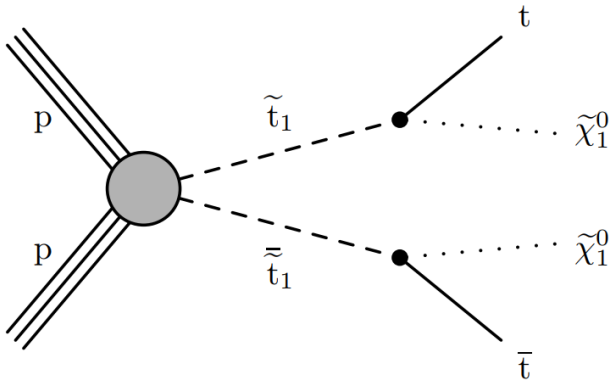
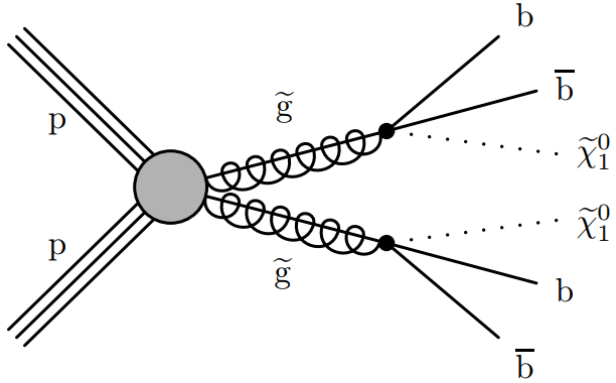
LHCP 2018

Bologna – June 5, 2018

Searches for strong production of SUSY particles in CMS

- Introduction
- Limits from 13 TeV
- Some recent analyses:
  - All hadronic inclusive α_T analysis
  - All hadronic with top tagger
  - Stops in 1ℓ final state with Δφ(ℓ,W)
  - Gluinos with $H \rightarrow b\bar{b}$
- Conclusions





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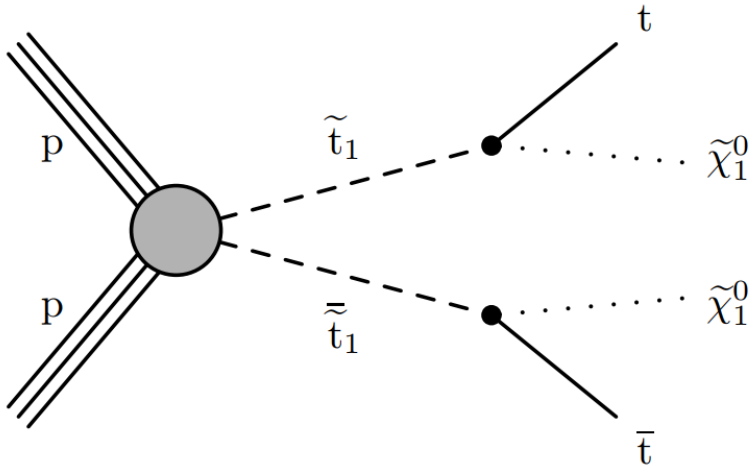
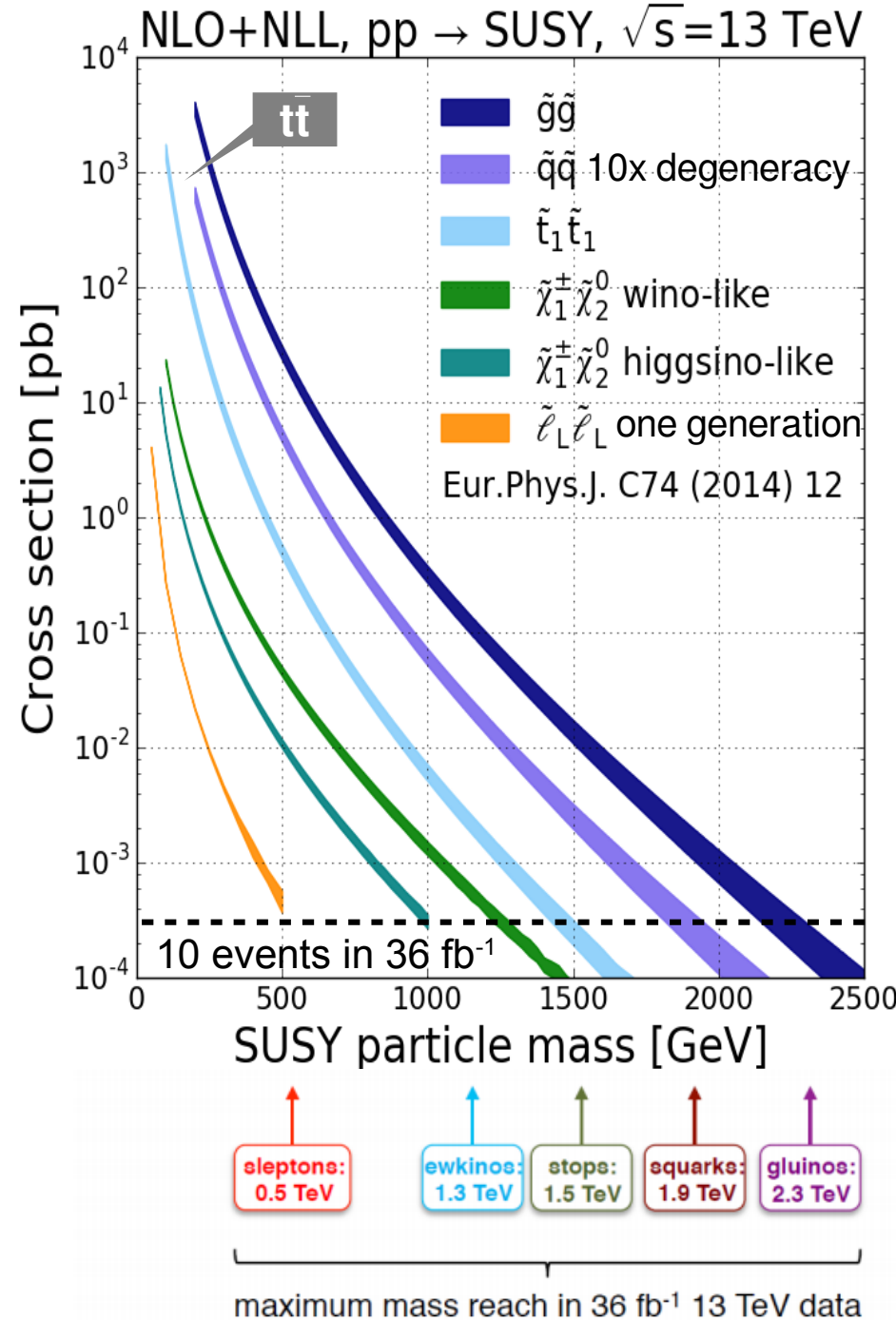
On behalf of the CMS Collaboration

SUSY strong production

- Higgs at m_H=125 GeV leads to large stop mass or large mixing in MSSM
- Naturalness favors light stops and higgsinos
- Currently sensitive to σ(SUSY)~10^{-3} pb
- Highest cross section for squarks, gluinos → strong production
  - This talk will only cover strong production, conserved R-parity and large mass splits
- Use Simplified Mass Spectra
  - Order ≥4 sparticles, ~2 masses are free
    - Assume all others are heavy & decoupled
  - Compute the acceptance x efficiency
  - Determine 95% CL upper limit on σxBR²



