

Searches for New Physics at CMS in Final States with Photons and Missing Energy



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LHC2TSP: Implications of LHC results for
TeV-scale physics, 13-17 July 2012, CERN



Overview

1. Introduction

2. Models Considered

1. Supersymmetry (SUSY)

2. Dark Matter

3. Extra Dimensions

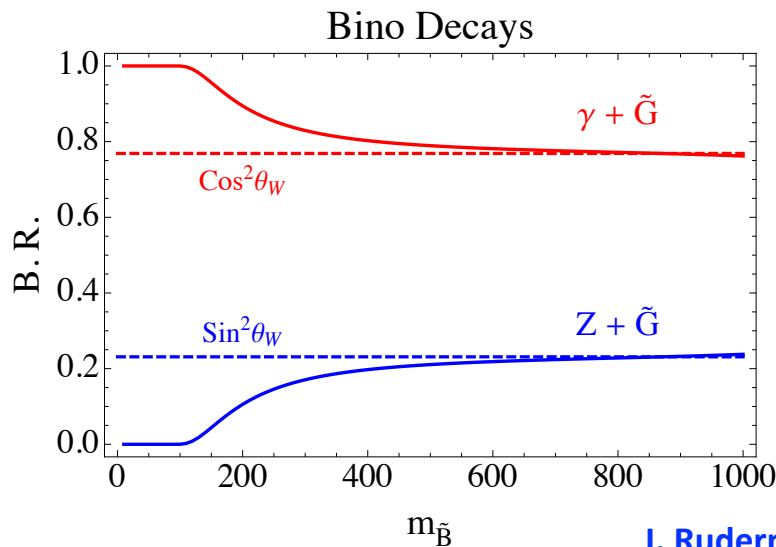
3. Analyses

4. Results & Interpretation

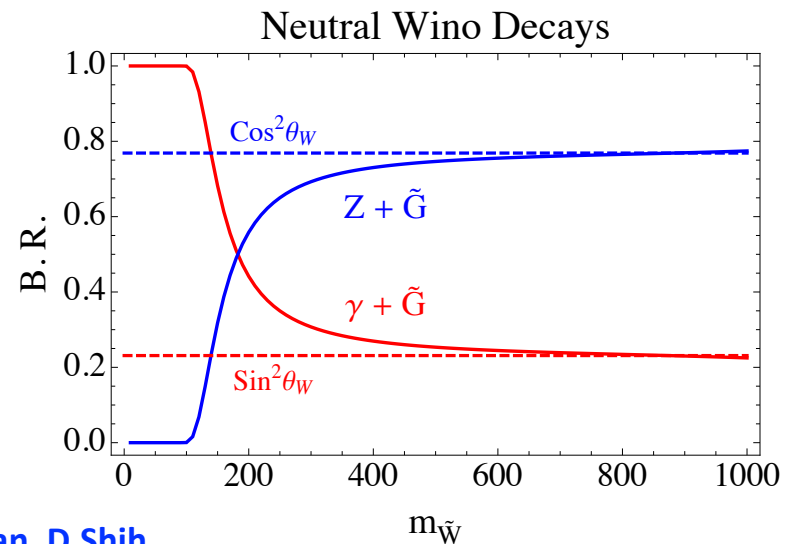
5. Summary

Models - SUSY with Large Missing Energy (MET)

- Gauge-mediated SUSY breaking (GMSB)
 - SUSY broken by gauge fields \rightarrow light Gravitino LSP
- General Gauge Mediation (GGM)
 - \rightarrow NLSP is admixture of Bino, Wino, Higgsino

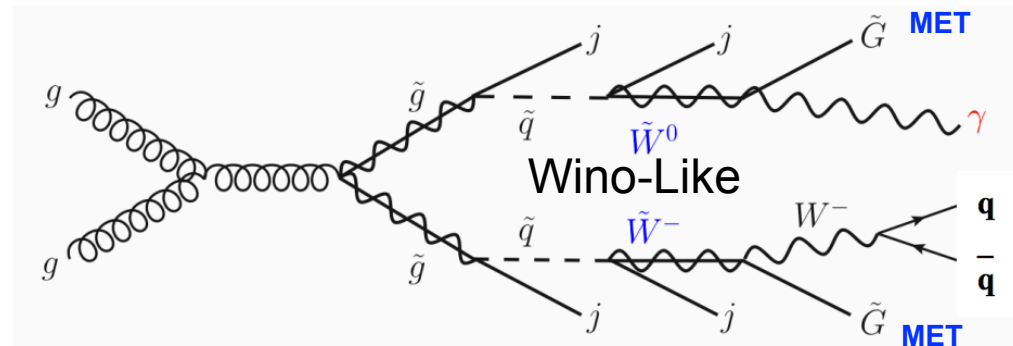
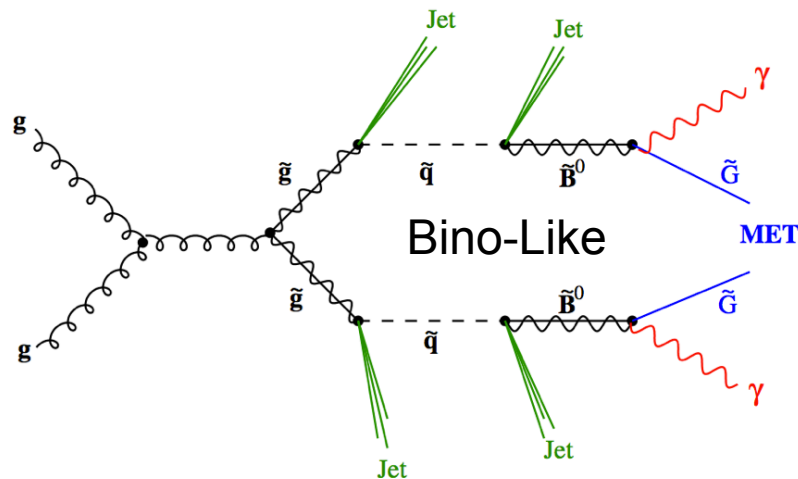


J. Ruderman, D. Shih
[arXiv:1103.6083v1](https://arxiv.org/abs/1103.6083v1)



Models - SUSY with Large Missing Energy (MET)

