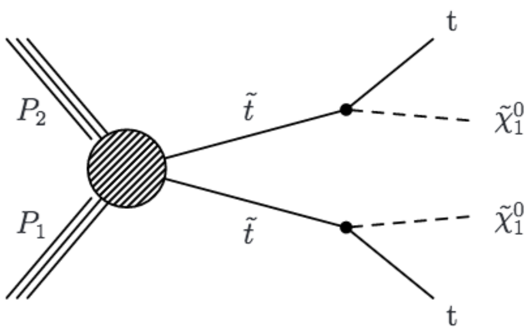
Searches for SUSY at CMS in Leptonic Final States with 13 TeV Data

C. Vince Welke

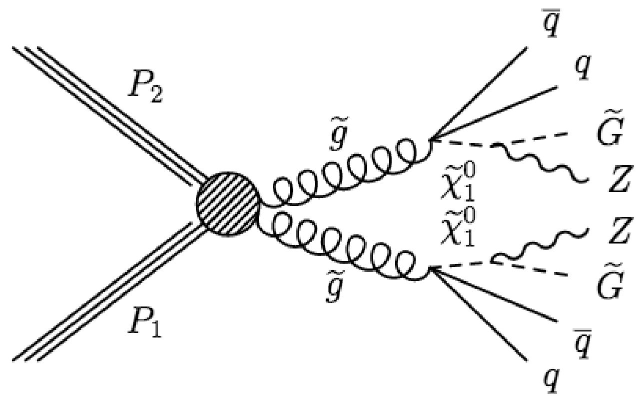
University of California – San Diego

On behalf of the CMS experiment

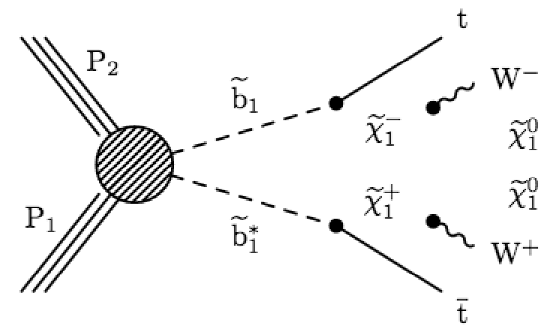
Examples of SUSY Models with leptons



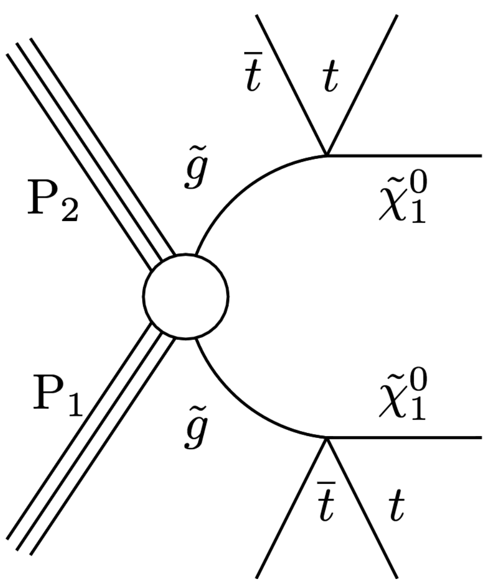
direct stop pair-production



Final state with Z(ll)+jets+MET

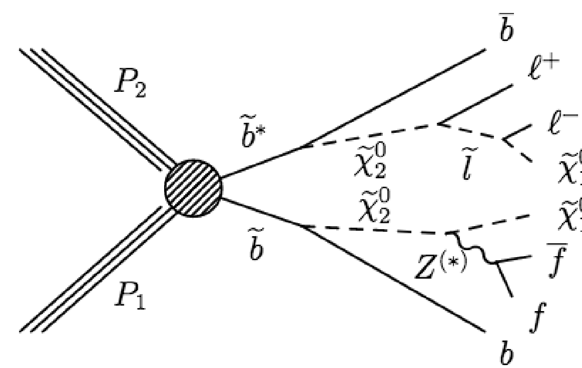


Final state with many leptons



Final state with many tops: high probability to decay to a lepton

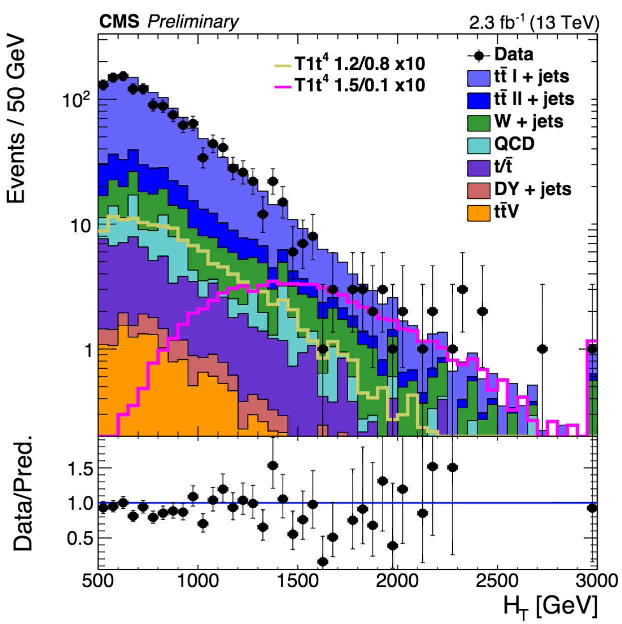
Many final states in SUSY with leptons!

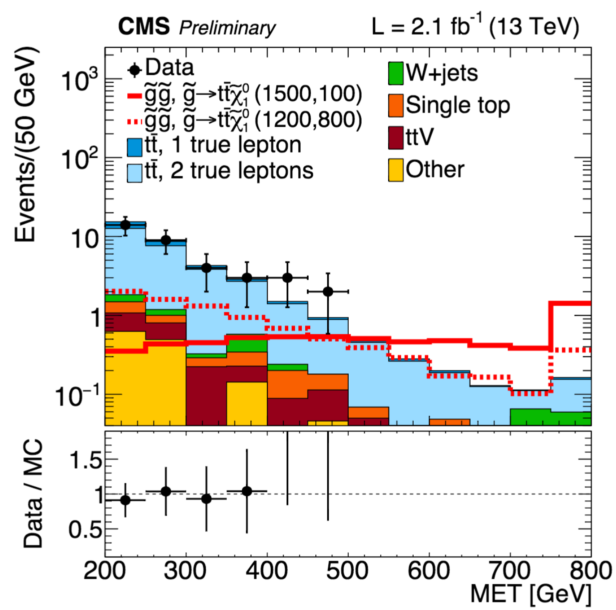


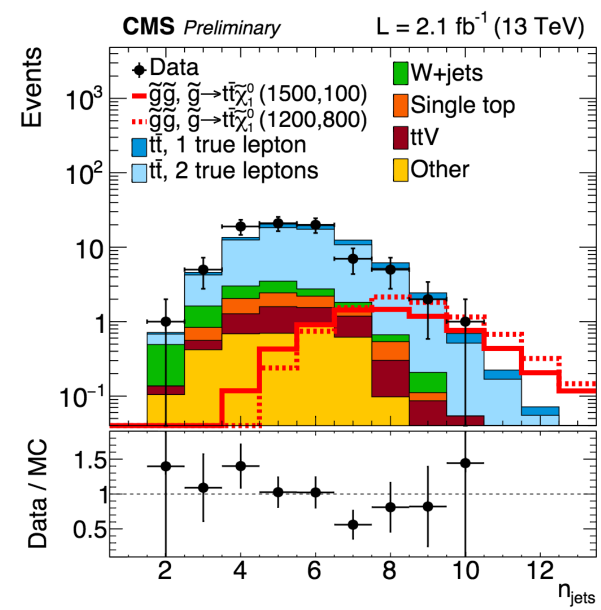
Produces kinematic edge in M_{ll}

Search Strategy

- Analyses target range of topologies with varying:
  - Visible energy (H_T, M_J)
  - Invisible energy (MET, M_T, M_{T2}, $d\phi$(lep, W), L_T)
  - Jet multiplicity (N_{jets})
  - Flavor content ($N_{b\text{-}tags}$)

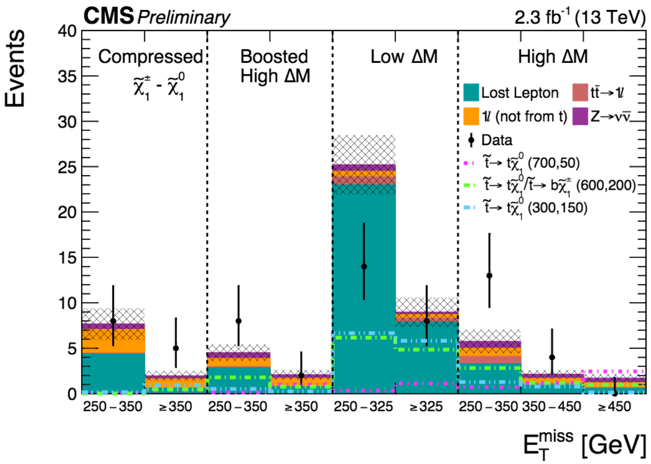






CMS Analyses with 1 lepton

Direct stop search in 1L final state



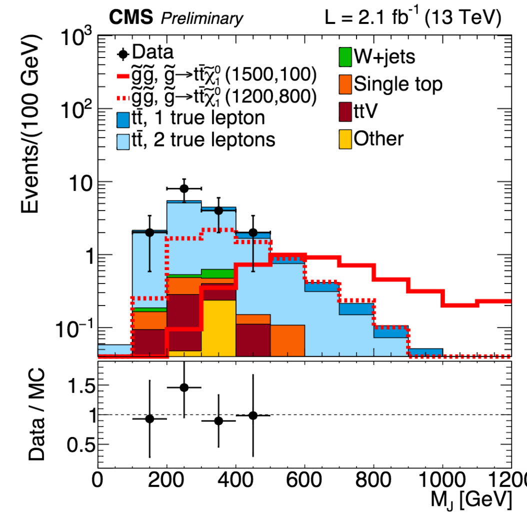
Signal regions optimized for different mass splittings and decay modes

Suppress 1L and 2L bkgs by tight cuts on M_T and MT2W, respectively, and search in tails of the MET distribution

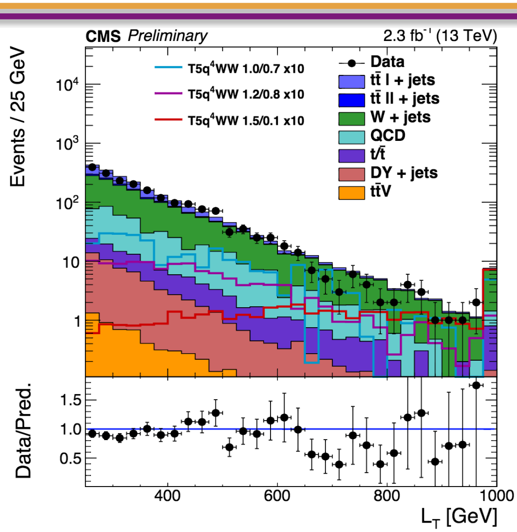
Search using sum of large-R jet masses

Cluster lepton & small-R jets into large-R jets and sum the masses

Sensitive to models where many tops are produced

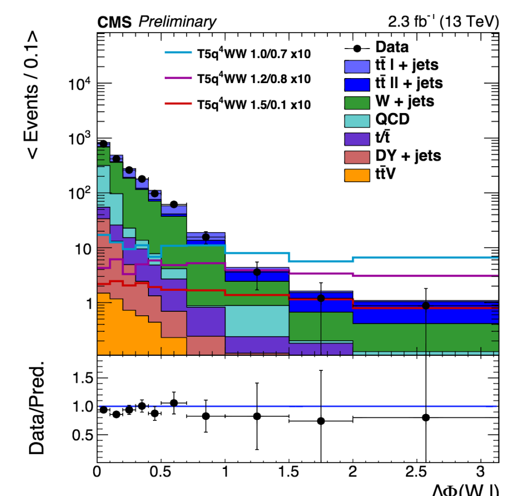


Inclusive search



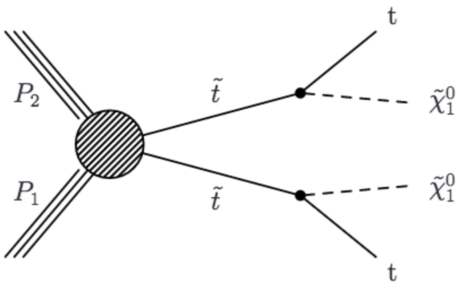
SM backgrounds largely reduced by cuts on L_T (Σp_T(lep)+MET), and dϕ(lep, W)