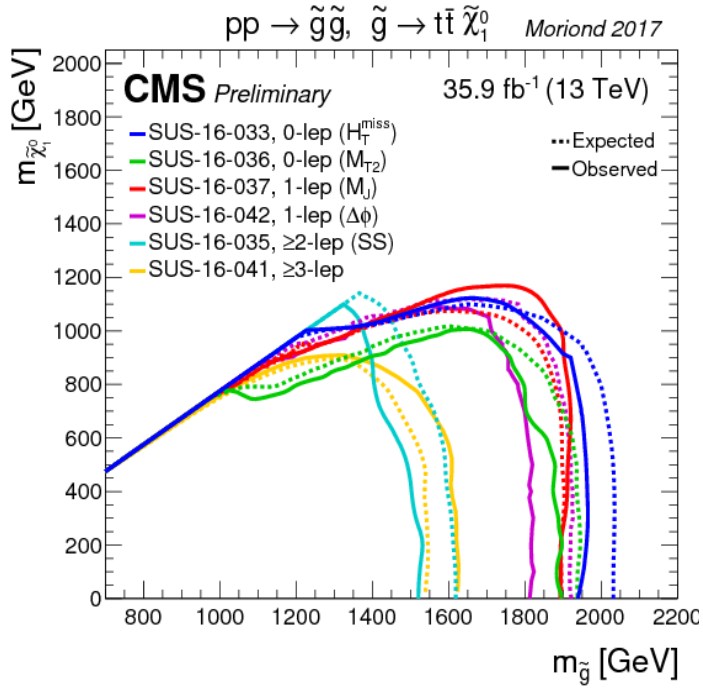


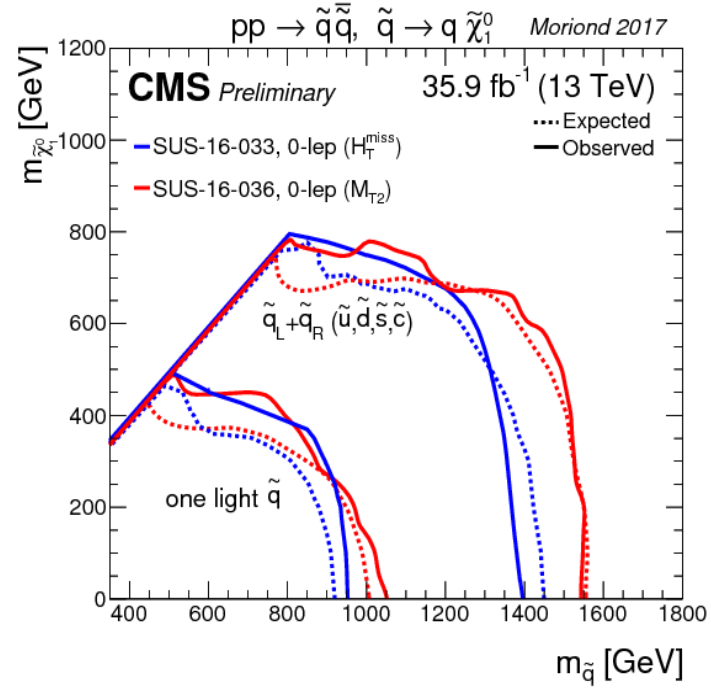
Strong production limits in Run2

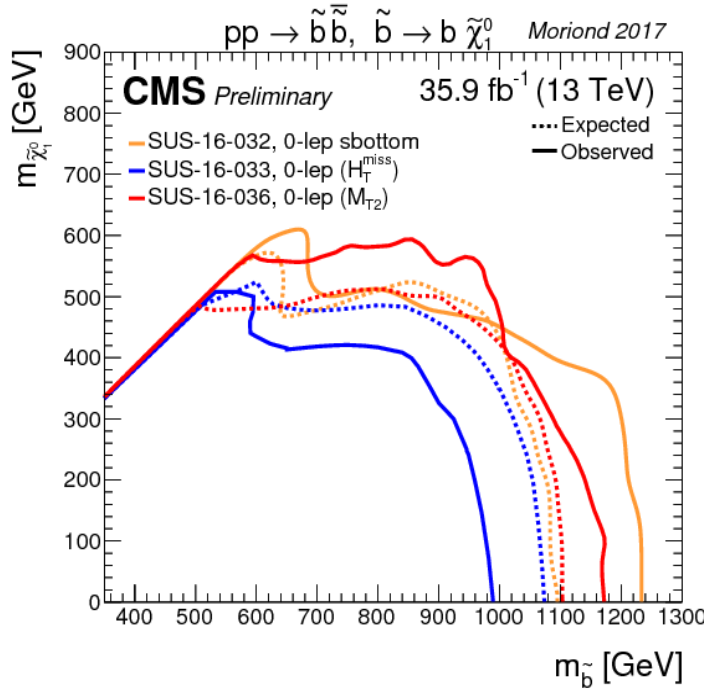
- Gluinos > 1.9 TeV
- Squarks > 1.5 TeV
- Stops > 1.1 TeV
- Sbottoms > 1.2 TeV

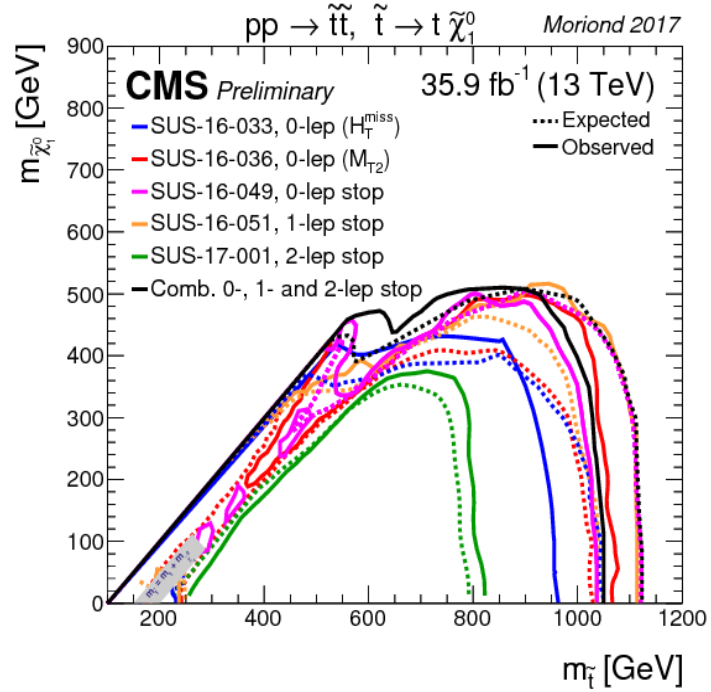
- MSSM and natural spectra heavily disfavored (not yet completely excluded)

- Complementarity of analyses
  - Many bins in several observables to obtain good sensitivity
  - Stay open to scenarios beyond benchmark models
  - Results in “aggregate” regions to facilitate interpretation





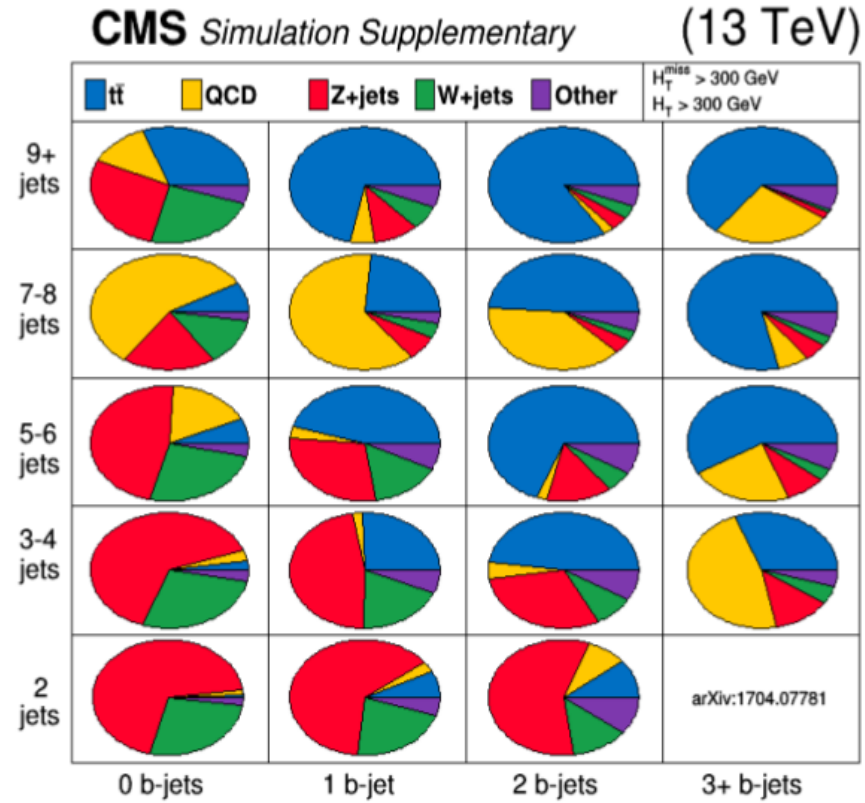




Background determination

Take all hadronic stop search as an example

- Control regions kinematically similar to signal region, but not overlapping
  - Use transfer factors to estimate SR yield from CR
- $t\bar{t}$ and W+jets (lost lepton) background:
  - μ+jets sample: invert ℓ veto, N_b bins
  - Correct TF for ℓ eff. and different background composition
- Z→νν background:
  - From Z→ℓℓ and γ+jets, enriched samples
  - Main unc. from b-tag, ε_γ, stats in CR
- QCD multijet background:
  - Enhance multijet by requiring MET and jets to overlap
  - TF determined on low-MET region and extrapolated using MC
- Check prediction in validation samples, or performing closure tests



$$N_{\rm pred}^{LL} = \frac{N_{\rm MC}^{0\ell}}{N_{\rm MC}^{1\ell}} \times N_{\rm data}^{1\ell}$$

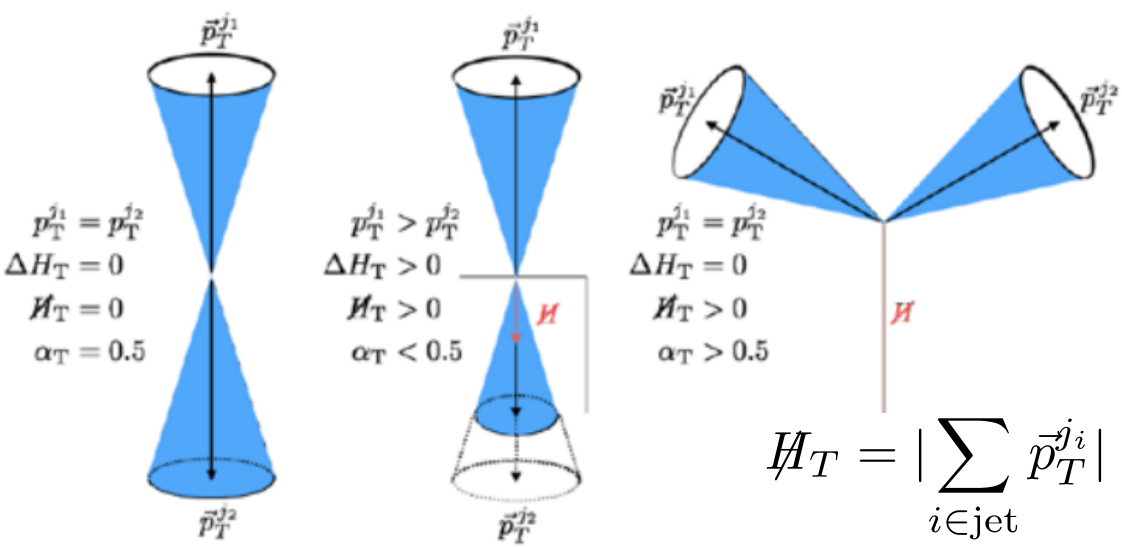
$$N_{\rm pred}^{Z\to\nu\nu} = N_{MC}^{Z\to\nu\nu} \times \frac{N_{\rm data}^{Z\to\ell\ell}}{N_{\rm MC}^{Z\to\ell\ell}} \times \frac{N_{MC}^{\gamma+jets}}{N_{\rm data}^{\gamma+jets}}(\not{E}_T^{\gamma})$$

