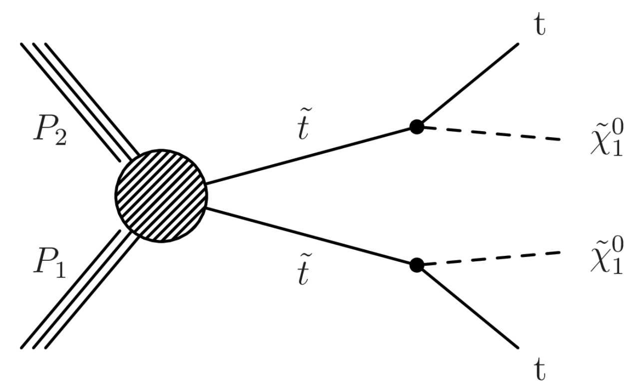
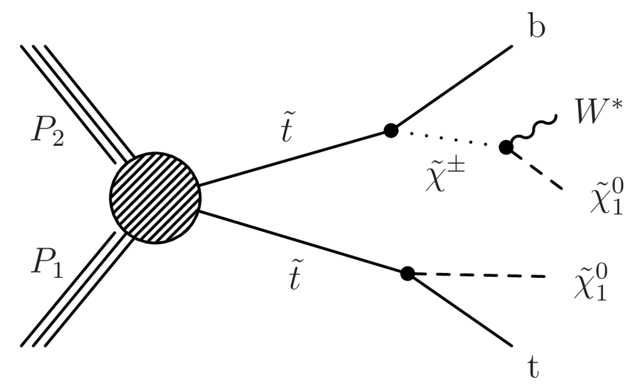
Pheno 2016

University of Pittsburgh – May 9, 2016

Searches for sbottoms and stops in CMS

- Introduction: targeted searches for third generation squarks
- Direct stop searches with 2.3 fb^{-1}
  - All hadronic
  - ℓ+jets
- Direct sbottom search with 2.3 fb^{-1}
- Interpretation
- Conclusions





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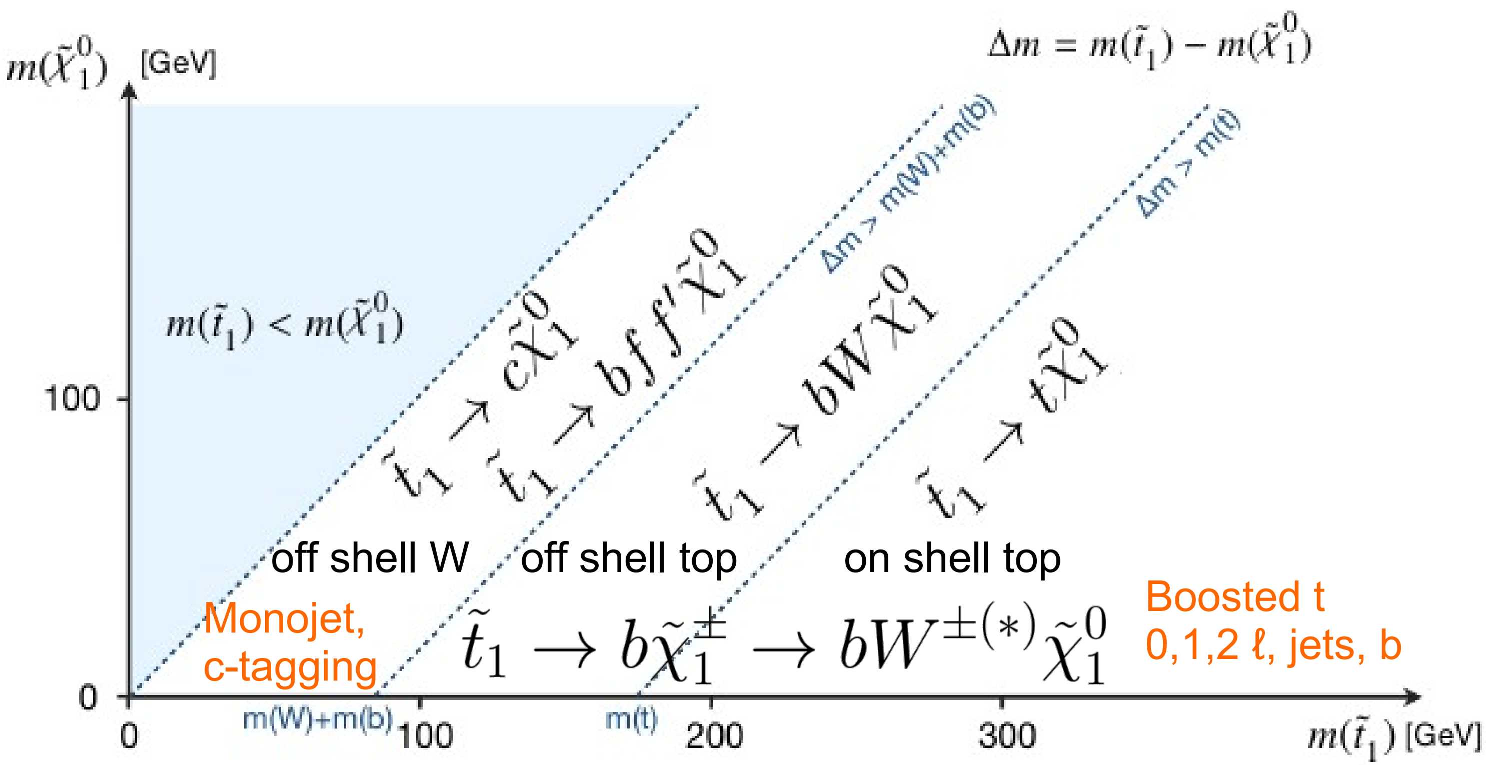
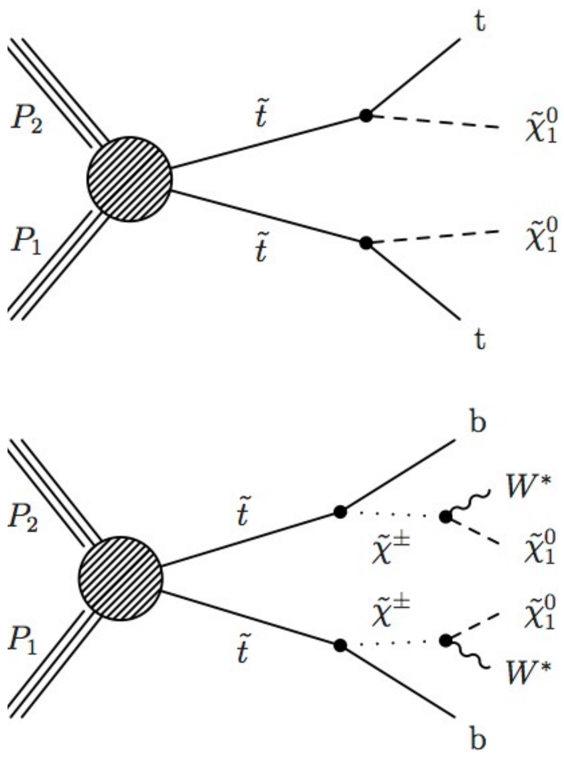
On behalf of the CMS Collaboration

Targeted stop and sbottom searches

- Light stop (and sbottom) and/or small $\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}^0}$ are well motivated
  - Stabilize Higgs mass, relic density (stop-χ co-annihilation), EWK baryogenesis
- Inclusive searches are broad and typically use a kinematic variable to reduce QCD
- Targeted searches for stop and sbottom: $\tilde{t}\tilde{t} \rightarrow t\chi^0 t\chi^0$ $\tilde{b}\tilde{b} \rightarrow b\chi^0 b\chi^0$
  - Can design specific variables that focus on difficult regions of phase space
  - Develop specific tools to reduce tt background, reconstruct top





Background determination

- Take all hadronic stop search as an example
- $t\bar{t}$ and W+jets (Lost lepton) background:
  - μ+jets sample: invert ℓ veto, $N_b \geq 1$
  - Correct TF for ℓ efficiencies and different background composition

$$N^{LL}_{\text{pred}} = \frac{N^{0\ell}_{\text{MC}}}{N^{1\ell}_{\text{MC}}} \times N^{1\ell}_{\text{data}}$$

- Z→νν background:
  - From Z→ℓℓ and γ+jets, enriched samples
  - Main unc from stats in γ+jets and JES in Z→ℓℓ

$$N^{Z\to\nu\nu}_{\text{pred}} = N^{Z\to\nu\nu}_{MC} \times \frac{N^{Z\to\ell\ell}_{\text{data}}}{N^{Z\to\ell\ell}_{\text{MC}}} \times \frac{N^{\gamma+jets}_{MC}}{N^{\gamma+jets}_{\text{data}}}(\not{E}^{\gamma}_{T})$$

- QCD multijet background:
  - Enhance multijet by requiring MET and jets to overlap
  - TF determined on low-MET region and extrapolated using MC

$$N^{QCD\Delta\bar{\phi}}_{\text{pred}} = (N^{\Delta\bar{\phi}}_{\text{data}} - N^{\Delta\bar{\phi}}_{\text{otherbkg.}}) \times \frac{N^{\Delta\phi}_{\text{MC}}}{N^{\Delta\bar{\phi}}_{\text{MC}}}$$

