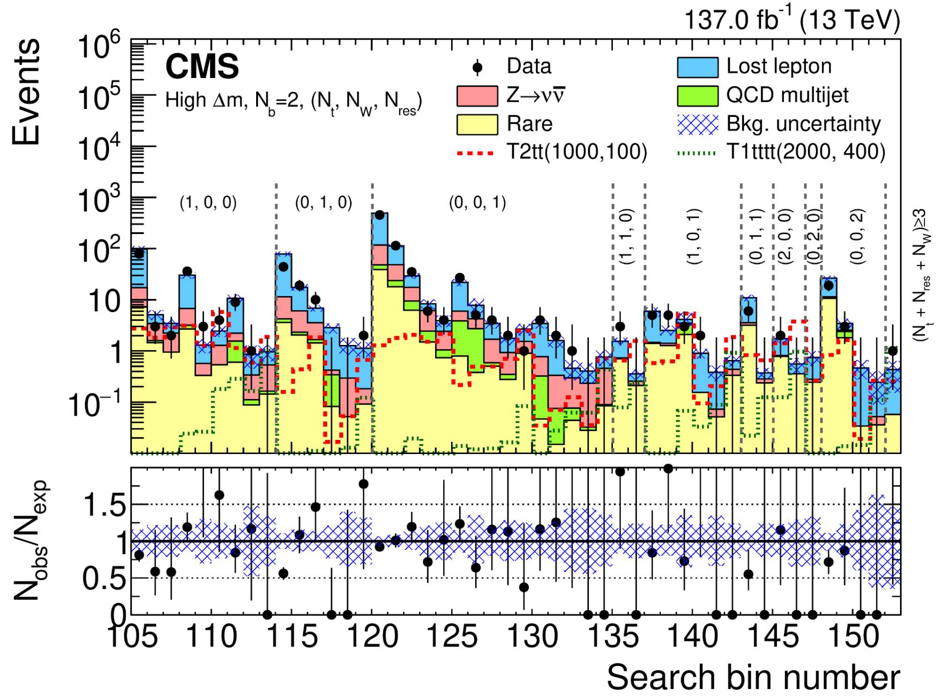
Misidentification rate for the DeepResolved top tagger is shown as a function of leading pT top candidate. Here a top candidate is defined as a trijet combination which passes the preselection on trijet mass, (100 to 250 GeV), the maximum angle (no jet is farther than 3.14 from the trijet centroid in dR), and the three jets must pass a pt> 40, 30, 20 GeV pt respectively. In addition the selected candidate must remain after the cross-cleaning process to remove overlaps with tagged AK8 jets and other trijet candidates with lower MVA scores. The highest pT candidate left after this selection is then selected as the top candidate for the event. The misidentification rate is calculated in a QCD simulation sample with a requirement of at least 300 GeV of Ht. The misidentification rate is then defined as the fraction of the potential candidates which pass the NN discriminator cut of 0.92.

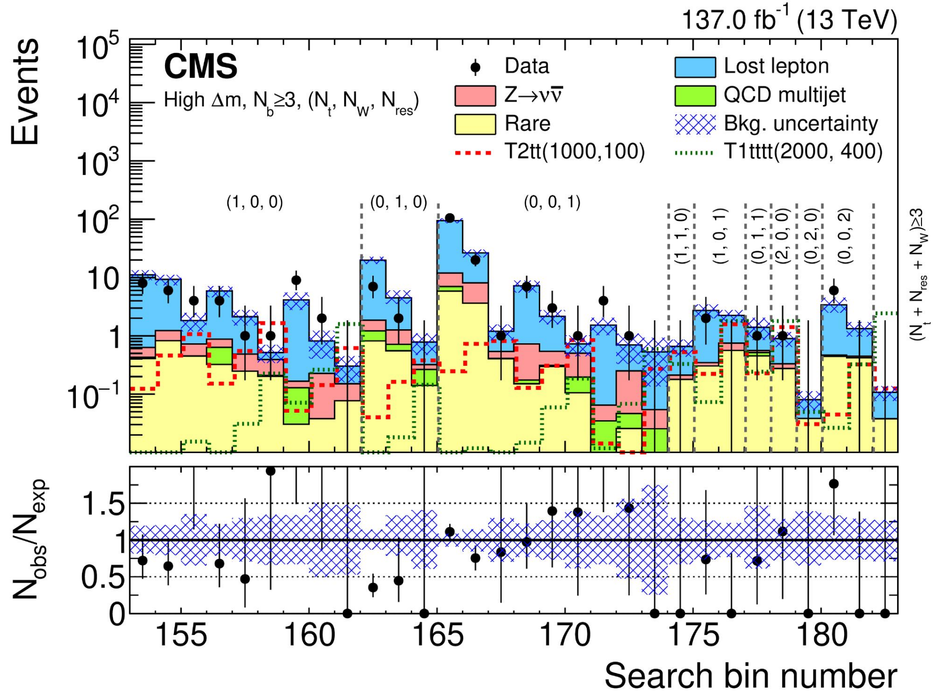
Data vs Prediction LM and HM $N_b = 1, \geq 2$



