SUSY Dark Matter Searches at CMS

Dark Interactions Workshop
BNL, June 11-13, 2014

F. Ratnikov (KIT, Germany)
for the **CMS** Collaboration

Introduction

SUSY models (supersymmetry between bosons and fermions) naturally resolves basic problems in understanding of the Universe:

- Higgs mass divergency problem in Standard Model
  - now with discovery at 125 GeV we do believe that Higgs mechanism takes place
- Hierarchy problem
- Dark matter WIMP nature
  - in R-parity conserving SUSY the lightest supersymmetric particle (LSP) is stable and mostly decoupled from the regular matter

SUSY searches are motivated by DM

Reverse perspective in this presentation:

- assume that DM is driven by SUSY LSP
- what are **implications of Run 1 SUSY analyses on expected properties of DM?**

Outline

- SUSY search strategies
  - Interpretation strategies
- Selected CMS Run 1 SUSY analyses
- Interpretation of CMS Run 1 observations in terms of DM properties
- Conclusions

General SUSY Search Strategy

① Reconstruct pronounced signatures in the event

- missing transverse energy (MET)
  - primary signature for RPC SUSY searches
- high-p_T leptons: e, μ, $\tau_{leptonic}$, $\tau_{hadronic}$
- high-E_T photons
- b-jets
- high-p_t jets
- total event energy H_T
- combined kinematical variables
  - α_T, M_T, M_{CT}, ...

② Combine several signatures: determine a region in phase space

- with significant expected contribution from BSM events
- with low and/or well determined contribution from SM events

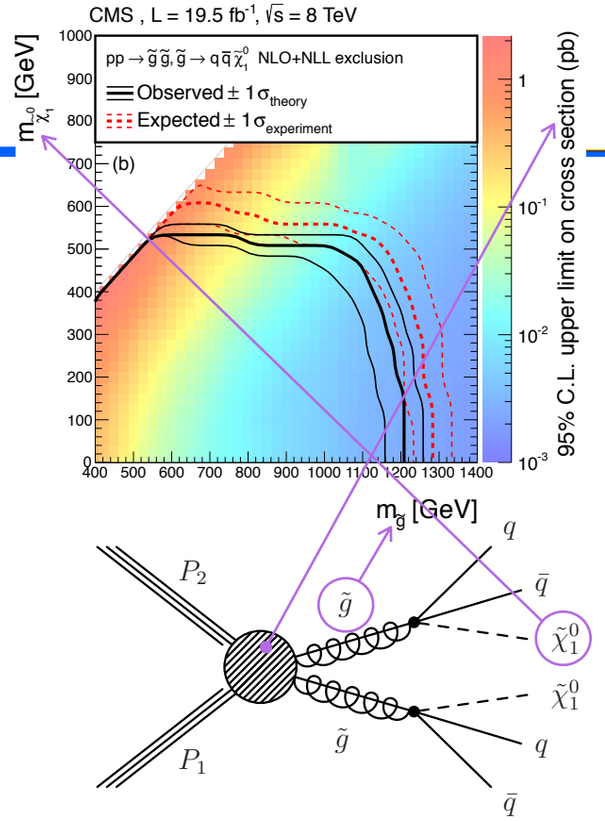
③ Interpret observed (in)consistency in terms of particular physics models and evaluate model parameters

Step ③: Interpretations

Two major approaches used in LHC Run 1

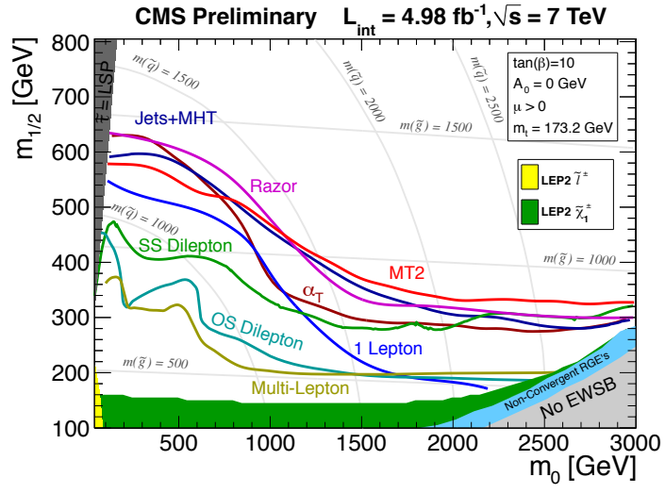
A. Simplified Models (SMS)

- select single signature process
  - driven by few ≲TeV scale SUSY particles
  - the rest of SUSY sector is assumed to be decoupled



B. Complete Physics Models

- Constrained MSSM (mSUGRA)
  - 5 parameters, oversimplified SUSY, mostly excluded
- Full (N)MSSM
  - 100+ parameters at GUT scale, technically impossible to work with
  - Practical solution: reduce number of parameters by using effective parameters defined on the EWK scale
- **Phenomenological MSSM Model (pMSSM)**



Phenomenological MSSM

Assumptions:

- no new sources of CP violation
- no flavor changing neutral currents
- degeneracy between 1st and 2nd generation

- 19-D parameter space at EWK scale:
  - M_1, M_2, and M_3 - ewkino masses
  - $\tan\beta$, μ, m_A
  - 10 sfermion mass parameters
  - A_t, A_b, and A_τ

pMSSM captures most of the phenomenological features of the RPC MSSM

Bayesian Approach

Flat pMSSM Parameters 19-D Priors

$$-3\,\text{TeV} \leq M_1, M_2 \leq 3\,\text{TeV}$$
$$0 \leq M_3 \leq 3\,\text{TeV}$$
$$-3\,\text{TeV} \leq \mu \leq 3\,\text{TeV}$$
$$0 \leq m_A \leq 3\,\text{TeV}$$
$$2 \leq \tan\beta \leq 60$$
$$0 \leq \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \leq 3\,\text{TeV}$$
$$-7\,\text{TeV} \leq A_t, A_b, A_\tau \leq 7\,\text{TeV},$$

no astrophysics data are included to demonstrate CMS effect

NB: absolute distributions strongly depend on choice of priors

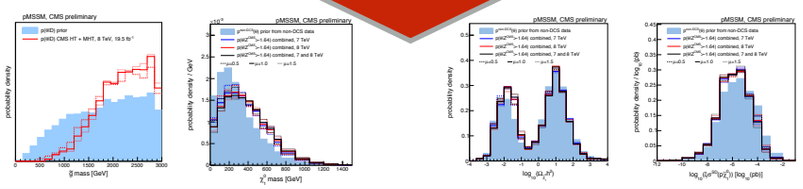
- variations from ▼ to ▼ illustrate effect of CMS measurements

Non-CMS Data Used

i	Observable $\mu_j(\theta)$	Constraint $D_j^{\text{non-DCS}}$	Likelihood function $L(D_j^{\text{non-DCS}}\|\mu_j(\theta))$	MCMC / post-MCMC
1a	$BR(b \to s\gamma)$	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian	MCMC
1b	$BR(b \to s\gamma)$	$(3.43 \pm 0.21^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.07^{\text{sys}}) \times 10^{-4}$	Gaussian	reweight
2a	$BR(B_s \to \mu\mu)$	observed CLs curve from	$d(1-CLs)/d(BR(B_s \to \mu\mu))$	MCMC
2b	$BR(B_s \to \mu\mu)$	$(2.9 \pm 0.7 \pm 0.29^{th}) \times 10^{-9}$	Gaussian	reweight
3a	$R(B_u \to \tau\nu)$	1.63 ± 0.54	Gaussian	MCMC
3b	$R(B_u \to \tau\nu)$	1.04 ± 0.34	Gaussian	reweight
4	Δa_μ	$(26.1 \pm 6.3^{\text{exp}} \pm 4.9^{\text{SM}} \pm 10.0^{\text{SUSY}}) \times 10^{-10}$	Gaussian	MCMC
5a	m_t	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	MCMC
5b	m_t	$173.20 \pm 0.87^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	reweight
6	$m_b(m_b)$	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
7	$\alpha_s(M_Z)$	0.1184 ± 0.0007	Gaussian	MCMC
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \leq m_h \leq m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$	reweight
9	sparticle masses	LEP (via micrOMEGAs)	1 if allowed 0 if excluded	MCMC

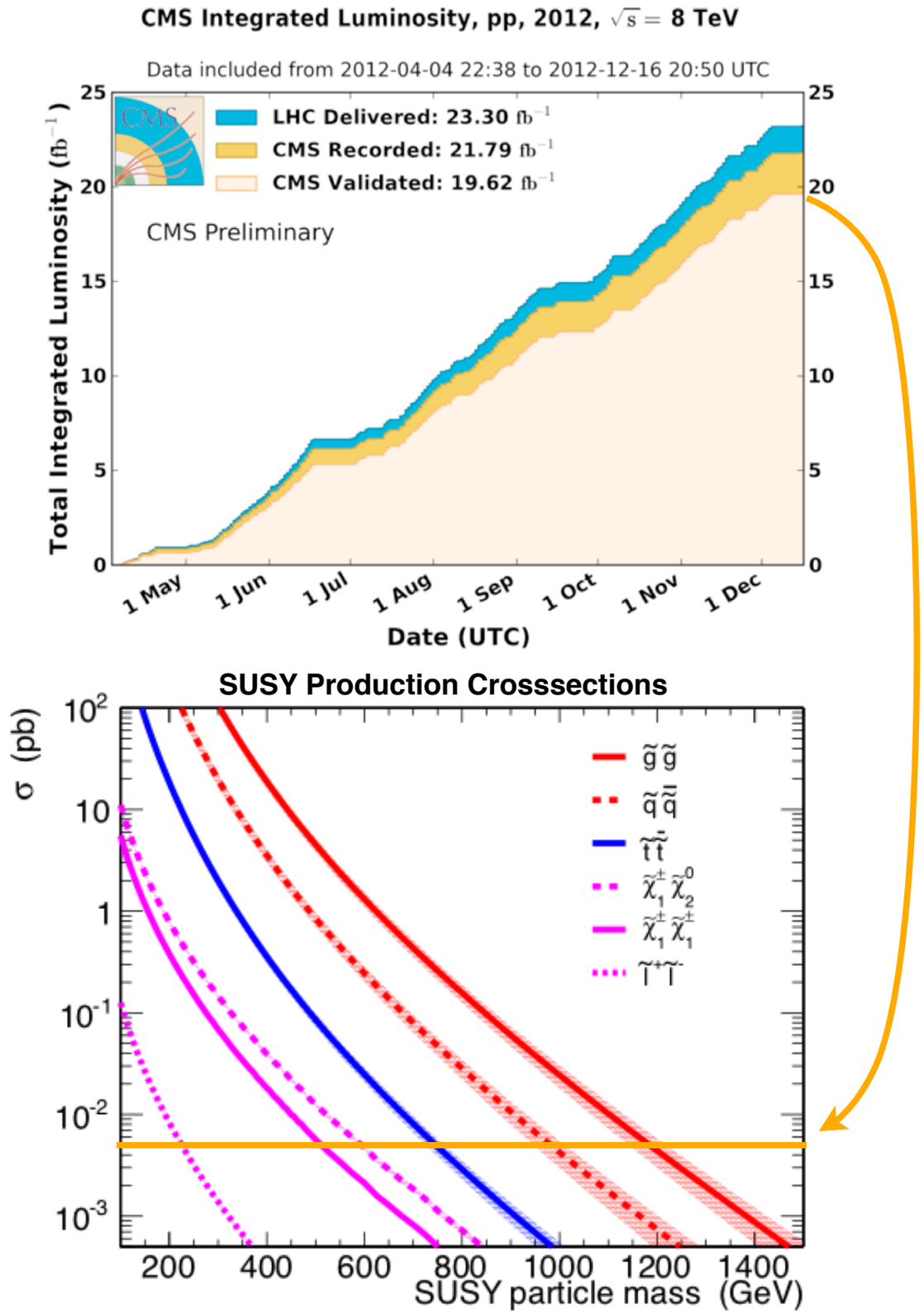
CMS Data Used

Analysis	$\sqrt{s}$	L	Likelihood	Ref.
Hadronic HT + MHT search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-011
Hadronic HT + MET + b-jets search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-003
Leptonic search for EW prod. of $\widetilde{\chi}^0$, $\widetilde{\chi}^{\pm}$, $\tilde{l}$	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-006
Hadronic HT + MHT search	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-13-012
Hadronic HT + MET + b-jets search	8 TeV	19.4 fb^{-1}	method 2	CMS-SUS-12-024
Leptonic search for EW prod. of $\widetilde{\chi}^0$, $\widetilde{\chi}^{\pm}$, $\tilde{l}$ (ss, 3l and 4l channels)	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-12-006



Collected LHC Data

- CMS and ATLAS would have produced ~100 events for:
  - 1.2 TeV gluinos
  - 700 GeV stops
  - 600 GeV charginos/ neutralinos (ewkinos)



