Signature-Based Searches for New Physics Involving Photons at the Tevatron

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Motivation

- As rare phenomenon are observed theorists get ever more creative in devising new possibilities for why
  - why limit ourselves to the current crop of TOE
  - review the exotic signatures and see if anything sticks out
- Photons are a good candidate since they don't add a big mass burden to the event and are reasonably rare
- Cautionary note
  - looking for rare phenomenon sometimes succeeds in finding fluctuations
    - one such fluctuation is the ee\gamma\gamma missing E_T event described in the 1995 PP workshop at FNAL
    - we've been looking for another for 15 years
- Perhaps because of the above event this has been a popular CDF sport
- D0 has a dark photon & GMSB search but nothing that fits this description so all the results here are from CDF
Where might you look?

- Searches described here include
  - $\gamma\gamma$ plus
    - $\tau$
    - $e$
    - $\mu$
    - Missing $E_T$
  - $\gamma+jet+b+missing\ E_T$
  - $\gamma+b+missing\ E_T+lepton\ (e\ or\ \mu)$
    - this one is of particular interest because it includes $t\bar{t}\gamma$ events
- Numerous as yet unconfirmed theories lead to such signatures
  - SUSY, Technicolor, associated Higgs production...
Diphoton + X searches

Two triggered photons
- 2 photon candidates
  - both isolated with $E_T > 12$ GeV
  - no isolation requirement but both with $E_T > 18$ GeV

Candidate events have:
- 2 candidates with $E_T > 13$ GeV & $0.05 < |\eta| < 1.05$
  - shower maximum lateral profile consistent with single shower
  - no high $P_T$ tracks pointing at the candidate
  - isolation (track and calorimeter) in a cone of $\Delta \eta, \Delta \phi$ with $R < 0.4$
    - calorimeter $0.1 X E_T$ for $E_T < 20$ GeV or $2.0$ GeV $+ 0.02 X (E_T - 20$ GeV) above $20$ GeV
    - track:: $2.0$ GeV $+ 0.005 X E_T$

Sample of $\gamma \gamma$ from $2.0 \pm 0.1$ fb$^{-1}$
- 31,116 candidates (~30% true diphotons)
- 42,708 control events with at least one failed $\gamma$
**γγ plus τ results**

- τ reconstruction using calorimeter and shower max. for π⁰ plus tracking
  - Mass <1.8 GeV/c²
  - Reconstruction in cone with size dependent on E_T
    - θ<0.17 for 30 GeV
    - θ<0.05 for 100 GeV
  - Isolation annulus with outer radius of 0.52
    - Track P_T<1.0GeV
    - π⁰E_T<0.6GeV
- 34 events observed in 2.0±0.1 fb⁻¹
  - Expect 46±10
$\gamma\gamma$ plus $\tau$ results

- Fake $\tau$ dominates the background (44 out of 46 events)
**$\gamma \gamma$ plus lepton results**

- $1.1 \pm 0.1 \text{ fb}^{-1}$
- $E_T > 20 \text{ GeV}$
- SM sources estimated using Madgraph+Pythia for $Z/W\gamma \gamma$ K factor of 1.4 for LO->NLO
- Background estimates come from event sample plus rates of jet or e to fake gamma
- Table includes a cut on silicon hits pointing at $\gamma$ (events plotted don't have this cut which adds 2 such events)

| Source       | electron       | muon         |
|--------------|----------------|--------------|
| $Z\gamma\gamma$ | $0.82 \pm 0.08$ | $0.50 \pm 0.05$ |
| $W\gamma\gamma$ | $0.15 \pm 0.02$ | $0.08 \pm 0.01$ |
| $l\gamma+e\rightarrow\gamma$ | $2.26 \pm 0.46$ | $0.004 \pm 0.004$ |
| $l\gamma+jet\rightarrow\gamma$ | $0.44 \pm 0.26$ | $0.12 \pm 0.08$ |
| Fake $l+\gamma\gamma$ | $0.12 \pm 0.05$ | $0.004 \pm 0.004$ |
| **Total** | **3.79 $\pm 0.54$** | **0.71 $\pm 0.10$** |
| **Observed** | **1** | **0** |
γγ plus electron results
Expected muon distributions
\( \gamma \gamma \) plus \( E_T \)

- Missing \( E_T \) modeled using detailed understanding of jet resolution and underlying event contribution
  - Significance constructed to estimate log likelihood of a given event missing \( E_T \)

- Several other sources estimated
  - Incorrect vertex
    - Other vertices considered and if one produces less missing \( E_T \) it is used instead
    - Leaves cases where other vertex is not reconstructed (this contribution is estimated)
  - Three gamma events with a missing gamma (this is estimated from the data)
  - Non collision events (cosmic rays) TDC's used to estimate this
\( \gamma\gamma \) plus missing \( E_T \)
$\gamma\gamma$ plus missing $E_T$

|                | signif.$>3$ | signif.$>4$ | signif.$>5$ |
|----------------|-------------|-------------|-------------|
| EWK            | $35.4 \pm 2.2$ | $29.9 \pm 2.0$ | $25.9 \pm 1.9$ |
| Total exp.     | $71.7 \pm 7.5$ | $39.0 \pm 3.1$ | $30.4 \pm 2.4$ |
| Observed       | 82          | 31          | 23          |
\(\gamma+\text{jet}+b+\text{missing } E_T\)  

