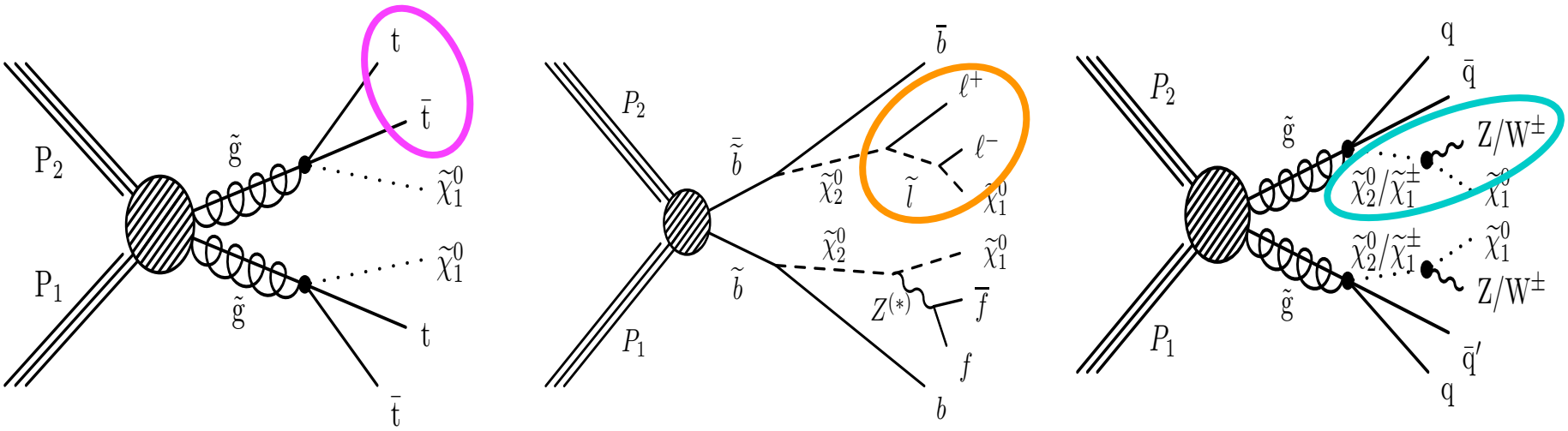
STRONG SUSY IN THE LEPTONIC FINAL STATES AT CMS

Hannsjörg Weber (Fermilab), Claudia Seitz (University Zürich) on behalf of the CMS collaboration

Fermilab

Universität Zürich[UZH]

Scope of this talk



- Leptons appear naturally in the decay chain of strongly produced gluinos/squarks:
  - In decays of **top quarks** from (virtual) top squark decays.
  - In decays involving **sleptons**.
  - In decays from **W/Z/H bosons** from chargino/neutralino decays.

- In this talk, I'll cover the multilepton final states: ≥ 2 charged leptons.
  - The 1ℓ final state will be covered in the plenary session: Claudia Seitz (Thursday).
  - I won't talk about leptonic searches for 3rd gen. squarks: Caroline Collard (Wednesday).

SUS-16-034

2ℓ: oppositely-charged, same flavor

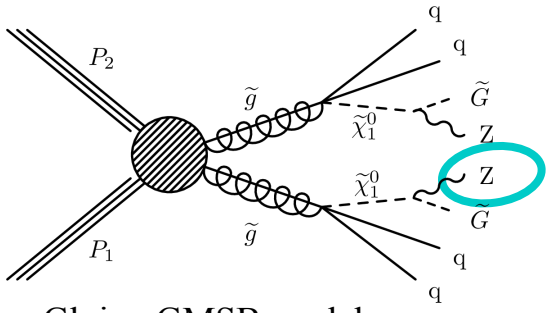
- Search in two distinct signatures:
  1. **Z boson production** (+ additional E_T^{miss})
  2. **Dilepton mass edge**

Selection:

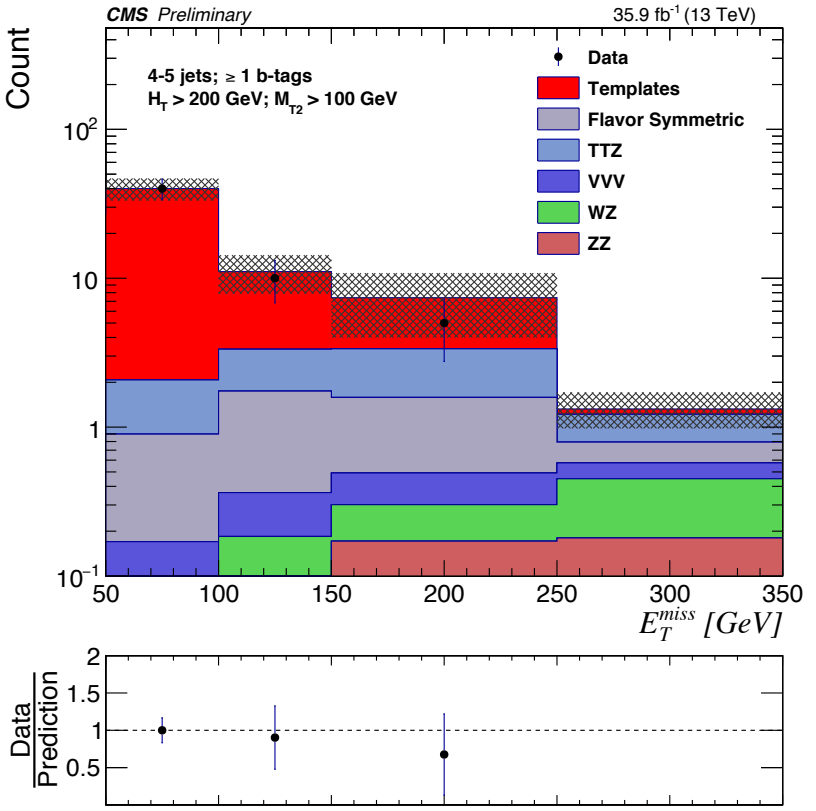
- $M_{\ell\ell}$ within Z mass window
- Large E_T^{miss} and hadronic H_T
- Binned in $\mathbf{N_{(b\text{-})jets}}$ (2-3, 4-5, ≥6 jets X 0-b, ≥1-b)
  - Additional binning in $\mathbf{E_T^{miss}}$
- $M_{T2}^{\ell\ell} > 80/100$ GeV (reduce $t\bar{t}\rightarrow 2\ell$)
  - Sharp decline around W mass for $t\bar{t}$

Background estimation:

- Flavor-symmetric: mostly $t\bar{t}\rightarrow 2\ell$
  - Estimated from an eμ data control sample.
  - $R_{SF/OF}$ corrects for flavor dependent trigger/ID efficiencies
- SM Z+jets production:
  - Estimated using γ+jets data control sample: γ emulates $Z\rightarrow 2\ell$ (see backup for $M_{T2}^{\ell\ell}$).
  - Binned in N_b



Gluino GMSB model



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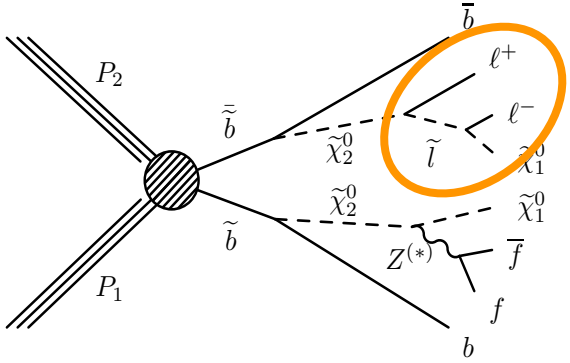
2ℓ: oppositely-charged, same flavor

- Search in two distinct signatures:
  1. Z boson production
  2. **Dilepton mass edge** (through virtual Z or slepton decay)



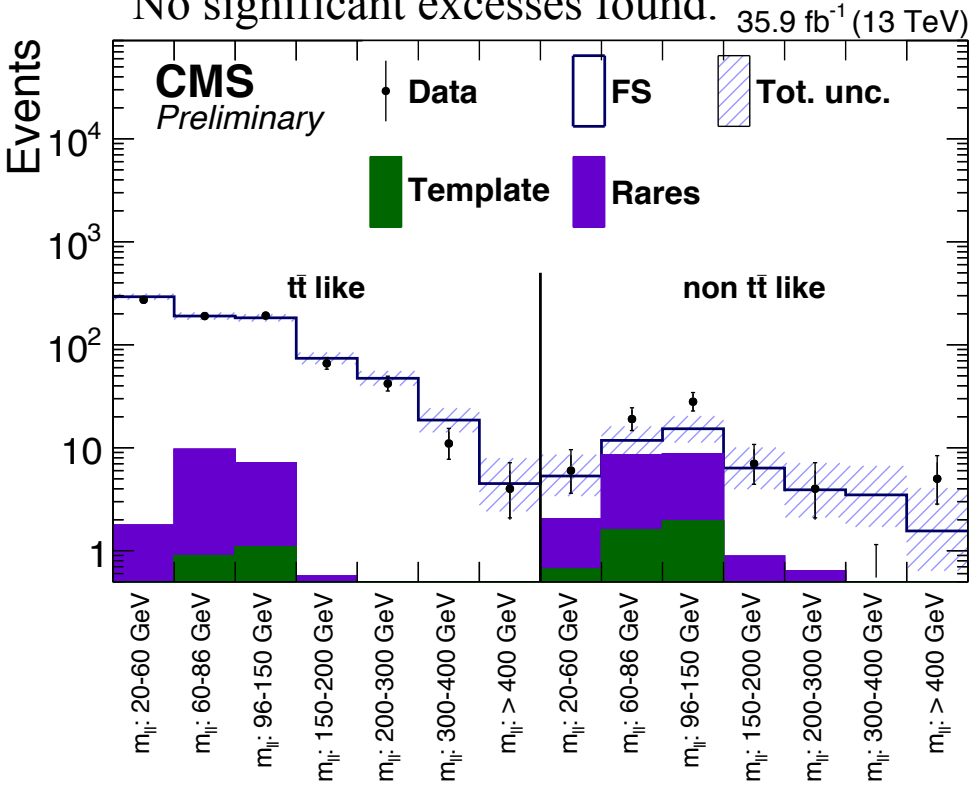
No significant excesses found.

Selection:

- High E_T^{miss} and ≥ 2 jets
- Binned in $\mathbf{M}_{\ell\ell}$
- $M_{T2}^{\ell\ell} > 80$ GeV (reduce $t\bar{t} \to 2\ell$)
- A $t\bar{t}$ likelihood for additional discrimination against $t\bar{t} \to 2\ell$.

Background estimation:

- Flavor-symmetric: mostly $t\bar{t} \to 2\ell$
  - Estimated from an eμ data control sample.



