# SUSY searches with Photons at CMS

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On behalf of the CMS collaboration

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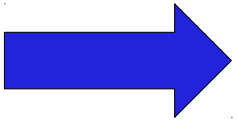
# Motivation & Outline

- Gauge mediated SUSY breaking (GMSB)
  - Messenger fields couple to sparticles through gauge interaction
  - Very light **Gravitino: LSP**
- General gauge mediation (GGM) P. Meade, N. Seiberg, D. Shih, arXiv:0801.3278v3
  - Neutralino **NLSP** mixture of **Bino**, Wino, Higgsino



Signatures with **photons + MET**

- Experimental results (CMS):
  - $\gamma$ + jets + **MET**
  - $\gamma + \gamma$ + **MET**

  } 1.14/fb

  - $\gamma$ + lepton + **MET** 35/pb

# GGM phenomenology at the LHC

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

- Bino-like NLSP

  $\chi_1^0 \to \gamma + G$ or $\chi_1^0 \to Z^0 + G$

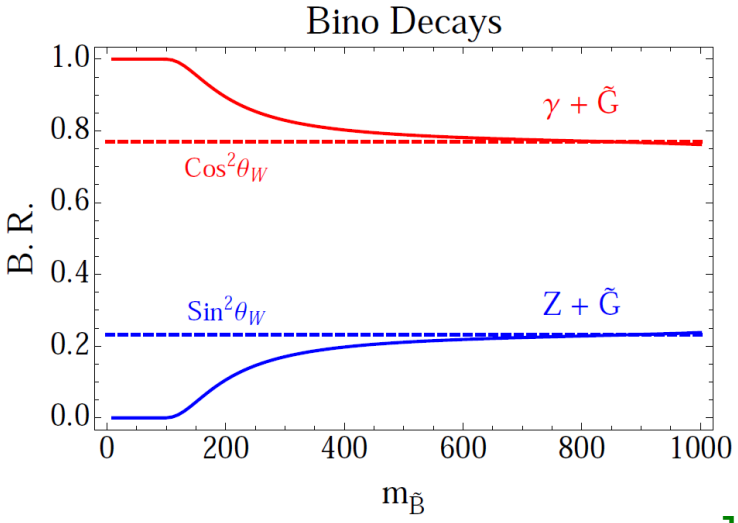
- Wino-like (co-)NLSP:

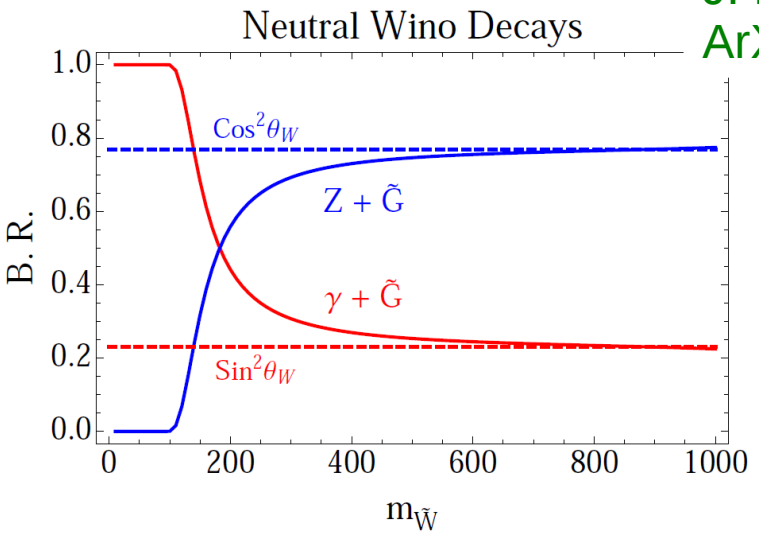
  $\chi_1^0 \to \gamma + G$ or $\chi_1^0 \to Z^0 + G$
  or $\chi_1^{\mp} \to W^{\mp}$+Gravitino

- Bino-Higgsino-like NLSP

  $\chi_1^0 \to \gamma + G$ or $\chi_1^0 \to Z^0 + G$
  or $\chi_1^0 \to h + G$

- R-parity conserved:
  two NLSP's per event




J. Ruderman, D.Shih
ArXiv:1103.6083v1

# Searches at CMS

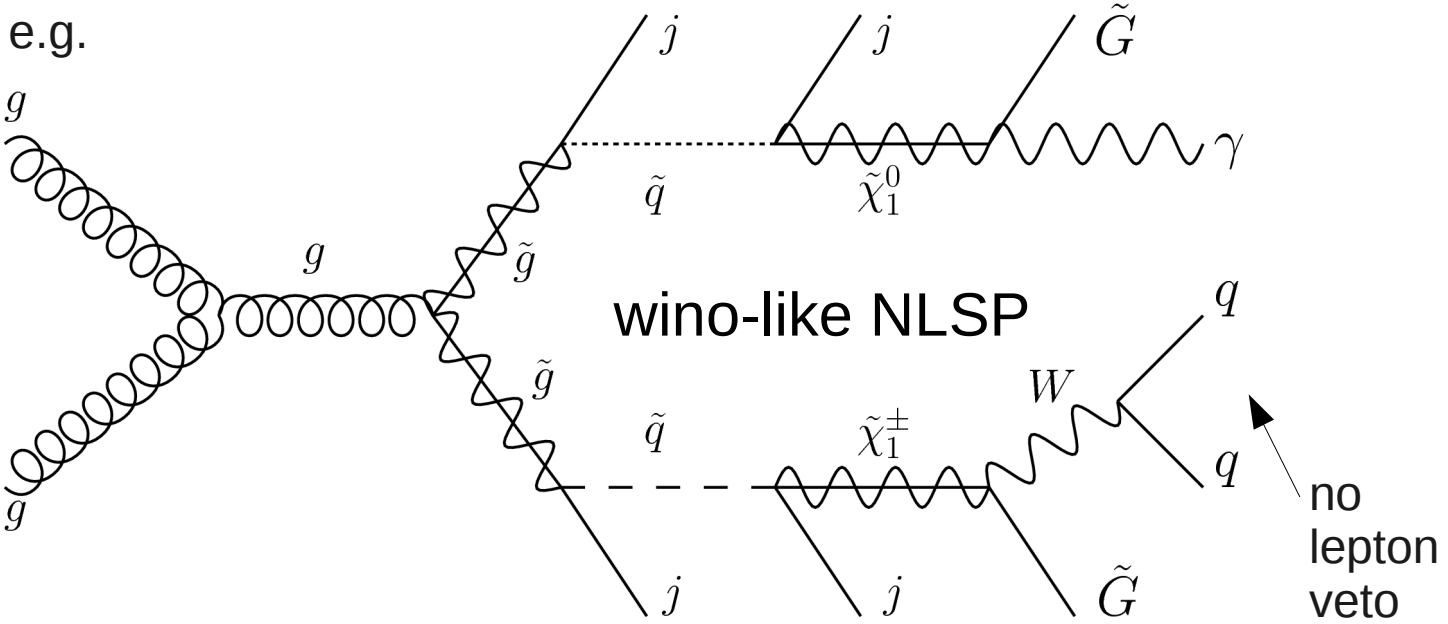
GGM final states with at least one photon:

# Searches at CMS

GGM final states with <u>at least one photon</u>:

- **γ + jets +MET**

  In case of bino-higgsino-like NLSP: γ + h(bb) +MET




<u>Analysis at CMS:</u> CMS PAS SUS-11-009

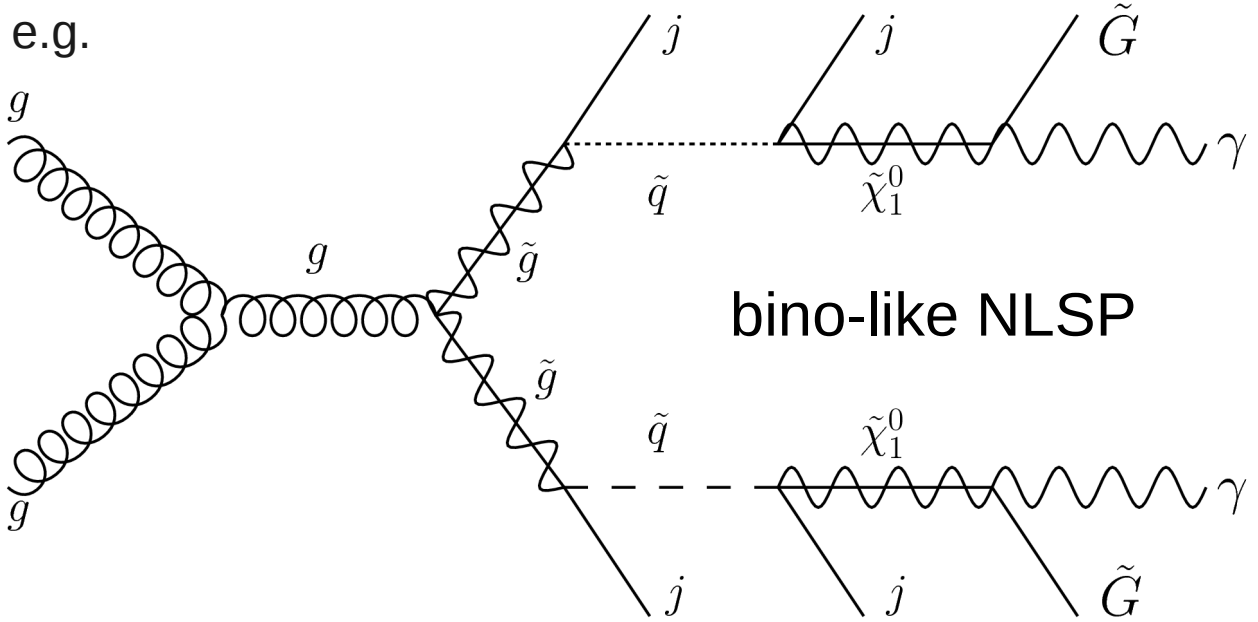
| photons | leptons | jets | MET | Lumi [fb$^{-1}$] |
|---|---|---|---|---|
| =1, $E_T$>75 GeV $\|\eta\|$<1.44 | | ≥ 3*, HT*>400 GeV $E_T$ > 30 GeV $\|\eta\|$<2.6 | > 200 GeV | 1.14 |

