Searches for SUSY in Final States with Photons at CMS

David Morse

for the CMS collaboration

SUSY2013

27 August 2013

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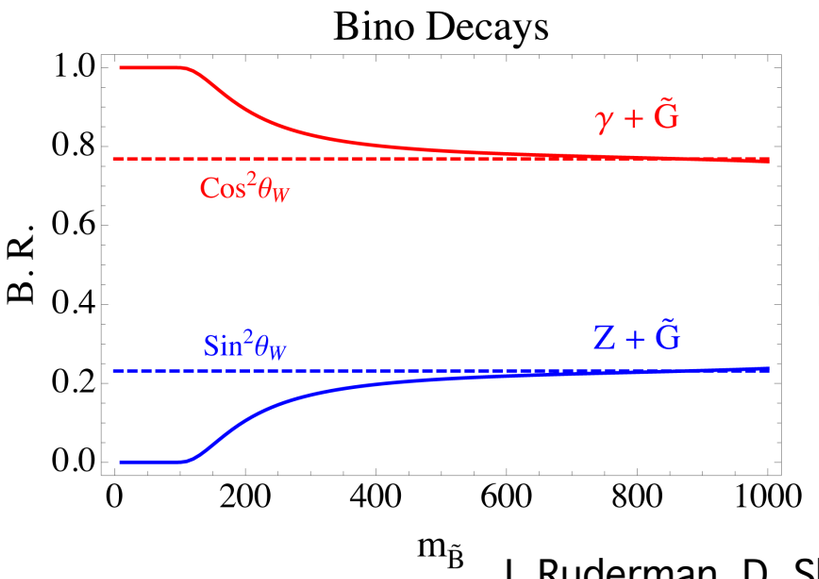
SUSY with Photons

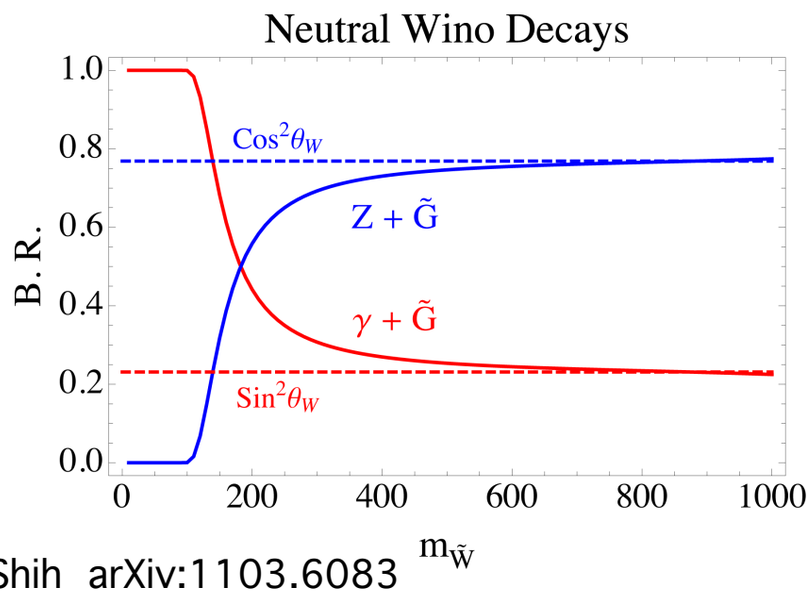
- Gauge Mediated Symmetry Breaking (GMSB)
  - Supersymmetry breaking communicated to the SM through the gauge interactions
  - eV-keV gravitino ($\tilde{G}$) LSP
- General Gauge Mediation (GGM)
  - NLSP is a mixture of Wino, Bino, and Higgsino

See talks by A. Gozzelino and B. Hooberman for more GMSB interpretations

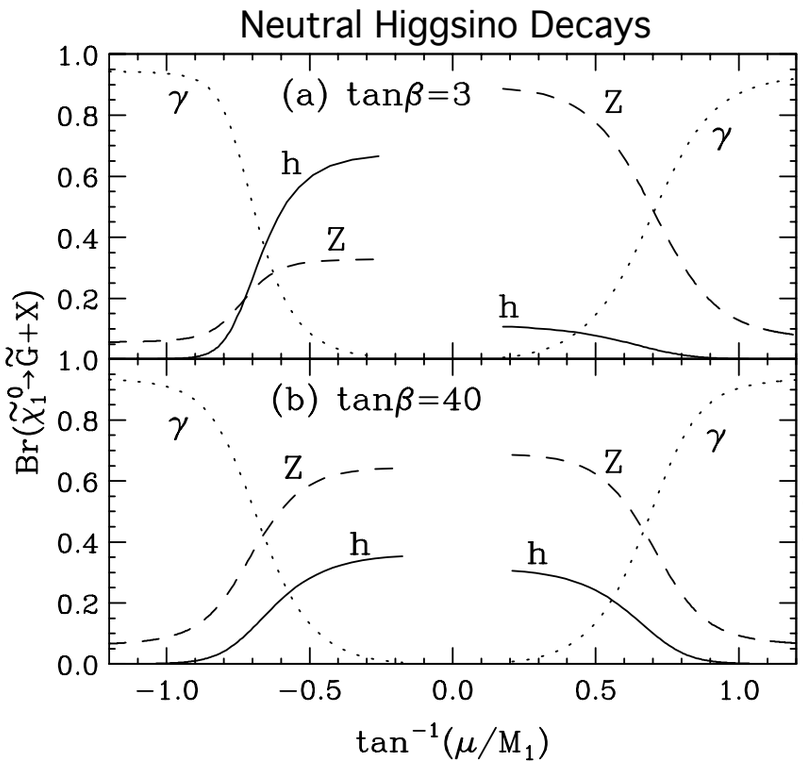
GGM Photon Production

Bino-like NLSP	Wino-like co-NLSP	Higgsino NLSP
$\tilde{\chi}_1^0 \to \gamma + \tilde{G}$ $\tilde{\chi}_1^0 \to Z^0 + \tilde{G}$	$\tilde{\chi}_1^0 \to Z^0 + \tilde{G}$ $\tilde{\chi}_1^0 \to \gamma + \tilde{G}$ $\tilde{\chi}_1^{\pm} \to W^{\pm} + \tilde{G}$	$\tilde{\chi}_1^0 \to h^0 + \tilde{G}$ $\tilde{\chi}_1^0 \to \gamma + \tilde{G}$ $\tilde{\chi}_1^0 \to Z^0 + \tilde{G}$





J. Ruderman, D. Shih arXiv:1103.6083



K. Matchev, S. Thomas arXiv:hep-ph/9908482

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SUSY with Photons at CMS

- Searches designed to cover as many NLSP and final states as possible

NLSP	High MET	Low MET
Bino	Di-Photon $\sqrt{s}$=8 TeV 4.04 fb^{-1} CMS PAS SUS-12-018	Stealth SUSY $\sqrt{s}$=7 TeV 4.98 fb^{-1} CMS PAS SUS-12-014
Wino	Single Photon $\sqrt{s}$=8 TeV 4.04 fb^{-1} CMS PAS SUS-12-018	
Higgsino	Stop-Higgsino $\sqrt{s}$=8 TeV 19.5 fb^{-1} CMS PAS SUS-13-014	

- Mostly focus on strong production

SUSY with Photons at CMS

- Searches designed to cover as many NLSP and final states as possible

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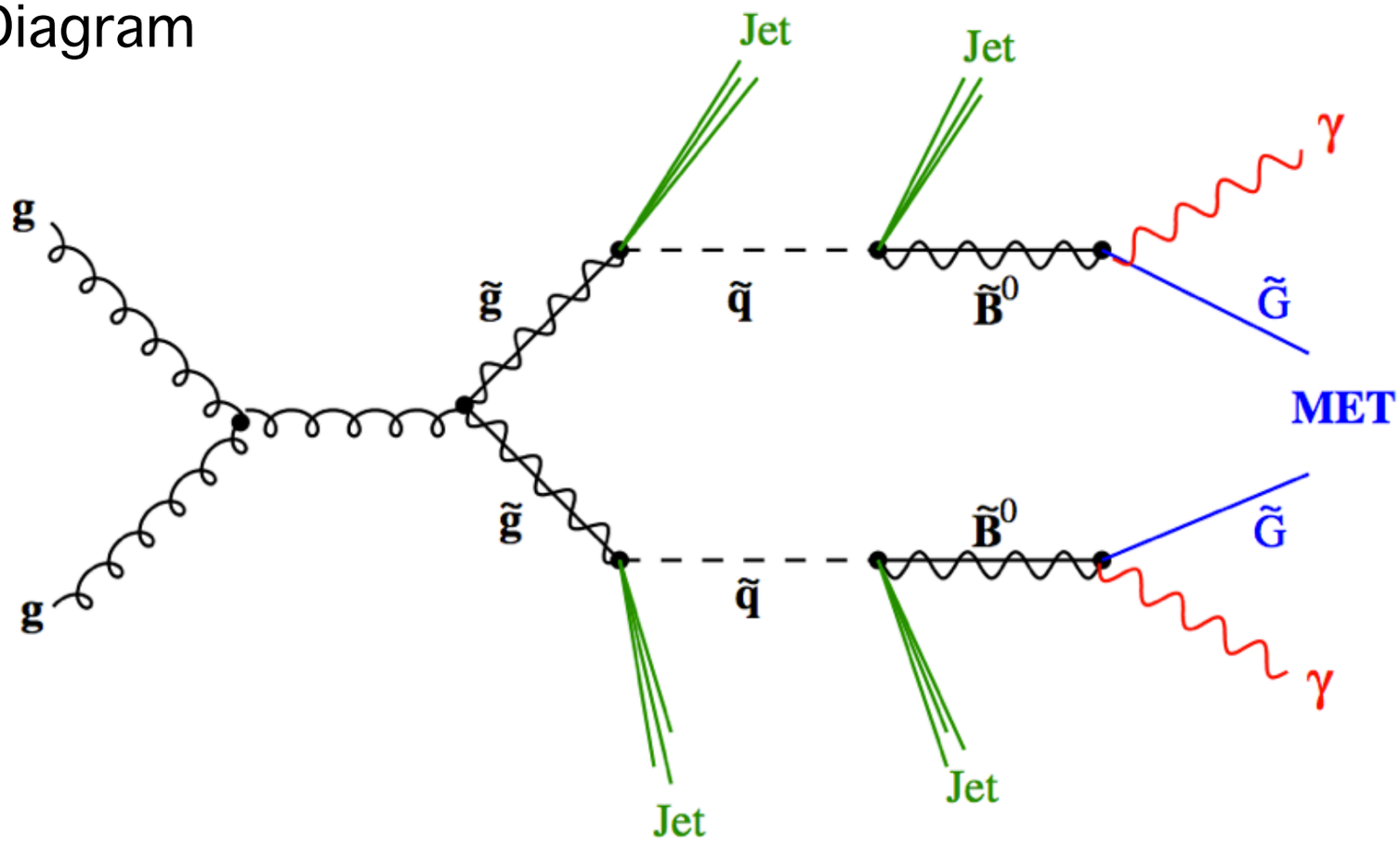
Higgsino	Stop-Higgsino $\sqrt{s}$=8 TeV 19.5 fb^{-1} CMS PAS SUS-13-014	NEW