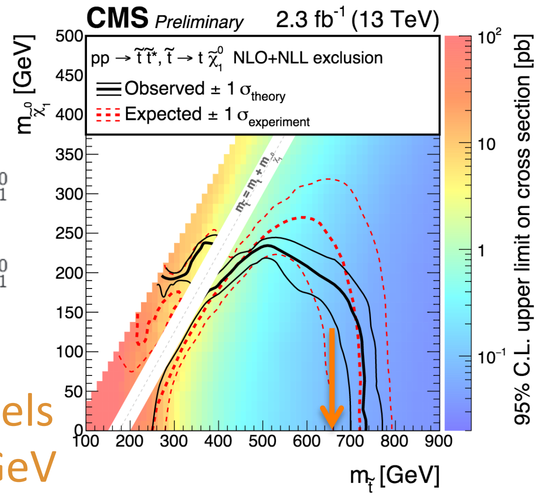
Signal region with no b-tags shown



Results of 1-Lepton Analyses

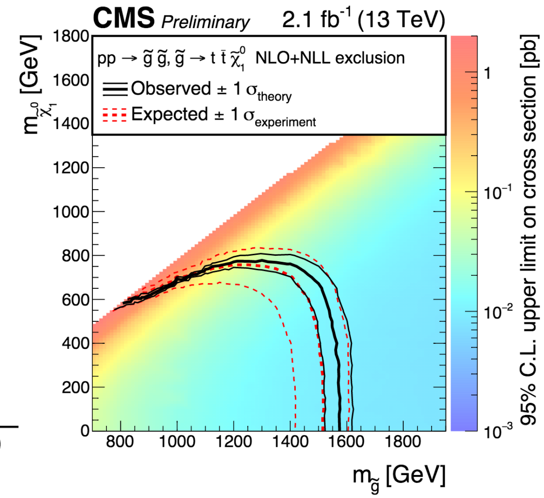
Direct stop search in 1L final state

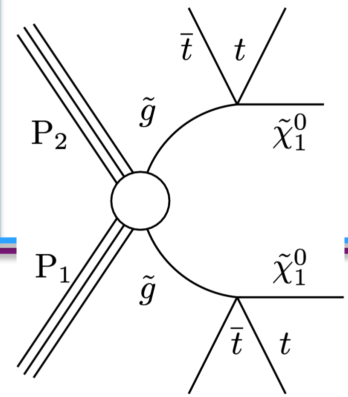




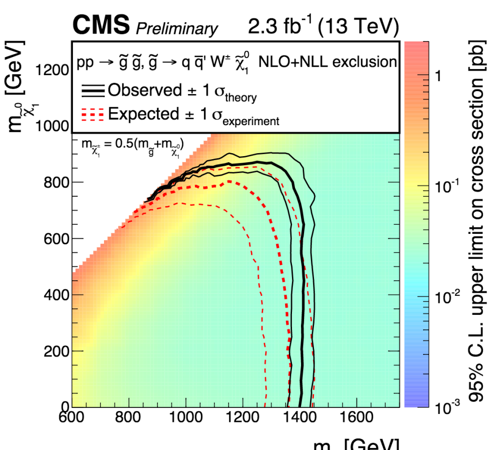
At 8 TeV excluded models with M_{stop} up to 1350 GeV in 1-lep channel

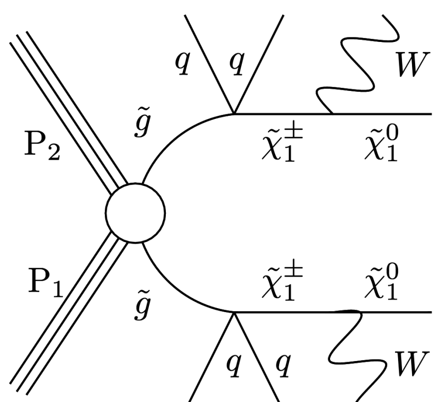
Search using sum of large-R jet masses



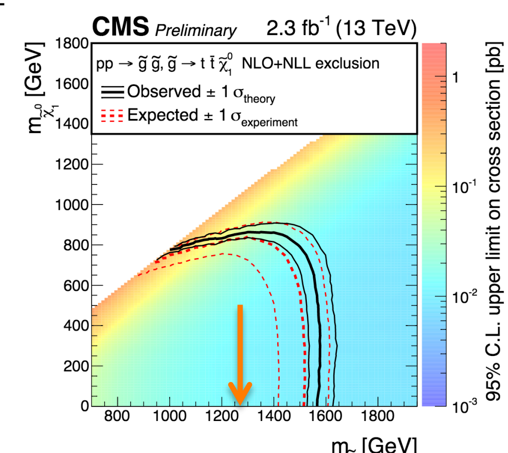


Inclusive search





At 8 TeV excluded models with M_{gluino} up to 1350 GeV

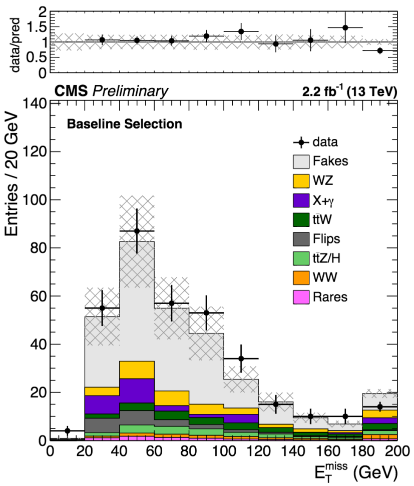


CMS Analyses with Multiple Leptons

Same-sign Dileptons

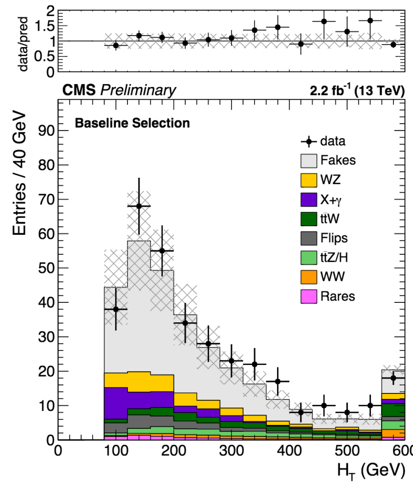
Analysis designed to cover broad range of models and different mass splittings

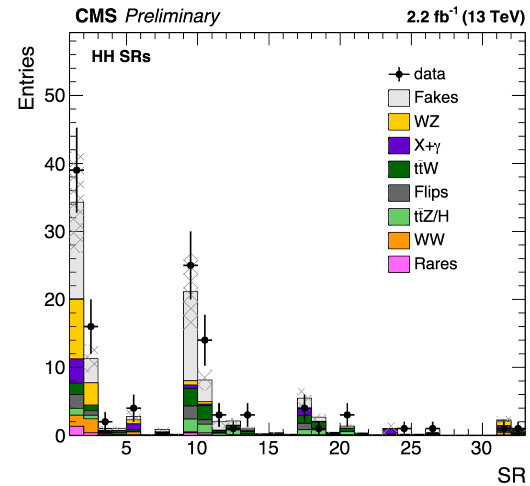
Signal regions split by two leading leptons' p_T, e.g. low-low (LL), high-low (HL) and high-high(HH)



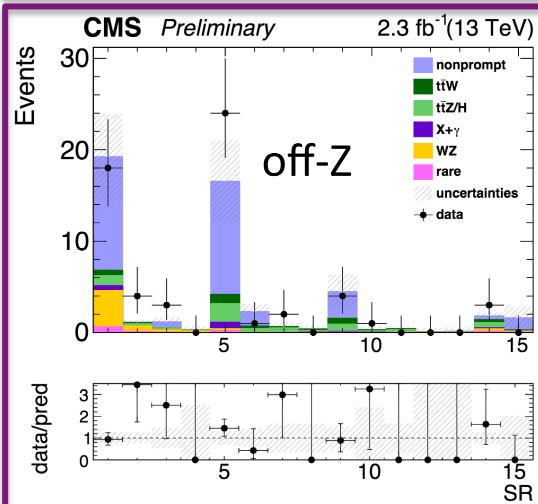
Signal regions start at MET > 50 GeV

Search in multiple bins across entire H_T range



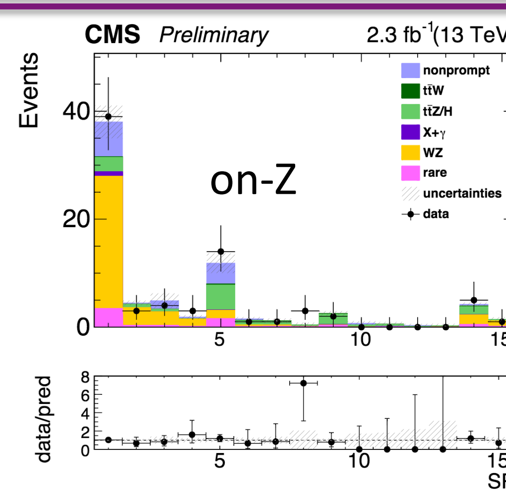


Multi-lepton



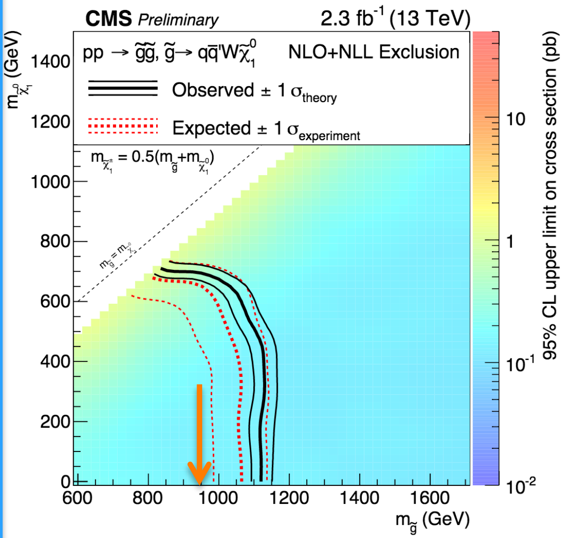
Search in events with ≥ 3 leptons & ≥ 2 jets bin in $N_{b\text{-tags}}$, H_T, MET

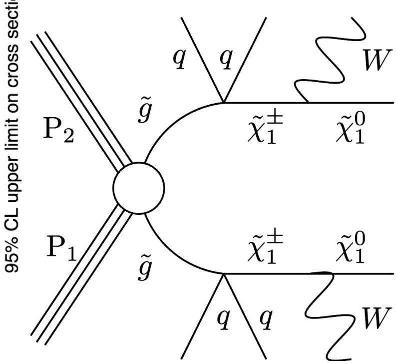
categorize events as on-Z if at least one opposite sign dilepton pair has M_{ll} consistent with M_Z (off-Z if otherwise)

