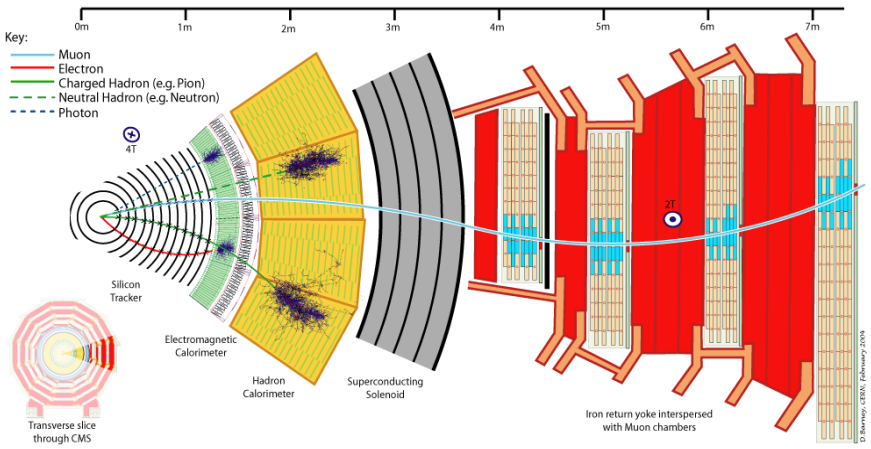
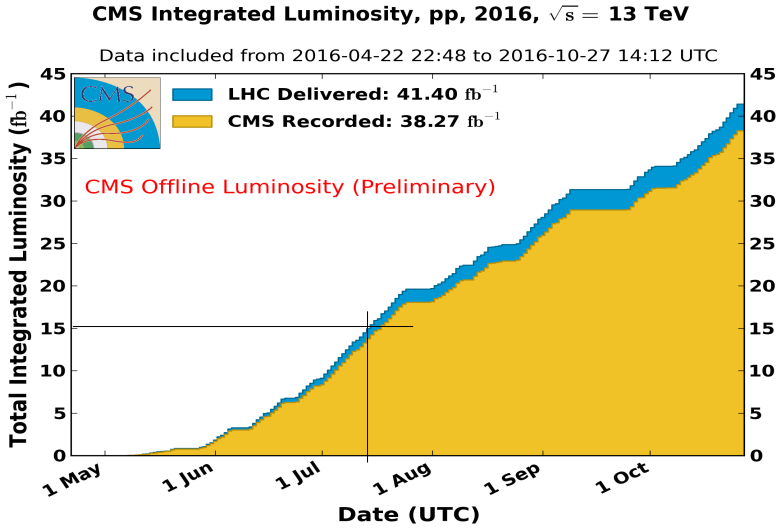
SUSY searches at CMS

Florent Lacroix
(U. of California Riverside)
on behalf of the CMS collaboration

Introduction

- Supersymmetry (SUSY) = symmetry between fermions and bosons
  - Solution for the hierarchy problem: additional particles stabilized Higgs mass
  - Dark matter candidate: if R-parity is conserved, lightest SUSY particle (LSP)
  - Unification of coupling constants at GUT scale
- SUSY can be realized in many ways: rich phenomenology
  - Minimal supersymmetric standard model (MSSM): >100 new parameters
  - ➢ Simplified Models are used for the interpretation of CMS results
- LHC has delivered >40fb^{-1} in 2016!
- Most of the results in this talk are based on the "ICHEP dataset" , corresponding to 12.9fb^{-1} of fully certified data recorded by the CMS detector.





CMS SUSY analyses

- Inclusive analyses
  - Hadronic final states
  - Leptonic final states
- 3rd generation searches
  - Focusing on "natural SUSY"
  - Stop and sbottom searches
- Electroweak production modes, Gauge-mediated SUSY breaking analyses
  - Photons or leptons final states
- More specialized searches
  - RPV analyses
  - Di-lepton mass-edge
  - Z-resonance

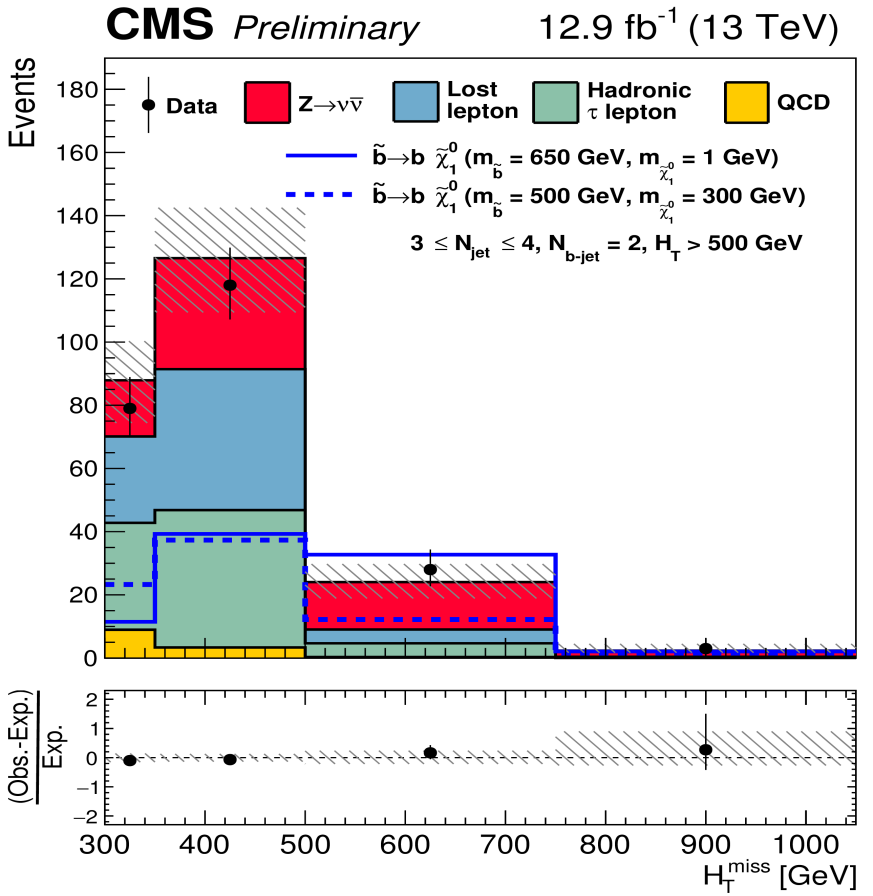
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

0-lepton inclusive: HT+MHT search

SUS-16-014

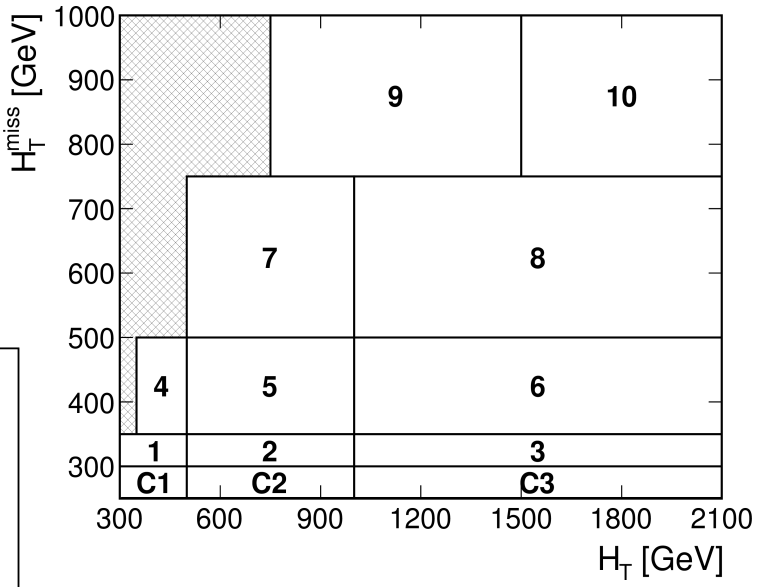
- Selection :
- 3 jets with pt > 50 GeV
- HT > 300 GeV
- MHT > 300 GeV
- DeltaPhi(jet, MHT) > 0.5,0.5,0.3
- Veto isolated e/mu, pt > 10 GeV

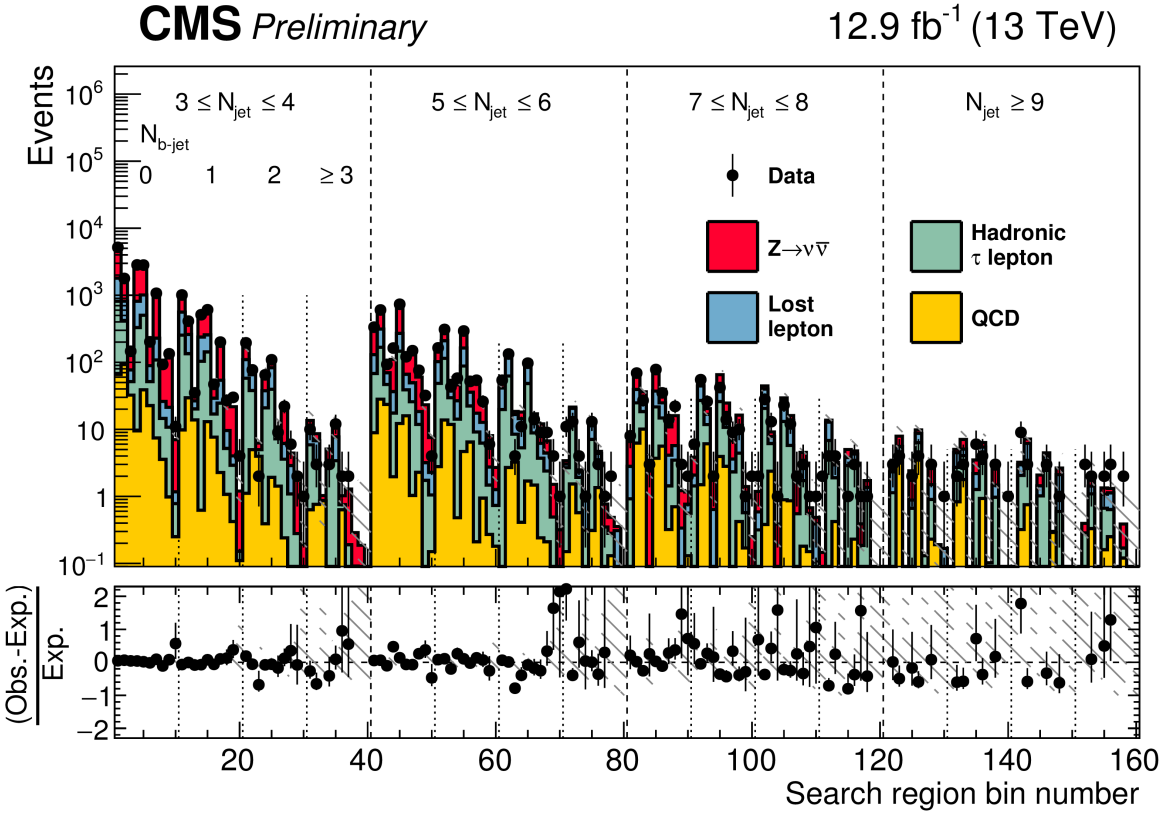
- Data driven methods are used to estimate each background.
  - muon+jet control sample is used to estimate W and ttbar background.
  - $Z \to \mu\mu$ and γ+jets events are used for the Z background estimation.
  - Inverted DeltaPhi events are used to estimate the QCD.

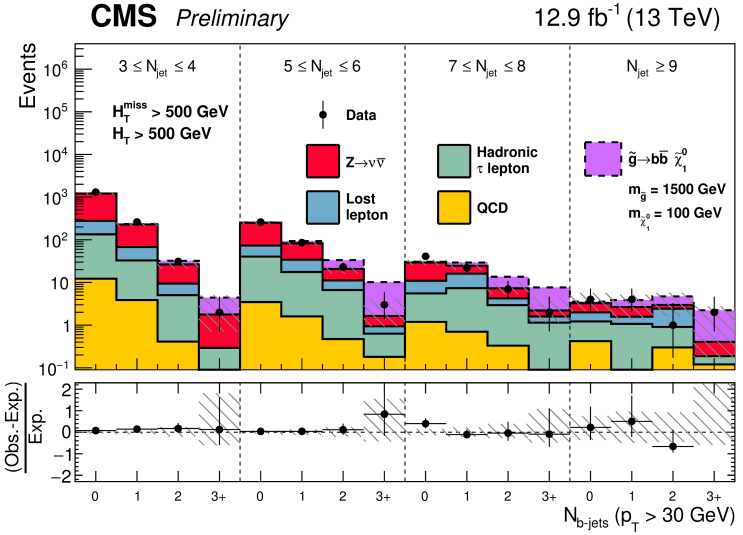


HT+MHT: search bins and results

- Inclusive analysis of 160 search regions, binned in Njets, Nbjets, HT and MHT.
- Data shows no significant excess.







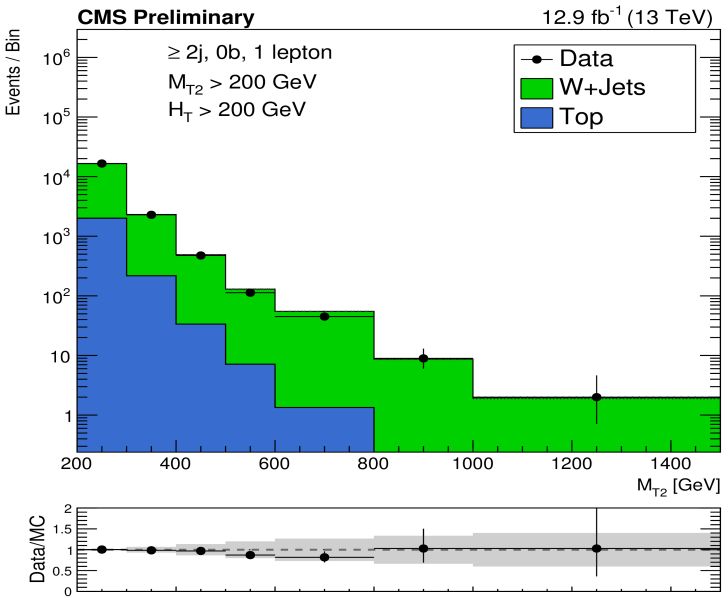
0-lepton inclusive: MT2 search

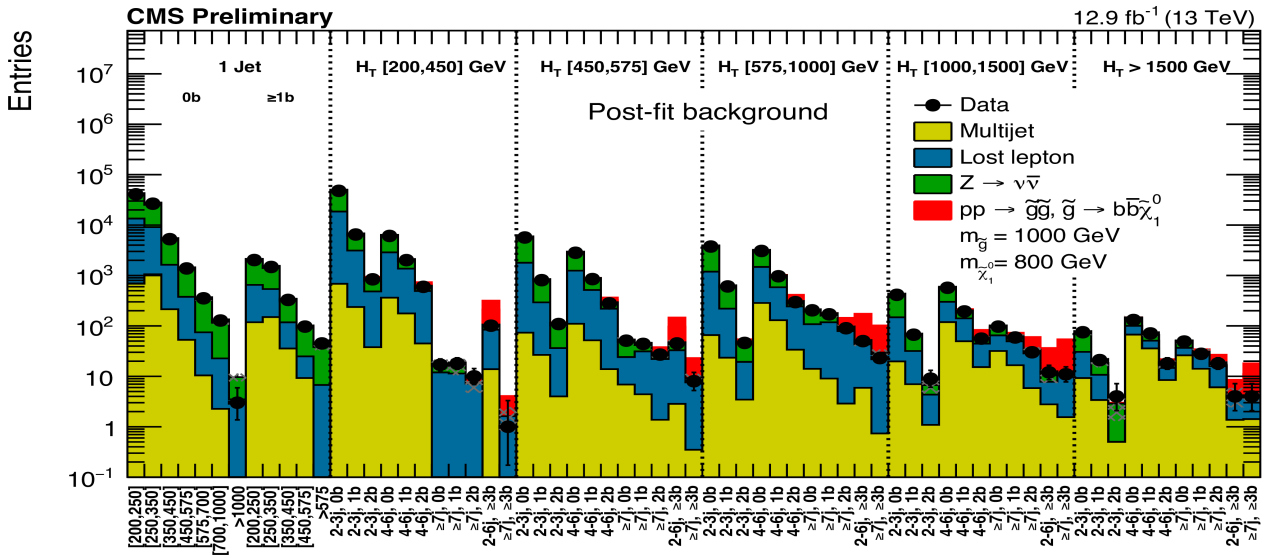
SUS-16-015

- MT2 is a generalization of the transverse mass MT for the case of 2 decay chains with 2 unobserved particles:

$$M_{T2}(m_{\tilde{\chi}}) = \min_{\vec{p}_T^{\tilde{\chi}(1)} + \vec{p}_T^{\tilde{\chi}(2)} = \vec{p}_T^{\text{miss}}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

- Sensitive variable to genuine MET:
- QCD high met events are mainly at low MT2, contrary to SUSY events.
- Includes now a monojet categorie (wo MT2).
- Search binned in HT, Nb, Njets and MT2.
- No significant excess observed.





