New Physics Interpretations at the LHC
Argonne Lab, Lemont IL
2-4 May 2016

BSM searches in multilepton final states at CMS

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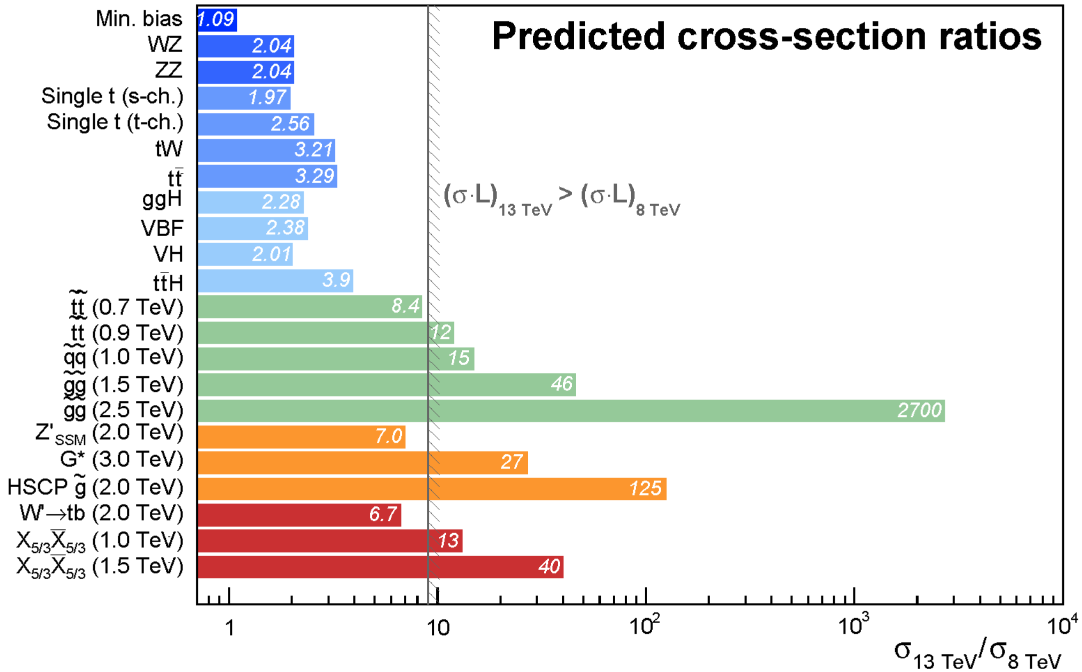
on behalf of CMS collaboration

LHC13: Going beyond

- LHC13 era started in 2015, 2.3/fb collected so far by CMS (was ~20/fb @LHC8)



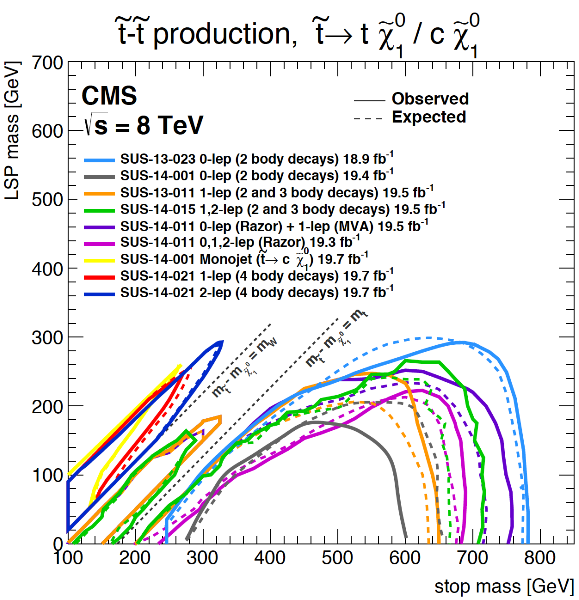
- Cross-section of many BSM benchmarks would significantly increase @LHC13
- E.g. gluino is what would be most abundantly produced (if exists)
- Sharp probes are need to scan all the challenging final states hiding NP

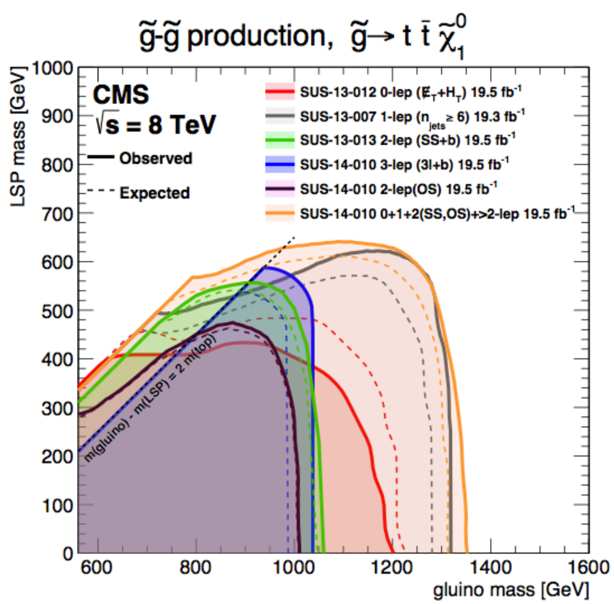
… focusing on *SUSY models* and *leptons*

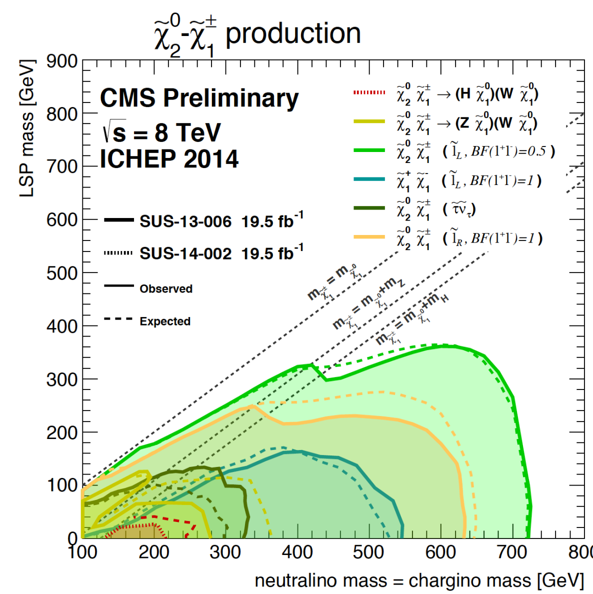
The SUSY 8 TeV legacy

CMS carried out a comprehensive search for SUSY: no excesses, but limits

- Covering a large number of signatures and final states
  - EWKino production, 3rd generation squarks, gluinos and heavy squarks





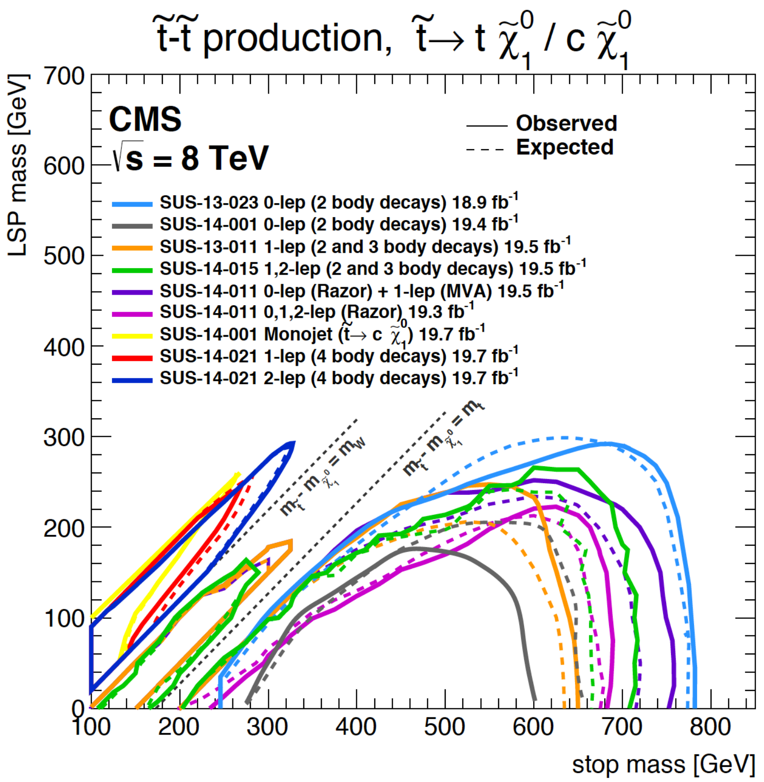


A caveat: we mostly deal with *simplified models*

- Assume 100% BR
- No statement on theory, but rather showing potential for a specific kinematics

How to read all this?

- Showing the potential of the different final states for a specific model



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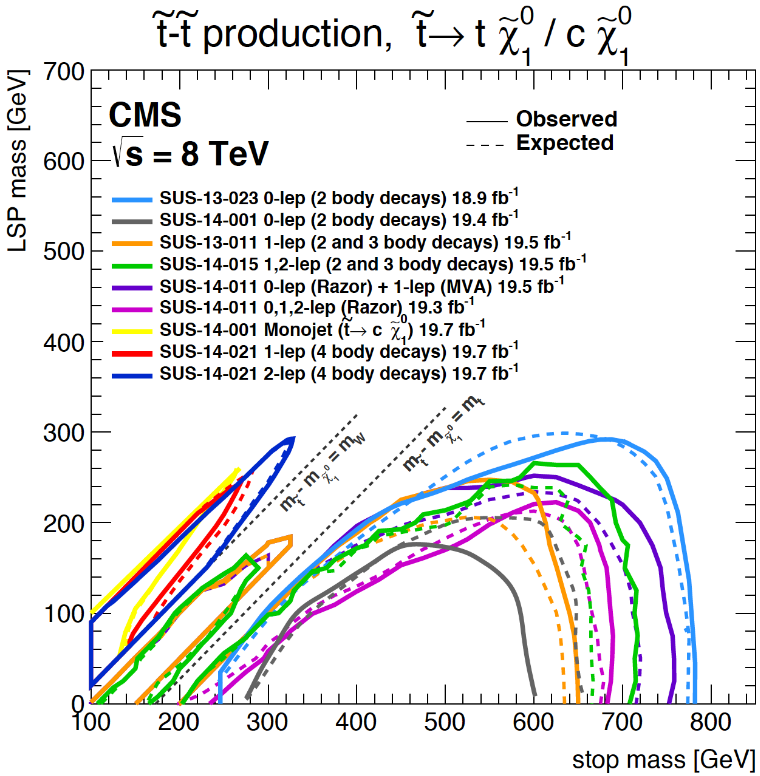

Bulk is proven by the hadronic, corners (*compressed*) mostly by leptonic final states

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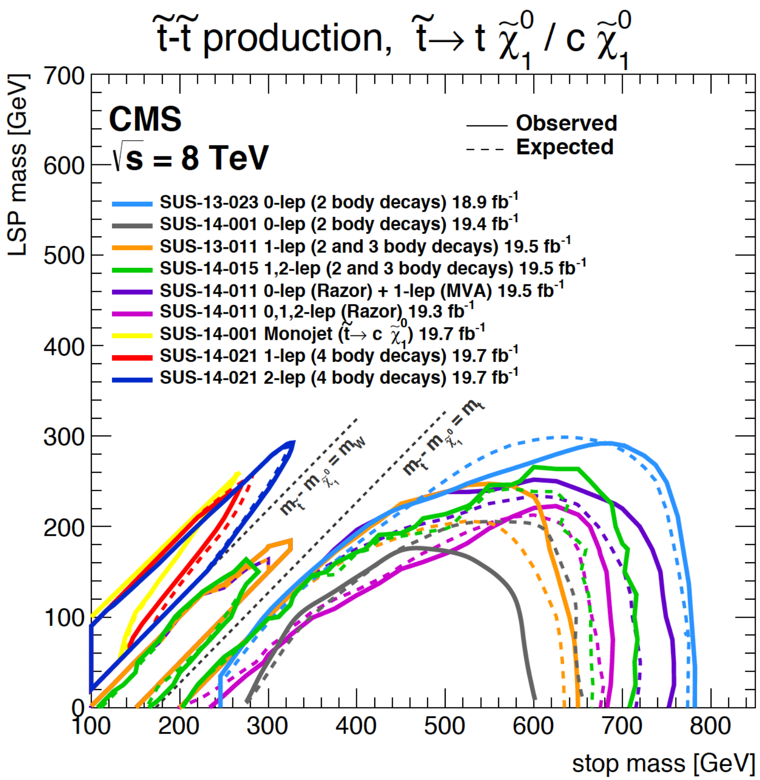

