Search for Gauge-Mediated Supersymmetry in the Di-Photon Channel

presented by

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Theoretical Framework Overview

- Standard Model
  - Quantum Field Theory (Quantum Mechanics + Special Relativity)
    - Particles and Mediators described as excitations of Quantum Fields
  - Equations obtained from Action Principle and Local Gauge Invariance
    - Mathematical group: \( SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \)
  - Incorporates Strong and Electroweak interactions (no Gravity)
    - Strong Interactions: \( SU(3)_C \)
    - Electroweak Interactions: \( SU(2)_L \otimes U(1)_Y \)
  - Classification scheme of particles (fermions) and mediators (bosons)
Theoretical Framework Overview

- Local Gauge Invariance in Electromagnetism

  - Classically: Electromagnetic field is invariant under gauge transformations
    \[ A_\mu \rightarrow A'_\mu = A_\mu + \partial_\mu \lambda(x) \quad , \quad F_{\mu\nu} \rightarrow F'_{\mu\nu} = F_{\mu\nu} \]

  - Classically: Field – particle interaction is invariant under gauge transformations
    \[ \partial_\mu j^\mu = 0 \quad \text{(Noether’s Theorem)} \]

  - Quantum Mechanically: \[ \mathcal{L} = \mathcal{L}_{\text{DIRAC}} + \mathcal{L}_{\text{FIELD}} + \mathcal{L}_{\text{INT}} \]
    \[ \mathcal{L}_{\text{DIRAC}} = i (\psi^\dagger \gamma^0) \gamma^\mu \partial_\mu \psi - m (\psi^\dagger \gamma^0) \psi \]
    \[ \mathcal{L}_{\text{FIELD}} = -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} \quad \text{(invariant under} \ A_\mu \rightarrow A_\mu + \partial_\mu \lambda(x) \text{)} \]
    \[ \mathcal{L}_{\text{INT}} = q (\psi^\dagger \gamma^0) \gamma^\mu \psi A^\mu \quad \text{(not invariant under} \ A_\mu \rightarrow A_\mu + \partial_\mu \lambda(x) \text{)} \]
Theoretical Framework Overview

• The total Lagrangian can remain invariant as long as both a local phase and gauge transformation applied (local gauge invariance):

\[ A_\mu \rightarrow A'_\mu = A_\mu + \partial_\mu \lambda(x) \quad \text{and} \quad \psi \rightarrow \psi' = e^{-i\lambda(x)}\psi \]

• Experiment confirms phase transformations (Bohm-Aharonov), therefore this is a defining property of the EM field.

• Local gauge invariance is required for every interaction:

  ➢ To preserve invariance additional fields are introduced (gauge fields)
  ➢ Particle-Field interaction is uniquely determined
  ➢ Field equations are uniquely determined (only gauge invariant terms)
  ➢ Mass terms for the gauge fields are not gauge invariant

  ➢ Gauge fields have zero mass
Theoretical Framework Overview

• Strong Interaction
  ➢ Color is the conserved quantity
  ➢ Local gauge invariance under SU(3)_C
  ➢ A set of eight gauge fields (gluons) is predicted
  ➢ Interaction’s short-range is explained (confinement)

• Weak Interaction
  ➢ For gauge invariance to exist it had to be completed
    ➢ Electroweak Interaction
    ➢ Local gauge invariance under SU(2)_L \otimes U(1)_Y
    ➢ A set of four gauge fields W^{\mu}, \mu = 0, 1, 2, 3 is predicted
    ➢ Interaction is short-range (massive mediators) and not explained by the model!
    ➢ Fermions are prohibited to have mass! (Dirac mass term)

• Higgs
  ➢ Extra field neither fermion nor gauge field
  ➢ Breaks the electroweak symmetry for the observable states
    ➢ Short-range of the weak forces is explained
    ➢ Fermions acquire mass through the Higgs field
Theoretical Framework Overview