- Check prediction in control samples, or perfoming closure tests

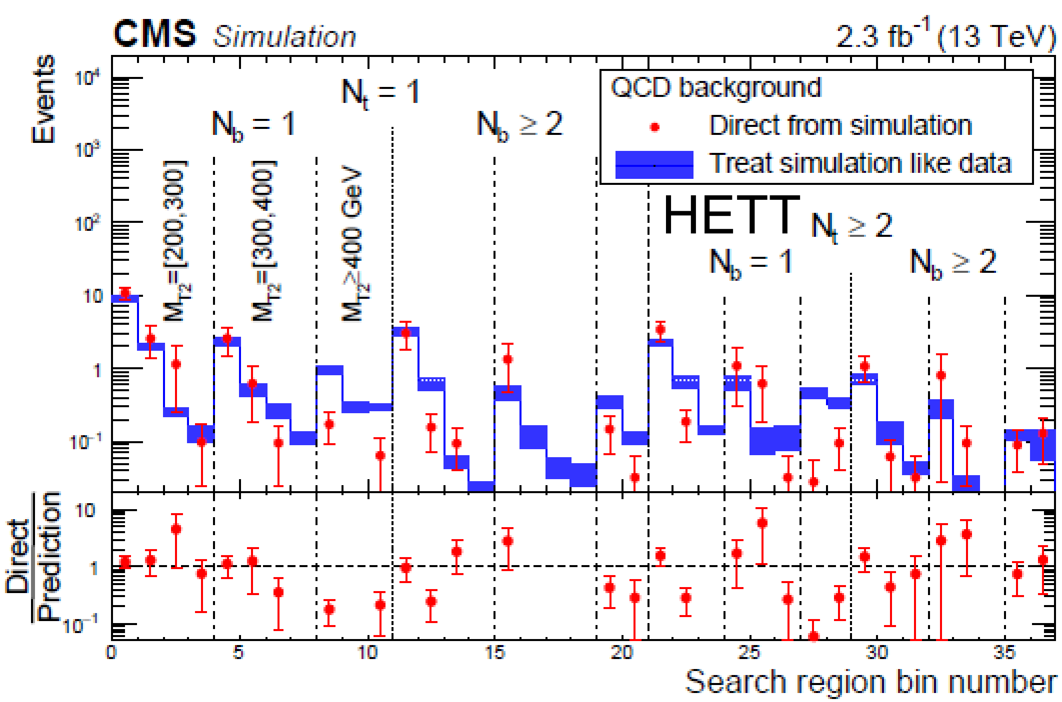
Stop search: all hadronic

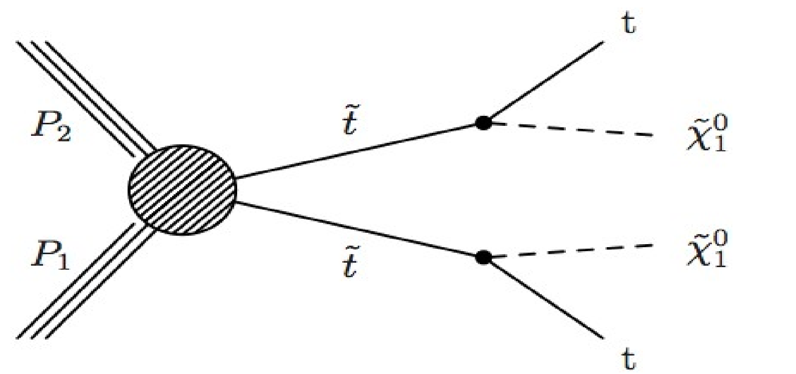
PAS-SUS-16-007

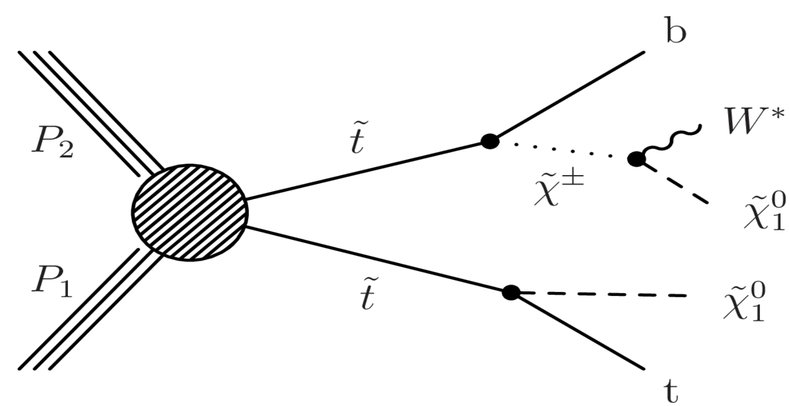
- Selection: veto ℓ, ≥4 jets+≥1btag, MET>200GeV
- High Purity Top Tagger (HPTT)
  - Optimized for low Δm, and mixed scenarios with T2tb decays
- High Efficiency Top Tagger (HETT)
  - More efficient for T2tt models with medium and large Δm

$$\Delta m = m_{\tilde{t}} - m_{\tilde{\chi}^0}$$

- Backgrounds derived from different data control samples
  - Analyses complement each other
  - Closure tests confirm good description

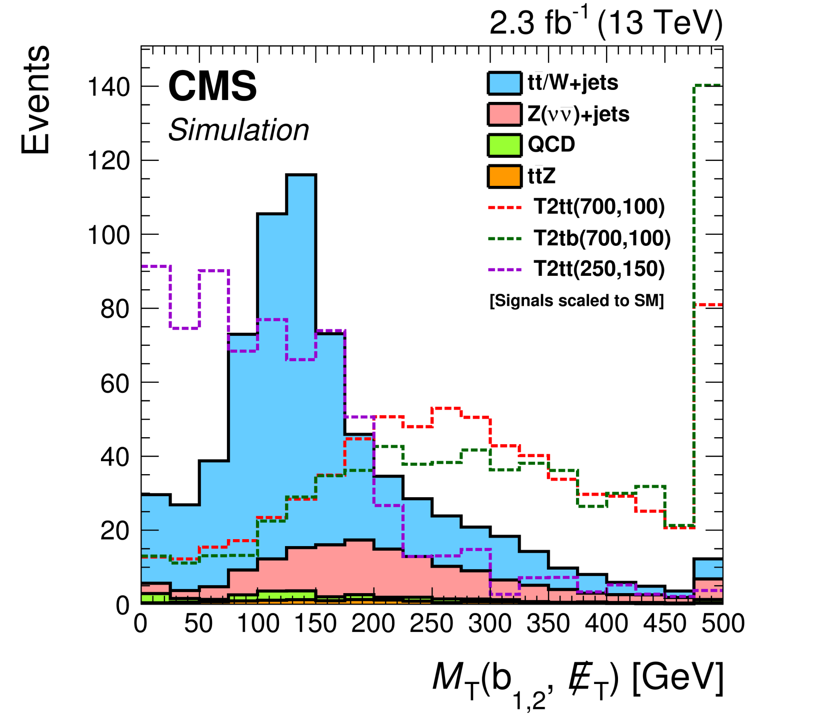




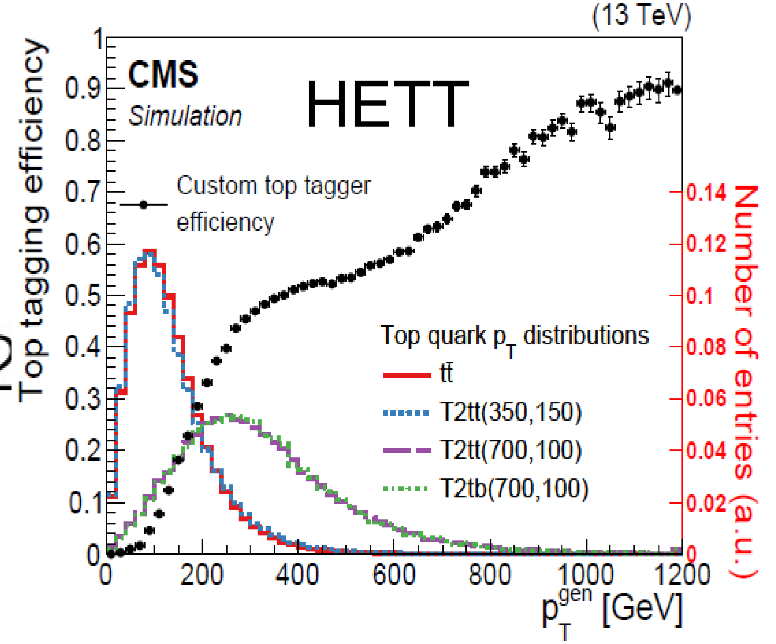


Top taggers

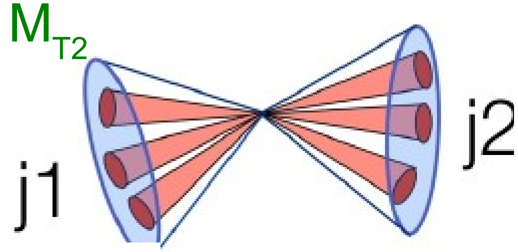
- **High Purity Top Tagger (HPTT)**
  - Cluster boosted top in ΔR=0.8 jet, with p_T>400 GeV, decompose into three subjets with mass m_{jjj}=[140,250] GeV, and m_{jj}>50 GeV
  - Bin analysis in N_t, N_b, N_j, M_T(b,MET)



- **High Efficiency Top Tagger (HETT)**
  - Cluster 3 ΔR=0.4 jets in cone ΔR=1.5 with m_{jj} and m_{jjj} within range of m_W and m_t
  - Allow for merged W and top jets, better efficiency in boosted top cases
  - Bin analysis in N_t, N_b, MET, M_{T2}



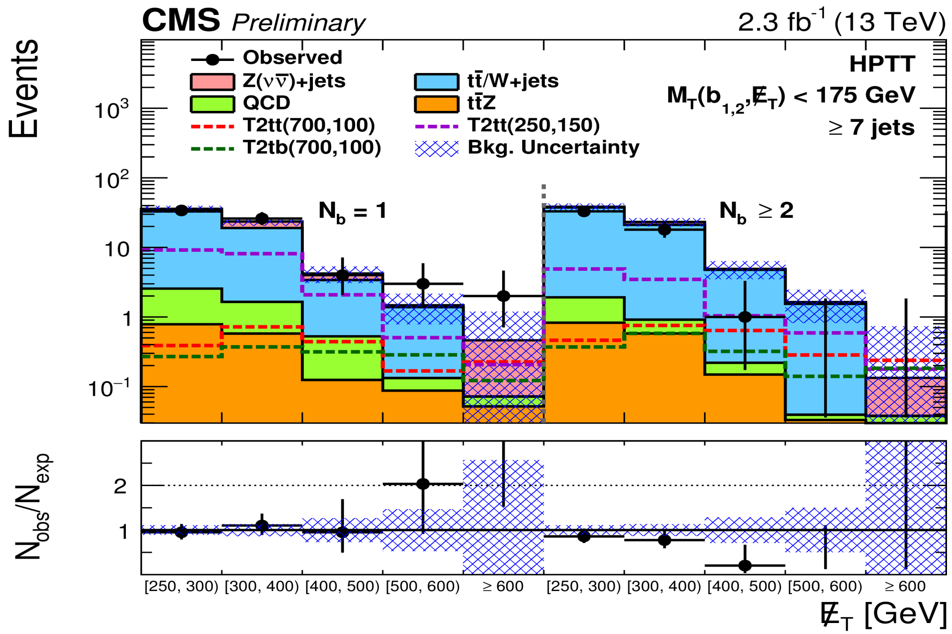
$$M_{T2}(m_\chi) = \min_{p_T^{\chi(1)}+p_T^{\chi(2)}=p_T^{miss}} \left[\max\left(m_T^{(1)}, m_T^{(2)}\right)\right],$$

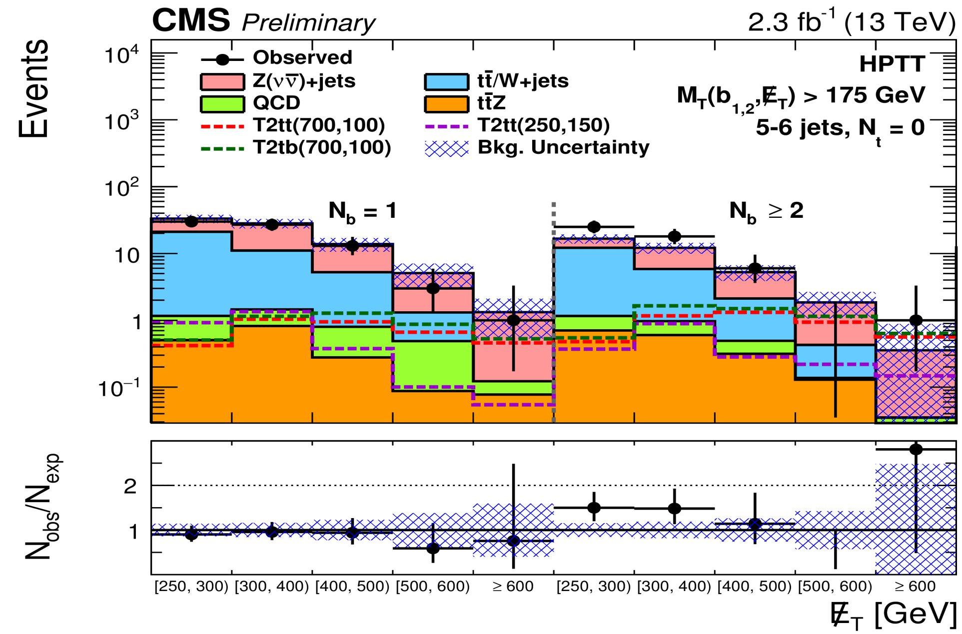


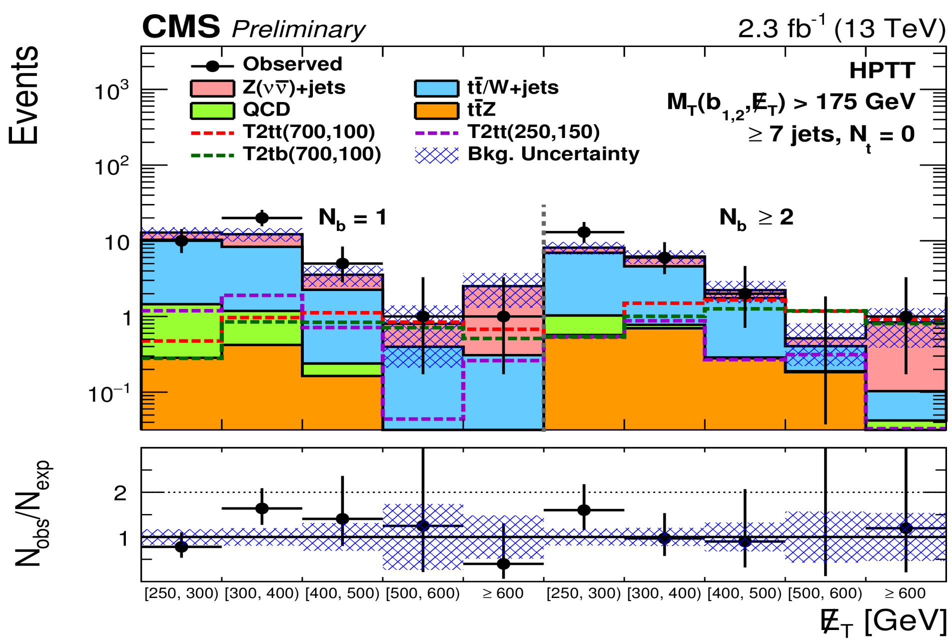
$$m_T^{(i)} = \sqrt{(m^{vis(i)})^2 + m_\chi^2 + 2\left(E_T^{vis(i)} E_T^{\chi(i)} - \mathbf{p}_T^{vis(i)} \cdot \mathbf{p}_T^{\chi(i)}\right)}.$$

