# Search for Z + $\gamma$ Events with Large Missing Transverse Energy

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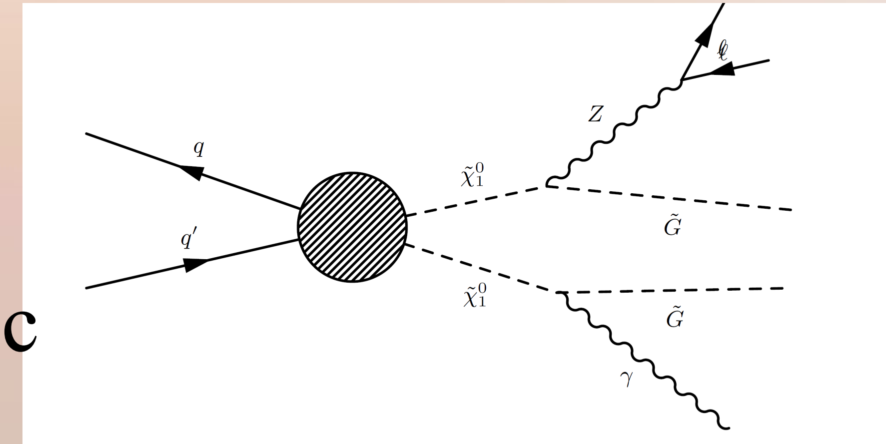
# GMSB SUSY Decays

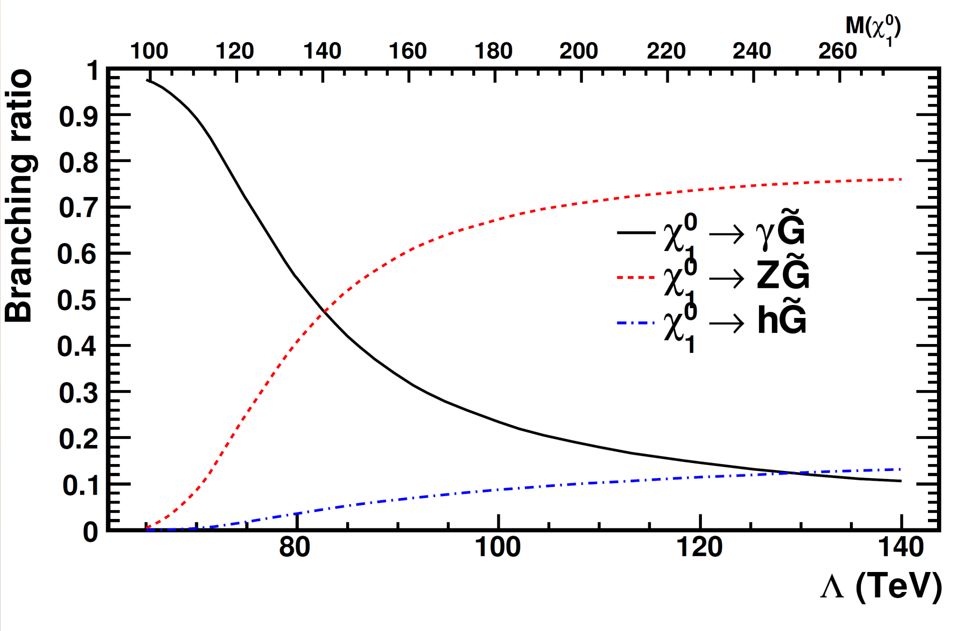
- In Gauge-Mediated Symmetry-Breaking (GMSB), gravitino ($\tilde{G}$) is the lightest super-symmetric (SUSY) particle




- Assuming R-parity is conserved, SUSY particles are produced in pairs
  - Cascade decays to next-lightest SUSY particle (NLSP)
  - If NLSP is neutralino ($\tilde{\chi}^0_1$), can decay to $Z\tilde{G}$ or $\gamma\tilde{G}$