## Model of Elementary Particles

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Leptons</th>
<th>$Q_v$ (Name)</th>
<th>$Q_v$ (Symbol)</th>
<th>Electric Charge</th>
<th>Number of Color Charges</th>
<th>Mass in MeV</th>
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<tbody>
<tr>
<td>I</td>
<td>I</td>
<td>Up</td>
<td>u</td>
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<td>~1300</td>
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<td></td>
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<td>Down</td>
<td>d</td>
<td>-1/3</td>
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<td>~7</td>
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<td>Strange</td>
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<td>Tau</td>
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**Force Carriers (Gauge Bosons)**

<table>
<thead>
<tr>
<th>$Q_v$ (Name)</th>
<th>$Q_v$ (Symbol)</th>
<th>$Q_v$ (Symbol)</th>
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<td>Photon</td>
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<tr>
<td>Gluon</td>
<td>$g$</td>
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<tr>
<td>Weak Interactions</td>
<td>$Z^0$</td>
<td>90,110</td>
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<tr>
<td>$W^\pm$</td>
<td>83,110</td>
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**Strong Interactions**

<table>
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**Electromagnetism**

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**Weak Interactions**

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<th>$Q_v$ (Name)</th>
<th>$Q_v$ (Symbol)</th>
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<tr>
<td>Weak</td>
<td>$Z^0$ 90,110</td>
</tr>
<tr>
<td>$W^\pm$</td>
<td>83,110</td>
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</table>
Theoretical Framework Overview

• Standard Model problems

➢ Hierarchy problem

❖ Masses of particles are determined by the Higgs (~200 GeV)

❖ BUT the Higgs mass is not bounded, it can be up to \(10^{12} - 10^{18} \text{ GeV}\)

❖ Why is so low?

➢ Higgs mass quadratically diverges in perturbation theory if the fermion and boson masses are not “near” equal”

❖ \(M_{h}^2 \sim M_{h0}^2 + \left(\frac{g^2_F}{4\pi^2}\right)(m_F^2 - m_S^2)\)

➢ Gravity is not included
Theoretical Framework Overview

• **Supersymmetry**
  - A gauge theory that combines all particles (fermions and bosons) into “superfields”
    - All superfields now have zero mass
  - Particles and their “superpartners” have all quantum numbers the same and they differ only by one-half unit of spin
  - Number of particles in the standard model doubles
  - Among known particles there are no superpartners
    - Supersymmetry must be broken

• **If Supersymmetry is broken:**
  - All particles (fermions, bosons and Higgs) acquire mass determined from the energy scale where supersymmetry is broken
  - Quadratic divergences of the Higgs mass are suppressed since $m_{\text{FERMIOS}} \approx m_{\text{SCALARS}}$
Theoretical Framework Overview

- **Gauge Mediation of SUSY Breaking**
  - SUSY is broken in a sector of superfields not containing the known particles or their superpartners (hidden sector)
  - Gauge interactions between the hidden sector and the rest of the superfields and known particles transmit SUSY breaking
  - Experimental predictions for this class of models, do not depend from the details of the SUSY breaking, but rather from the features of the model after the breaking

- **GMSB model features**
  - Few parameters define the phenomenology
    - SUSY breaking scale in the messenger sector, \( F \)
    - Number of messenger pairs, \( N_{mess} \)
    - Messenger mass scale, \( M \)
Theoretical Framework Overview

• GMSB model features (cont.)
  - Universal mass scale of SUSY particles, $\Lambda$
  - Ratio of Higgs vacuum expectation values, $\tan\beta$
  - Sign of the Higgs sector mixing parameter, $\text{sign}(\mu)$

- R-parity invariance
  - $R = (-1)^{3(B-L)+2S}$  $S = \text{spin}, B = \text{baryon number}, L = \text{lepton number}$
  - Pair-production of SUSY particles that all finally decay
  - Lightest SUSY particle (LSP) must be absolutely stable
    - Cosmological constrains also require to be neutral

- LSP in R-parity-conserving SUSY escapes the detector
  - Experimental Signature $\Rightarrow$ Missing Transverse Energy

- Gravitino is the LSP: $m_G = 2.4 \left( \sqrt{\frac{F}{100 \text{ TeV}}} \right)^2 \text{ eV}$
Theoretical Framework Overview

• GMSB model features (cont.)
  
