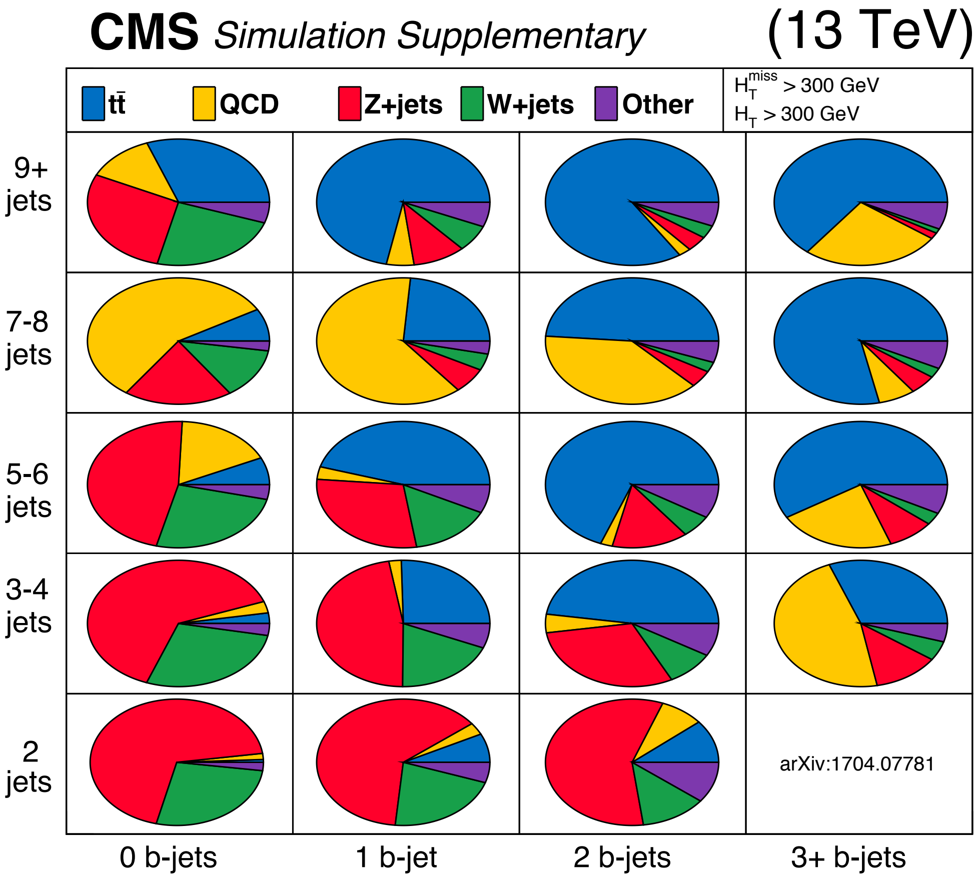
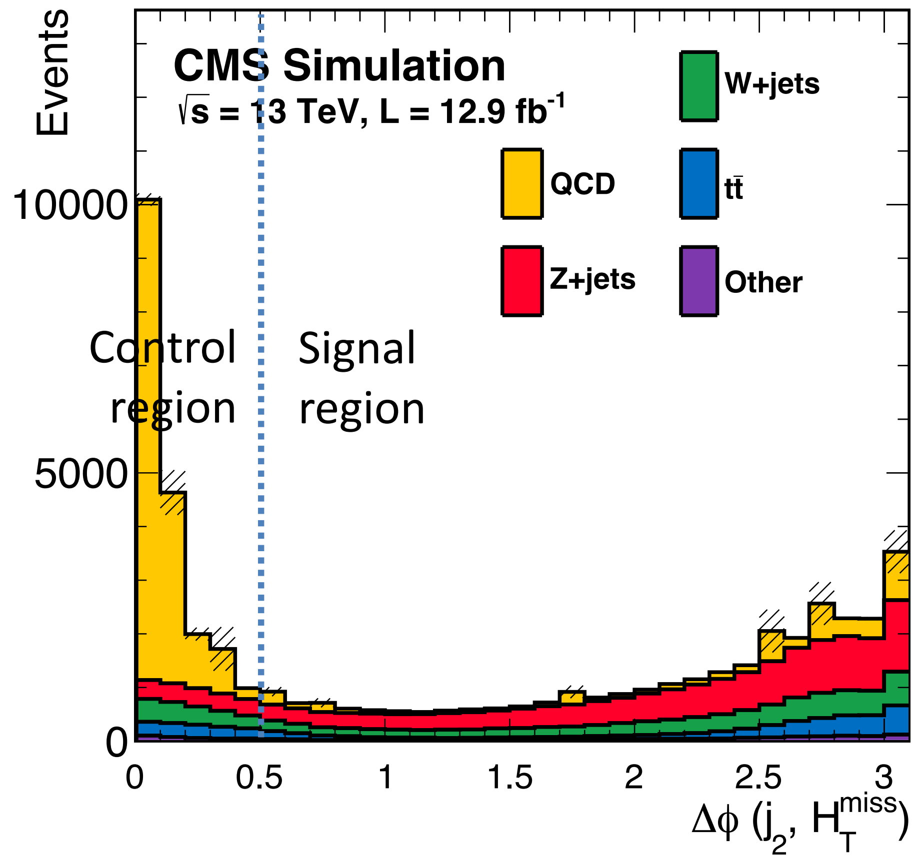
Jets + p_T^{miss} search: background composition



QCD background estimation method



Background composition varies significantly across the analysis bins:

- High jet and b-jet multiplicity → ttbar
- Lower jet and b-jet multiplicity→ Z + jets

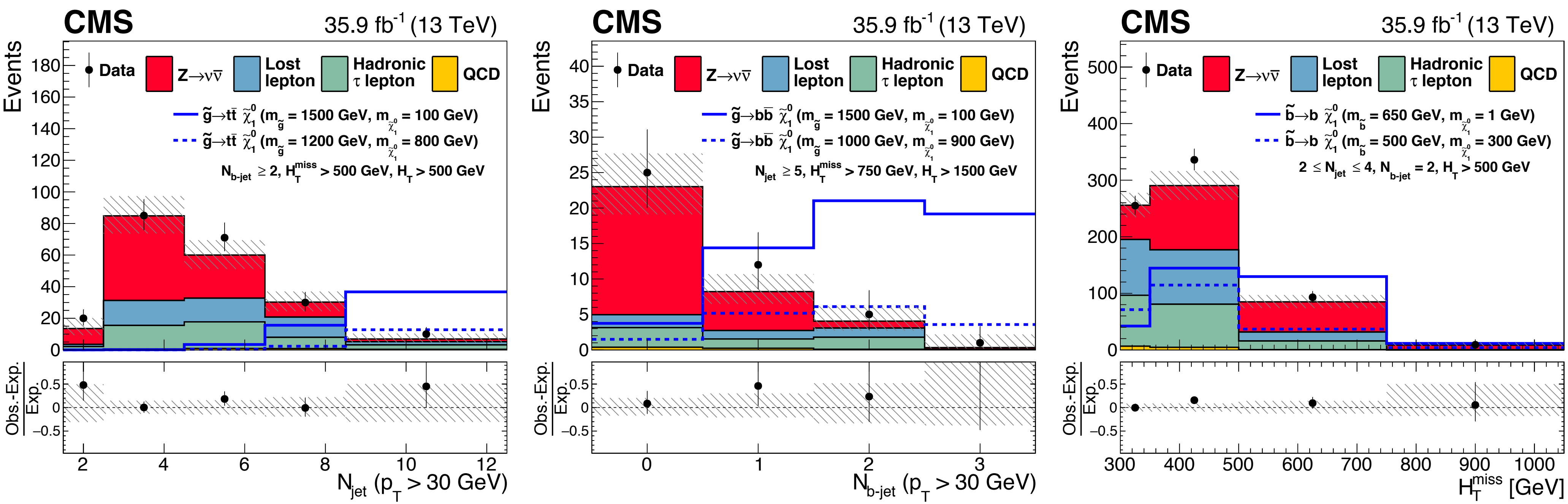
Veto events if any of the four highest p_T jets is aligned with the p_T^{miss} vector:

Veto if
$$\Delta\varphi(J_{1,2}, p_T^{miss}) < 0.5$$
$$\Delta\varphi(J_{3,4}, p_T^{miss}) < 0.3$$

Jets + p_T^{miss} search: some projections of the data

Background estimation: control samples x scale factors:

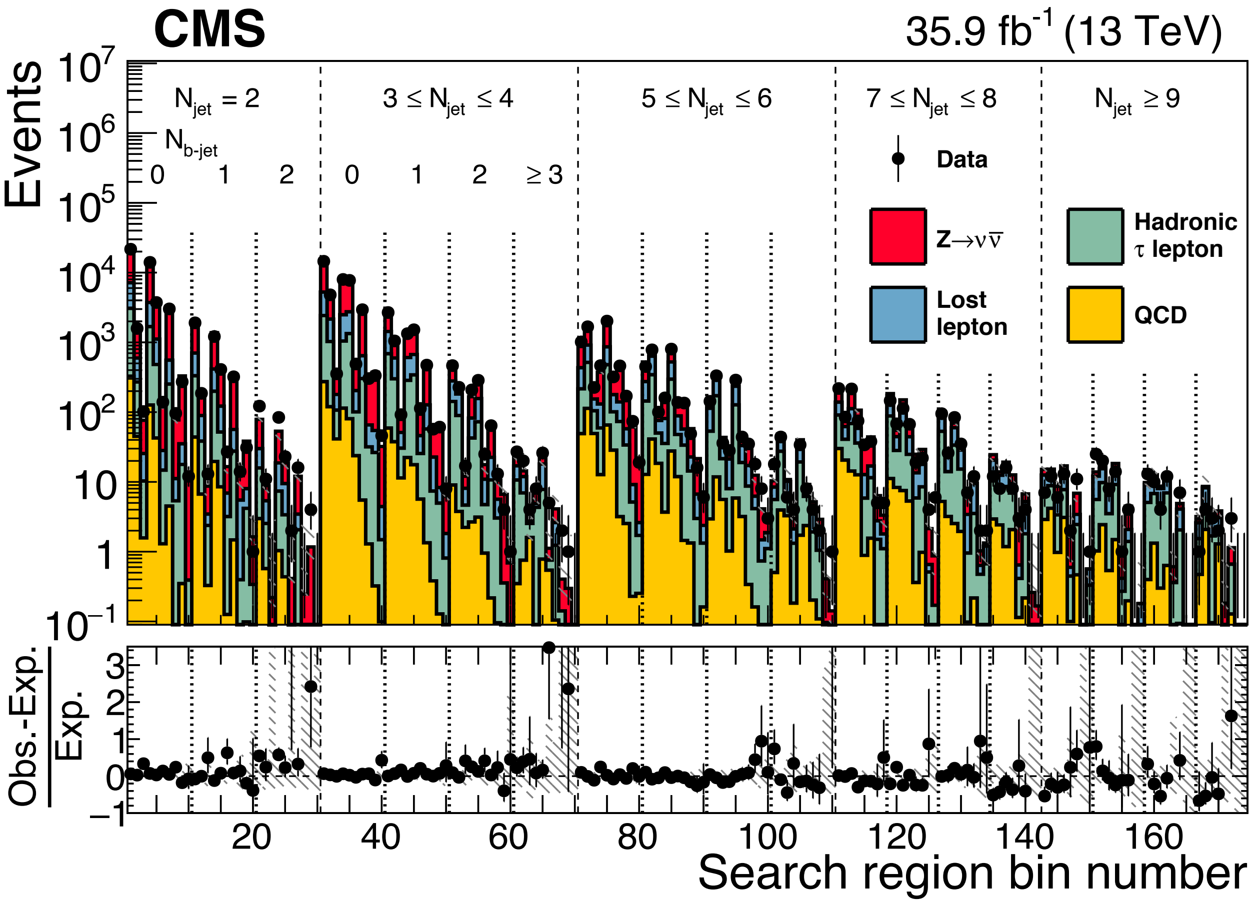
- QCD background - from “inverted $\Delta\varphi$” control samples
- $Z \rightarrow \nu\nu$ + jets - from $Z \rightarrow \ell^+\ell^- +$ jets and γ +jets conrol samples
- “Lost lepton”: ttbar $W \rightarrow (e, \mu)\nu$ and $W \rightarrow \ell\nu$ + jets - from 1-lepton control samples
- ttbar $W \rightarrow \tau\nu \rightarrow$ hadrons + ν - from 1-lepton control samples

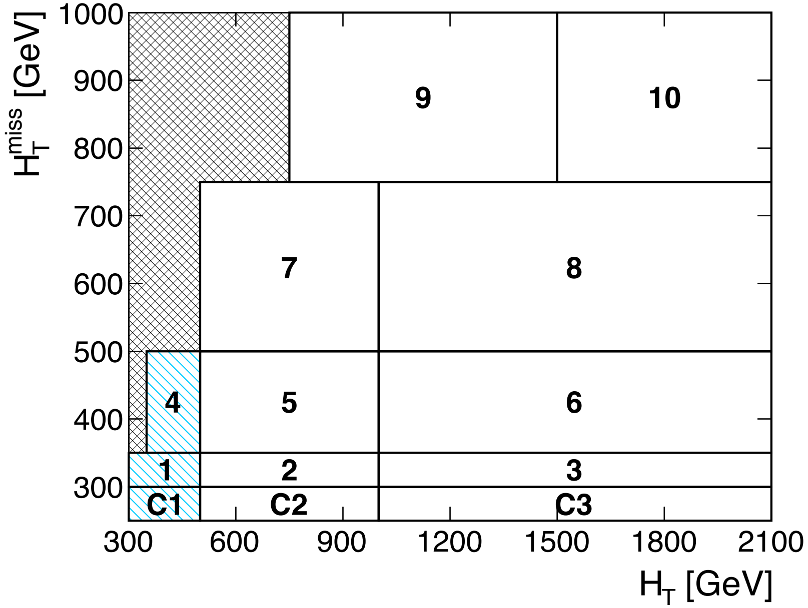


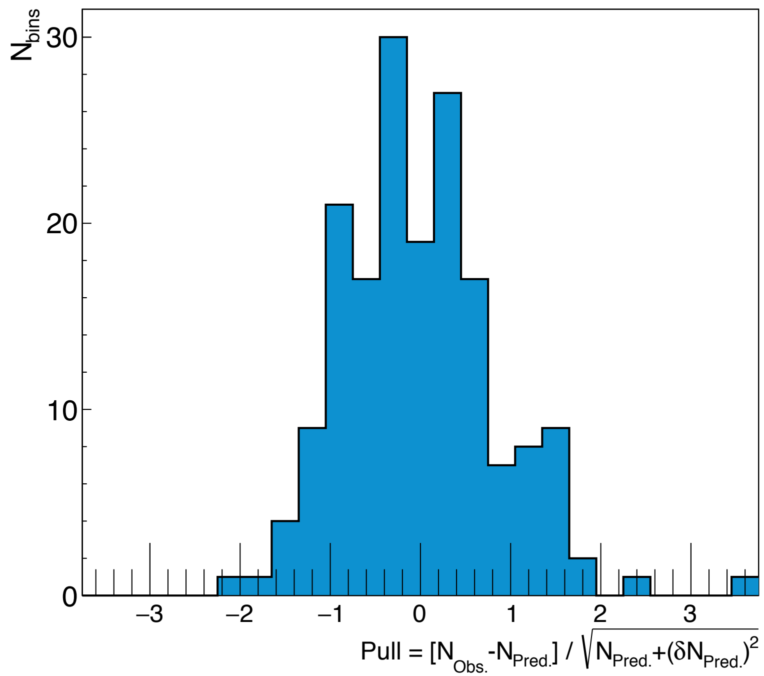
No evidence for a large/significant excess event yield above the SM background prediction.

Jets + p_T^{miss} search: observed yields in signal regions

Bin numbering: increasing: Njets, Nbjets, HT & HTmiss (order according to plot at right)

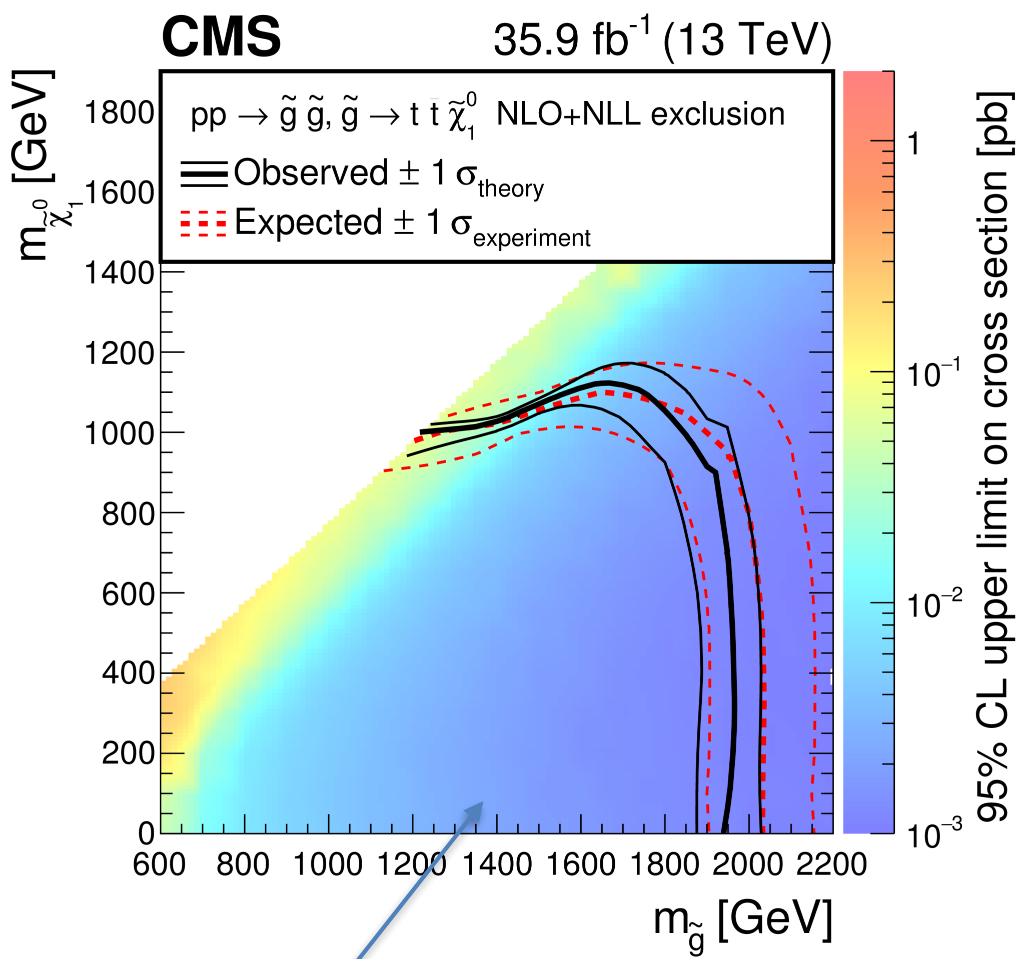


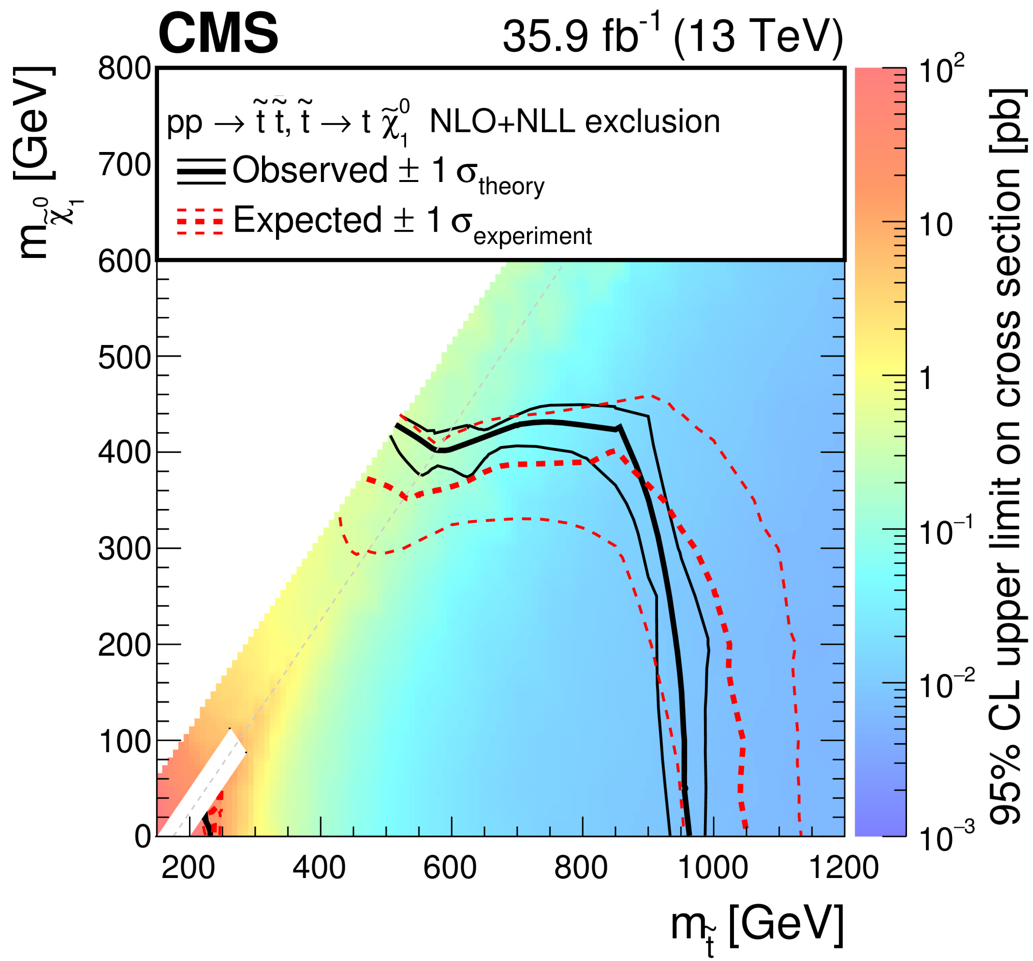




In each bin, each main background is predicted separately from control sample(s) in the data that is (are) dominated by that background.