Di-Photon

Example Diagram



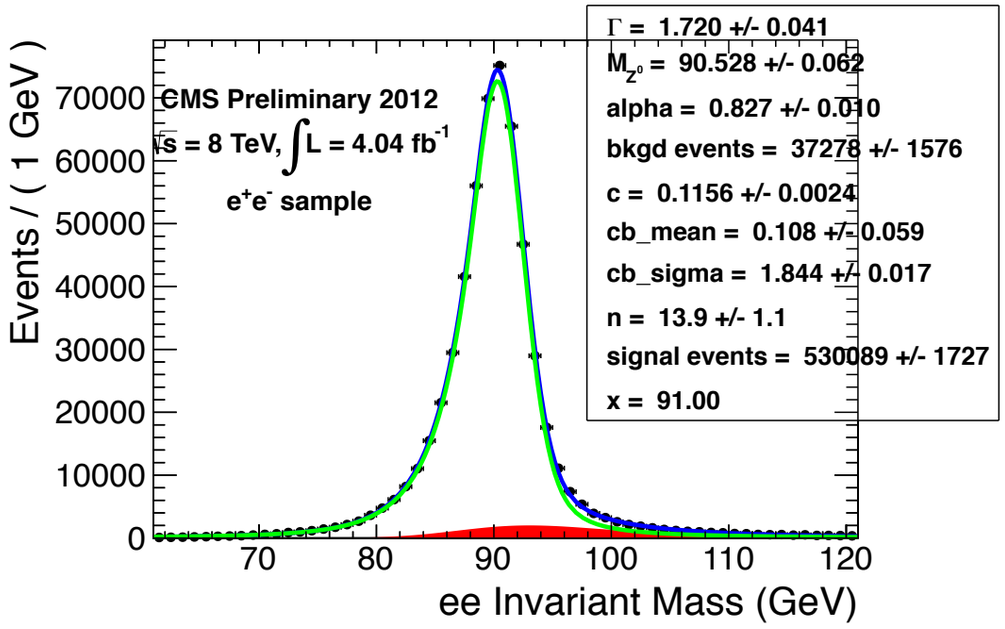
CMS PAS SUS-12-018

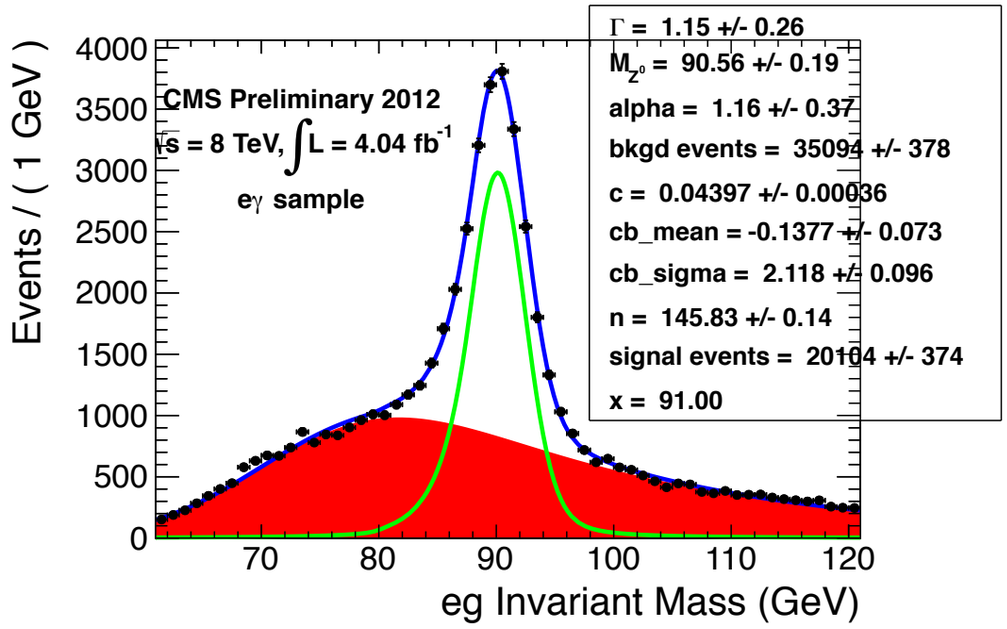
2 photons, Jets, high MET

Photons	Jets	Signal Region	∫Ldt
≥2 leading(trailing) p_T>40(25) GeV |η|<1.4442 isolation, shower shape requirements	≥1 particle flow anti-kT (R=0.5) pT>30 GeV |η|<2.6 separated from photons	MET>50 GeV	√s=8 TeV 4.04 fb^{-1}

Di-Photon

Sub-dominant bg EWK Wγ,Wjet with real MET estimated using electron to photon fake rate extracted from Z peaks in ee and eγ samples



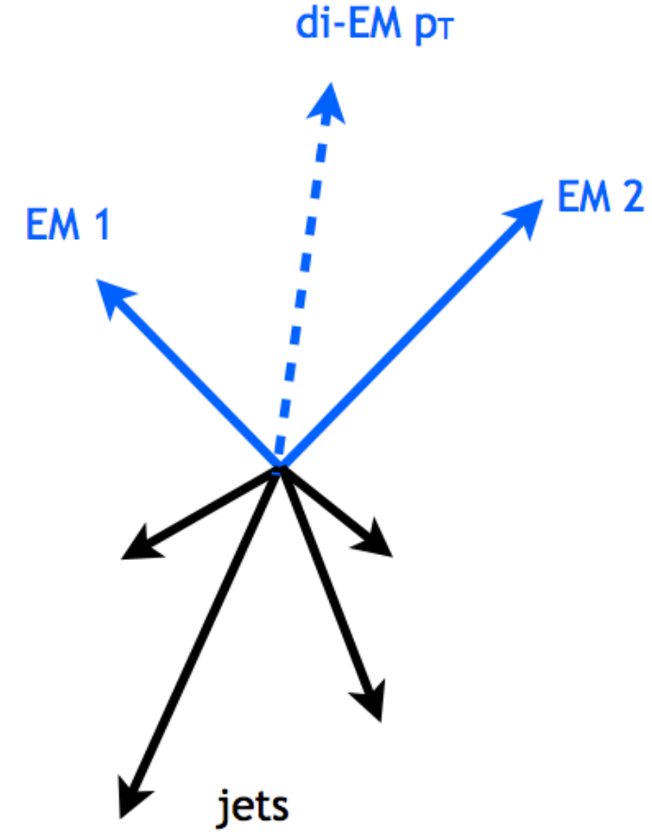


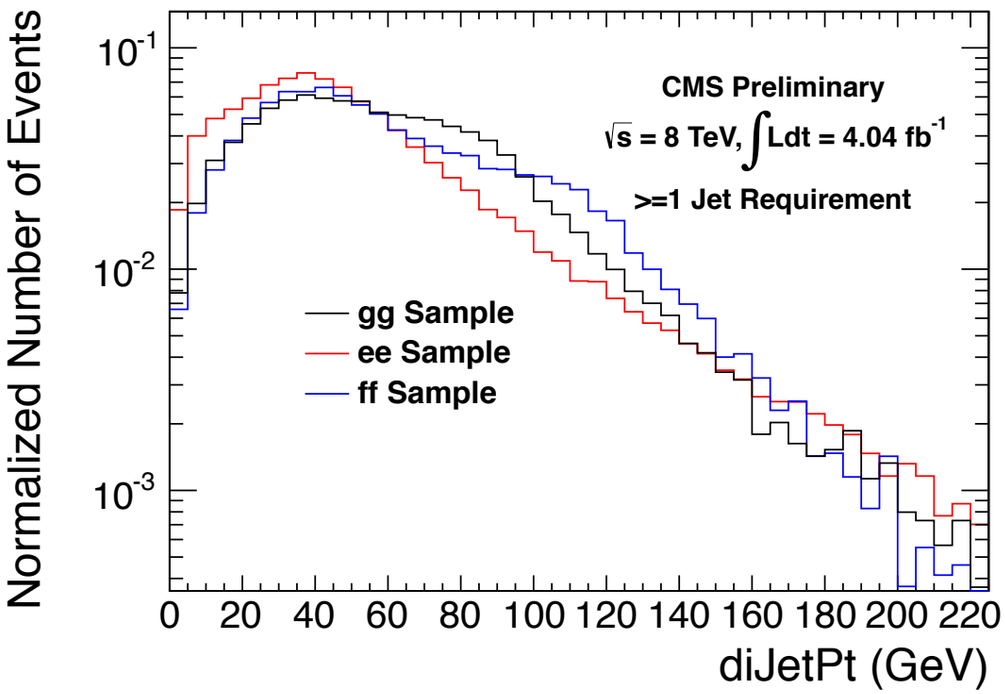
$$f_{e\to\gamma} = 0.0181 \pm 0.0003(\text{stat.}) \pm 0.0009(\text{syst.})$$

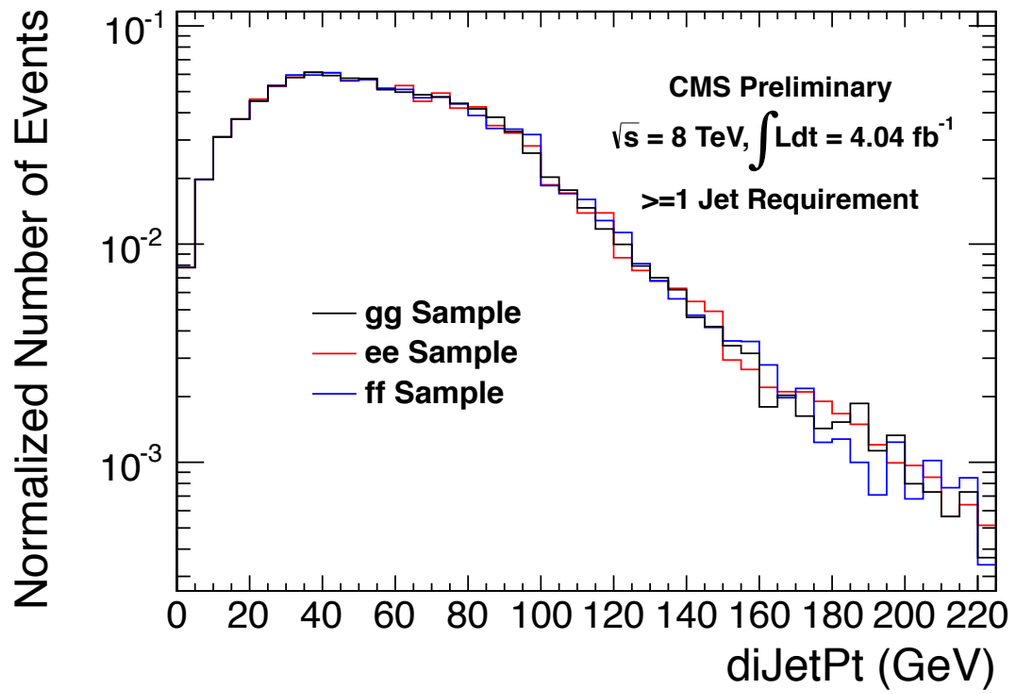
eγ sample scaled by fake rate to estimate EWK component of SM background

Di-Photon

- Dominant bg QCD γγ, γ-jet, di-jet with fake MET estimated using EM-fluctuated jets (fake photons) in data → ff sample
- MET arises from mis-measurement of event objects
- Re-weighted to model γγ hadronic recoil in event

