



Search for SUSY in the di-lepton final state in CMS

SUSY 2015, Lake Tahoe

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on behalf of the CMS Collaboration

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1 Searching for dilepton events in CMS

2 Opposite-sign lepton pairs

3 Opposite sign dileptons with b-jets

4 Same-sign lepton pairs

5 Summary

- Leptons produced in SUSY events if SM-Vectorbosons or sleptons are part of the decay chain
- Clear experimental signatures of leptons offer reduction of SM backgrounds → lower E_T^{miss} and H_T thresholds compared to hadronic searches
- Signatures with hadronically decaying τ s suffer both from reduced identification efficiency and much larger backgrounds from misidentified jets

Triggers

Triggers used in the presented analyses

- ee, $\mu\mu$, e μ trigger with $p_T > 17(8)$ GeV for leading (trailing) lepton)
- ee, $\mu\mu$, e μ trigger with $p_T > 10$ GeV and $H_T > 175$ GeV

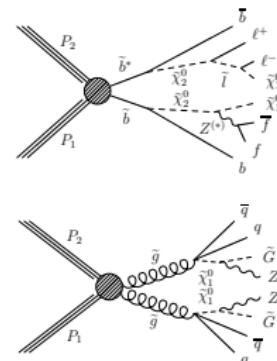
Common objects

Objects used in all presented analyses, reconstructed by particle flow (PF) algorithm

- Hadronic jets clustered with anti- k_T algorithm, distance parameter $R = 0.5$ p_T and $|\eta|$ thresholds analysis dependent
- E_T^{miss} reconstructed from particle candidates identified by PF algorithm

Search for opposite-sign same-flavour leptons

- Search focused on flavour-correlated production of OS leptons
- Edge-structure in $m_{\ell\ell}$ distribution from $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \ell^+ \ell^-$ decays given by mass difference of neutralinos
- On-shell Z boson production for example in GMSB scenarios
- Perform counting experiment and dedicated kinematic fit searching for an edge



Event selection

- 2 SF OS leptons with $p_T > 20$ GeV
- $E_T^{\text{miss}} > 150$ GeV and $N_{\text{jets}} \geq 2$
or
 $E_T^{\text{miss}} > 100$ GeV and $N_{\text{jets}} \geq 3$
- Split sample in lepton $|\eta|$:
 - Central (both < 1.4)
 - Forward (at least one > 1.6)
- On-Z part uses finer binning in E_T^{miss}

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Background prediction

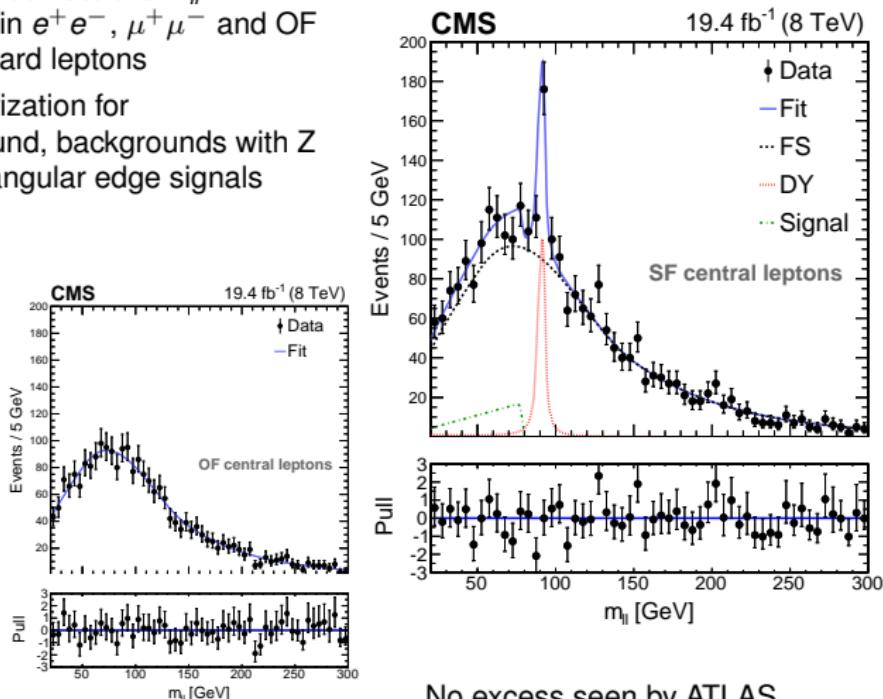
- Off-Z: flavour-symmetric processes dominant ($> 98\%$), mostly $t\bar{t}$
Predict from OF data with high precision (4-8% syst. uncert.)
- Contribution of backgrounds containing Z bosons estimated by combination of data driven techniques and simulation