Jets + p_T^{miss} search: example interpretations





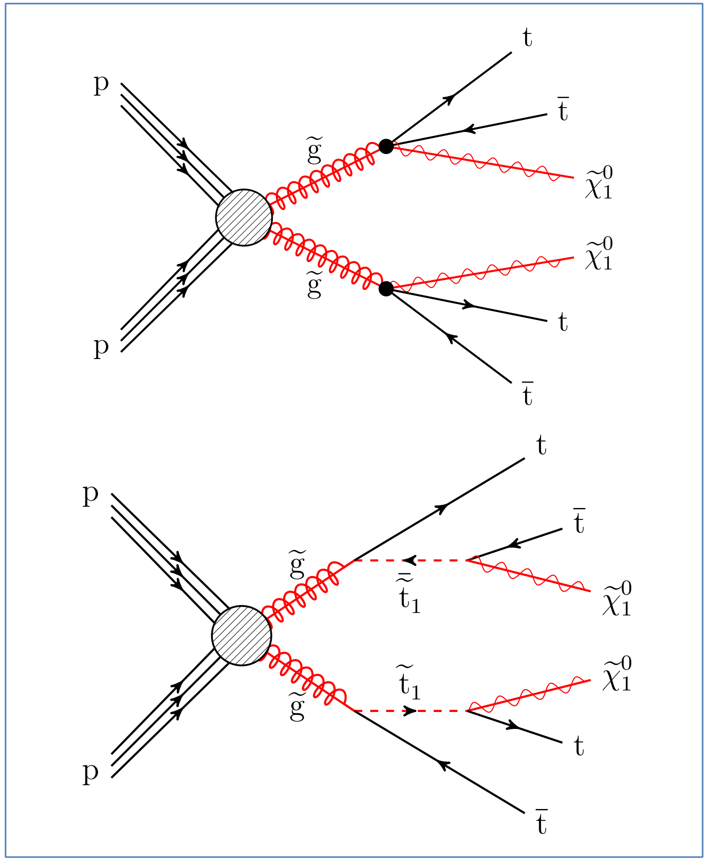
Color map shows the excluded cross section (95% CL)
Comparison of this cross section with a theoretical reference cross section for the signal gives the boundary of the excluded model points.

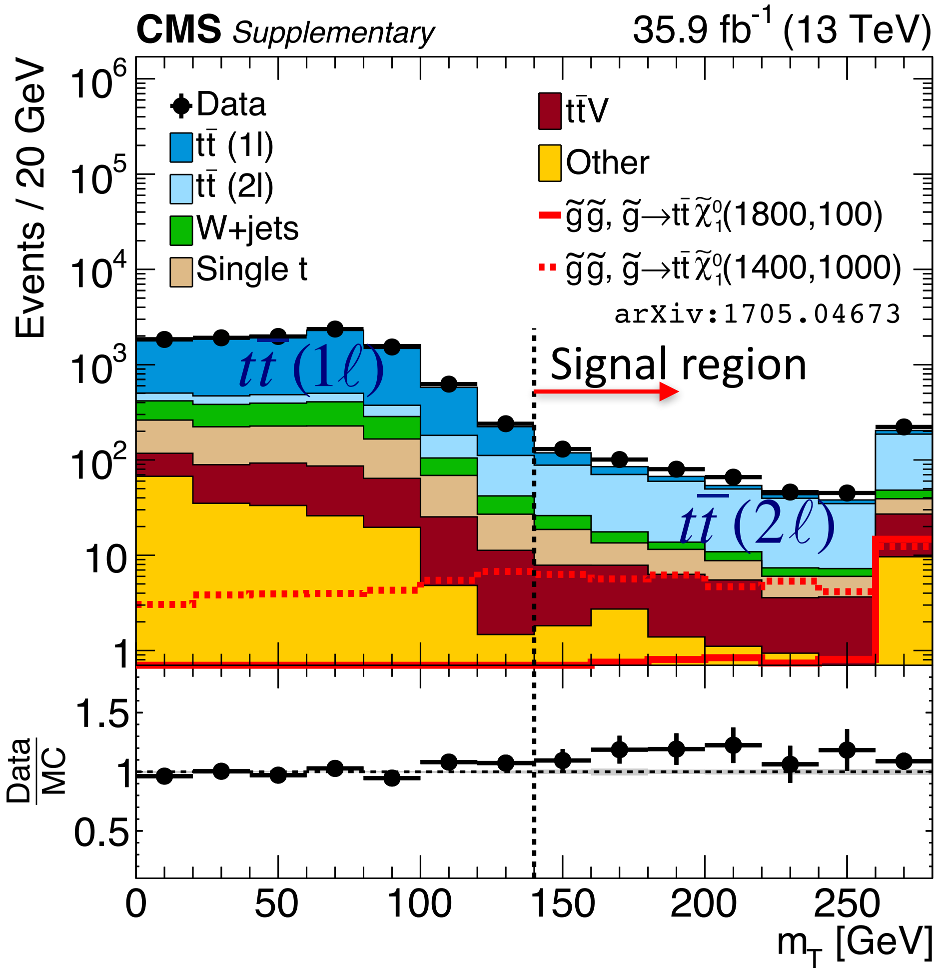
Many more interpretations available at
http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS-16-033/index.html

Single-lepton + (b)-jets + p_T^{miss} search

Search targets processes prominent in natural SUSY models.

$$m_T = \sqrt{2 p_T^{\ell} p_T^{\text{miss}} \left[1 - \cos(\varphi_\ell - \varphi_{p_T\text{miss}})\right]}$$





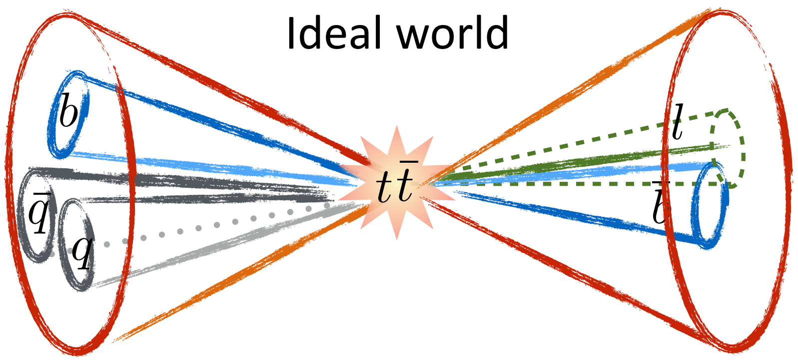
https://arxiv.org/abs/1705.04673

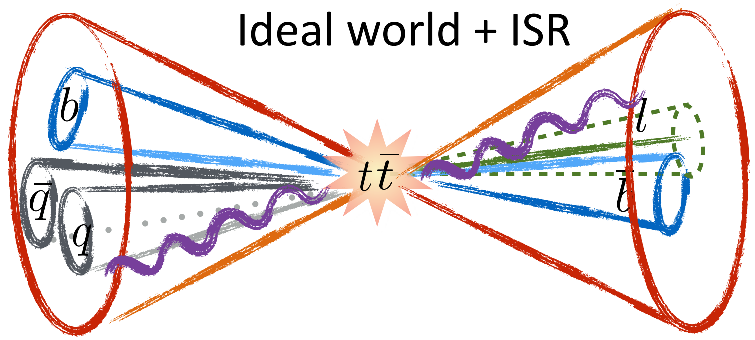
- Single-lepton events capture ~40% of the signal.
- Can strongly suppress 1-lepton ttbar and W+jets with cut on transverse mass of lepton-pTmiss system.
- High jet multiplicity suppresses 2-lepton ttbar; but is still background with ISR!

Single-lepton search: large-R jets and Initial State Radiation

- Reconstruct large-radius jets *J* with R=1.2 rather than the usual R=0.4.
- Start from standard jets and apply clustering algorithm to them.

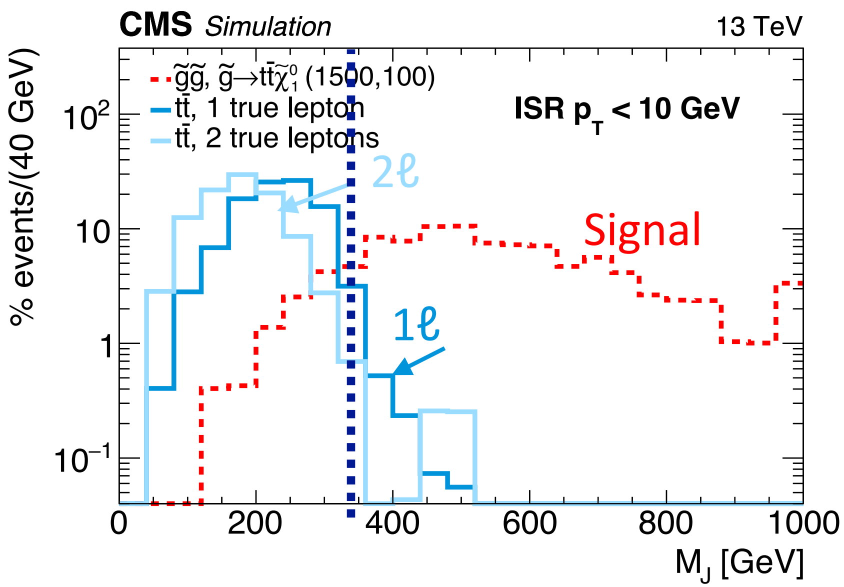
$$M_J = \sum_{\text{Large-}R\text{ jets}} m(J_i) \qquad R=1.2$$

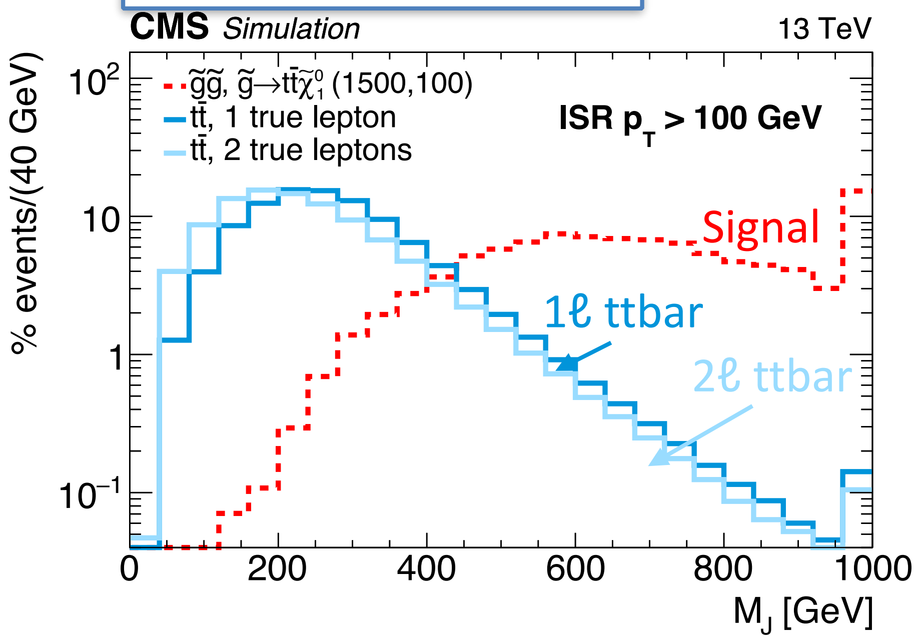




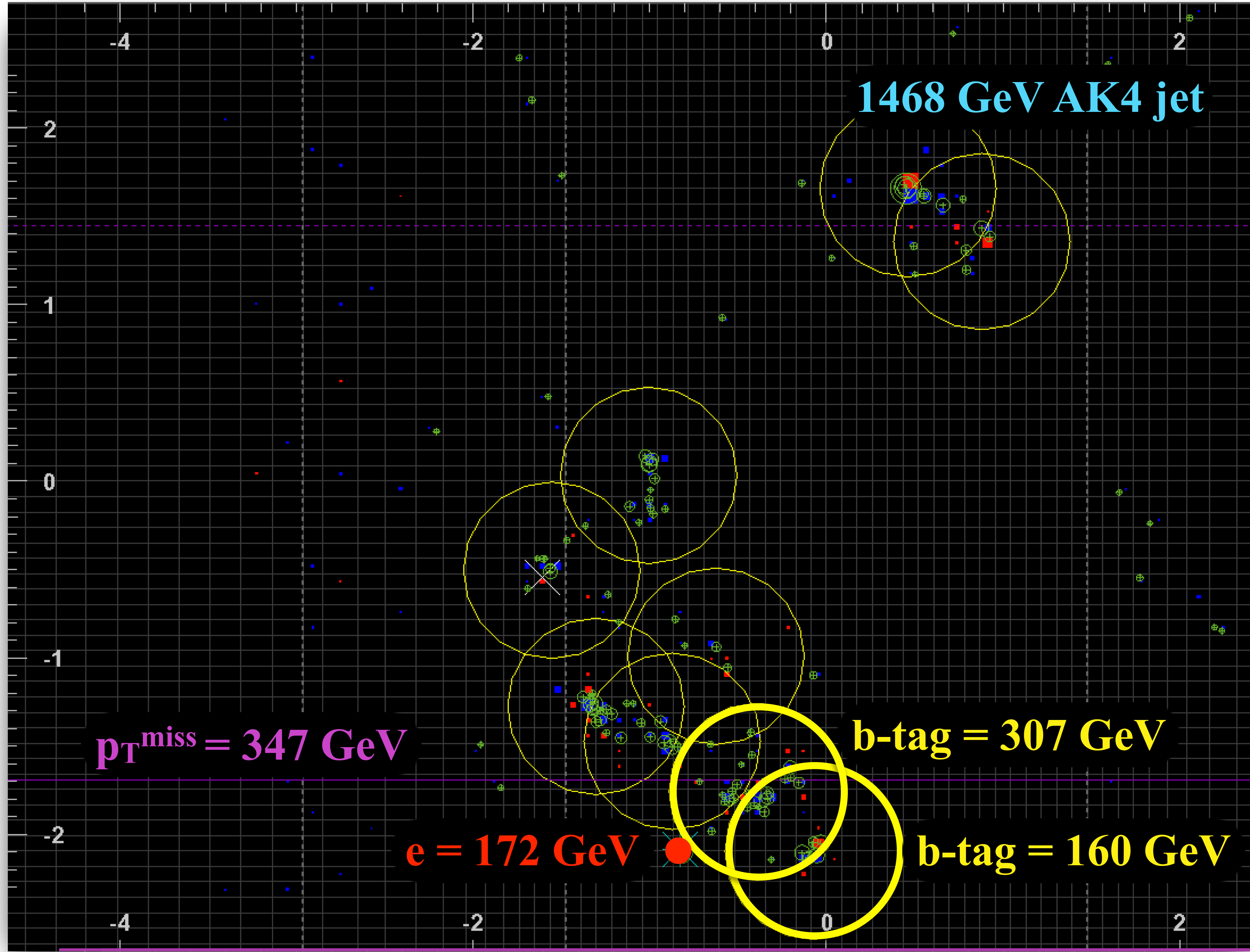
Low ISR: $p_T < 10$

High ISR: $p_T > 100$ GeV

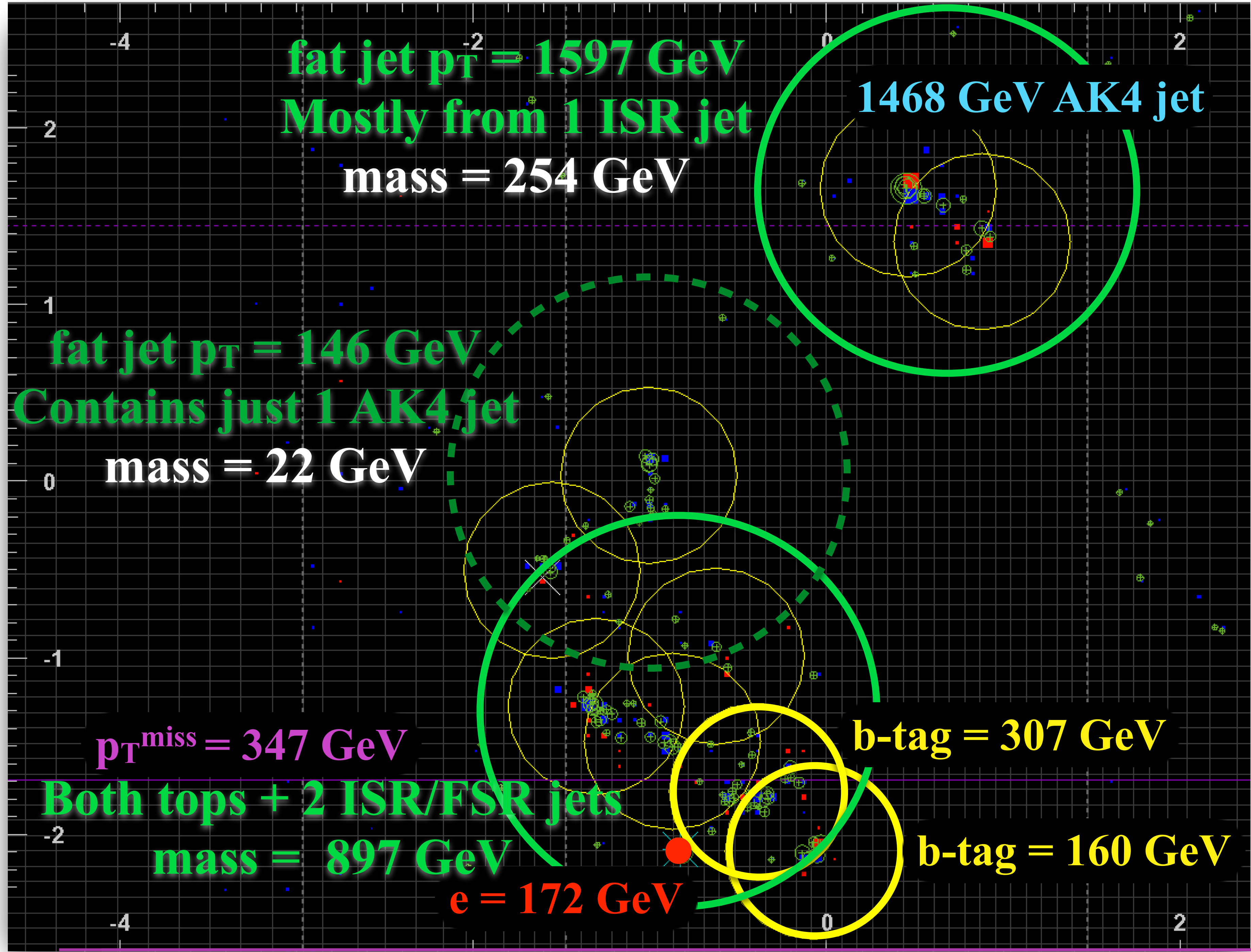




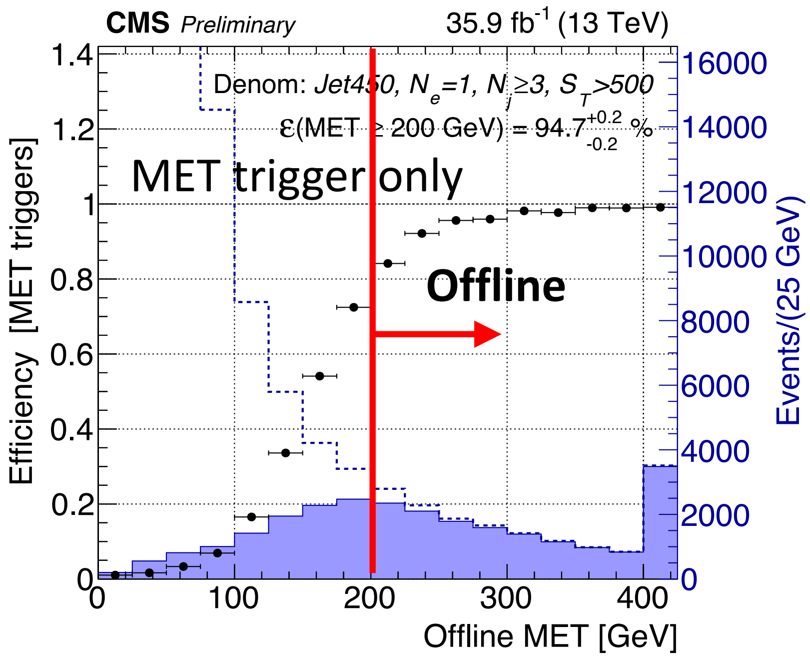
Event with 9 jets, 1 isolated electron, M_J = 1173 GeV

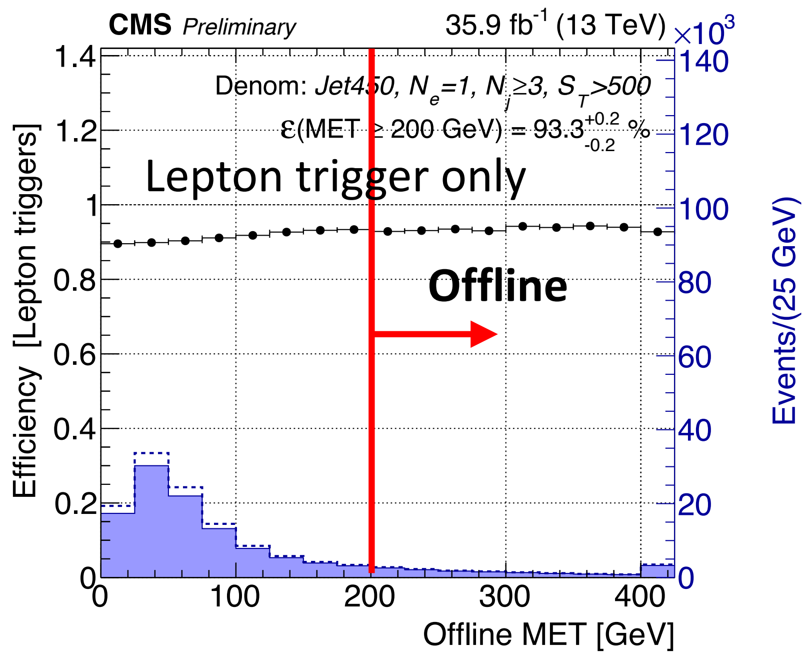


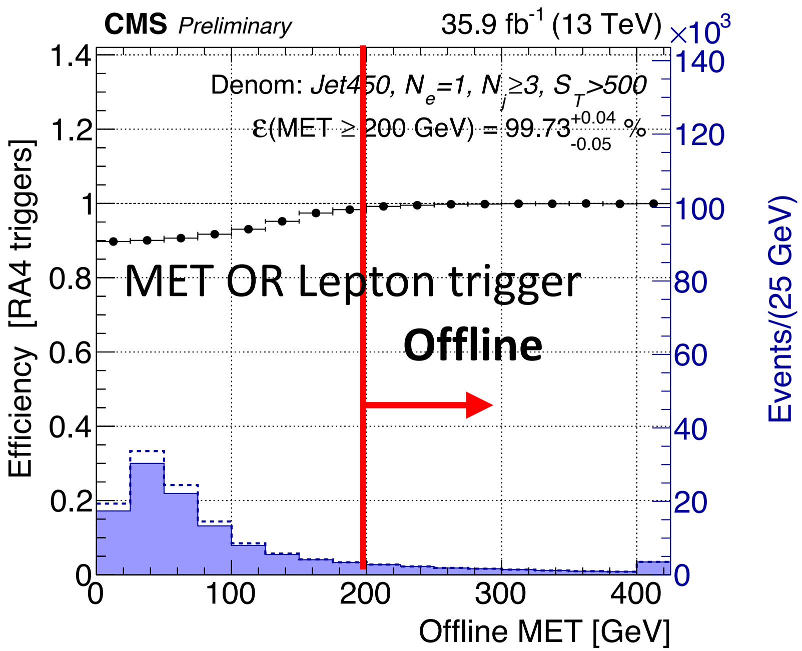
Event with 9 jets, 1 isolated electron, M_J = 1173 GeV