*scalar $p_T$ sum of jets (calorimeter jets, $p_T$>40 GeV, $|\eta|$<3.0, no rejection of photons)
*particle flow jets, anti $k_T$ (R=0.5), photon rejected)

# Searches at CMS

GGM final states with <u>at least one photon</u>:

- $\gamma$ + jets +MET
- **$\gamma$ + $\gamma$ + MET**



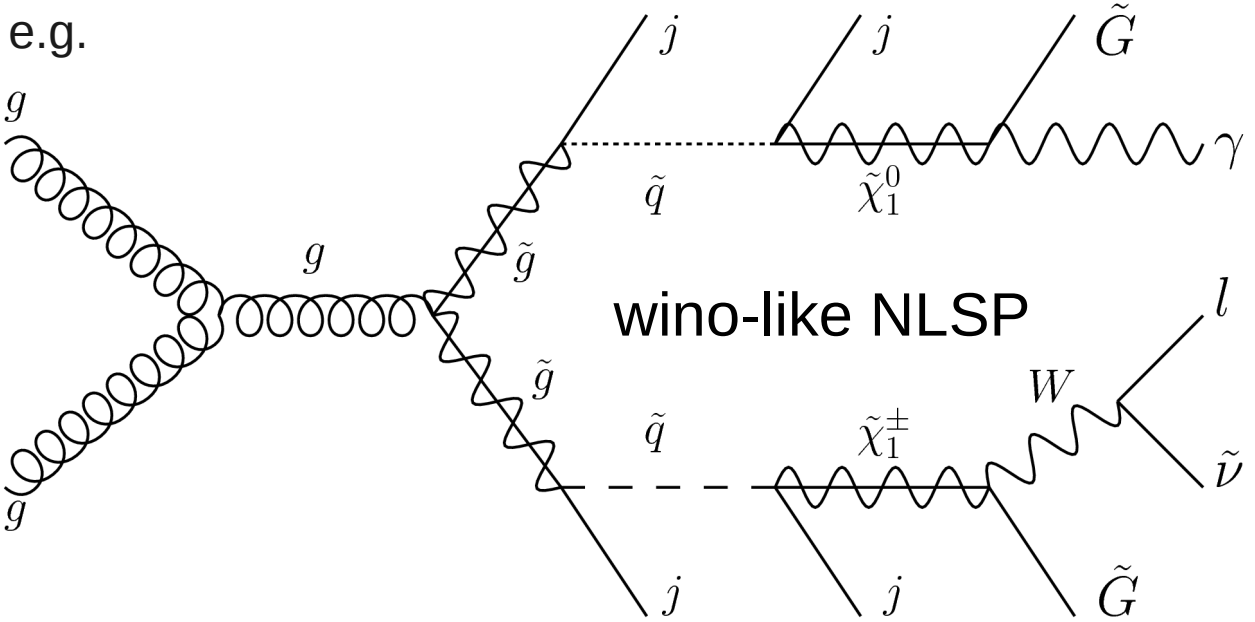

<u>Analysis at CMS:</u> CMS PAS SUS-11-009

| photons | leptons | jets | MET | Lumi [fb$^{-1}$] |
|---|---|---|---|---|
| ≥2,<br>$E_T$>45,30 GeV<br>\|η\|<1.44 | | ≥ 1<br>$E_T$ > 30 GeV<br>\|η\|<2.6 | > 100 GeV | 1.14 |

# Searches at CMS

GGM final states with <u>at least one photon</u>:

- γ + jets +MET
- γ + γ + MET
- **γ + l +MET**




<u>Analysis at CMS:</u> JHEP 1106:093 (2011)

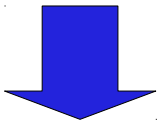
| photons | leptons | jets | MET | Lumi [fb$^{-1}$] |
|---|---|---|---|---|
| ≥1,<br>$E_T$>30 GeV<br>\|η\|<1.44 | ≥ 1<br>$E_T$ > 20 GeV<br>\|η\|<2.1 | | > 100 GeV | 0.36 |

Estimation of Standard Model backgrounds

# SM backgrounds

| Analysis | Fake photons - QCD (jets) | Fake photons - EWK (electrons) | Irreducible (photons) |
|---|---|---|---|
| $\gamma$ + jets +MET | $\gamma$ +jet<br>j$\rightarrow\gamma$ | | |
| $\gamma$ + $\gamma$ +MET | $\gamma$ +jet<br>j$\rightarrow\gamma$ | | |
| $\gamma$ + l +MET | j$\rightarrow$lepton | | |

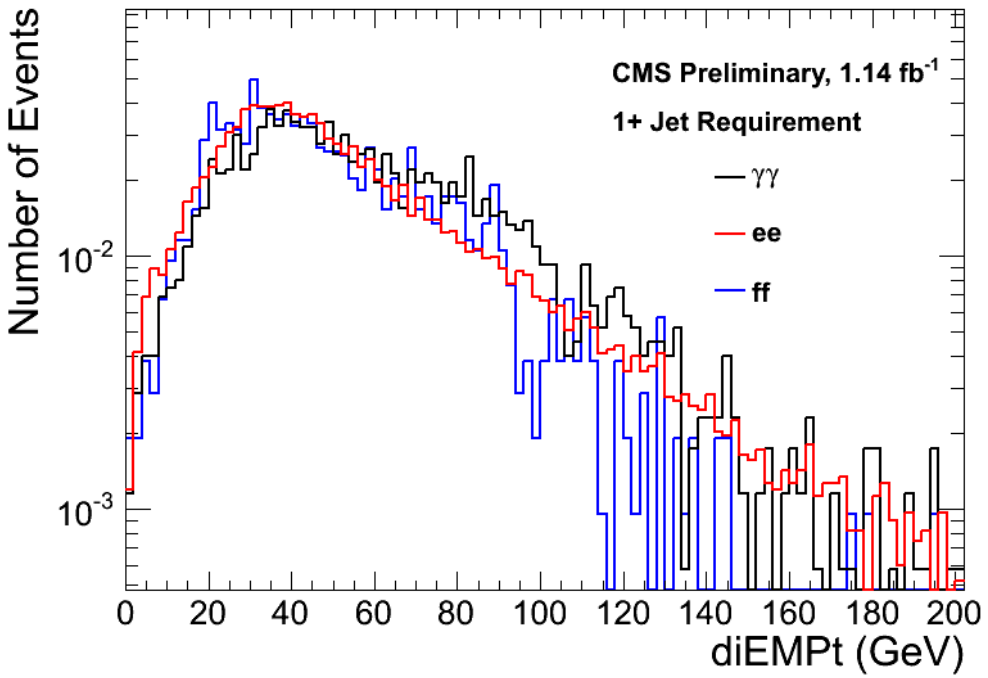
main background
subdominant
negligible



data driven
estimates

# QCD background

- Mostly no intrinsic MET → MET due to jet mismeasurement
  1) Select control sample(s) in data: electrons or 'fake' leptons/photons
     - similar selection, but e.g. looser isolation
  2) Reweight control sample to match $p_T$ distribution of candidate sample
  3) Normalize distributions in low MET region (no signal contribution expected)




- $\gamma\gamma$ +jet+MET:
  - Control sample
    - Di-electron & di-fake
  - normalized MET<20 GeV

