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Searches for Supersymmetry at CMS in Final States with Photons

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CMS PAS SUS-12-018

Overview

- Gauge-mediated SUSY Breaking (GMSB)
  - SUSY couples to normal matter through gauge interactions
  - Gravitino: LSP
- General Gauge Mediation (GGM) e.g.: P. Meade, N. Seiberg, D. Shih, arXiv:0801.3278v3
  - neutralino NLSP a mixture of Bino, Wino, and Higgsino
  - photon/Z+Gravitino or W+Gravitino final states
    - one or two photons + MET
  - focus on strong production: many jets

- CMS: Two independent analyses:
  1. Single photon + MET + jets
  2. Di-photon + MET (+ jets)

Updated here with 4fb^{-1} of 8 TeV data from 2012 running

Will also show results from 2011

Public Documents: CMS PAS SUS-12-001, SUS-12-018

GGM Phenomenology at the LHC

Neutralino NLSP mixture of Bino, Wino, and Higgsino, e.g.,

- Bino-like NLSP:

$$\tilde{\chi}_1^0 \to \gamma + G \quad \text{or} \quad \tilde{\chi}_1^0 \to Z^0 + G$$

- Wino-like (co-)NLSP:

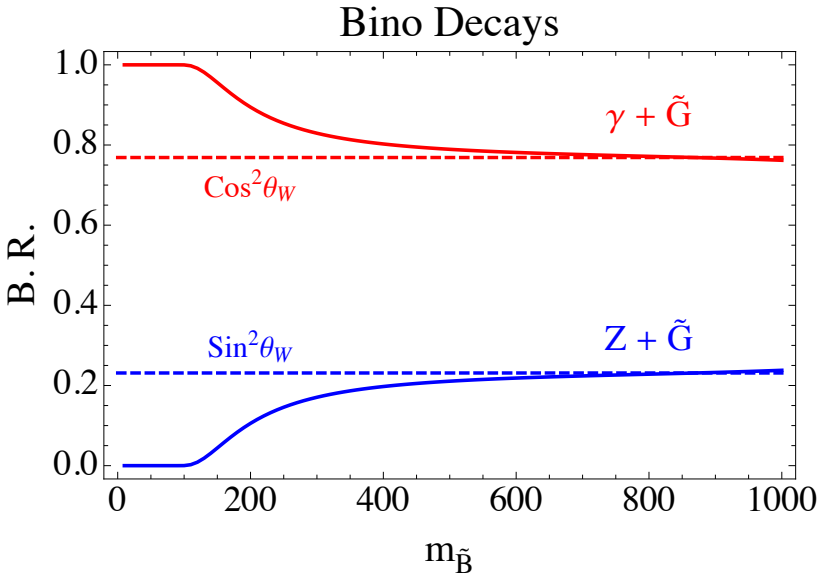
$$\tilde{\chi}_1^0 \to \gamma + G \quad \text{or} \quad \tilde{\chi}_1^0 \to Z^0 + G$$
$$\text{and/or} \quad \tilde{\chi}_1^{\pm} \to W^{\pm} + G$$

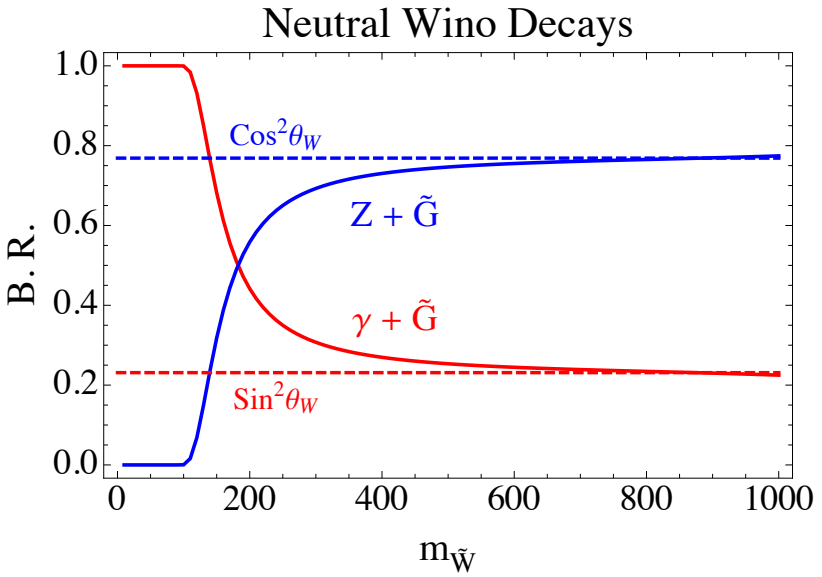
- Bino-Higgsino-like NLSP:

$$\tilde{\chi}_1^0 \to \gamma + G \quad \text{or} \quad \tilde{\chi}_1^0 \to Z^0 + G$$
$$\text{and/or} \quad \tilde{\chi}_1^0 \to h + G$$

- R-parity is conserved:
  - 2 LSPs per event

★ MET is defining signature





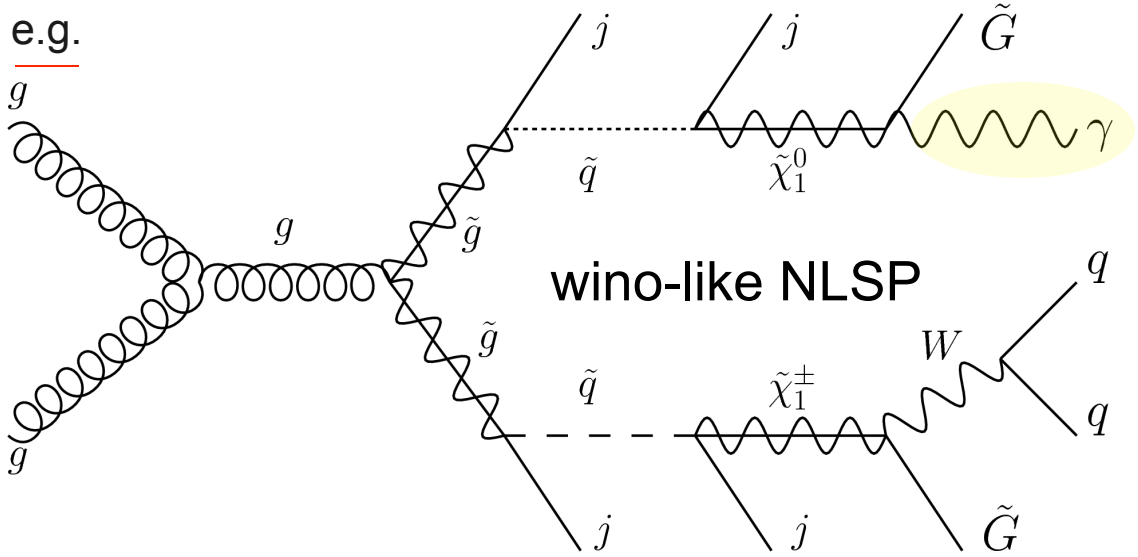
J. Ruderman, D.Shih ArXiv:1103.6083v1

GGM with Photons: Searches at CMS

Final states with at least one photon:

- **γ + Jets + MET**

For the case of bino-higgsino-like NLSP, γ + h(bb) + MET



Photons	Jets*	MET	∫Ldt
=1 E_T > 80 GeV $E_{iso}(0.3)$ < 6 GeV $\|\eta\|$ < 1.442	≥ 2, H_T > 450** GeV p_T > 30 GeV $\|\eta\|$ < 2.6	> 100 GeV	4.0 fb^{-1}