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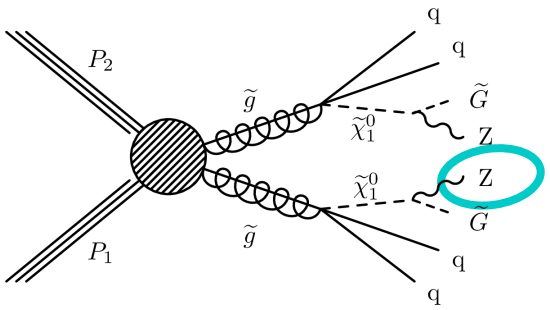
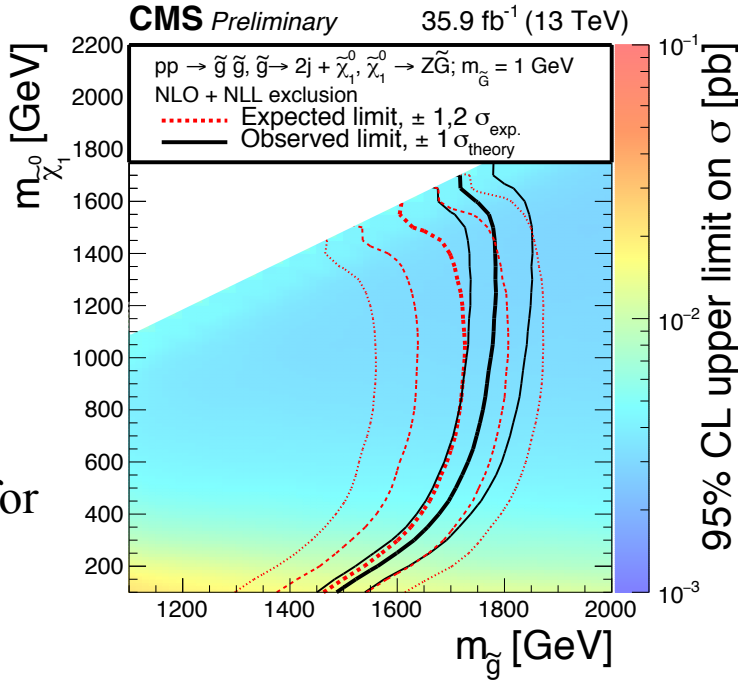
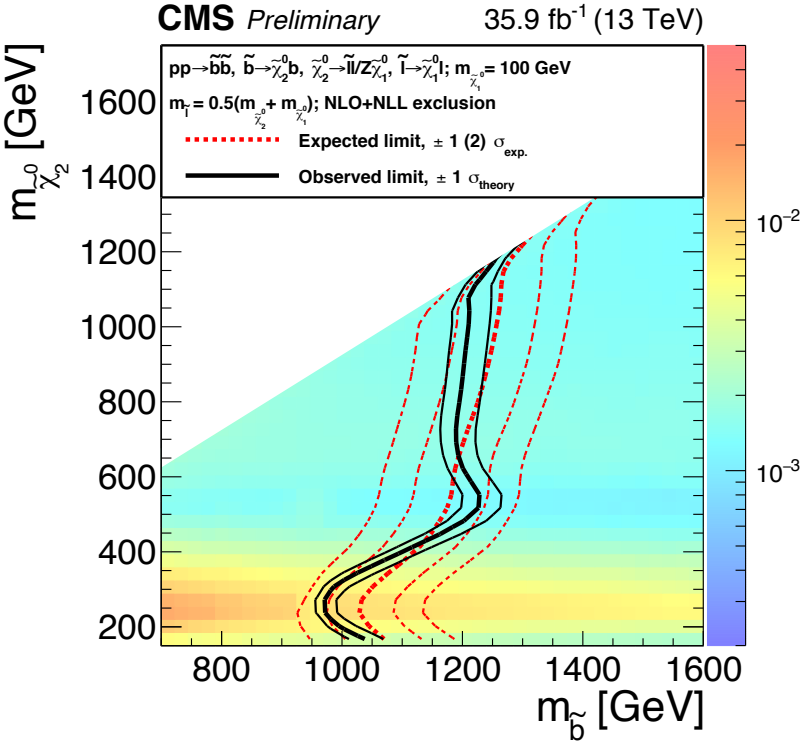
2ℓ: oppositely-charged, same flavor

Interpretation for on-Z search GMSB gluino





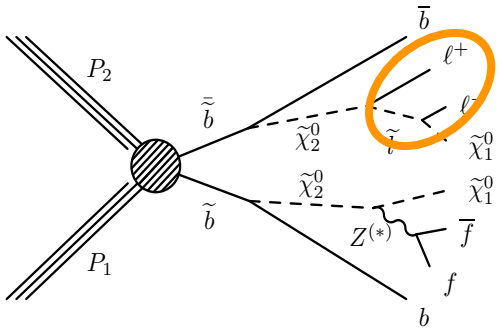


Interpretation for dilepton mass edge search.

← $M_{\ell\ell}^{max} \sim 735$ GeV

← $M_{\ell\ell}^{max} \sim 375$ GeV

← $M_{\ell\ell}^{max} \sim 145$ GeV



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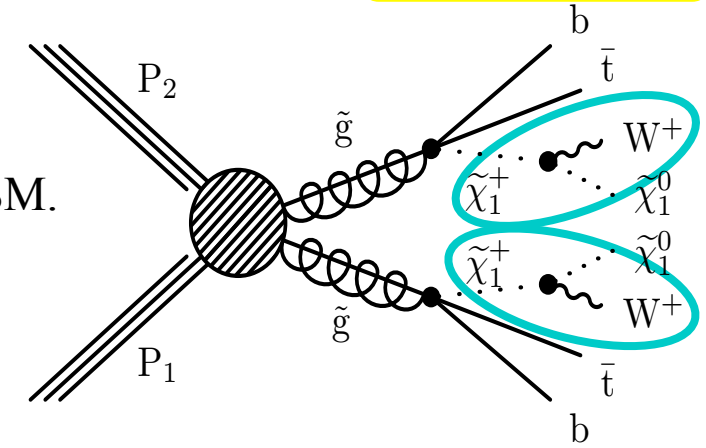
SUS-16-035

2ℓ: equally-charged

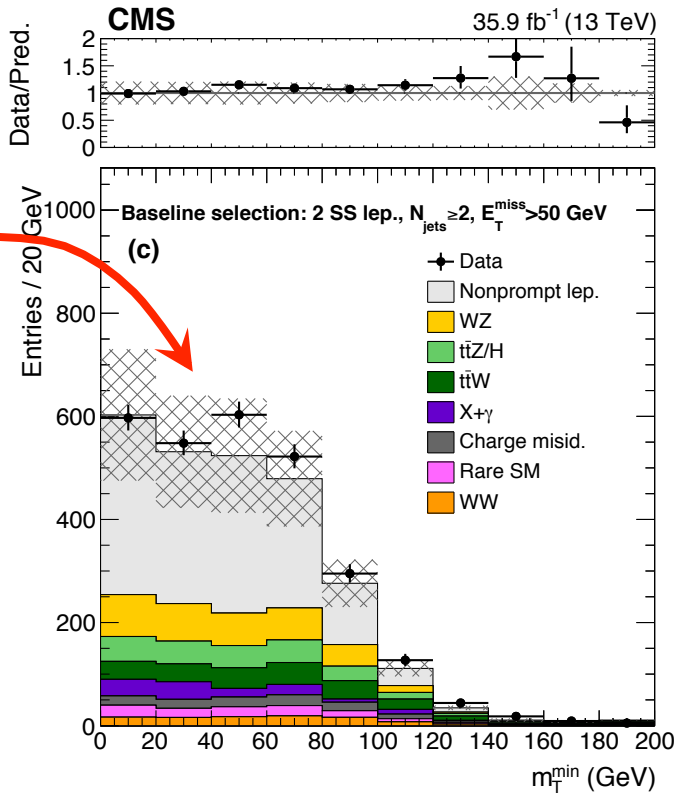
- **Two "same-sign" leptons** are rarely produced in the SM.
- However, can appear natural in SUSY scenarios.



Selection:

- Two equally charged lepton.
- Large E_T^{miss}.
- Large H_T and multiple jets.
- Selection on min(M_T^{ℓ}): for $t\bar{t}\rightarrow 1\ell$ have $M_T^{\ell} \lesssim M_W$.
  - Creates signal regions with low non-prompt bkg
- Selection on ++ vs. −−:
  - The SM is asymmetric in charge.

- **Use variables to cover a large variety of signals**:
  - 100 signal regions



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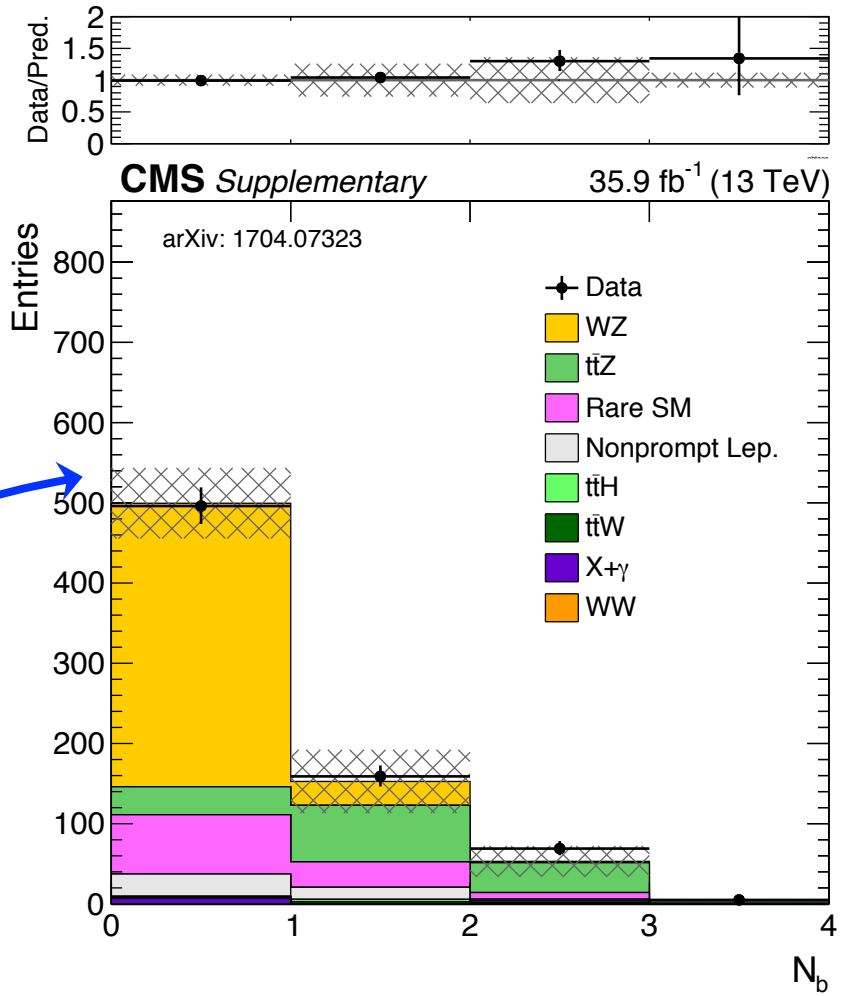
2ℓ: equally-charged

Backgrounds:

1. Non-prompt leptons: mostly $t\bar{t} \rightarrow 1\ell$ with semileptonic heavy flavor decay.
   - Estimated with "tight-to-loose" method from a data sideband where lepton passes only loose identification/isolation criteria.

2. SM production of equally charged leptons: mostly WZ and $t\bar{t}W/t\bar{t}Z$.
   - Estimated using 3ℓ data, with 2 lepton compatible to be from a Z boson decay.

3. Charge misidentification: only for $e^{\pm}$.
   - Comparison of data yield within the Z mass window of $e^{\pm}e^{\pm}$ vs. $e^{\pm}e^{\mp}$.