# SM backgrounds

| Analysis | Fake photons - QCD (jets) | Fake photons - EWK (electrons) | Irreducible (photons) |
|---|---|---|---|
| $\gamma$ + jets +MET | $\gamma$ +jet<br>j$\rightarrow\gamma$ | W, top (e$\rightarrow\gamma$) | |
| $\gamma$ + $\gamma$ +MET | $\gamma$ +jet<br>j$\rightarrow\gamma$ | W+$\gamma$, W+jet<br>(e$\rightarrow\gamma$,j$\rightarrow\gamma$) | |
| $\gamma$ + l +MET | j$\rightarrow$lepton | DY,WW, top<br>(e$\rightarrow\gamma$)<br>W+jet (j$\rightarrow\gamma$) | |

main background
subdominant
negligible

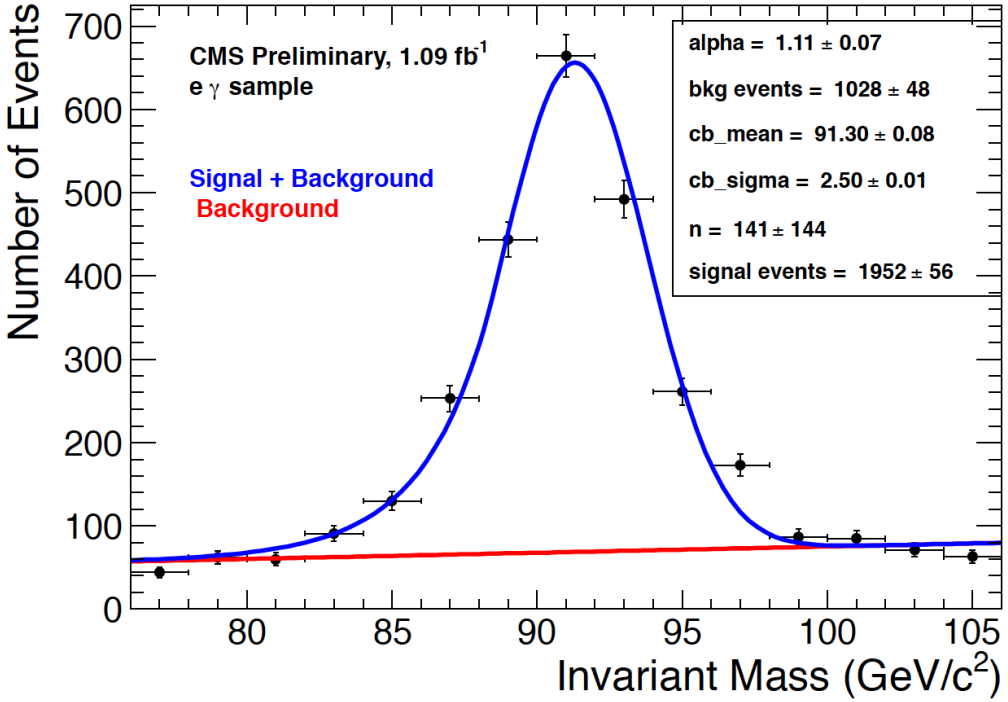
data driven estimates

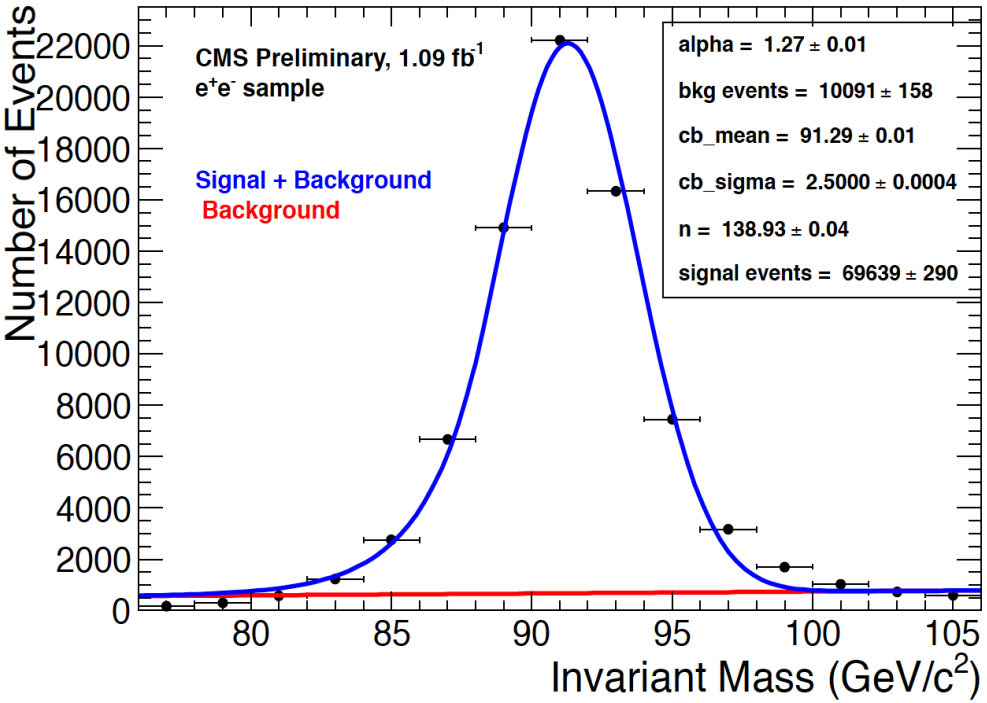
data driven estimates

# EWK background

- Use Z→ee events (ratio ee/ey) to derive fake rate

Used by all presented analyses




Fakerate $f_{e->y}$ =0.014 +/- 0.002 +/- 0.0004

Estimate EWK background with electron sample measured in data: Reweight with $f_{e->y}$

# SM backgrounds

| Analysis | Fake photons - QCD (jets) | Fake photons - EWK (electrons) | Irreducible (photons) |
|---|---|---|---|
| γ + jets + MET | γ +jet<br>j→γ | W, top (e→γ) | W/Z/top+γ<br>MadGraph<br>100% uncertainty |
| γ + γ +MET | γ +jet<br>j→γ | W+γ, W+jet<br>(e→γ,j→γ) | W/Z+γγ |
| γ + l +MET | j→lepton | DY,WW, top<br>(e→γ)<br>W+jet (j→γ) | W+γ<br>top+γ<br>MadGraph tune D6T,<br>BAUR NLO,<br>k-factor ~2-3 |