  ➢ Since LSP is stable, the next to LSP determines the phenomenology of GMSB models
    
    ❖ NLSP is either neutralino $\chi^0_1$ or a slepton
  
  ➢ NLSP lifetime is not fixed by the model
  
  ➢ Signatures depend on the NLSP type and decay length.
    
    ❖ Non-pointing photons in photon plus jets final state.
    
    ❖ Non-pointing $Z$’s from the primary vertex in final state
Theoretical Framework Overview

• GMSB model features (cont.)

\[ p\bar{p} \rightarrow \text{gauginos} \rightarrow W^{(*)}, Z^{(*)}, l + \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow \gamma\gamma + \tilde{G}\tilde{G} + X \]
Run II - Tevatron Collider

- Run I 1992-95
- Run II 2001-09(?) 100 × larger dataset at increased energy
- Collision energy, $\sqrt{s} = 1.96$ TeV
- Bunch crossing, $\Delta t = 396$ ns
Run II - DØ Detector

- Tracking System: Silicon, Fiber Tracker, Solenoid, Central & Forward Preshowers
- Muon Toroid
- Forward Mini-Drift Tubes
- Muon Scintillation Counters
- Shielding
- Platform
- Calorimeter
- Tracking System
- Fiber Tracker/Preshower VLPC Readout System
Run II - DØ Detector

- Interaction Point
  - Protons and antiprotons collide in bunches
  - Gaussian distribution
    - $z = 0$ with $\sigma = 28$ cm

- Hybrid Design
  - Barrels: For $r - \phi$ coverage
  - Disks: For $r-\phi$ and $r-z$ coverage

- Individual detectors
  - Ladders (barrels)
  - Wedges (disks)

- Measured with Optical Gauging Platform (OGP)

- Assembled under Coordinate Measuring Machine (CMM)
Run II - DØ Detector

- Compensating sampling calorimeter
  - $e/h = 1 \pm 0.02$

- Liquid Argon
  - Active sampling medium

- Depleted Uranium
  - Absorber material

- Three types of modules
  - EM section
  - FH section
  - CH section

- Energy resolution
  - $(\sigma/E)^2 = c^2 + S^2/E^{1/2} + N^2/E$
• Electromagnetic showers develop through multiplication of photons and electrons
  - Bremsstrahlung
  - Electron-positron pair production

• Electron-originated and photon-originated showers have pretty much the same profile in the calorimeter
Run II - DØ Detector

- Three level trigger
  - L1: Raw detector info
    - List of candidates from each subdetector (cal $E_T$ towers, ca:-trk match etc)
  - L2: Correlation Algorithms
    - List of trigger terms & physics objects
    - Combines correlations
  - L3: Event Filtering Algorithms
    - Online reconstructed e, µ, j
    - “physics tools”
    - Event topologies

FRAMEWORK

L1: HARDWARE

7 MHz:
Lum = $2 \times 10^{32}$cm$^{-2}$s$^{-1}$
396 ns → 132 ns crossing time

L2: HARDWARE

L3: SOFTWARE

TO DAQ & TAPE STORAGE

L1
4.2 µs

L2
100 µs

L3
100 ms
50 nodes

5-10 kHz
128 bits

1 kHz
128 bits

50 Hz

100 ms
50 nodes

5-10 kHz
128 bits

1 kHz
128 bits

50 Hz

L3: SOFTWARE

TO DAQ & TAPE STORAGE
Physics objects have to be reconstructed from detector readout

Dedicated software for object reconstruction (DØReco)

A set of identification variables is used in order to isolate the various candidates

Only EM objects are used in this analysis (EMID variables)
Reconstruction and Particle ID