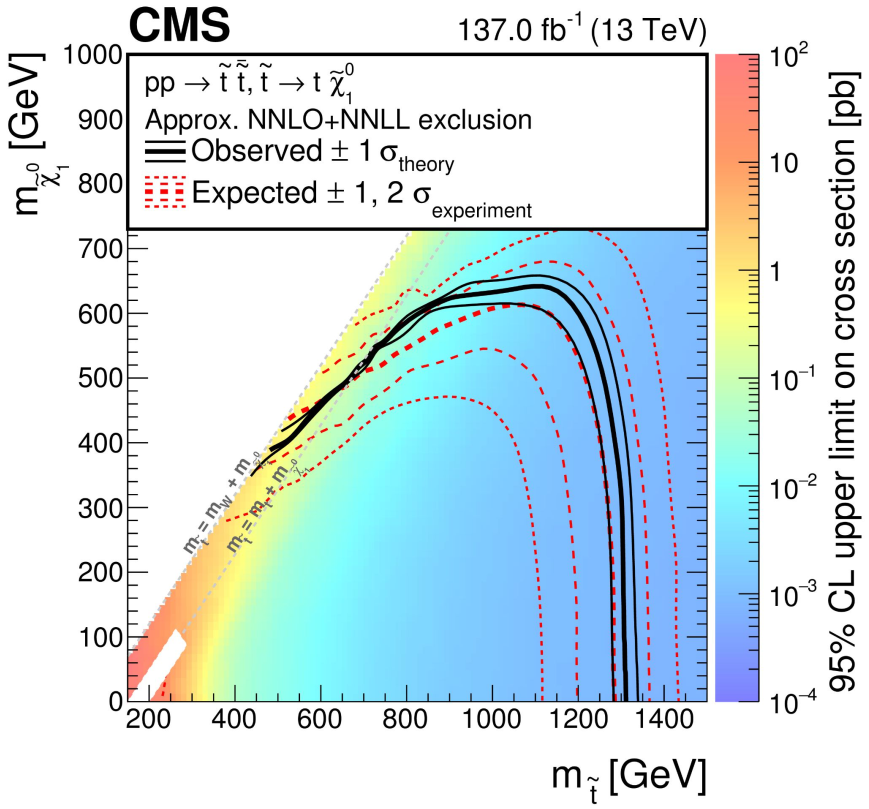


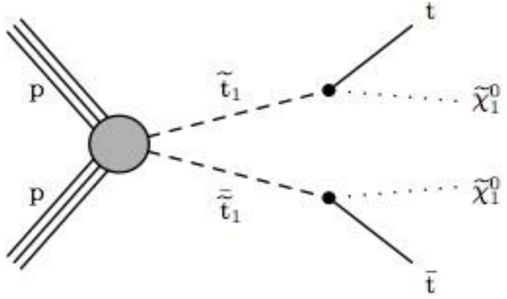
Data vs Prediction HM $N_b = 2, \geq 3$





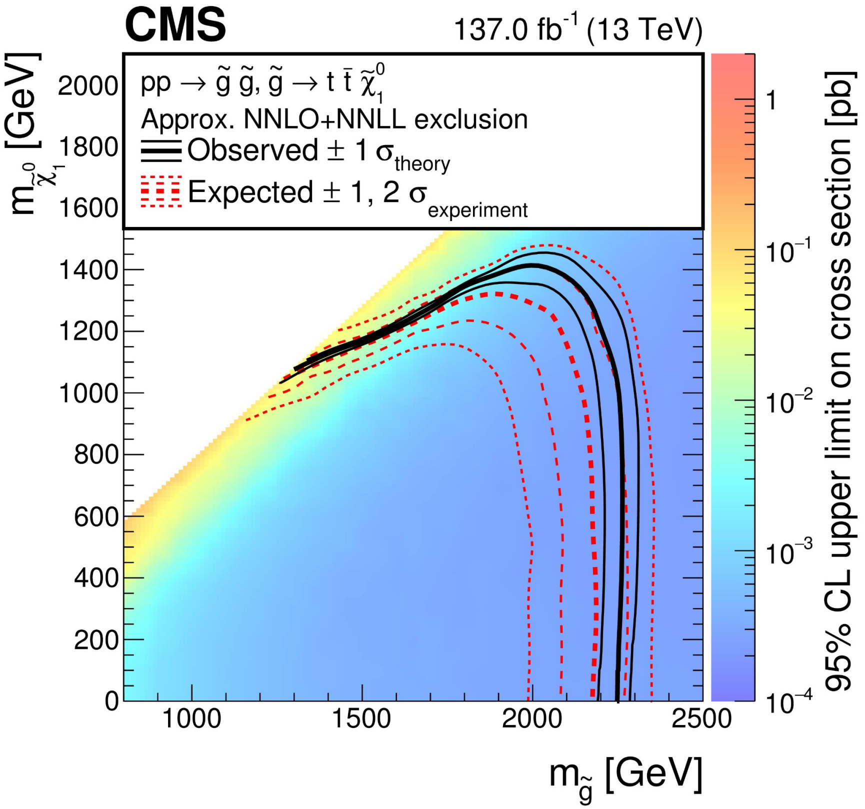
Expected/Observed Limit for T2tt

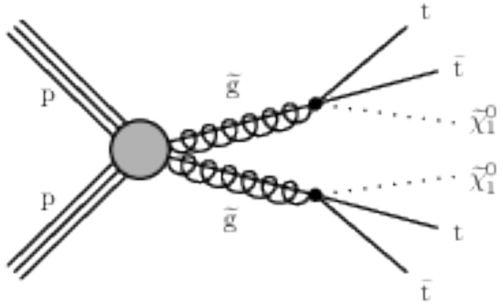




- Direct production model
- Maximum likelihood fit used to calculate limits
- Limit reaches 1.3 TeV on stop mass with small neutralino mass
  - Extended from 1120 GeV at low LSP (expected limit, SUS-16-049/050)

