Searches for Supersymmetry at CMS

LEXI Workshop, DESY

UHH SUSY Group:

Arne Rasmus Draeger, Ulla Gebbert, Johannes Haller, Kristin Heine, Malte Hoffmann, Teresa Lenz, Daniele Marconi, Friederike Nowak, Christian Sander, Peter Schleper, Matthias Schröder, Valentina Sola, Lukas Vanelderen, Annika Vannhoefer

Universität Hamburg

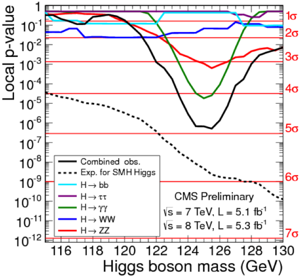
October 11, 2012

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

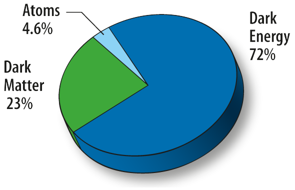
LEXI
LANDESEXZELLENZINITIATIVE HAMBURG

Supersymmetry

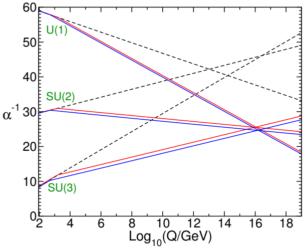
- Symmetry between fermions and bosons
- Requires the introduction of new particles



Higgs mass of 126 GeV w/o (much) fine-tuning



Dark Matter candidates

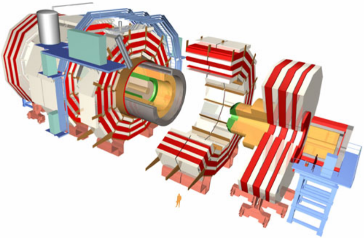


Unification of gauge-coupling strengths

Are there any new particles at the TeV scale?

Searches for Supersymmetry at CMS

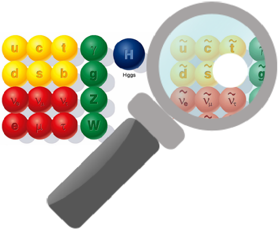
- Generic
  - Signature-based rather than model-based
- Broad
  - Many different signatures covered
- Robust
  - Data-based methods
  - Complementary methods



– broad →

↓ complementary –

Fully Hadronic	Leptons 1, 2, >2	Photons 1, 2
$\not{H}_T$		
α_T	…	
razor	$+$ b-multiplicity	
$M_{T,2}$		



More details at

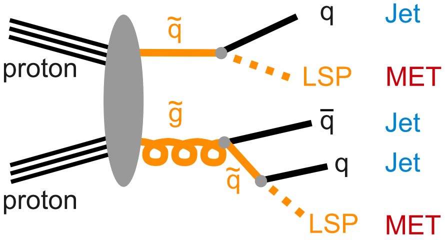
`https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS`

Outline

1. SUSY Searches by the UHH Group
   - Jets + $\not{H}_{\mathrm{T}}$
   - τ + Jets + $\not{H}_{\mathrm{T}}$
   - γ + Jets + $\not{E}_{\mathrm{T}}$
2. Conclusions from the CMS Searches

Jets + $\not{H}_T$ Analysis

- Signature motivated by R-parity conserving SUSY
  - Several high-p_T jets and large missing transverse momentum
  - No light leptons
- High sensitivity to squark and gluino production



- Sensitive variables

$$H_T = \sum_{\text{jets}} |\vec{p}_T|$$

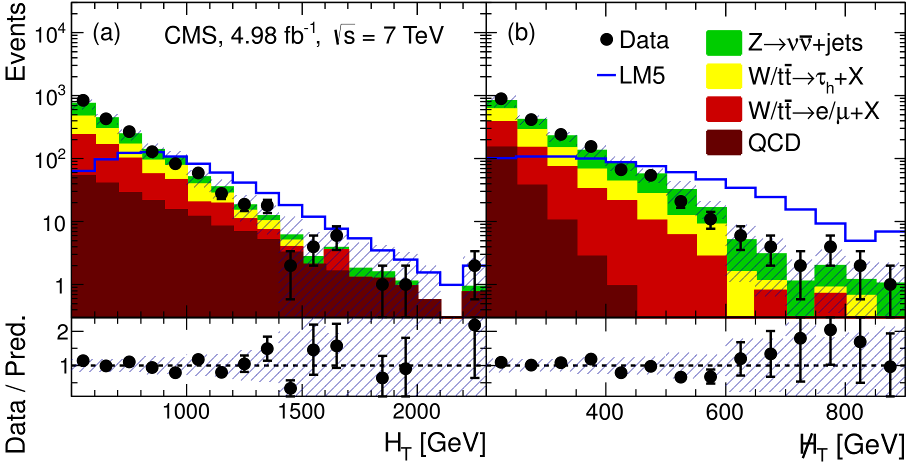
$$\not{H}_T = \left| -\sum_{\text{jets}} \vec{p}_T \right|$$