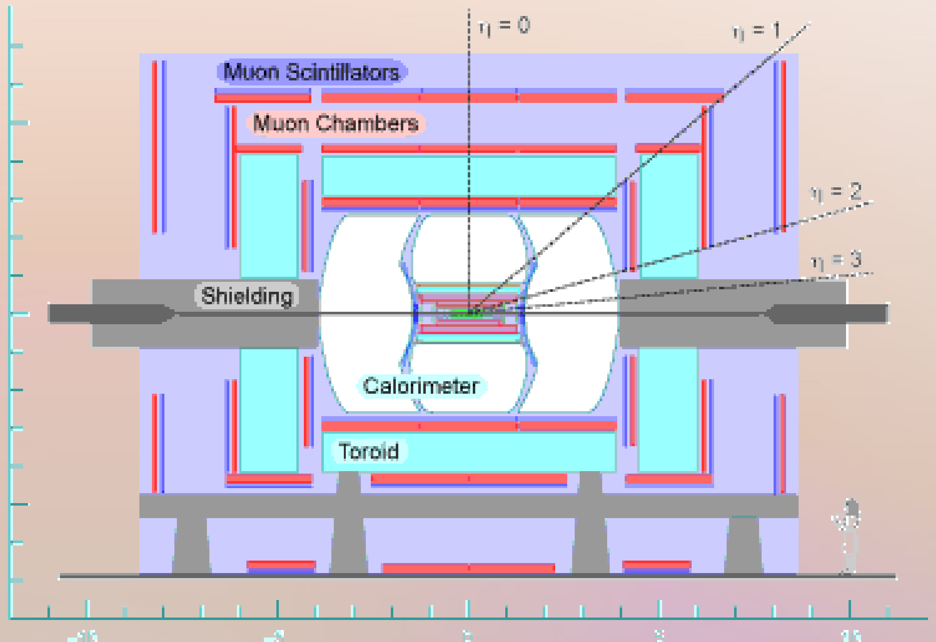
# GMSB SUSY Decays

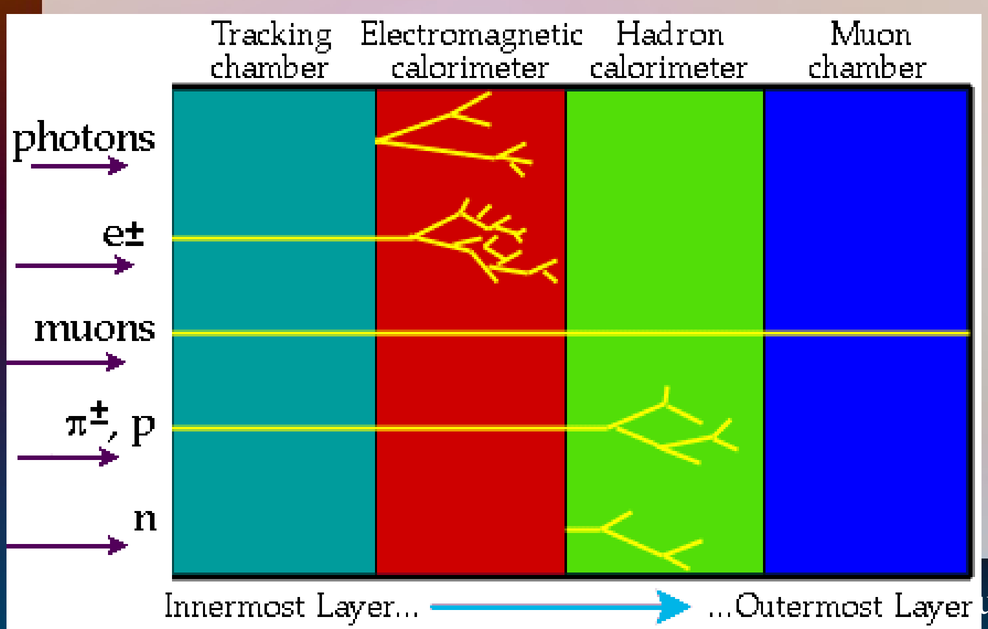
- If lightest neutralino more higgsino than bino-like, $\tilde{\chi}^0_1 \rightarrow Z\tilde{G}$ significant
- Generate signal with ISAJET + PROSPINO next-to-leading order (NLO) corrections
- For this analysis, consider "Model Line E" from
  H. Baer, P. G. Mercadante, X. Tata, and Y. Wang, Phys. Rev. D 62, 095007 (2000).
  - Vary SUSY breaking scale $\Lambda$ in our fit from 70 to 95 TeV
  - The masses of SUSY particles vary with $\Lambda$

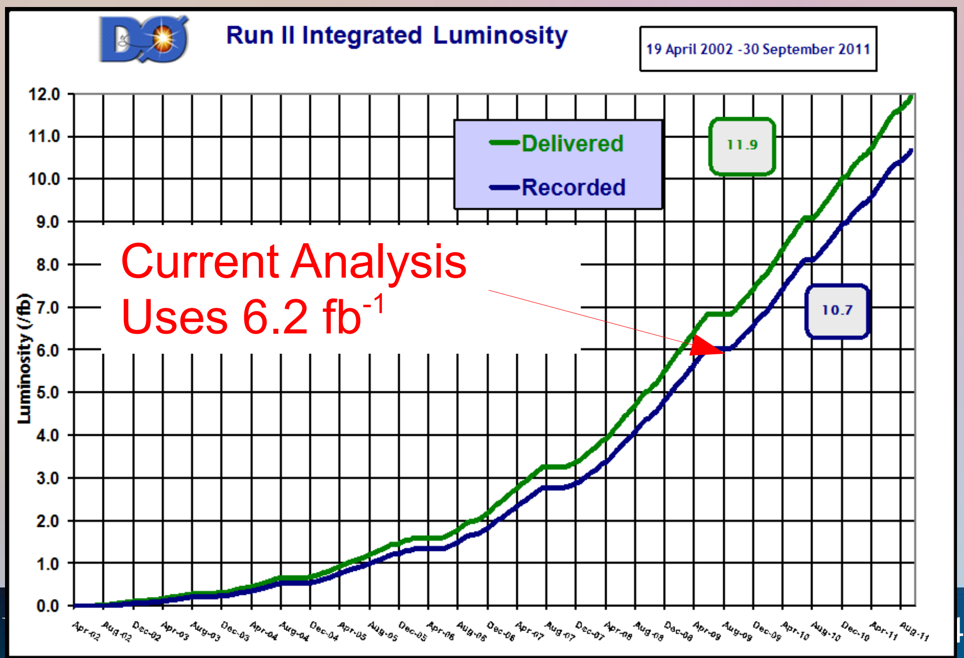


# The DØ Experiment

- A multipurpose particle detector
- Innermost detectors are the trackers, followed by calorimetry and muon chambers

