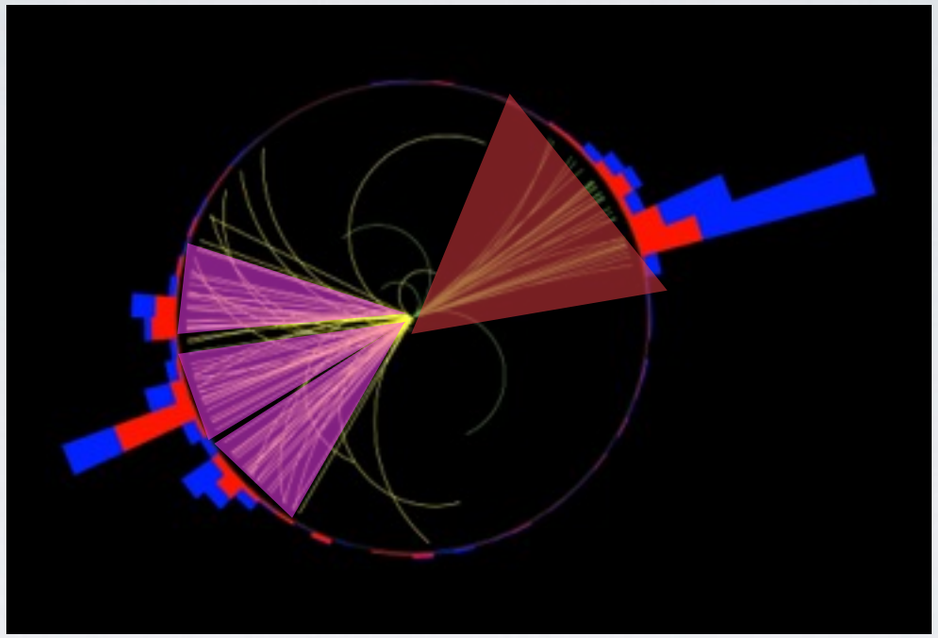


SEARCHES FOR SUSY:

BOOSTED OBJECTS AT CMS

Rishi Patel

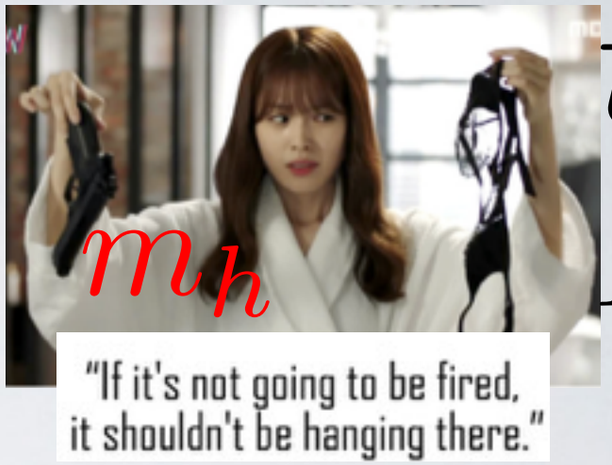
University of Colorado Boulder

Fermilab

STANDARD MODEL DRAMA

- **If the SM is a dramatic ACT I:** the Higgs mass is the loaded rifle. LHC community is asking what happens in ACT II??
  - If SUSY is ACT II: Gun is fired to give light (few TeV) third generation squarks, higgsinos, and gluinos to give quantum corrections to the higgs mass that cancel SM contributions

Chekhov Rule

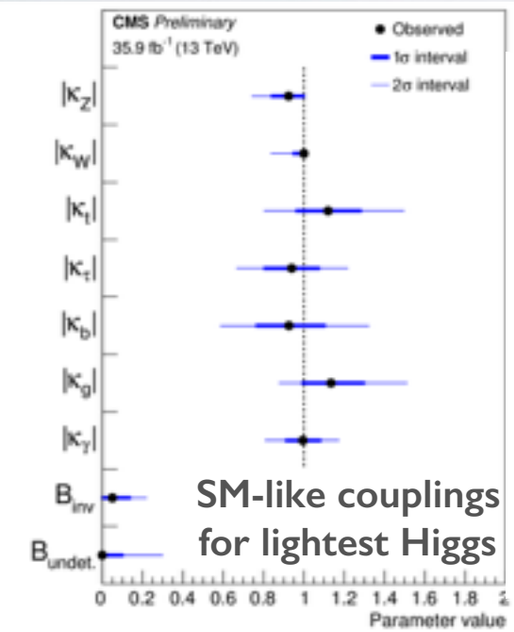


$\tilde{t}$

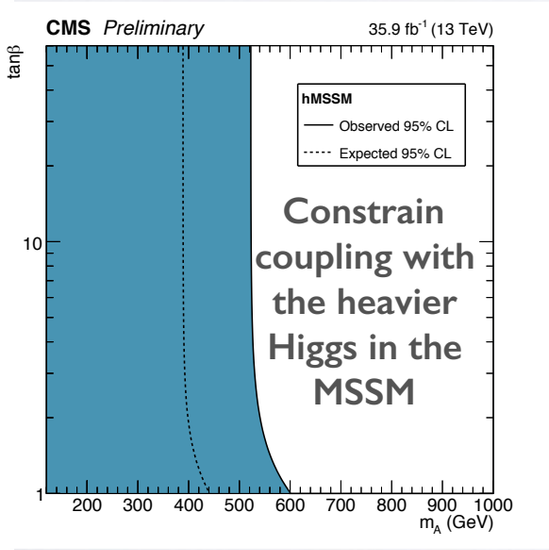
$\tilde{H}$

SM and SUSY Higgs sector

Measurement of SM Higgs couplings and direct searches for new scalars provide complementary approaches for Beyond SM physics