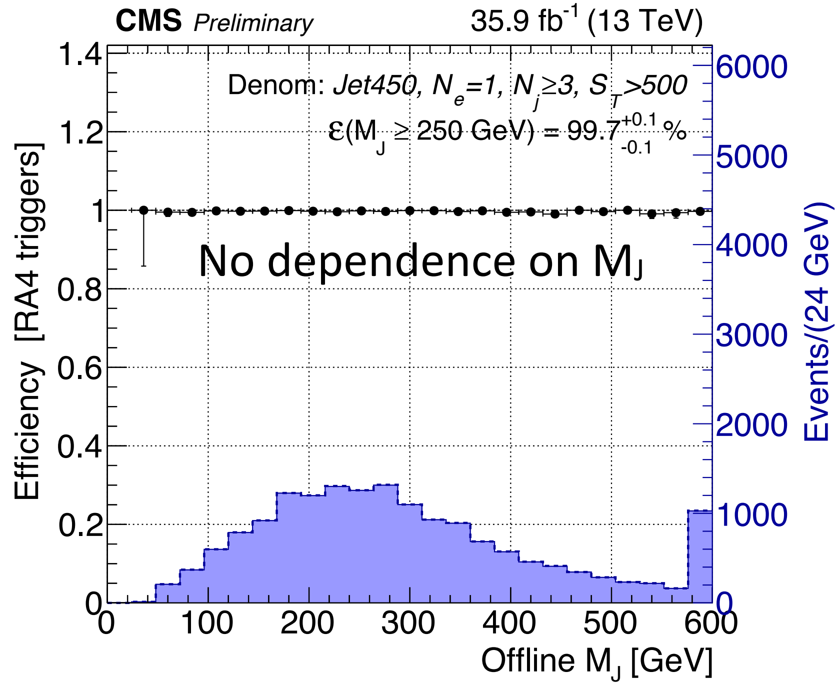


1 lepton + (b)-Jets + p_T^{miss}: trigger considerations







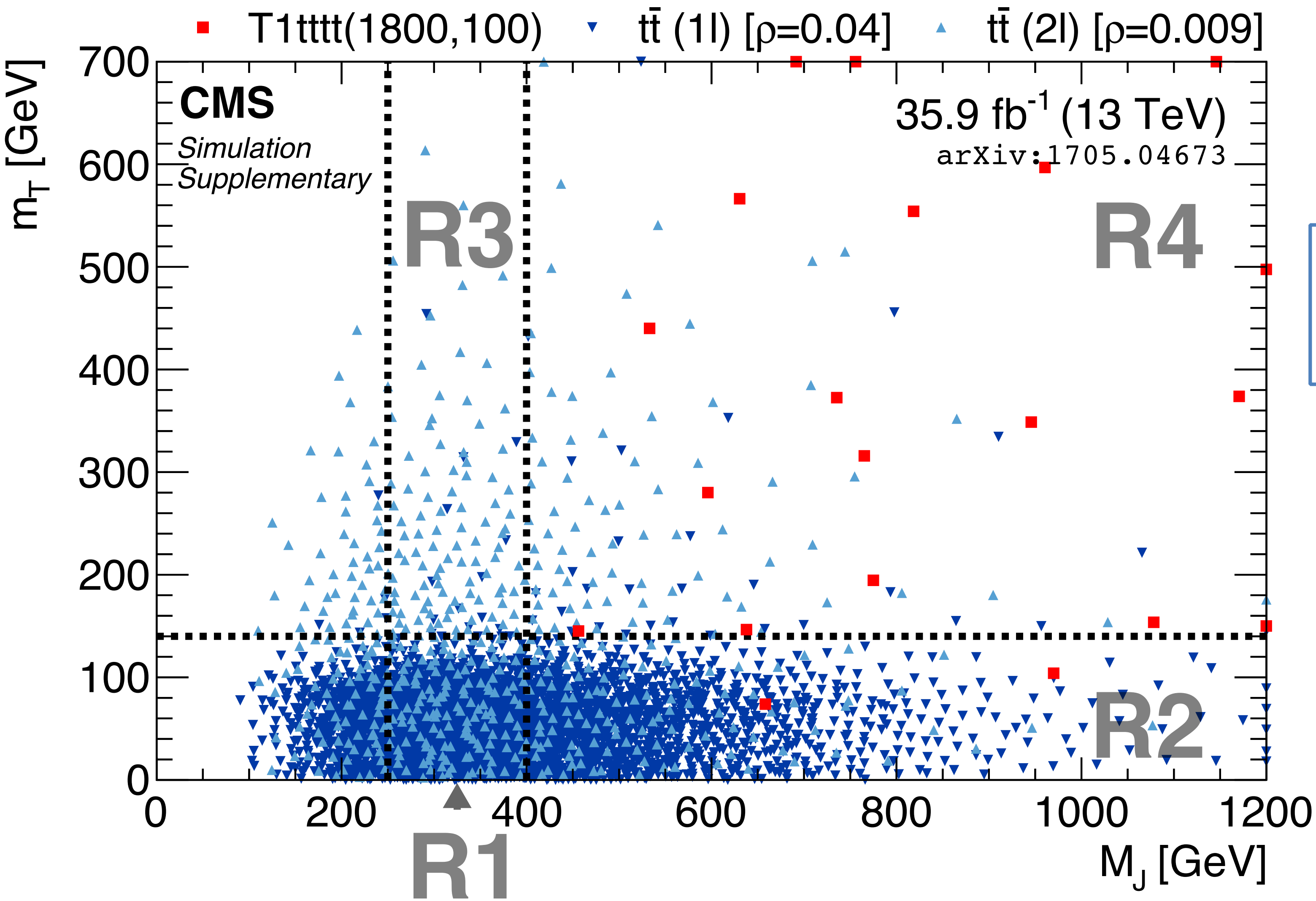


Single-lepton + (b)-jets + p_T^{miss} search

Baseline selection:

1 lepton (e or μ), pTmiss > 200 GeV, Njets ≥ 6, S_T > 500 GeV, $N_{\text{veto leptons}}$ =0

→ 80% of background is ttbar



Basic idea for background estimation

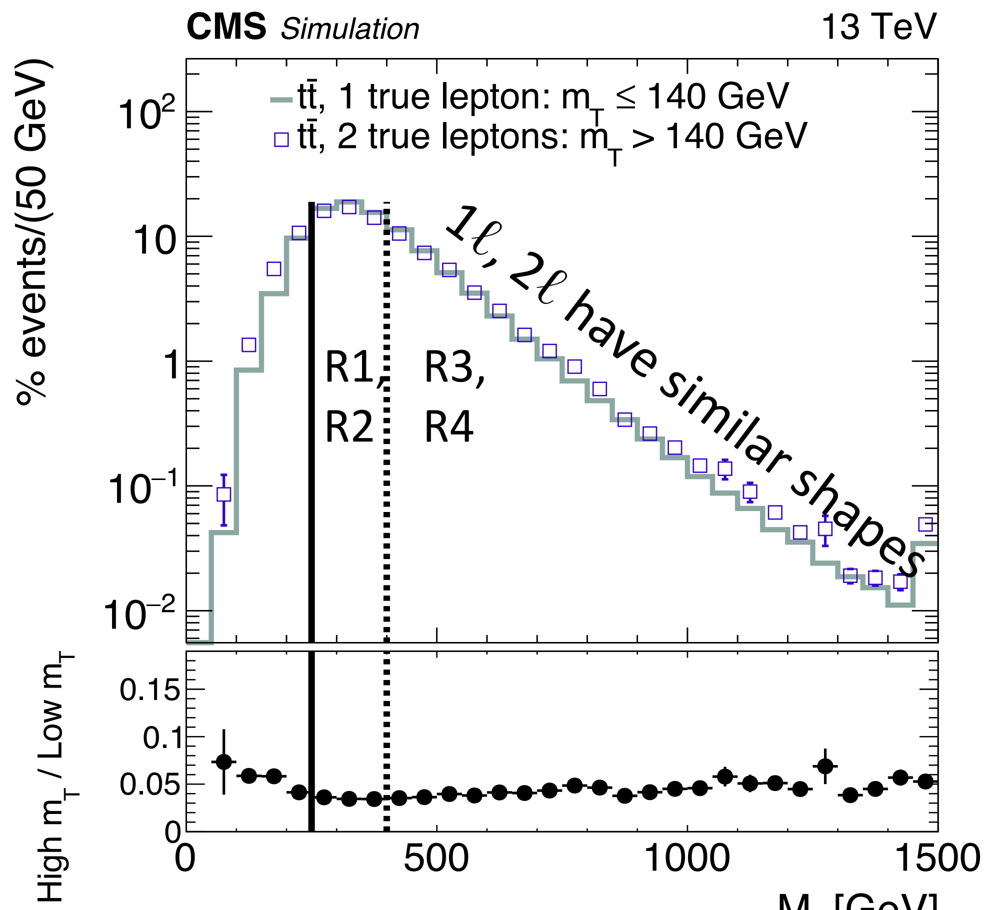
$$\mu_{\text{R4}}^{\text{back}} \simeq N_{\text{R3}} \cdot \frac{N_{\text{R2}}}{N_{\text{R1}}}$$

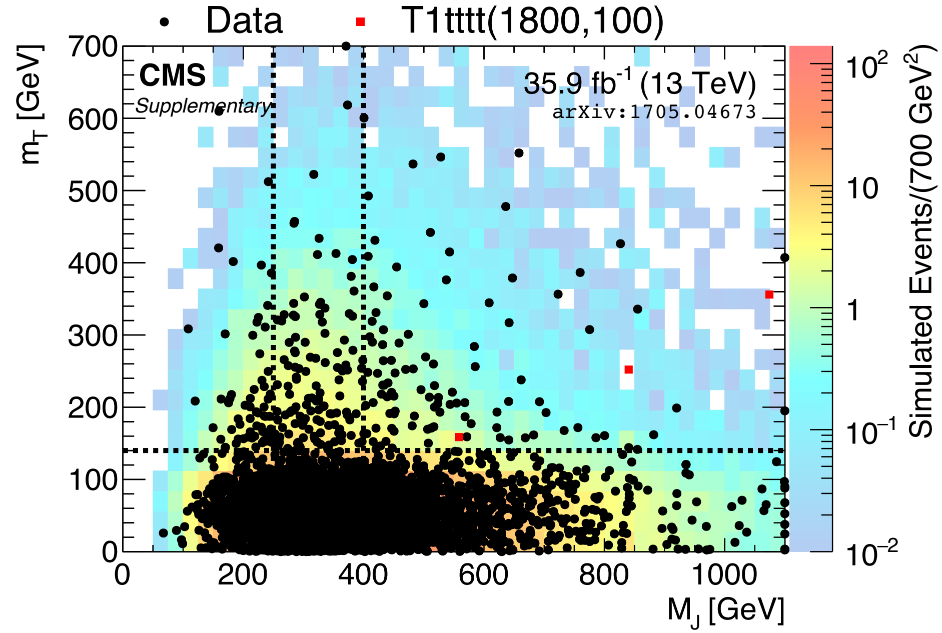
In practice,

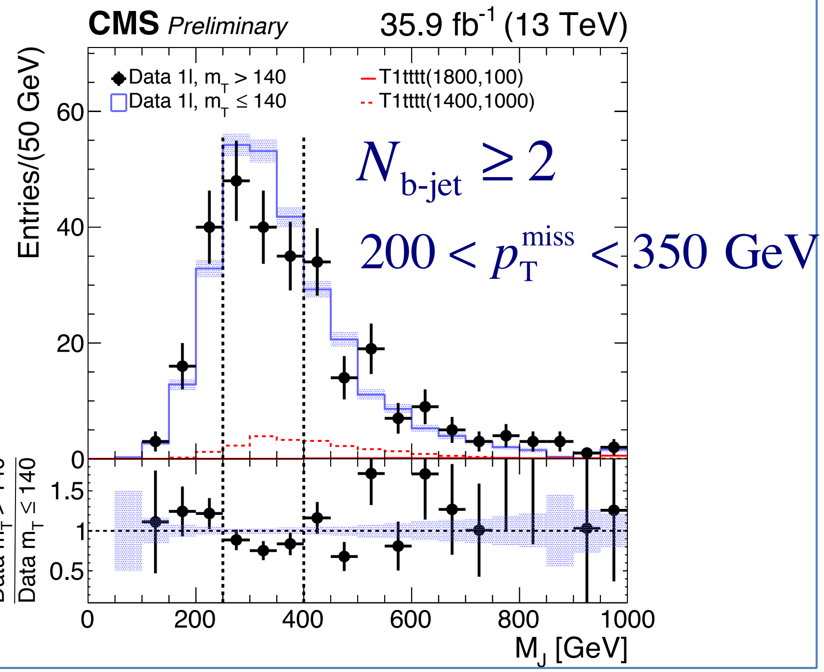
- Incorporate this into a fit that allows for signal contamination in R1, R2, and R3.
- Apply MC correction to account for small residual correlation.

Single-lepton + (b)-Jets + p_T^{miss} search

Comparison of MJ shapes in simulation: ttbar 1ℓ with low m_T vs. ttbar 2ℓ at high m_T. Shapes are very similar.





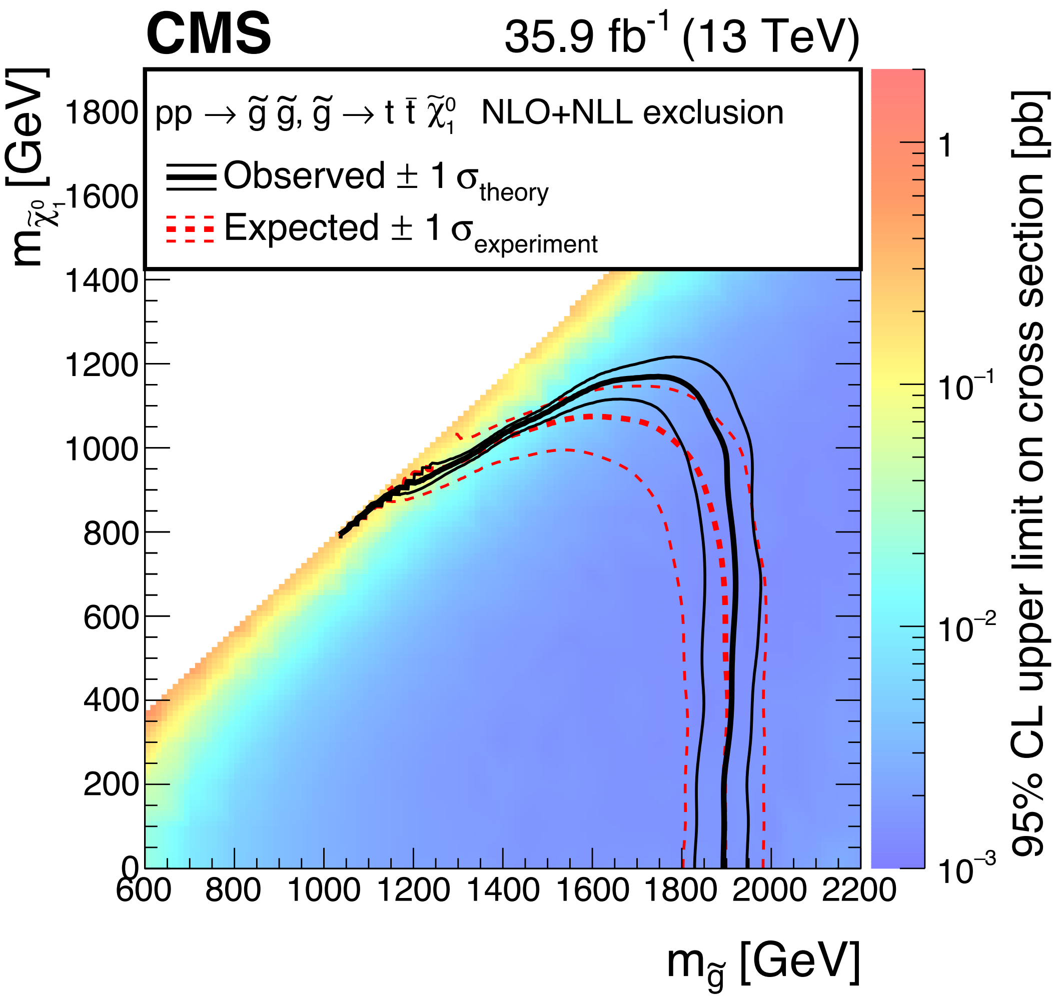


To improve the sensitivity, analysis is binned in Njets, Nbjets, and pTmiss.

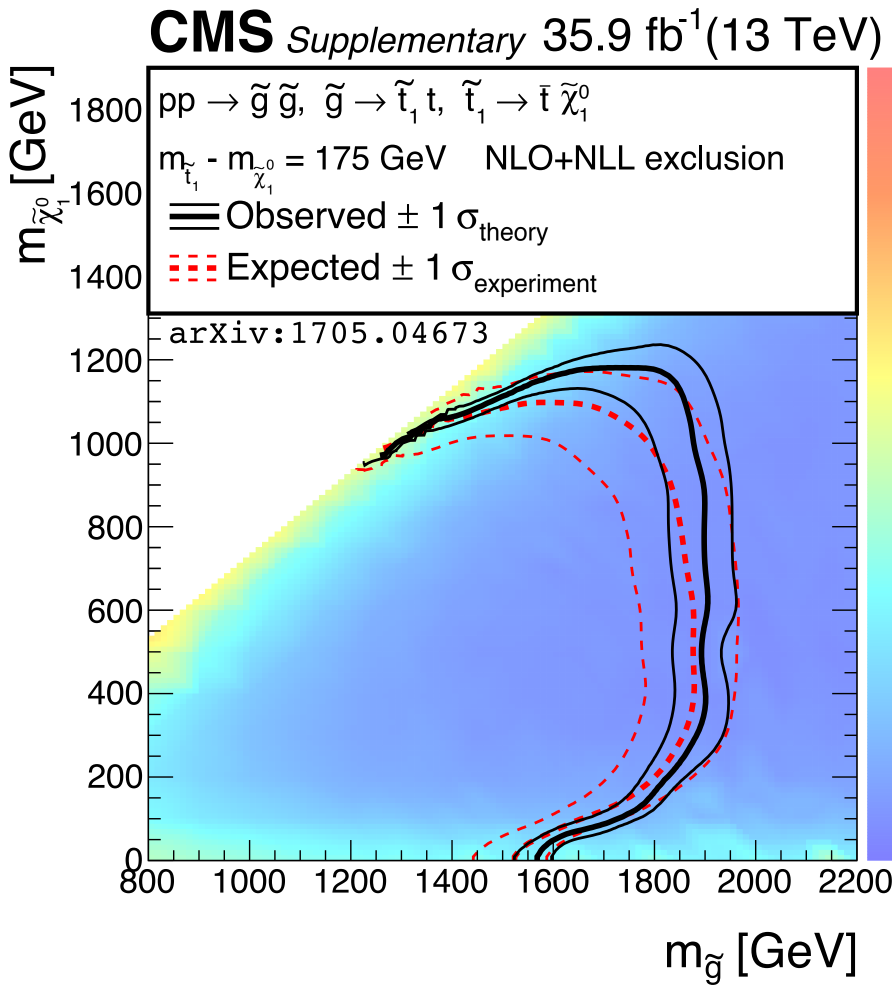
Single-lepton + (b)-Jets + p_T^{miss} search

No significant excess is observed in data → set limits on gluino pair production with decays to top squarks.

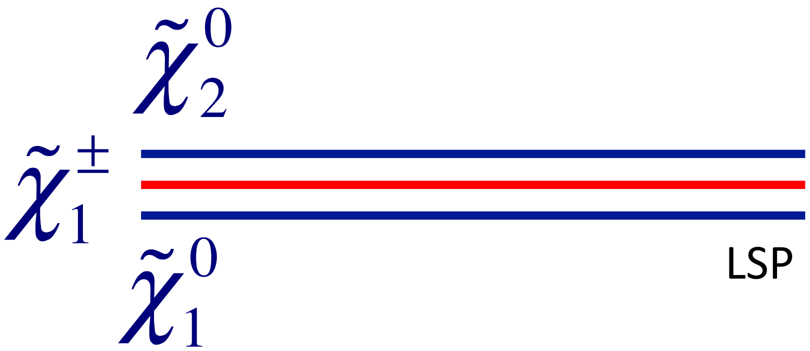
3-body gluino decays



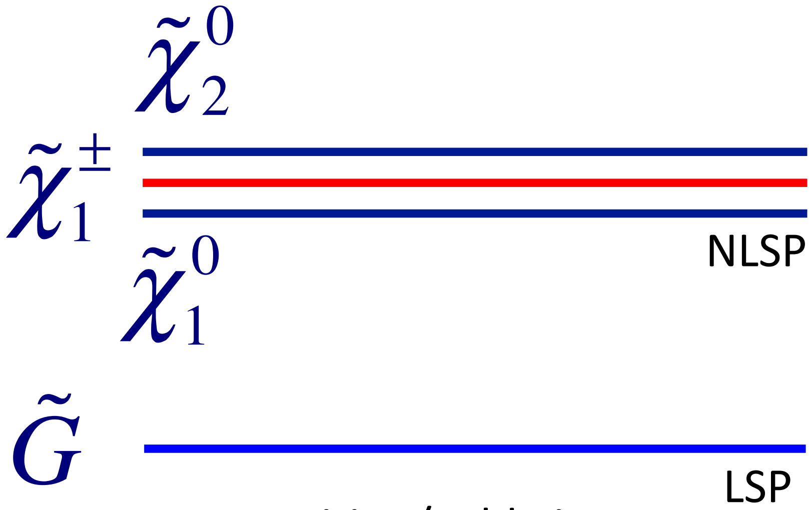
2-body gluino decays



Higgsino search in GMSB SUSY models

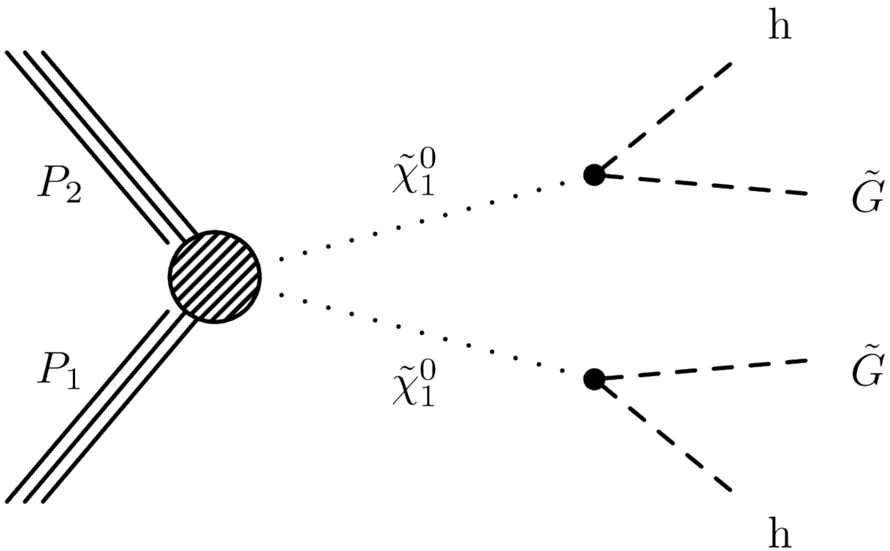


scenario in gauge-mediated SUSY breaking



Small mass splitting implies that decay products are very soft and the LSP does not carry much p_T^{miss}

gravitino/goldstino - Goldstone particle from SUSY breaking - very light in GMSB models