main background
subdominant
negligible

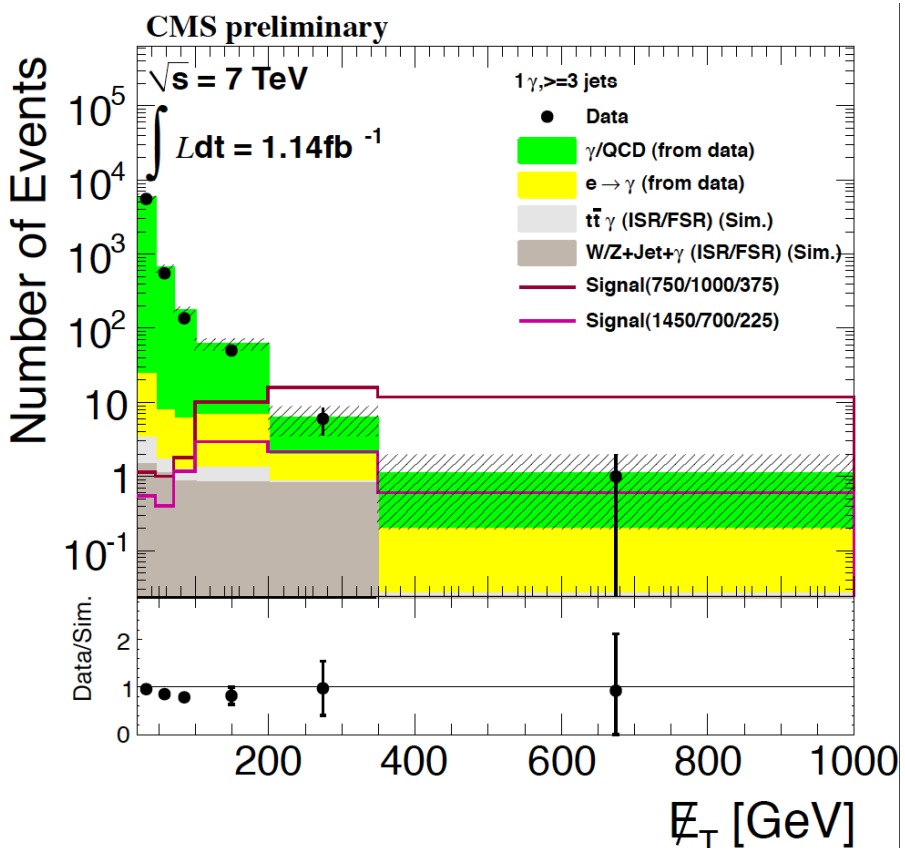
data driven estimates

data driven estimates

Simulation

# Results & Interpretation

# Candidate MET distribution



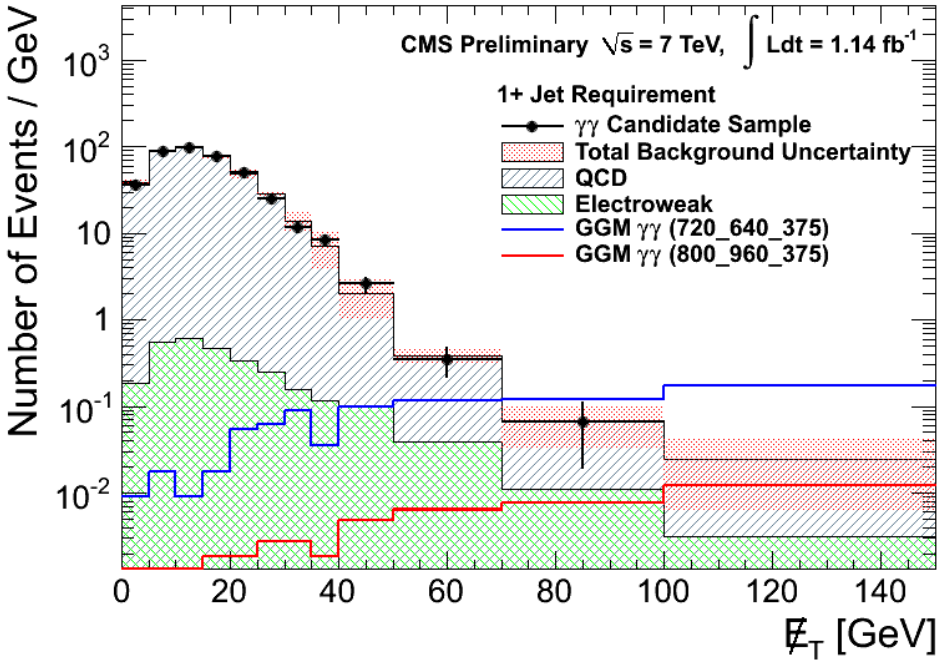

## $\gamma$ +jet+MET, 1.1/fb

No excess over
SM expectation observed

Signal region: MET>200 GeV

| Sample | Event yield | (stat.) | (syst.) |
|---|---|---|---|
| Data | 7 | | |
| QCD (est. from data) | 5.16 | $\pm$2.58 | $\pm$0.62 |
| EWK $e \to \gamma$ (est. from data) | 1.22 | $\pm$0.13 | $\pm$0.04 |
| FSR/ISR ($W \to \mu/\tau\nu, Z \to \nu\nu$) (Sim.) | 0.80 | $\pm$0.31 | $\pm$0.80 |
| FSR/ISR ($t\bar{t} \to \mu/\tau\nu + X$) (Sim.) | 0.07 | $\pm$0.05 | $\pm$0.07 |
| Total SM background estimate | 7.24 | $\pm$2.6 | $\pm$1.53 |

# Candidate MET distribution



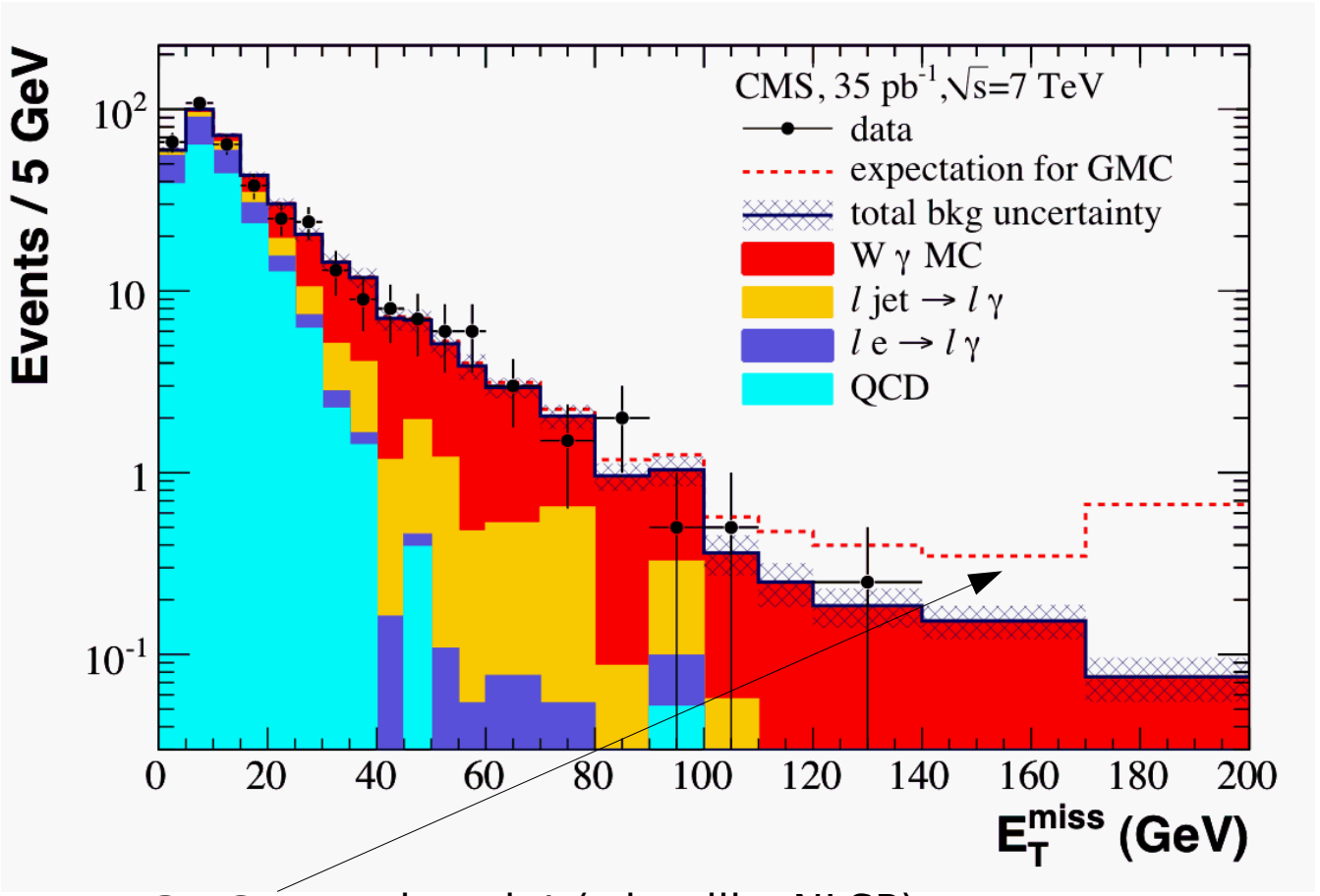

## $\gamma\gamma$ +jet+MET, 1.1/fb

No excess over
SM expectation observed

Signal region: MET>100 GeV

| Type | Events | stat. error | scal. error | norm. error |
|---|---|---|---|---|
| $\gamma\gamma$ candidates | 0 | | | |
| $ff$ QCD background | $2.3 \pm 2.2$ | $\pm 2.19$ | $\pm 0.13$ | $\pm 0.10$ |
| $ee$ QCD background | $1.0 \pm 0.8$ | $\pm 0.82$ | $\pm 0.02$ | $\pm 0.03$ |
| EWK background | $0.3 \pm 0.1$ | $\pm 0.06$ | $\pm 0.0$ | $\pm 0.03$ |
| Total background ($ff$) | $2.5 \pm 2.2$ | | | |
| Total background ($ee$) | $1.3 \pm 0.8$ | | | |

# Candidate MET distribution




GMC: sample point (wino-like NLSP)
- $m_{squark} \sim m_{gluino} = 450$ GeV
- $m_{neutralino/chargino} = 195$ GeV
- $\tan\beta = 2$

## γ +l+MET, 35/pb

- No excess over SM expectation observed
- Combination of eγ & μγ
- Signal region: MET>100 GeV
  - Observed: 2
  - Expected: 3.3 +/- 0.8

# Limit setting

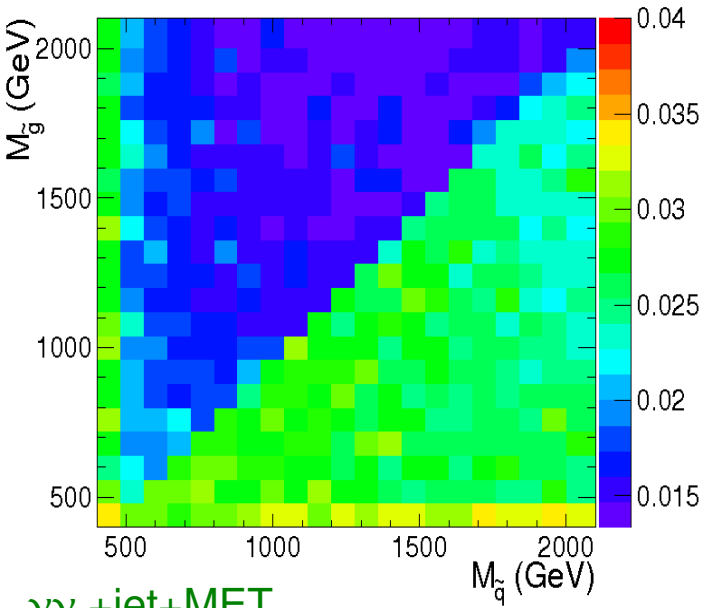
- Photon efficiency Data/MC: 0.953 +- 0.068
  - Includes error on PU
- Systematic uncertainty on acceptance:
  - JES 2%
  - PDF uncertainty: 0.1-9 %
- PDF uncertainty on XS: 4-66%

- CLs limit with likelihood-ratio test-statistics at 95%CL
- Lumi = 1.14/fb +- 4.5% error
- GGM signal MC