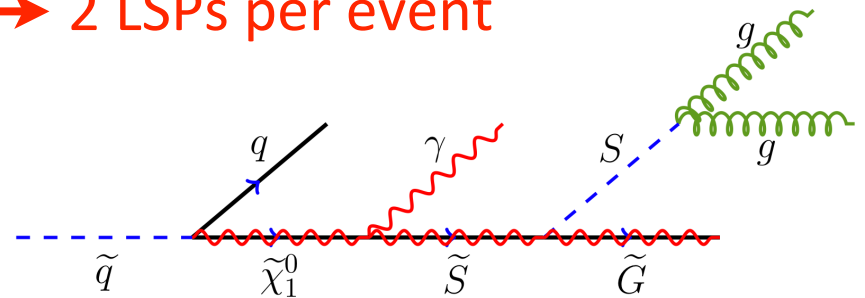
- Search for Gauge-mediated SUSY breaking (GMSB) scenarios with Bino-like or Bino/Wino-like NLSP
 - Assume R-parity is conserved \longrightarrow 2 LSPs per event
 - γ/Z +Gravitino or $\gamma/Z/W$ +Gravitino final states \longrightarrow 1 or 2 γ + large MET + jets



If neutralino is pure Wino, lightest chargino is mass degenerate, decays to W^+ +Gravitino

Models - SUSY with Low MET

- Search for SUSY/new physics cases which do not have the characteristic SUSY signal of high MET (Stealth SUSY)
- General search, inclusive to many models
 - Hidden sector at weak scale → Singlino and Singlet
 - SUSY approximately conserved in hidden sector
 - Hidden sector superpartners nearly mass degenerate
 - Assume R-parity is conserved → 2 LSPs per event
 - Assume $\text{Br}(\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{S}) = 1$
 - $\gamma + \text{Gravitino final state}$
 - Soft MET spectrum from LSP
→ $2 \gamma + \text{low MET} + \text{jets}$

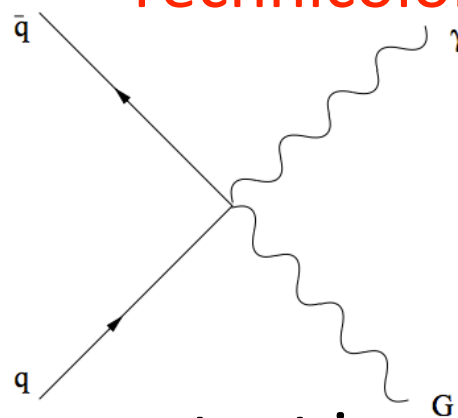


Models - Dark Matter (DM)

- Direct search for massive Dark Matter Candidate χ in $q\bar{q} \rightarrow \chi\bar{\chi}\gamma$ interaction $\longrightarrow \gamma + \text{MET final state}$
- γ comes from initial state radiation (ISR) from one of the quarks
- This s-channel pair production can be related to the t-channel χ -nucleon elastic scattering
 - s-channel effective operator can be a vector or axial vector
 - \longrightarrow spin-dependent and spin-independent interpretations

Models - Large Extra Dimensions (LED)

- Arkani-Hamed, Dimopoulos and Dvali (ADD) framework
 - Gravitational and gauge interactions unify at the electroweak scale - solves Hierarchy problem w/o SUSY, Technicolor
 - space-time is $R^4 \times M_n$, M_n is a compact manifold of dimension n and volume R^n
 - $M_{Pl}^2 = M_D^{n+2} R^n$ where M_D is Planck's Constant in $4+n$ dimensions
 - Assuming $M_D \sim M_{EW}$, large value of Planck's constant is a result of large $R^n \longrightarrow O(\sim \text{mm})$ extra dimensions
 - Theory predicts direct production of gravitons



$\longrightarrow \gamma + \text{MET final state}$

Analyses

1. $\gamma\gamma$ + Large MET

- PAS SUS-12-018 **SUSY: Large MET**

2. γ + Jets + Large MET

- PAS SUS-12-018 **SUSY: Large MET**

3. $\gamma\gamma$ + Jets + Low MET

- PAS SUS-12-014 **SUSY: Low MET**

4. γ + MET

- [arXiv:1204.0821v1](https://arxiv.org/abs/1204.0821v1) **DM,LED**

Analyses

	photons	jets	event
$\gamma\gamma$ + Large MET (SUSY)	≥ 2 $E_T > 40, 25$ $\eta < 1.4442$	$\geq 0, \geq 1$ $E_T > 30$ $\eta < 2.6$	
γ + Jets + Large MET (SUSY)	≥ 1 $E_T > 80$ $\eta < 1.4442$	$\geq 2, \geq 3$ $E_T > 30$ $\eta < 2.6$	$H_T > 450$
$\gamma\gamma$ + Jets + Low MET (SUSY)	≥ 2 $E_T > 40, 25$ $\eta < 1.4442$	$\geq 4, \geq 5$ $E_T > 20$ $\eta < 2.4$	
γ + MET (EXO)	≥ 1 $E_T > 95$ $\eta < 1.4442$		MET > 80

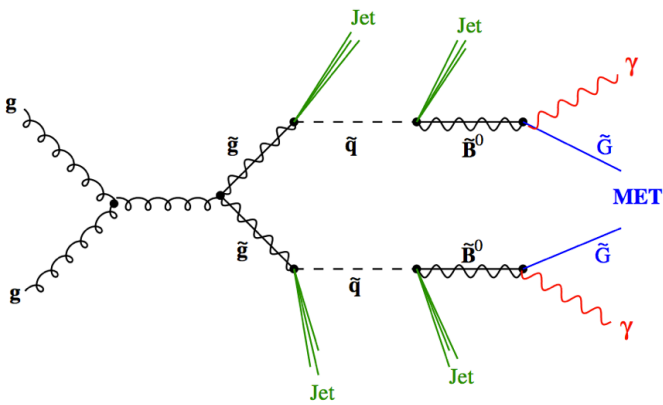
Backgrounds

negligible sub-dominant dominant

	Physics	$e \rightarrow \gamma$	$j \rightarrow \gamma$
$\gamma\gamma$ + Large MET (SUSY)	$W/Z+\gamma\gamma$	$W/Z+\gamma$ $W/Z+j$ $TTbar$	QCD $j+\gamma$
γ + Jets + Large MET (SUSY)	ISR/FSR($W/Z/top$)	W/top	QCD j
$\gamma\gamma$ + Jets + Low MET (SUSY)	$W/Z+\gamma\gamma$	$W/Z+\gamma$ $W/Z+j$ $TTbar$	QCD $j+\gamma$
γ + MET (EXO)	$Z(\rightarrow inv.)+\gamma$ $W+\gamma$	W/top	QCD j