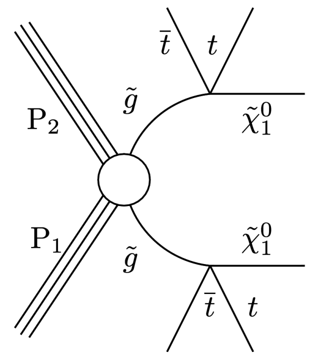


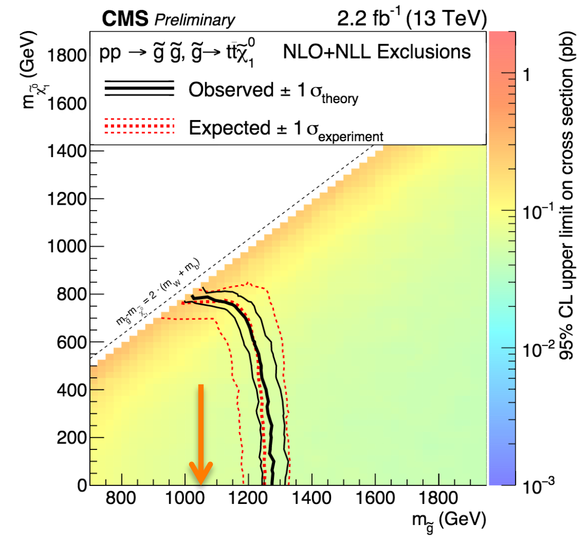
Results of multi-lepton Analyses

Same-sign Dileptons







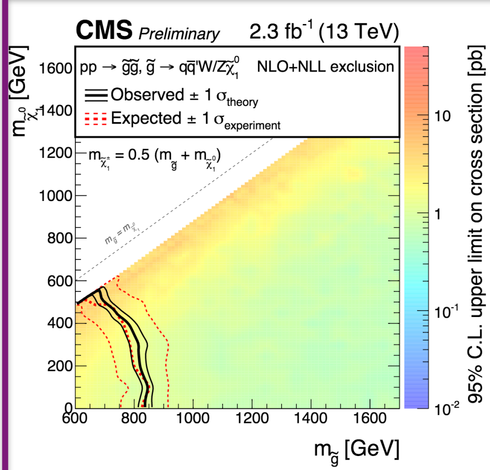


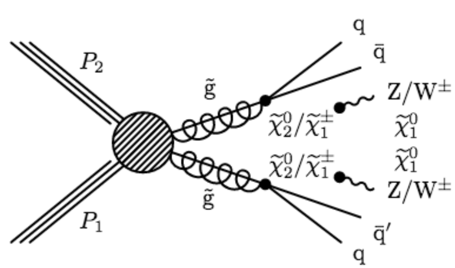
At 8 TeV excluded models with M_{gluino} up to 950 GeV

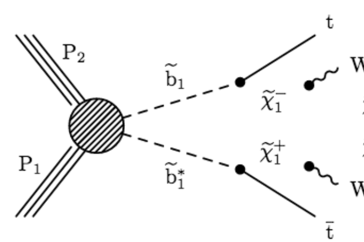
Sensitivity increases as # of high p_T leptons in final state increases

At 8 TeV excluded models with M_{gluino} up to 1050 GeV

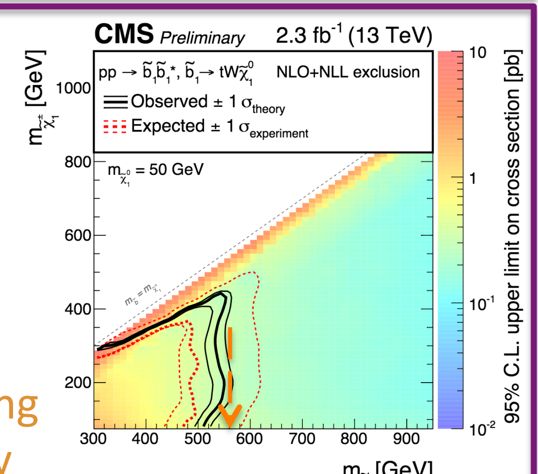
Multi-lepton (≥ 3)







Limits approaching 8 TeV sensitivity

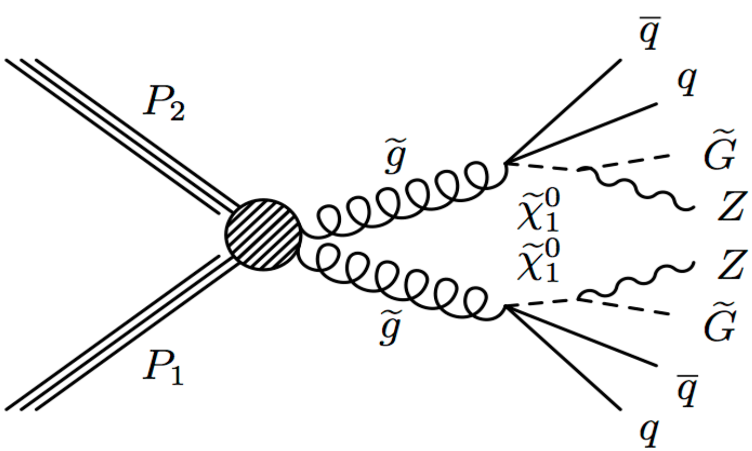


Exploring 8 TeV Excesses at 13 TeV: OS dilepton analysis

Physics Motivation

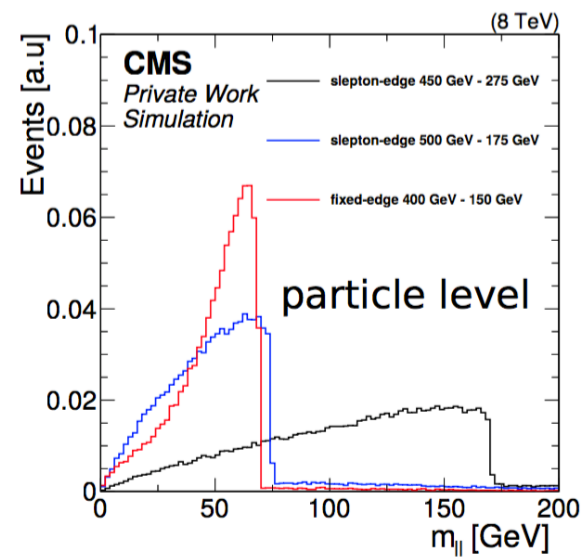
on-Z Signature

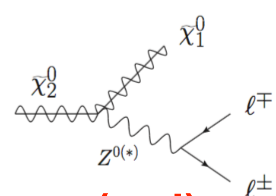
- Search for new physics in Z(ll) + jets + MET final state



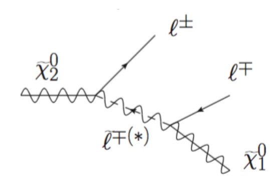
Edge-like Signature

- Look for edge shape excess in the di-lepton invariant mass





(red)

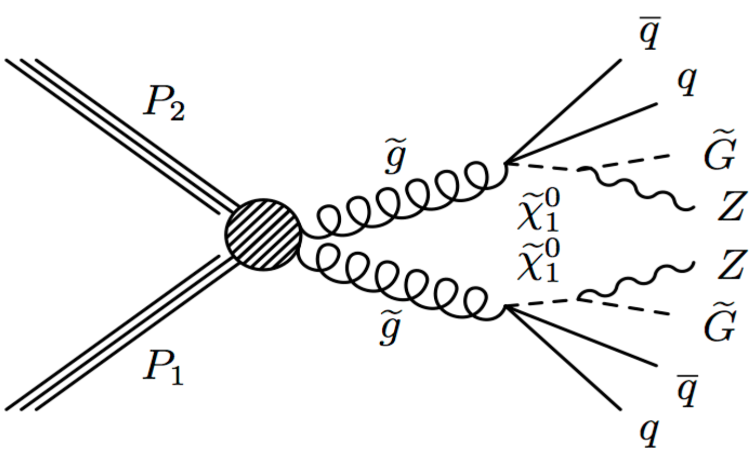


(black, blue)

Search Strategy

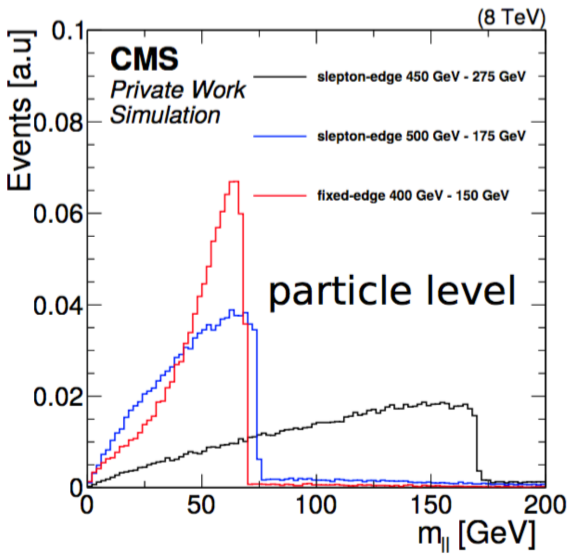
on-Z Signature

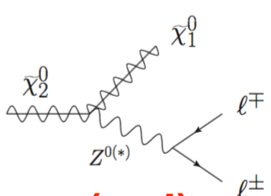
- Require OS dilepton pair with $|M_{ll} - M_Z| < 10$ GeV, ≥ 2 jets and large MET and H_T
  - Additional cut on dφ(jets,MET) applied to reduce backgrounds where MET is largely due to mismeasurement of jets



Edge-like Signature

- Require OS dilepton pair with $M_{ll} > 20$ GeV, ≥ 2 jets and large MET





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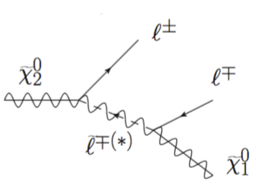
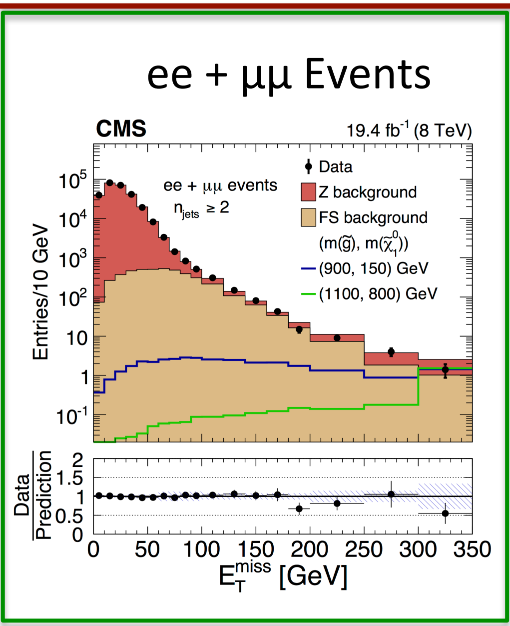


(black, blue)

CMS results at 8 TeV in OS dileptons



CMS on-Z results

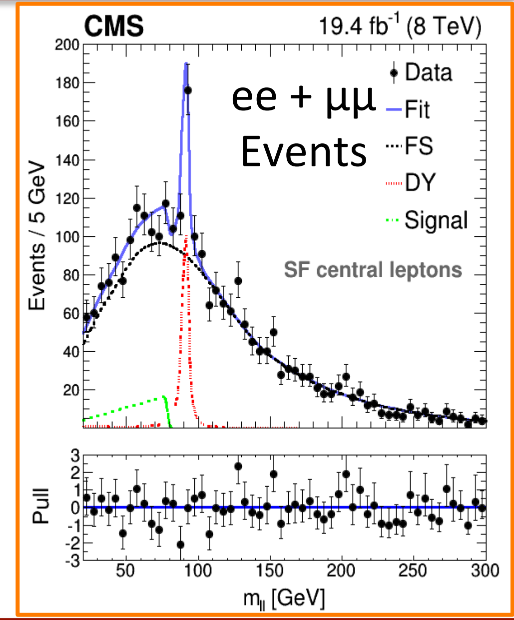
(M_{ll} 81-101 GeV)

no excess seen

CMS edge results:

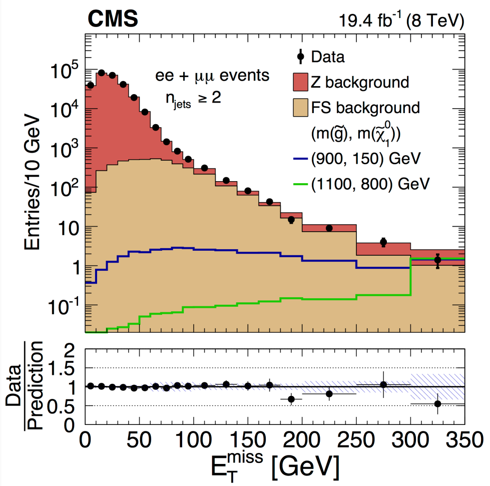
(M_{ll}: 20-70 GeV)

2.6 σ excess seen



Excesses seen at 8 TeV in OS dileptons

ee + μμ Events



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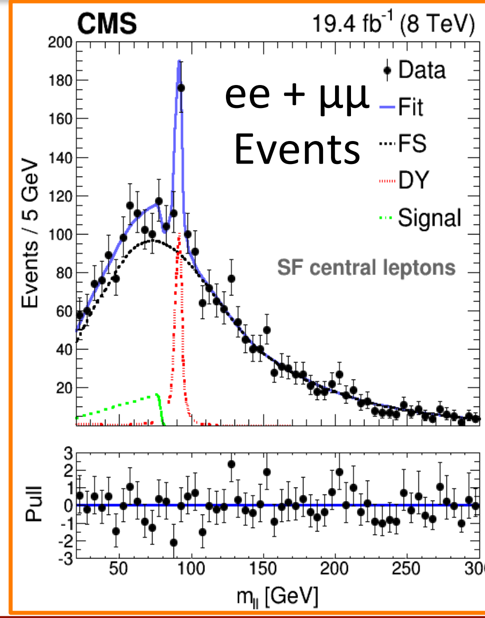
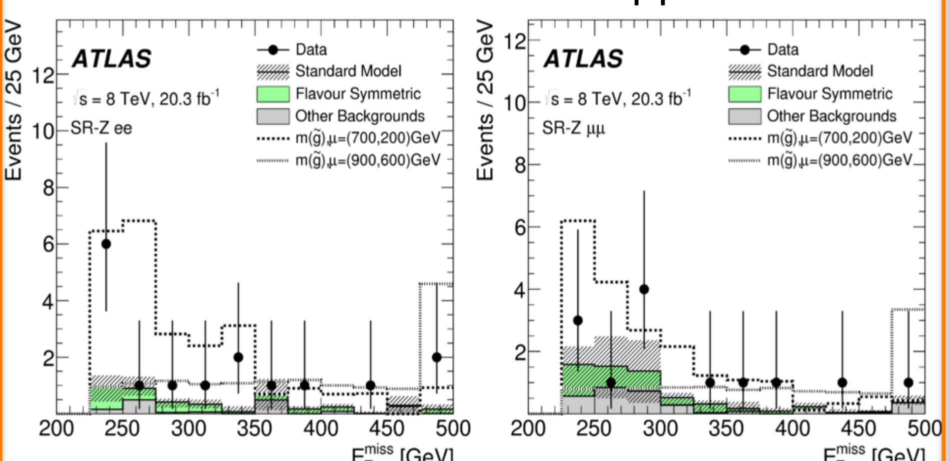


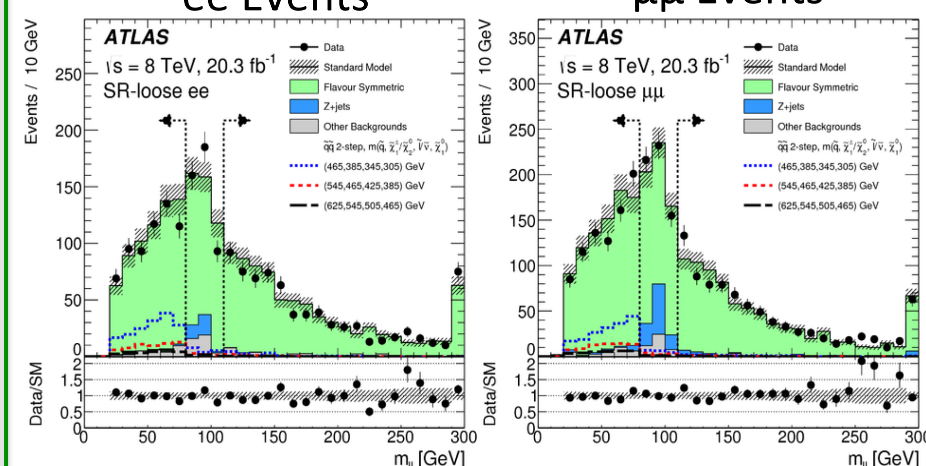
ATLAS on-Z results at 8 TeV: 3.0 σ excess seen

ee Events   μμ Events



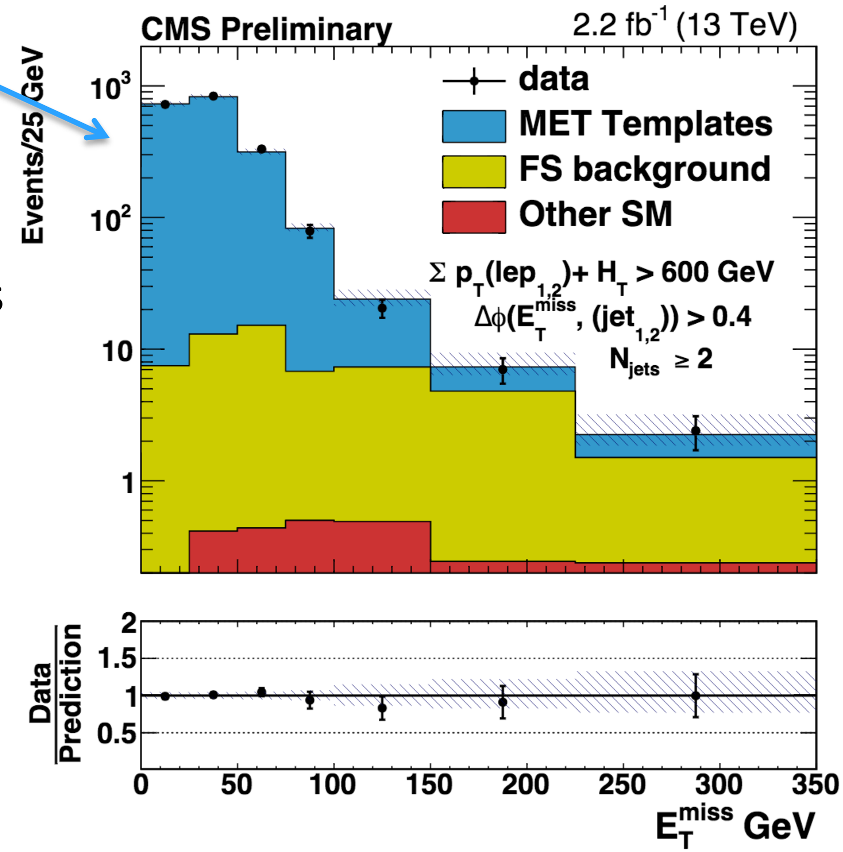
ATLAS edge results at 8 TeV: no excess seen

ee Events   μμ Events



Backgrounds

- DY Background w/ no real MET
  - Z+jets, WZ→2l2Q, ZZ→2L2Q …
  - Predicted with γ+jets data
    - MET Template method
  - scale on-Z prediction for edge M_{ll} regions



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  - Z+jets, WZ→2l2Q, ZZ→2L2Q …
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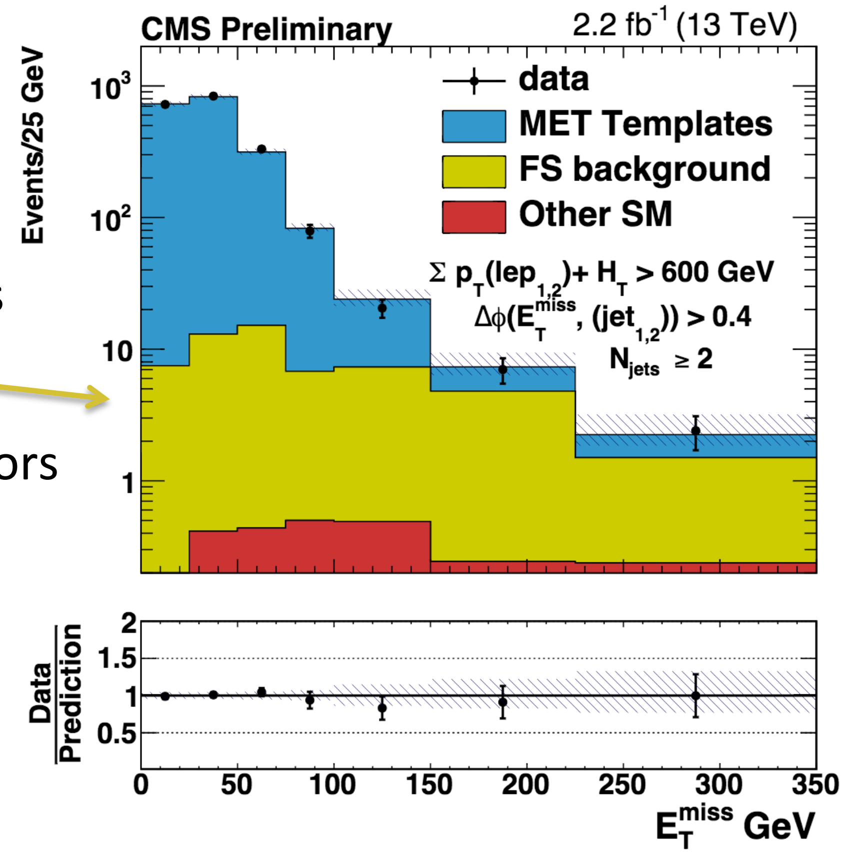
  - scale on-Z prediction for edge M_{ll} regions
- Flavor Symmetric Background
  - Background where final state lepton flavors are not correlated
    - ttbar, single top, WW, DY→ττ
  - Predict ee+μμ with eμ data



