Search for direct stop pair production in the fully hadronic final state at CMS

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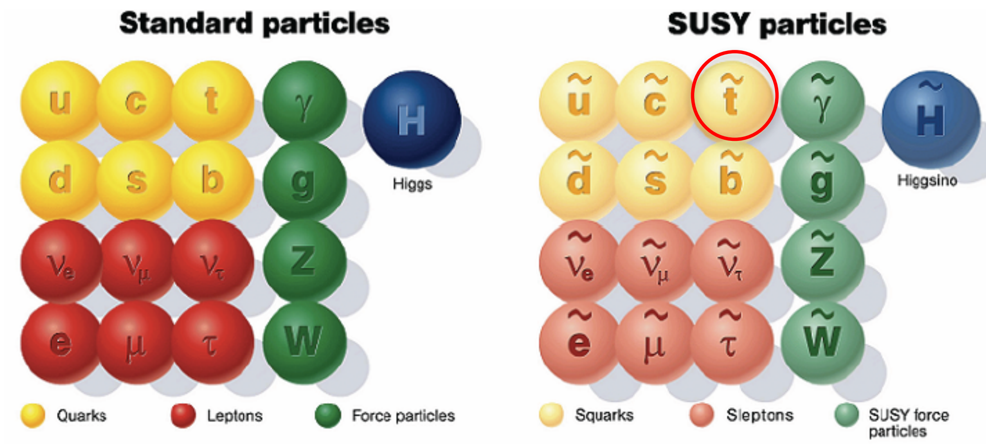
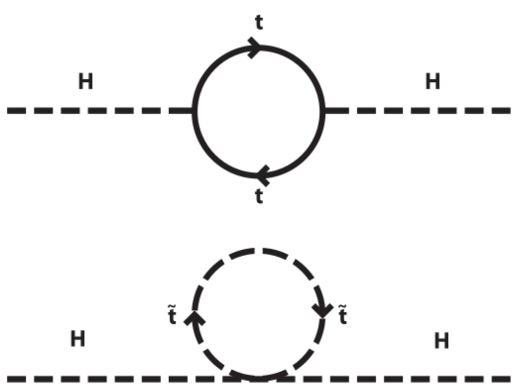
Introduction

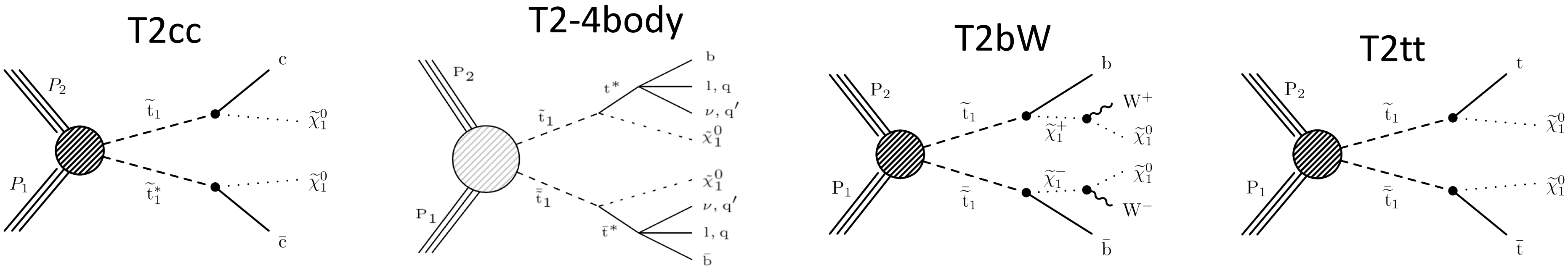
- SUSY is a fundamental global symmetry between fermions and bosons
  - Gauge coupling unification
  - Dark matter candidate
  - Solving the hierarchy problem

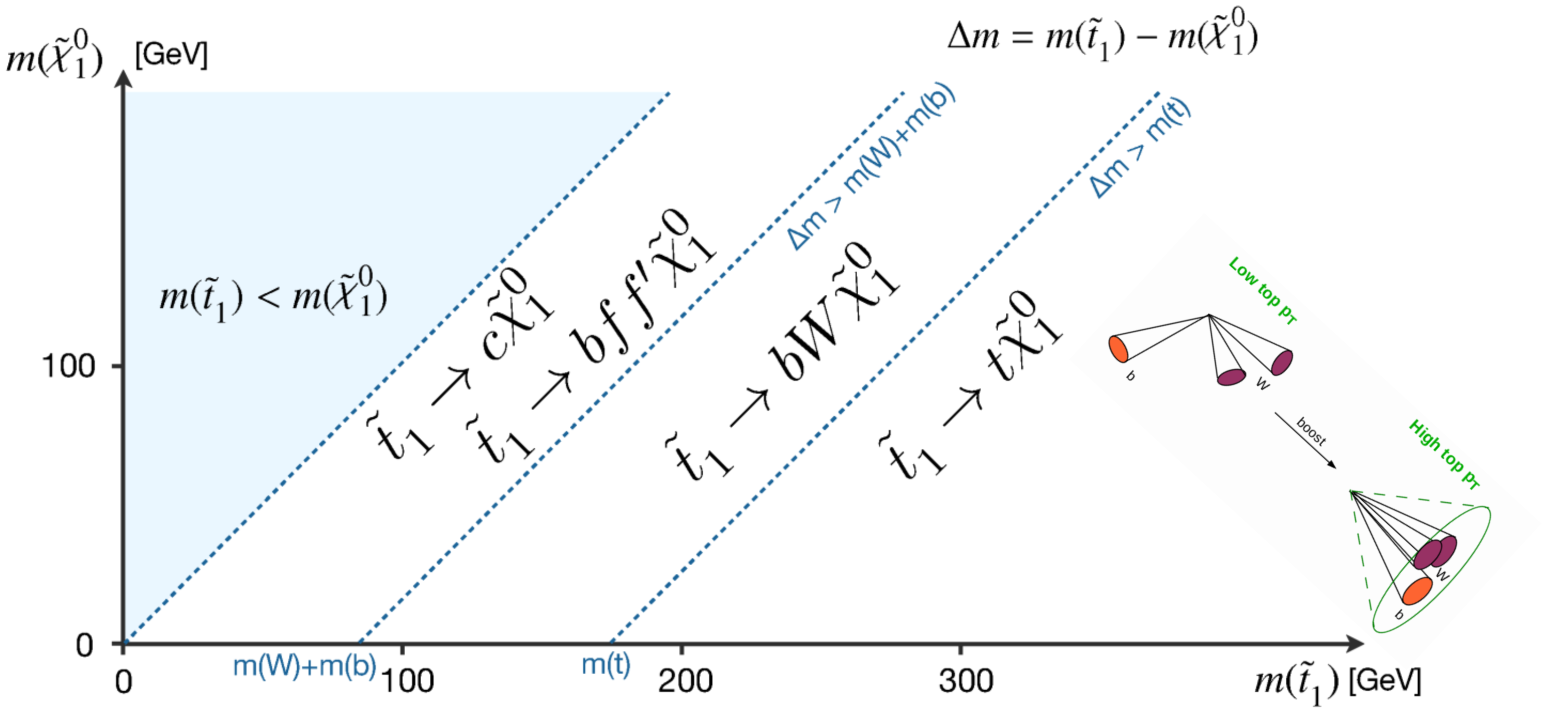


- SUSY provides the cancellation of the Higgs boson quadratic mass renormalization between top and stop
- Naturalness arguments prefer light stop/sbottom, reachable by LHC



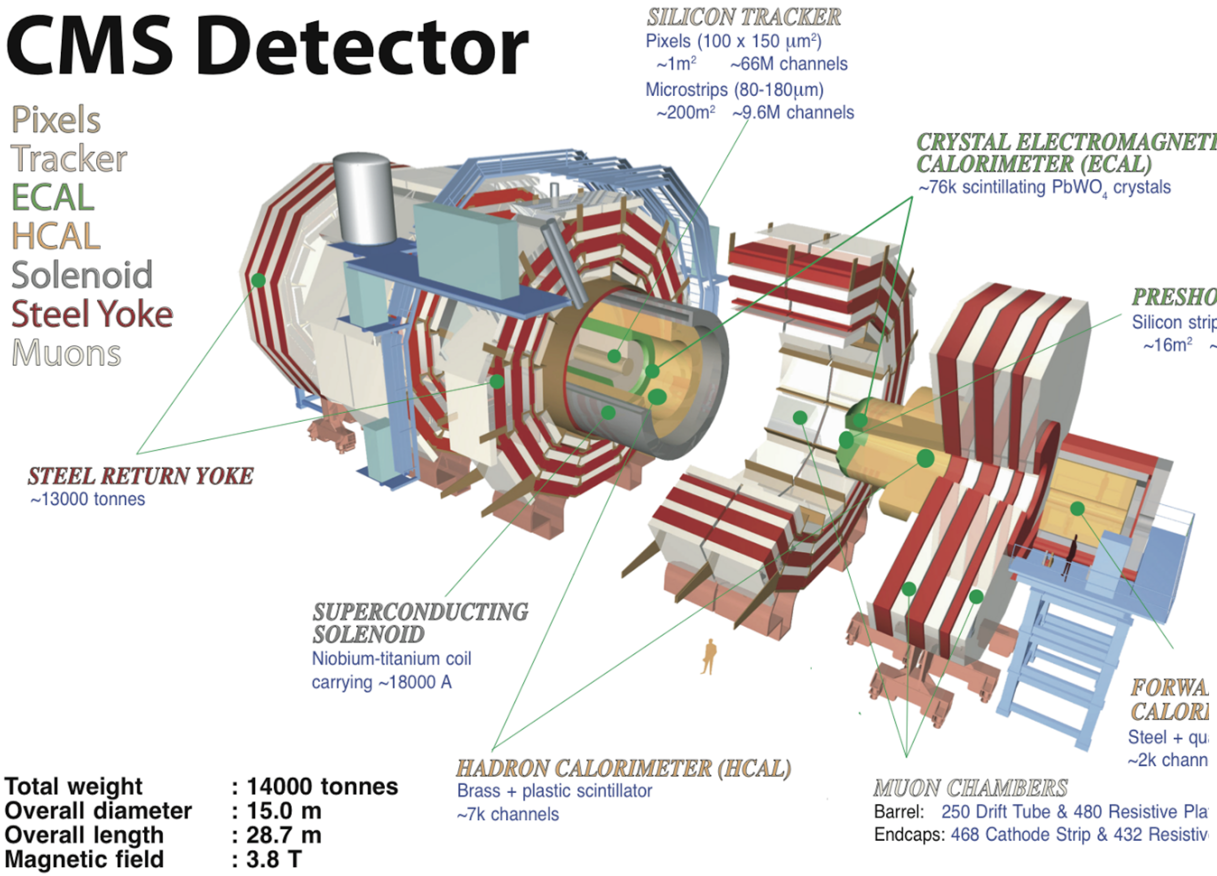
Top Squark

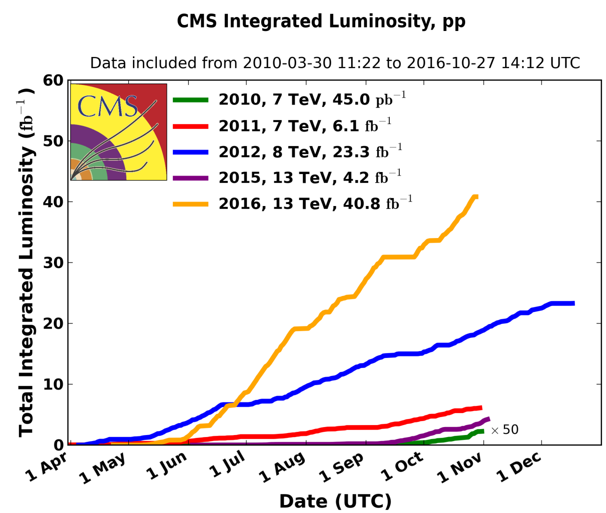

T2cc
T2-4body
T2bW
T2tt


$m(\tilde{\chi}_1^0)$ [GeV]
$\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$
$m(\tilde{t}_1) < m(\tilde{\chi}_1^0)$
$\tilde{t}_1 \to c\tilde{\chi}_1^0$
$\tilde{t}_1 \to bff'\tilde{\chi}_1^0$
$\Delta m > m(W)+m(b)$
$\tilde{t}_1 \to bW\tilde{\chi}_1^0$
$\Delta m > m(t)$
$\tilde{t}_1 \to t\tilde{\chi}_1^0$
Low top p_T
boost
High top p_T
100
0
0
m(W)+m(b)
100
m(t)
200
300
$m(\tilde{t}_1)$ [GeV]

