Searches at the Tevatron

Bill Orejudos
CDF Collaboration
Lawrence Berkeley National Laboratory
ICHEP 2002
July 24-31, 2002
Outline

• Tevatron, CDF, D0 upgrades
• Searches
  – new gauge bosons
  – technicolor, compositeness, topcolor
  – long-lived heavy charged particles
  – new physics with photons
  – Large Extra Dimensions
  – Supersymmetry: see talk by V. Zutshi
• Conclusion
The Tevatron

$\bar{p}p$ collider

$\sqrt{s} = 1.8$ TeV at Run I (1992 - 96)
about 0.1 fb$^{-1}$ per experiment

First phase of Run II (Run IIa)
started spring 2001

$\sqrt{s} = 1.96$ TeV

goal : 2 fb$^{-1}$ per experiment
CDF Upgrade

Time-of-Flight (TOF) added

CTC replaced by COT

SVX replaced layer of silicon added to beampipe

Intermediate Silicon Layers (ISL) added

Upgrade will allow operation at high luminosity and extend physics capabilities

New Electronics, Trigger, DAQ

End Plug Calorimeters upgraded, extended to larger $\eta$

New Forward Detectors

Plug Shower Max added

Muon System upgraded
D0 Upgrade

- Forward Mini-drift chambers
- Central Scintillator
- Forward Scintillator
- Shielding
- New Solenoid, Tracking System
  Si, SciFi, Preshowers

+ New Electronics, Trig, DAQ
CDF W' Search

Older analysis looks for decay of $W'$ to 2 leptons

No sensitivity in the case that the leptonic decay is suppressed

New CDF Run I analysis looks for $W' \rightarrow tb$

Select events which pass high $p_T$ lepton trigger
Remove dilepton events
Require lepton to be central and isolated
Require missing $E_T > 20$ GeV (to select W candidates)
Require 2 or 3 jets with $E_T > 15$ GeV
Require at least one jet to be tagged as a b-jet
CDF $W'$ Results

$\ell \nu jj$ invariant mass distribution:

- $p_T^\nu = \text{missing } E_T$
- $p_Z^\nu : \text{constrain } M_{\ell \nu}$

- to be 80.22 GeV/$c^2$

Background: QCD, tt, single top

$48.0 \pm 6.0$ expected from bkgnd,

57 observed

Excluded:

- $225 < M_w^< < 536 (M_w^>, >> M_{\nu R})$
- $225 < M_w^< < 566 (M_w^<, < M_{\nu R})$
**D0 W' Results**

Events from jet triggers selected
Jet $E_T > (115, 85, 50, 30)$ GeV

Dijet mass distribution shows no evidence of an excess

Excluded:
$400 < M_{W'} < 625$ GeV/c$^2$
Drell-Yan Production

Dilepton final state can be used in searches for:
- new gauge bosons (Z')
- large extra dimensions
- quark-lepton compositeness
- technicolor

This would be modified by the presence of some sort of new physics – could exchange a new gauge boson, Kaluza-Klein (KK) tower, etc

Could also have new diagrams leading to dilepton final states, e.g. 2 gluons coupling to KK tower.
Selection of Dilepton Events

CDF Run I Dilepton mass distribution

Events selected with $\mu$ and $e$ triggers
Leptons required to:

- Be oppositely charged
- Have a high transverse momentum
  - electron: $E_T > 25$ GeV
  - muon: $p_T > 20$ GeV/c
- Be isolated
- Originate from single vertex

Background low at high lepton inv. mass:

$M_{\ell^+\ell^-} > 300$ GeV/$c^2$: $5.6 \pm 0.6$ events
$M_{\ell^+\ell^-} > 400$ GeV/$c^2$: $1.3 \pm 0.1$ events

No deviation from SM
Results and Run II Reach (Z')

CDF Z' search

Limits on Z' production (95% C.L.)

- σB predicted using SM couplings
- 95% C.L. σB limit (CDF e+μμ, 110pb⁻¹)
- 690 GeV/c²

M_{Z'}, > 690 GeV/c²

Z' Run IIa reach: 1000 GeV/c²
Z peaks, Run II data

Analyses to look for an excess in the high mass region in progress by both CDF and D0
Drell-Yan searches can also be used to look for evidence of technicolor and quark-lepton compositeness. D0 Run I limits:

\[ \rho_{T1}, \omega_{T1} \rightarrow e^+ e^- \rightarrow M_{\rho_{T1}, \omega_{T1}} > 225 \text{ GeV}/c^2 \] (other decays suppressed)

Run IIa reach : 410 GeV/c²

compositeness scale from \( e^+ e^- \) \( \Lambda^+(\Lambda^-) > 3.3(4.2) \text{ TeV} \)