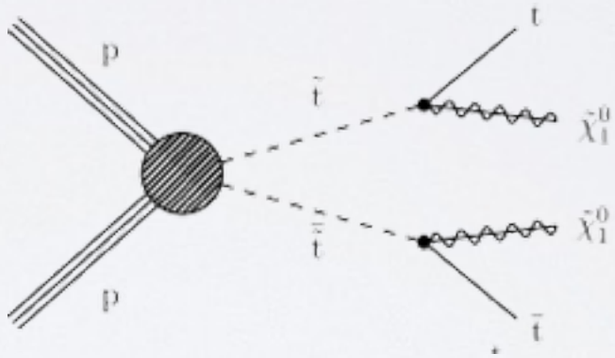


HIG-17-031

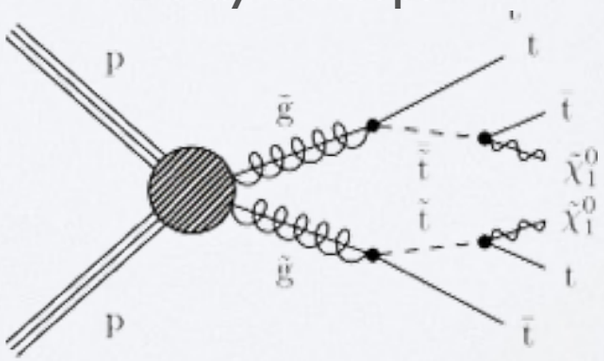


Searches for Stop

Stop Production

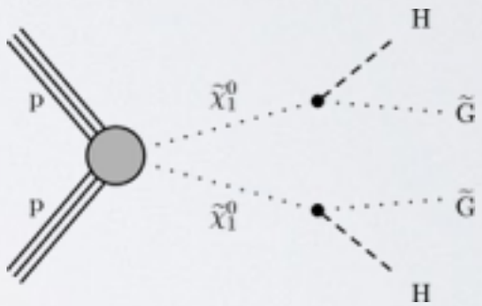


Gluino Production: Decay via stops

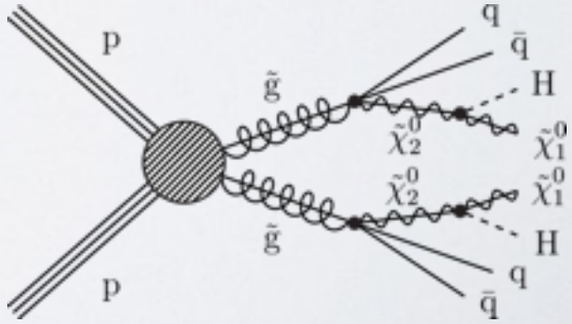


SUSY Searches with H in the final state

Higgsino Production



Higgsino/Heavy Higgs Production

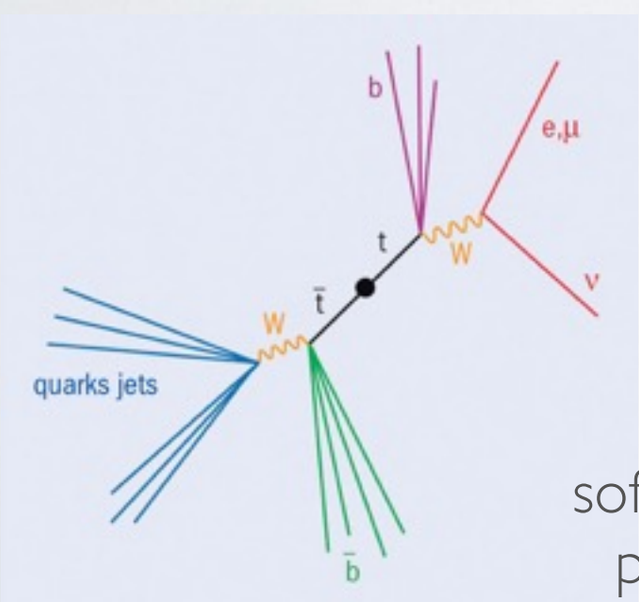


STOP SEARCH STRATEGY

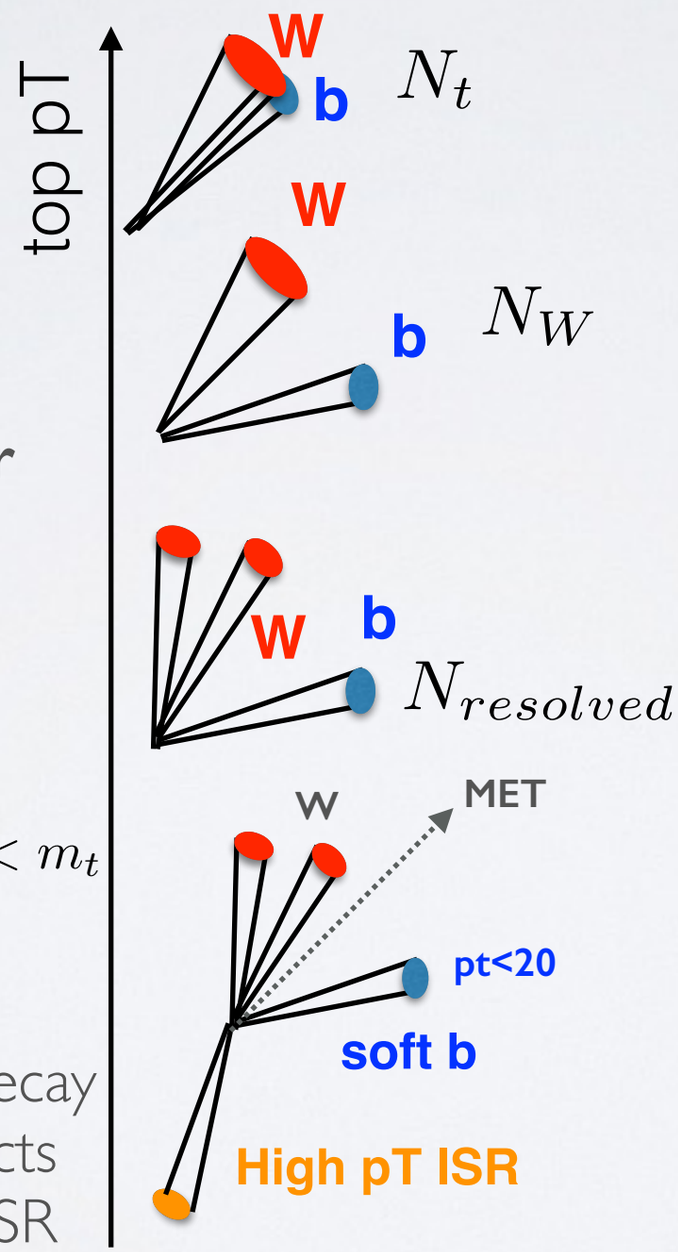
- Search regions/selection need to be optimized to cast a wide net over stop decay topologies: Depending on $\Delta m = M_{\tilde{t}} - M_{LSP}$

Fully reconstruct tops from more granular jets with ΔR<0.4 (and) or wide cones of ΔR<0.8

High signal purity with **mainly background from SM Semi-leptonic top for Hadronic Stop searches**



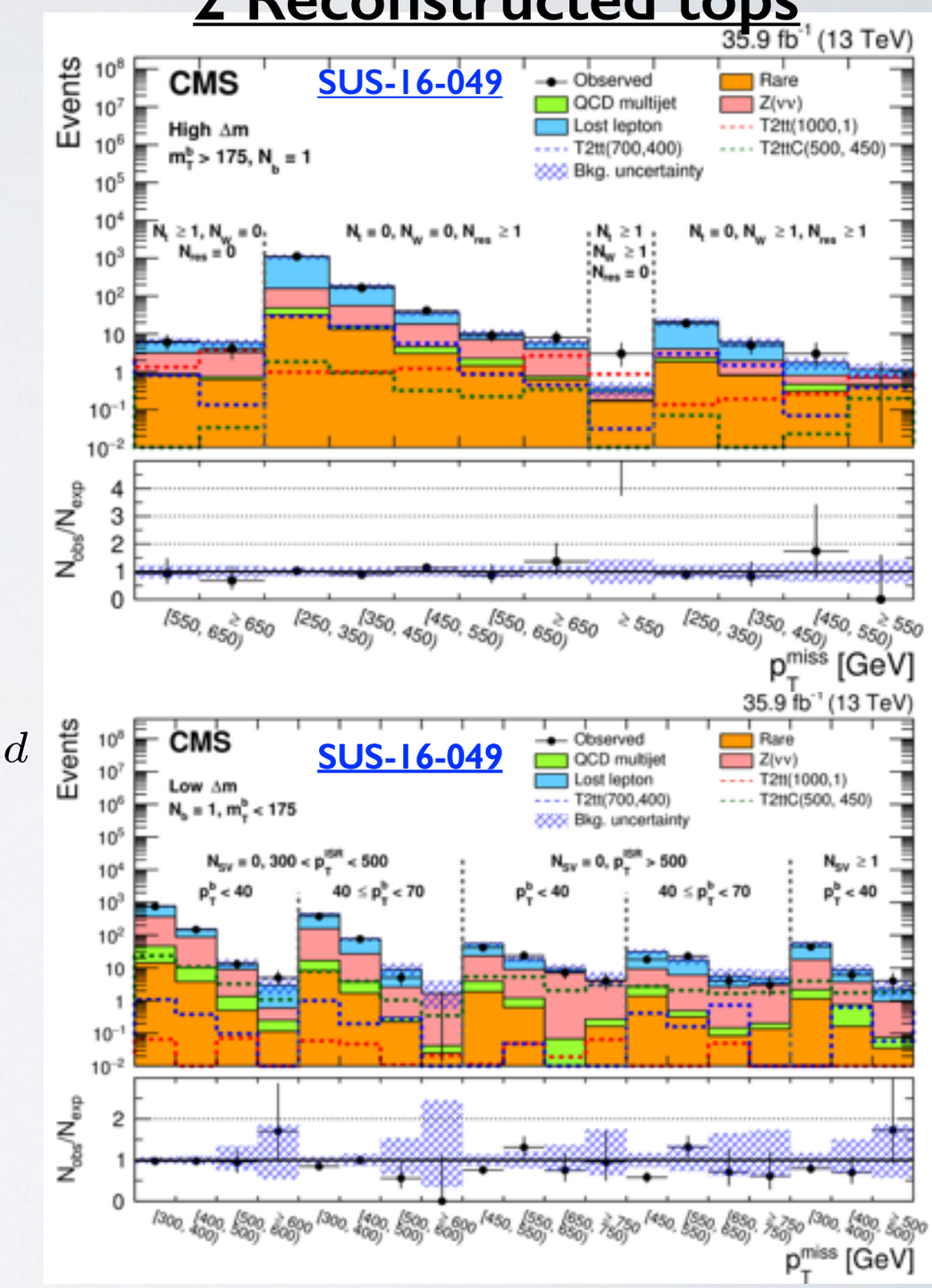
$\Delta m > m_t$



$\Delta m < m_t$

softer decay products need ISR

2 Reconstructed tops



TOP TAGGING

- Two strategies are explored to provide high reconstruction efficiency across a range of top quark pT:
  - **SUS-16-049:** Boosted Decision Trees for tagging