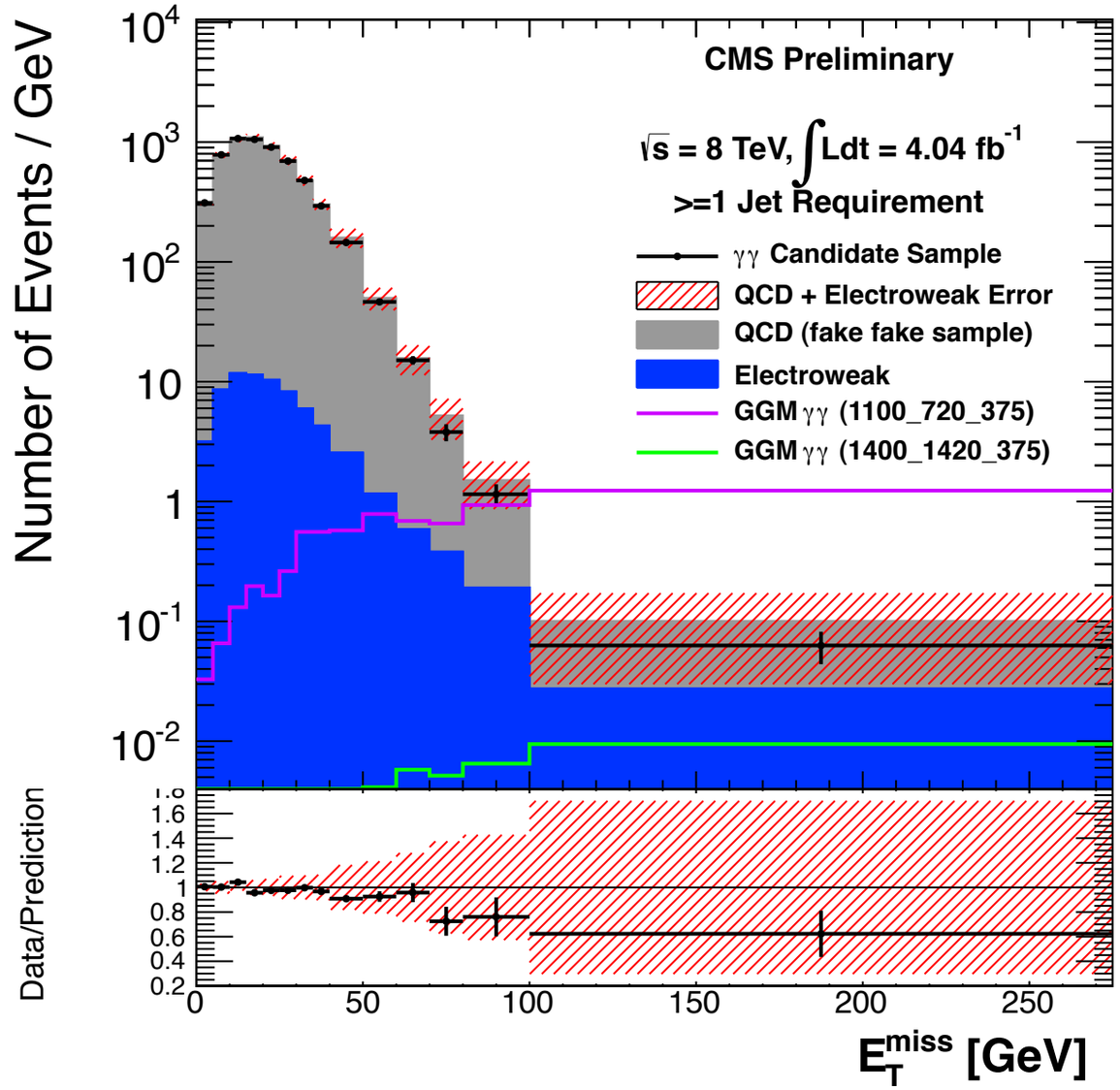






Di-Photon

- MET is discriminating variable
- ff MET spectrum normalized to low MET γγ minus small EWK component
- No excess observed over SM expectation



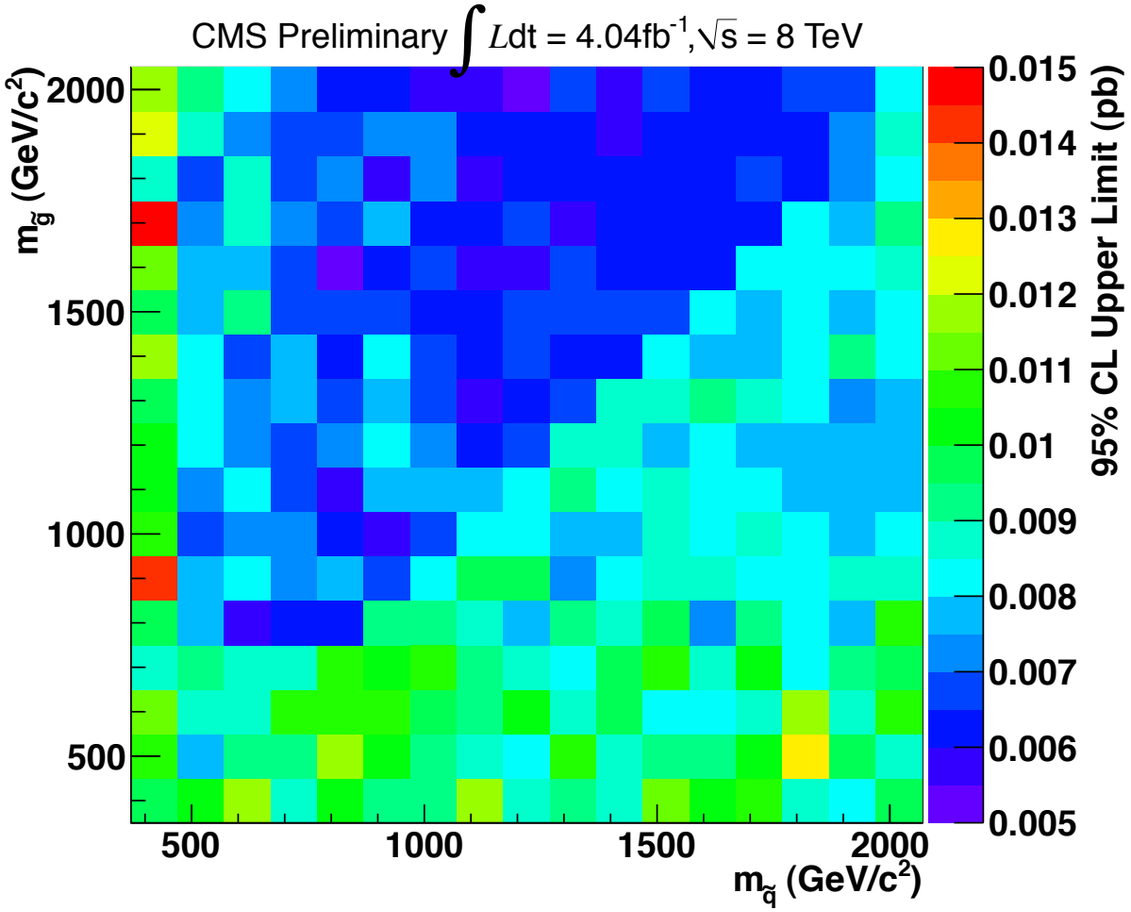
Di-Photon

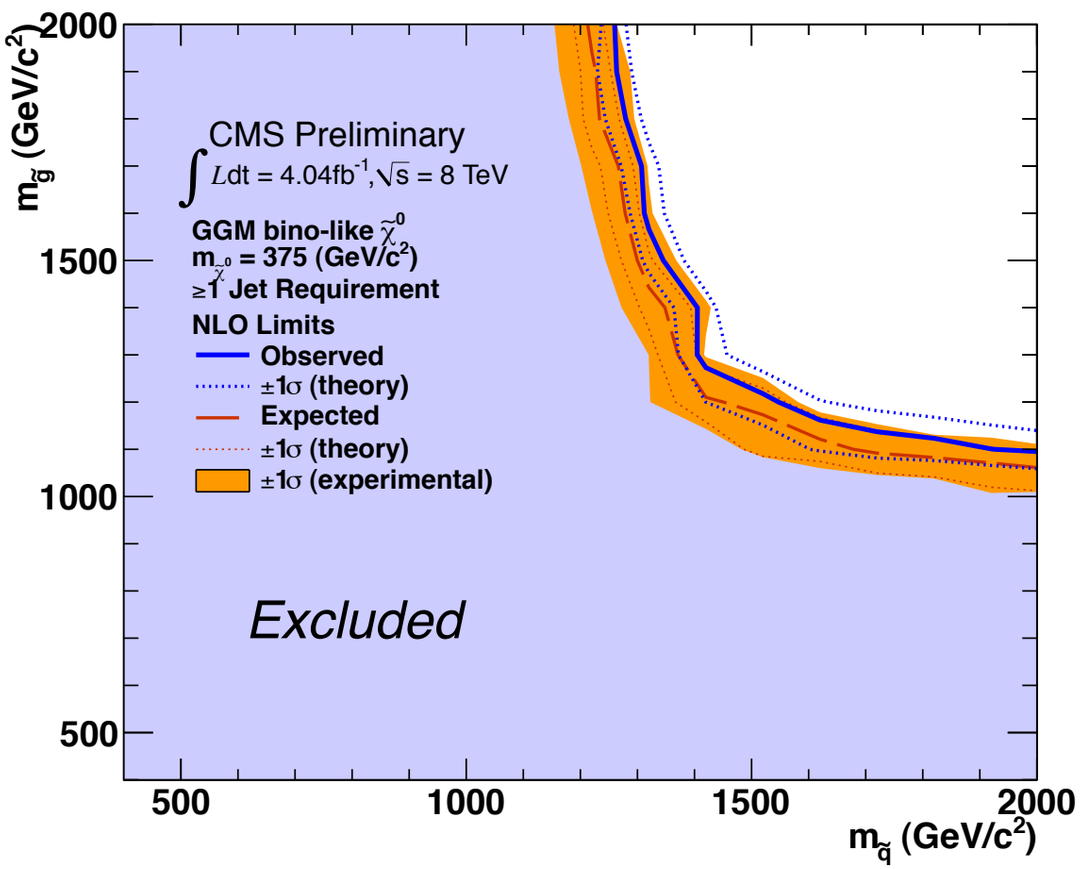
GGM Bino-like NLSP signal scan

$m_{\tilde{\chi}0}$=375 GeV, 400<$m_{\tilde{q},\tilde{g}}$<2000 GeV

All other superpartners pushed to 3.5 TeV, heavy right-handed squarks

Limits set on production cross section using binned CL_S method with likelihood-ratio test statistics at 95% confidence level with full propagation of errors. NLO signal cross sections calculated in Prospino





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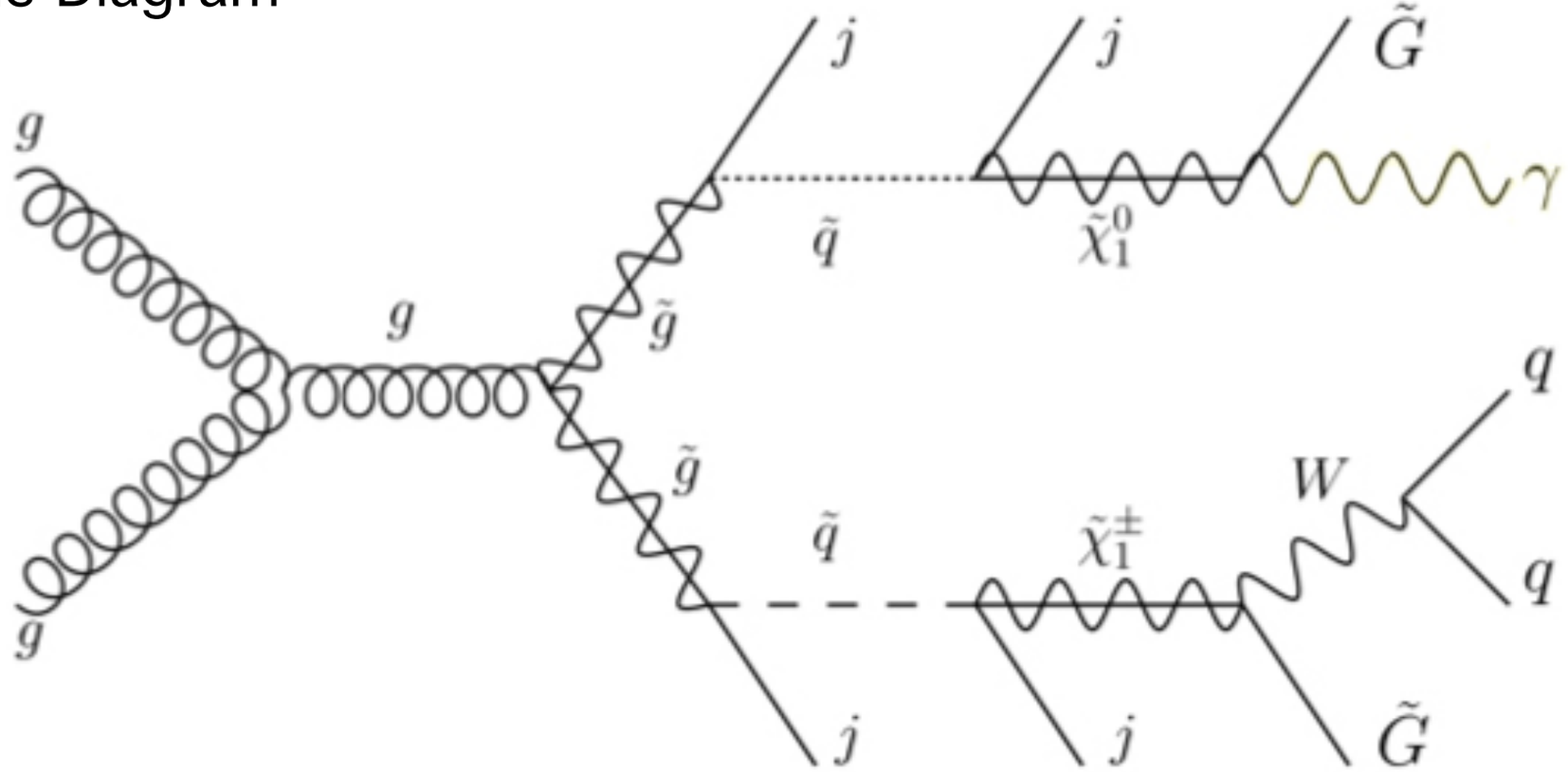
Single Photon