Plenty CMS SUSY Analyses

Journal Publications with 2012 8 TeV Data

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
Searches for electroweak production of charginos, neutralinos, and sleptons decaying to leptons and W,Z, and Higgs bosons in pp collisions at 8 TeV		CMS-SUS-13-006	19.5/fb	Submitted to EPJC arXiv:1405.7570 NEW
Search for top-squark pair production with Higgs and Z bosons in the final state in pp collisions at 8 TeV	SUS13024	CMS-SUS-13-024	19.5/fb	Submitted to PLB arXiv:1405.3886 NEW
Search for anomalous production of events with three or more leptons in pp collisions at 8 TeV	SUS13002	CMS-SUS-13-002	19.5/fb	Submitted to PRD arXiv:1404.5801 NEW
Search for New Physics in Multijets and Missing Momentum Final State in pp collisions at 8 TeV	SUS13012	CMS-SUS-13-012	19.5/fb	Accepted by JHEP arXiv:1402.4770
Search for SUSY Partners of Top and Higgs Using Diphoton Higgs Decays in pp collisions at 8 TeV	SUS13014	CMS-SUS-13-014	19.5/fb	Accepted by PRL arXiv:1312.3310
Search for new physics in events with same-sign dileptons and jets in pp collisions at 8 TeV	SUS13013	CMS-SUS-13-013	19.5/fb	JHEP 01 (2014) 163 arXiv:1311.6736
Search for supersymmetry using events with a single lepton, multiple jets, and b-tags	SUS13007	CMS-SUS-13-007	19.3/fb	Submitted to PLB arXiv:1311.4937
Search for top-squark pair production in the single lepton final state in pp collisions at 8 TeV	SUS13011	CMS-SUS-13-011	19.5/fb	EPJC 73 (2013) 2677 arXiv:1308.1586
Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags	SUS13003	CMS-SUS-13-003	19.5/fb	PRL 111, 221801 (2013), arXiv:1306.6643
Search for supersymmetry using the shape of the HT and MET, and b-jet multiplicity distributions	SUS12024	CMS-SUS-12-024	19.4/fb	PLB 725 243 (2013), arXiv:1305.2390
Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, 3, or ≥ 4 b jets in 8 TeV pp collisions	SUS12028	CMS-SUS-12-028	11.7/fb	EPJC 73 (2013) 2568, arXiv:1303.2985
Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at √s = 8 TeV	SUS12017	CMS-SUS-12-017	10.5/fb	JHEP03 (2013) 037, JHEP07(2013)041, arXiv:1212.6194

Recent Preliminary Results with 2012 8 TeV Data

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
Phenomenological MSSM Interpretation of the 7 and 8 TeV results	SUS13020	PAS-SUS-13-020	19.5/fb	NEW
Search for direct production of a pair of bottom squarks	SUS13018	PAS-SUS-13-018	19.4/fb	NEW
Search for electroweak production of higgsinos in channels with two Higgs bosons decaying to b quarks in pp collisions at 8 TeV	SUS13022	PAS-SUS-13-022	19.5/fb	NEW
Search for supersymmetry in hadronic final states using MT2 with the CMS detector at 8 TeV	SUS13019	PAS-SUS-13-019	19.5/fb	NEW
Search for direct production of stops decaying to a charm and LSP using the monojet + MET final state	SUS13009	PAS-SUS-13-009	19.7/fb	NEW
Search for top squarks in multijet events with large missing momentum in pp collisions at 8 TeV	SUS13015	PAS-SUS-13-015	19.4/fb	NEW
A search for new physics in events with one lepton, high jet multiplicity and high b-tagged jet multiplicity in pp collisions at 8 TeV	SUS12015	PAS-SUS-12-015	19.3/fb	
Search for Direct Top Squark Pair Production with Higgs bosons in the Final State in pp collisions at 8 TeV	SUS13021	PAS-SUS-13-021	19.5/fb	
Search for SUSY in Opposite Sign Dilepton events, large number of jets, b-jets and MET in pp collisions at 8 TeV	SUS13016	PAS-SUS-13-016	19.7/fb	
Search for electroweak production of charginos and neutralinos in final states with a Higgs boson in pp collisions at 8 TeV	SUS13017	PAS-SUS-13-017	19.5/fb	
Search for SUSY using razor variables in events with b-jets in pp collisions at 8 TeV	SUS13004	PAS-SUS-13-004	19.3/fb	
Search for supersymmetry in the 3 lepton + b-tag final state in pp collisions at 8 TeV	SUS13008	PAS-SUS-13-008	19.5/fb	
Search for RPV SUSY in the 4-lepton final state in pp collisions at 8 TeV	SUS13010	PAS-SUS-13-010	19.5/fb	
A Search for Anomalous Production of Events with three or more leptons using 9.2 fb-1 of √s = 8 TeV CMS Data	SUS12026	PAS-SUS-12-026	9.2/fb	Updated with more data above
Search for RPV supersymmetry with three or more leptons and b-tags	SUS12027	PAS-SUS-12-027	9.2/fb	
Search for electroweak production of charginos, neutralinos and sleptons using leptonic final states in pp collisions at 8 TeV	SUS12022	PAS-SUS-12-022	9.2/fb	Updated with more data above
Search for Supersymmetry in Events with Photons and Missing Energy √s = 8 TeV	SUS12018	PAS-SUS-12-018	4.04/fb	
Search for direct top squark pair production in events with a single isolated lepton, jets and missing transverse energy at √s = 8 TeV	SUS12023	PAS-SUS-12-023	9.7/fb	Updated with more data above
Search for supersymmetery in final states with missing transverse energy and 0, 1, 2, or ≥ 3 b jets in 8 TeV pp collisions	SUS12016	PAS-SUS-12-016	3.9/fb	Updated with more data above

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

Plenty CMS SUSY Analyses

Journal Publications with 2012 8 TeV Data

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
Searches for electroweak production of charginos, neutralinos, and sleptons decaying to leptons and W,Z, and Higgs bosons in pp collisions at 8 TeV		CMS-SUS-13-006	19.5/fb	Submitted to EPJC arXiv:1405.7570 NEW
Search for top-squark pair production with Higgs and Z bosons in the final state in pp collisions at 8 TeV	SUS13024	CMS-SUS-13-024	19.5/fb	Submitted to PLB arXiv:1405.3886 NEW
Search for anomalous production of events with three or more leptons in pp collisions at 8 TeV	SUS13002	CMS-SUS-13-002	19.5/fb	Submitted to PRD arXiv:1404.5801 NEW
Search for New Physics in Multijets and Missing Momentum Final State in pp collisions at 8 TeV	SUS13012	CMS-SUS-13-012	19.5/fb	Accepted by JHEP arXiv:1402.4770
Search for SUSY Partners of Top and Higgs Using Diphoton Higgs Decays in pp collisions at 8 TeV	SUS13014	CMS-SUS-13-014	19.5/fb	Accepted by PRL arXiv:1312.3310
Search for new physics in events with same-sign dileptons and jets in pp collisions at 8 TeV	SUS13013	CMS-SUS-13-013	19.5/fb	JHEP 01 (2014) 163 arXiv:1311.6736
Search for supersymmetry using events with a single lepton, multiple jets, and b-tags	SUS13007	CMS-SUS-13-007	19.3/fb	Submitted to PLB arXiv:1311.4937
Search for top-squark pair production in the single lepton final state in pp collisions at 8 TeV	SUS13011	CMS-SUS-13-011	19.5/fb	EPJC 73 (2013) 2677 arXiv:1308.1586
Search for stop in R-parity-violating supersymmetry with three or more leptons and b-tags	SUS13003	CMS-SUS-13-003	19.5/fb	PRL 111, 221801 (2013), arXiv:1306.6643
Search for supersymmetry using the shape of the HT and MET, and b-jet multiplicity distributions	SUS12024	CMS-SUS-12-024	19.4/fb	PLB 725 243 (2013), arXiv:1305.2390
Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, 3, or ≥ 4 b jets in 8 TeV pp collisions	SUS12028	CMS-SUS-12-028	11.7/fb	EPJC 73 (2013) 2568, arXiv:1303.2985
Search for new physics in events with same-sign dileptons and b-tagged jets in pp collisions at √s = 8 TeV	SUS12017	CMS-SUS-12-017	10.5/fb	JHEP03 (2013) 037, JHEP07(2013)041, arXiv:1212.6194

Recent Preliminary Results with 2012 8 TeV Data

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
Phenomenological MSSM Interpretation of the 7 and 8 TeV results	SUS13020	PAS-SUS-13-020	19.5/fb	NEW
Search for direct production of a pair of bottom squarks		PAS-SUS-13-018	19.4/fb	NEW
Search for electroweak production of higgsinos in channels with two Higgs bosons decaying to b quarks in pp collisions at 8 TeV	SUS13022	PAS-SUS-13-022	19.5/fb	NEW
Search for supersymmetry in hadronic final states using MT2 with the				
Search for direct production of stops decaying to a charm and LSP u				
Search for top squarks in multijet events with large missing momentum in pp collisions at 8 TeV	SUS13015	PAS-SUS-13-015	19.4/fb	NEW
A search for new physics in events wit pp collisions at 8 TeV				
Search for Direct Top Squark Pair Prod				
Search for SUSY in Opposite Sign Dilepton events, large number of jets, b-jets and MET in pp collisions at 8 TeV	SUS13016	PAS-SUS-13-016	19.7/fb	
Search for electroweak production of charginos and neutralinos in final states with a Higgs boson in pp	SUS13017	PAS-SUS-13-017	19.5/fb	
	SUS13004	PAS-SUS-13-004	19.3/fb	
	SUS13008	PAS-SUS-13-008	19.5/fb	
Search for RPV SUSY in the 4-lepton final state in pp collisions at 8 TeV	SUS13010	PAS-SUS-13-010	19.5/fb	
A Search for Anomalous Production of Events with three or more leptons using 9.2 fb-1 of √s = 8 TeV CMS Data	SUS12026	PAS-SUS-12-026	9.2/fb	Updated with more data above
Search for RPV supersymmetry with three or more l				
Search for electroweak production of charginos, ne collisions at 8 TeV				th more
Search for Supersymmetry in Events with Photons a		12-018		
Search for direct top squark pair production in events with a single isolated lepton, jets and missing transverse energy at √s = 8 TeV	SUS12023	PAS-SUS-12-023	9.7/fb	Updated with more data above
Search for supersymmetery in final states with missing transverse energy and 0, 1, 2, or ≥ 3 b jets in 8 TeV pp collisions	SUS12016	PAS-SUS-12-016	3.9/fb	Updated with more data above

pMSSM interpretations

generic EWKino search

generic hadronic SUSY search

3rd generation hadronic SUSY search

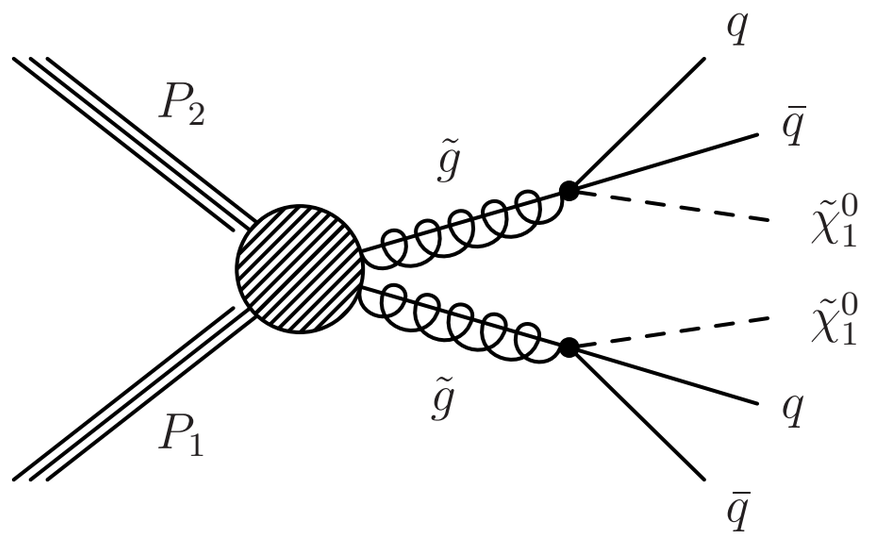
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