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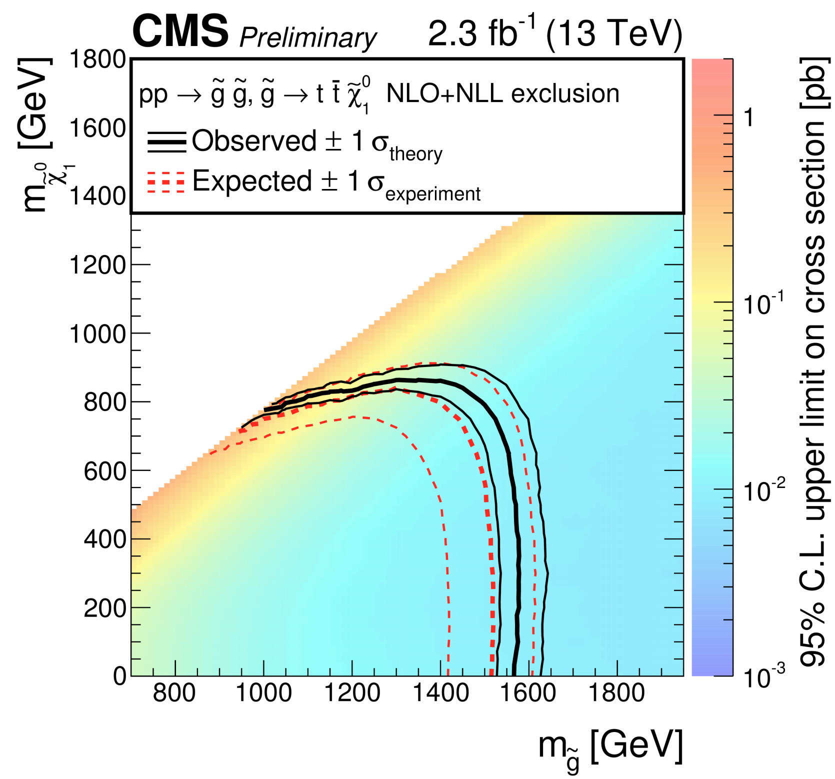
- Model independent limits on the cross section for a specific final state (+ specific benchmark contour)



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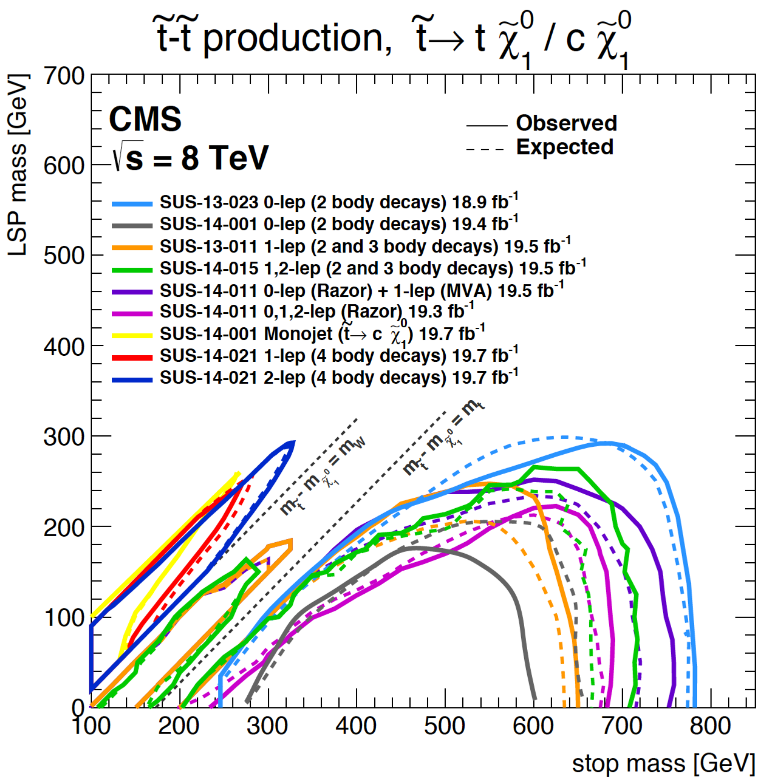

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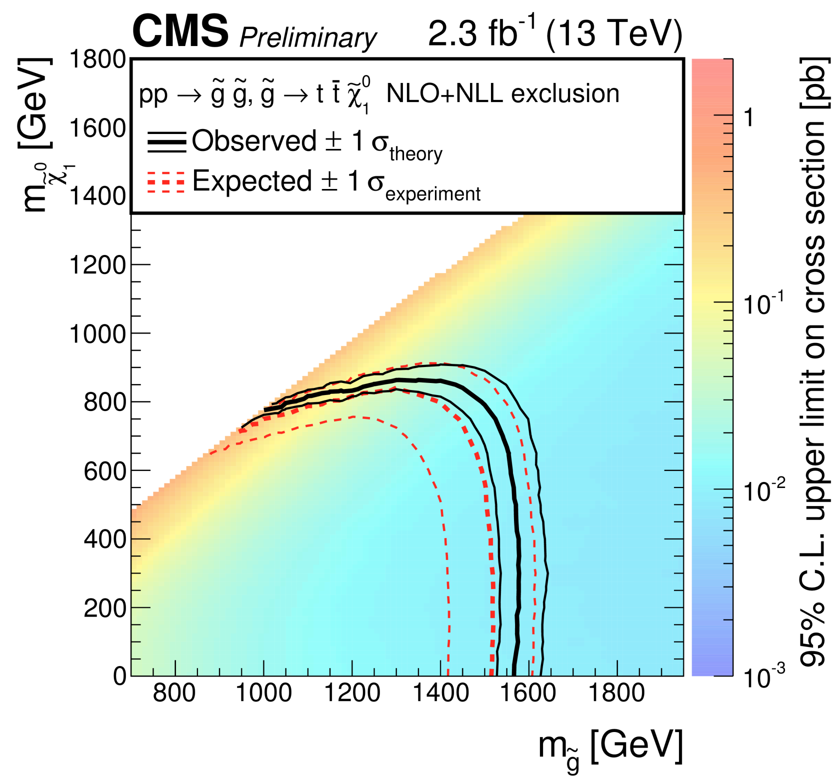

Can be reinterpreted in any other model with the same final state (modulo signal efficiency)

The importance of being *lepton*

- In R-parity SUSY, LSP is the most natural DM candidate
- LSP at rest = nothing in the detector, need a (transverse) boost

  the key: Missing Transverse Energy (MET)

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+ leptons: leptonic final states

- Targeting generic decays but also corners of phase space (e.g. compressed)
- Smaller BR, but low SM background

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton

Large — SM backgrounds → Low

← sensitivity to strongly produced SUSY

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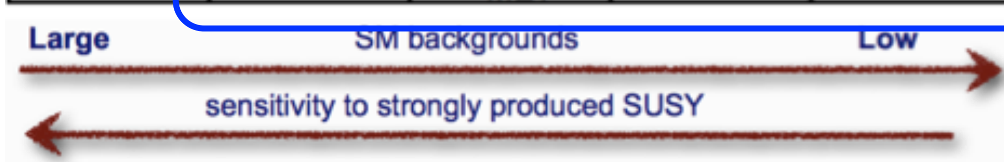
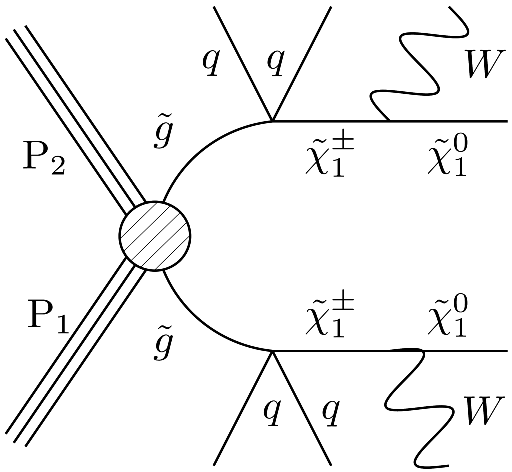


1 lepton + MET

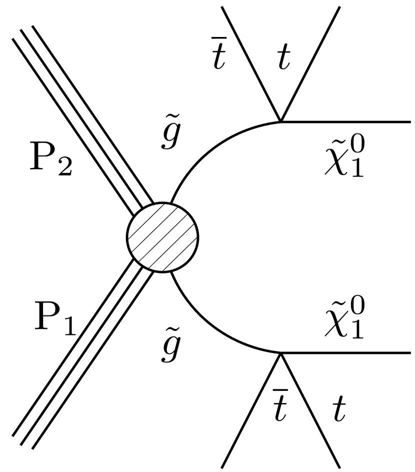
CMS-SUS-15-006

1 lepton in a nutshell

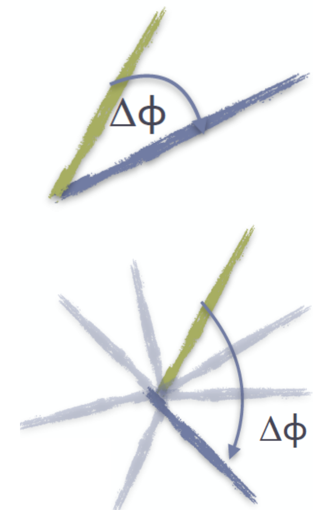
- *Benchmarks*: targeting gluino induced processes (T5qqqqWW and T1tttt)



0 b-tag



High b-tag multiplicity

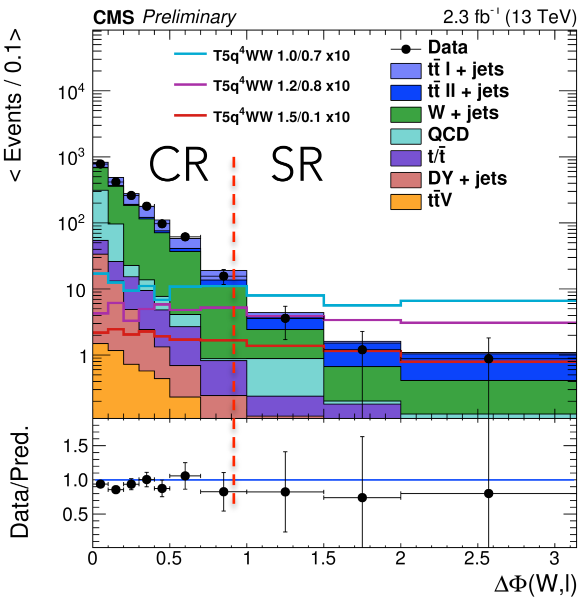


- *Selection*: one lept. pT> 25 GeV, HT[*]>500 GeV, LT[*]>250 GeV, veto for other lept.
- *Main backgrounds*: ttbar, W+jets and QCD
- *Categorization*: #jets, #b-jets, HT, LT
- *Discriminator*: Δϕ (l,W), low values for SM, randomized for SUSY signal