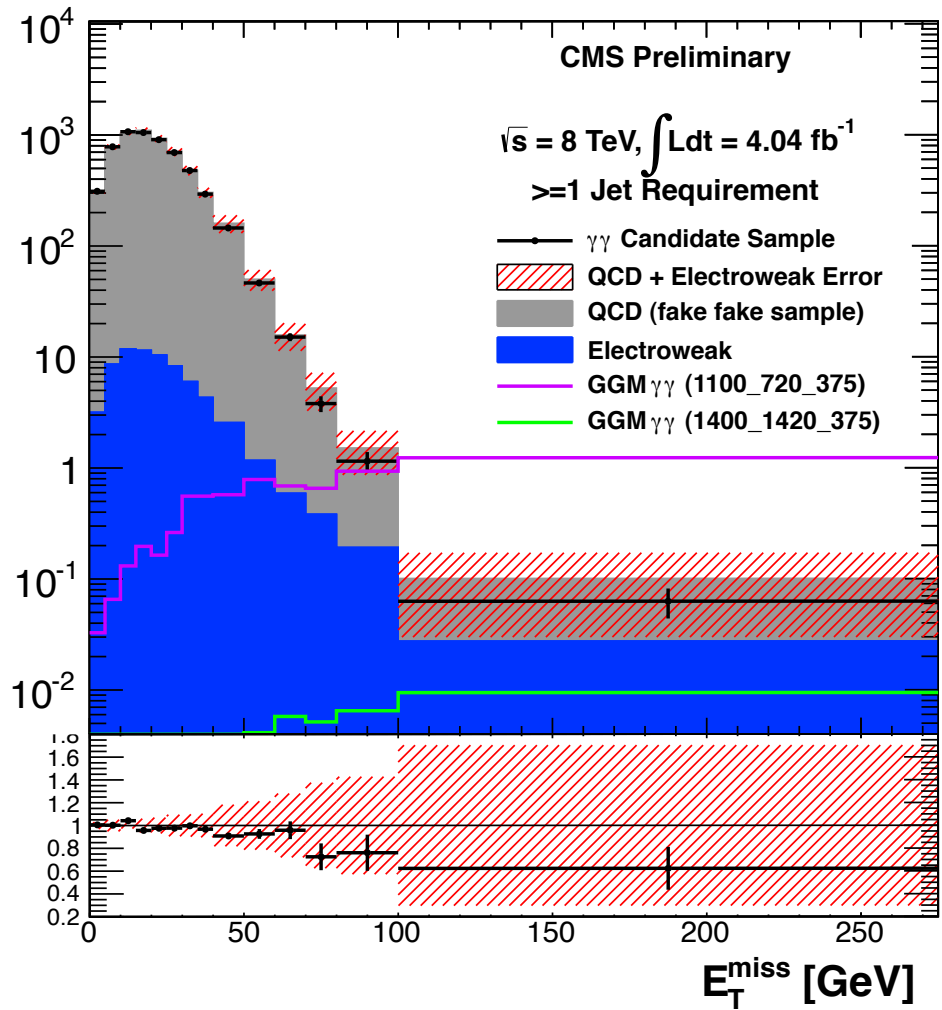
$\gamma\gamma$ +Large MET: ≥ 1 Jet

$\sqrt{s}=8$ TeV, $\int Ldt=4.04$ fb $^{-1}$



- Irreducible backgrounds negligible
- QCD and **electroweak** backgrounds calculated mostly from data-driven methods

Number of Events / GeV

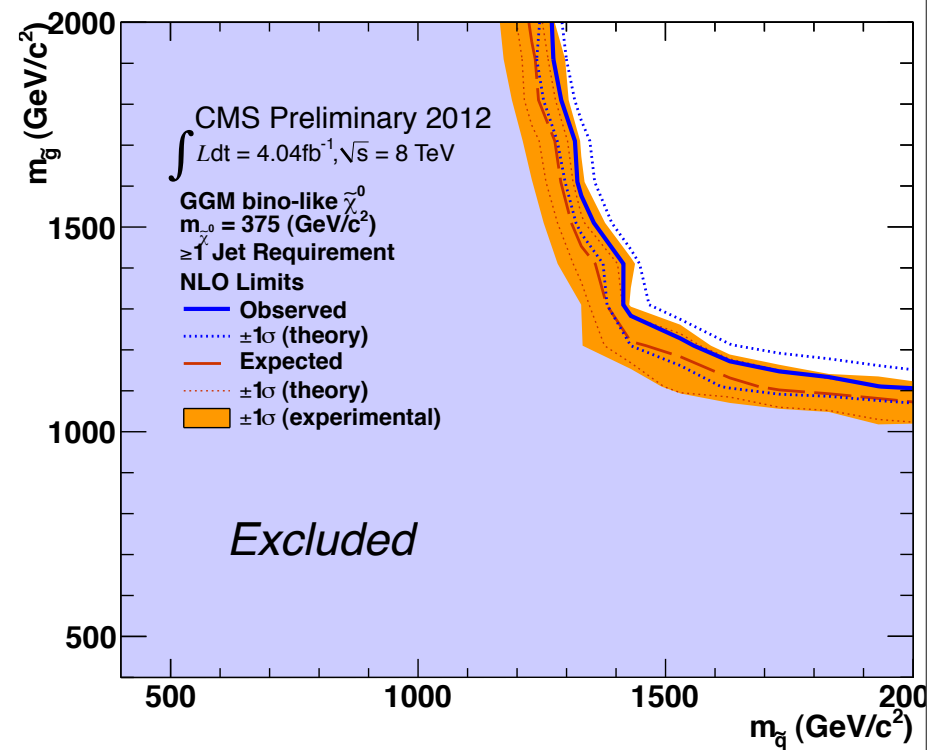
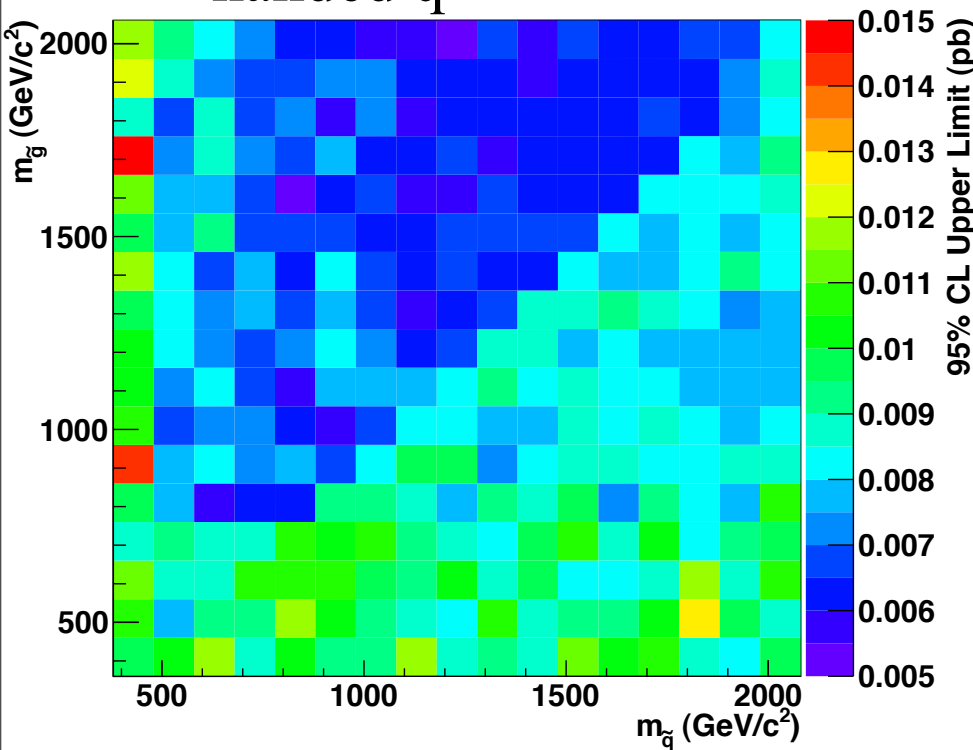