$\gamma$ +jet+MET/$\gamma\gamma$ +jet+MET

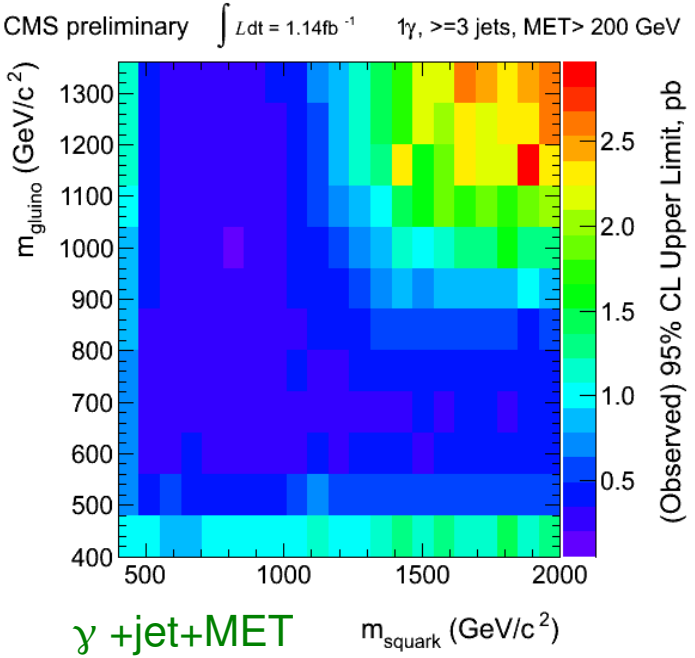
XS upper limits

Bino-like neutralino




$\gamma\gamma$ +jet+MET

Wino-like neutralino

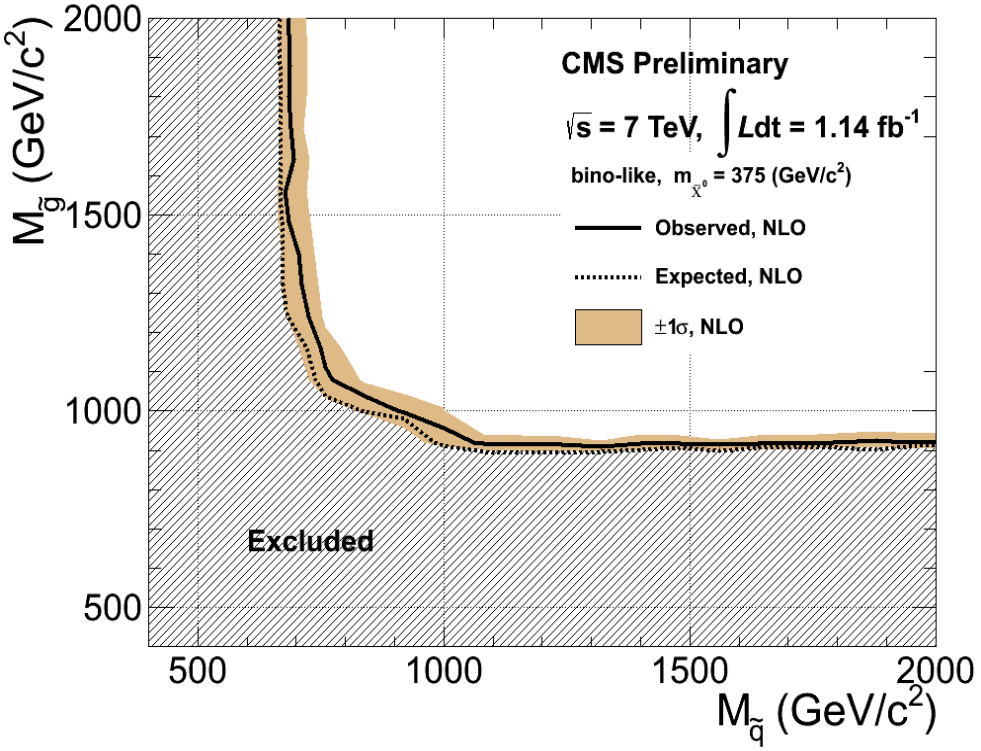



$\gamma$ +jet+MET

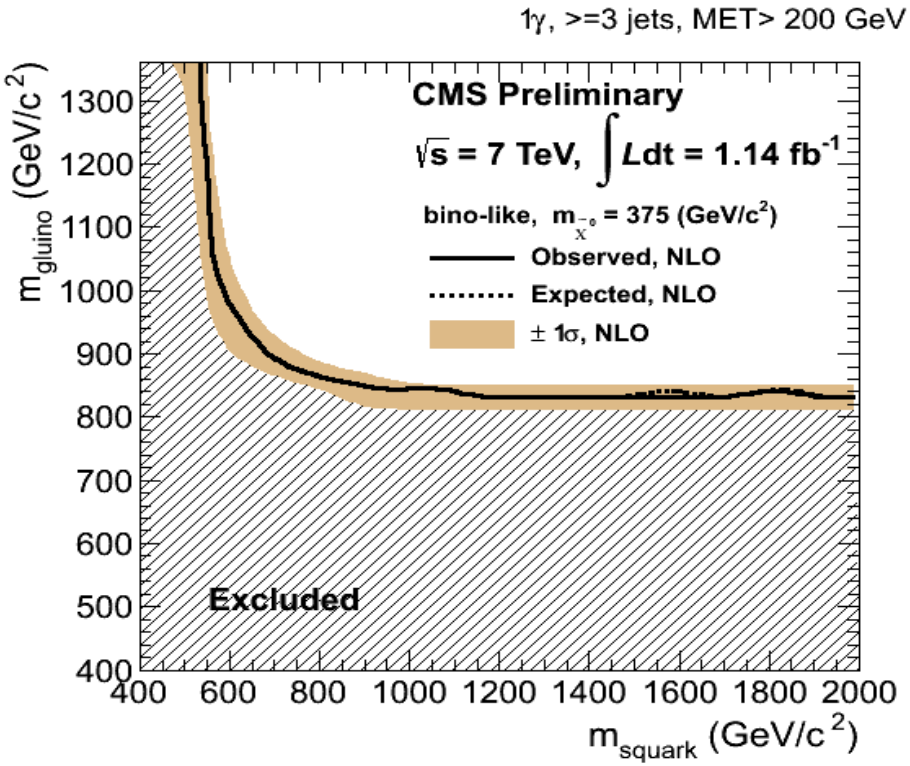
# Interpretation - Bino

- "Bino like" GGM scan: $m_{\chi 0}$=375 GeV, $m_{squark,gluino}$=400...2000 GeV, steps 80 GeV, ~ 10000 Evts
- Sleptons and all gauginos except NLSP: 3.5 TeV, heavy right handed squarks