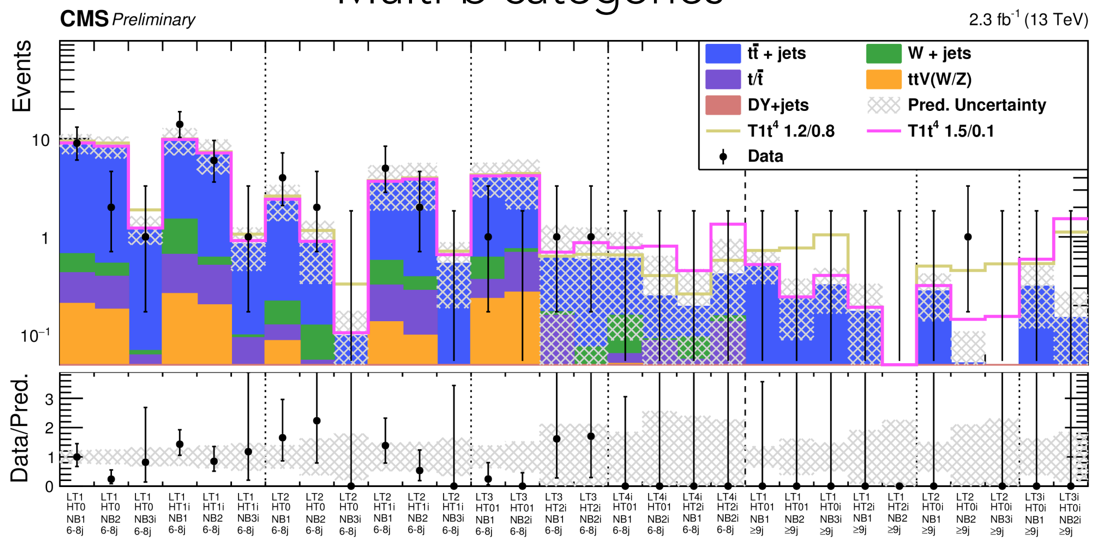
[*] HT= scalar sum of jet pT ; LT= scalar sum of pT(lep) and MET

Background vs signal

- Signal regions (SR) defined by sliding Δφ cut (decreasing for high LT)



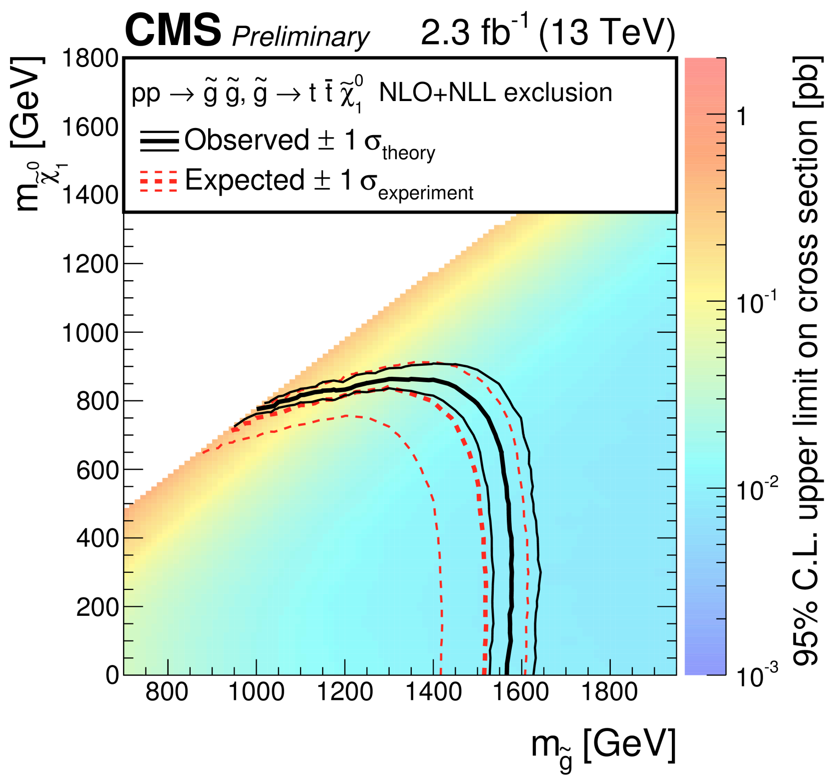
Multi-b categories



- From low Δφ CR to high Δφ SR, computing transfer factor (tt, W+j) in low #jets SB
- QCD due to mis-id jets as electrons computed in enriched CR (failing ele ID)
- 13 SR for the 0-b, 30 SR for multi-b category, no significant excess observed

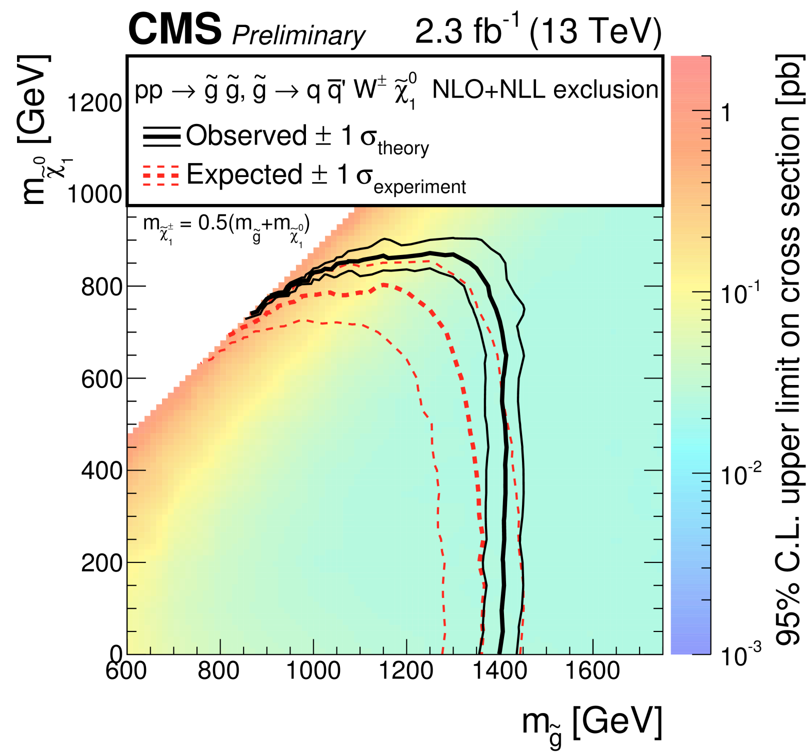
Interpretations

T1tttt, b-tag multiplicity



m_{gluino}<1.57 TeV for m_{LSP}<600 GeV
(extend 8 TeV limit of 250 GeV)

T5qqqqWW, 0 b-tag



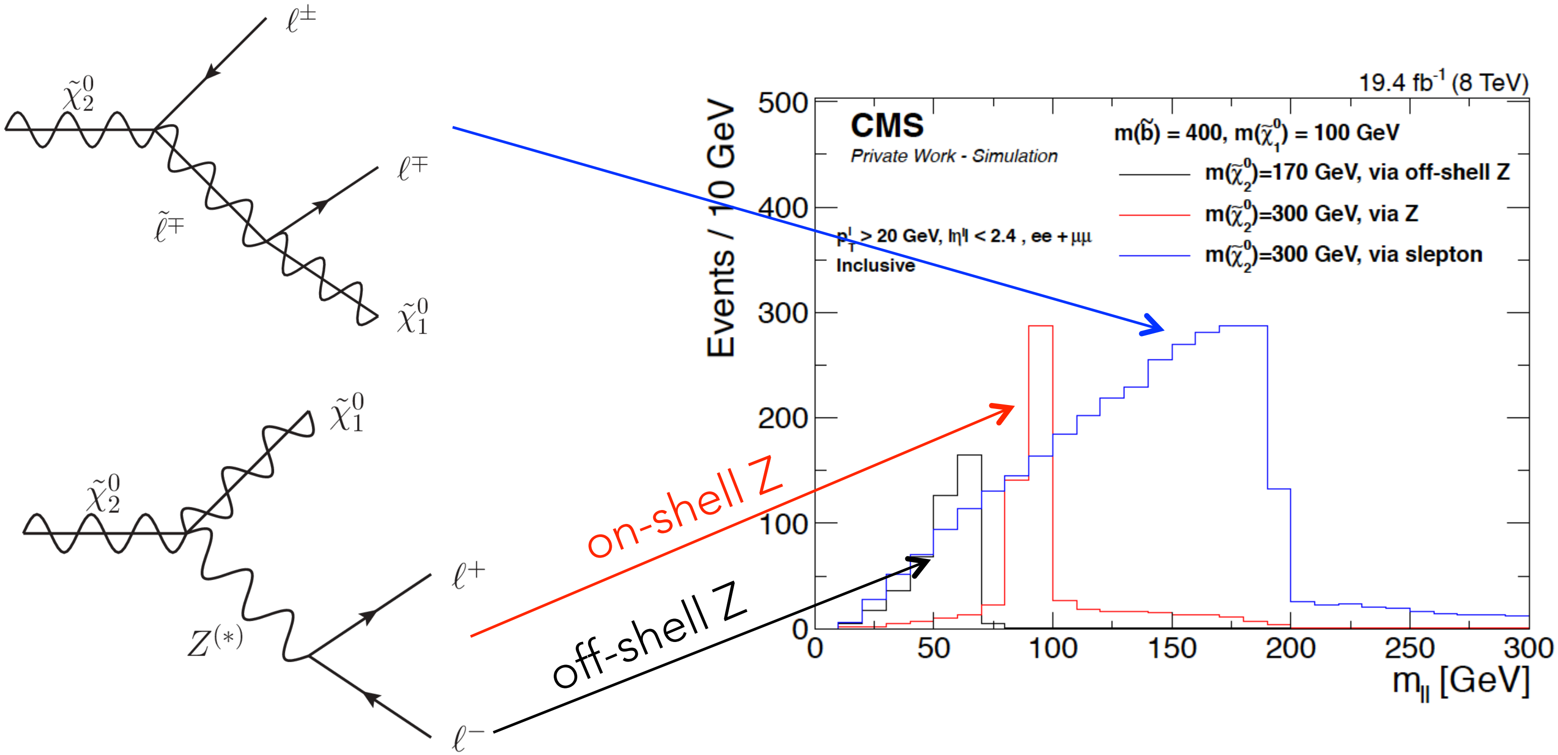
m_{gluino}<1.4 TeV for m_{LSP}<725 GeV

2 leptons + MET

CMS-SUS-15-011 (opposite sign)
CMS-SUS-15-008 (same sign)

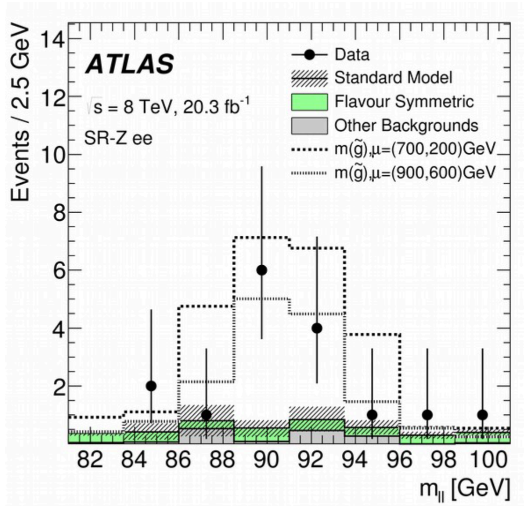
Opposite sign: the footprint

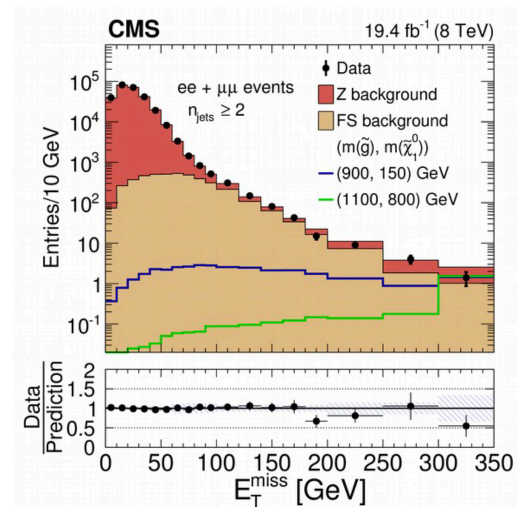
- *Final state*: two opposite-sign, same-flavour leptons, MET, # jets >=2
- *The key observable*: invariant mass of the dilepton system