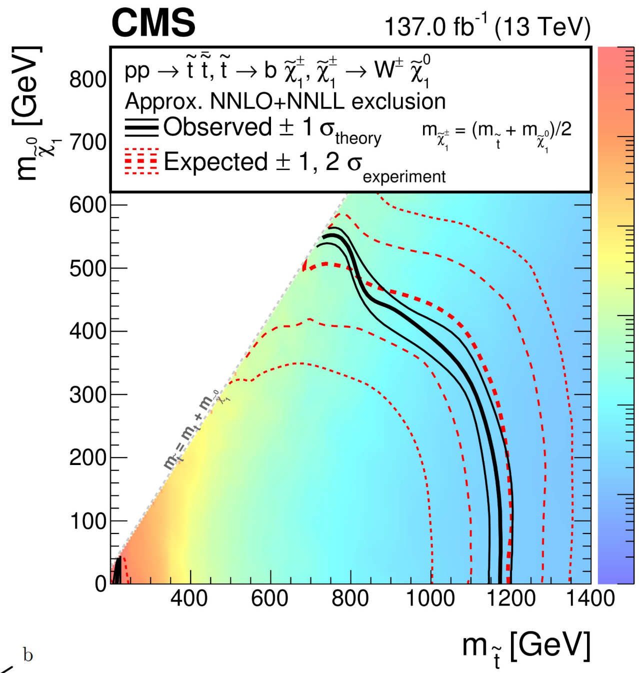
Expected/Observed Limit for T1tttt

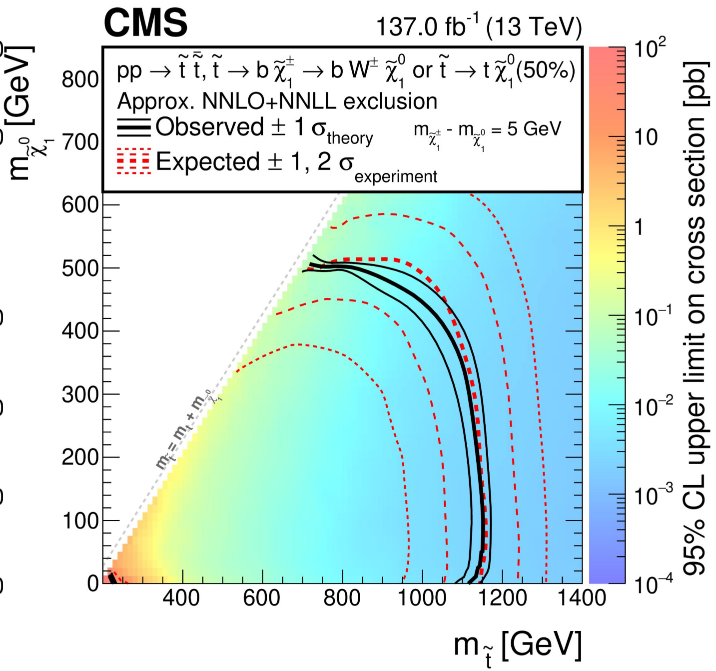


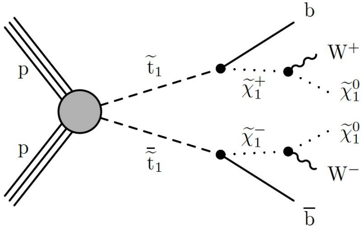


- Gluino-mediated model
- Limit reaches 2.19 TeV on gluino mass with small neutralino mass
  - Extended from 2020 GeV (T1tttt) at low LSP (expected limit, SUS-16-050)

