SUSY searches in photon final states with the CMS detector

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1. Physikalisches Institut B

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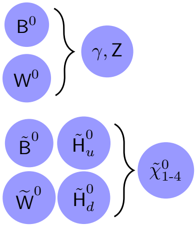
Motivation

Gauge Mediated Supersymmetry Breaking (GMSB)

- Gravitino $\widetilde{\mathrm{G}}$ is lightest SUSY particle
- Assume neutralino $\widetilde{\chi}_1^0$ is next-to-lightest SUSY particle
- $\widetilde{\chi}_1^0$ decays to massless $\widetilde{\mathrm{G}}$ and a neutral SM boson
- Assume R-parity conservation: $\widetilde{\mathrm{G}}$ stable, SUSY pair production



$\widetilde{\chi}_1^0$ decays

Bino/Wino:

- Decay to γ or Z
- Branching fraction mass dependent

$$BF(\widetilde{\chi}_1^0 \to \gamma\widetilde{\mathrm{G}}) \xrightarrow{m\to\infty} \begin{cases} \cos^2\theta_\mathrm{W} & \text{Bino} \\ \cos^2\theta_\mathrm{W} & \text{Wino} \end{cases}$$

Higgsino:

- Decay to H (use di-γ decay to tag H)

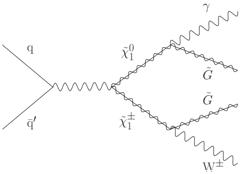
Interpretation

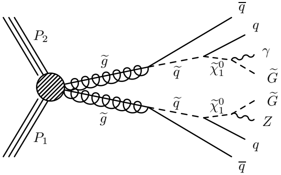
General Gauge Mediation (GGM):

- Natural decay probabilities
- Mixture of different processes
- Closer to reality

Simplified models:

- Branching fractions set to fixed value (usually 100%)
- Simulate only one production model
- Easier to reinterpret





Overview

- Variety of analyses probing many SUSY processes with different analysis strategies
- Covering bino, wino and higgsino neutralino mixtures
- Search for third generation, strong and electroweak production
- Full 2012 dataset (8 TeV) and first results for 13 TeV are published

	Signature	Publication links
CMS-SUS-13-014	$\mathrm{H}\to\gamma\gamma$ + bb + $E_{\mathrm{T}}^{\mathrm{miss}}$	PRL 112 (2014) 161802
CMS-SUS-14-004	γ + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$	PRD 92 (2015) 072006
CMS-SUS-14-008	$\gamma\gamma$ + Razor	PRD 92 (2015) 072006
CMS-SUS-14-009	$\gamma\gamma/e^{\pm}\mu^{\mp}$ + jets, $E_{\mathrm{T}}^{\mathrm{miss}}$ inclusive	PLB 743 (2015) 503
CMS-SUS-14-013	γ + e/μ + $E_{\mathrm{T}}^{\mathrm{miss}}$	PLB 757 (2016) 6
CMS-SUS-14-016	γ + $E_{\mathrm{T}}^{\mathrm{miss}}$	Submitted to PLB (arxiv:1602.08772)
CMS-SUS-14-017	$\mathrm{H}\to\gamma\gamma$ + Razor	CDS:2047472
CMS-SUS-15-012	$\gamma\gamma$ + $E_{\mathrm{T}}^{\mathrm{miss}}$ (13 TeV)	CDS:2143897

↳ See next talk by Arka Santra after the coffee break

Common background estimation for electrons being misidentified as photons

Method

Use pixel hits to distinguish between photons and electrons

- Calculate the probability that a real electron does not leave hits in the pixel detector
- Use tag&probe method on the $Z \rightarrow ee$ resonance to find real electrons

$$f_{e\rightarrow\gamma} \approx 1.5\%$$

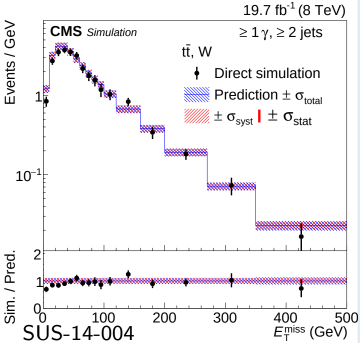
Usage in the analysis:

- Select event similar to the signal selection, except that the photon object has hits in the pixel detector (electron control sample)
- Scale this sample using the misreconstruction probability

$\Rightarrow$ Use this sample as prediction for electrons misreconstructed as photons