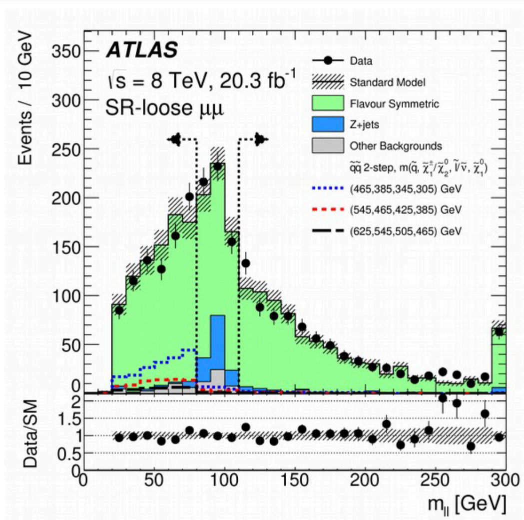
Some *tensions* from 8TeV

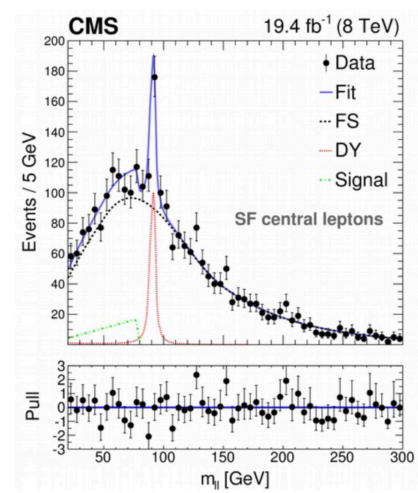
On- shell Z





Off- shell Z





ATLAS

CMS

Some *tensions* from 8TeV

	ATLAS	CMS
On- shell Z	- 3.0 sigma excess - high MET region - high HT region	No excess
Off- shell Z	No excess	- 2.6 sigma excess - around m_{ll} ~ 79 GeV - b-tagged events
	Eur. Phys. J. C75 (2015) 318	JHEP 04 (2015) 124

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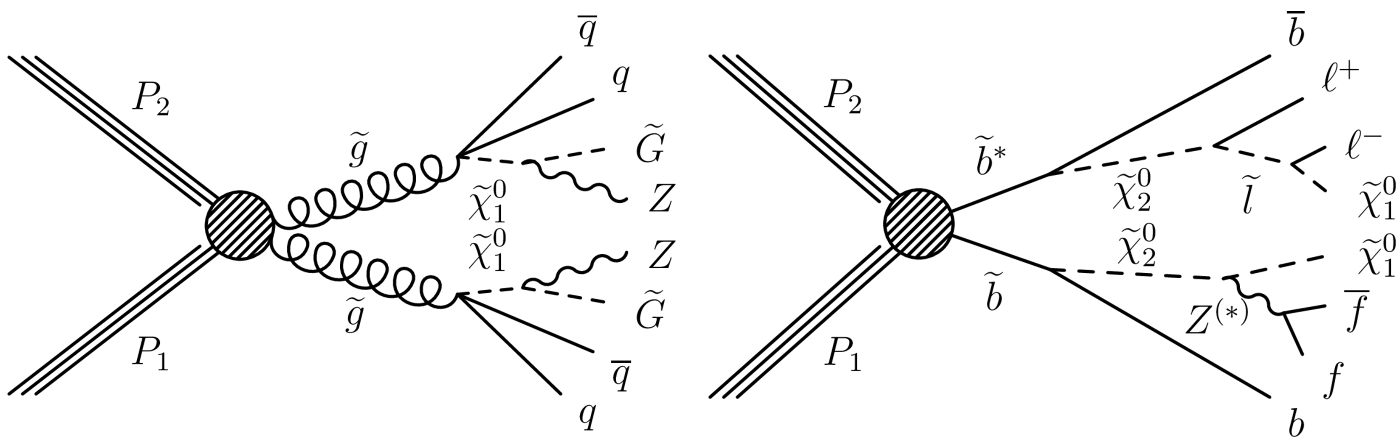
In contradiction?
13 TeV data should tell

Opposite sign in a nutshell

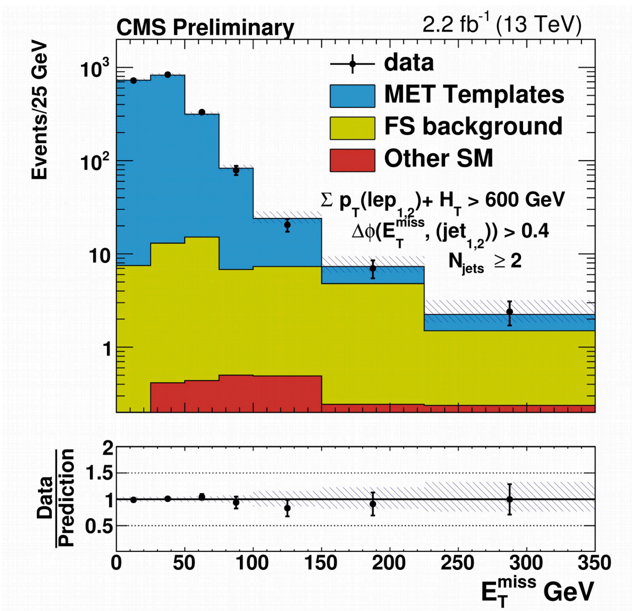
- *Benchmarks*: gluino (GMSB) and b-squark pair production (slepton edge)



- *Selection*: lepton pT>20 GeV, M_{ll}> 20 GeV, jet pT>35 GeV
- *Main backgrounds*: DY+jets and flavor-symmetric (ttbar, WW, Z->$\tau\tau$, …)
- *Categorization*: # jets, #b-jets, HT, MET, on-Z / off-Z (edge)
  - For the off-Z five regions of M_{ll} spectrum
  - For the on-Z an ATLAS-like SR, relaxing ΔR(l1,l2)<0.1, more boosted Z

Background vs signal

- Z+jets: i.e. MET from jet mis-measurement (using γ+jet)
- Flavor symmetric: extracted from the OS-OF region
- Cut and count analysis in each SR



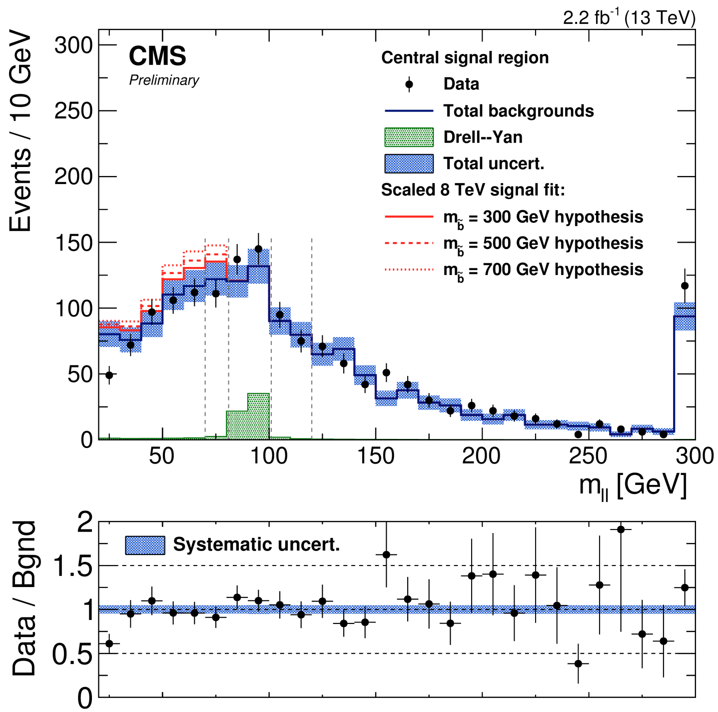
ATLAS-like region

N_{jets}/H_T	N_{b-jets}	E_T^{miss}	predicted	observed
SRA, 2-3 jets and $H_T > 400$	== 0	100-150	$28.2^{+5.4}_{-4.8}$	28
		150-225	$8.7^{+3.2}_{-1.9}$	6
		225-300	$3.3^{+2.5}_{-1.0}$	5
		> 300	$1.9^{+1.4}_{-0.7}$	6
	≥ 1	100-150	$14.2^{+4.4}_{-3.3}$	21
		150-225	$5.8^{+3.4}_{-2.1}$	6
		225-300	$5.0^{+3.3}_{-2.0}$	1
		> 300	$1.6^{+2.4}_{-0.9}$	3
SRB, ≥ 4 jets	== 0	100-150	$23.1^{+4.9}_{-3.7}$	20
		150-225	$8.2^{+3.4}_{-2.1}$	10
		225-300	$0.8^{+1.2}_{-0.2}$	2
		> 300	$1.5^{+2.4}_{-0.9}$	0
	≥ 1	100-150	$44.6^{+7.7}_{-6.6}$	43
		150-225	$16.7^{+5.1}_{-3.9}$	22
		225-300	$0.6^{+1.2}_{-0.3}$	3
		> 300	$1.4^{+2.4}_{-0.9}$	3
ATLAS - SR:				
$H_T+p_T^{l1}+p_T^{l2} > 600$ GeV	$E_T^{miss} > 225$ GeV	$\Delta\phi_{E_T^{miss},j1,j2} > 0.4$	$12.0^{+4.0}_{-2.8}$	12

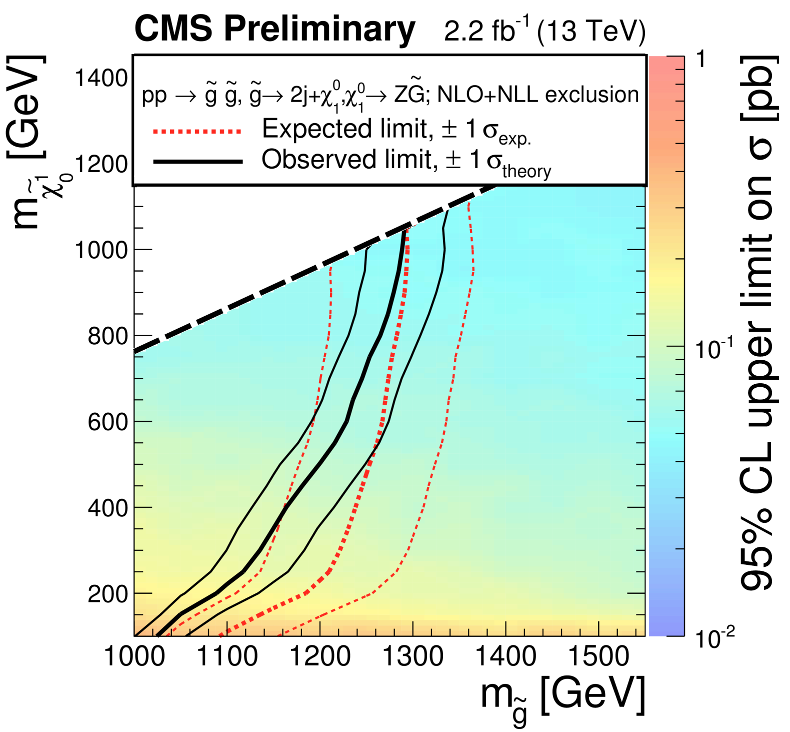
- On-Z: largest discrepancy seen in b-veto SR, nothing in ATLAS-like region

Interpretations

- Edge: at 13 TeV no evidence of the 2.6 σ excess in the region around 79 GeV



Central leptons, #b-jets>0



- Limits on GMSB model: m_{gluino}<(1.1)1.4 TeV for (low) high m_{LSP}

(+ 150 GeV w.r.t 8TeV)

So, what?