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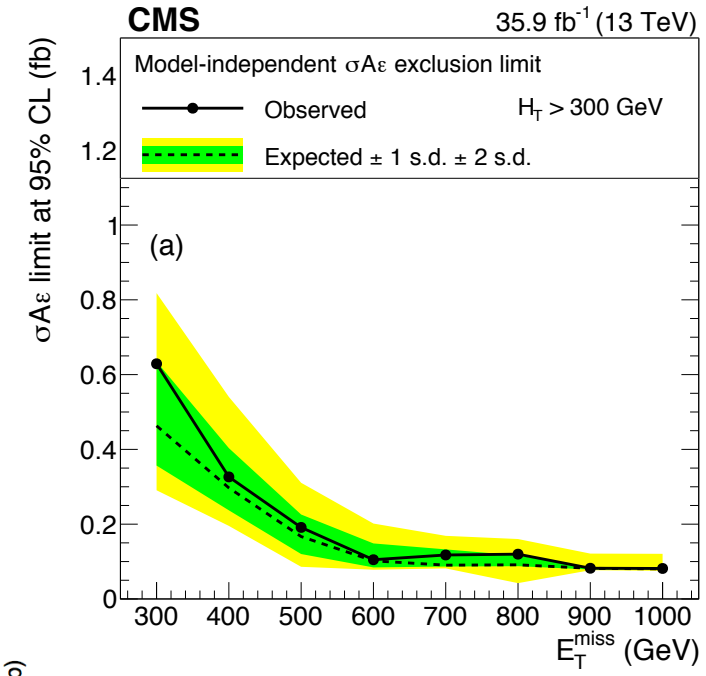
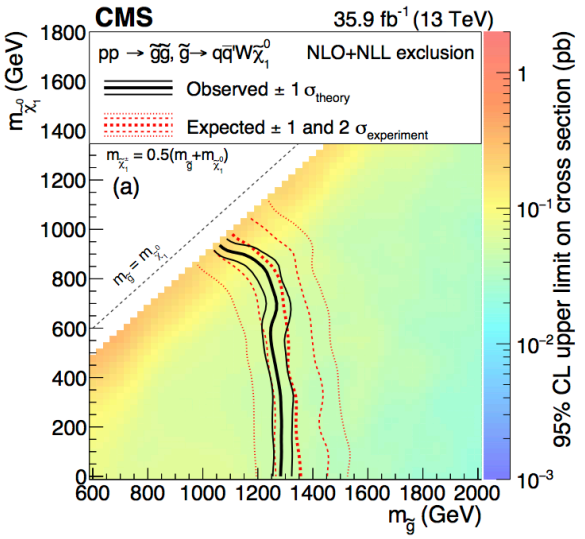
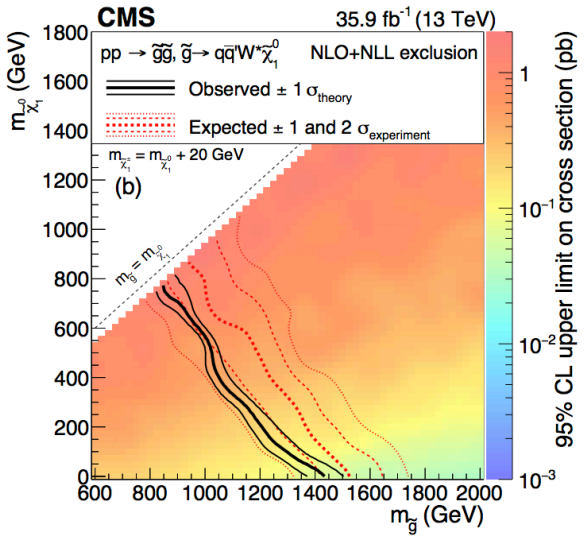
2ℓ: equally-charged

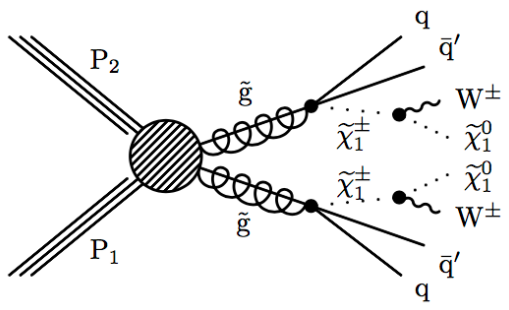
Results:

- No significant excess.
- Beyond usual simplified model interpretation, this analysis provides model independent interpretations on production cross section.









Different mass splittings between chargino and neutralino

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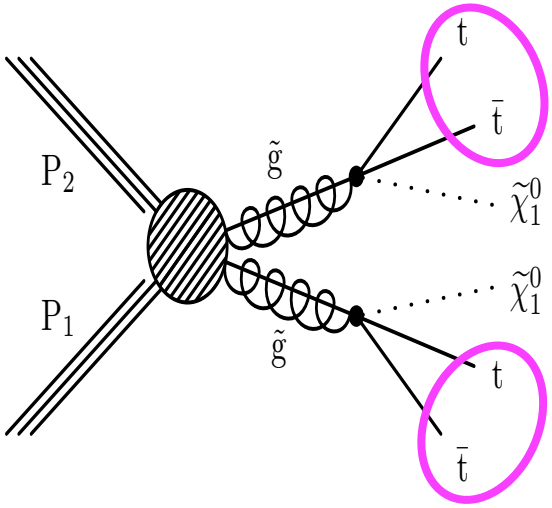
≥3ℓ



- **≥3ℓ processes** are rare in the SM, but can be natural to SUSY production.

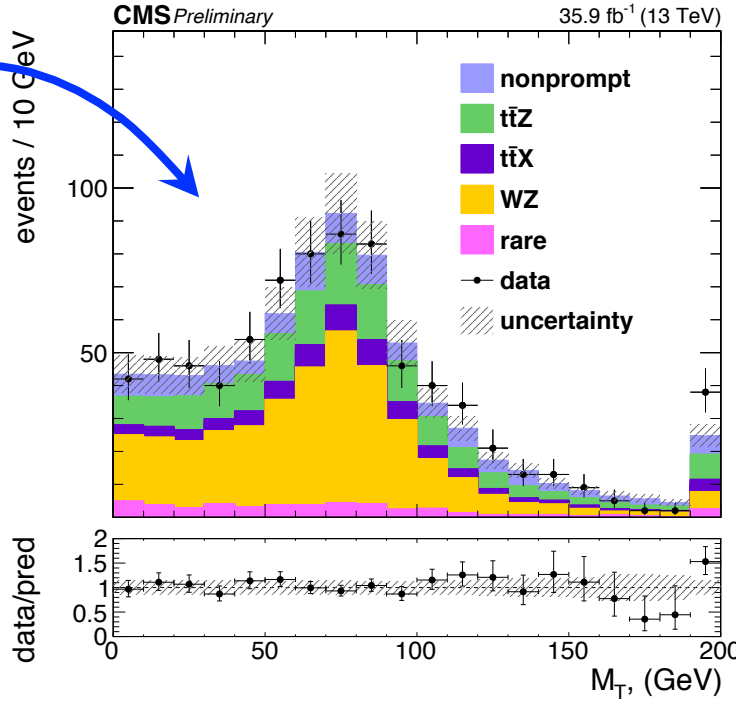
Selection:

- ≥3ℓ, with or without Z→2ℓ boson candidate.
- Large E_T^{miss} and H_T.
- Multiple (b-tagged) jets.
- Selection on M_T^{ℓ}: for WZ have $M_T^{\ell} \lesssim M_W$.
  - Uses lepton not from Z or the one that gives min(MT^{ℓ})

Define **multiple (46) search regions**.

Backgrounds:

1. Non-prompt leptons,
2. WZ/ttZ:
   - Estimated as in the "same-sign" analysis
3. Other rare backgrounds: ZZ, ttW, VVV:
   - Estimated from simulation.



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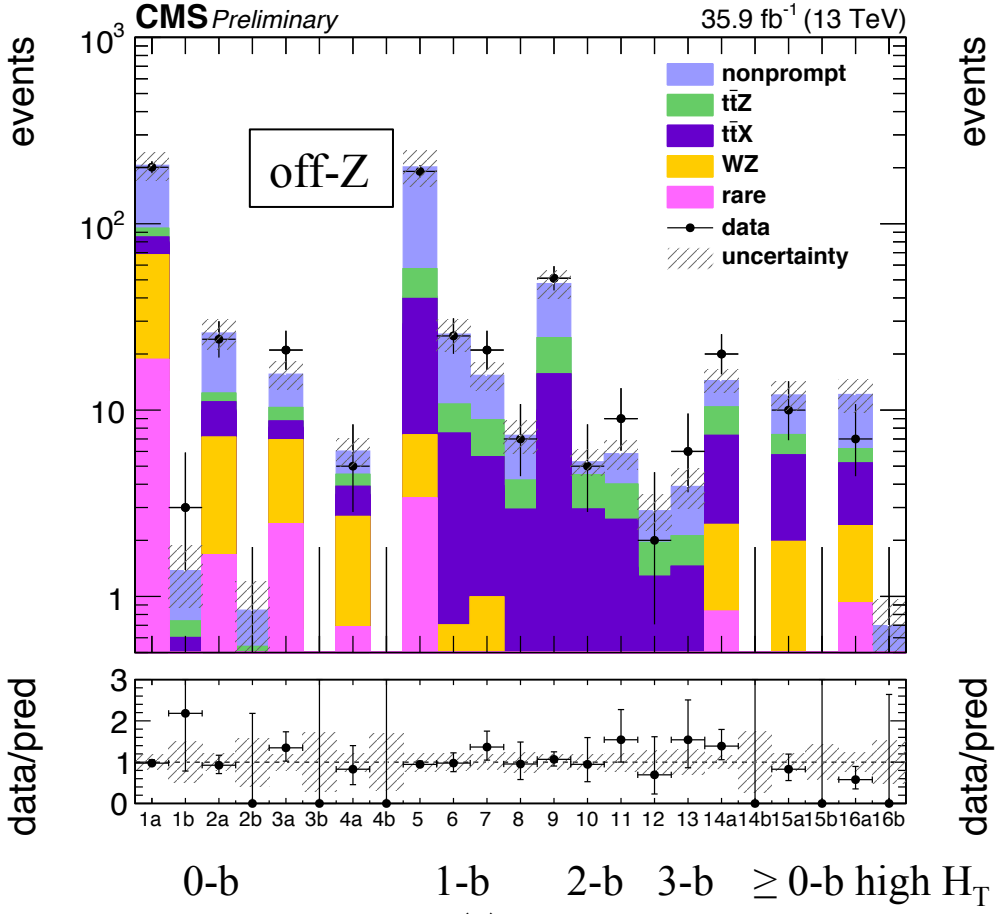
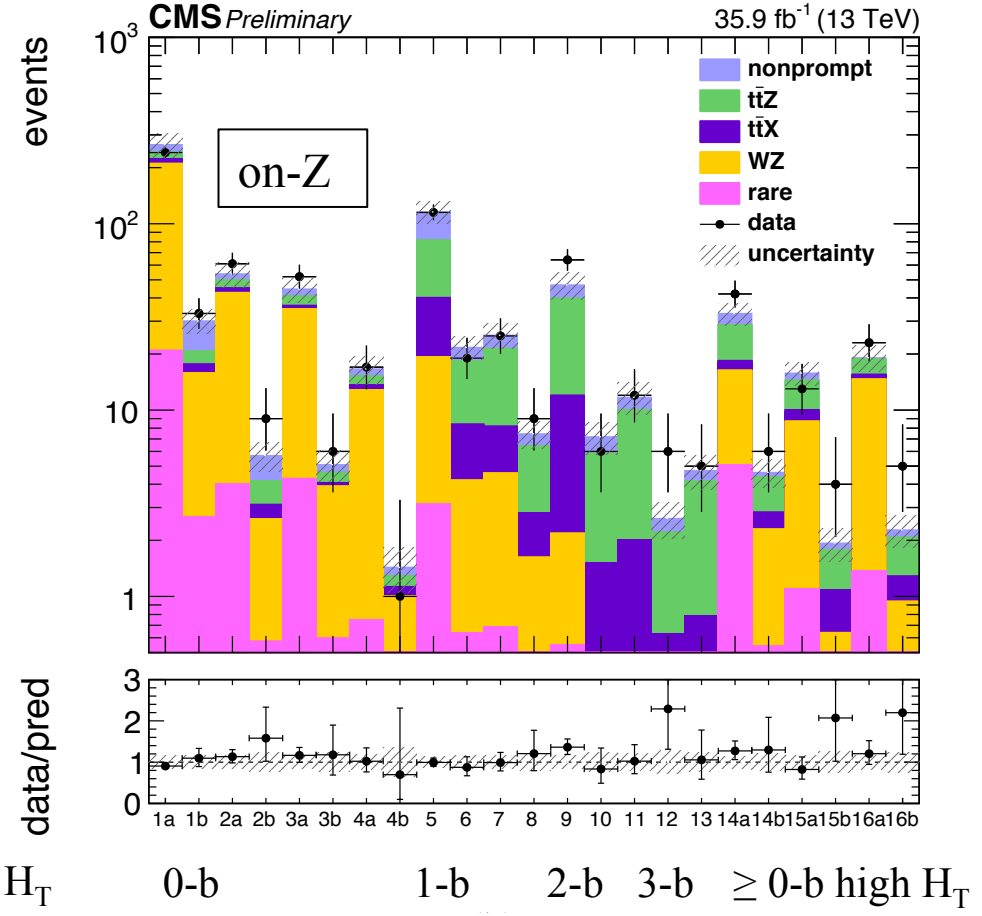
≥3ℓ

- "Off-Z signal regions" have no excess, the observation is slightly above the background prediction in the "on-Z signal regions" but within systematic precision.