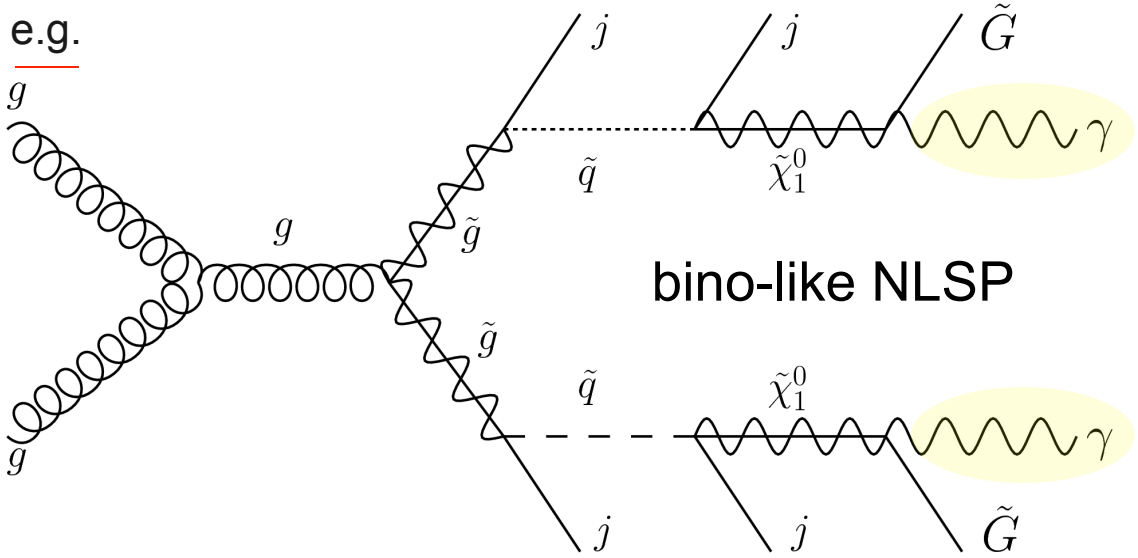
* particle flow jets, anti-kT (R=0.5), photon-rejected

** scalar sum of p_T of all jets with p_T>40 GeV, $|\eta|$ < 3.0, no photon rejection

GGM with Photons: Searches at CMS

Final states with at least one photon:

- γ + Jets + MET
- **γ + γ + Jets + MET**



Photons	Jets*	MET	∫Ldt
=2 E_T > 40, 25 GeV $E_{iso}^{**}(0.3)$ < 6 GeV $\|\eta\|$ < 1.442	≥ 1 p_T > 30 GeV $\|\eta\|$ < 2.6	> 100 GeV	4.0 fb^{-1}

* particle flow jets, anti-kT (R=0.5), photon-rejected

** Isolation variables corrected for pileup effects in all photon selections

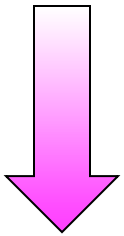
Estimating Standard Model Backgrounds

Analysis	Fake Photons - QCD (jets)	Fake Photons - EWK (electrons)	Irreducible - (photons)
γ + Jets + MET	γ + jet j $\rightarrow \gamma$		
γ + γ + Jets + MET	γ + jet j $\rightarrow \gamma$		

Dominant Background

Sub-dominant Background

Negligible Background

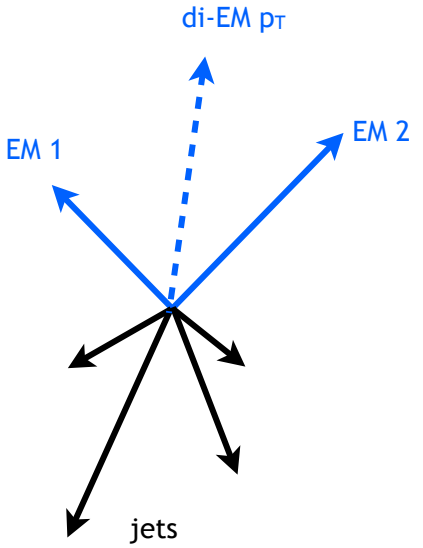


Data-Driven methods

QCD Backgrounds

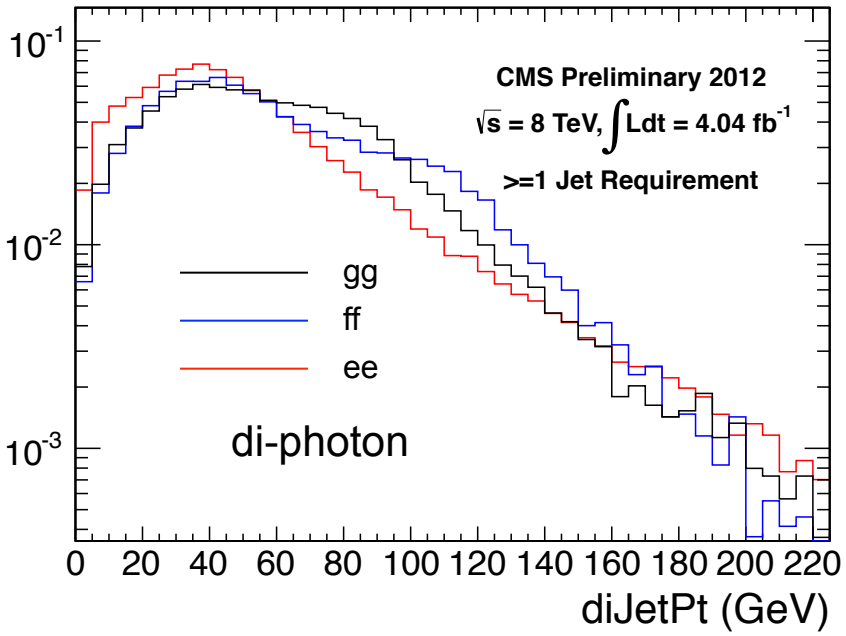
QCD sources: no intrinsic MET

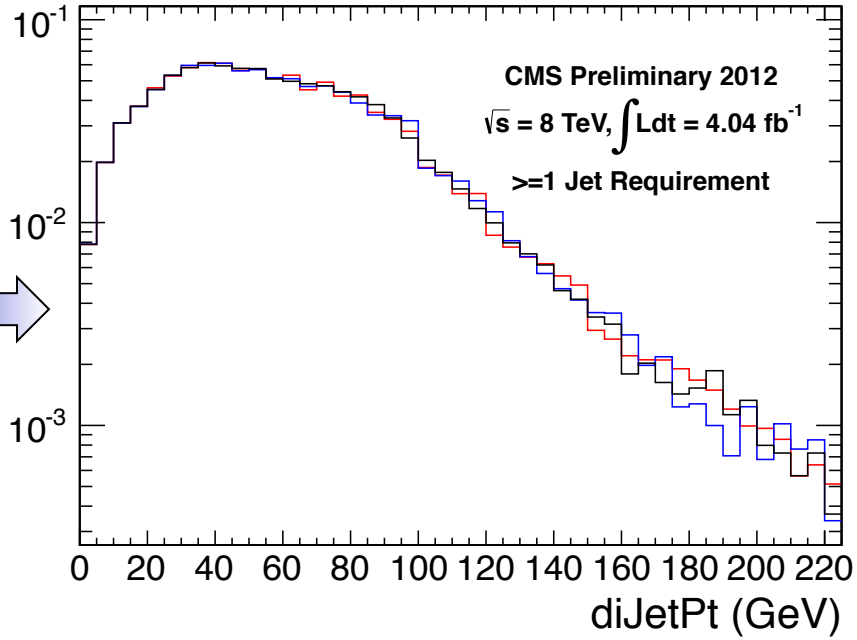
- MET from mis-reconstruction of non-photon event objects
- select QCD-enriched control samples in data
  - "fake" photons that look very similar to final candidates
    - fail "tight" selections, but pass looser criteria:
      - "fake" fails tight isolation or shower shape cuts
      - single photon fake $\gamma \equiv \gamma_{jet}$, di-photon: fake $\gamma \equiv f$
- (di-)photon system is well-measured →
  1. reweight (di-)photon E_T spectrum for control sample to match signal sample
  2. normalize MET spectrum of control distribution to match target "signal" in low MET region
     - single photon: γ_{jet} normalized to γ spectrum for photon MET < 100 GeV
     - di-photon: fake-fake distribution normalized to $\gamma\gamma$ spectrum for MET<20 GeV