Example Diagram



CMS PAS SUS-12-018

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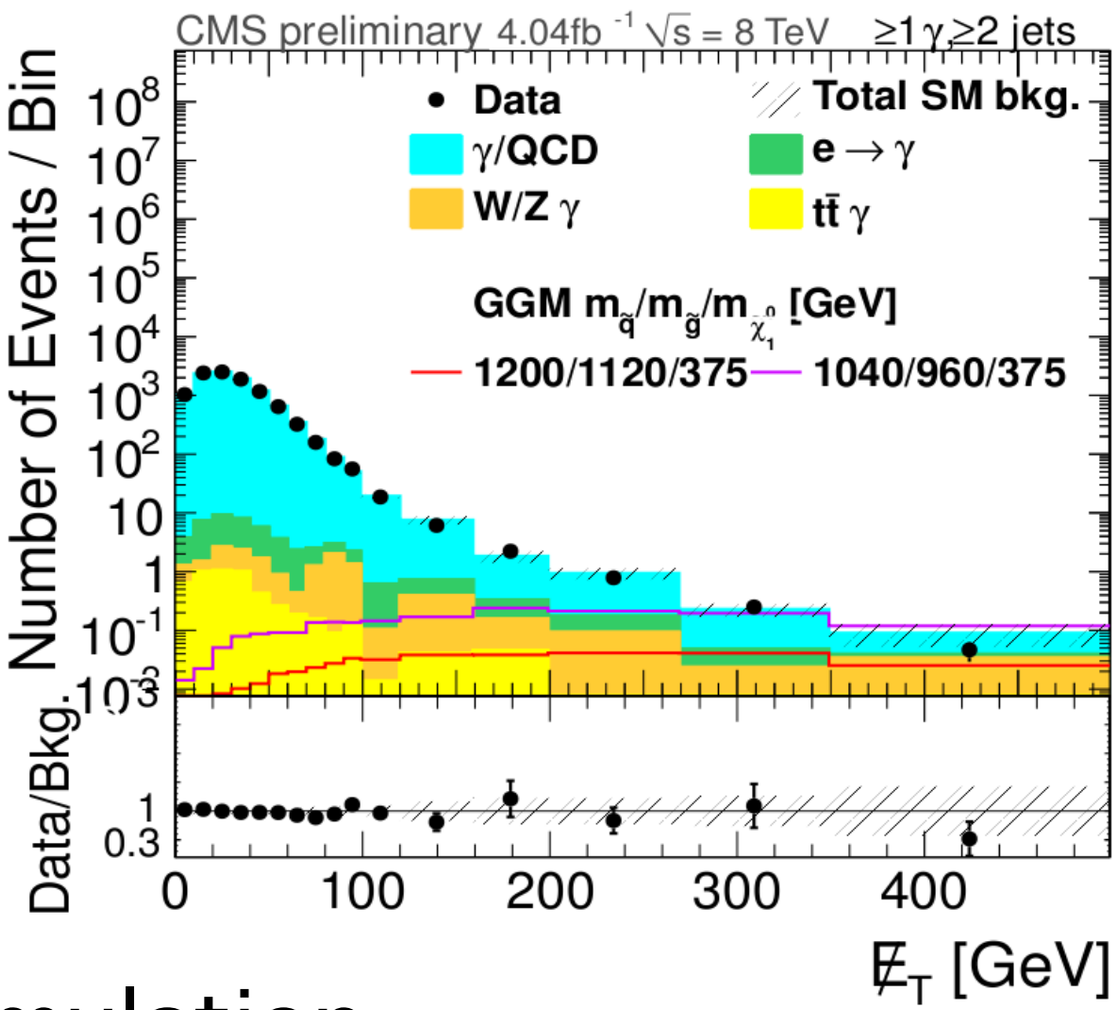
1 photons, Jets, high MET

Photons	Jets	Signal Region	∫Ldt
≥1 p_T>80 GeV |η|<1.4442 isolation, shower shape requirements	≥2 particle flow anti-kT (R=0.5) pT>30 GeV |η|<2.6 separated from photons $H_T = \sum_{Jets} p_T > 450$ GeV	MET>100 GeV	√s=8 TeV 4.04 fb^{-1}

Single Photon

- Dominant bg QCD γjet, dijet estimated using EM-fluctuated jets in data re-weighted to model γ hadronic recoil in event
- Sub-dominant bg EWK Wγ,Wjet estimated using data eγ sample and electron to photon fake rate

$$f_{e\to\gamma} = 0.011 \pm 0.002(\text{stat.}) \pm 0.001(\text{syst.})$$



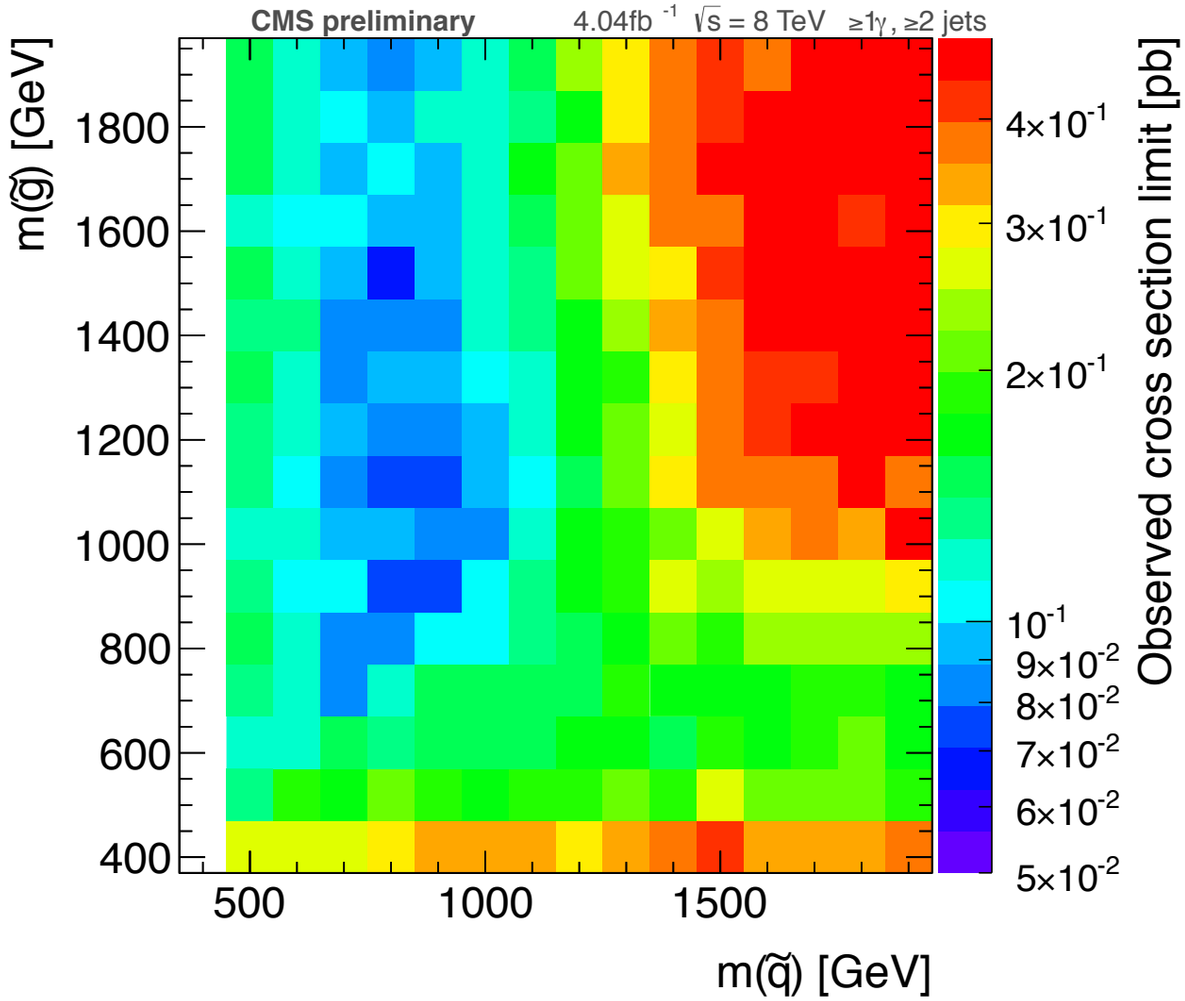
- Irreducible ISR/FSR W/Zγ,ttγ estimated from simulation
- MET is discriminating variable
- No excess observed