- Electromagnetic Isolation
  - $EM_{iso} = \frac{E_{TOT}(R<0.4)}{E_{EM}(R<0.2)} - 1$
  - $(\Delta R)^2 = (\Delta \phi)^2 + (\Delta \eta)^2$
  - Deep and narrow measure
    - Photons and electrons ⇒ narrow
    - Hadronic showers ⇒ wider and deeper

- Electromagnetic Fraction
  - $EM_{fract} = \frac{E_{EM,FH1}}{E_{TOTAL}}$
  - It measures the deposition of energy within the cluster
**Reconstruction and Particle ID**

- **H-matrix variable**
  - Takes into account the shape of the shower itself
    - Longitudinal shower shape
    - Transverse shower shape
    - Energy deposition within the cluster
  - It measures how similar the shower is to an electron (photon) or a hadronic shower

- **Track match / veto**
  - All the above variables are calorimeter based
    - Allow for QCD processes to contaminate the sample
    - Doesn’t distinguishes electrons from photons
  - Tracking system (CFT and SMT) is used to reconstruct tracks
  - Tracks are matched with EM clusters spatially
    - $\chi^2_{\text{spatial}} = (\frac{\delta \phi}{\sigma_\phi})^2 + (\frac{\delta z}{\sigma_z})^2$
Reconstruction and Particle ID

- Photon pointing
  - DØ Calorimeter has excellent segmentation
    - Transverse and Longitudinal

Using calorimeter only information the point of origin of a photon can be found
  - Impact parameter
  - Z-position
$z(\text{RECO Vertex}) - z(\text{Pointing Vertex})$

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<td>Entries</td>
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<tr>
<td>RMS</td>
<td>9.19</td>
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<tr>
<td>$\chi^2 / \text{ndf}$</td>
<td>22.85 / 16</td>
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<tr>
<td>C1</td>
<td>1768 ± 28.8</td>
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<tr>
<td>Mean1</td>
<td>0.01349 ± 0.03961</td>
</tr>
<tr>
<td>Sigma1</td>
<td>2.918 ± 0.050</td>
</tr>
<tr>
<td>Par1</td>
<td>0 ± 0.0</td>
</tr>
<tr>
<td>C2</td>
<td>148.9 ± 19.3</td>
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<tr>
<td>Mean2</td>
<td>0.06016 ± 0.24448</td>
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<tr>
<td>Sigma2</td>
<td>8.306 ± 0.448</td>
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<tr>
<td>Par2</td>
<td>0 ± 0.0</td>
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$b(\text{RECO}) - b(\text{Pointing})$

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<td>$\chi^2 / \text{ndf}$</td>
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<tr>
<td>C1</td>
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<td>Mean1</td>
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<tr>
<td>Sigma1</td>
<td>1.948 ± 0.027</td>
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<tr>
<td>Par1</td>
<td>0 ± 0.0</td>
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<tr>
<td>C2</td>
<td>89.93 ± 9.20</td>
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<tr>
<td>Mean2</td>
<td>0.5461 ± 0.1712</td>
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<tr>
<td>Sigma2</td>
<td>-5.815 ± 0.218</td>
</tr>
<tr>
<td>Par2</td>
<td>0 ± 0.0</td>
</tr>
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</table>
Data Sample Selection

• Trigger Requirements
  ➢ Single and di-EM triggers (threshold above 20 GeV)
    ❖ Efficiency: \(\varepsilon_{\text{trigger}}(p_T > 20 \text{ GeV}) = 0.97 \pm 0.01\)
    ❖ Luminosity: \(\mathcal{L}_{\text{RECO}} = 263 \pm 17 \text{ pb}^{-1}\)

• Identification - offline cuts
  ➢ Simple cone reconstruction algorithm “scone”
  ➢ \(E_T > 20 \text{ GeV}, |\eta_{\text{Det}}| < 1.1, \text{EM}_{\text{iso}} < 0.15, \text{EM}_{\text{frac}} > 0.90, \chi^2_{\text{HMx7}} < 15\)
  ➢ Track match
    ❖ Electrons \(\chi^2_{\text{(spatial)}} > 10^{-3}\), photons otherwise
    ❖ \(\varepsilon_{\text{track}} = 0.936 \pm 0.002 \text{ (stat)} \pm 0.004 \text{ (syst)}\)
  ➢ Track isolation
    ❖ \(\left( \sum_{\text{tracks}} p_{\text{track}}^T \right)_{0.05 < R < 0.4} |z_{\text{PV}} - z_{\text{DCA}}| < 2 \text{ cm} < 2 \text{ GeV}\)
    ❖ \(\varepsilon_{\text{trk-iso}} = 0.96 \pm 0.02\)
Data Sample Selection