Backgrounds

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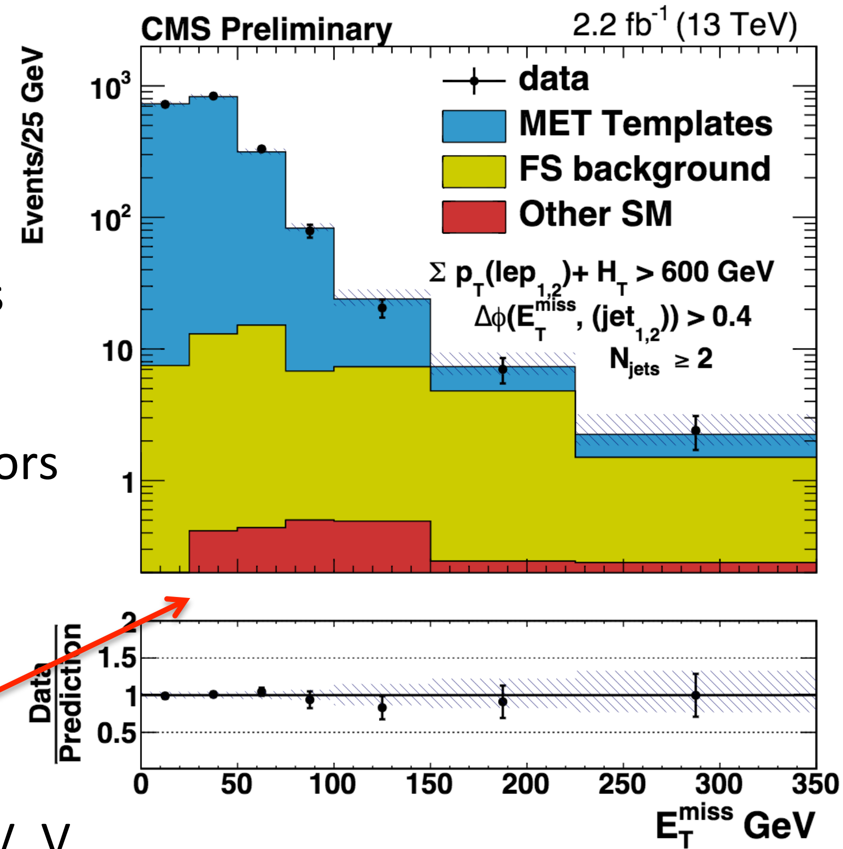
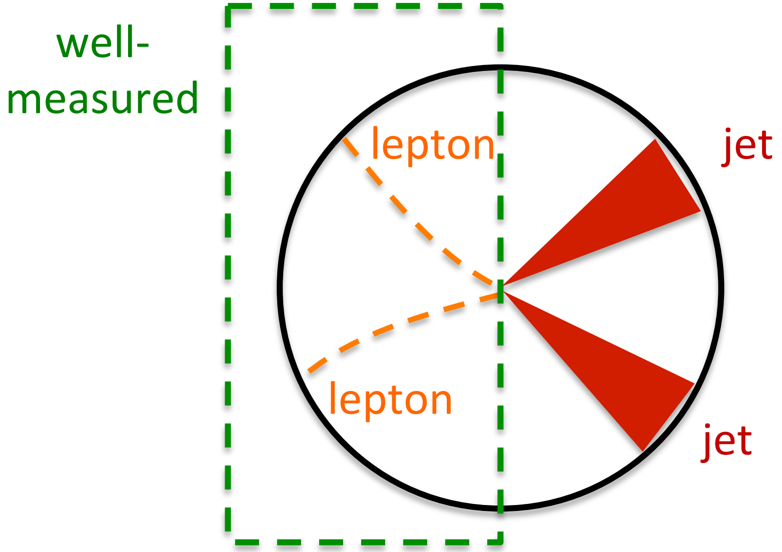
- Flavor Symmetric Background
  - Background where final state lepton flavors are not correlated
    - ttbar, single top, WW, DY→ττ
  - Predict ee+μμ with eμ data
- MC used for other SM processes
  - Including TTV, VV with real MET, and VVV, V = W,Z,H

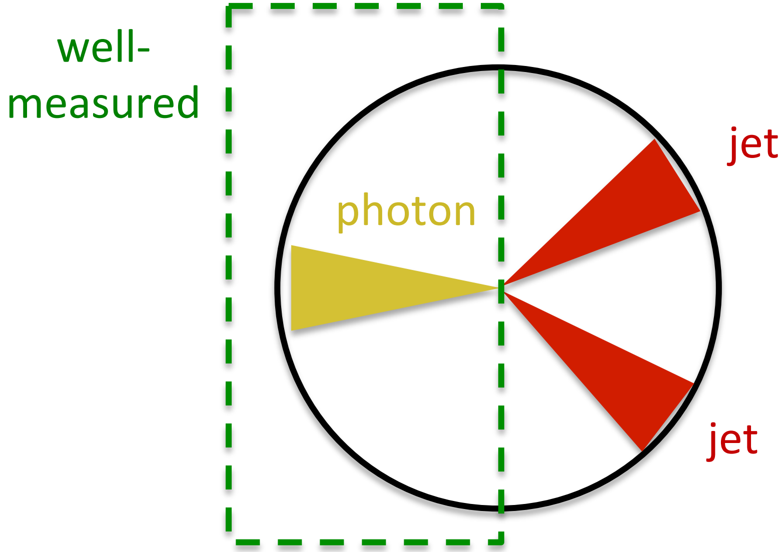


MET Template Method

- **Use γ+jets data to model MET spectrum in Z+jets**
  - Z+jets and γ+jets events contain no "real" MET
  - leptons and γs are well-measured compared to jets
    - "fake" MET comes from jet mismeasurement



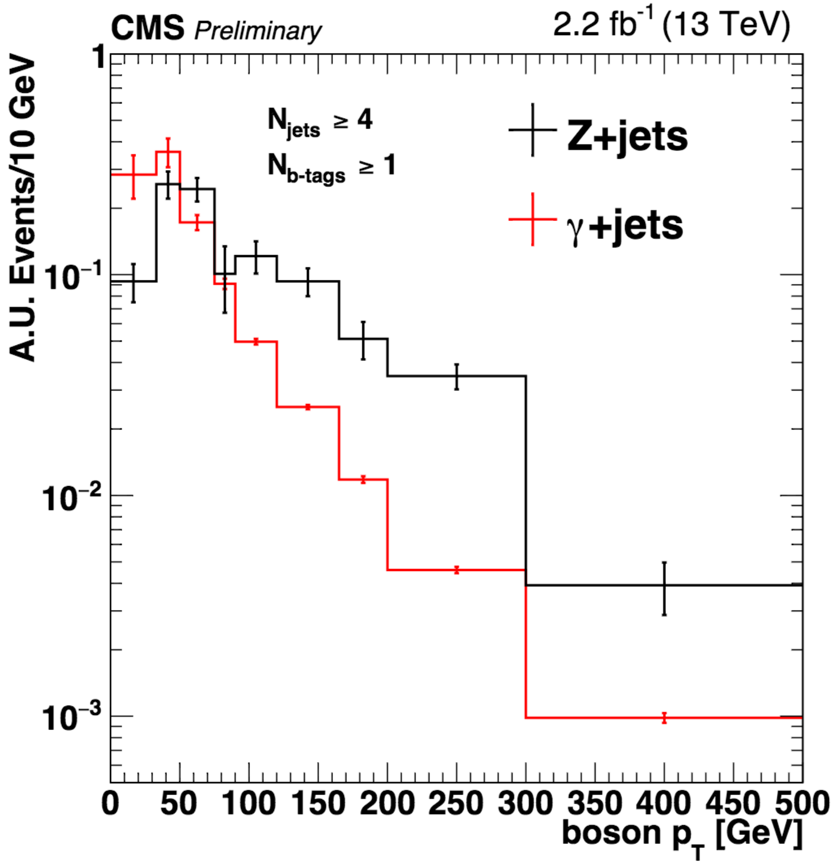
Z + jets

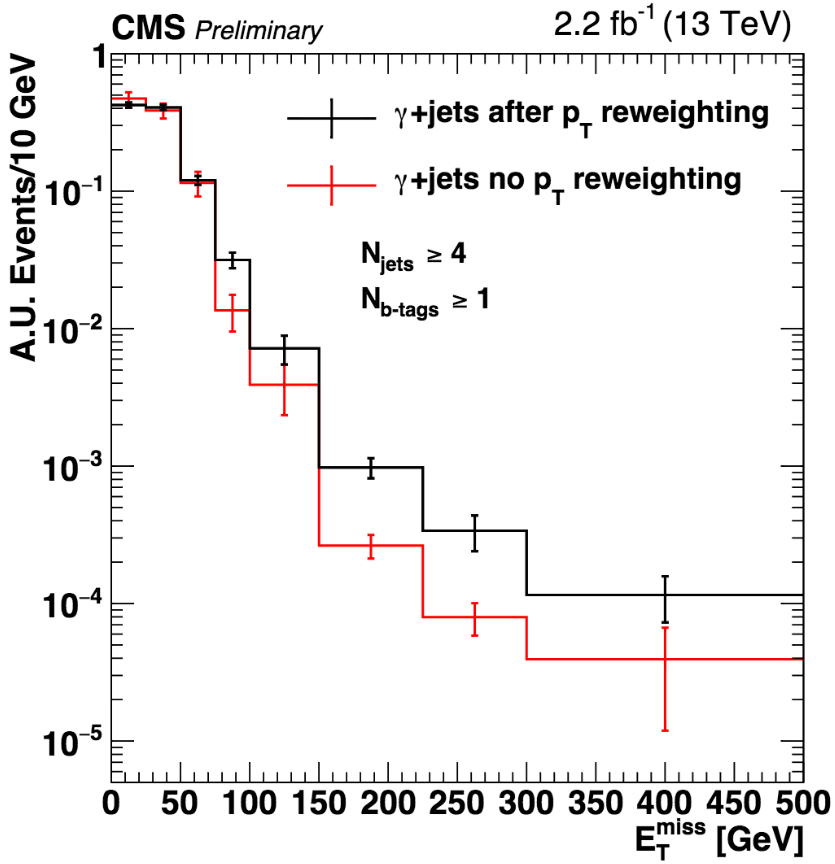


photon + jets

MET Template Method

- Use γ+jets data to model MET spectrum in Z+jets
- **Reweight γ p_T spectrum to expected Z p_T in data**
  - pT shape different due to mass of Z

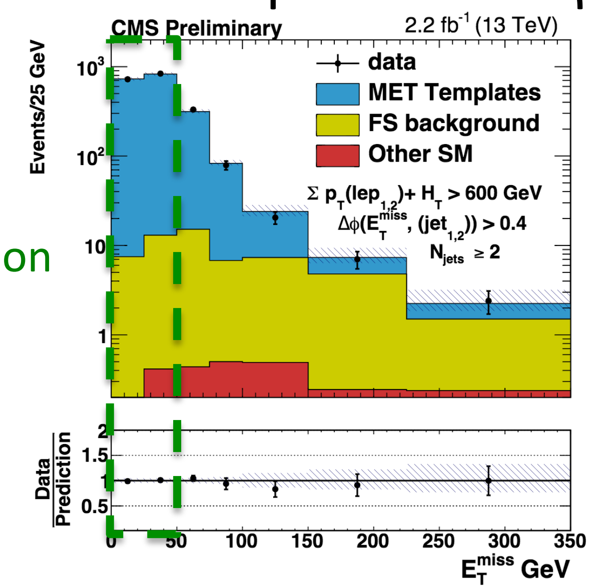




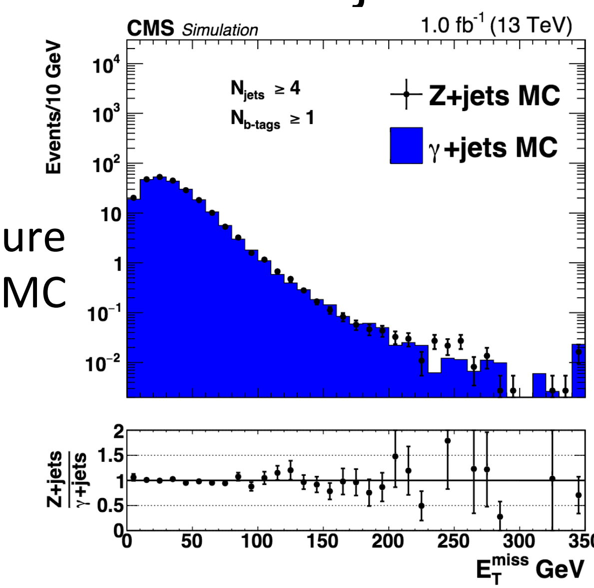
MET Template Method

- Use γ+jets data to model MET spectrum in Z+jets
- Reweight γ p_T spectrum to expected Z p_T in data
- **Prediction normalized in Z+jets dominated region, i.e. MET < 50 GeV**
  - Systematic uncertainties derived using MC
    - Derive templates with γ+jets MC to predict MET in Z+jets MC