David Morse - LHC2TSP - Searches for new physics with photon(s)+MET



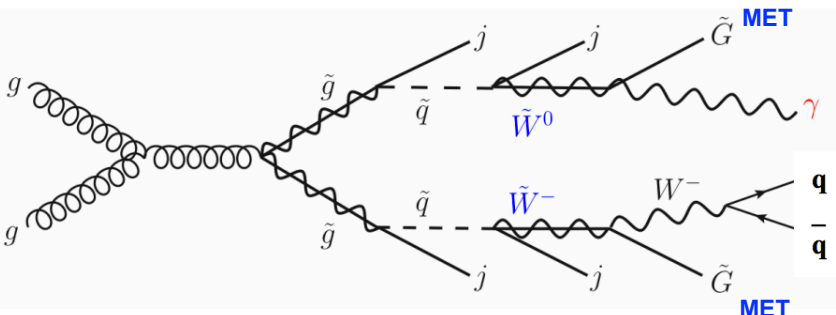
$\gamma\gamma$ +Large MET: Bino-like NLSP, ≥ 1 Jet

- GGM scan in \tilde{g}, \tilde{q} plane with “Bino-like” NLSP
 - $m_{\tilde{\chi}_0^0} = 375$ GeV, $m_{\tilde{q}, \tilde{g}} = 400 \dots 2000$ GeV in 80 GeV steps
 - Sleptons and all gauginos except NLSP: 3.5 TeV, heavy right handed \tilde{q}

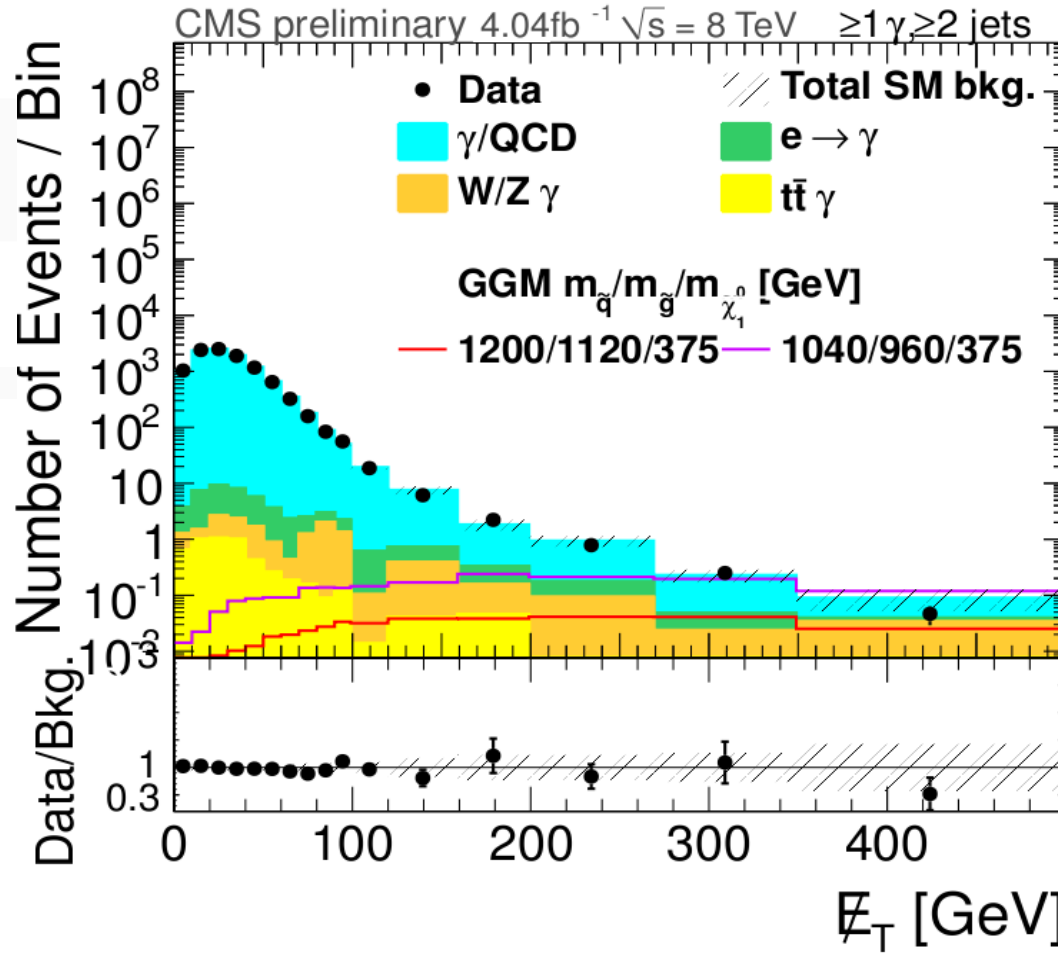


γ +Jets+Large MET: ≥ 2 Jets

$\sqrt{s}=8$ TeV, $\int Ldt=4.04$ fb $^{-1}$



- QCD and electroweak backgrounds calculated from data-driven methods
- $t\bar{t} + \gamma$, $W/Z + \gamma$ taken from simulation