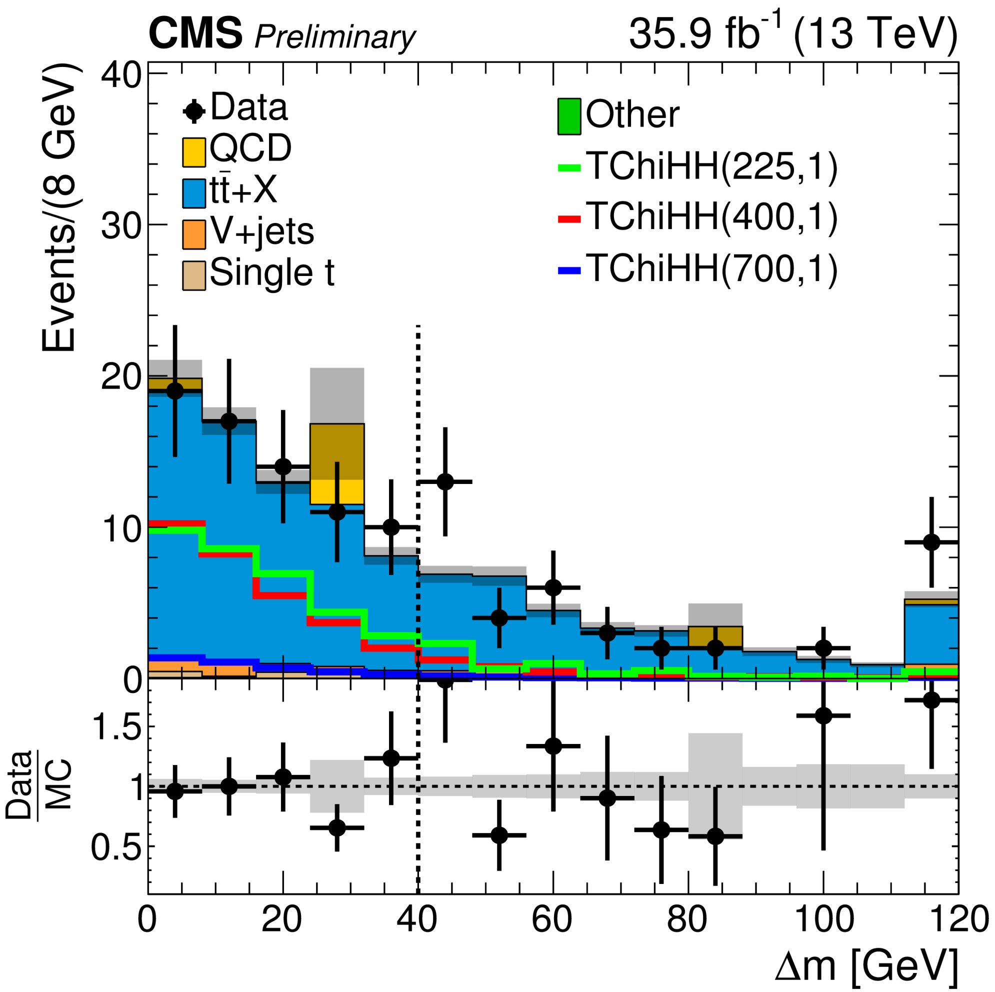
$$\tilde{\chi}_i\tilde{\chi}_j \rightarrow H\tilde{G}H\tilde{G} \rightarrow HH + p_T^{miss}$$

$$\rightarrow H(b\bar{b})H(b\bar{b}) + p_T^{miss}$$

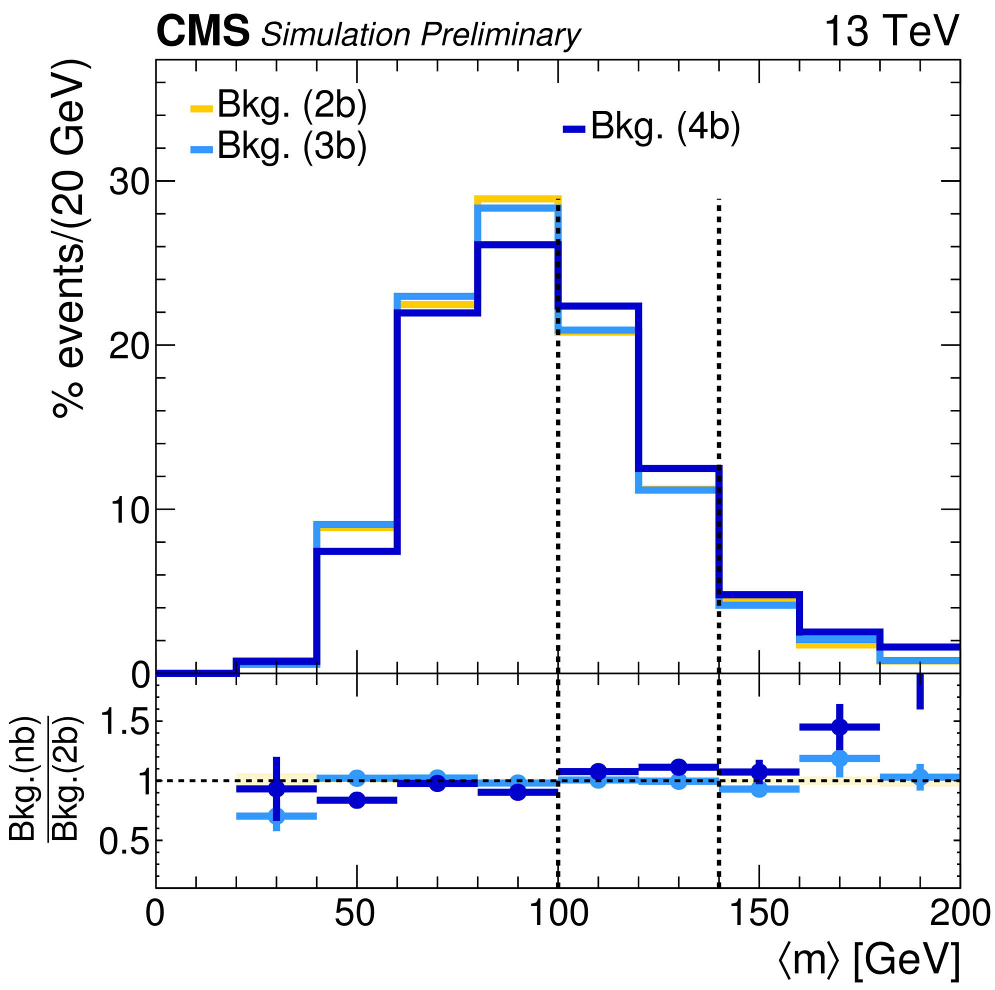
A SUSY signature with mass peaks!

Higgsino search in GMSB SUSY models

- Require 4-5 jets, ≥3 b-jets, pTmiss > 150 GeV, no leptons.
- Additional kinematic cuts to suppress ttbar.
- b-jets: find the pairs that minimize Δm between the two Higgs. candidates and require Δm < 40 GeV.

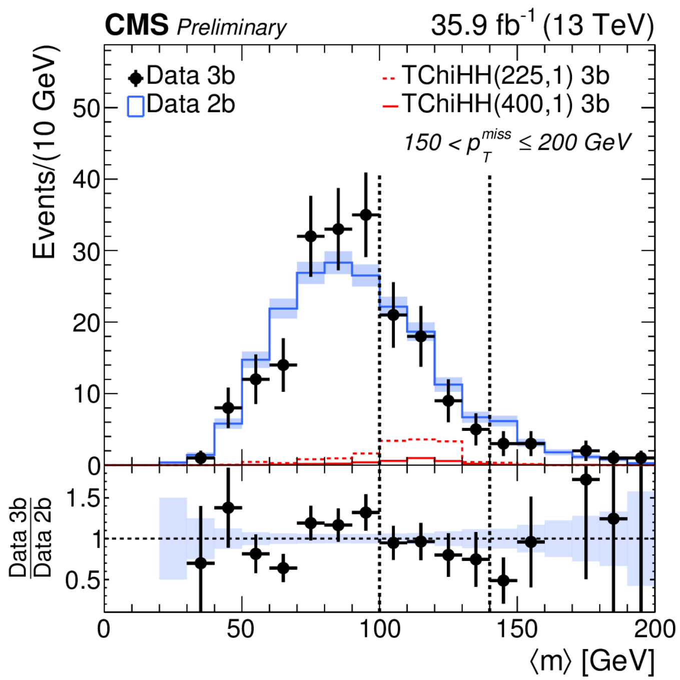


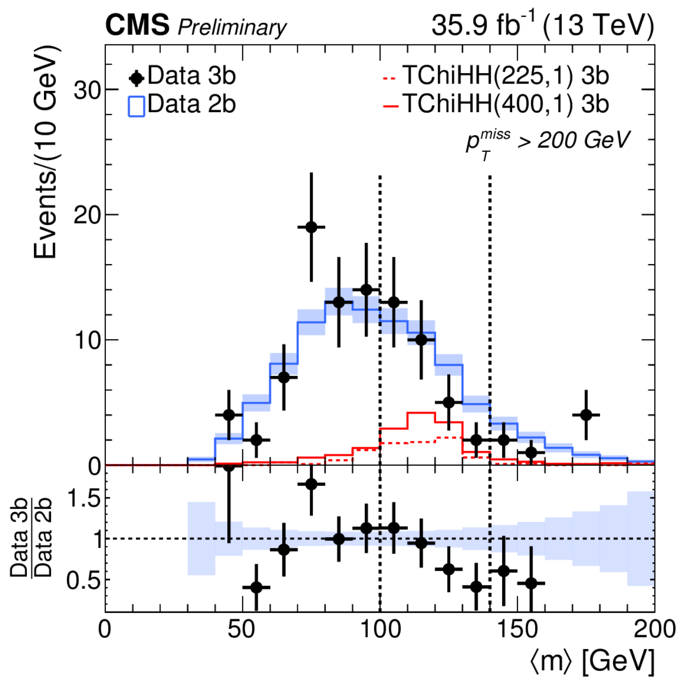
Background shape independent of N_b

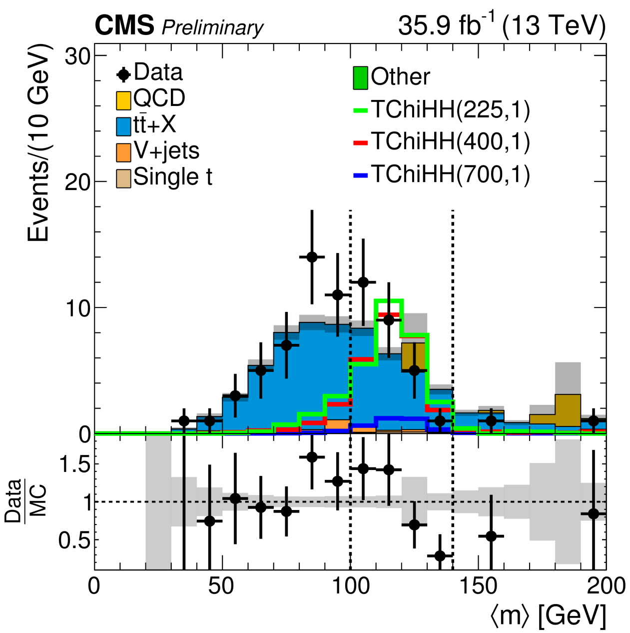


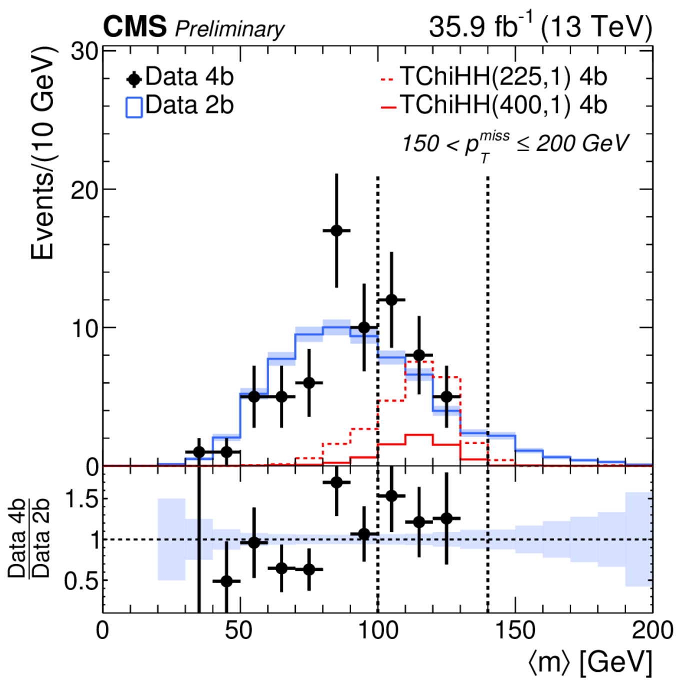
Higgsino search in GMSB SUSY models

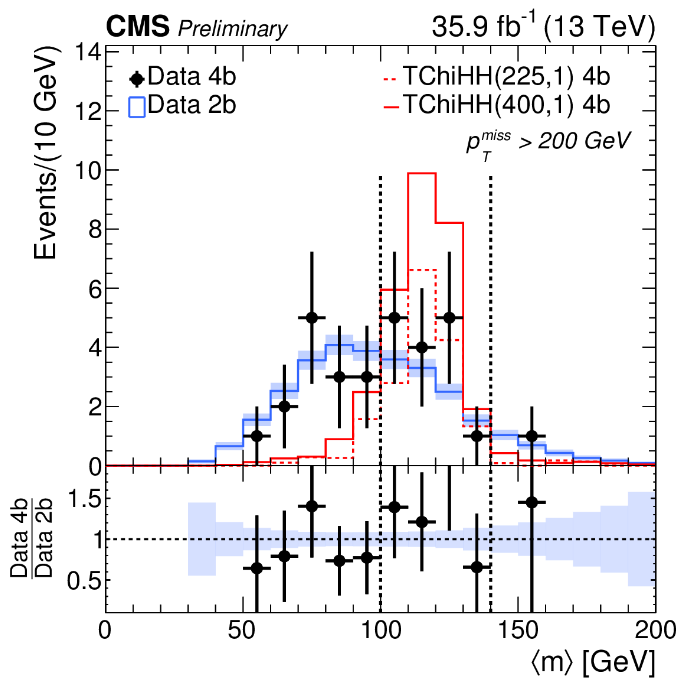
- Use 2 b-jet sample to obtain background shape.
- Normalize to m(H) sidebands in 3 b-jet and 4 b-jet samples.
- No MC correction needed.



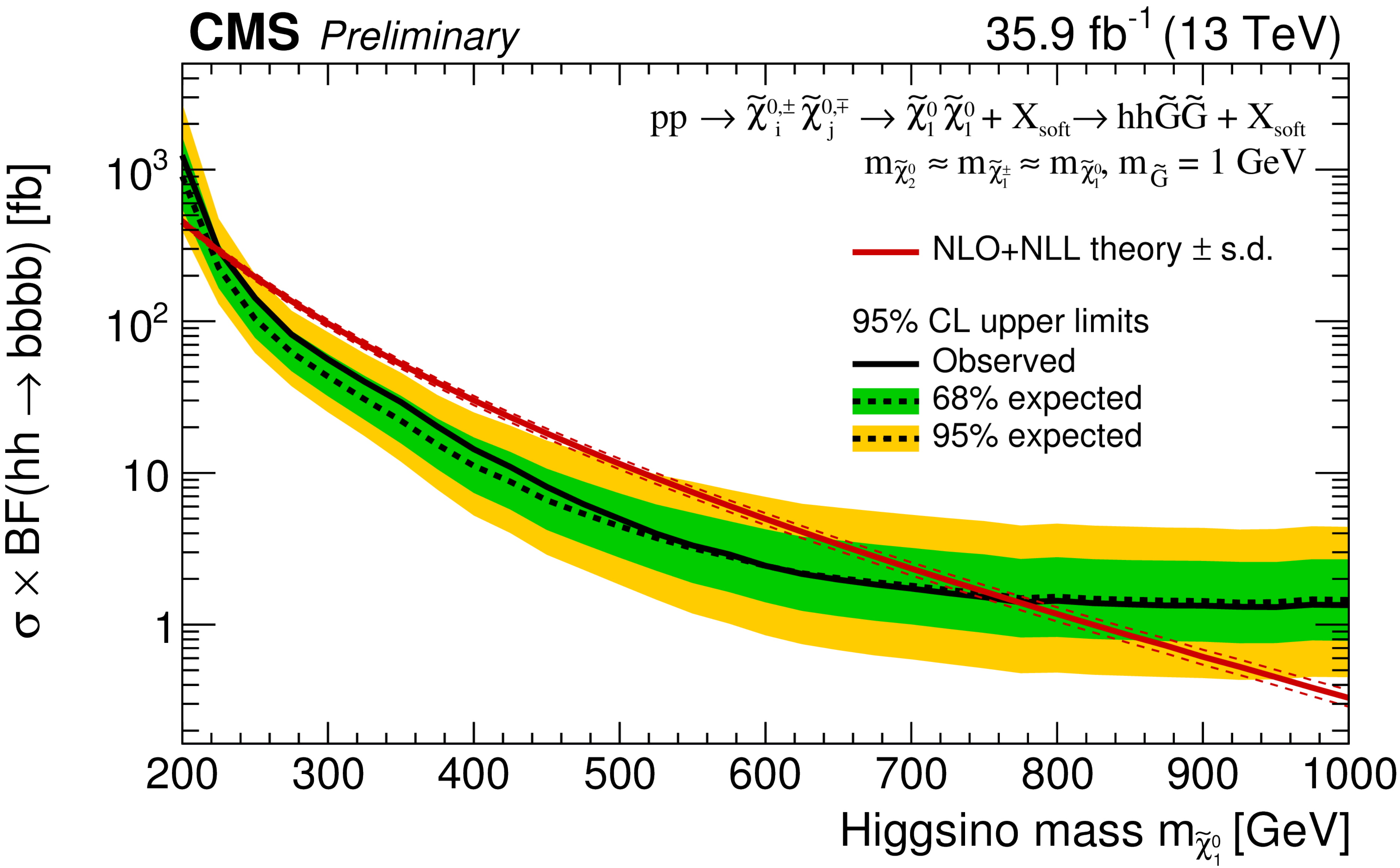






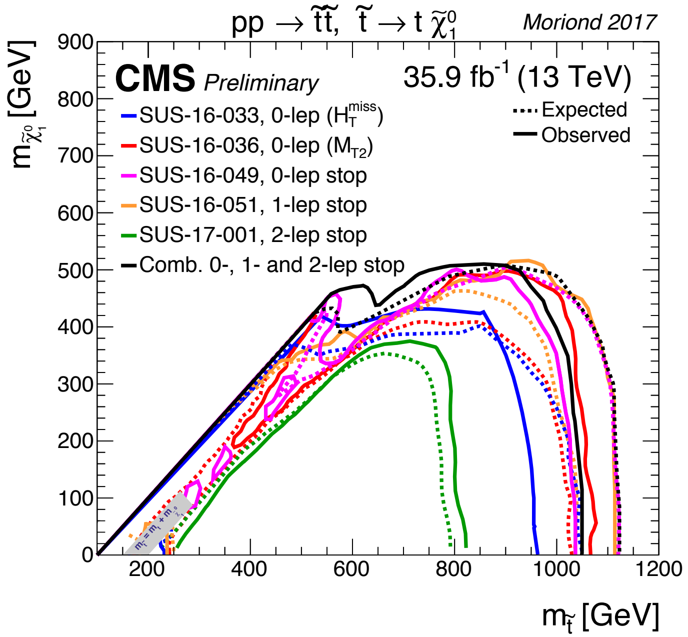


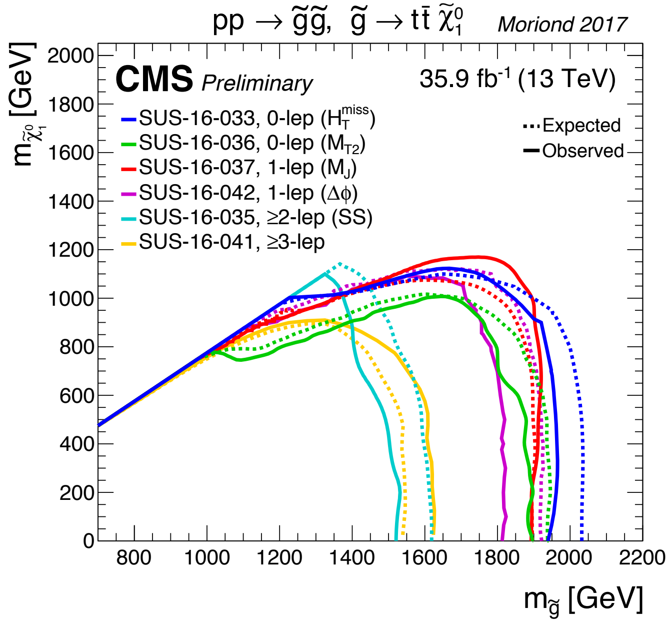
Higgsino search in GMSB SUSY models

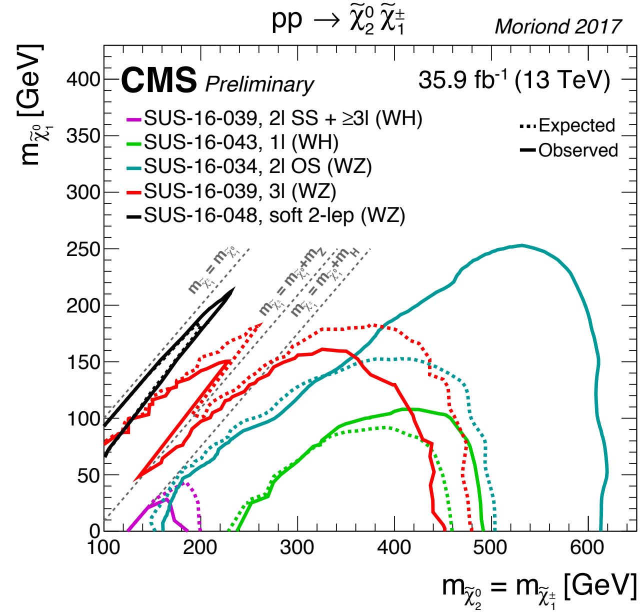


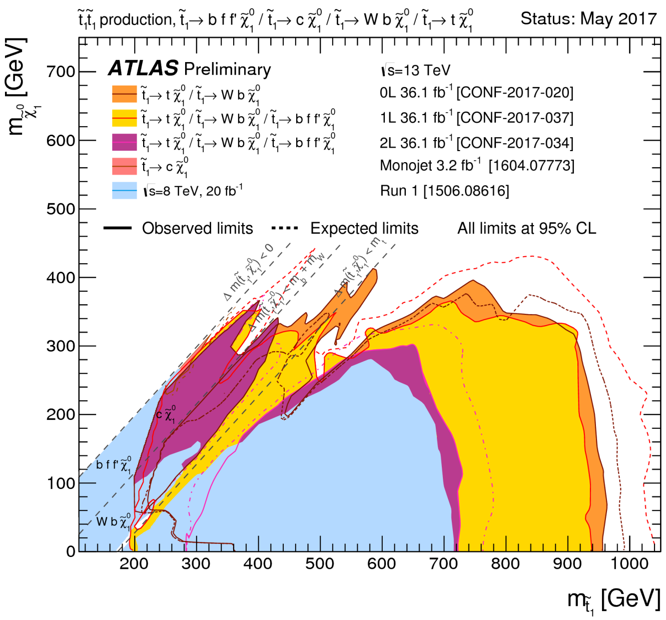
Excludes Higgsinos in mass range 230-770 GeV.