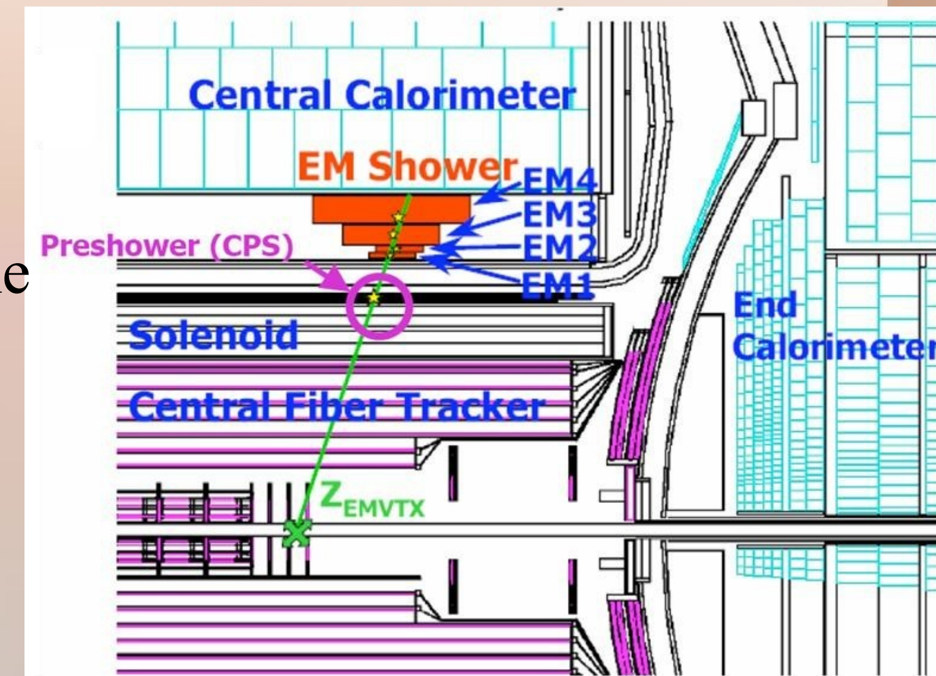


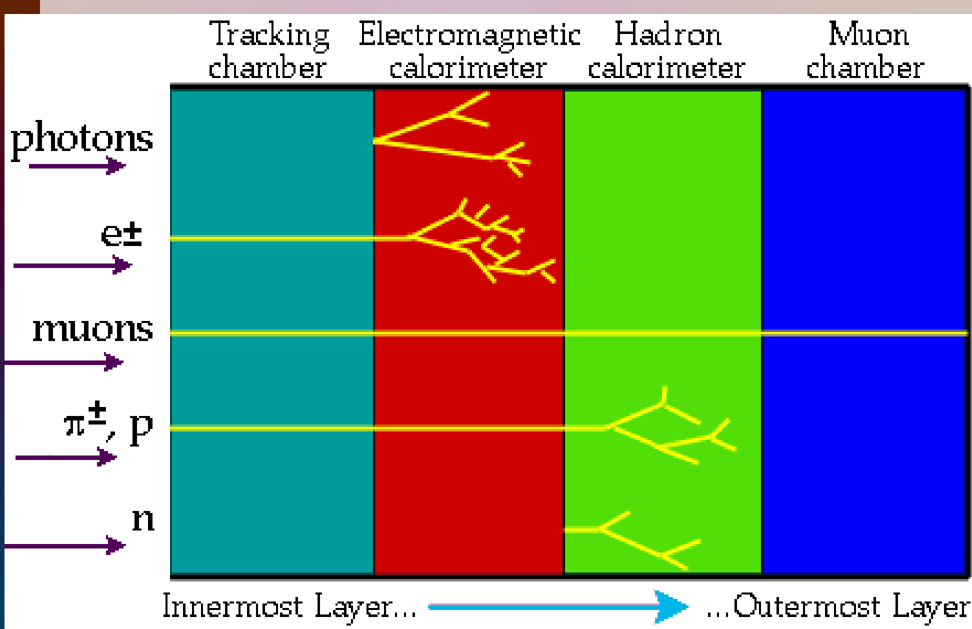



# Electrons and Photons

- Both e and $\gamma$ are identified using isolated EM calorimeter clusters
  - Must also be isolated in hollow cone of $0.05 < \Delta R < 0.4$ in tracker
  - Multivariate techniques separate jets from e, $\gamma$