Search for opposite-sign same-flavour leptons

- Unbinned maximum-likelihood fit to the $m_{\ell\ell}$ distribution simultaneously in e^+e^- , $\mu^+\mu^-$ and OF leptons for central and forward leptons
- Model consists of parametrization for flavour-symmetric background, backgrounds with Z bosons and a shape for triangular edge signals

	Central	Forward
Drell-Yan	158 ± 23	71 ± 15
OF yield	2270 ± 44	745 ± 25
R_{SF}/OF	1.03	1.02
Signal events	126 ± 41	22 ± 20
$m_{\ell\ell}^{\text{edge}}$	$78.7 \pm 1.4 \text{ GeV}$	
Local significance	2.4σ	

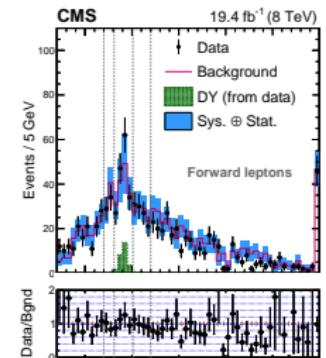
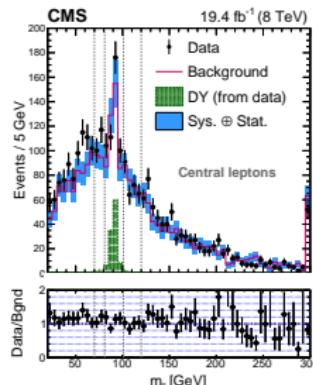
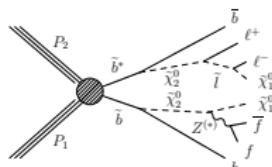
- Fitted edge position $78.7 \pm 1.4 \text{ GeV}$
- 126 ± 41 signal events for central leptons
- No significant signal component for forward leptons
- 2.4σ local significance



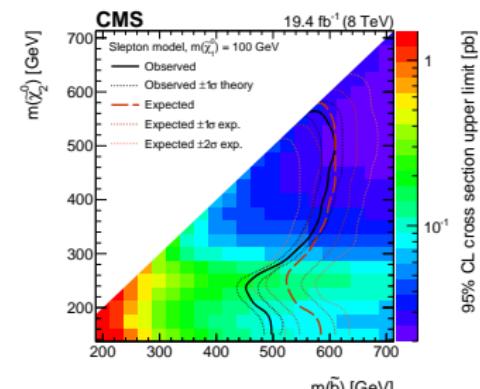
No excess seen by ATLAS
using a similar signal selection

Search for opposite-sign same-flavour leptons

- Counting experiment in three $m_{\ell\ell}$ bins
- For $20 \text{ GeV} < m_{\ell\ell} < 70 \text{ GeV}$:
Excess of 130^{+48}_{-49} events,
 2.6σ (local)
- results consistent with fit

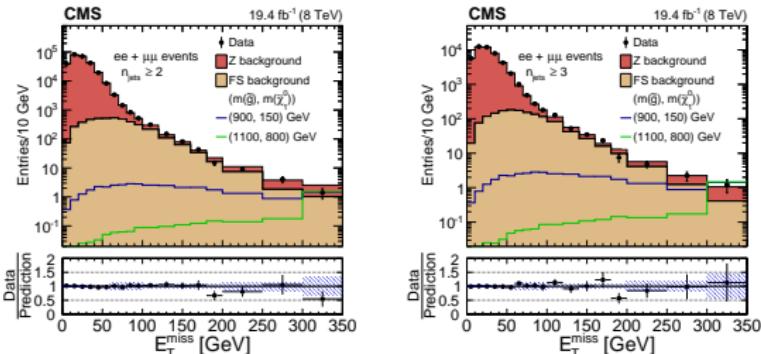
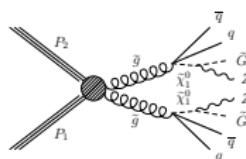