Validate the method using simulation

- Apply the same methods to simulation
- Compare to generated electrons reconstructed as photons
- Good agreement, method works well



SUS-14-004: γ + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$

Selection

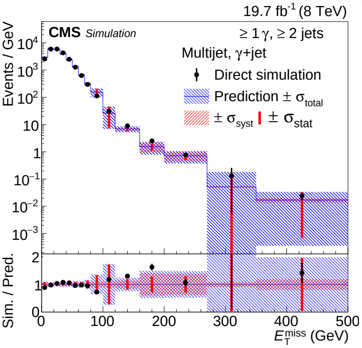
- $\geq 1\gamma$, $p_{\mathrm{T}}* > 110$ GeV
- $H_{\mathrm{T}} > 500$ GeV, $\geq$ 2jets
- no e/μ
- $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV

$Z\gamma$, $W\gamma$, $t\bar{t}\gamma$ background

Use MadGraph simulation, scaled to NLO cross section using MCFM

Multijet and γ+Jet background

- Select control sample with unisolated photon candidates (jets) instead of photons
- Normalize in $E_{\mathrm{T}}^{\mathrm{miss}} < 100$ GeV to photon (signal) selection
- Do this is bins of H_{T} and the hadronic recoil to minimize correlations

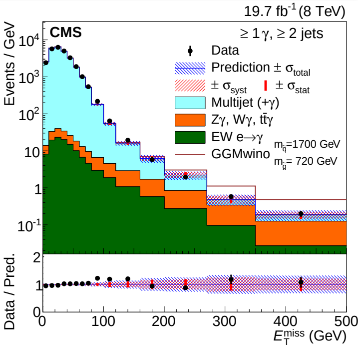


$\Leftarrow$

Validation of the multijet background estimation method

$\Rightarrow$

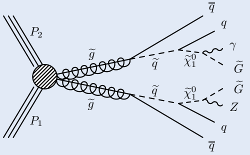
Right: Data to background comparison

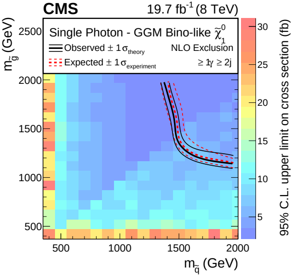


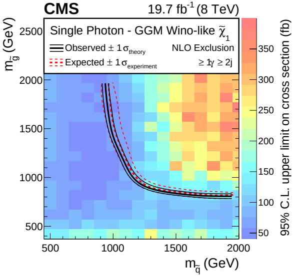
SUS-14-004: γ + jets + $E_{\mathrm{T}}^{\mathrm{miss}}$: Interpretation

GGM

Squark or gluino production,
$\widetilde{\chi}_1^0$ decay depends on mixing

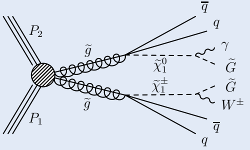


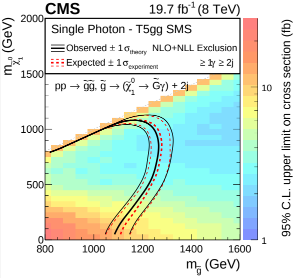


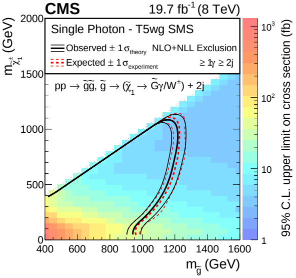


Simplified model

Gluino production,
$BF(\widetilde{g} \to qq\widetilde{\chi}_1^0) = 100/50\%$







SUS-14-013: $\gamma + e/\mu + E_{\mathrm{T}}^{\mathrm{miss}}$

Selection

- $\geq 1\gamma$, $p_{\mathrm{T}} > 40$ GeV
- $\geq 1e/\mu$, $p_{\mathrm{T}} > 25$ GeV
- $\Delta R(\gamma, \ell) > 0.8$
- $|m_{e\gamma} - m_Z| > 10$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 120$ GeV
- $M_T(\gamma, E_{\mathrm{T}}^{\mathrm{miss}}) > 100$ GeV

Jets misreconstructed as photons

Fit two templates to distribution of photon-shower width to data with low $E_{\mathrm{T}}^{\mathrm{miss}}$

- Real-photon template: Select real photons with $m_{\mu\mu\gamma} \approx m_Z$
- Fake-photon template: Unisolated photon candidates