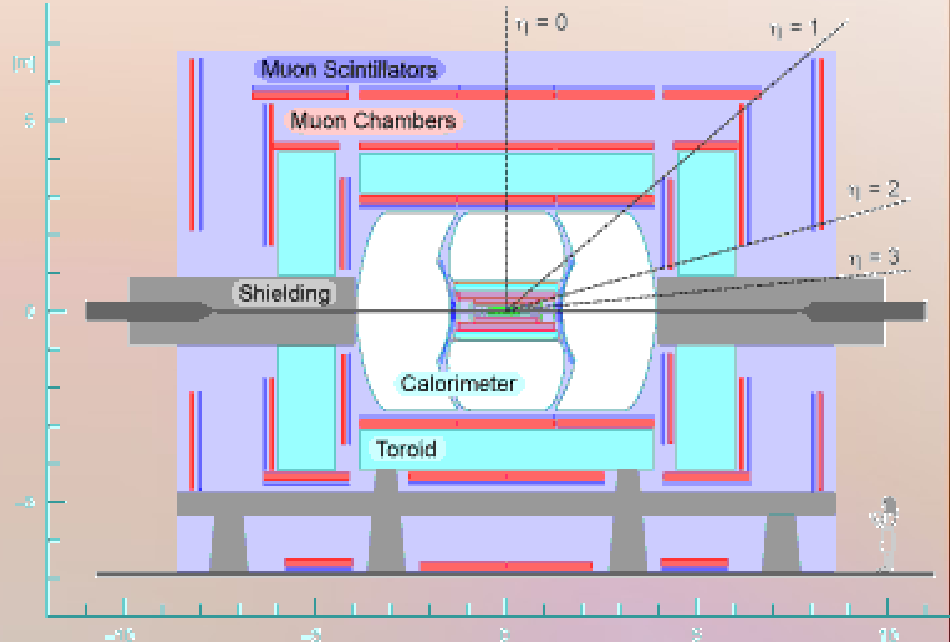


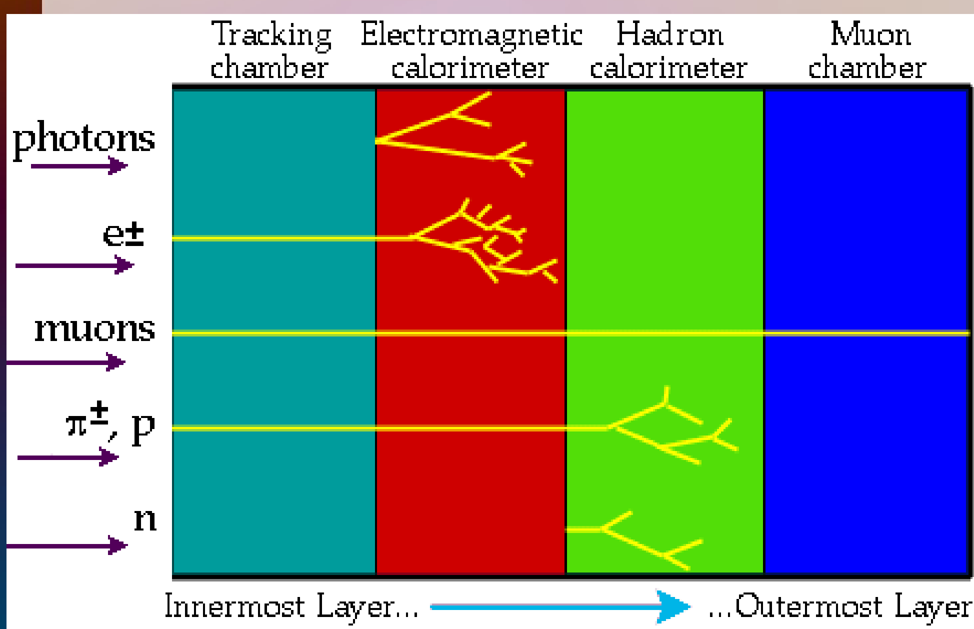




- We differentiate e from $\gamma$ by presence of matched track
  - For $\gamma$, also require minimal energy deposits in tracker along probable e paths

# Muons and Missing Energy

- Muons are reconstructed by matching tracks in central tracker to hits in tracking system outside calorimeter
  - Calorimeters absorb other particles
  - Use central track for momentum estimate