- Interpret results in Simplified Model containing sbottom pair production
- $\tilde{\chi}_2^0$ decays into $\ell\ell\tilde{\chi}_1^0$ via slepton or Z boson with 50% probability each
- Exclude sbottom masses below 450 to 600 GeV depending on $m_{\tilde{\chi}_2^0}$



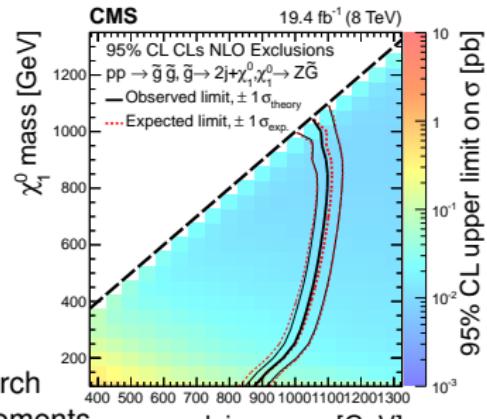
Search for opposite-sign same-flavour leptons

- Dedicated analysis of on-Z region ($81 \text{ GeV} < m_{ll} < 101 \text{ GeV}$)
- several bins in E_T^{miss} for $N_{\text{jets}} \geq 2$ and ≥ 3
- Good agreement between data and background estimation over full E_T^{miss} range



- Interpret results in Simplified Model in GMSB model containing gluino pair production
- Final state includes several jets, two Z bosons and E_T^{miss} from undetected gravitinos
- Exclude gluino masses below 900 to 1100 GeV depending on $m_{\tilde{\chi}_1^0}$

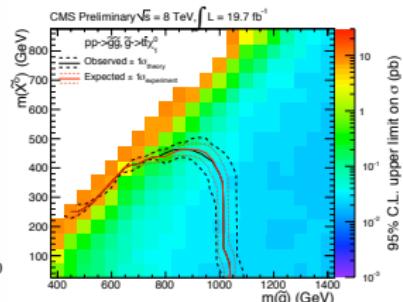
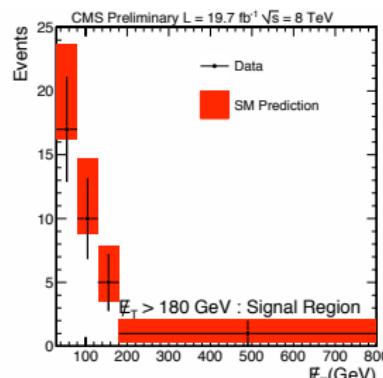
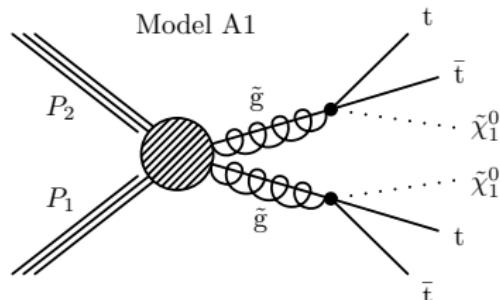
3σ excess in ATLAS on-Z search
Very different kinematic requirements
→ can't compare to this result



Opposite-sign dileptons with b-jets

- Search focussed on gluino pair production with decays to $t\bar{t}$ and LSP
- Select opposite-sign ee, $\mu\mu$, and $e\mu$ events
- Require $E_T^{\text{miss}} > 180 \text{ GeV}$, > 4 jets, and > 2 b-tags
- Two leading jets: $|\eta| < 1.0$

- Backgrounds estimated from jet- $|\eta|$ sideband by multiplication with extrapolation factor obtained on data in events with 2 b-tags
- Expected background yield: $1.20 \pm 0.86 \text{ (stat.)} \pm 0.60 \text{ (syst.)}$ events
- Observed: 1 event
- For $m_{\tilde{g}} < 1 \text{ TeV}$, $m_{\tilde{\chi}_1^0} < 450 \text{ GeV}$ can be excluded

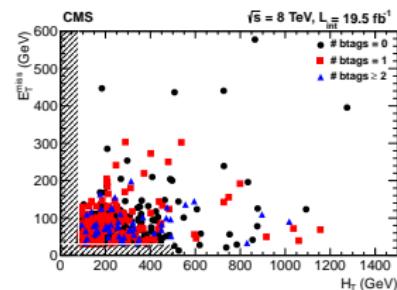
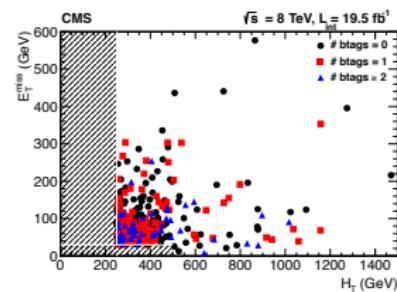