• Identification - offline cuts (cont.)
  ➢ Jet reconstruction
    ❖ Reconstructed within a 0.5 cone, and for jets passing standard
cuts their energy was corrected
    ❖ Reject events for which: $\sum E_T$ (bad jets) > 30 GeV
      ▪ $\varepsilon_{\text{bad jets}} = 0.97 \pm 0.02$ (sample independent)
  ➢ Topological cuts
    ❖ Misvertexing: $\Delta \phi$ (EM, MET) > 0.5
    ❖ Mismeasured jets: $\Delta \phi$ (jet, MET) < 2.5
Data Sample Selection

Only one track matched

Entries 5233
Mean 75.08
RMS 25.18
$\chi^2$/ndf 32.99 / 26
p0 $1308 \pm 47.86$
p1 $91.45 \pm 0.1724$
p2 $4.417 \pm 0$
p3 $-8103 \pm 4308$
p4 $247.5 \pm 109.3$
p5 $-0.7387 \pm 0.6696$
p6 $-0.055 \pm 0$

Two track matches

Entries 12053
Mean 89.33
RMS 13.05
$\chi^2$/ndf 240.2 / 37
p0 $9608 \pm 104.9$
p1 $91.17 \pm 0.05104$
p2 $4.417 \pm 0$
p3 $5120 \pm 935$
p4 $-285.1 \pm 48.33$
p5 $3.987 \pm 0.6242$
p6 $-0.05826 \pm 0.001669$
SUSY Signal Generation

- Event generator packages
  - Branching fractions and sparticle masses with ISAJET v7.58
    - better than PYTHIA’s SUSY generator
  - Event generation PYTHIA v6.202 with CTEQ5M structure functions
- Detector Simulation with DØGSTAR package
  - DØ GEANT Simulation of the Total Apparatus Response
  - Detector geometry and materials in each volume
  - Magnetic field
  - Simulates the passage of particles through the detector volume.
- Electronics Simulation with DØSim package
  - Digitization
  - Adds noise and detector inefficiencies
- Reconstruction with DØReco package
- Trigger Simulation with DØTrigSim
## SUSY Signal Generation

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<thead>
<tr>
<th>Point</th>
<th>$\Lambda$</th>
<th>$\frac{M}{\Lambda}$</th>
<th>$\tan\beta$</th>
<th>$N_5$</th>
<th>$m_{\tilde{\chi}_1^0}$ (GeV)</th>
<th>$m_{\tilde{\chi}_1^+}$ (GeV)</th>
<th>$\sigma^{\ell\ell\gamma}_{TOT}$ (pb)</th>
<th>$K$-factor</th>
<th>Efficiency</th>
<th>95% CL Limit, pb</th>
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<tr>
<td>1</td>
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<td>2</td>
<td>5</td>
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<td>69.4</td>
<td>122.0</td>
<td>0.861</td>
<td>1.240</td>
<td>0.081 ± 0.008</td>
<td>0.209</td>
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<tr>
<td>2</td>
<td>60</td>
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<td>1</td>
<td>76.9</td>
<td>136.2</td>
<td>0.534</td>
<td>1.229</td>
<td>0.103 ± 0.010</td>
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<td>3</td>
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<td>84.5</td>
<td>150.5</td>
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</table>
### SUSY Signal Generation