Normalization region



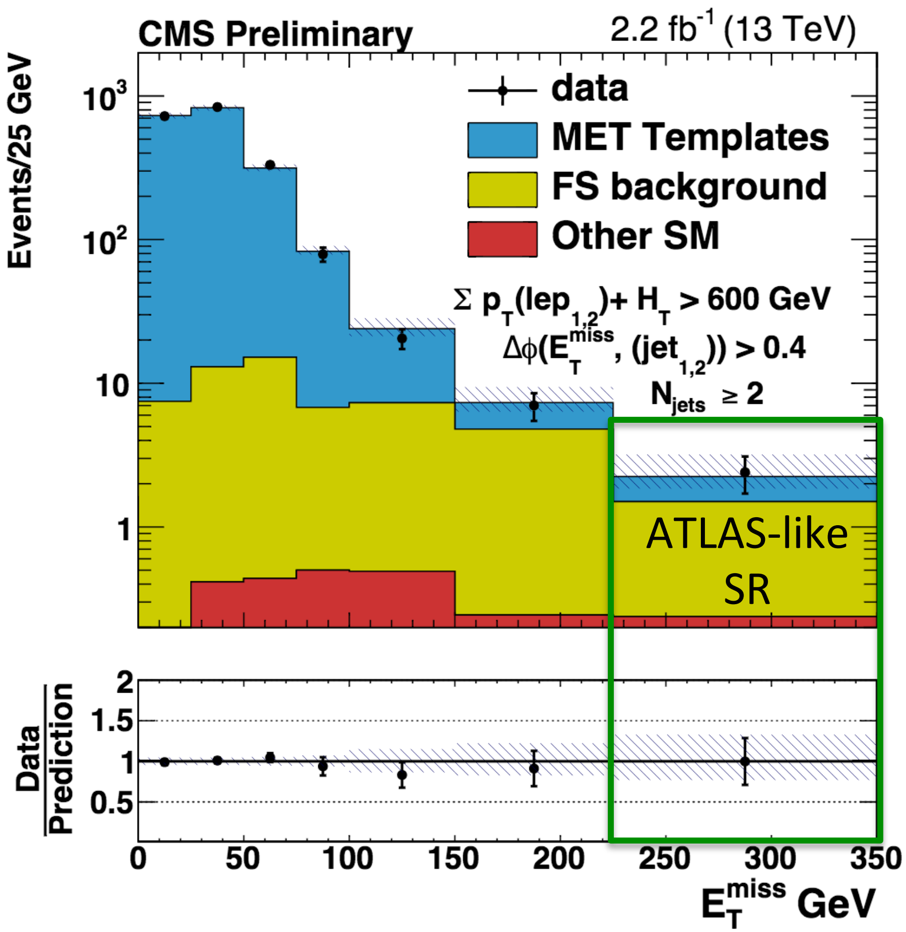
Good Closure seen in MC

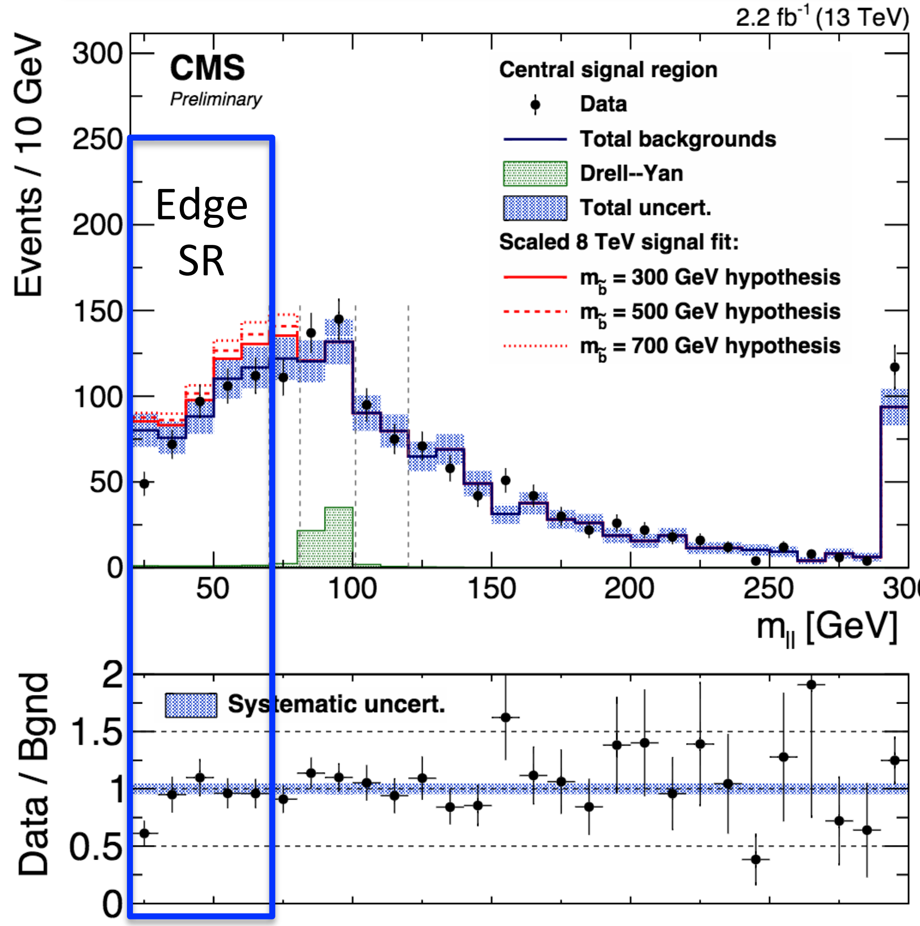


OS Dilepton Results

- No excess seen in 13 TeV
  - Largest background from FS

	ATLAS-like SR	Edge SR
Predicted	$12.0^{+4.0}_{-2.8}$	470.9 ± 29.9
Observed	12	437





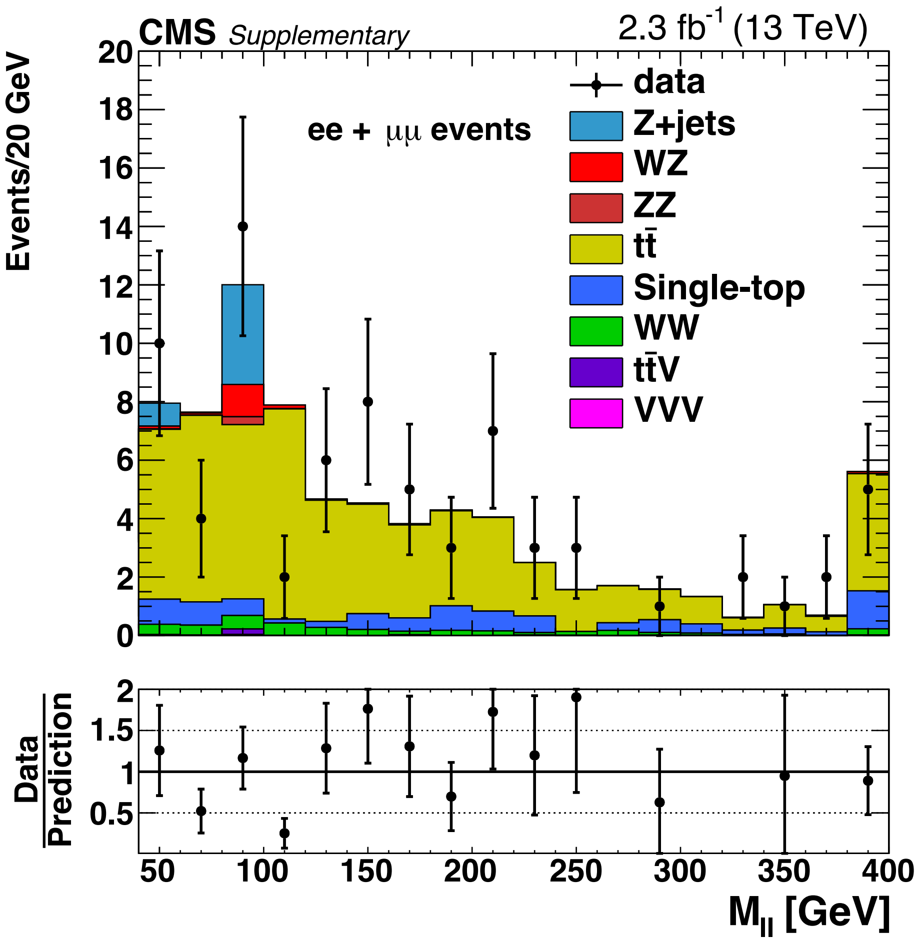
Conclusion

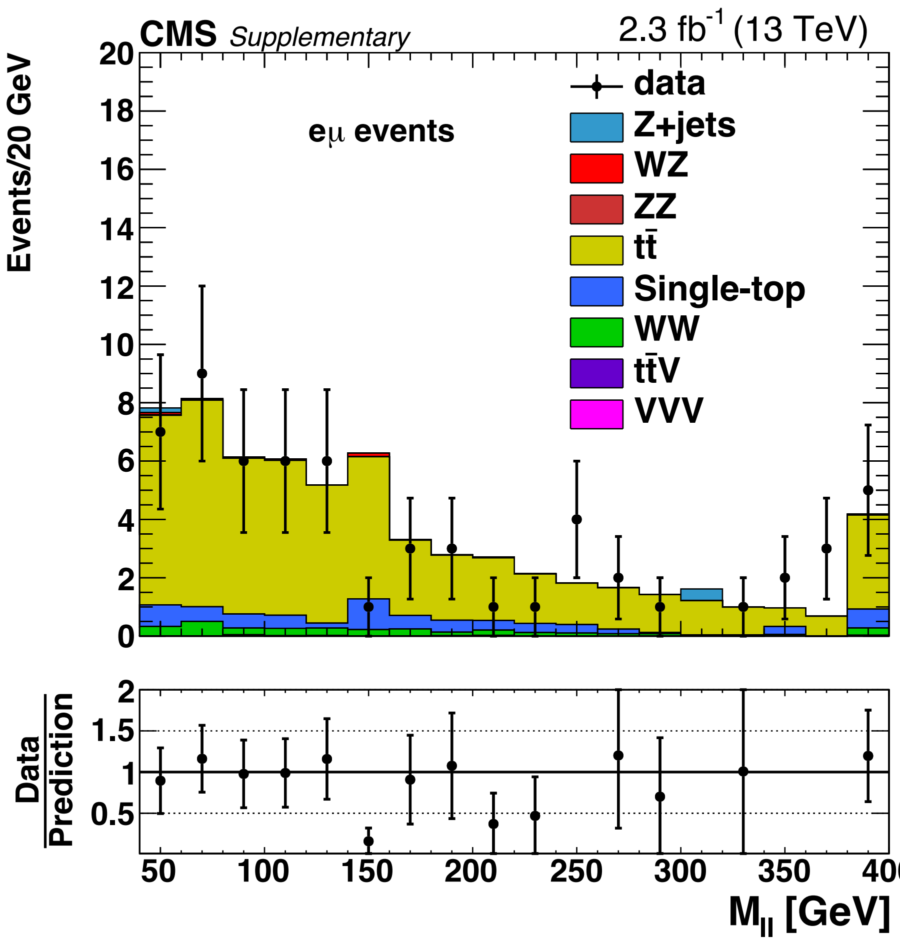
- Wide variety of SUSY searches performed in leptonic final states with CMS in 2015
- re-analyzed OS dilepton regions where excesses were seen in run I
- No significant excesses seen at 13 TeV
- Looking forward to more data in 2016!