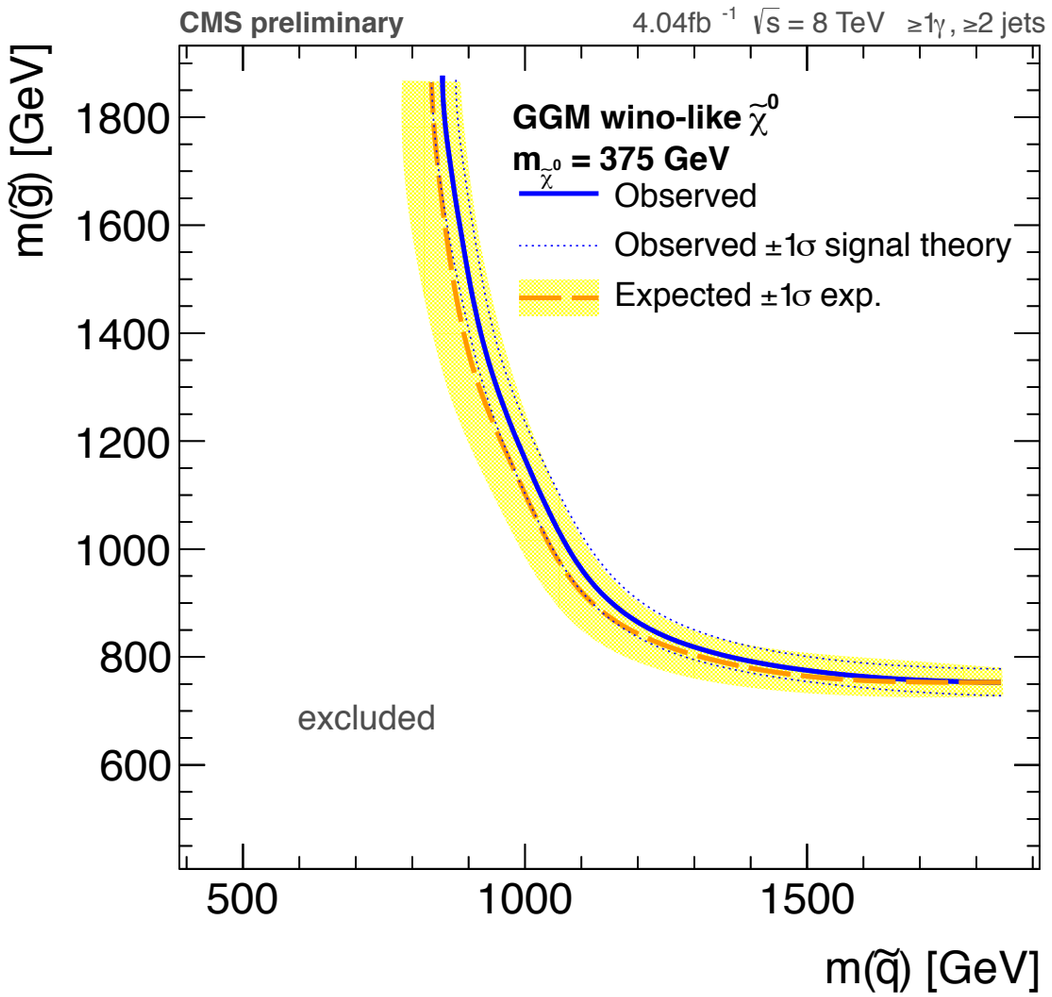
Single Photon

GGM Wino-like co-NLSP signal scan

$m_{\tilde{\chi}0}$=375 GeV, 400<$m_{\tilde{q},\tilde{g}}$<2000 GeV

All other superpartners pushed to 3.5 TeV, heavy right-handed squarks





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Stop-Higgsino

NEW

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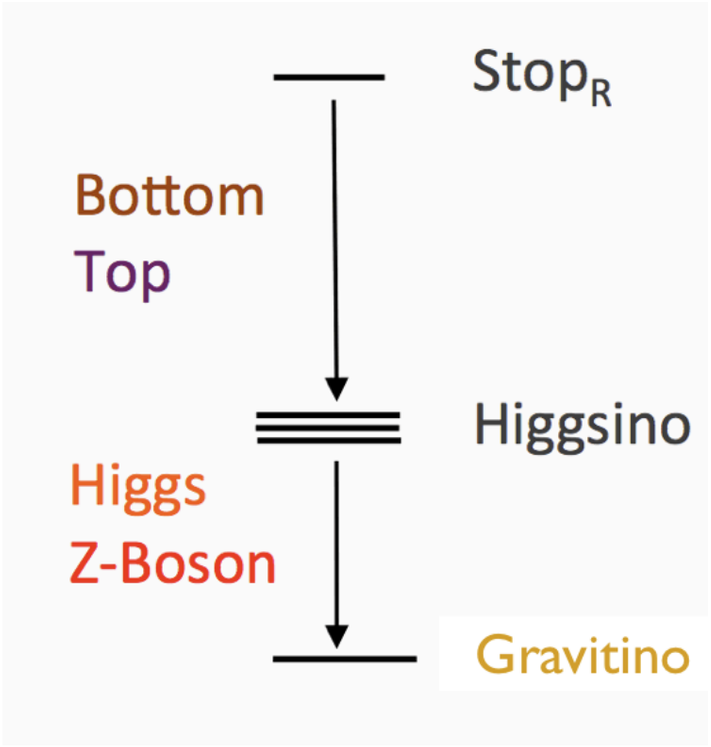
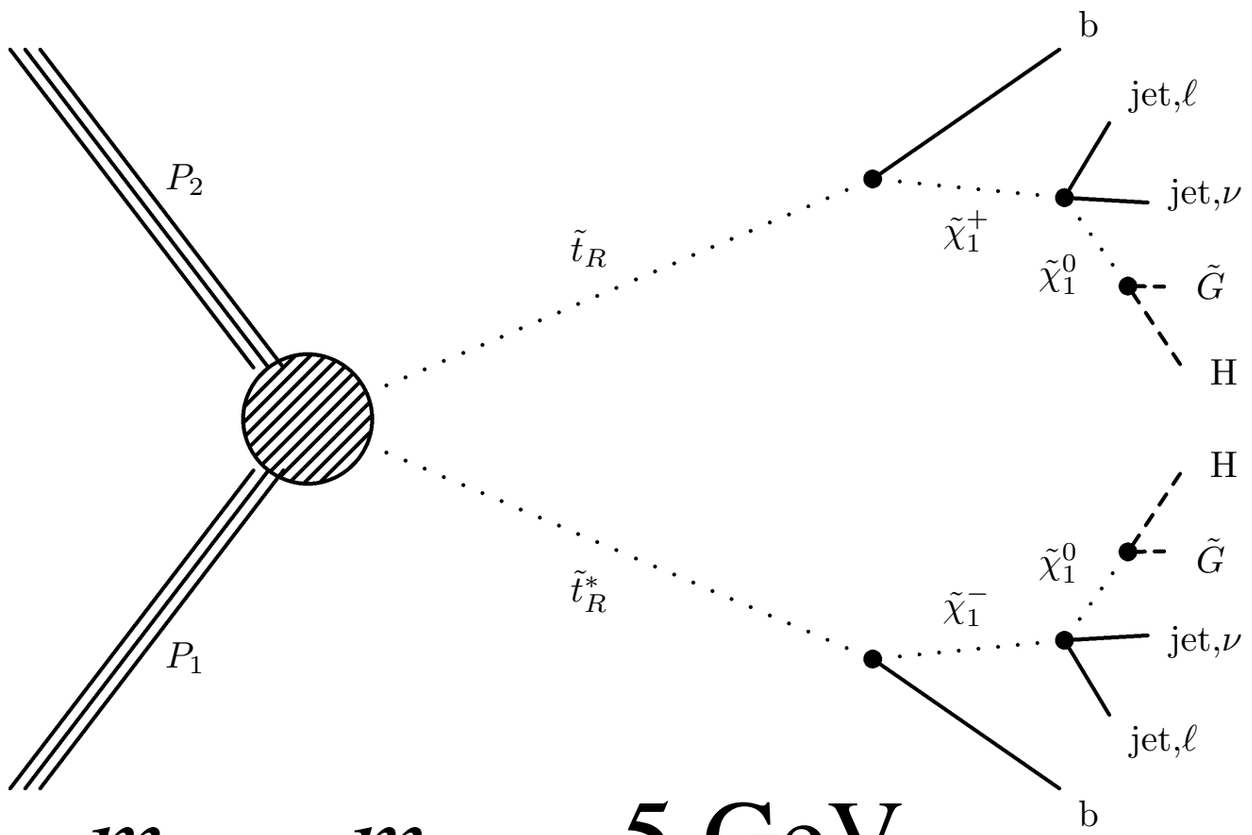
- Motivated by recent discovery of Higgs boson
- 'Naturalness' - low Higgsino and stop masses reduce fine-tuning
- Lightest chargino and neutralino are nearly mass degenerate





$$m_{\tilde{t}} - m_{\tilde{H}^{\pm}} < m_t \ , \ m_{\tilde{H}^{\pm}} - m_{\tilde{H}^0} = 5 \text{ GeV}$$

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Stop-Higgsino

NEW

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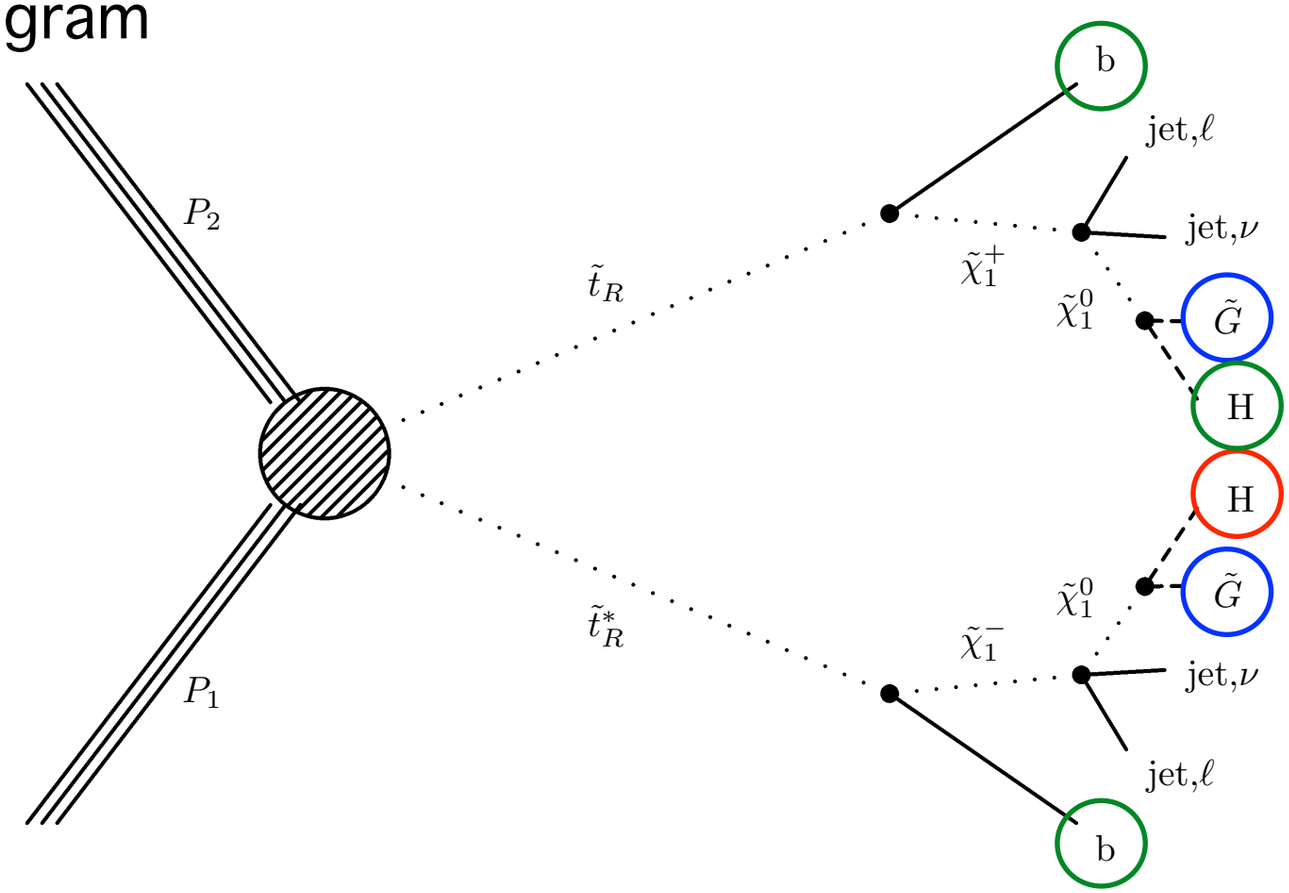
Example Diagram



CMS PAS SUS-13-014

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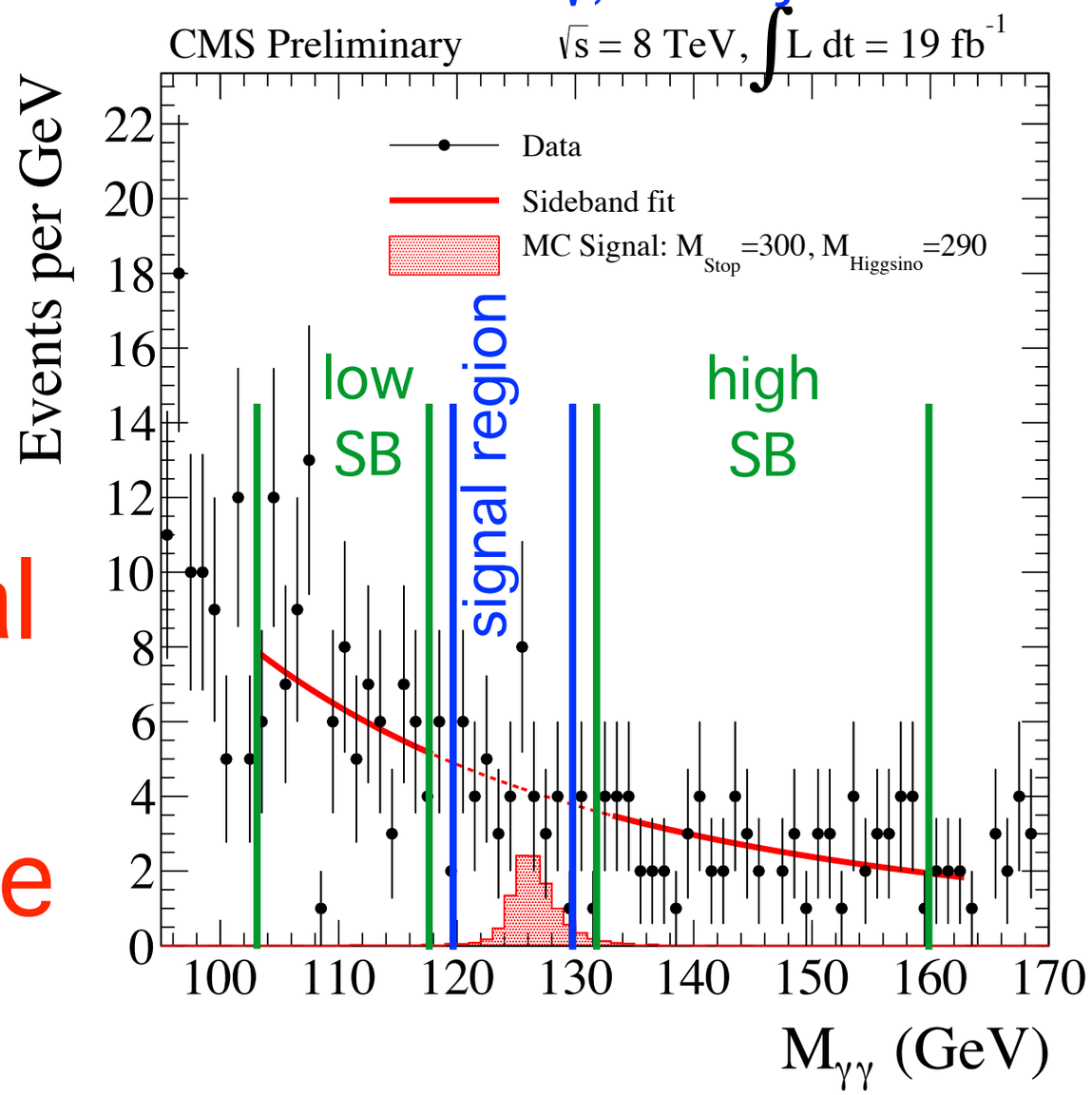
2 photons, ≥2 b-Jets, high MET