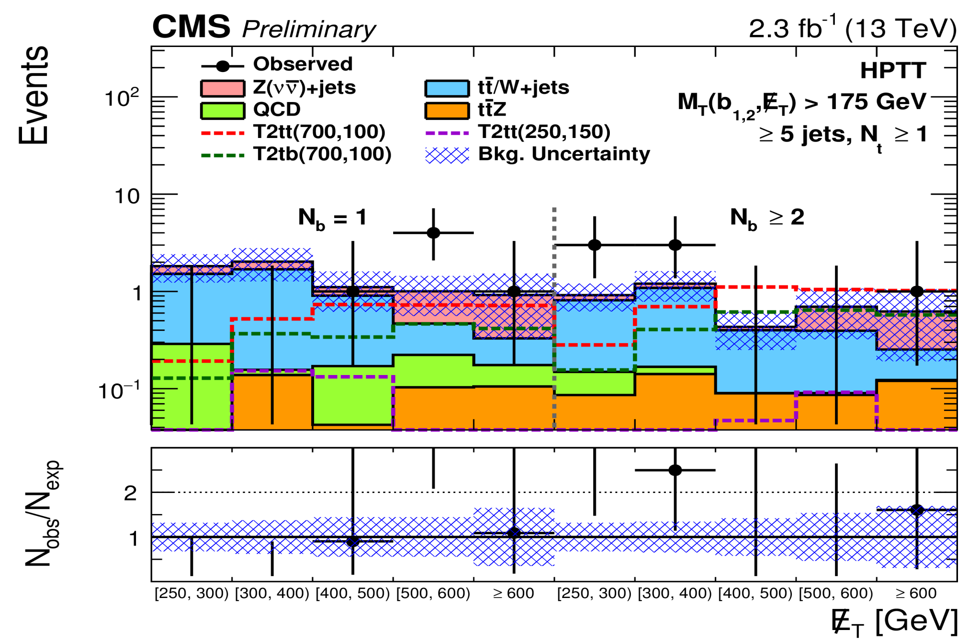
HPTT analysis: data

- Analysis has a total of 50 exclusive search regions



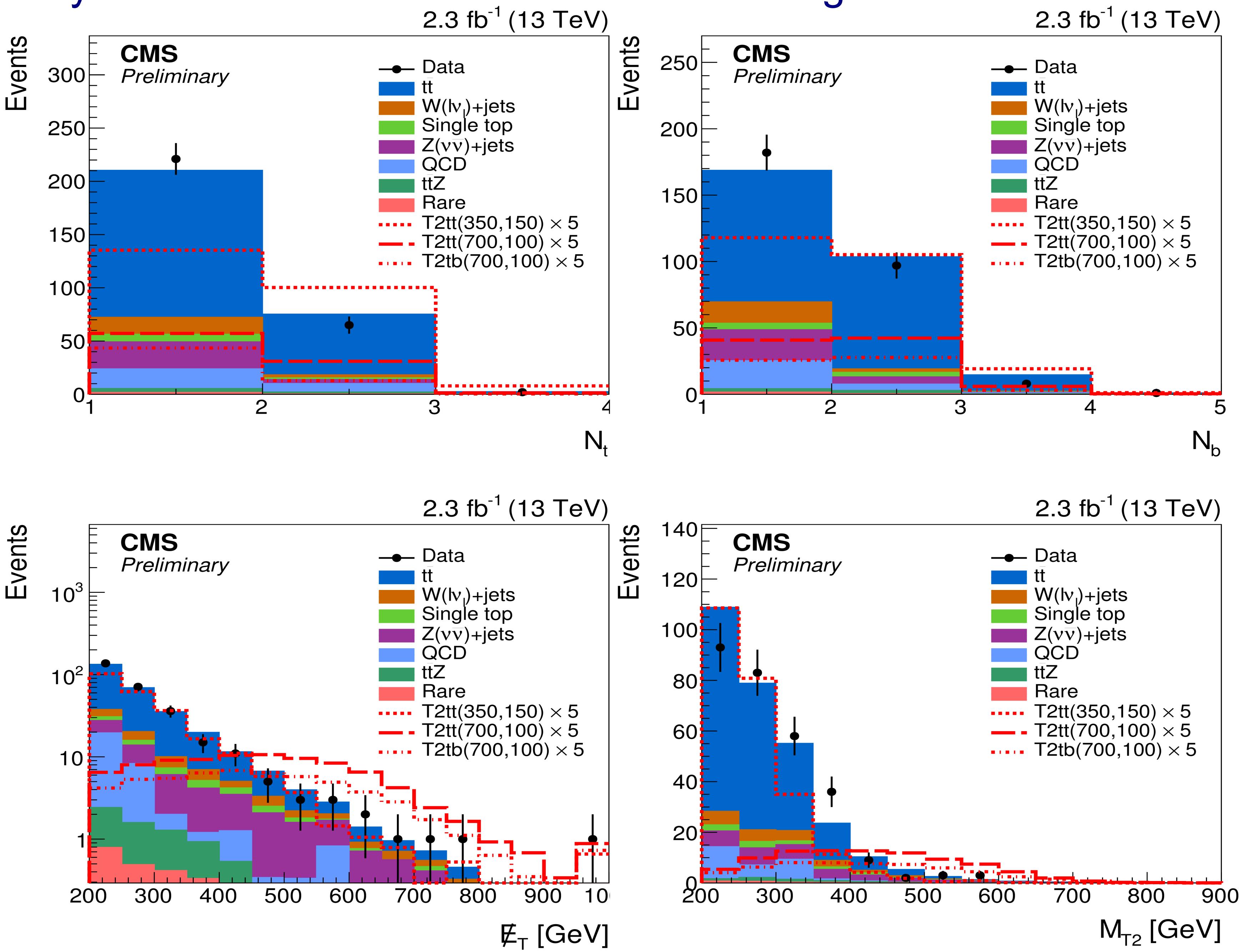






HETT analysis: data

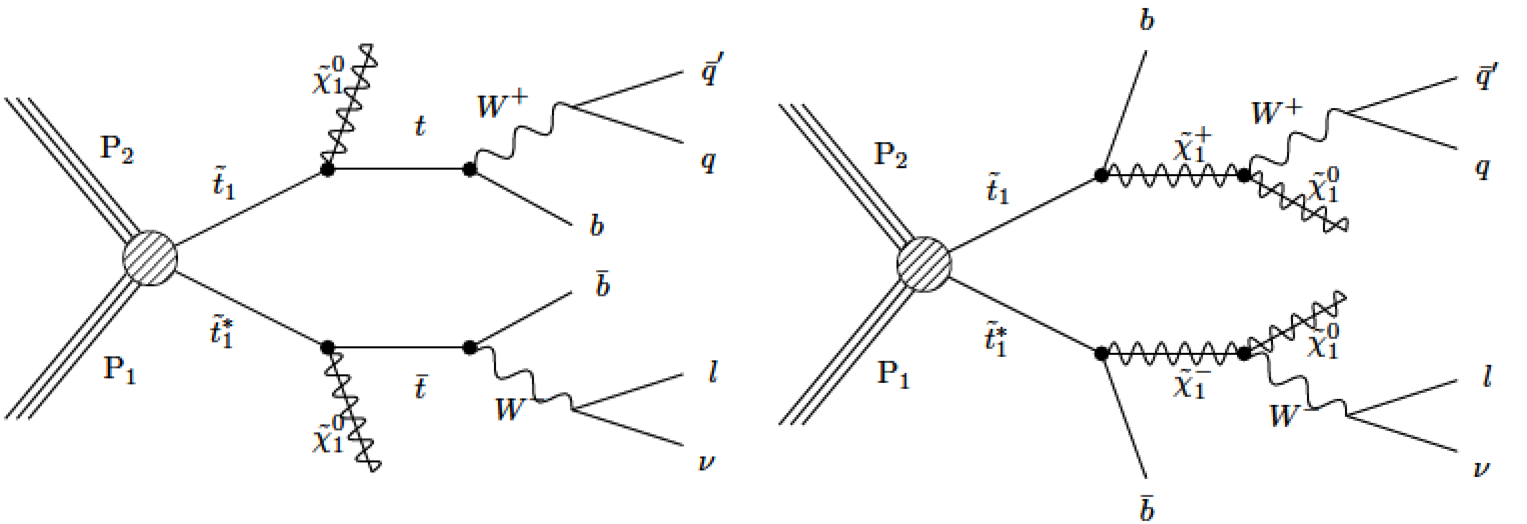
- Analysis has a total of 37 exclusive search regions



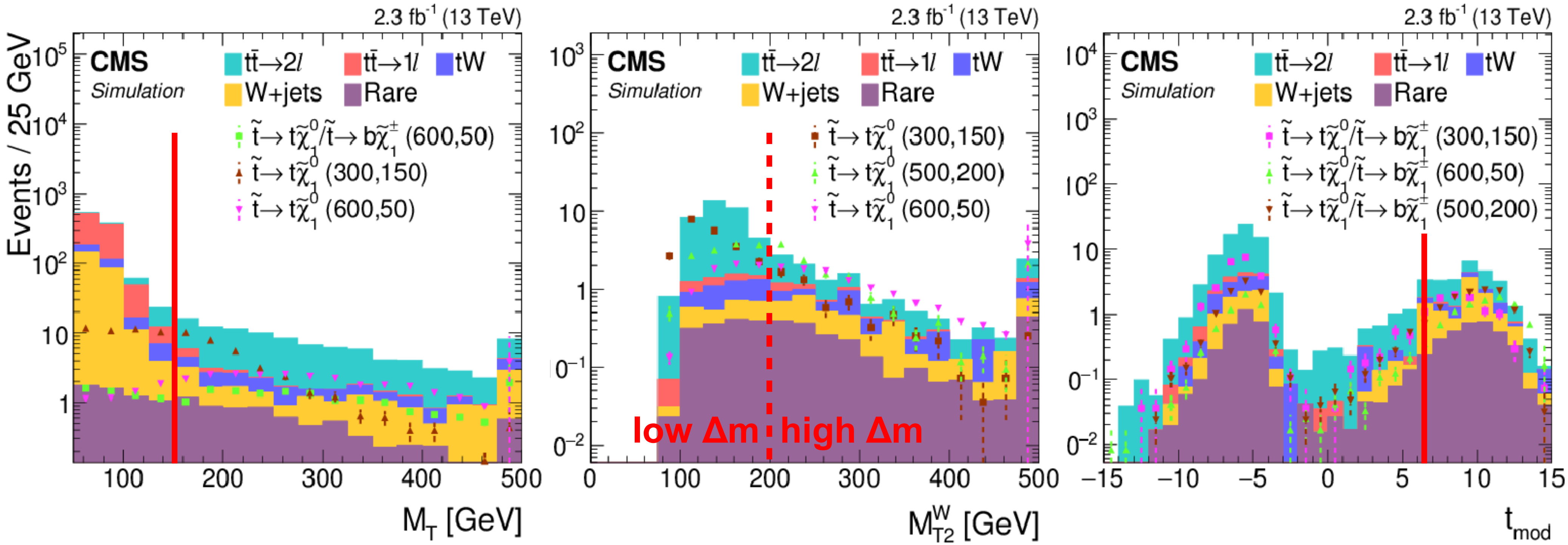
Stop search: ℓ+jets

PAS-SUS-16-002

- Sensitive to $t_1 \rightarrow t\chi^0$ and $t_1 \rightarrow b\chi^- \rightarrow bW^-\chi^0$ decays, and now also mixed
- Final state $b\ell\nu bqq$+MET: For $t\bar{t}$, 32% BR and reduced QCD background
- Selection: one isolated ℓ p_T>20 GeV; 2,3,≥4 jets with p_T>30 GeV, ≥1 b-tag, MET>250 GeV, $M_T(\ell,\text{MET})$> 150 GeV; veto other ℓ, isolated track, or τ_{had}
- Main background is $t\bar{t} \rightarrow \ell\ell$ with lost lepton
- Bin in 9 exclusive regions in N_j, M_{T2}^W, topness and MET
  - M_{T2}^W: minimum m_t imposing Ws are on shell and other constraints (arXiv:1203.4813)
  - Topness: minimize reconstructed m_W and m_t with exp resolutions (arXiv:1212.4495)