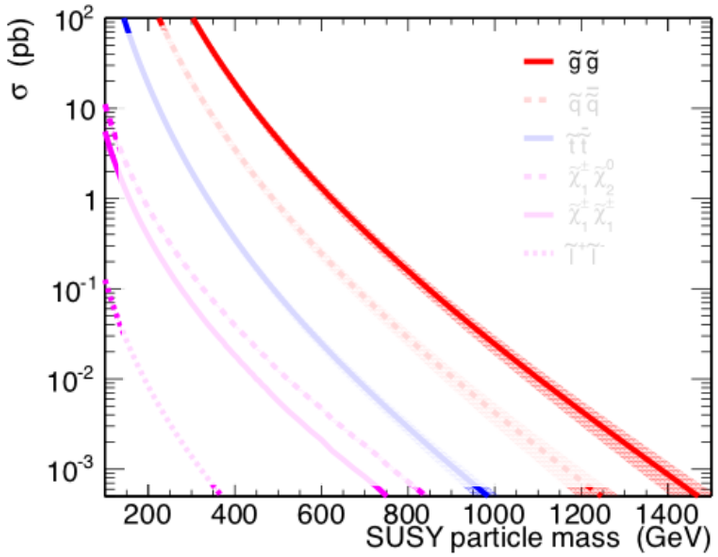
SUSY Search in Inclusive All-Hadronic Events

CMS-SUSY-13-012

Signature: MET + Jets

- ≥3 jets with pT > 50 GeV,
  - no b-jets
- veto events with isolated leptons
- veto event if MET is aligned with any of 3 leading jets





Search in bins of

- jet multiplicity (3-5, 6-7, ≥8 jets)
- event transverse energy H_T $\quad H_T = \sum_{j=jets} \left| \vec{p}_T^{\,j} \right|$
- jets missing energy MHT $\quad \not{H}_T = \left| -\sum_{j=jets} \vec{p}_T^{\,j} \right|$

SUSY Search in Inclusive All-Hadronic Events

36 inclusive search regions

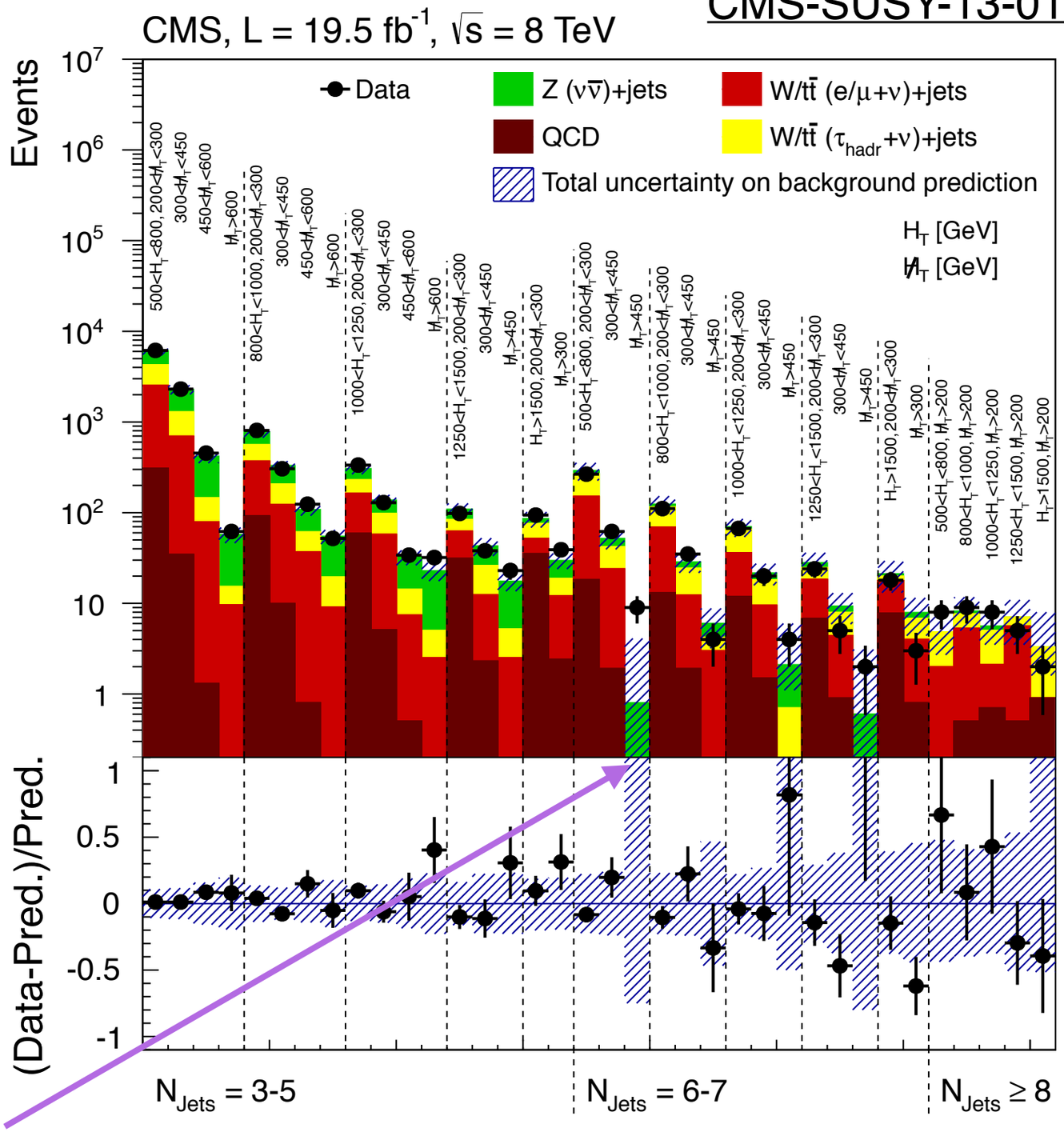
Background predictions is the trickiest part

- for example: how would you evaluate background from Z($\nu\nu$)+6 jets?

Most observations are consistent with background predictions

- P(n≥9, μ=0.8+3.3-0.6)=0.15
  - NB: Look Elsewhere Effect

CMS-SUSY-13-012

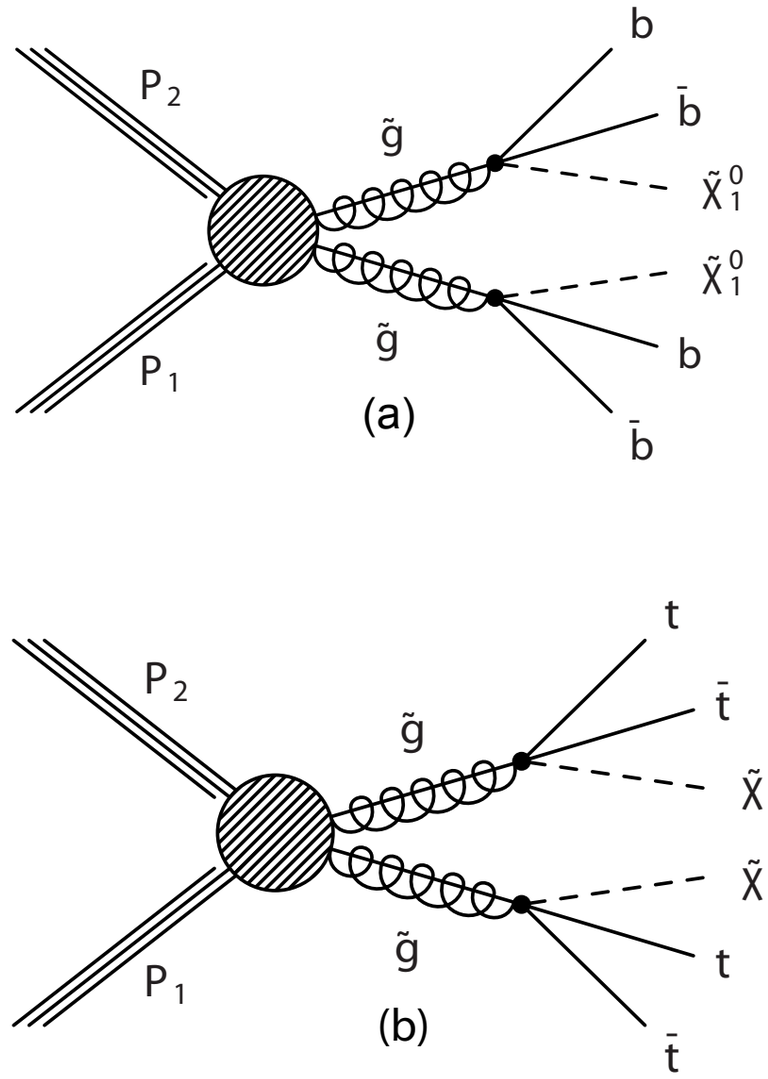


SUSY Search in All-Hadronic Events With b-jets

CMS-SUSY-12-024

Signature: MET + b-jets

- ⩾3 jets with $p_T > 50$ GeV
  - 2 leading jets $p_T > 70$ GeV
  - ⩾1 b-jets



Search in bins of

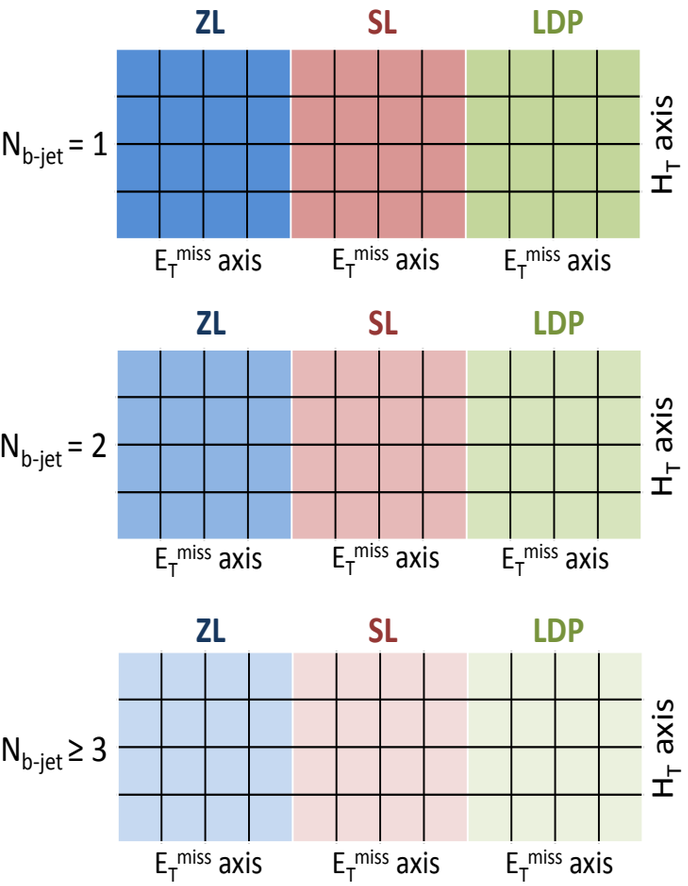
- b-jet multiplicity (1, 2, ≥3 jets)
- event transverse energy H_T
- event missing energy MET

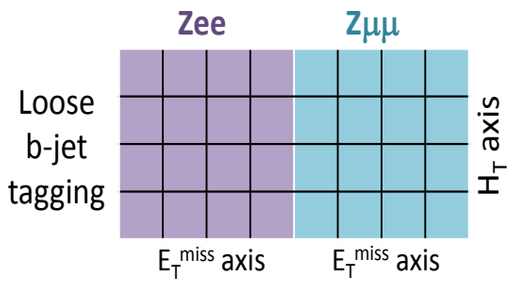
SUSY Search in All-Hadronic Events With b-jets

