New Physics Searches at the Tevatron

Amitabh Lath
Rutgers University/CDF
For the CDF and D0 Collaborations

ICHEP 2004
Beijing
Tevatron: The Energy Frontier

- 1.96 TeV CM Energy
- 500 pb\(^{-1}\) to tape NOW
- 4 fb\(^{-1}\) to tape by FY 2009.

(8 fb\(^{-1}\) possible?)

- *When will new physics show up?*
- *What will it look like?*
- *Will our triggers and analyses be sensitive to it?*

We need to think beyond established theories
New Physics: Beyond Higgs, SUSY

- **Use familiar objects:** $e, \mu, \tau, \gamma, \text{jet, } E_T$
  - **Massive Objects:**
    - $Z'/W'$, Gravitons (leptons, photons)
    - Leptoquarks (leptons, $E_T$, jets)
    - Extra dimensions (leptons, jets, $E_T$)
  - **Compositeness:**
    - Excited Fermions (leptons, photons)
    - Technicolor (leptons)
- **Truly Exotic Objects**
  - Charged Massive Particles (CHAMPS)
  - Magnetic Monopoles
The Classic Searches

$e^+e^-$: Probe Z’, RS Graviton...

CDF Run II Preliminary (200 pb$^{-1}$)

D0 Run II 200 pb$^{-1}$

DiEM Mass Spectrum

Note: agreement over 2 orders of magnitude in $m_{ee}$. 

Hypothetical Z’

Large Extra dimensions
The Classic Searches continued

$\mu^+\mu^- : \text{Probe Z}', \ RS \ Graviton...$

e,\mu \text{ complimentary:}

e \rightarrow \text{uses EM calorimeter, resolution better at harder e.}

$\mu \rightarrow \text{uses tracker, resolution better at softer } \mu.$
Historically ee, (µµ) searches have paid off handsomely at hadron machines.

Insensitive to QCD remnants.
Dilepton Cross-Section Limits: ee

CDF Run II Preliminary (200 pb$^{-1}$)

D0 Run II Preliminary

CDF : $Z' \rightarrow ee$ Limit  750 GeV/c$^2$

D0: $Z' \rightarrow ee$ Limit  780 GeV/c$^2$

D0 200 pb$^{-1}$
### Dilepton Cross-Section Limits: $\mu\mu$

**CDF Run II Preliminary (200 pb$^{-1}$)**

- $\sigma_{BR}(Z' \rightarrow \mu\mu)$ (95% C.L.)
- $\sigma_{BR}(Z_H \rightarrow \mu\mu)$ (LO\times1.3)

**D0 250 pb$^{-1}$**

- $\sigma \times BR(Z' \rightarrow \mu\mu)$ (LO\times1.3)

**Limiting Values**

- **CDF**: $Z' \rightarrow \mu\mu$ Little Higgs
  - $\cot\theta = 0.7$: 720 GeV/c$^2$
- **D0**: $Z' \rightarrow \mu\mu$ (SM)
  - > 680 GeV/c$^2$

**Limits**

- $\sim 60$ fb
Almost there! Need another order of magnitude
Another promising channel: Diphoton

Diphoton Mass = 405 GeV
Photon Et = 172, 175 GeV

$\gamma \rightarrow$ an e without a track.

CDF Preliminary, 345 pb$^{-1}$

Entries/5 GeV/c$^2$

$10^3$

$10^2$

$10^1$

$10^{-1}$

$10^{-2}$

$10^{-3}$

$0$ $50$ $100$ $150$ $200$ $250$ $300$ $350$ $400$ $450$ $500$

$m_{\gamma\gamma}$ (GeV/c$^2$)

Total Background

CDF Run II Preliminary (345 pb$^{-1}$)

$\sigma$BR(G $\rightarrow$ $\gamma\gamma$) limit (95 % C.L.)