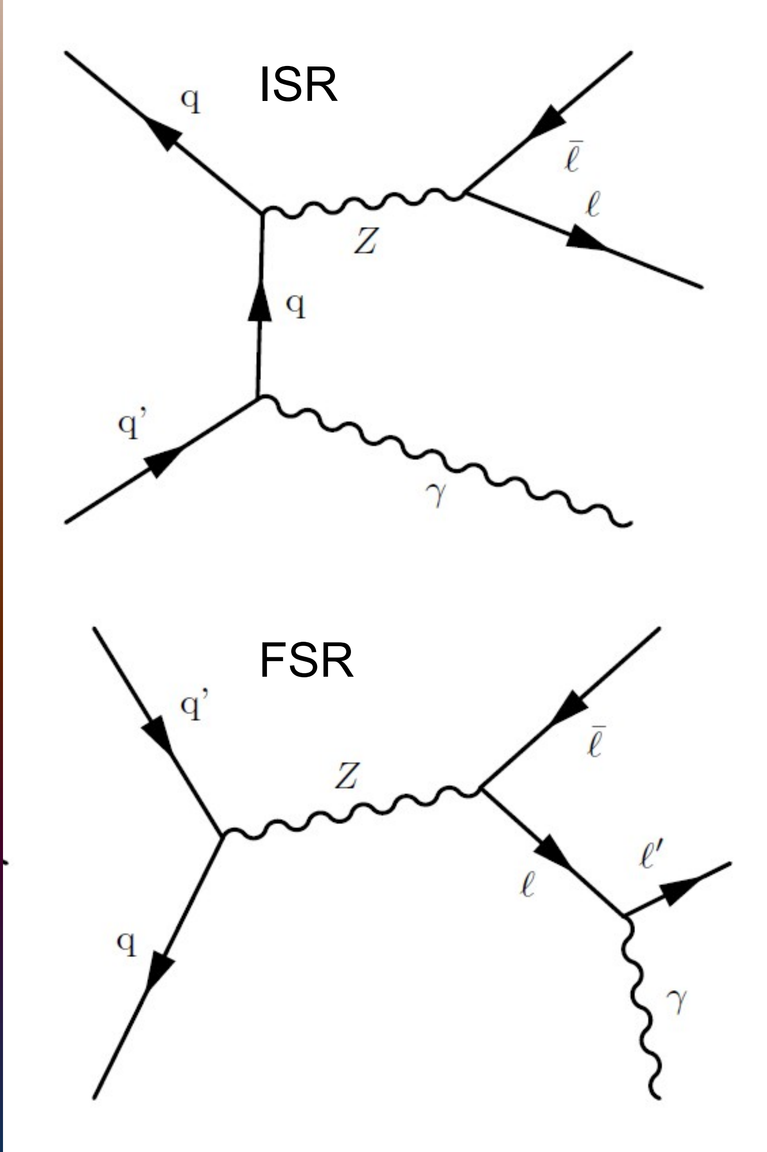




- To determine Missing Energy, take the negative vector sum of calorimeter energy with μ, e, jet corrections
  - Possibly from missed particle
  - Can arise from mismeasurement

# Event Selection

- We consider events with two isolated, oppositely charged leptons and one photon
  - Leptons are either ee or $\mu\mu$
  - Photons from Central Calorimeter only
- We require the invariant mass of the dileptons to be consistent with the Z mass
- We require MET > 30 (40) GeV for $ee\gamma$ ($\mu\mu\gamma$)
  - We also require MET significance > 5.0
  - MET significance is the number of $\sigma$ MET is from 0, based on momentum resolution of objects in event

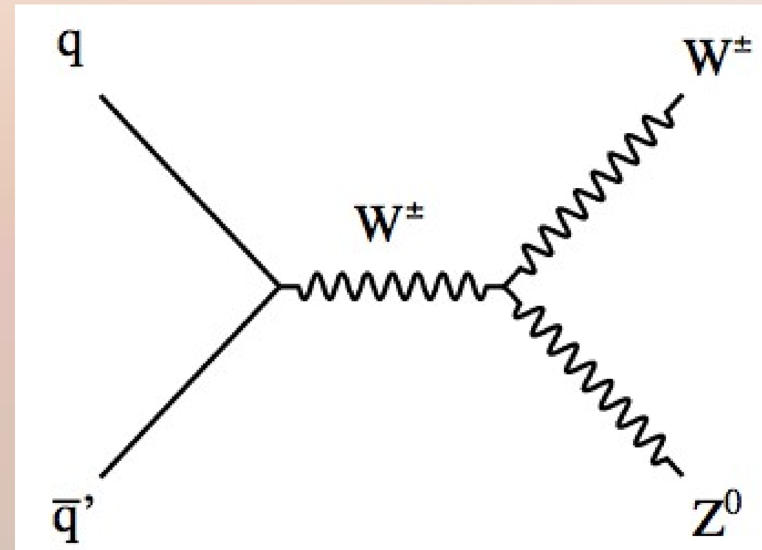
# Standard Model Backgrounds

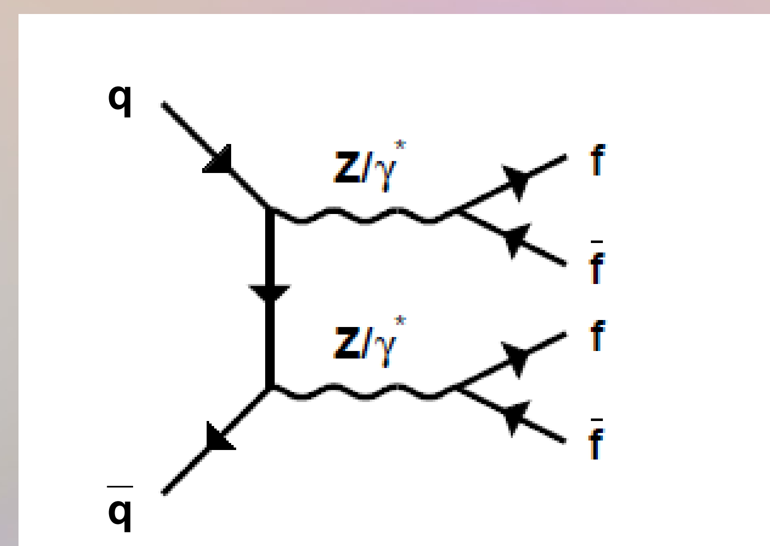


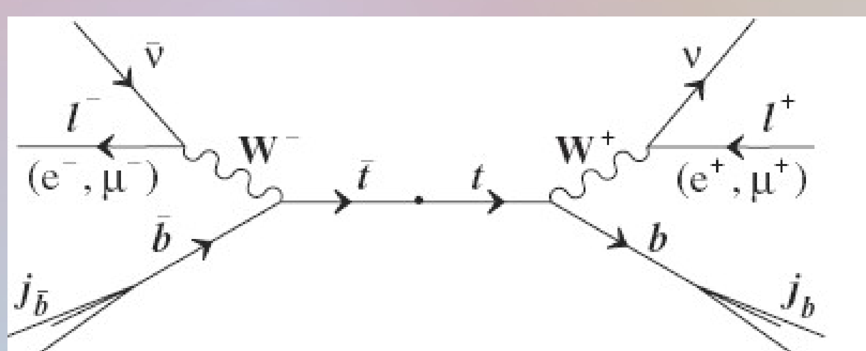

- $Z\gamma$, diboson, $t\bar{t}$, and Z+jet process can all mimic signal
- The most significant background for this analysis is $Z\gamma$ + mismeasured MET
  - Estimated using Pythia, with NLO corrections for ISR
  - To reduce FSR, $\Delta R(l,\gamma) > 0.7$ and $M(ll\gamma) > 120$ GeV
  - FSR contribution fit in low MET region, found to be small