The CMS Experiment

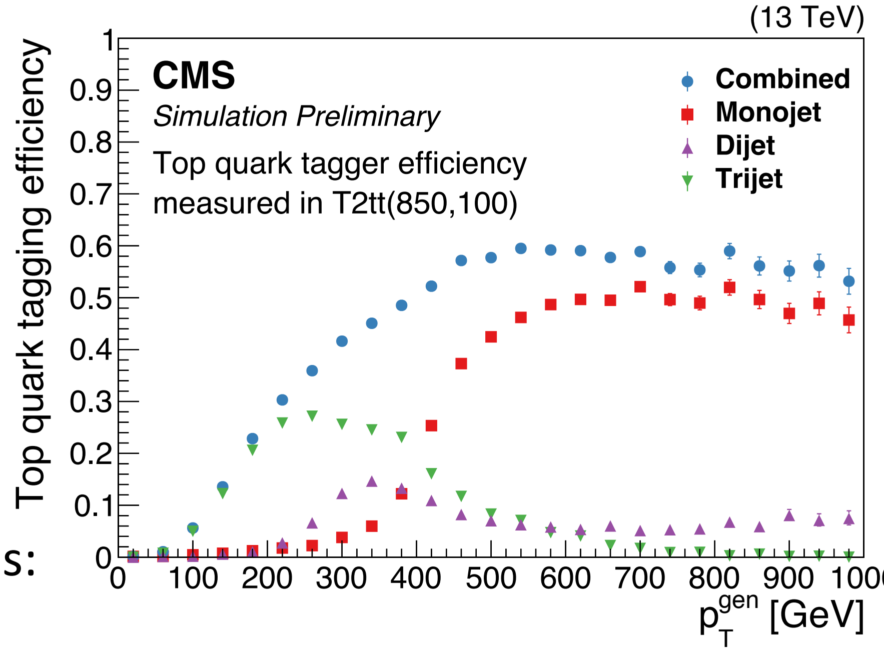
- This talk presents recent CMS results of direct stop searches in hadroinc final state with full 2016 data(36fb^{-1})
  - CMS-SUS-16-050 and CMS-SUS-16-049





Stop Search with Hadronic t-Tagging

- Hadronic top tagger developed for wide p_T range of top
- Fully merged top (monojet)
  - AK8 jet tagged as top with soft drop
- Partially merged top (W + b jet)
  - AK8 jet tagged as W boson
  - Combine with a nearby AK4 jet
  - Require mass ratio consistent with $m_{W/}m_t$
- Resolved top with 3 AK4 jets
  - MVA tagger trained with jet properties: jet p, b-tagging value, q/g likelihood etc.

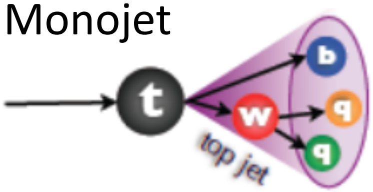


- Overlap among categories are removed, ~20% mistag rate

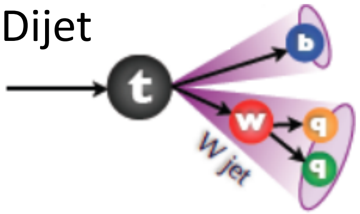
SUS-16-050

New

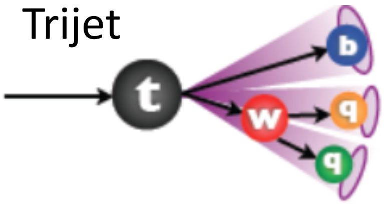
Monojet



Dijet



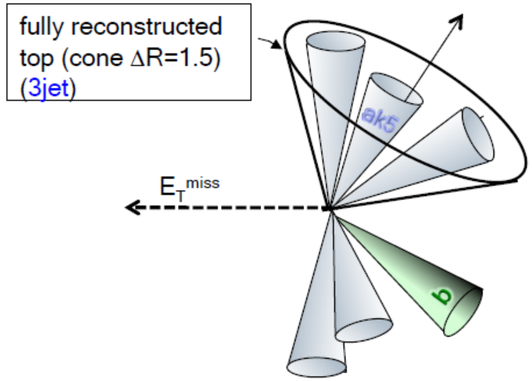
Trijet

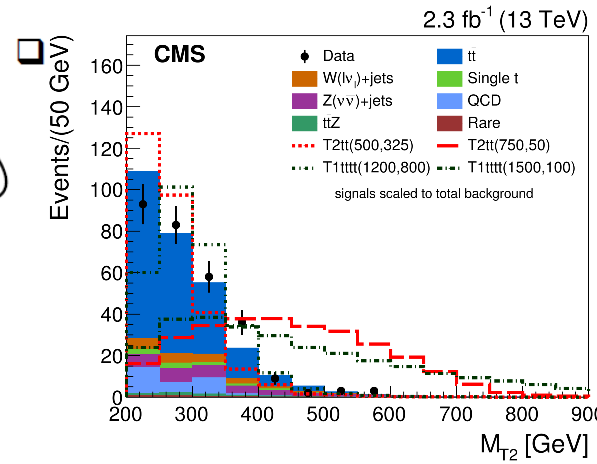


Diagrams from Vincenzo S.

Search Variables

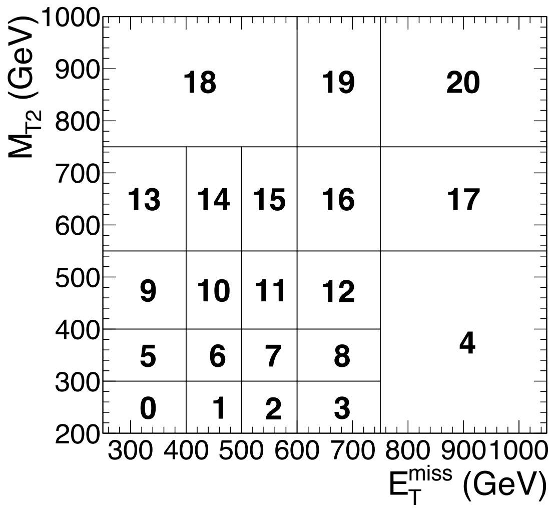
- N_t : NO. of tops
- N_b : NO. of b-tagged jets
- E_T^{miss}
- H_T : scalar sum of jet p_T
- M_{T2} : stransverse mass



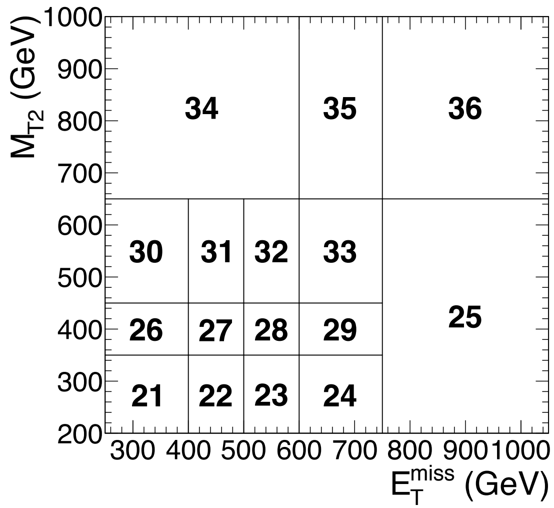


$$M_{T2} \equiv \min_{\vec{q}_{T,1}+\vec{q}_{T,2}=\vec{p}_T^{miss}} \left\{ \max \left[m_T^2(\vec{p}_{T,1}; m_{p,1}, \vec{q}_{T,1}; m_{\tilde{\chi}_1^0}), m_T^2(\vec{p}_{T,2}; m_{p,2}, \vec{q}_{T,2}; m_{\tilde{\chi}_1^0}) \right] \right\},$$