- Bins in H_T, $\not{H}_T$
  - Sensitivity to different parameter points

Dominant SM Backgrounds

- $t\bar{t}$ and W/Z+jets: $\not{H}_T$ from ν
- QCD: $\not{H}_T$ from mismeasurements

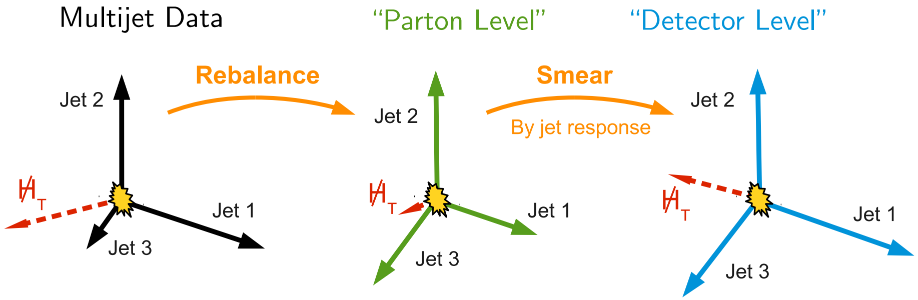
Results: Observed and Predicted Number of Events



Observed number of events in 4.98 fb^{-1} of $\sqrt{s} = 7$ TeV data consistent with SM expectation

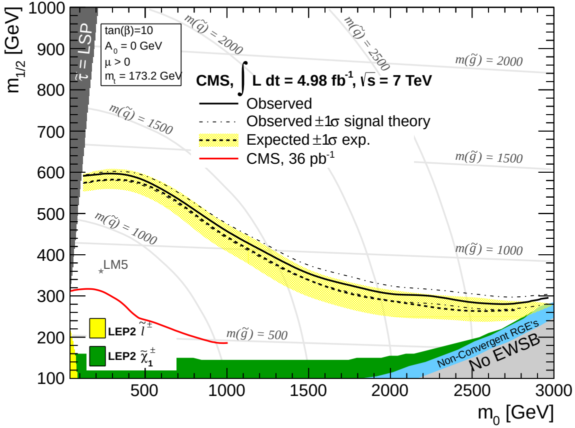
QCD-Background Prediction: Rebalance-and-Smear

- $\not{H}_T$ from jet-p_T mismeasurements
- Challenging to predict
  - Understanding of QCD effects
  - Understanding of jet-p_T resolution



Total relative precision of $\approx 70\%$

CMSSM Limits from 4.98 fb^{-1} of $\sqrt{s} = 7$ TeV Data



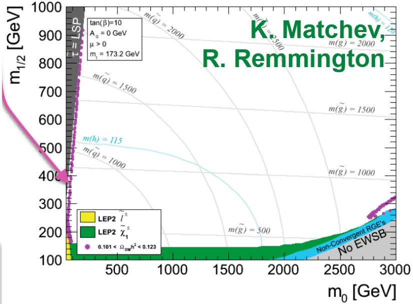
- Among the most sensitive analyses
- Lower limit of ≈ 1.3 TeV for $m_{\tilde{q}} = m_{\tilde{g}}$

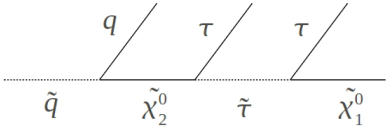
τ + Jets + $\not{H}_T$ Analysis

- LSP DM: relic-density constraints on cross sections
  - Annihilation $\tilde{\chi}^0\tilde{\chi}^0 \to f\bar{f}$
  - Co-annihilation $\tilde{\chi}^0\tilde{f} \to f\gamma$

- CMSSM: $m_{\tilde{\tau}} \approx m_{\tilde{\chi}^0}$ at small m_0
  - Large co-annihilation cross section
- Looking for final states with τ leptons + jets + $\not{H}_T$