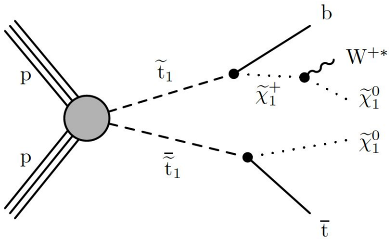
Expected/Observed Limits for T2bW, T2tb



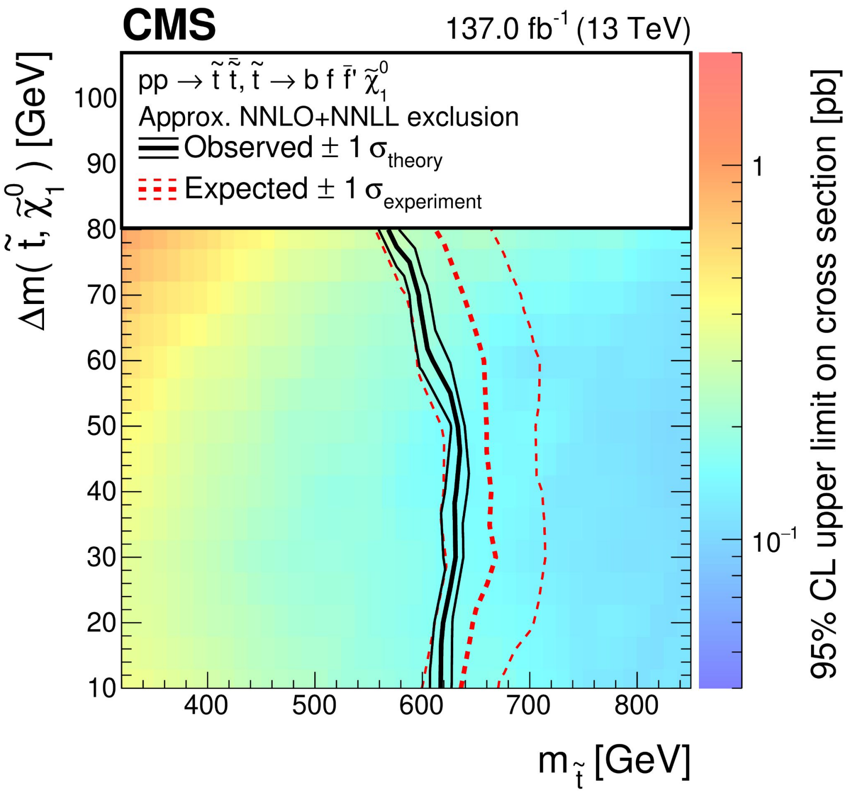


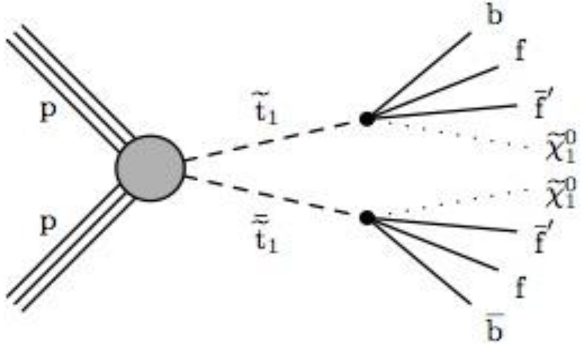


High stop mass limit extended from 850 GeV (T2bW) & 970 GeV (T2tb) respectively (expected limits, SUS-16-049)