Run IIa \( \Lambda^+(\Lambda^-) \) reach : 6.5 (10) GeV/c²

Quark compositeness searched for in dijets. D0 Run I limits:

compositeness scale \( \Lambda^+(\Lambda^-) > 2.7(2.4) \text{ TeV} \)

excited quarks : \( q^* \rightarrow qg \) \( M_{q^*} > 775 \text{ GeV}/c^2 \)

Run IIa reach : 940 GeV/c²
Technicolor searched for in other channels. CDF limits:

\[ \rho_{T1} \to W \pi_{T1} \to \ell \nu b\bar{b} \]

170 < \( M_\rho \) < 200 GeV/\( c^2 \)
excluded (\( M_\pi \approx M_{\rho/2} \))

\[ e^- (\mu) \text{ with } E_T (p_T) > 20 \text{ GeV} \]
Missing \( E_T > 20 \) GeV
2 jets, \( E_T > 15 \) GeV, one b-tagged
160-240 GeV/\( c^2 \) at Run IIa

\[ \omega_{T1} \to \gamma \pi_{T1} \to \gamma b\bar{b} \]

240 < \( M_\omega \) < 310 GeV/\( c^2 \)
excluded (\( M_\pi = 120 \) GeV/\( c^2 \))

\[ E_T^\gamma > 25 \text{ GeV} \]
2 jets, \( E_T > 20 \) GeV, one b-tagged
140 < \( M_\rho \) < 290 GeV/\( c^2 \)
excluded (\( M_\pi = 60 \) GeV/\( c^2 \))

\[ \rho_{T8} \to \pi_{LQ} \pi_{LQ} \to b\bar{b} \nu \bar{\nu} \]

2,3 jets with \( E_T > 15 \) GeV, one b-tagged
No other jets with \( E_T > 7 \) GeV, no leptons
Missing \( E_T > 40 \) GeV

\( M_\rho < 600 \) GeV/\( c^2 \)

850 GeV/\( c^2 \) at Run IIa
Topcolor

Look for particle decaying to \( tt \) (leptophobic \( Z' \))

- \( e^- (\mu) \) with \( E_T (p_T) > 20 \text{ GeV} \)
- Missing \( E_T > 20 \text{ GeV} \)
- 4 jets, \( E_T > 15 \text{ GeV} \)
  4\(^{th}\) jet: \( E_T > 8 \text{ GeV} \) if one other jet b-tagged
- Fit performed to get \( M_{tt} \)

\( M_{tt} \) distribution consistent w/ SM

Run IIa reach 1100 GeV/c\(^2\)
\((\Gamma = 0.04 M_{Z'})\)

\( M_{Z'} > 780 (480) \text{ GeV/c}^2 \) for nat. width \( \Gamma = 0.04 M_{Z'} (0.012 M_{Z'}) \)
**CHAMPS**

**Charged Massive Particles**, long-lived enough to leave detector

- Heavy, slow moving particle
  - Large time-of-flight (TOF)
  - Large $dE/dx$

**CDF Run I analysis:**
- High $p_T$ track with large $dE/dx$
- Use high $p_T$ muon trigger

**background**: $12 \pm 2.0$ events
**observed**: 12 events

Limit: $220 (190)$ GeV/$c^2$ for stable up(down) - type 4th generation quark
**CHAMPS at Run II**

Sensitive region of momentum spectrum for 100 GeV stau using dE/dx.

Stable stau pair production.

Separation at higher values of $\beta\gamma$ using time-of-flight.
CDF Run II CHAMP Analysis

Select events with high $p_T$ muon trigger.

Track must have large $p_T$, be isolated, have large TOF.

Signal Sample: $p_T > 40$ GeV/c
Control Sample: $p_T > 20, < 40$ GeV/c
- Control1: $p_T > 20, < 30$ GeV/c
- Control2: $p_T > 30, < 40$ GeV/c

$$\text{TOF}^{\text{Diff}} = \text{TOF}^{\text{Meas}} - \text{TOF}^{\text{Exp}}$$

Expected Background:

$$N_{\text{TOF}^{\text{Diff}}}^{\text{Sig}} > m = \frac{N_{\text{TOF}^{\text{Diff}}}^{\text{Sig}} > -0.2}{N_{\text{TOF}^{\text{Diff}}}^{\text{Control}} > -0.2} \times N_{\text{TOF}^{\text{Diff}}}^{\text{Control}} > m$$

2.2 ± 0.8 bck. exp. (TOF$_{\text{diff}} > 1.0$ ns)
Photon Physics at Run II

Searches for new physics are in progress…

Reconstruction of $\pi^0 / \eta$ in CDF detector

Reconstruction of $\rho$ in CDF detector
New Physics with Photons

CDF has searched for new physics in the Run I diphoton sample:

- $E_T > 22$ GeV, both photons
- Photons isolated
- Bckgnd: Jets faking photons

No excess in diphoton sample.