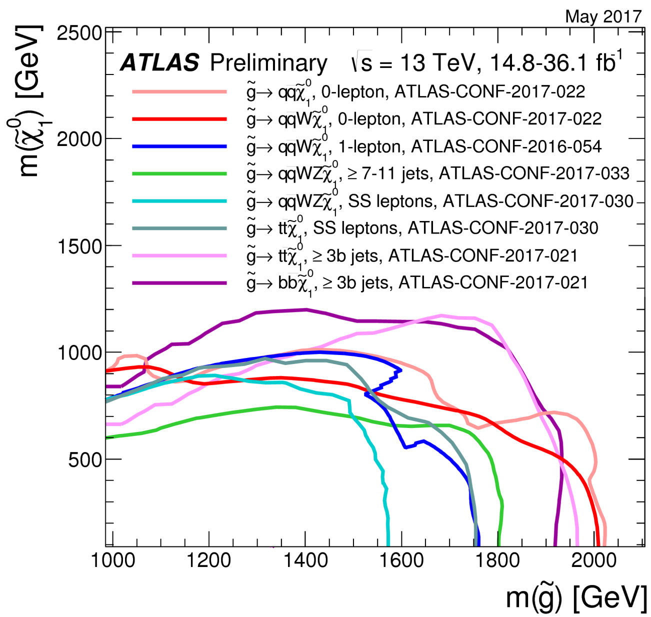
A lot of spaghetti, but no signals…

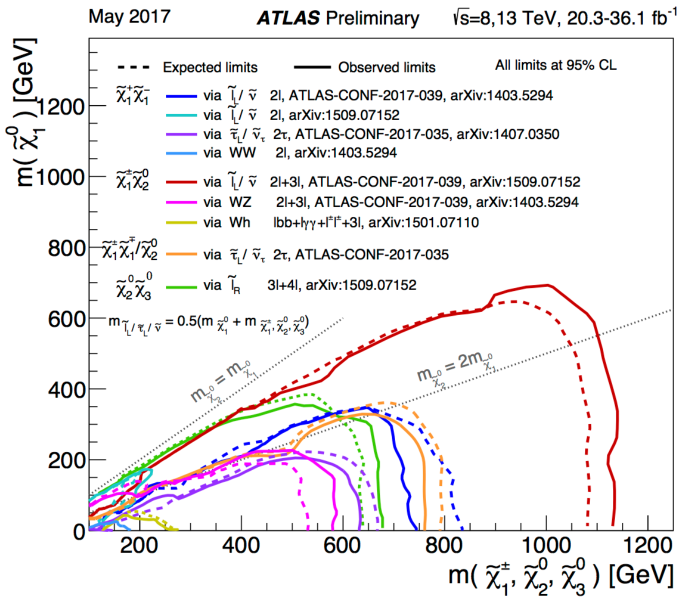




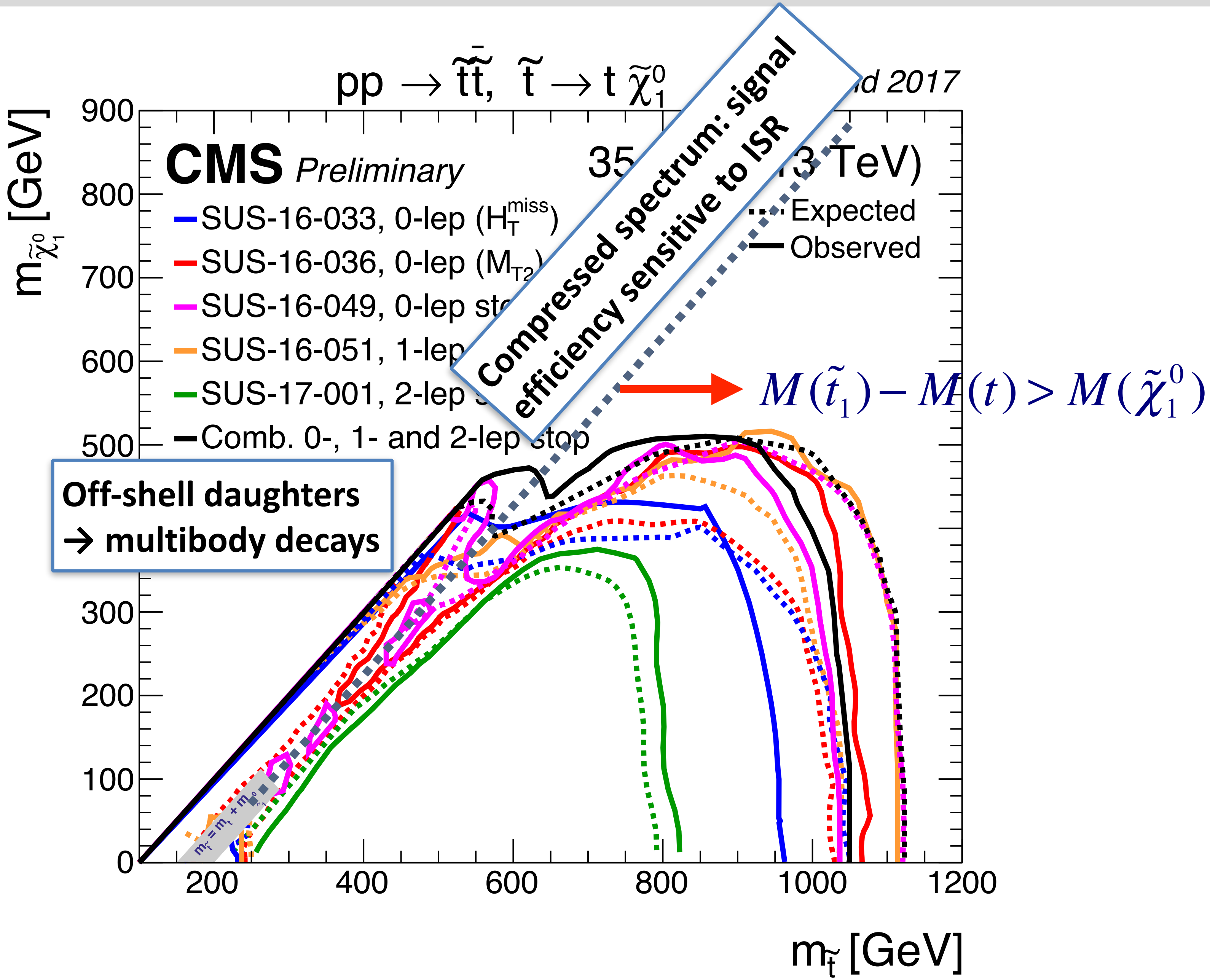




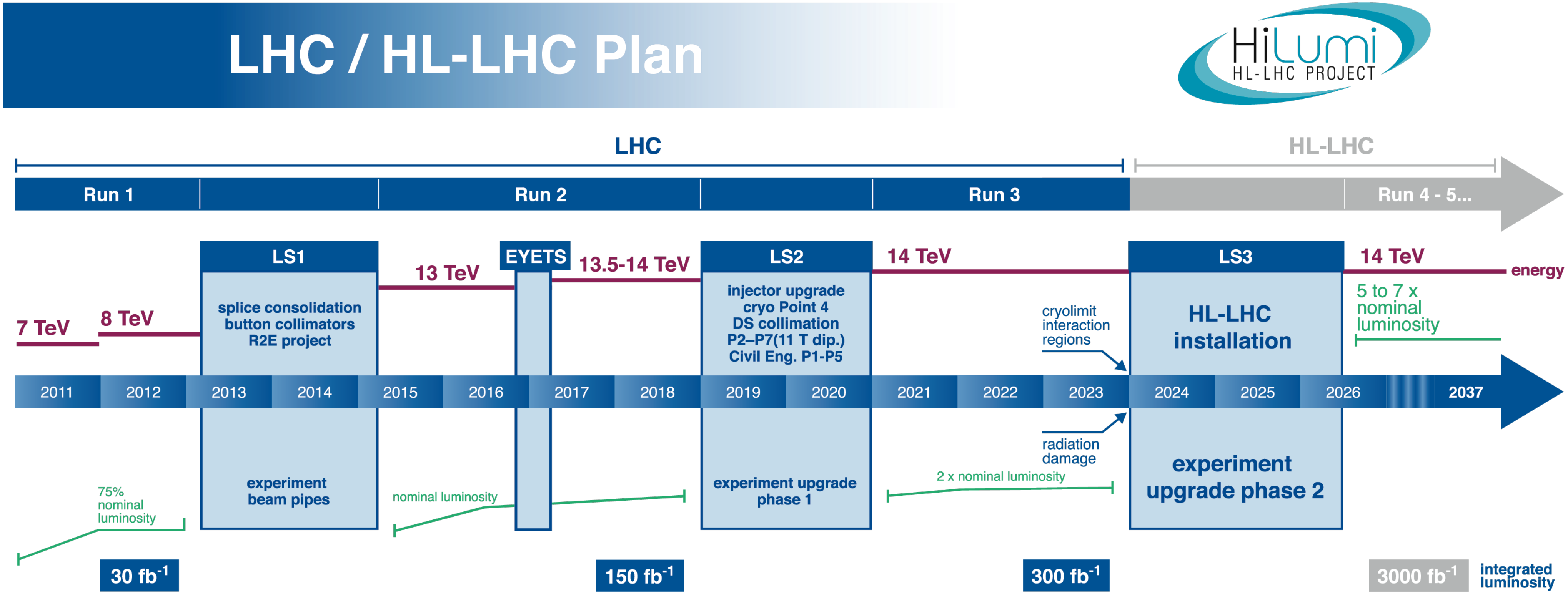




Exclusion limits on top squark pair production



LHC timeline



Conclusions and prospects

- Early Run 2 searches have already significantly extended the mass reach for strongly produced SUSY particles.
- There is now considerable pressure on natural SUSY.
- But…
  - SUSY has many ways to hide. We have to keep looking.
  - significant assumptions used in obtaining our exclusion limits.
- If no significant excess is observed with ~300 fb^{-1}, the strongest discovery possibilities may be associated with EWK processes.
- Evidence of an excess event yield over the SM with ~300 fb^{-1} will open the door to an intensive HL-LHC program to illuminate the nature of the excess.
- We are at a relatively early phase in the exploration of the TeV energy scale. It took ~10^2 years to understand the 1 GeV scale!

History and a prediction

New York Times, January 5, 1993

January 5, 1993

315 Physicists Report Failure In Search for Supersymmetry

By MALCOLM W. BROWNE

Three hundred and fifteen physicists worked on the experiment.

Their apparatus included the Tevatron, the world's most powerful particle accelerator, as well as a $65 million detector weighing as much as a warship, an advanced new computing system and a host of other innovative gadgets.

New York Times, January 5, 2024

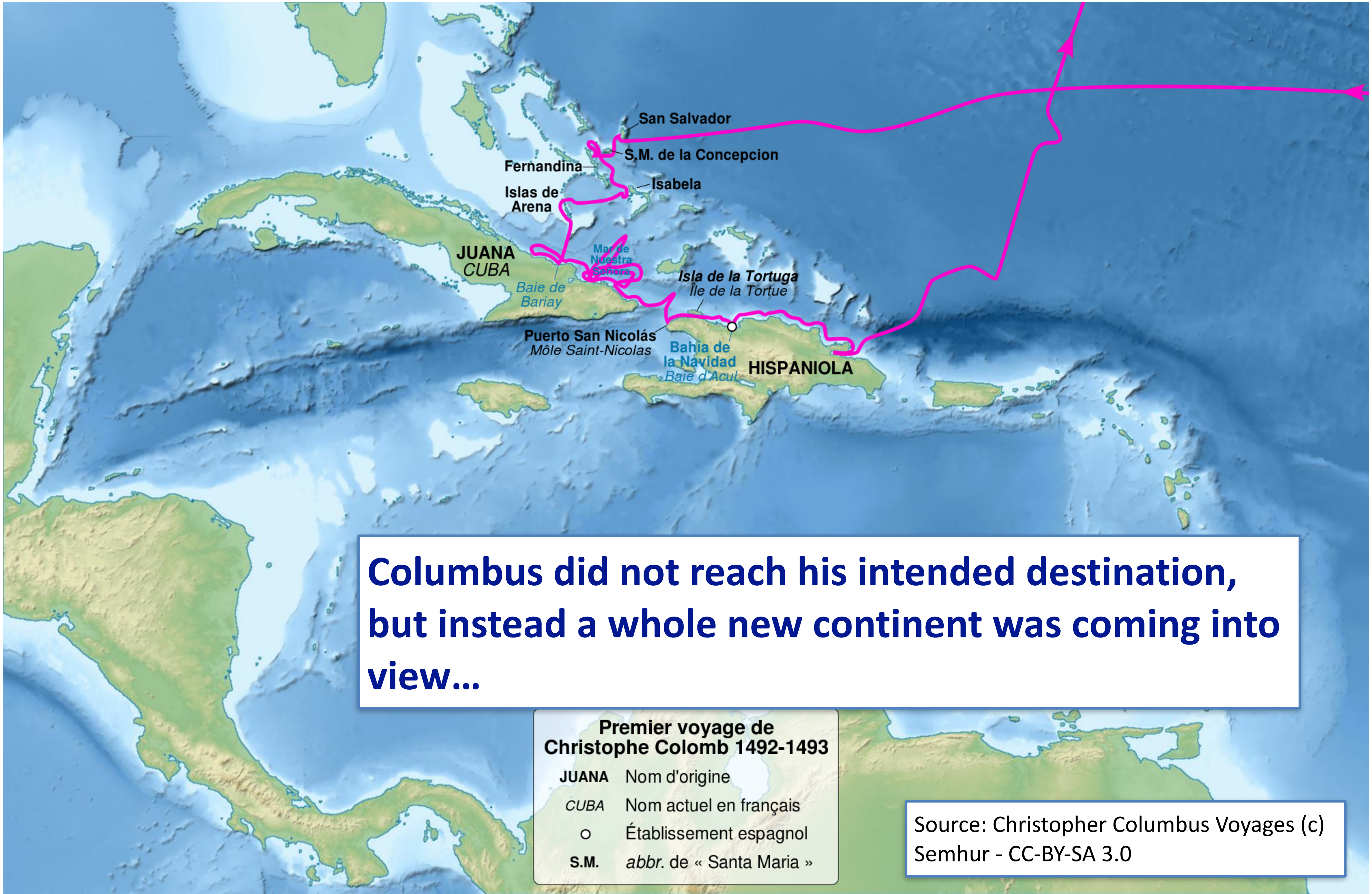
8,345 Physicists Report Discovery of Something But Aren't Exactly Sure What It Is

Eight thousand, three hundred and forty five physicists worked on two gigantic experiments, ATLAS and CMS.

Their apparatus included the Large Hadron Collider, the world's most powerful particle accelerator, as well as…

Backup slides

You can discover something and not know what it is

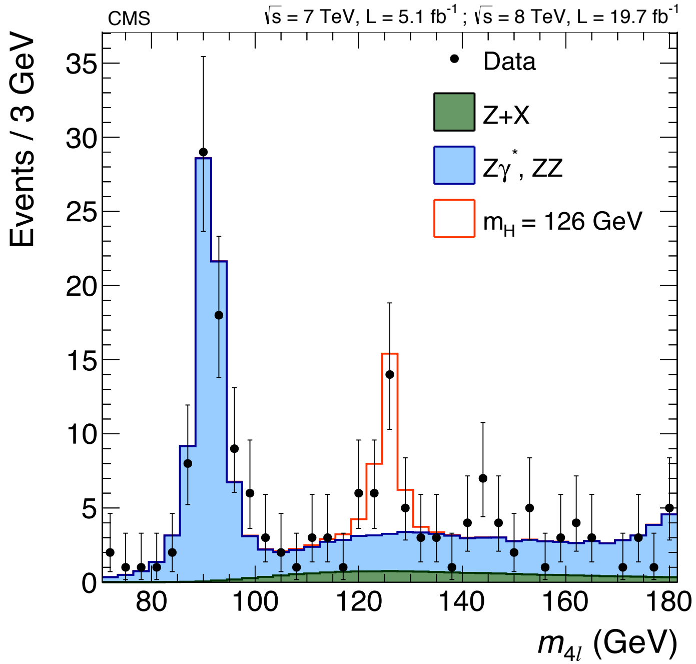


Columbus did not reach his intended destination, but instead a whole new continent was coming into view...

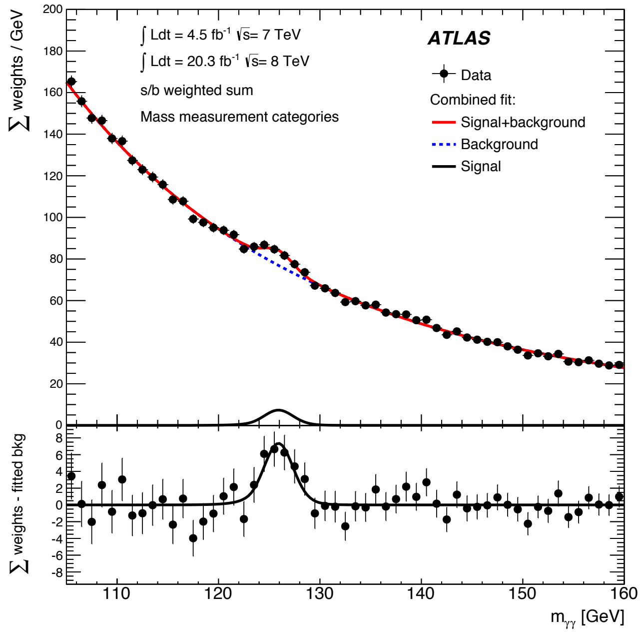
Source: Christopher Columbus Voyages (c) Semhur - CC-BY-SA 3.0