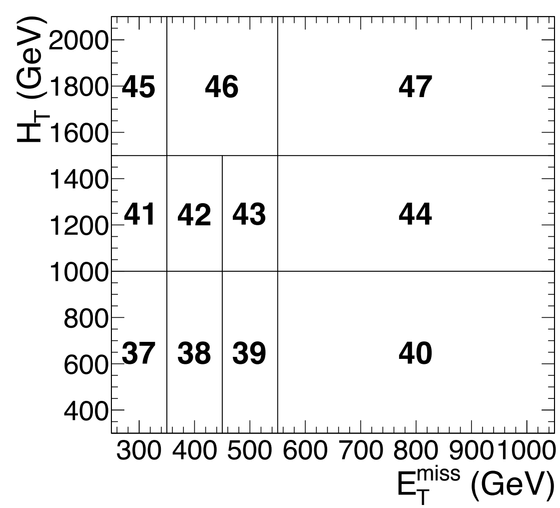
N_b=1 & N_t=1



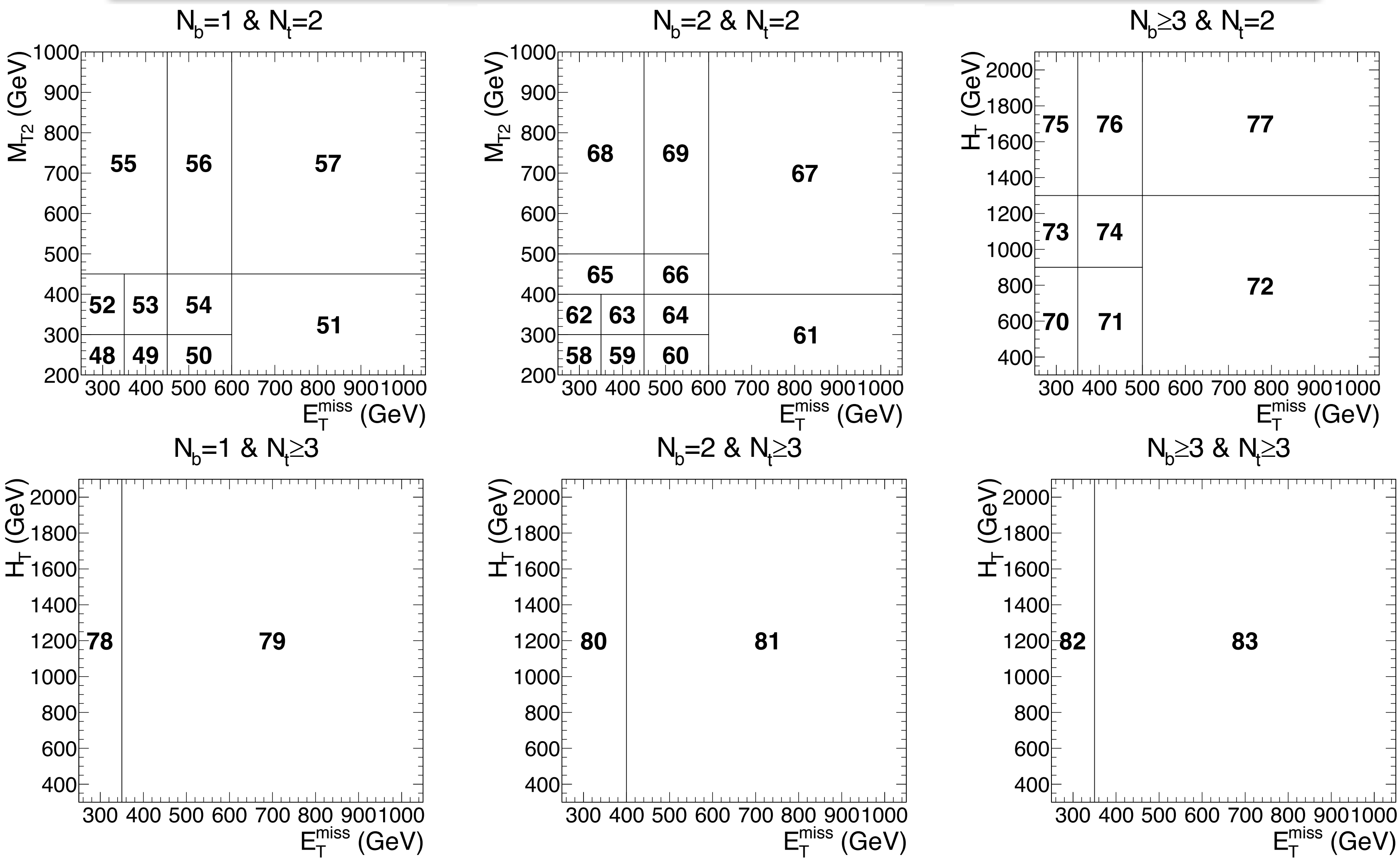
N_b=2 & N_t=1



N_b≥3 & N_t=1



Search Bin Design

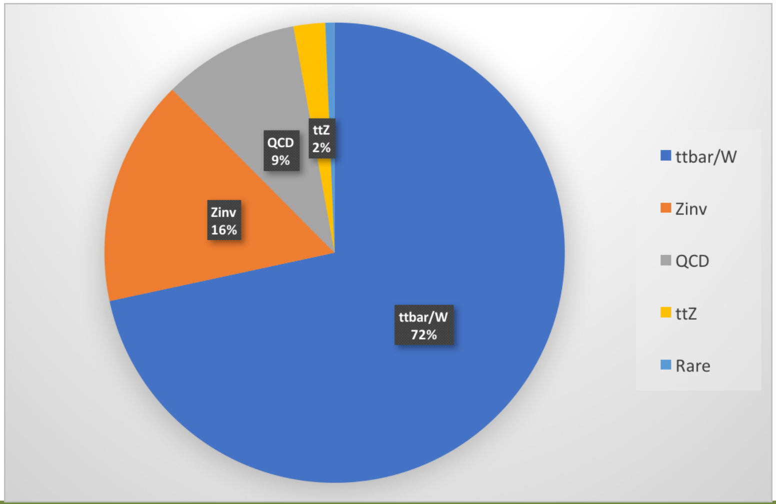


84 search bins in N_t, N_b, M_{T2}, E_T^{miss}, HT, targeting T2tt and T1tttt (gluino to ttbar+LSP)

Baseline Selection

- Pass CMS MET trigger
- Electron/muon/isolated track veto
- AK4PF-CHS jets:
  - N_{jets} (p_T > 30) ≥ 4
  - N_{jets} (p_T > 50) ≥ 2
- $N_b \geq 1$
- E_T^{miss} >250 GeV
- H_T > 300GeV
- $\Delta\phi(E_T^{miss}, jet_{1,2,3})$>0.5, 0.3, 0.3 to reduce QCD
- At least 1 top identified with the top tagger
- M_{T2} >200 GeV

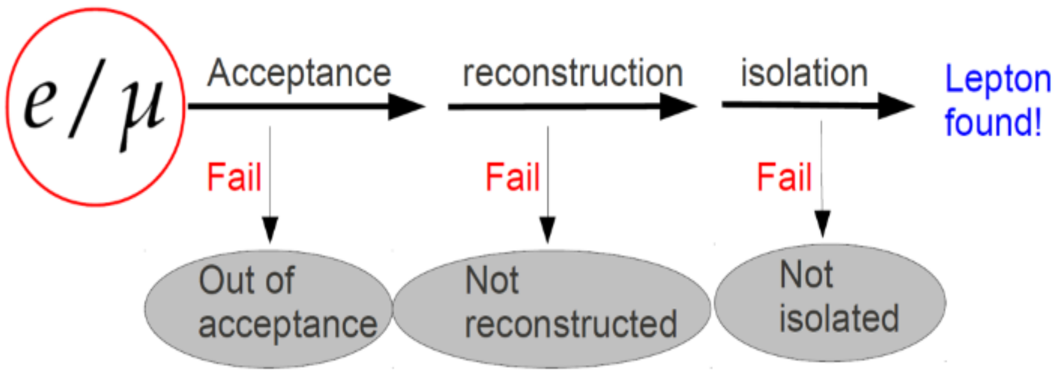
- Main Backgrounds (data driven)
  - ttbar/W + jets
  - Z → νν + jets
  - QCD
- Sub-dominant backgrounds
  - ttZ: Estimated from MC, validated with data in 3-lepton channel
  - Diboson/Triboson etc: Estimated from MC

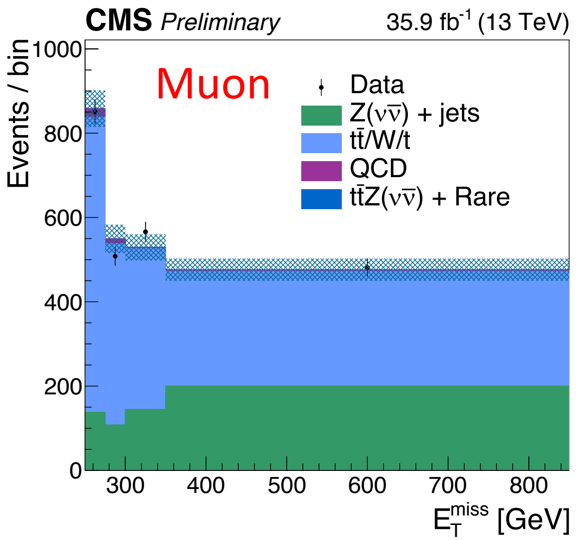


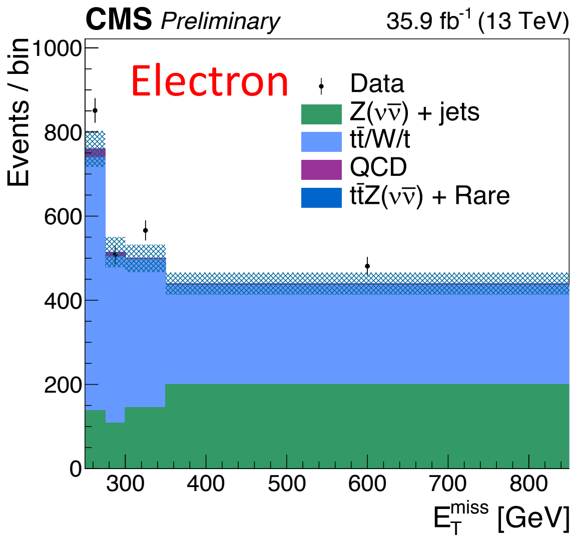
Lost Lepton Background

- Use single muon/electron data as control region (CR)
- Measure TF = N_{SR} / N_{CR} for every search bin from MC
- TF measured for lost e/μ and hadronic tau respectively, using MC truth information

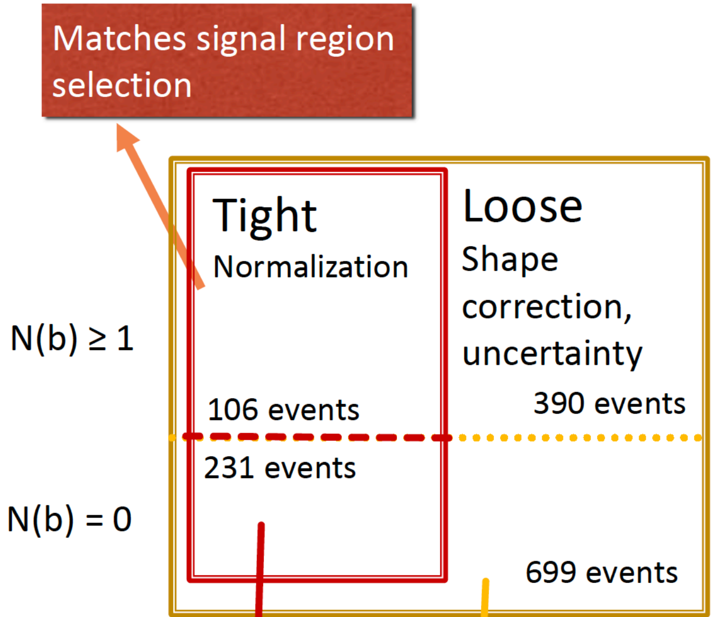
- Validation in the data sideband ($N_b \geq 2$, $N_t = 0$) shows good agreement in both electron and muon channel