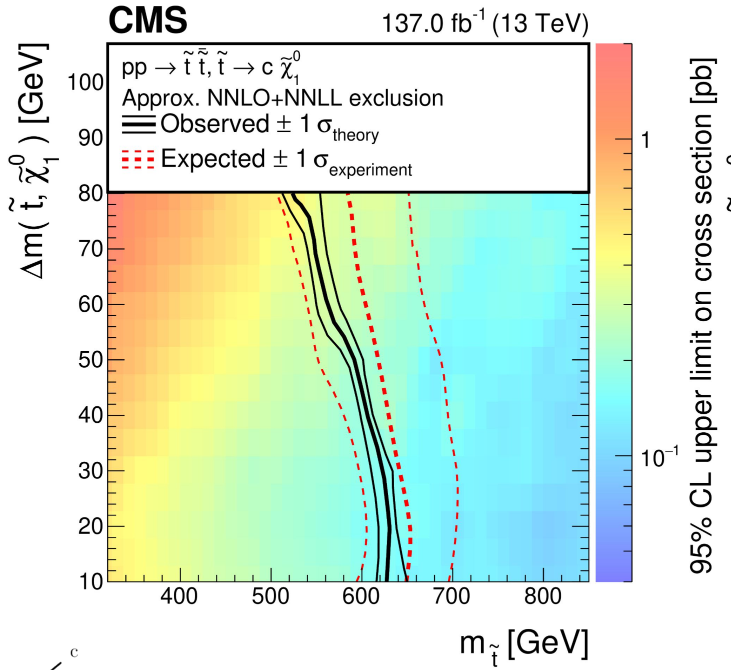
Expected/Observed Limit for T2ttC

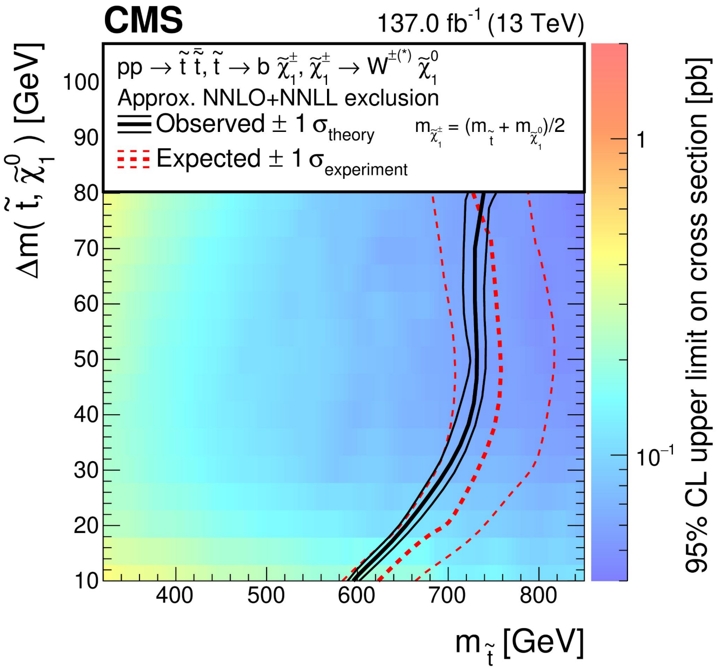


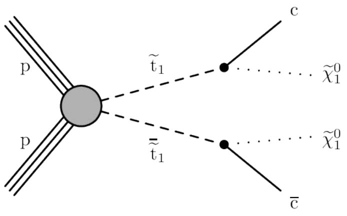


- High stop mass limit extended from 575 GeV (expected limit, SUS-16-049).