Categorize |ΔR|<0.8 jets by soft-drop mass and jet pT

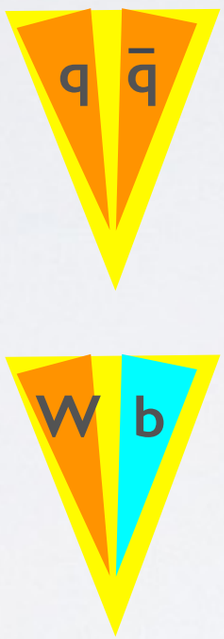
De-cluster into 2-subjets

Boosted W

$p_T^j \geq 200 \; 50 < M^j \leq 110$

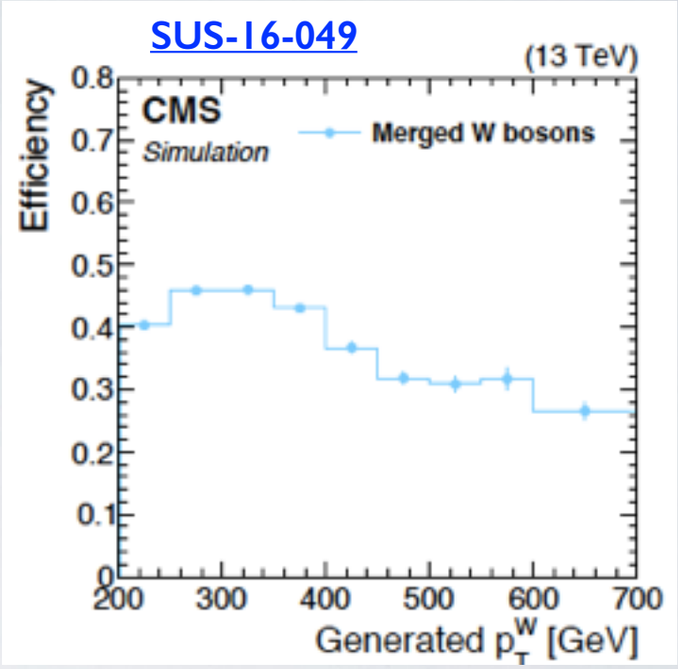
Boosted Top

$p_T^j \geq 400 \quad M^j \geq 110$

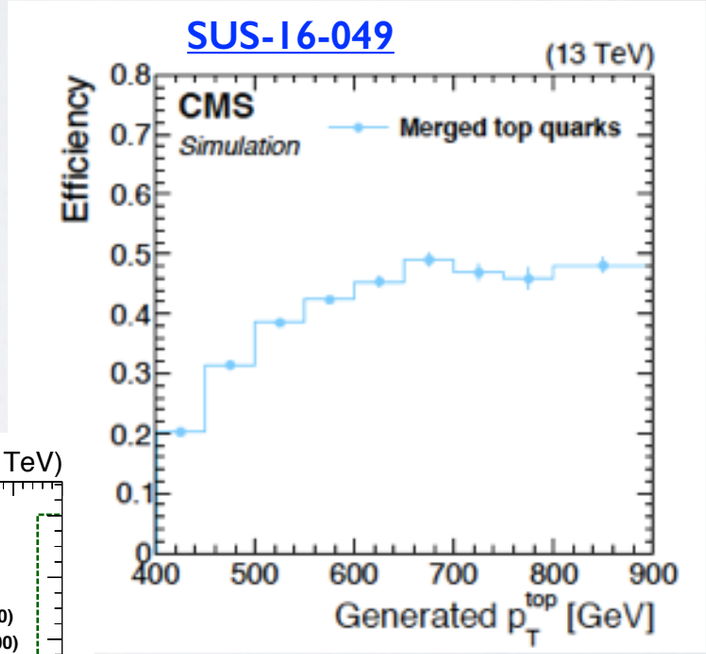


BDT Inputs

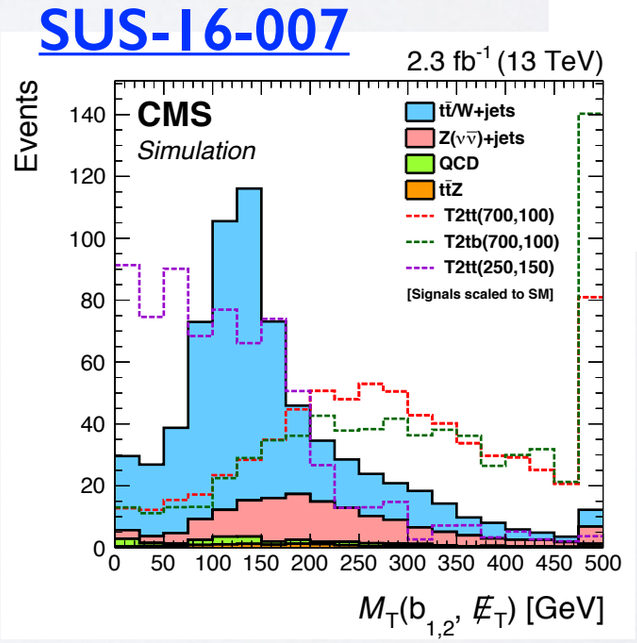
τ2/τ1, τ3/τ2,
b-tag discriminator
ΔpT(subjets)
subjet mass
q/g discriminator



2-10% mistag rate in q or g jets



1-4% mistag rate



$$m_b^T = \sqrt{2 p_T^b p_T^{miss} (1 - \cos\Delta\phi)}$$

- Categorize the events based on the smallest Transverse Mass of the b-jet (use the highest b-discriminator jets)
- Classify events according to top pT: Count if you have boosted top or boosted W

TOP TAGGING

SUS-16-050: Tag |ΔR|<0.8 jets by cutting on sub-jettiness

Categorize |ΔR|<0.8 jets by soft-drop mass ,jet pT and Subjettiness

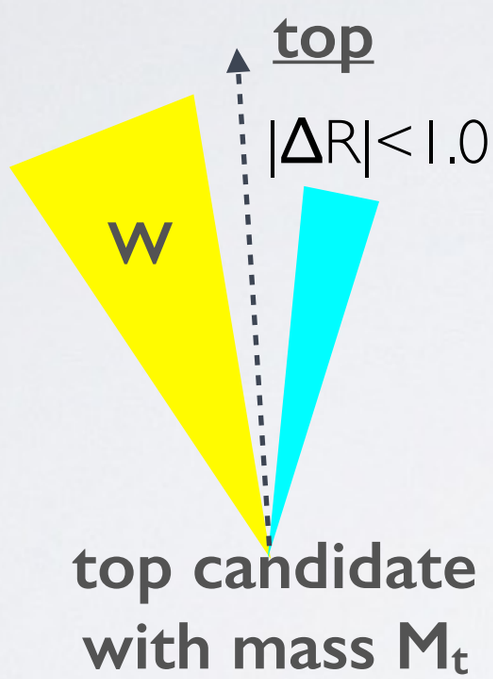
Combine with a |ΔR|<0.4 jet with pT>30GeV

Boosted W

$p_T^j \geq 200$

$\tau_2/\tau_1 < 0.6$

$65 \leq M_j \leq 100$



top tagged if:

$100 \leq M_t^j \leq 250$

$0.85 < \frac{M_W}{M_t} < 1.2$

Boosted Top

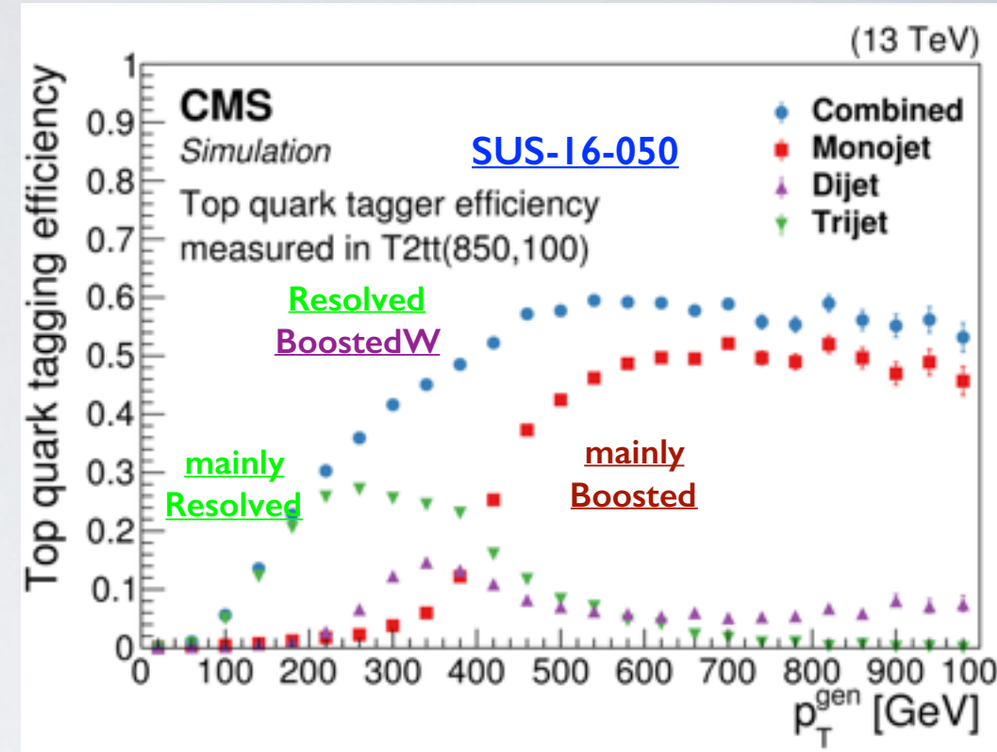
$p_T^j \geq 400$

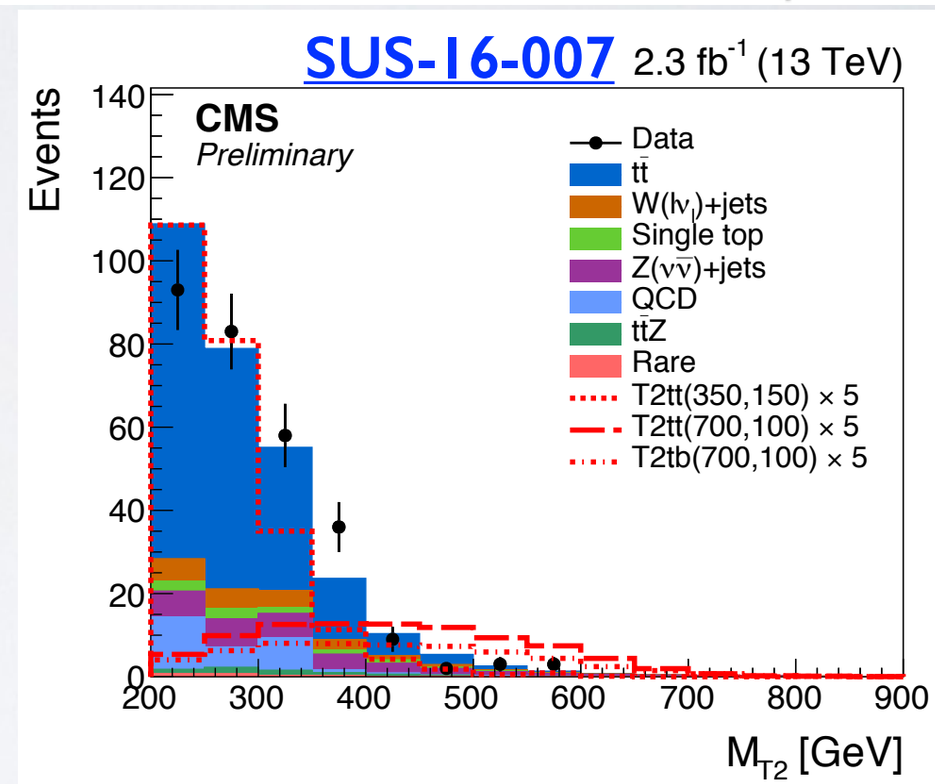
$\tau_3/\tau_2 < 0.65$

$105 \leq M_j \leq 210$

Search bins:

- Count tops that are tops tagged with either method
- Use MT2 (transverse mass for pair-produced particles) to get a kinematic upper limit for a a stop mass

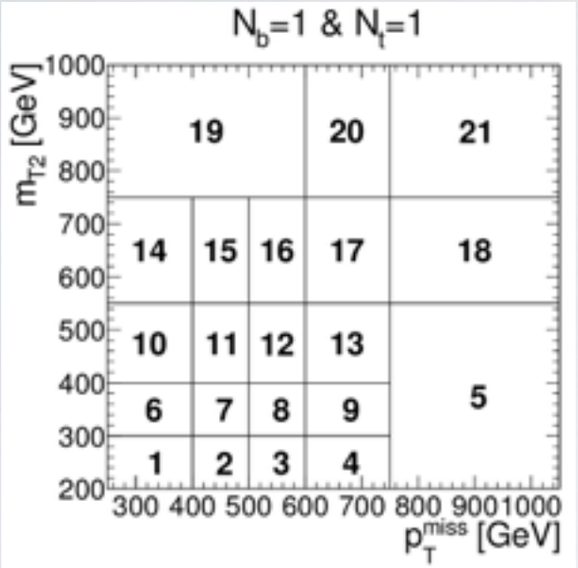


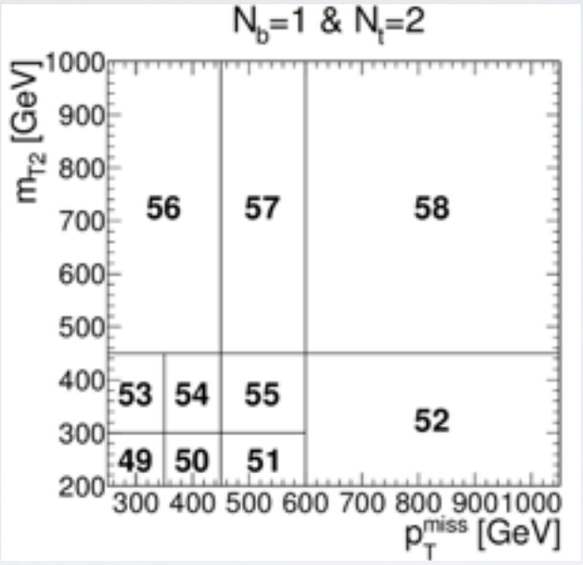


$$m_T^2(\vec{p}_T; m_P, \vec{q}_T; m_{\tilde{\chi}_1^0}) \equiv m_P^2 + m_{\tilde{\chi}_1^0}^2 + 2(E_T^p E_T^q - \vec{p}_T \cdot \vec{q}_T)$$