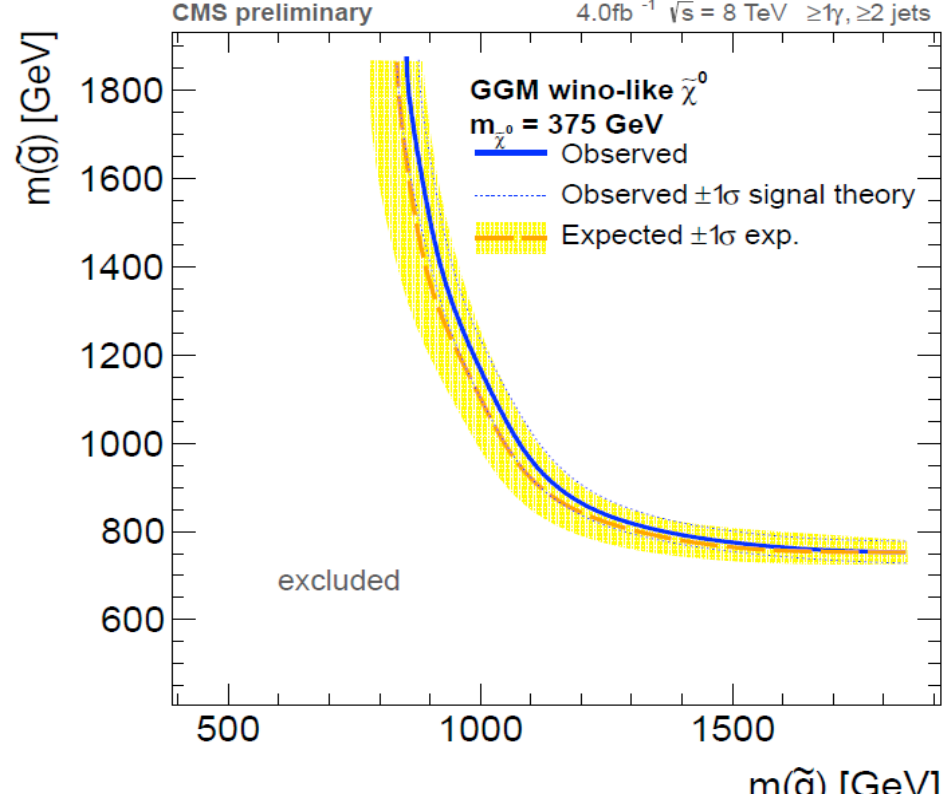
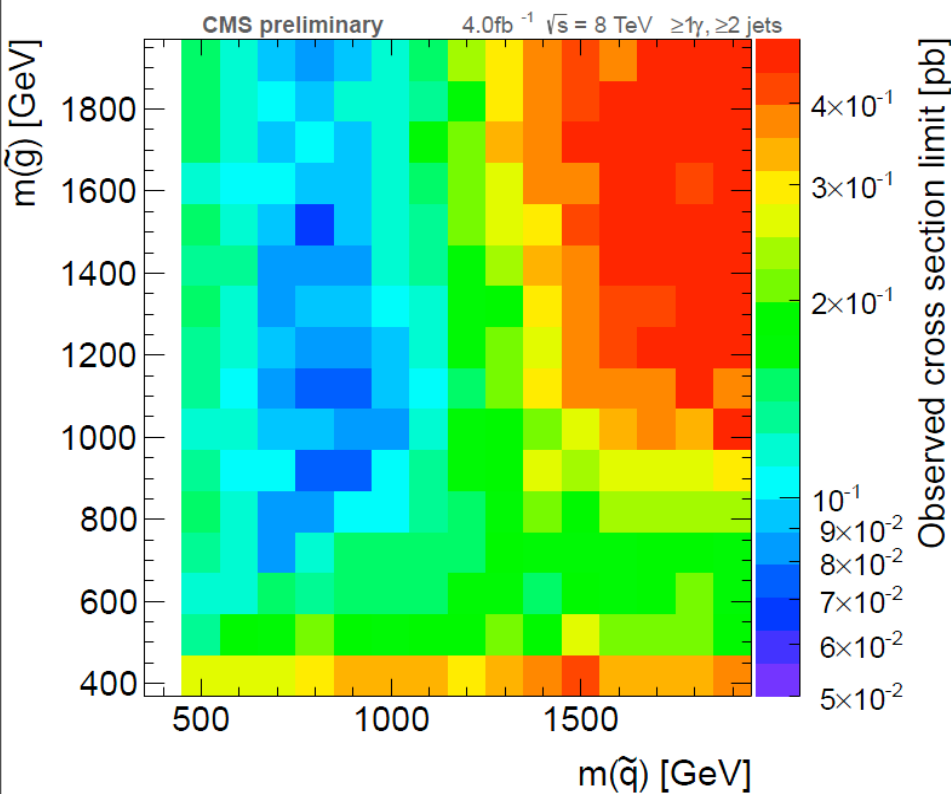


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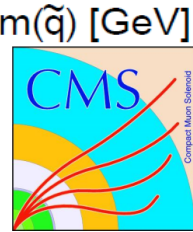


γ +Jets+Large MET: Wino-like NLSP, ≥ 2 Jets

- GGM scan in \tilde{g}, \tilde{q} plane with “Wino-like” NLSP
 - $m_{\tilde{\chi}_0} = 375$ GeV, $m_{\tilde{q}, \tilde{g}} = 400 \dots 2000$ GeV in 80 GeV steps
 - Sleptons and all gauginos except NLSP: 3.5 TeV, heavy right handed \tilde{q}