QCD Backgrounds

- The resulting MET distribution is taken as the background due to mis-measurement of hadronic energy in QCD events
- systematic errors due to shape estimation, possible signal contamination
- di-photon analysis uses Drell-Yan ee events to estimate an independent shape error





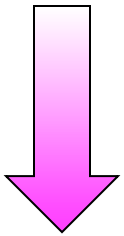
Estimating Standard Model Backgrounds

Analysis	Fake Photons - QCD (jets)	Fake Photons - EWK (electrons)	Irreducible - (photons)
γ + Jets + MET	γ + jet j $\rightarrow \gamma$	W, top (e$\rightarrow\gamma$)	
γ + γ + Jets + MET	γ + jet j $\rightarrow \gamma$	W+γ, W+jet (e$\rightarrow\gamma$, j$\rightarrow\gamma$)	

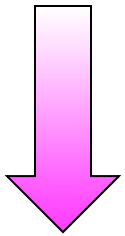
Dominant Background

Sub-dominant Background

Negligible Background



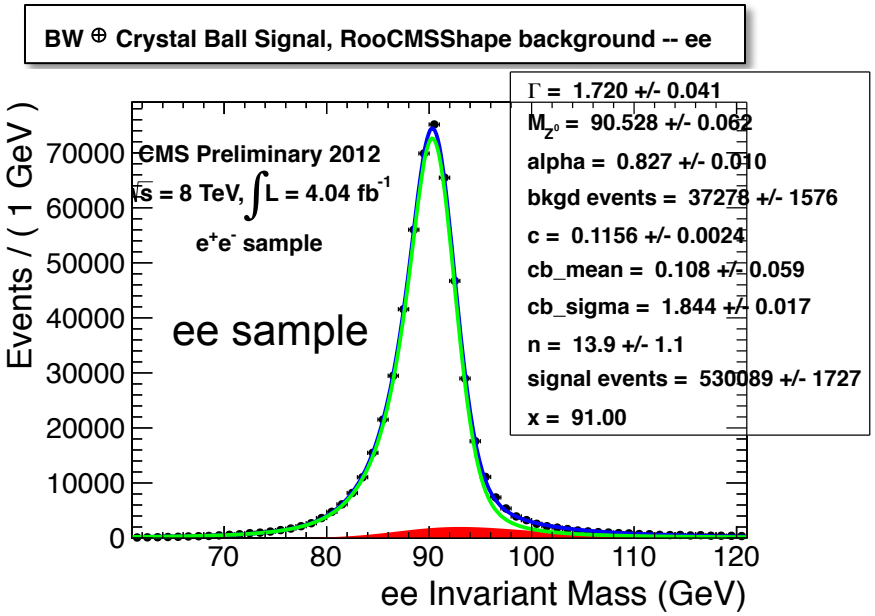
Data-Driven methods

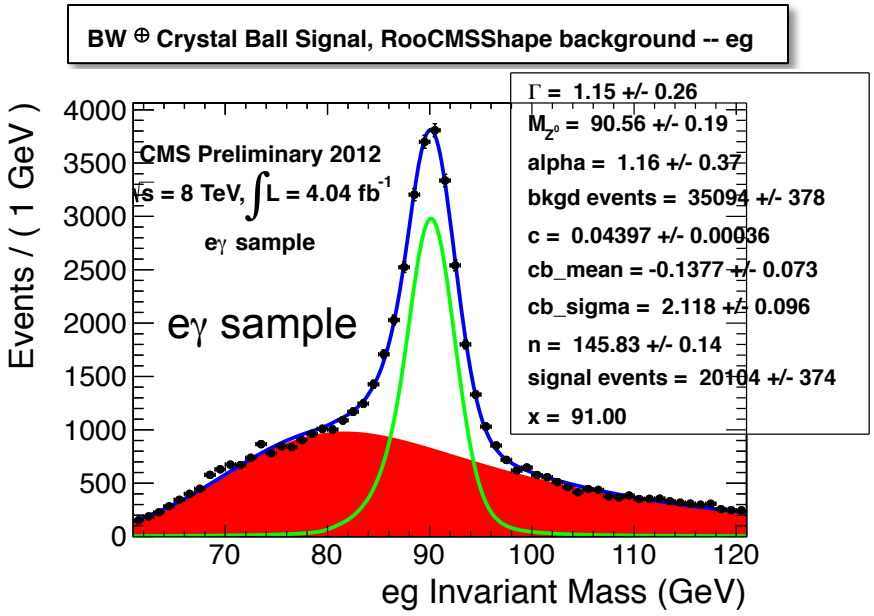


Data-Driven methods

EWK Backgrounds

- Compare Z→ee events to Z→eγ events to obtain e→γ fake rate:





- Ratio of signals used to estimate fake rate $f_{e\to\gamma}$
  - average value: $f_{e\to\gamma}$ = 0.0181 ± 0.0003(stat) ± 0.0009(syst)
  - Single photon analysis uses p_T > 80 GeV:
    - $f_{e\to\gamma}$ = 0.011 ± 0.002(stat) ± 0.001(syst)
- Inclusive electron spectrum scaled by $f_{e\to\gamma}$ to obtain EWK background

Estimating Standard Model Backgrounds

Analysis	Fake Photons - QCD (jets)	Fake Photons - EWK (electrons)	Irreducible - (photons)
γ + Jets + MET	γ + jet j $\rightarrow \gamma$	W, top (e$\rightarrow\gamma$)	ISR/FSR W/Z/top + γ
$\gamma + \gamma$ + Jets + MET	γ + jet j $\rightarrow \gamma$	W+γ, W+jet (e$\rightarrow\gamma$, j$\rightarrow\gamma$)	W/Z + $\gamma\gamma$