CMS-PAS-SUS-13-016

- Production of same-sign lepton pairs is rare in the SM
- Can be much more common in SUSY
- Select events with same-sign dileptons ($e\bar{e}$, $\mu\mu$, $e\mu$) and at least two jets
- Events with three leptons are rejected if there is a SF-OS-lepton pair with $m_{\ell\ell} < 12$ GeV or compatible with m_Z

Analysis strategy

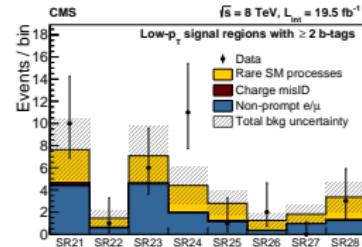
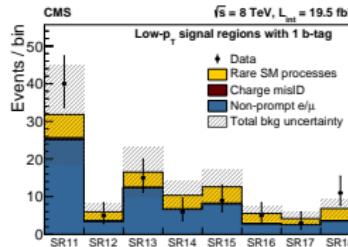
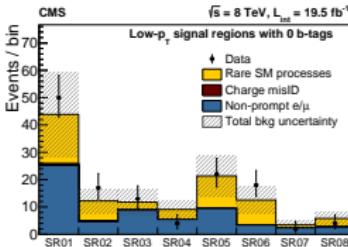
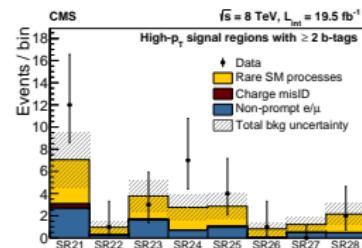
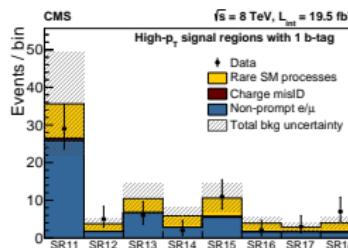
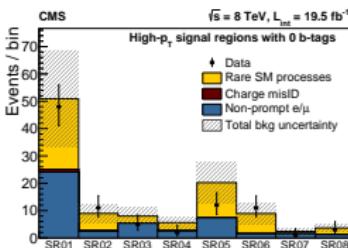
- Perform a low lepton p_T (> 10 GeV) and high lepton p_T (> 20 GeV) analysis
- Low p_T analysis sensitive to compressed spectra
- High p_T analysis focuses on lepton from W/Z boson decays
- Low p_T analysis has higher H_T requirement (> 250 GeV) due to trigger requirements
- Use E_T^{miss} , H_T , N_{jets} , and $N_{\text{b-jets}}$ to classify events
- Results in 28 search regions for each high and low p_T analysis



Search for same-sign lepton pairs

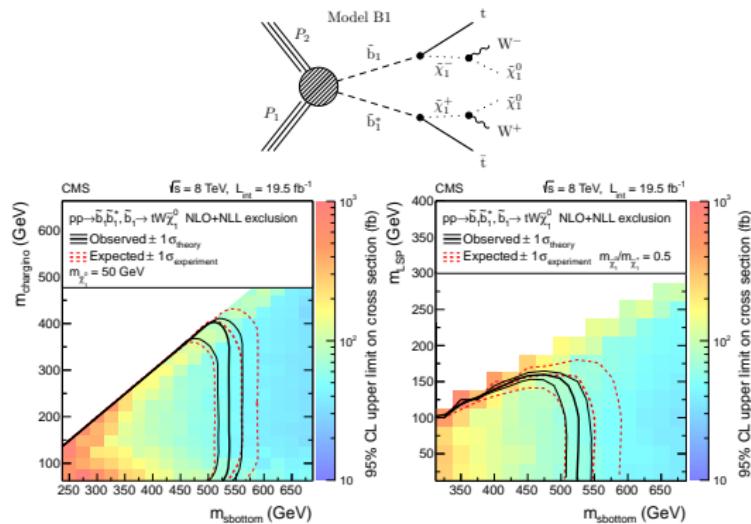
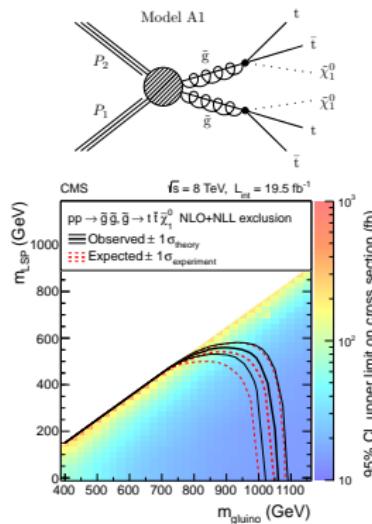
SM backgrounds