Backup

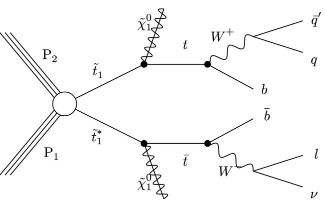
M_{ll} Distribution in ATLAS-like Signal Region

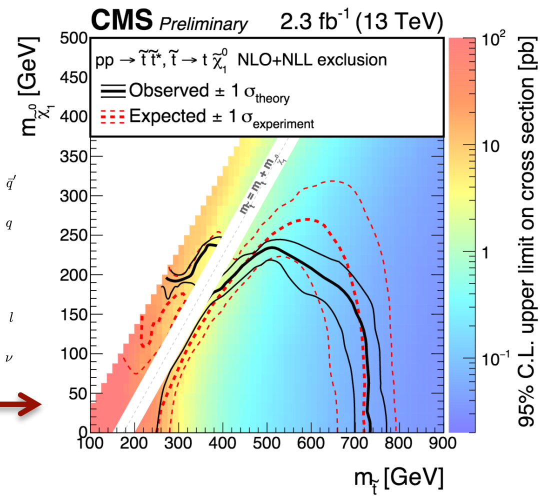
- Background predictions from MC
- M_{ll} shown after all other ATLAS-like cuts applied

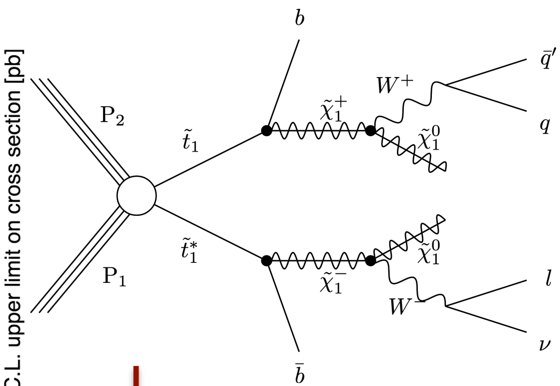


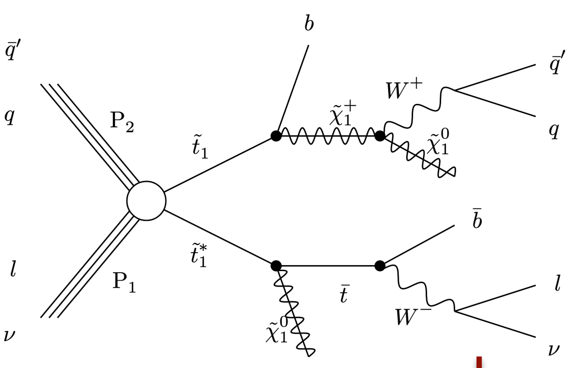


1 lepton Stop Results



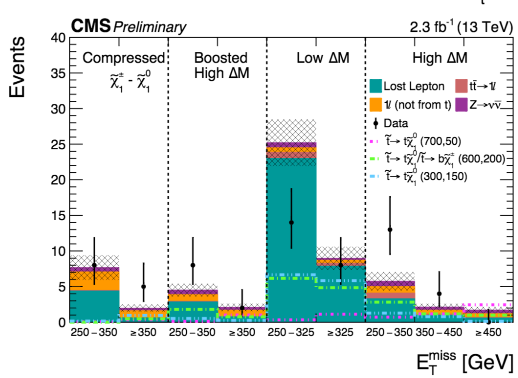




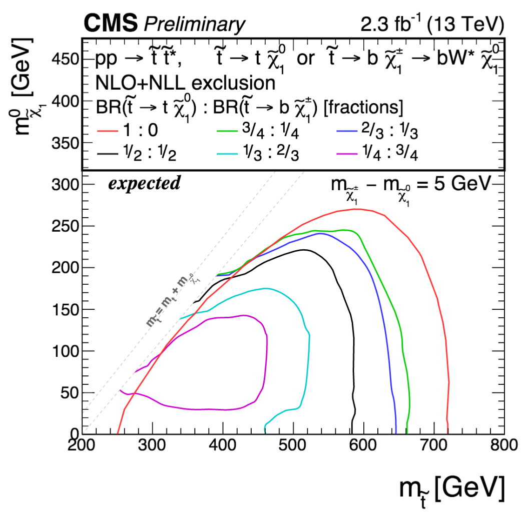


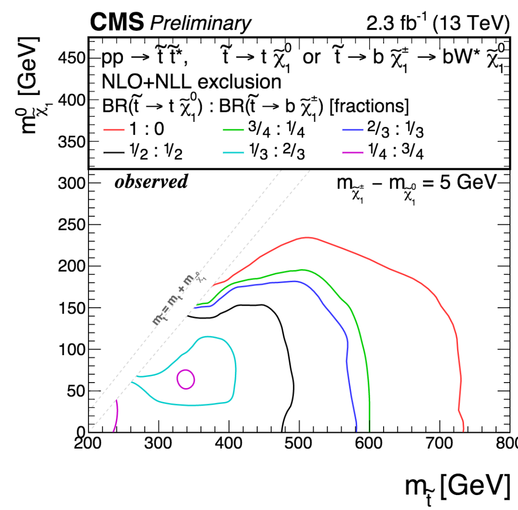
Consider different branching fractions for $\tilde{t}_1 \to t^{(*)}\tilde{\chi}^0{}_1$ and $\tilde{t}_1 \to b\tilde{\chi}^{\pm}{}_1$ decay modes

The chargino is assumed to be nearly mass-degenerate with the LSP

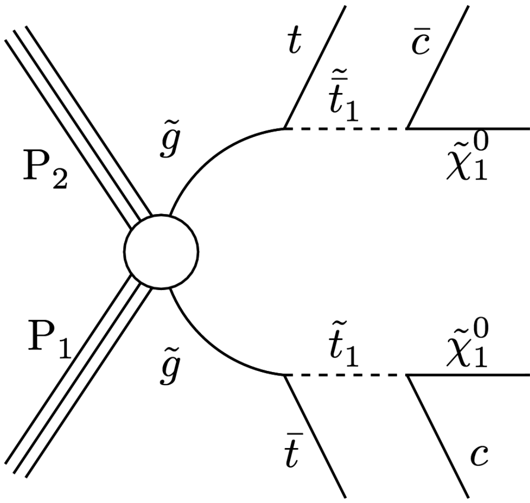


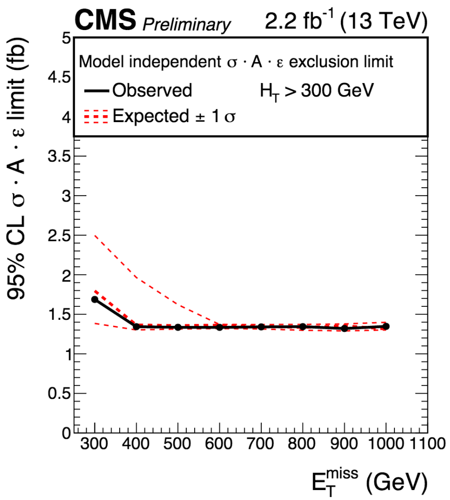
E_T^{miss} [GeV]	Lost Lepton	1ℓ (not from top)	$t\bar{t} \to 1\ell$	$Z \to \nu\bar{\nu}$	Total background	Data
	Compressed $\tilde{\chi}^{\pm}_1 - \tilde{\chi}^0_1$: 2 jets, $t_{mod} > 6.4$					
250 − 350	4.36 ± 1.44	2.61 ± 0.99	0.09 ± 0.09	0.60 ± 0.12	7.67 ± 1.73	8
> 350	0.62 ± 0.23	0.98 ± 0.47	0.00 ± 0.03	0.36 ± 0.13	1.96 ± 0.54	5
	Boosted High ΔM: 3 jets, $M_{T2}^W > 200$ GeV					
250 − 350	2.83 ± 0.73	0.92 ± 0.52	0.12 ± 0.12	0.64 ± 0.13	4.51 ± 0.91	8
> 350	0.74 ± 0.21	0.88 ± 0.50	0.05 ± 0.05	0.41 ± 0.09	2.08 ± 0.55	2
	Low ΔM: ≥ 4 jets, $M_{T2}^W \leq 200$ GeV					
250 − 325	22.97 ± 3.21	0.61 ± 0.61	0.88 ± 0.88	0.74 ± 0.17	25.20 ± 3.38	14
> 325	7.85 ± 1.54	0.45 ± 0.45	0.40 ± 0.40	0.30 ± 0.11	8.98 ± 1.62	8
	High ΔM: ≥ 4 jets, $M_{T2}^W > 200$ GeV					
250 − 350	3.29 ± 0.91	0.92 ± 0.46	0.78 ± 0.78	0.76 ± 0.19	5.75 ± 1.29	13
350 − 450	0.94 ± 0.27	0.54 ± 0.34	0.18 ± 0.18	0.46 ± 0.14	2.13 ± 0.48	4
> 450	0.57 ± 0.21	0.55 ± 0.36	0.07 ± 0.07	0.52 ± 0.17	1.71 ± 0.45	0

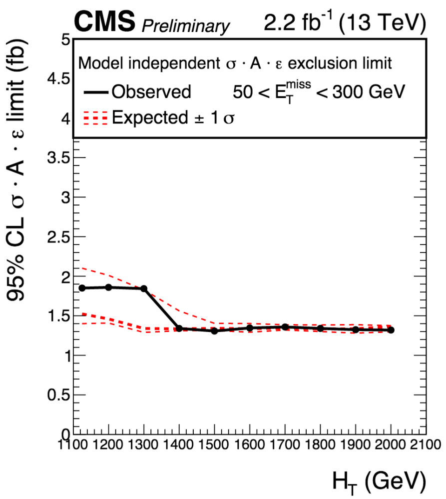


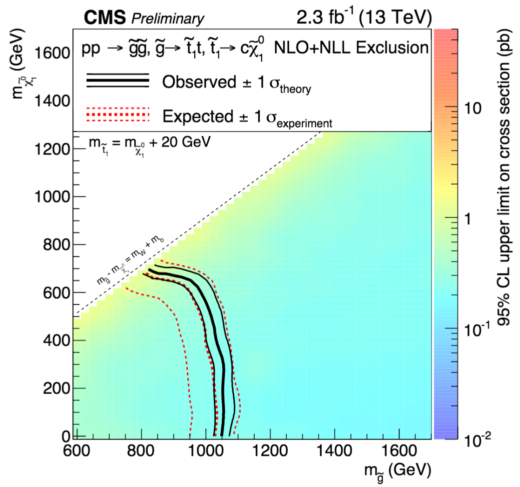


dilepton same-sign Results (1/3)

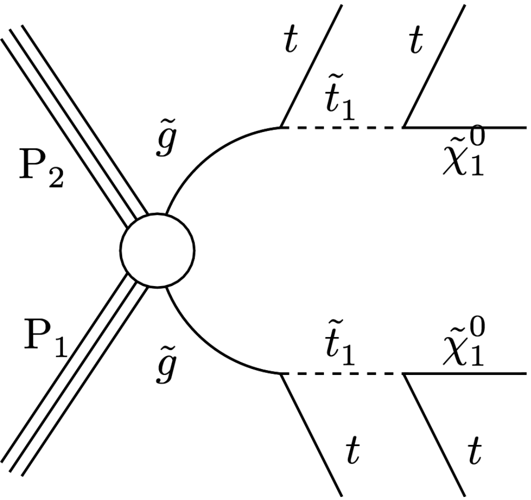


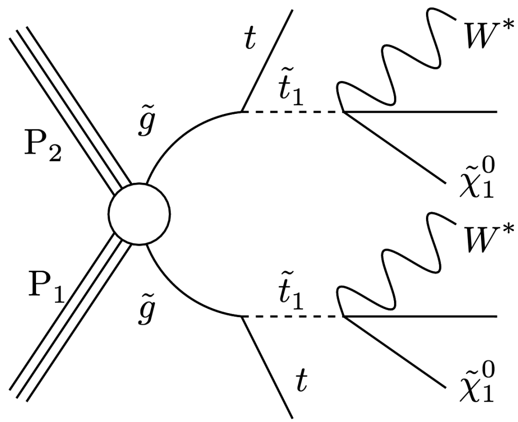


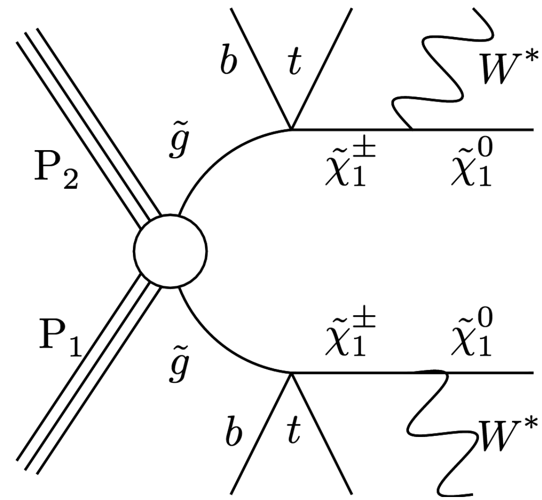


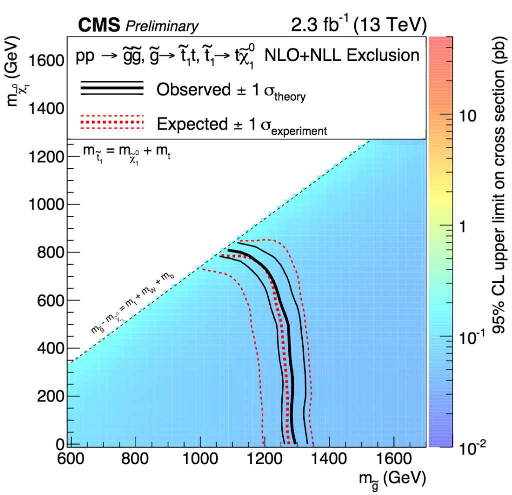


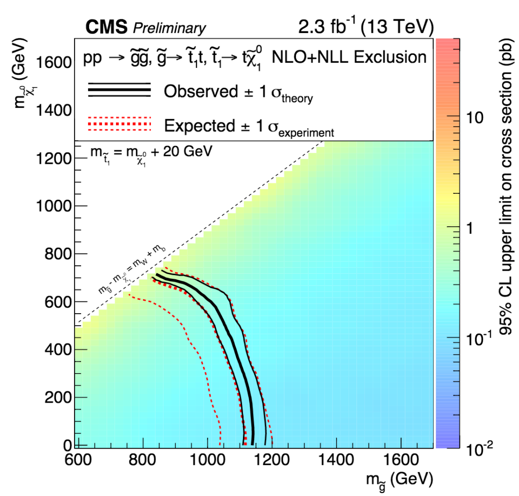
dilepton same-sign Results (2/3)