MadGraph; 50% uncertainty on Xsec

Dominant Background

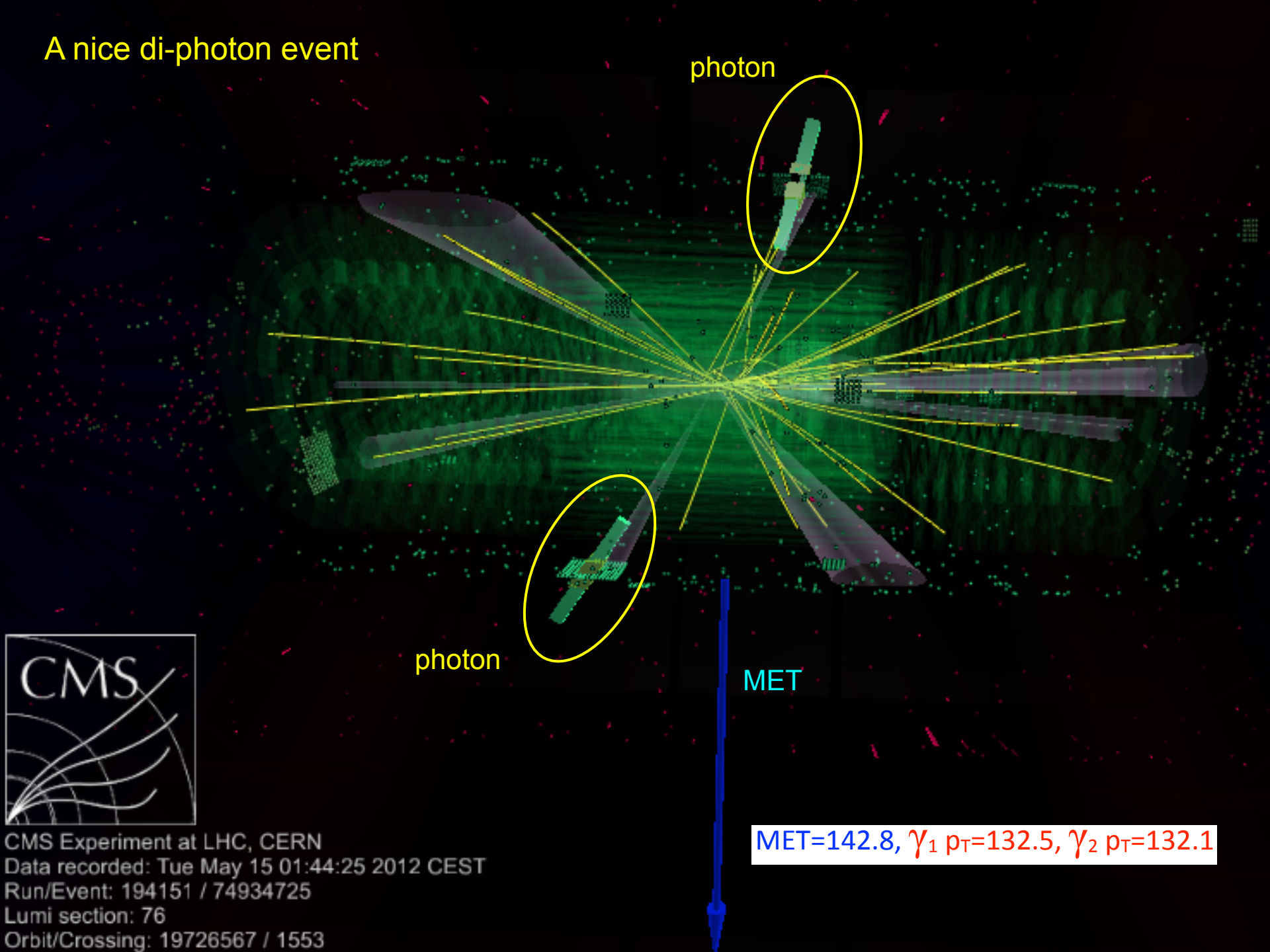
Sub-dominant Background

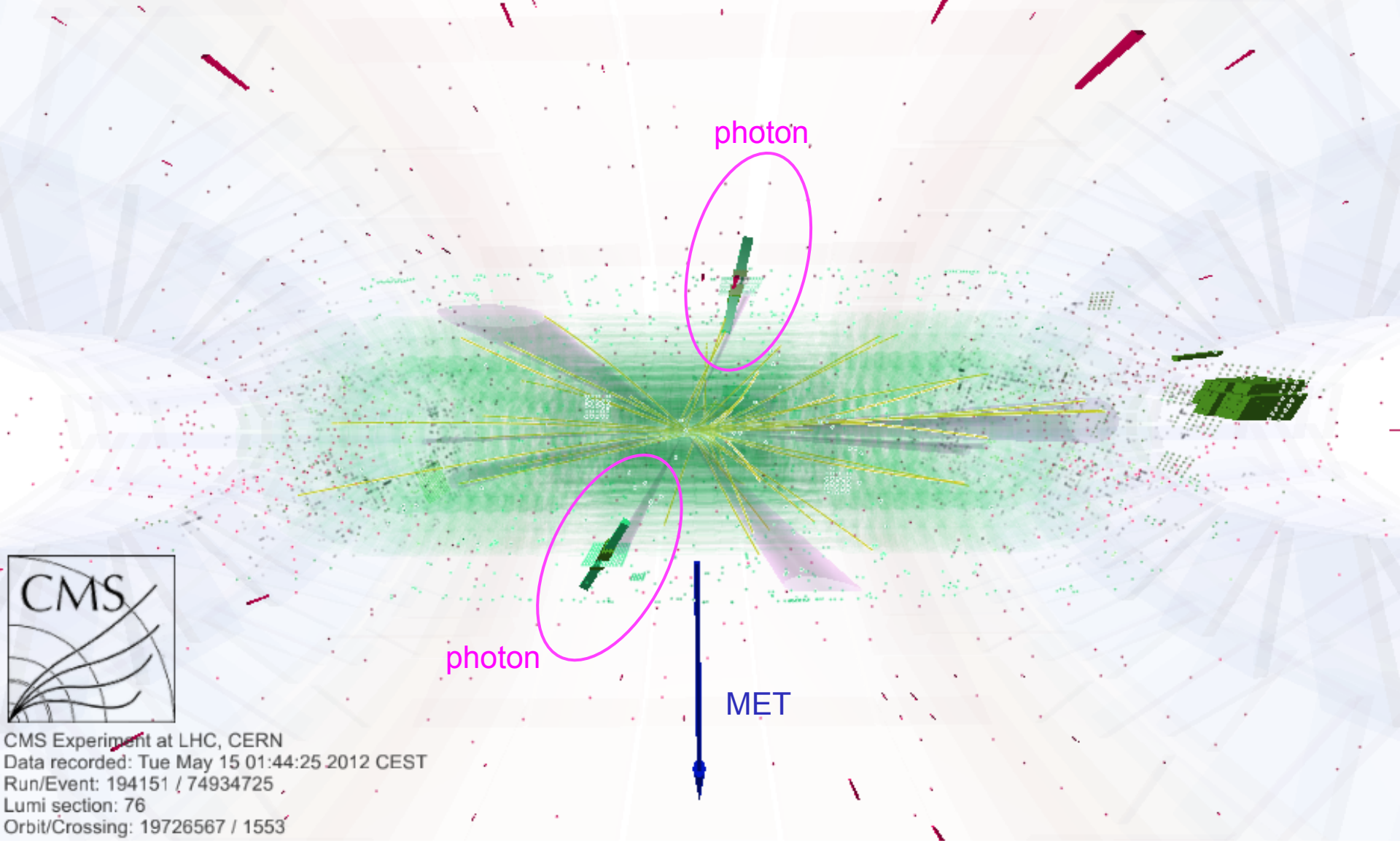
Negligible Background

Data-Driven methods

Data-Driven methods

Simulation

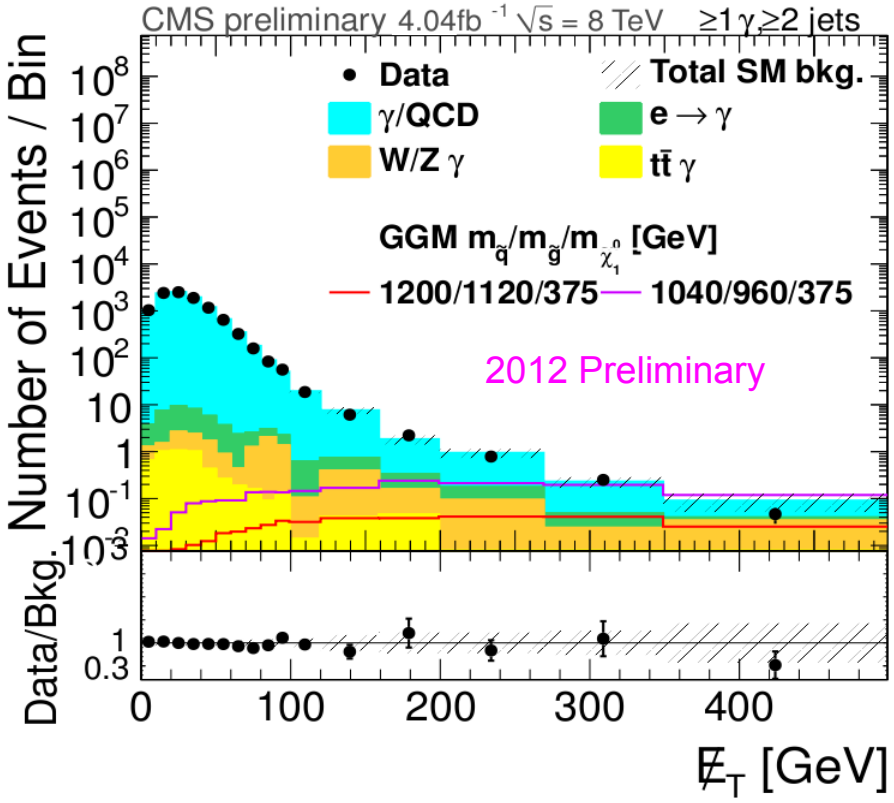

A nice di-photon event
photon
photon
MET
CMS
CMS Experiment at LHC, CERN
Data recorded: Tue May 15 01:44:25 2012 CEST
Run/Event: 194151 / 74934725
Lumi section: 76
Orbit/Crossing: 19726567 / 1553
MET=142.8, γ1 pT=132.5, γ2 pT=132.1



MET=142.8, γ_1 p_T=132.5, γ_2 p_T=132.1

RESULTS & INTERPRETATION

Single Photon MET Spectrum

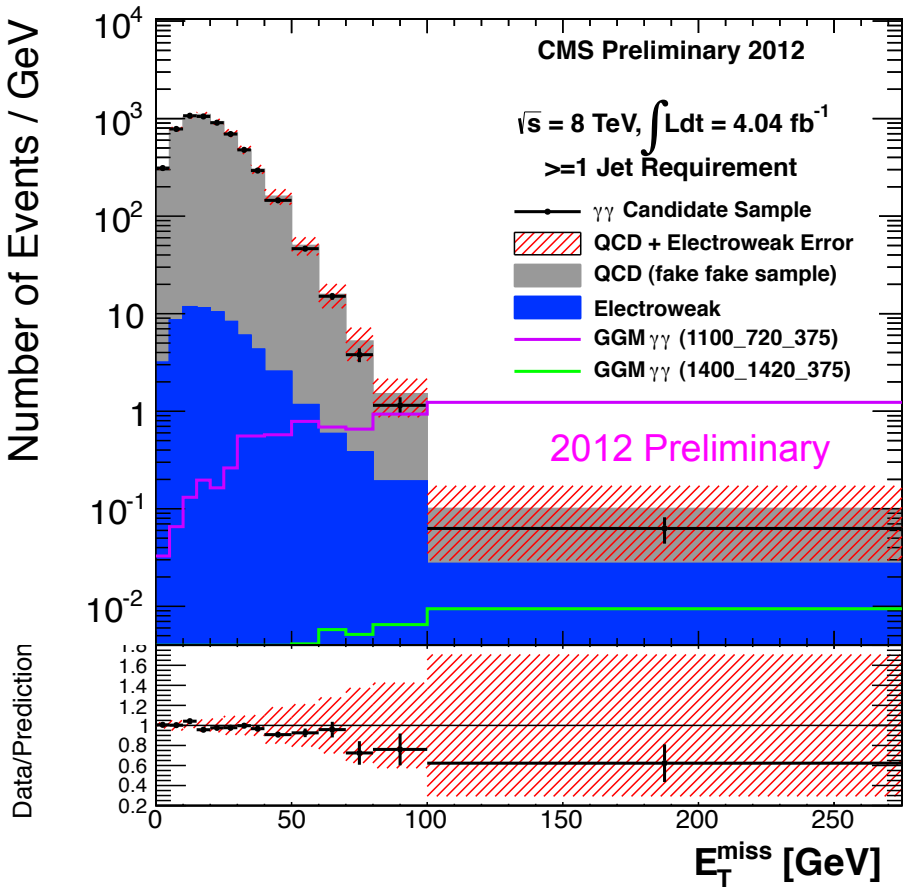


- Integrated Luminosity: 4 fb^{-1} @ 8 TeV
- No excess observed over SM expectations
- Six bins in MET above MET>100 GeV used to set limits
  - lower edges [100,120,160,200, 270, 350]

Data vs. predictions for 3 MET bins:

E_T^{miss} bins [GeV]	[200,270)	[270,350)	[350,∞)
QCD	53.7±14.6	14.5±4.7	8.9±4.3
EWK	5.6±1.6	1.9±0.5	1.0±0.3
ISR/FSR	5.9±3.7	1.7±1.3	4.7±4.7