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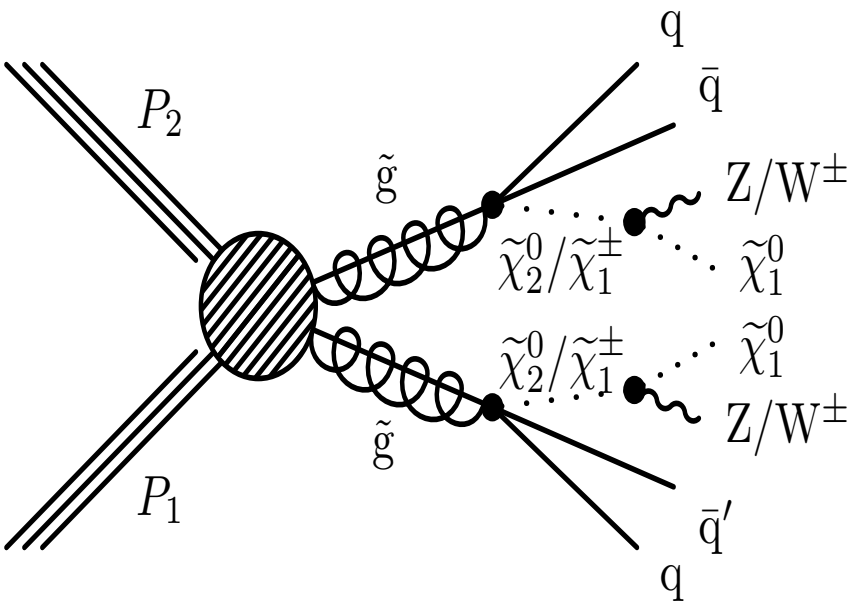
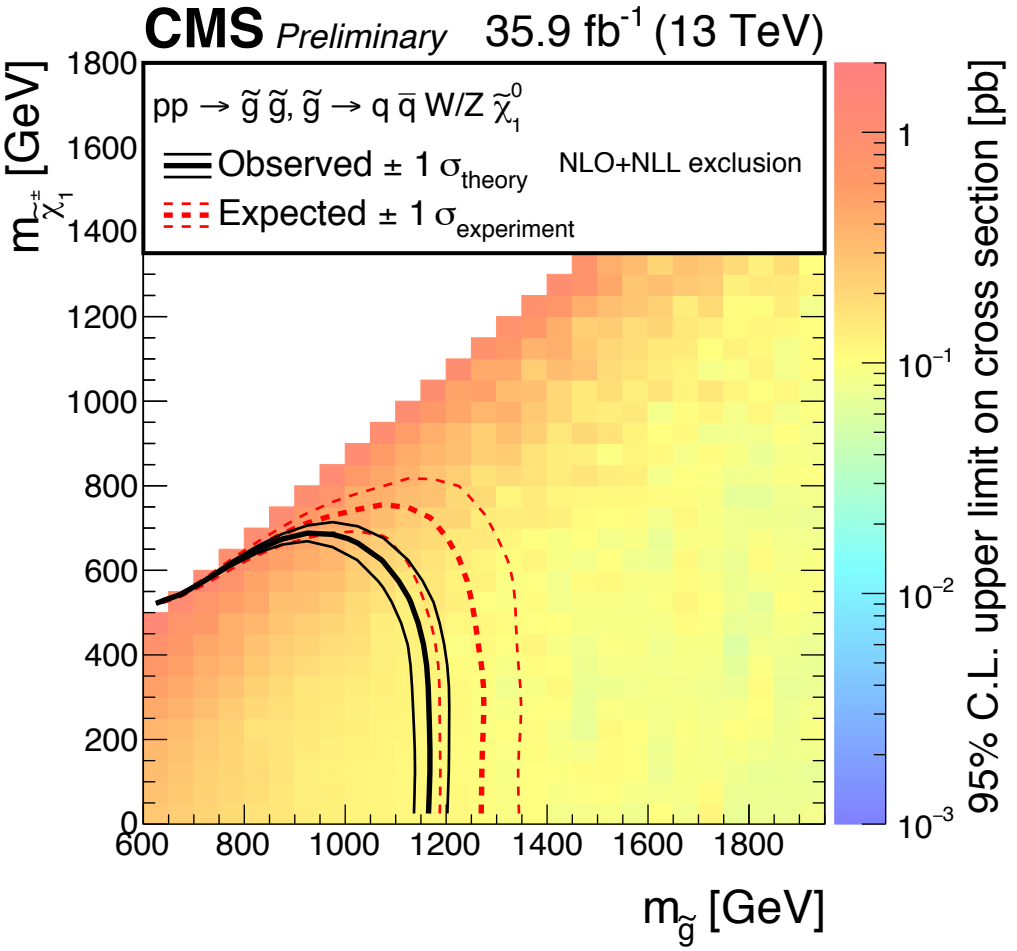
≥3ℓ

Interpretation:





Summary

- No evidence for physics beyond the SM found in searches for strongly-produced sparticles in final states with multiple leptons.
  - 2ℓ - same-sign; opposite-sign same-flavor (on- and off-Z)
  - $\geq 3\ell$

- For results for strong SUSY searches in other final states, please go to
  - in hadronic channel (Kin Ho Lo, earlier this session),
  - the 3rd generation (Caroline Collard, parallel Wednesday), and
  - the general [incl. 1ℓ final state] (Claudia Seitz, plenary Thursday).

- The CMS SUSY analyses presented (and most other) provide
  - aggregated signal regions (order of 5-10 signal regions instead of 50-100+)
  - and/or background correlation/covariance matrices

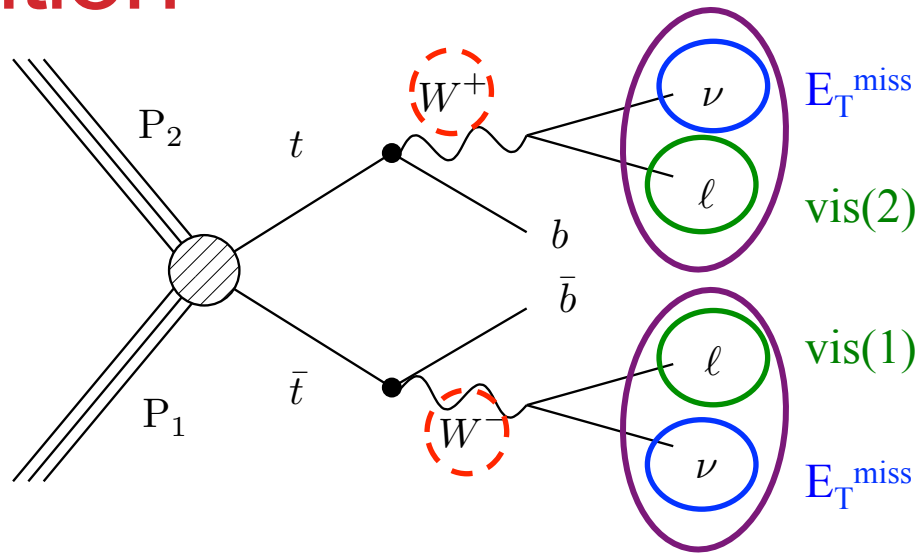
  for easier reinterpretation by phenomenologists, see
  http://cms-results.web.cern.ch/cms-results/public-results/publications/SUS/.

Backup

2ℓ SFOS: M_{T2} definition

- Generalization of transverse mass M_T:
  - Split E_T^{miss} so that don't overshoot "true M_T".

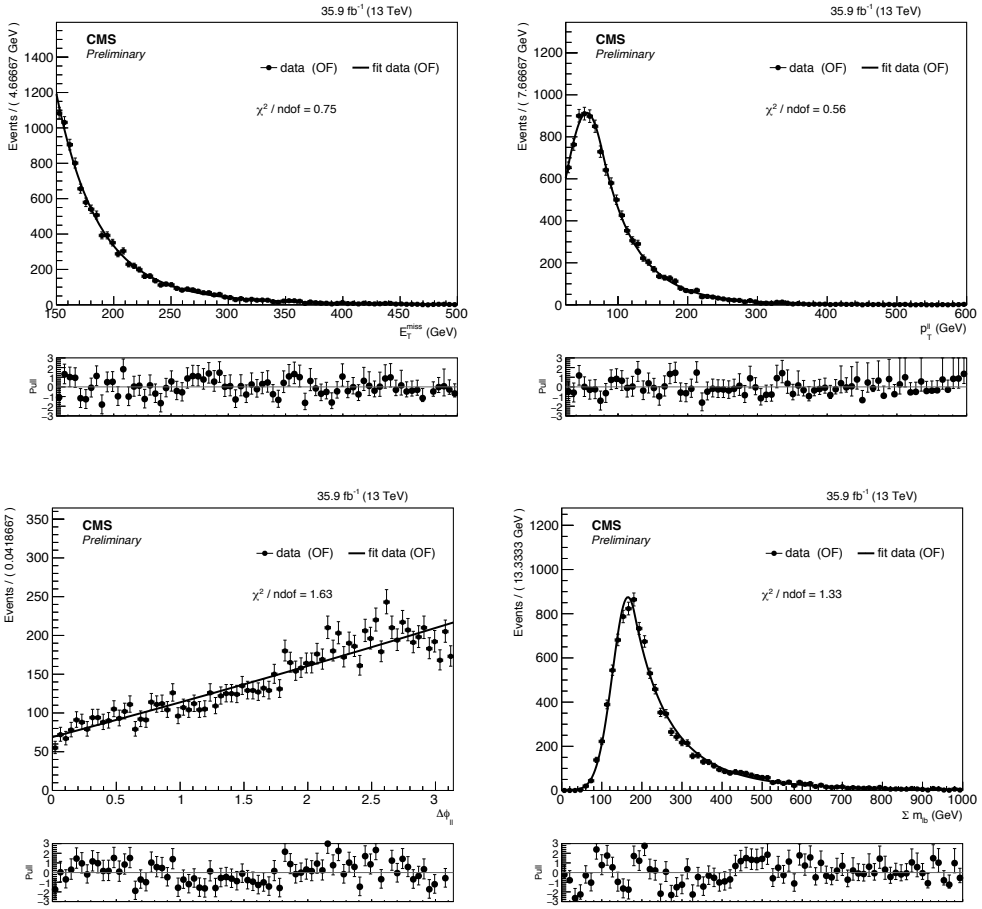
$$M_{T2} = \min_{\vec{p}_T^{\chi(1)}+\vec{p}_T^{\chi(2)}=\vec{E}_T^{miss}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$



- For the γ data control sample emulate dilepton final state, by assuming photon decays into a $\ell^+\ell^-$ as expected from a Z boson.