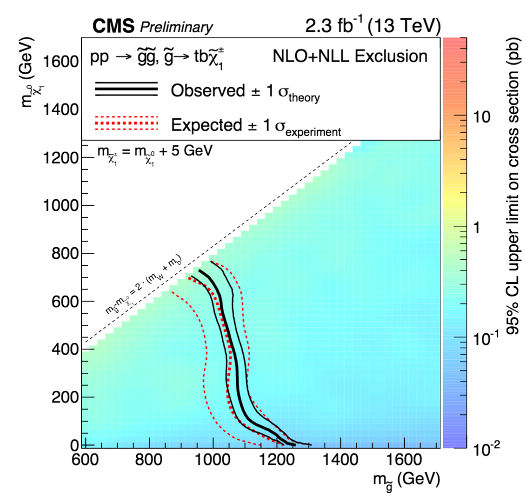




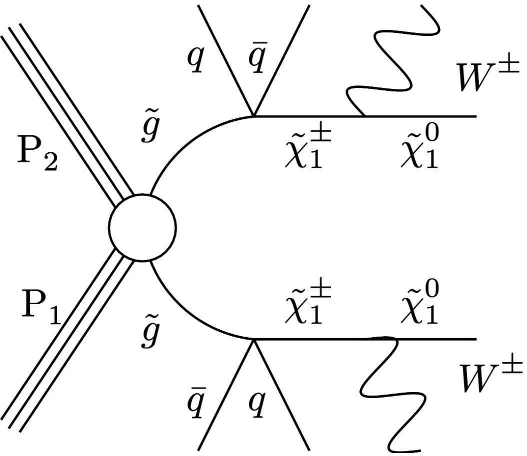


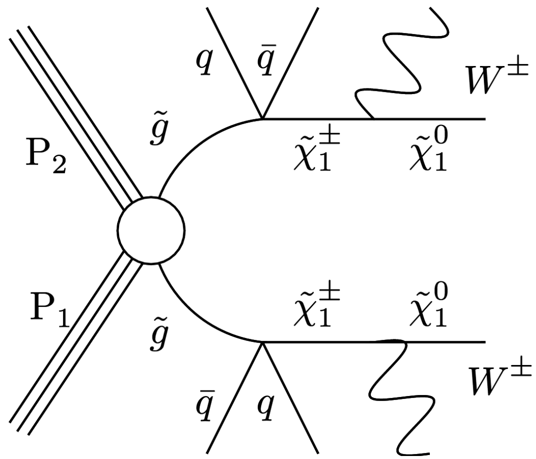


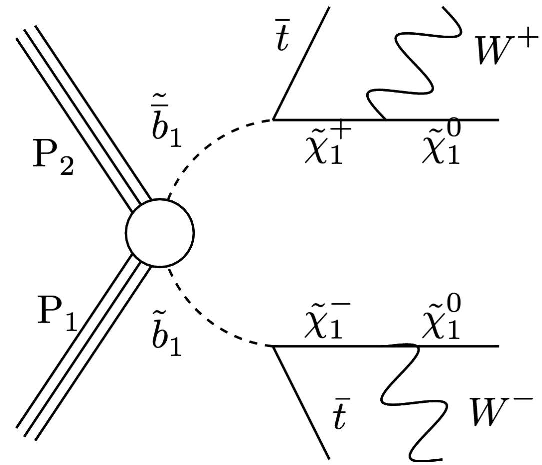




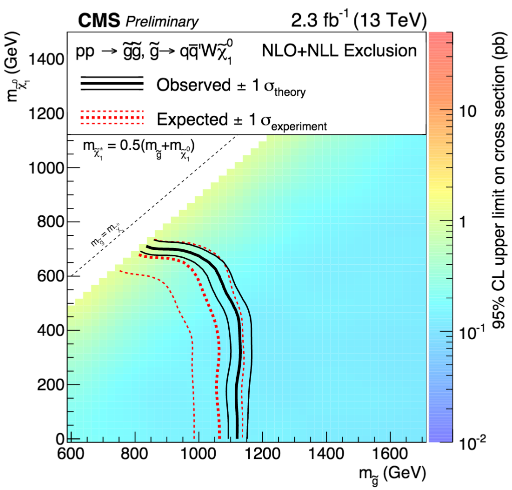
dilepton same-sign Results (3/3)

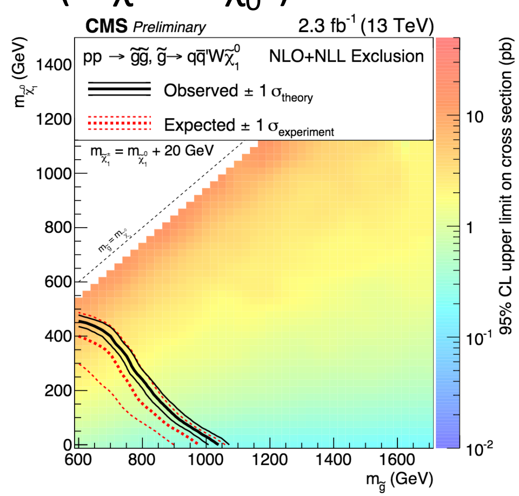


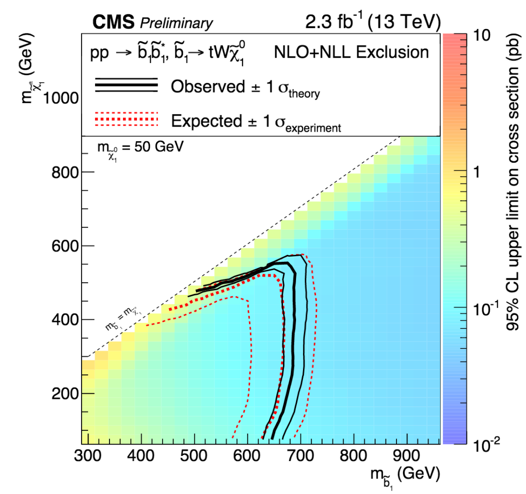




$\Delta(M\tilde{\chi}^{\pm} - M\tilde{\chi}_0^{1}) = 20$ GeV

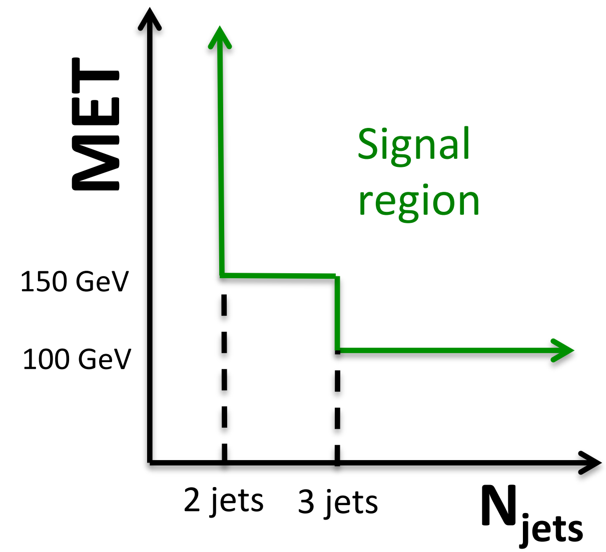






OS dilepton Signal Region Definitions

ATLAS-like on-Z region	Edge region
• 2 OSSF leptons, p_T > 20 GeV – Note: ATLAS uses 50, 25 GeV • M_{ll}: 81-101 GeV • at least 2 jets • $H_T + \Sigma(p_T(\text{leps}))$ > 600 GeV • $d\varphi(\text{jet}_{1,\,2},\text{MET})$ > 0.4 • MET > 225 GeV	• 2 OSSF leptons with p_T > 20 GeV • M_{ll}: 20-70 GeV • at least 2 jets + cut on MET

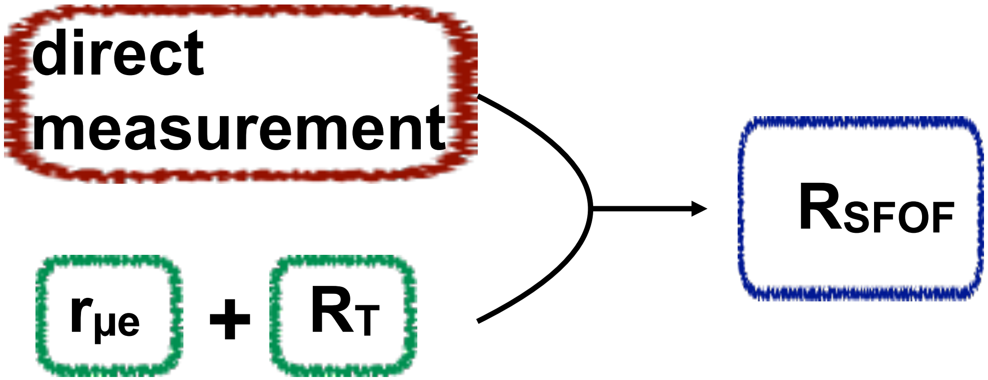


FS BG Prediction Method (1/2)

- **Flavor symmetric processes produce OF and SF equally**
  - Include ttbar, single-top, Z→ττ, ttW, off-Z regions of WZ, ttZ
  - Only true at gen level, corrections needed for trigger/reco effects
  - Use OF sample to predict SF contribution
    - Calculate transfer factor, **Rsfof**

- **Calculation done in two ways:**
  1. directly from orthogonal ttbar sample outside of signal region
  2. factorizing object and trigger efficiencies

- Use **weighted average** for final number



FS BG Prediction Method (2/2)

- Combine results from direct measurement and factorization method to get final R_{sfof} value
- 5% systematic for central and forward regions

	Central		**Forward**	
	Data	MC	Data	MC
$\frac{1}{2}\left(r_{\mu/e} + r_{\mu/e}^{-1}\right)$	1.008 ± 0.013	1.008± 0.012	1.022± 0.042	1.026± 0.046
R_T	1.003 ± 0.072	1.027± 0.067	1.061± 0.090	1.029± 0.071
		$R_{SF/OF}$		
from factorization	1.011 ± 0.074	1.035 ± 0.068	1.084 ± 0.103	1.057 ± 0.087
direct measurement	1.055 ± 0.061	1.050 ± 0.013	1.107 ± 0.134	1.079 ± 0.021
weighted average	**1.037 ± 0.047**	**1.049 ± 0.013**	**1.097 ± 0.068**	**1.079 ± 0.020**