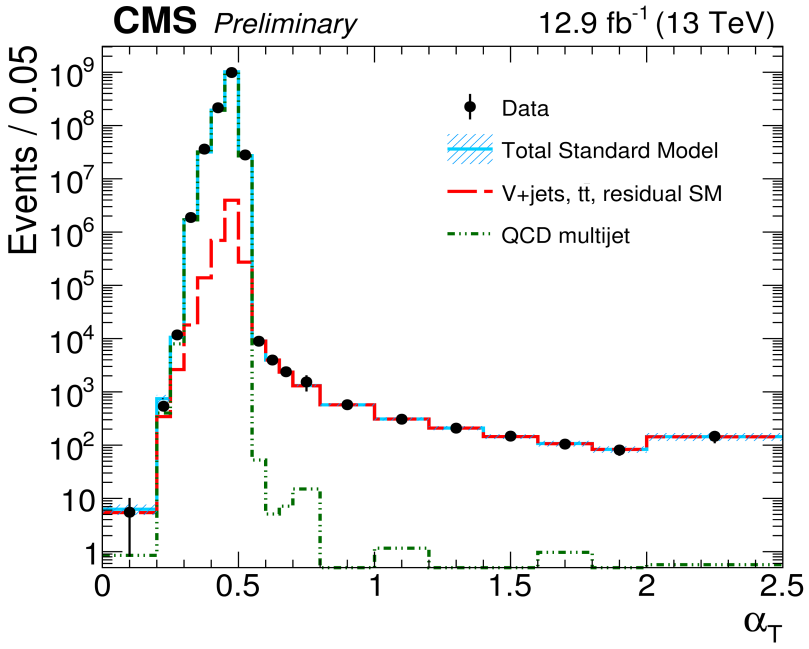
0-lepton inclusive: AlphaT search

SUS-16-016

- Inclusive search based on kinematic variable alphaT:
  - Cluster jets into 2 pseudo-jets
  - $\alpha_T = \frac{E_T^{j_2}}{M_T(j_1, j_2)}$
  - If njets ≥ 3:

$$\alpha_T = \frac{1}{2} \cdot \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}} = \frac{1}{2} \cdot \frac{1 - (\Delta H_T / H_T)}{\sqrt{1 - (\not{H}_T / H_T)^2}}$$

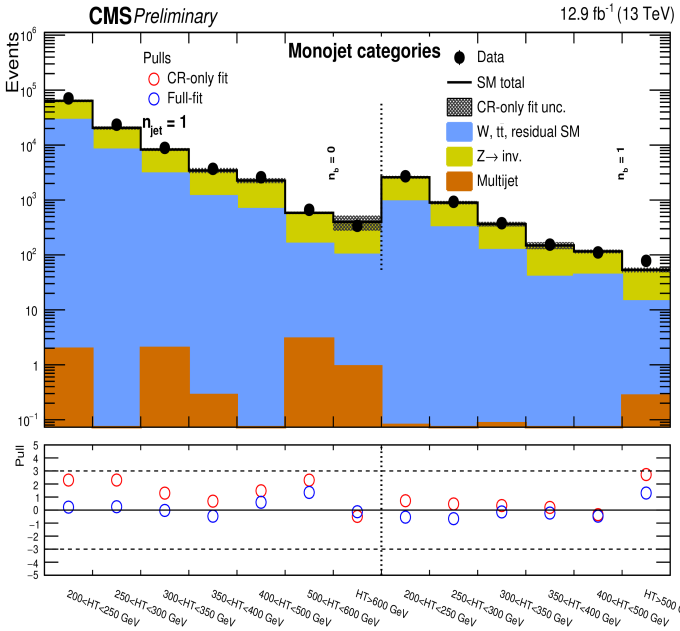
- Basic idea :
  - alphaT=0.5: perfect dijet event
  - alphaT<0.5: events with mismeasured jets
  - alphaT>0.5: events with genuine MET
  - ➢ Very effective discriminant against QCD background.

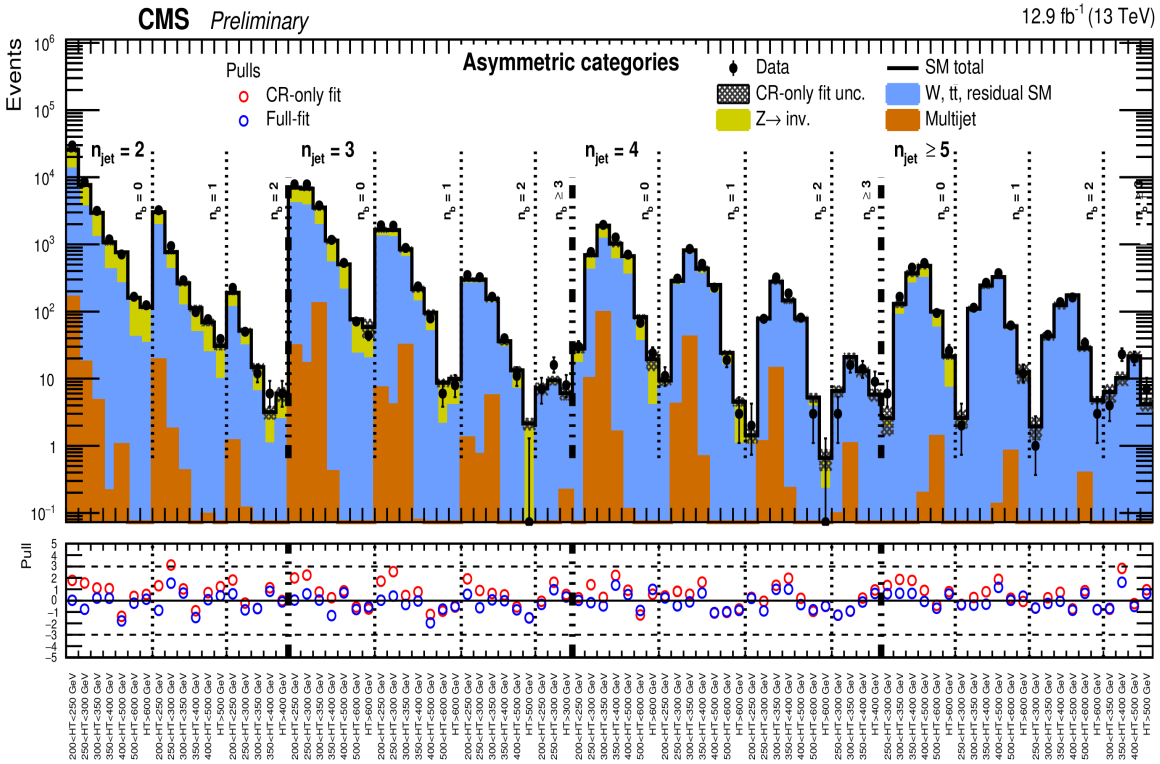


- Selection:
- HT > 200 GeV, MET>130 GeV
- Includes now monojet and asymmetric jet selections
- alphaT > 0.52
- Veto isolated e/mu/photon

alphaT: search bins and results

- Search is binned in HT, N jets, N bjets and alphaT
- Data driven background estimates from muon+jets, di-muons+jets and photon+jets control samples, using transfer factors.
- All results are compatible with SM expectation.

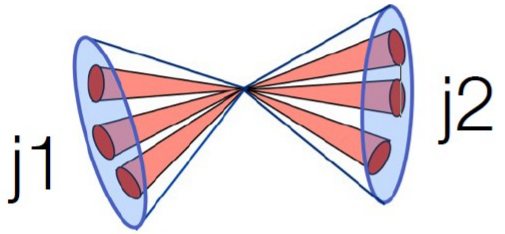




Inclusive: Razor search

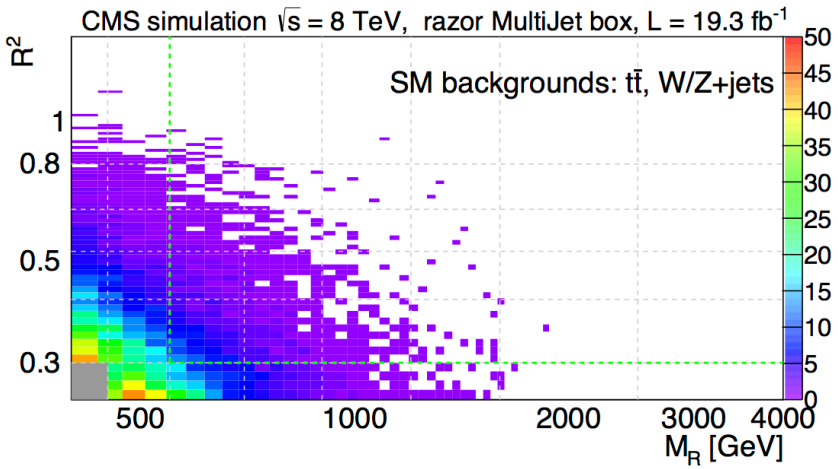
- Compute MR and R2 from the mega jets and the MET.
- MR broadly peaks at the caracteristic mass scale: $\frac{M_{\tilde{q}}^2 - M_{\tilde{\chi}}^2}{M_{\tilde{q}}}$
- Categorized events into « boxes » by lepton content, and jet and bjet multiplicities.

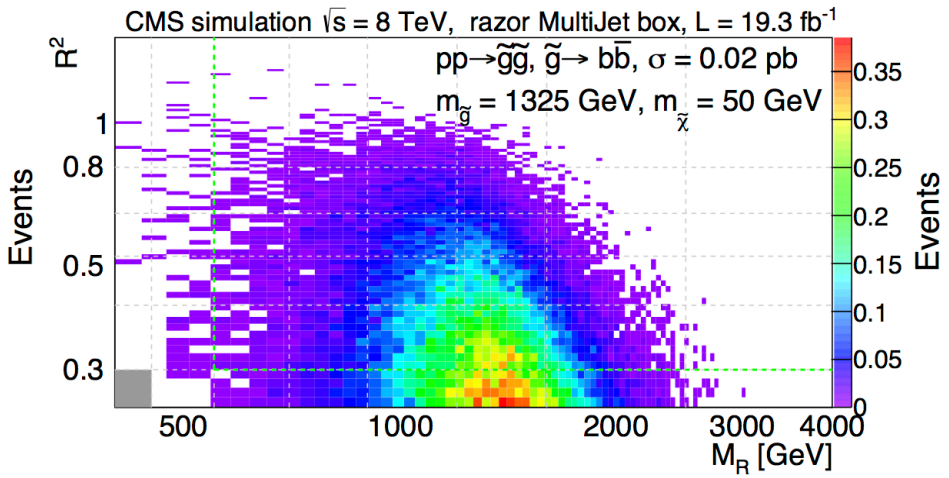
SUS-15-004, arXiv:1609.07658



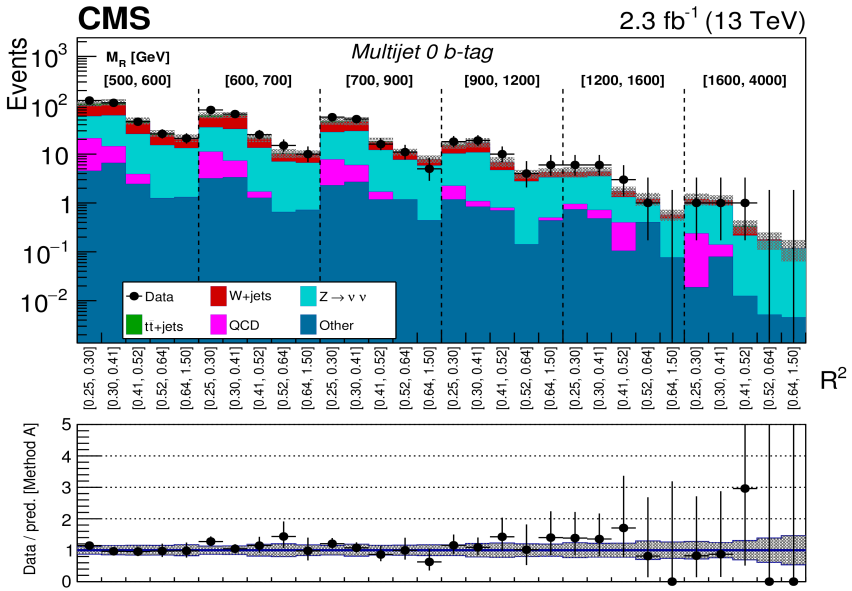
$$M_R = \sqrt{(|\vec{p}^{j1}| + |\vec{p}^{j2}|)^2 - (p_z^{j1} + p_z^{j2})^2}$$

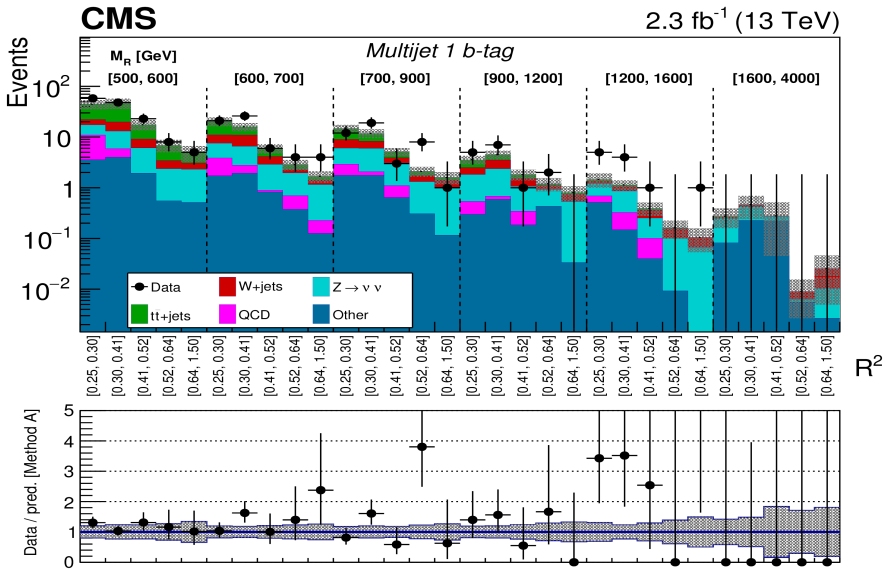
$$R \equiv \frac{M_T^R}{M_R} \qquad M_T^R \equiv \sqrt{\frac{E_T^{\text{miss}}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{\text{miss}} \cdot (\vec{p}_T^{j1} + \vec{p}_T^{j2})}{2}}$$

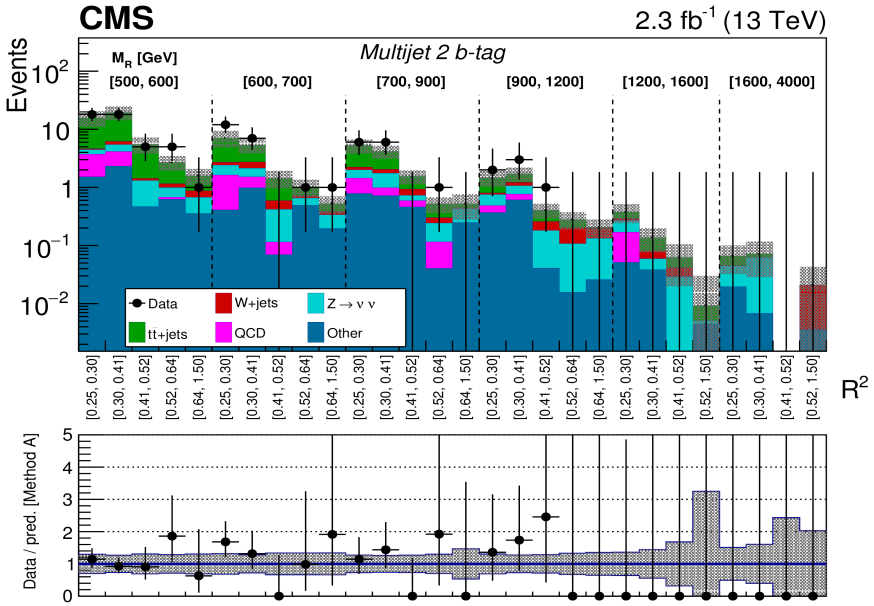


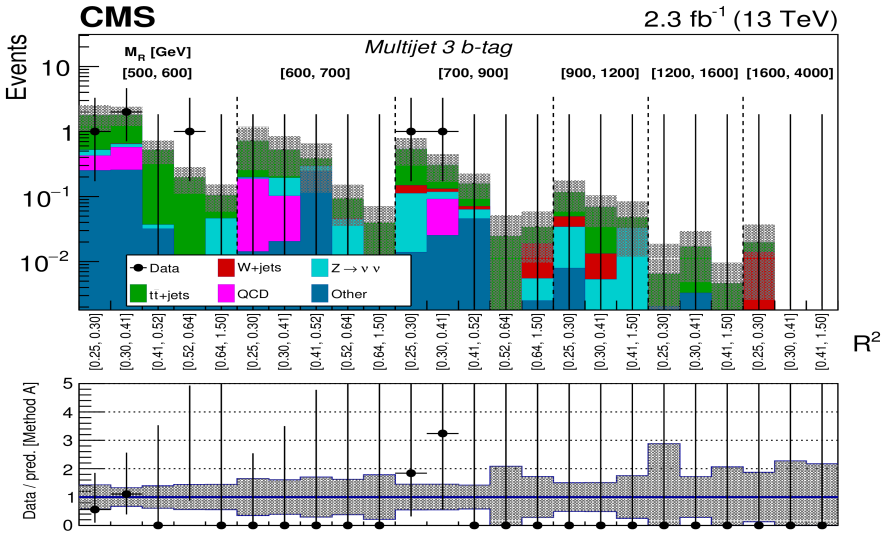


Razor: results



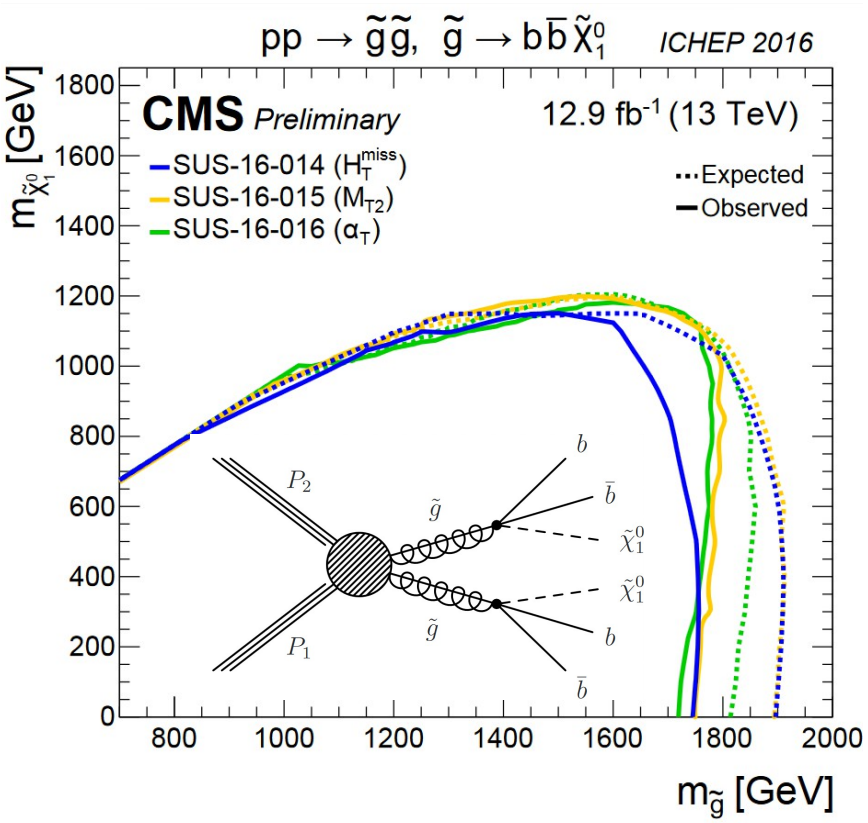


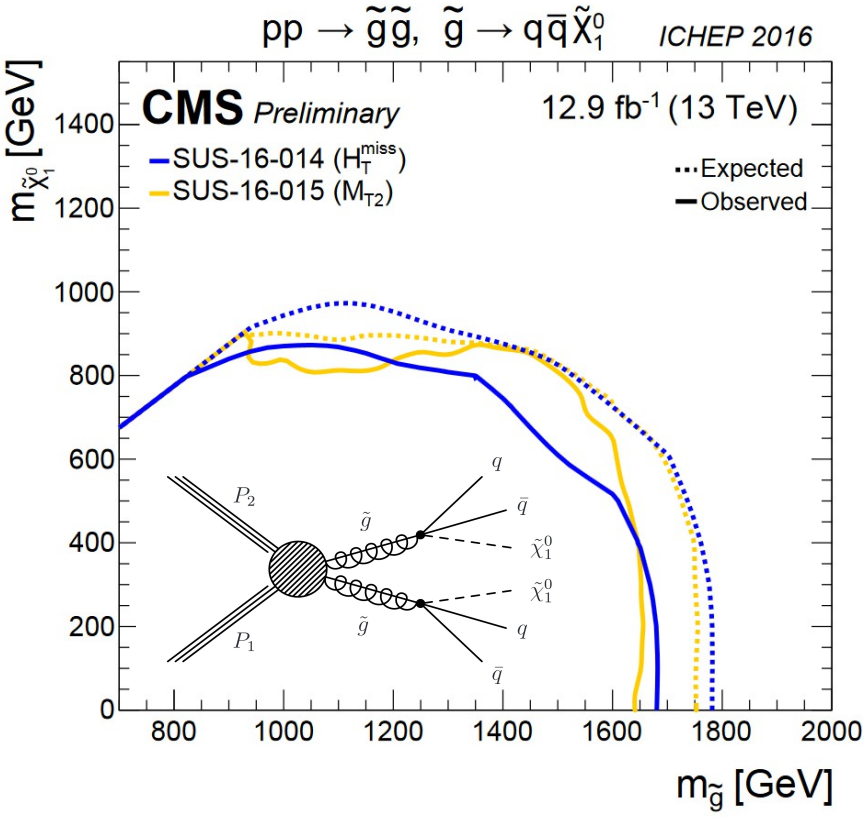




0-lepton summary: gluinos

- Interpretation with Simplified Models for gluino-mediated production:

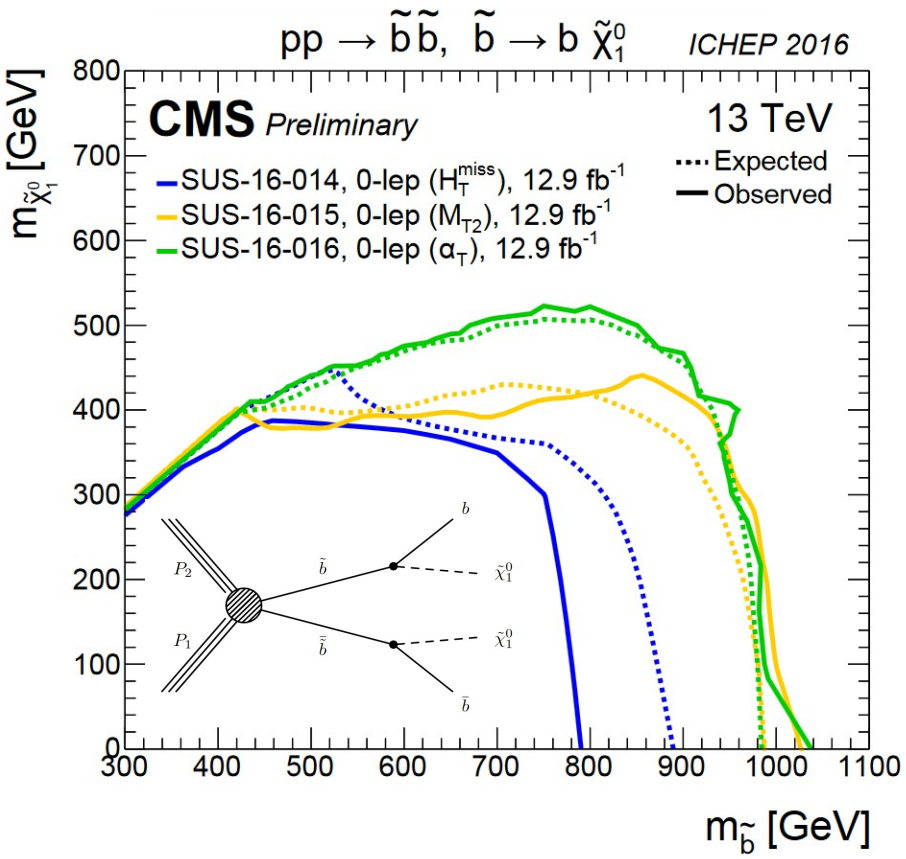


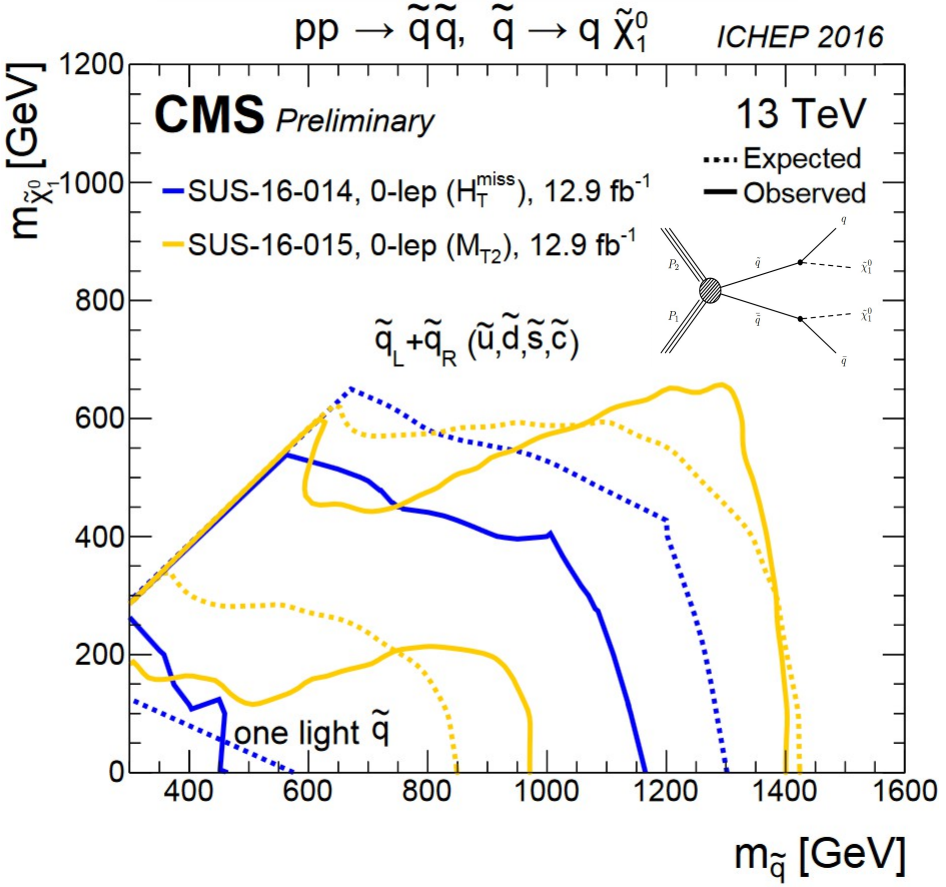


- All analyses have similar sensitivity.

0-lepton summary: squarks

- Interpretation with Simplified Models for direct production:





- Here MT2 and alphaT variables help due to lower signal cross-section.

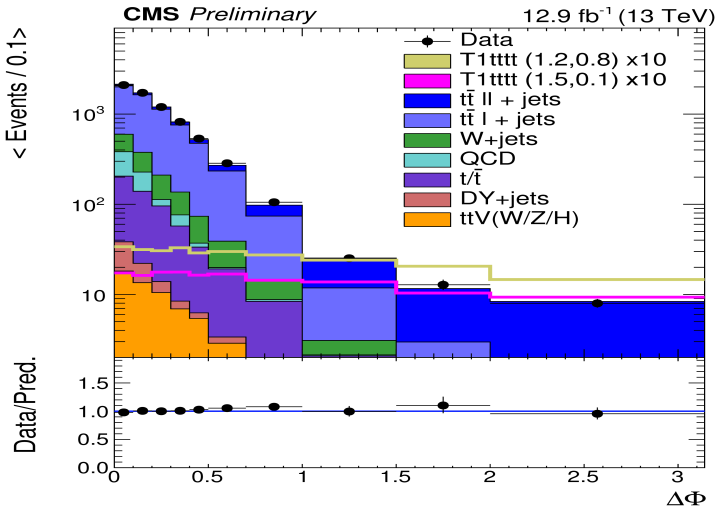
1-lepton inclusive: DeltaPhi search

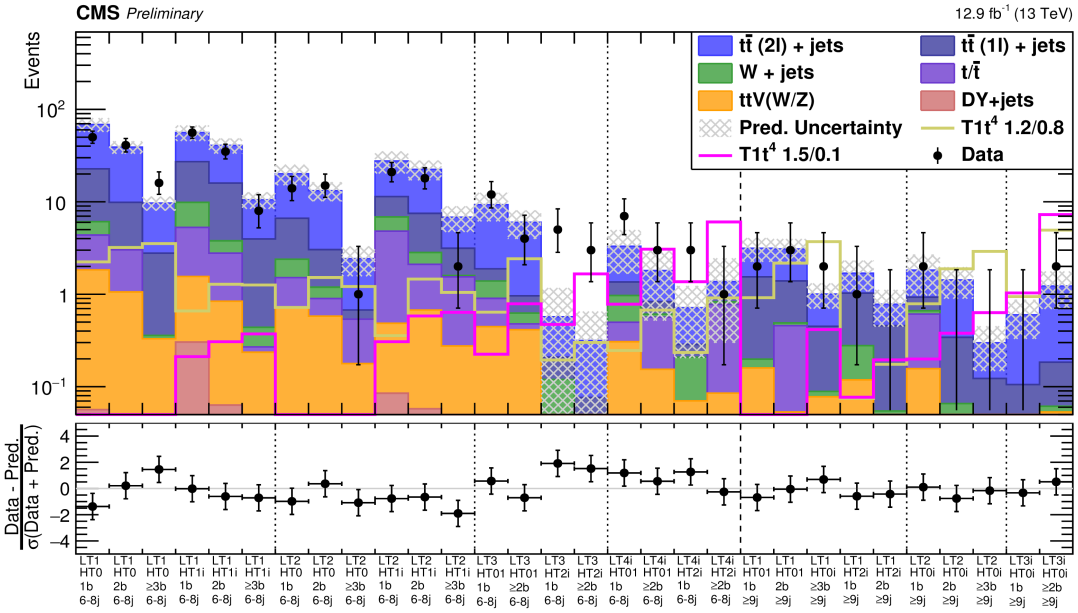
SUS-16-019

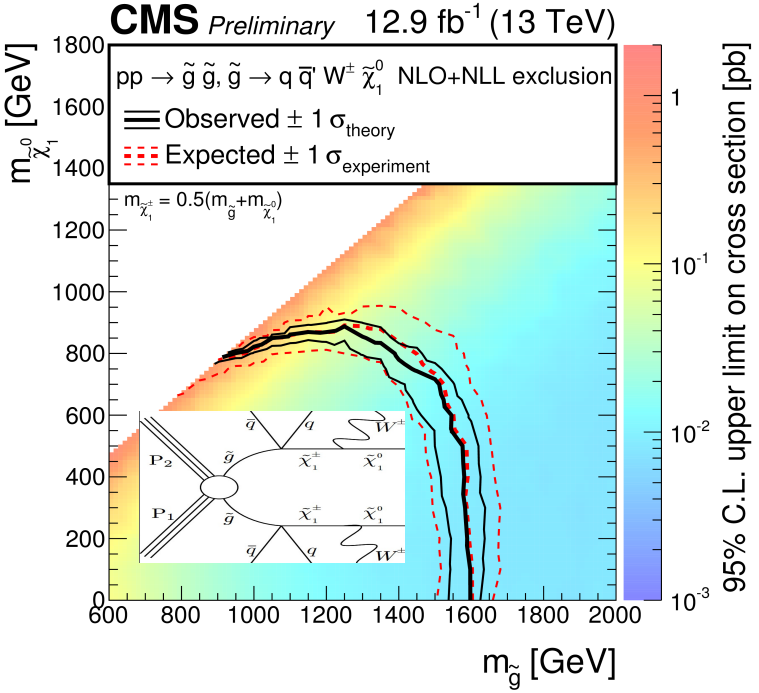
- DeltaPhi(ptW,lepton pt) is used to separate signal and W+jets and ttbar backgrounds.

$$p_{\mathrm{T}}^{\mathrm{W}} = |\vec{p}_{\mathrm{T}}^{\,\ell} + \vec{p}_{\mathrm{T}}^{\,\mathrm{miss}}|$$

- Search bins in b-jet multiplicity (≥5 jets, no b and ≥6 jets, ≥1 b)



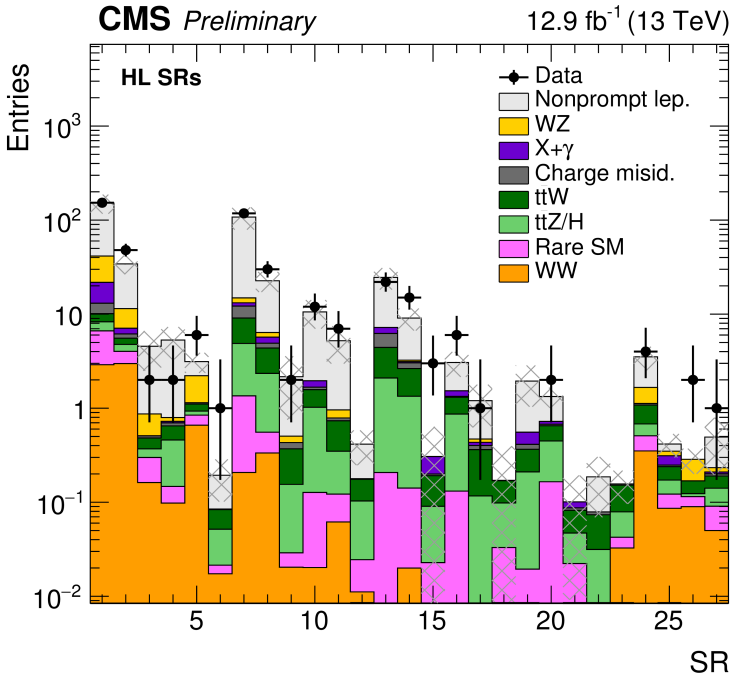


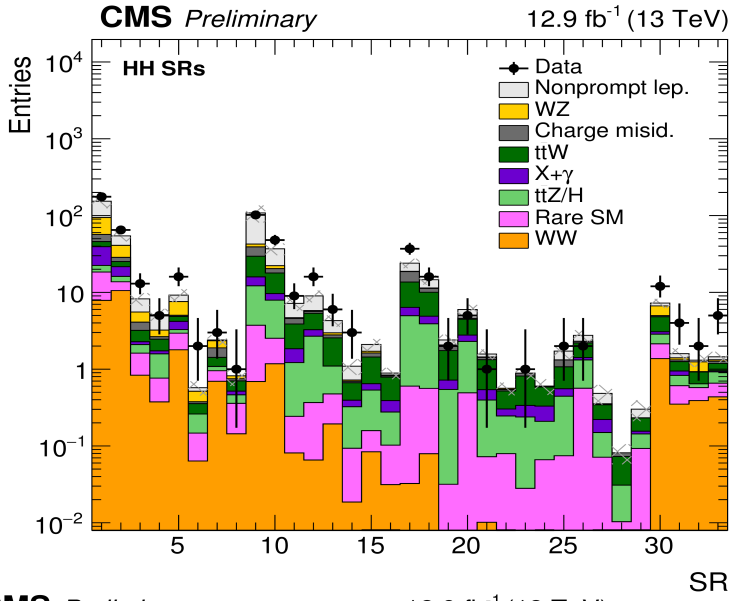


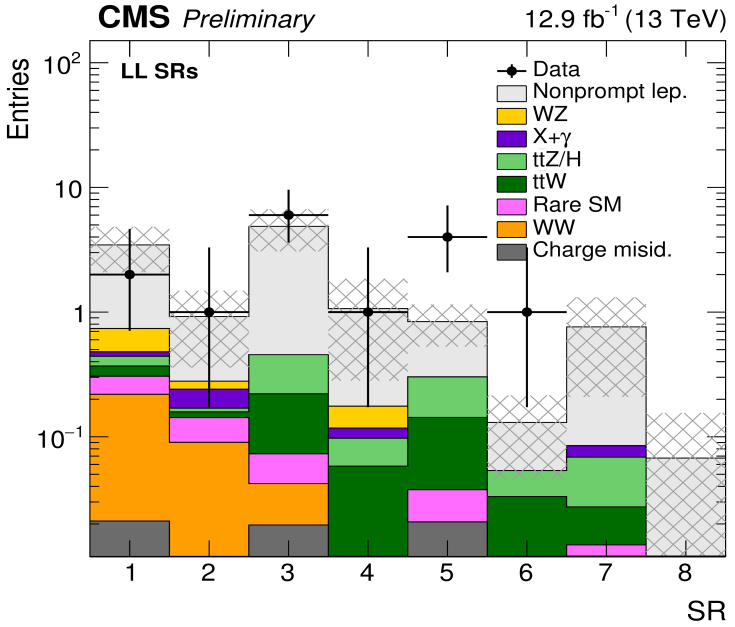
2-leptons: SS search

SUS-16-020

- Same sign di-lepton analysis.
- Main background from non prompt leptons, estimated using « tight-to-loose » ratio technique based on control samples in data.
- Three regimes, depending on lepton pT (10<pt<25 GeV or >25 GeV), high-high, high-low and low-low.