2ℓ SFOS: tt likelihood

- Inputs to likelihood (PDFs determined from opposite flavor data sample):
  - E_T^{miss} → double exponential
  - $p_T(\ell^+\ell^-)$ → crystal-ball
  - $|\Delta\phi(\ell^+\ell^-)|$ → 2nd-order polynomial
  - $\sum M_{\ell b}$ → crystal-ball
- The negative logarithm of the likelihood is taken as discriminant:
  - Non-tt̄-like region defined as being 5% efficient in tt̄→2ℓ.



2ℓ SFOS: edge mass fit

The FS background component is described using a Crystal-Ball [53] function: $\mathcal{P}_{CB}(m_{\ell\ell})$:

$$\mathcal{P}_{CB}(m_{\ell\ell}) = \begin{cases} \exp\left(-\frac{(m_{ll}-\mu_{CB})^2}{2\sigma_{CB}^2}\right) & \text{if } \frac{m_{ll}-\mu_{CB}}{\sigma_{CB}} < \alpha, \\ A(B+\frac{m_{ll}-\mu_{CB}}{\sigma_{CB}})^{-n} & \text{if } \frac{m_{ll}-\mu_{CB}}{\sigma_{CB}} > \alpha, \end{cases}$$

where

$$A = \left(\frac{n}{|\alpha|}\right)^n \exp\left(-\frac{|\alpha|^2}{2}\right) \quad \text{and} \quad B = \frac{n}{|\alpha|} - |\alpha|.$$

The DY background component

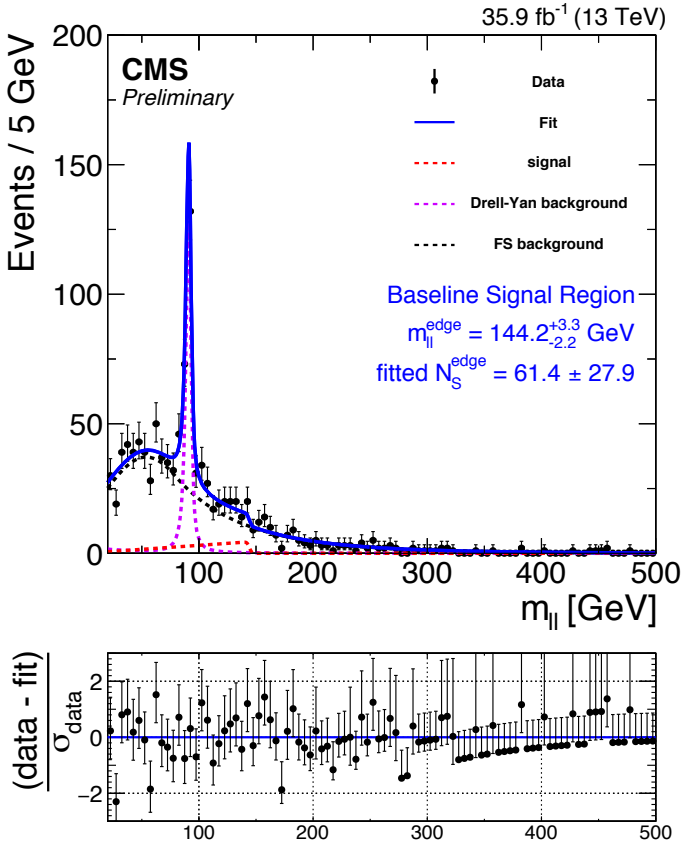
$$\mathcal{P}_{DSCB}(m_{\ell\ell}) = \begin{cases} A_1(B_1 - \frac{m_{ll}-\mu_{DSCB}}{\sigma_{DSCB}})^{-n_1} & \text{if } \frac{m_{ll}-\mu_{DSCB}}{\sigma_{DSCB}} < -\alpha_1, \\ \exp\left(-\frac{(m_{ll}-\mu_{DSCB})^2}{2\sigma_{DSCB}^2}\right) & \text{if } -\alpha_1 < \frac{m_{ll}-\mu_{DSCB}}{\sigma_{DSCB}} < \alpha_2, \\ A_2(B_2 + \frac{m_{ll}-\mu_{DSCB}}{\sigma_{DSCB}})^{-n_2} & \text{if } \frac{m_{ll}-\mu_{DSCB}}{\sigma_{DSCB}} > \alpha_2, \end{cases} \quad (3)$$

The full model for the on-Z DY lineshape is thus:

$$\mathcal{P}_{DY,\,\text{on-Z}}(m_{\ell\ell}) = \int \mathcal{P}_{DSCB}(m_{\ell\ell})\mathcal{P}_{BW}(m_{\ell\ell} - m')dm'. \quad (4)$$

The signal component is described by a triangular shape, convolved with a Gaussian distribution to account for the experimental resolution:

$$\mathcal{P}_S(m_{\ell\ell}) \propto \frac{1}{\sqrt{2\pi}\sigma_{\ell\ell}} \int_0^{m_{\ell\ell}^{edge}} y \cdot \exp\left(-\frac{(m_{\ell\ell}-y)^2}{2\sigma_{\ell\ell}^2}\right) dy. \quad (5)$$



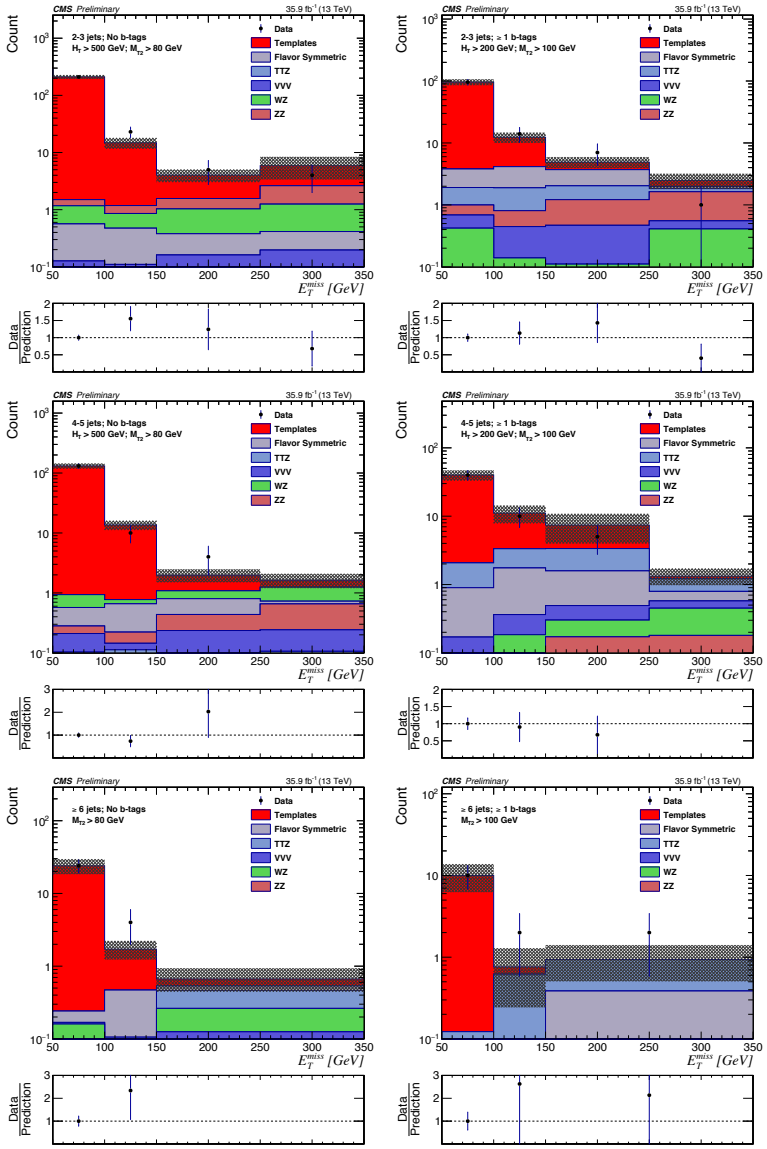
Drell–Yan	191 ± 19
OF yield	768 ± 24
$R_{SF/OF}$	1.07 ± 0.03
Signal events	61.4 ± 27.9
$m_{\ell\ell}^{edge}$	$144.2^{+3.3}_{-2.2}$ GeV
Local significance	$2.3\,\sigma$
Global significance	$1.5\,\sigma$

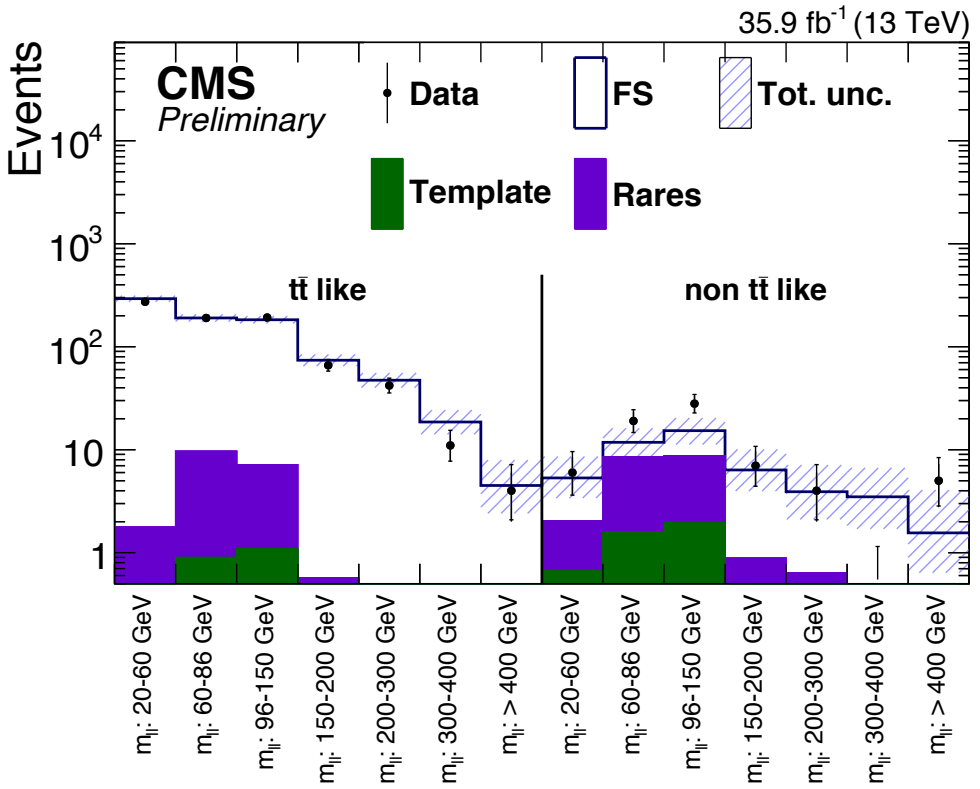
2ℓ SFOS: signal regions

Table 1: Summary of all signal region selections.