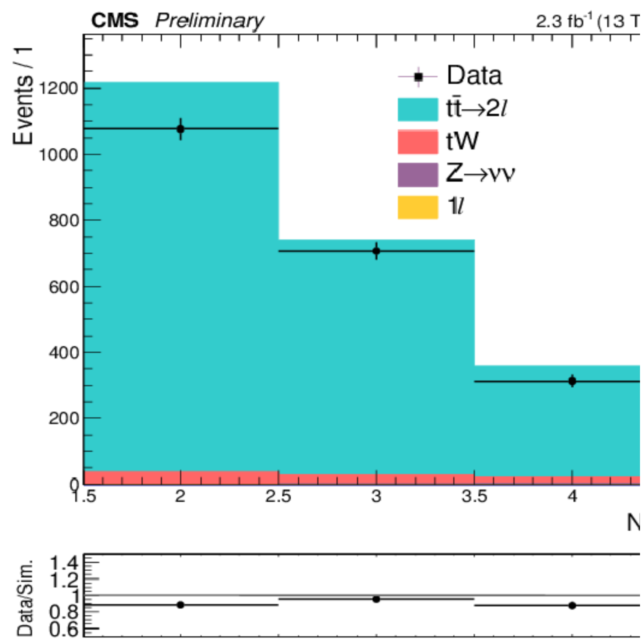


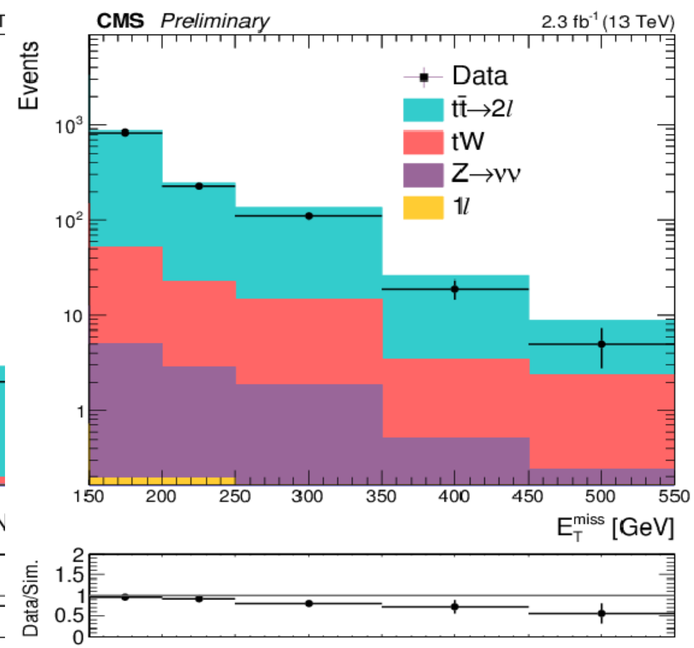
Stop ℓ+jets: data



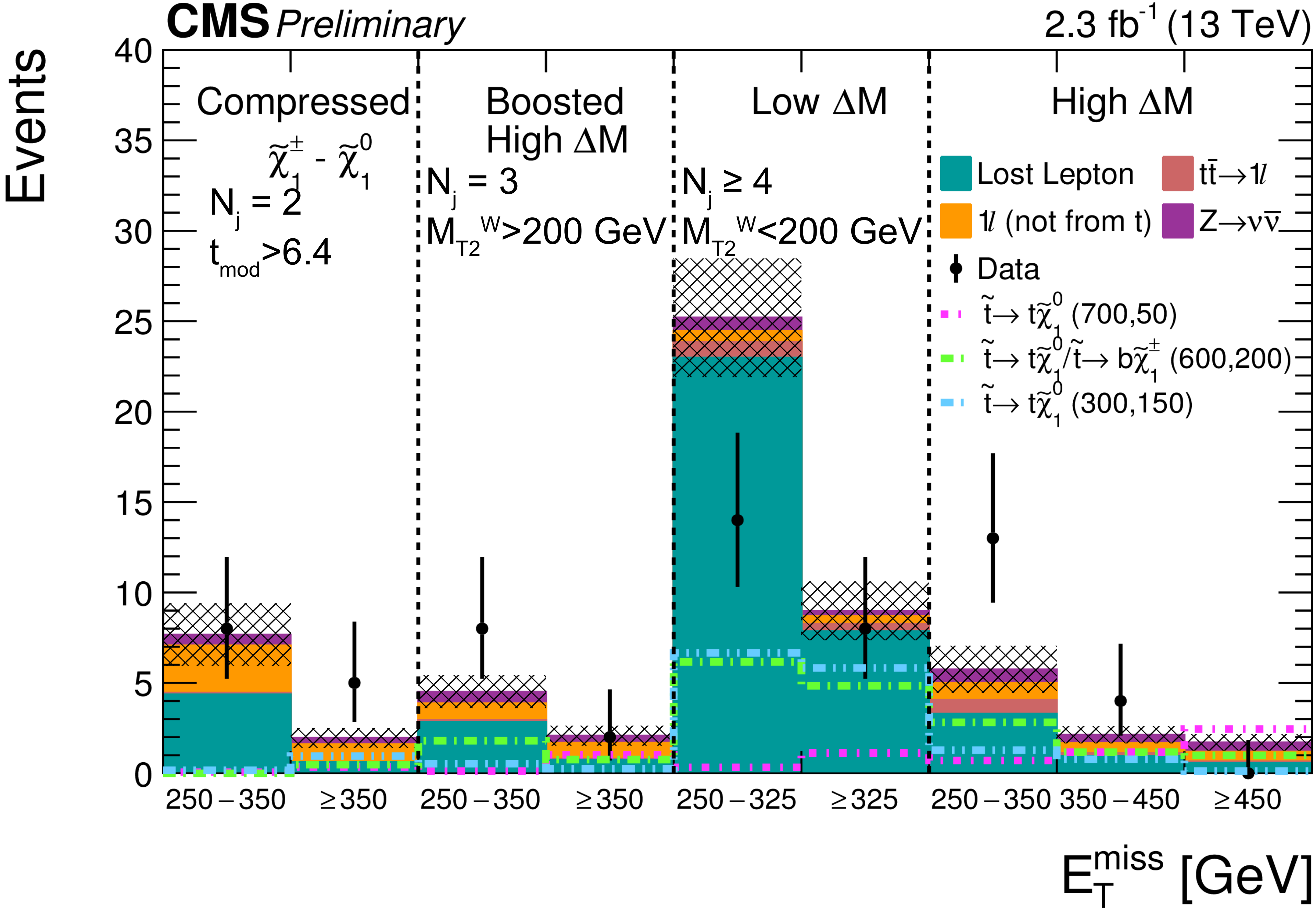
- Derive lost lepton background from data sample with inverted extra ℓ veto, and merged N_j and MET

$$N^{Data}_{lost-\ell} = N^{Data}_{2\ell} \times \frac{N^{MC}_{lost-\ell}}{N^{MC}_{2\ell}} \times \frac{N^{MC}_{lost-\ell}(NJ,\ E_T^{miss})}{N^{MC}_{lost-\ell}}$$