## γγ +jet+MET, 1.1/fb

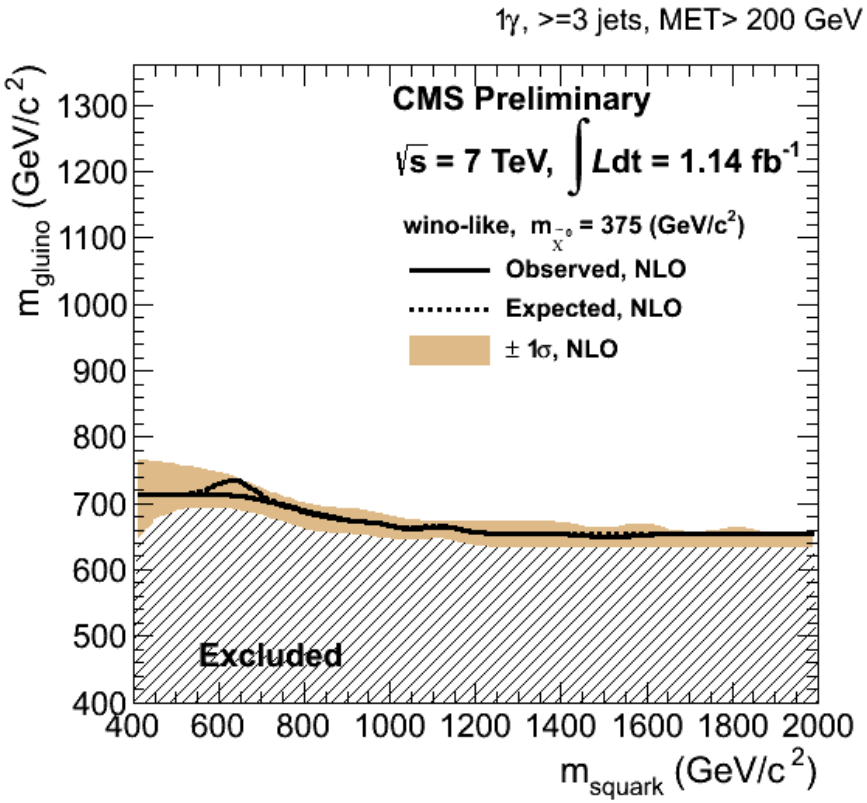



## γ +jet+MET, 1.1/fb



# Interpretation - Wino

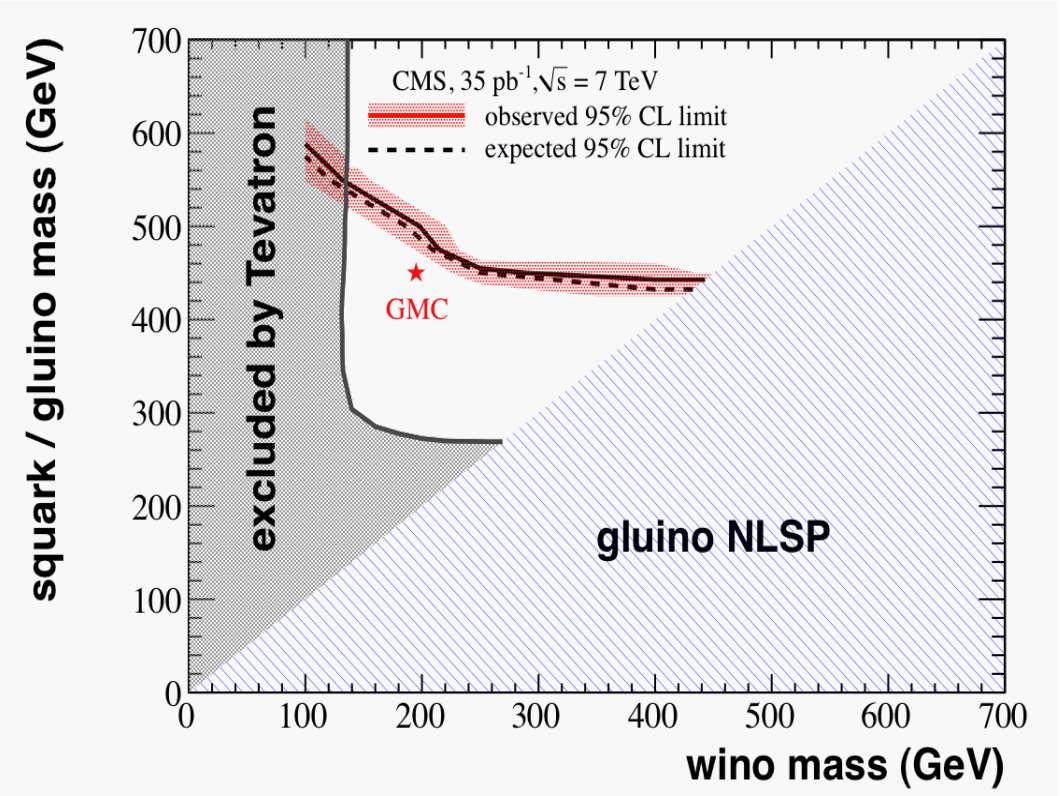
## $\gamma$ +jet+MET,1.1/fb




"Wino like" GGM scan:

- Sleptons & gauginos (except NLSP):3.5 TeV
- heavy right handed squarks
- NLSP mass = 375 GeV

## $\gamma$ +l+MET,35/pb




"Wino like" NLSP -slightly different scenario:

- $m_{squark} \sim m_{gluino}$,NLSP mass > 100 GeV
- tan β = 2
- Bayesian upper limit

# Summary

- Final states with photons expected in GMSB SUSY scenarios
  - Branching ratios to photon & W,Z,H depend on neutralino mixture

- CMS analyses designed to cover broad range of possible final states
  - $\gamma$ + jets +MET
  - $\gamma + \gamma$ + MET
  - $\gamma$ + l +MET

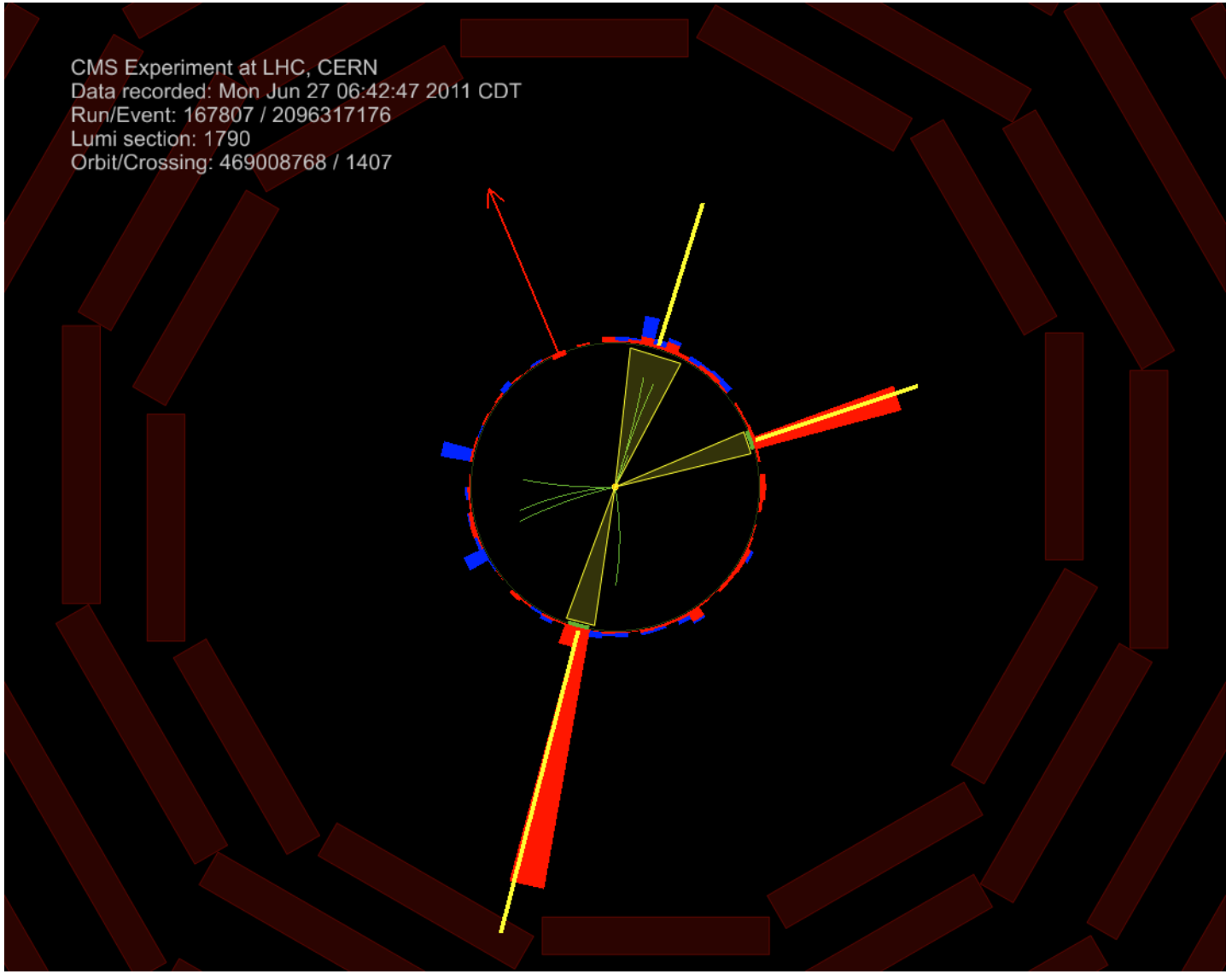
  } 1.14/fb results published: PAS-SUS-11-09

  35/pb result published: JHEP 1106:093 (2011)

- Data driven estimates for QCD/EWK backgrounds in place
- No excess observed in data

- Limits calculated for wino- and bino-like neutralino
  - bino-like NLSP $\approx m_{squark} \leq 650$ GeV & $m_{gluino} \leq 910$ GeV excluded
  - wino-like NLSP $\approx m_{gluino} \leq 650$ GeV excluded

# Backup

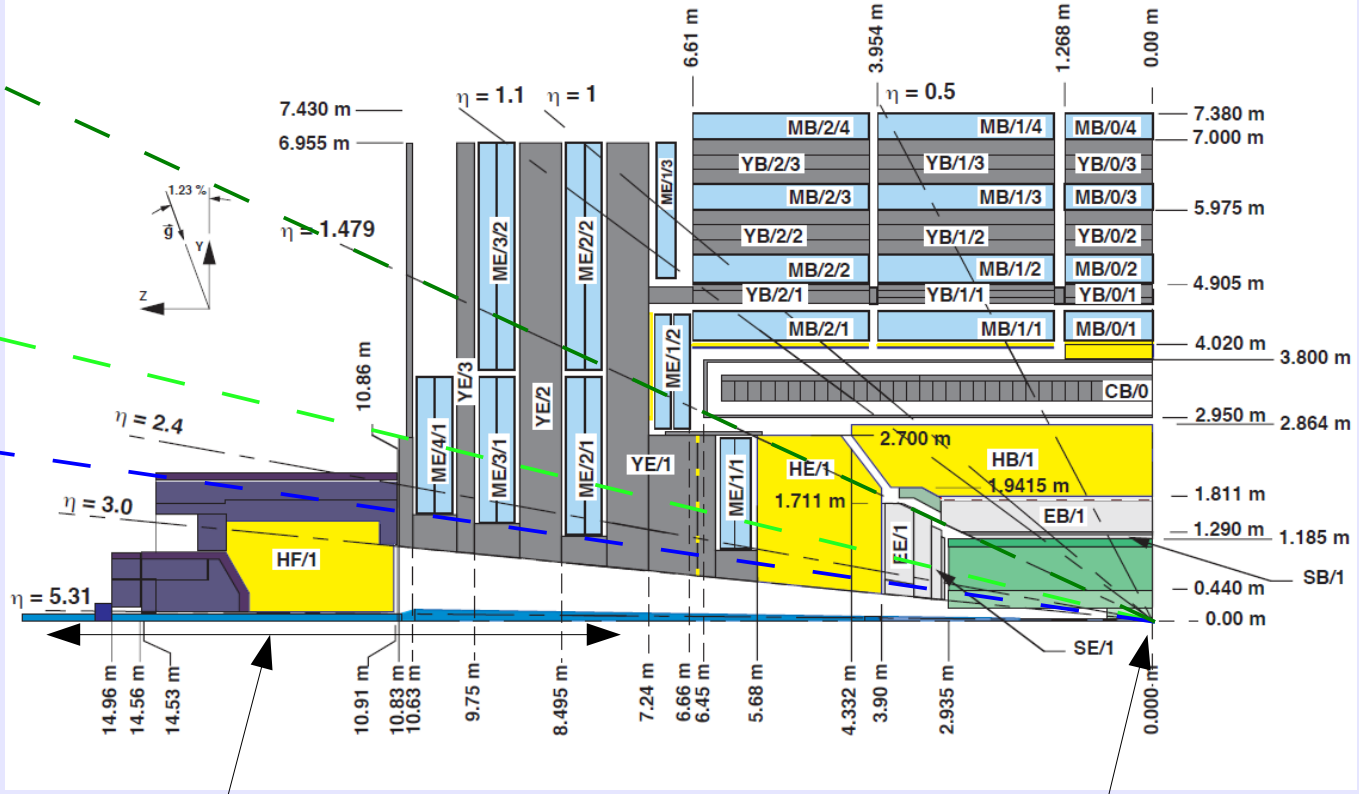

CMS Experiment at LHC, CERN
Data recorded: Mon Jun 27 06:42:47 2011 CDT
Run/Event: 167807 / 2096317176
Lumi section: 1790
Orbit/Crossing: 469008768 / 1407