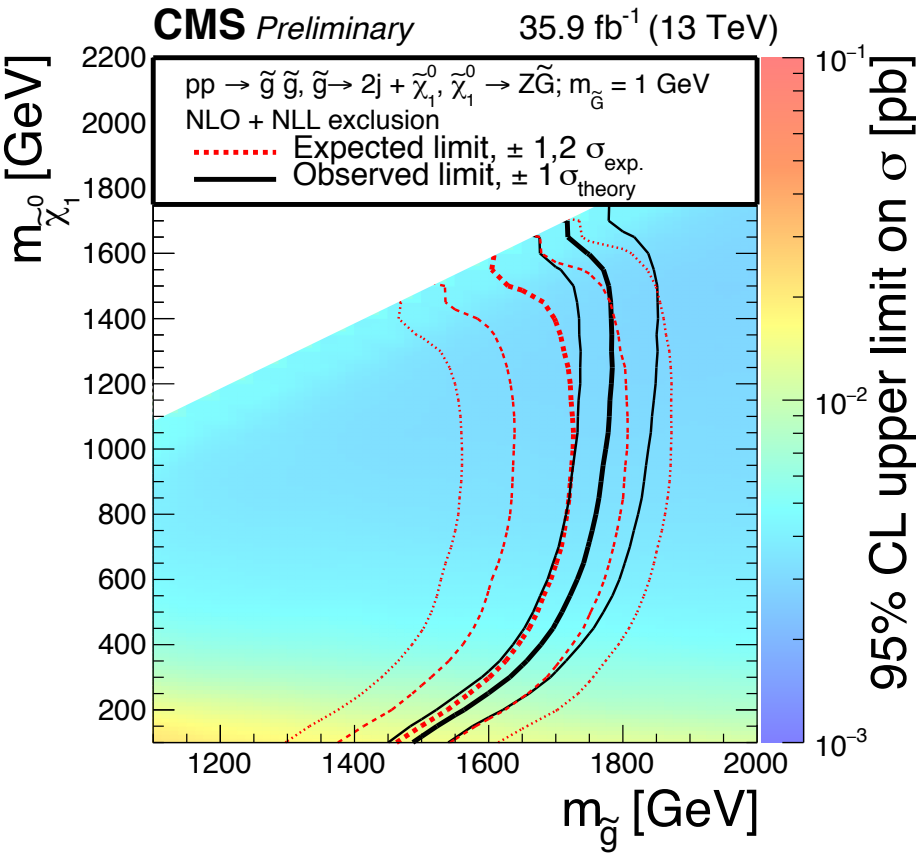
Strong on-Z Signal Regions					
Region	N_{jets}	$N_{\text{b-jets}}$	H_{T}	$\text{M}_{\text{T2}}(\ell\ell)$	$E_{\text{T}}^{\text{miss}}$ binning [GeV]
SRA b-veto	2–3	= 0	$>$ 500 GeV	$>$ 80 GeV	[100,150,250,∞]
SRB b-veto	4–5	= 0	$>$ 500 GeV	$>$ 80 GeV	[100,150,250,∞]
SRC b-veto	$\geq$ 6	= 0	-	$>$ 80 GeV	[100,150,∞]
SRA b-tag	2–3	$\geq$ 1	$>$ 200 GeV	$>$ 100 GeV	[100,150,250,∞]
SRB b-tag	4–5	$\geq$ 1	$>$ 200 GeV	$>$ 100 GeV	[100,150,250,∞]
SRC b-tag	$\geq$ 6	$\geq$ 1	-	$>$ 100 GeV	[100,150,∞]
Electroweak on-Z Signal Regions					
Region	N_{jets}	$N_{\text{b-jets}}$	dijet mass	M_{T2}	$E_{\text{T}}^{\text{miss}}$ binning [GeV]
VZ	$\geq$ 2	= 0	$\text{m}_{\text{jj}} < 110$ GeV	$\text{M}_{\text{T2}}(\ell\ell) > 80$ GeV	[100,150,250,350,∞]
HZ	$\geq$ 2	= 2	$\text{m}_{\text{bb}} < 150$ GeV	$\text{M}_{\text{T2}}(\ell b \ell b) > 200$ GeV	[100,150,250,∞]
Edge Signal Regions					
Region	N_{jets}	$E_{\text{T}}^{\text{miss}}$	$\text{M}_{\text{T2}}(\ell\ell)$	$\text{t}\bar{\text{t}}$ likelihood	$m_{\ell\ell}$ binning [GeV]
Edge Fit	$\geq$ 2	$>$ 150 GeV	$>$ 80 GeV	-	$>$ 20
$\text{t}\bar{\text{t}}$ like	$\geq$ 2	$>$ 150 GeV	$>$ 80 GeV	$<$ 21	[20,60,86],[96,150,200,300,400,∞]
non-$\text{t}\bar{\text{t}}$ like	$\geq$ 2	$>$ 150 GeV	$>$ 80 GeV	$>$ 21	[20,60,86],[96,150,200,300,400,∞]

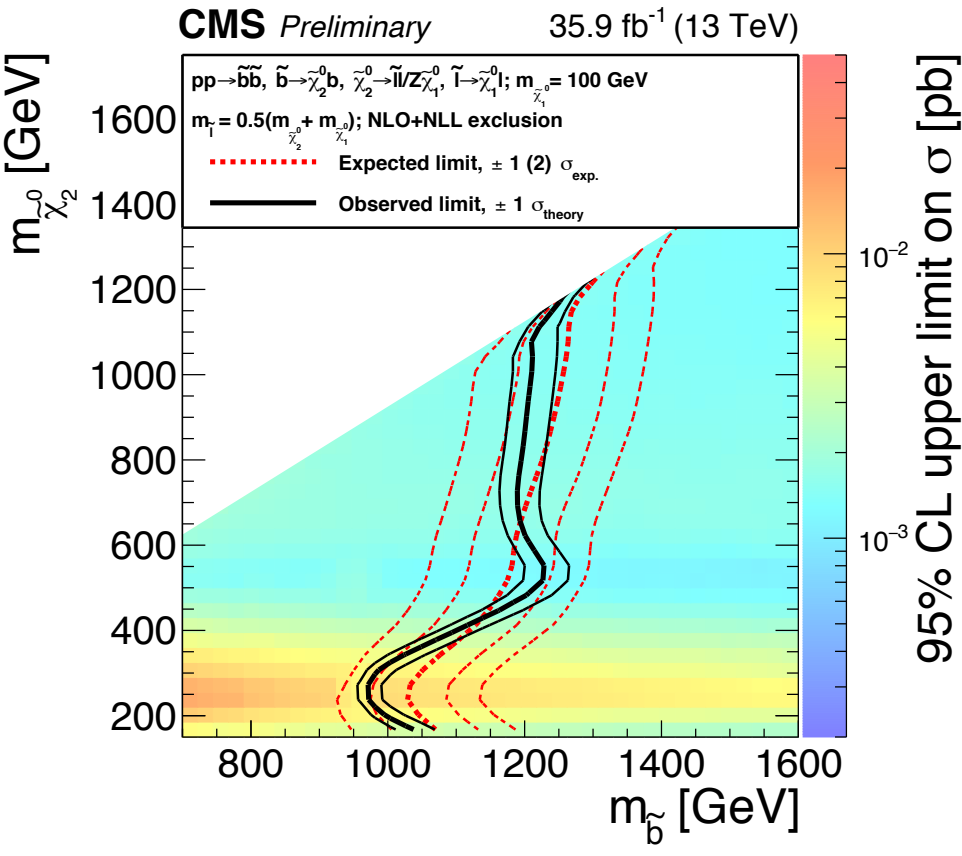
2ℓ SFOS: results





2ℓ SFOS: interpretation





2ℓ SS: signal regions

Table 2: Signal region definitions for the HH selection. Regions split by charge are indicated with (++) and (--).

N_b	m_T^{min} (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T \in [1125, 1300]$ GeV	$H_T \in [1300, 1600]$ GeV	$H_T > 1600$ GeV
0	< 120	$50 - 200$	2-4	SR1	SR2	SR46 (++) / SR47 (--)	SR48 (++) / SR49 (--)	SR50 (++) / SR51 (--)
			≥ 5	SR3	SR4			
		$200 - 300$	2-4		SR5 (++) / SR6 (--)			
			≥ 5		SR7			
	> 120	$50 - 200$	2-4		SR8 (++) / SR9 (--)			
			≥ 5		SR10			
		$200 - 300$	2-4					
			≥ 5					
1	< 120	$50 - 200$	2-4	SR11	SR12			
			≥ 5	SR13 (++) / SR14 (--)	SR15 (++) / SR16 (--)			
		$200 - 300$	2-4		SR17 (++) / SR18 (--)			
			≥ 5		SR19			
	> 120	$50 - 200$	2-4		SR20 (++) / SR21 (--)			
			≥ 5		SR22			
		$200 - 300$	2-4					
			≥ 5					
2	< 120	$50 - 200$	2-4	SR23	SR24			
			≥ 5	SR25 (++) / SR26 (--)	SR27 (++) / SR28 (--)			
		$200 - 300$	2-4		SR29 (++) / SR30 (--)			
			≥ 5		SR31			
	> 120	$50 - 200$	2-4		SR32 (++) / SR33 (--)			
			≥ 5		SR34			
		$200 - 300$	2-4					
			≥ 5					
≥ 3	< 120	$50 - 200$	≥ 2	SR35 (++) / SR36 (--)	SR37 (++) / SR38 (--)			
		$200 - 300$			SR39			
	> 120	$50 - 300$	≥ 2	SR40	SR41			
inclusive	inclusive	$300 - 500$	≥ 2	-	SR42 (++) / SR43 (--)			
		> 500		-	SR44 (++) / SR45 (--)			

2ℓ SS: signal regions

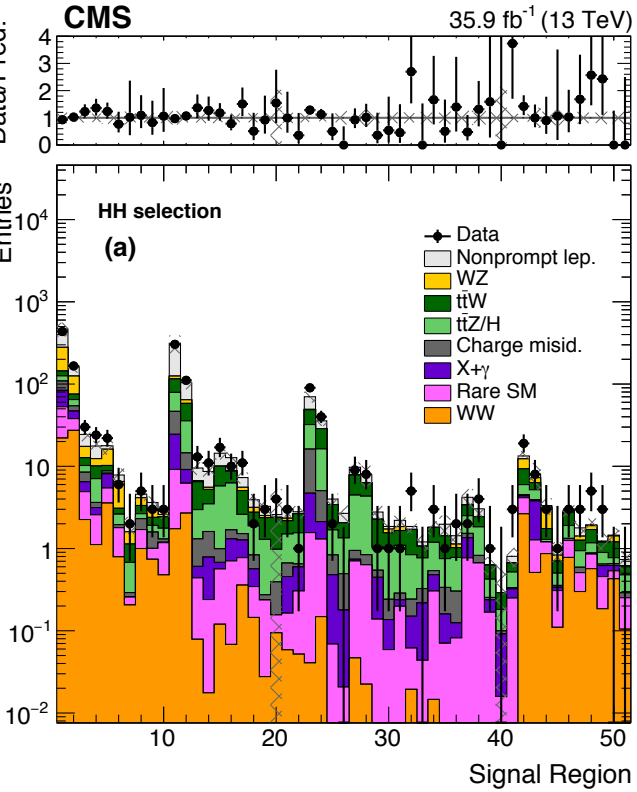
Table 3: Signal region definitions for the HL selection. Regions split by charge are indicated with (++) and (--).