CMS-SUSY-12-024

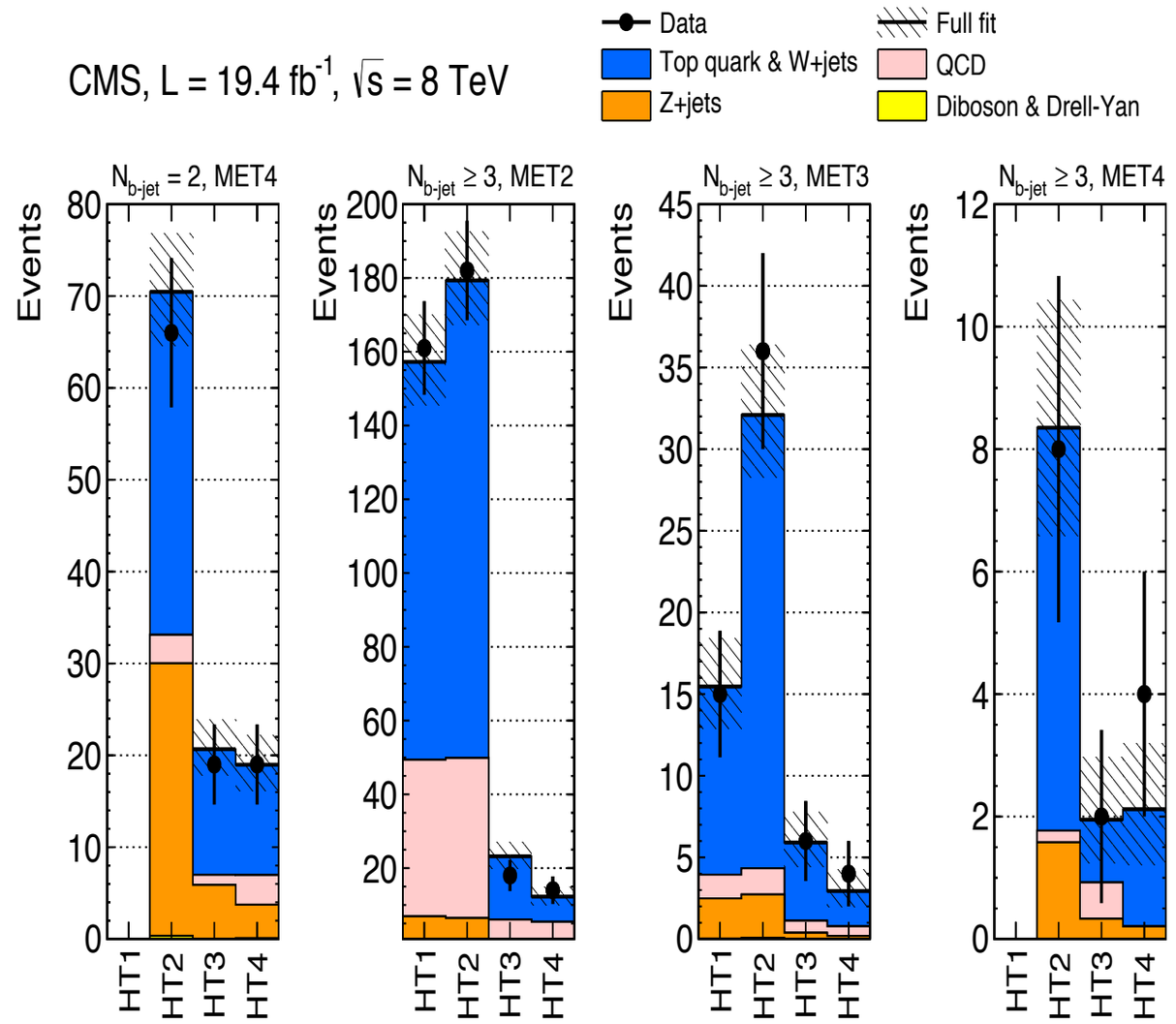
Event sample legend

ZL = Zero Lepton; signal sample	**SL** = Single Lepton; top & W+jets control sample	**LDP** = low $\Delta\hat{\phi}_{min}$; QCD control sample	**Zee** = $Z \to e^+e^-$; Z to $\nu\bar{\nu}$ control sample	**Zμμ** = $Z \to \mu^+\mu^-$; Z to $\nu\bar{\nu}$ control sample





Bin	H_T (GeV)	E_T^{miss} (GeV)
1	400 – 500 (HT1)	125 – 150 (MET1)
2	500 – 800 (HT2)	150 – 250 (MET2)
3	800 – 1000 (HT3)	250 – 350 (MET3)
4	> 1000 (HT4)	> 350 (MET4)



16 most significant channels

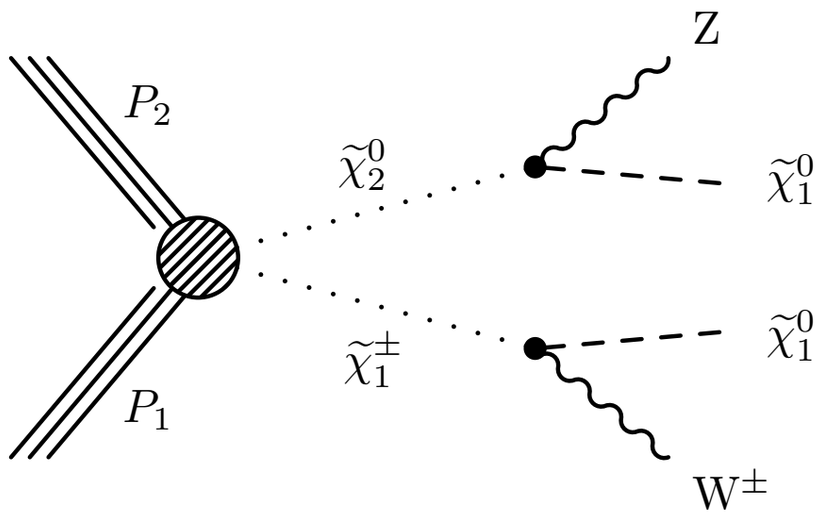
- 176 total channels, 3D shape analysis in (H_T, MET, $N_{b\text{-jets}}$)
  - 48 essentially signal search regions
  - 128 essentially control regions to constrain different backgrounds

Searches for Elecroweakino Production

CMS-SUSY-13-006

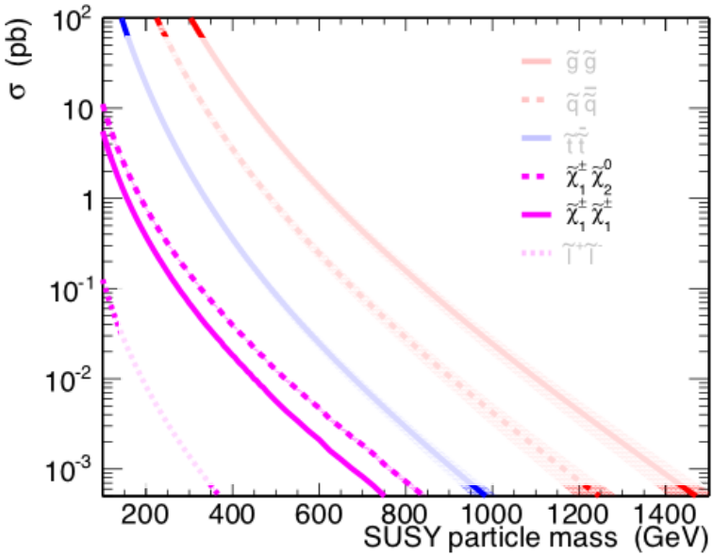
Signature: MET + leptons

- ⩾3 leptons with $p_T > 10$ GeV,
  - leading lepton $p_T > 20$ GeV
- or 2 leptons (Z) + 2 jets (W)
- veto events with b-tags



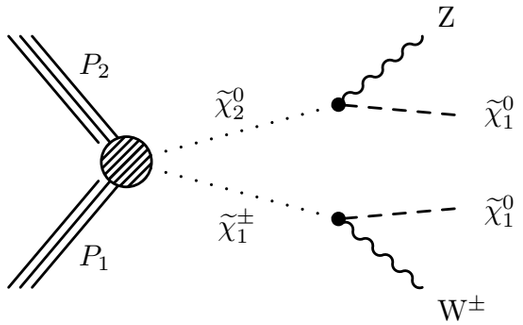
Search in bins of:

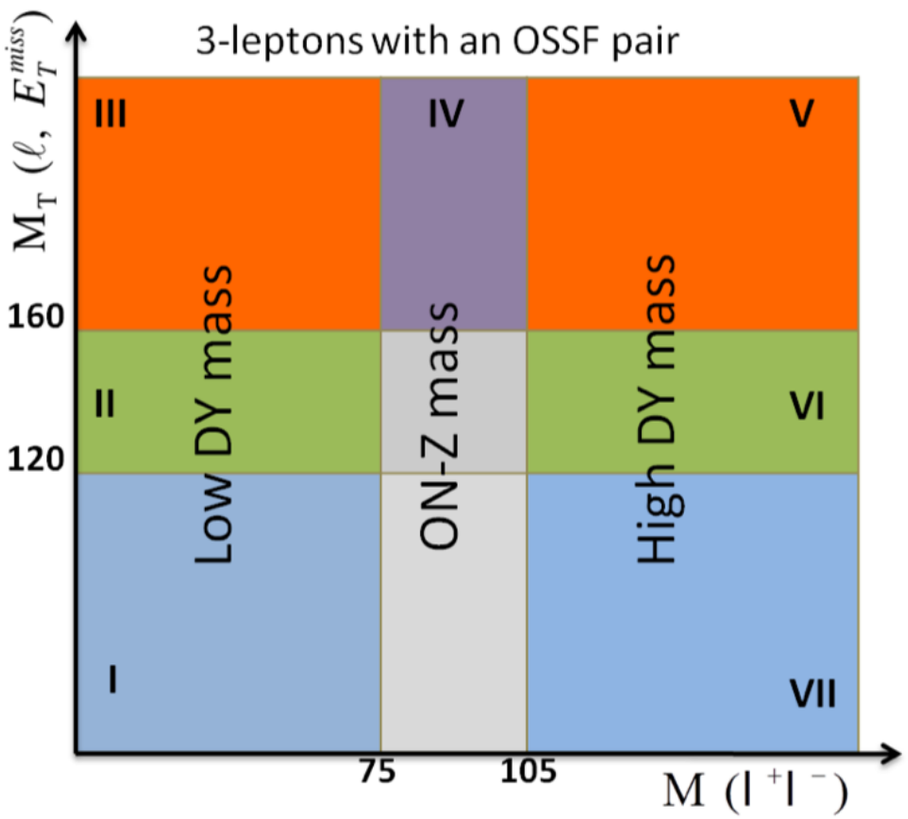
- leptons combinatoric
- event missing energy
- effective W mass