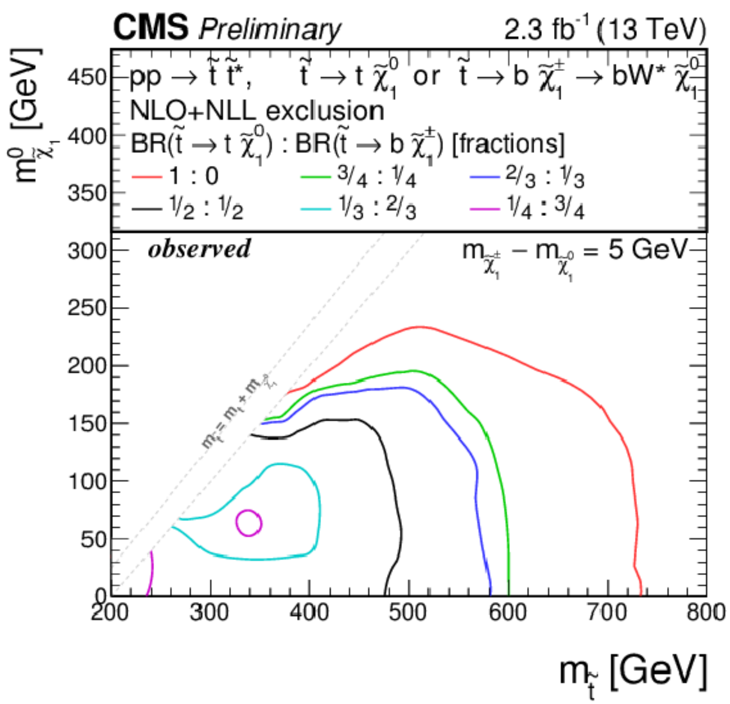


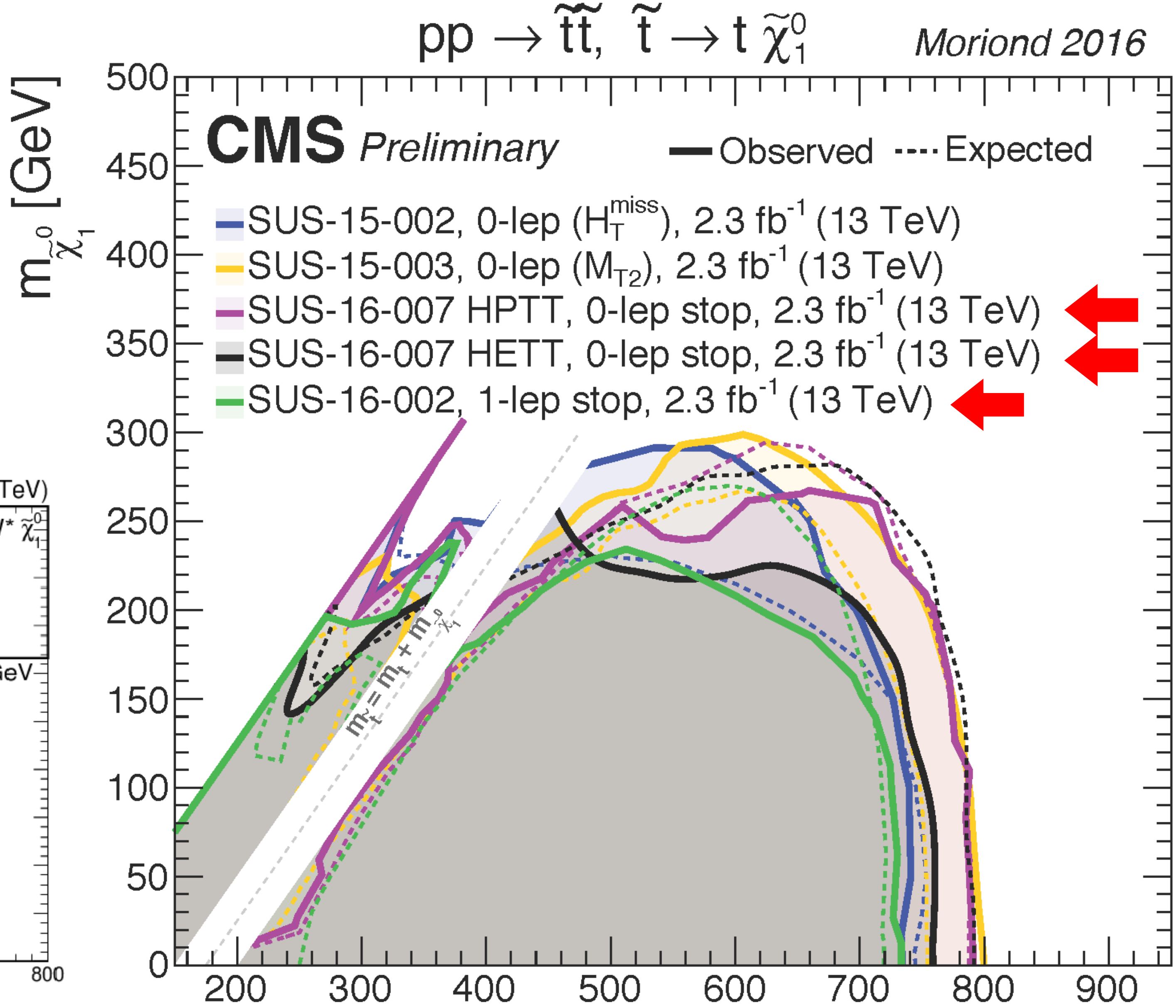
Stop ℓ+jets: results



Stop searches: limits

- HPTT is more stringent than HETT
- Similar reach as inclusive searches for low mLSP
- Limits weaken as BF for $t \rightarrow b\chi^{\pm}$ increases





$m_{\tilde{t}}$ [GeV]

See talk by S. Casasso on inclusive searches

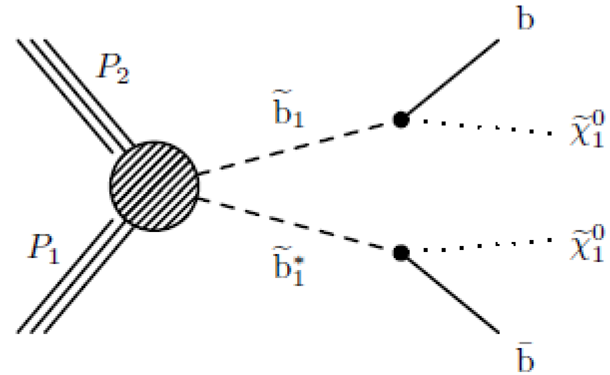
Sbottom search

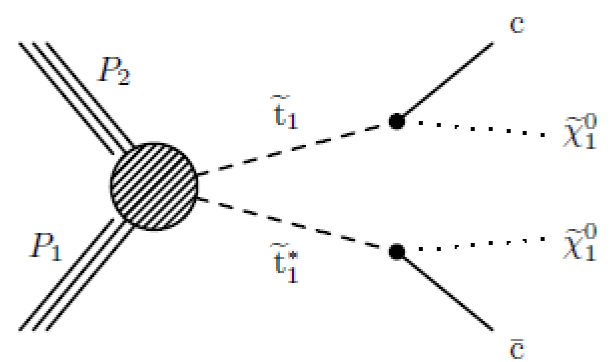
PAS-SUS-16-001

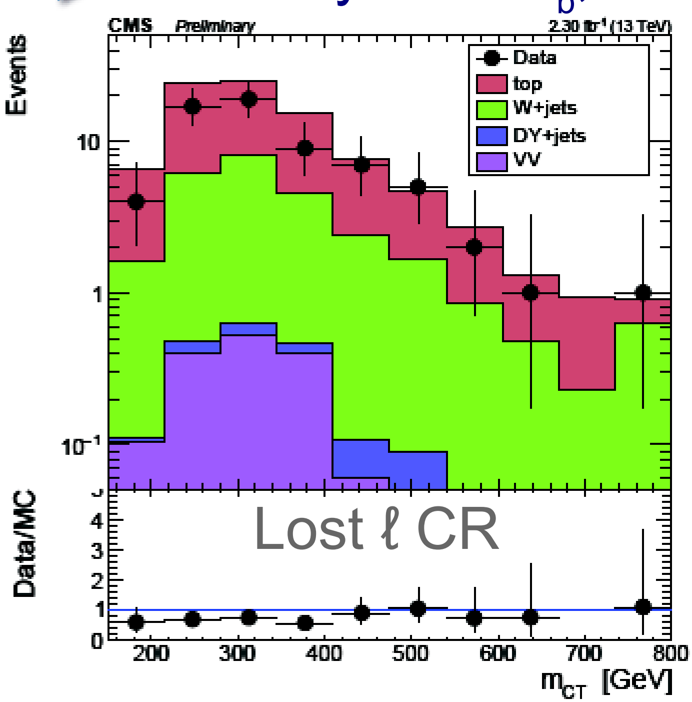
- Selection: veto ℓ, two or three jets with p_T>40 GeV, MET>250 GeV
  - Non-compressed: $p_T(j_1)$>100 GeV, $p_T(j_2)$>75 GeV, j_1 and j_2 are b-tagged, H_T>200 GeV, m_{CT}>250 GeV

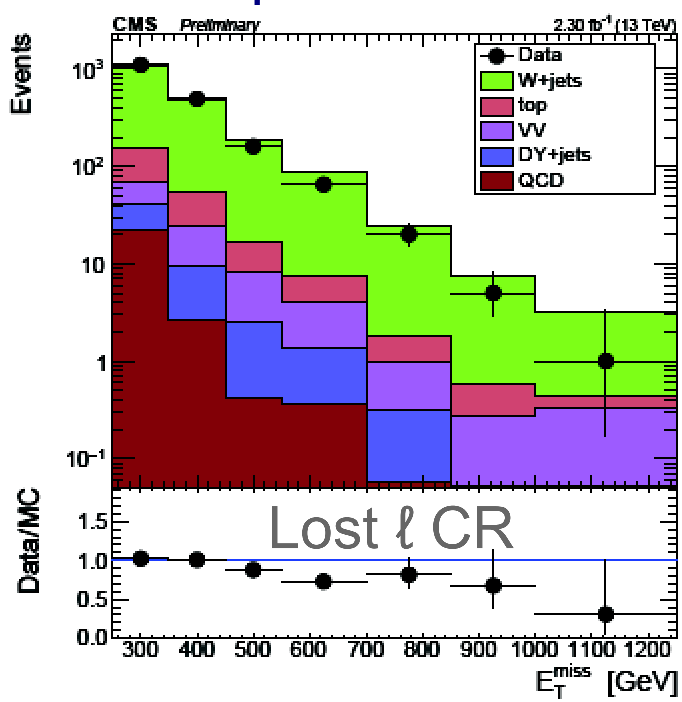
$$m_{CT}^2=2p_T(j_1)p_T(j_2)[1+\cos\Delta\varphi(j_1,j_2)]$$

  - Compressed: $p_T(j_1)$>250 GeV, $p_T(j_2)$>60 GeV, j_1 is NOT b-tagged, $\Delta\varphi(j_1,\mathrm{MET})$>2.3
  - Other topological cuts
- Bin analysis in H_T and m_{CT} for non-compressed
- Bin analysis in N_b, MET for compressed