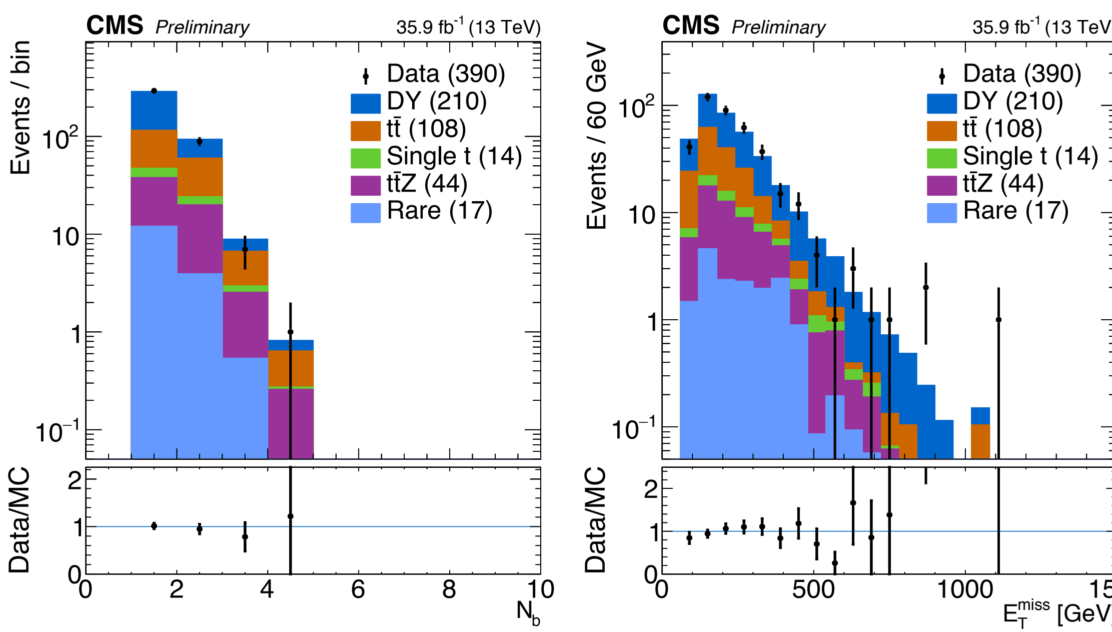
Z invisible Background



$$\hat{N}_B = R_{norm} \sum_{events \in B} S_{DY}(N_{jet}) w_{MC}$$

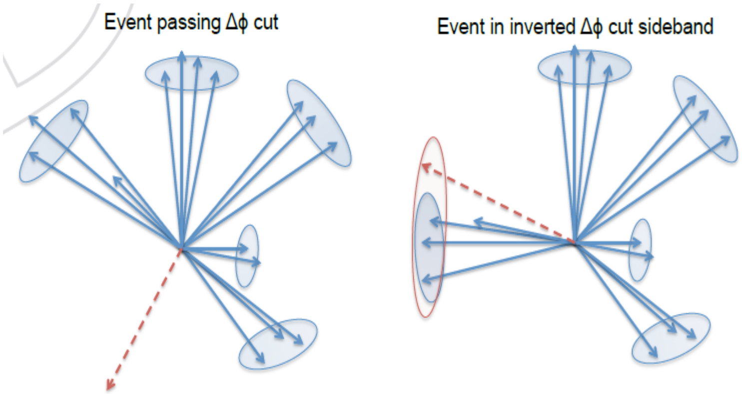
$$w_{MC} = (\sigma \times \mathcal{L}) \epsilon_{trig} w_{btag} w_{pileup}$$

- MC base estimate, validated in Z→μμ control sample
- Derive a scale factor ($S_{DY}(N_{jet})$) for $DY \to \mu\mu$ in the loose control region, and apply this to the $Z \to \nu\nu$ MC in the signal region
- After reweighting, the Z→μμ shows good data/MC agreement



QCD Background

- Use **inverted Δϕ control sample to predict the number of QCD events**, using a translation factor.



$$N_{QCD}^{SR} = N_{QCD}^{\Delta\overline{\phi}} \times T_{QCD}$$

- The number of QCD events in inverted Delta phi region is the number of observed data minus other SM background :

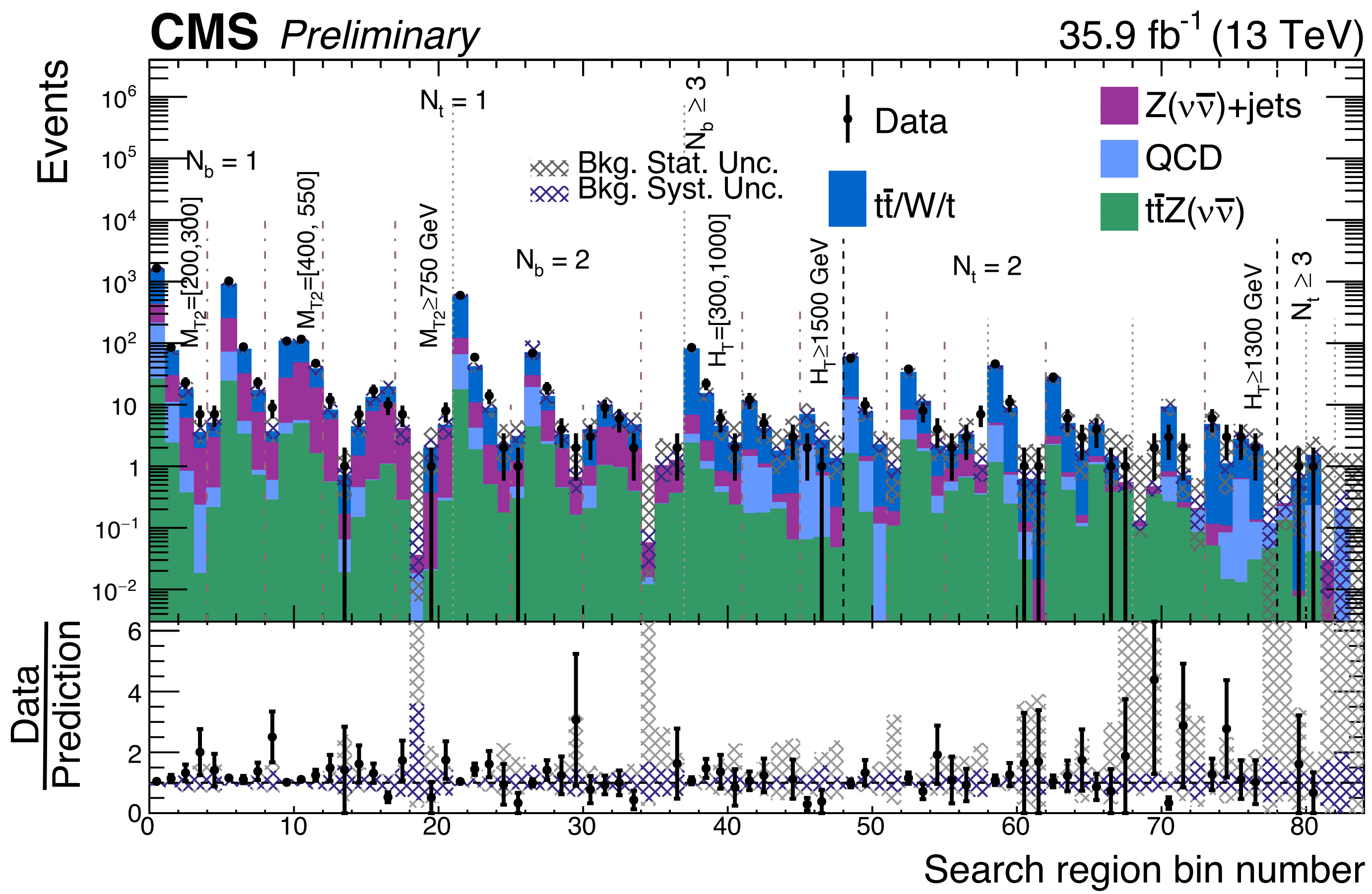
$$N_{QCD}^{\Delta\overline{\phi}} = N_{Data}^{\Delta\overline{\phi}} - N_{LL}^{\Delta\overline{\phi}} - N_{\tau_h}^{\Delta\overline{\phi}} - N_{Z\to\nu\nu}^{\Delta\overline{\phi}}$$

- The T-factor is measured in data in a sideband region and extrapolate in higher met region using MC results.

$$T_{QCD} = \frac{N_{QCD}^{\Delta\phi}}{N_{QCD}^{\Delta\overline{\phi}}}$$

Stop Search with Hadronic t-Tagging

- Search regions are binned with N_t, N_b, M_{T2}, E_T^{miss}, H_T
- No statistically significant deviation between data and background prediction



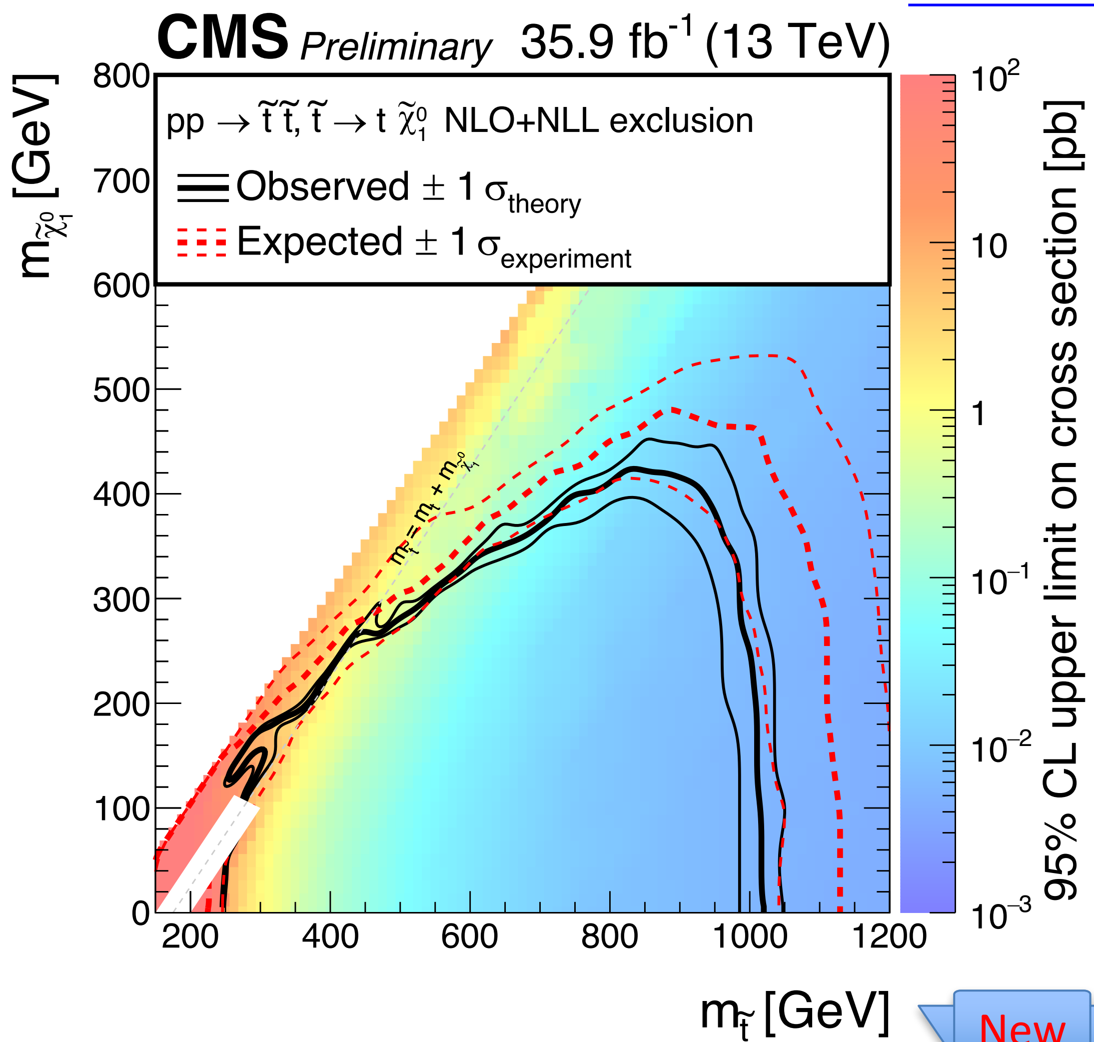
[SUS-16-050](SUS-16-050)