# Diboson and top Backgrounds

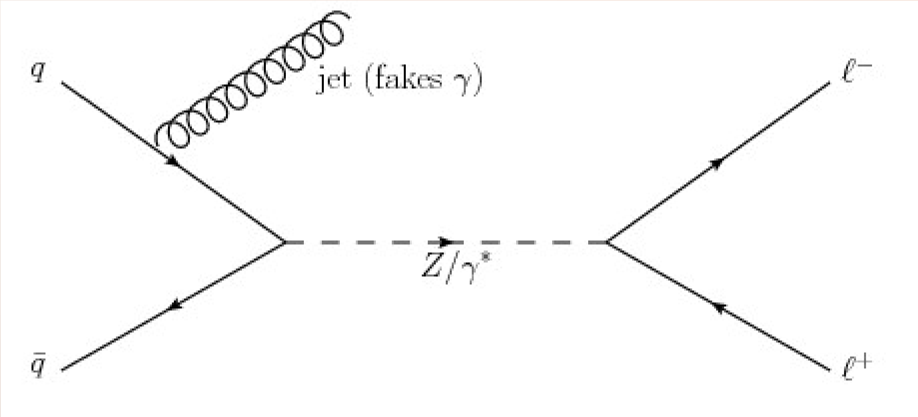
- Diboson (WW, WZ, ZZ) modeled with PYTHIA with NLO corrections
- $t\bar{t}$ modeled with ALPGEN + PYTHIA with approximate next-to-next-to-NLO corrections