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

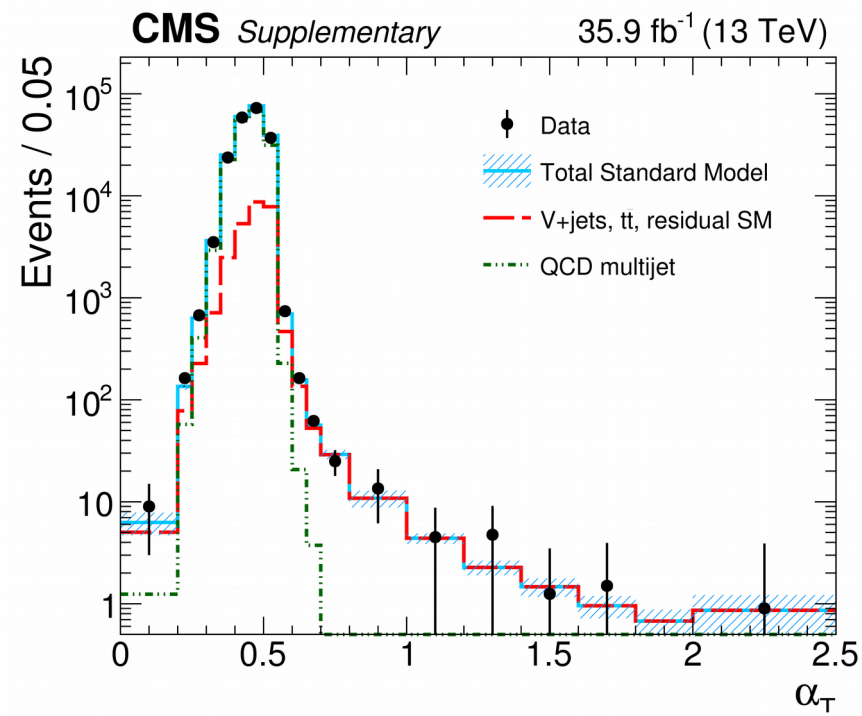
Inclusive hadronic search with α_T

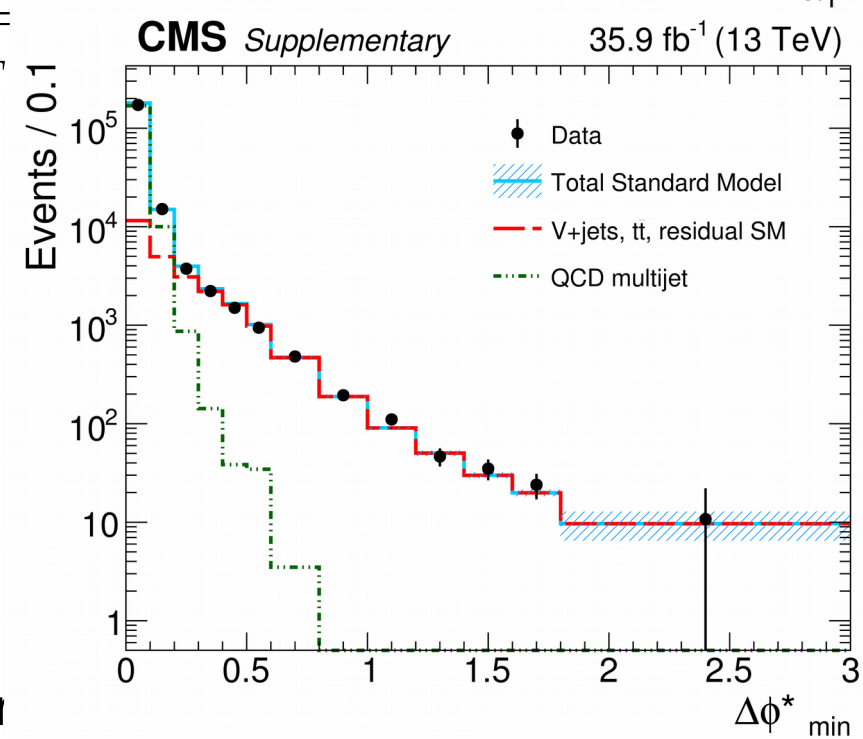
- 35.9 fb^{-1} search binned in N_j, N_b, H_T and MHT
- All jets defined by p_T > 40 GeV and $|\eta|$ < 2.4
- MHT/MET<1.25, H_T>200 GeV, MHT>200 GeV
- Misreco'd jets rejection: $\alpha_T \gtrsim 0.55$, $\Delta\phi^*_{min}$>0.5
  - $\Delta\phi^*_{min}$ = minimum angle between jet and MHT vector without that jet
  - A factor 10^5 reduction in QCD background

$$\alpha_T = \frac{E_T^{j_2}}{M_T} \underset{m\to 0}{=} \sqrt{\frac{E_{T,2}}{2E_{T,1}(1-\cos\phi)}} \to \frac{H_T - \Delta H_T}{2\sqrt{H_T^2 - \not{H}_T^2}}$$



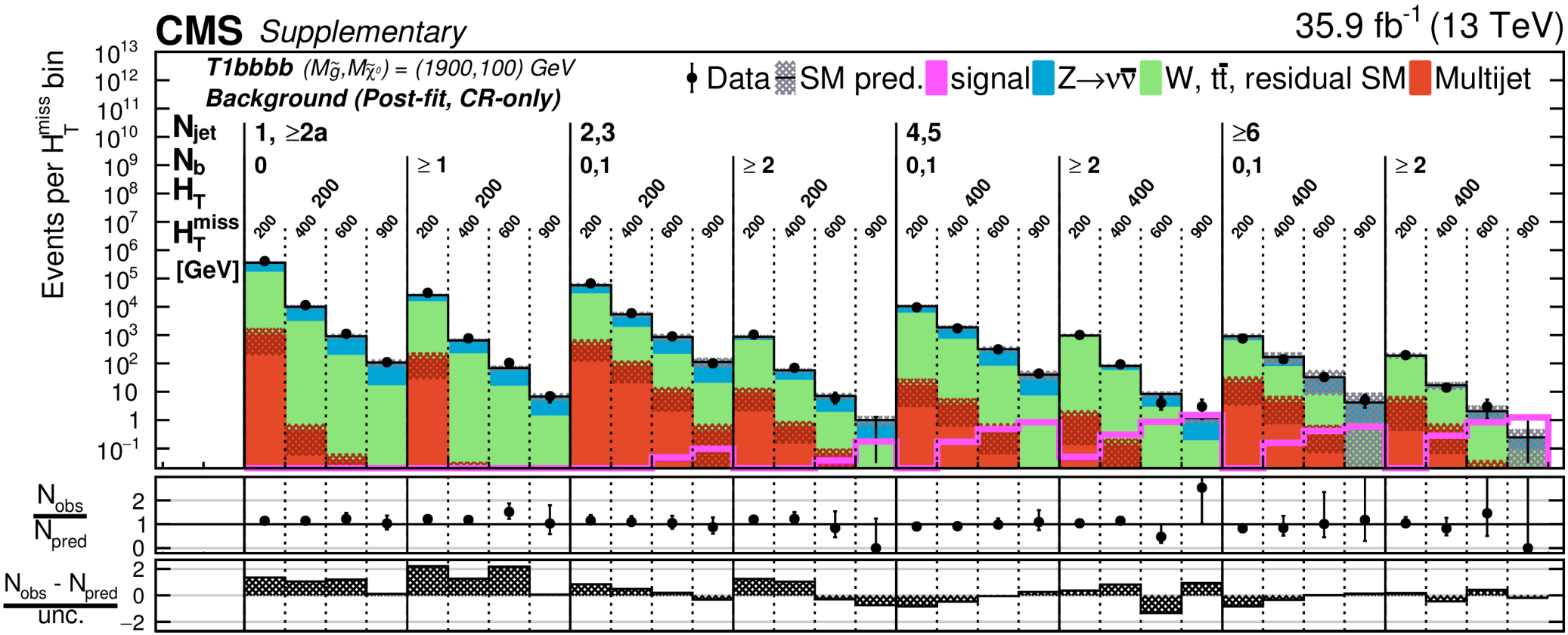
$$\not{H}_T = |\sum_{i\in\text{jet}} \vec{p}_T^{\,j_i}|$$





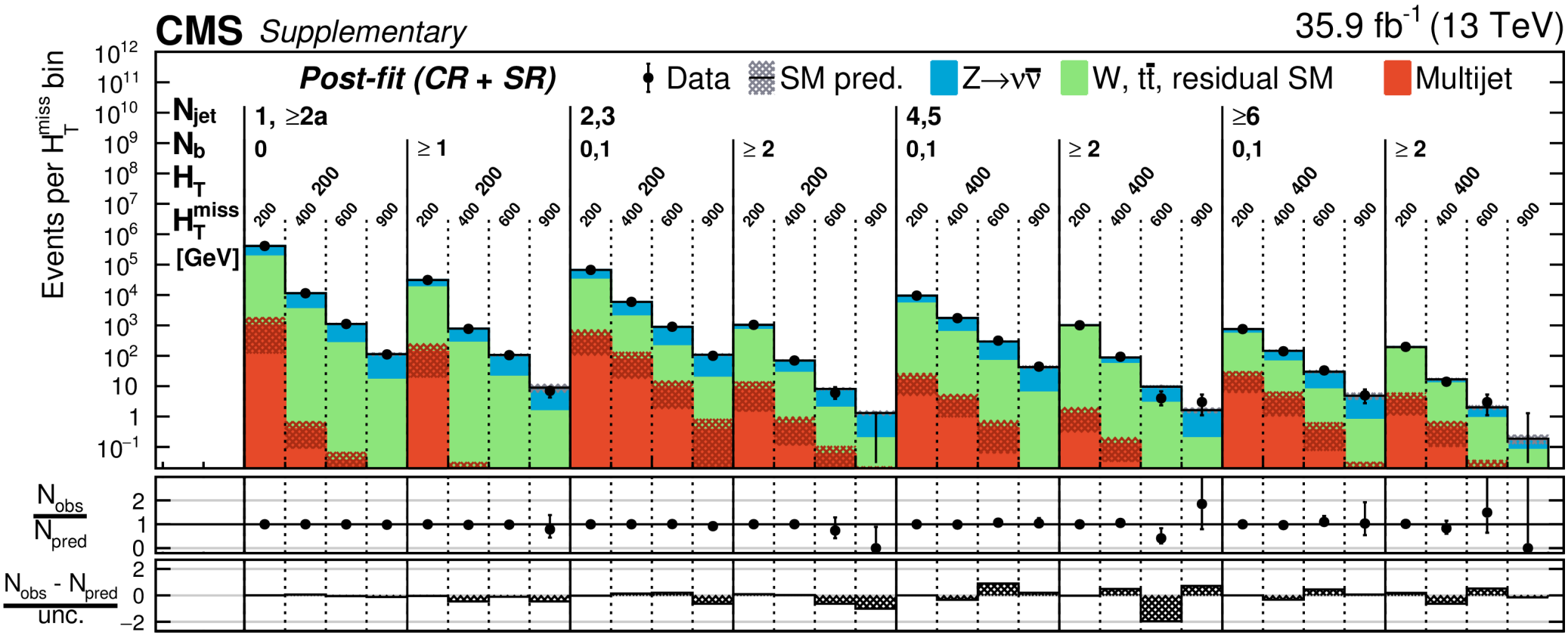
Backgrounds in α_T search (1)