Perspective from Run 1

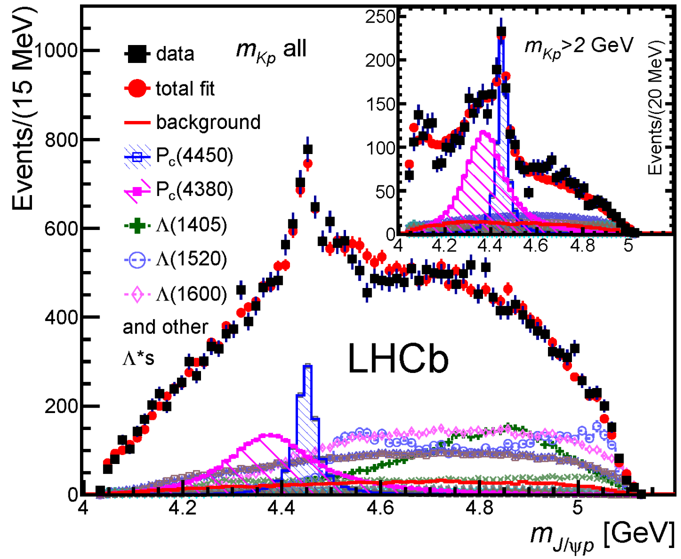
$H \to ZZ^*$



$H \to \gamma\gamma$



$\Lambda_b^0 \to K^- P_c^+(\bar{c}cuud);\ P_c^+ \to J/\psi\, p$

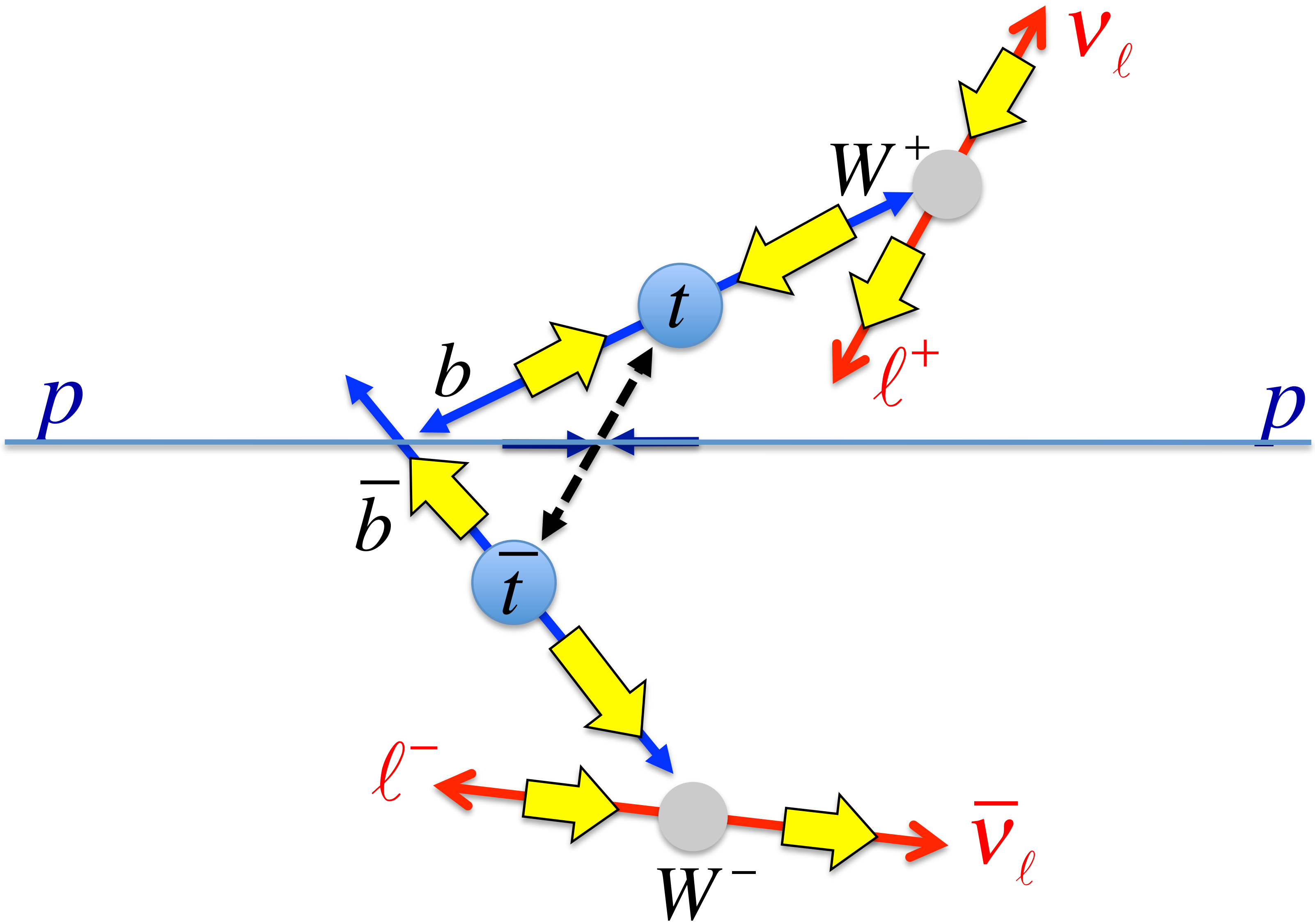


Phys. Rev. Lett. 115 (2015) 072001

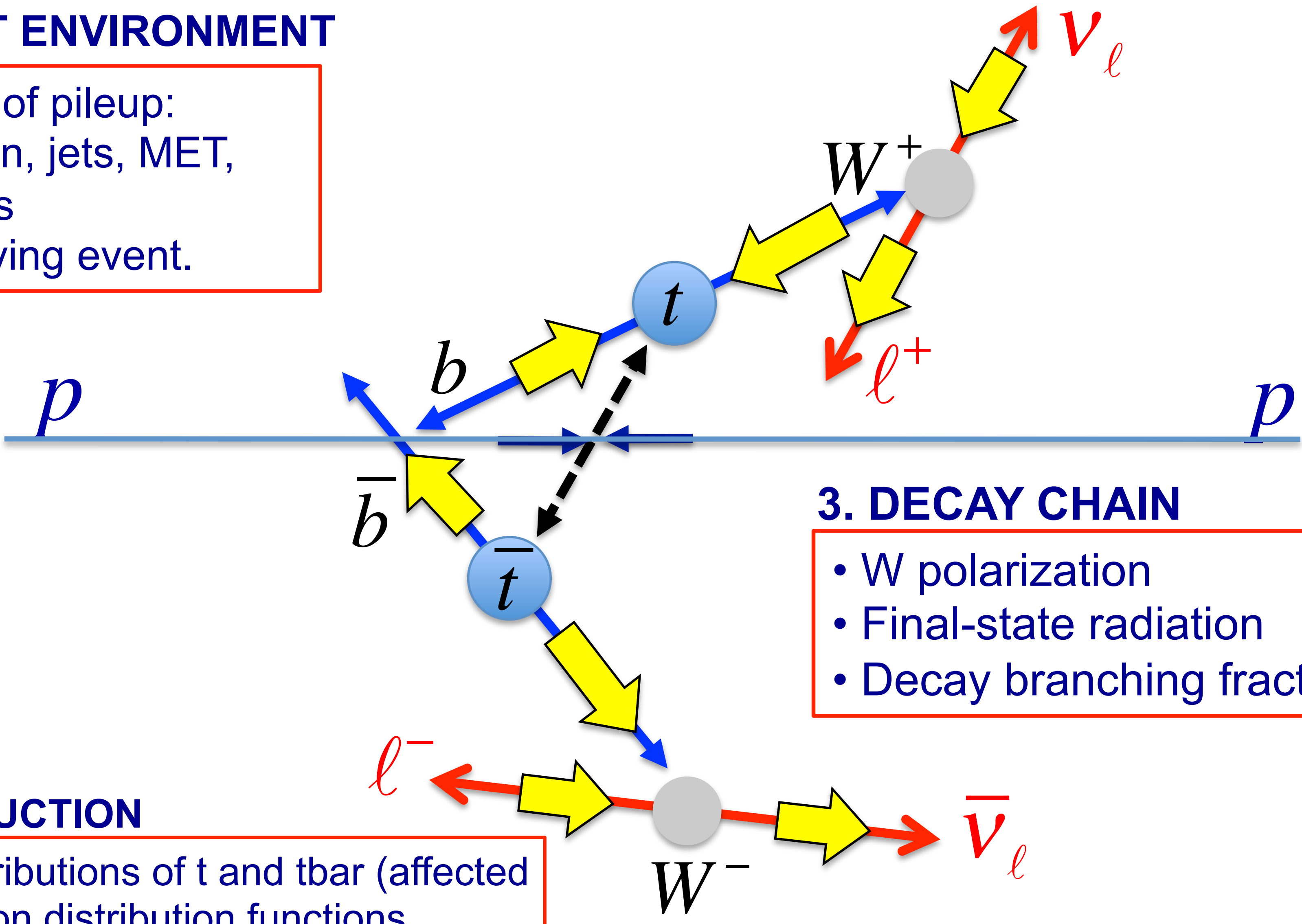
Rapid interpretation of Higgs discovery!

- Higgs discovery: strong evidence for our overall picture of EW symmetry breaking. **But the question of how the EW mass scale is stabilized against short-distance quantum corrections is now even more urgent.**
- LHC-b: Two charmonium-pentaquark states → **Still a lot to learn about the hadronic (~1 GeV) mass scale, 70 years after discovery of the pion.**
- **A guess: it will take at least as long to understand the physics of the EW scale.**

The most SUSY-like SM background: ttbar



The most SUSY-like SM background: ttbar



1. EVENT ENVIRONMENT

- Effects of pileup: isolation, jets, MET, vertices
- Underlying event.

2. PRODUCTION

- pT distributions of t and tbar (affected by parton distribution functions, QCD renorm & factorization scales)
- Effect of initial-state radiation
- Spin correlations of t and tbar

3. DECAY CHAIN

- W polarization
- Final-state radiation
- Decay branching fractions

Quick look at three example SUSY searches

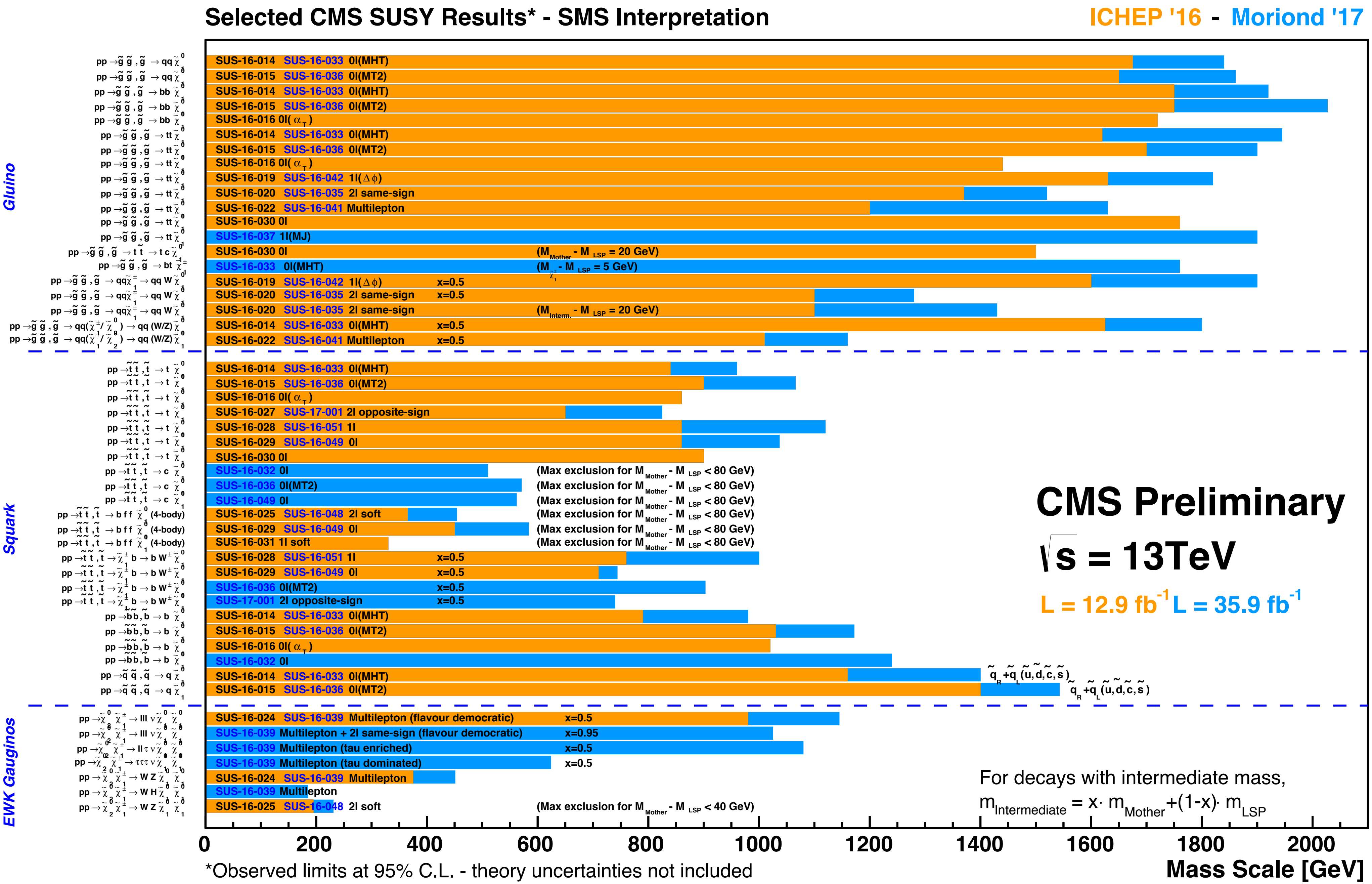
Signature	Trigger(s)	Dominant backgrounds	Background determination
All hadronic: Jets + p_T^{miss} Inclusive, heavily binned, search targets broad range of strongly produced SUSY	p_T^{miss}	ttbar 1 lepton (e, mu), ttbar $\tau \rightarrow$had, Z + jets, QCD multijet events	Control region(s) for each background; correction factors for each background/ analysis bin
1 lepton + (b)-jets + p_T^{miss} Targets strongly produced natural SUSY with higher jet multiplicity	p_T^{miss} OR single lepton	ttbar dilepton events with one “lost” lepton	ABCD method with small MC correction; systematics from additional control samples
HH + p_T^{miss}; H$\rightarrow$ bb Targets electroweak production of higginos in gauge-mediated SUSY breaking models	p_T^{miss}	ttbar 1 lepton events with lost lepton	ABCD method with no MC correction

Quick look at three example SUSY searches

Signature	Scenarios	Dominant backgrounds	Background determination
All hadronic: Jets + p_T^{miss} Inclusive, heavily binned, search targets broad range of strongly produced SUSY	**More inclusive: addresses wider range of SUSY scenarios.**	**More inclusive: wider range of backgrounds to understand.**	**More inclusive: search regions span broader range → more reliance on MC for background estimation.**
1 lepton + (b)-Jets + p_T^{miss} Targets strongly produced natural SUSY with higher jet multiplicity			
HH + p_T^{miss}; H→ bb Targets electroweak production of higginos in gauge-mediated SUSY breaking models	**More specific: better sensitivity to targeted process.**	**More specific: limited set of backgrounds.**	**More specific: less dependence on MC for background estimation.**

More control samples → more ways to find problems that you didn't even think of!

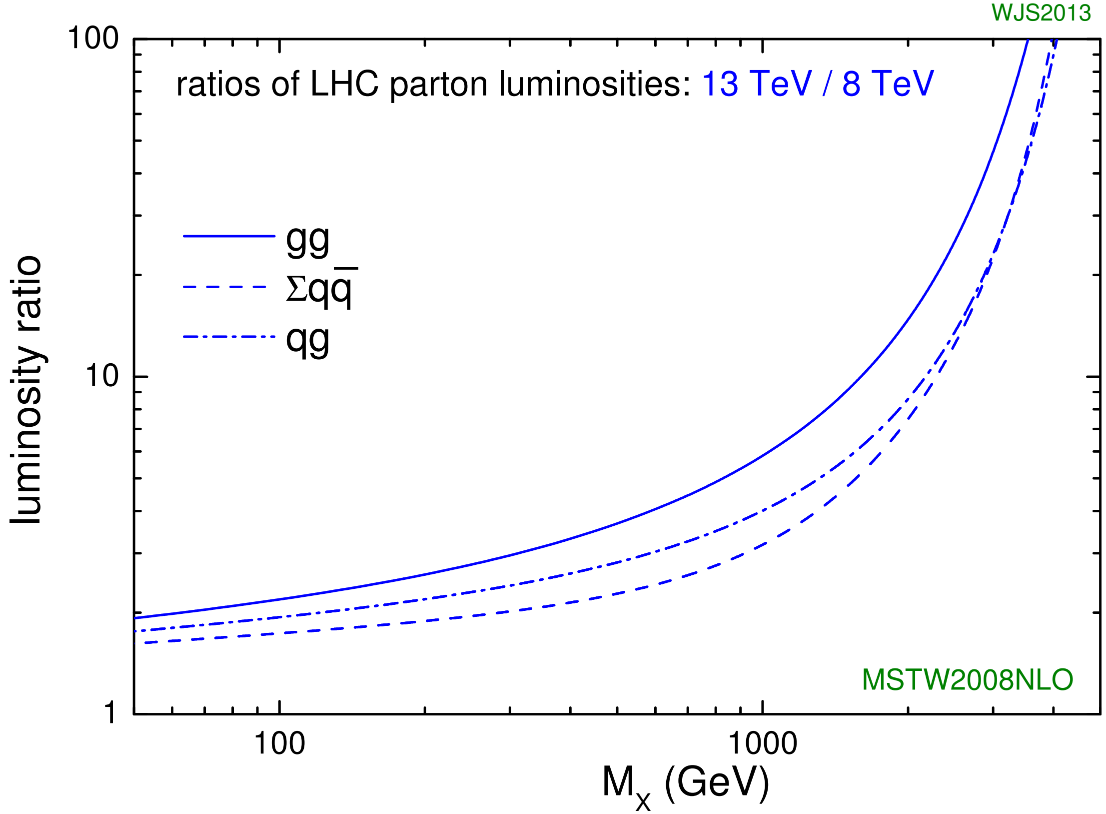
Searching for SUSY is a major program

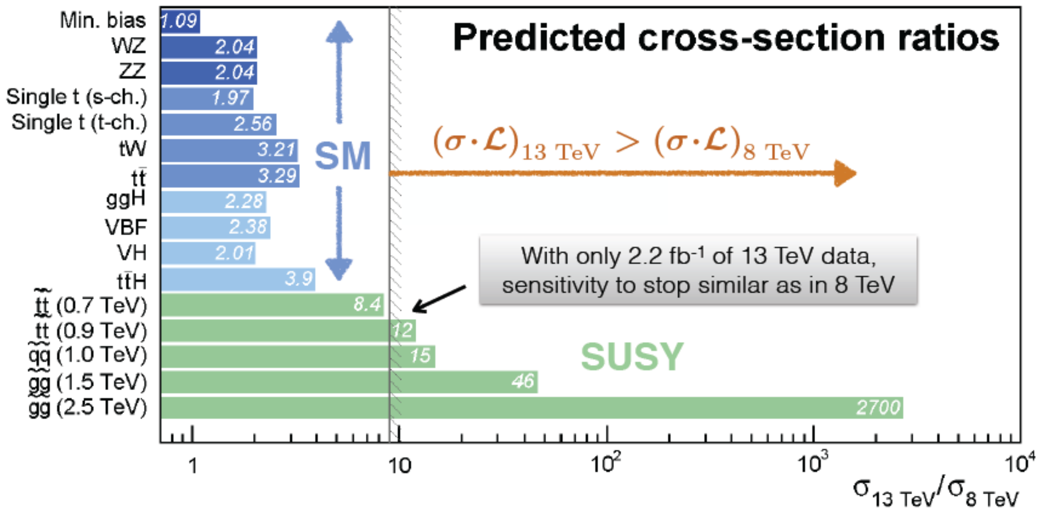


*Observed limits at 95% C.L. - theory uncertainties not included

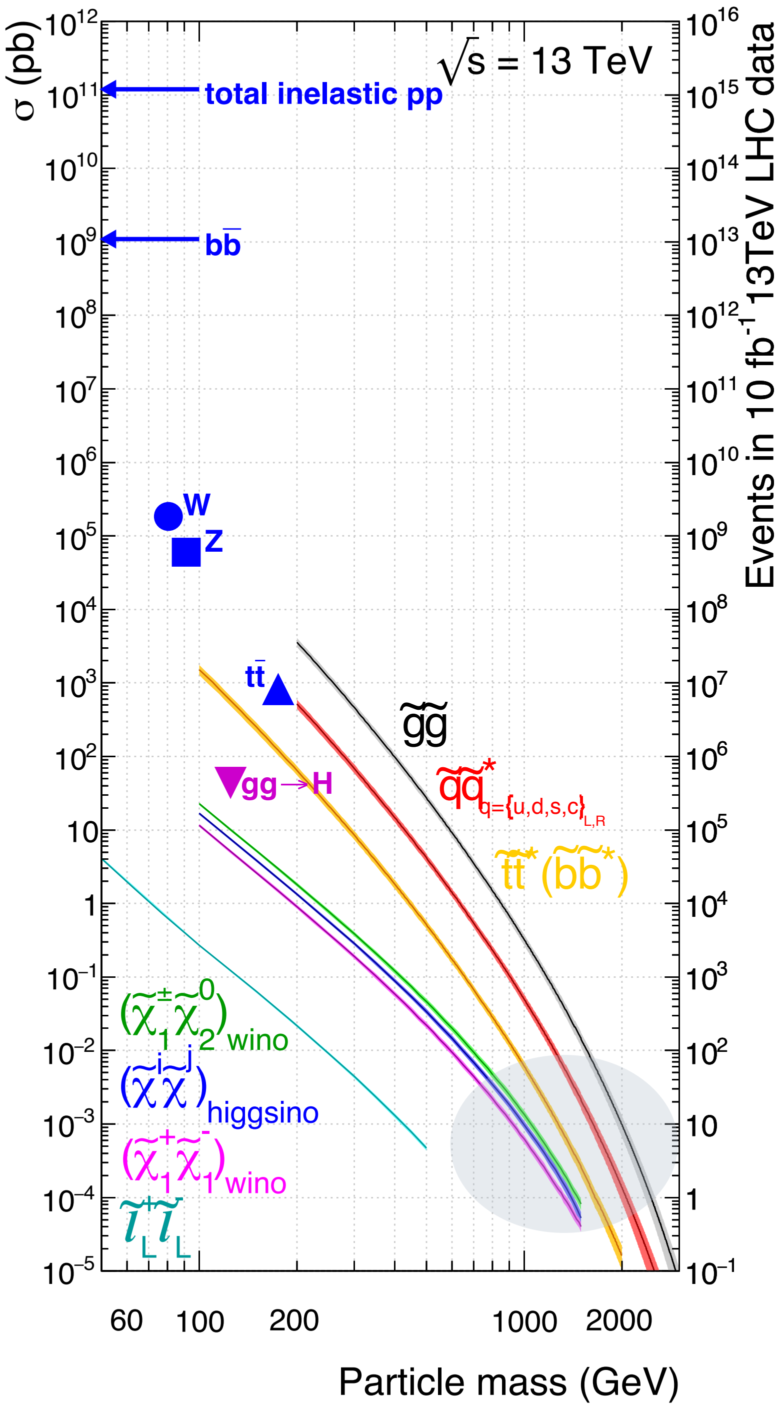
Only a selection of available mass limits. Probe *up to* the quoted mass limit for $m_{LSP} \approx 0$ GeV unless stated otherwise

From 8 TeV to 13 TeV



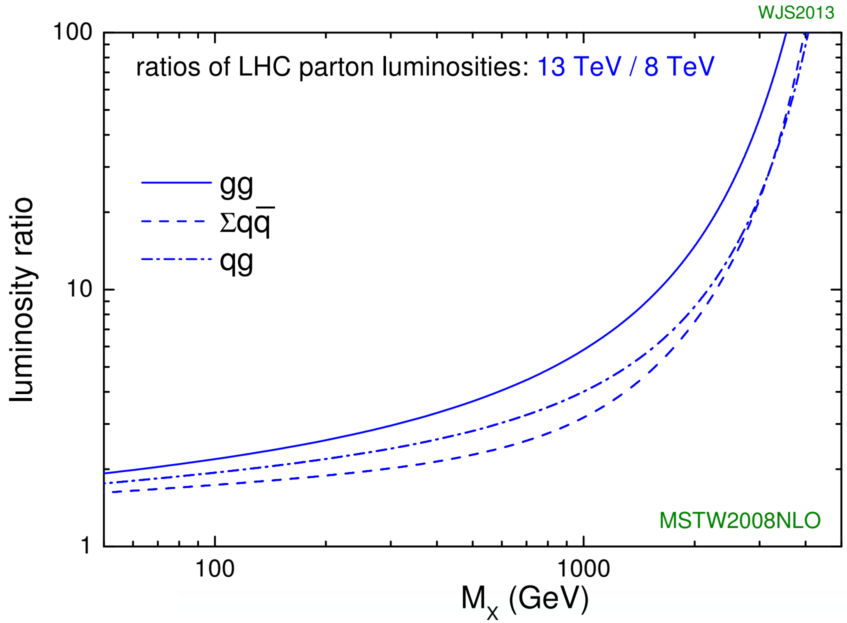


Remarks on backgrounds and methods

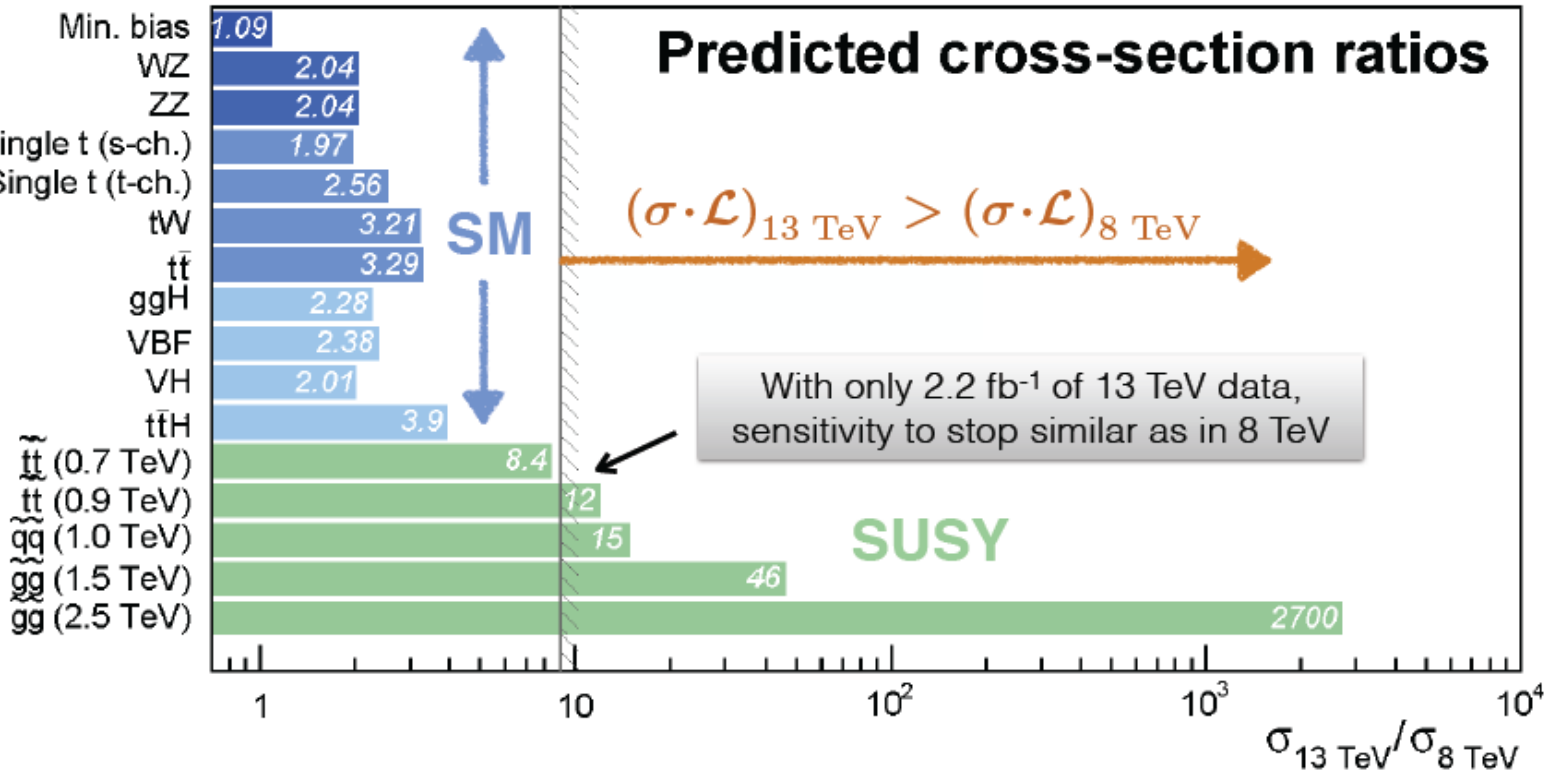


- Have entered the territory where SUSY cross sections are much less than those of the dominant SM backgrounds.
- Very tight kinematic cuts; operate on extreme tails of SM distributions such as E_T^{miss}. "Weak" signatures (no peaks).
- Need highly robust background estimation methods. Rely extensively on control samples, less on MC.