Photons	Jets	Signal Region	∫Ldt
≥2 leading(trailing) p_T>40(25) GeV |η|<1.4442 isolation, shower shape requirements	≥2 particle flow anti-kT (R=0.5) >=1 CSV Medium, >=1 CSV Loose b-tags pT>30 GeV |η|<2.6 separated from photons	bins of MET	√s=8 TeV 19.5 fb^{-1}

Stop-Higgsino

NEW

- Take advantage of narrow resonance of H→γγ
- Fit γγ invariant mass sidebands outside signal region to make robust SM background estimate
- SM Higgs negligible
- Inclusive selection split into 3 categories:



=2 b-jets $95<m_{bb}<155$	=2 b-jets $m_{bb}<95$ or $m_{bb}>155$	≥3 b-jets

Stop-Higgsino

NEW

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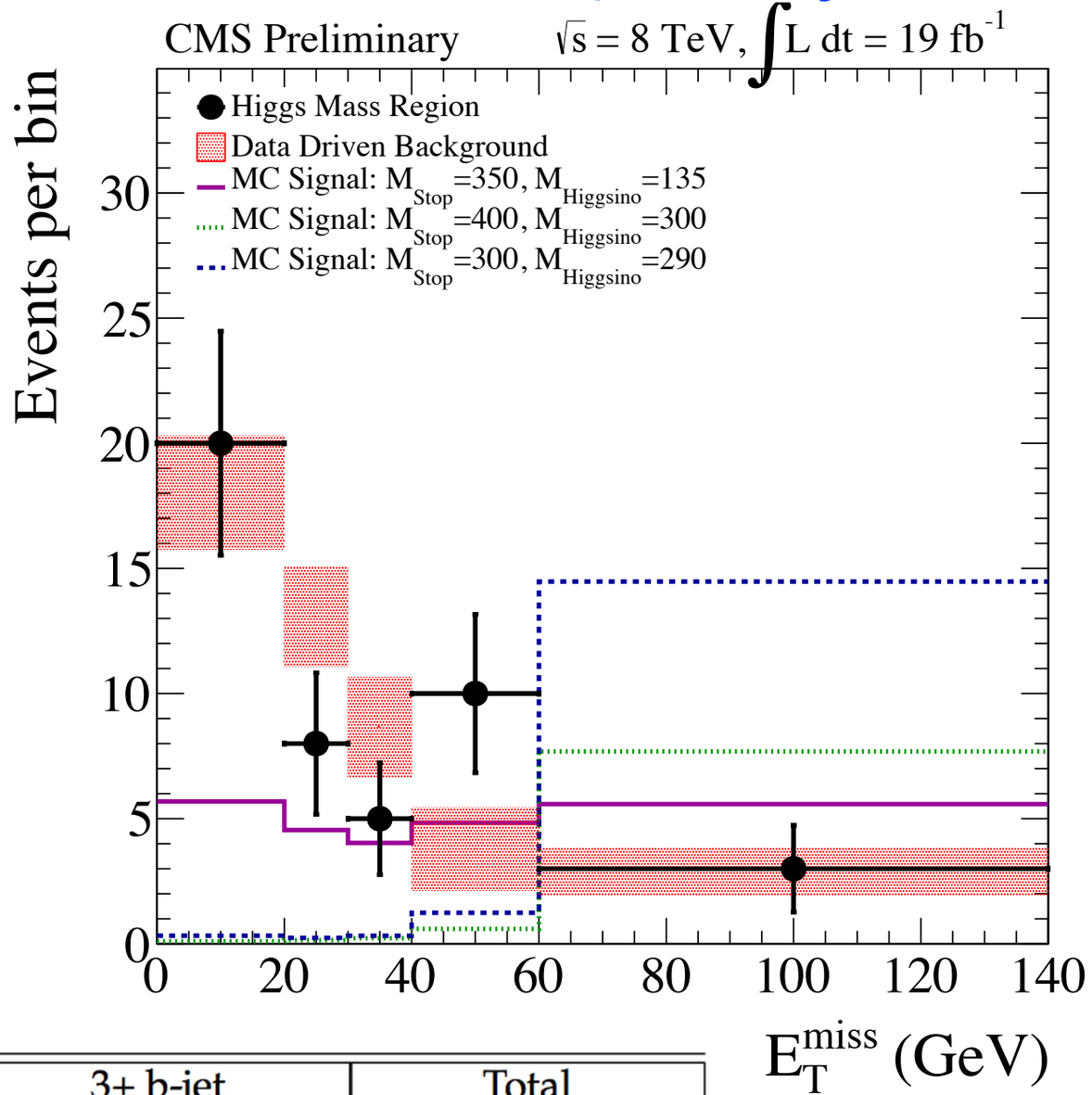
- MET is discriminating variable
- MET spectra of sidebands normalized to signal region fit integral
- No excess observed in any of 3 categories, which are then recombined in limit setting



	2 b-jets on h mass		2 b-jets off h mass		3+ b-jet		Total	
E_T^{miss} (GeV)	Data	Bkg	Data	Bkg	Data	Bkg	Data	Bkg
0-20	3	5.0 ± 1.3	15	11.0 ± 1.8	2	1.77 ± 0.73	20	18.1 ± 2.3
20-30	2	3.4 ± 1.3	4	7.9 ± 1.7	1	1.8 ± 1.1	7	13.1 ± 2.0
30-40	0	1.39 ± 0.71	5	6.3 ± 1.3	1	0.73 ± 0.84	6	8.7 ± 2.0
40-60	1	0.58 ± 0.68	7	2.2 ± 1.7	2	0.73 ± 0.84	10	3.8 ± 1.6
60+	1	0.19 ± 0.28	2	1.35 ± 0.73	0	1.3 ± 1.0	3	2.8 ± 1.0

Stop-Higgsino

NEW

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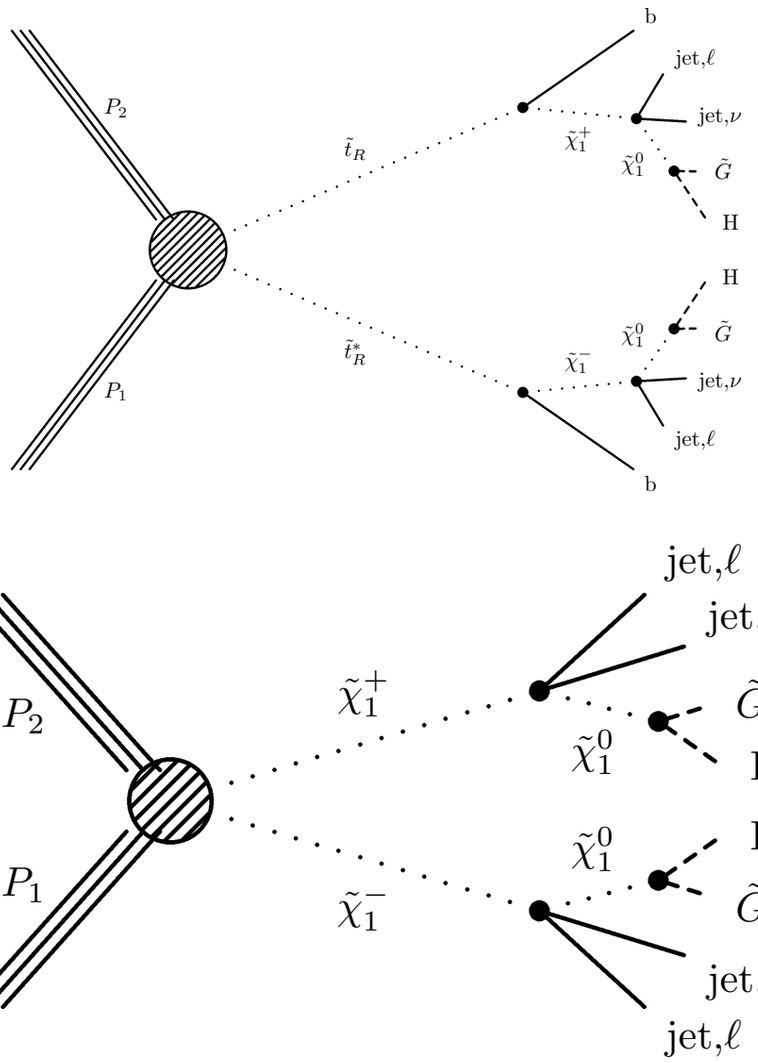
GGM Higgsino-like NLSP signal scan

