Some recent results from CDF

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pp $\rightarrow$ pp+pp
Eff $\sim$ $10^7/10^{12}$
Repeat at 1Hz

36 "bunches" each
10$^{11}$ protons/bunch
10$^{10}$ antiprotons/bunch
40 µm beam spot
Integrated Luminosity

![Graph showing the integrated luminosity over time from December 2001 to December 2005. The graph includes two lines: one labeled 'Delivered' and another labeled 'Recorded.' The 'Delivered' line shows a steady increase, while the 'Recorded' line fluctuates but overall shows an upward trend.]
CDF is pursuing a broad physics program

- QCD
- Top
- B
- EWK
- New physics

My interest is (mostly) in searches for new physics
Searching for new phenomena

Why?
• SM is incomplete

What?
• Higgs
• Supersymmetry
• Extra generations
• Extra forces
• Extra dimensions

How?
• SM++
Searching for a Z’
Electron Identification

Atypical $\text{Z} \rightarrow \text{ee}$ event  A typical di-jet event
Electron Identification

Require little energy in hadron calorimeter

\[ \pi^+ \rightarrow \pi^0 \rightarrow 2 \text{ photons} \]
Electron Identification

Require little energy around the EM cluster

\[ \pi^+ \rightarrow 2 \text{ photons} \]
Electron Identification

Require a matching track

\[ \pi^+ + \pi^0 \rightarrow 2\ \text{photons} \]
Electron Identification

Require a matching track

\[ \pi^+ \rightarrow 2 \text{ photons} \]
Electron Identification

Require a matching track

$\pi^+ \rightarrow 2$ photons

Electron

Photon

$\pi^0 \rightarrow 2$ photons
Electron Identification using a likelihood

CDF RunII Preliminary (173pb$^{-1}$)

- Black: electrons (data)
- Red: electrons (MC)
- Blue: jets passing trigger

Graph shows distribution of electron likelihood with selection criteria indicated.
Electron Identification using a likelihood

CDF Run II Preliminary (173 pb$^{-1}$)
In fact, the electron id differs between “central” and “forward” electrons.

Reduced tracking in the forward region calls for new techniques.
Particle Tracking Coverage

antiproton → [Diagram of particle tracking] → proton

\( e^+ \)  \( e^+ \)  \( e^- \)  \( e^- \)
Intermediate Silicon Layers
SVX Ladder From Innermost Layer

L00 Ladder From Innermost Layer

![Graph of 95% Depletion (V) vs. CDF Delivered Luminosity (pb⁻¹) for SVX Ladder](chart1)

![Graph of 95% Depletion (V) vs. CDF Delivered Luminosity (pb⁻¹) for L00 Ladder](chart2)
Forward Electron Tracking Algorithm

1. Form 2 seed tracks, one of each sign, from calorimeter & beam spot
Forward Electron Tracking Algorithm

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2. Project into silicon and attach hits using standard silicon pattern recognition
Forward Electron Tracking Algorithm

1. Form 2 seed tracks, one of each sign, from calorimeter & beam spot

2. Project into silicon and attach hits using standard silicon pattern recognition

3. Select best $\chi^2$ match
Plug Alignment

Align plug to COT using the subset of COT tracks which match plug electrons just above $|\eta|=1$. Then align silicon to the COT.
Plug Calorimeter Alignment

Global

Internal
Obtain ≈1mm resolution
Results from central electrons
Results from central muons
Limits

![Graph showing limits for spin-0, spin-1, and spin-2](image)

hep-ex/0507104
More recent results

CDF Run II Preliminary (448 pb$^{-1}$)

- Data
- Poisson Stat. Uncertainty
- $Z/\gamma \rightarrow e^+e^-$ MC
- Dijet background
- Other backgrounds

$\chi^2$/dof = 69.4/56

Events/2 GeV/c$^2$

$M_{ee}$ (GeV/c$^2$)
Angular Distribution: sensitive to interference

\[ e^+ e^- \rightarrow \bar{u} u \rightarrow e^+ e^- \]

\[ 1 + \cos^2 \theta \]