- Two control regions:
  - Single muon data→$t\bar{t}$ and W+jets
  - μμ+jets data → Z(νν)+jets
- Use transfer factors to predict backgrounds
- Check with fit in control regions only: constrain non-multijet backgrounds

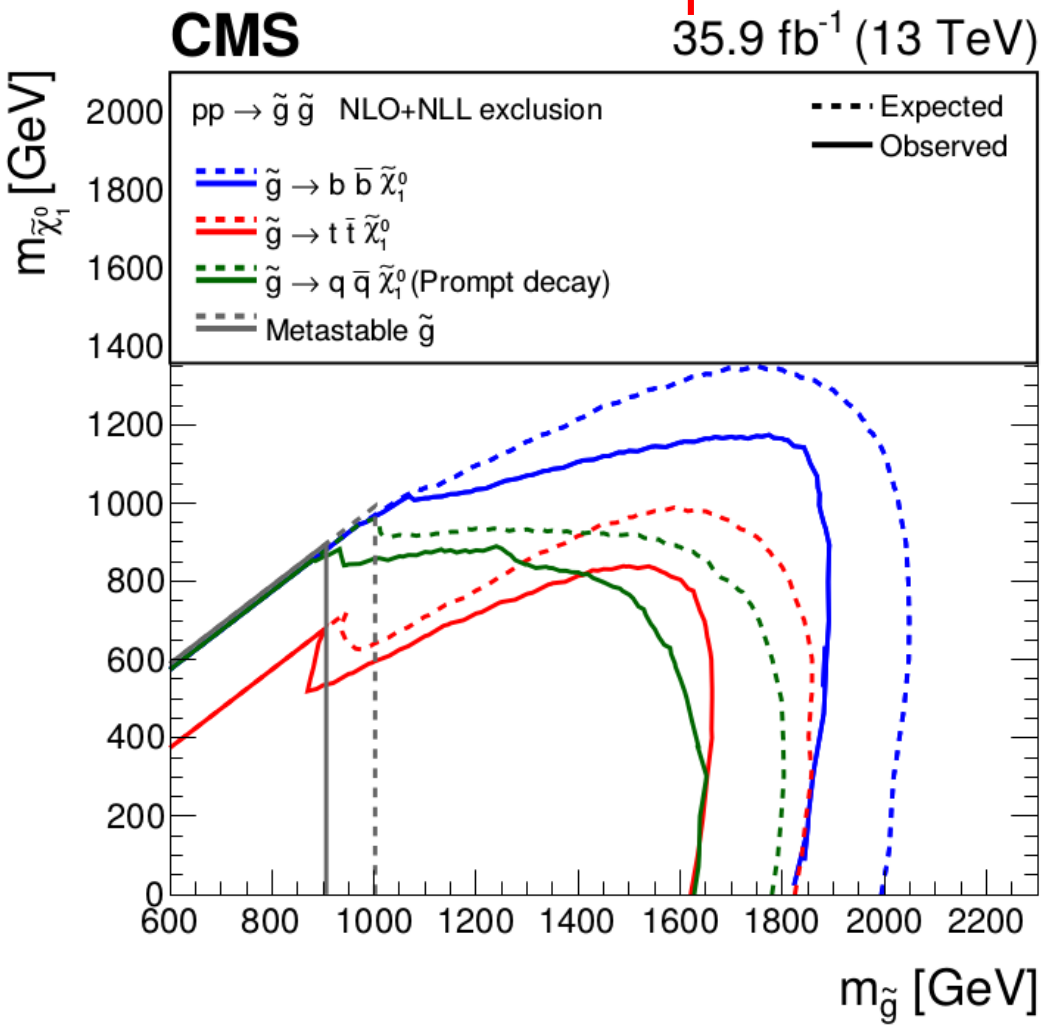


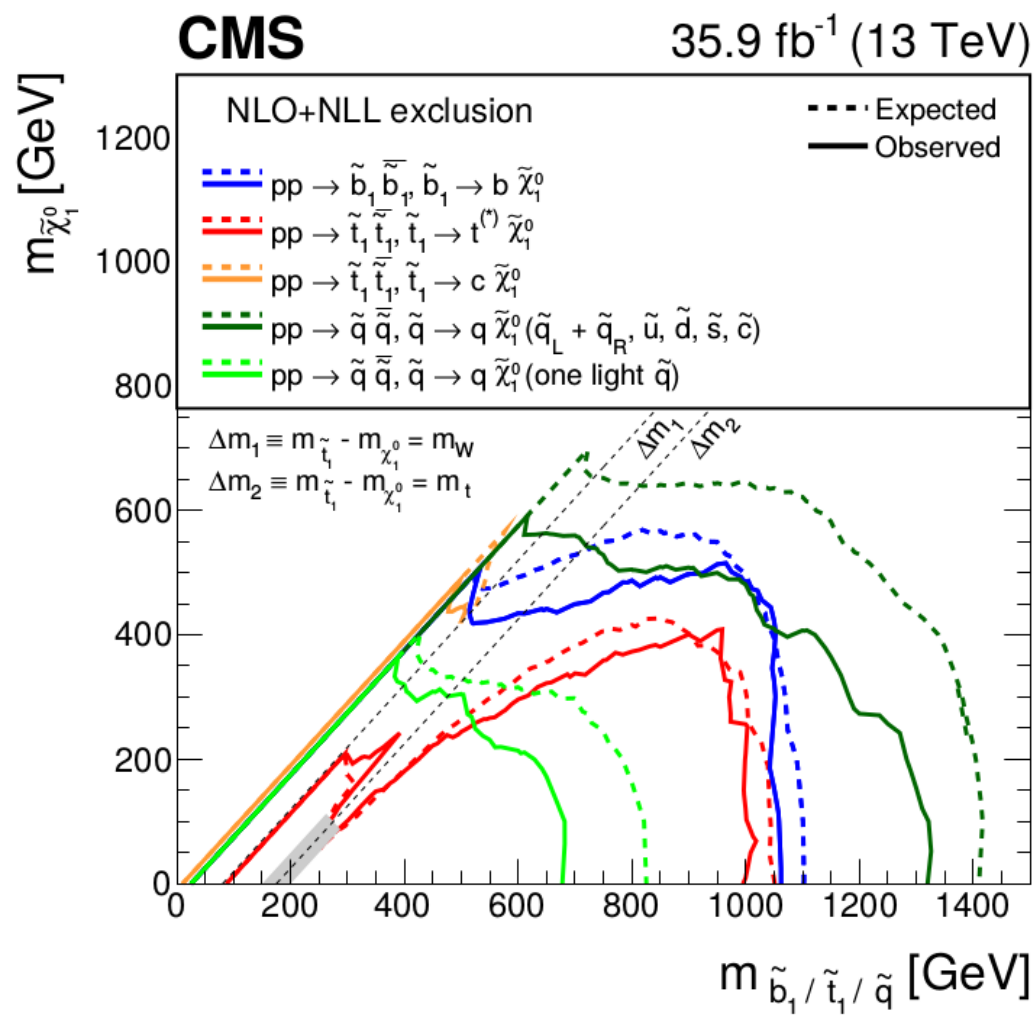
Backgrounds in α_T search (2)

- Two control regions:
  - Single muon data→$t\bar{t}$ and W+jets
  - μμ+jets data → Z(νν)+jets
- Use transfer factors to predict backgrounds
- Final results from a simultaneous fit between the signal and control regions



α_T search results



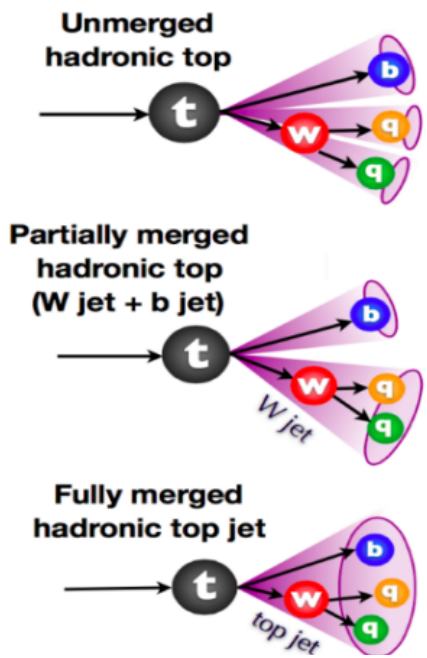


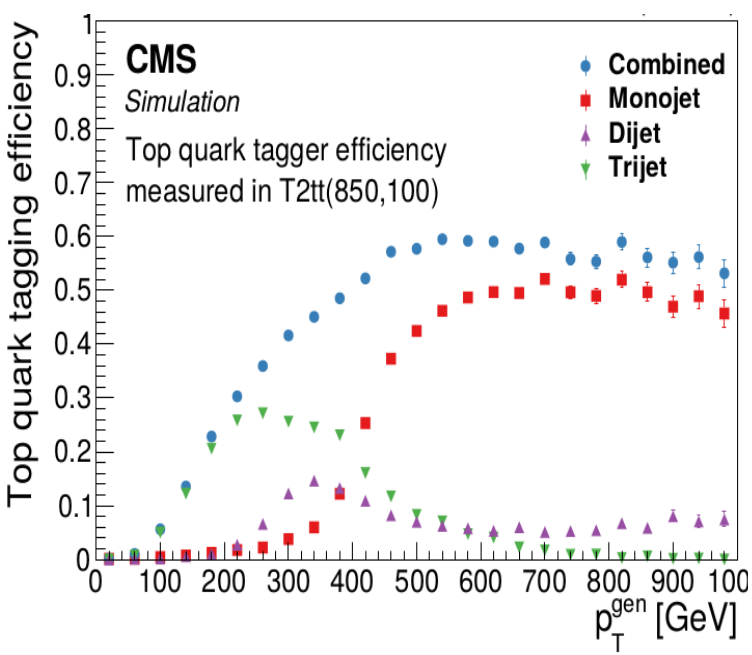
- Gluinos > 1.9 TeV → Neutralino > 1.2 TeV
- Squarks > 1.3 TeV → Neutralino > 575 GeV
- Complementary analysis to other more targeted searches
- Similar sensitivity to M_{T2} search
- Additional interpretation in split SUSY models with long-lived gluinos