BUILDING SEARCH REGIONS

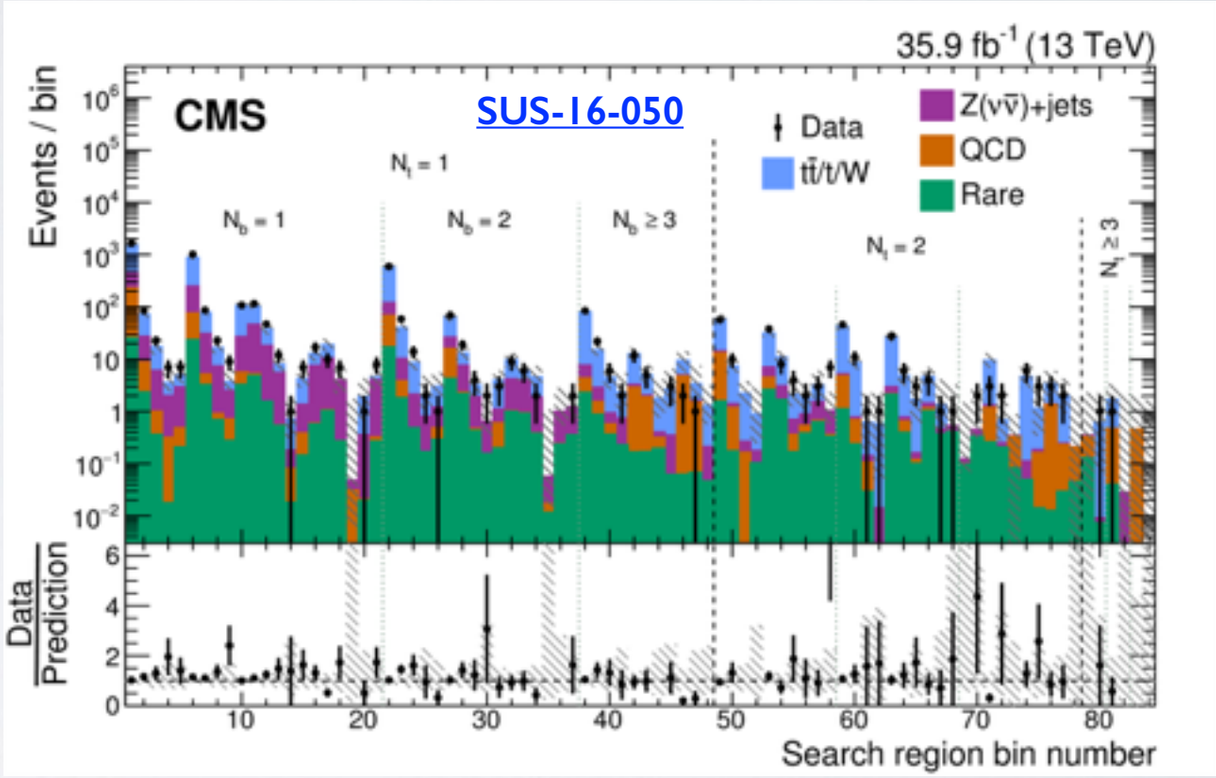
- **SUS-16-050**: Count total top-tags



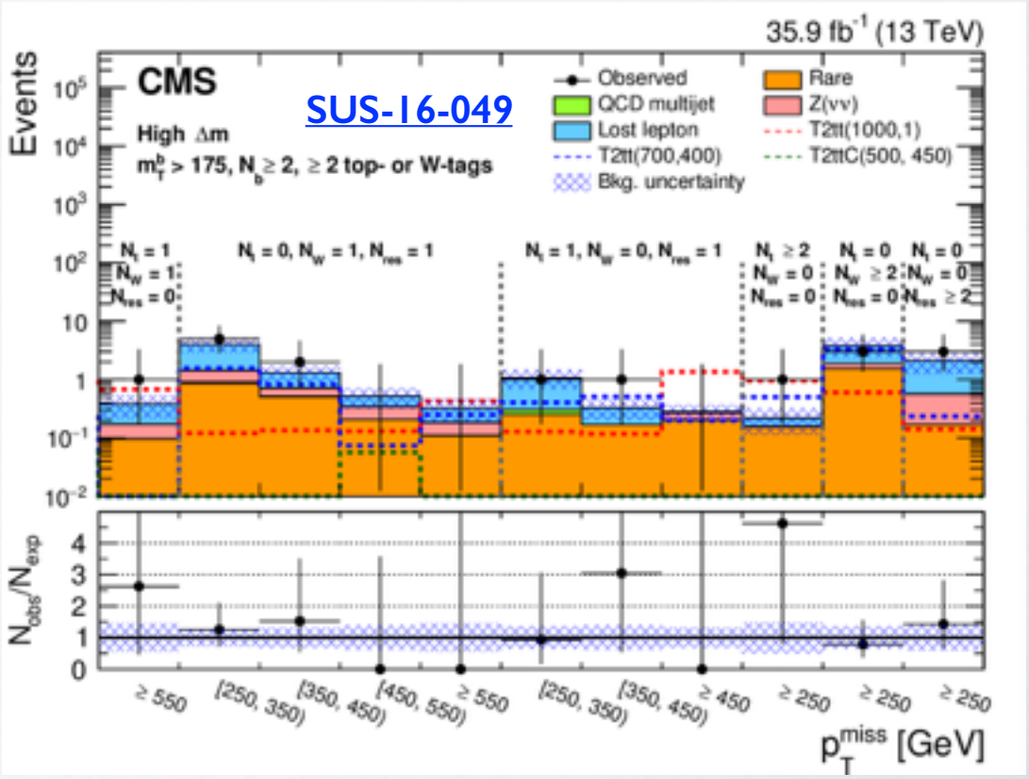


less top tags → more top tags

bin finely in mT2 — coarser mT2 regions

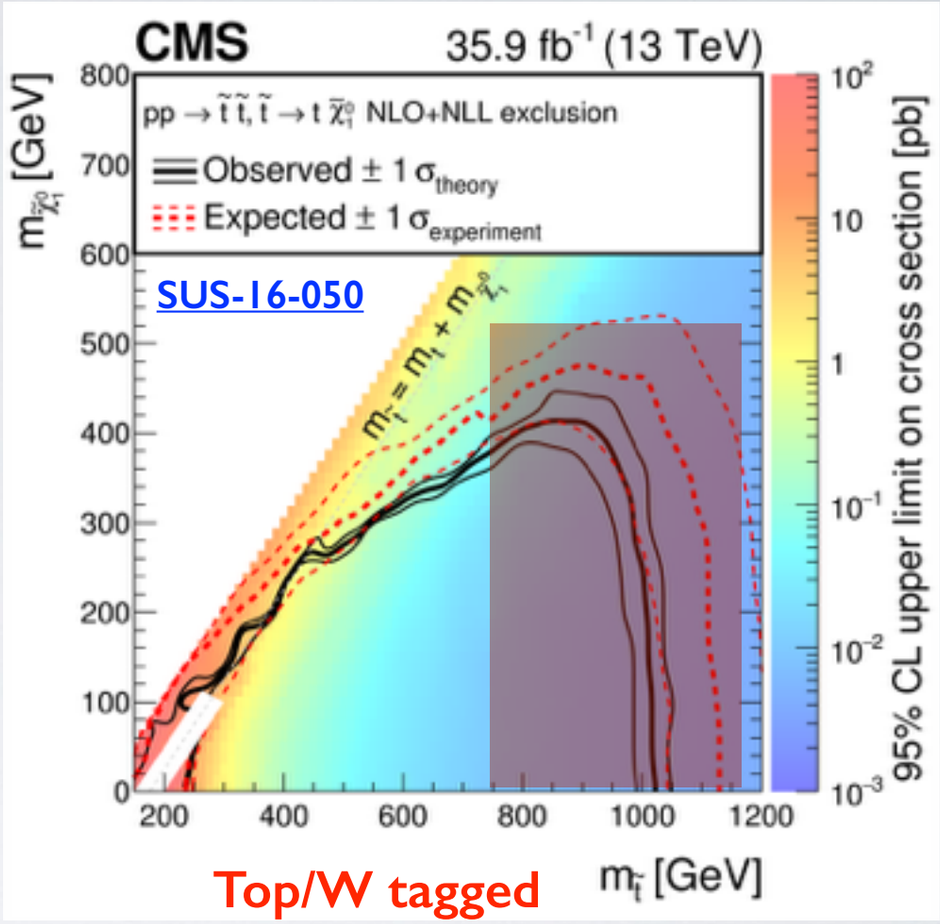


- **SUS-16-049**: Bin based on top pT
  - Bin according to resolved, boosted W, or boosted Top count. Split by 2-3 MET bins where the ranges depend on the top pT