New

Stop Search with Hadronic t-Tagging

SUS-16-050

- Excludes T2tt with stop mass up to 1020GeV and LSP mass up to 430GeV
- Additional material for reinterpretation (aggregated search regions and a simplified version of the top tagger) will be released soon



New

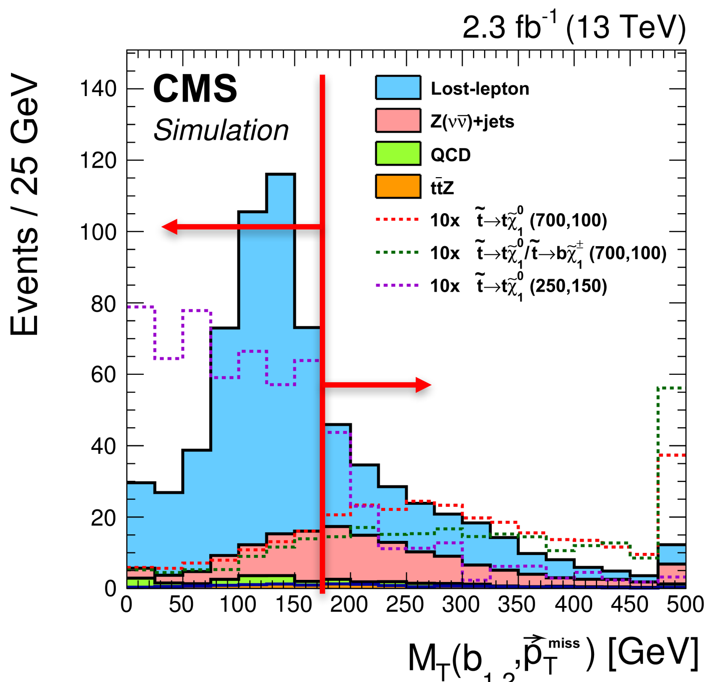
Stop Search with 0-lep

SUS-16-049

- Different search strategy targeting different signal phase space
  - Low Δm (compressed) region and high Δm region, separated by $M_T(b, p_T^{miss})$
- Search regions use different tagging technique of b, W, top
  - low Δm : N_j, N_b, $N_{soft\text{-}b}$, p_T^{ISR}, p_T^{b}, E_T^{miss}
  - high Δm : N_j, N_b, N_t, N_W, $N_{resolved\text{-}t}$, E_T^{miss}

Low Δm category

- $M_T(b, p_T^{miss})$<175 GeV
- Target low Δm signal
- ISR tagging
- Soft b-tagging



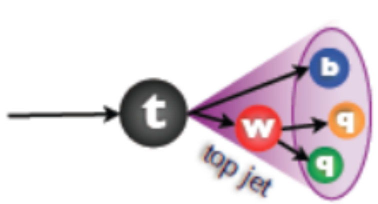
High Δm category

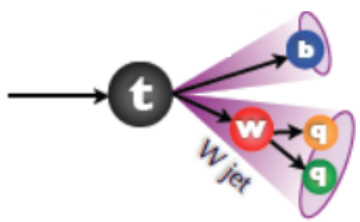
- $M_T(b, p_T^{miss})$>175 GeV
- Target high Δm signal
- BDT top/W tagging
- BDT resolved top tagging

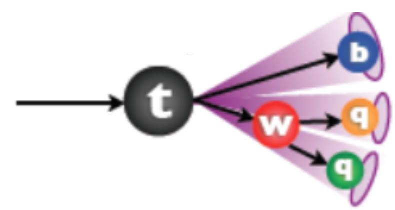
Stop Search with 0-lep

[SUS-16-049]

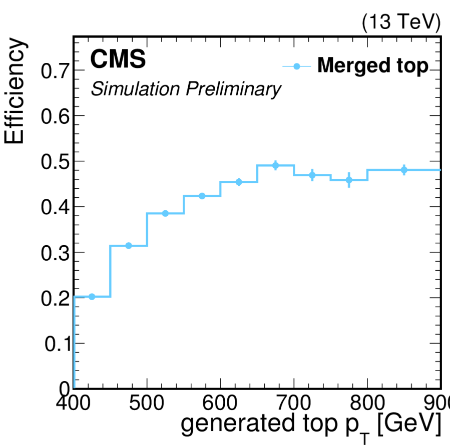
- The signature of top quark decay varies along its p_T range
  - Merged top tagger: BDT to tagger boosted top quark with p_T > 400GeV in ”large-R” jets
  - W tagger: BDT to tagger boosted W boson with p_T > 200GeV in ”large-R” jets
  - Resolved top tagger: BDT to select 3-jets combination as top candidate

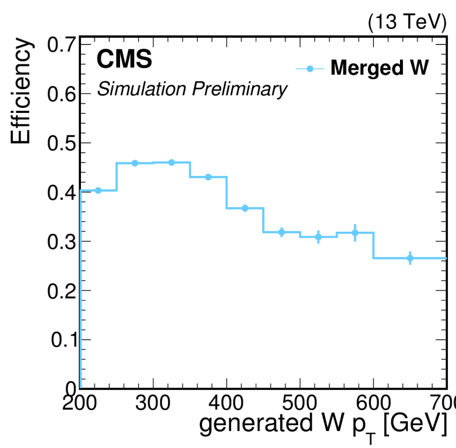


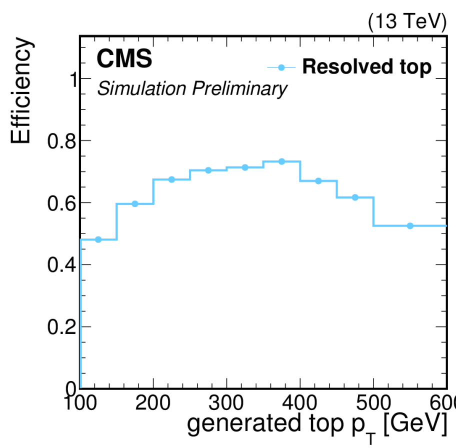


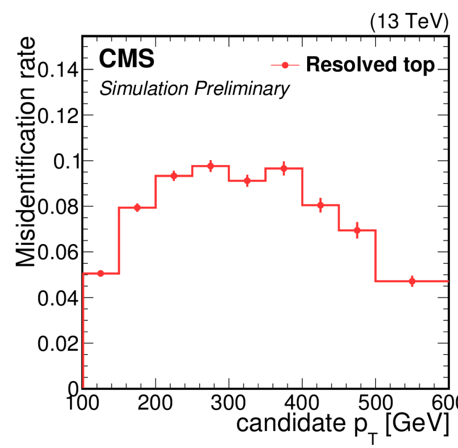


Diagrams from Vincenzo S.

