The Search for the W' and Right-Handed Neutrino at DZero

Guy Grubbs
Nevis Labs, Columbia University
Outline

I. The Tevatron and DZero
II. Motivation for W' - right-handed neutrino search
III. Process used in search
IV. Results
V. Questions
I. The Tevatron

- Cyclotron
- Proton and Anti-proton collisions every 396ns
- 1.96 TeV Center of Mass energy
- 2 large detectors (CDF and D0)
DZero Detector

- Named after location
- Composed of:
  - Tracking System
  - Calorimeter
  - Muon System
  - Trigger System
Tracking System

- Surrounded by 2T Solenoid
- Silicon Microstrip Tracking – Silicon Wafers
- Central Fiber Tracking – Scintillating Fibers
  - Precise tracking for most charged particles
Calorimeters

- Liquid Argon (78 degrees K) – ionized
- Uranium – dense absorber, cause showers
- Steel
Muon System

- In 1.66T Toroidal Magnet
- Proportional Drift Tubes (PDTs)
- Scintillators
- Iron Shielding
Trigger System

- 3 Level triggering system
  - L1 = hardware based
  - L2 = global processor
  - L3 = purely software, requires processor farm
Particle Detection

- Quarks and gluons from collision can produce jets of particles in different directions.
**FUNDAMENTAL PARTICLES AND INTERACTIONS**

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

### FERMONS

**Leptons**
- **Flavor**
  - \(e^-\) electron
  - \(\mu^-\) muon
  - \(\tau^-\) tau

**Quarks**
- **Flavor**
  - \(u\) up
  - \(d\) down
  - \(c\) charm
  - \(s\) strange
  - \(b\) bottom
  - \(t\) top

**Electric charge**
- \(0\)
- \(-1\)
- \(2/3\)

### BOSONS

**Unified Electroweak**
- **Name**
  - \(\gamma\) photon
  - \(W^+\)
  - \(W^-\)
  - \(Z^0\)

**Color Charge**
- **Each quark carries one of three types of strong color charge.**
- **These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons.**

**Residual Strong Interaction**
- Baryons and antibaryons are color-neutral and form nucleons. They are due to residual strong interactions between their color-charged constituents. It is similar to the residual electromagnetic interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

**Mesons**
- **q\(\bar{q}\)**
- **qq**

### PROPERTIES OF THE INTERACTIONS

- **Gravitational**
  - **Interaction**
  - **Acts on:**
  - **Mass = Energy**
  - **Particles experiencing:**
  - **Particles mediating:**
  - **Strength relative to electromagnetism**

- **Weak (Electroweak)**
  - **Color Charge**
  - **Electric Charge**

- **Strong (Color)**
  - **Residual**

### Baryons and Antibaryons
- **qq**
  - **Baryons are fermionic hadrons.**
  - **There are about 120 types of baryons.**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Quark content</th>
<th>Electric charge</th>
<th>Mass GeV/c²</th>
<th>Spin</th>
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<tbody>
<tr>
<td>(p)</td>
<td>proton</td>
<td>uud</td>
<td>1</td>
<td>0.938</td>
<td>1/2</td>
</tr>
<tr>
<td>(\bar{p})</td>
<td>anti-proton</td>
<td>(\bar{u}\bar{d}\bar{d})</td>
<td>-1</td>
<td>0.938</td>
<td>1/2</td>
</tr>
<tr>
<td>(n)</td>
<td>neutron</td>
<td>udd</td>
<td>0</td>
<td>0.940</td>
<td>1/2</td>
</tr>
<tr>
<td>(\Lambda)</td>
<td>lambda</td>
<td>udds</td>
<td>0</td>
<td>1.116</td>
<td>1/2</td>
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<tr>
<td>(\Omega^-)</td>
<td>omega</td>
<td>SSS</td>
<td>-1</td>
<td>1.672</td>
<td>3/2</td>
</tr>
</tbody>
</table>

### Matter and Antimatter
- Every particle type is a corresponding antiparticle type, denoted by a bar over the particle symbol. Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., \(Z^0, \gamma\), and \(\omega, \phi\)) have not \(\bar{c}\). Their own antiparticles.

### Figures
- These diagrams are an artist's conception of physical processes. They are not exact and have no meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.

- A neutron decays to a proton, an electron, and an antineutrino via a virtual \(W\) boson. This is known as \(\beta\) decay.

- An electron and positron (antielectron) colliding at high energy can annihilate to produce \(\gamma\) and \(Z\) mesons via a virtual \(Z\) boson or a virtual photon.

- Two protons colliding at high energy can produce various hadrons plus very high mass particles such as \(Z\) bosons. Events such as this are rare but can yield vital clues to the structure of matter.

**The Particle Adventure**
- Visit the award-winning website The Particle Adventure at http://ParticleAdventure.org

This chart has been made possible by the generous support of:
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II. Motivation for Search: Standard Model

Explains:
- Strong Force (QCD)
- Weak Interactions
- Electromagnetism (QED)

Cannot account for:
- Neutrino Mass
- Different generations
Beyond the Standard Model (SM)

- Many extensions to SM predict $W'$
  - $W$ only interacts left-handed
  - $W'$ might only interact right-handed
- Neutrino having mass means possible frame in which neutrino is right-handed
Proposed $W'$ Decay Channel

• Proton + Antiproton at 1.96 TeV = $W'$

• $W'_\pm$ decays to lepton$\pm$ and right-handed neutrino

• Right-handed neutrino decays to $W_\pm$ and lepton$\mp$

• $W$ decays to 2 quarks which cause jets

• End Results = 2 Jets + 2 Leptons
Plot Explanation

Background → Signals →

Expected Number of Events

Variable Measured (Arbitrary Name)
Measurement Explanation

- Missing Et

- Z Mass and Pt = sum of leptons
Measurement Explanation (cont.)