- **Non-prompt leptons:** Predicted from events with leptons passing loose selection criteria, multiplied by tight-to-loose ratio
- **Charge misidentification:** Negligible for muons, for electrons predicted from OS events multiplied by charge mis-ID probability (10^{-4} - 10^{-5})
- **Rare SM:** $t\bar{t}V$, VV , $t\bar{t}H$, and VH predicted from Simulation



Search for same-sign lepton pairs

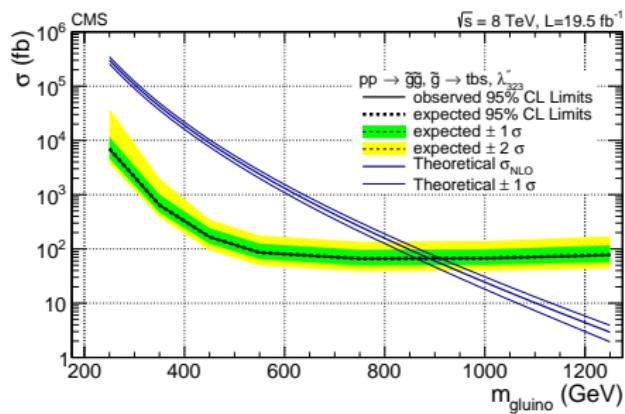
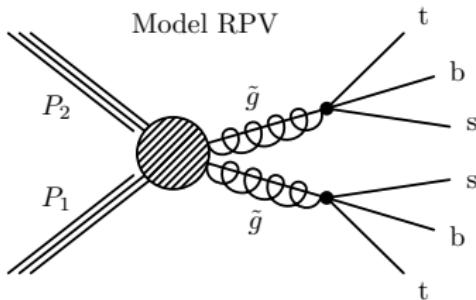
- Results interpreted in different simplified SUSY models, combining the most relevant search regions
- Show two examples here
- Summarizing all results, \tilde{g} masses up to 1050 GeV and \tilde{b} masses up to 500 GeV are probed



Search for same-sign lepton pairs

Dedicated RPV search

- Dedicated search region for R-parity violating SUSY using the high- p_T leptons
- At least 2 jets, at least 2 b-tags, $H_T > 500$ GeV, no E_T^{miss} requirement
- Expected: 5.3 ± 2.1 events Observed: 5 events
- Interpreted in a Simplified Model of gluino pair production with decays $\tilde{g} \rightarrow tbs$ ($t\bar{b}\bar{s}$)
- Lower limit on $m_{\tilde{g}}$ of 900 GeV



- CMS performs a wide variety of searches for SUSY and new physics in general
- Presented here are searches focused on the dilepton final state
- Kinematic properties of different production mechanisms or decay chains are exploited for maximum sensitivity
- In general good agreement between expectations and observation
- Largest deviation: 2.6σ excess in edge search, under scrutiny in Run II
- Interpretation of results in several simplified model scenarios
- In both RPC and RPV scenarios, gluino masses in the TeV range are probed
- For bottom squarks, limits in the order of 500-600 GeV are set



Backup

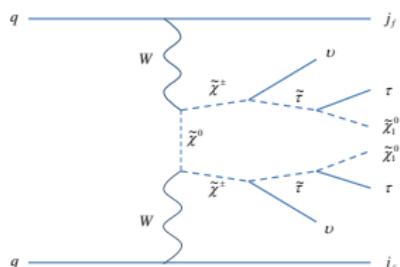


Search for same-sign lepton pairs

Object	p_T (GeV)	$ \eta $
Electrons	$>10(20)$	<2.4 and $\notin [1.4442, 1.566]$
Muons	$>10(20)$	<2.4
Jets	>40	<2.4
b-tagged jets	>40	<2.4