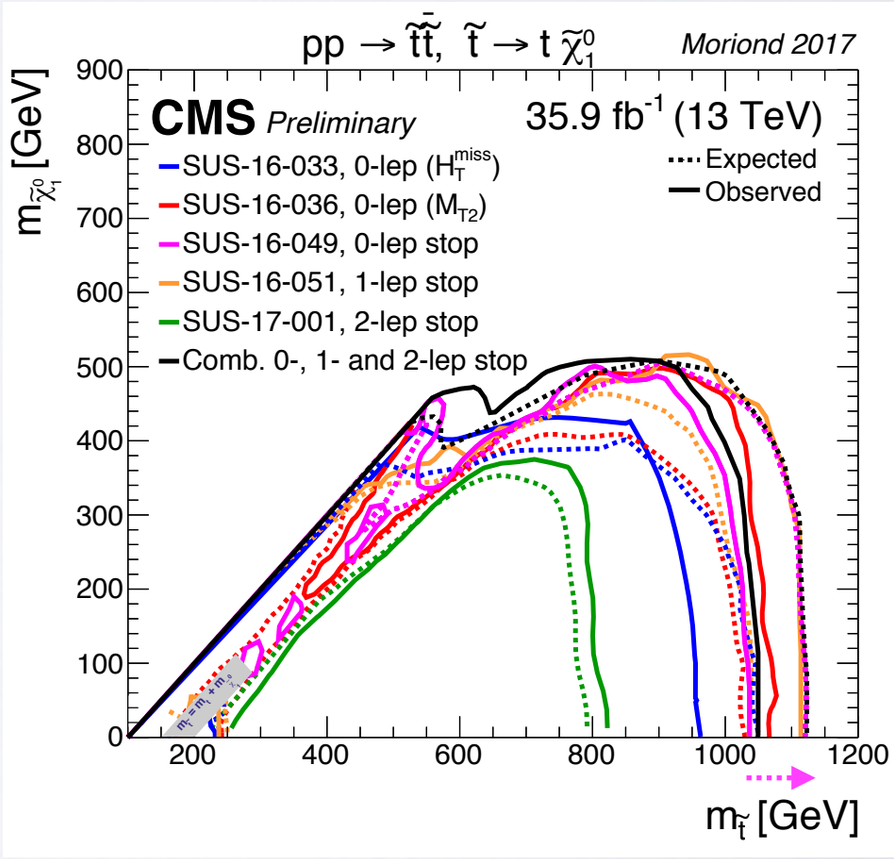


RESULTS: REACH IN STOP MASS

- In the TeV Stop range now the stop masses are mainly driven by the W-tagging and boosted Top techniques
- **Fully hadronic decays** of tops drive the sensitivity for high stop mass points when combining with searches with leptons
- Also reconstructing the the tops extends the sensitivity in stop mass reach compared to inclusive hadronic SUSY searches:
  - Furthest exclusion when counting b-jets in regions of jet multiplicity: mStop=1050GeV using **MHT** or **MT2 search bins**
  - **Using the boosted top tagging techniques this extends to above mStop=1125GeV**



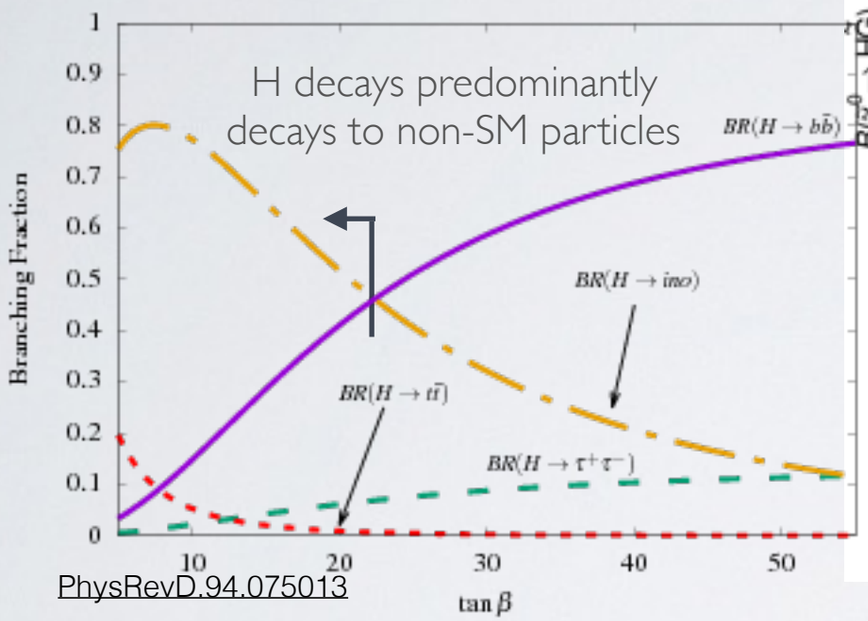
Top/W tagged domains



SEARCHES WITH HIGGS+MET

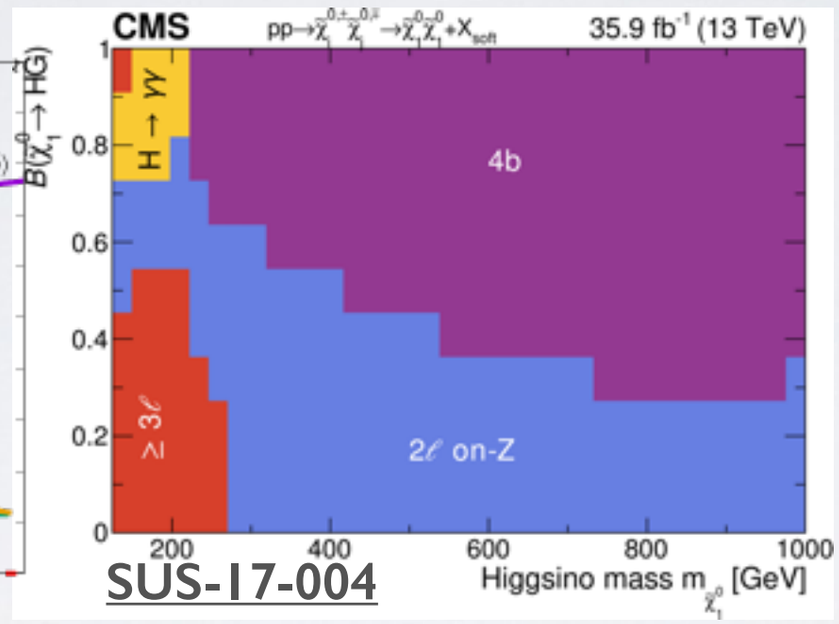
- Similar to the Stop results, Higgs tags extend the sensitivity to high mass SUSY parent particles:

Heavy Higgs decays



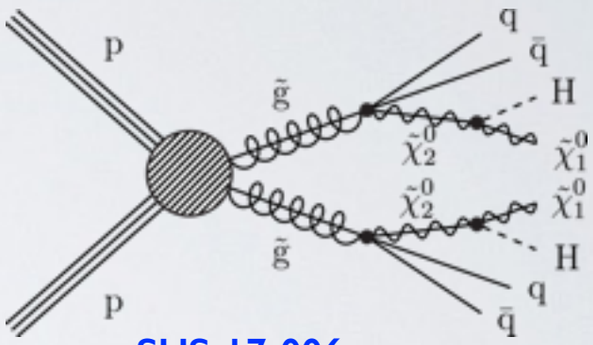
PhysRevD.94.075013

Higgsinos



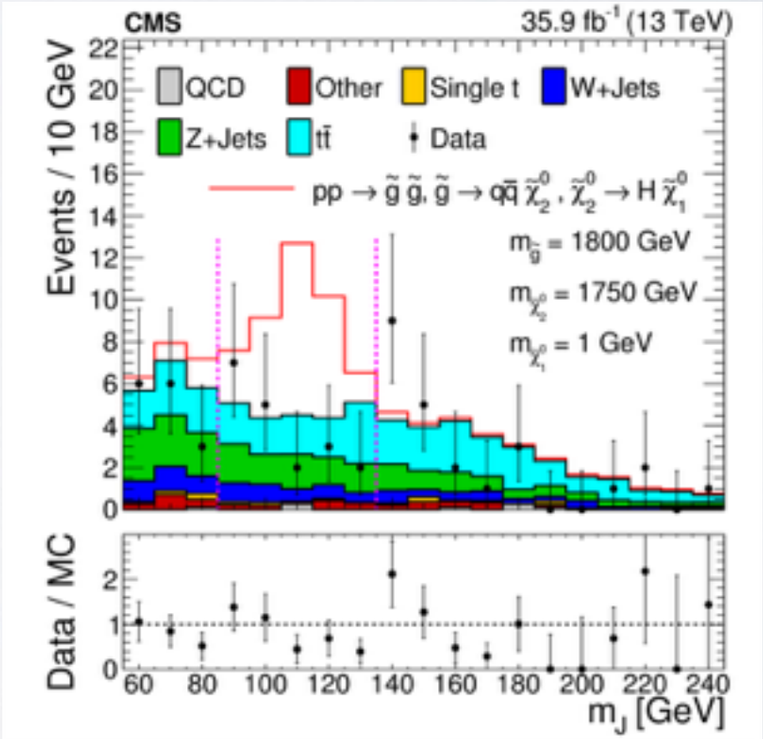
SUS-17-004

- Investigate sensitivity using strong production:



SUS-17-006

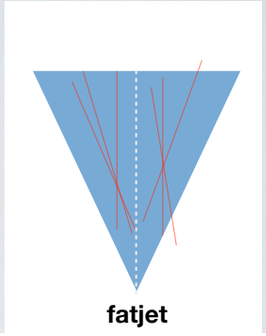
$$\Delta M = M_{\tilde{g}} - M_{\tilde{\chi}_2^0} = 50GeV$$



- In this signature there is a H—>bb mass resonance at high MET on top of a mainly non-resonant background:
  - Look for wide cone jets consistent with 2 b-quarks on top of a background of mis-tags and single b jets from top
  - Boosted Tops are part of the background in the sidebands

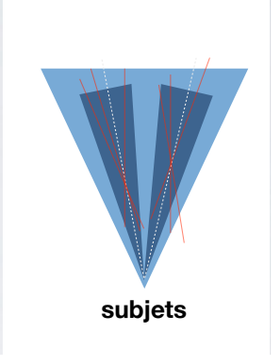
HIGGS TAGGING

- Want a measure of the heavy flavor content of a wide cone jet
  - **Loose tag:** use b-tagging on the large cone jets. This will have no rejection power against jets from top
  - **Tight tag:** Decluster the jet into two sub-jets and require each subjet to be b-tagged. This will reject top jets, but can be too tight given the number of tracks in each subjet (require a SIP)
  - **Double-b tag:** Use the subjets for the b-direction and check for SV's that you can find along that direction. Also make use of the opening angle for a heavy particle decay

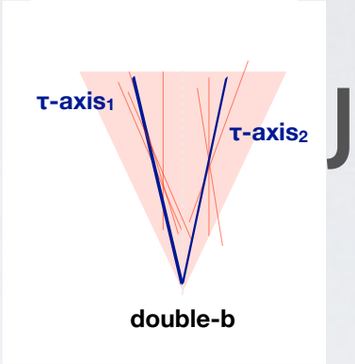


BTV-15-002

Too loose

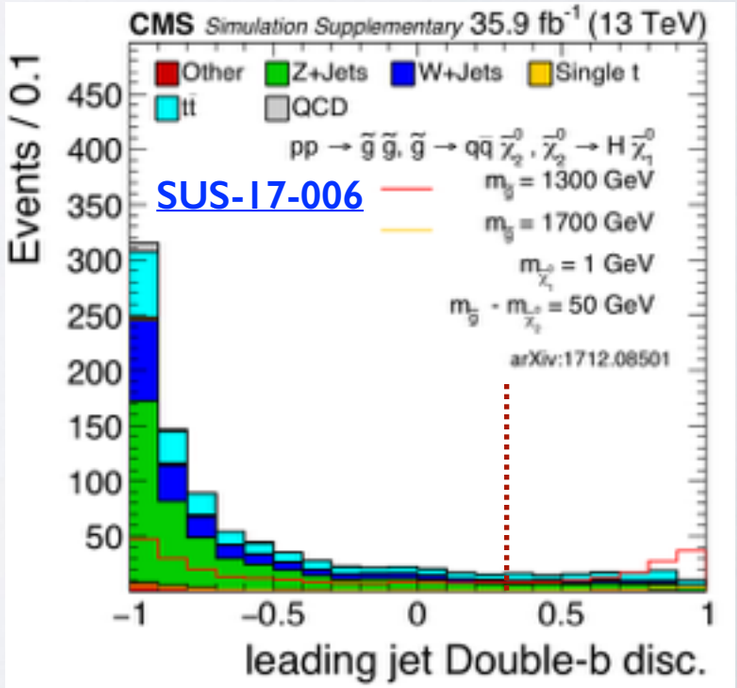


Too tight



Just right!

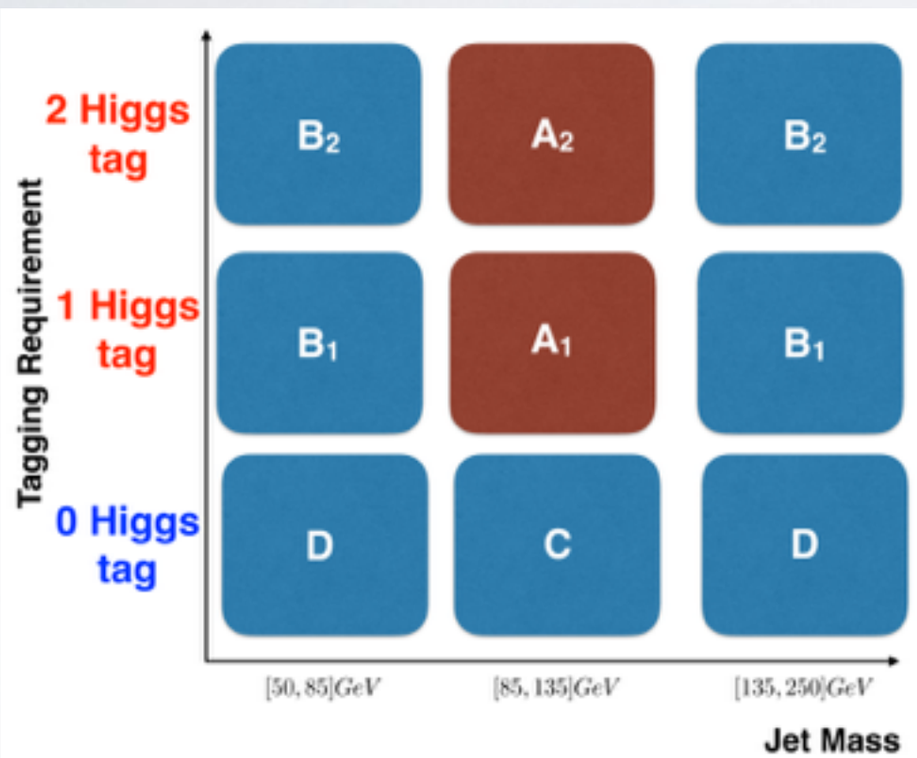
- **Search for Higgs production at large missing energy**;
  - Low MET searches are dominated by the bulk of QCD-multijets, so they rely on tighter tagging for bkg. suppression.
  - For SUSY we can afford to have a looser tagging requirement, we are dominated by mistags and single-b background from top