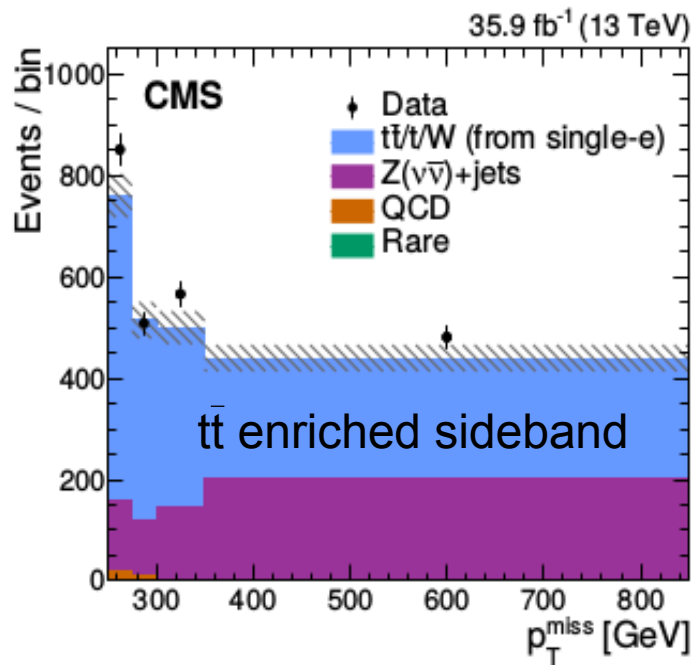
SUS-16-038; JHEP 05 (2018) 025

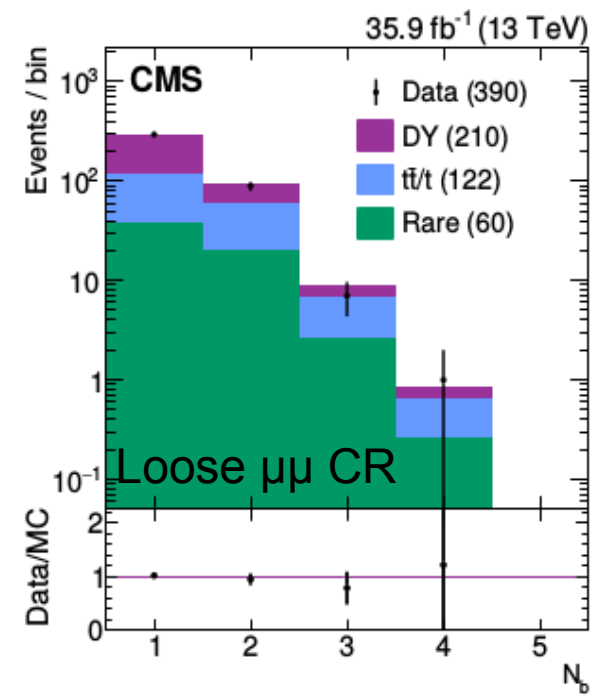
All hadronic with identified top quarks

- 35.9 fb^{-1} Three categories:
  - Unmerged: Three anti-k_T 0.4 (AK4) jets
  - Partially merged: AK8 is boosted W, combined with AK4 jet
  - Fully merged: AK8 is boosted top
    - Different p_T, softdrop mass, and N-subjetiness cuts
- Top tagger provides high ε over large p_T range
- Baseline: MET>250 GeV; H_T>300 GeV; 1 btag (ε_b~65%)
- Estimate $t\bar{t}$ bkgd from data with translation factors
- 84 bins in N_b, N_{top}, $M_{T2}(H_T)$, MET