$N_{\text{b-jets}}$	E_T^{miss} (GeV)	N_{jets}	$H_T \in [200, 400]$ (GeV)	$H_T > 400$ (GeV)
$= 0$	50-120	2-3	SR01	SR02
		≥ 4	SR03	SR04
	> 120	2-3	SR05	SR06
		≥ 4	SR07	SR08
$= 1$	50-120	2-3	SR11	SR12
		≥ 4	SR13	SR14
	> 120	2-3	SR15	SR16
		≥ 4	SR17	SR18
≥ 2	50-120	2-3	SR21	SR22
		≥ 4	SR23	SR24
	> 120	2-3	SR25	SR26
		≥ 4	SR27	SR28

- Limits on $m_{\tilde{\chi}^\pm}$ reach 720 GeV for $m_{\tilde{\chi}^0} = 0$
- Go down to 100 GeV for $\Delta m = m_{\tilde{\chi}^\pm} - m_{\tilde{\chi}^0} = 50$ GeV
- Vector boson fusion topology with two forward jets offers great separation between signal and SM backgrounds
- Increased sensitivity to compressed spectra
- Pair production of $\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm$, $\tilde{\chi}_1^\pm \tilde{\chi}_1^\mp$, $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$, and $\tilde{\chi}_2^0 \tilde{\chi}_2^0$
- Decays: $\tilde{\chi}_1^\pm \rightarrow \tilde{\tau} \nu_\tau$, $\tilde{\chi}_2^0 \rightarrow \tilde{\tau} \tau$, $\tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$

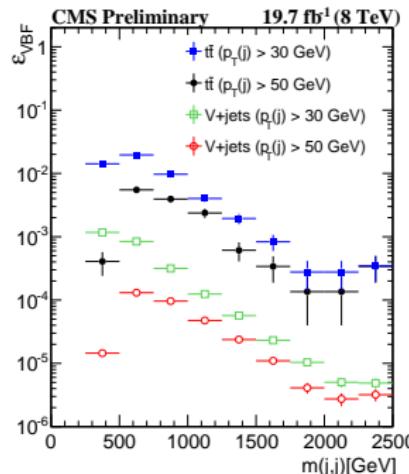


Event selection

- Final state: $\ell\ell + jj$, where $\ell\ell = e\mu, \mu\mu, \mu\tau_h$, and $\tau_h\tau_h$
- *Central selection:*
 $E_T^{\text{miss}} > 75$ GeV (30 GeV for $\tau_h\tau_h$),
 veto on b-tagged jets
- *VBF selection:*
 two jets with $p_T > 50$ GeV (30 GeV for $\mu^\pm \mu^\pm$),
 $m_{jj} > 250$ GeV with $\Delta\eta > 4.2$ and $\eta_1 \times \eta_2 < 0$

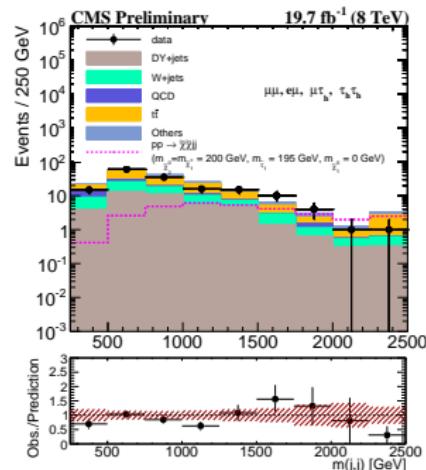
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Search for SUSY using the VBF topology

- Background predicted from yields in the central selection
- $N_B^{\text{prediction}} = N_{\text{central selection}} \times \epsilon_{\text{VBF selection}}$
- $\epsilon_{\text{VBF selection}}$ measured in data
- $N_{\text{central selection}}$ obtained from data or corrected simulation
- Correction factors and VBF efficiencies determined process dependent
- Agreement between estimates and observation in all channels
- Fluctuations in different channels at 2σ level