From 8 TeV to 13 TeV: 2 fb^{-1} goes a long way!

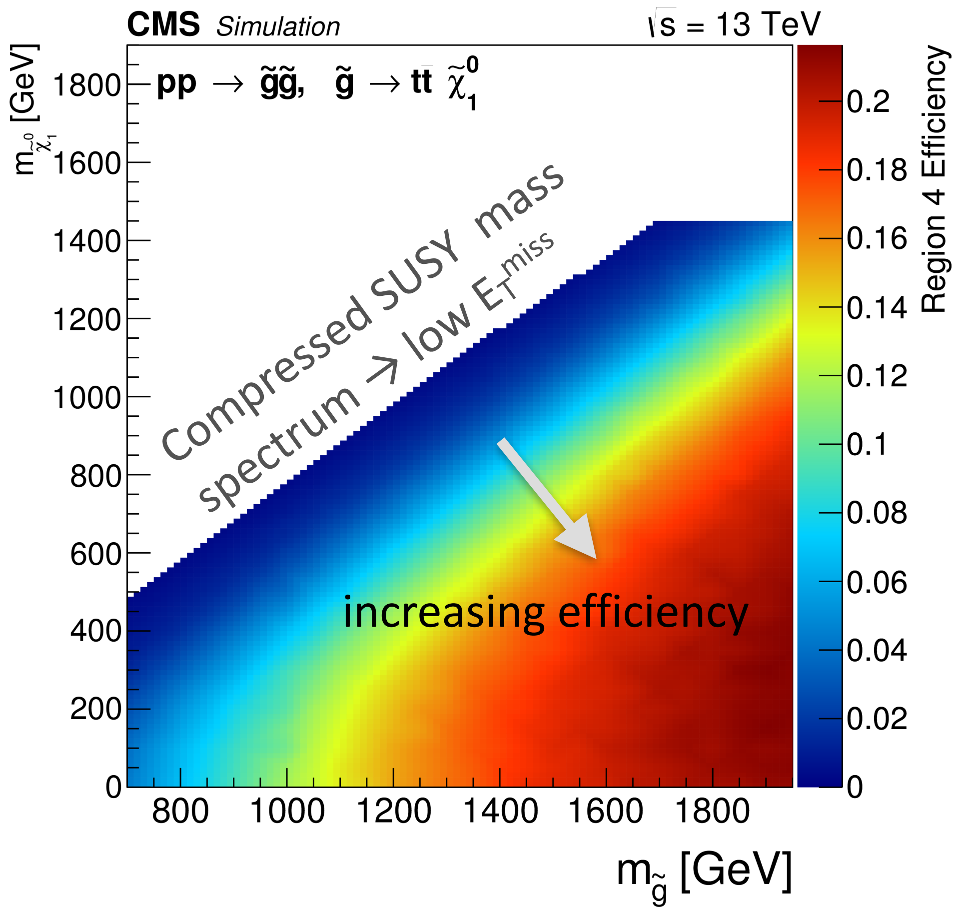


- The 13 TeV data sample has only ~1/10 the luminosity of the 8 TeV data sample.
- But sensitivity for this search still surpasses that at 8 TeV!

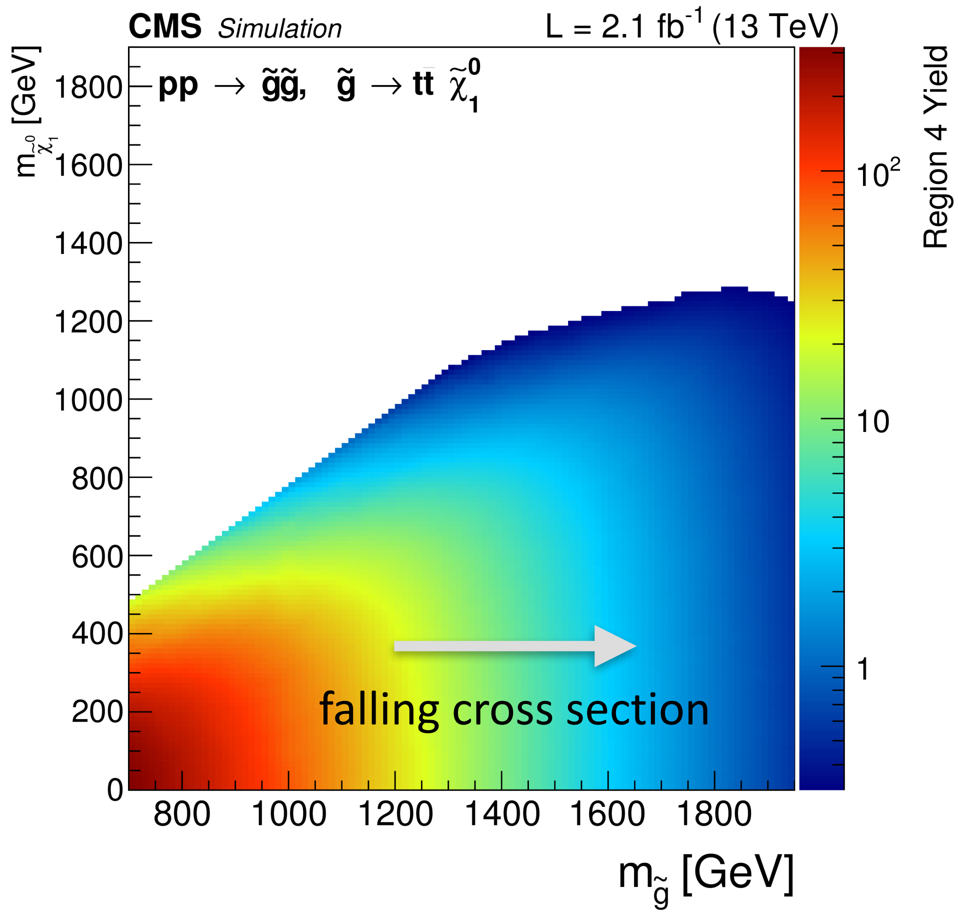


Signal efficiency and expected yields for T1tttt

Signal efficiency vs. M($\tilde{g}$) and M($\tilde{\chi}_1^0$)



Signal event yield vs. M($\tilde{g}$) and M($\tilde{\chi}_1^0$)

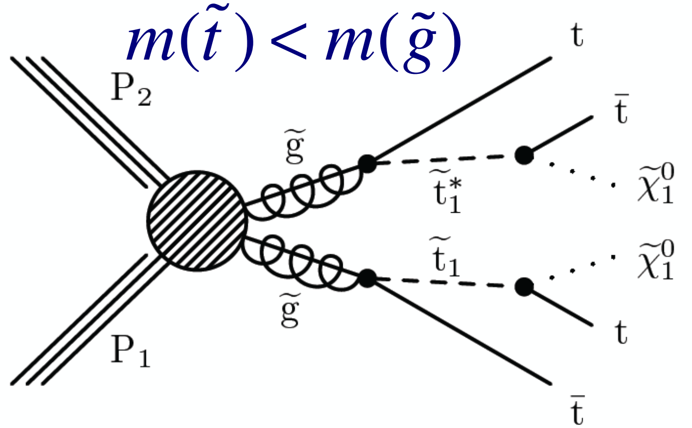


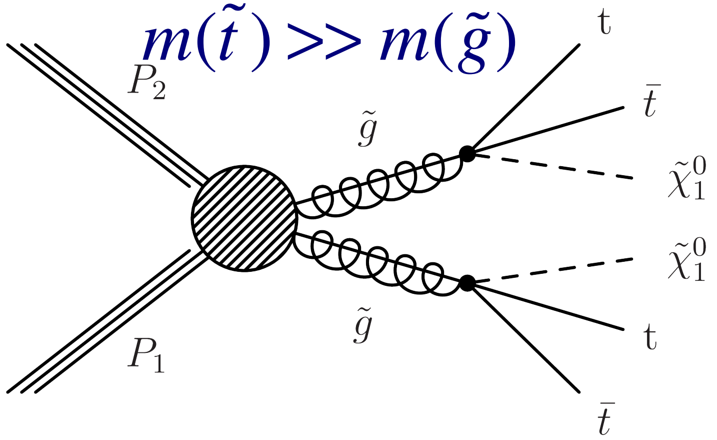
- Signal efficiency increases moving away from the diagonal, where the spectrum compresses and E_T^{miss} becomes small.
- Expected signal event yield decreases with increasing m($\tilde{g}$).

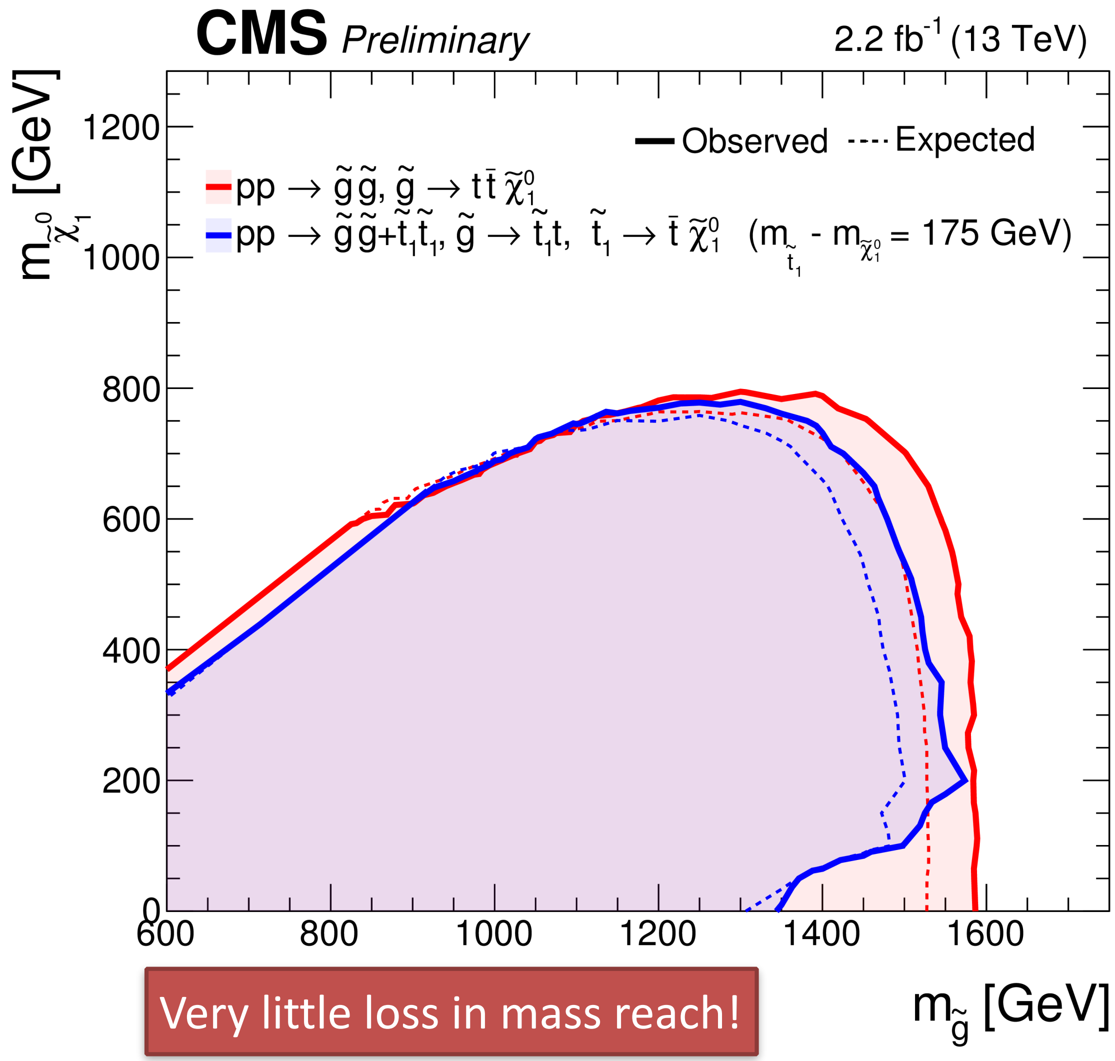
Excluded region for on-shell top squarks

How would intermediate-state, on-shell top squarks in gluino decay affect the limits?

Most difficult case (lowest efficiency) corresponds to the smallest allowed top squark mass for a given LSP mass: $m(\tilde{t}) = m(\tilde{\chi}_1^0) + m(t) \simeq m(\tilde{\chi}_1^0) + 175\ \mathrm{GeV}$



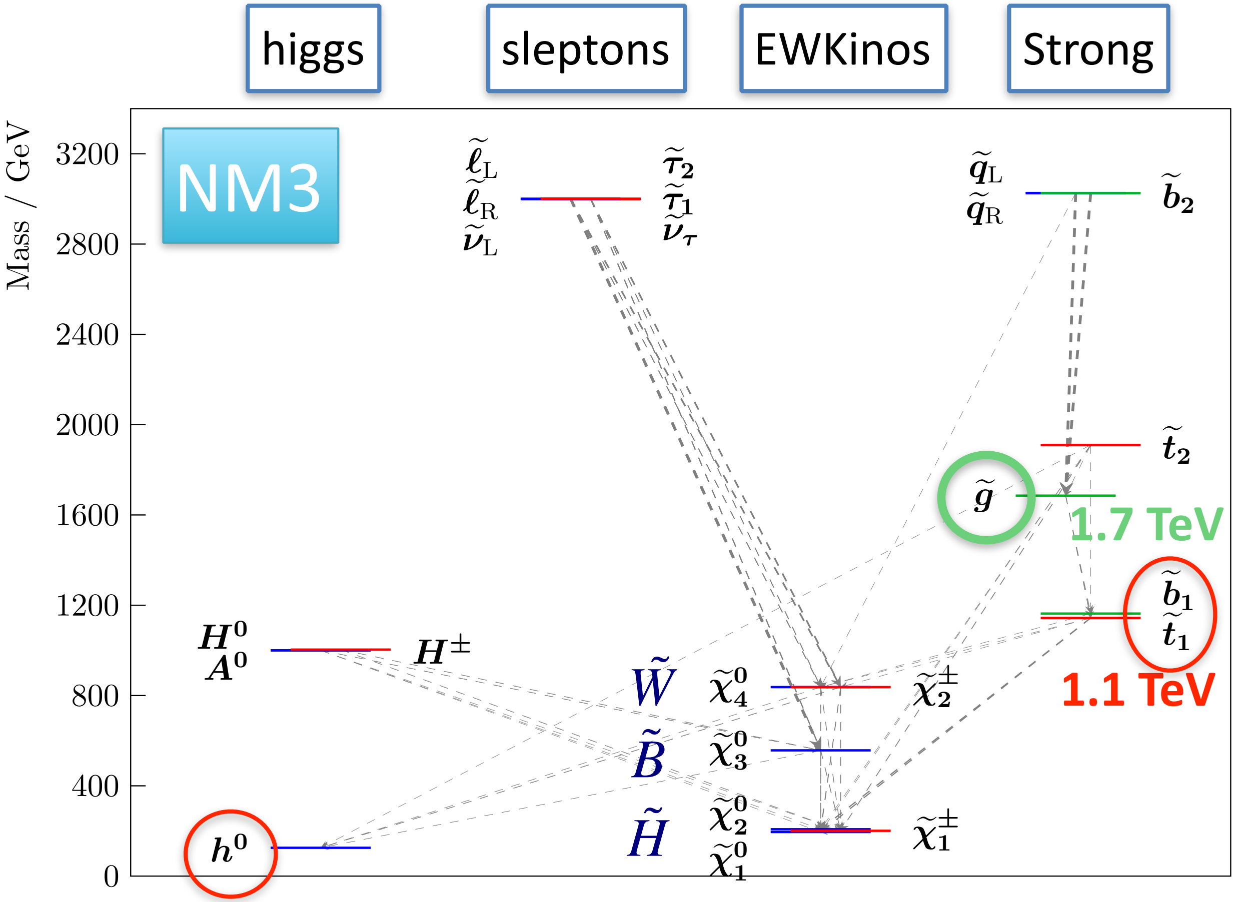




Very little loss in mass reach!

Discovery scenarios with full-spectrum models

CMS PAS SUS-14-012



The nature of the EWKino sector has a large influence on the decays of the top squark.

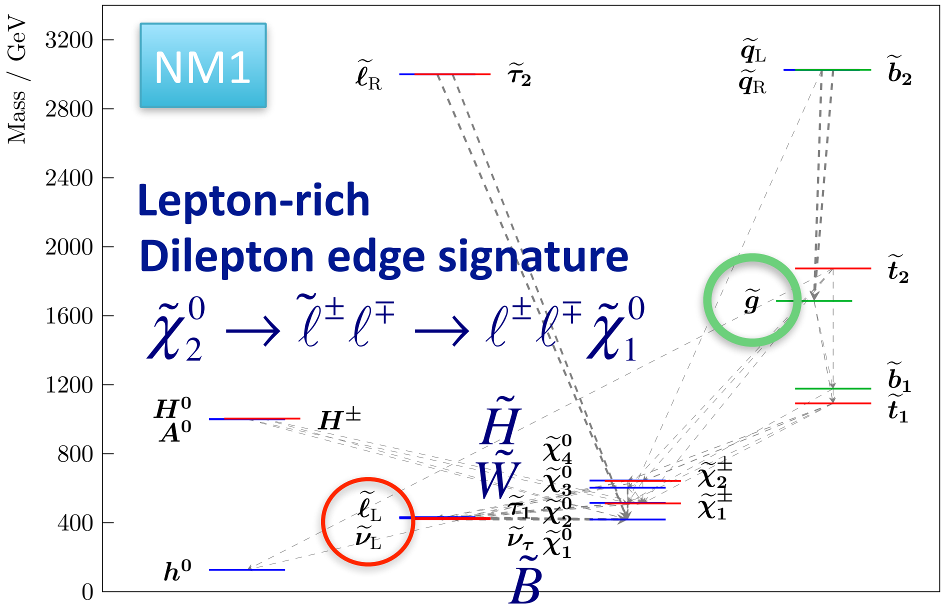
	NM1	NM2	NM3
$B(\tilde{t} \rightarrow t\tilde{\chi}_1^0)$	0.6%	1.5%	39%

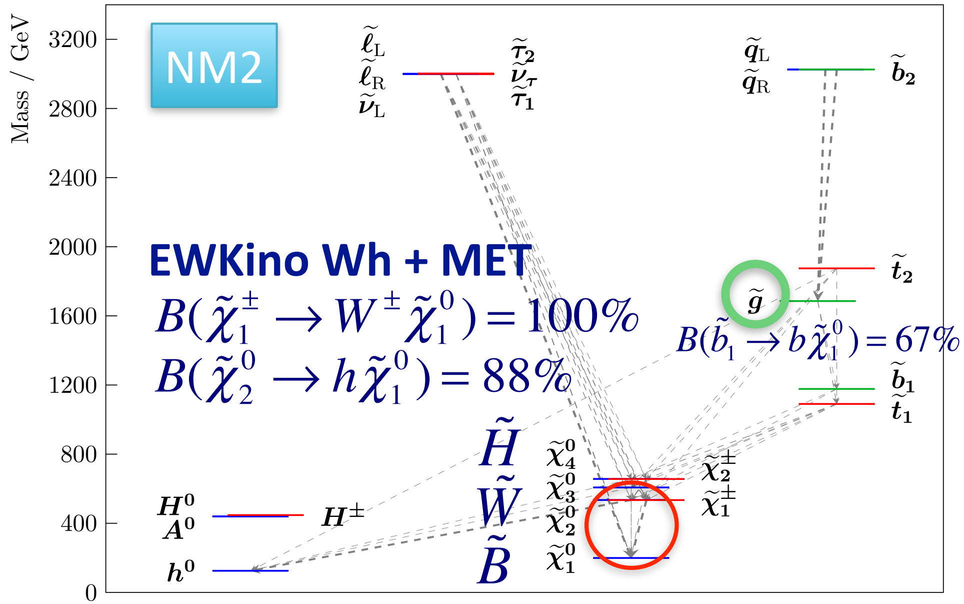
- **Studied 5 full-spectrum SUSY models.**
- **9 analyses performed in parallel.**
- m_H = 125 GeV
- **NM 1,2,3** ="Natural" Model 1, 2, 3

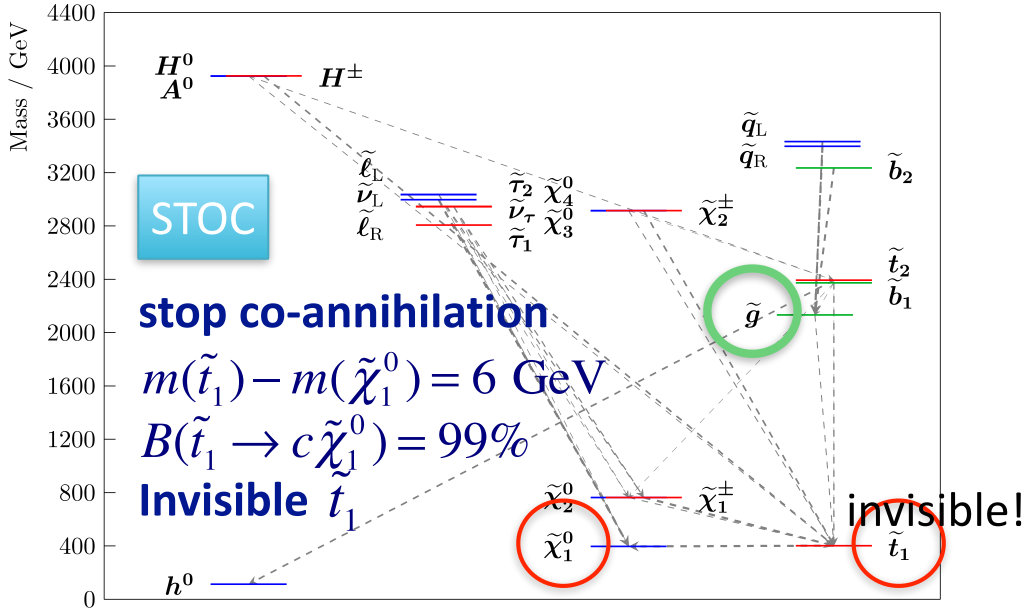
  $m(\tilde{g})$=1.7 TeV, $m(\tilde{t})$=1.1 TeV
- **STC** -Stau co-annihilation $m(\tilde{\tau}_1) \approx m(\tilde{\chi}_1^0) \approx 190$ GeV
- **STOC**-Stop co-annihilation $m(\tilde{t}_1) \approx m(\tilde{\chi}_1^0) \approx 400$ GeV