# Z + jet Background

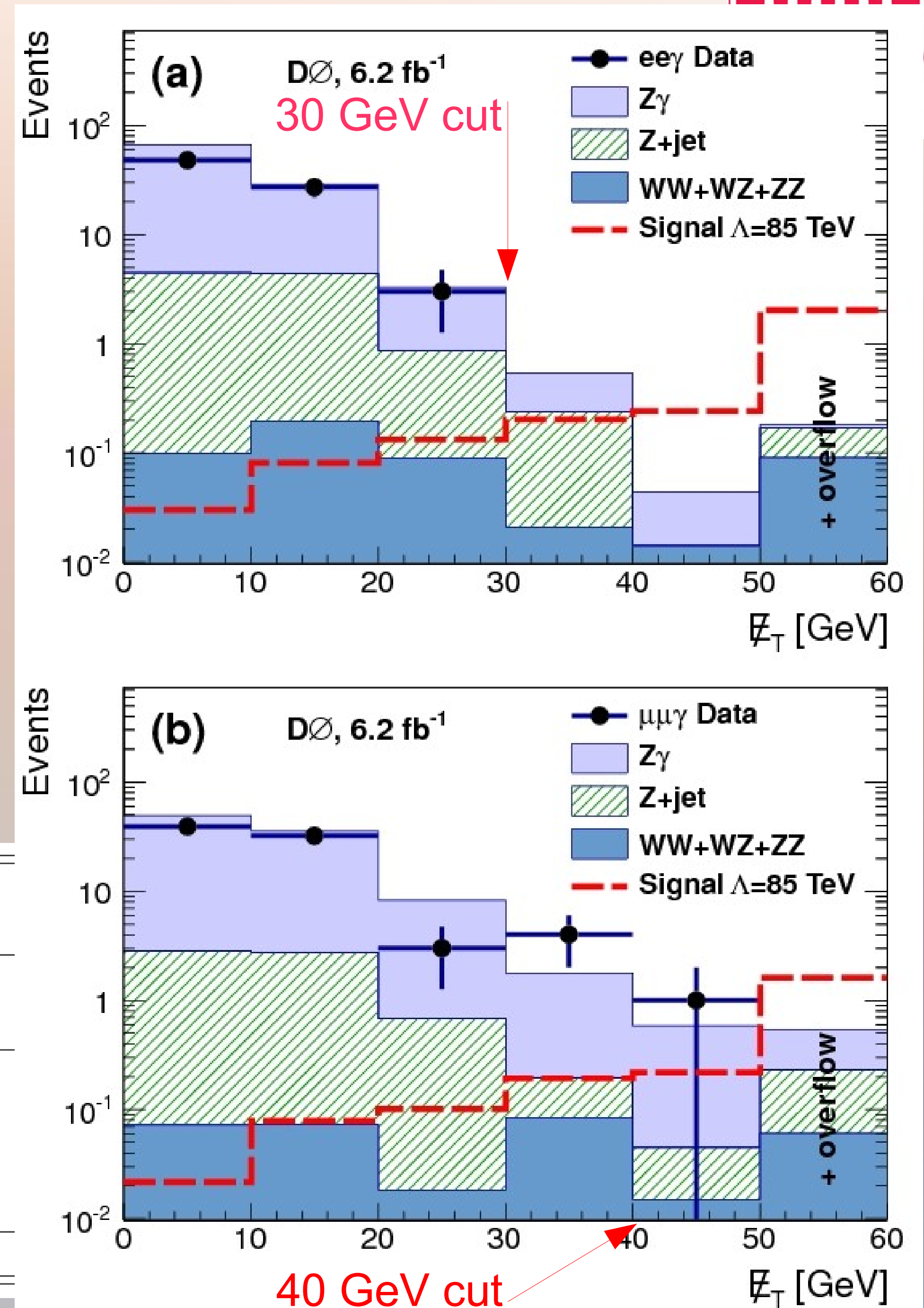



- Z+jets background estimated using data
- Two methods used, give consistent results
  - First method uses photon-jet NN shape
    - Templates of photon & jet fake NN shapes derived from MC
    - Fit to data NN shape for fake estimate
  - Second uses events with two leptons + photon-like jet
    - Sample normalized using jet to photon fake ratio calculated in a jet dominated sample

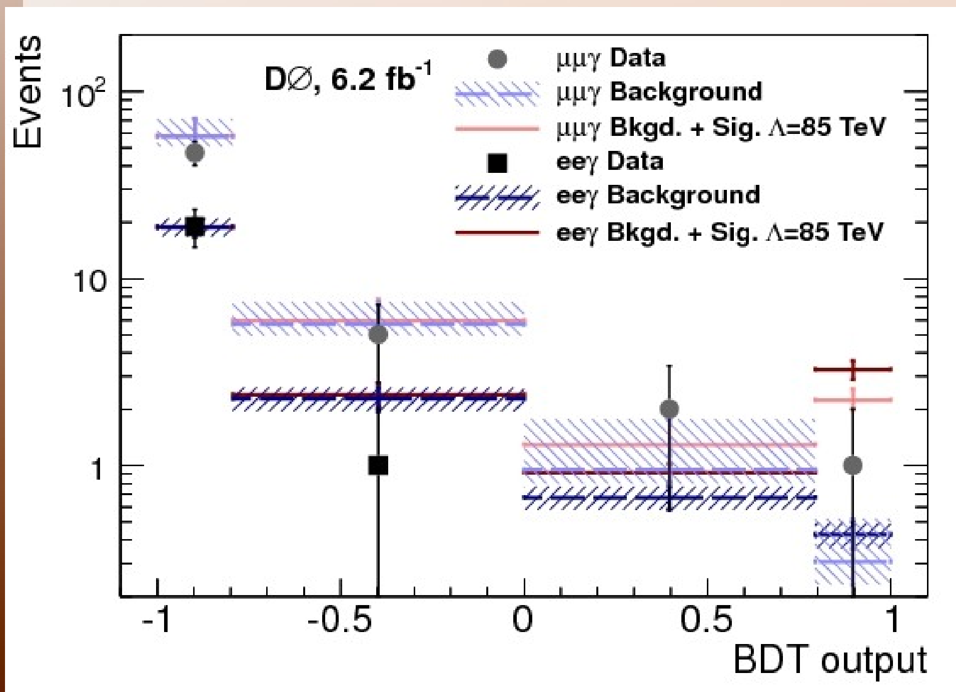
# Data/MC Comparison

- Find good agreement
- Find 1 event in signal region, expect 1.2
- However, only looking at MET ignores other significant information

| | $ee\gamma + \not{E}_T$ Signal region | $\mu\mu\gamma + \not{E}_T$ Signal region |
|---|---|---|
| Signal ($\Lambda = 80$ TeV) | $3.28 \pm 0.09 \pm 0.24$ | $2.42 \pm 0.08 \pm 0.31$ |
| Signal ($\Lambda = 90$ TeV) | $1.48 \pm 0.03 \pm 0.11$ | $1.06 \pm 0.03 \pm 0.14$ |
| $Z\gamma$ | $0.23 \pm 0.05 \pm 0.02$ | $0.43 \pm 0.05 \pm 0.40$ |
| $Z$+jet | $0.09 \pm 0.08 \pm 0.01$ | $0.17 \pm 0.16 \pm 0.02$ |
| $WW + WZ + ZZ$ | $0.13 \pm 0.05 \pm 0.01$ | $0.08 \pm 0.03 \pm 0.01$ |
| $t\bar{t}$ | $0.05 \pm 0.01 \pm 0.01$ | $0.04 \pm 0.01 \pm 0.01$ |
| All backgrounds | $0.50 \pm 0.11 \pm 0.03$ | $0.71 \pm 0.17 \pm 0.40$ |
| Data | 0 | 1 |