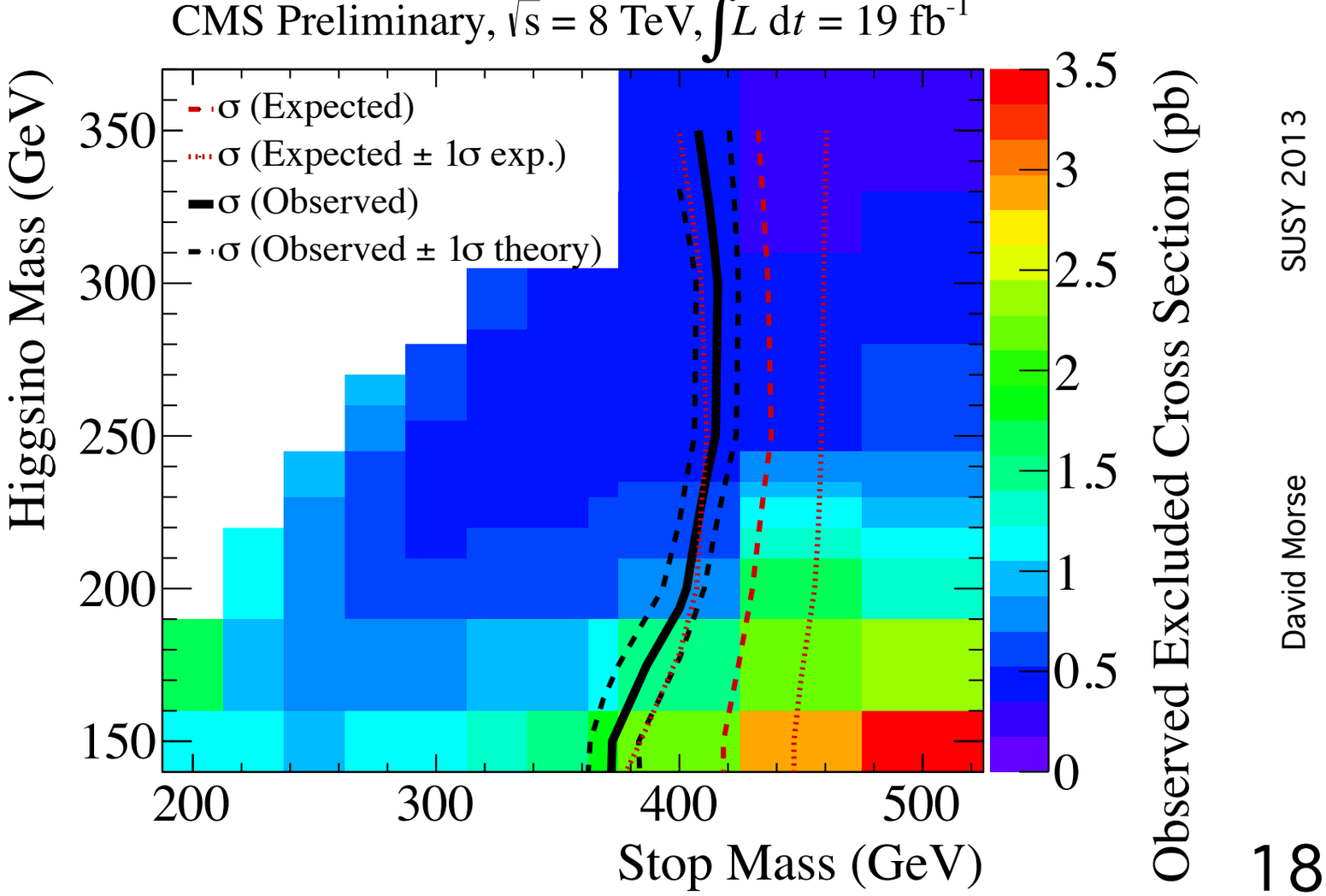
$$m_{\tilde{t}} - m_{\tilde{H}^{\pm}} < m_t \ , \ m_{\tilde{H}^{\pm}} - m_{\tilde{H}^0} = 5 \text{ GeV} \ , \ m_{\tilde{g}} = 5.05 \text{ TeV}$$

All other superpartners pushed to 4 TeV



Strong+Electroweak production

$$BF\left(\tilde{H}^0 \rightarrow h^0 \tilde{G}\right) = 1$$



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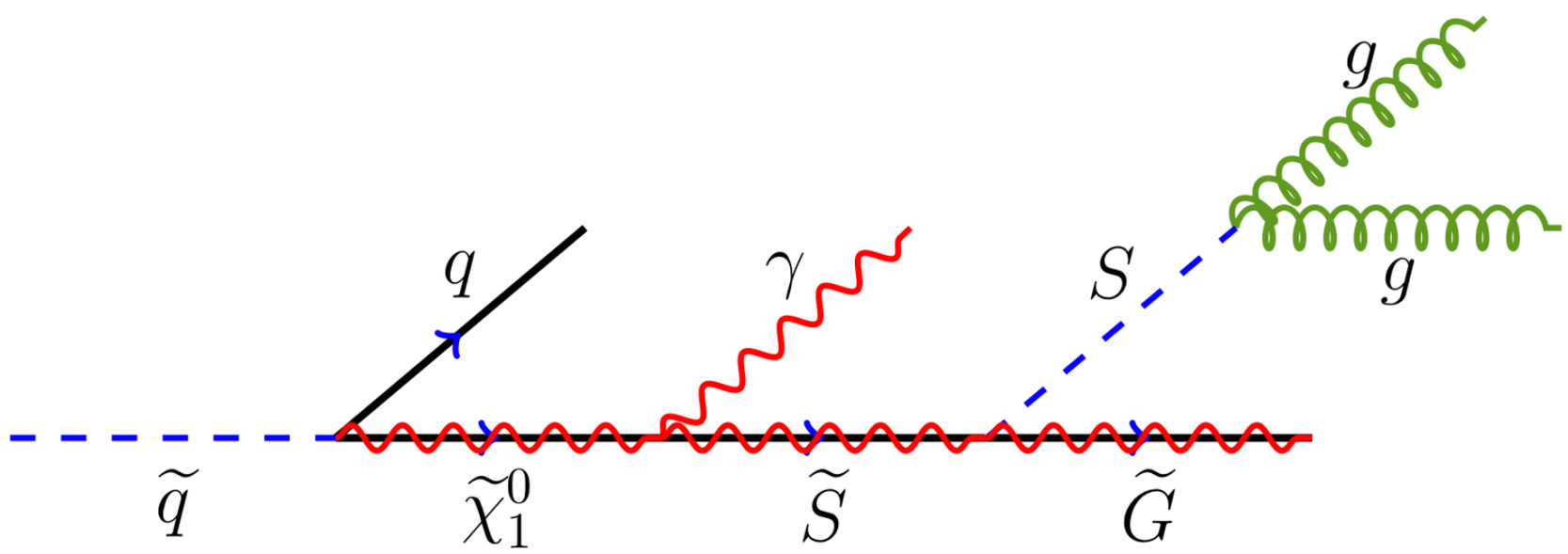
Stealth SUSY

Introduce a hidden sector with singlet S and superpartner singlino $\tilde{S}$ with small mass splitting, and hence inherently low MET. $\tilde{S}$ is lightest visible supersymmetric particle (LVSP).



CMS PAS SUS-12-014

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2 photons, Jets, low MET

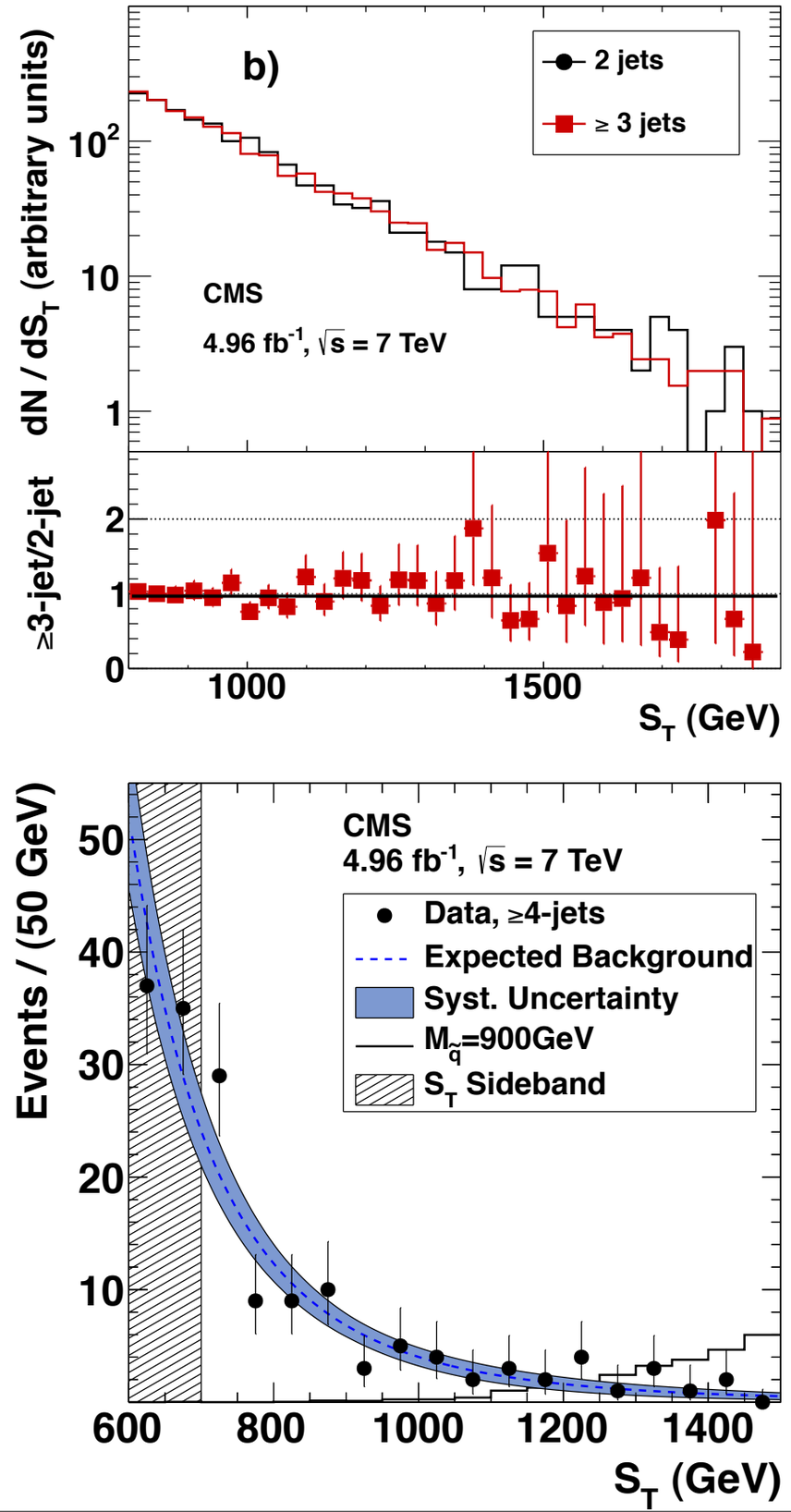
Photons	Jets	Signal Region	∫Ldt
leading(trailing) p_T>40(25) GeV |η|<1.4442 isolation, shower shape requirements	≥4 particle flow anti-kT (R=0.5) pT>20 GeV |η|<2.6	S_T cut optimized at each squark mass	√s=7 TeV 4.98 fb^{-1}

Stealth SUSY

- S_T is discriminating variable

$$S_T = \sum_{jets} p_T + \sum_{photons} p_T + E_T^{miss}$$

- S_T shape invariant under jet multiplicity
- Main backgrounds are QCD γ-jet,dijet
- Data-driven BG estimation using low nJets (shape) and low S_T (normalization) sidebands



Stealth SUSY

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Simplified T2 model ($\tilde{q}\tilde{q}^*$ production, CMS PAS SUS-11-016) with additional singlet/singlino pair

$$m_{\tilde{S}} = 100 \text{ GeV}, \quad m_{\tilde{S}} - m_S = 10 \text{ GeV}, \quad \mathrm{m}_{\tilde{g}} = 1500 \text{ GeV}, \; \mathrm{m}_{\tilde{B}} = \frac{1}{2} m_{\tilde{q}}$$