$\sigma$BR(G $\rightarrow$ $\gamma\gamma$) (PYTHIA $\times$ 1.3)

Randall-Sundrum Model

LIMTS

$\sim$70 fb

365 GeV/c$^2$

565 GeV/c$^2$

690 GeV/c$^2$
Combined Limits: Graviton, LED

- Pairs of hard, isolated leptons and photons are powerful tools to hunt new physics.
- The SM backgrounds are small and well understood.
- The results are $\sigma \times \text{BR}$, which can be interpreted in a variety of ways by different models (some of which haven’t been published yet!)

$\eta = \frac{F}{M_s^4}$

$\eta$ limit: 0.24 TeV$^{-1}$

$M_{\text{PL}} > 1.43$ TeV (GRW) World’s best limit on $M_{\text{PL}}$
Adding $E_T$: $W'$ Search

- Electron + $E_T$
  - Neutrinos show up as MET
- Many sources of $E_T$ tails:
  - Muons
  - Cracks in detector
  - Energy calib.
- Plot shows we have good understanding of $E_T$.

$W'$ limit plot
work in progress.
**e+γ: Compositeness (Excited electrons)**

- **Compositeness**
- **Contact**
- **Gauge mediated**

3 events seen

![Graph showing entries and integrated number of entries](image)

- **CDF Run II Preliminary**
- **L = 200 pb⁻¹**
- **Zeγ**
- **m_{eγ}**
- **Integrated # of Entries**
- **Total Background**
- **Total Uncertainty**
- **Meγ (GeV)**
Limits on excited electrons

CDF Run II Preliminary
\[ \int L \cdot dt = 200 \text{ pb}^{-1} \]

\( \sigma \cdot BR(e^* \rightarrow e \gamma) \) (pb)

\( M_{e^*} \) (GeV)

95% CL Limit

208 GeV

CDF Run II Preliminary

95% C.L. Exclusion Region

\( f/\Lambda \) (GeV\(^{-1}\))

\( \Gamma/\Gamma_{\text{meas}} = 2, \Gamma \text{ Full BW Width} \)

ZEUS (1994–1997)

H1

L3

LIMITS
\(~70 \text{ fb}\)
**Electrons+Jets: Leptoquarks**

Two energetic electrons.

Two jets

1st gen. LQ

Scalar Energy sum, $e_\text{ejj}$
Electrons+Jets: Leptoquarks

Two energetic electrons. Two jets

- Limit ~ 100 fb
- More challenging at lower mass.
  - QCD bg requires hard cuts that affect limit at low mass.

- Jets harder to study than e, γ
  - Jet multiplicity hard to simulate.
  - Jet \( \leftrightarrow \) quark, g correspondence hard to disentangle
  - Jet energy resolution not nearly that of e, γ.
Electron+Jets+$E_T$: Leptoquarks

- One energetic electron.
- $E_T$
- Two jets

Limit $\sim 100$ fb
Jets + $E_T$: Leptoquark

CDF Run II Preliminary

$\int L \, dt = 191 \text{ pb}^{-1}$

- Data
- QCD prediction
- + SM EWK / $t\bar{t}$ prediction
- LQ ($m = 125 \text{ GeV/c}^2$)

- CDF Upper Limit, 95% CL
- Theoretical cross section (PRL 79, 1997)
- CTEQ5M, $Q=m(LQ)$
- CTEQ5M, $Q=0.5m(LQ)$, $2m(LQ)$

No electrons in final state
Leptoquark goes to $\nu$, jet.

Challenging at low mass.