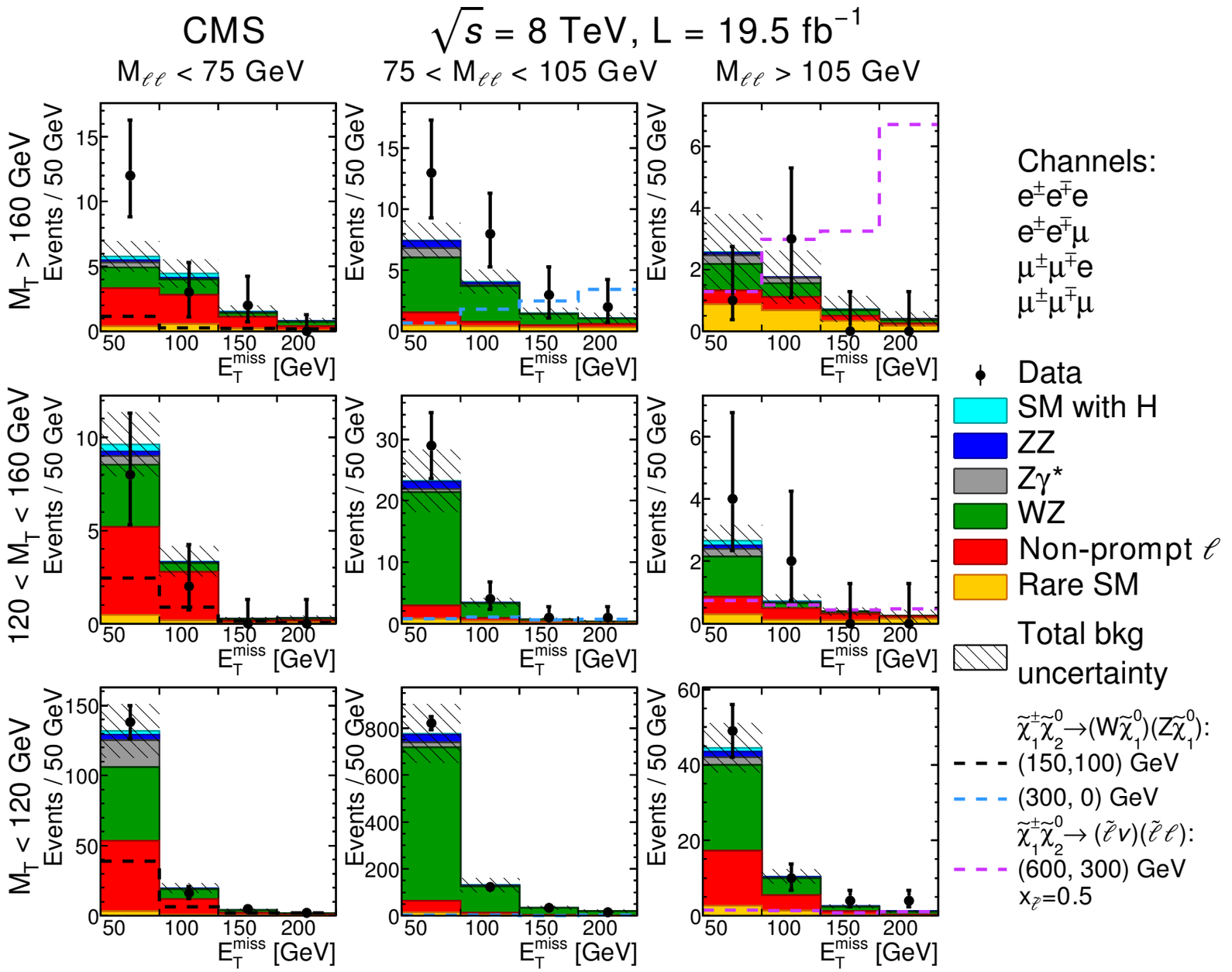


Searches for Elecroweakino Production

CMS-SUSY-13-006



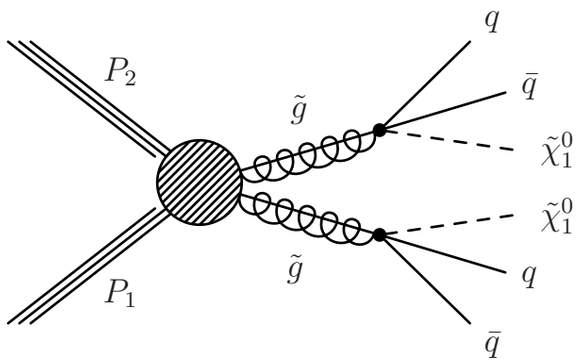


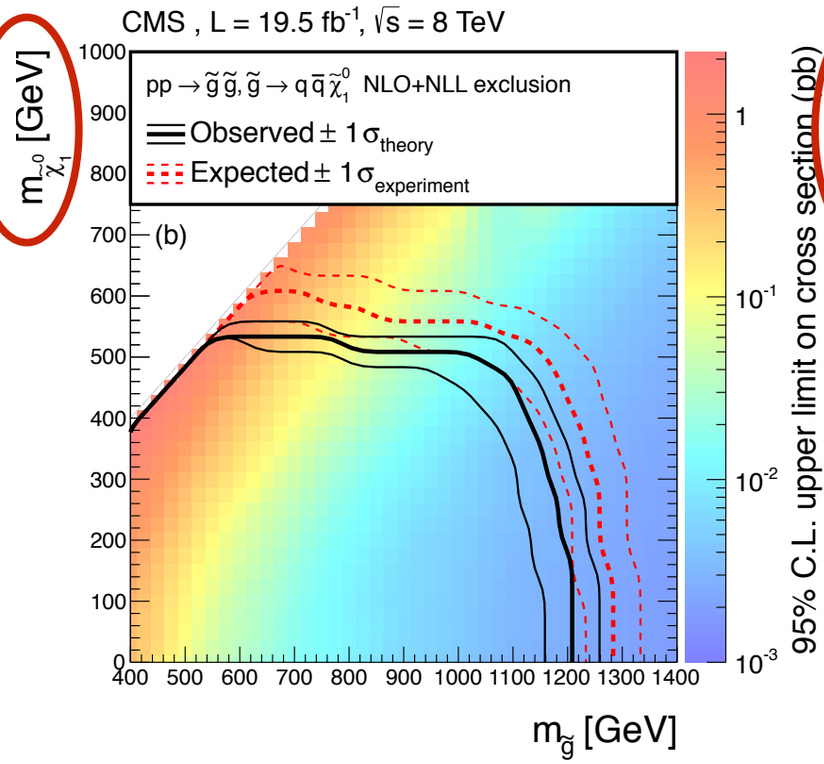


- 36 3-leptons search regions
- 5 (2-leptons)&(2-jets) search regions
- Main background is from SM WZ production

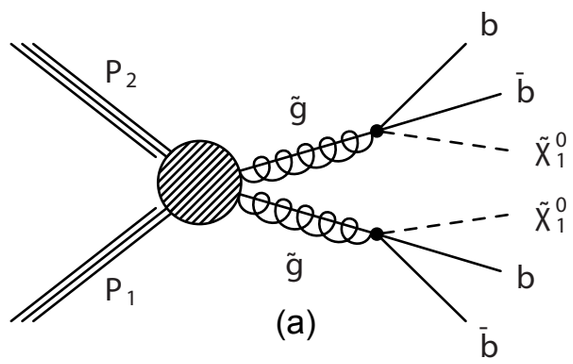
Interpretations in Simplified Models

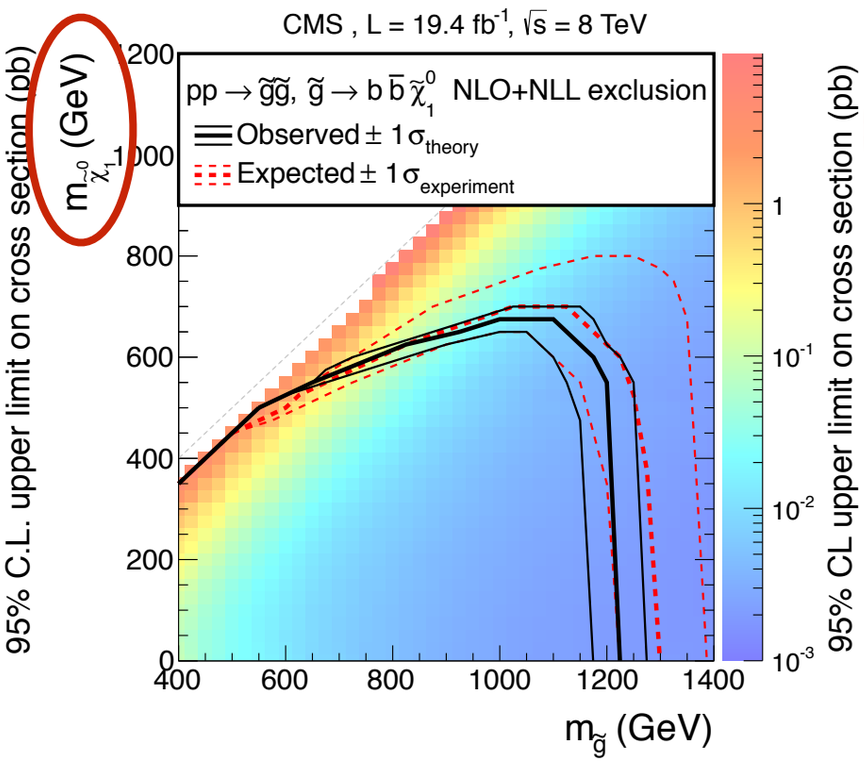
CMS-SUSY-13-012



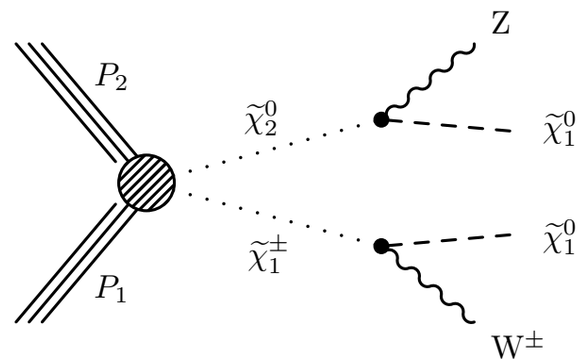


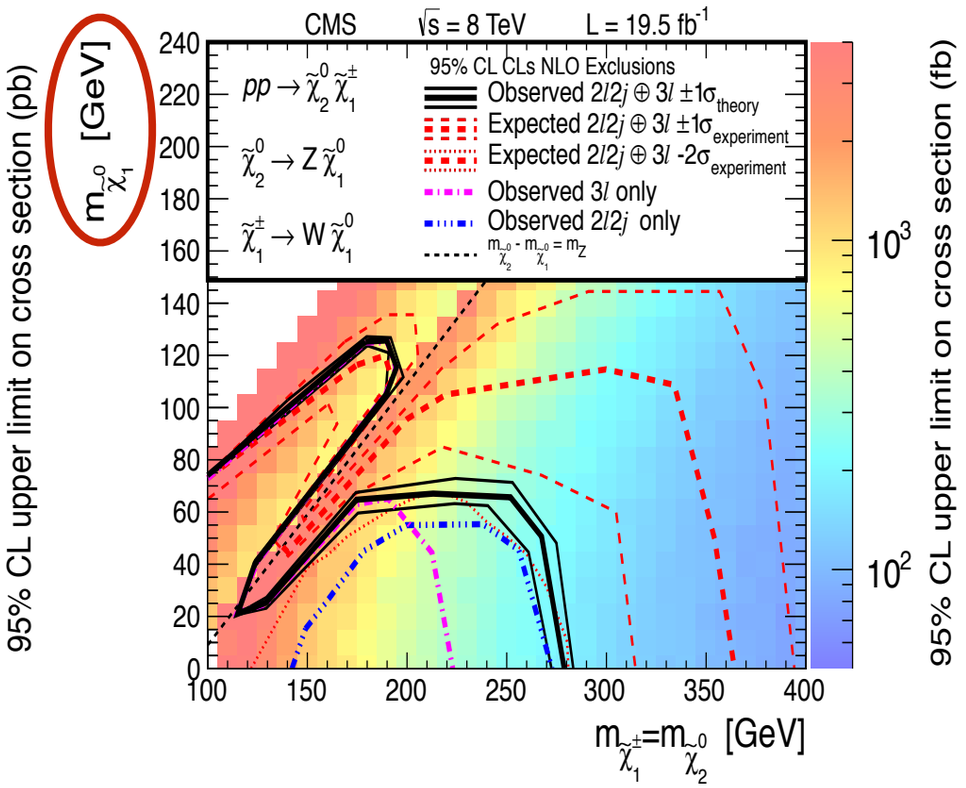
CMS-SUSY-12-024





CMS-SUSY-13-006





- Assumes exclusive contribution of given production/decay mode
  - artificial model used to quantify consistency between expected and observed signals
  - limits **may not** be interpreted as an observed physics limits on neutralino WIMP mass

pMSSM Interpretations

Flat pMSSM Parameters 19-D Priors

$$-3\,\text{TeV} \le M_1, M_2 \le 3\,\text{TeV}$$
$$0 \le M_3 \le 3\,\text{TeV}$$
$$-3\,\text{TeV} \le \mu \le 3\,\text{TeV}$$
$$0 \le m_A \le 3\,\text{TeV}$$
$$2 \le \tan\beta \le 60$$
$$0 \le \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \le 3\,\text{TeV}$$
$$-7\,\text{TeV} \le A_t, A_b, A_\tau \le 7\,\text{TeV},$$

no astrophysics data are included to demonstrate CMS effect

NB: absolute distributions strongly depend on choice of priors

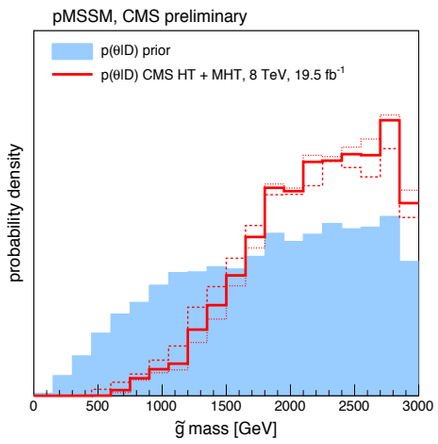
- variations from ▼ to ▼ illustrate effect of CMS measurements

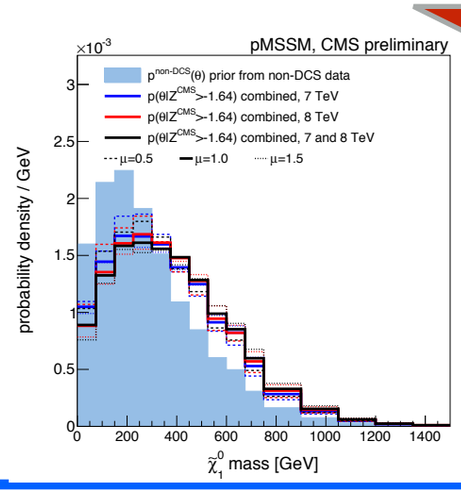
Non-CMS Data Used

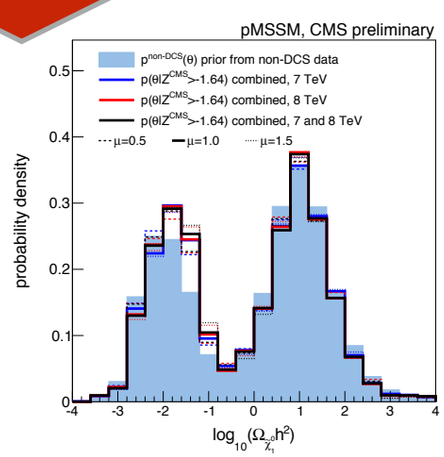
i	Observable $\mu_j(\theta)$	Constraint $D_j^{\text{non-DCS}}$	Likelihood function $L(D_j^{\text{non-DCS}}\|\mu_j(\theta))$	MCMC / post-MCMC
1a	$BR(b\to s\gamma)$	$(3.55 \pm 0.23^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.09^{\text{sys}}) \times 10^{-4}$	Gaussian	MCMC
1b	$BR(b\to s\gamma)$	$(3.43 \pm 0.21^{\text{stat}} \pm 0.24^{\text{th}} \pm 0.07^{\text{sys}}) \times 10^{-4}$	Gaussian	reweight
2a	$BR(B_s\to\mu\mu)$	observed CLs curve from	$d(1-CLs)/d(BR(B_s\to\mu\mu))$	MCMC
2b	$BR(B_s\to\mu\mu)$	$(2.9 \pm 0.7 \pm 0.29^{th}) \times 10^{-9}$	Gaussian	reweight
3a	$R(B_u\to\tau\nu)$	1.63 ± 0.54	Gaussian	MCMC
3b	$R(B_u\to\tau\nu)$	1.04 ± 0.34	Gaussian	reweight
4	Δa_μ	$(26.1 \pm 6.3^{\text{exp}} \pm 4.9^{\text{SM}} \pm 10.0^{\text{SUSY}}) \times 10^{-10}$	Gaussian	MCMC
5a	m_t	$173.3 \pm 0.5^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	MCMC
5b	m_t	$173.20 \pm 0.87^{\text{stat}} \pm 1.3^{\text{sys}}$ GeV	Gaussian	reweight
6	$m_b(m_b)$	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
7	$\alpha_s(M_Z)$	0.1184 ± 0.0007	Gaussian	MCMC
8a	m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \ge m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
8b	m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \le m_h \le m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$	reweight
9	sparticle masses	LEP (via micrOMEGAs)	1 if allowed 0 if excluded	MCMC