Forward-Backward Asymmetry

\[ M_{e^+e^-} \text{ [GeV/c}^2\text{]} \]
Limits of about 845 GeV/c^2 for Z' with SM couplings

Next, we could

- look for other modes
  - Z' → τ^+τ^-
  - Z' → t \bar{t}
- exclude other models
Geometrical factor generates TeV masses

\[ m = m_0 \, e^{-kR\pi} \]

where \( k \) is a scale of order the Planck scale. \( kR\approx12 \) generates the observed hierarchy. Similarly, the graviton mass becomes

\[ \Lambda = M_{Pl} \, e^{-kR\pi} \approx 1 \, \text{TeV} \]
Strong Gravity

Coupling $\propto \frac{k}{M_{Pl}}$

Also $\mu\mu$, $\gamma\gamma$, $tt$, $WW$, $HH$, $ZZ$
High Mass Diphoton Search

Background is 2/3 dijets, 1/3 $\gamma\gamma$. 
Diphoton RS Graviton Search, Mass Limits

CDF Run II Preliminary (345 pb⁻¹)

- $\sigma \cdot \text{BR}(G \to \gamma \gamma)$ limit (95 % C.L.)
- $\sigma \cdot \text{BR}(G \to \gamma \gamma)$ (PYTHIA × 1.3)

Randall-Sundrum Model

- $365 \text{ GeV/c}^2$
- $565 \text{ GeV/c}^2$
- $690 \text{ GeV/c}^2$

Graviton Mass (GeV/c²)

- $k/M_{pl} = 0.100$
- $k/M_{pl} = 0.055$
- $k/M_{pl} = 0.025$
- $k/M_{pl} = 0.010$
Other di-boson modes in progress

Several modes (eeee, eενν, eejj) with potentially very low backgrounds; Z mass constraint rejects background, and SM Z bosons are low $p_T$. 
What else could lead to high $p_T$ $Z$ bosons?
What else could lead to high $p_T$ Z bosons?
What else could lead to high $p_T$ Z bosons?
Z bosons from GMSB

Weak coupling could lead to long life.
Z bosons from a 4\textsuperscript{th} generation quark

Weak coupling, $V_{tb'}<<1$, could lead to long life.
Search for displaced Z’s

Search strategy

- Select dimuons from a Z
- Require a good vertex measurement (verify efficiency with J/Ψ’s)

### Tracking Quality cuts:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td># COT hits</td>
<td>≥ 60</td>
</tr>
<tr>
<td># rφ Silicon hits</td>
<td>≥ 3</td>
</tr>
<tr>
<td>Silicon $\chi^2$/dof</td>
<td>&lt; 8</td>
</tr>
<tr>
<td>(Track $d_0$ error)$^2$</td>
<td>&lt; $8 \times 10^{-5}$ cm$^2$</td>
</tr>
<tr>
<td>(Track $\phi_0$ error)$^2$</td>
<td>&lt; $8 \times 10^{-8}$ rad$^2$</td>
</tr>
<tr>
<td>(Track curvature error)$^2$</td>
<td>&lt; $8 \times 10^{-12}$ cm$^{-2}$</td>
</tr>
<tr>
<td>$\Delta z$ of 2 muons at $L_{xy}$ intersection</td>
<td>&lt; 1.5 cm</td>
</tr>
<tr>
<td>$\Delta \phi_0$ of 2 muons</td>
<td>2° &lt; $\Delta \phi_0$ &lt; 175°</td>
</tr>
<tr>
<td>$\Delta t_0$</td>
<td>&lt; 3 ns</td>
</tr>
</tbody>
</table>

### Muon ID Cuts, both legs:

- On both legs:
  - $E_{EM}$: $< 2 + \max(0, 0.0115 \times (p - 100))$ GeV
  - $E_{Had}$: $< 6 + \max(0, 0.0280 \times (p - 100))$ GeV
  - Isolation Fraction: $< 0.1$