The fact: ATLAS reported an on-Z excess (3σ local) at 8 TeV of 18 events

Speculations:

- Assuming GMSB gluino production, scaling this excess by luminosity and cross-section:
  - 12/19/32 events for gluino masses of 500/800/1100 GeV
- Observed results at 13 TeV give an upper limit on the signal yield of 9 events

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The fact: CMS reported an off-Z excess (2.6σ local) at 8 TeV of 130 events

Speculations:

- Assuming GMSB gluino production, scaling this excess by luminosity and cross-section
  - 86/35/228 events for gluino masses of 500/800/1100 GeV
- Assuming sbottom pair production we would expect an excess at 13 TeV of:
  - 61/86/117 events for gluino masses of 300/500/700 GeV
- Observed results at 13 TeV give an upper limit on the signal yield of 57 events

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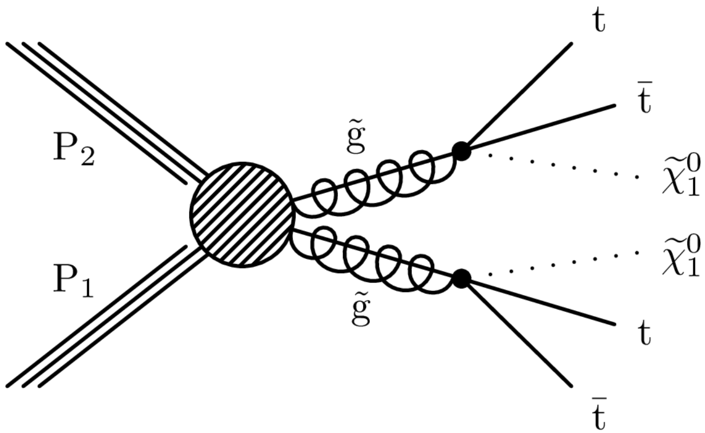
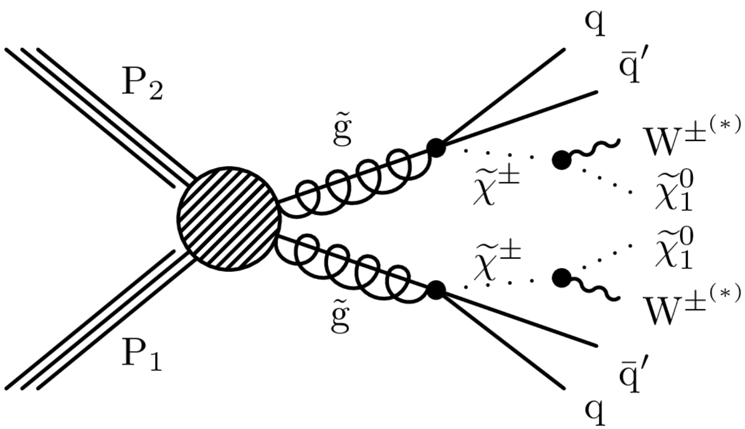
Same sign in a nutshell

- *Benchmarks*: gluino pair production + models with compressed hierarchy



Boosted region: isolation technique



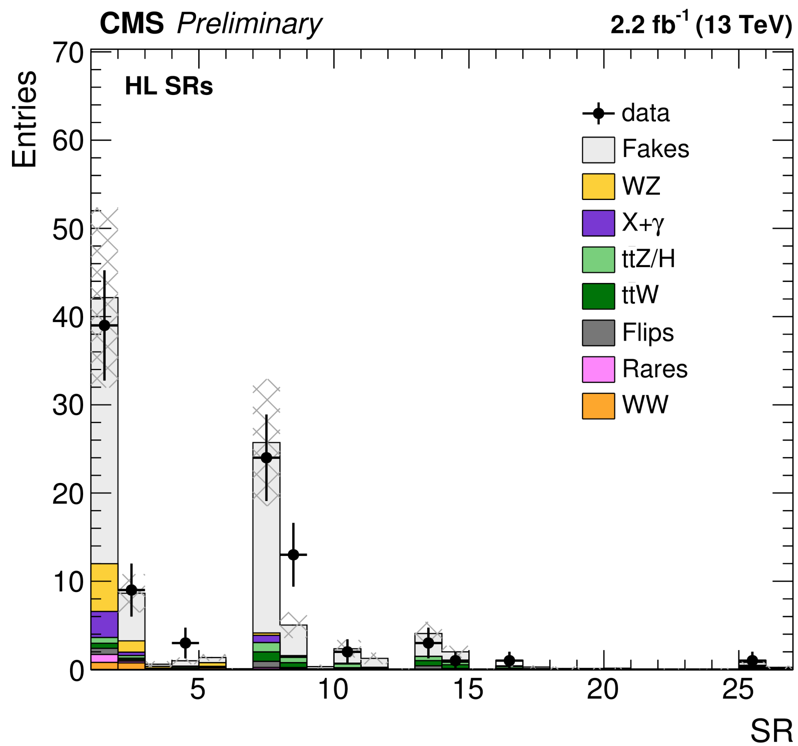
Compressed region: lowering pT threshold

- *Selection*: 2 μ/e pT>10/15 GeV, 2 jets pT>40 GeV, MET> 50 GeV, OS veto
- *Main backgrounds*: non-prompt (tt,W+j), SM same-sign (WZ, ttW), charge mis-ID
- *Categorization*: lepton pT (HH[*], HL, LL), # jets, # b-jets. MET, HT
- *Discriminator*:
  - MT_{min} = min(MT(l1,MET), MT(l2,MET))<120 GeV (contain non-prompt SS from ttbar)

[*] H= lepton pT>25 GeV ; L= lepton pT>10 (15) for μ(e)

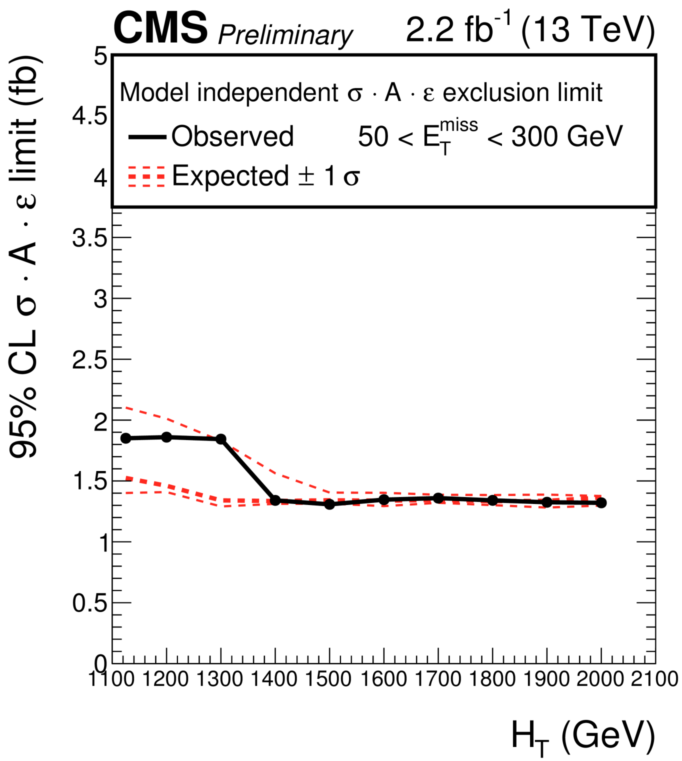
Results and interpretations

The HL signal regions



Largest deviation (2.3σ local) in SR8
(1 b-jet, MET=[50,200] GeV, HT= [300-1125] GeV)
Expected: 5.1+/- 1.5
Observed: 13

Model independent limits [*]



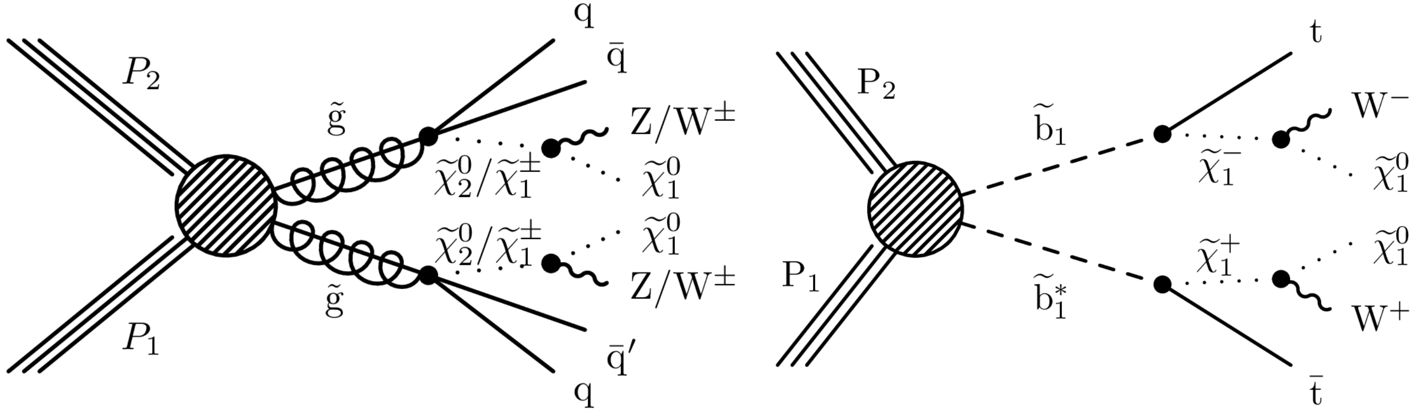
[*] Full efficiency assumed for ET,HT
Lepton efficiency 70-90% (50-75%)

multi-leptons + MET

CMS-SUS-16-003

Multileptons in a nutshell

- *Benchmarks*: gluino and sbottom pair production bringing to > 2 leptons



- *Selection and acceptance*:
  - pT(l) > 20/15/10 GeV, M^{OSSF}_{ll} > 12 GeV, 2 bjets pT>30 GeV, HT>60 GeV, MET>50 GeV
- *Main background*: di-boson, ttV, ttH, non prompt/mis-id leptons (ttbar)
- *Categorization*: #jets, #b-jets, HT, $|M^{OSSF}_{ll} - M_Z|$ <15 GeV (on/off Z)

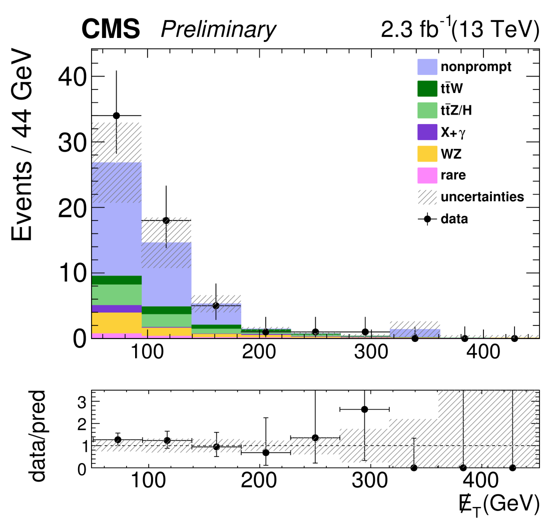
Background vs signal

Data-driven fraction of *fake* leptons

- Evaluated as the probability of non-prompt leptons to pass full set of requirements
- Using QCD (fake-enriched) control region, checked in application region (1 lepton)

Diboson (mainly WZ) from enriched CR (0 b-tag)