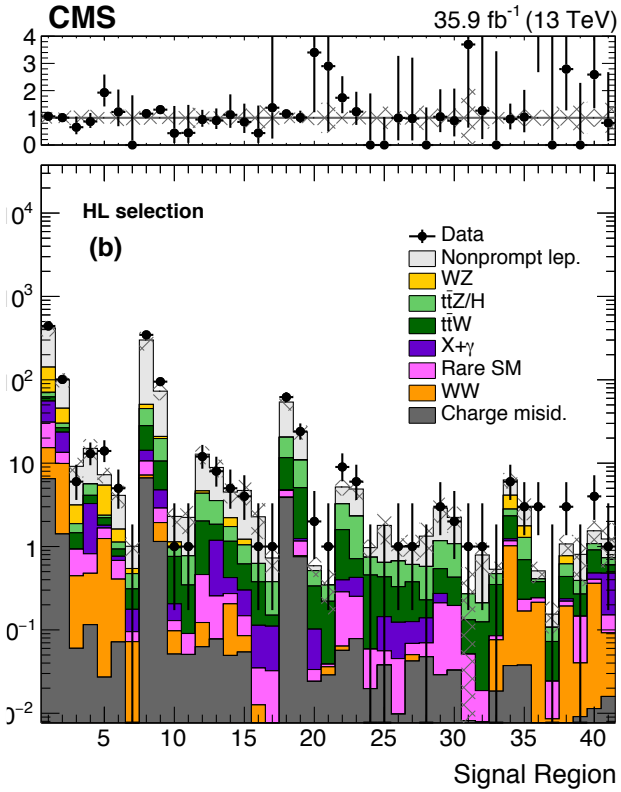
N_b	m_T^{min} (GeV)	E_T^{miss} (GeV)	N_{jets}	$H_T < 300$ GeV	$H_T \in [300, 1125]$ GeV	$H_T \in [1125, 1300]$ GeV	$H_T > 1300$ GeV
0	< 120	$50 - 200$	2-4	SR1	SR2	SR38 (++) / SR39 (--)	SR40 (++) / SR41 (--)
			≥ 5	SR3	SR4		
		$200 - 300$	2-4		SR5 (++) / SR6 (--)		
			≥ 5		SR7		
1	< 120	$50 - 200$	2-4	SR8	SR9		
			≥ 5	SR10 (++) / SR11 (--)	SR12 (++) / SR13 (--)		
		$200 - 300$	2-4		SR14 (++) / SR15 (--)		
			≥ 5		SR16 (++) / SR17 (--)		
2	< 120	$50 - 200$	2-4	SR18	SR19		
			≥ 5	SR20 (++) / SR21 (--)	SR22 (++) / SR23 (--)		
		$200 - 300$	2-4		SR24 (++) / SR25 (--)		
			≥ 5		SR26		
≥ 3	< 120	$50 - 200$	≥ 2	SR27 (++) / SR28 (--)	SR29 (++) / SR30 (--)		
		$200 - 300$			SR31		
inclusive	> 120	$50 - 300$	≥ 2	SR32	SR33		
inclusive	inclusive	$300 - 500$	≥ 2	-	SR34 (++) / SR35 (--)		
		> 500		-	SR36 (++) / SR37 (--)		

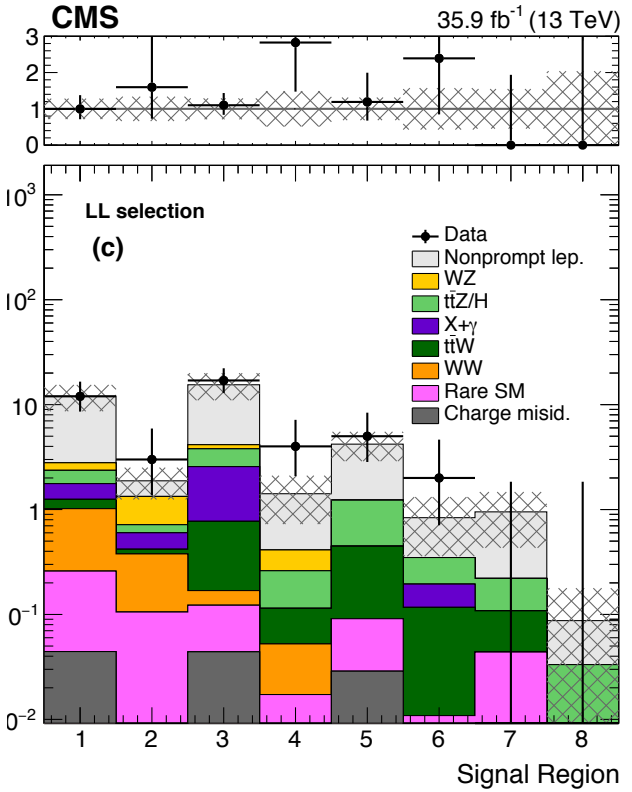
Table 4: Signal region definitions for the LL selection. All SRs in this category require $N_{jets} \geq 2$.

N_b	m_T^{min} (GeV)	H_T (GeV)	$E_T^{miss} \in [50, 200]$ GeV	$E_T^{miss} > 200$ GeV
0	< 120	> 300	SR1	SR2
1			SR3	SR4
2			SR5	SR6
≥ 3			SR7	
Inclusive	> 120		SR8	