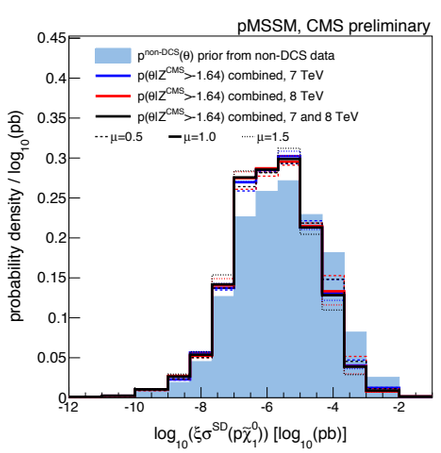
CMS Data Used

Analysis	$\sqrt{s}$	L	Likelihood	Ref.
Hadronic HT + MHT search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-011
Hadronic HT + MET + b-jets search	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-003
Leptonic search for EW prod. of $\tilde{\chi}^0$, $\tilde{\chi}^\pm$, $\tilde{l}$	7 TeV	4.98 fb^{-1}	method 1	CMS-SUS-12-006
Hadronic HT + MHT search	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-13-012
Hadronic HT + MET + b-jets search	8 TeV	19.4 fb^{-1}	method 2	CMS-SUS-12-024
Leptonic search for EW prod. of $\tilde{\chi}^0$, $\tilde{\chi}^\pm$, $\tilde{l}$ (ss, 3l and 4l channels)	8 TeV	19.5 fb^{-1}	method 1	CMS-SUS-12-006







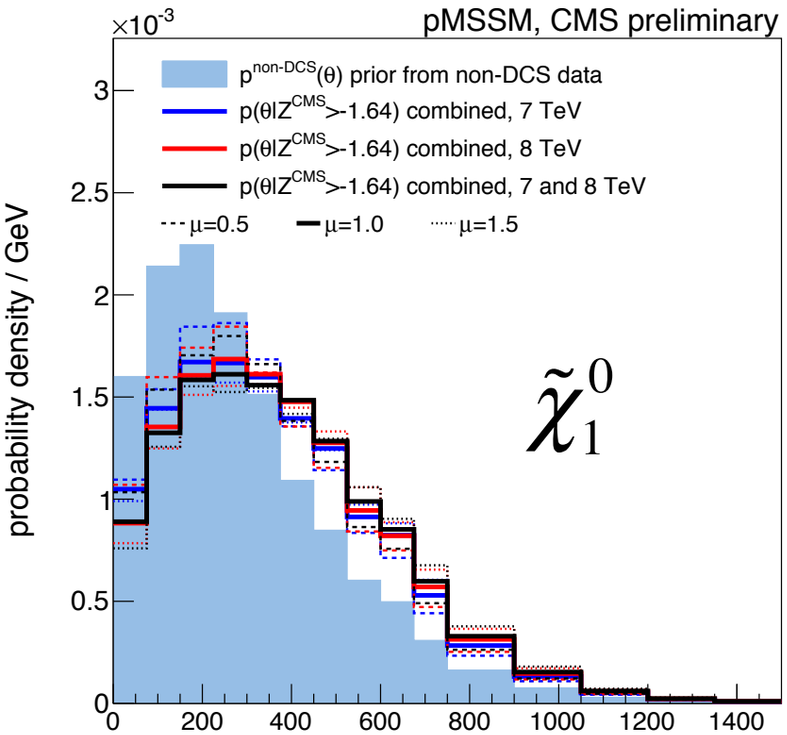


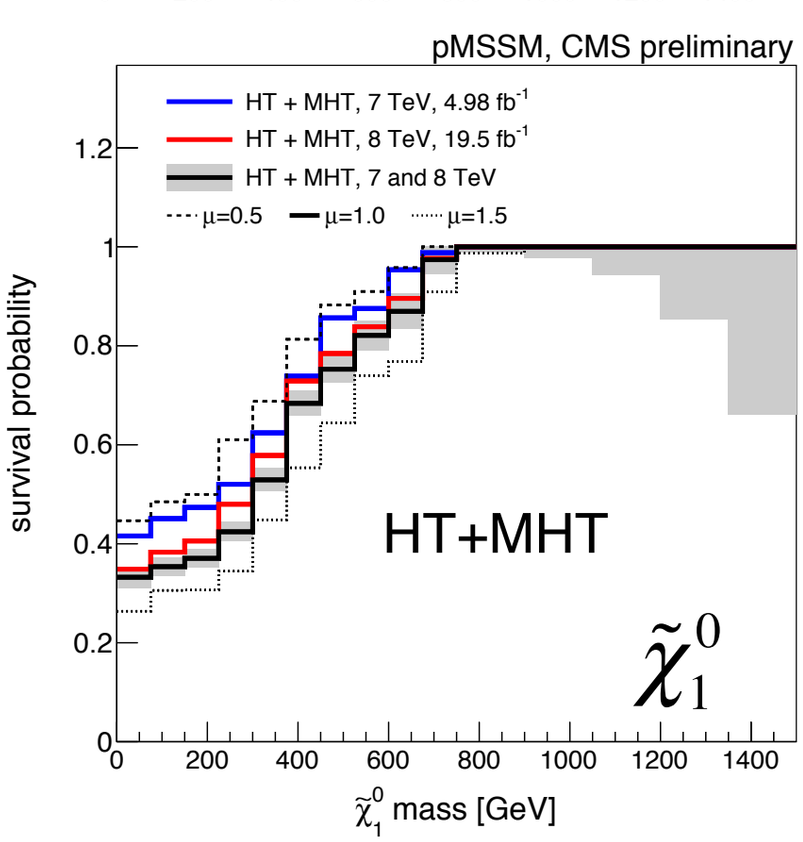
Implication for DM: WIMP Mass

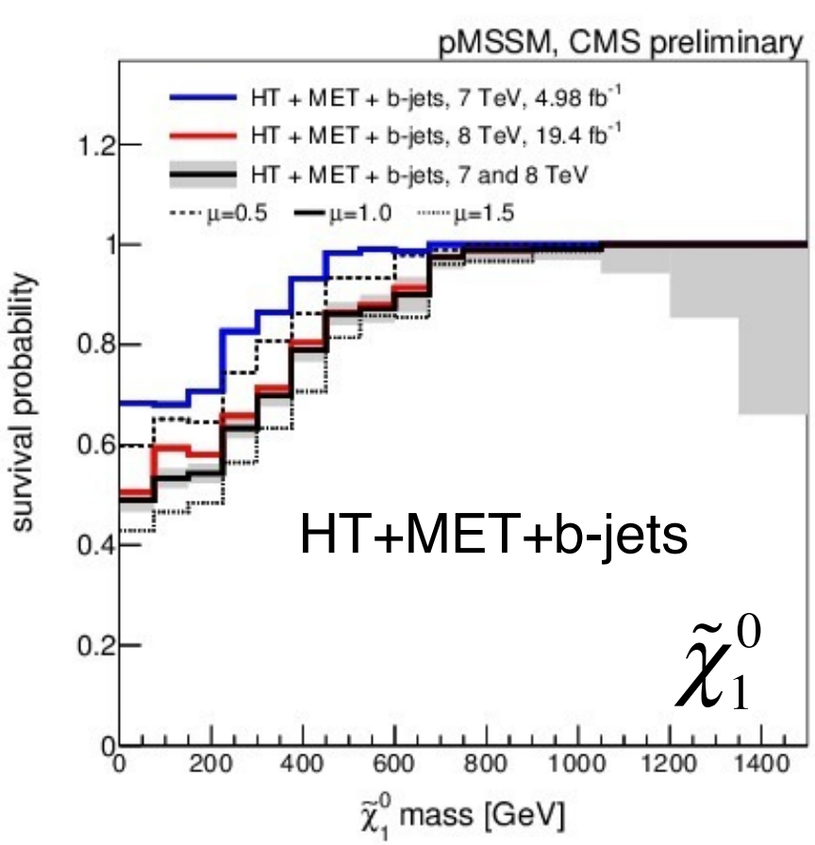
CMS-SUSY-13-020

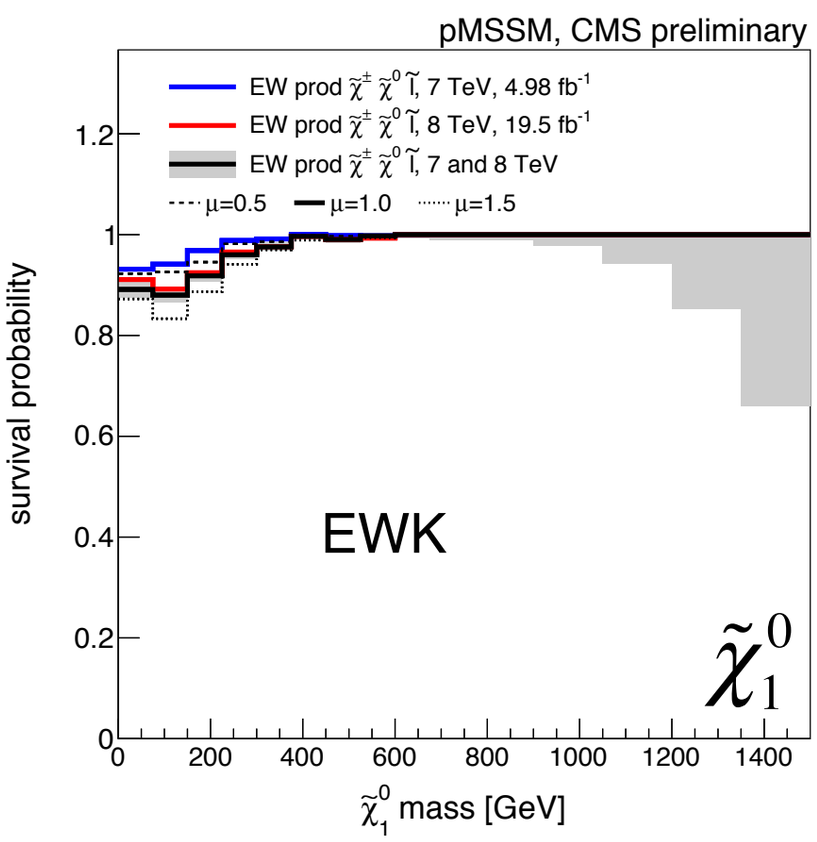
CMS Run 1 observations disfavor small neutralino masses

- HT+MET: sensitive up to 800 GeV
- HT+MET+b-jets: sensitive up to 600 GeV
- EWKino: sensitive up to 400 GeV