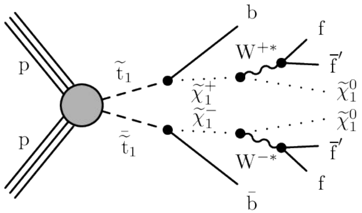
Expected/Observed Limits for T2cc, T2bWC



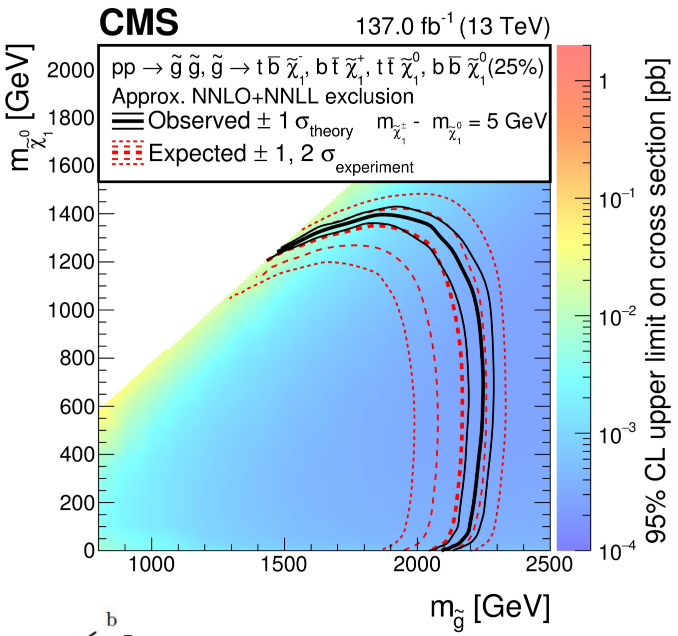


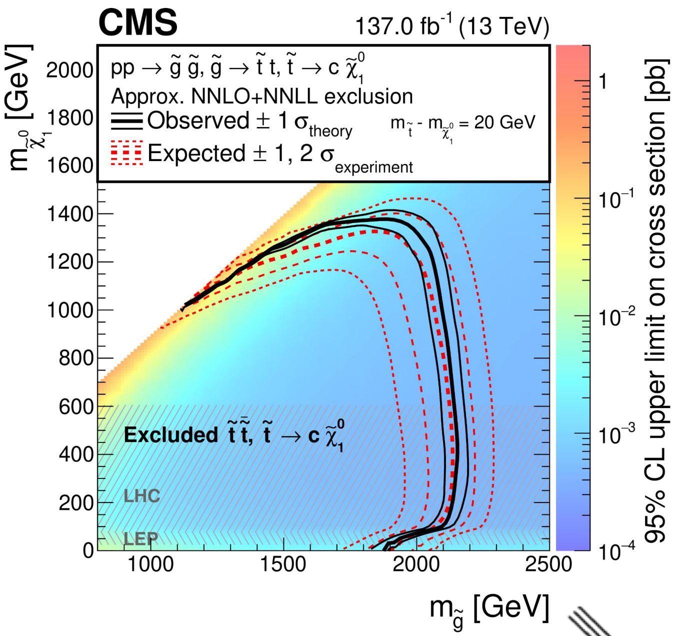


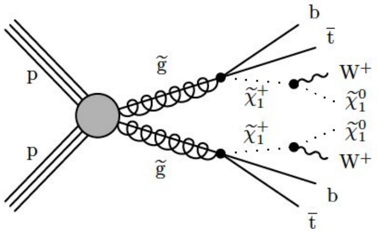
High stop mass limit extended from 530 GeV (T2cc) & 650 GeV (T2bWC) respectively (expected limits, SUS-16-049)



Expected/Observed Limits for T1ttbb, T5ttcc







High gluino mass limit extended from 1950 GeV (T1ttbb) & 1940 GeV (T5ttcc) (expected limits, SUS-16-050)