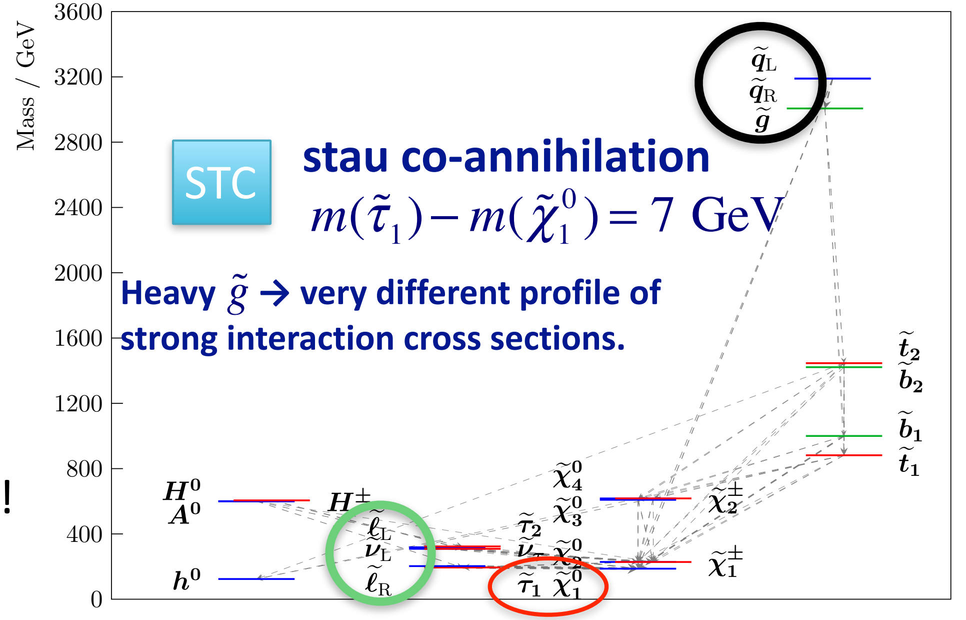
Discovery scenarios with full-spectrum models

CMS PAS SUS-14-012









SUSY models & multi-signature fingerprints

SUSY Model

Experimental signature

Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300				$< 3\sigma$	$3-5\sigma$
	3000				$3-5\sigma$	$> 5\sigma$
all-hadronic (M_{T2}) search	300	$3-5\sigma$	$> 5\sigma$	$> 5\sigma$		
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$		
all-hadronic $\tilde{b}_1$ search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$> 5\sigma$	$< 3\sigma$
1-lepton $\tilde{t}_1$ search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	$< 3\sigma$
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$
monojet $\tilde{t}_1$ search	300					$3-5\sigma$
	3000					$3-5\sigma$
$m_{\ell^+\ell^-}$ kinematic edge	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$		
	3000	$> 5\sigma$	$< 3\sigma$	$< 3\sigma$		
multilepton + b-tag search	300	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$3-5\sigma$	
	3000	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	$> 5\sigma$	
multilepton search	300	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	$< 3\sigma$	
	3000	$3-5\sigma$	$3-5\sigma$	$< 3\sigma$	$3-5\sigma$	
ewkino WH search	300		$< 3\sigma$			
	3000		$3-5\sigma$			

$< 3\sigma$ | $3-5\sigma$ | $> 5\sigma$

No mass peaks! Interpretation will be very complex. Is it even SUSY?
Different signatures can require very different amounts of data to detect!

SUSY models & multi-signature fingerprints

SUSY Model

Experimental signature

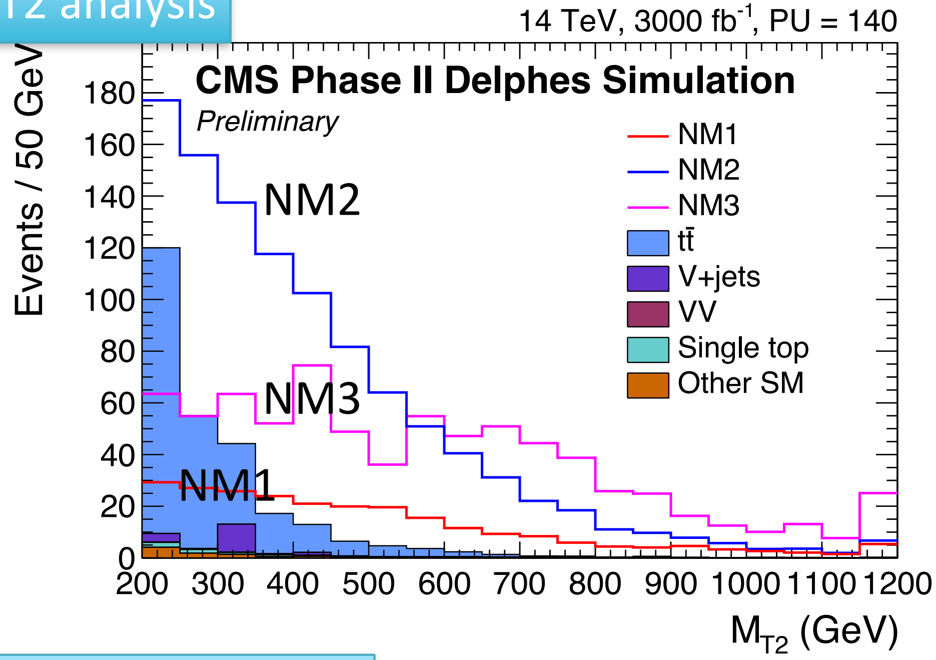
Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300					
	3000					
all-hadronic (M_{T2}) search	300					

- Powerful approach, but in reality, there are an infinite number of possible theories (not 5), so the challenge is very significant.
- Multi-signature fingerprint will require large data samples to acquire.
- Different search channels can produce significant signals at very different times.
- Interpretation of a significant excess is likely to be much slower than for the Higgs discovery.
- "Discovery" could take place with multiple 3-4 σ excesses, rather than a single 5σ excess.

$< 3\sigma$	$3 - 5\sigma$	$> 5\sigma$

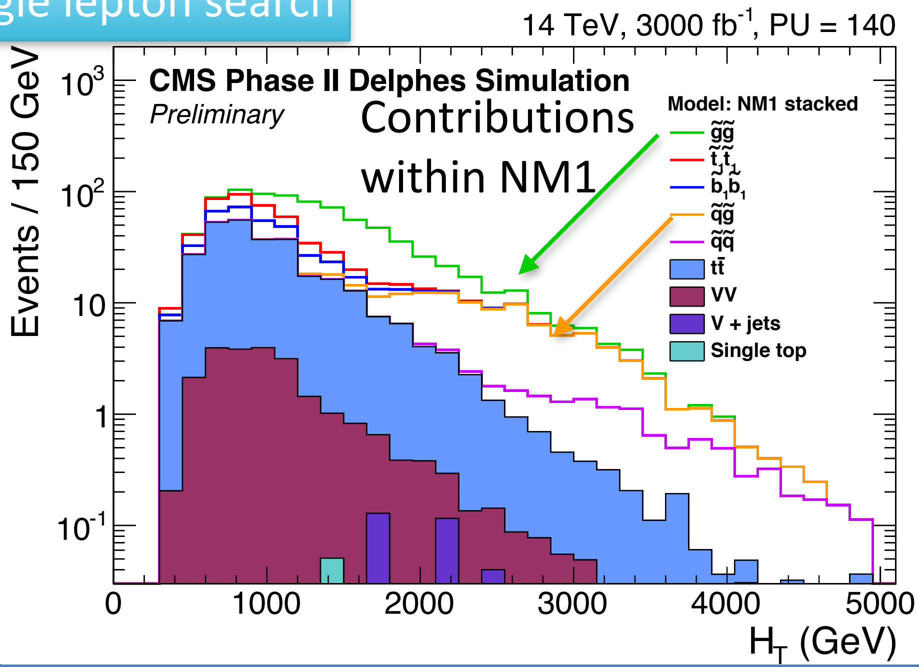
CMS: lessons from full-spectrum SUSY studies

MT2 analysis



- Search for all-hadronic jets + MET.
- MT2 can provide valuable information on the kinematics/ mass splittings of the signal processes
- NM1: more leptons → few events in hadronic channel.

Single lepton search



- Designed as 1-lepton search for top-squark pair production.
- Show stacked contributions from NM1 model. Target process does not dominate the observed yield!
- **“Discovery” does not mean you found what you were looking for!**

PDG for CMS full-spectrum SUSY models

CMS PAS SUS-14-012

Process	Cross section (fb)				
	NM1	NM2	NM3	STC	STOC
$\tilde{g}\tilde{g}$	5.4	5.4	5.4	0.007	0.53
$\tilde{q}\tilde{g}$	2.0	2.0	2.0	0.05	0.30
$\tilde{q}\tilde{q}$, $\tilde{q}\tilde{q}^*$	0.14	0.14	0.14	0.07	0.03
$\tilde{b}_1\tilde{b}_1^*$	2.6	2.6	2.8	8.3	-
$\tilde{t}_1\tilde{t}_1^*$	4.4	4.4	3.1	19	2110
$\tilde{\chi}_1^\pm\tilde{\chi}_1^0$	1.1	0.2	520	11	-
$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$	29	22	460	1104	5.5
$\tilde{\chi}_1^0\tilde{\chi}_2^0$	-	-	258	0.02	-
$\tilde{\chi}_1^+\tilde{\chi}_1^-$	15	11	278	553	2.6
$\tilde{\ell}^+\tilde{\ell}^-$	3.3	-	-	34	-
$\tilde{\ell}^+\tilde{\nu}, \tilde{\ell}^-\tilde{\nu}^*$	12	-	-	32	-
$\tilde{\nu}\tilde{\nu}^*$	3.3	-	-	13	-

Decay	Branching fraction				
	NM1	NM2	NM3	STC	STOC
$\tilde{g} \to \tilde{t}_1\bar{t}, \tilde{t}_1^* t$	59%	60%	53%	28%	50%
$\tilde{g} \to \tilde{b}_1\bar{b}, \tilde{b}_1^* b$	41%	40%	47%	28%	50%
$\tilde{g} \to \tilde{t}_2\bar{t}, \tilde{t}_2^* t$	-	-	-	22%	-
$\tilde{g} \to \tilde{b}_2\bar{b}, \tilde{b}_2^* b$	-	-	-	21%	-
$\tilde{t}_1 \to t\tilde{\chi}_1^0$	0.6%	1.5%	39%	20%	-
$\tilde{t}_1 \to t\tilde{\chi}_2^0$	13%	13%	41%	5.4%	-
$\tilde{t}_1 \to t\tilde{\chi}_3^0$	22%	23%	1.3%	20%	-
$\tilde{t}_1 \to t\tilde{\chi}_4^0$	30%	30%	5.5%	9.2%	-
$\tilde{t}_1 \to b\tilde{\chi}_1^+$	16%	12%	2.1%	12%	-
$\tilde{t}_1 \to b\tilde{\chi}_2^+$	18%	21%	11%	34%	-
$\tilde{t}_1 \to c\tilde{\chi}_1^0$	-	-	-	-	99%
$\tilde{b}_1 \to b\tilde{\chi}_1^0$	1.5%	1.0%	1.3%	67%	-
$\tilde{b}_1 \to b\tilde{\chi}_2^0$	11%	10%	1.0%	2.2%	5.7%
$\tilde{b}_1 \to b\tilde{\chi}_3^0$	0.6%	0.6%	0.4%	8.2%	-
$\tilde{b}_1 \to b\tilde{\chi}_4^0$	4.5%	5.7%	5.7%	7.6%	-
$\tilde{b}_1 \to t\tilde{\chi}_1^-$	32%	34%	80%	3.4%	11%
$\tilde{b}_1 \to t\tilde{\chi}_2^-$	49%	48%	12%	12%	-
$\tilde{b}_1 \to W^-\tilde{t}_1$	0.4%	0.7%	-	< 0.1%	65%
$\tilde{b}_1 \to b\tilde{g}$	-	-	-	-	18%
$\tilde{\chi}_1^+ \to \ell^+\tilde{\nu}$	56%	-	-	-	-
$\tilde{\chi}_1^+ \to \nu\tilde{\ell}^+$	43%	-	-	100% (only $\nu_\tau\tilde{\tau}_1^+$)	-
$\tilde{\chi}_1^+ \to W^+\tilde{\chi}_1^0$	1.8%	100%	-	-	-
$\tilde{\chi}_1^+ \to q\bar{q}'\tilde{\chi}_1^0$	-	-	70%	-	-
$\tilde{\chi}_1^+ \to \ell^+\nu\tilde{\chi}_1^0$	-	-	30%	-	-
$\tilde{\chi}_1^+ \to \tilde{t}_1\bar{b}$	-	-	-	-	100%
$\tilde{\chi}_2^0 \to \tilde{\ell}^+\ell^-, \tilde{\ell}^-\ell^+$	59%	-	-	100%	-
$\tilde{\chi}_2^0 \to \tilde{\nu}\bar{\nu}, \tilde{\nu}^*\nu$	41%	-	-	-	-
$\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0$	< 0.1%	12%	-	-	-
$\tilde{\chi}_2^0 \to H\tilde{\chi}_1^0$	-	88%	-	-	-
$\tilde{\chi}_2^0 \to q\bar{q}\tilde{\chi}_1^0$	-	-	56%	-	-
$\tilde{\chi}_2^0 \to \ell^+\ell^-\tilde{\chi}_1^0$	-	-	10%	-	-
$\tilde{\chi}_2^0 \to \nu\bar{\nu}\tilde{\chi}_1^0$	-	-	21%	-	-
$\tilde{\chi}_2^0 \to q\bar{q}'\tilde{\chi}_1^\pm$	-	-	8.8%	-	-
$\tilde{\chi}_2^0 \to \ell^+\nu\tilde{\chi}_1^-, \ell^-\bar{\nu}\tilde{\chi}_1^+$	-	-	4.0%	-	-
$\tilde{\chi}_2^0 \to \tilde{t}_1\bar{t}, \tilde{t}_1^* t$	-	-	-	-	100%

gluino: $\tilde{t}\tilde{t} + \tilde{b}\tilde{b}$

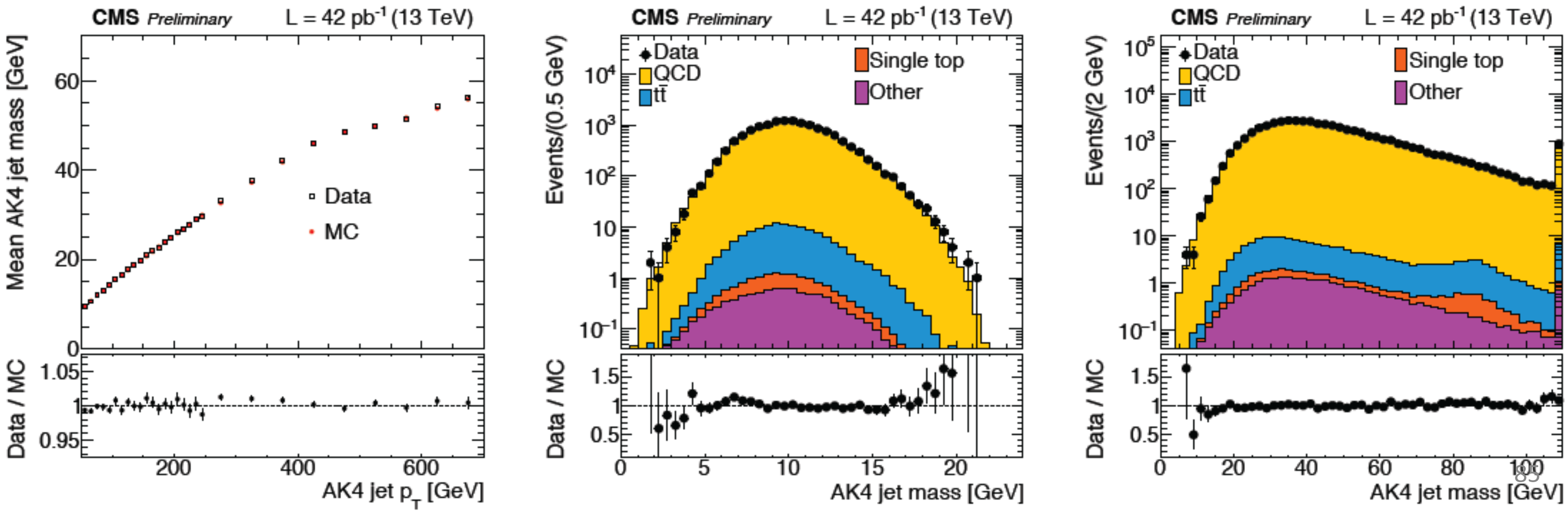
Object reconstruction

Reconstruction object	*Method/criteria*	*Performance/Comments*
Jets **Large-R jets**	**$p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$** **Cluster particle-flow objects using anti-kT with R = 0.4** **Rejected if jet contains isolated lepton, as defined below.** **Cluster standard jets with anti-kT and**	
b - tagged jets	**N(b-tag) ≥ 1, $p_T > 30$ GeV, $\lvert\eta\rvert < 2.4$** **Combined secondary vertex algorithm**	**ϵ(b) = 60 - 70%, increasing with pT** **ϵ(c) ≈ 10 - 15% [mistag rate]** **ϵ(light quark) ≈ 1 - 2% [mistag rate]**
electrons	**$p_T > 20$ GeV, $\lvert\eta\rvert < 2.5$** **Isolation: $I^{rel} = \Sigma_{i\text{ in cone}}\, p_{T,i} / p_{T,e} < 0.1$** **with p_T-dependent cone size ($\sim 1/p_{T,e}$)**	**ϵ(e) = 50-80%, increasing with pT** **[includes isolation efficiency]** **$\sigma(p_T)$ = 1-3% (p_T = 5 - 100 GeV)**
muons	**$p_T > 20$ GeV, $\lvert\eta\rvert < 2.4$** **Isolation: $I^{rel} = \Sigma_{i\text{ in cone}}\, p_{T,i} / p_{T,e} < 0.2$** **with p_T-dependent cone size ($\sim 1/p_{T,e}$)**	**ϵ(e) =70-95%, increasing with pT** **[includes isolation efficiency]**
p_T^{miss} and $E_T^{miss} = \lvert p_T^{miss}\rvert$	**$p_T^{miss} = -\Sigma_{\text{Particle-flow objects } i}\, p_{T,i}$** **with PF candidates in jet replaced by calibrated jet p_T**	

Validation of M_J modeling using data

Before using MJ, we performed an extensive set of studies in data and Monte Carlo.

- By clustering AK4 PF jets (pT>30 GeV, |η|<2.4), we are robust against pile-up effects because standard jets are already corrected for pile-up.
- Simulation of M_J distributions tested in QCD, ttbar, Z+jets, W+jets dominated samples in 8 TeV data.



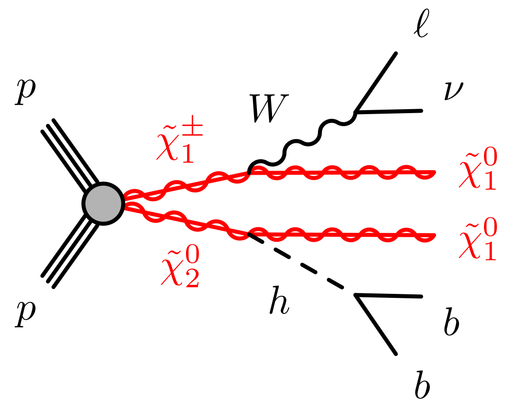
CMS: $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ with $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm}\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \rightarrow h\tilde{\chi}_1^0$

Search for Wh(bb) + E_T^{miss}

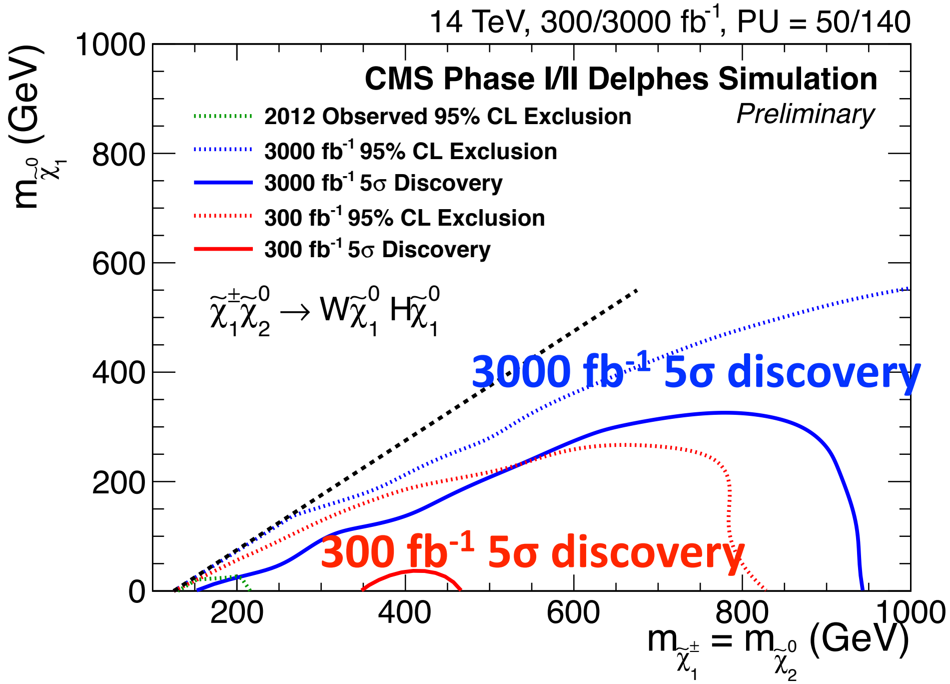
1 lepton + m(bb) + E_T^{miss} + mT cut + mCT

Dominant SM background: ttbar production

CMS-PAS-SUS-14-012



Discovery sensitivity: up to ~950 GeV.



Effect of aged Run 1 detector performance on search for Wh(bb) + E_T^{miss}

Study based on full simulation.

- Emulated aged detector with worse E_T^{miss} resolution (→impact MT), b-tagging efficiency, e/μ efficiency.
- Discovery sensitivity substantially reduced with aged detector.