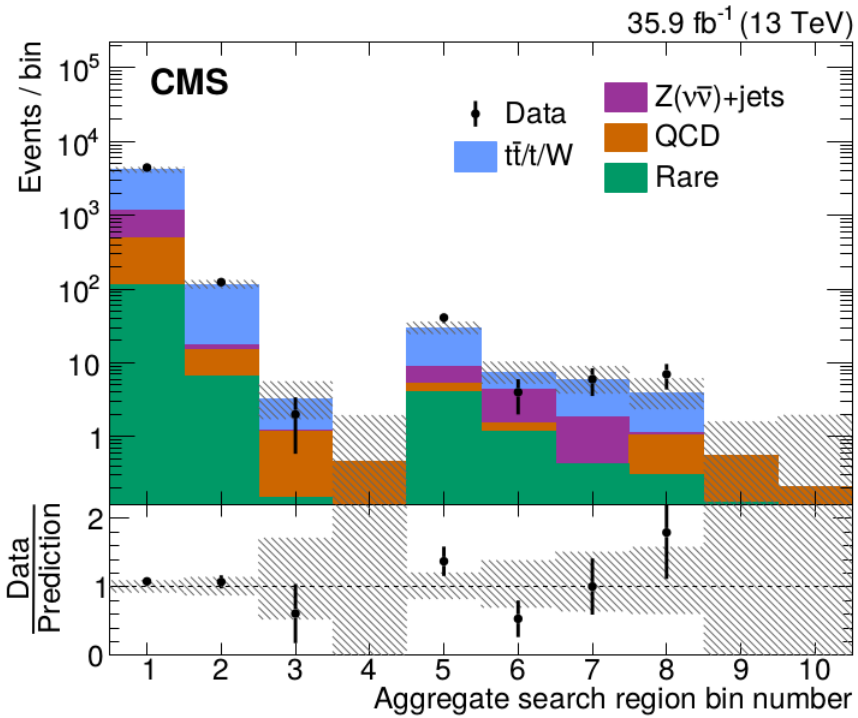


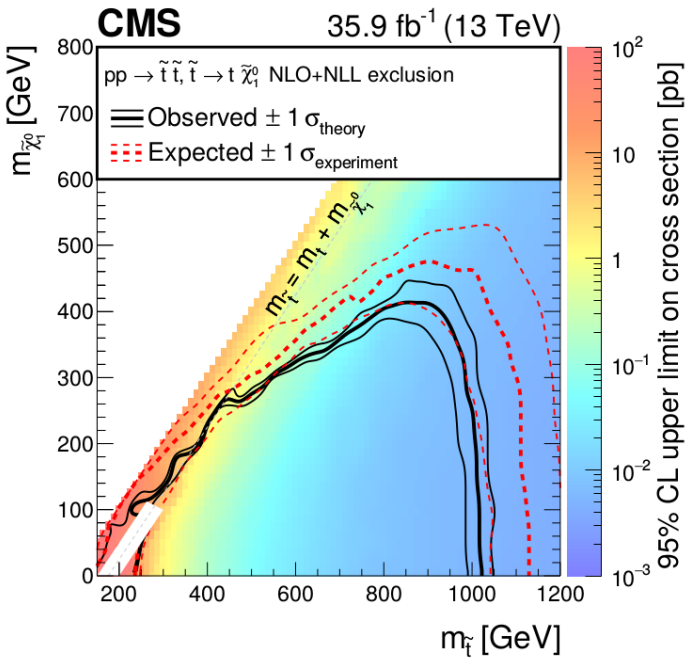


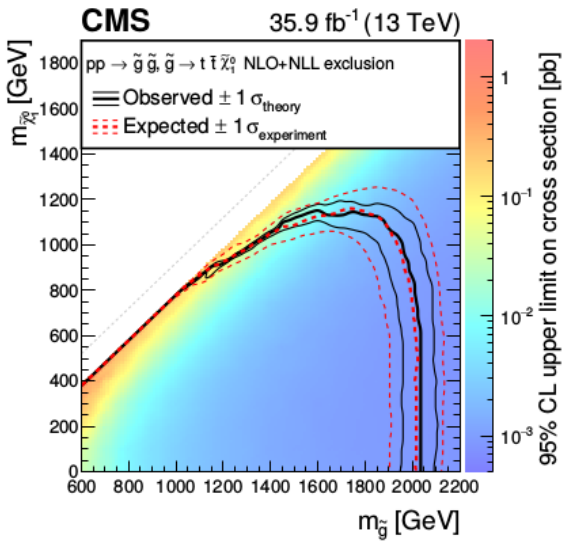


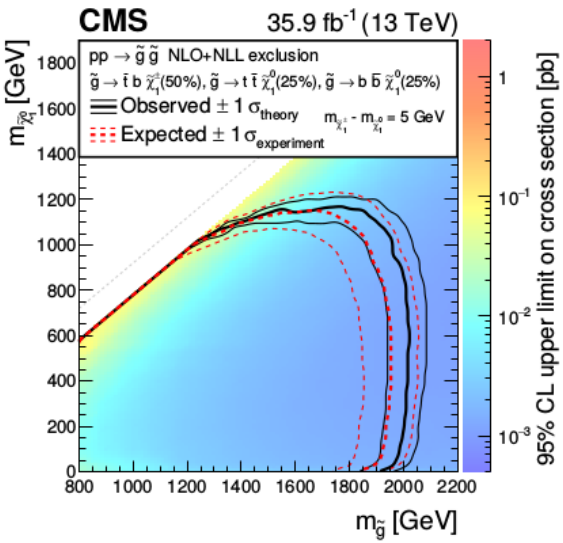


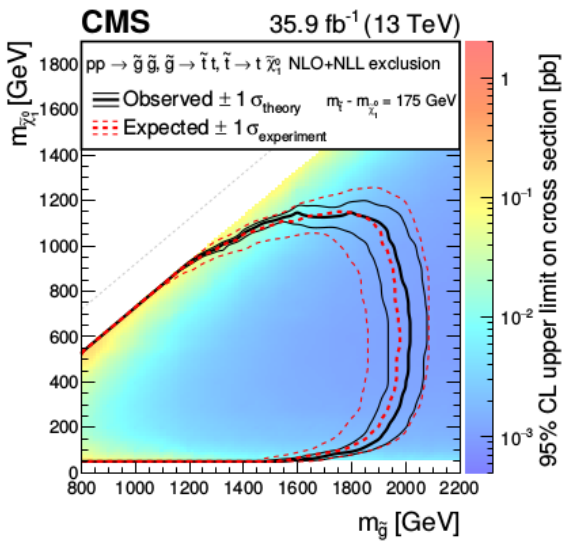
All hadronic with identified top quarks

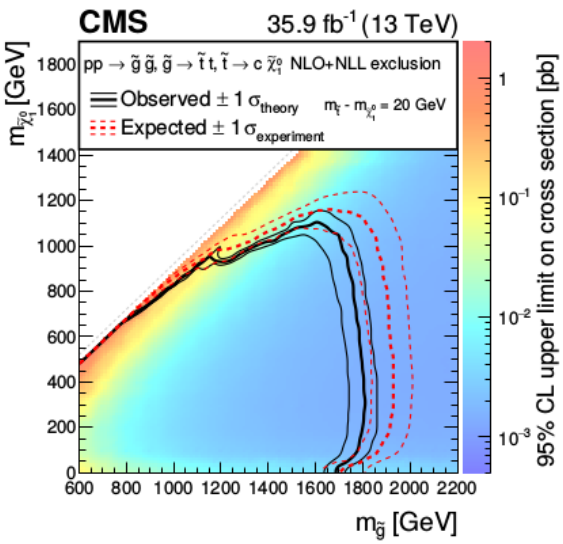








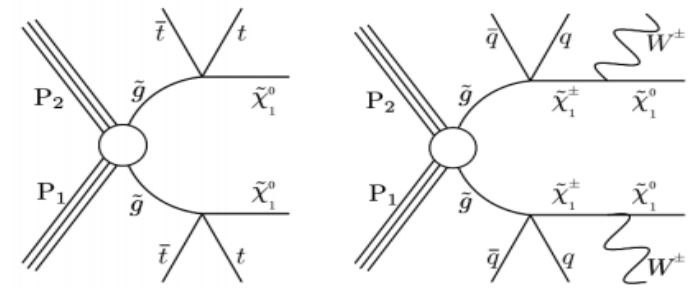


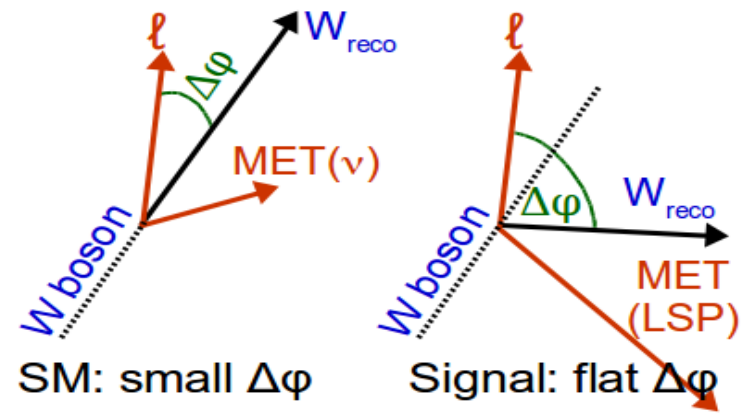


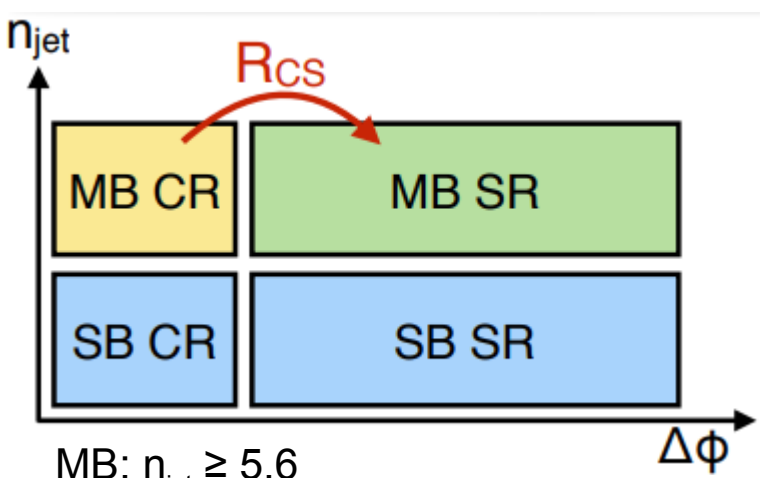
SUS-16-050
PRD 97 (2018) 012007

Stops and charginos in 1ℓ with Δφ

- 35.9 fb^{-1}
  - L_T=MET+$p_T(\ell)$ > 250 GeV, 5+ jets, H_T > 500 GeV
  - Discriminant variable: Δφ(ℓ,W)
  - Main backgrounds W+jets and $t\bar{t}$: small Δφ
- Background prediction $N_{MB}^{SR} = \kappa \frac{N_{SB}^{SR}}{N_{SB}^{CR} - N_{QCD,SB}^{CR}} N_{MB}^{CR}$
  - κ: MC corr. for differences in (b-) jet multiplicity between side band (SB) and main band (MB)
  - Search performed in b-tagged ($t\bar{t}$ dominated) and b-veto (W+jets and $t\bar{t}$) regions
  - QCD estimated from tight-to-loose ratio