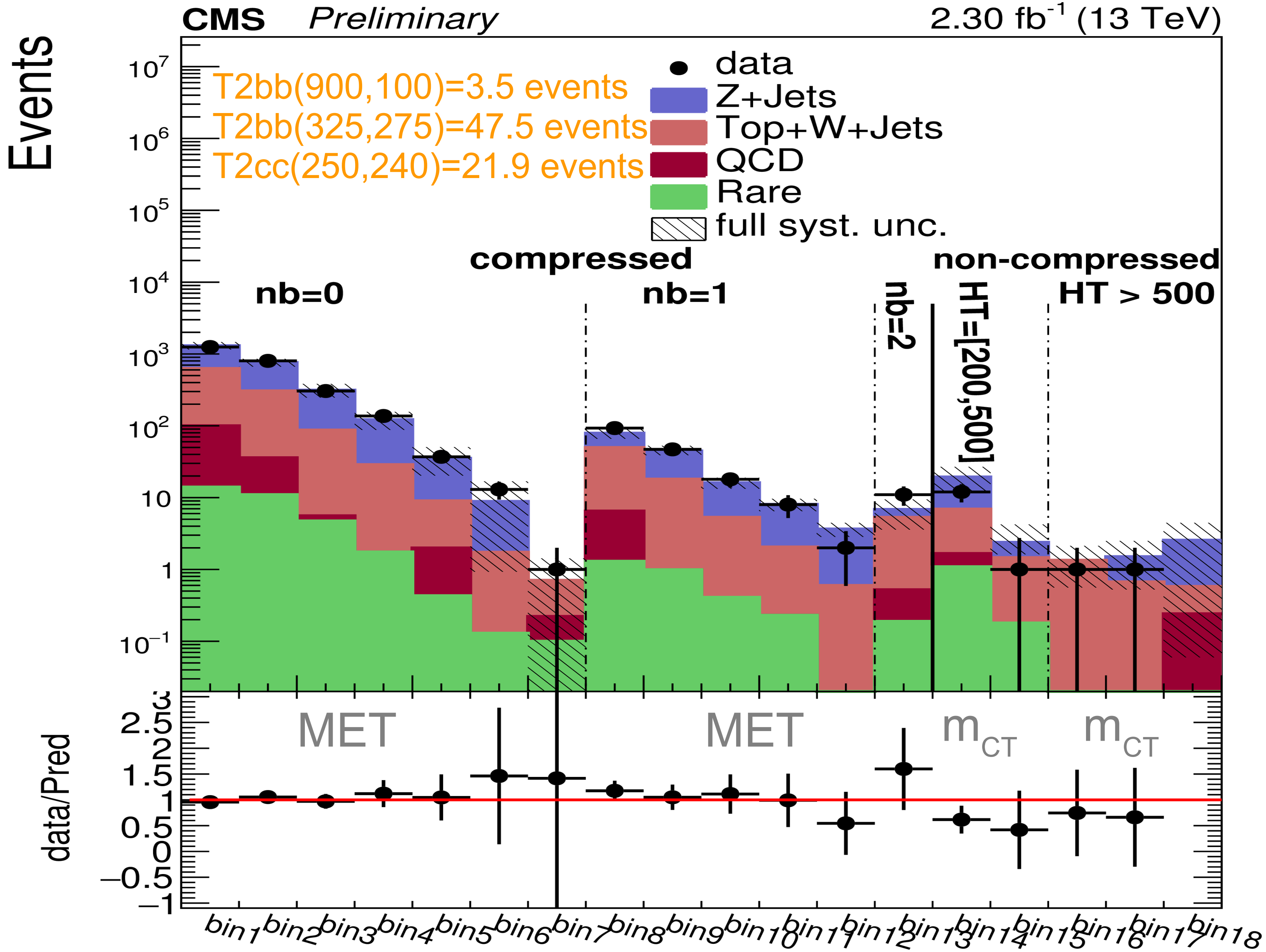




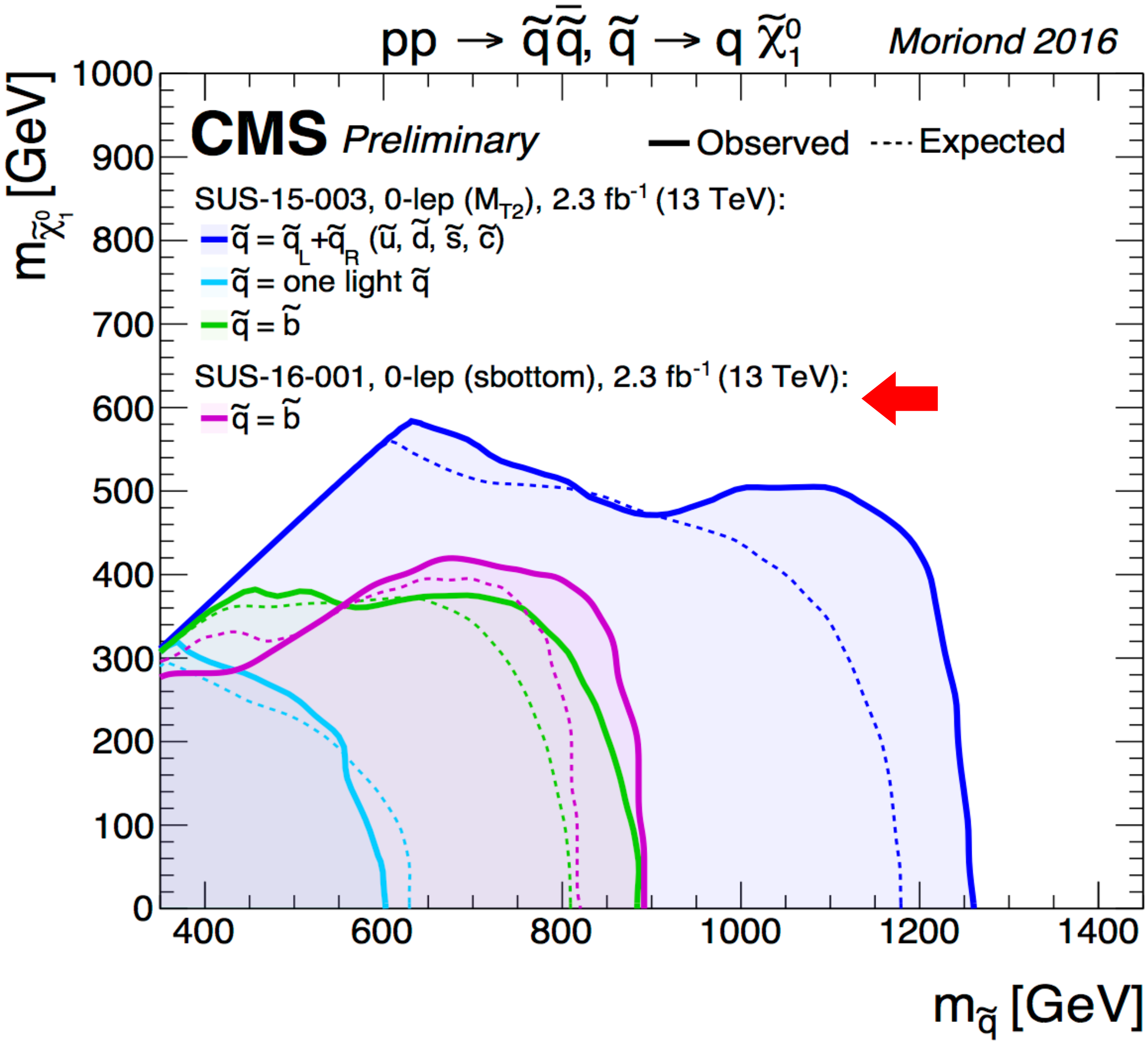


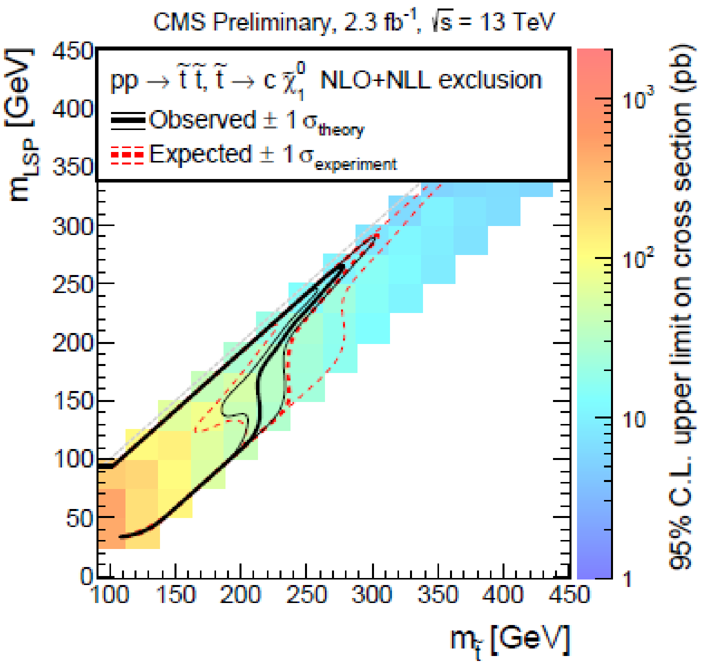


Sbottom results



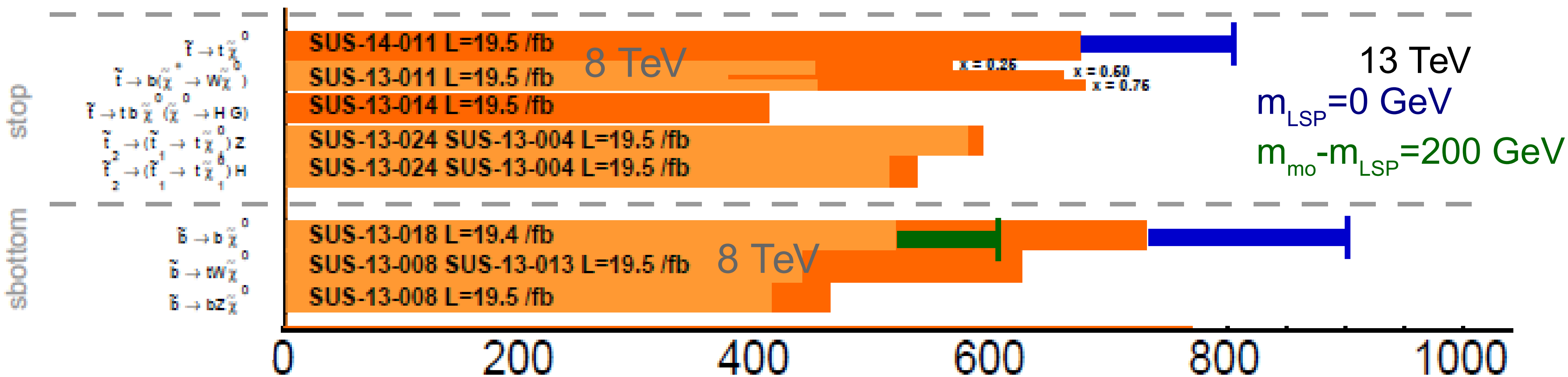
Sbottom searches: limits





Conclusions

- Targeted searches for third generation squarks
  - Covering specific signatures with dedicated tools
  - Develop top-taggers, use specific variables in different search regions
- No evidence yet, but Run2 will boost the reach
  - Focus on compressed scenarios, and $\Delta m \approx m_t$
  - Work on isolation, boosted objects, high pileup
  - Expand interpretations
- Stop searches with 2015 data beginning to surpass 8 TeV limits
  - $m_{\tilde{t}}$ > 800 GeV for low m_{LSP}
  - $m_{\tilde{b}}$ > 900 GeV for low m_{LSP}

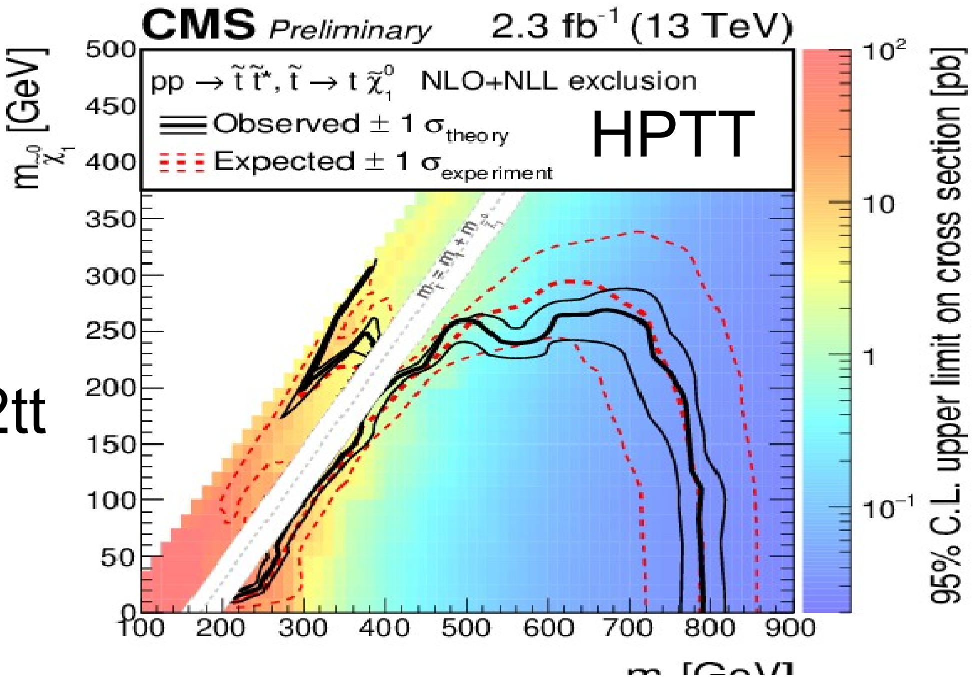


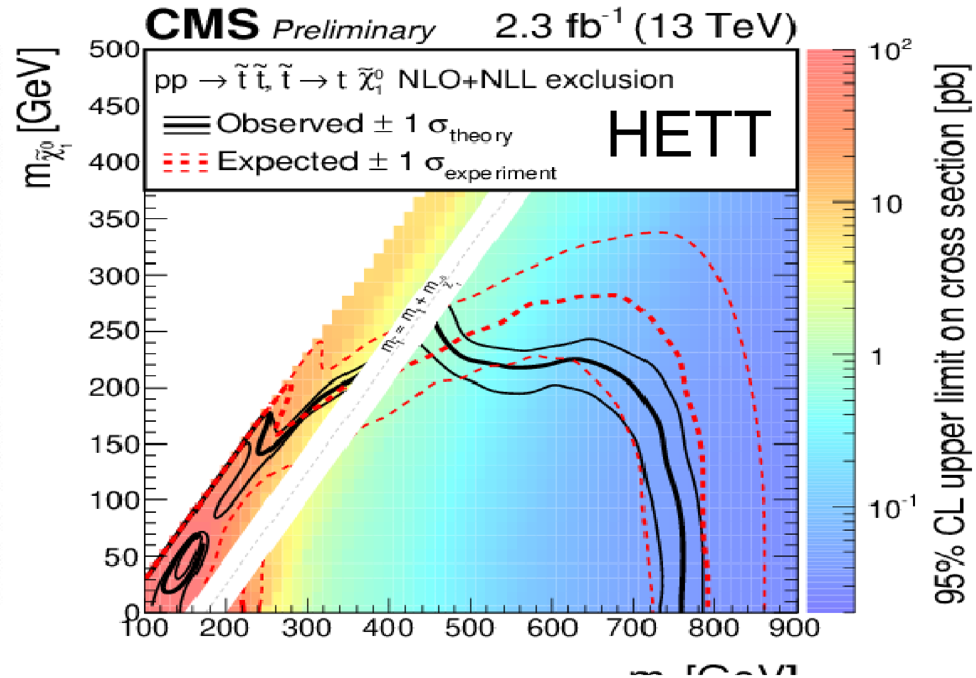
Latest results:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Extras