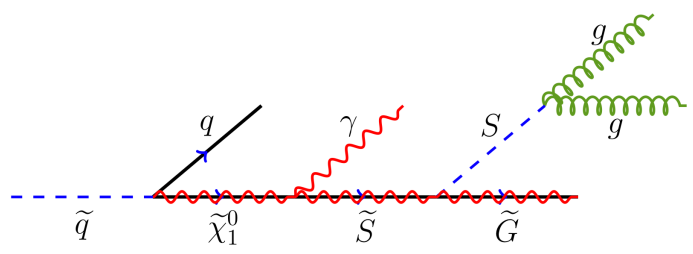


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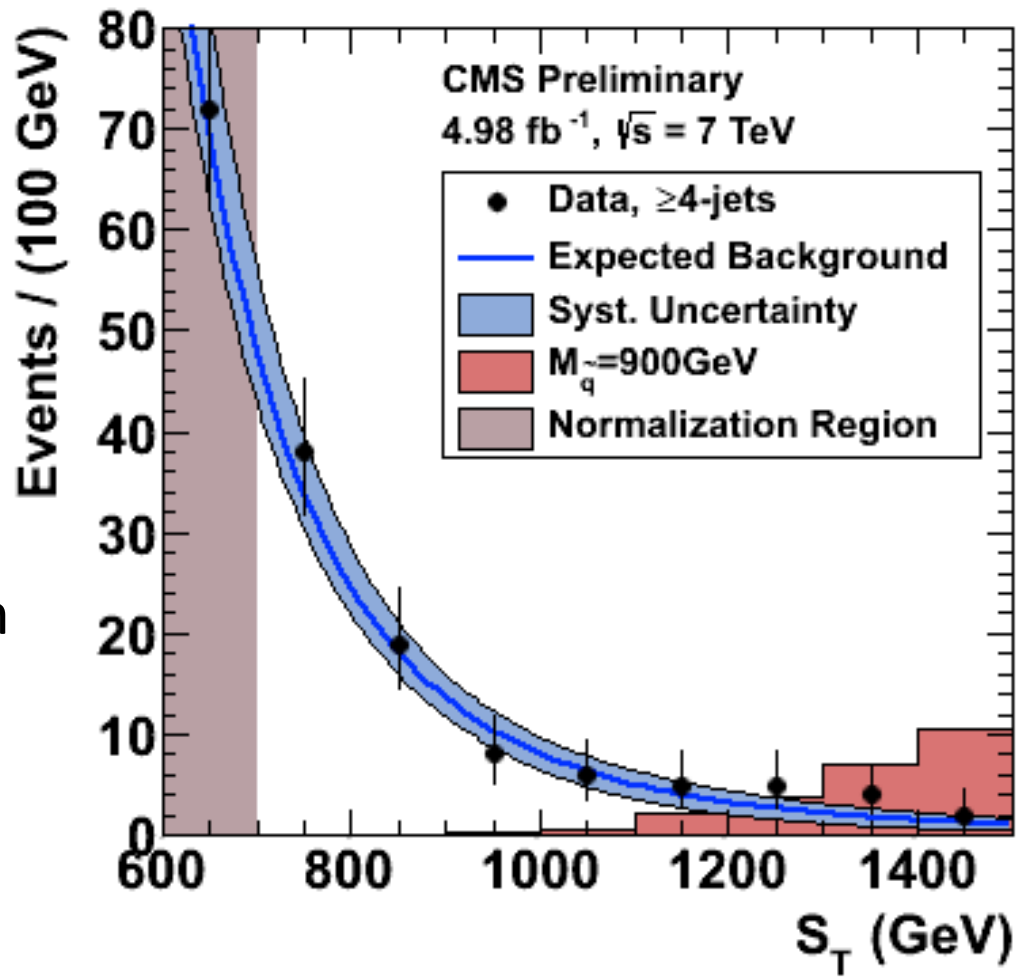


$\gamma\gamma$ +Jets+Low MET: ≥ 4 Jets

$\sqrt{s}=7$ TeV, $\int L dt=4.98$ fb $^{-1}$



- Irreducible backgrounds negligible
- QCD and electroweak backgrounds calculated from data-driven fit
- Uses $S_T = MET + \sum_{\gamma} E_T + \sum_{jets} p_T$ as discriminating variable
- **First search of its kind**

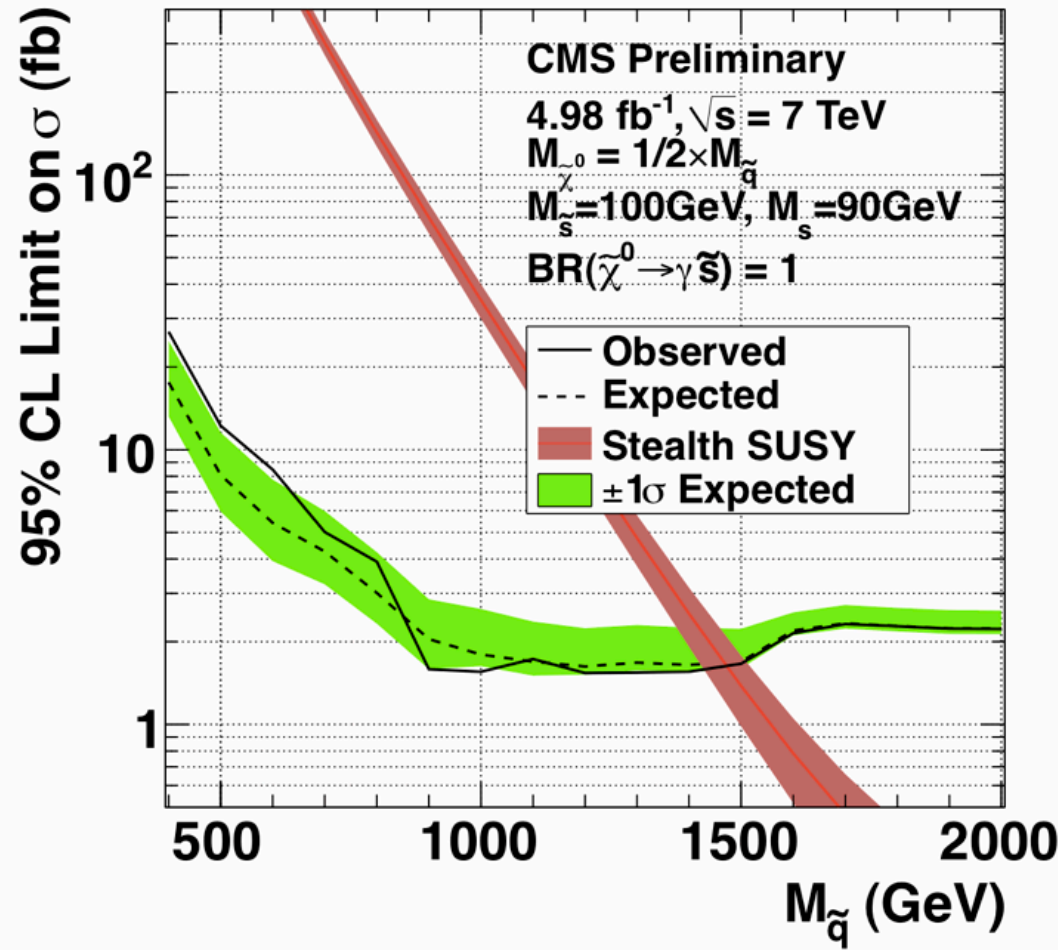


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$\gamma\gamma$ +Jets+Low MET: ≥ 4 Jets

- Model Assumptions:
 - Based on T2 simplified model CMS-PAS-SUS-11-016
 - $m_{\tilde{g}} = 1500 \text{ GeV}$
 - $m_{\tilde{s}} = 100 \text{ GeV}$
 - $m_s = 90 \text{ GeV}$
 - $m_{\tilde{\chi}_1^0} = \frac{1}{2} m_{\tilde{q}}$
 - $BR(\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{s}) = 1$