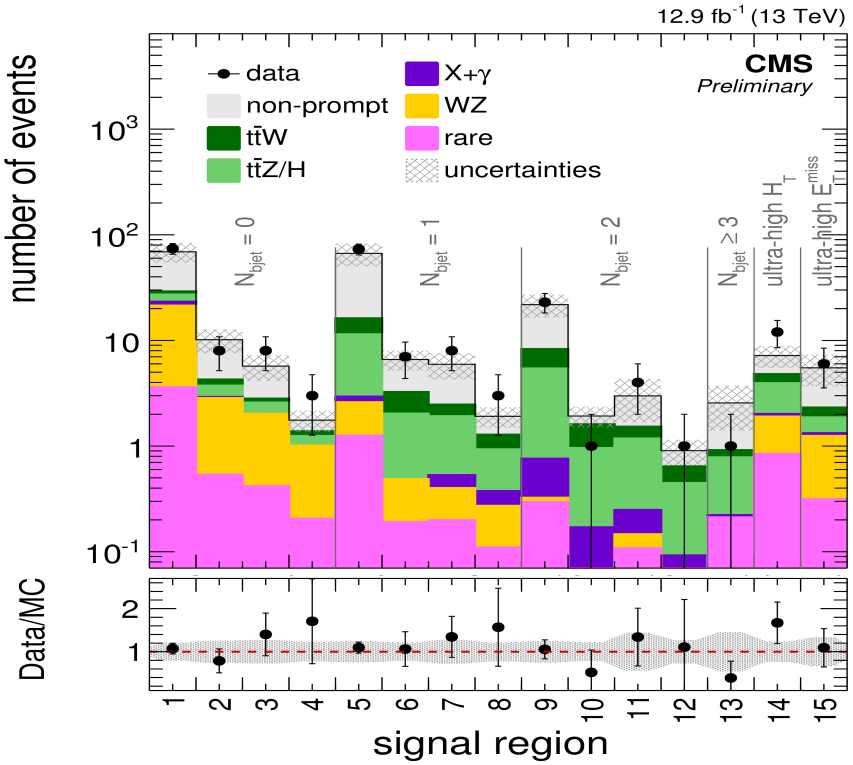


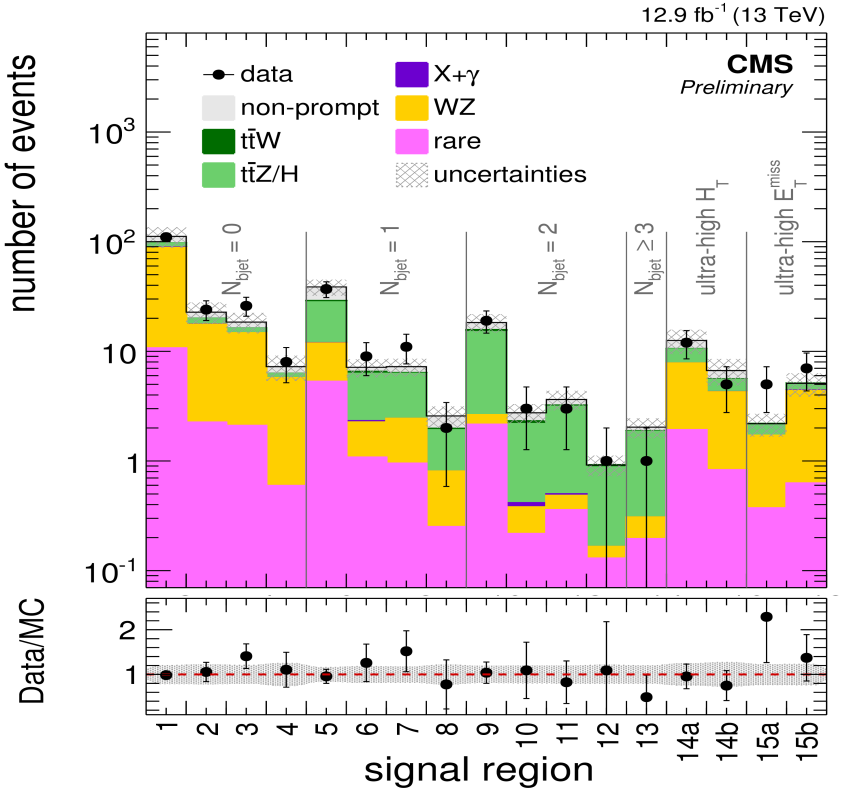


multi-leptons search

SUS-16-022

- ≥3 electrons or muons
- 15 off-Z signal regions and 17 on-Z signal regions
  - On-Z if OS same flavor pair find with an invariant mass within a 15 GeV window around the Z mass
- Physics backgrounds from simulation (WZ/ZZ sample is normalized to data in a control region); misidentified-lepton backgrounds from data

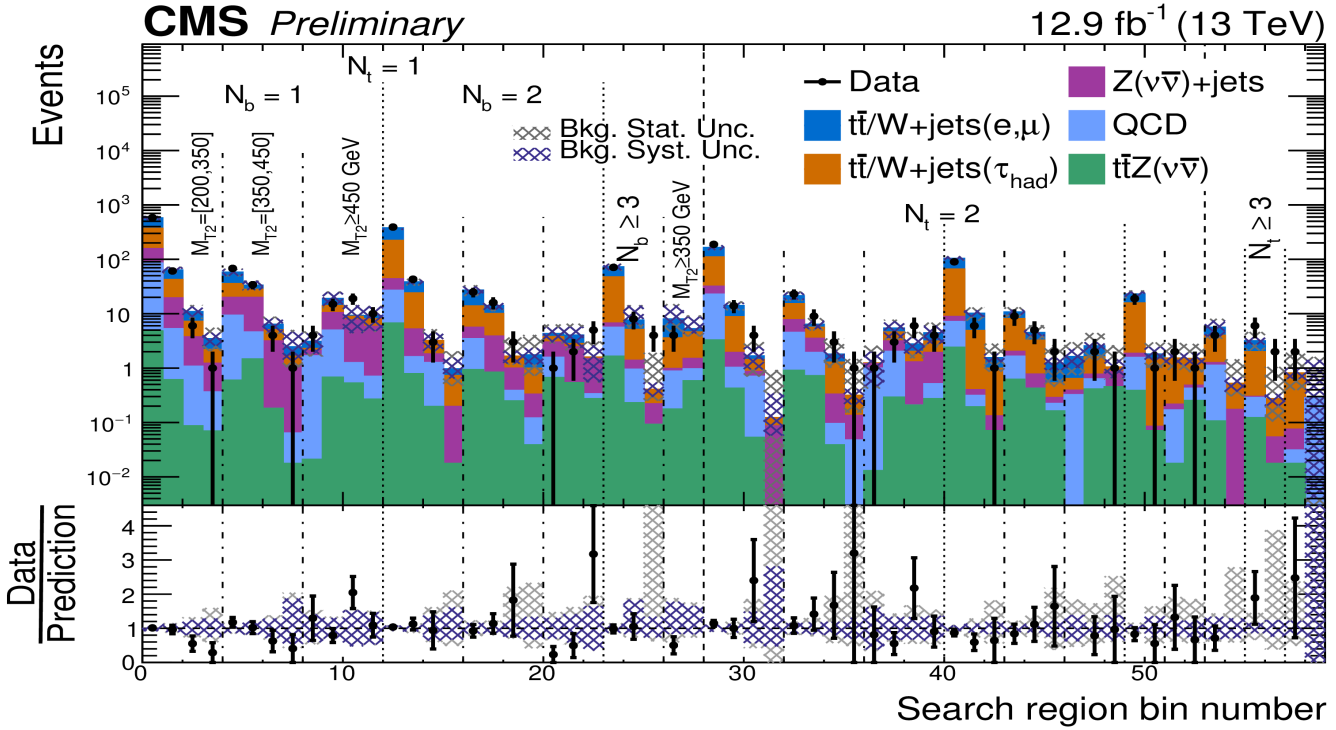




3rd generation searches: 0-lepton top tagger

- Inclusive search using a custom, highly efficient top tagger :
  - combination of three ak4 jets of at least 30 GeV in a cone of radius 1.5
  - two jets with one consistent with a merge W
  - monojet with a mass consistent with the top mass.
- W+jets and ttbar background is estimated from muon+jet control sample.
- QCD from inverted dphi events, ttZ and Zinv from MC, corrected from data/MC differences.
- Categorization of events in bins of Ntop, Nbjets, MET and MT2.

SUS-16-030

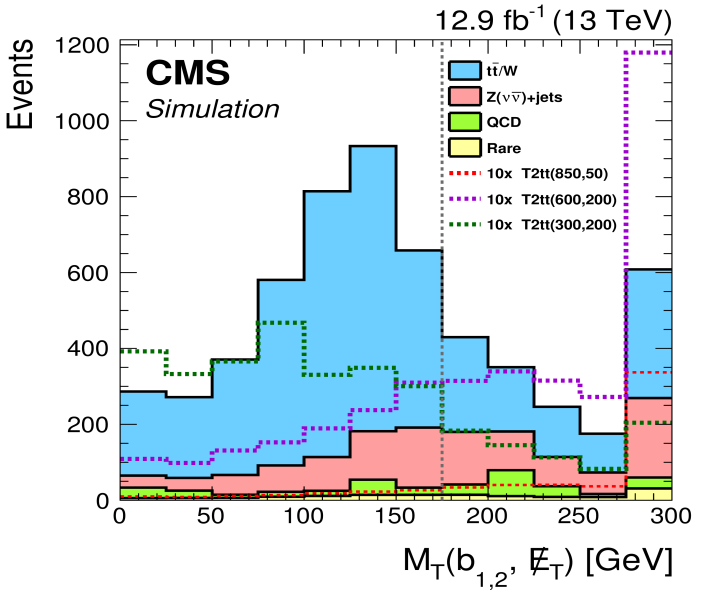


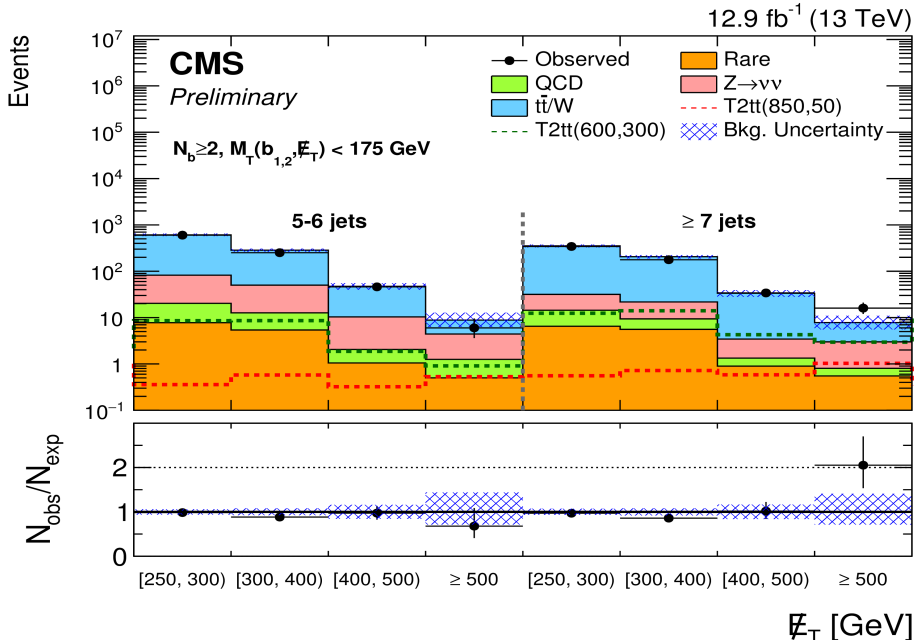
0-lepton stop

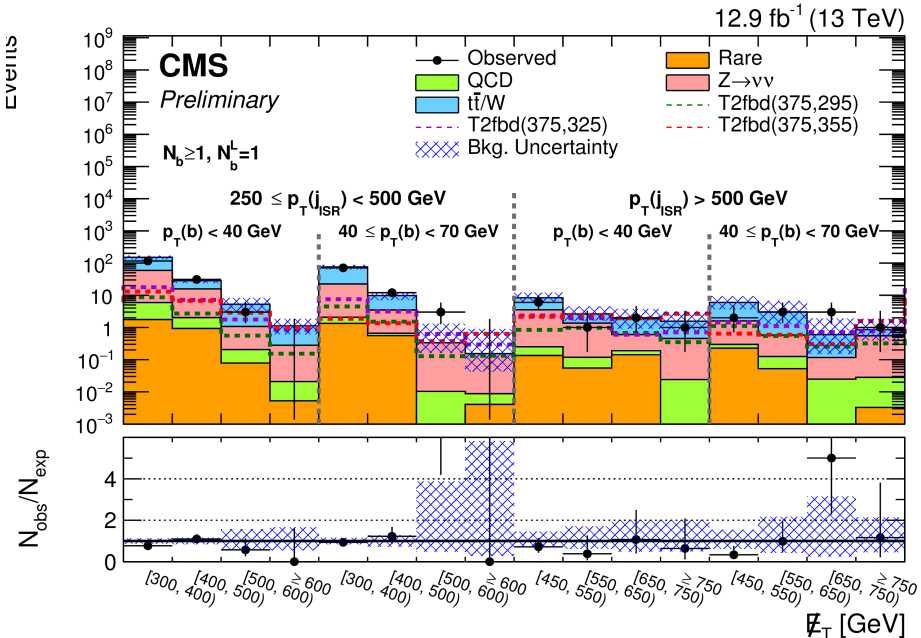
SUS-16-029

- Dedicated 0-lepton stop search.
- Use top tagging and W tagging.
- Backgrounds estimated from data control regions.
- Categorization : Njets, Nbjets, MT(b12,MET), MET, NW, Ntop.

$$\mathrm{Min}[m_T(b_1, E_T^{miss}), m_T(b_2, E_T^{miss})] \equiv M_T(b_{1,2}, E_T^{miss})$$



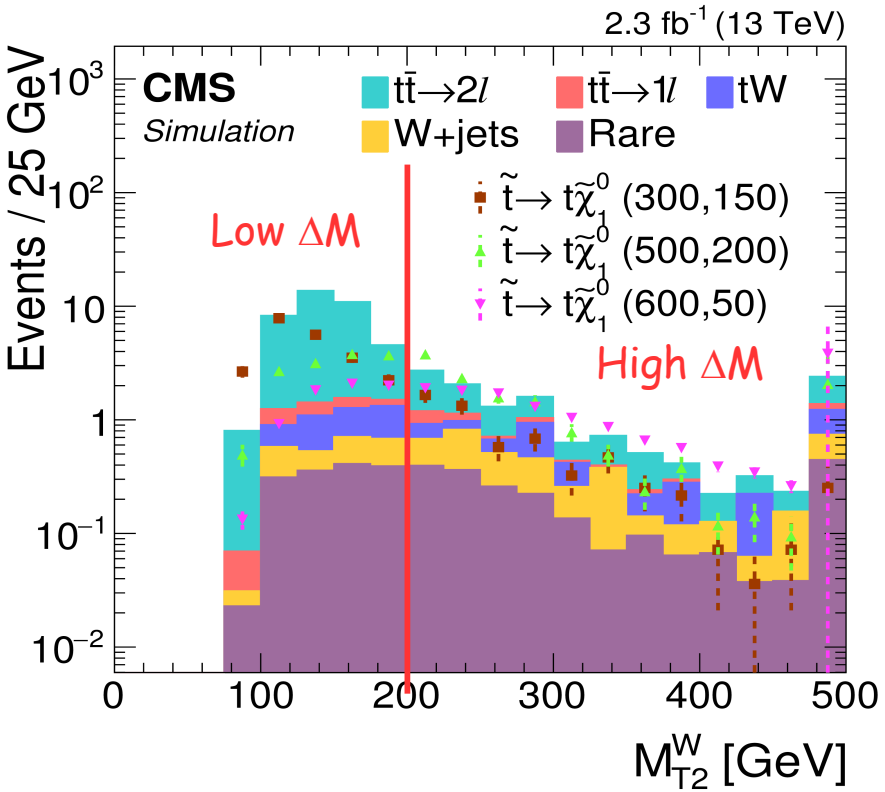


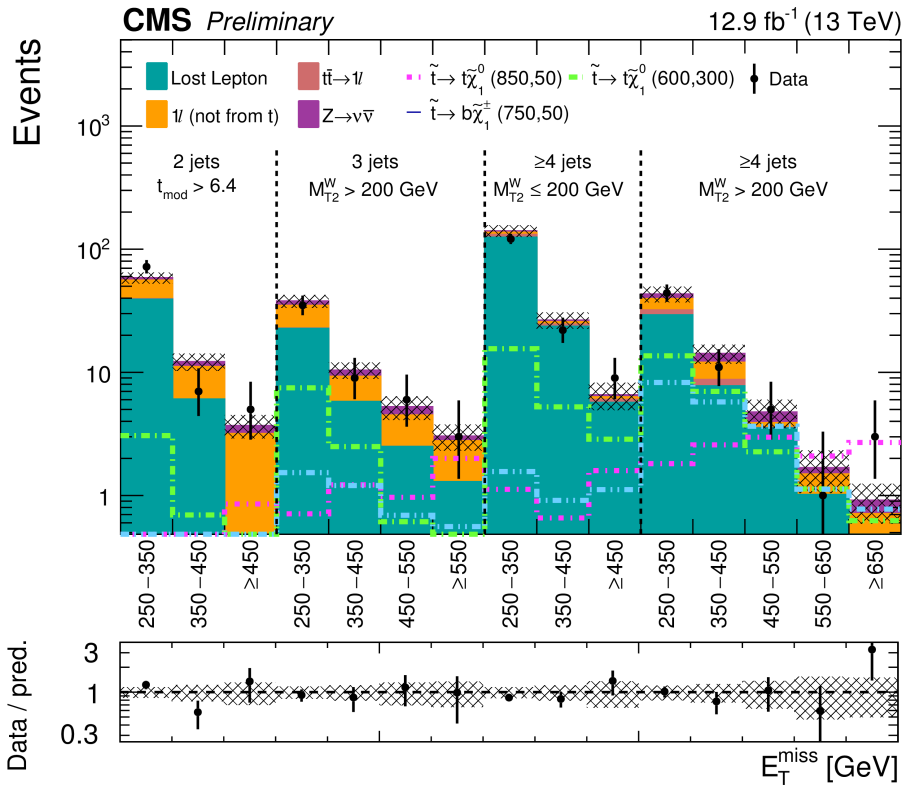


3rd generation searches: 1-lepton stop

SUS-16-028

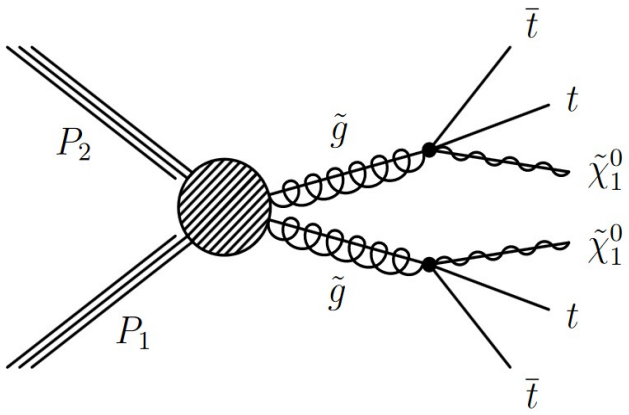
- The main variables used in this analysis are :
  - MT2W, the minimum mother mass compatible with all the decay products and on-shell constraints (cf arXiv:1203.4813).
  - The modified topness variable : $t_{\mathrm{mod}} = \ln(\min S)$ with $S(\vec{p}_W, p_{\nu,z}) = \frac{(m_W^2 - (p_\nu + p_\ell)^2)^2}{a_W^4} + \frac{(m_t^2 - (p_b + p_W)^2)^2}{a_t^4}$.