Rare ttH, ttV from MC normalization



b-tags	H_T (GeV)	E_T^{miss} (GeV)	Expected	Observed	T1tttt ($m_{\tilde{g}}$=1000 GeV,$m_{\tilde{\chi}_1^0}$=600 GeV)	T1tttt ($m_{\tilde{g}}$=1150 GeV,$m_{\tilde{\chi}_1^0}$=100 GeV)	SR
0 b-tags	60-400	50-150	$19.26^{+4.81}_{-4.80}$	18	0.23 ± 0.06	0.00 ± 0.00	SR1
		150-300	$1.16^{+0.31}_{-0.20}$	4	0.14 ± 0.04	0.04 ± 0.01	SR2
	400-600	50-150	$1.20^{+0.47}_{-0.40}$	3	0.05 ± 0.02	0.00 ± 0.00	SR3
		150-300	$0.29^{+0.44}_{-0.09}$	0	0.06 ± 0.02	0.04 ± 0.01	SR4
1 b-tags	60-400	50-150	16.57 ± 4.52	24	0.92 ± 0.20	0.03 ± 0.01	SR5
		150-300	$2.32^{+0.80}_{-0.76}$	1	0.65 ± 0.14	0.07 ± 0.02	SR6
	400-600	50-150	$0.67^{+0.45}_{-0.09}$	2	0.25 ± 0.06	0.04 ± 0.01	SR7
		150-300	$0.48^{+0.29}_{-0.07}$	0	0.33 ± 0.08	0.09 ± 0.02	SR8
2 b-tags	60-400	50-150	$4.49^{+1.81}_{-1.79}$	4	1.12 ± 0.24	0.04 ± 0.01	SR9
		150-300	$0.31^{+0.44}_{-0.09}$	1	0.86 ± 0.18	0.08 ± 0.02	SR10
	400-600	50-150	$0.40^{+0.27}_{-0.26}$	0	0.42 ± 0.10	0.05 ± 0.02	SR11
		150-300	$0.08^{+0.43}_{-0.08}$	0	0.58 ± 0.13	0.13 ± 0.03	SR12
60-600	≥ 3 b-tags	50-300	$0.13^{+0.43}_{-0.09}$	0	2.26 ± 0.47	0.21 ± 0.05	SR13
> 600	inclusive	50-300	$1.84^{+0.44}_{-0.37}$	3	1.49 ± 0.31	1.47 ± 0.30	SR14
inclusive	inclusive	≥ 300	$1.62^{+1.22}_{-1.19}$	0	1.95 ± 0.40	3.04 ± 0.61	SR15

off-Z category

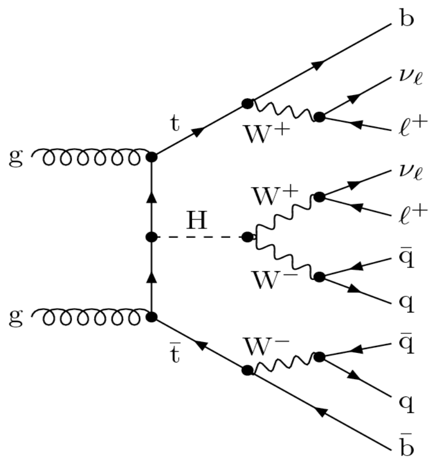
- Some fluctuations, but all consistent with predicted background yields

multi-leptons in the SM

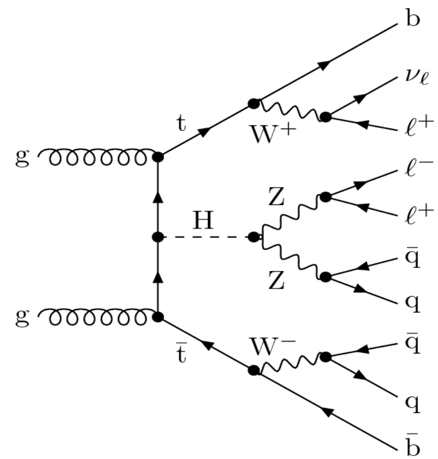
CMS-HIG-15-008

ttH: the other side of the coin

- Measuring top Yukawa sector in the same multilepton final states
  - ttH, with H->WW, H->ττ, H->ZZ (leptonic decay of at least one boson)



2 SS leptons + bjets

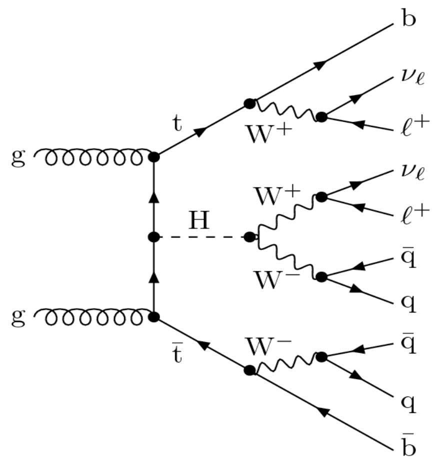


tri-leptons + b-jets

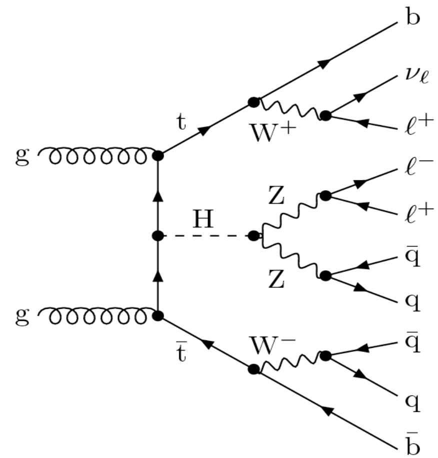
- Moreover, intriguing deviation observed at 8 TeV [HIG-13-020]
  - Signal strength measured $\mu = 3.7^{+1.6}_{-1.4}$
  - Driven by SS dimuon channel ($\mu = 8.4^{+3.3}_{-2.7}$)

ttH: the other side of the coin

- Measuring top Yukawa sector in the same multilepton final states
  - ttH, with H->WW, H->$\tau\tau$, H->ZZ (leptonic decay of at least one boson)



2 SS leptons + bjets



tri-leptons + b-jets

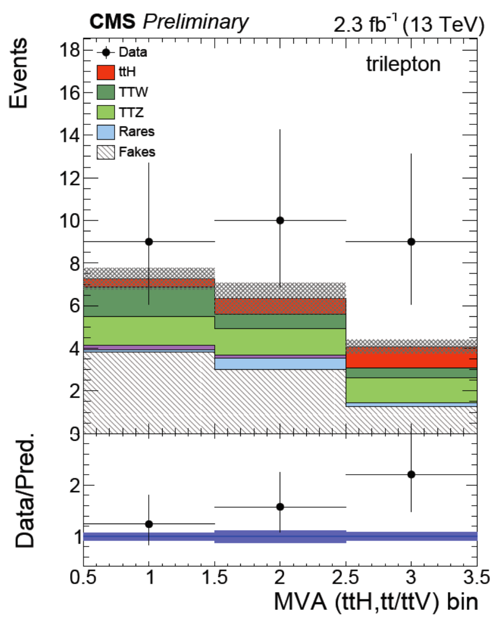
- Moreover, intriguing deviation observed at 8 TeV [HIG-13-020]
  - Signal strength measured $\mu = 3.7^{+1.6}_{-1.4}$
  - Driven by SS dimuon channel ($\mu = 8.4^{+3.3}_{-2.7}$)

"But, are we really looking at the same coin?"

ttH in a nutshell

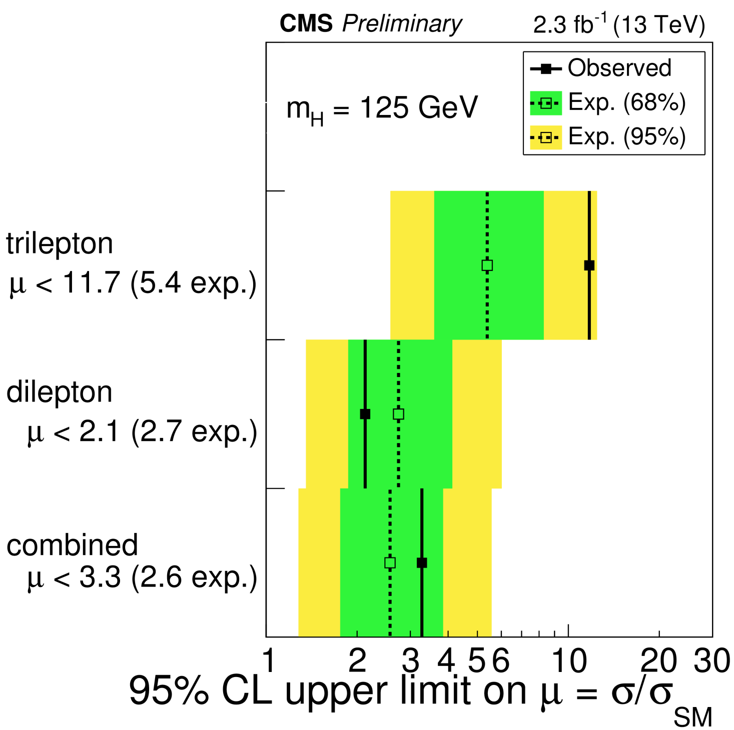
- *Selection and cceptance*:
  - 2 lepton same sign: pT(l) > 20,10 GeV, # jets> 3, # b-jets >1, | m_{ee} - m_Z| > 10 GeV
  - Trilepton: pT(l) > 20/10/10 GeV , # jets> 1, # b-jets >1, | m_{SFOS} - m_Z| > 10 GeV
- *Categorization*: lepton flavour and charge, presence of τ_h, #b-tags
- *Main background*: irreducible: tt+V, reducible: tt+jets (fake leptons)
- Separation of prompt leptons from fakes via Boosted Decision Tree (BDT)
- Modelling of fake backgrounds from CR relaxing lepton selection
  - Mis-identification (fakes) as function of pT
  - Charge mis-reconstruction of electrons (flips)

	$\mu\mu$	ee	$e\mu$	3ℓ
$t\bar{t}W$	3.22 ± 0.16	1.47 ± 0.11	4.95 ± 0.19	2.56 ± 0.14
$t\bar{t}Z/\gamma^*$	0.82 ± 0.03	1.14 ± 0.14	2.42 ± 0.17	3.75 ± 0.18
WZ	0.09 ± 0.05	0.06 ± 0.06	0.25 ± 0.11	0.33 ± 0.11
tttt	0.19 ± 0.03	0.11 ± 0.02	0.28 ± 0.03	0.22 ± 0.03
tZq	0.10 ± 0.06	0.00 ± 0.00	0.12 ± 0.13	0.44 ± 0.17
rare SM bkg.	0.06 ± 0.03	0.04 ± 0.04	0.13 ± 0.06	0.16 ± 0.59
non-prompt (data)	3.99 ± 0.38	3.58 ± 0.38	10.10 ± 0.65	8.08 ± 0.67
charge mis-ID (data)		1.11 ± 0.05	1.65 ± 0.05	
all backgrounds	8.47 ± 0.42	7.52 ± 0.44	19.90 ± 0.73	15.55 ± 0.95
$t\bar{t}H$ signal	1.53 ± 0.08	0.69 ± 0.05	2.27 ± 0.10	2.12 ± 0.09
data	9	11	11	28