Important for squark/gluino searches
Leptoquarks (1\textsuperscript{st} Gen. Limits)

\[ \beta = \text{Branching Ratio (LQ} \rightarrow \text{eq)} \]

\[ \begin{array}{cccccc}
140 & 160 & 180 & 200 & 220 & 240 \\
\end{array} \]

\[ \begin{array}{cccccc}
0.2 & 0.4 & 0.6 & 0.8 & 1.0 \\
\end{array} \]

\[ \begin{array}{cccccc}
0 & 0.2 & 0.4 & 0.6 & 0.8 & 1.0 \\
\end{array} \]

\[ \begin{array}{cccccc}
140 & 160 & 180 & 200 & 220 & 240 \\
\end{array} \]

DØ Run II Preliminary  D0 200 pb\(^{-1}\)

\[ \begin{array}{cccccc}
e^+\nu+2\text{jets} & e^-e^++2\text{jets} & \text{DØ Run II Combined Limit} \\
\end{array} \]
Now with \( \mu: \) LQ 2\(^{nd} \) Generation

Two muons,
Two jets.

Limit \(~ 70 \text{ fb}\)

CDF Run II Preliminary (198 pb\(^{-1}\))

Cylindrical sig/bkg discrimination

Int. Lum = 2.5 fb\(^{-1}\)

LQ m=220 MC

DY,Top MC

Search for 2\(^{nd} \) Generation
Scalar Leptoquarks, \( \beta = 1 \)

Leptoquark Mass (GeV/c\(^2\))

Limit

\( M_{LQ} > 241 \text{ GeV/c}\(^2\) \)

CDF upper limit, 95% CL

2 events observed

Theoretical Cross Sections, Phys Rev Lett 79, 341, '97

CTEQ4M, Q = M\(_{LQ}\)

CTEQ4M, Q = 0.5, 2 M\(_{LQ}\)

\( \sigma \times \beta^2 \) (pb)
Jets+MET: Large Extra Dimensions

**QCD**

**Data**

**MC**

**Signal**

**Most stringent**

**No k factor**

Need to understand calorimetry, tracking, acceptance in excruciating detail.

D0 Run II Preliminary

D0 Run I

CDF Run I

L3

**Nd**

Number of Dimensions

**Events / 10**

missing ET

**Events / 10**

second jet pT

**D0** Run II Preliminary

Data

MC

Signal

**D0** prelim.
A special sort of jet: $\tau \rightarrow \text{hadrons}$

See Weiming Yao’s talk for more on taus.
Truly Exotic: CHAMPS

- CHAMPS are \textit{slow moving}
  - Large Ionization loss
  - Long time of flight
- Highly penetrating
  - Will look like a muon

\[ \int L \, dt = 53 \text{ pb}^{-1} \]

CDF Run 2 Preliminary

\[ \text{Cross section (pb)} \]

\[ \text{Stop Mass (GeV/c}^2 \text{)} \]

\[ m_{\text{isolated-stop}} > 108 \text{ GeV/c}^2 \]

\[ \approx 10,000 \text{ fb} \]
Truly Exotic: Monopole

- Bends in the *wrong* plane (→ high pt)
- Large ionization in scint (>500 Mips!)
- Large dE/dx in drift chamber

CDF Run II Preliminary

**m_{monopole} > 350 GeV/c^2**

95% CL Limit

LIMITS ~300 fb
Summary

- **Tevatron luminosity is ramping up.**
  - 4 fb\(^{-1}\) promised by 2009. *Exciting physics possible.*

- **Translating detector understanding to physics.**
  - Objects like \(e, \mu, \gamma, \tau, E_T, \) jets, (b) are now reconstructed w/ excellent efficiency, purity. We use these to search for \(V',\) Technicolor, LQ, excited fermions, extra dim...
  - Going to get even better: More luminosity, better understanding.
  - Now, limits \(~50 - 100\) fb (leptons, photons). *Soon, \(~10\) fb!* 

- **We think outside the box.**
  - Hunt for new objects like CHAMPS, monopoles…
  - Could use help from theorists here.

- **We hope to see new physics soon.**
  *We are sick and tired of making exclusion plots!*
Backup slides
Tevatron Promises High Luminosity…

- Aug04: ~0.7fb⁻¹ delivered: > design
- 12 pb⁻¹ / week currently: above “design”
- 4 fb⁻¹ line: 2009? Earlier?

Slam dunk!

Oct 03
But can they deliver?

Recent news is encouraging!