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- Photon candidate with \(E_T > 25\) GeV and \(|\eta|<1.1\)
- Two jets with \(E_T > 15\) GeV and \(|\eta|<2.0\)
- \(\Delta R > 0.4\) for all of the above (\(\gamma\) and jets)
- Missing \(E_T > 25\) GeV
- \(\Delta \phi(\text{jet and met}) > 0.3\)
- 1 SECondary VerTeX (SECVTX) b tag
  - 617 events satisfy above
  - Expect \(607 \pm 74\) (stat.) \(\pm 86\) (syst.)
  - This includes \(115 \pm 49 \pm 54\) fake \(\gamma\) and \(141 \pm 6 \pm 30\) true \(\gamma\) fake b
  - \(\gamma\) b \((341 \pm 18 \pm 91)\) dominates
- Veto events with track (\(P_T > 20\) GeV) carrying \(> 90\%\) track \(\Sigma P_T\) in \(\Delta R < 0.4\)
  - 17 events eliminated by this cut
- 600 events satisfy all cuts in 2.0 fb\(^{-1}\) sample
\( \gamma + \text{jet} + b + \text{missing } E_T \)
$\gamma + b + \text{missing } E_T + \text{lepton (e or } \mu \text{)}$

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- $\gamma + b + \text{missing } E_T + \text{lepton (e or } \mu \text{)}$ 1.9 fb$^{-1}$ (trigger on high P$_T$ lepton)
  - Central photon with E$_T>10$ GeV
  - B tagged jet with E$_T>15$ GeV
  - Missing E$_T>20$ GeV
  - e or $\mu$ with E$_T>20$ GeV

- 28 events observed
  - Expect 31.0(+4.1-3.9)
  - Dominated by jets faking $\gamma$ and mistagged b jets (7.58$\pm$3.11 & 7.65$\pm$0.70 respectively)
  - Top plus gamma come in next (semileptonic: 3.58$\pm$0.65 & dilepton: 2.32$\pm$0.41)

- subsample rich in $t\bar{t}\gamma$
  - require $H_T>200$ GeV
  - require $N_{\text{jets}} \geq 3$
\( \gamma + b + \text{missing } E_T + \text{lepton (e or } \mu) \)

| SM Source                  | \( e\gamma bE_T \) | \( \mu\gamma bE_T \) | \((e+\mu)\gamma bE_T\) |
|----------------------------|---------------------|----------------------|------------------------|
| \( tt\gamma \) semileptonic| 2.06 ± 0.38         | 1.52 ± 0.28          | 3.58 ± 0.65            |
| \( tt\gamma \) dileptonic  | 1.30 ± 0.23         | 1.02 ± 0.18          | 2.32 ± 0.41            |
| \( W^\pm c\gamma \)       | 0.75 ± 0.16         | 0.72 ± 0.15          | 1.47 ± 0.26            |
| \( W^\pm c\gamma \)       | 0.08 ± 0.04         | 0.22 ± 0.06          | 0.30 ± 0.08            |
| \( W^\pm b\gamma \)       | 0.62 ± 0.11         | 0.42 ± 0.08          | 1.04 ± 0.17            |
| \( Z(\tau\tau)\gamma \)   | 0.13 ± 0.09         | 0.11 ± 0.08          | 0.24 ± 0.12            |
| \( WZ \)                   | 0.08 ± 0.04         | 0.01 ± 0.01          | 0.09 ± 0.04            |
| \( \tau \to \gamma \) fake| 0.12 ± 0.01         | 0.10 ± 0.01          | 0.22 ± 0.01            |
| Jet faking \( \gamma \)    | 4.56 ± 1.92         | 3.02 ± 1.19          | 7.58 ± 3.11            |
| Mistags                   | 4.11 ± 0.41         | 3.54 ± 0.37          | 7.65 ± 0.70            |
| QCD                       | 1.49 ± 0.77         | 0^{+1}_{-0}           | 1.49^{+1.30}_{-0.77}   |
| \( eeE_T b, e \to \gamma \)| 1.50 ± 0.28         | -                     | 1.50 ± 0.28            |
| \( \mu eE_T b, e \to \gamma \)| -                   | 0.45 ± 0.10          | 0.45 ± 0.10            |

Predicted | 16.8 ± 2.2\((\text{tot})\) | 11.1^{+1.7}_{-1.4}\((\text{tot})\) | 27.9^{+3.6}_{-3.5}\((\text{tot})\) |

Observed | 16 | 12 | 28 |
$\gamma + b + \text{missing } E_T + \text{lepton (e or } \mu \text{)}$
Require $H_T > 200$ GeV and $N_{jets} > 2$

16 events with ~ 4 expected top plus gamma (11.2+2.3-2.1 expected total)
$\gamma + b + \text{missing } E_T + \text{lepton (e or } \mu\text{)}$

- Subtracting non-top sources yields $0.15 \pm 0.08\text{pb for } t\bar{t}\gamma$
Conclusion

- No surprises so far.
- Tevatron physics is going strong!
  - Sensitive to processes that are two orders of magnitude rarer than top production
  - Lots more data to come