Search for bosophilic higgs

$H \, W/Z \rightarrow \gamma\gamma \, W/Z$

Selecting $W/Z$:
- $e$ ($\mu$) with $E_T \, (p_T) > 20$ GeV \textbf{OR}
- Missing $E_T > 20$ GeV \textbf{OR}
- 2 jets, $E_T > 15$ GeV, $M_{jj} > 40, < 130$ GeV/$c^2$

$M_H > 82$ GeV/$c^2$
# Inclusive Photon+Lepton Search

CDF has performed a model independent search at Run I for new physics that gives leptons, photons, missing $E_T$ in final state.

## CDF Preliminary (86 pb$^{-1}$)

| Category          | Predicted $\mu_{SM}$ | Observed $N_0$ | $P(N > N_0 | \mu_{SM})\%$ |
|-------------------|-----------------------|----------------|----------------------------|
| All $l,\gamma,X$  | –                     | 77             | –                          |
| $Z$ - like $e,\gamma$ | –                     | 17             | –                          |
| Two - Body $l,\gamma,X$ | 24.9 ± 2.4           | 33             | 9.3                        |
| Multi - Body $l,\gamma,X$ | 20.2 ± 1.7           | 27             | 10.0                       |
| Multi - Body $l,l,\gamma,X$ | 5.8 ± 0.6            | 5              | 61.0                       |
| Multi - Body $l,\gamma,\gamma,X$ | 0.02 ± 0.02        | 1              | 1.5                        |
| Multi - Body $l,\gamma,MET,X$  | 7.6 ± 0.7            | 16             | 0.7                        |

## Main Backgrounds:

$W + \gamma$, $Z + \gamma$, $l$ + fake $\gamma$
Large Extra Dimensions

D0 has searched for LED in diphoton/dielectron sample

2 EM objects
  ➢ $E_T > 45$ GeV for each
  ➢ Missing $E_T < 25$ GeV

1282 events in sample

Bckgnd: Drell-Yan, $\gamma\gamma$, fakes

Invariant mass, angular dist. of EM objects considered

No deviation from SM,

Limit on eff. string scale $M_S$

$M_S > 1.1$ (1.0) TeV/$c^2$ for const. (dest.) interference between Kaluza-Klein and SM contributions
CDF search with $\gamma + $ Missing $E_T$

Graviton emission:

$$q\bar{q} \rightarrow G_{kk}\gamma$$

$E_T^\gamma > 55$ GeV
Missing $E_T > 45$ GeV
No jets with $E_T > 15$ GeV
No tracks with $p_T > 5$ GeV/c
Main bckgnd : Cosmic Rays,

$Z \rightarrow \nu\nu\gamma$

$11.0 \pm 2.2$ expected, $11$ observed

$M_s > 549$ GeV/c$^2$ ($n = 4$)
$M_s > 581$ GeV/c$^2$ ($n = 6$)
$M_s > 602$ GeV/c$^2$ ($n = 8$)
**D0 search with jets and missing $E_T$**

LED search, $G_{KKg}$ final state

- $E_T$ (jet1) > 150 GeV
- $E_T$ (jet2) < 50 GeV
- Missing $E_T$ > 150 GeV
- Missing $E_T$, jet2 > 15° apart
- No isolated muons

Main bckgnd: $Z \rightarrow \nu \nu$ jets
- QCD/Cosmics
- W $\rightarrow \tau \nu$ jets

38.0 ± 9.6 expected, 38 observed

$$M_s > 886 \text{ GeV}/c^2 (n = 2)$$

$$M_s > 617 \text{ GeV}/c^2 (n = 7)$$
Limits from Run II

D0 has repeated LED search in diphoton/dielectron final state
- 2 EM objects
  - $E_T > 25$ GeV for each
  - Missing $E_T < 30$ GeV
- $9.85 \pm 0.38 \text{ pb}^{-1}$ used

No deviation from SM

$M_S > 0.82 \text{ TeV}/c^2$ for const. interference between Kaluza-Klein and SM contributions

D0 leptoquark search
- 2 EM clusters w/ $E_T > 25$ GeV
- $>1$ jet w/ $E_T > 20$ GeV
- $Z$ veto

Main bckgnd: Drell-Yan, fakes
- $8.0 \pm 0.8 \text{ pb}^{-1}$

No excess above SM

$M_{LQ} > 113 \text{ GeV}/c^2$

Still need more data to improve on Run I results
Conclusion

• D0 and CDF have searched for new physics with many different signatures
  – Dileptons
  – Dijets
  – Diphotons
  – Jets with a heavy flavor tag
  – Jets and missing $E_T$
  – Photon and missing $E_T$
  – Inclusive photons+leptons
  – Large dE/dx and large time-of-flight
• Many different models have been explored
• No evidence yet for new physics
• Run II has started, searches are in progress!