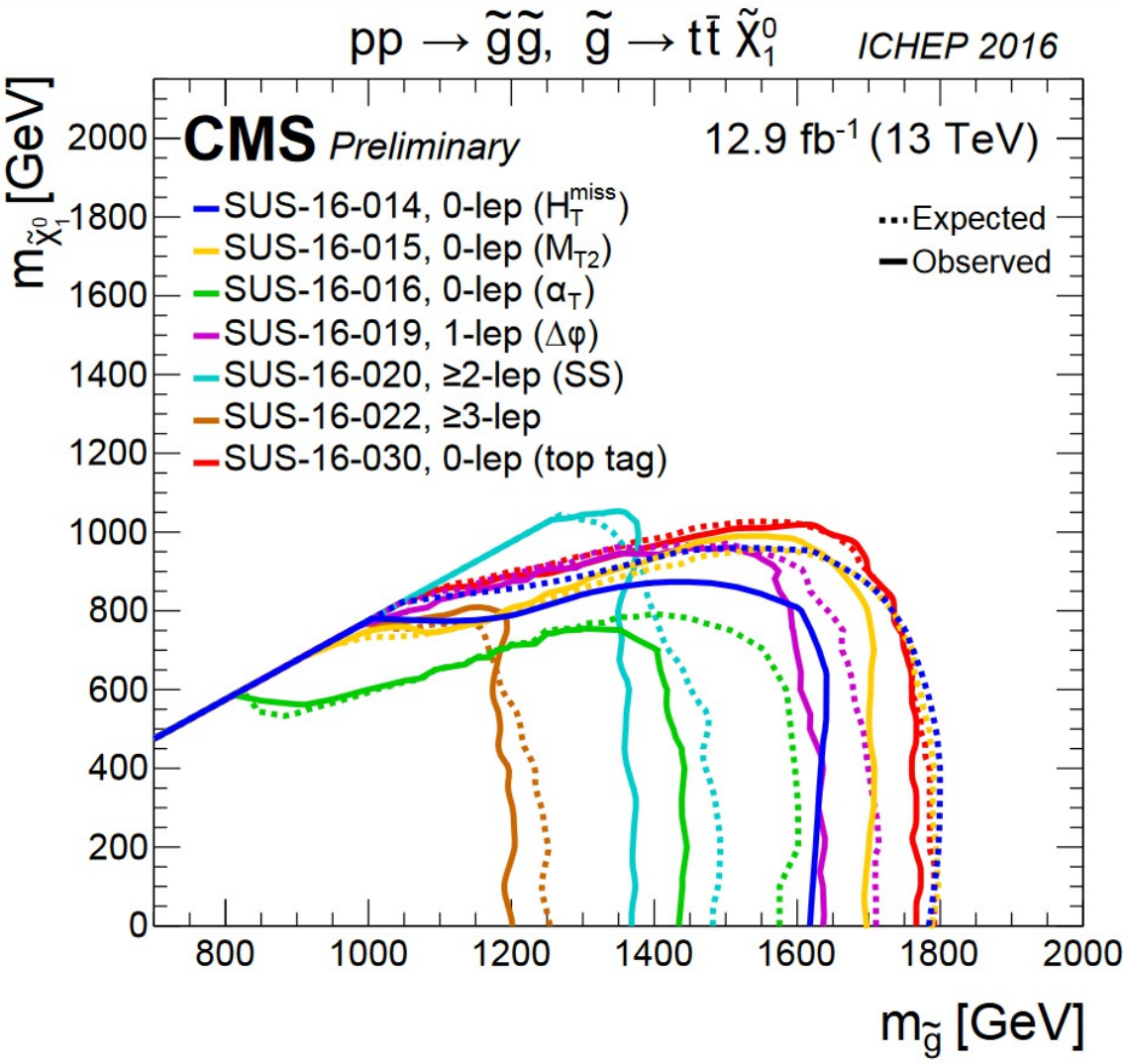




Summary for gluino-mediated stops

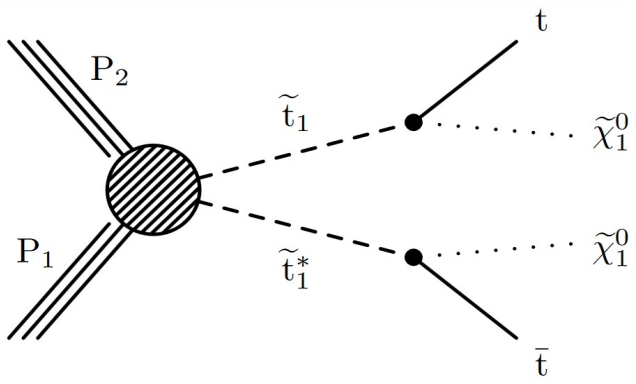
- Interpretation with Simplified Models for gluino-mediated production:

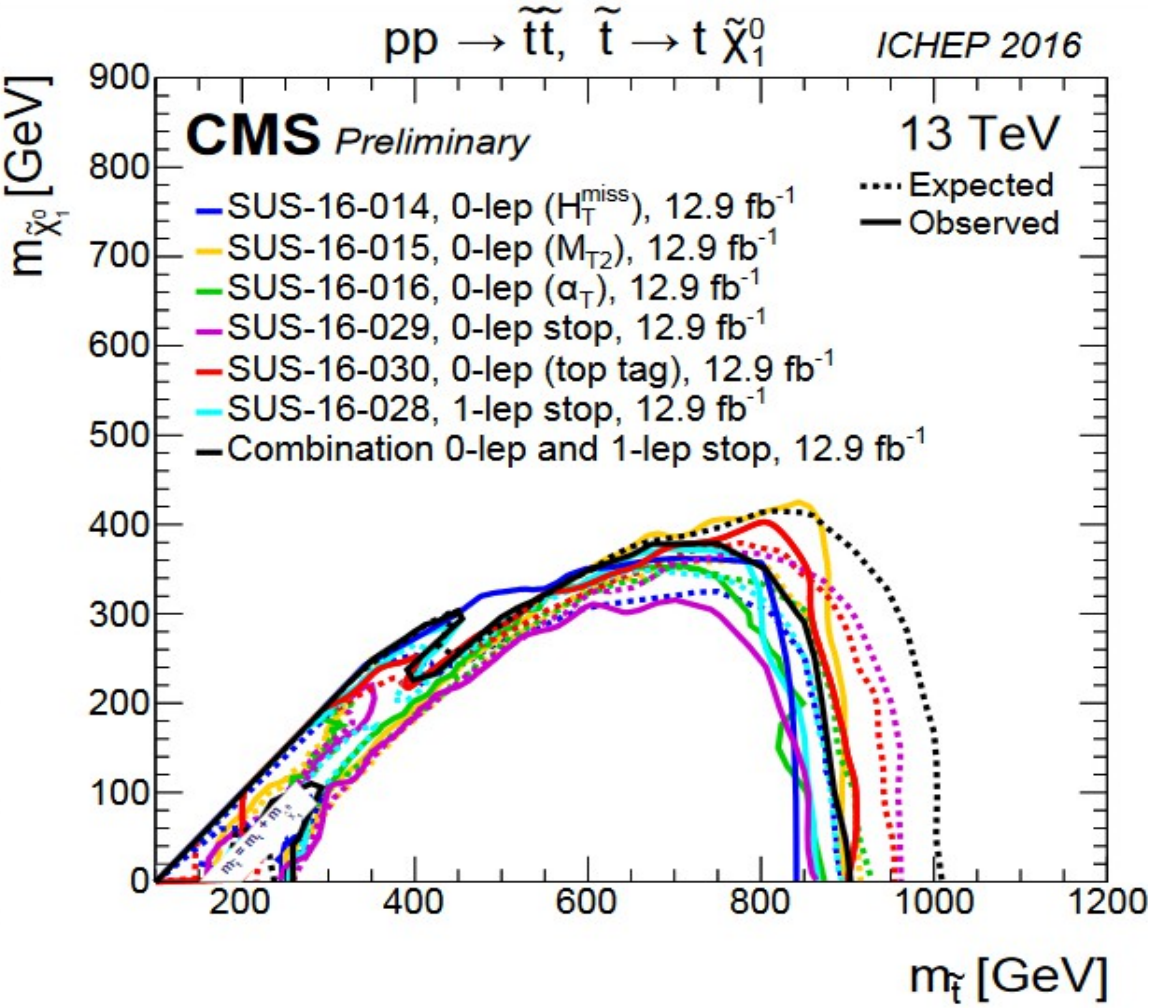




Summary of direct stop limits

- Interpretation with Simplified Models for direct production:

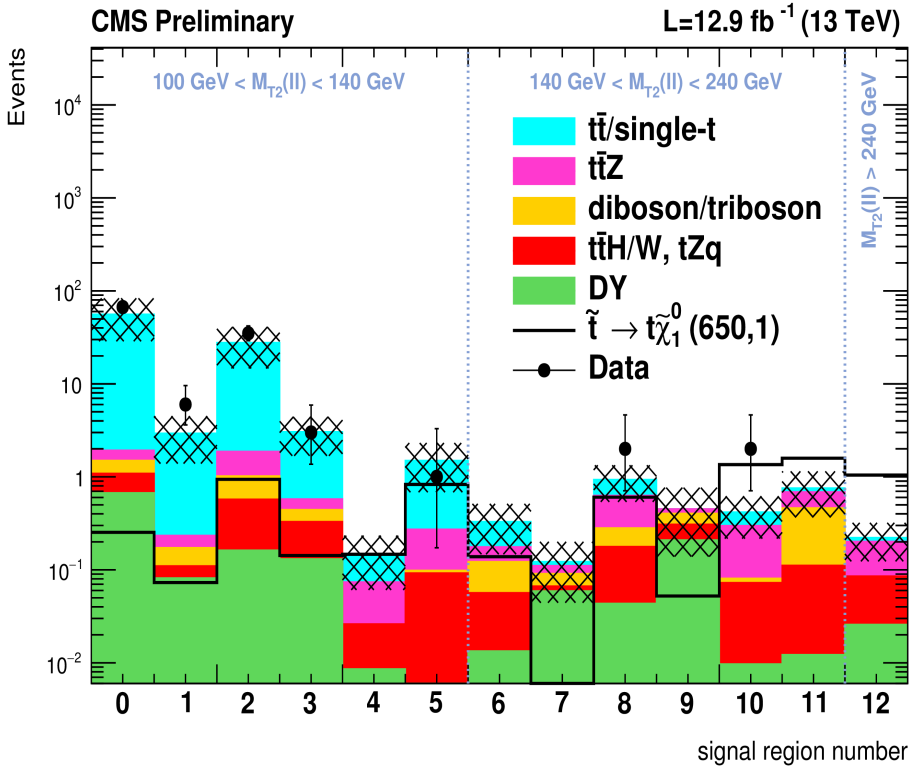


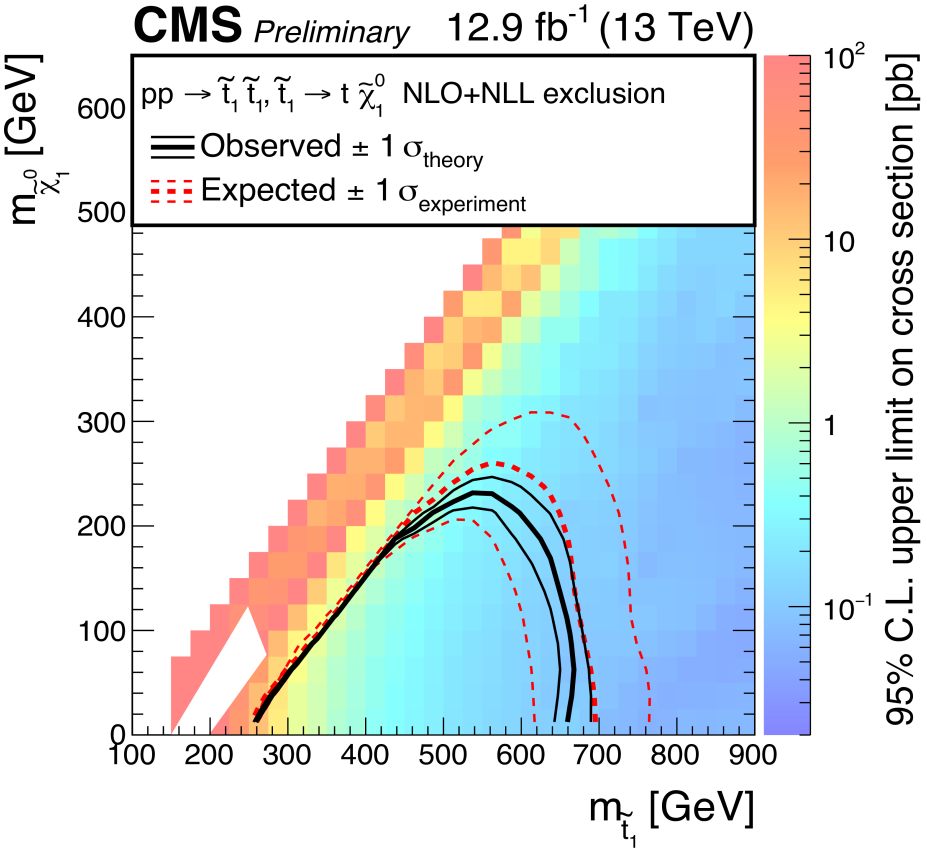


OS di-lepton stop search

SUS-16-027

- Search for direct stop pair production in di-lepton final states
- Three MT2 variables (ll,bb and blbl) are used to control the top quark background and define the search regions

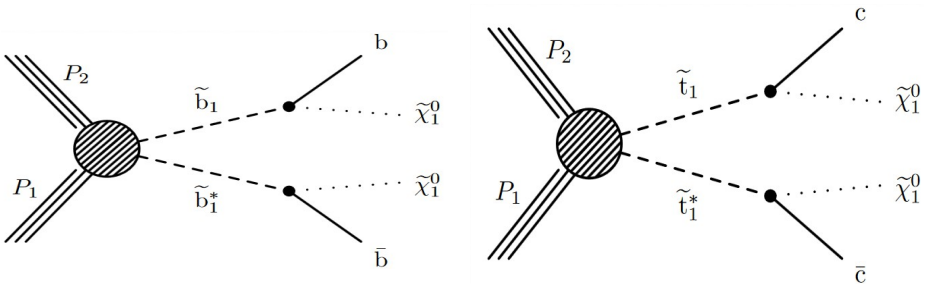


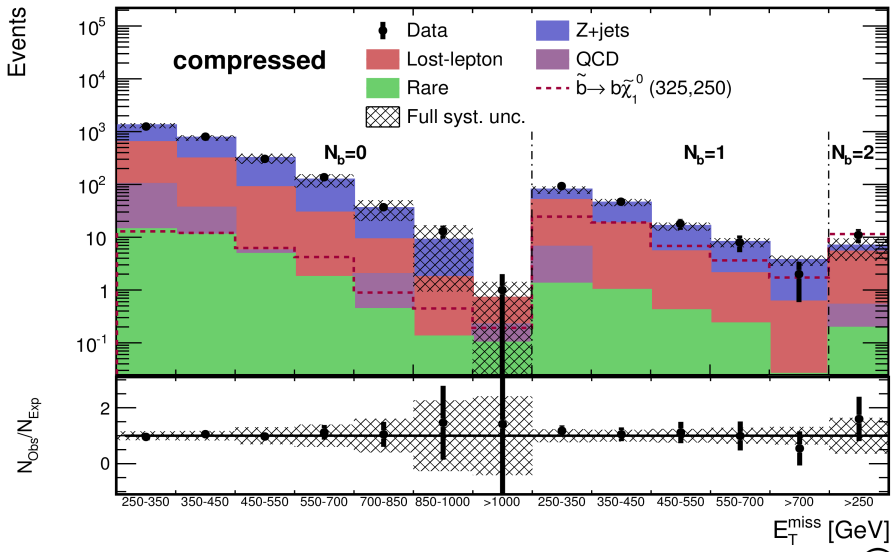


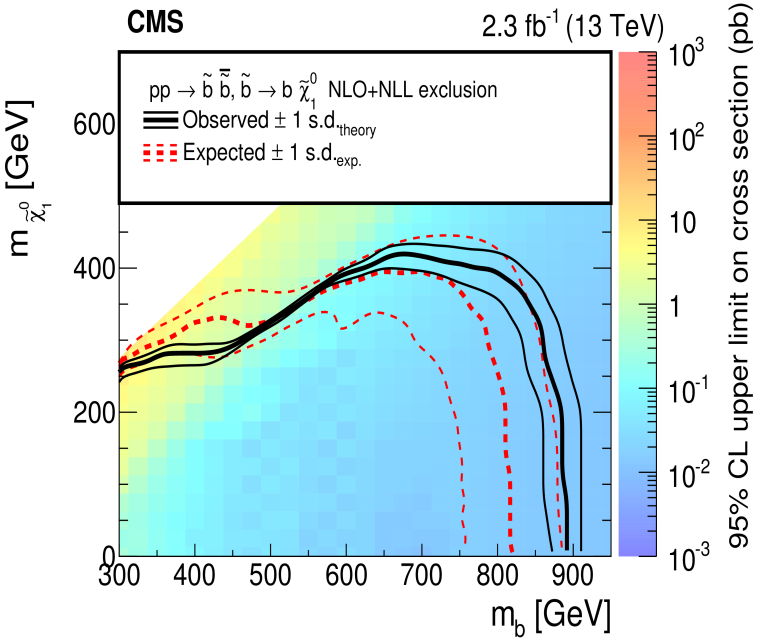
sbottom analysis

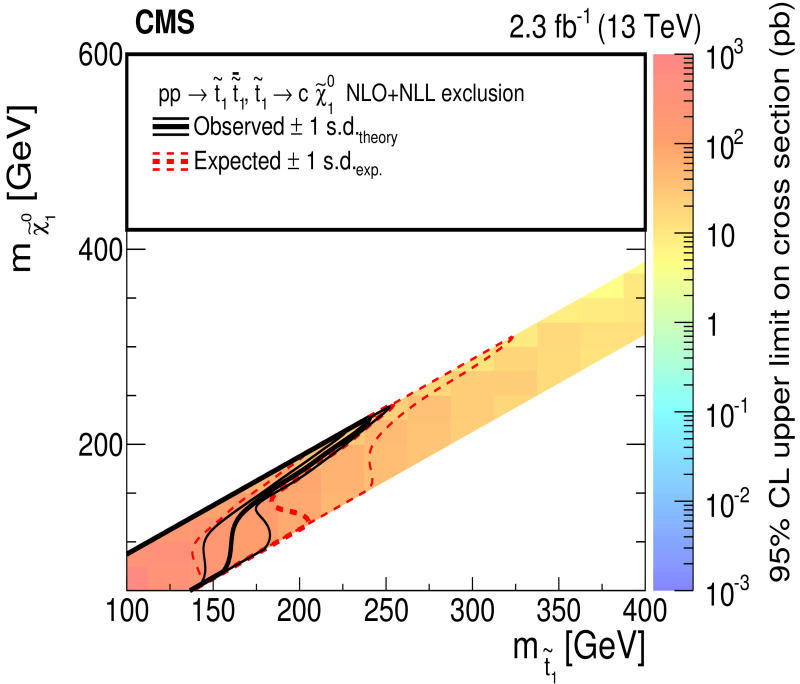
SUS-16-008

- Sbottom analysis is looking for direct pair production of sbottom, but also to stop decaying to charm quarks (compressed region).