### Muon ID Cuts, tight leg:

- CMU $|\Delta X|$: $< 3.0$ cm (CMUP)
- CMP $|\Delta X|$: $< 5.0$ cm (CMUP)
- CMX $|\Delta X|$: $< 6.0$ cm (CMX)

### Muon ID Cuts, loose leg:

- No stub requirements

### Signal Definition:

$L_{xy} > 0.1$ cm
Search for displaced Z’s

Search strategy

- Select dimuons from a Z

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- Opening angle cut
Search for displaced Z’s

Search strategy

• Select dimuons from a Z

• Require a good vertex measurement (verify efficiency with J/Ψ’s)

• Opening angle cut

• Require $p_T > 30$ for Z

Aim for simple selection to limit model dependence. (I.e., $X \rightarrow YZ$)
Search for displaced $Z$'s

CDF Run II Preliminary  $L = 163 \text{ pb}^{-1}$

- Expect $1.1 \pm 0.8$, observe 3
- A posteriori inspection consistent with background hypothesis.
And now for something completely different…

While the prospect of a discovery that can lead us to the theory beyond the SM is exciting, the most probable answer in each such measurement is

\[
\text{Data} - \text{Background} = 0.
\]

It is appealing to better measure the SM properties along the way....

So, let me tell you about a measurement where we \textit{don’t already know} the answer.
We can calculate this

But what we measure is this
u ≈ 2d, plus much going on in the sea that is incalculable. But, we can measure it.
u/d ratio causes an asymmetry in W production
Asymmetry in W production complicated by unknown $\nu p_z$

$$A(y_W) = \frac{d\sigma(W^+)/dy - d\sigma(W^-)/dy}{d\sigma(W^+)/dy + d\sigma(W^-)/dy}$$

Use lepton asymmetry

$$A(\eta_l) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta}$$

Which convolves production asymmetry with V-A decay.
Production asymmetry largest in forward direction, but so is decay asymmetry

We use our forward tracking algorithm to probe the $|\eta|>1$ region.
W Event Selection

- Electron with $E_T > 25$ GeV
- Missing $E_T > 25$ GeV
- $50 < M_T < 100$ GeV/c$^2$
- No other EMO with $E_T > 25$ GeV to suppress DY and QCD
- Calorimeter seeded silicon track:
  - We are less worried about acceptance/purity here
  - and more worried about charge identification:
    - $\#\text{ hits } \geq 4$
    - $\chi^2 < 8$
    - $\Delta\chi^2 > 0.5$
    - Pull Ratio $\equiv \frac{\chi^2_{\text{seed/dof}}}{\chi^2_{\text{seed/dof}}}$ for track with lesser $\chi^2_{\text{total/dof}} < 0.4$
Observed asymmetry (before any corrections)
Charge mis-identification

\[ A = \frac{A_{\text{raw}} + f_+ - f_-}{1 - f_+ - f_-} \]

Measured with same vs opposite sign electrons from \( Z \rightarrow \text{ee} \)

Large uncertainty in the forward direction, due to poisson fluctuations, is the dominant systematic uncertainty.
Backgrounds

Correct for

• $Z \rightarrow ee$ (lost leg)
• $W \rightarrow \tau\nu \rightarrow e\nu\nu\nu$
• QCD fakes
Fully corrected asymmetry

$$A(-\eta) = -A(\eta), \text{ with } \chi^2 = 9.5/11 \text{ dof}$$
We can enhance the sensitivity to the production asymmetry

Ideally, we’d reconstruct the W’s direction to avoid the decay smearing…

Since we can’t, we instead use the electron’s kinematics:

For $\eta_e=1.8$, e.g., look at $y_W$ and $x$ of u quark.

Different $E_T$ electrons probe different $x$ regions.
We can enhance the sensitivity to the *production* asymmetry.
Compare to existing pdf fits

PRD 71, 051104

25 < $E_T$ < 35 GeV

35 < $E_T$ < 45 GeV

MRST02

CTEQ6.1m
The End...

...but more to come.
Auxiliary slides
What else could lead to high $p_T$ Z bosons?