All other superpartners pushed out of kinematic possibility

$$BF\left(\tilde{B} \rightarrow \gamma \tilde{S}\right) = 1$$

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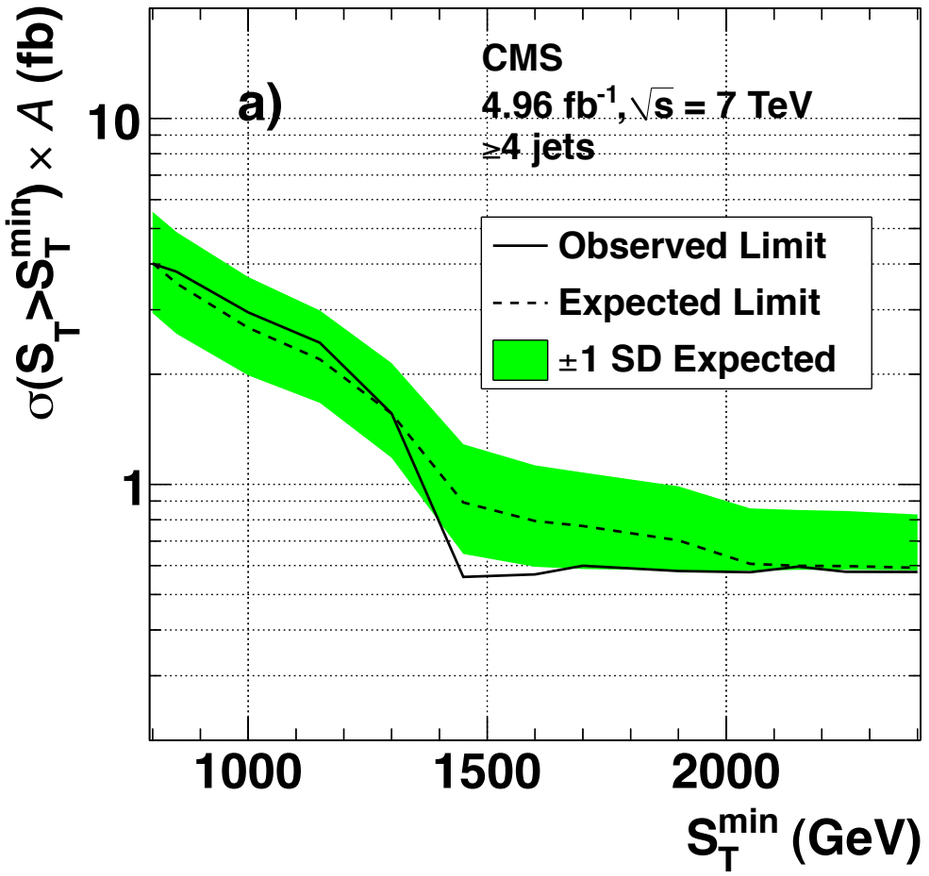
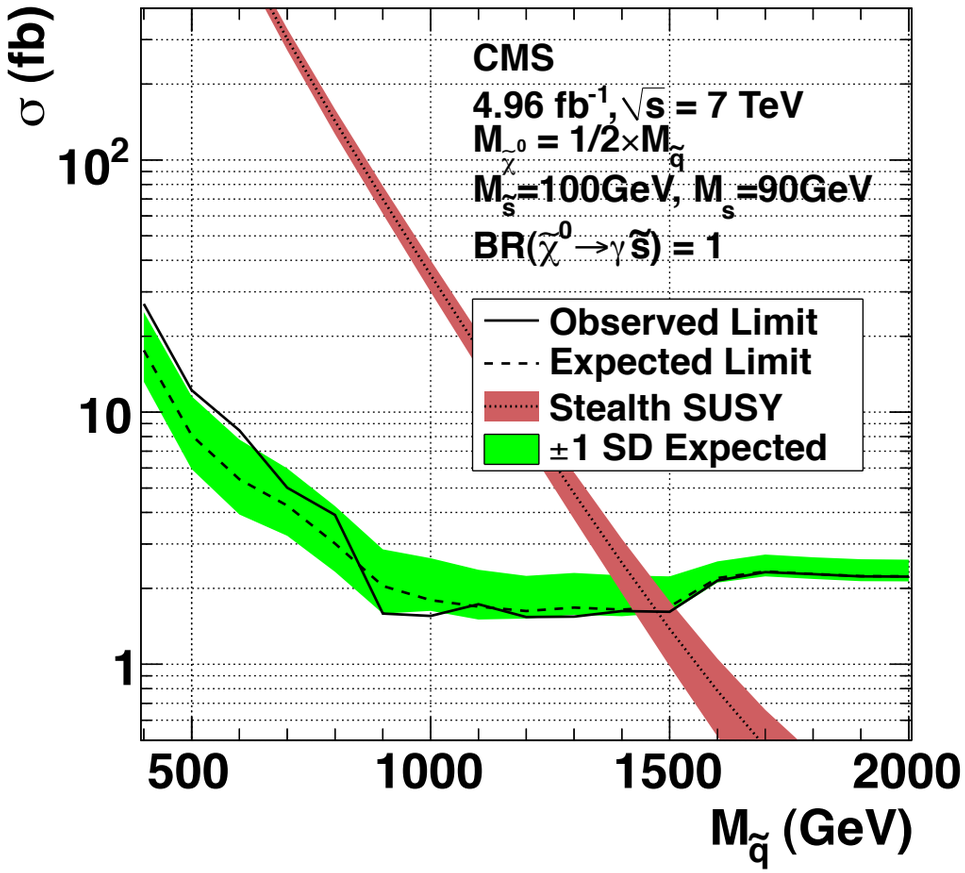
Model-independent limit at the 95% CL on the product of the acceptance and cross section for events with ≥4 jets.



Stealth SUSY cross-section limit at the 95% CL as a function of squark mass, including the predicted NLO + NLL cross section from stealth SUSY.



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Summary

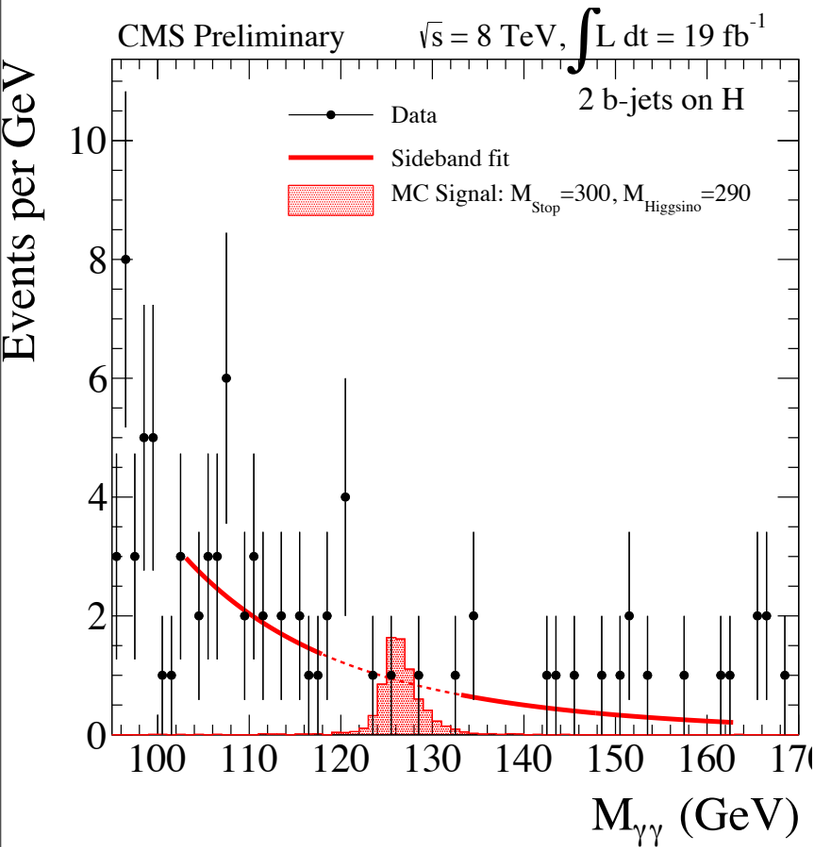
- Photons provide a clean signature for SUSY searches
- CMS has developed analyses to cover a broad range of final states and models
- No excesses are seen over SM expectations
- Exclusion limits have been set in Bino, Wino, and for the first time Higgsino-like NLSP scenarios
  - bino-like: probe up to $m_{\tilde{q}} < 1.2\ \text{TeV}, m_{\tilde{g}} < 1.1\ \text{TeV}$
  - stealth bino-like: probe up to $m_{\tilde{q}} < 1430\ \text{GeV}$
  - wino-like: probe up to $m_{\tilde{q}} < 900\ \text{GeV}, m_{\tilde{g}} < 800\ \text{GeV}$
  - higgsino-like: probe up to $m_{\tilde{t}} < 360\ \text{GeV}$ for all Higgsino masses, as high as $m_{\tilde{t}} < 410\ \text{GeV}$ for some Higgsino masses
- 19.5fb^{-1} bino/wino and more higgsino results coming soon

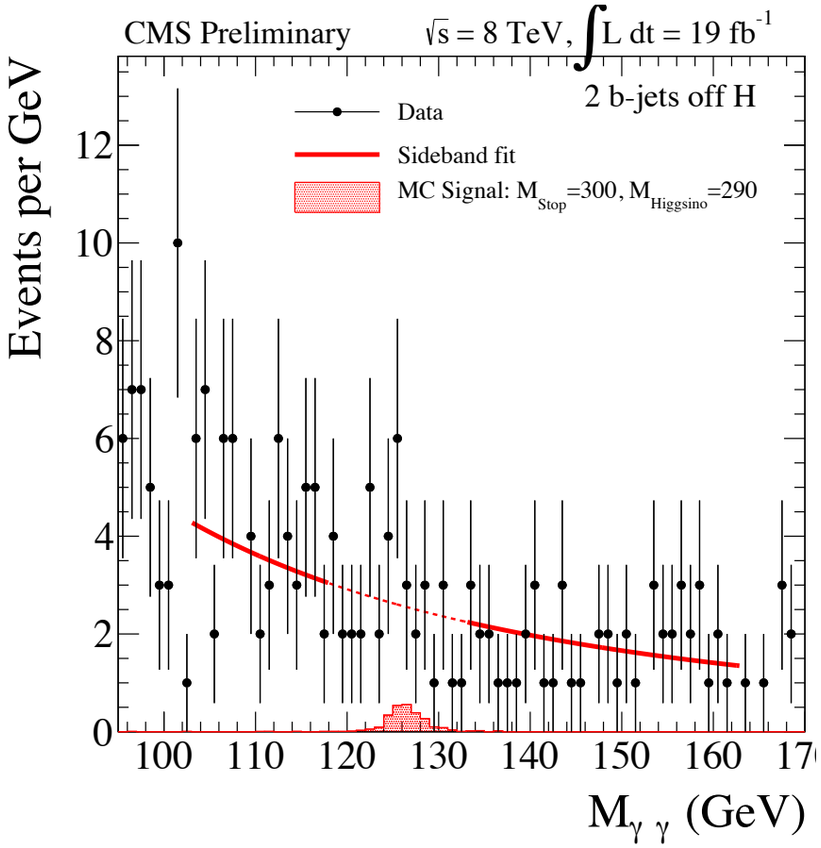
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

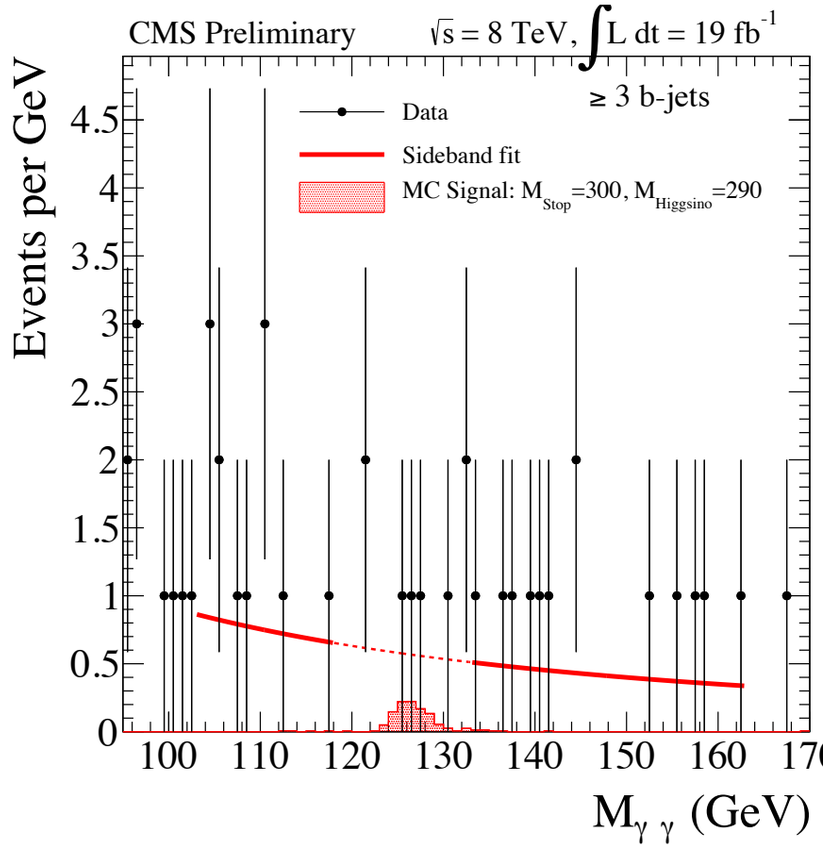
BACKUP

Stop-Higgsino

=2 b-jets $95<m_{bb}<155$	=2 b-jets $m_{bb}<95$ or $m_{bb}>155$	≥3 b-jets







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Stop-Higgsino

=2 b-jets 95<m_{bb}<155	=2 b-jets m_{bb}<95 or m_{bb}>155	≥3 b-jets