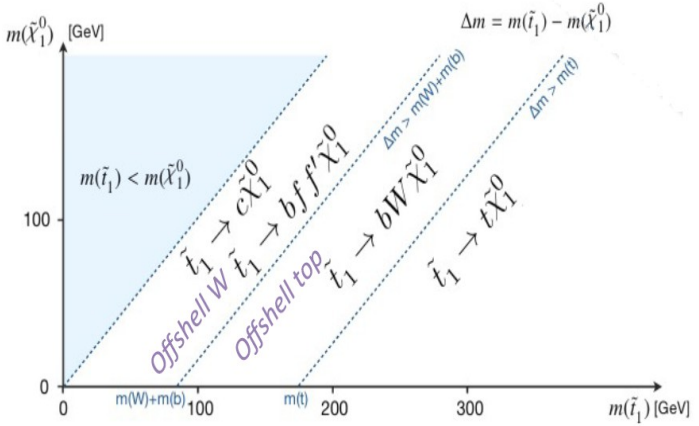


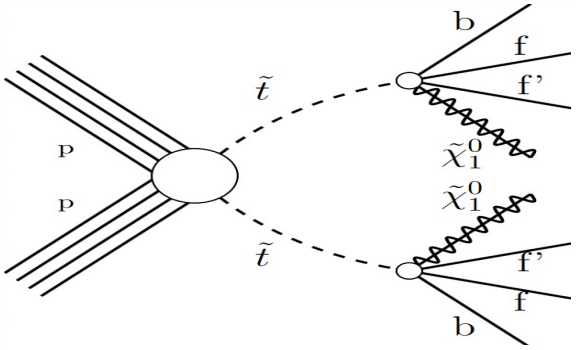


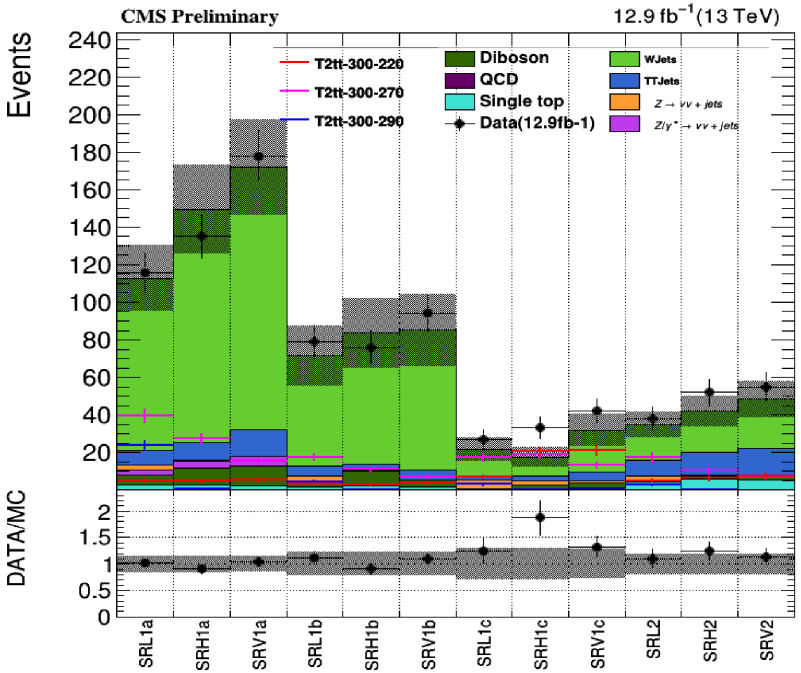
Compressed: 4-body stop decays

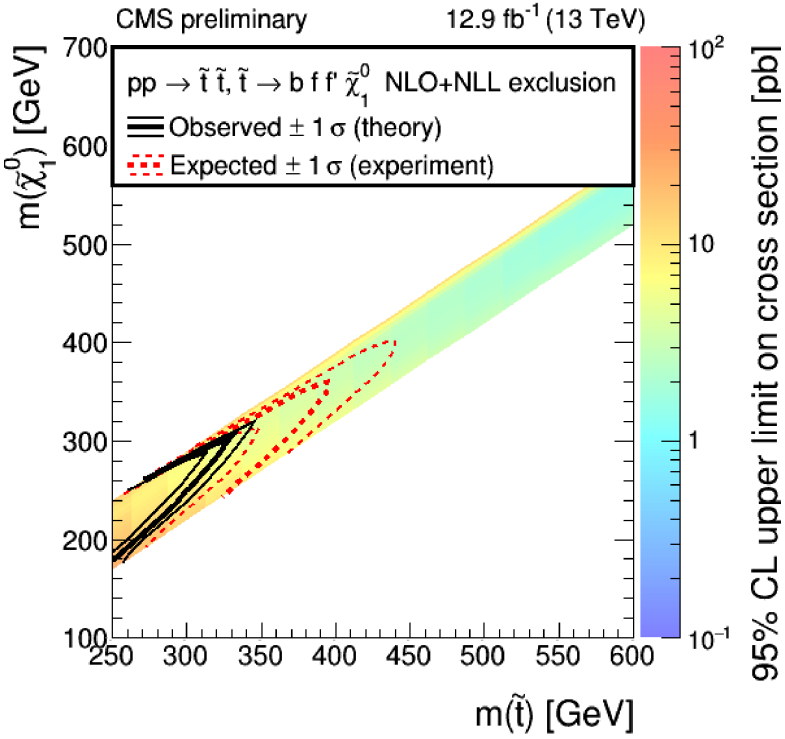
SUS-16-031

- One soft lepton analysis (5 GeV < pt < 30 GeV) + a hard ISR jet





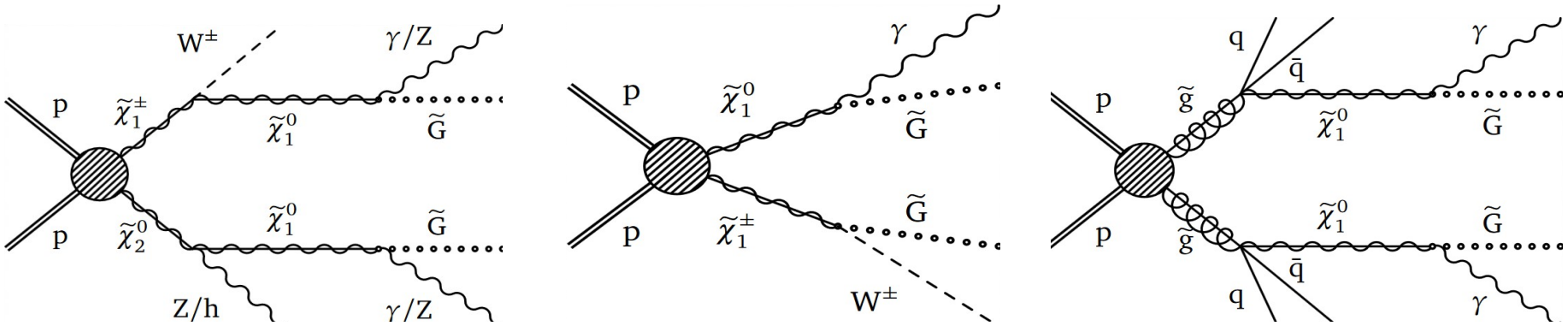


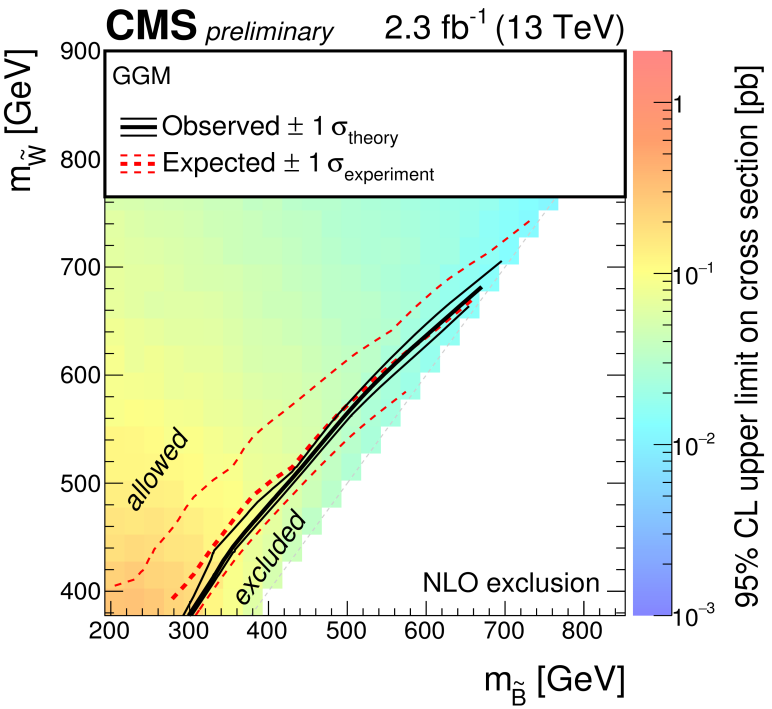


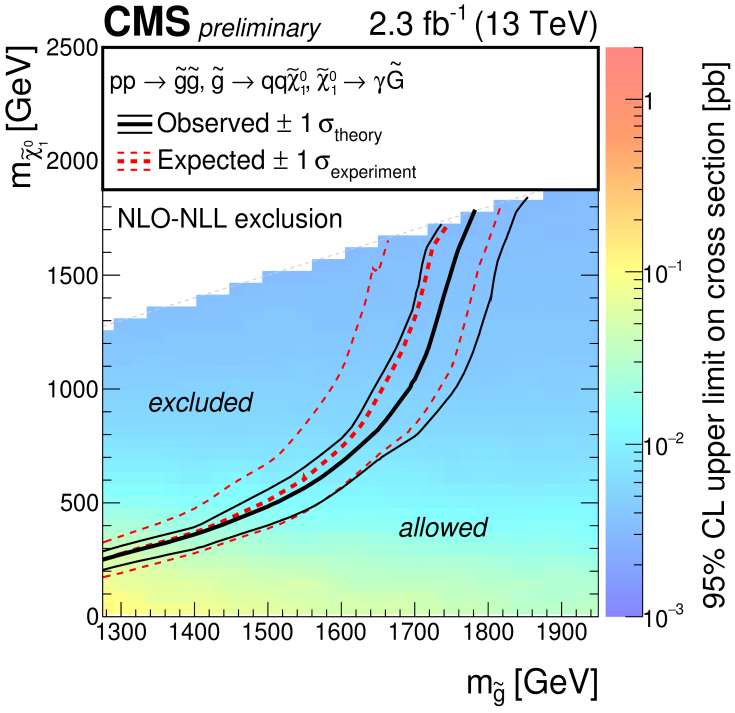
EW SUSY with photons

SUS-16-023

- Number of interesting signatures with photons+MET in GMSB models



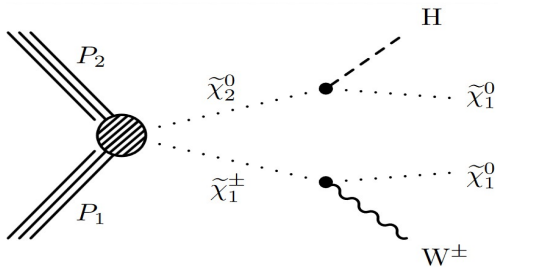


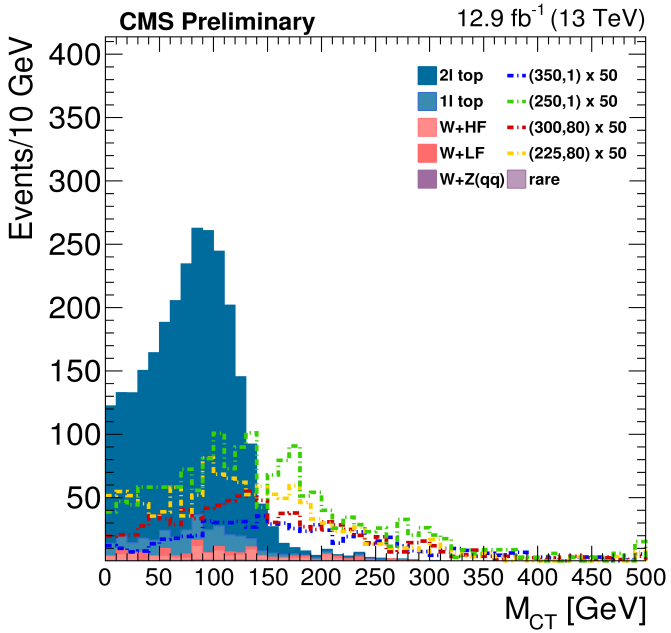


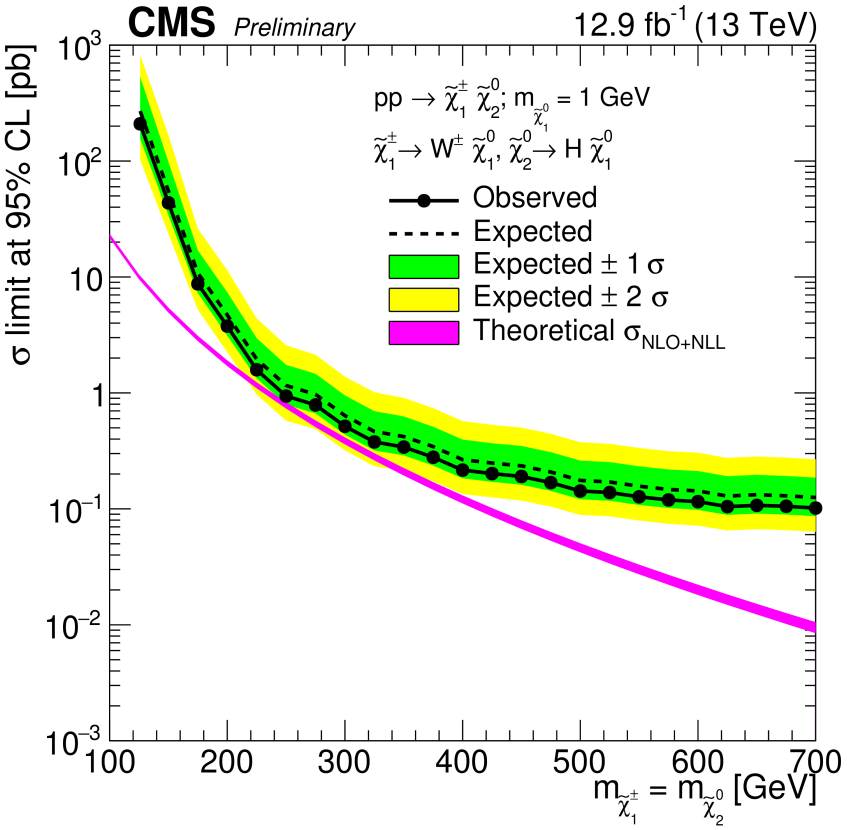
EW production: 1-lepton

SUS-16-026

- Dedicated search for WH production in SUSY decays
- Use single lepton and H(bb) decay
- Use cotransverse mass variable MCT $M_{CT}^2 = 2p_T^{b1}p_T^{b2}(1+\cos\Delta\phi_{bb})$,
- Main backgrounds from W+jets and ttbar estimated using control regions



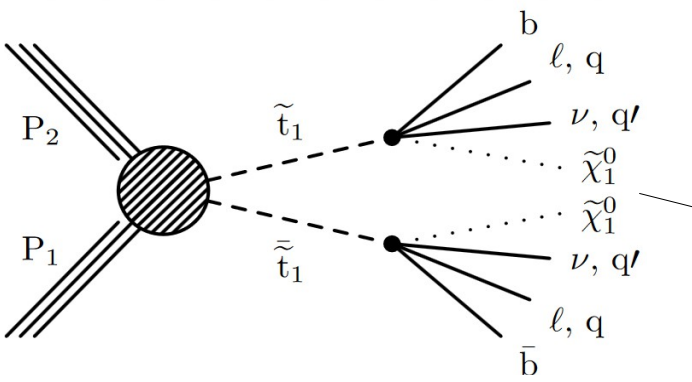


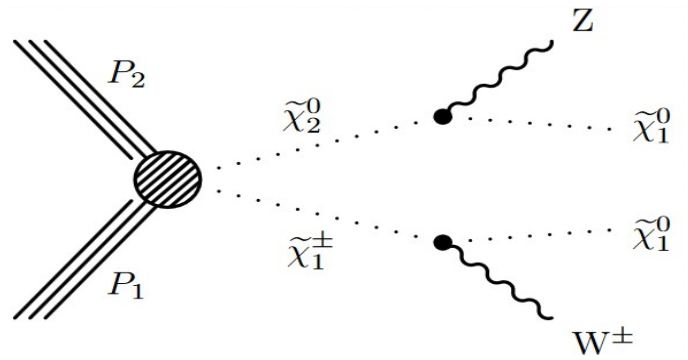


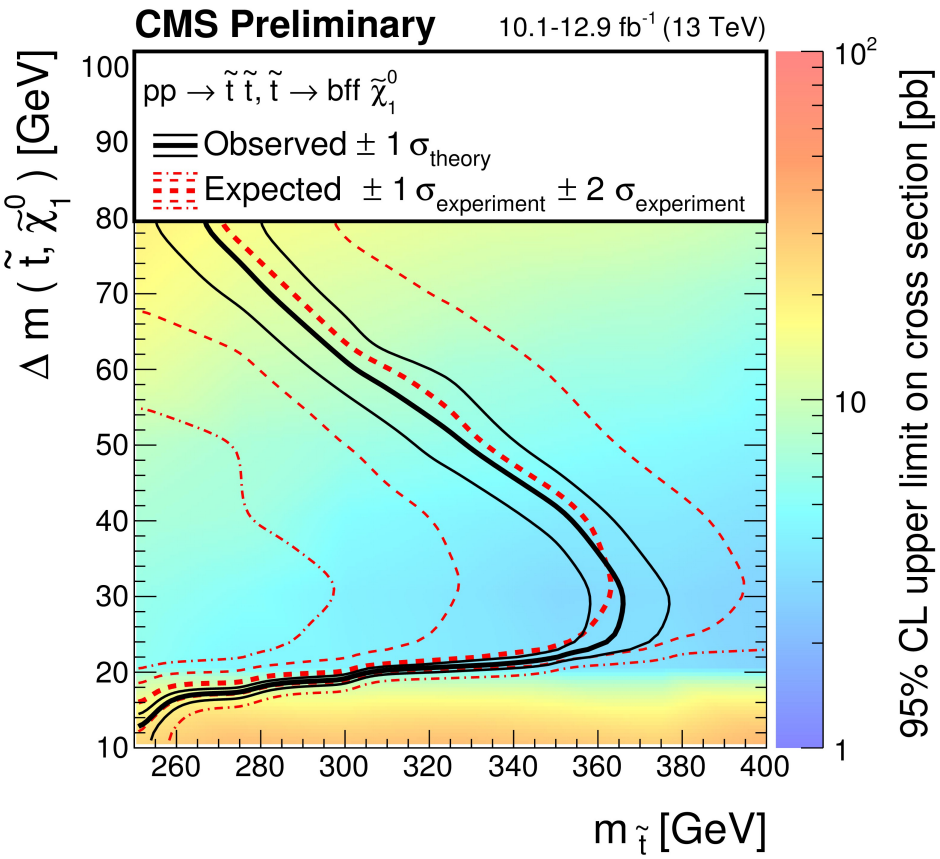
EW production: soft OS di-lepton search

- Two OS di-leptons (5 < pT < 30 GeV)
- Sensitive to EW SUSY with small mass splitting