- Di-τ: typically $\geq 2\tau$ produced
- Single τ: low p_T, low ID efficiency



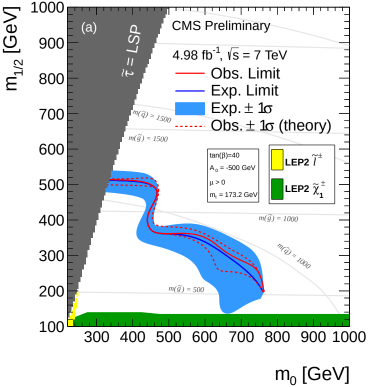


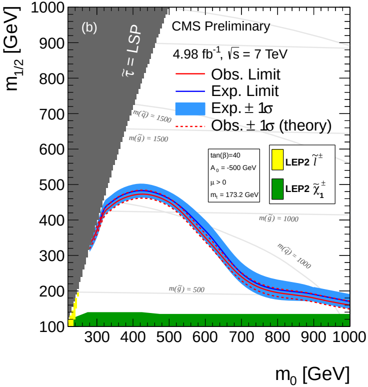
Dominant SM Backgrounds

- Real τ: W+jets, $t\bar{t}$

CMSSM Limits from 4.98 fb^{-1} of $\sqrt{s} = 7$ TeV Data

$N_\tau = 1$ $N_\tau \geq 2$



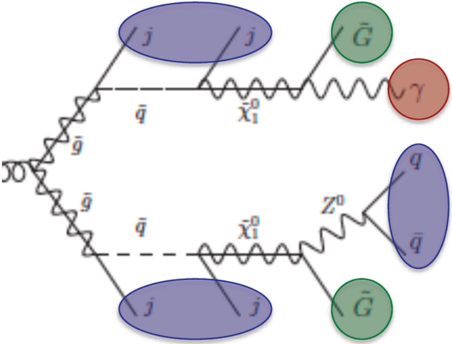


- Best sensitivity in co-annihilation region
- Sensitivity also at larger m_0

- Lower limit of $m_{\tilde{g}} = 1.15$ TeV for $m_0 < 400$ GeV

γ + Jets + $\not\!\!E_T$ Analysis

- General Gauge Mediation (GGM) Models
  - SUSY breaking through gauge interactions
- LSP: gravitino
- NLSP: $\tilde{\chi}^0 = \tilde{B}^0 + \tilde{W}^3 + \tilde{H}^0$
  - $\tilde{\chi}^0 \to \gamma + \tilde{G}$
  - $\tilde{\chi}^0 \to Z + \tilde{G}$
  - $\tilde{\chi}^0 \to h + \tilde{G}$



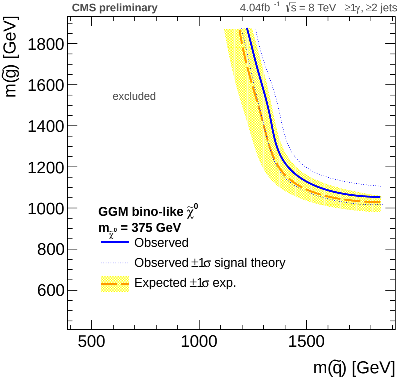
- γ can be well reconstructed
- Signature: $\geq 1\gamma$ + jets + $\not\!\!E_T$

Dominant SM Backgrounds

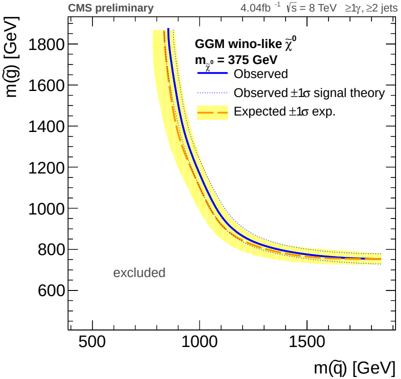
- QCD: γ+jet, fake γ
- $W/Z + \gamma$: ISR / FSR

GGM Limits from 4.04 fb^{-1} of $\sqrt{s} = 8$ TeV Data

Bino-Like NLSP



Wino-Like NLSP



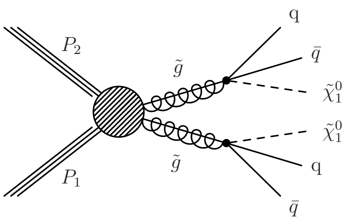
- Lower limits on squark and gluino masses
  - Bino-like: $\approx$ 1.1 TeV
  - Wino-like: $\approx$ 800 GeV