BACKGROUND STRATEGY

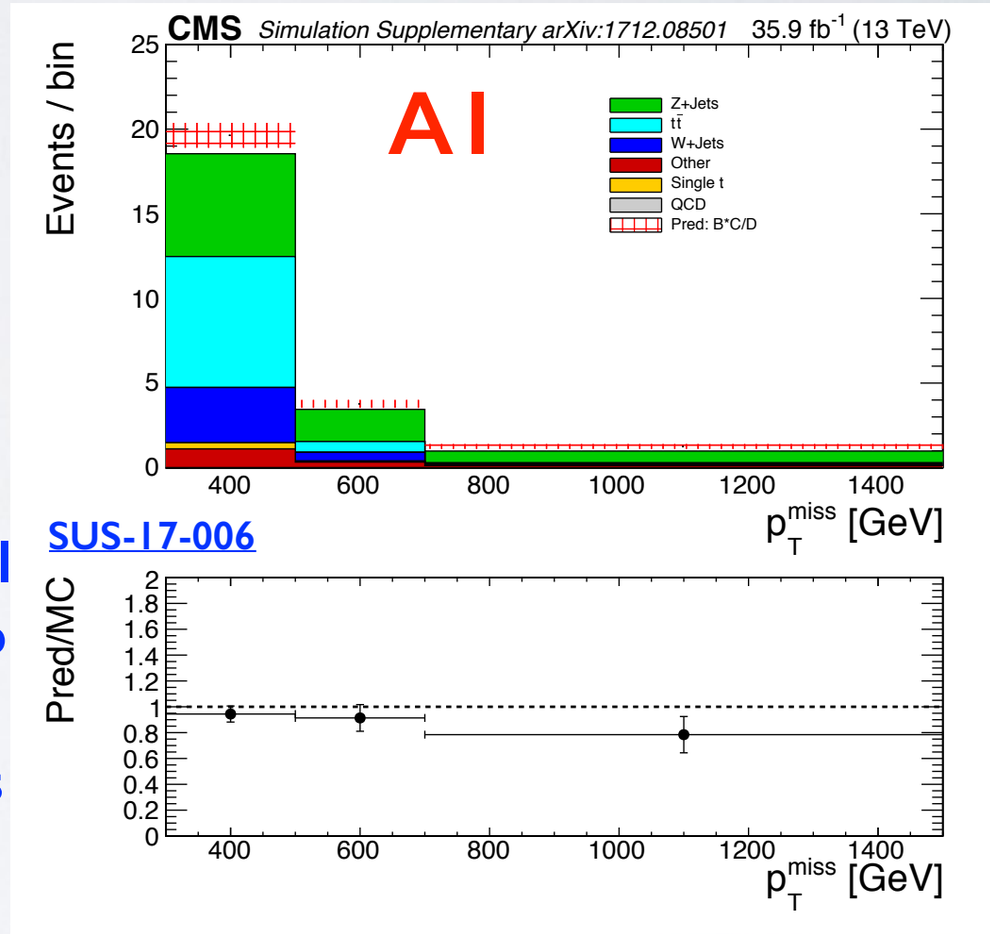
- A key feature of the analysis is that the double-b tagging uses variables that are not correlated with the jet mass, so the mass-sideband and the un-tagged events can be used for a control region for an ABCD method

Search regions require <u>either 1 or 2 double-b tags</u>, both jets need to have a mass compatible with the higgs



κ closure correction is assigned to model any effects due to correlation between jet-mass and tagging.

Closure is measured in MC that is scaled to data based on data validation regions for each background component

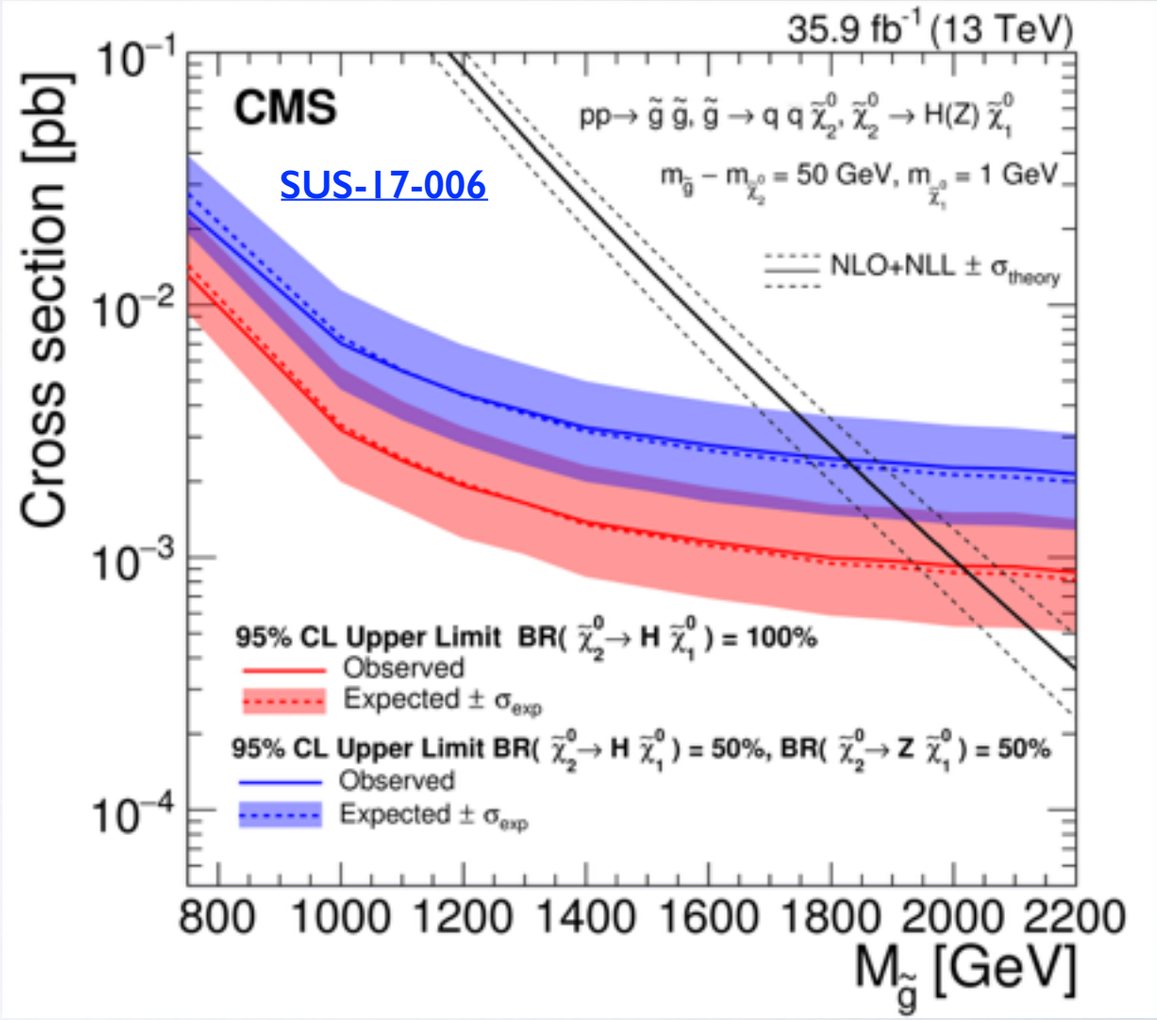


Syst. comes from varying the bkg composition within SF unc.

RESULTS: HIGGS+MET

- The main uncertainty is due to the control sample statistics
  - Observations are compatible with the SM prediction
- Upper limits are set on gluino pair-production for HH and HZ final (50% BR) states at high MET
  - **HH**: Exclude up to 2010 GeV
  - **HZ**: Exclude up to 1825 GeV

N_H	p_T^{miss} (GeV)	κ	$A_{predicted}$	A	B	C	D
1	300 – 500	0.98 ± 0.11	17.7 ± 3.8	15	112	44	273
1	500 – 700	0.86 ± 0.16	3.4 ± 1.5	2	20	12	60
1	>700	0.86 ± 0.17	0.61 ± 0.45	1	5	4	28
2	300 – 500	0.73 ± 0.14	1.52 ± 0.57	1	13	44	273
2	500 – 700	0.43 ± 0.12	0.09 ± 0.08	0	1	12	60
2	>700	0.62 ± 0.30	$0.09^{+0.11}_{-0.09}$	0	1	4	28



CONCLUSIONS

- Boosted SUSY searches offer the unique opportunity to characterize jets instead of just counting
- SUSY features unique signatures with top-production and Higgs production at high MET with large Lorentz boost
- Boosted Object searches at high MET probes SUSY production at the TeV scale

Knowledge about jets

Searches for SUSY

Analysis Index	Arxiv	Journal
SUS-16-049	arxiv:1707.03316	JHEP
SUS-16-050	arxiv:1710.11188	PRD
SUS-17-006	arxiv:1712.08501	PRL