SUS-16-025



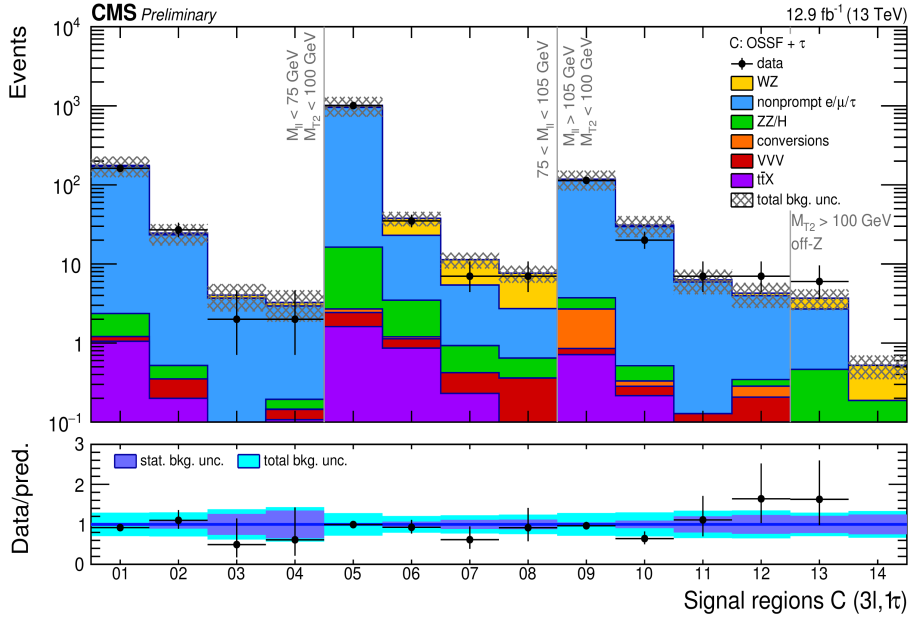


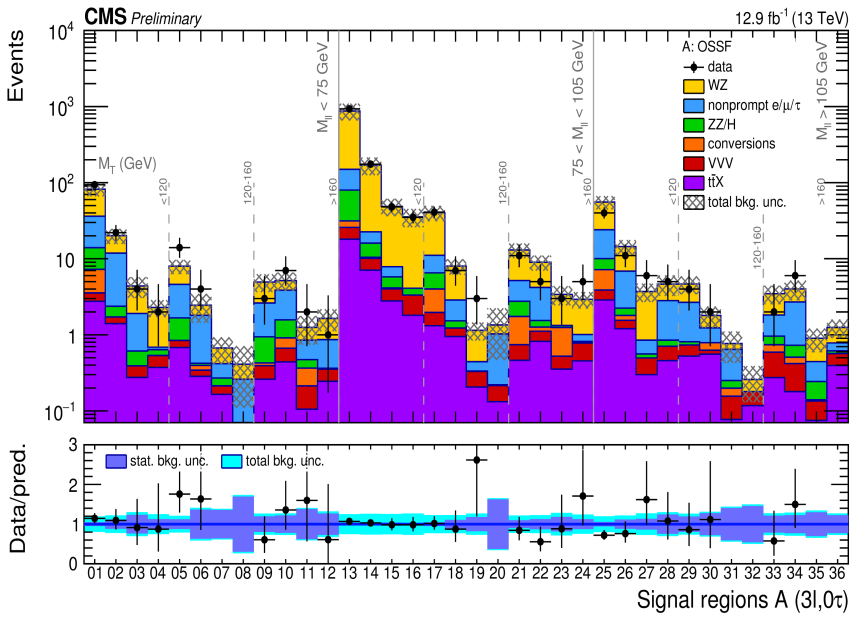


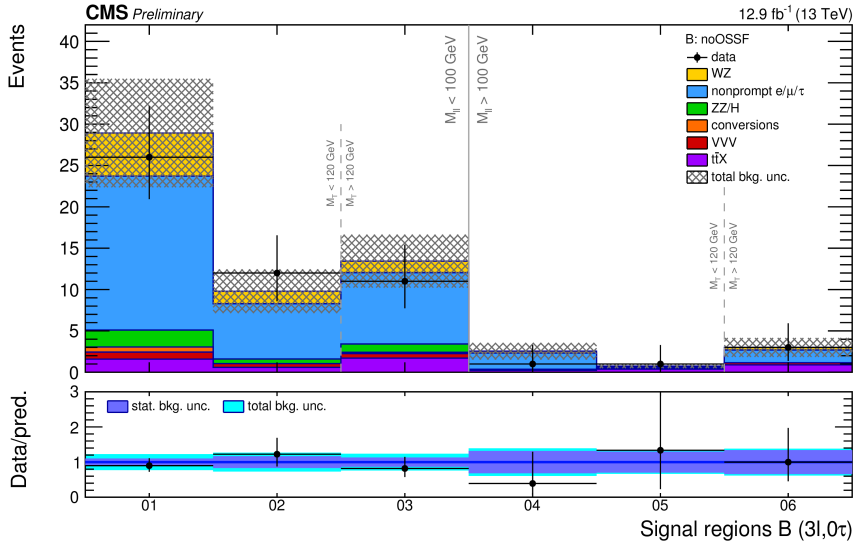
EW production: multileptons

SUS-16-024

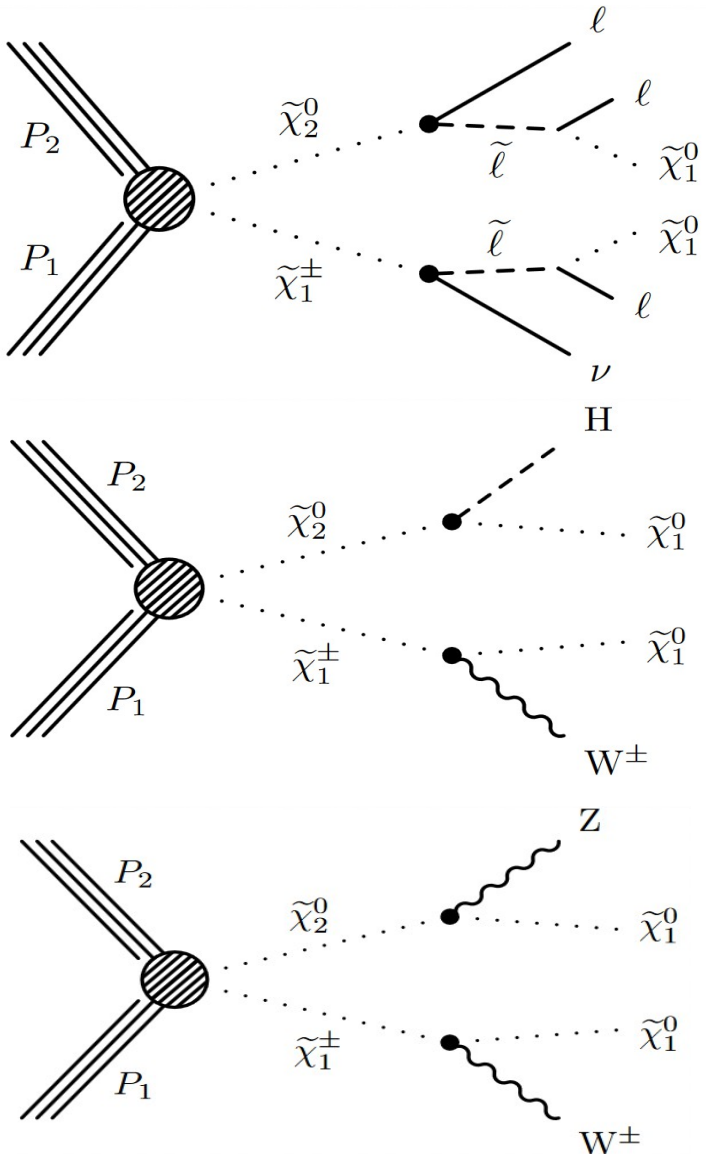
- Multilepton analysis includes SS di-lepton (e,mu), 3-leptons (e,mu,up to two had tau) and 4-leptons (e,mu,had tau).
- Low backgrounds, WZ normalized to control sample.
- Several signal scenarios considered.



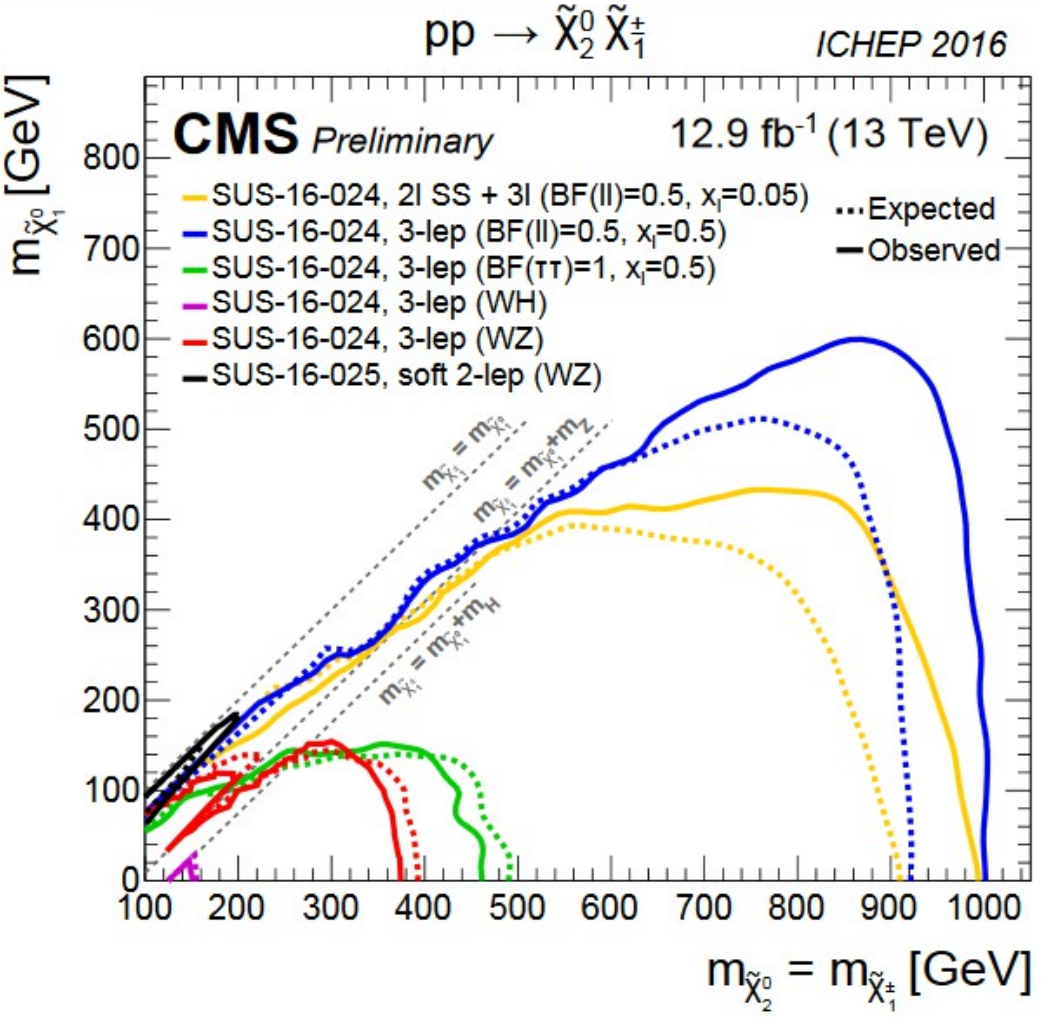




Electroweakino pair production



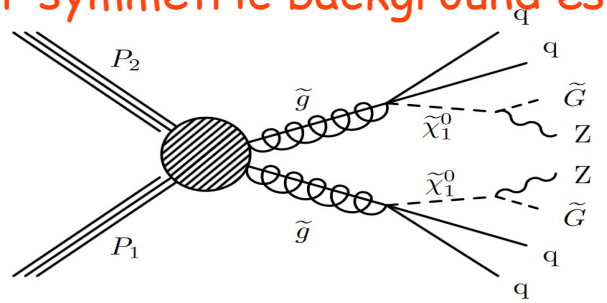
$$m_{\tilde{\ell}} = m_{\tilde{\nu}} = m_{\tilde{\chi}_1^0} + x_{\tilde{\ell}}\,(m_{\tilde{\chi}} - m_{\tilde{\chi}_1^0}),$$

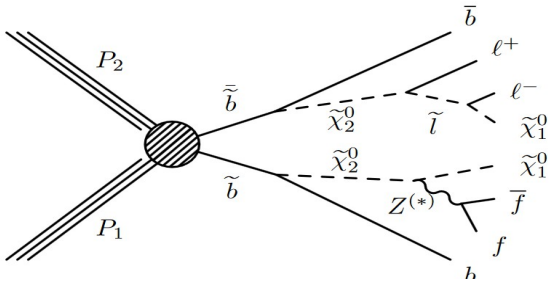


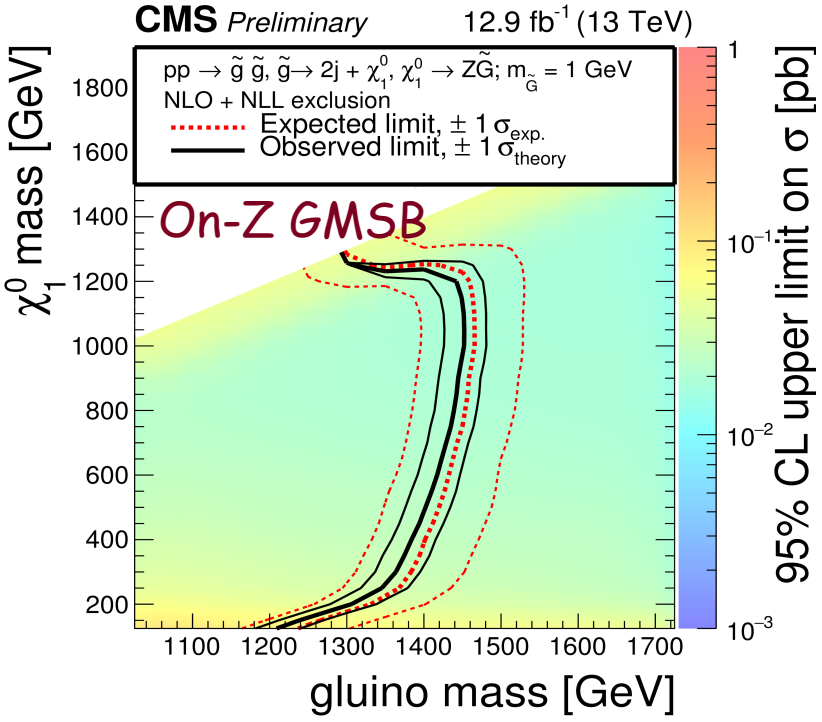
OS di-lepton search

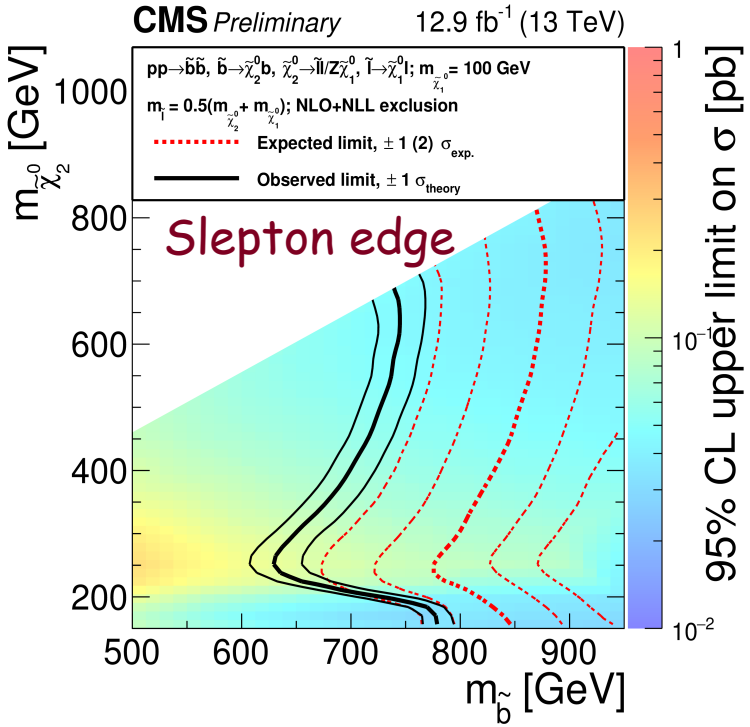
SUS-16-021

- Classic analysis where SUSY could results in an "edge"
- Some excitement from CMS run 1 result (and ATLAS run 1 on Z-excess)
- Flavor symmetric background estimated from emu sample