Outline

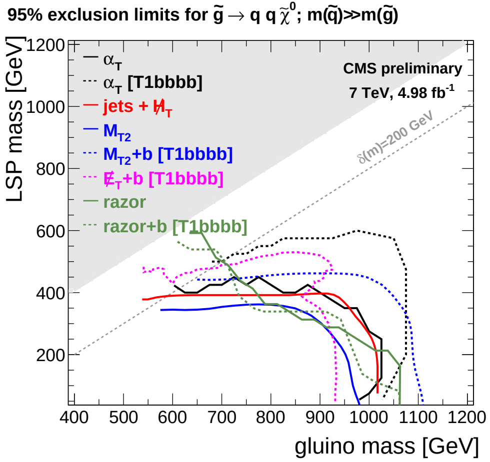
1. SUSY Searches by the UHH Group
   - Jets + $\not{H}_\mathrm{T}$
   - τ + Jets + $\not{H}_\mathrm{T}$
   - γ + Jets + $\not{E}_\mathrm{T}$
2. Conclusions from the CMS Searches

Model-Independent Representation of Search Results

- "Simplified Model Spectra"
- Allows reinterpretation in more specific models



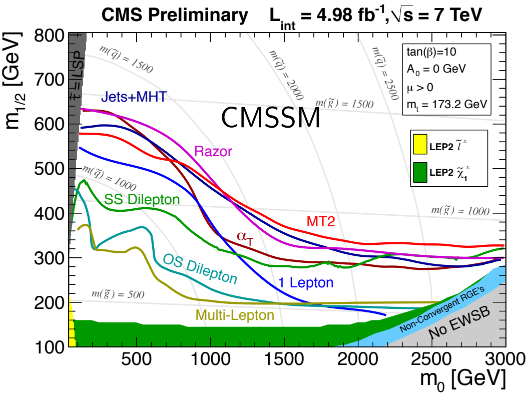
- Specific final state
- Few generic new particles
- Cross section parametrised by particle masses



CMS-PAS-SUS-11-016
https://twiki.cern.ch/twiki/bin/view/CMSPublic/SUSYSMSSummaryPlots

Conclusions from the CMS Searches

- Squarks and gluinos excluded up to ≈ 1 TeV
- Simple SUSY models lose naturalness
- But searches less sensitive to 3rd generation squarks



Light? Natural SUSY?

- Searches for SUSY with light 3rd-generation squarks
  - Dedicated 3rd-generation searches
  - Reinterpretation of existing limits

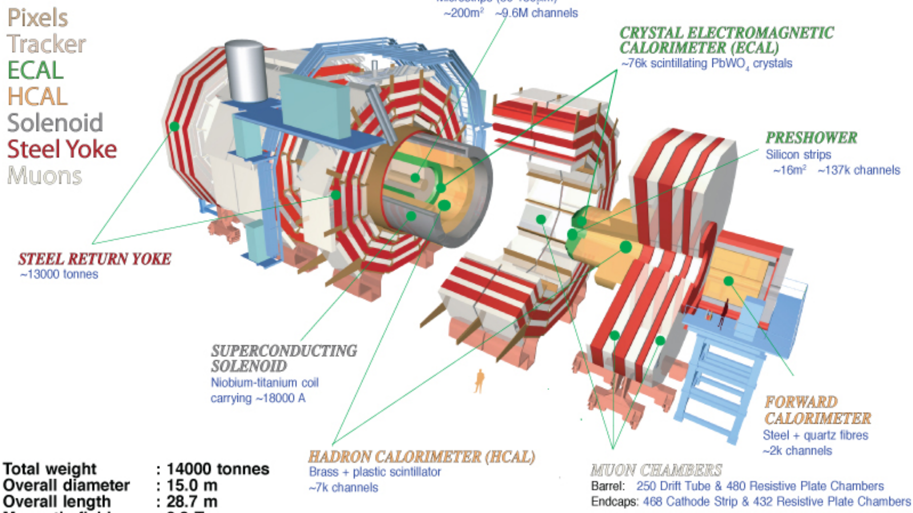
Summary & Outlook

- CMS performs a broad variety of searches for SUSY-motivated new physics
  - Strong participation by University of Hamburg group
- So far, no sign of any new physics
- But developed sophisticated analysis techniques, gained detailed understanding of SM backgrounds
- Well equipped for searches for more specific SUSY models e. g. with light 3rd-generation squarks
- Targeting question of natural SUSY