# CMS detector

photons ← EB edge |η|=1.479

leptons ← ME edge |η|=2.1

jets ← HF edge |η|=2.6




beam line

Interaction point

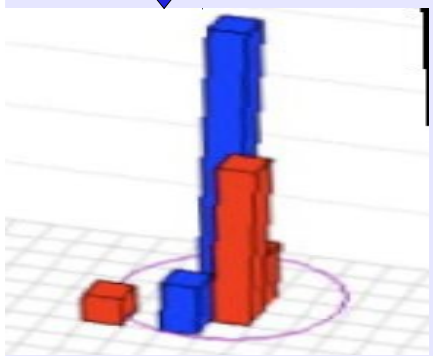
# $\not{E}_T$ Rekonstruktion

$\not{E}_T := -\sum \vec{E}_i$

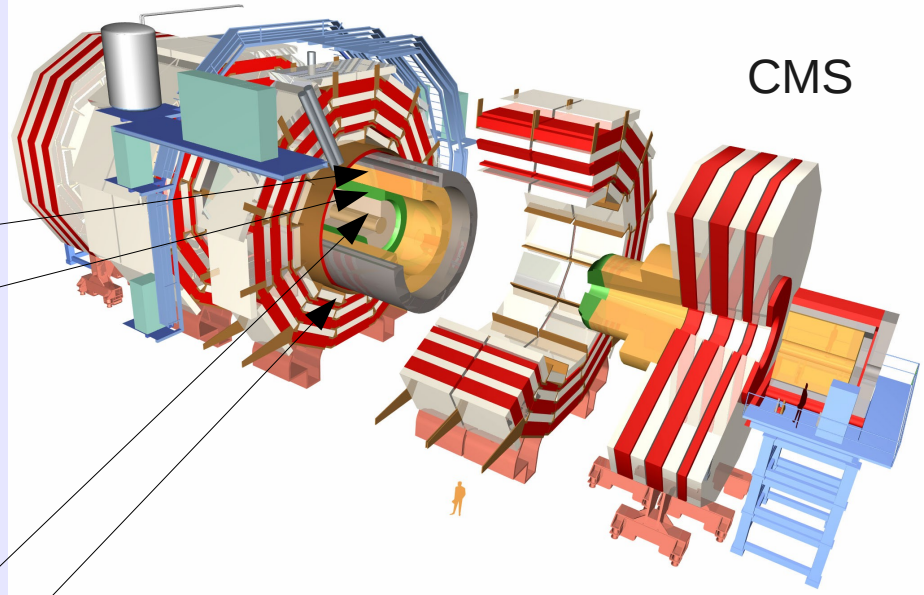
3 different Algorithms commissioned

hadronic Calorimeter

electromagnetic Calorimeter

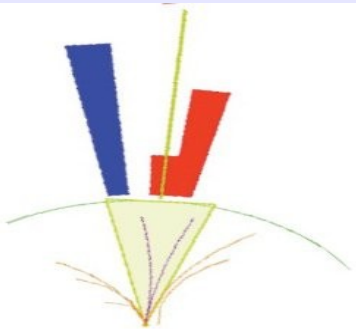


Calo $\not{E}_T$:
Negative transverse vectorsum over the calorimetric energydeposits

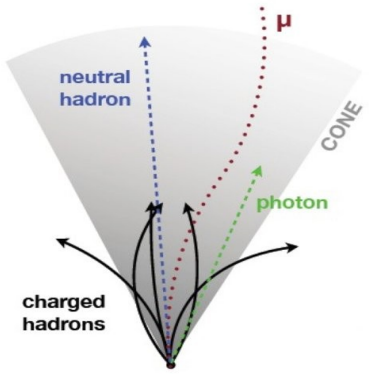



Muonchambers

Tracker



Tc $\not{E}_T$: Inclusion of the measured track momenta → Correction of calorimeter only measurement




Pf $\not{E}_T$:
Negative transverse vectorsum of calibrated particles („particle flow“)

# Object definitions - $\gamma$ /$\gamma\gamma$ + jets+MET

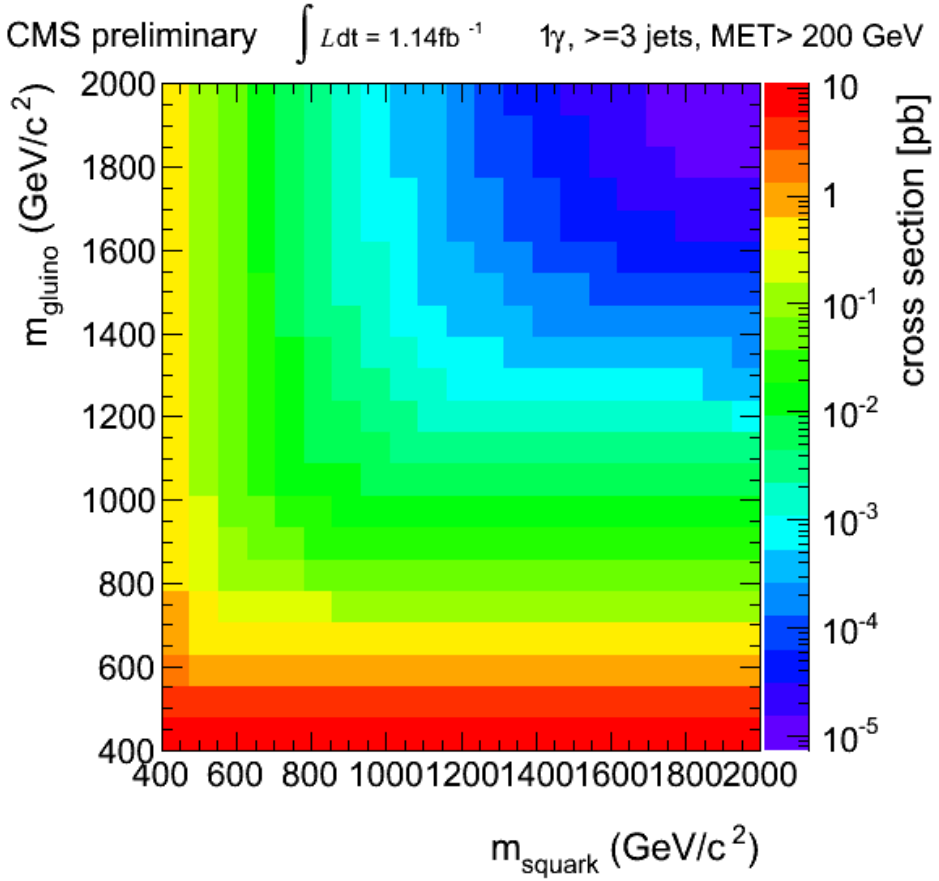
- In general all objects are particle flow objects (exception: photon, HT calculation)
- Jets are L1FastL2L3 corrected (Data: + Residual ), anti $k_T$ (R=0.5)
- MET Type-I corrected (for JES)
- Photon Id: (optimized for photons & electrons)
  - No Track: no matching hit pattern in pixel detector
  - Isolation: ecalIso()<4.2+0.006*pt &
    hcalIso()<2.2+0.0025*pt &
    trackIso()<2.0+0.001*pt
  - Shower shape: $\sigma_{i\eta i\eta}$<0.011 &
    HadronicOverEm()<0.05 &
    r9()<0.98
- Electrons: like photon Id, but with pixel seed
- HT: scalar $p_T$ sum of jets (CaloJets, anti $k_T$ (R=0.5),pT>40 GeV, $|\eta|$<3.0, no rejection of photons)