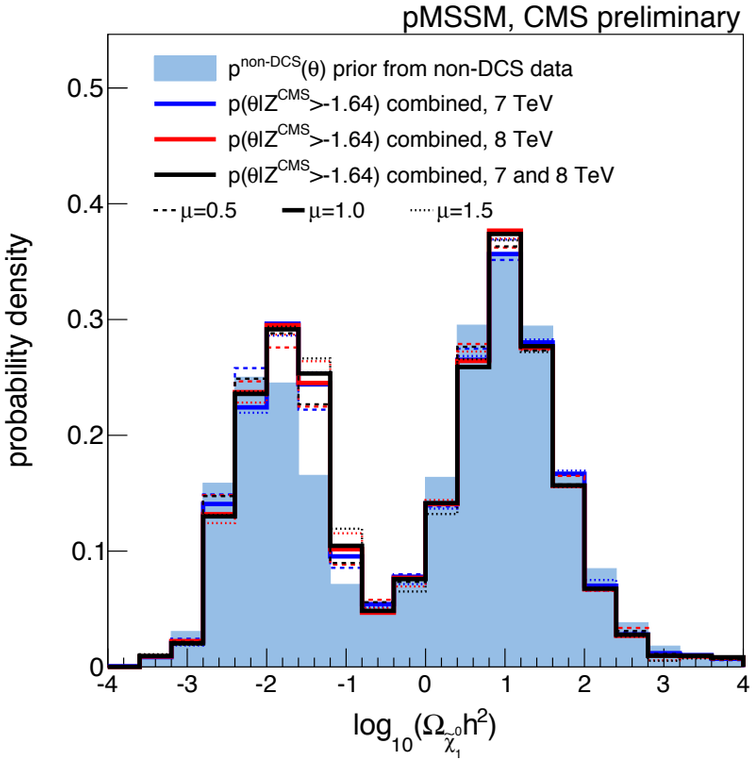


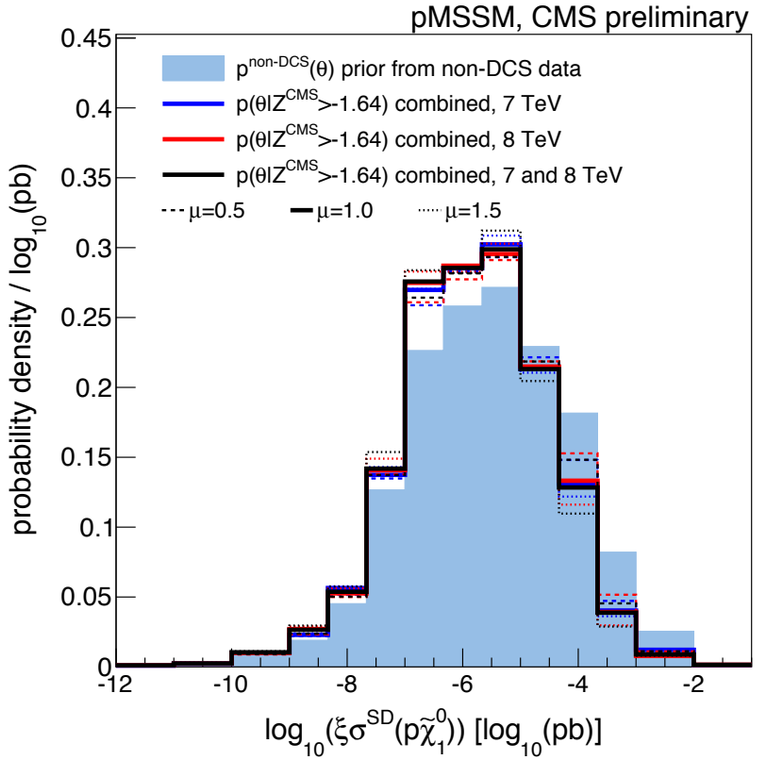


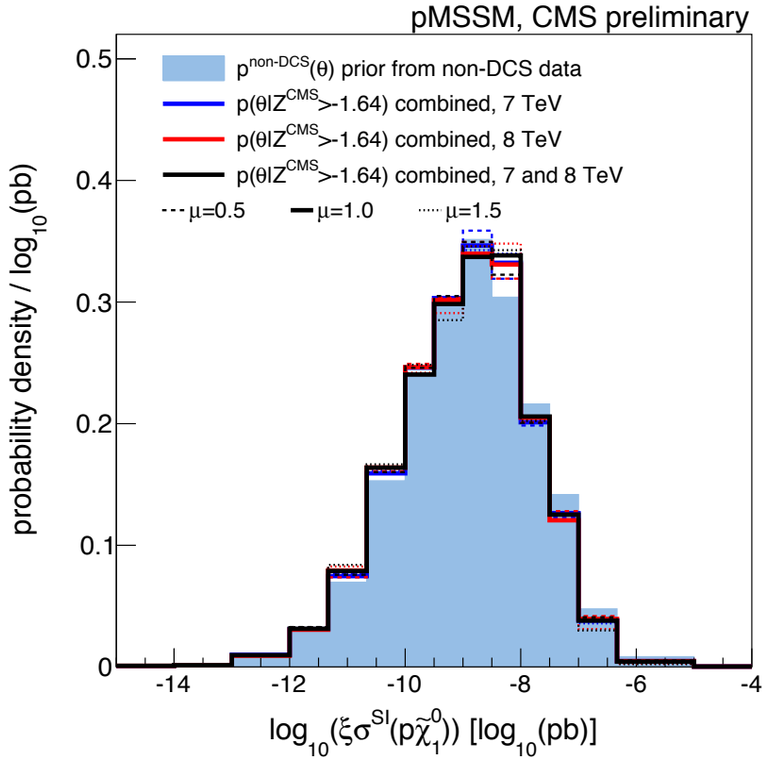


Implications for DM:Relict Density and WIMP Cross Sections

CMS-SUSY-13-020







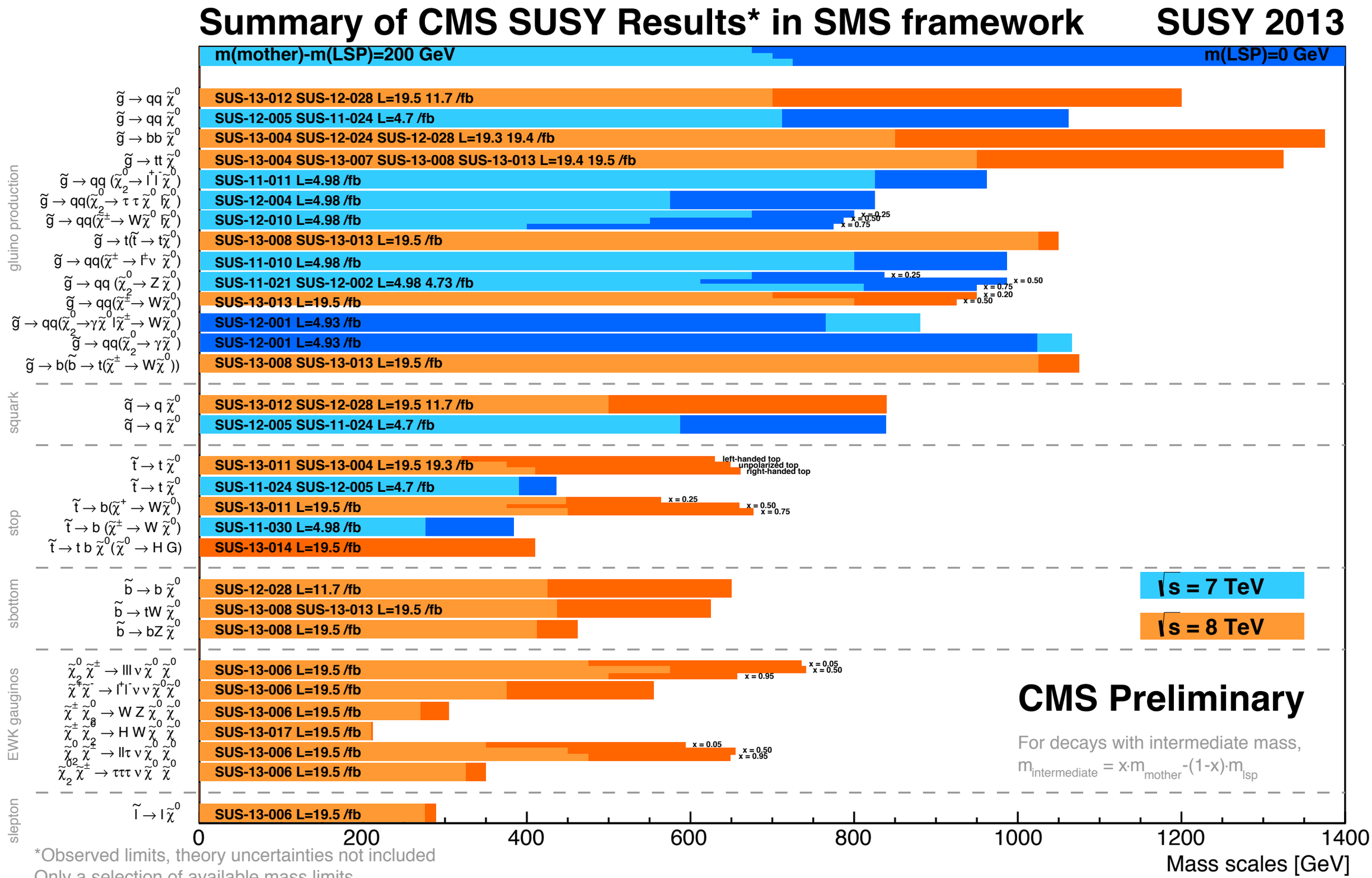
- PLANK Ωh^2 window is right at the dip
- CMS data slightly prefer lower densities
- lower $p\chi^0_1$ cross sections are marginally favored

Conclusions

- CMS has a comprehensive program for SUSY searches
  - particularly motivated by DM observations
- No clear SUSY signatures are found in LHC Run 1
- Bayesian approach is applied to see effects on DM parameters
- CMS SUSY analyses are marginally sensitive to relict density and DM detection cross sections
- CMS Run 1 data disfavor neutralino WIMP masses below 800 GeV