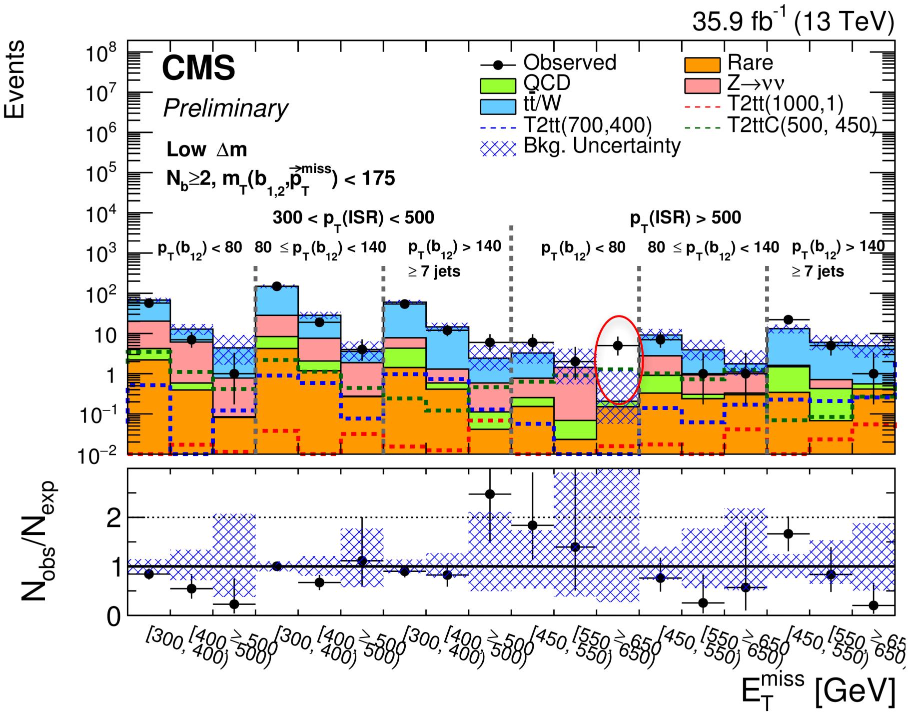


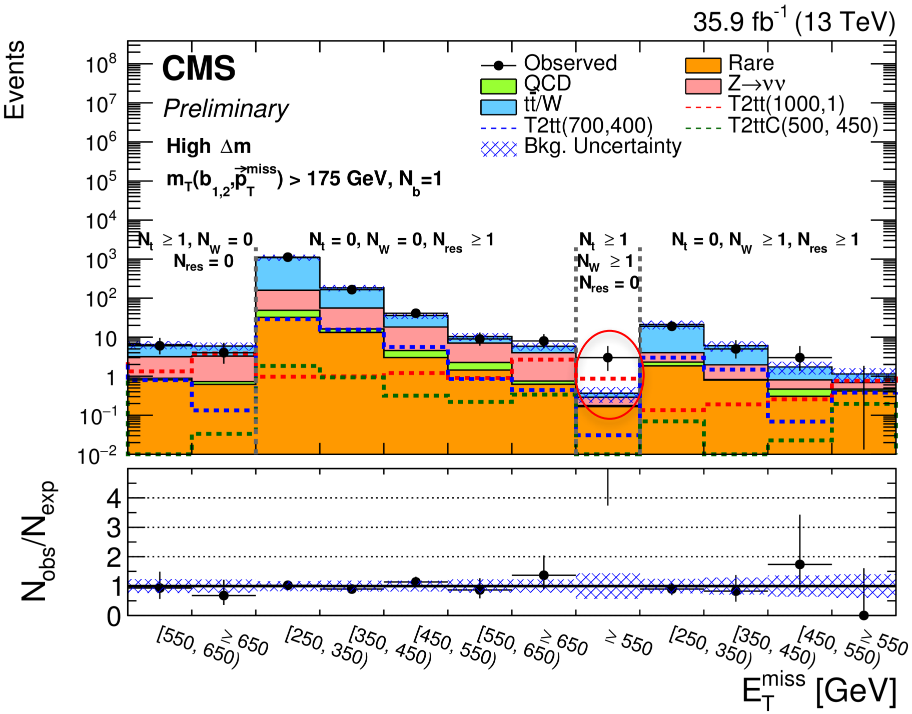






Stop Search with 0-lep

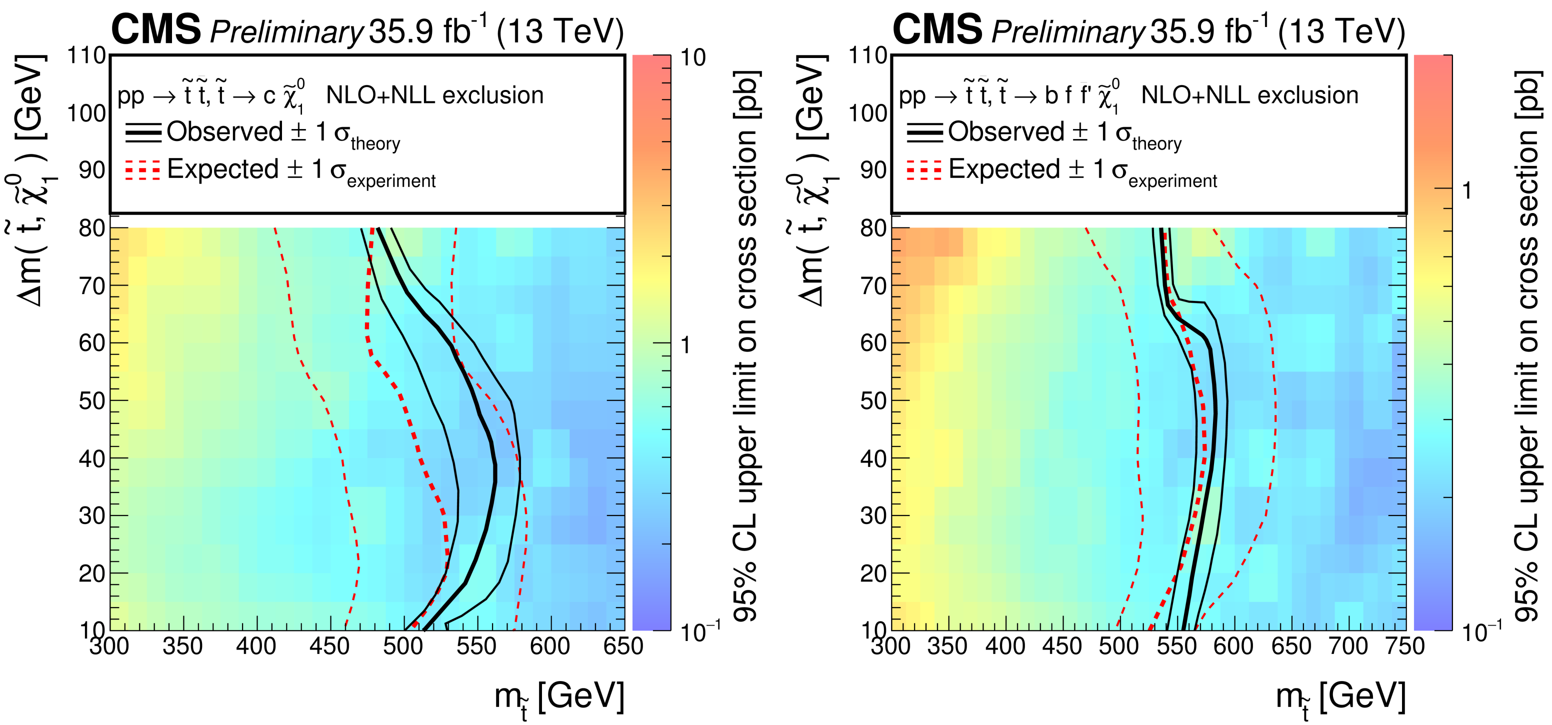




- Observed data are in general agreement with background predictions
- Two search regions with small discrepancies, corresponding to local significances of 2.3 (left) and 1.9 (right) sigma.
- Deviation can be attributed to statistical fluctuation of data.

SUS-16-049

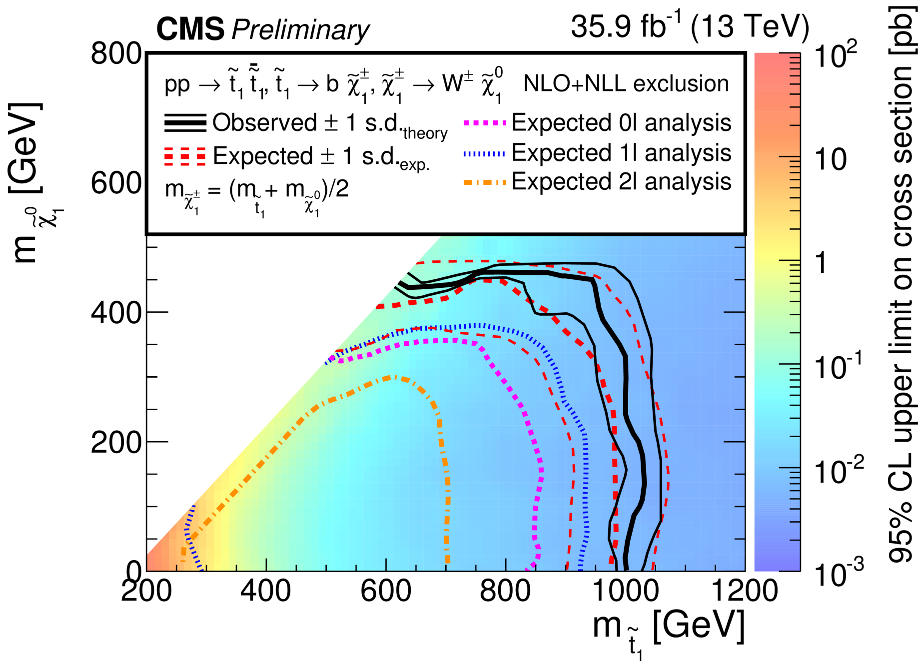
Stop Search with 0-lep

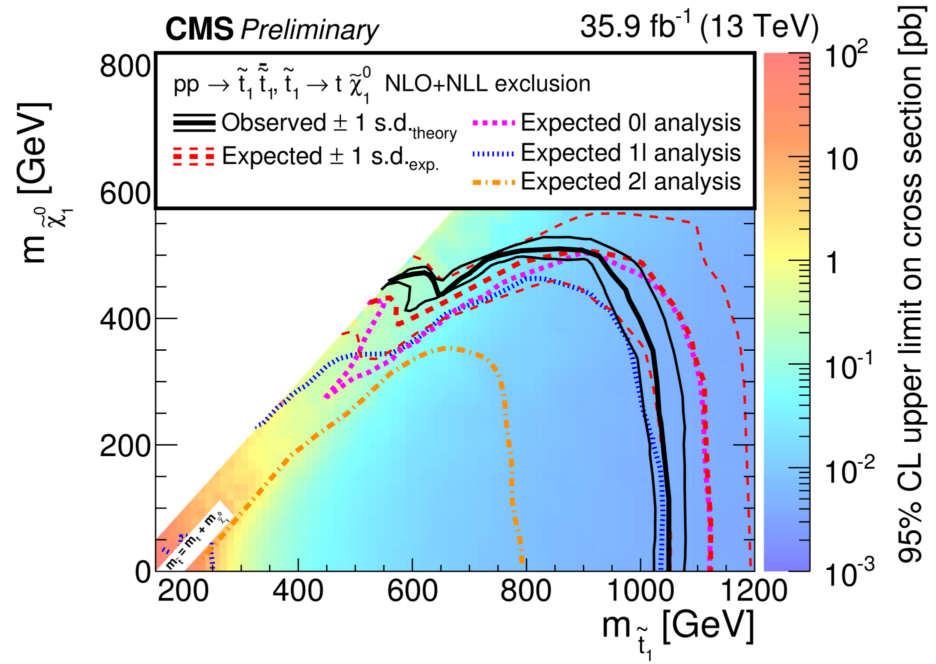


- Limits on low Δm signal scenarios
  - Exclude stop mass up to 560GeV and LSP mass up to 520GeV for T2cc
  - Exclude stop mass up to 580GeV and LSP mass up to 540GeV for stop four body decay

SUS-16-049

Combine Limit



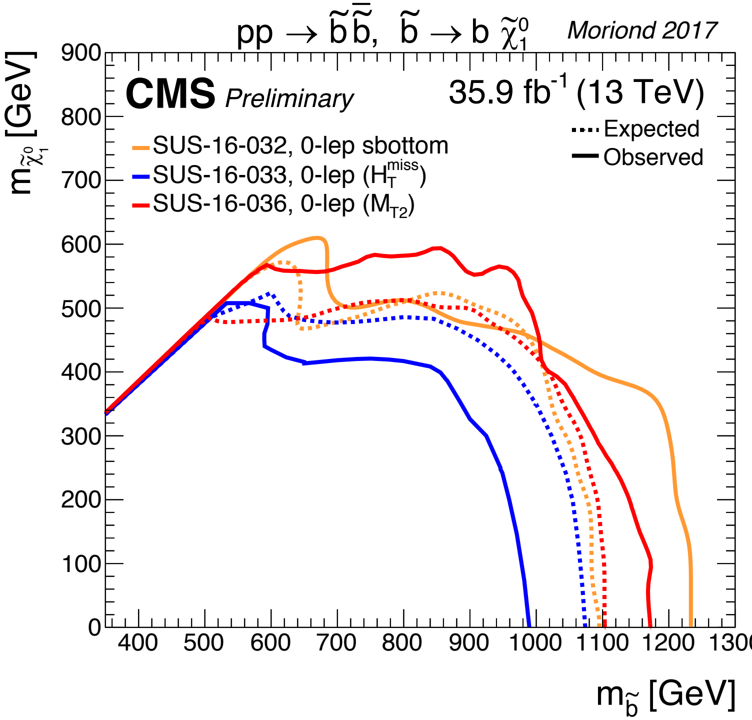


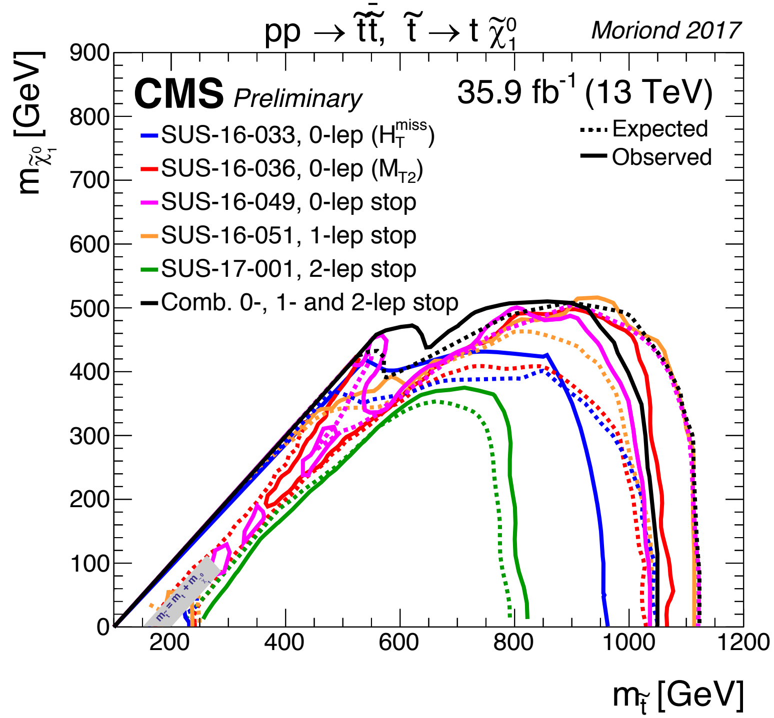
- Combination with stop search with single lepton (SUS-16-051) and dilepton (SUS-17-001)
- For T2bW, the combine excludes stop mass up to 1000GeV and LSP mass up to 450 for a 900 stop
- For T2tt, the combine excludes stop mass up to 1050GeV and LSP mass up to 500 for a 900 stop