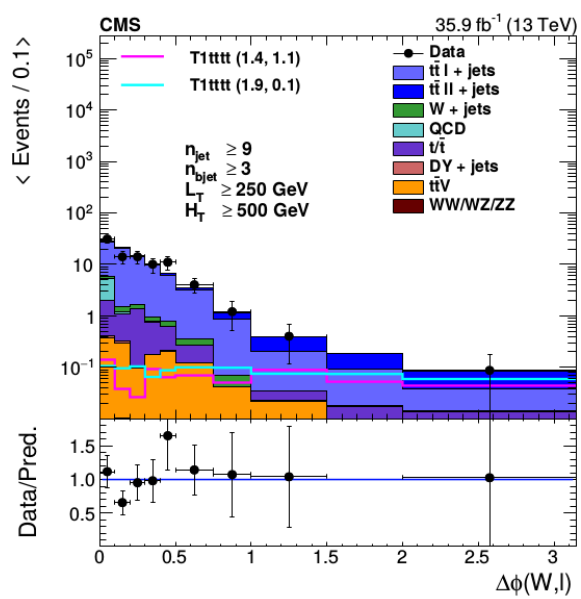


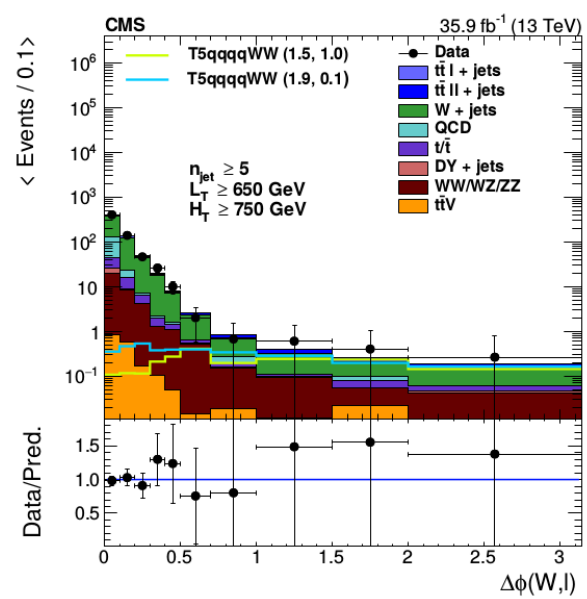




MB: $n_{jet} \geq 5,6$

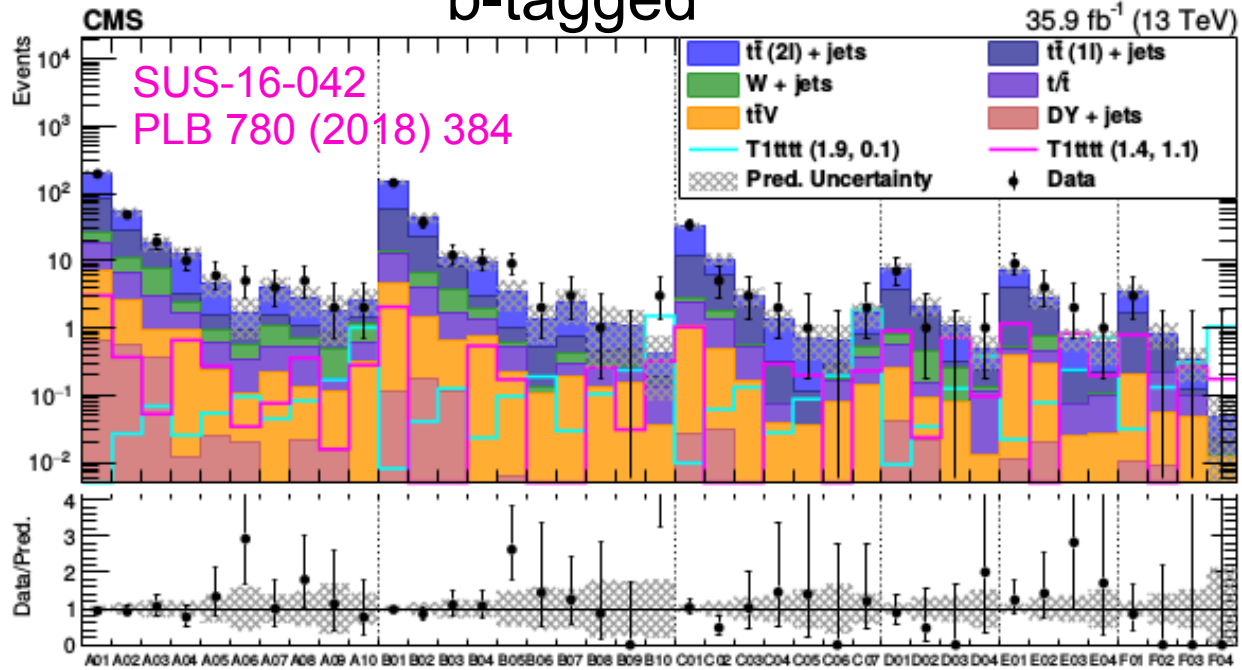
SB: $n_{jet} \in [3,4],[4,5]$

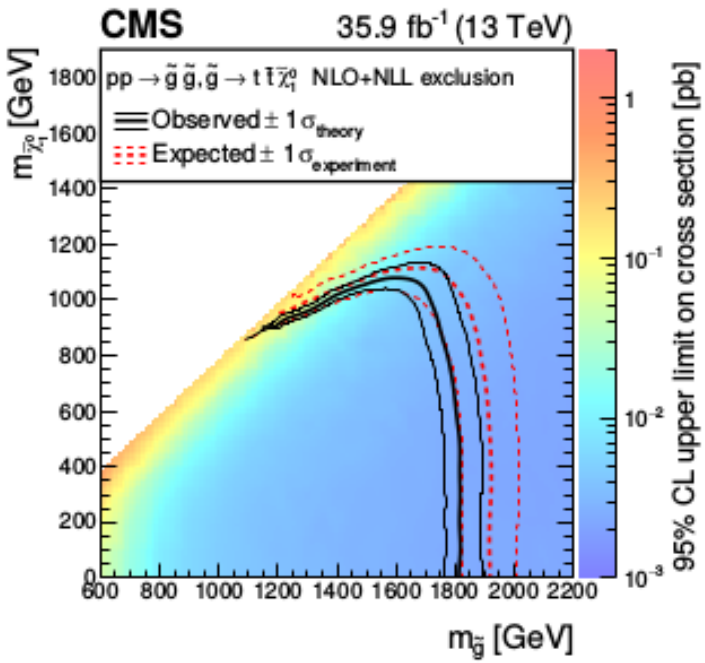




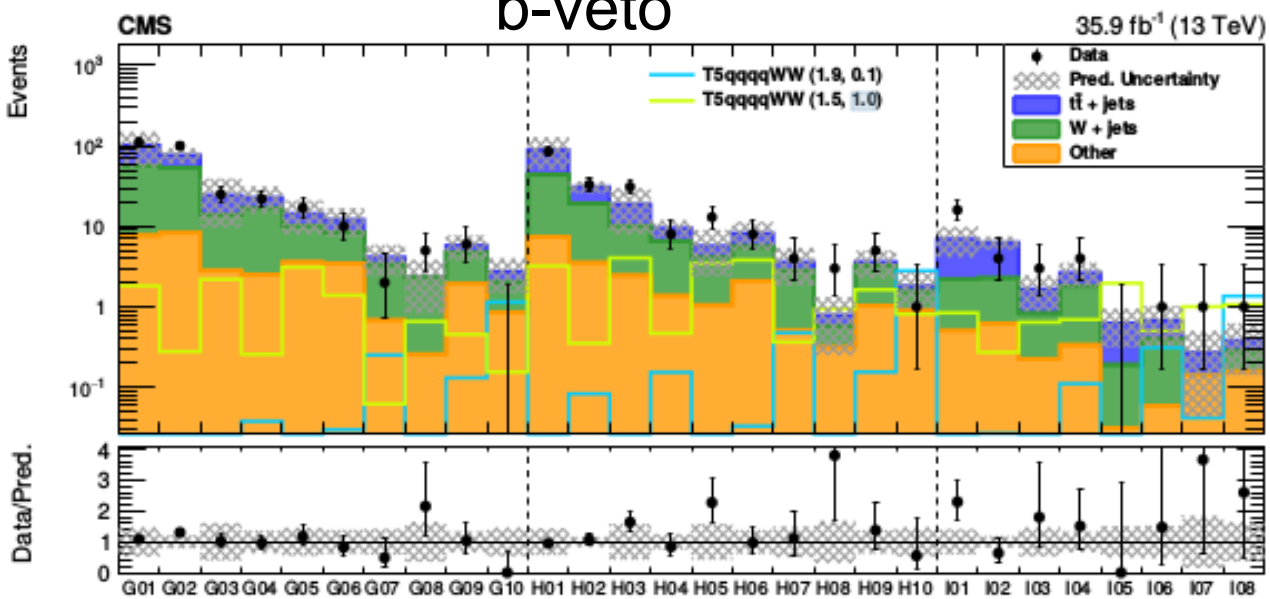
Single lepton search with Δφ

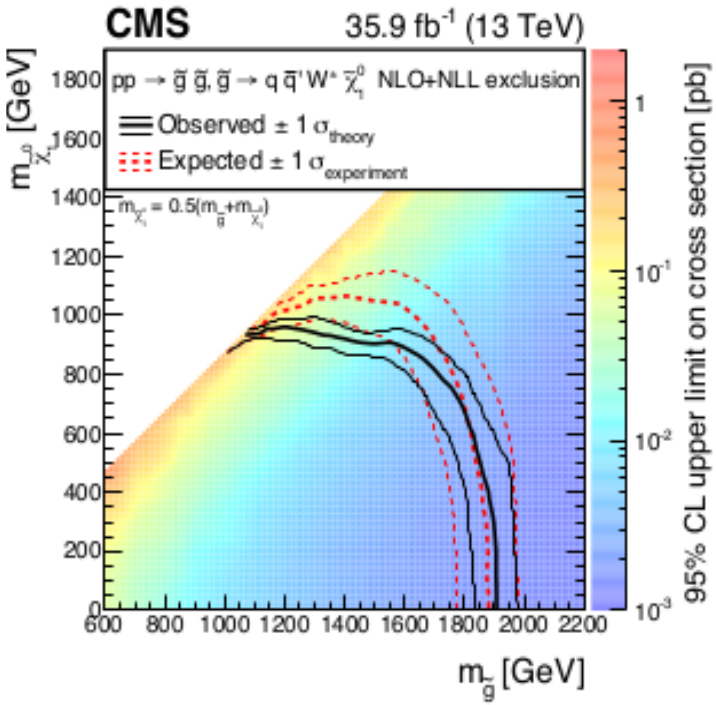
b-tagged





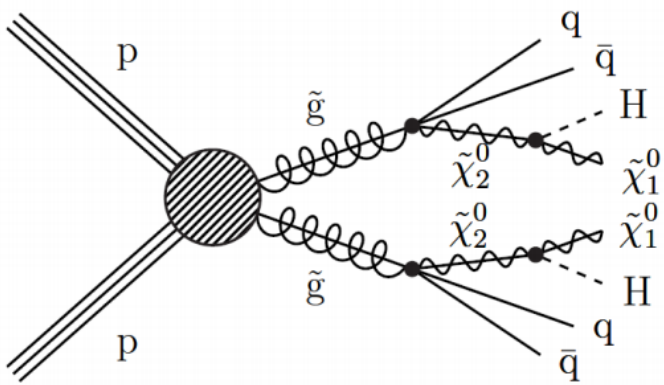
b-veto

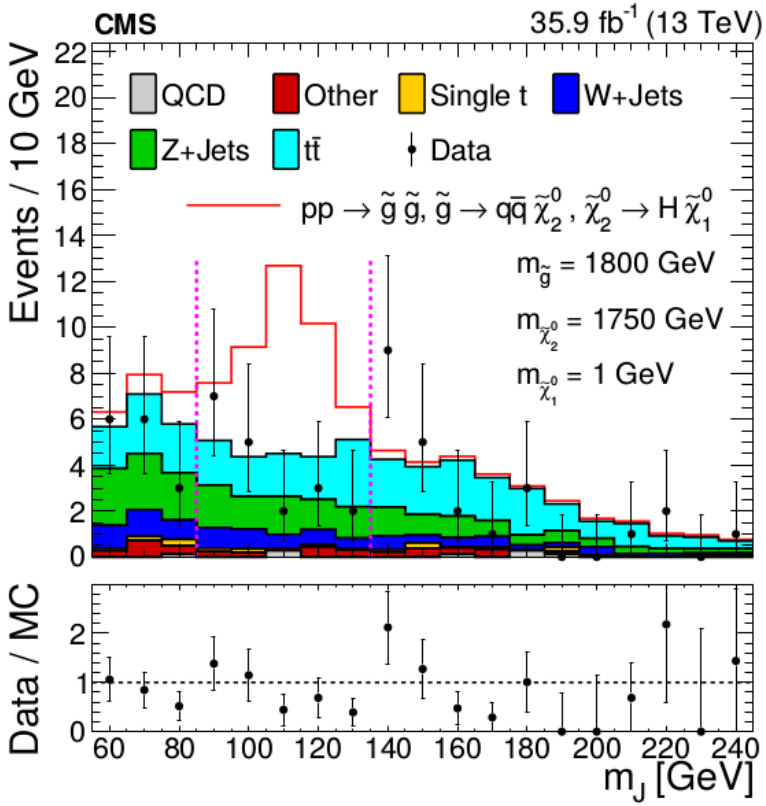


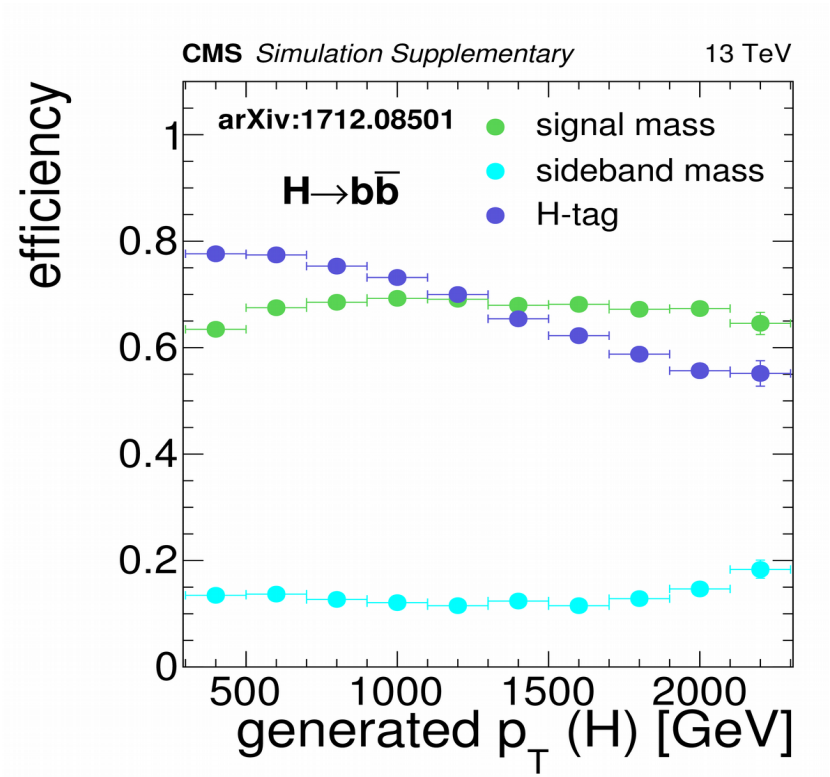


Gluinos+hadronic Higgs

- Signature: two Higgs bosons with two AK8 jets
  - Large gluino m: H is boosted; H→bb has 58% BR
  - H_T>600 GeV, MET>300 GeV
  - 2 AK8 jets with p_T>300 GeV, 50<m_J<250 GeV
  - H-tag: MVA algorithm resolves decays of two b-hadrons inside AK8 jet; require 85<m_J<135GeV
  - Jet pruning to improve mass resolution



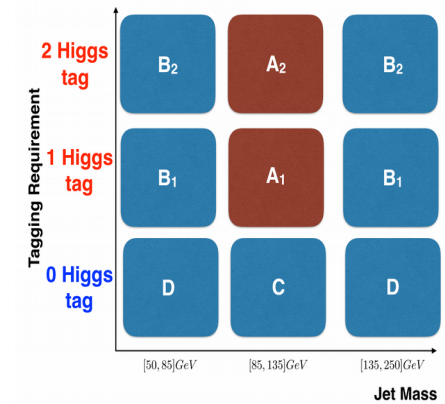


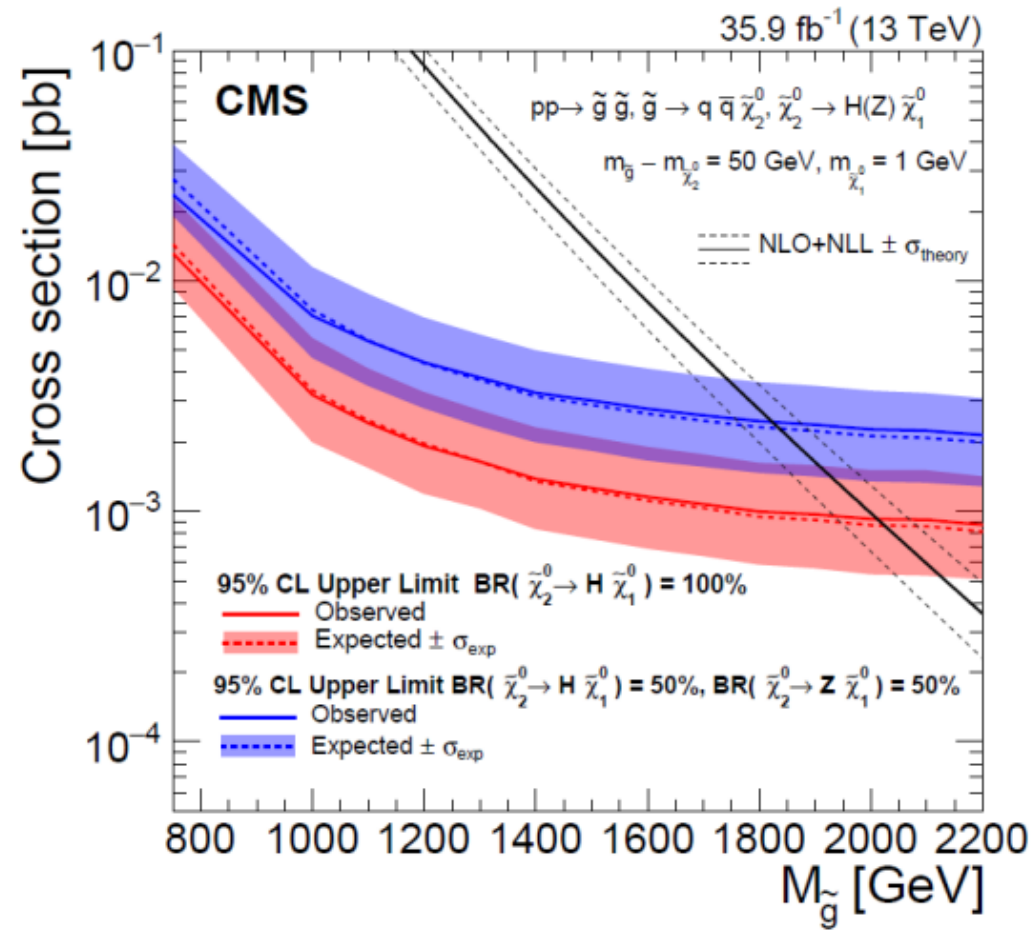


Gluinos+hadronic Higgs

- Estimate the background as an ensemble using "ABCD" method
- Sideband regions (B,D) are used to make background prediction in the signal region (A,C)
- Scaling ratios are not the same for all samples
  - Composition changes with MET