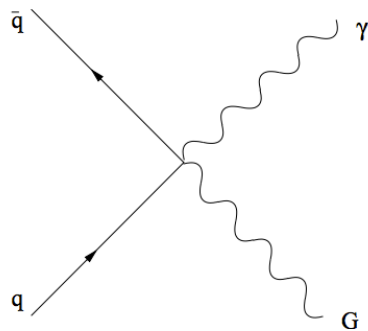


David Morse - LHC2TSP - Searches for new physics with photon(s)+MET

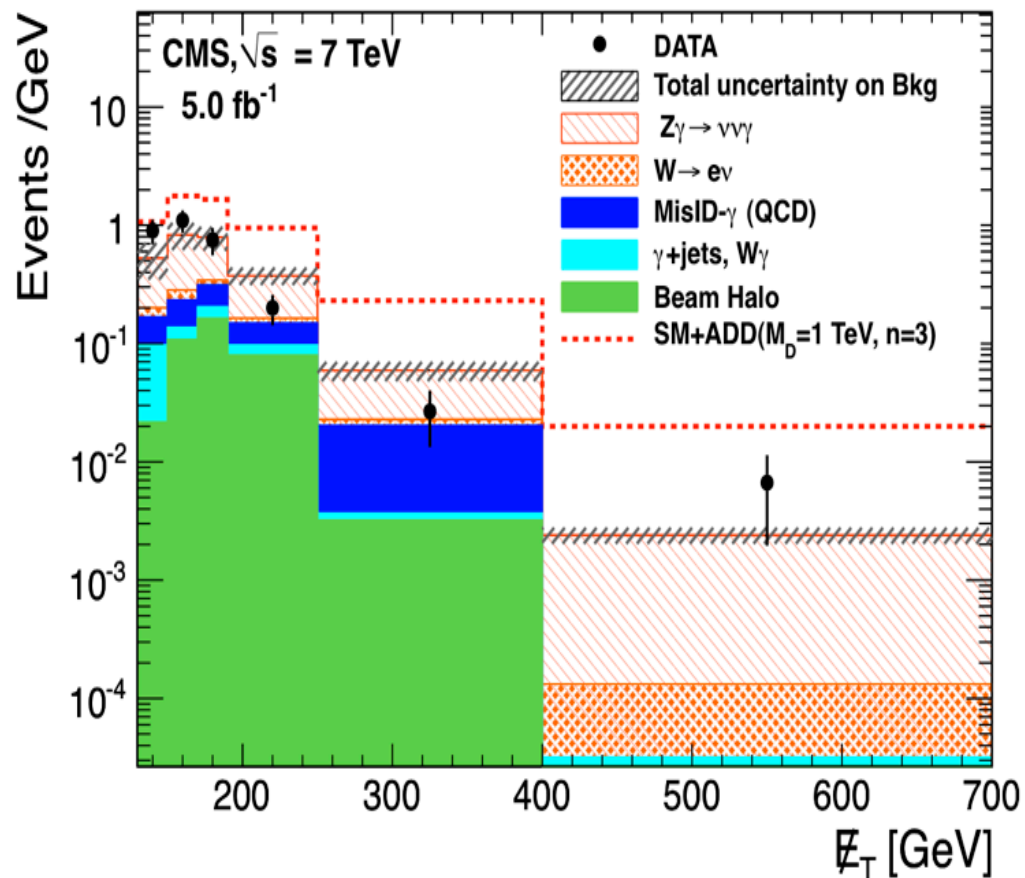


γ +MET

$\sqrt{s}=7$ TeV, $\int Ldt=5.0$ fb $^{-1}$

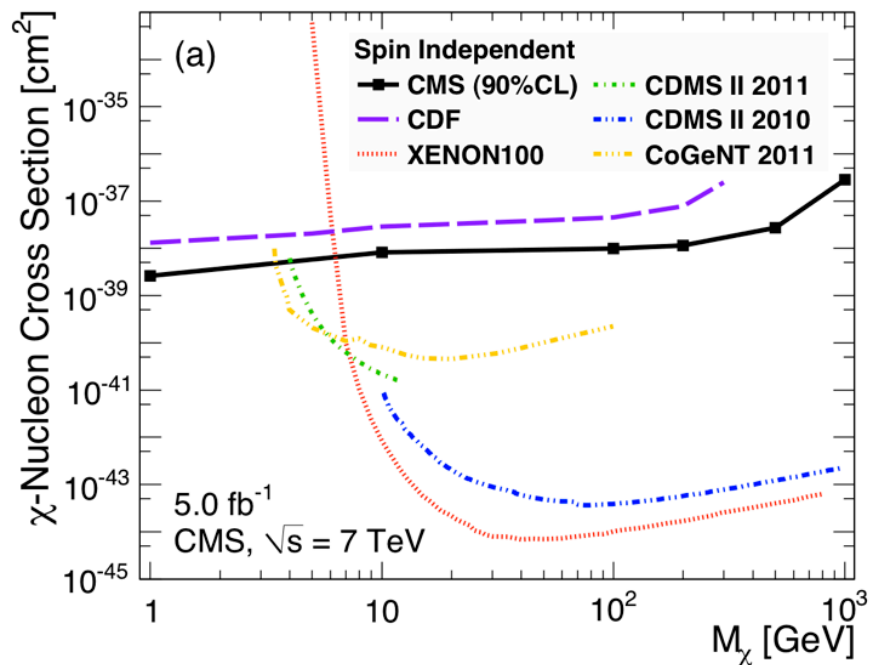
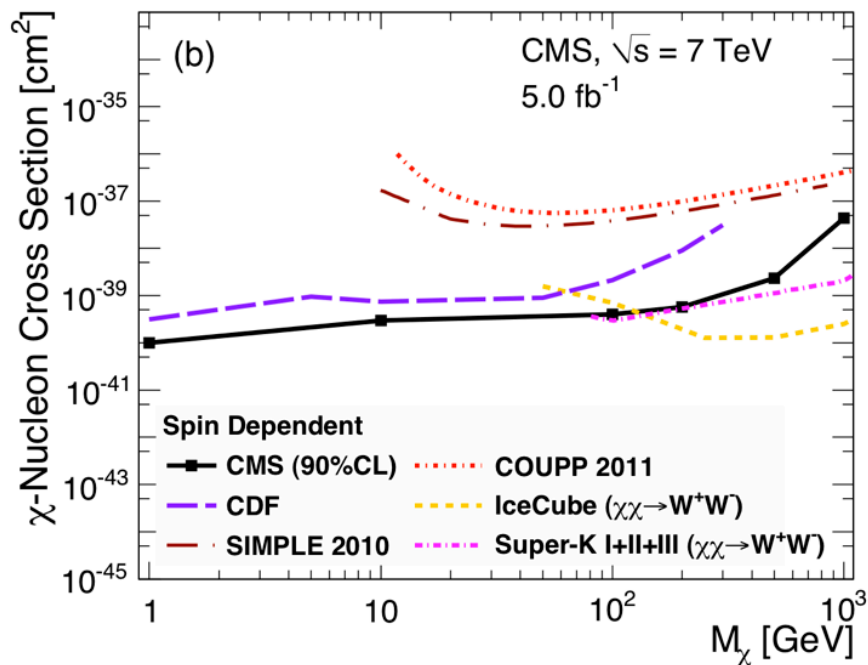


- QCD and electroweak backgrounds calculated from data-driven methods
- W/Z+ γ , γ +jets, $W\gamma$, Beam Halo taken from simulation