# Boosted Decision Tree (BDT) Discriminant

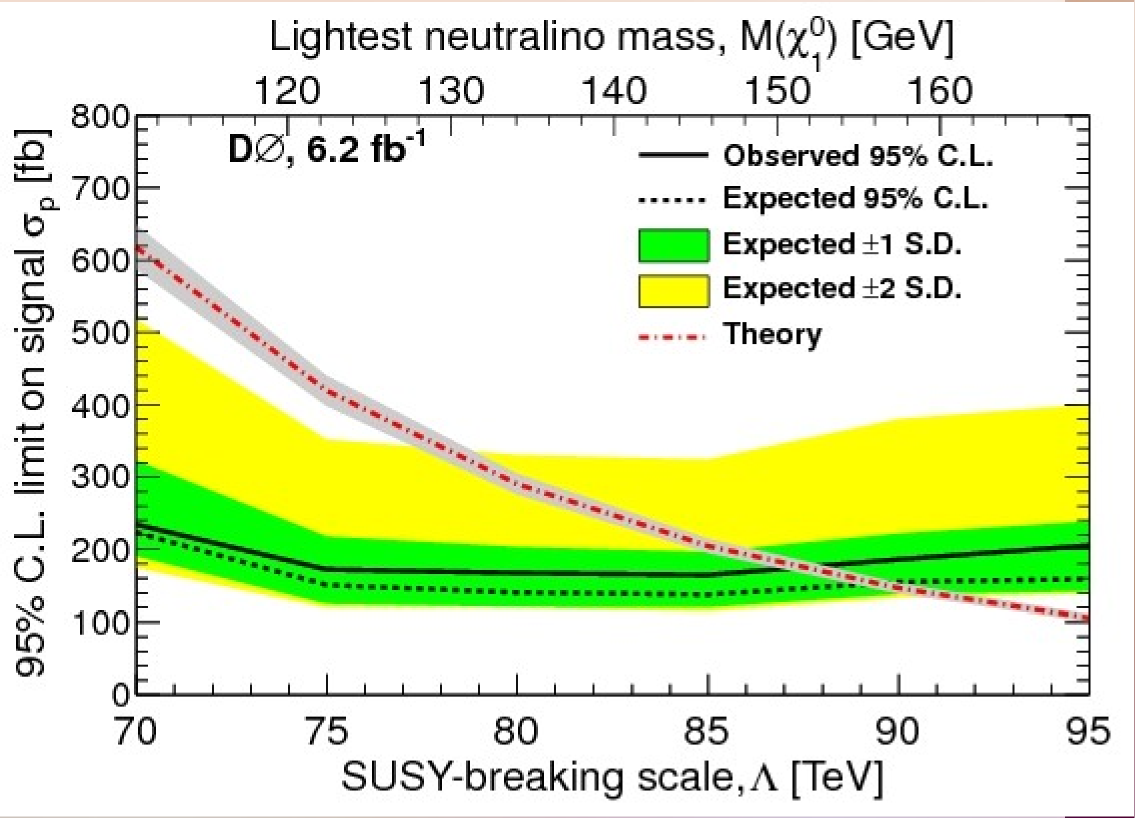



| | $ee\gamma + \not{E}_T$ BDT $> 0.8$ | $\mu\mu\gamma + \not{E}_T$ BDT $> 0.8$ |
|---|---|---|
| Signal ($\Lambda = 80$ TeV) | $3.95 \pm 0.10 \pm 0.50$ | $2.69 \pm 0.08 \pm 0.33$ |
| Signal ($\Lambda = 90$ TeV) | $1.73 \pm 0.05 \pm 0.21$ | $1.22 \pm 0.04 \pm 0.15$ |
| $Z\gamma$ | $0.23 \pm 0.11 \pm 0.02$ | $0.10 \pm 0.03 \pm 0.20$ |
| $Z$+jet | - | - |
| $WW + WZ + ZZ$ | $0.06 \pm 0.04 \pm 0.01$ | $0.16 \pm 0.19 \pm 0.02$ |
| $t\bar{t}$ | $0.14 \pm 0.03 \pm 0.02$ | $0.05 \pm 0.02 \pm 0.01$ |
| All backgrounds | $0.43 \pm 0.12 \pm 0.03$ | $0.31 \pm 0.10 \pm 0.20$ |
| Data | 0 | 1 |

- To train BDT to separate GMSB, backgrounds
- Use 14 variables as inputs
  - $p_T(l_1)$, $p_T(l_2)$, $p_T(\gamma)$
  - $p_T(ll)$, $p_T(ll\gamma)$
  - $p_T(l_1)$-$p_T(\gamma)$, $p_T(l_2)$-$p_T(\gamma)$
  - MET, MET significance
  - Components of MET ⊥ and ∥ to Z $p_T$
  - $M(ll\gamma)$, $M_T(\gamma,\text{MET})$

# Limits on GMSB

- Results consistent with background, so proceed to set limits
- Consider events passing BDT > 0.8 using CLs method with LLR test statistic
- Exclude $\Lambda < 87$ TeV [$M(\tilde{\chi}^0_1) < 151$ GeV] at 95% CL




| $\Lambda$ [TeV] | $\sigma_p$ [fb] | $M_{\tilde{\chi}^0_1}$ [GeV] | obs. (exp.) limit on $\sigma_p$ [fb] |
|---|---|---|---|
| 70 | 618 | 111 | < 234 (223) |
| 75 | 419 | 123 | < 172 (150) |
| 80 | 290 | 135 | < 167 (140) |
| 85 | 205 | 147 | < 163 (137) |
| 90 | 146 | 159 | < 186 (155) |
| 95 | 106 | 169 | < 205 (159) |

# Summary/Conclusions

Submitted to PRL: arXiv:1203.5311v1 [hep-ex]

- Have searched for new physics in the $Z\gamma$+MET final state in $p\bar{p}$ collisions at $s^{1/2}$ =1.96 TeV in 6.2 $fb^{-1}$ of data collected at DØ
- In GMSB "Model Line E", exclude $\Lambda$ < 87 TeV [$M(\tilde{\chi}^0_1)$ < 151 GeV] at 95% CL