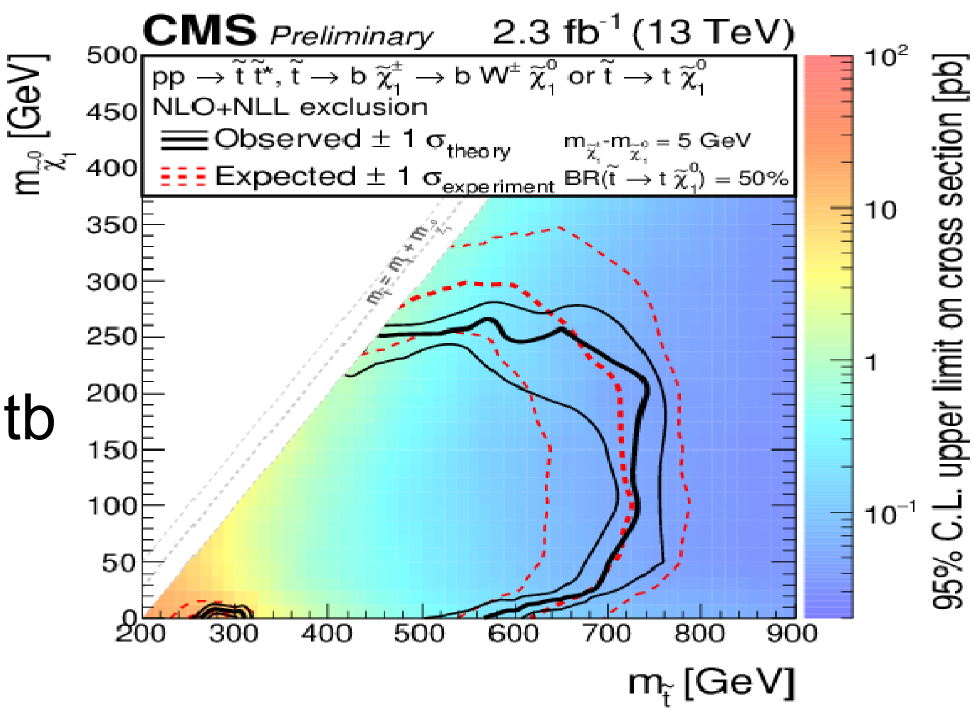
Stop: all hadronic

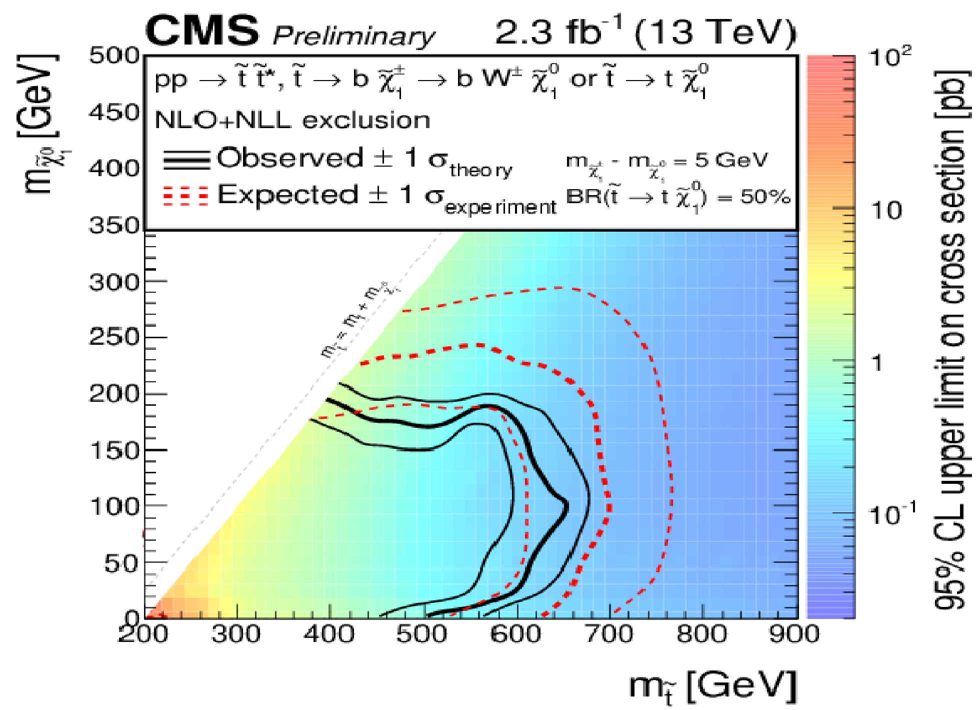
T2tt



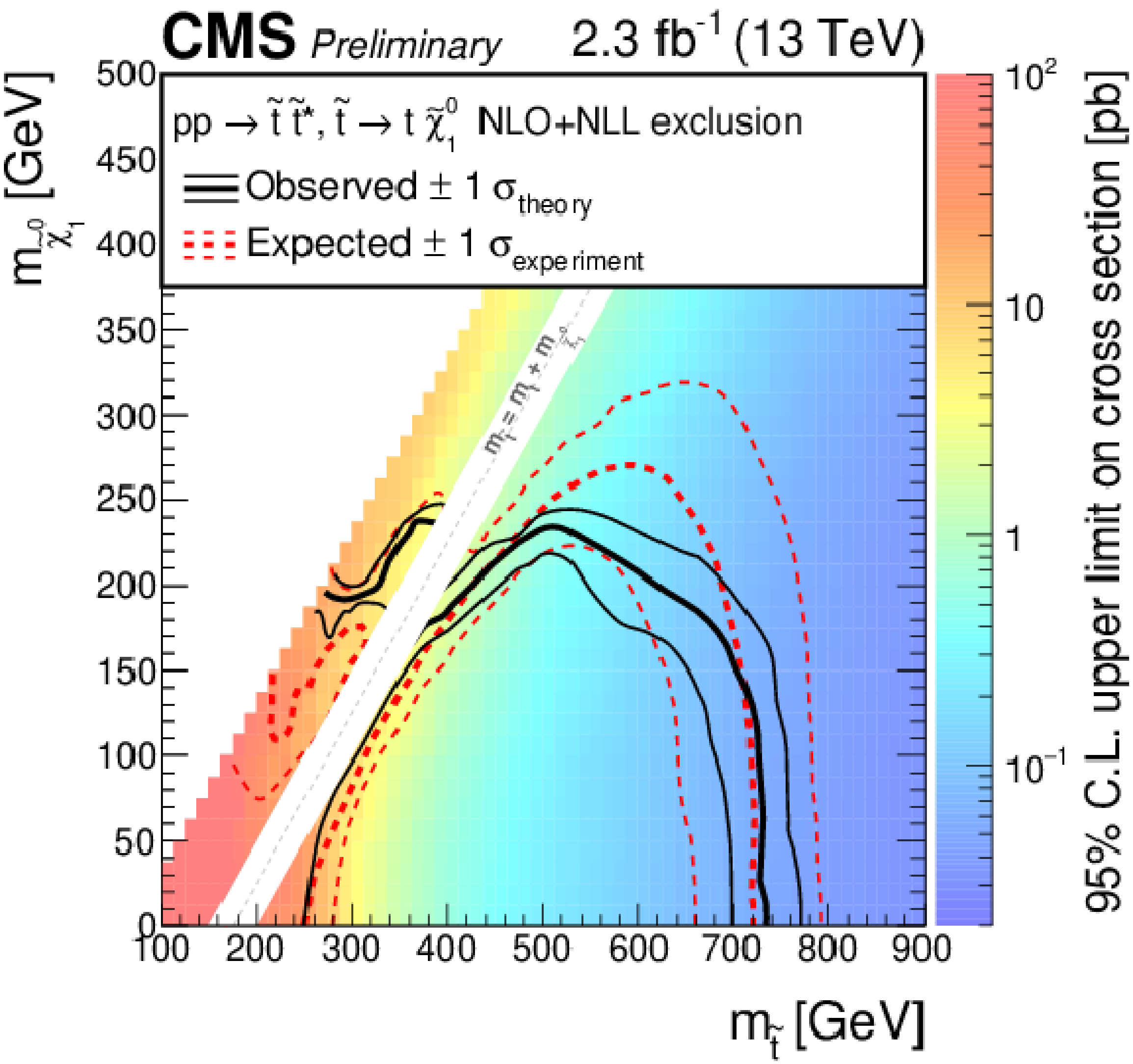


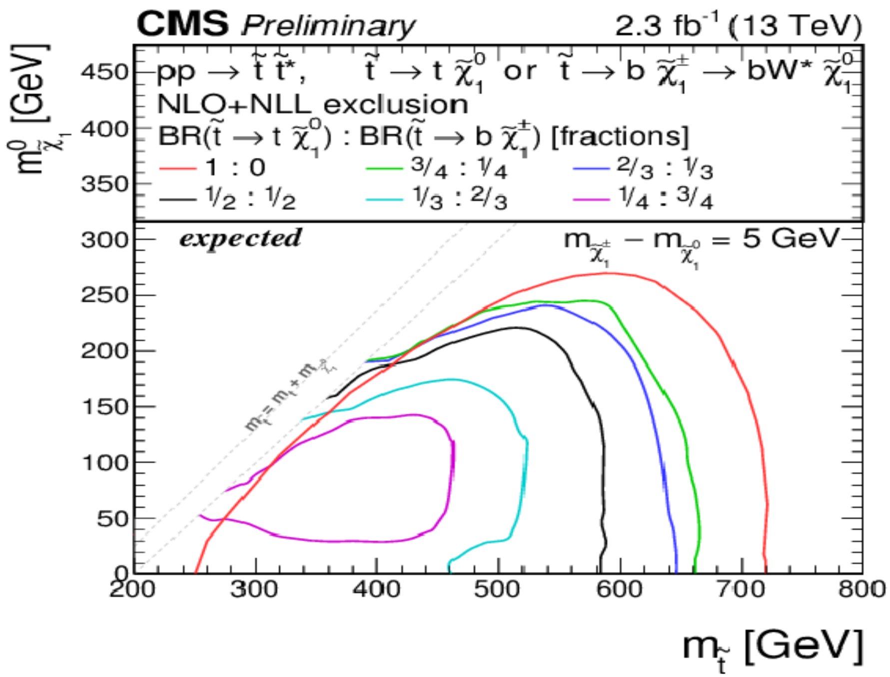
T2tb

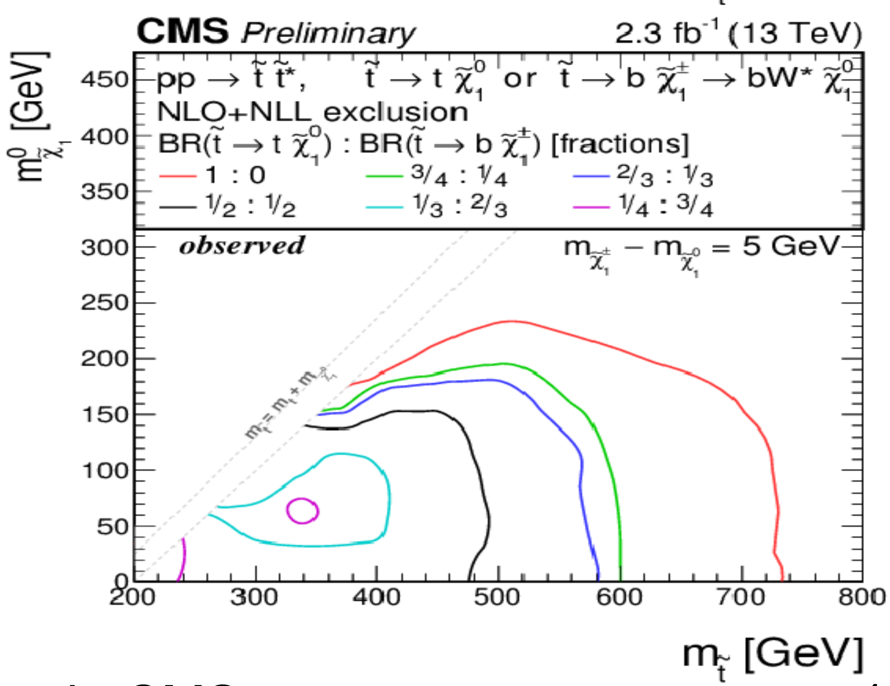




Stop: ℓ+jets

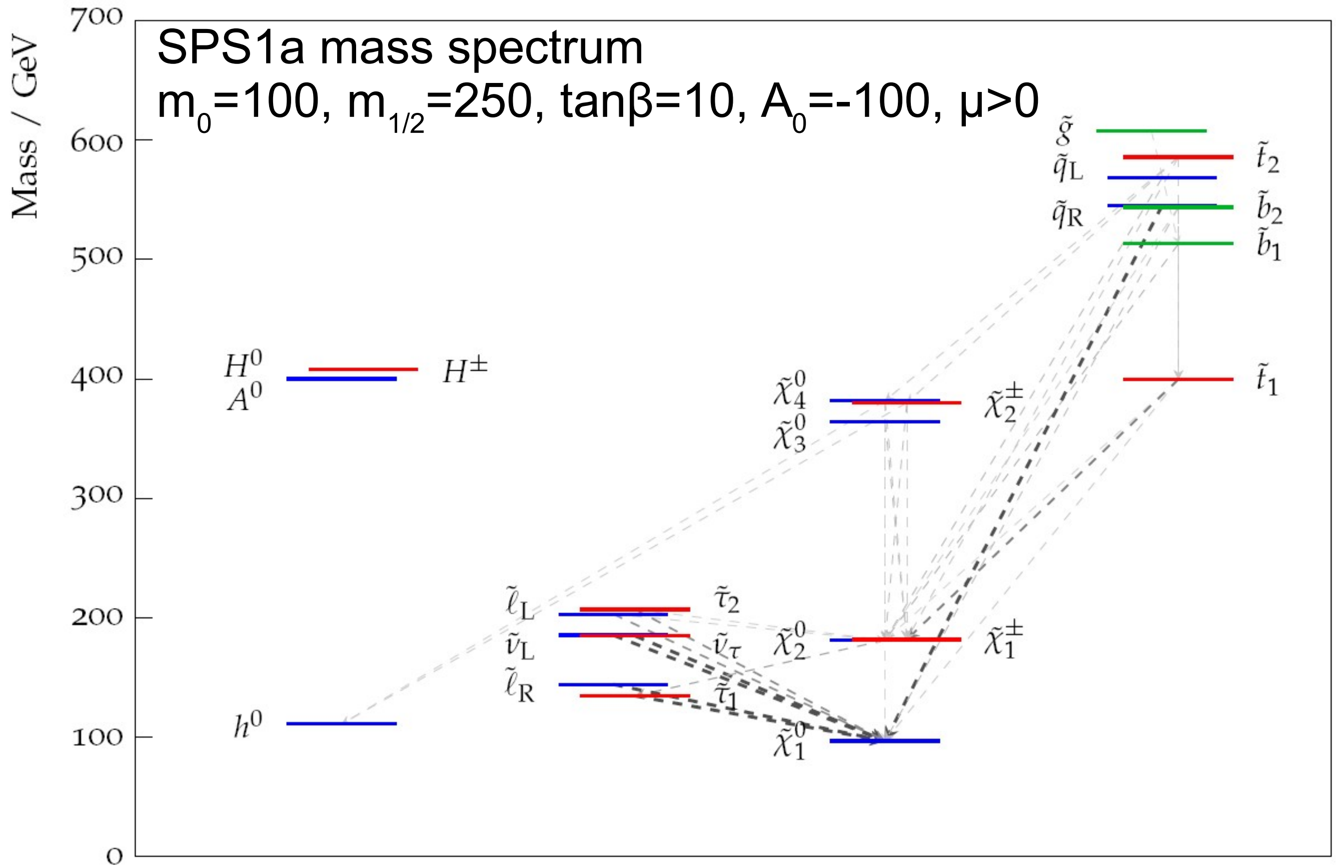






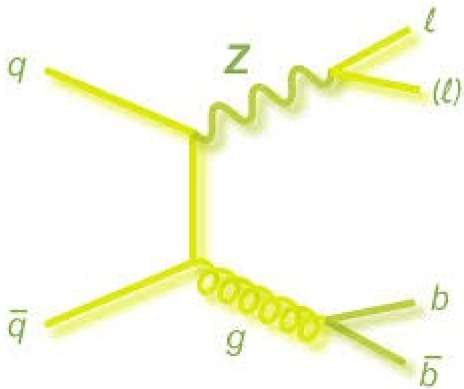
Focus of current searches

- Higgs at m_H=125 GeV leads to large $\tilde{t}$ mass or large mixing in MSSM
  - Compressed spectra
- Naturalness favors light stops and higgsinos

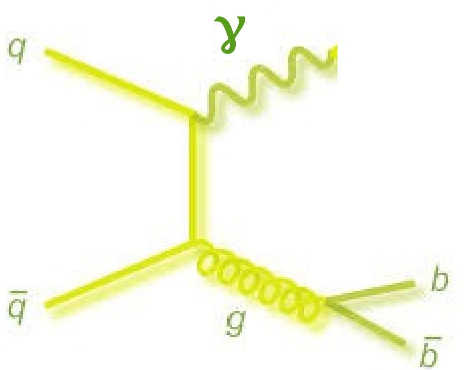


Background determination

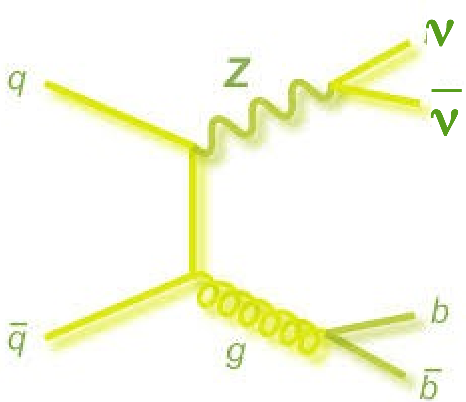
- Illustrative example: $Z \rightarrow \nu\nu$+jets (irreducible background in jets+MET)



- $Z \rightarrow \ell\ell$+jets control sample
  - Strength: very clean, easy to select
  - Weakness: low stats (1/6 of $Z \rightarrow \nu\nu$+jets)



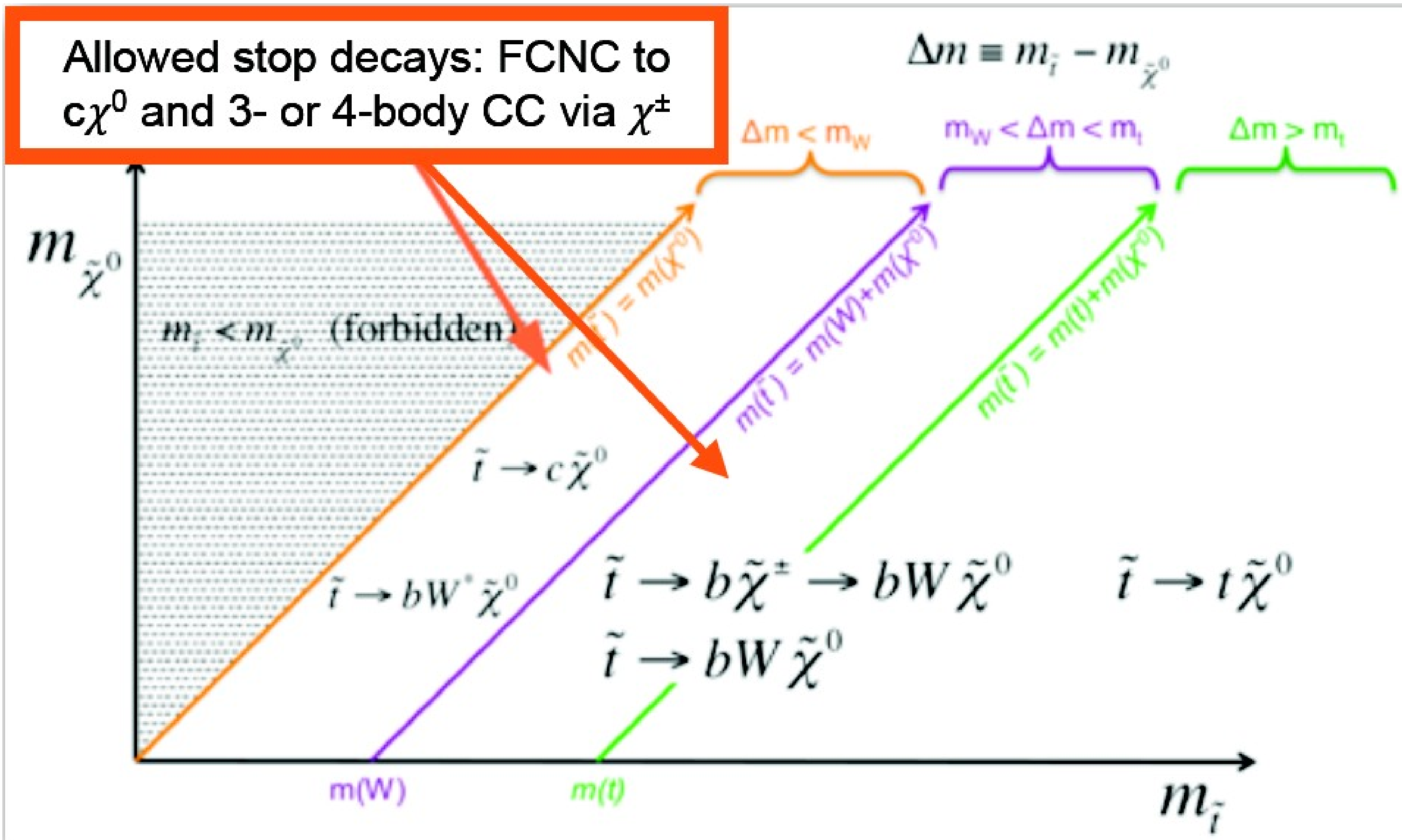
- γ+jets control sample
  - Strength: large stats, clean for high E_γ