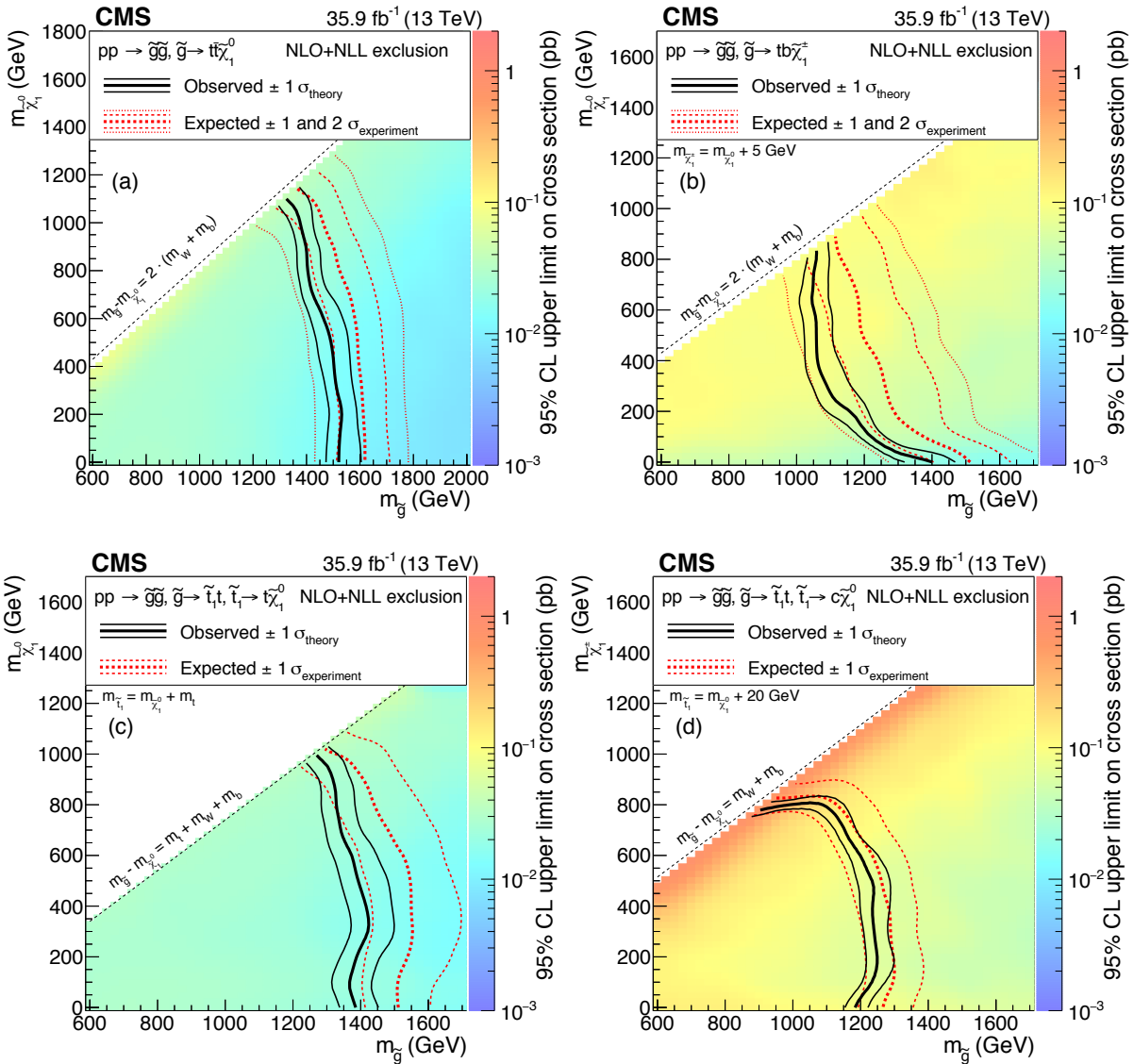
2ℓ SS: results



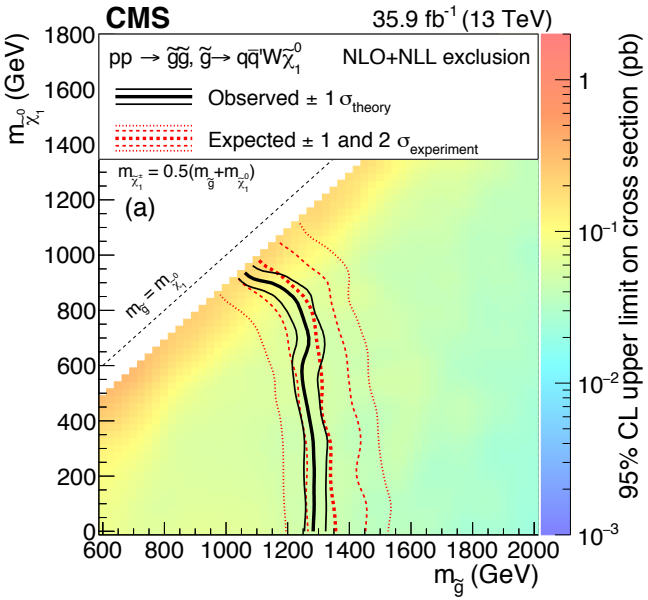


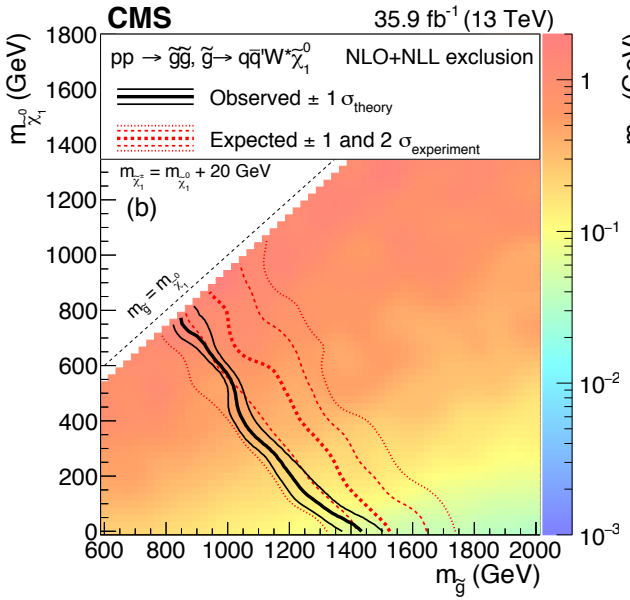


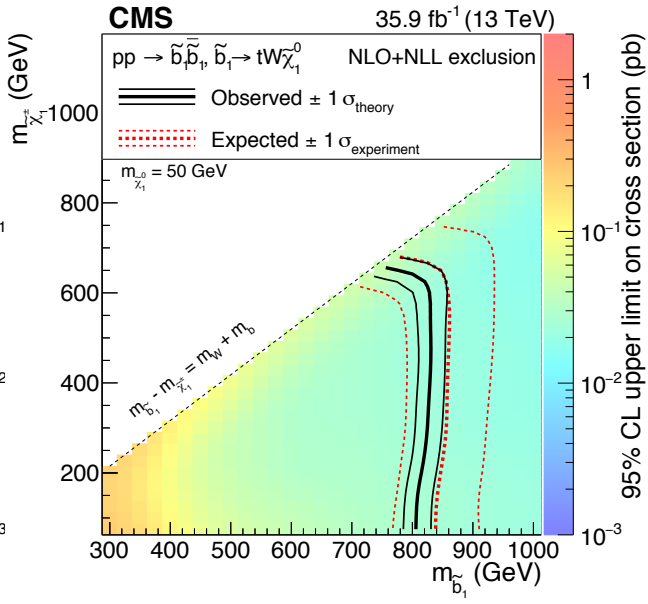
2ℓ SS: interpretation



2ℓ SS: interpretation





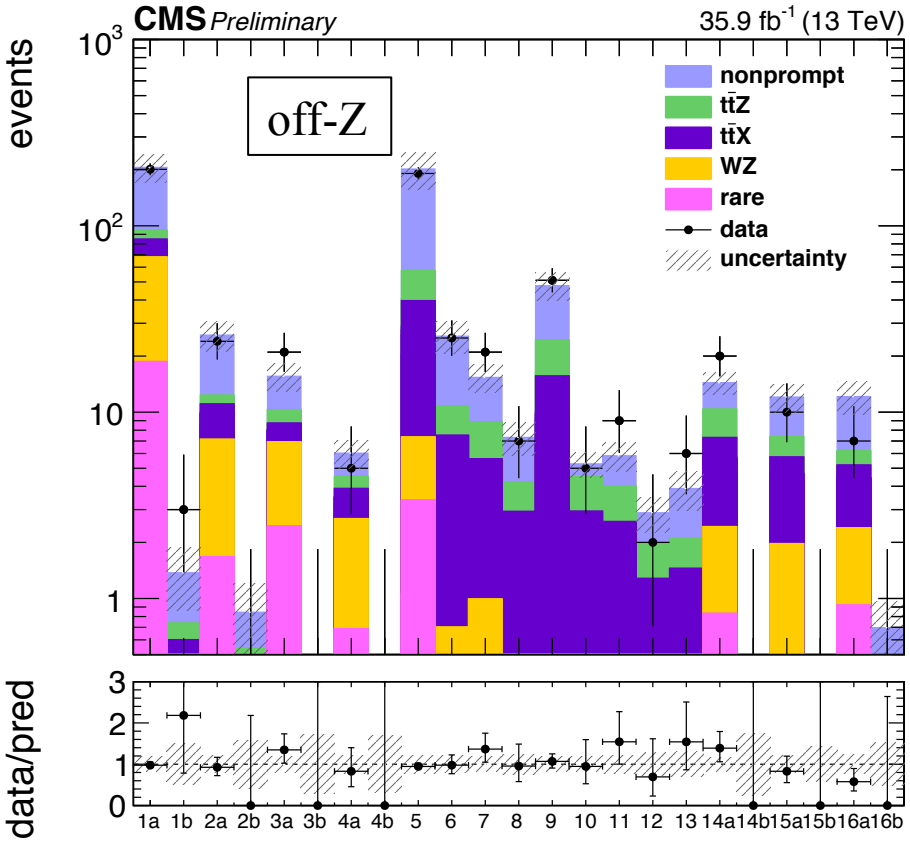


≥3ℓ: signal regions

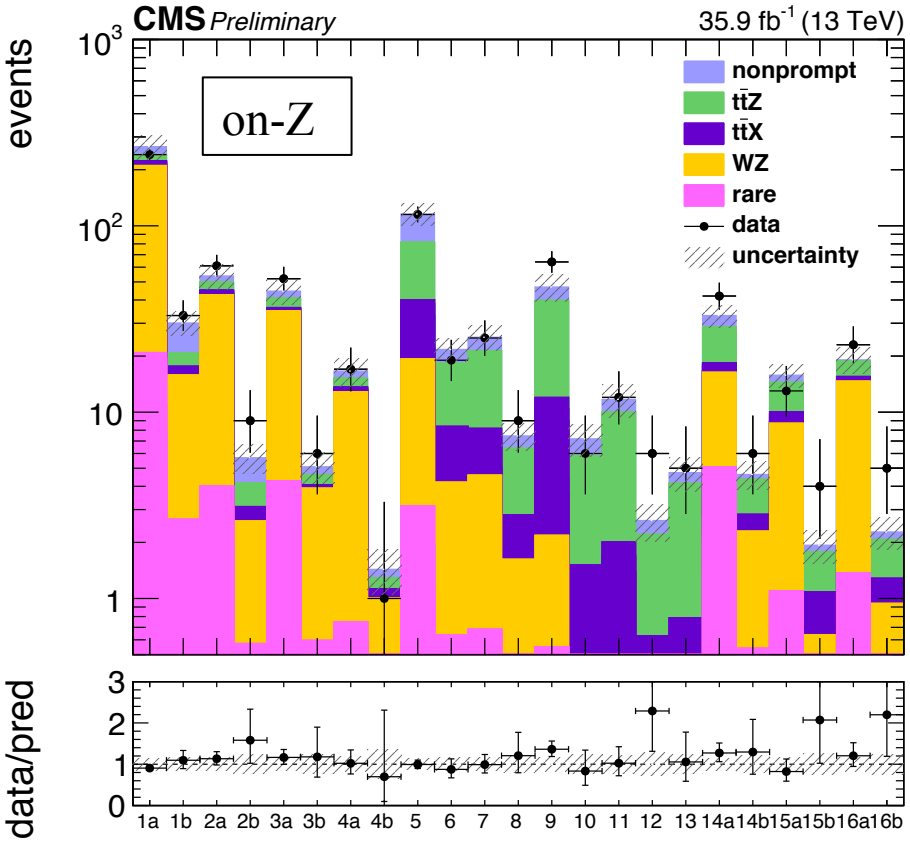
Table 2: Summary of the definition of the signal regions. The minimum $E_{\mathrm{T}}^{\mathrm{miss}}$ requirement is raised from 50 to 70 GeV only for on-Z SR1 and SR5. The dagger sign indicates signal regions that are further subdivided at $M_{\mathrm{T}}^{\mathrm{min}}$ = 120 GeV. The search regions are mirrored in on- and off-Z region.

N_{jets}	$N_{\mathrm{b\,jets}}$	H_{T} (GeV)	$50(70)\,\mathrm{GeV} \leq E_{\mathrm{T}}^{\mathrm{miss}} < 150\,\mathrm{GeV}$	$150\,\mathrm{GeV} \leq E_{\mathrm{T}}^{\mathrm{miss}} < 300\,\mathrm{GeV}$	$E_{\mathrm{T}}^{\mathrm{miss}} \geq 300\,\mathrm{GeV}$
≥ 2	0	$60-400$	SR1 †	SR2 †	SR16 †
		$400-600$	SR3 †	SR4 †	
	1	$60-400$	SR5	SR6	
		$400-600$	SR7	SR8	
	2	$60-400$	SR9	SR10	
		$400-600$	SR11	SR12	
	≥ 3	$60-600$	SR13		
	inclusive	≥ 600	SR14 †	SR15 †	

≥3ℓ: results

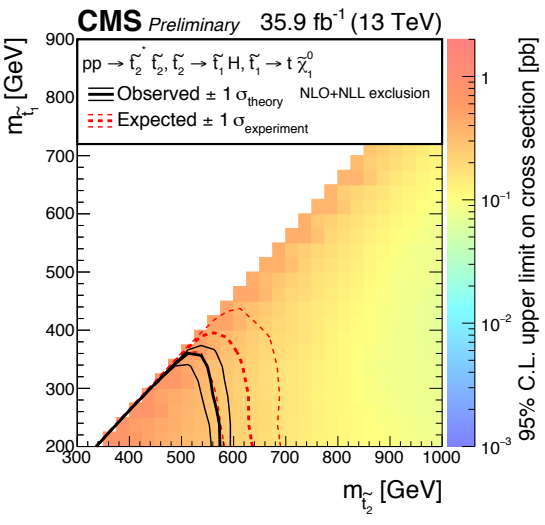


(a)

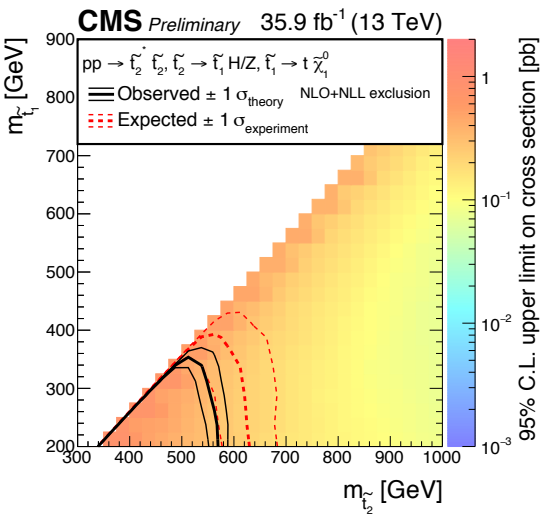


(b)

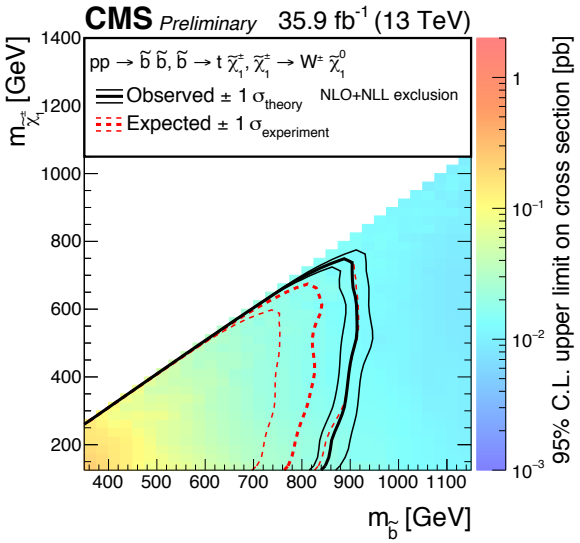
≥3ℓ: interpretation

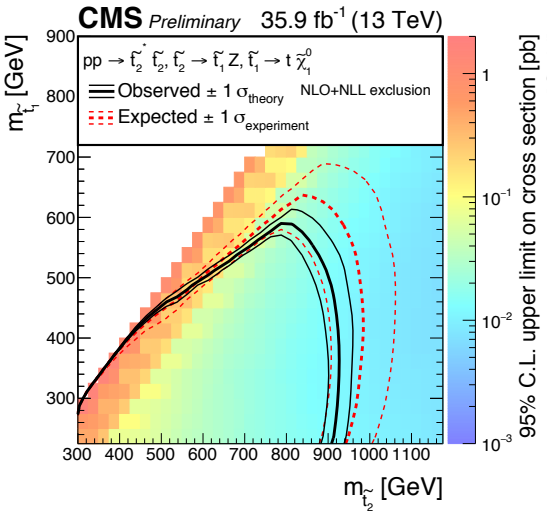


(a)

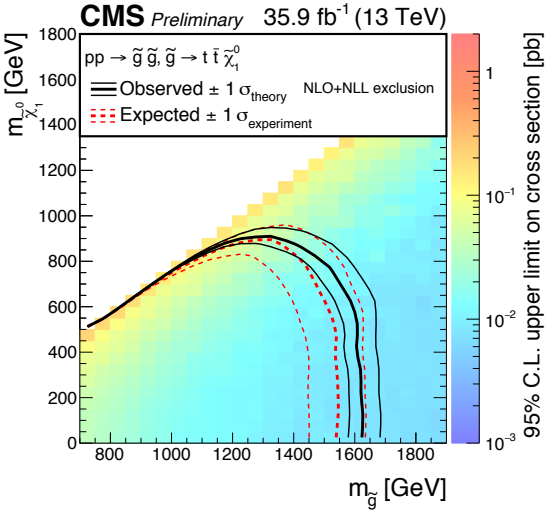


(b)

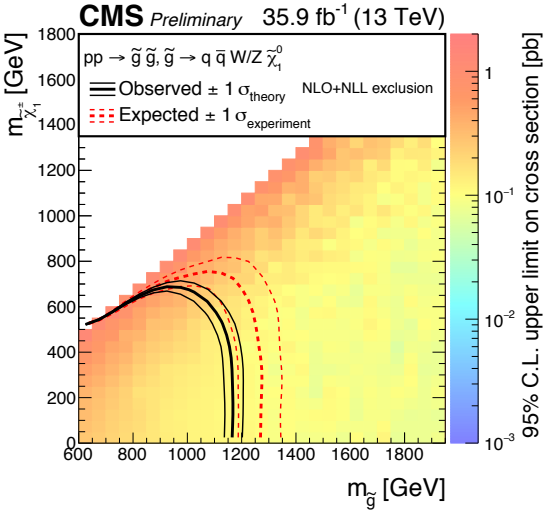




(c)



(a)



(b)