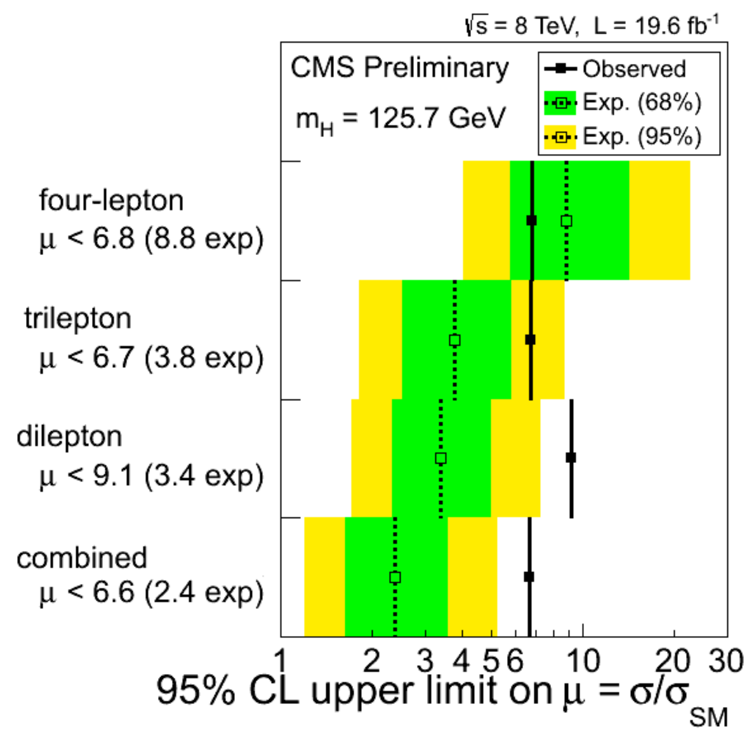


Results

Upper limit on the signal strength 13 TeV



Upper limit on the signal strength 8 TeV



- 8 TeV dilepton excess not visible at 13 TeV (~x2 stats to reach 8TeV sensitivity)
- Slight deficit in 2l SS, modest (non-significant) excess in 3l

ttH SRs do not match the SUSY ones: hard to perform direct comparisons

Summary

- Leptonic final states used to probe BSM physics, SUSY models here
- Interpretation needs to be handled with care (simplified models)
- Massive categorization to enhance specific signal topology

- Few mild excesses from LHC8 seem vanished, or have moved
  - OS: no confirmation for both ATLAS (on-z) and CMS (edge) excesses
  - SS: small tension in events with 1 b-jet and relaxed lepton pT

- Same final states have also been targeted by SM measurement of ttH
  - Phase space and categories might have little overlap with SUSY
  - Understanding the compatibility between 2lSS and 3l

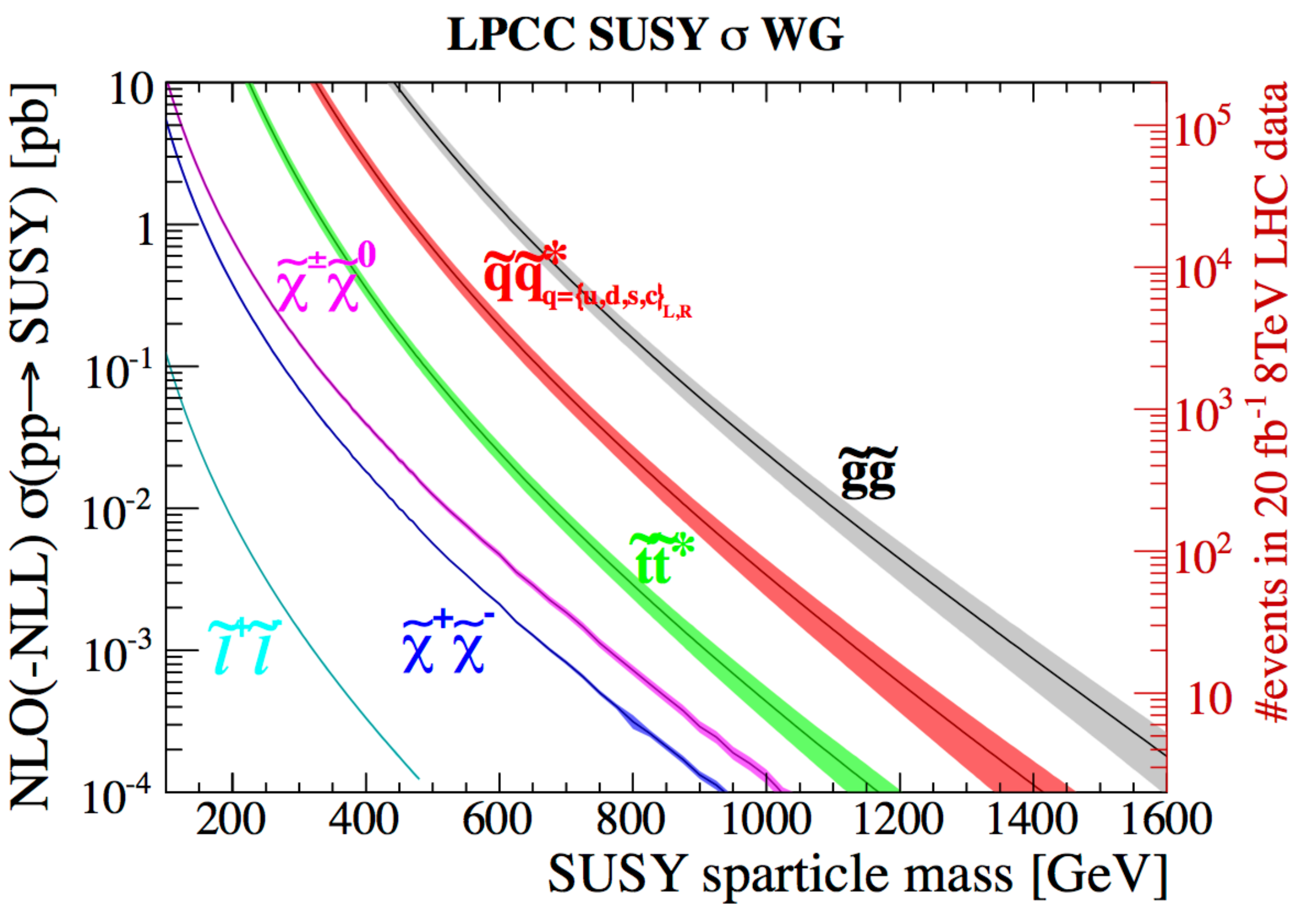
So, not yet time for final conclusions.

The SUSY program in 2016 in multilepton final state

- Top up and refinement of current analyses
- Extension to other models (EWKino sector and compressed spectra)

BACKUP

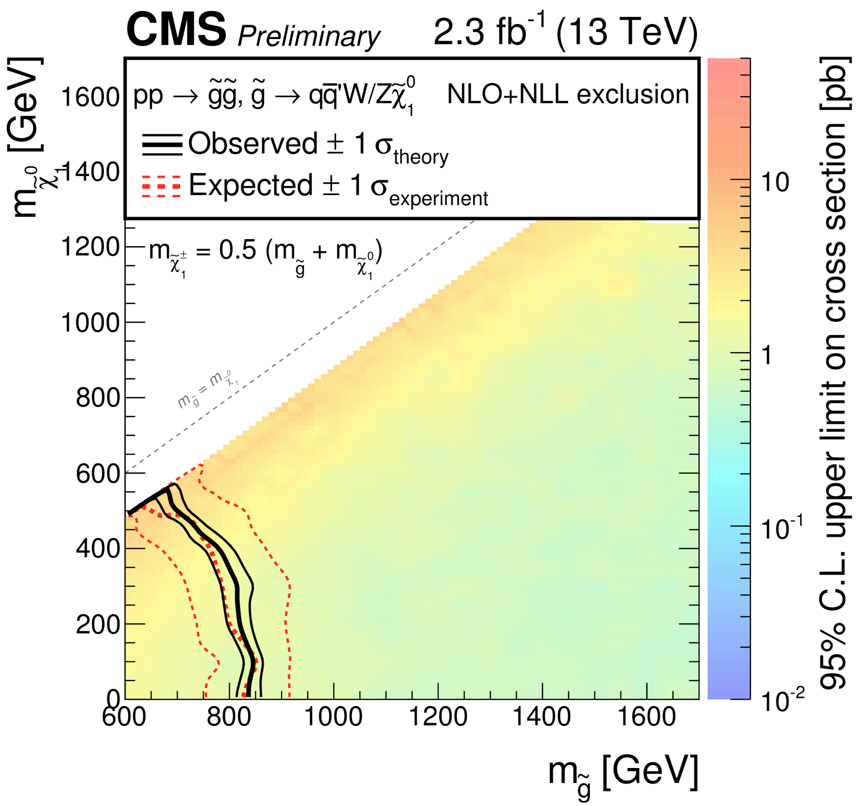
SUSY sparticle pair x-section



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/SUSYCrossSections arXiv:1206.2892

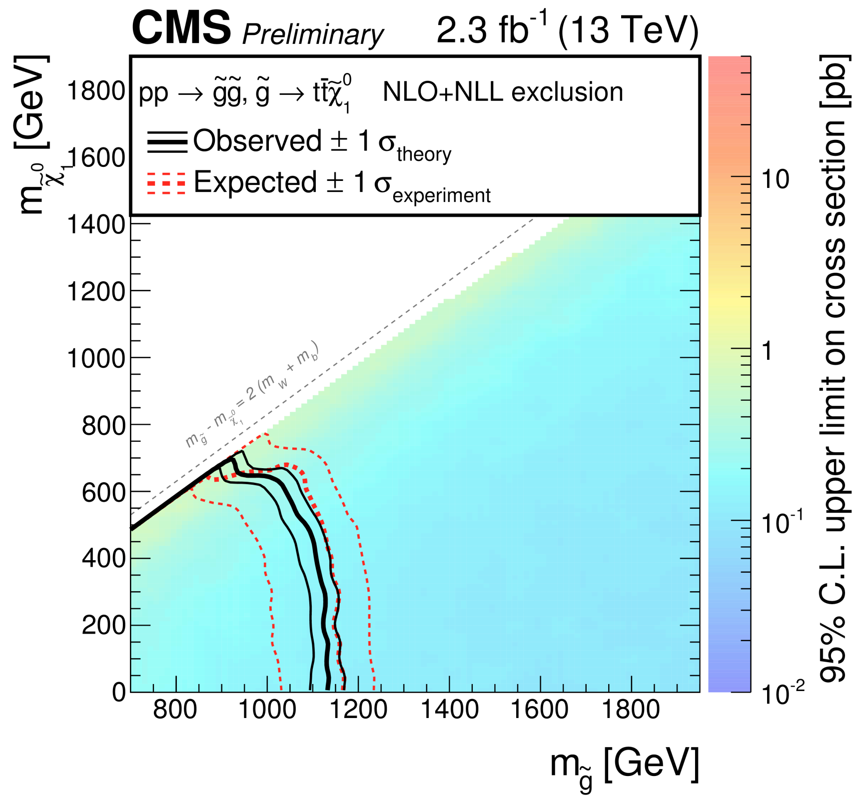
Multileptons: interpretations

Gluino pair production (T5qqqqWZ)



M_{gluino}< 825 GeV for m_{LSP}< 200 GeV
(assuming BR=2/3 for gg->qqWN1 and 1/3 for gg->qqZN1)

Gluino pair production (T1tttt)



M_{gluino}< 1125 GeV for m_{LSP}< 400 GeV
(+ 150 GeV w.r.t 8TeV)

SUSY same sign SR

- SR8: 2-4 jest,1 b-jet, MT<120 GeV, MET=[50,200] GeV, HT= [300-1125] GeV

HH

Table 3: Signal region definitions for the HH lepton selection.