  - Weakness: Noisy for E_γ < 100 GeV, theory uncertainties



- $Z \rightarrow \nu\nu$+jets

$$N^{predicted}_{Z\rightarrow\nu\nu} = \frac{N^{MC}_{Z\rightarrow\nu\nu}}{N^{MC}_{control}} \, x \, N^{data}_{control}$$

  - Study different control samples and understand their weaknesses and strengths
  - Verify MC extrapolation factor by predicting e.g. Z+jets from W+jets


Allowed stop decays: FCNC to $c\chi^0$ and 3- or 4-body CC via $\chi^{\pm}$
$\Delta m \equiv m_{\tilde{t}} - m_{\tilde{\chi}^0}$
$\Delta m < m_W$
$m_W < \Delta m < m_t$
$\Delta m > m_t$
$m_{\tilde{\chi}^0}$
$m_{\tilde{t}} < m_{\tilde{\chi}^0}$ (forbidden)
$m(\tilde{t}) = m(\tilde{\chi}^0)$
$m(\tilde{t}) = m(W)+m(\tilde{\chi}^0)$
$m(\tilde{t}) = m(t)+m(\tilde{\chi}^0)$
$\tilde{t} \rightarrow c\tilde{\chi}^0$
$\tilde{t} \rightarrow bW^* \tilde{\chi}^0$
$\tilde{t} \rightarrow b\tilde{\chi}^{\pm} \rightarrow bW\tilde{\chi}^0$
$\tilde{t} \rightarrow bW\tilde{\chi}^0$
$\tilde{t} \rightarrow t\tilde{\chi}^0$
m(W)
m(t)
$m_{\tilde{t}}$