SUS-16-051

Summary

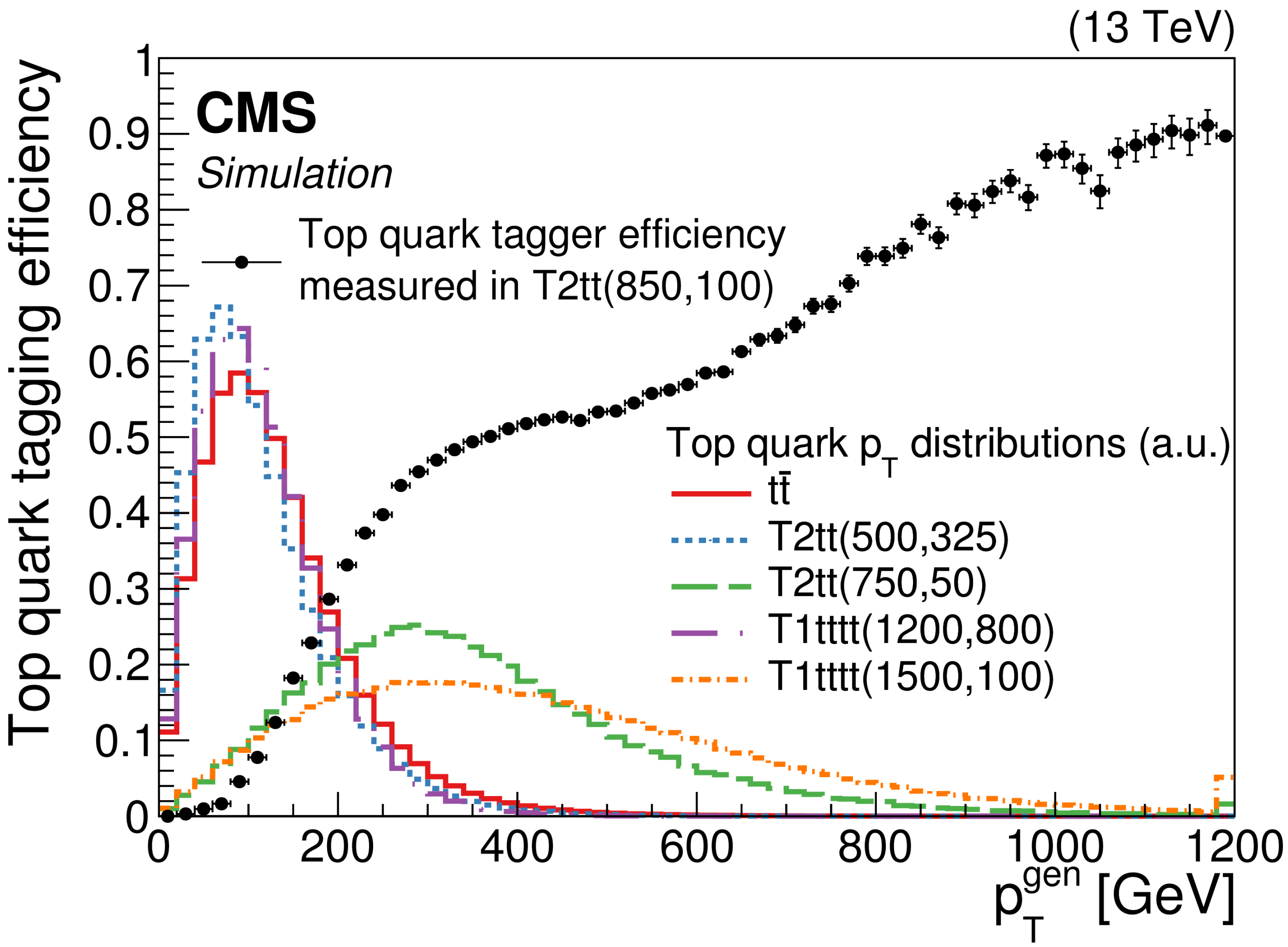
- CMS searches for stop/sbottom production in various final state with 2016 dataset.
  - No significant excess are observed
- CMS excludes stop pair production with mass above 1TeV, subject to simplified model assumption
- LHC will restart pp collision in June. Stay tune.





BACKUP

ICHEP Top Tagger

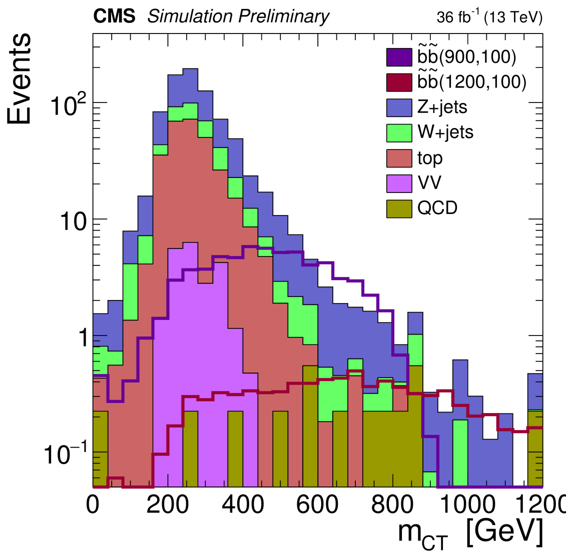


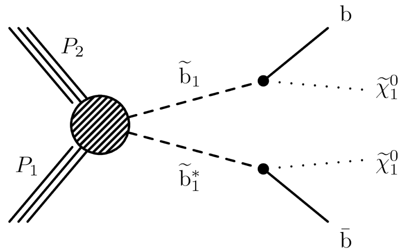
Bottom Squark

- Direct search for sbottom with:
  - NO. of b-tagged jet
  - NO. of c-tagged jet
  - H_T : scalar sum of jet p_T
  - E_T^{miss} and M_{CT}

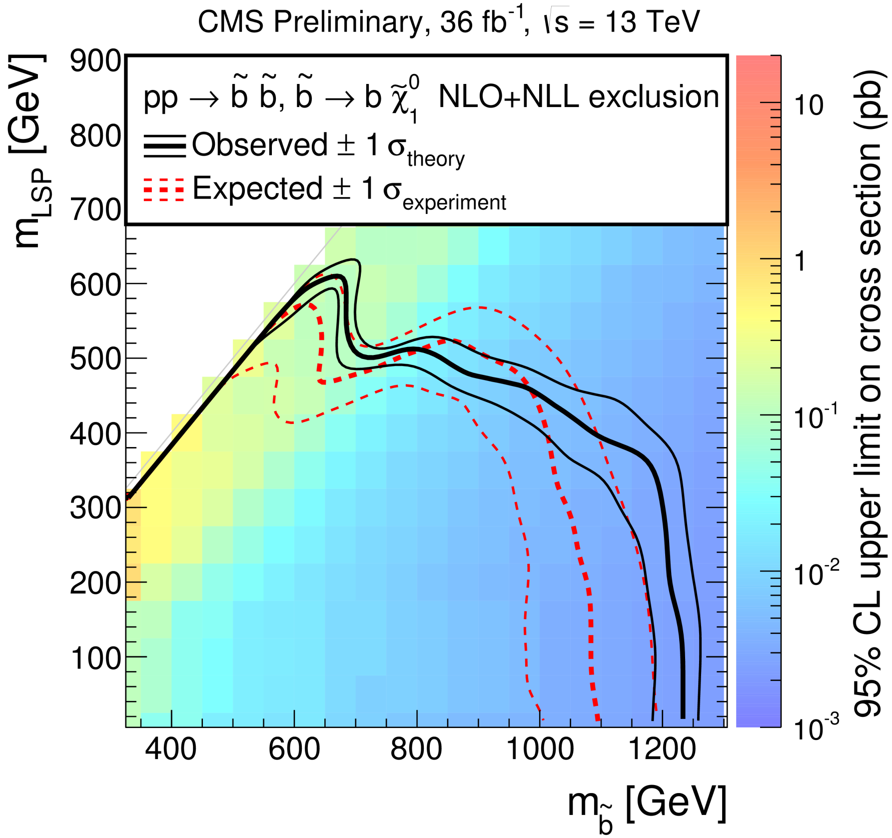
$$m_{CT}^2(j_1, j_2) = [E_T(j_1) + E_T(j_2)]^2 - [\vec{p}_T(j_1) - \vec{p}_T(j_2)]^2 = 2p_T(j_1)p_T(j_2)(1 + \cos\Delta\phi(j_1, j_2)),$$

- No excess above the SM prediction





SUS-16-032



Stop Search with 2-leps

SUS-17-001

- Search in final states of 2 leptons, jets, b-jets and E_T^{miss}
- Dominant ttbar background is reduced by M_{T2}

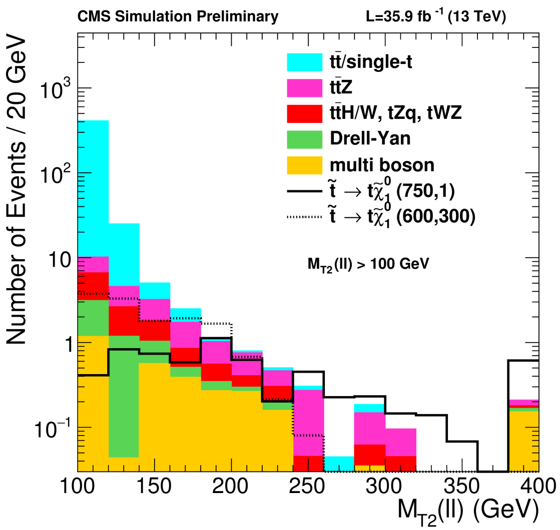
$$M_{T2}(\ell\ell) = \min_{\vec{p}_{T1}^{\text{miss}}+\vec{p}_{T2}^{\text{miss}}=\vec{p}_{T}^{\text{miss}}} \left(\max \left[M_T(\vec{p}_{T}^{\text{vis1}}, \vec{p}_{T1}^{\text{miss}}), M_T(\vec{p}_{T}^{\text{vis2}}, \vec{p}_{T2}^{\text{miss}}) \right] \right)$$