$N_{\mathrm{b\,jets}}$	$M_T^{\min}$ (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T > 1125$ GeV
0	< 120	$50 - 200$	2-4	SR1	SR2	SR32
			5+	SR3	SR4	
		$200 - 300$	2-4		SR5	
			5+		SR6	
	> 120	$50 - 200$	2-4		SR7	
			5+		SR8	
		$200 - 300$	2-4			
			5+			
1	< 120	$50 - 200$	2-4	SR9	SR10	
			5+	SR11	SR12	
		$200 - 300$	2-4		SR13	
			5+		SR14	
	> 120	$50 - 200$	2-4		SR15	
			5+		SR16	
		$200 - 300$	2-4			
			5+			
2	< 120	$50 - 200$	2-4	SR17	SR18	
			5+	SR19	SR20	
		$200 - 300$	2-4		SR21	
			5+		SR22	
	> 120	$50 - 200$	2-4		SR23	
			5+		SR24	
		$200 - 300$	2-4			
			5+			
3+	< 120	$50 - 200$	2+	SR25	SR26	
		$200 - 300$	2+	SR27	SR28	
	> 120	> 50	2+	SR29	SR30	
inclusive	inclusive	> 300	2+		SR31	

(black boxes indicate regions that are not considered)

HL

Table 4: Signal region definitions for the HL lepton selection.

$N_{\mathrm{b\,jets}}$	$M_T^{\min}$ (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T > 1125$ GeV
0	< 120	$50 - 200$	2-4	SR1	SR2	SR26
			5+	SR3	SR4	
		$200 - 300$	2-4		SR5	
			5+		SR6	
1	< 120	$50 - 200$	2-4	SR7	SR8	
			5+	SR9	SR10	
		$200 - 300$	2-4		SR11	
			5+		SR12	
2	< 120	$50 - 200$	2-4	SR13	SR14	
			5+	SR15	SR16	
		$200 - 300$	2-4		SR17	
			5+		SR18	
3+	< 120	$50 - 200$	2+	SR19	SR20	
		$200 - 300$	2+	SR21	SR22	
inclusive	> 120	$50 - 300$	2+	SR23	SR24	
inclusive	inclusive	> 300	2+		SR25	

Table 5: Signal region definitions for the LL lepton selection. The $H_T > 300$ GeV requirement is applied in all search regions in the LL category.

$N_{\mathrm{b\,jets}}$	$M_T^{\min}$ (GeV)	H_T (GeV)	$E_T^{\mathrm{miss}} \in [50 - 200]$ GeV	$E_T^{\mathrm{miss}} > 200$ GeV
0	< 120	> 300	SR1	SR2
1	< 120		SR3	SR4
2	< 120		SR5	SR6
3+	< 120		SR7	
inclusive	> 120		SR8	

LL

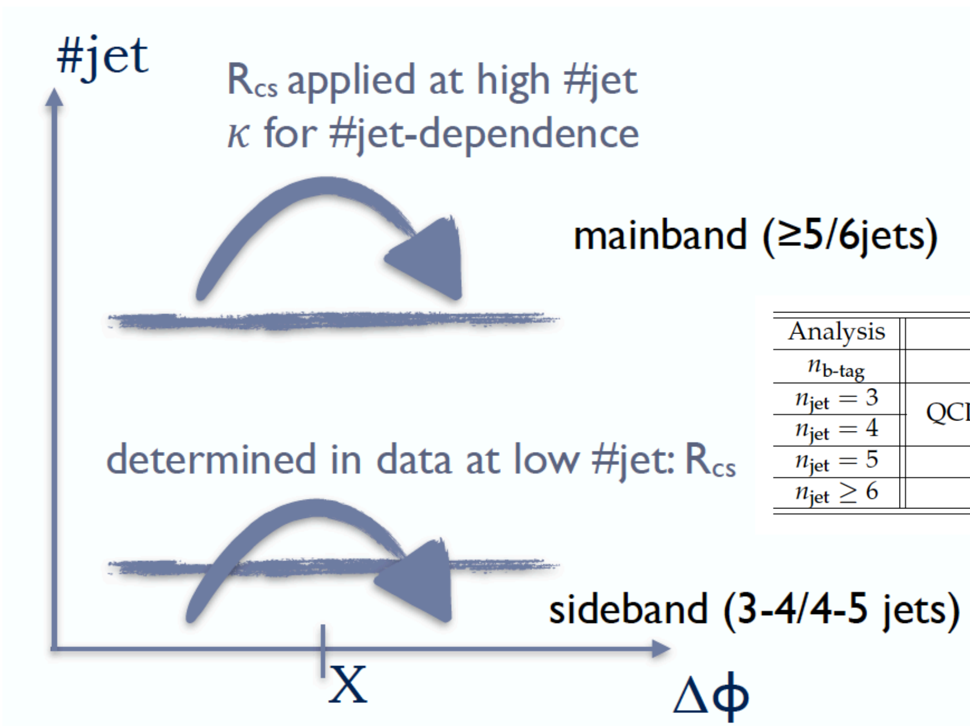
SUSY multilepton SR

- For both on-Z and off-Z

N_{jets}	$N_{\text{b jets}}$	E_T^{miss} (GeV)	$60\,\text{GeV} \leq H_T < 400\,\text{GeV}$	$400\,\text{GeV} \leq H_T < 600\,\text{GeV}$	$H_T \geq 600\,\text{GeV}$
≥ 2	0	$50 - 150$	SR1	SR3	SR14
		$150 - 300$	SR2	SR4	
	1	$50 - 150$	SR5	SR7	
		$150 - 300$	SR6	SR8	
	2	$50 - 150$	SR9	SR11	
		$150 - 300$	SR10	SR12	
	≥ 3	$50 - 300$	SR13		
	inclusive	≥ 300	SR15		

Single lepton background

- From low Δϕ CR to high Δϕ SR, computing the transfer factor Rcs

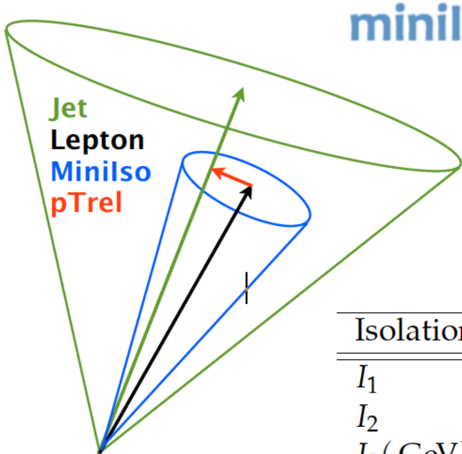


$$R_{CS}^{data} = \frac{N_{data}^{SR}}{N_{data}^{CR} - N_{QCD\ estimate}^{CR}}$$

Analysis	Multi-b analysis		Zero-b analysis	
$n_{\text{b-tag}}$	$n_{\text{b-tag}} = 0$	$n_{\text{b-tag}} \geq 1$	$n_{\text{b-tag}} = 0$	$n_{\text{b-tag}} = 1$
$n_{\text{jet}} = 3$	QCD Fit (el. sample)		$R_{CS}(W^{\pm})$ det. (μ sample), QCD Fit (el. sample)	
$n_{\text{jet}} = 4$	QCD Fit (el. sample)	R_{CS} det.	$R_{CS}(W^{\pm})$ det. (μ sample), QCD Fit (el. sample)	$R_{CS}(t\bar{t})$ det.
$n_{\text{jet}} = 5$		R_{CS} det.	MB	$R_{CS}(t\bar{t})$ det.
$n_{\text{jet}} \geq 6$		MB	MB	

Mini-isolation

$\text{miniIso} < A \ \&\& \ (p_T^{ratio} > B \ || \ p_T^{rel} > C)$



miniIso radius: $R(p_T^\ell) = \dfrac{10\,\text{GeV}}{\min\left[\max\left(p_T^\ell, 50\,\text{GeV}\right), 200\,\text{GeV}\right]}$.

$$p_T^{ratio} = \frac{p_T^\ell}{p_T^{jet}},$$

$$p_T^{rel} = \frac{(\vec{p}(\text{jet}) - \vec{p}(\ell)) \cdot \vec{p}(\ell)}{|\vec{p}(\text{jet}) - \vec{p}(\ell)|}.$$

Isolation value		Loose leptons	μ	e
I_1	A	0.4	0.16	0.12
I_2	B	0	0.76	0.80
I_3 (GeV)	C	0	7.2	7.2

- Improved lepton selection to recover efficiency for prompt leptons overlapping jets.
- The lepton must be isolated in the **small cone (miniIso)**; then we require either isolation in a **larger cone (p_T^{ratio})** or large **p_T^{rel}**.
- Comparable performance with respect to MVA with same variables, large improvement over previous working points, plain miniIso or p_T^{rel}

Lepton MVA in ttH

Kin

- **p_T, η**

Iso

- **PF miniRelIso, charged** had. (R=0.3)
- **PF miniRelIso, neutral** had. & photon (R=0.3, scaled EA)

IP

- **3D IP significance** (SIP_{3D})
- **2D IP $|d_{xy}|$** and **$|d_z|$**

Lep-Jet

- **Lepton's closest jet** (JEC applied only to hadronic activity)
  - $p_T(\ell)/p_T(jet)$: « p_T ratio »
  - Lepton's p_T^{rel} wrt jet
  - jet CSV b-tag
  - #charged tracks in jet

ID

- **(μ) Segment compatibility**
- **(e) Electron ID MVA (EGM POG)**

ATLAS OS

2.2σ excess in the on-Z SR

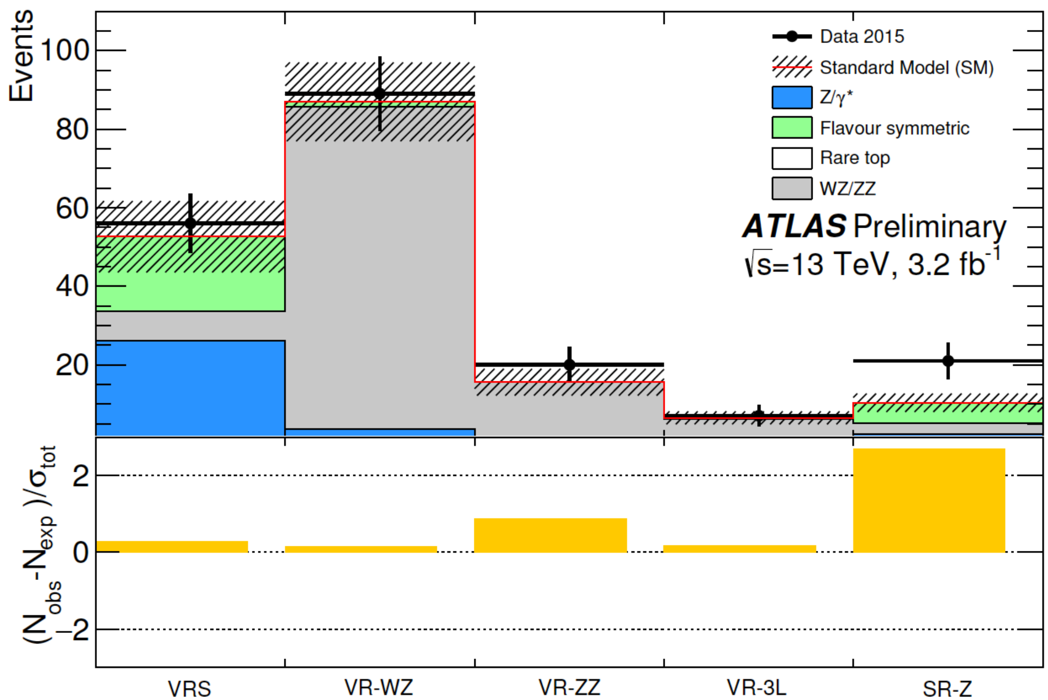


Figure 3: The observed and expected yields in the validation regions and signal region. Here the lower panel shows the difference in standard deviations between the observed and expected yields. This significance is calculated from the systematic and statistical uncertainties on the background expectation and a Gaussian approximation for the Poisson fluctuations on the background observation, Sig = $(N_{\text{obs}} - N_{\text{exp}})/\sqrt{\sigma_{\text{stat.+syst.}} + N_{\text{exp}}}$.