Background	65.2±15.1	18.2±4.9	14.6±6.4
Data	55	20	8

Di-Photon MET Spectrum



- Integrated Luminosity: 4 fb^{-1} @ 8 TeV
- No excess observed over SM expectations
- Six bins in MET above MET>100 GeV used to set limits
  - lower edges [50, 60, 70, 80, 100]

Data vs. predictions for highest MET bin:

Type	E_T^{miss} >100, ≥1 jet	Stat	Syst
$\gamma\gamma$	11		
QCD background	12.9	3.7	11.9
EWK background	4.6	0.3	0.2
Total background	17.8	3.7	11.9

Limit Calculations

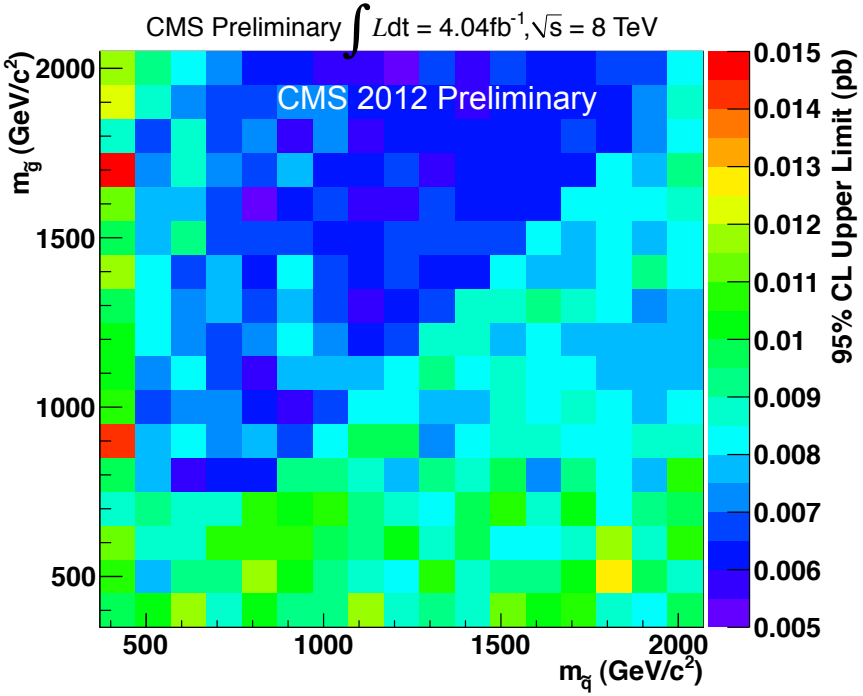
- Systematic Errors
  - Integrated luminosity: 5%
  - cross section uncertainties from PDFs: 4-66%
  - renormalization scale uncertainty from SUSY masses: 4-28%
  - Theory errors: scale and PDF errors are combined at each point and cross section varied by 1σ.
  - single-photon analysis includes an extra 3% trigger efficiency uncert.
- Limit Calculation:
  - CL_S method with likelihood-ratio test statistics at 95%
  - full propagation of errors
  - GGM Signal Monte Carlo (grid scan)
    - Prospino used for NLO cross-sections