Analysis of 8 TeV data in full swing — more results expected soon

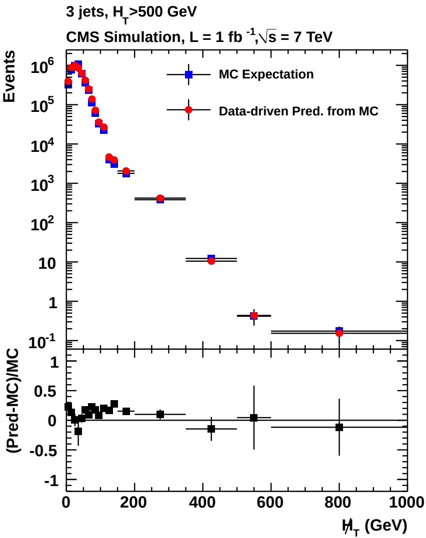
Backup

CMS Detector



Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Rebalance-And-Smear Validation



- Increased statistical precision by bootstrap method
- Closure within 30 – 50%
- Dominant systematic uncert.
  - Intrinsic bias
  - Jet-p_T resolution
  - Pile-up

  10 – 50% in regions with sizable QCD bkg.

Total uncertainty 65 – 75%

$N_\tau = 1$: Event Selection

- **Trigger:** missing transverse energy
- **Baseline / Full selection:**
  - $HT^{50} > 400 / 600$ GeV

$$H_T^{50} = \sum_{p_T > 50 \text{ GeV}, \ |\eta| < 2.5} p_T$$

  - MHT > 250 (trigger fully efficient) / 400 GeV

$$MHT = \not{H}_T = \left| - \sum_{p_T > 30 \text{ GeV}, \ |\eta| < 5} \vec{p}_T \right|$$

  - Exactly one isolated τ_{had}: $p_T > 15$ GeV, $|\eta| < 2.1$
  - No isolated light leptons: $p_T > 10$ GeV
- **Main backgrounds from Standard Model processes:**
  - $W (\longrightarrow \tau\nu)$ + jets / $t\bar{t}$ / QCD + small contributions from $Z (\longrightarrow \nu\nu)$ + jets and VV

Background From Real τ ($N_\tau = 1$)

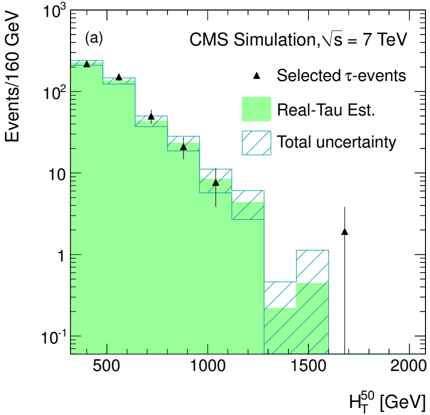
- Constitutes $\gtrsim 80\%$, mostly $W \to \tau\nu$+jets
- Prediction from μ+jets control sample using lepton universality

1. Exactly one isolated muon
2. Event weight

$$\frac{P(\mu \text{ not from } \tau)}{\epsilon_\mu^{\text{ID}} \cdot \epsilon_\mu^{\text{iso}}} \cdot \epsilon_\tau^{\text{ID}} \cdot \mathcal{B}(\tau \to \text{had})$$

3. $p_T(\mu)$ smeared according to τ-p_T response template
4. Recalculation of H_T and $\not{H}_T$

Total relative precision of 13%



$N_\tau = 1$: Background from MisID τs

Background with misID taus (sub dominant)

- Quark/gluon jet can be mis-identified as τ
- Dominant contribution: QCD multi-jet; smaller contribution: $Z\,(\longrightarrow \nu\nu)$ + jets and $W\,(\longrightarrow l\nu)$ + jets

Background estimation:

(1) Make Baseline/Full selection + τ veto

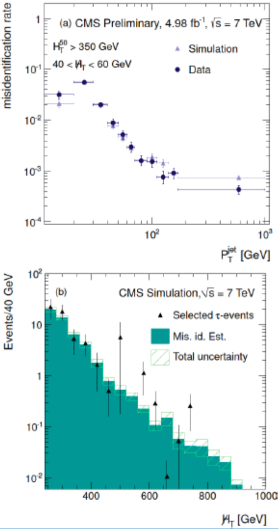
(2) Weight events with probability to misID a τ:

$$w_{\text{event}} = 1 - \Pi_{i=\text{jets}}(1 - p_i^{\text{misID}})$$

Remarks:

- Measure τ misID rate per jet $p^{\text{misID}}(p_T, \eta)$ in QCD dominated region:
  - HT^{50}>350 GeV, 40 GeV < MHT < 60 GeV

    → 99% purity (estimated from MC)
  - Jet = jet with matched τ candidate: $\Delta R < 0.1$, $p_T > 15$ GeV and $|\eta| < 2.1$
- Method validated in MC as well as in QCD dominated side band regions → no systematic bias observed



$N_\tau \geq 2$: Background Estimation

- Define control regions (CR) which are selected similar to the signal region (SR), but enriched with events from the background process
  - **TTbar CR:** SR + 2 *b*-tags
  - ***W* + jets CR:** SR + 0 *b*-tags
  - ***Z* + jets CR:** SR + opposite sign muon pair
  - **QCD CR:** SR but "inverted" $\Delta\phi(\mathrm{MHT}, \mathrm{jet}_2)$ cut ($\Delta\phi<0.1$)
- Measure selection efficiencies, jet multiplicities and/or jet → τ misID rates in those control regions
- Extrapolate from the control region to the signal region

GGM Phenomenology @ the LHC

Neutralino NLSP mixture of Bino, Wino and Higgsino

- **Bino-like NLSP:**

  $\tilde{\chi}_1^0 \rightarrow \gamma + G$ or $\tilde{\chi}_1^0 \rightarrow Z^0 + G$

- **Wino-like (co-)NLSP:**

  $\tilde{\chi}_1^0 \rightarrow \gamma + G$ or $\tilde{\chi}_1^0 \rightarrow Z^0 + G$

  and/or $\tilde{\chi}_1^{\pm} \rightarrow W^{\pm} + G$

- **Bino-Higgsino-like NLSP:**

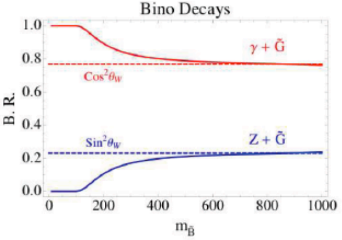
  $\tilde{\chi}_1^0 \rightarrow \gamma + G$ or $\tilde{\chi}_1^0 \rightarrow Z^0 + G$

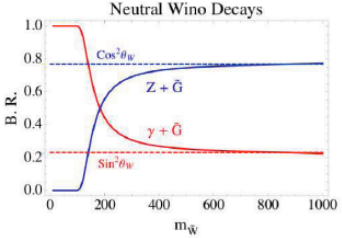
  and/or $\tilde{\chi}_1^0 \rightarrow h + G$

R-parity is conserved

-> 2 LSPs per event

★ MET is defining signature





[J. Ruderman, D. Shih, arXiv:1103.6083]

Event Selection

- $\geq 1\gamma$ with $p_{\mathrm{T}} > 80$ GeV
- ≥ 2 jets with $p_{\mathrm{T}} > 30$ GeV
- $H_{\mathrm{T}} > 450$ GeV (H_{T} from all jets with $p_{\mathrm{T}} > 40$ GeV)
- $\not\!\!E_{\mathrm{T}} > 100$ GeV

Standard Model Backgrounds

Fake photons - QCD (jets)	Fake photons - EWK (electrons)	Irreducible (photons)
γ + Jet $j \rightarrow \gamma$	W, top $e \rightarrow \gamma$	ISR/FSR Z/W/top + γ
Dominant Background	Sub-dominant Background	Sub-dominant Background
Data - Driven	Data - Driven	Simulation

QCD Background

- $\not\!\!E_T$ from jet-p_T mismeasurements
  - Direct γ+jet production
  - QCD-multijets, one jet misidentified as γ
- Prediction from control sample ('γ_{jet}')
  - Inverted γ-isolation criterion

- Weights for different $p_T(\gamma)$ spectra in control and signal sample
- From signal-depleted region $\not\!\!E_T < 100$ GeV

- Total relative precision of 13 – 50%