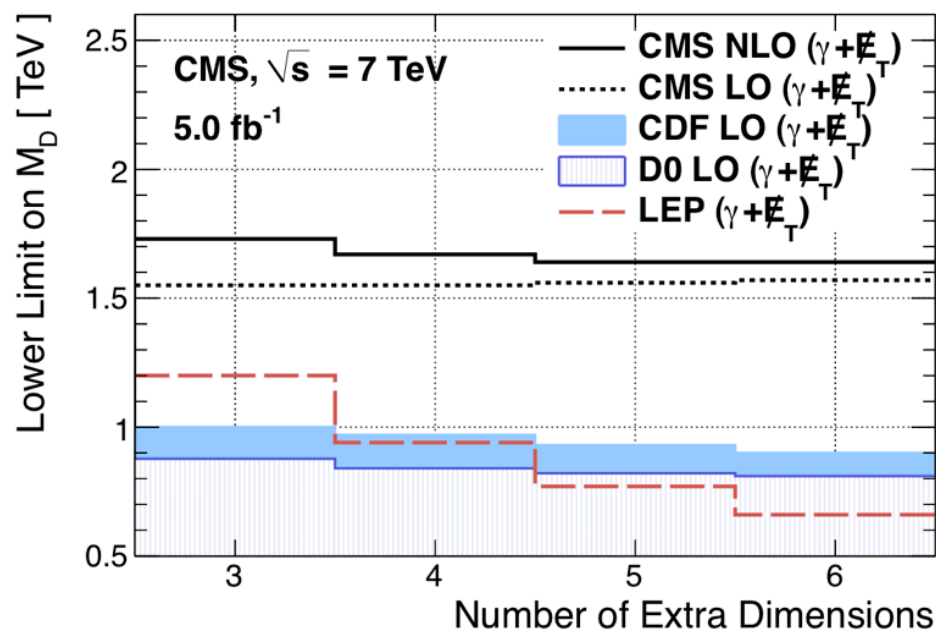
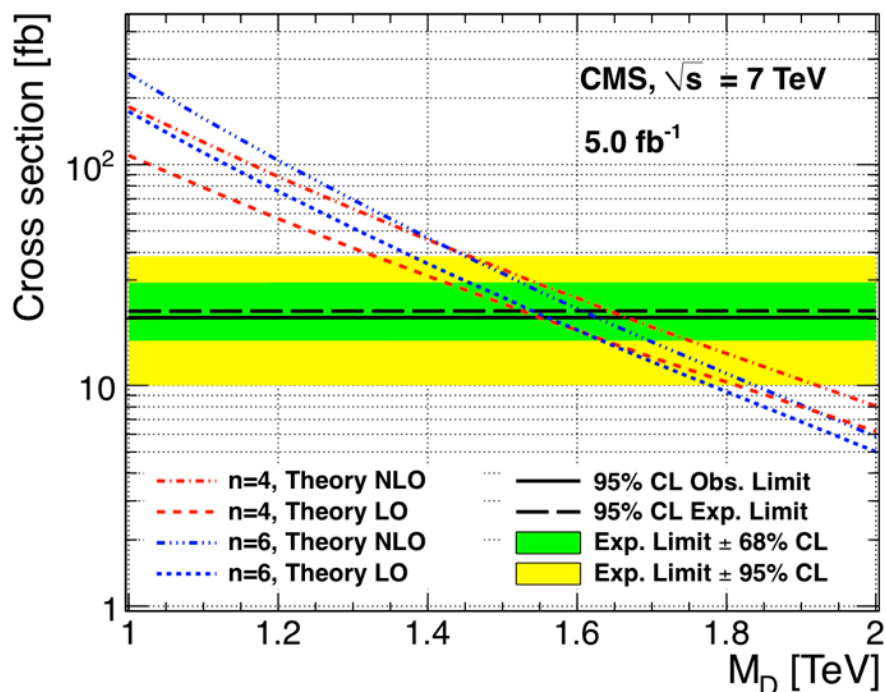
γ +MET: Dark Matter

- 90% CL limits are set on χ -nucleon elastic scattering cross sections, as a function of Dark Matter particle mass M_χ , for both spin dependent and independent scattering. Previous results are also shown.



γ +MET: Extra Dimensions

- 95% CL cross sections are calculated on 4+n dimensional Planck's Constant M_D . Limits are shown as a function of n



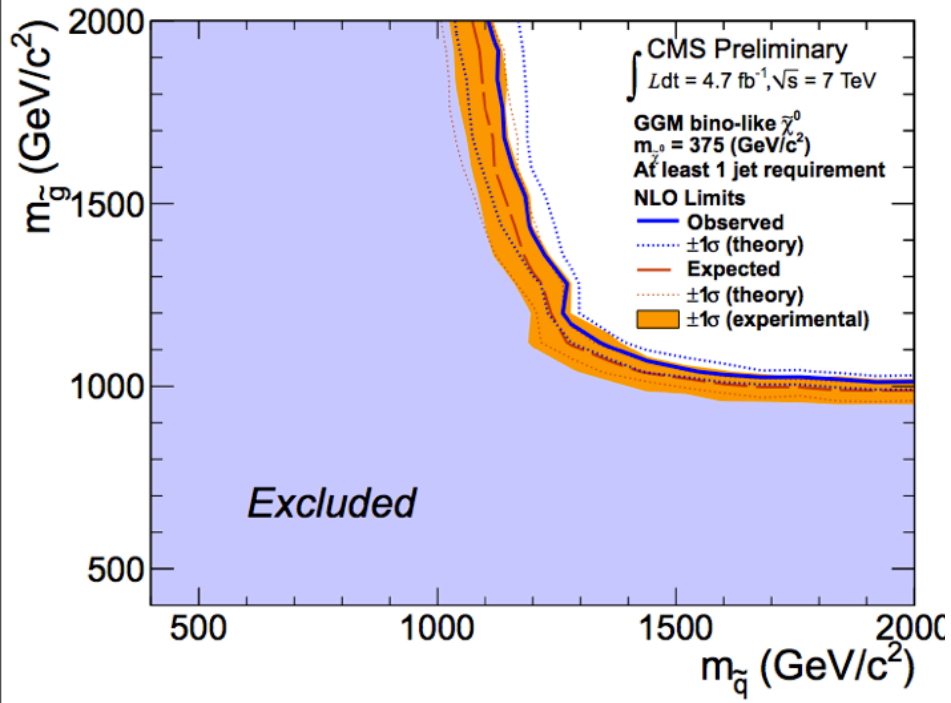
Conclusions

- A number of complementary searches have been performed at CMS for physics beyond the standard model in the framework of Supersymmetry, Dark Matter, and Extra Dimensions in events with photons and MET
- No excesses above Standard Model backgrounds have been observed
- Limits have been set on squark mass, squark-gluino mass plane, M_D , and χ -nucleon elastic scattering

Backup

Di-Photon: Bino-Like limit Comparison

SUS-12-001



SUS-12-018