- A combination of data and MC is used to correct for the non-closure
- High-mass gluino points rely on sensitivity from high MET bins
- Low-mass gluinos have a large σ and all bins contribute to the sensitivity
- Gluino mass > 2 TeV in HH model
- Gluino mass > 1.8 TeV in ZH model

$$A_{1,2} = B_{1,2}\frac{C}{D}$$





SUS-17-006 (PRL) arXiv:1712.08501

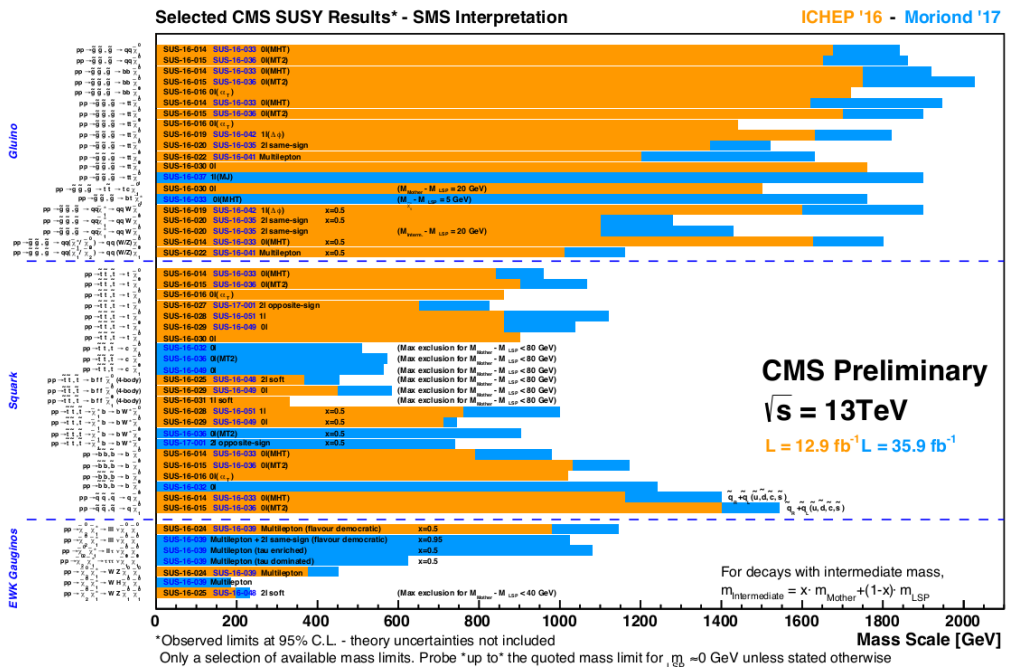
Conclusions

- SUSY strong production involves the dominant production modes
  - Both inclusive and dedicated searches → complementary analyses
    - Covering specific signatures with dedicated tools, top taggers, angular variables...
    - Fine binning targeting limits and more generic “aggregate” search bins
- No evidence yet for SUSY → stringent constraints
- “Natural” SUSY could still be hidden
  - Focus on compressed scenarios, RPV, split SUSY, EW production, VBF…
  - Work on isolation, soft leptons, boosted objects, high pileup
  - Expand interpretations
- Analyses with full Run2 dataset will come in 2019 (>100 fb^{-1})

Typical limits from 13 TeV data:

- m_{gluino} > 2 TeV
- $m_{squarks}$ > 1.5 TeV
- m_{stop} > 1.1 TeV
- $m_{sbottom}$ > 1.4 TeV

Latest results in this link



Extras