# Photon/lepton ID efficiency

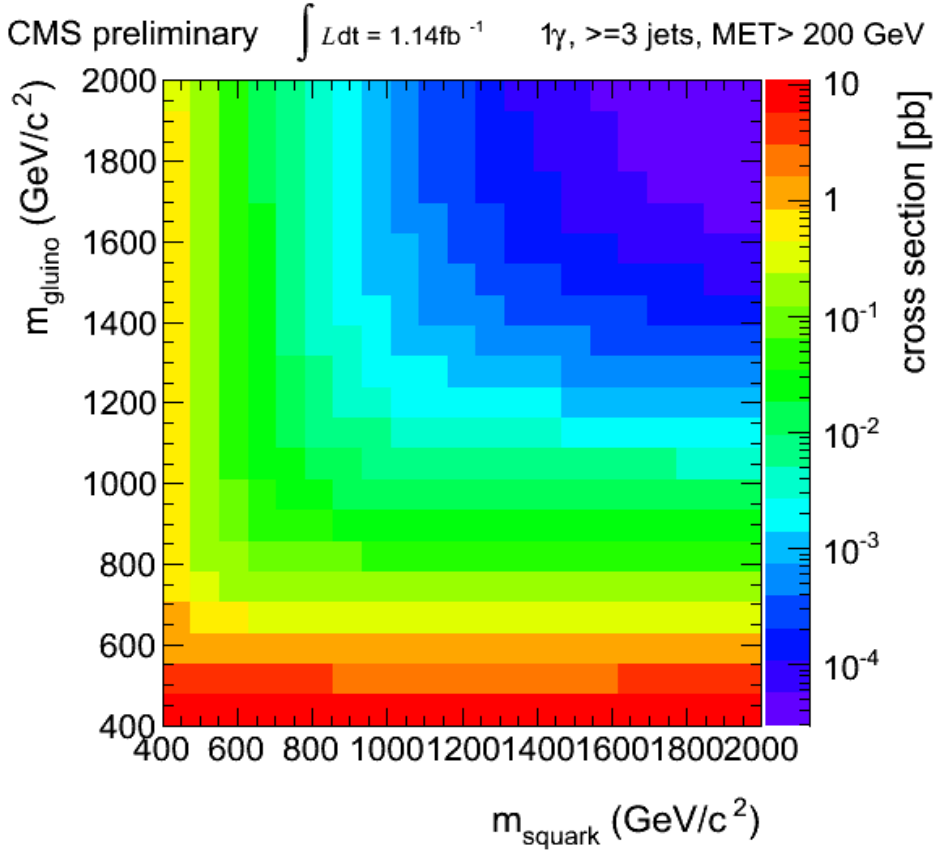
- Photon/lepton efficiency from MC, corrected by $\varepsilon_{data}/\varepsilon_{MC}$
  - Use Z→ee and Z→μμ events
- Signal MC acceptance * efficiency * $\varepsilon_{data}/\varepsilon_{MC}$ (per photon/lepton)
  - Pixel match veto efficiency (MC): 96.4 +/- 0.5%
  - Photon: $\varepsilon_{data}/\varepsilon_{MC}$=0.953 +/- 0.068
  - Electron: $\varepsilon_{data}/\varepsilon_{MC}$=0.928 +/- 0.015 → Considered systematics:
    - Z signal and background shape
    - signal fit over/underestimation
    - pile up effects
    - MC electron/photon difference
  - Muon: $\varepsilon_{data}/\varepsilon_{MC}$=0.99 +/- 0.001

# NLO Prospino XS

Bino-like neutralino




Wino-like neutralino



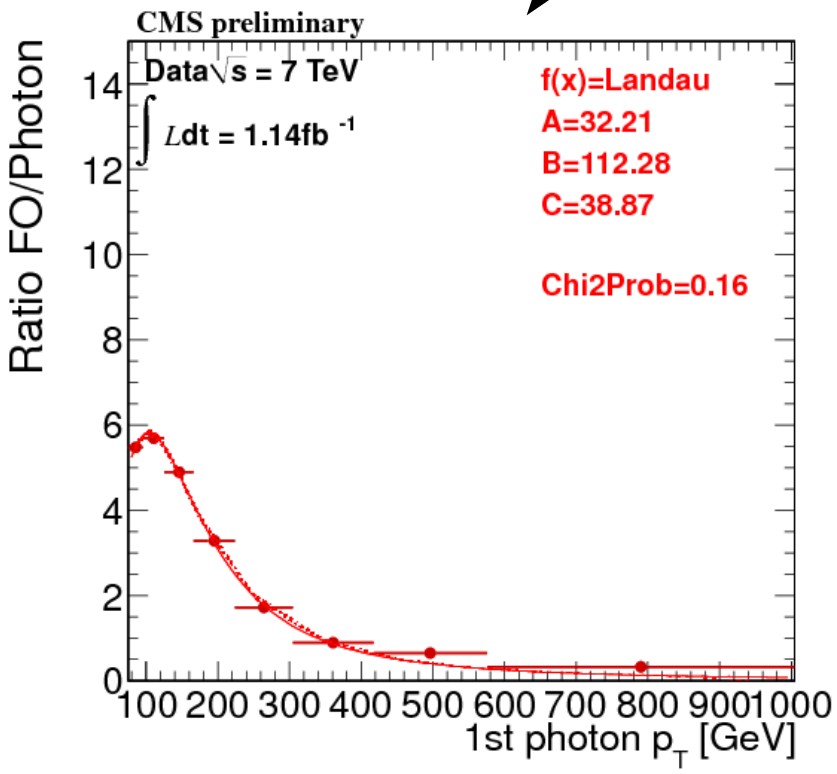
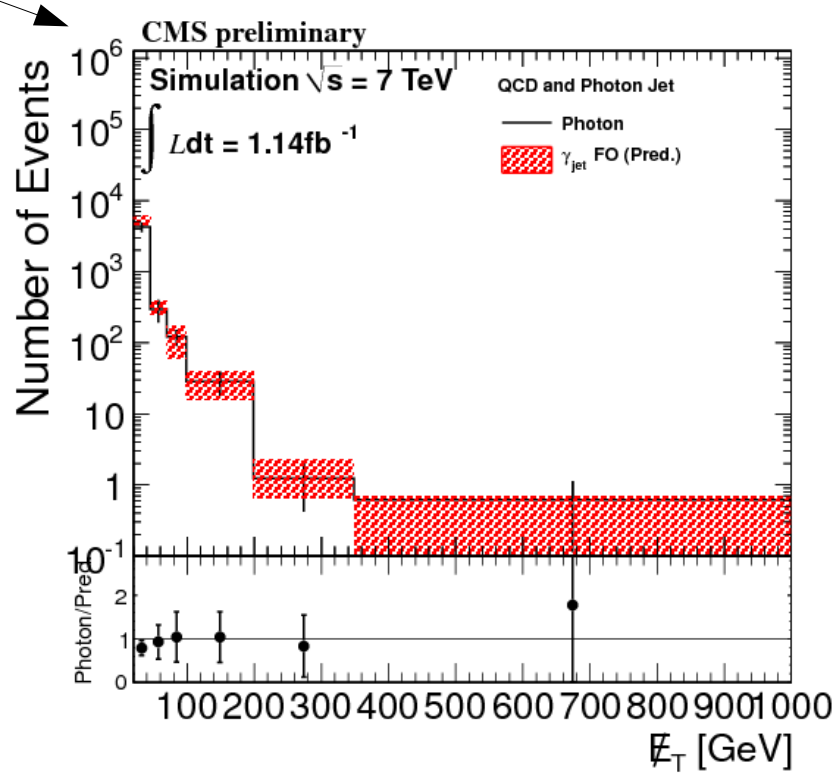
# Event yields: $\gamma$ + l +MET

| ELECTRON | No $E_{\mathrm{T}}^{\mathrm{miss}}$ selection | $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV | $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV |
|---|---|---|---|
| W$\gamma$ | $44.5 \pm 9.2$ | $16.1 \pm 3.4$ | $1.68 \pm 0.42$ |
| jet$\rightarrow \gamma$ | $20.3 \pm 4.5$ | $3.1 \pm 0.9$ | $0.02 \pm 0.02$ |
| e $\rightarrow \gamma$ | $70.5 \pm 19.1$ | $0.3 \pm 0.1$ | $0.04 \pm 0.03$ |
| QCD | $134 \pm 28$ | $0.4 \pm 0.2$ | $0.00 \pm 0.00$ |
| Total background | $269 \pm 18$ | $19.9 \pm 3.7$ | $1.74 \pm 0.43$ |
| data | 264 | 16 | 1 |
| SUSY GMC prediction | $3.94 \pm 0.79$ | $3.76 \pm 0.75$ | $2.79 \pm 0.56$ |

| MUON | No $E_{\mathrm{T}}^{\mathrm{miss}}$ selection | $E_{\mathrm{T}}^{\mathrm{miss}} > 40$ GeV | $E_{\mathrm{T}}^{\mathrm{miss}} > 100$ GeV |
|---|---|---|---|
| W$\gamma$ | $44.8 \pm 9.3$ | $15.9 \pm 3.4$ | $1.40 \pm 0.37$ |
| jet$\rightarrow \gamma$ | $18.0 \pm 4.0$ | $3.7 \pm 1.1$ | $0.10 \pm 0.09$ |
| e $\rightarrow \gamma$ | $1.2 \pm 0.4$ | $0.6 \pm 0.2$ | $0.09 \pm 0.04$ |
| QCD | $58.3 \pm 15.1$ | $0.2 \pm 0.1$ | $0.00 \pm 0.00$ |
| Total background | $122.3 \pm 12.3$ | $20.4 \pm 3.7$ | $1.59 \pm 0.39$ |
| data | 126 | 27 | 1 |
| SUSY GMC prediction | $5.12 \pm 1.02$ | $4.84 \pm 0.96$ | $3.66 \pm 0.73$ |

# QCD background

- $\gamma$ +jet+MET:
  - Control sample: fake-photon
  - Reweight ratio photon/fake (MET<100 GeV)

MC Closure

- $\gamma$ +l+MET:
  - Control sample: Di-electron & fake lepton + fake photon
  - Normalize MET<30 GeV