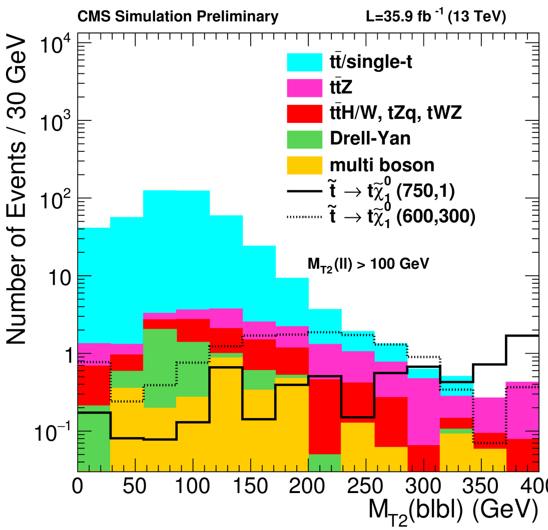
- Search regions are defined by E_T^{miss} , $M_{T2}(ll)$, $M_{T2}(blbl)$
- No excesses found, provide 3 aggregate search bins for reinterpretation

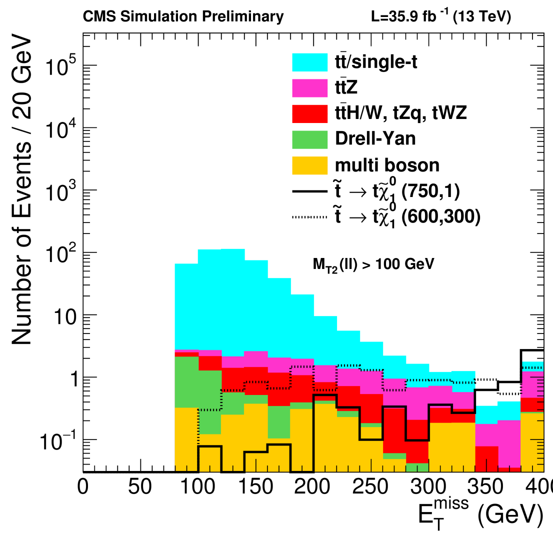
Dilepton Selection

leptons	2 (e or μ), opposite charge
$m(ll)$	≥ 20
$\lvert M_Z - m(ll) \rvert$	$> 15\,\text{GeV}$, same flavor only

signal region	$M_{T2}(blbl)$	E_T^{miss} (GeV)	$M_{T2}(ll)$	expected	observed
A0		≥ 200	100 – 140	20.8 ± 8.8	22
A1	≥ 0	≥ 200	140 – 240	6.2 ± 1.0	6
A2		≥ 80	≥ 240	1.1 ± 0.5	1

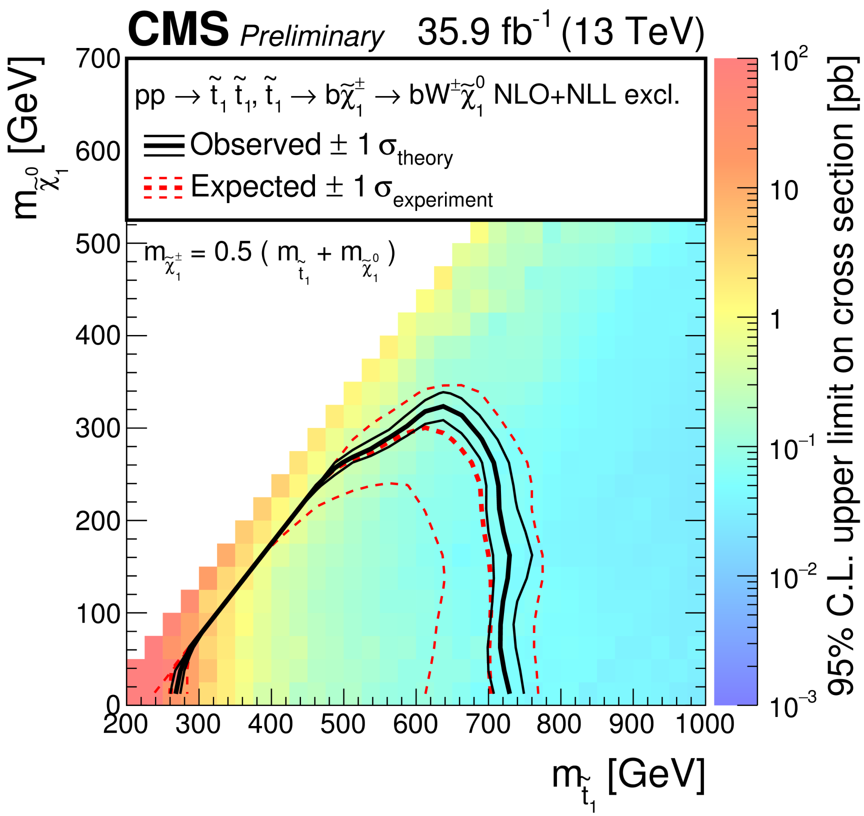


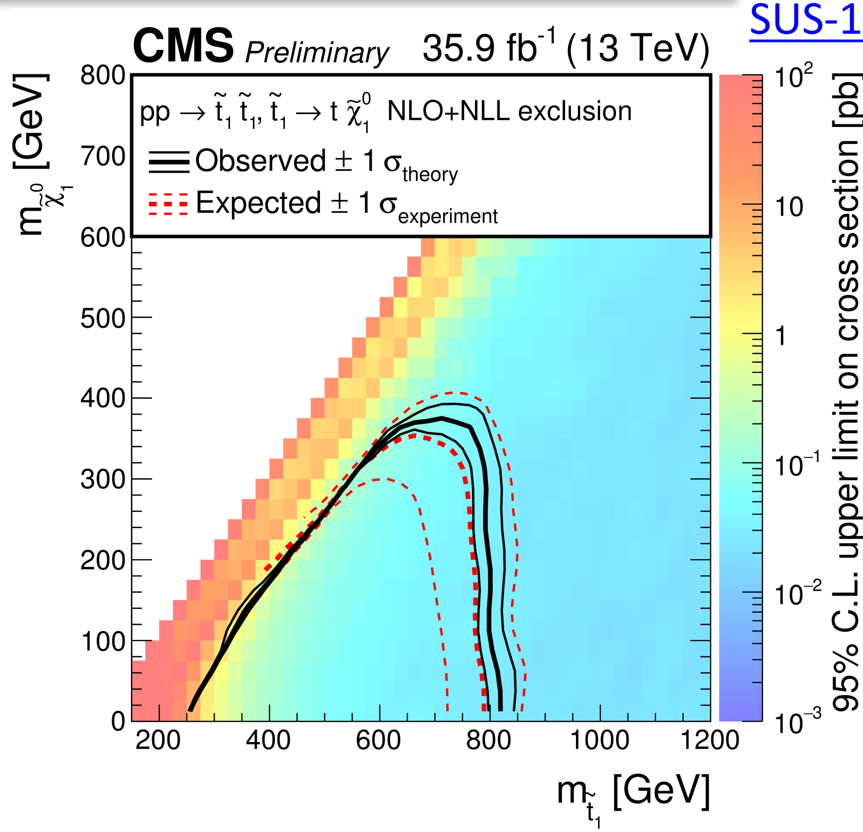




Stop Search with 2-leps

SUS-17-001





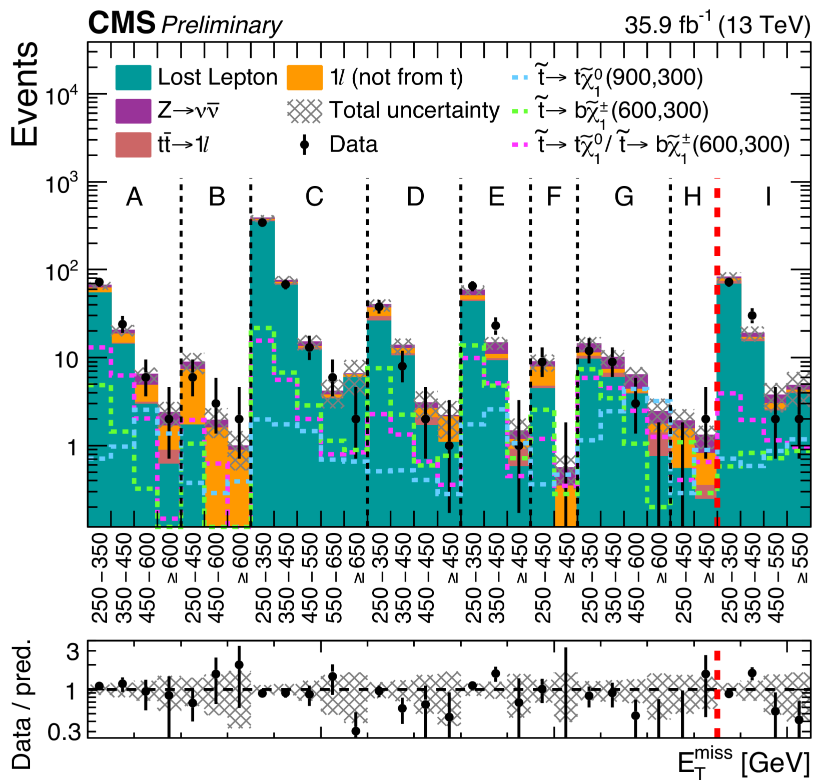
- No excesses found, limits at 95% CL are set
- Provide 3 aggregate search bins for reinterpretation

signal region	(GeV)	E_T^{miss} (GeV)	(GeV)	expected			observed
A0		≥ 200	100 – 140	20.8	$\pm$	8.8	22
A1	≥ 0	≥ 200	140 – 240	6.2	$\pm$	1.0	6
A2		≥ 80	≥ 240	1.1	$\pm$	0.5	1

Stop Search with 1-lep

SUS-16-051

- Search in final state with 1 lepton, jets, b-jets and E_T^{miss}
- Search regions are defined by N_j, E_T^{miss}, M_{lb}, and modified version of topness $t_{\text{mod}} = \ln(\min S)$, with $S(\vec{p}_W, p_z, \nu) = \frac{(m_W^2 - (p_\nu + p_\ell)^2)^2}{a_W^4} + \frac{(m_t^2 - (p_b + p_W)^2)^2}{a_t^4}$.
- The data yields are statistically compatible with estimated backgrounds



A: $N_J \leq 3$, $t_{mod} > 10$, $M_{lb} \leq 175$ GeV

B: $N_J \leq 3$, $t_{mod} > 10$, $M_{lb} > 175$ GeV

C: $N_J \geq 4$, $t_{mod} \leq 0$, $M_{lb} \leq 175$ GeV

D: $N_J \geq 4$, $t_{mod} \leq 0$, $M_{lb} > 175$ GeV

E: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} \leq 175$ GeV

F: $N_J \geq 4$, $0 < t_{mod} \leq 10$, $M_{lb} > 175$ GeV

G: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} \leq 175$ GeV

H: $N_J \geq 4$, $t_{mod} > 10$, $M_{lb} > 175$ GeV

I: Compressed region