| \( \Lambda \) TeV | \( m(\chi_1^0) \) GeV | \( \sigma_{\text{TOT}}^{(LO)} \) pb | Acceptance for given mE_T cut, % |
|-----------------|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                 |                 |                 | > 25 | > 30 | > 35 | > 40 | > 45 | > 50 |
| 55              | 69.4            | 0.860           | 16.2 | 14.5 | 13.3 | 11.7 | 9.80 | 8.45 |
| 60              | 77.0            | 0.532           | 17.2 | 15.9 | 14.6 | 13.2 | 11.2 | 10.1 |
| 65              | 84.5            | 0.339           | 19.3 | 18.1 | 16.8 | 15.6 | 13.6 | 12.4 |
| 70              | 92.0            | 0.225           | 21.8 | 21.0 | 20.0 | 18.5 | 17.0 | 15.5 |
| 75              | 99.5            | 0.151           | 22.8 | 21.7 | 20.6 | 19.7 | 18.3 | 17.3 |
| 80              | 106.8           | 0.103           | 22.0 | 21.3 | 20.5 | 19.5 | 18.3 | 17.2 |
| 85              | 114.2           | 0.071           | 21.2 | 20.0 | 19.4 | 18.1 | 17.1 | 16.7 |
Standard Model Backgrounds

• Two sources of SM di-photon events with MET

  ➢ Events where MET is due to mis-measurement
    ❖ QCD: \( \gamma j , jj , \gamma \gamma \) (jet faking \( \gamma \) - dominant)
      ▪ \( mE_T \) resolution must be similar for \( \gamma \) and jet faking \( \gamma \)
    ❖ Drell-Yan: electrons identified as photons due to lost tracks

  ➢ Events with true MET and lost tracks
    ❖ \( W \gamma \to e \nu \gamma \) (dominant)
    ❖ \( W j \to e \nu \gamma \) (jet faking \( \gamma \) - dominant)
    ❖ \( Z \to \tau \tau \to e e + X \)
    ❖ t t , W W , W Z etc.
Standard Model Backgrounds

• Di-photon sample (inclusive)
  - Simple cone reconstruction algorithm “scone”
  - $E_T > 20 \text{ GeV}, |\eta_{\text{Det}}| < 1.1, E_{\text{M}_{\text{iso}}} < 0.15, E_{\text{M}_{\text{fract}}} > 0.90, \chi^2_{\text{HMx7}} < 15$
  - Topological cuts
    - Misvertexing: $\Delta \phi (\text{EM, MET}) > 0.5$
    - Mismeasured jets: $\Delta \phi (\text{jet, MET}) < 2.5$
Standard Model Backgrounds

\[ \Delta \phi \text{ (Radians)} \]

Events / 0.033 rads

\[ \Delta \phi \text{ (Radians)} \]
Standard Model Backgrounds

• QCD Background (and Drell-Yan)
  ➢ Require track veto to suppress Drell-Yan
  ➢ Idea is that MET resolution is very similar for
    ❖ di-photon events
    ❖ photons plus jets faking photons
  ➢ Estimate can be done if the same cuts are used as with di-photons but
    with at least one EM object having reverse-photon cuts
  ➢ Same base sample as for di-photons
  ➢ Require HMx7 > 20 and HMx8 < 200
  ➢ EM objects with EM$_{iso}$ < 0.15 and EM$_{frac}$ > 0.90

• Use low MET region (MET < 15 GeV) to normalize QCD sample to
di-photon

• Predict QCD background for high-$p_T$
Standard Model Backgrounds

- **Electroweak background**
  - Electron plus photon sample used
  - Same base sample as for di-photons
  - Require track match and track isolation
    - Electrons: $\chi^2_{\text{spatial}} > 10^{-3}$, Photons: otherwise
    - $(\sum_{\text{tracks}} p_T^{\text{track}})_{0.05<R<0.4} |z_{PV-zDCA}|<2\text{cm} < 2 \text{ GeV}$
  - Contains QCD part that is extracted as in the di-photon case

- **After extraction remaining sample is multiplied by ratio $\frac{1-\epsilon_{\text{trk}}}{\epsilon_{\text{trk}}}$:**
  - Probability an electron to be identified as photon, $(1-\epsilon_{\text{trk}})$
  - Probability an electron to obtain background estimate to the di-photon, $\epsilon_{\text{trk}}$
# Standard Model Backgrounds