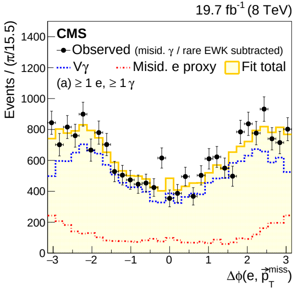
$f_{\mathrm{jet}\to\gamma} = 0.08 - 0.25$

Prediction: Scale control sample with unisolated photons using this factor

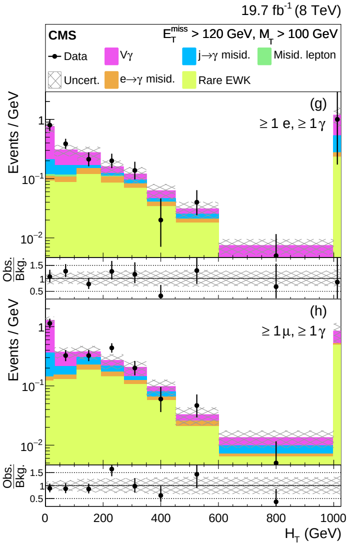
Misidentified leptons and electroweak processes

Fit two templates to distribution of $\Delta\Phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}})$ to data with medium $E_{\mathrm{T}}^{\mathrm{miss}}$

- Misidentified lepton template: Inverted lepton isolation for leptons (red dashed line)
- Electroweak process template: Simulation (blue dashed line)



Data to background comparison:



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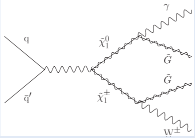
Simplified model of $\widetilde{\chi}_1^0\widetilde{\chi}_0^\pm$ production



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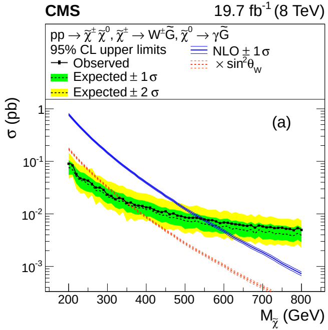
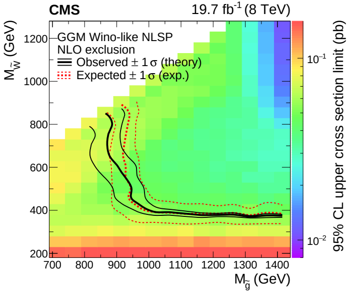
GGM model with gluino and electroweak production





Interpreted in bins of H_{T}, $E_{\mathrm{T}}^{\mathrm{miss}}$ and p_{T}^{γ}

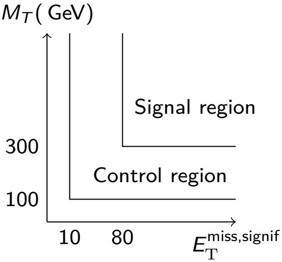
Selection

- $\geq 1\gamma$, $p_{\mathrm{T}} > 40$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV
- $M_T > 300$ GeV
- $E_{\mathrm{T}}^{\mathrm{miss,signif}} > 80$ (low for events with large particle uncertainties and therefore prone to mismeasurement)

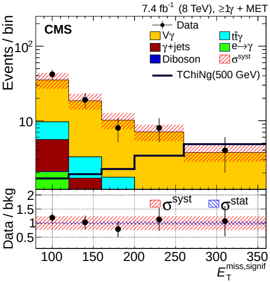
Major backgrounds

- γ+Jet
- $\mathrm{V}\gamma = \mathrm{W}\gamma$, $\mathrm{Z}(\nu\nu)\gamma$, $\mathrm{t\bar{t}}\gamma$

Scale background simulation to data in control region, extrapolate to signal region



Signal region:

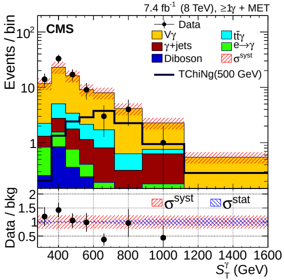


Diboson/$\mathrm{t\bar{t}}\gamma$ background

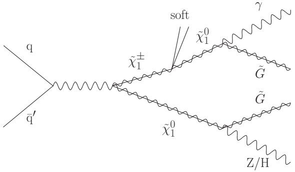
Direct simulation

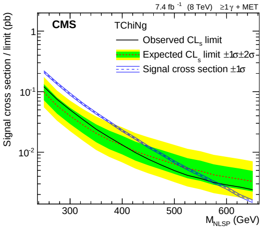
Divide signal region in low/high $E_{\mathrm{T}}^{\mathrm{miss}}/S_T$ to increase sensitivity