Interpretation: Bino-like NLSP

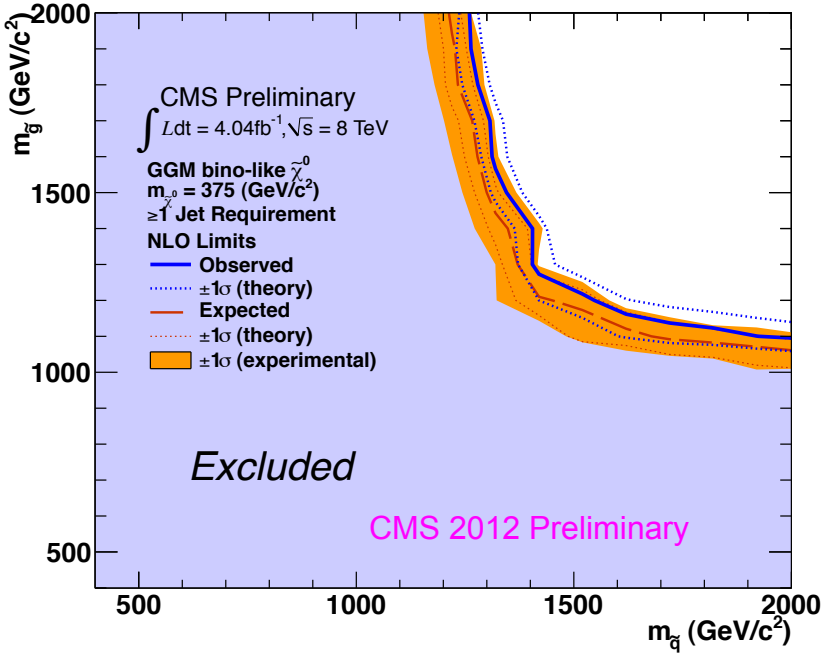
"Bino like" GGM scan: $m_{\chi 0}$=375 GeV, $m_{squark,gluino}$=400...2000 GeV, steps 80 GeV, ~ 10000 Events/point

- Sleptons and all gauginos except NLSP: 3.5 TeV, heavy right handed squarks

$\gamma\gamma$ + MET + ≥1 jet



$\gamma\gamma$ + MET + ≥1 jet

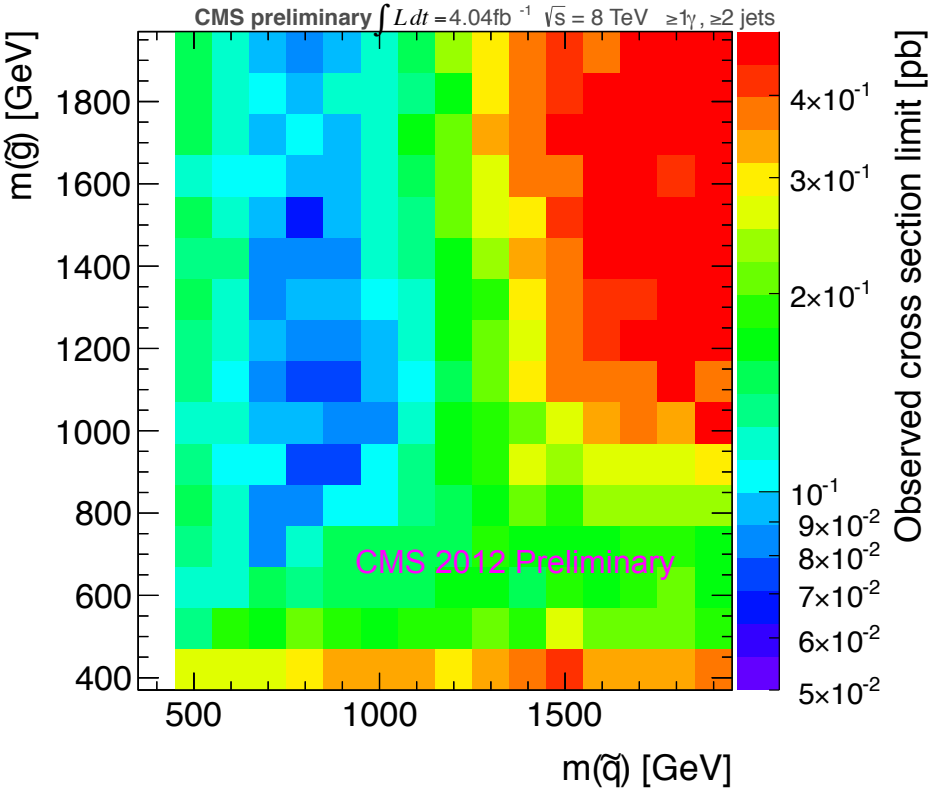


Interpretation: Wino-like NLSP

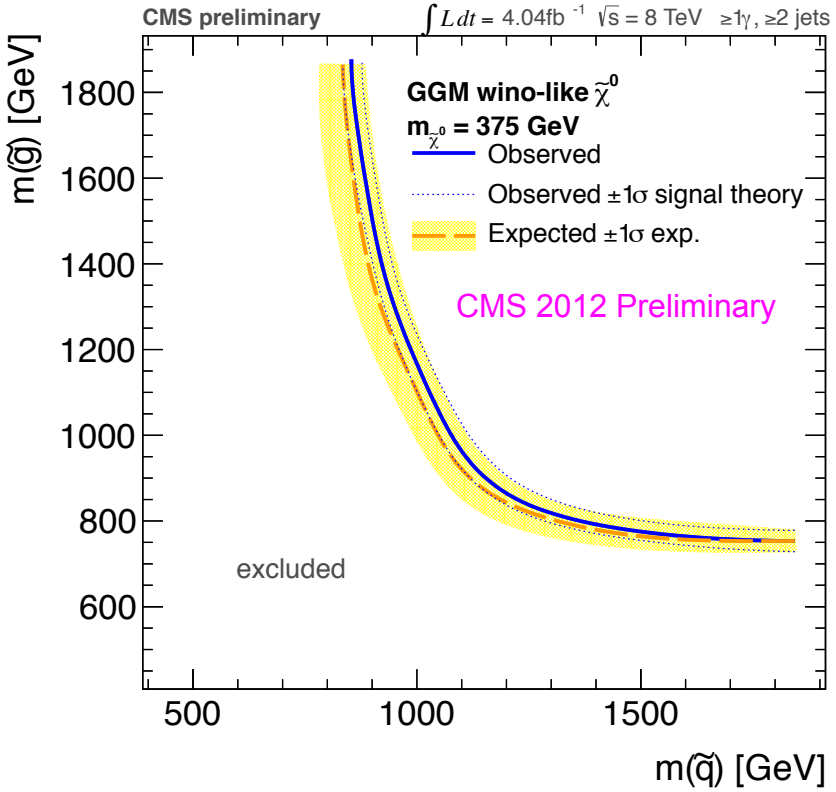
"Wino like" GGM scan: Sleptons & gauginos (except NLSP):3.5 TeV