<table>
<thead>
<tr>
<th></th>
<th>Total events</th>
<th>$E_T &lt; 15$ GeV</th>
<th>$&gt; 20$ GeV</th>
<th>$&gt; 30$ GeV</th>
<th>$&gt; 40$ GeV</th>
<th>$&gt; 45$ GeV</th>
<th>$&gt; 50$ GeV</th>
<th>$&gt; 55$ GeV</th>
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<tr>
<td>$\gamma\gamma$</td>
<td>1909</td>
<td>1800</td>
<td>34</td>
<td>6</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>$e\gamma$</td>
<td>889</td>
<td>782</td>
<td>70</td>
<td>34</td>
<td>15</td>
<td>10</td>
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<td>QCD</td>
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<td>73</td>
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<td>22</td>
<td>15</td>
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<td>QCD BG to $\gamma\gamma$</td>
<td>35.5 ± 2.1</td>
<td>7.6 ± 0.9</td>
<td>2.8 ± 0.5</td>
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<td>QCD BG to $e\gamma$</td>
<td>15.4 ± 1.0</td>
<td>3.3 ± 0.4</td>
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<td>$e\gamma$ total</td>
<td>54.6 ± 8.4</td>
<td>30.7 ± 5.8</td>
<td>13.8 ± 3.8</td>
<td>9.0 ± 3.2</td>
<td>4.3 ± 2.2</td>
<td>3.5 ± 2.0</td>
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<td>$e\gamma$ BG to $\gamma\gamma$</td>
<td>3.7 ± 0.6</td>
<td>2.1 ± 0.4</td>
<td>0.9 ± 0.3</td>
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<td>0.3 ± 0.1</td>
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<td>Total BG to $\gamma\gamma$</td>
<td>39.2 ± 2.2</td>
<td>9.7 ± 1.0</td>
<td>3.7 ± 0.6</td>
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<td>1.9 ± 0.4</td>
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</table>
Standard Model Backgrounds

![Graph showing data points, background contributions, and SUSY signal](image)

- **Γγ Data**
- **Fake $E_T$ background**
- **Total background**
- **SUSY signal x10**

![Graph axes](image)

- **$E_T$ (GeV)**
- **Events / 5 GeV**
Standard Model Backgrounds

- $e\gamma$ Data
- QCD
- QCD+W
- QCD+Wj+W

Events / 5 GeV

$E_T$ (GeV)
Optimization and Limits Setting

- **Optimal missing $E_T$ cut**
  - Maximizing signal to background “significance”
  - Devise a measure of significance as a function of the missing $E_T$
  - Plot this measure for all signal points
  - Choose as optimal missing $E_T$ the minimum
  - Optimal missing $E_T$ cut was found to be 40 GeV

- **Limit Setting**
  - Standard prescription used by DØ
  - Uses Bayesian approach
Optimization and Limits Setting

\[ M_m = 2\Lambda, N_5 = 1, \tan\beta = 15, \mu > 0 \]

\[ \sigma = K \cdot \sigma_{\text{th}} \]

\[ \sigma_{95\%} \]

\[ m_{\tilde{\chi}_i} \] (GeV)

\[ \Lambda \] (TeV)
Optimization and Limits Setting

\[ M_m = 2 \Lambda, N_5 = 1 \]
\[ \tan \beta = 5, \mu > 0 \]
$M_m = 10\Lambda, N_5 = 2$
$tan\beta = 5, \mu > 0$
Conclusions

• No excess of events above the Standard Model background prediction is found, for all missing $E_T$ explored.

• From the observed number of events, lower limits have been set at the 95% C.L. for masses of the lightest neutralino and chargino.
  
  ✓ Lower limit of 107.7 GeV for the neutralino mass
  ✓ Lower limit of 194.9 GeV for the chargino mass

• Results published in Phys. Rev. Lett.
  