$S_T = E_{\mathrm{T}}^{\mathrm{miss}} + p_{\mathrm{T}}^{\gamma}$:

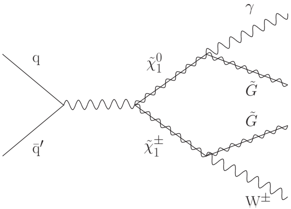


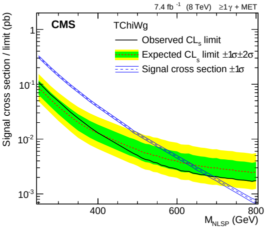
Mixed $\widetilde{\chi}_1^0\widetilde{\chi}^\pm$ and $\widetilde{\chi}^\pm\widetilde{\chi}^\pm$ production, where $\widetilde{\chi}_1^0$ and $\widetilde{\chi}^\pm$ are mass degenerate



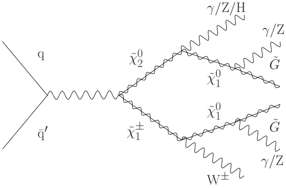


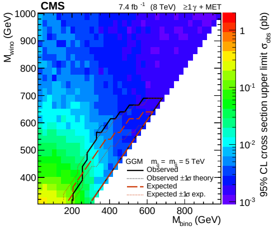
Same model as γ+e/μ analysis





Dominant process for GGM, but also other $\widetilde{\chi}_1^0$ production allowed



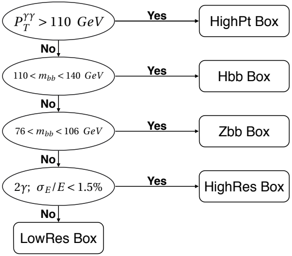


Very sensitive to electroweak production

SUS-14-017: $H \to \gamma\gamma$ + Razor

Selection

- $\geq 2\gamma$, $p_T > 40(25)$ GeV
- $m_{\gamma\gamma} \approx m_H$
- ≥ 1 jet
- Razor variables (M_R, R): Discriminates SM versus pair-produced heavy particles
- Categorization according to:

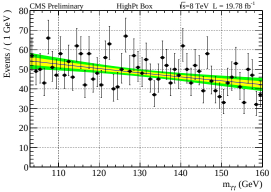


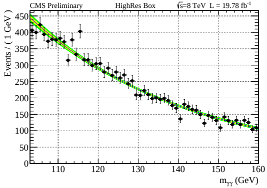
Background estimation for each category

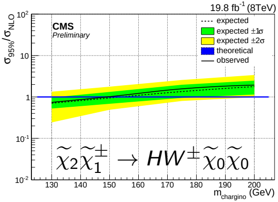
Combinatorics:

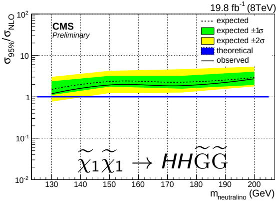
- Fit exponential in sideband above and below the expected $H \to \gamma\gamma$ peak $(M_R, R$ inclusive)
- Extrapolate from sidebands to $H \to \gamma\gamma$ peak in high M_R, R

SM H from simulation

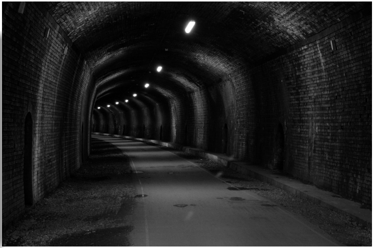






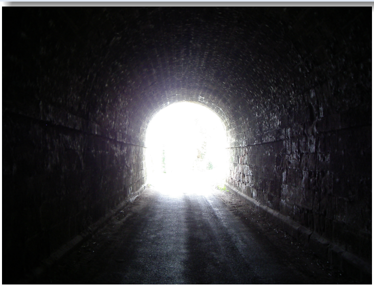


Summary



Status at 8 TeV

- Searched for SUSY with final states containing photons
- Studied bino-, wino- and higgsino-like neutralino mixtures
- Interpretation in GMSB and simplified models
- No hint for SUSY found yet



Are there photons at the end of the tunnel?