Reco Wqq →

Reco Wq →
**Measurement Explanation (cont.)**

- \( \text{Reco } W' = \text{Jets } + \text{Leptons} \)

\[ \text{L}_W' - W \Delta \Phi \]

\[ \text{L}_\text{Neutrino} - W \Delta \Phi \]

(Used most)
III. Process Used in Search

- Learned interactive Root (ongoing process)
- Validate MC signals
- Pair correct lepton with $W$ to reconstruct neutrino – look for patterns
- Construct algorithm which pairs correctly without prior knowledge
Process Used in Search (cont.)

- Apply algorithm to background + data (approximately 5.3 pb^-1)
- Make tighter cuts if necessary
- Study any interesting points
- Draw conclusions about limits on the W' and right-handed neutrino masses
Validating MC Signals

Checked if reconstructed $W'$ mass peaked correctly when lepton and jet energy summed.
Basic Cuts

- Reconstructed W Pt > 50 GeV
- Reconstructed Z Pt > 75 GeV
- Reconstructed Z Mass > 170 GeV
- MissingEt < 50 GeV
- Lepton Pt's > 20 GeV
- At least 1 jet present
- Removes badly modeled background, makes data set more manageable
Looking for Patterns

Lepton with smallest angle difference from W summed with W→

$\text{Neutrino Mass} = \leftarrow$Lepton with greatest angle difference from W summed with W
Algorithm Chosen

- W reconstructed from 2 jets if present, otherwise 1
- Small L and W Delta Phi = used to reconstruct neutrino mass for low neutrino mass signals
- Opposite was true for high mass signals
- \( W' \) = sum of reconstructed W and both leptons
### 400_100 Cuts Applied

- Other signals turned off

#### --No Cuts--

<table>
<thead>
<tr>
<th></th>
<th>400_100</th>
<th>QCD</th>
<th>Ttbar</th>
<th>Wjets</th>
<th>WW</th>
<th>WZ</th>
<th>ZZ</th>
<th>Zjets</th>
<th>Data</th>
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<tbody>
<tr>
<td>Act. Events</td>
<td>3396</td>
<td>984</td>
<td>316929</td>
<td>2256</td>
<td>4513</td>
<td>20057</td>
<td>37923</td>
<td>4403370</td>
<td>80517</td>
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<tr>
<td>Event Yield</td>
<td>595.7</td>
<td>4081.2</td>
<td>157.5</td>
<td>78.5</td>
<td>56.2</td>
<td>173.7</td>
<td>144.6</td>
<td>77656.9</td>
<td>80517</td>
</tr>
</tbody>
</table>

![Graph showing event counts and yields](chart.png)
Basic Cuts Applied

400_100: 29% of signal remaining. (172/596)
Data: 0.08% of data remaining. (62/80517)
Background: 0.08% of background remaining. (68/82349)

----------Standard Cuts----------

<table>
<thead>
<tr>
<th>Process</th>
<th>Actual Events</th>
<th>Event Yield</th>
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<tbody>
<tr>
<td>400_100</td>
<td>962</td>
<td>172.6</td>
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<tr>
<td>QCD</td>
<td>6</td>
<td>22.8</td>
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<td>TTbar</td>
<td>4169</td>
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<tr>
<td>Wjets</td>
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<td>0.63</td>
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<tr>
<td>WW</td>
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<tr>
<td>WZ</td>
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<td>0.09</td>
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<tr>
<td>ZZ</td>
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<td>0.39</td>
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<td>Zjets</td>
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<tr>
<td>Data</td>
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</table>
Signal Specific Cuts

- Optimize cuts = Keep signal, cut background
- Delta Phi's and Pt's graphed using equation:
  \[
  \frac{\text{Signal Yld.}}{\sqrt{\text{Signal Yld.} + \text{Background Yld.}}}
  \]
  for each bin
- Yield taken for each bin looking left on one graph and right on the other
- Cut made at the peak of the applicable graph
QCD problem points apparent

Cut this angle above 1.3 rad

Cut this angle below 2.7 rad
Angle Cuts Applied

400_100: 22.49% of signal remaining. (134/596)
Data: 0.02% of data remaining. (20/80517)
Background: 0.02% of background remaining. (13/82349)

----------Standard Cuts----------

<table>
<thead>
<tr>
<th>Category</th>
<th>Actual Events</th>
<th>Event Yield</th>
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<tbody>
<tr>
<td>400_100</td>
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<tr>
<td>Data</td>
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</table>
IV. Results

- No interesting data points, limit can be set
- Repeat process with other 4 signals
Collie: A Confidence Level Limit Evaluator

- Optimized signal cuts sent in as .root file
- Output limits on $W'$ and right-handed neutrino masses with 95% confidence level

<table>
<thead>
<tr>
<th>$W'$ Mass (GeV)</th>
<th>Neutrino Mass (GeV)</th>
<th>Expected Scaling Factor</th>
<th>Observed Scaling Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>700</td>
<td>1.54</td>
<td>1.54</td>
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<tr>
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<td>100</td>
<td>4.98</td>
<td>4.01</td>
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<td>300</td>
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<tr>
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<td>100</td>
<td>.05</td>
<td>.10</td>
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<tr>
<td>200</td>
<td>100</td>
<td>1.01</td>
<td>1.24</td>
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</table>
Acknowledgments

- Thomas Gadfort
- Gustaaf Brooijmans
- Nevis Labs
V. Questions
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