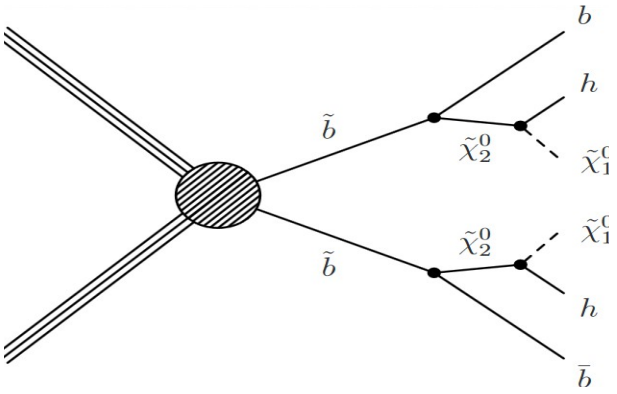


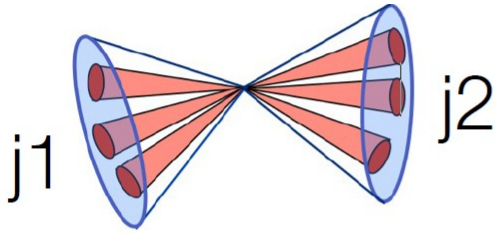


Higgs decaying to two photons

SUS-16-012

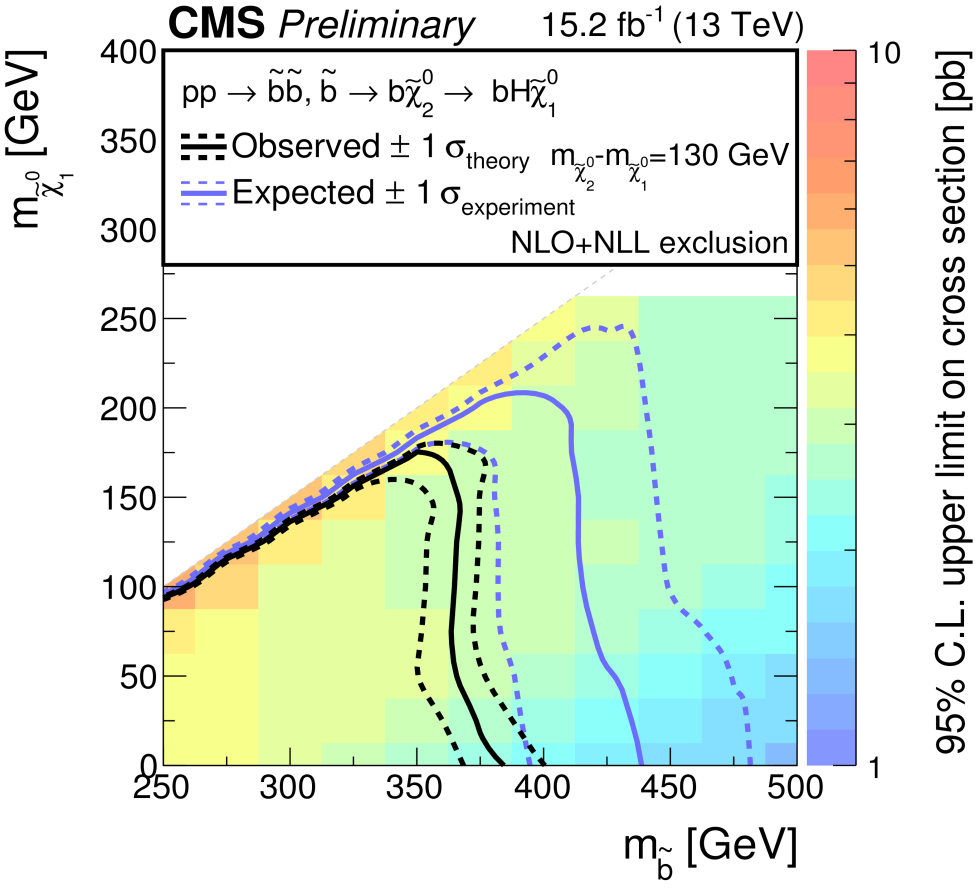
- Search for SUSY in events with Higgs decaying to two photons using razor variables.





$$M_R = \sqrt{(|\vec{p}^{\,j1}| + |\vec{p}^{\,j2}|)^2 - (p_z^{j1} + p_z^{j2})^2}$$

$$R \equiv \frac{M_T^R}{M_R} \qquad M_T^R \equiv \sqrt{\frac{E_T^{\rm miss}(p_T^{j1} + p_T^{j2}) - \vec{E}_T^{\rm miss}\cdot(\vec{p}_T^{\,j1} + \vec{p}_T^{\,j2})}{2}}$$



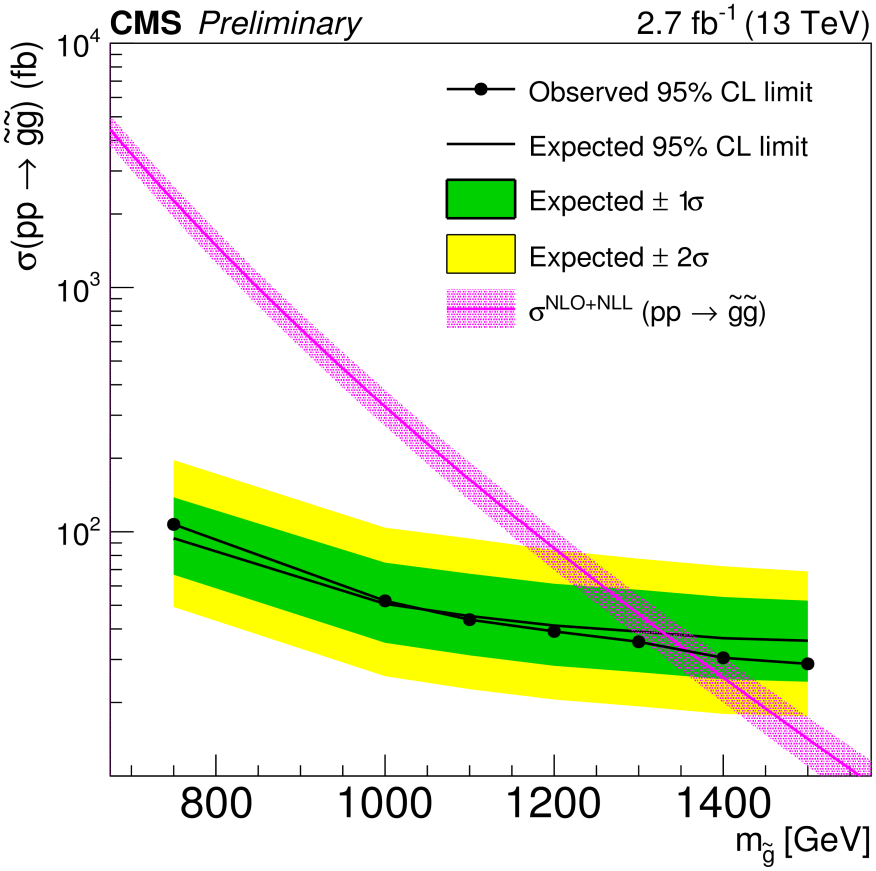
R-Parity violation

SUS-16-013

- Search in high multiplicity final states with zero or one reconstructed lepton
- Results interpreted in a model in which the gluino decays exclusively to tbs
- Use the variable Mj: sum of the masses of large radius jets

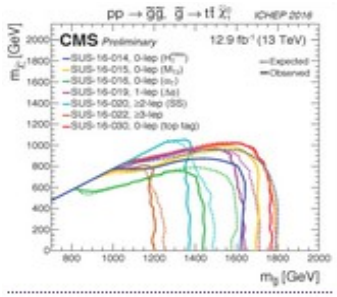
N_{lep}	M_J [GeV]	N_{jet}			
		4–5	6–7	8–9	≥ 10
0	500–800	CR	CR	SR	SR
	> 800	CR	CR	SR	SR
1	500–800	CR	SR	SR	
	> 800	CR	SR	SR	

- No significant excess is observed

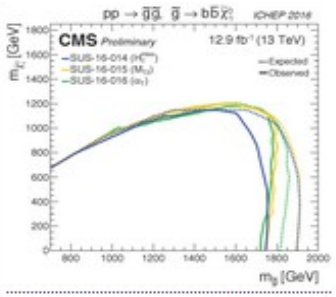


Conclusions

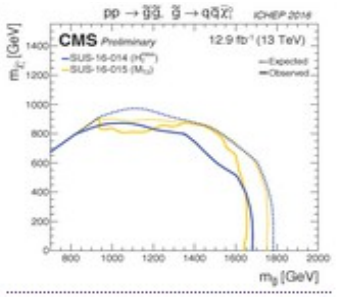
- CMS has a broad susy program
  - Inclusive analyses
  - 3rd generation dedicated analyses
  - Electroweak production
  - RPV, etc
- Good sensitivity observed with only a limited amount of 2016 data
- No significant deviation from Standard Model observed so far
- Stay tuned for the results with full dataset



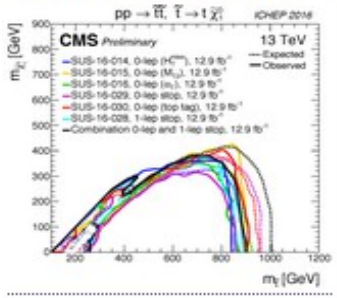
Limits on gluino pairs to 4 tops



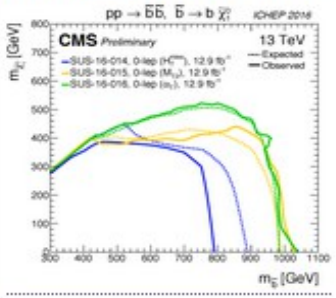
Limits on gluino pairs to 4 bottoms



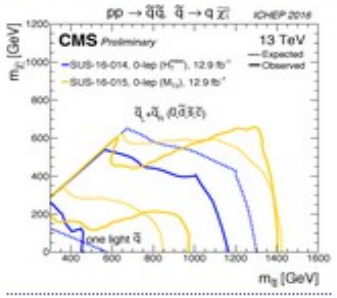
Limits on gluino pairs to light quarks



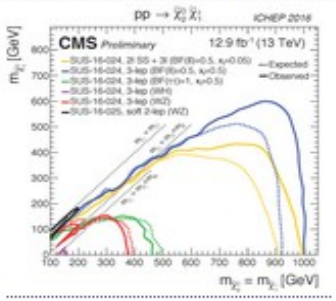
Limits on stop pairs to 2 tops

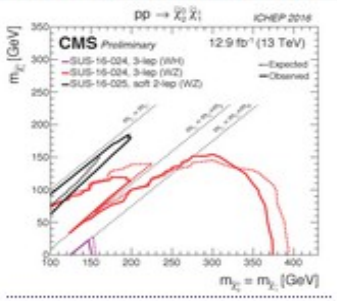


Limits on sbottom pairs to 2 bottoms



Limits on squark pairs to 2 quarks





Limits on ewk-ino production

Zoomed limits on ewk-ino production

BACK UP

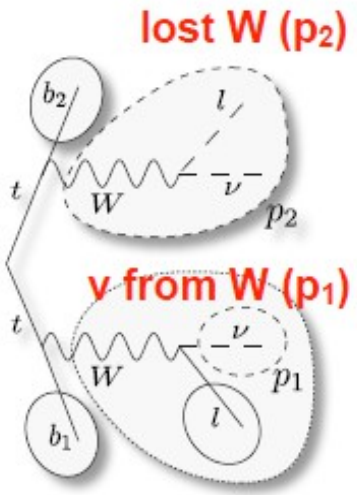
SLIDES

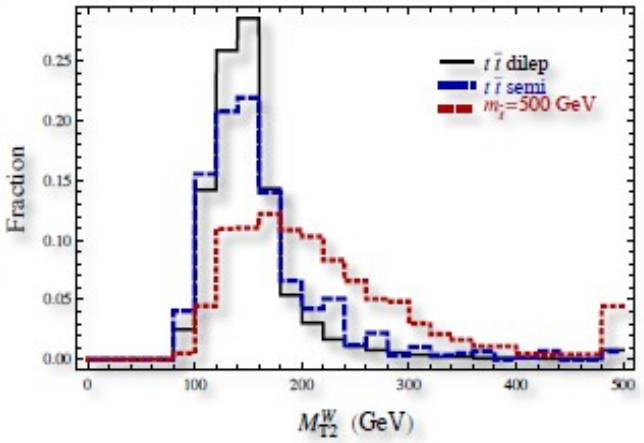
1-lepton stop: MT2W

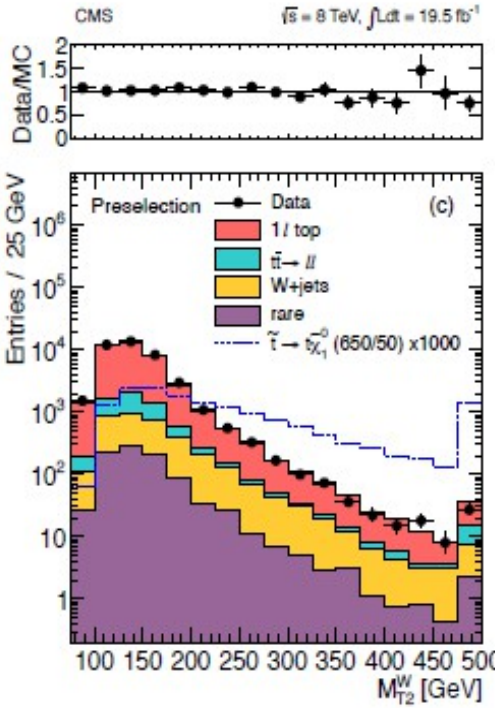
- Here is the definition of the M^{W}_{T2} variable designed to reconstruct tt events with a lost lepton:

$$M^{W}_{T2} = \min\left\{ m_y \text{ consistent with: } \left[\vec{p}^{\,T}_1 + \vec{p}^{\,T}_2 = \vec{E}^{\,\text{miss}}_T,\ p_1^2 = 0,\ (p_1 + p_\ell)^2 = p_2^2 = M_W^2,\ (p_1 + p_\ell + p_{b_1})^2 = (p_2 + p_{b_2})^2 = m_y^2 \right] \right\}$$

- The tt events with lost lepton exhibit endpoint at $m_y = m_t$, while the signal has long tail

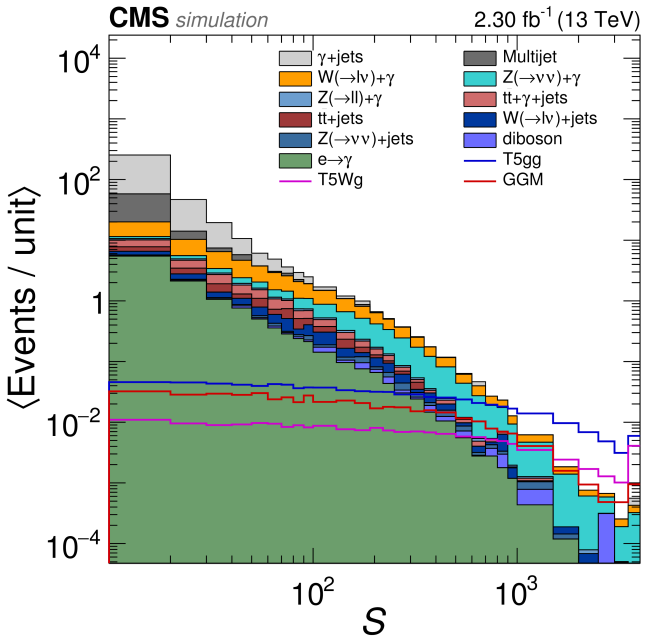


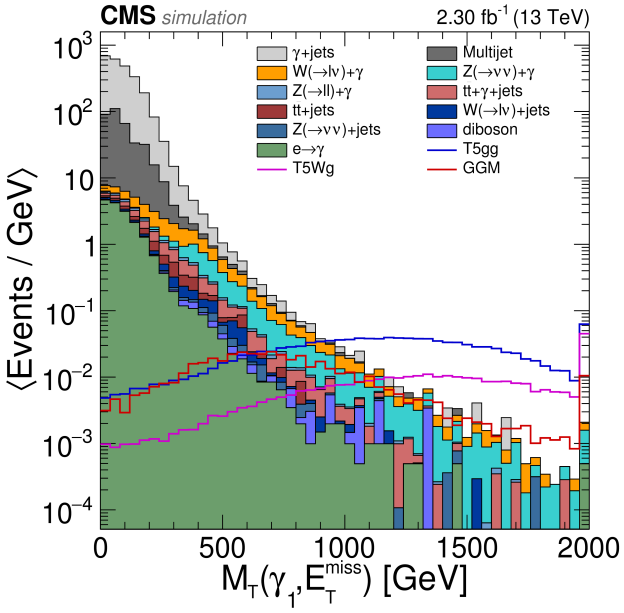


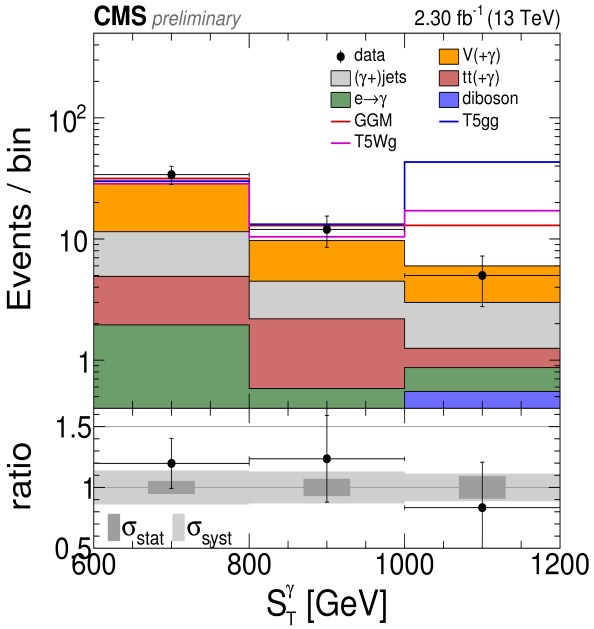


Bai, Cheng, Gallicchio, Gu, arXiv:1203.4812

EW SUSY with photons







OS di-lepton search

SUS-16-021

Table 7: Predicted and observed results for the edge search in the four $m_{\ell\ell}$ versus NLL regions for 12.9 fb^{-1} of data.

		ttbar-like	non-ttbar-like
mll $<$ 81 GeV	pred. FS	1374.4 ± 48.1	105.8 ± 10.9
	pred. DY	13.5 ± 4.6	7.3 ± 2.5
	pred. total	1387.9 ± 48.3	113.1 ± 11.2
	obs	1417	135
mll $>$ 101 GeV	pred. FS	2435.8 ± 72.2	208.3 ± 15.7
	pred. DY	7.6 ± 2.6	4.1 ± 1.4
	pred. total	2443.4 ± 72.3	212.4 ± 15.7
	obs	2347	285

to an excess in the observed number of events compared to the SM background estimate of 2.0(1.1) σ local (global) standard deviations.

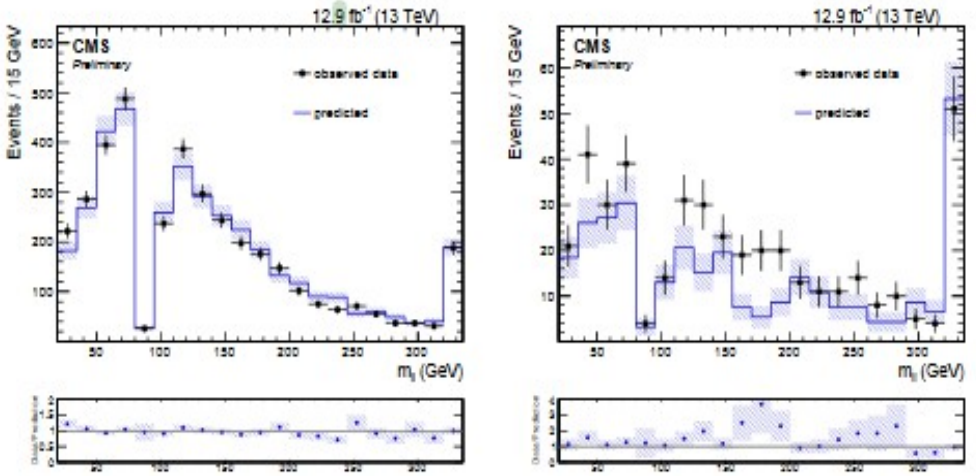


Figure 4: Overview of the results in the strong search shown in the $m_{\ell\ell}$ spectrum of the two leptons. The left plot shows the region with $t\bar{t}$-like events while the right shows events which are classified as non-$t\bar{t}$-like. The region left of the empty bin corresponds to the low mass region, the region right of it to high-mass.

Higgs decaying to two photons