- Cross section for heavy (SUSY) particles increases significantly with $\sqrt{s}$
- With this years data, sensitive increases especially for high sparticle masses

BACKUP

Razor variables

The variable M_{R} is defined as

$$M_{\mathrm{R}} \equiv \sqrt{\left(|\vec{p}^{\,\mathrm{j}_1}| + |\vec{p}^{\,\mathrm{j}_2}|\right)^2 - \left(p_z^{\mathrm{j}_1} + p_z^{\mathrm{j}_2}\right)^2}, \tag{1}$$

where $\vec{p}^{\,\mathrm{j}_i}$ and $p_z^{\mathrm{j}_i}$ are, respectively, the momentum of the ith megajet and the magnitude of its component along the beam axis. The p_{T} imbalance in the event is quantified by the variable $M_{\mathrm{T}}^{\mathrm{R}}$, defined as

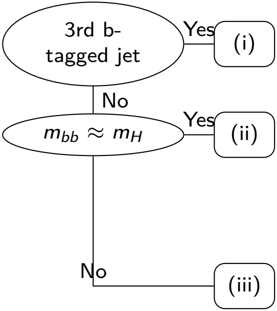
$$M_{\mathrm{T}}^{\mathrm{R}} \equiv \sqrt{\frac{E_{\mathrm{T}}^{\text{miss}}\left(|\vec{p}_{\mathrm{T}}^{\,\mathrm{j}_1}| + |\vec{p}_{\mathrm{T}}^{\,\mathrm{j}_2}|\right) - \vec{p}_{\mathrm{T}}^{\,\text{miss}} \cdot \left(\vec{p}_{\mathrm{T}}^{\,\mathrm{j}_1} + \vec{p}_{\mathrm{T}}^{\,\mathrm{j}_2}\right)}{2}}, \tag{2}$$

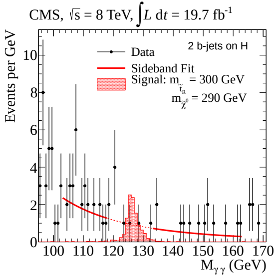
where $\vec{p}_{\mathrm{T}}^{\,\mathrm{j}_i}$ is the transverse component of $\vec{p}^{\,\mathrm{j}_i}$. The razor ratio R is defined as

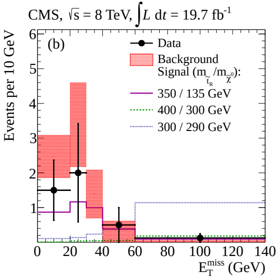
$$\mathrm{R} \equiv \frac{M_{\mathrm{T}}^{\mathrm{R}}}{M_{\mathrm{R}}}. \tag{3}$$

Selection

- $\geq 2\gamma, p_{\mathrm{T}} > 40(25)$ GeV
- $m_{\gamma\gamma} \approx m_H$
- $\geq$ 2 b-tagged jets
- bins in $E_{\mathrm{T}}^{\mathrm{miss}}$



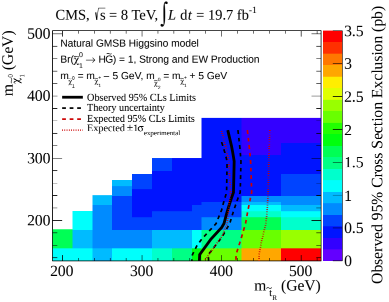




In each category (i), (ii) and (iii):

Background

- Fit sidebands above and below $H \rightarrow \gamma\gamma$ peak
- Use events from sideband to predict $E_{\mathrm{T}}^{\mathrm{miss}}$

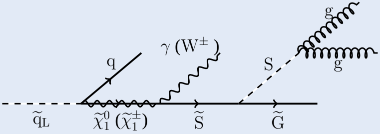


Stealth SUSY

- New hidden sector at EWK scale
- Small mass splitting between $\tilde{S}$ and S

$\Rightarrow$ LSP carries little momentum

$\Rightarrow$ low $E_{\mathrm{T}}^{\mathrm{miss}}$



Selection

- $\geq 2\gamma$, $p_{\mathrm{T}} > 40(25)$ GeV
- $N_{\mathrm{jet}} \geq 4$
- $S_T = \sum_{\gamma,e,\mu,jet,E_{\mathrm{T}}^{\mathrm{miss}}} p_{\mathrm{T}} >$ 1200 GeV