- heavy right handed squarks
- NLSP mass = 375 GeV

γ + MET + ≥2 jets

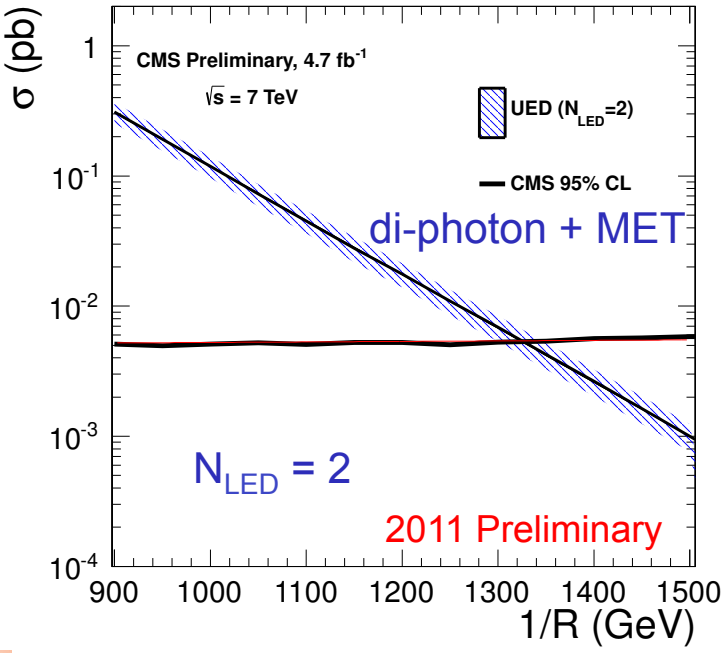


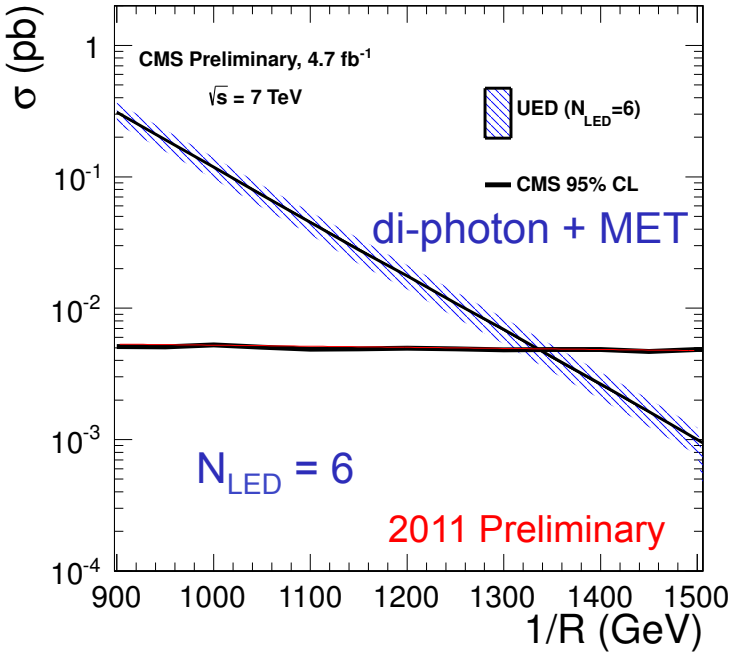
γ + MET + ≥2 jets



Interpretation: Extra Dimensions

- MET + photon(s) signature can also result from the production of KK-towers of quarks or gluons
  - lightest KK tower (LKP) decays gravitationally, resulting in final states with a photon and a Gravitino
- UED model: embedded in N extra dimensions with $R\Lambda = 20$, gravitational decay widths are set by N and M_D ($M_D = 5$ TeV)





Summary

- Final states with large missing energy and photons expected in SUSY GMSB scenarios
  - Branching ratios to photons depend on NLSP admixture
- CMS analyses designed to cover a broad range of final states
  - γ + Jets + MET
  - $\gamma\gamma$ + Jets + MET

  Updated here with 4fb^{-1} of 8 TeV data from 2012 running
  - Data-driven background estimates for QCD/EWK sources
  - no excesses seen over SM predictions
- Exclusion limits set in bino- and wino-like neutralino NLSP:
  - bino-like: $m_{squark} < 1.2$ TeV, $m_{gluino} < 1.1$ TeV excluded
  - wino-like: $m_{squark} < 900$ GeV, $m_{gluino} < 800$ GeV excluded
- UED interpretation: 1/R < 1300 TeV excluded
- Coming soon:
  - limits for EW production
  - Simplified models: T1gg and T1lg

Additional Slides

Additional References

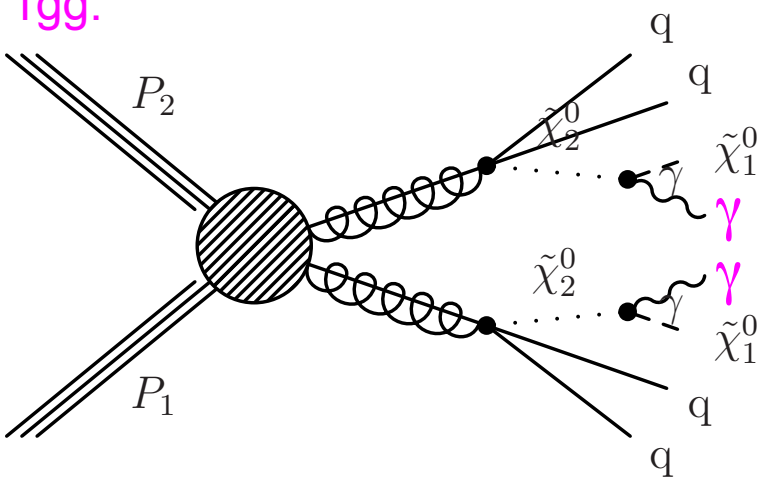
- Gauge Mediation, review and history:
  - G. F. Giudice and R. Rattazzi, Phys. Rept. **322**, 419 (1999)
  - P. Fayet, Phys. Lett. **B70** (1977) 461
  - H. Baer, M. Brhlik, C. H. Chen et al., Phys. Rev. **D55** (1997) 4463
  - S. Dimopoulos, S. Thomas, and J. D. Wells, Nucl. Phys. **B488** (1997) 39
  - J. R. Ellis, J. L. Lopez, and D. V. Nanopoulos, Phys. Lett. **B394** (1997) 354
- Direct Mediation:
  - I. Affleck, M. Dine and N. Seiberg, Nucl. Phys. **B 256**, 557 (1985)
- Weakly-coupled MSSM-charged messenger fields plus SUSY-breaking spurions:
  - e.g., M. Dine, A. E. Nelson, Y. Nir and Y. Shirman, Phys. Rev. **D 53**, 2658 (1996)
- Weakly-coupled SUSY-breaking fields with global symmetry:
  - e.g., K. I. Izawa, Y. Nomura, K. Tobe and T. Yanagida, Phys. Rev. **D 56**, 2886 (1997)
- Other formulations of General Gauge Mediation:
  - A. G. Cohen, T. S. Roy and M. Schmaltz, **JHEP** 0702, 027 (2007)