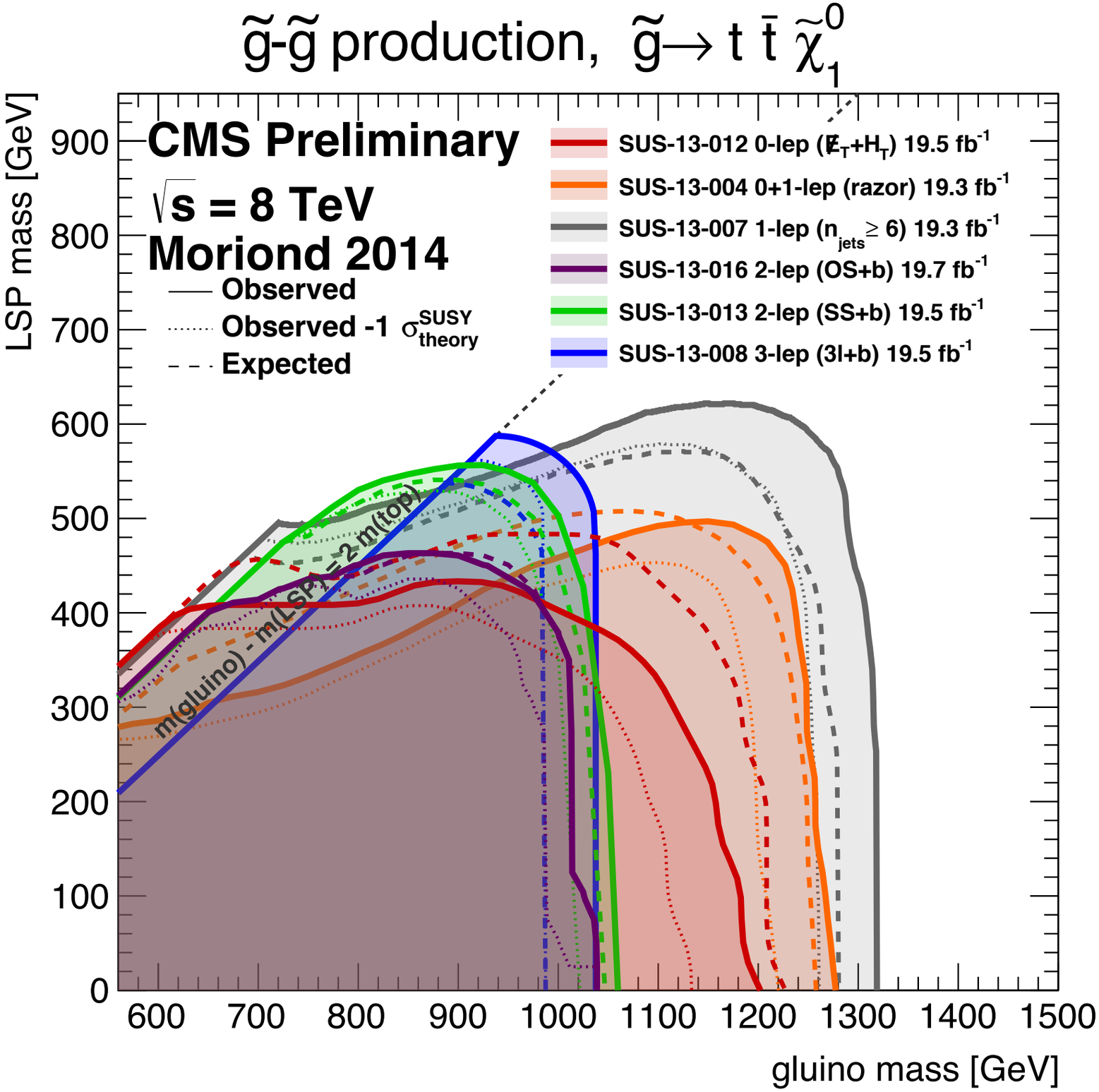
Backup

CMS SUSY Physics Results

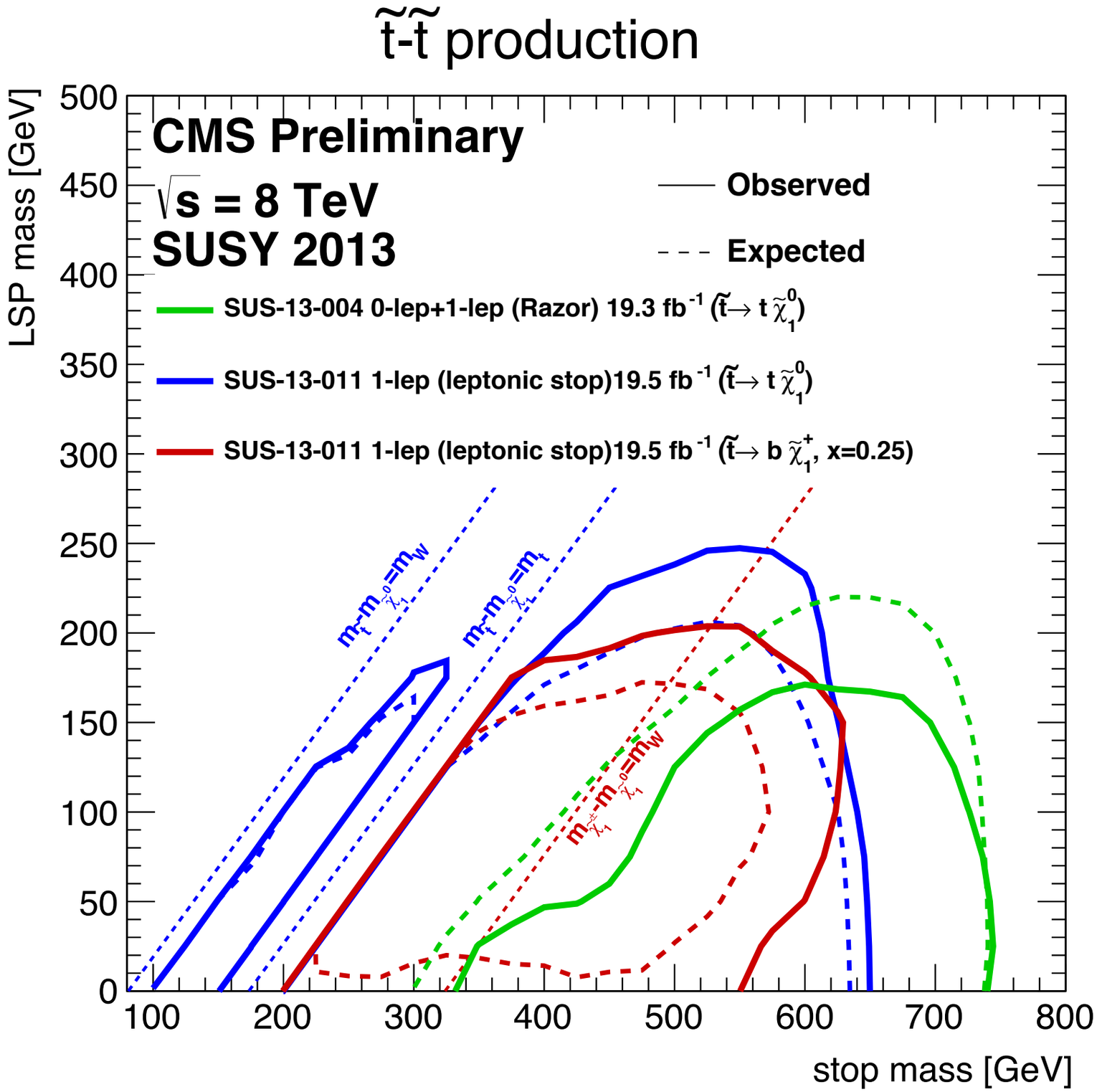


*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit

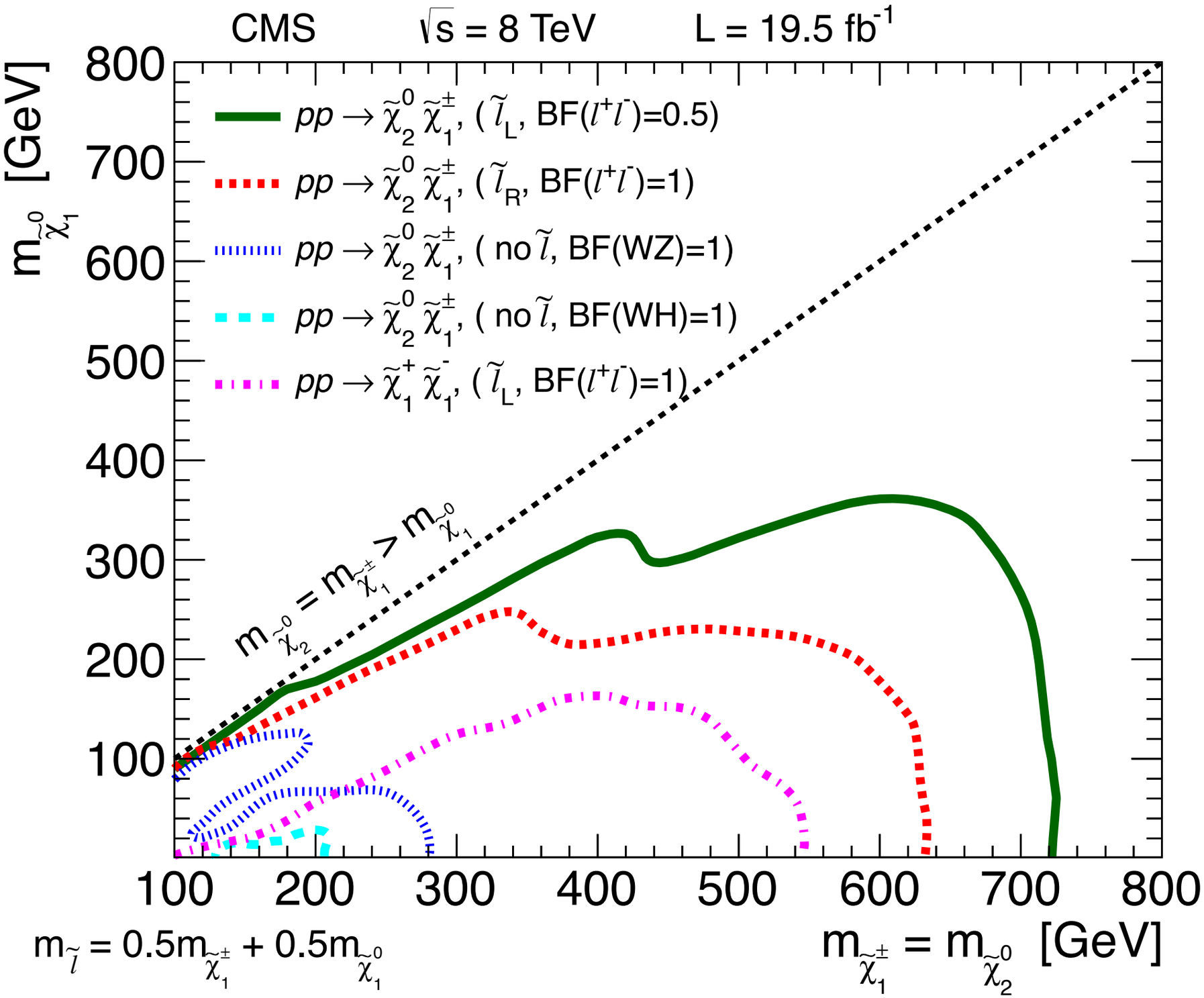
Gluino Production Results



Stop Production Results



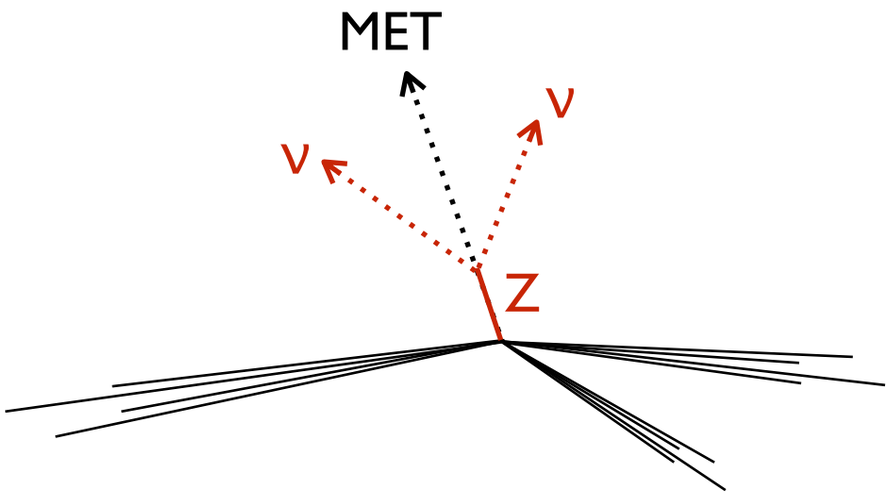
Electroweakino Production Results

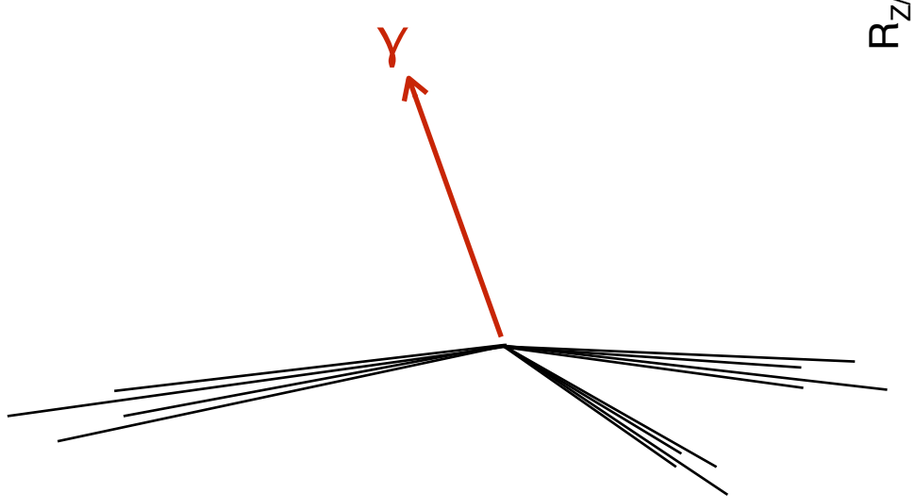


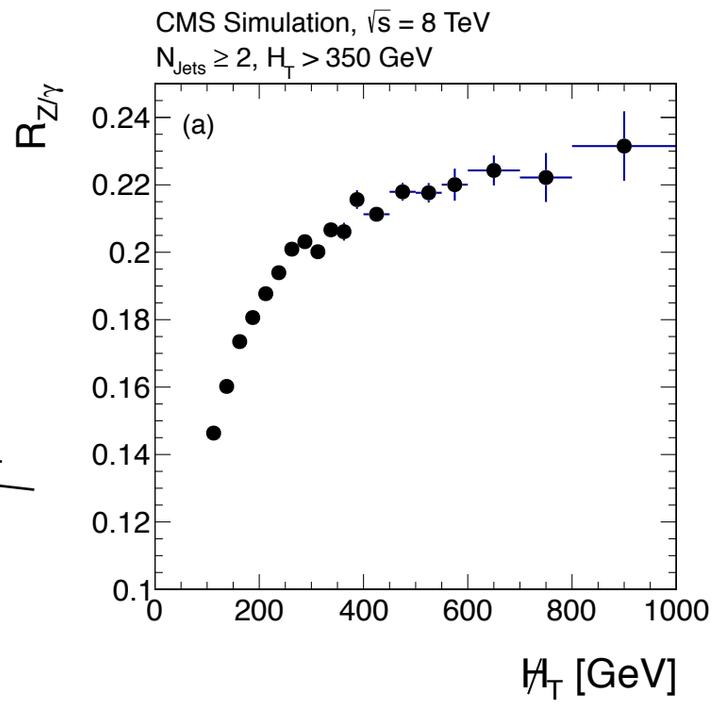
Data Driven Background Estimations

How do we evaluate background from Z(νν)+6 jets?

if the best NLO estimation goes up to 4 jets on the parton level







- Z and photon have coupling and mass, but are similar for associated QCD production
- production cross section ratio R(Z+jets/γ+jets) is known within 20%
- use photon+jets events and rescale by cross section, efficiencies etc to evaluate Z+jets backgrounds