Process	$\mu^\pm \mu^\pm jj$	$e^\pm \mu^\pm jj$	$\mu^\pm \tau_h^\pm jj$	$\tau_h^\pm \tau_h^\pm jj$
DY + jets	4.3 ± 1.7	$3.7 \pm^{+2.1}_{-1.9}$	19.9 ± 2.9	12.3 ± 4.4
W + jets	< 0.01	$4.2 \pm^{+2.5}_{-2.5}$	17.3 ± 3.0	2.0 ± 1.7
VV	2.8 ± 0.5	3.1 ± 0.7	2.9 ± 0.5	0.5 ± 0.2
$t\bar{t}$	24.0 ± 1.7	$19.0 \pm^{+2.3}_{-2.4}$	11.7 ± 2.8	—
QCD	—	—	—	6.3 ± 1.8
Higgs	1.0 ± 0.1	1.1 ± 0.5	—	1.1 ± 0.1
VBF Z	—	—	—	0.7 ± 0.2
Total	32.2 ± 2.4	$31.1 \pm^{+4.6}_{-4.1}$	51.8 ± 5.1	22.9 ± 5.1
Observed	31	22	41	31

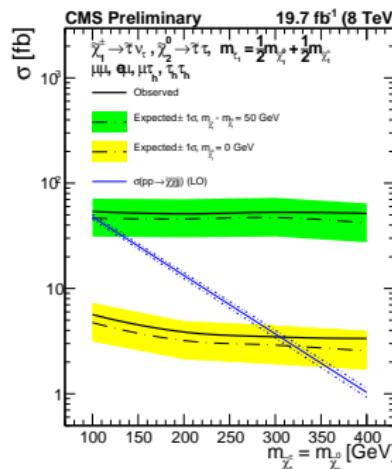
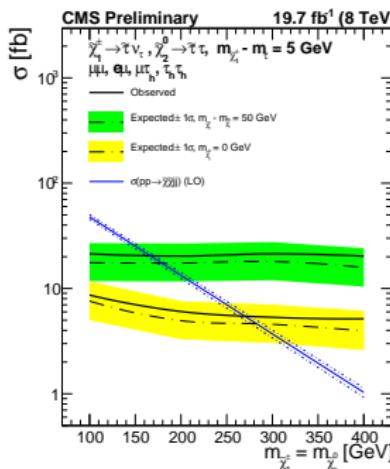
Process	$\mu^\pm \mu^\pm jj$	$e^\pm \mu^\pm jj$	$\mu^\pm \tau_h^\pm jj$	$\tau_h^\pm \tau_h^\pm jj$
DY + jets	< 0.01	$0 \pm^{+1.7}_{-0}$	0.5 ± 0.2	< 0.01
W + jets	$0.1 \pm 8.2 \times 10^{-4}$	$0 \pm^{+3.0}_{-0}$	9.3 ± 2.3	0.5 ± 0.1
VV	2.1 ± 0.3	$1.9 \pm^{+0.4}_{-0.2}$	1.1 ± 0.2	$0.1 \pm 6.5 \times 10^{-2}$
$t\bar{t}$	3.1 ± 0.1	$3.5 \pm^{+0.7}_{-0.9}$	6.7 ± 2.8	$0.1 \pm 1.2 \times 10^{-2}$
Single top	—	—	—	< 0.1
QCD	—	—	—	7.6 ± 0.9
Higgs	—	—	—	< 0.01
Total	5.4 ± 0.3	$5.4 \pm^{+3.5}_{-0.9}$	17.6 ± 3.8	8.4 ± 0.9
Observed	4	5	14	9

Search for SUSY using the VBF topology

- No signal observed → combine subchannels to derive exclusion limits
- Two scenarios:

$$m_{\tilde{\chi}_1^\pm} - m_{\tilde{\tau}} = 5 \text{ GeV}$$

$$m_{\tilde{\tau}} = \frac{1}{2} m_{\tilde{\chi}_1^0} + \frac{1}{2} m_{\tilde{\chi}_1^\pm}$$



- Yellow band: $m_{\tilde{\chi}_1^0} = 0 \text{ GeV}$ Green band: $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50 \text{ GeV}$
- Exclude $\tilde{\chi}$ masses below 300 GeV for $m_{\tilde{\tau}} = \frac{1}{2} m_{\tilde{\chi}_1^0} + \frac{1}{2} m_{\tilde{\chi}_1^\pm}$ and $m_{\tilde{\chi}_1^0} = 0 \text{ GeV}$
- Limit drops to 170 GeV for $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\chi}_1^0} = 50 \text{ GeV}$ and $m_{\tilde{\chi}_1^\pm} - m_{\tilde{\tau}} = 5 \text{ GeV}$

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