Interpretation: Simplified Models

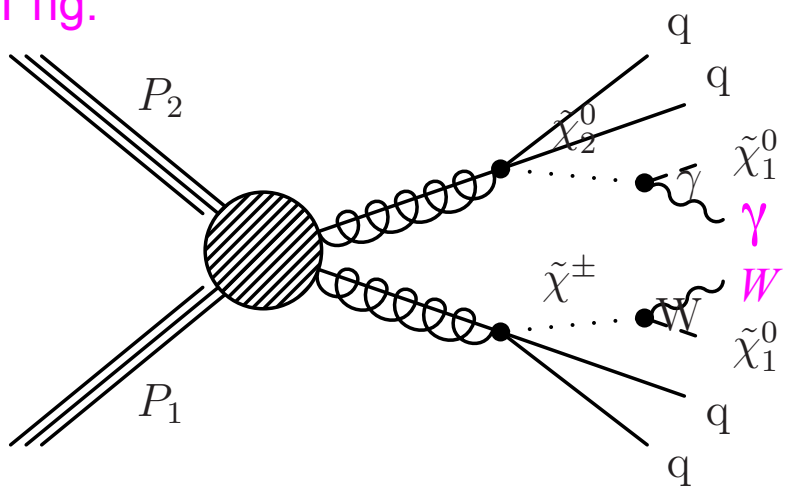
These analyses can be applied to two related simplified models

- Pair production of gluinos, decay to jets and $\chi^{\pm}$ or χ^{0}
  - T1gg: both gluinos decay to jets + χ^{0}, $\chi^{0} \rightarrow G\gamma$
    - Both single and di-photon analyses sensitive
  - T1lg: one gluino decays to $\chi^{\pm}$, $\chi^{\pm} \rightarrow$ W+X, W $\rightarrow$ jets
    - Single photon analysis only

T1gg:



T1lg:



Object Definitions

- In general, all objects are Particle Flow objects (except photons)
- Jets are corrected for
- MET is corrected for Jet Energy Scale
- Photon ID: (optimized for photons in jetty environment)
  - CombIso (Ecal + Hcal + Track) < 6 GeV
  - shower shape:
    - $\sigma_{i\eta i\eta}$ < 0.011
    - H/EM < 0.05
    - R9 (E_{center}/E_{3x3}) < 1.0
  - No PixelSeed (track) in road between EM cluster and IP
    - Electrons: require pixel seed

Fake Photon Objects:

Same as photon, but

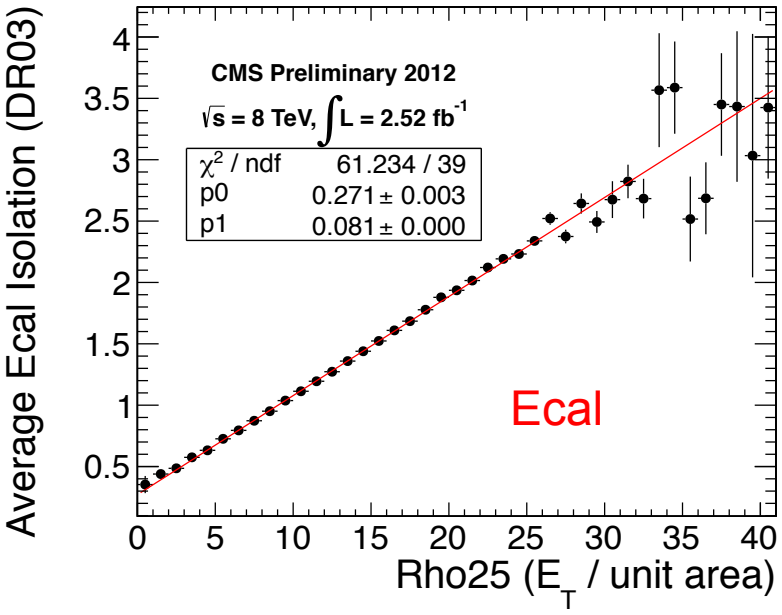
CombIso < min(30,0.3*p_T)

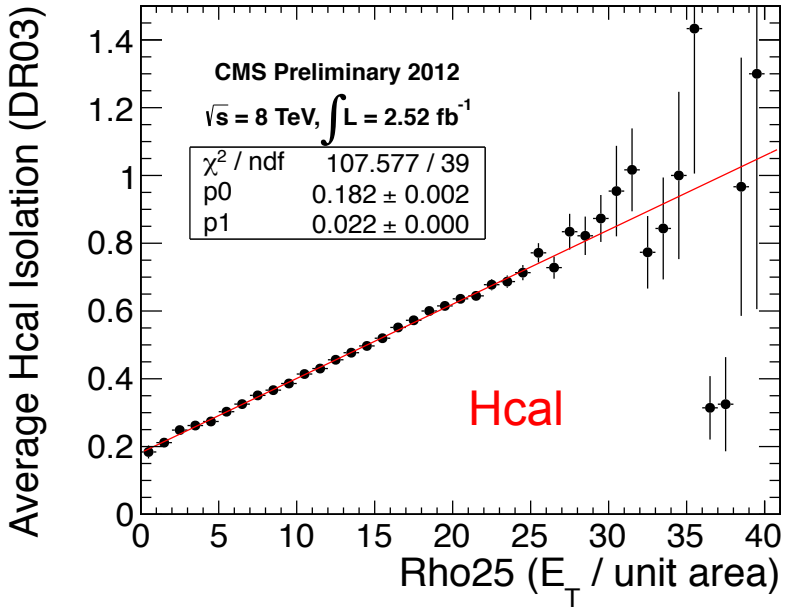
(CombIso > 6) || ($\sigma_{i\eta i\eta}$ > 0.011)

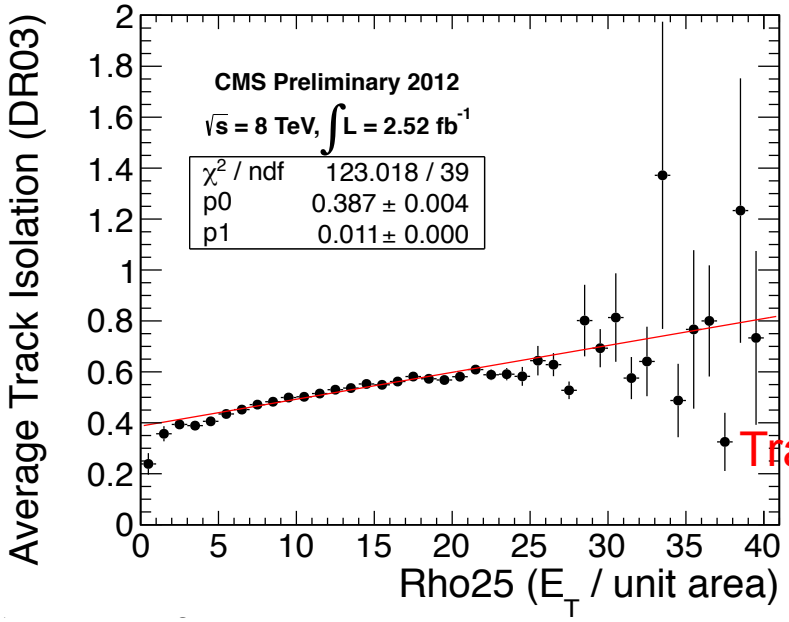
Di-Photon Analysis: Triggers

- Higgs→γγ triggers:
  - HLT_Photon36_CaloId10_Iso50_Photon22_CaloId10_Iso50 (*Signal*)
  - HLT_Photon36_CaloId10_Iso50_Photon22_R9Id85
  - HLT_Photon36_R9Id85_Photon22_CaloId10_Iso50
  - HLT_Photon36_R9Id85_Photon22_R9Id85
  - Where:
    - CaloId10: h/e<0.1 && $\sigma_{i\eta i\eta}$<0.014
    - R9Id85: R9 > 0.85
    - Iso50:
      - EcalIsoDR03 <5.0+Et*0.012
      - HcalIsoDR03 <5.0+Et*0.005
      - TrackIsoDR03<5.0+Et*0.002

Pileup Corrections: Calo Isolation







$$Iso_{X,\text{compensated}} = Iso_X - \rho * A_{Eff,X}$$

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Single-photon high-MET event